Diffraction 2016
3-7 September, 2016 Acireale, Italy

ALICE results on vector meson photonuclear production in Pb-Pb collisions

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Czech Technical University

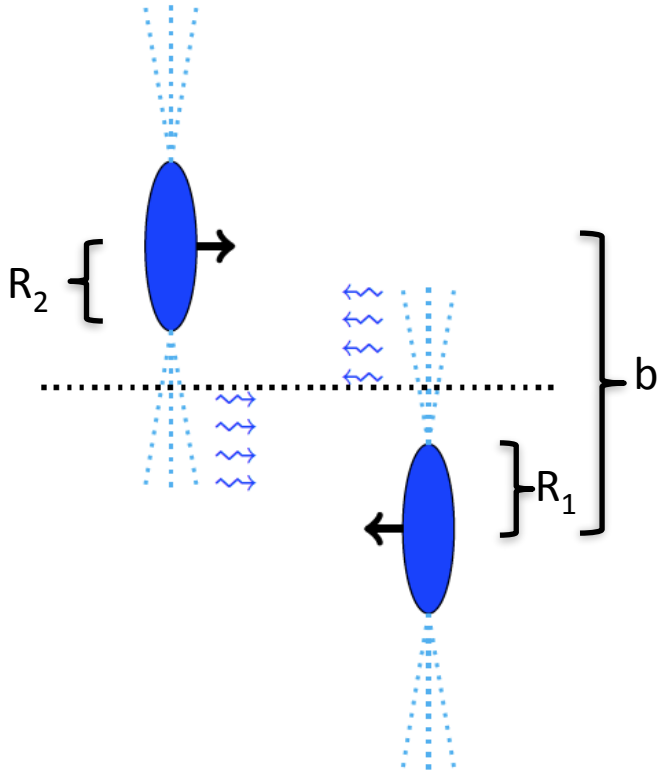
on behalf of the ALICE Collaboration

September 7, 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



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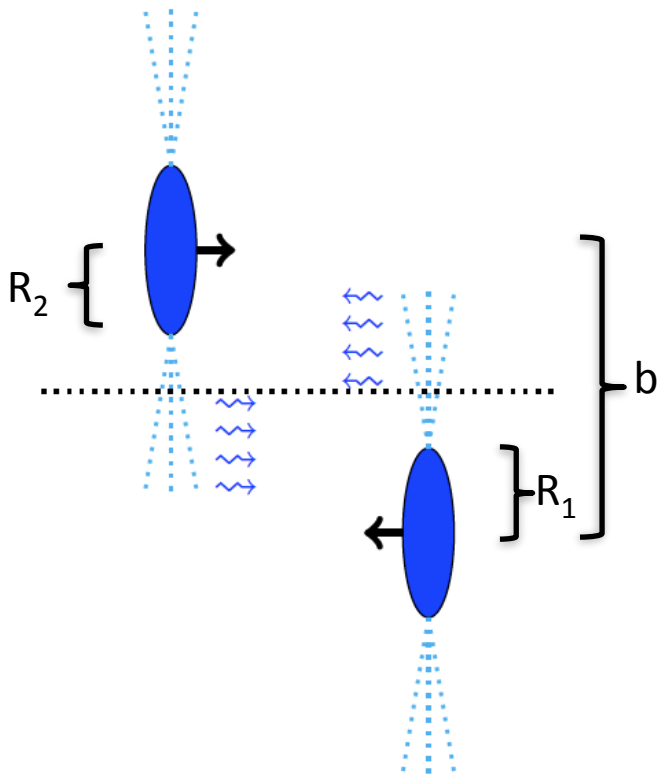
There are two potential sources, correspondingly two potential targets.



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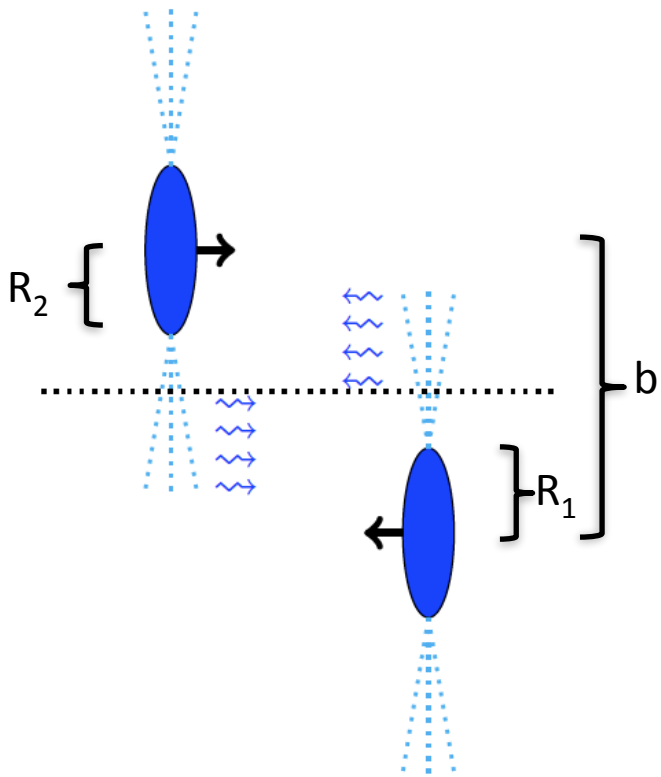

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The photon is coherently emitted by the source and its virtuality is restricted by the radius of the emitting particle:

$Q^2 \sim 1/R^2$

✓ γ from Pb: $Q^2 \approx (30\ \text{MeV})^2$

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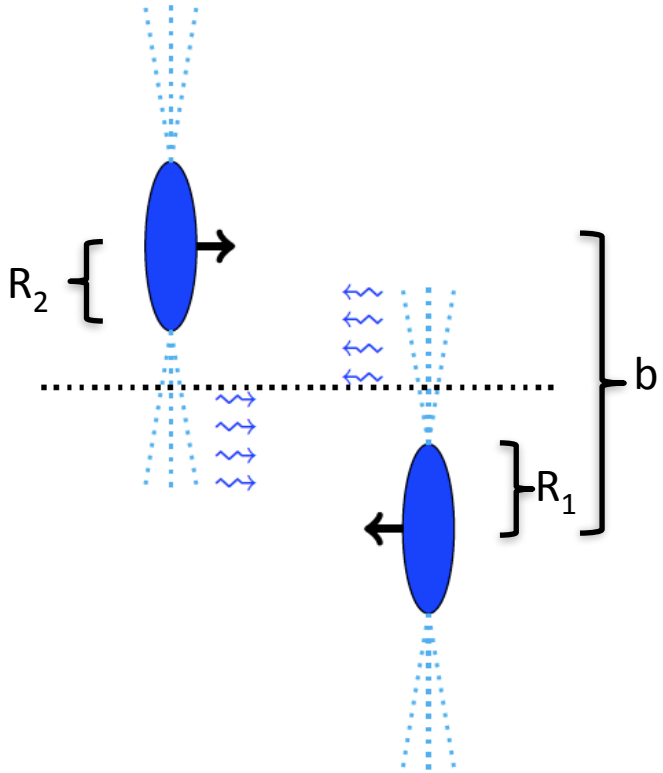

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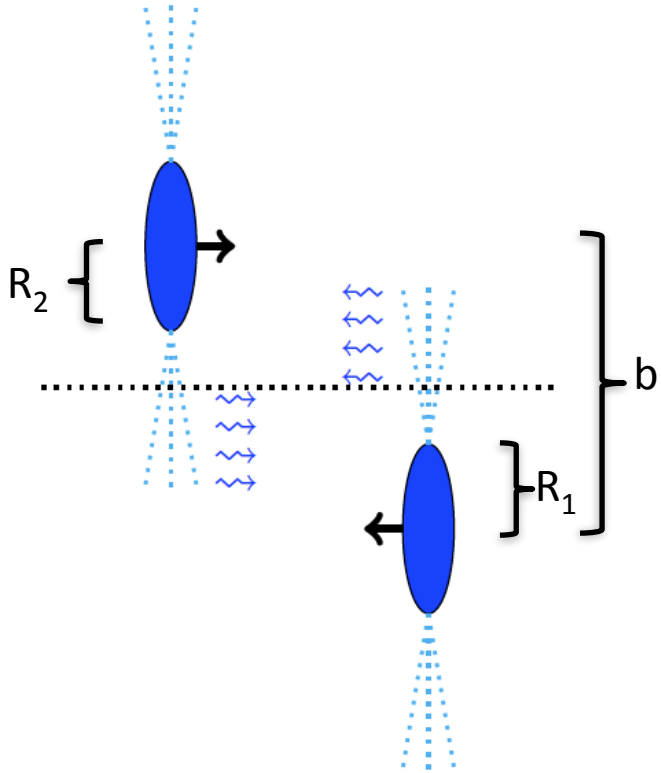

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✓ Run2: larger energies possible

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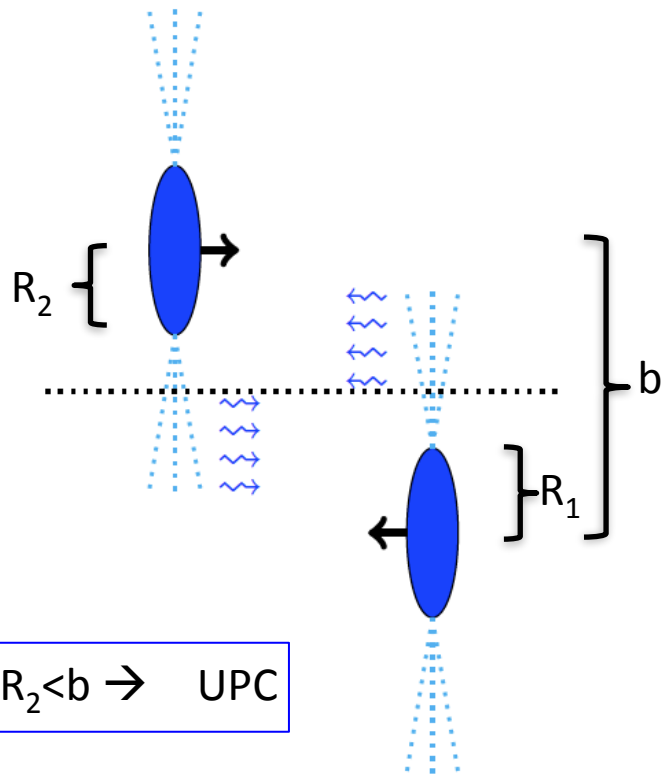

$R_1+R_2<b \rightarrow$ UPC

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Note 5:

Interactions at large impact parameters involve photons.

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 particle:
→ The intensity is orders of magnitude larger for Pb w.r.t. proton beams.

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

The strategy is to use the facts that

1. Strong interactions tend to produce particles at all rapidities, while electromagnetic interactions produce large rapidity gaps
2. 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 fragmentation)

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

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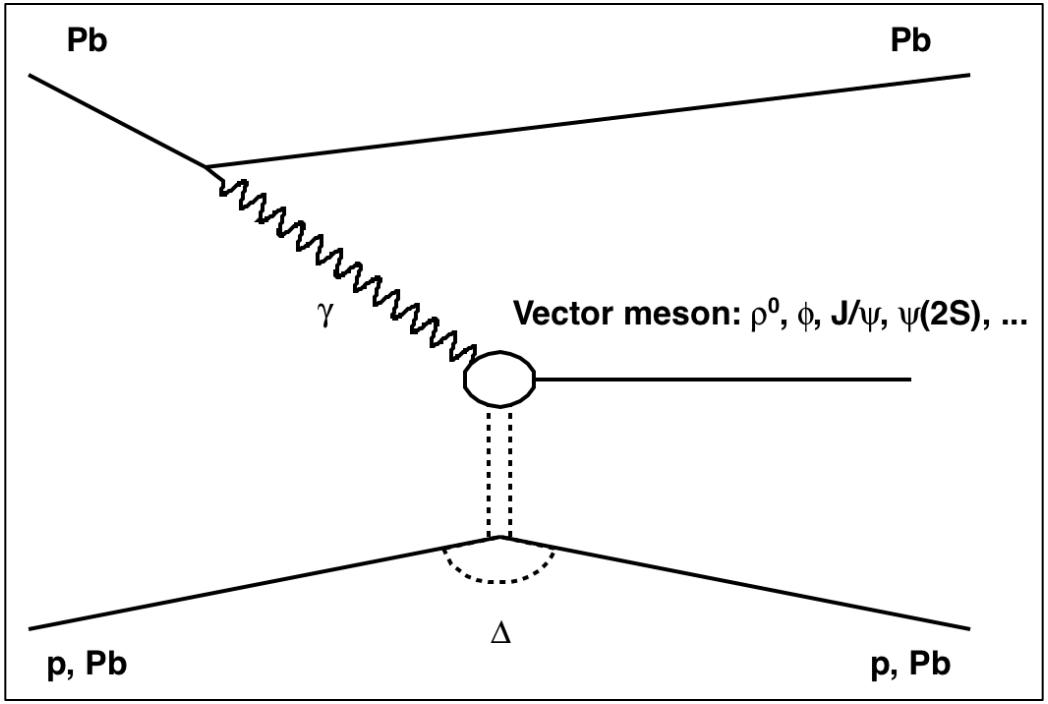
These are called Ultra-Peripheral Collisions (UPC)

Exclusive photoproduction of vector mesons and ALICE

Exclusive vector meson production



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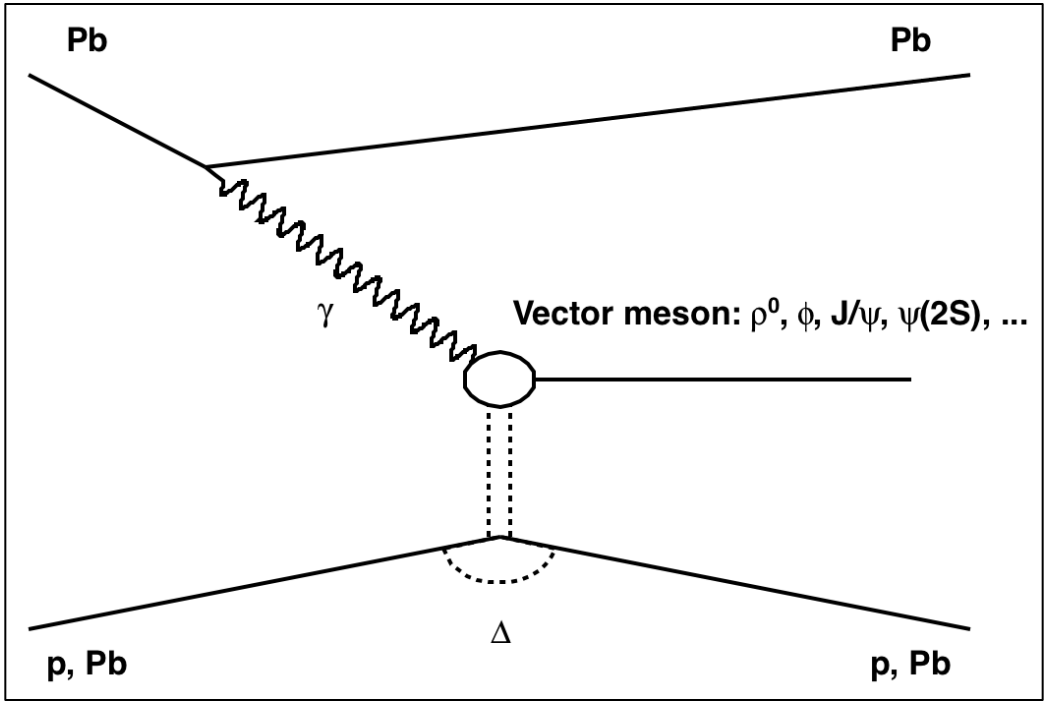

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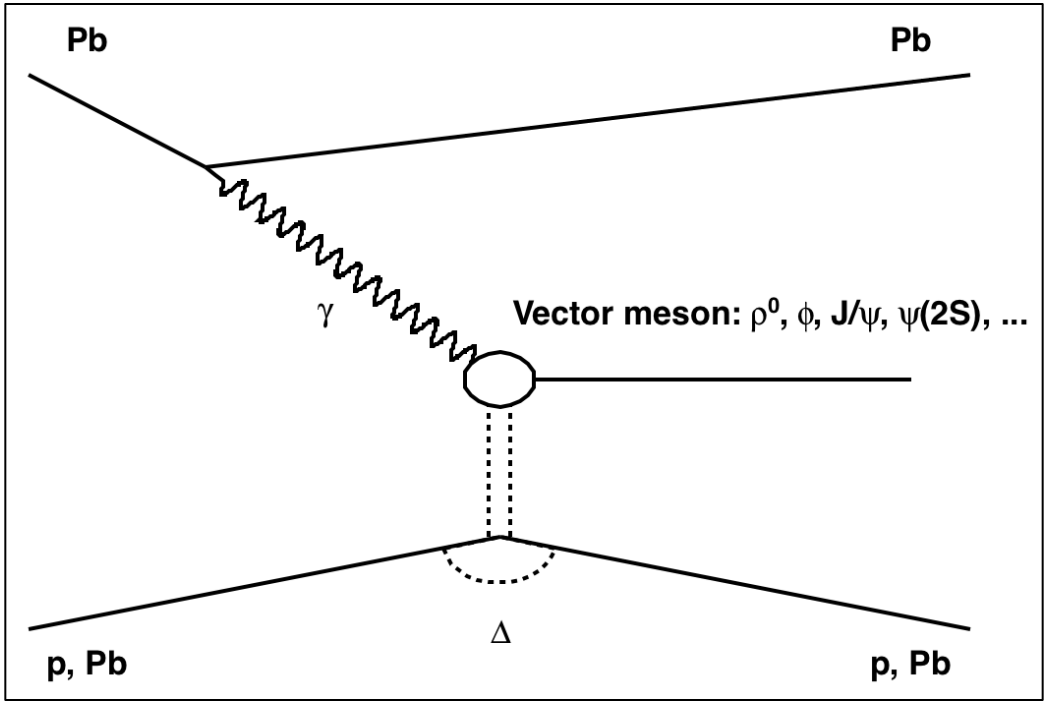

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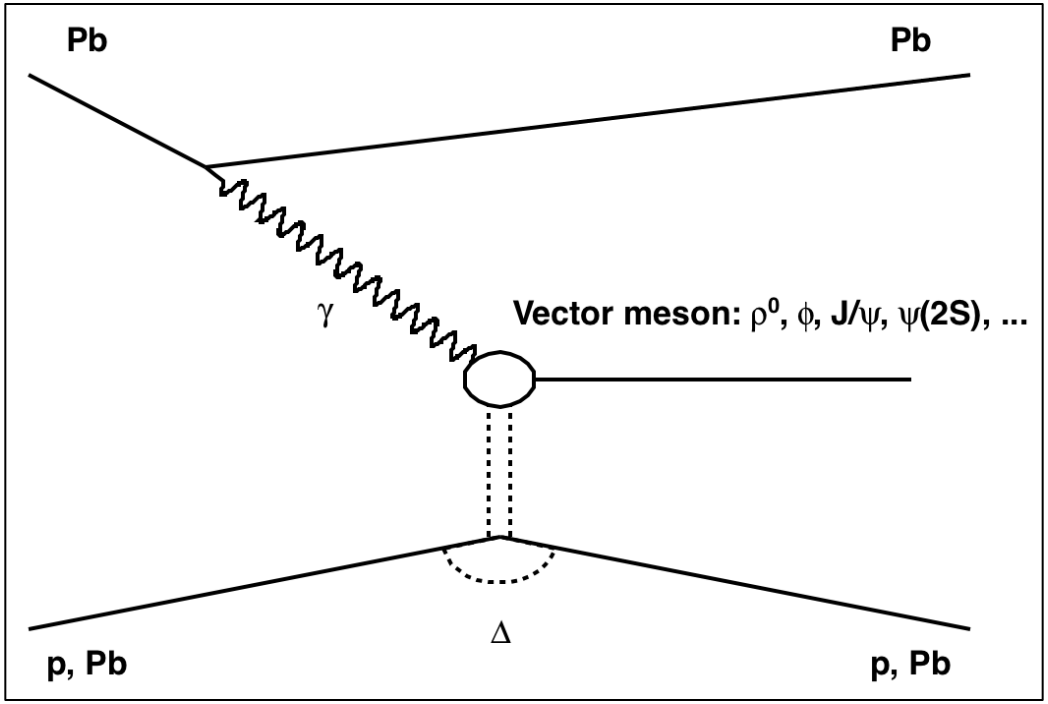

