Charmonium measurements with the ALICE experiment

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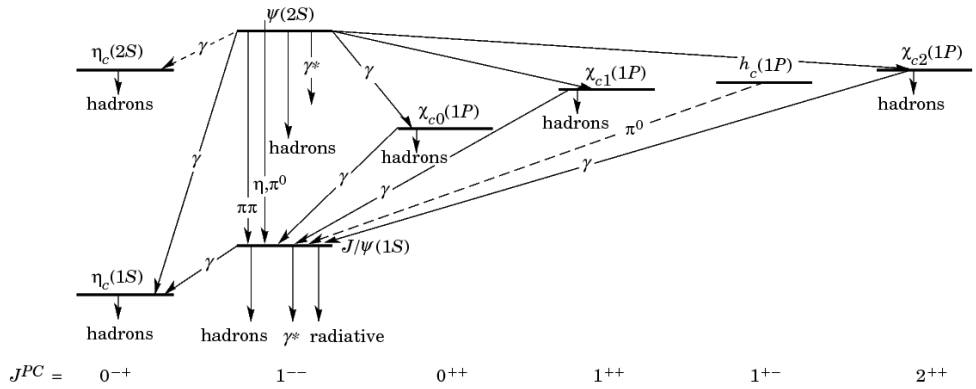
Outline

Charmonium: physics motivations

Vector mesons composed by a c $\bar{c}$ pair

Heavy quarkonium production is usually considered a two-stage process:

- Perturbative $q\bar{q}$ production
- Non-perturbative evolution when the bound state is formed

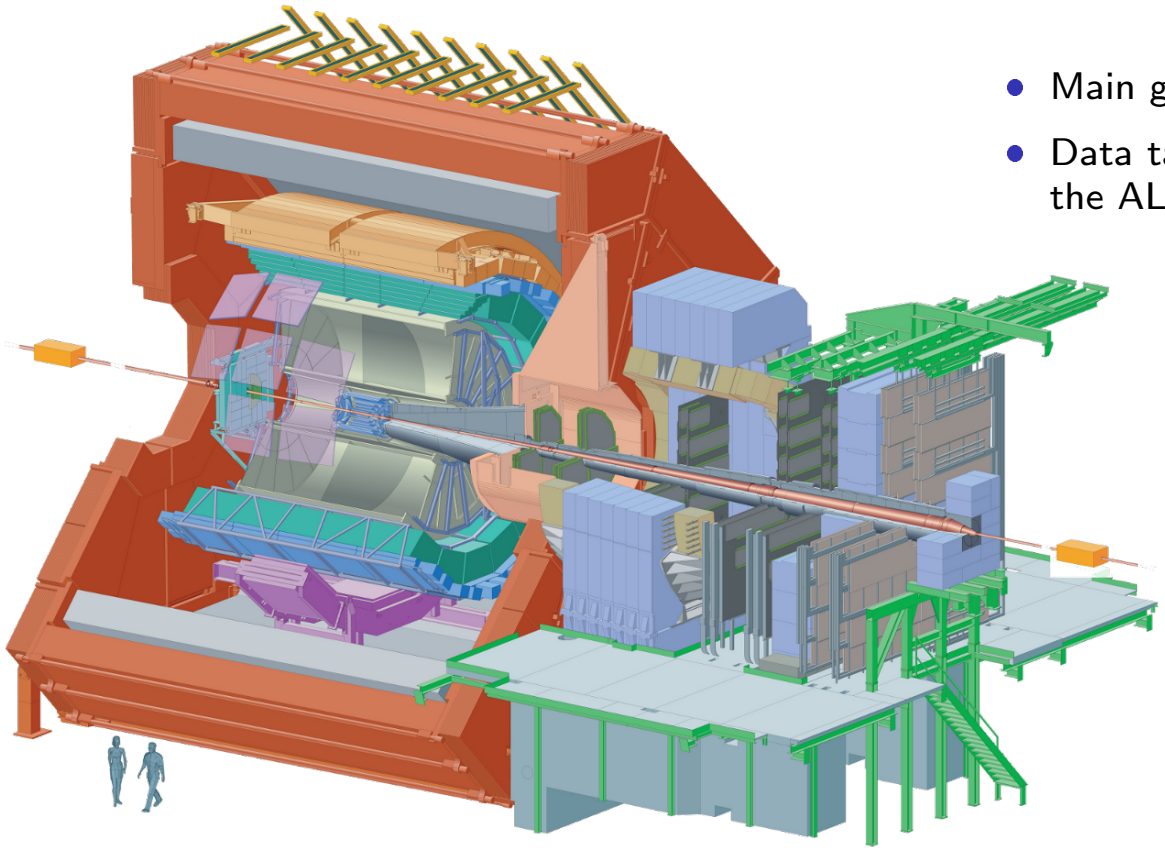


- Charmonium represent a good laboratory to test non-perturbative QCD
- Different models are available for the description of the production mechanism
- A measurement of the production cross section, integrated and y- and p_t-differential, and the polarization will give new clues

Charmonium states are expected to be a successful probe for the medium formed in ultra-relativistic heavy ion collisions

- Colour Debye screening: dissociation of bound states
- Charmonium regeneration due to recombination of $c\bar{c}$ pairs
- Thermal production of $c\bar{c}$ pairs at LHC energies?

The ALICE experiment



- Main goal: heavy-ion collisions
- Data taking in p-p collisions also included in the ALICE physics programme

ALICE in numbers

- $\sim$ 1000 members
- 111 institutes
- 31 countries
- 18 sub-detectors
- 10000 tons
- $16 \times 16 \times 26m$

Central Barrel

- $|\eta| \leq 0.9$
- Hadrons, electrons and photons
- $p_t \rightarrow 0$

Muon Spectrometer

- $-4 \leq \eta \leq -2.5$
- muons
- $p_{muons} > 4GeV/c$

Forward Detectors

- large η
- Interaction trigger
- event centrality

Charmonium measurements in ALICE

J/ψ in ALICE

- In the forward muon spectrometer ($2.5 < y < 4$) in the $\mu^+\mu^-$ channel
- In the central barrel ($|y| < 0.9$) in the e^+e^- channel
- Both measurements down to $p_t = 0$

Goal

- Inclusive J/ψ production cross section measurement

$$\sigma_{J/\psi} = \frac{N_{J/\psi}}{Acc_{J/\psi} \times \epsilon} \times \frac{1}{L}$$

Ingredients

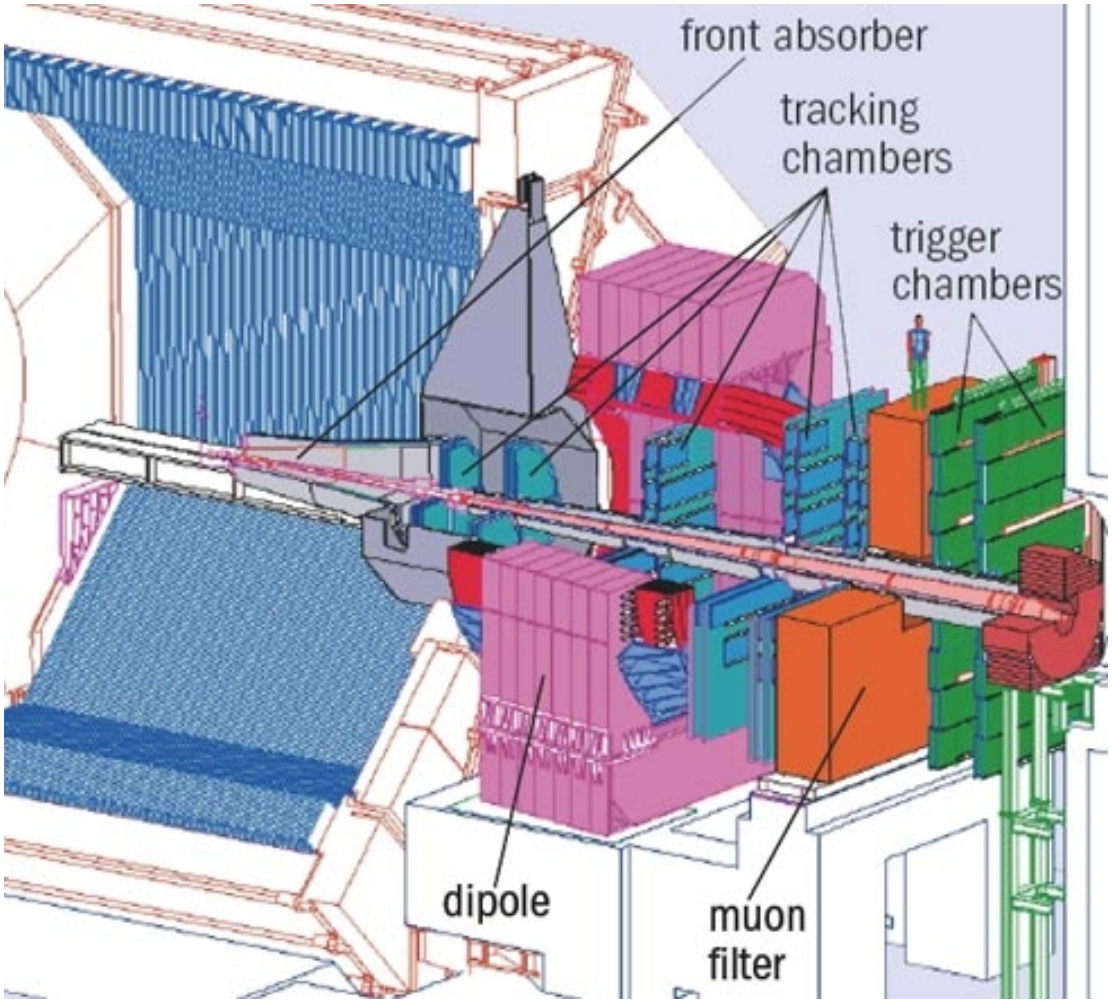
- Number of detected J/ψ
- Acceptance and efficiency determination
- Luminosity normalization

2010 data taking

- Collected data in different conditions: p-p collisions at 7 Tev and 2.76 TeV; Pb-Pb collisions at 2.76 TeV/N
- Charmonium analysis ongoing on these different sets of data
- Will be shown preliminary results on inclusive J/ψ production in p-p at 7 TeV: a paper is under preparation and will be out soon.

