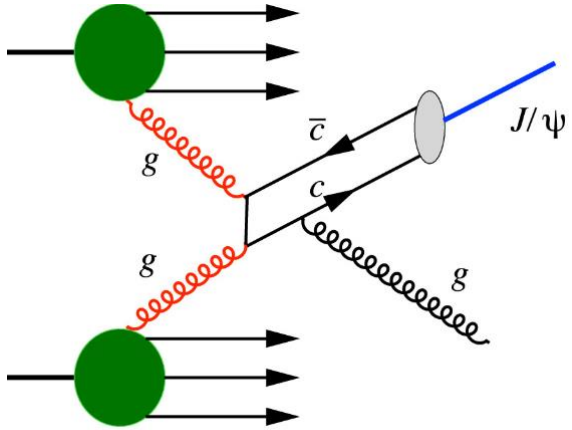
Dependence of the angular coefficients of J/ψ meson on the transverse momentum in pp collisions at $\sqrt{s_{NN}}$ = 27 GeV using the Pythia generator

Bykovskii Mikhail, Bulekov Oleg

michael.bykovskij@yandex.ru

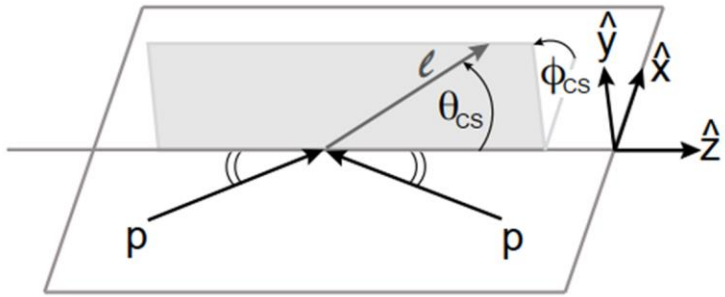
J/ψ meson differential cross section



Goal: extract angular coefficients as functions of J/ψ kinematics (p_T)

$J/\psi \rightarrow \mu^+\mu^-$; BF = 5.96 ± 0.03%, Γ = 93 ± 2 keV

$$\frac{d\sigma}{dp_T\, dy\, d\cos\vartheta\, d\varphi} = \frac{3}{4\pi\,(3+\lambda_\vartheta)}\frac{d\sigma}{dp_T\, dy}\,[1 + \lambda_\vartheta \cos^2\vartheta + \lambda_{\vartheta\varphi} \sin 2\vartheta \cos\varphi + \lambda_\varphi \sin^2\vartheta \cos 2\varphi],$$



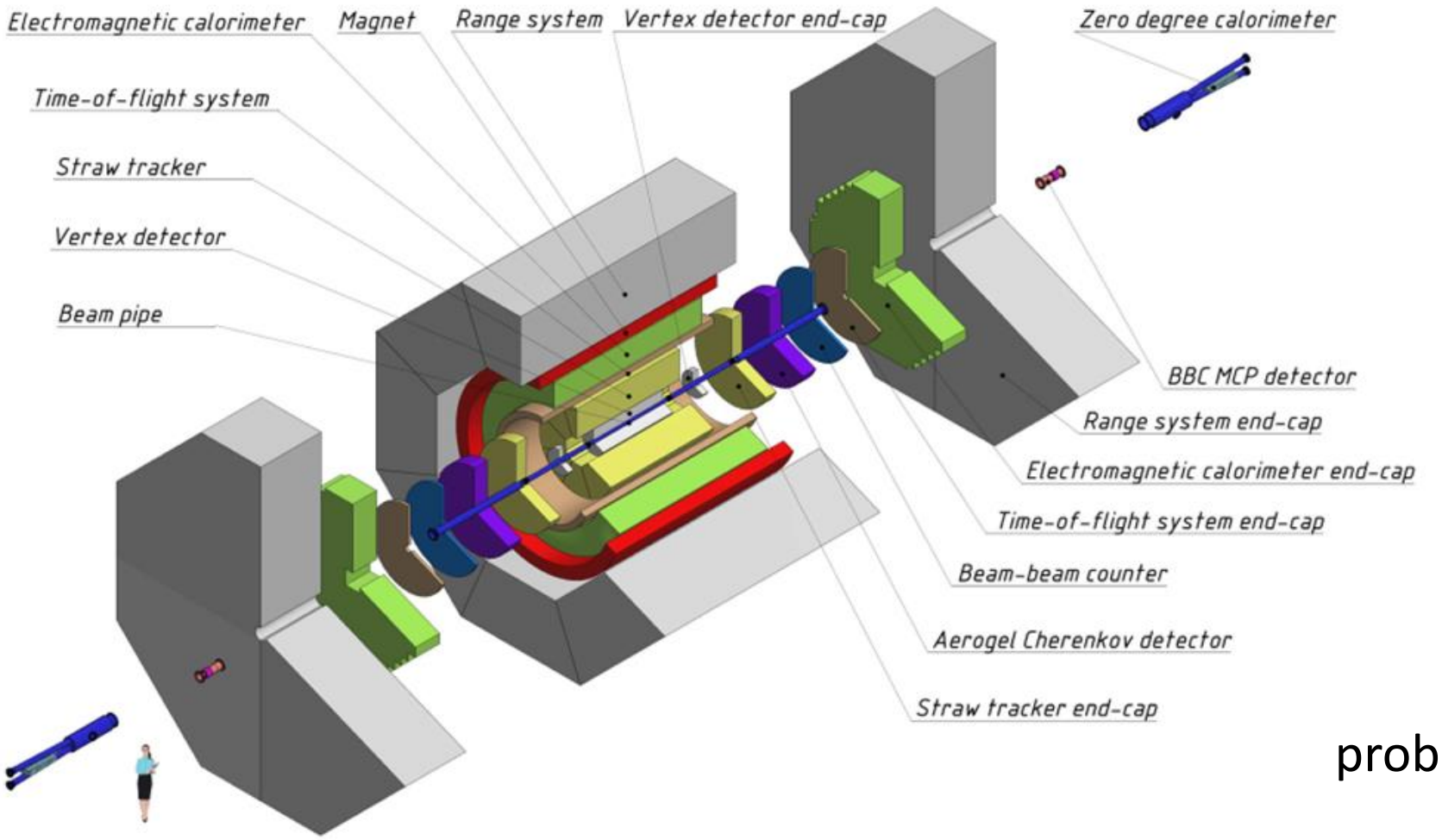
p_T, y – J/ψ meson variables in the pp center-of-mass frame

$\cos\vartheta$, φ – decay μ^- variables in the J/ψ rest-frame, (Collins-Soper frame)

λ_ϑ, λ_φ, $\lambda_{\vartheta\varphi}$ – J/ψ meson angular coefficients

Mirkes E., Kim C. S. J/Ψ decay lepton distribution in hadronic collisions //Physics Letters B. – 1995. – Т. 346. – №. 1-2. – С. 124-128.

SPD experiment (2030+) at NICA collider



$p^{\uparrow}\ p^{\uparrow}$ $\sqrt{s}$ = 27 GeV

$d^{\uparrow}\ d^{\uparrow}$ $\sqrt{s}$ = 13.5 GeV

U, L, T

polarization ~ 70%

luminosity ~ 10^{32} cm^{-2} s^{-1}

SPD main task:
probe gluon PDFs (collinear, TMD)

Arbuzov A. et al. On the physics potential to study the gluon content of proton and deuteron at NICA SPD //Progress in Particle and Nuclear Physics. – 2021. – T. 119. – C. 103858.

