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Measurement of J/ψ -p femtoscopy in pp collisions at $\sqrt{s_{NN}} = 13.6 \text{ TeV}$

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J/ψ -proton Femtoscopy

- Insights into J/ψ -N interaction through J/ψ -proton femtoscopy
 - No measurement yet

Correlation function

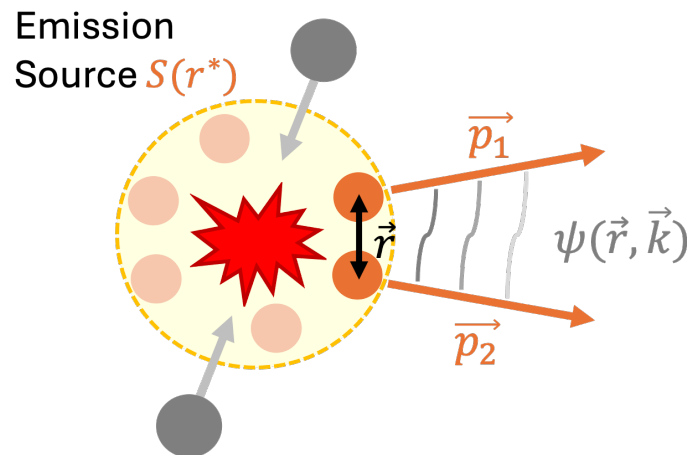
S. Pratt, PRC (1990) 2646-2652
S. E. Koonin, PLB 70 (1977) 43-47

$$C(k^*) = \underbrace{\mathcal{N} \frac{N_{\text{same}}(k^*)}{N_{\text{mixed}}(k^*)}}_{\text{Experiment}} = \underbrace{\int S(\vec{r}^*) |\psi(\vec{k}^*, \vec{r}^*)|^2 d^3\vec{r}^*}_{\text{Theoretical definition}}$$

Relative momentum:

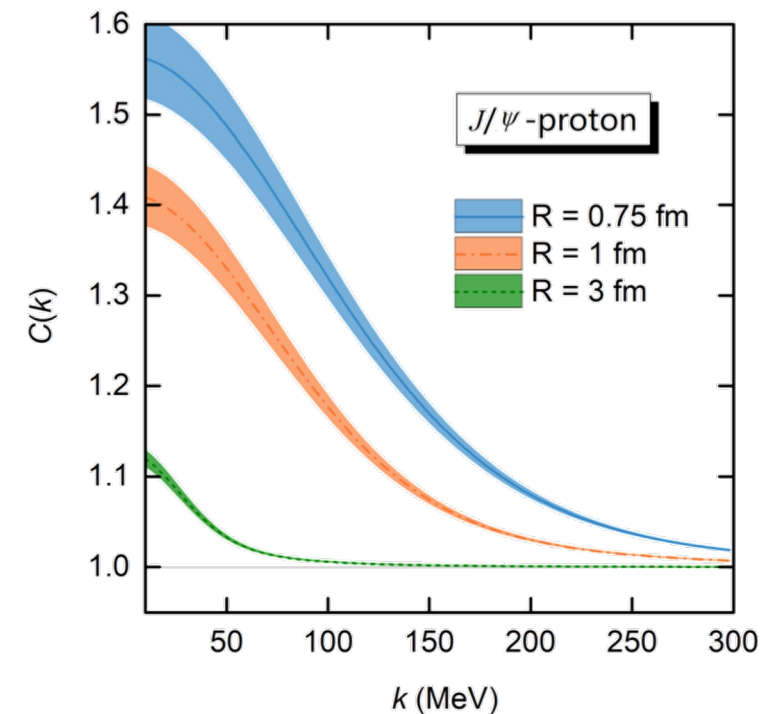
$$k^* = \frac{1}{2} |\vec{p}_1 - \vec{p}_2|, \quad \vec{p}_1 + \vec{p}_2 = 0$$

Relative position: $r^* = \vec{r}_1 - \vec{r}_2$



PRD 112 (2025) 5, 054019
PLB 860 (2025) 139178

Calculations based on HAL QCD



J/ψ -N Scattering Length

- The **theory** calculated J/ψ -N scattering length **differ** by several orders of magnitude
 - Constraining gluon distributions inside nucleon
 - Looking for possible bound states
 - e.g. pentaquark and charmonium molecule

a [fm]	Method
$3 \sim 25 \cdot 10^{-3}$	Photoproduction (VMD) [1]
O(1)	Photoproduction (unitarity) [2]
$0.2 \sim 3 \cdot 10^{-3}$	Coupled channel [3]
0.47(1)	LQCD ($m_\pi = 700$) [4]
≈ 0	LQCD ($m_\pi = 266$) [5]
0.33(4)	LQCD ($m_\pi = 146$) [6]

[1] L. Pentchev, I.I. Strakovsky, Eur. Phys. J. A 57 (2021) 81

[2] JPAC, Phys. Rev. D 108 (2023) 5, 054018

[3] M.L. Du et al, Eur. Phys. J. C 80 (2020) 1053

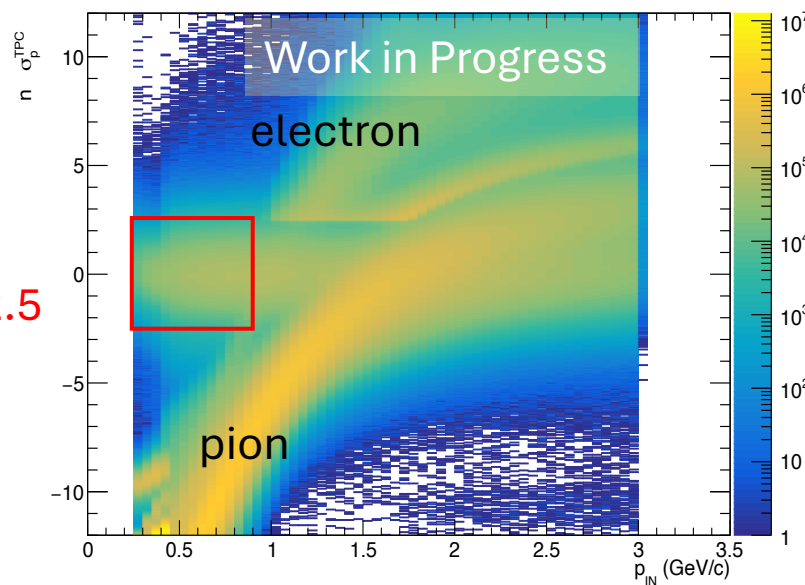
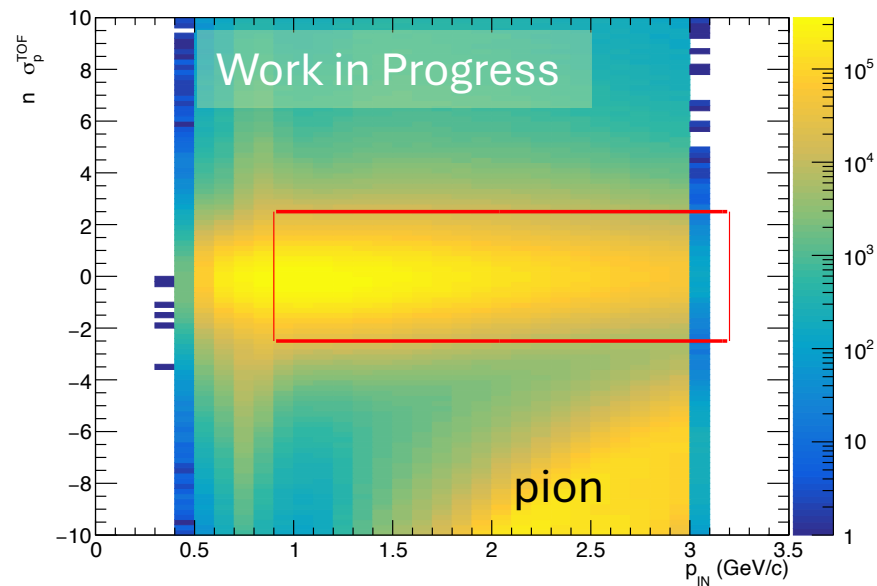
[4] T. Sugiura et al, PoS LATTICE2018 (2019) 093.

[5] S. Skrebis et al, Phys. Rev. D 99, 094505 (2019).

