The 13th International Workshop on Heavy Quarkonium

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on behalf of the ALICE collaboration

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SEZIONE DI TORINO

ALICE

Preliminary results on J/ψ polarization in Pb-Pb collisions

Introduction

J/ψ polarization basic concepts

In two-body decays the geometrical shape of the angular distribution of the two decay products reflects the polarization of the quarkonium state

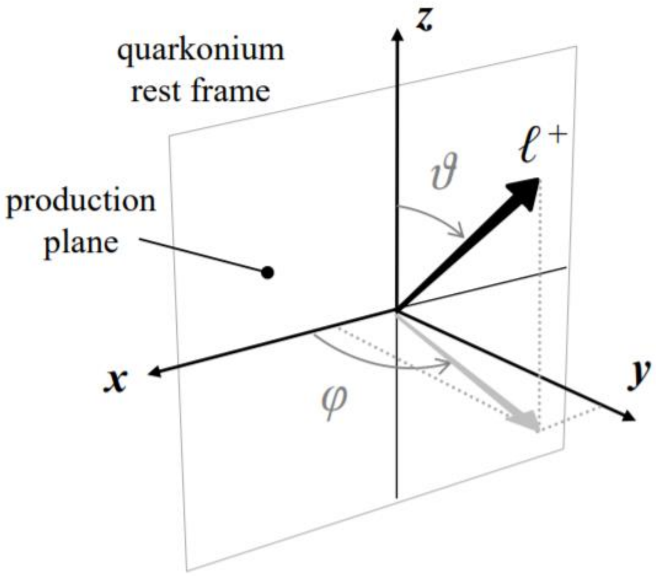
Observable angular distribution

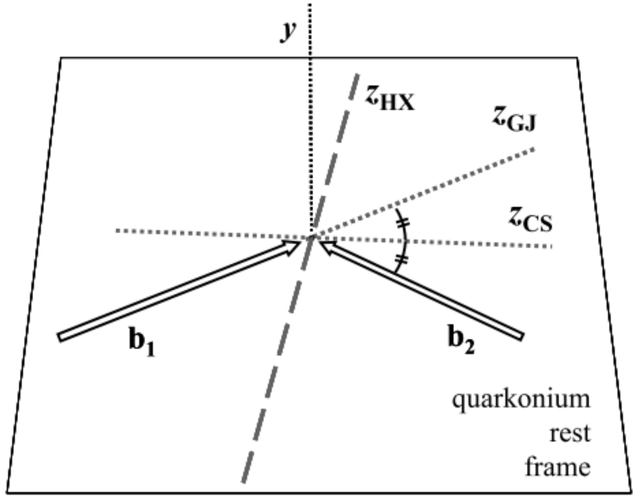
$$W(cos\theta,\varphi) \propto \frac{1}{3+\lambda_\theta} \cdot (1+\lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta\, cos2\varphi + \lambda_{\theta\varphi} sin2\theta cos\varphi)$$

$(\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}) = (0,0,0)$ ➡ No polarization

$(\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}) = (-1,0,0)$ ➡ Pure longitudinal polarization

$(\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}) = (+1,0,0)$ ➡ Pure transverse polarization





Polarization can be measured in different reference frames

polarization axis:

- ❑ Helicity (HX): direction of J/ψ in the collision center of mass frame
- ❑ Collins-Soper (CS): the bisector of the angle between the beam and the opposite of the other beam, in the J/ψ rest frame
- ❑ Gottfried-Jackson (GJ): direction of one beam in the J/ψ rest frame (used for fixed target experiments)

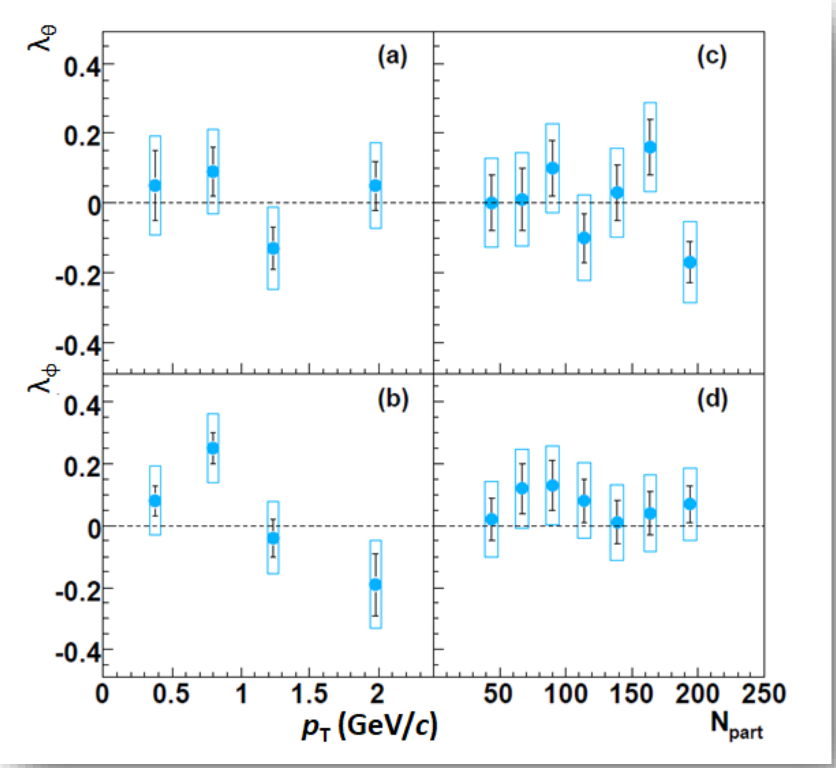
Figures from P.Faccioli et al. EPJ C69 (2010) 657-673

Polarization in pp and AA collisions

Polarization in pp collisions → Crucial for the understanding of the J/ψ production mechanism

- ❑ **LO NRQCD** predicted transverse polarization for high-p_T J/ψ
- ❑ **NLO color singlet model** predicted longitudinal polarization

Polarization in AA collisions



R.Arnaldi et al. (NA60), NPA830 (2009) 345c

"Dense parton matter may then screen out of the existence a large part of quarkonia . . . but those of them that survive will carry the information about the mechanism of their formation throughout the collision"

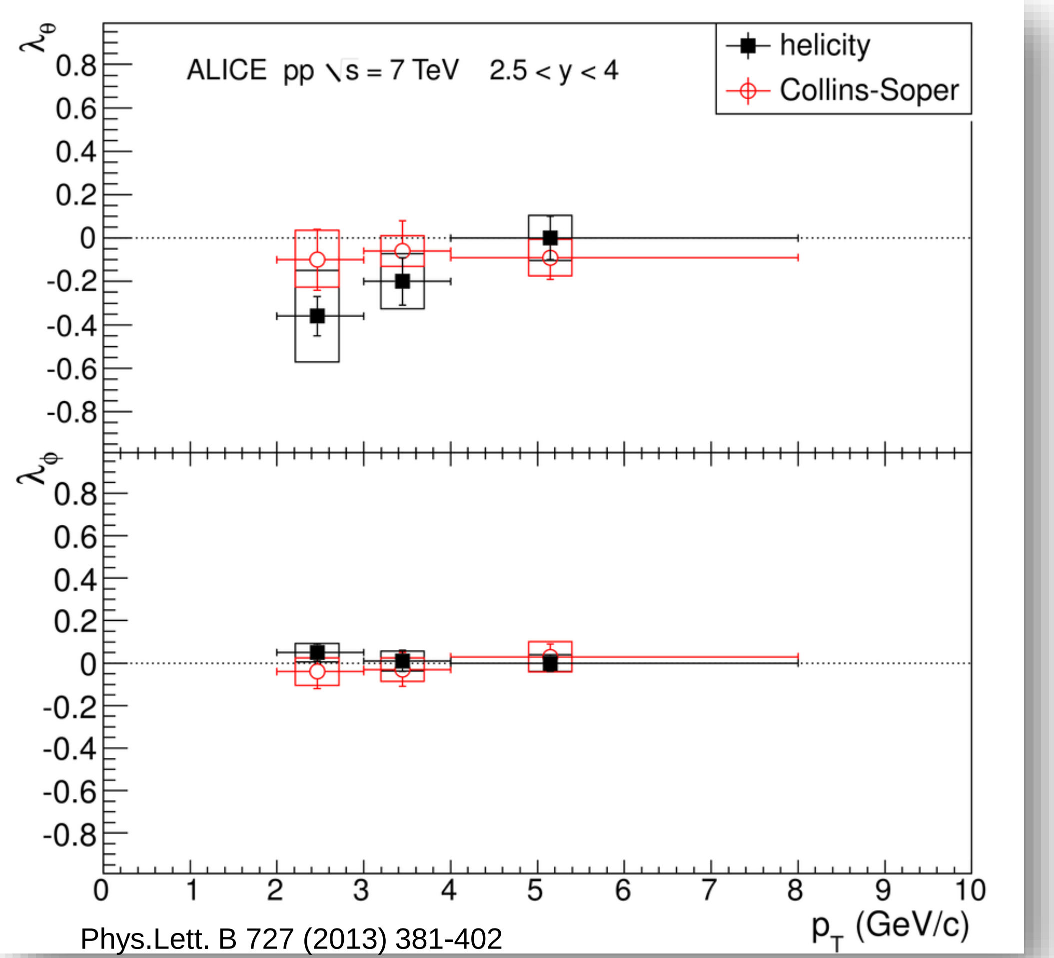
Ioffe & Kharzeev, Phys. Rev. C68 (2003) 061902

- ❑ QGP is produced at LHC energies
- ❑ The suppression mechanism induced by the strongly interacting medium produced in heavy ion collisions affects differently the various quarkonium states
- ❑ May change the J/ψ polarization with respect to pp because the feed-down fractions change

