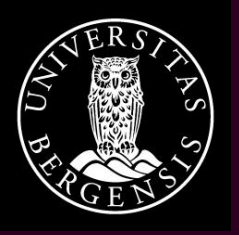


ALICE Physics Results

Alexander Bylinkin

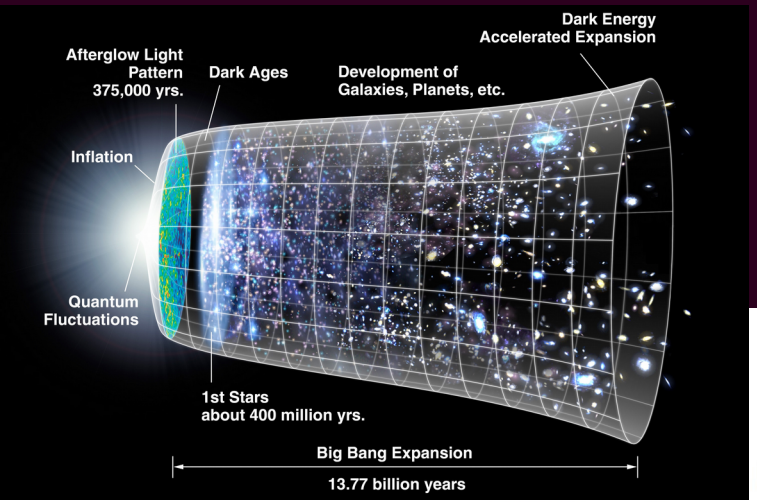
The University of Bergen

NorCC Workshop, 27-28 September 2023, Bergen, Norway

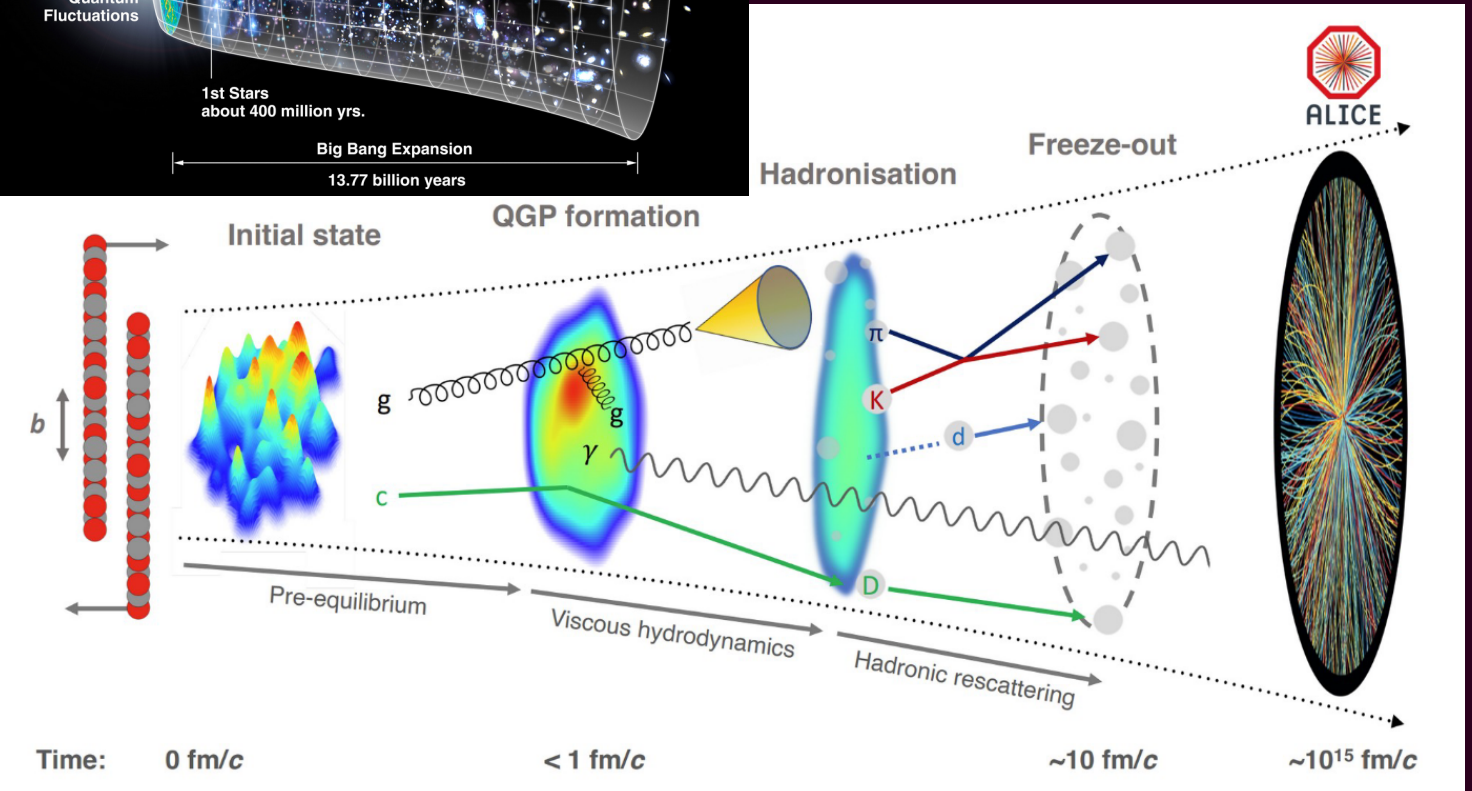
Outline

- Introduction
- ALICE Detector
- Charmonium production
  - p-p collision
  - Pb-Pb collisions
  - Peripheral Pb-Pb Collisions
- Ultra-Peripheral Collisions
  - Exclusive four pion production
  - Plans for Run 3 analyses
- Summary

Relativistic Heavy-Ion Collisions



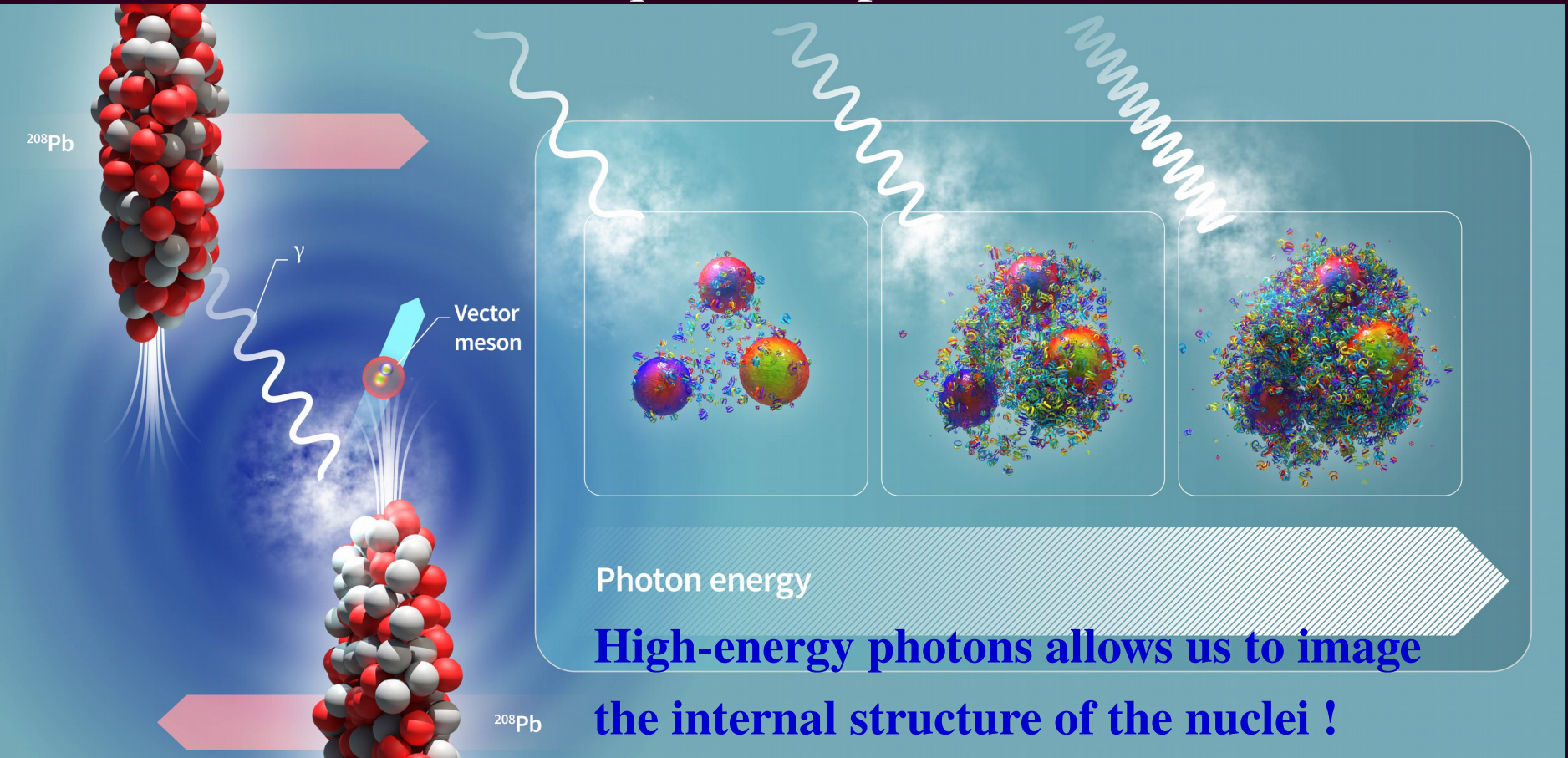
- With heavy-ion collisions we aim to reproduce the conditions existed a few moments after the Big Bang.
- Hot and dense matter form the Quark-Gluon Plasma (QGP).