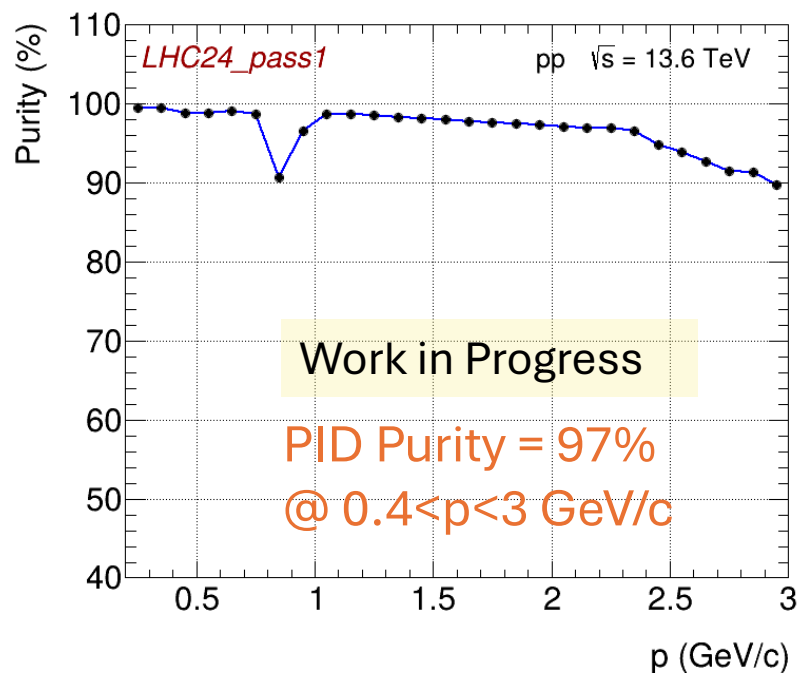
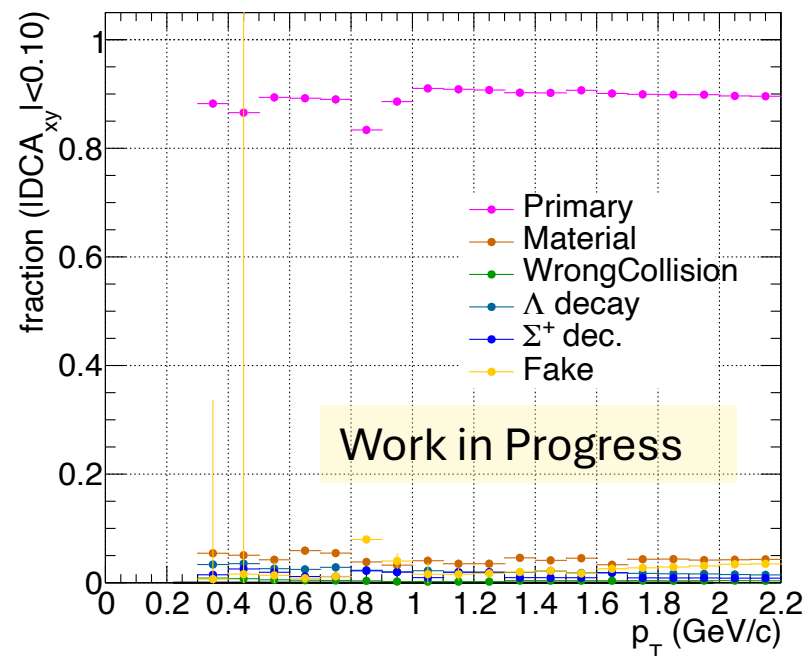
[6] Yan Lyu et al, Phys. Lett. B 860 (2025) 139178

Proton Selection

$p < 0.9 \text{ GeV/c}$
 $-2.5 < \text{TPC } n\sigma_p < 2.5$



$p > 0.9 \text{ GeV/c}$:
 $-2.5 < \text{TPC } n\sigma_p < 2.5$
 $-2.5 < \text{TOF } n\sigma_p < 2.5$



Primary proton
 fraction = 89%
 @ $0.4 < p < 3 \text{ GeV/c}$

- Primary proton fraction gotten from MC template fit to data

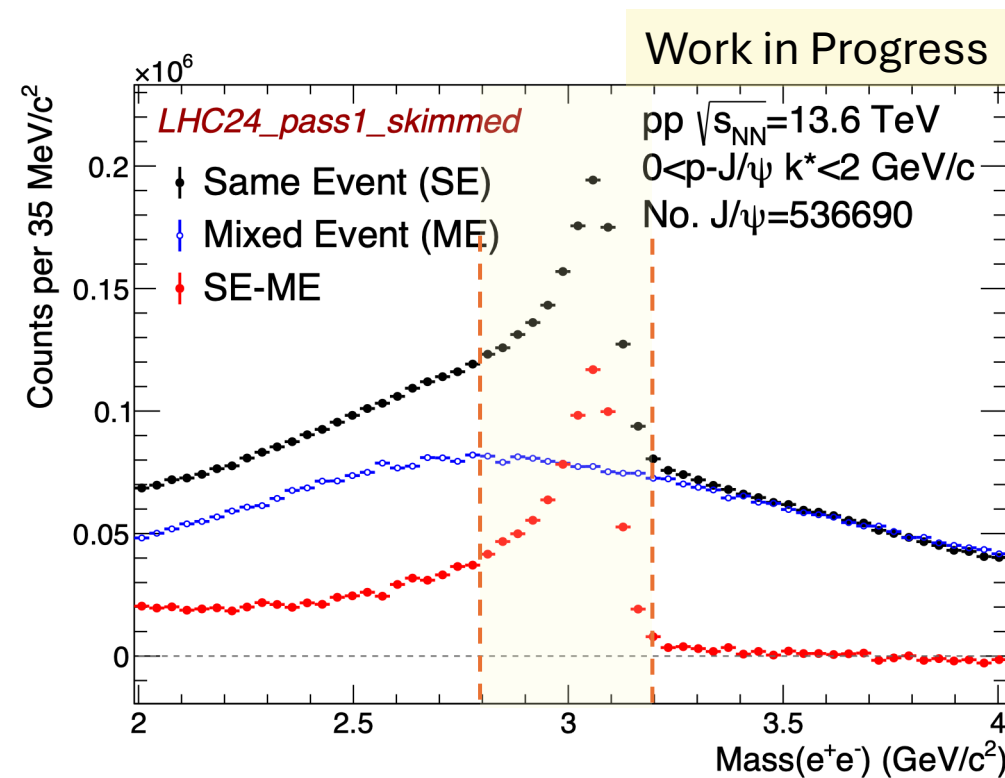
J/ψ Reconstruction

- Electron selection for $J/\psi \rightarrow e^+e^-$
 - $p_T > 1 \text{ GeV}/c$, $-0.8 < \eta < 0.8$
 - $-2 < \text{TPC } n\sigma_e < 3$, $\text{TPC } n\sigma_\pi > 3.5$, $\text{TPC } n\sigma_p > 3.5$
- Combinatorial backgrounds for J/ψ
 - Mixed-event (ME) method

Normalization range:
 $3.4 < M(e^+e^-) < 4 \text{ GeV}/c^2$

	J/ψ combinatorial backgrounds from ME
p- J/ψ same event	electron1 (event1), electron2 (event2), proton (event1)
p- J/ψ mixed event	electron1 (event1), electron2 (event2), proton (event3)

