

# High mass dilepton measurements with ALICE at the LHC

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on behalf of the ALICE Collaboration

GDR QCD  
25/11/2021

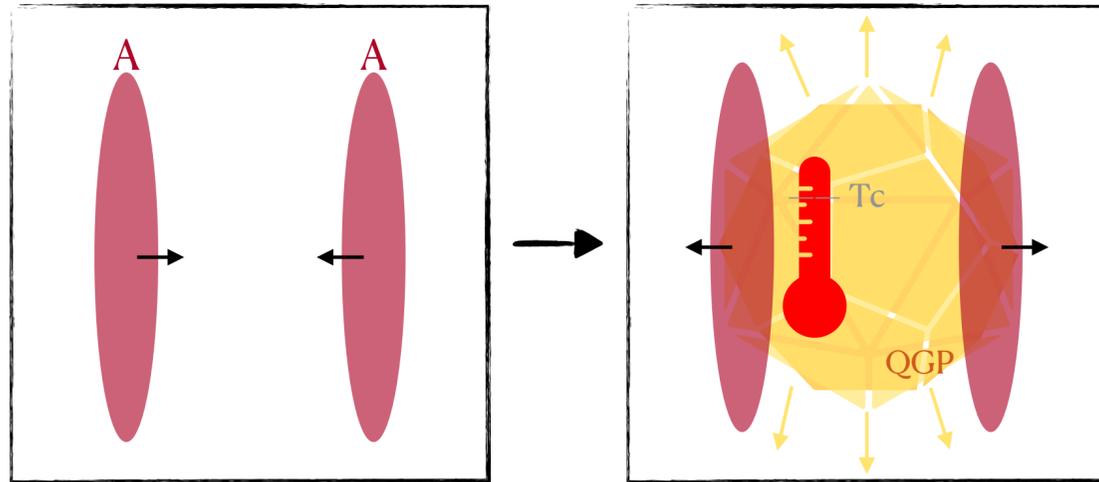
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**ALICE**

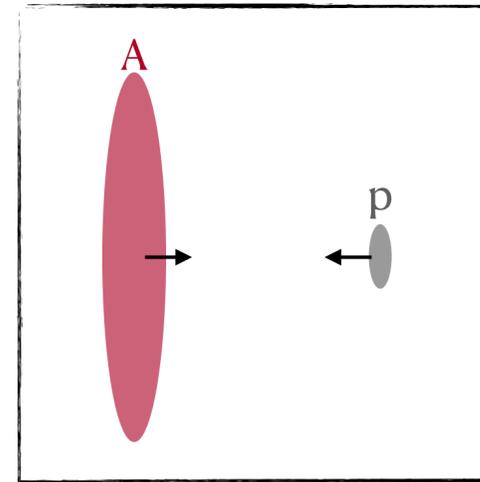


# Study of Quark Gluon Plasma



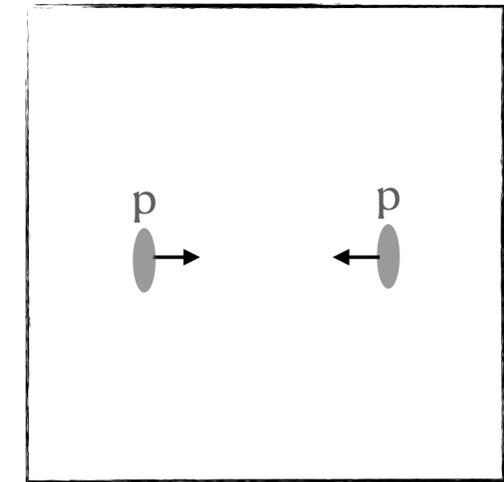
## Study of QGP properties:

- ❖ Thermalization
- ❖ Hydrodynamic expansion
- ❖ Transport coefficient
- ❖ Hadronization
- ...



## Cold Nuclear Matter Effects:

- ❖ nPDFs modifications
- ❖ Energy loss
- ❖ Possible final state effects
- ...



## QCD study in vacuum:

- ❖ Test of pQCD calculations
- ❖ Hadronization models
- ...



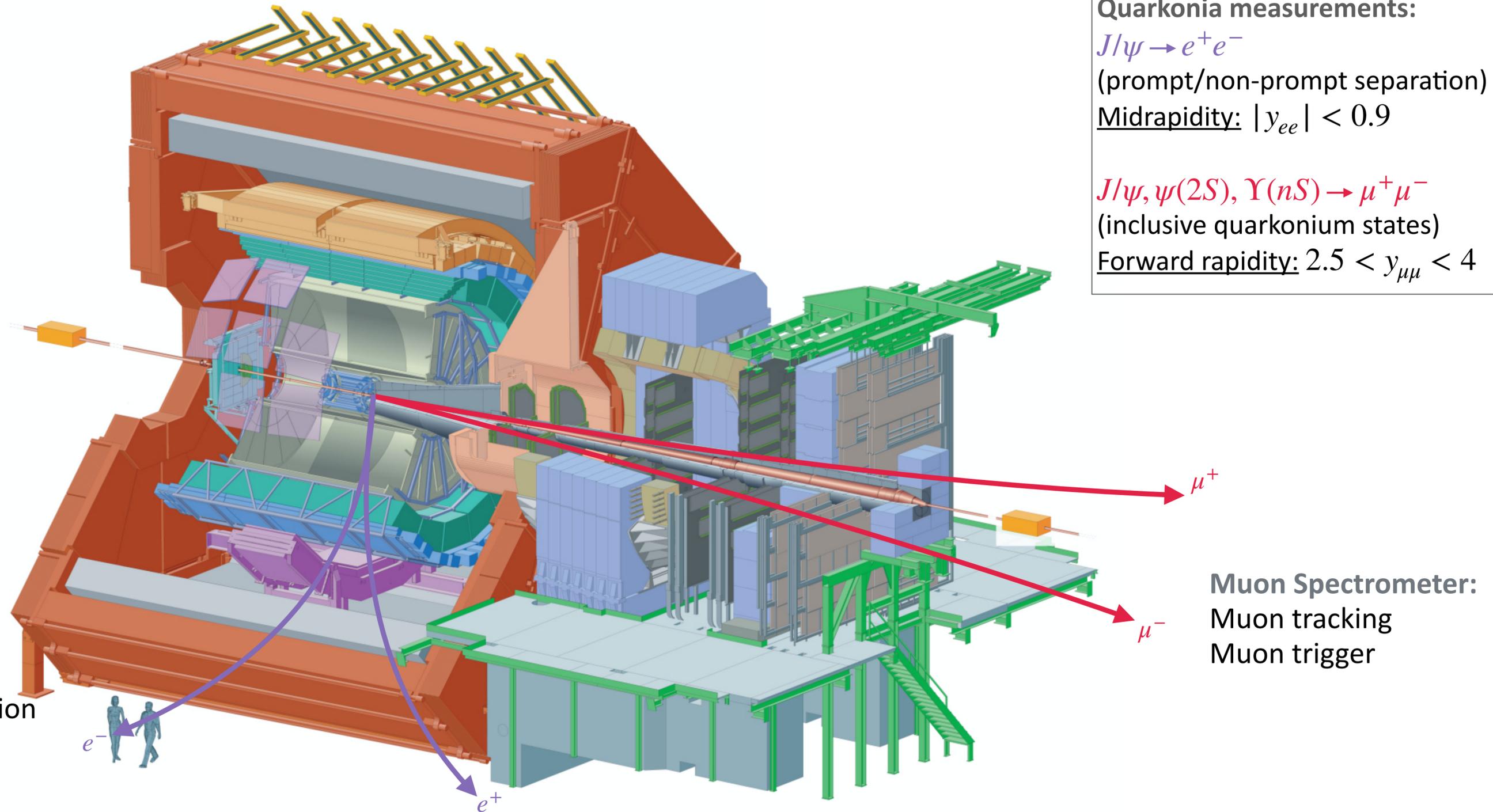
# A Large Ion Collider Experiment

**Time Projection Chamber:**  
Charged particle tracking  
Particle identification

**Inner Tracking System:**  
Particle tracking  
Vertex reconstruction

**V0:**  
Trigger detector  
Event characterization

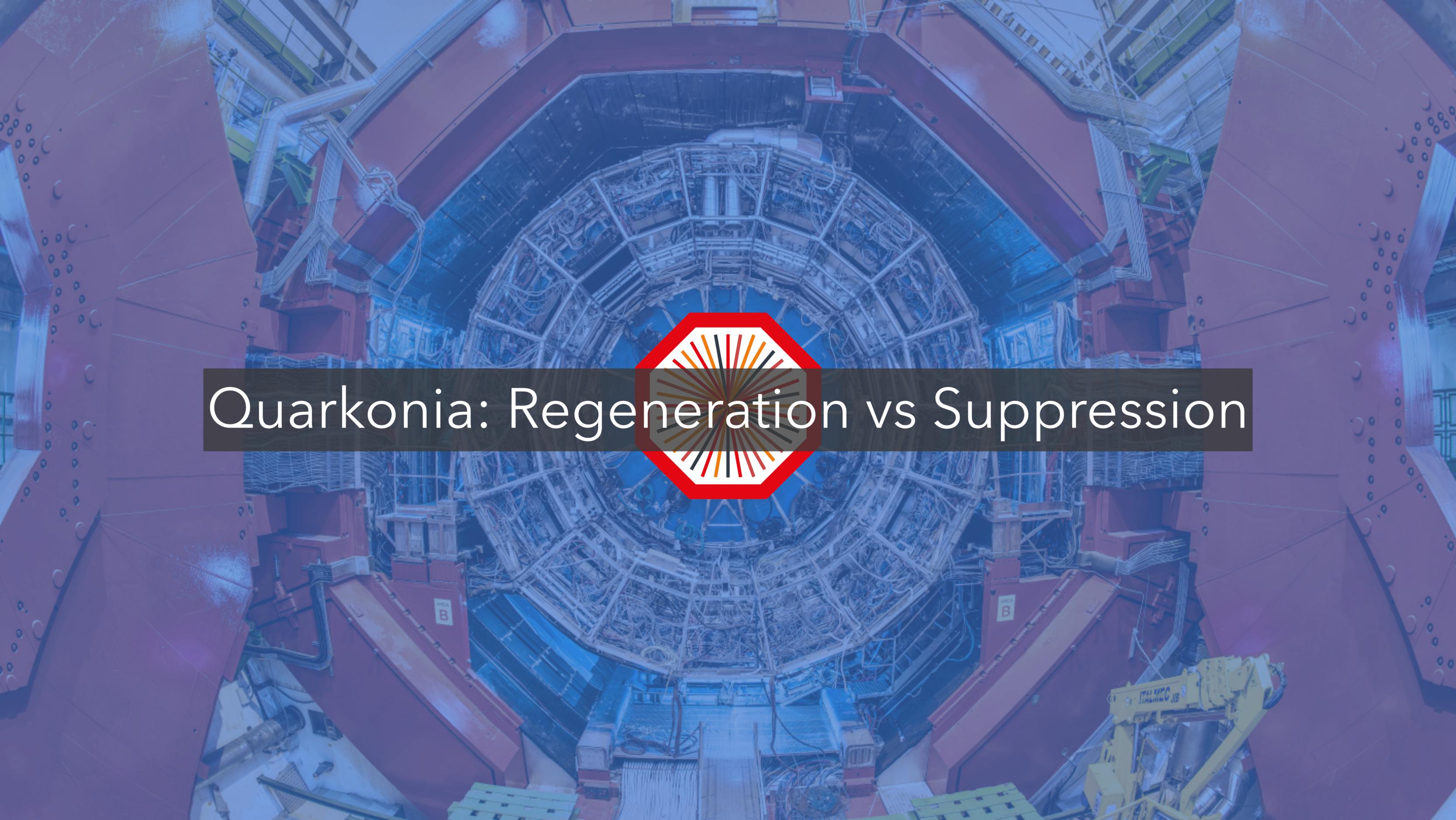
**Time Of Flight:**  
Charged particle identification



**Quarkonia measurements:**  
 $J/\psi \rightarrow e^+e^-$   
(prompt/non-prompt separation)  
Midrapidity:  $|y_{ee}| < 0.9$

$J/\psi, \psi(2S), \Upsilon(nS) \rightarrow \mu^+\mu^-$   
(inclusive quarkonium states)  
Forward rapidity:  $2.5 < y_{\mu\mu} < 4$