Monte – Carlo based signal/background study

Simulation features:

Pythia8 pp √s = 27 GeV, all SPD subsystems are included

Background: minimum bias (133M events)
all pairs of opposite charge tracks are considered

Signal: J/ψ → $\mu^+\mu^-$ (12M events)
pdg code of tracks and mother particle are checked

Preliminary selection:

for tracks: p_T > 0.3 GeV/c, > = 1 hit in RS

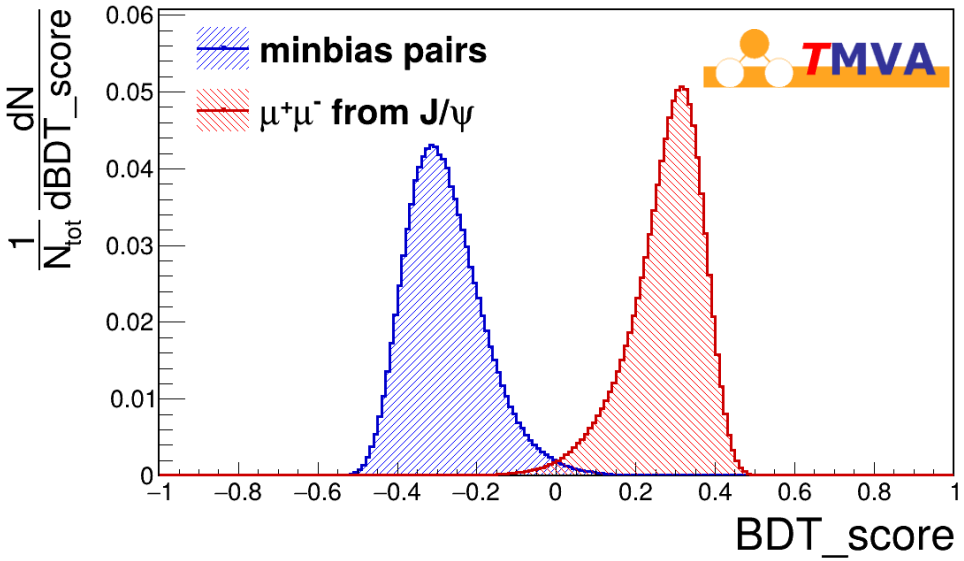
for tracks pair: 3,0 < M < 3,2 GeV/c^2
1.5M minbias pairs and 8.9M signal pairs

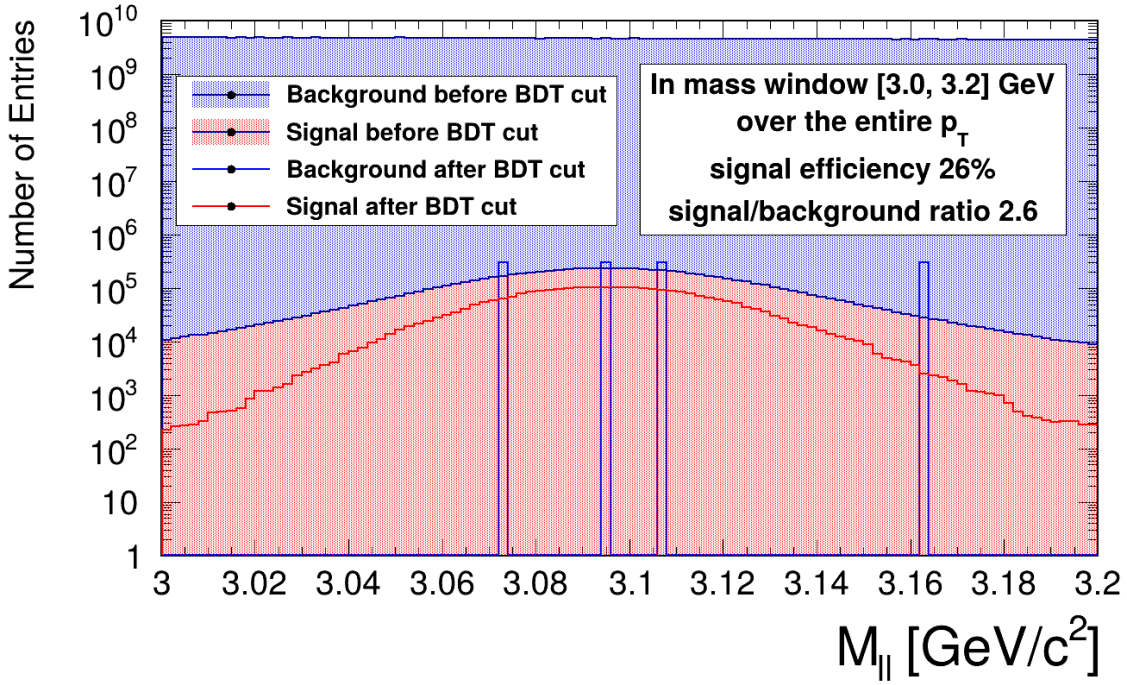
Inputs to the classifier:

Reconstructed track info: kinematics, PV geometry, TS (hits, dE/dx), ECal (energy), RS (length in iron, nhits)

Training:

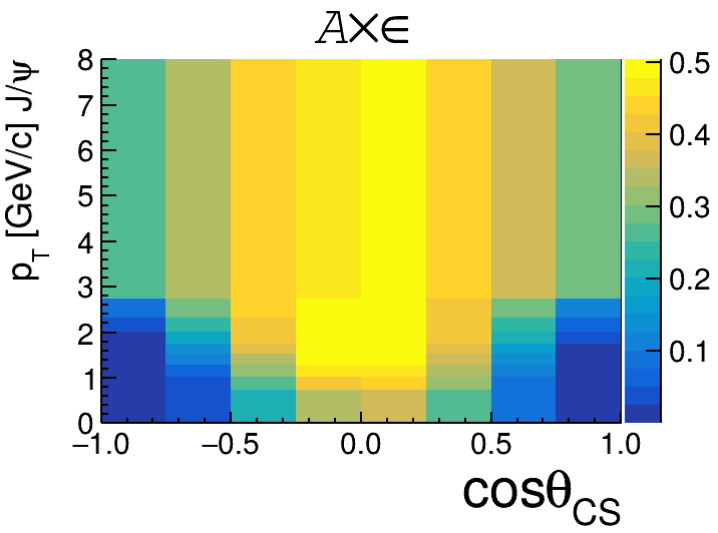
To study signal/background separation, two BDTs folds were implemented, i.e for each pair, the score of the BDT classifier trained on the other half of the pairs was applied.