NA60 is the only experiment that measured polarization parameters for J/ψ in nuclear collisions (In-In, $\sqrt{s_{NN}} = 17$ GeV)

→ No sizeable polarization observed

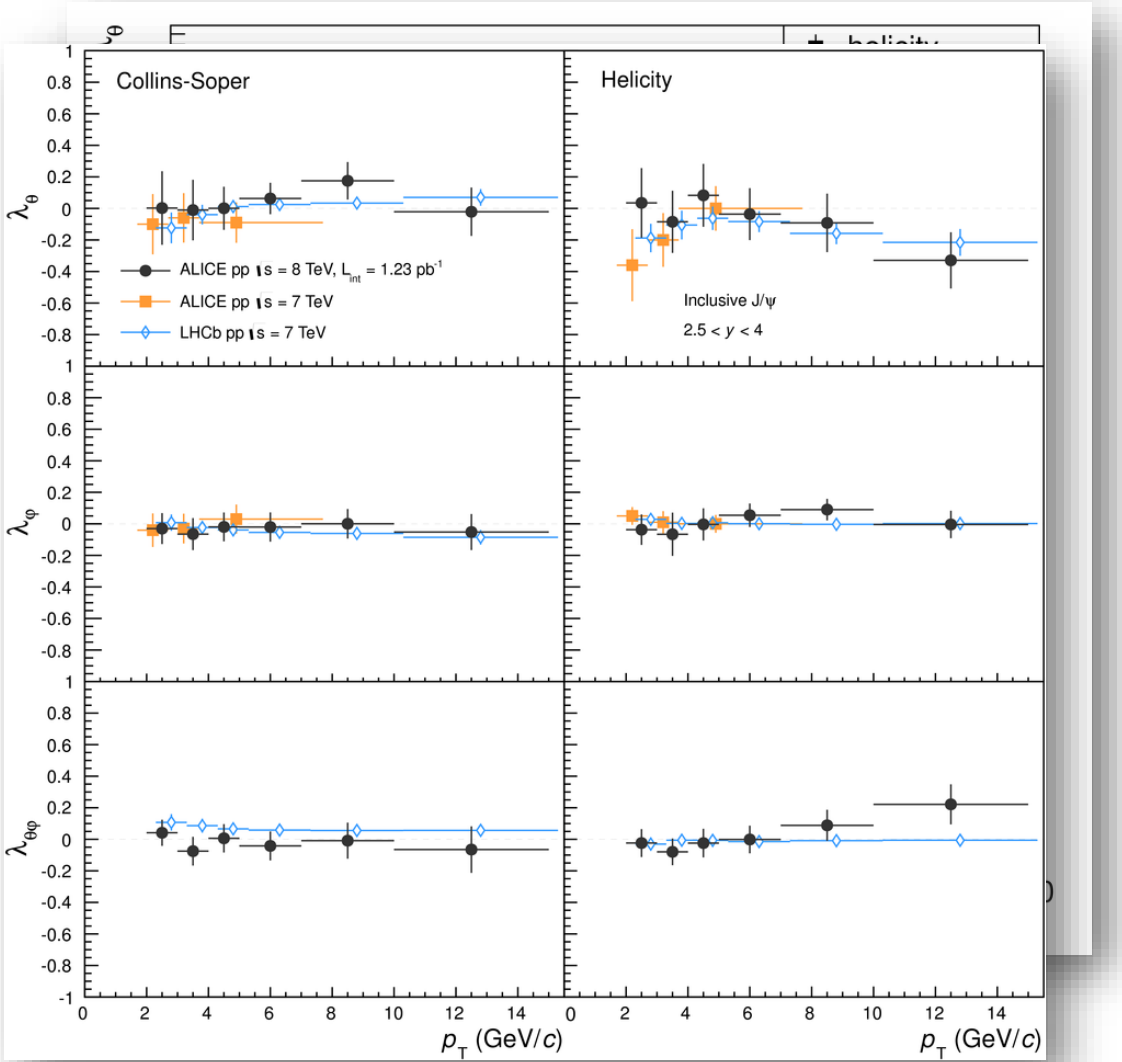
Quarkonium polarization at LHC



The ALICE experiment published the first measurement of <u>inclusive</u> J/ψ polarization in pp collisions at $\sqrt{s} = 7$ TeV , $2.5 < y < 4$

λ_θ and λ_φ compatible with zero

Quarkonium polarization at LHC



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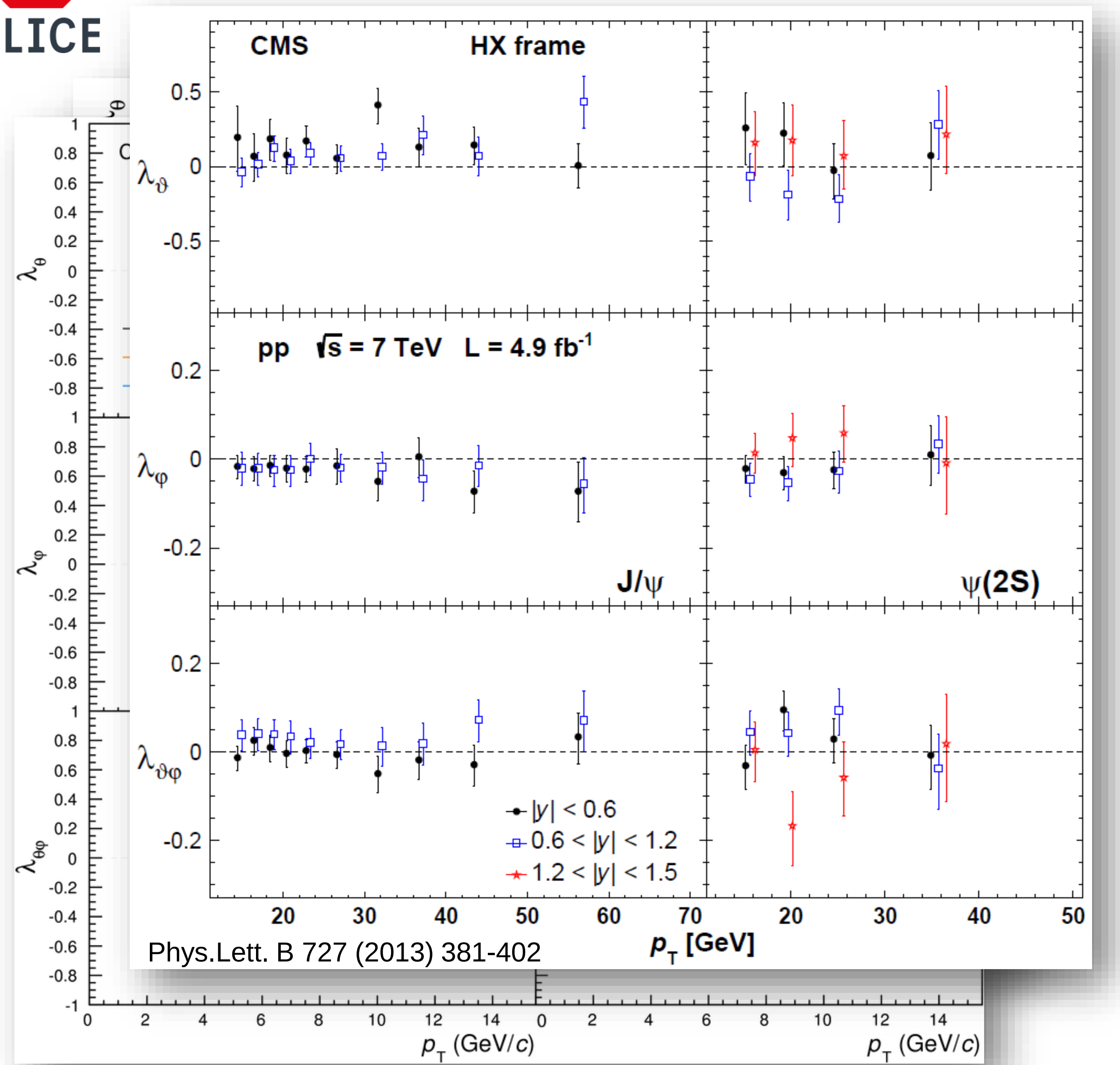
- LHCb measured with increased precision <u>prompt</u> J/ψ polarization in pp collisions at $\sqrt{s} = 7\ \mathrm{TeV}$, $2 < y < 4.5$ [EPJ C 73 (2013) 2631]
- ALICE measured <u>inclusive</u> J/ψ polarization in pp collisions at $\sqrt{s} = 8\ \mathrm{TeV}$ [EPJ C 78 (2018) 562]

