Exploring the possibility of studying the Drell-Yang process in the SPD (NICA) and PANDA (FAIR) experiments.

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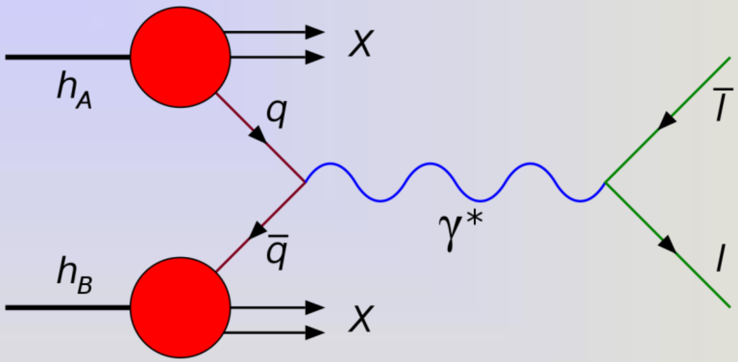


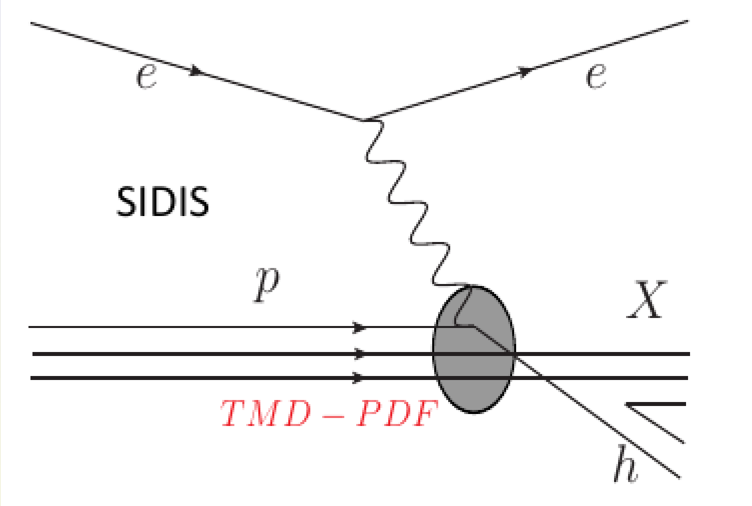
Процессы Дрелл-Яна представляют собой столкновения адронов при высоких энергиях, рождающих при взаимодействии кварка и антикварка нейтральный калибровочный бозон — виртуальный фотон или слабый Z0 бозон, который затем распадается на пару противоположно заряженных лептонов

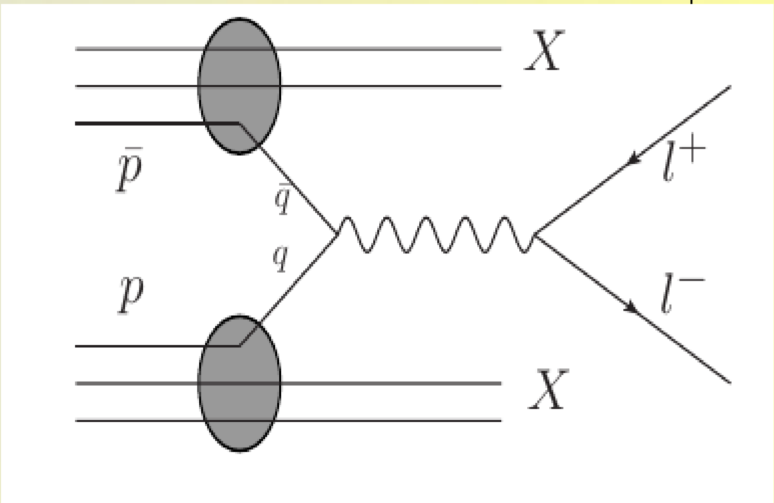
Они являются **уникальными процессами для исследования спиновых эффектов** в адронных взаимодействиях, позволяют получить **доступ к партонным распределениям** *(описывающим распределения кварков и глюонов в адронах (ядрах) по двум переменным: x (доля продольного момента k адрона, переносимого активным партоном) и pT (поперечного импульса активного партона))* и **извлечь новую информацию о структуре ядерной материи и элементарных частиц.**

Прецизионное извлечение партонных распределений из одних экспериментальных данных позволяет использовать их для предсказаний в других физических процессах.

Экспериментальные исследования процессов Дрелл-Яна позволяют непосредственно измерить различные спиновые асимметрии в столкновениях неполяризованных, поперечно- и продольно-поляризованных адронов.

Реакции Дрелла-Яна являются важным дополнением к другим реакциям (таким как, например, полуинклюзивные реакции глубоконеупругого рассеяния (SIDIS)).





TMD-PDF **связаны с функциями фрагментации**

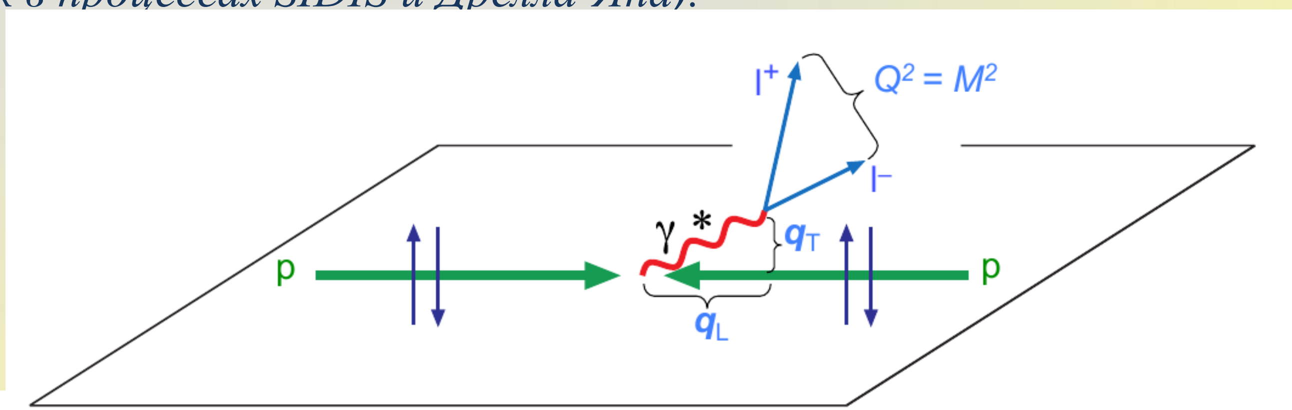
Почему Drell-Yan? -

Прямой доступ к TMD-PDFs

По отношению к DIS (инклюзивному или полу-инклюзивному) путем вращения Фейнмановской диаграммы, Drell-Yan является s-канальным процессом, а SIDIS - t-канальным.

Анализ измеренных спиновых характеристик позволяет извлечь информацию о партонных импульсных распределениях TMD *(относительно __поперечного__ и __продольного__ импульса активного партона)* и *PDF (относительно __продольного__ импульса активного партона)*, **являющихся универсальными непертурбативными функциями** *(описывающие эффекты на больших расстояниях / или при малых значениях импульсов)*, **не зависящими от типа физического процесса характеристиками** *(за исключением T-нечетных TMD (T-odd TMD Боера-Малдерса и Сиверса), меняющим знак в процессах SIDIS и Дрелла-Яна).*

Партонные распределения *есть матричные элементы операторов, построенных в терминах кварковых и глюонных полей, и усредненных по адронным состояниям (состояния вакуума).*



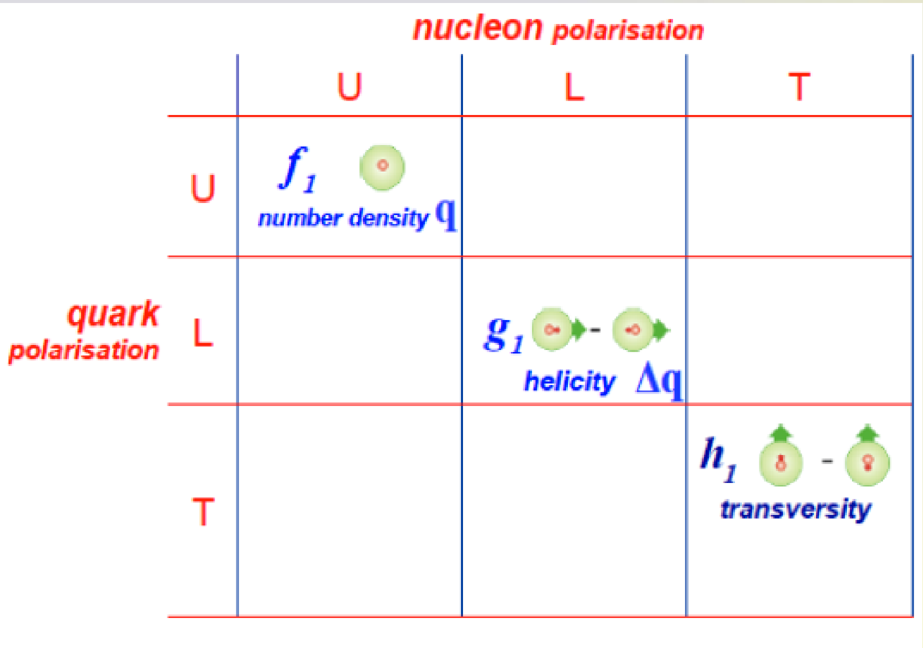
$$\mathrm{d}\sigma^{D-Y} = \sum_q f_q(x_1, \boldsymbol{k}_{\perp 1}; Q^2) \otimes f_{\bar{q}}(x_2, \boldsymbol{k}_{\perp 2}; Q^2)\, \mathrm{d}\hat{\sigma}^{q\bar{q}\to\ell^+\ell^-}$$

Для извлечения PDF распределений наиболее подходит условия когда когда M_{inv}^{l+l-} (=Q-переданный 4-х импульс) и PT^{l+l-} одного порядка. Для извлечения информации о TMD распределениях идеален масштаб M_{inv}^{l+l-} (=Q) >> PT^{l+l-} лептонной пары ~ поперечного импульса кварков и глюонов kT внутри сталкивающихся адронов.

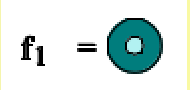
Parton Distribution Functions

A number of PDFs depends on the order of the QCD approximations.

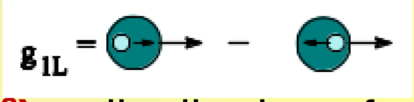
At leading order *(LO, twist-2)* 3 collinear *(integrated over kt)* PDFs are needed for a full description of the nucleon structure:



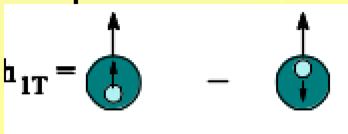
- **Density f_1 (x, Q^2)** — distribution of the parton Number/ probability to find quarks within the non-polarized (U) nucleon carrying a fraction x of the nucleon momentum



- **Helicity (chirality) g_1 (x, Q^2) ≡ g_{1L} (x, Q^2)** distribution of longitudinal polarization of quarks in longitudinally polarized (L) nucleon/ the difference in probabilities to find quarks in a longitudinally polarized nucleon with their spin aligned or anti- aligned to the spin of the nucleon



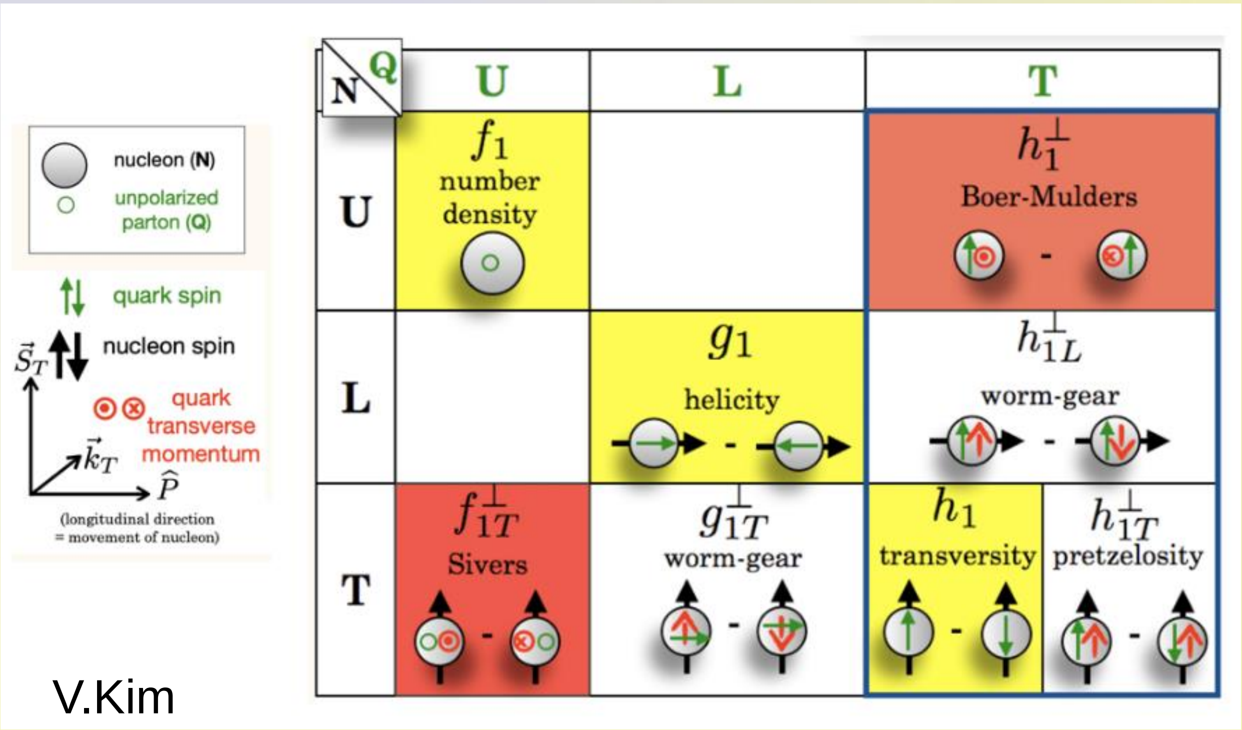
- **Transversity h_1 (x, Q^2)** - distribution of transverse polarization of quarks in transversely polarized (T) nucleon



The PDFs f_1 and g_1 are measured rather well. The PDF h_1 (x, Q^2) is poorly studied. *It was historically introduced right for DY process.*

The structure of the proton: TMD PDF

Taking into account the **quark intrinsic transverse momentum kT**, at leading order 8 TMD **(5 additional) PDFs** are needed for a full description of the nucleon structure, which are *functions of 3 variables (x, kT,Q^2)*. They are vanishes when integrating over kT.

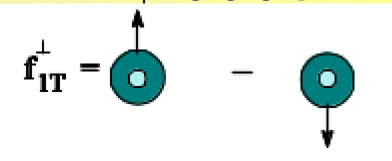


Leading twist TMD distribution functions. The **U,L,T** correspond to **u**npolarized, **l**ongitudinally polarized and **t**ransversely polarized nucleons (columns) and quarks (rows).

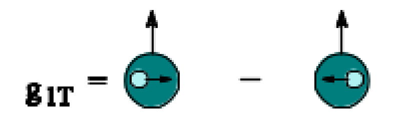
At the sub-leading twist (twist-3), there are still 16 TMD PDFs containing the information on the nucleon structure. *They have no definite physics interpretation yet.*

Since TMD distributions are nonperturbative functions, they **cannot be calculated within the framework of QCD**. Therefore, the main model-independent tool for studying TMD is **the analysis of spin effects in SIDIS and Drell-Yang processes**.

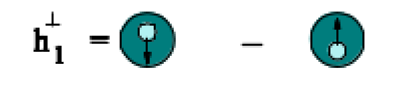
- **$f^{\perp}_{1T}$ (Sivers)** - represents the distribution over the transverse momentum of non-polarized quarks in a transversely polarized nucleon (transverse spin);



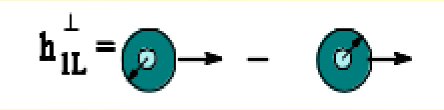
- **$g^{\perp}_{1T}$ (Worm-gear-T)** **-** correlation between the transverse spin and the longitudinal quark polarization;



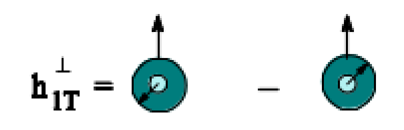
- **$h^{\perp}_{1}$ (Boer-Mulders)** - distribution over the transverse momentum of transversely polarized quarks in the non-polarized nucleon ;



- **$h^{\perp}_{1L}$ (Worm-gear-L)** **-** correlation between the longitudinal polarization of the nucleon (longitudinal spin) and the transverse momentum of quarks;



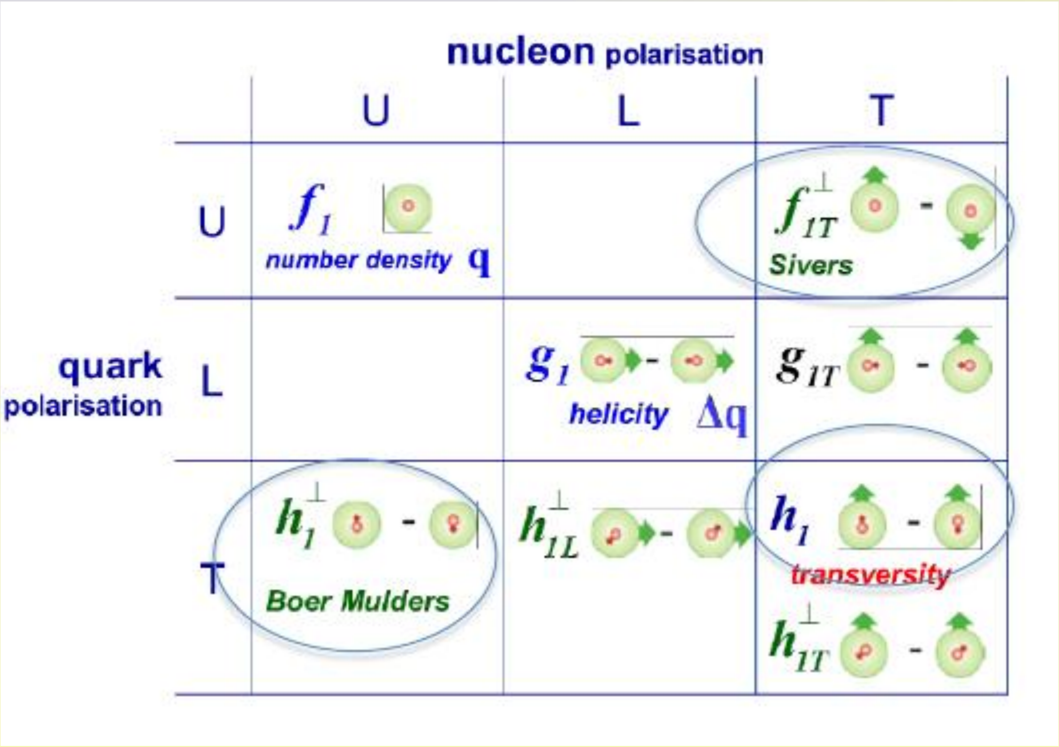
- **$h^{\perp}_{1T}$ (Pretzelosity)** **-** distribution over the transverse momentum of transversely polarized quarks in the transversely polarized nucleon.



It is very **important to measure Worm-gear-T, L and Pretzelosity** which are still not measured or measured with large uncertainties.

The last one would give new information (at least within some models) on the **possible role of constituent`s orbital momenta in the resolution of the nucleon spin crisis**.

Transverse momentum dependence PDFs @ PANDA



Unpolarized DY

Boer-Mulders (BM) $h^{\perp}_{1}$

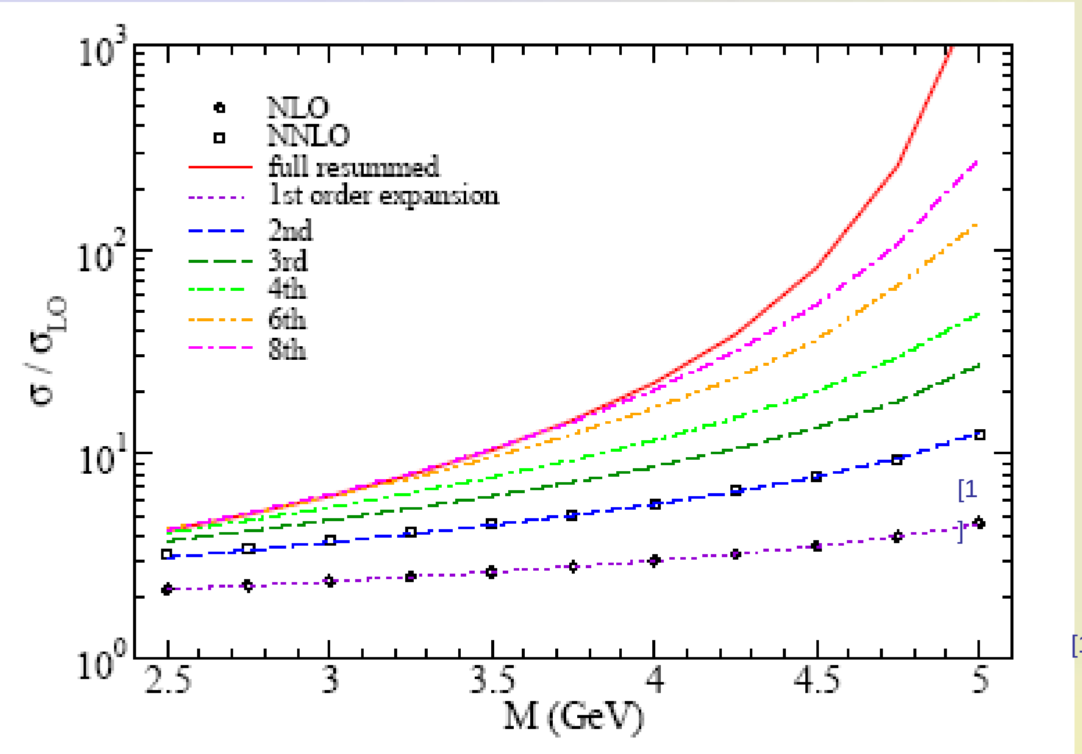
the distribution of **transversely polarised partons** in **unpolarised hadrons**;

In case of Single-polarized DY
(if a polarised target will become available)

Sivers, Transversity $f^{\perp}_{1T}$, $h^{\perp}_{1T}$, h_1

the distributions of respectively **unpolarised and transversely polarised partons** in a **transversely polarised nucleon**

Unpolarised Drell-Yan $-\bar{p}p \rightarrow \mu^+\mu^- X$



$S \sim 30\ GeV^2$

Perturbative corrections[1] are expected to be large in the PANDA energy range

[1]H. Shimizu et al., Phys. Rev. D71 (2005) 114007

Unpolarised DY cross-section allow the investigation of:

- limits of the factorisation and perturbative approach
- relation of perturbative and not perturbative dynamics in hadron scattering

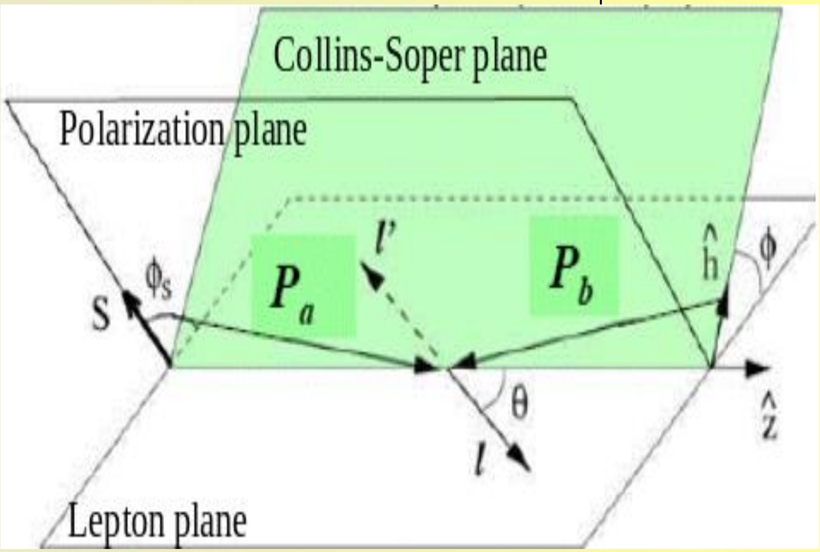
The PDFs studies via asymmetry of the DY pairs production cross sections

The **cross section** of the DY pair's production **cannot be measured directly** because there is **no single beam containing particles with the U, L and T polarization**.

To ***measure SF`s*** one can use the following procedure:

1-st - ***to integrate differential cross section over*** the azimuthal ***angle φ*** between the Lepton and Hadron planes in the Collins-Soper reference frame,

2-nd - following the SIDIS practice, ***to measure azimuthal asymmetries*** of the DY *pairs production cross sections*.



The **azimuthal asymmetries** can be **calculated** as ***ratios*** of ***cross sections differences*** to the ***sum*** of the integrated over φ ***cross sections*** σ_{int} :

- The **numerator** of the ratio is calculated as a *difference* of the DY pair's production cross sections in the collision of hadrons h_a and h_b with *different polarizations*.
- The **denominator** of the ratio is calculated as a *sum of* σ_{int}*`s* calculated for the same hadron polarizations and same x_a, x_b regions as in numerator.

Previouse Drell-Yan experiments

Experiment	Interaction	Reaction	Energy
CERN-NA3	pN(Pt)	p Nucleus --> mu+ mu- X	Plab = 400 GeV
CERN-NA10	pi-N(W)	pi- Nucleus --> mu+ mu- X	Plab = 194, 286 GeV
CERN-WA11	pi-N(Be)	pi- Nucleus --> mu+ mu- X	Plab = 150/175 GeV
CERN-WA39	pi+N(W) pi-N(W)	pi+ Nucleus --> mu+ mu- X, pi- Nucleus --> mu+ mu- X	Plab = 39.5 GeV
CERN-R108	pp	p p --> e+ e- X	Plab(Ecm) = 62.4 GeV
CERN-R209	pp	p p --> mu+ mu- X	Plab (sqrt(s)) = 44, 62 GeV
CERN-R808	pp	p p --> e+ e- X	Plab (sqrt(s)) = 53, 63 GeV
CERN-UA2	pbar p	pbar p --> mu+ mu- X	Plab = 630 GeV
Fermilab-E288	pN(Pt)	p Nucleus --> mu+ mu- X	Plab = 200/300/400 GeV
Fermilab-E325	pN(Cu)	p Nucleus --> mu+ mu- X	Plab = 200,300,400 GeV
Fermilab-E326	pi-N(W)	pi- Nucleus --> mu+ mu- X	Plab = 225 GeV
Fermilab-E439	pN(Cu)	p Nucleus --> mu+ mu- X	Plab = 400 GeV
Fermilab-E444	pN(C, Cu, W)	p Nucleus --> mu+ mu- X, pi+ Nucleus --> mu+ mu- X, pi- Nucleus --> mu+ mu- X	Plab = 225 GeV
Fermilab-E537	Pbar N(W), pi- N(W)	pbar p --> e+ e- X, pbar N --> mu+ mu- X, pi- Nucleus --> mu+ mu- X	Plab = 125 GeV
Fermilab-E605	pN(Cu)	p Nucleus --> mu+ mu- X	Plab = 800 GeV
Fermilab-E615	pi- N(W)	pi- Nucleus --> mu+ mu- X	Plab = 252 GeV
Fermilab-E740(D0)	pbar p	pbar p --> e+ e- X	Ecms (sqrt(s)) = 1800 GeV
Fermilab-E741(CDF)	pbar p	pbar p --> mu+ mu- X , pbar p --> e+ e- X	Ecms (sqrt(s)) = 1800 GeV
Fermilab-E772	pp	p p --> mu+ mu- X	Plab = 800 GeV
Fermilab-E866(NUSEA)	pp	p p --> mu+ mu- X	Plab = 800 GeV

Experiments studying nucleon spin structure

experiment	CERN, COMPASS-II	FAIR, PANDA	FNAL, E-906	RHIC, STAR	RHIC-PHENIX	NICA, SPD
mode	Fixed Target	Fixed T.	Fixed T.	collider	collider	collider
Beam/target	π- , p	anti-p, p	π- , p	pp	pp	pp, pd,dd
Polarization:b/t	0; 0.8	0; 0	0; 0	0.5	0.5	0.9
Luminosity	$2\cdot10^{33}$	$2\cdot10^{32}$	$3.5\cdot10^{35}$	$5\cdot10^{32}$	$5\cdot10^{32}$	10^{32}
$\sqrt{s}$, GeV	19	<5.5	16	200, 500	200, 500	10 - 26
$x_{1(beam)}$ range	0.1-0.9	0.1-0.8	0.1-0.5	0.03-1.0	0.03-1.0	0.1-0.8
q_T, GeV	0.5 -4.0	0.5 -1.5	0.5 -3.0	1.0 -10.0	1.0 -10.0	0.5 -6.0
Lepton pairs,	μ-μ+	μ-μ+	μ-μ+	μ-μ+	μ-μ+	μ-μ+, e+e-
Data taking	2015	>2025	2013	>2016	>2016	>2020
Transversity	NO	NO (?)	NO	YES	YES	YES
Boer-Mulders	YES	YES	YES	YES	YES	YES
Sivers	YES	YES (?)	YES	YES	YES	YES
Pretzelosity	NO	NO	NO	NO	YES	YES
Worm Gear	NO	NO	NO	NO	NO	YES

arXiv:1408.3959, 2014

The experiments at the SPD will have a number of advantages for DY measurements related to the nucleon structure studies:

- **Running with pp, pd and dd beams,**
- **Scan of the effects over a *range of beam energies*,**
- **Measurements via *muon* and *electron-positron pairs* simultaneously,**
- **Running with non-polarized, transverse and longitudinally polarized beams and their combinations.**

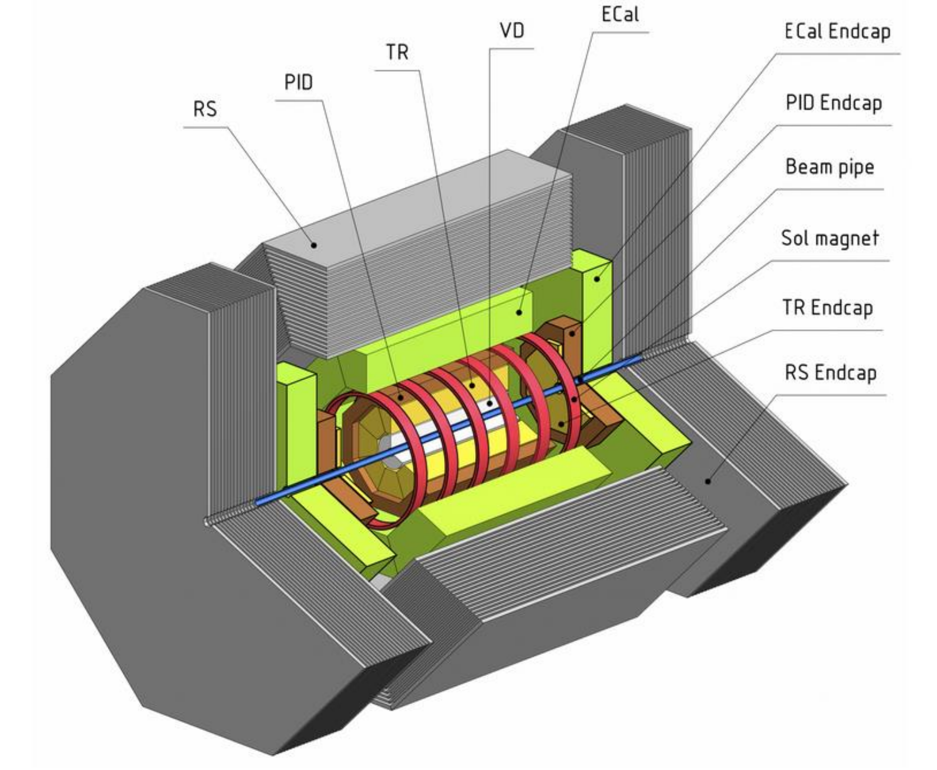
The above advantages permit, for the first time, to perform comprehensive studies of **all leading twist PDFs** of the nucleon in a **single experiment** with minimal systematic errors.

