DIS16
DESY, HAMBURG 11-15 APRIL 2016

Coherent photo-nuclear production of vector mesons at mid-rapidities in Pb-Pb collisions

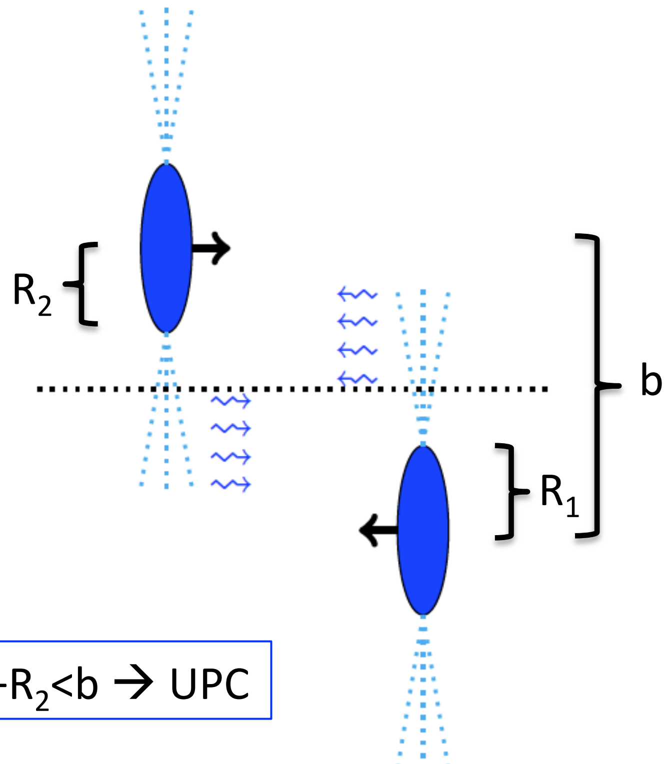
Guillermo Contreras
Czech Technical University

April 13, 2016

Beams of quasi-real photons at the LHC

The LγHC and LγγC

The EM field of protons and ions at the LHC can be viewed as a beam of quasi real photons



$R_1+R_2<b \rightarrow$ UPC

Note 1:
There are two potential sources, correspondingly two potential targets.

Note 2:
The photon is coherently emitted by the source and its virtuality is restricted by the radius of the emitting particle: $Q^2 \approx hc/(2\pi R)^2$
✓ γ from Pb: $Q^2 \approx (30\ \mathrm{MeV})^2$

Note 3:
The intensity of the photon beam is proportional to Z^2

Note 4:
The max energy of the photons in the lab system is determined by the boost of the emitting particle
✓ Run2: larger energies possible

Note 5
Interactions at large impact parameters are of electromagnetic origin.

Why Pb-ions as source of photons?

The LHC accelerates both protons and Pb nuclei

As mentioned before, the intensity of the photon beam depends on the square of the electric charge of the accelerated particule:
→ The intensity is orders of magnitude larger for Pb w.r.t. proton beams.

It is necessary to separate the collisions of hadrons, for which the LHC and its detectors were optimized, from the collisions involving quasi-real photons.

The strategy is to use the facts that

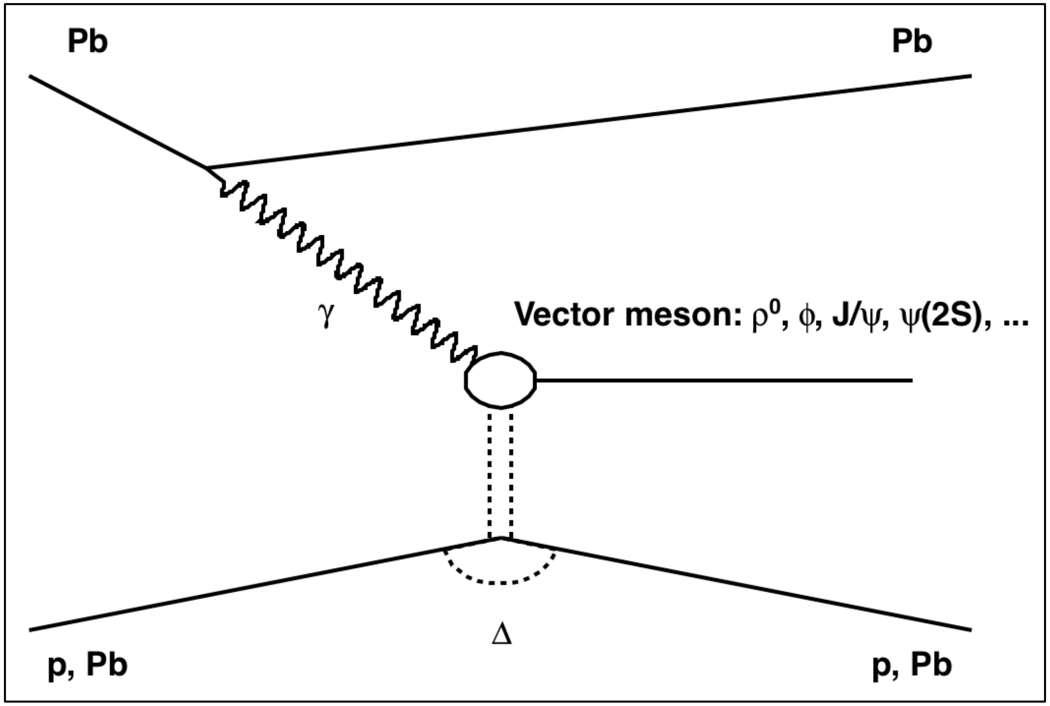
1. Pb nuclei are very fragile objects, which break in all hadronic interactions … and ALICE is able to detect with very high efficiency if a Pb nucleus breaks (by measuring in the very forward direction neutrons from the nuclear fragmentatio)
2. Strong interactions tend to produce particles at all rapidities, while electromagnetic interactions produce large rapidity gaps

→ Look for processes with intact outgoing nuclei and large rapidity gaps

These are called Ultra-Peripheral Collisions (UPC)

Exclusive photo-production of vector mesons and ALICE

Exclusive vector meson production



- If the target is a nucleus and interacts as a whole, these processes are called coherent vector meson production.
- Kinematics completely determined:
  - ✓ Rapidity measures the energy of the photon-target interaction
  - ✓ The square of the transverse momentum of the vector meson is related to Δ the momentum transferred in the target vertex
- The production of the vector meson does not break the target
- The transverse momentum transferred, Δ, is very small, being bounded by the size of the target. It is smaller for Pb targets, than for p targets.
- The only particles reaching the detector are the decay products of the vector meson (and may be some other very forward particles)

Very clean signature

What do we need?