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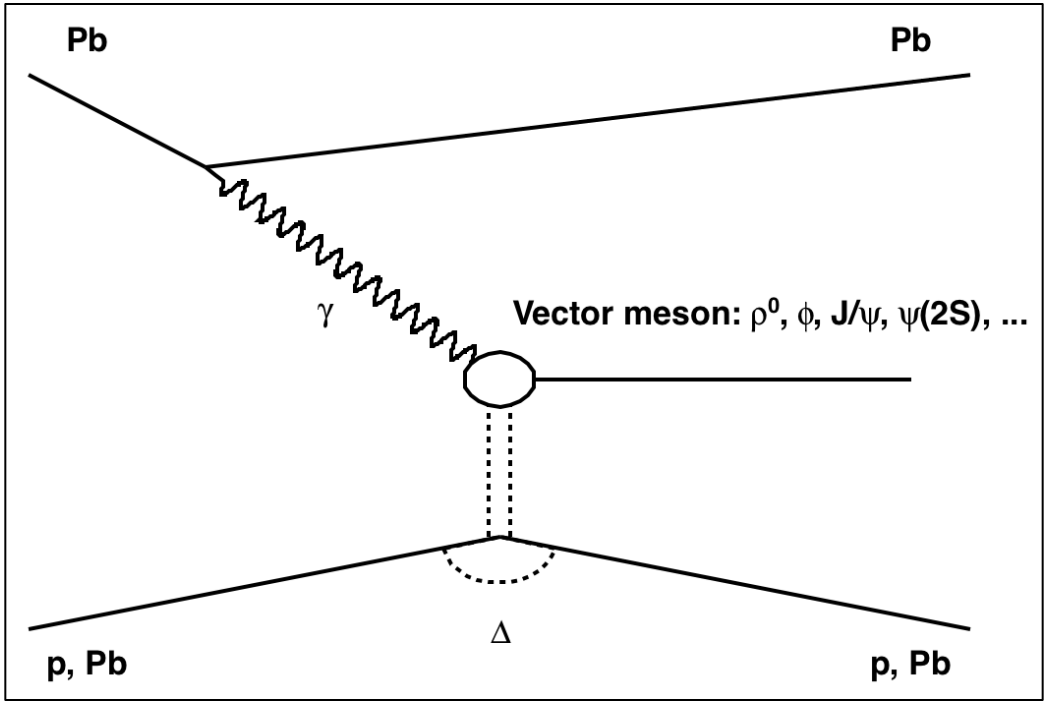

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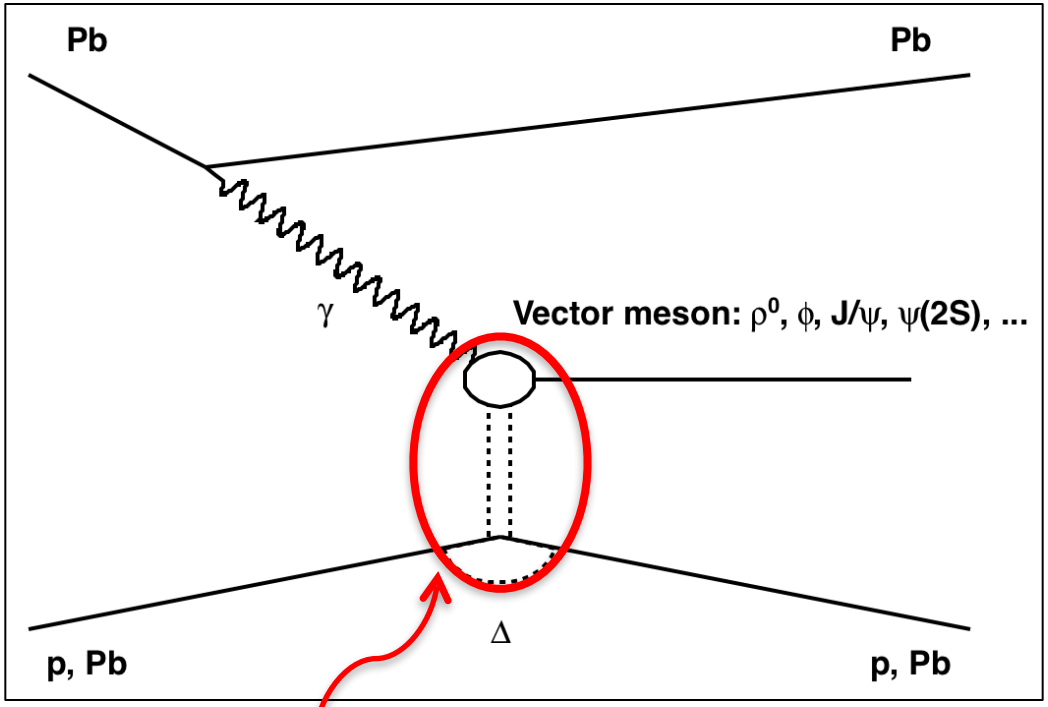
Very clean signature

The QCD structure of the target



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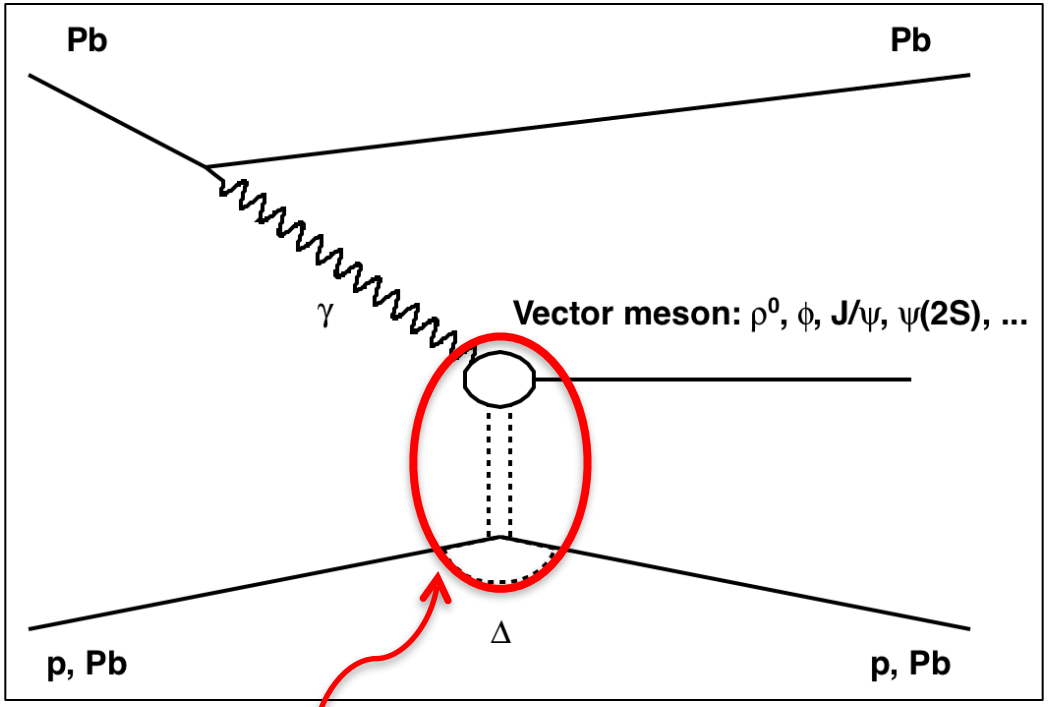

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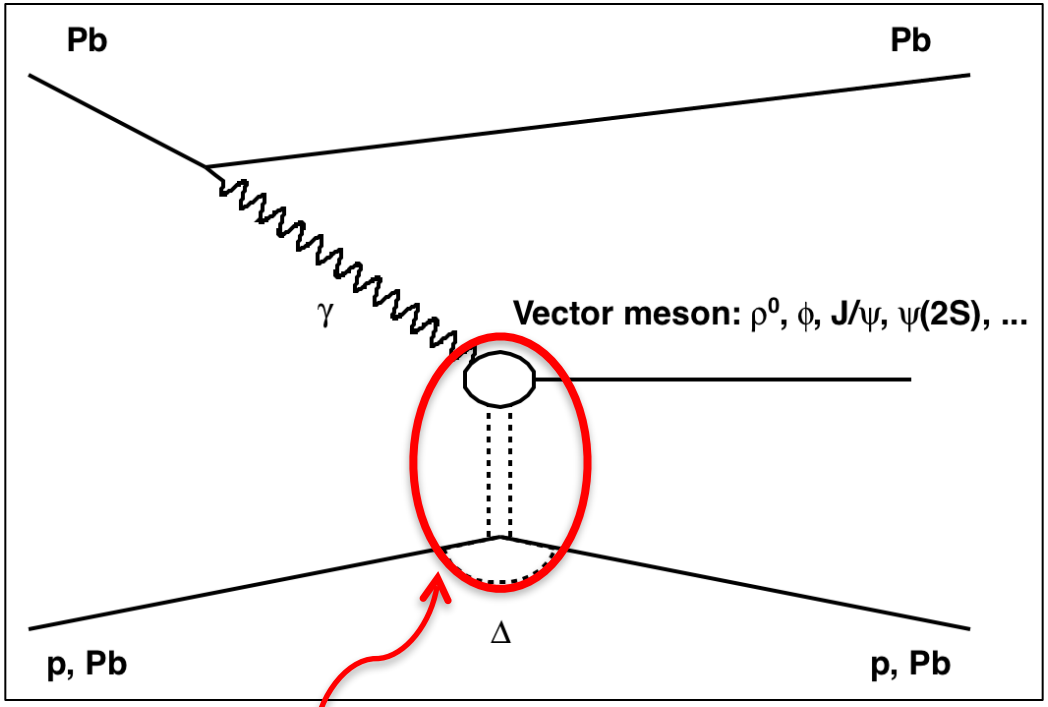

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p-Pb (p target): saturation
Pb-Pb (Pb target): shadowing

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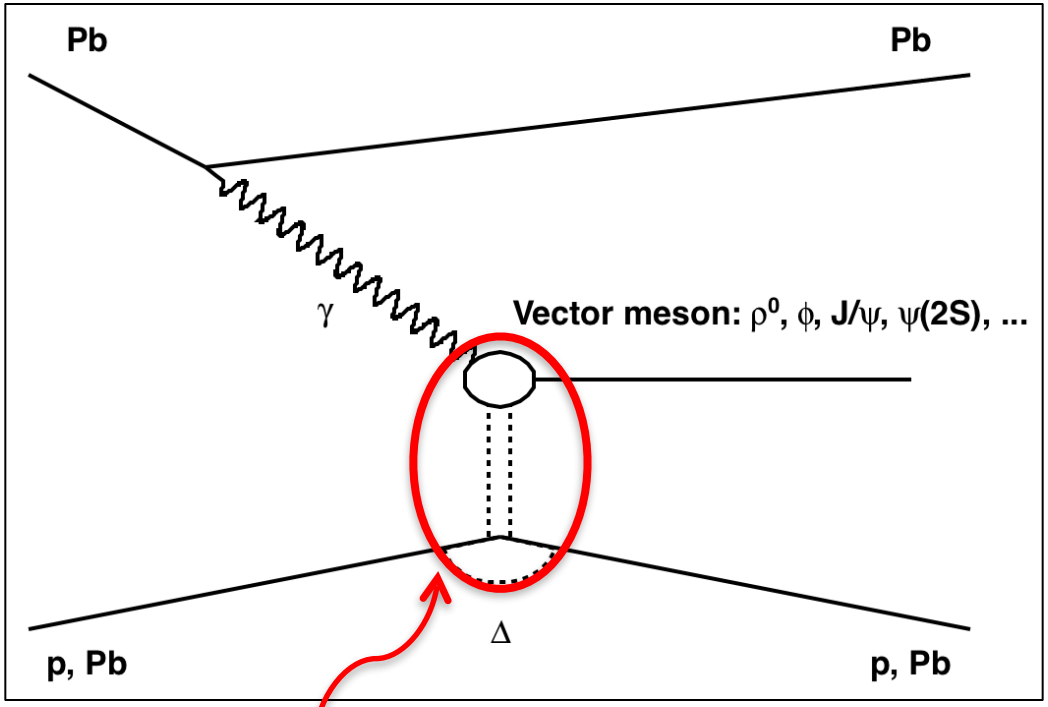

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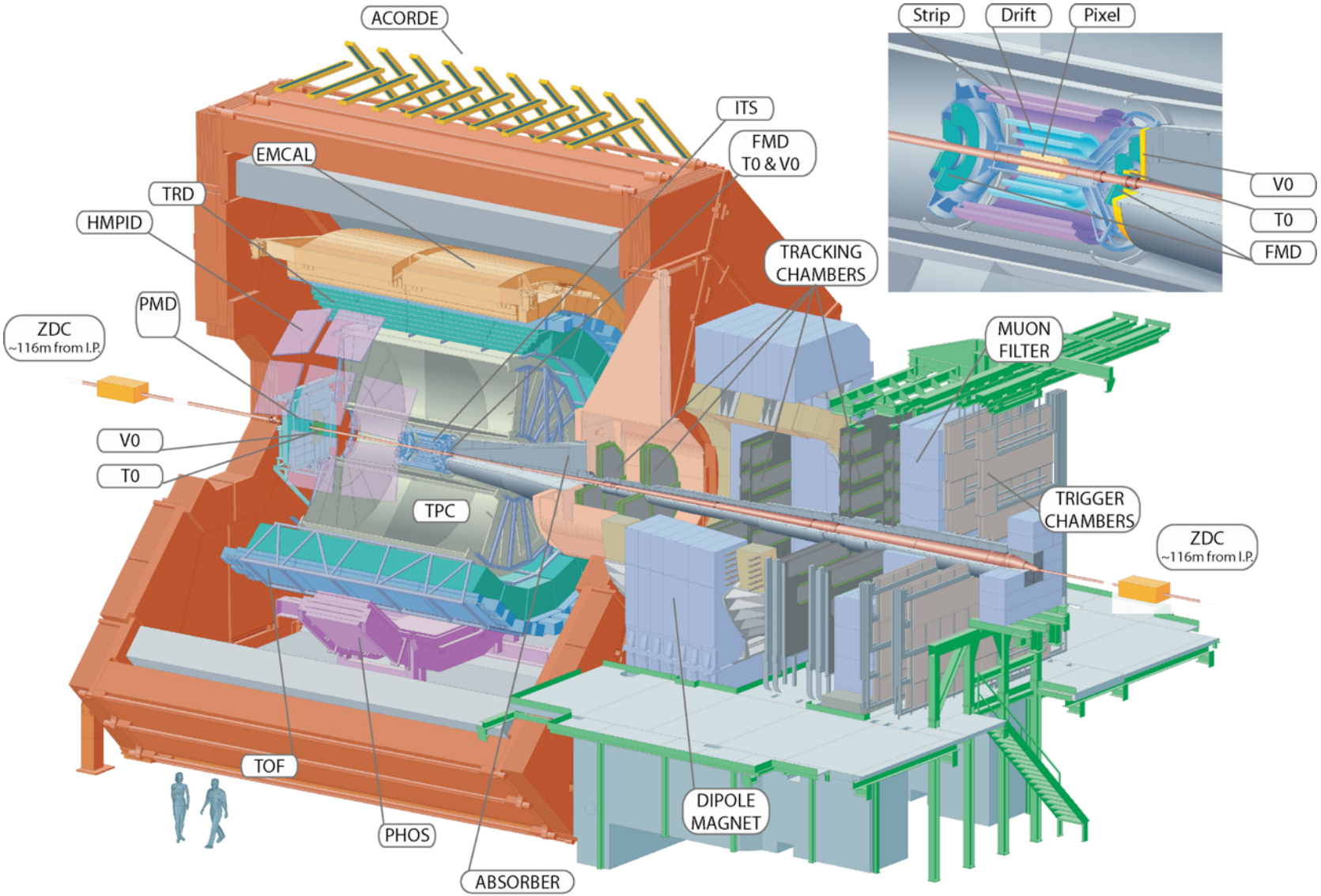
See next talk by Jarda Adam!

