Study of feasibility of η_c measurements at SPD in resonance decays

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

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

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

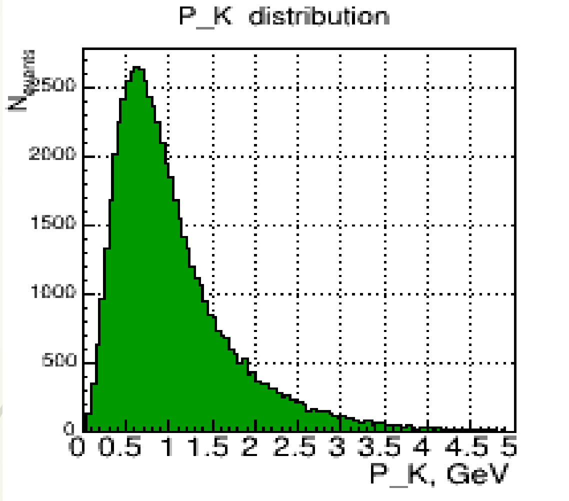
(We can also expect for **g g** → η_c cross-section $\sigma_{\eta c}$ **= 2230 nb** - ***5.36 times higher !!!***)

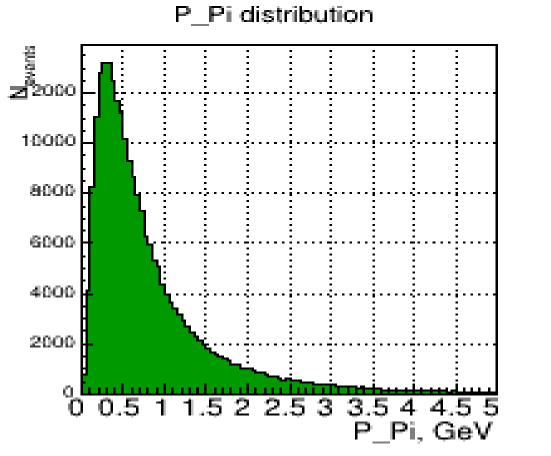
η_c is forced to decay to $\varphi\ \varphi$, thus the final cross-section for

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

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

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





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

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

At the region **1.2 GeV < $P_{K\pm}$ < 1.4 GeV** ~ 95%

(see talks of Artem Ivanov of 6.10.2022 & 27.04.2023).

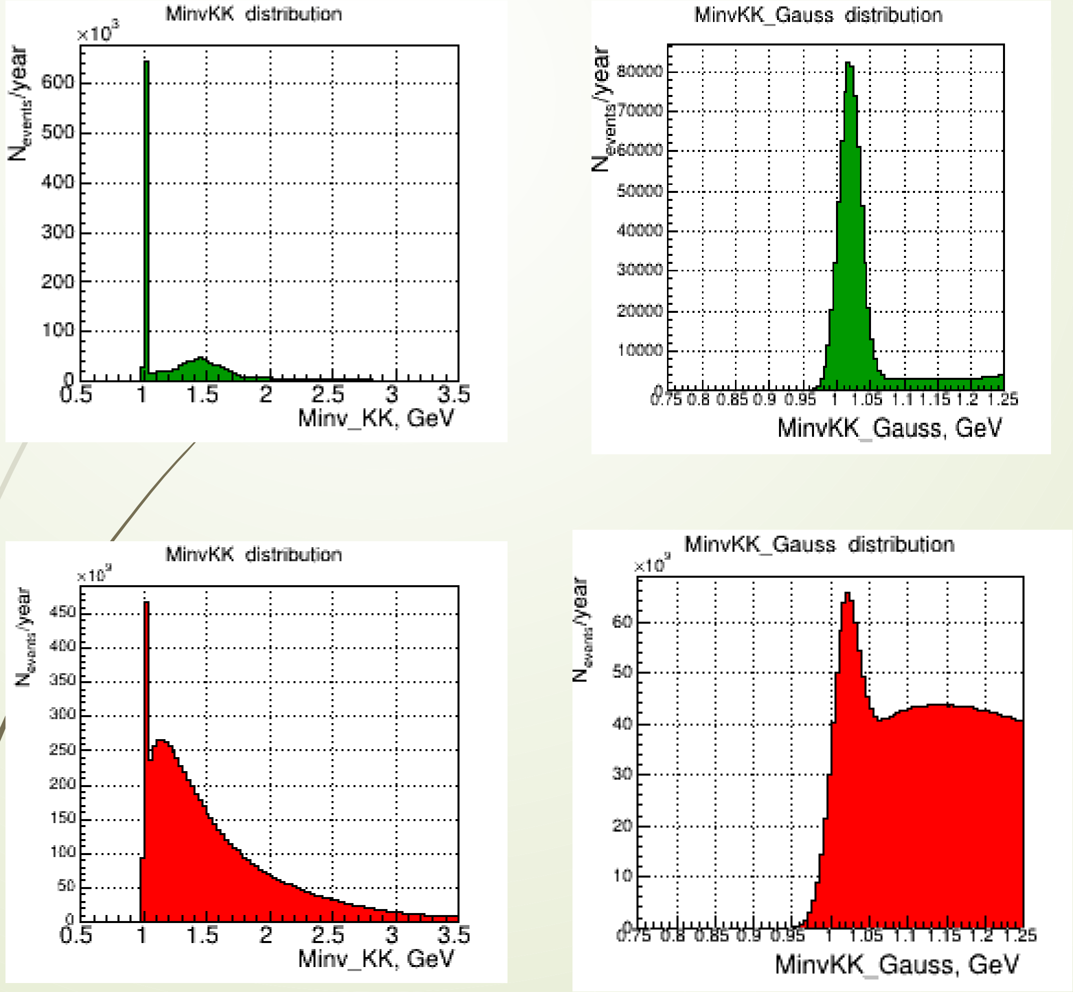
So at first approximation we considered the condition

when **all 4 signal $K^{\pm}$ 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