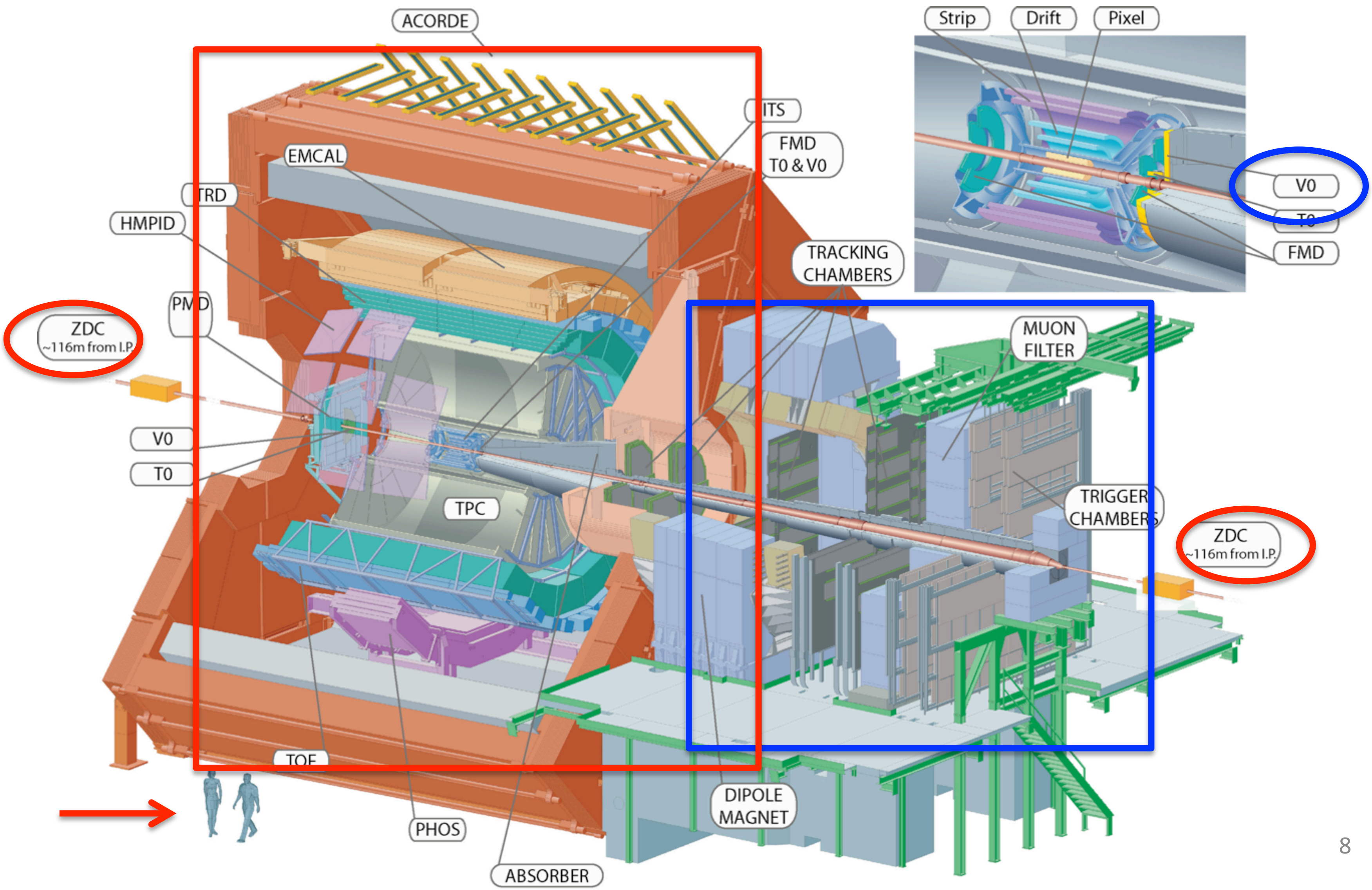
1. To measure the decay products of a vector meson with very low transverse momentum:
   - ρ to $\pi^+ + \pi^-$
   - J/ψ to $\mu^+ + \mu^-$ or $e^+ + e^-$
   - $\psi(2S)$ to $\mu^+ + \mu^-$, $e^+ + e^-$ or $J/\psi + \pi^+ + \pi^-$

2. To make sure there is nothing else in the detector:
   Large rapidity coverage to veto particles

3. To make sure that the source/target do not break:
   Zero degree calorimeters (ZDC)

ALICE

Magnetic field of 0.5 T in the central region



Results from Pb-Pb collisions

Four topics:

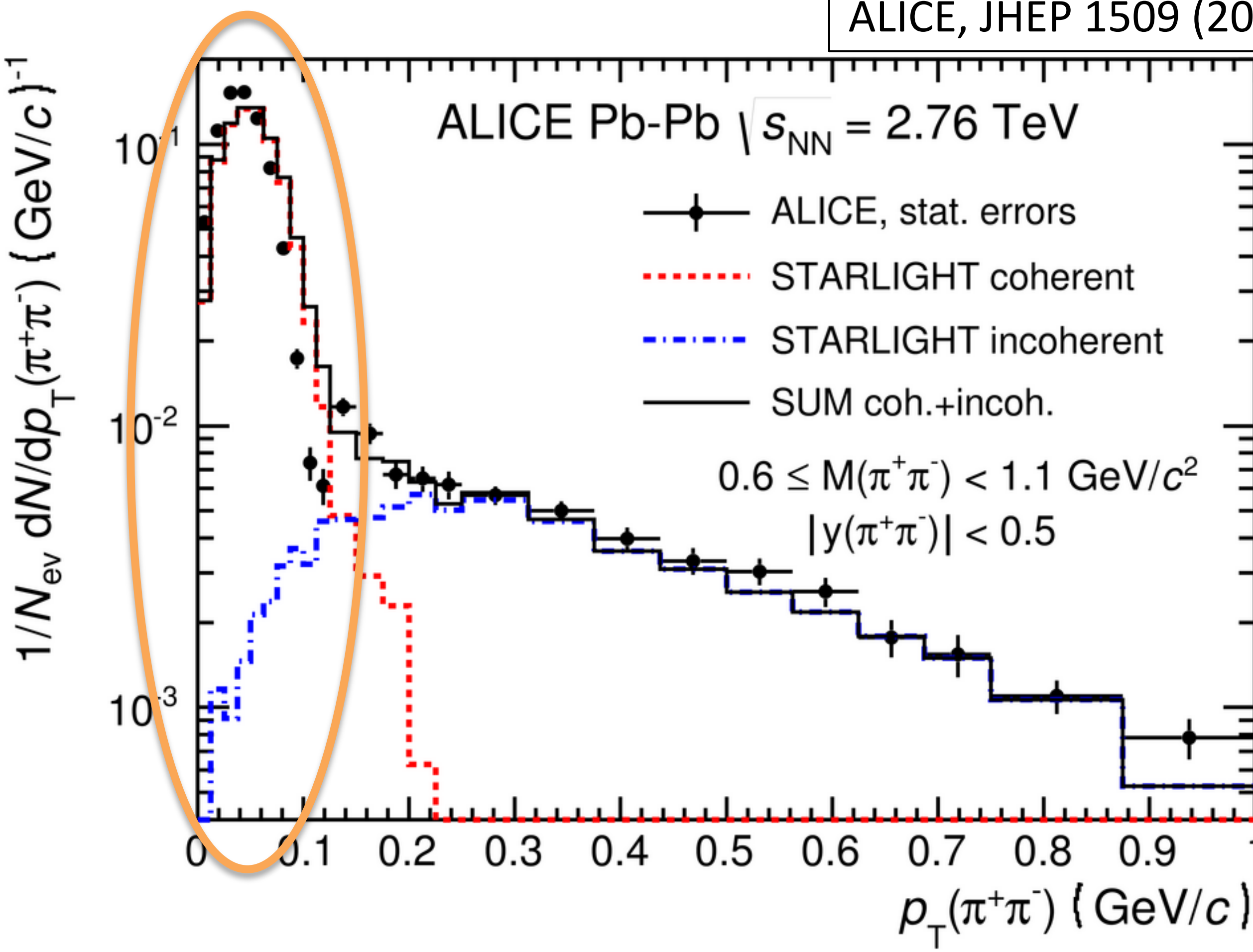
1. Coherent ρ production
2. Coherent and incoherent J/ψ production
3. Coherent $\psi(2S)$ production
4. A surprise!

Coherent ρ production

- ✓ Coherent: photon couples to full nuclei: VM has **very** low transverse momentum
- ✓ Incoherent: photon couples to one nucleon: VM has low transverse momentum

