Inclusive J/ψ production at ALICE

Birmingham HEP seminar - 15th Dec 2010

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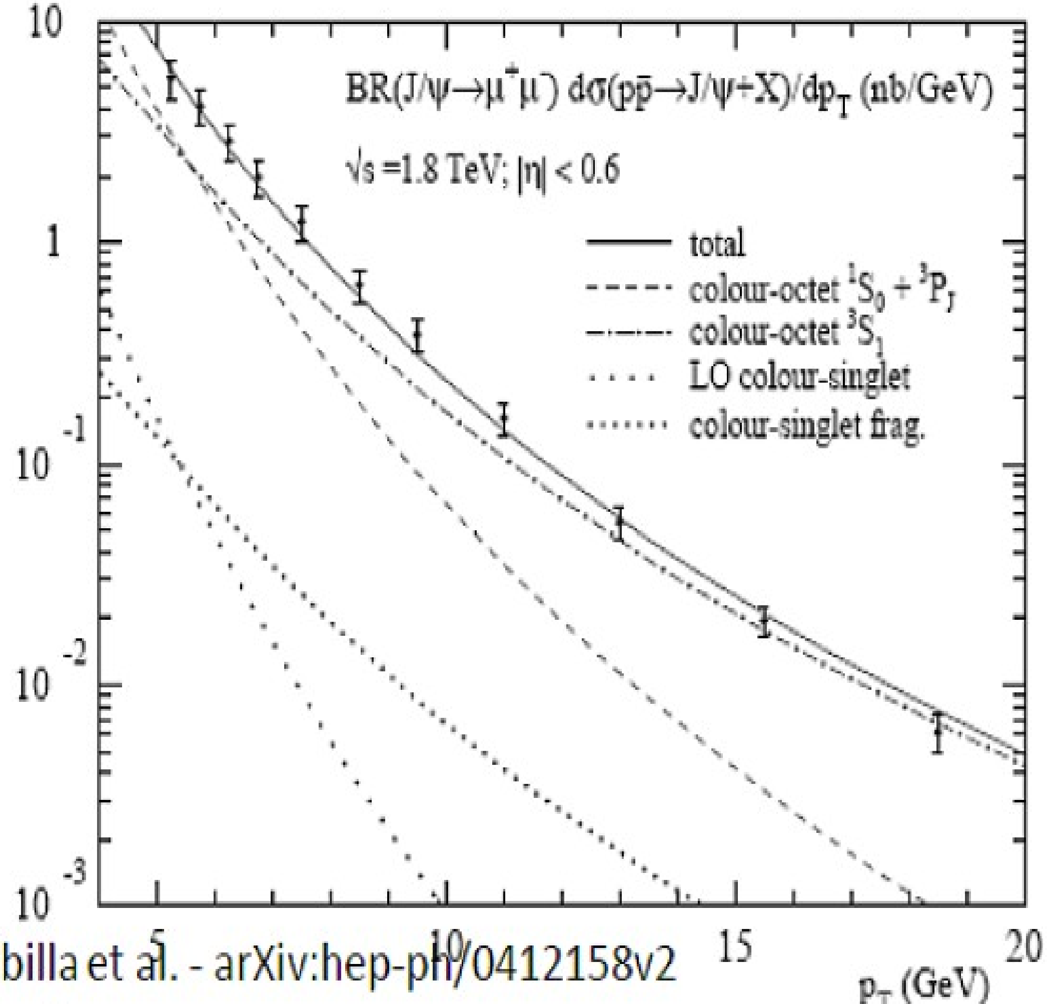
Plan of this talk

- **Quarkonia production in p+p**
  - Physics motivation
  - ALICE detector and collected data
  - Data analysis
  - Comparison to theoretical models
- **What is next?**
  - Quarkonia production in Pb+Pb
  - Exclusive production, polarisation, ...
- **Summary**

Hadro-production of heavy quarkonia states

Several models have been proposed to describe the Tevatron and RHIC data

- Colour Evaporation Model (CEM)
- Colour Octet Model (COM)
- Colour Singlet Model (CSM)

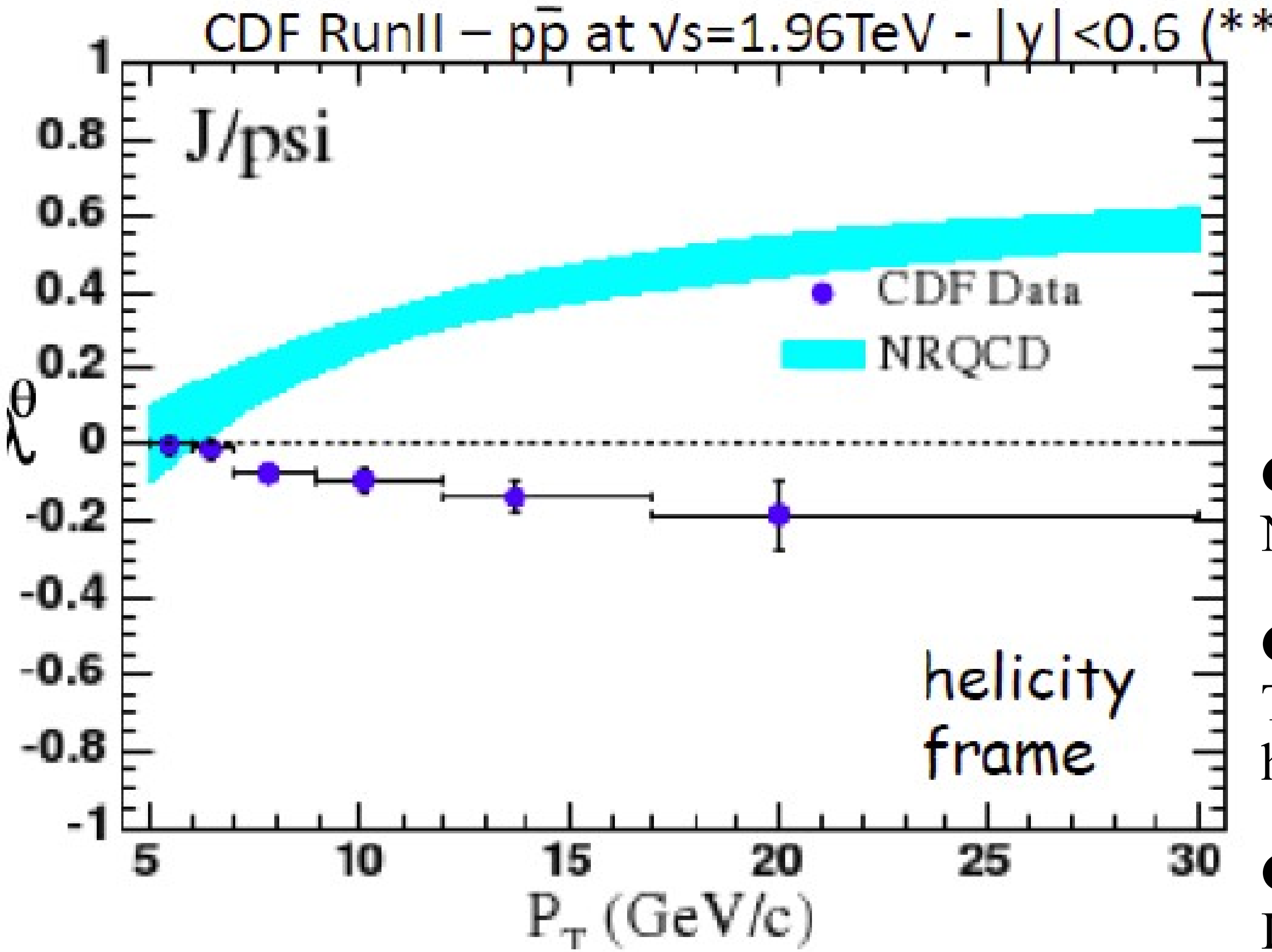


N.Brambilla et al. - arXiv:hep-ph/0412158v2

Mainly differ in the relative weight of the color singlet and color octet intermediate qq states that, once hadronised, will form the final observed resonance.

Polarisation of heavy quarkonia states

The models are not able to reproduce consistently the production cross section, the transverse momentum (pT) distributions and the polarisartion.



$$\frac{dN}{d\cos\theta} = A(1+\lambda\cos^2\theta)$$

λ>0 transverse
λ<0
longitudinal

CEM:
No predictions

COM:
Transverse polarisation at high pT

CSM:
Longitudinal at high pT

The ALICE experiment at the CERN LHC

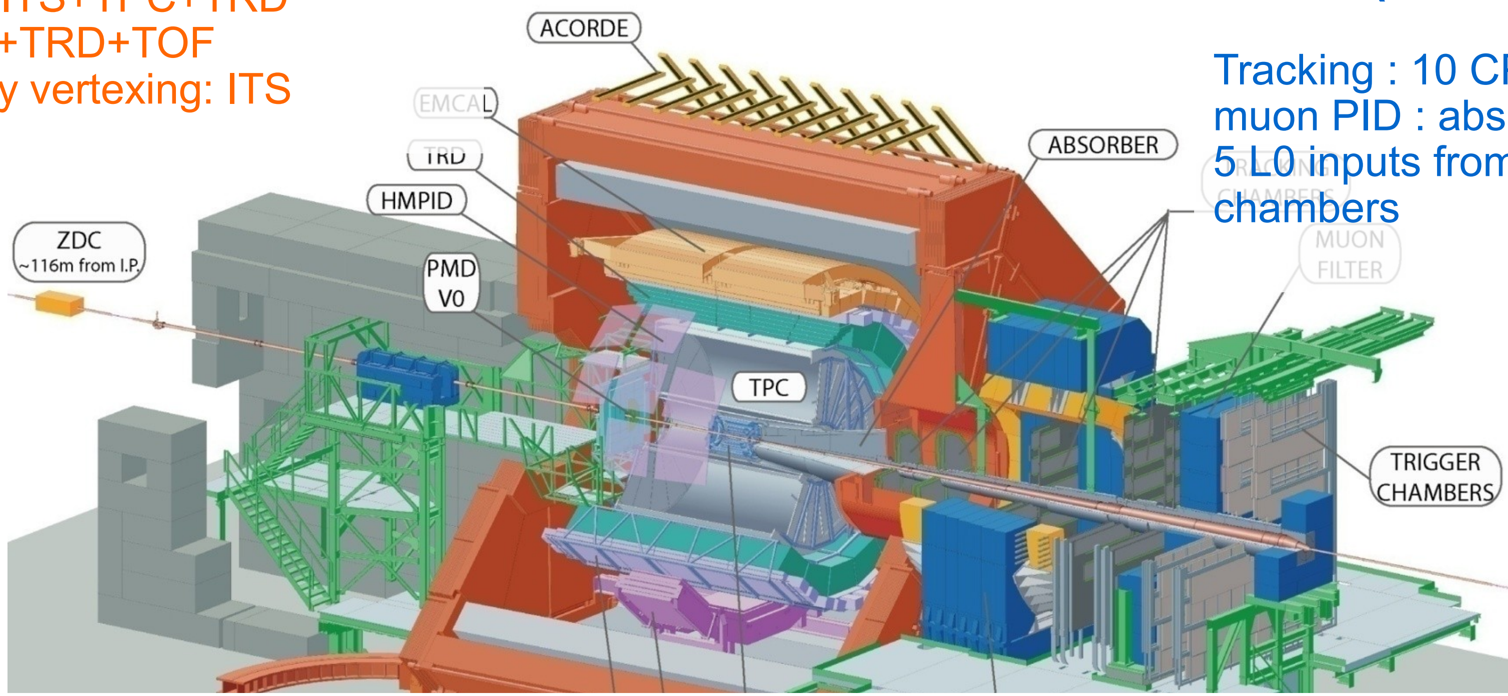
The ALICE detector

Central barrel (|η|<0.9)

Tracking: ITS+TPC+TRD
PID: TPC+TRD+TOF
Secondary vertexing: ITS

Muon spectrometer (-4.0<η<-2.5)

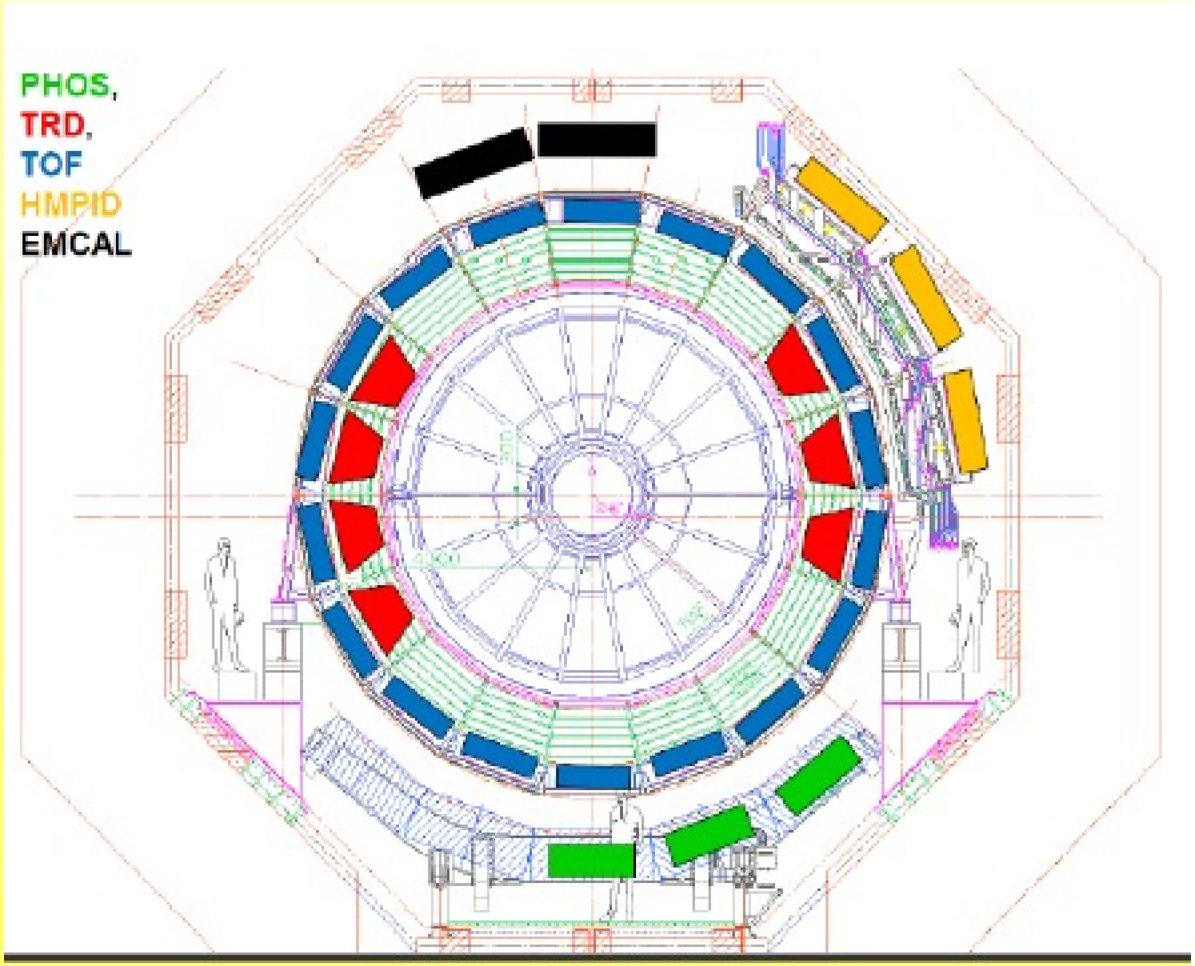
Tracking : 10 CPC planes
muon PID : absorbers
5 L0 inputs from trigger chambers



- Using the central barrel: J/ψ → e^-e^+ (BR = 5.94 %)
- With the muon spectrometer: J/ψ → $\mu^-\mu^+$ (BR = 5.93 %)

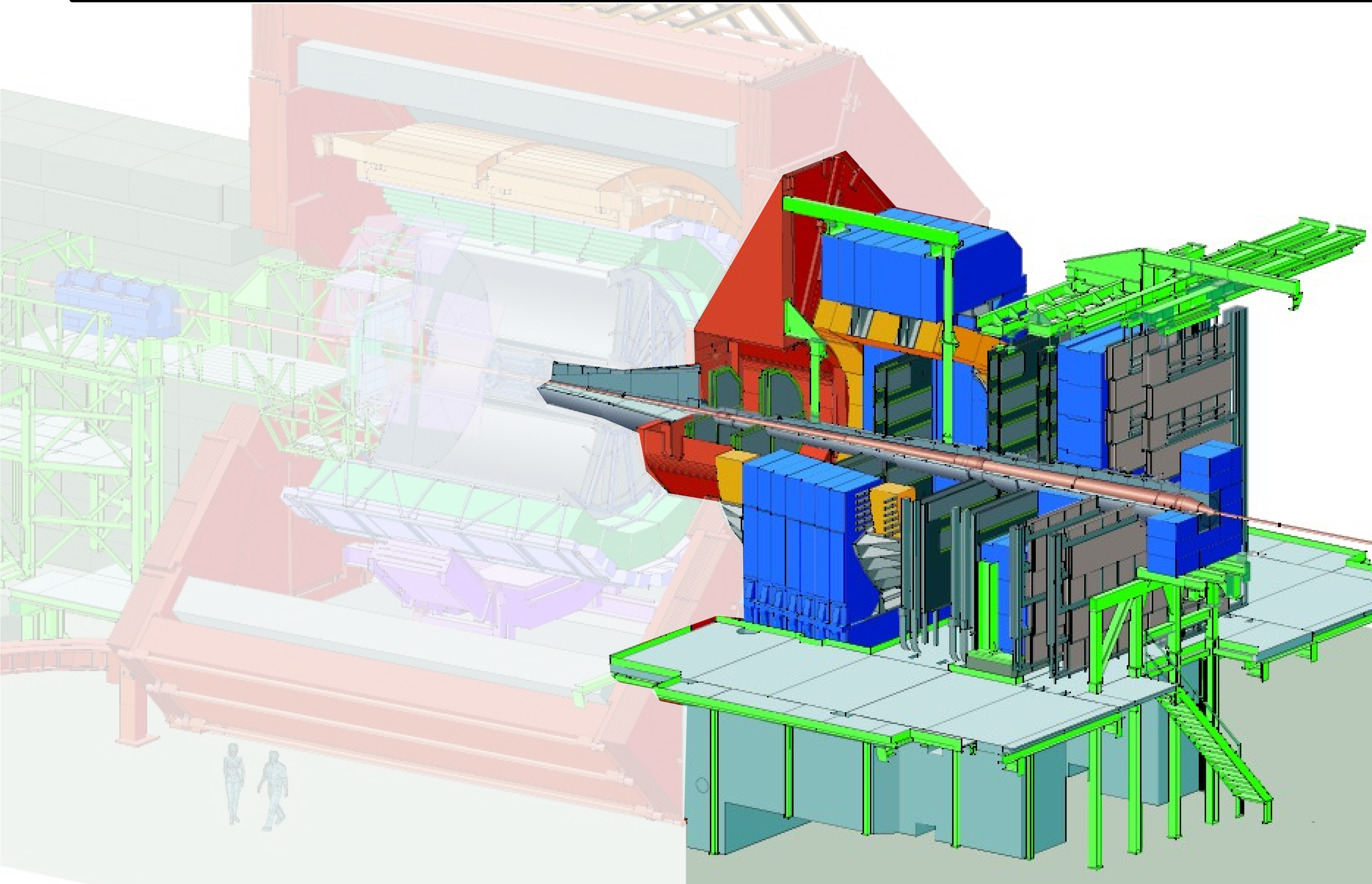
ALICE 2010

- ITS, TPC, TOF, HMPID, MUON, V0, T0, FMD, PMD, ZDC (100%)
- TRD* (7/18)
- EMCAL* (4/12)
- PHOS (3/5)