$0.92 < M_{inv}(K^+K^-) < 1.08$ GeV

⇓

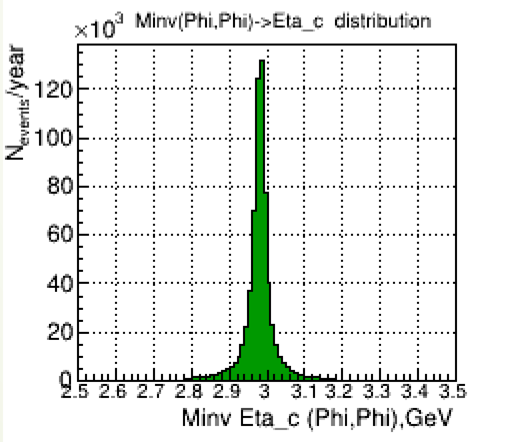
$0.99 < M_{inv}(K^+K^-) < 1.05$ GeV

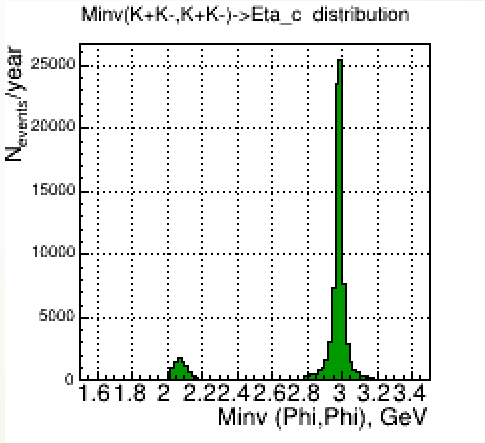
including 1.5% Gauss smearing of **P**

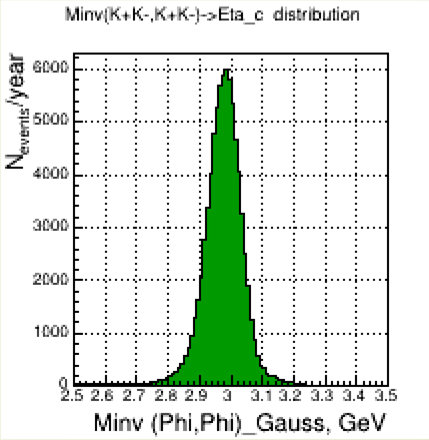
η_c reconstruction

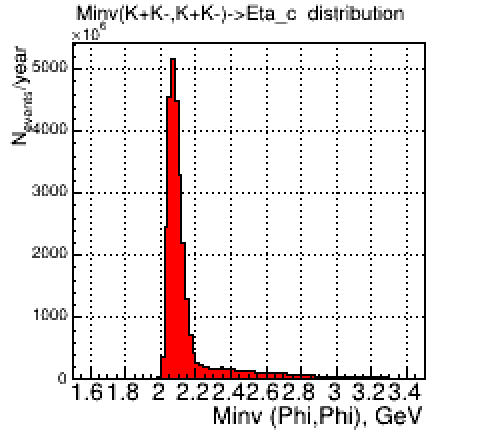
Signal

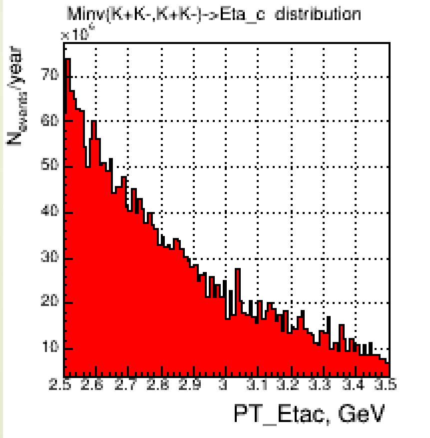
Backgd











For η_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} η_c

$2.94 < M_{inv} (\varphi\varphi) < 3.05$ GeV

⇓

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

Obtained σ_{signal} = **$2.26 * 10^{-2}$ nb**

⇓

~ 22600 events/year

Current results

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 **766.3 nb** *(typos & errors in the last talk)*

to the level of **$3.22 * 10^{-3}$ %** that corresponds to

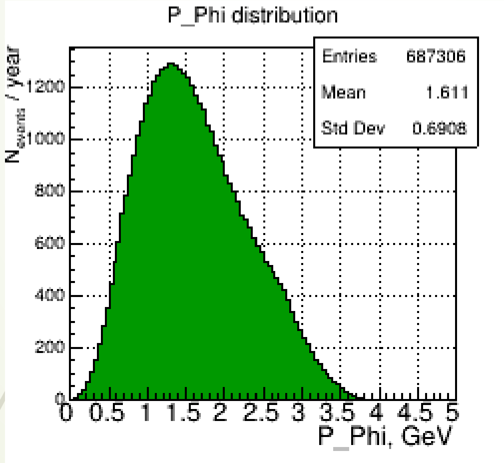
$S/B = 2.94 * 10^{-5}$ for **g g** → $\boldsymbol{\eta_c}$ **+ *g*** channel.

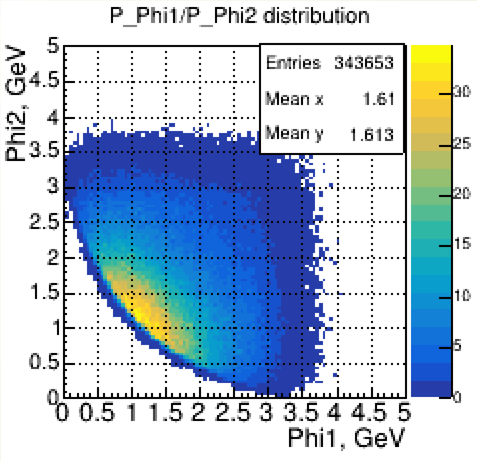
Thus we can expect **$S/\sqrt{(S+B)} \approx 0.815$**