ALICE, JHEP 1509 (2015) 095

- ✓ 2010 data
- ✓ Decay into $\pi^+\pi^-$



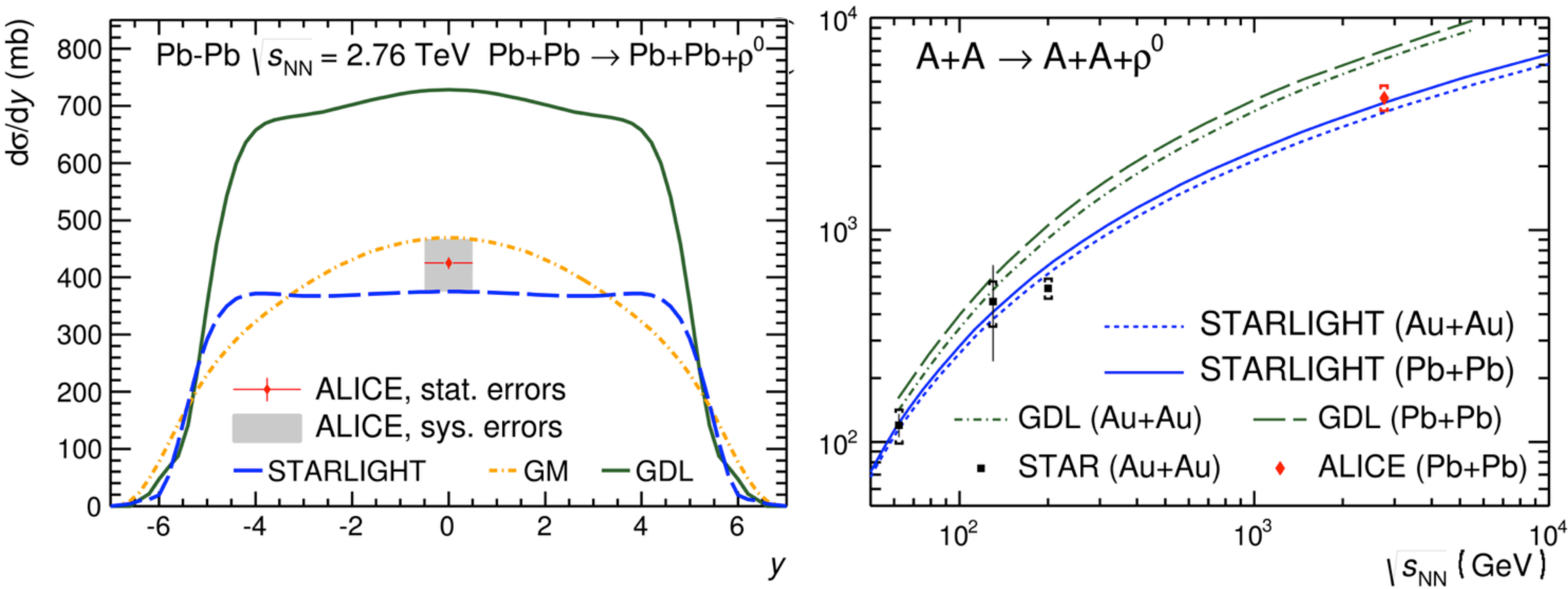
- ✓ Transverse momentum less than 150 MeV/c to reject incoherent contribution

Coherent ρ production: cross section

L. Frankfurt, M. Strikman, M. Zhalov (GDL): QM Glauber + DL fit to HERA data

V.P. Gonçalves, M.V.T. Machado (GM): Color dipole model with CGC-like saturation

S.R. Klein, J. Nystrand (STARLIGHT): Classical Glauber model + fit to HERA data



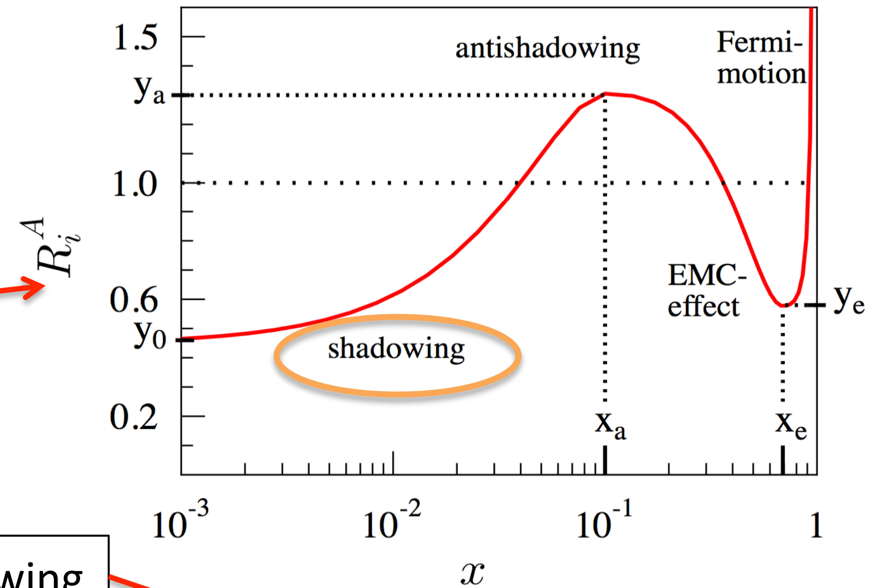
- ✓ Somehow surprising agreement with Starlight
- ✓ Disagreement with GDL model may be explained by inelastic nuclear shadowing (see Phys.Lett. B752 (2016) 51-58)

ALICE, JHEP 1509 (2015) 095

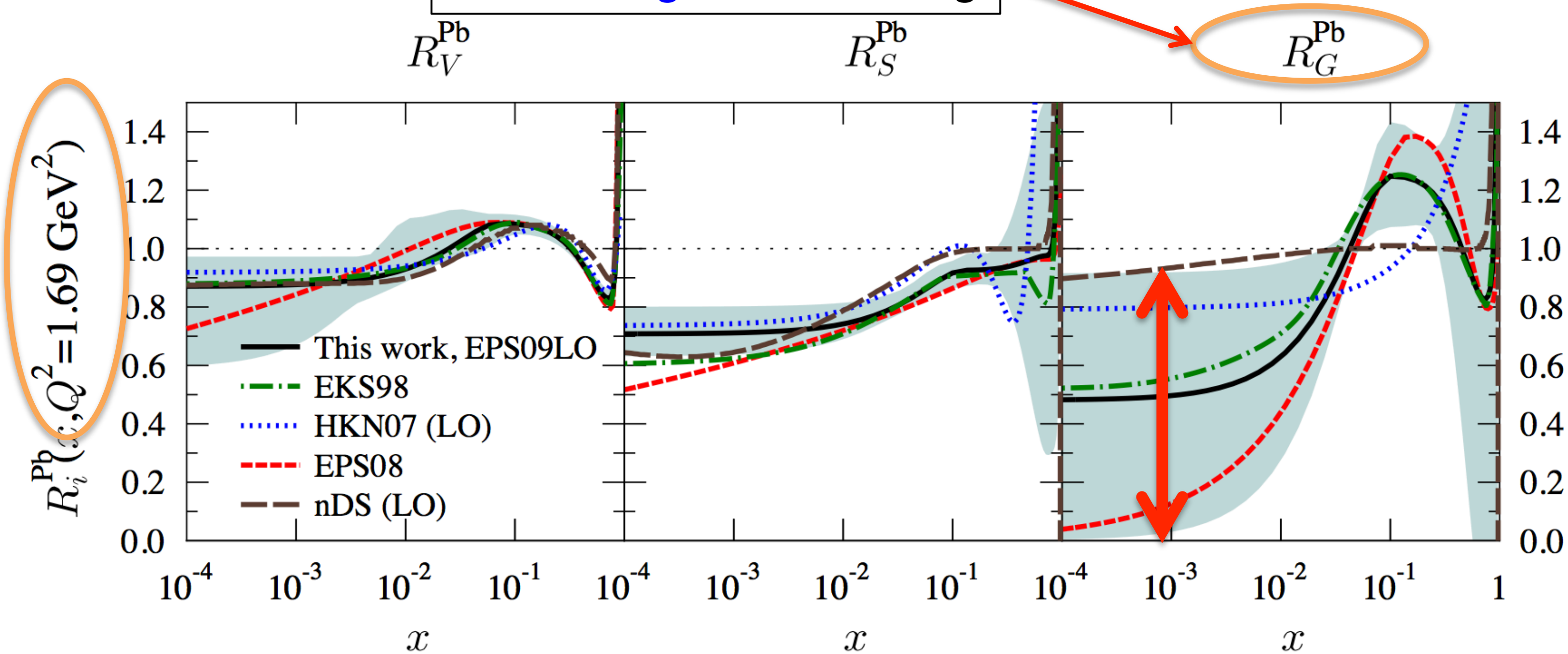
Shadowing

It is an experimental fact that the structure of nuclei is not just a superposition of the structure of protons and neutrons