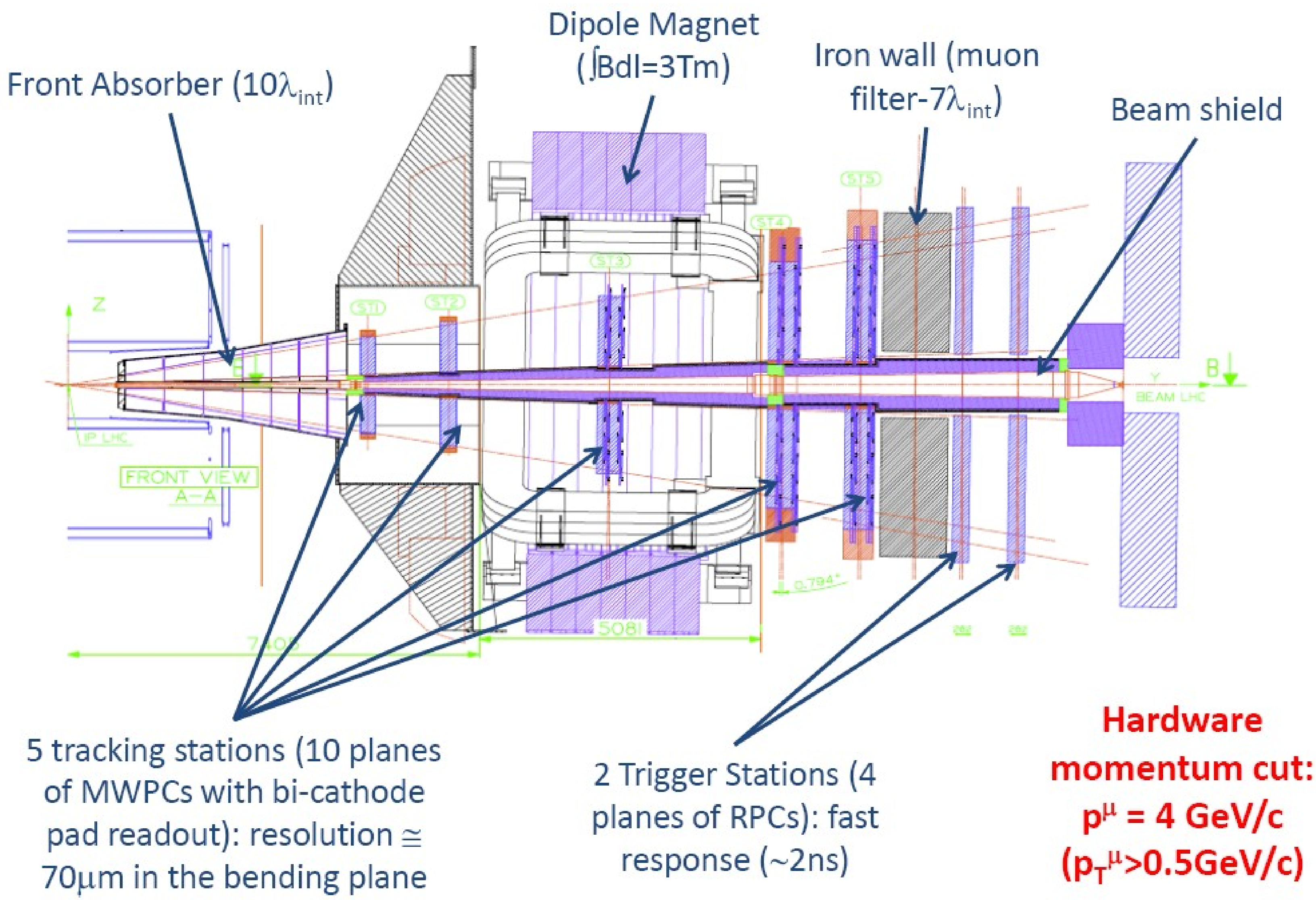


*upgrade to the original setup

The ALICE Muon Spectrometer

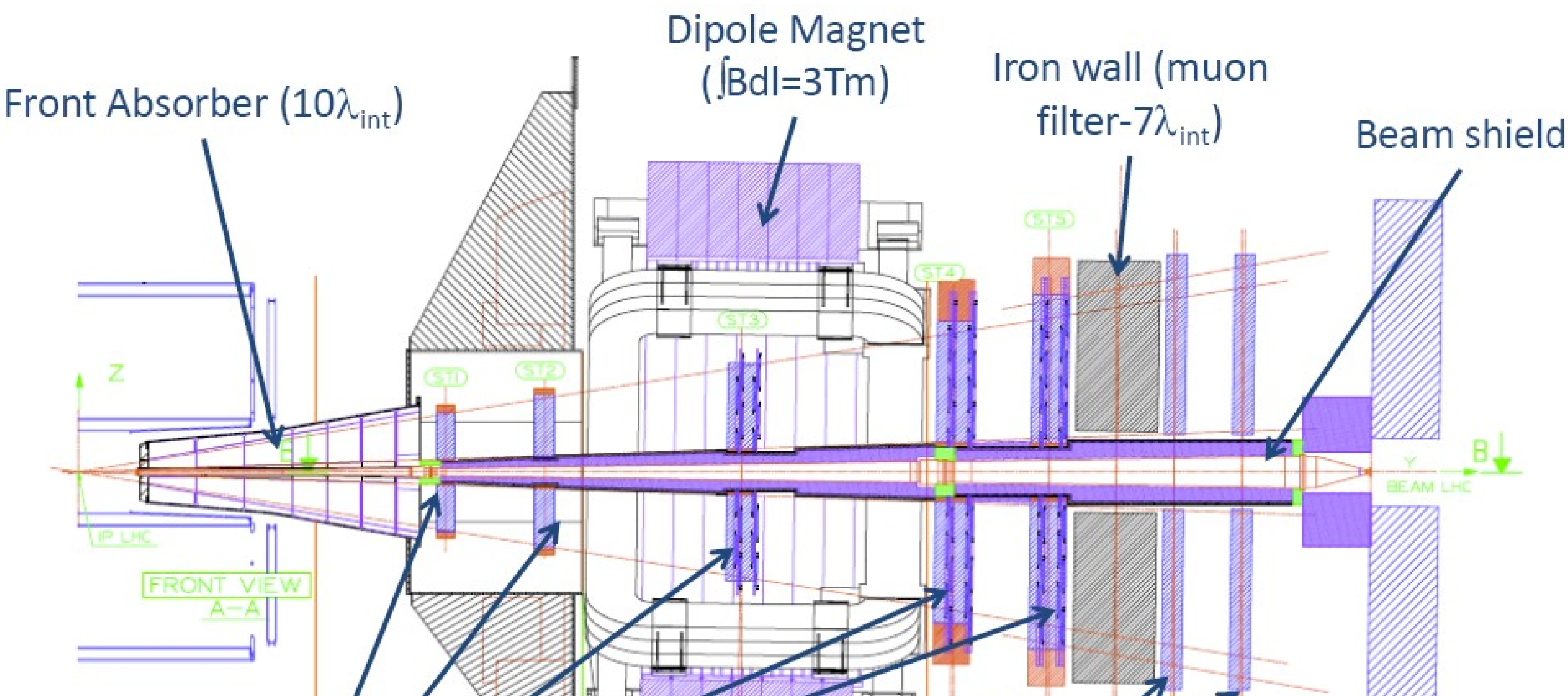


The ALICE Muon Spectrometer



Hardware momentum cut:
p^{μ} = 4 GeV/c
(p_T^{μ}>0.5GeV/c)

The ALICE Muon Spectrometer



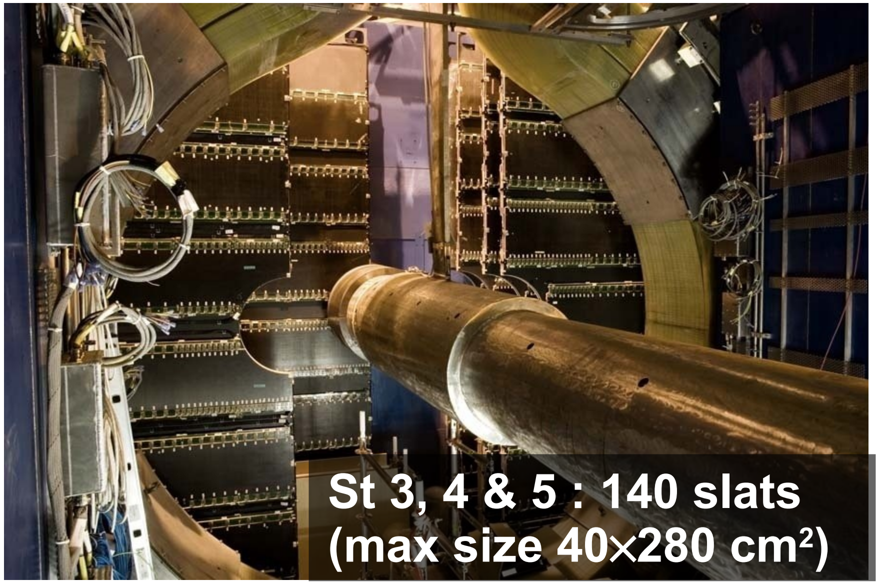
I. **Mass resolution for ϒ < 100 MeV/c² → spatial resol. < 100 μm along y (bending direction)**

II. **Up to 500 hits/central Pb-Pb collision on the 1rst station** (assuming $dN_{ch}/dy|_{y=0}$ = 8000)

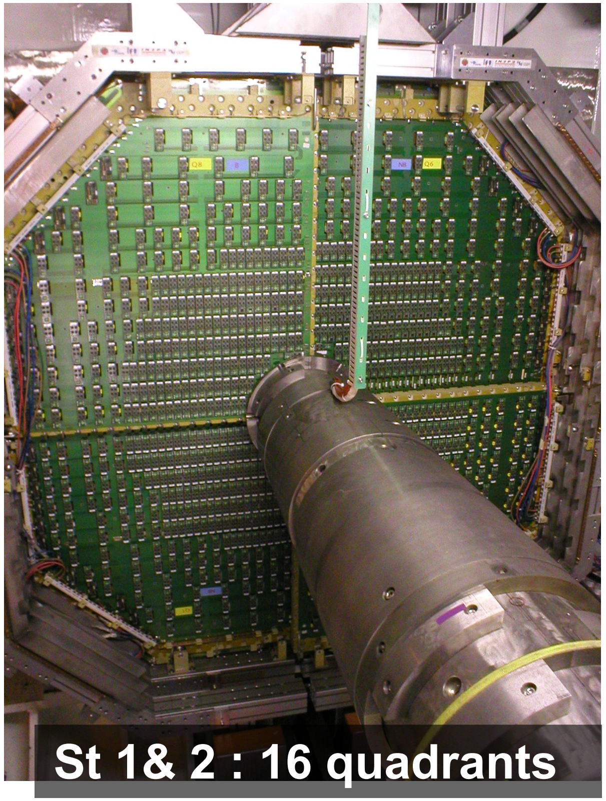
III. **Trigger rate < ~1 kHz (DaQ bandwidth for muon)**
   - **8 kHz Pb-Pb collisions with L = 10^{27} $cm^{-2}s^{-1}$**

Muon Tracking Chambers

- 5 stations of two Cathode Pad Chambers ~ 100 m2
- 1.1×10^6 channels, smallest pads 4.2×6.3 mm^2 : occupancy < 5% (in Pb+Pb)
  → Read out at 1 kHz
- Chamber thickness ~ 3% X0
- Beam test results for the spatial resolution : 50 μm for a required resolution < 100 μm
- measurement of detectors displacement with an accuracy < 50 μm (GMS)



St 3, 4 & 5 : 140 slats (max size 40×280 cm^2)



St 1& 2 : 16 quadrants

Collaboration France, India, Italy, Russia

Trigger chambers

- 72 RPCs located on 2 stations of 2 chambers
- "low resistivity" bakelite working in streamer mode or saturated avalanche (p-p)
- 2 mm single gap
- Time resol. < 2 ns
- 20992 readout strips (pitch 1, 2 and 4 cm; length 17 to 72 cm)

- FEE : 2384 Front-End boards with 8 ch. ADULT ASIC read each 25 ns.
- Decision electronics : 16 VME crates with 242 local trigger cards. Decision delay of 250 ns

- Trigger decision in < 700 ns
- Readout 140 μs
- Deliver 5 output signals/triggers for single μ, like-sign and unlike-sign μ pairs above 2 $p_{\perp}$ thresholds (1 or 2 GeV/c)

Collaboration France, and Italy

Quarkonia measurments at ALICE

- in the central barrel in the e^+e^- channel ($|y|<0.9$)
- in the forward spectrometer in the $\mu^+\mu^-$ channel ($2.5<y<4$)

3 sources of J/ψ

1) Direct production
2) Feed down from heavier cc states

} Prompt J/ψ — radiative decay $\chi_c \rightarrow J/\psi\gamma$ in the central barrel

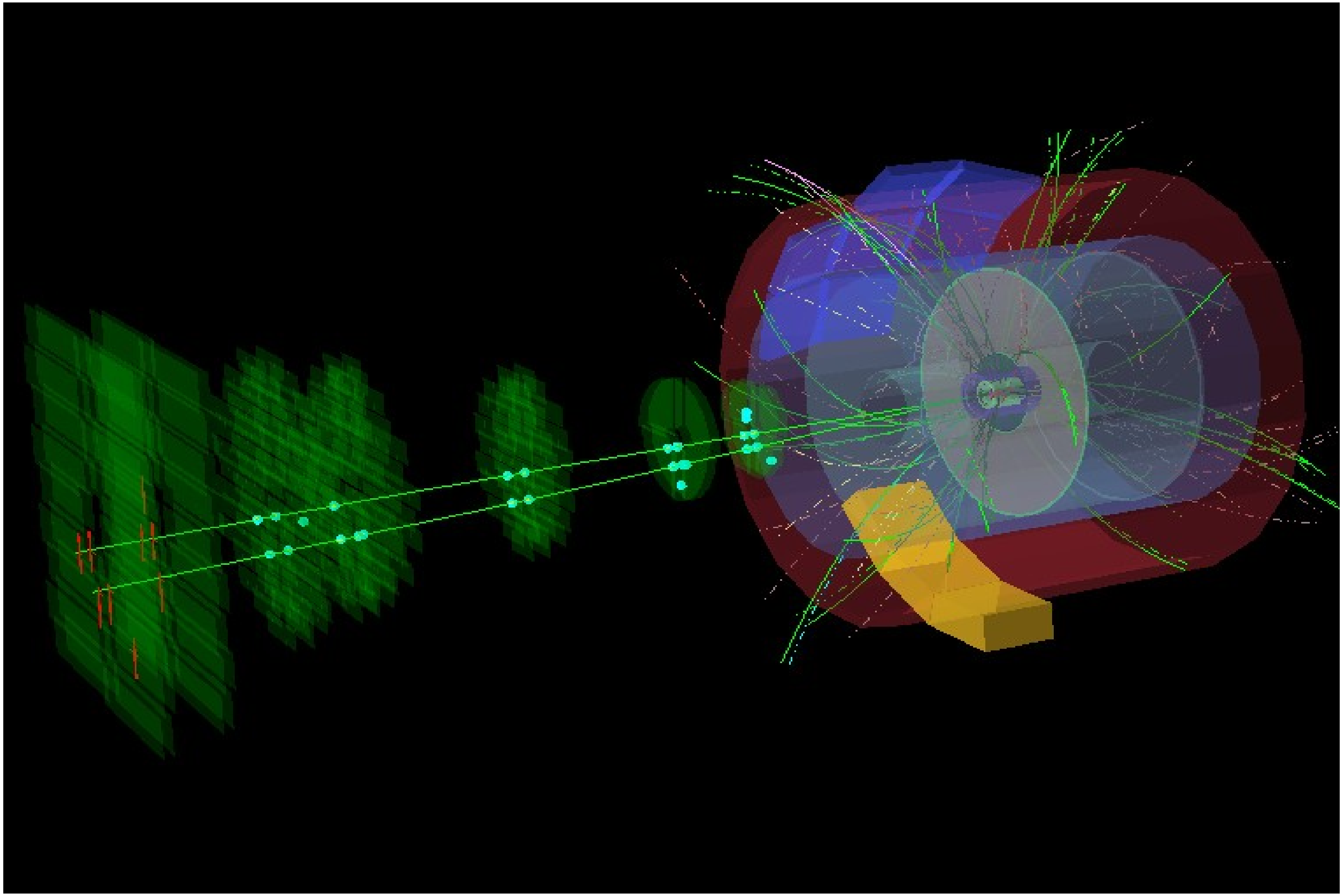
3) J/ψ from b-hadron decay

→ can be identified in the central barrel, good impact parameter resolution ($\sigma_{r\phi}$ < 60 μm for p_T>1 GeV/c)

→ forward detection more difficult
→ 3-muon events
B cross section from single-μ
Semileptonic decays of B pairs

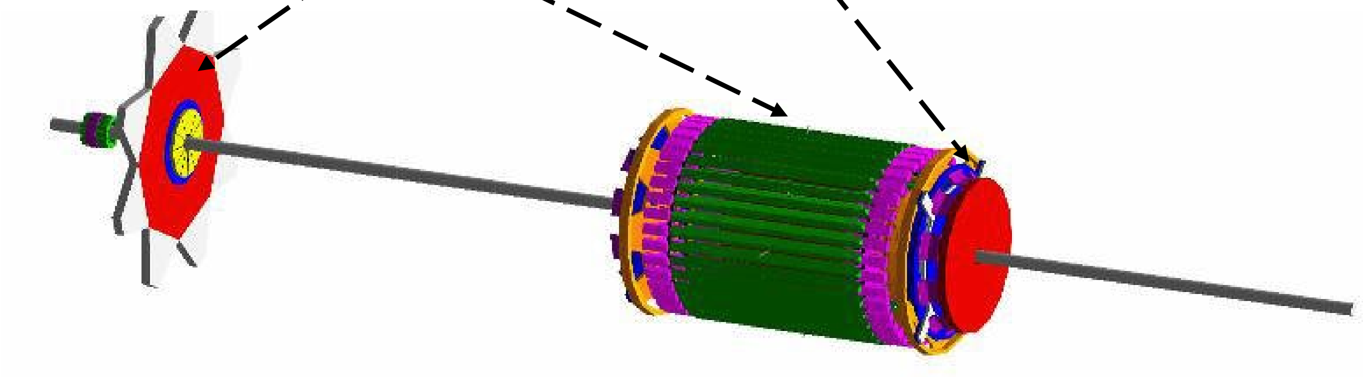
Preliminary ALICE results refer to inclusive J/ψ production