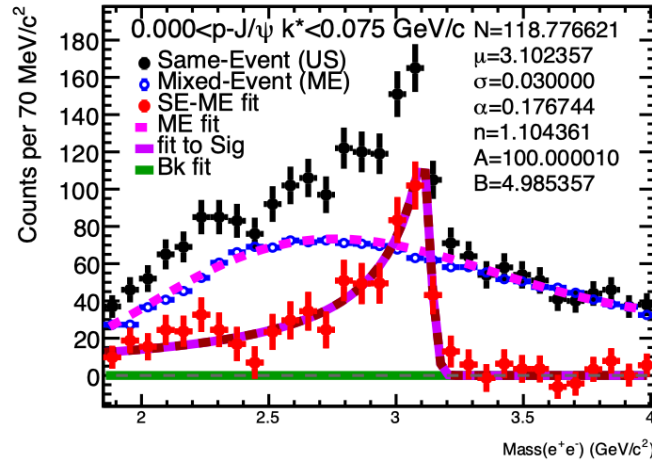
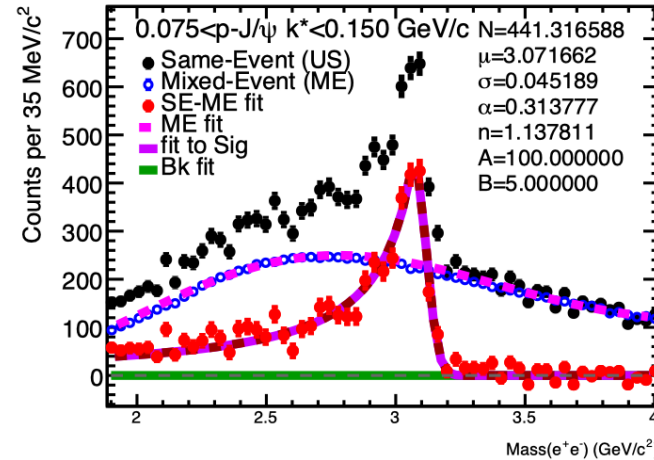
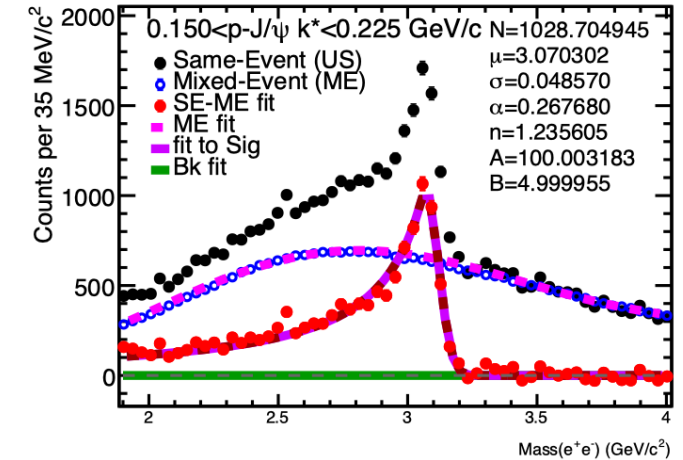
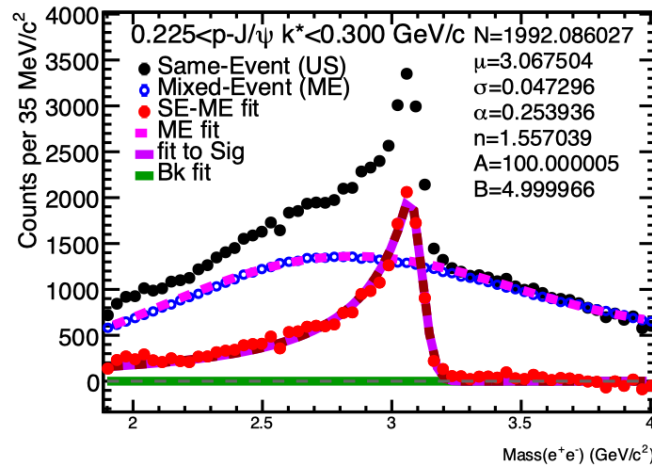
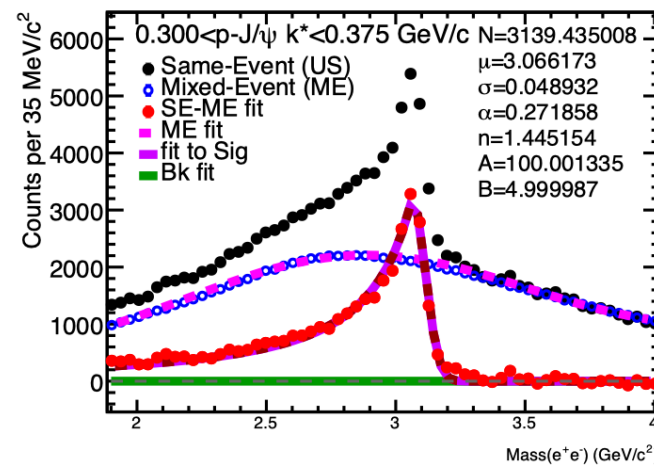
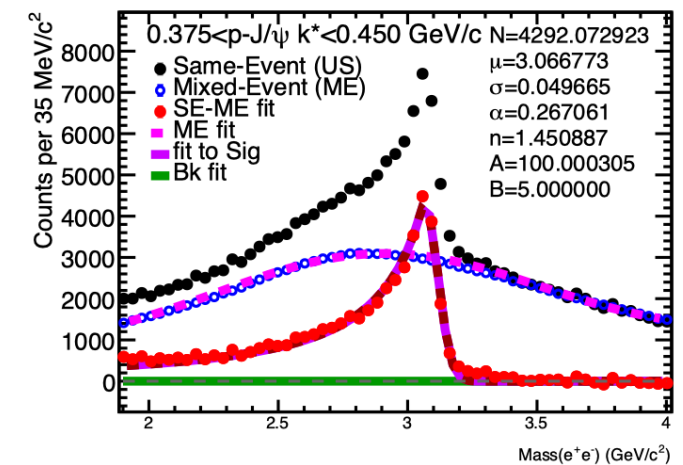
- J/ψ Mass cut
 - $2.8 < M(e^+e^-) < 3.2 \text{ GeV}/c^2$



J/ψ signal in each k^* interval for Jpsi-proton from same event

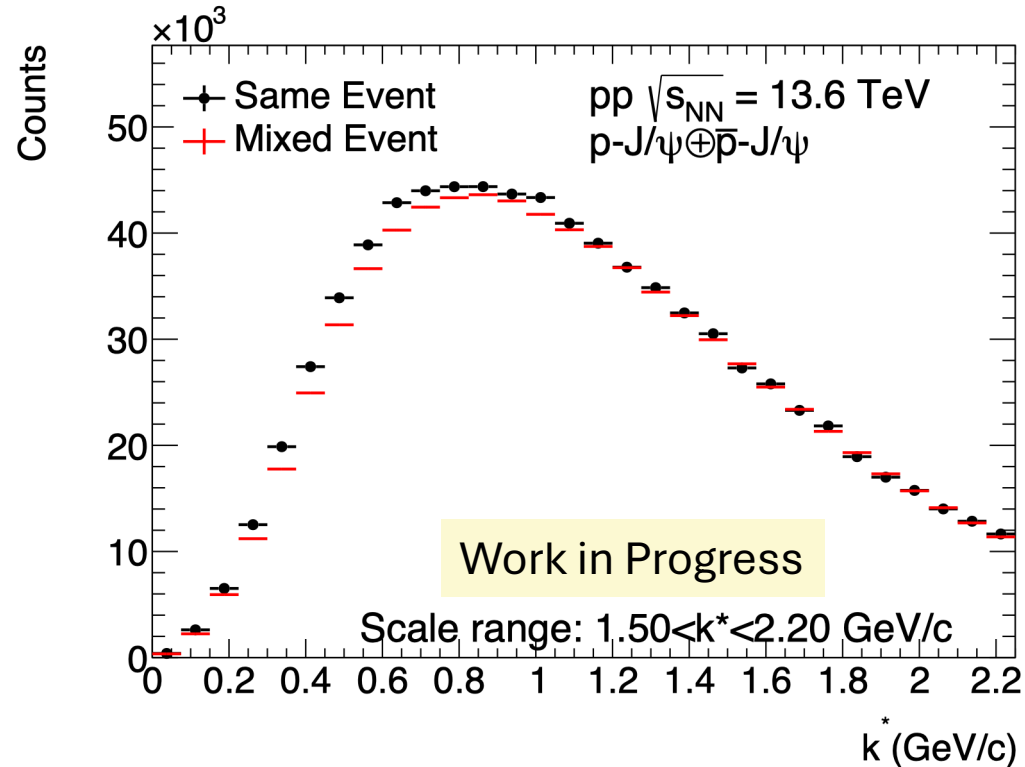
- Example of J/ψ signal distribution in each k^* interval at $k^* < 0.36$ GeV/c