R^A_i = (scaled parton i PDF in A)/(parton PDF in p)



amount of gluon shadowing



EPS, JHEP 0904 (2009) 065

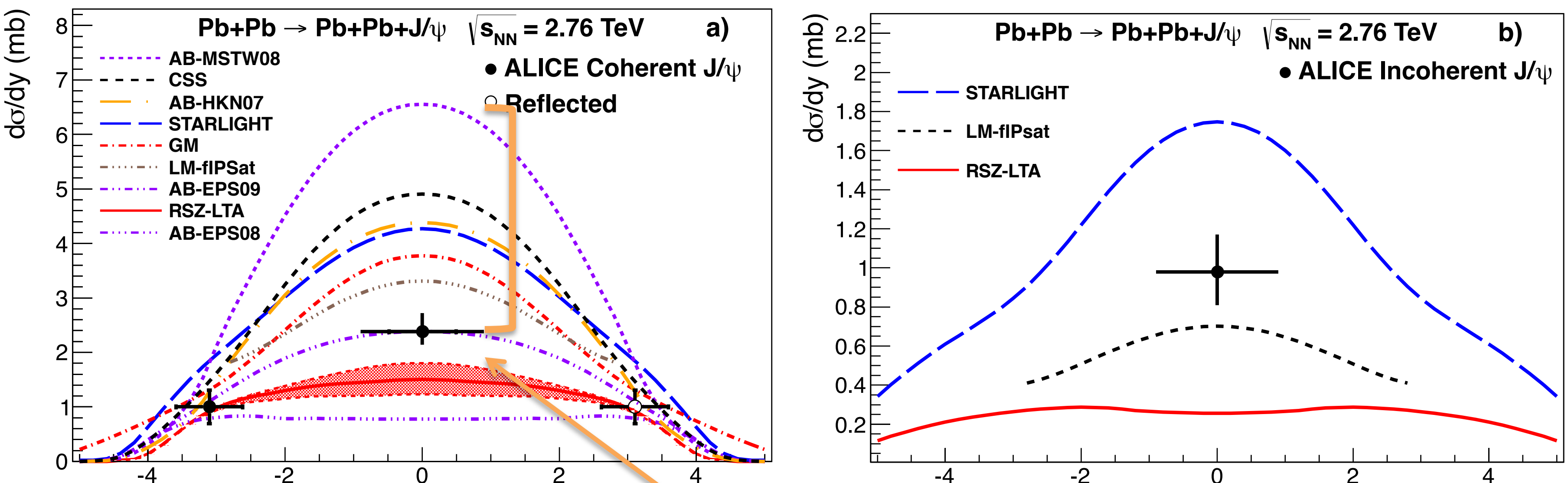
Coherent and incoherent J/ψ production: cross sections

ALICE: Phys.Lett. B718 (2013) 1273-1283 and Eur. Phys. J. C (2013) 73:2617

L. Frankfurt, M. Strikman, M. Zhalov (GDL1): QM Glauber + DL fit to HERA data

T. Lappi, H. Mäntysaari : color dipole model with saturation + Glauber

S.R. Klein, J. Nystrand (STARLIGHT): Classical Glauber model + fit to HERA data



ALI-PUB-66209

$x \sim 10^{-2}$ $x \sim 10^{-3}$

Direct observation of (moderate) gluon shadowing

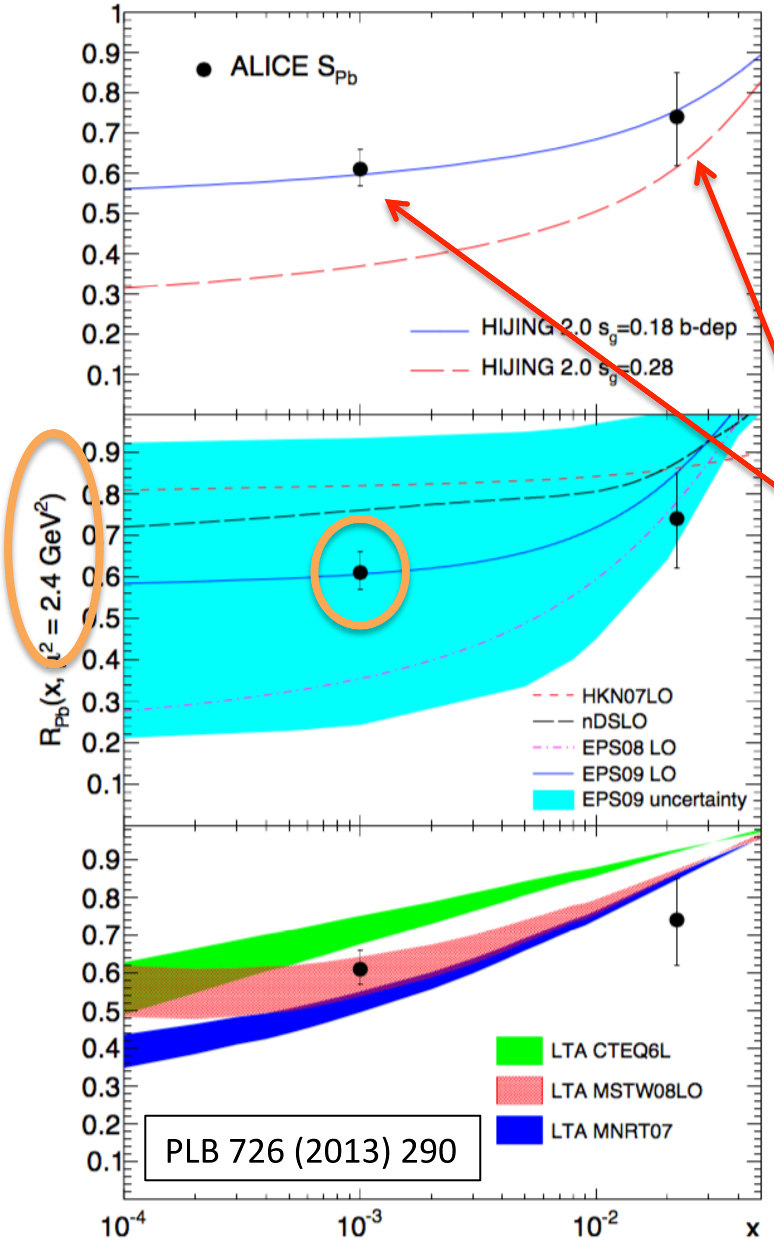
Cisek, Szczurek, Schäfer (CSS): Color dipole model with unintegrated gluon distribution

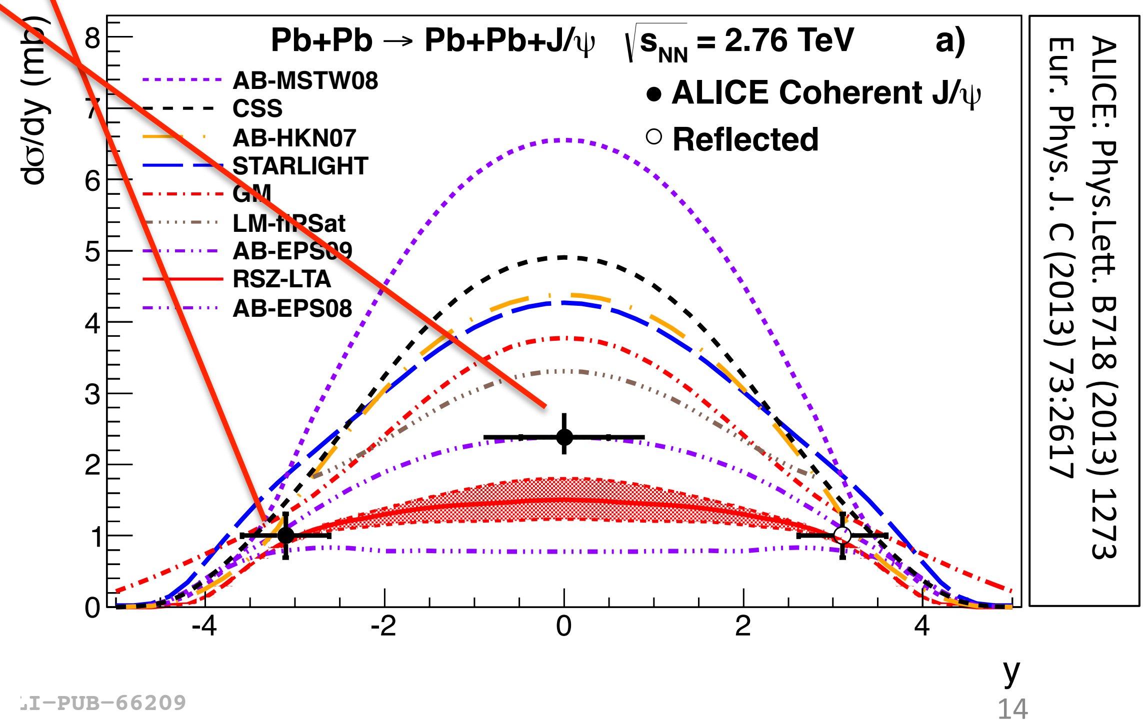
V.P. Gonçalves, M.V.T. Machado (GM): Color dipole model with CGC-like saturation