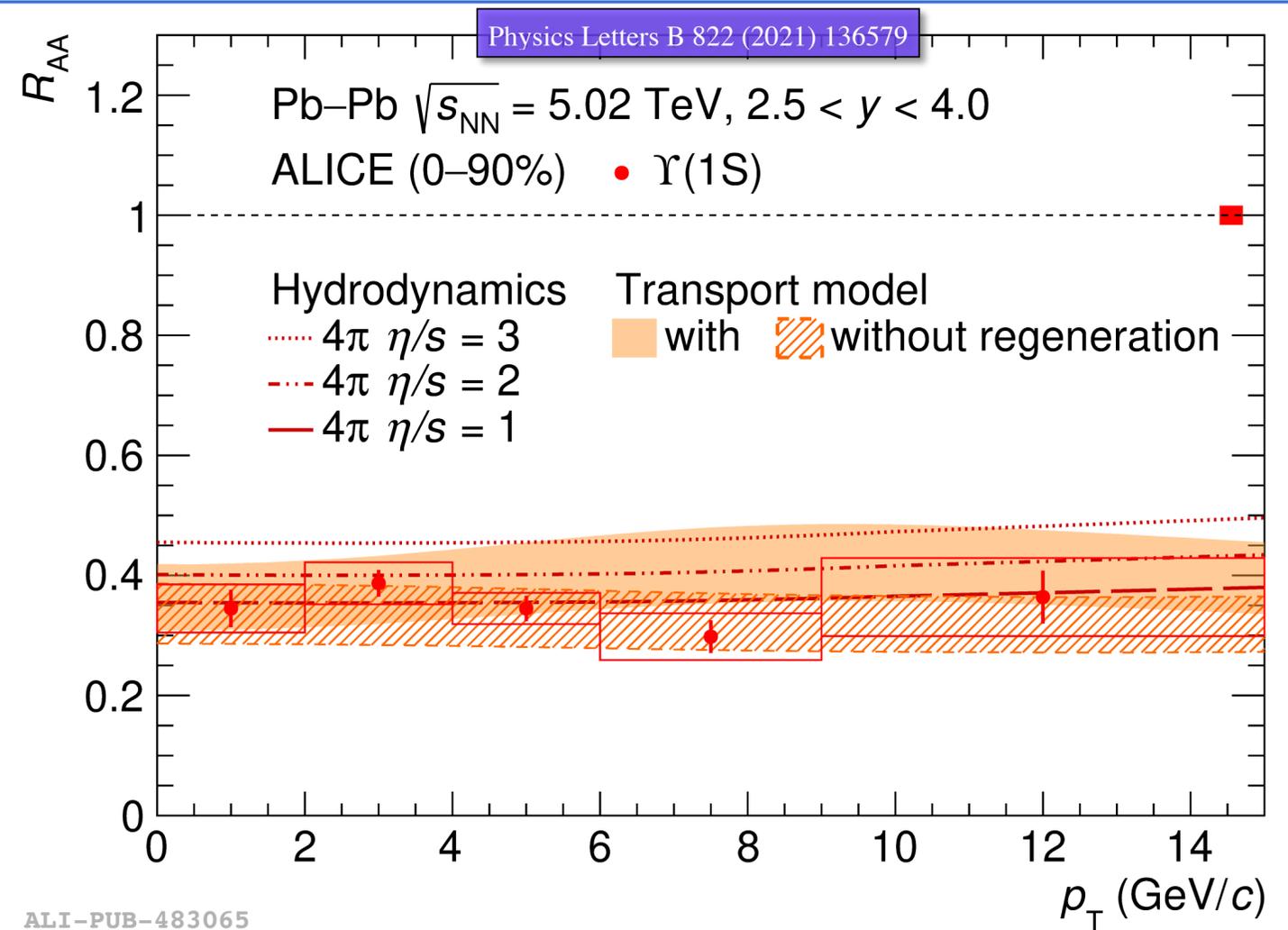
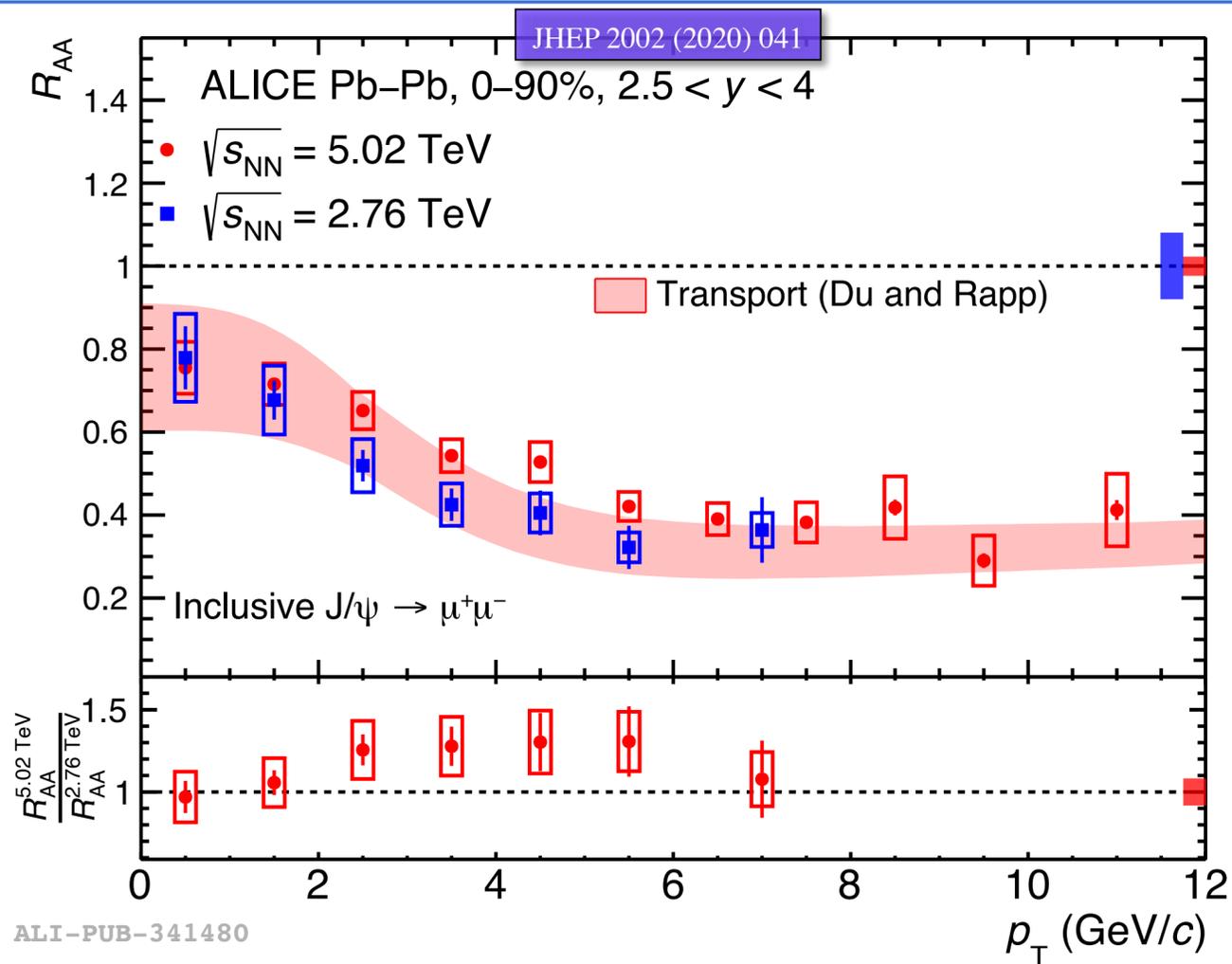
**Muon Spectrometer:**  
Muon tracking  
Muon trigger



# Quarkonia: Regeneration vs Suppression



# Quarkonia: Nuclear Modification Factor



The nuclear modification factor:

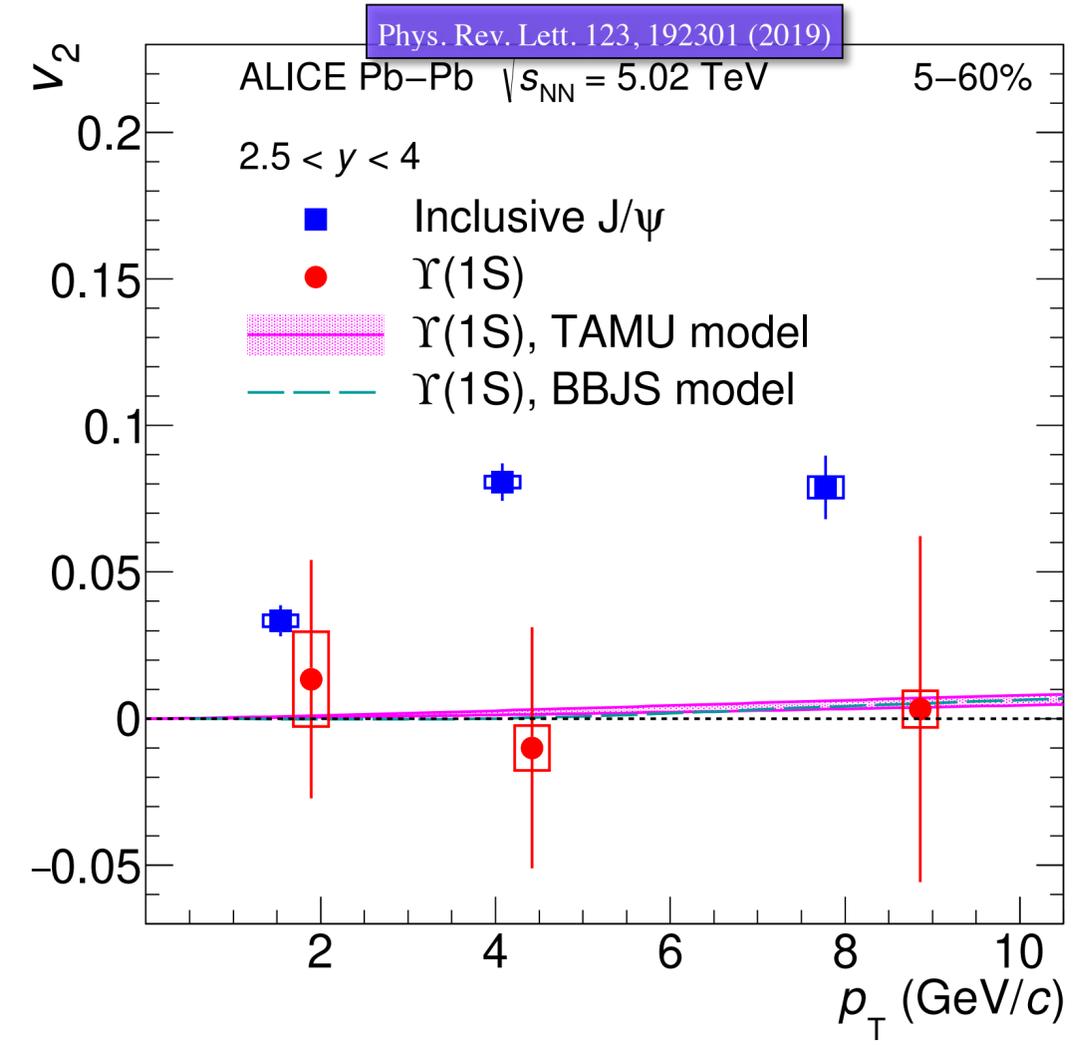
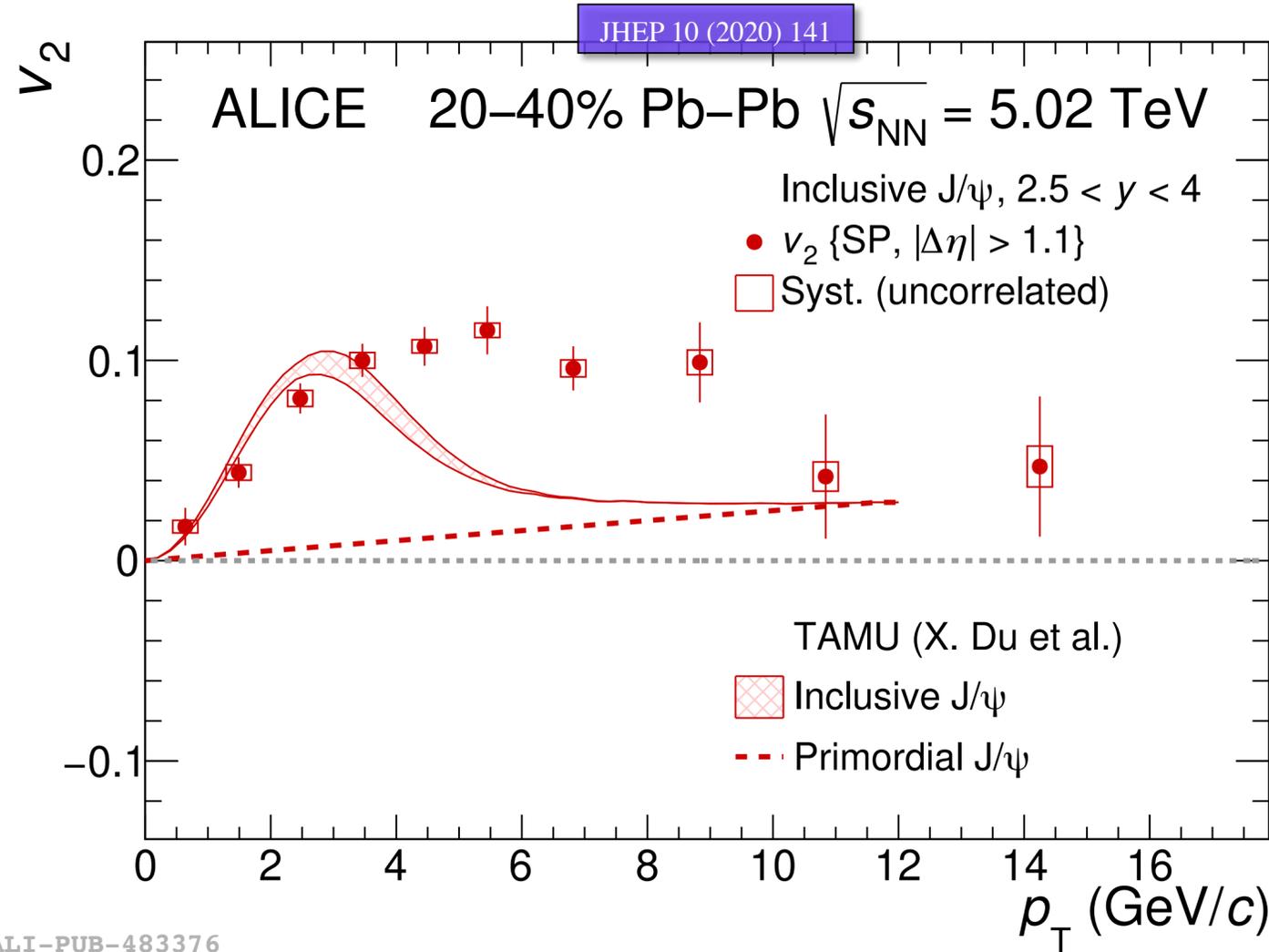
$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \cdot \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

❖  $R_{AA}$  measurements of  $J/\psi$  have been done with ALICE at mid and forward rapidity at 5.02 TeV and for the  $\Upsilon(1S)$  and  $\Upsilon(2S)$  at forward rapidity.

