QGP France
Tours

# ALICE Quarkonia overview

*newest results*

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*03/05/22*

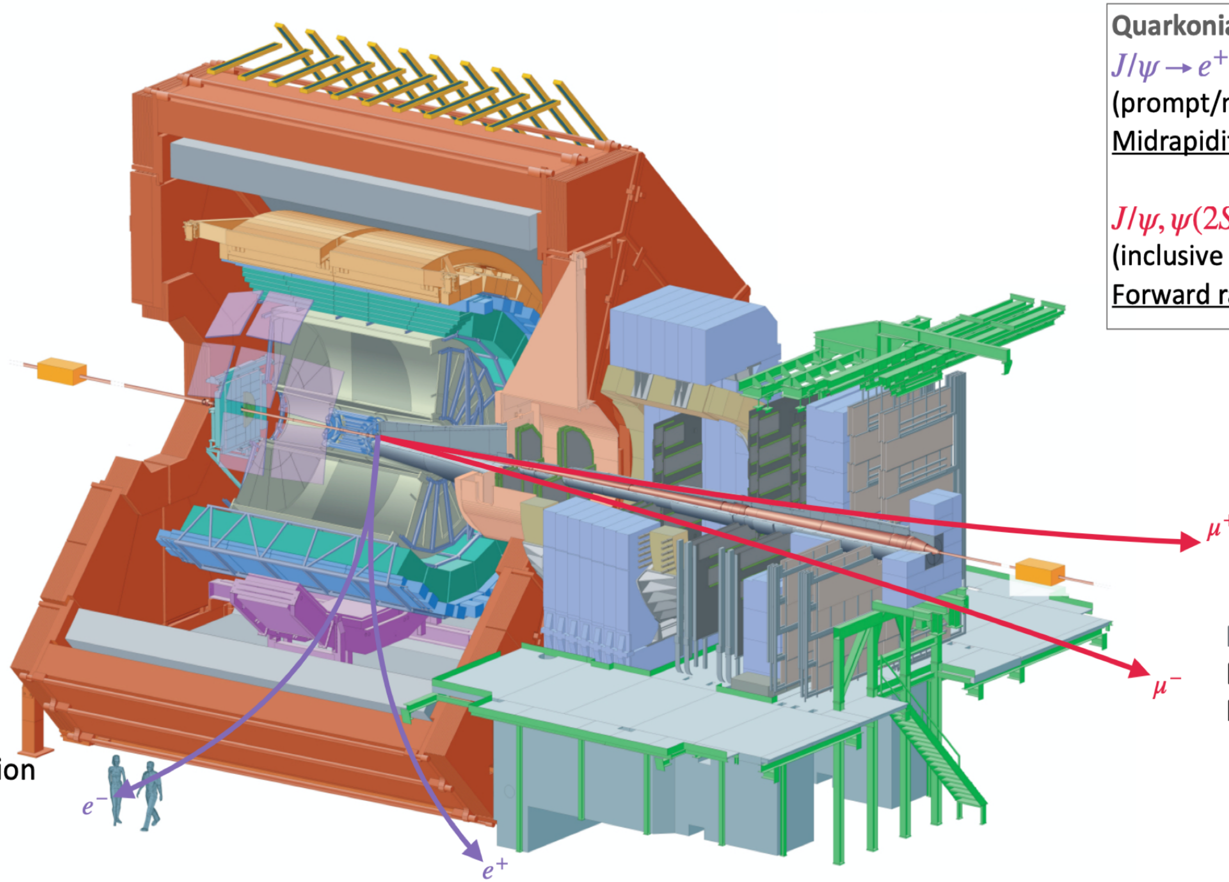
# ALICE & quarkonia

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

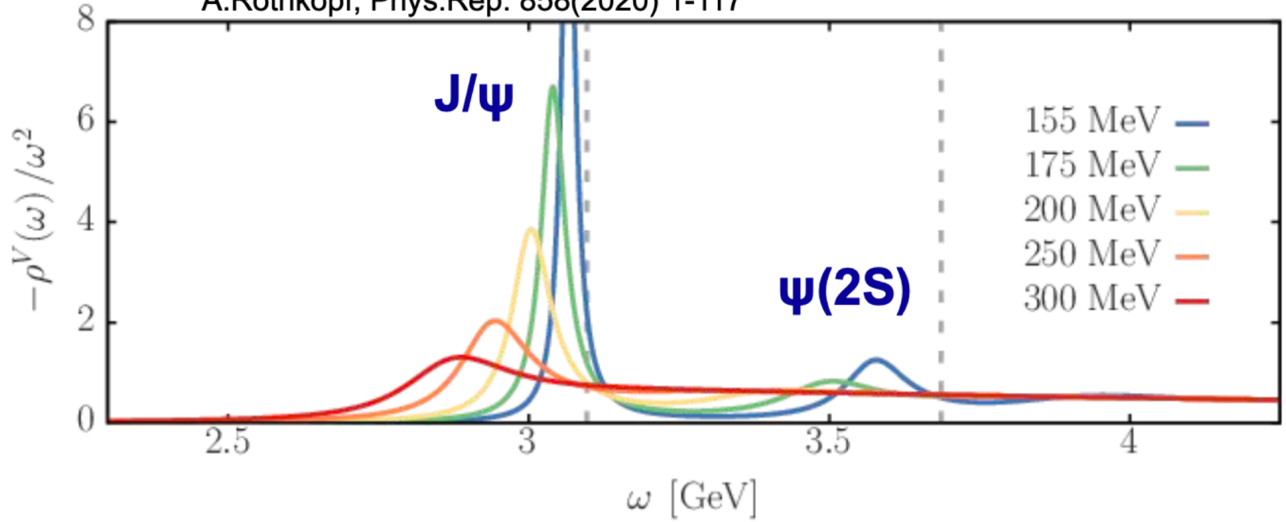
$J/\psi, \psi(2S), \Upsilon(nS) \to \mu^+\mu^-$
(inclusive quarkonium states)
Forward rapidity: $2.5 < y_{\mu\mu} < 4$

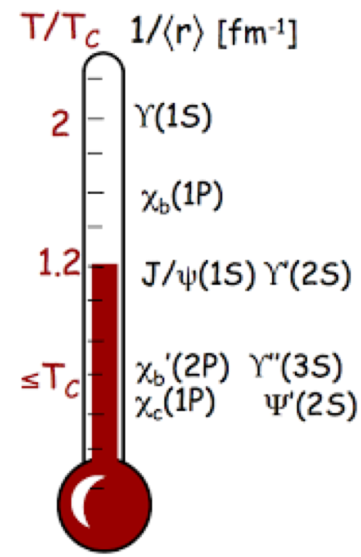
**Muon Spectrometer:**
Muon tracking
Muon trigger

## Sequential dissociation

- Sensitive to medium temperature
- Static vs. Dynamic suppression
- Stronger suppression of ground states w.r.t excited states

A.Rothkopf, Phys.Rep. 858(2020) 1-117



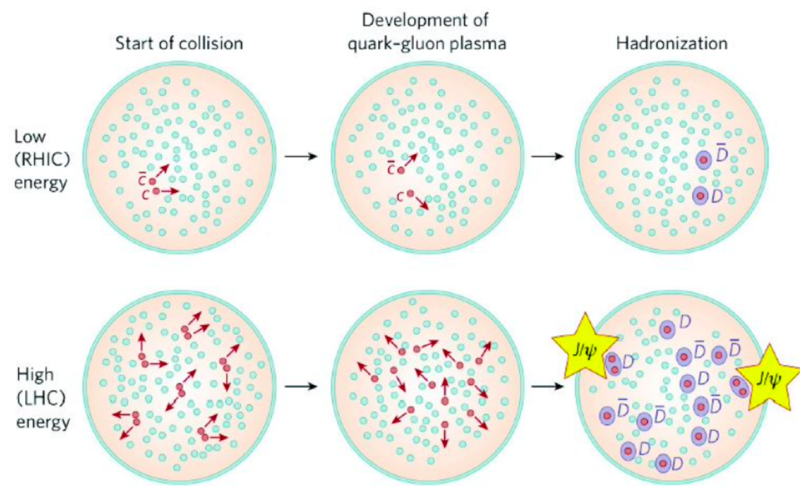




*Eur. Phys. J, C61, 2009*

# Why quarkonia in AA ?

## Regeneration

- Strong effect at LHC energy




Braun-Munzinger, P., Stachel, J. The quest for the quark–gluon plasma. *Nature* 448, 302–309 (2007)

- When does it occur?
  - *Phase boundary and/or during the QGP phase ?*
- Excited-to-ground state ratio useful to disentangle various scenarii

# *Why quarkonia in AA ?*

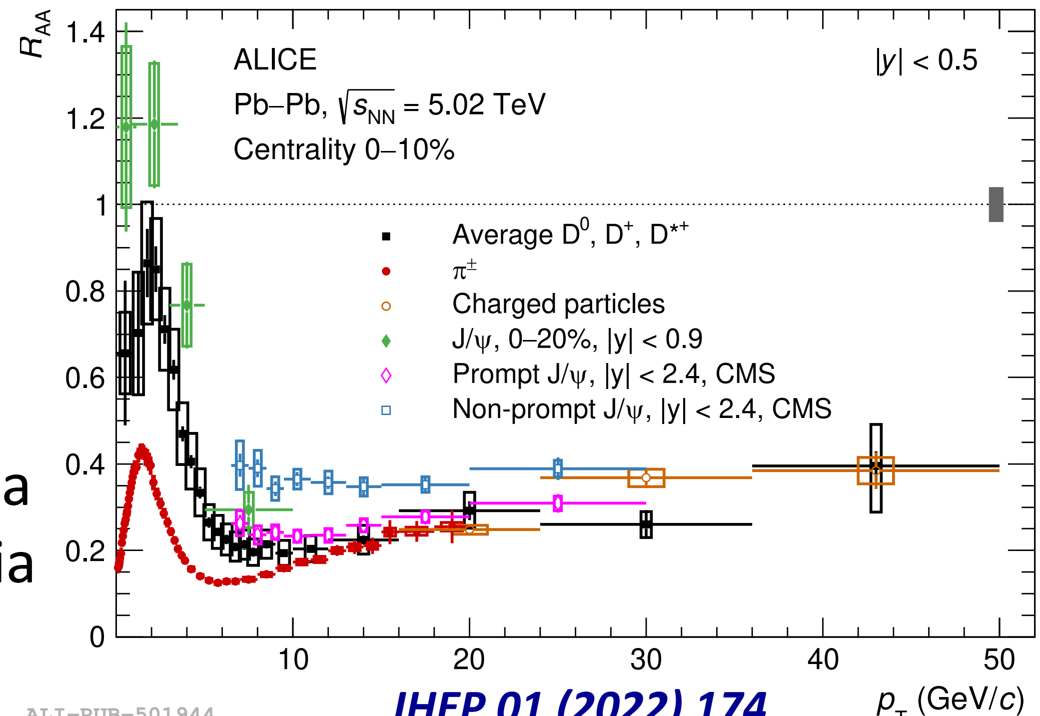


## Energy loss : charm versus beauty

- Heavy quark (b & c) produced early during the collision via hard parton scattering
  - *Energy loss in QGP via collisional & radiative processes*
  - *Dead cone effect reduces radiative losses for beauty*

