J/ψ production in pp collisions with the ALICE experiment at the LHC

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QWG – 8th International Workshop on Heavy Quarkonium

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Outline

The ALICE experiment and its capabilities for quarkonia detection

J/ψ production cross-section at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 2.76 TeV

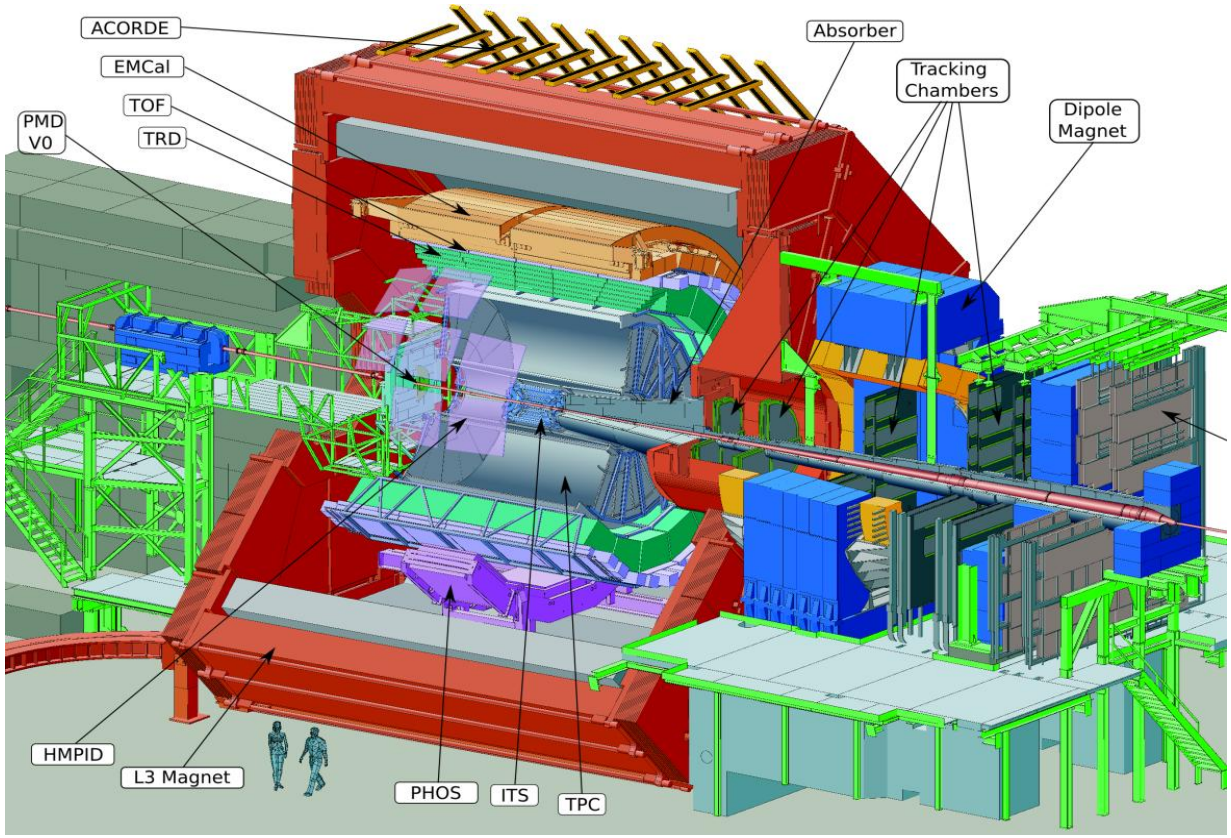
Multiplicity dependence of J/ψ production in pp collisions at $\sqrt{s}$= 7 TeV

Determination of the fraction B$\rightarrow$J/ψ at central rapidity and low p_T

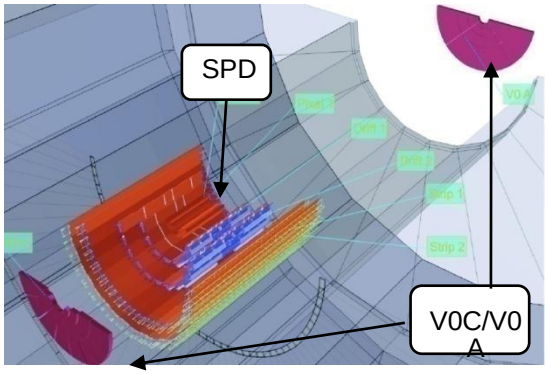
NEW Inclusive J/ψ polarization study at $\sqrt{s}$ = 7 TeV

Conclusions and prospects

The ALICE experiment



ALICE studies J/ψ production down to p_T=0 both at mid-rapidity (**|y|<0.9**) in the di-electron channel and at forward rapidity (**2.5<y<4**) in the di-muon channel



Inner Tracking System (ITS), 6 layers:
- 2 pixel layers (SPD)
- 2 drift layers (SDD)
- 2 strip layers (SSD)

Time Projection Chamber (TPC): main tracking detector, used for PID via specific energy loss

V0: scintillator arrays at forward and backward rapidities – used for MB trigger (with SPD) and for centrality determination

Muon Spectrometer:
- Front absorber
- 5 tracking stations
- Dipole magnet
- Iron wall
- 2 trigger stations

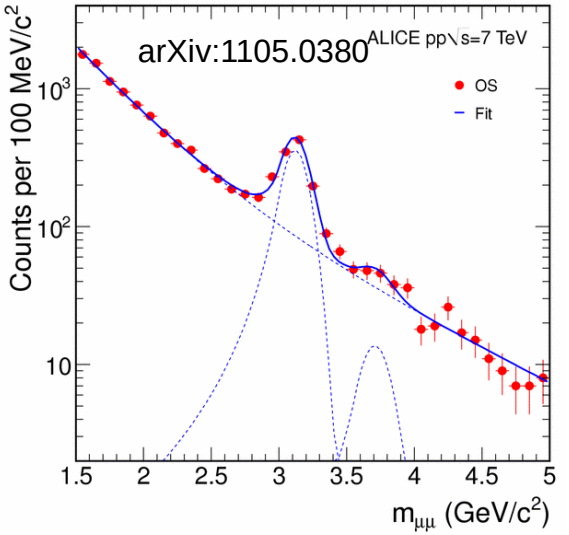
$pp \rightarrow J/\psi + X$ studies in ALICE

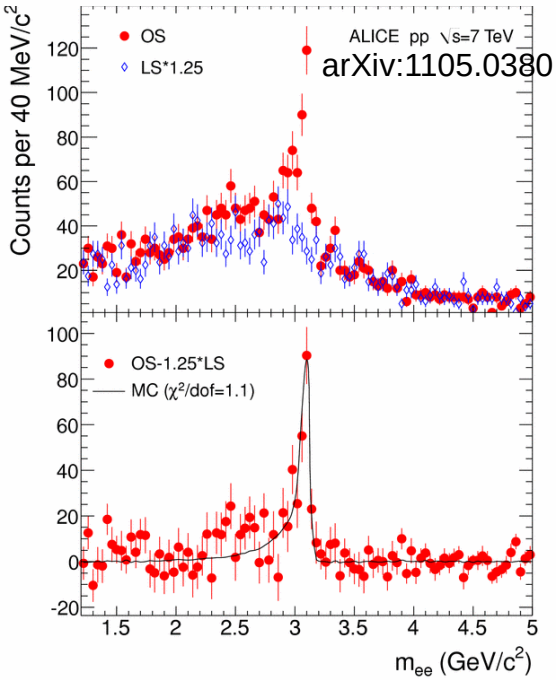
$J/\psi \to \mu^+\mu^-$ ($\to e^+e^-$) in pp: cross-sections studies

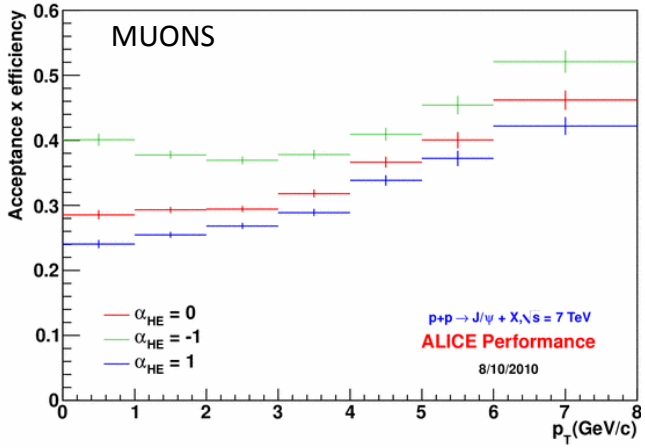
ALICE took data in pp runs at 7 TeV (arXiv:1105.0380, accepted by Phys. Lett. B) and 2.76 TeV. Integrated luminosity for these analysis:

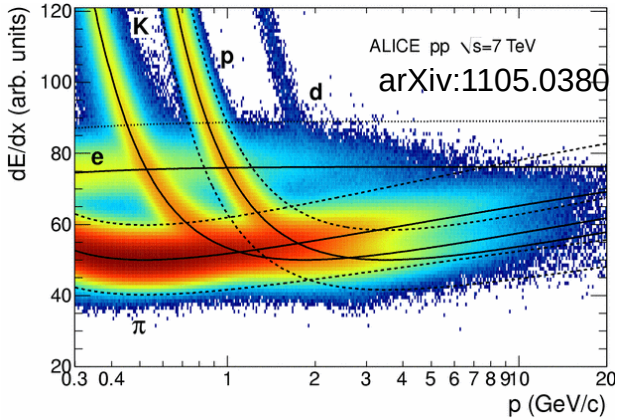
	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
$\sqrt{s}$ = 7 TeV	15.6 nb^{-1}	3.9 nb^{-1}
$\sqrt{s}$ = 2.76 TeV	20.2 nb^{-1}	1.1 nb^{-1}

IMPORTANT:
for both e^+e^- and $\mu^+\mu^-$ studies the acceptances do not depend strongly on p_T and the measurement extends down to p_T=0









pp at √s=7TeV & 2.76TeV: cross-section

Integrated inclusive J/ψ production cross sections:

$\sigma(2.5<y<4) = 6{,}31 \pm 0.25(\text{stat}) \pm 0.8(\text{syst})^{+0.95(\lambda_{CS}=+1)}_{-1.96(\lambda_{CS}=-1)}$ μb
$\sigma(|y|<0.9) = 10{,}7 \pm 1.2(\text{stat}) \pm 1.7(\text{syst})^{+1.6(\lambda_{HE}=+1)}_{-2.3(\lambda_{HE}=-1)}$ μb