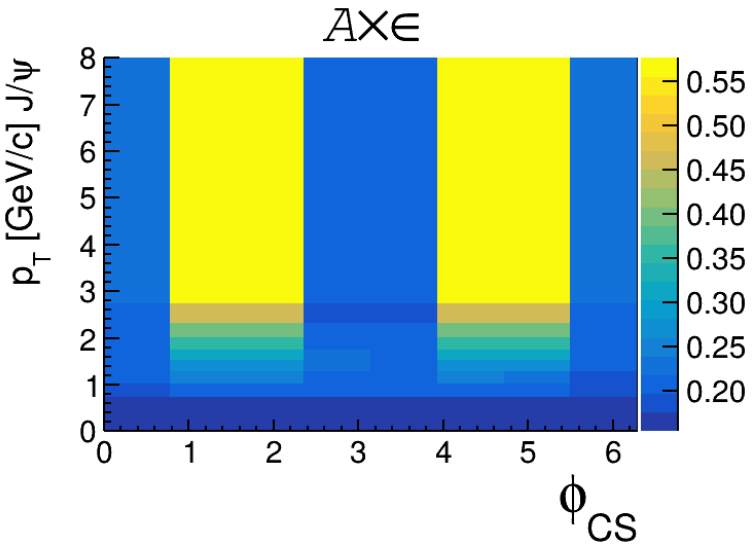


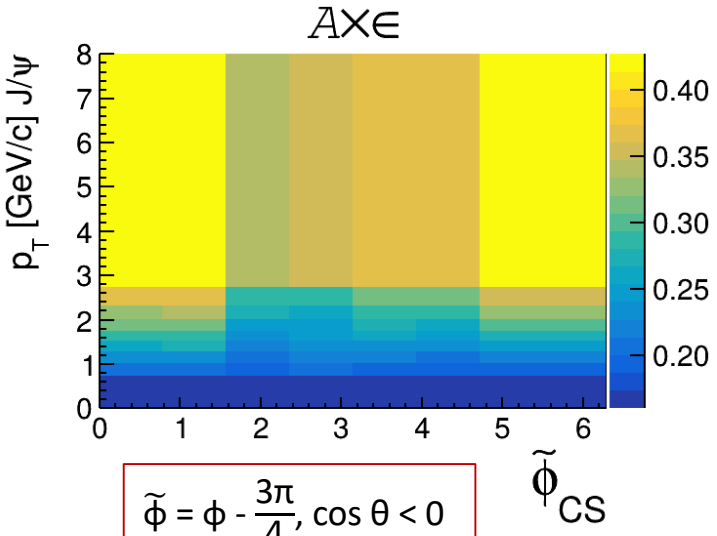


Angular distributions correction

$A \times \varepsilon$ were evaluated in 9 p_T J/ψ bins (GeV/c): [0; 0,73], [0,73; 1,03], [1,03; 1,29], [1,29; 1,53], [1,53; 1,75], [1,75; 2,01], [2,01; 2,31], [2,31; 2,75], [2,75; 8]

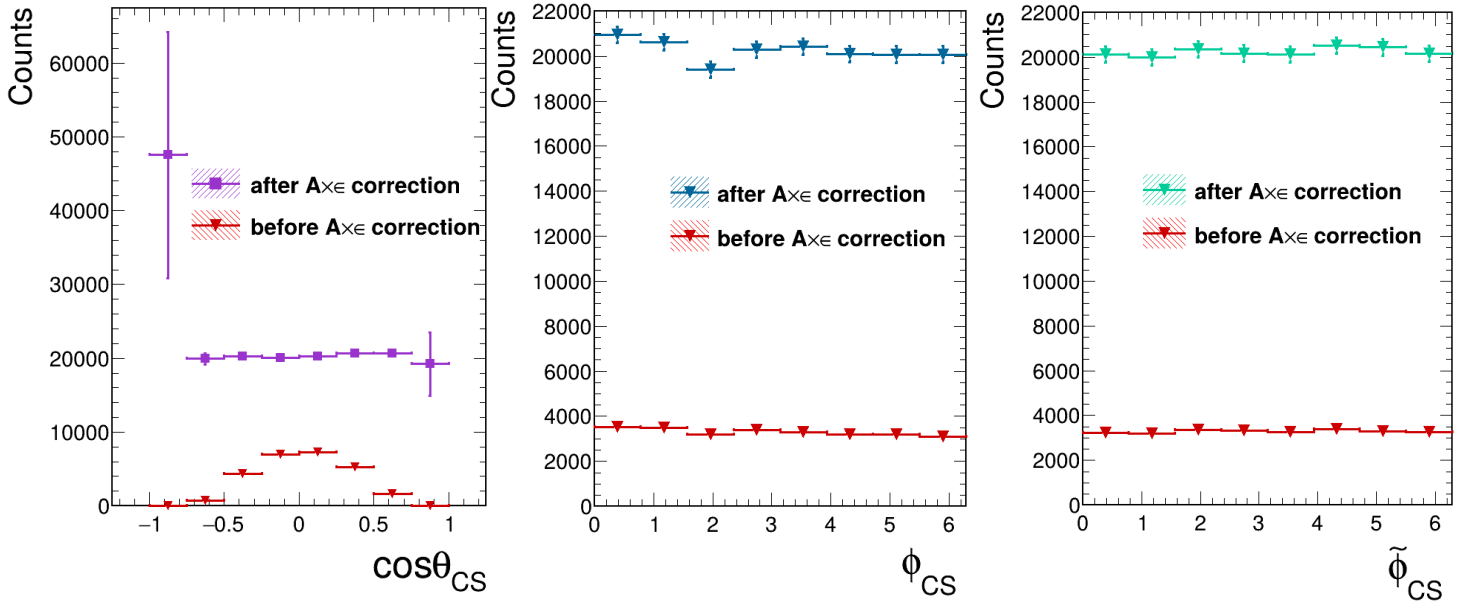






$\tilde{\phi} = \phi - \frac{3\pi}{4}$, $\cos\theta < 0$

$\tilde{\phi} = \phi - \frac{\pi}{4}$, $\cos\theta > 0$



Procedure:

- subsample of 300K selected $\mu^+\mu^-$ was corrected
- The correction factor was introduced separately for ($\cos\theta_{CS}$| ϕ_{CS}| $\tilde{\phi}_{CS}$) distributions (as example, for $p_T < 0.73$ bin on the left)

For models that include polarization, a dedicated A × ε evaluation may be required.

Simultaneous fitting 1D angular distributions

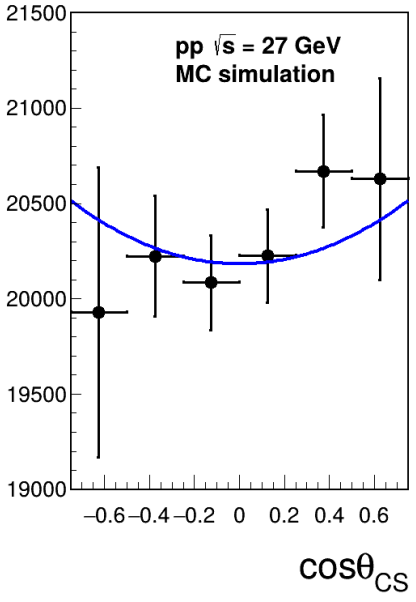
A simultaneous fit is performed by minimizing the combined χ^2-function for each p_T-interval