**Mass dependence of parton energy loss** expected from light to heavy-flavor

- Accessible via bottomonia or non-prompt charmonia



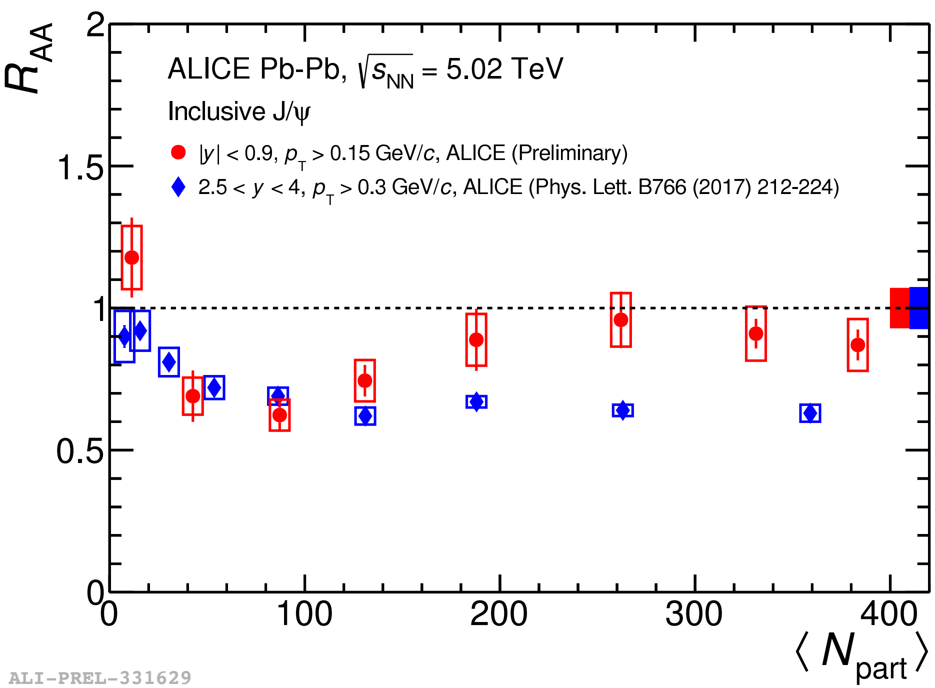

*JHEP 01 (2022) 174*

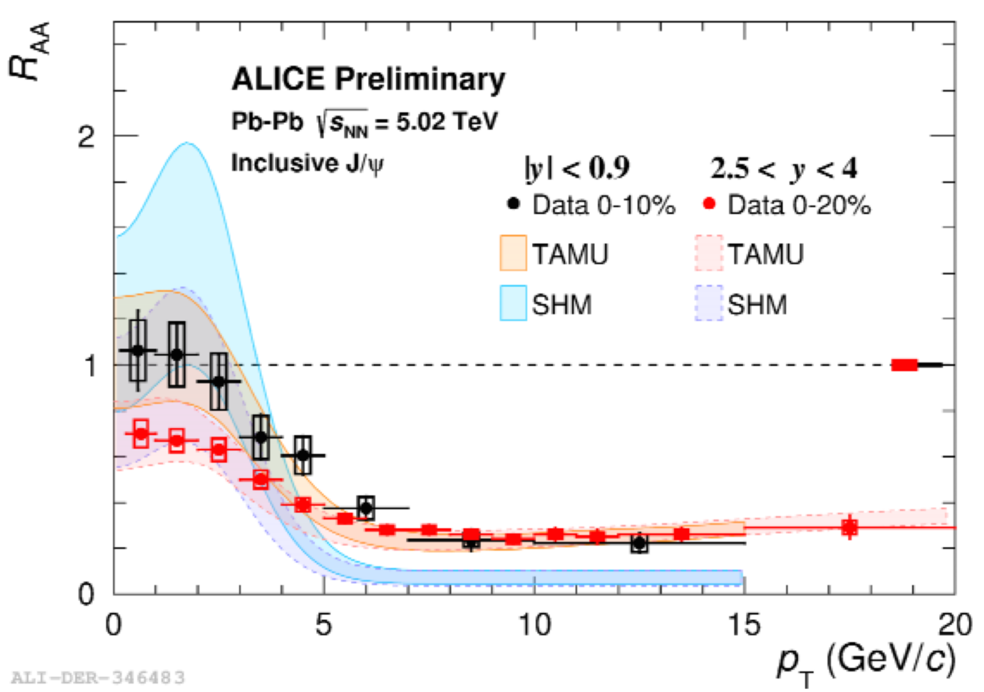
# Inclusive J/ψ



## Suppression vs. regeneration

- More regeneration at mid-rapidity w.r.t forward
  - *in more central events*
  - *at low $p_T$*
- No strong conclusion from model comparison on pheno.



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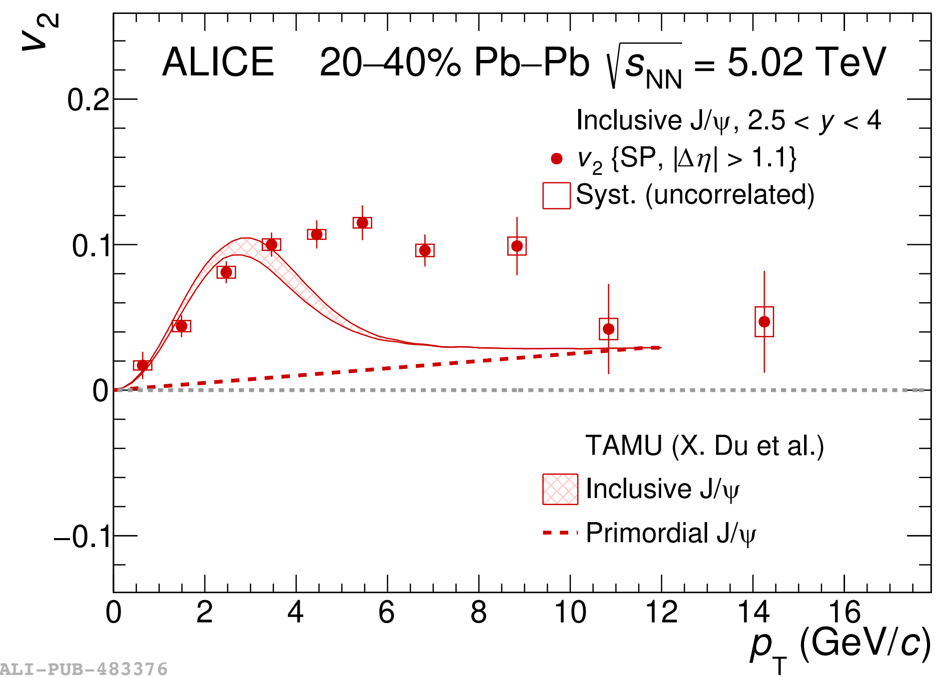
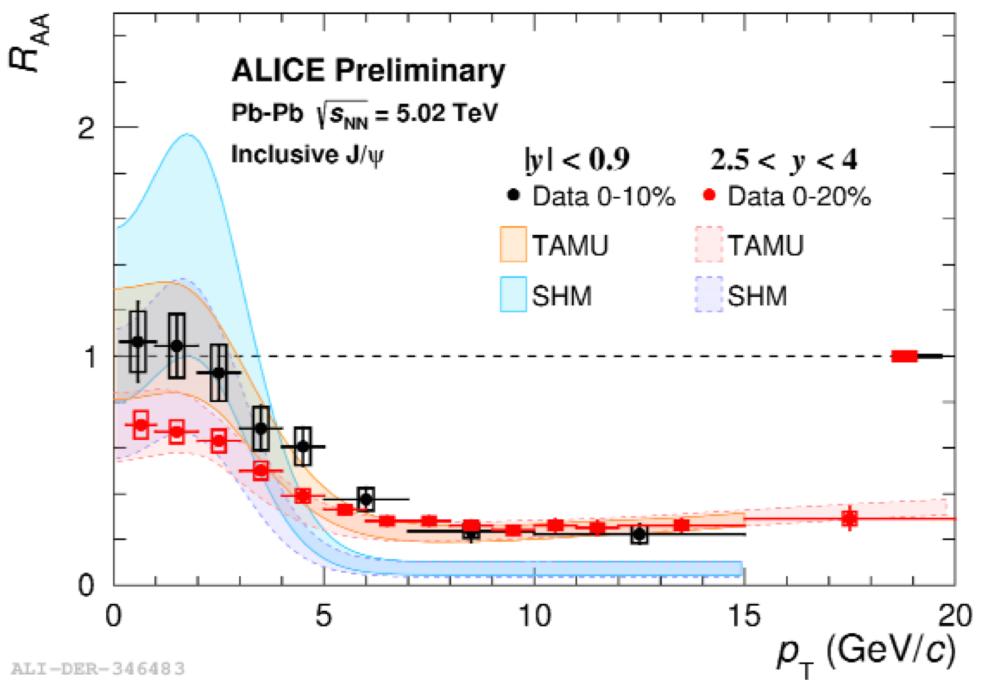


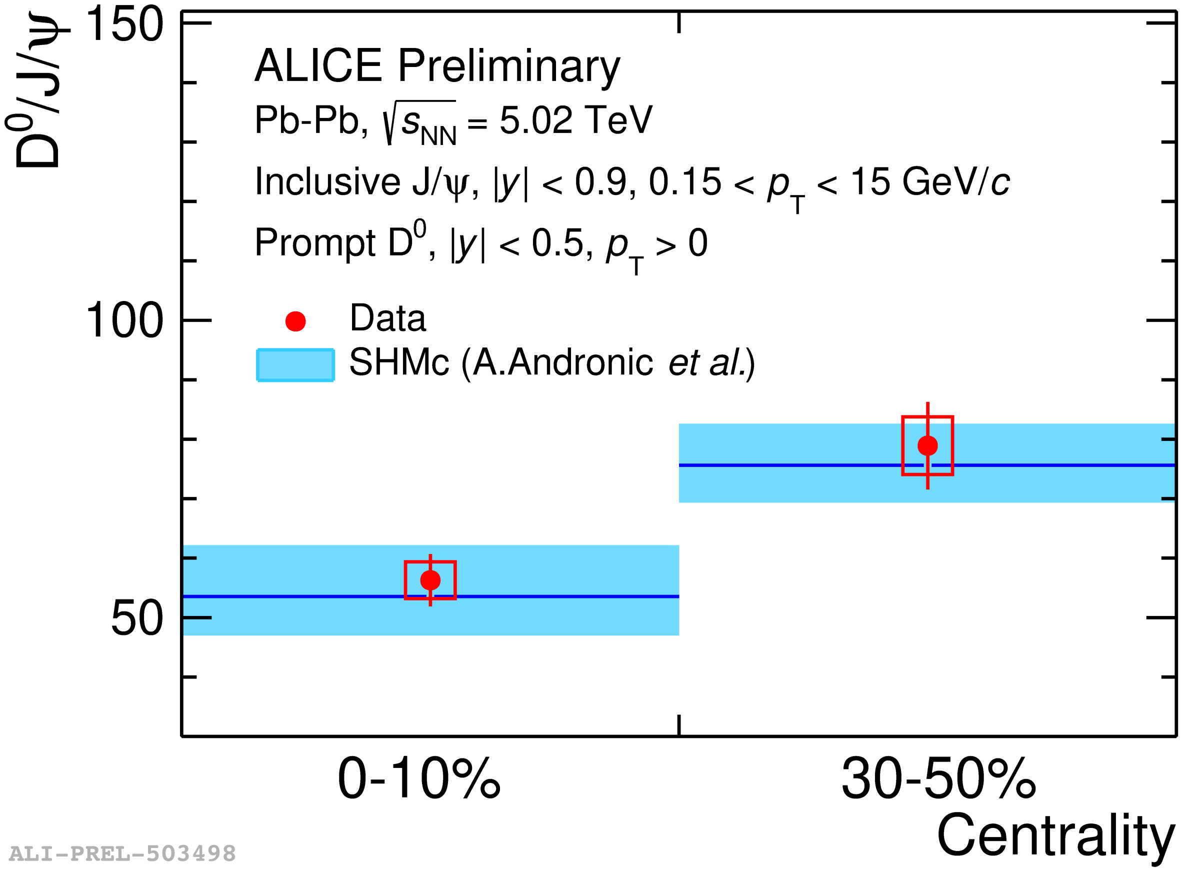



# $D^0$ to $J/\psi$ ratio



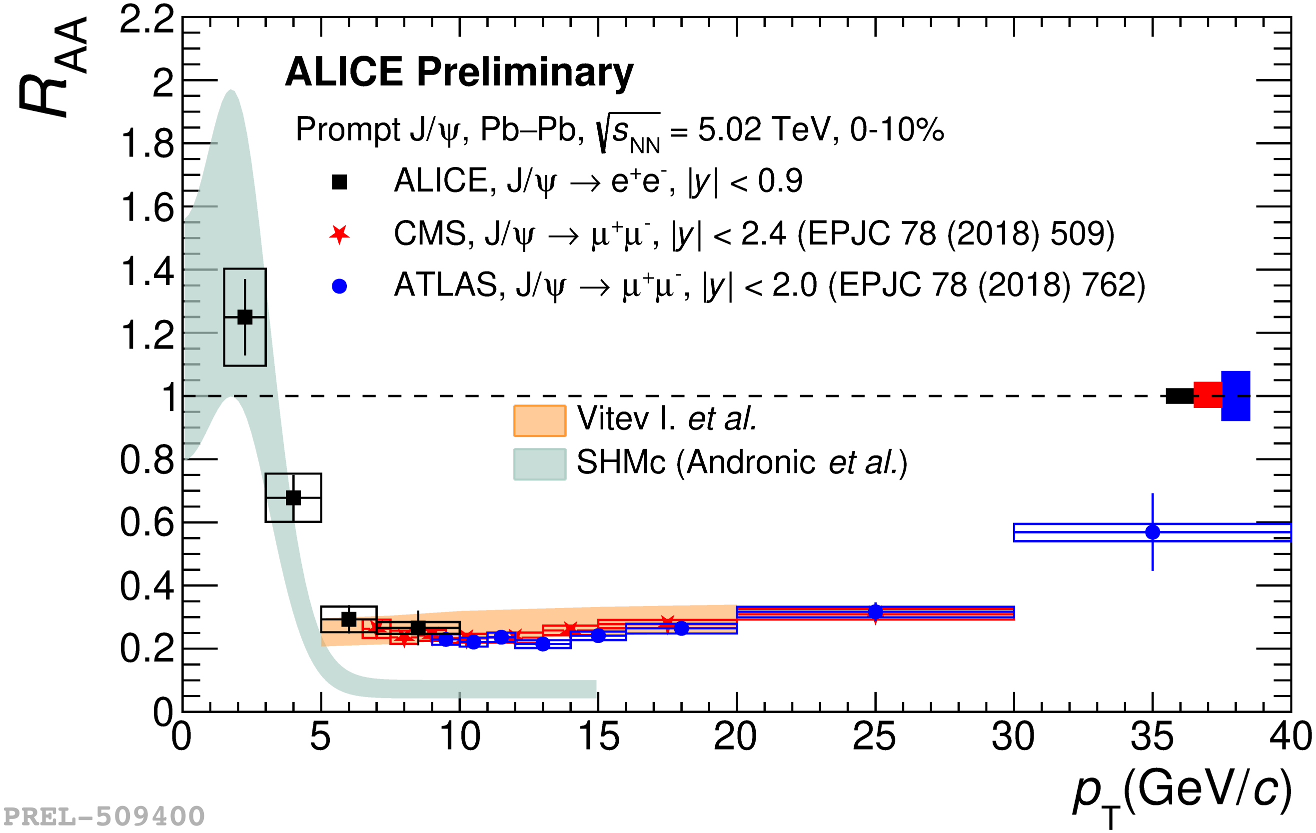
## Regeneration : quest for its origin

- Compatible with regeneration scenario
- Inclusive measurement : 10-20% contribution from non-prompt



