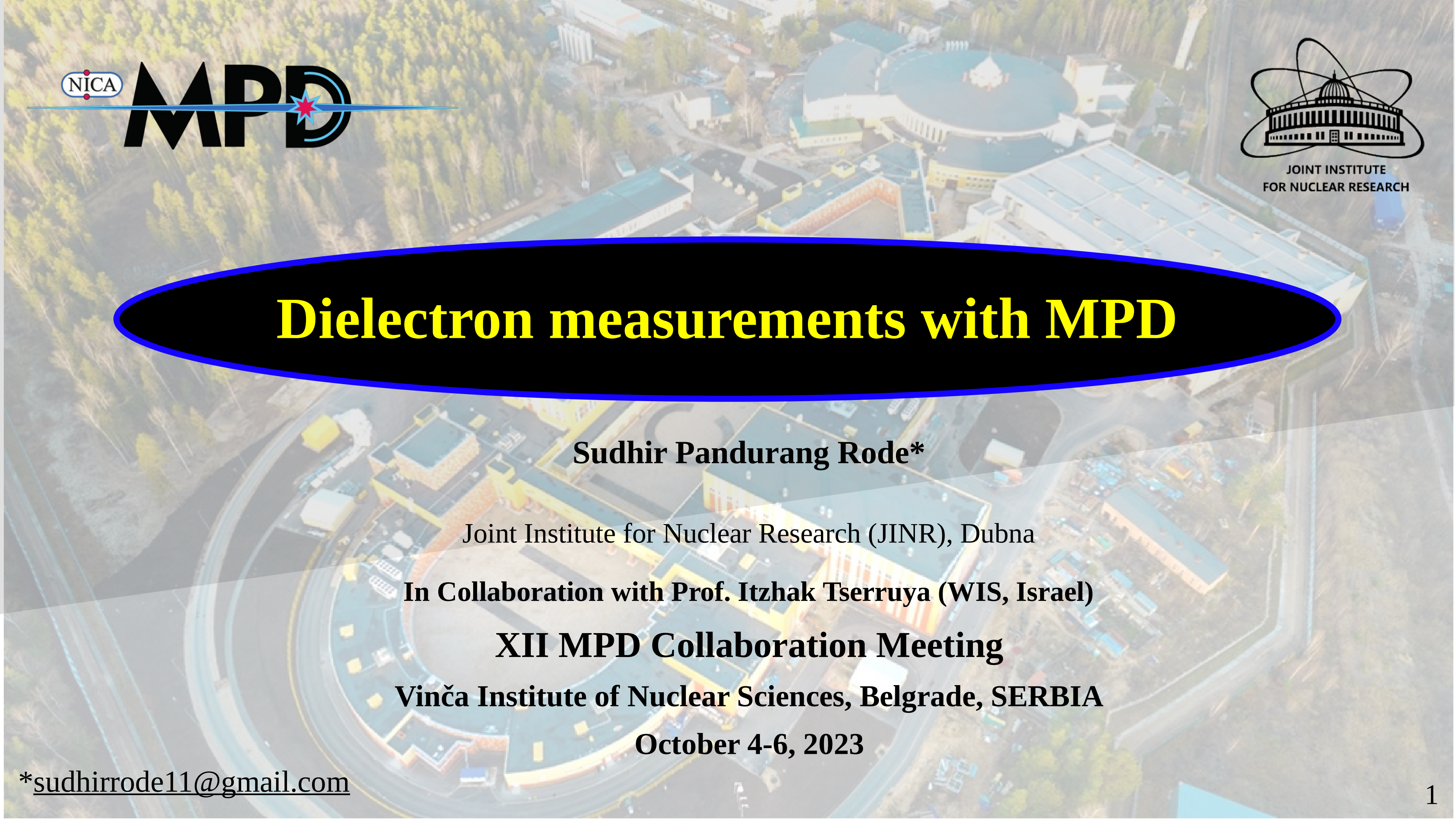

Dielectron measurements with MPD

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XII MPD Collaboration Meeting

Vinča Institute of Nuclear Sciences, Belgrade, SERBIA

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Outline

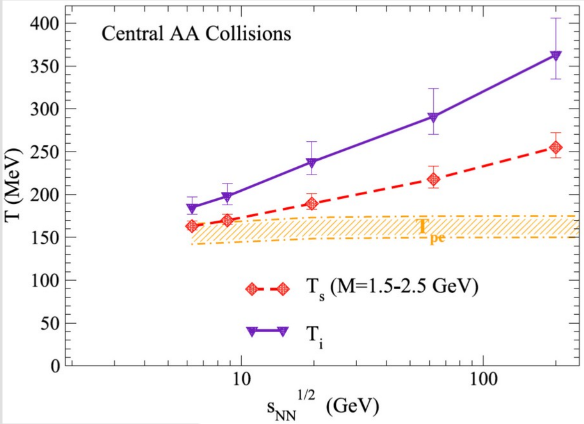
- Motivation and Pre-requisite
- Principle study: Possible improvement in the CB reduction.
  - Ideal Pluto and UrQMD with no detector effect
  - Realistic case with Detector effect
- Implementation: Improvement with current reconstruction algorithm.
  - Pair analysis in UrQMD
- Efforts for further improvement
- Conclusion and Outlook

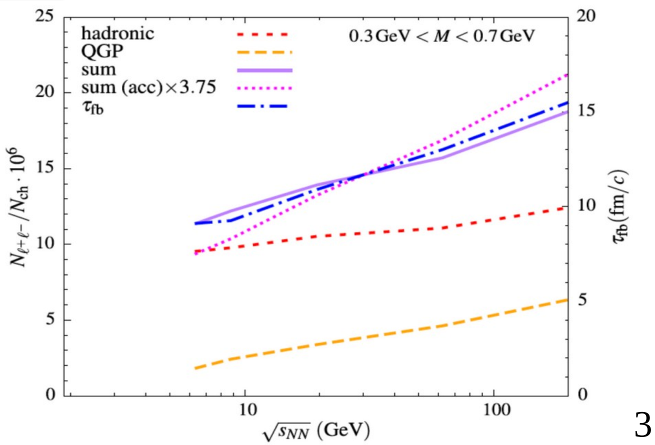
Dileptons

- Penetrative probe of hot and dense nuclear matter.
- Advantages: Interacts electromagnetically → Large mean free path compared to system size → Provide information at the time of their production.
- Challenges: Inherit large combinatorial background from Dalitz as well as conversions.

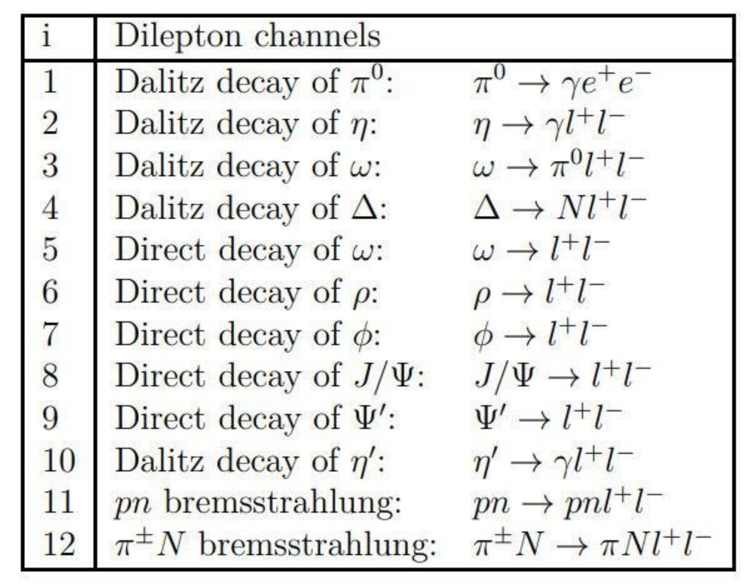
- Intermediate Mass Region: Excitation function of the inverse-slope parameter, T_s ($M = 1.5 - 2.5$ GeV).
- Closely related to the initial temperature T_i of the fire ball: “thermometer” for the heavy-ion collisions.
- Low Mass Region: Sum of QGP and hadronic contributions proportional to fireball lifetime: “chronometer” for heavy-ion collisions

Phys. Lett. B 753, 586 (2016)

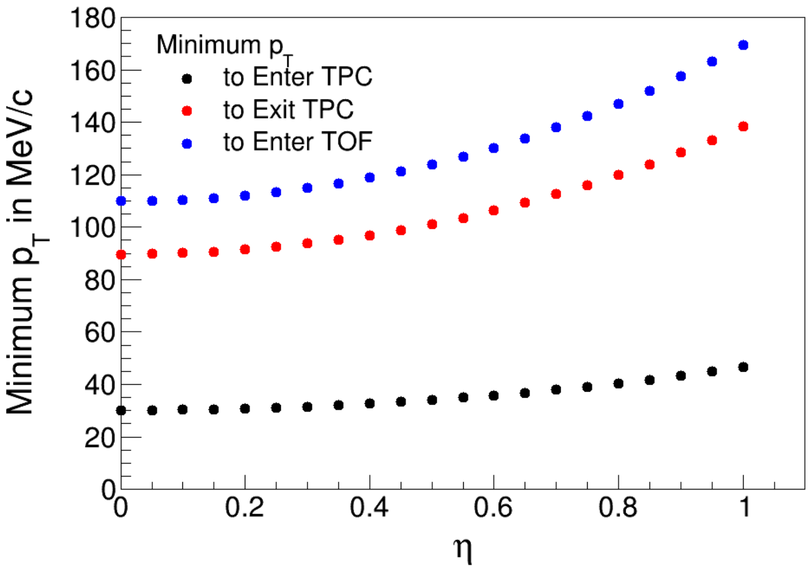




Motivation and Pre-requisite



i	Dilepton channels	
1	Dalitz decay of π^0:	$\pi^0 \to \gamma e^+ e^-$
2	Dalitz decay of η:	$\eta \to \gamma l^+ l^-$
3	Dalitz decay of ω:	$\omega \to \pi^0 l^+ l^-$
4	Dalitz decay of Δ:	$\Delta \to N l^+ l^-$
5	Direct decay of ω:	$\omega \to l^+ l^-$
6	Direct decay of ρ:	$\rho \to l^+ l^-$
7	Direct decay of ϕ:	$\phi \to l^+ l^-$
8	Direct decay of J/Ψ:	$J/\Psi \to l^+ l^-$
9	Direct decay of Ψ':	$\Psi' \to l^+ l^-$
10	Dalitz decay of η':	$\eta' \to \gamma l^+ l^-$
11	pn bremsstrahlung:	$pn \to pn l^+ l^-$
12	$\pi^\pm N$ bremsstrahlung:	$\pi^\pm N \to \pi N l^+ l^-$



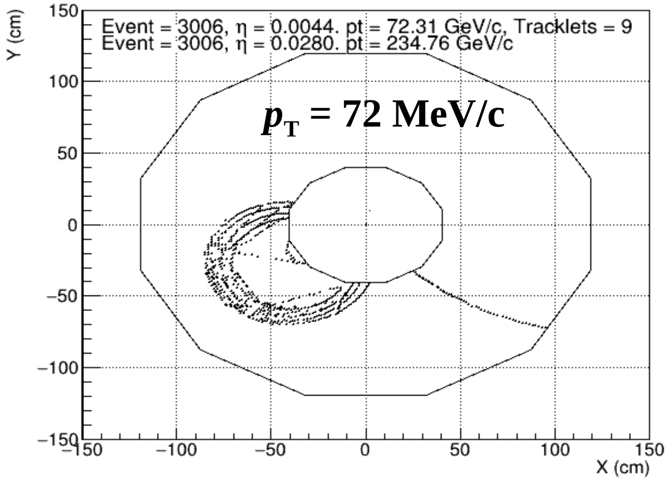
- Major source of combinatorial background: π^0 Dalitz decays (and conversions in beam pipe) where only one track is reconstructed whereas its partner is not.

- Assuming:
  - ✓ TPC inner radius: 40.3 cm
  - ✓ TPC outer radius 119.5 cm
  - ✓ TOF inner radius 146.5 cm

$$\boxed{p_T \sim 0.3*B*r}$$

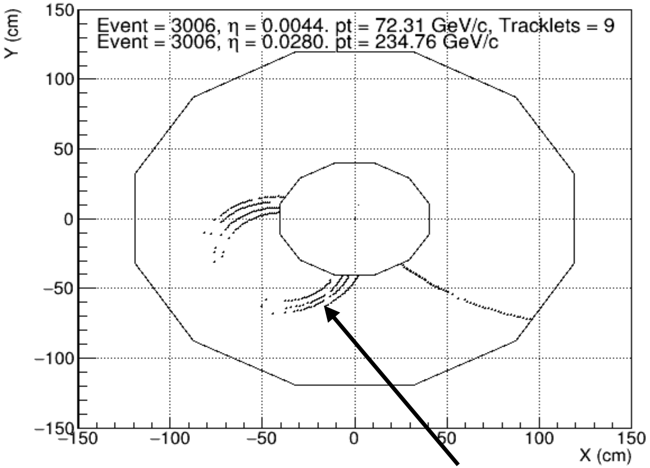
Low p_T track reconstruction with current algorithm

Reconstructed hits



p_T = 72 MeV/c

Reconstructed tracks



Partially reconstructed spiral track

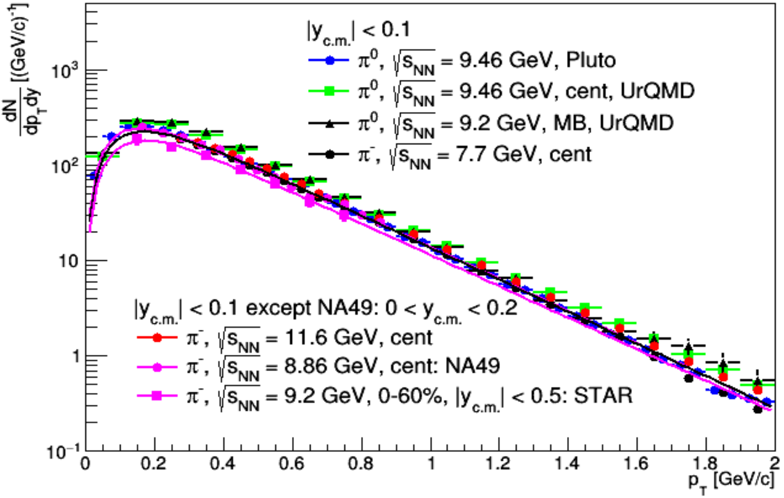
- With current track reconstruction algorithm, low p_T tracks are not reconstructed properly even though full hit information is available in the detector for tracks with $p_T \gtrapprox$ 30 MeV/c.
- Question: in an ideal detector, what would be the maximum possible benefit in the CB reduction, if we were to detect the low pt tracks that enter the TPC ($p_T >$ 30 Mev/c).

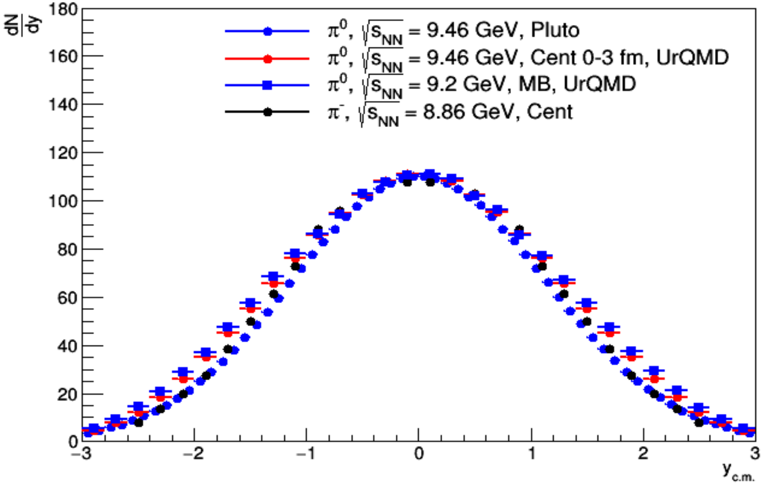
Principle study using Pluto and UrQMD

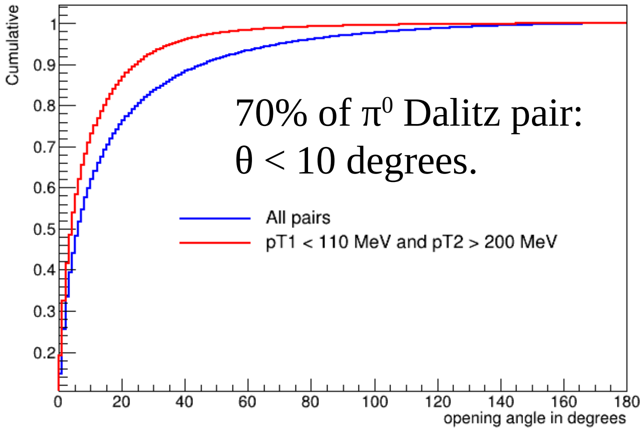
- Pluto: single π^0 Dalitz decay.
- UrQMD: Min. Bias BiBi at 9.2 GeV

Comparison with Data

- Analysis maybe sensitive to the shape of the pT and rapidity spectra.
- pT spectra of pions in Pluto is rescaled to match with the data.
- Rapidity spectra is reasonably reproduced without rescaling.







70% of π^0 Dalitz pair: $\theta < 10$ degrees.

Strategy: Ideal scenario with no detector effect

- Divide the acceptance into fiducial and veto areas.
  - In this study, we use a very conservative fiducial region, $|y| < 0.3$ and veto is $0.3 < |y| < 1.0$.
- Assume that electron is fully reconstructed if it has a pt > 110 MeV and it is reconstructed in TPC only if it has a 30 < pt < 110 MeV.
- Assume signal (N_s) is proportional to the number of Dalitz pairs with both legs $p_T > 200$ MeV and within $|y| < 0.3$
- Assume background (N_b) is proportional to the square of the single tracks originating from Dalitz decay where one leg has pT > 200 MeV in $|y| < 0.3$ and other leg is not reconstructed.
- **Absolute values of S/B in these slides have no meaning, however, the relative difference between them is meaningful.**
- Close TPC cut: Assume ideal detector and that an electron with 30 < pt < 110 MeV and within an opening angle of 10 degrees of a reconstructed track is the partner of a Dalitz decay

Possible improvement in S/B

S = N_s = No of Dalitz pair in <u>|y| < 0.3 with both legs pt > 200 MeV</u>

B = $(N_b)^2$ = (No of single tracks from Dalitz in <u>|y| < 0.3 with pt > 200 MeV</u> with partner anywhere in fid. or veto

<u>Pluto</u>

<u>Acc. |y| < 0.3</u> S/B = = 323 **(absolute value has no meaning)**

Maximum gain in S/B (assuming partner with pT > 30 MeV and opening angle <10 deg is fully recognized)**:**

|y| < 0.3 S/B = 1259 ~ **factor 4 improvement**

<u>UrQMD</u>

<u>Acc. |y| < 0.3</u> S/B = 142

Maximum gain in S/B (assuming partner with pT > 30 MeV and opening angle <10 deg is fully recognized):

|y| < 0.3 S/B = 692 ~ **factor 5 improvement**

Strategy: Realistic scenario with detector

- Now with more realistic case, with detector effect.
- UrQMD: Request 11 production: Min. Bias BiBi at 9.2 GeV
- Pluto using MPD ROOT used for request 11: π^0 Dalitz decay.
- Applied track selection and PID cuts.
- $|Vz| < 50$ cm
- Nhits > 39
- DCA < 3σ
- -1 < TPC nSigma_e < 2σ
- |TOF beta| < 2σ
- TPC-TOF matching 2σ for dφ and dz.
- <u>Close TPC cut:</u> Electron pool without TOF (TPC only tracks) and opening angle < 10 degrees.

