Charmonium production as a function of charged-particle multiplicity with the ALICE experiment at the LHC

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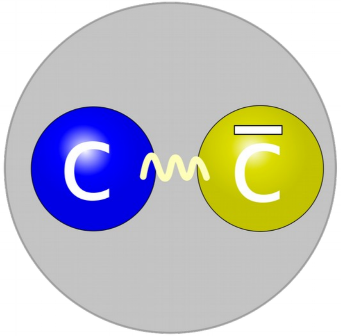
What is charmonia ?

A bound state of charm and anti-charm quarks

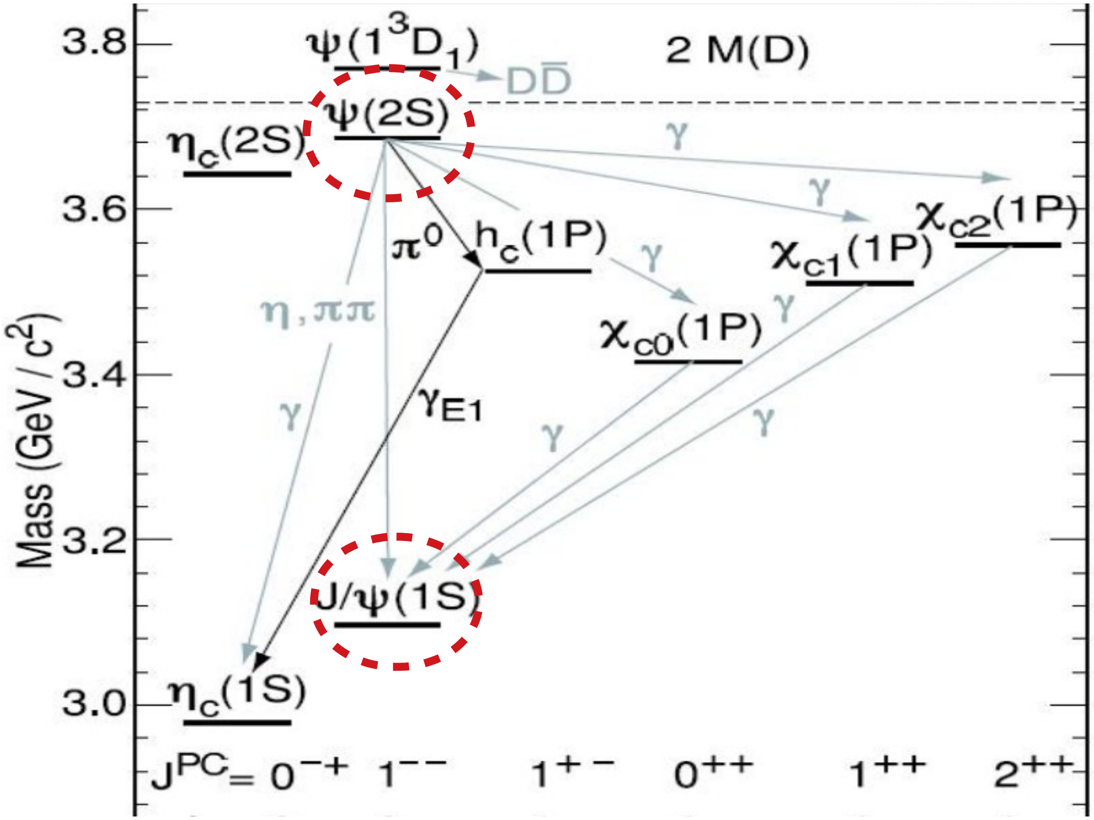
c-quarks has a very high mass ~ 1.5 GeV.
→ created during hard QCD process.

While the bound state is only few MeV
→ The bound state is formed during soft QCD process.



Charmonia are an interesting tools to study the correlation between perturbative and non perturbative QCD processes.

Charmonia

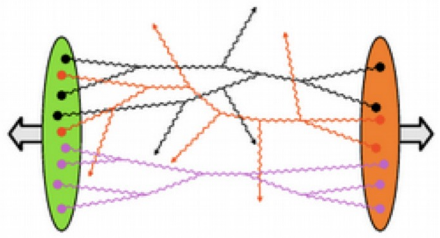


3.8
3.6
3.4
3.2
3.0
Mass (GeV / c²)
ψ(1³D₁)
DD̄
2 M(D)
ψ(2S)
η_c(2S)
γ
γ
π⁰
h_c(1P)
χ_c2(1P)
χ_c1(1P)
γ
γ
η, ππ
χ_c0(1P)
γ
γ_E1
γ
γ
γ
J/ψ(1S)
η_c(1S)
J^PC = 0⁻⁺ 1⁻⁻ 1⁺⁻ 0⁺⁺ 1⁺⁺ 2⁺⁺

Why as a function of charged-particle multiplicity ?

To study multiparton interactions (MPI)

Multiparton interactions: Several parton-parton interactions in a single hadron-hadron collision.



understanding MPIs could give an explanation for some of unexpected behaviors observed in pp and p-Pb collisions :

Elliptic flow of charged particles: long-range angular correlation.
JHEP 10.1007/09(2010).