Muon Spectrometer

- Quarkonia (J/ψ, ψ' and $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$) down to $p_t = 0$
- Open heavy flavours via single muons and dimuons
- Electroweak bosons (Z^0 and $W^{\pm}$)



Expected mass resolutions

	Single muon p_t cut
$\sim 70 MeV/c^2 \rightarrow J/\psi$	$1 GeV/c$
$\sim 100 MeV/c^2 \rightarrow \Upsilon$	$2 GeV/c$

Dipole

- B = 3 T m

Tracking System

- 5 stations of 2 planes of Cathode Pad Chambers (CPC) each
- 1.1M read-out channels
- spatial resolution $< 100 \mu m$ (bending plane)

Trigger System

- 2 stations of 2 planes of Resistive Plate Chambers (RPC) each
- 21k read-out channels
- 2 programmable p_t cuts.
- 5 different trigger signals sent in $\sim 800 ns$

$J/\psi \to \mu^+\mu^-$ - p-p collisions at $\sqrt{s} = 7\mathrm{TeV}$

Data sample

- Data collected between May and July 2010
- Integrated luminosity: $L = 13.6\mathrm{nb}^{-1}$

Trigger conditions

- Single muon trigger in coincidence with a minimum bias interaction trigger. A minimum bias trigger is delivered when at least one of the V0 scintillators or the silicon pixel detector has a physical signal.
- Hardware single muon trigger p_t cut: $\sim 0.5\mathrm{GeV/c}$

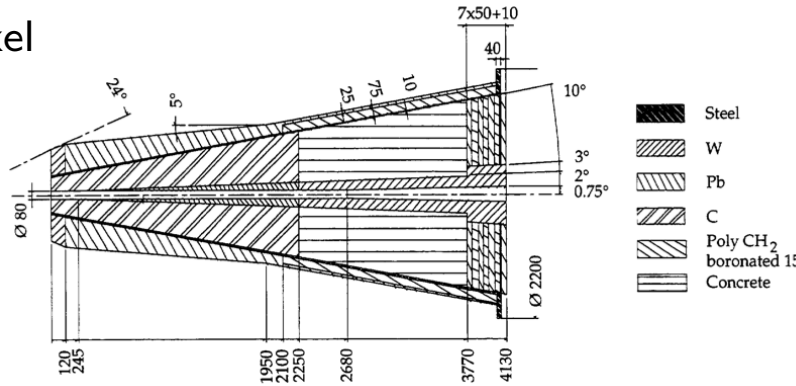
Run selection

- Quality checks on the stability of the tracking and the trigger system
- Runs with high pile-up probability where discarded

$J/\psi \to \mu^+\mu^-$ - Event selection

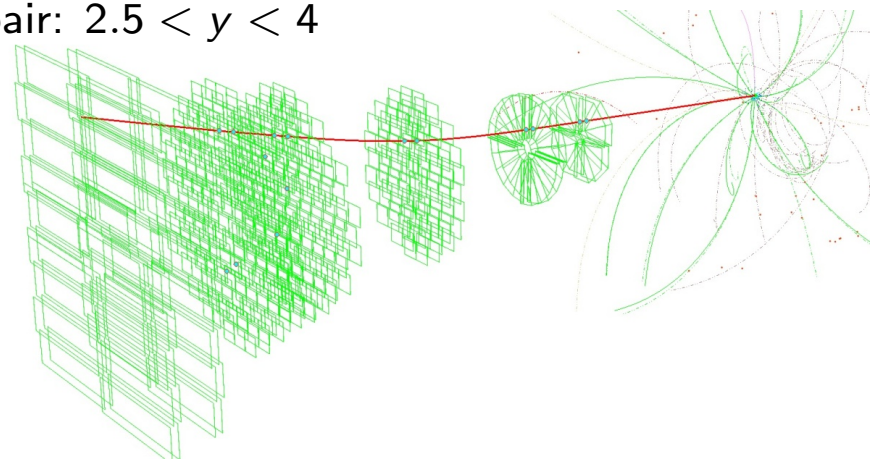
Requirements

- At least one vertex reconstructed by the silicon pixel detector
- At least one muon reconstructed in the tracking chambers that fired the trigger
- Cut on the position of the track at the end of the front absorber: discard small angle-muons travelling a long distance in the beam shield
- Kinematical requirement for the muon pair: $2.5 < y < 4$



Dimuon sample

- Opposite sign: $1.36 \cdot 10^5$

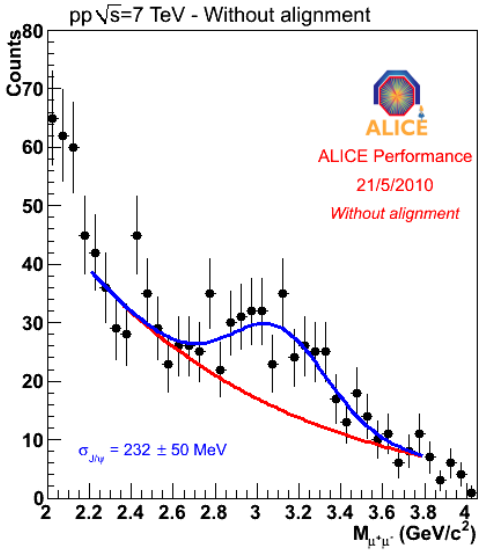


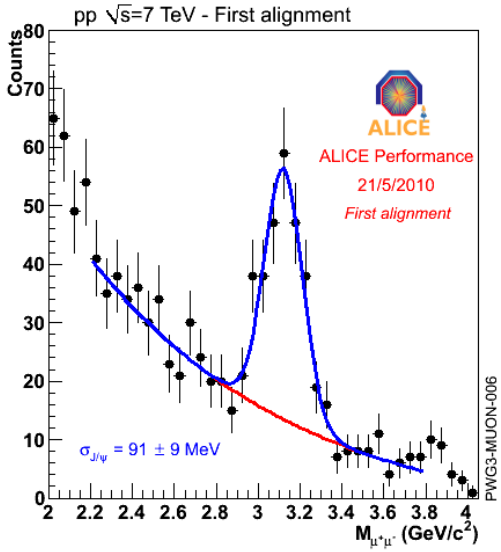
$J/\psi \to \mu^+\mu^-$ - Alignment

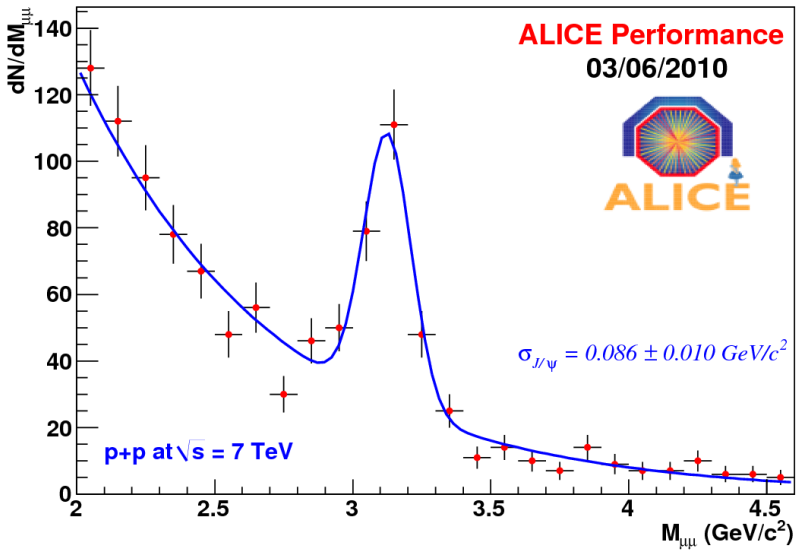
- Offline alignment of the tracking chambers: crucial point in the identification of resonances in the $\mu^+\mu^-$ channel
- Dedicated field-off run: $2 \cdot 10^5$ tracks
- MILLEPEDE algorithm
- Further alignment studies with and without B field are ongoing