Work in Progress

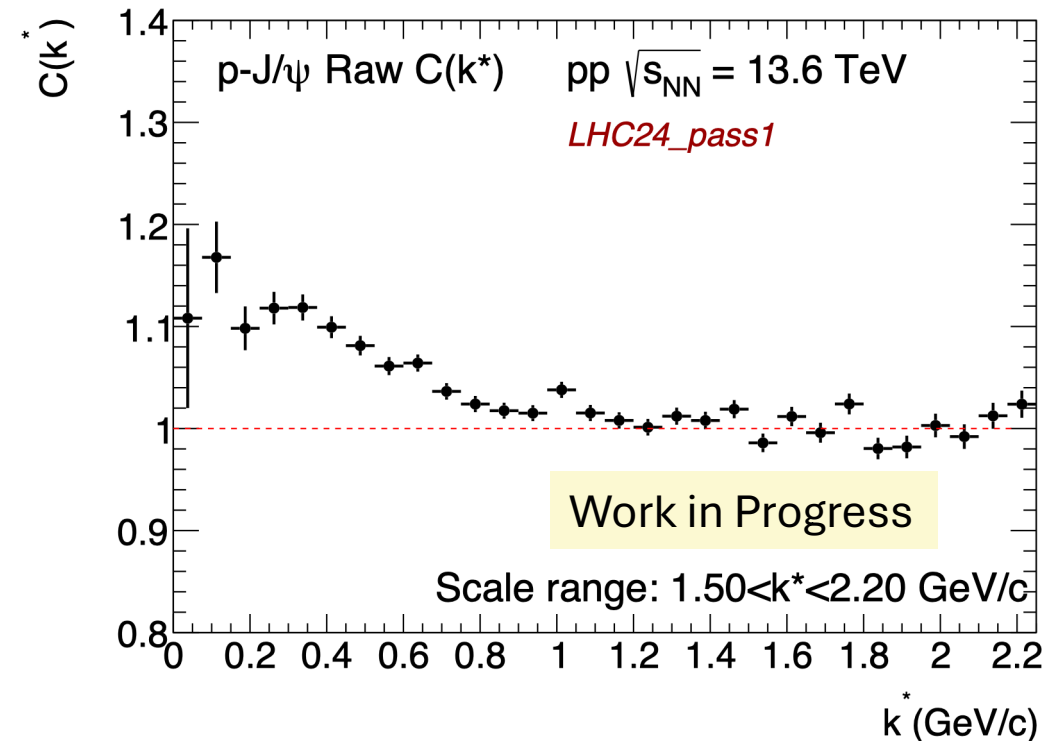


p-J/ψ Pair Raw k* Distributions and Raw C(k*)

p-J/ψ pair counts vs k*



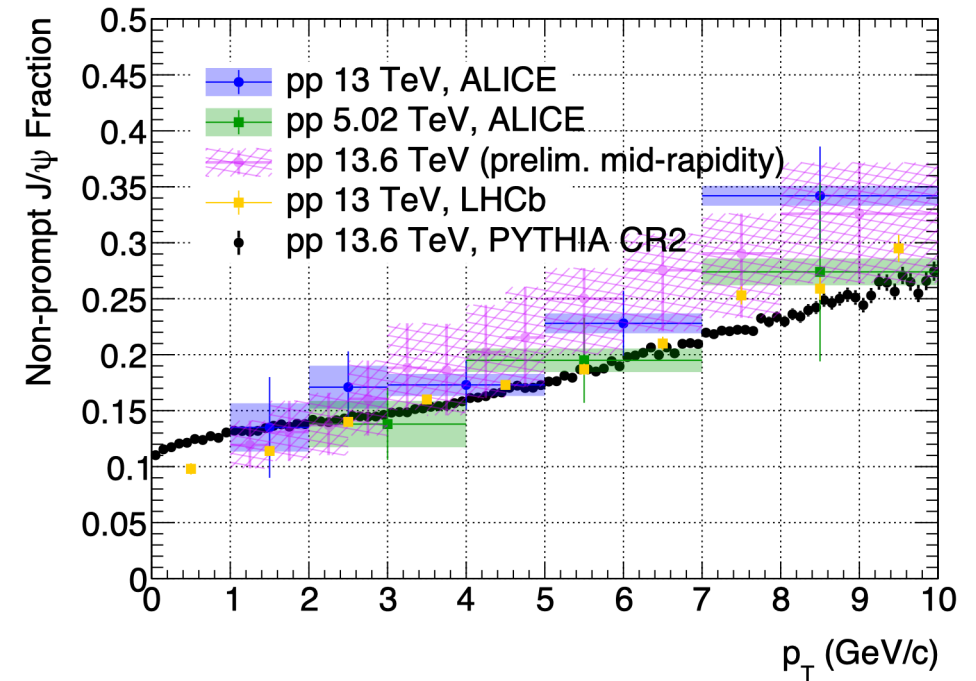
$$C(k^*) = \frac{N(p-J/\psi)}{N(p)N(J/\psi)} = \frac{N(\text{Same Event})}{N(\text{Mixed Event})}$$



- Enhanced C(k*) at k* < 1 GeV/c region in raw p-J/ψ C(k*) distributions
 - Femtoscropy interactions are expected only at very low k* region (e.g. k* < 0.3 GeV/c)
 - Backgrounds need to be subtracted