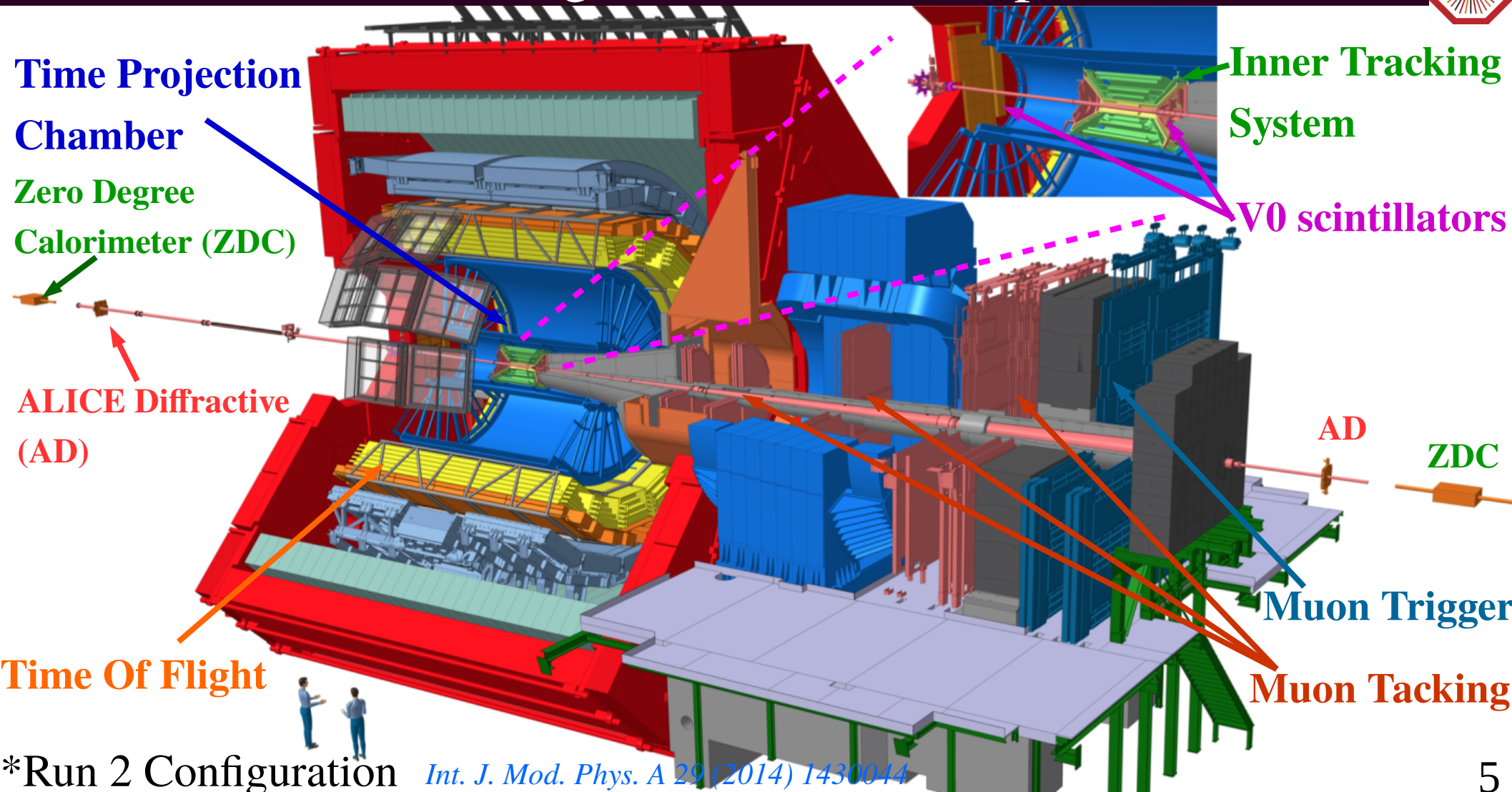
- Experimentally we measure only the remnants of the QGP decay.
- All stages of the nuclear collision need to be understood simultaneously.
- Ultra-Peripheral Collisions (UPCs) give us understanding of the initial state of the nuclei.

Ultra-Peripheral Heavy-Ion Collisions

- Ultrarelativistic moving nuclei produce strong electromagnetic fields that can be treated as a quasi-real photons flux



ALICE (A Large Ion Collider Experiment)



*Run 2 Configuration

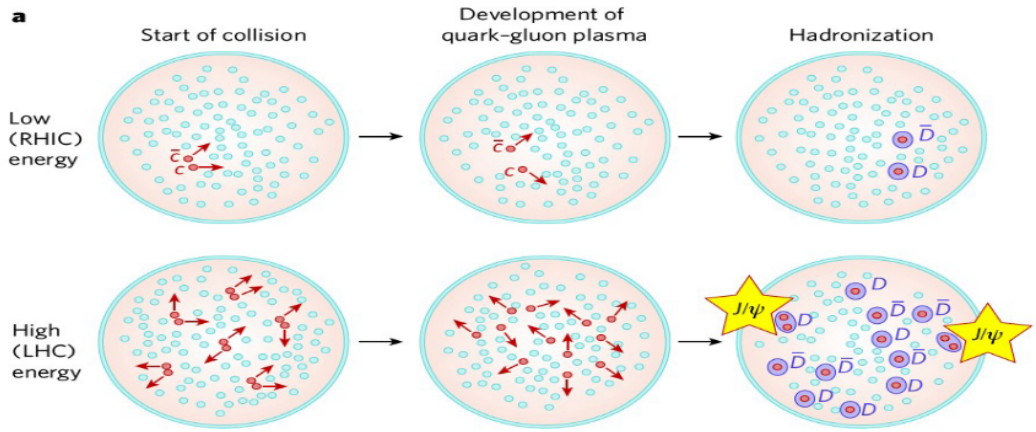
Int. J. Mod. Phys. A 29 (2014) 1430044

Runs 3 & 4 Outlook

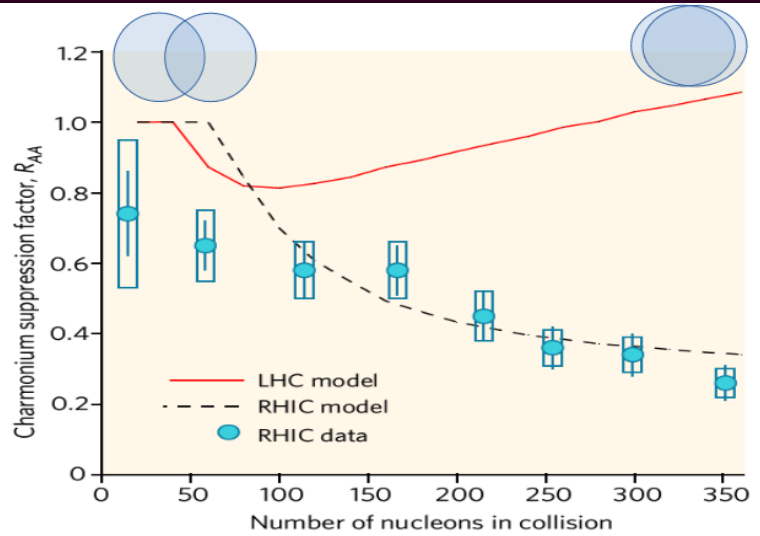
- Continuous readout → higher data collection efficiency
- Siginificant detector upgrades
- ***L*** increase **Run 3 and 4**:
  - → Pb-Pb: ~13 nb^{-1} (> 10x current ALICE lumi at mid-y) !!
  - → p-Pb: ~0.6 pb^{-1}
  - → p-p: ~200 pb^{-1} (using High Level Triggers)
- ALICE Norway is involved in some of the main physics topics and instrumentation projects, as well as computing & software upgrade:
  - New analysis-level trigger will allow to increase p-p data sample by a factor of a few 1000s in the central barrel.

Heavy quarkonium production in QGP

- Heavy quarkonium (e.g. J/ψ) is suppressed in a deconfined medium due to **colour screening** and the **dynamic dissociation**



$$R_{AA} = \frac{1}{N_{coll}} \frac{Y_{AA}}{Y_{pp}}$$



Braun-Munzinger and Stachel, Nature 448 (2007) 302-309

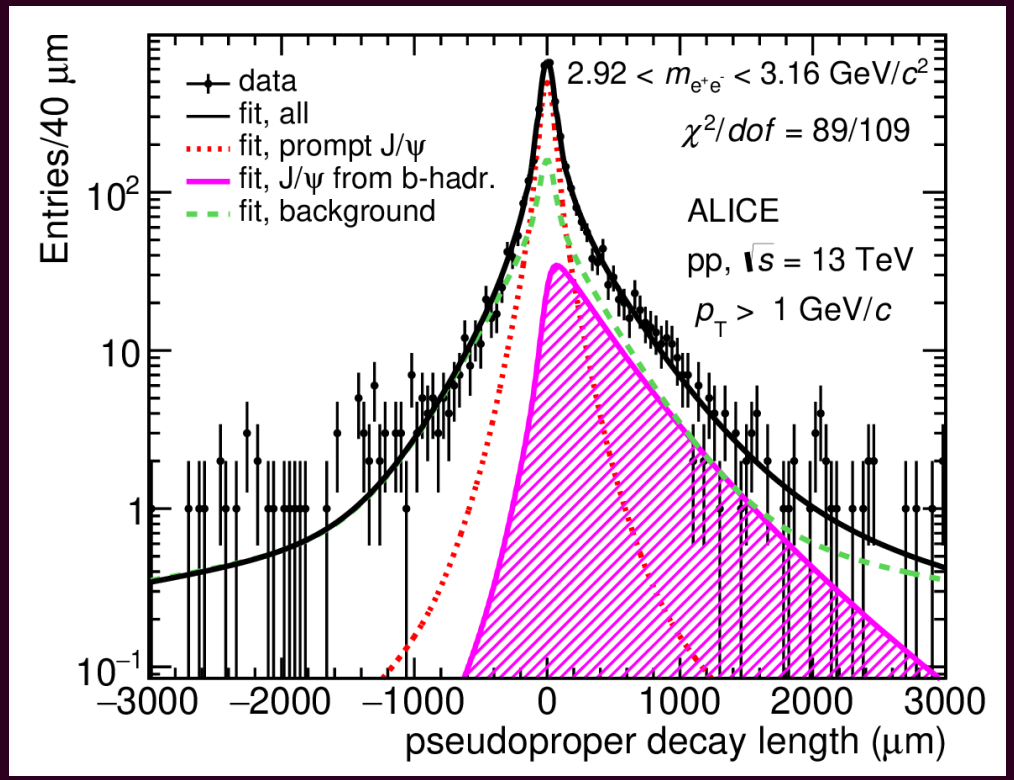
- Charmonium can be produced on a statistical basis, during the system evolution
  → enhancement of charmonium states at the LHC