Resolution achieved

$$\sigma_{J/\psi} \sim 90 MeV/c^2$$







$J/\psi \to \mu^+\mu^-$ - Signal extraction

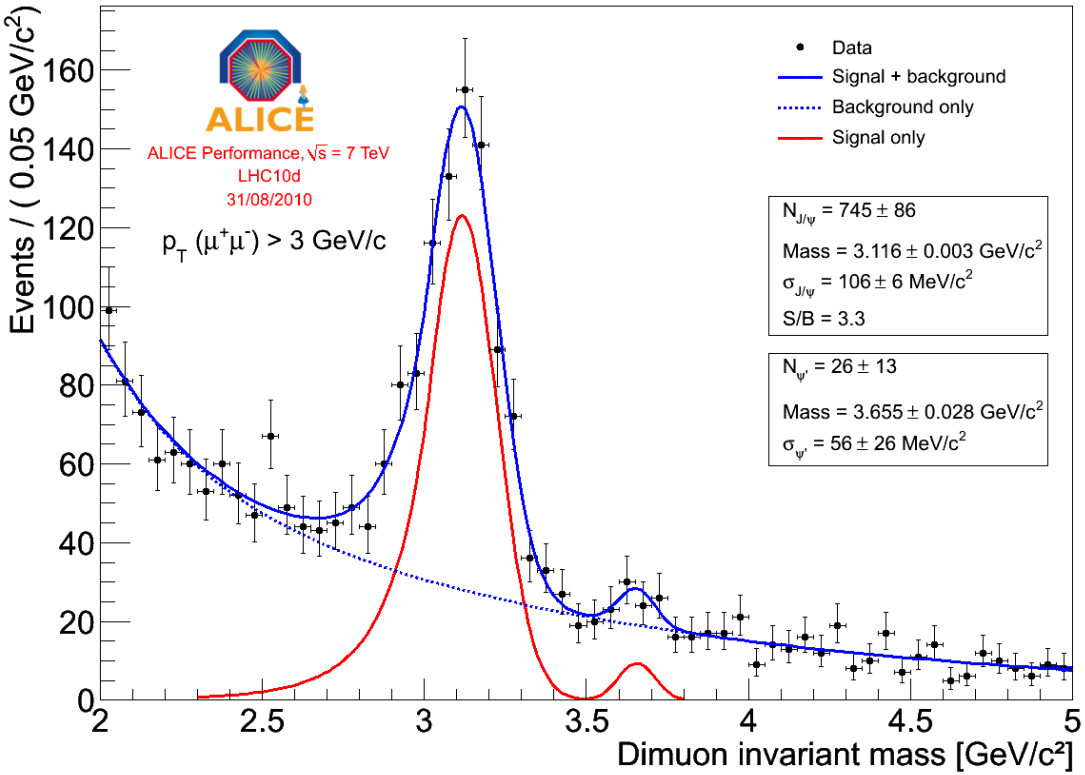
Number of J/ψ up to the end of June 2010

- Fit to the invariant mass spectrum: $1.5 < m_{\mu\mu} < 5\mathrm{GeV/c^2}$
- Signal (J/ψ and ψ'): Cristal Ball function
  - The functions are tuned on pure MC: simulation input from realistic differential distributions
  - Due to the small statistics ψ' parameters tied to the J/ψ ones
- Background: double exponential

J/ψ statistics available

$$N_{J/\psi} = 1974 \pm 77$$

$$S/B(2.9 < m_{\mu\mu} < 3.4) \sim 2.4$$



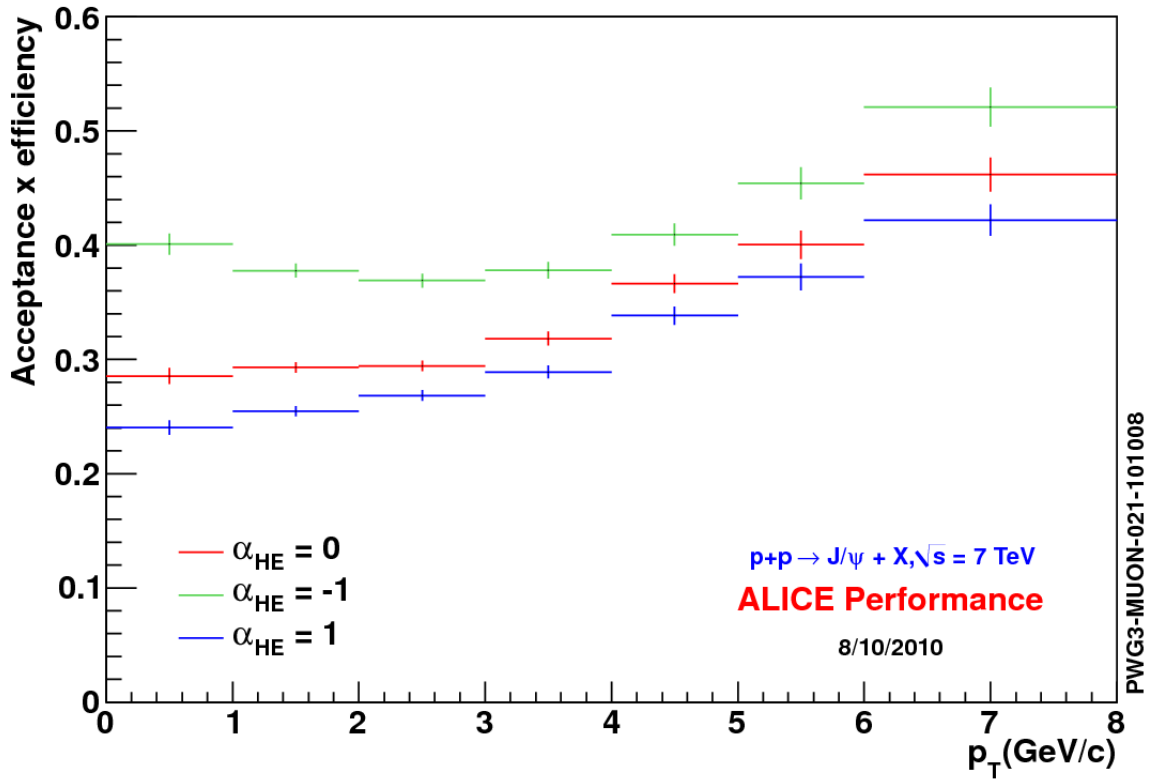
$J/\psi \to \mu^+\mu^-$ - Acceptance x Efficiency

Simulations

- Data sample subdivided in periods with constant detector configuration
- Realistic simulation for each period, embedded in the simulations the real conditions of the detectors
- Pure signal simulations: p_t distribution extrapolated from CDF, y distribution from CEM calculations

J/ψ polarization effects

- Polarization still unknown
- For each period samples with different polarizations have been simulated
- Different reference frames explored (Helicity and Collins-Soper)



$J/\psi \to \mu^+\mu^-$ - Normalization

Reference process

- Normalization to the total integrated luminosity, estimated via the measured cross section for a reference process
- Process chosen: occurrence of the minimum bias condition itself

Normalization

$$\sigma_{J/\psi} = \frac{N_{J/\psi}}{Acc \times \epsilon} \times \sigma_{MB}$$

- Measured in dedicated vdM scans the coincidence of V0 scintillators on both sides of the IP
- V0 coincidence is a known fraction of minimum bias events
- $\sigma_{MB} = \sigma_{V0_{coincidence}} \times N_{MB}/N_{V0_{coincidence}}$
- The stability of the V0 data checked on a run-by-run basis
- Pile-up correction performed on a run-by-run basis

Inclusive J/ψ production cross section

$$\sigma_{J/\psi} = \frac{N_{J/\psi}}{Acc_{J/\psi} \times \epsilon} \times \frac{1}{L}$$

- In the rapidity acceptance of the muon spectrometer

$$\sigma_{J/\psi}(2.5 < y < 4) = 7.25 \pm 0.26(stat) \pm 0.98(syst)^{+0.87}_{-1.50}(syst.pol.)\ \mu\mathrm{b}$$

- Systematics due to the unknown polarization are quoted separately

$J/\psi \to \mu^+\mu^-$ - Systematics

Signal extraction

- Released left tail parameter of Cristal Ball functions
- Other fit functions tried: Gaussian with different background shapes

7.5%

Acceptance

- Varied p_t and y input distributions
- p_t: $+2\%$ -1.3%
- y: $+1.4\%$ -1.3%

Efficiency

- Trigger efficiency: discrepancy between $N_{J/\psi}$ asking for 1 or 2 triggered muons. 4%
- Tracking efficiency: dead-areas embedded in MC. 2%

Luminosity and BR

- Reference cross section (preliminary, dominated by beam intensity determination during vdM scan)

10%

- The branching ratio of J/ψ decay to leptons pair uncertainty

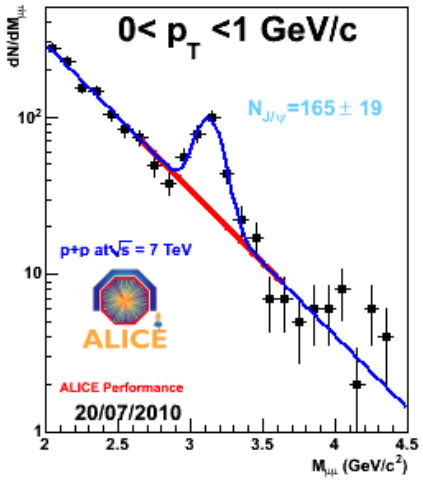
1%

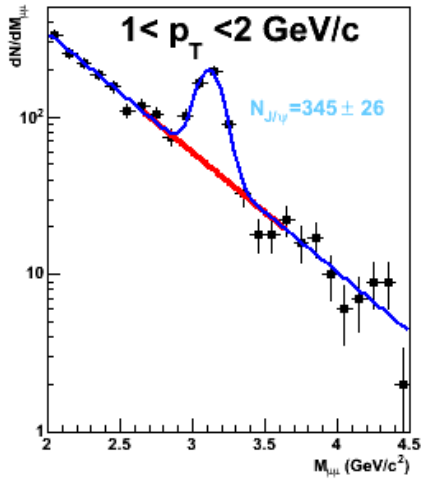
Systematics

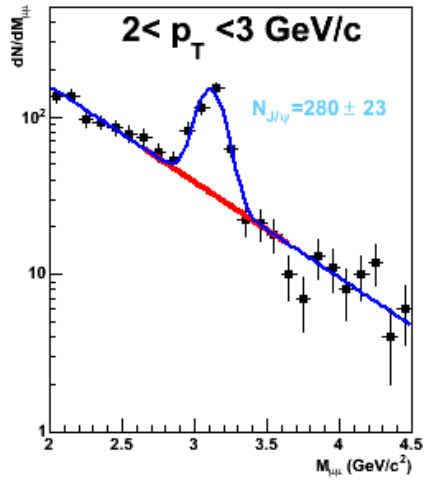
- Errors from polarization quoted separately
- Other systematics added quadratically