Background sources

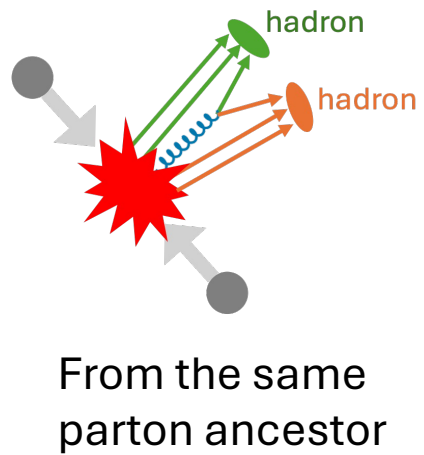
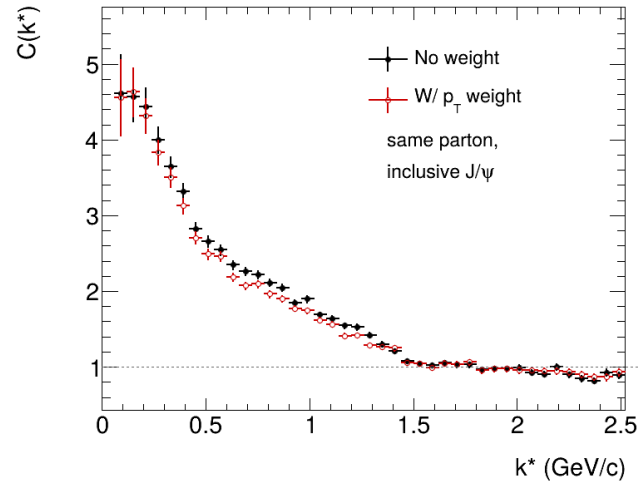
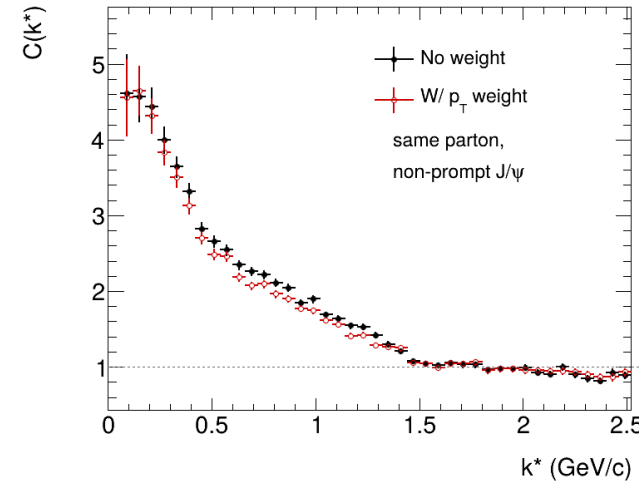
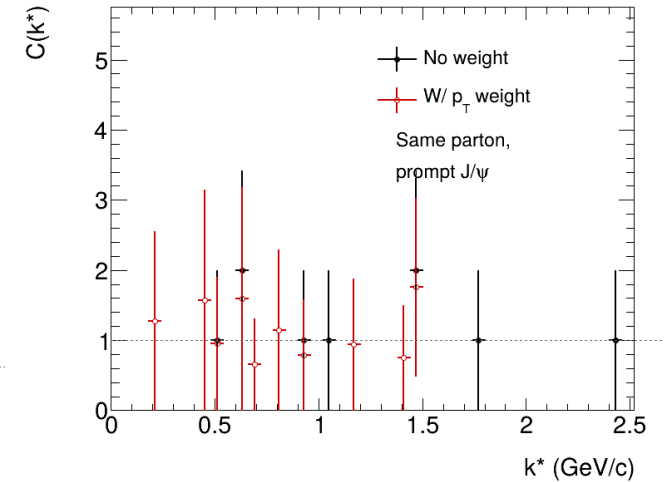
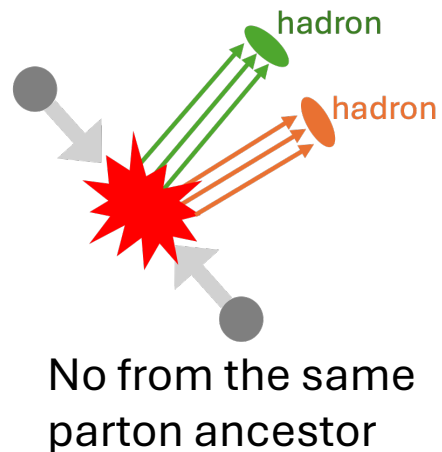
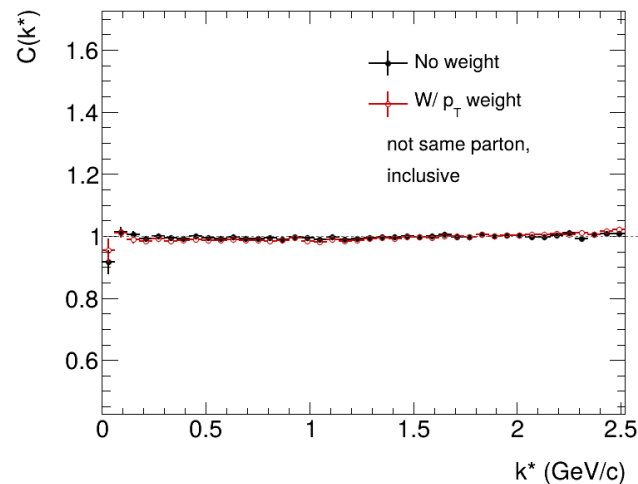
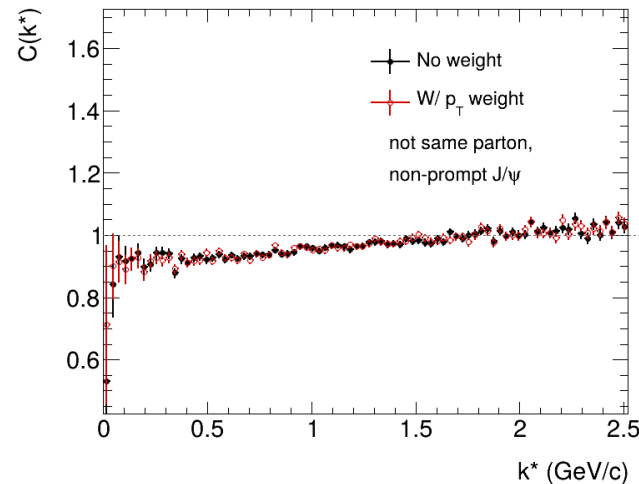
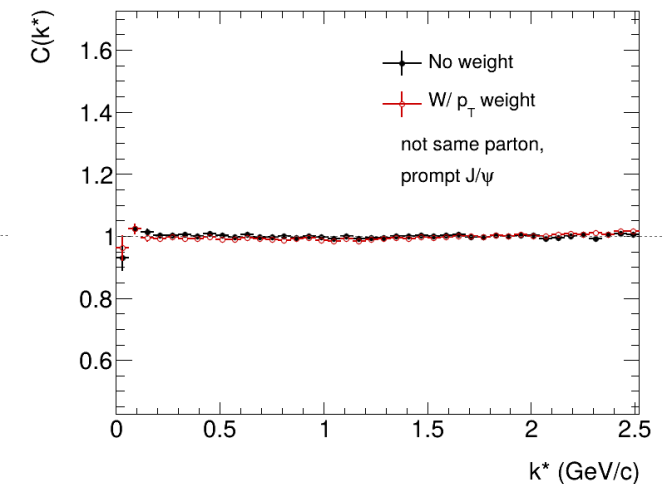
- Correction of impurity of proton, non-prompt protons
- Jet-like correlations
 - Can be studied by PYTHIA
- Non-prompt J/ψ (B hadrons $\rightarrow J/\psi$)
 - Strong interaction between B hadrons and proton
 - From hadron decay kinematics
 - e.g. B hadrons $\rightarrow J/\psi + \text{proton} + X$
- J/ψ from resonance decays



Common vs. different parton ancestors (PYTHIA)

- PYTHIA tune: Color Reconnection mode2
- The J/ψ and proton p_T distribution are reweighted to match data acceptance
- Jet-like correlation can be observed in those pairs with the same parton ancestor from PYTHIA

J/ψ $-0.8 < \eta < 0.8$
proton $-0.8 < \eta < 0.8$



Towards prompt J/ψ and proton C(k*)

prompt, not direct: Chi2_c, psi(2S) -> J/psi

$$\lambda_{p-J/\psi}^{\text{prompt,not direct}} C_{p-J/\psi}^{\text{prompt,not direct}}(k^*) + \lambda_{p-J/\psi}^{\text{prompt,direct}} C_{p-J/\psi}^{\text{prompt,direct}}(k^*)$$

Mini-jet backgrounds
contributions for **prompt J/psi**

$$C^{\text{raw}}(k^*) = C_{\text{bkgd}}^{\text{prompt}}(k^*) \times [\lambda_{p-J/\psi}^{\text{prompt}} C_{p-J/\psi}^{\text{prompt}}(k^*)] +$$

$$C_{\text{bkgd}}^{\text{non-prompt}}(k^*) \times [\lambda_{p-J/\psi}^{\text{non-prompt}} C_{p-J/\psi}^{\text{non-prompt}}(k^*)] + \lambda_{\text{flat}}$$

Mini-jet backgrounds contributions
for **non-prompt J/psi + hadron**
decays

- B hadron final state interaction with proton (femtoscopic)
Non-prompt Jpsi: b -> J/ψ

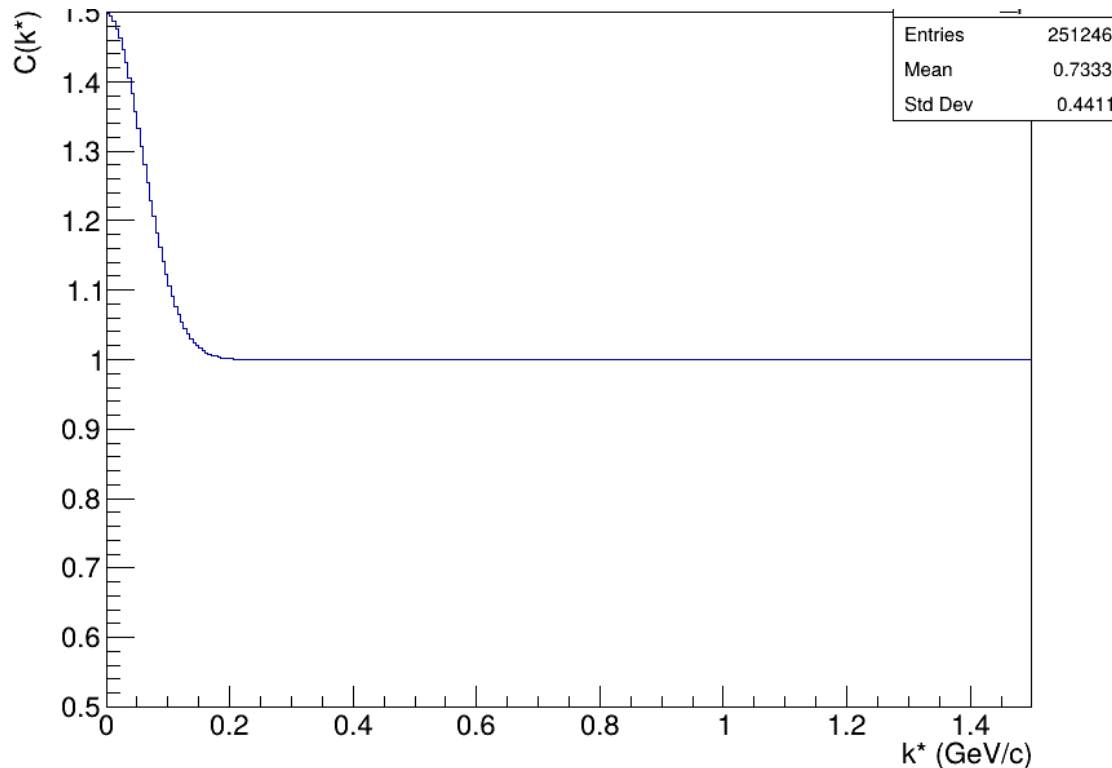
Proton mis-PID and
non-primary proton

Contributions from B and proton interaction

$B^0 \rightarrow J/\psi$

Input p-B0 correlation

(Empirically parameterized input using p-D)