Enhanced production of strange hadrons similar to Pb-Pb collisions.
Nature Phys 13, 535–539 (2017).

Where to look for MPIs

- **Double Charmonia production** (ideal tool)
  - Direct probe for MPIs.
  - Information about single charmonia production.

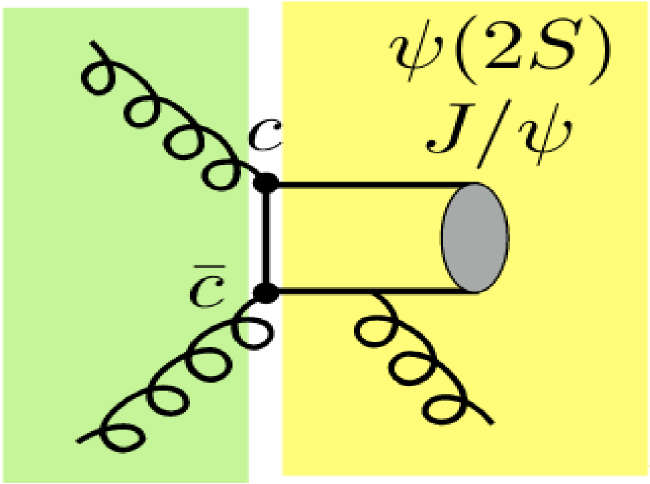
  Needs a lot of statistics to perform differential cross section.

- **Charmonia production vs charged-particle multiplicity**
  - Indirect probe for MPIs.
  - Provide information for the soft and hard QCD process.

Charmonium production as a function of charged-particle multiplicity with the ALICE experiment.

In p-Pb collisions

The effect of the nuclear environment on charmonia production ?



©b. Diab

Initial state effects

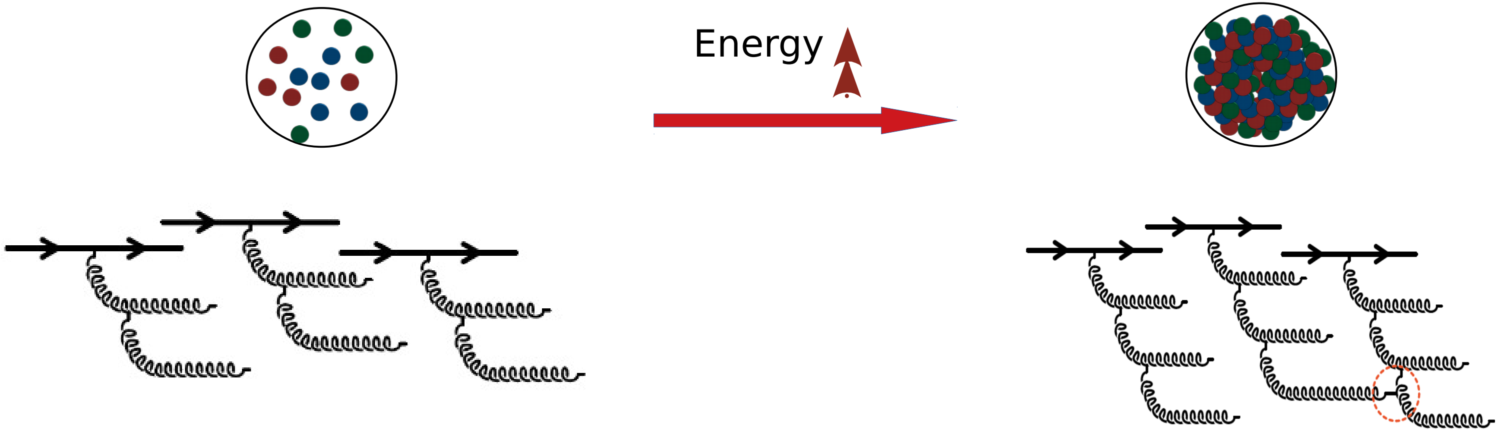
Initial-final state effects.

Final state effects

Effects of the nuclear environment

Initial-state effects

Due to a very high density of quark and gluons in the initial colliding particles.



Increasing the energy of the partons started to overlap → several parton recombine into one parton reducing the number of effective partons == saturation.

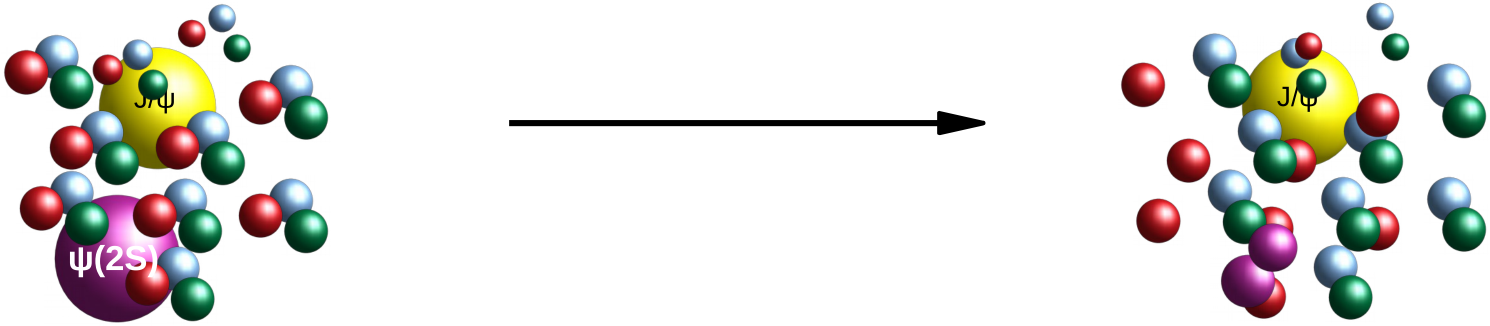
Percolation is one of theoretical models based on saturation