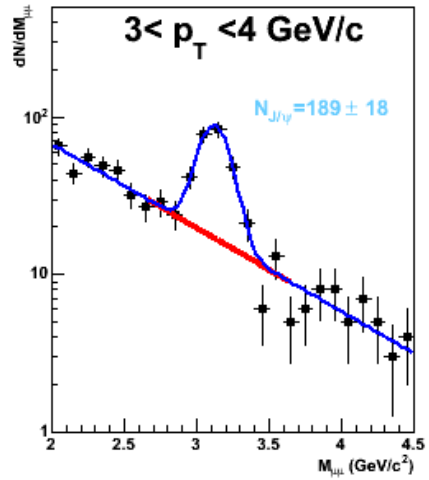
13.5%

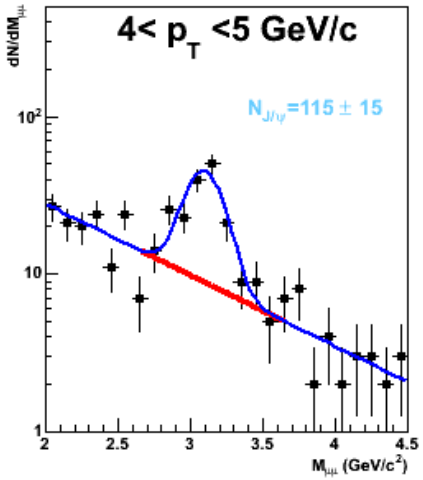
$J/\psi \to \mu^+\mu^-$ - p_t distributions

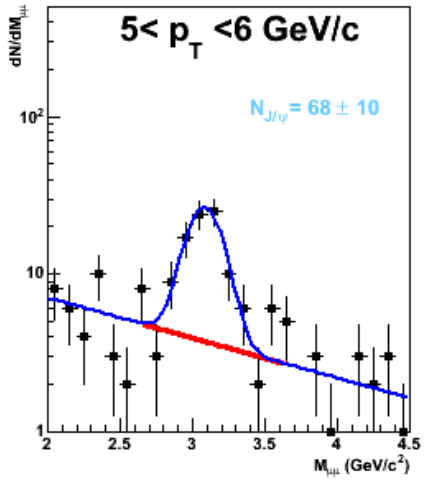


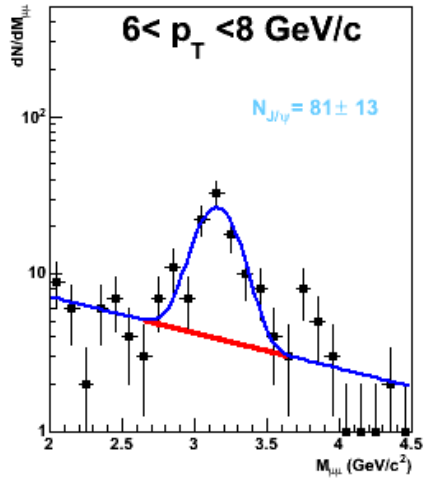








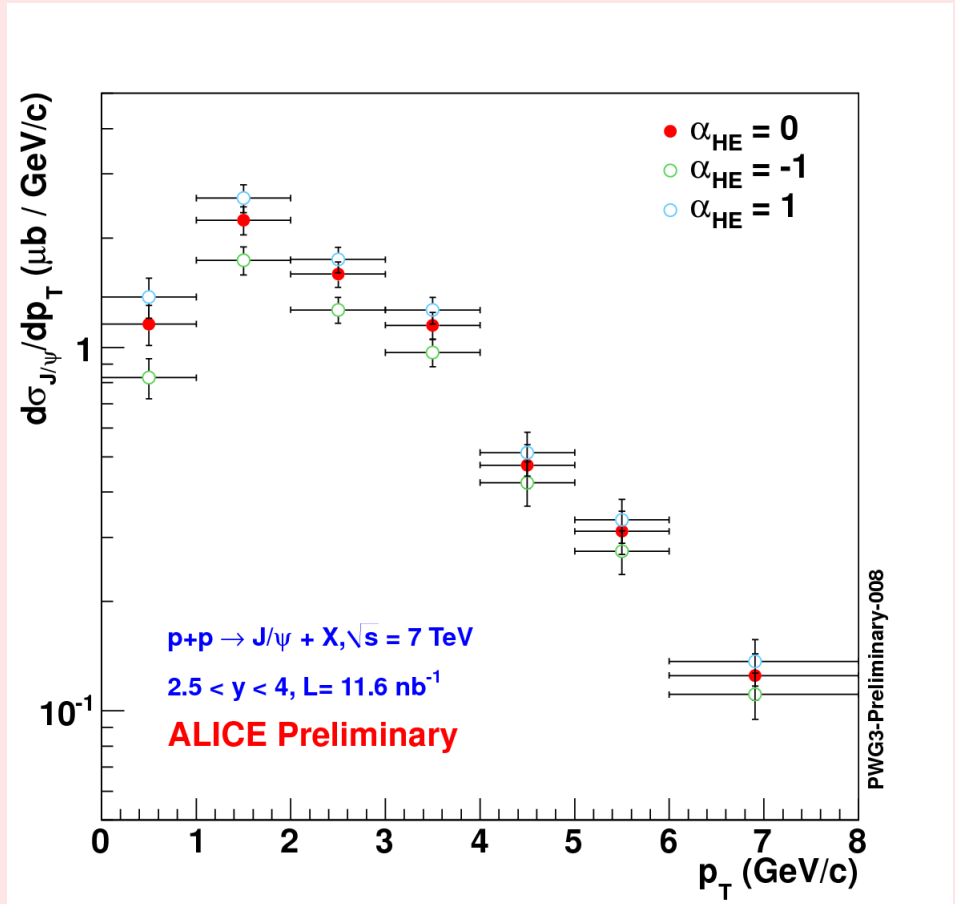


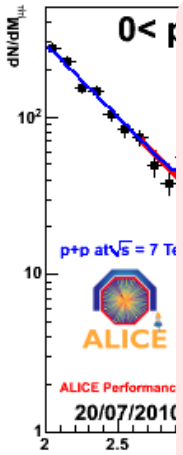


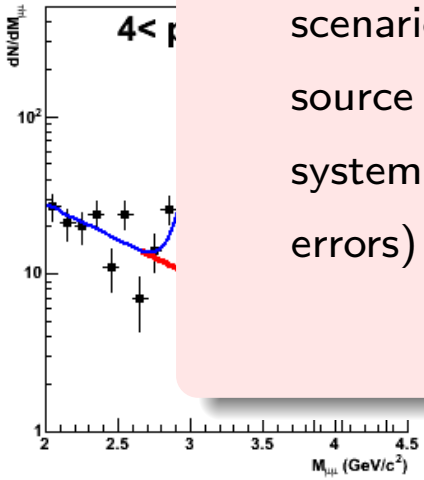
- Data sample:
  $L = 11.6\ \mathrm{nb} - 1$
- 7 bins:
  $0 < p_t < 8\ \mathrm{GeV/c}$ and
  $2.5 < y < 4$

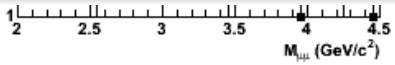
$J/\psi \to \mu^+\mu^-$ - p_t distributions

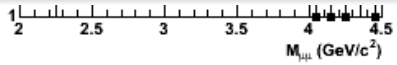
- J/ψ transverse momentum distribution in the 3 different polarization scenarios (main source of systematic errors)