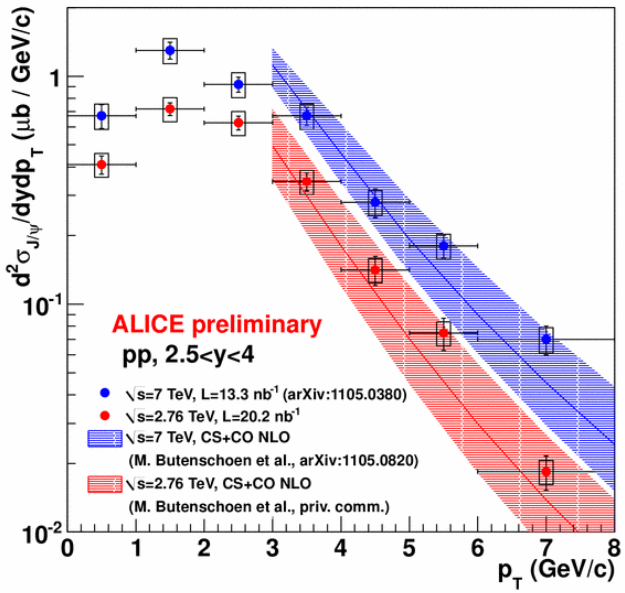
7 TeV
arXiv:1105.0380

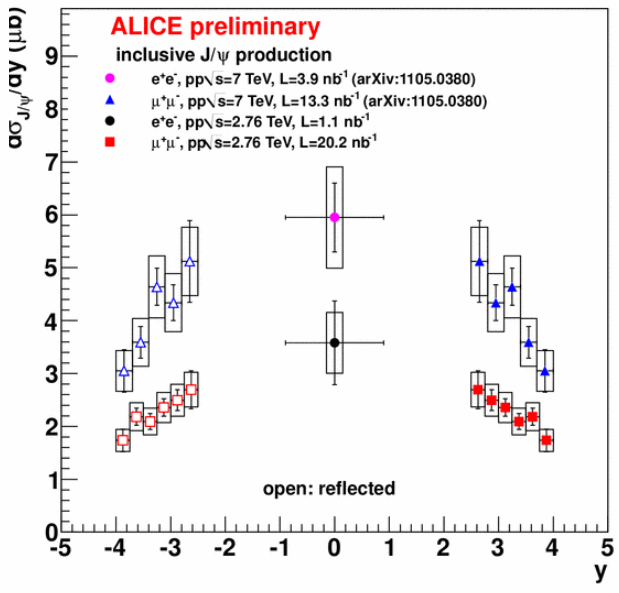
$\sigma(2.5<y<4) = 3{,}46 \pm 0.13(\text{stat}) \pm 0.32(\text{syst}) \pm 0.28(\text{lumi})^{+0.55(\lambda_{CS}=+1)}_{-1.11(\lambda_{CS}=-1)}$ μb
$\sigma(|y|<0.9) = 6{,}44 \pm 1.42(\text{stat}) \pm 0.88(\text{syst}) \pm 0.52(\text{syst})^{+0.64(\lambda_{HE}=+1)}_{-1.42(\lambda_{HE}=-1)}$ μb

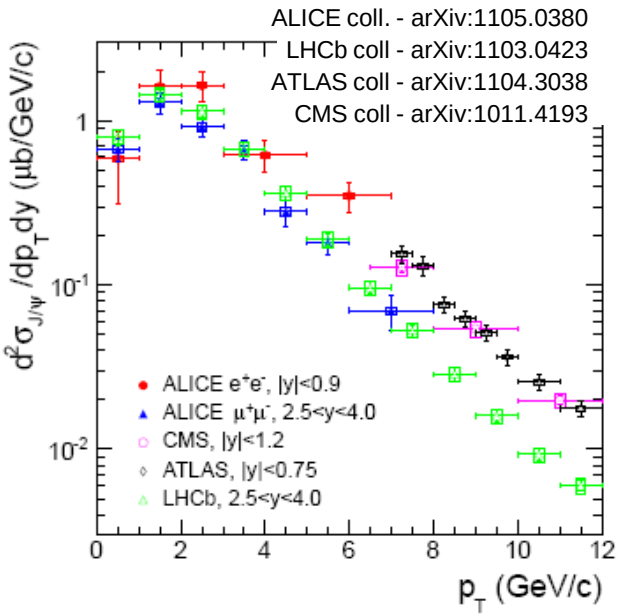
2.76 TeV
arXiv:1107.0137

At forward rapidity the $d^2\sigma/dydp_T$ was extracted at both the energies → well reproduced by NRQCD calculations at NLO

Comparison of 7 TeV results with other LHC experiments: fair agreement both at forward rapidity (with LHCb) and at mid rapidity, where ALICE is complementary to ATLAS and CMS

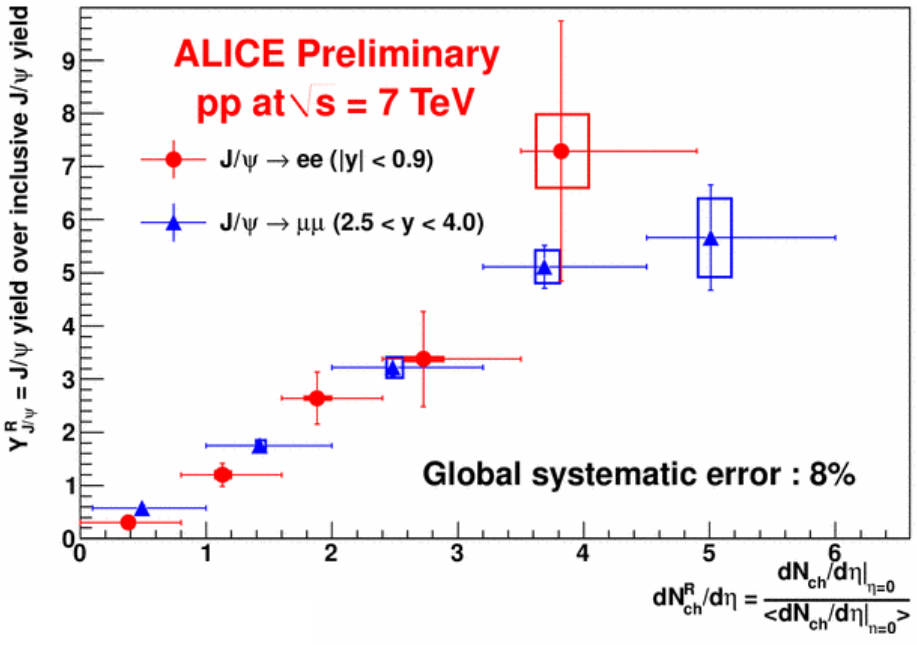


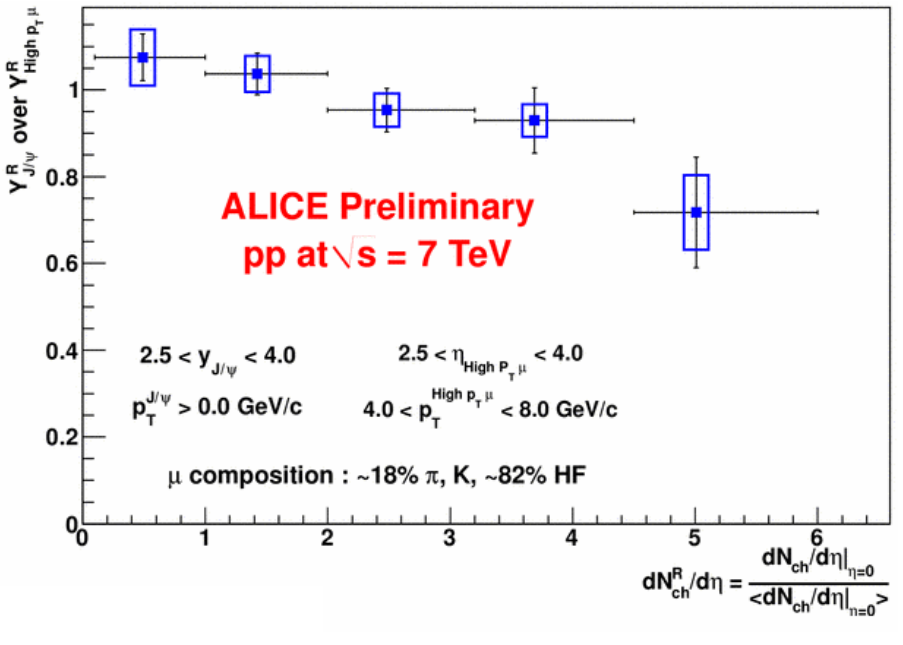




J/ψ production VS multiplicity at √s=7TeV

J/ψ yield as a function of the charged particle multiplicity studied at central and forward rapidities.
Linear increase observed





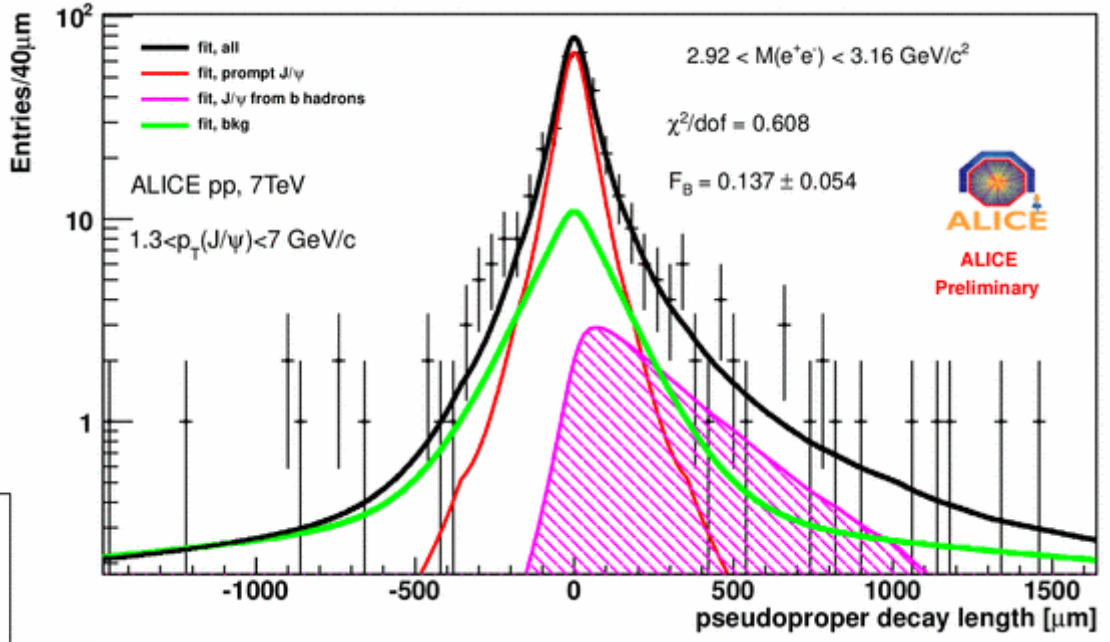
The J/ψ yield exhibits a weaker increase with $dN_{ch}/d\eta$ than the high p_T muons (>80% of which are coming from heavy flavors). Different mechanisms can explain this observation such as kinematical effects, modification of the p_T distribution, modification of the bottom to charm ratio, multi parton interactions, etc..