Effects of the nuclear environment

Final-state effects

Comovers model

Do we expect different effects for different particles?



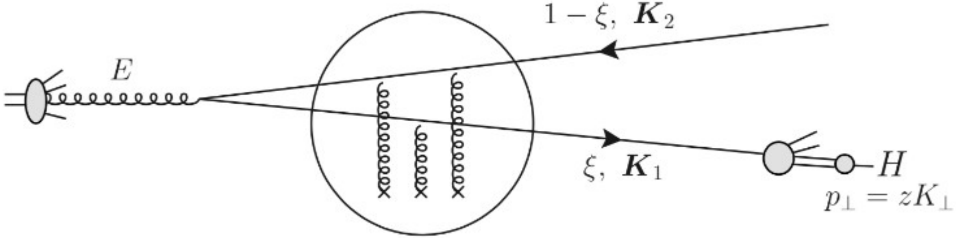
The effect of the interaction of the final state particles with the comoving-particles

Effects of the nuclear environment

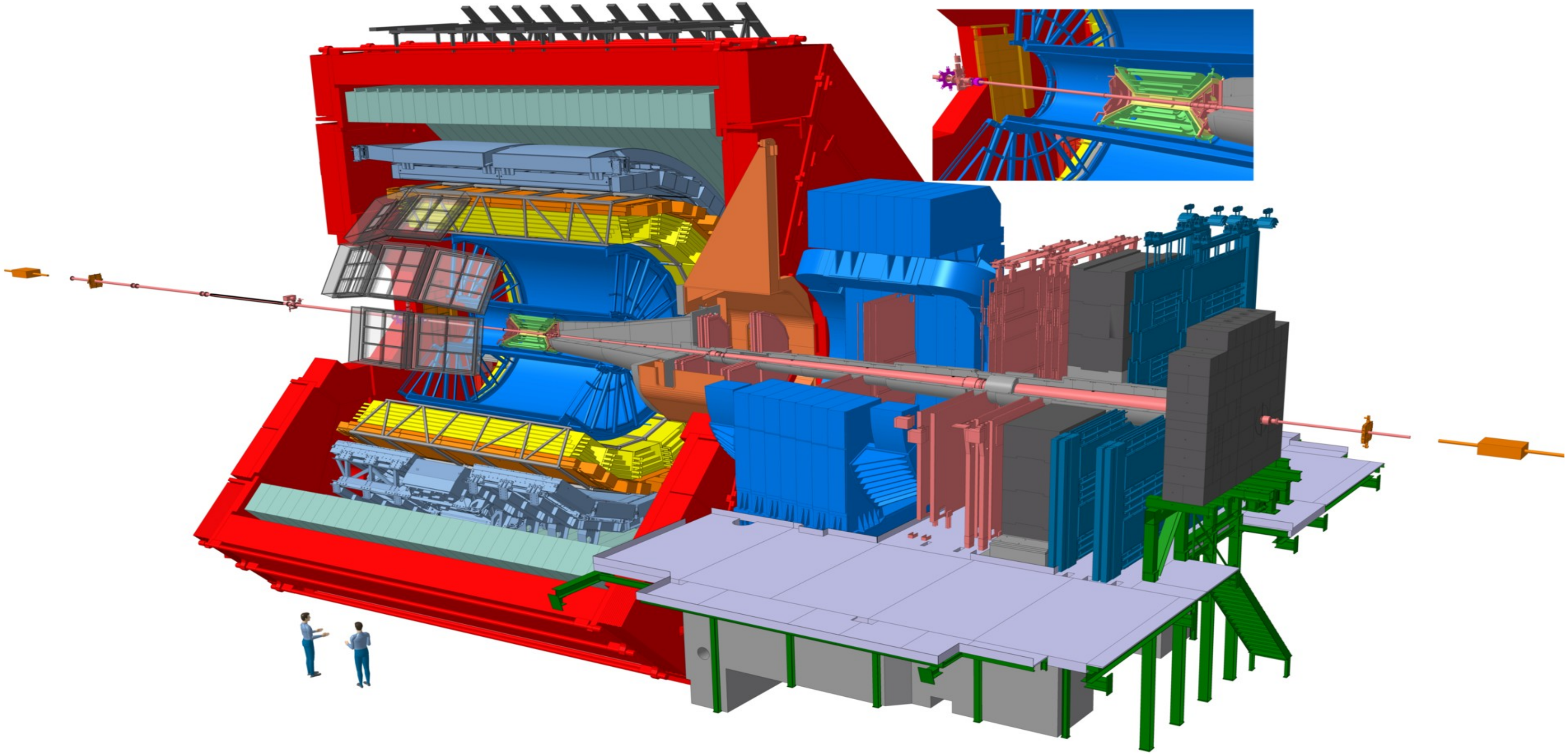
Intial-final state effects

Affecting both initial and final state particles

Fully coherent energy loss:by partons via gluon emission.



