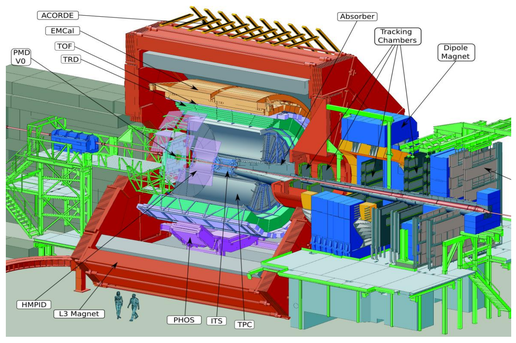
J/ψ polarization in p-p collisions at √s = 7 TeV with the ALICE experiment at the LHC

Livio Bianchi on behalf of the ALICE Collaboration*

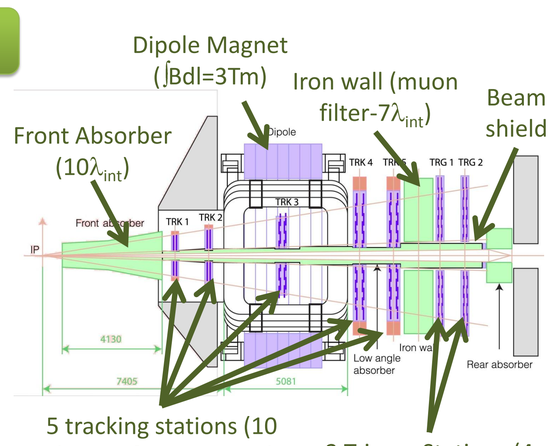
Abstract

The first measurement of inclusive J/ψ polarization at the LHC was carried out in pp collisions at √s = 7 TeV, by the ALICE experiment [1]. Reconstructing J/ψ in the dimuon channel at forward rapidity ($2.5 < y < 4.0$), we have measured its polarization to be rather small, with a hint for a non-zero value only for the lowest measured bin in transverse momentum, 2-3 GeV/*c*, in the helicity reference frame.

ALICE and the Muon Spectrometer



ALICE [10] is the experiment at the LHC specifically dedicated to the study of the hot and dense matter created in ultra-relativistic heavy-ion collisions (QGP).



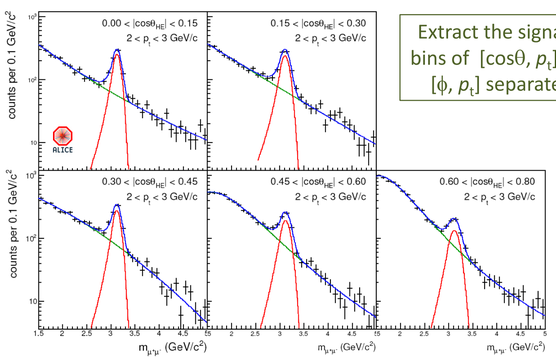
5 tracking stations (10 planes of MWPCs with bi-cathode pad readout)

2 Trigger Stations (4 planes of RPCs)

Muon offset with respect to primary vertex cannot be accurately determined → inclusive J/ψ measurement

Analysis Steps

Bulk part of data collected during 2010 (~100 nb^{-1})



Extract the signal in bins of [cosθ, p_t] and [ϕ, p_t] separately → Correct for A×ε → Fit the corrected spectra with:

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

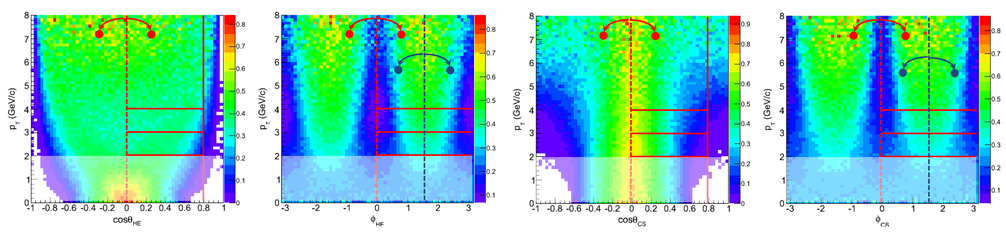
$$W(\varphi) \propto 1+\frac{2\lambda_\varphi}{3+\lambda_\theta}\, cos2\varphi$$

(integration of (1) over ϕ and cosθ respectively [7])