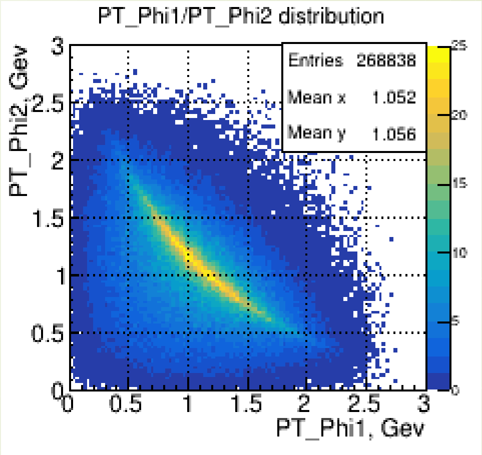
!!! *Fraction of signal events where at least 1K in 2 (K^+K^-) combination is fake one is* **~ 0.67%**

|Pφ$_{candidate}$| correlations

Signal



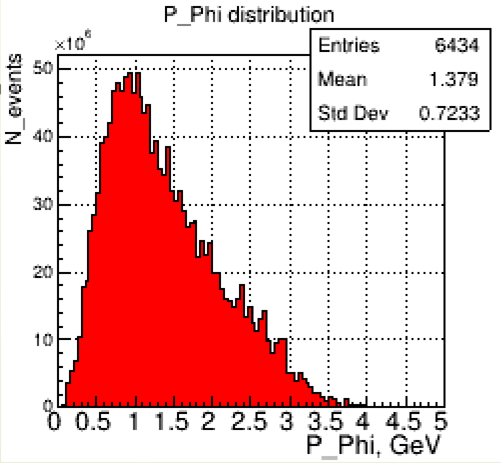


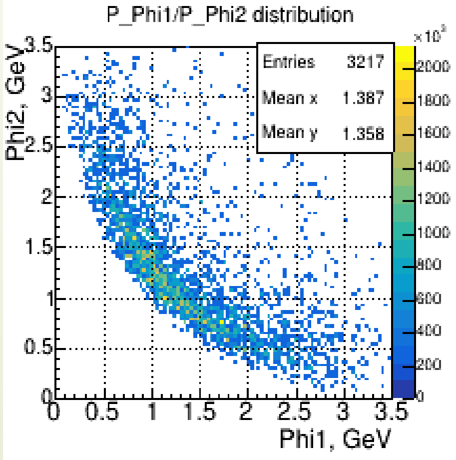


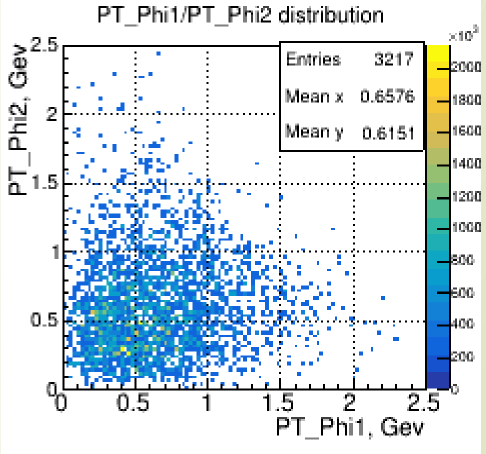
Distributions of |Pφ| look rather similar, but for |PTφ| distributions we have some difference