With ALICE Experiment



Muon Spectrometer

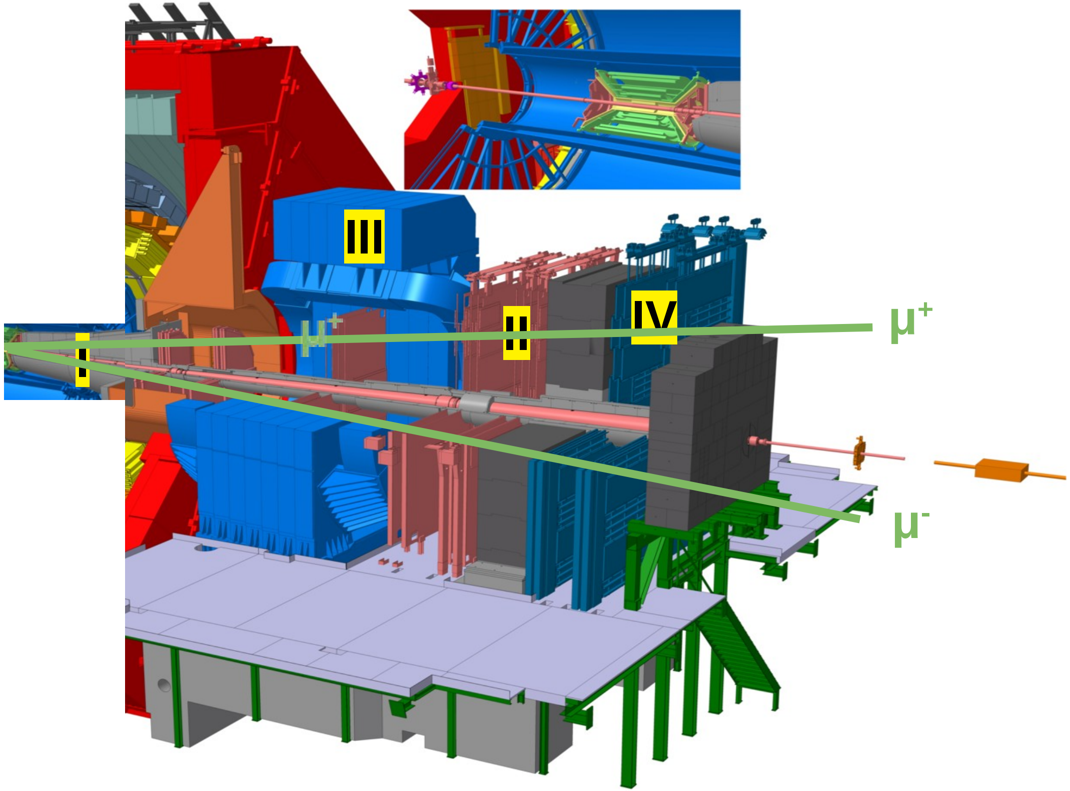
$J/\psi, \psi(2S) \rightarrow \mu^{-}\mu^{+}$
$2.5 < y_{lab} < 4.0$

I. Front absorber.

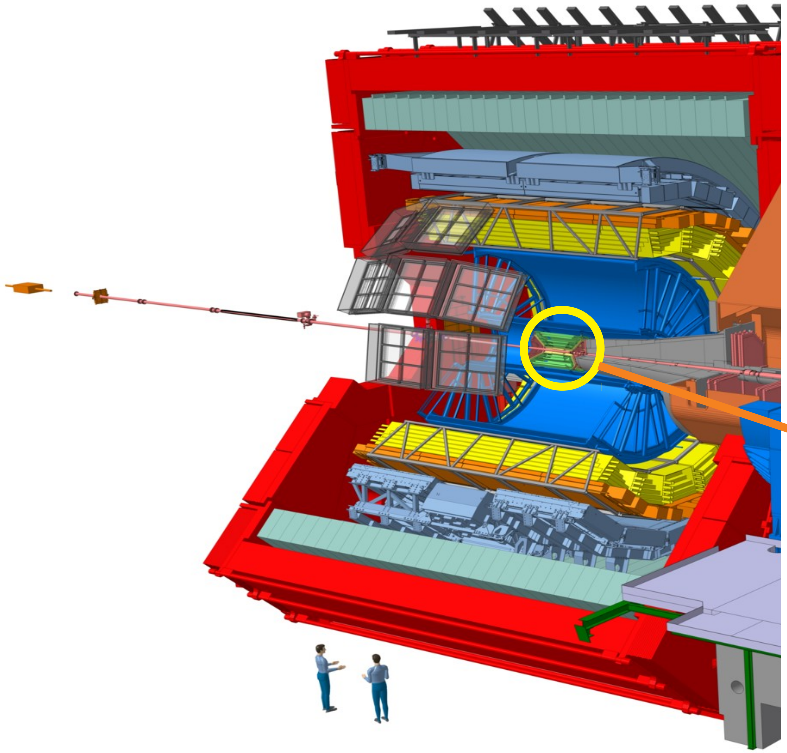
II. Muon tracking chambers.