Signal extracted in the p_t region 2÷8 GeV/*c* and with the following binning

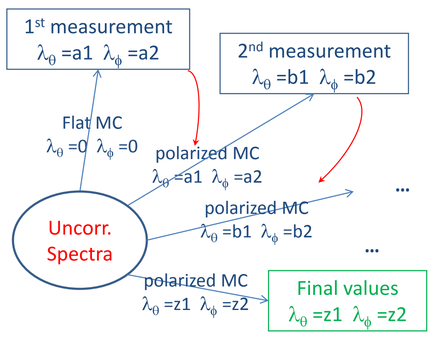
|cosθ|: [0-0.15], [0.15-0.3], [0.3-0.45], [0.45-0.6], [0.6-0.8]
|ϕ|: [0-0.63], [0.63-0.94], [0.94-1.26], [1.26-π/2]
p_t: [2-3], [3-4], [4-8] GeV/*c*

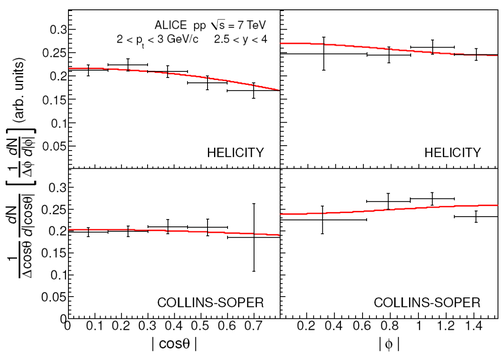
Acceptance and efficiency evaluated through realistic Monte Carlo.
As a starting point FLAT cosθ and ϕ input distributions in the simulation.



Integration of the signal over the angular variables
↓
Need to make an assumption on the polarization set in the MC sample used for acceptance correction → POSSIBLE BIAS!
↓
An iterative procedure is used: at each step polarization in the MC tuned to the values estimated at the previous step

The procedure converges if at the step *n* the values are the same estimated at the step *n-1*.
Convergence observed after at most 2-3 iterations!





After each step of the iterative procedure the corrected spectra were fitted simultaneously in the two reference frames. The invariance condition:

$$\mathcal{F} = \frac{\lambda_\theta^{HE} + 3\lambda_\phi^{HE}}{1-\lambda_\phi^{HE}} = \frac{\lambda_\theta^{CS} + 3\lambda_\phi^{CS}}{1-\lambda_\phi^{CS}}$$

is required in the fit, so that the number of free angular parameters reduces from 4 to 3.

Several sources of systematic uncertainty were investigated: signal extraction, input p_t and *y* distributions in the MC, cosθ fitting range in the lowest p_t bin, trigger and tracking efficiency

Quarkonium Production

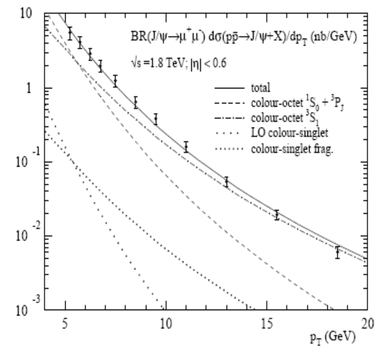
Quarkonium hadroproduction is an issue which is still not theoretically understood.
Several models on the market [2]. Among them:

- **Colour Singlet Model (CSM)**: heavy quark pair produced in a color singlet state;
- **Colour Octet Model (COM)**: two quarks created in a color octet state and then evolves in a colorless bound state with the emission of soft gluons

The two models are different truncations of the effective field theory called Non-Relativistic QCD (NRQCD) [2].

The CSM-LO was ruled out by the CDF Run I p_t differential cross-section [3], while NRQCD described perfectly the shape [2].