$$C^{raw}(k^*) = C_{bkgd}^{prompt}(k^*) \times [\lambda_{p-J/\psi}^{prompt} C_{p-J/\psi}^{prompt}(k^*)] + C_{bkgd}^{non-prompt}(k^*) \times [\lambda_{p-J/\psi}^{non-prompt} C_{p-J/\psi}^{non-prompt}(k^*)] + \lambda_{flat}$$

- Take **$B^0 \rightarrow J/\psi$** as an example
- Still on-going for full decay channels

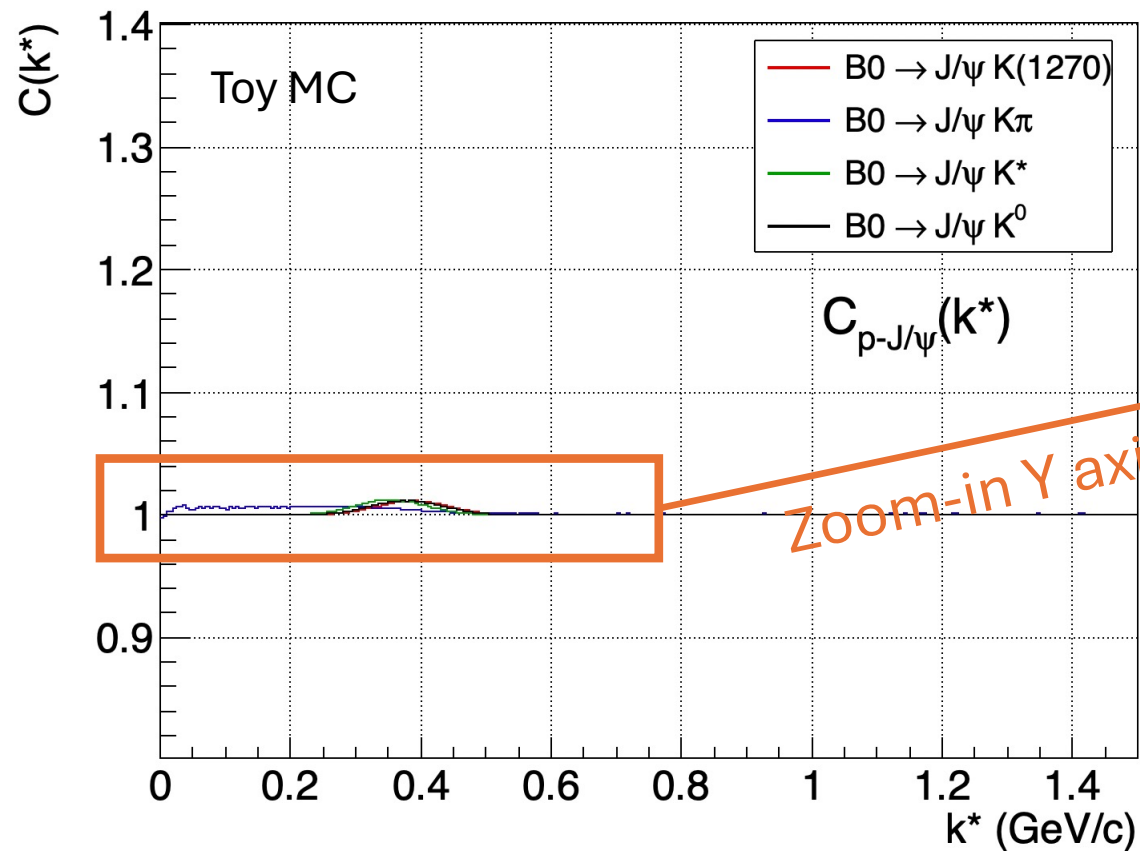
Steps:

- 1, Generate B^0 and proton
- 2, Decay B^0 to J/ψ
- 3, Calculate proton and J/ψ $C(k^*)$

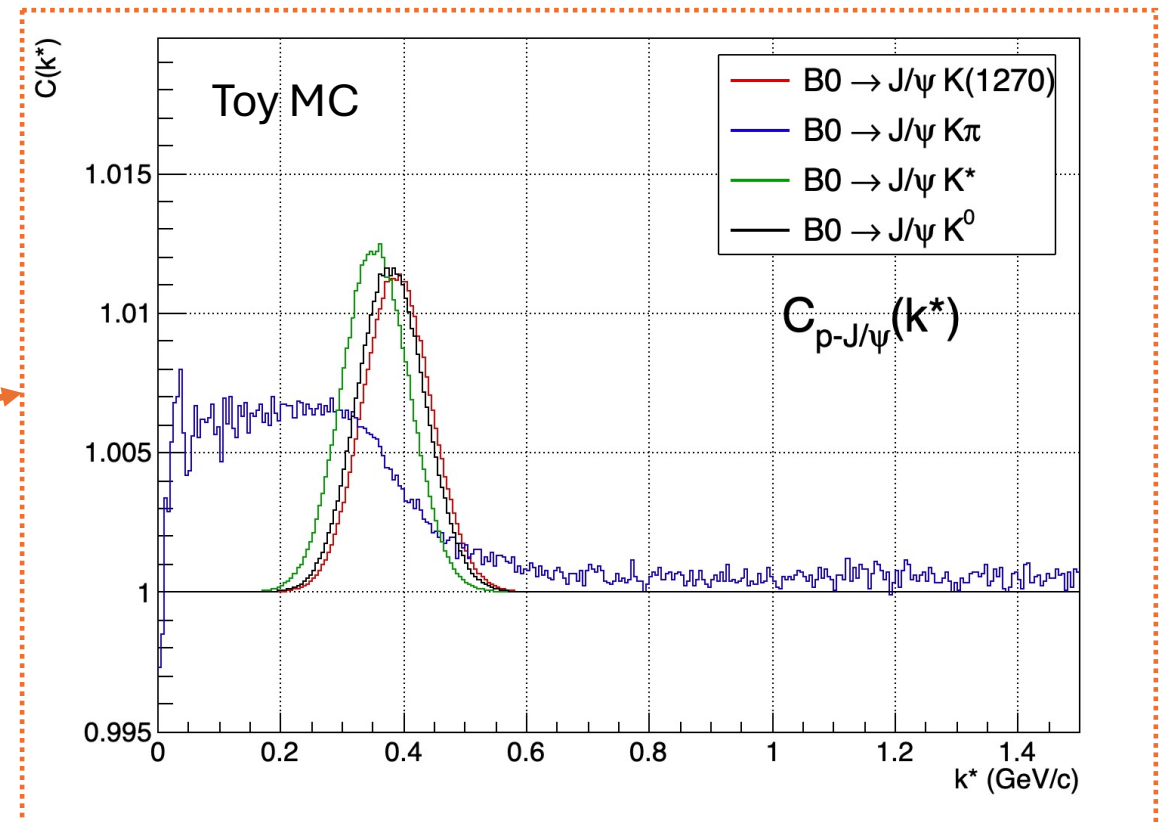
Taken look at following channels:

$$\begin{aligned} B^0 &\rightarrow J/\psi K^*(892) \quad (BR = 0.127\%) \\ B^0 &\rightarrow J/\psi K^0(1270) \quad (BR = 0.13\%) \\ B^0 &\rightarrow J/\psi K^+ \pi^+ \quad (BR = 0.115\%) \\ B^0 &\rightarrow J/\psi K^0 \quad (BR = 0.089\%) \end{aligned}$$