SPD — Spin Physics Detector

Beam energies:

p↑-p↑($\sqrt{s_{pp}}$) = 12 ÷27 GeV (5 ÷12.6 GeV of proton kinetic energy),
d↑-d↑($\sqrt{s_{NN}}$) = 4 ÷13.5 GeV (2 ÷5.9 GeV/u of ion kinetic energy),
p↑-d↑($\sqrt{s_{NN}}$) ≤ 19 GeV

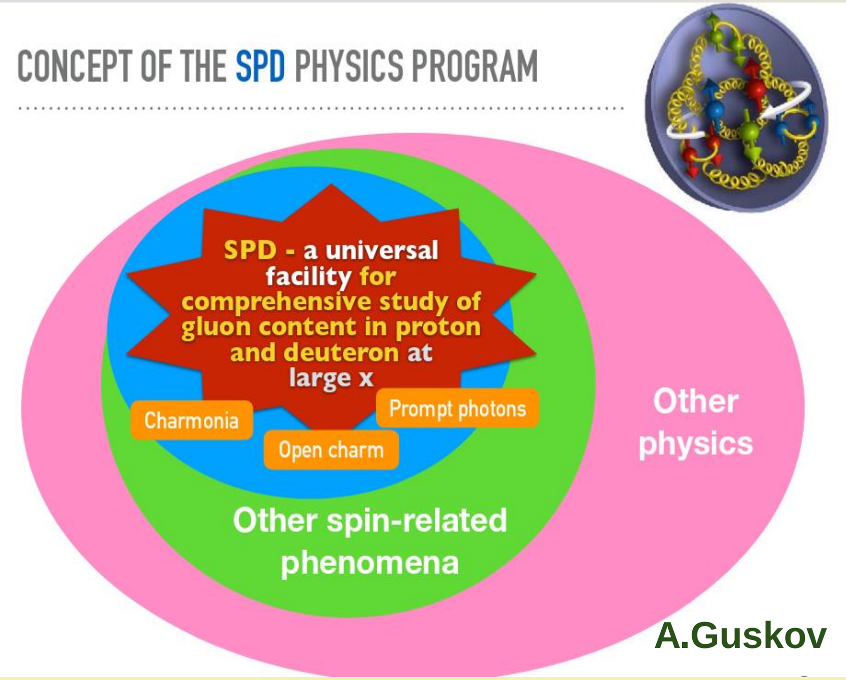
- **Luminosity up to $1 \cdot 10^{32}$ cm^{-2}s^{-1} (p-p)**
- **$0.25 \cdot 10^{32}$ cm^{-2}s^{-1} (d-d)**
- Universal 4π detector with advanced tracking and particle identification capabilities based on modern technologies.
- Capability to detect events with high collision rate (up to 4MHz)
- Tracking : ~<100 μm vertex resolution
- Photon detection with the energy resolution ~ 5%/√E
- Transverse momentum resolution $\sigma_{pT}/pT \approx 2\%$



SPD Conceptual Design Report
arXiv:2102.00442v2 [hep-ex], 2021

SPD Physics Program

The Spin Physics Detector (SPD) project aims to investigate the nucleon spin structure and polarization phenomena in polarized p-p and d-d collisions.



«Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams» **arXiv:2102.08477**, 2021

«On the physics potential to study the gluon content of proton and deuteron at NICA SPD» **arXiv:2011.15005**, 2021

The plans to study Drell-Yan (DY) at SPD initially were the first in the list of physics proposal at SPD facility

«Spin Physics Experiments at NICA-SPD with polarized proton and deutron beams>. LoI **arXiv:1408.3959**,2014

V.A. Matveev, R.M. Muradian, A.N. Tavkhelidze (MMT)

(V.A. Matveev, R.M. Muradian, A.N Tavkhelidze, JINR-P2-4543, JINR, Dubna, 1969; SLAC-TRANS-0098)

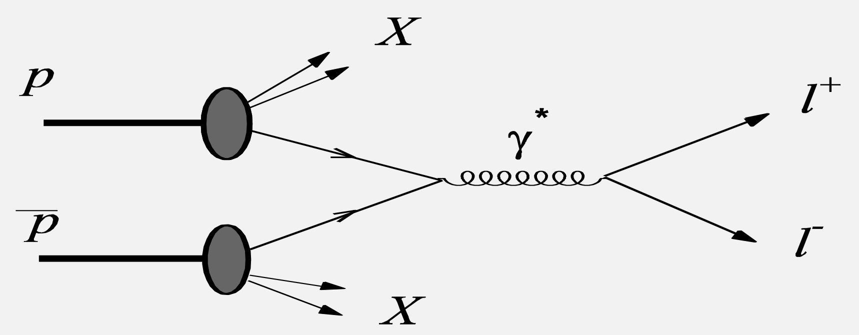
process, called also as Drell-Yan

(S.D. Drell, T.M. Yan, SLAC-PUB-0755, Jun 1970,12p.; Phys.Rev.Lett. 25(1970)316-320, 1970)

The dominant mechanism of the $\ell^+\ell^-$ production is the perturbative QED/QCD partonic 2 → 2 process

$\bar{q}q \to \gamma^* / Z^\circ \to \ell^+\ell^-$

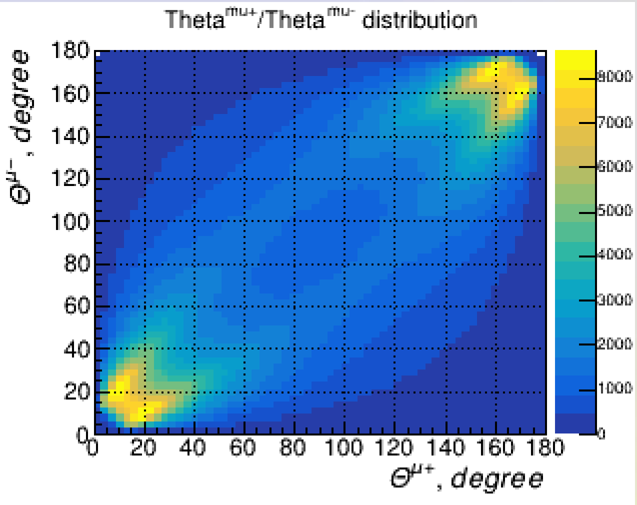
$\sigma = 9.6 * 10^3$ pb

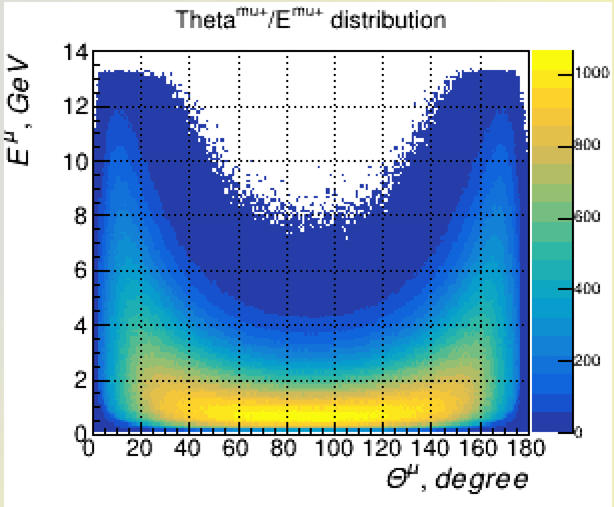


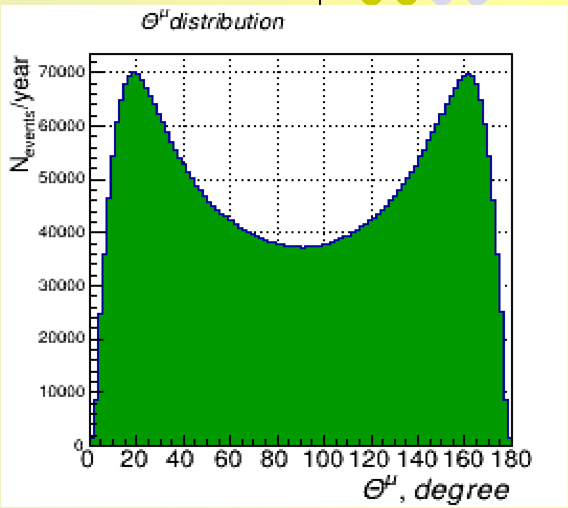
PYTHIA 6.4 simulation for the E_{cms} = 27 GeV

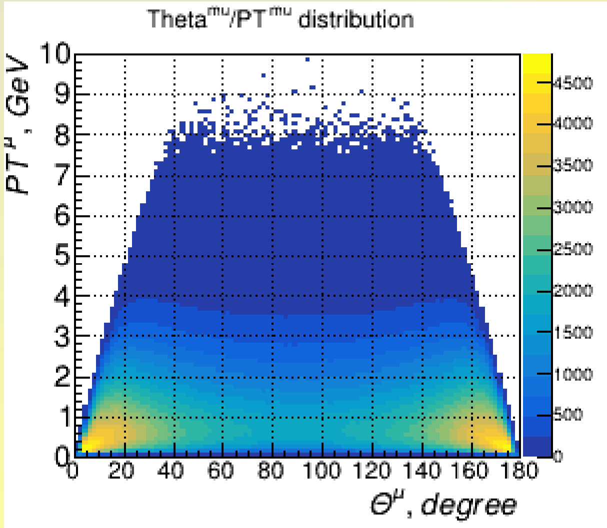
For the Luminosity L = 1 × 10^{32} $cm^{-2}s^{-1}$ with assumption of 10^7 sec/year of beam operation we expect up to 9.5×10^6 Drell-Yan events/year (without any cuts) & ~79 700 Drell-Yan events/year for M_{inv} $(\mu^+\mu^-) > 4$ GeV (and first 2 cuts)

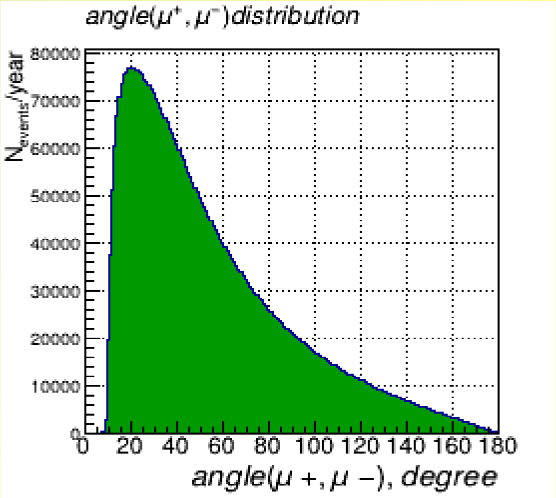
Some signal μ correlation distributions











Main backgrounds

Main contribution to backgrounds for $\bar{q}\,q \rightarrow \gamma^* \rightarrow \mu^+\mu^-$ process comes from two sources: QCD(+charmonium) and Minimun-bias events

Initial conditions for simulation (both signal and BKG) are:

- **ISR ON**
- **FSR ON**
- **MPI ON**
- **Lund fragmentation**

We allow particles decay (and produce muons) in the volume before the Muon (Range) System :
cylindr radius R = 2 400 mm,
size from the centre along Z axis L = 4 000 mm
and search for muons in the angle region 3º < Θ < 177º

Contribution from b-quarks *(subprocesses 81, 82, 461- 479)* **is negligible**.
Total cross-section is **0.34×10^{-6} mb**. Initial **S/B =~ 27**.
After first 3 cut it improves to **S/B = 815**

Processes with charmonium production

1) $q_i \bar{q}_i \rightarrow \gamma^* \rightarrow c\bar{c} \rightarrow J/\Psi \rightarrow l^+l^- + X$

86) $g\,g \rightarrow J/\Psi + g \rightarrow l^+l^- + X$ R.Baier and R.Rücke, Z.Phys. C19 (1983) 251

106) $g\,g \rightarrow J/\Psi + \gamma \rightarrow l^+l^- + X$ M.Drees and C.S.Kim, Z.Phys. C53 (1991) 673

421) $g\,g \rightarrow c\bar{c}\,[^3S_1{}^{(1)}]\,g \rightarrow ll + X$

422) $g\,g \rightarrow c\bar{c}\,[^3S_1{}^{(8)}]\,g \rightarrow ll + X$

423) $g\,g \rightarrow c\bar{c}\,[^3S_0{}^{(8)}]\,g \rightarrow ll + X$

424) $g\,g \rightarrow c\bar{c}\,[^3P_J{}^{(8)}]\,g \rightarrow ll + X$

425) $g\,q \rightarrow c\bar{c}\,[^3S_1{}^{(8)}]\,q \rightarrow ll + X$

426) $g\,q \rightarrow c\bar{c}\,[^3P_J{}^{(8)}]\,q \rightarrow ll + X$

427) $g\,g \rightarrow c\bar{c}\,[^3S_1{}^{(1)}]\,q \rightarrow ll + X$

428) $q\,\bar{q} \rightarrow c\bar{c}\,[^3S_1{}^{(8)}]\,g \rightarrow ll + X$

429) $q\,\bar{q} \rightarrow c\bar{c}\,[^1S_0{}^{(8)}]\,g \rightarrow ll + X$

430) $q\,\bar{q} \rightarrow c\bar{c}\,[^3P_J{}^{(8)}]\,g \rightarrow ll + X$

431) $g\,g \rightarrow c\bar{c}\,[^3P_0\,(^1)]\,g \rightarrow ll + X$

432) $g\,g \rightarrow c\bar{c}\,[^3P_1\,(^1)]\,g \rightarrow ll + X$

433) $g\,g \rightarrow c\bar{c}\,[^3P_2\,(^1)]\,g \rightarrow ll + X$

434) $g\,q \rightarrow c\bar{c}\,[^3P_0\,(^1)]\,q \rightarrow ll + X$

435) $g\,q \rightarrow c\bar{c}\,[^3P_1\,(^1)]\,q \rightarrow ll + X$

436) $g\,q \rightarrow c\bar{c}\,[^3P_2\,(^1)]\,q \rightarrow ll + X$

437) $q\,q \rightarrow c\bar{c}\,[^3P_0\,(^1)]\,g \rightarrow ll + X$

438) $q\,\bar{q} \rightarrow c\bar{c}\,[^3P_1\,(^1)]\,g \rightarrow ll + X$

439) $q\,\bar{q} \rightarrow c\bar{c}\,[^3P_2\,(^1)]\,g \rightarrow ll + X$

G.T.Badwin, E.Braten and G.P.Lepage, Phys.Rev. D51 (1995) 1125 [Erratum: ibid D55 (1997) 5883];

M.Beneke, MKrämer and M.Vänttinen, Phys.Rev.D57 (1998) 4258;

B.A.Kniehl and J.Lee, Phys.Rev. D62 (2000) 114027

Main backgrounds

Main contribution to backgrounds comes from two sources:
QCD (+charmonia) and Minimun-bias events

Contribution from charmonia *(subprocesses 86, 87-89, 104-105, 106, 421-439)* **is less than from QCD and Mini-bias, but significant**.

Their cross-section is **8.6×10^{-4} mb**. Initial **S/B = 1.0×10^{-2}.**

It was considered separately before (see talk at SPD@NICA2019).

Now it is included in the **total list of QCD events** modeling *(subprocesses 10-14, 28-29, 53, 68)*, **σ = 212.9 mb**, which includes also small fraction of indirect D-meson production (0.0014% of events).

The main contributions come from the following partonic subprocesses:

$q + g \rightarrow q + g$ (gives 43.5**%** of QCD events with the **σ** = **92.7** mb);

$g + g \rightarrow g + g$ (gives 46.7**%** of QCD events with the **σ** = **99.5** mb);

$q + q' \rightarrow q + q'$ (gives 9.2**%** of QCD events with the **σ** = **19.7** mb);

For QCD background S/B ≃ 4.6×10^{-8}

(one order stronger than Mini-bias!)

Open charm and Minimum-bias backgrounds

Open Charm production **σ = 1.9 x 10^{-3} mb.** **S/B ≃ 5.2 x 10^{-3}** is simulated via two main processes:

81. q + qbar --> c cbar (**3.1 x 10^{-4} mb**)

82. q + g --> c cbar (**1.5 x 10^{-3} mb**)

(which include 99.12% processes with D-mesons production). *{Easy to suppress}*

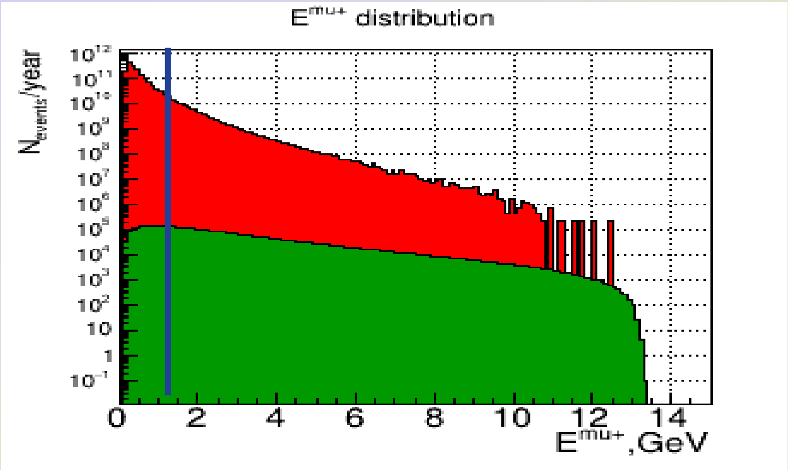
Minimum-Bias processes **σ = 23.7 mb.** **S/B ≃ 4.2 x 10^{-7}**

95. Low - PT scattering (~65**%** of MB events with the **σ** = **14.0** mb);

92-93. Single diffractive (24.8**%** of MB events with the **σ** = **7.35** mb);

94. Double diffractive (7.2**%** of MB events with the **σ** = **2.12** mb);

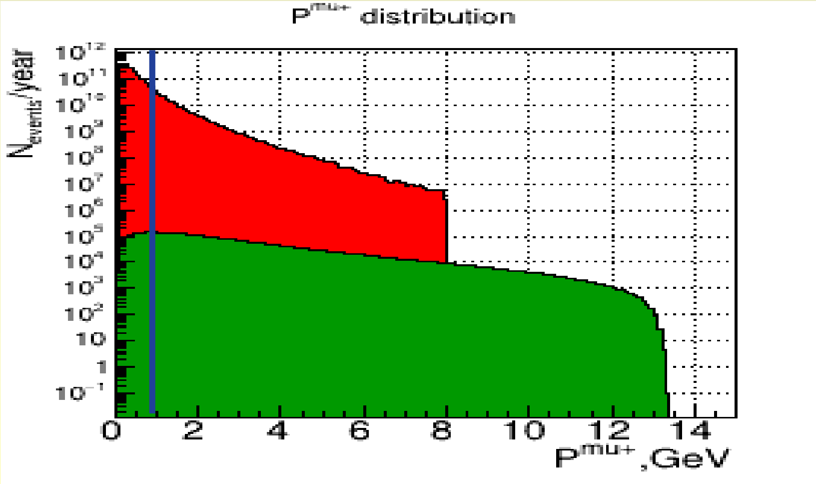
First cuts - on E(P) and PT

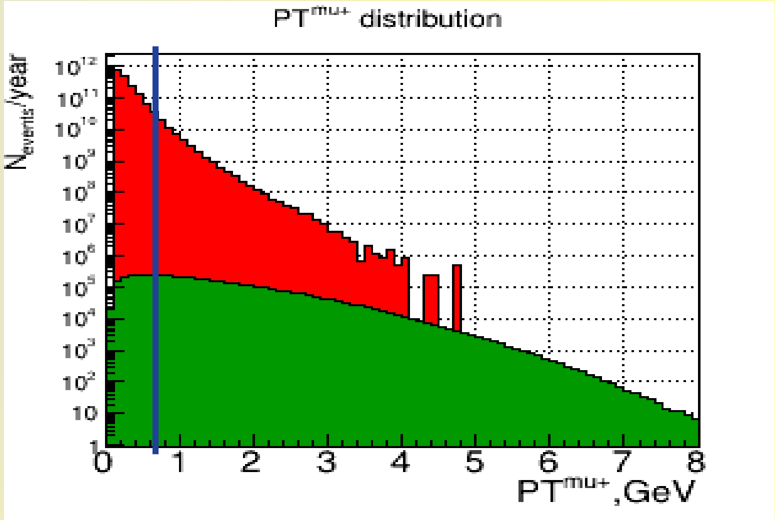


Effective cut off on E(P) only in the region

$E^{\mu}_{bkg} < 1.5$ GeV ***(example $E^{\mu}_{bkg} = 1.0$ GeV)***

where is the maximum gradient in E^{μ}_{bkg} distribution





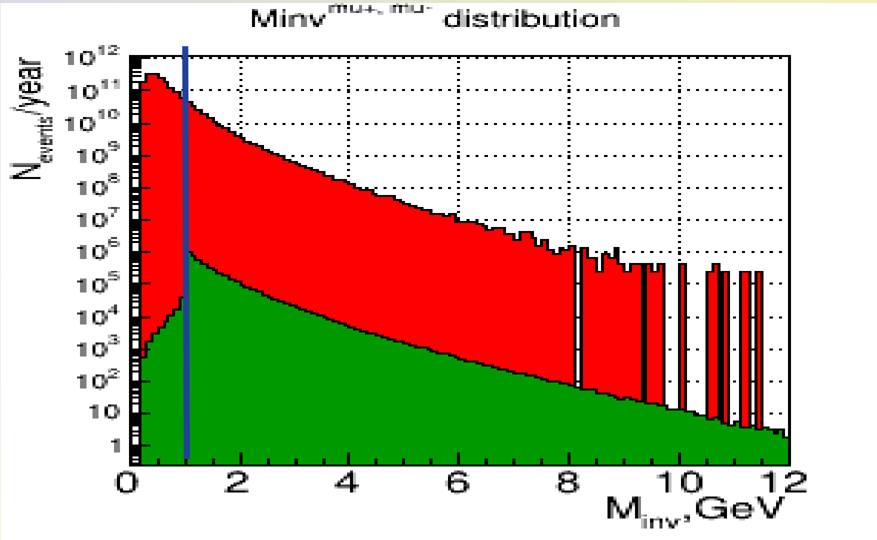
The most effective cuts off are in the region

$PT^{\mu}_{bkg} < 1.5$ GeV

(for example $PT^{\mu}_{bkg} = 0.6$ GeV)

Invariant mass cut

(picture corresponds to minimum-bias backgrounds)



The most effective cut is in the region **~ 1 GeV.**

Further increase of Minv cut has no sense for Minimum-bias background events (it leads to significant loss of signal events without real improvement of S/B ratio) except backgrounds in the regions of J/Ψ and other resonances production.

Efficiency of M_{inv} (μ^+,μ^-) cut

Together with the cut on $E(P)^{\mu} > 1$ GeV, $PT^{\mu} > 0.6$ GeV and opposite sign leptons

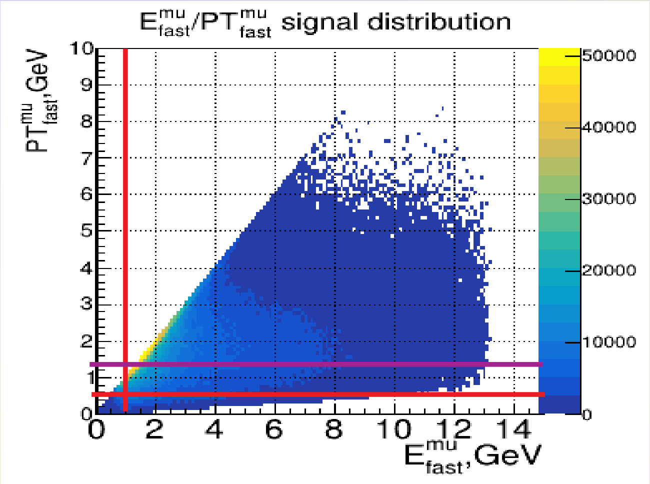
Cut efficiency = Nev(cutN) / Nev(init)

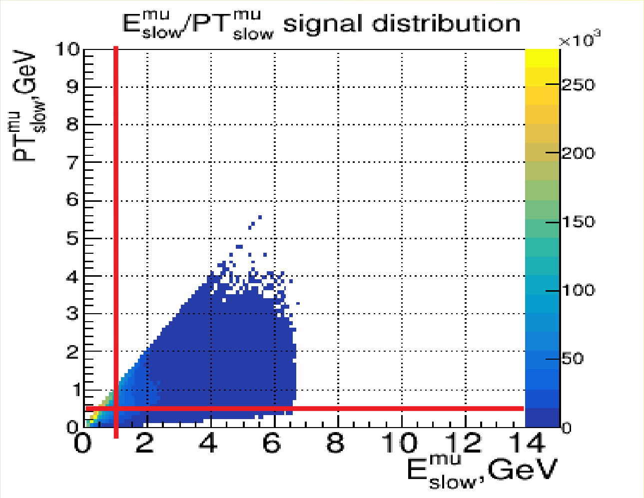
Minv cut	Rest of BKG	Cut efficiency for BKG	Rest of SIG	Rest of SIG events/year	Cut efficiency for SIG	S/B
$M^{\mu\mu}_{inv} > 1.0$ GeV	1.70×10^{-2} %	1.36	**40.5 %**	**3 869 571**	1.02	**1.0×10^{-4} %**
$M^{\mu\mu}_{inv} > 1.5$ GeV	1.35×10^{2} %	1.69	16.7 %	1 595 601	2.97	6.3×10^{-5} %
$M^{\mu\mu}_{inv} > 2.0$ GeV	9.57×10^{-3} %	2.41	8.3 %	793 023	7.28	4.4×10^{-5} %
$M^{\mu\mu}_{inv} > 2.5$ GeV	6.05×10^{-3} %	3.80	4.5 %	429 952	15.9	3.8×10^{-5} %
$M^{\mu\mu}_{inv} > 3.0$ GeV	3.70×10^{-3} %	6.22	2.5 %	238 862	32.0	3.4×10^{-5}%
$M^{\mu\mu}_{inv} > 3.5$ GeV	2.24×10^{-3} %	10.3	1.4 %	133 762	60.7	3.2×10^{-5} %
$M^{\mu\mu}_{inv} > 4.0$ GeV	1.38×10^{-3} %	16.7	**0.8 %**	**76 435**	110.1	**2.9×10^{-5} %**
$M^{\mu\mu}_{inv} > 4.5$ GeV	8.49×10^{-4}%	27.1	0.5 %	47 772	192.2	3.0×10^{-5} %
$M^{\mu\mu}_{inv} > 5.0$ GeV	5.28×10^{-4} %	43.7	0.3 %	28 663	328.0	2.9×10^{-5} %

Minv cut doesn"t influence much on S/B ratio. But at **$M^{\mu\mu}_{inv} > 4.0$ GeV** we have **too small number of events/year.**

E^{μ}/PT^{μ} correlations for muons with **max**(fast) / **min**(slow) E^{μ} in the pair

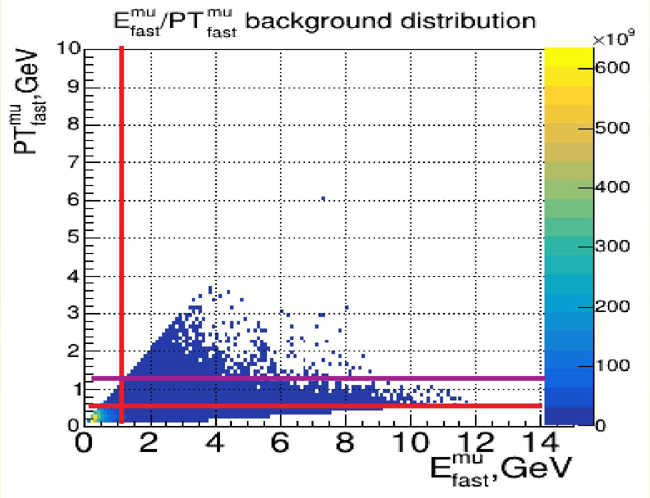
S I G

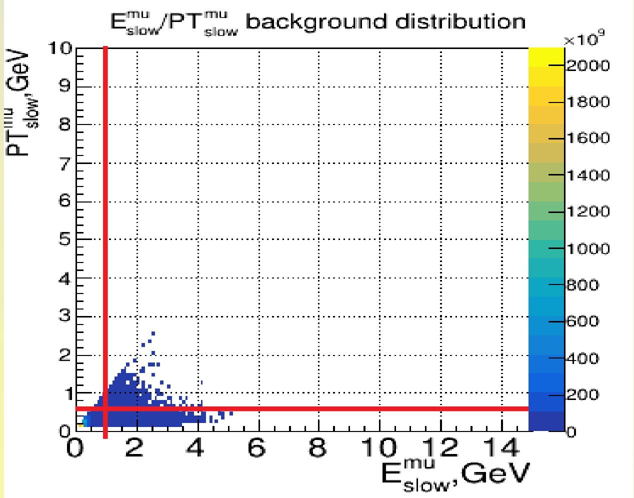




$PT^{\mu}_{fast} > 1.5$ GeV

B K G

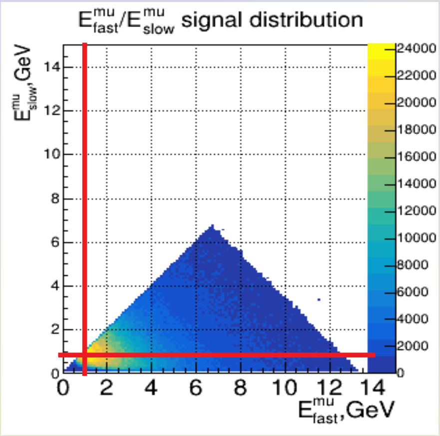


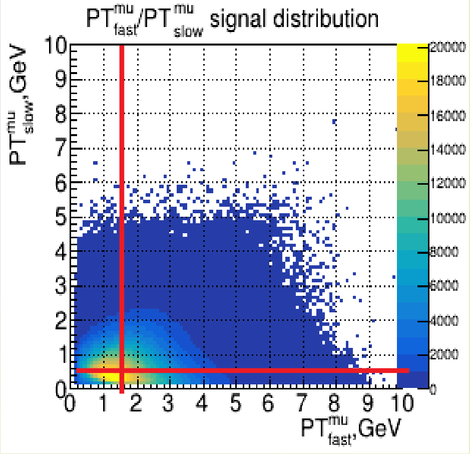


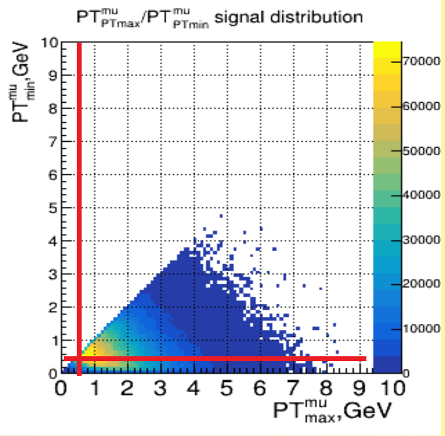
Cut on $PT^{\mu} > 0.6$ GeV and $E^{\mu} > 1.0$ GeV

E^{μ}_{max}(fast) /E^{μ}_{min}(slow), $PT^{\mu}_{fast}/PT^{\mu}_{slow}$, $PT^{\mu}_{max}/PT^{\mu}_{min}$ distributions

