Forward rapidity $\psi(2S)$ production in p-Pb collisions with ALICE

Graduate School in Physics and Astrophysics
XVIII cycle: 2nd year seminar

candidate: **Marco Leoncino**

Supervisors: Roberta Arnaldi, Enrico Scomparin
PhD Tutor: Mauro Gallio

Overview of my activities

I am a member of the ALICE Collaboration and currently I am associated to CERN with an INFN Simil-Fellow contract.

My research activity is mainly dedicated to the study of the ψ(2S) charmonium state in p-Pb collisions with the ALICE detector:

- **Suppression of ψ(2S) production in p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV:** results published on JHEP 1412 (2014) 073, member of the Paper Committee.
- **Event activity dependence of the inclusive ψ(2S) production in p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV:** in preparation, member of the Paper Committee.

I am also involved in the following activities:

- Quality assurance analysis and on-call shifter for the Zero Degree Calorimeter (ZDC) detector.
- Measurement of visible cross sections in proton-proton collisions at $\sqrt{s}$ = 8 TeV in van der Meer scans: analysis ongoing, member of the Paper Committee.

Summary of this talk

PART 1: $\psi(2S)$ production in p–Pb collisions

Charmonia: a brief introduction

Charmonia in the medium

The ALICE detector

Data taking conditions

Results in p–Pb collisions

Conclusions

PART 2: other activities

Zero Degree Calorimeters data quality assurance (QA)

Measurement of cross section in vdM scans

Charmonia: a brief introduction

Charmonia are bound states of **charm-anticharm** ($c\bar{c}$) heavy quarks

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CHARMONIUM PROPERTIES:

- Smaller than light hadrons, different E_b ($E_b^{J/\psi}$~0.6 GeV, $E_b^{\psi(2S)}$~0.05 GeV)
- Reconstructed via their dilepton decay:

$$B.R.\ J/\psi \rightarrow \mu^+\mu^- = (5.93 \pm 0.06)\cdot 10^{-2}$$

$$B.R.\ \psi(2S) \rightarrow \mu^+\mu^- = (7.8 \pm 0.9)\cdot 10^{-3}$$

Sensitive to the medium created in the collisions

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CHARMONIUM PRODUCTION MECHANISMS:

- Production via hard scattering of gluons
- Decay from higher charmonium states

} "**prompt**" production

- Decay from b-mesons ("b-decay")

} "**non-prompt**" production

Prompt + non-prompt = Inclusive production

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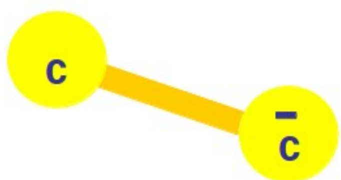
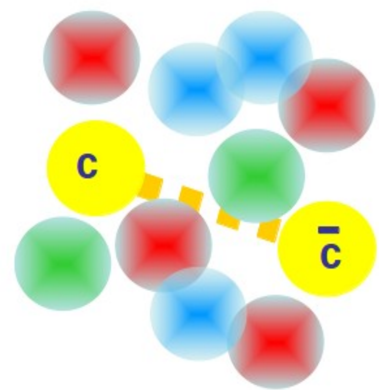
Prompt + non-prompt = **Inclusive production**

This presentation is dedicated to the ψ(2S) **inclusive** production

Nucleus-nucleus (A-A) collisions: Hot (and Cold) Nuclear Matter effects

Color screening: suppression of quarkonia (high color density in a Quark Gluon Plasma)





$$V(r) = -\frac{\alpha}{r} + kr \quad \Rightarrow \quad V(r) = -\frac{\alpha}{r} e^{-r/\lambda_D}$$

$$\lambda_D(PQCD) = \frac{1}{\sqrt{\left(\frac{N_c}{3} + \frac{N_f}{6}\right) g^2 T}}$$

Debye screening lenght: maximum distance by which two color charges can form a bound state in a QGP

→ The high color density induces a screening of the coulombian term of the potential (Debye screening)

→ The “confinement” contribution disappears

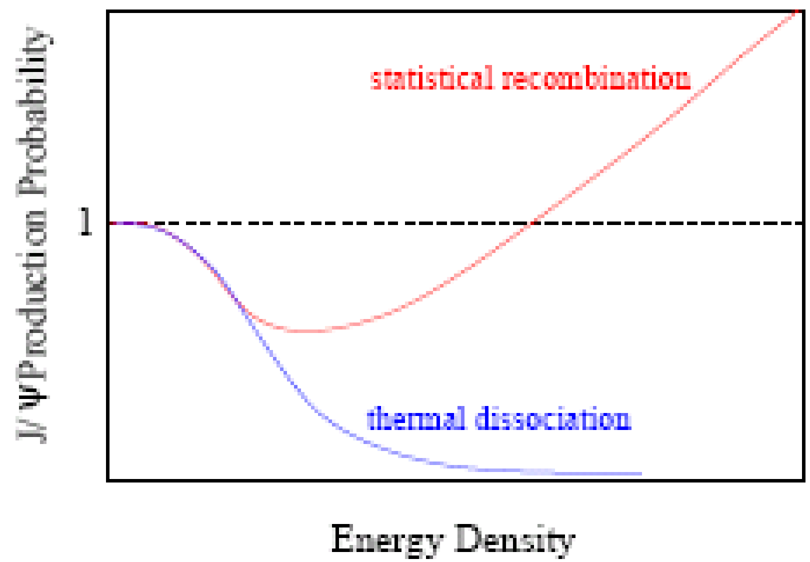
Charmonia in the medium: A-A collisions

Nucleus-nucleus (A-A) collisions: Hot (and Cold) Nuclear Matter effects

Color screening: suppression of quarkonia (high color density in a QGP)

Recombination: at high collision-energies $c\bar{c}$ pairs are produced abundantly (recombination probability $\propto N^2_{c\bar{c}}$)

In most central A-A collisions	SPS 20 GeV	RHIC 200 Gev	LHC 2.76 TeV
N_{ccbar}/event	~0.2	~10	~60



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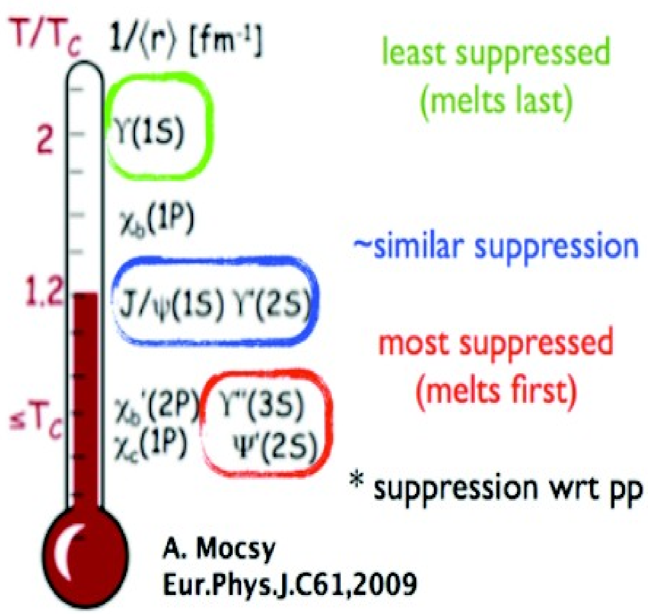
Cold Nuclear Matter effects: also present in A-A collisions



The dissociation is expected to depend on the binding of the charmonium state

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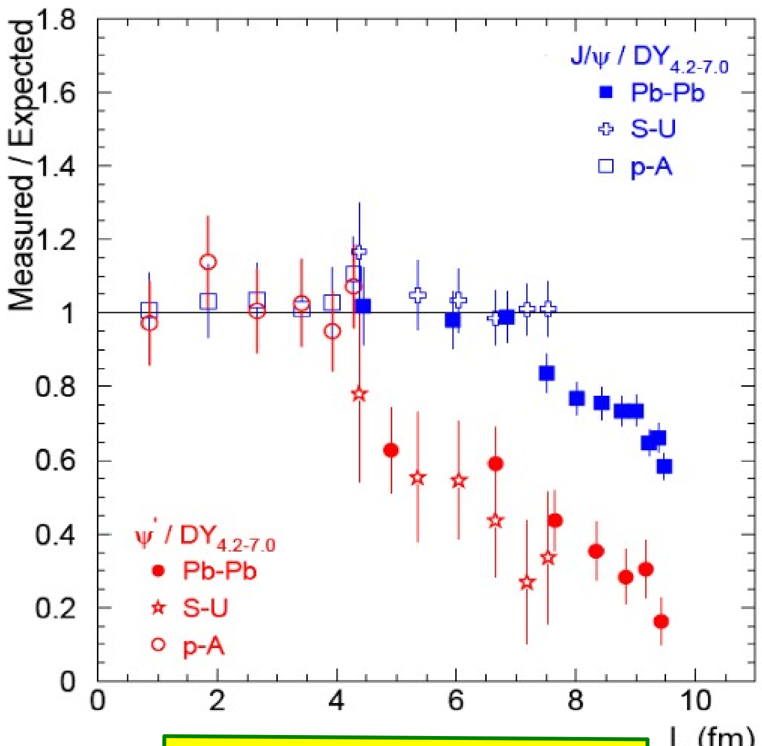


NA50 Collaboration
Eur. Phys. J. C 49 (2007)

The dissociation is expected to depend on the binding of the charmonium state

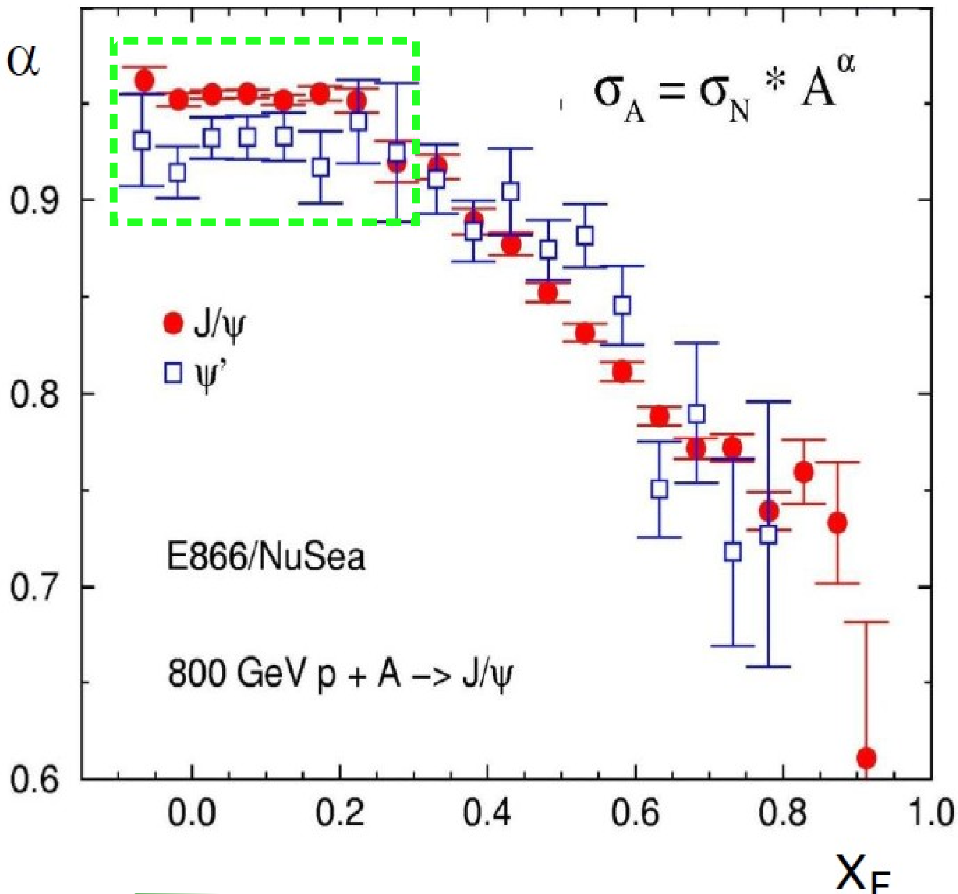
NA50 results in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 17 GeV show that the loosely bound ψ(2S) is more suppressed compared to strongly bound J/ψ, in agreement with a sequential melting scenario

Charmonia in the medium: p-A collisions

Proton-nucleus (p-A) collisions: Cold Nuclear Matter effects

Initial/final state: shadowing, energy loss, $c\bar{c}$ pair break-up
(the $c\bar{c}$ pair break-up should be negligible at the LHC energies)

Intriguing results already at lower energies (NA50, E866, HERA-B)



E866 Collab., PRL 84 (2000) 3256

E866 results in 800 GeV p-A collisions at:

x_F~0 (central rapidity)

show that the ψ(2S) is slightly more suppressed compared to the J/ψ

τ_c > τ_f fully formed resonance traversing the nucleus

Charmonia in the medium: p-A collisions

Proton-nucleus (p-A) collisions: Cold Nuclear Matter effects

Initial/final state: shadowing, energy loss, $c\bar{c}$ pair break-up
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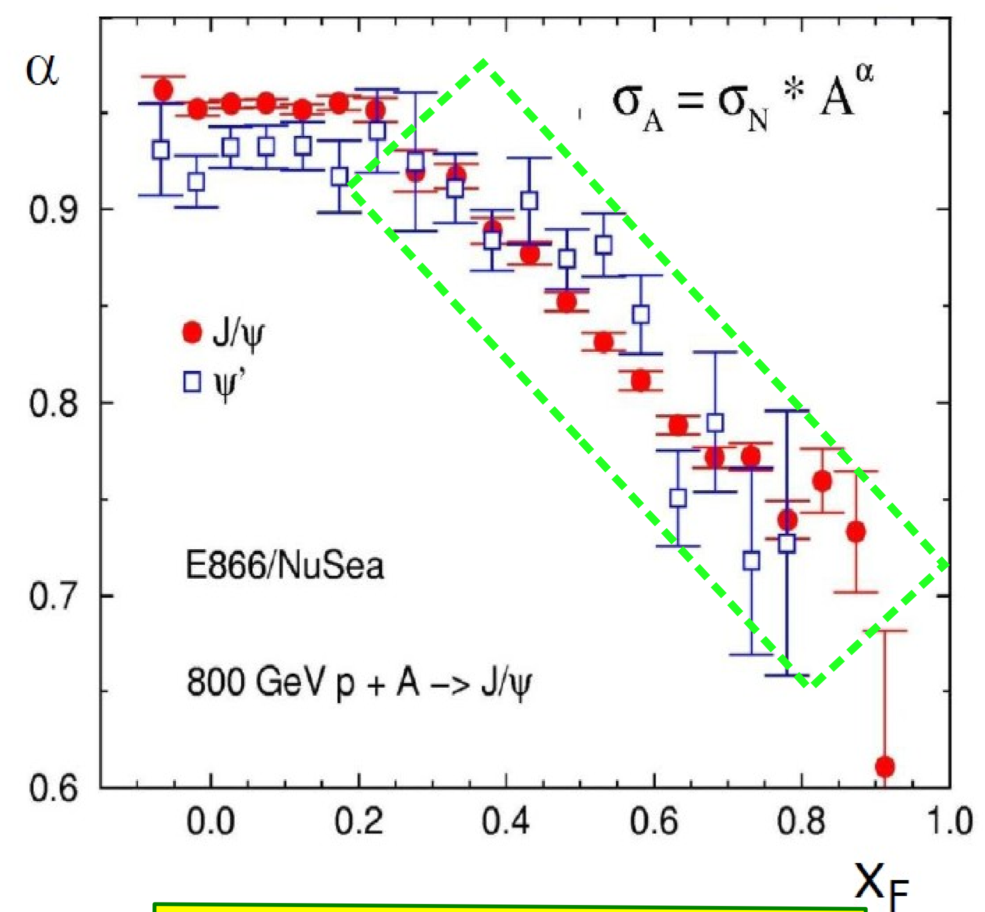


E866 Collab., PRL 84 (2000) 3256

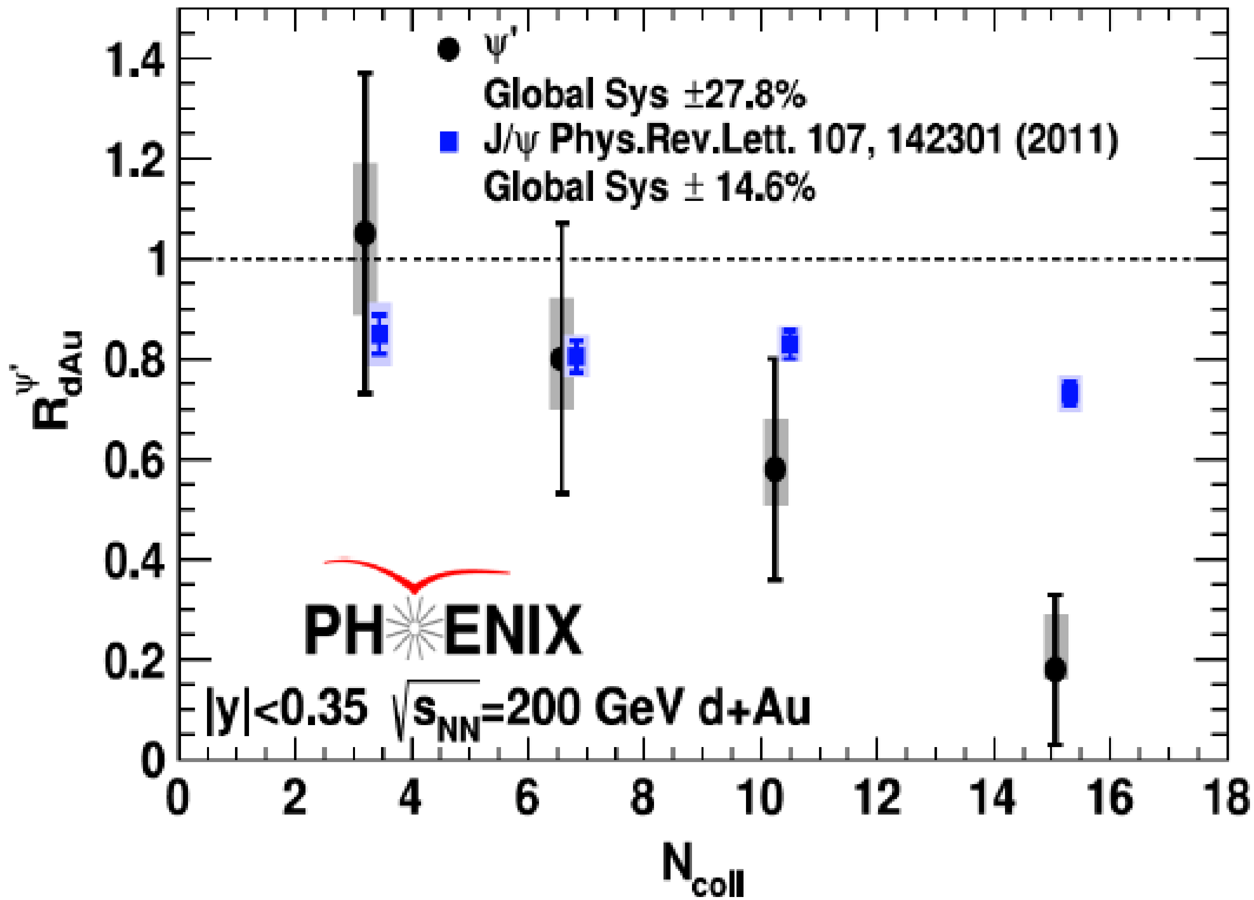
E866 results in 800 GeV p-A collisions at