First results from p+p $\sqrt{s_{NN}}$=7 TeV



MB triggers during the p+p runs this year

Minimum Bias Triggers	MB1	SPD or (V0A or V0C)
	MB3	SPD and (V0A and V0C)



at least 1 charged particle in 8 rapidity units

Aat least 2 pixels in coincidence with beams

V0A $2.8 < \eta < 5.1$

V0C $-1.7 < \eta < -3.7$

Global Fast Or (GFO) is the trigger from the Silicon Pixel Detector (SPD)

$J/\psi \rightarrow \mu^+\mu^-$: $p+p$ @ $\sqrt{s}$=7 TeV sample

- **Data sample:**

  Integrated luminosity = 13.6 nb^{-1}, corresponding to data collected between May and July 2010 (~ 10-15% of the 2010 total statistics)

  Trigger: muon in the forward spectrometer, in coincidence with minimum bias interaction trigger

Run Selection:

Runs selected according to quality checks on the stability of the muon spectrometer tracking and trigger performances

- **Event Selection:**

  at least one muon reconstructed in the tracking and trigger chambers satisfying the trigger algorithm

  at least one vertex reconstructed in the silicon pixel detector

  cut on the track position at the end of the front absorber ($2^0<\theta_{abs}<9^0$)

rapidity window: 2.5<y<4
transverse momentum window $0<p_T<8$ GeV/c (statistics)

$J/\psi \rightarrow \mu^+\mu^-$: signal extraction

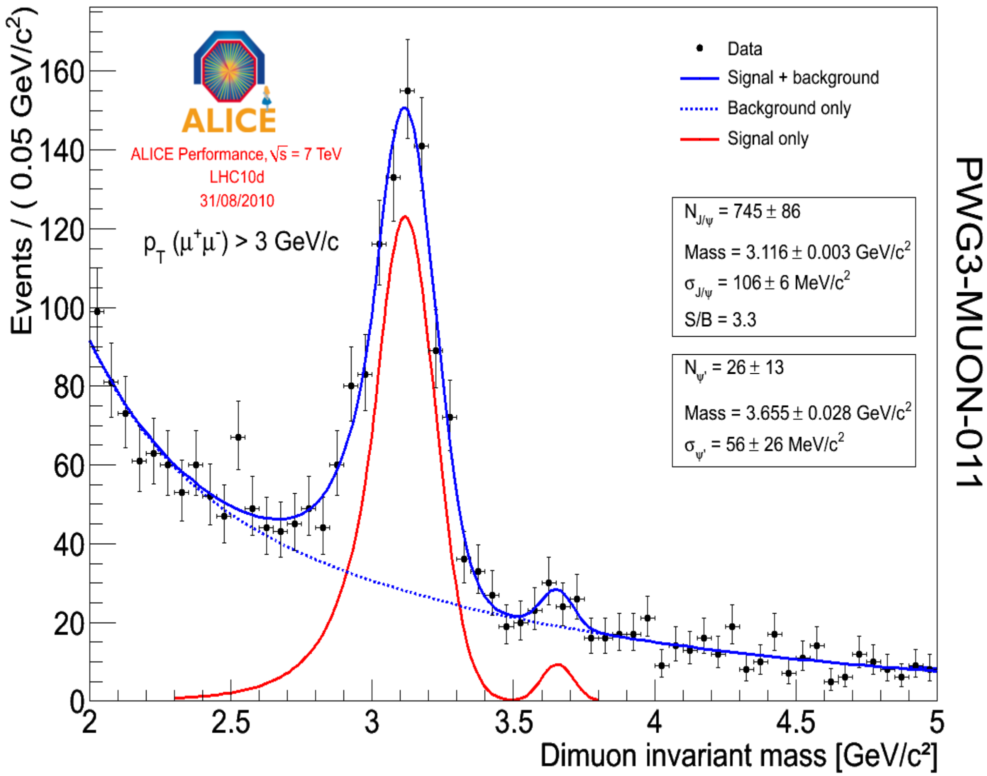
The number of J/ψ is extracted from a fit to the invariant mass spectrum using

Crystal Ball shape for the signal (J/ψ and ψ')
Sum of two exponentials for the background

The available J/ψ statistics, used for the cross section determination is

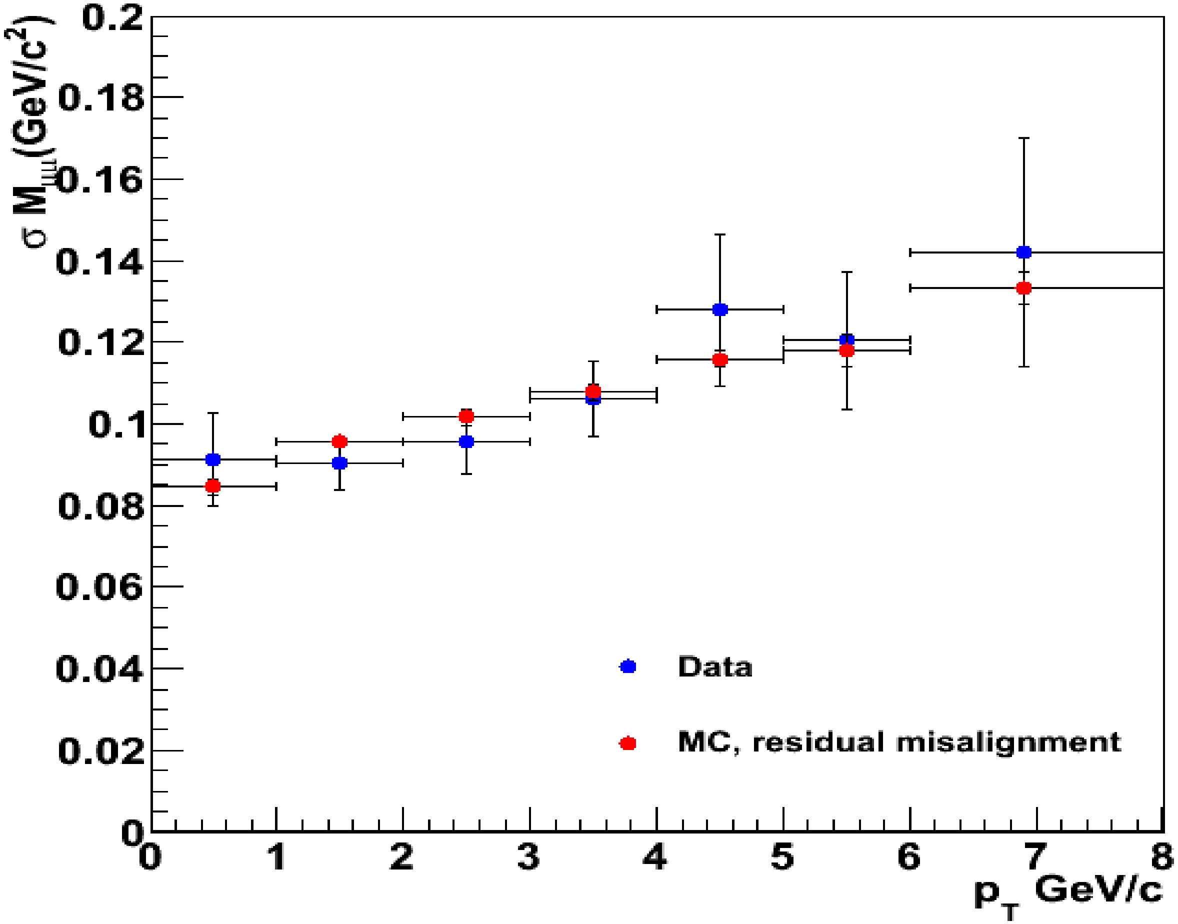
$N_{J/\psi}$ = 1909 ± 78

S/B (2.9<M<3.3) ~ 2.4



With a suitable p_T cut (smaller background), also the ψ(2S) signal is visible, but with a much lower statistical significance

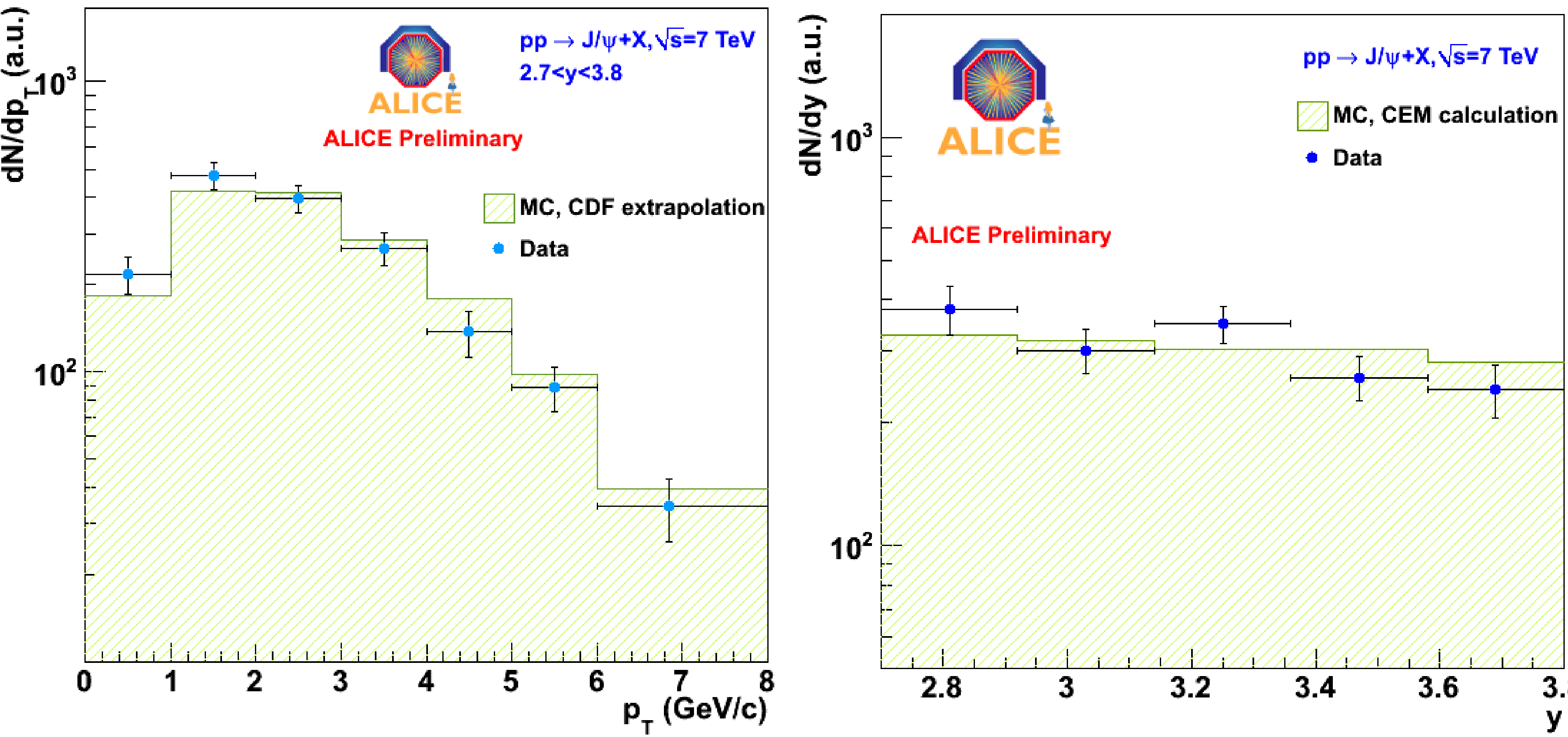
J/ψ → $\mu^+\mu^-$: Comparison to the MC



J/ψ peak width well reproduced by MC :

- alignment
- data taking conditions

$J/\psi \rightarrow \mu^+\mu^-$: acceptance $\times$ efficiency



Data corrected for acceptance and efficiency

→data somewhat softer than the MC

Generated MC distribution “CDF pp 7TeV”

- p_T extrapolated from CDF results, y obtained from CEM calculations, no polarisation

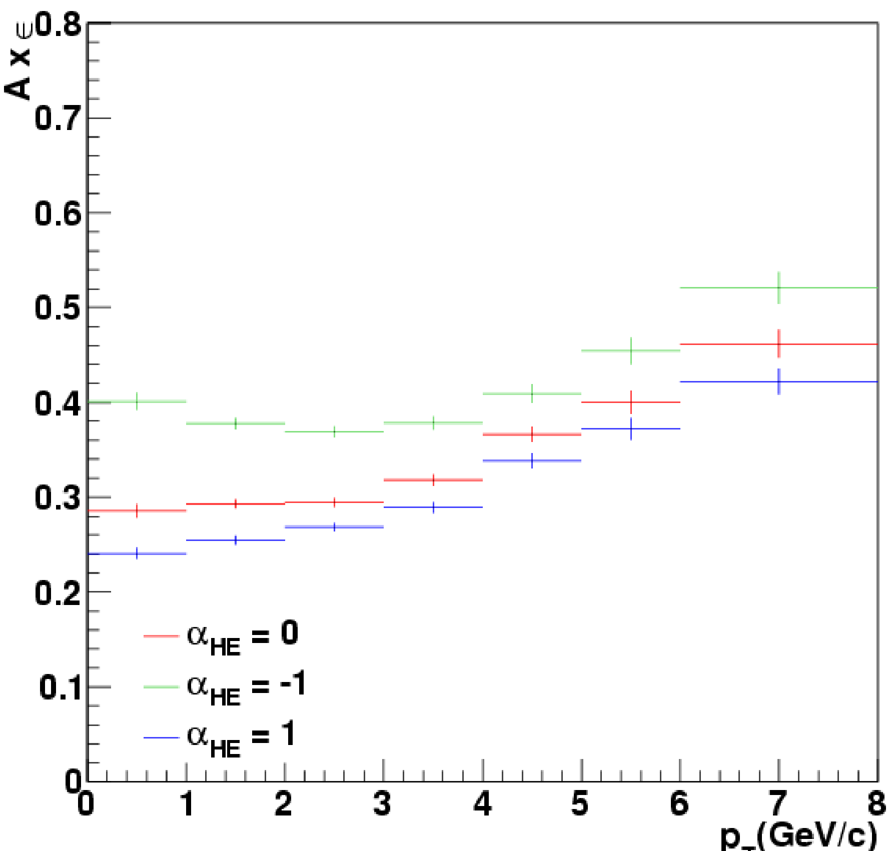
$J/\psi \to \mu^+\mu^-$: *acceptance × efficiency*

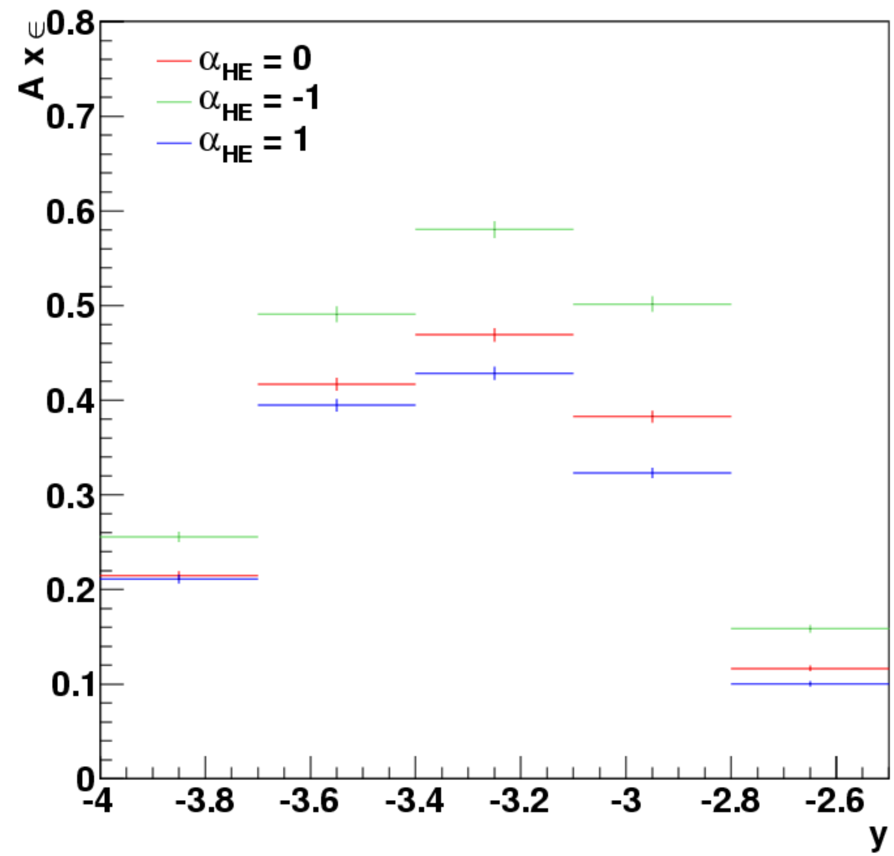
Based on simulations performed separately for each LHC period, in order to reproduce in a realistic way, the detector status

Input: realistic y and p_T J/ψ distributions

p_T → CDF extrapolation
y → CEM calculation

Study of differential distributions: 1D acceptance correction





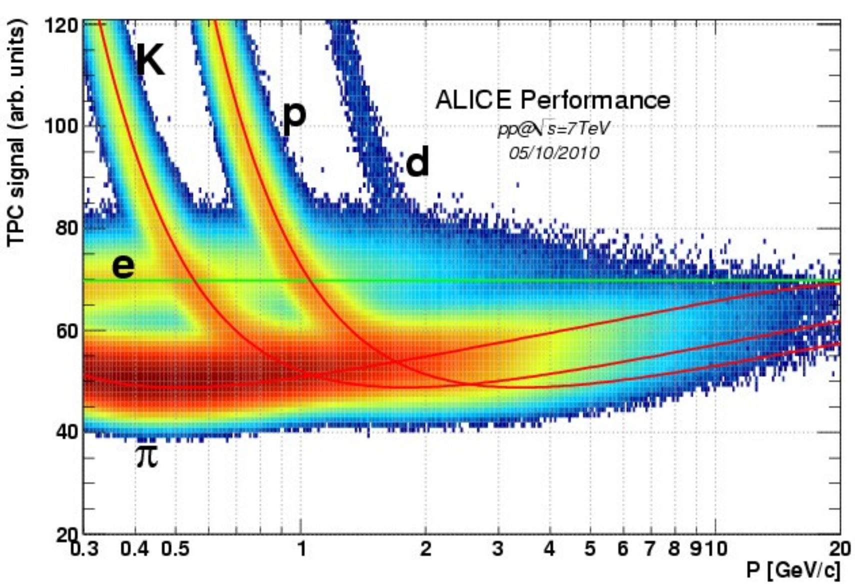
$J/\psi \rightarrow e^+e^-$: p+p @ $\sqrt{s}$=7 TeV sample and signal extraction

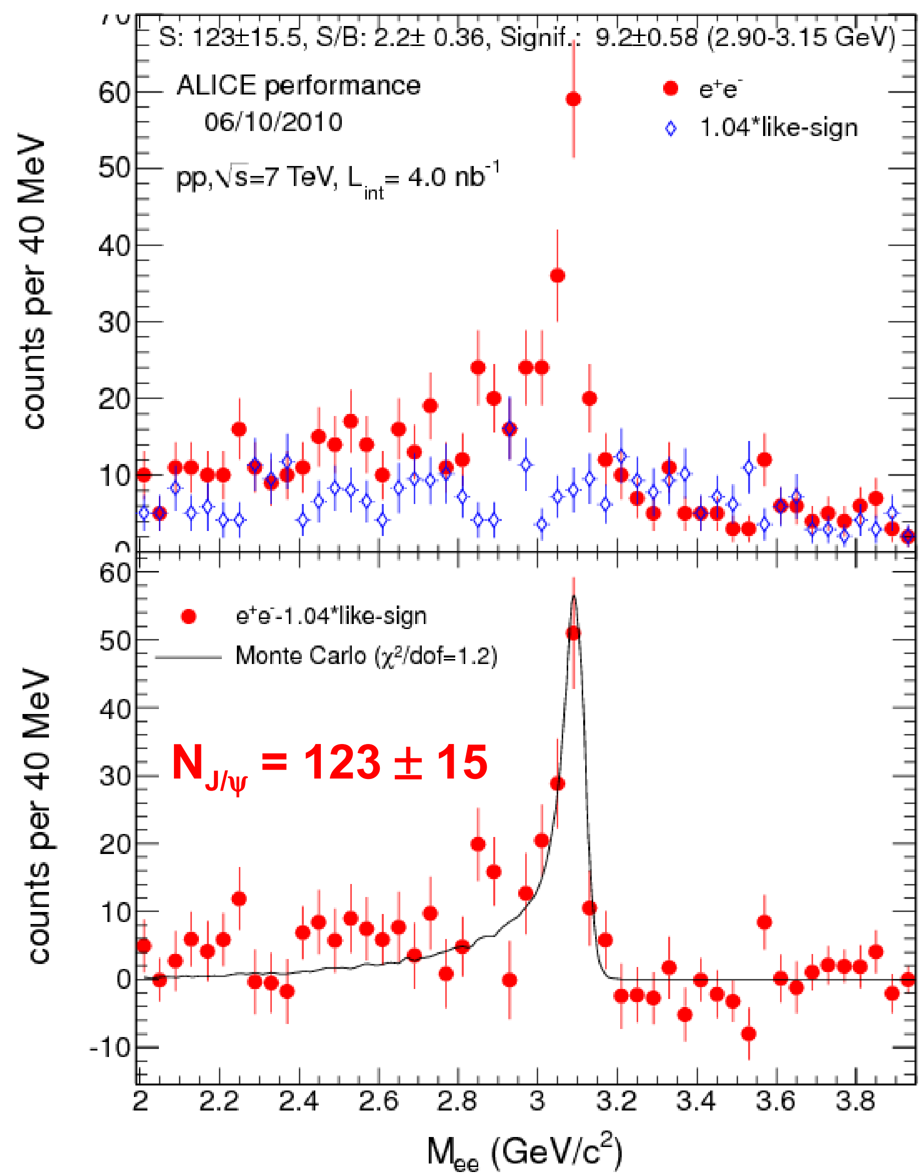
Analysis is based, for the moment, on a smaller data sample wrt to $J/\psi \rightarrow \mu^+\mu^-$
→ L=4.0 nb^{-1} (~15% of 2010 stat.)