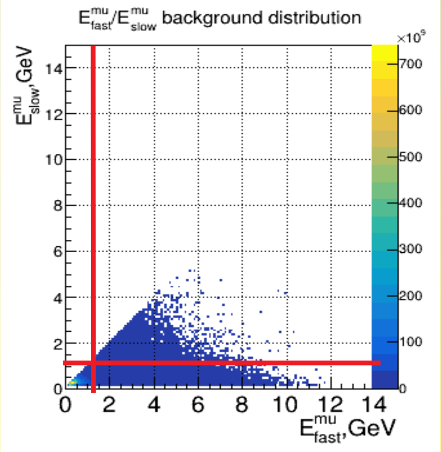
SIG

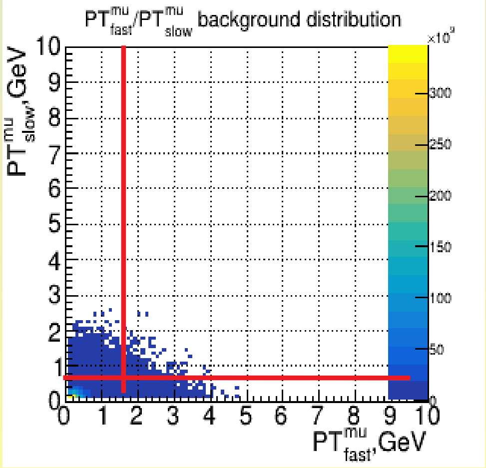


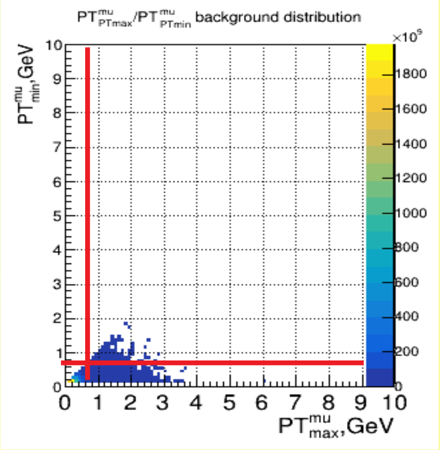




BKG

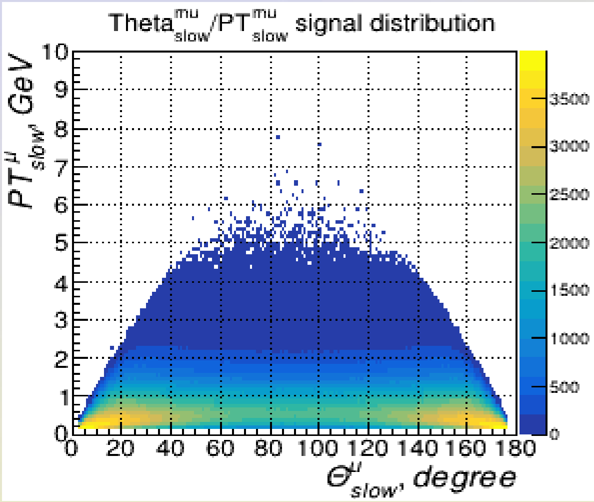


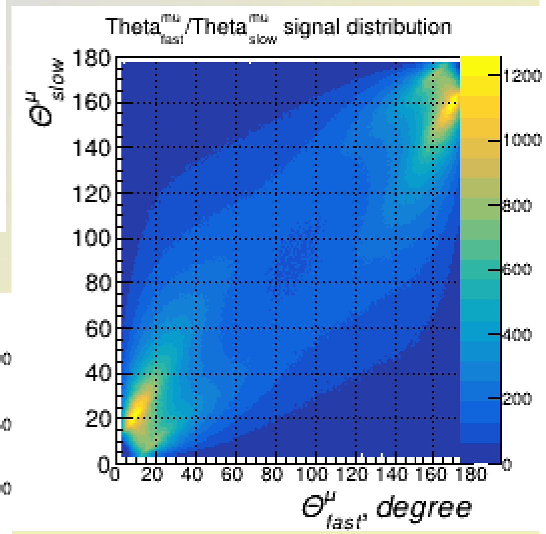


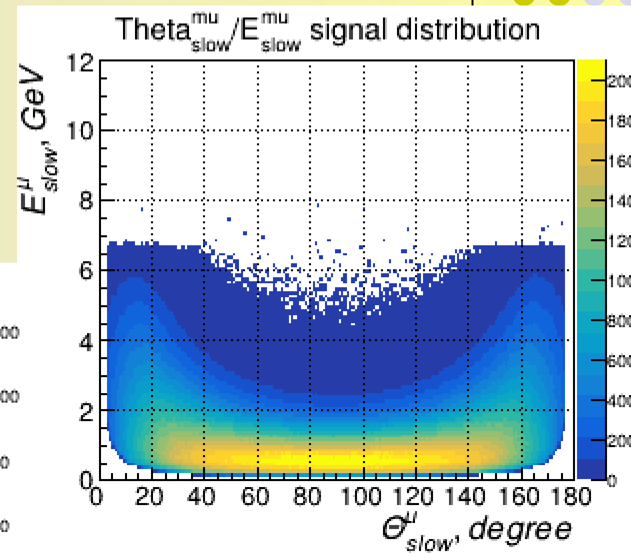


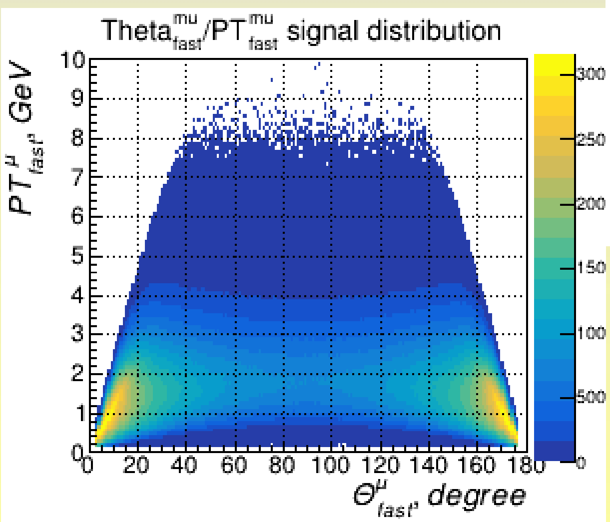
$E^{\mu} > 1.0$ GeV $PT^{\mu}_{fast} > 1.5$ GeV $PT^{\mu} > 0.6$ GeV

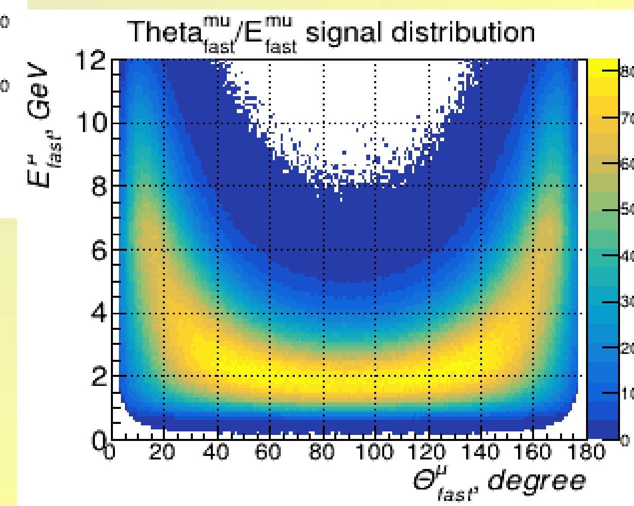
Angle and E, PT for fast and slow signal μ correlation distributions



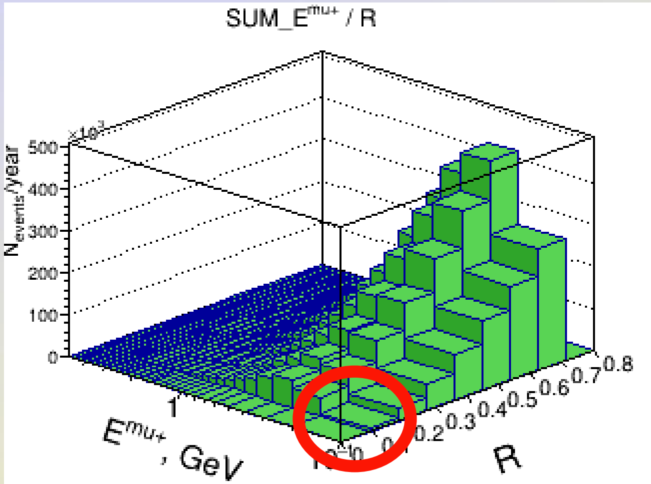


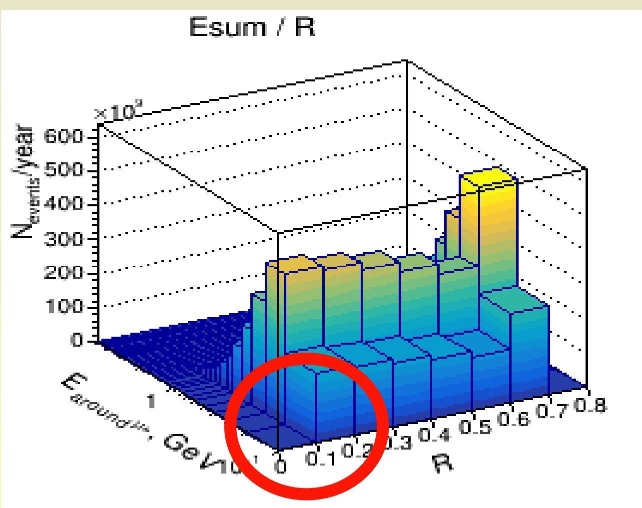






Lepton (μ) isolation criteria





The plots show the distributions over ***summarized energy*** of the final state charged particles in the cones of radius **$R_{isolation} = \sqrt{\Delta\eta^2+\Delta\varphi^2}$** respect to the

(η – pseudorapidity, φ — azimuthal angle)

upper plot **signal events**

bottom plot **Mini-bias background**

Isolation criteria **($R_{isolation} = 0.2$)**

E_{sum} (of particles) < 0.5 GeV

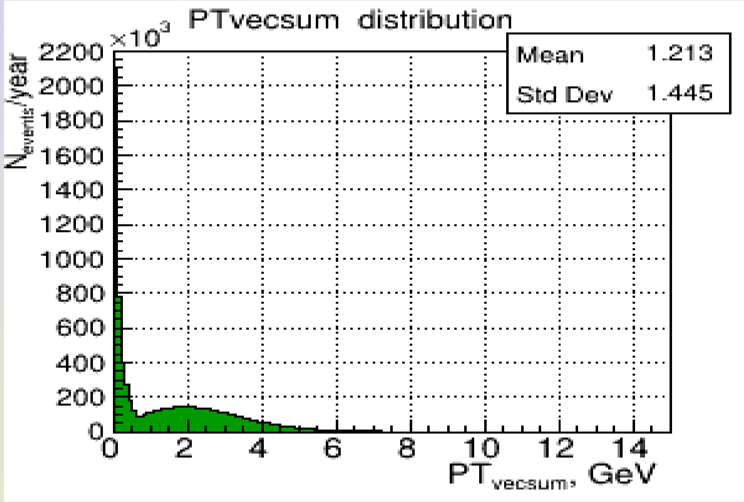
allows to separate most part

of Mini-bias & QCD bkg muons

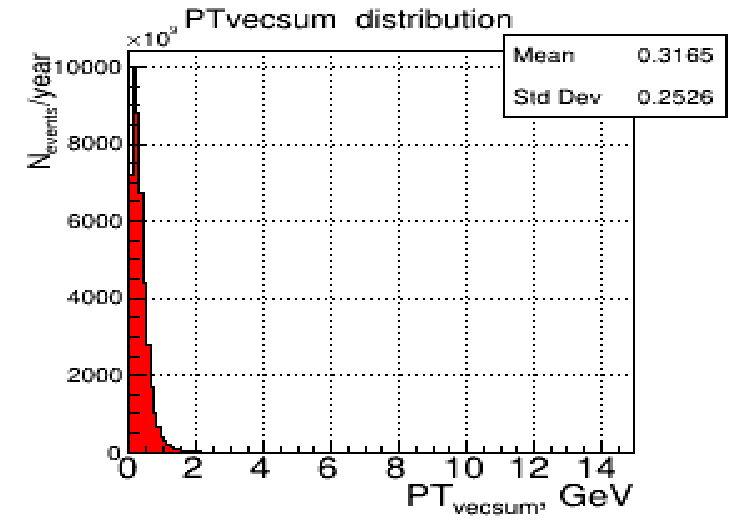
with additional loss of **0.7%** of signal events

Cut on PT_{vecsum} - vector sum of all particles transverse momenta in event

S I G

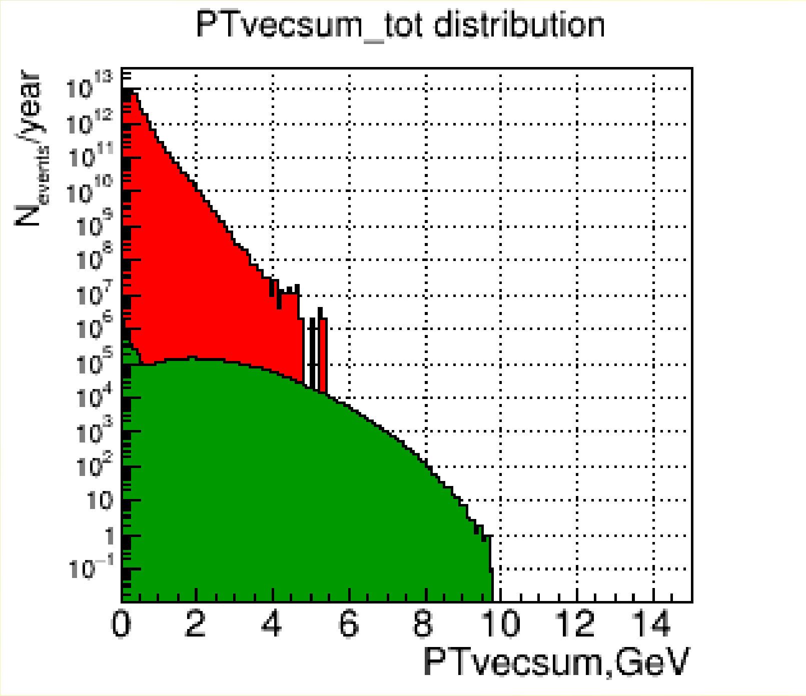


B K G



Sig & BKG

in log scale

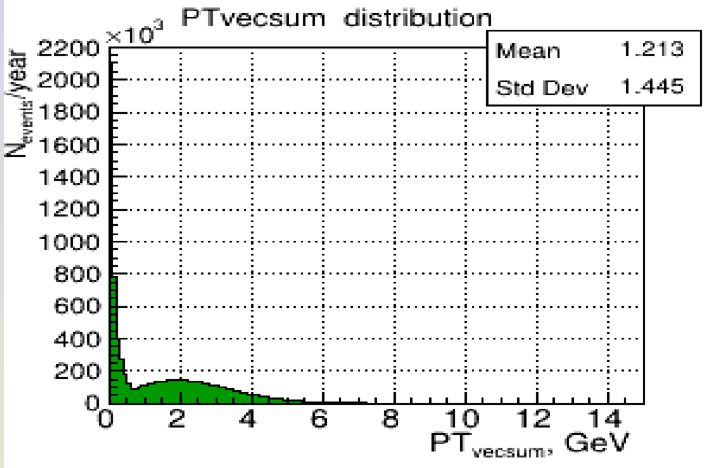


$PT_{vecsum} < 0.2$ GeV

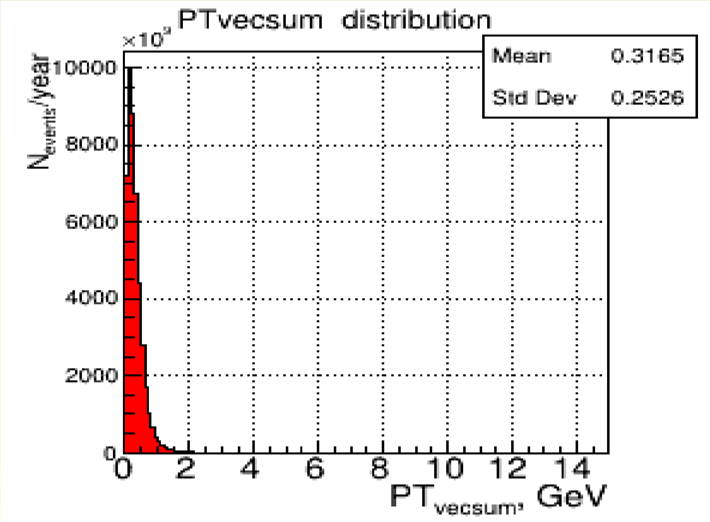
BKG suppression factor (Eff) = 4

Analogous cut on P_{vecsum} - vector sum of all particles momenta in event

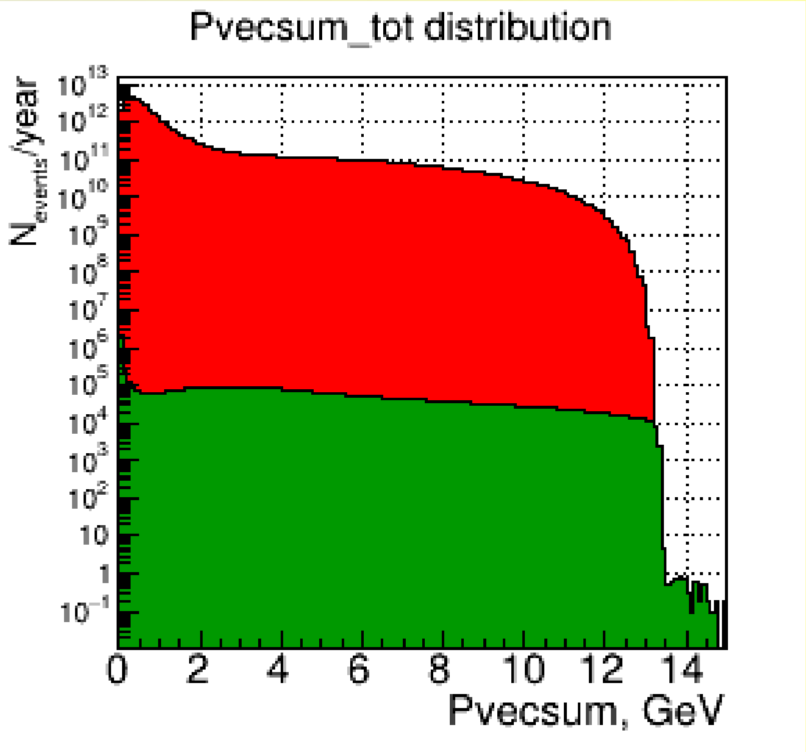
S I G



B K G



Sig & BKG
in log scale

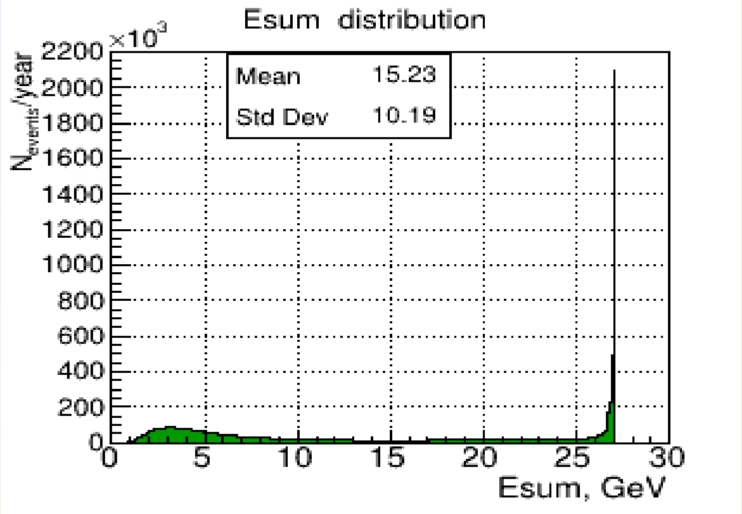


P_{vecsum} < 0.2 GeV

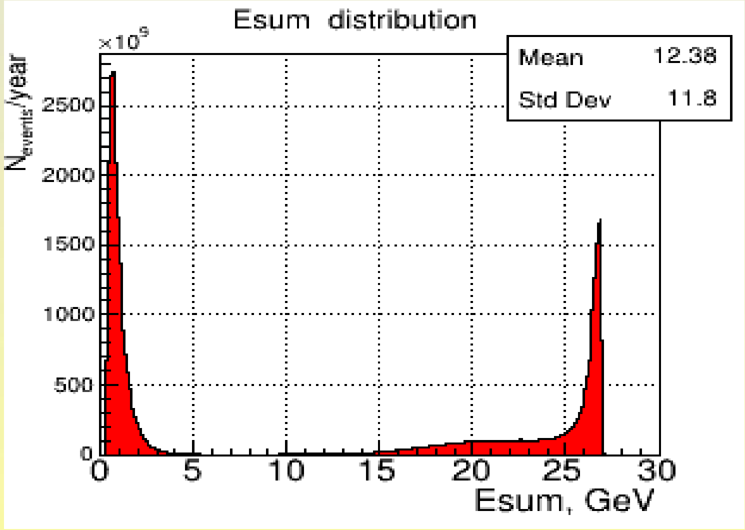
BKG suppression factor (Eff)= 18 - 19

Cut on E_{sum} - summarized energy of all detected particles in event

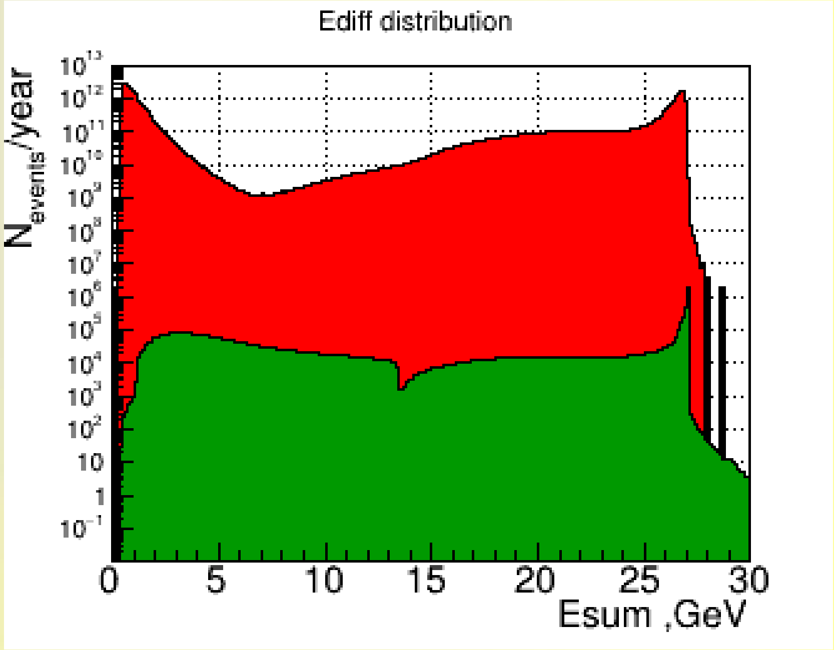
S I G



B K G



Sig & BKG
in log scale



E_{sum} > 26.8 GeV

BKG suppression factor (Eff) = 58 (MB) – 67 (QCD)

Proposed cuts

1. Events with only 2 muons with **PT^{μ} > 0.6 GeV, E^{μ} > 1.0 GeV**
2. Muons are of the **opposite sign**
3. **M_{inv} (μ^+, μ^-) > 1.0 GeV**
4. **PT^{μ}_{fast} > 1.5 GeV**
5. The vertex of production placed within the **distance** from the interaction point R < 1(30) mm
   But! Fit program can misidentify **μ** and **π** as one track due to small angle of **π->μ (+ν)** decay .
6. Cut on summarized energy of all detected (without pipe zone and neutrino) particles in event **E_{sum} > 26.8 GeV**
7. Isolation criterion **$E^{sum}_{(R\ isolation\ =\ 0.2)}$ < 0.5 GeV**

Cuts separate and summarized efficiency for Open Charm background events (10^7)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with **PT^{μ} > 0.6 GeV, $P(E)^{\mu}$ > 1.0 GeV**	0.10	Eff (1,init) = **47.14**	2.1 %	2.45	40.8 %
2^{+1} *2μ are of the **opposite sign***	0.12	Eff (2,1) = **1.21**	1.7 %	1.01	40.5 %
3^{+2+1} M_{inv} *(μ+,μ-) > 1.0 GeV*	0.14	Eff (3,2) = **1.19**	1.4 %	1.01	40.0 %
4^{+3+2+1} PT^{μ}_{Emax} *> 1.5 GeV*	0.82	Eff (4,3) = **8.77**	1.7 x 10^{-1} %	1.53	26.2 %
5^{+3+2+1} E^{all}_{sum} *> 26.8 GeV*	263.3	Eff (5,3) = **5401**	2.7 x 10^{-4} %	2.93	13.6 %
6^{+3+2+1} PT^{all}_{vecsum} *< 0.2 GeV*	1.18	Eff (6,3) = **14.31**	1.0 x 10^{-1} %	1.73	23.1 %
7^{+3+2+1} P^{all}_{vecsum} *< 0.2 GeV*	7.04	Eff (7,3) = **131.6**	1.1 x 10^{-2} %	2.67	15.0 %
8^{+3+2+1} ***Isolation criterium***	> 20433	Eff (8,3) **> 145845**	< 1.0 x 10^{-5} %	1.02	**39.3 %**
9^{+3+2+1} R_{vertex} *< 1 mm*	764.8	Eff (9,3) = **5401**	2.7 x 10^{-4} %	1.01	39.7 %
10^{+3+2+1} R_{vertex} *< 30 mm*	18.6	Eff (10,3) = **131.6**	1.1 x 10^{-2} %	1.01	39.7 %
$5^{+4+3+2+1}$ E^{all}_{sum} > 26.8 GeV	**1306**	Eff (5,4) = **4157**	4.0 x 10^{-5} %	2.61	**10.0 %**
$8^{+4+3+2+1}$ **Isolation criterium**	**> 13238**	Eff (8,4) > **16627**	< 1.0 x 10^{-5} %	1.03	**25.4 %**
$8^{+5+4+3+2+1}$ **Isolation criterium**	**> 5178**	Eff (8,5) > **4**	< 1.0 x 10^{-5} %	1.01	**9.95 %**

Cuts separate and summarized efficiency for Minimun-bias background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with $PT^{\mu} > 0.6$ GeV, $P(E)^{\mu} > 1.0$ GeV	$5.1 * 10^{-4}$	Eff (1,init) = **3480**	2.9×10^{-2} %	2.3	44.1 %
2^{+1} *2μ are of the opposite sign*	$8.9 * 10^{-4}$	Eff (2,1) = **1.8**	1.6×10^{-2} %	1.01	43.8 %
3^{+2+1} $M_{inv}(\mu+,\mu-) > 1.0$ GeV	$1.2 * 10^{-3}$	Eff (3,2) = **1.3**	1.2×10^{-2} %	1.01	43.8 %
4^{+3+2+1} $PT^{\mu}_{Emax} > 1.5$ GeV	$1.1 * 10^{-2}$	Eff (4,3) = **13.2**	9.1×10^{-4} %	1.43	30.5 %
5^{+3+2+1} $E^{all}_{sum} > 26.8$ GeV	$2.6 * 10^{-2}$	Eff (5,3) = **58.3**	2.1×10^{-4} %	2.63	16.6 %
6^{+3+2+1} $PT^{all}_{vecsum} < 0.2$ GeV	$2.9 * 10^{-3}$	Eff (6,3) = **4.1**	2.9×10^{-3} %	1.70	25.7 %
7^{+3+2+1} $P^{all}_{vecsum} < 0.2$ GeV	$9.4 * 10^{-3}$	Eff (7,3) = **18.4**	6.5×10^{-4} %	2.34	18.7 %
8^{+3+2+1} *Isolation criterium*	47.6	Eff (8,3) **= 30177**	4.0×10^{-7} %	1.01	**43.2 %**
9^{+3+2+1} $R_{vertex} < 1$ mm	$8.5 * 10^{-1}$	Eff (9,3) = **710**	1.7×10^{-5} %	1.01	43.5 %
10^{+3+2+1} $R_{vertex} < 30$ mm	$7.1 * 10^{-1}$	Eff (10,3) = **597**	2.0×10^{-5} %	1.01	43.5 %
$5^{+4+3+2+1}$ $E^{all}_{sum} > 26.8$ GeV	$2.3 * 10^{-1}$	Eff (5,4) = **52.7**	1.7×10^{-5} %	2.52	12.1 %
$8^{+4+3+2+1}$ Isolation criterium	24.7	Eff (8,4) = **2280**	4.0×10^{-7} %	1.02	**29.9 %**
$8^{+5+4+3+2+1}$ Isolation criterium	> 54	Eff (8,5) > **173**	$< 1.0 \times 10^{-7}$ %	1.87	**16.3 %**

Cuts separate and summarized efficiency for QCD (+charmonia) background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with PT^{μ} > 0.6 GeV, $P(E)^{\mu}$ > 1.0 GeV	$4.4 * 10^{-5}$	Eff (1,init) = **2471**	4.0×10^{-2} %	2.8	35.3 %
2^{+1} *2μ are of the opposite sign*	$7.4 * 10^{-5}$	Eff (2,1) = **1.7**	2.3×10^{-2} %	1.2	33.3 %
3^{+2+1} M_{inv} (μ+,μ-) > 1.0 GeV	$1.0 * 10^{-4}$	Eff (3,2) = **1.3**	1.7×10^{-2} %	1.0	33.3 %
4^{+3+2+1} PT^{μ}_{Emax} > 1.5 GeV	$7.4 * 10^{-4}$	Eff (4,3) = **14.1**	1.2×10^{-3} %	1.9	17.6 %
5^{+3+2+1} E^{all}_{sum} > 26.8 GeV	$2.4 * 10^{-3}$	Eff (5,3) = **67.4**	2.5×10^{-4} %	2.8	11.7%
6^{+3+2+1} PT^{all}_{vecsum} < 0.2 GeV	$2.5 * 10^{-4}$	Eff (6,3) = **4.2**	4.0×10^{-3} %	1.7	19.6 %
7^{+3+2+1} P^{all}_{vecsum} < 0.2 GeV	$9.3 * 10^{-4}$	Eff (7,3) = **19.7**	8.6×10^{-4} %	2.2	15.7 %
8^{+3+2+1} *Isolation criterium*	> 17	Eff (8,3) **> 169847**	< 1.0×10^{-7} %	1.0	**33.3 %**
9^{+3+2+1} R_{vertex} < 1 mm	$5.5 * 10^{-2}$	Eff (9,3) = **551**	3.0×10^{-5} %	1.0	33.3 %
10^{+3+2+1} R_{vertex} < 30 mm	$4.8 * 10^{-2}$	Eff (10,3) = **479**	3.5×10^{-5} %	1.0	33.3 %
$5^{+4+3+2+1}$ E^{all}_{sum} > 26.8 GeV	$1.6 * 10^{-2}$	Eff (5,4) = **64.5**	1.8×10^{-5} %	3.0	5.9 %
$8^{+4+3+2+1}$ Isolation criterium	> 9	Eff (8,4) **> 12066**	< 1.0×10^{-7} %	1.0	**17.6 %**
$8^{+5+4+3+2+1}$ Isolation criterium	> 3	Eff (8,5) > **187**	< 1.0×10^{-7} %	1.0	**5.9 %**

Conclusion

The proposed cuts:

1. Events with only 2 muons with **$PT^{\mu} > 0.6$ GeV, $E^{\mu} > 1.0$ GeV**
2. Muons are of the **opposite sign**
3. **$M_{inv}(\mu^+, \mu^-) > 1.0$ GeV**
4. **$PT^{\mu}_{fast} > 1.5$ GeV**
5. Cut on summarized energy of all detected (without pipe zone and neutrino) particles in event **$E_{sum} > 26.8$ GeV**
6. Isolation criterion **$E^{sum}_{(R\ isolation = 0.2)} < 0.5$ GeV**

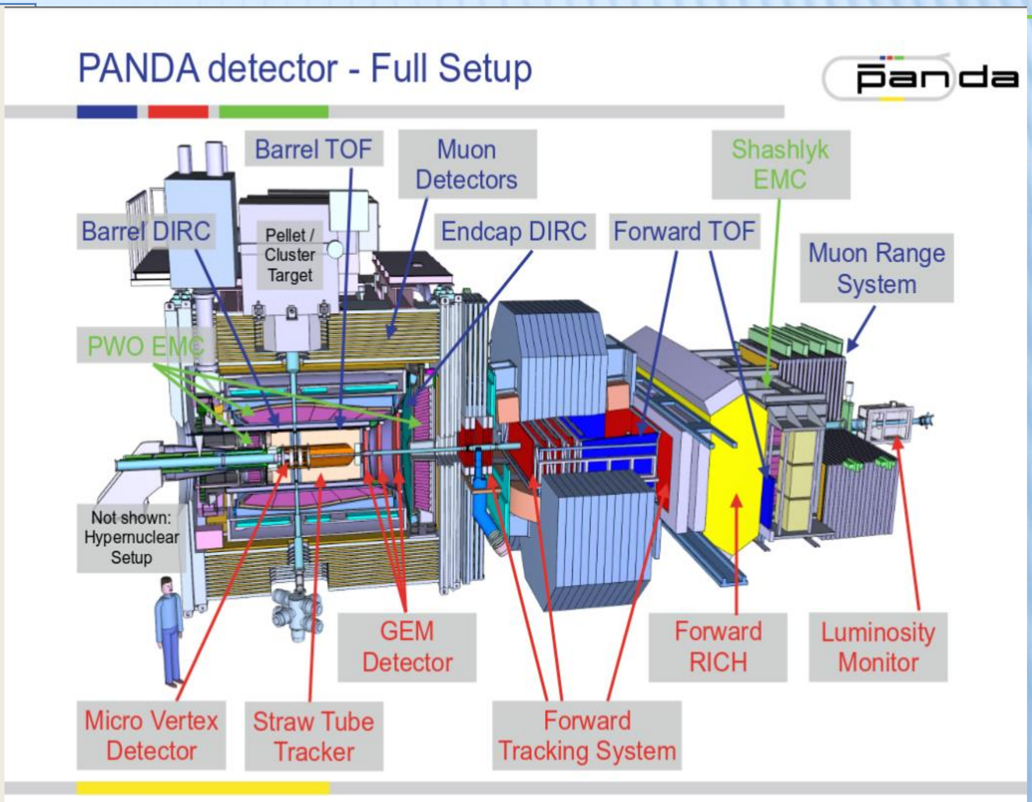
*Allow (in the ideal case) to suppress Mini-bias bkgd up to **S/B ~ 50**, QCD background – up to **S/B >~ 17.***

The SPD Collaboration made a decision to suspend the study of such reactions. **In reality we will not be able to extract experimentally the DY signal from combinatorial background.**

The experience of the Panda collaboration has shown that with similar results, a full simulation taking into account the installation shows worse results than the simulation in Pythia predicted.

