Study of the feasibility of η_c measurements at SPD in $\eta_c \to \varphi\,\varphi \to 2\,(K^+K^-)$ decay

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The Study is focused on possibility of background separation

- Pythia 8.309 (p + p, √ s = 27 GeV). The main background – minimum-bias (SoftQCD:nonDiffractive)

- Taking as a starting point cross section of η_c production ~ **400 nb**, we consider the channel

  g g → $\boldsymbol{\eta_c + g}$ (cross-section from PYTHIA8 $\boldsymbol{\sigma_{\eta c\ +g}}$ **= 416 nb**)

Formulae for η_c production in Pythia8 were taken as proposed by Anton Anufriev in his talk (11.04.23)

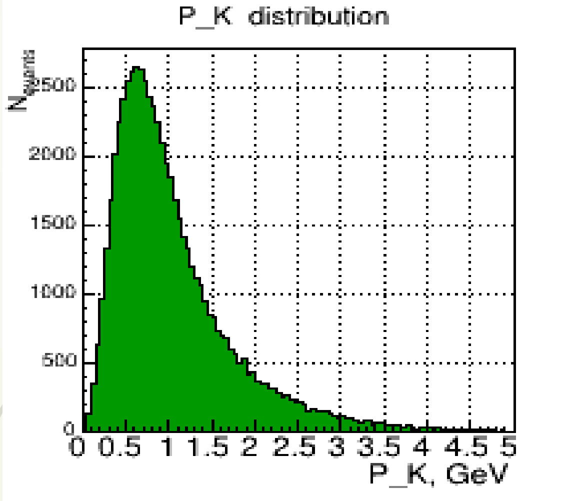
(We can also expect for **g g** → $\boldsymbol{\eta_c}$ cross-section $\boldsymbol{\sigma_{\eta c}}$ **= 2230 nb** - ***5.36 times higher !!!***)

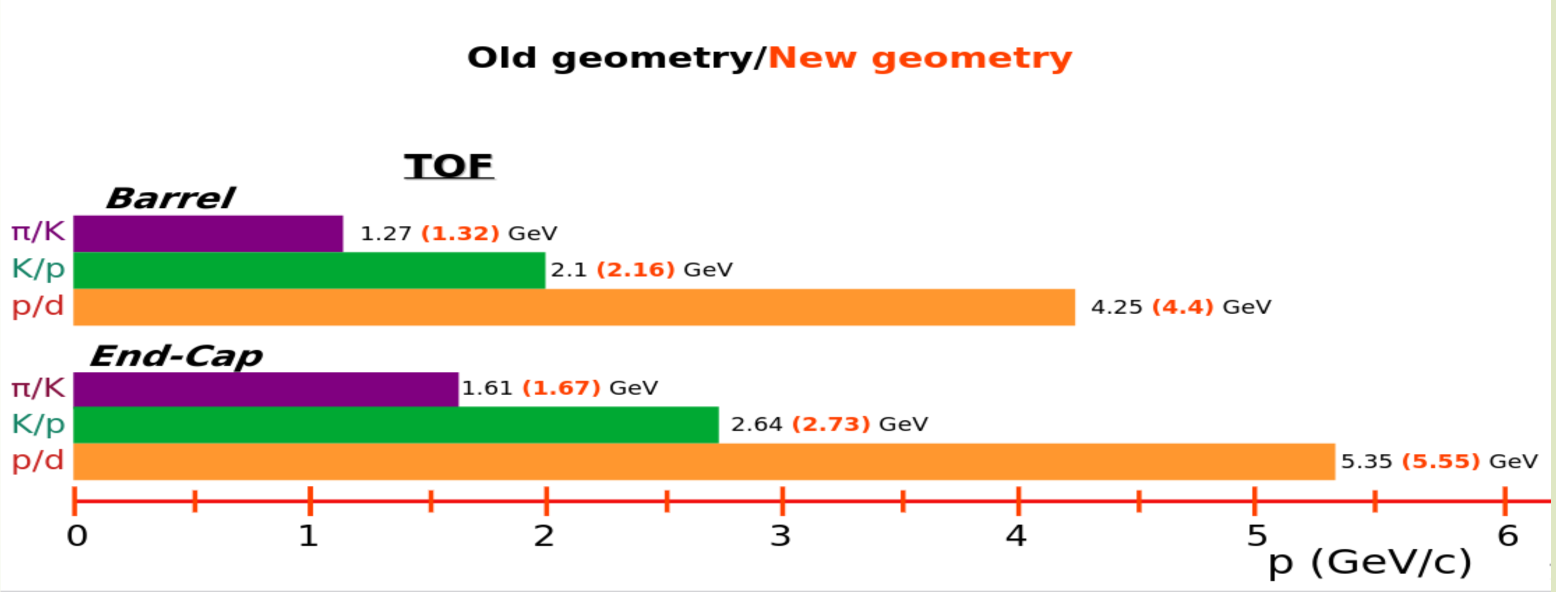
$\boldsymbol{\eta_c}$ is forced to decay to $\boldsymbol{\varphi\ \varphi}$**,** thus the final cross-section for

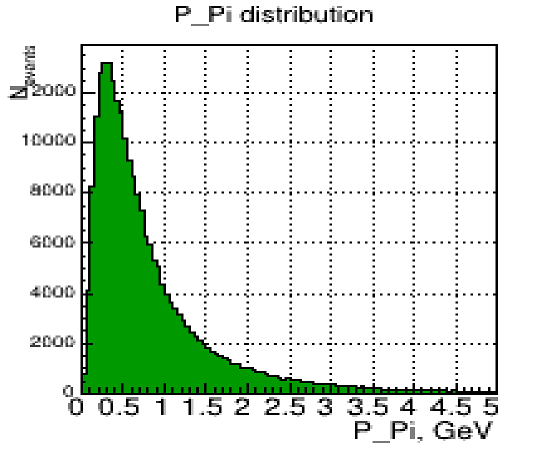
- **g g** → $\boldsymbol{\eta_c + g \to \varphi\ \varphi + g \to 2\ (K^+K^-) + g}$ should be $\boldsymbol{\sigma_{\eta c\ +g}}$ **= 0.159 nb** → **~1.59 * 10^5 events/year**