Mpdroot dev branch: 50110a2507fc3da34d55648c9e7912f319af5455

Possible improvement in S/B

S = N_s = No of Dalitz pair in |y| < 0.3 with both legs pt > 200 MeV

B = $(N_b)^2$ = (No of single tracks from Dalitz in |y| < 0.3 with pt > 200 MeV with partner anywhere in fid. or veto

Pluto

Acc. |y| < 0.3   S/B = = 229

Maximum gain in S/B (assuming partner with pT > 30 MeV and opening angle <10 deg is fully recognized)**:**

|y| < 0.3   S/B = 1080   ~ **factor 5 improvement**

UrQMD

Acc. |y| < 0.3   S/B = 101

Maximum gain in S/B (assuming partner with pT > 30 MeV and opening angle <10 deg is fully recognized)**:**

|y| < 0.3   S/B = 8308   ~ **factor 8 improvement**

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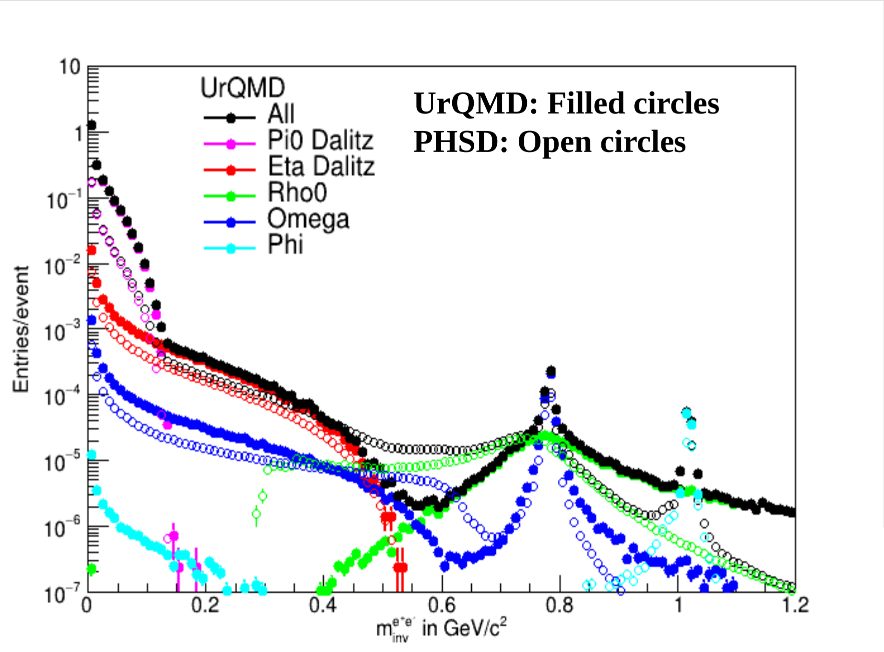
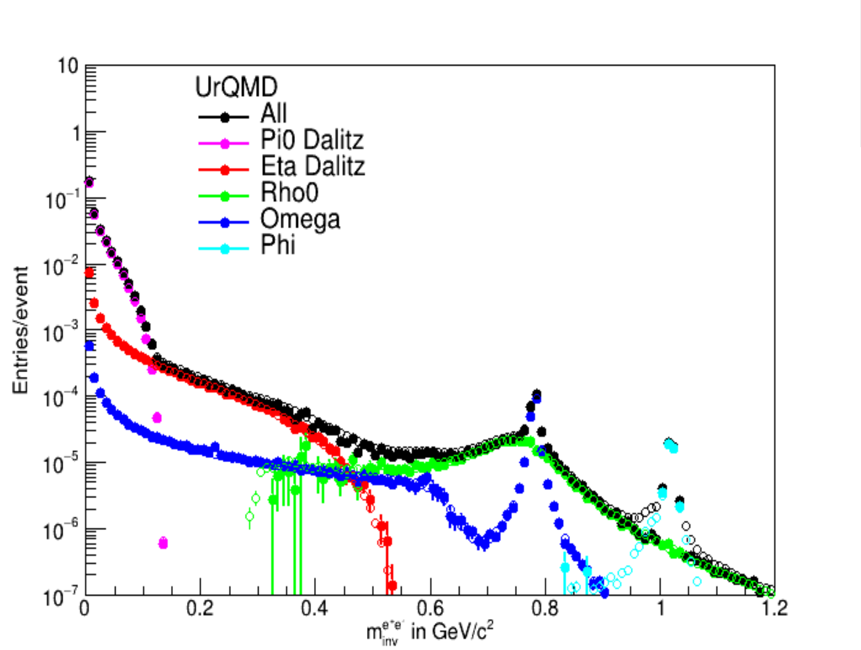
Implementation

Di-electron cocktail



UrQMD: Filled circles
PHSD: Open circles

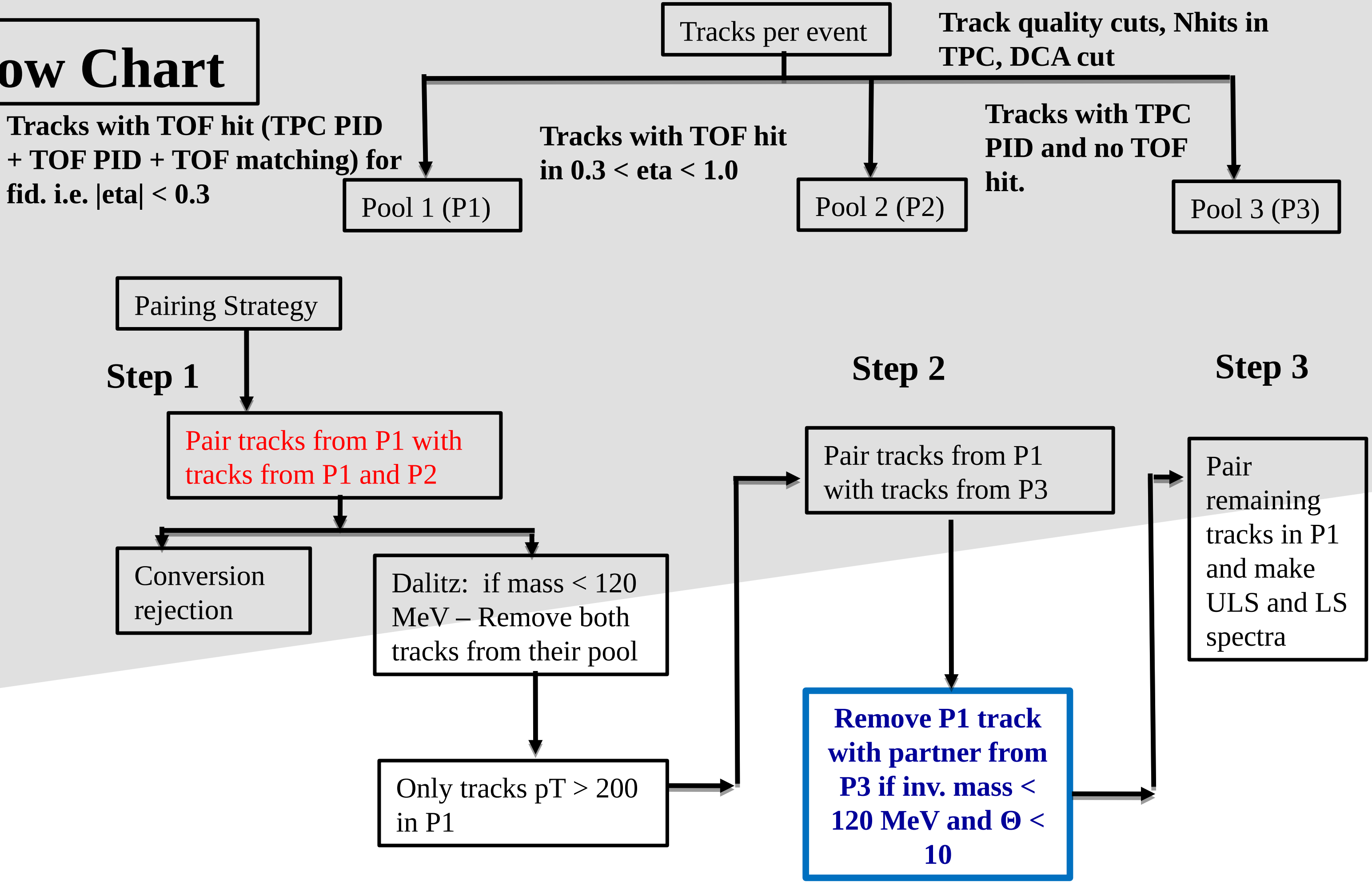
- Shapes and Multiplicities are different in PHSD and UrQMD.
- Need to scale down to PHSD.



Strategy: Pair analysis

- Three electron pools:
  - Pool-1 for fully reconstructed tracks in fiducial area (|eta| < 0.3)
  - Pool-2 for fully reconstructed tracks in veto area 0.3 < eta < 1.0.
  - Pool-3 with TPC only tracks.
- **Step 1 -No further pairing:** Tracks belonging to fully reconstructed π^0 Dalitz are tagged and not used for further pairing.
- **Step 2 - Close TPC cut:** Track from Pool-1 in an event is paired with tracks from Pool-3 in the same event and both tracks are **removed** as a potential Dalitz pair if they have $M_{inv} < M_{cutoff}$ MeV/c2 and opening angle < 10 degrees.
- **Step 3** - Rest of the tracks with pt > 200 MeV from Pool-1 are paired among themselves to build ULS and LS pair spectra.

Flow Chart



Tracks per event

Track quality cuts, Nhits in TPC, DCA cut

Tracks with TOF hit (TPC PID + TOF PID + TOF matching) for fid. i.e. |eta| < 0.3

Pool 1 (P1)

Tracks with TOF hit in 0.3 < eta < 1.0

Pool 2 (P2)

Tracks with TPC PID and no TOF hit.

Pool 3 (P3)

Pairing Strategy

Step 1

Pair tracks from P1 with tracks from P1 and P2

Conversion rejection

Dalitz: if mass < 120 MeV – Remove both tracks from their pool

Only tracks pT > 200 in P1

Step 2

Pair tracks from P1 with tracks from P3

Remove P1 track with partner from P3 if inv. mass < 120 MeV and Θ < 10

Step 3

Pair remaining tracks in P1 and make ULS and LS spectra

Selection cuts: Pair analysis

Request 25 → 36M events:

1. **Fully reconstructed tracks: Pool 1**
    1) |Vz| < 100 cm.
    2) DCA x,y,z < 3σ.
    3) Nhits > 39
    4) TPC nSigma -2 to 2 sigma at p = 0 and -1 to 2 sigma for p > 800 MeV/c
    5) TOF nSigma -2 to 2 sigma
    6) TOF matching -2 to 2 sigma
    7) Limiting the eta acceptance of the reconstructed track to 0.3
2. **Cuts on Partner: Pool 2**
    1) Same as Pool 1 except in 0.3 < Eta < 1.0
3. **Cuts on Partner for Close TPC Cut: Pool 3**
    1) |Eta| < 2.5, Nhits > 10
    2) DCA > 3.5 sigma
    3) |TPC nSigma| < 2 sigma, Those tracks who DO NOT Matched in TOF within 2 Sigma (TPC ONLY).

- STEP 1: No further pairing: Pairing between Pool 1 and 2
    1. Dalitz rejection: pairs with M < 120 MeV/c2
    2. Pairing: **pT > 200 MeV/c**

- STEP 2: Close TPC Cut: Pairing between Pool 1 and 3
    1. Dalitz rejection: **No further pairing of pairs with M < 2D cut**
    2. Pairing: **pT > 200 MeV/c**

Invariant mass vs Opening angle: Pairs after STEP 1

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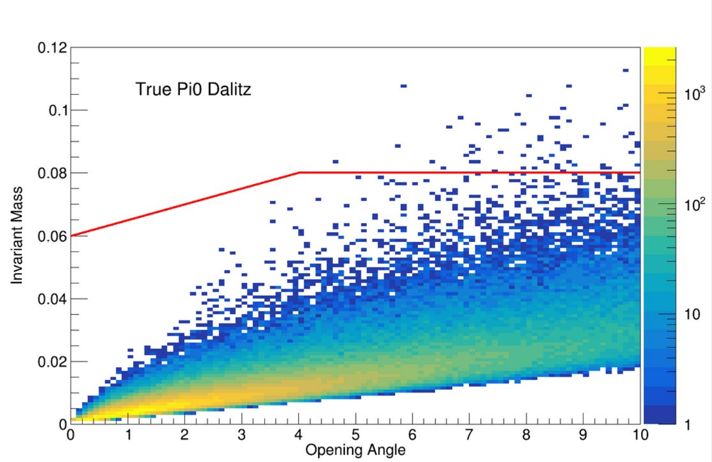
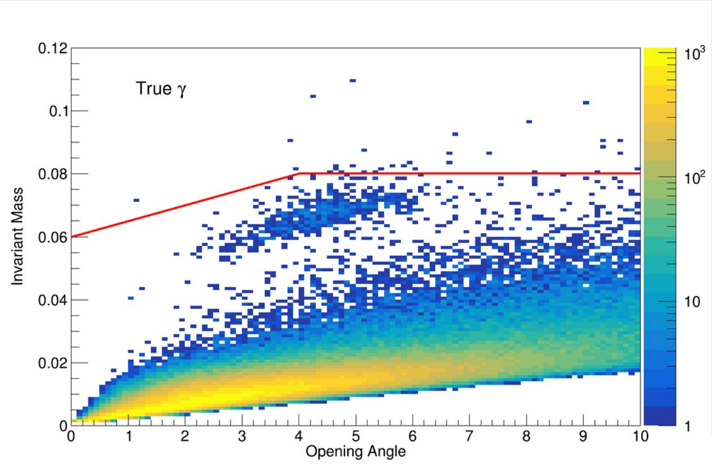
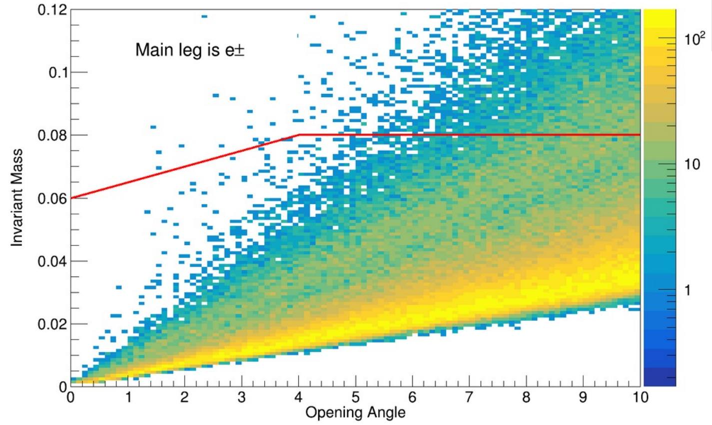
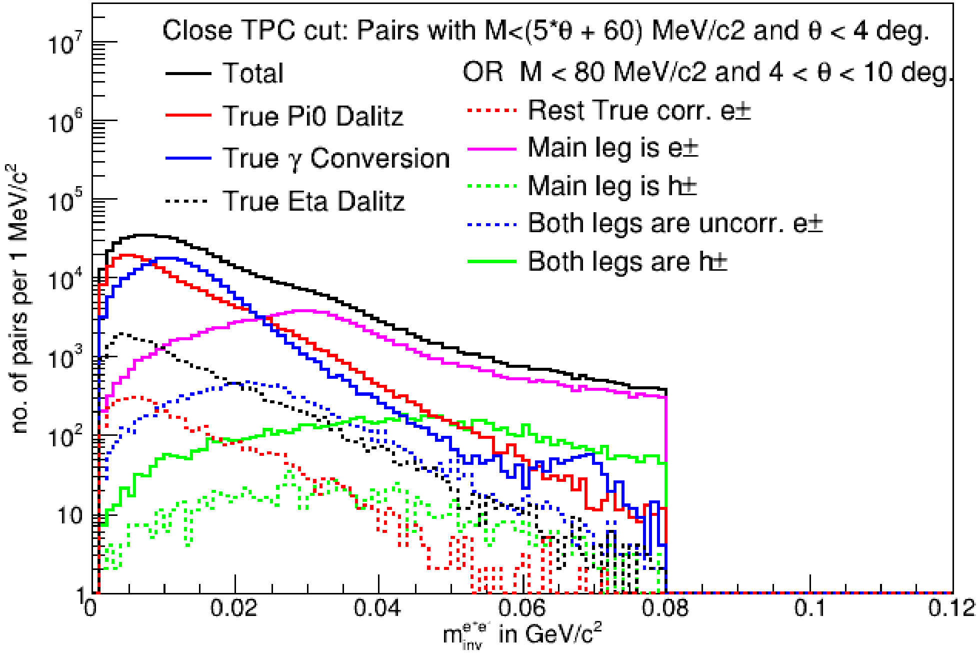






- Two-dimensional invariant mass selection criteria → Avoid signal loss (as much as possible) → subject to tuning.
- Due to sensitivity and statistics, effect of this cut may not be visible.