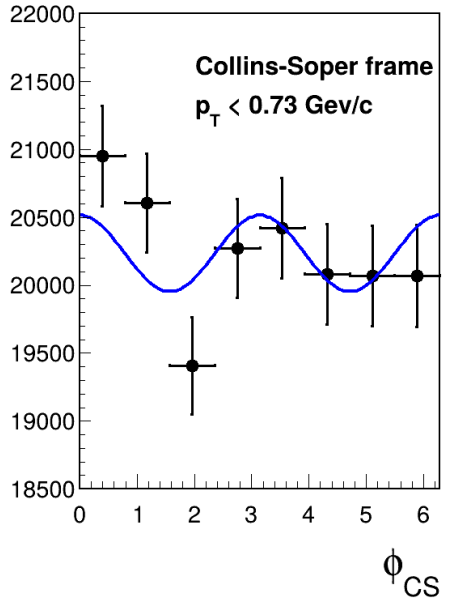
$$W(\cos\vartheta) = \frac{3}{2(3+\lambda_\vartheta)}\left[1+\lambda_\vartheta\cos^2\vartheta\right]$$

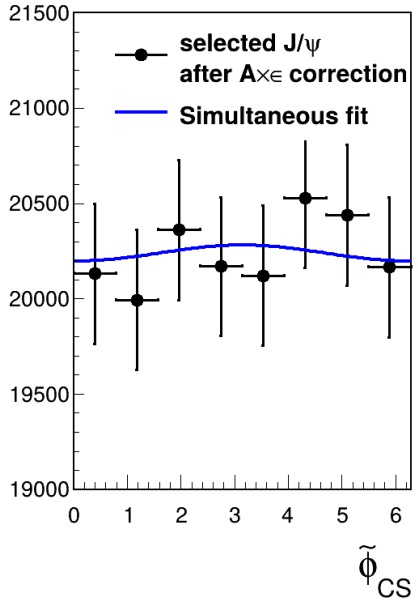
$$W(\varphi) = \frac{1}{2\pi}\left[1+\frac{2\lambda_\varphi}{3+\lambda_\vartheta}\cos 2\varphi\right]$$

$$W(\tilde{\varphi}) = \frac{1}{2\pi}\left[1+\frac{\sqrt{2}\lambda_{\vartheta\varphi}}{3+\lambda_\vartheta}\cos\tilde{\varphi}\right]$$

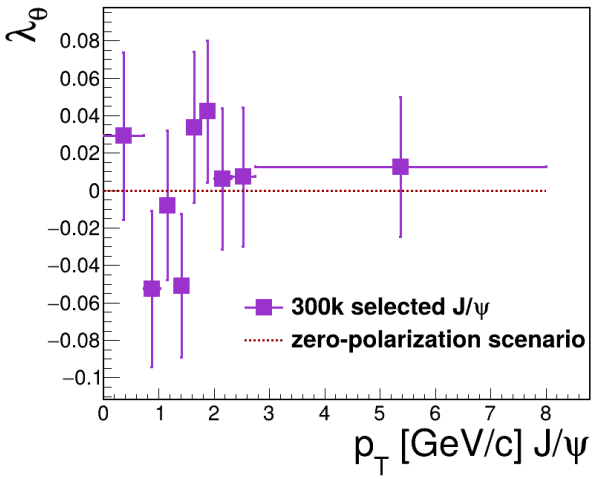
λ_ϑ , λ_φ, $\lambda_{\vartheta\varphi}$ – free parameters

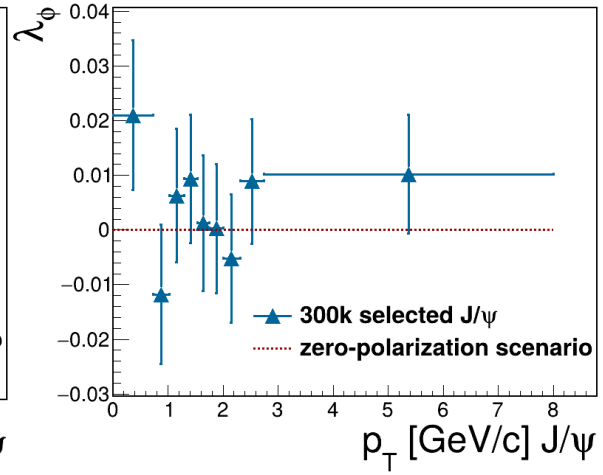


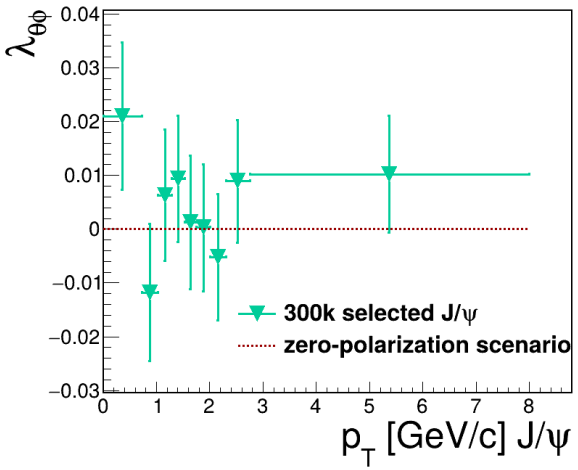




all χ^2/ndf in [0.2, 1.3]







The A × ε correction results in zero λ_ϑ , λ_φ, $\lambda_{\vartheta\varphi}$ (as expected for Pythia8)

Stat. uncertainties (1 eff. year):
$\Delta_{\lambda\vartheta}$ ~ 0.014, $\Delta_{\lambda\varphi}$ ~ 0.004
$\Delta_{\lambda\vartheta\varphi}$ ~ 0.005

Conclusion

Results:

We estimated the signal-to-background ratio for J/ψ → $\mu^+\mu^-$ in pp-collisions at √s = 27 GeV under SPD conditions. The estimate is based on Monte Carlo simulation using two BDT classifiers.

- a s/b ratio 2.6 with signal selection efficiency 26% in invariant mass window [3.0; 3.2] GeV/c^2 over the entire p_T range

We also performed a simultaneous fit of the A × ε corrected angular distributions of 300k selected muons from J/ψ in the Collins–Soper frame.

- fitted J/ψ's λ_ϑ , λ_φ, $\lambda_{\vartheta\varphi}$ are consistent with zero (as expected for unpolarized J/ψ production in Pythia8)
- stat. uncertainties: $\Delta_{\lambda\vartheta}$ ~ 0.014, $\Delta_{\lambda\varphi}$ ~ 0.004, $\Delta_{\lambda\vartheta\varphi}$ ~ 0.005 (1 eff. year, 9 p_T bins)

Plans:

- Comparison of BDT with other machine learning approaches in signal/background separation
- Analysis in reconstructed kinematic variables, accounting for event migrations

Backup

Input variables: kinematics

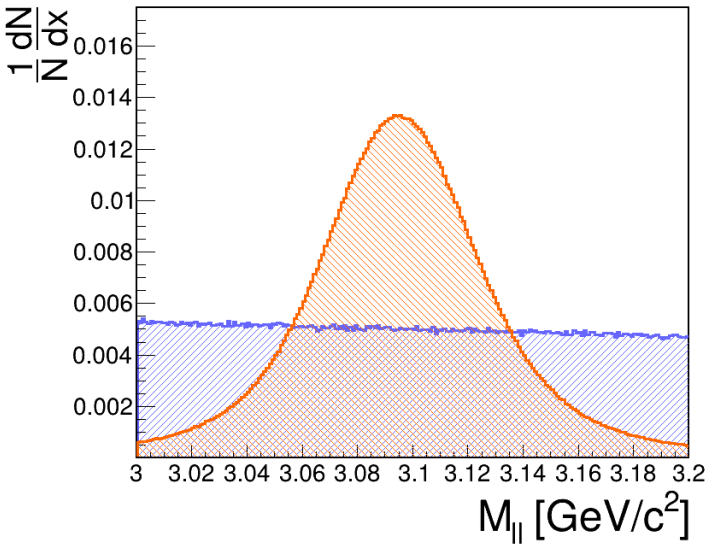
for tracks: p_T > 0.3 GeV/c, > = 1 hit in RS

