# Photoproduction J/ψ polarization measurement in Pb-Pb collisions with nuclear overlap at $\sqrt{s_{NN}}$ = 5.02 TeV

Rencontres QGP France,
Jun 26 – 29, 2023
Bagnoles de l'Orne , France

Dukhishyam Mallick
IJCLab, Orsay

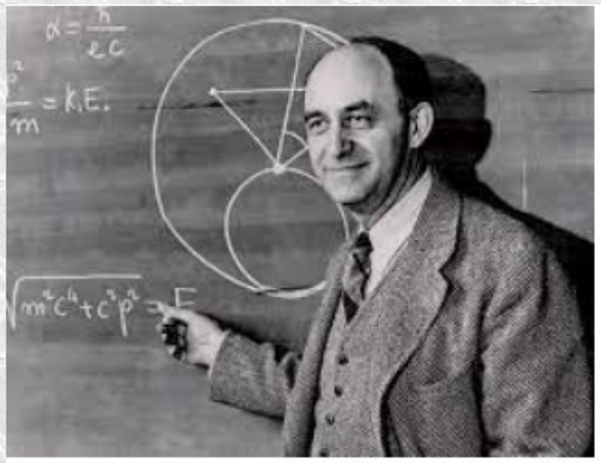
# Outline

- Motivation
- Analysis details
- Results:
  - -- Invariant mass distributions, raw yield
  - -- Acceptance x Efficiency
  - -- Corrected angular distributions
- Summary and outlook


*dukhishyam.mallick@cern.ch*

# Why photon-induced process ??

## Equivalent Photon Approximation :

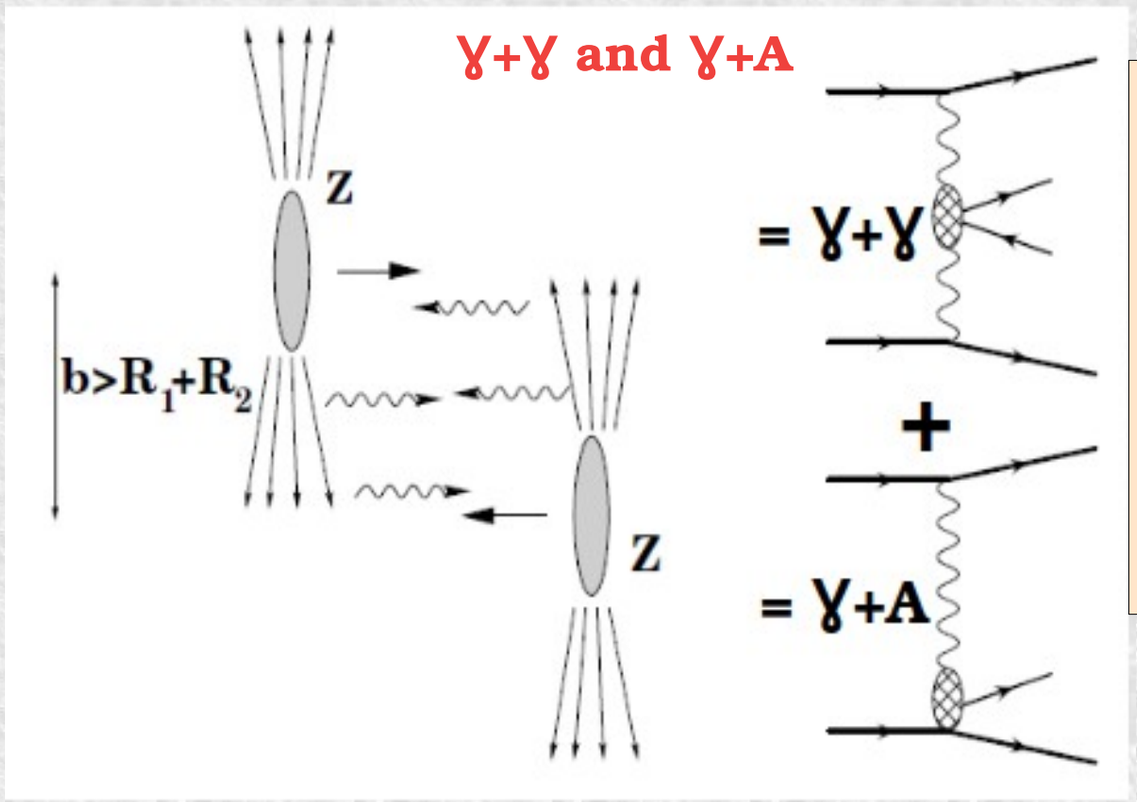


**Electromagnetic Field ~ photon flux**
Fast moving charged particle is equivalent to a flux of photons
(E. Fermi, 1924), Nuovo Cim.,2:143-158,1925, arXiv:hep-th/0205086

Later, this method was extended to relativistic region by Weizsacker[1] and Williams[2], known as **Weizsacker-Williams Methods.**

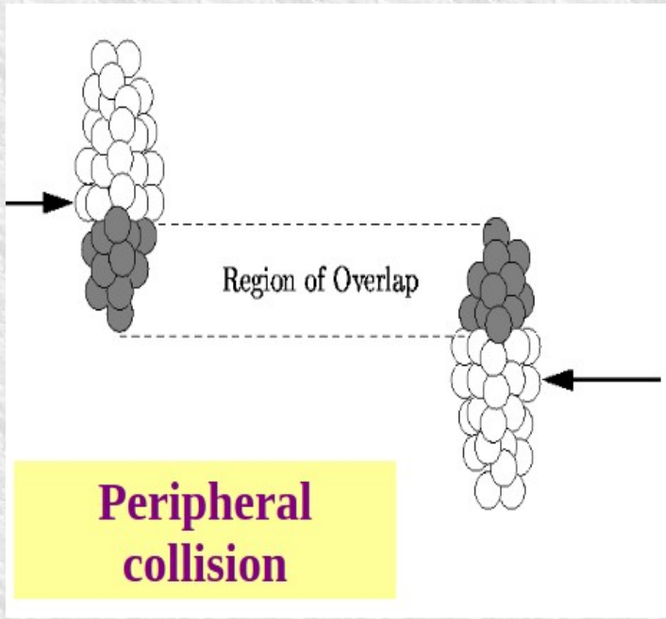
**LHC: Photon-Photon and Photon-Hadron Collider** at the highest available energies

**UltraPeripheral Collisions (UPCs) : b ≥ $R_1$+ $R_2$**




**Peripheral Collisions (PCs) : b large and b ≤ $R_1$+ $R_2$**

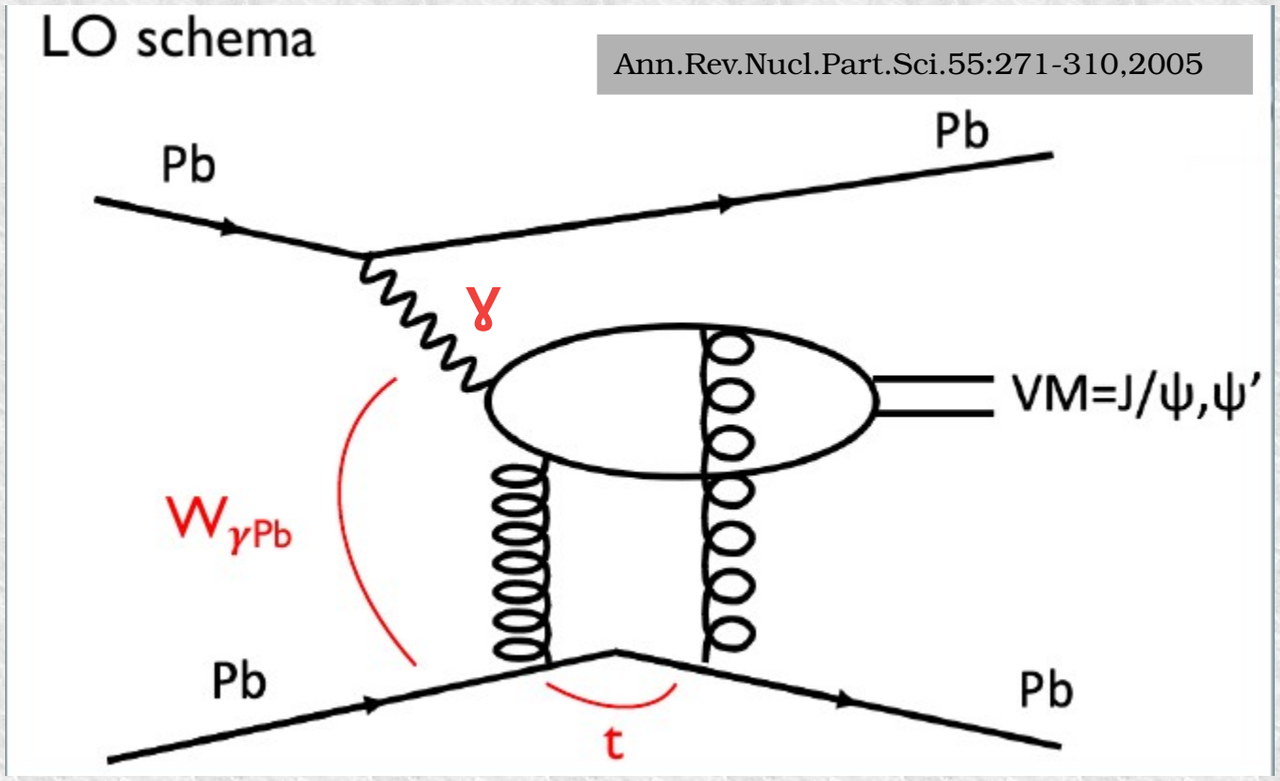
- **Photon flux density ∝ $Z^2$**
- **Electromagnetic interactions are dominant**
- **Hadronic interactions are suppressed**




**Photon-induced (γ+A) process** are present both in UPCs and PCs with nuclear overlap

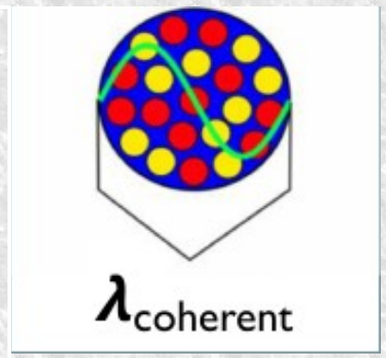
[1] Z. Phys. 88, 612 (1934)
[2] Kgl. Danske Videnskab. Selskab Mat.-Fys. Medd. 13, 4 (1935)]