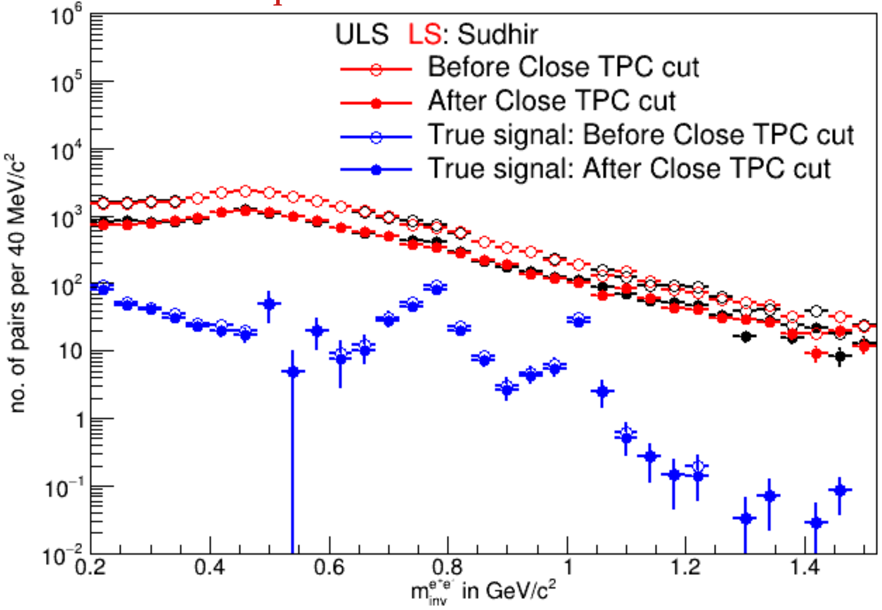
Sources of removed pairs in Close TPC Cut



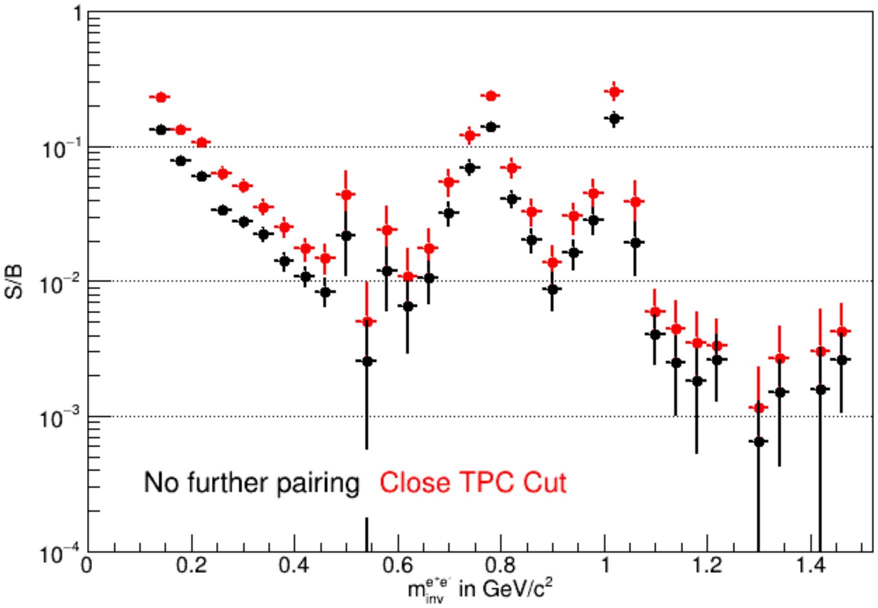
Composition	# pairs	%
Total	673118	100
True gamma conversions	258256	38.4
True Pi0 Dalitz pairs	251892	37.4
Main track is electron and other is hadron	113104	16.8
True Eta Dalitz pairs	25961	3.9
Both tracks are electron but uncorrelated	11086	1.7
Both are hadrons	7657	1.1
Rest True correlated pairs	4327	0.6
Main track is hadron and other is electron	835	0.1

S/B: Pair analysis

Request 25 → 36M events



~ 75% improvement after applying close TPC cut.



0.2 < M < 1.5 GeV/c²	Signal (S)	S loss	LS(B)	CB reduc.	S/B	S/√(S+B)
Before Close TPC Cut	644.5+/-34.4		26285.2+/-145.3		0.024+/-0.001	3.07
After Close TPC Cut	575.9+/-33.7	11%	13317.7+/-103.7	1.97 factor	0.043+/-0.003	5.41

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What’s next?

Remaining tracks after Close TPC Cut

- ✓ Trying to understand the origin of remaining background after close TPC cut.

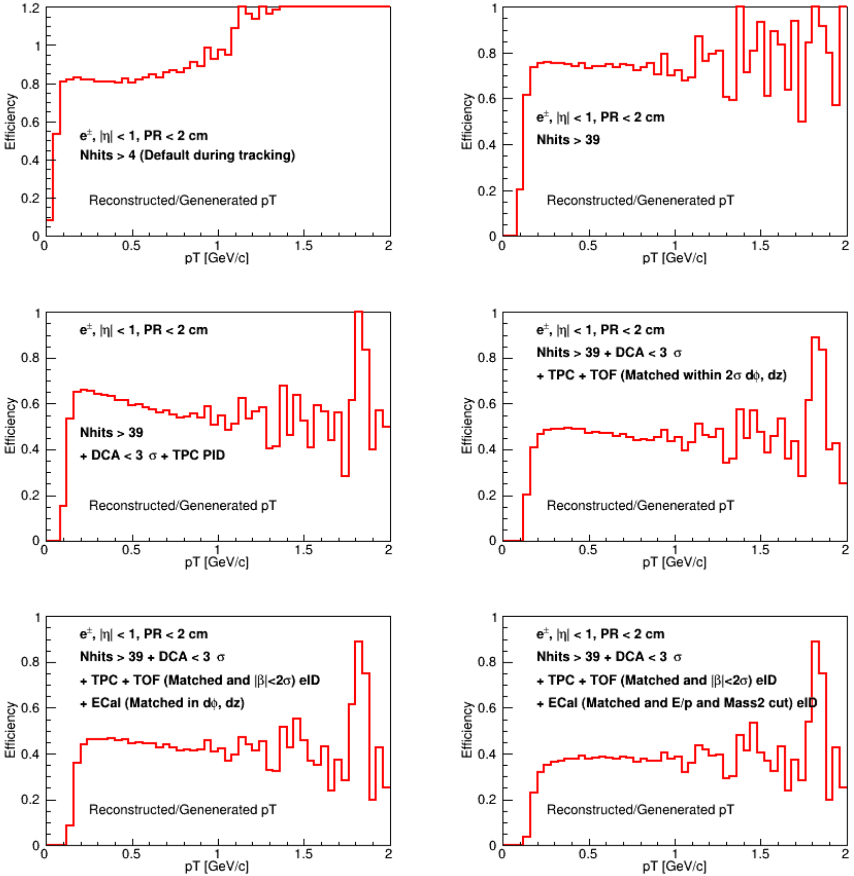
Total reconstructed tracks after close TPC cut:	**1.69268e+06**
Below: Only Conversion and π^0 Dalitz sources are considered --	
a. Track has Partner with pT < 35 MeV (|η| < 2.5):	**419595 (~25%)**
b. Track has Partner inside TPC i.e. 35 < pT < 100 MeV (|η| < 2.5):	**580428 (~34%)**
c. Track has Partner with pT > 110 MeV (|η| < 2.5):	**266075 (~16%)**
Track is hadron:	**102041 (~6%)**
Rest (Signal (η, etc), conversion, π^0 Dalitz whose partner outside TPC, ...)	**324536 (~19%)**

- ✓ Is **b.** reflecting inefficiency of the current tracking algorithm for low p_T tracks? Need expert help to improve the low-p_T tracking reconstruction.
- ✓ Additional and independent venue:
  - ✓ Improve the overall eid efficiency using Machine Learning techniques (both TPC Only and TPC+TOF+ECal) → Will help in improving the signal as well as S/B.

PID using Machine Learning

Special thanks to Igor Rufanov

Step-by-step reconstruction efficiency of electron using Selection cuts



Req 25: UrQMD BiBi at 9.2 GeV

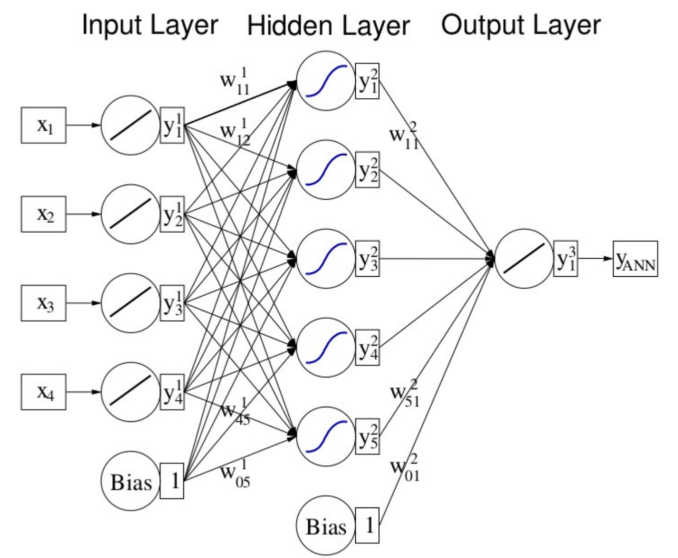
- Efficiency drops significantly when track selection cuts are applied:
- No of hits in the TPC < 39
- DCA < 3 sigma
- TPC dEdX eID
- TOF Matching 2σ
- TOF beta 2σ
- Ecal Matching
- Ecal eID (E/p and Mass^2)

This necessitates the use of Machine Learning approach.

- Numerator: Reconstructed spectrum of $e^{+/-}$ tracks with cuts.
- Denominator: Generated spectrum of $e^{+/-}$ tracks from event generator (irrespective of whether track is "reconstructible" or not) → What's thrown into the detector
- Reconstructible: Particles should have MC points in the TPC (should reach the TPC) → Not a well-defined category.

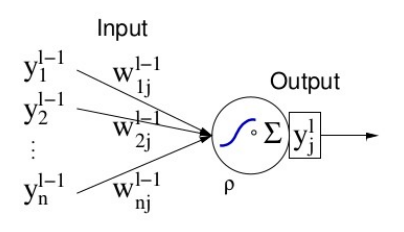
Neural Network: Multi-Layer Perceptrons (MLP)

Multilayer perceptron with one hidden layer.



The neurons are organized in layers and only allowing direct connections from a given layer to the following layer

Response function



The neuron response function ρ maps the neuron input i_1 , . . . , i_n onto the neuron output

synapse function (κ) and neuron activation function (α)

$$\kappa : \left(y_1^{(\ell)},..,y_n^{(\ell)} \middle| w_{0j}^{(\ell)},..,w_{nj}^{(\ell)}\right) \rightarrow \begin{cases} w_{0j}^{(\ell)} + \sum\limits_{i=1}^{n} y_i^{(\ell)} w_{ij}^{(\ell)} & \textit{Sum}, \\ w_{0j}^{(\ell)} + \sum\limits_{i=1}^{n} \left(y_i^{(\ell)} w_{ij}^{(\ell)}\right)^2 & \textit{Sum of squares}, \\ w_{0j}^{(\ell)} + \sum\limits_{i=1}^{n} \left|y_i^{(\ell)} w_{ij}^{(\ell)}\right| & \textit{Sum of absolutes}, \end{cases}$$

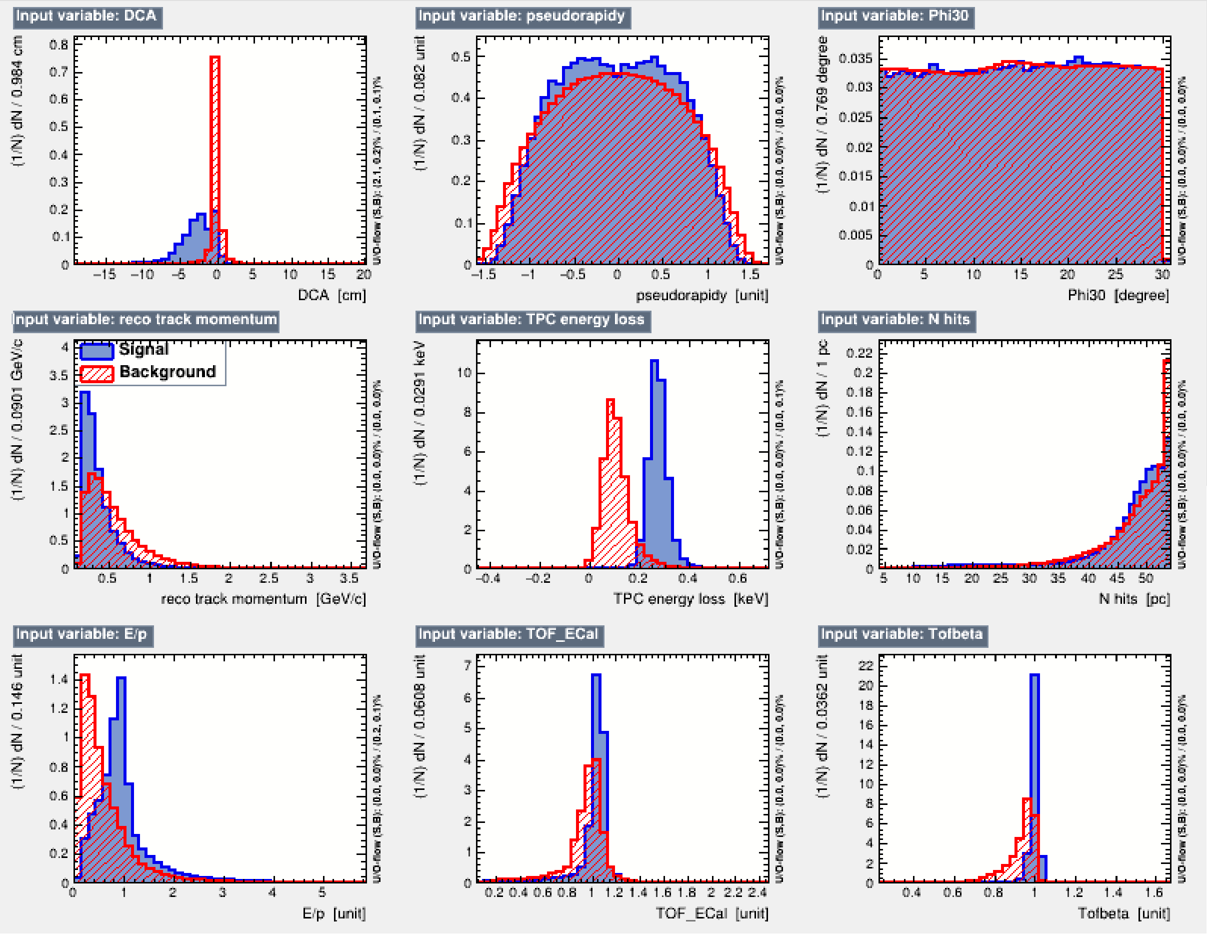
$$\alpha : x \rightarrow \begin{cases} x & \textit{Linear}, \\ \dfrac{1}{1+e^{-kx}} & \textit{Sigmoid}, \\ \dfrac{e^{x}-e^{-x}}{e^{x}+e^{-x}} & \textit{Tanh}, \\ e^{-x^2/2} & \textit{Radial}. \end{cases}$$

The neuron response function ρ often separated into *these* functions:

$$\rho = \alpha \circ \kappa$$

Disclaimer: I am not an expert on Machine Learning. This is just for information

Input variables: Multi-Layer Perceptrons (MLP)



- Request 25 production is used.
- Only negative particles are studied at the moment.
- Electrons (e^-) with Monte Carlo hit in TOF and Ecal: (if(mcTr→GetPdgCode() == 11 AND (mcTr→GetNPoints(kTOF) == 0 OR mcTr→GetNPoints(kECAL) == 0)) continue;).
- For non-electrons - no requirement → all.
- Total Signal → PDG = 11 → 346728.
- Background → PDG != 11 → 19728150.
- Variables: p, dEdx, Hits, E/p (<10), beta from TOF (>0.2) and Ecal, DCA, eta (<1.6) and phi30 (>0).

Network performance

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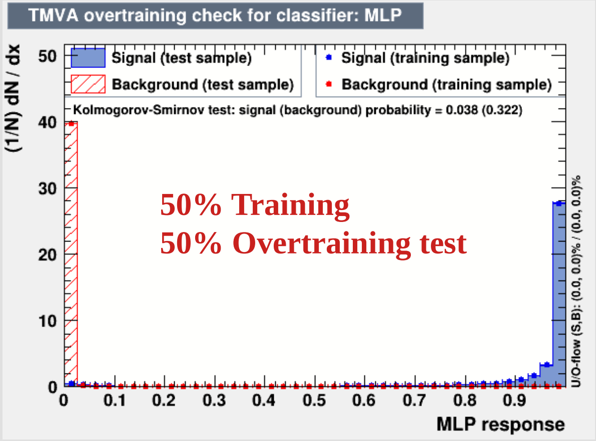
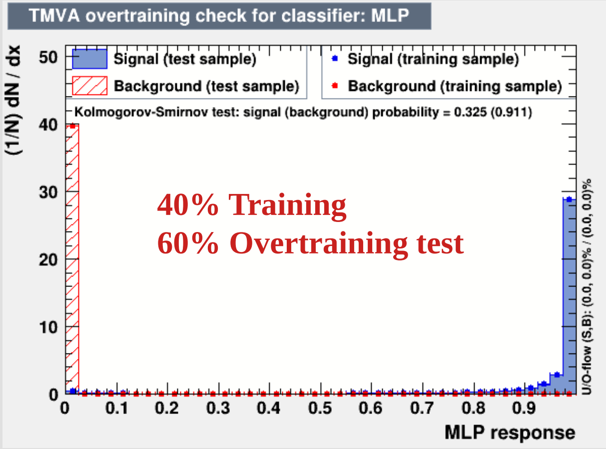
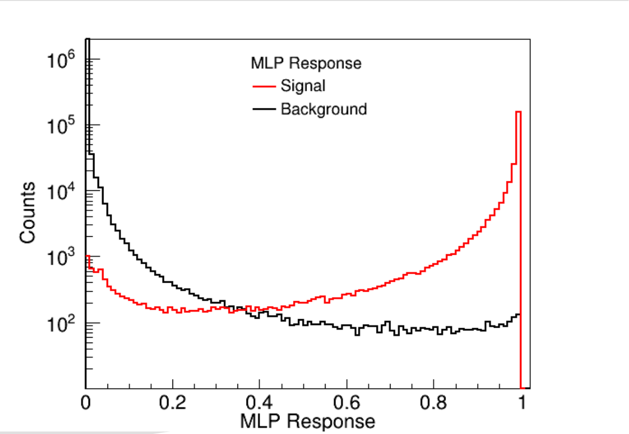
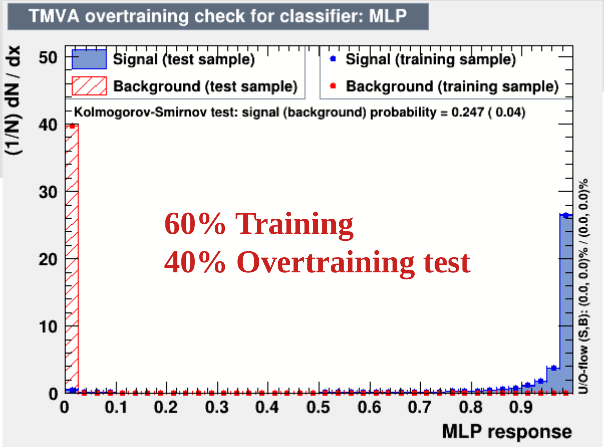


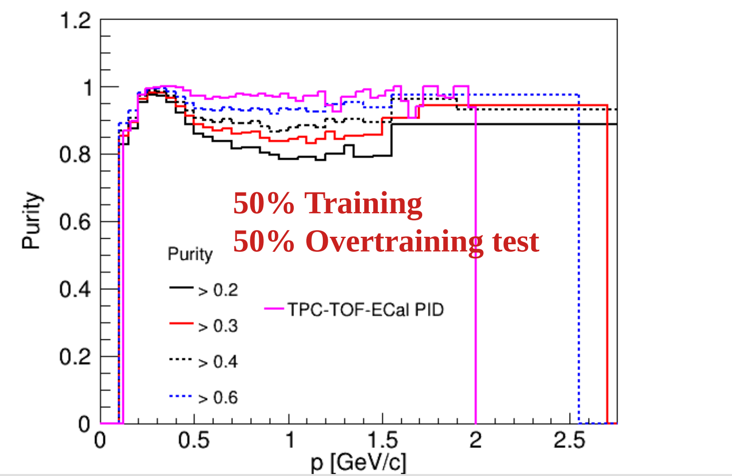




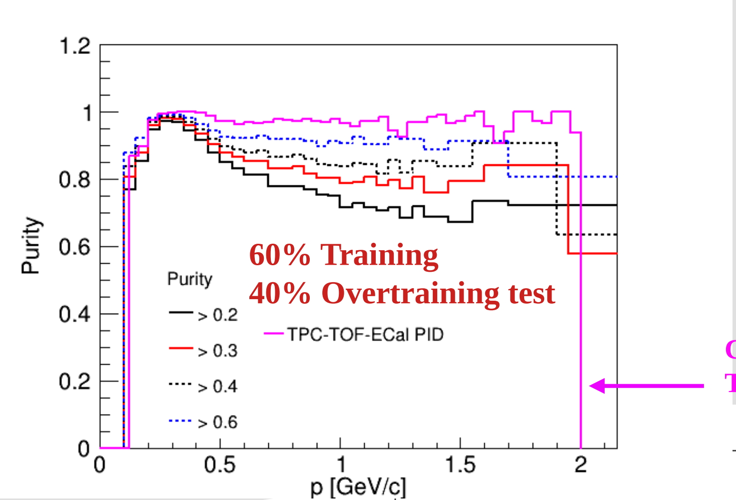


- Training sample divided into two sub-samples for training and checking the overtraining (3 combinations tried).
- Models corresponding to three cases are trained reasonably well.
- The Kolmogorov Smirnov test used for overtraining test: provides a p-value equal to the statistical probability that two samples are drawn from the same distribution.
- The smaller the p, the greater the overtraining. As a rule of thumb, it is recommended to try to reduce overtraining if $p < 0.01$, especially if the separation is visibly poorer for the testing samples than for the training samples.