Adeluyi and Bertulani, (AB): LO pQCD + K-factor + nuclear PDFs

Coherent J/ψ cross section

Under some assumptions, ALICE measurements can be translated into LO pQCD constraints for gluon shadowing at small x

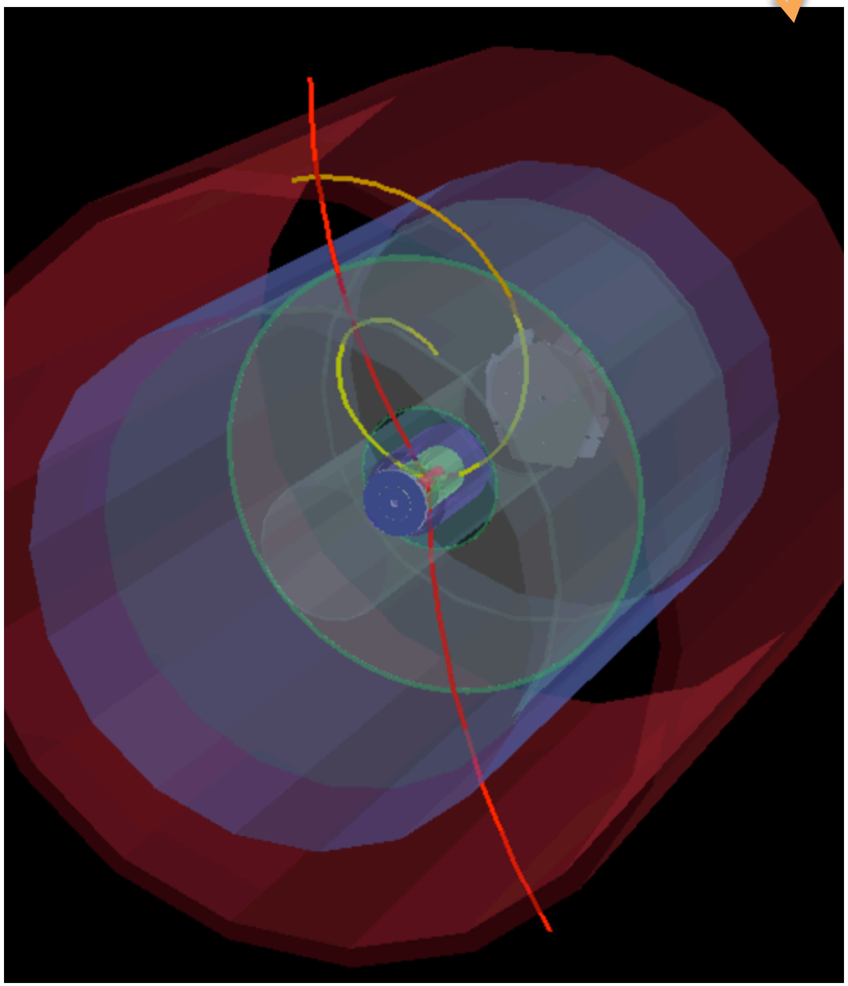


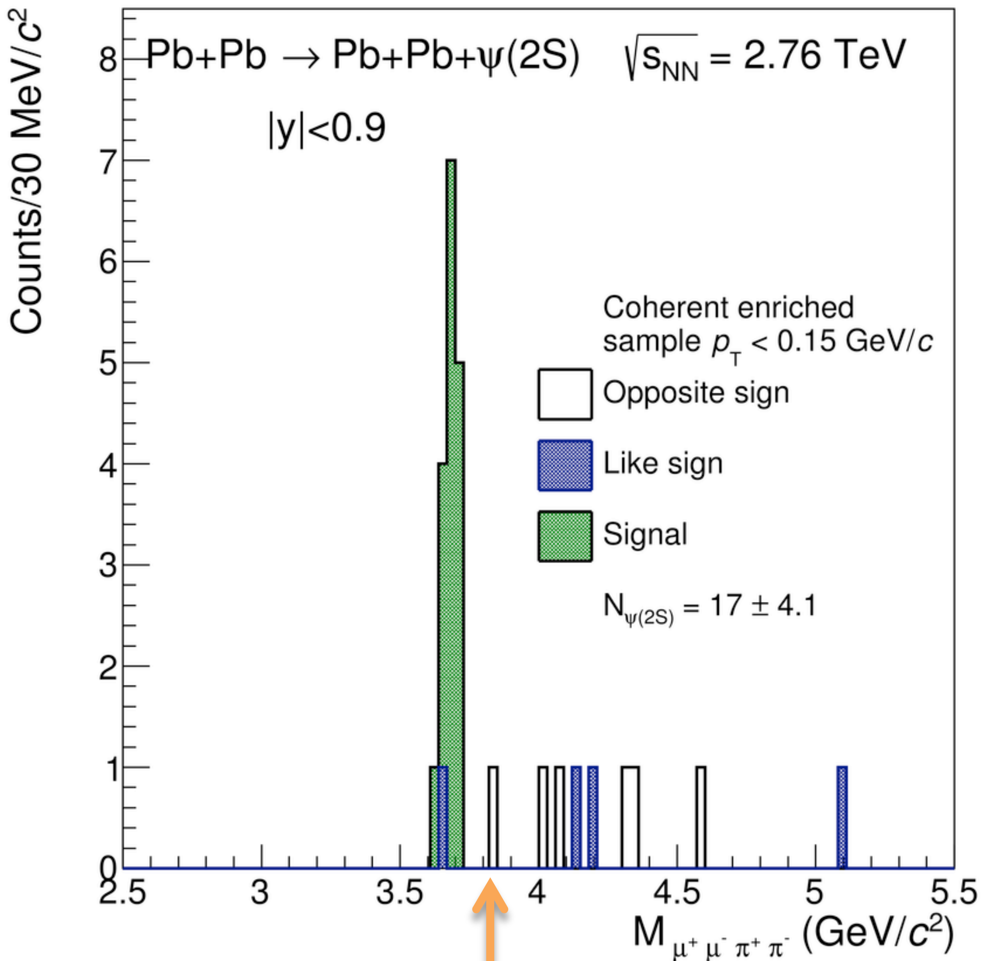


Coherent $\psi(2s)$ production

- ✓ Measured decay channels:
  $\psi(2s)\rightarrow l^+l^-$ and $\psi(2s)\rightarrow J/\psi\pi^+\pi^-$