*(Year = 10^7 sec, Lum =10^{32} /cm^2 *sec)*

$\pi^{\pm}$ / $K^{\pm}$ reconstruction







PID in SPD is taking place in VD, Straw, TOF & Aerogel

But the best separation power for $\pi^{\pm}$ / $K^{\pm}$ gives **TOF**

(see talk of Artem Ivanov **25.10.2023** *SPD CM and others).*

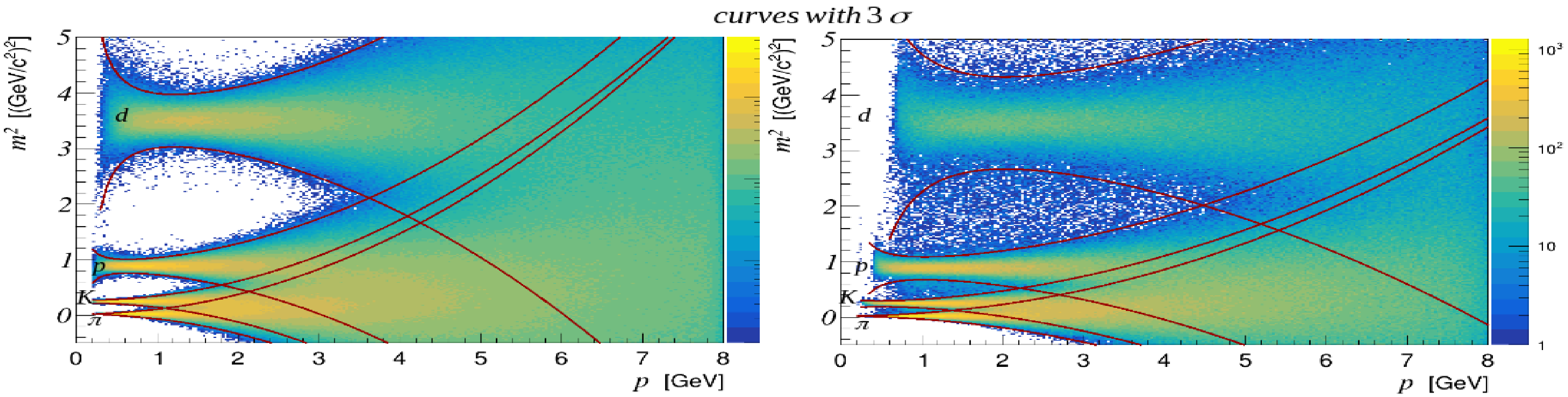
At **P > 1.4 GeV** we potentially can have problems with $\pi^{\pm}$ / $K^{\pm}$ misidentification.

$\pi^\pm$ / $K^\pm$ reconstruction

m² vs p

(see talks of Artem Ivanov of ***25.10.23****, 6.10.2022 & 27.04.2023).*

Barrel **End-Cap**



For the moment we have at **$P_{K\pm}$ < 1.32 GeV** (1.2 GeV before) — 100% identification.

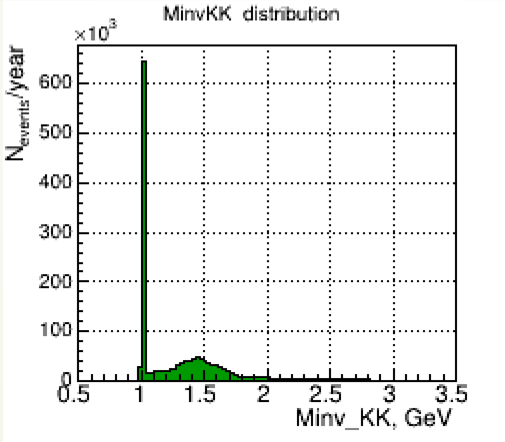
At the region **1.32 GeV < $P_{K\pm}$ < 1.67 GeV** (1.2 GeV < $P_{K\pm}$ < 1.4 GeV before) ~ 95%.

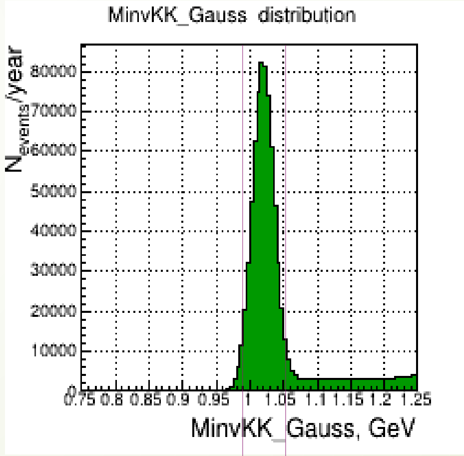
So at first approximation we considered the condition