Electron (e^-) purity: MLP and Selection cuts

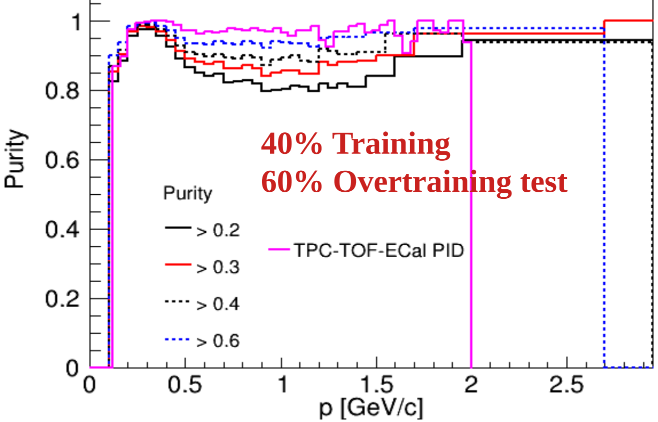


50% Training
50% Overtraining test



60% Training
40% Overtraining test

Current purity using
TPC+TOF+ECAL PID

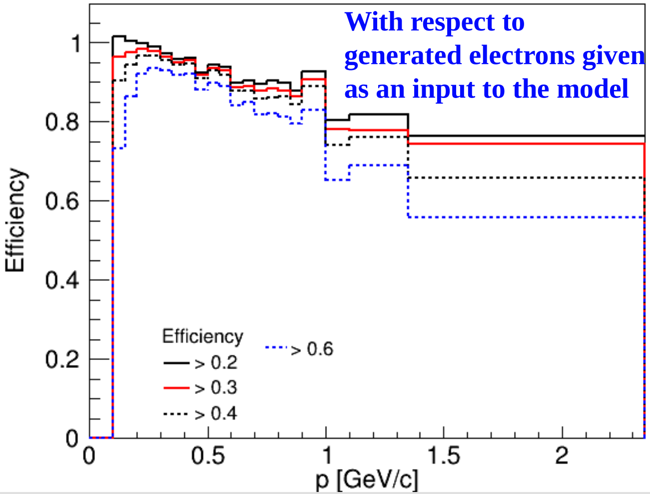


40% Training
60% Overtraining test

- **Purity:** <u>Numerator</u> → Reconstructed momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + |eta| < 1.
- <u>Denominator</u> → Reconstructed momentum distribution of all tracks (e^- with Monte Carlo hit in TOF and Ecal) within MLP response cut (0.2,0.3 etc) |eta| < 1.

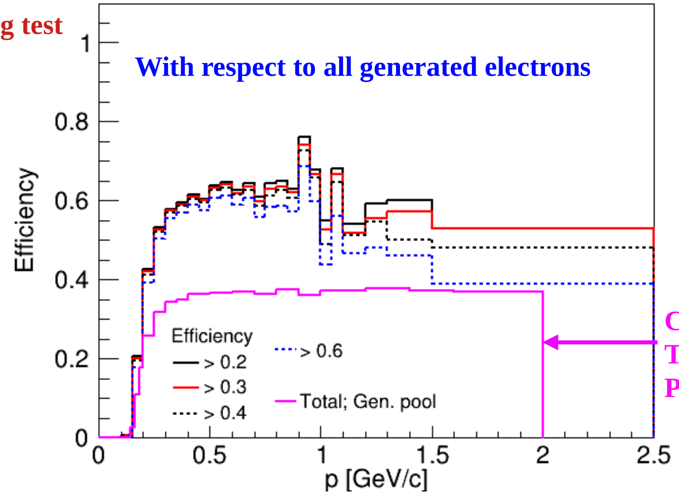
Observed similar efficiency and almost similar purity in all 3 cases.

Electron (e-) efficiency: MLP and Selection cuts



With respect to generated electrons given as an input to the model

40% Training
60% Overtraining test



With respect to all generated electrons

Current TPC+TOF+ECAL PID efficiency

- **Efficiency:** <u>Numerator</u> → Reconstructed momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- <u>Denominator</u> → Generated momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within Production radius < 2 cm + |eta| < 1.

- **Efficiency:** <u>Numerator</u> → Reconstructed momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- <u>Denominator</u> → Generated momentum distribution of e$^-$ within Production radius < 2 cm + |eta| < 1

<u>This is obtained by taking average of total spectrum (e^{+}+e^{-})/2</u>

Overall, the Machine Learning tool seems to be helping in improving the efficiency keeping purity to the maximum.

Summary

1) Using a close TPC track cut, a significant improvement in the S/B can be obtained.

2) Current tracking reconstruction algorithm brings about ~70-80% improvement.

3) Improving the tracking algorithm for low pt tracks could bring a larger improvement. Need a tracking expert on board.

4) Further improvement: currently, the e-id involves many (about 7) independent one-dimensional cuts. Use of Artificial Neural Networks or Machine Learning techniques hints at the improvement in the electron identification efficiency.

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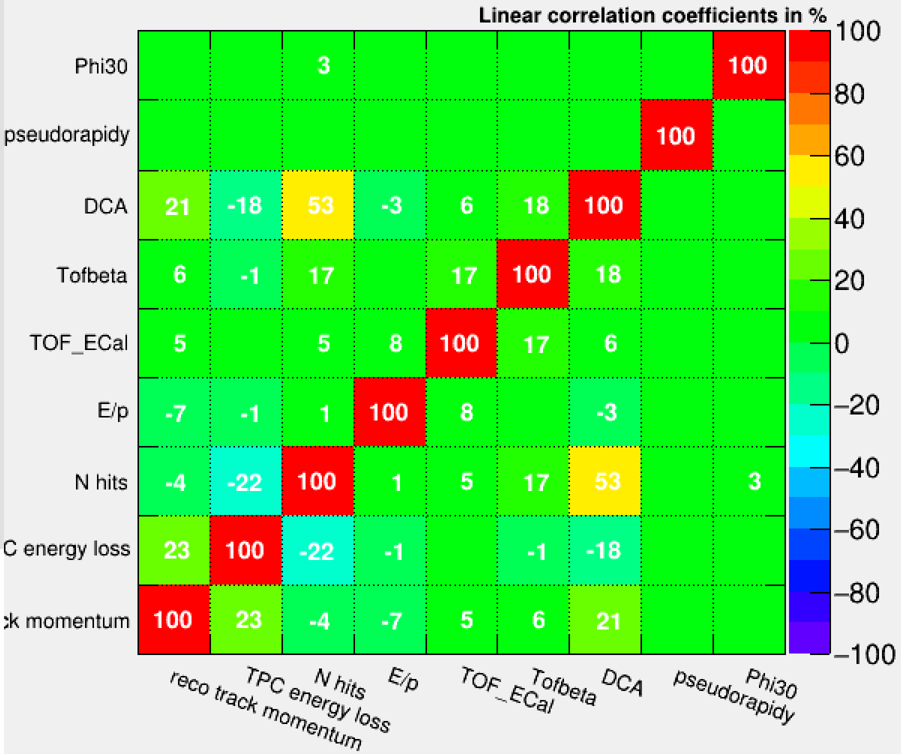
BACK-UP

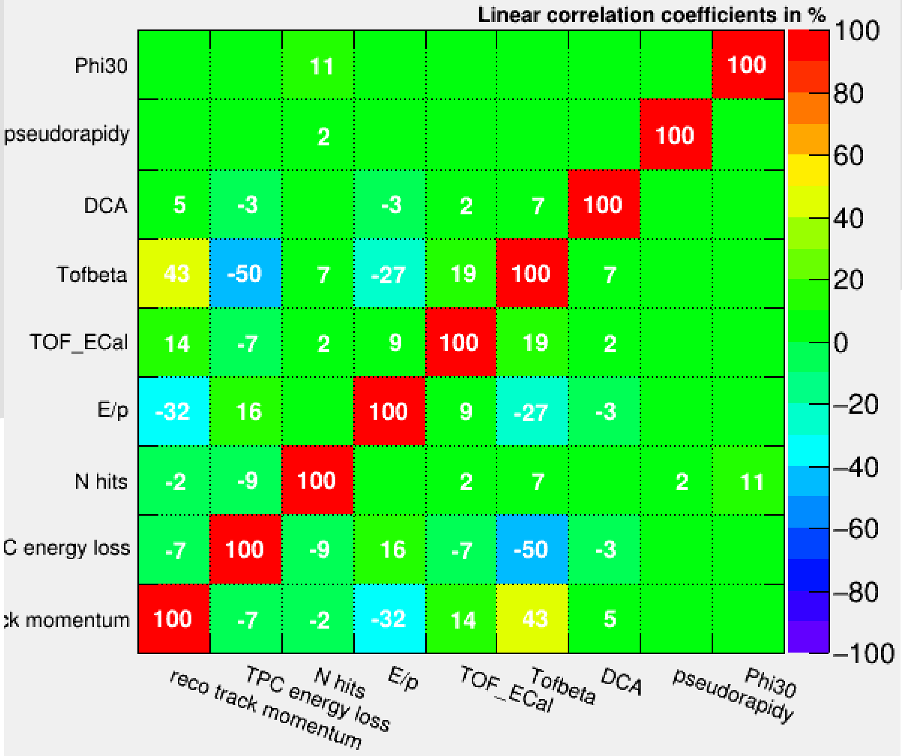
Correlation

Correlation Matrix (signal)



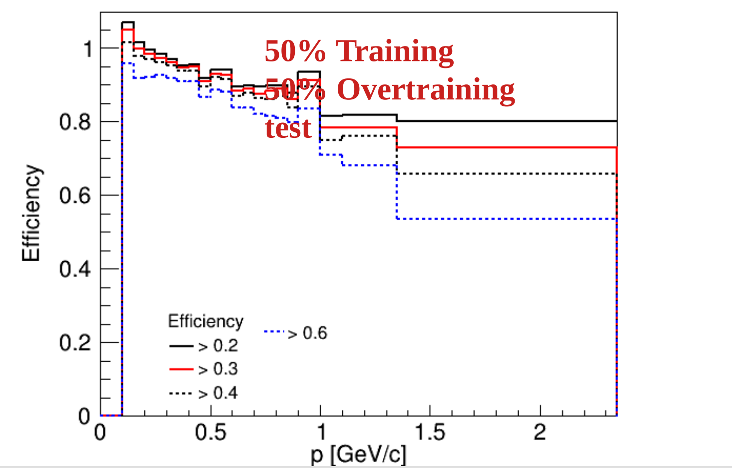
	reco track momentum	TPC energy loss	N hits	E/p	TOF_ECal	Tofbeta	DCA	pseudorapidy	Phi30
Phi30			3						100
pseudorapidy								100	
DCA	21	-18	53	-3	6	18	100		
Tofbeta	6	-1	17		17	100	18		
TOF_ECal	5		5	8	100	17	6		
E/p	-7	-1	1	100	8		-3		
N hits	-4	-22	100	1	5	17	53		3
C energy loss	23	100	-22	-1		-1	-18		
ck momentum	100	23	-4	-7	5	6	21		

Correlation Matrix (background)

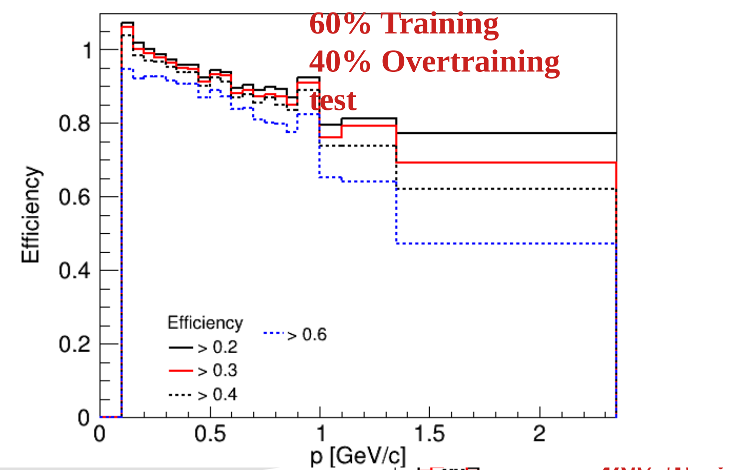


	reco track momentum	TPC energy loss	N hits	E/p	TOF_ECal	Tofbeta	DCA	pseudorapidy	Phi30
Phi30			11						100
pseudorapidy			2					100	
DCA	5	-3		-3	2	7	100		
Tofbeta	43	-50	7	-27	19	100	7		
TOF_ECal	14	-7	2	9	100	19	2		
E/p	-32	16		100	9	-27	-3		
N hits	-2	-9	100		2	7		2	11
C energy loss	-7	100	-9	16	-7	-50	-3		
ck momentum	100	-7	-2	-32	14	43	5		

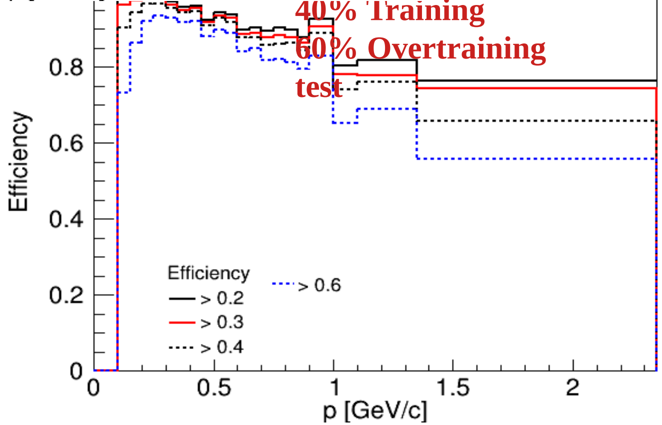
Efficiency of e^- in the testing sample with MLP



50% Training
50% Overtraining
test



60% Training
40% Overtraining
test

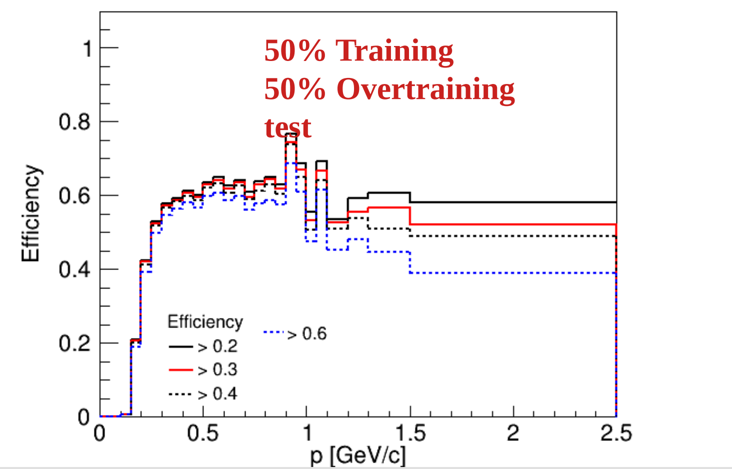


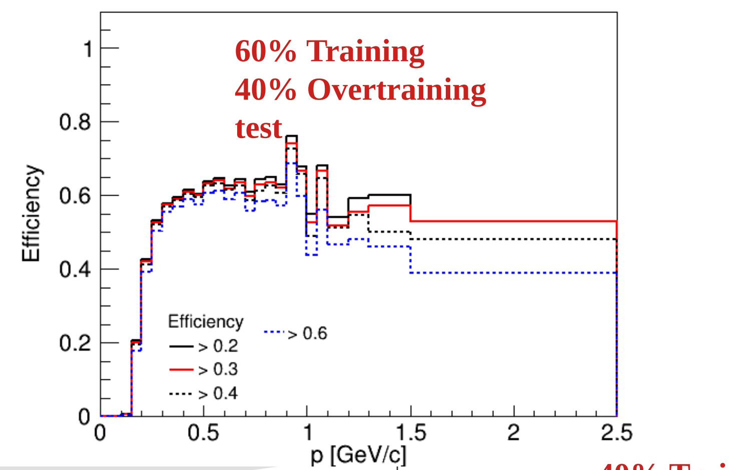
40% Training
60% Overtraining
test

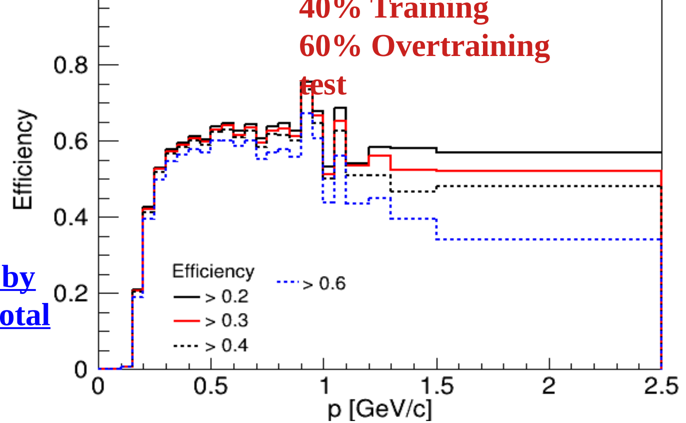
- **Efficiency:** Numerator → Reconstructed momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- Denominator → Generated momentum distribution of e^- within Production radius < 2 cm + |eta| < 1