III. Dipole magnet 3T.m.

IV. Muon trigger chambers.

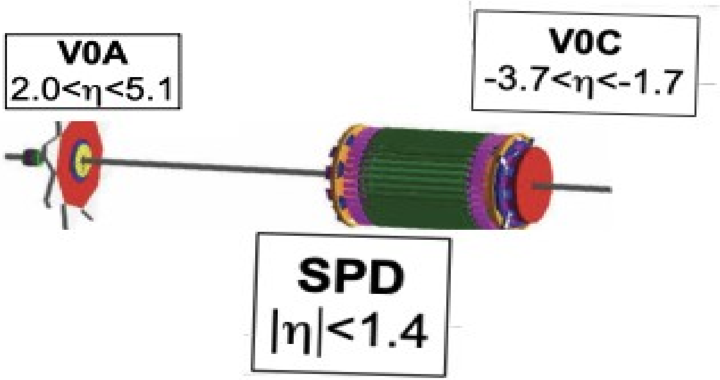


Central barrel



Measure charged-particle multipicity

- V0 scintillators.
- Silicon pixel detector (SPD)

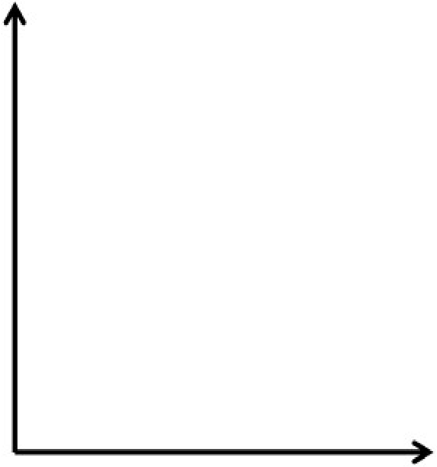


Charmonium production vs charged-particle multiplicity

The observable

Relative charmonium production yield as a function of relative charged-particle multiplicity.

$$\frac{\mathrm{d}N_Q/\mathrm{d}y}{<\mathrm{d}N_Q/\mathrm{d}y>}$$



$$\frac{\mathrm{d}N_{ch}/\mathrm{d}\eta}{<\mathrm{d}N_{ch}/\mathrm{d}\eta>}$$

Why self-normalised quantities ?

- Various corrections canceled in the ratio.
- Easier to compare various energies and collision systems.

Charmonium production vs charged-particle multiplicity

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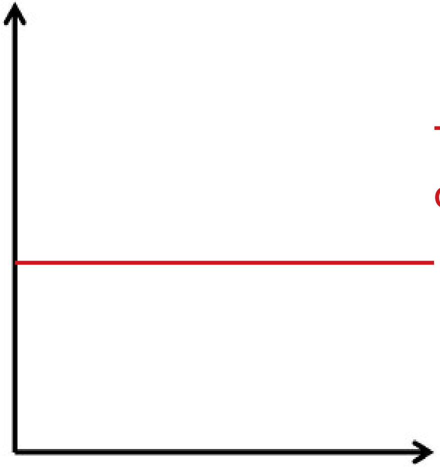
$$\frac{\mathrm{d}N_Q/\mathrm{d}y}{< \mathrm{d}N_Q/\mathrm{d}y >}$$



The production is independent of underlying events

$$\frac{\mathrm{d}N_{ch}/\mathrm{d}\eta}{< \mathrm{d}N_{ch}/\mathrm{d}\eta >}$$

Charmonium production vs charged-particle multiplicity

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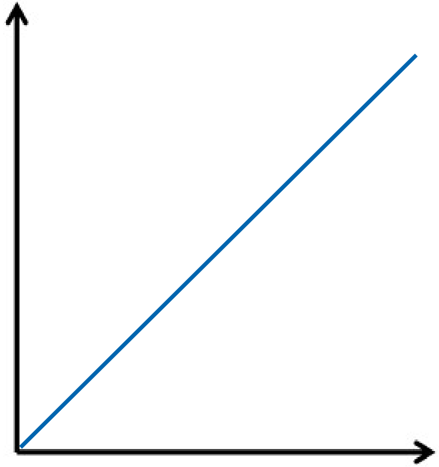


$$\frac{\mathrm{d}N_{ch}/\mathrm{d}\eta}{<\mathrm{d}N_{ch}/\mathrm{d}\eta>}$$

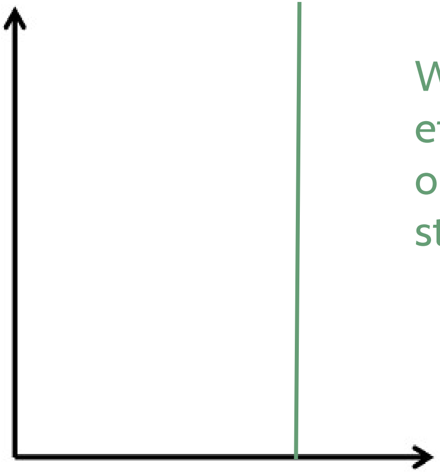
The charmonium production scales with the multiplicity.