Track selection:

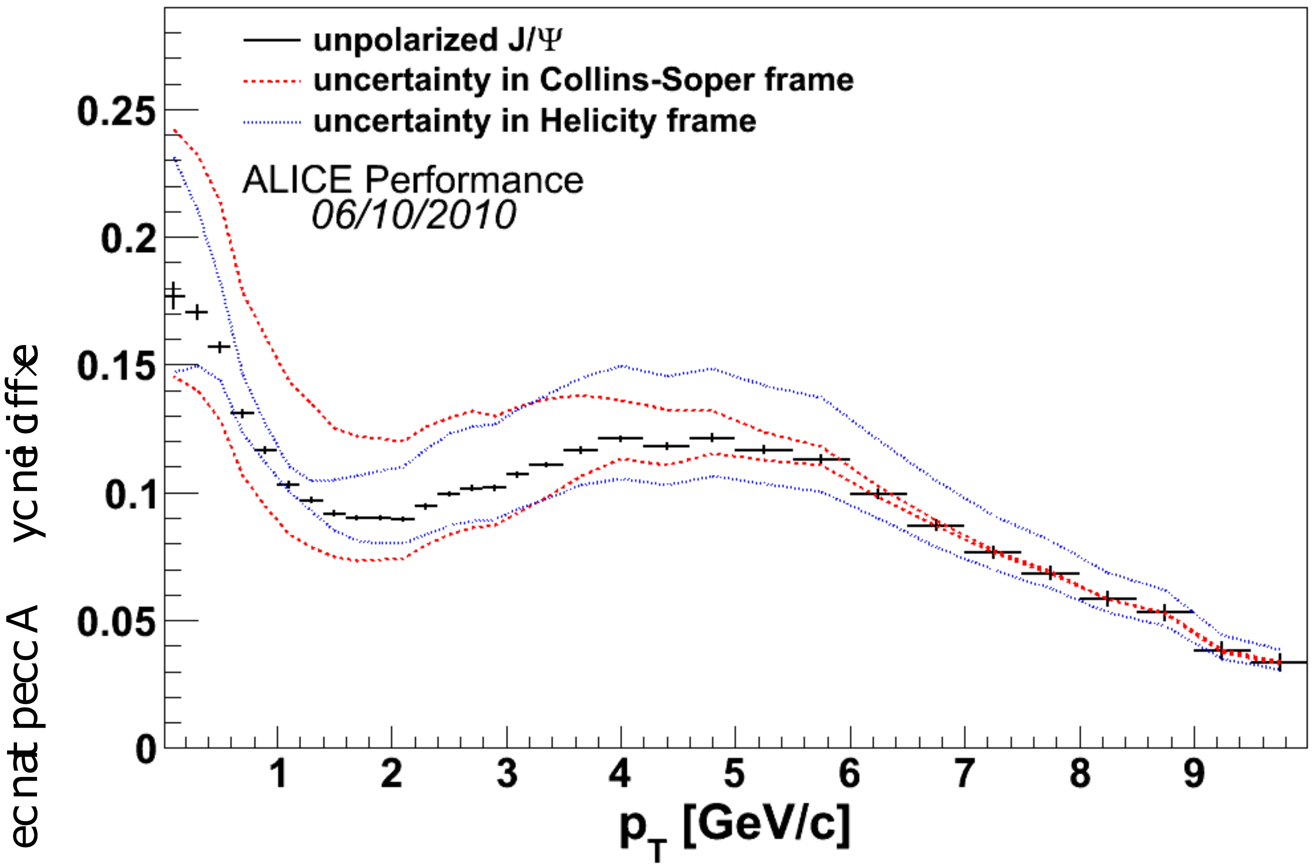
$|\eta^{e+,e-}|<0.88$ and $|y^{J/\psi}|<0.88$
$p_T^{\,e+,e-} > 1$ GeV/c

TPC-based PID





J/ψ → e⁺e⁻ : acceptance × efficiency



As for the muon channel, J/ψ reconstruction down to $p_T = 0$

$J/\psi \rightarrow \mu^+\mu^-$: Luminosity normalisation

- To get an estimation of the luminosity we use the signal from the V0 (V0A and V0C in coincidence → V0and).
- Using a Van der Meer scan we get the Luminosity
  → σ_{V0and} = **62.3 mb** with 10% systematic
- With low intensity runs (to avoid large pile-up) we can extract the ratio V0and/CINT1B.
- CINT1B is our main MB trigger in pp. CINT1B = V0A or V0C or SMB (a pixel trigger)
  → $\sigma_{CINT1B} = \sigma_{V0and}$ / (V0and/CINT1B) = **71.4 mb**

We use σ_{CINT1B} to normalize the cross section with the following formula (most of data come from single μ trigger):

$$\sigma_{J/\psi} = \frac{N_{J/\psi|single\ \mu}}{Acc \times \varepsilon} \times \frac{1}{N_{\mu|single\ \mu}} \times \frac{N_{\mu|CINT1B}}{N_{CINT1B\ (pile\ up\ corr)}} \times \sigma_{CINT1B}$$

Integrated cross section(s)

Cross section calculated as

$$\sigma_{J/\psi}\left(2.5 < y < 4\right) = \frac{N_{J/\psi}}{Acc_{J/\psi} \times \varepsilon} \times \frac{1}{L}$$

The ALICE results, integrated over y and p_T, are:

$$\sigma_{J/\psi}(-0.88 < y < 0.88) = 12.95 \pm 2.15(stat) \pm 2.32(syst)^{+1.26}_{-2.55}(syst.pol.)\,\mu b$$

$$\sigma_{J/\psi}(2.5 < y < 4) = 7.25 \pm 0.29(stat) \pm 0.98(syst)^{+0.87}_{-1.50}(syst.pol.)\,\mu b$$

(polarisation-related errors calculated in the helicity frame)

➡ Good agreement with the corresponding LHCb result obtained at forward rapidity (ICHEP2010)

$$\sigma_{J/\psi}(2.5 < y < 4) = 7.65 \pm 0.19(stat) \pm 1.10(syst)^{+0.87}_{-1.27}(syst.pol.)\,\mu b$$

Systematic errors

Muons

Source of systematic error	
Uncertainty on signal extraction	7.5 %
p_T and y shapes in the MC	2%
Trigger efficiency	4%
Tracking efficiency	2%
Normalization	10 %
Total systematic error	**13.5 %**

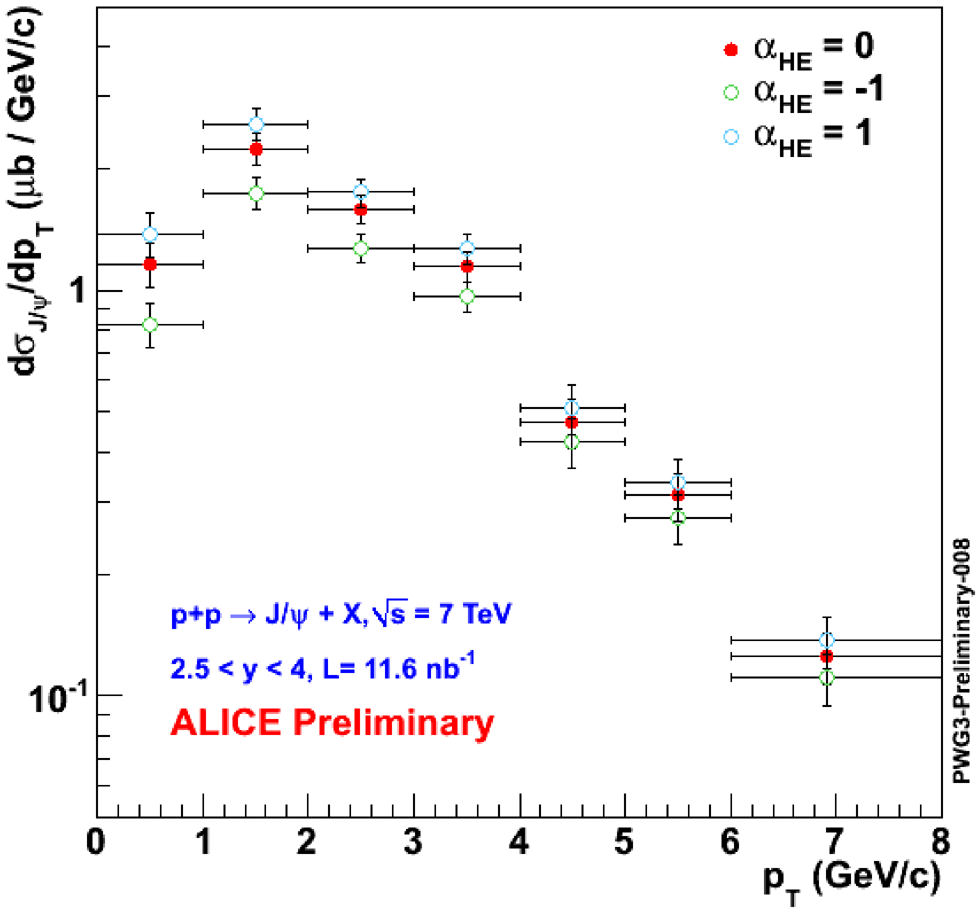
polarization	λ=-1	λ=1
Helicity	-21%	+12%
Collins-Soper	-31%	+15%

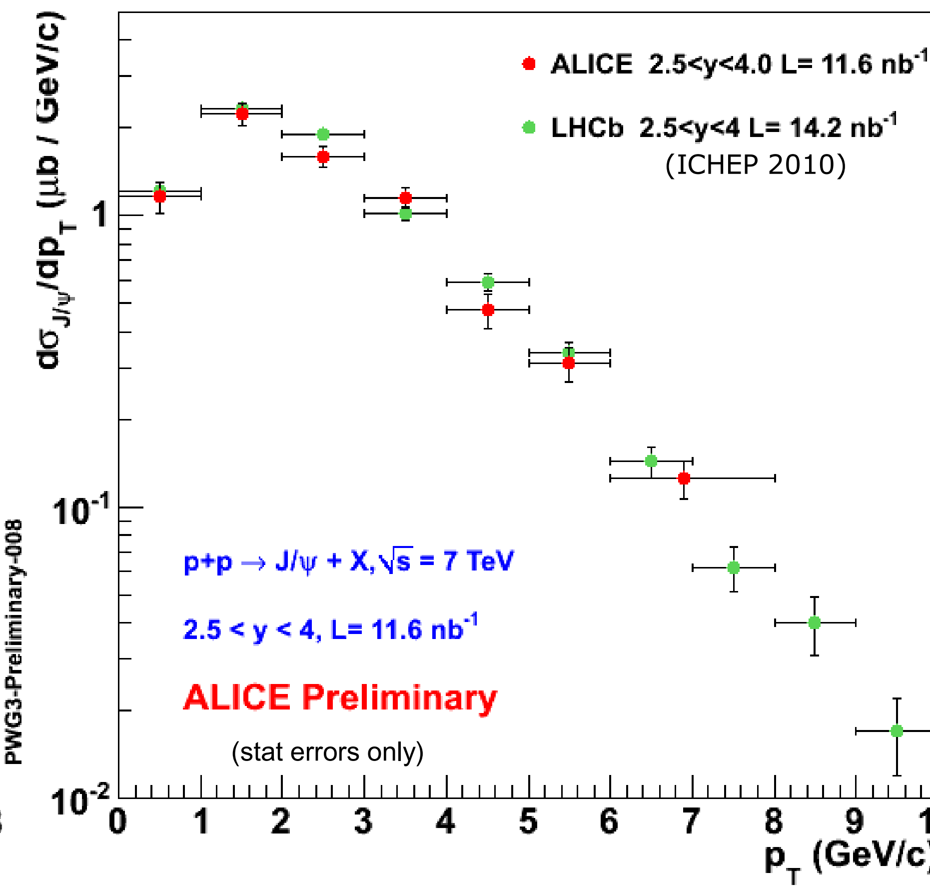
Electrons

Source of systematic error	
Kinematics	<1%
Track quality,#clusters TPC	10%
PID cuts	10%
Signal extraction range	4%
Normalization	10 %
Total systematic error	**18 %**

polarization	λ=-1	λ=1
Helicity	-20%	+10%
Collins-Soper	-25%	+12%

Differential cross section: $d\sigma_{J/\psi}/dp_T$ (2.5<y<4)

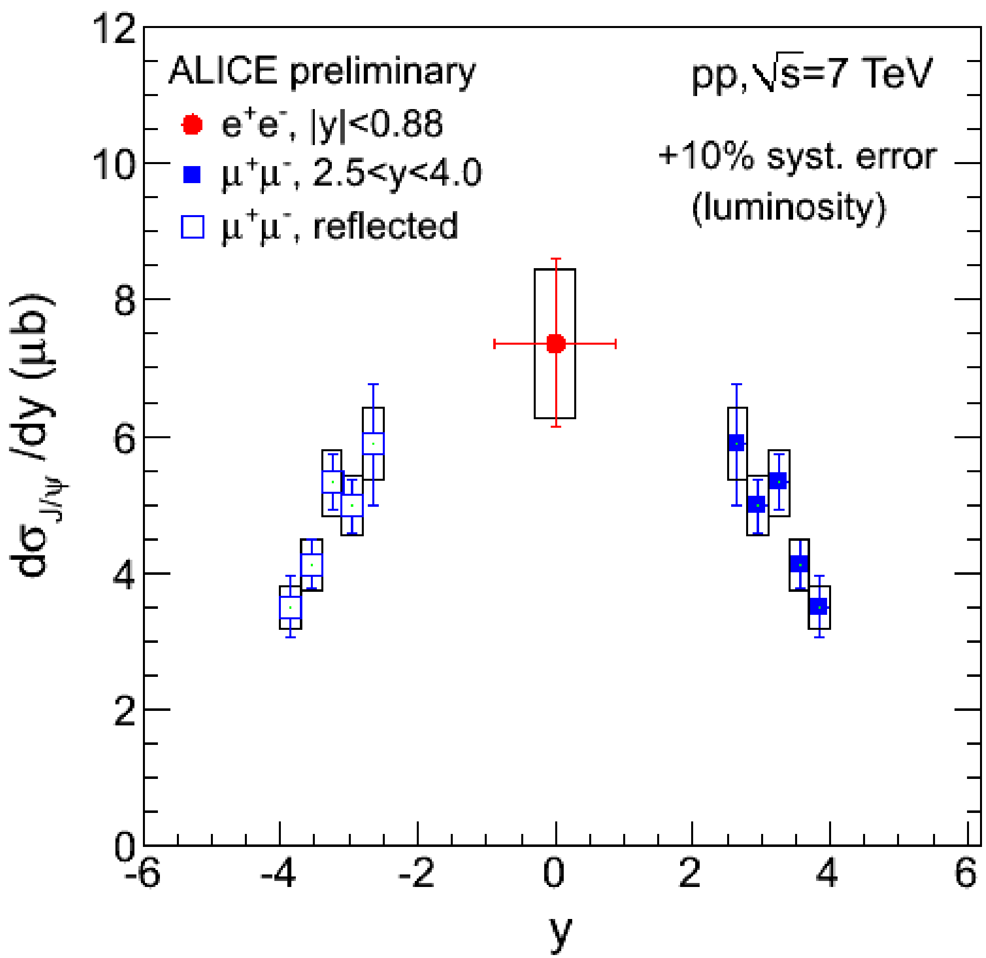




Good agreement with the LHCb result in the same rapidity range

Other sources of point to point systematic errors (signal extraction, acceptance input) vary between 3 and 10% (not yet fully evaluated)