← **This is obtained taking average of spectrum $(e^{+}+e^{-})/2$**

Efficiency of e$^-$ in the testing sample



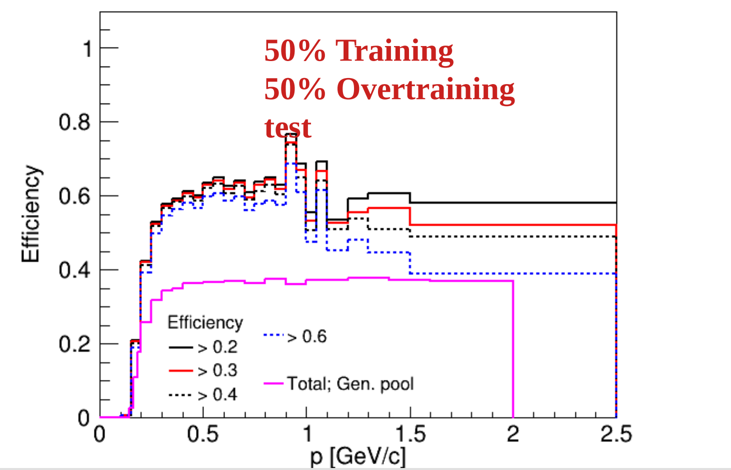




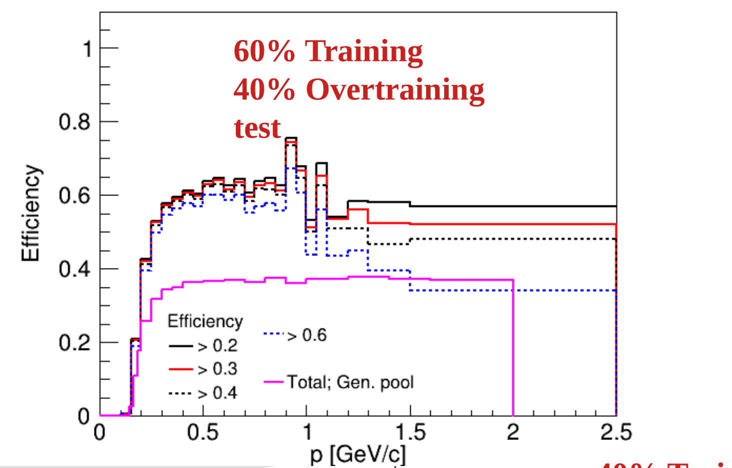
- **Efficiency:** Numerator → Reconstructed momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- Denominator → Generated momentum distribution of e$^-$ within Production radius < 2 cm + |eta| < 1

← This is obtained by taking average of total spectrum (e$^+$+e$^-$)/2

Efficiency of e$^-$ in the testing sample

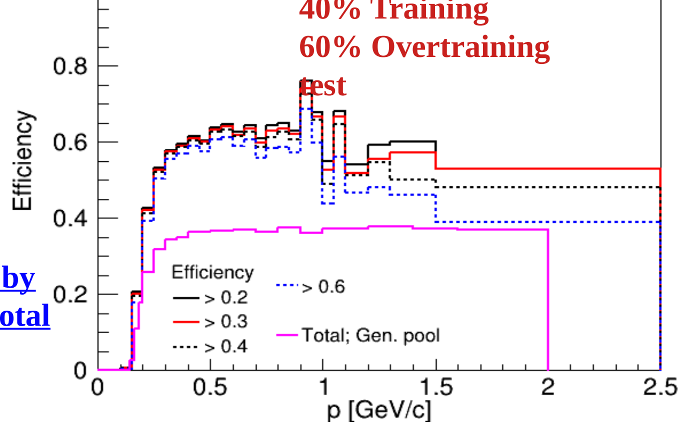


50% Training
50% Overtraining
test



60% Training
40% Overtraining
test

Current
TPC+TOF+ECAL
PID efficiency



40% Training
60% Overtraining
test

- **Efficiency:** Numerator → Reconstructed momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- Denominator → Generated momentum distribution of e$^-$ within Production radius < 2 cm + |eta| < 1

← This is obtained by taking average of total spectrum $(e^{+}+e^{-})/2$

Efficiency and Purity of e$^-$ in the testing sample

50% Training
50% Overtraining test

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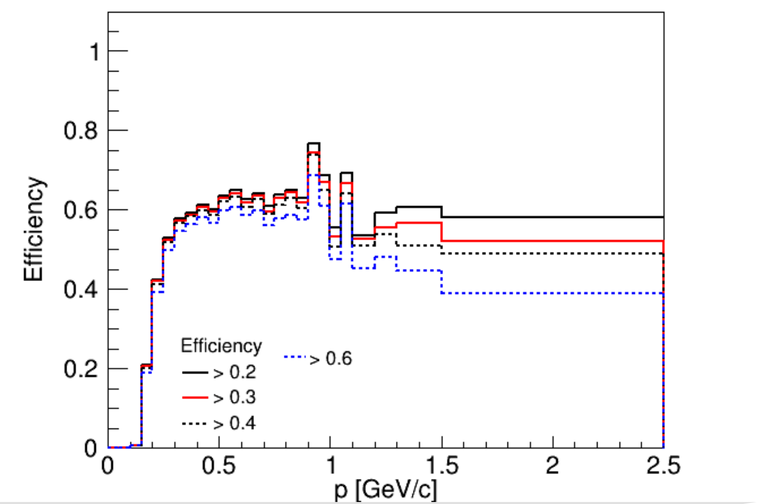

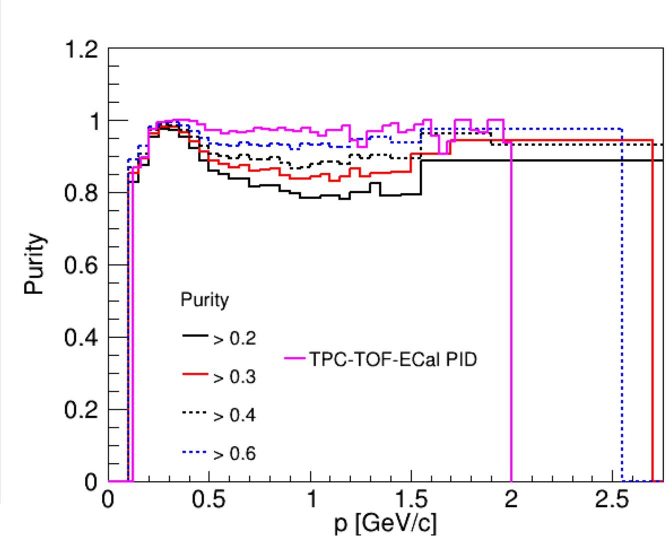

Current purity in analysis

- **Efficiency:** Numerator → Reconstructed momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- Denominator → Generated momentum distribution of e$^-$ within Production radius < 2 cm + |eta| < 1. ← **This is obtained by taking average of total spectrum (e$^+$+e$^-$)/2**

- **Purity:** Numerator → Reconstructed momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + |eta| < 1.
- Denominator → Reconstructed momentum distribution of all tracks with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) |eta| < 1.

Efficiency and Purity of e^- in the testing sample

60% Training
40% Overtraining test

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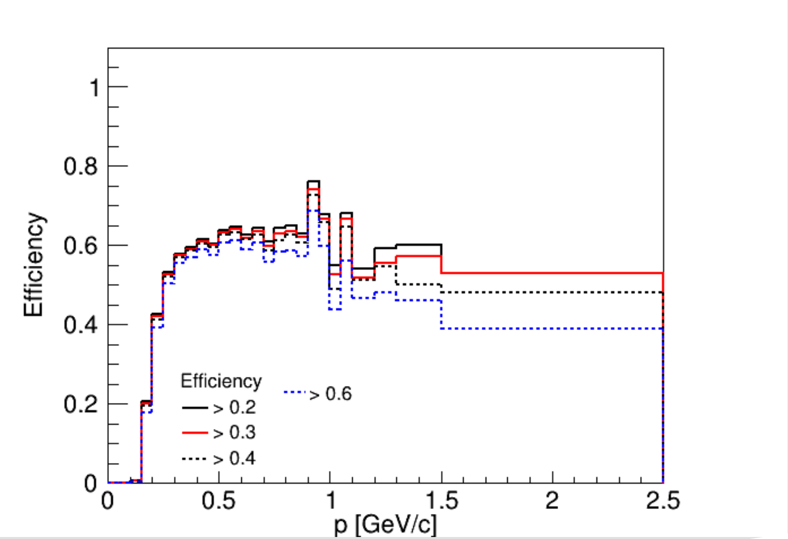
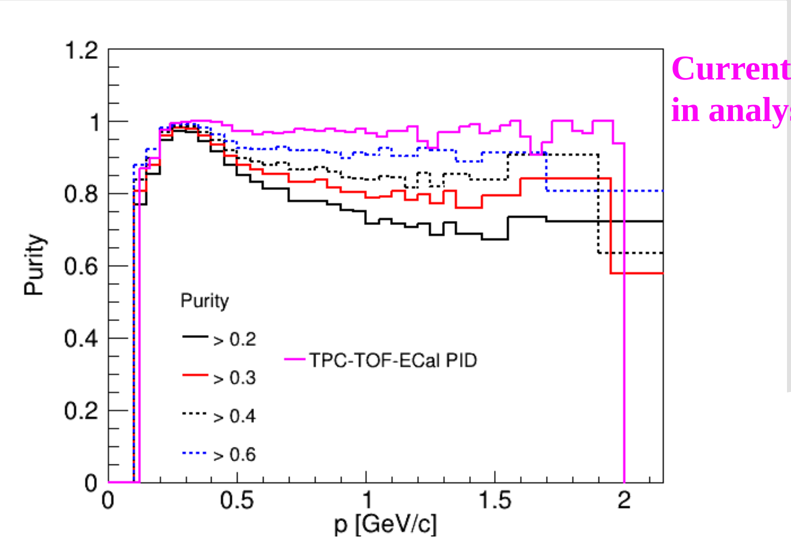




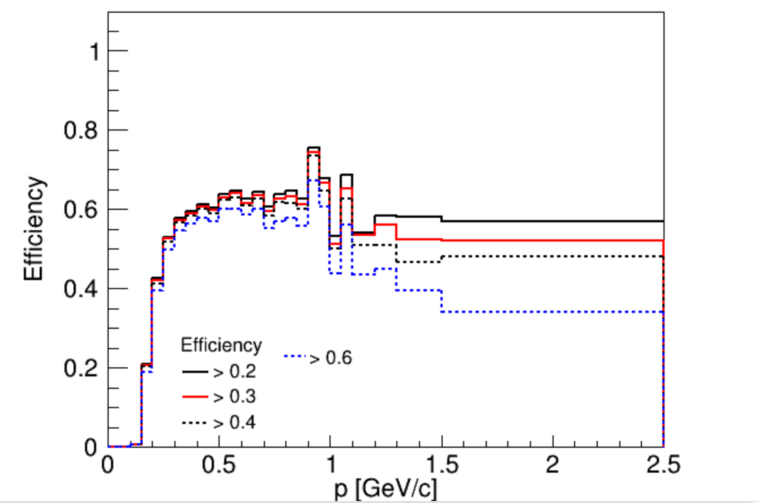
Current purity in analysis

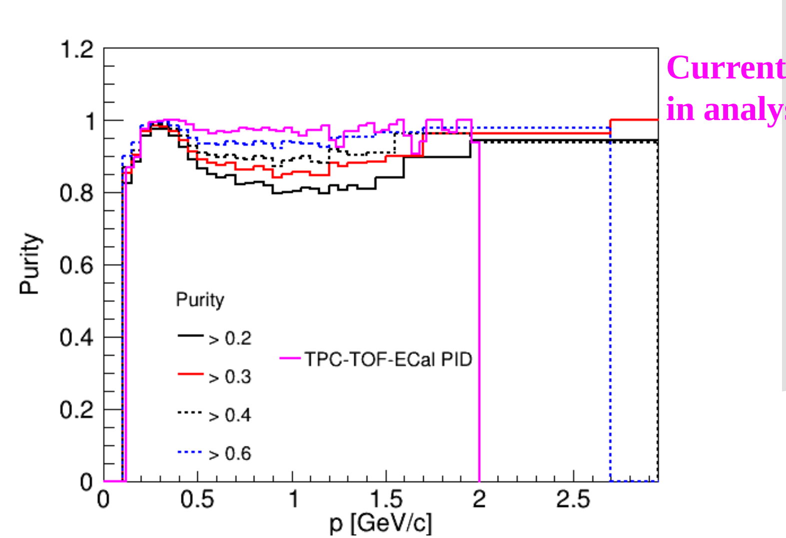
- **Efficiency:** Numerator → Reconstructed momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- Denominator → Generated momentum distribution of e^- within Production radius < 2 cm + |eta| < 1. ← **This is obtained by taking average of total spectrum (e^++e^-)/2**

- **Purity:** Numerator → Reconstructed momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + |eta| < 1.
- Denominator → Reconstructed momentum distribution of all tracks with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) |eta| < 1.

Efficiency and Purity of e$^-$ in the testing sample

40% Training
60% Overtraining test





Current purity in analysis

- **Efficiency:** <u>Numerator</u> → Reconstructed momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- <u>Denominator</u> → Generated momentum distribution of e$^-$ within Production radius < 2 cm + |eta| < 1. ← **<u>This is obtained by taking average of total spectrum (e$^+$+e$^-$)/2</u>**
- **Purity:** <u>Numerator</u> → Reconstructed momentum distribution of e$^-$ with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + |eta| < 1.
- <u>Denominator</u> → Reconstructed momentum distribution of all tracks with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) |eta| < 1.

Efficiency and Purity of e^- in the testing sample

50% Training
50% Overtraining test

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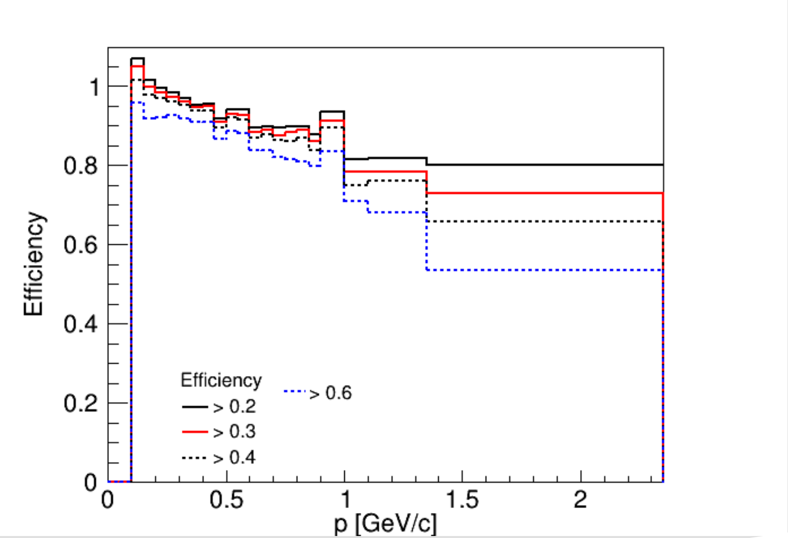
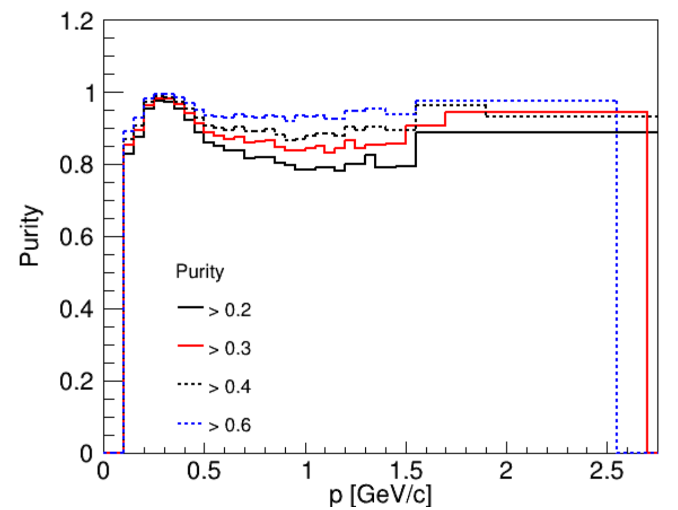


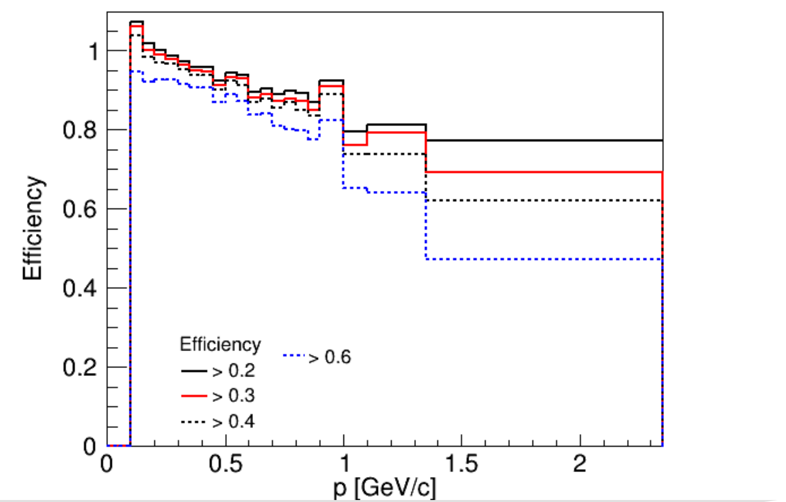


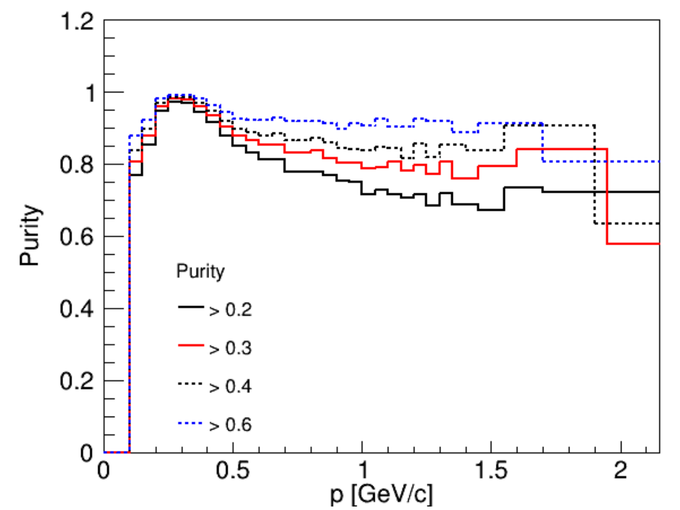
- **Efficiency:** Numerator → Reconstructed momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- Denominator → Generated momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within Production radius < 2 cm + |eta| < 1.