THE PANDA DETECTOR

- $\bar{p}p$, $\bar{p}A$ collisions **p_{beam} = 1.5 – 15 GeV/c** *($\sqrt{s}$ from 2.25 up to 5.46 GeV)*
- Internal targets: - Foils (pA,)
  - Cluster jet and pellet (pp)
- P_{beam} with unprecedented degree of monochromaticity $\delta p/p \leq 4\cdot10^{-5}$
- **Luminosity up to $2\cdot10^{32}$ $cm^{-2}s^{-1}$**
- Capability to detect events with high rate (up to $2 \cdot 10^{7}$ s^{-1} interactions)
- **Nearly 4π solid angle** for large acceptance
- Tracking : ~50 μm vertex resolution
- Different PID techniques:
  $\pi^{\pm}$, $K^{\pm}$, $e^{\pm}$, $\mu^{\pm}$, γ identification
  Photon detection from 1 MeV to 10 GeV
- Efficient event selection & good momentum (~1%) and angular resolution



Anti-Proton ANnihilation at DArmstadt

Panda physics overview

Nucleon Structure

Transition Distribution Amplitudes (TDA) (meson production)

Generalised Distribution Amplitudes (GDA) (time-like Compton, hard exclusive processes)

Time-like Electromagnetic Form Factors (Low and high E, e and μ pairs production)

Transverse Parton Distributions (Drell-Yan process)

Nuclear Physics

Hypernuclear physics:

Double Λ hypernuclei

γ-spectroscopy of hypernuclei

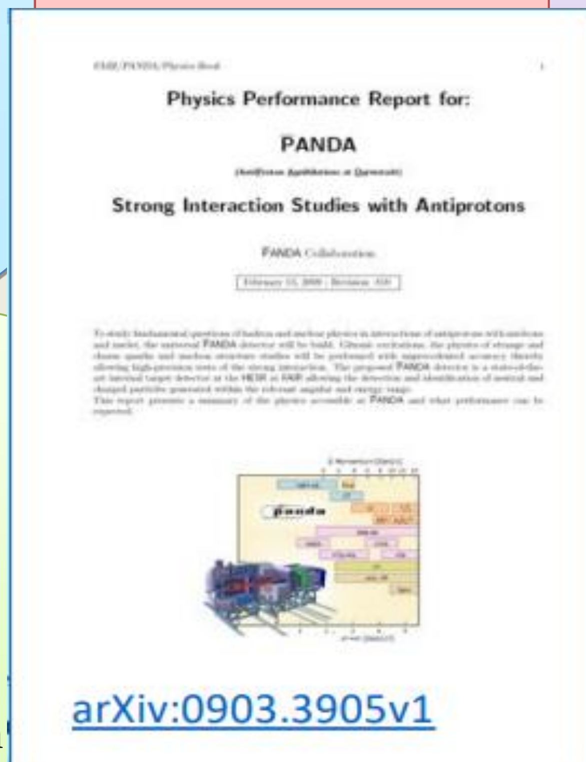
Hyperon interaction

Antihyperon in Nucleai

Hadrons in nuclei:

Charm and strangeness in the medium

Bound states and Dynamics of strong interactions



Physics Performance Report for:

PANDA

Strong Interaction Studies with Antiprotons

PANDA Collaboration

arXiv:0903.3905v1

Hadron spectroscopy

Production of states of all quantum numbers

Resonance scanning with high resolution

Precision determination of mass, width & quantum numbers J^{PC} of resonances

Charm hadrons: charmonia, D-mesons, charm-baryons –> Understand new XYZ states, $D_s(2317)$ and others

Production of exotic QCD states:

Glueballs, hybrids, multi-quarks

Strangeness

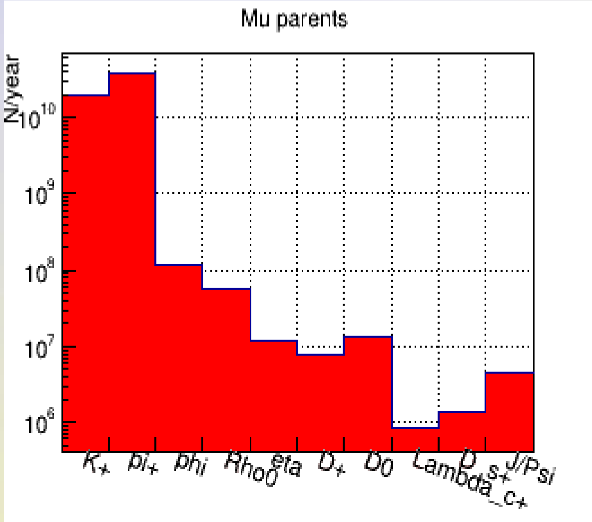
Strange baryons:

Spectroscopy

Polarisation

DY and Background

PYTHIA 6.4 simulation for the E_{cms} = 5.474 GeV



For the Luminosity L = 2×10^{32} cm^{-2} s^{-1} with assumption of the 10^{7} sec/year beam operation we expect up to

9.2 x 10^{7} Drell-Yan events/year

Drell-Yan cross section σ = 4.6 * 10^{3} pb

The most probable parents of bkg muons - are charged π and K

The most probable grandparents of bkg muons - are «string» (Lund model), ρ^0, ρ^+, K^0_S, K^{*0}, K^+, η'

Background cross sections : PYTHIA =~ 37.4 mb

DPM =~ 44.23 mb → initial S/B = 1.04 * 10^{-7}

PYTHIA and DPM give similar kinematical distributions and cross-sections of background events

Thus for reduction of backgrouns the preselection cuts (filters) were chosen as:

Presence of at least 1 (**K+** or **π+**) & (**K-** or **π-**) **with** ***PT > 0.3 GeV*** **and** ***P > 1.5 GeV***

Now for Background calculations we have used **DPM generator** with PandaRoot version ***PandaRoot oct19, FairRoot v18.2, FairSoft june19p1***

Muon identification

Initial number of background generated in DPM events – 1026444289
after precut – 90.000.000 ($9*10^8$)

Used PID algorithm "PidAlgoMvd; PidAlgoStt; PidAlgoDrc; PidAlgoEmcBayes; PidAlgoDisc; PidAlgoMdtHardCuts "
(It was checked with BOX generator that these 6 algorithms allow to detect muons beteer in backward direction compared to stand alone PidAlgoMdtHardCuts)

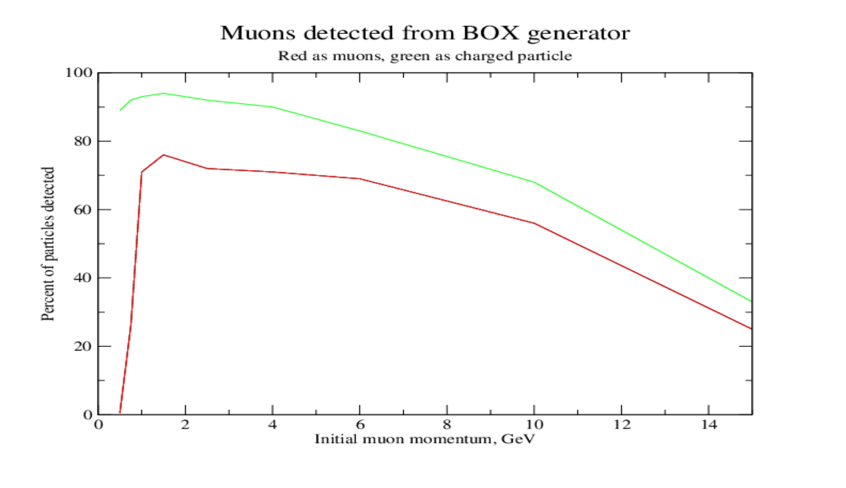
Initial assumption of even **Tight muons (P ≥ 0.5)** **for signal DY events** **(200 000)** give significant loss of muons/event:
0μ= 12,46% 1μ= 46.37% **2μ= 35.31%** 3μ= 5.19% 4μ=0.59% 5μ=0.06% 6μ<0.01%

Finally were taken in consideration Muons **VeryTight** – required **(probability) P ≥ 0.9**
And for DY events we have:
0μ= 18.92% 1μ= 51.46% **2μ= 27.32%** 3μ= 2.12% 4μ=0.15% 5μ<0.01%

There were considered 2 cases :

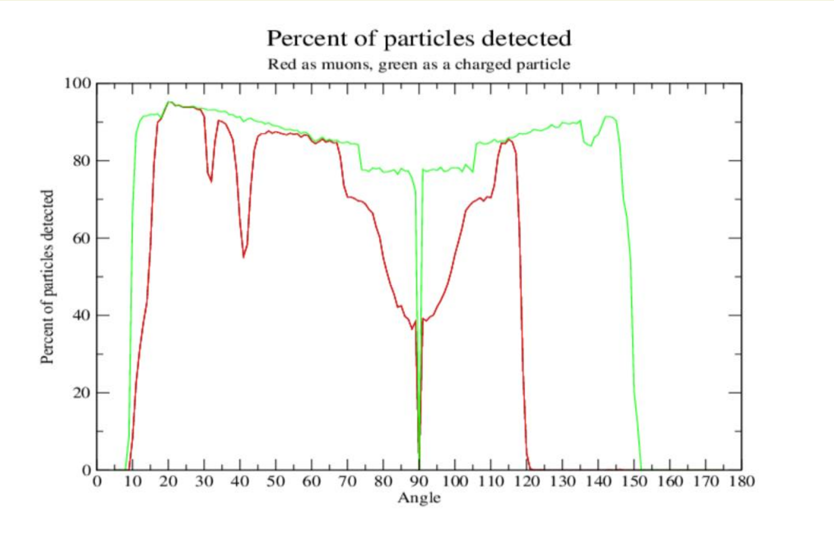
1. All obtained data (without momenta selection*) /all following plots are made for this case/*
2. Only events with "well" measured momenta (ΔP/P < 3%)

Оценка эффективности регистрации мюонов в детекторе на основе Box генератора (10000 events)



Процент обнаружения мюона (красная линия) или произвольной заряженной частицы (зеленая линия) в зависимости от энергии заряженной частицы.

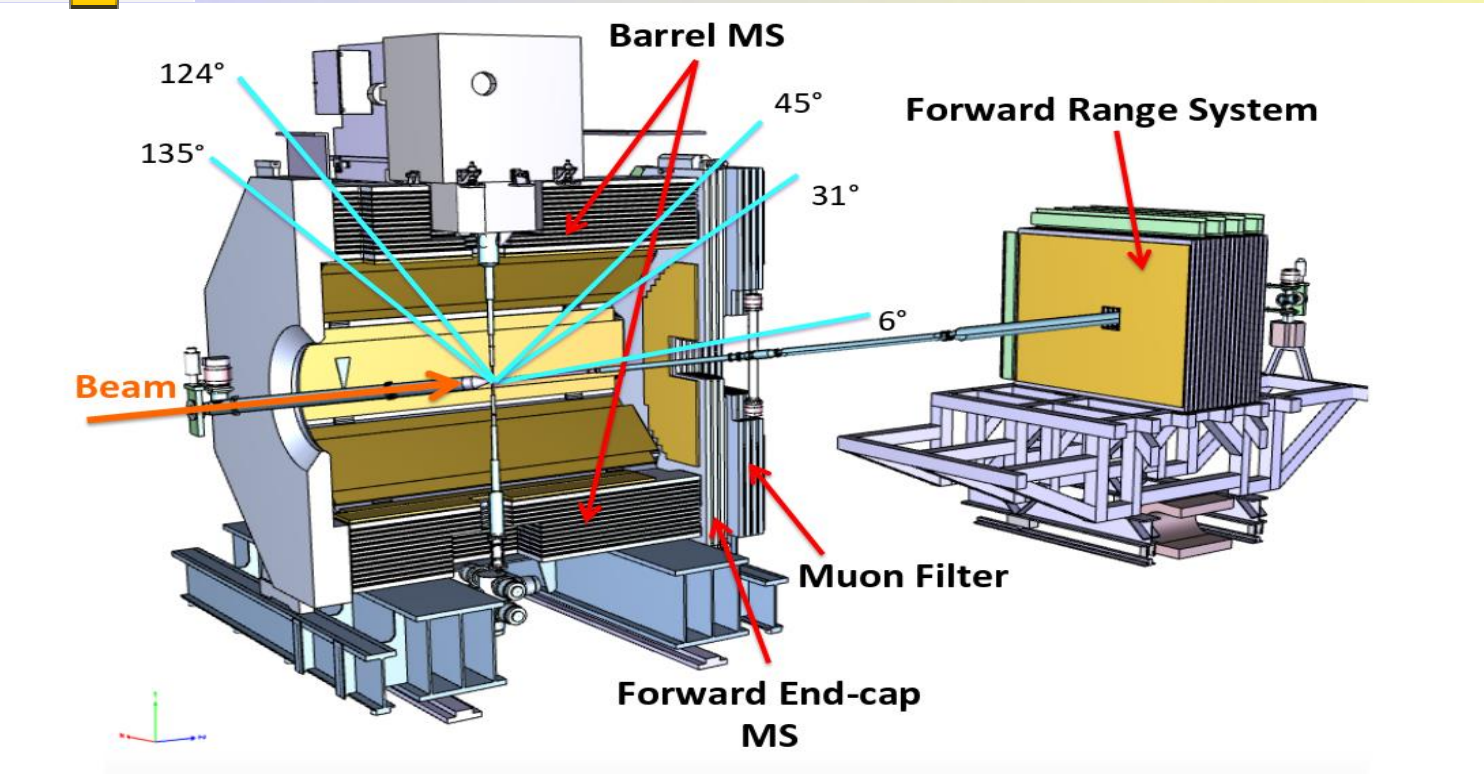
Эффективность регистрации единичного мюона < 70%, пары мюонов < 50%.



Зависимость от угла Θ детектирования мюона в генераторе BOX с одиночным мюоном 5 ГэВ, при угле $5^o < \Theta < 175^o$ с шагом 1^o градус, 10000 событий для каждого угла.

Красная линия - детектируемые мюоны, зеленая - произвольная заряженная частица. Стат погрешность 3 процента.

Muon detectors



The range system technique is used, which is based on a sampling structure of active and passive layers in all subsystems of the MS: Barrel MS, the Forward End-cap, the Muon Filter and the Forward Range System.

The main concept of this technique is the sequential energy loss and particle tracking of charged particles inside a system of alternating active and passive layers. The active layers of the PANDA Muon System will be based on Mini Drift Tubes (MDT's), which are rectangular drift tubes with a central anodic wire for the measurement of one of two coordinates along the detector planes. the second coordinate will be reconstructed by strip boards, placed on top of the MDT's, in which a signal is induced by a particle while traversing the MDT's.

The innermost layer (zero bi-layer) has a double detection layer structure and will be placed in front of the first detection layer. It allows to perform a precise measurement of the starting point coordinate of each particle track in front of the MS and helps the track back propagation to the interaction point.

π/μ rejection

For 5λ of path length in iron.

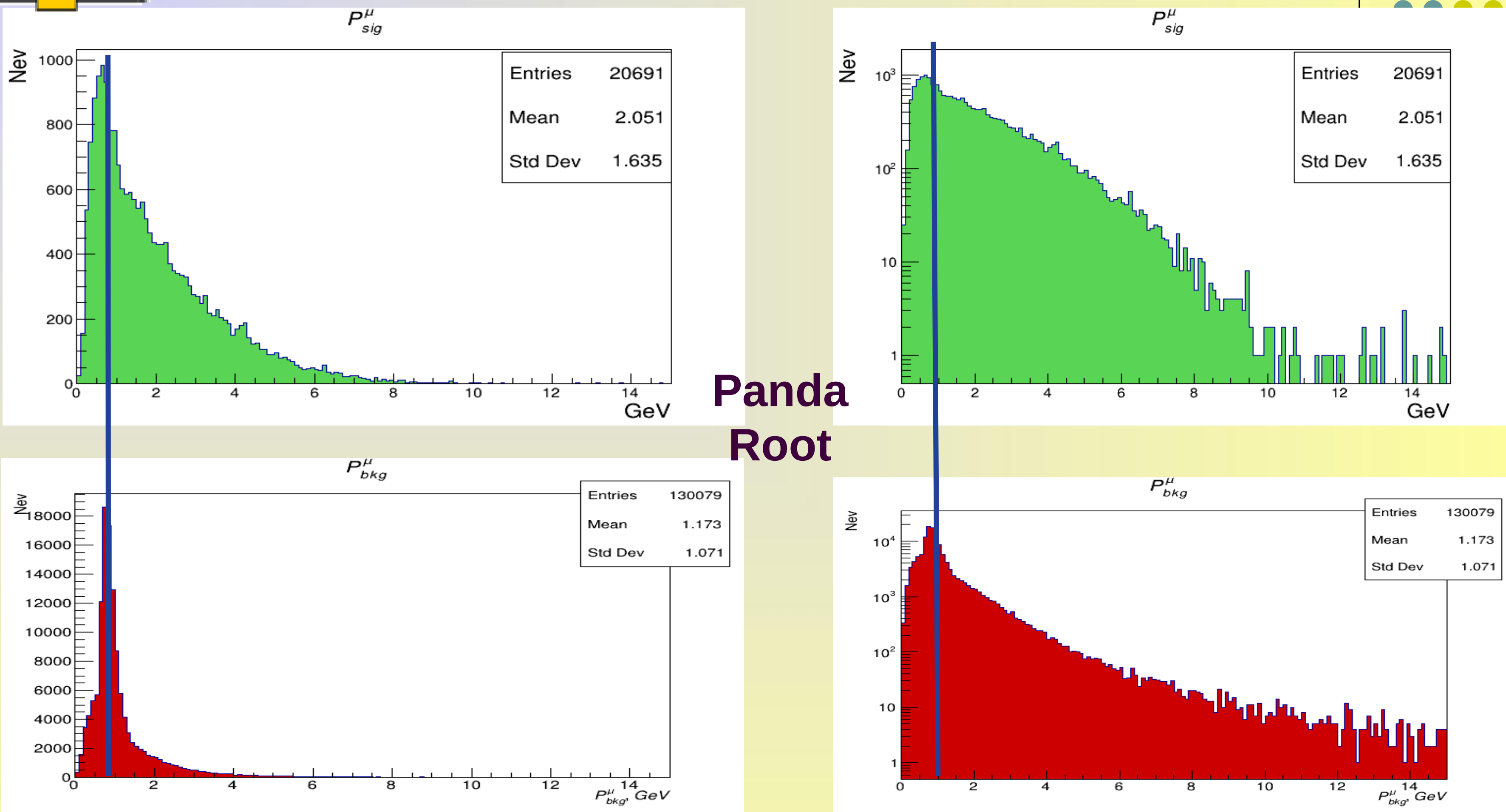
Particle momentum	**π/μ rejection**
0.5 — 1 GeV	~ 80 % (experiment with MS prototype)
1 — 1.5 GeV	~ 90 % (assumption)
> 1.5 GeV	~ 99 % (assumption)

EPJ Web Conf., 177 (2018) 04001

The path length of a charged particle track inside the sandwich structure serves as one of the most powerful variables for μ/π separation, which is challenging due to the similar rest mass of muon and pion

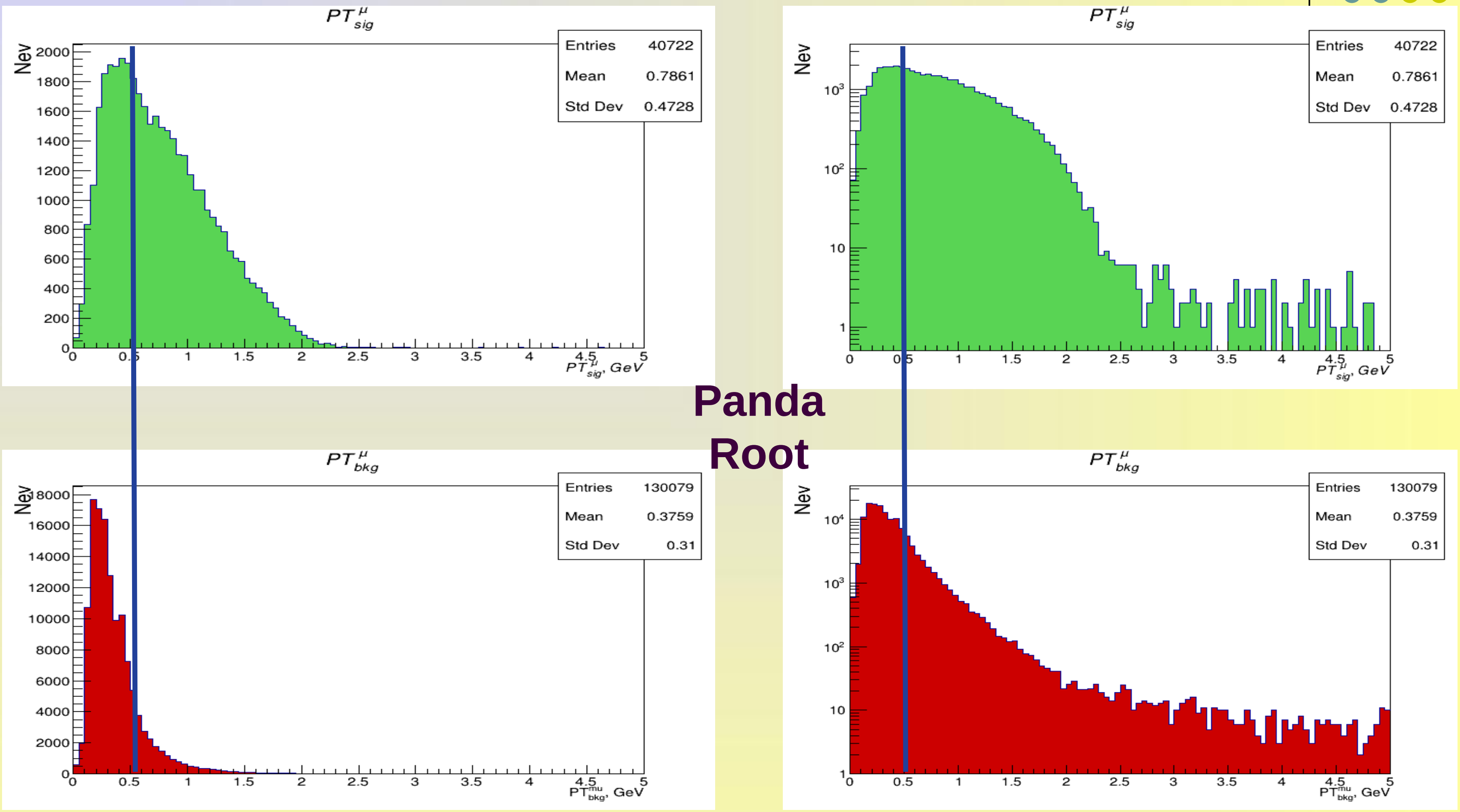
In PANDA detector we have only **~3λ** path length (EMC+MS) in barrel (+ ~5% muon misidentification) and > 5λ (~0.7% misidentification) in forward region.

First cuts — on E(P)$^{\mu}$



Effective cut off is **$P^{\mu} > 1.0$ GeV**

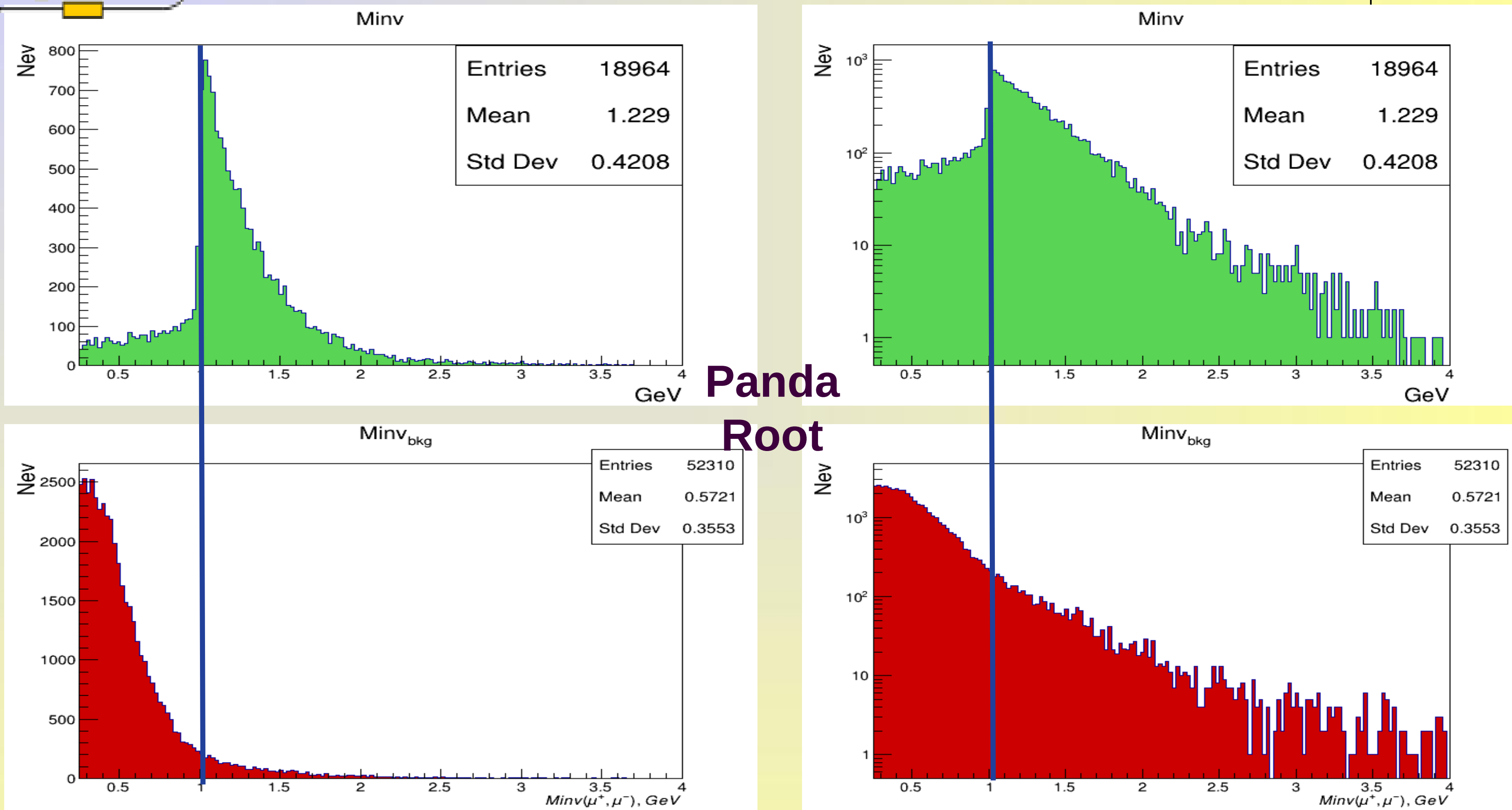
First cuts — on PT^{μ}



Panda Root

Effective cut off is **PT^{μ} ~ 0.5 GeV**

Invariant mass Minv(μ^+, μ^-) cut



The most effective cut is in the region **Minv >1 GeV**.

The peak at 1 GeV for DY is caused by some internal PYTHIA restrictions.