when **all 4 signal K± have $P_{K\pm}$ < 1.4 GeV** *(~ ½ of events)*

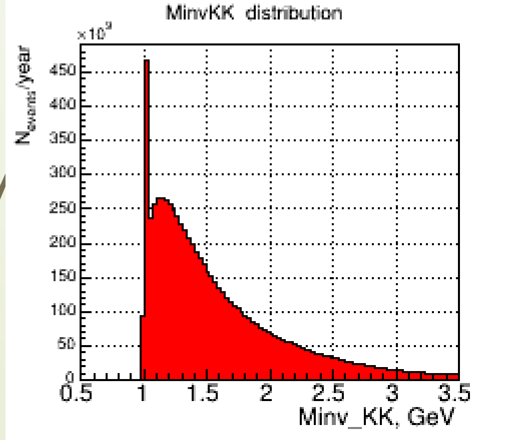
φ reconstruction

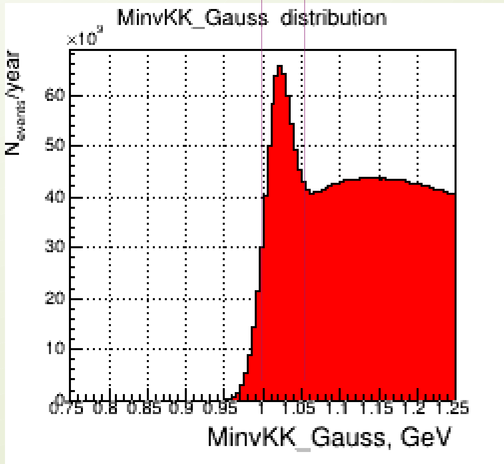
Signal





Backgd





For **φ** reconstruction we are looking for

K^+K^- combinations (**φ** candidate)

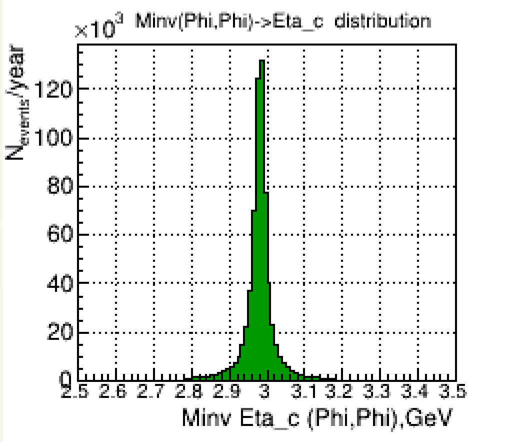
in the region

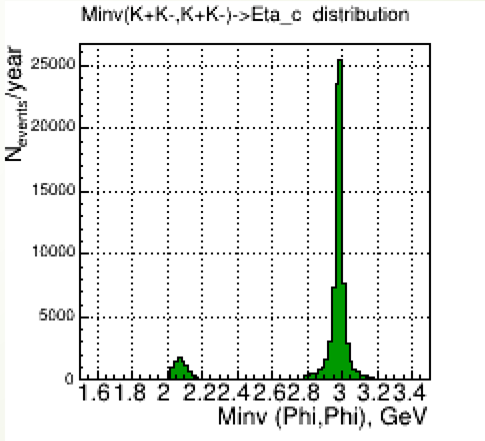
$0.99 < M_{inv}(K^+K^-) < 1.05$ GeV

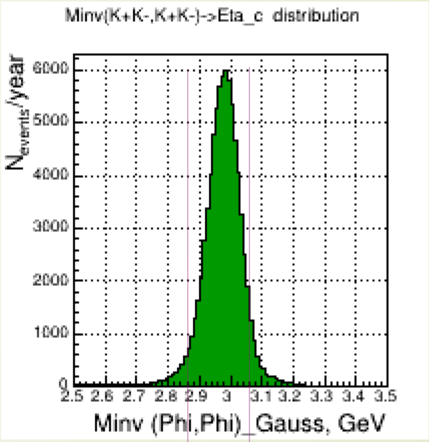
including 1.5% Gauss smearing of **P**

η_c reconstruction

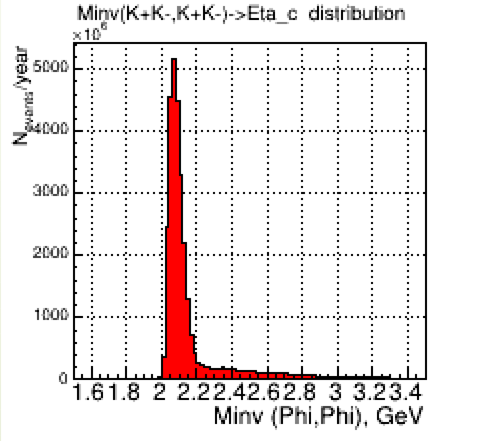
Signal

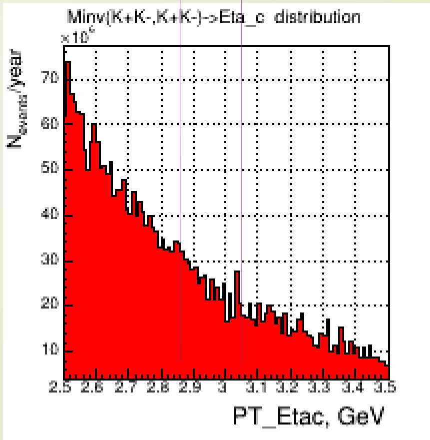






Background





For $\boldsymbol{\eta_c}$ reconstruction

we are looking for exactly 2 K^+K^- combinations

(φ candidates in the spread

$0.99 < M_{inv} (K^+K^-) < 1.05$ GeV)

in the region of M_{inv} $\boldsymbol{\eta_c}$

$2.85 < M_{inv} (\varphi\varphi) < 3.09$ GeV

Obtained $\boldsymbol{\sigma}_{signal}$ = **$9.68 * 10^{-2}$ nb**

⇓

~ 96780 events/year

Current results

10^7 Signal and $3*10^8$ Background events now were generated

The proposed selection criteria

P ($K^\pm$) < 1.4 GeV && 0.99 < M_{inv} (K^+K^-) < 1.05 GeV && 2.85 < M_{inv} ($\varphi\varphi$) < 3.09 GeV

allowed to achieve **background suppression** to **741 nb** *($3.11 * 10^{-3}$ %)* that corresponds to