# Vector Meson (VM) photoproduction



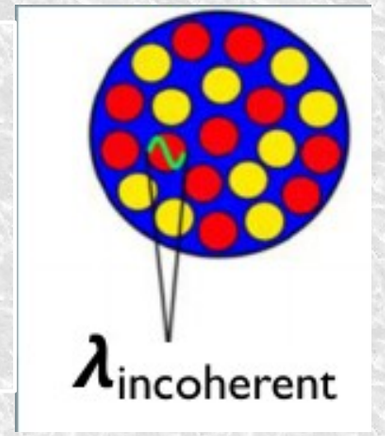

**Coherent photoproduction:**

- Photon (γ) couples coherently to all nucleons
- $\langle p_T \rangle^{J/\Psi} \sim 1/R \sim 60$ MeV
- Usually no breaking of target nucleus




**Incoherent photoproduction:**

- Photon (γ) couples to single nucleon
- $\langle p_T \rangle^{J/\Psi} \sim 500$ MeV
- Usually target nucleus breaks




$W_{\gamma Pb}$ : Center-of-mass energy of photon-lead system

$$|t| \approx p_{\perp}^2$$

- Vector meson production at very low $p_T$
- Gives access to gluon distributions in nuclei at low Bjorken-x
- Allows to study vector meson polarization

$$x = (m_{J/\psi}/\sqrt{s_{NN}})\exp(\pm y)$$

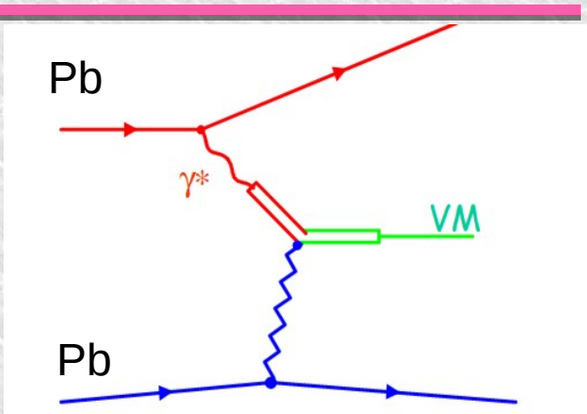
$10^{-5} < x < 10^{-2}$ at LHC energies

# Vector meson Polarization : Previous findings

**s-channel helicity conservation (SCHC)**: **helicity of photon ( $Q^2$ ~0) transferred to vector meson**

Vector meson has retained same helicity and polarization as that of the initial photon that interacted with the target

Phys. Lett. B 31 (1970) 387-390, JETP Lett. 68 (1998) 696-703




**$\rho^0$ meson measurement : consistent with SCHC**

Phys. Rev. D 7, 3150, (1970) by SLAC Collaboration
Z. Phys. C 53, 581–594, (1992) by CERN SPS

**$\rho^0$ [1] , $\omega$[2] and $\varphi$ [3] photoproduction by CLAS Collaboration : SCHC violation**

[1] Eur. Phys. J. A 39, 5–31, (2009)
[2] Int. J. Mod. Phys. Conf. Ser. 26,1460063, (2014)
[3] Phys.Rev.C 90, 019901, (2014)

**ρ0 photoproduction by STAR Collaboration : consistent with SCHC**

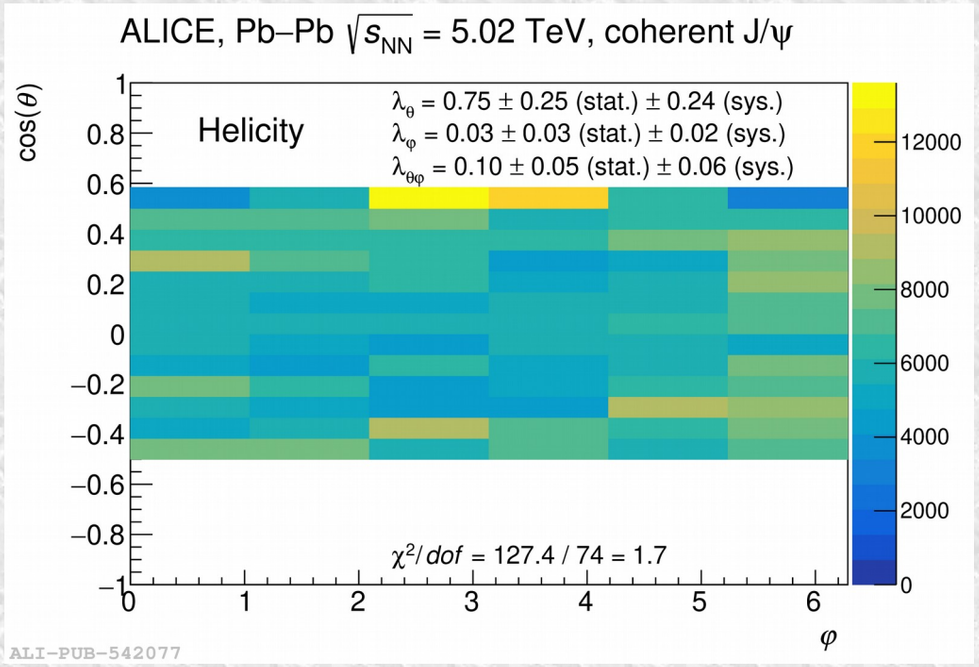
Phys. Rev. C 77 (2008) 034910

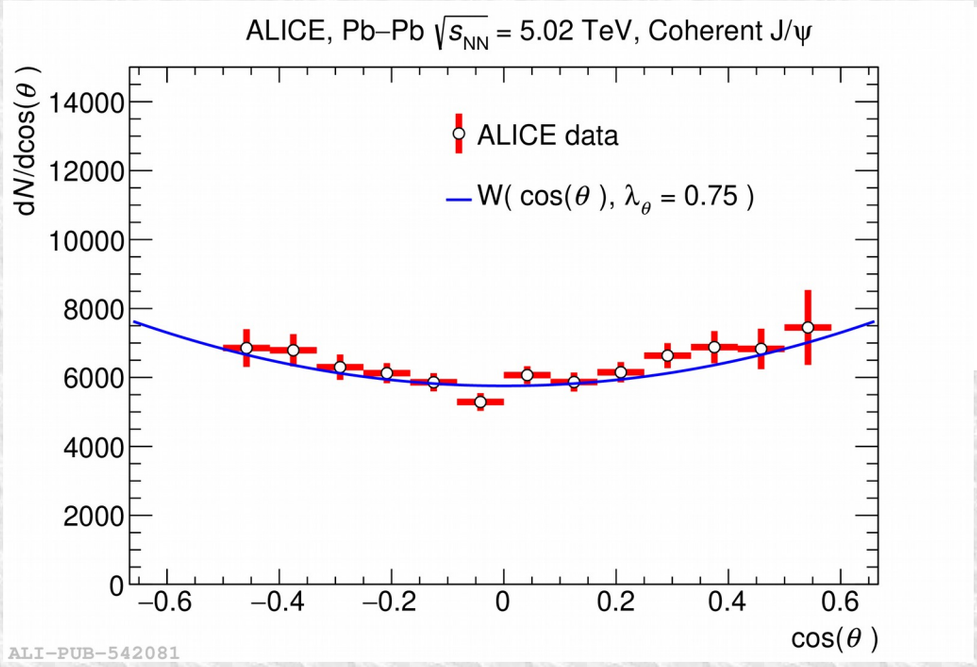
**Exclusive J/ψ photoproduction by H1 and ZEUS collaborations : consistent with SCHC**

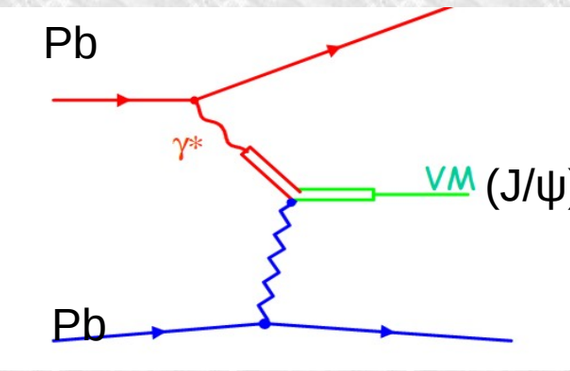
[1] Eur. Phys. J. C 46 , 585–603 (2006)

[2] Nucl. Phys. B 695, 3–37 (2004)

# Motivation: Polarization




**Coherently photoproduced J/ψ in UPCs at $\sqrt{s_{NN}}$ = 5.02 TeV** (arXiv:2304.10928)

- Transversely polarized
- Consistent with SCHC hypothesis

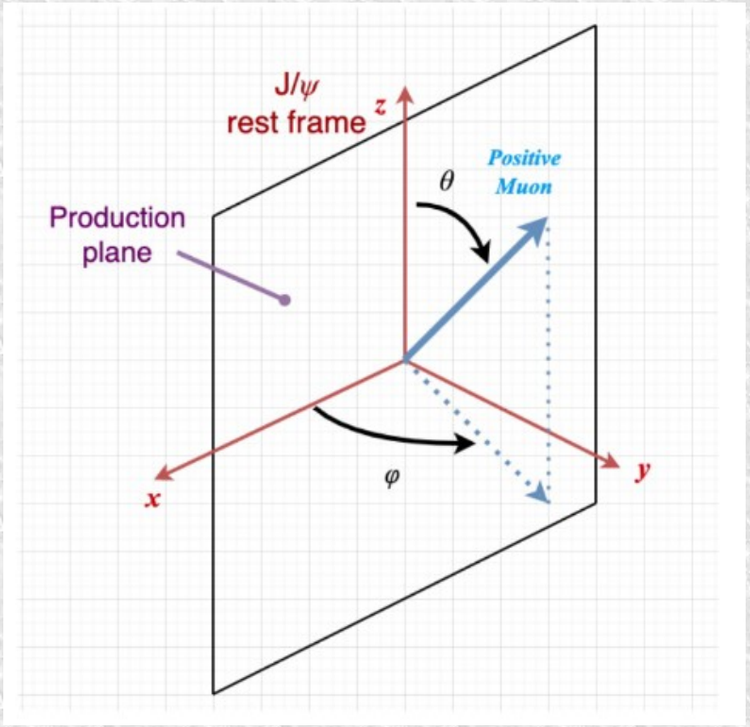
**Do we see similar observation for J/ψ at low $p_T$ ( < 0.3 GeV/c) in Peripheral Pb-Pb collisions with nuclear overlap?**

- ✓ Is the **J/ψ transversely polarized** and therefore obey **the SCHC hypothesis** ?
- ✓ Another way to test the **production mechanism** at the origin of the J/ψ **very low $p_T$ excess**
- ✓ Also **complementary to the UPCs** measurement