## Regeneration : charm only

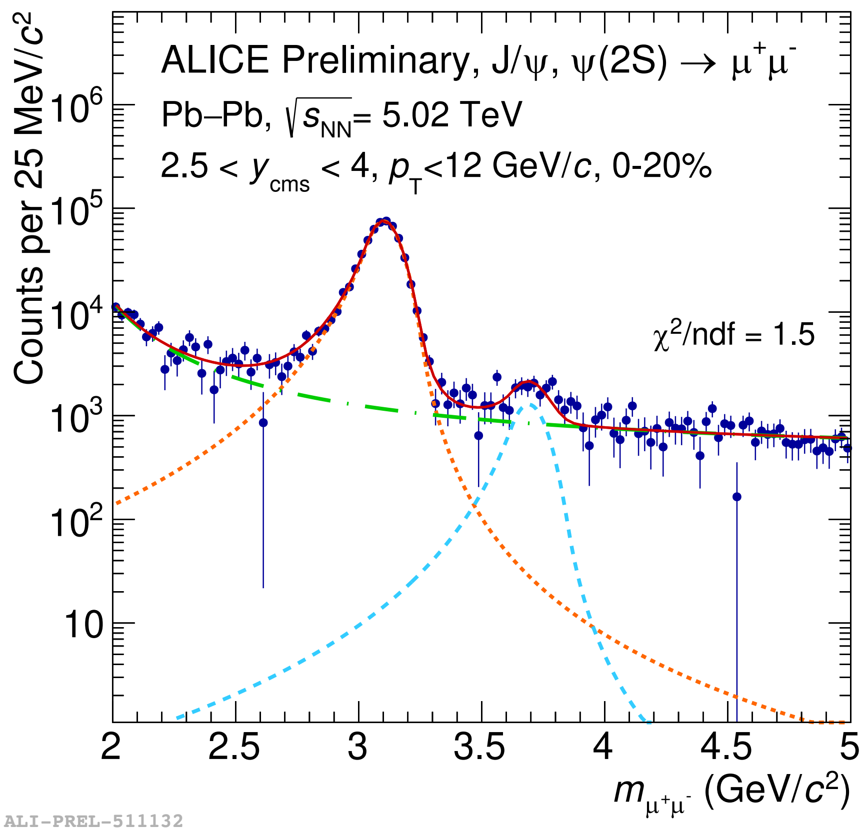
- Compatible with regeneration scenario
- Dynamic description of the dissociation in agreement

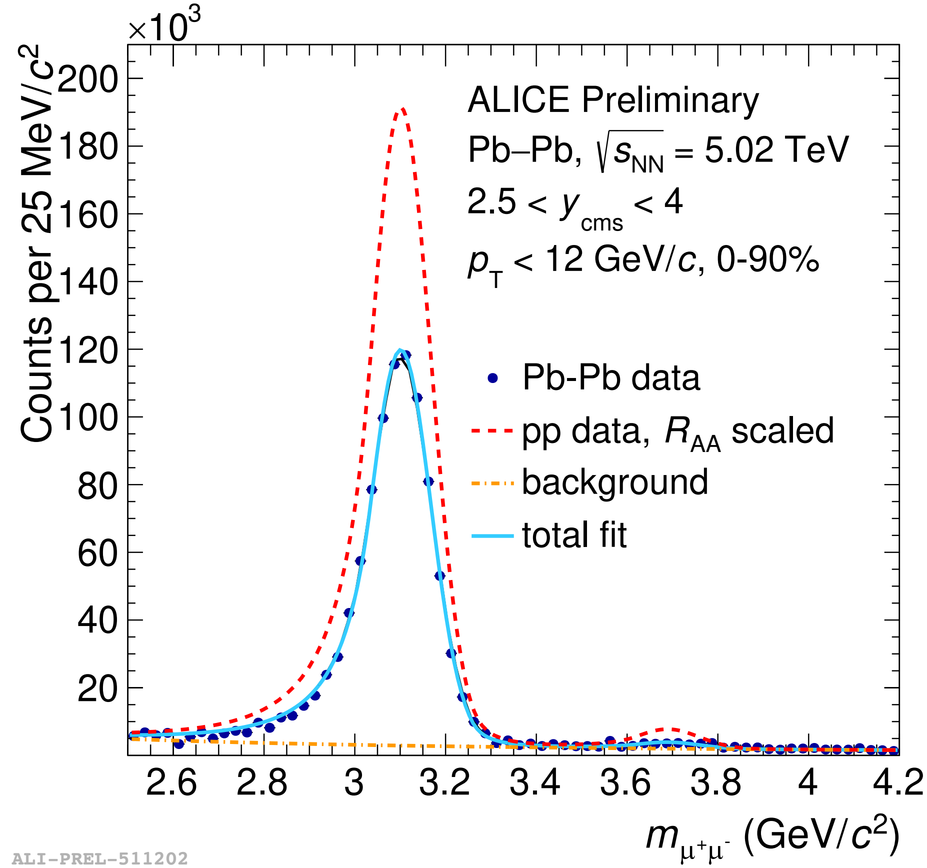


# Excited states: $\psi(2S)$

## New results with full Run 2 statistics

- Down to most central events
- Down to $p_T = 0$



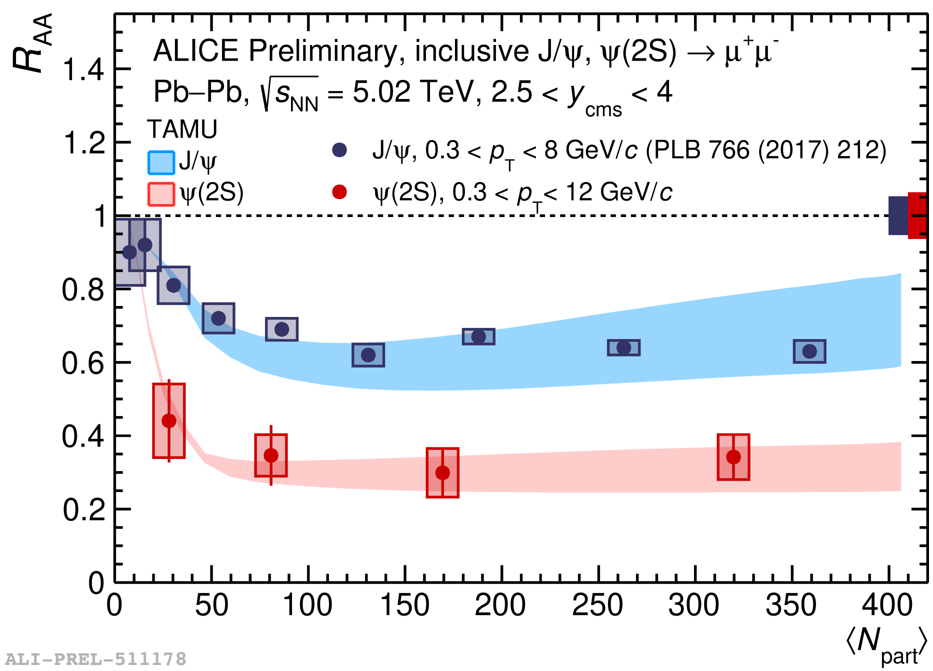



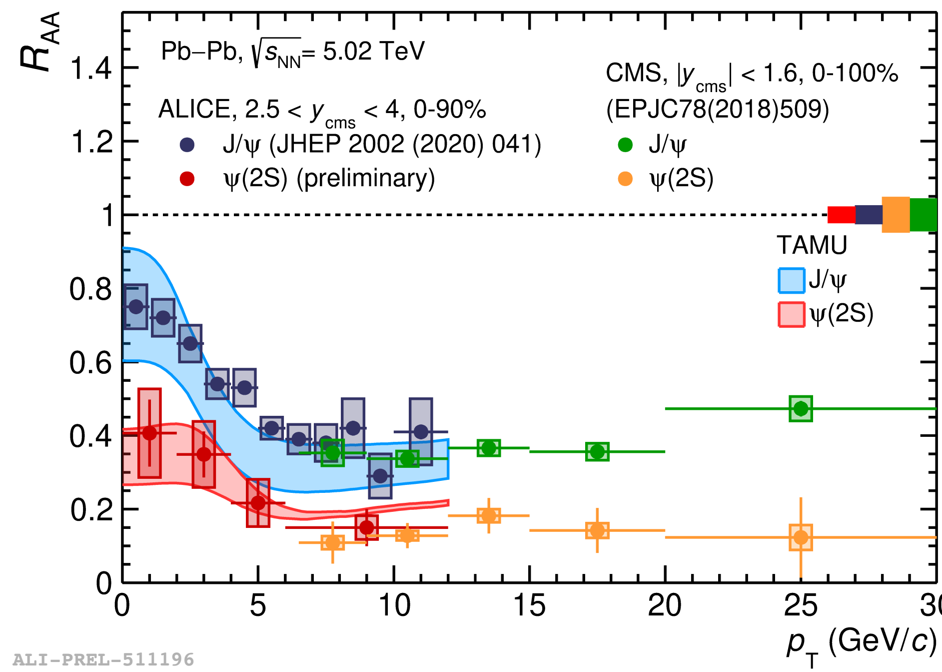
# Excited states: $\psi(2S)$



## Regeneration: quest on its origin… returns

- Higher suppression of $\psi(2S)$ compared to $J/\psi$
- Compatible with regeneration scenario (transport model shown)



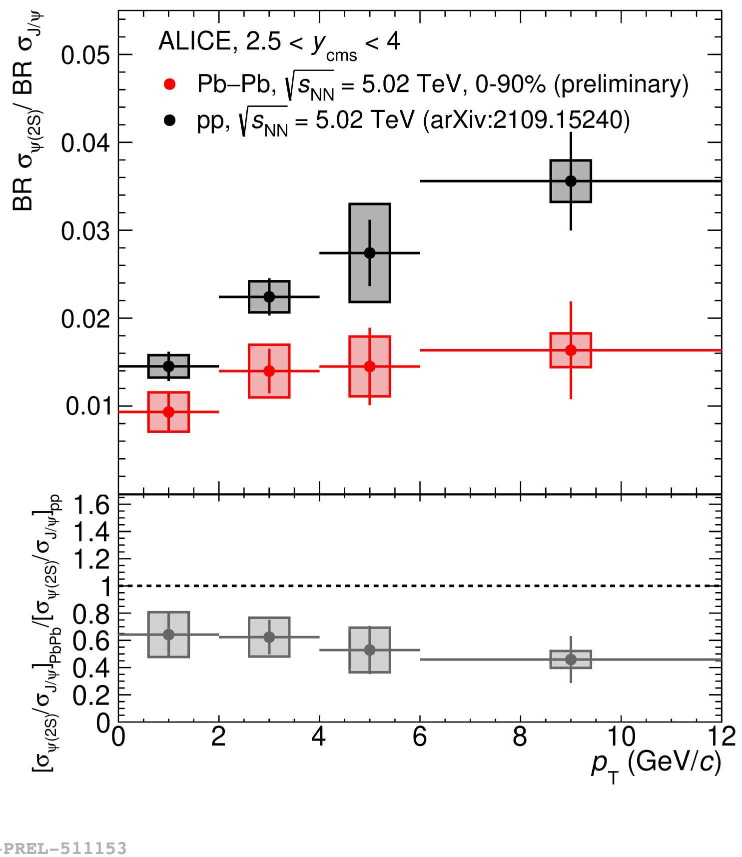

*Large uncertainties on models… can we do better?*

# *Excited states: ψ(2S)*



## Smaller uncertainties

- IS effect largely cancels for models
- Ratio theoretically weakly dependent on charm production X-sec.