E^{μ}/PT^{μ} correlations for muons with max(fast)/min(slow) E^{μ} in the pair

S
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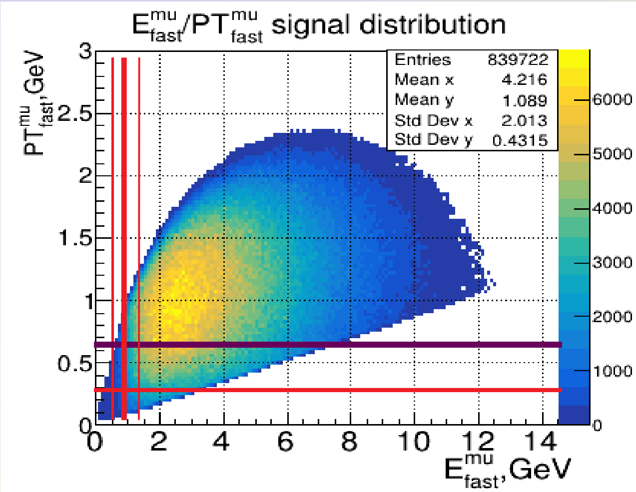
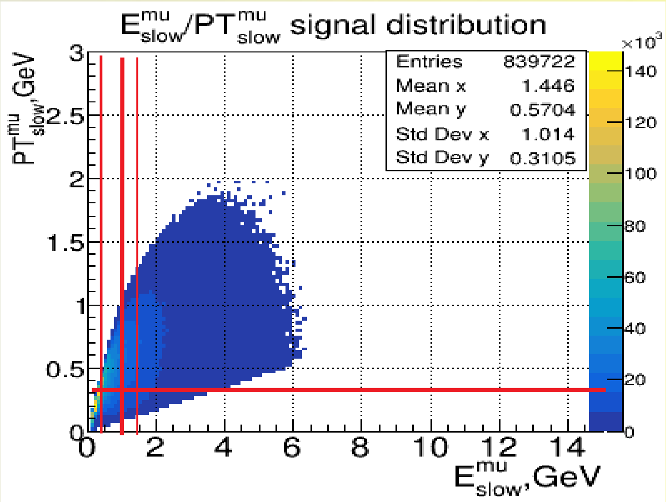
G





P
Y
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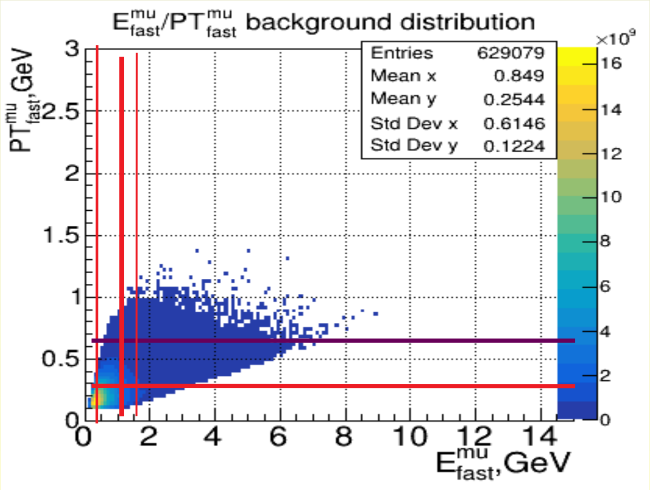
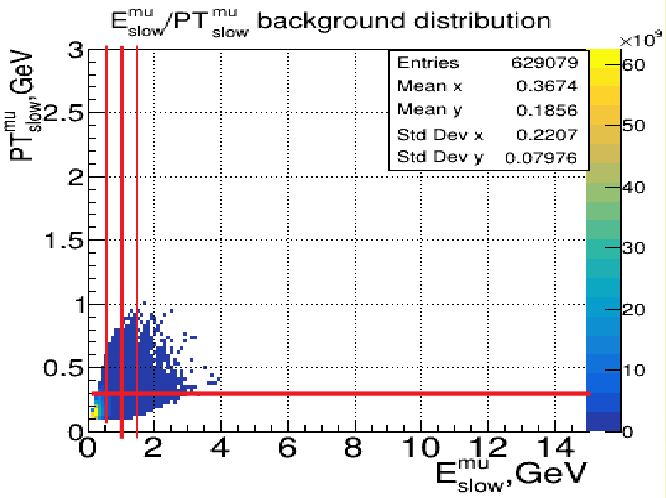
$PT^{\mu}_{\mathcal{E}max}$ > 0.7 GeV can also be considered

B
K
G

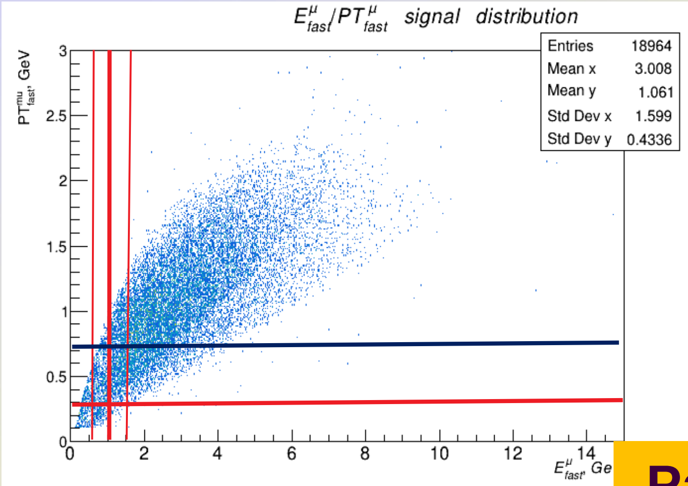


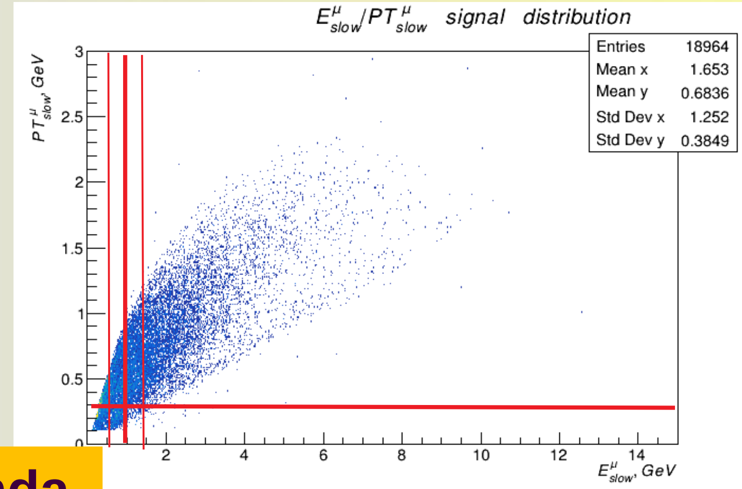


Cut on PTμ > 0.3 GeV and E(P)μ > 1.0 (0.5, 1.5) GeV

E^{μ}/PT^{μ} correlations for μ muons with max(fast)/min(slow) E^{μ} in the pair

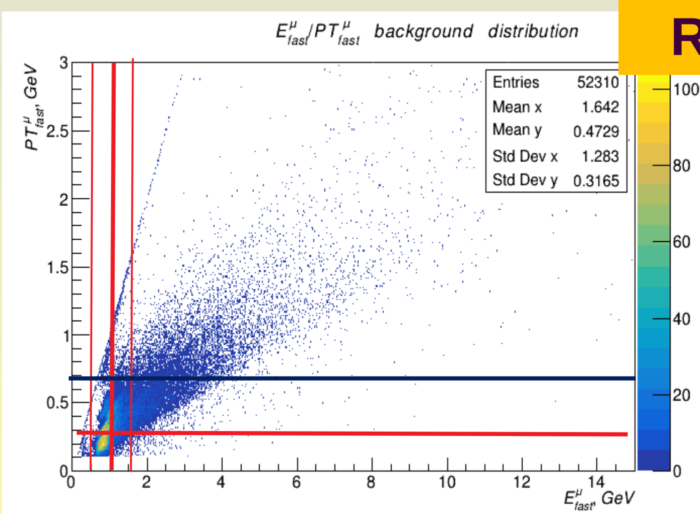
S I G

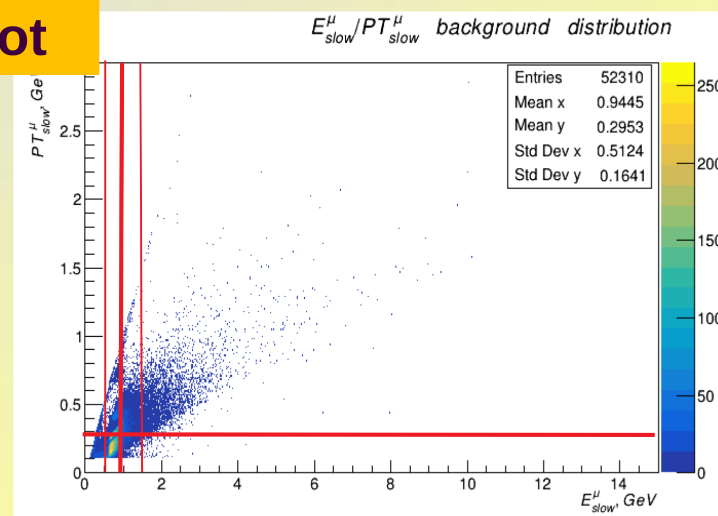




Panda Root

B K G



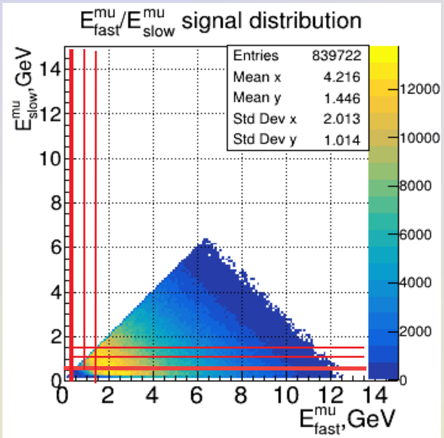


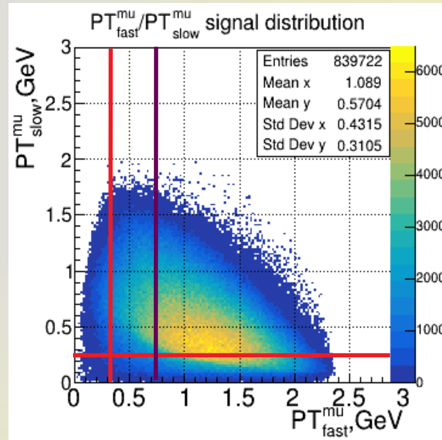
PT^{μ}_{Emax} > 0.7 GeV *additionally will be more efficient*

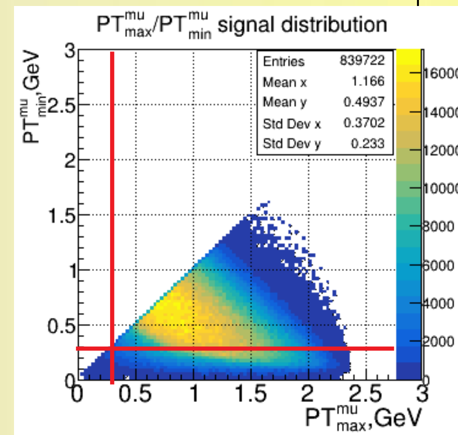
Cut on PTμ > 0.3 GeV and E(P)μ > 1.0 (0.5, 1.5) GeV

E_{max}(fast) /E_{min}(slow), PT_{fast} /PT_{slow}, PT_{max}/PT_{min} distributions

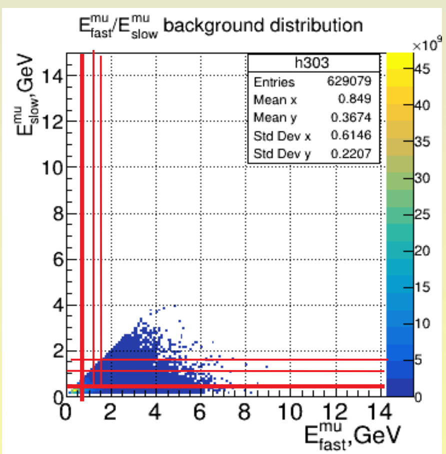
S I G

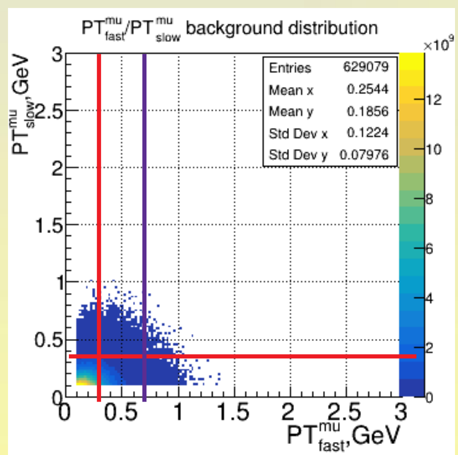


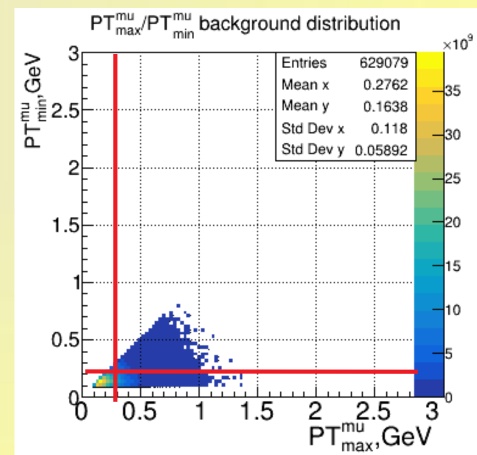




B K G







P Y T H I A

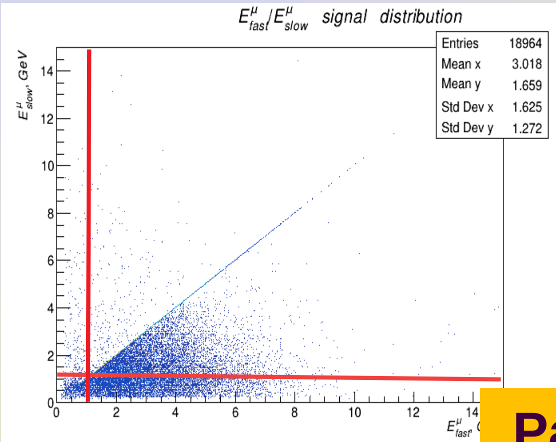
E(P) > 0.5 GeV
E(P) > 1.0, 1.5 GeV

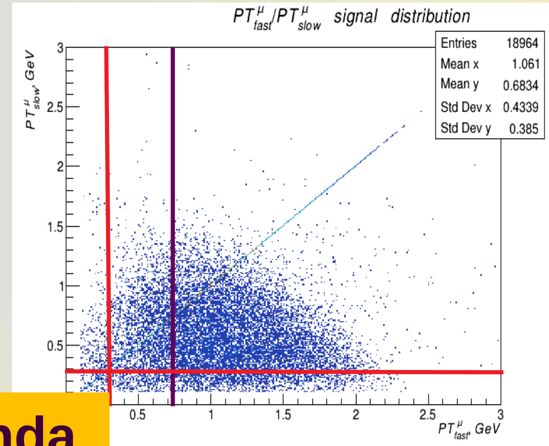
PT > 0.3 GeV,
PT_{fast} > 0.7 GeV

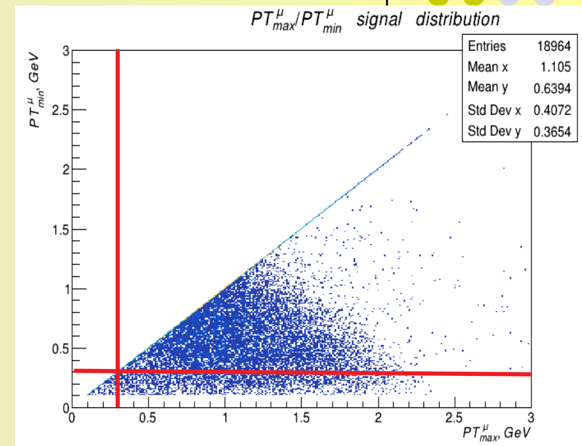
PT > 0.3 GeV

E_{max}(fast) /E_{min}(slow), PT_{fast} /PT_{slow}, PT_{max}/PT_{min} distributions

S I G

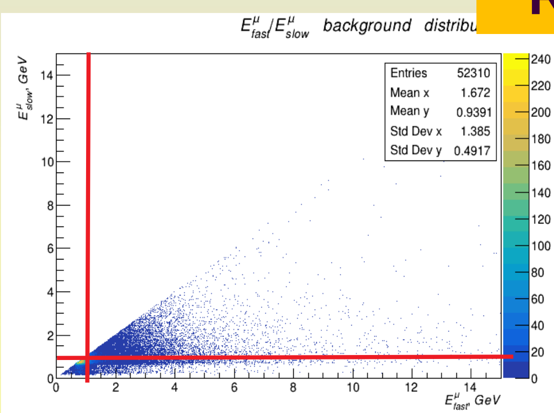


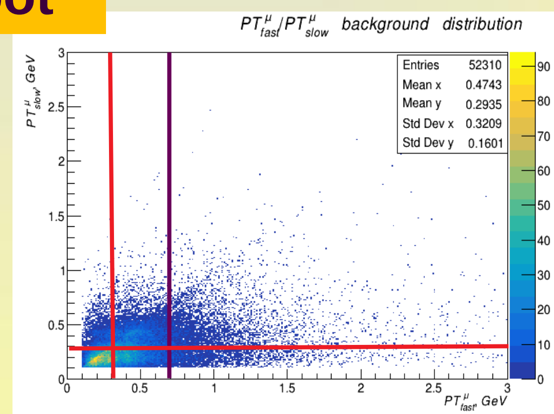


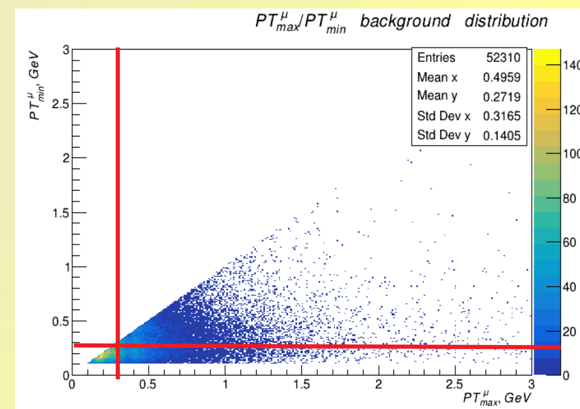


Panda Root

B K G







E(P) > 1.0 GeV

PT > 0.3 GeV,
PT_{fast} > 0.7 GeV

PT > 0.3 GeV

P
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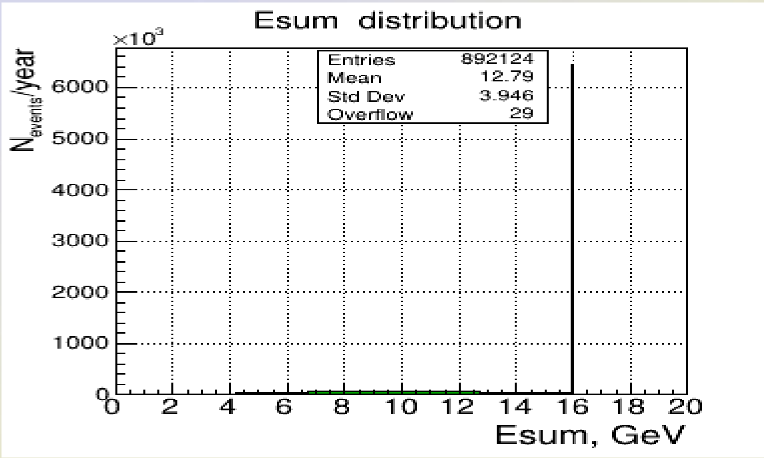
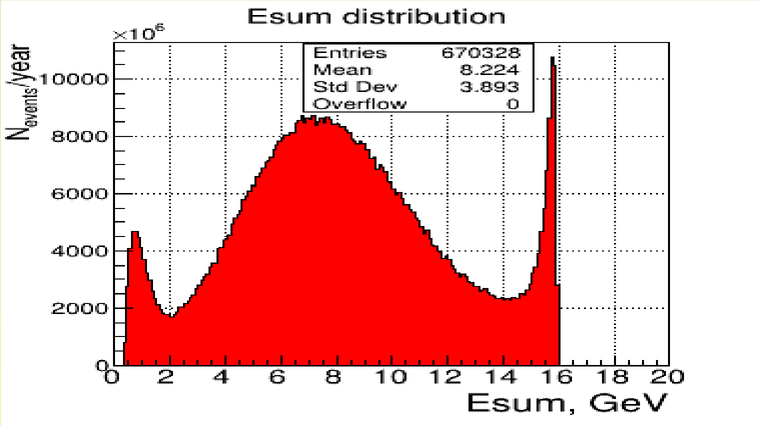
Cut on E_{sum} - summarized energy of all particles in event

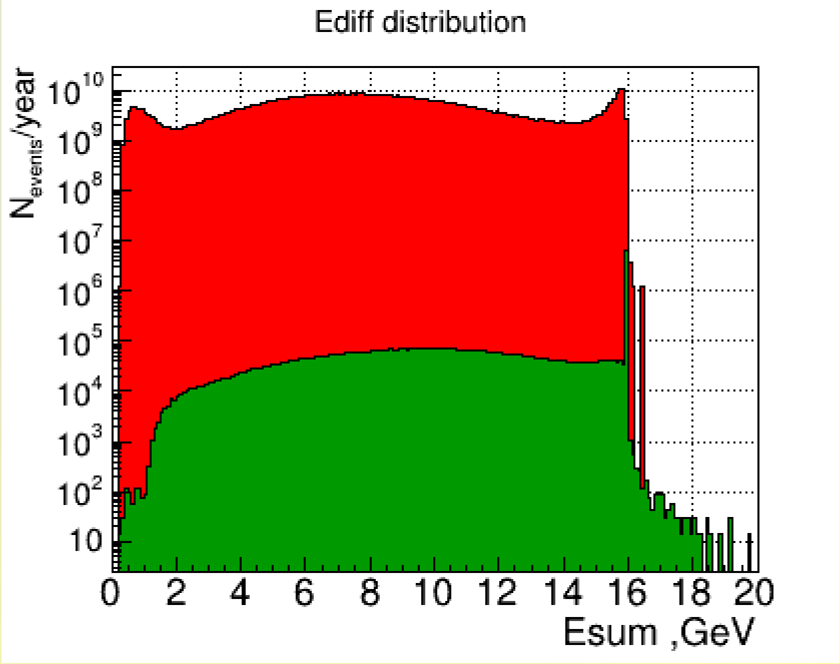
S
I
G



B
K
G



Sig & BKG
in log scale

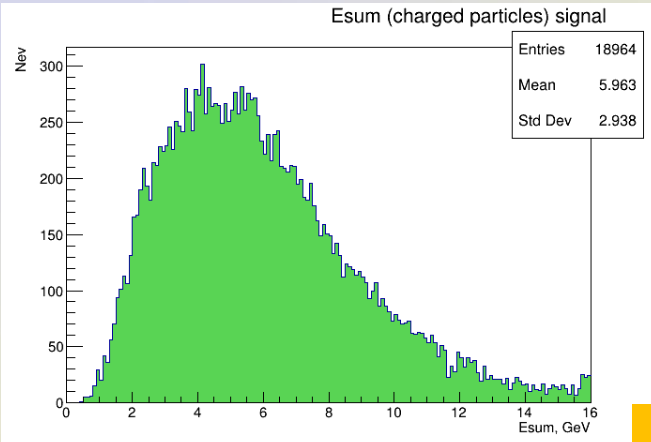


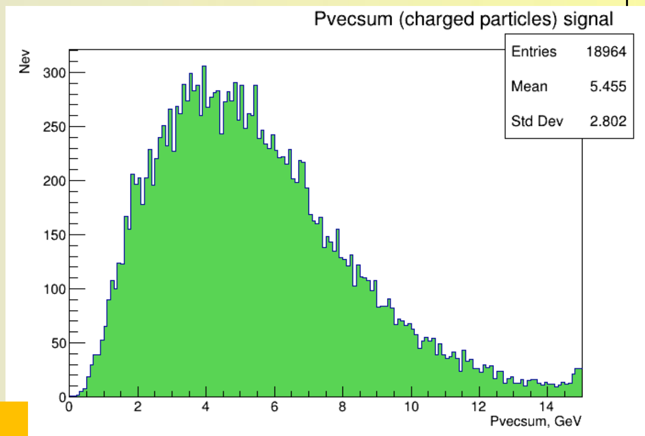
E_{sum} > 15.8 GeV

Excpected BKG suppression factor (Eff) ~ 50-100

Cut on Esum - summarized energy of all *charged particles* in event and their vector sum of P

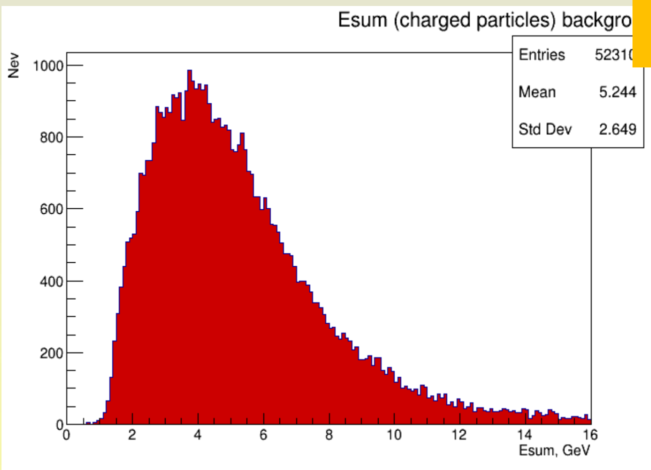
S I G

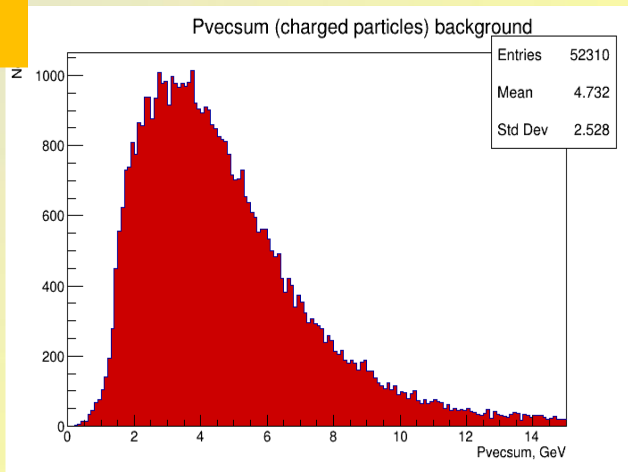




Panda Root

B K G

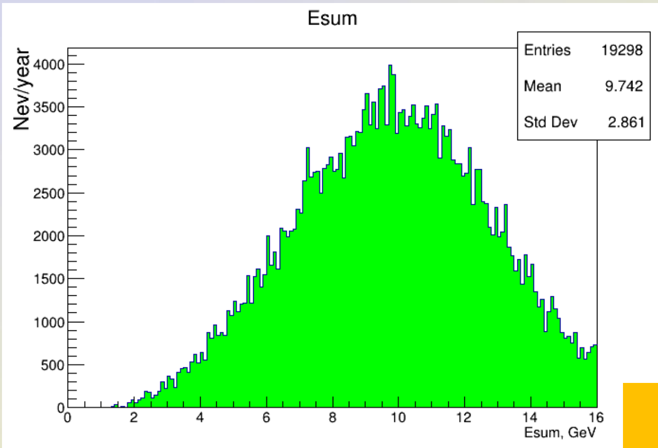


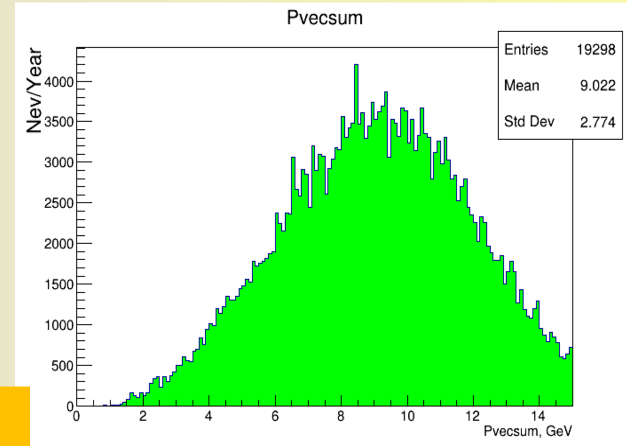


For only charged particles these variables obviously do not work

Esum - summarized energy of *all particles* in event and Pvecsum- their momenta vector sum

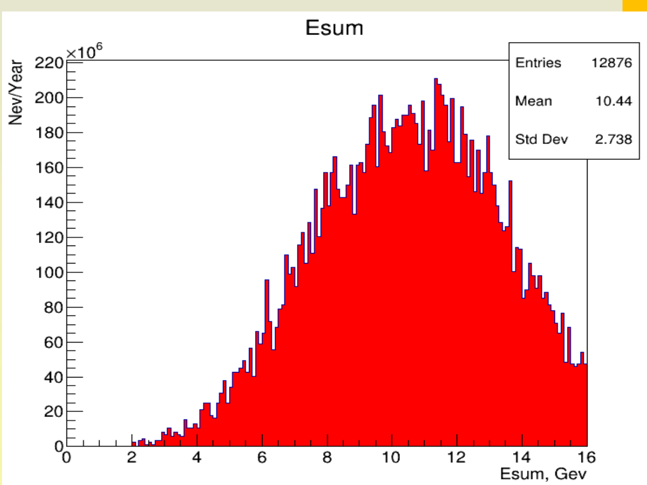
SIG

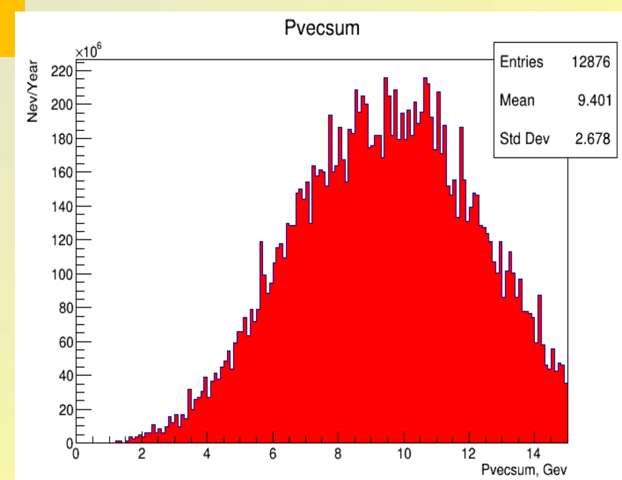




Panda Root

BKG

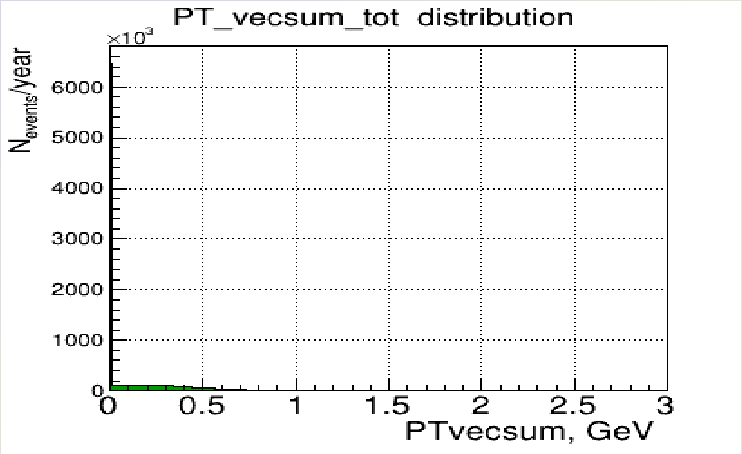




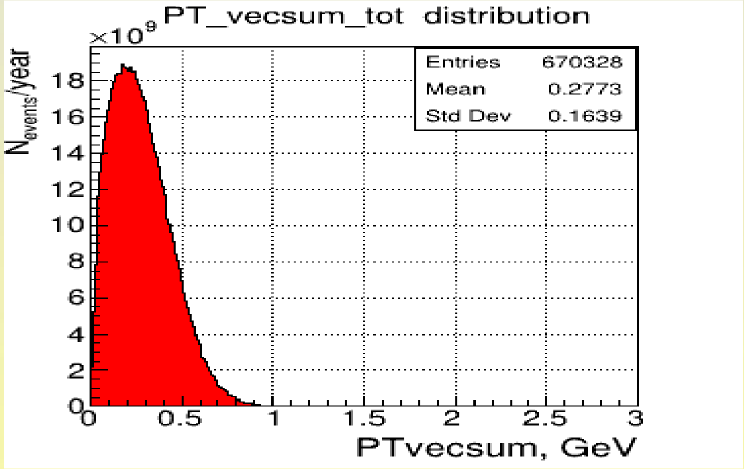
For all particles these variables also do not work

Cut on PTvecsum - vector summa of all particles transverse momenta in event

S I G



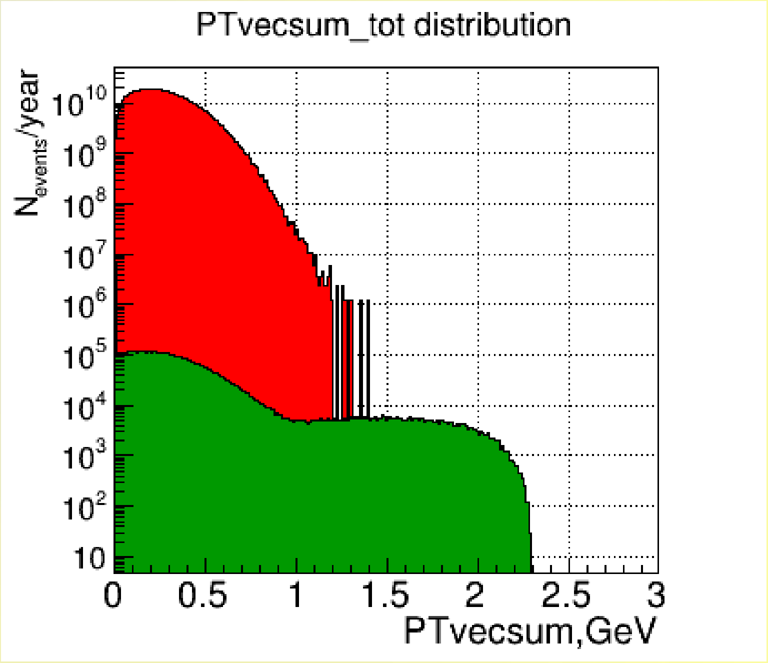
B K G



PT_{vecsum} < 0.2 GeV

Sig & BKG

in log scale

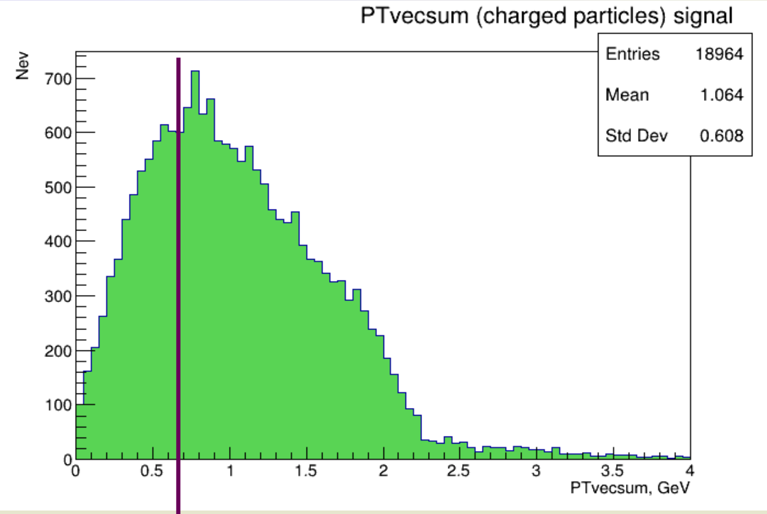


P Y T H I A

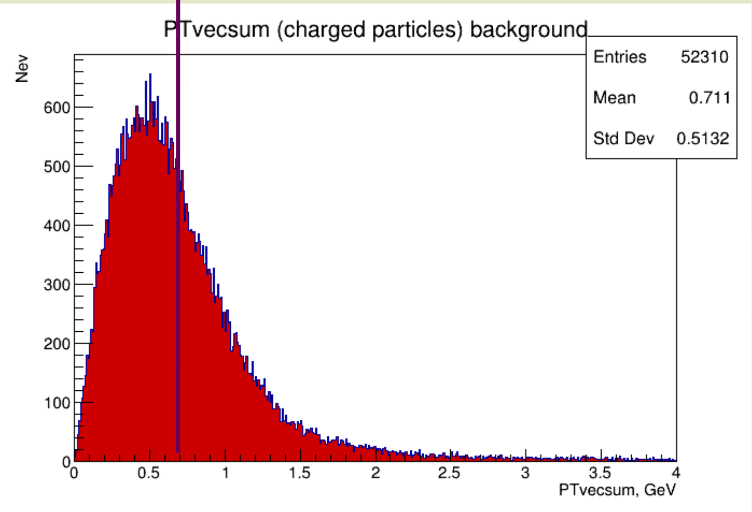
Excpected BKG suppression factor (Eff) ~ 3

Cut on PT- vector sum of all charged particles transverse momenta in event

S I G



B K G



Panda Root

PT_{vecsum} > 0.7 GeV can help to improve S/B ratio (?)