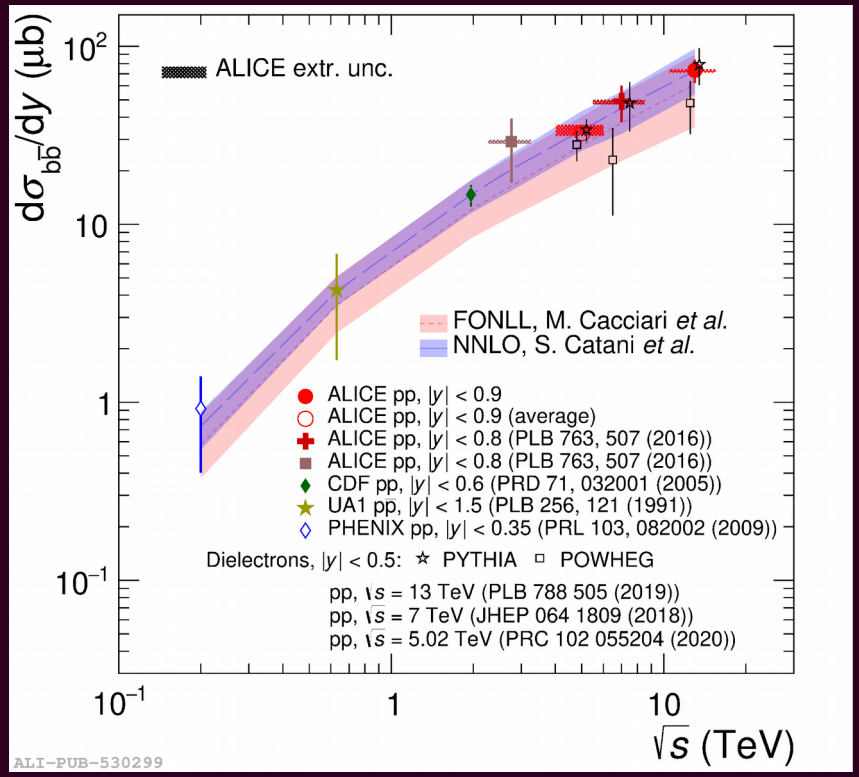
Braun-Munzinger and Stachel, PLB 490 (2000) 196

Thews et al., PRC 63 (2001) 054905

J/ψ production in p-p

- Provide the important vacuum reference and stringent test for QCD calculations



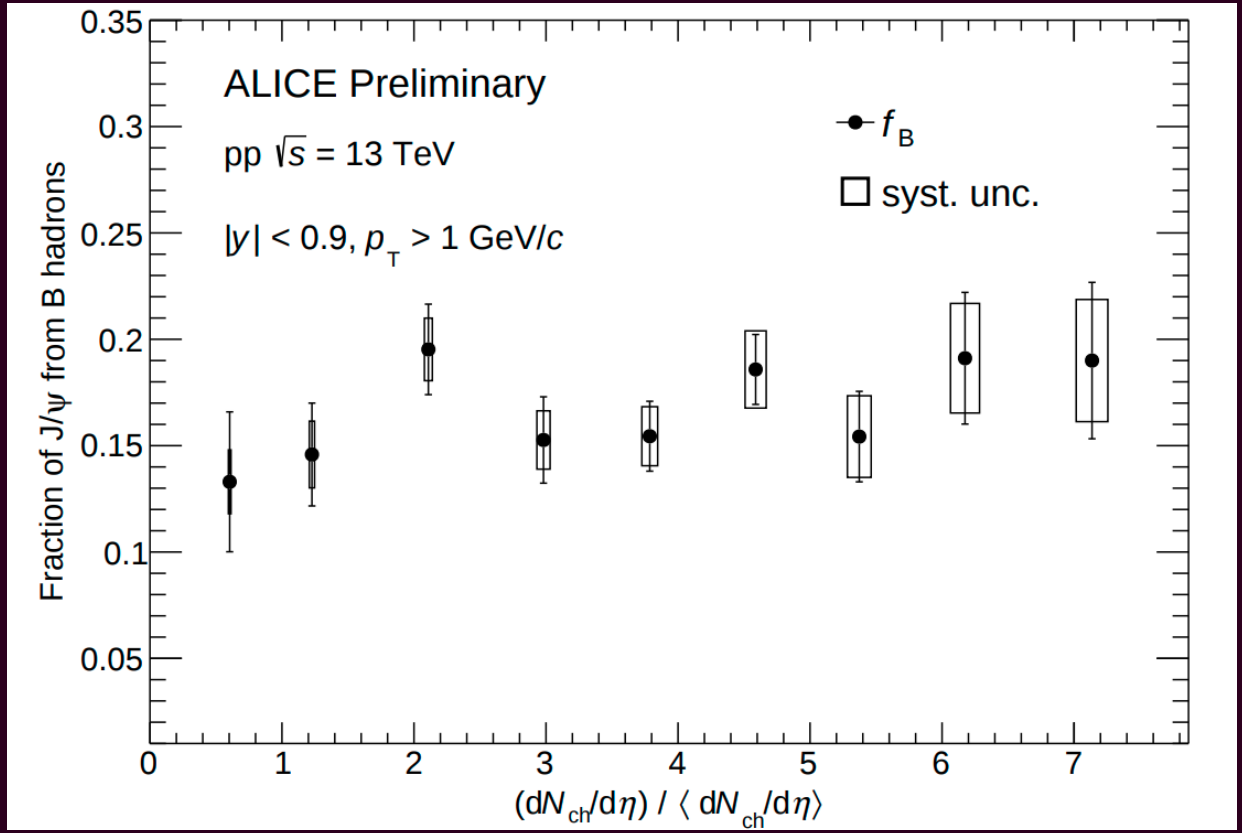


- Prompt J/ψ production – directly from a "charm" quark-antiquark pair
- Non-promt J/ψ production – from the decays of "beauty" hadron

  → Also a good tool to study the production of beauty-flavour

J/ψ production in p-p as a function of multiplicity

- Understanding J/ψ production in various conditions is essential for a good reference.