⇓

Backgd





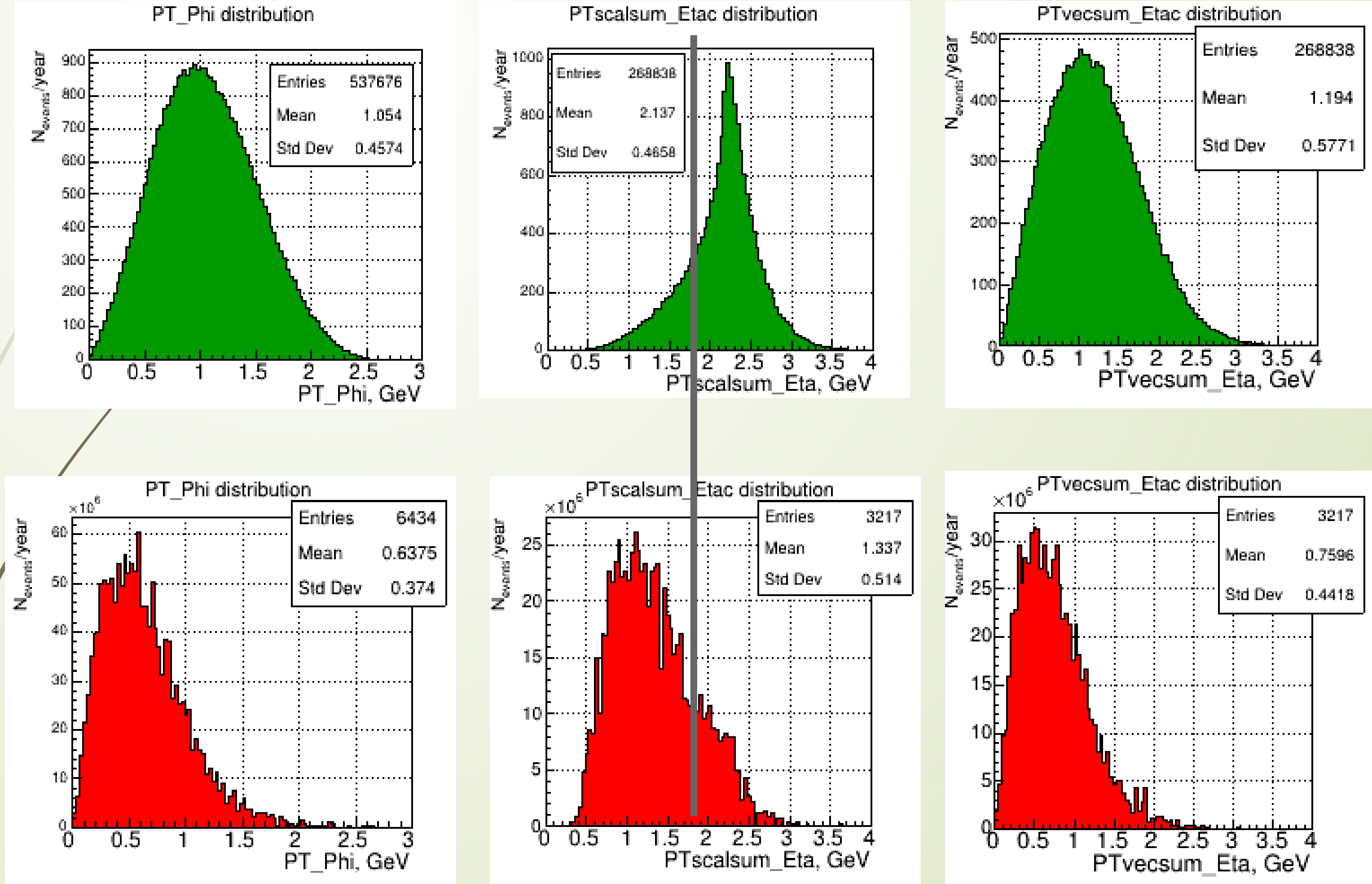


Can be used

|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

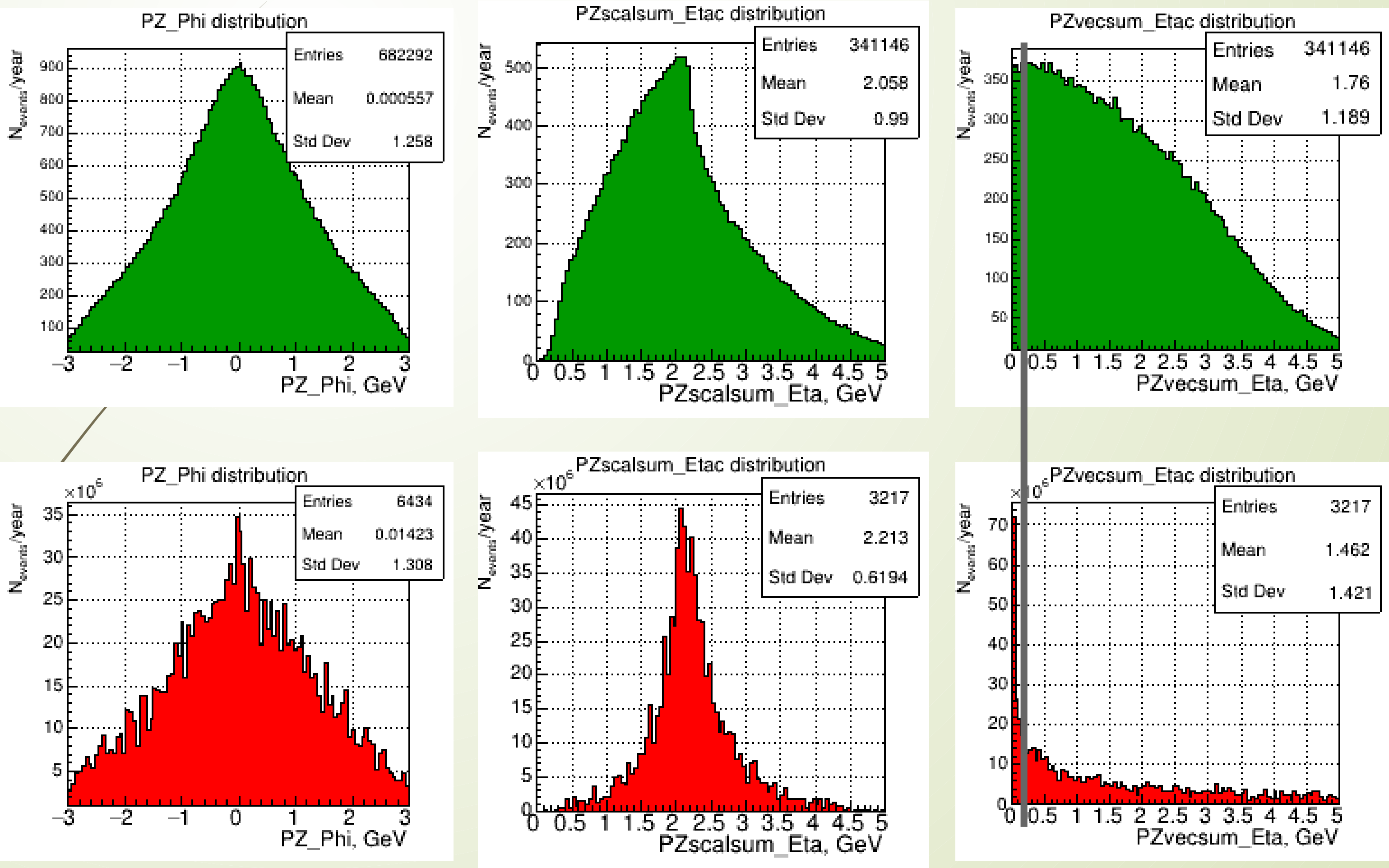
⇓

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

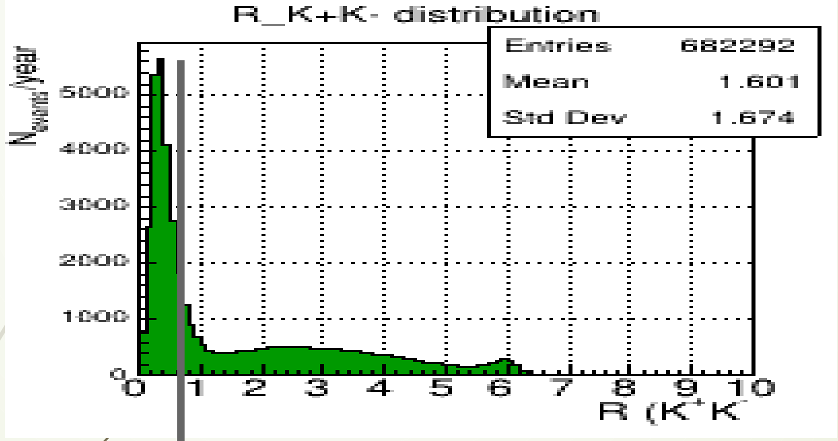
⇓

Can be used for BKG suppression :

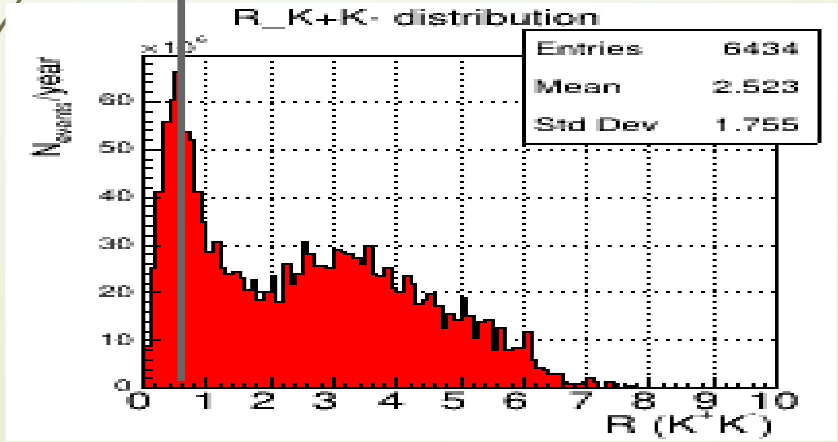
Cut: PZ vecsum > 0.2 GeV

R (K^+K^-) distributions

Signal



Backgd



Distributions of

$$R = \sqrt{\Delta\eta^2+\Delta\varphi^2} = \sqrt{(\eta_{K+} - \eta_{K-})^2 + (\varphi_{K+} - \varphi_{K-})^2}$$

shows some difference

⇓

Can be used **R < 0.6**

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 (K^+K^-) > 0.6 GeV***
3. **N1 +** ***PT scalsum 4K > 1.8 GeV***
4. **N1 +** ***0.2 GeV < PZ vecsum 4K***