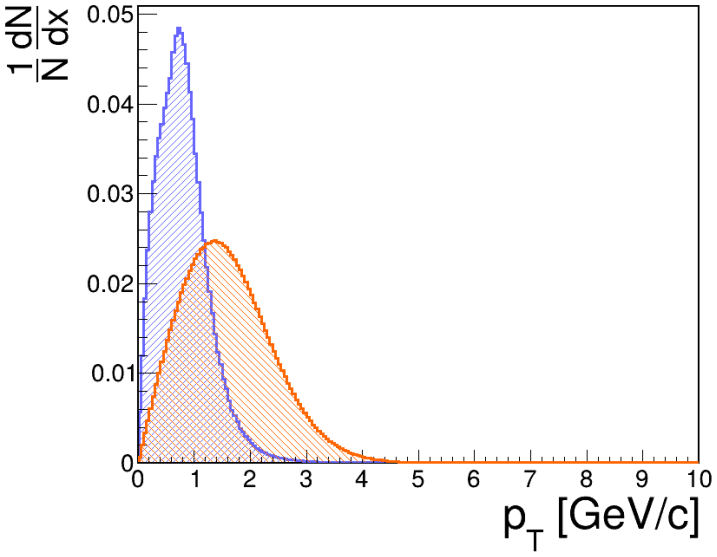
for tracks pair: 3,0 < M < 3,2 GeV/c^2

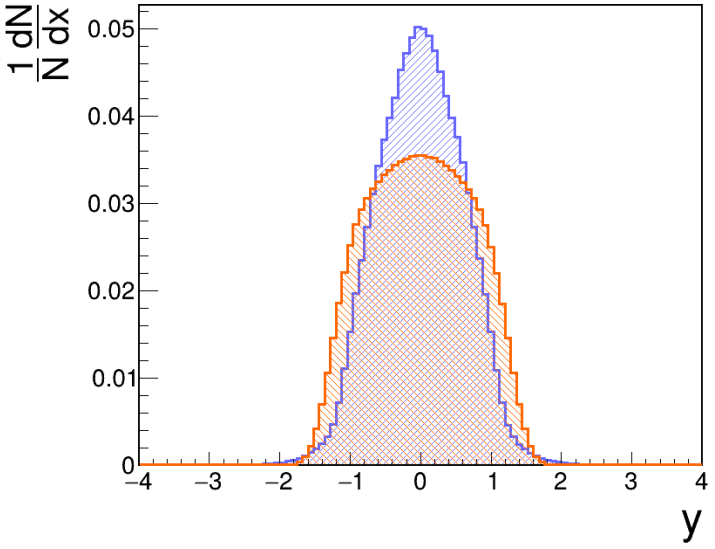
for minbias pairs: "μ^+" = positively charged track, "μ^-" = negatively charged track

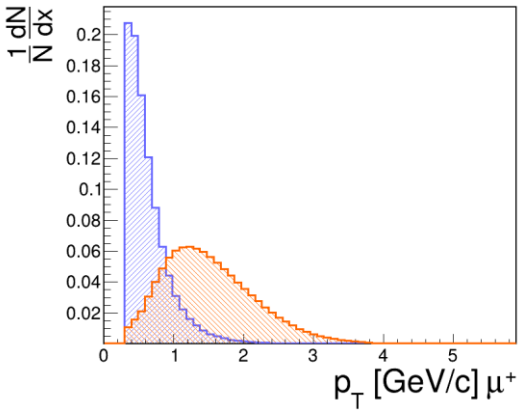
minbias pairs

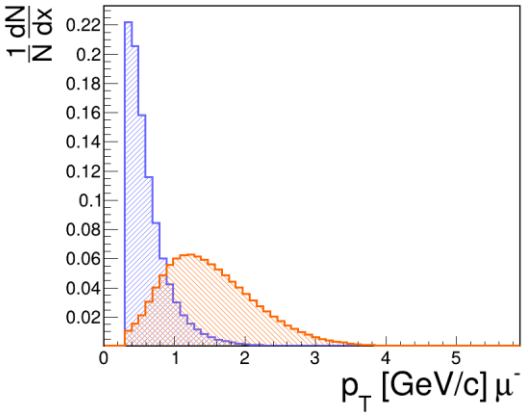
$\mu^+ \mu^-$ from J/ψ

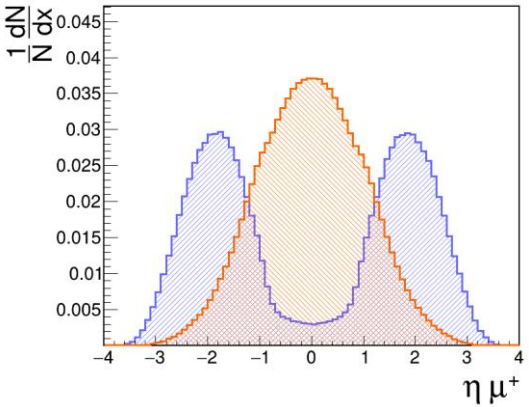


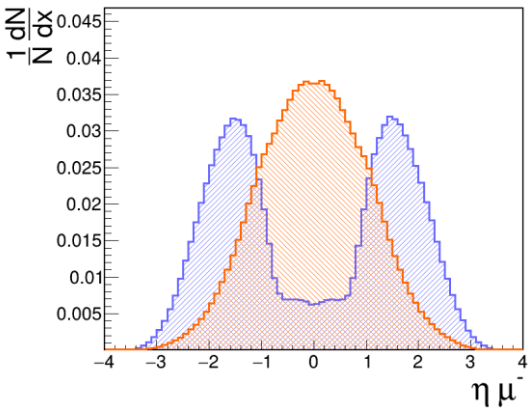












Input variables: ITS, TS

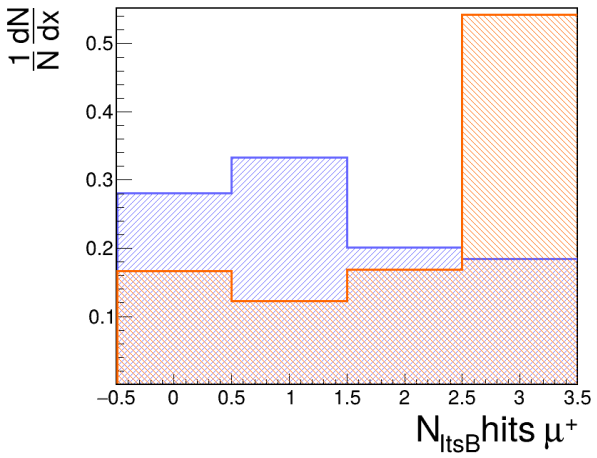
for tracks: $p_T > 0.3$ GeV/c, > = 1 hit in RS