$x_F \geq 0.2$ (forward rapidity)

show that the ψ(2S) suppression trend is similar to the J/ψ

$\tau_c < \tau_f$ the influence of the nuclear matter on the pre-hadronic state is independent of the particular resonance being produced

Charmonia in the medium: p-A collisions

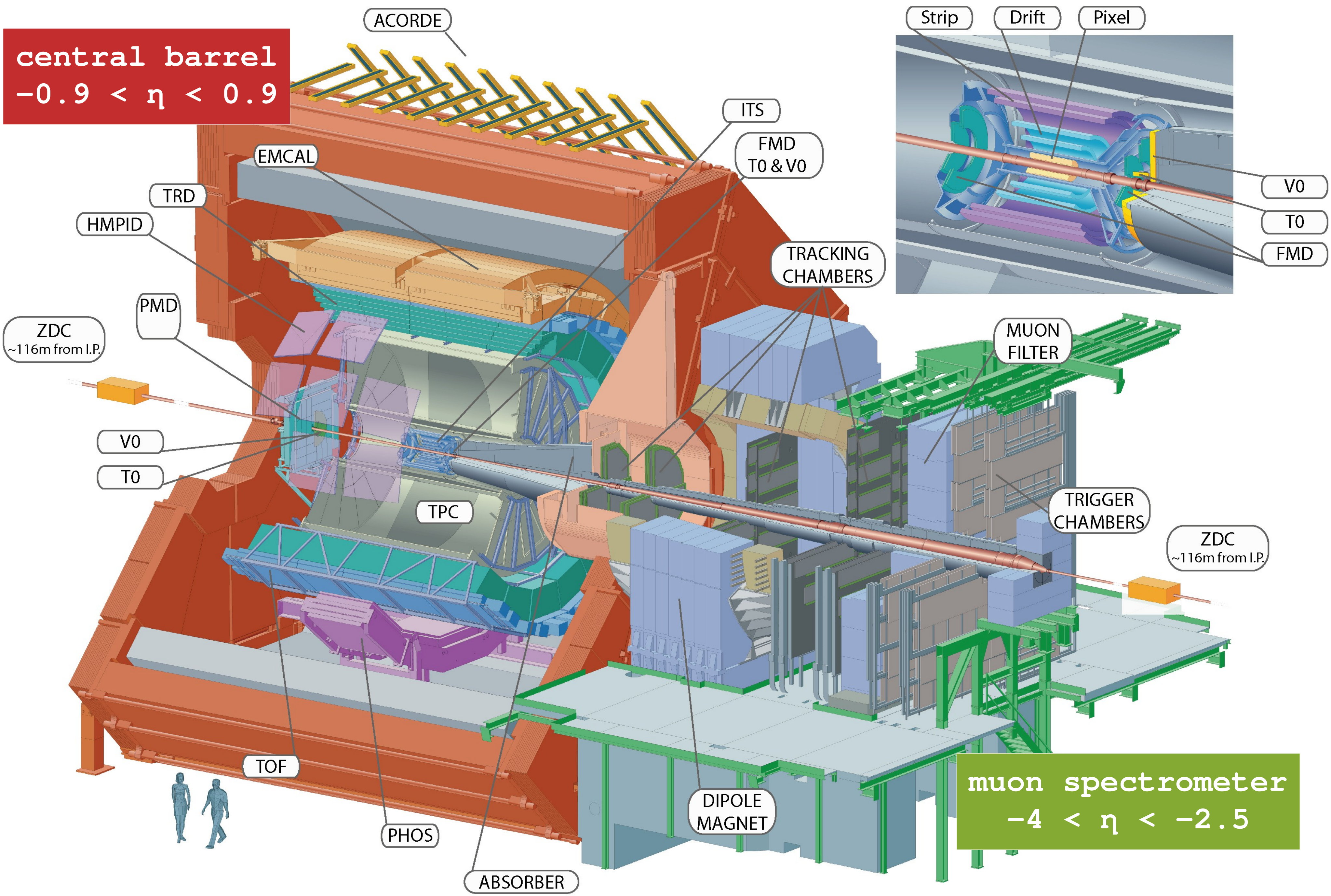


PHENIX Collab., PRL 111 (2013) 202301

PHENIX result in d-Au collisions at $\sqrt{s_{NN}}$ = 200 GeV show a stronger ψ(2S) suppression than that of the J/ψ: the strong ψ(2S) suppression is unexpected because at RHIC $\tau_c < \tau_f$

The ALICE detector

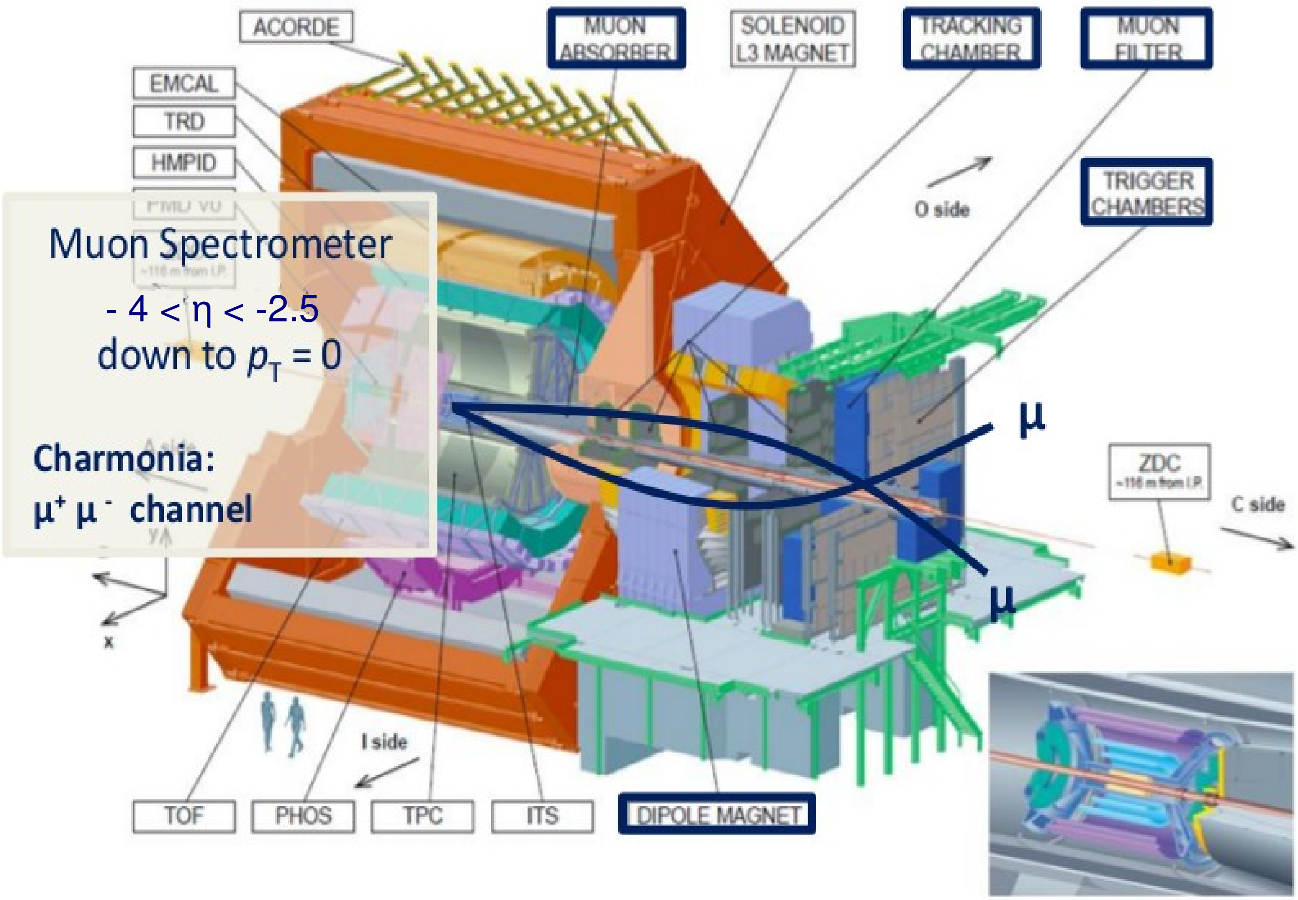
central barrel
$-0.9 < \eta < 0.9$



muon spectrometer
$-4 < \eta < -2.5$

The ALICE detector

Charmonia can be detected with ALICE in the $\mu^+\mu^-$ decay channel



Forward muon spectrometer: $\psi(2S) \rightarrow \mu^+\mu^-$

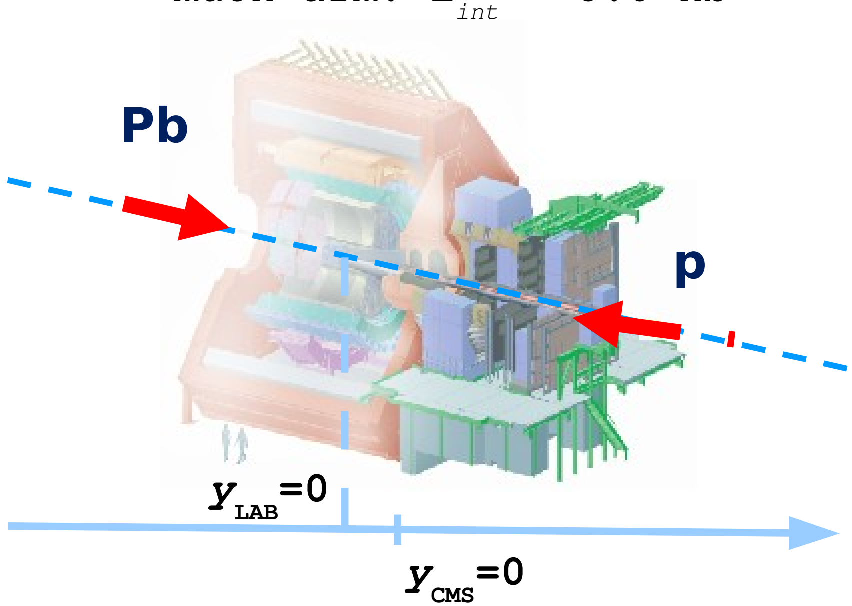
Muons identified and tracked in the muon spectrometer (10 planes of tracking chambers, 2 stations of trigger chambers, absorber system, dipole magnet)

2013 p-Pb run at $\sqrt{s_{NN}}$=5.02 TeV

Beam energy asymmetry (E_p=4 TeV, E_{Pb}=1.58 A·TeV) causes a shift in rapidity:

$$|\Delta y_{CMS}| = 0.5 \log (Z_{Pb}A_p/Z_pA_{Pb}) = 0.465$$

Pb-p: lead beam moving towards the muon arm. L_{int} = 5.8 nb^{-1}

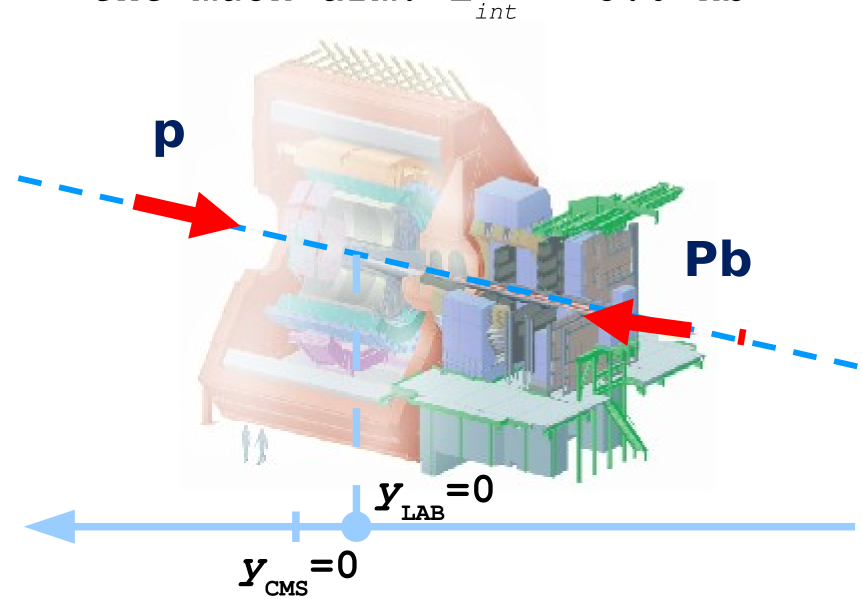


Backward rapidity configuration

(in the centre of mass frame)

$-4.46<y_{CMS}<-2.96$

p-Pb: proton beam moving towards the muon arm. L_{int} = 5.0 nb^{-1}



Forward rapidity configuration

(in the centre of mass frame)

$2.03<y_{CMS}<3.53$

ψ(2S) signal extraction

1) Fit of the opposite-sign dimuon invariant mass spectra:

→ Signal: extended Crystal Ball and pseudo-Gaussian functions

→ Background: variable width Gaussian and polynomial·exponential functions

→ ψ(2S) position and width are tied to the J/ψ:

$$m_{\psi(2S)} = m_{J/\psi} + (m^{MC}_{\psi(2S)} - m^{MC}_{J/\psi})$$

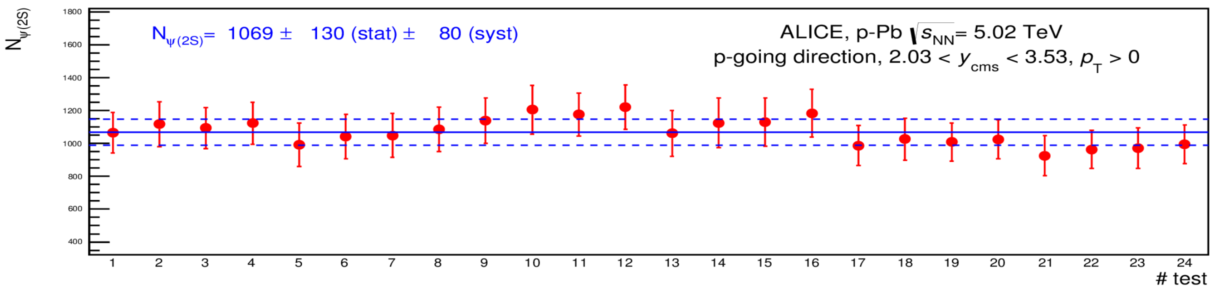
$$\sigma_{\psi(2S)} = \sigma_{J/\psi} \cdot (\sigma^{MC}_{\psi(2S)} / \sigma^{MC}_{J/\psi})$$

2) Systematic uncertainty on the signal extraction:

→ A large number of fits to the invariant mass spectra is performed using various combinations of signal shapes, background shapes, start/end point of the fit range

→ Final ψ(2S) yield is obtained as the average of the results of the fits

→ Systematic uncertainty on the signal is obtained as the RMS of the distribution