Additional challenge w.r.t UPC measurement : Deal with a contamination from hadronic J/ψ

# Angular distributions of dimuon decay daughters

Polarization refers to the spin alignment with respect to a chosen direction

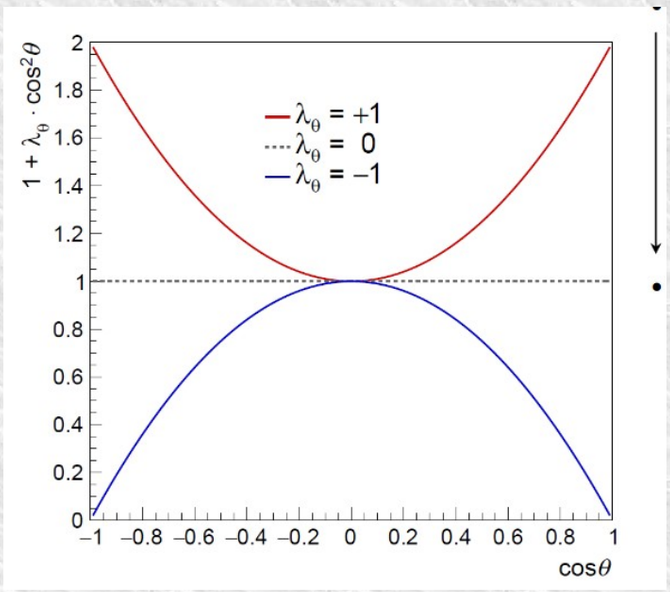



**Helicity frame**
Z-axis (polarisation axis): flight direction of the J/ψ in its rest frame

**Collins-Soper frame**
Z-axis (polarisation axis): bisector of the direction of the two beams in the J/ψ rest frame

$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta}\cdot(1+\lambda_\theta\cos^2\theta+\lambda_\phi\sin^2\theta\cos2\phi+\lambda_{\theta\phi}\sin2\theta\cos\phi)$$

Faccioli et al. EPJC 69 (657-673), 2010




$(\lambda_\theta,\lambda_\phi,\lambda_{\theta\phi}) = (0,0,0) \Rightarrow$ No polarization

$(\lambda_\theta,\lambda_\phi,\lambda_{\theta\phi}) = (+1,0,0) \Rightarrow$ Transverse polarization

$(\lambda_\theta,\lambda_\phi,\lambda_{\theta\phi}) = (-1,0,0) \Rightarrow$ Longitudinal polarization

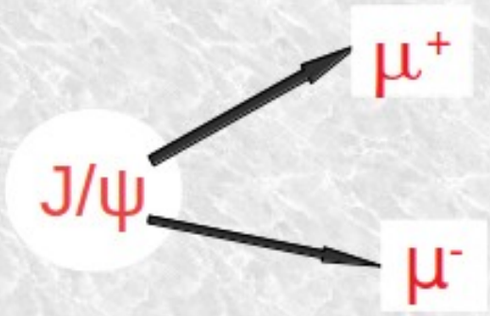
Spin densitty matrix element

$$r_{00}^{04} = \frac{1-\lambda_\theta}{3+\lambda_\theta}$$

$$r_{1,-1}^{04} = \frac{\lambda_\varphi}{2}\cdot(1+r_{00}^{04})\,.$$

**Observables : Extract angular variables and spin density matrix element**

# Invariant mass distributions: Angular variables

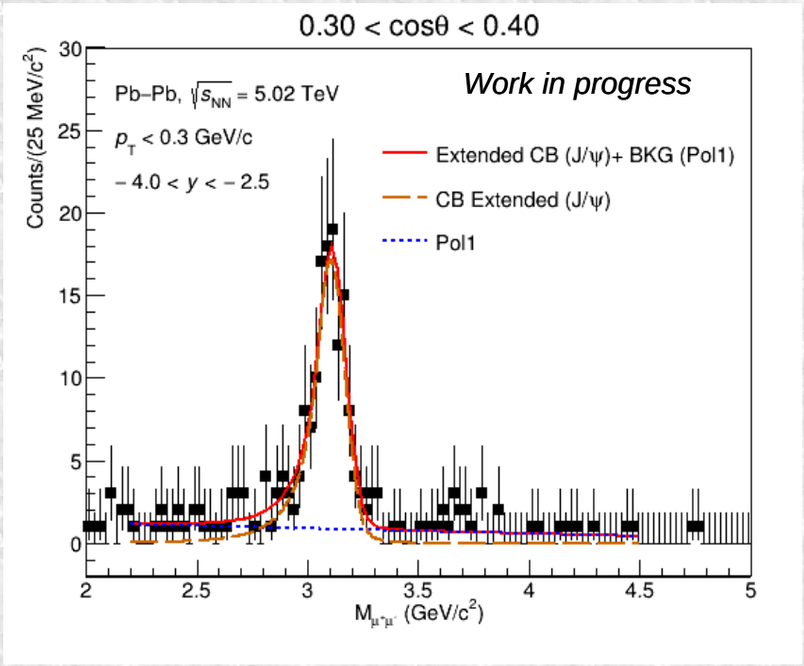


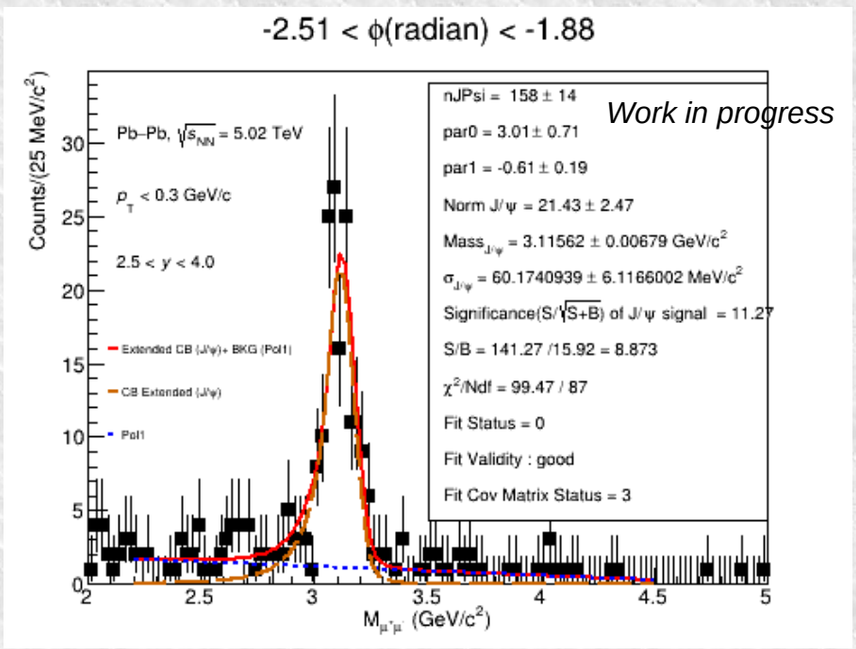

**Invariant mass method**

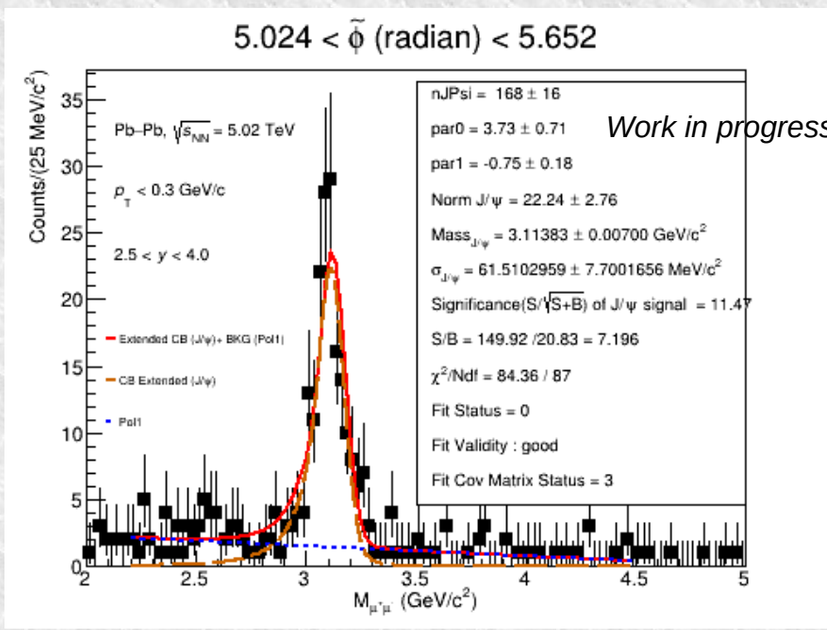
$$m^2 = E^2 - \vec{p}^2 = (E_{\mu^+} + E_{\mu^-})^2 - (\vec{p_{\mu^+}} + \vec{p_{\mu^-}})^2$$