p-J/ ψ C(k^*) with assumed B^0 -proton interactions



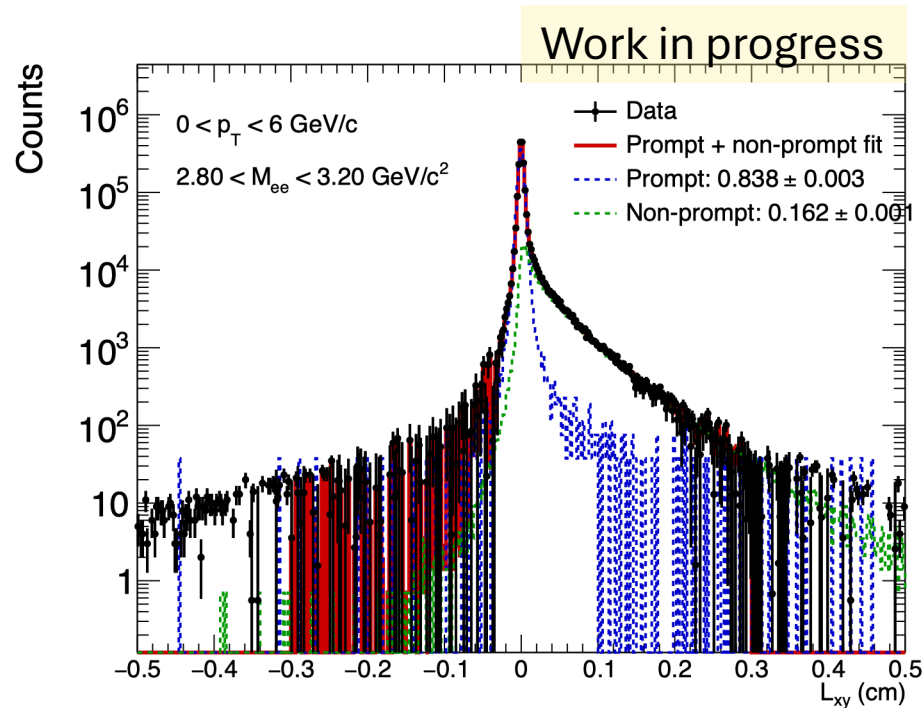
Zoom-in Y axis:



- The contributions from B hadron and proton interaction are rather tiny and negligible with current data uncertainties.

Components to get $C_{p-J/\psi}^{prompt}(k^*)$

$$C^{raw}(k^*) = C_{bkgd}^{prompt}(k^*) \times [\lambda_{p-J/\psi}^{prompt} C_{p-J/\psi}^{prompt}(k^*)] + C_{bkgd}^{non-prompt}(k^*) \times [\lambda_{p-J/\psi}^{non-prompt} C_{p-J/\psi}^{non-prompt}(k^*)] + \lambda_{flat}$$



- Distribution of L_{xy} from data is unlike sign – like sign

- From template fit

$$\text{Frac}(\text{non-prompt } J/\psi) = 16.2\%$$

- Primary proton fraction = 89%

$$\lambda_{p-J/\psi}^{prompt} = 0.746$$

$$\lambda_{p-J/\psi}^{non-prompt} = 0.144$$

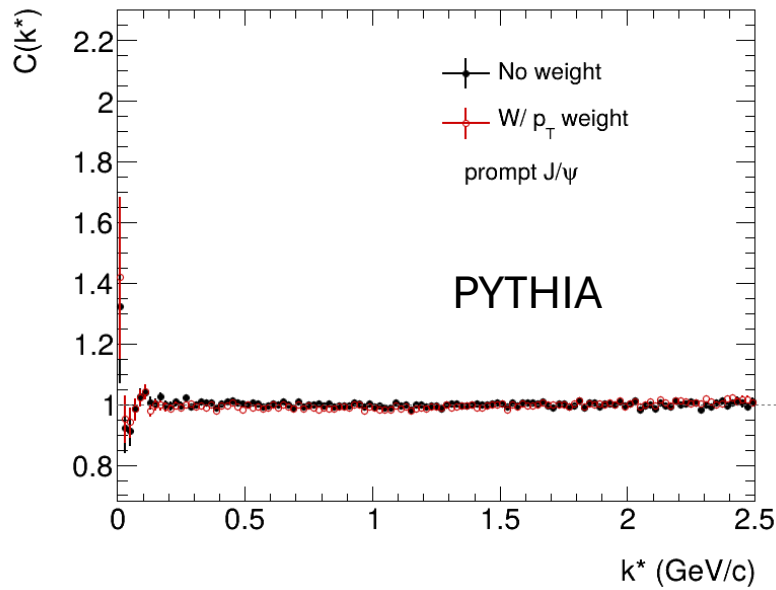
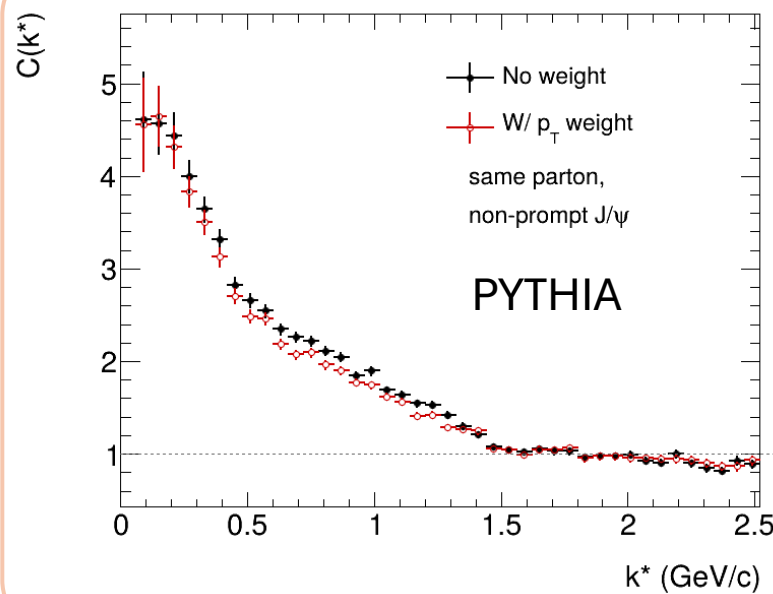
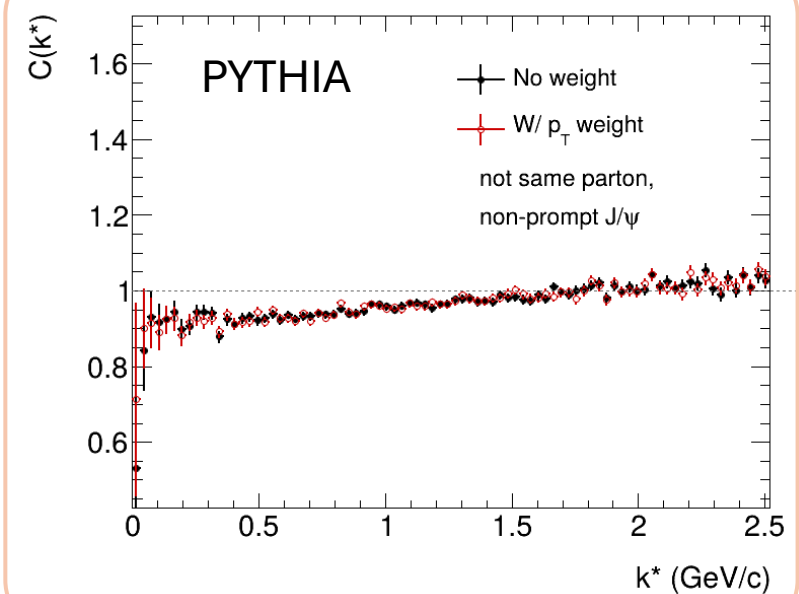
$$\lambda_{flat} = 0.11$$