Lepton (μ) isolation criteria

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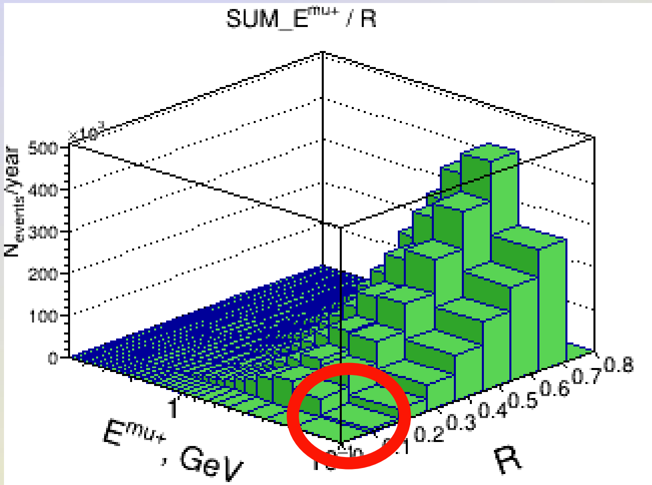
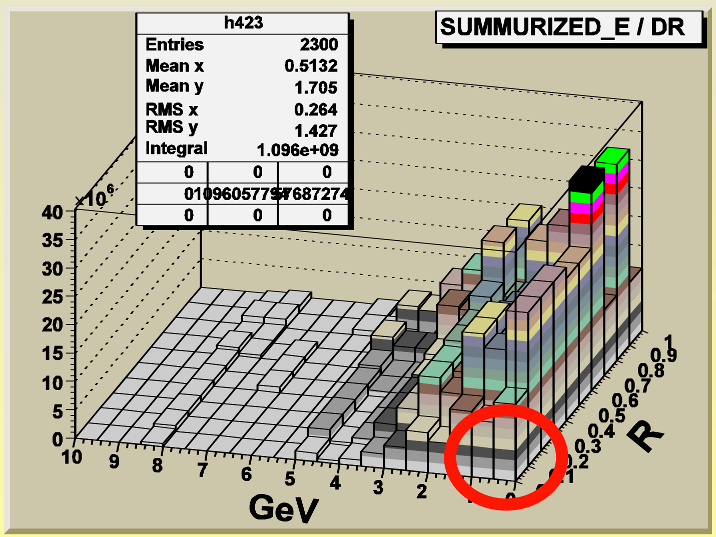




The plots show the distributions over ***summarized energy*** of the final state charged particles in the cones of radius $R_{isolation} = \sqrt{\Delta\eta^2+\Delta\varphi^2}$ respect to the *(η – pseudorapidity, φ — azimuthal angle)*

upper plot - **signal events**

bottom plot - **Mini-bias background**

Isolation criteria ($R_{isolation} = 0.2$)

$E^{(of\ particles)} < 0.5$ GeV

allows to separate most part

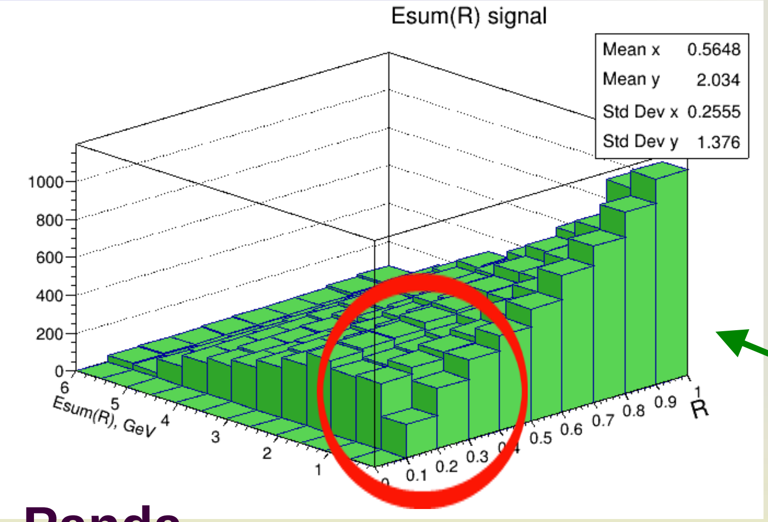
of Mini-bias & QCD bkg muons

with the loss of < **0.7 %** of signal events

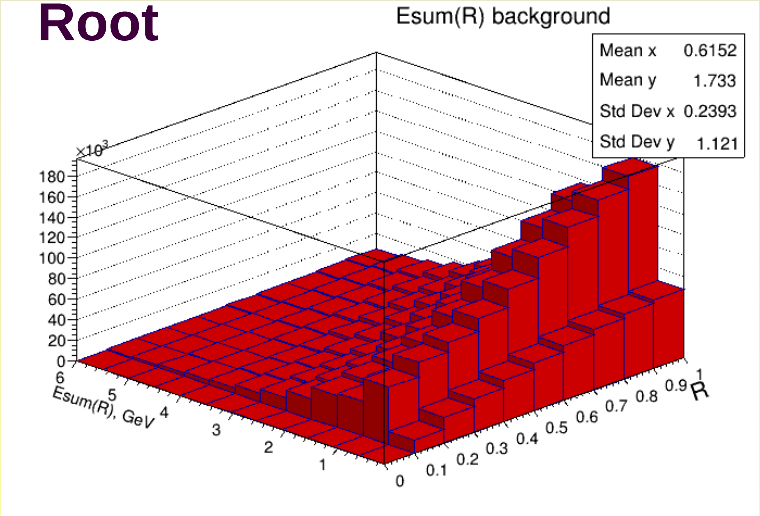
after applied cuts discussed above

But! ***In PandaRoot shows tentatively worse results***

Lepton (μ) isolation criterion



Panda Root



The plots show the distributions over ***summarized energy*** of the final state charged particles in the cones of radius **$R_{isolation} = \sqrt{\Delta\eta^2+\Delta\varphi^2}$** respect to the *(η – pseudorapidity, φ — azimuthal angle)*

upper plot - **signal events**

bottom plot **- background**

Isolation criteria **($R_{isolation}$ = 0.2)**
$E_{(of\ particles)}$ < 0.5 GeV

<u>"Isolation criterion" in Full PandaRoot simulation shows visibly worse results than in "pure" generators</u>

Proposed cuts

1. *Events with only 2 muons with*

$PT_{\ell} > 0.3$ GeV, $E(P)_{\ell} > 1.0$ GeV

2. *Muons are of the opposite sign*

3. *$M_{inv}(l^+, l^-) > 1.0$ GeV*

4. $PT^{\mu}_{fast} > 0.7$ GeV

5. Vector sum of charged particles $PT^{sum} > 0.7$ GeV

6. *Isolation criterion $E^{sum}_{(R\ isolation = 0.2)} < 0.5$ GeV*

P
Y
T
H
I
A

Summarized efficiency of subsequent cuts for minimum-bias background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with $PT_l > 0.3$ GeV, $E(P)_l > 0.5$ GeV	**$3.14 * 10^{-4}$**	Eff (1,init) = **3879**	2.6×10^{-2} %	1.6	62.3 %
2^{+1} *2μ are of the opposite sign*	**$4.75 * 10^{-4}$**	Eff (2,1) = **1.52**	1.7×10^{-2} %	1.6	62.3 %
3^{+2+1} *$M_{inv}(\mu^+,\mu^-) > 1.0$ GeV*	**$3.47 * 10^{-3}$**	Eff (3,2) = **7.48**	2.3×10^{-3} %	1.02	60.8 %
4^{+3+2+1} *$PT^{\mu}_{fast} > 0.7$ GeV*	**$2.01 * 10^{-2}$**	Eff (4,3) = **6.92**	3.3×10^{-4} %	1.2	50.7 %
$5^{+4+3+2+1}$ $E^{all}_{sum} > 15.8$ GeV	**1.0**	Eff (5,4) = **86.5**	1.0×10^{-7} %	1.7	**29.2 %**
$6^{+5+4+3+2+1}$ $PT^{all}_{vecsum} < 0.2$ GeV	**---==---**	Eff (6,5) = **1**	---==---	1	**---==---**
$7^{+5+4+3+2+1}$ $P^{all}_{vecsum} > 14.8$ GeV	**---==---**	Eff (7,5) = **1**	---==---	1	**---==---**
$8^{+4+3+2+1}$ **Isolation criterium**	**> 65**	Eff (8,4) > **3288**	$< 1.0 \times 10^{-7}$ %	1.01	**50.0 %**
$8^{+5+4+3+2+1}$ **Isolation criterium**	**> 38**	Eff (8,5) > **216**	$< 1.0 \times 10^{-7}$ %	1	**29.2 %**

PT^{all}_{vecsum} and P^{all}_{vecsum} cuts are correlated with the cut on E^{all}_{sum}

Cuts separate and summarized & their efficiencies for DPM background events

("Good" P)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with $PT_l > 0.3$ GeV, $P_l > 1.0$ GeV	$3.90 * 10^{-5}$	Eff (1,init) =12011.8	8.32×10^{-3} %	**32.05**	**3.12 %**
2^{+1} *2μ are of the opposite sign*	$5.11 * 10^{-5}$	Eff (2,1) = 1.45	5.74×10^{-3} %	1.10	2.82 %
3^{+2+1} $M_{inv}(\mu^+,\mu^-) > 1.0$ GeV	$8.91 * 10^{-5}$	Eff (3,2) = 7.45	7.70×10^{-4} %	1.06	2.66 %
4^{+3+2+1} $PT^{\mu}_{all\,Emax} > 0.7$ GeV	$4.56 * 10^{-4}$	Eff (4,3) = 1.44	5.36×10^{-4} %	1.13	2.35 %
5^{+3+2+1} $PT_{vecsum} > 0.7$ GeV	$8.47 * 10^{-4}$	Eff (5,3) = 3.11	2.48×10^{-4} %	1.32	2.02 %
6^{+3+2+1} *Isolation criterion*	$3.65 * 10^{-4}$	Eff (6,3) =1.09	7.03×10^{-4} %	1.08	2.47 %
$5^{+4+3+2+1}$ $PT^{all}_{vecsum} > 0.7$ GeV	$1.03 * 10^{-3}$	Eff (5,4) = 1.33	1.85×10^{-4} %	1.10	**1.82 %**
$6^{+4+3+2+1}$ Isolation criterion	$4.62 * 10^{-4}$	Eff (6,4) =1.09	4.90×10^{-4} %	1.08	2.18 %
$6^{+5+4+3+2+1}$ Isolation criterion	$1.01 * 10^{-3}$	Eff (6,5) =1.44	1.72×10^{-4} %	1.20	**1.68 %**

So, finaly, "Isolation criterion" doesn't bring *additional* background suppression

Conclusion

So final Full generation of Signal (PYTHIA6) and Background (DPM) with PandaRoot has shown ~4 orders of magnitude worse S/B separation results that were predicted by Fast generation.

The best achieved ***S/B ratio = 1/1000***

That can be caused by:

1. *Not good enough current particle identification (only ~30% of signal is fully determined) {could give factor x2-3}.*
2. *Errors in momenta determination (even within Std.Dev. account) {could be factor x3, in comparison with Fast simulation}*

/finally ~10 times less signal events after the1st cut/

That all together with some adjustments of kinematical parameters (using neural networks) in the very best case could give total a factor ~x10.

But!!! That will not allow to improve S/B to any acceptable level.

e^+e^- case

Simulation of e+e- pairs was performed for the E_{beam} = 15 GeV (E_{cms} =5.474 GeV) with use of PandaRoot & Geant 4 with the set of 100.000 signal & 2.000.000 background events generated by PYTHIA6.4 (& compared to DPM).

According to PYTHIA6.4, the total cross section of **e+e- pairs production** process (Drell-Yan) at the energy of **p** beam E_{beam} = 15 GeV is **4.6×10^{-6} mb**. The total cross section for the **background processes (QCD & Minimim-bias)** is **37.4 mb**. Thus the initial ratio of the signal to background is **$S/B = 1.23 \times 10^{-7}$**.

Proposed separation criteria

1. *Events with exactly $1e^+$ $1e^-$ with* $PT_e > 0.2$ GeV, $E(P)_e > 0.2$ GeV
2. *Leptons are of the opposite sign*
3. *$Minv_e$ $(l^+, l^-) > 0.7$ GeV*
4. $PT_{fast} > 0.4$ GeV
5. *Isolation criterion* $E^{sum}_{(R\ isolation\ =\ 0.2)} < 0.5$ GeV

Cuts and their efficiencies for background e+e- events

Panda Root

Initial signal to background raion is S/B = 1.23 x 10^{-7}.

The percentage ratio of events with a certain number of registered e^{+} (e^{-}) in event:

Criterion	background, %	signal, %
0 electrons	**95.0079**	**27.80**
1 electron (positron)	**3.58**	**30.33**
> 1 electrons (positrons)	**0.2462**	**4.34**
exactly 1 electron + 1 positron	**1.166**	**37.53**

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 ***Exactly 2e*** with **PT_l > 0.2 GeV, P_l > 0.2 GeV**	**6.23 * 10^{-4}**	Eff (1,init) =18099	5.5 x 10^{-3} %	**3.01**	**33.22 %**
+1 **2** ***2e*** *are of the* ***opposite sign***	**6.95 * 10^{-4}**	Eff (2,1) = 1.99	2.77 x 10^{-3} %	1.82	18.27 %
+2+1 **3** ***$M_{inv}(e^+,e^-)$ > 0.7 GeV***	**2.76 * 10^{-3}**	Eff (3,2) = 5.18	5.35 x 10^{-4} %	1.28	14.24 %
+3+2+1 **4** ***PT^{μ}_{Emax} > 0.4 GeV***	**4.50 * 10^{-3}**	Eff (4,3) = 2.27	2.35 x 10^{-4} %	2.40	10.17 %

"Isolation criterion" doesn't bring *additional* background suppression.
No more kinematical variables for S/B separation are visible.

Achieved S/B is not enough for the signal allocation

Thank you for your attention!

and

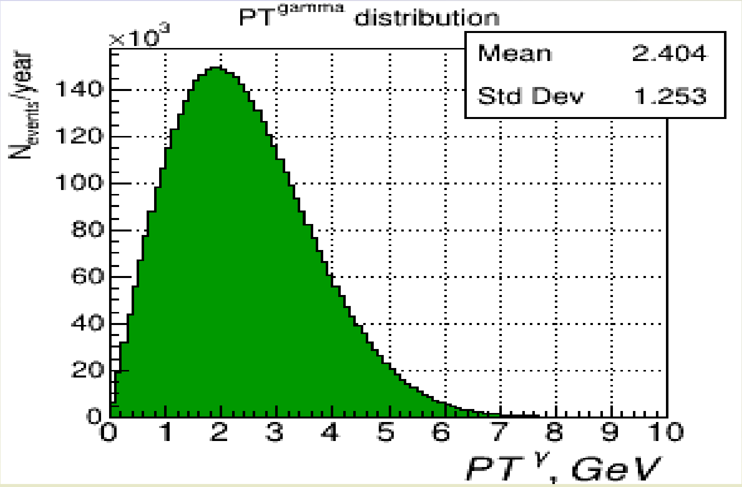
Happy and healthy New Year !

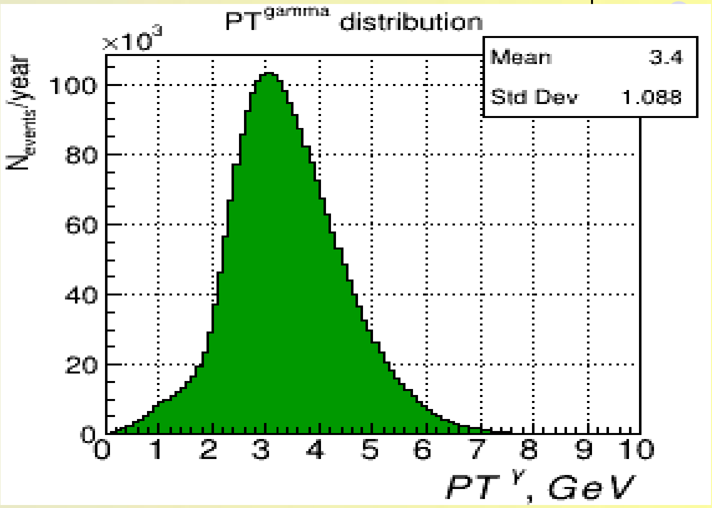
Back up slides

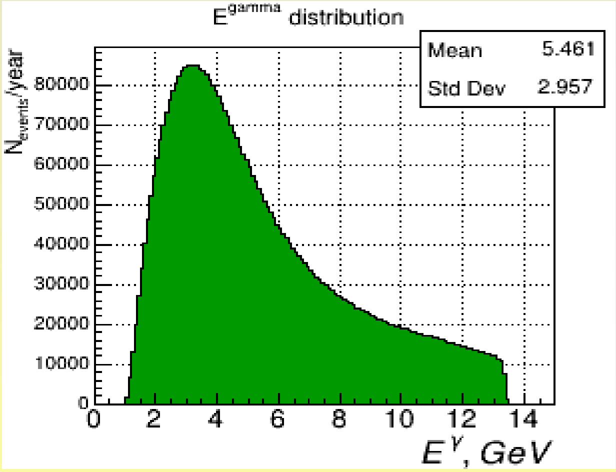
Intermediate γ* distributions

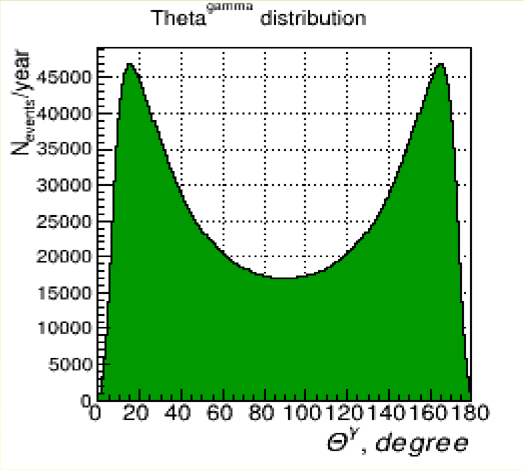
Without cuts

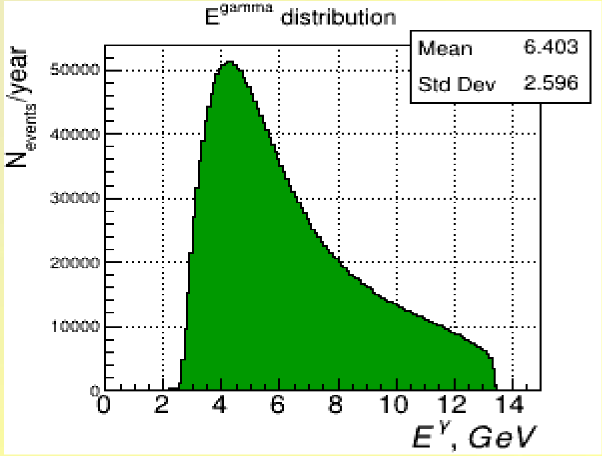
After cuts





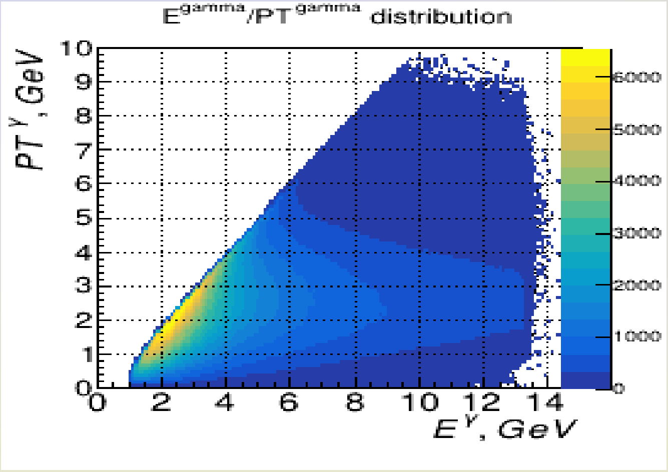




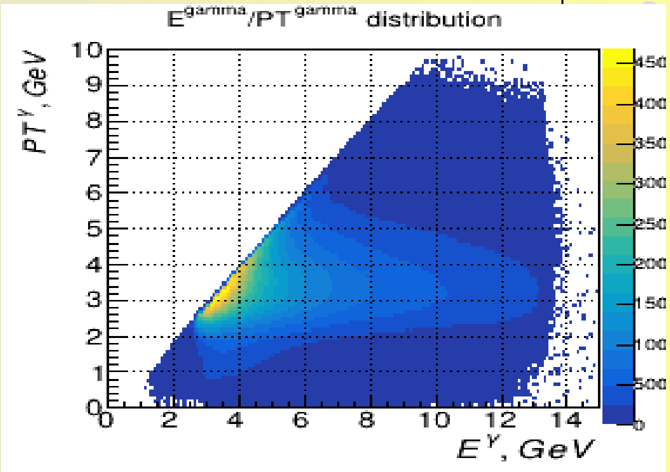


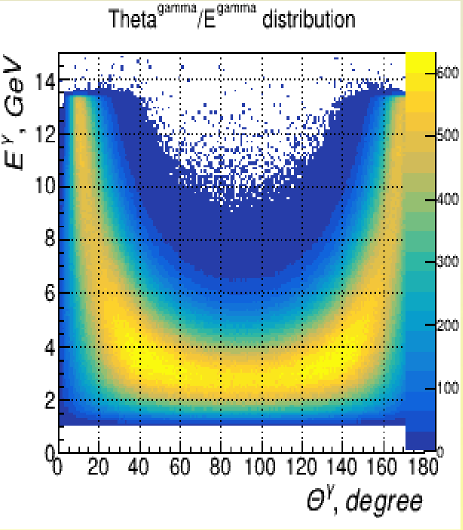
Intermediate γ* correlation distributions

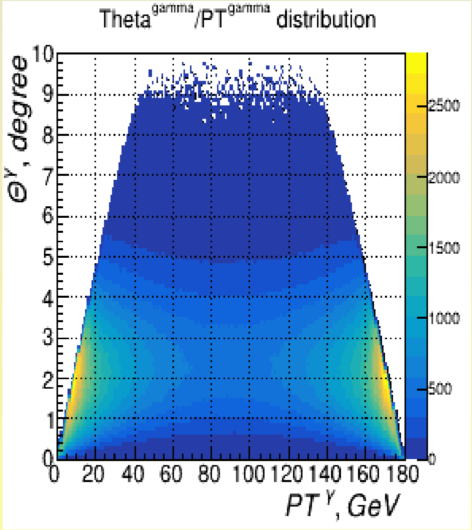
Without cuts

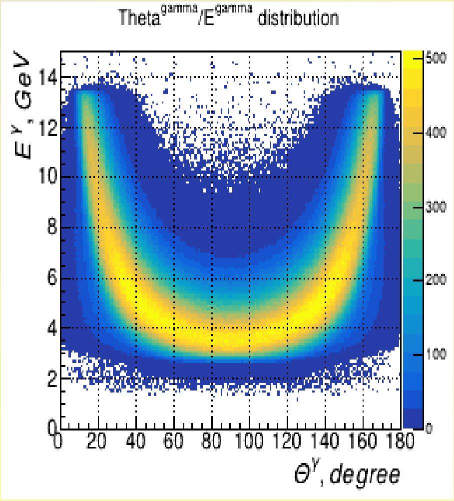


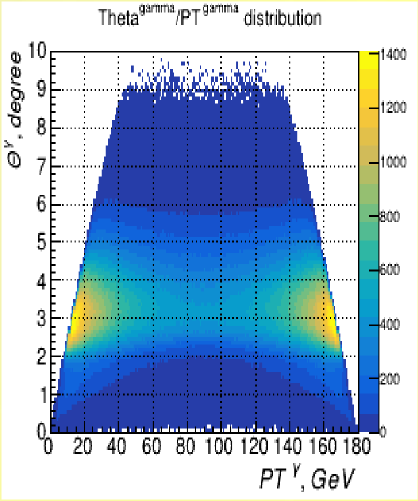
After cuts







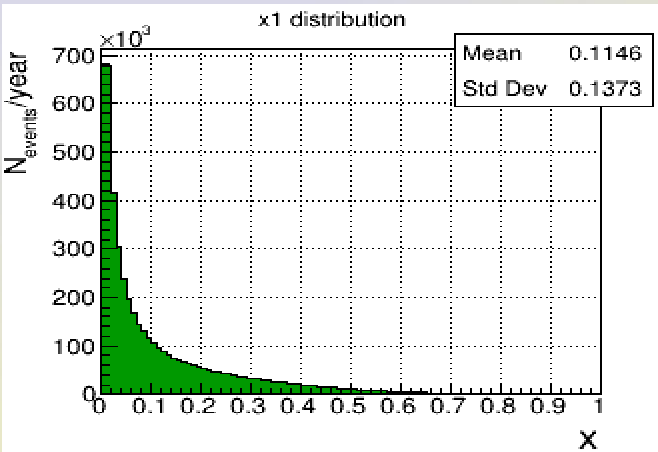


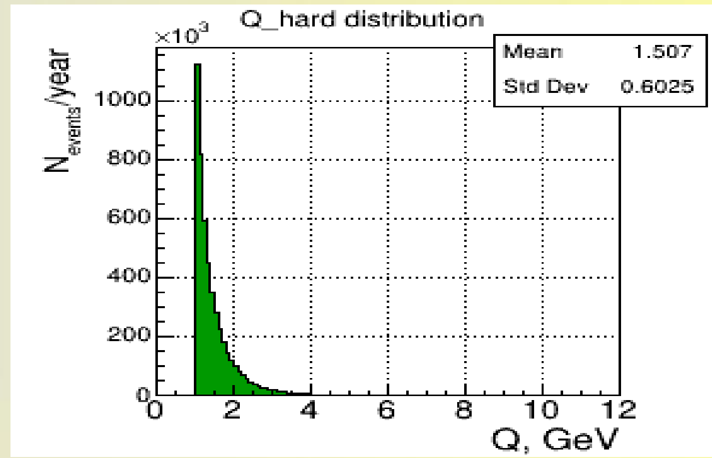


General Drell-Yan event variables for pp collision at E_{cms} =27 GeV

Доля импульса x, уносимая партонами

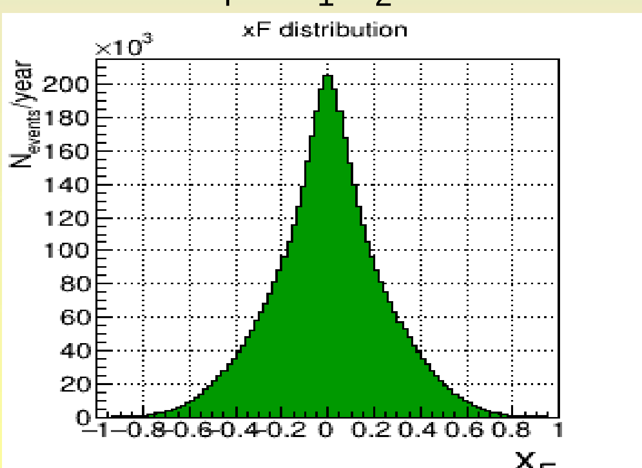
Q жесткого подпроцесса

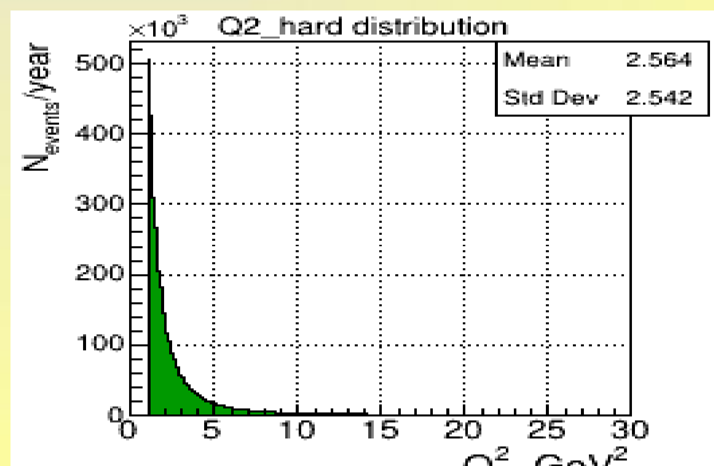




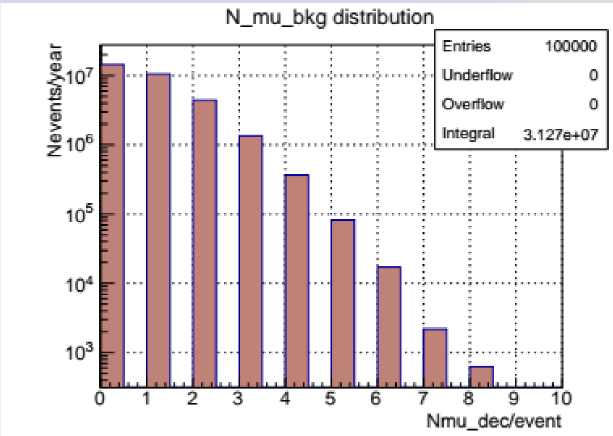
$X_F = x_1 - x_2$

Q^2 жесткого подпроцесса



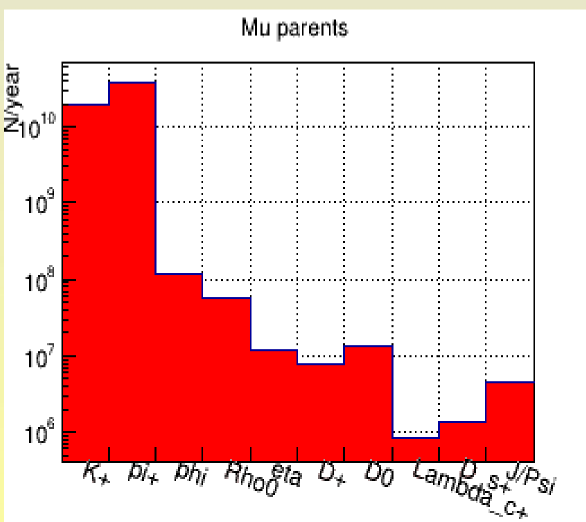


Background muons in signal events



53.5 % of signal events contais >2 muons - up to 8μ/event

We allow particles decay (and produce muons) in the volume before Muon (Range) System :
cylindr radius **R = 2 400 mm**,
size from the centre along Z axis **L = 4 000 mm**
and search for muons in the angle region **9º< Θ < 171º**



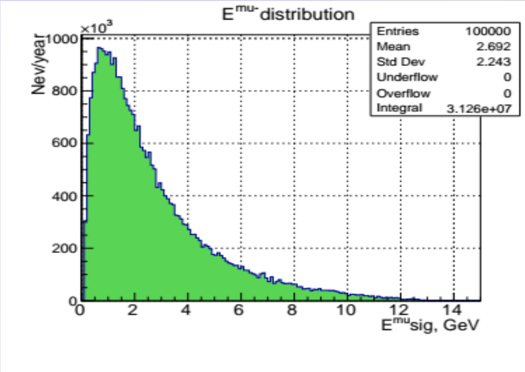
The most probable parents of bkg muons - are charged π and K

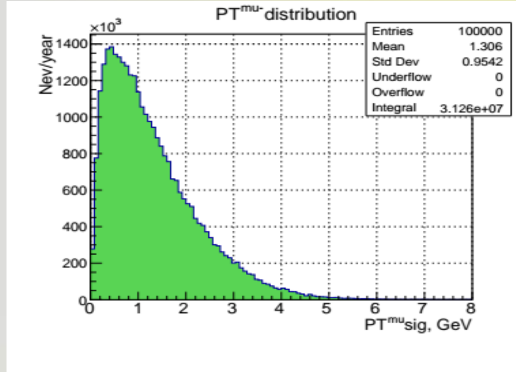
The most probable grandparents of bkg muons - are «string» (Lund model),

$\rho^0, \rho^+, K_S^0, K^{*0}, K^+, \eta'$

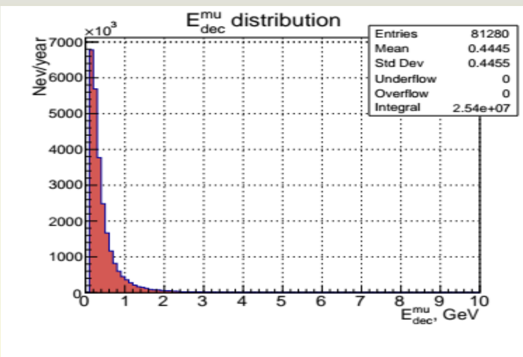
Decay muons in signal events

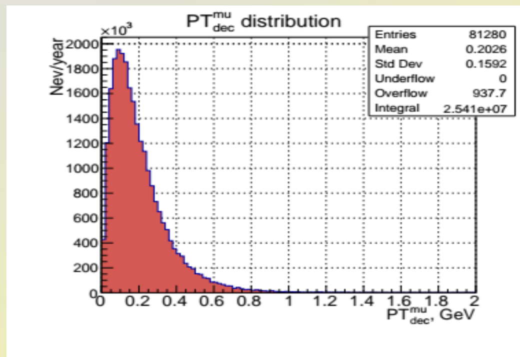
SIG



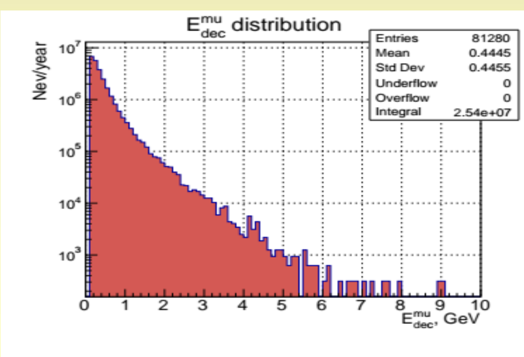


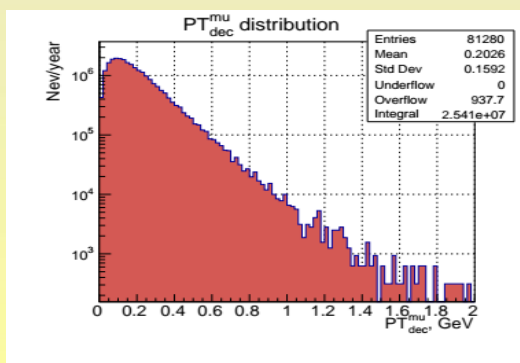
DEC





DEC (log)





Cuts : **exactly 2 muons**	**E > 0.8 GeV PT > 0.4 GeV**	**E > 1.0 GeV PT > 1.0 GeV**
Reminder of signal events	54.1%	23.5%
Fraction of initial signal events with additional muons	2.1%	0.08%
Fraction of remaining signal events with additional muons	3.9 %	0.3%

Another situation when we have exactly 2 μ —
first signal, the second — survived fake one.