- **Purity:** Numerator → Reconstructed momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + |eta| < 1.
- Denominator → Reconstructed momentum distribution of all tracks with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) |eta| < 1.

Efficiency and Purity of e^- in the testing sample

60% Training
40% Overtraining test





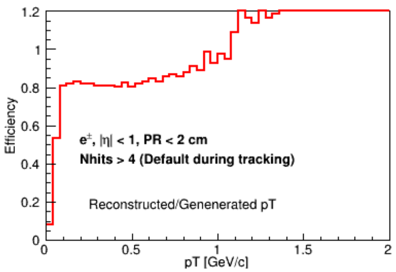
- **Efficiency:** Numerator → Reconstructed momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + Production radius < 2 cm + |eta| < 1.
- Denominator → Generated momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within Production radius < 2 cm + |eta| < 1.

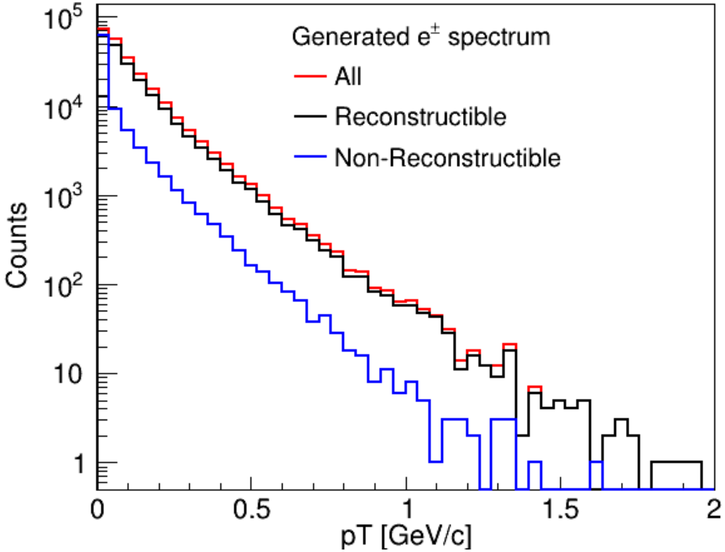
- **Purity:** Numerator → Reconstructed momentum distribution of e^- with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) + |eta| < 1.
- Denominator → Reconstructed momentum distribution of all tracks with Monte Carlo hit in TOF and Ecal within MLP response cut (0.2,0.3 etc) |eta| < 1.

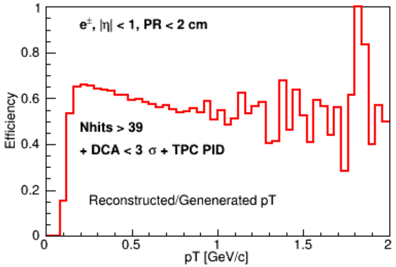
Definitions of Efficiency and Purity using Selection cuts

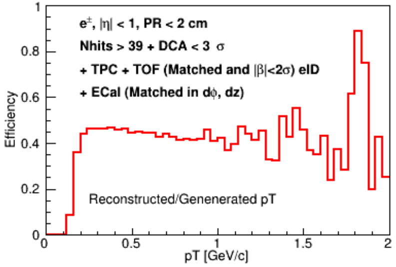
- **Efficiency**:
  - **Denominator**: Generated momentum spectrum of Electron Monte Carlo tracks (-1 < eta < 1 and PR < 2 cm) (from generated sample/MC stack).
  - **Numerator**: Reconstructed momentum spectrum of electron tracks (-1 < eta < 1 and PR < 2 cm)
    - Nhits ≥ 39
    - DCA < 3 sigma
    - Matched TOF and Ecal
    - TPC dEdX (p dependent -1 (0) to 2 sigma)
    - TOF β (-2 to 2 sigma)
    - ECal PID (E/p and mass2).
- **Purity**:
  - **Denominator**: Reconstructed momentum spectrum of all Tracks (-1 < eta < 1)
    - Nhits
    - DCA < 3 sigma
    - Matched in TOF and ECal
    - TPC dEdX (p dependent -1 (0) to 2 sigma)
    - TOF β (-2 to 2 sigma)
    - Ecal PID (E/p and mass2).
- **Numerator**: Same cuts but only electrons

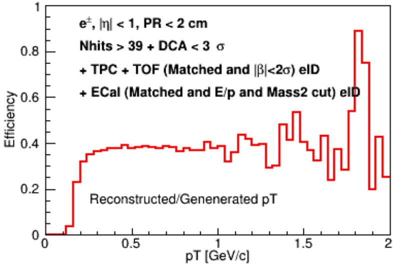
Efficiency of electron using Selection cuts









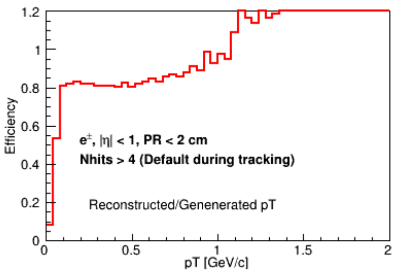


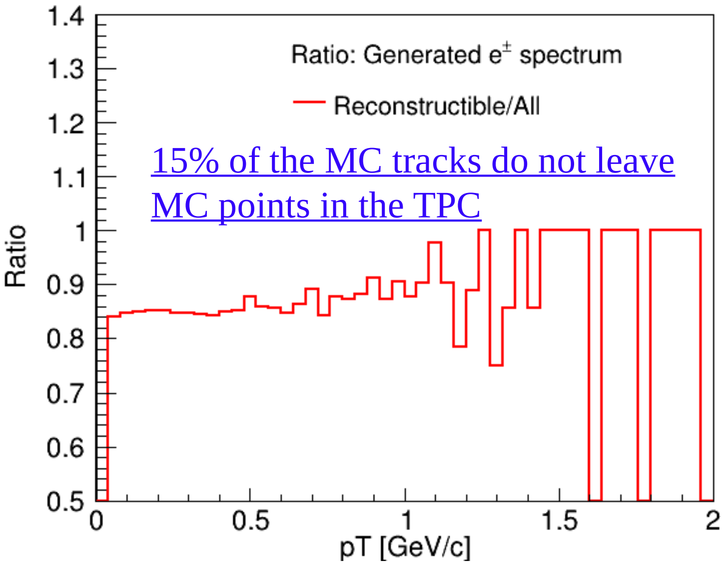
- Efficiency drops significantly as various track selection cuts are applied:
- No of hits in the TPC
- DCA
- TPC dEdX eID
- TOF Matching 2σ
- TOF beta
- Ecal Matching
- Ecal eID (E/p and Mass^2)

This necessitates the use of Machine Learning approach.

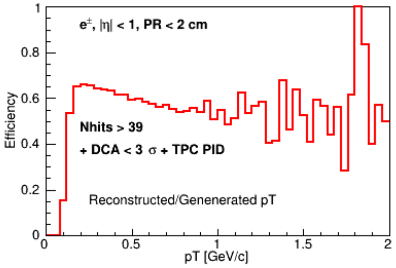
- Denominator: Generated spectrum of electron tracks from event generator (irrespective of whether track is “reconstructible” or not)
- Reconstructible: Particles should have MC points in the TPC (should reach the TPC) → Not a well-defined category.

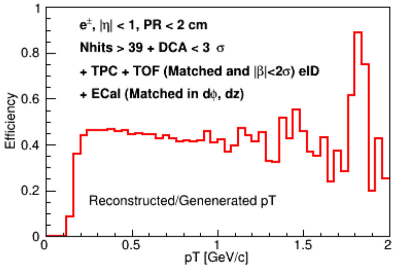
Efficiency of electron using Selection cuts

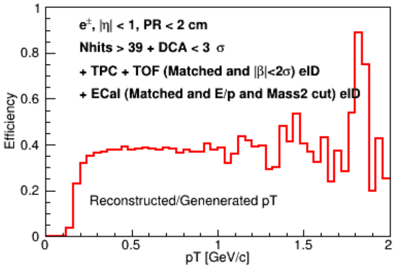




15% of the MC tracks do not leave MC points in the TPC







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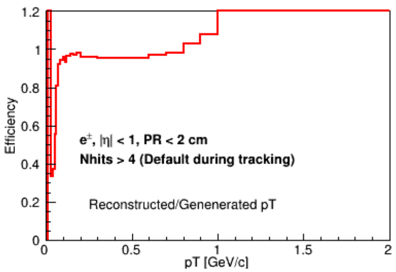
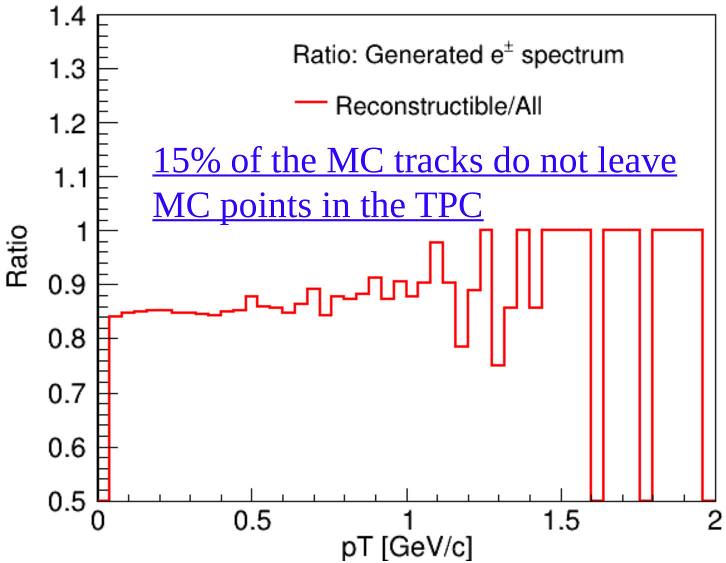
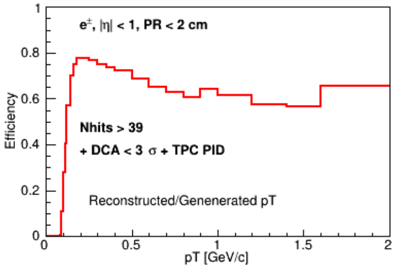
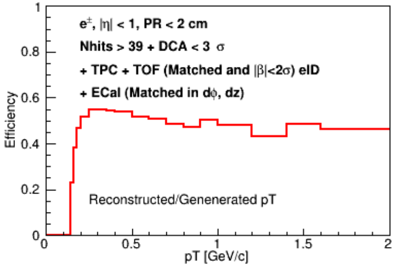
Efficiency of electron using Selection cuts

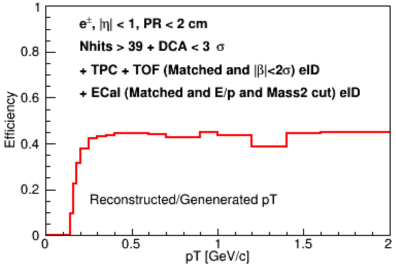




15% of the MC tracks do not leave MC points in the TPC







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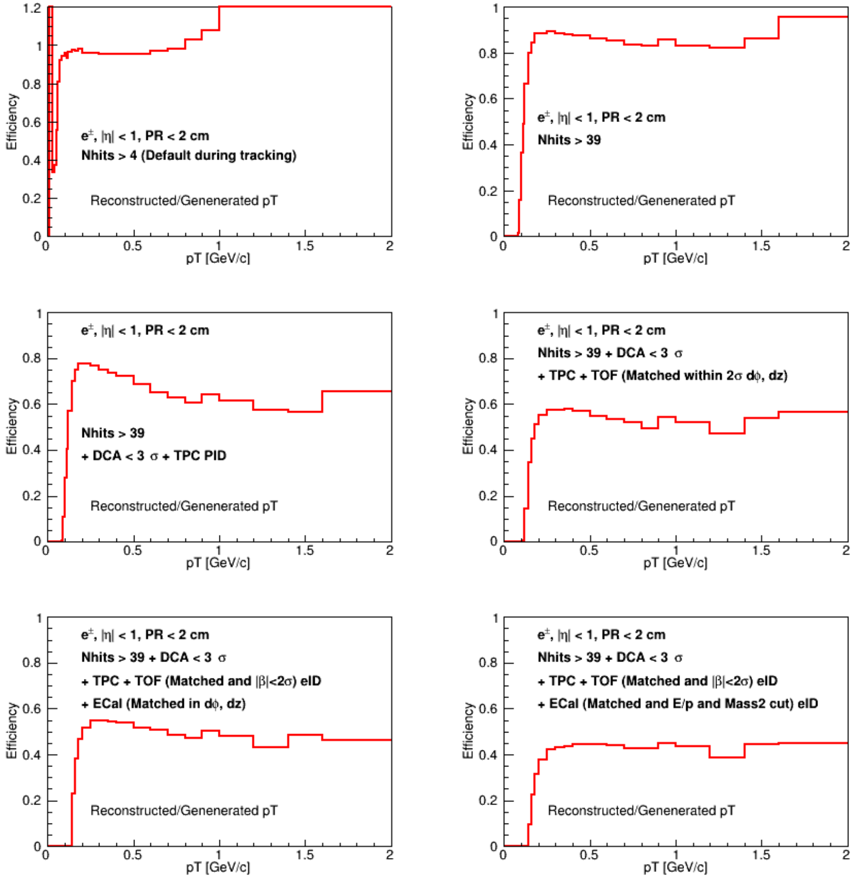
This necessitates the use of Machine Learning approach.

- Denominator: Generated spectrum of electron tracks from event generator (only “reconstructible” tracks)
- Reconstructible: Particles should have MC points in the TPC (should reach the TPC) → Not a well-defined category.

Efficiency of electron using Selection cuts



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- TOF Matching 2σ
- TOF beta
- Ecal Matching
- Ecal eID (E/p and Mass^2)

This necessitates the use of Machine Learning approach.

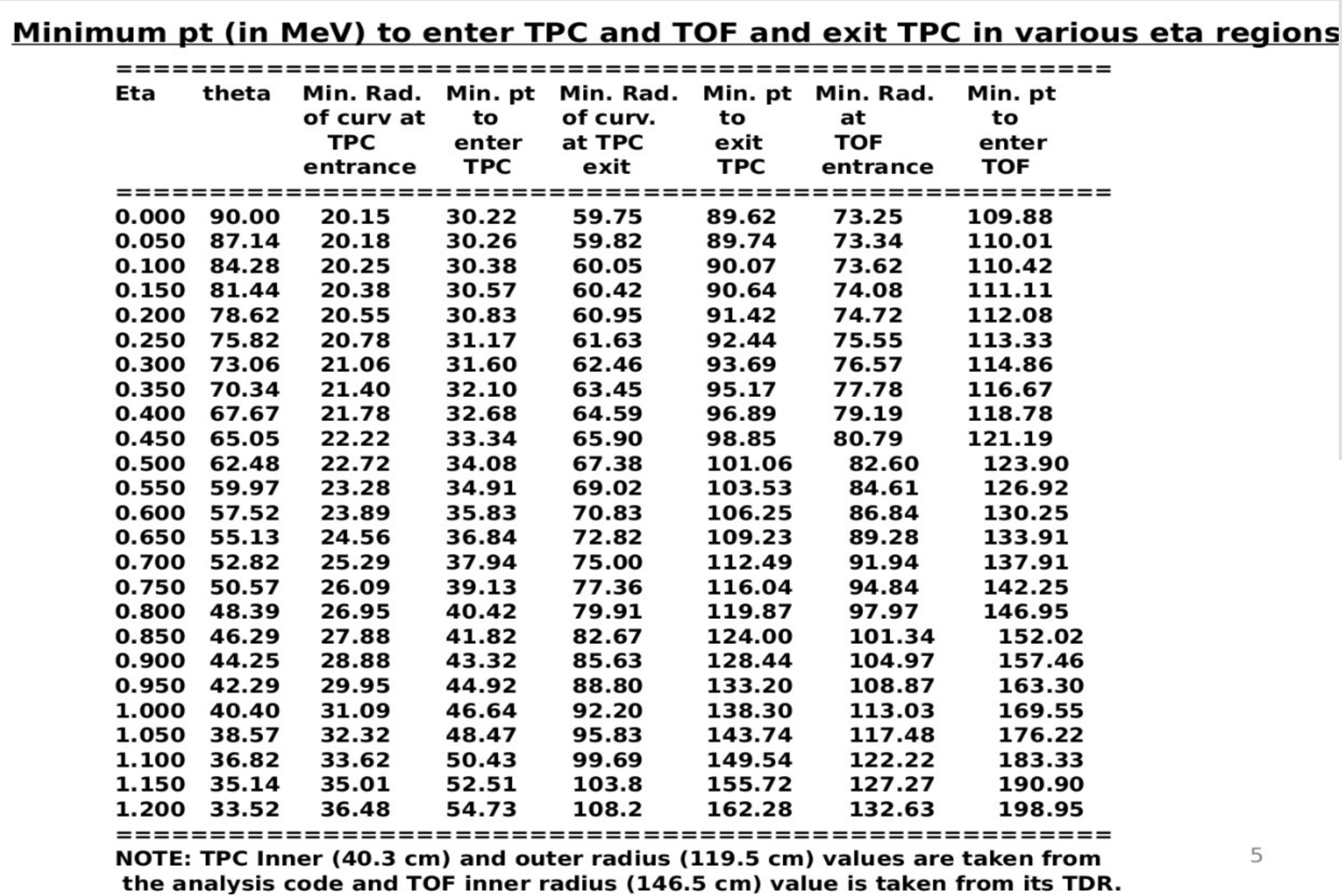
- <u>Denominator</u>: Generated spectrum of electron tracks from event generator (only “<u>reconstructible</u>” tracks)
- <u>Reconstructible:</u> Particles should have MC points in the TPC (should reach the TPC) → Not a well-defined category.