ALICE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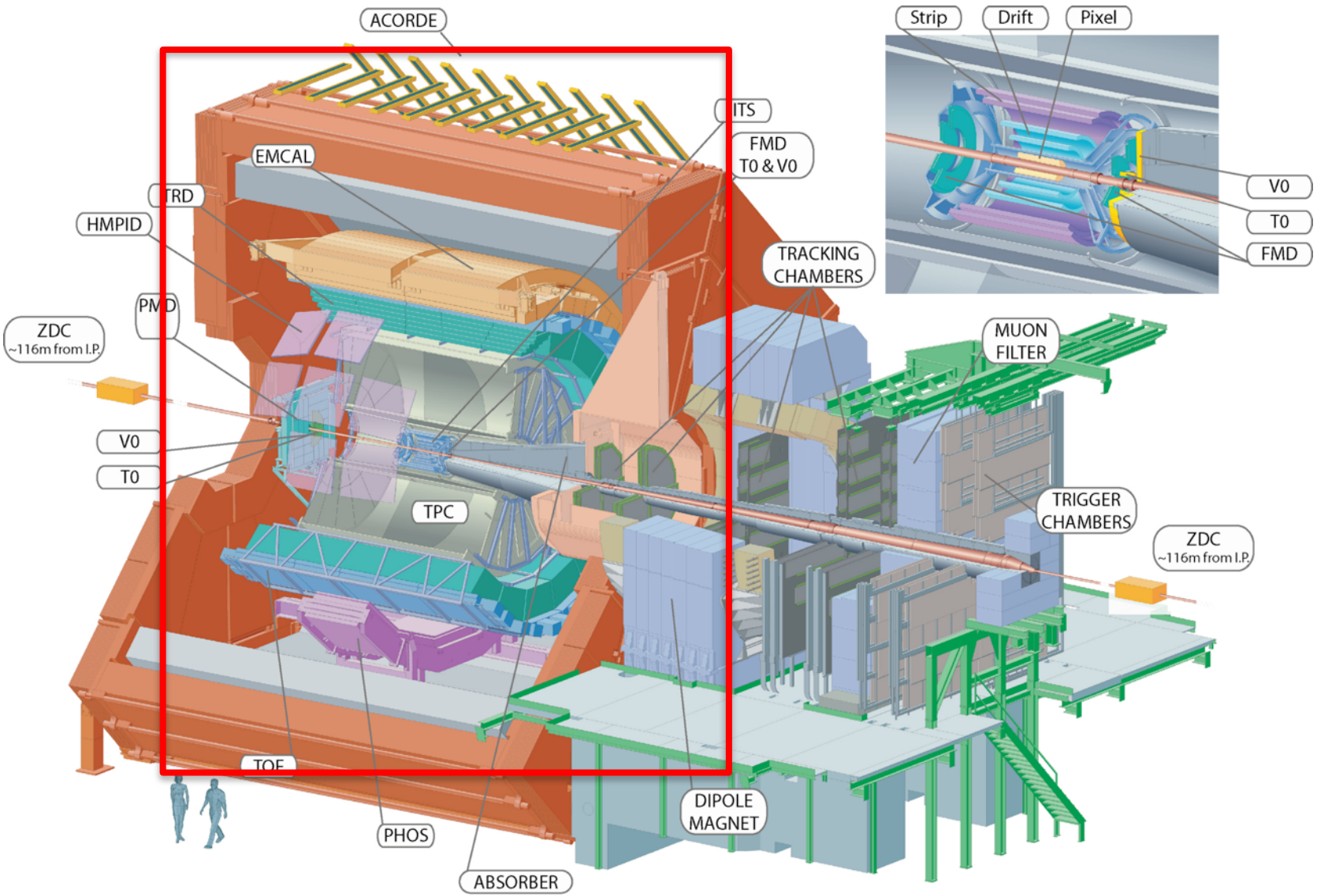
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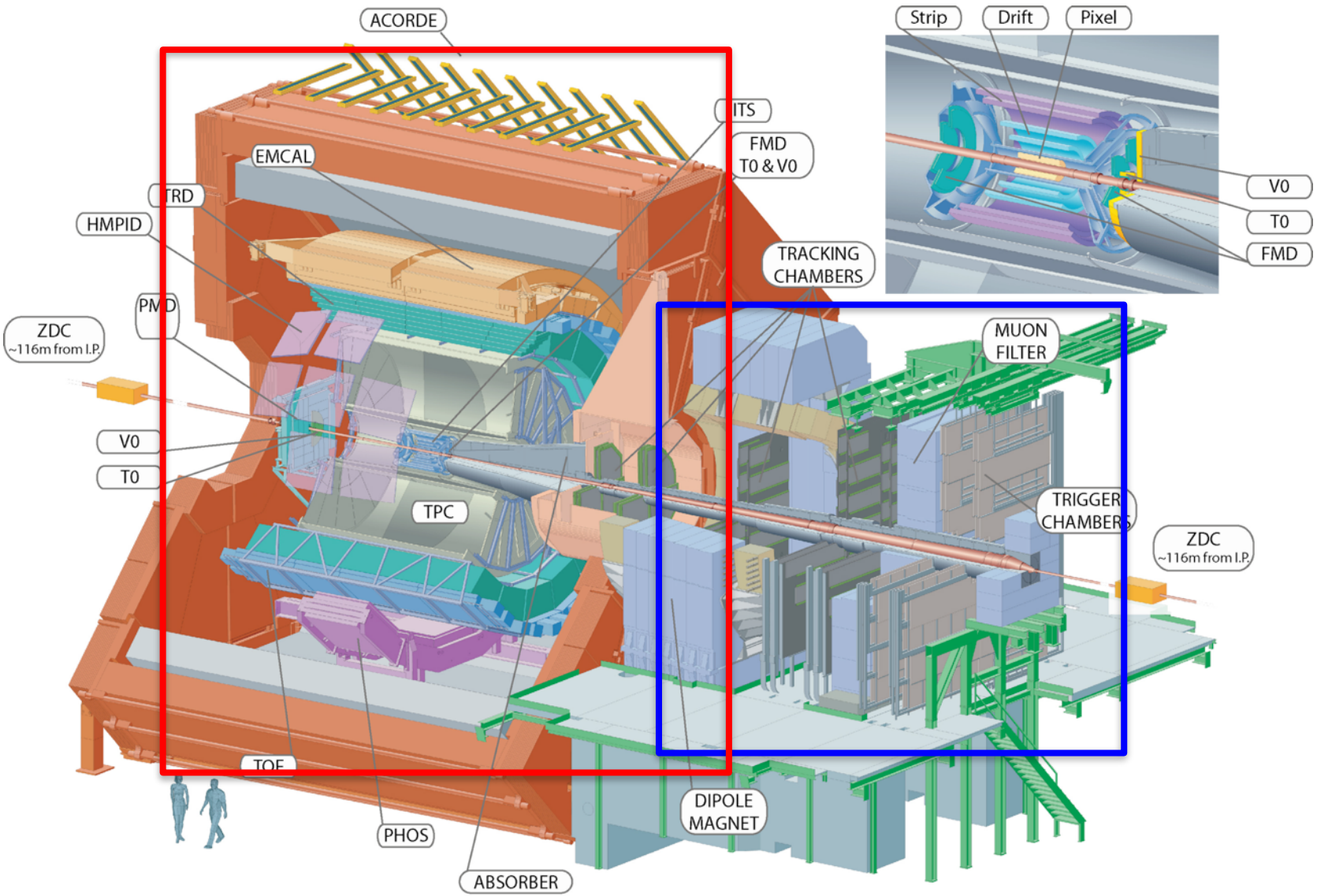
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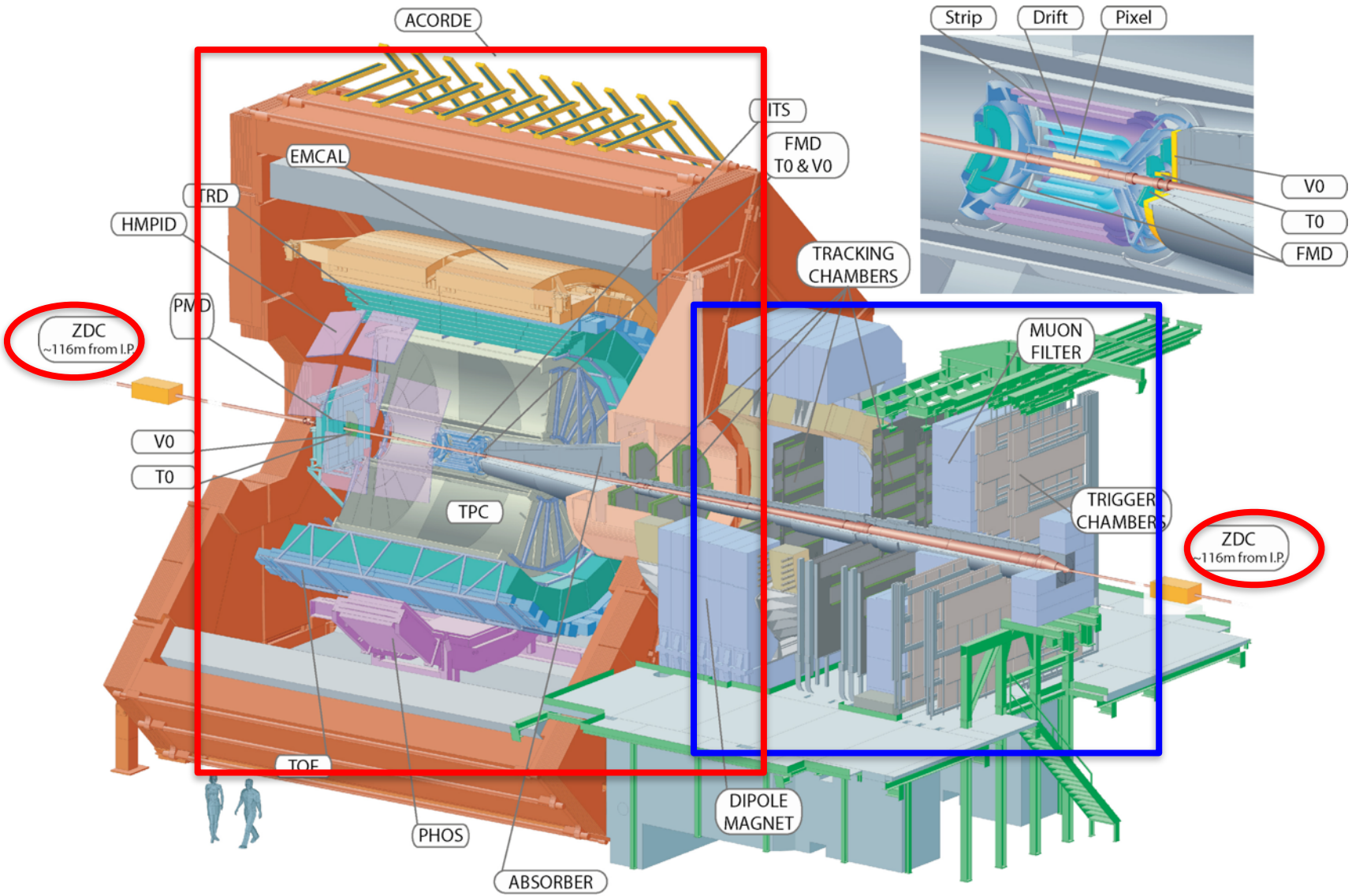
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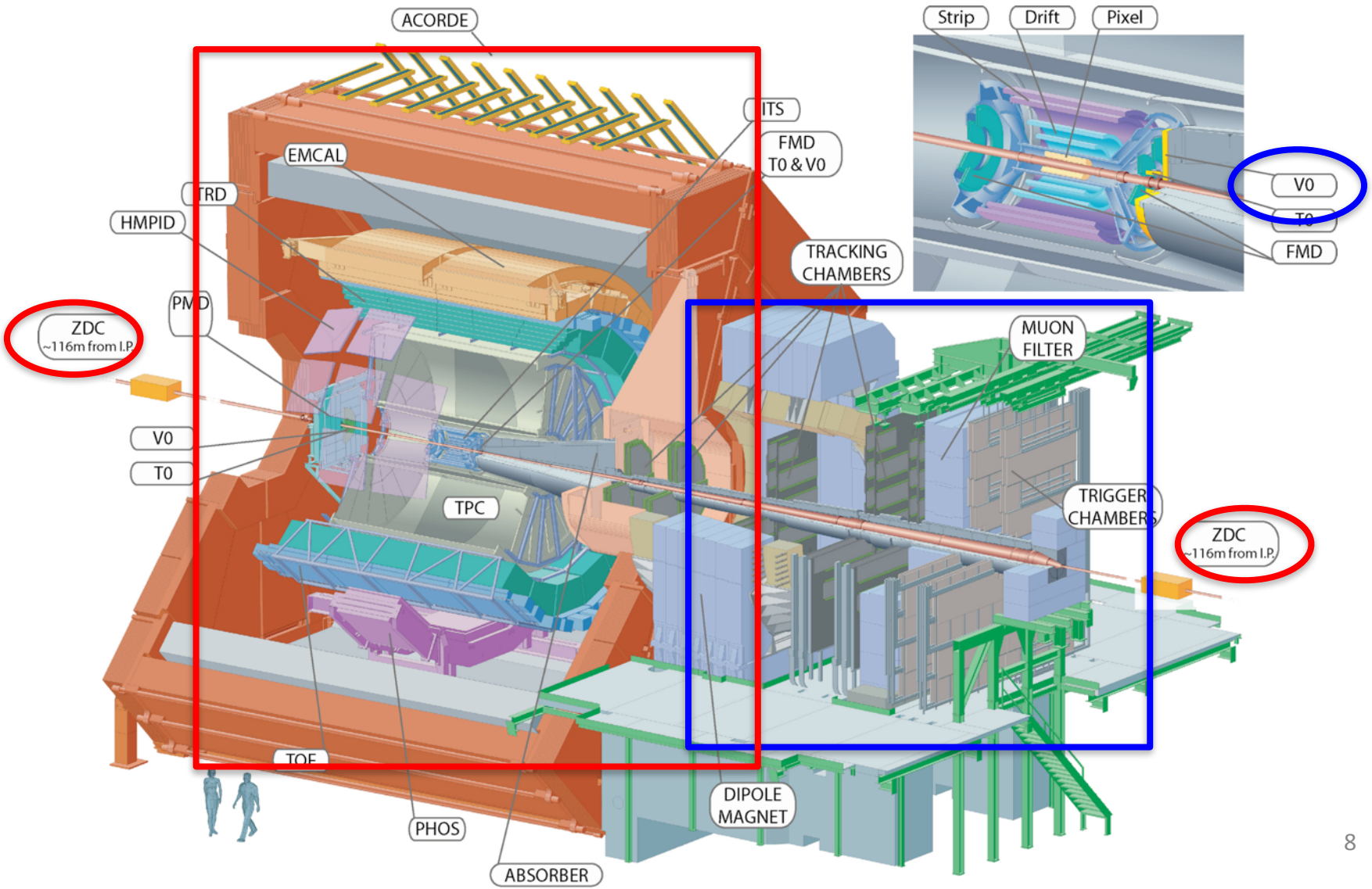
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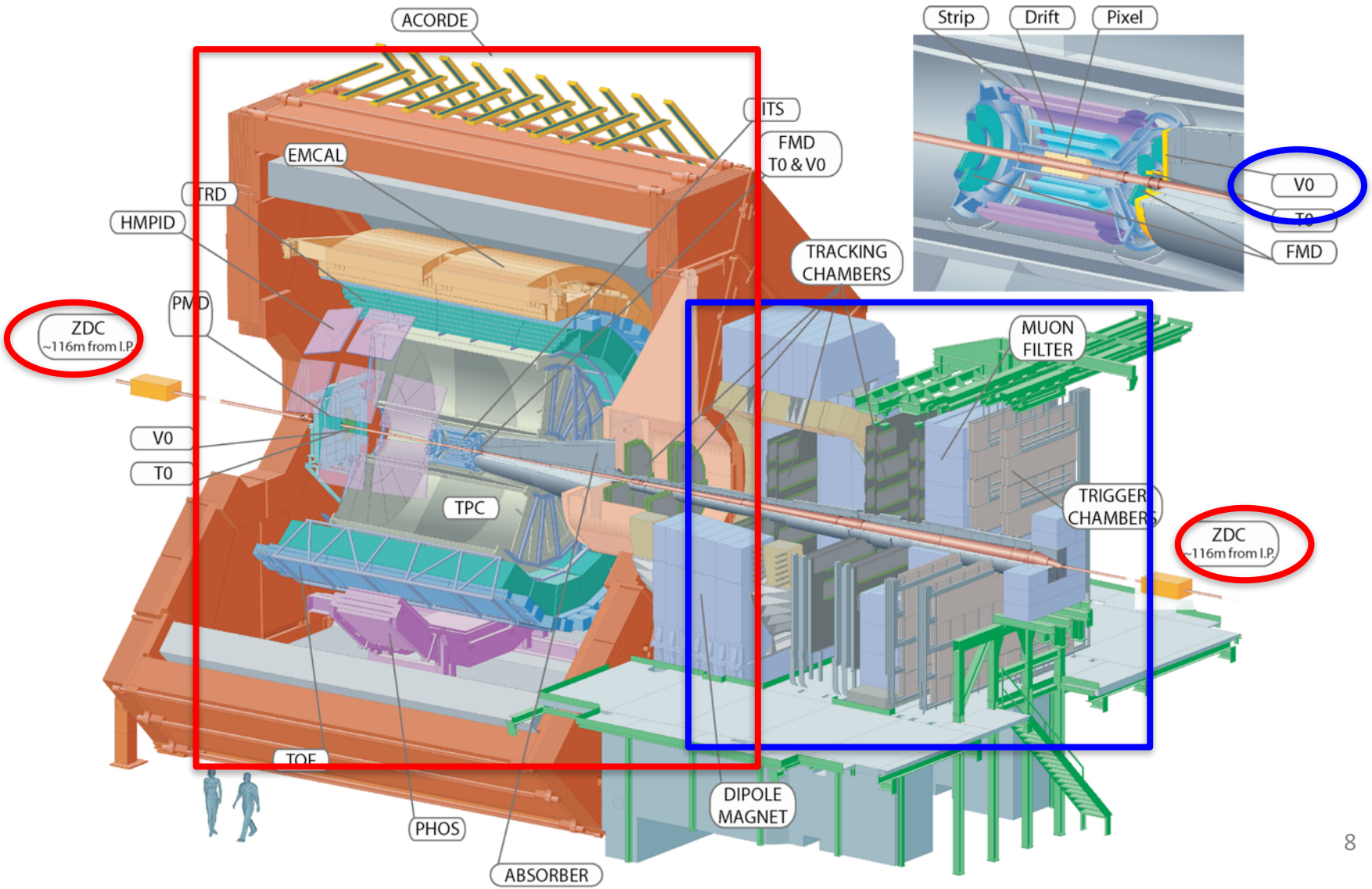
ALICE

Magnetic field of 0.5 T in the central region



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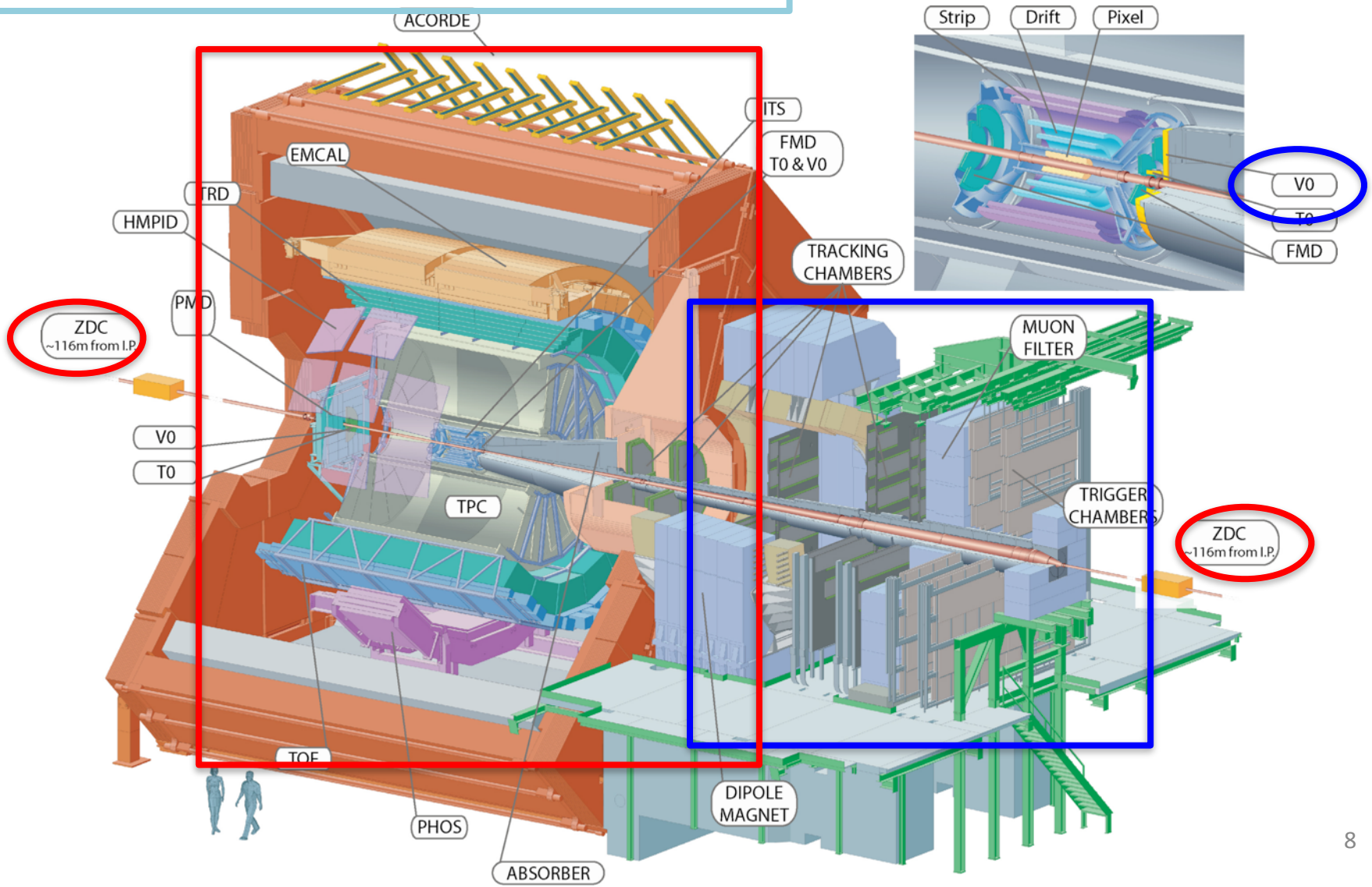
Trigger: V0 veto, SPD and TOF signals (with topology)