Additional details in the Gines's talk next Thursday

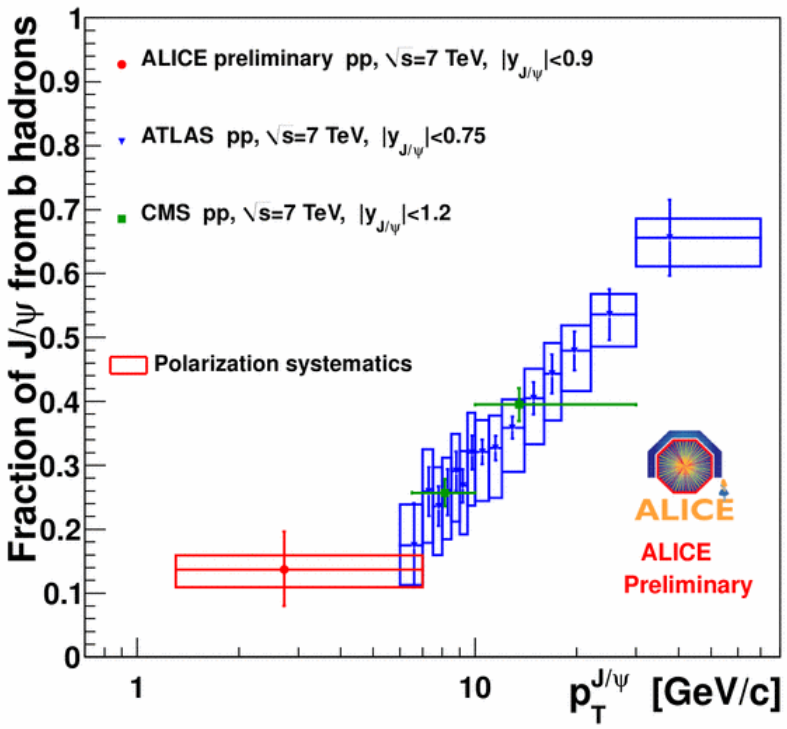
Identification of non-prompt J/ψ

At mid-rapidity (|y|<0.9) ALICE is able to extract the non-prompt fraction of the total inclusive J/ψ cross-section:
log-likelihood fit to the pseudo-proper decay length distribution

Resolution on the impact parameter:
$\sigma_{r\varphi}$ < 75 μm for p_T > 1 GeV/c



The measurement extends the p_T reach of the LHC experiments at central rapidity down to 1.3 GeV/c



$F_B(1.3<p_T<7\text{GeV/c},|y|<0.9)=$
$\mathbf{0.137}\pm0.054(\text{stat})^{+0.025}_{-0.018}(\text{syst})^{+0.040(\lambda_{HE}=+1)}_{-0.021(\lambda_{CS}=-1)}$

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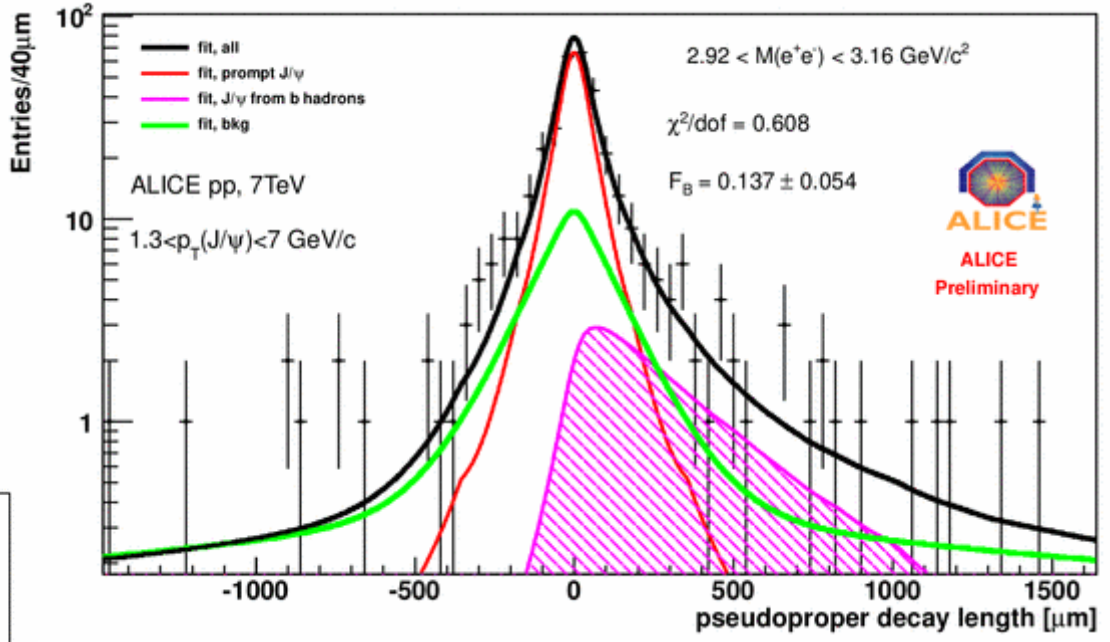

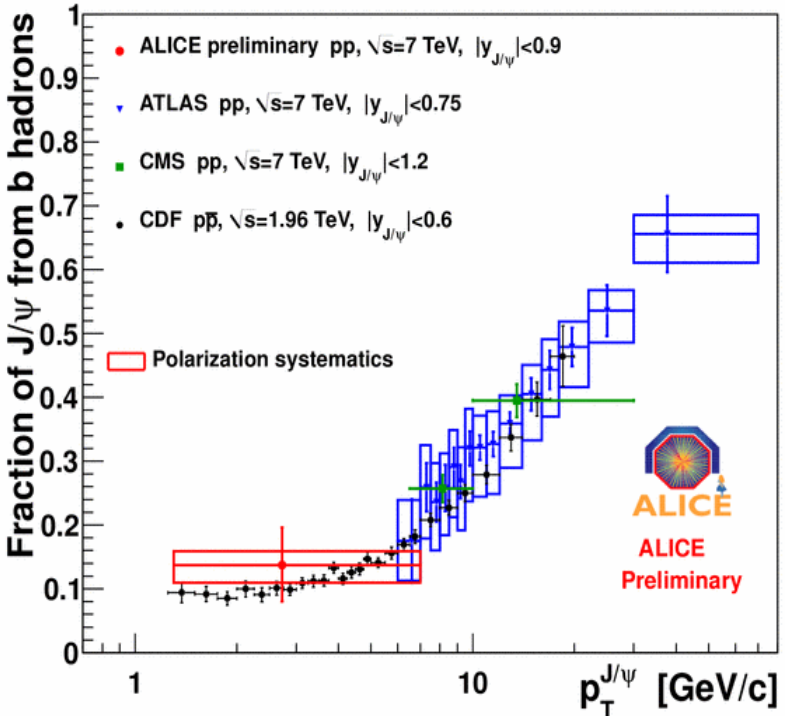

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$$F_B(1.3<p_T<7\text{GeV/c},|y|<0.9) = \mathbf{0.137} \pm 0.054(\text{stat}) {}^{+0.025}_{-0.018}(\text{syst}) {}^{+0.040(\lambda_{HE}=+1)}_{-0.021(\lambda_{CS}=-1)}$$

The extracted value is in agreement with CDF results

Larger statistics in 2011 data with a new triggering strategy (EMCAL)

J/ψ polarization in pp at √s = 7 TeV at forward rapidity

NEW

Polarization in a nutshell

The polarization of the J/ψ can be measured through the angular analysis of its daughter particles. Taking as a reference the μ^+, its angular distribution can be expressed as:

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

The reference frame can be chosen in different ways and is defined on a event-by-event basis

The parameters can be extracted in a 1D approach

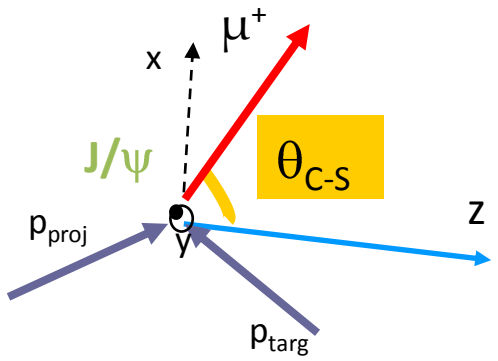
$$W(\cos\vartheta) \propto \frac{1}{3+\lambda_\vartheta}\left(1+\lambda_\vartheta \cos^2\vartheta\right)$$ Integrating over ϕ

$$W(\varphi) \propto 1 + \frac{2\lambda_\varphi}{3+\lambda_\vartheta}\cos 2\varphi$$ Integrating over cosθ

$$W(\tilde{\varphi}) \propto 1 + \frac{\sqrt{2}\,\lambda_{\vartheta\varphi}}{3+\lambda_\vartheta}\cos\tilde{\varphi}\,.$$ Defining $\tilde{\varphi} = \begin{cases} \varphi - \frac{3}{4}\pi & \text{for } \cos\vartheta < 0 \\ \varphi - \frac{\pi}{4} & \text{for } \cos\vartheta > 0 \end{cases}$ and integrating over cosθ

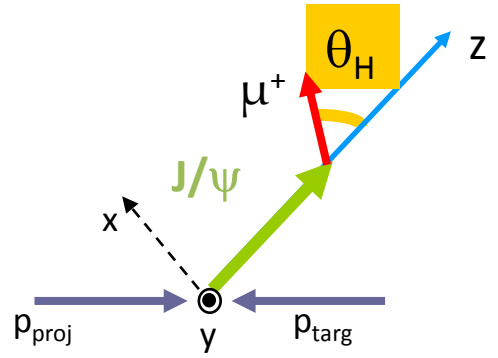
P.Faccioli *et al.*, arXiv:1006.2738

Collins-Soper



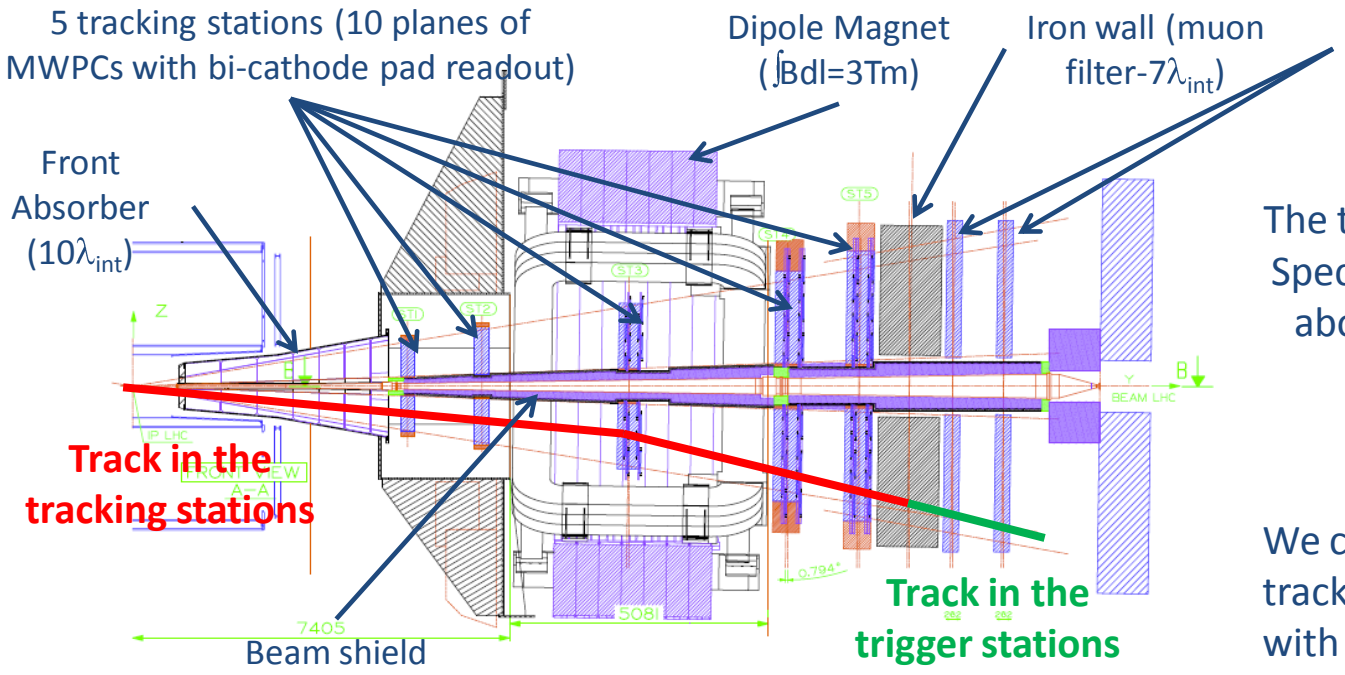
bisector of the angle between proj. and (-) target in the quarkonium C.M. frame.

Helicity



Direction of the quarkonium in the C.M. frame of the collision.