5. **N3 + N4 (** ***Pz vecsum Cut + PT scalsum Cut*** **)**
6. **N2 + N3 (** ***R (K^+K^-) Cut + PT scalsum Cut*** **)**
7. **N2 + N4 (** ***R (K^+K^-) Cut + PZ vecsum Cut*** **)**
8. **N2 + N3 + N4 (** ***R (K^+K^-) Cut + PT scalsum Cut + PZ vecsum Cut*** **)**

Results of additional cuts 2-6 on the events sample after 1-st set of cuts is shown in the table below

Current results

Cut N	Rest of Sig	Rest od BKG	S/B ratio
2.	29.7 %	4.9 %	$1.78 * 10^{-4}$
3.	79.6 %	19.9 %	$1.18 * 10^{-4}$
4.	82.7 %	48.8 %	$4.99 * 10^{-5}$
5.	64.7 %	9.0 %	$2.12 * 10^{-4}$
6.	27.7 %	3.2 %	$2.55 * 10^{-4}$
7.	23.8 %	2.1 %	$3.34 * 10^{-4}$
8.	22.1 %	1.3 %	**$5.01 * 10^{-4}$**

Thus the best possible

$S/\sqrt{(S+B)} \approx 1.58$

And final statistics ~ 5000 events/year

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

In the case of bigger η_c cross section *we can assume better results*

$\eta_c \rightarrow \rho\rho \rightarrow 2(\pi^+\pi^-)$ decay

The main PDG parameters

- Branching $\eta_c \rightarrow \rho\rho$ = (1.5 ± 0.4) %
- ρ (770) Mass ≈ 762 ÷ 775 MeV ~ 0.77 GeV
- ρ (770) Width ≈ 147 ÷ 151 MeV ~ 0.149 GeV
- Branching ρ $(770)^0 \rightarrow \pi^+\pi^-$ =~ 100 %

Thus

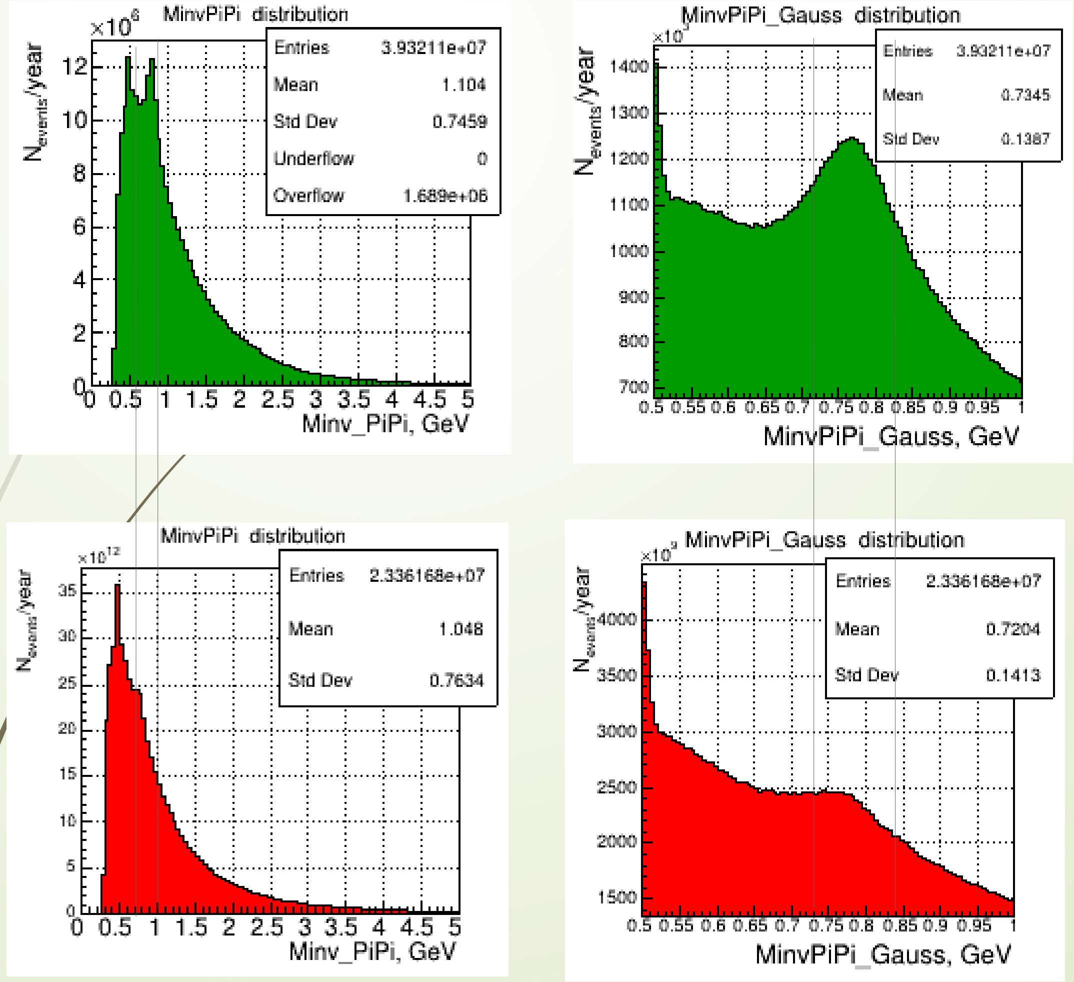
- Total Branching $\eta_c \rightarrow \rho\rho \rightarrow 2(\pi^+\pi^-)$ =~ **1.5 x 10^{-2}**
- $\sigma_{\eta c\ +g \rightarrow\ \rho\rho\ \rightarrow\ 2(\pi+\pi-)}$ **= 6.284 nb → ~ 6.284 * 10^6 events/year**