**Centrality :** 70 -90%

**Transverse momentum ($p_T$)** < 0.3 GeV/c (for coherent study)

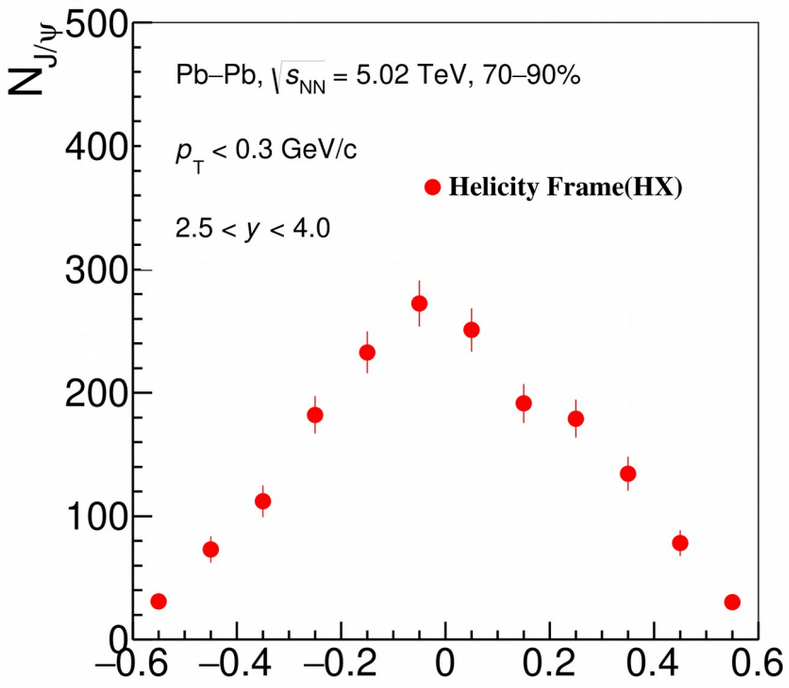


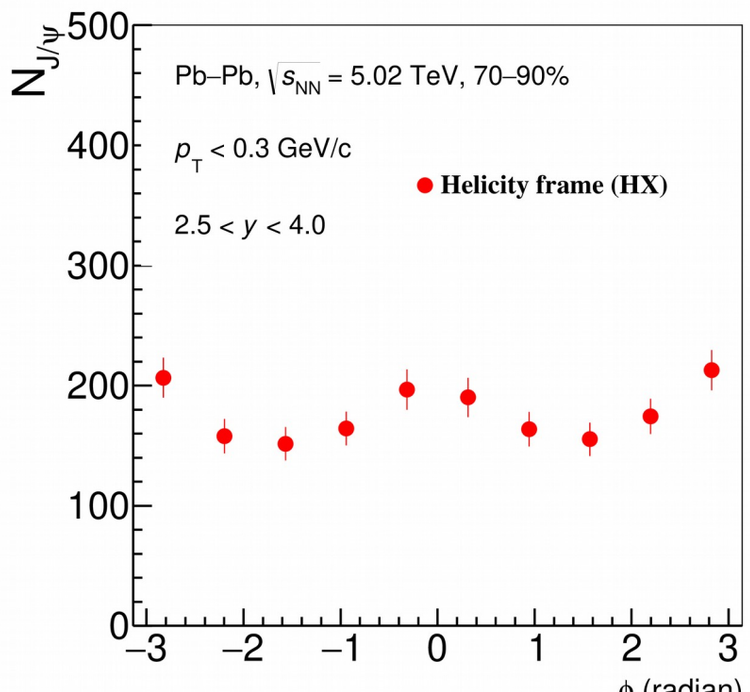



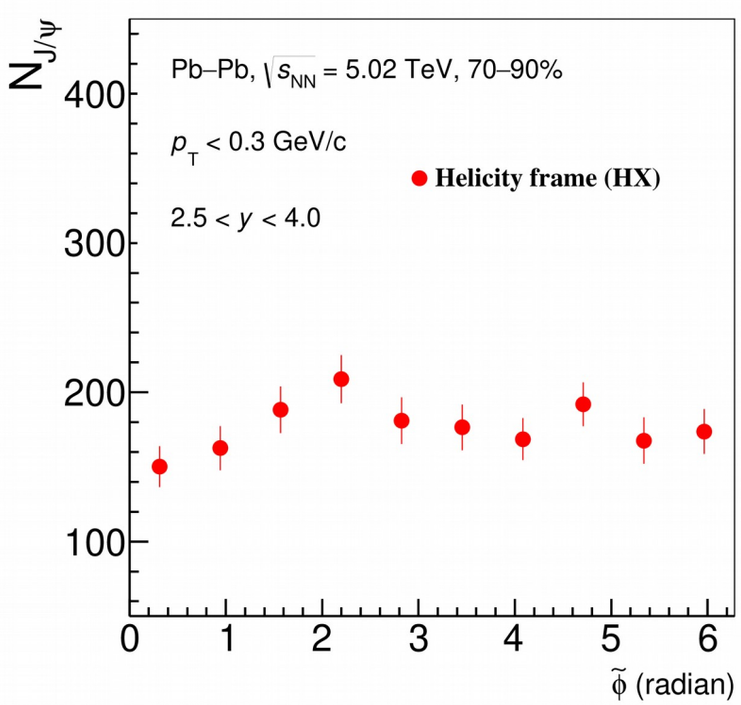

J/ψ signal is extracted for different angular variables using Helicity frame

# Raw yield, $N_{J/\psi}$ vs. different angular variables



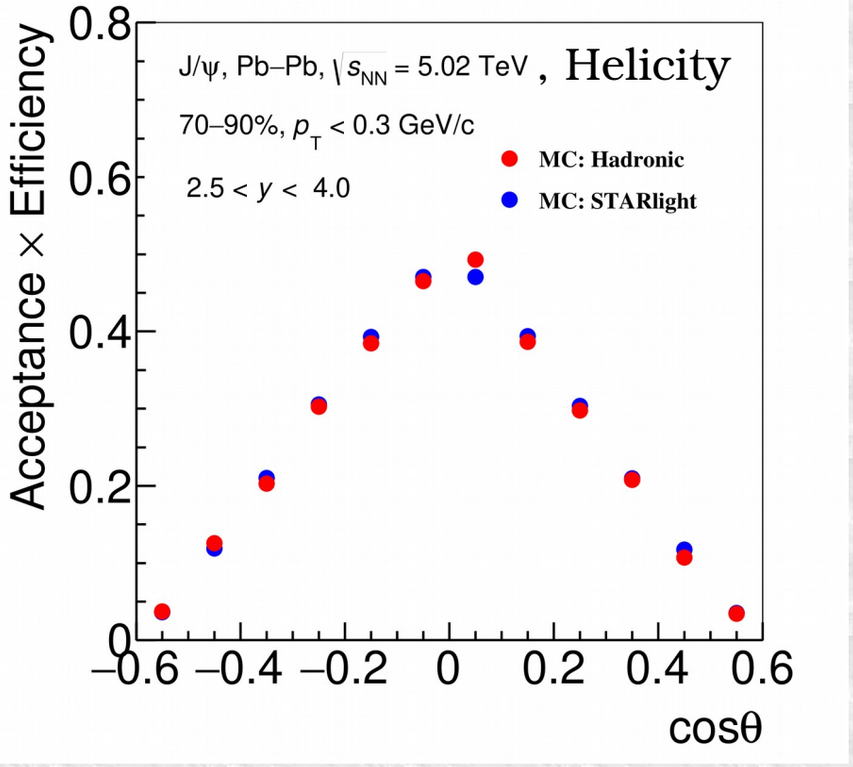



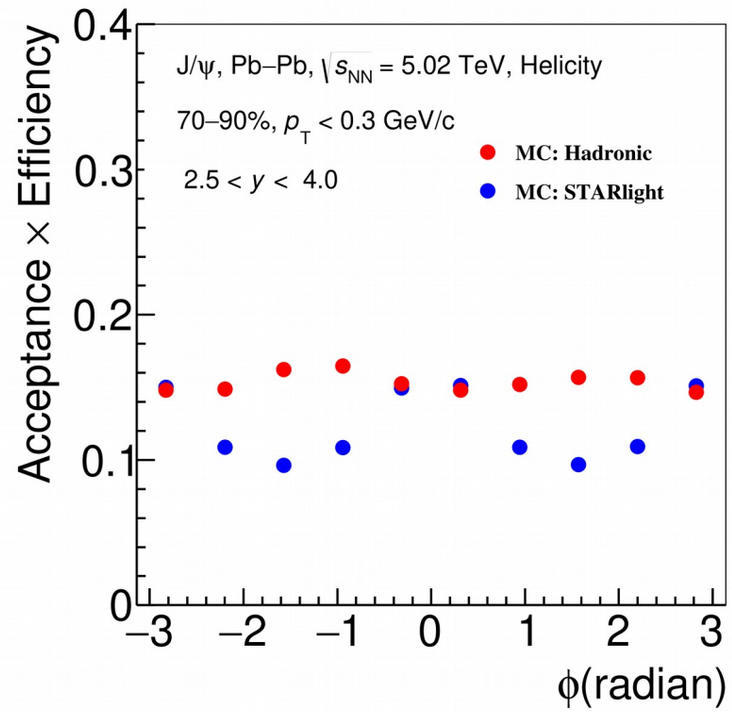

*Work in progress*



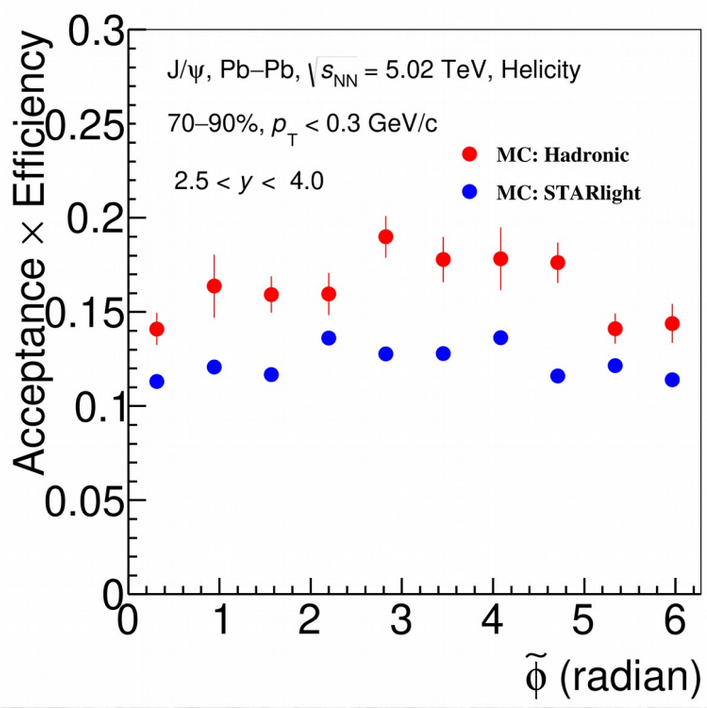

- ✓ J/ψ raw yields are extracted in cosθ, phi and tildephi intervals .
- ✓ Angular dependence is observed