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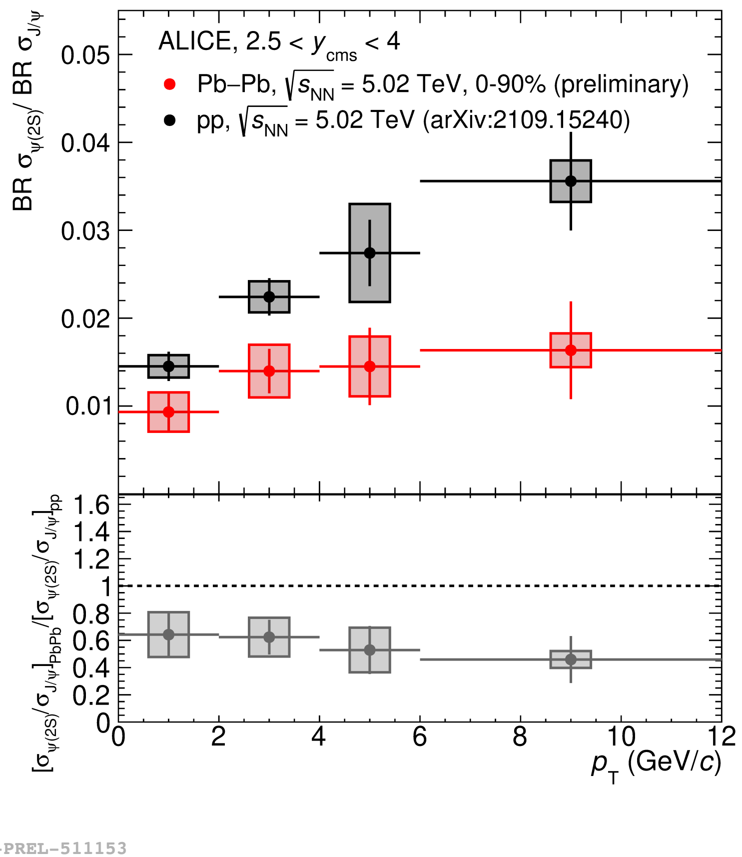
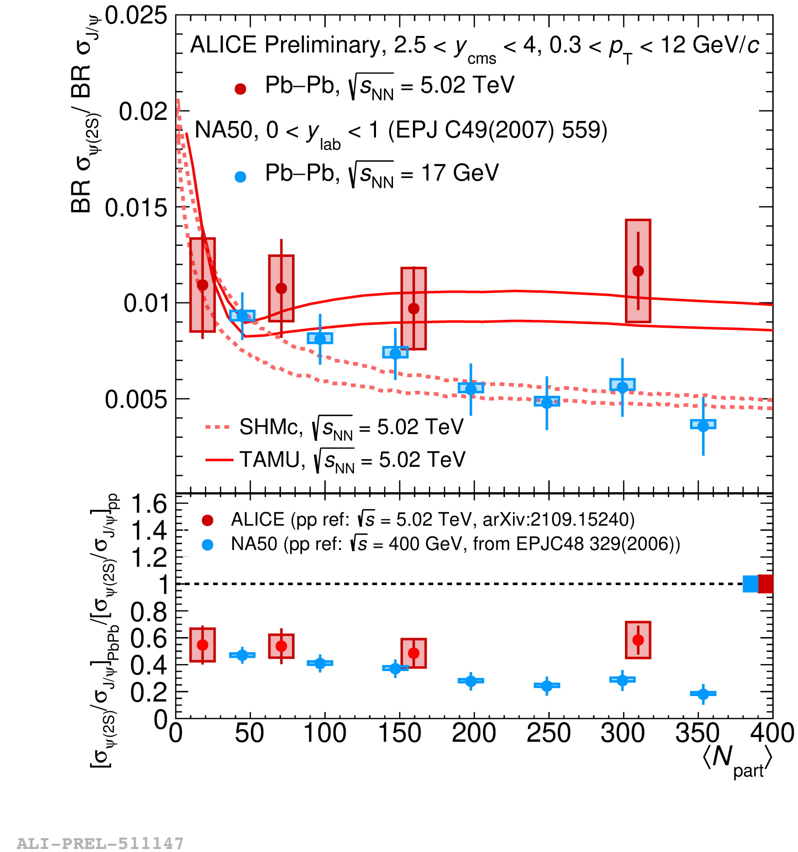


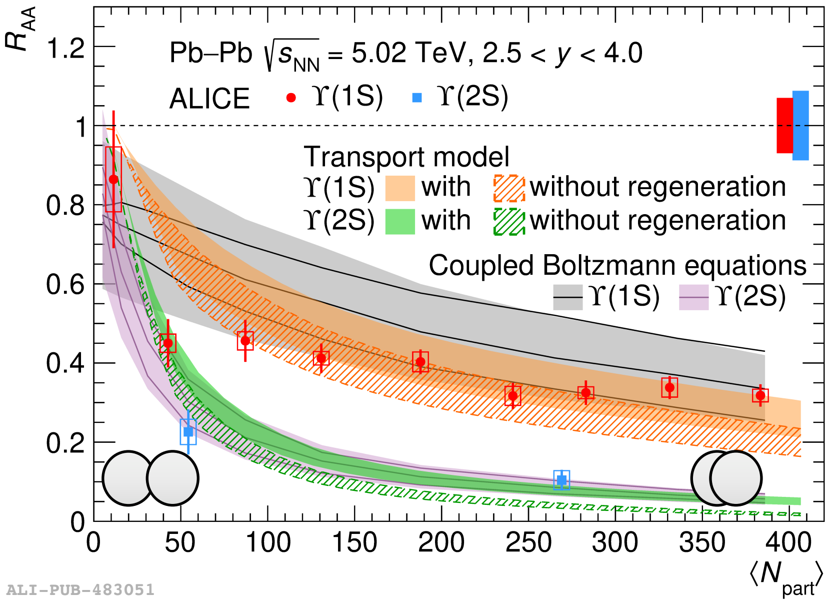



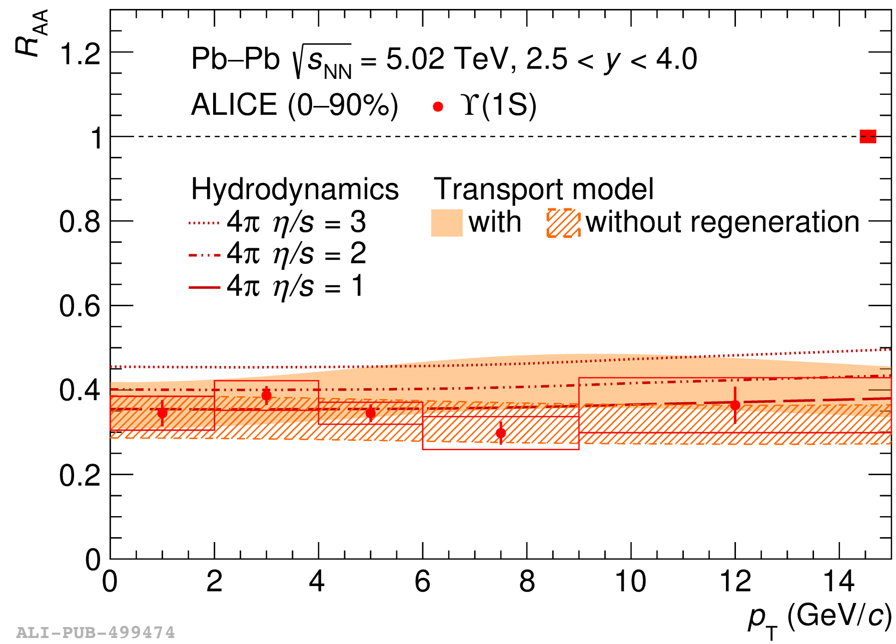
# Bottomonia production in Pb-Pb



## Weak regeneration effect for beauty

- ϒ(1S) suppressed by a factor 3 w.r.t p-p
- ϒ(2S) suppressed by a factor 2-3 w.r.t ϒ(1S)



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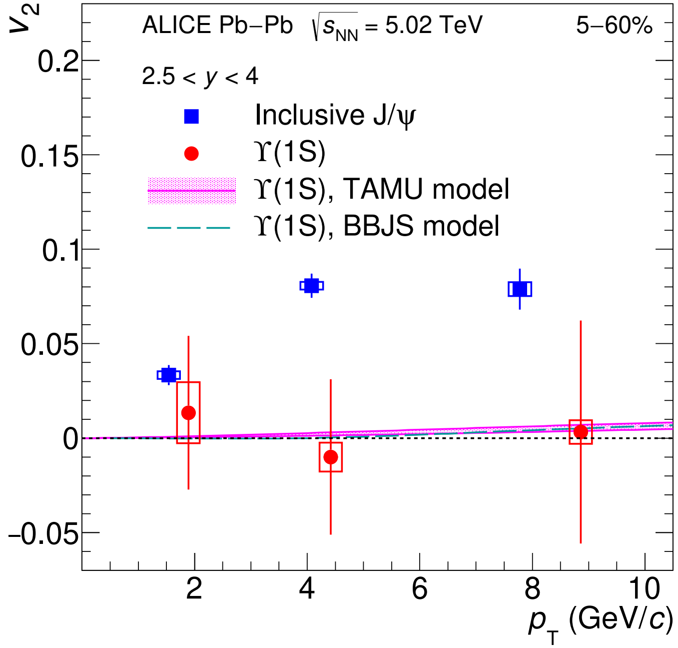
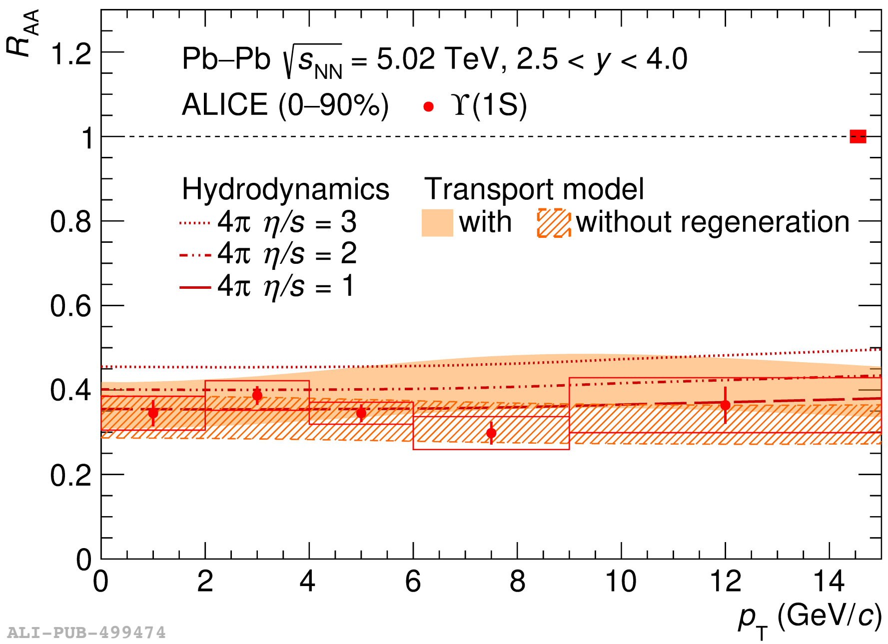


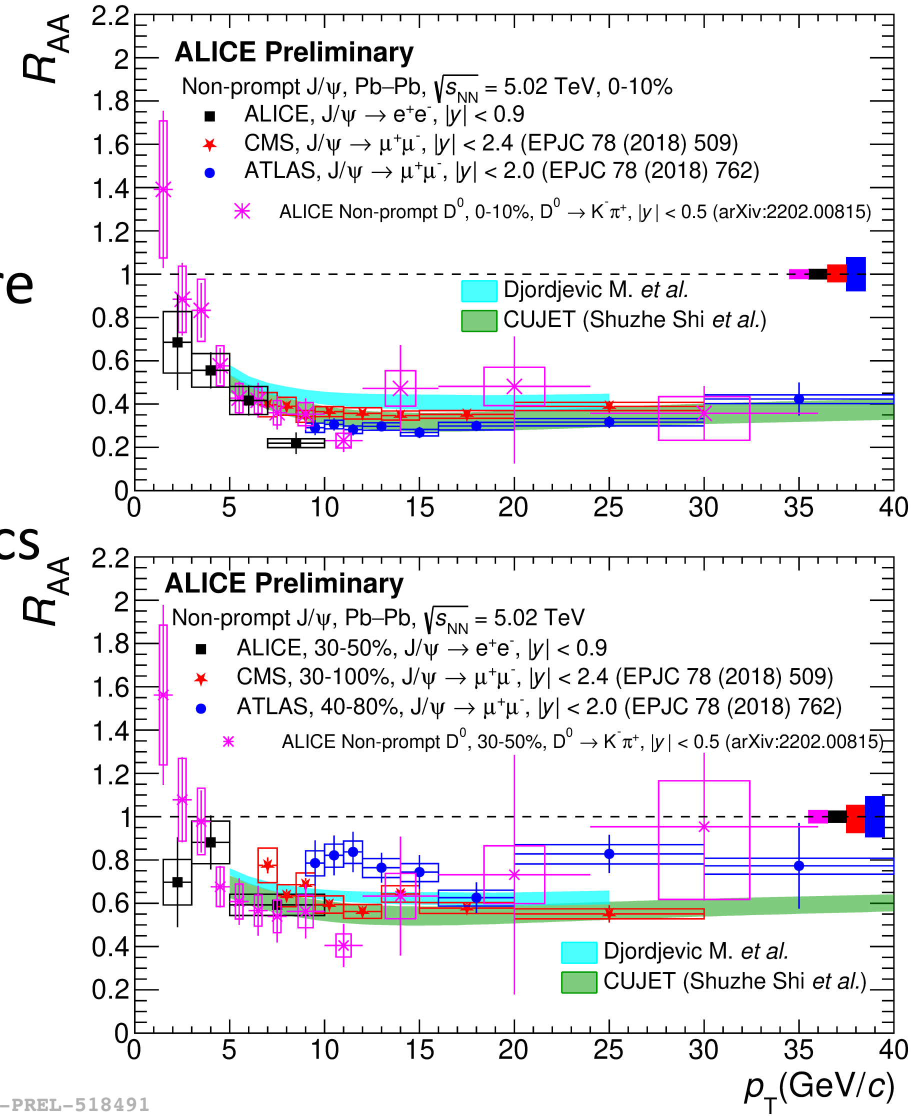




- Beauty not strongly affected by regeneration at LHC

# Beauty via non-prompt $J/\psi$

## Energy loss : charm vs. beauty

- Strong suppression at high-$p_T$
- Increases toward low $p_T$
  - hints that heavy quarks are pushed toward lower $p_T$
- Similar trend for $J/\psi$ and $D^0$
  - ≠ can arise from kinematics
- Collisional & radiative $E_{loss}$ models compatible with data