Invariant mass spectra: p-Pb

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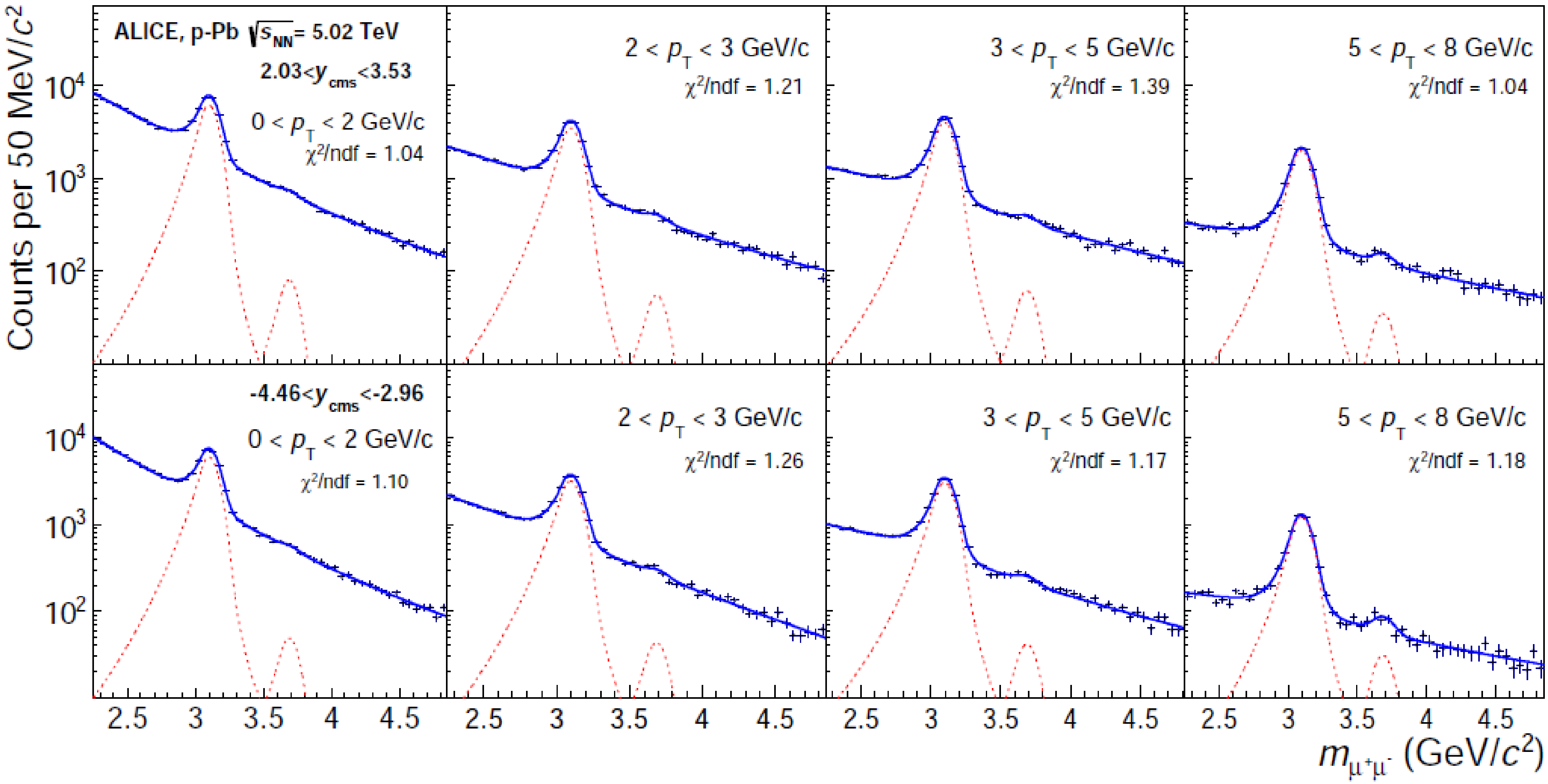
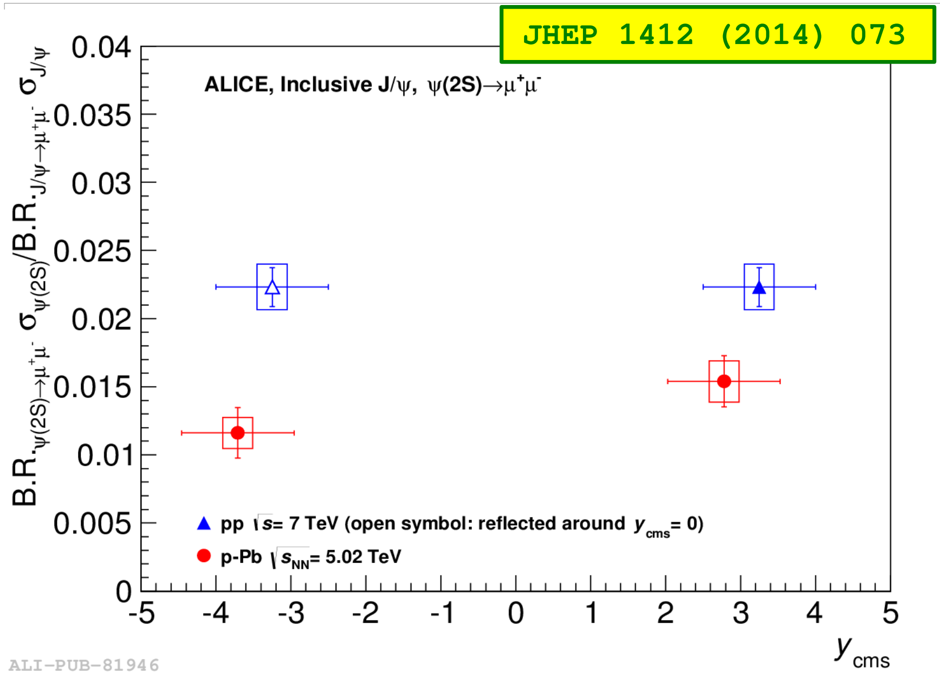


→ Extraction of ψ(2S) yields via a fit to the opposite sign invariant mass spectra based on signal and background shapes

→ sizeable statistics in p-Pb allows for differential studies

$\psi(2S)/J/\psi$ and $[\psi(2S)/J/\psi]_{pPb}/[\psi(2S)/J/\psi]_{pp}$

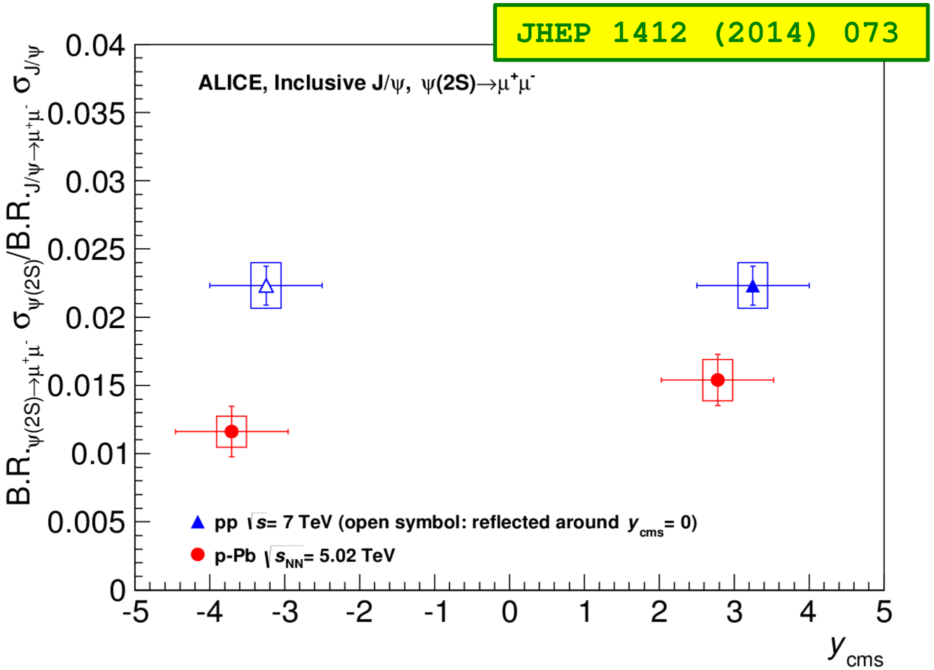


$\psi(2S)/J/\psi$ ratio

Stronger* $\psi(2S)$ suppression (compared to the J/ψ) in p-Pb with respect to $\sqrt{s}$=7 TeV pp collisions

* 2.0 σ-level at forward-y
* 3.2 σ-level at backward-y

$\psi(2S)/J/\psi$ and $[\psi(2S)/J/\psi]_{pPb}/[\psi(2S)/J/\psi]_{pp}$



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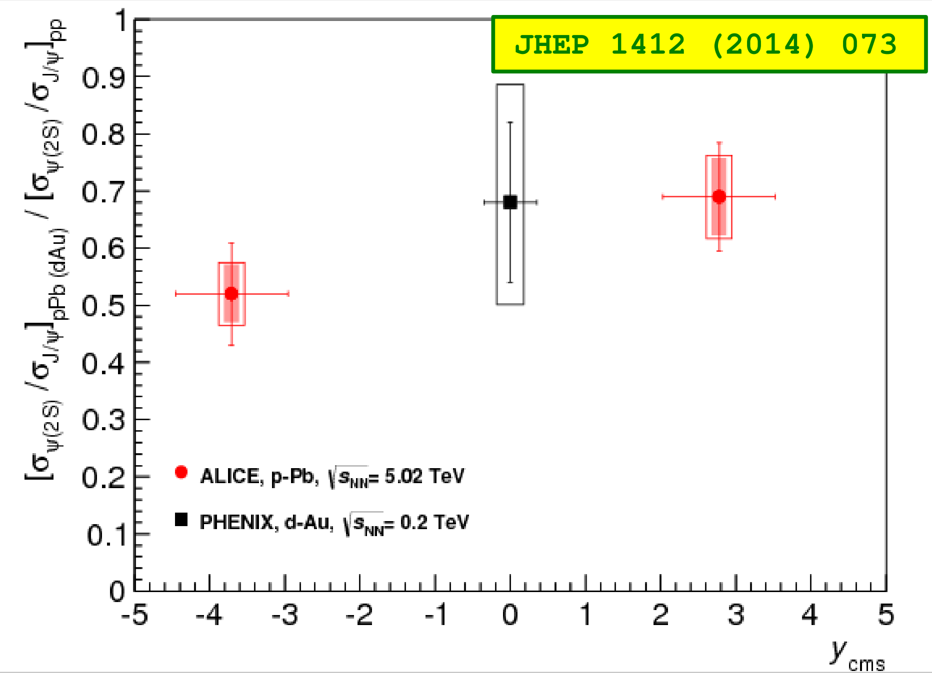

$[\psi(2S)/J/\psi]_{pPb}/[\psi(2S))/J/\psi]_{pp}$

PHENIX results (PRL 111 (2013) 202301) in d-Au collisions at $\sqrt{s_{NN}}=0.2$ TeV at midrapidity are qualitatively similar to ALICE measurements

The collision energy is different in pp and p-Pb collisions: possible dependences on the energy and y are included in the systematics

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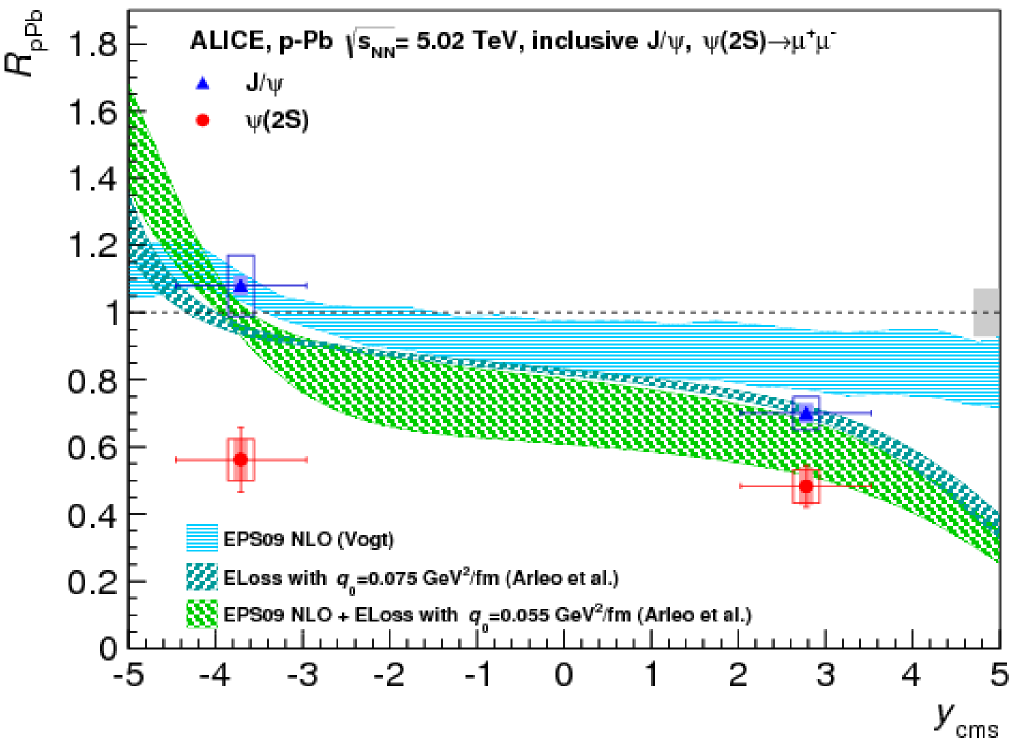

ψ(2S) nuclear modification factor

→ Stronger ψ(2S) suppression compared to the J/ψ

→ Same shadowing and coherent energy loss expected for both the J/ψ and the ψ(2S)

→ Theoretical predictions (based on shadowing and on energy loss) do not describe the observed ψ(2S) suppression

The suppression of ψ(2S) can be quantified using the nuclear modification factor:

$$R_{pA}^{\psi(2S)} = \frac{\sigma_{pA}^{\psi(2S)}}{A_{Pb} \cdot \sigma_{pp}^{\psi(2S)}}$$

R_{pA} = 1 → no medium effects

$R_{pA} \neq 1$ → medium effects!

Is this effect related to the breakup of the weakly bound ψ(2S) in the nuclear medium?

$\psi(2S)\, R_{pPb}$ as a function of rapidity

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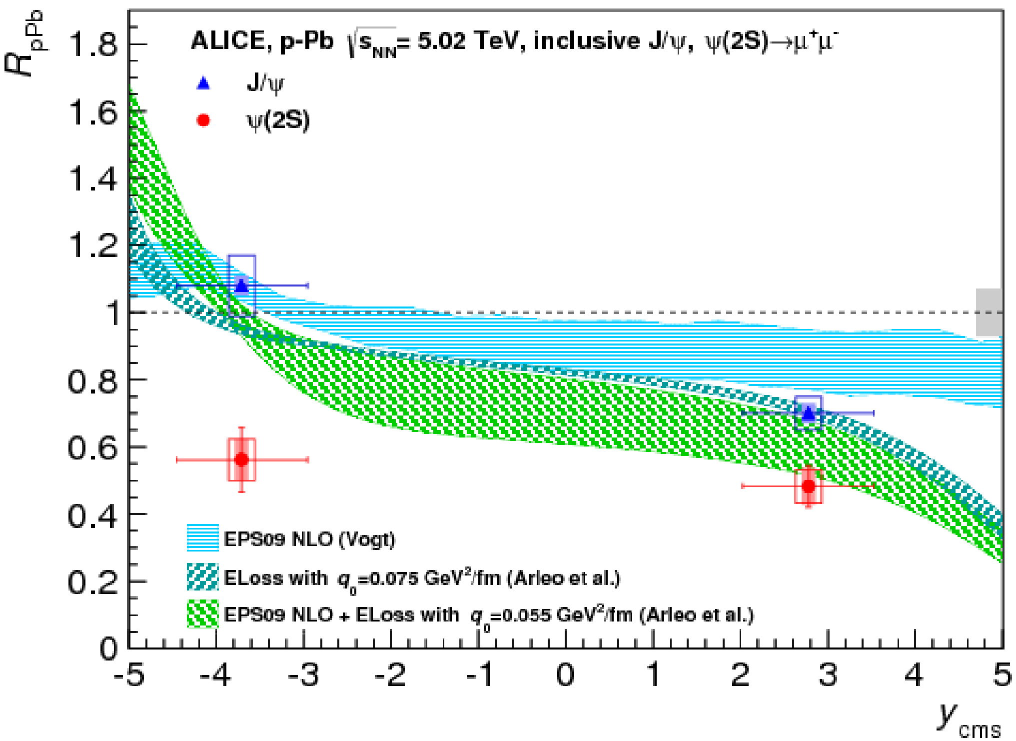


$$\tau_c = \frac{\langle L \rangle}{\beta_z \gamma}$$

τ_c and τ_f references:

PRC 87,054910 (2013)

Phys. Rev. Lett. 111 (2013) 202301

<L> = average length of nuclear matter traversed by the $c\bar{c}$ pair

β = $\tanh y_{c\bar{c}}^{rest}$

γ = $E_{c\bar{c}}/m_{c\bar{c}}$

The ψ(2S) breakup is possible if the resonance:

formation time < crossing time

$\tau_f \sim (0.05\text{–}0.15)\,\mathrm{fm}/c < \tau_c$

→ **forward-y:** $\tau_c \sim 10^{-4}$ fm/c

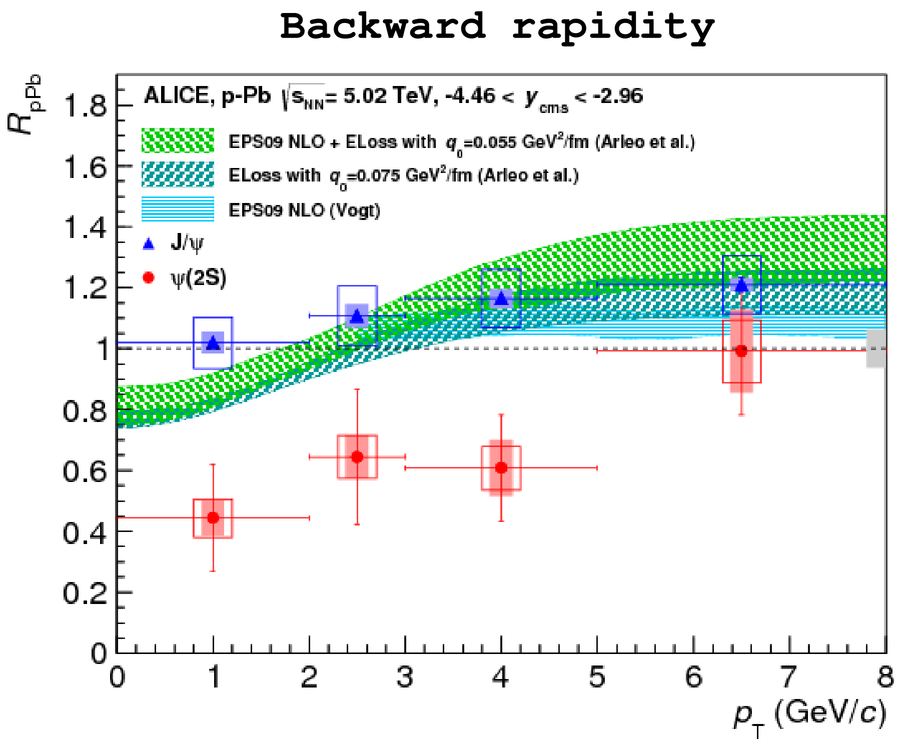
breakup effects are excluded

→ **backward-y:** $\tau_c \sim 7\cdot10^{-2}$ fm/c

($\tau_f \sim \tau_c$) breakup effects can hardly explain the big difference between J/ψ and ψ(2S) R_{pPb}

Other final state effects related to the hadronic matter are required to describe the stronger ψ(2S) suppression