Muon Spectrometer and Trigger strategy



Hardware momentum cut: p_μ = 4 GeV/c

In this analysis the bulk part of **2010 data** is used

The data sample corresponds to
12400 J/ψ (L_{int}~100nb^{-1})

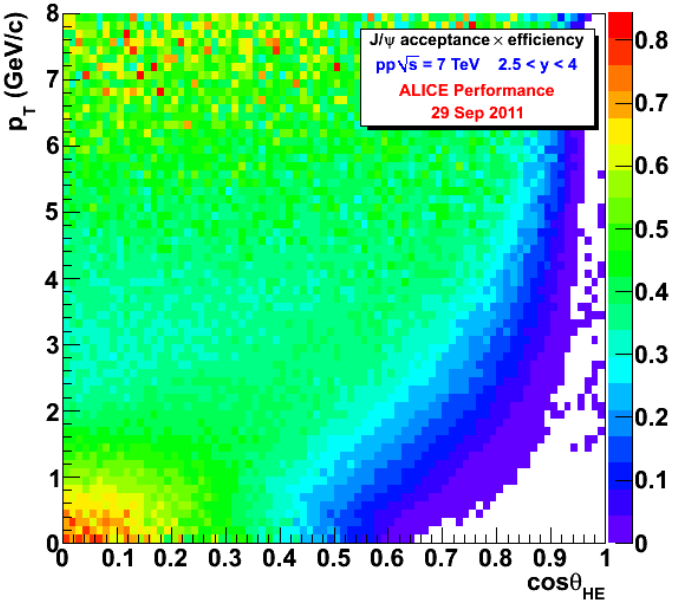
At least one muon matching the trigger (**1-MATCH**) is required
With this choice no p_T or cosθ cuts are introduced in the J/ψ sample

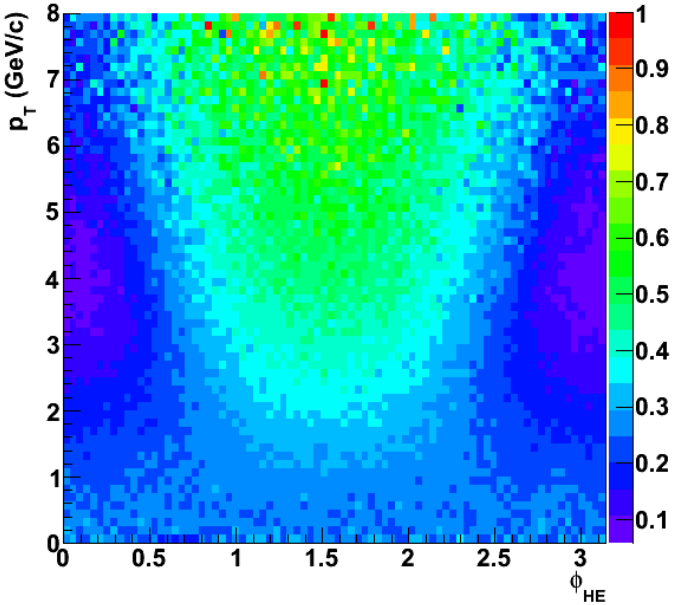
The trigger system of the Muon Spectrometer can select tracks above a p_T threshold (in this analysis 1 GeV/c).
The cut is not sharp.

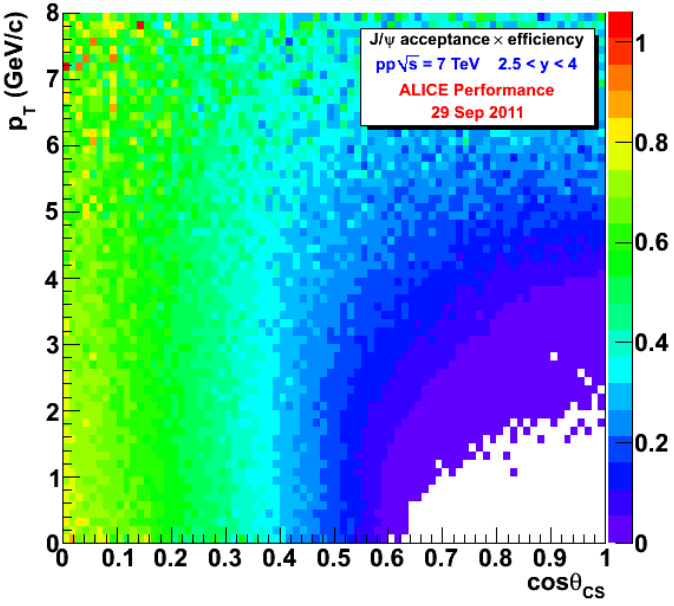
We can ask the track in the tracking stations to be matched with the track in the trigger part.
For a dimuon we can ask:

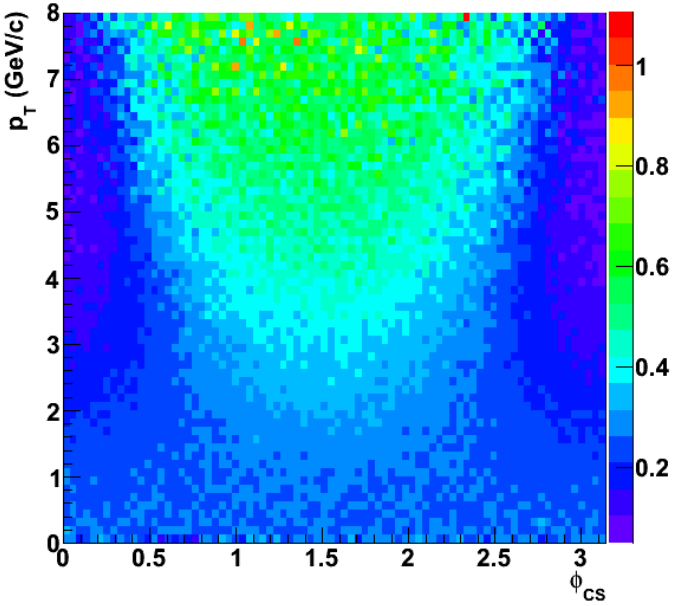
- No requirement on the matching of the track (**NO-MATCH**)
- At least 1 of the two muons matching the trigger (**1-MATCH**)
- Both the muons matching the trigger (**2-MATCH**)

2D Acceptances and kinematical constraints









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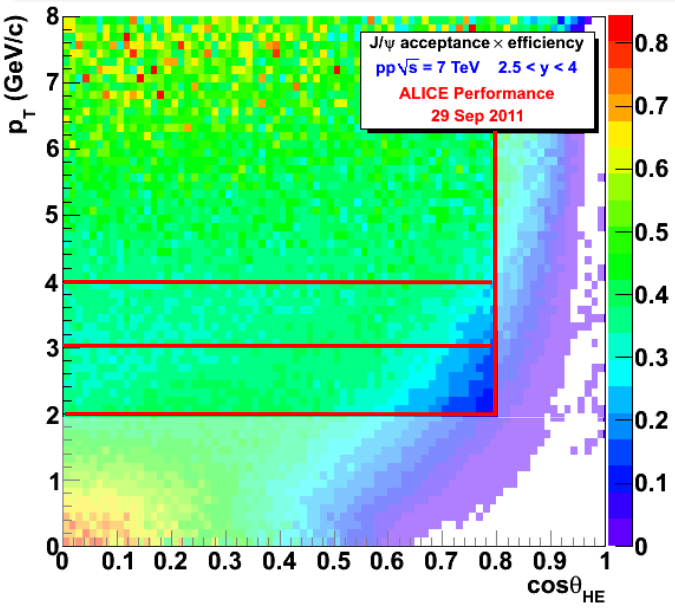
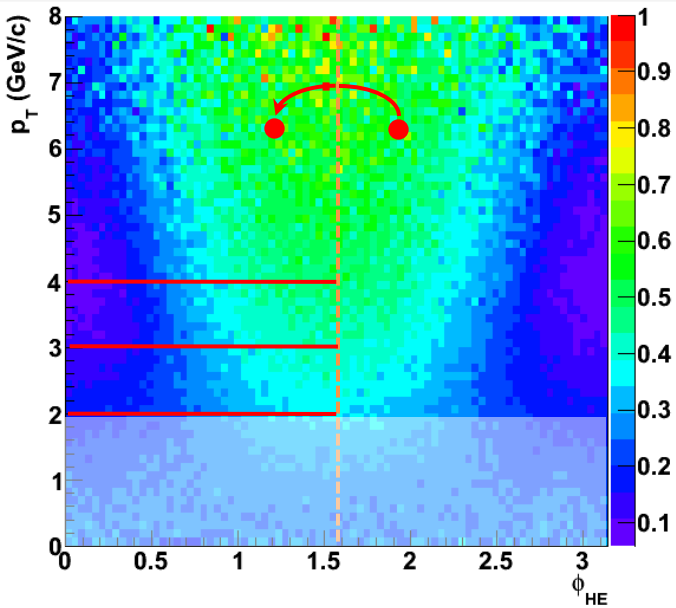
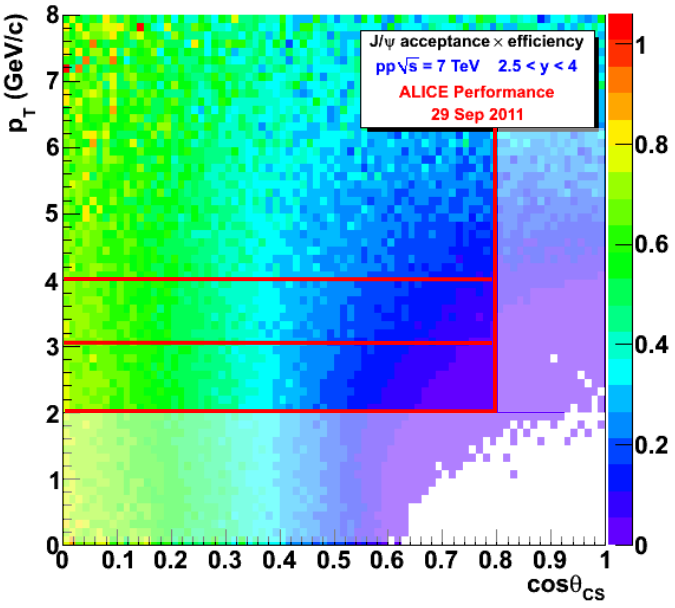
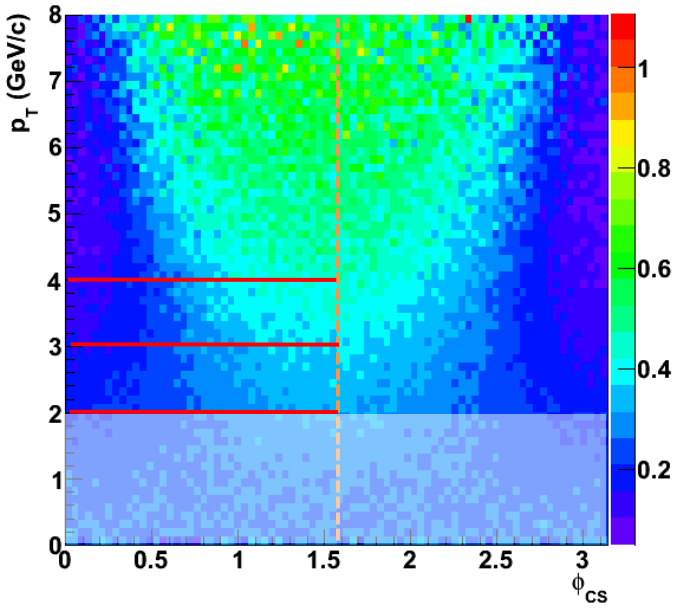




The 2D acceptance $[p_T, \cos\theta]$ becomes low for large $\cos\theta$ and low p_T

The analysis is performed in the region
$2 < p_T < 8$ GeV/c
$0 < |\cos\theta| < 0.8$