  ➡ $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ compatible with zero

Quarkonium polarization at LHC



Phys.Lett. B 727 (2013) 381-402

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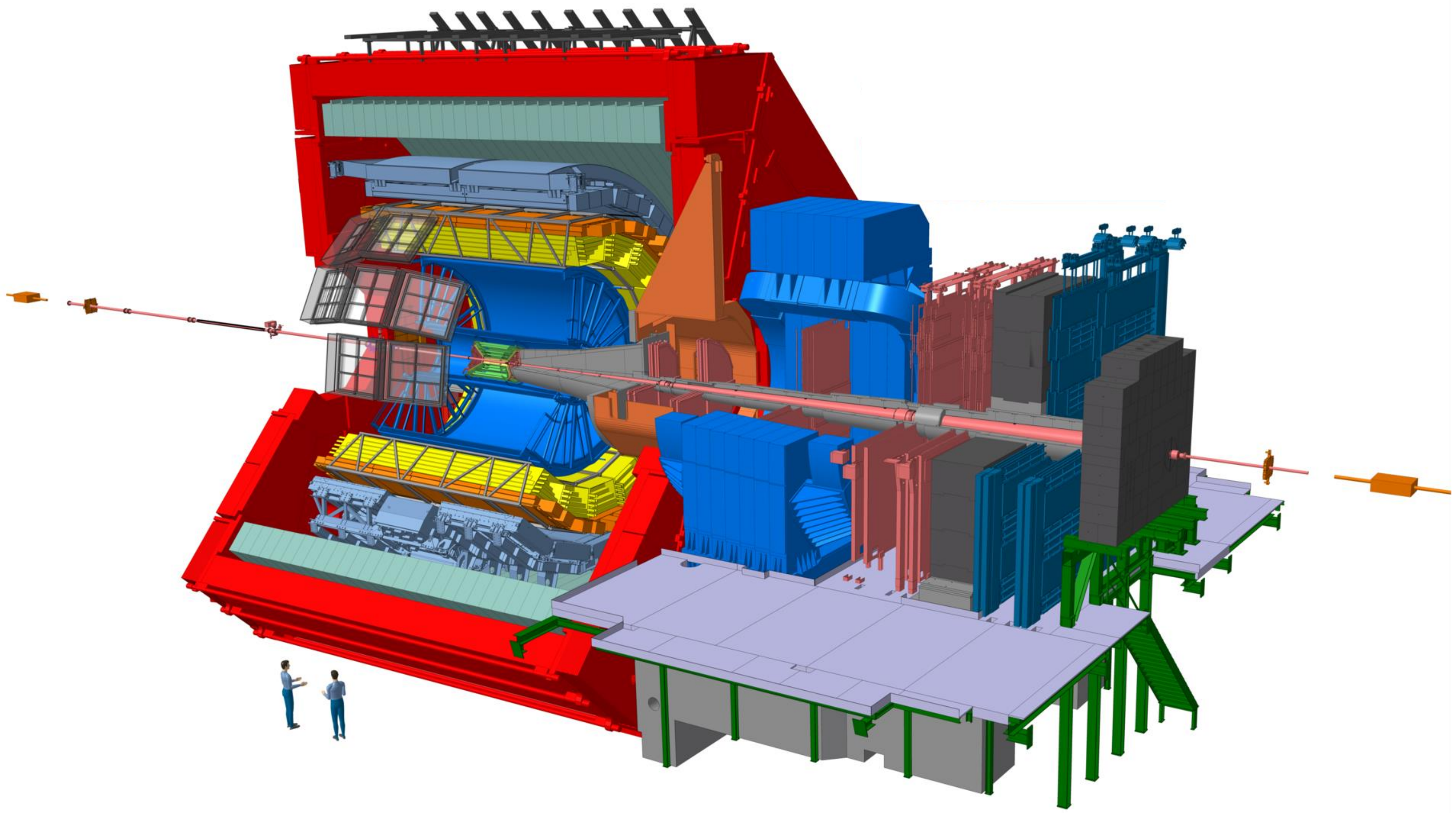
- ALICE measured inclusive J/ψ polarization in pp collisions at $\sqrt{s} = 8$ TeV [EPJ C 78 (2018) 562]
  - ➡ $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ compatible with zero
- CMS measured prompt J/ψ and $\psi(2S)$ polarization in pp up to 70 GeV/c at $\sqrt{s} = 7$ TeV, $|y| < 1.5$
  - ➡ $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ compatible with zero

The ALICE experiment

The ALICE experiment at LHC is designed for the study of heavy ion collisions



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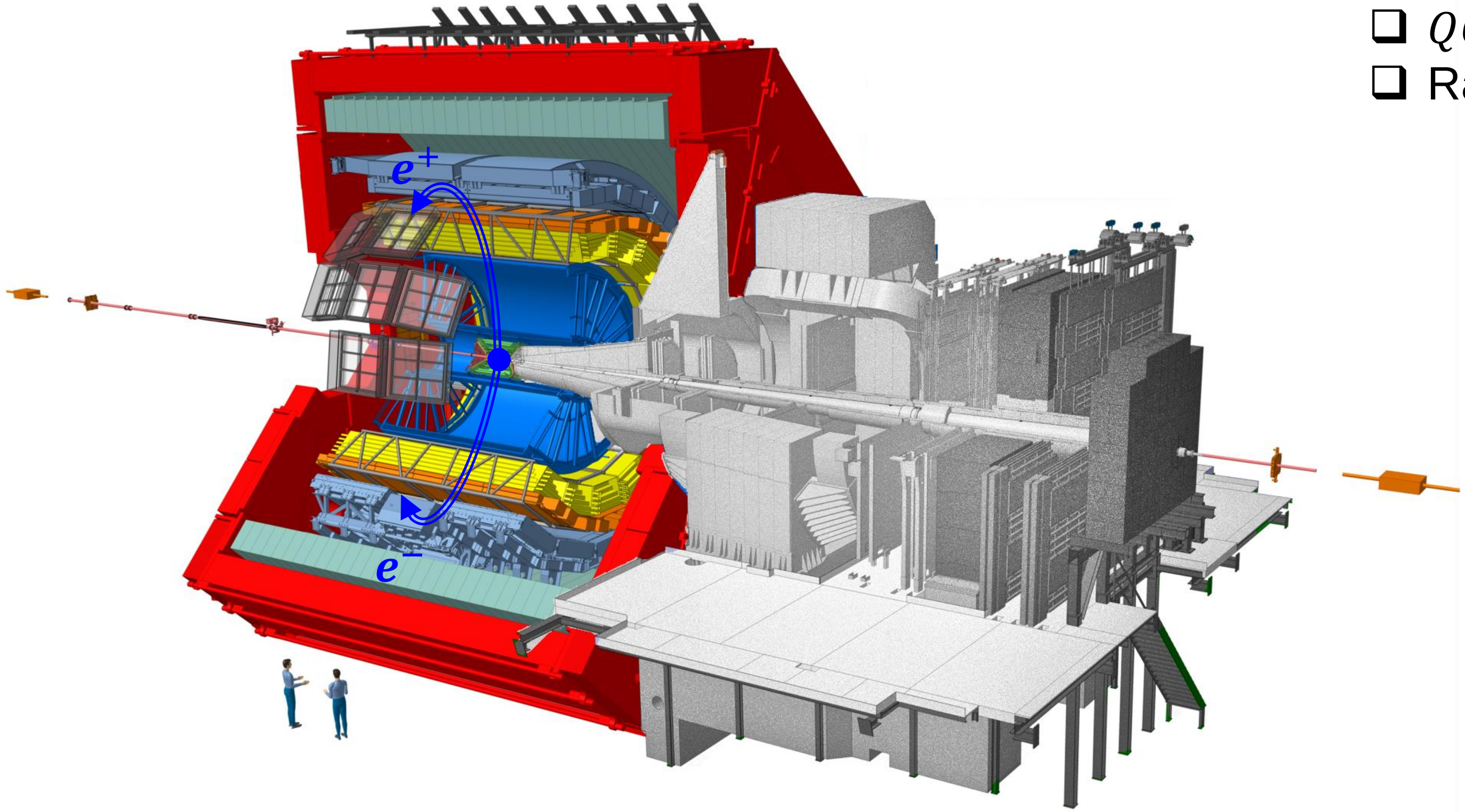

Central barrel :

- $Q\bar{Q}$ decay mode : e^+e^-
- Rapidity coverage : $|y| < 0.9$

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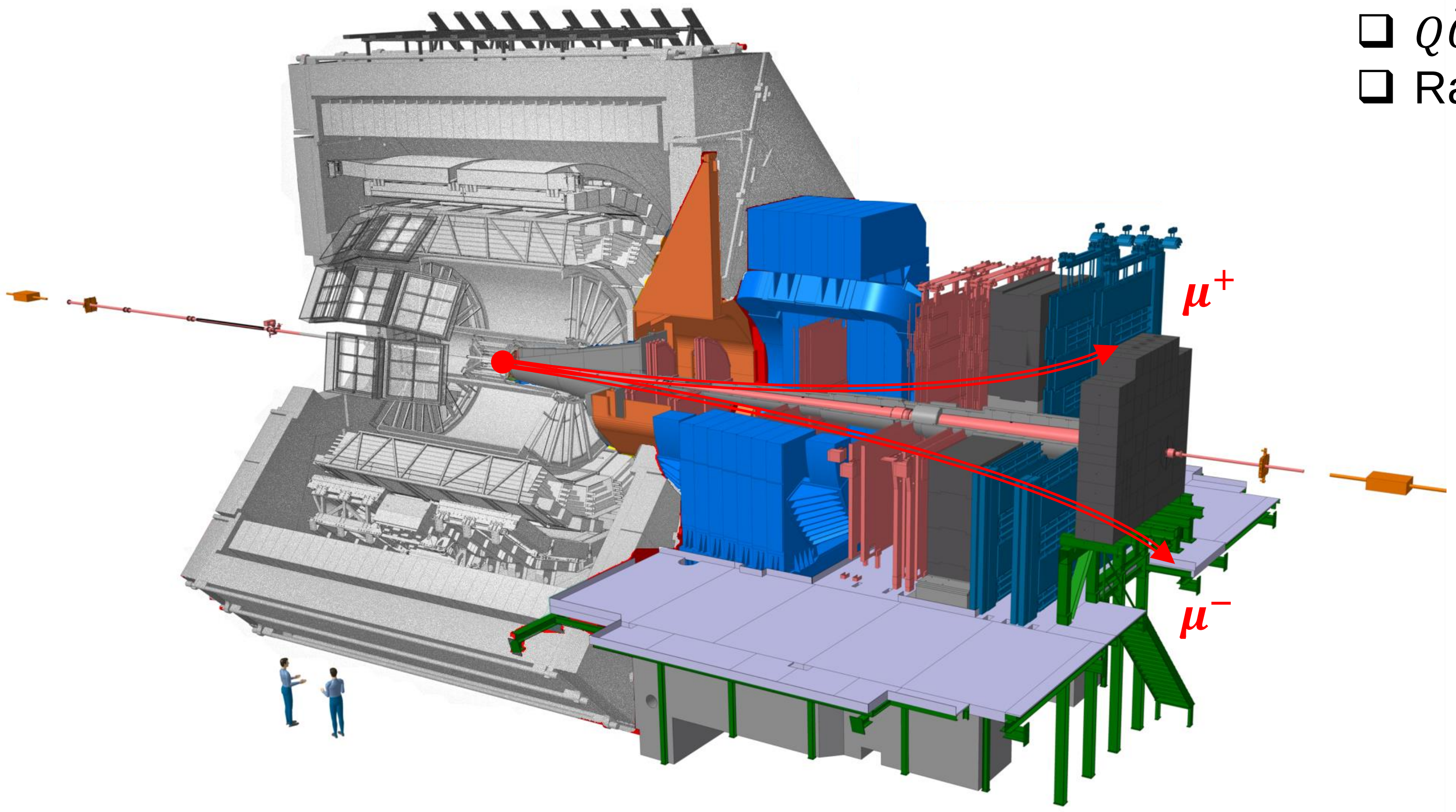