- ❖ High suppression due to color screening can be observed for both particles.
- ❖ Regeneration effects visible at low  $p_T$  for  $J/\psi$ . For  $\Upsilon(1S)$ , the effects are negligible (in this model with/without regeneration).



# Collectivity



The elliptic flow coefficient:

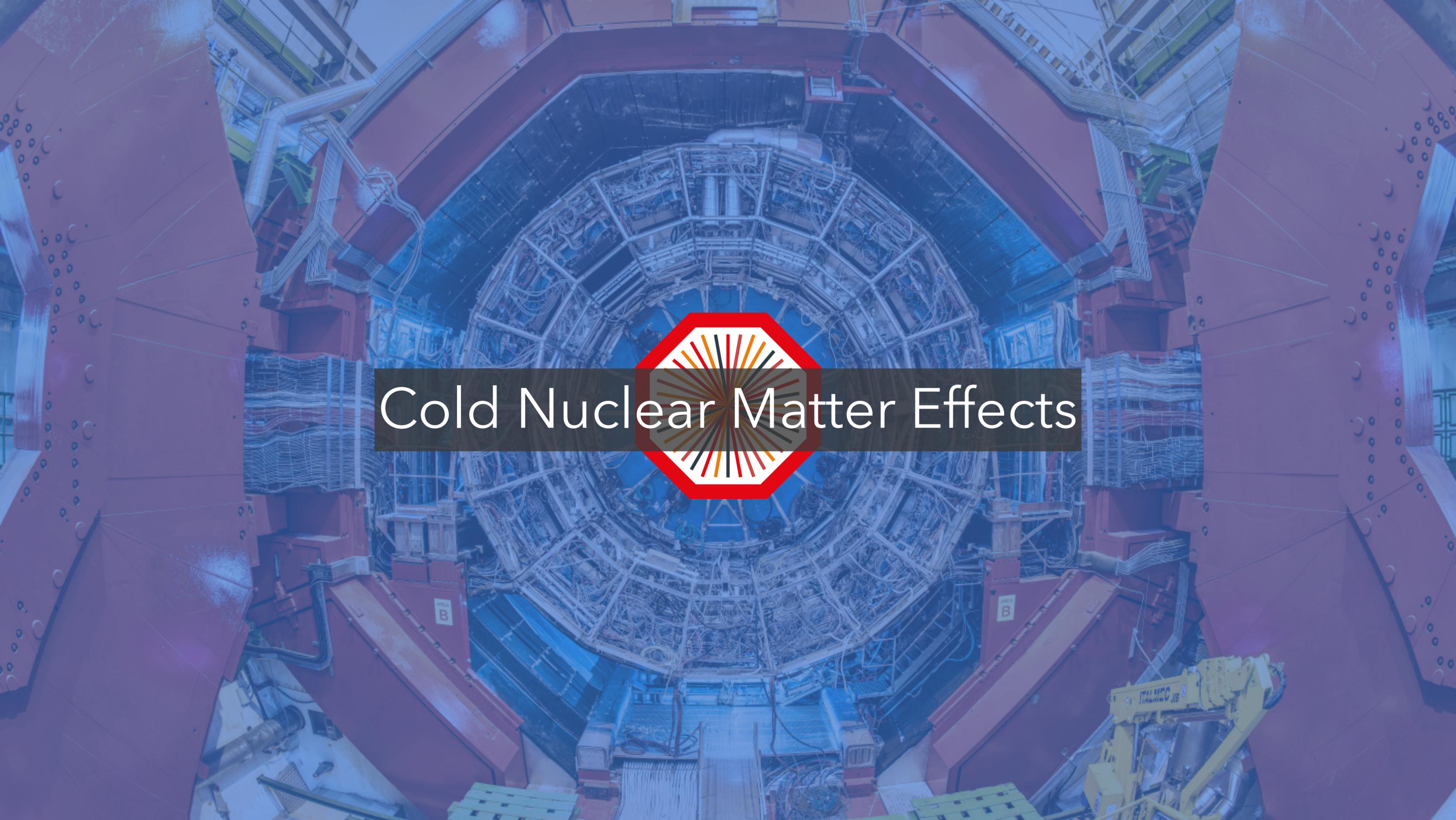
$$v_2(p_T, y) = \langle \cos(2(\varphi - \Psi_{RP})) \rangle$$

↘ angle w.r.t Reaction-Plane

❖ Elliptic flow has been studied for  $J/\psi$  with ALICE at central and forward rapidity of Pb-Pb collisions at 5.02 TeV and for  $\Upsilon(1S)$  at forward rapidity.

❖  $J/\psi$ : Elliptic flow increases at low  $p_T$  → direct effect from regeneration. A decrease is then observed for  $p_T$  → 6 GeV/c.

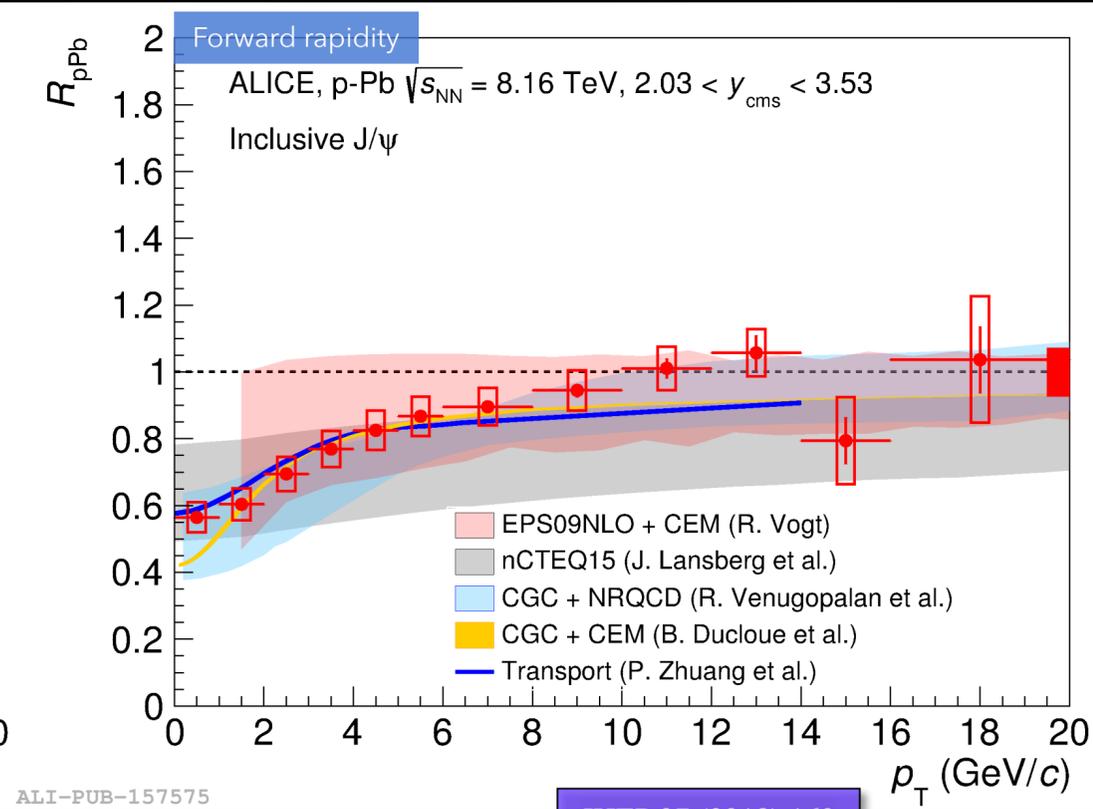
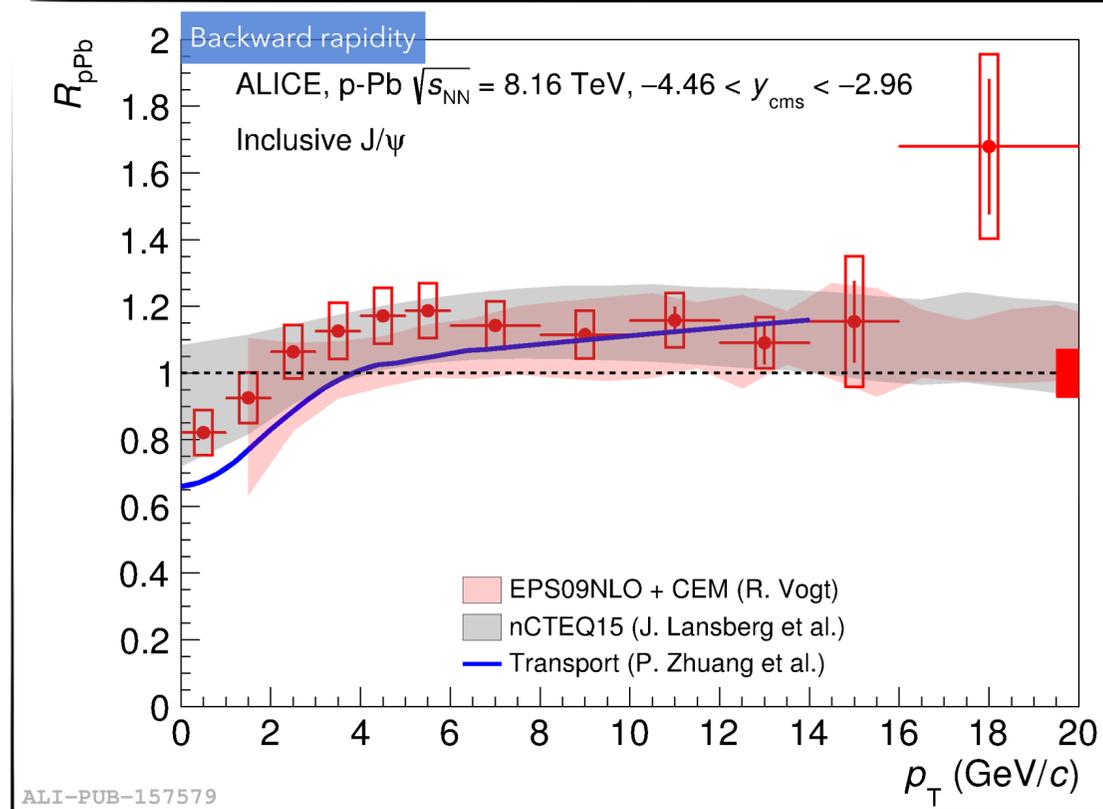
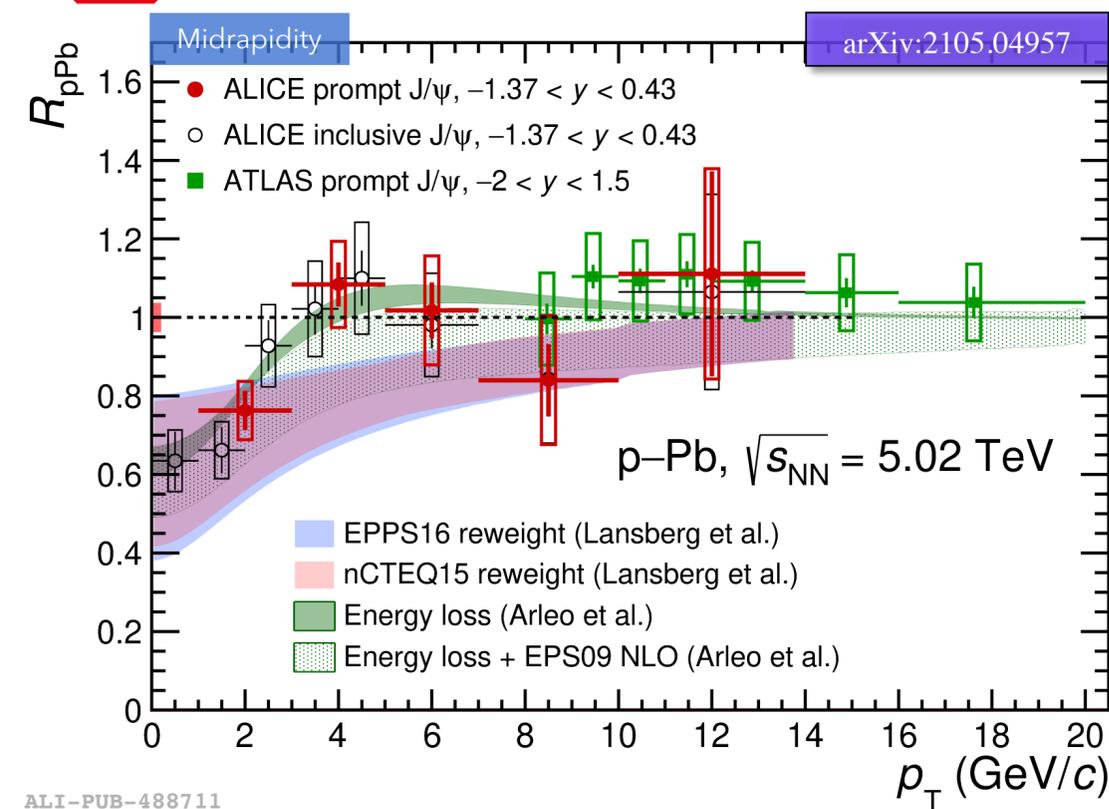
❖  $\Upsilon(1S)$ : As expected, results fluctuate around 0. (Models in agreement with data with/without regeneration).