ψ(2S) R_{pPb} as a function of p_T



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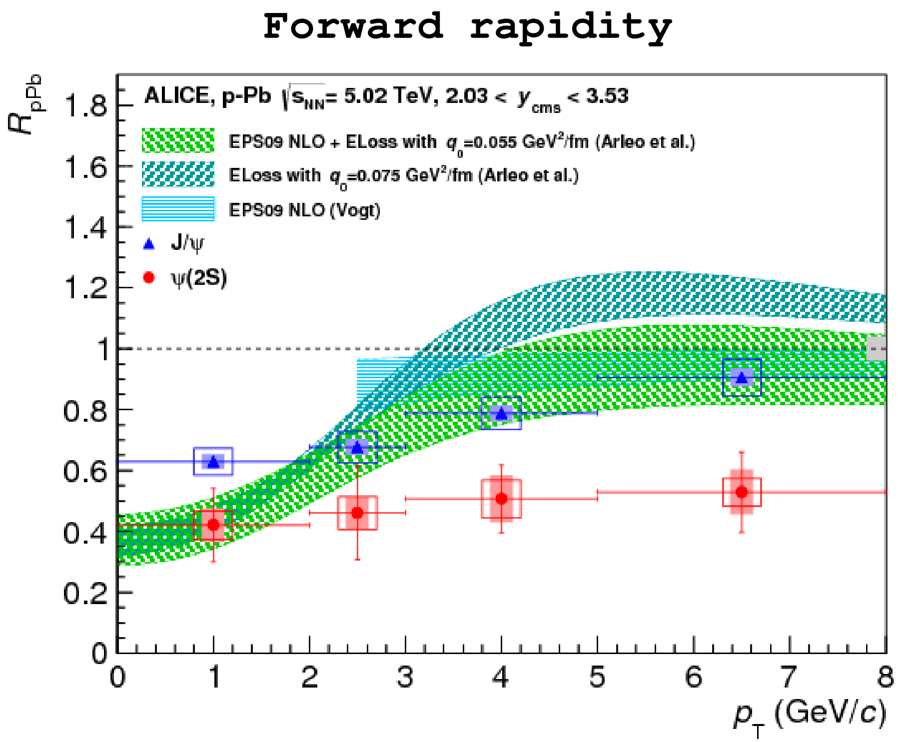

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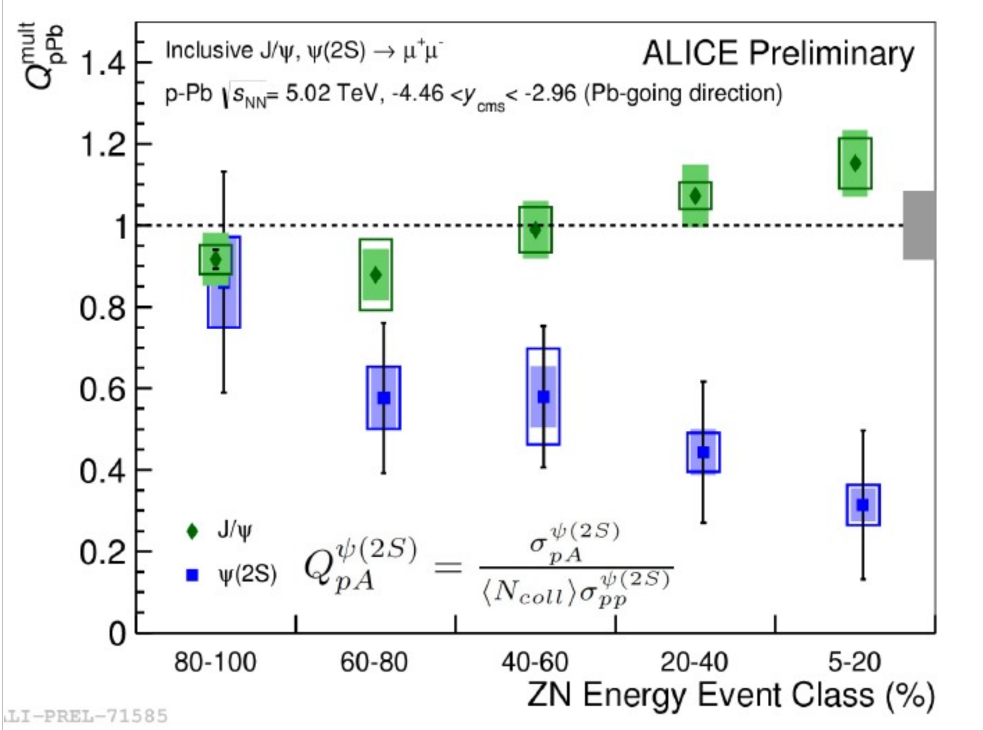
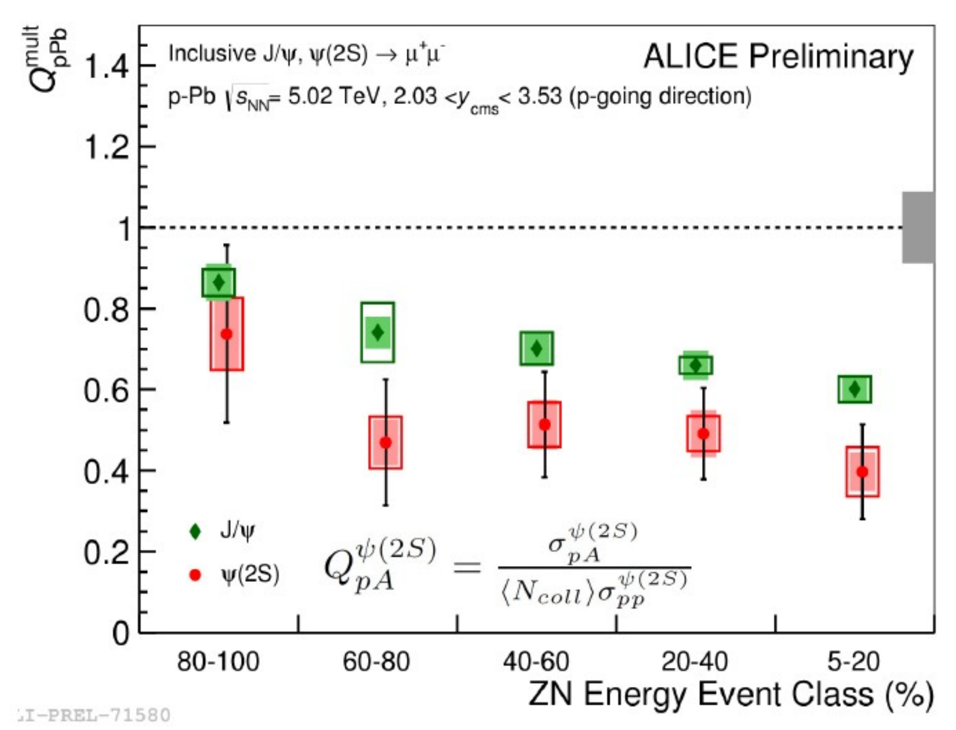
- The available statistics allow to study the ψ(2S) R_{pPb} in p_T bins
- Crossing time "sampling", at backward rapidity: τ_c~0.07 fm/c (at p_T=0 GeV/c) – τ_c~0.03 fm/c (at p_T=8 GeV/c)
- The ψ(2S) is more suppressed than the J/ψ
- Theoretical models, in fair agreement with the J/ψ, overestimate the ψ(2S) result

$\psi(2S)$ Q_{pPb} vs event activity

Backward rapidity

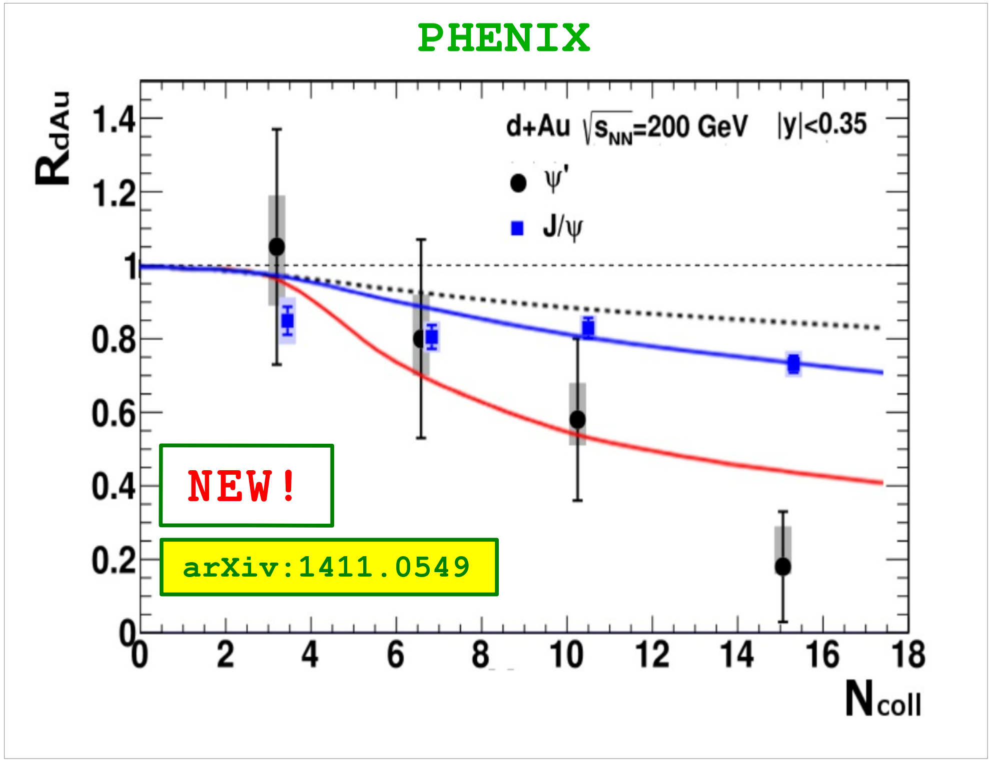


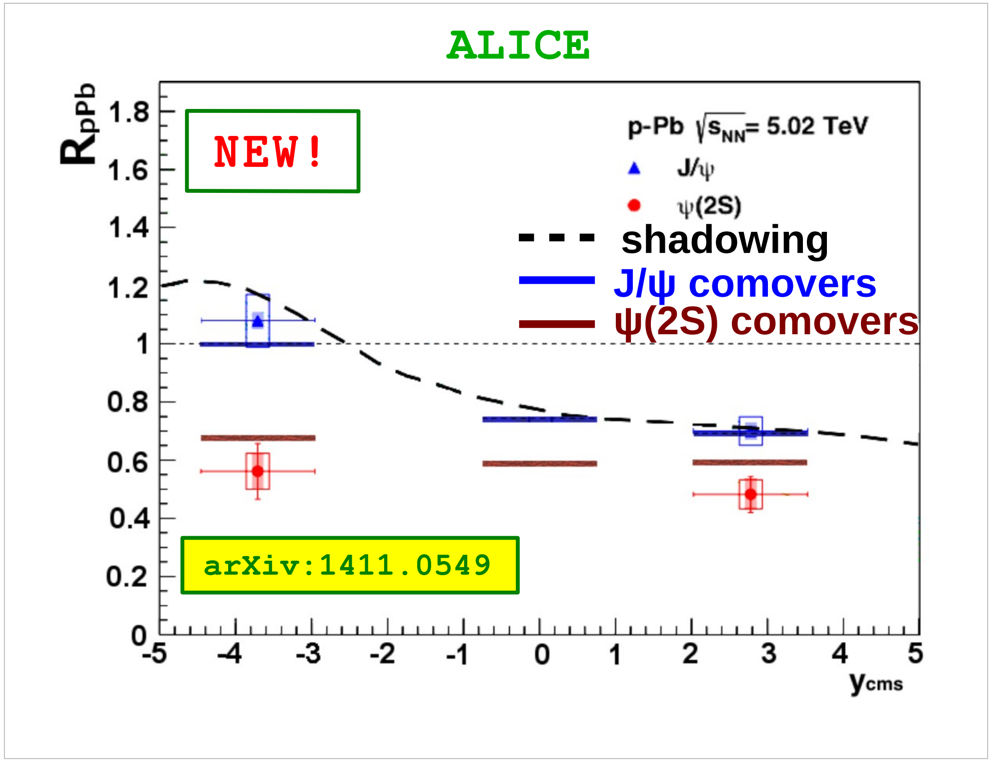
Forward rapidity



- Q_{pPb} variable instead of R_{pPb} (possible bias from the centrality estimator), as a function of the event activity
- At backward rapidity the $\psi(2S)$ and J/ψ Q_{pPb} trends are different: the $\psi(2S)$ Q_{pPb} decreases with increasing event activity
- At forward rapidity the Q_{pPb} trend is similar for J/ψ and $\psi(2S)$

Interaction with comovers (E. Ferreiro)





→ Suppression caused by scattering of the resonance with produced particles that travel along with the $c\bar{c}$ pair

→ the comovers dissociation effects are stronger:

- for the ψ(2S) than the J/ψ (the ψ(2S) has larger size than J/ψ)
- with increasing centrality and at backward rapidity due to higher comover density

→ model based on comover interactions + EPS09 shadowing is in fair agreement with PHENIX and ALICE data

Conclusions

The $\psi(2S)$ production has been studied in p-Pb collisions as a function of rapidity, transverse momentum and event activity

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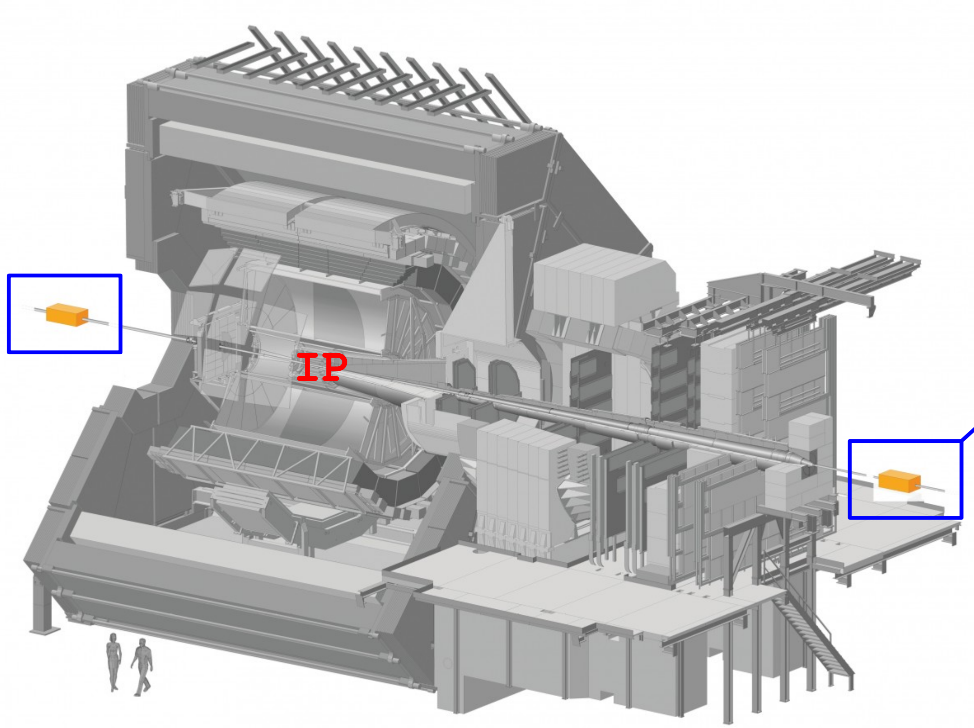
Final state affecting the ψ(2S) need to be invoked to explain the ALICE result: raising interest between theoretician to provide models describing the ψ(2S) suppression

Other activities

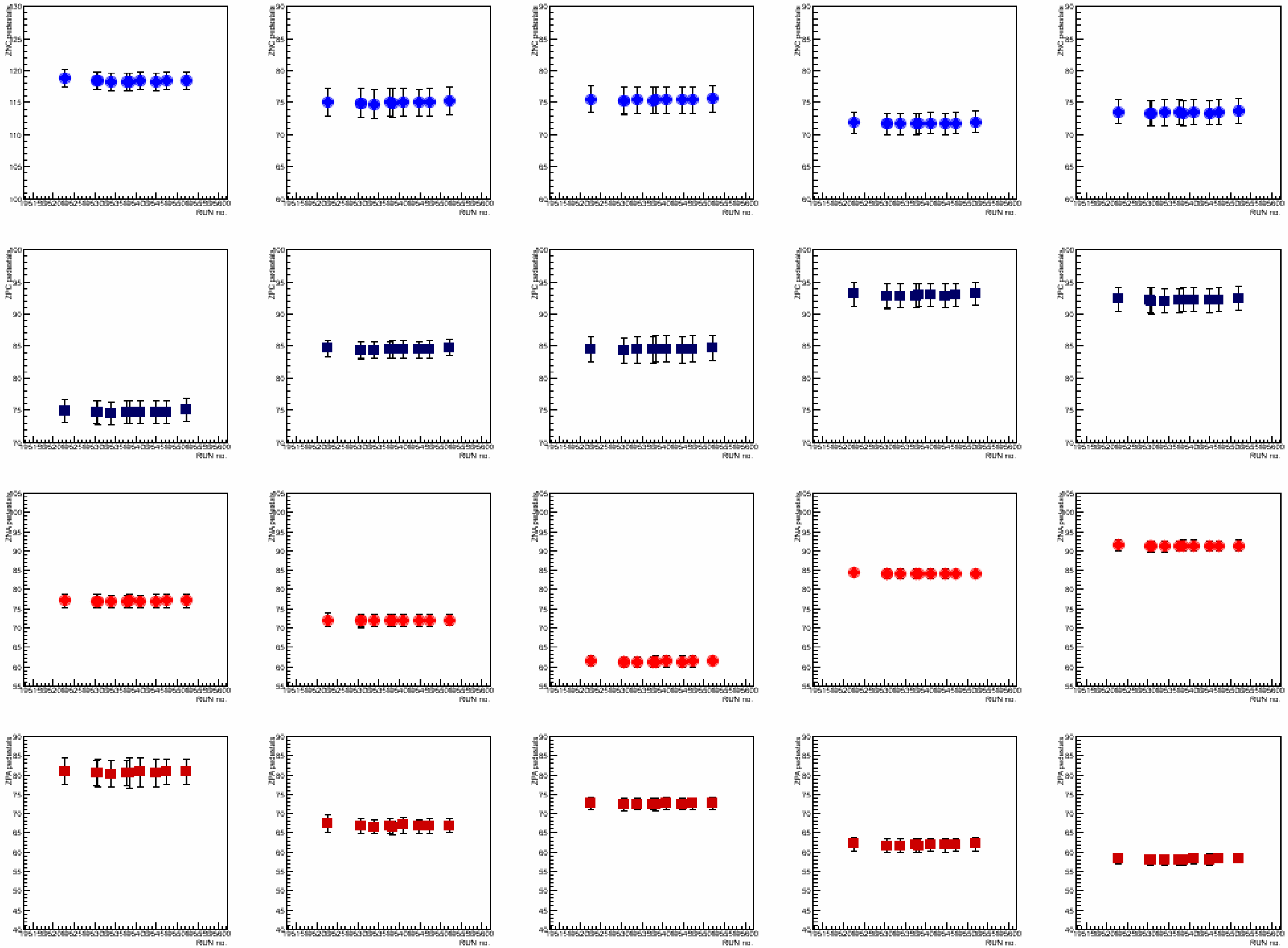
Zero Degree Calorimeter (ZDC)

I am in charge of ZDC Data Quality Assurance from the beginning of 2013 and responsible as ON-CALL shifter. I am also partecipating to the ZDC recommissioning after the Long-Shutdown 1.