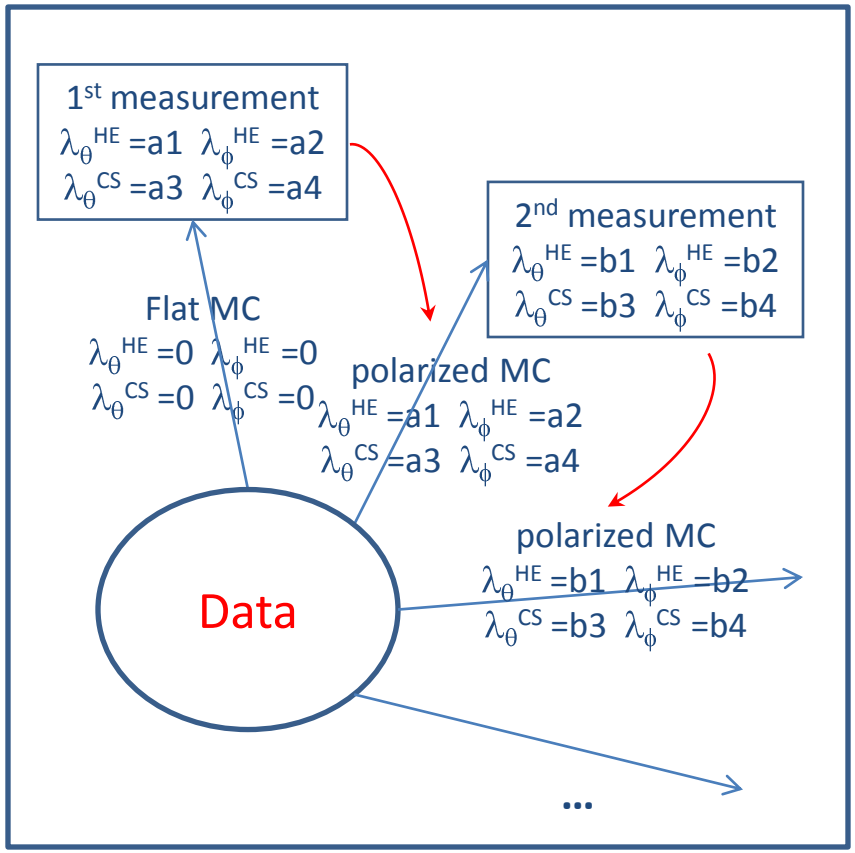




The 2D acceptance $[p_T, |\phi|]$ is symmetric wrt $|\phi|=\pi/2$: we perform the analysis mirroring the values of $|\phi| > \pi/2$ to the region $|\phi| \in [0,\pi/2]$

Analysis strategy

Since we integrate over ϕ ($\cos\theta$) to extract λ_θ (λ_ϕ) we use an iterative procedure which tunes the MC in order to take into account the correlations between the variables



The method performs quite well, converging in less than 4 iterations

Iterative procedure could be used also to extract $\lambda_{\theta\phi}$ but
with 3 variables the procedure is less stable.
We assume it to be 0 in our MC.
We will check our assumption a-posteriori

The acc×eff corrected spectra are fit simultaneously in the four variables
$\cos\theta_{HE}$ ϕ_{HE} $\cos\theta_{CS}$ ϕ_{CS}

Furthermore the invariance of the quantity

$$\tilde{\lambda} \equiv \mathcal{F}_{\{-3,0,1\}} = \frac{\lambda_\vartheta + 3\lambda_\varphi}{1 - \lambda_\varphi}.$$

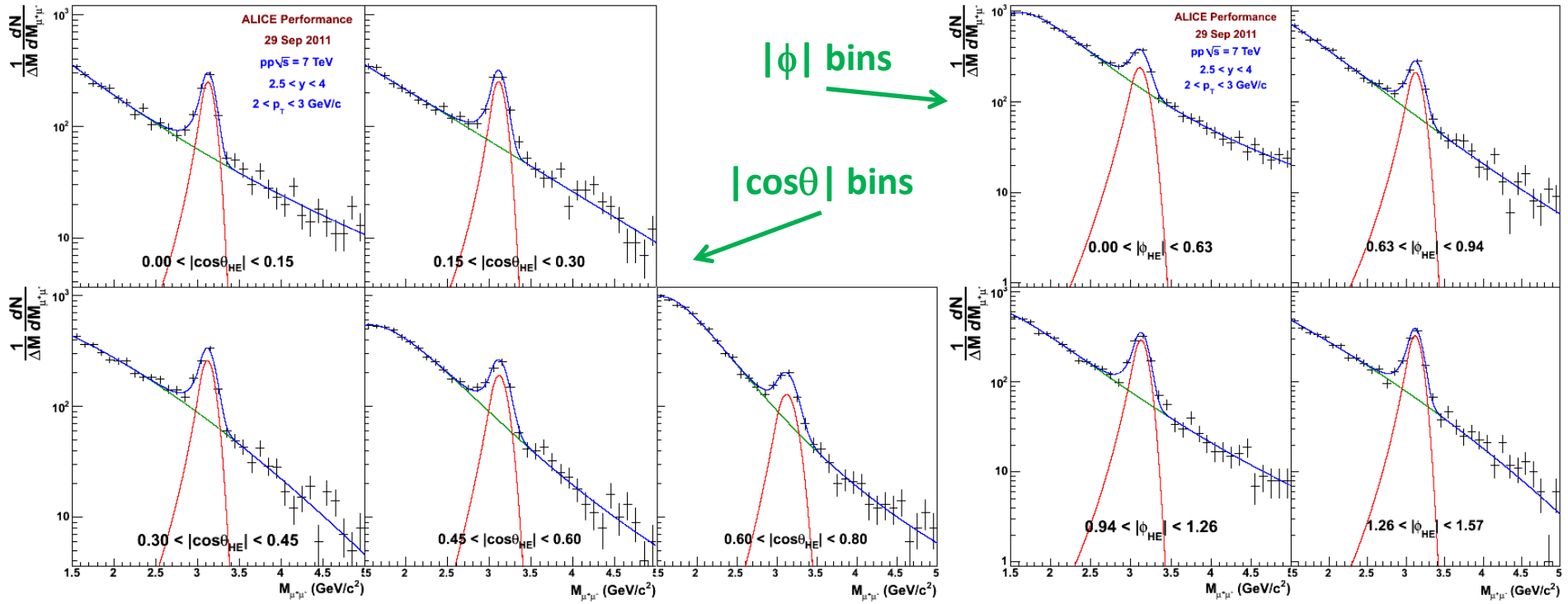
is imposed while fitting: in this way we better constrain the fit and we require "by construction" the compatibility between the two reference frames.

Some fits: helicity frame (2 < p_T < 3 GeV/c)

Binning used:
|cosθ|: [0.00,0.15] [0.15,0.30] [0.30,0.45] [0.45,0.60] [0.60,0.80]
|φ|: [0.00,0.63] [0.63,0.94] [0.94,1.26] [1.26,1.57]

The invariant mass spectra can be fit with the sum of a signal component (parameterized as a Crystal Ball function) and of a background component (parameterized via an empirical function).

The signal is clearly visible in all the bins (here some examples for 2<p_T<3 GeV/c). The S/B further increases…….



Some fits: helicity frame (4 < p_T < 8 GeV/c)

Binning used:

|cosθ|: [0.00,0.15] [0.15,0.30] [0.30,0.45] [0.45,0.60] [0.60,0.80]

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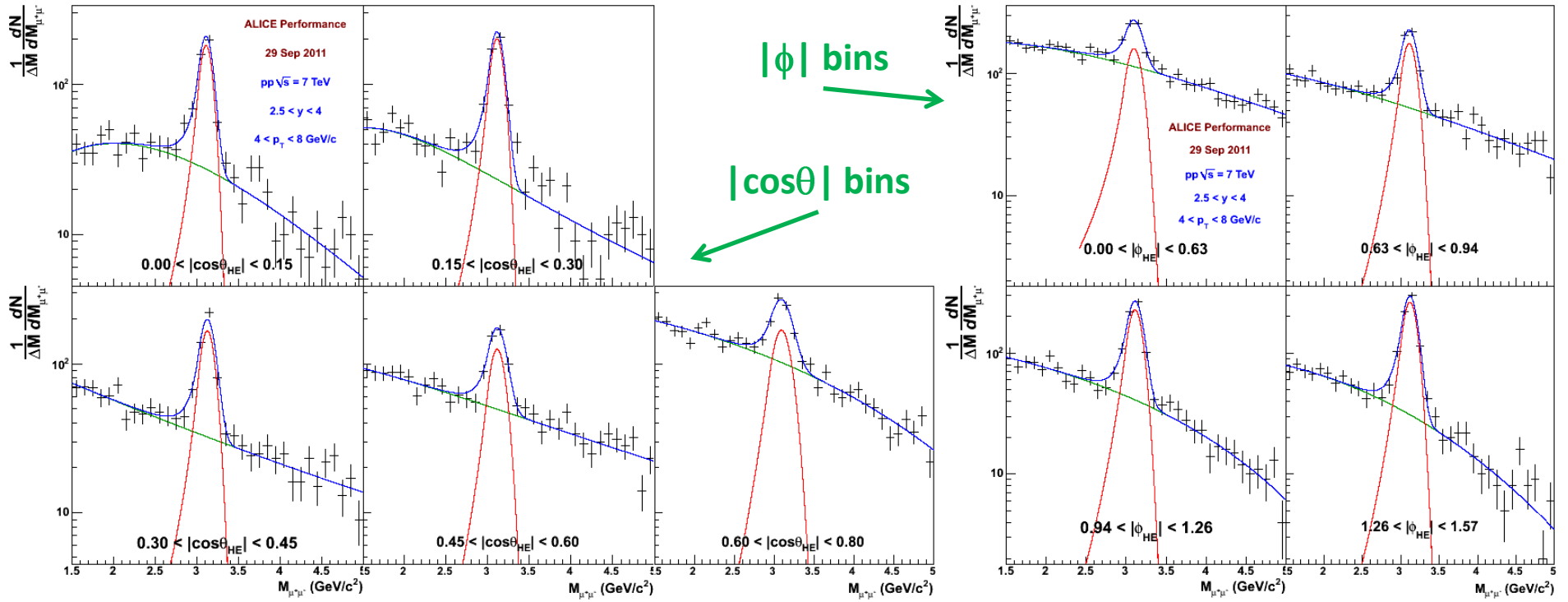
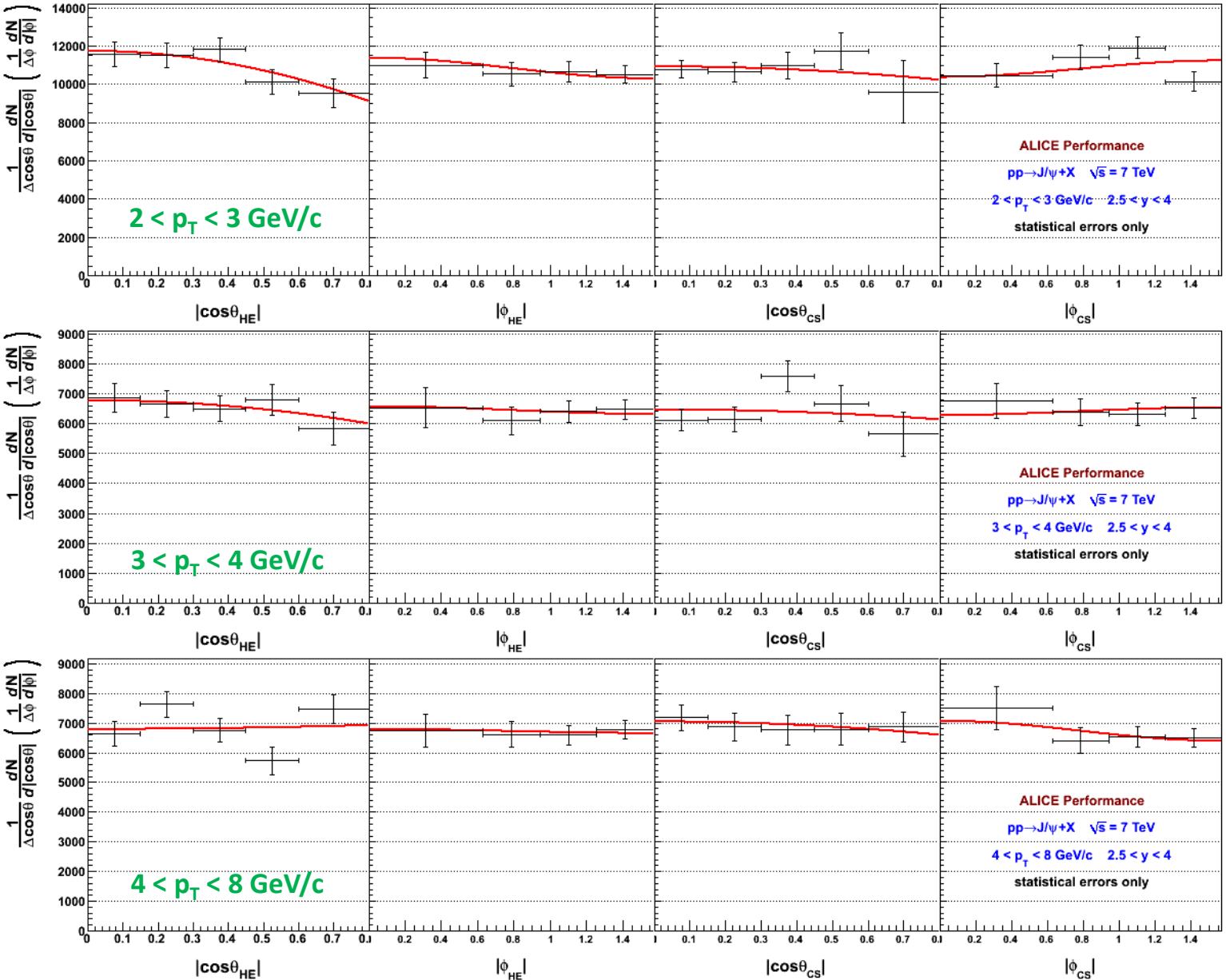
The invariant mass spectra can be fit with the sum of a signal component (parameterized as a Crystal Ball function) and of a background component (parameterized via an empirical function).