# Cold Nuclear Matter Effects



# $J/\psi$ production in p-Pb collisions



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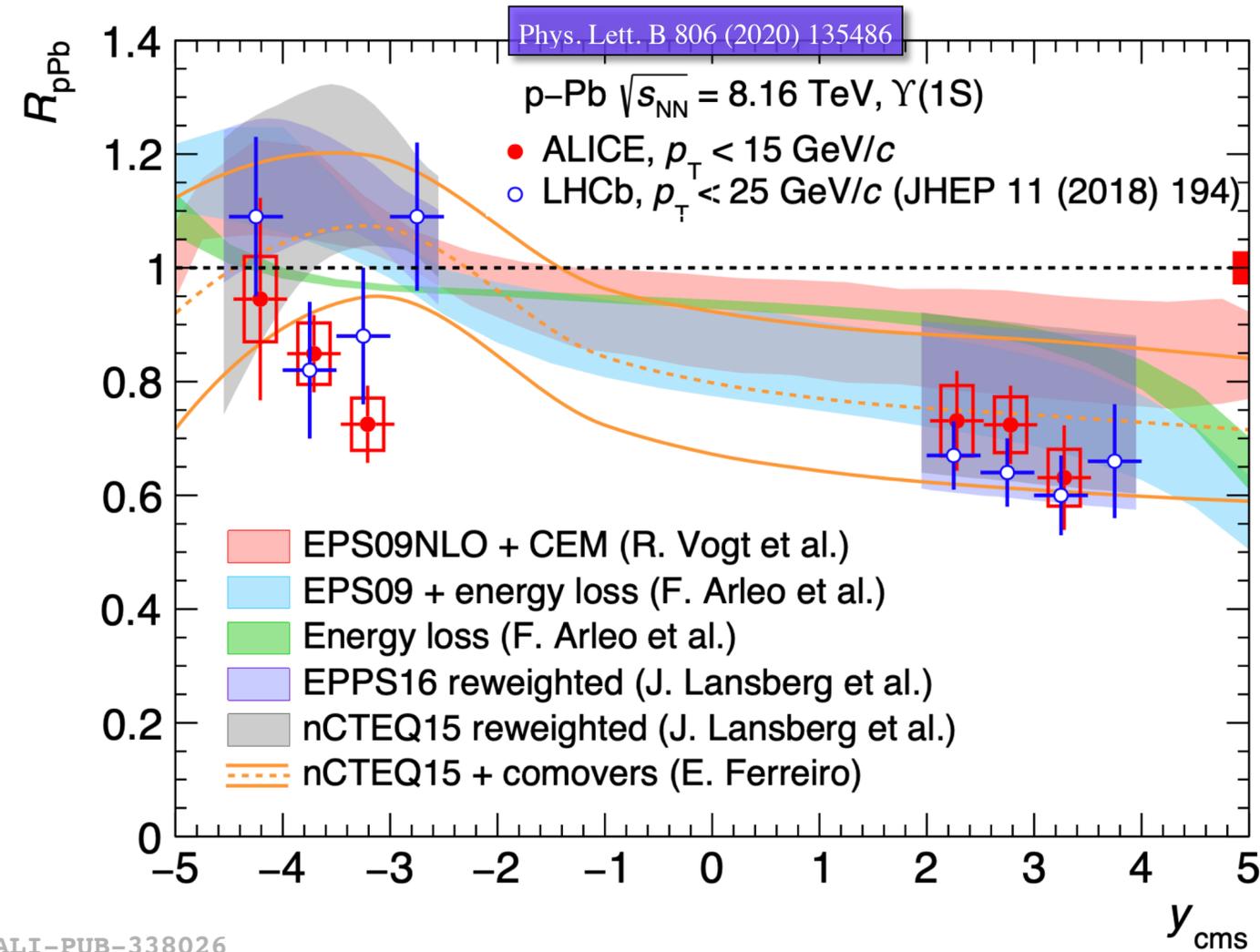
❖ The  $R_{pPb}$  for  $J/\psi$  and  $\psi(2S)$  in p-Pb collisions at 5.02 TeV and at 8.16 TeV measurements have been done with ALICE at central, forward and backward rapidity.

- ❖ Midrapidity: strong  $J/\psi$  suppression at low  $p_T$  observed.
- ❖ Backward+Forward: models in agreement with data, forward-y data more suppressed w.r.t backward-y data.
- ❖ Centrality dependance study: suppression of  $J/\psi$  at backward rapidity in peripheral collisions but enhancement in central collisions observed. Opposite trend at forward rapidity, where  $J/\psi$  suppression increases from peripheral to central collisions.

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# $\Upsilon(1S)$ production in p-Pb collisions

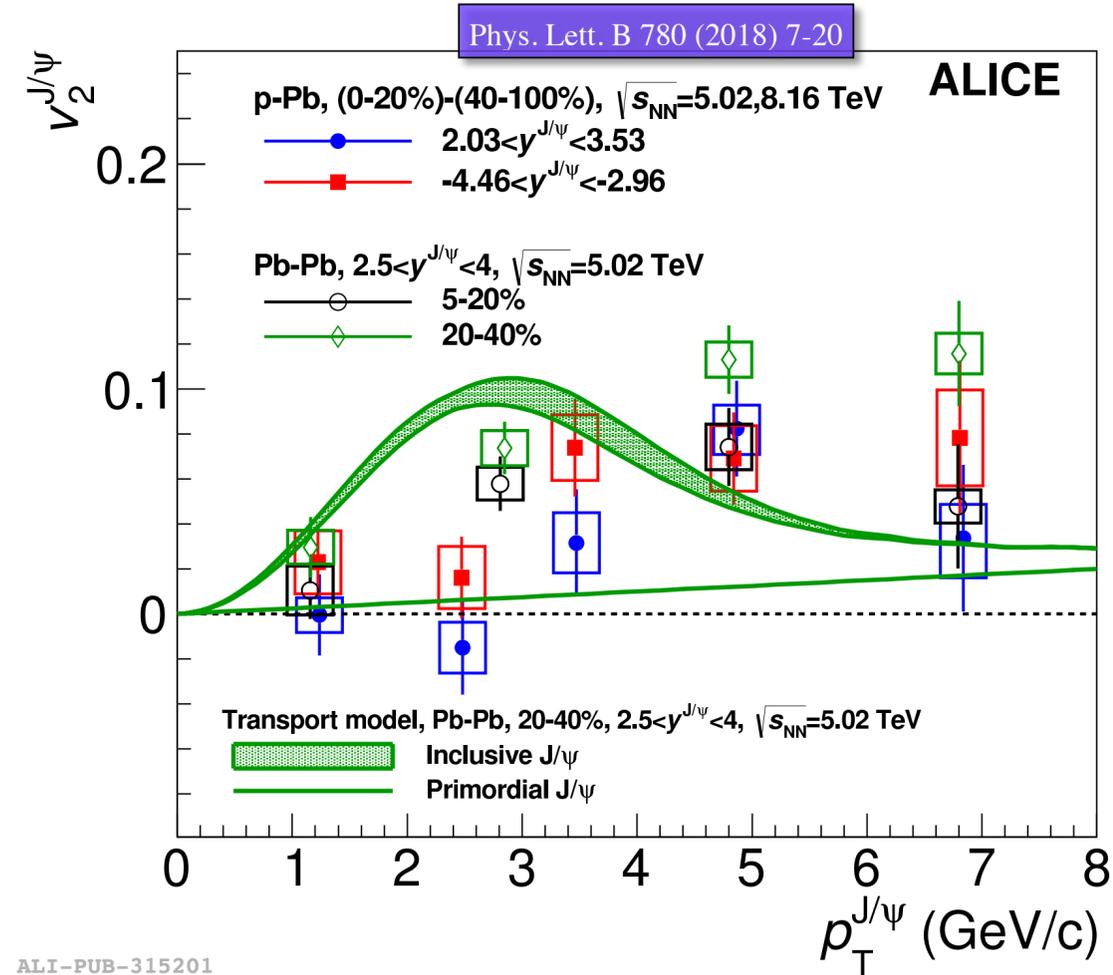
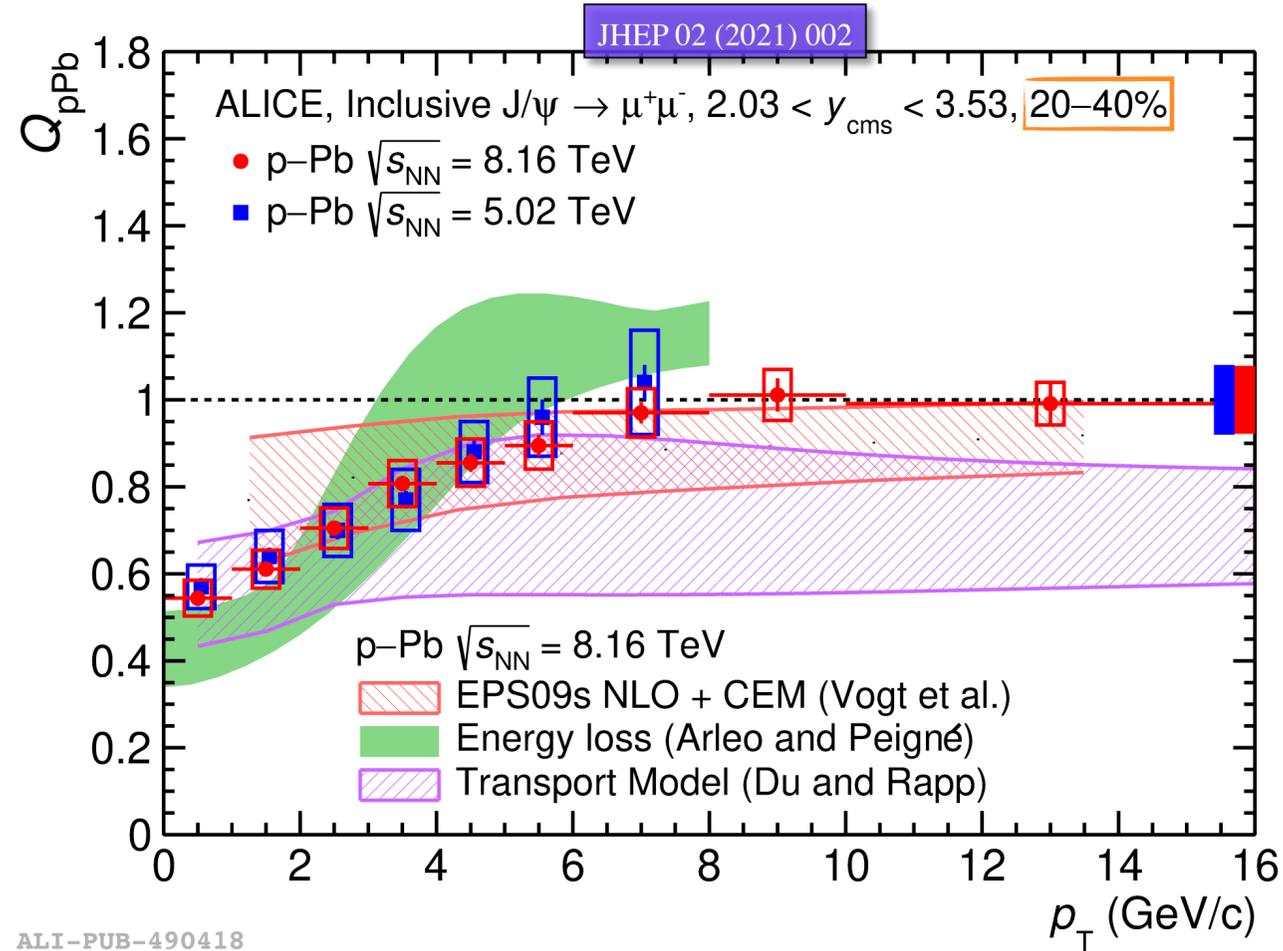


❖  $R_{pPb}$  of  $\Upsilon(1S)$ ,  $\Upsilon(2S)$  and  $\Upsilon(3S)$  in p-Pb and Pb-p collisions at 8.16 TeV measurements have been done with ALICE at forward and backward rapidity.

- ❖ Suppression of  $\Upsilon(1S)$  at low  $p_T$  is observed for both rapidity regions  $\rightarrow$  nuclear shadowing influence.
- ❖ Models describe forward rapidity  $R_{pPb}$ , while overestimating the backward rapidity measurements.

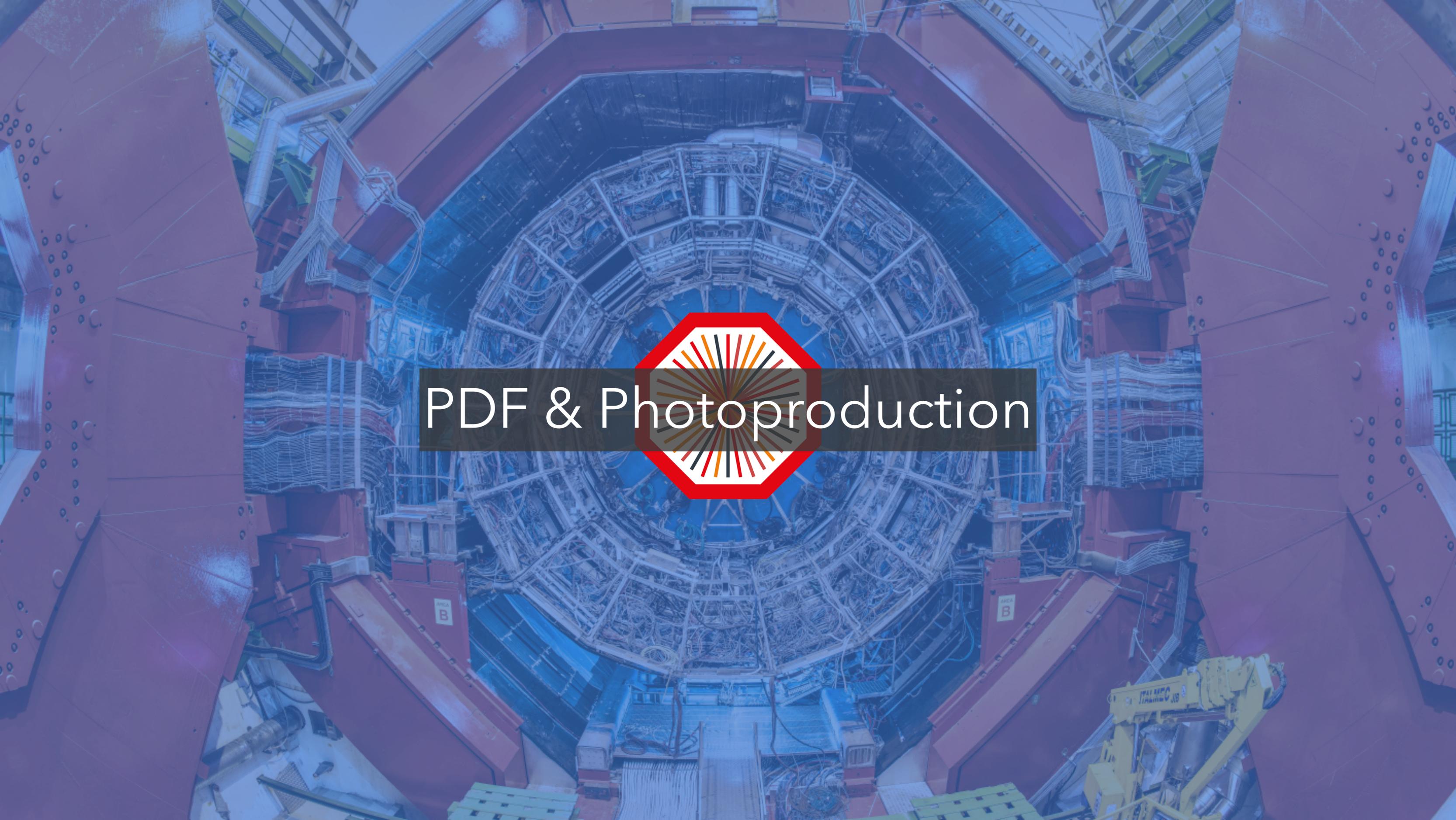


# Collectivity?



❖ Measurements of the elliptic flow for inclusive  $J/\psi$  in p–Pb collisions done at forward and backward rapidity at 5.02 TeV and 8.16 TeV.