Higher order calculations of CSM [4] are approaching the data (PHENIX and STAR [5,6])



J/ψ polarization: how and why

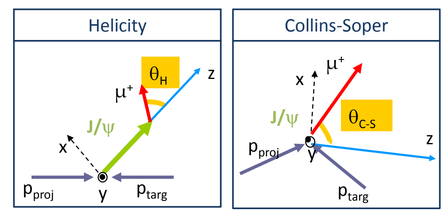
J/ψ polarization is measured [7] through the study of the angular distribution of the decay products which, taking as a reference the μ^+, is given by:

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

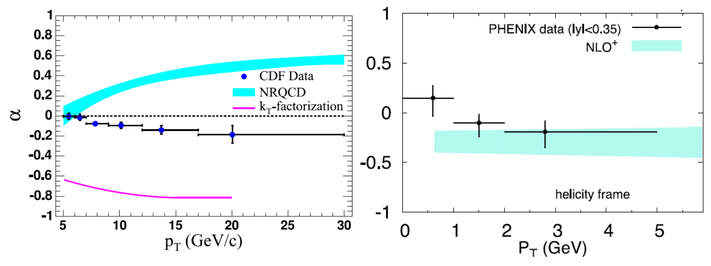
λ_θ is the fundamental parameter, directly affected by polarization:

λ_θ = +1 → **transverse polarization**
λ_θ = 0 → **no polarization**
λ_θ = -1 → **longitudinal polarization**

The angular distribution is measured in a given reference frame. Two definitions used:



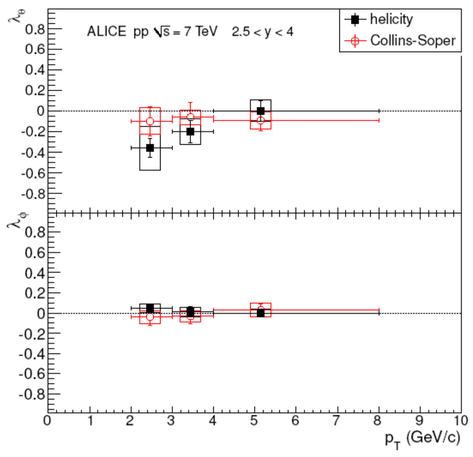
CSM and NRQCD make different predictions on p_t dependence of λ_θ:
- COM fails the prediction of CDF Run II measurement [8]
- CSM-NLO makes a better job for Tevatron and Phenix data at mid-rapidity [4,9]



Results and comparison with theory

Hint (1.6σ level) for longitudinal polarization at very low p_t in the helicity frame. It vanishes at ~5 GeV/*c*

In the Collins-Soper frame λ_θ everywhere compatible with zero (systematically slightly lower)



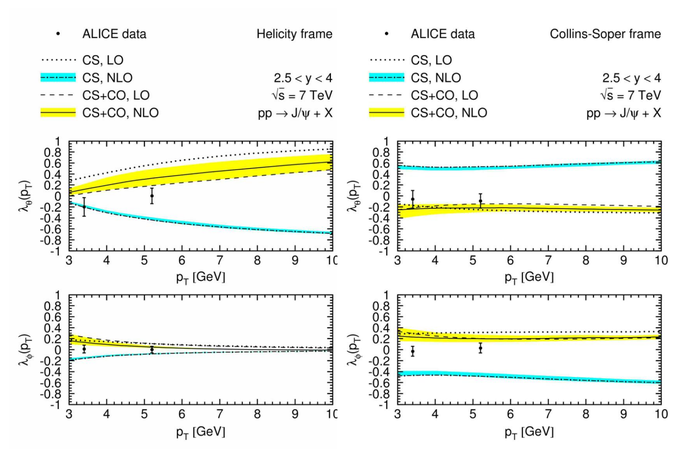
λ_ϕ compatible with zero in all the explored p_t range

$\lambda_{\theta\phi}$ assumed to be zero. The assumption was checked *a-posteriori* to be realistic

NLO full calculations of NRQCD (CSM+COM) and CSM carried out very recently [11,12].
Also a prediction on J/ψ polarization at the LHC energy has been provided:

CAVEAT: curves for direct production, our data for inclusive

Result of the comparison promising.
NRQCD is favored with respect to CSM, especially in the Collins-Soper reference frame, where the strong transverse polarization expected is not observed in our results



Conclusions

ALICE studied inclusive J/ψ polarization in pp collisions at √s = 7 TeV

No significant polarization observed. λ_ϕ everywhere compatible with zero, while the λ_θ parameter in the helicity frame gives a hint for longitudinal polarization at low p_t. In the Collins-Soper frame λ_θ is compatible with zero in all the p_t range, but systematically slightly negative.

The comparison of the results with calculations of NRQCD and CSM at NLO is encouraging and favors the first approach, especially in the Collins-Soper frame.

Reference:

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Contact: lbianchi@to.infn.it

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*INFN Torino