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- $Q\bar{Q}$ decay mode : e^+e^-
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Muon spectrometer:

- $Q\bar{Q}$ decay mode : $\mu^+\mu^-$
- Rapidity coverage : $2.5 < y < 4$

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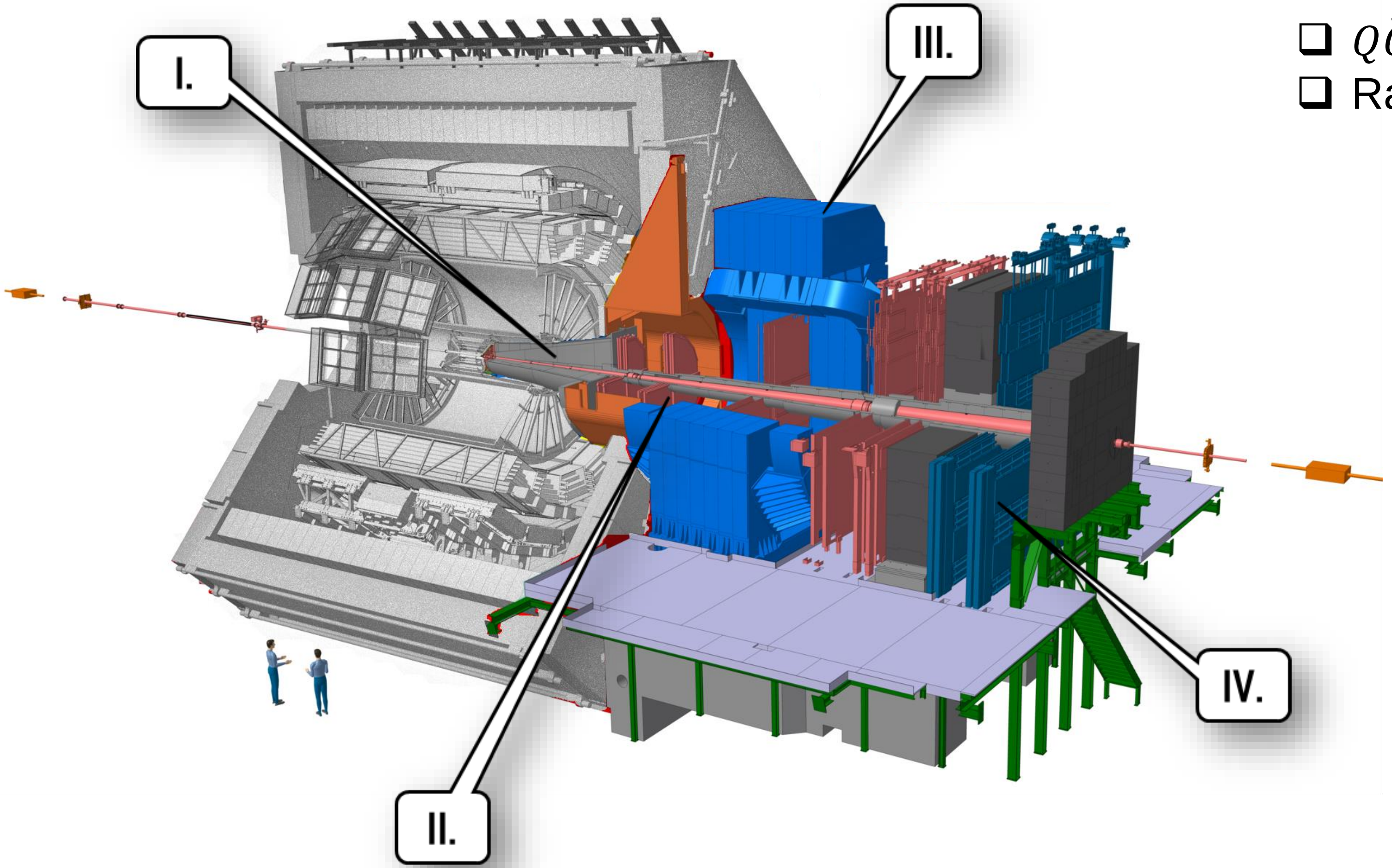

Central barrel :

- ❑ $Q\bar{Q}$ decay mode : e^+e^-
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Muon spectrometer:

- ❑ $Q\bar{Q}$ decay mode : $\mu^+\mu^-$
- ❑ Rapidity coverage : $2.5 < y < 4$

- ❑ In this analysis J/ψ is studied decaying to a muon pair

➔ Focus on the muon spectrometer:

- I. Front absorber
- II. Tracking system
- III. Dipole magnet
- IV. Trigger system

Data analysis

Data sample and analysis procedure

In this analysis J/ψ is studied using the Pb-Pb collision dataset collected at $\sqrt{s_{NN}} = 5.02$ TeV in 2015 ($L_{int} \sim 0.2\ nb^{-1}$)

SINGLE MUON CUTS

- $-4 < \eta_{\mu} < -2.5$ to reject tracks at the edge of the spectrometer acceptance
- Matching of a track reconstructed in the tracking chambers with a track reconstructed in the trigger system with $p_T > 1$ GeV/c
- Cut on the distance of closest approach to primary interaction vertex

DIMUON CUTS

- $2.5 < y_{\mu\mu} < 4$ to cope with the spectrometer acceptance

Data sample and analysis procedure

In this analysis J/ψ is studied using the Pb-Pb collision dataset collected at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV in 2015 ($L_{\mathrm{int}} \sim 0.2\ nb^{-1}$)

ANALYSIS PROCEDURE

I. Signal extraction

Number of J/ψ obtained fitting the $\mu^+\mu^-$ invariant mass distribution as a function of $cos\theta$ and φ

II. Acceptance × efficiency correction

Number of J/ψ corrected with the $A \times \varepsilon$ obtained in with a MC simulation

III. Polarization parameters extraction

Fit to the J/ψ $A \times \varepsilon$-corrected distribution with:

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

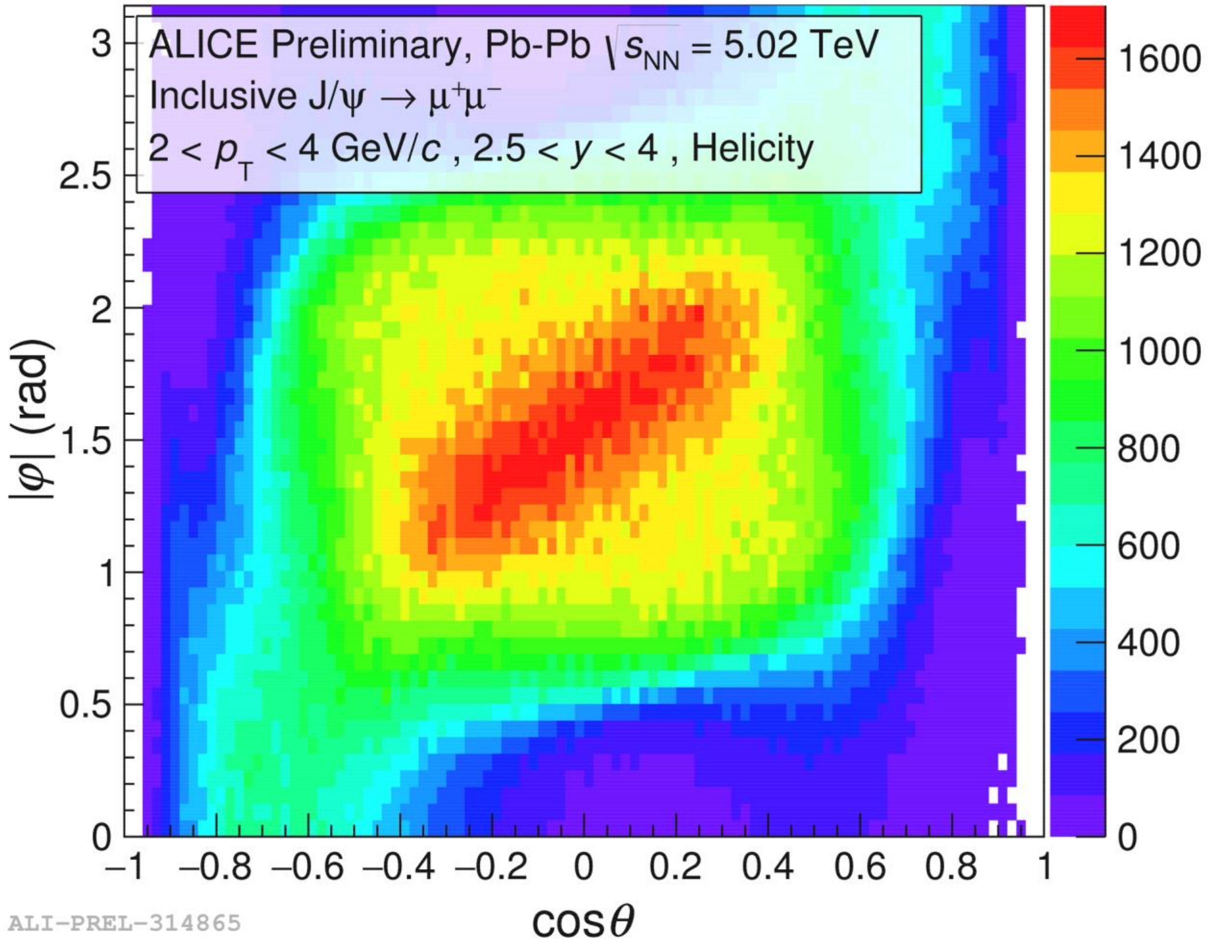
GOAL

$\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$

evaluation

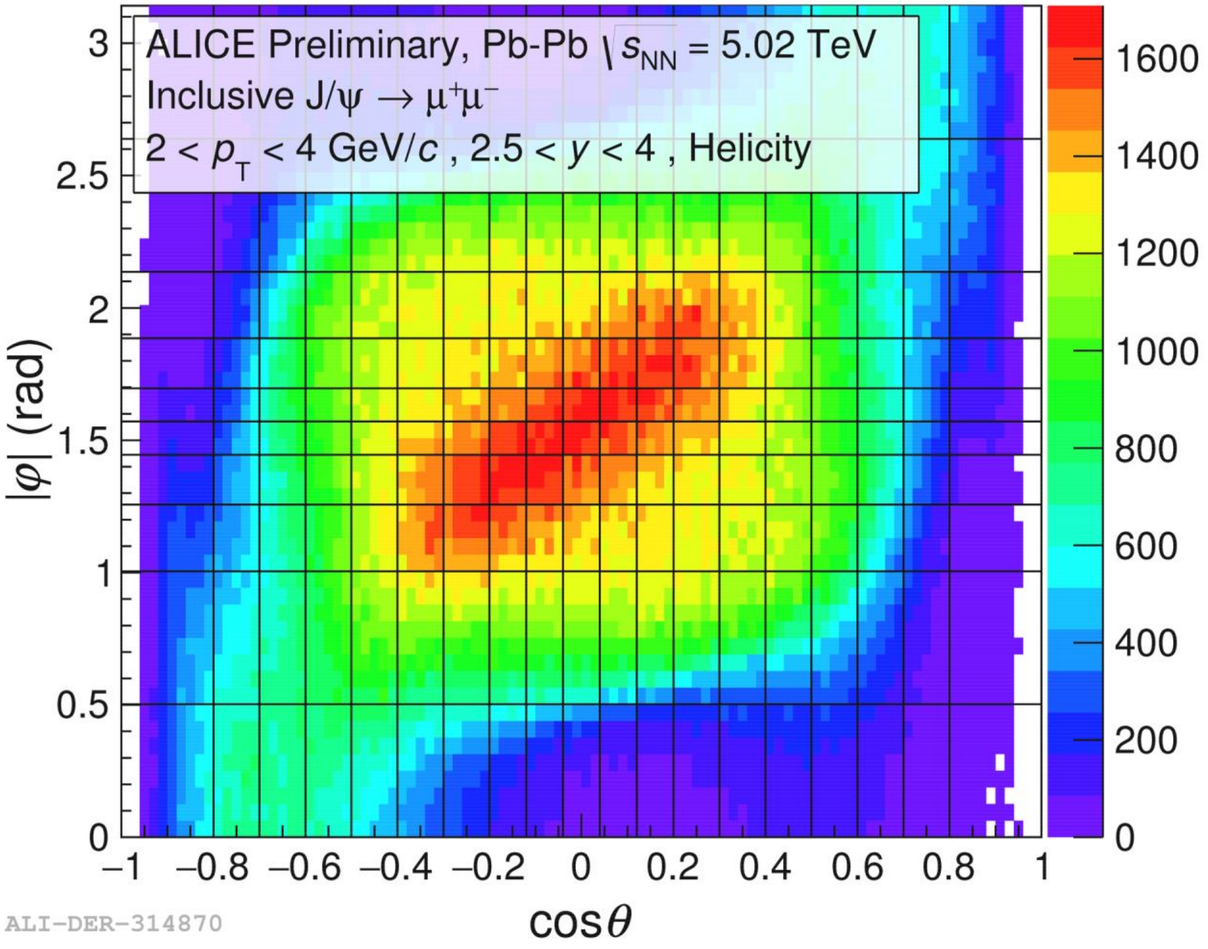
Signal extraction

- ❑ $\mu^+\mu^-$ angular distribution as a function of $cos\theta$ and φ for $2 < m_{\mu\mu} < 5\ \mathrm{GeV}/c^2$



Signal extraction

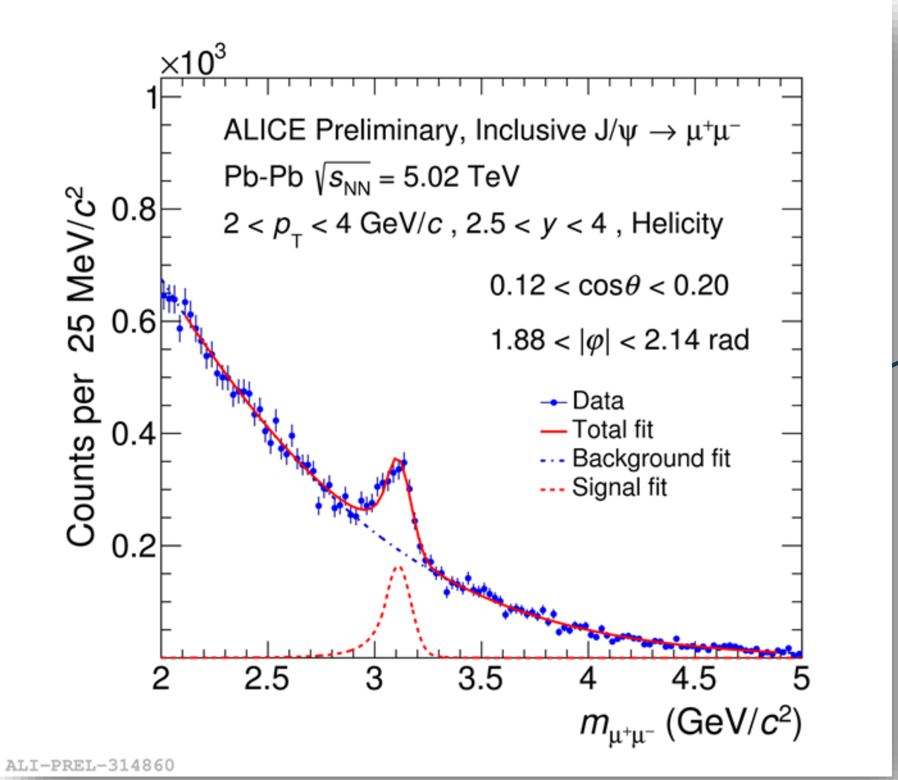
- ❑ $\mu^{+}\mu^{-}$ angular distribution as a function of $cos\theta$ and φ for $2 < m_{\mu\mu} < 5\ \mathrm{GeV}/c^2$
- ❑ Creation of a 2D grid for signal extraction