Charmonium production vs charged-particle multiplicity

The observable

Relative charmonium production yield as a function of relative charged-particle multiplicity.

$$\frac{\mathrm{d}N_Q/\mathrm{d}y}{<\mathrm{d}N_Q/\mathrm{d}y>}$$

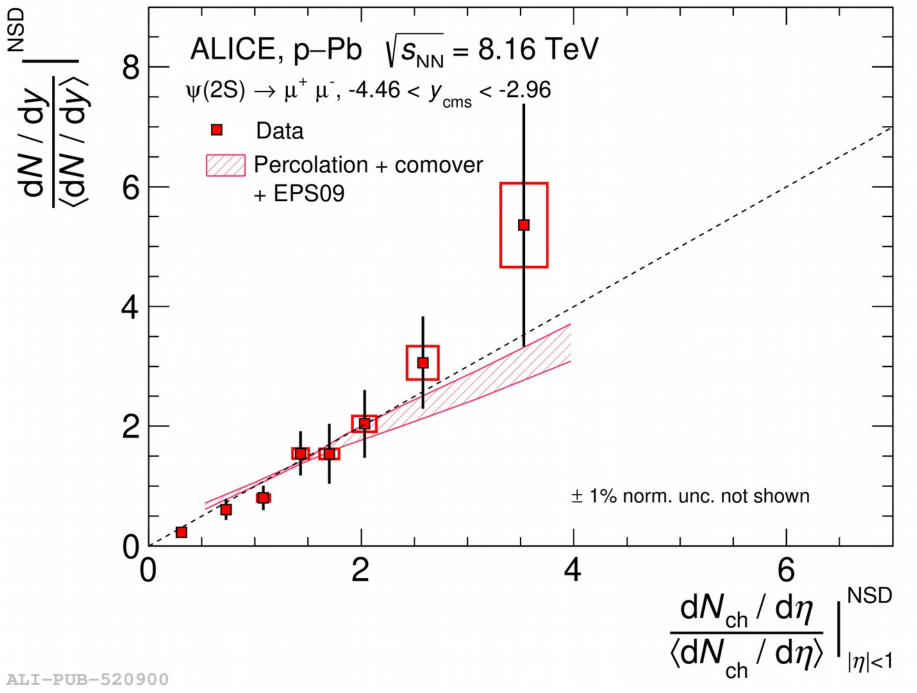


When reach high multiplicity several effects start to play a role, e.g, saturation or comovers dissociation of excited states

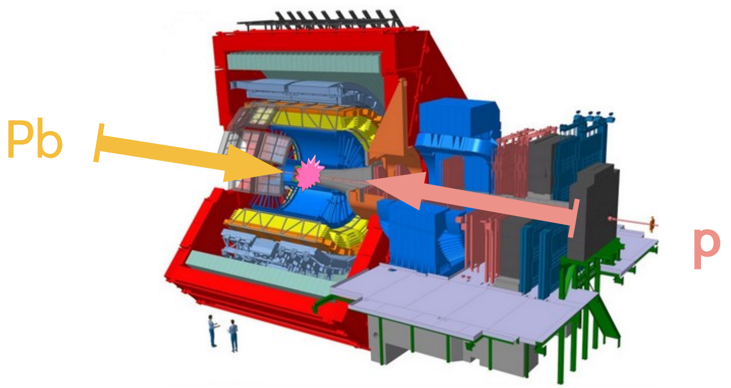
$$\frac{\mathrm{d}N_{ch}/\mathrm{d}\eta}{<\mathrm{d}N_{ch}/\mathrm{d}\eta>}$$

ψ(2S) production vs multiplicity

arXiv:2204.10253



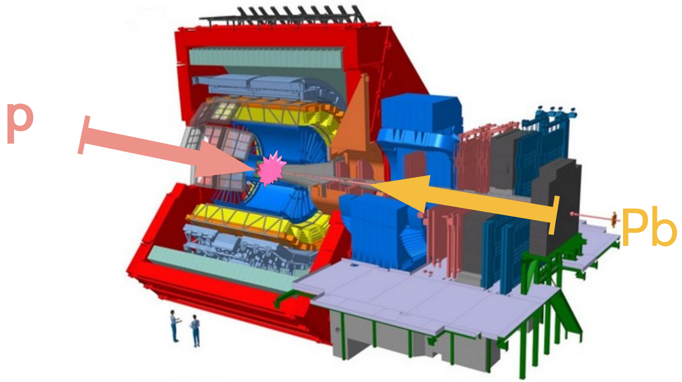
Muon reconstructed at backward rapidity.
Pb-going direction.
$-4.46 < y_{cms} < -2.96$