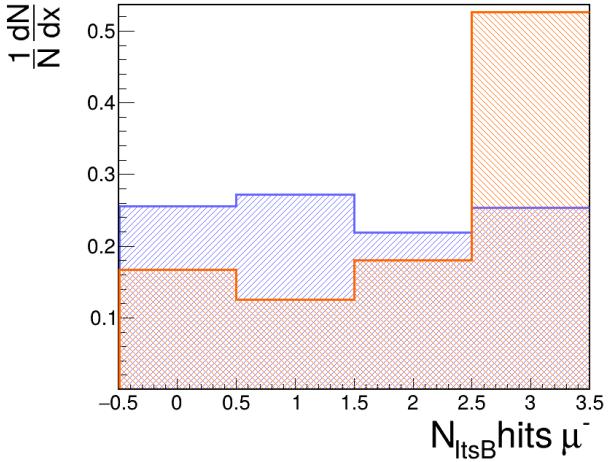
for tracks pair: $3{,}0 < M < 3{,}2$ GeV/c^2

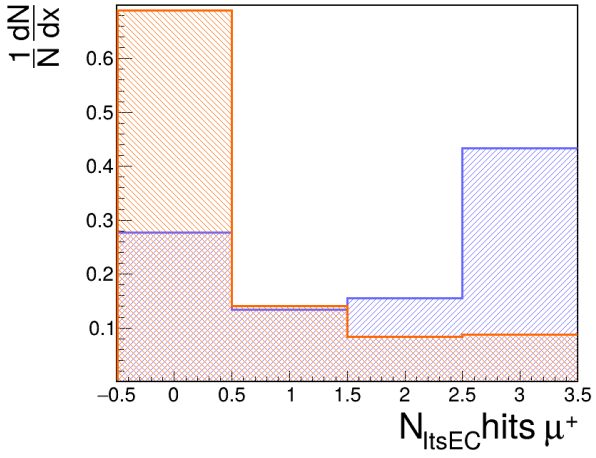
for minbias pairs: "μ^+" = positively charged track,
"μ^-" = negatively charged track

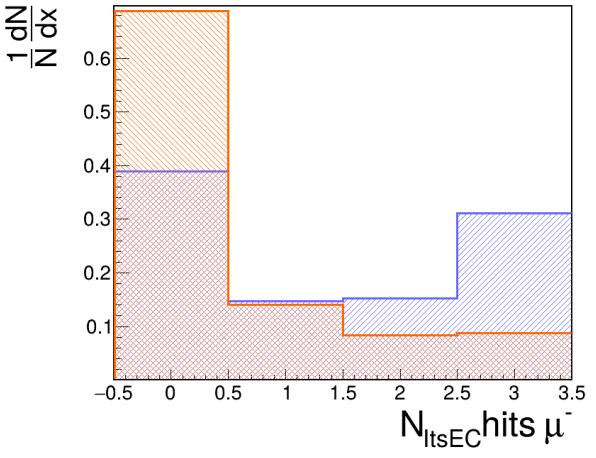
minbias pairs

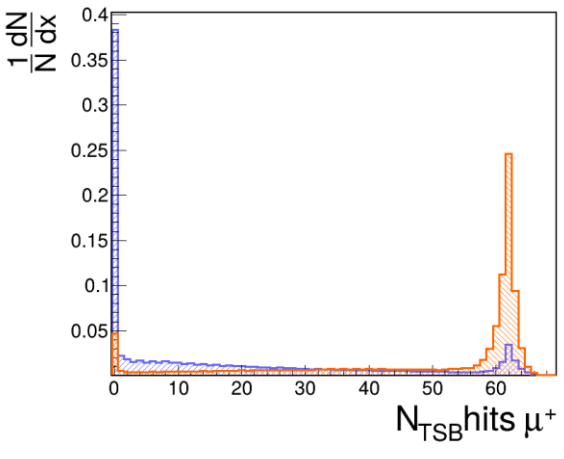
$\mu^+ \mu^-$ from J/ψ

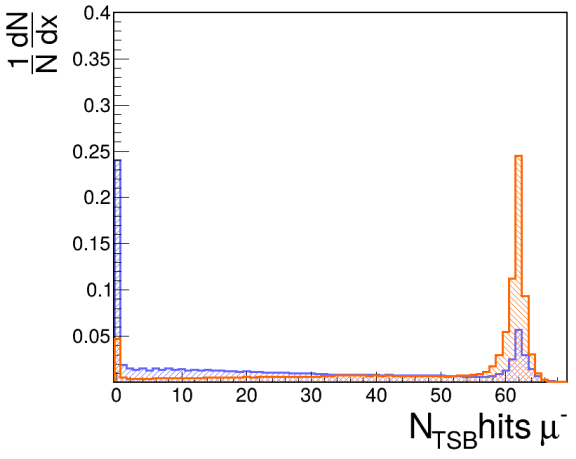


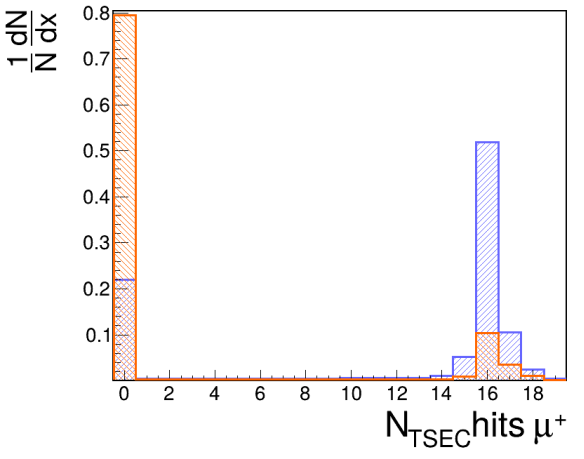


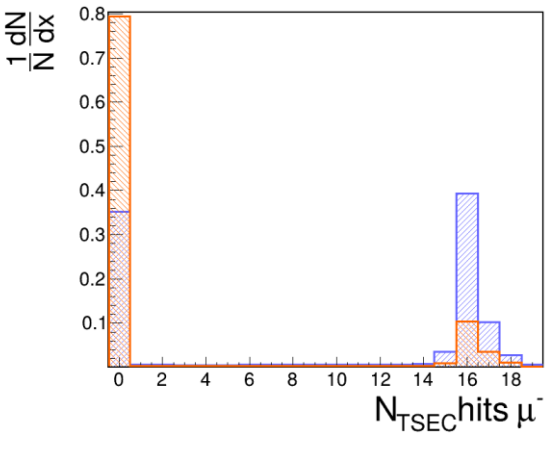












Input variables: dE/dx, ECAL

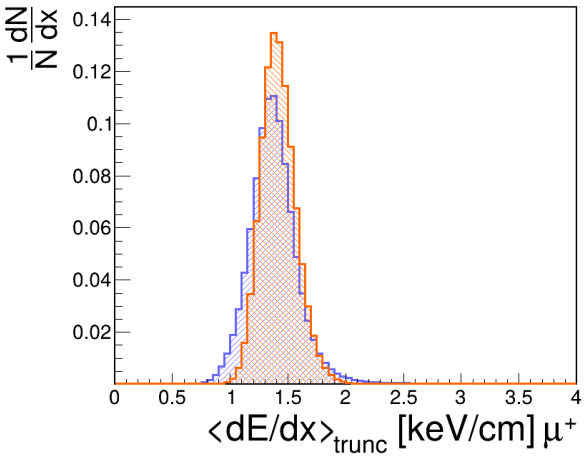
for tracks: $p_T > 0.3$ GeV/c, > = 1 hit in RS