The signal is clearly visible in all the bins. The S/B further increases…….when moving to higher p_T (here some examples for 4<p_T<8 GeV/c).



Fits to the corrected angular spectra

Result of the simultaneous fits after the last iteration of the correction procedure

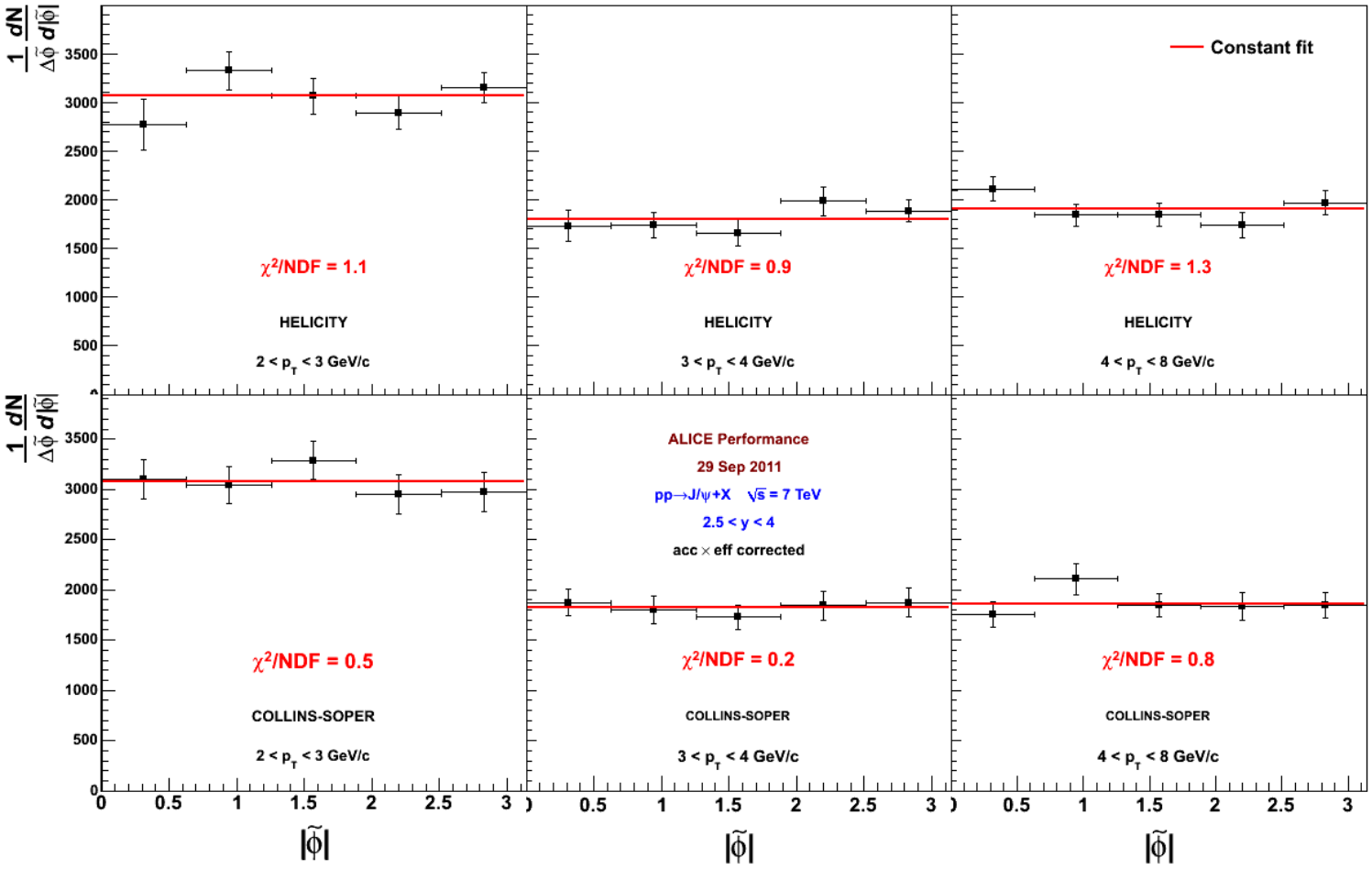


Considerations on $\lambda_{\theta\phi}$

The $\lambda_{\theta\phi}$ value in the MC iterative procedure was assumed to be zero
We can check the validity of our assumption by correcting the $\tilde{\phi}$ distribution with the MC tuned in the λ_θ and λ_ϕ parameters after the last iteration!

All the corrected $\tilde{\phi}$ spectra are flat

We conclude that the assumption $\lambda_{\theta\phi}$=0 in the analysis procedure is reasonable



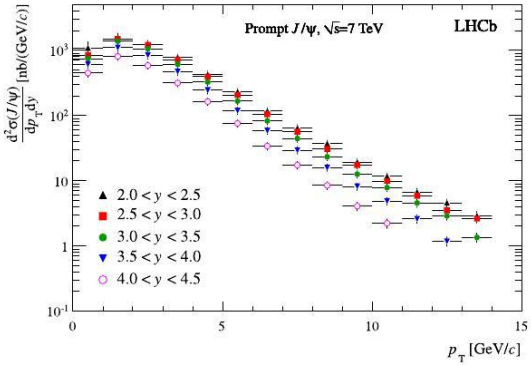
Considerations on B feed-down

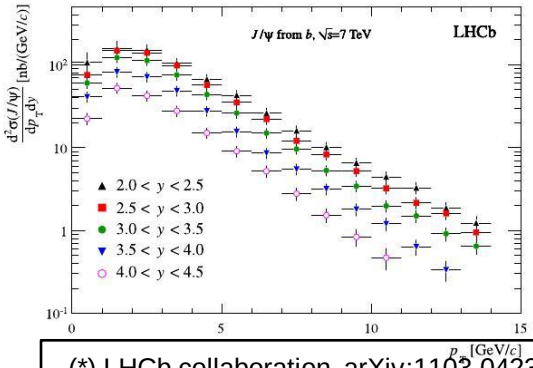
We are measuring the polarization of inclusively-produced J/ψ

What would be the value of the polarization parameters for prompt J/ψ?

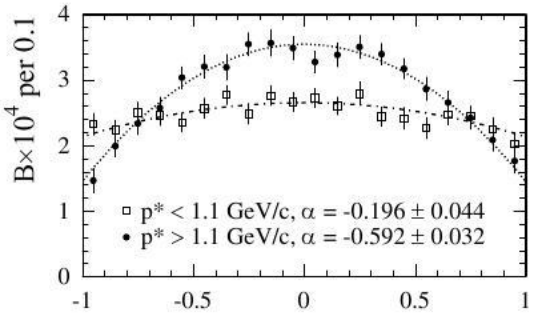
We know the fraction of J/ψ coming from B decay from LHCb(*) (from 10% in our first p_T bin to 15% in the last)

The polarization that a J/ψ coming from B decay acquires in the B hadron rest frame is largely diluted when observed in the J/ψ rest frame (see LHCb MC study(*) which uses the BaBar measurement(**) of non-prompt J/ψ polarization)