Remaining CB after CTC

- Total reconstructed tracks after close TPC cut: 1.70796e+06

- Below: Only Conversion and pi0 Dalitz sources are considered --
  - Track has Partner Inside TPC i.e. between 35 MeV < pT < 100 MeV: 564974
  - hTrackIsNotElectron (Hadron): 104390
  - Track has Partner with pT < 35 MeV: 433735
  - Track has Partner with pT > 100 MeV: 272506
- Rest: 332355

-321 ======= 2694
-211 ======= 1
-13 ======= 11
-11 ======= 1886
11 ======= 20
13 ======= 9
22 photon - partner is outside TPC acceptance ======= 107804
111 #pi^{0} - partner is outside TPC acceptance ======= 79031
130 ======= 7434
221 #eta - partner is outside TPC acceptance ======= 105725
321 ======= 4739
331 ======= 220

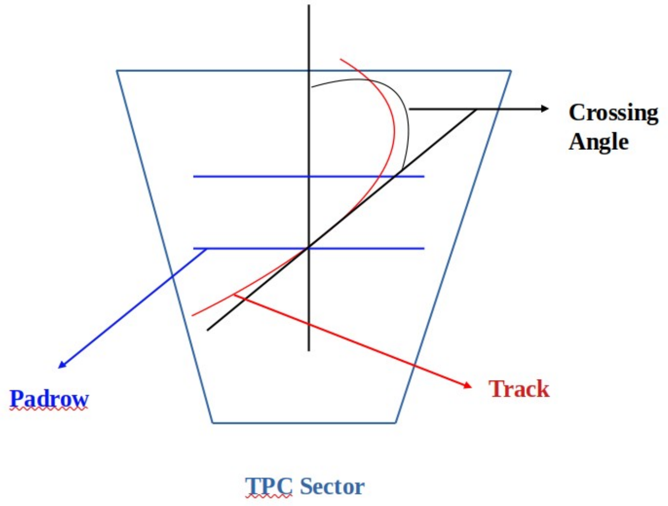


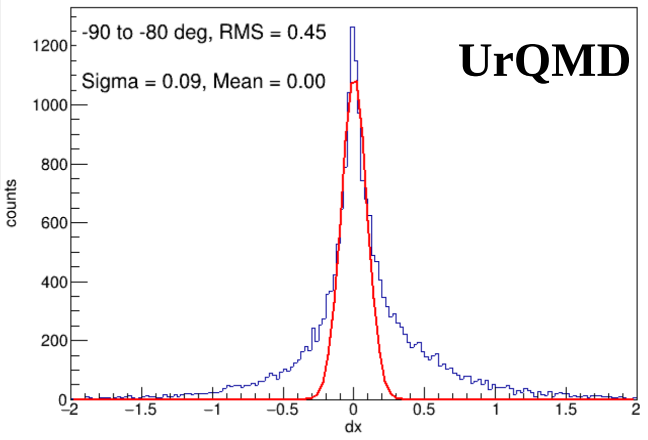
Minimum pt (in MeV) to enter TPC and TOF and exit TPC in various eta regions

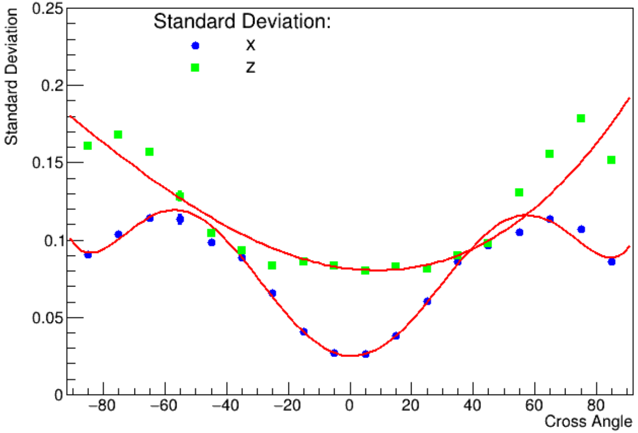
```
===========================================================================
Eta     theta   Min. Rad.    Min. pt   Min. Rad.   Min. pt   Min. Rad.   Min. pt
                of curv at     to      of curv.      to        at          to
                  TPC        enter     at TPC       exit      TOF         enter
                entrance      TPC       exit        TPC     entrance      TOF
===========================================================================
0.000   90.00    20.15       30.22      59.75      89.62      73.25      109.88
0.050   87.14    20.18       30.26      59.82      89.74      73.34      110.01
0.100   84.28    20.25       30.38      60.05      90.07      73.62      110.42
0.150   81.44    20.38       30.57      60.42      90.64      74.08      111.11
0.200   78.62    20.55       30.83      60.95      91.42      74.72      112.08
0.250   75.82    20.78       31.17      61.63      92.44      75.55      113.33
0.300   73.06    21.06       31.60      62.46      93.69      76.57      114.86
0.350   70.34    21.40       32.10      63.45      95.17      77.78      116.67
0.400   67.67    21.78       32.68      64.59      96.89      79.19      118.78
0.450   65.05    22.22       33.34      65.90      98.85      80.79      121.19
0.500   62.48    22.72       34.08      67.38     101.06       82.60      123.90
0.550   59.97    23.28       34.91      69.02     103.53       84.61      126.92
0.600   57.52    23.89       35.83      70.83     106.25       86.84      130.25
0.650   55.13    24.56       36.84      72.82     109.23       89.28      133.91
0.700   52.82    25.29       37.94      75.00     112.49       91.94      137.91
0.750   50.57    26.09       39.13      77.36     116.04       94.84      142.25
0.800   48.39    26.95       40.42      79.91     119.87       97.97      146.95
0.850   46.29    27.88       41.82      82.67     124.00       101.34      152.02
0.900   44.25    28.88       43.32      85.63     128.44       104.97      157.46
0.950   42.29    29.95       44.92      88.80     133.20       108.87      163.30
1.000   40.40    31.09       46.64      92.20     138.30       113.03      169.55
1.050   38.57    32.32       48.47      95.83     143.74       117.48      176.22
1.100   36.82    33.62       50.43      99.69     149.54       122.22      183.33
1.150   35.14    35.01       52.51      103.8     155.72       127.27      190.90
1.200   33.52    36.48       54.73      108.2     162.28       132.63      198.95
===========================================================================
NOTE: TPC Inner (40.3 cm) and outer radius (119.5 cm) values are taken from
 the analysis code and TOF inner radius (146.5 cm) value is taken from its TDR.
```

Current status

1) Limitations in Standard algorithm:
   - Hit requirement of 39 is too strong for low pT tracks.
   - Not able to reach pad rows above apogee (low p_T tracks stop before that).
   - In many cases, track stops even before apogee due to high χ^2 value (hence hit is not added to the track) ← this can be improved by performing **crossing angle correction** (more important for low p_T tracks).

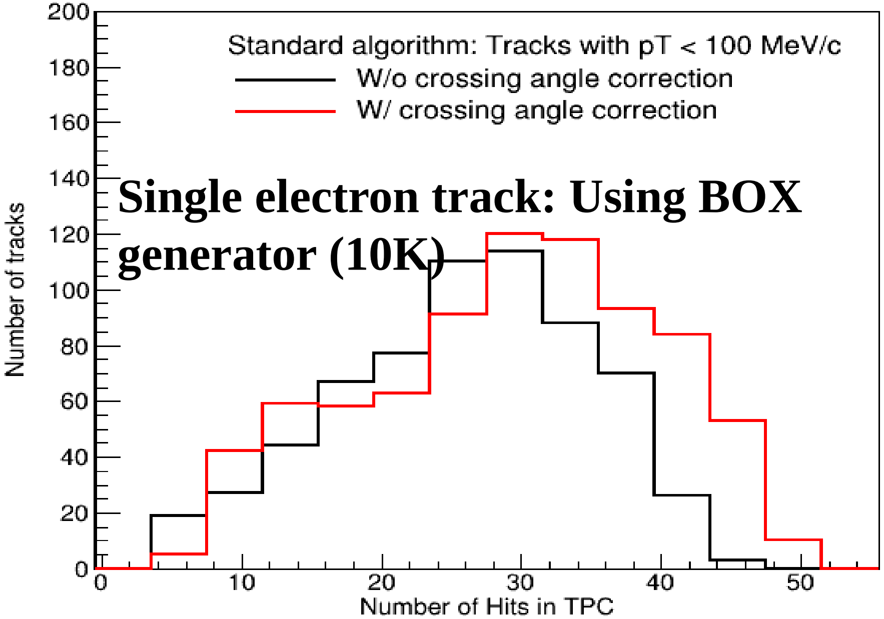






Suggested by Alexander Zinchenko

Current status: Improvement due to crossing angle correction

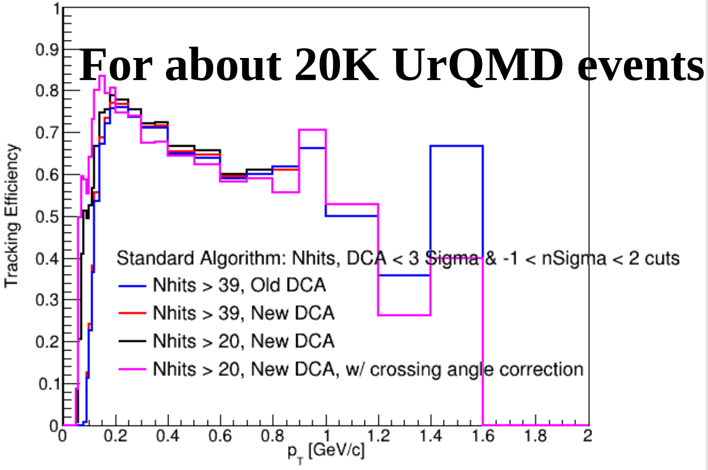


Single electron track: Using BOX generator (10K)

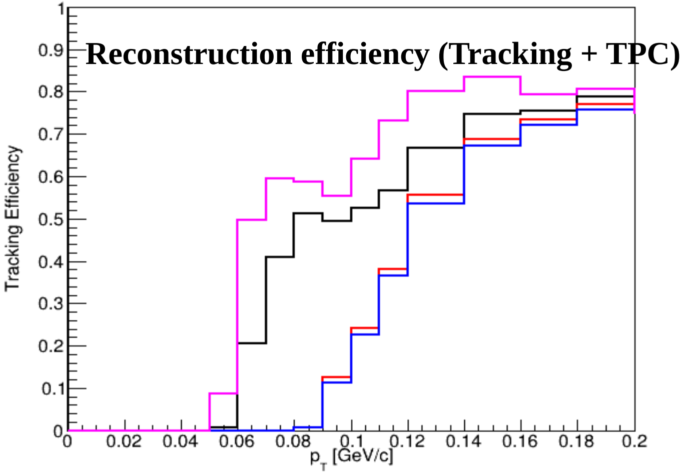
- Many of the reconstructed hits corresponding to a particular track are not found and therefore not added to the track.
- Simulate single electron track using BOX generator for both with and without crossing angle correction to get hit distribution (After DCA selection).
- Crossing angle correction seems to find more hits and therefore, added to the track.

- Apart from crossing angle correction, what can be done?
  - Reduce number of hits on the partner.
  - Improve DCA parametrization at low pT.

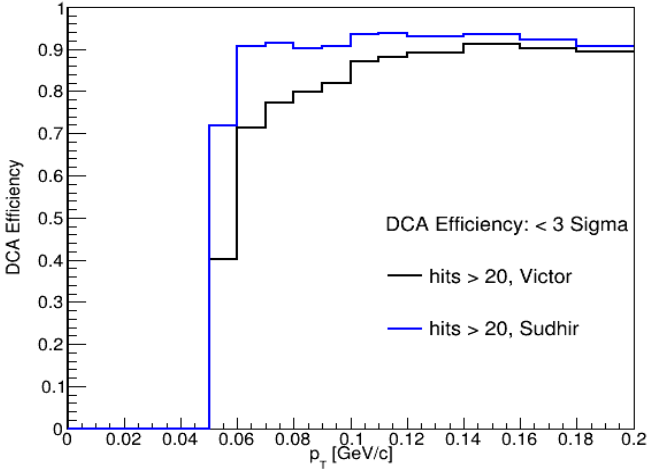
Current status: Improvement in tracking + TPC efficiency



For about 20K UrQMD events

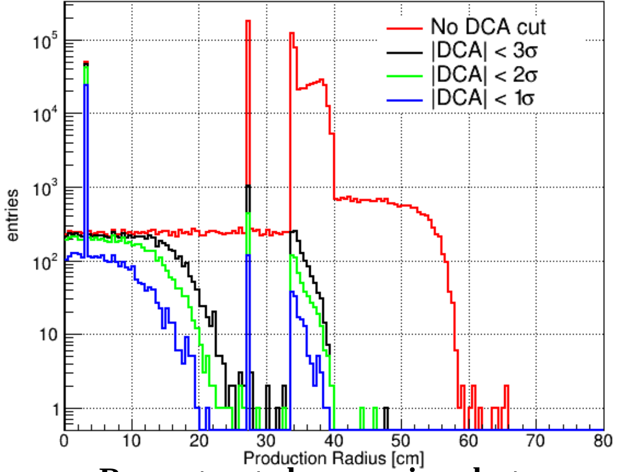


Reconstruction efficiency (Tracking + TPC)

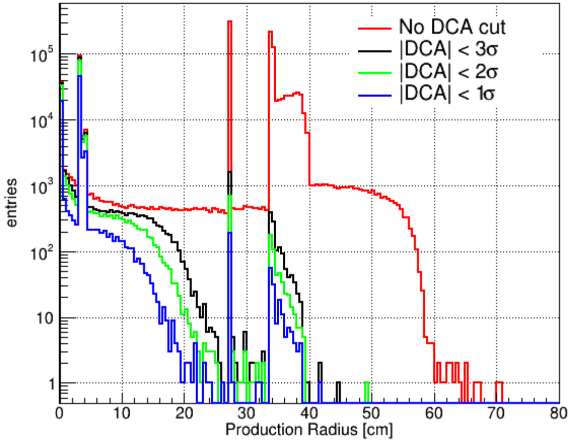


- Cuts: No of Hits, DCA and TPC PID.
- DCA parametrizations are updated at very low pT (enhances efficiency for tracks with Nhits > 20 but slight improvement for tracks with 39 hits → negligible effect on conversion rejection).
- Hits on the partner tracks reduced to 20.
- Effect of crossing angle correction.
- Observed improvement in the efficiency.

Request 11: 2M events

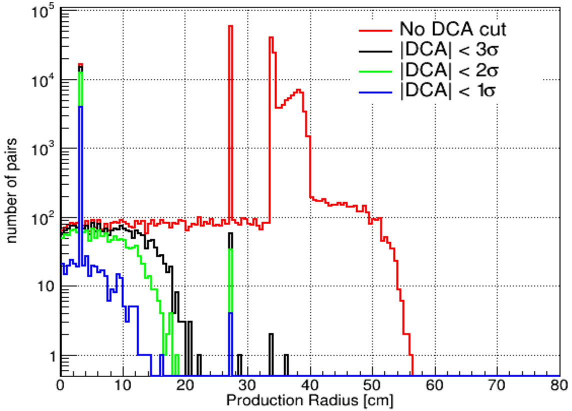


Reconstructed conversion electrons

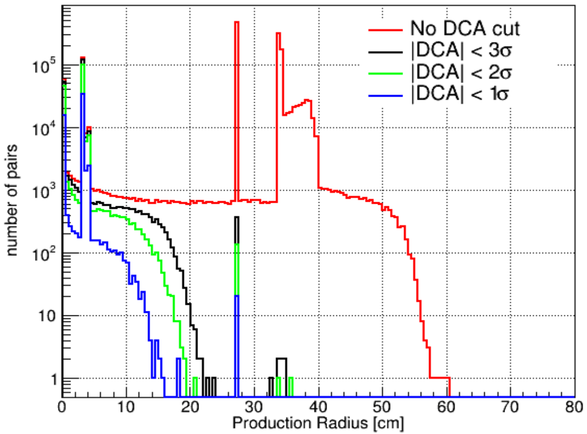


Request 25: 2.6M events

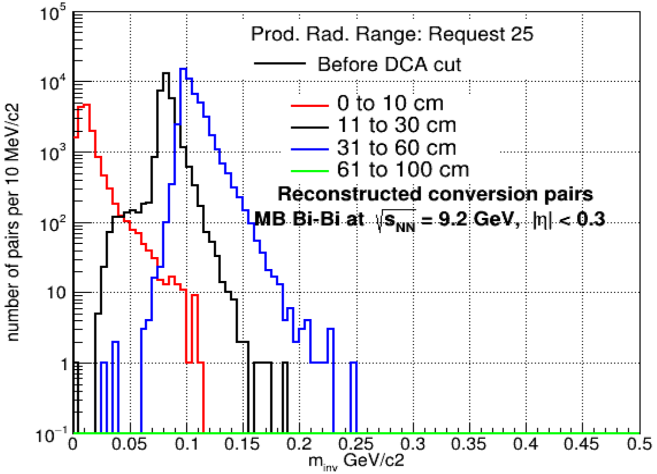
Request 11



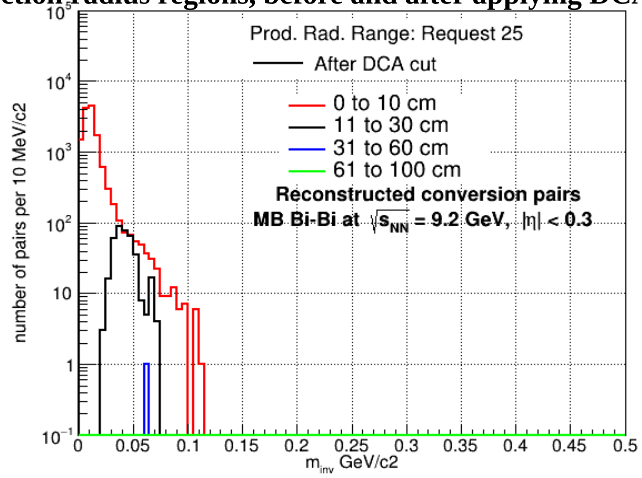
Reconstructed conversion pairs

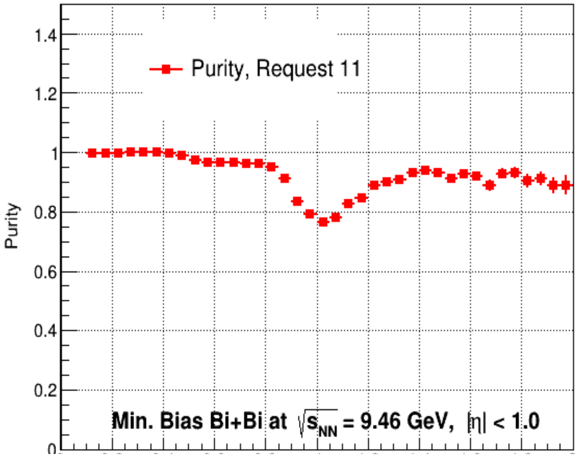


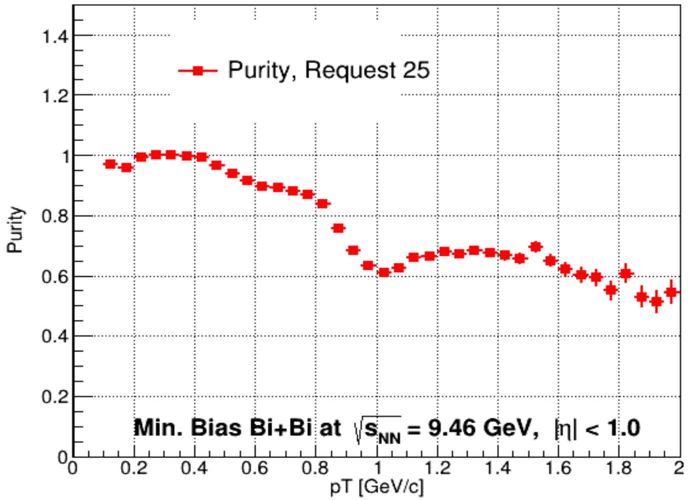
Request 25



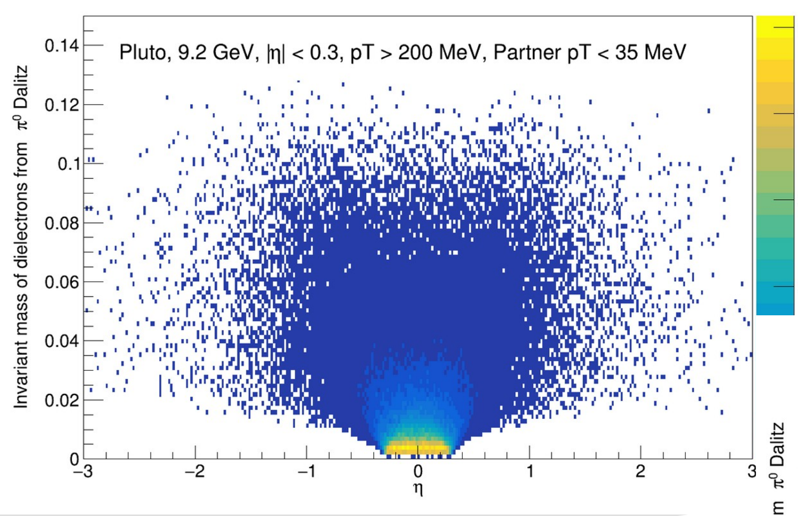
Invariant mass spectra of reconstructed conversion pairs in different production radius regions, before and after applying DCA selection.