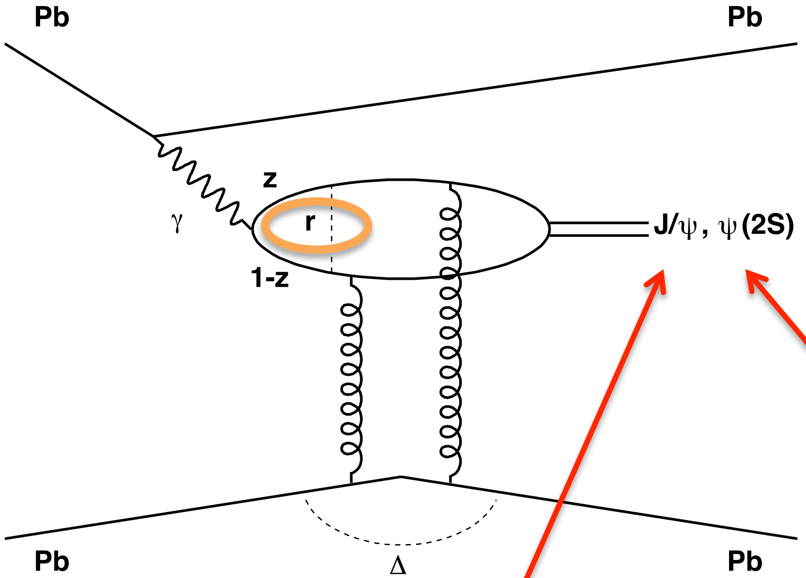
ALICE, PLB 751 (2015) 358





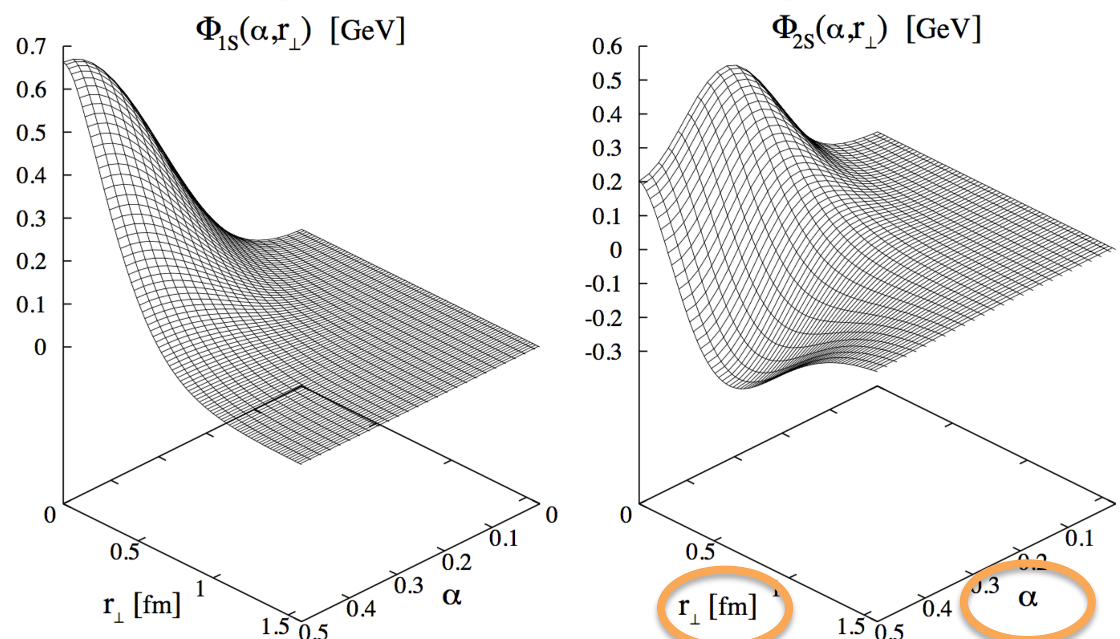
- ✓ Few signal events with almost no background

ψ(2s) wave function



- The wave function of excited states present so called nodes (Nemchik et al, ZPC75 (1997) 71)
- These nodes have a negative contribution for large dipole sizes, where saturation effects are expected

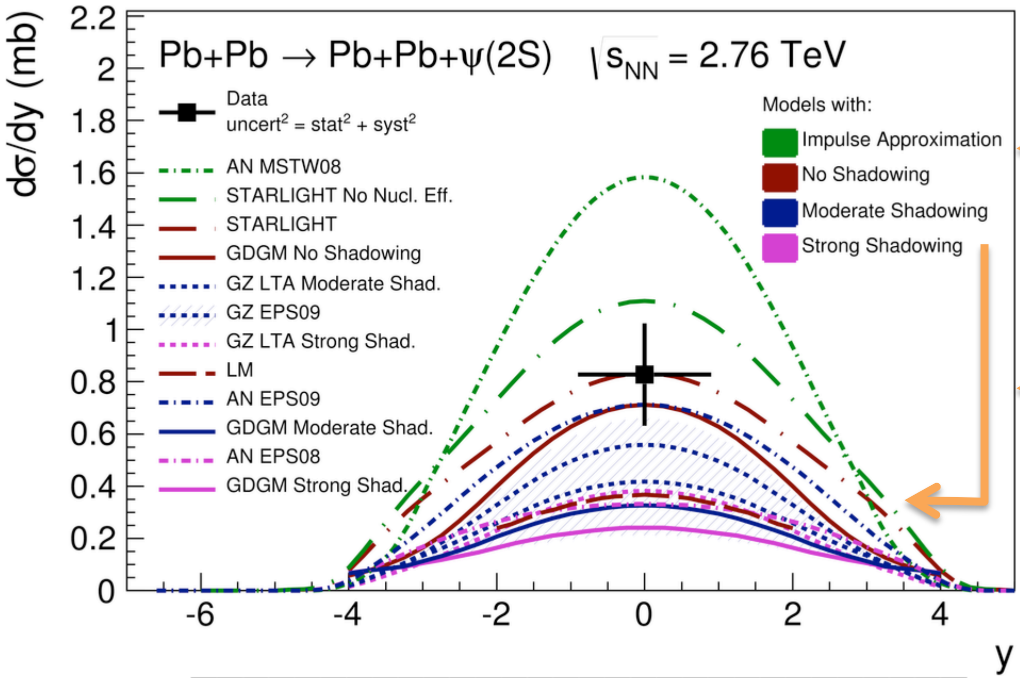
PRD 62 (2000) 094022



(α=z, see diagram)

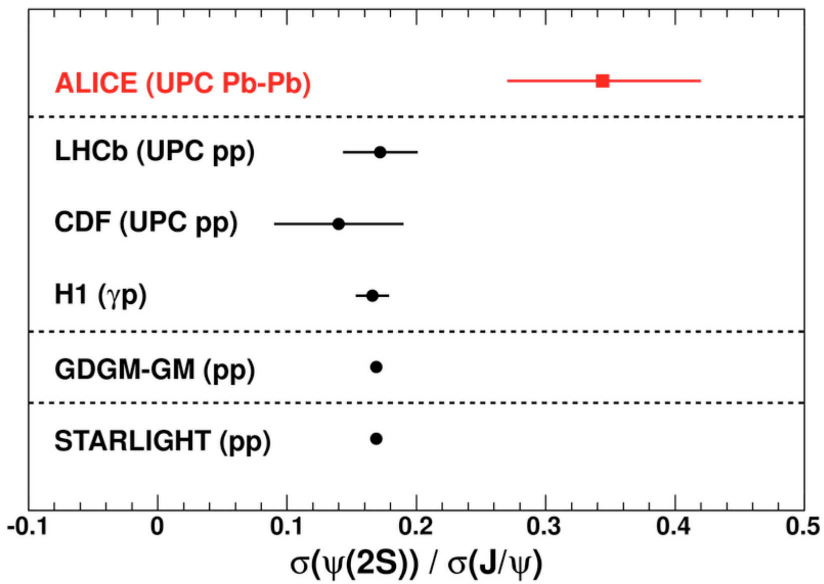
Coherent ψ(2s) production: cross section

ALICE, PLB 751 (2015) 358



Both impulse approximations should be equal …

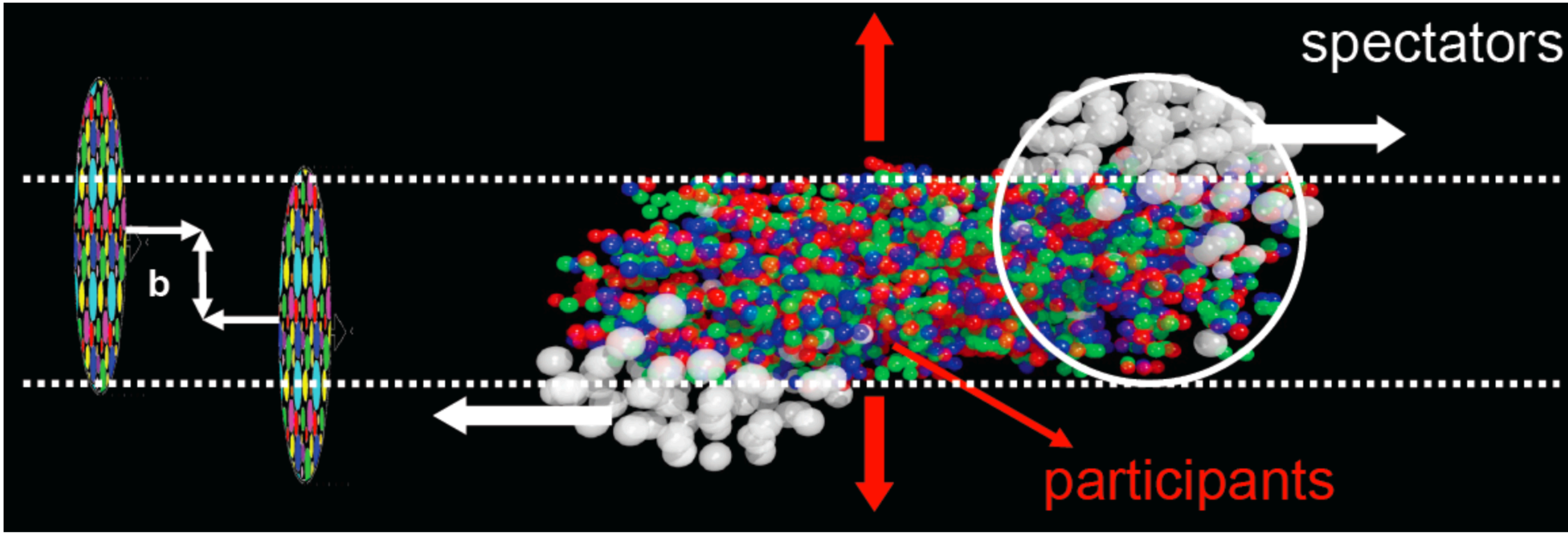
Strong shadowing is disfavoured …



Do nuclear effects affect differently 1S and 2S states?