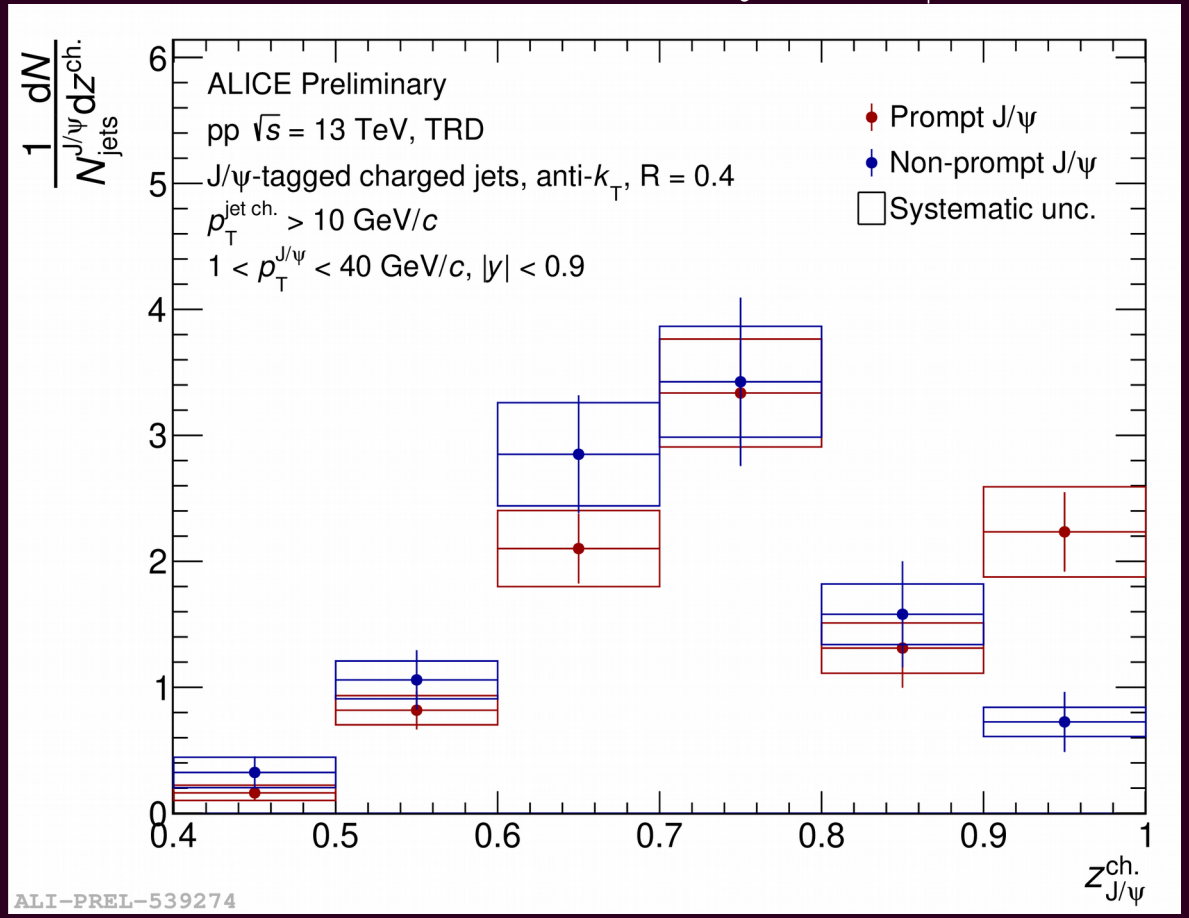


- Increase of the fraction of non-promt J/ψ with multiplicity is observed

  → multi parton interaction (MPI) play an important role at higher multiplicities

Jet fragmentation in J/ψ in p-p collisions

- The fraction of transverse momentum carried by the J/ψ within a charged jet

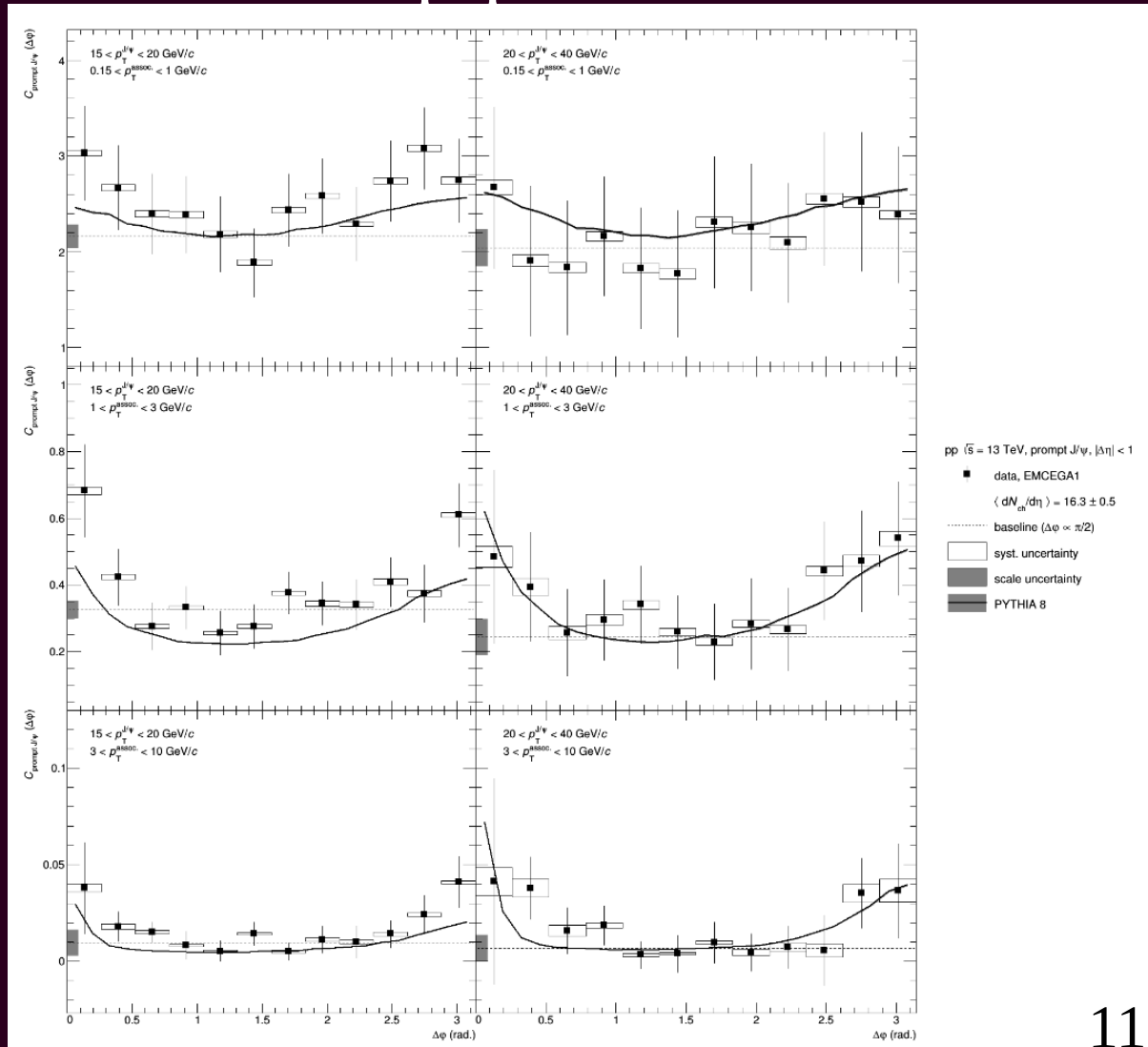


- Measured both for promt and non-promt J/ψ production.

J/ψ-hadron correlations in p-p collisions

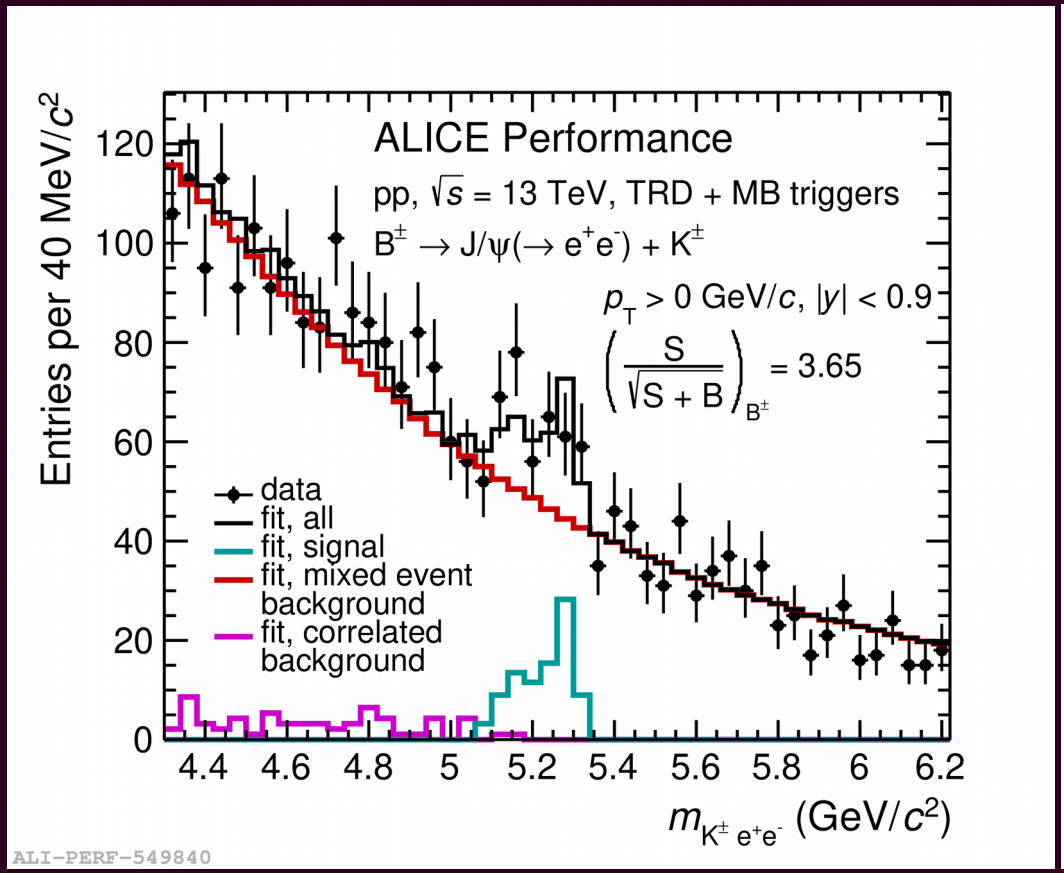
- Provide information on the hadronization process and the relation between perturbative and non-pertubative regimes.

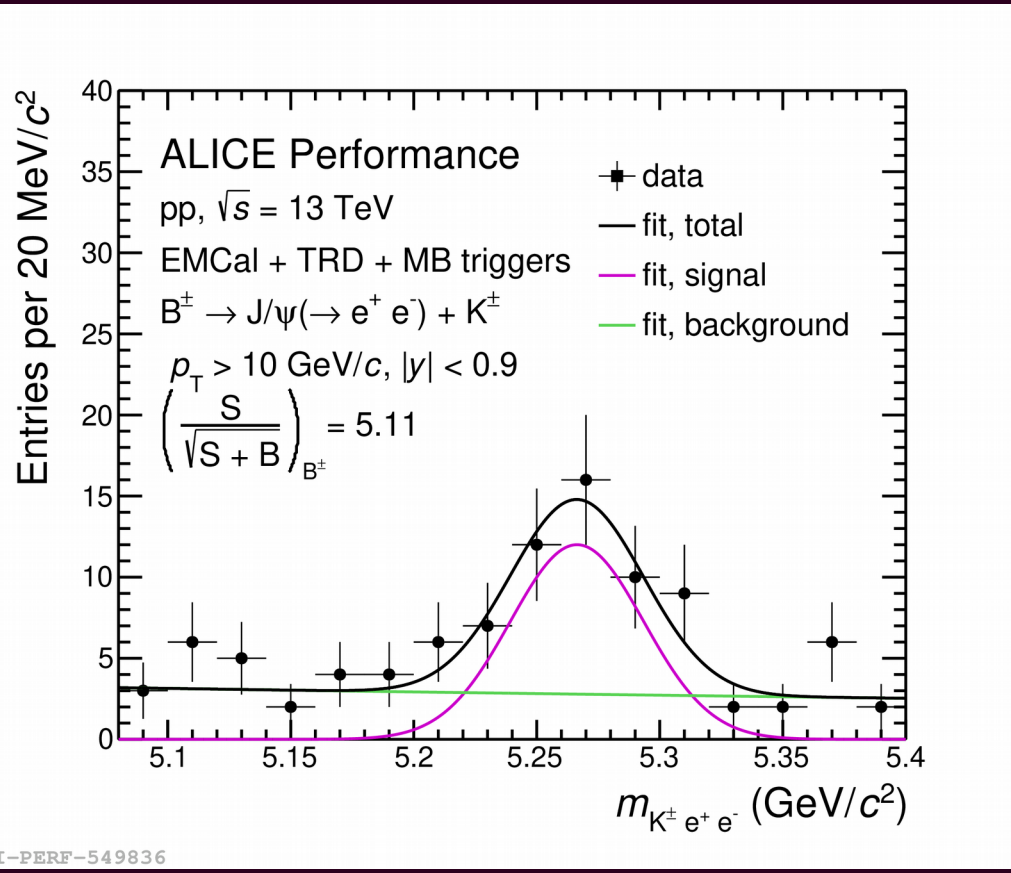
- Rather good agreement with PYTHIA MC is observed.



B-meson production in p-p collisions

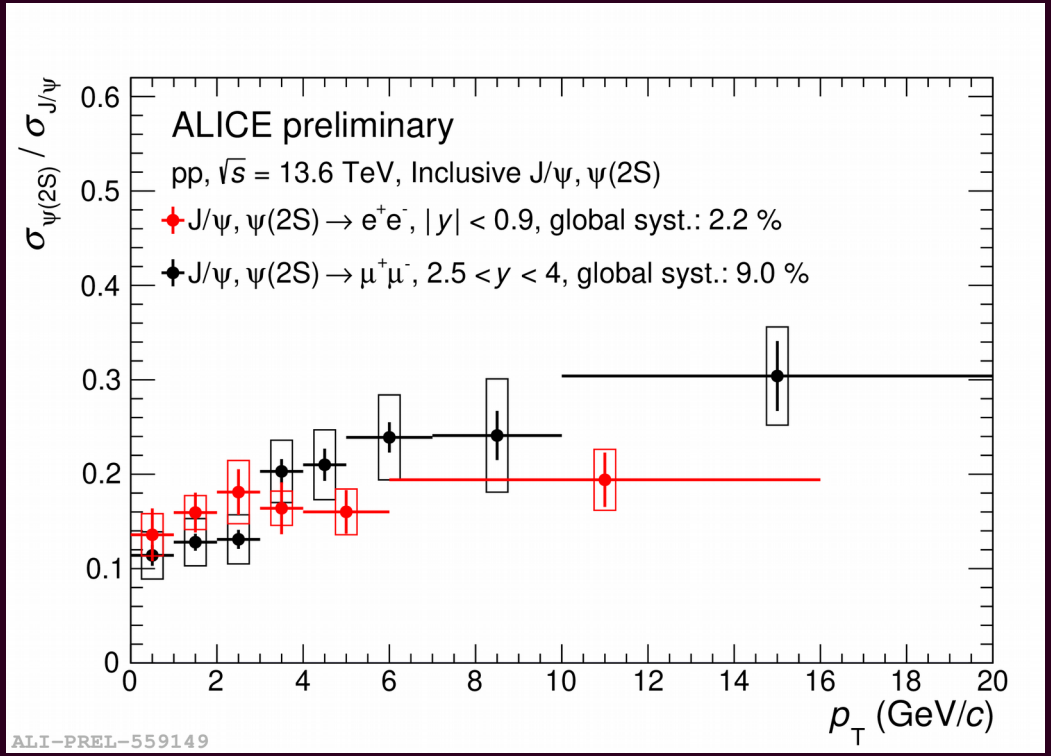
- Important input for non-promt J/ψ production.