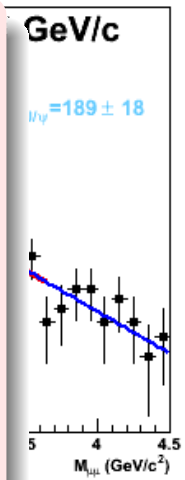












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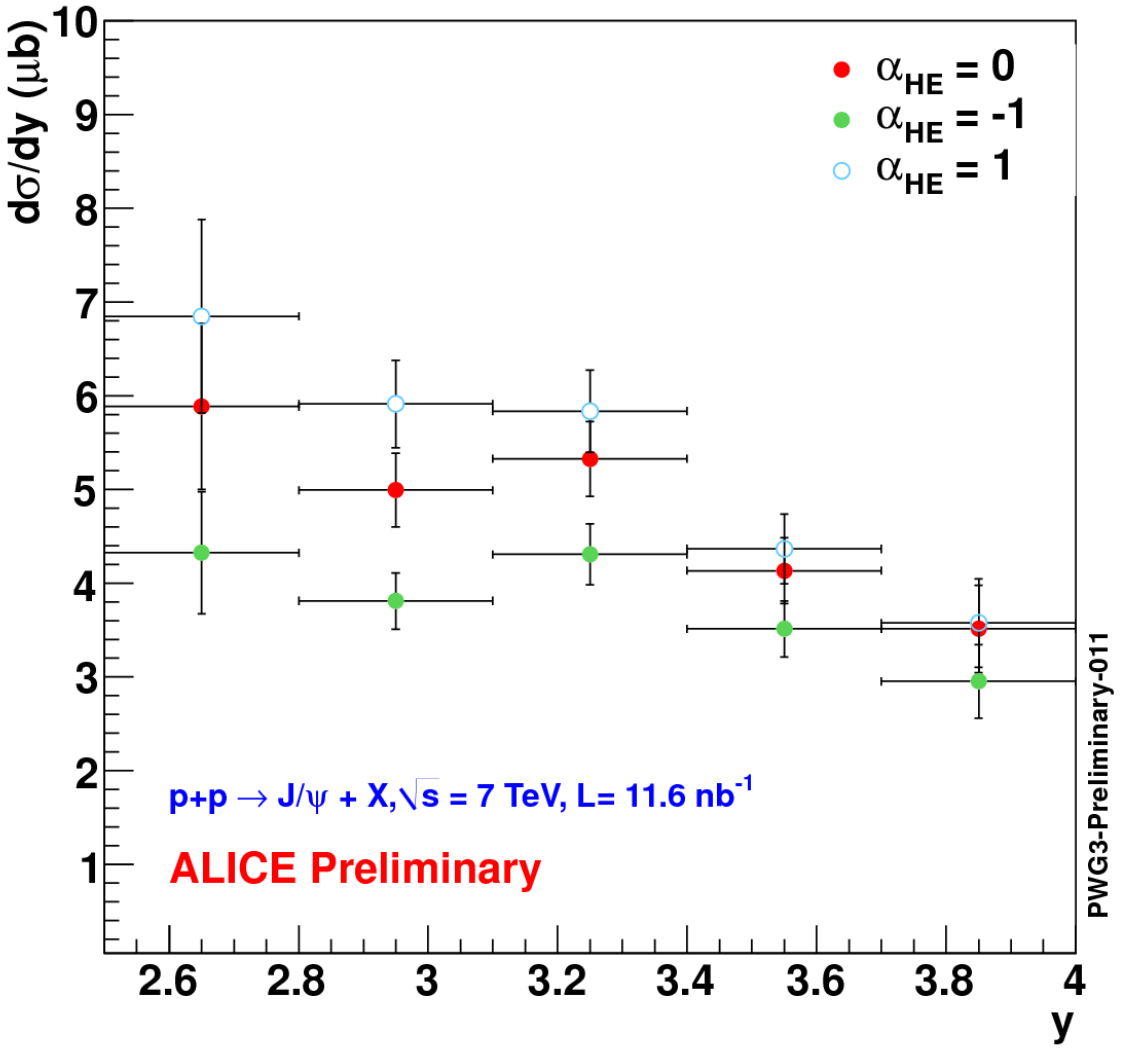
GeV/c and

$J/\psi \to \mu^+\mu^-$ - rapidity distributions

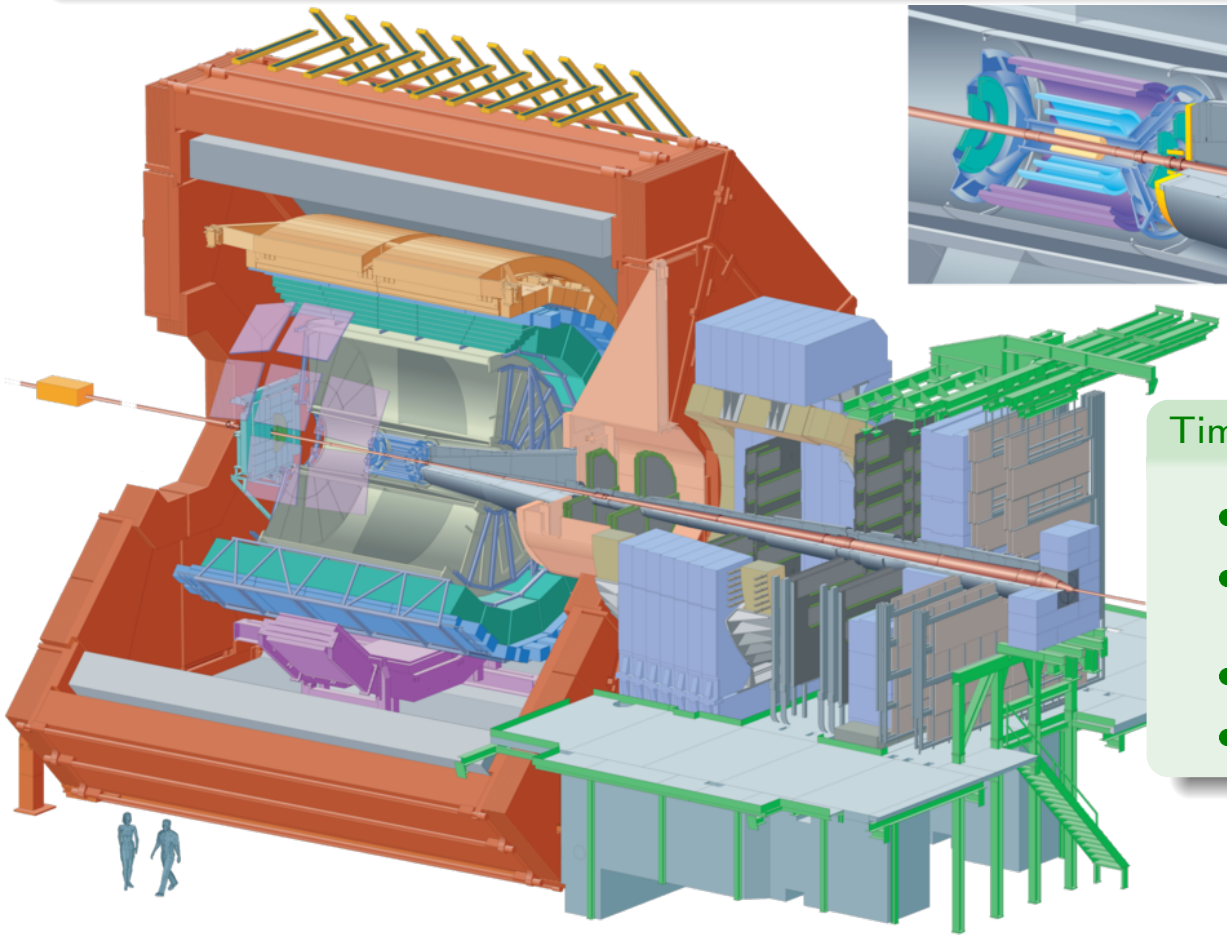
- Similar approach for $d\sigma_{J/\psi}/dy$



Central Barrel

Inner Tracking System

- two layers each of silicon pixel, drift and strip detectors
- between 4 and 44 cm from the interaction point
- vertexing detector (primary and secondary)
- used in minimum bias trigger



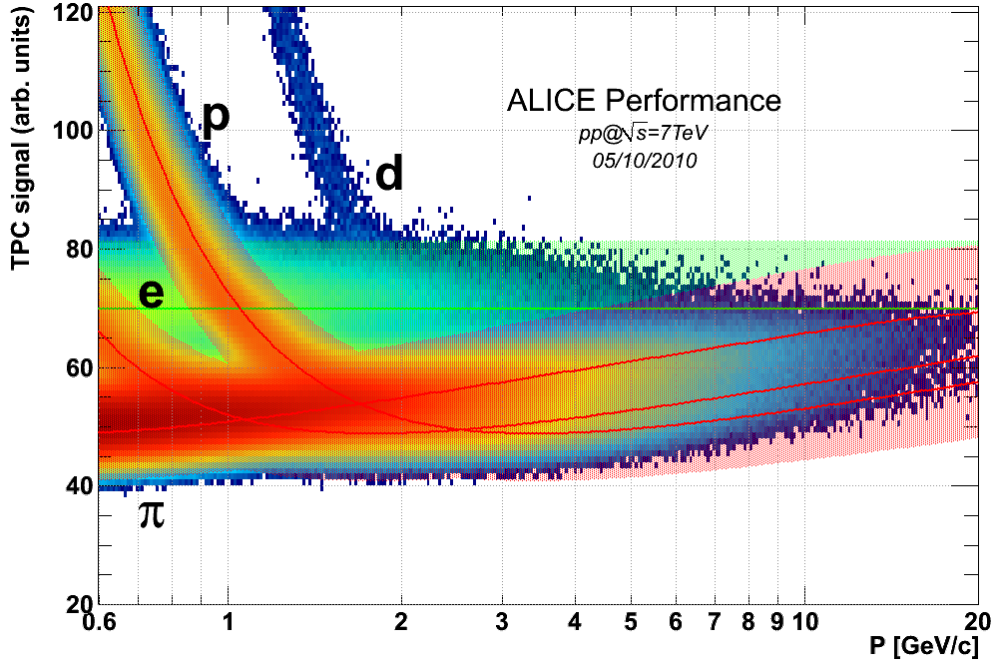
Time Projection Chamber

- 90 m^3 of active volume
- 72 multiwire proportional readout chambers in 18 sectors
- main tracking detector
- PID via specific energy loss (dE/dx)