Need more precise data!

Pb-Pb collisions for $b<2*R_A$

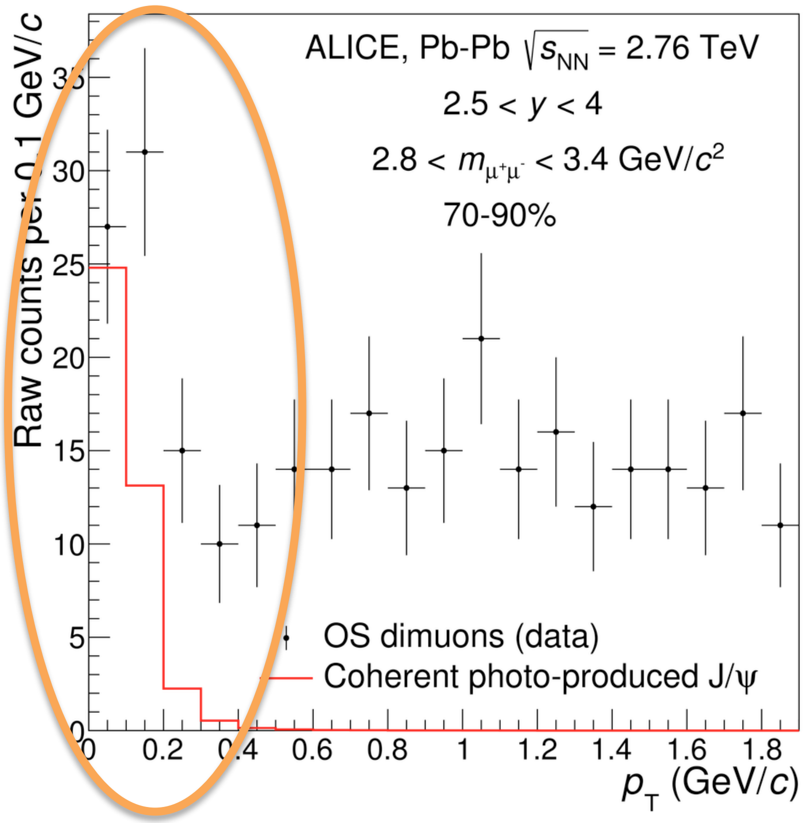


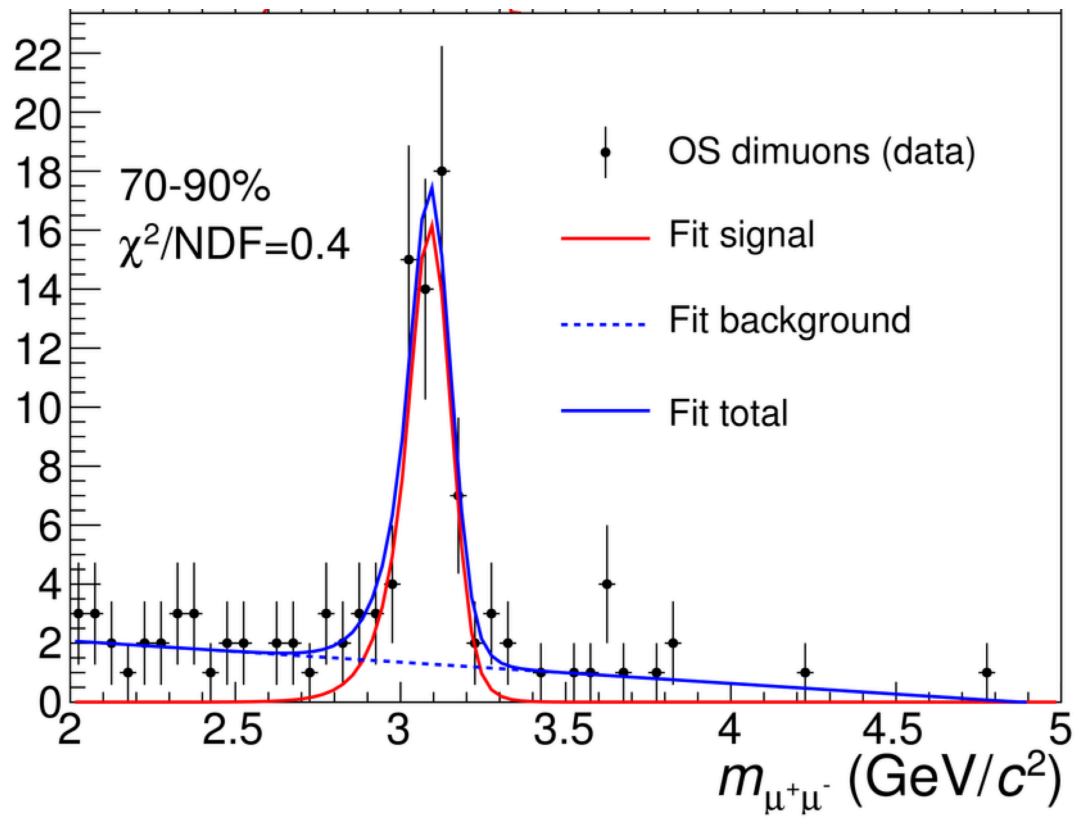
For collisions at impact parameters smaller than the sum of radii of the interacting particles, the nuclei interact hadronically and they break

Head-on collisions are called central, and at larger impact parameters are called peripheral