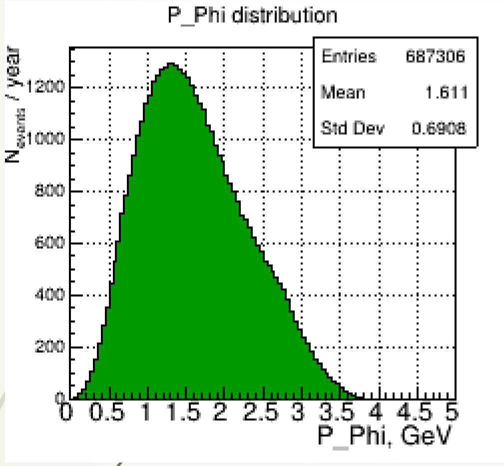
S/B = $1.3 * 10^{-4}$ for **g g** → η_c + g channel.

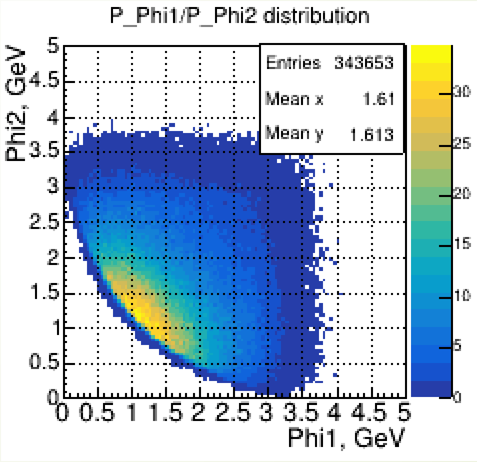
Thus we can expect **S/√(S+B) ≈ 3.55** *(improved at higher statistics and some change in algorithm!)*

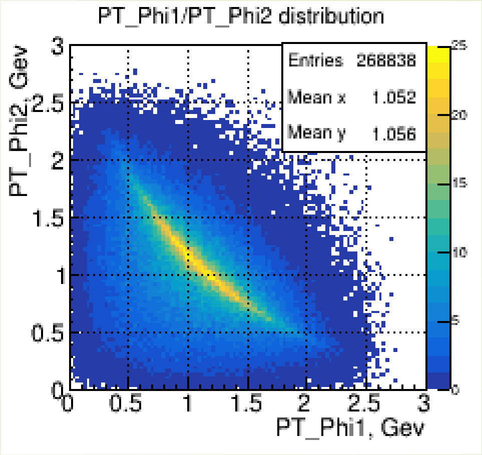
!!! *Fraction of signal events where at least 1K in 2 (K^+K^-) combination is fake one is* **~ 0.65%**

|Pφ$_{candidate}$| correlations

Signal



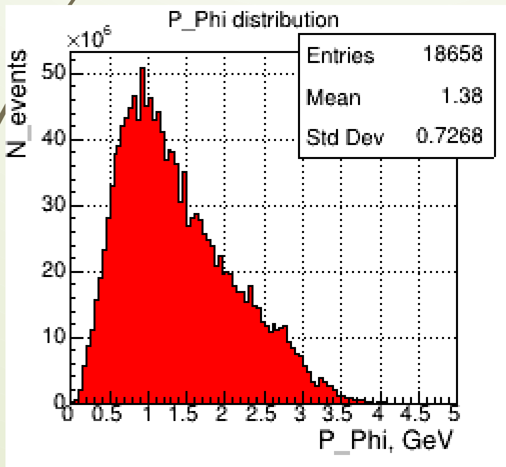


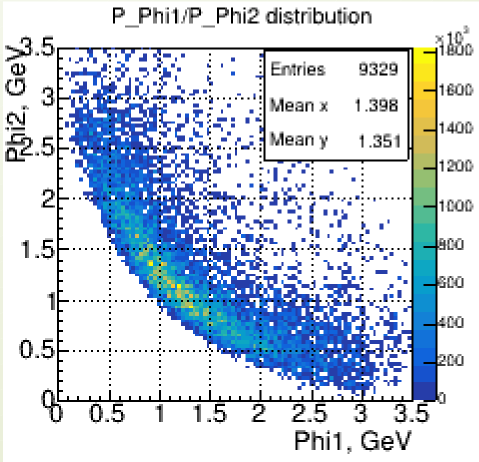


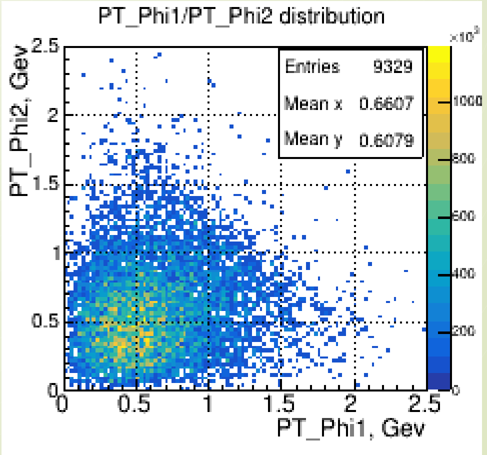
Distributions of |Pφ| look rather similar, but for |PTφ| distributions we have some difference