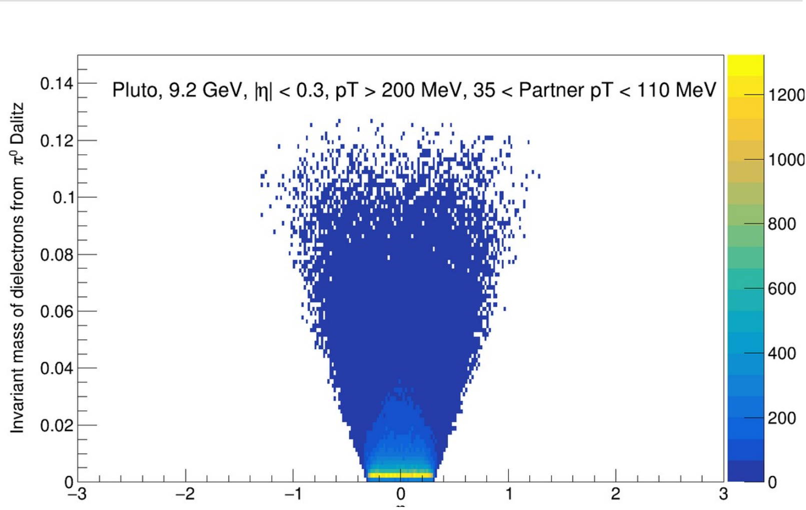


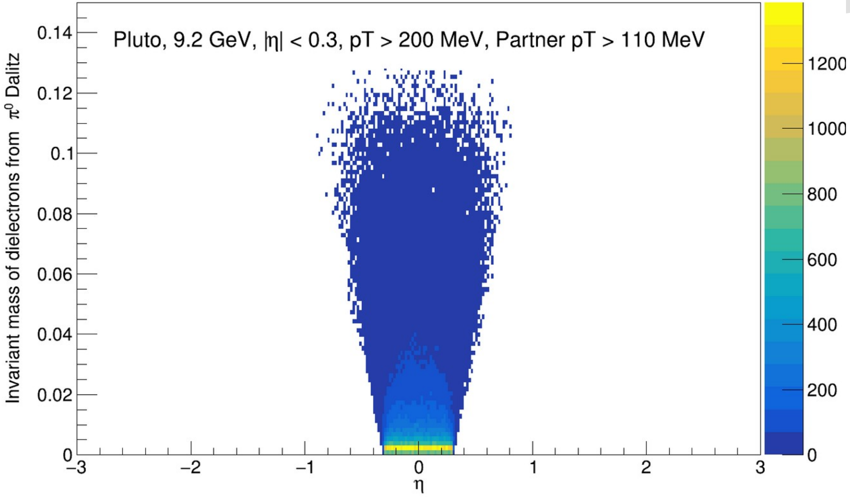




η vs Invariant mass: π^0 Dalitz pairs







Possible improvement in S/B

S = N_s = No of Dalitz pair in <u>|y| < 0.3 with both legs pt > 200 MeV</u>

B = $(N_b)^2$ = (No of single tracks from Dalitz in <u>|y| < 0.3 with pt > 200 MeV</u> with partner anywhere in fid. or veto

<u>Pluto</u>

<u>Acc. |y| < 0.3</u> S/B = = 229 **(For representation only)**

Maximum gain in S/B (assuming partner with pT > 30 MeV and opening angle <10 deg is fully recognized)**:**

|y| < 0.3 S/B = 1080 ← **factor 5 improvement**

Gain in S/B (i.e. using TPC current reconstruction software and requiring Nhits > 39 and opening angle < 10 deg.)**:**

|y| < 0.3 S/B = 326 ← **factor 1.42 improvement**

<u>UrQMD</u>

<u>Acc. |y| < 0.3</u> S/B = 101 **(For representation only)**

Maximum gain in S/B (assuming partner with pT > 30 MeV and opening angle <10 deg is fully recognized)**:**

|y| < 0.3 S/B = 8308 ← **factor 8 improvement**

Gain in S/B (i.e. using TPC current reconstruction software and requiring Nhits > 39 and opening angle < 10 deg.)**:**

|y| < 0.3 S/B = 128 ← **factor 1.26 improvement**

Selection cuts: Pair analysis

Request 25 → 36M events:

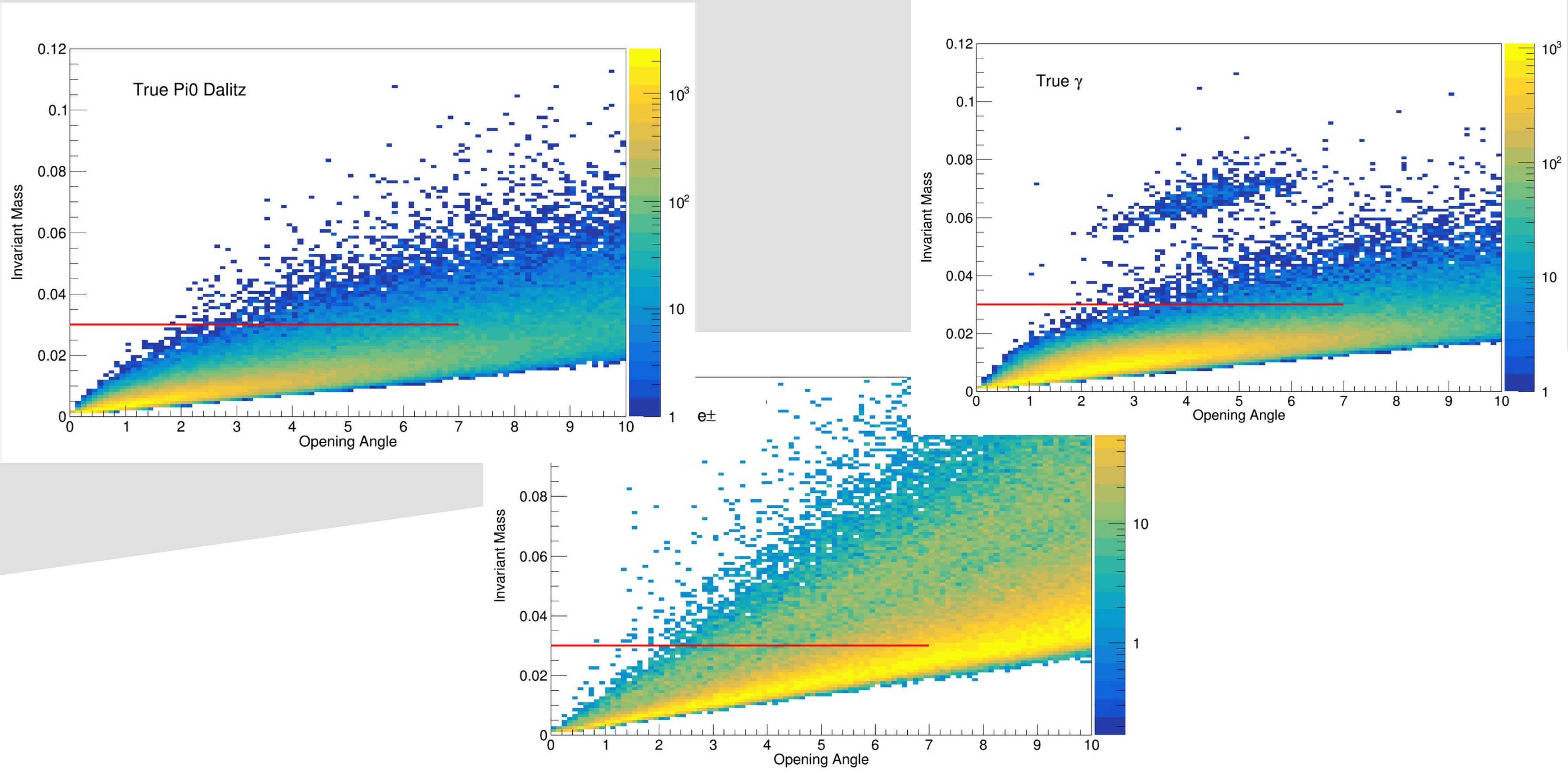
1. **Fully reconstructed tracks: Pool 1**
   1) |Vz| < 100 cm.
   2) DCA x,y,z < 3σ.
   3) Nhits > 39
   4) TPC nSigma -2 to 2 sigma at p = 0 and -1 to 2 sigma for p > 800 MeV/c
   5) TOF nSigma -2 to 2 sigma
   6) TOF matching -2 to 2 sigma
   7) Limiting the eta acceptance of the reconstructed track to 0.3
2. **Cuts on Partner: Pool 2**
   1) Same as Pool 1 except in 0.3 < Eta < 1.0
3. **Cuts on Partner for Close TPC Cut: Pool 3**
   1) |Eta| < 2.5, Nhits > 10
   2) DCA > 3.5 sigma
   3) |TPC nSigma| < 2 sigma, Those tracks who DO NOT Matched in TOF within 2 Sigma (TPC ONLY).
4. **Cuts on Partner (tracks excluding Pool 1, 2 and 3): Pool 4**
   1) |Eta| < 2.5, Nhits > 6, DCAz > 5 sigma, |TPC nSigma| < 3 sigma, Those tracks who DO NOT Matched in TOF within 2 sigma (TPC ONLY) **OR** Matched within 3 sigma having TOF nSigma with -3 to 3 sigma.

- No further pairing: Pairing between Pool 1 and 2
  1. Dalitz rejection: pairs with M < 120 MeV/c2
  2. Pairing: **pT > 200 MeV/c**

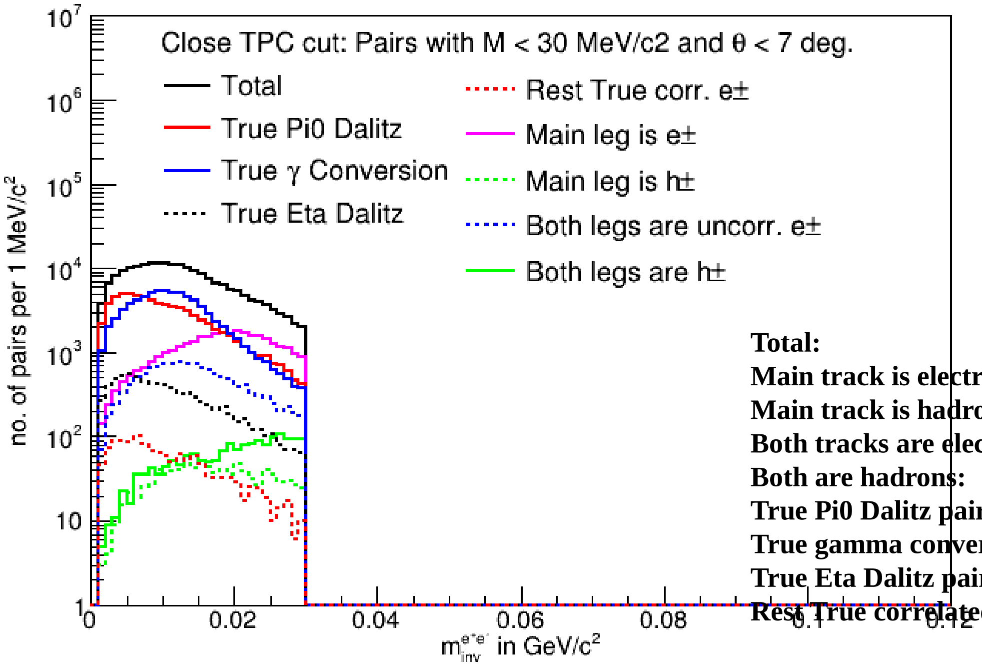
- Close TPC Cut: Pairing between Pool 1 and 3
  1. Dalitz rejection: No further pairing of pairs with M < cut off.
  2. Pairing: **pT > 200 MeV/c**

- Close TPC Cut 2.0: Pairing between Pool 1 and 4
  1. Dalitz rejection: No further pairing of pairs with M < cut off.
  2. Pairing: **pT > 200 MeV/c**

2D spectra of pairs after CTC



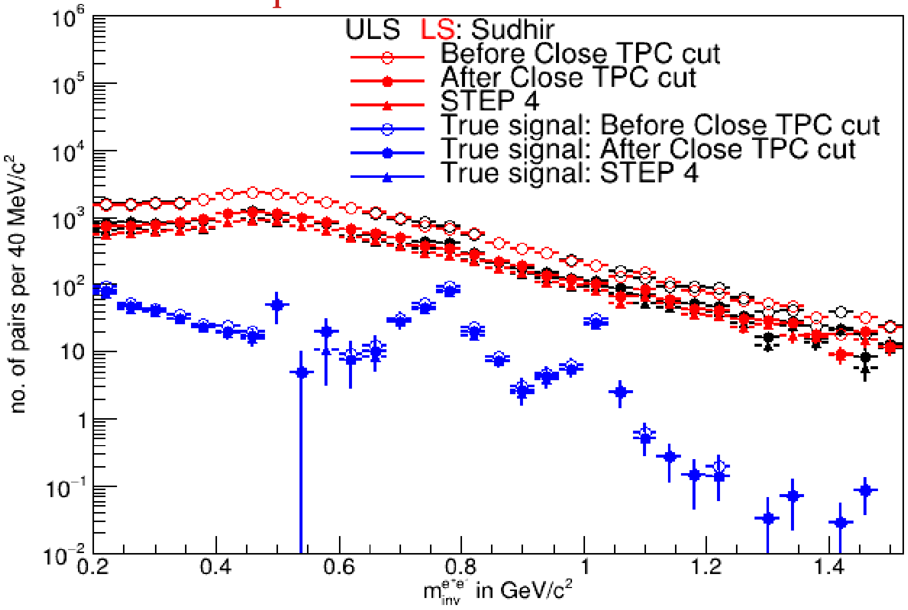
Sources of removed pairs in STEP 4



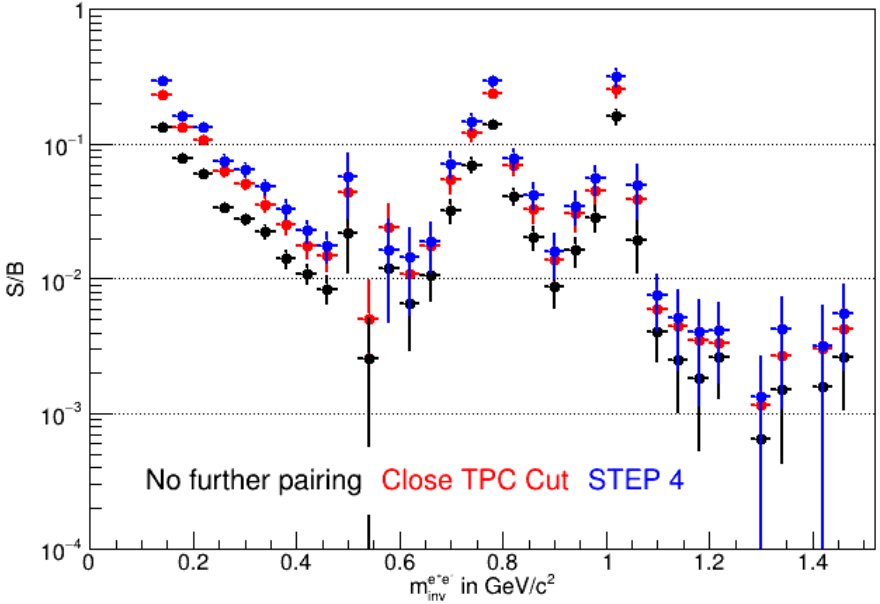
Total:	**204857**	**100 %**
Main track is electron and other is hadron:	**31993**	**15.6172 %**
Main track is hadron and other is electron:	**907**	**0.442748 %**
Both tracks are electron but uncorrelated:	**12899**	**6.29659 %**
Both are hadrons:	**1658**	**0.809345 %**
True Pi0 Dalitz pairs:	**71904**	**35.0996 %**
True gamma conversions:	**76221**	**37.2069 %**
True Eta Dalitz pairs:	**7946**	**3.8788 %**
Rest True correlated pairs:	**1329**	**0.648745 %**

S/B: Pair analysis

Request 25 → 36M events



~ 80% improvement after applying close TPC cut.



0.2 < M < 1.5 GeV/c^2	Signal (S)	S loss	LS(B)	CB reduc.	S/B	S/√(S+B)
Before Close TPC Cut	644.5+/-25.4		26285.2+/-145.3		0.024+/-0.001	3.07
After Close TPC Cut	575.9+/-24.0	11%	13317.7+/-103.7	1.97 factor	0.043+/-0.003	5.41
STEP 4	536.4+/-23.2	17%	10200.0+/-90.8	2.58 factor	0.053+/-0.003	6.58

Remaining tracks after Close TPC Cut 2.0 (STEP4)

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- ✓ Trying to understand the origin of remaining background after close TPC cut 2.0 (STEP 4).

Total reconstructed tracks after close TPC cut:	**1.48786e+06**
Below: Only Conversion and π^0 Dalitz sources are considered --	
a. Track has Partner with pT < 35 MeV ($|\eta| < 2.5$):	**407257 (~27%)**
b. Track has Partner inside TPC i.e. 35 < pT < 100 MeV ($|\eta| < 2.5$):	**521056 (~35%)**
c. Track has Partner with pT > 110 MeV ($|\eta| < 2.5$):	**153655 (~10%)**
Track is hadron:	**99503 (~7%)**
Rest (Signal (η, etc), conversion, π^0 Dalitz whose partner outside TPC, ...)	**306386 (~21%)**

- ✓ Is **b.** reflecting inefficiency of the current tracking algorithm for low p_T tracks? Need expert help to improve the low-p_T tracking reconstruction.
- ✓ Additional and independent venue:
  - ✓ Improve the overall eid efficiency using Machine Learning techniques (both TPC Only and TPC+TOF+ECal) → Will help in improving the signal as well as S/B.