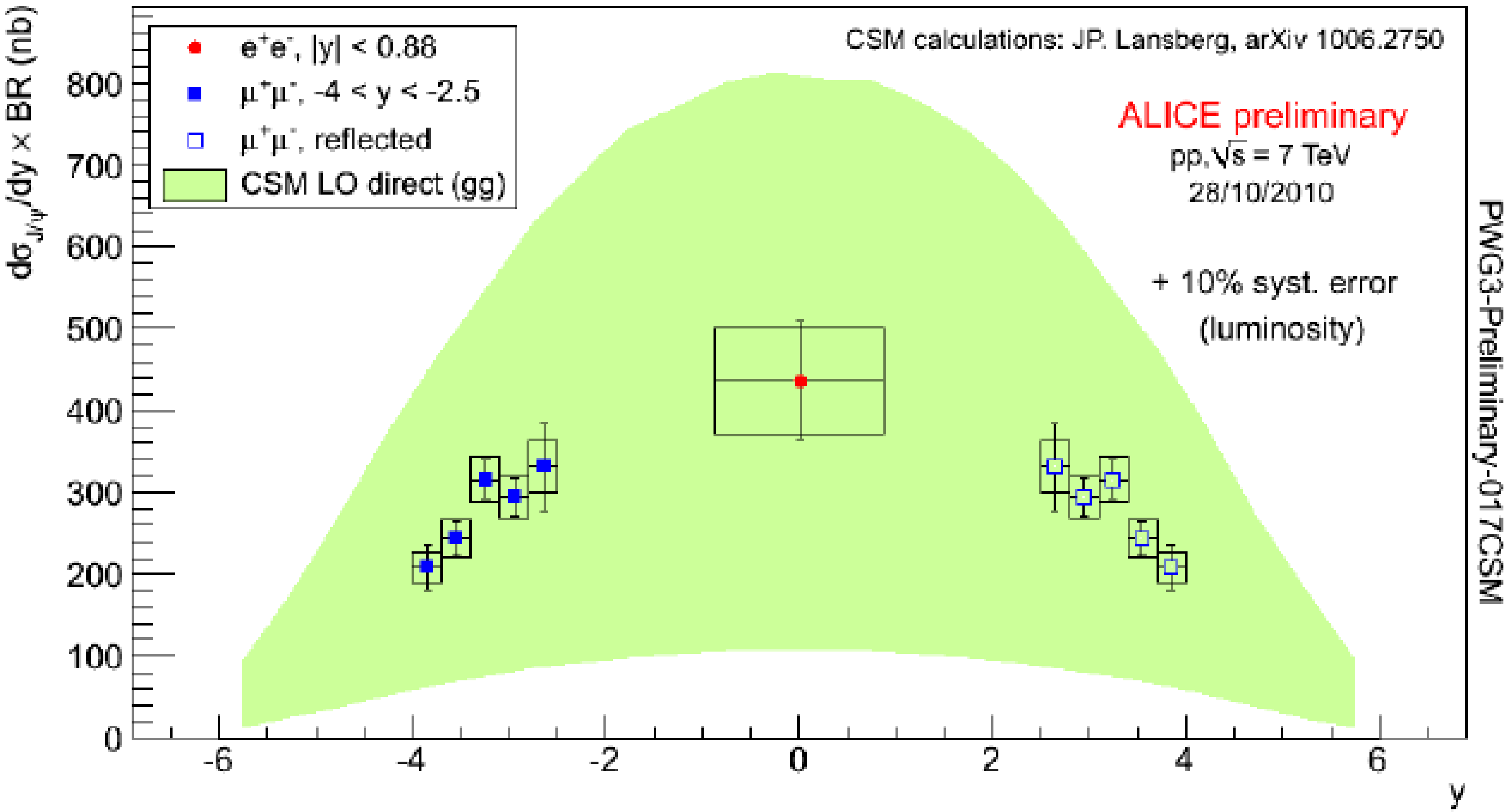
Differential cross section: $d\sigma_{J/\psi}/dy$ (p_T>0)



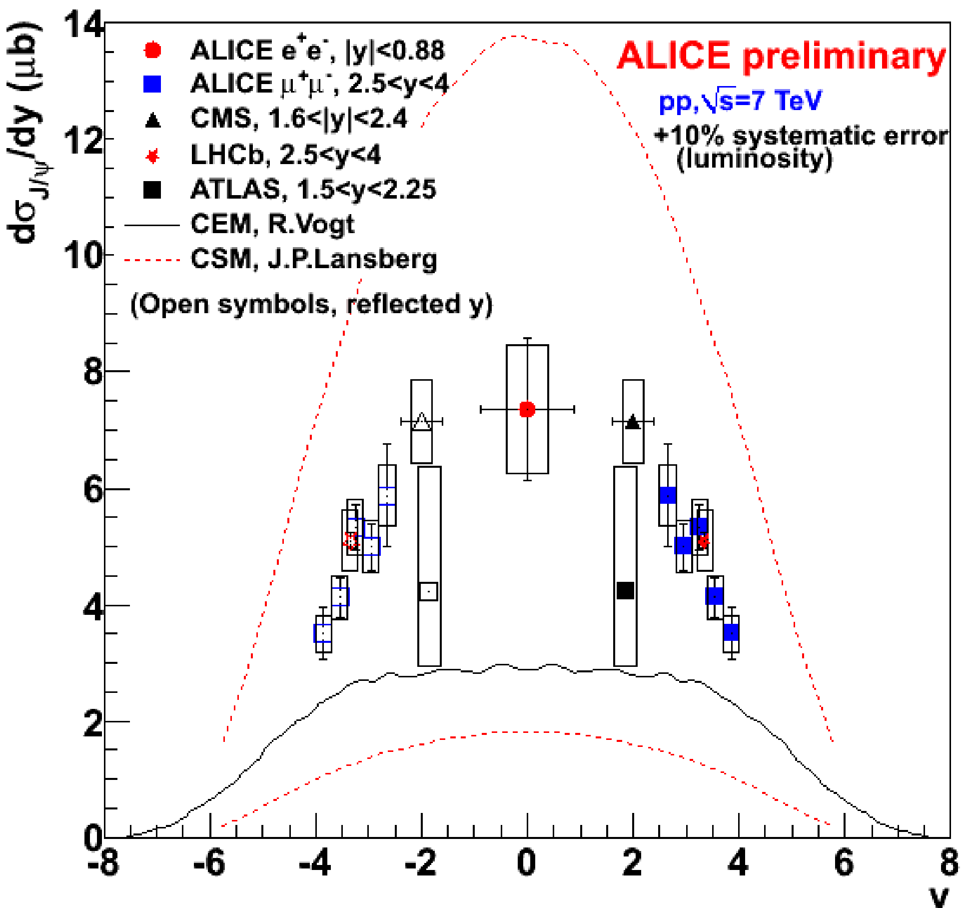
ALICE can measure the distribution of the inclusive J/ψ production in a wide rapidity range

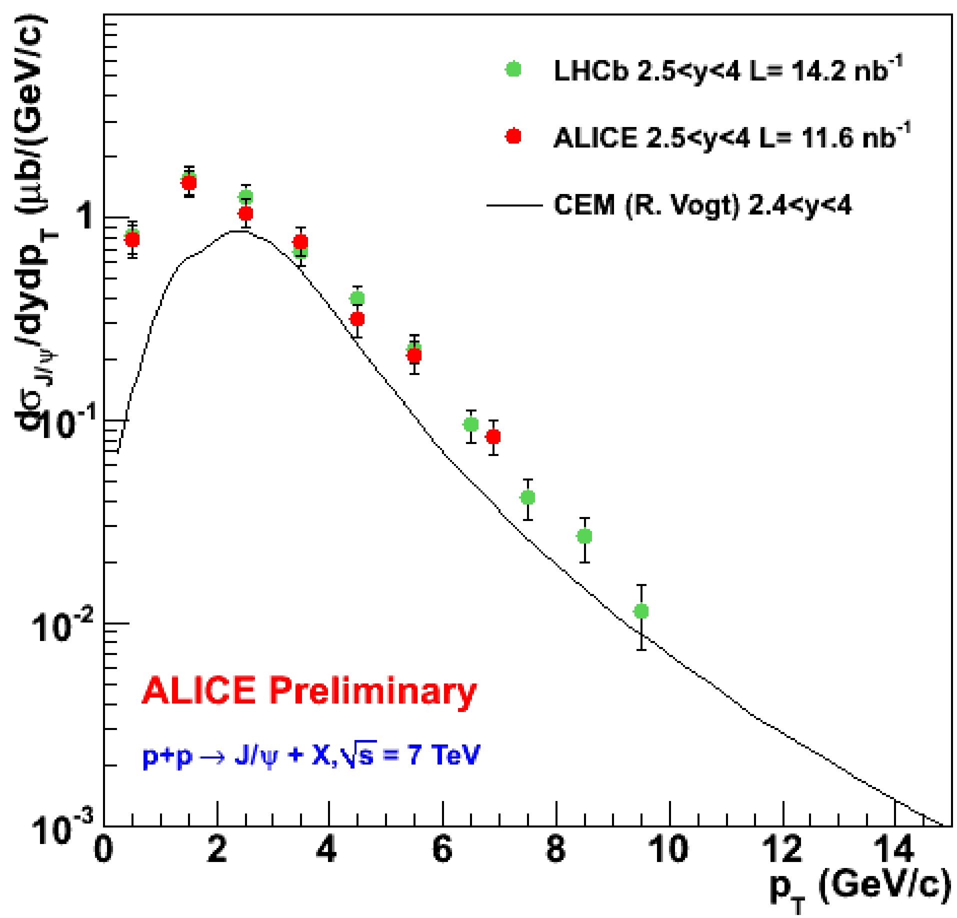
p_T coverage extends to zero at both central and forward rapidities

Preliminary comparison(s)



Preliminary comparison(s)





Model calculations:

R.Vogt, Phys. Rev. C 81 (2010) 044903

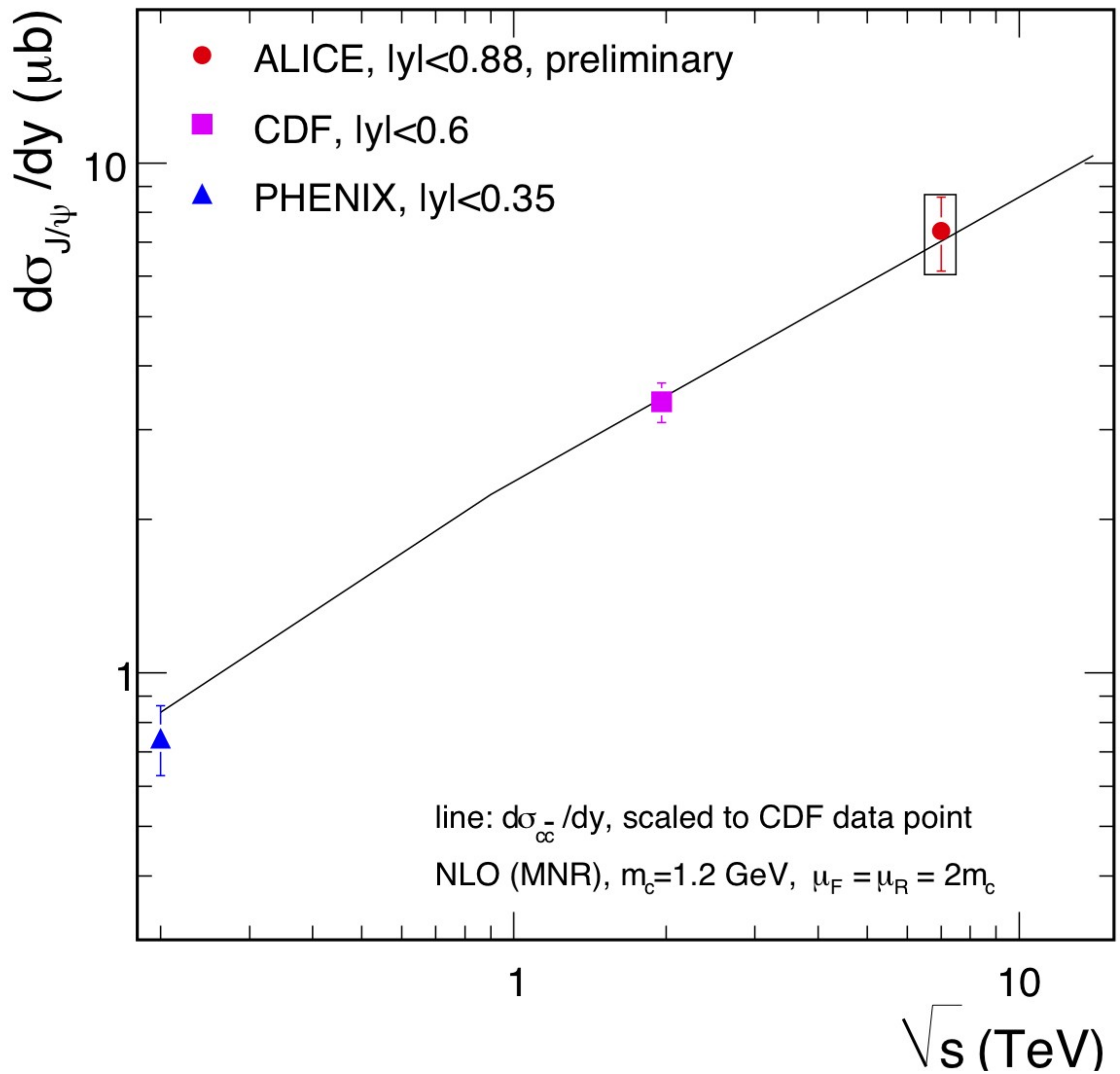
J.P. Lansberg, arXiv:1006.2750

CMS: p_T-integrated cross section 1.6<y<2.4 from (arXiv:1011.4193)

ATLAS: dσ/dy 1.5<y<2.25, ATLAS-CONF-2010-062

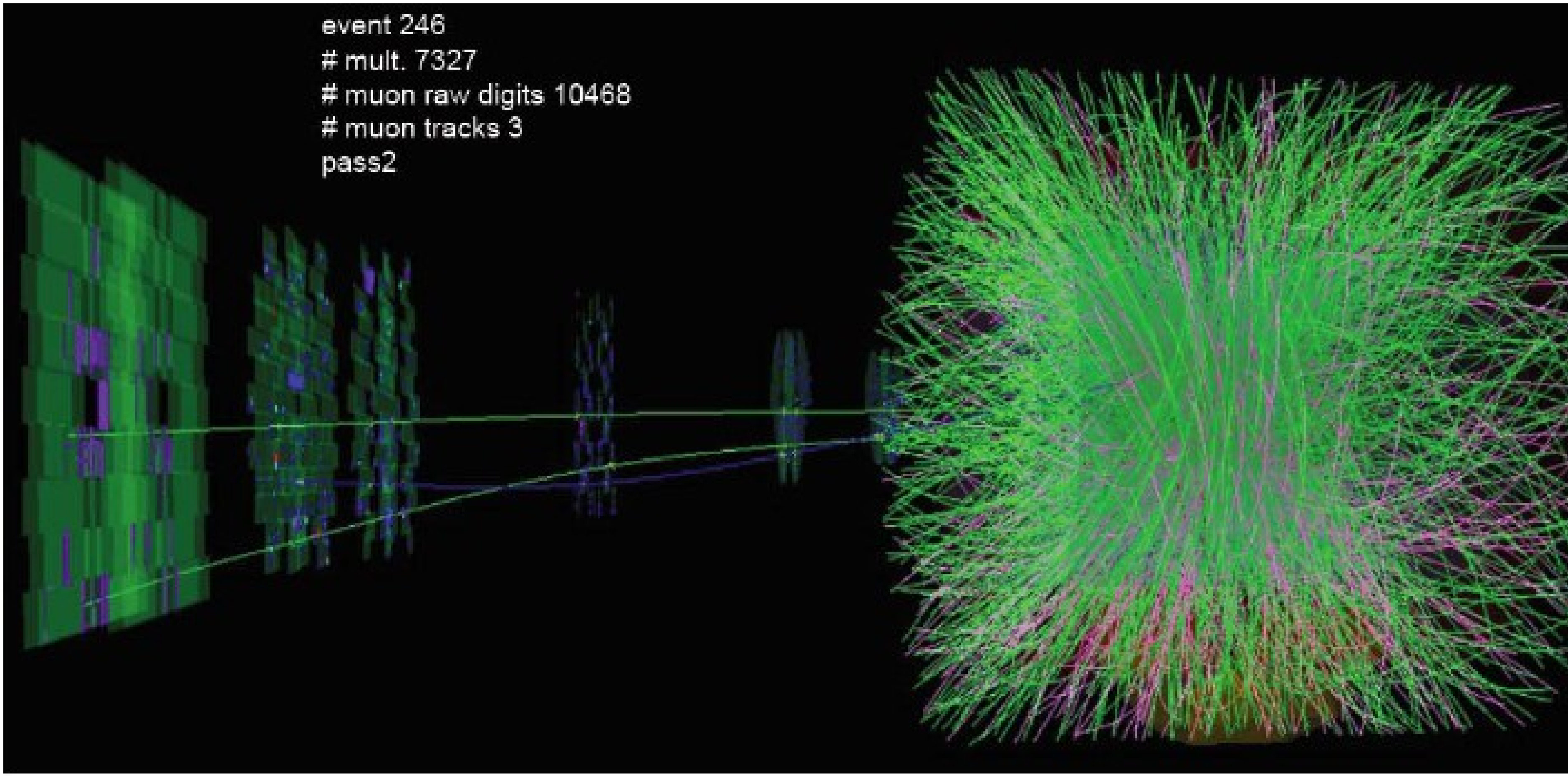
LHCb: dσ/dy 2.5<y<4 from LHCb-CONF-2010-010

√s-dependence of inclusive J/ψ



- NLO calculation for cc by Mangano et al., normalized to the CDF point
  Same √s-dependence for the inclusive J/ψ cross section

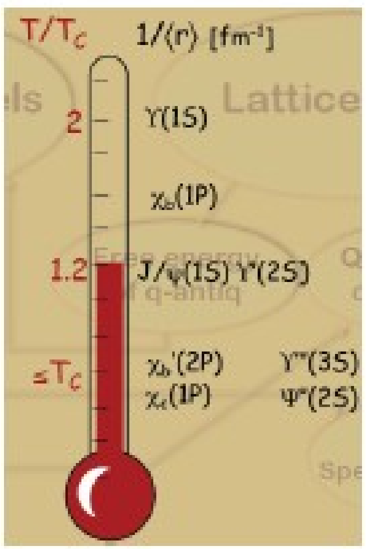
7th November 2010: moving from p-p to Pb-Pb (2.76 TeV)

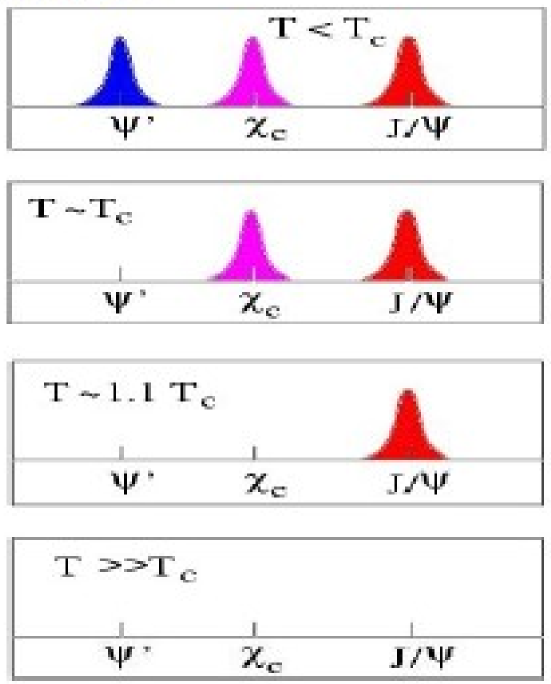


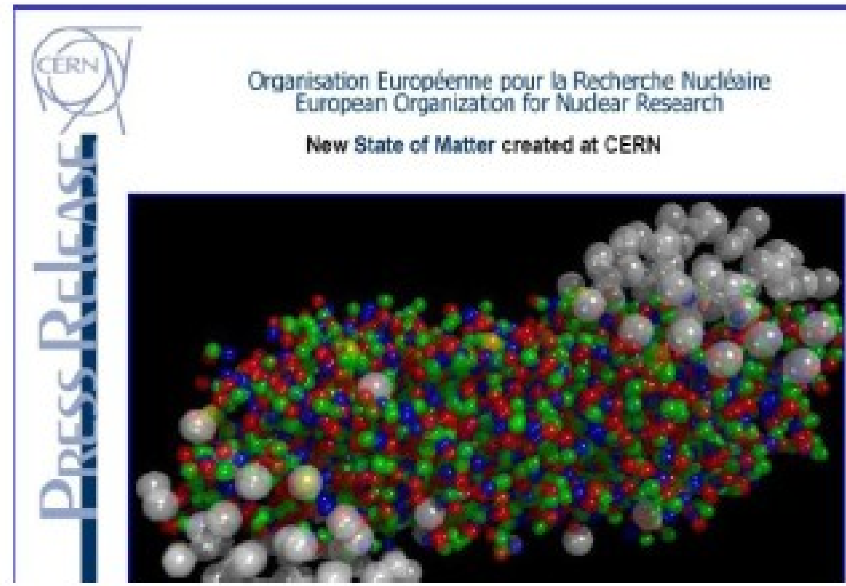
Higher occupancy with respect to Pb-Pb
Re-tuning of reconstruction parameters