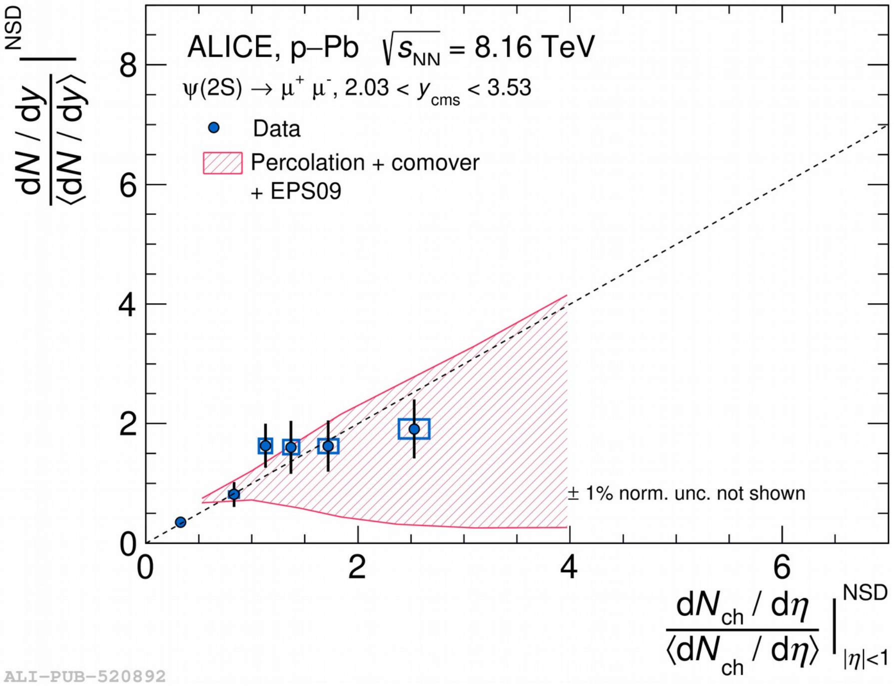


- The ψ(2S) yield increases with increasing $dN_{ch}/d\eta$ in p–Pb collisions.
- The model includes nPDFs and the final state effect in its calculation.

ψ(2S) production vs multiplicity

Muon reconstructed at forward rapidity.
p-going direction.
$2.03 < y_{cms} < 3.53$

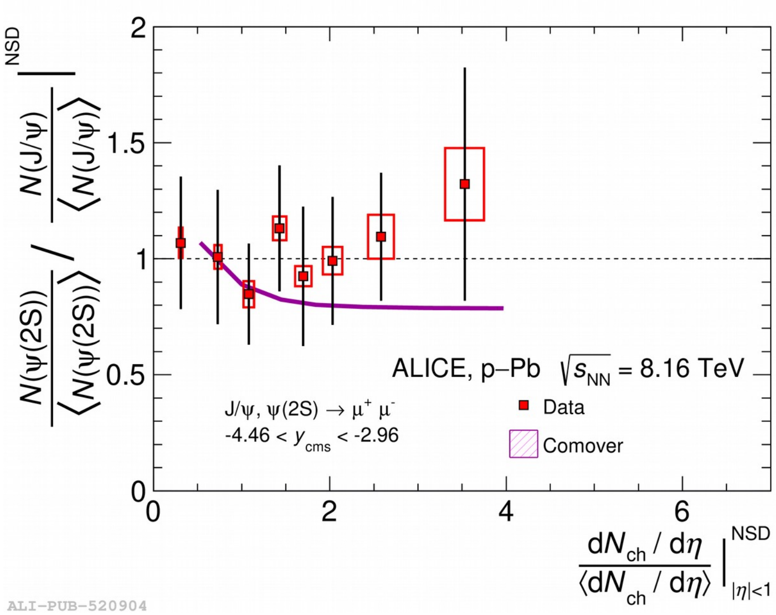


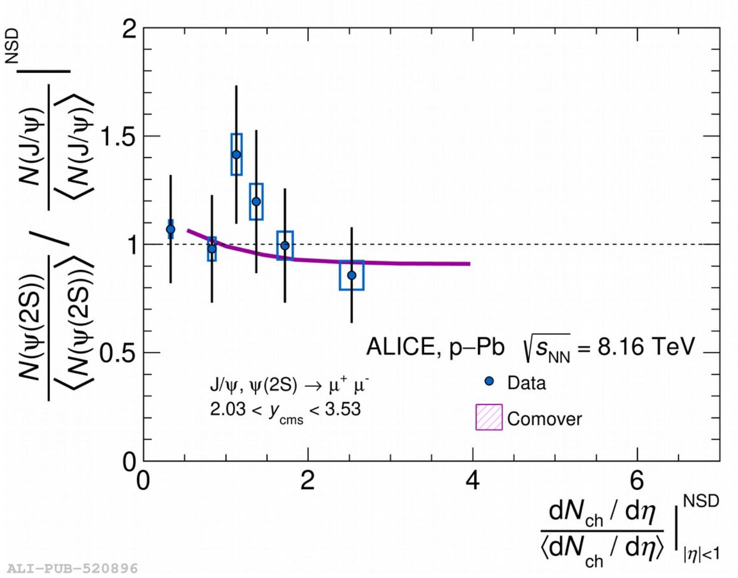


- The ψ(2S) yield increases with increasing $dN_{ch}/d\eta$ in p–Pb collisions.
- The model includes nPDFs and the final state effect in its calculation.