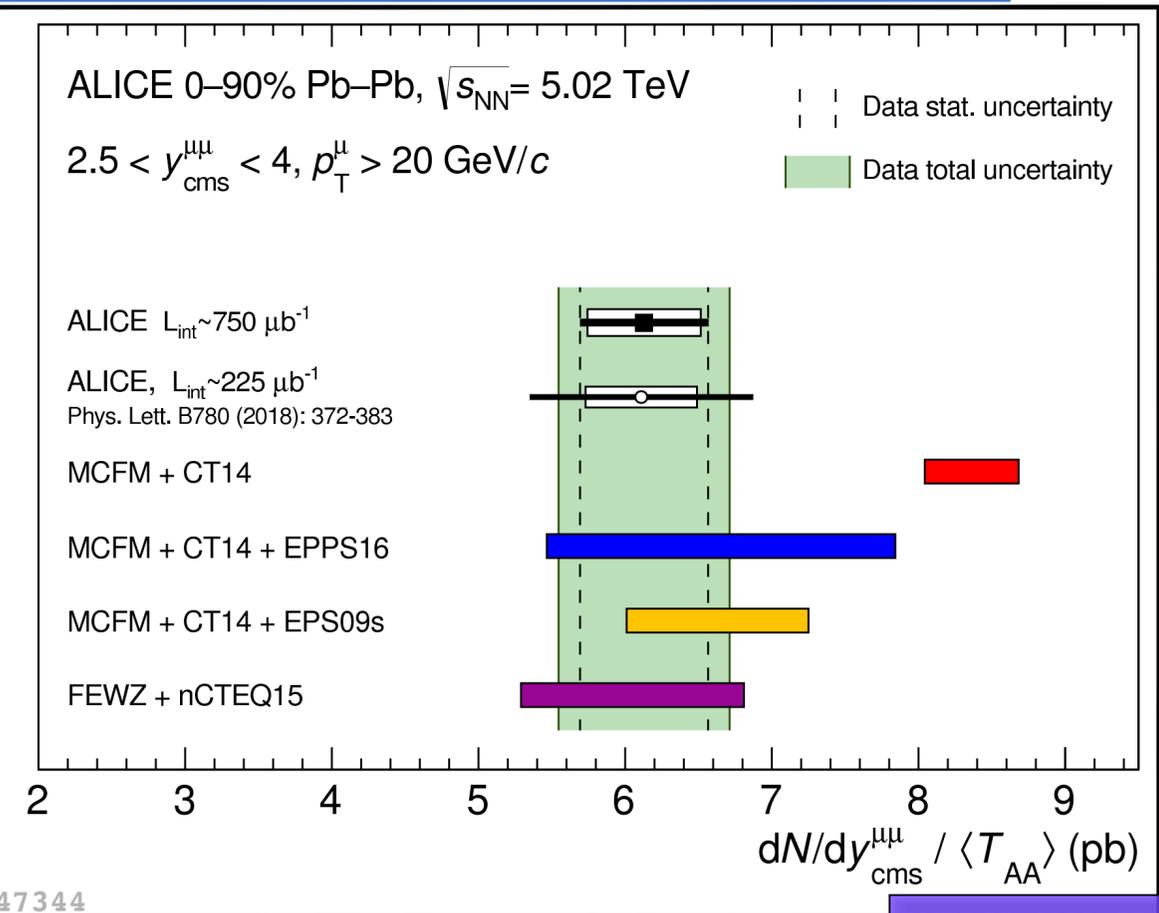
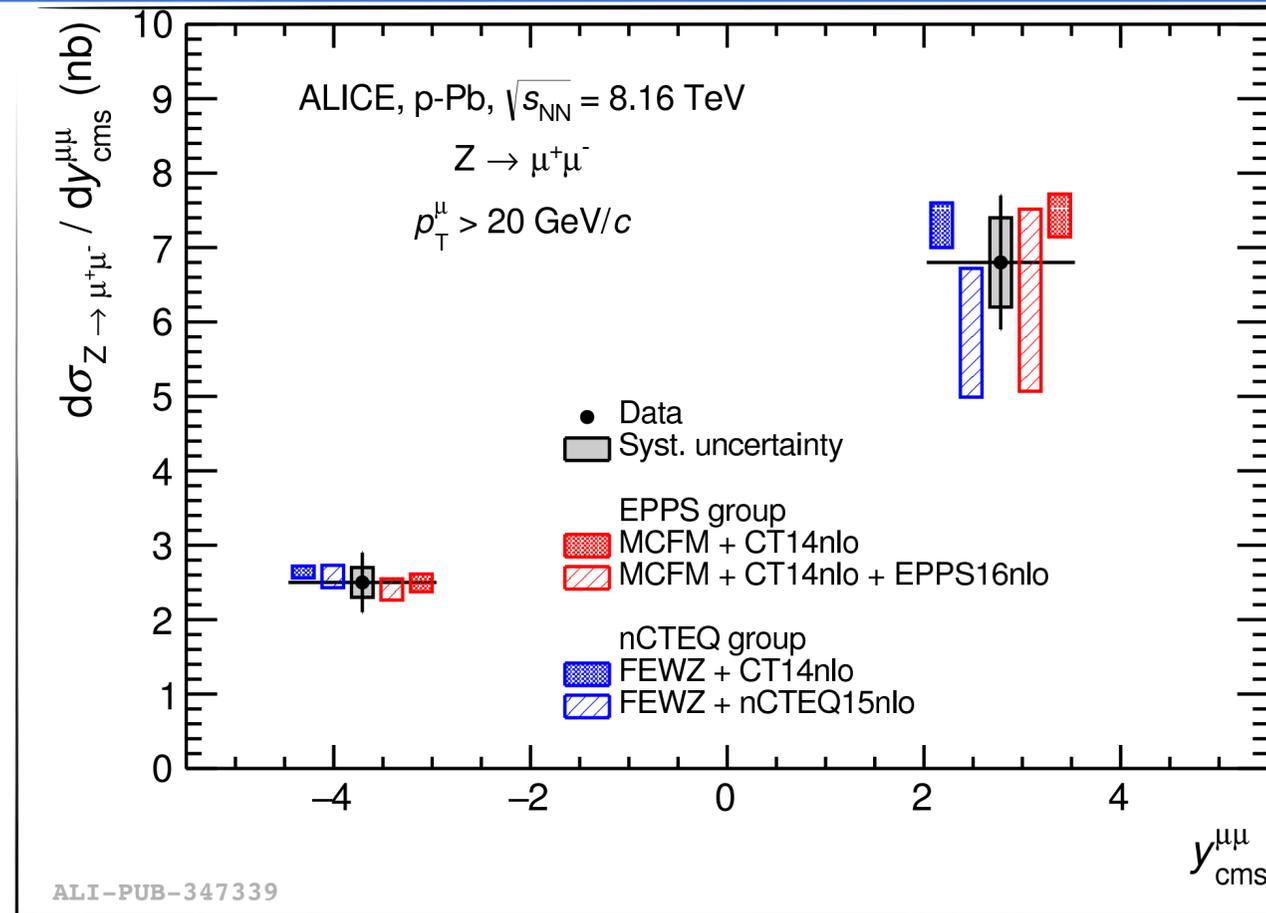
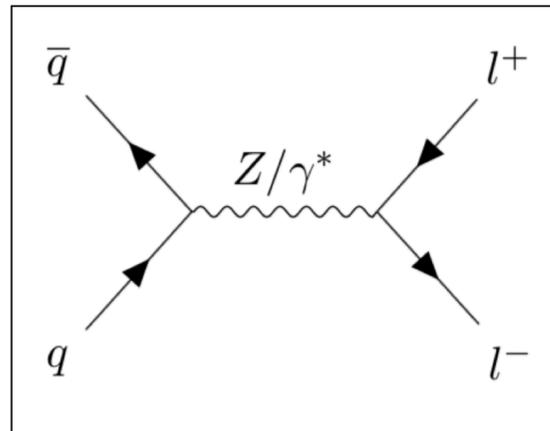
- ❖ Data for  $v_2$  at  $p_T < 3$  GeV/c compatible with 0  $\rightarrow$  in accordance with p-Pb expected  $v_2$  measurements, small rate charm-quark production.
- ❖ For  $3 < p_T < 6$  GeV/c,  $v_2$  is positive and comparable to  $v_2$  measurement done in Pb-Pb collisions (within uncertainties)  $\rightarrow$  responsible mechanism not understood, similar to Pb-Pb collisions?



PDF & Photoproduction



# PDF constraints with Z boson



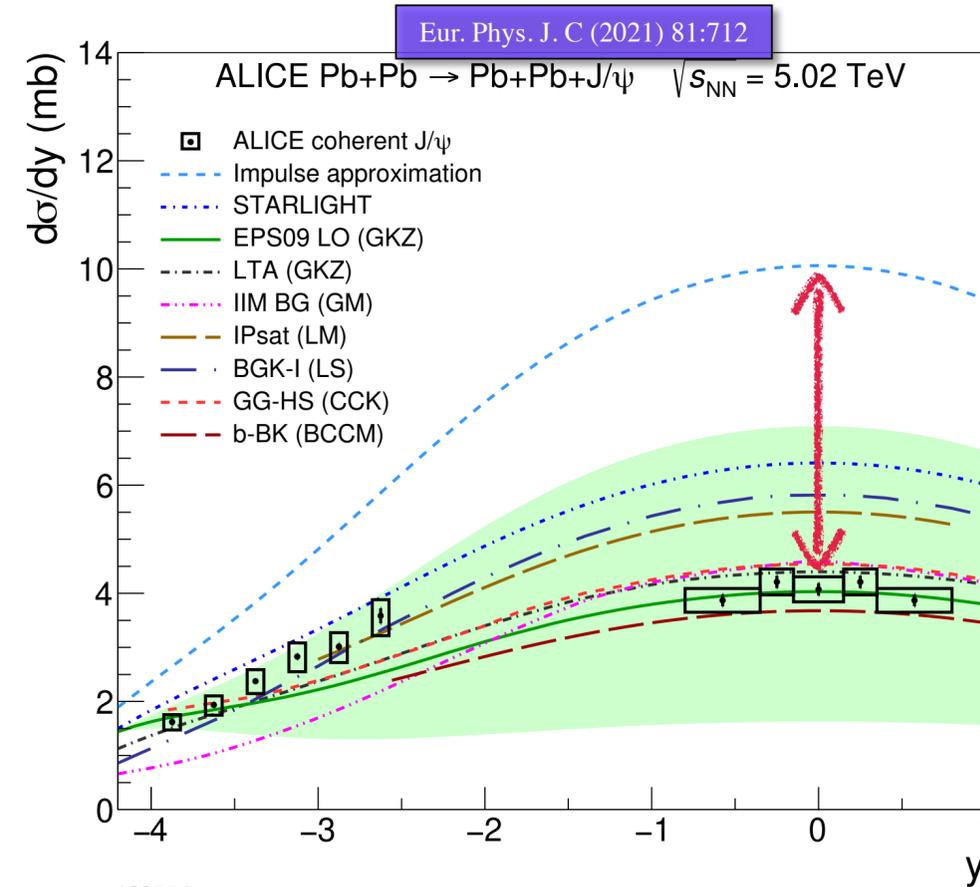
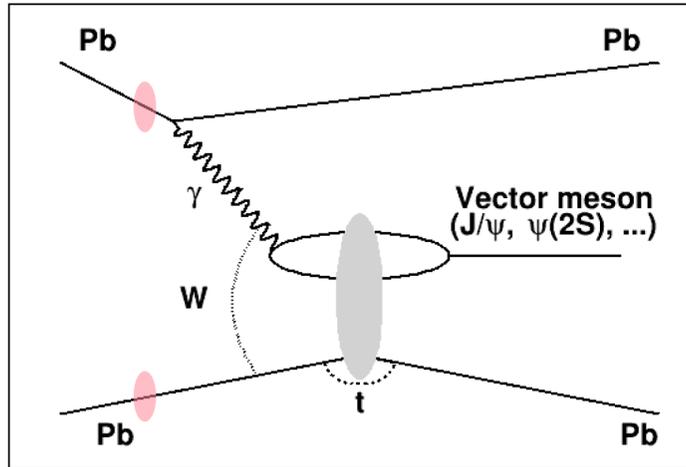
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❖ Measurements of Z-boson production in p–Pb collisions at 8.16 TeV and Pb–Pb collisions at 5.02 TeV is done at forward and backward rapidities.