⇓

Background





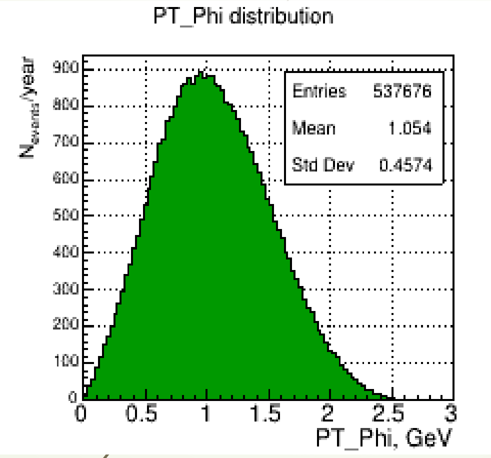


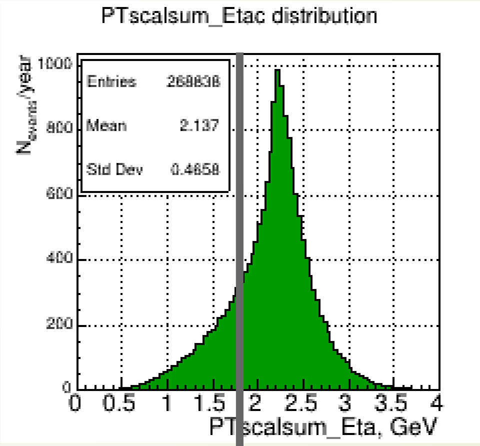
Can be used

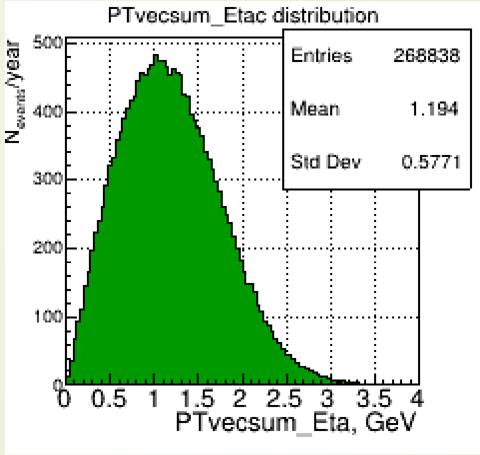
|PTφ| correlations

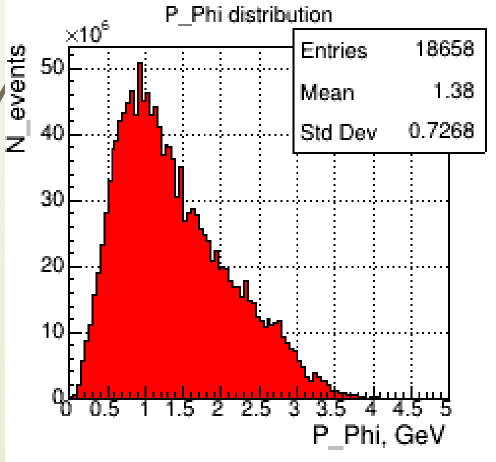
Signal

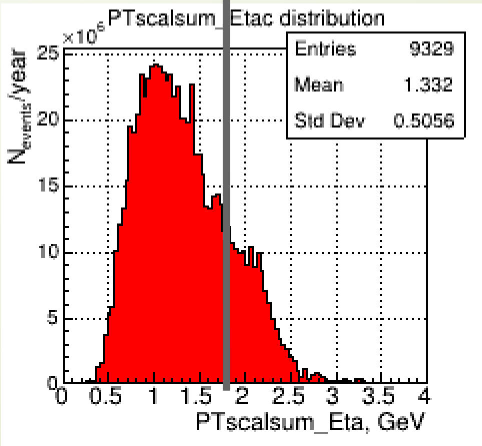
Backgd

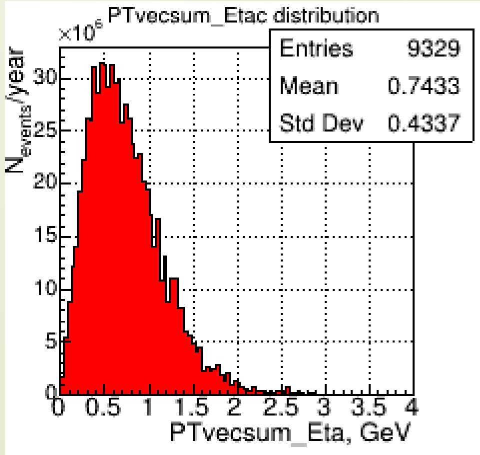












PT vecsum = vector sum of PT's of $(K^+K^-)(K^+K^-)$ forming η_c candidate.

PT scalsum = scalar sum of PT's of $(K^+K^-)(K^+K^-)$ forming η_c candidate. -->
Shows better difference in distributions

⇓

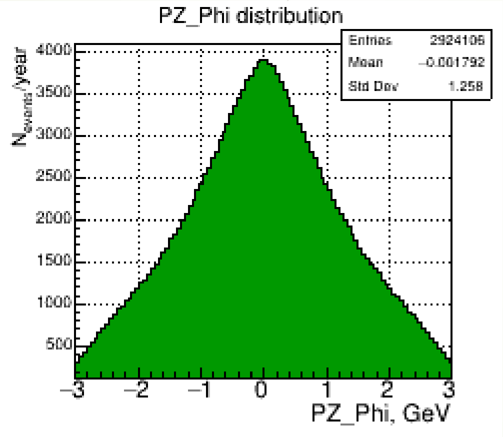
Can be used for BKG suppression :