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

ρ reconstruction

Signal

Background



For **ρ** reconstruction we are looking for

$\pi^+ \pi^-$ combinations (**ρ** candidate)

in the region

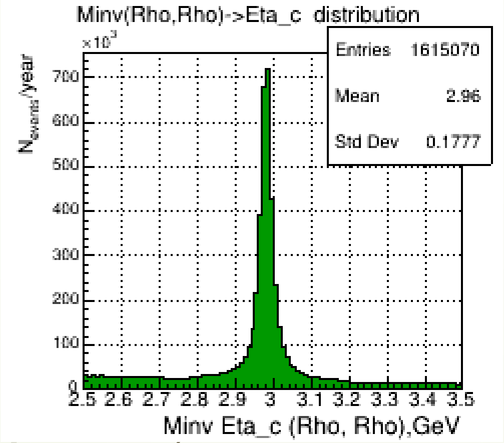
$0.73 < M_{inv} (\pi^+\pi^-) < 0.83$ GeV

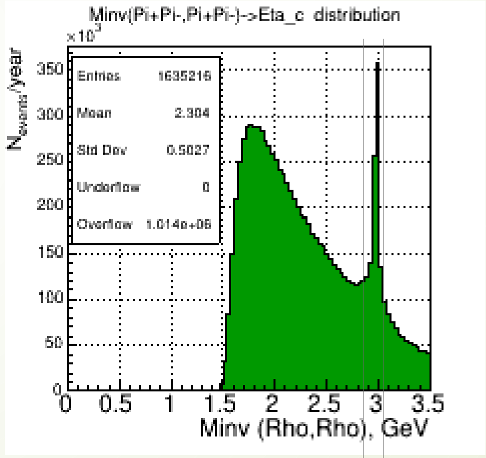
including 1.5% Gauss smearing of **P**

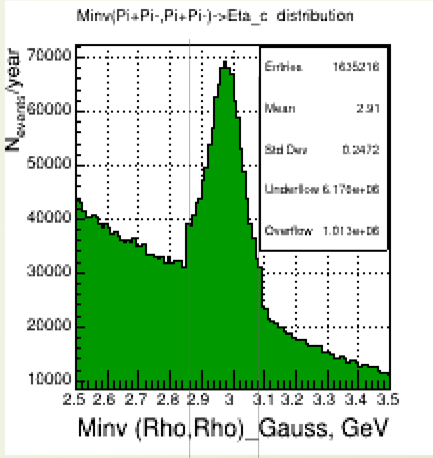
*(up to **58 $\pi^+\pi^-$** combinations / signal event & up **11 ρ** candidates / signal event)*

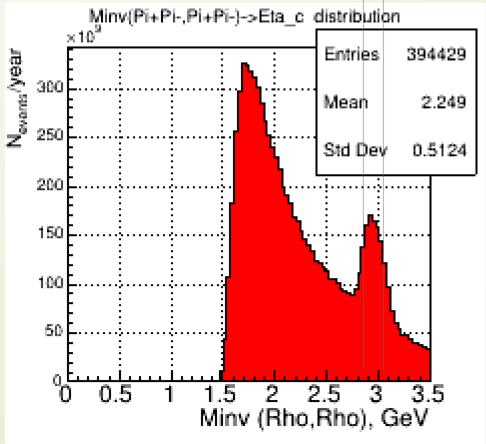
η_c reconstruction

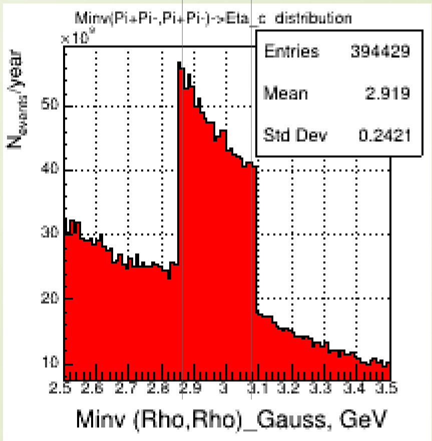
Signal Backgd











For η_c reconstruction we are looking for $\geq 2\ \pi^+\pi^-$ combinations

(ρ candidates in the spread

$0.73 < M_{inv}(\pi^+\pi^-) < 0.83$ GeV)

giving the only 1 η_c candidate in the region of $M_{inv}\eta_c$

$2.89 < M_{inv}(\rho\rho) < 3.09$ GeV

Obtained σ_{signal} = **0.237** nb

$\Downarrow$

~ 237200 events/year

Current results

The proposed selection criteria

$P(\pi^{\pm}) < 1.4$ GeV && $0.73 < M_{inv}(\pi^+\pi^-) < 0.83$ GeV && $2.89 < M_{inv}(\rho\rho) < 3.09$ GeV

allowed to achieve **background suppression** to **$9.13 * 10^5$ nb**
to the level of **$3.82 * 10^{-3}$** that corresponds to

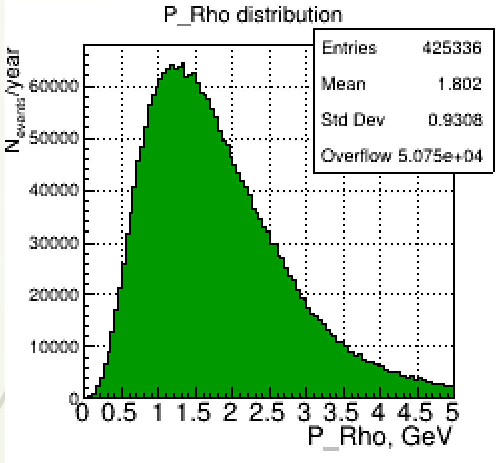
$S/B = 2.59 * 10^{-7}$ for **g g** → ***η_c* + *g*** channel.

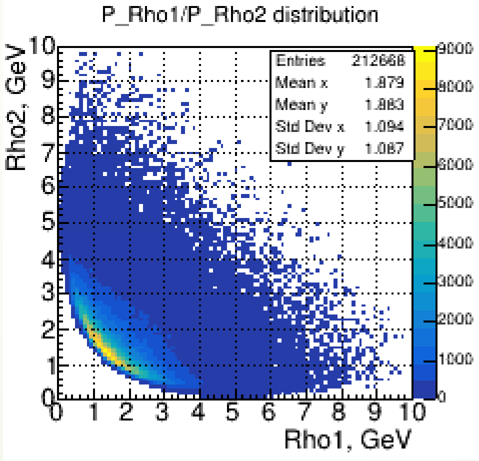
!!! At the same time the part of signal events where at least 1π in 2($\pi^+\pi^-$) combination is fake one ~ 55% ⇒ wrong η_c reconstruction. !!!