Components to get $C_{p-J/\psi}^{prompt}(k^*)$

$$C^{raw}(k^*) = C_{bkgd}^{prompt}(k^*) \times [\lambda_{p-J/\psi}^{prompt} C_{p-J/\psi}^{prompt}(k^*)] + C_{bkgd}^{non-prompt}(k^*) \times [\lambda_{p-J/\psi}^{non-prompt} C_{p-J/\psi}^{non-prompt}(k^*)] + \lambda_{flat}$$

$$C_{bkgd}^{prompt}(k^*)$$

$$C_{bkgd}^{non-prompt}(k^*) = f_{sp} * C_{bkgd,same}^{non-prompt}(k^*) + (1 - f_{sp}) * C_{bkgd,not\ same}^{non-prompt}(k^*)$$



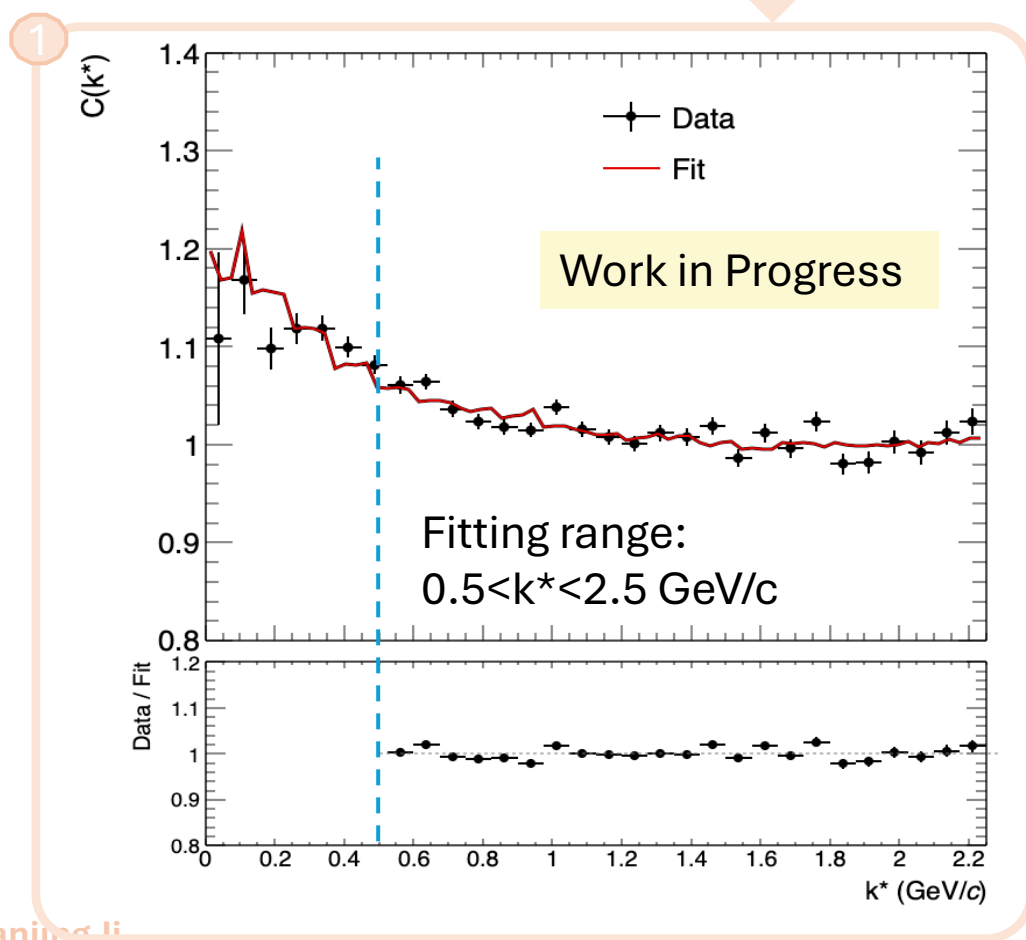
f_{sp} is the reweighting parameter, which is gotten from fitting to data

Reweight non-prompt mini-jet backgrounds

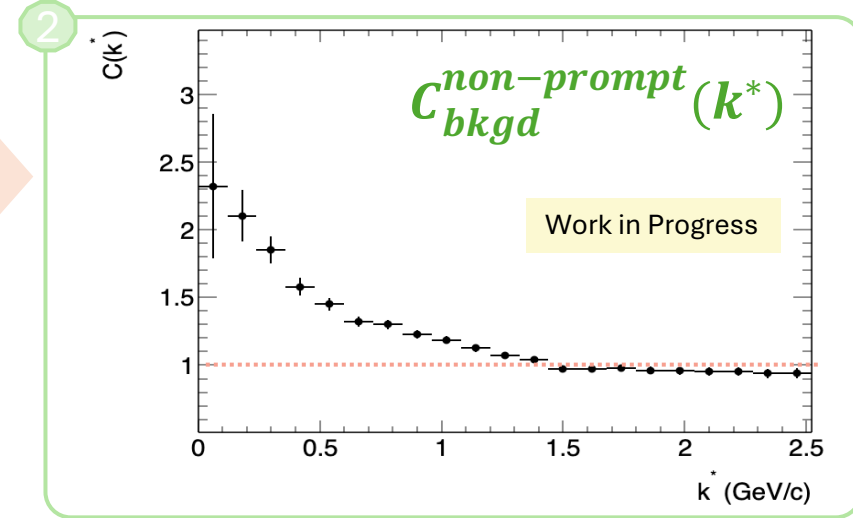
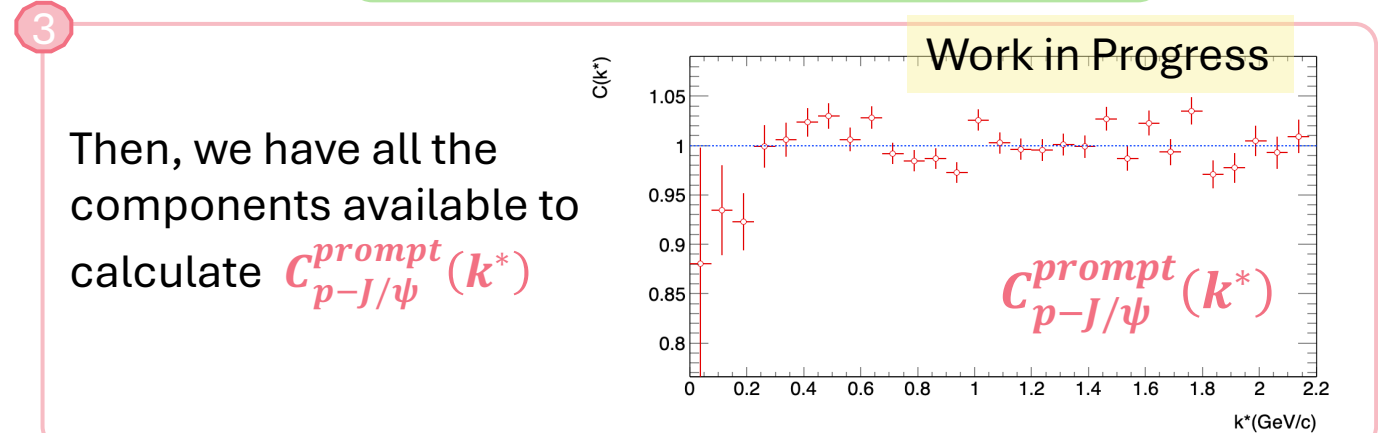
$$C^{raw}(k^*) = C_{bkgd}^{prompt}(k^*) \times [\lambda_{p-J/\psi}^{prompt} C_{p-J/\psi}^{prompt}(k^*)] + C_{bkgd}^{non-prompt}(k^*) \times [\lambda_{p-J/\psi}^{non-prompt} C_{p-J/\psi}^{non-prompt}(k^*)] + \lambda_{flat}$$

Fit to data in $0.5 < k^* < 2.5$ GeV/c
with **only one free parameter** f_{sp}

$$C_{bkgd}^{non-prompt}(k^*) = f_{sp} * C_{bkgd,same}^{non-prompt}(k^*) + (1 - f_{sp}) * C_{bkgd,not\ same}^{non-prompt}(k^*)$$



$$f_{sp} = 0.341957$$



Summary

- **p- J/ψ femtoscopy in pp collisions using data collected by ALICE in 2024**
 - Provide insights into proton and J/ψ interaction
 - First measurement on proton and J/ψ correlation function $C(k^*)$
 - Prompt J/ψ and proton correlation function
 - Further study on suppress the non-prompt J/ψ is on-going