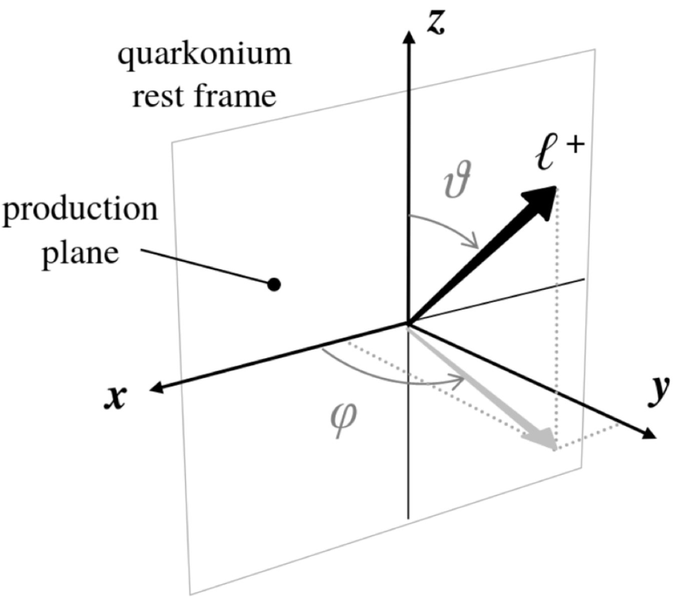
# *quarkonia* polarization : introduction



**Related to spin alignment of a particle w.r.t a given axis :**

- For a vector meson ($\boldsymbol{\nu}$), the total angular momentum ($\boldsymbol{J}, \boldsymbol{J_z}$) is :

$$|\boldsymbol{\nu}:\boldsymbol{J},\boldsymbol{J_z}\rangle = \boldsymbol{b_{+1}}|1,+1\rangle + \boldsymbol{b_0}|1{,}0\rangle + \boldsymbol{b_{-1}}|1,-1\rangle$$




- The angular distribution of the decay products is linked to the spin alignment
  - $(\lambda_\vartheta, \lambda_\varphi, \lambda_{\vartheta\varphi}) = (0,0,0)$ $\Longrightarrow$ no polarization
  - $(\lambda_\vartheta, \lambda_\varphi, \lambda_{\vartheta\varphi}) = (+1,0,0)$ $\Longrightarrow$ pure longitudinal
  - $(\lambda_\vartheta, \lambda_\varphi, \lambda_{\vartheta\varphi}) = (-1,0,0)$ $\Longrightarrow$ pure transverse

$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta} \cdot (1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi)$$

# *quarkonia* polarization : motivation

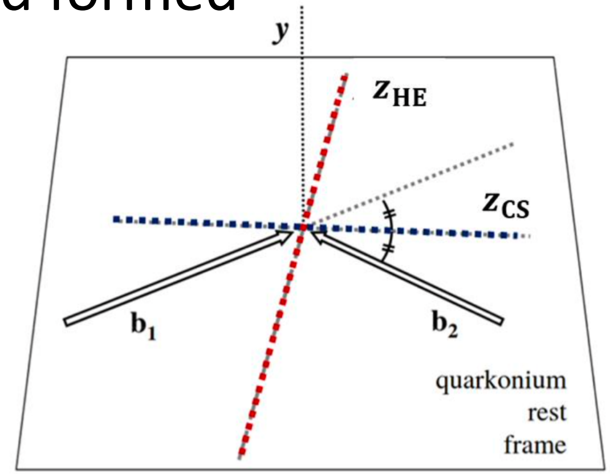


## Various interest depending on system size & centrality

- Bring constraints to production mechanisms, NRQCD in pp
- Sensitive to the feed-down contribution & regeneration in central AA
- In non-central events, polarization is sensitive:
  - to the large angular momentum due to the rotating medium
  - the short-living but huge magnetic field formed

## Reference frames:

- **Helicity (HE):** direction of the vector meson in the collision c.m. frame
- **Collins-Soper (CS):** bisector of the angle between beams in the vector meson rest frame

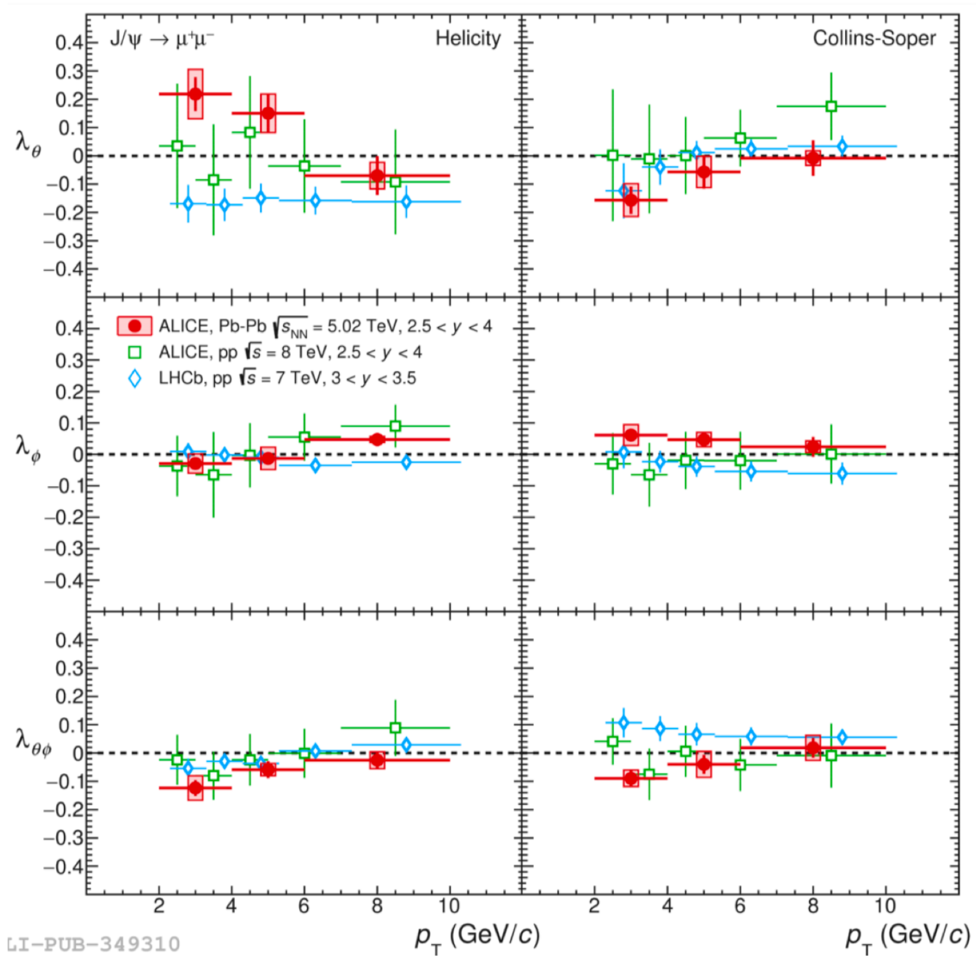


# $J/\psi$ polarization



## Small differences between pp & PbPb:

- Up to $3\sigma$ in HE compared to LHCb
- Can it be due to regeneration/suppression ?
- Role of the angular momentum and of the magnetic field ?

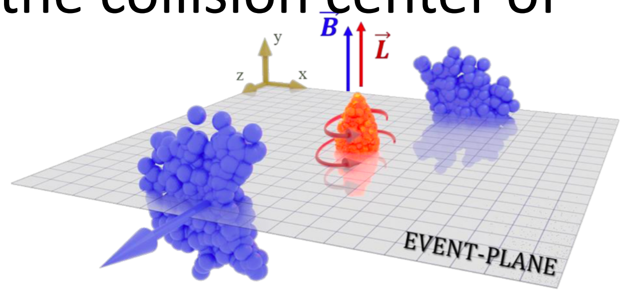


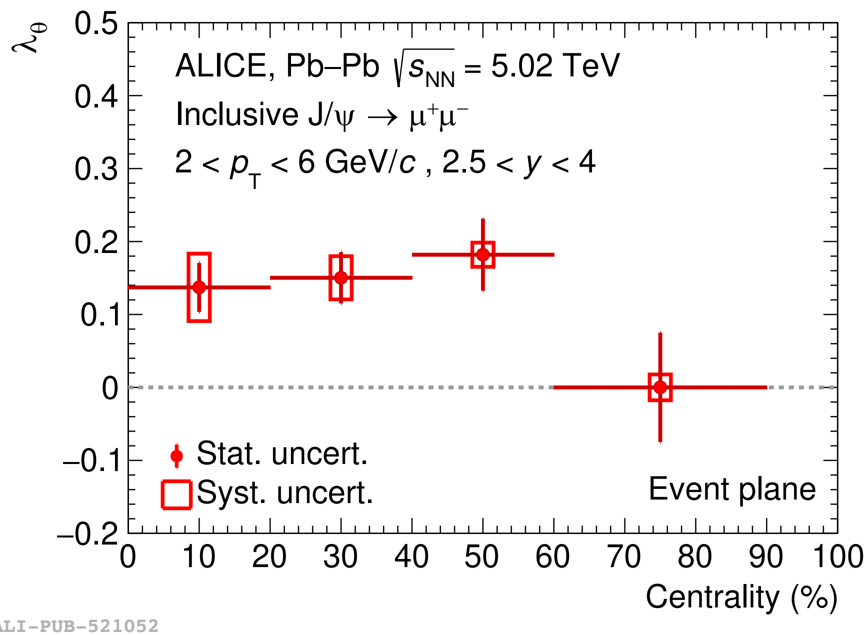
# J/$\psi$ polarization in EP frame

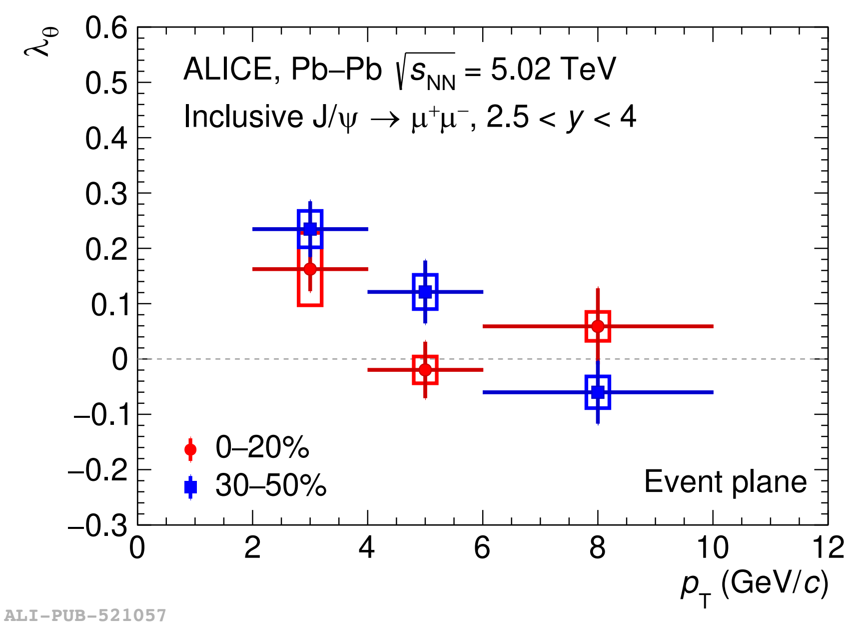


## New measurement using an Event Plane (EP) based frame

- Axis orthogonal to the Event Plane in the collision center of mass frame
- > 3.5 $\sigma$ deviation from 0 observed
- Full theoretical description needed