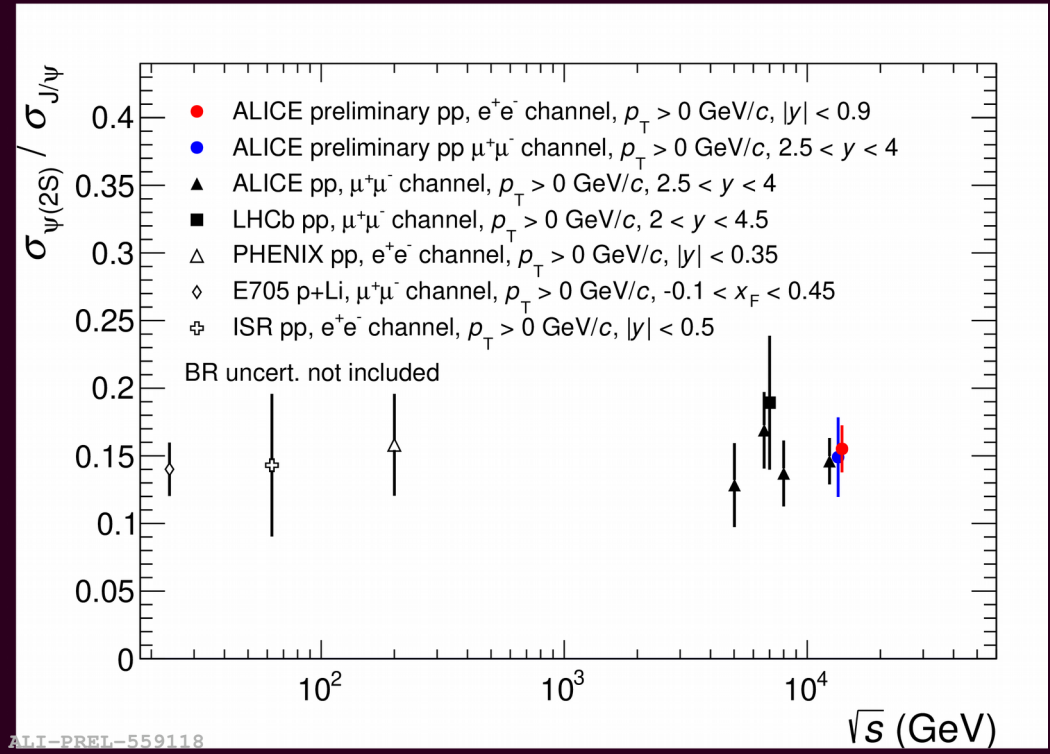




- B-meson production is observed both for low-p_T and high-p_T regions.

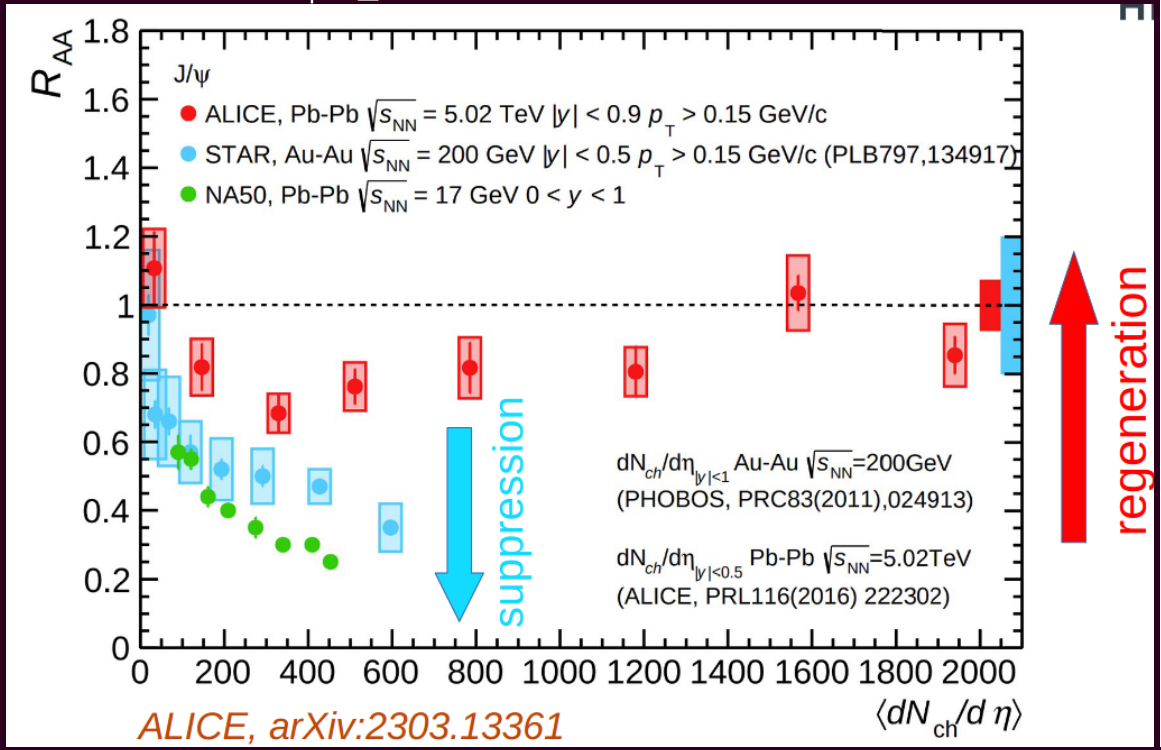
ψ(2s) to J/ψ ratio in p-p collisions **Run 3 data**

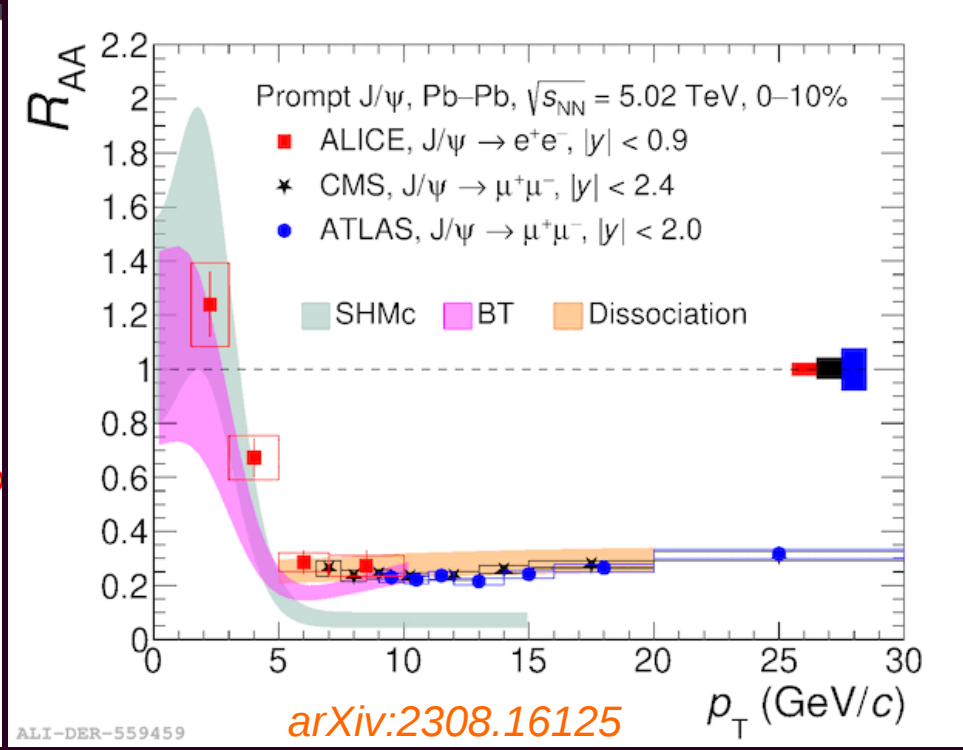




- The measurement performed both in di-electron and di-muon channels
  → both at mid- and forward rapidities.
- Stronger suppression is observed at low-p_T values.