Coherent J/ψ production in peripheral collisions

ALICE, arXiv 1509.08802



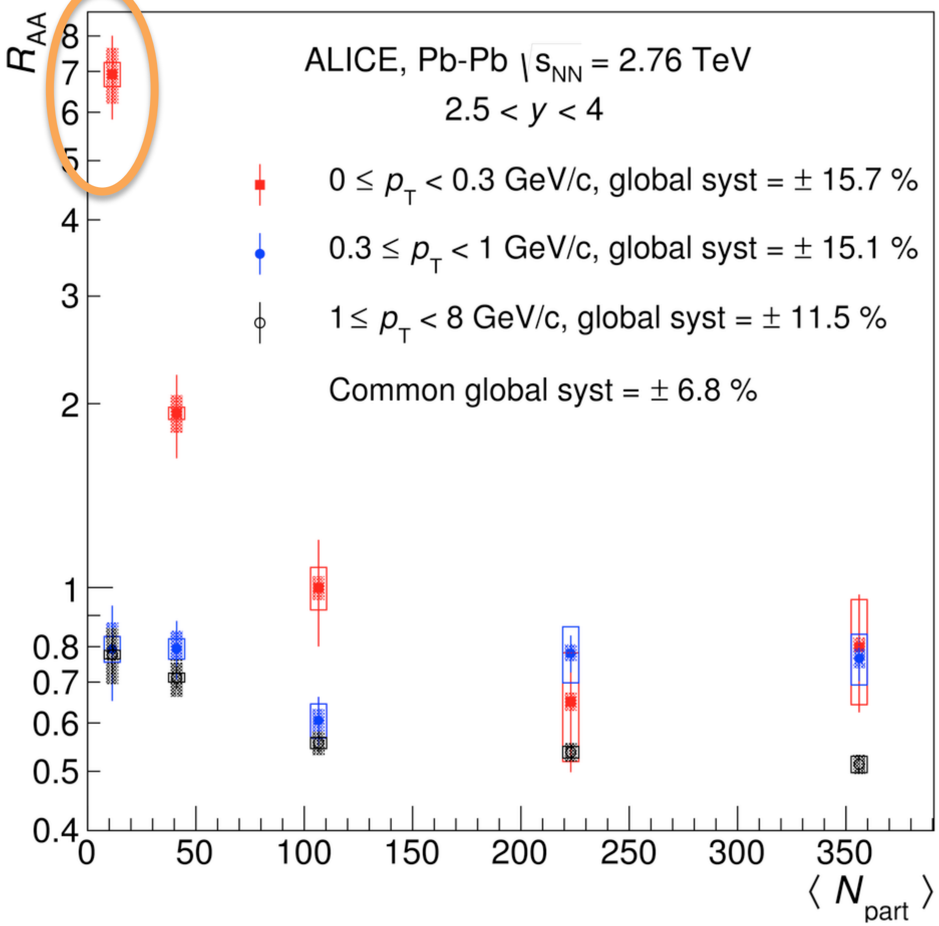


Clear excess in the yield at low p_T for peripheral collisions

And the excess is clearly from J/ψ

Coherent J/ψ production in peripheral collisions

ALICE, arXiv 1509.08802



If photo-production is assumed as the underlying interaction we obtain

Centrality class	Cross section (μb)
0-10 %	<318
10-30%	<290
30-50%	$73\pm44^{+26}_{-27}$
50-70%	$58\pm16^{+8}_{-10}$
70-90%	$59\pm11^{+7}_{-10}$

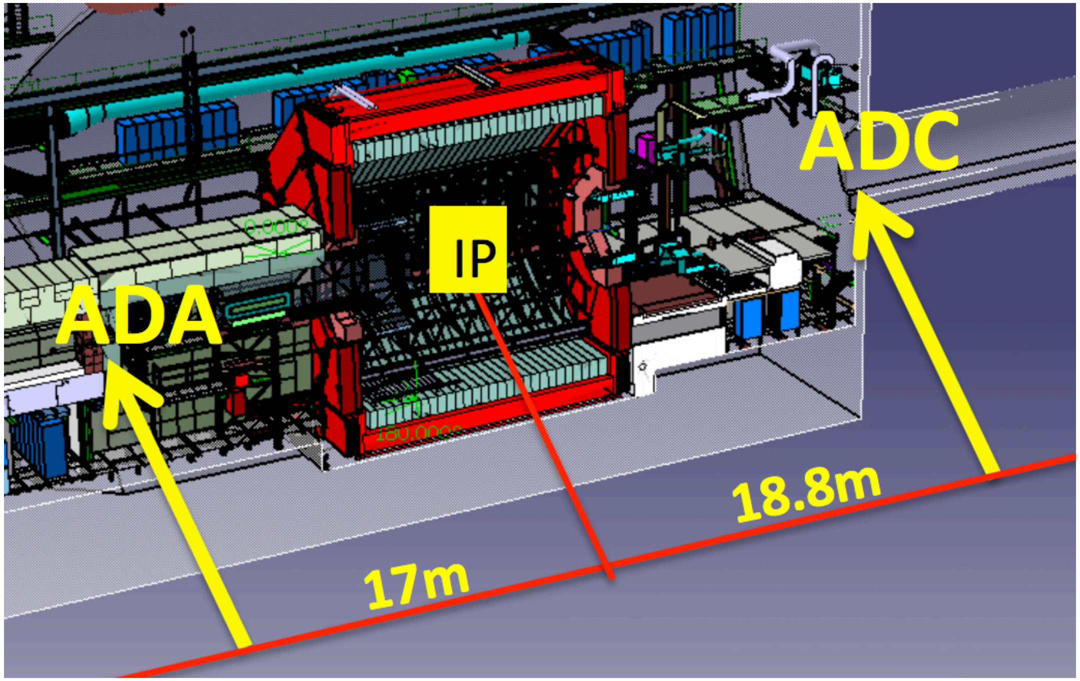
If excess were from hadronic production, the R_{AA} would reach up to 7!
(Standard expectation is $R_{AA} \sim O(1)$)

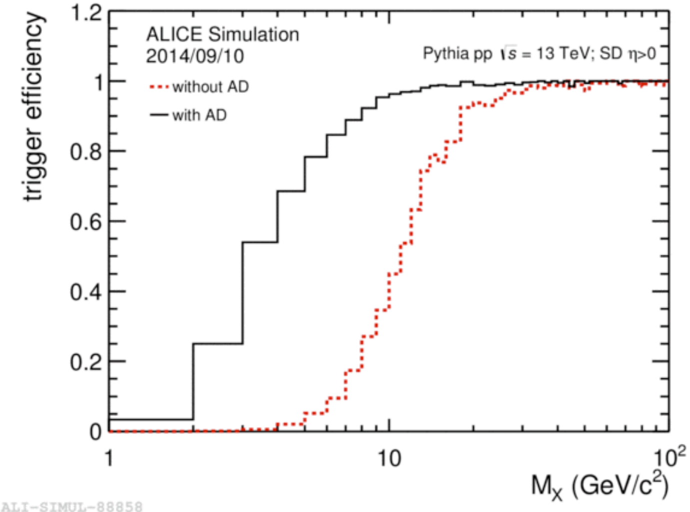
No theoretical calculations available for coherent photoproduction in peripheral collisions

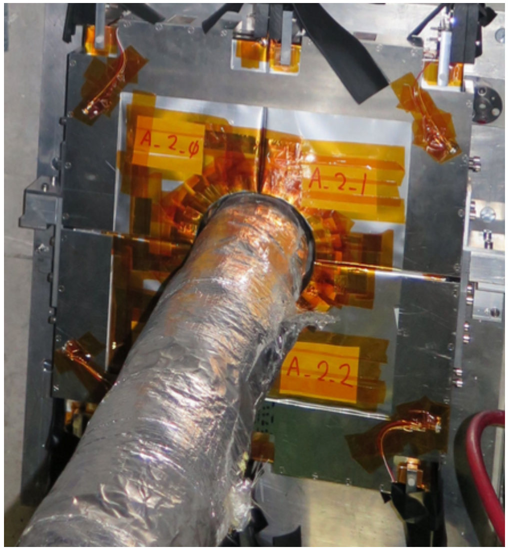
(A first try is in arXiv: 1509:03173)

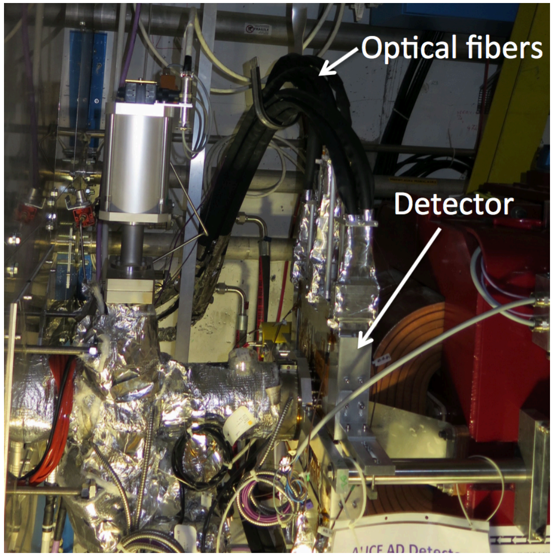
A word on Run 2

The AD detector









- ✓ Modules of plastic scintillator read out with PMTs
- ✓ Time resolution 300 (500) ps in C (A) side, allows to reject out of time background
- ✓ Enlarges ALICE geometric rapidity coverage to
  - ✓ $-6.9 < \eta < -4.9$
  - ✓ $4.9 < \eta < 6.3$
- ✓ It increases ALICE capability to impose a veto in extra activity for exclusive processes in UPC

Run2 data

For PbPb:

- Factor of two increase on the PbPb center of mass energy
  - Increase in the cross section, mainly due to an increase in the photon flux
  - Increase in the kinematic reach: a factor of two lower values of Bjorken x will be accessible

- Improved detector and trigger capabilities
  - Cleaner samples, smaller systematic error
  - Access to other vector mesons, e.g. ϕ
  - Better use of detector acceptance

- Increase in the luminosity available for UPC
  - Harvest from 2015 Pb-Pb collisions several times larger than sample from 2011 Pb-Pb run
  - These data is being analyzed now and we expect new results to start appearing soon

Summary and outlook

The LγHC (and L$\gamma\gamma$C) are delivering very interesting physics

Exciting times are ahead of us, so stay tuned!