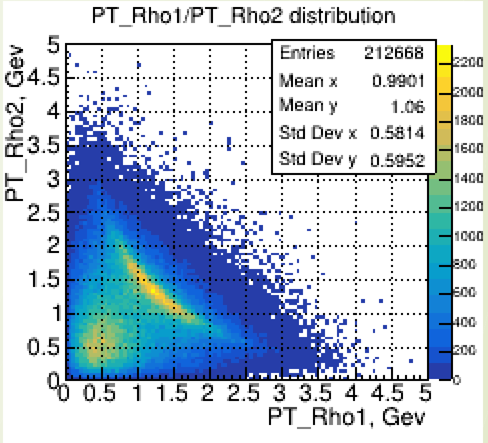
⇒ **???** *May be to test 1-st algorithm in which we choose a case with* ***exactly 2 $\pi^+\pi^-$*** *combinations (ρ candidates) in the giving $M_{inv}\rho$ / $M_{inv}\eta_c$ spread ⇒ possible big loss of statistics*

|Pρ| correlations

Signal



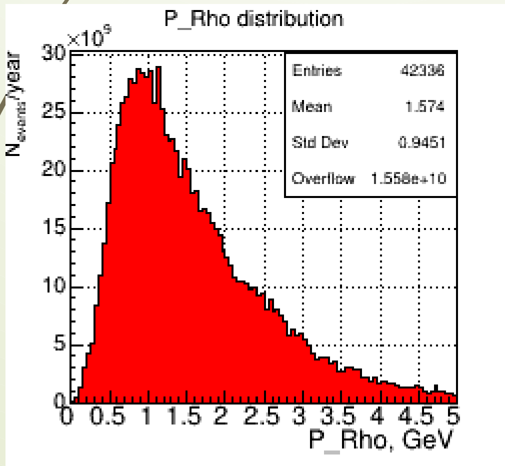


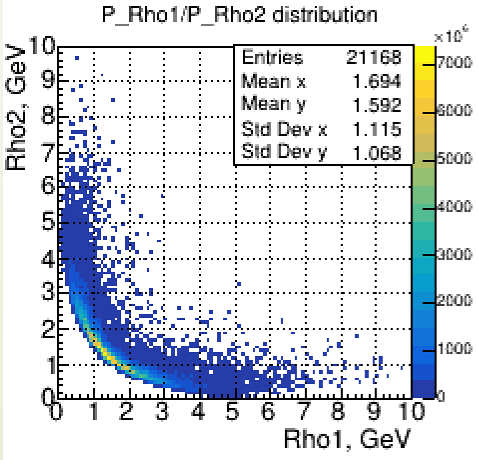


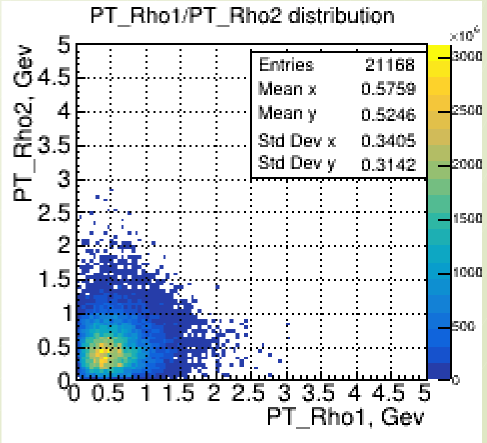
Distributions of |Pρ| look rather similar, but for |**PTρ**| distributions we have some difference