# Acceptance x Efficiency vs. cosθ, Φ and tilde Φ intervals



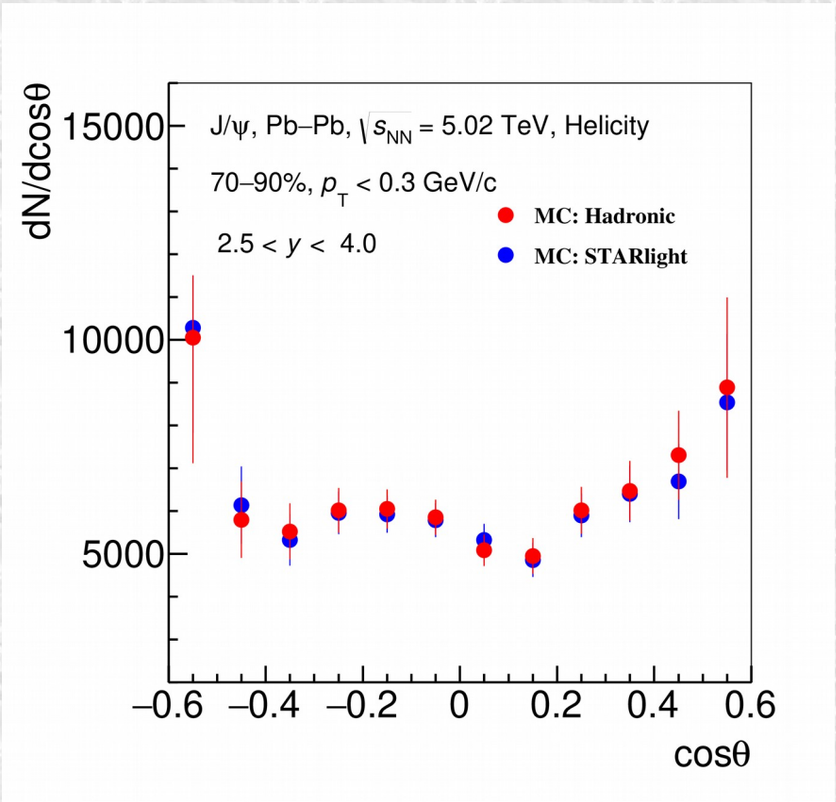




*Work in progress*

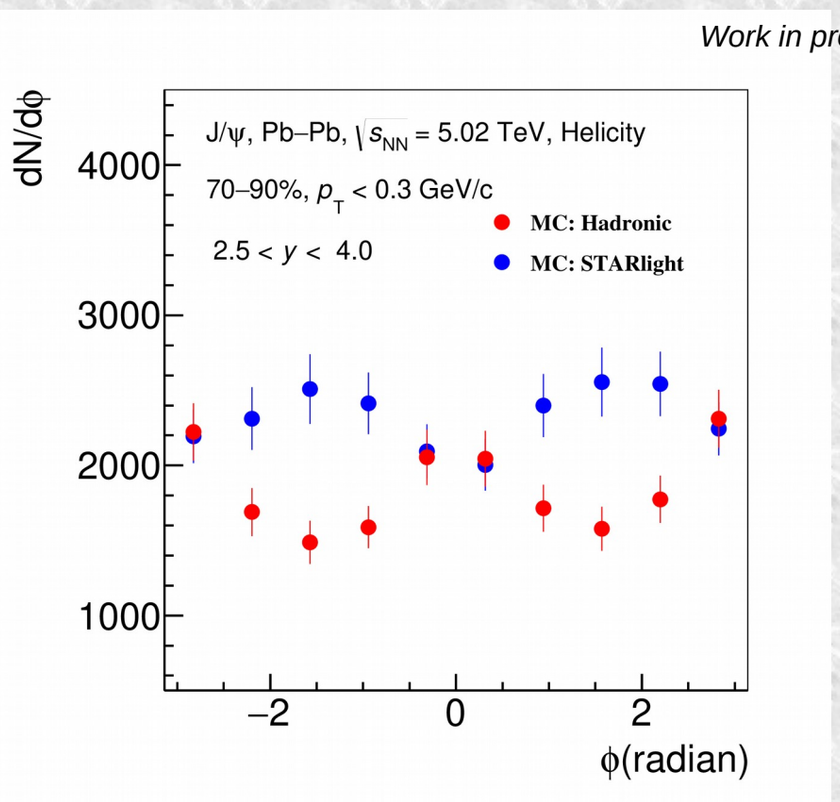


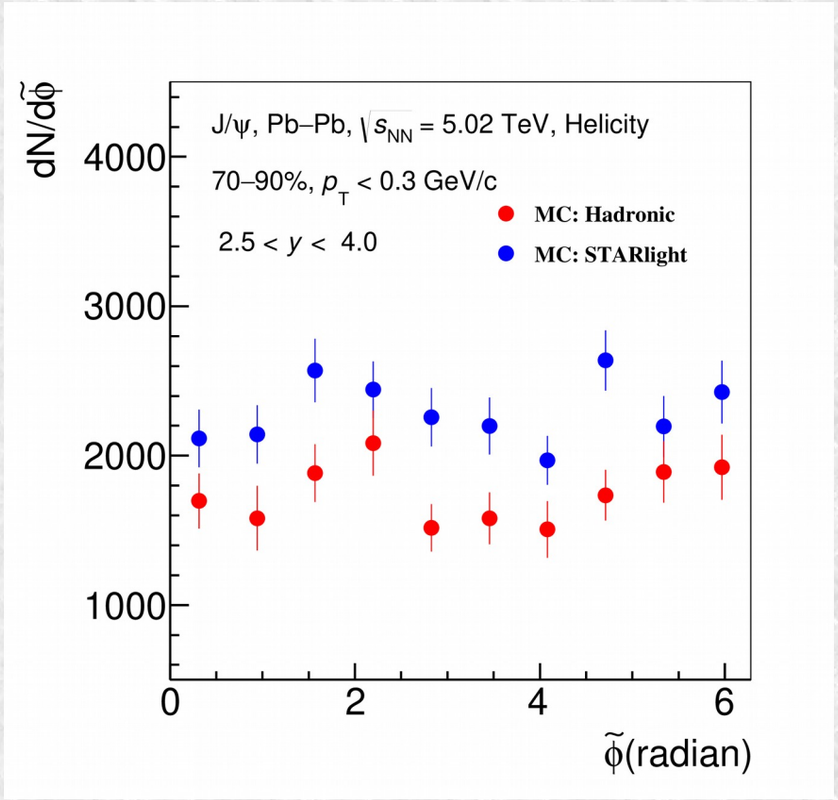

- ✓ Similar behavior is observed AxE vs. cosθ for both MC productions
- ✔ Different behavior is seen for Φ and tilde Φ intervals