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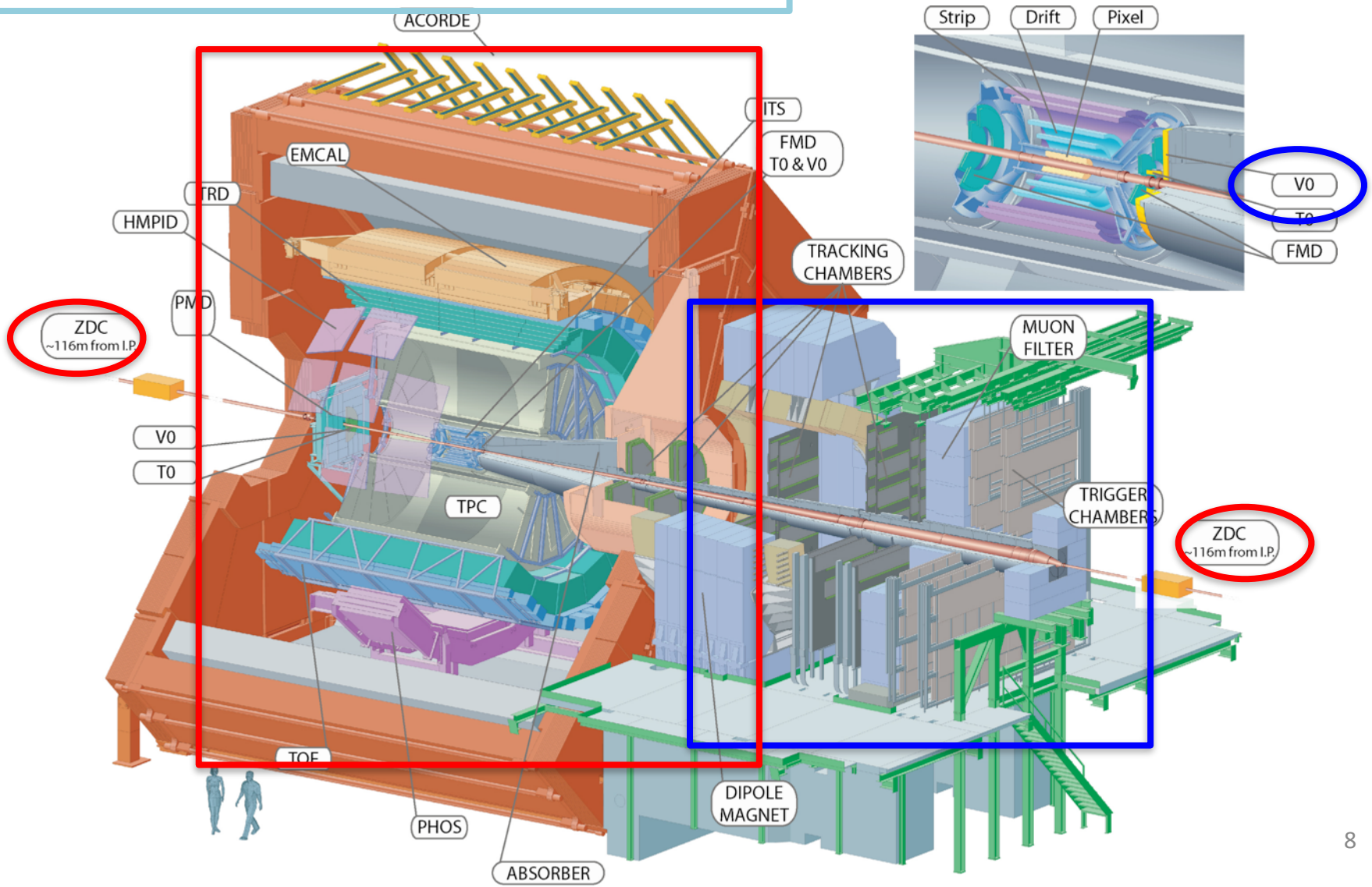
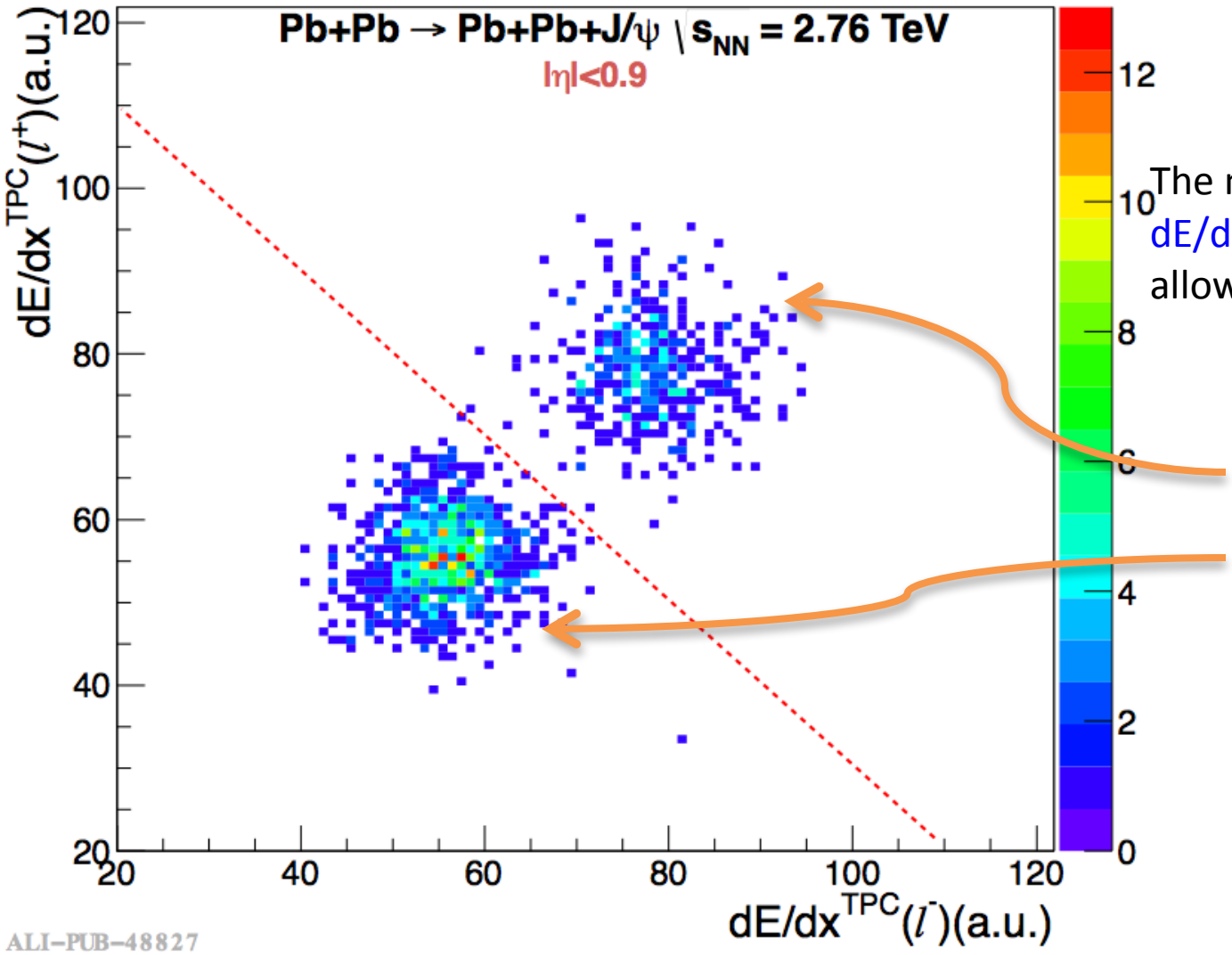
Trigger: V0A veto, muons in MUON (+signal in V0C)



Particle identification using dE/dx

ALICE: Eur. Phys. J. C (2013) 73:2617



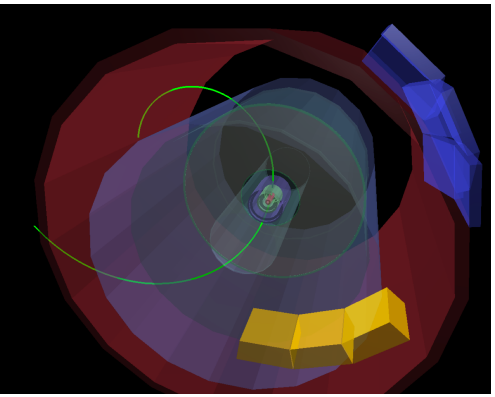
The measurement of dE/dx performed by the TPC allows a clear separation of

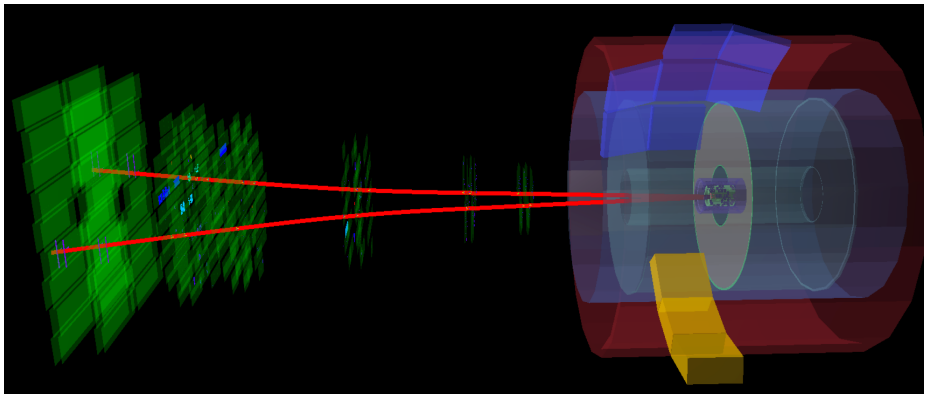
electrons

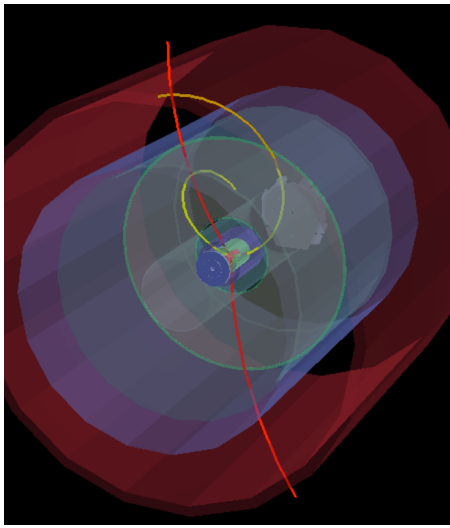
muons/pions

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 to $e^+ + e^-$
   - $\psi(2S)$ to $\mu^+ + \mu^-$, $e^+ + e^-$ or to $J/\psi + \pi^+ + \pi^-$







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: neutron Zero Degree Calorimeters (ZDC)

γ-Pb: Results from Pb-Pb collisions in Run1

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Four topics:

① Coherent ρ production

② Coherent and incoherent J/ψ production

③ Coherent $\psi(2S)$ production

④ A surprise!

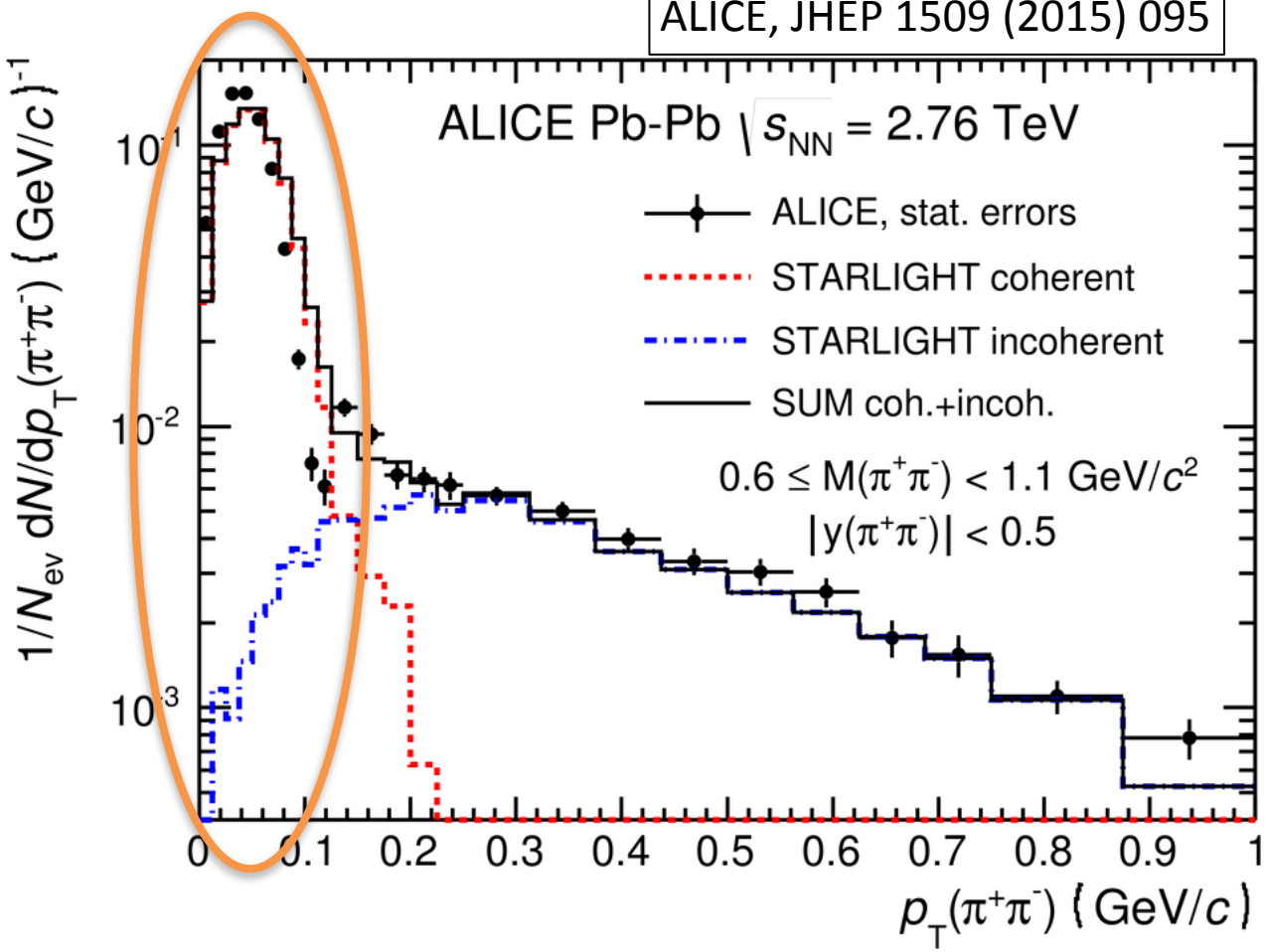
Coherent ρ production

- ✓ 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

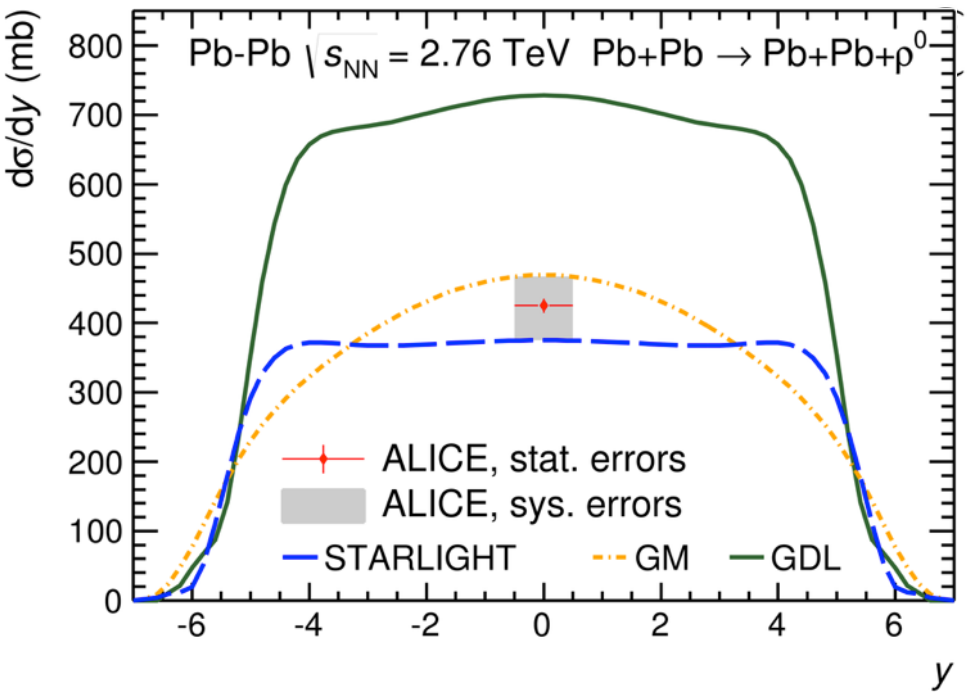
- ✓ 2010 data
- ✓ Decay into $\pi^+\pi^-$

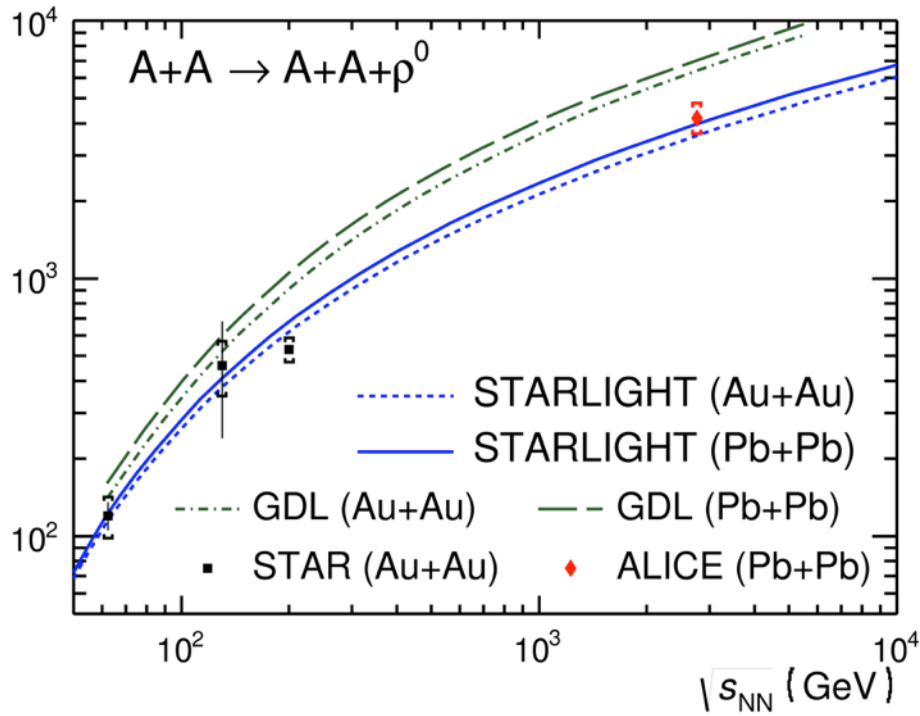
Distribution of transverse momentum for coherent ρ is wider in STARLIGHT than in data
To be studied in Run2