$J/\psi \rightarrow e^+e^-$ - Track selection

Kinematical cuts

- $|\eta^{e^+,e^-}| < 0.88$
- $|p_t^{e^+,e^-}| > 1\mathrm{Gev/c}$
- $|y^{J/\psi}| < 0.88$



Quality cuts

- ITS + TPC Tracks
- Number of cluster in TPC > 90
- A hit in the ITS first layer (3.9 cm in radius), to minimise the effect of photon conversions

Particle identification

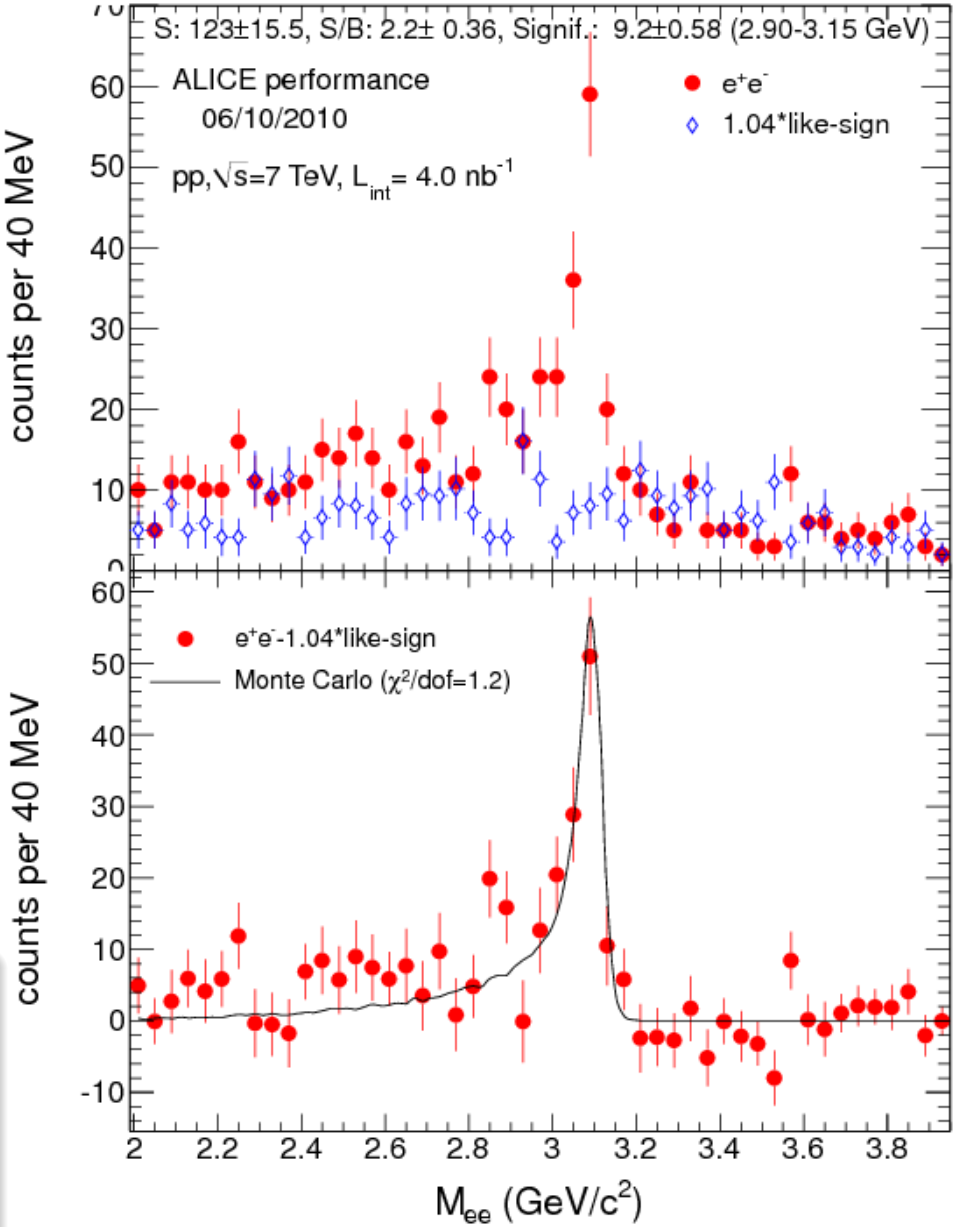
- dE/dx in TPC
- Select electrons by a 3σ inclusion around the Bethe-Bloch line
- Pions and proton rejection within 3σ of the corresponding Bethe-Bloch line

$J/\psi \to e^+e^-$ - Signal Extraction

- Bin counting for yield extraction
- Background contribution obtained from like-sign pairs ($N^{++} + N^{--}$)
- Like-sign spectra scaled to match the integral of unlike-sign distribution
- Scaling needed because of correlated background and misidentified electrons
- Good agreement with the MC shape both for the signal and for the bremsstrahlung tail

$$N_{J/\psi} = 123 \pm 15$$

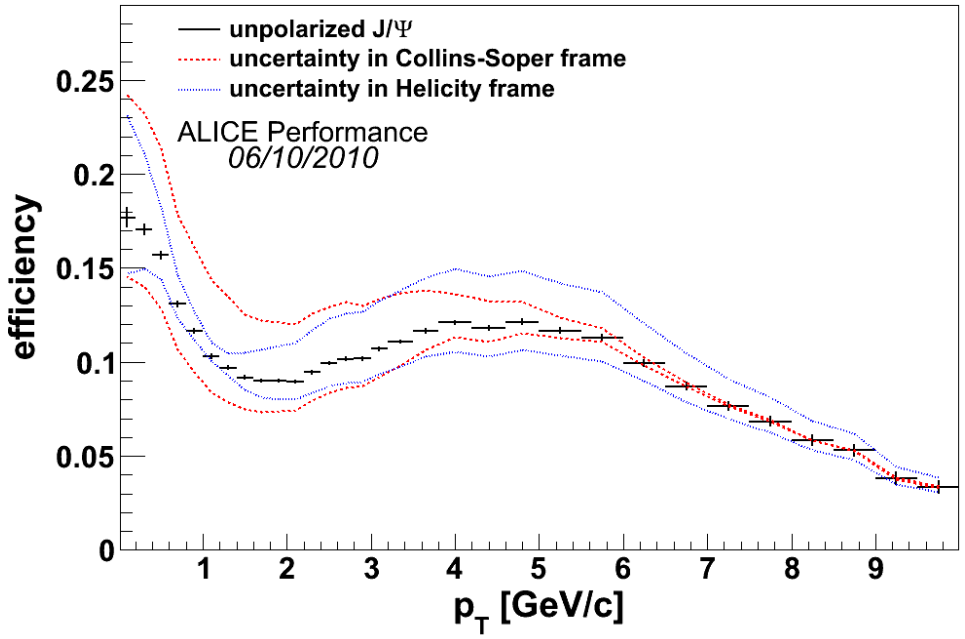
$$\mathit{Significance} = 9.2 \pm 0.58$$



$J/\psi \rightarrow e^+e^-$ - Acceptance and Systematics

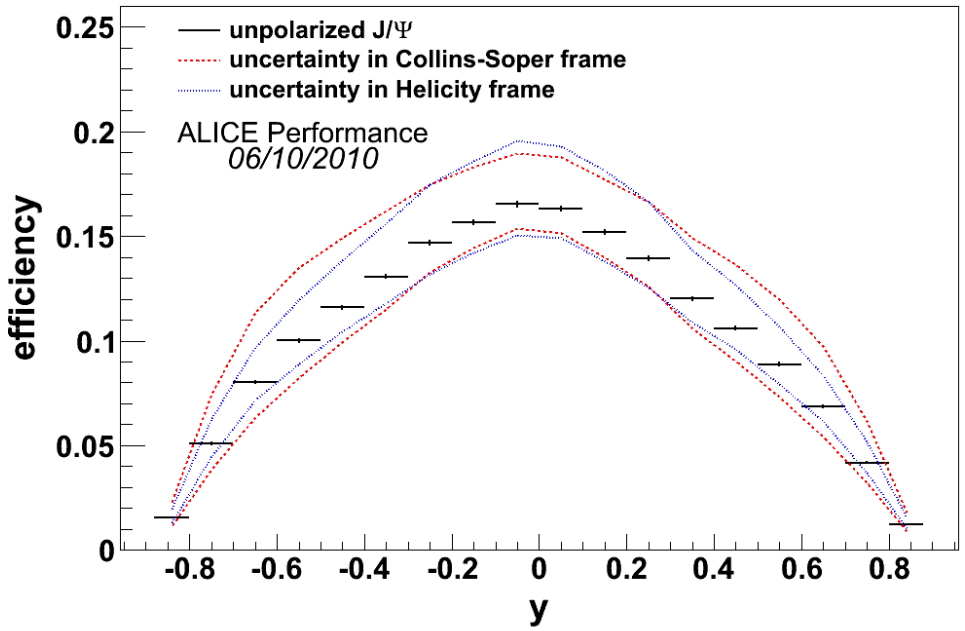
Acceptance x efficiency

- Realistic simulations including detector status for each run of data taking
- Polarization effects taken into account in the Helicity and in the Collins-Soper frame