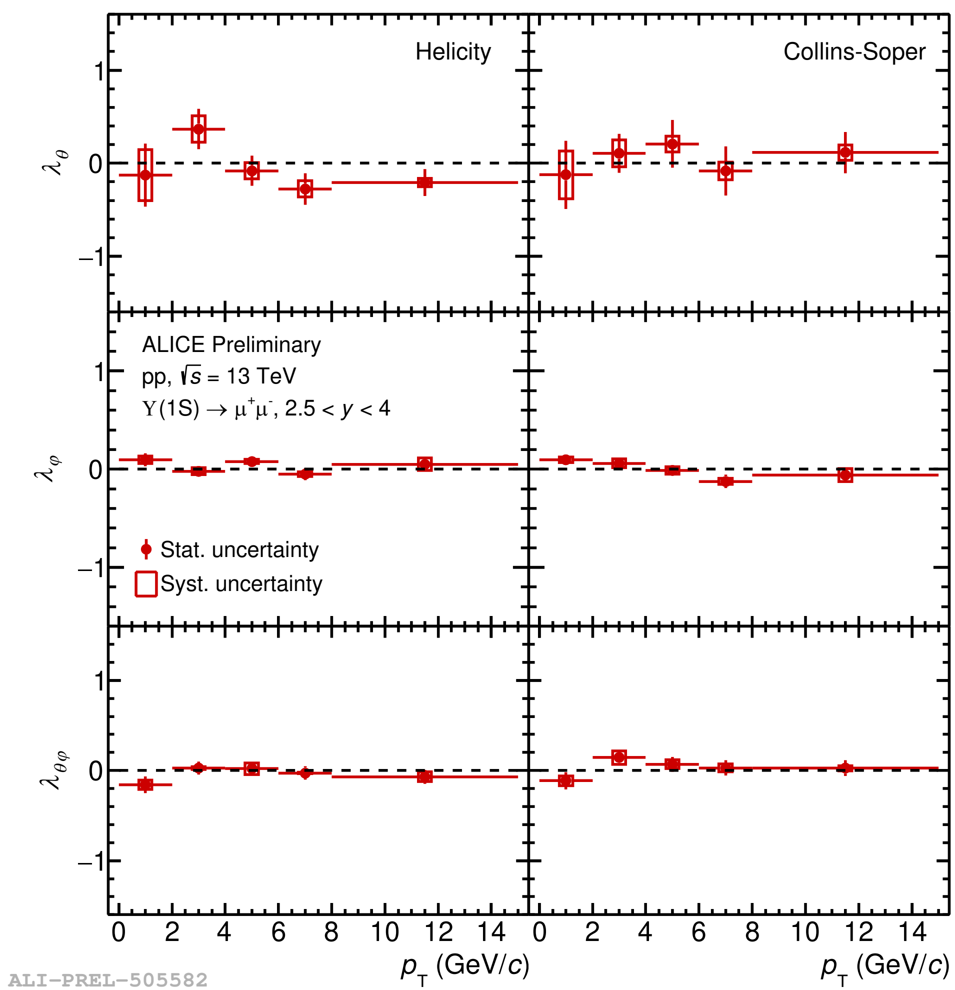



# $\Upsilon(1S)$ polarization



## No polarization and no $p_T$ dependence in pp

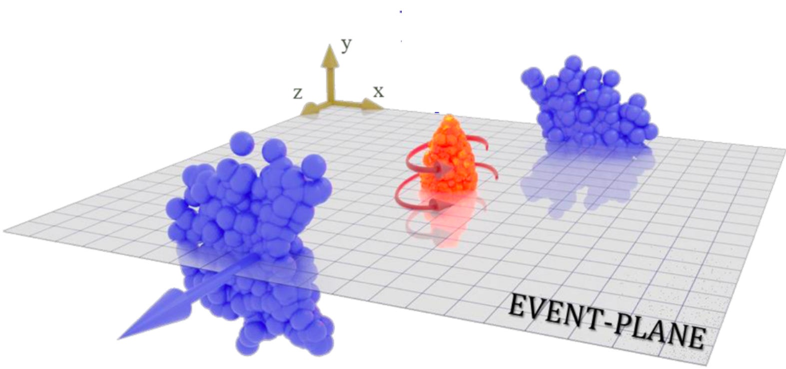


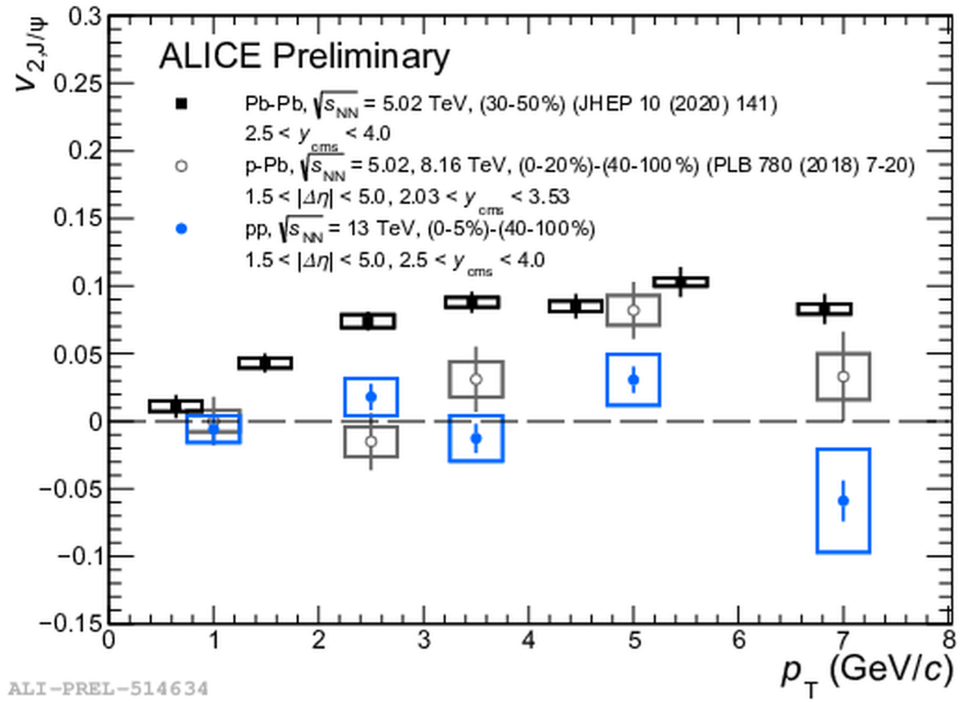
# $J/\psi$ flow in small systems



## Collectivity in small system

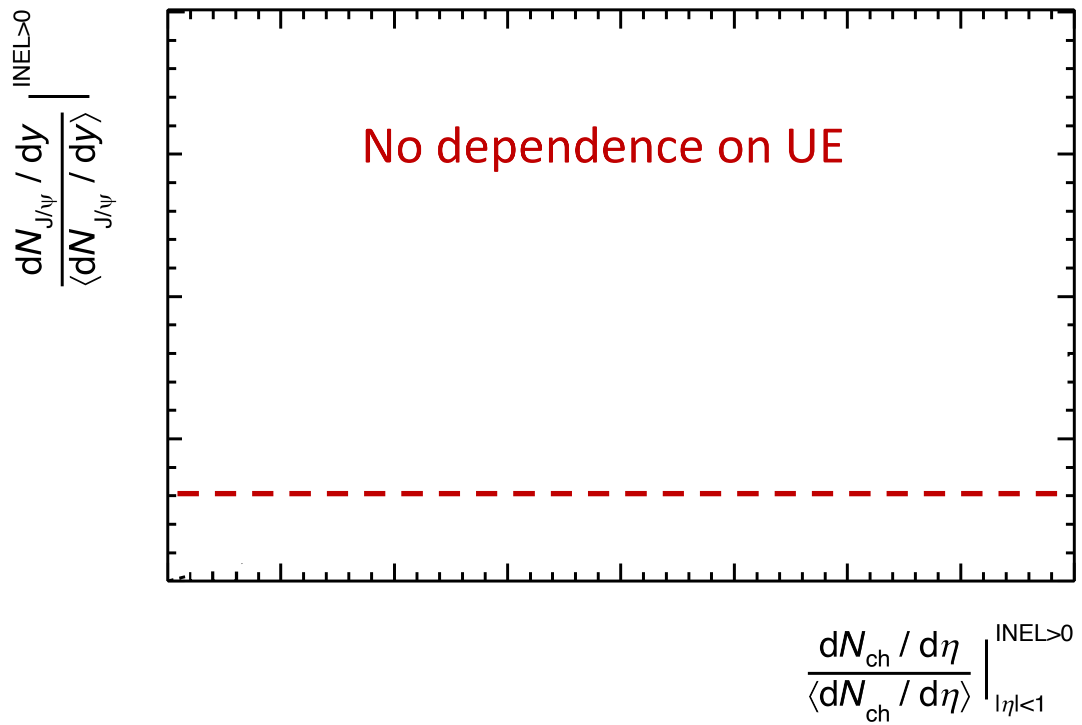
- Finite $v_2$ measured in pPb
- Similar pattern compared to PbPb and light flavors
- 1st attempt to measure $v_2$ in pp down to 0 $p_T$ with ALICE
  - Compatible with 0 despite significant signal in the light flavour sector



# MPI as the based mechanism to produce collectivity

- Another way to look at collectivity in small systems
- What should we expect ?



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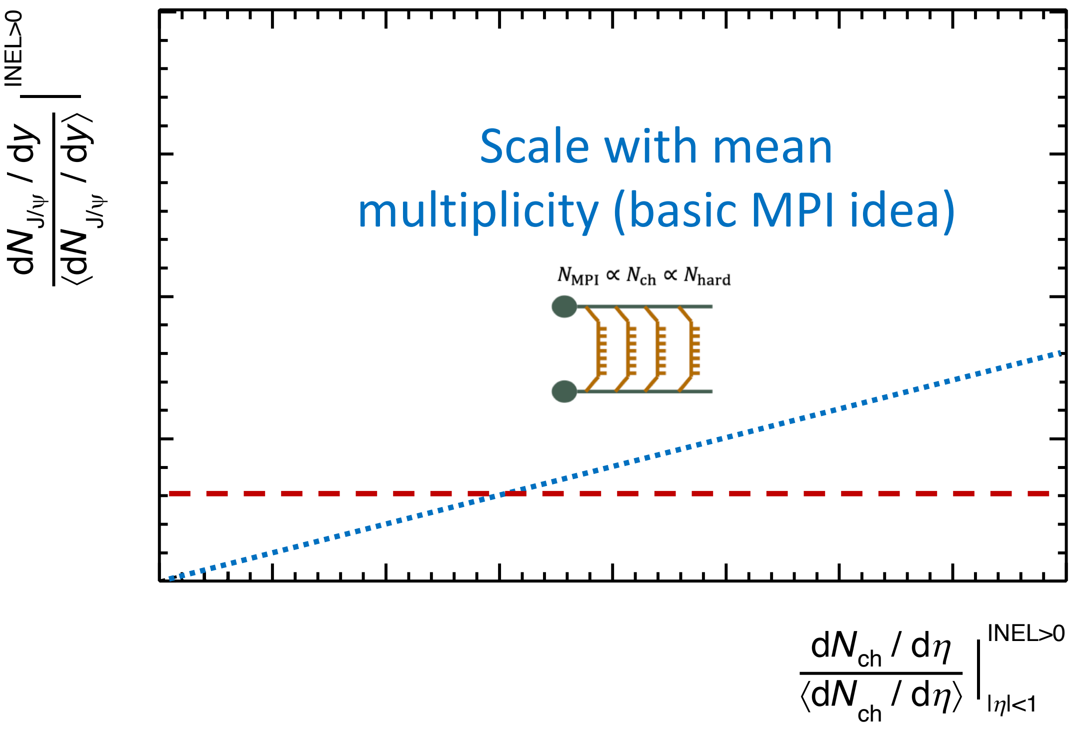