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

Coherent ρ production: cross section





ALICE, JHEP 1509 (2015) 095

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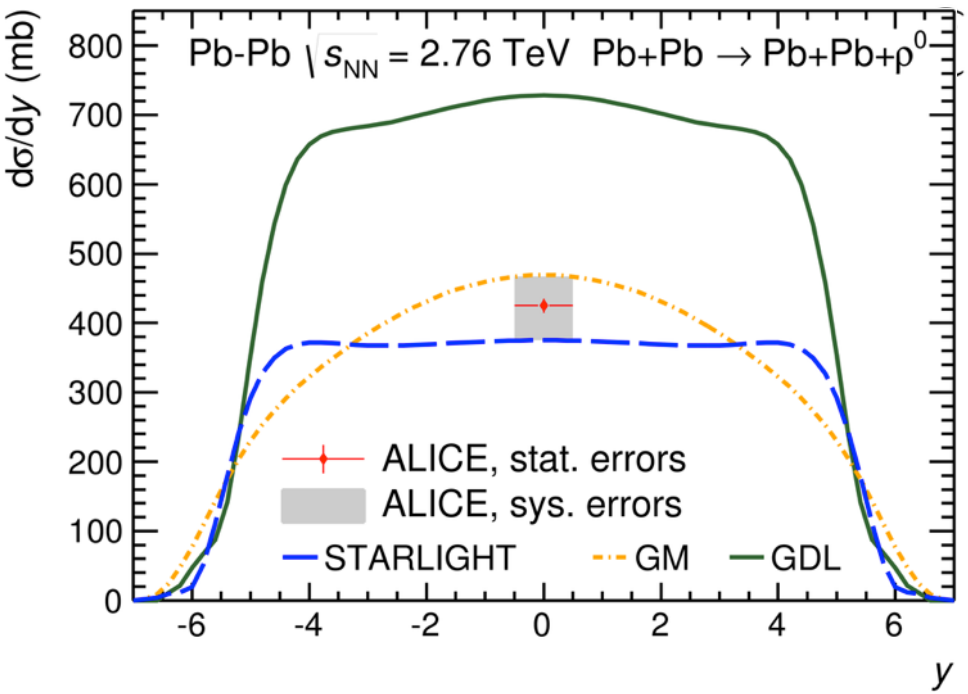

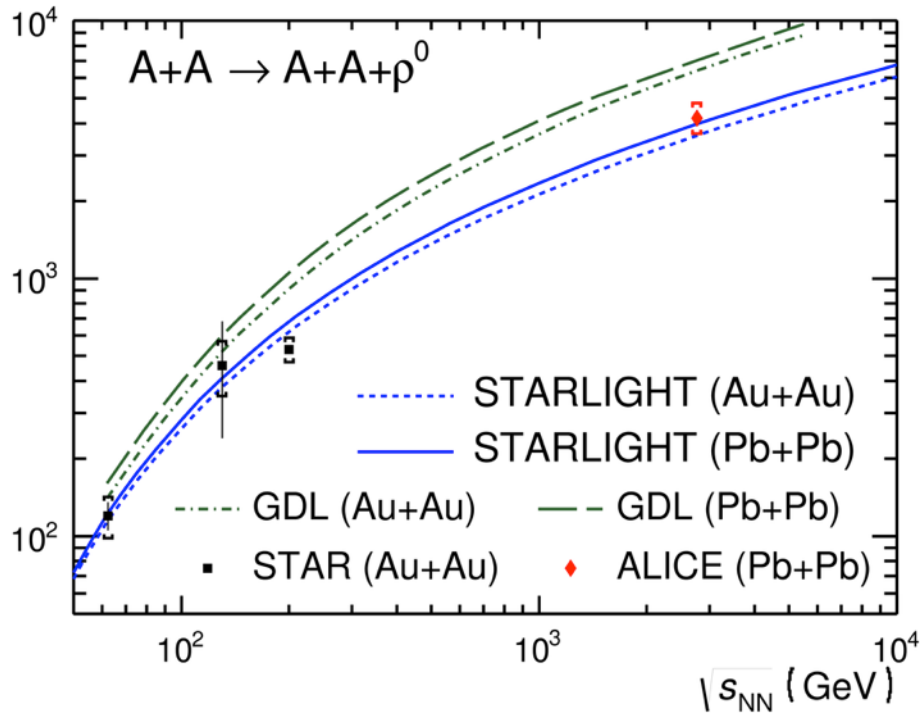

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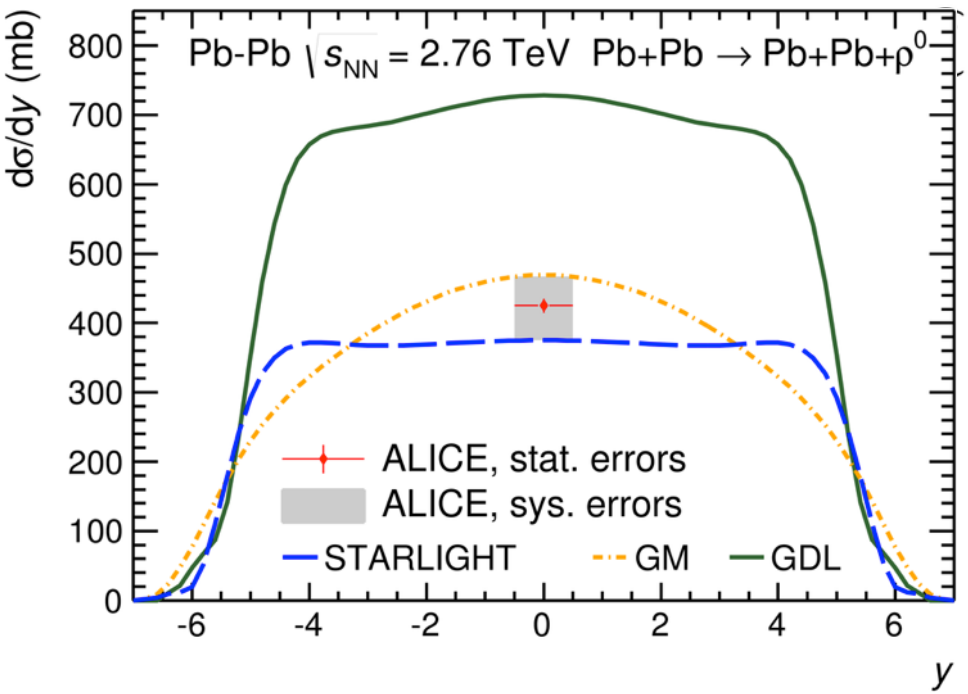
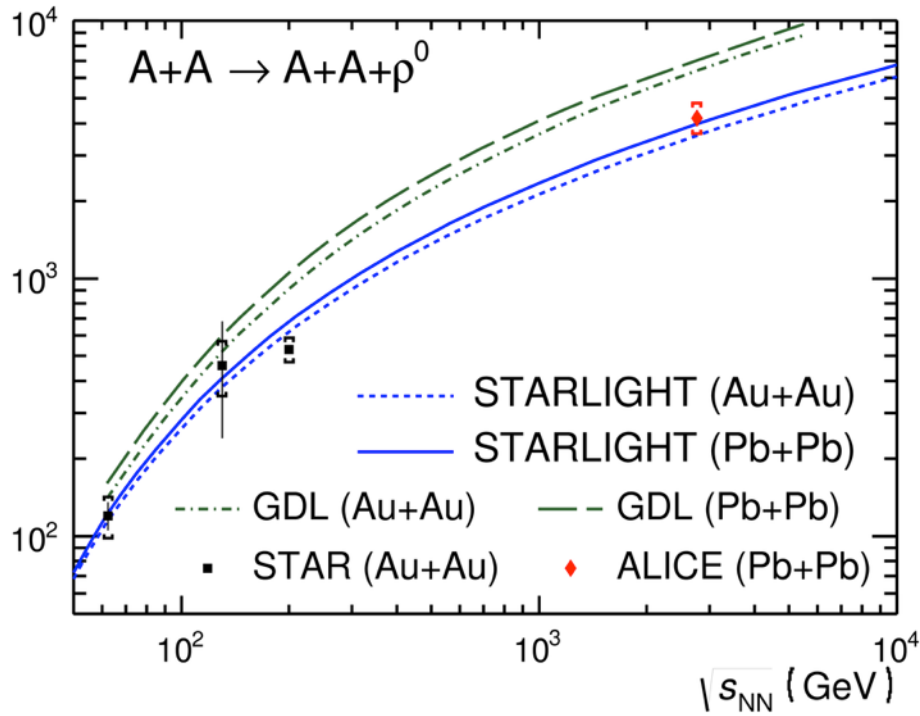


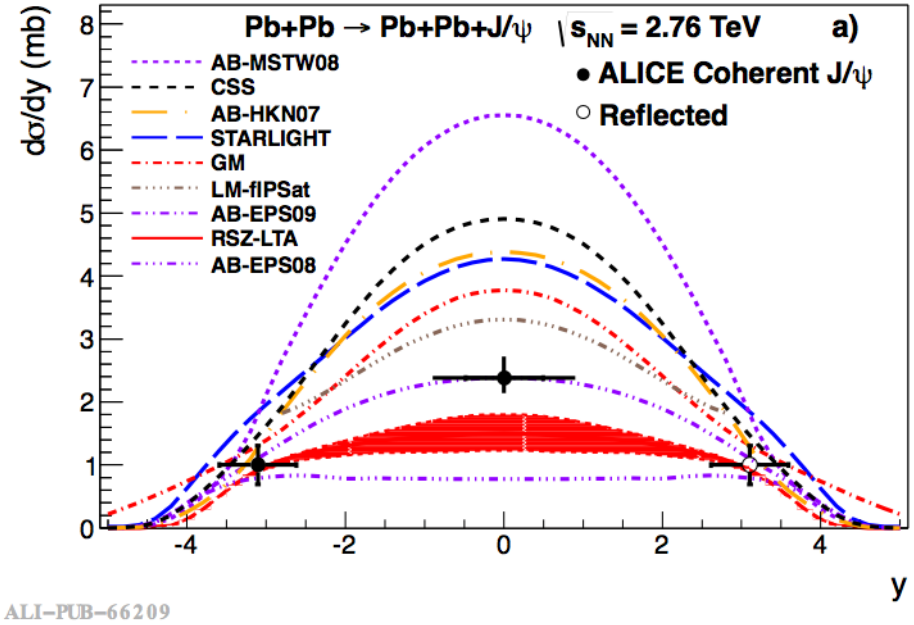


- ✓ Agreement with STARLIGHT
- ✓ Disagreement with GDL model may be explained by inelastic nuclear shadowing (see Phys.Lett. B752 (2016) 51-58)

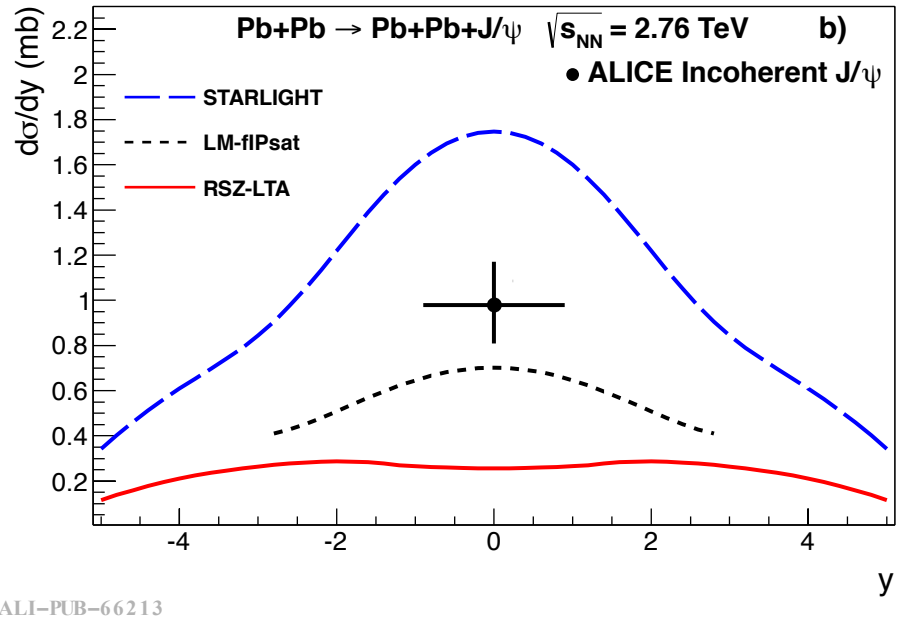
ALICE, JHEP 1509 (2015) 095

Coherent and incoherent J/ψ production: cross sections

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



ALI-PUB-66209



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Coherent and incoherent J/ψ production: cross sections

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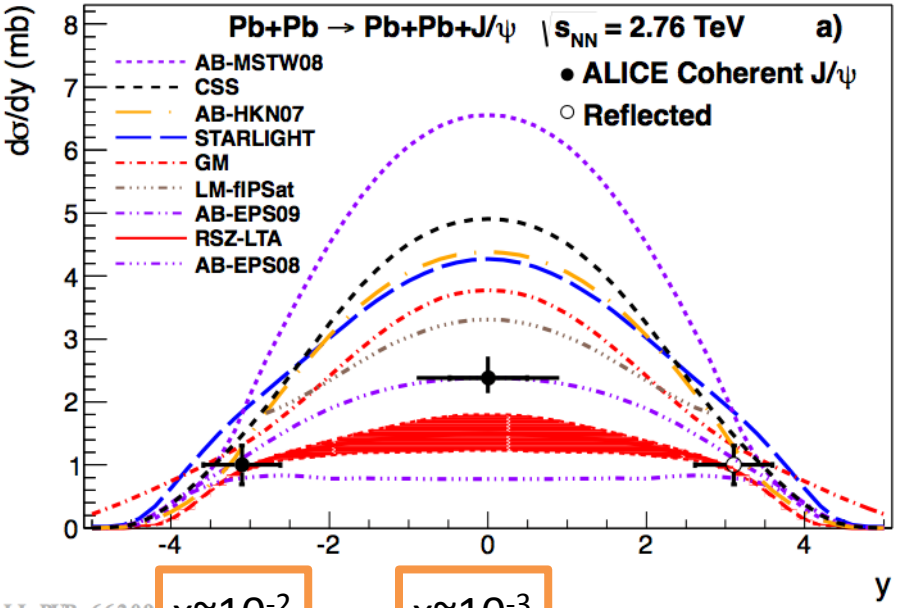
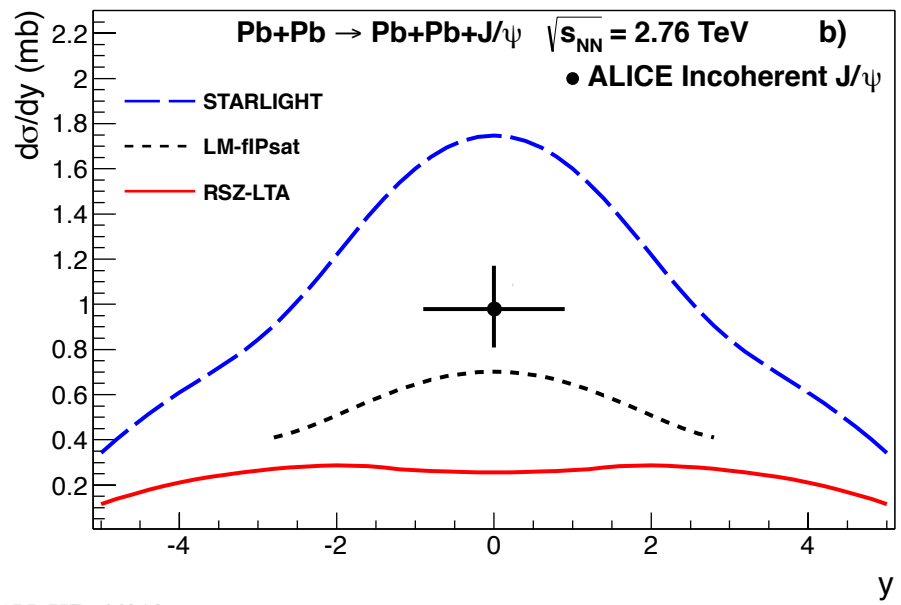


$x \sim 10^{-2}$

$x \sim 10^{-3}$



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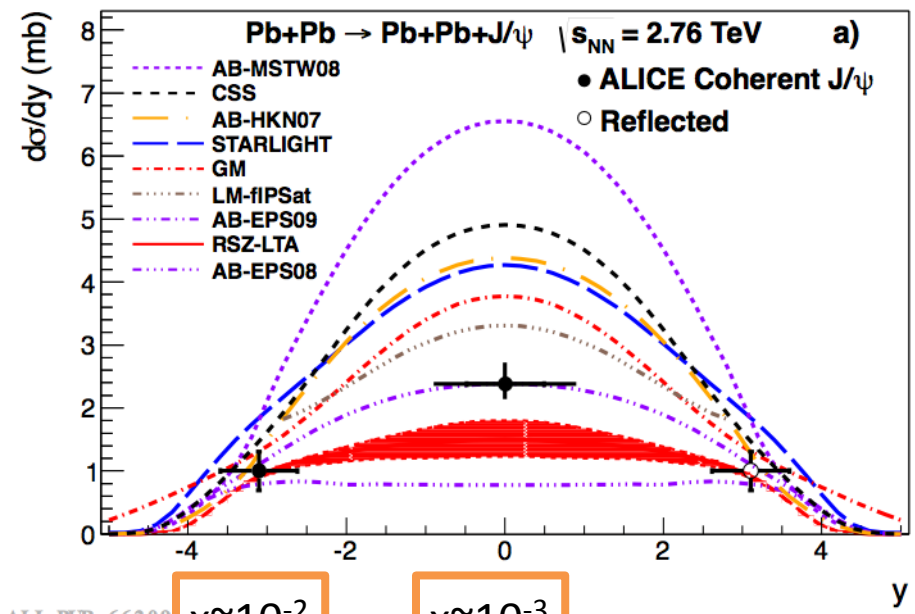

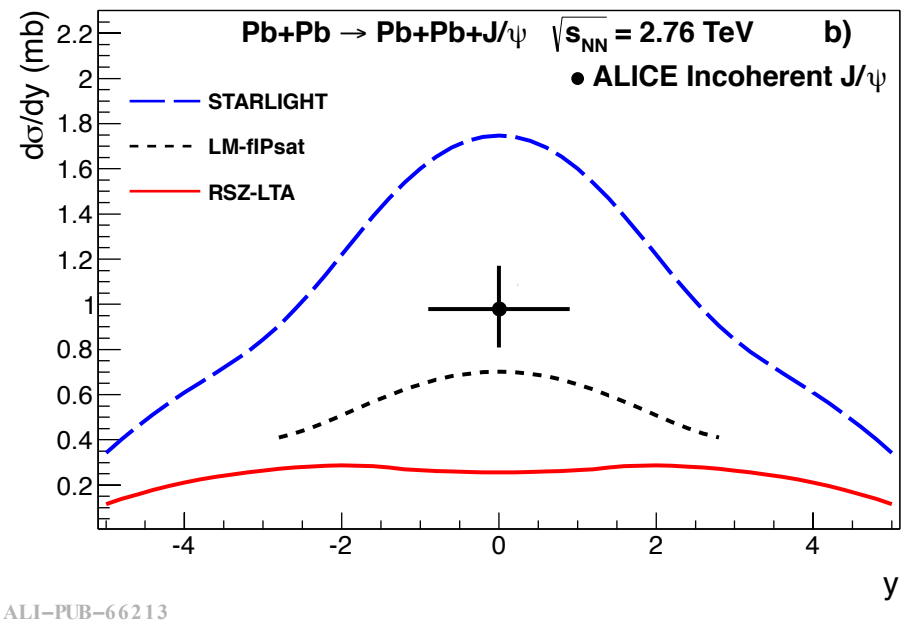

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[5] Cisek, Szczurek, Schäfer (CSS): Color dipole model with unintegrated gluon distribution