# Corrected distributions for different angular variables




*Work in progress*



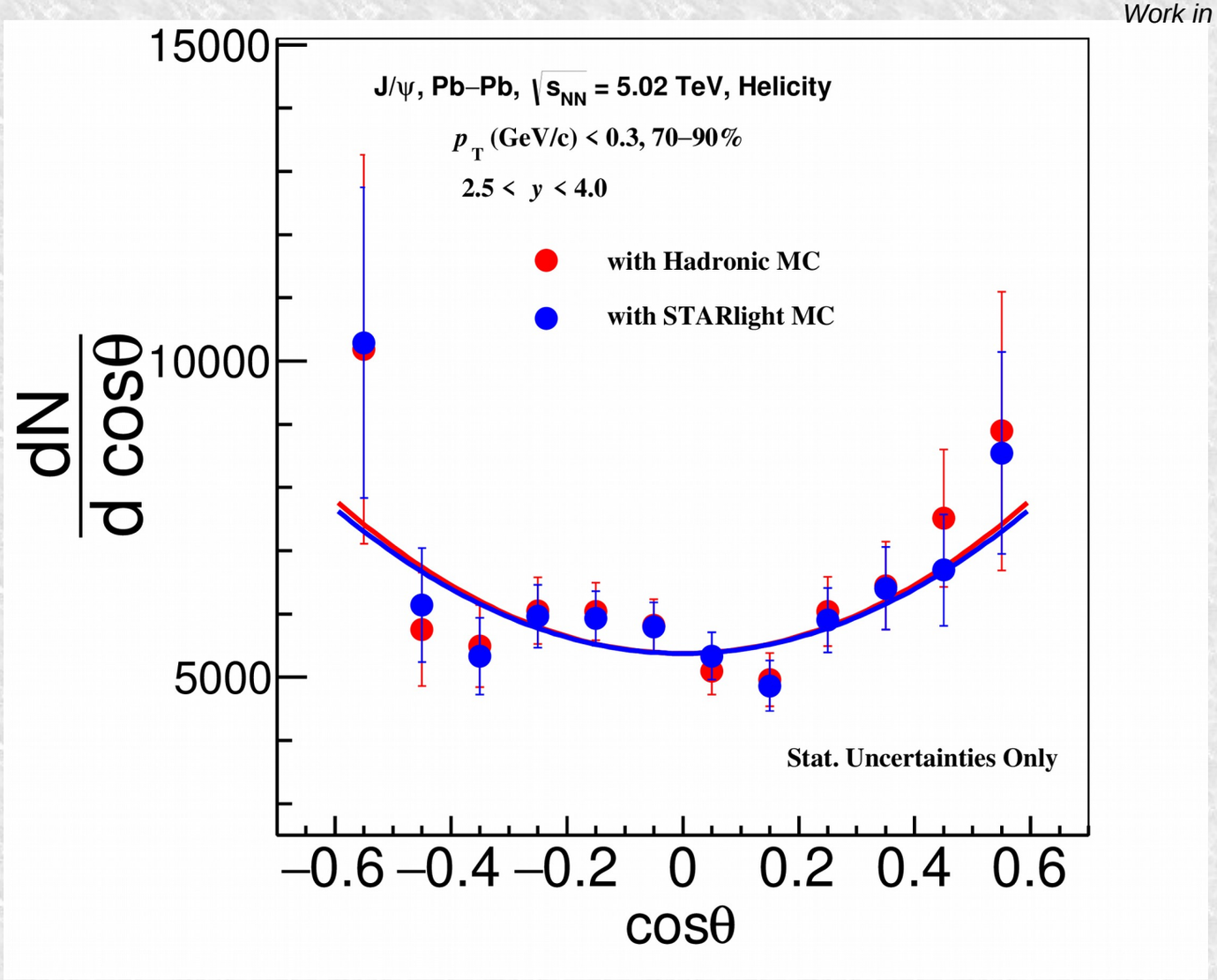



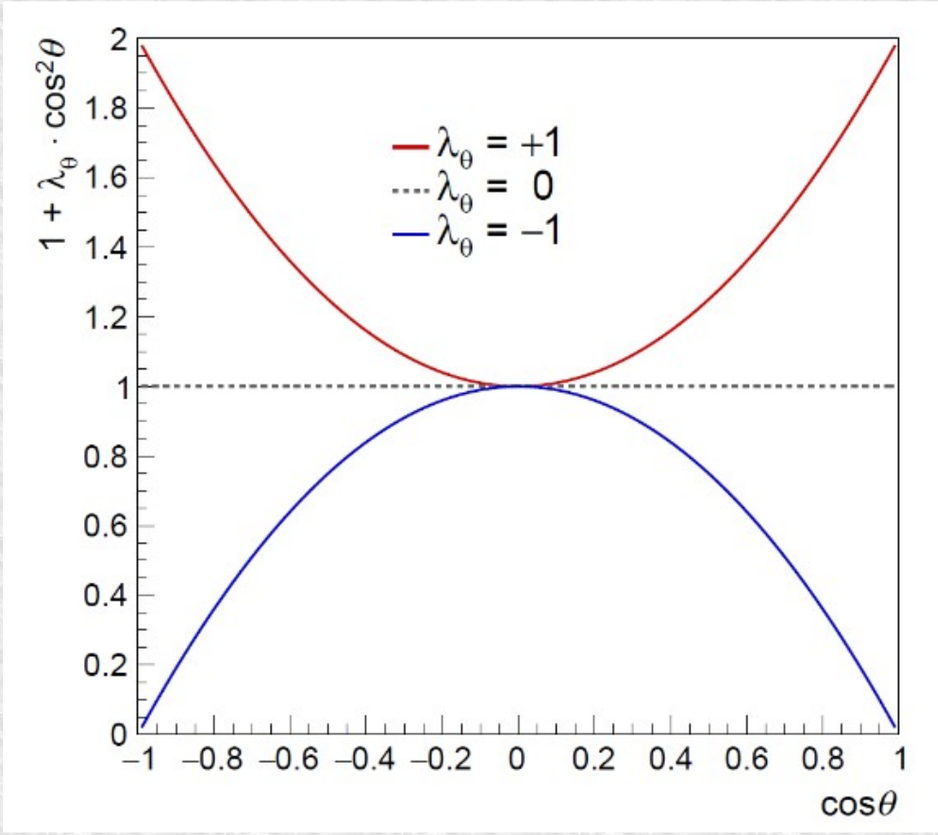



dukhishyam.mallick@cern.ch

# Extraction of polariation parameter : $\lambda_\theta$

*Work in progress*




$\lambda_\theta$ (with Hadronic MC) : 1.212 ± 0.535

$\lambda_\theta$ (with STARlight MC) : 1.148 ± 0.478

- ✓ Cosθ dependence of photoproduced J/ψ yield is observed
- ✓ Data tend to favor a transverse polarization for very low $p_T$ J/ψ in peripheral events although large uncertainties

Extraction of other variables are ongoing

# Summary and outlook

- Rapidity differential and polarization measurements of photoproduced J/ψ have been studied in Pb-Pb collisions with nuclear overlap at $\sqrt{s_{NN}}$ = 5.02 TeV

- Cosθ dependence of photoproduced J/ψ yield is observed and corrected distribution tends to favor a transverse polarization scenario

# outlook

-- Systematic study is ongoing

-- Extraction of all angular parameters using 1D fit (simultaneous fit explored if time)

-- Systematic uncertainty associated to contamination by hadronic J/psi to be considered

-- Extract other angular variables and do the same using Collin-Soper frame

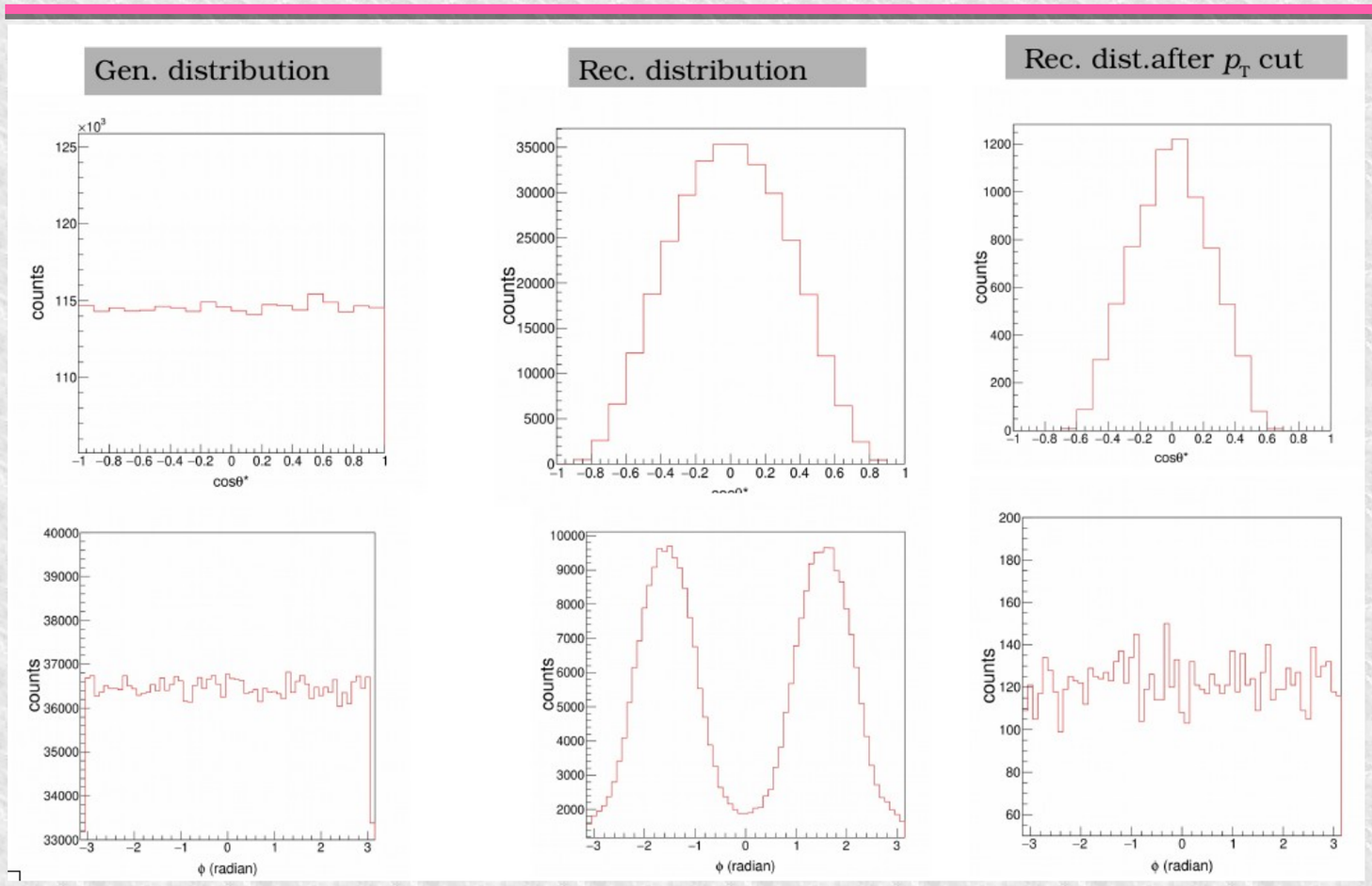


*dukhishyam.mallick@cern.ch*

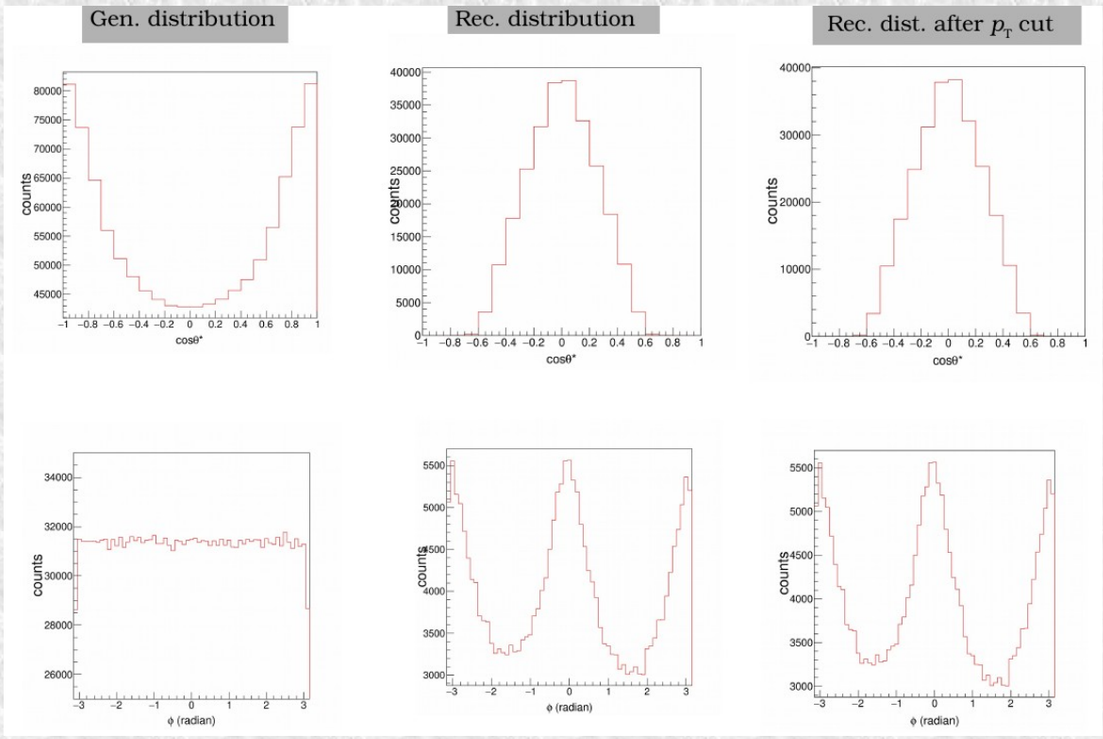
**Thank you.**

***For you for your kind attention***

# Angular distributions : MC




Hadronic MC

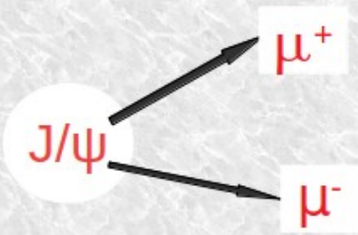


# Analysis details and observables

**Collision system** : Pb-Pb
(Data : LHC15+18 productions, MC : Hadronic and STARlight)
**Center of mass energy** = 5.02 TeV

**Event and track selection** : Events with unlike sign dimuon pairs and standard track selection criteria (arXiv:2204.10684)

J/ψ is reconstructed from its decay daughters using invariant mass method




$$m^2 = E^2 - \vec{p}^2 = (E_{\mu^+} + E_{\mu^-})^2 - (\overrightarrow{p_{\mu^+}} + \overrightarrow{p_{\mu^-}})^2$$

**Signal Functions :** Crystall Ball and NA60
**Bkg. Functions :** VWG, polynomial and exponential

**Centrality :** 70 -90%

**Transverse momentum ($p_T$)** < 0.3 GeV/c (for coherent study)

-> Using Helicity and Collin-Soper frames, for different angular variables

-> Observables : **Coefficient of angular distributions ( $\lambda_\theta$, $\lambda_\phi$ and $\lambda_{\theta\phi}$)**

Dilepton decay angular distribution P. Faccioli et al., Eur.Phys.J.C69:657-673, 2010

$$W(\cos\theta, \phi) \propto \frac{1}{3+\lambda_\theta} \cdot (1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi)$$

$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (0,0,0) \implies$ No polarization

$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (+1,0,0) \implies$ Transverse polarization