Quarkonia in heavy-ions

Quarkonia suppression was one of the main pieces of evidence for CERN's claim to have produced a QGP phase at SPS energies





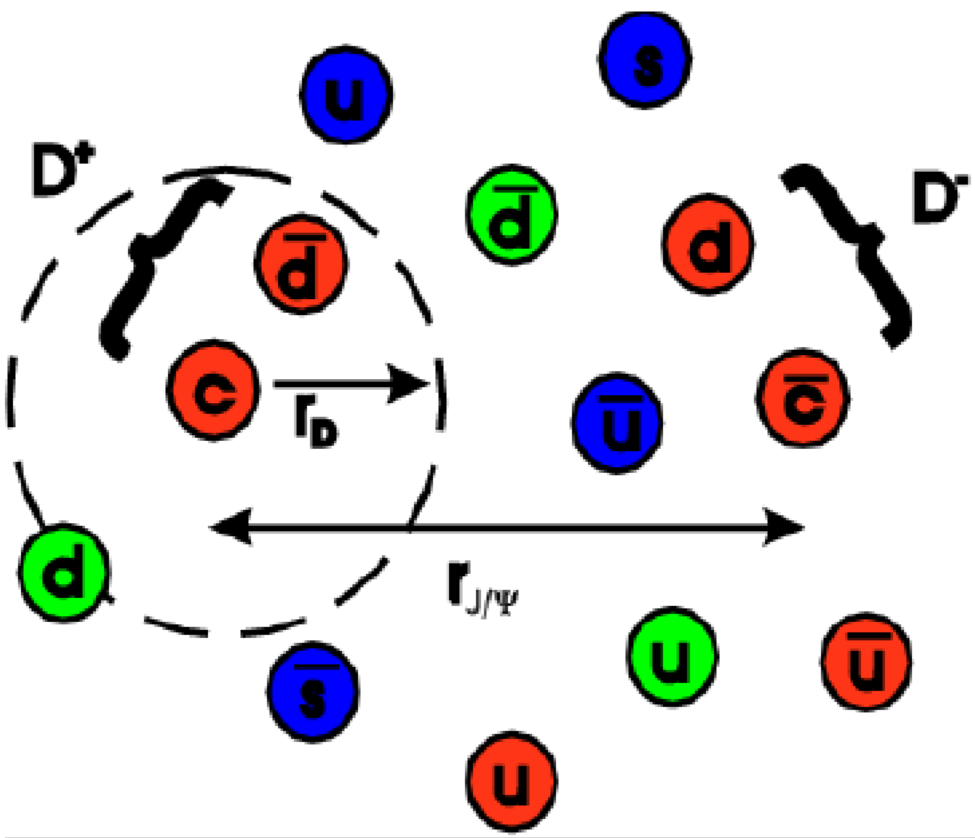


Debye screening predicted to destroy J/ψ's in a QGP with other states "melting" at different temperatures due to different sizes or binding energies

Different lattice calculations do not agree on whether the J/ψ is screened or not

measurements will have to tell!

J/ψ Suppression

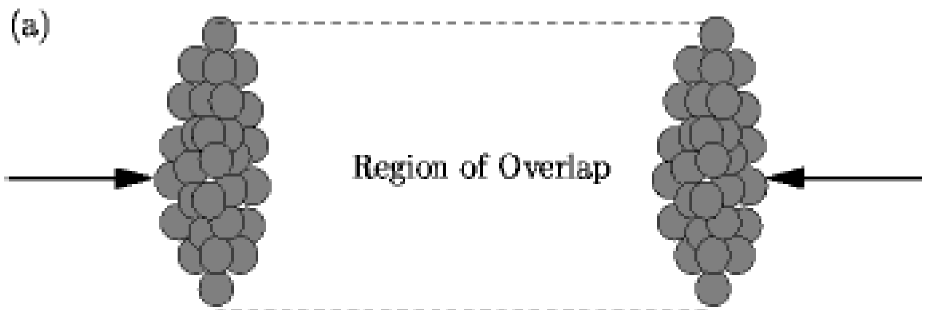


Colour screening in QGP:
Screening radius < size of J/ψ (~0.5 fm)

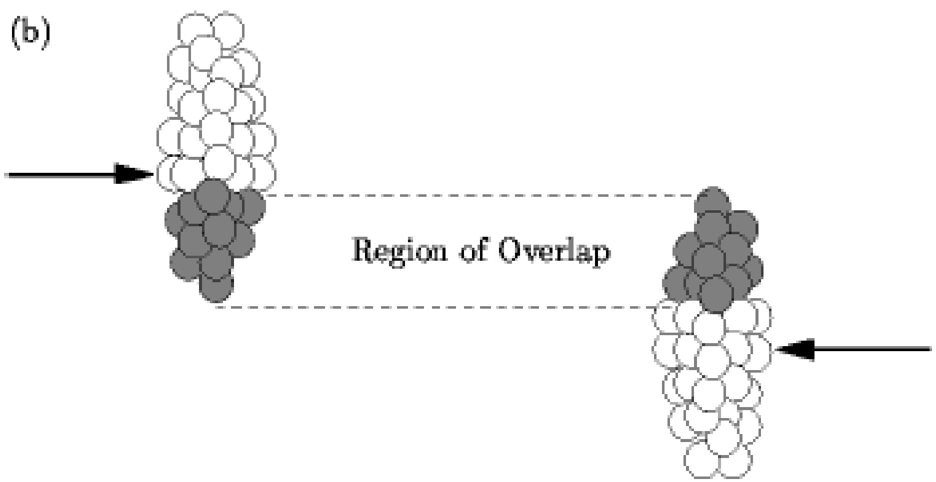
So $c\bar{c}$ bound state cannot survive in QGP.
Seen at SPS energies

At LHC energies, colour screening could be strong enough to break-up Υ ($b\bar{b}$) or maybe just Υ' or Υ''.

Terminology



Central Collision

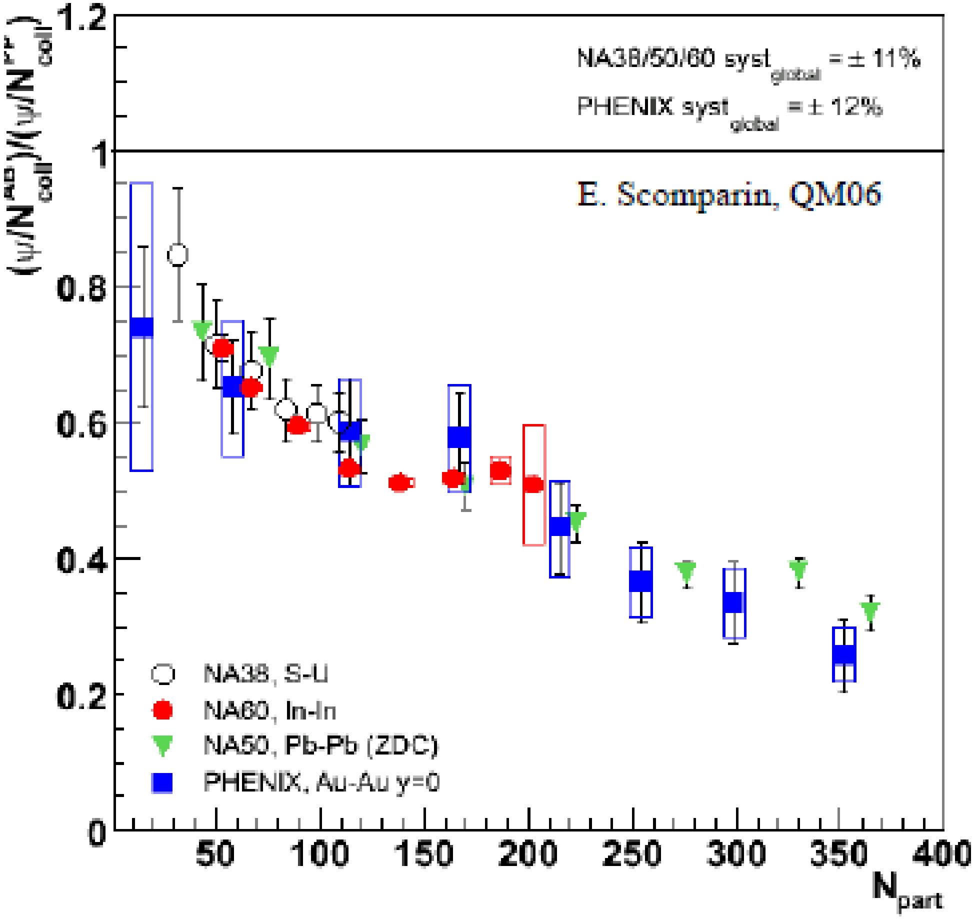


Peripheral Collision

- **Collision Centrality**
  - Describes the overlap of two incoming ions at the point at which they collide
  - The more central the collision, the greater number of participating nucleons (N_{part} or N_{wound})
  - Energy of system increases with collision centrality
- **Multiplicity**
  - Number of charged particles produced in the collision

Steve Bull

Anomalous suppression of J/ψ production at SPS and RHIC



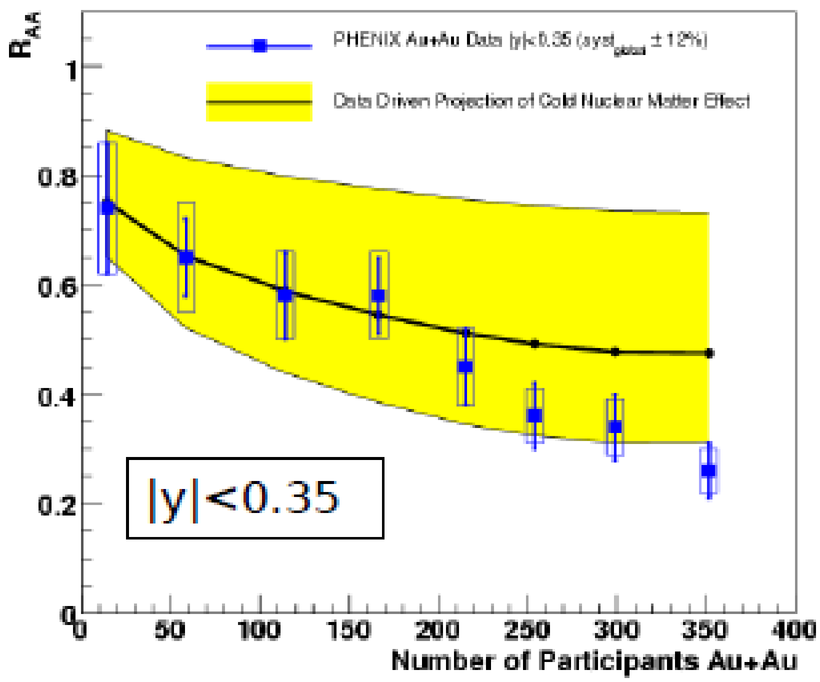
Peripheral collisions exhibit a J/ψ yield in agreement with the normal nuclear absorption pattern derived from pA collisions.

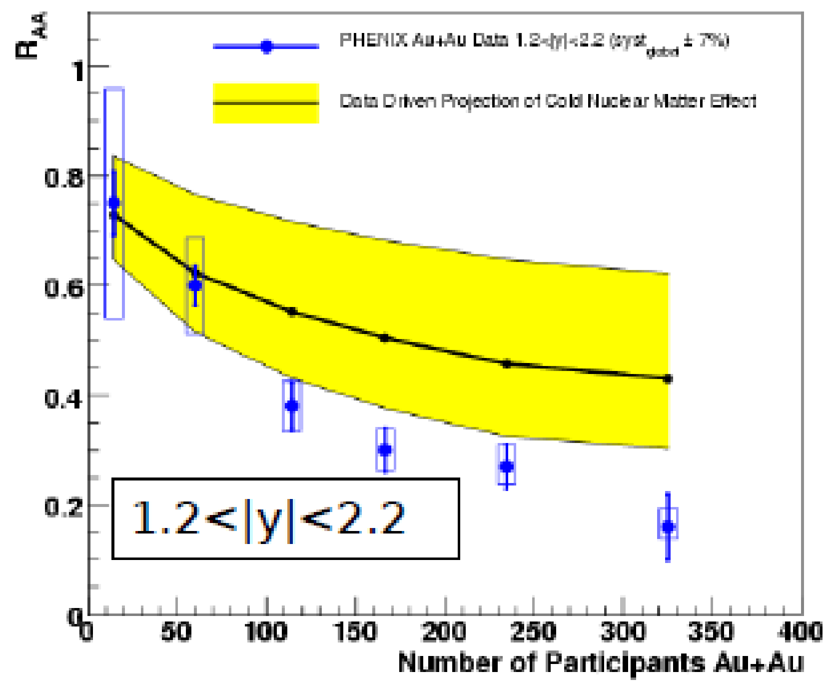
As the centrality of the collision increases → the J/Ψ yield decreases: **anomalous J/ψ suppression**

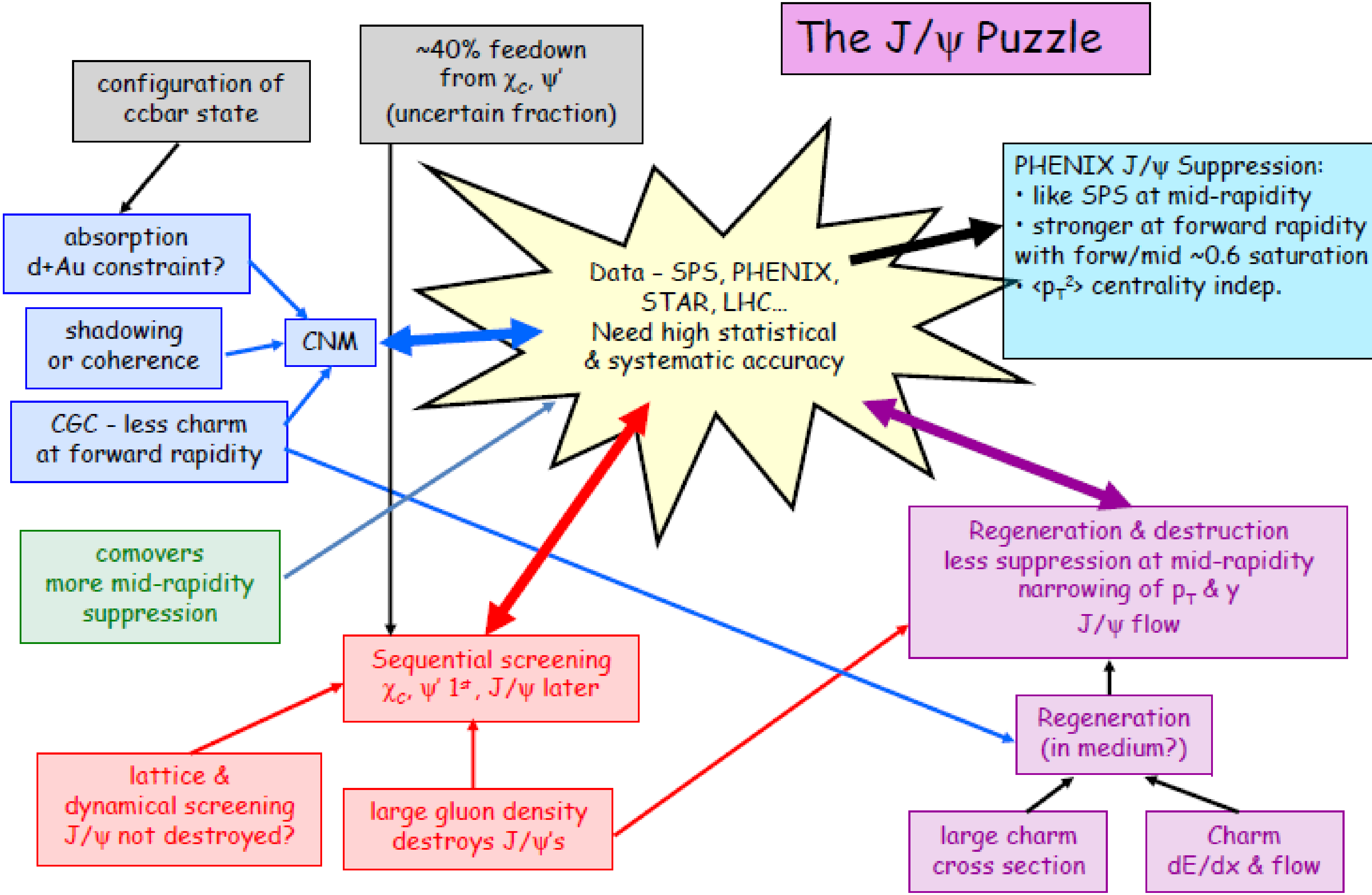
Suppression patterns are surprisingly similar at SPS and RHIC!