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

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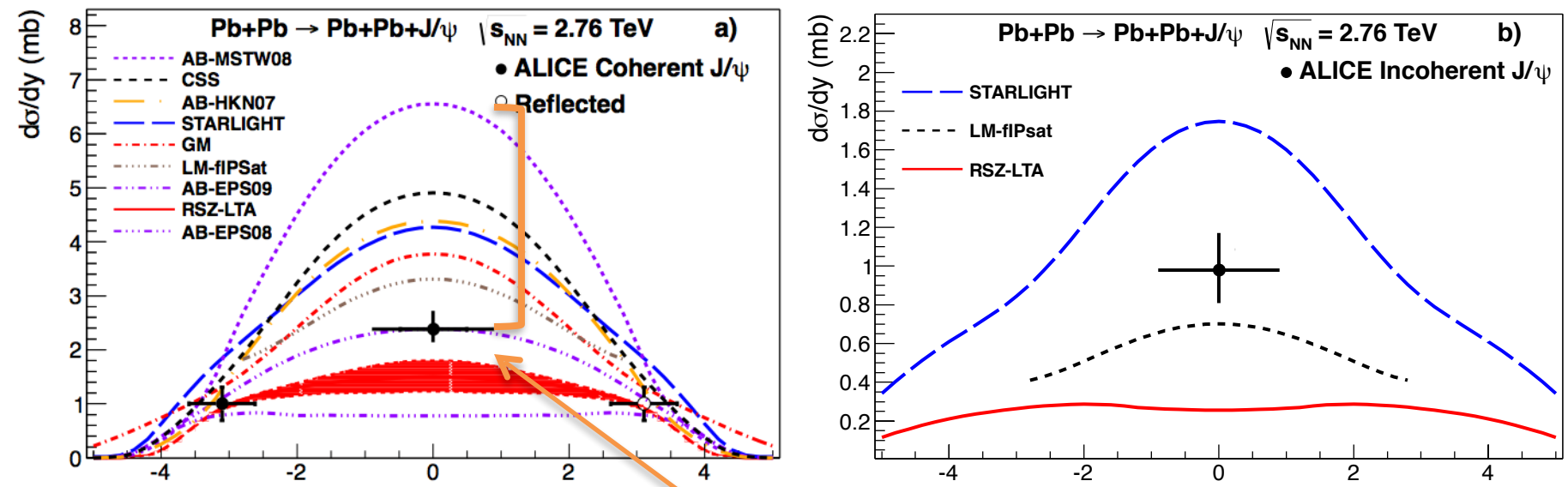

ALI-PUB-66209

x~10^{-2}

x~10^{-3}

Direct observation of (moderate) gluon shadowing

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

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Coherent J/ψ cross section

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

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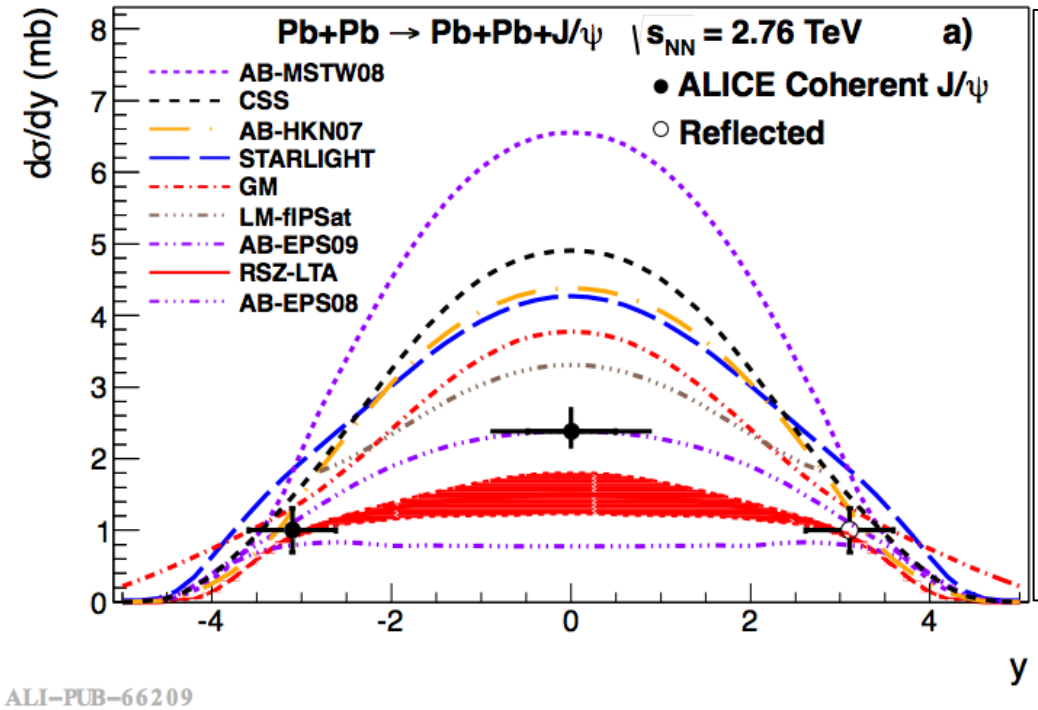

ALICE: Phys.Lett. B718 (2013) 1273
Eur. Phys. J. C (2013) 73:2617

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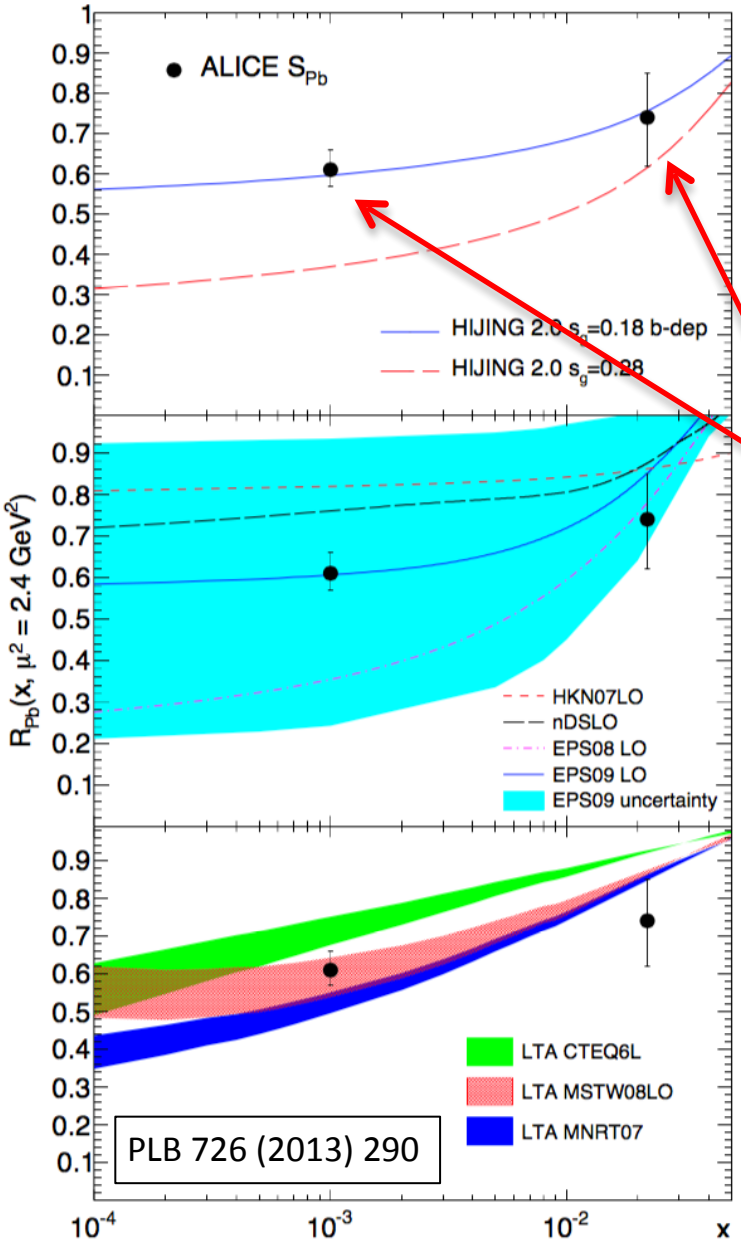
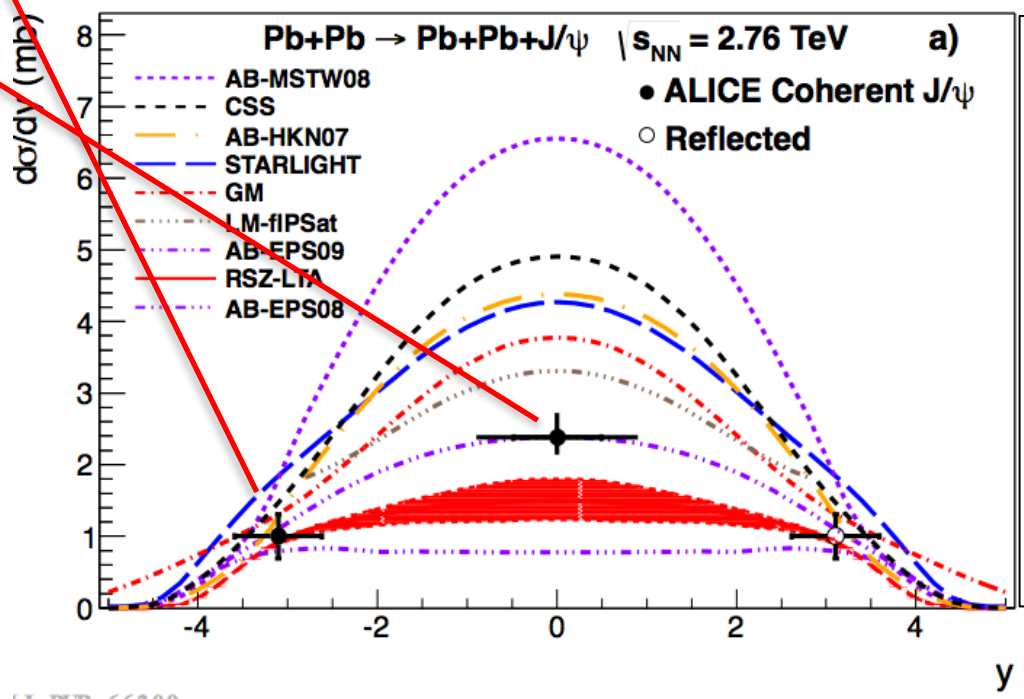


PLB 726 (2013) 290

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



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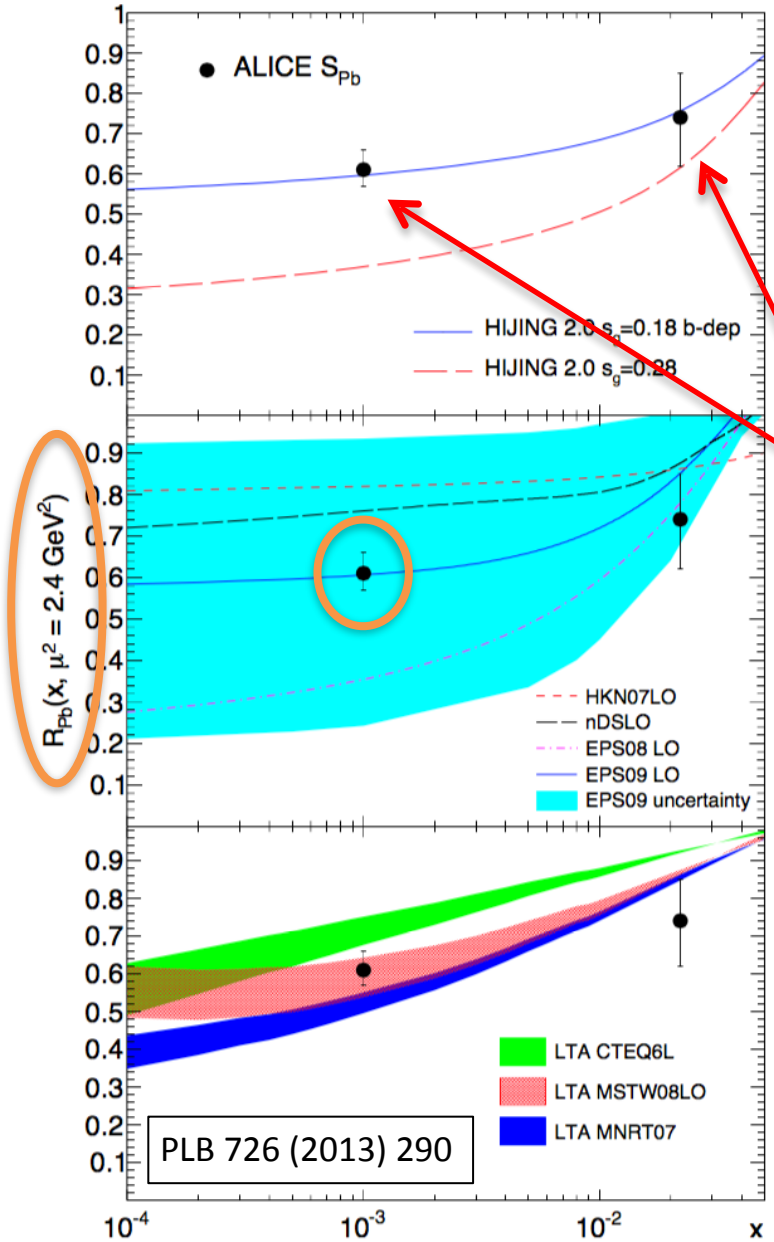
Eur. Phys. J. C (2013) 73:2617

Note: $R_{Pb}(x,\mu^2) = g_{Pb}(x,\mu^2)/(A_{Pb} g_p(x,\mu^2))$

Coherent J/ψ cross section



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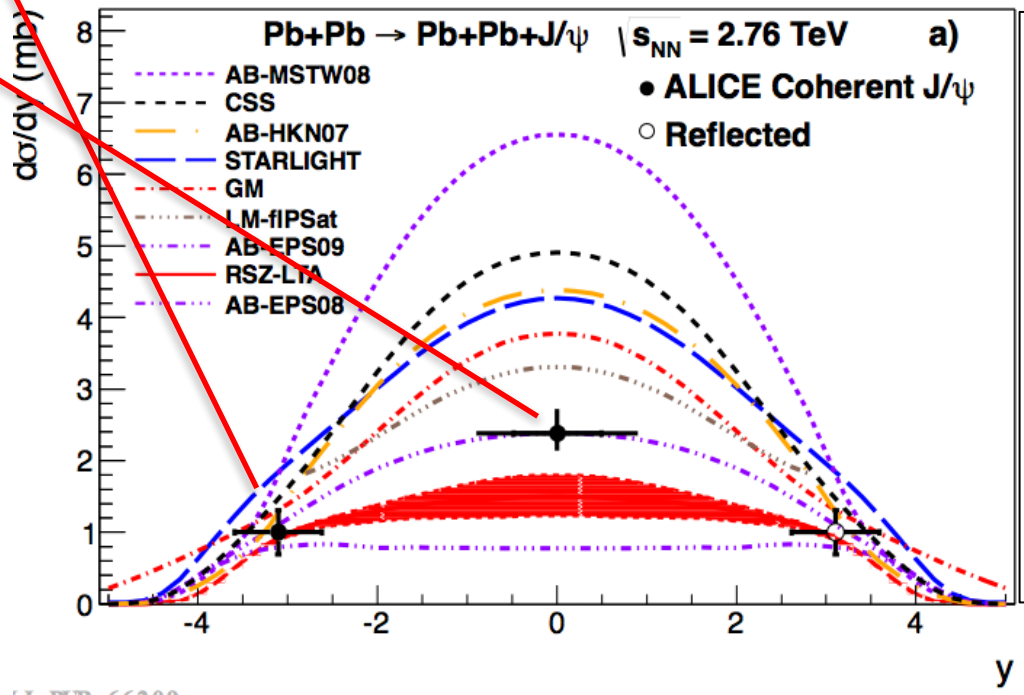

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Coherent $\psi(2S)$ production

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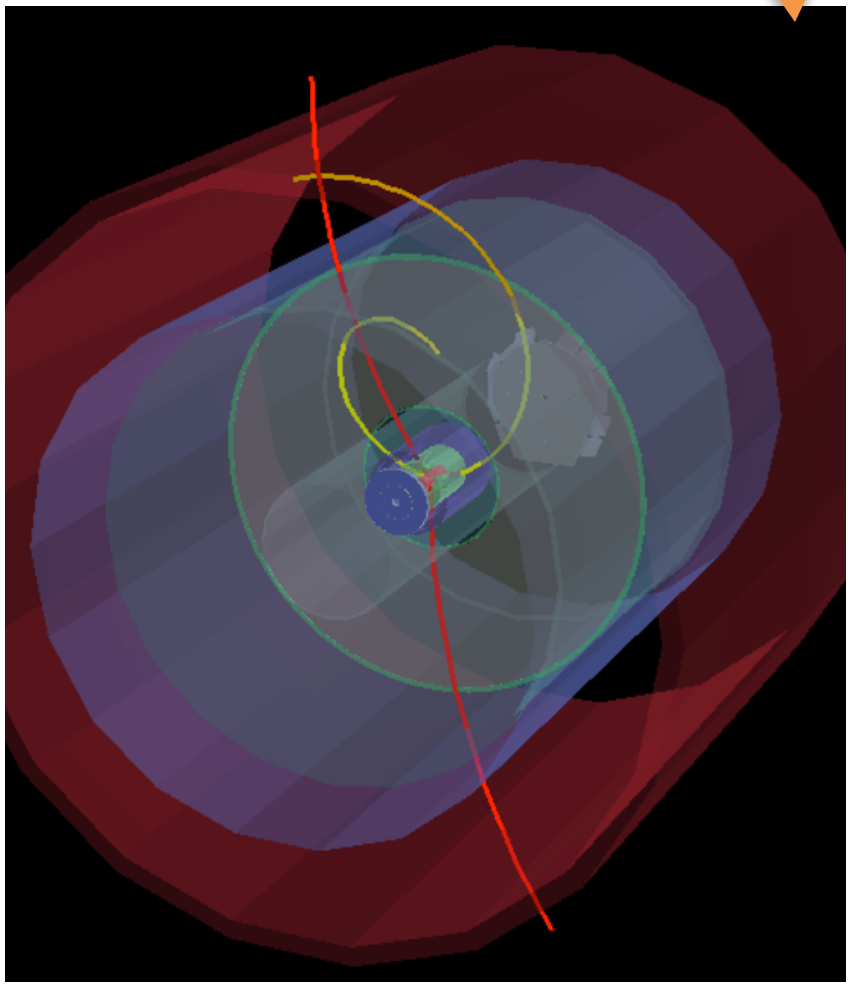
✓ Measured decay channels:
$\psi(2S) \rightarrow l^+l^-$ and $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$