⇓

Backgd





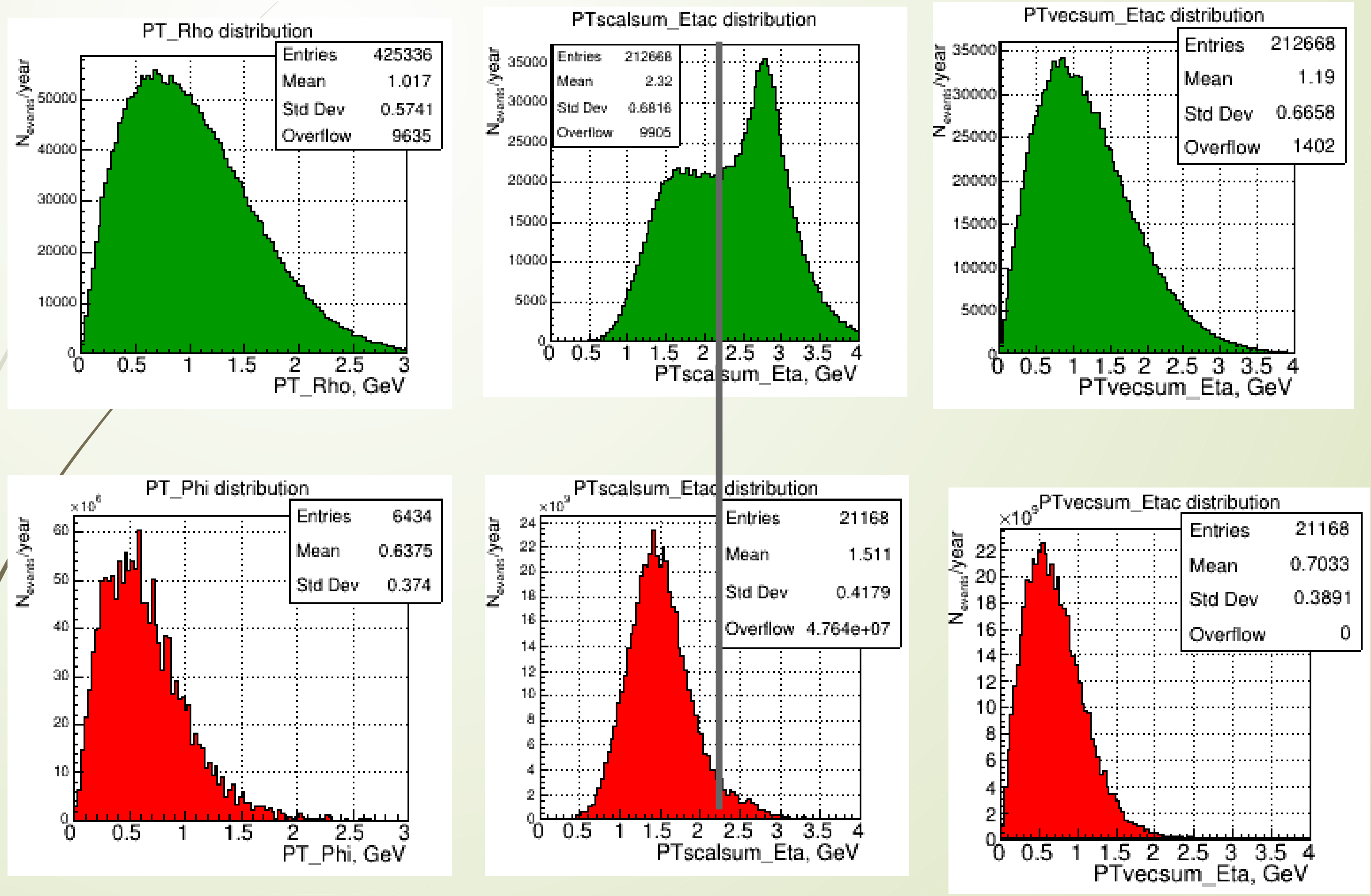


Can be used

|PTρ| correlations

Signal

Backgd



PT vecsum = vector sum of PT's of ***2π⁺π⁻*** forming η_c candidate.

PT scalsum = scalar sum of PT's of ***2π⁺π⁻*** forming η_c candidate. -->

Shows better difference in distributions

⇓

Can be used for BKG suppression :

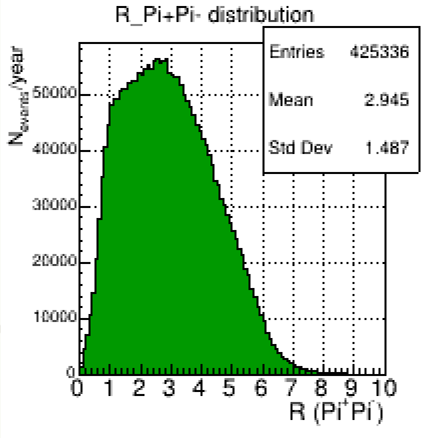
Cut $PT_{scalsum}$ > 2.3 GeV

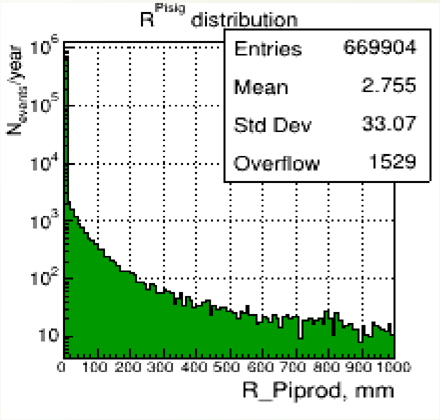
No significant difference in Z direction

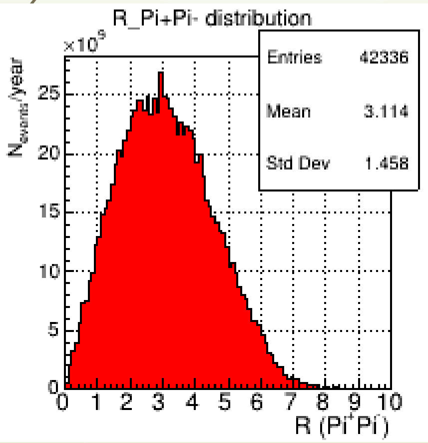
R $(\pi^+\pi^-)$/ $R\pi_{vertex}$ distributions

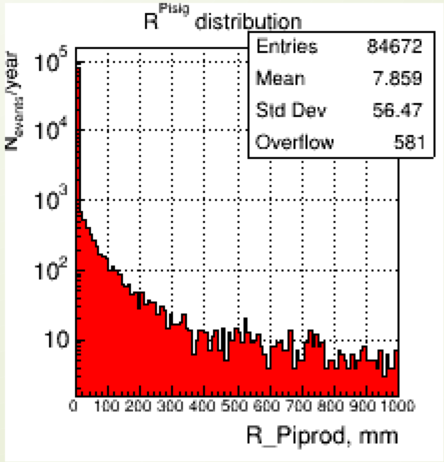
Signal

Backgd









Distributions of

$$R = \sqrt{\Delta\eta^2+\Delta\varphi^2} = \sqrt{(\eta_{\pi+} - \eta_{\pi-})^2 + (\varphi_{\pi+} - \varphi_{\pi-})^2}$$

Now do not show any difference

Some part of π's in signal combinatoin show $R_{\pi\ \text{production vertex}} > 0 \Rightarrow$ fake π

(~17% fake signal event combinations)

$R\_\pi_{vtx} < 1$ mm **should be used**

Current results

Proposed cuts

1. **P ($K^{\pm}$) < 1.4 GeV && 0.73 < M_{inv} ($\pi^+\pi^-$) < 0.83 GeV && 2.89 < M_{inv} ($\rho\rho$) < 3.09 GeV**

2. **N1 +** ***R_π_{vtx} < 1 mm***
3. **N1 +** ***PT scalsum 4π > 2.3 GeV***
4. **N2 + N3 (** ***R_π_{vtx} Cut + PT scalsum Cut*** **)**

Cut N	Rest of Sig	Rest od BKG	S/B ratio
2.	9.25 %	23.7 %	$1.01 * 10^{-7}$
3.	53.6 %	4.78 %	$2.91 * 10^{-6}$
4.	2.43 %	0.81 %	**$7.82 * 10^{-7}$**

Thus the best possible

$S/\sqrt{(S+B)} \approx 0.067$

And final statistics ~ 5700 events/year

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

Conclusions

- With the current algorithm of particle sampling there is no chance to observe **η_c** in ***$\eta_c \to \rho\,\rho \to 2\,(\pi^+\pi^-)$ decay*** channel.
  The algorithm with the presence of **exactly** ***2ρ candidates*** in event will be considered later.

- If the cross section of **η_c** production turns out to be higher, as shown **A.Anufriev**, we will have the opportunity to observe **η_c** in ***$\eta_c \to \varphi\,\varphi \to 2\,(K^+K^-)$* decay** channel.

- Some other other variables (for example ***R(ρ,ρ), R(φ,φ)***) can also be considered for background suppression

Thank you for your attention!