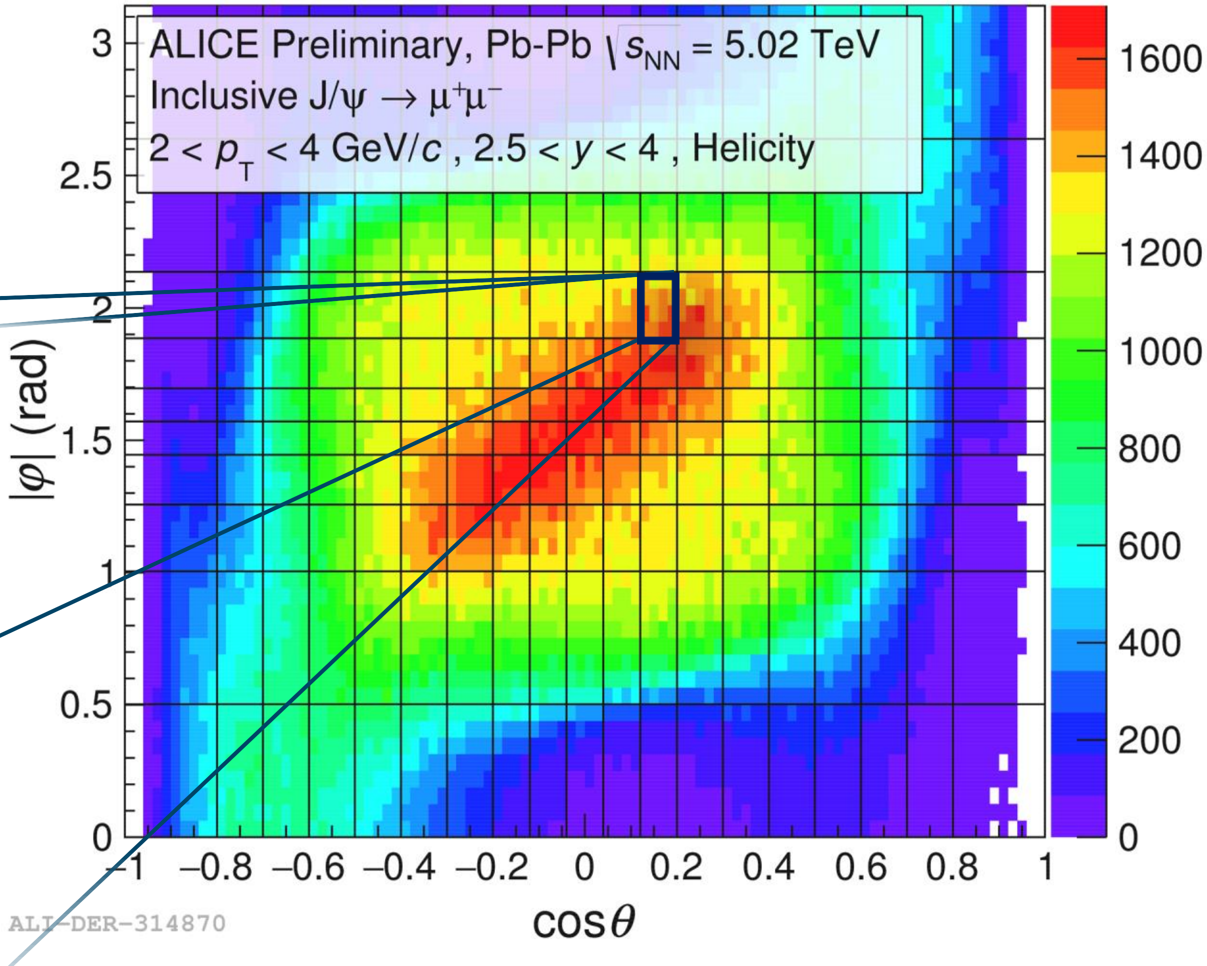


Angular binning tuned according to the statistical significance of the signal

Signal extraction

- ❑ $\mu^+\mu^-$ angular distribution as a function of $cos\theta$ and φ for $2 < m_{\mu\mu} < 5\ \mathrm{GeV}/c^2$
  - ❑ Creation of a 2D grid for signal extraction
- ❑ Fit to the $\mu^+\mu^-$ invariant mass distribution with various signal and background shapes





Angular binning tuned according to the statistical significance of the signal

Acceptance × Efficiency

$A \times \varepsilon$ evaluated in a Monte-Carlo simulation

- In the MC simulation J/ψ are generated flat as a function of $cos\theta$ and φ $(\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi} = 0)$

$A \times \varepsilon$ sensitive to the input MC shape?

- **iterative procedure**: tuning of J/ψ generated distribution according to data

$A \times \varepsilon$ from "flat Monte-Carlo"

↓

$N_{J/\psi}$ distribution corrected with $A \times \varepsilon$

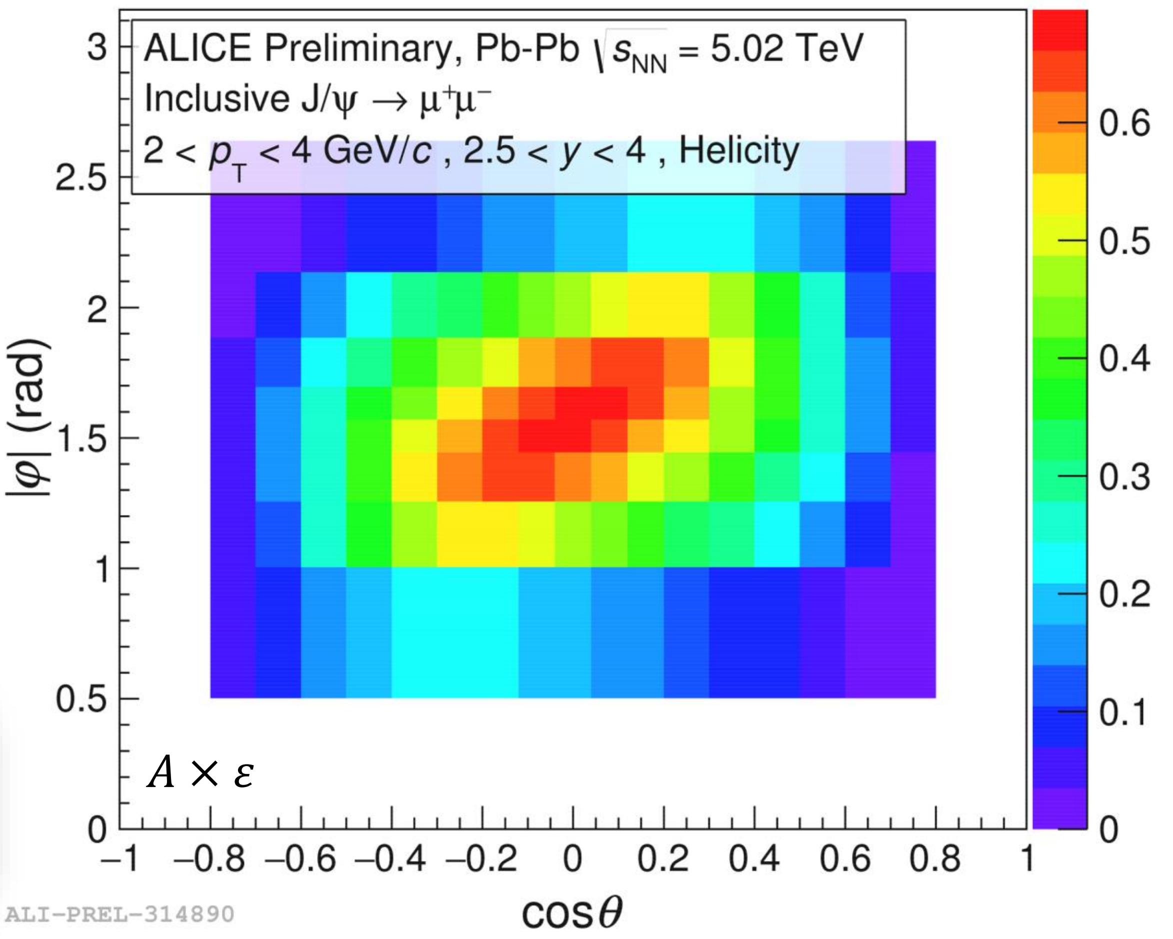
↓

Evaluation of $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$

↓

$\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ from previous step used for a new "polarized" Monte-Carlo

→ New evaluation of $A \times \varepsilon$ → ($N_{J/\psi}$ distribution corrected with $A \times \varepsilon$)

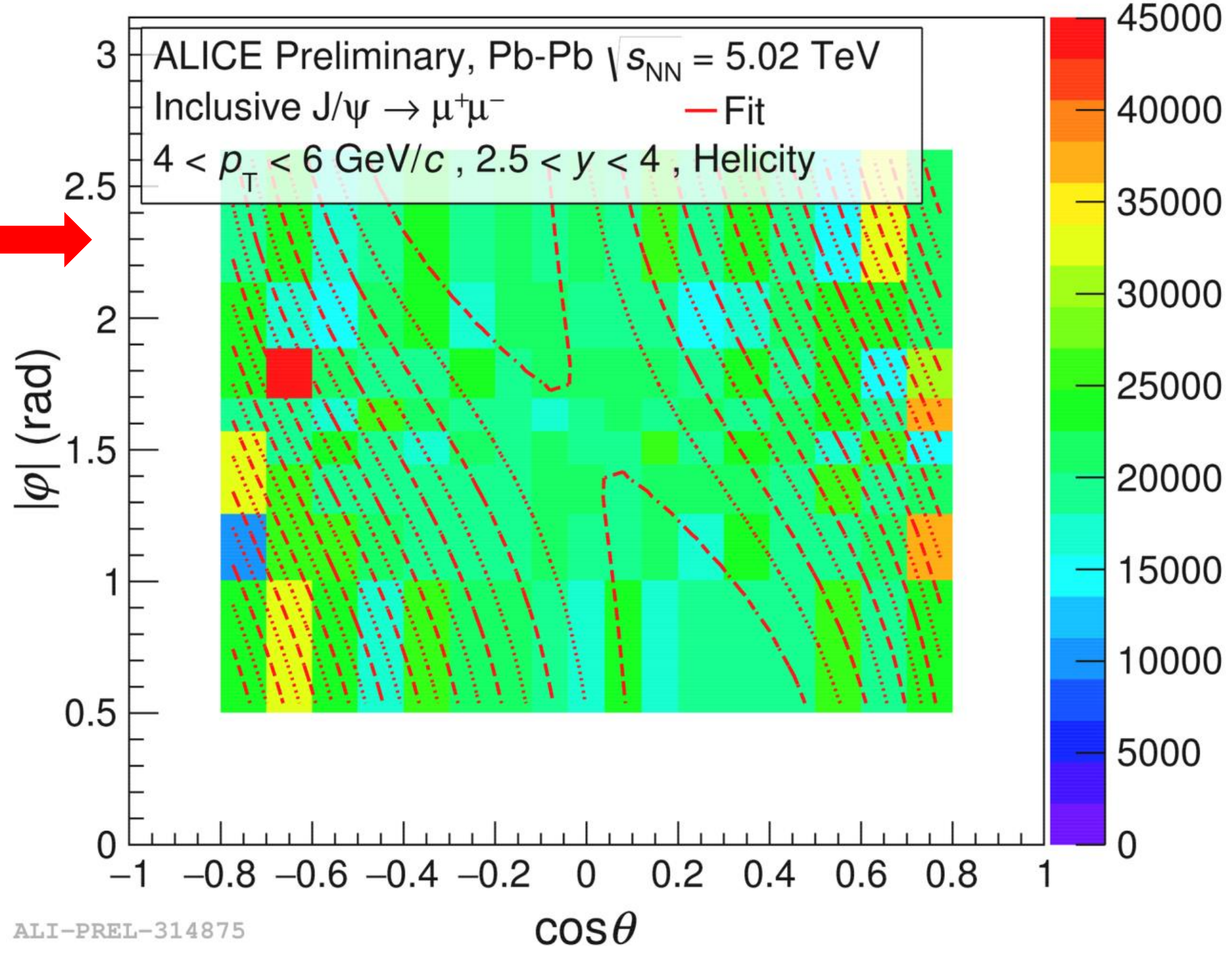


→ **STOP**: no significant variation from one iteration to the other (5 iterations done)