Anomalous suppression of J/ψ production at RHIC

J/ψ Nuclear modification factor

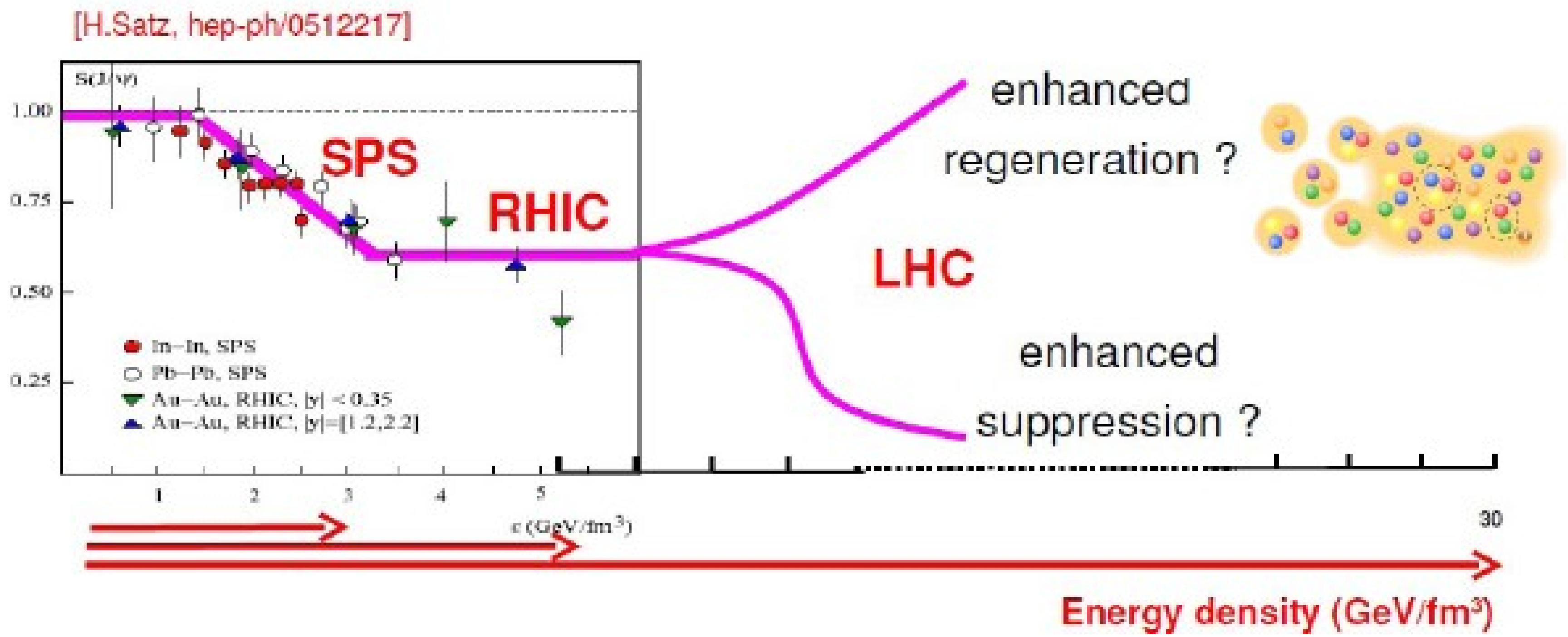




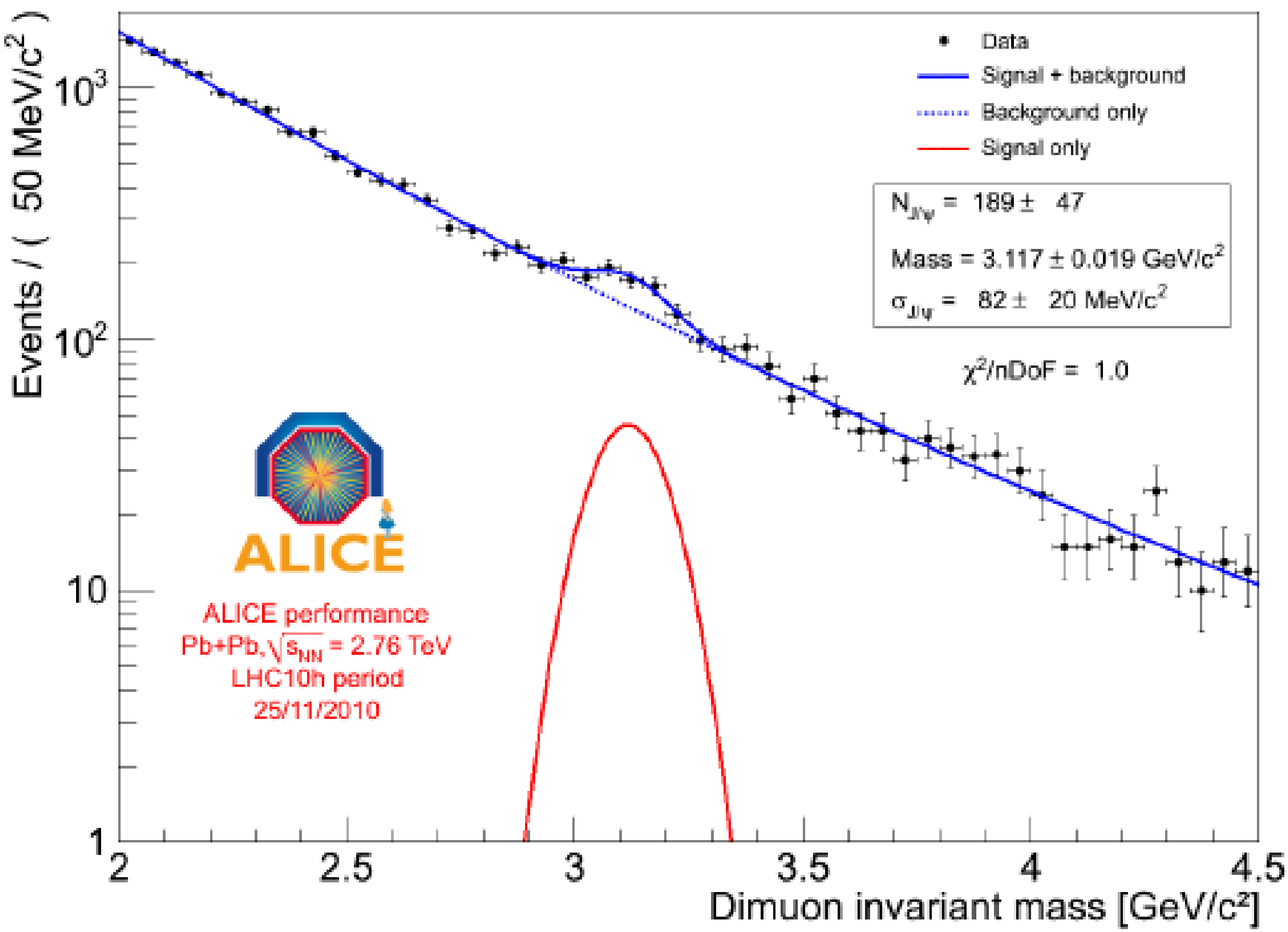


The J/ψ Puzzle
configuration of ccbar state
~40% feedown from χc, ψ′ (uncertain fraction)
absorption d+Au constraint?
shadowing or coherence
CGC - less charm at forward rapidity
CNM
comovers more mid-rapidity suppression
Data - SPS, PHENIX, STAR, LHC... Need high statistical & systematic accuracy
PHENIX J/ψ Suppression:
• like SPS at mid-rapidity
• stronger at forward rapidity with forw/mid ~0.6 saturation
• <pT2> centrality indep.
Sequential screening χc, ψ′ 1st, J/ψ later
lattice & dynamical screening J/ψ not destroyed?
large gluon density destroys J/ψ's
Regeneration & destruction
less suppression at mid-rapidity
narrowing of pT & y
J/ψ flow
Regeneration (in medium?)
large charm cross section
Charm dE/dx & flow

J/ψ production at LHC energies: regeneration/suppression?



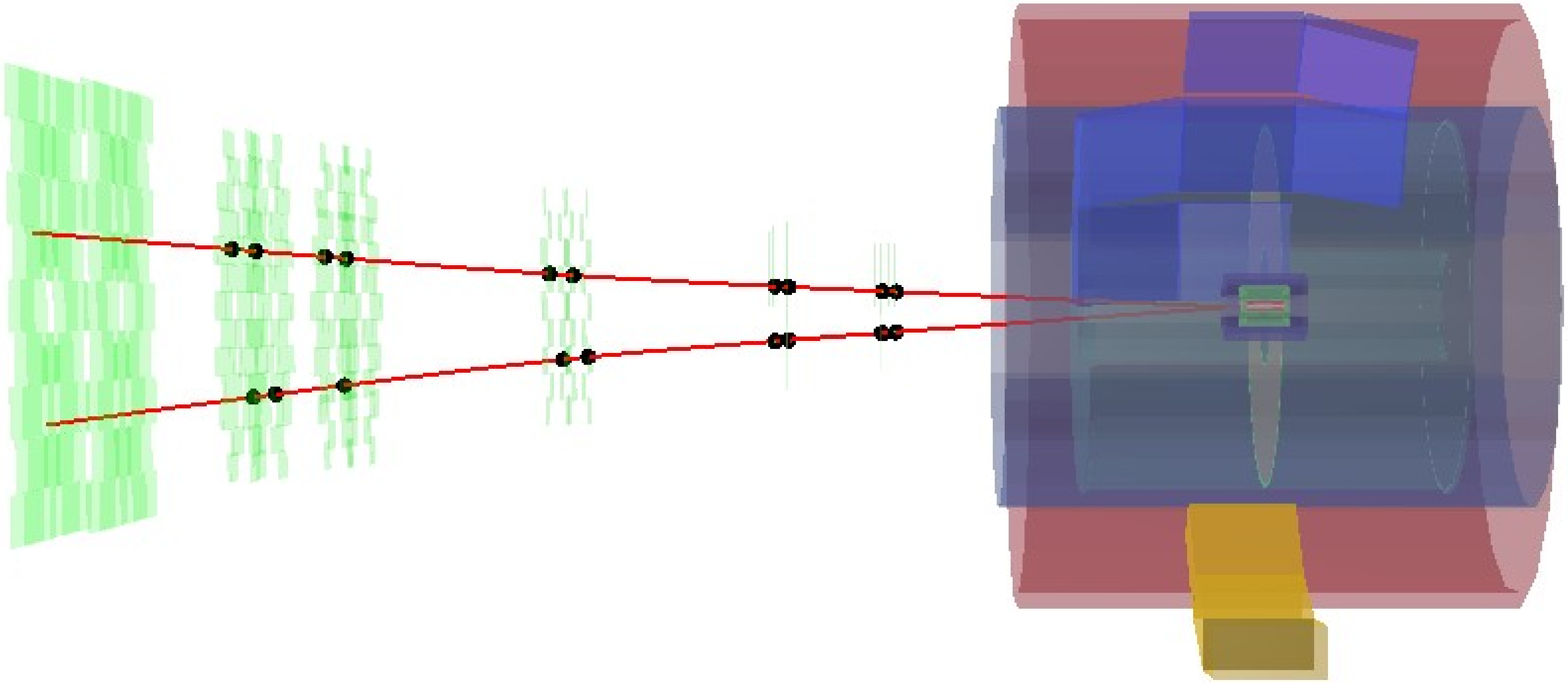
J/ψ signal from Pb-Pb collisions



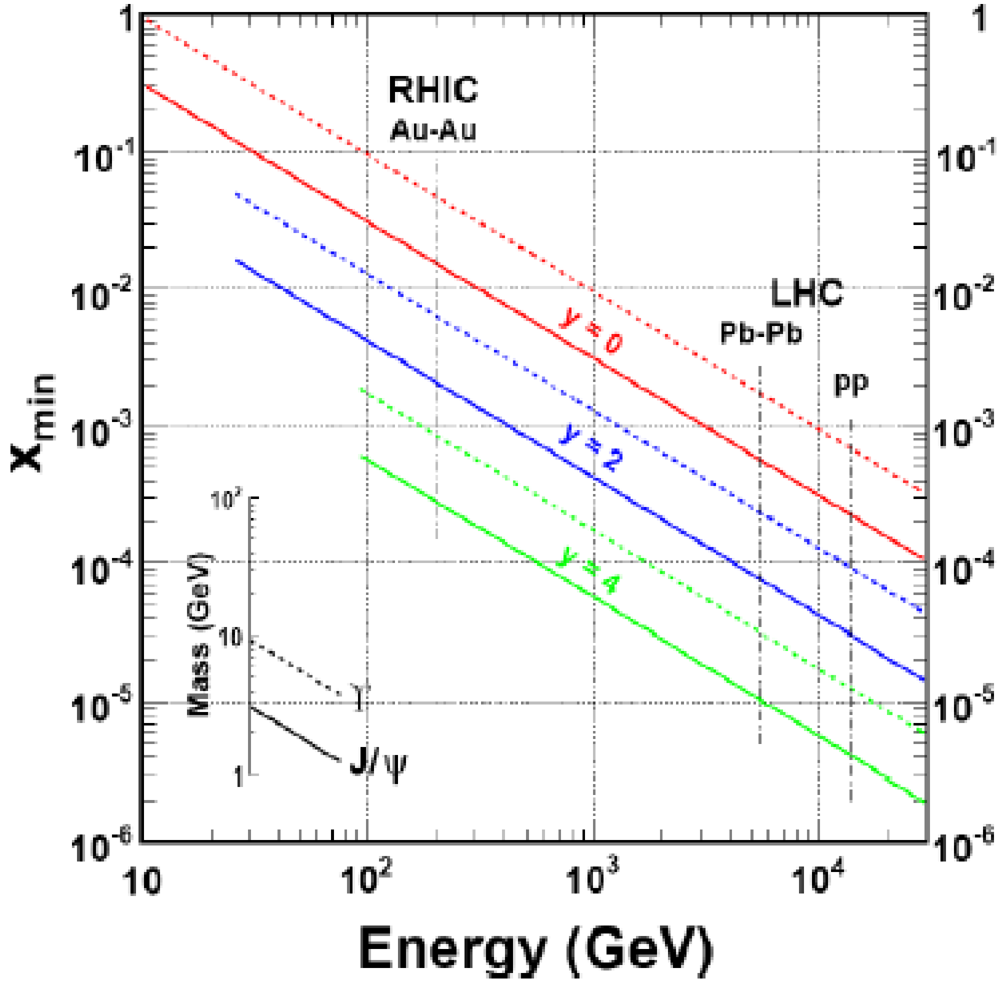
The J/ψ is not completely suppressed!
Expected final statistics for Pb run → O(10^3)
Extract R_{AA} in (some) centrality bins

Exclusive J/ψ production in p+p

- Two tracks in otherwise an empty detector



The small-*x* regime



From RHIC to LHC

$x_{min} \searrow \sim 10^{-2}$

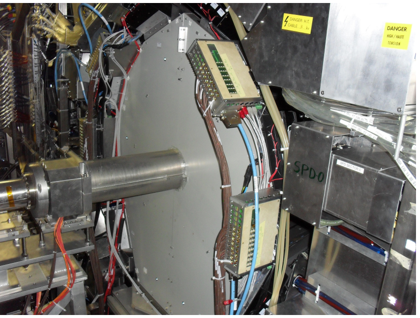
- factor 1/30 due to energy
- factor 1/3 larger rapidity

With J/ψ at rapidity 4

- Pb+Pb collisions $x_{min} \sim 10^{-5}$
- p+p collisions $x_{min} \sim 3\times10^{-6}$