J/ψ production in Pb-Pb collisions: ALICE Results



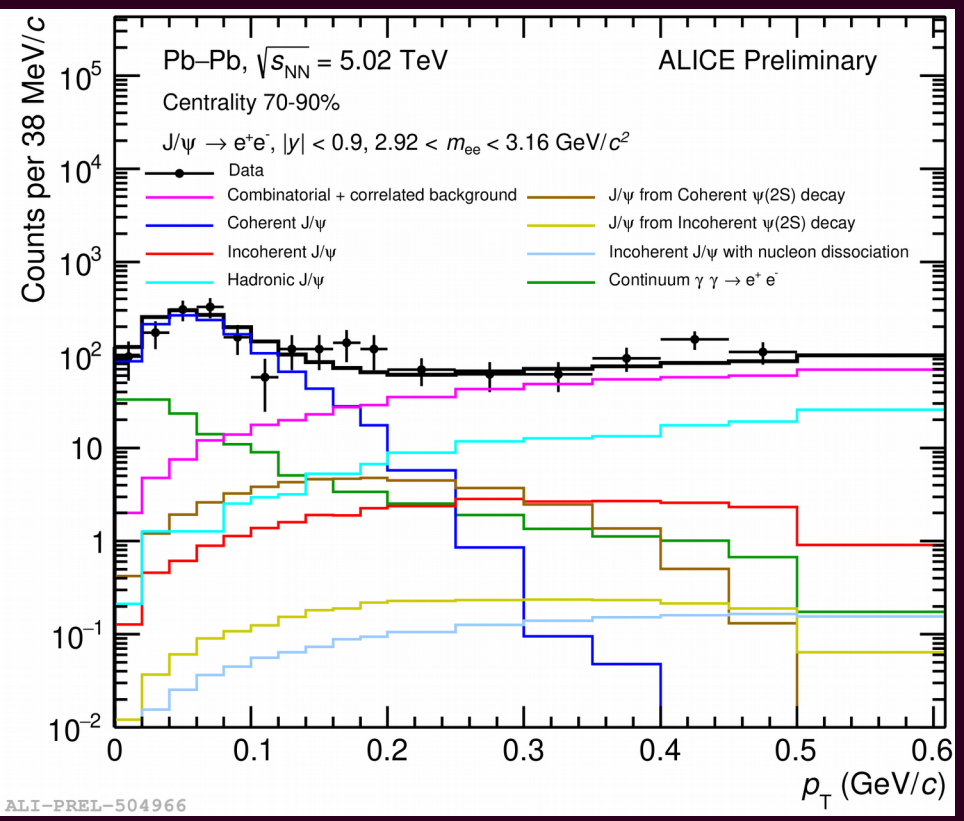


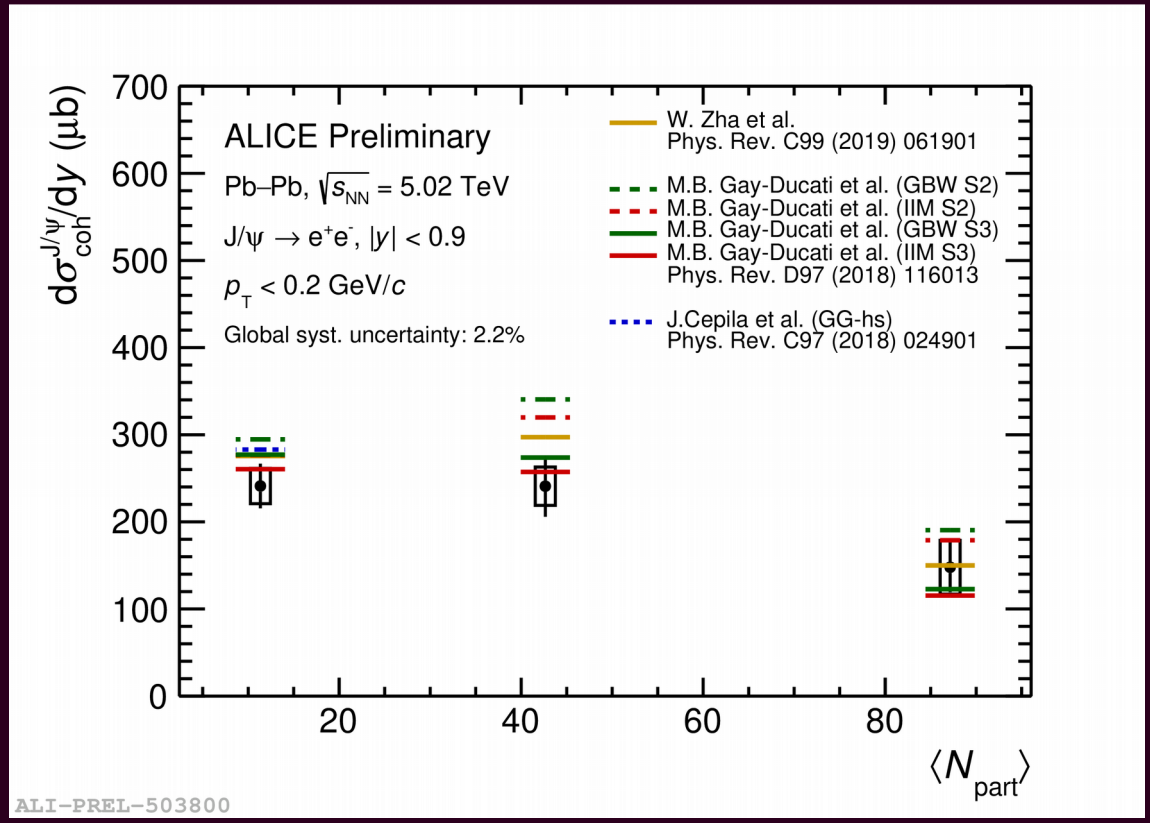
- Strong suppression observed at SPS and RHIC
- Nearly no suppression at the LHC:
  → regeneration of quarkonia

- The SHMc model and transport microscopic calculations that include a contribution from regeneration are compatible with the measured prompt J/ψ R_{AA} at low p_T

J/ψ production in peripheral Pb-Pb collisions

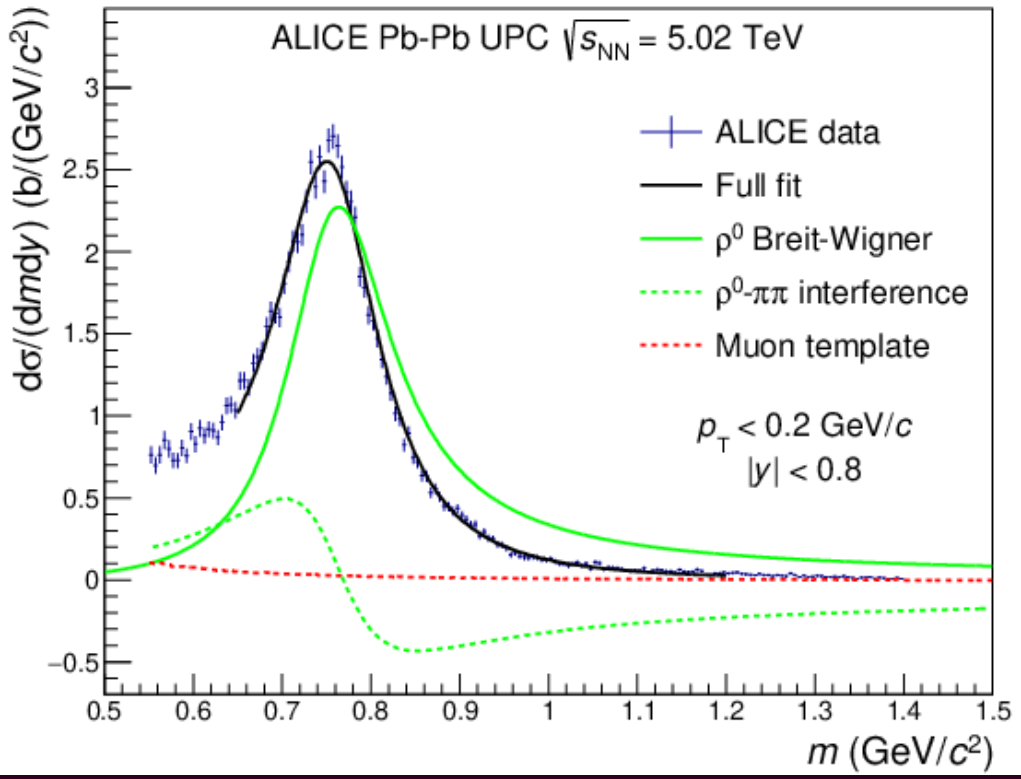
- Possibility to observe photon-induced interactions in collisions with nuclear overlap

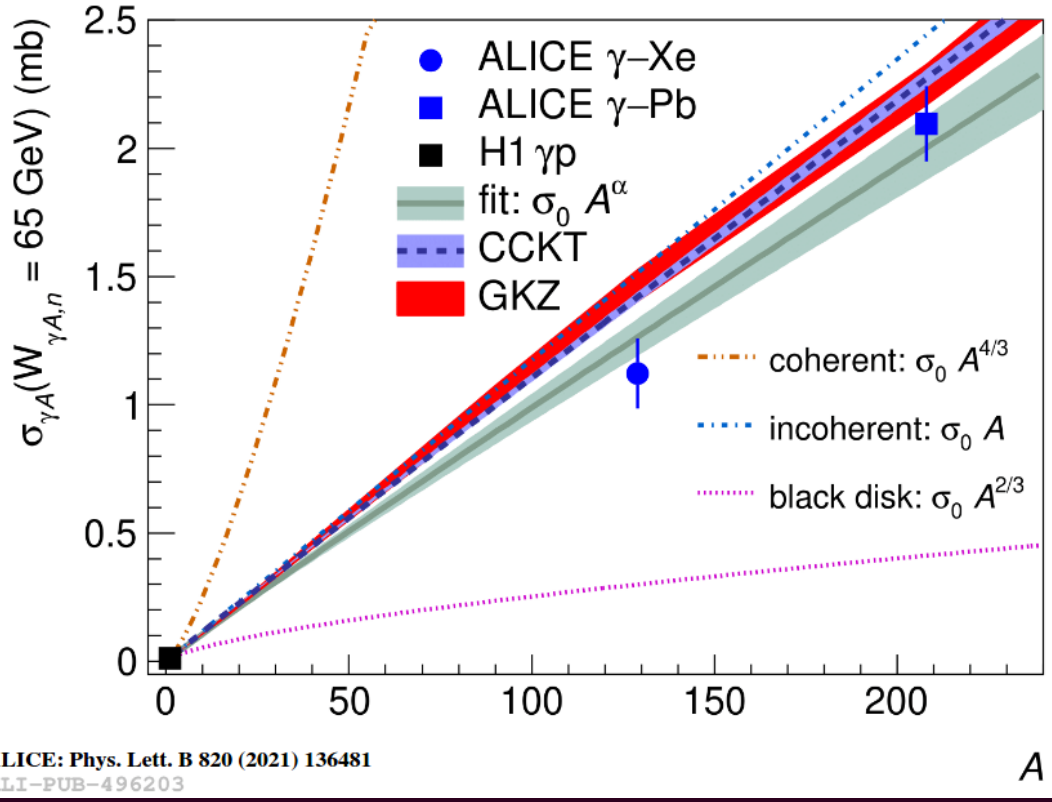




- Excess of low-pT J/ψ-s is a clear signature of photon induced interactions.

Coherent $\rho^0(770)$ photoproduction in UPC PbPb and XeXe





$\rho^0(770)$ is a great tool to study the nuclear structure and effects like nuclear-shadowing!

It has been also extensively studied in *pPb* UPCs by CMS and in *ep* by H1 and ZEUS.

Excited ρ states: *High-mass two-pion final state*

Not much is known about the excited ρ: PDG lists **ρ(1450)**, **ρ(1700)**

Both of them can decay into 2 or 4 pions.

JHEP 06 (2020) 035

ρ(1450) $I^G(J^{PC}) = 1^+(1^{--})$

See the review on "Spectroscopy of Light Meson Resonances."

Mass $m = 1465 \pm 25$ MeV [i]

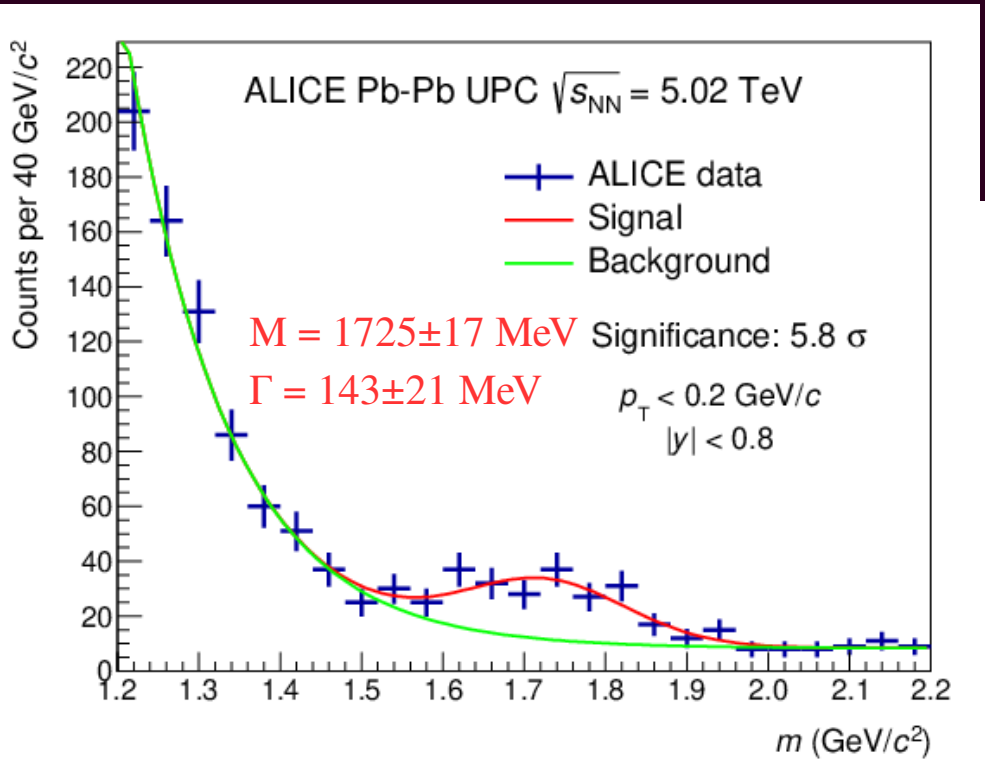
Full width $\Gamma = 400 \pm 60$ MeV [i]