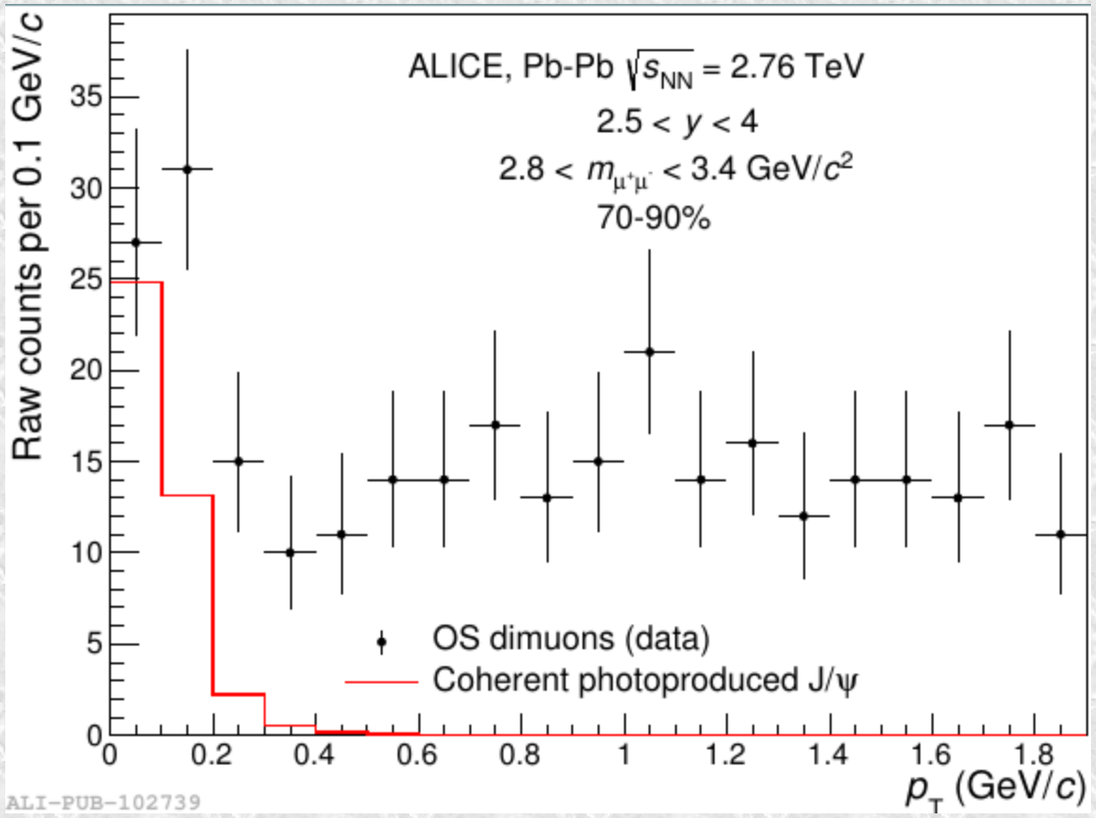
$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (-1,0,0) \implies$ Longitudinal polarization

# VM photoproduction in heavy-ion collisions with nuclear overlap

Very **low-$p_T$ J/ψ excess** in peripheral Pb-Pb collisions measured in ALICE at forward y and at $\sqrt{s_{NN}}$ = 2.76 (significance = 5.4σ) and 5.02 TeV (24σ) for 70-90 %

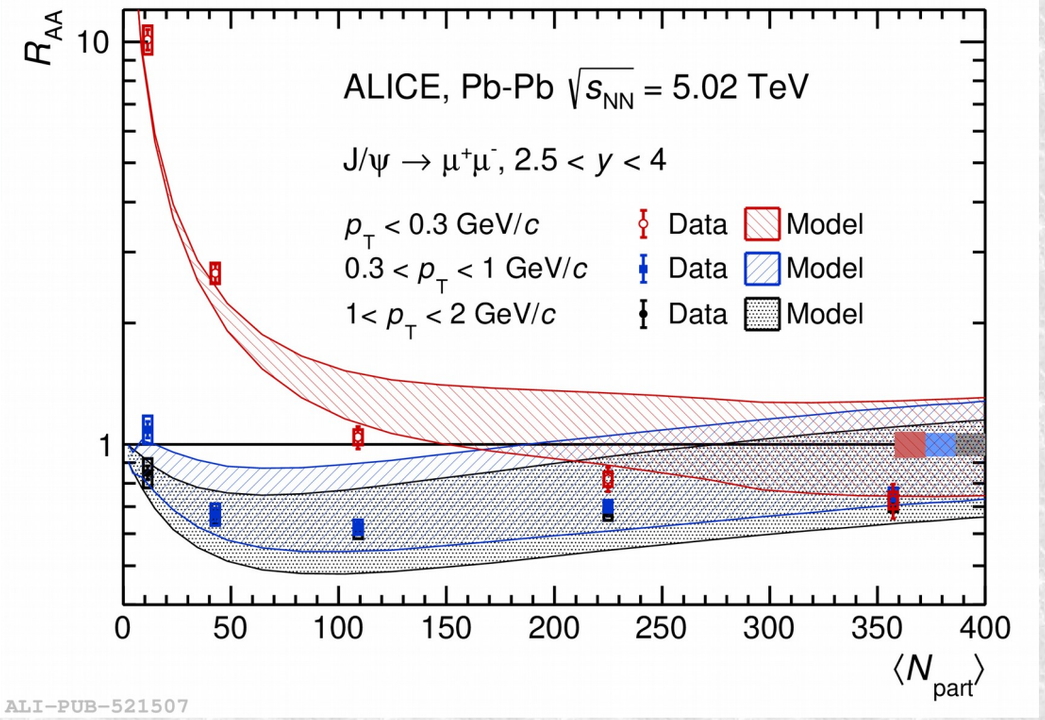
-> Interpreted as **coherent photoproduction**

PRL 116, 222301 (2016)




$$R_{AA}=\frac{Y_{J/\psi}^{Pb-Pb}}{\langle T_{AA}\rangle \sigma_{J/\psi}^{pp}}$$

arXiv:2204.10684




**Model** : Wei Shi et. al, Phys. Lett. B 777 (2018)

Similar observation confirmed by other experiments:

by STAR Collaboration: PRL 123, 132302 (2019),

by LHCb Collaboration: PRC105 (2022) L032201

Some theoretical developments to describe VM photoproduction in AA collisions with nuclear overlap:

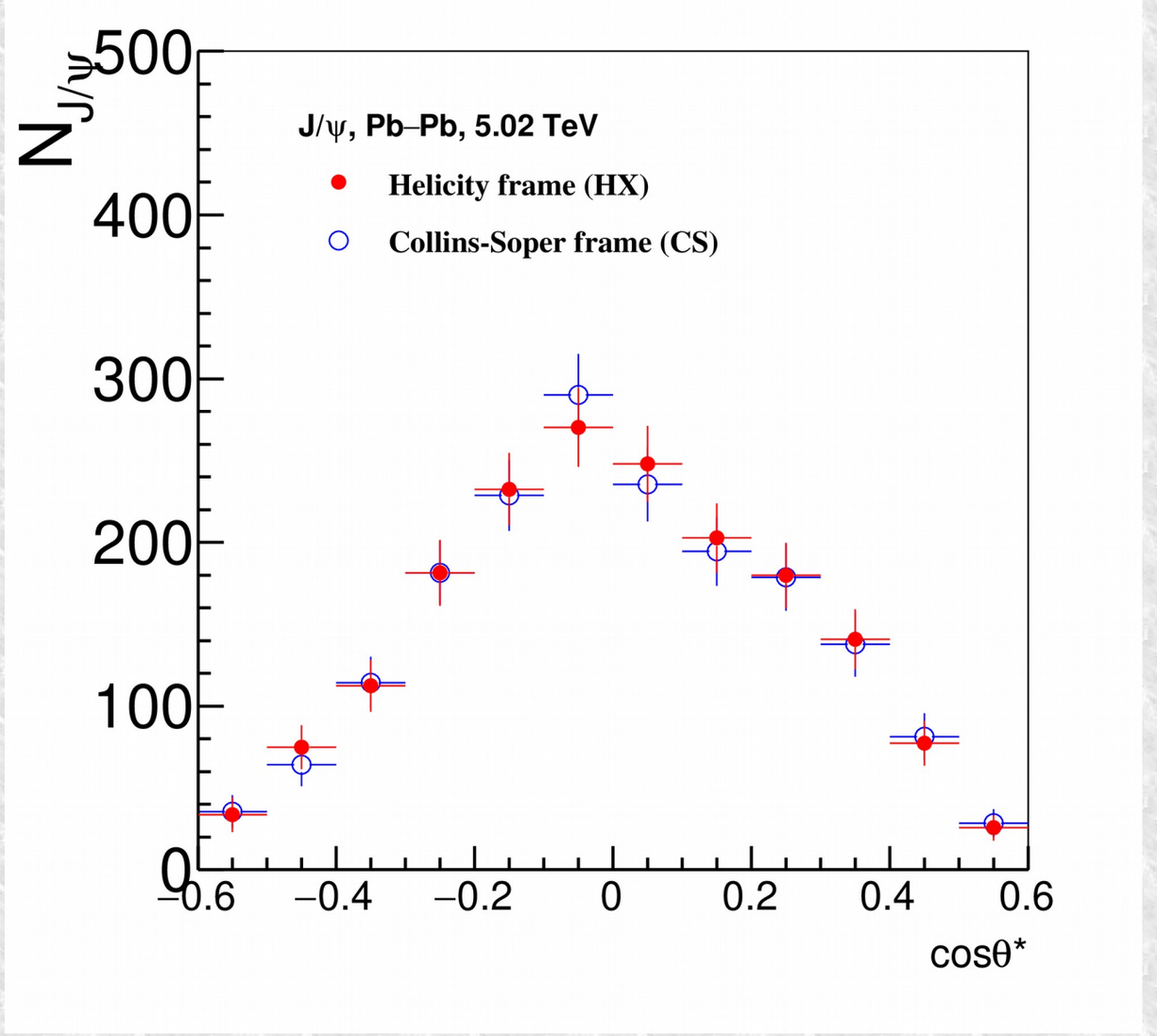
M.K.Gawenda et. al, PRC 93, 044912(2016),