Multiplicity dependence of ψ(2S)-over-J/ψ

arXiv:2204.10253





- Similar behavior of J/ψ and ψ(2S) vs multiplicity in p-Pb.
- Similar trend of the ψ(2S)-to-J/ψ ratio vs multiplicity in both rapidity regions.
- The comovers calculation describes the data within statistical and systematic uncertainties.

Conclusion

- ψ(2S) production as a function of charged-particle multiplicity in p-Pb collisions.
  - Yield increase with increasing multiplicity at both forward and backward rapidity regions.
  - The trend is described by models include intial and final state effects in the calculations.

Outlook

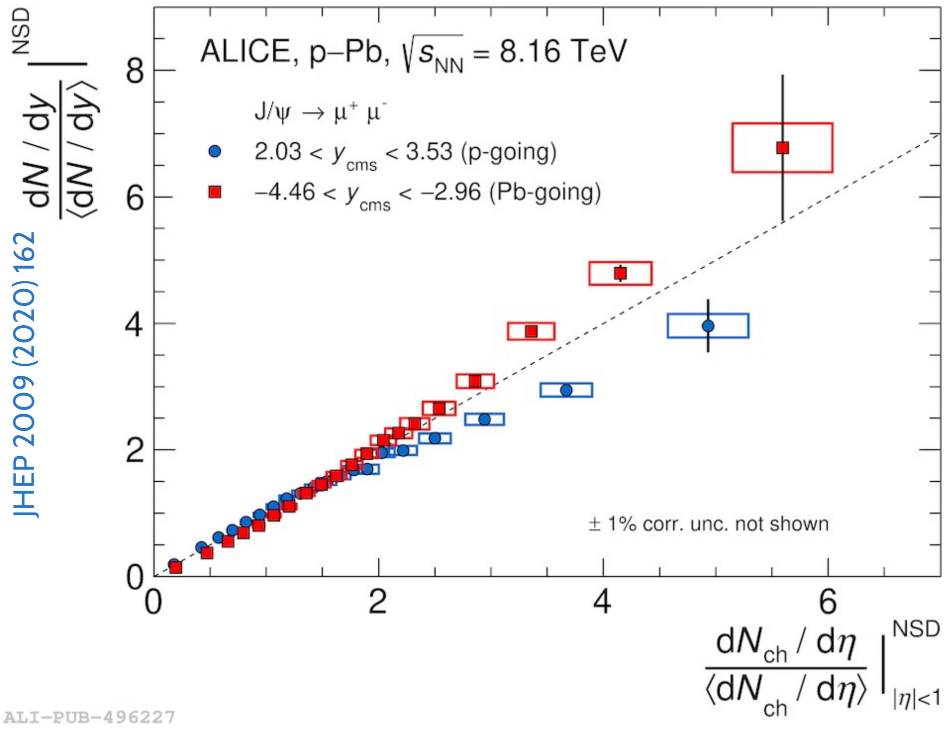
- HL-LHC run will start next week after 1.5 year delay:
  - This will provide a higher statistics to do more precise measurements.
  - Testing the MPI scenario by looking into associated particle production e.g: double J/ψ production.

Thank you
:D

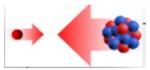
Multiplicity dependence of J/ψ production

measured at forward-backward rapidity

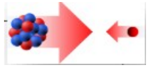
JHEP 2009 (2020) 162



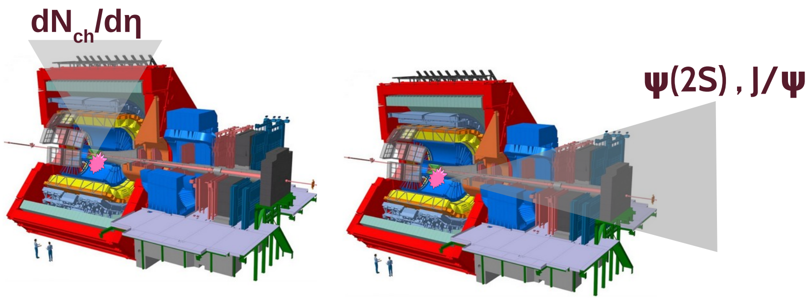
- J/ψ yields increase with $dN_{ch} / d\eta$ in both rapidity regions.
- Faster (Slower) than linear increase observed at backward (forward) rapidity.
- The different behavior likely due to different Bjorken-*x* regions probed.



p-Pb (p-going direction)



Pb-p (Pb-going direction)



T.TORK

Nuclear PDFs