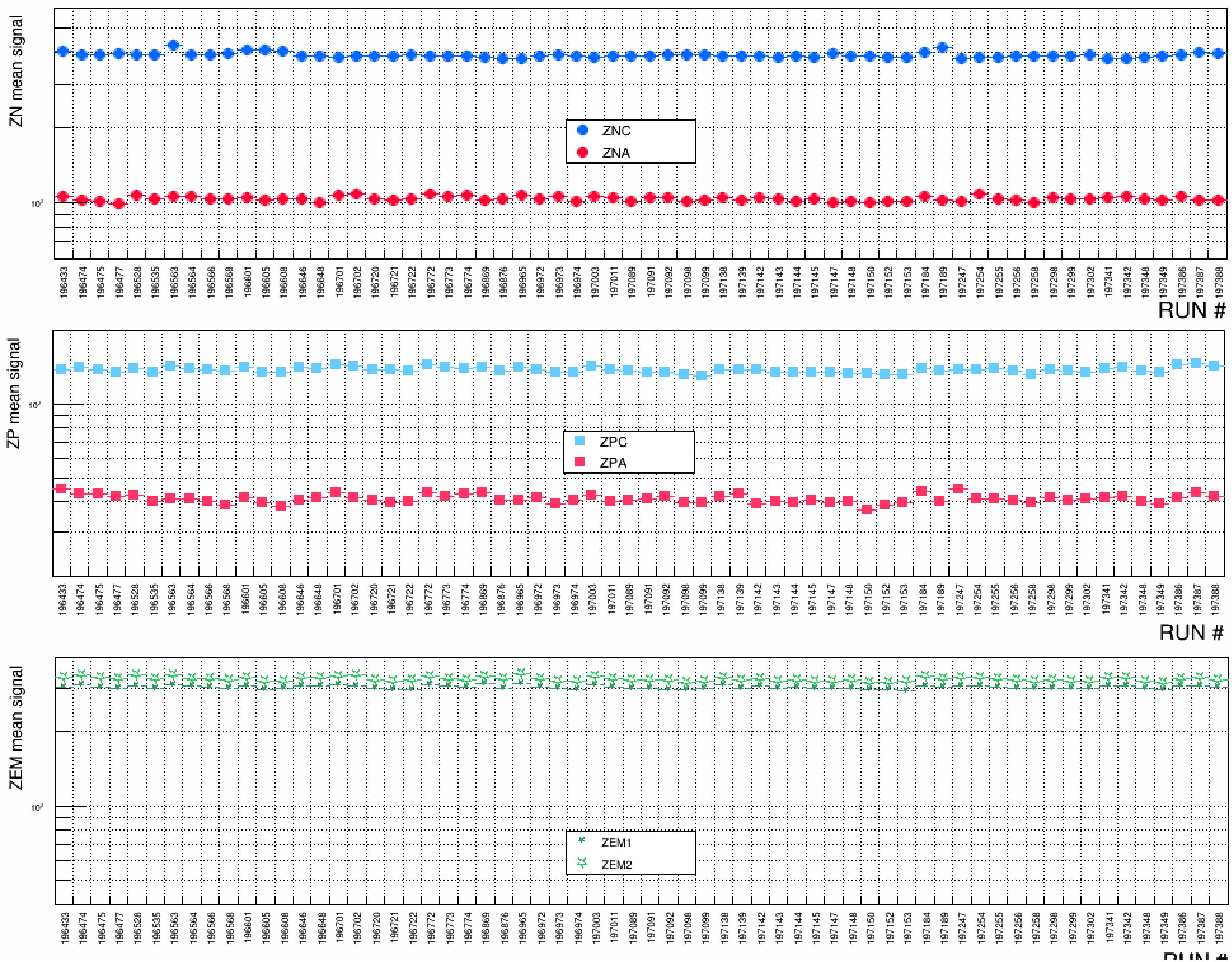
- Two identical sets of Zero Degree Calorimeter (ZDC) are placed at at ~114 m from the interaction point.
- ZDCs have the role to determine the centrality in p-Pb and Pb-Pb collisions.
- Incident particles in a dense absorber (the "passive" material) produce Cherenkov radiation in quartz fibers (the "active" material)

Data quality assurance for ZDC



Pedestal stability check as a function of the run

Data quality assurance for ZDC



Signal stability check as a function of the run

Analysis of van der Meer data

- The measurement of the visible cross section is of fundamental importance for a lot of ALICE analyses, including the determination of the charmonia production cross-sections.

- I also joined the "ALICE vdM group": my objective is to compute the cross section in pp collisions at $\sqrt{s} = 8$ TeV.

- The analysis is on-going and I am a member of the Paper Committee.

- In vdM scans the two beams are moved across each other in the transverse directions x and y. The luminosity L for head-on collisions of a pair of bunches with particle intensities N1 and N2 is:

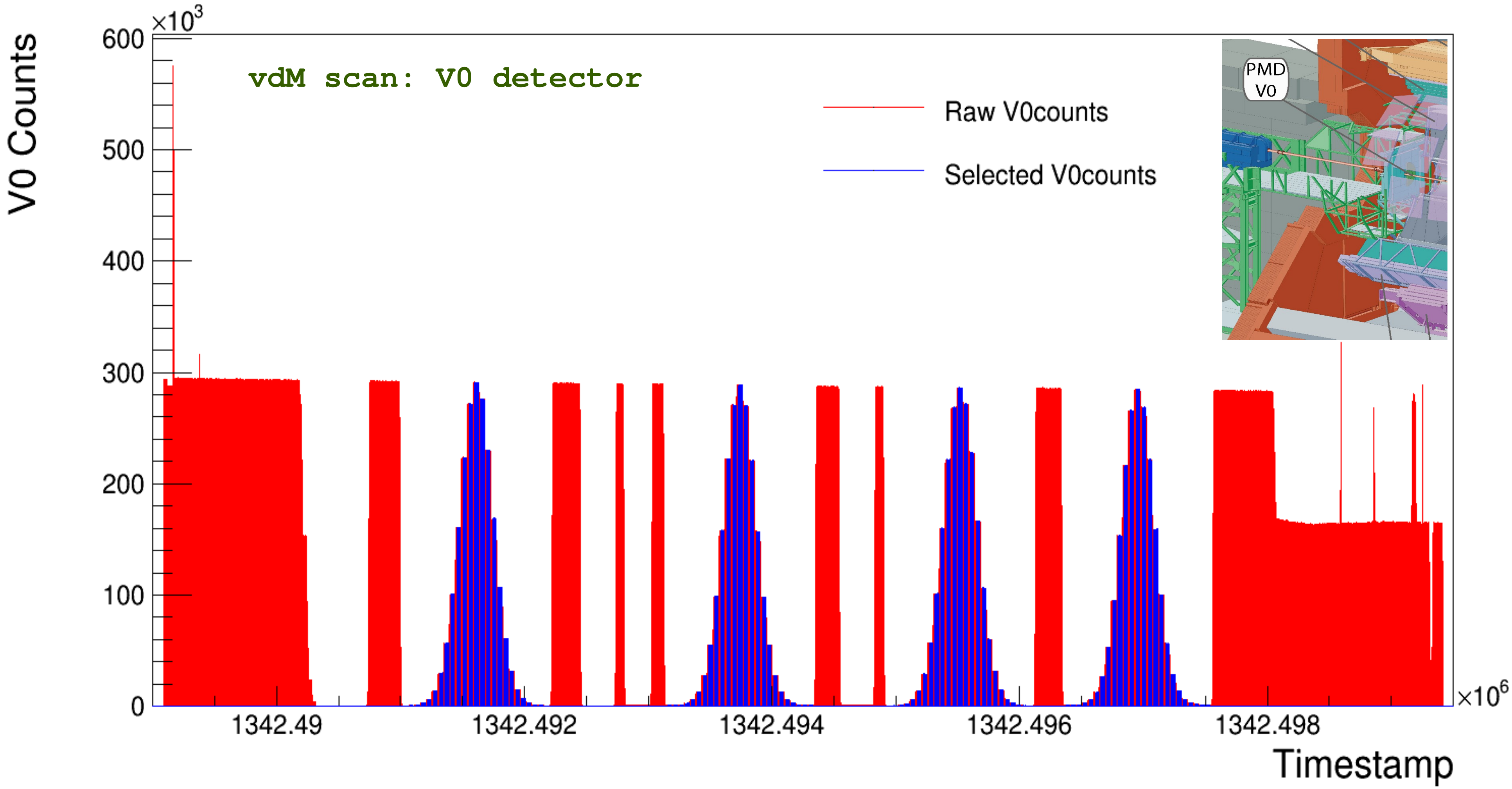
$$\mathbf{L = N_1 N_2\ f_{rev} / (h_x h_y)}$$

(f_{rev} is the accelerator revolution frequency and $h_x h_y$ are the effective beam widths in the two transverse directions).

Analysis of van der Meer data

→ The effective beam widths are measured as the area below the R(Dx,0) and R(0,Dy) curve (scan area).

→ The cross section is: **σ = R(0,0)/L**



Perspectives

- Publish the second paper dedicated to the **Event activity dependence of the inclusive ψ(2S) production in p–Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV.**

- Finalizing the **vdM analysis in pp collisions at $\sqrt{s}$ =8 TeV** and publish the results.

- Analysis of the **vdM scans in the first 2015 pp collisions** to publish a fast-paper on the J/ψ production cross-section.

- Follow the ZDC operations during data taking.

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- Finalizing the **vdM analysis in pp collisions at $\sqrt{s}$ =8 TeV** and publish the results.

- Analysis of the **vdM scans in the first 2015 pp collisions** to publish a fast-paper on the J/ψ production cross-section.

- Follow the ZDC operations during data taking.

- **And, finally**...

Perspectives

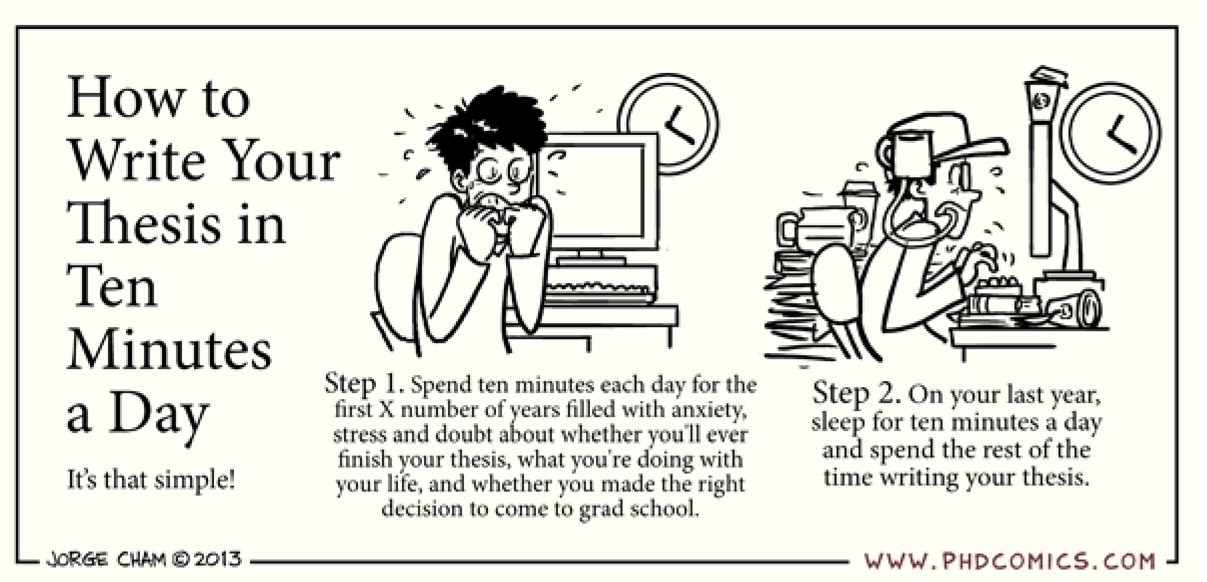
→ Publish the second paper dedicated to the **Event activity dependence of the inclusive ψ(2S) production in p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV.**

→ Finalizing the **vdM analysis in pp collisions at $\sqrt{s}$ =8 TeV** and publish the results.

→ Analysis of the **vdM scans in the first 2015 pp collisions** to publish a fast-paper on the J/ψ production cross-section.

→ Follow the ZDC operations during data taking.

→ **Write a Thesis!**



Conferences, PhD schools and publications

CONFERENCE/SCHOOL ORAL PRESENTATIONS AND POSTERS:

Quarkonium 2014, 10-14 November 2014, CERN.
Oral presentation: "ψ(2S) production in p-Pb and Pb-Pb collisions with ALICE at the LHC".

Hot Quarks 2014, 21-28 September 2014, Las Negras, Spain.
Oral presentation: "ψ(2S) production in p-p, p-Pb and Pb-Pb collisions with ALICE at the LHC".

XXVI Seminario Nazionale di Fisica Nucleare e Subnucleare "Francesco Romano", 4-11 June 2014, Otranto.

Oral presentation: "ψ(2S) production in p-Pb collisions with ALICE at the LHC".

Quark Matter 2014, 17-24 May 2014, Darmstadt, Germany.
Poster: "ψ(2S) signal extraction in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC".

IFAE, Incontri di Fisica delle Alte Energie 2014, 9-11 April 2014, l'Aquila, Italy.
Oral presentation: "Produzione di J/ψ e ψ(2S) in collisioni p-Pb a $\sqrt{s_{NN}}$= 5.02 TeV con l'esperimento ALICE (LHC)".

52nd International Winter Meeting on Nuclear Physics, 27-31 January 2014, Bormio, Italy.
Oral presentation: "J/ψ and ψ(2S) production in p-Pb collisions with ALICE at the LHC".

XCIX Congresso Nazionale della Societa' Italiana di Fisica, 23-27 September 2013, Trieste, Italy.
Oral presentation: "Forward rapidity J/ψ production in Pb-Pb and p-Pb collisions with ALICE at the LHC".

Lecture Week on Hard Probes in heavy-ion collisions, April 26 - May 3 2013, San Gimignano, Italy. Oral presentation: "Charmonium vs bottomonium: what can we learn comparing their suppression pattern?"

Ph.D. SCHOOLS

- **XXVI Seminario Nazionale di Fisica Nucleare e Subnucleare "Francesco Romano"** 4-11 June 2014, Otranto.
- **XXIII Giornate di studio sui Rivelatori**, 22-25 October 2014, Torino, Italy. (also member of the Organizing Committee).
- **Quark Gluon Plasma and Heavy Ion Collisions, 2013: past, present, future**, 9-13 July 2013 Siena, Italy.
- **Lecture Week on Hard Probes in heavy-ion collisions**, April 26 - May 3 2013, San Gimignano, Italy.
- **Rivelatori ed Elettronica per Fisica delle Alte Energie, Astrofisica, Applicazioni Spaziali e Fisica Medica**, 15-19 April 2013, LNR Legnaro, Italy.

WORKSHOPS

- **Detectors for the LHC Upgrade - 14th LNF Mini-workshop**, 28 November 2013, Frascati, Italy.
- **Alice Muon Meeting 2013**, 9-10 May 2013, Barolo, Italy.