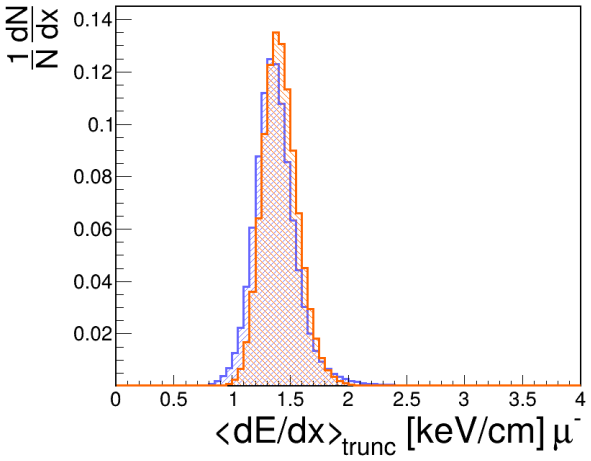
for tracks pair: $3{,}0 < M < 3{,}2$ GeV/c^2

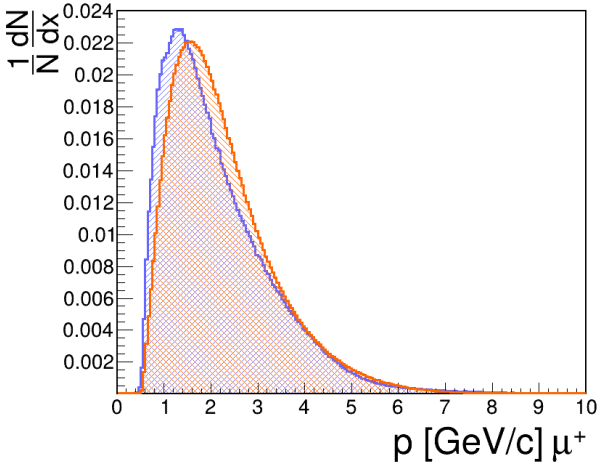
for minbias pairs: "μ^+" = positively charged track, "μ^-" = negatively charged track

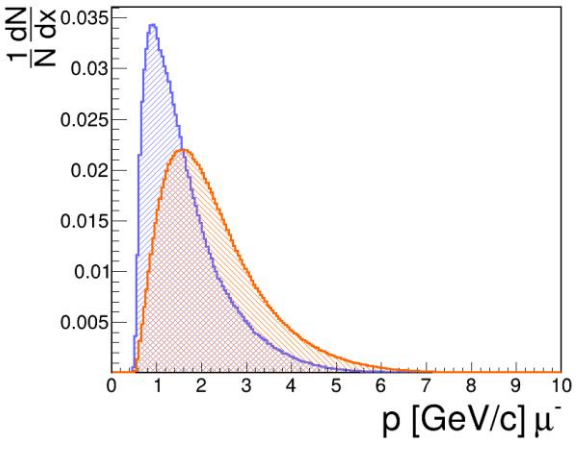
minbias pairs

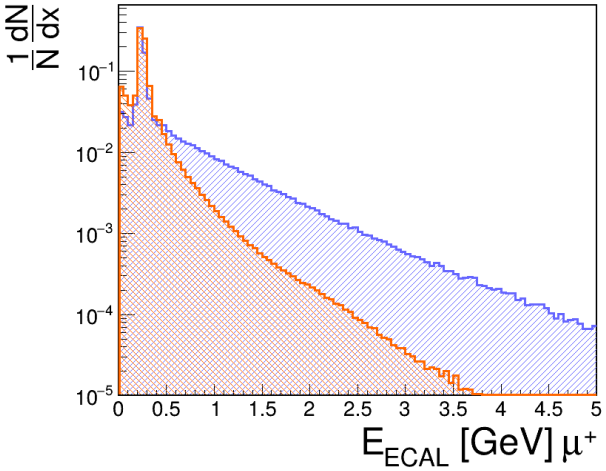
$\mu^+ \mu^-$ from J/ψ

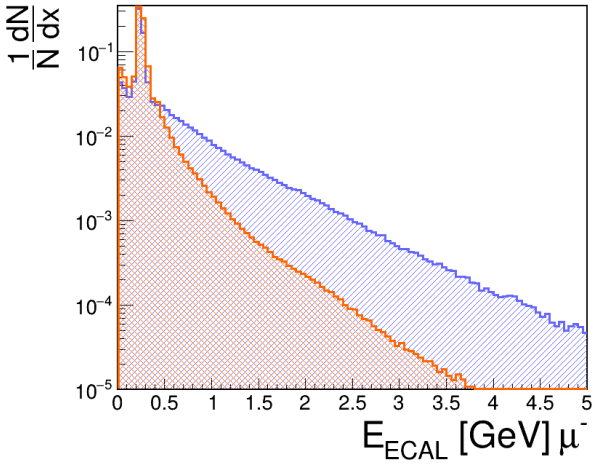


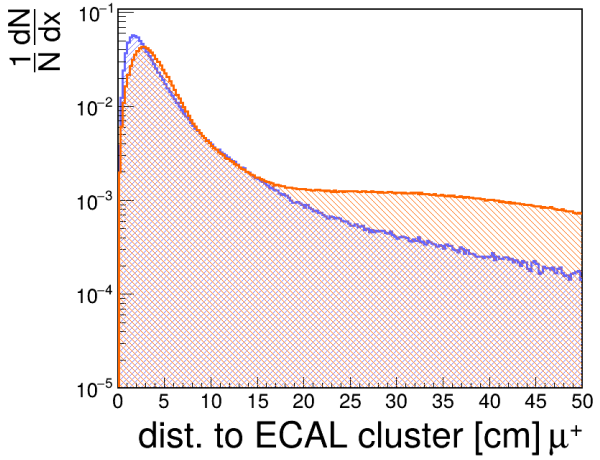


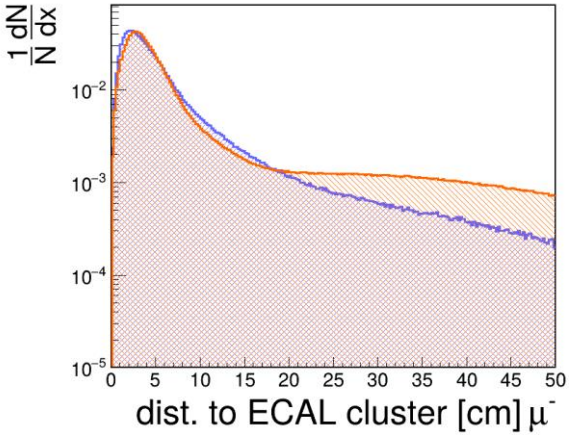












Input variables: RS

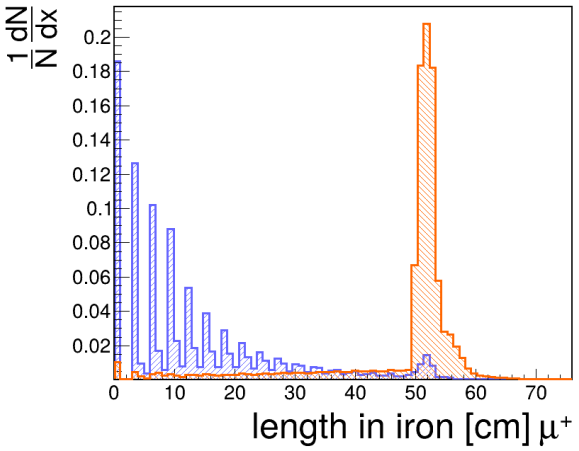
for tracks: p_T > 0.3 GeV/c, > = 1 hit in RS