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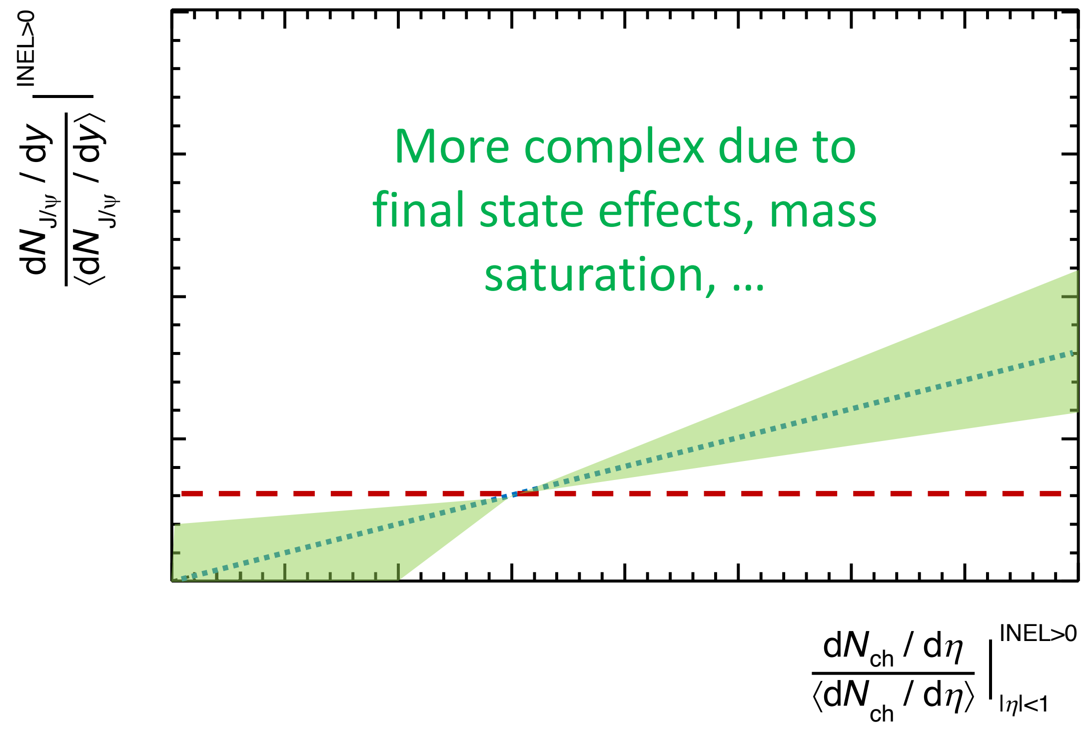
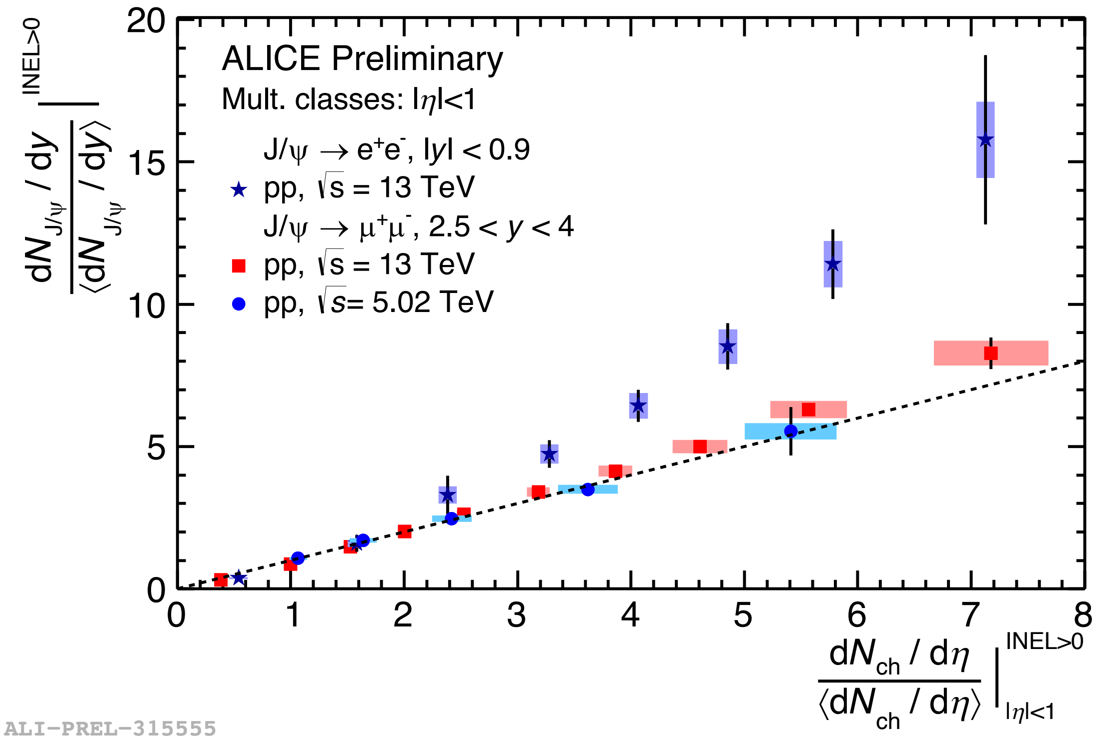


# $J/\psi$ puzzle !



## Non trivial correlation in ALICE central barrel

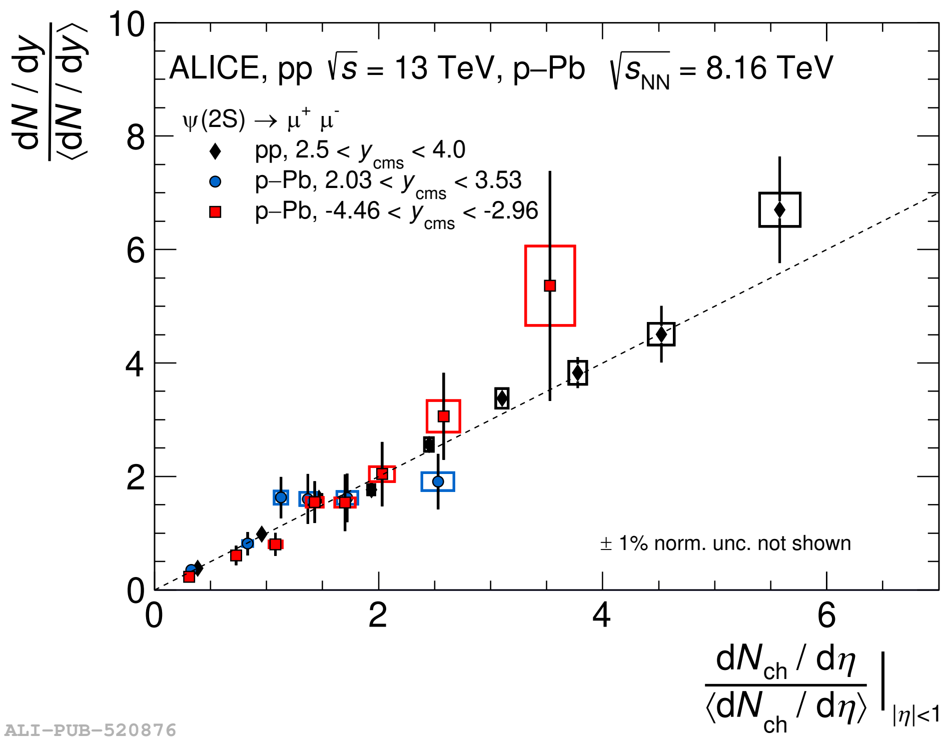
- No model able to reproduce this qualitatively
- Important to understand the interplay soft-hard here
- More results for other systems and particles

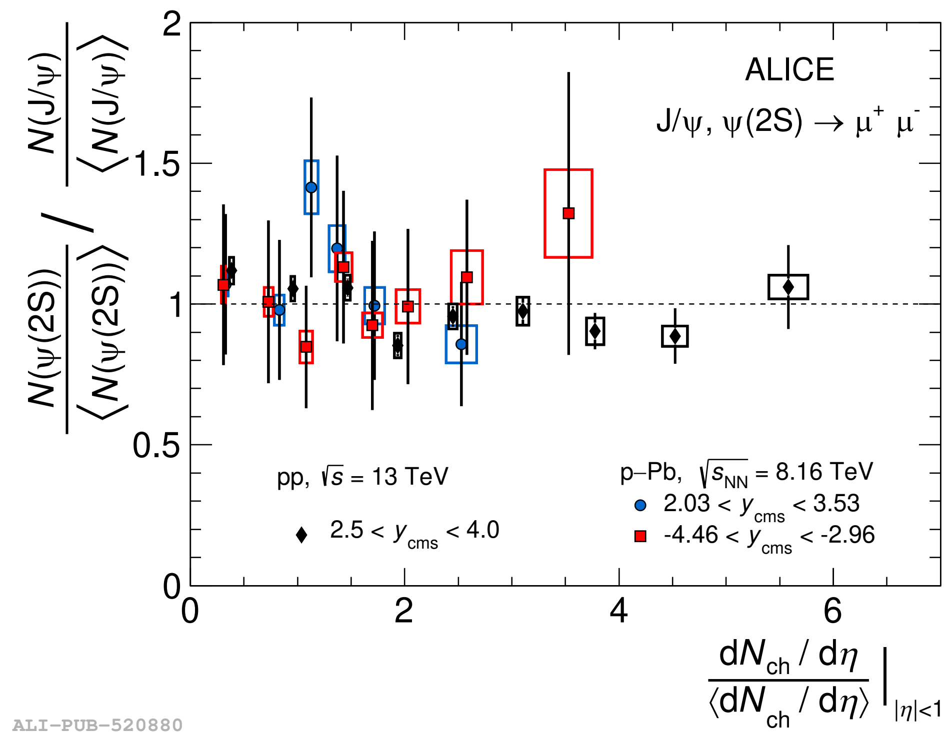


# What about the $\psi(2S)$ at forward ?

## Non trivial correlation in ALICE central barrel

- linear increase for $\psi(2S)$ normalized yield vs. multiplicity
- flat behaviour for $\psi(2S)$ / $J/\psi$ ratio vs. multiplicity
- Same behaviour regardless of the system size



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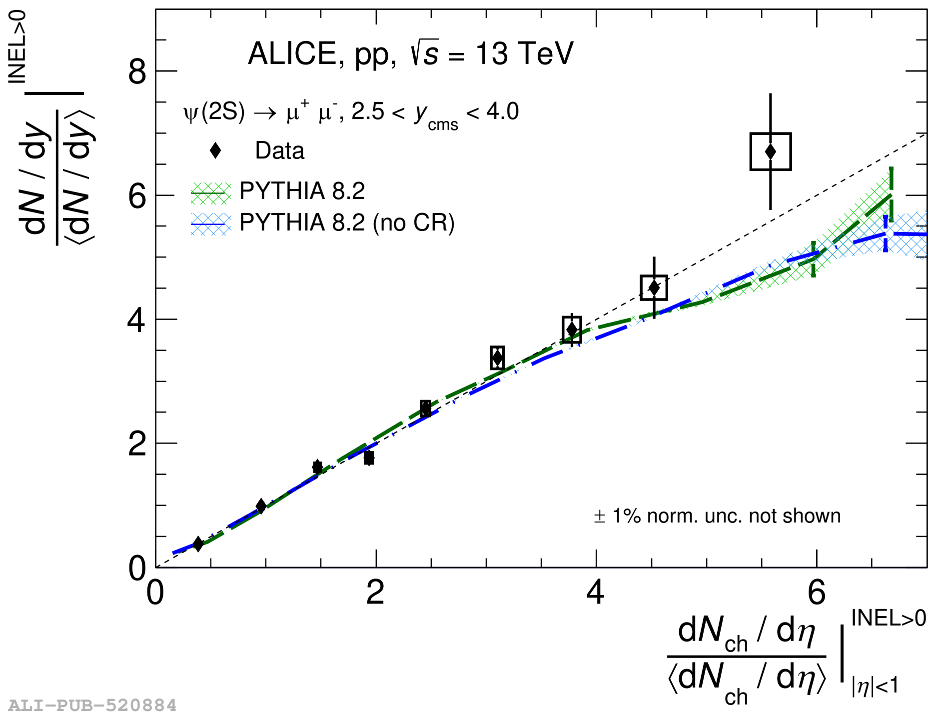
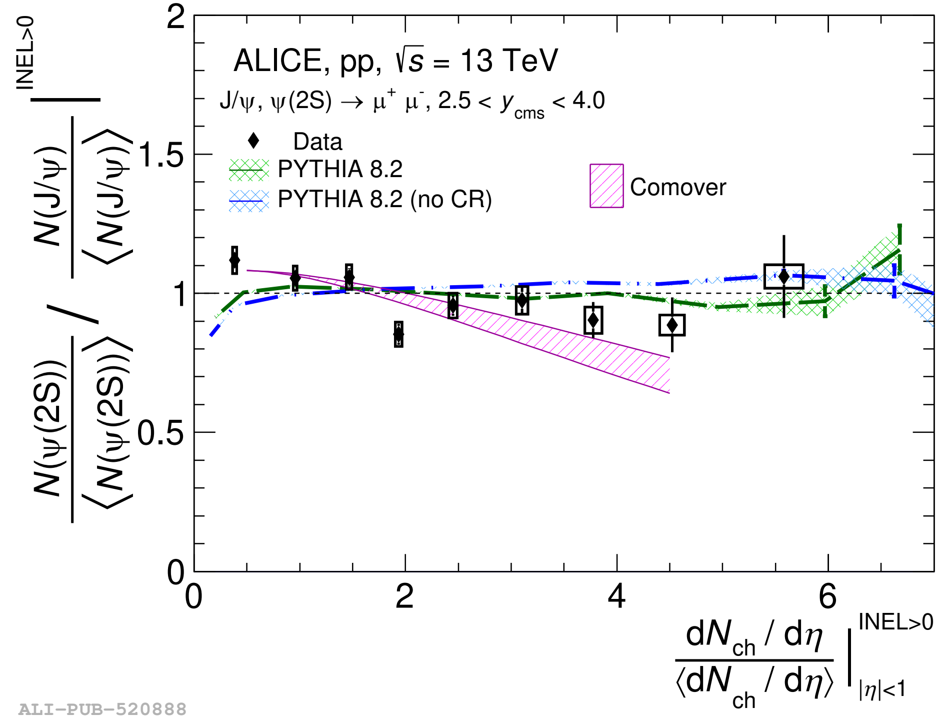
- linear increase for $\psi(2S)$ normalized yield vs. multiplicity
- flat behaviour for $\psi(2S)$ / J/$\psi$ ratio vs. multiplicity
- Same behaviour regardless of the system size
- Models: agreement at low mult. / tension at high mult.