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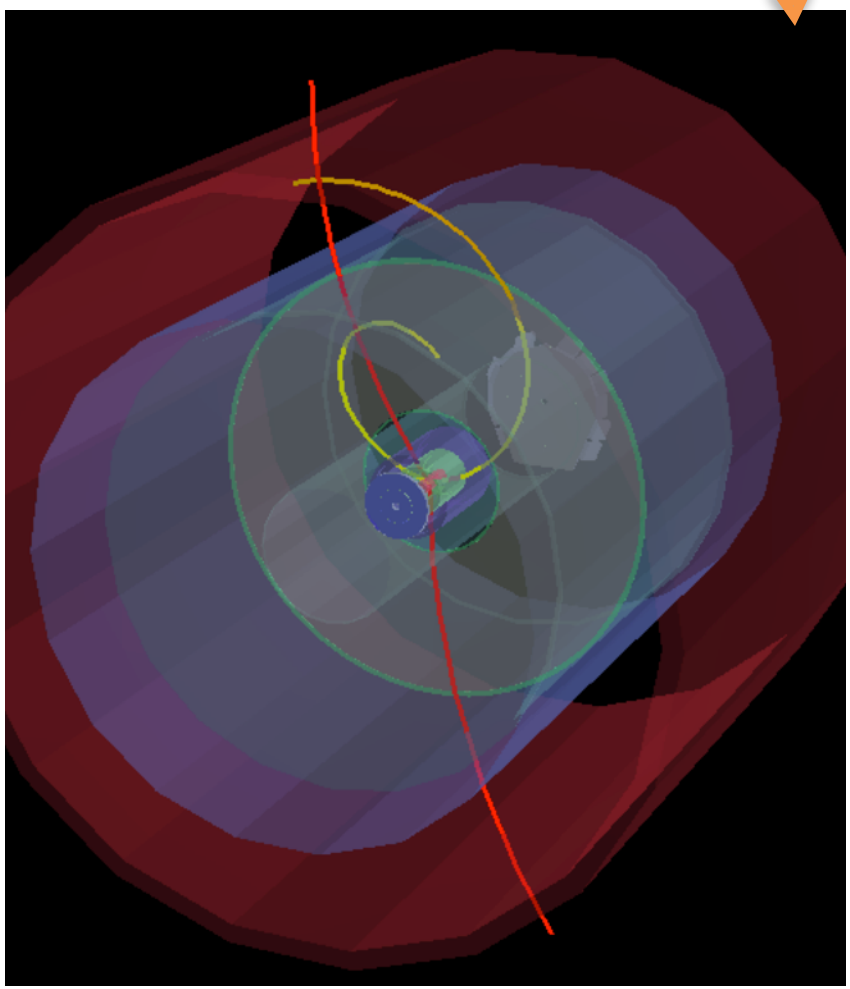
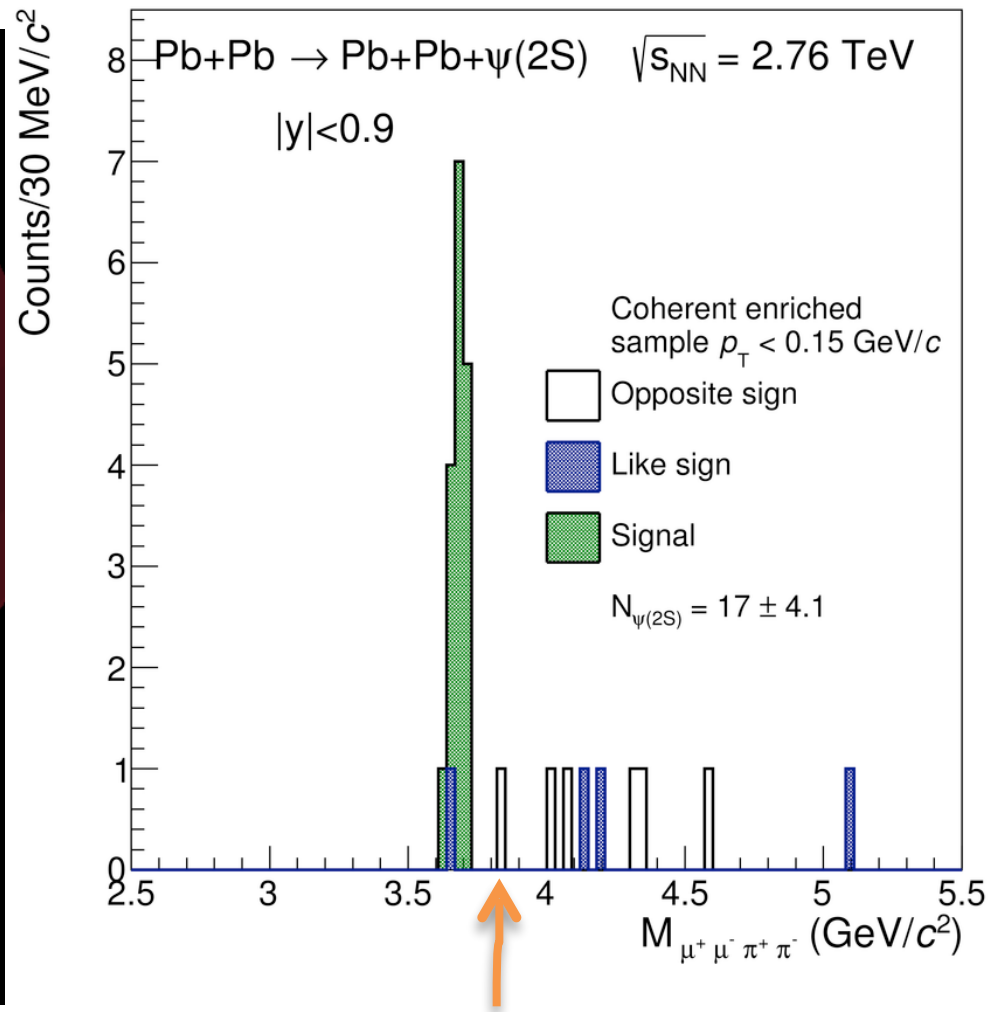
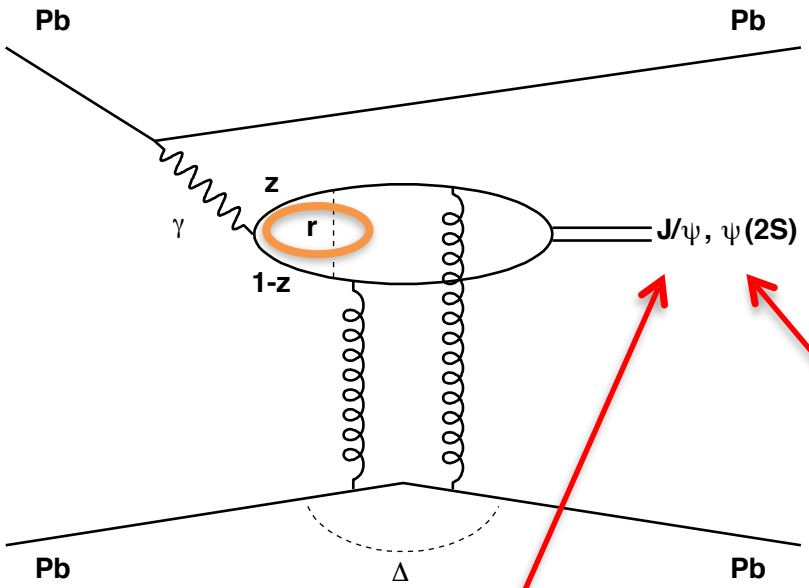
ALICE, PLB 751 (2015) 358

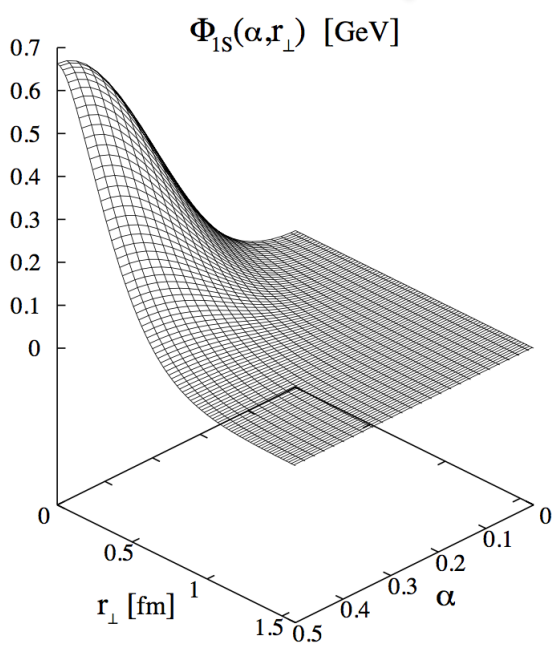


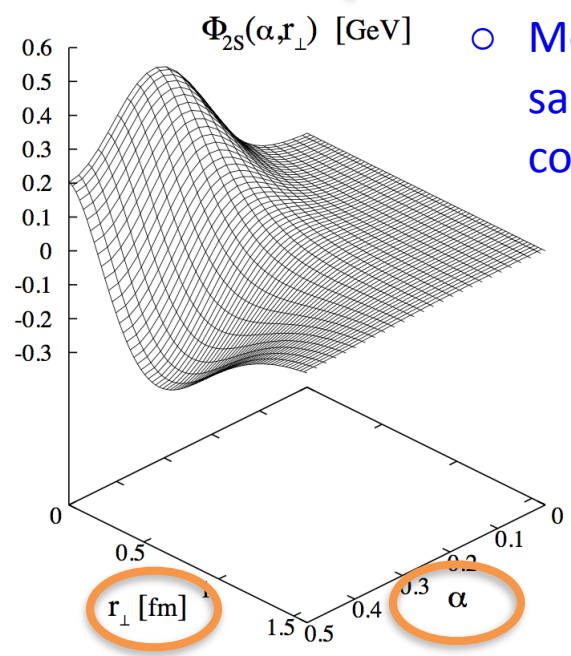


✓ Few signal events with almost no background

ψ(2S) wave function







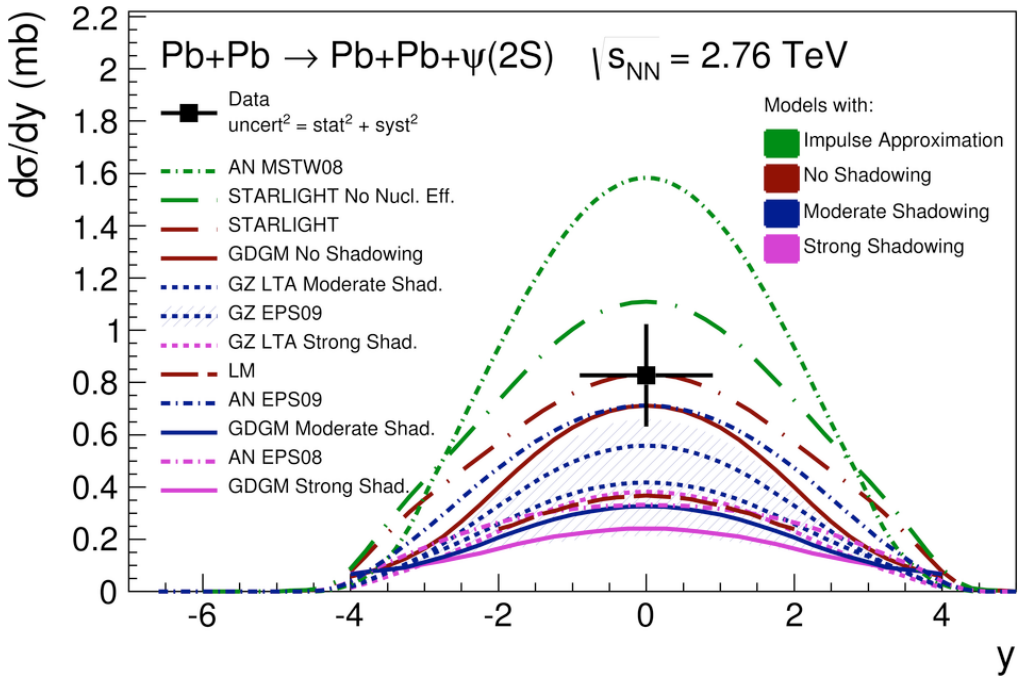
PRD 62 (2000) 094022

- 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
- Measure J/ψ and ψ(2S) in the same kinematic region and compare them

(α=z, see diagram)

Coherent ψ(2S) production: cross section

ALICE, PLB 751 (2015) 358



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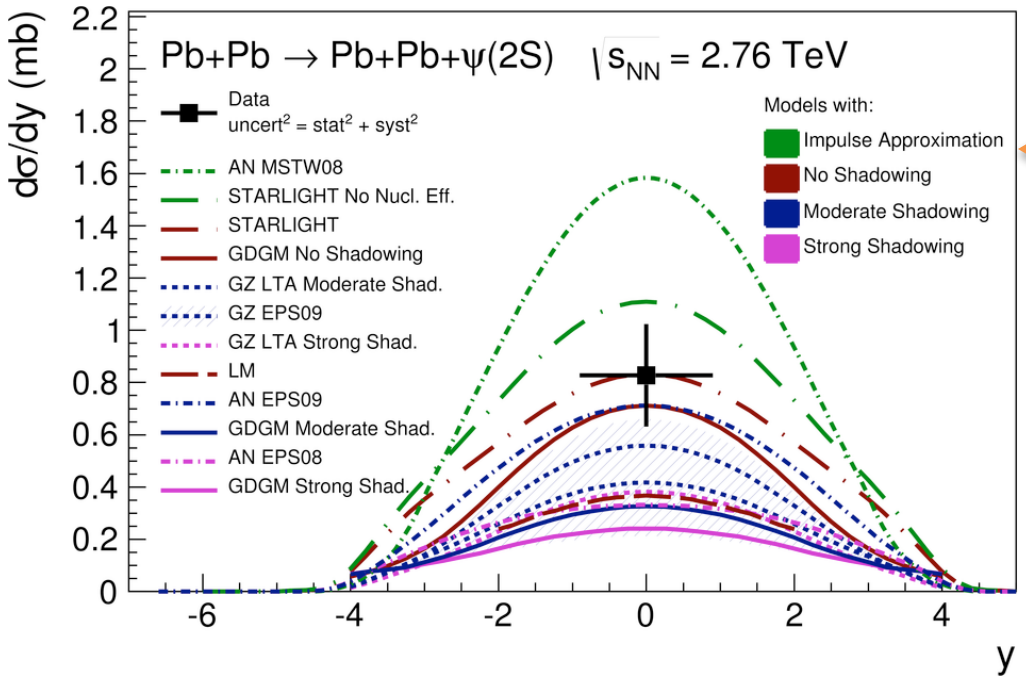
ALICE, PLB 751 (2015) 358



Both impulse approximations should be equal …

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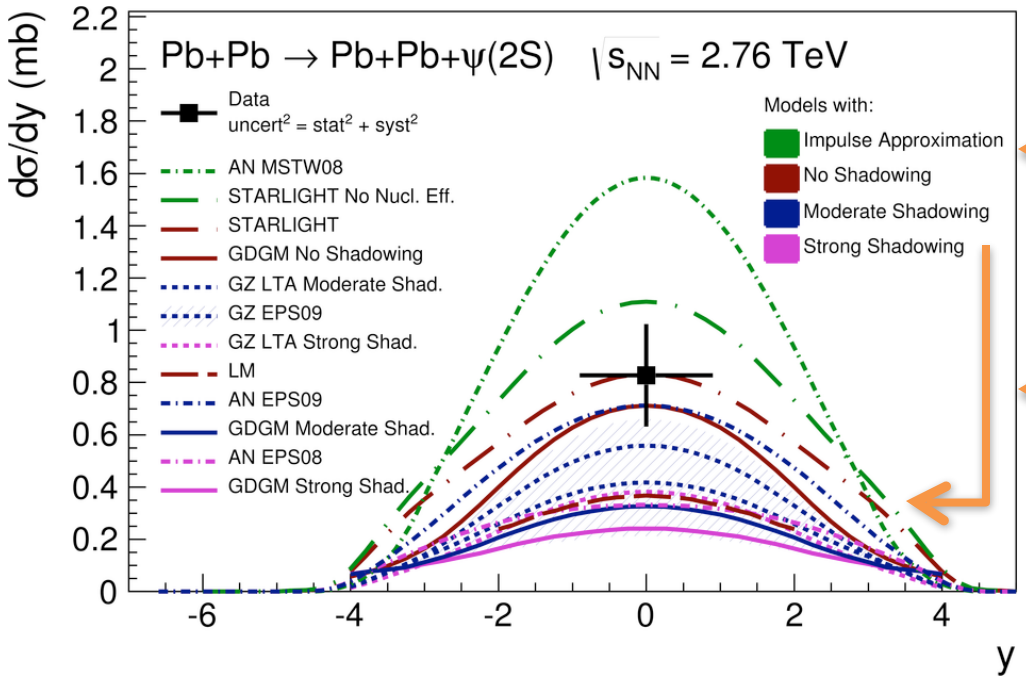
ALICE, PLB 751 (2015) 358



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Strong shadowing is disfavoured …

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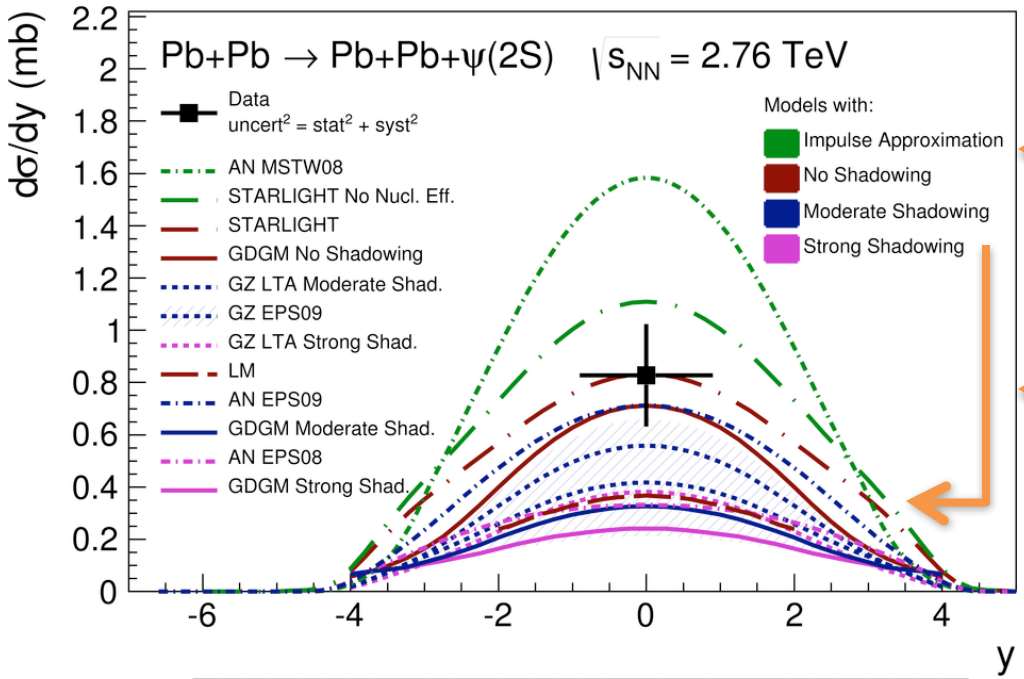