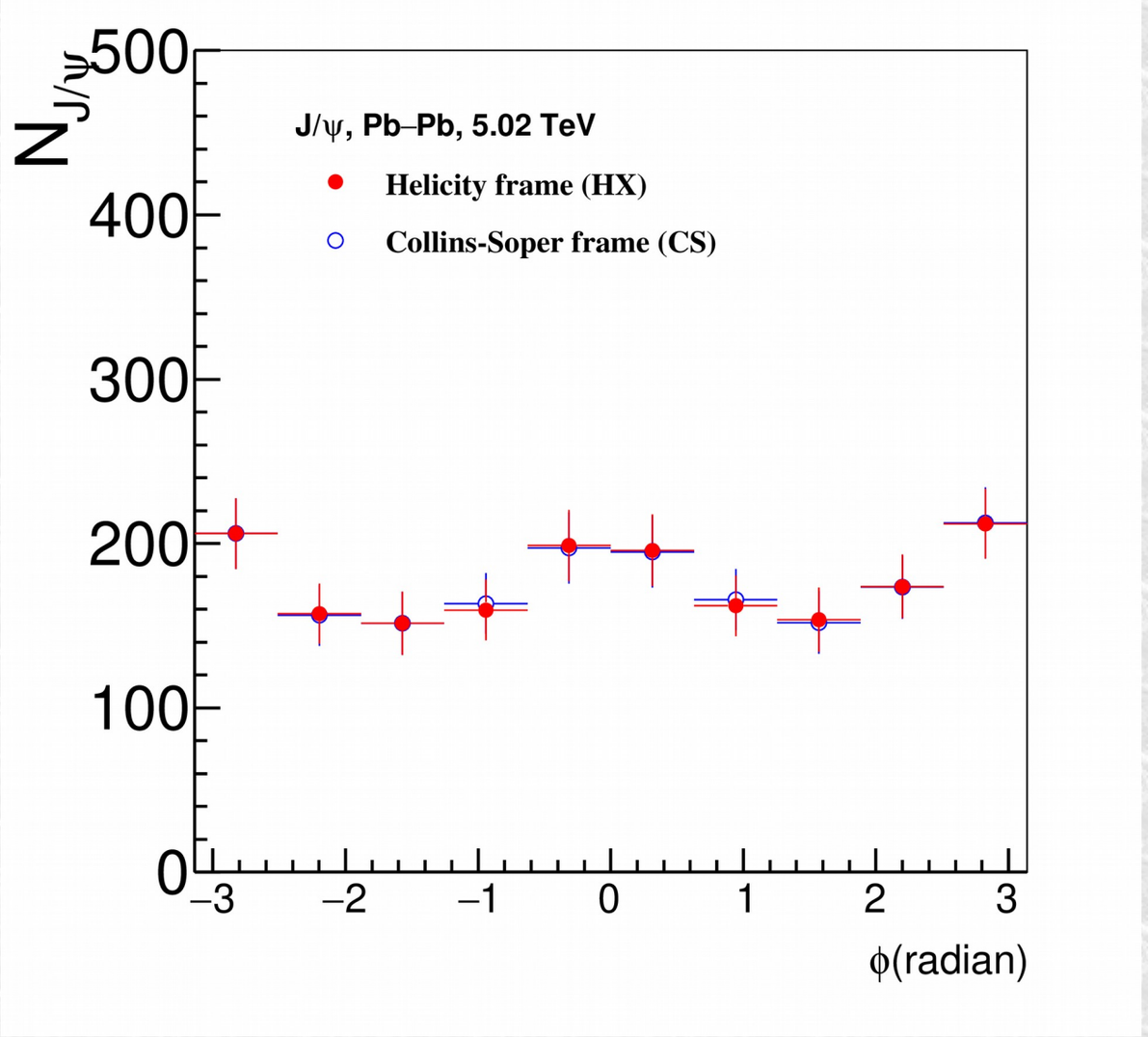
W. Zha et. al, PRC 97, 044910 (2016),

J.G. Contreras, PRC 96, 015203 (2017), and,

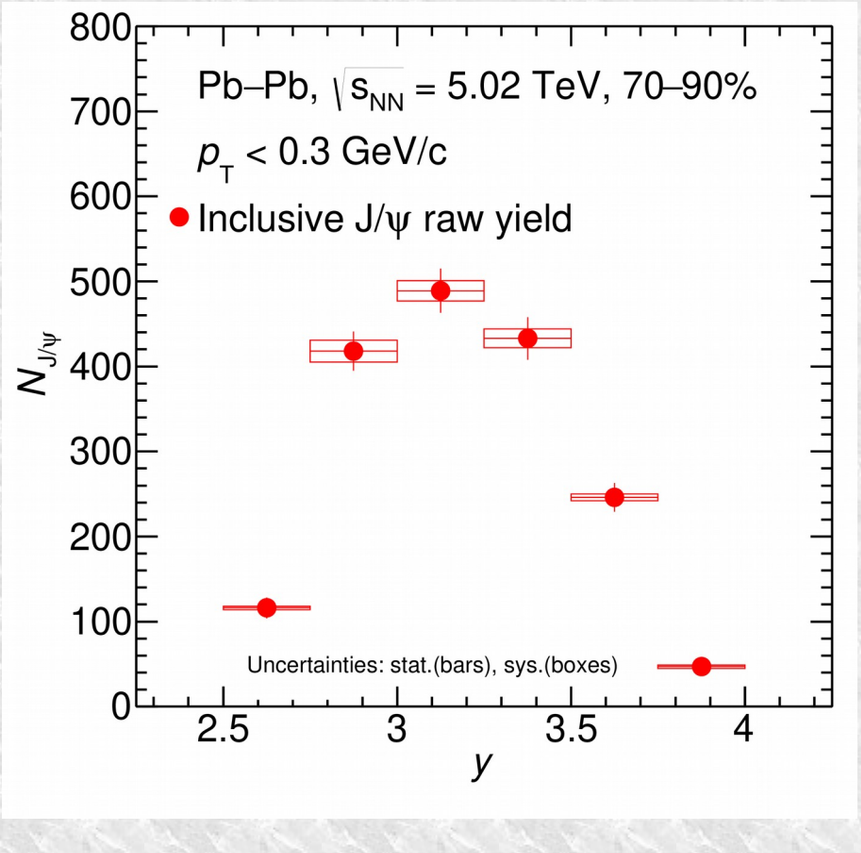
M. B. Gay Ducati et. al, PRD 97 116013 (2018)

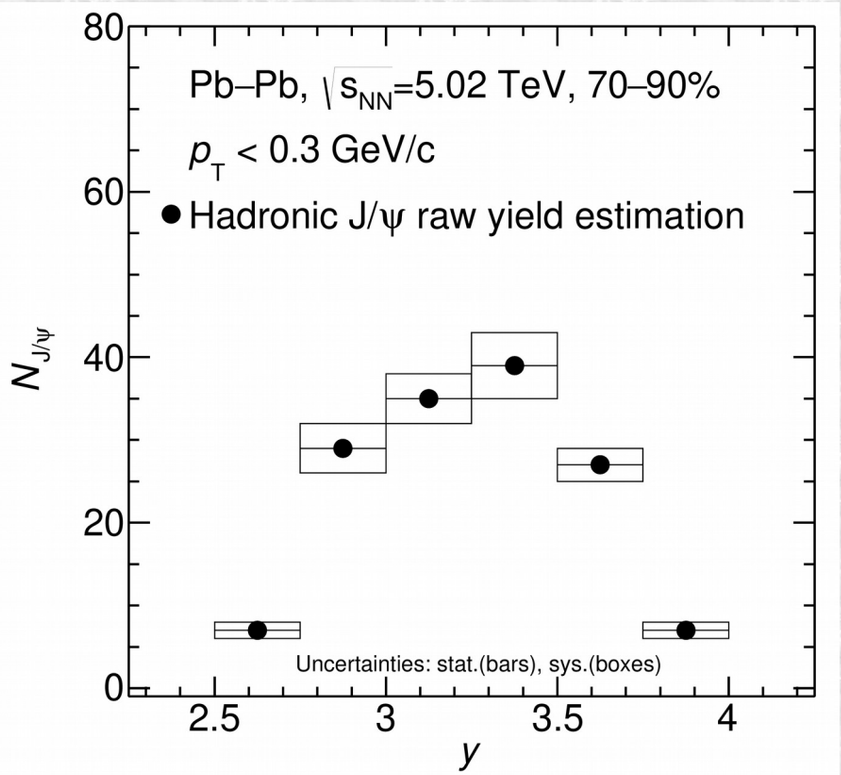
# Angular distributions

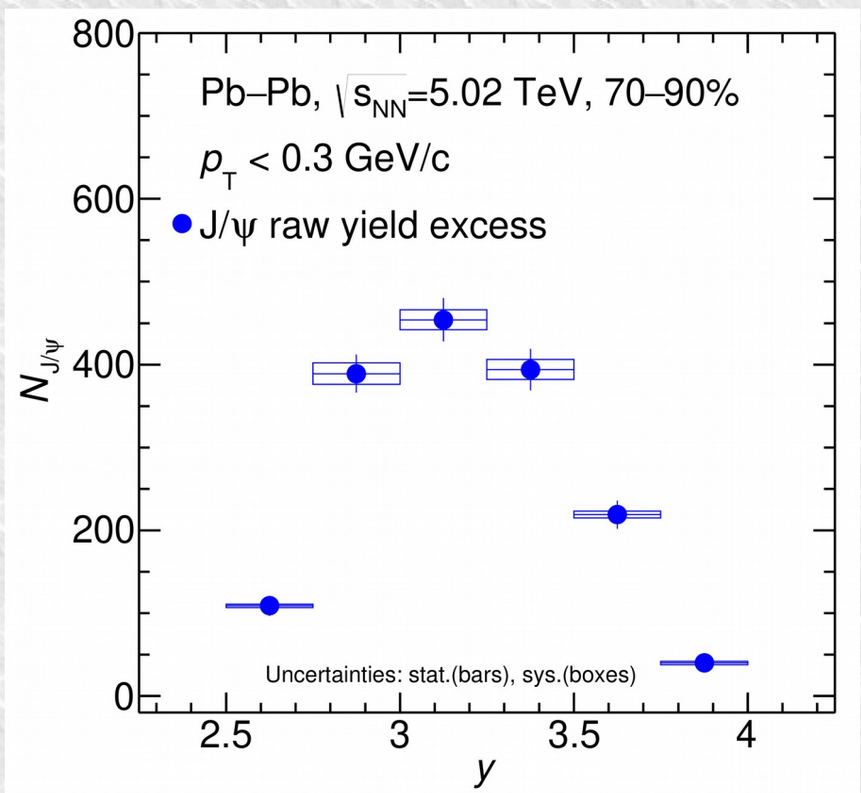


# Results : Estimation of $N_{J/\psi}$ excess vs. y




**J/ψ raw yield excess** : coherent J/ψ photoproduction + incoherent J/ψ photoproduction + coherent ψ(2S) to J/ψ photoproduction