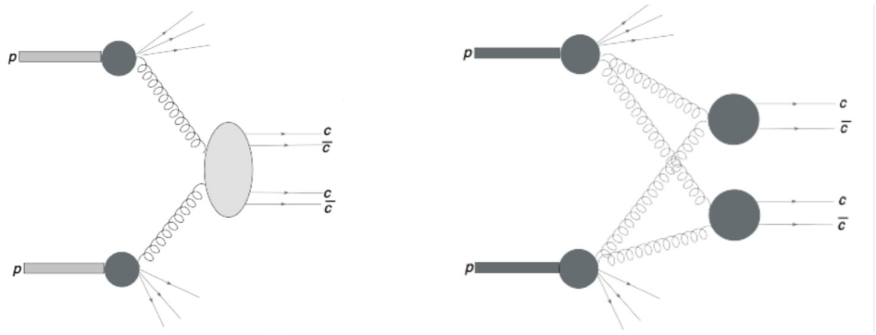



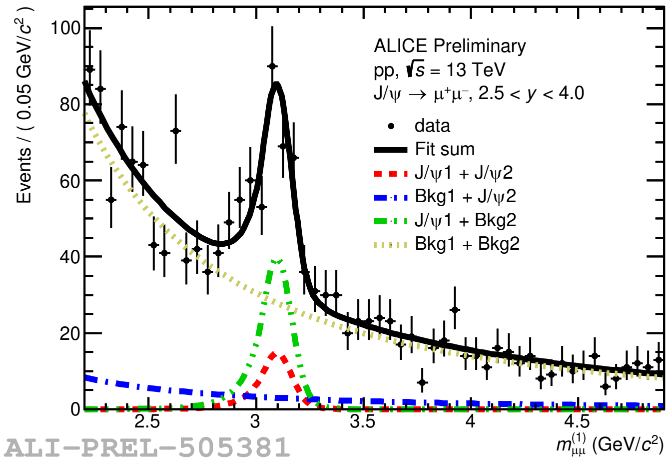
# $J/\psi$ pair production

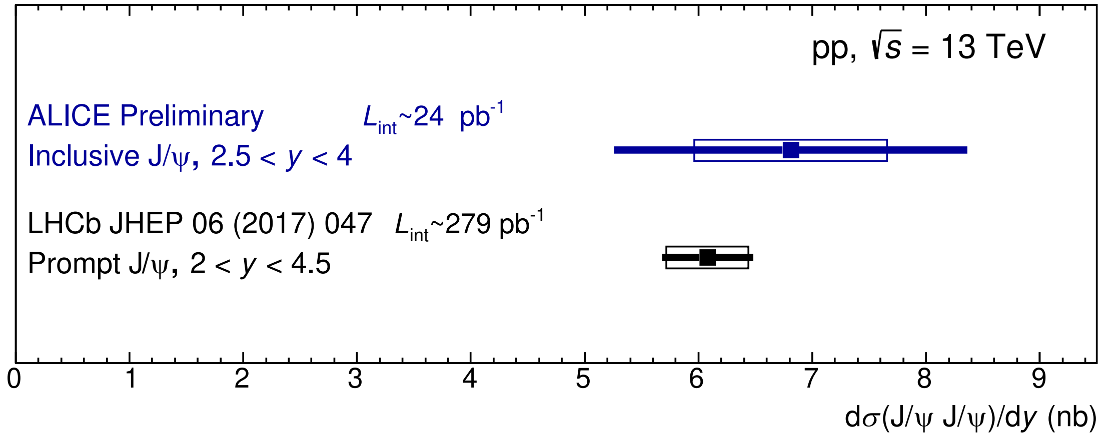
## Non trivial correlation in ALICE central barrel

- Constraint on:
  - DP scattering
  - $J/\psi$ production, NRQCD
- Good agreement w/ LHCb
  - ALICE is inclusive
  - ≠ acceptances

*AIP, 1523 (2013) 1*





# Conclusion



## Suppression / Regeneration

- All results consistent so far with strong regeneration at LHC
- Underlying mechanism (when does the regeneration occurs) is still to be understood
  - High precision ground-to-excited state ratio may help
  - SHM has difficulty to reproduce the current data

## Polarization

- Significant polarization observed in PbPb for J/$\psi$ in HE and EP frame
- Full theoretical description is still missing

## Small system

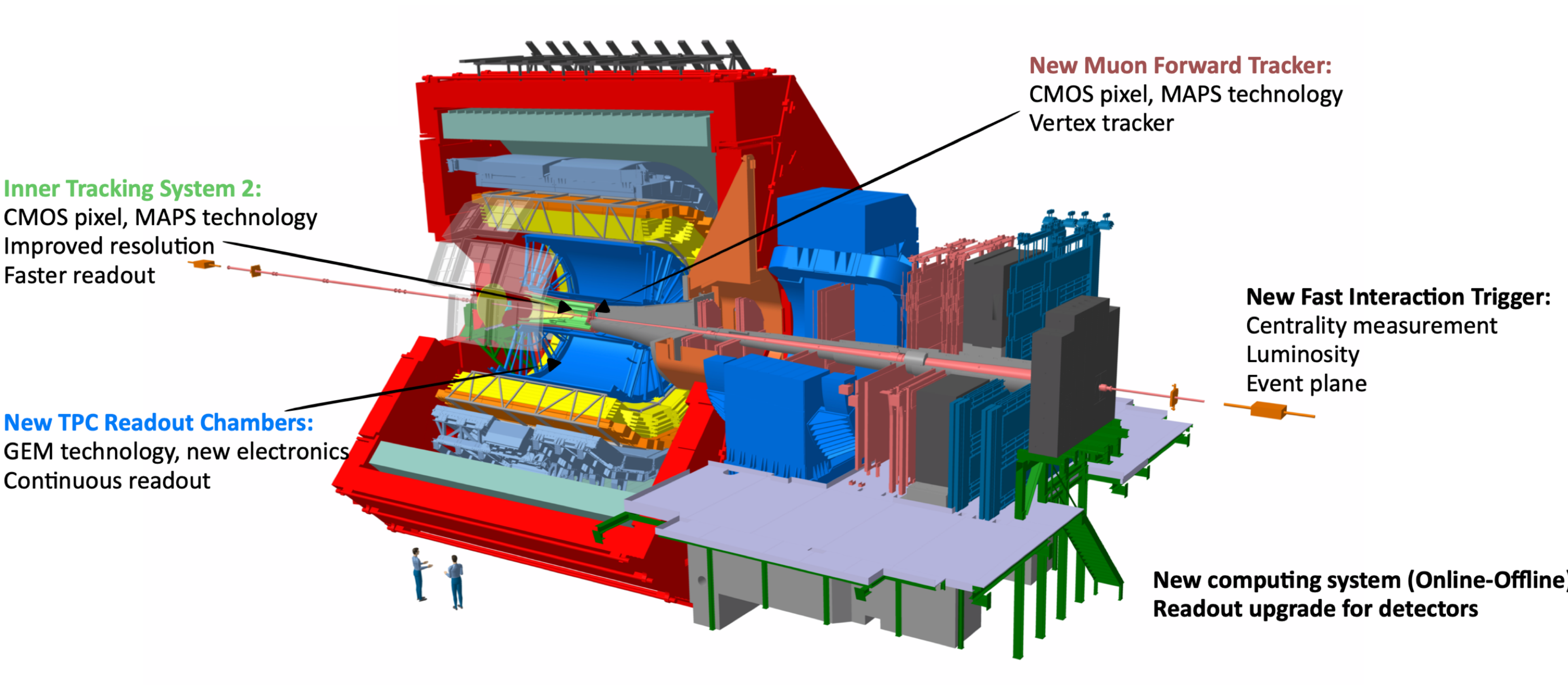
- J/$\psi$ flow compatible with 0 and
- Quarkonia production multiplicity dependence seems to scale with multiplicity: standard MPI scenario

# RUN 3 prospective



## Increased luminosity :

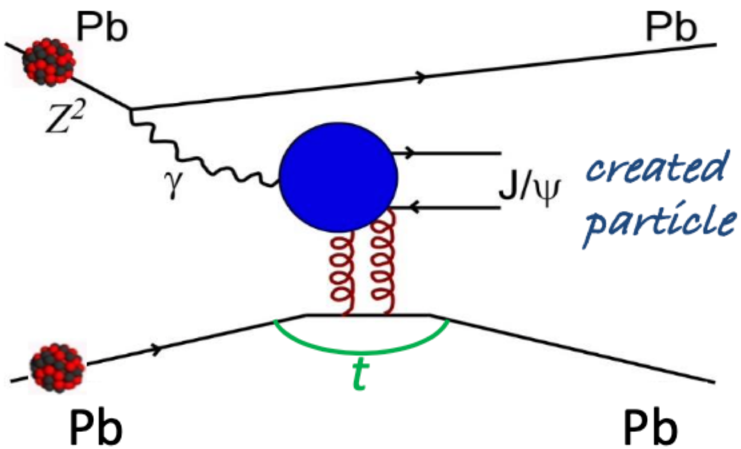
- in AA a factor 10-100 can be expected depending on the observable



# Backup

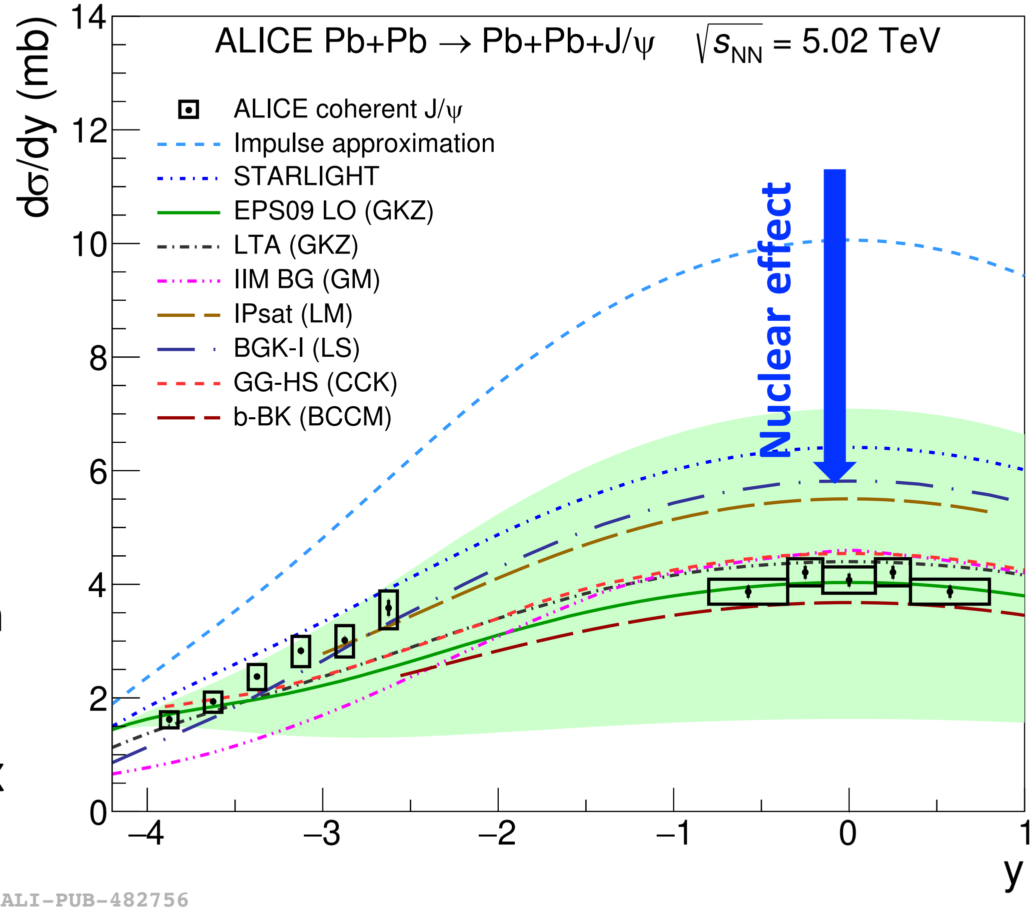
# J/Ψ coherent photoproduction in Pb-Pb UPC events

- Probing nuclear gluon density




  - Cross section sensitive to gluon distribution function

- New measurement probes low-x gluon nuclear PDFs
  - Extracted gluon shadowing factor: $R_g = 0.65 \pm 0.03, x \sim 10^{-3}$



# $J/\Psi$ low-$p_T$ excess in Pb-Pb

**Extraction as a function of centrality down to 30-50%**

- Measurement of coherent J/Ψ photoproduction
- May open the door for new probes for QGP