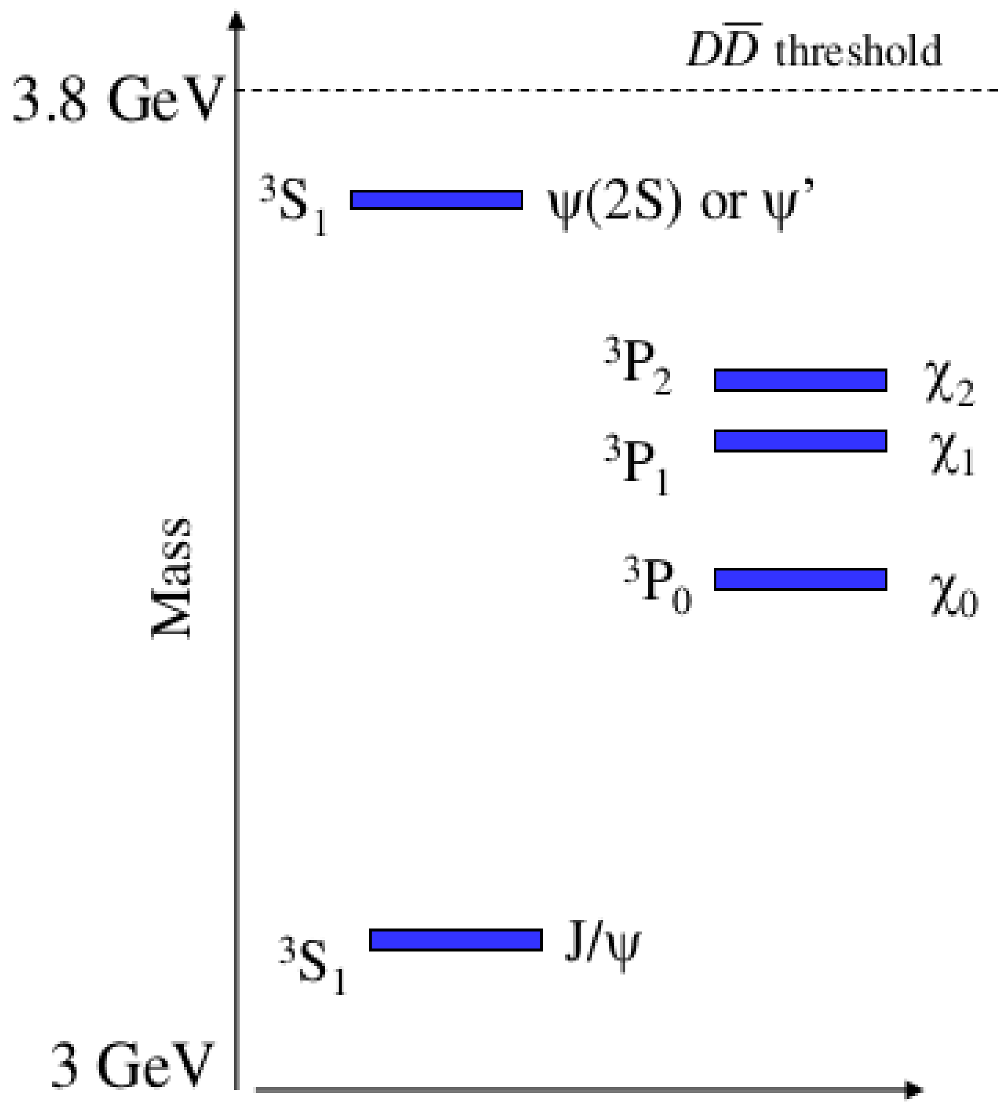
PUBLICATIONS:

- **“Suppression of ψ(2S) production in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV”**, [arXiv:1405.3796], JHEP 1412 (2014) 073 (Paper Committee Member).
- **“Event activity dependence of the inclusive ψ(2S) production in p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV”**: member of the Paper Committee.
- **Hot quarks 2014 proceedings to be published**
  Proceeding title: ψ(2S) production in p-Pb and Pb-Pb collisions with ALICE at the LHC.
- **IFAE 2014 proceedings to be published**
  Proceeding title: “Produzione di J/ψ e ψ(2S) in collisioni p-Pb a $\sqrt{s_{NN}}$= 5.02 TeV con l'esperimento ALICE (LHC)”.
- **Bormio 2014 proceedings published on PoS (Proceedings of Science).**
  Proceeding title: J/ψ and ψ(2S) production in p-Pb collisions with ALICE at the LHC.
- **66 publication as a co-author** for the ALICE collaboration

Thank you!

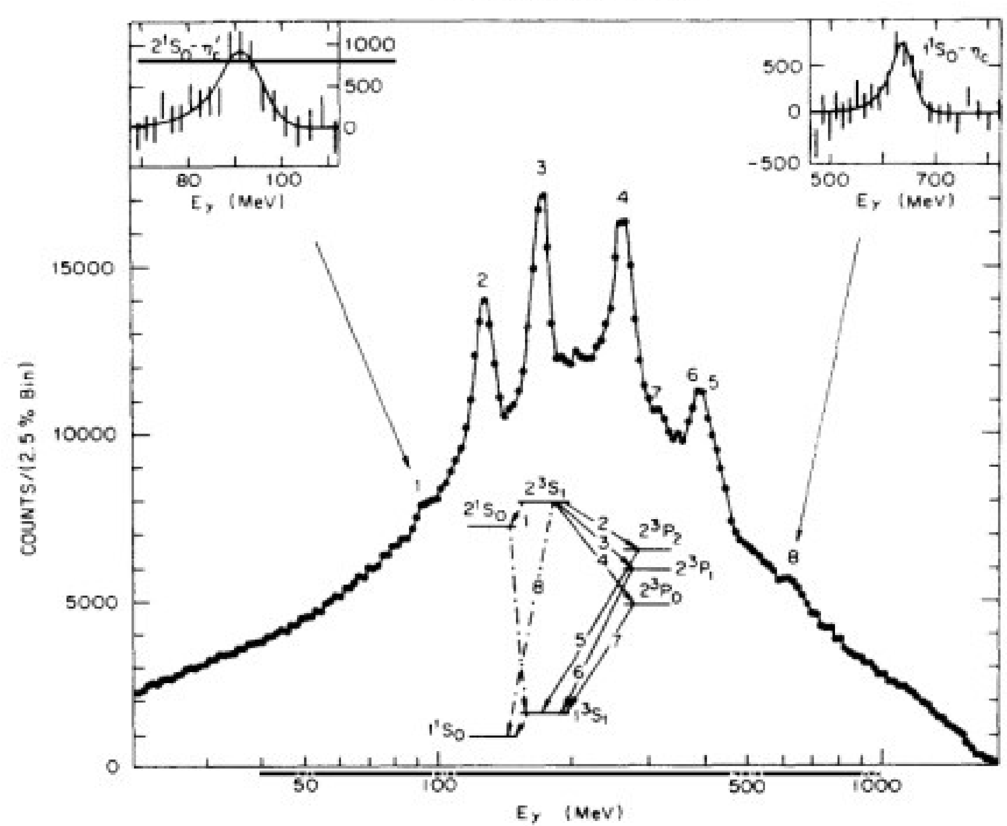
Backup slides

Charmonium family



state	J/ψ	χ_c	$\psi(2S)$
Mass(GeV)	3.10	3.53	3.69
ΔE (GeV)	0.64	0.20	0.05
r_o(fm)	0.25	0.36	0.45

Crystal Ball



Charmonium decays

$J/\psi(1S)$ DECAY MODES

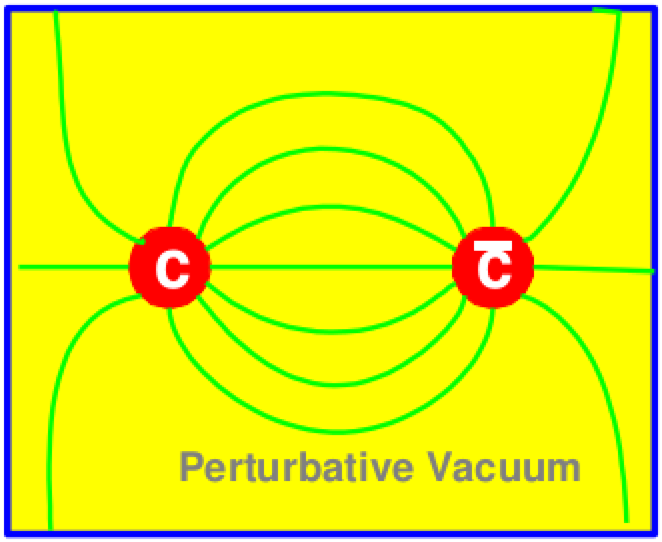
	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	hadrons		(87.7 ± 0.5) %	
Γ_2	virtual $\gamma \to$ hadrons		(13.50 ± 0.30) %	
Γ_3	ggg		(64.1 ± 1.0) %	
Γ_4	γgg		(8.8 ± 1.1) %	
Γ_5	e^+e^-		(5.94 ± 0.06) %	
Γ_6	$e^+e^-\gamma$	[a]	$(8.8 \pm 1.4) \times 10^{-3}$	
Γ_7	$\mu^+\mu^-$		(5.93 ± 0.06) %	

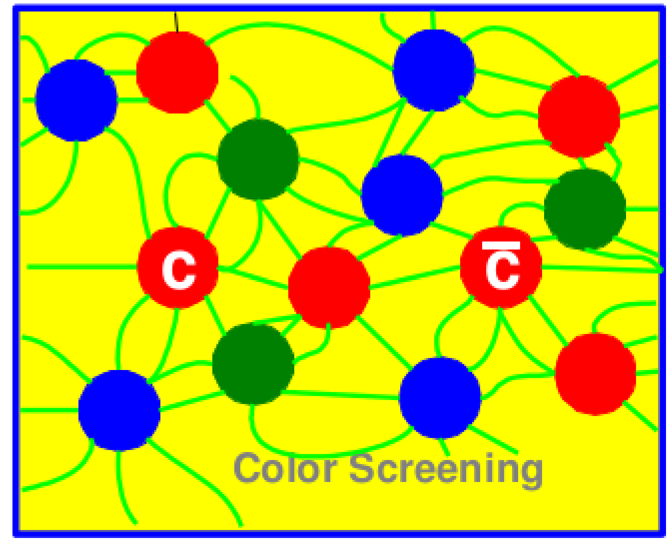
$\psi(2S)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	hadrons	(97.85 ± 0.13) %	
Γ_2	virtual $\gamma \to$ hadrons	(1.73 ± 0.14) %	S=1.5
Γ_3	ggg	(10.6 ± 1.6) %	
Γ_4	γgg	(1.03 ± 0.29) %	
Γ_5	light hadrons	(15.4 ± 1.5) %	
Γ_6	e^+e^-	$(7.73 \pm 0.17) \times 10^{-3}$	
Γ_7	$\mu^+\mu^-$	$(7.7 \pm 0.8) \times 10^{-3}$	
Γ_8	$\tau^+\tau^-$	$(3.0 \pm 0.4) \times 10^{-3}$	

Quarkonia production mechanisms

- In the **Color-Singlet Model** perturbative QCD is used to model the production of on-shell heavy quark pairs,with the same quantum numbers as the quarkonium into which they hadronize
- In the **Color Evaporation Model**, the production cross section of a given quarkonium state is considered proportional to the cross section of its constituting heavy quark pair, integrated from the sum of the masses of the two heavy quarks to the sum of the masses of the lightest corresponding mesons (D or B)
- In the framework of **Non Relativistic QCD**, contributions to the quarkonium cross section from the heavy-quark pairs produced in a color-octet state are also taken into account, in addition to the color-singlet contributions described above



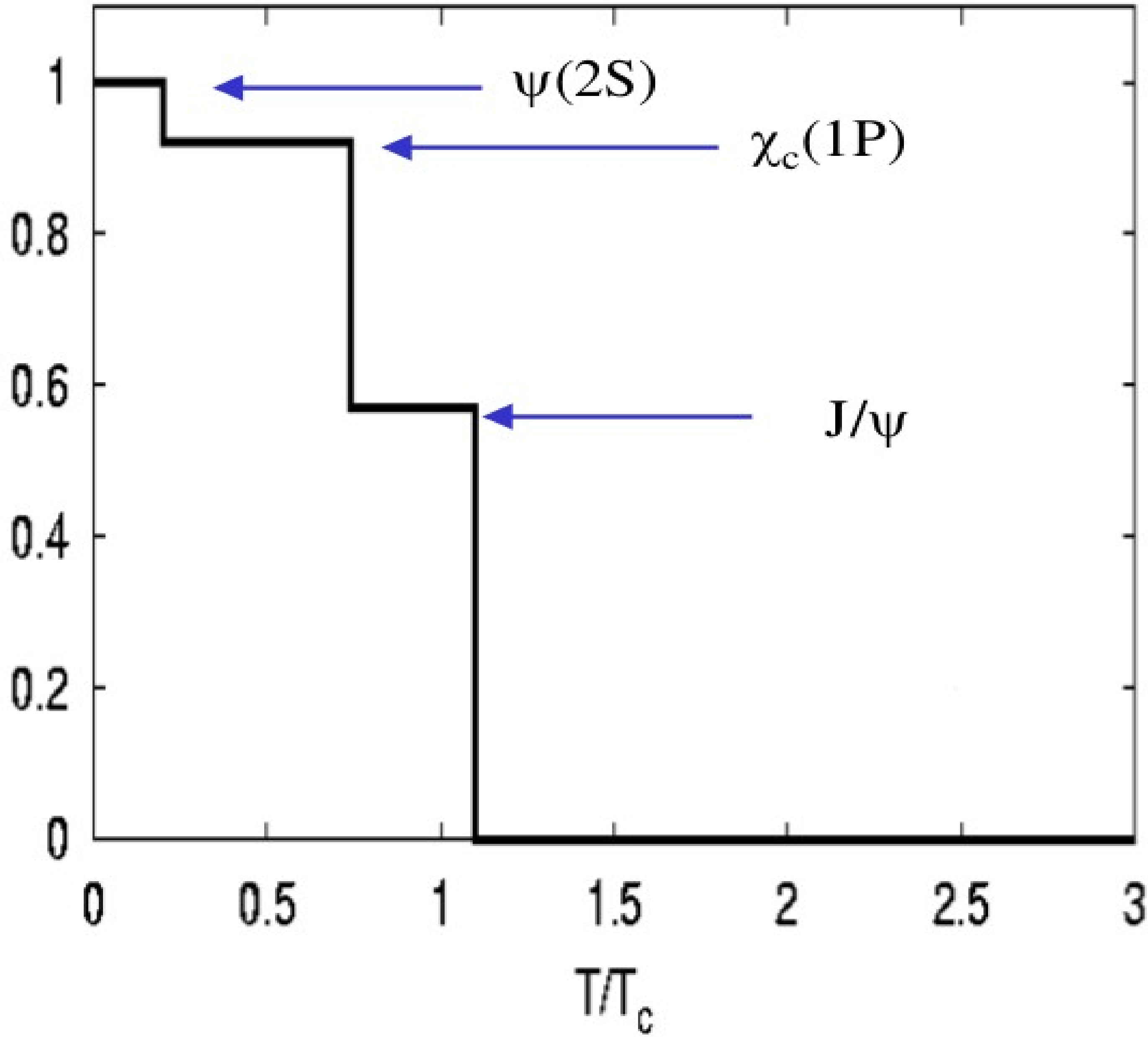


$$V(r) = -\frac{\alpha}{r} + kr \quad \Rightarrow \quad V(r) = -\frac{\alpha}{r} e^{-r/\lambda_D}$$

$$\lambda_D(PQCD) = \frac{1}{\sqrt{\left(\frac{N_c}{3} + \frac{N_f}{6}\right) g^2 T}}$$

$(g^2 = (\pi/3)\,\alpha)$

Charmonium sequential melting



Standard selection criteria

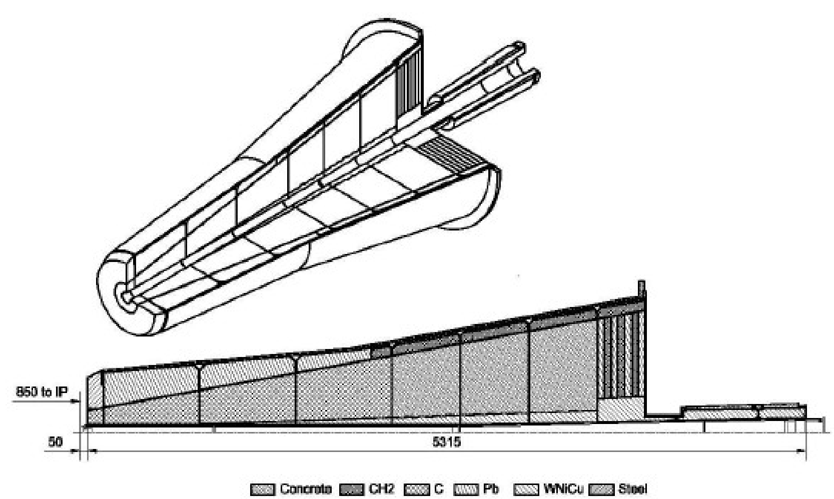
The following criteria are applied to remove hadrons escaping (or produced) in the front absorber, muons from pion and kaon decays and fake muon tracks, before performing the signal extraction:

→ muon trigger-tracking matching;

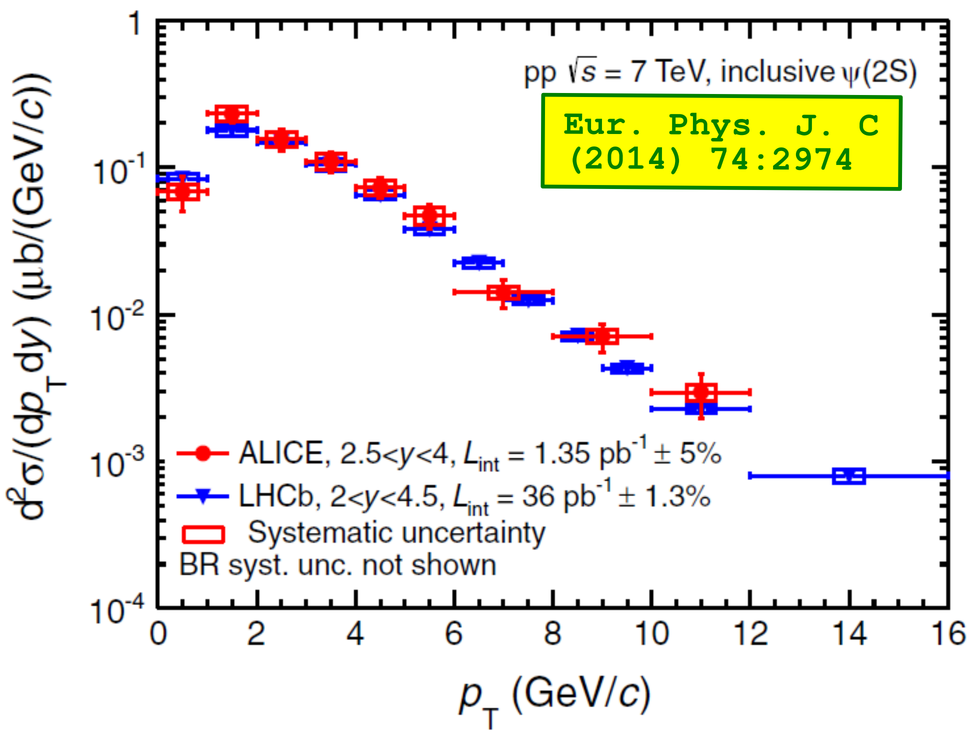
→ tracks are in the range: $-4 \leq \eta_{lab} \leq -2.5$