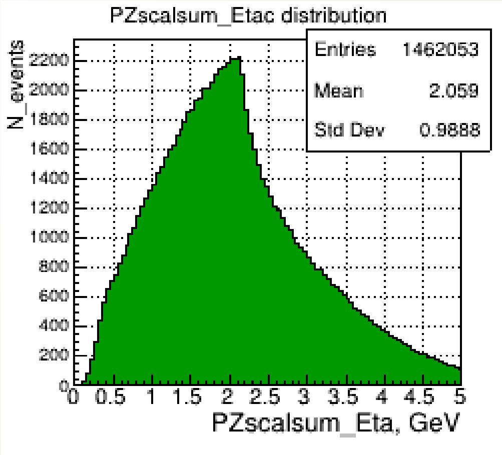
Cut PT scalsum > 1.8 GeV

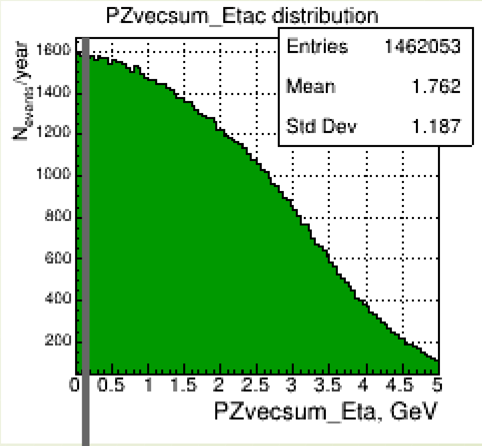
PZφ correlations

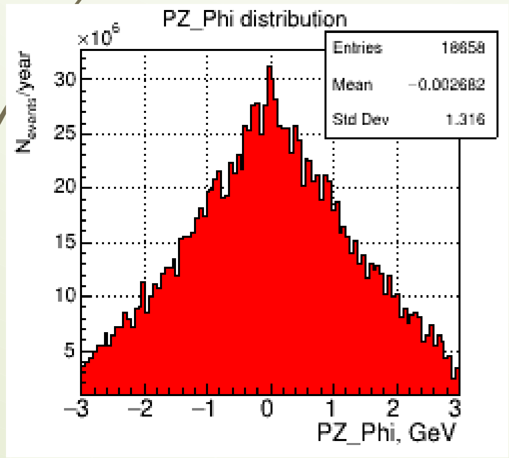
Signal

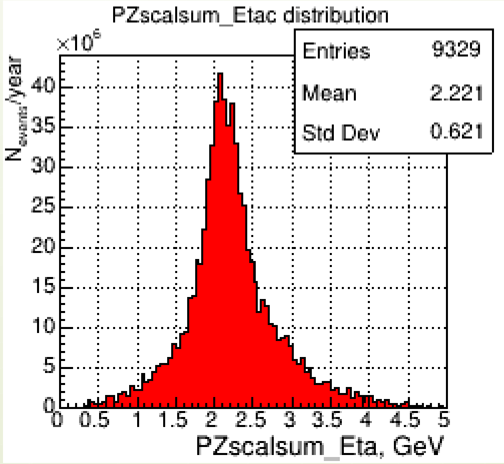
Backgd

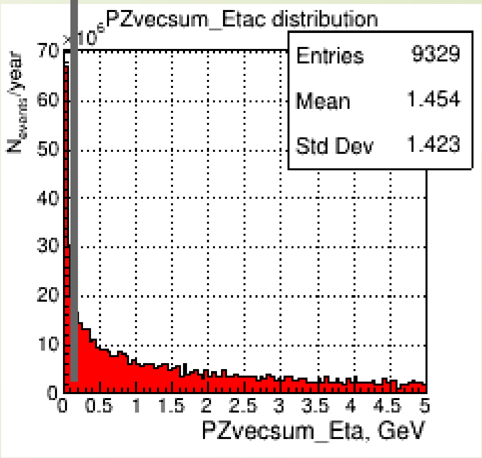












Pz scalsum = scalar sum of Pz's of $(K^+K^-)(K^+K^-)$ forming η_c candidate.

Pz vecsum = vector sum of Pz's of $(K^+K^-)(K^+K^-)$ forming η_c candidate. -->
Shows better difference in distributions

⇓

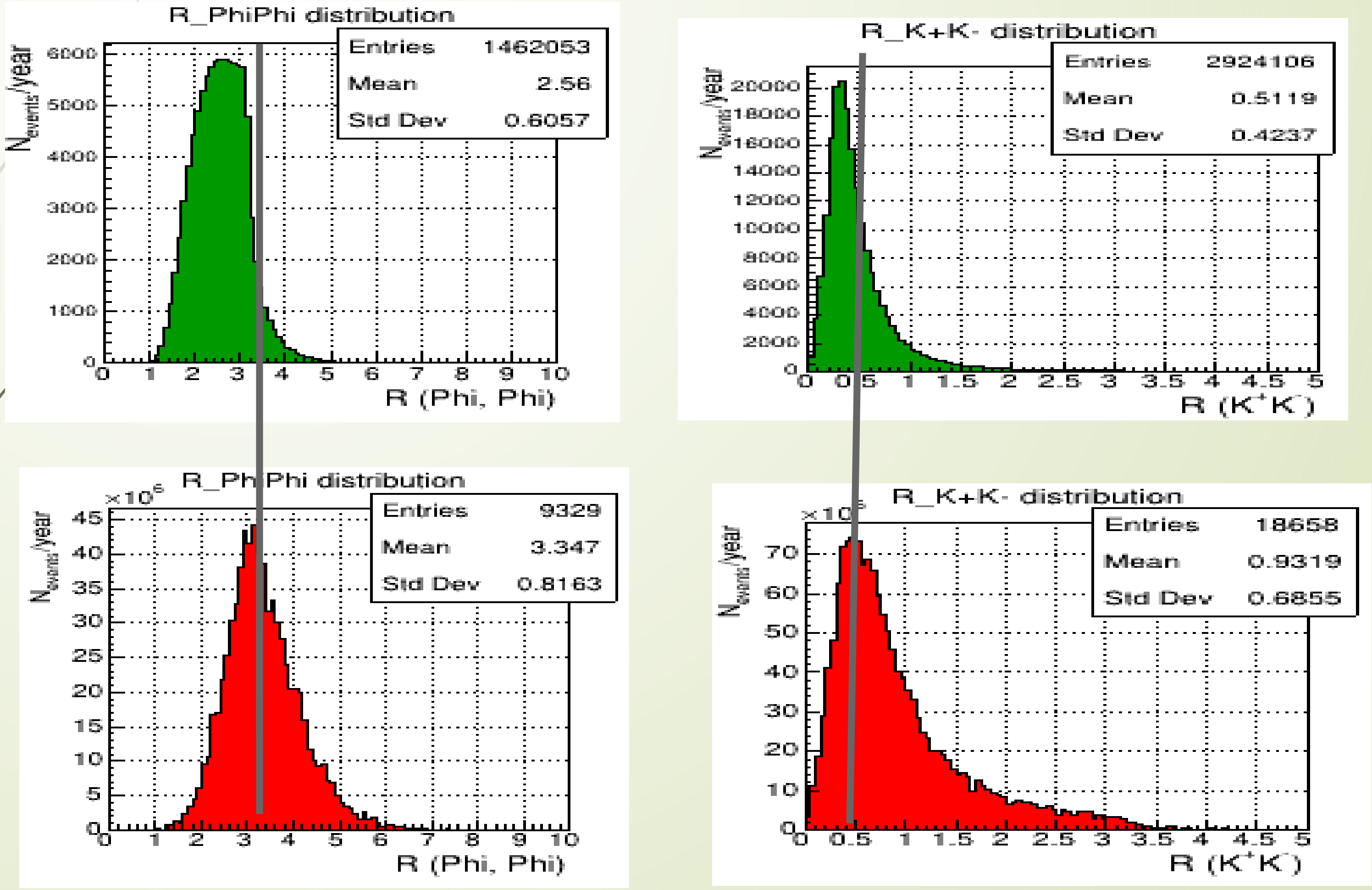
Can be used for BKG suppression :