Diffractive Physics Today

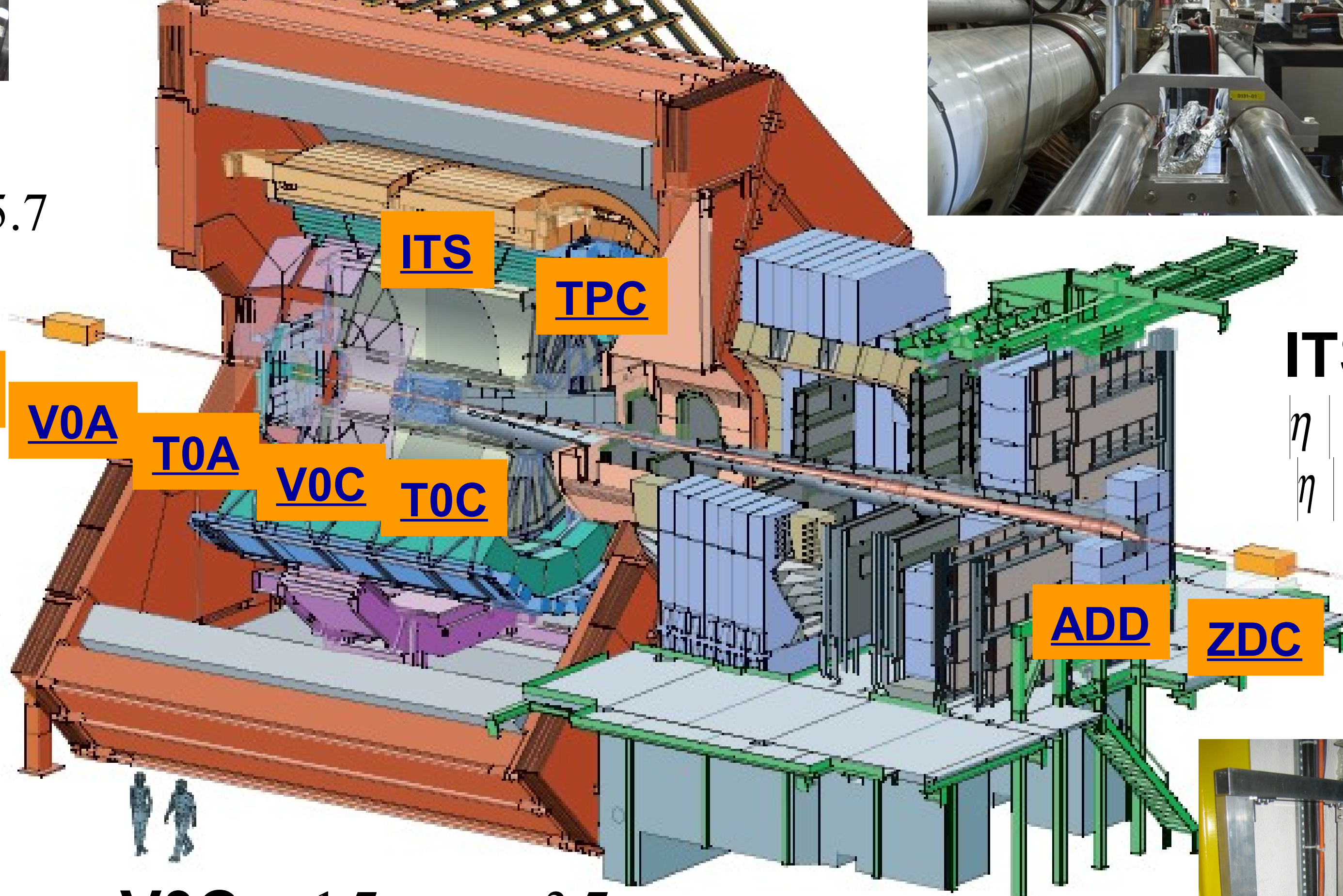
V0A $2.8 < \eta < 5.1$



ZN $|\eta| > 8.7$ **ZP** $|\eta| > 8.4$

TPC $|\eta| < 0.9$

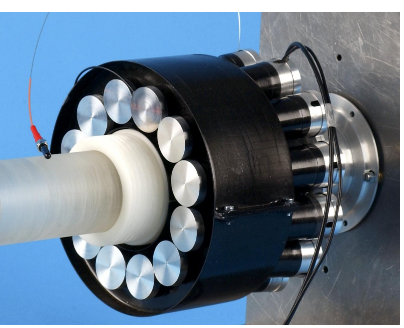
ZEM $4.8 < \eta < 5.7$



ITS
$|\eta| < 1.4$
$|\eta| < 2.0$

T0A $4.5 < \eta < 5.0$

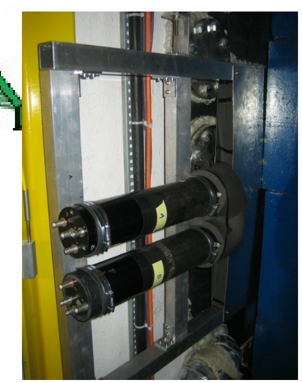
T0C
$-2.9 < \eta < -3.3$



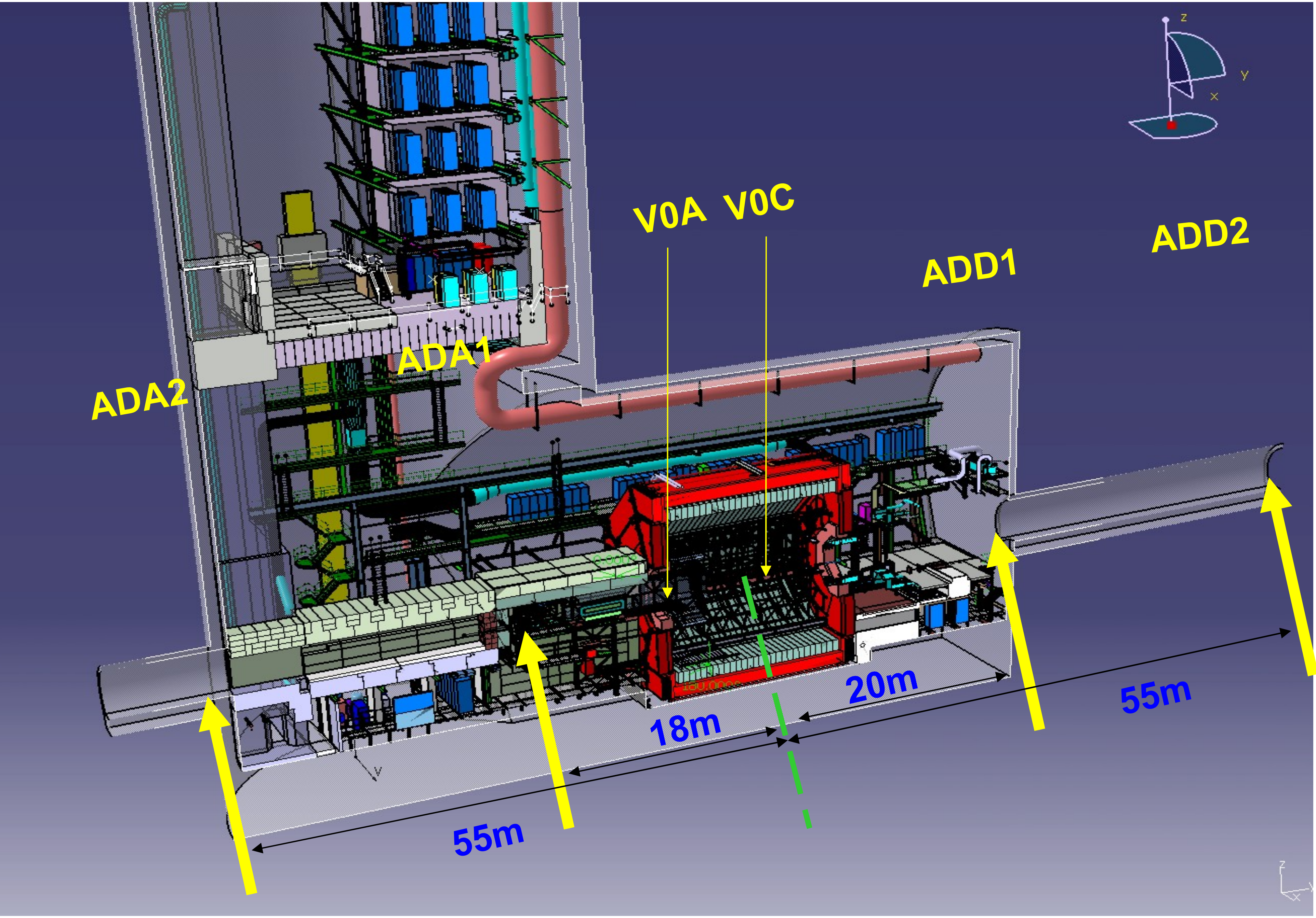
V0C $-1.7 < \eta < -3.7$

FMD $1.7 < \eta < 5.0$ $-3.4 < \eta < -1.7$

ADD $-4.9 < \eta < -6.0$



4 stations of scintillator detectors



Summary

- Preliminary results on inclusive J/ψ production
  - Analysis in both electron and muon decay channels.
  - Integrated and differential cross sections
  - Comparison to theoretical models of quarkonia production
- Prospects of measuring J/ψ production in Pb+Pb interactions, in exclusive p+p (Pb+Pb) reactions

Thanks,

Merry Christmas
and a happy new year
2011!

Additional slides

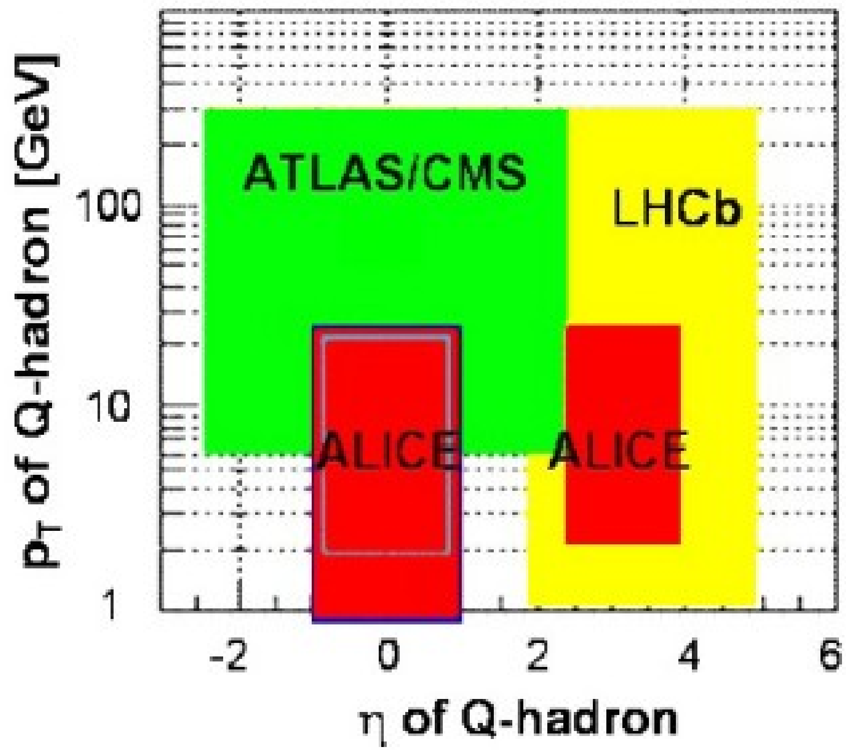
Quarkonia challenges at the LHC

- $J/\psi, \Upsilon \rightarrow \ell^+\ell^-$ measurements require $\mu^\pm$, $e^\pm$, secondary-vertex detectors
  - ✓ ATLAS/CMS within $-2.5 < \eta < 2.5$, full ϕ
  - ✓ LHCb within $2 < \eta < 5$, full ϕ

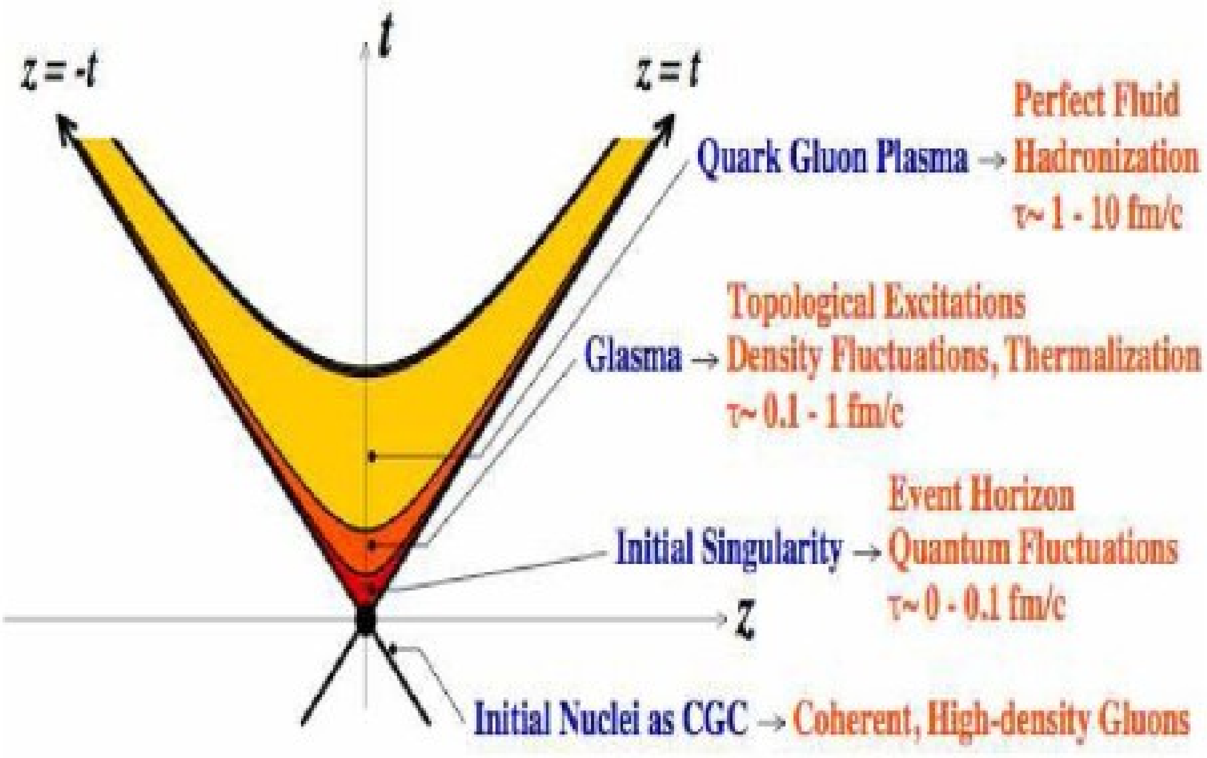
$B \rightarrow J/\psi$ (20%)contribution

- Focus on dimuons at moderately high-p_T (ATLAS/CMS), low-p_T (LHCb)
- Dielectron channels accessible but more difficult: large X_0/X in front of ECALs (ATLAS/CMS).
- Early measurements (low lumi, dedicated low-thresh. triggers):
  ATLAS/CMS: p-p & Pb-Pb studies
  LHCb: p-p studies only

1-year pp 14 TeV (nominal Luminosity)



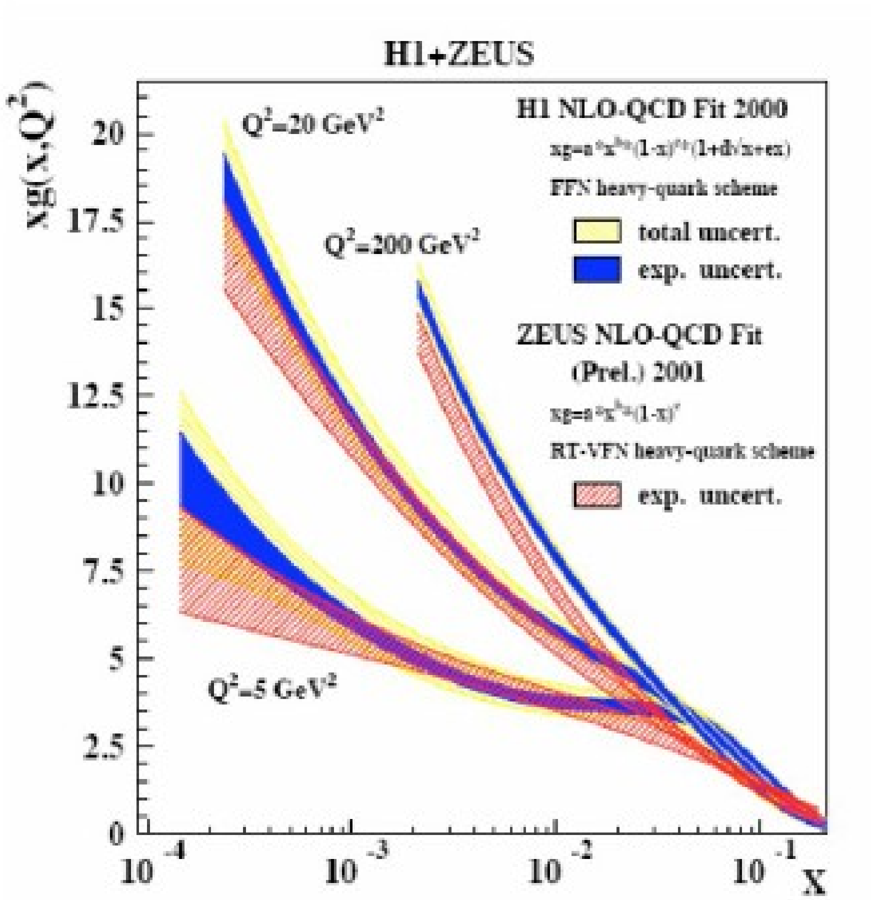
Heavy-ion collisions



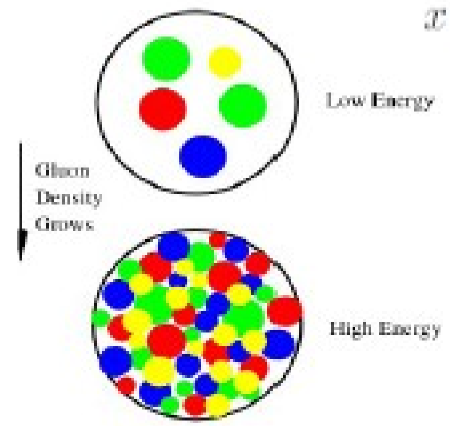
The CGC provides a framework to describe nucleus-nucleus collisions up to a time of

$$\tau \sim Q_s^{-1}$$

Small-x physics and non-linear evolution



$x = E_{\text{constituent}} / E_{\text{hadron}}$



$y \sim \ln(1/x).$

- At low x, there must be a regime (at $q^2 < Q_s^2$) where partons overlap. Here, the increase in the number of small x partons becomes limited by gluon fusion.
- *Saturation scale* Q_S^2 (x) to be determined experimentally.

This is the quantum evolution of the hadron wavefunction. Because the saturation momentum is larger in nuclei than it is in protons, it is more difficult to produce glue at small x. Therefore as one goes to smaller values of x, there should be fewer particles at small x relative to the expectation from incoherent scattering.... L.M.

Parton Distribution Functions in nuclei

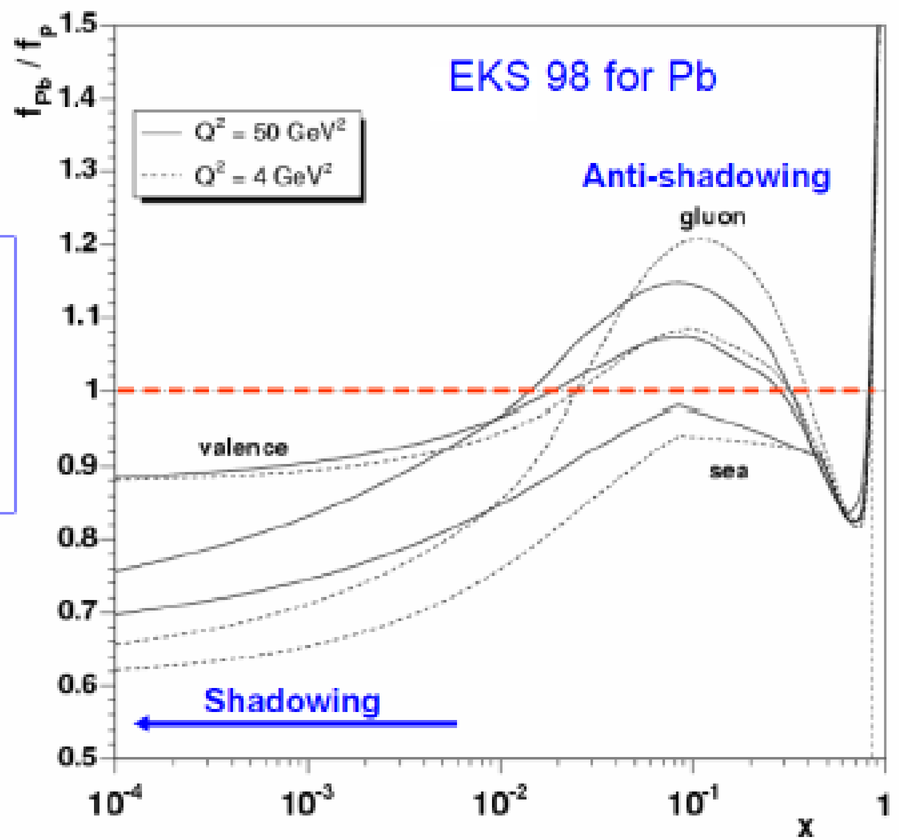
Is a free proton the same as a proton inside a nucleus?
No! Some "nuclear effects" modify the probabilities of finding partons of given *x* when the proton is inside a nucleus
The "EKS 98 model" (among others) provides the ratio between the PDFs in a "proton of a nucleus of mass number A" and in a "free proton"

$$R_i^A(x,Q^2) = \frac{f_i^A(x,Q^2)}{f_i^p(x,Q^2)}$$

<u>"Shadowing" or "anti-shadowing":</u>

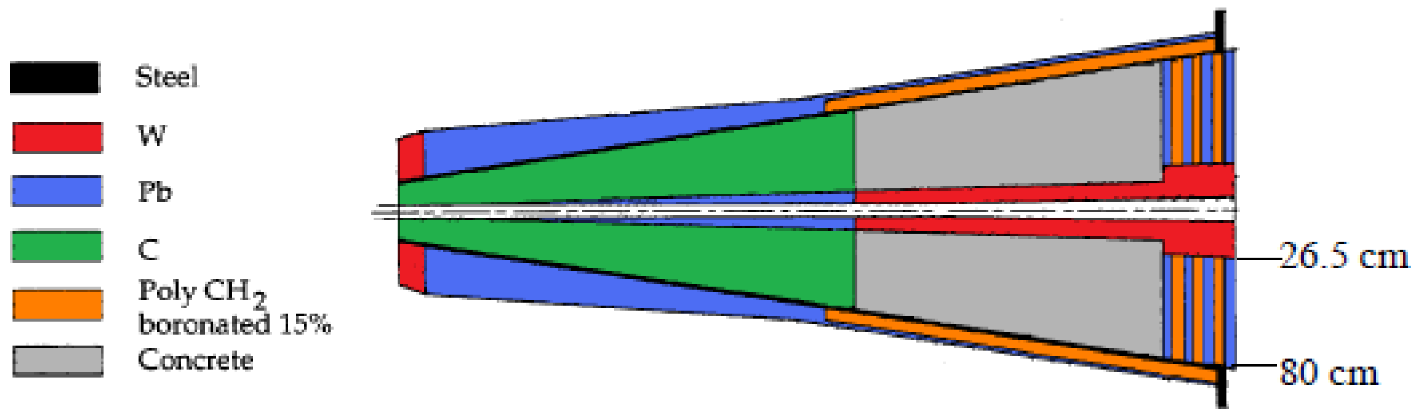
Decrease or increase of the parton's density in the nucleus, in a certain kinematic range…

For a given collision energy and a given produced mass, the *x* values depend on the rapidity range where the measurement is made



(Shadowing means that some of the partons are obscured by virtue of having another parton in front of them. For hard spheres, for example, this would result in a decrease of the scattering cross section relative to what is expected from incoherent independent scattering.)

Absorbeur composé de plusieurs matériaux



$\mathbf{R}_{abs}$: distance entre la ligne faisceau et la trace au bord de l'absorbeur.