Extraction of the polarization parameters

- Polarization parameters are obtained fitting the J/ψ angular distribution corrected for $A \times \varepsilon$

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



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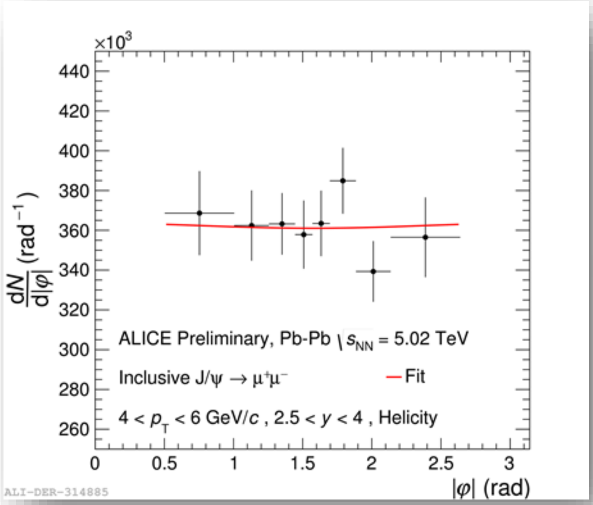
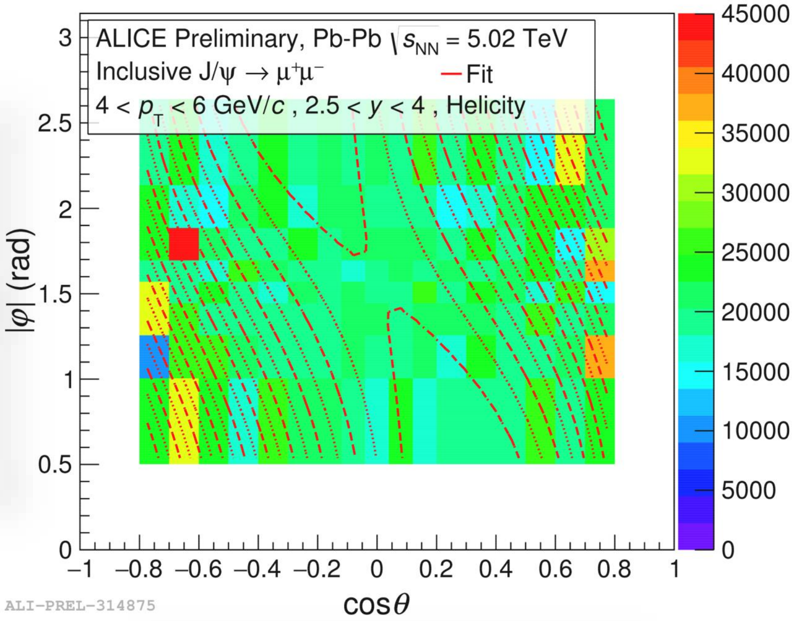
$$W(\cos\theta,\varphi) \propto \frac{1}{3+\lambda_\theta}\cdot(1+\lambda_\theta\cos^2\theta+\lambda_\varphi\sin^2\theta\cos2\varphi + \lambda_{\theta\varphi}\sin2\theta\cos\varphi)$$

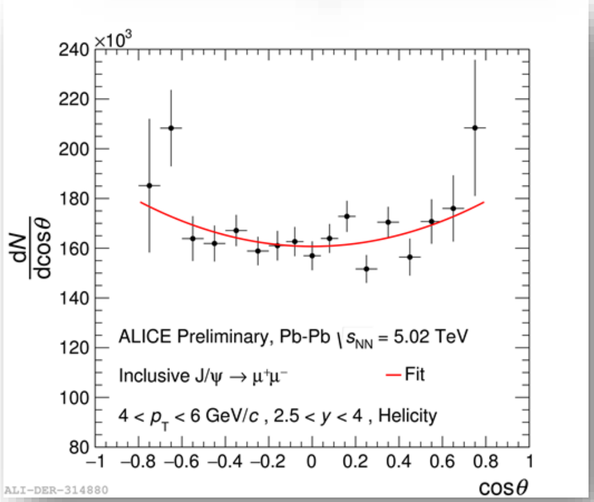




Check of the fit projecting the distribution along $\cos\theta$ and φ

$$\int W(\cos\theta,\varphi)d\varphi \rightarrow W(\cos\theta) \propto \frac{1}{3+\lambda_\theta}\cdot(1+\lambda_\theta\cos^2\theta)$$

$$\int W(\cos\theta,\varphi)d\cos\theta \rightarrow W(\varphi) \propto +\frac{2\lambda_\varphi}{3+\lambda_\theta}\cdot\cos2\varphi$$



Systematic uncertainties

Signal extraction

- Choice of various signal and background shapes for the fit to the invariant mass distributions
- Fix to the MC or keep free the J/ψ width in the signal extraction procedure

Input MC shape

- Evaluation of the impact of different p_{T}, y MC input shapes on the polarization parameters

Trigger efficiency

- Use single muon trigger response function extracted from data or MC

Tracking efficiency

- Calculated from single muon tracking efficiencies extracted from data or MC (negligible)