Systematics

Source	
Kinematics	$< 1\%$
Track quality and clusters in TPC	10%
PID cuts	10%
Signal extraction range	4%
Normalization	10%
Total	18%



$J/\psi \rightarrow e^+e^-$ - Results

J/ψ inclusive cross section $|y| < .88$

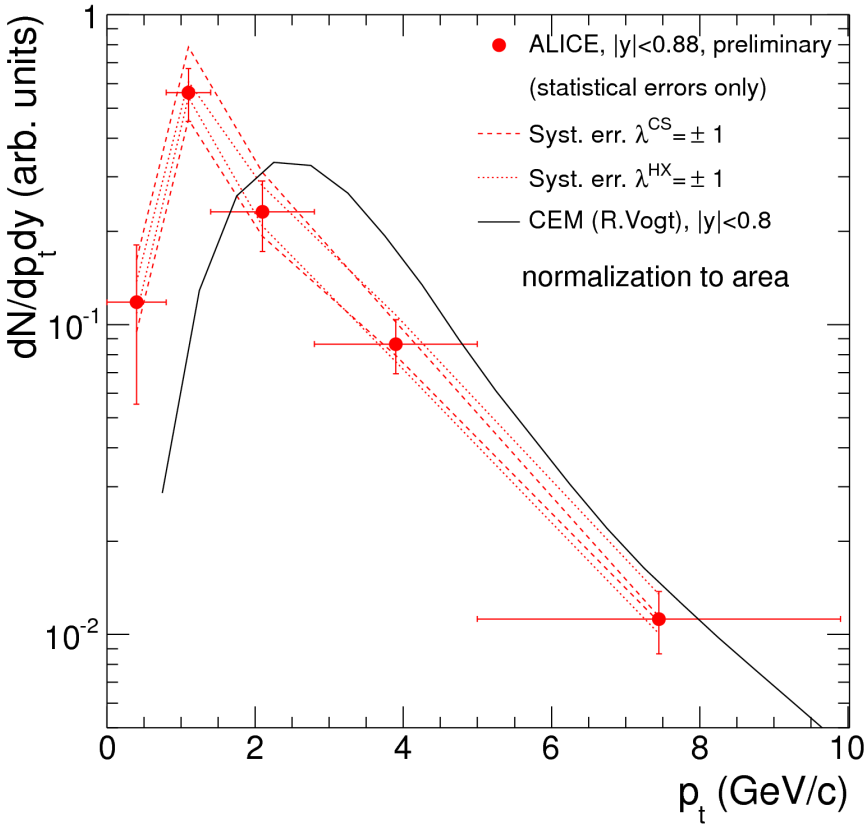
$$\frac{d\sigma_{J/\psi}}{dy} = 7.36 \pm 1.22(stat) \pm 1.32(syst)\ \mu b$$

Polarization syst

	$\alpha = -1$	$\alpha = +1$
CS	-19.7	9.7
He	-24.8	11.9

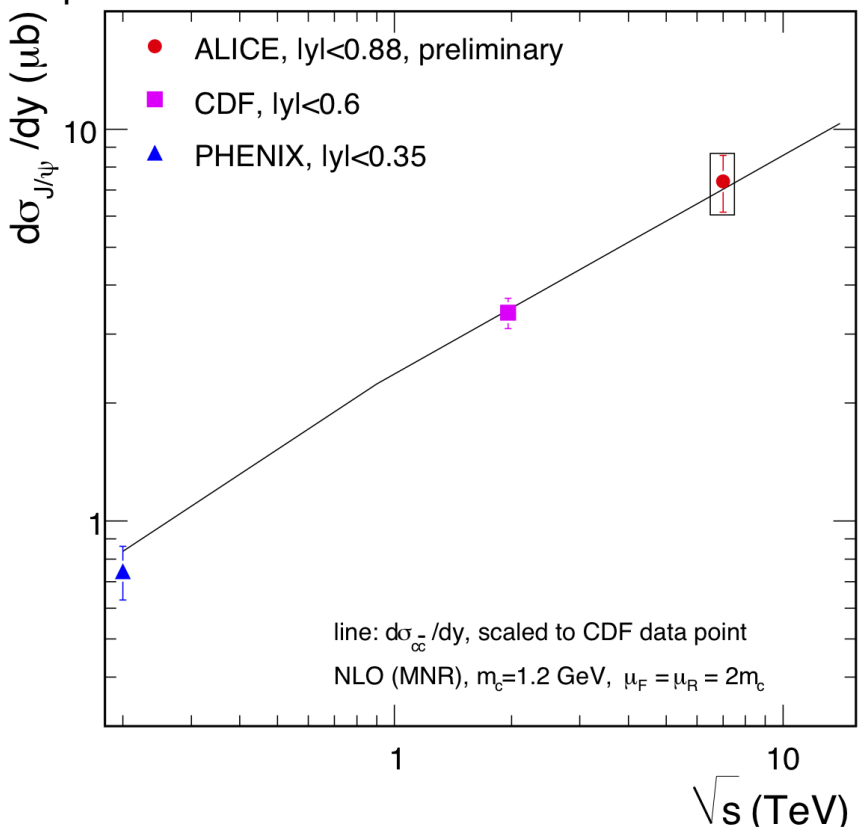
J/ψ transverse momentum distribution

- $d\sigma_{J/\psi}/dp_t$ in progress



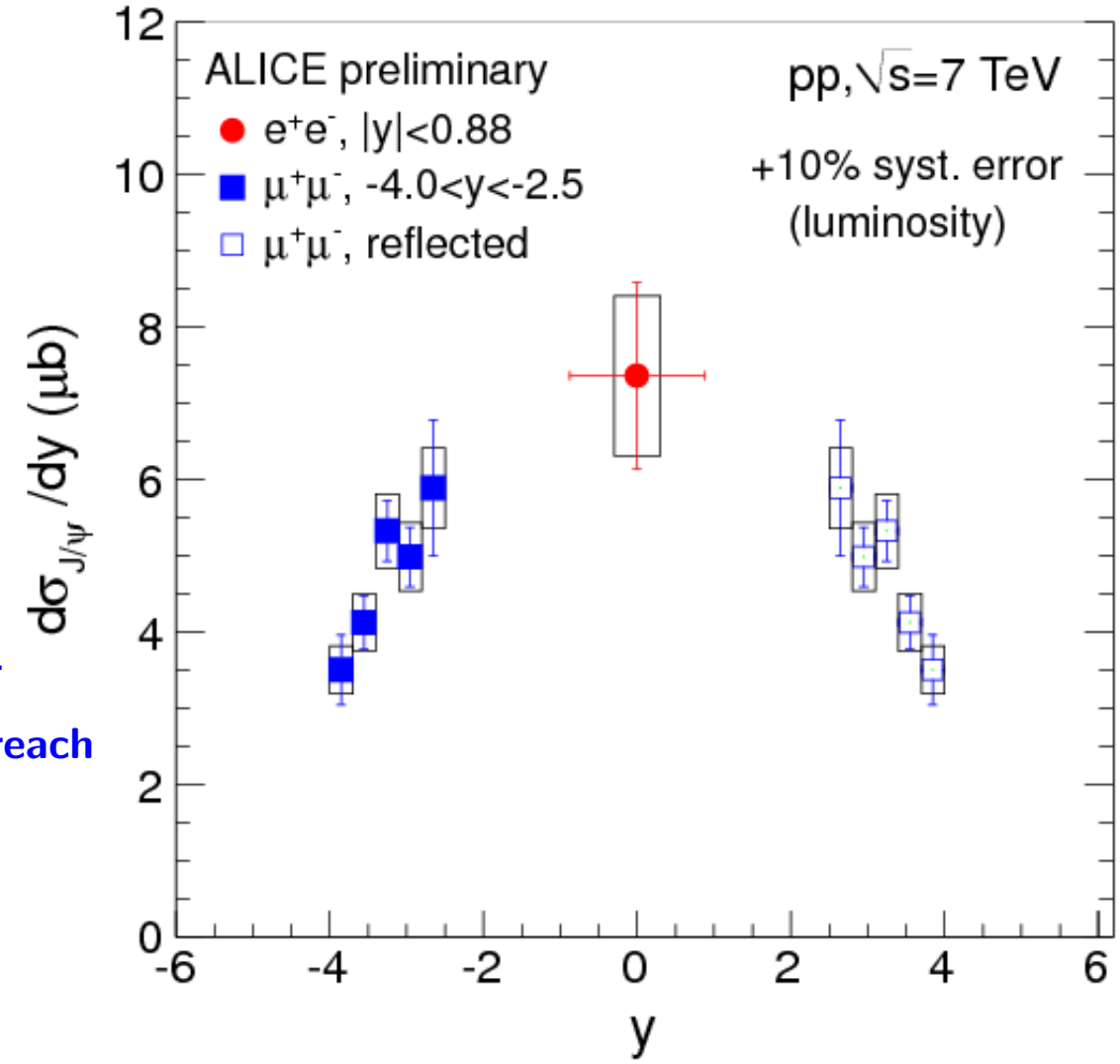
J/ψ mid rapidity xsection vs $\sqrt{s}$

- MNR NLO calculation scaled to match CDF point



$J/\psi \to e^+e^-$ and $J/\psi \to \mu^+\mu^-$

- Inclusive J/ψ production cross section measured in the two rapidity ranges covered by the ALICE experiment
- $p_t \to 0$
- **Unique measurement at LHC for rapidity coverage and lowest p_t reach**