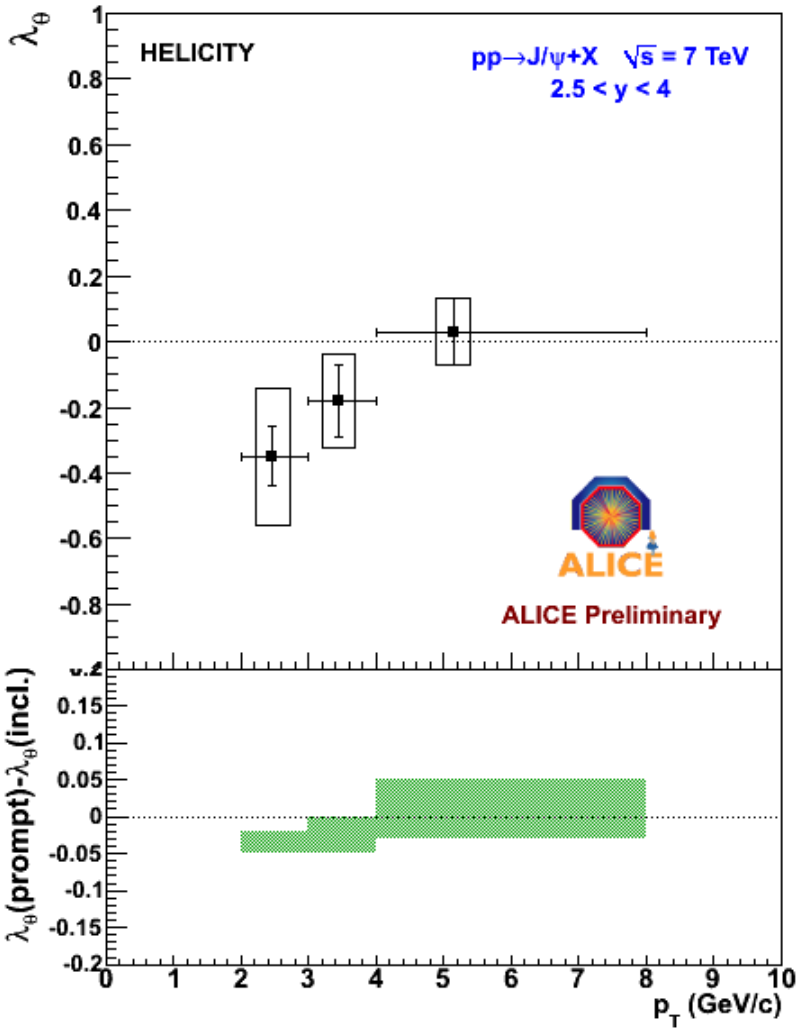
(*) LHCb collaboration, arXiv:1103.0423

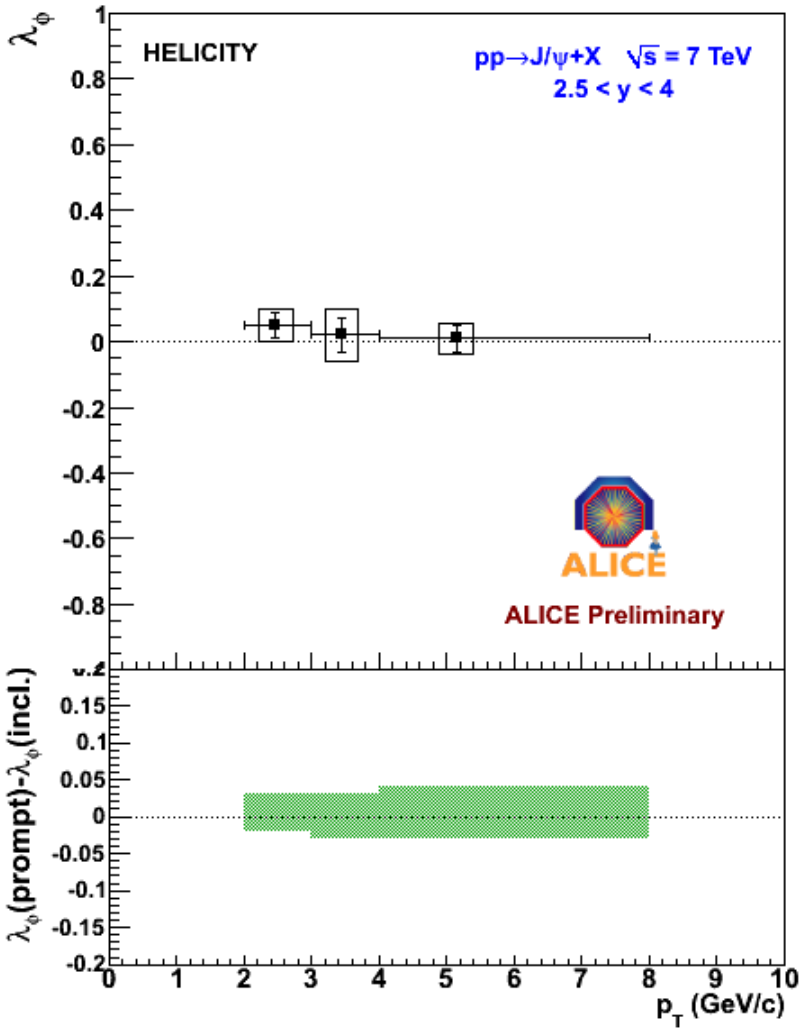


(**) BaBar collaboration, arXiv:hep-ex/0207097

We subtract from the measured cosθ (ϕ) distribution a (conservative) $\lambda_\theta(\lambda_\phi) = \pm 0.2$ **distribution weighted for the B-decay fraction**: refitting the resulting distribution we find the bias we introduce considering inclusive production

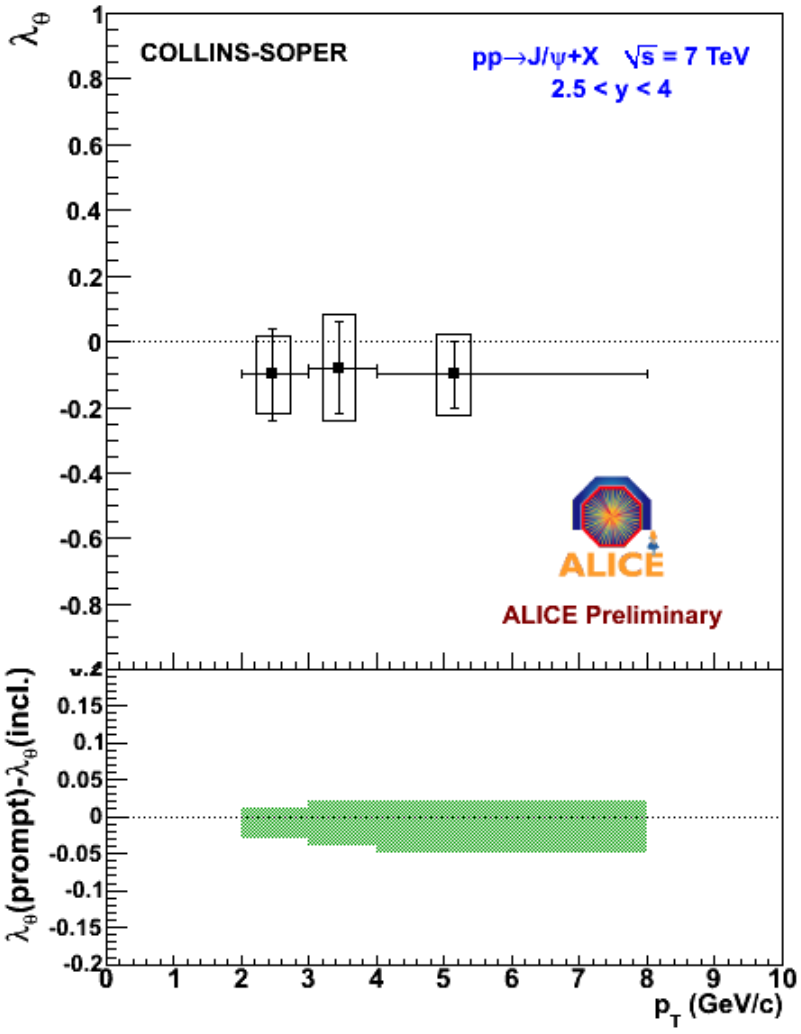
Results: helicity frame

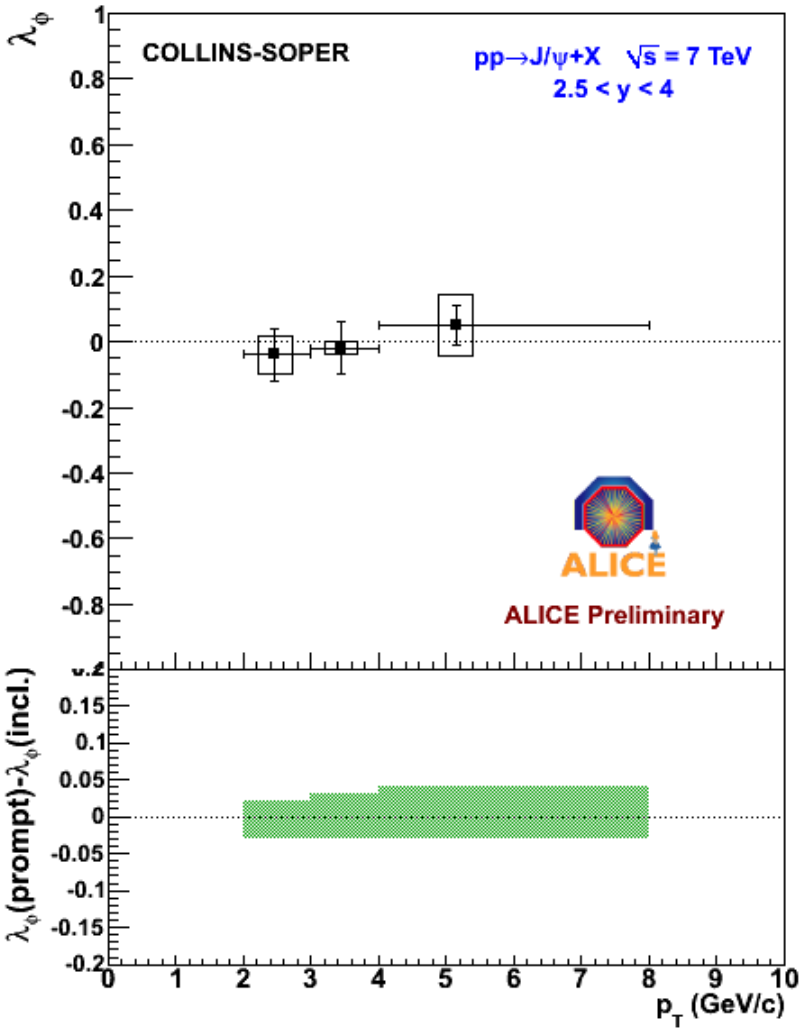




Slightly longitudinal polarization tending to vanish when increasing p_T. λ_ϕ is compatible with zero in the p_T range under study. **The estimated values for promptly-produced J/ψ are only slightly different (green boxes) from the inclusive ones**

Results: Collins-Soper frame





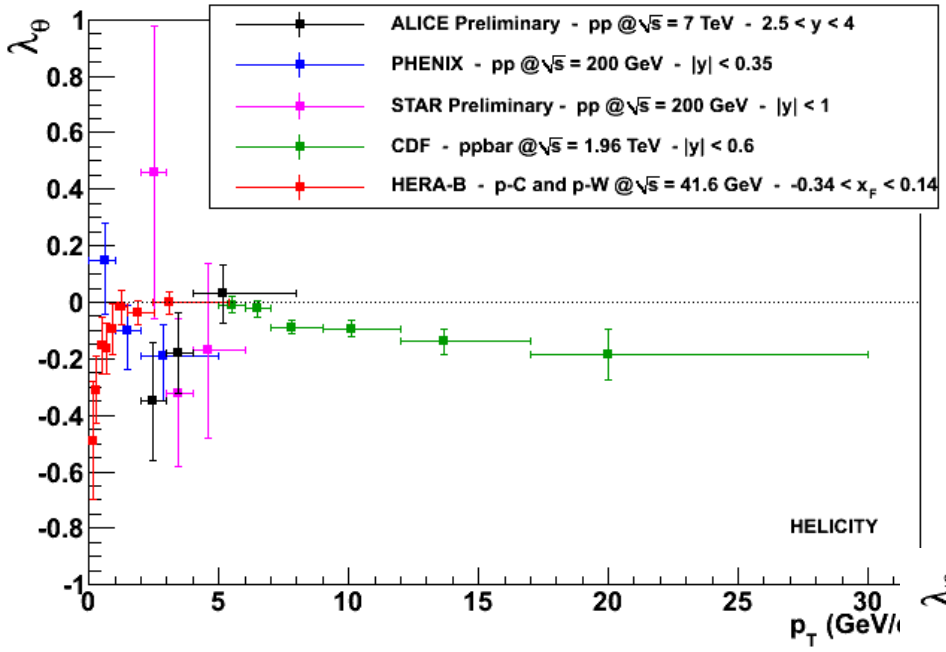
Results may show a slightly longitudinal polarization, but sizable errors prevent any strong conclusion

Systematic uncertainties

The systematics shown in the plots are the quadratic sum of the values found studying several sources:

Systematic source	p_T bin	HE		CS	
		λ_θ	λ_ϕ	λ_θ	λ_ϕ
Signal extraction	2-3	±0.01	±0.04	±0.03	±0.05
	3-4	±0.03	±0.06	±0.15	±0.01
	4-8	±0.09	±0.02	±0.11	±0.08
Trigger Efficiency	2-3	±0.00	±0.00	±0.01	±0.00
	3-4	±0.08	±0.02	±0.00	±0.01
	4-8	±0.03	±0.02	±0.02	±0.02
Tracking efficiency	2-3	±0.04	±0.01	±0.03	±0.02
	3-4	±0.03	±0.02	±0.06	±0.01
	4-8	±0.01	±0.03	±0.02	±0.03
MC inputs	2-3	±0.14	±0.03	±0.04	±0.01
	3-4	±0.11	±0.04	±0.01	±0.01
	4-8	±0.04	±0.02	±0.05	±0.03
cosθ range	2-3	±0.15	±0.01	±0.10	±0.01

Compilation of available hadroproduction results

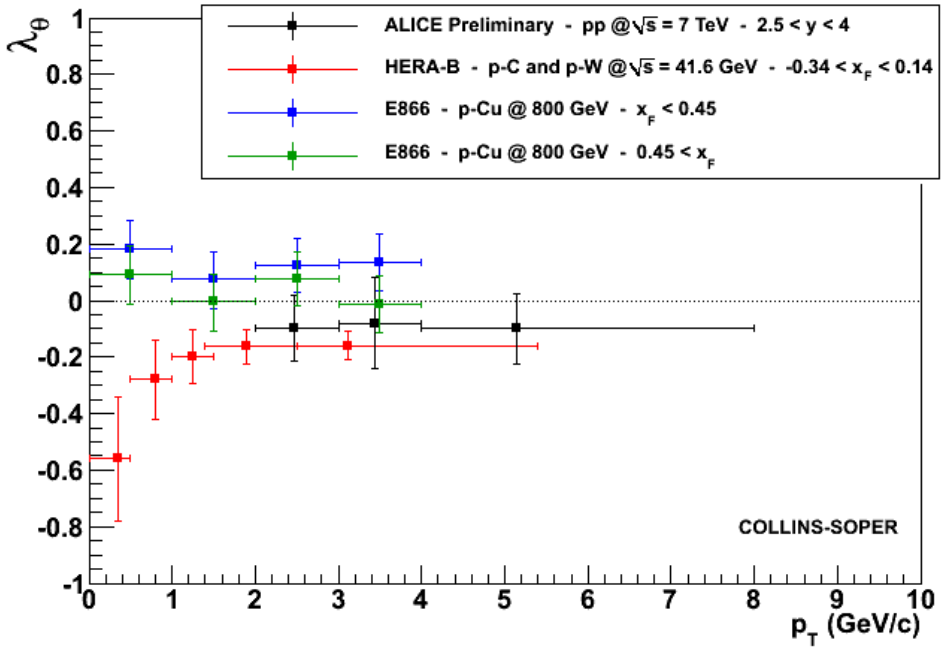


Disclaimer: taking into account the very different kinematical domains and the wide range of the center-of-mass energies we don't expect a p_T scaling

Only ALICE and HERA-B measured the azimuthal component of the angular distribution

In the Collins-Soper frame we can compare only to pA experiments

It would be very interesting to go to higher p_T: possible with 2011 data!



Conclusions

ALICE has studied inclusive J/ψ production in a large rapidity region extending from midrapidity to y=4 with a down to zero p_T coverage

The inclusive production cross-sections in pp collisions at 7 TeV measured by the four LHC experiments are in good agreement at both forward and mid-rapidity
Results at 2.76 TeV have also been obtained, crucial for the normalization of the heavy-ion results

NRQCD NLO calculations at both the energies describe well the measured $d^2\sigma/dp_T dy$

The inclusive J/ψ yield shows a linear increase as a function of $dN_{ch}/d\eta$

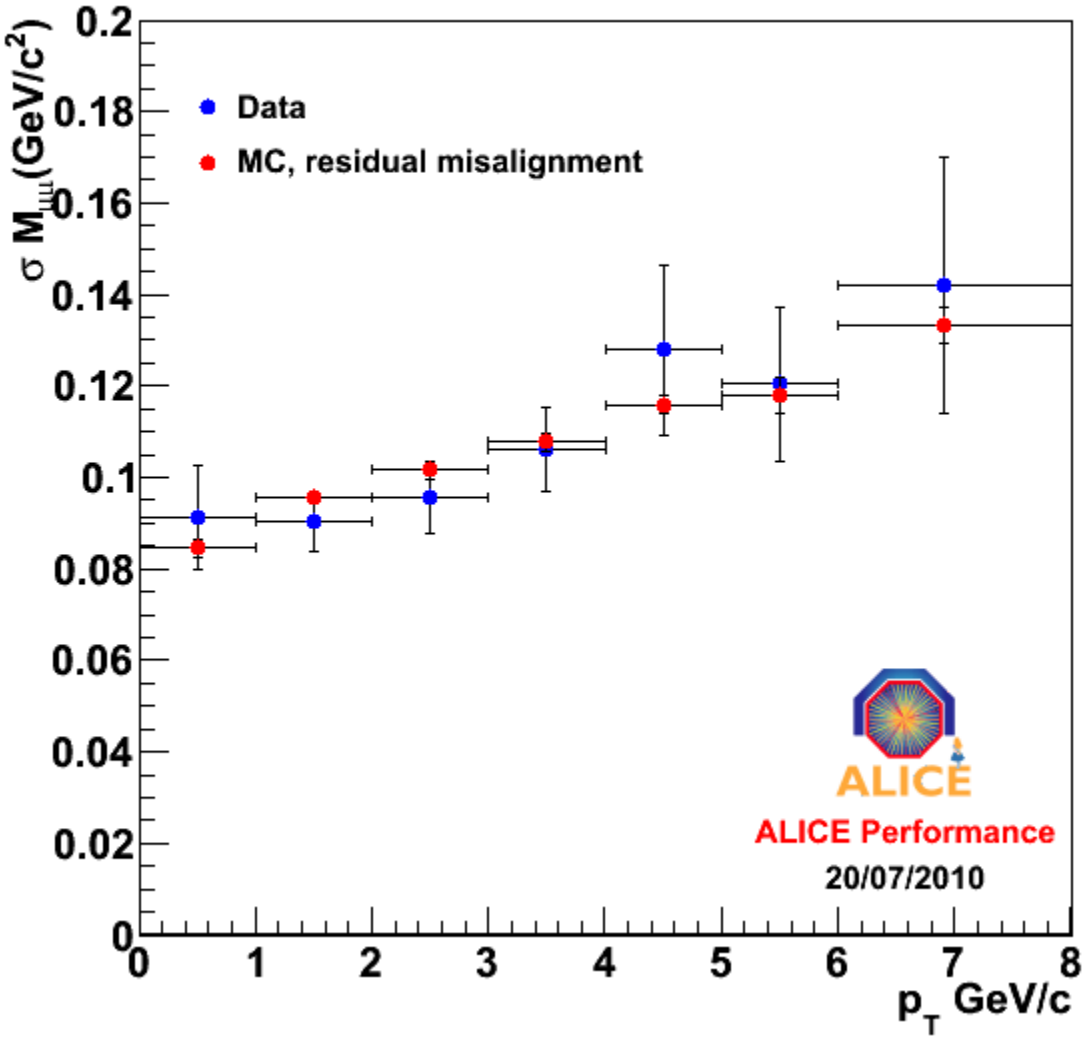
At mid-rapidity (|y|<0.9) ALICE estimates the contribution of J/ψ from the B feed-down to the inclusive cross-section for $p_T > 1.3$ GeV/c

The polarization parameters λ_θ and λ_ϕ were extracted in 3 p_T bins ($2 < p_T < 8$ GeV/c) in the helicity and Collins-Soper frames.
λ_θ(HE) is the only parameter significantly different from zero in the studied p_T region

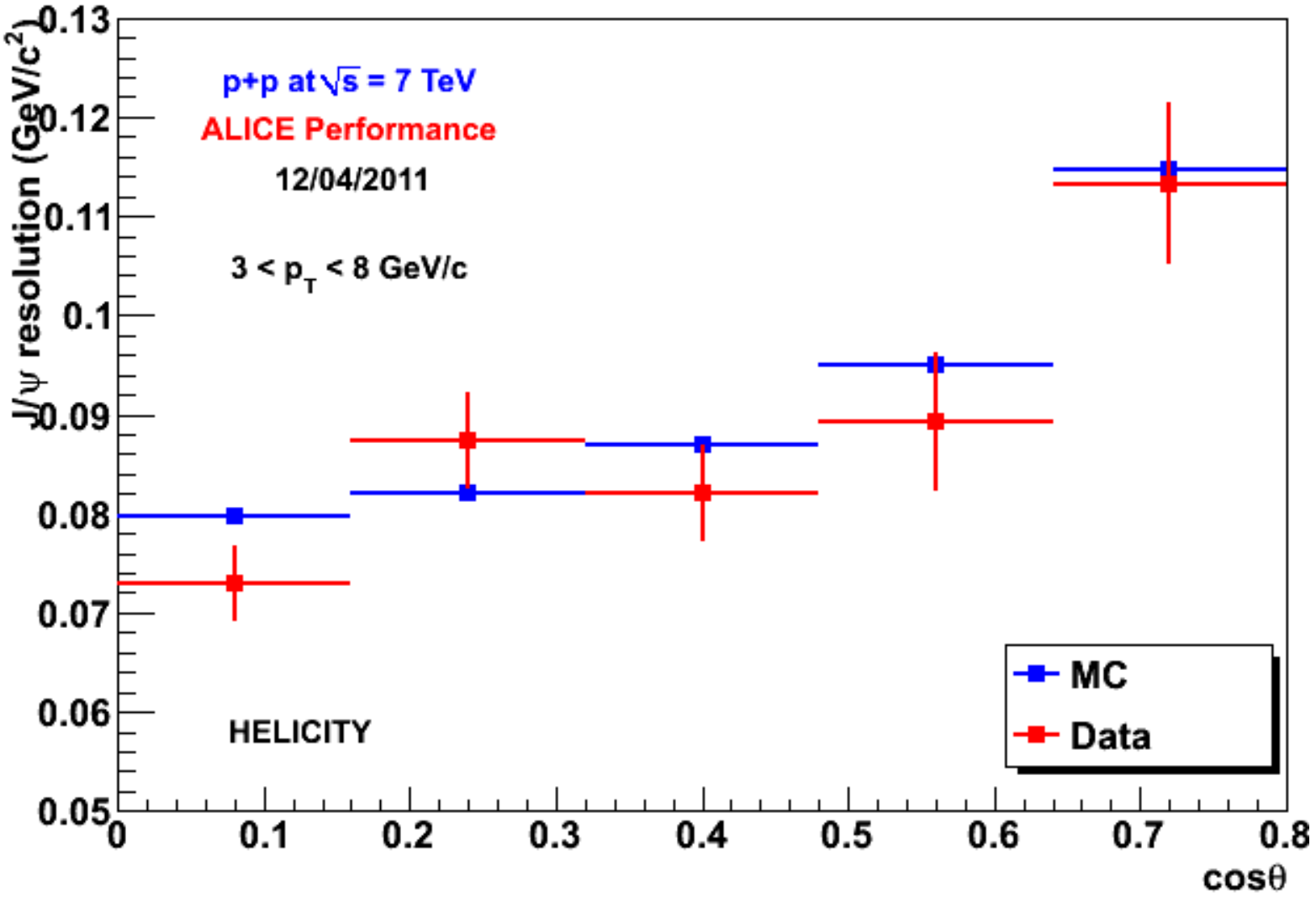
Thank you

Backup

Evolution of resolution VS p_T



MC Sample


p+p at √s = 7 TeV
ALICE Performance
12/04/2011
3 < p_T < 8 GeV/c
HELICITY
MC
Data
J/ψ resolution (GeV/c²)
cosθ
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8