- ❖ **Left:**  
 Cross section of the Z-boson is compared with pQCD calculations and FEWZ calculations  
 —> Results in agreement with calculations **with** and **without** nuclear modifications.
- ❖ **Right:**  
 Results in good agreement with calculations using three different nPDFs models.  
**Without** nPDF —> calculations overestimate data by  $3.4\sigma$ .



# PDF constraints with photoproduction



❖ Coherent photoproduction  $J/\psi$  and  $\psi'$  was measured in UPC Pb–Pb collisions at 5.02 TeV.

❖ **Impulsive approximation:**

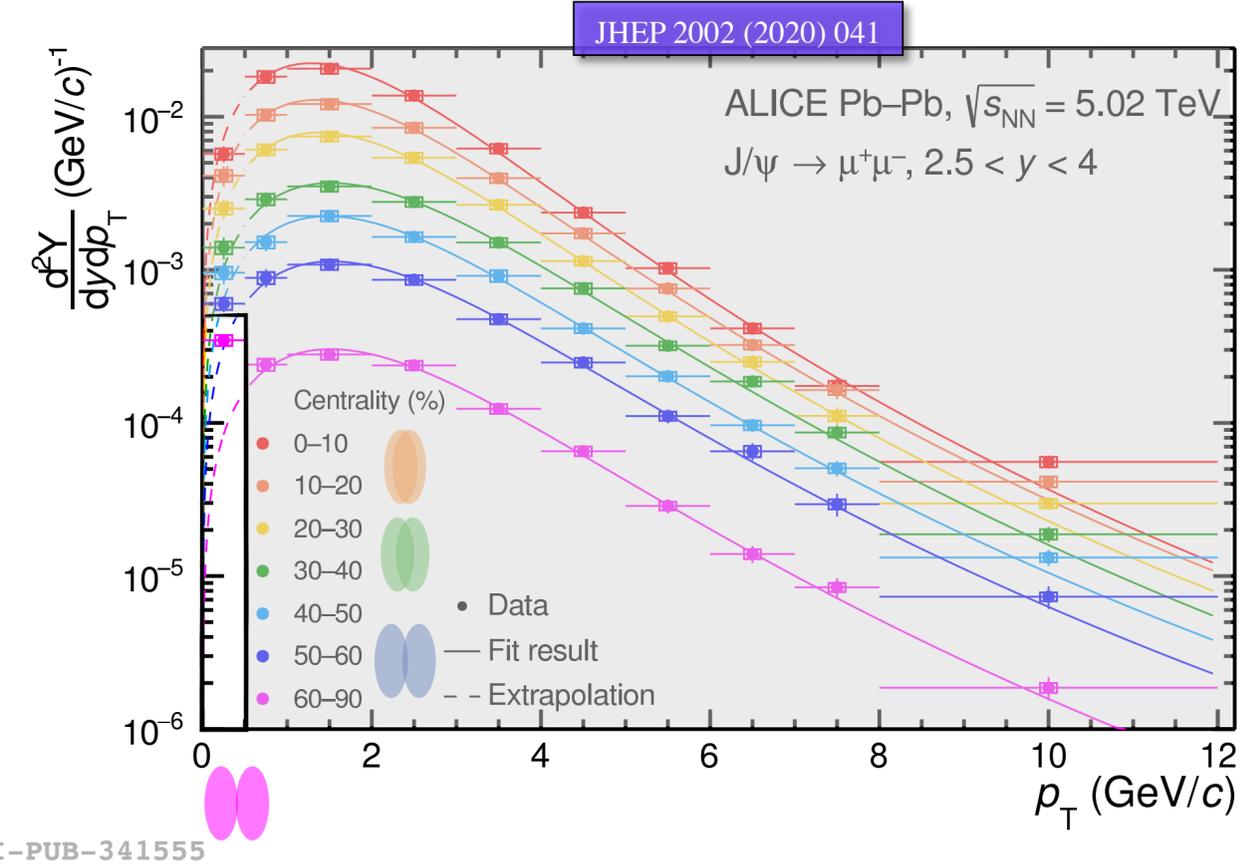
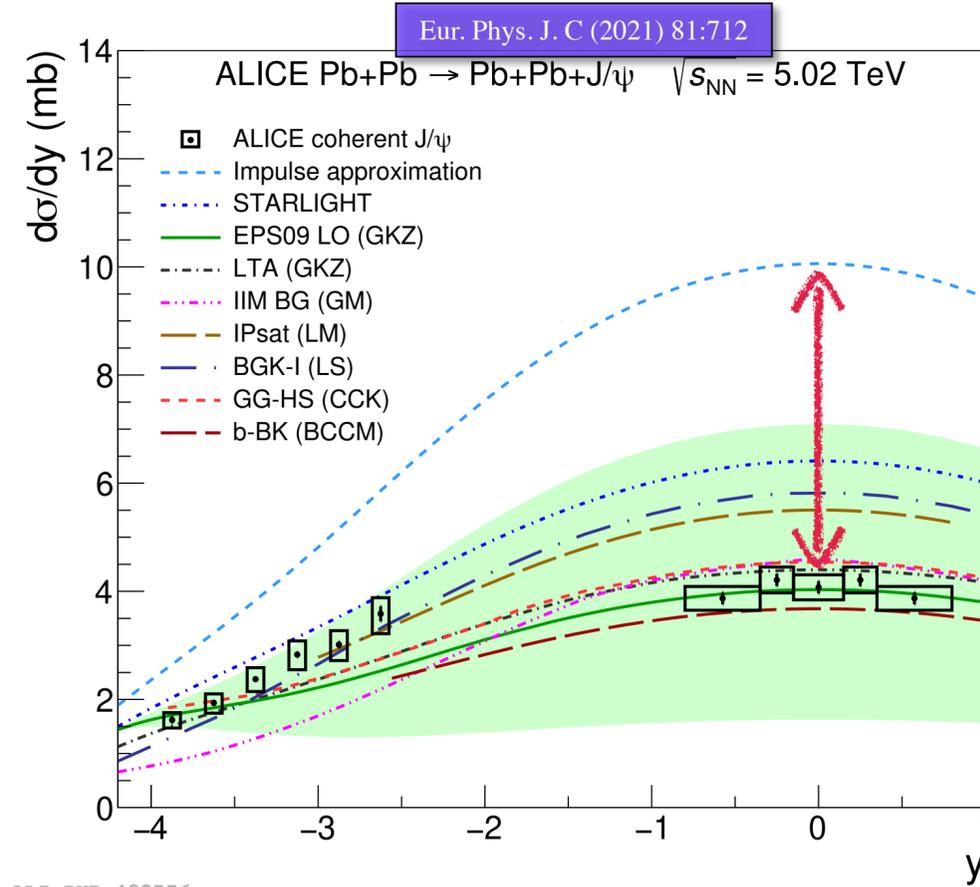
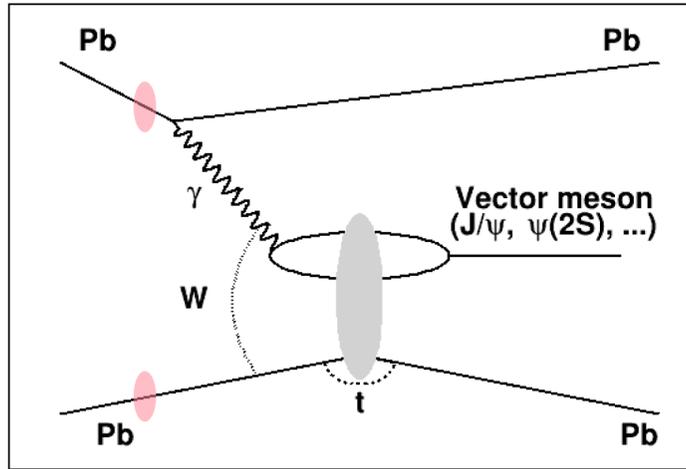
Based on data from  $J/\psi$  photoproduction with protons, neglects all nuclear effects except for the coherence.

Extracted nuclear suppression factor:  $R_g = 0.65 \pm 0.03 \rightarrow$  Bjorken- $x \sim 10^{-3}$

❖ No model describes data in both rapidity regions.



# Excess due to photoproduction



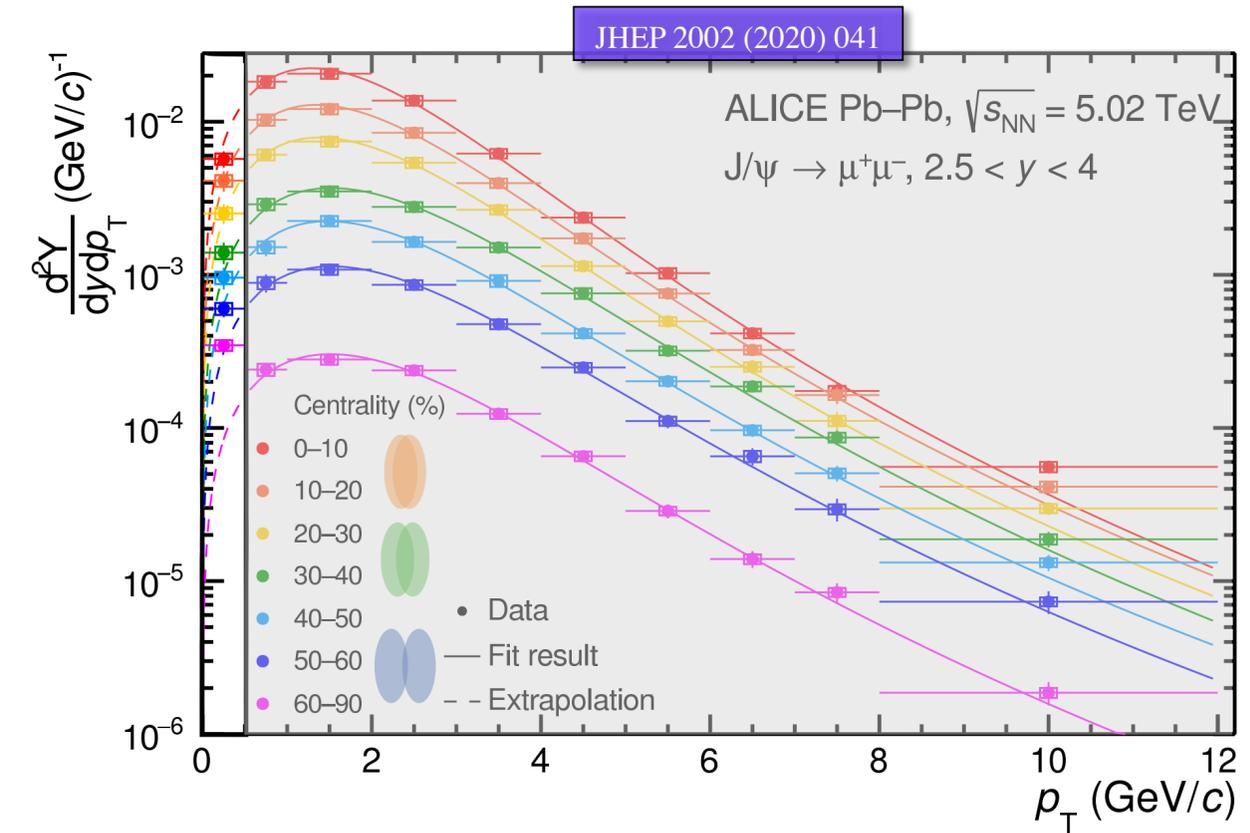
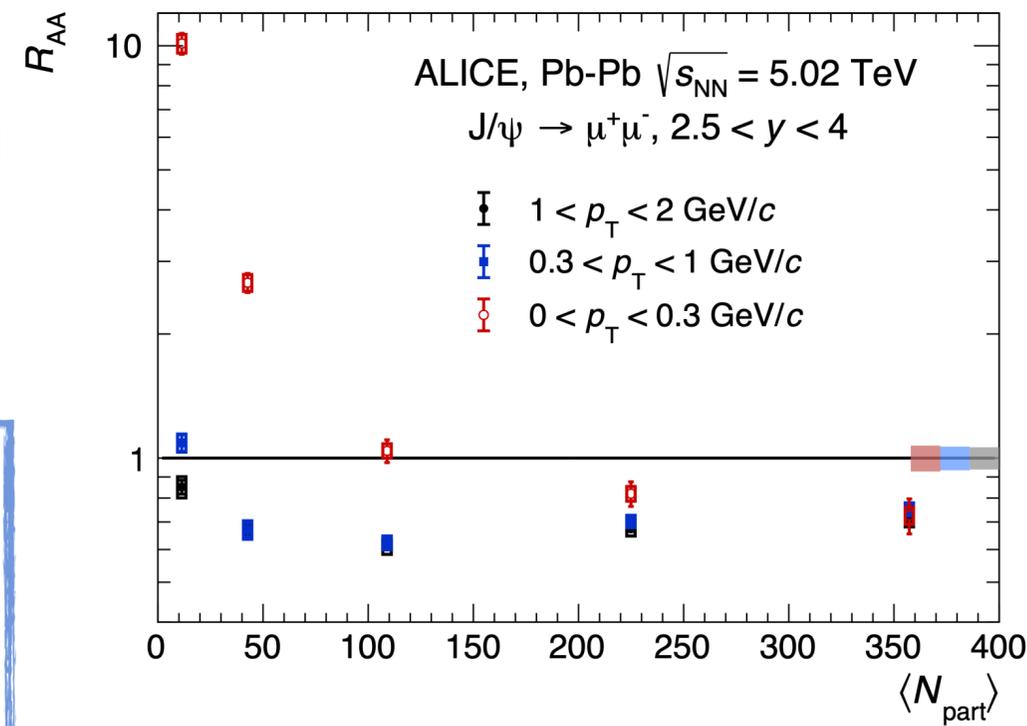


# Coherent $J/\psi$ photoproduction

❖  $J/\psi$  measurements at low  $p_T$  performed in forward rapidity from peripheral to more central events in Pb-Pb collisions at 5.02 TeV.