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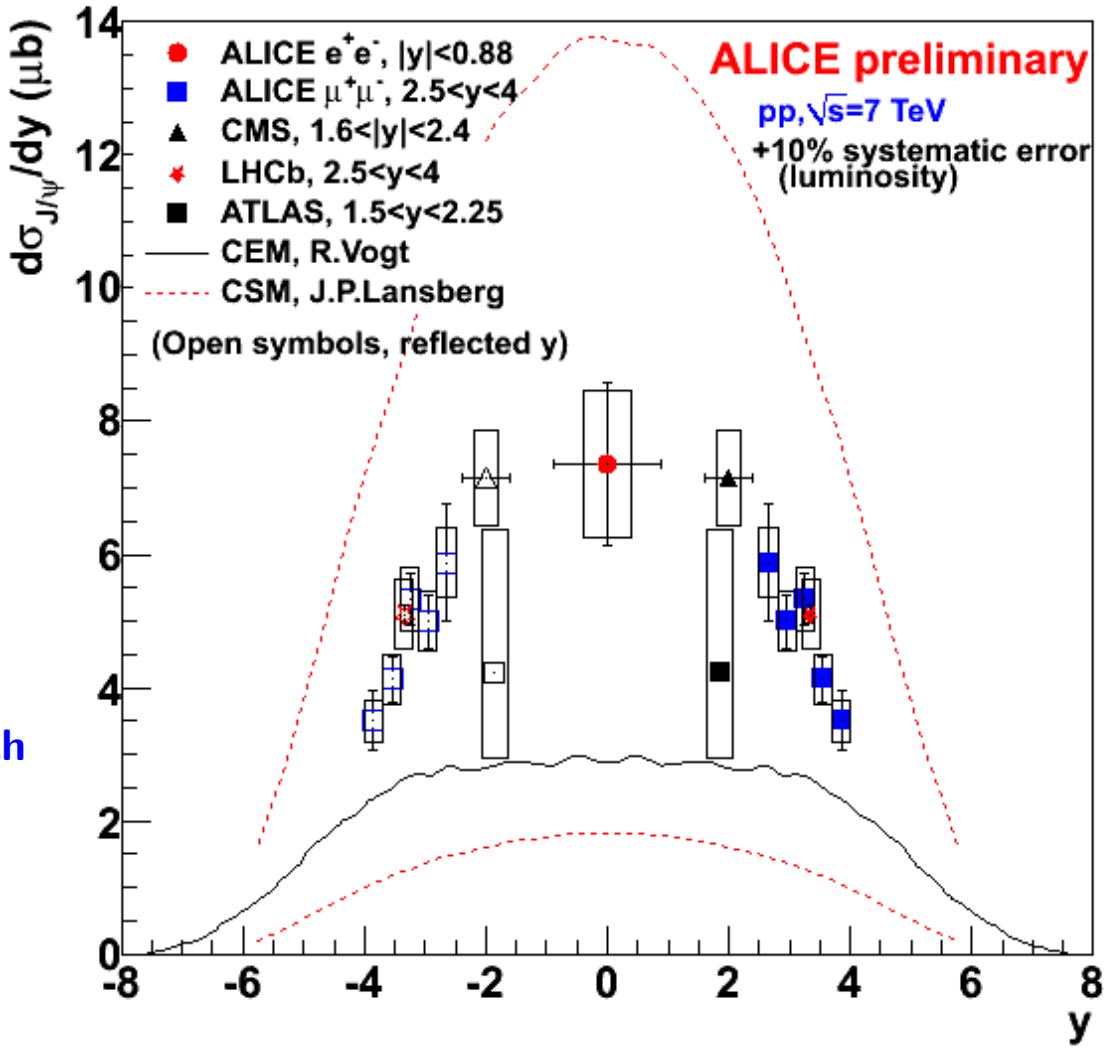
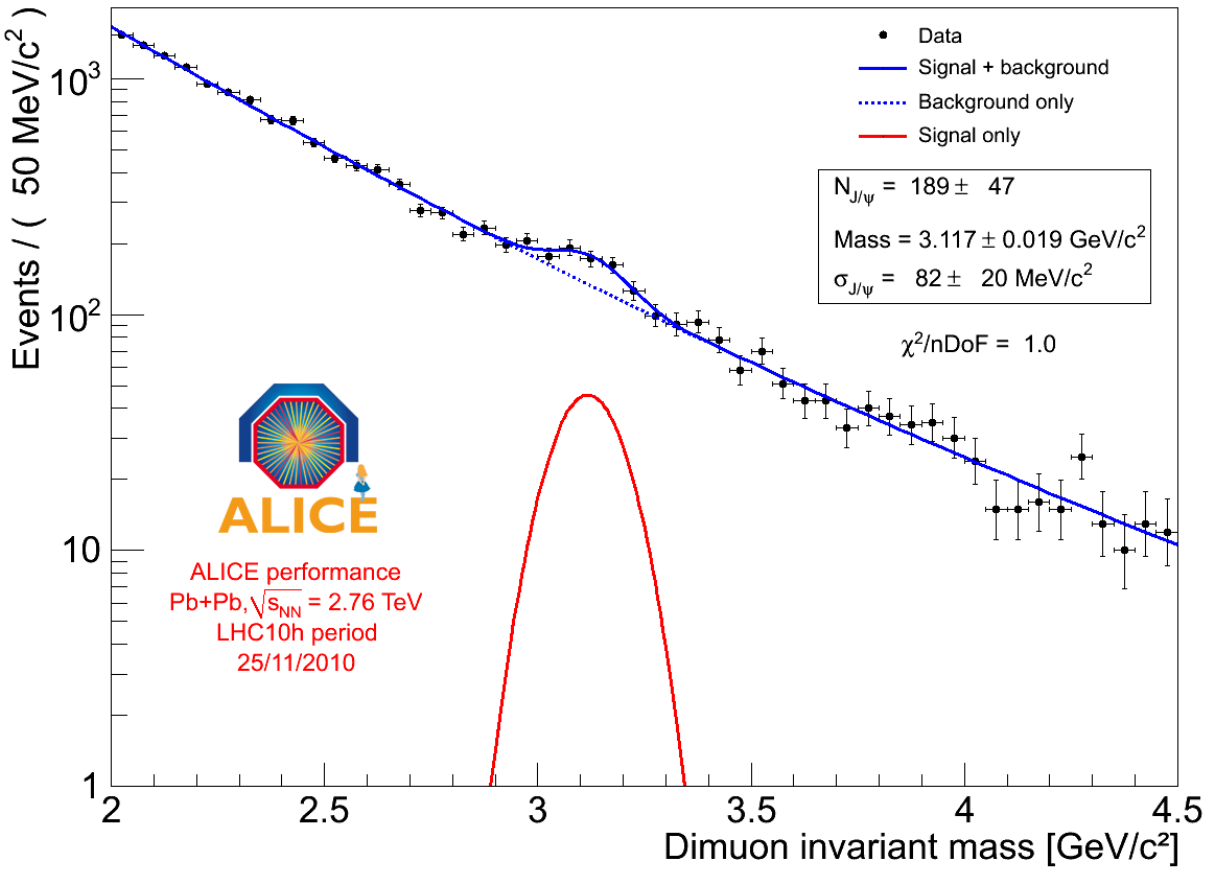


- **Unique measurement at LHC for rapidity coverage and lowest p_t reach**
- Good agreement between LHC experiments
- Theories have still large uncertainties

J/ψ in PbPb collisions - outlook

- November-December 2010: LHC collided ion beams at $\sqrt{s_{NN}} = 2.76$ TeV
- A first look to the invariant mass spectrum in the muonic channel
- Analysis ongoing... more news soon!

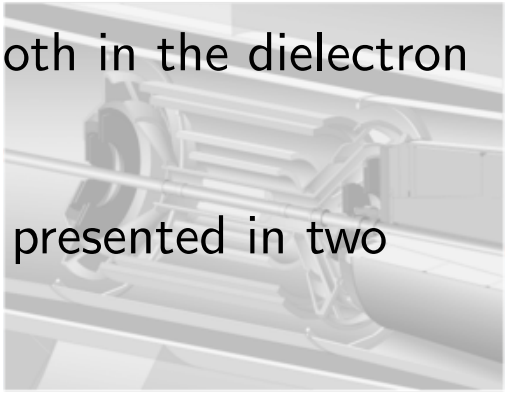


- One of the key measurements to study the hot nuclear phase is the Nuclear Modification Factor

$$R_{AA}^{J/\psi} = \frac{yield_{AA}^{J/\psi}}{\langle N_{coll} \rangle \cdot yield_{pp}^{J/\psi}}$$

- The reference measurement in pp should be carried out at the same energy of nucleon collisions
- It is possible a twofold way
- LHC provided few fills for pp collisions at $\sqrt{s} = 2.76$ TeV
- The collected statistics will be probably enough for measuring the integrated cross section at least at forward rapidity
- An interpolation of the J/ψ cross section was also carried out starting from the available data (F.Bossù et al., arXiv:1103.2394v1 [nucl-ex])

Conclusions



- Preliminary results on charmonium production both in the dielectron and in the dimuon channel have been presented
- Inclusive J/ψ production cross section has been presented in two rapidity ranges
  - $|y| < 0.88$
  - $2.5 < y < 4$
- First measurement of differential cross section distributions in p_t and y
- A paper on the J/ψ production at $\sqrt{s} = 7\ \mathrm{TeV}$ is going to be published, final discussion at the collaboration level.
- Looking forward to having results in PbPb