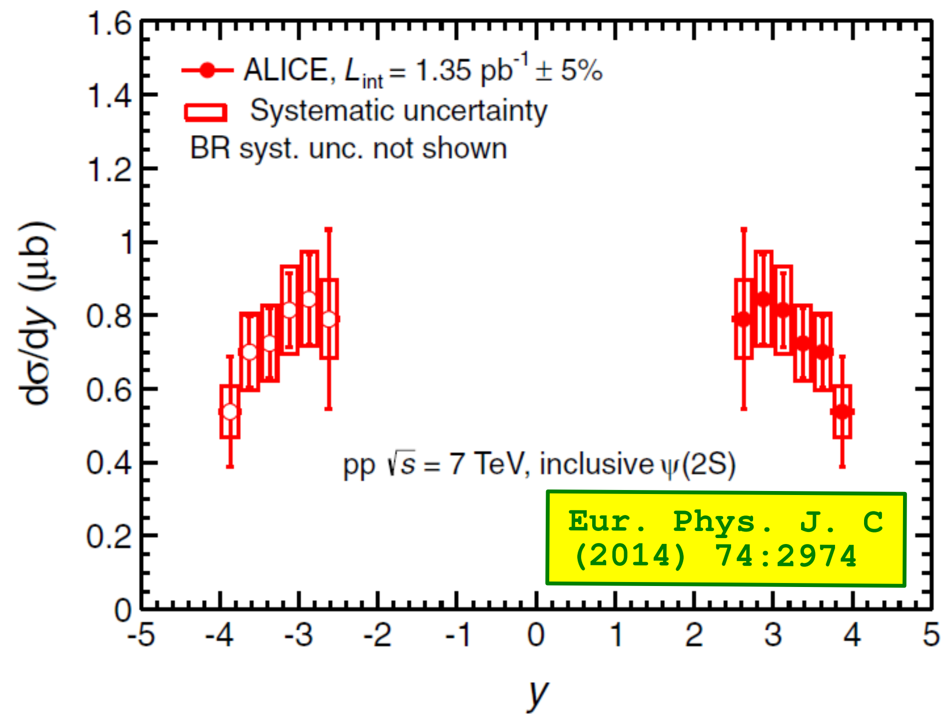
→ track radial position at the absorber end is in the range: $17.6 \leq R_{abs} \leq 89.5$ cm

→ dimuon rapidity is in the range: $2.5 \leq y_{lab} \leq 4$



ψ(2S) differential cross section in pp





→ The ψ(2S) production cross section, in pp collisions, have been studied in p_T and y intervals:

$$\sigma = \frac{1}{L_{\rm int}} \frac{N}{{\rm BR}_{\mu^+\mu^-} \times \langle A\varepsilon \rangle}$$

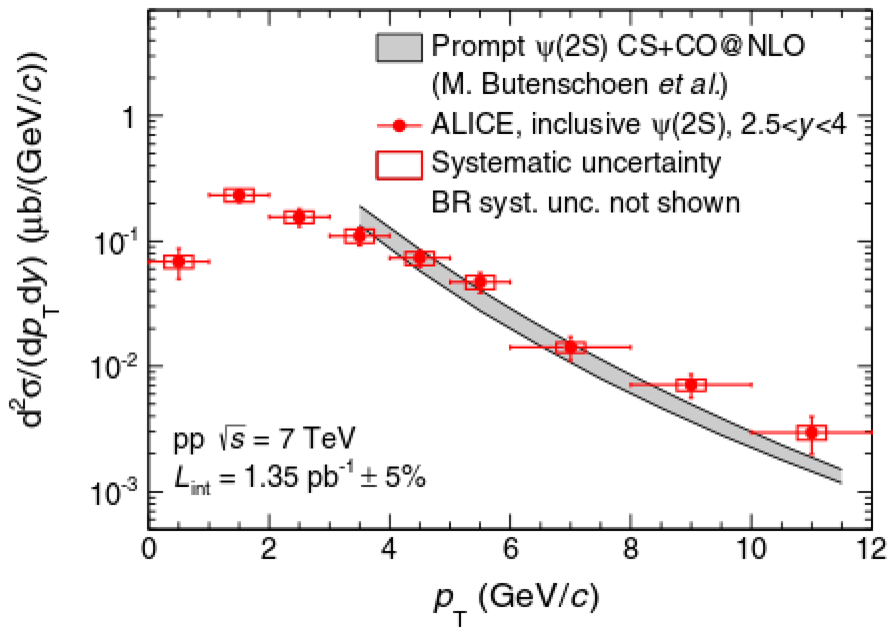
(L_{int}= integrated luminosity, BR(ψ(2S)→$\mu^+\mu^-$=0.78±0.09%, Aε=detector acceptance-efficiency)

→ LHCb results, obtained in a slightly different y range, are also shown
Results are in a good agreement with ALICE

→ pp data useful to build reference for p-Pb and Pb-Pb studies

ψ(2S) in pp: comparison to models

Eur. Phys. J. C (2014) 74:2974



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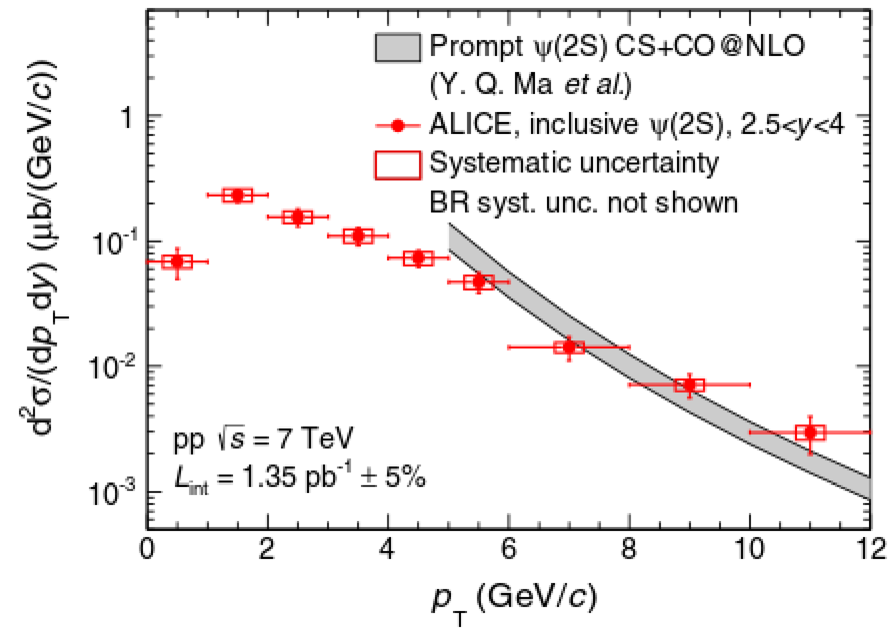
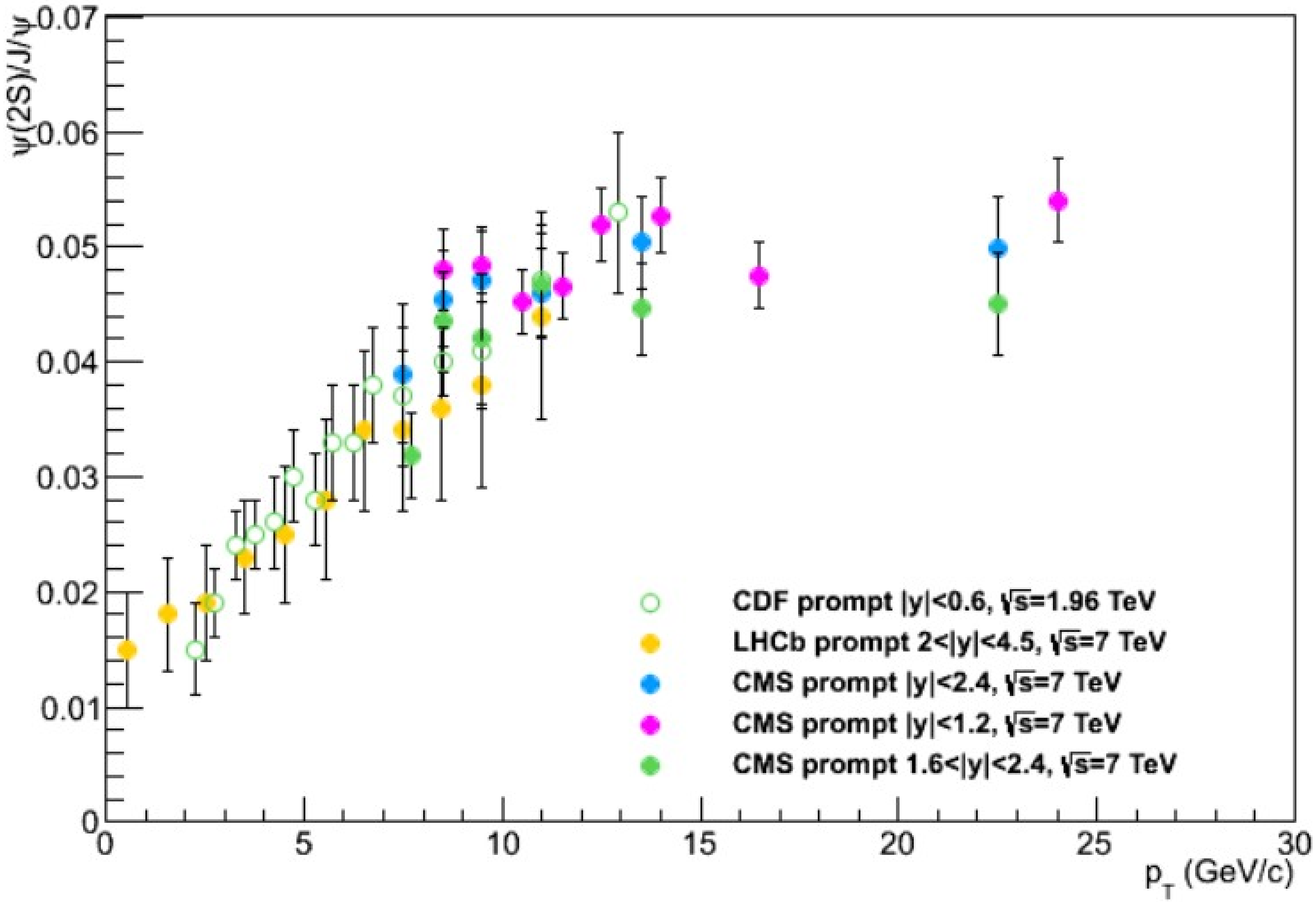


→ comparison the inclusive ψ(2S) differential production cross section to two NRQCD production at NLO (left: arXiv:1105.0820, right: arXiv:1012.1030)

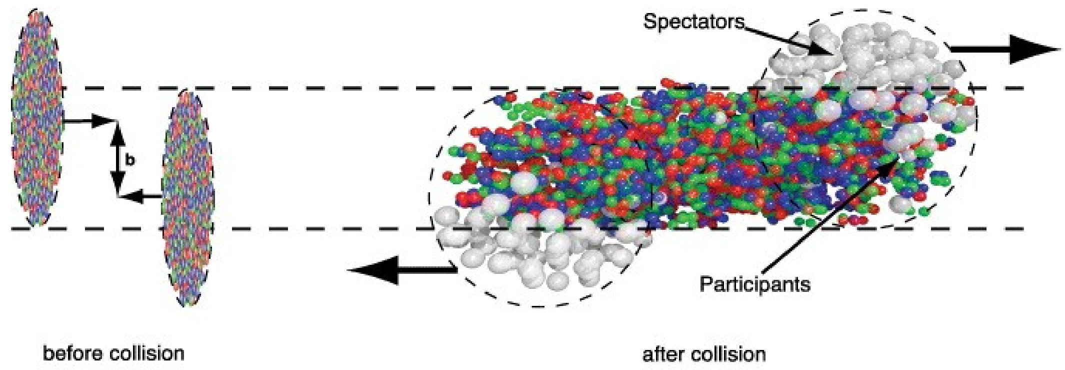
→ both calculations show reasonable agreement with data

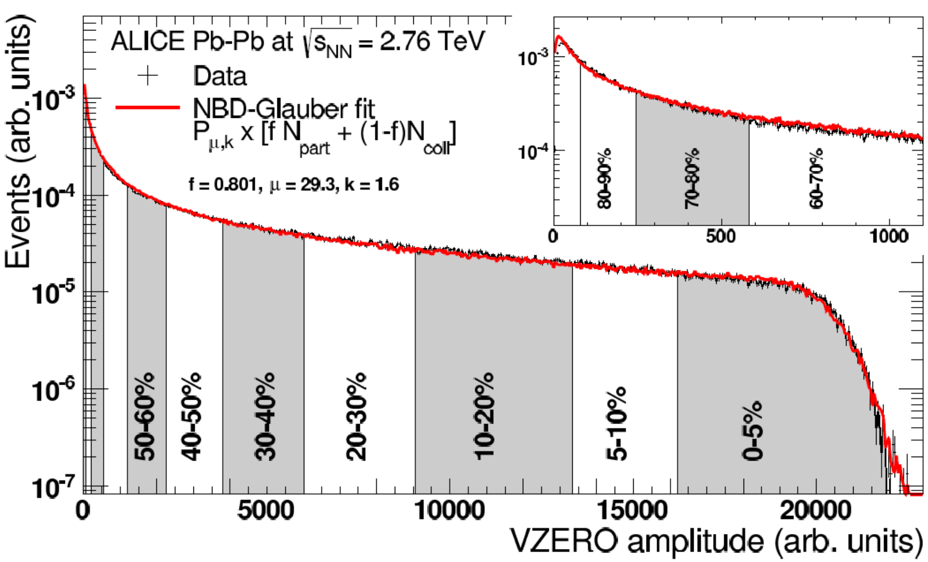
ψ(2S)/J/ψ in pp collisions

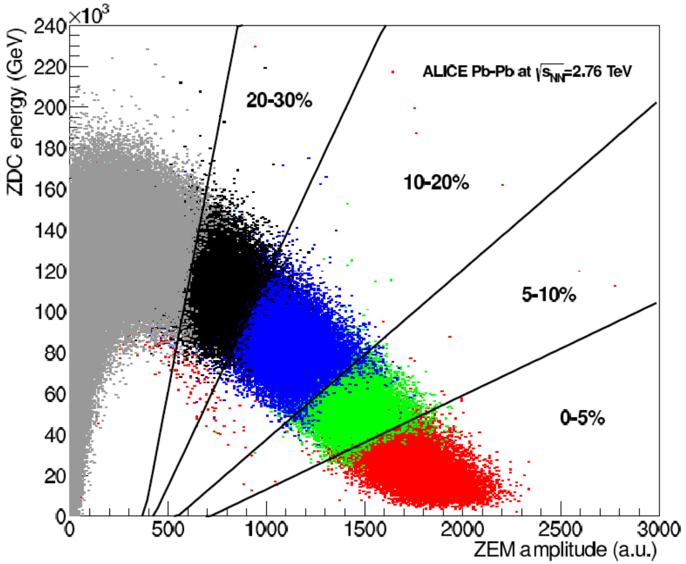


Centrality in Pb-Pb collisions

Phys. Rev. C 88, 044909 (2013)

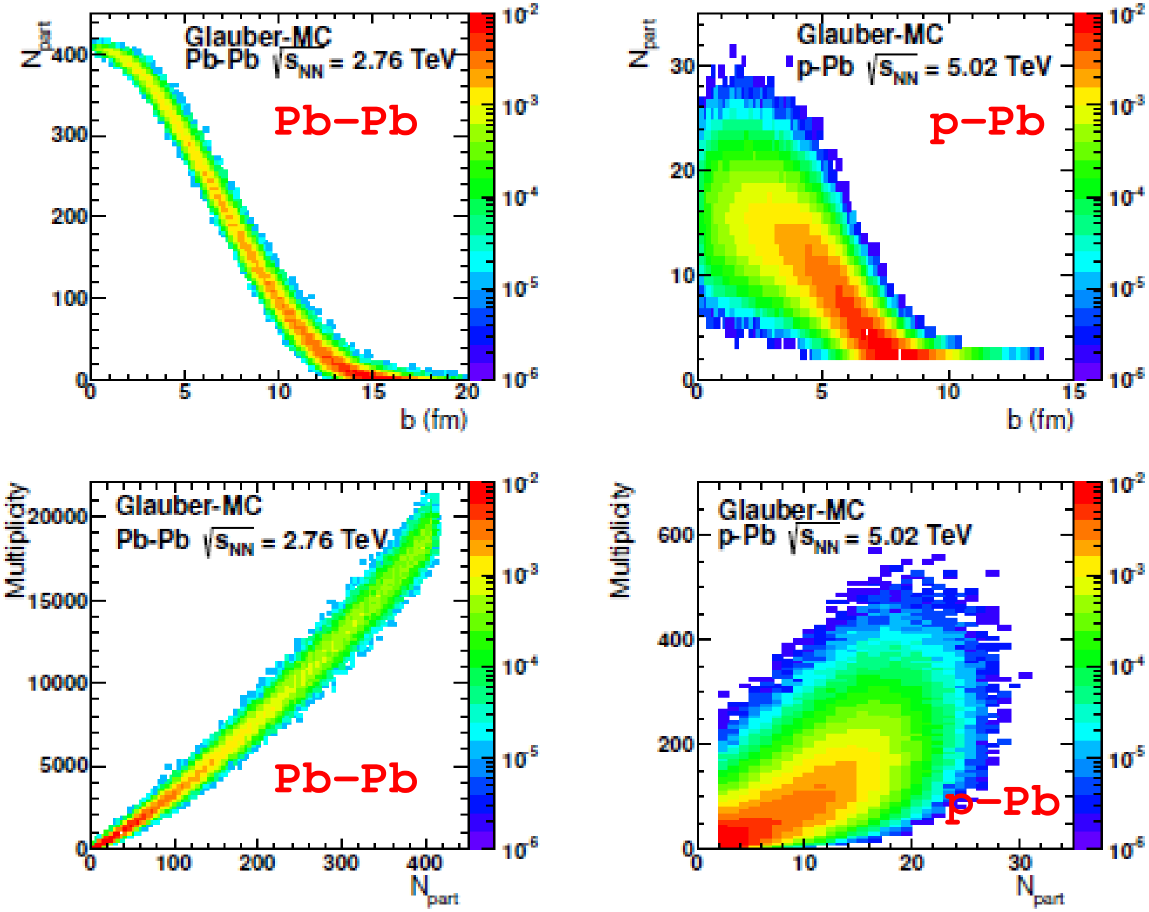






- → VZERO amplitude and Glauber model used to determine centrality percentiles (0-90%)
- → Alternative definition based on ZDC+ZEM (0-30%)