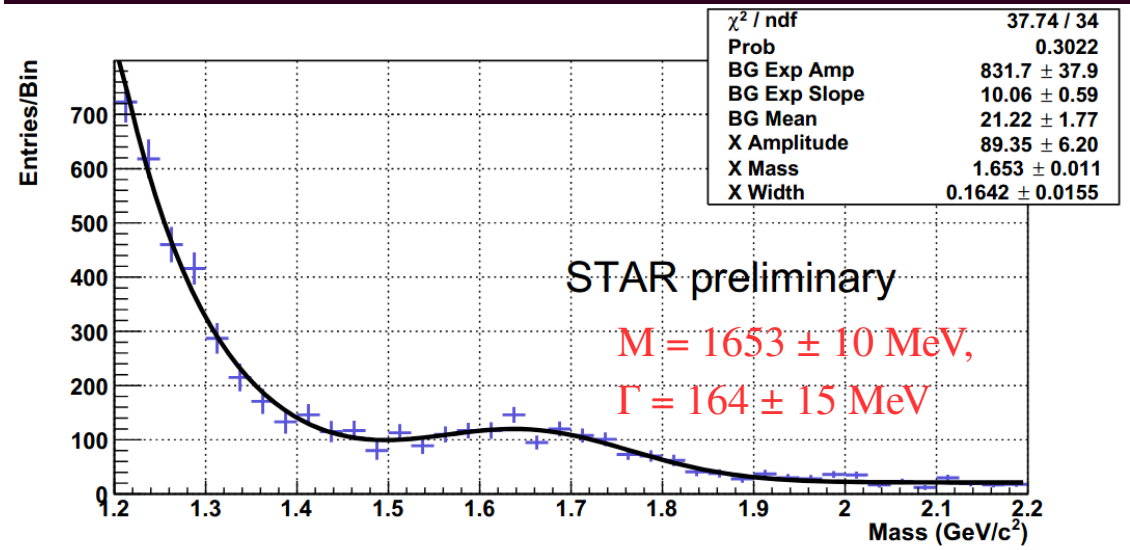
ρ(1700) $I^G(J^{PC}) = 1^+(1^{--})$

See the review on "Spectroscopy of Light Meson Resonances."

Mass $m = 1720 \pm 20$ MeV [i] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

Full width $\Gamma = 250 \pm 100$ MeV [i] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)



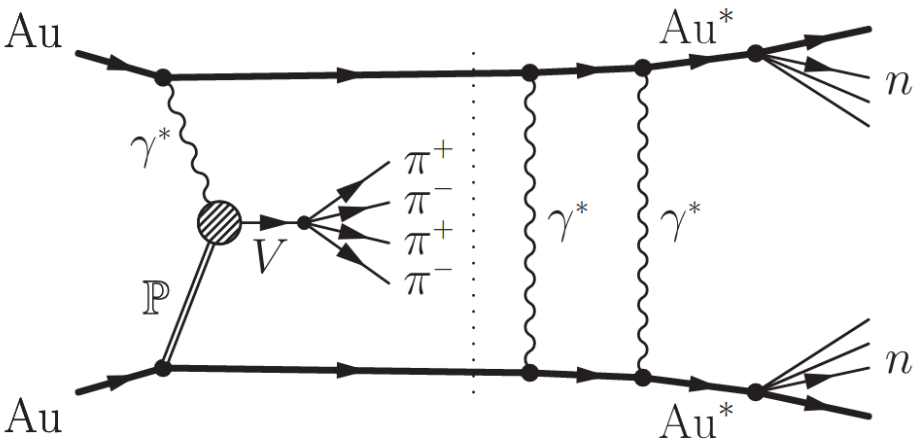


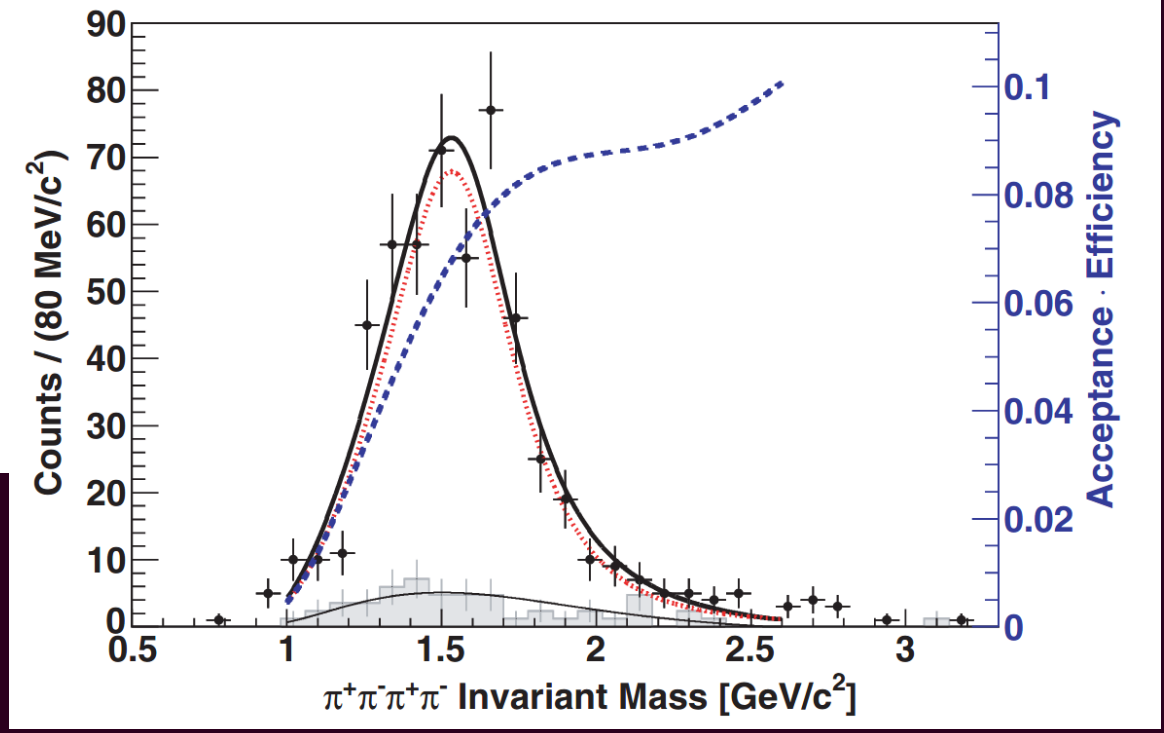
Consistent with **ρ(1700)**

Exclusive four pion in UPCs

*never studied in UPCs at LHC

STAR Collaboration: Phys Rev C 81 044901, *2010*





M = 1540±40 MeV Γ = 570±60 MeV

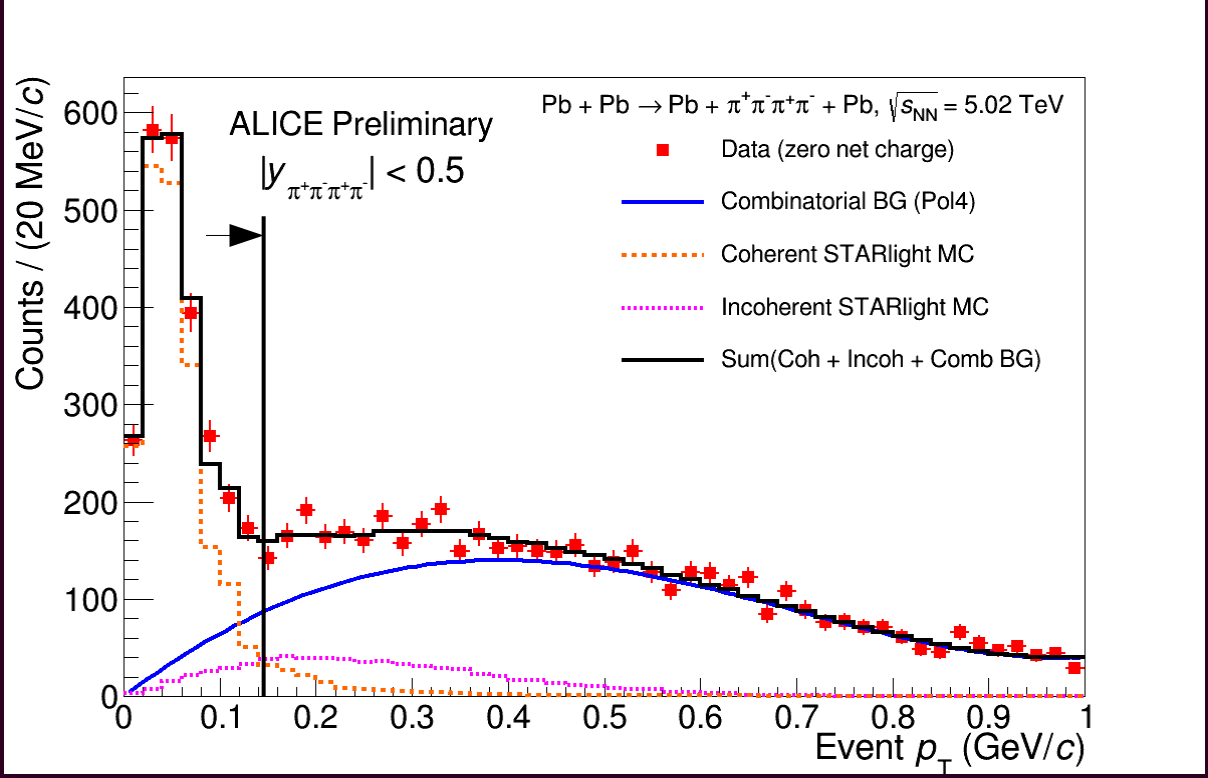
"In agreement with the data for **ρ(1700)**"

One resonance does not describe the peak shape well. However, the low statistics of the data does not allow for the extraction of the resonance and mixing parameters for a two-resonance scenario.