Cut: PZ vecsum > 0.2 GeV

R (φφ) / R (K^+K^-) distributions

S i g n a l B a c k g d

$R = \sqrt{\Delta\eta^2+\Delta\varphi^2} = \sqrt{(\eta_{K+} - \eta_{K-})^2 + (\varphi_{K+} - \varphi_{K-})^2}$ - shows some difference ⇒ can be used



$R_{K+K-} < 0.6$

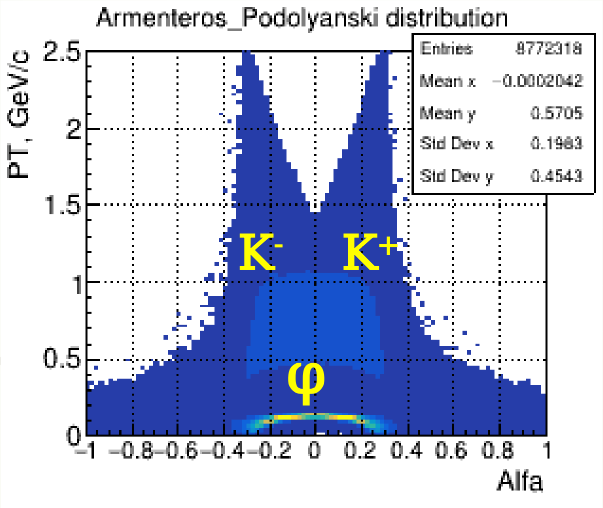
⇓

$R_{K+K-} < 0.5$

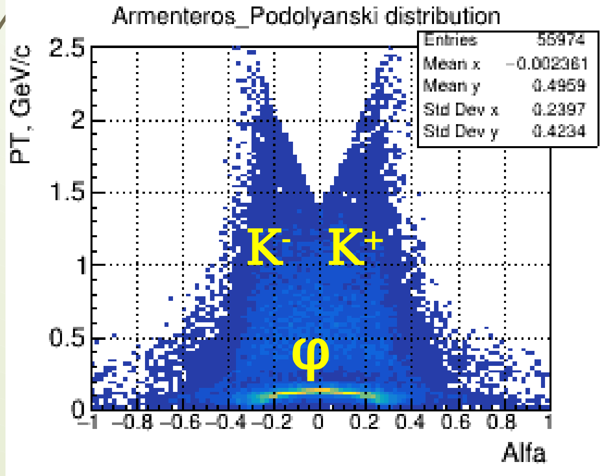
$R_{\varphi\varphi} < 3.3$

Armenteros - Podolanski distributions

Signal



Backgd



$\alpha = (P^{K+} - P^{K-}) / (P^{K+} + P^{K-})$

No significant difference

Proposed cuts

1. **P ($K^{\pm}$) < 1.4 GeV && 0.99 < M_{inv} (K^+K^-) < 1.05 GeV && 2.85 < M_{inv} ($\varphi\varphi$) < 3.09 GeV**

2. **N1 + *R (φ φ) < 3.3 GeV***
3. **N1 + *R (K^+K^-) < 0.5 GeV***
4. **N1 + (*R (K^+K^-) Cut + R (φ φ) Cut*)**

5. **N1 + *PT scalsum 4K > 1.8 GeV***
6. **N1 + *PZ vecsum 4K > 0.2 GeV***
7. **N1 + (*Pz vecsum Cut + PT scalsum Cut*)**

8. **N1 + (*Pz vecsum Cut + PT scalsum Cut*) + *R (K^+K^-) Cut***
9. **N1 + (*Pz vecsum Cut + PT scalsum Cut*) + (*R (K^+K^-) Cut + R (φ φ) Cut*)**

Results of additional cuts 2-9 on the events sample after 1-st set of cuts is shown in the table below (with fractions relative to the remainder after the first restriction)