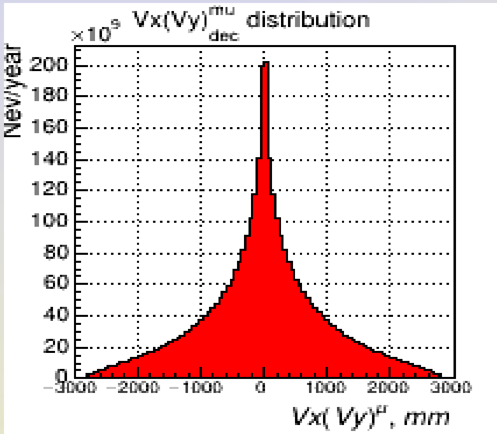
We have 2 situations -

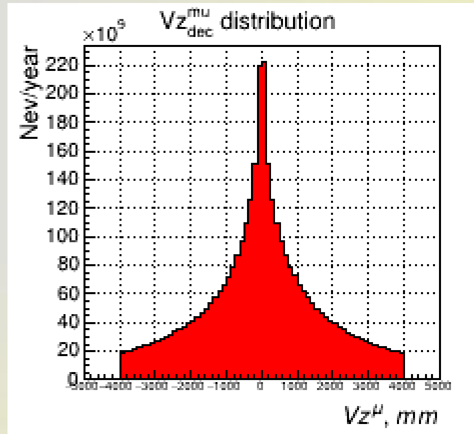
1. Muons are of the same sign — easy to cut off
2. Muons are of different signes

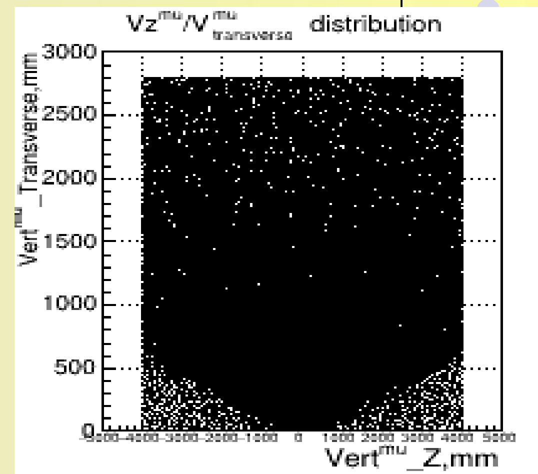
After cutting off the events with additional (>2) muons we have

Cuts: **exactly 2 muons with opposite signes**	E > 0.8 GeV PT > 0.4 GeV	E > 1.0 GeV PT > 1.0 GeV
Reminder of signal events	51.9%	23.4%
Fraction of initial signal events with fake muons of the same sign	0.9%	0.09%
Fraction of remaining signal events with muons of the same sign	1.7 %	0.4%
Reminder of signal events after cut off the events with the muons of the same sign	51.0%	23.4%
Fraction of initial signal events with fake muons of different sign	0.9%	0.1%
Fraction of remaining signal events with muons of different sign	1.8 %	0.4%

Vertex & angle distributions







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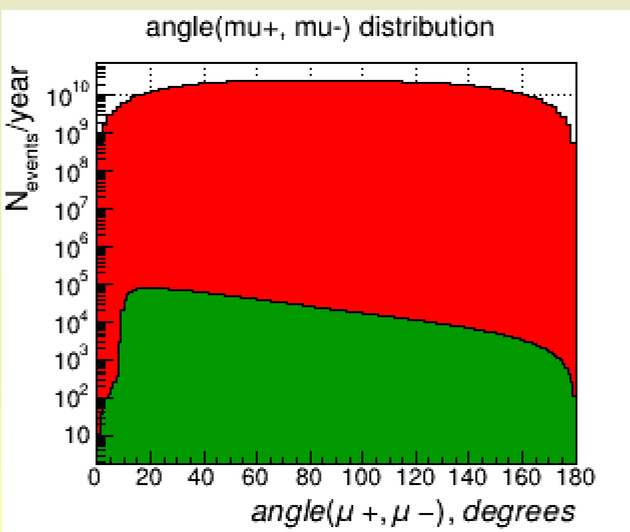

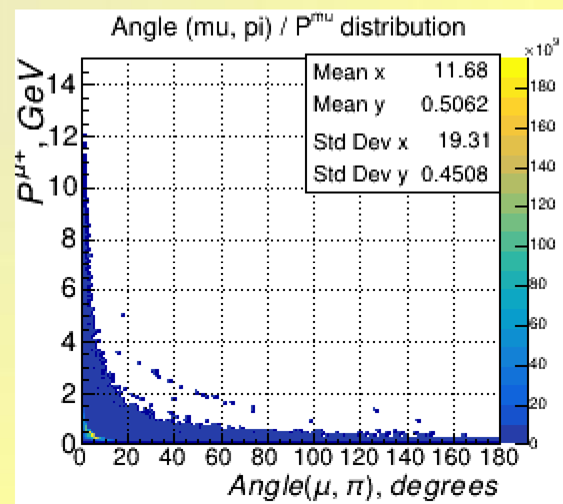

π/μ rejection

Particle momentum	**π/μ rejection**
0.5 — 1 GeV	~ 80 % (experiment with MS prototype)
1 — 1.5 GeV	~ 90 % (assumption)
> 1.5 GeV	~ 99 % (assumption)

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For 5λ of path length in iron.

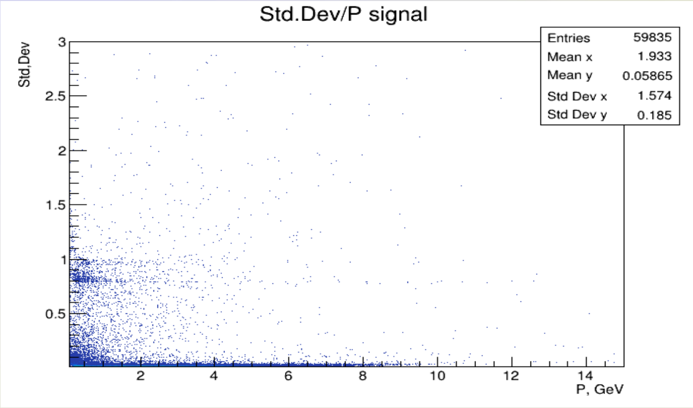
for **3λ** path length (+4.9 % muon misidentification)
for **4λ** path length (+1.8 % muon misidentification)
for **5λ** path length (+0.67 % muon misidentification)

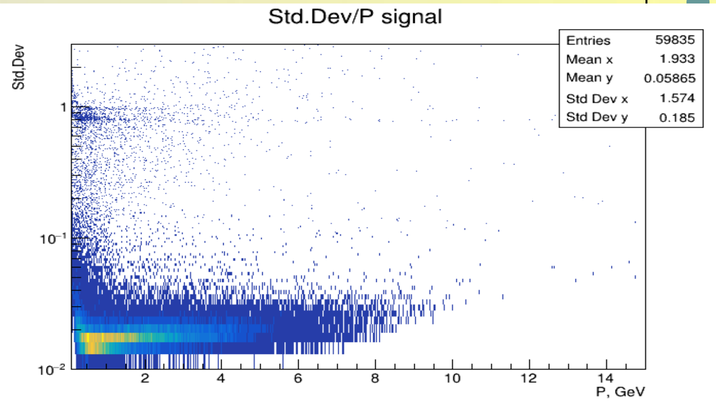
λ_{FE} ~= 17cm

Deviations in muons momenta resolution

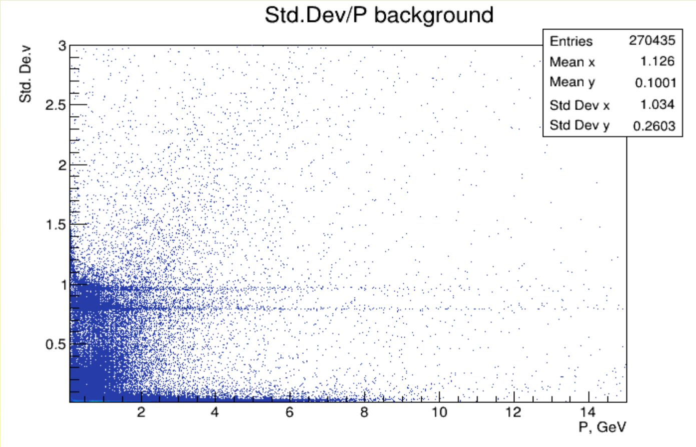
Sig & BKG in log scale

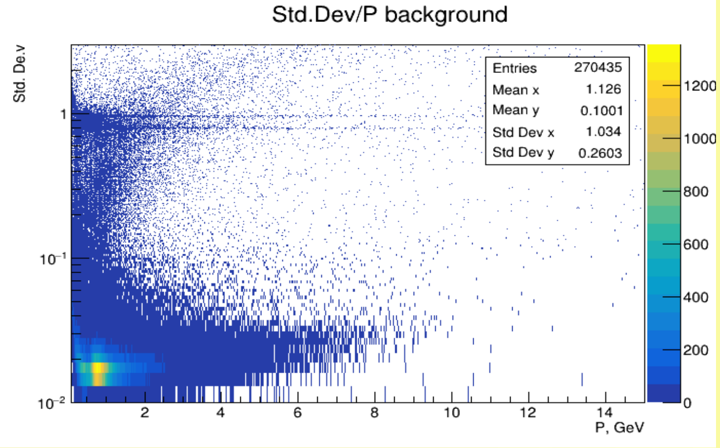
S I G





B K G





To safe the most part of statistics we have chosen ΔP/P < 3% GeV

(Where ΔP is a square root of the sum of diagonal elements of 3x3 covariance matrix of momentum vector described in P3Cov() method of RhoCandidate)

Cuts separate and summarized & their efficiencies for DPM background events (all)

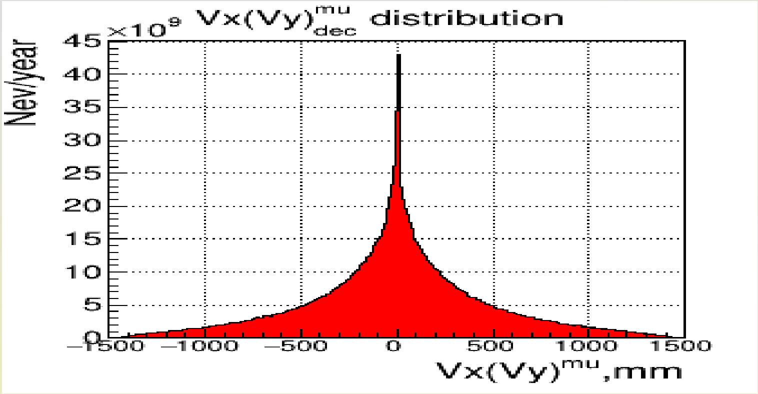
Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

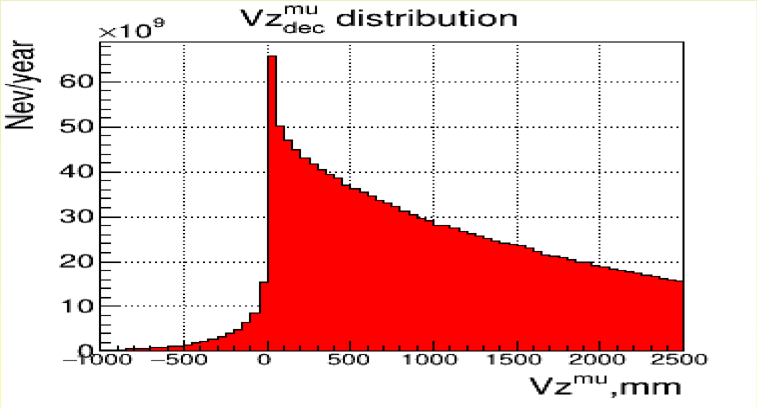
N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with **PT_l > 0.3 GeV, P_l > 1.0 GeV**	**$2.13 * 10^{-5}$**	Eff (1,init) = 4907.2	2.03×10^{-2} %	24.2	4.14 %
2+1 *2μ are of the opposite sign*	**$3.11 * 10^{-5}$**	Eff (2,1) = 1.69	1.20×10^{-2} %	1.15	3.59 %
3+2+1 ***$M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV***	**$1.92 * 10^{-4}$**	Eff (3,2) = 6.69	1.80×10^{-3} %	1.07	3.33 %
4+3+2+1 ***$PT_{\mu}^{all\,Emax}$ > 0.7 GeV***	**$2.41 * 10^{-4}$**	Eff (4,3) = 1.42	1.27×10^{-3} %	1.13	2.94 %
5+3+2+1 ***PT_{vecsum} > 0.7 GeV***	**$3.01 * 10^{-4}$**	Eff (5,3) = 2.09	$8,61 \times 10^{-4}$ %	1.33	2.49%
6+3+2+1 ***Isolation criterion***	**$7.48 * 10^{-4}$**	Eff (6,3) =1.29	1.39×10^{-3} %	1.11	**3.00 %**
5+4+3+2+1 ***PT_{vecsum}^{all} > 0.7 GeV***	**$4.00 * 10^{-4}$**	Eff (5,4) = 1.29	6.63×10^{-4} %	1.11	2.55 %
6+4+3+2+1 **Isolation criterion**	**$2.84 * 10^{-4}$**	Eff (6,4) =1.31	9.68×10^{-4} %	1.12	**2.65 %**
6+5+4+3+2+1 **Isolation criterion**	**$3.84 * 10^{-4}$**	Eff (6,5) =1.86	4.61×10^{-4} %	1,24	**2.01 %**

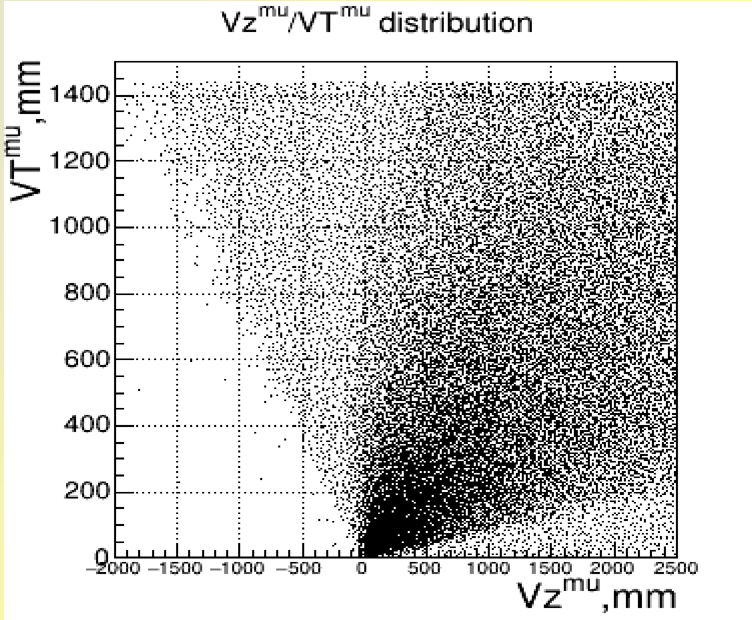
Vertex distributions

Still under big question the possibility of kink resolution in π→μν decay trajectory (which is ~ 1-3 degrees) *(no manpower)***.**
Most probable it will be very hard due to the Straw detector geometry, thus the **criterium of muon vertex production point is very effective, but not realistic.**

P Y T H I A







P Y T H I A

Cuts separate efficiency for minimum-bias background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with PT_l > 0.3 GeV, $E(P)_l$ > 0.5 GeV	$3.14 * 10^{-4}$	Eff (1,init) = **3879**	2.6×10^{-2} %	1.6	62.3 %
2^{+1} *2μ are of the opposite sign*	$4.75 * 10^{-4}$	Eff (2,1) = **1.52**	1.7×10^{-2} %	1.6	62.3 %
3^{+2+1} $M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV	$3.47 * 10^{-3}$	Eff (3,2) = **7.48**	2.3×10^{-3} %	1.02	60.8 %
4^{+3+2+1} PT_{all}^{Emax} > 0.7 GeV	$2.01 * 10^{-2}$	Eff (4,3) = **6.92**	3.3×10^{-4} %	1.2	50.7 %
5^{+3+2+1} E_{all}^{sum} > 15.8 GeV	$1.94 * 10^{-1}$	Eff (5,3) = **105.4**	2.2×10^{-5} %	1.9	46.1 %
6^{+3+2+1} PT_{all}^{vecsum} < 0.2 GeV	$6.49 * 10^{-3}$	Eff (6,3) = **2.59**	8.8×10^{-4} %	1.4	32.3 %
7^{+3+2+1} P_{vecsum} > 14.8 GeV	$1.10 * 10^{-1}$	Eff (7,3) = **58.23**	3.9×10^{-5} %	1.8	43.8 %
8^{+3+2+1} *Isolation criterium*	2.78	Eff (8,3) = **813.4**	2.8×10^{-6} %	1.01	**33.1 %**
9^{+3+2+1} R_{vertex} < 1 mm	$1.89 * 10^{-1}$	Eff (9,3) = **55.13**	4.1×10^{-5} %	1.01	60 %
10^{+3+2+1} R_{vertex} < 25 mm	$1.72 * 10^{-1}$	Eff (10,3) = **50.37**	4.5×10^{-5} %	1.01	60 %

P Y T H I A

Cuts separate and summarized efficiency for Minimum-bias background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 ***Exactly 2μ*** with **PT_l > 0.3 GeV, P_l > 1.0 GeV**	**$1.01 * 10^{-3}$**	Eff (1,init) = **17417**	5.7×10^{-3} %	2.1	47.1 %
2_{+1} ***2μ** are of the **opposite sign***	**$1.5 * 10^{-3}$**	Eff (2,1) = **1.49**	3.8×10^{-3} %	1.0	47.0 %
3_{+2+1} ***$M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV***	**$9.0 * 10^{-3}$**	Eff (3,2) = **6.08**	6.3×10^{-4} %	1.0	46.4 %
4_{+3+2+1} ***PT_{μ} > 0.7 GeV***	**$3.84 * 10^{-2}$**	Eff (4,3) = **4.96**	1.3×10^{-4} %	1.3	36.1 %
5_{+3+2+1} ***E_{all}^{Emax} > 15.8 GeV***	**$5.2 * 10^{-1}$**	Eff (5,3) = **103.7**	6.1×10^{-6} %	1.9	24.6 %
6_{+3+2+1} ***PT_{all}^{sum} < 0.2 GeV***	**$1.6 * 10^{-2}$**	Eff (6,3) = **2.42**	2.7×10^{-4} %	1.4	33.1 %
7_{+3+2+1} ***P_{all}^{vecsum} > 14.8 GeV***	**$3.1 * 10^{-1}$**	Eff (7,3) = **12.14**	1.0×10^{-5} %	1.8	25.4 %
8_{+3+2+1} ***Isolation criterium***	**9.5**	Eff (8,3) = **212.5**	6.0×10^{-7} %	1.0	**43.8 %**
9_{+3+2+1} ***R_{vertex} < 1 mm***	**$2.8 * 10^{-1}$**	Eff (9,3) = **33.3**	2.0×10^{-5} %	1.0	43.8 %
10_{+3+2+1} ***R_{vertex} < 25 mm***	**$2.7 * 10^{-1}$**	Eff (10,3) = **30.1**	2.1×10^{-5} %	1.0	43.8 %
$5_{+4+3+2+1}$ **E_{all}^{sum} > 15.8 GeV**	**1.76**	Eff (5,4) = **75**	7.0×10^{-7} %	1.6	**22.7 %**
$8_{+4+3+2+1}$ **Isolation criterium**	**> 49**	Eff (8,4) > **1275**	< 1.0×10^{-7} %	1.0	**36.0 %**
$8_{+5+4+3+2+1}$ **Isolation criterium**	**> 32**	Eff (8,5) > **61**	< 1.0×10^{-7} %	1.1	**22.4 %**

P Y T H I A

Cuts separate and summarized efficiency for Minimum-bias background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with $PT_l > 0.3$ GeV, $P_l > 1.5$ GeV	$2.73 * 10^{-3}$	Eff (1,init) = **71772**	1.4×10^{-3} %	3.0	32.7 %
2^{+1} *2μ are of the opposite sign*	$3.99 * 10^{-3}$	Eff (2,1) = **1.46**	9.5×10^{-4} %	1.0	32.6 %
3^{+2+1} $M_{inv}(\mu^+,\mu^-) > 1.0$ GeV	$2.08 * 10^{-2}$	Eff (3,2) = **5.35**	1.8×10^{-4} %	1.0	32.2 %
4^{+3+2+1} $PT^{\mu} > 0.7$ GeV	$8.37 * 10^{-2}$	Eff (4,3) = **4.26**	4.2×10^{-5} %	1.3	25.2 %
5^{+3+2+1} $E^{all}_{Emax} > 15.8$ GeV	$9.54 * 10^{-1}$	Eff (5,3) = **80.9**	2.2×10^{-6} %	2.0	16.1 %
6^{+3+2+1} $PT^{all}_{sum} < 0.2$ GeV	$3.37 * 10^{-2}$	Eff (6,3) = **2.14**	8.3×10^{-5} %	1.6	21.5 %
7^{+3+2+1} $P^{all}_{vecsum} > 14.8$ GeV	$6.66 * 10^{-1}$	Eff (7,3) = **53.9**	3.3×10^{-6} %	1.9	16.9 %
8^{+3+2+1} vecsum *Isolation criterium*	12.3	Eff (8,3) = **593**	3.0×10^{-7} %	1.0	**32.2 %**
9^{+3+2+1} $R_{vertex} < 1$ mm	$3.42 * 10^{-1}$	Eff (9,3) = **16.5**	1.08×10^{-5} %	1.0	32.2 %
10^{+3+2+1} $R^{all}_{vertex} < 25$ mm	$3.33 * 10^{-1}$	Eff (10,3) = **16.0**	1.11×10^{-5} %	1.0	32.2 %
$5^{+4+3+2+1}$ $E_{sum} > 15.8$ GeV	2.85	Eff (5,4) = **59.7**	7.0×10^{-7} %	1.5	**16.7 %**
$8^{+4+3+2+1}$ Isolation criterium	> 35	Eff (8,4) > **418**	$< 1.0 \times 10^{-7}$ %	1.0	**25.2 %**
$8^{+5+4+3+2+1}$ Isolation criterium	> 20	Eff (8,5) > **22**	$< 1.0 \times 10^{-7}$ %	1.0	**15.4 %**

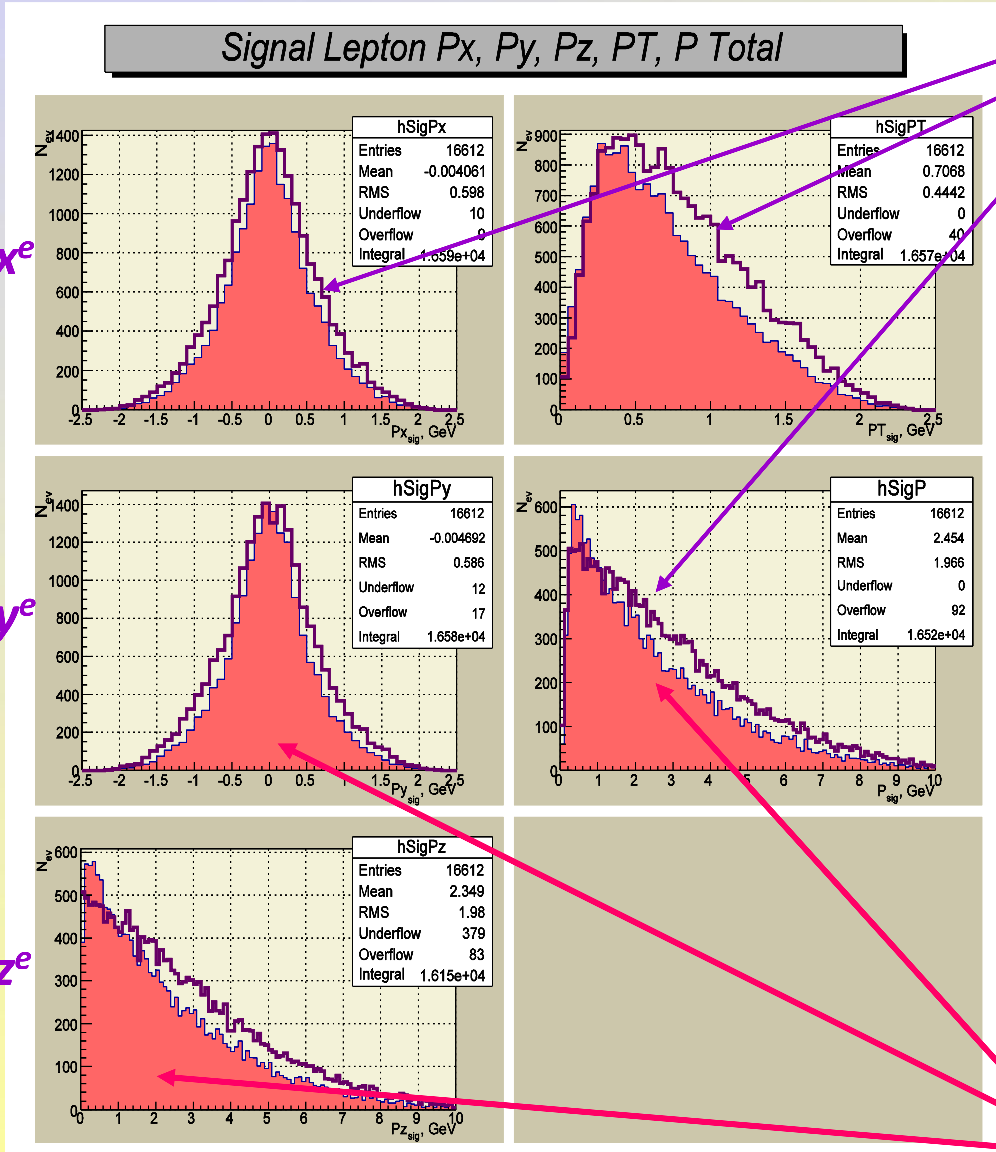
PYTHIA

Cuts **separate** and **summarized** efficiency for QCD background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with **PT_l > 0.3 GeV, P_l > 1.5 GeV**	**3.67 * 10 $^{-3}$**	Eff (1,init) = **20198**	4.9 x 10^{-3} %	3.0	32.7 %
+1 **2** *2μ are of the **opposite sign***	**4.90 * 10 $^{-3}$**	Eff (2,1) = **1.33**	3.71 x 10^{-3} %	1.0	32.6 %
+2+1 **3** ***$M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV***	**1.19 * 10 $^{-2}$**	Eff (3,2) = **2.45**	1.51 x 10^{-3} %	1.0	32.2 %
+3+2+1 μ **4** ***PT > 0.7 GeV***	**1.85 * 10 $^{-2}$**	Eff (4,3) = **2.06**	7.3 x 10^{-4} %	1.3	25.2 %
+3+2+1 all Emax **5** ***E > 15.8 GeV***	**6.76 * 10 $^{-1}$**	Eff (5,3) = **87.5**	1.7 x 10^{-5} %	2.0	16.1 %
+3+2+1 all sum **6** ***PT < 0.2 GeV***	**2.51* 10 $^{-2}$**	Eff (6,3) = **2.45**	6.2 x 10^{-4} %	1.6	21.5 %
+3+2+1 all vecsum **7** ***P > 14.8 GeV***	**3.76 * 10 $^{-1}$**	Eff (7,3) = **48.2**	3.1 x 10^{-5} %	1.9	16.9 %
+3+2+1 vecsum **8** ***Isolation criterium***	**> 178**	Eff (8,3) **> 15141**	< 1.0 x 10^{-7} %	1.0	**32.2 %**
+3+2+1 **9** ***R < 1 mm***	**1.52**	Eff (9,3) = **128.3**	1.2 x 10^{-5} %	1.0	32.2 %
+3+2+1 vertex **10** ***R < 25 mm***	**1.27**	Eff (10,3) = **107.4**	1.4 x 10^{-5} %	1.0	32.2 %
+4+3+2+1 all vertex **5** **E > 15.8 GeV**	**0.94**	Eff (5,4) = **77.1**	9.5 x 10^{-6} %	1.5	**16.7 %**
+4+3+2+1 sum **8** **Isolation criterium**	**> 136**	Eff (8,4) > **7328**	< 1.0 x 10^{-7} %	1.0	**25.2 %**
+5+4+3+2+1 **8** **Isolation criterium**	**> 116**	Eff (8,5) > **173**	< 1.0 x 10^{-7} %	1.0	**15.4 %**

Total Px^e, Py^e, Pz^e, PT^e, P^e of signal ($e^+ + e^-$)



Px^e

Py^e

Pz^e

PT^e

P^e

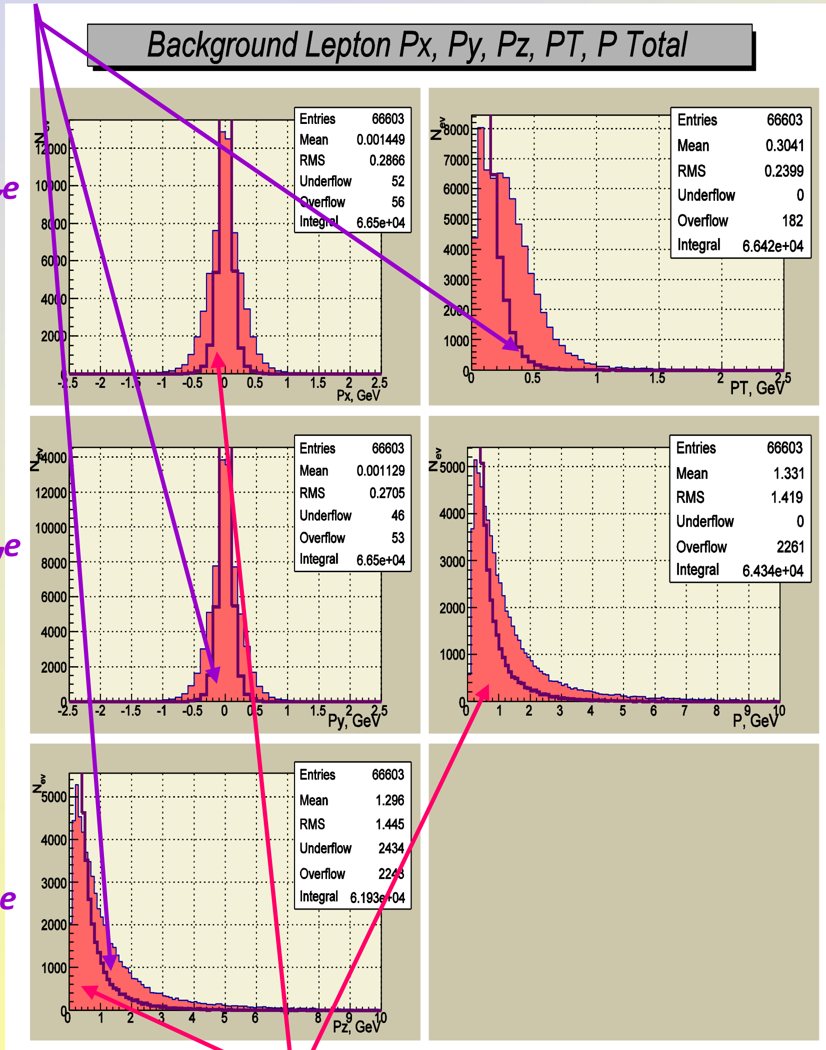
PYTHIA6.4

- Like in the case of the **e^+/e^-**, taken separately:
- Distributions over **Px and Py** are *identical to each other and follow the initial distributions* at PYTHIA level except ***some loss of events***
- Distribution over **PT** shows the **shift** of the spectrum **to the lower values** comparing to PYTHIA one**. At small PT<0.3 GeV** the PandaRoot number of events is **slightly exceed** the initial distributions. At the **higher PT > 0.4 GeV** their number is **reduced significantly**.
- Distributions over the **Pz & P** show the **excess** over PYTHIA results in the region of small **0.2 < Pz,P < 0.8 GeV** and some **reduction** of number of events at the medium values of **1 < Pz,P < 8 GeV**.