Centrality in p-Pb collisions (1)



Missing correlation between N_{part} and impact parameter (b) in p–Pb collisions

Missing correlation between N_{part} and multiplicity in p–Pb collisions

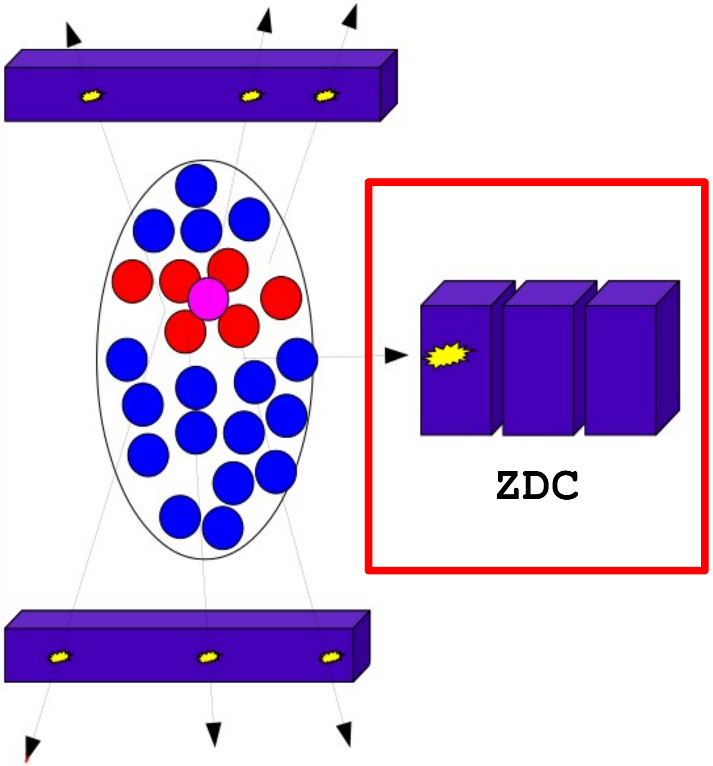
→ Bias when using estimators based on multiplicity (VZERO-A amplitude)

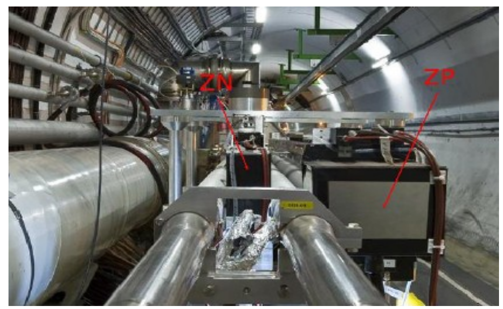
→ The range of multiplicities used to select the centrality in p-Pb collisions is of similar magnitude as the fluctuations

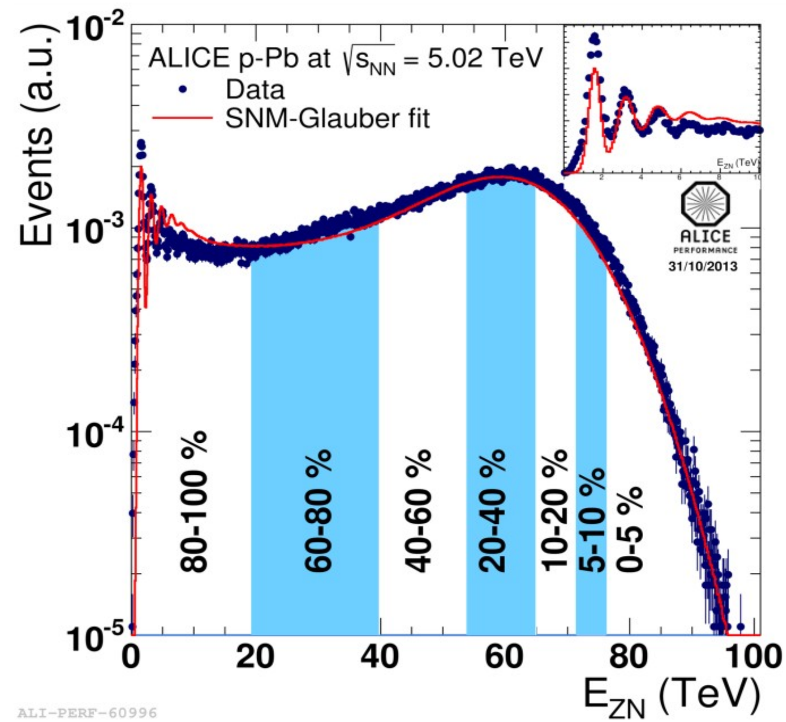
→ Centrality selection based on multiplicity may select a biased sample of nucleon-nucleon collisions

A.Toia's talk QM14

Centrality in p-Pb collisions (2)



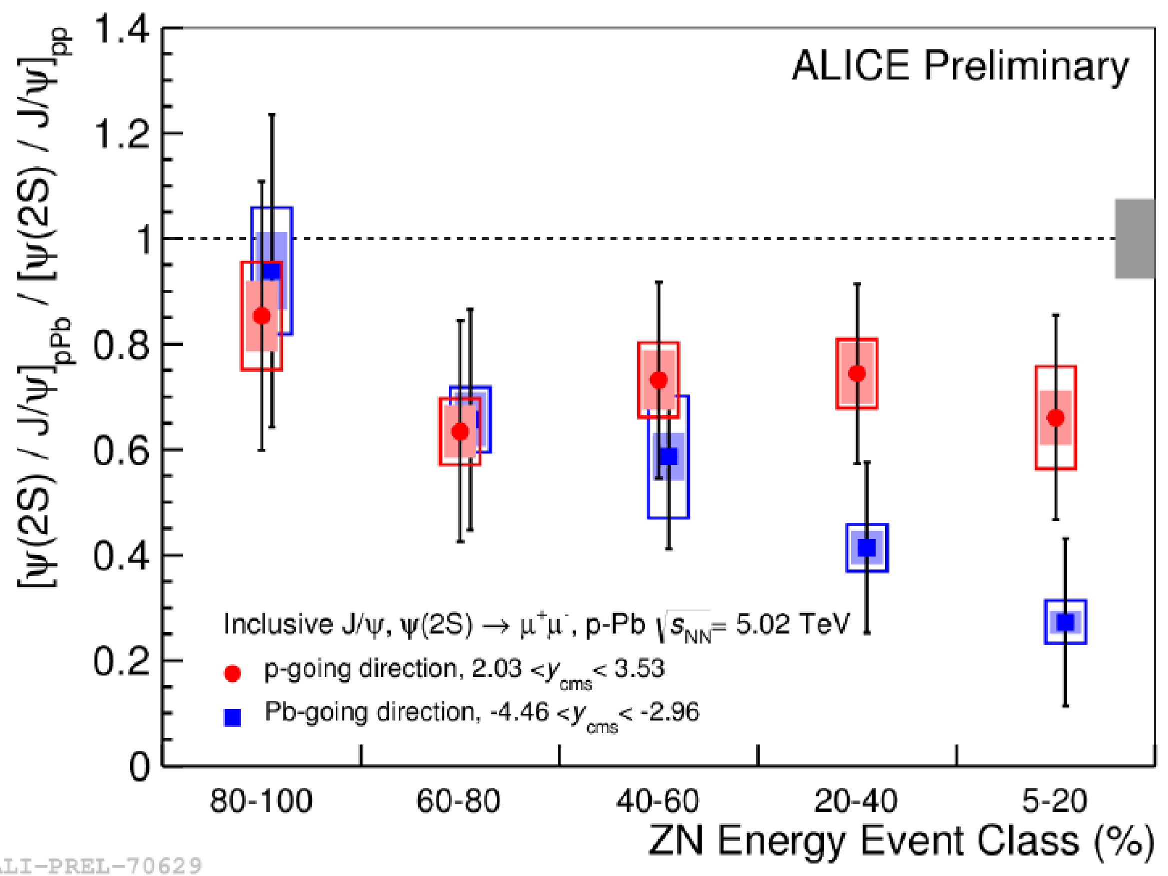




- Zero Degree Calorimeters detect slow nucleons, which are monotonically related to N_{coll} (and can be used as centrality estimator)
- "Black" nucleons: $\beta < 0.25$, "gray" nucleons: $0.25 < \beta < 0.7$
- ZDC provide centrality estimation ~without biases, because of the large η-separation fromt the central part of ALICE
- Glauber + Slow Nuclear Model for Zero-Degree Energy

A.Toia's talk
QM14

$\psi(2S)/J/\psi|_{pPb}/\psi(2S)/J/\psi|_{pp}$ vs event activity



- The $[\psi(2S)/J/\psi]_{pPb}/[\psi(2S)/J/\psi]_{pp}$ ratio has also been studied as a function of the event activity
- At backward rapidity the ψ(2S) is more suppressed than the J/ψ for large event activities
- Another hint that final state effects can affect the ψ(2S) production

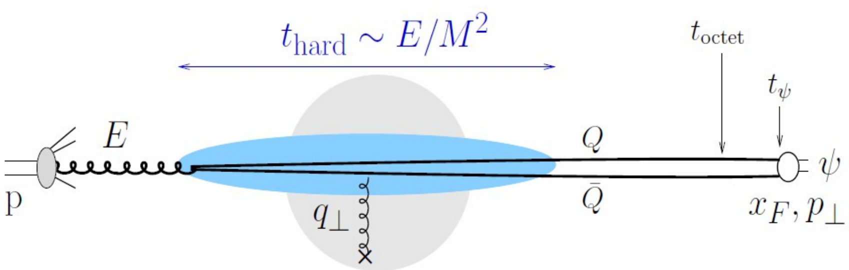
Shadowing (Int. J. Mod. Phys. E22 (2013) 1330007)

Results are obtained in the CEM at NLO in the total cross section. In the CEM, the quarkonium production cross section is a fraction F_C of all $Q\overline{Q}$ pairs below the $H\overline{H}$ threshold where H is the lowest mass heavy-flavor hadron:

$$\sigma_C^{\mathrm{CEM}}(s) = F_C \sum_{i,j} \int_{4m^2}^{4m_H^2} ds \int dx_1\, dx_2\; f_i^p(x_1, \mu_F^2)\; f_j^p(x_2, \mu_F^2)\; \hat{\sigma}_{ij}(\hat{s}, \mu_F^2, \mu_R^2)$$

- $ij = q\overline{q}$ or gg
- $\hat{\sigma}_{ij}(\hat{s})$ is the $ij \to Q\overline{Q}$ subprocess cross section
- F_C is fit to the forward J/ψ cross section data on only p , Be, Li, C, and Si targets

Energy loss (JHEP 1303 (2013) 122)



The heavy quark $Q\bar{Q}$ pair of mass M is produced in a color octect state within the time $\tau_{Q\bar{Q}} \sim 1/M$ and remain color octet for a time $\tau_{octect} >> \tau_{Q\bar{Q}}$

The $Q\bar{Q}$ pair arises from the splitting of an incoming gluon, followed by a rescattering in the nucleus

$$\omega \frac{\mathrm{d}I}{\mathrm{d}\omega} = \frac{N_c \alpha_s}{\pi} \left\{ \ln\left(1 + \frac{\ell_{\perp A}^2 E^2}{M_\perp^2 \omega^2}\right) - \ln\left(1 + \frac{\Lambda_{\rm p}^2 E^2}{M_\perp^2 \omega^2}\right) \right\} \Theta(\ell_{\perp A}^2 - \Lambda_{\rm p}^2)$$

→ $\Delta q_\perp^2 \equiv \ell_\perp^2 \simeq \hat{q}\, L$ momentum broadening through the nucleus A, $M_\perp = (M^2 + p_\perp^2)^{\frac{1}{2}}$ transverse mass of the $Q\bar{Q}$ pair and $\Lambda_{\rm p}^2 = \max(\Lambda_{\rm QCD}^2, \ell_{\perp \rm p}^2)$

→ Average energy loss: $\Delta E \propto E$.

→ Energy loss is coherent: neither a purely initial nor final state effect

→ $\hat{q}_0 = 0.075 \pm 0.005~\mathrm{GeV}^2/\mathrm{fm}$: transport coefficient, is the only parameter, extracted from E866 data

Interactions with comovers (arXiv:1411.0549)

The rate equation that governs the density of charmonium at a given transverse coordinate *s*, impact parameter *b* and rapidity *y* obeys the expression:

$$\tau \frac{\mathrm{d}\rho^{\psi}}{\mathrm{d}\tau}(b,s,y) = -\sigma^{co-\psi}\, \rho^{co}(b,s,y)\, \rho^{\psi}(b,s,y)$$

$\sigma^{co-\psi}$ is the cross section of charmonium dissociation due to interactions with the comoving medium of transverse density $\rho^{co}(b,s,y)$

$$S_{\psi}^{co}(b,s,y) = \exp\left\{-\sigma^{co-\psi}\, \rho^{co}(b,s,y) \ln\left[\frac{\rho^{co}(b,s,y)}{\rho_{pp}(y)}\right]\right\}$$

$S_{\psi}^{co}(b,s,y)$ is the survival probability of the resonance interacting with comovers (the interaction stops when the densities have diluted, reaching the value of the p+p density at the same energy)

$$\rho^{co}(b,s,y) = n(b,s)\, S_{co}^{sh}(b,s)\, \frac{3}{2}(dN_{ch}^{pp}/dy)$$

- → $n(b,s)$ number of binary nucleon-nucleon collisions per unit transverse area at given impact parameter
- → S_{co}^{sh} shadowing of the parton distribution functions in a nucleus that affects the comover multiplicity
- → 3/2 factor to account for neutral comovers
- → $\rho_{pp}(y) = \frac{3}{2}(dN_{ch}^{pp}/dy)/\pi R_p^2$ (comover density in pp) R_p is the proton radius

τ_c (PRC 87, 054910,2013)

Average time the $c\bar{c}$ pair spends in the nucleus for several experiments and targets

Experiment	$\sqrt{s_{NN}}$ (GeV)	A	y_{beam}	y_{cm}	L (fm)	$\langle p_T \rangle$ GeV/c	τ (fm/c)
PHENIX	200	Au	5.36	-2.08-2.32	4.36	1.90	0.283 - 0.0035
HERA-B	41.6	W	7.58	0.0	4.26	1.36	0.178
E866	38.8	W	7.44	-0.39-2.1	4.26	1.32	0.283 - 0.024
NA50	29.1	W	6.87	0.0	4.26	1.22	0.258
NA50	27.4	Pb	6.75	0.0	4.44	1.20	0.286
NA3	19.4	Pt	6.06	0.0	4.34	1.14	0.396
NA60	17.3	Pb	5.82	0.3	4.44	1.12	0.339

Drell-Yan normalization

NA50 Collaboration
Eur. Phys. J. C 49 (2007)

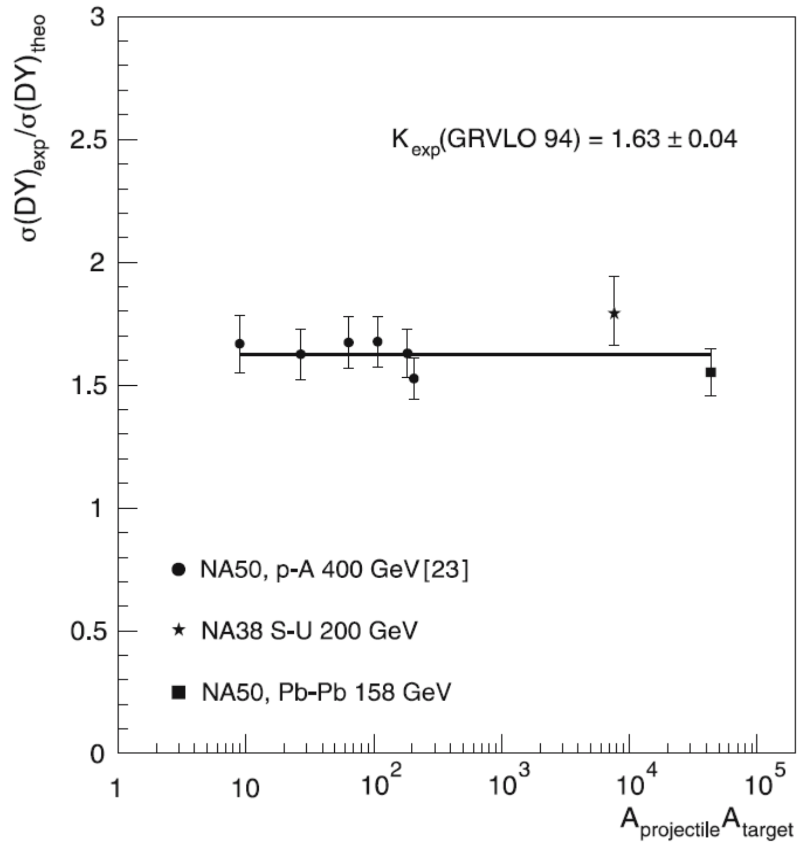


Fig. 2. The Drell–Yan K_{exp} factor measured at 158–400 GeV/c beam momenta in p–A and A–B collisions. GRV LO94 PDFs are used in the theoretical calculations and in the extraction of the measured values

"K_{exp} factor" = ratio between the measured Drell-Yan cross-section and the lowest order theoretical Drell-Yan cross-section. The constant behaviour of this ratio from p-Be to Pb-Pb collisions shows that the Drell-Yan process is proportional to the number of nucleon-nucleon collisions in the NA38/NA50 phase space window.