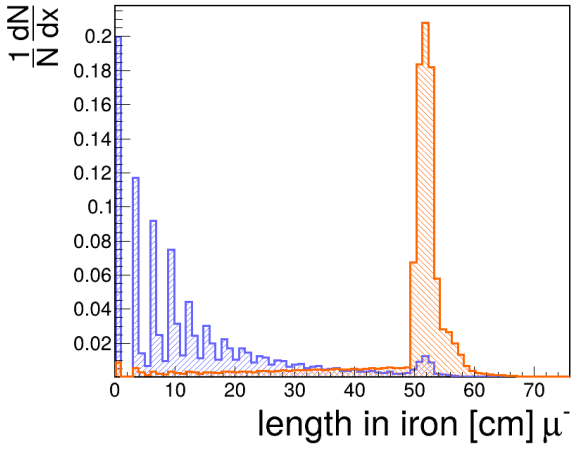
for tracks pair: 3,0 < M < 3,2 GeV/c^2

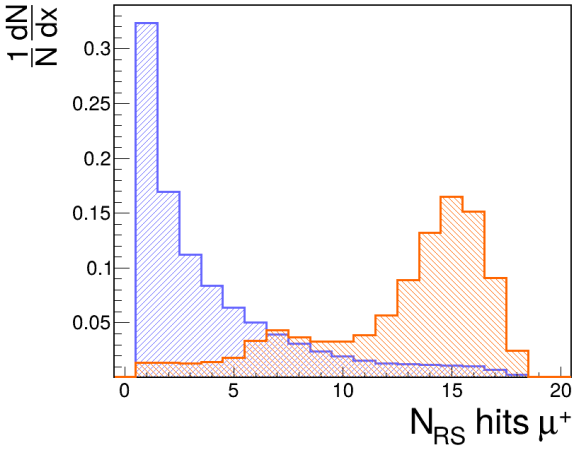
for minbias pairs: "μ^+" = positively charged track,
"μ^-" = negatively charged track

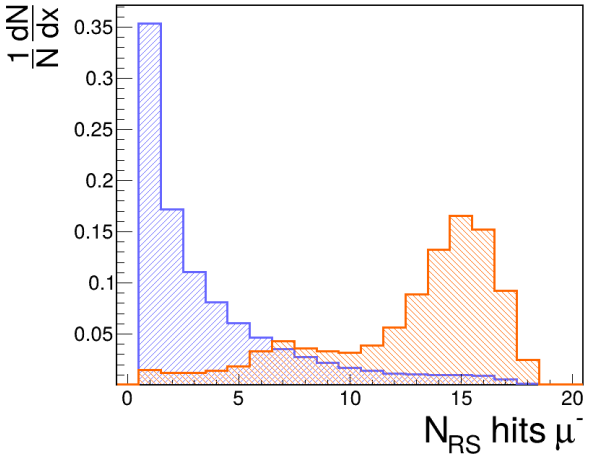
minbias pairs

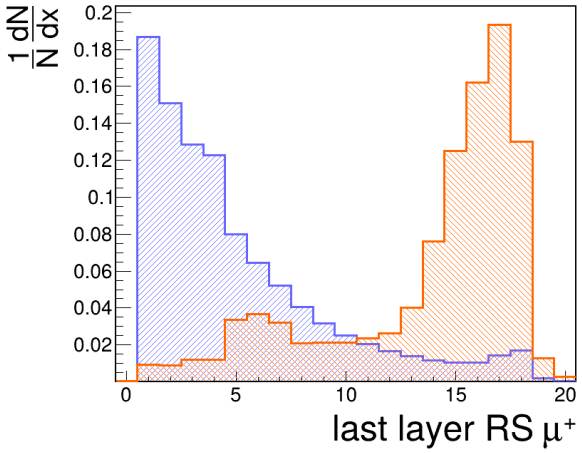
$\mu^+ \mu^-$ from J/ψ

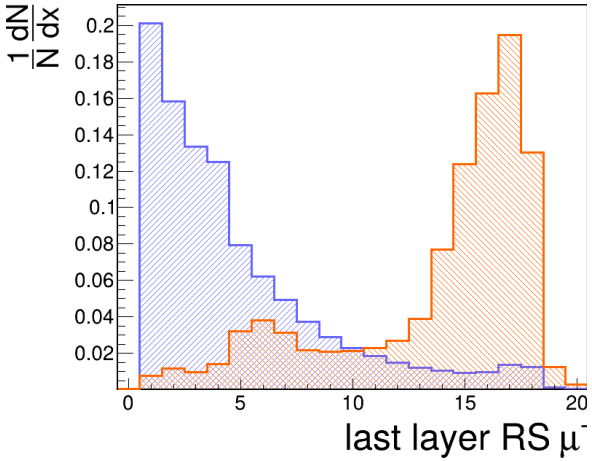


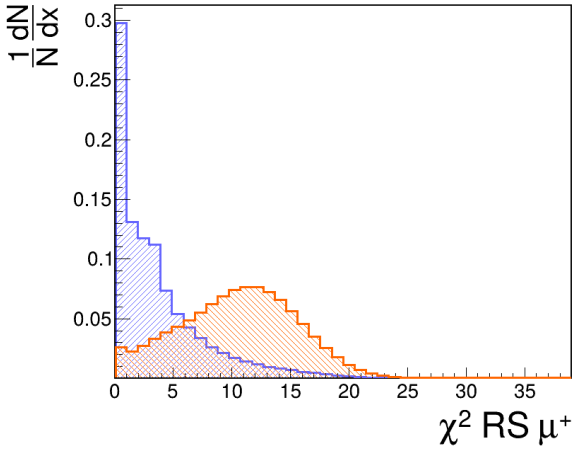


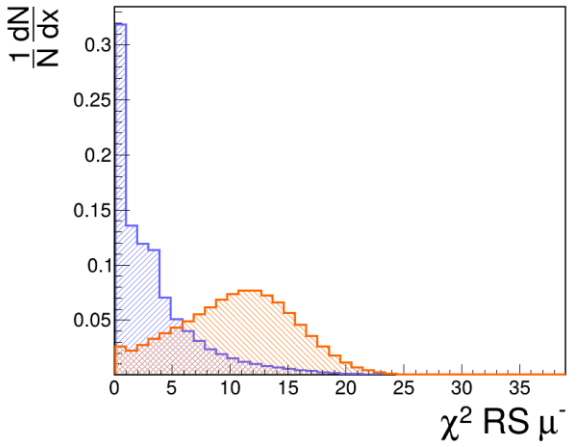












Input variables: PV

for tracks: p_T > 0.3 GeV/c, > = 1 hit in RS

for tracks pair: 3,0 < M < 3,2 GeV/c^2

for minbias pairs: "μ^+" = positively charged track,
"μ^-" = negatively charged track