PandaRoot & Geant 4

Px^e, Py^e, Pz^e, PT^e, P^e distributions from 10^5 mini-bias BKG events

PYTHIA6.4



Px^e

Py^e

Pz^e

PT^e

P^e

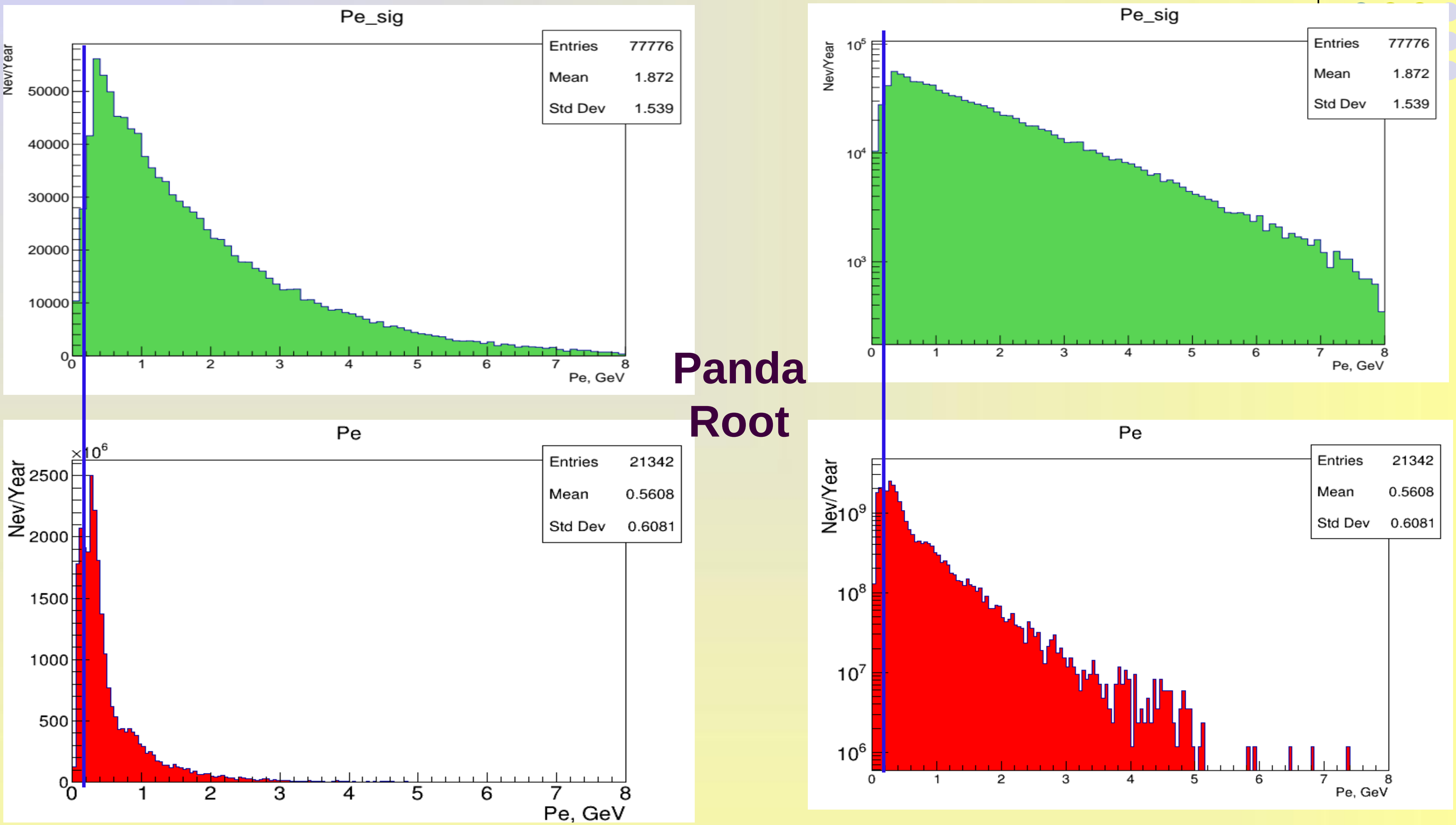
PandaRoot & Geant 4

- e^+/e^- produced *from decays* of different particles in detector volume happen to be **more energetic** in comparison with analogous ones simulated in PYTHIA:

They have ≈ *0.5 GeV higher momentum* in transverse plane (Px, Py and PT),

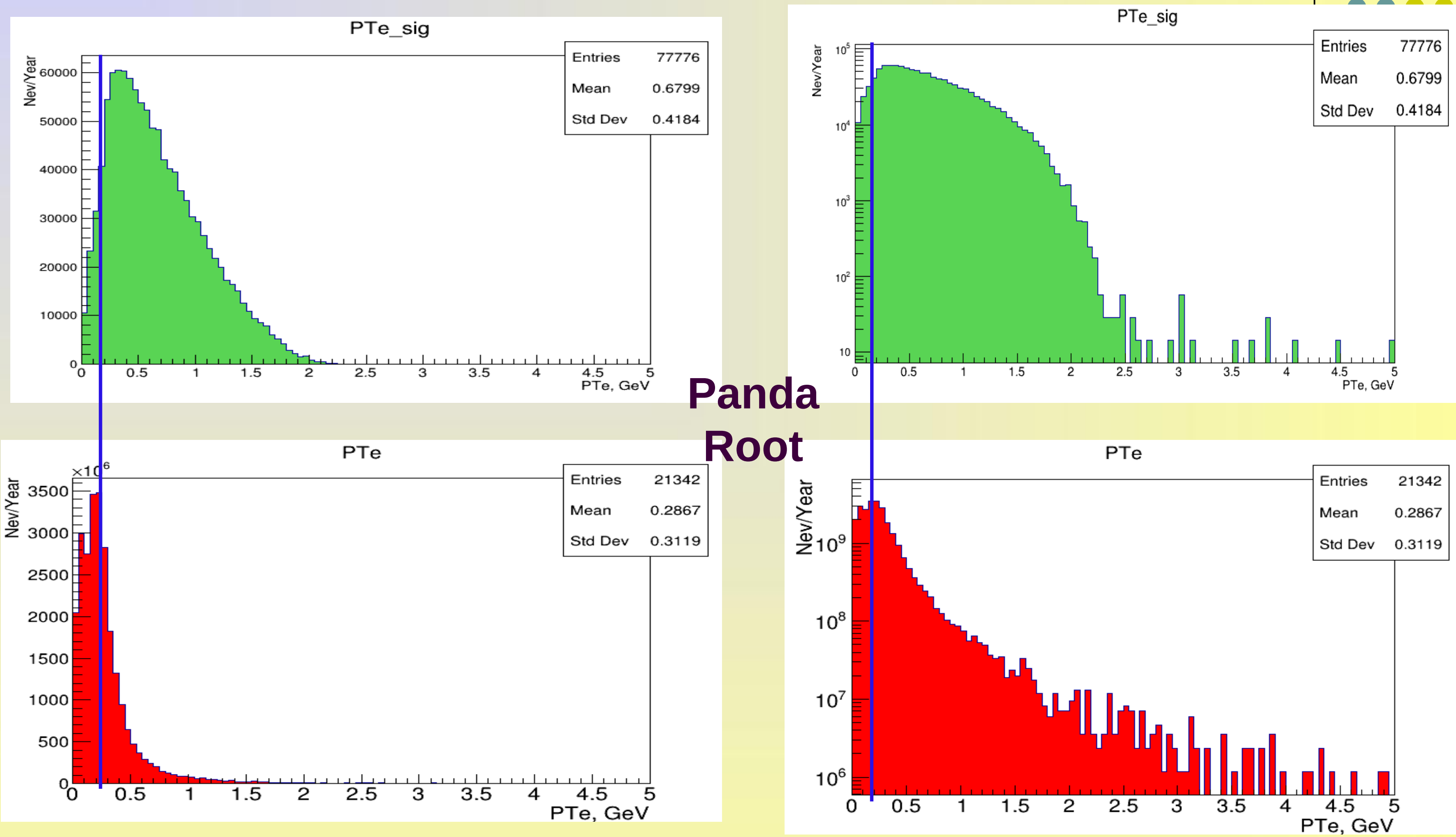
and ≈ *1 GeV higher momentum in* longitudinal component (Pz and P).

First cuts — on $E(P)^e$



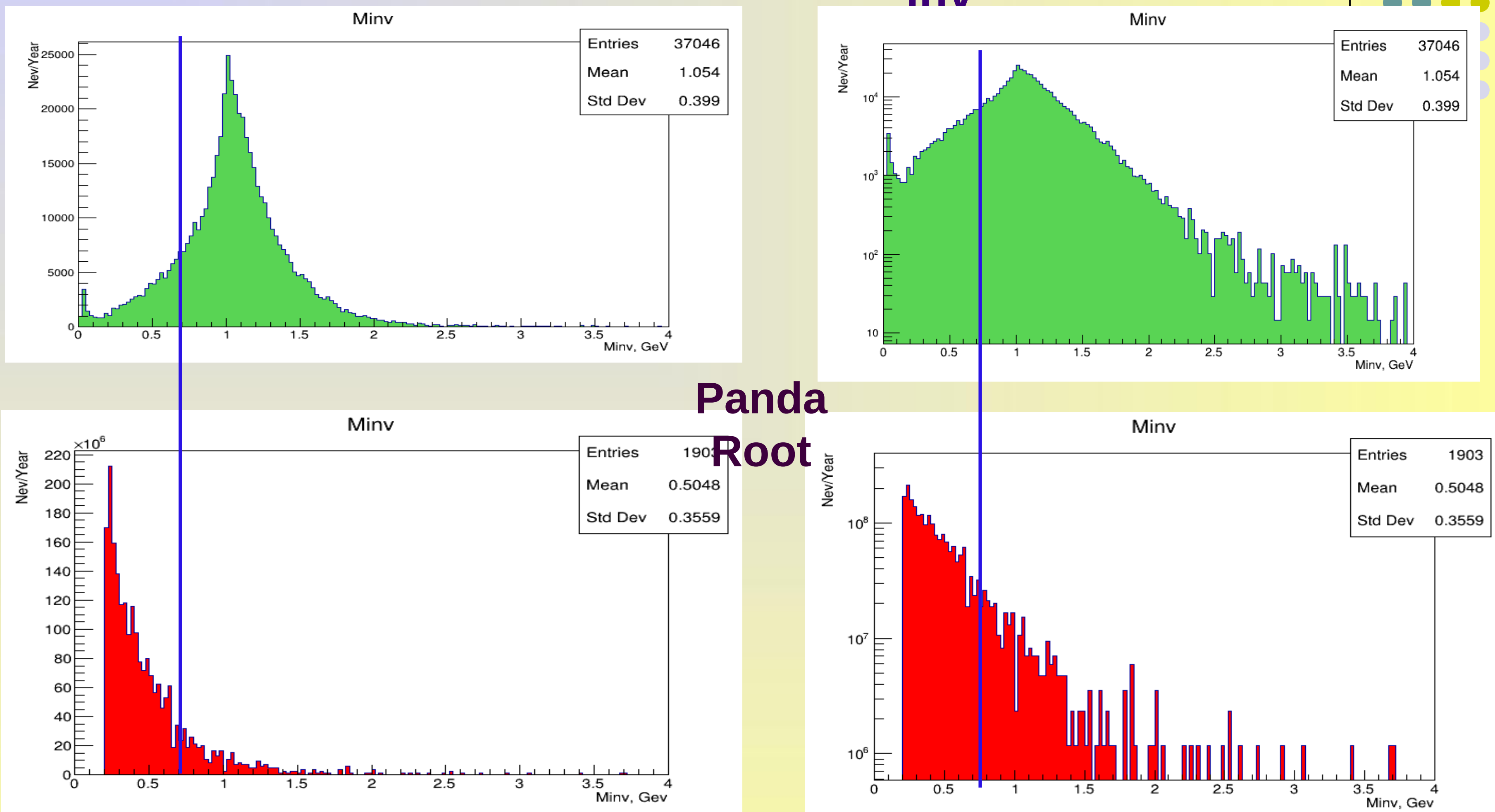
Proposed cut off is **$P^e > 0.2$ GeV**

First cuts — on PT^e



Proposed cut off is **PT^e > 0.2 GeV**

Invariant mass $M_{inv}(e^+,e^-)$ cut



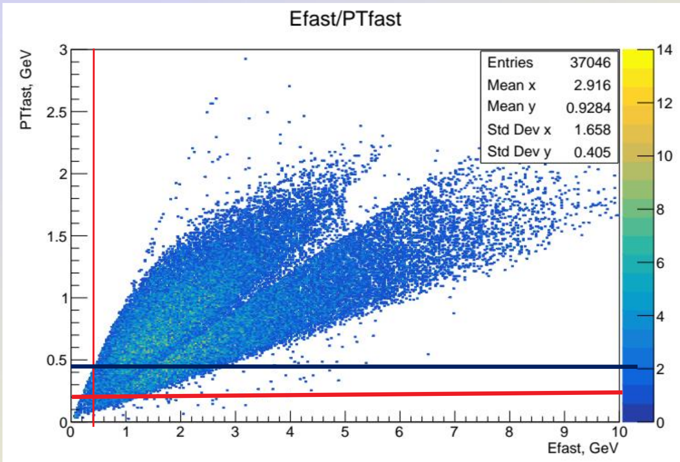
The most effective cut is in the region **Minv > 0.7 GeV**.

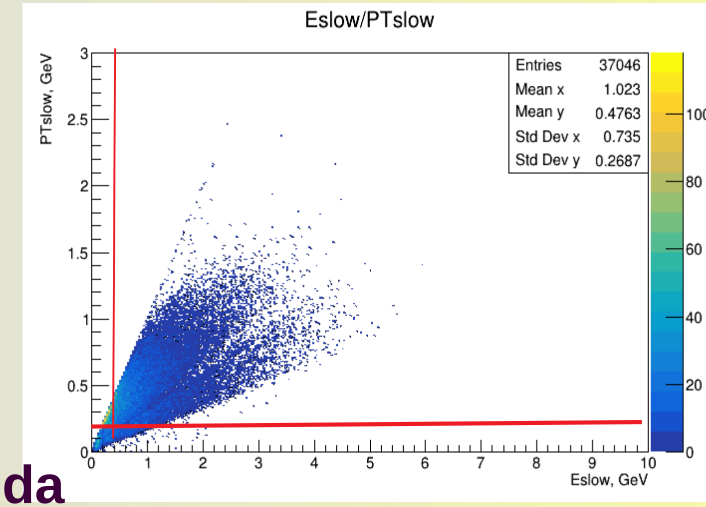
Criterion on $M_{inv}^{e+/e-}$	Efficiency for background, %	Efficiency for the signal, %	Signal to background ratio S/B
$M_{inv}^{e+/e-}$ > **0.0 GeV**	0.0766	30.76	**4.939 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **0.2 GeV**	0.0475	30.44	**7.882 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **0.3 GeV**	0.0430	30.35	**8.681 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **0.4 GeV**	0.0385	30.25	**9.664 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **0.5 GeV**	0.0345	29.96	**1.068 x 10^{-4}**
$M_{inv}^{e+/e-}$ > **0.6 GeV**	0.0295	29.45	**1.228 x 10^{-4}**
$M_{inv}^{e+/e-}$ > 0.7 GeV	**0.0282**	**28.45**	**1.241 x 10^{-4}**
$M_{inv}^{e+/e-}$ > **0.8 GeV**	0.0275	26.89	**1.202 x 10^{-4}**
$M_{inv}^{e+/e-}$ > **0.9 GeV**	0.0267	24.44	**1.126 x 10^{-4}**
$M_{inv}^{e+/e-}$ > **1.0 GeV**	0.0237	20.34	**1.055 x 10^{-4}**
$M_{inv}^{e+/e-}$ > **1.1 GeV**	0.0200	14.71	**9.046 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **1.2 GeV**	0.0178	10.59	**7. 317x 10^{-5}**
$M_{inv}^{e+/e-}$ > **1.3 GeV**	0.0158	7.47	**5.815 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **1.4 GeV**	0.0147	5.24	**4.384 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **1.5 GeV**	0.0133	3.53	**3.264 x 10^{-5}**

Criterion on $M_{inv}^{e+/e-}$	Efficiency for background, %	Efficiency for the signal, %	Signal to background ratio S/B
$M_{inv}^{e+/e-}$ > **1.6 GeV**	0.0121	2.34	**2.378 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **1.7 GeV**	0.0112	1.71	**1.878 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **1.8 GeV**	0.0103	1.27	**1.516 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **1.9 GeV**	0.0091	0.81	**1.094 x 10^{-5}**
$M_{inv}^{e+/e-}$ > **2.0 GeV**	0.0069	0.56	**9.982 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.1 GeV**	0.0062	0.36	**7.142 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.2 GeV**	0.0053	0.28	**6.498 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.3 GeV**	0.0045	0.24	**6.560 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.4 GeV**	0.0042	0.20	**5.857 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.5 GeV**	0.0037	0.16	**5.318 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.6 GeV**	0.0034	0.15	**5.426 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.7 GeV**	0.0032	0.14	**5.381 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.8 GeV**	0.0028	0.11	**4.832 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **2.9 GeV**	0.0025	0.10	**4.919 x 10^{-6}**
$M_{inv}^{e+/e-}$ > **3.0 GeV**	0.0023	0.09	**4.813 x 10^{-6}**

E_e/PT_e correlations for e^+/e^- with max(fast)/min(slow) E_e in the pair

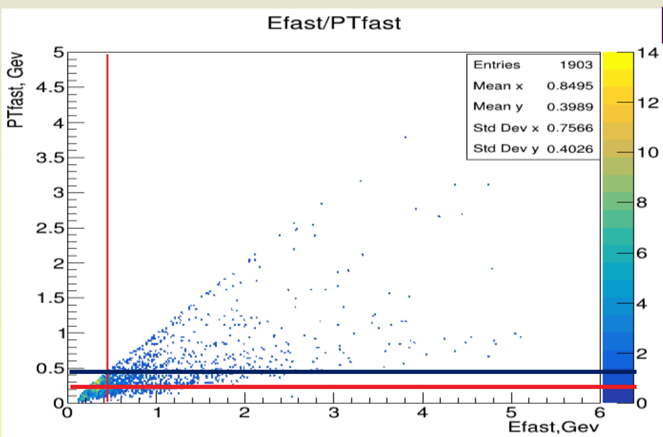
S
I
G

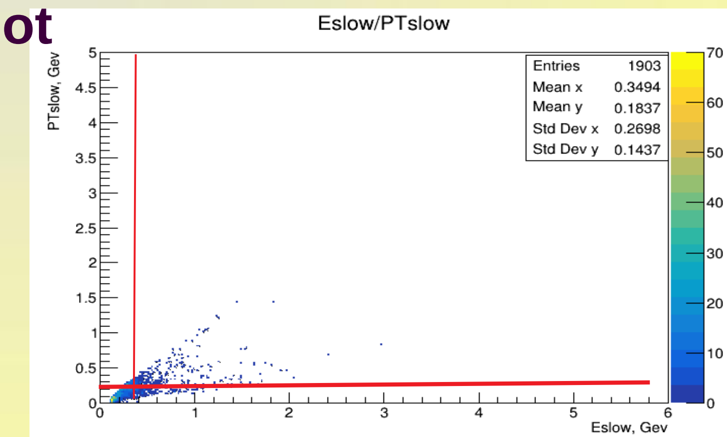




Panda Root

B
K
G





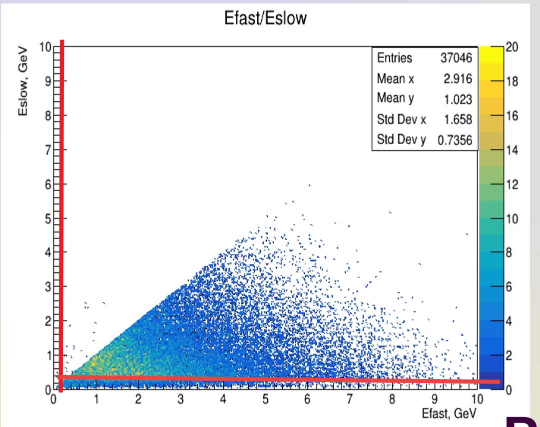
$PT^{\mu}_{Emax} > 0.4$ GeV

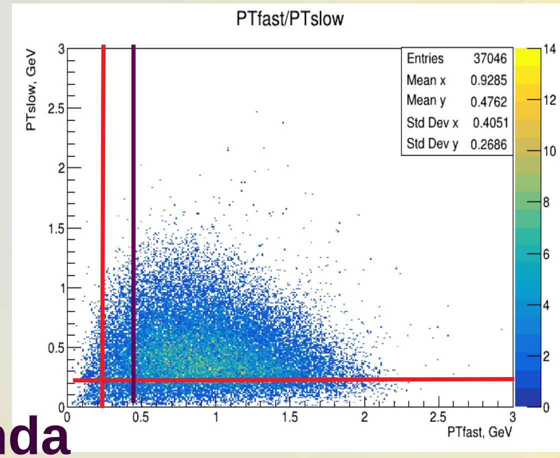
additionally can be more efficient

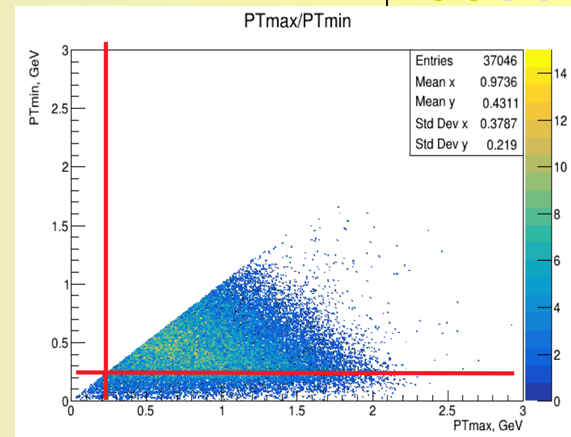
Cut on PTμ > 0.2 GeV and E(P)μ > 0.2 GeV

E^e_{fast}/E^e_{slow}, PT^e_{fast}/PT^e_{slow}, PT^e_{max}/PT^e_{min} distributions

SIG

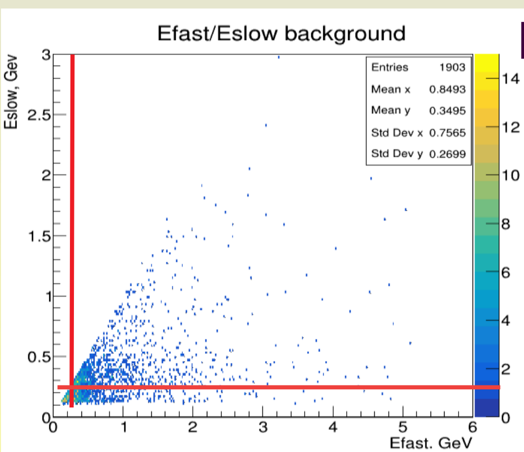


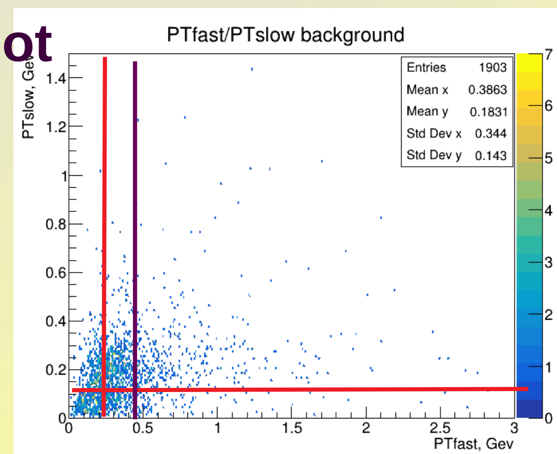


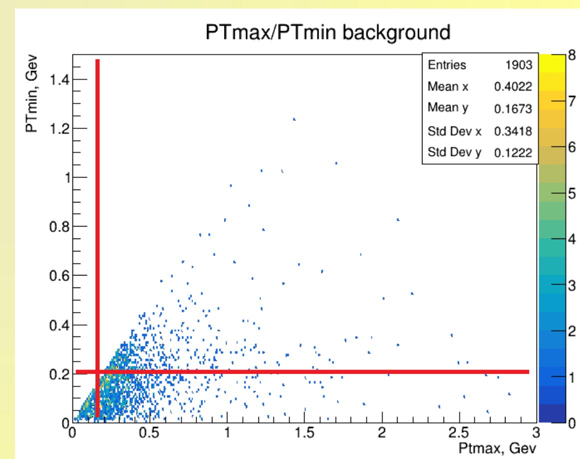


Panda Root

BKG





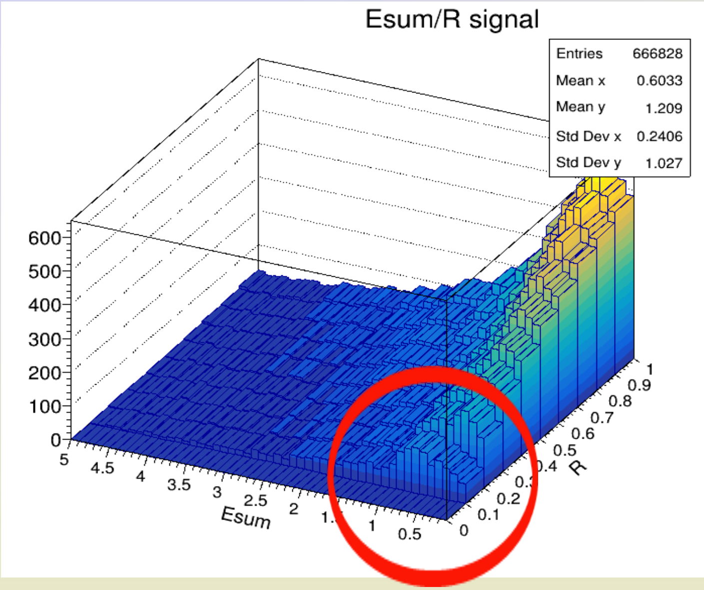


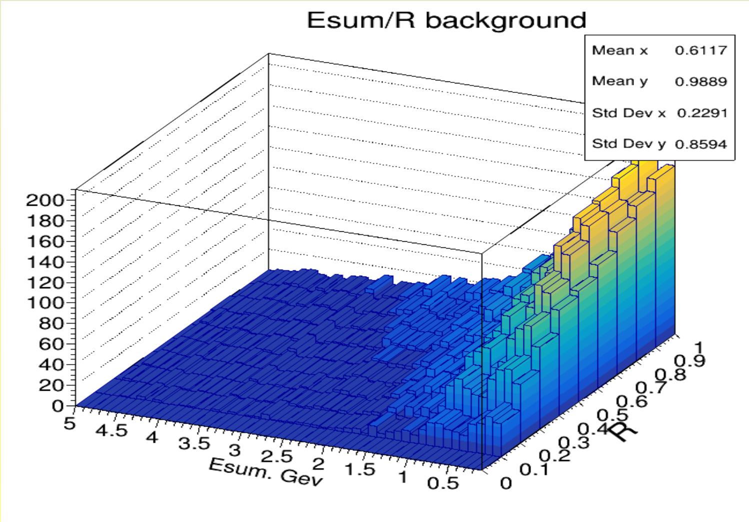
E(P) > 0.2 GeV

PT > 0.2 GeV, PT_{fast} > 0.4 GeV

PT > 0.2 GeV

Panda Root — Lepton (e) isolation criterion





The plots show the distributions over ***summarized energy*** of the final state charged particles in the cones of radius **$R_{isolation} = \sqrt{\Delta\eta^2+\Delta\varphi^2}$** respect to the (η – *pseudorapidity*, φ — ***azimuthal angle***)

upper plot - **signal events**

bottom plot **- background**

Isolation criteria **($R_{isolation}$ = 0.2)**
$E^{(of\ particles)}$ < 0.5 GeV

"Isolation criterion" doesn`t help here