Preliminary results

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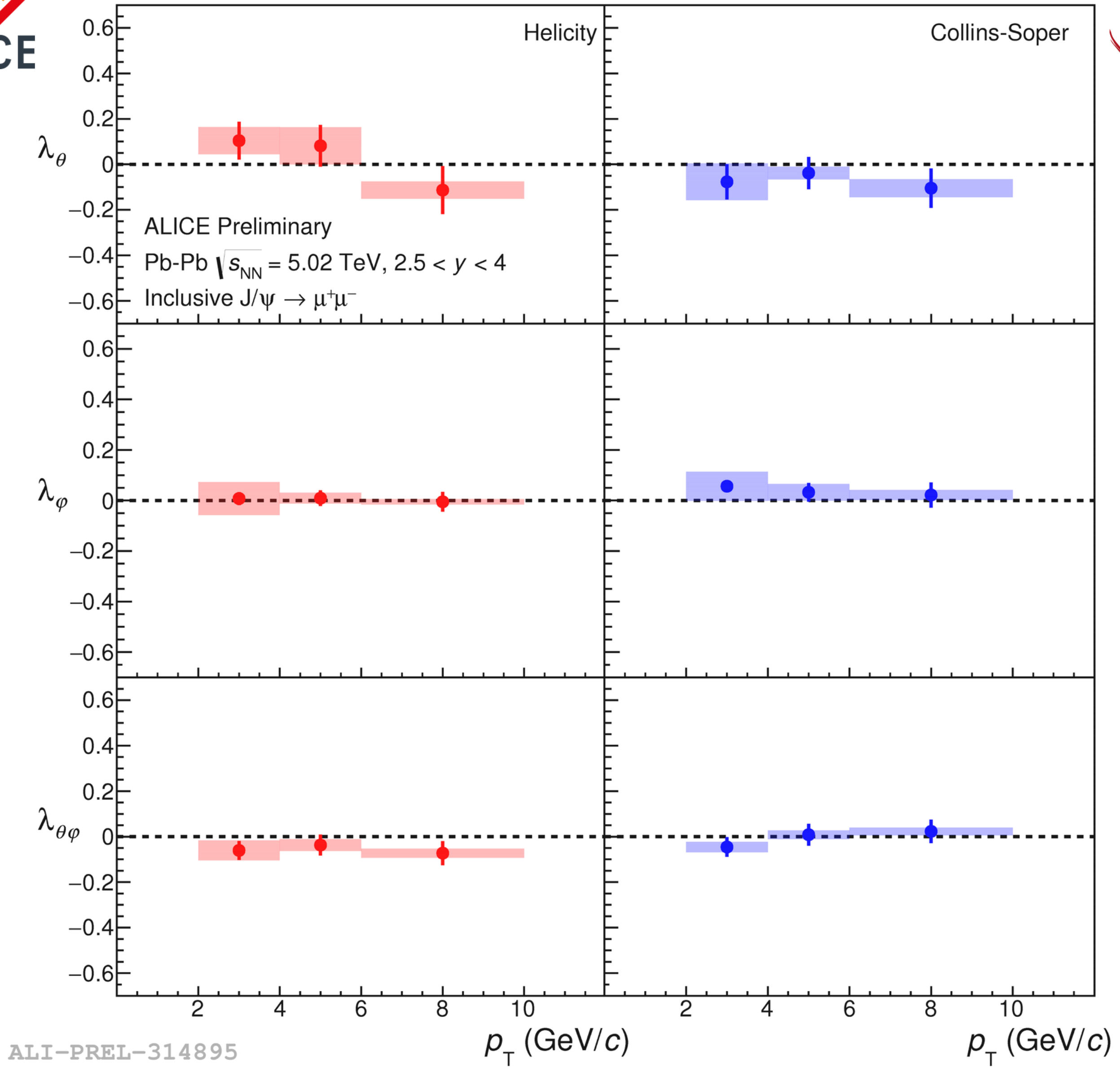
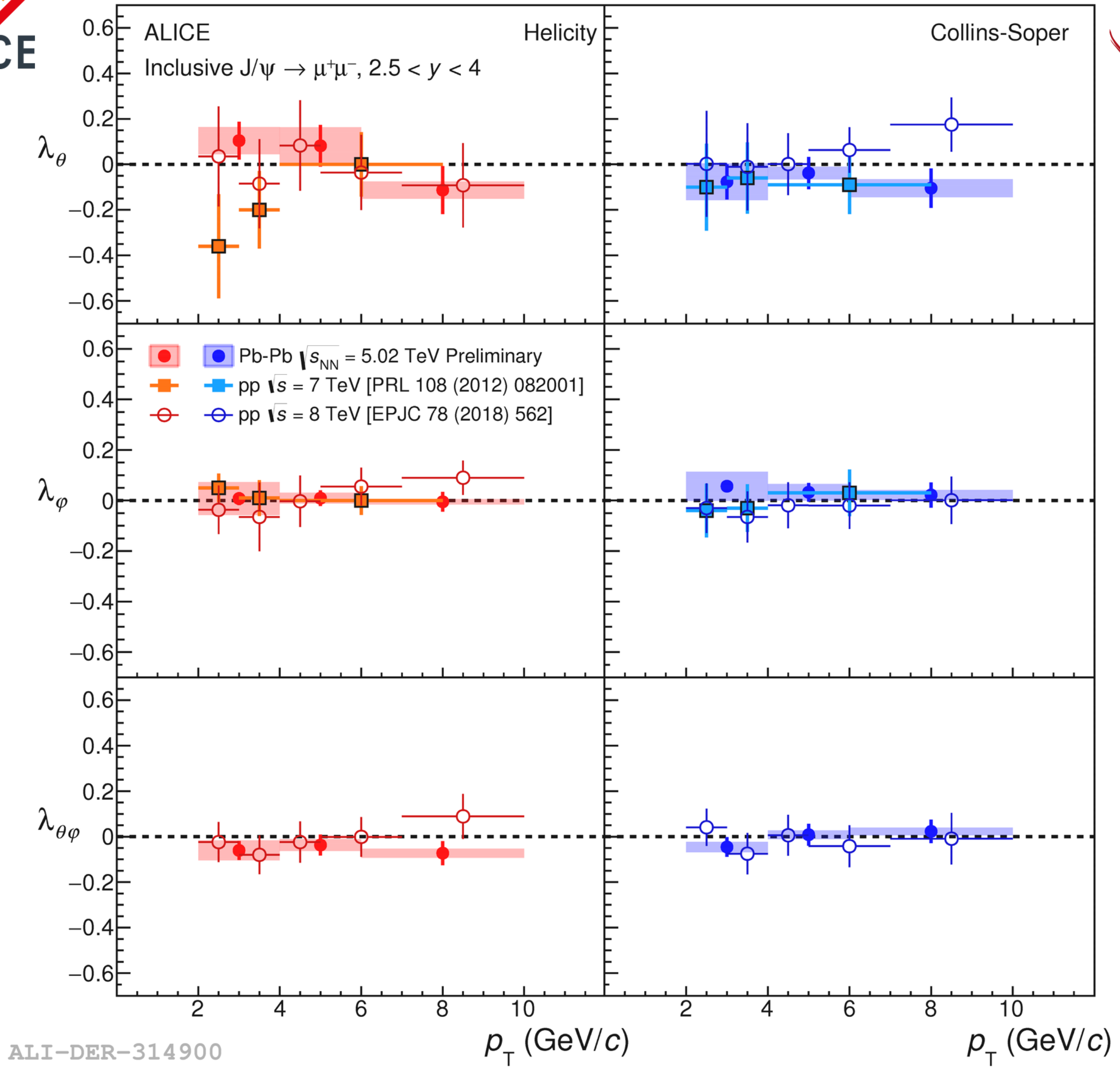


Polarization parameters as a function of p_T in the Helicity and Collins-Soper reference frames

- $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ compatible with zero
- This first measurement suggests weak or no J/ψ polarization also in heavy-ion collisions

Preliminary results



- Polarization parameters as a function of p_{T} in the Helicity and Collins-Soper reference frames
  - $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ compatible with zero
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- Comparison with ALICE results at $\sqrt{s} = 7$ and $8\ \mathrm{TeV}$ in pp collisions
  - No significant difference between $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ obtained in Pb-Pb and pp collisions

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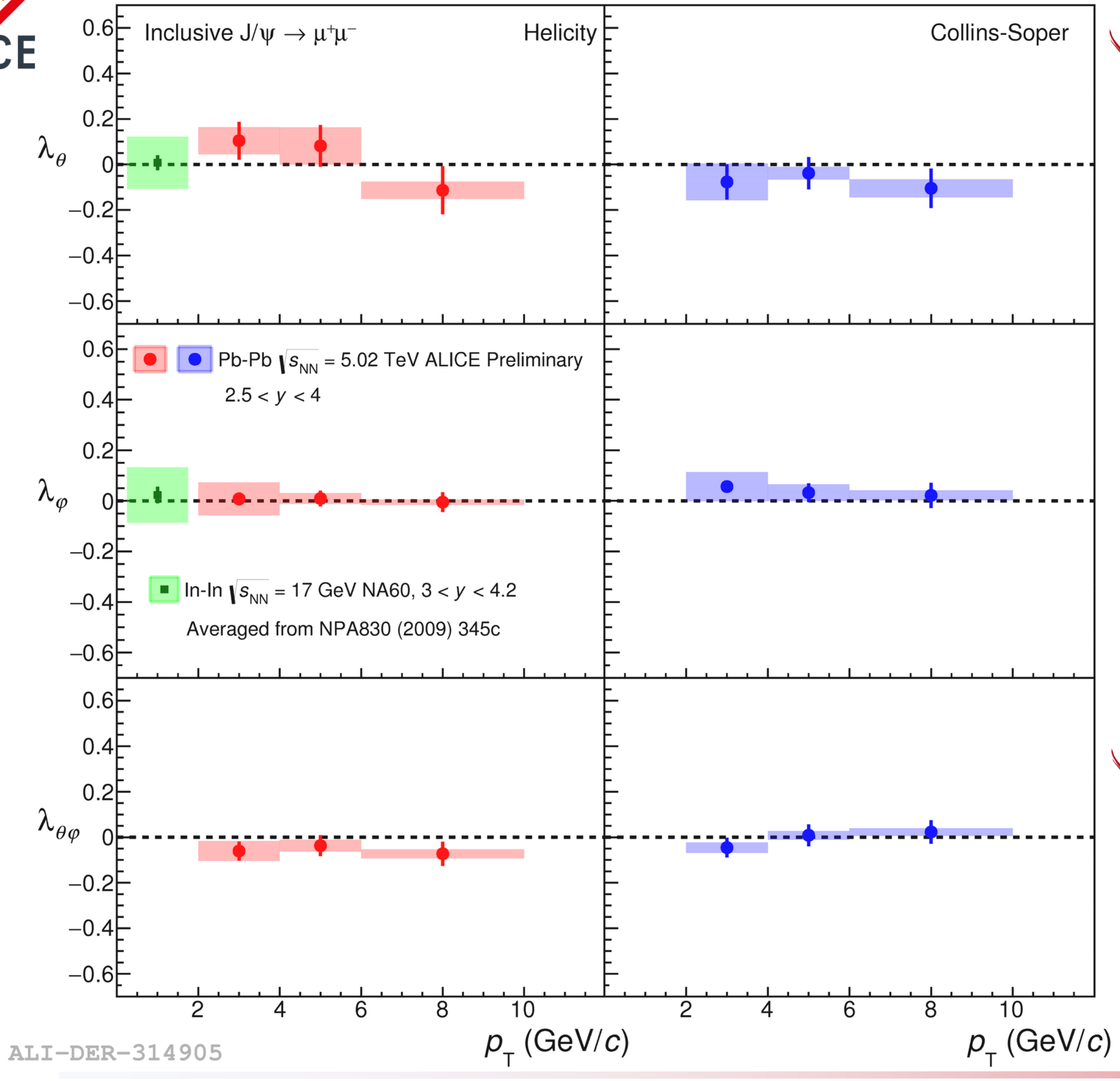

- Polarization parameters as a function of p_T in the Helicity and Collins-Soper reference frames
  - $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ compatible with zero
  - This first measurement suggests weak or no J/ψ polarization also in heavy-ion collisions
- Comparison with ALICE results at $\sqrt{s} = 7$ and 8 TeV in pp collisions
  - No significant difference between $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$ obtained in Pb-Pb and pp collisions
- Comparison with NA60 (preliminary) results in In-In collisions at $\sqrt{s_{NN}} = 17$ GeV
  - Similar behaviour in Pb-Pb and In-In collisions

Conclusions & future steps

ALICE

❗ **First measurement of J/ψ polarization in Pb-Pb collisions at the LHC**

ALICE preliminary results suggest polarization parameters close to zero in Pb-Pb collisions

Results in agreement with
- ❑ ALICE measurements of J/ψ polarization in pp collisions
- ❑ NA60 measurement of J/ψ polarization in a different colliding system (In-In) at lower energies

Future steps

- ❑ Study of the centrality dependence of the J/ψ polarization using the high statistics 2018 data set
- ❑ Study of the J/ψ polarization with respect to the event plane of the collision

➡ In more peripheral events, the collision geometry may lead to the formation of an intense magnetic field and/or to the formation of a fluid with non-zero vorticity