❖ *Excess of  $J/\psi$  observed at very low  $p_T$ , with  $R_{AA} \sim 10$  for peripheral collisions in  $p_T$  region  $0 < p_T < 0.3$  GeV/c.*

❖ Coherent photoproduction suggested as underlying mechanism.



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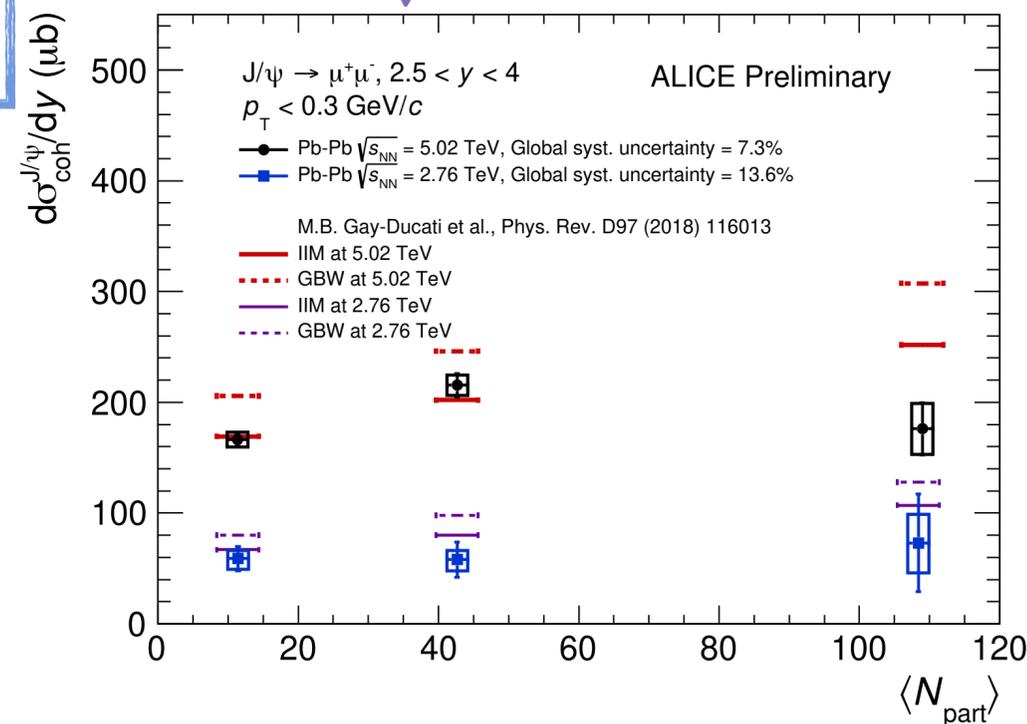
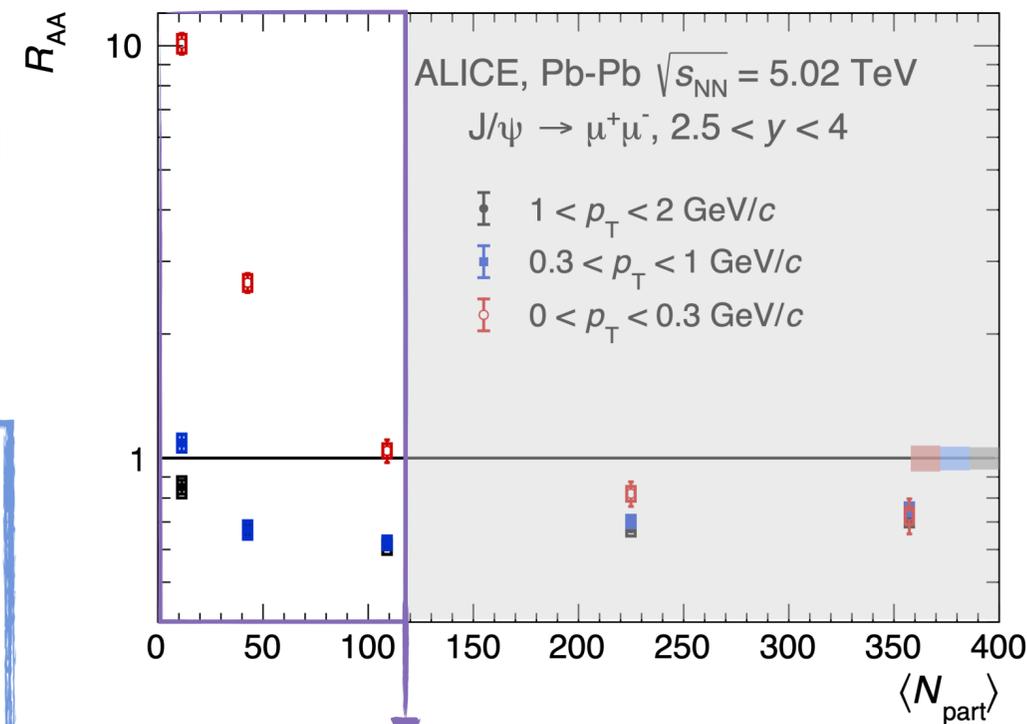


# Coherent $J/\psi$ photoproduction

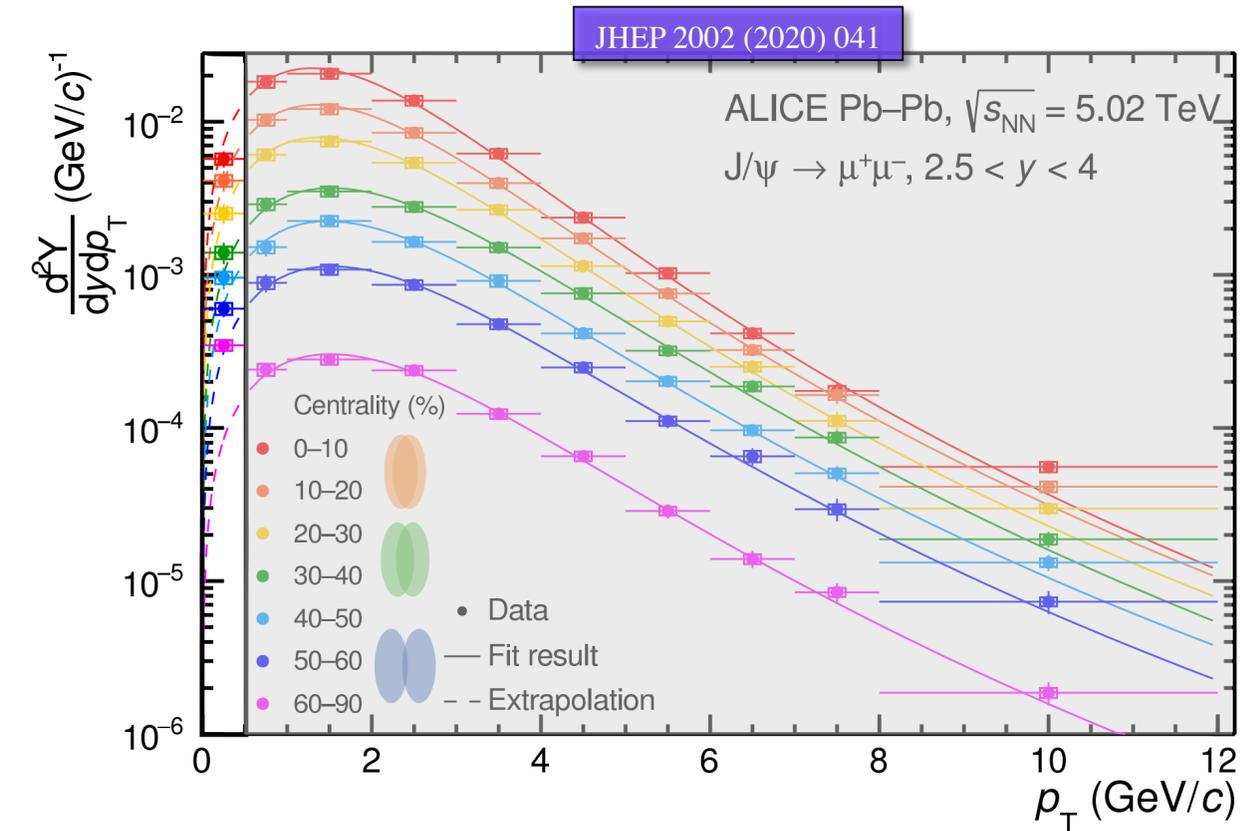
- $J/\psi$  measurements at low  $p_T$  performed in forward rapidity from peripheral to more central events in Pb-Pb collisions at 5.02 TeV.

- Excess of  $J/\psi$  observed at very low  $p_T$  with  $R_{AA} \sim 10$  for peripheral collisions in  $p_T$  region  $0 < p_T < 0.3$  GeV/c.

- Coherent photoproduction suggested as underlying mechanism.



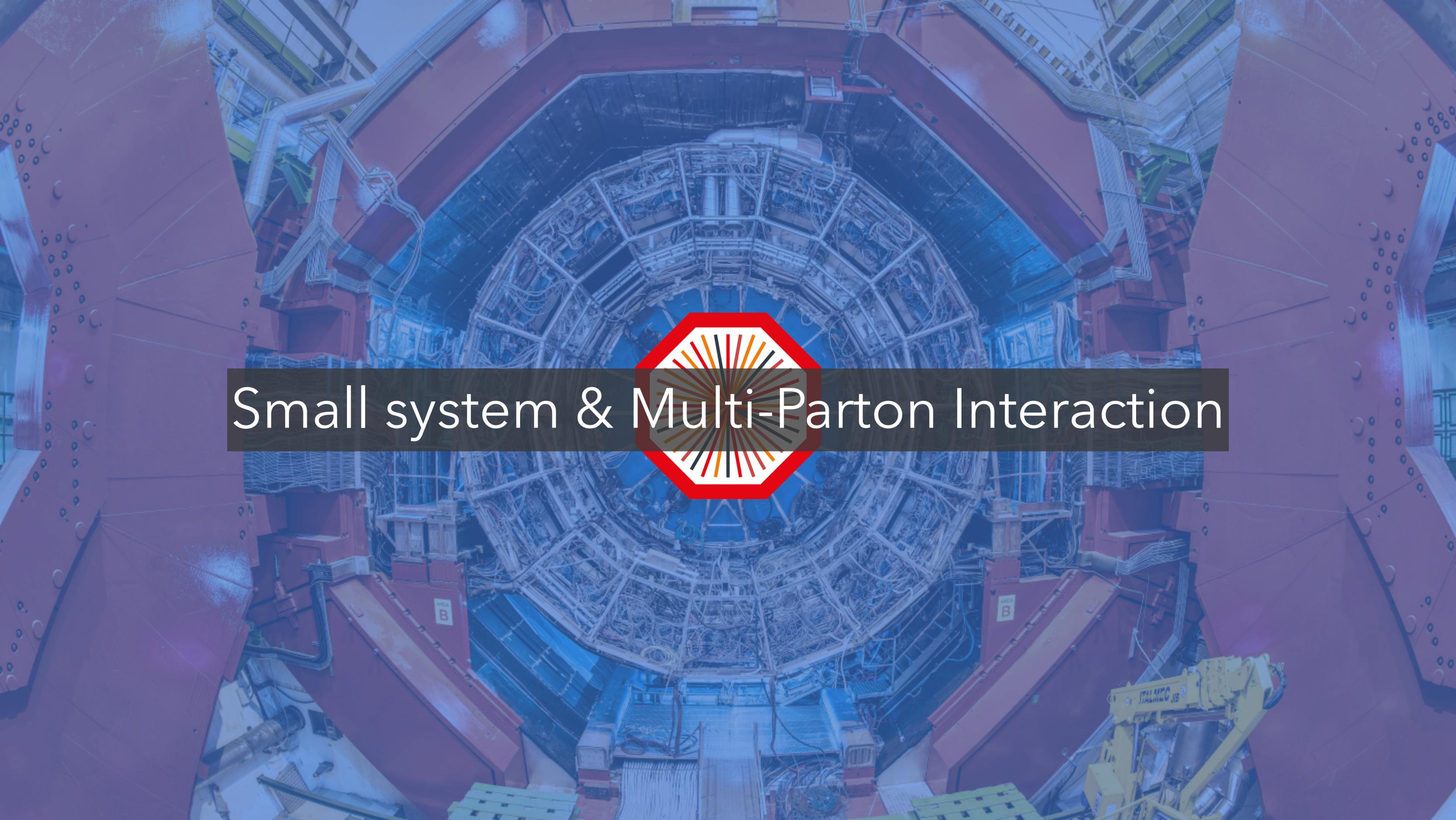
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- Peripheral events  $\rightarrow$  agreement with UPC based models with modification of the photon flux.

- Semi-central events  $\rightarrow$  photonuclear cross section modification required.