Current results

Cut N	Rest of Sig	Rest of BKG	S/B ratio	$S/\sqrt{(S+B)}$
2.	91.1 %	52.9 %	$2.25 * 10^{-4}$	4.45
3.	37.7 %	9.5 %	$5.27 * 10^{-4}$	3.10
4.	37.3 %	8.2 %	$5.90 * 10^{-4}$	4.60
5.	**79.5 %**	**19.3 %**	**$5.37 * 10^{-4}$**	**6.42**
6.	93.5 %	81.8 %	$1.50 * 10^{-4}$	3.69
7.	**74.5 %**	**16.2 %**	**$6.01 * 10^{-4}$**	**6.58**
8.	33.9 %	5.04 %	$8.79 * 10^{-4}$	5.37
9.	33.8 %	4.97 %	$8.88 * 10^{-4}$	5.36

Thus the best combination of cuts is N7 (& N5)

N1 + (*Pz vecsum Cut + PT scalsum Cut*)
that gives

$S/\sqrt{(S+B)} \approx$ 6.58 (6.42)

which corresponds to the final statistics
~ 72000 events/year

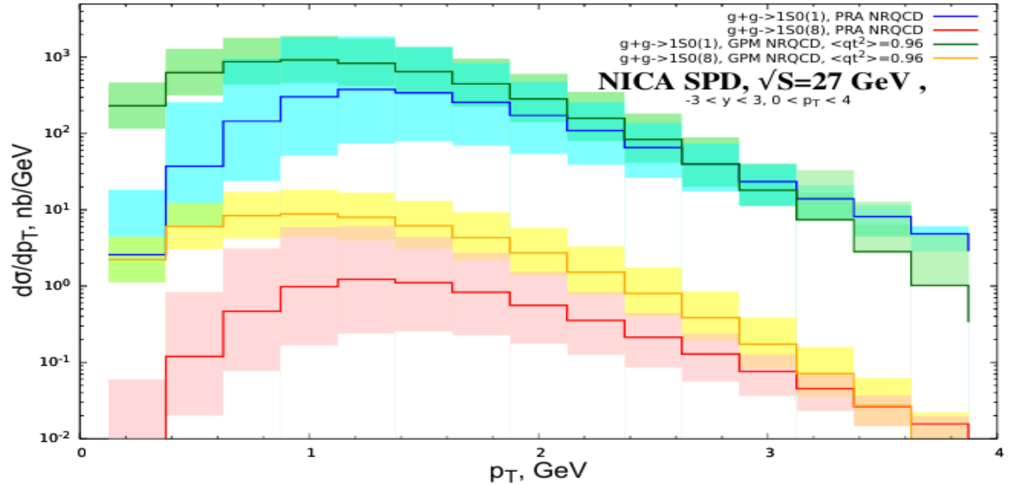
(in the case of $\sigma_{\eta c} \approx$ 400 nb)

Case of 2→1 process **g g → η_c**

Predictions for SPD NICA within NRQCD

Total cross-section

- PRA CSM: $\sigma_{tot} = 0.48\,\mu b$
- PRA NRQCD: $\sigma_{to} = 0.49\,\mu b$
- GPM CSM: $\sigma_{tot} = 1.3\,\mu b$
- GPM NRQCD: $\sigma_{tot} = 1.31\,\mu b$



A. Anufriev, V. Saleev
The XXVth International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics"
21 September 2023, Dubna

Some theoretical approaches give us cross-section for **g g → η_c** up to **$\sigma_{\eta c}$ = 1310 nb** ***!***

Case of 2→1 process g g → η_c

The calculation were made under the assumption $\sigma_{\eta c} \approx$ 1250 nb

(We can also expect for **g g** → η_c cross-section $\sigma_{\eta c}$ **= 2230 nb** (PYTHIA prediction))

Cut N	Rest of Sig	Rest of BKG	S/B ratio	S/√(S+B)
2.	90.4 %	52.9 %	$7.56 * 10^{-4}$	15.0
3.	38.4 %	9.5 %	$1.18 * 10^{-3}$	15.2
4.	38.0 %	8.2 %	$2.04 * 10^{-3}$	16.0
5.	**78.9 %**	**19.3 %**	**$2.06 * 10^{-3}$**	**24.6**
6.	92.6 %	81.8 %	$5.07 * 10^{-4}$	12.4
7.	**73.2 %**	**16.2 %**	**$2.01 * 10^{-3}$**	**22.0**
8.	34.2 %	5.04 %	$3.01 * 10^{-3}$	18.4
9.	34.1 %	4.97 %	$3.04 * 10^{-3}$	18.4

Here the best combination of cuts is N5 (& N7)

N1 + *PT scalsum Cut* that gives

S/√(S+B) ≈ 24.6 (22.0)

that corresponds to the final statistics

~ 295 000 events/year

(in the case of $\sigma_{\eta c} \approx$ 1250 nb)

Thank you for your attention!

• $\eta_c \to \varphi\varphi \to 2(K^+K^-)$ decay

• The main PDG parameters

- η_c (1S) Mass = 2983.9 ± 0.4 MeV ~ *2.984 GeV*
- η_c (1S) Width = 32.0 ± 0.7 MeV ~ *0.032 GeV*
- Branching $\eta_c \to \varphi\ \varphi$ = (1.58 ± 0.19) x 10^{-3}

- φ (1020) Mass = 1019.461 ± 0.016 MeV ~*1.019 GeV*
- φ (1020) Width = 4.249 ± 0.013 MeV ~ *0.00425 GeV*
- Branching φ (1020) → K^+K^- = (49.1 ± 0.5) %

Thus Branching $\varphi\ \varphi \to$ **2** (K^+K^-) = 24.1 %

- Total Branching $\eta_c \to \varphi\ \varphi \to 2\ (K^+K^-)$ = **3,8090798** x 10^{-4}