Background Estimation

Template fit

Paper figure



Three Contributions:

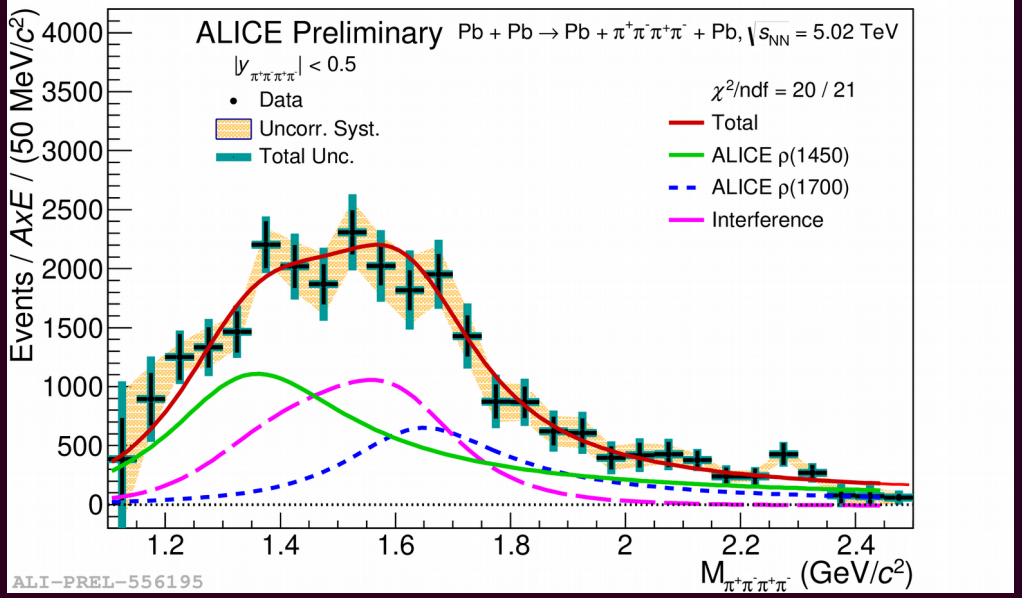
- Signal ~50 MeV
  - STARlight MC (reweighted)
- Incoherent production ~200 MeV
  - STARlight MC
- Combinatorial Background >500 MeV
  - Non-zero net charge events

Most backgrounds are rejected by the requirement: **Event p_T < 150 MeV**.

The template fit is needed to estimate the remaining contributions.

Fit with interference

$$\frac{d\sigma}{dm_{\pi\pi\pi\pi}} = |A \cdot \sqrt{BW_1} + e^{-i\phi} \cdot B \cdot \sqrt{BW_2}|^2;$$



M_1 = 1385 ± 14 (stat.) ± 36 (syst.) MeV,
Γ_1 = 431 ± 36 (stat.) ± 82 (syst.) MeV,
M_2 = 1663 ± 13 (stat.) ± 22 (syst.) MeV,
Γ_2 = 357 ± 31 (stat.) ± 49 (syst.) MeV

$\rho(1450)$ $I^G(J^{PC}) = 1^+(1^{--})$

See the review on "Spectroscopy of Light Meson Resonances."
Mass $m = 1465 \pm 25$ MeV [i]
Full width $\Gamma = 400 \pm 60$ MeV [i]

$\rho(1700)$ $I^G(J^{PC}) = 1^+(1^{--})$

See the review on "Spectroscopy of Light Meson Resonances."
Mass $m = 1720 \pm 20$ MeV [i] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)
Full width $\Gamma = 250 \pm 100$ MeV [i] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

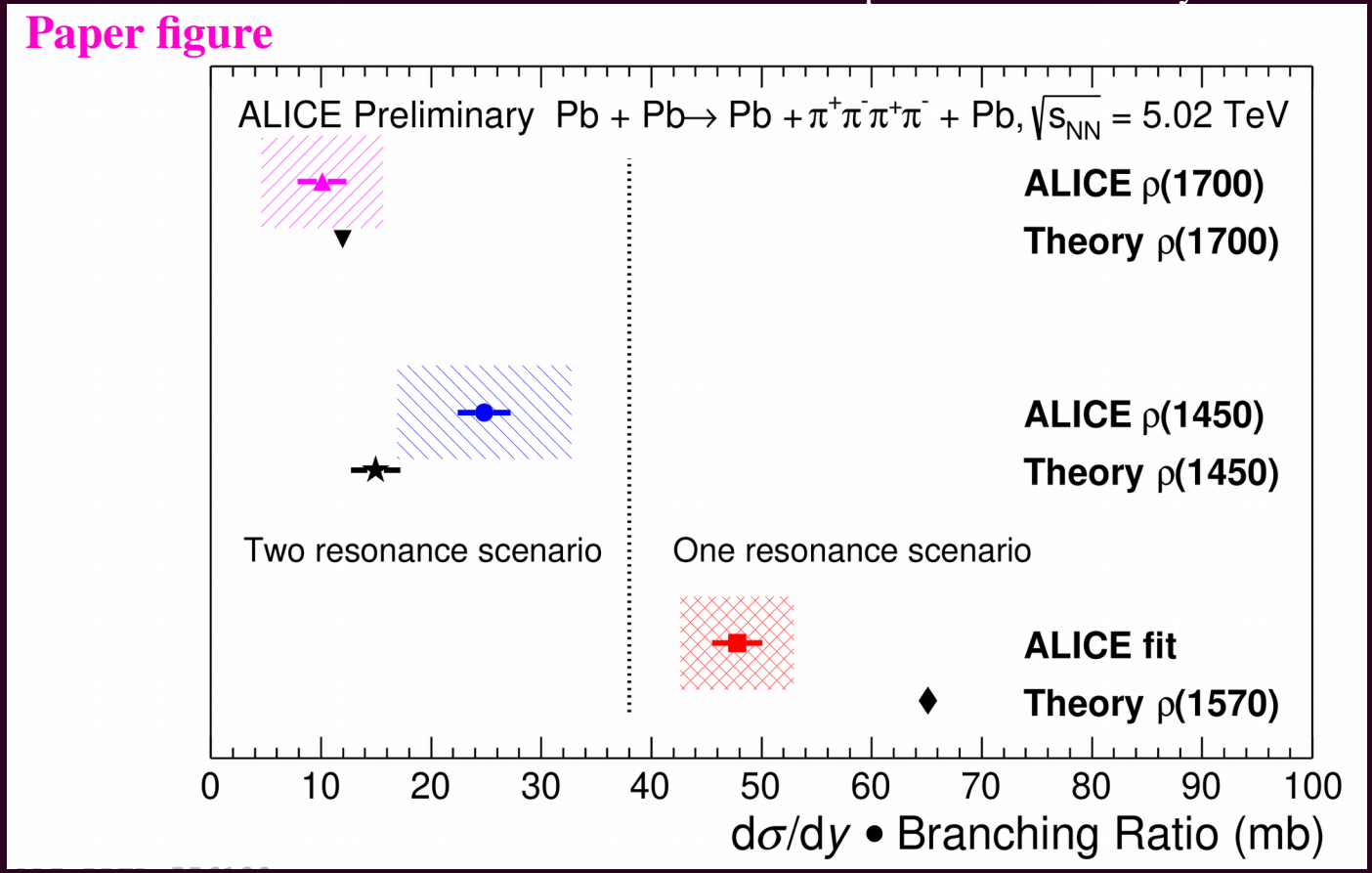
Φ = 1.52 ± 0.16 (stat.) ± 0.19 (syst.)

Simultaneous production of two resonances and the interference between them is observed.

Cross section measurement

M. Klusek and D. Tapia Takaki Acta Phys. Polon. B 51 (2020) 6, 1393

Paper figure



The total cross section is below the calculation assuming one wide resonance, while the results extracted from the fit with the interference are rather close to the respective lines.

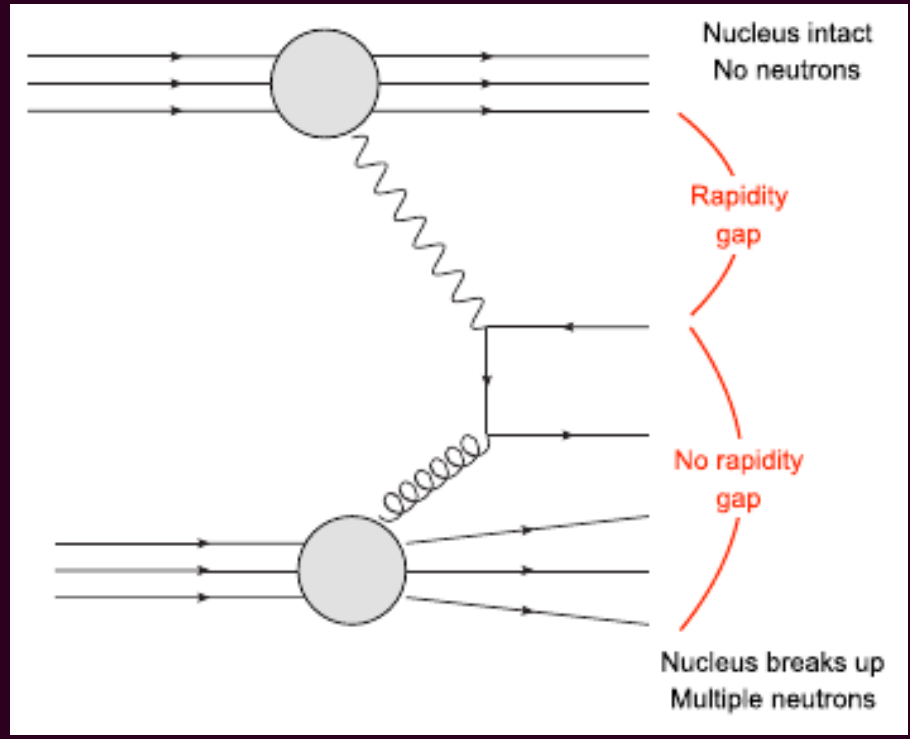
General photonuclear interaction

- Rapidity gap, void of particles, on the side of the photon-emitting nucleus.

✗ Was not possible during Runs 1 & 2 due to a symmetric trigger veto

✔ Continuous read-out will allow to select events with activity on one side only.

- Can 'trigger' events by requiring activity:
  One side of **Tracker** and **ZDC**.



New rich field for investigations!

- Collective effects in γ+Pb systems
- Radial and elliptic flow
- Open "charm" production
- Jet productions

Summary

- ALICE Experiments provide unique opportunities to recreate and study the conditions existed the very first moments after the Big Bang.
- Understanding the properties of the Quark-Gluon Plasma requires the knowledge of all the stages of the nuclear collisions.
  - Various observables in p-p collision provide the stringent tests for QCD models and the important vacuum reference for Pb-Pb interactions.
  - Ultra-Peripheral Collisions allow to image the gluon distributions inside the nuclei with high-energy photons and thus understand the initial state of the collisions.
- Run 3 & 4 from ALICE data will allow to perform the most precise and differential measurements of these and new processes.

Thank you very much for your attention!