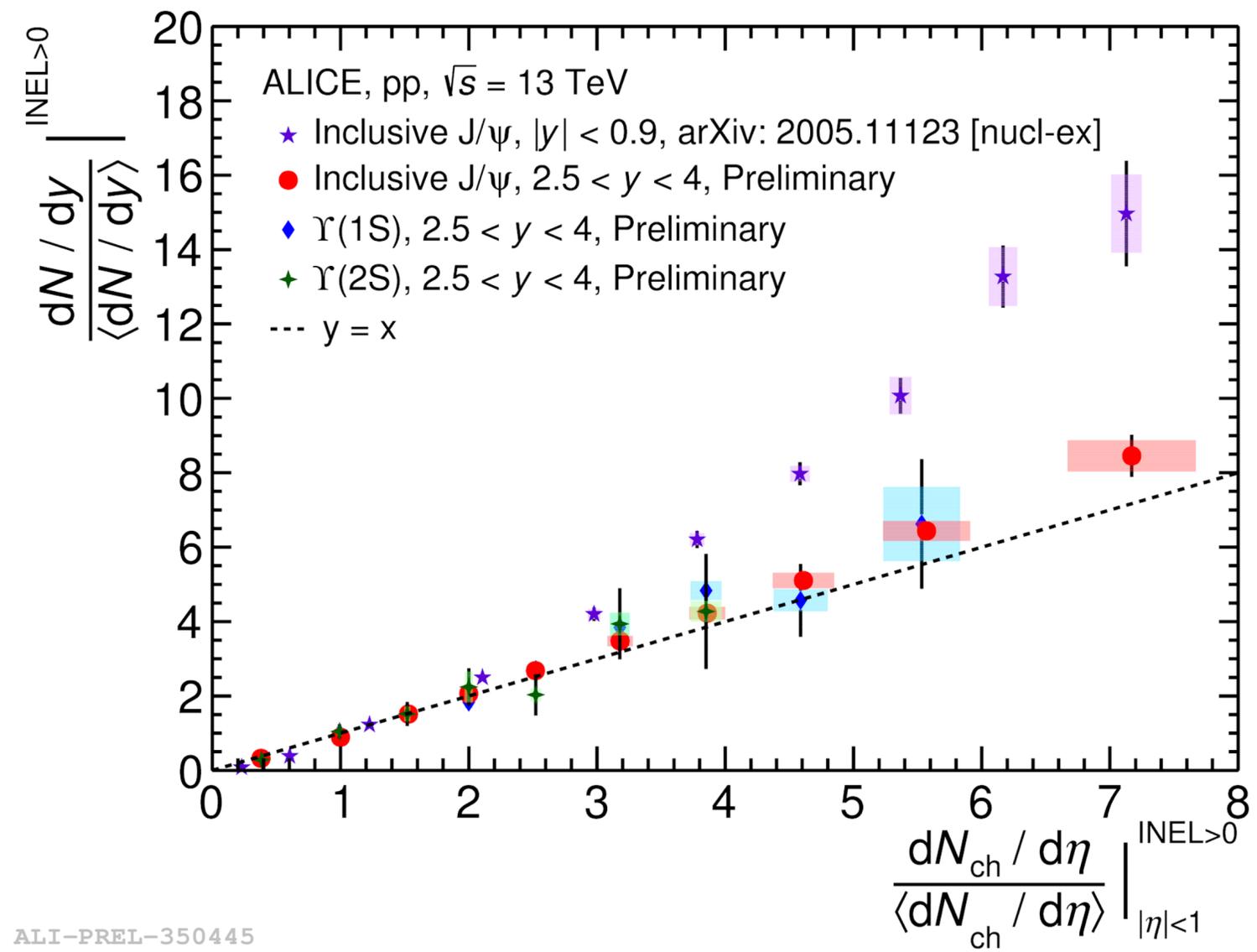
# Small system & Multi-Parton Interaction



# Quarkonia multiplicity-dependent measurements

❖ Measurements of  $J/\psi$ ,  $\psi(2S)$ ,  $\Upsilon(1S)$  and  $\Upsilon(2S)$  production as a function of charged particle multiplicity have been done in pp collisions at central and forward rapidity regions.

- ❖ **Midrapidity region:**  
non trivial correlations observed  $\rightarrow$  yield increase stronger than linear expected trend as a function of multiplicity.
- ❖ **Forward rapidity region:**  
yield compatible with linear dependence on multiplicity.





# Outlook & Conclusions



# ALICE for Runs 3 & 4

## Increased Luminosity

For AA collisions an increase of a factor 10-100 (depending on observable)

## Inner Tracking System 2:

CMOS pixel, MAPS technology  
Improved resolution  
Faster readout

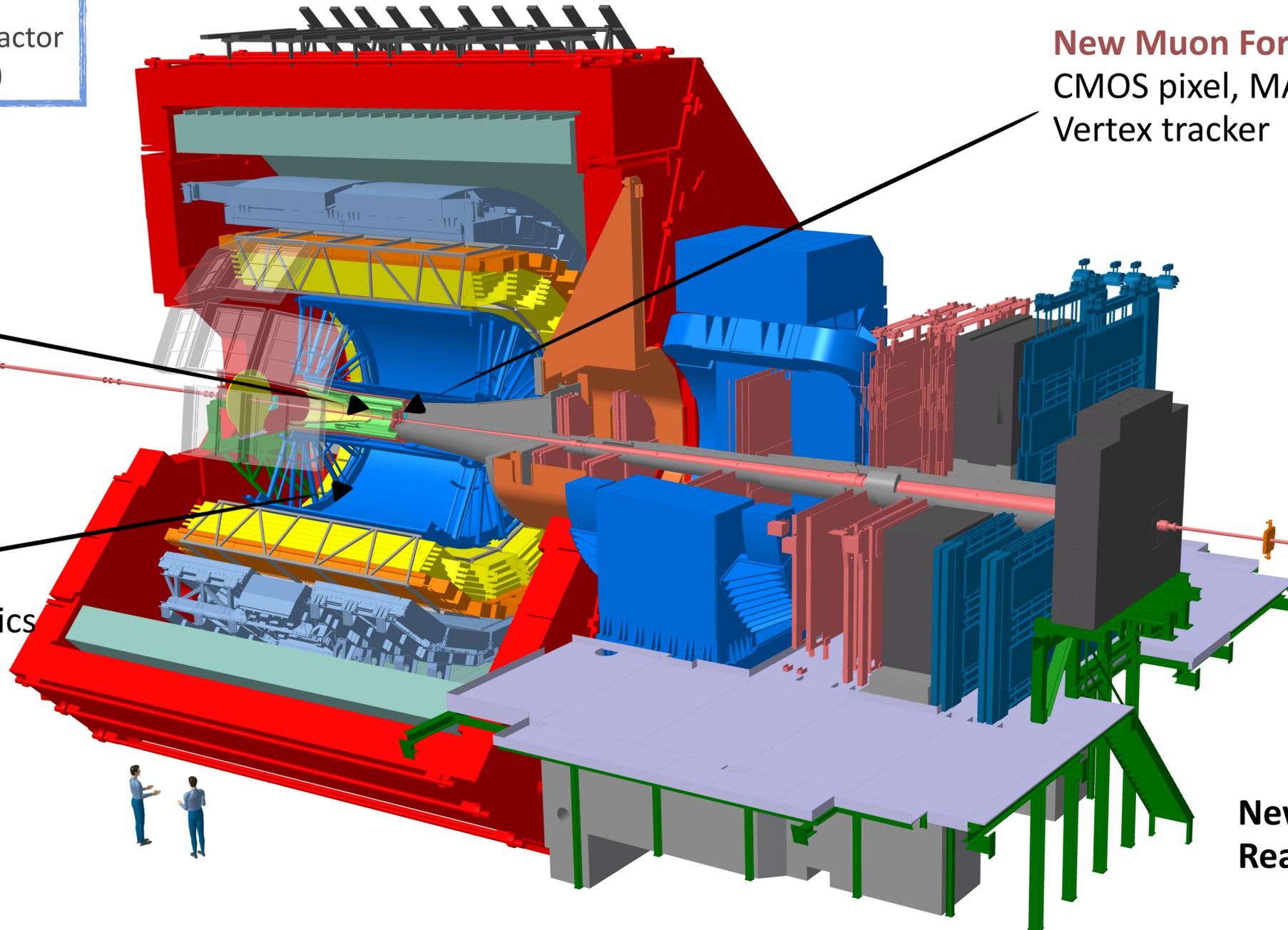
## New TPC Readout Chambers:

GEM technology, new electronics  
Continuous readout

**New Muon Forward Tracker:**  
CMOS pixel, MAPS technology  
Vertex tracker

**New Fast Interaction Trigger:**  
Centrality measurement  
Luminosity  
Event plane

**New computing system (Online-Offline)**  
Readout upgrade for detectors





# Conclusions

## ‣ **Quarkonia: Regeneration vs Suppression in AA collisions**

Measurements presented on the  $J/\psi$  Nuclear Modification Factor and the elliptic flow in Pb-Pb collisions:

Regeneration at low  $p_T$ , suppression at high  $p_T$ .

Nuclear Modification Factor of  $\Upsilon(1S)$  presented in Pb-Pb collisions along with the elliptic flow:

Strong suppression, no participation in elliptic flow.

## ‣ **Cold Nuclear Matter Effects:**

Measurements of Nuclear Modification Factor for  $J/\psi$  and  $\Upsilon(1S)$  in p-Pb collisions presented.

$J/\psi$  elliptic flow measurements in p-Pb collisions:

Collective behavior.

## ‣ **PDF & Photoproduction:**

Z-boson measurements presented:

Cross section results well reproduced with models.

Z-boson production calculations without nPDF overestimate data.

Coherent  $J/\psi$  photoproduction in UPC Pb-Pb collisions.

Excess of low  $p_T$   $J/\psi$  production  $\rightarrow$  coherent  $J/\psi$  photoproduction study in Pb-Pb collisions.

## ‣ **Small system & MPI:**

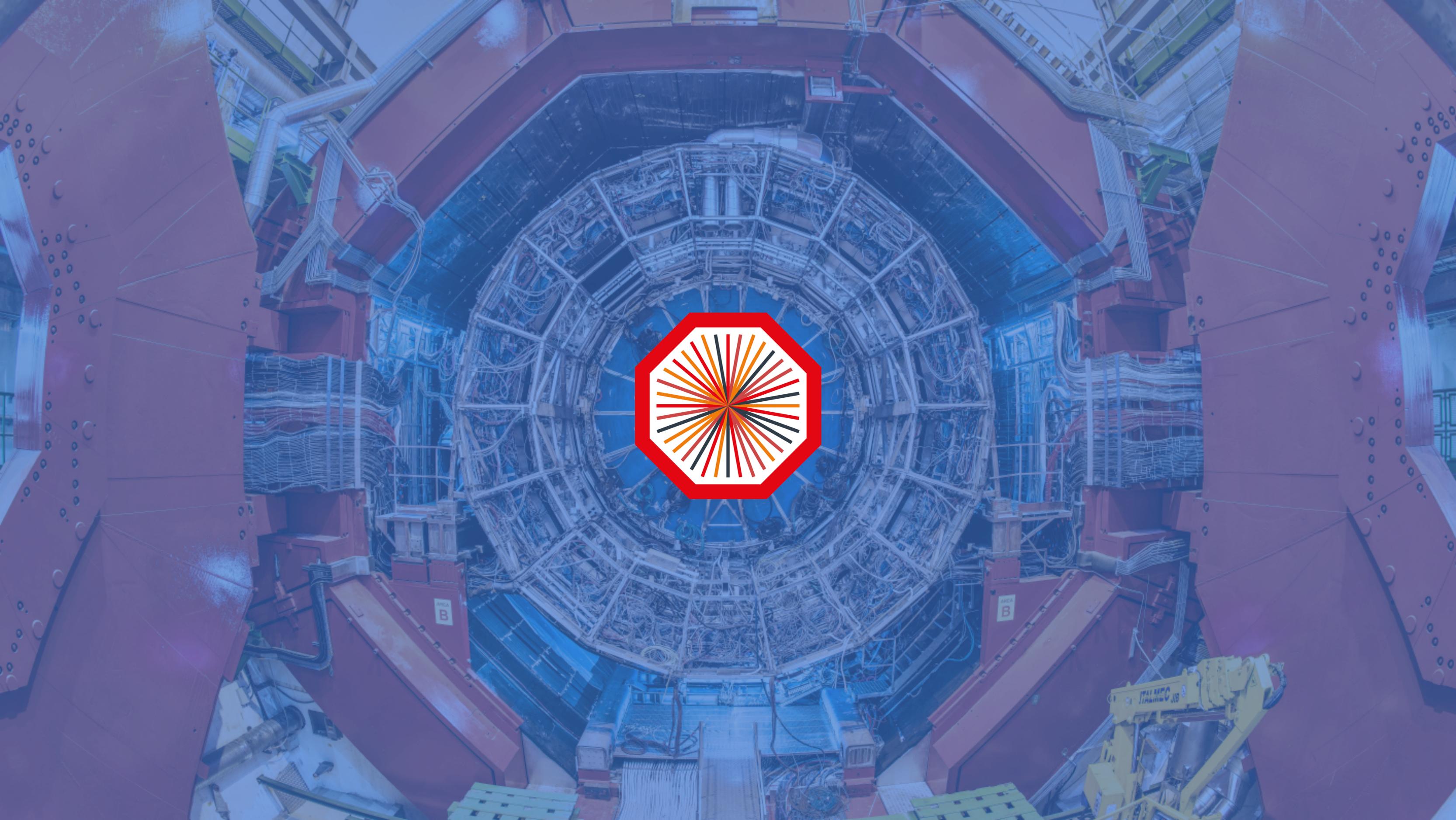
Measurements of quarkonia multiplicity-dependent production:

Difference observed between  $J/\psi$  production at mid and forward rapidity regions .

## ‣ **ALICE in Runs 3 & 4:**

Major improvements and upgrades, new results expected  $\rightarrow$  more precise and differential measurements.

Thank you for your attention!



# Quarkonia multiplicity-dependent measurements

- ❖ Comparison of data for normalized inclusive  $J/\psi$  yield at as a function of charged particle multiplicity at midrapidity in pp collisions at 13 TeV with model predictions.

- ❖ Trend well described all by model calculations: calculations predict an increase faster than linear.
- ❖ CPP, CGC and 3-Pomeron models are in agreement with data.
- ❖ Different mechanisms predict the charged-particle multiplicity reduction: Color string reconnection or percolation, gluon saturation, coherent particle production, 3-gluon fusion in gluon ladders/Pomerons.