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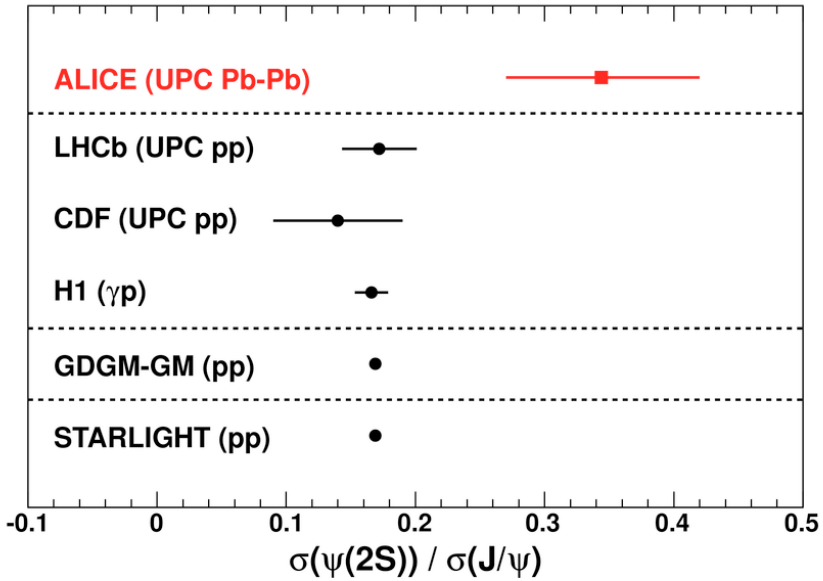
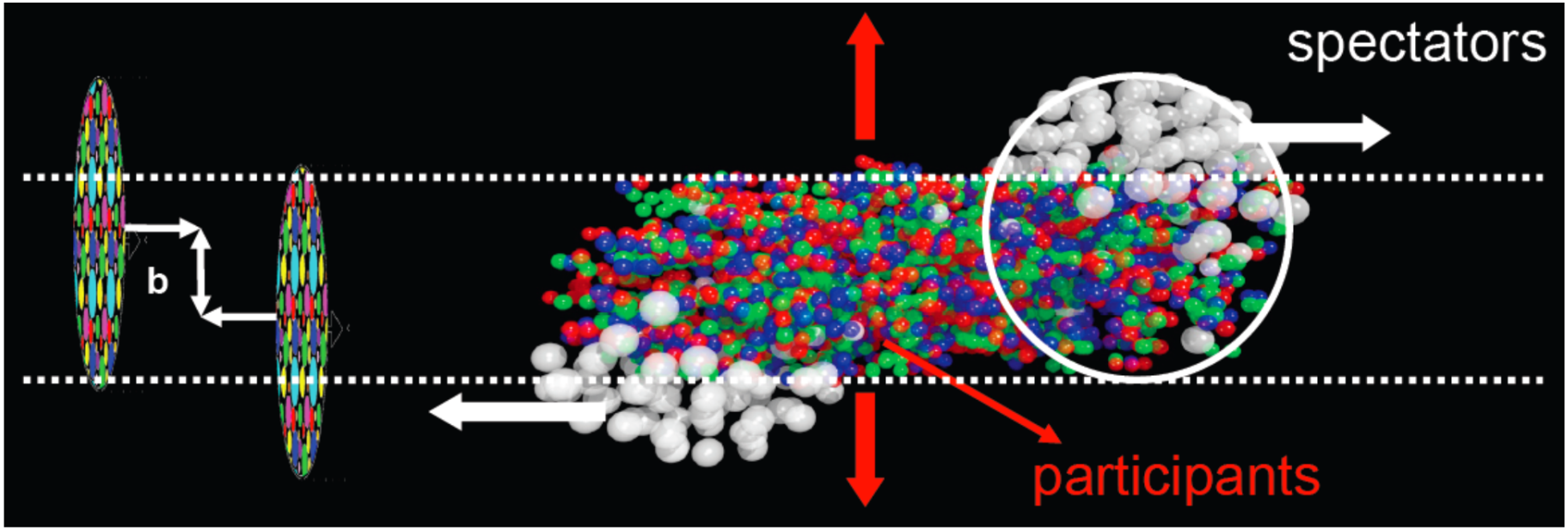


Do nuclear effects affect differently 1S and 2S states?

Need more precise data!

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

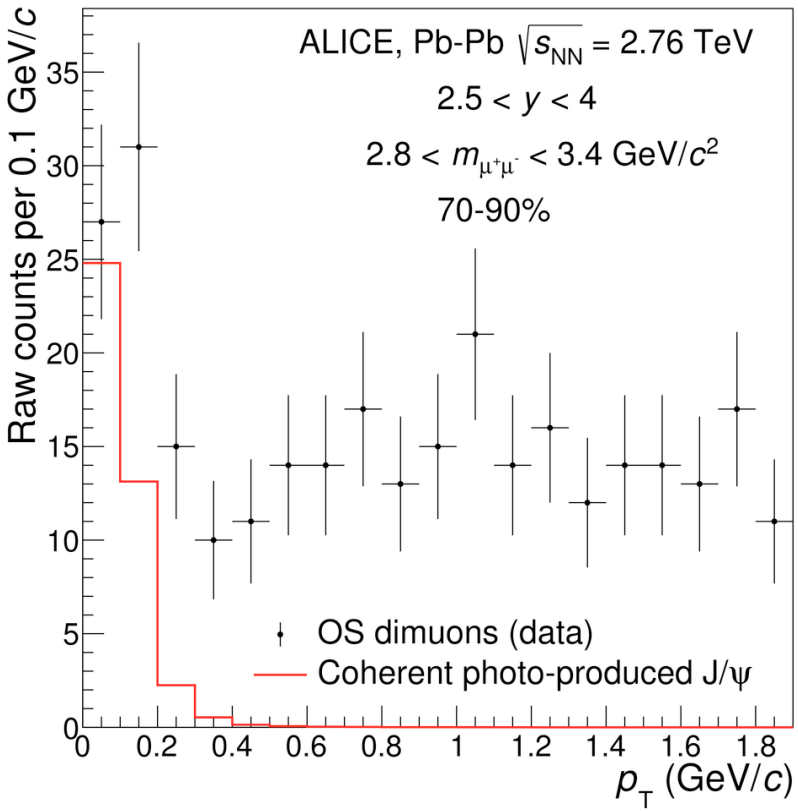
Pb-Pb collisions for $b<2*R_A$



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

Coherent J/ψ production in peripheral collisions

ALICE, Phys.Rev.Lett. 116 (2016) 222301



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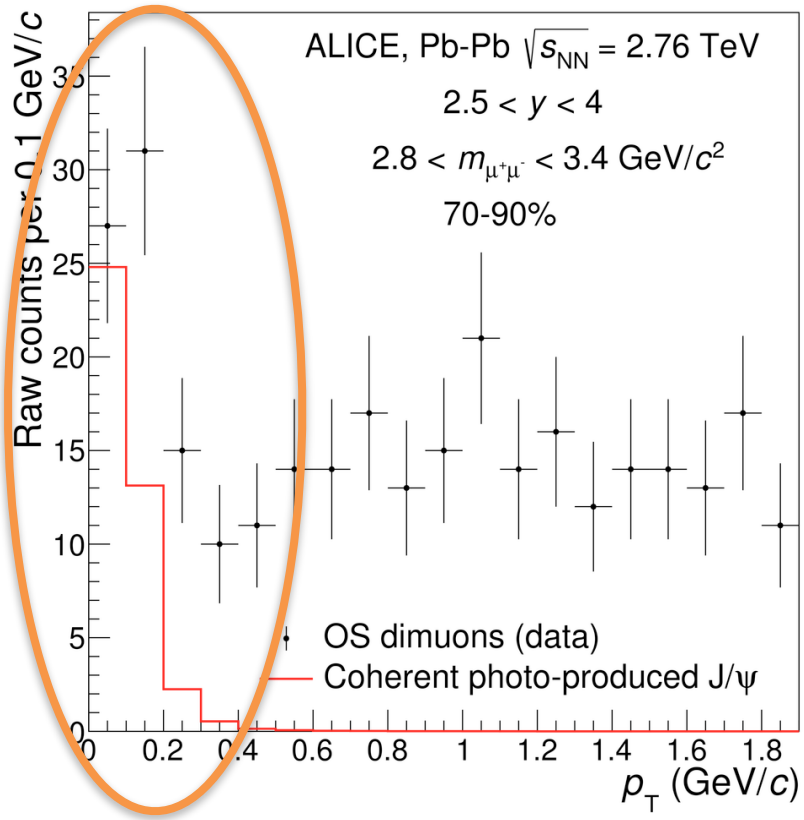
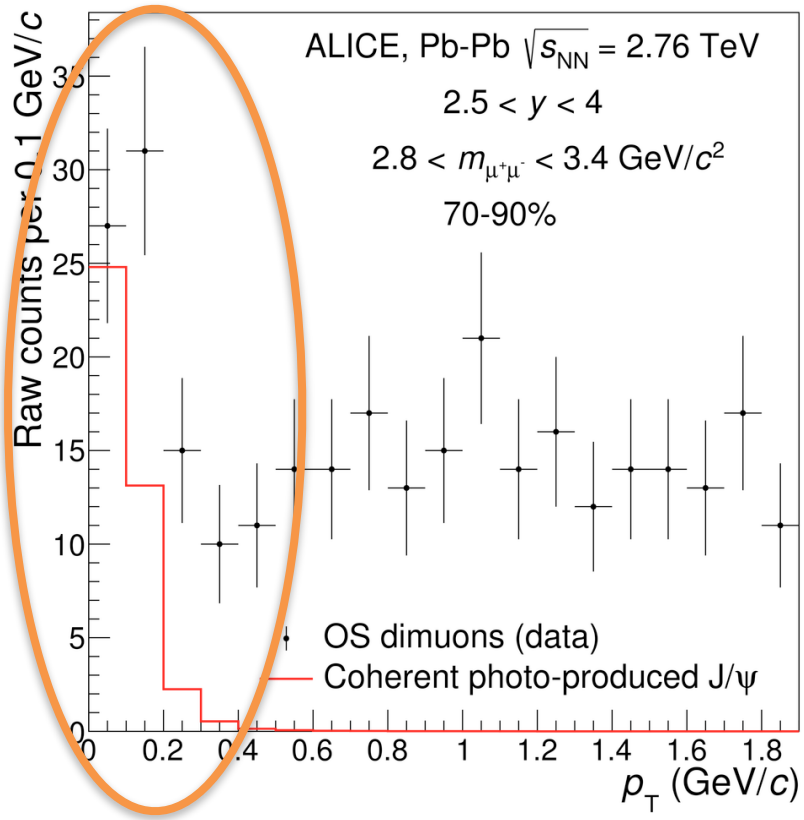
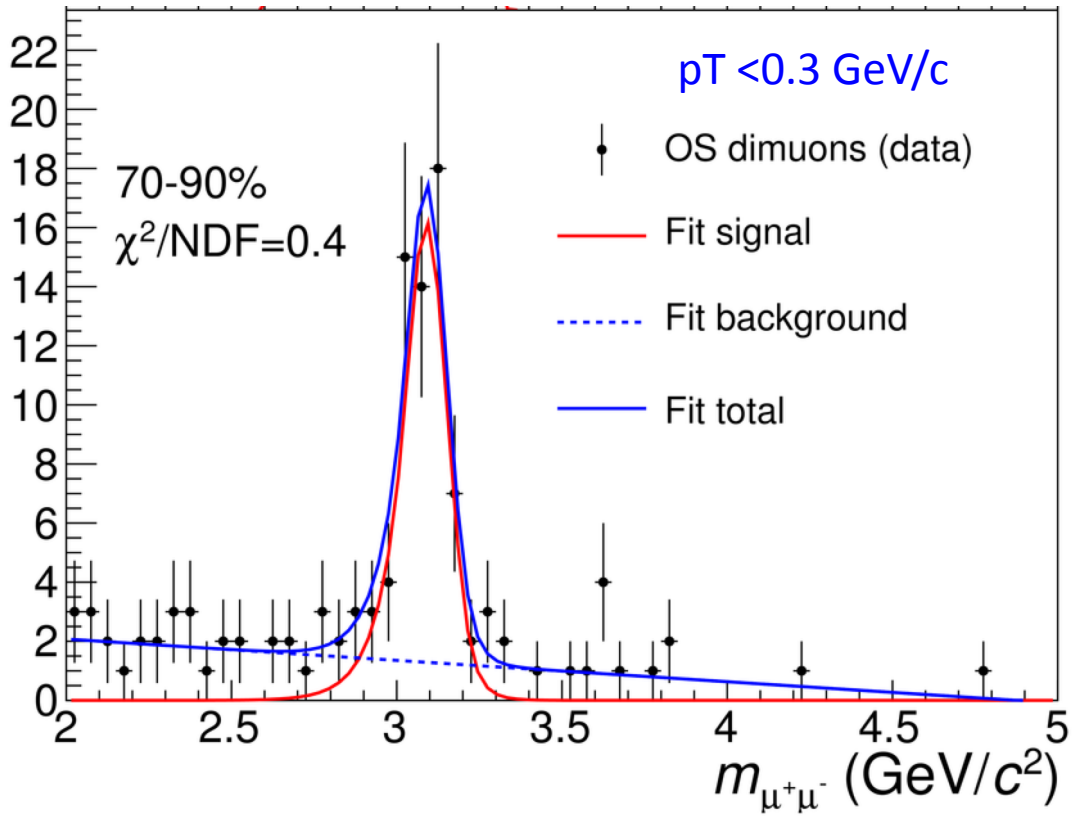


Clear excess in the yield at low p_T for peripheral collisions

Coherent J/ψ production in peripheral collisions

ALICE, Phys.Rev.Lett. 116 (2016) 222301



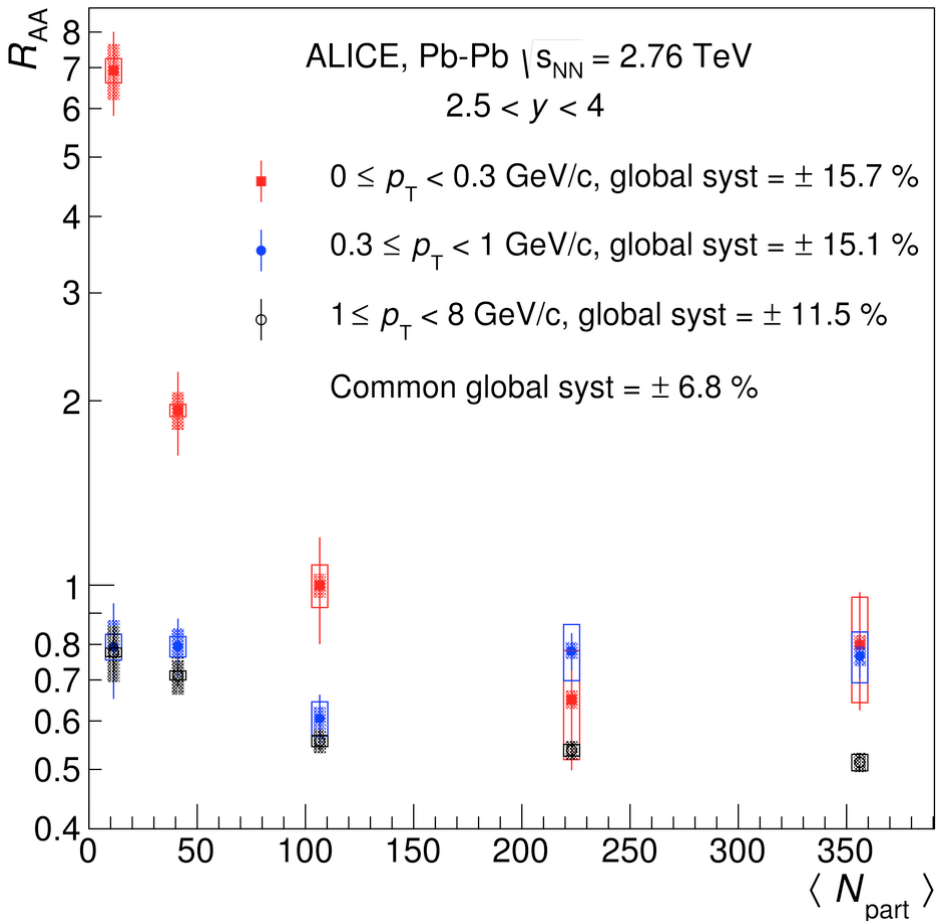


Clear excess in the yield at low p_T for peripheral collisions

And the excess is clearly from J/ψ

Coherent J/ψ production in peripheral collisions

ALICE, Phys.Rev.Lett. 116 (2016) 222301



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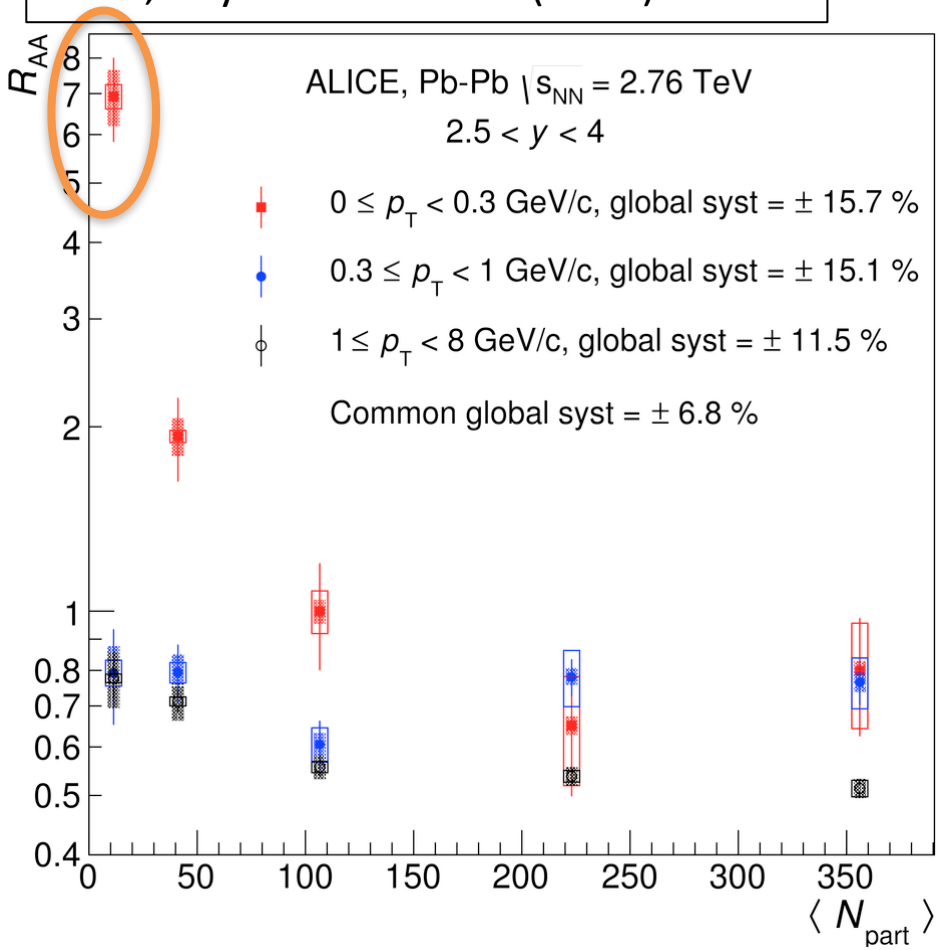
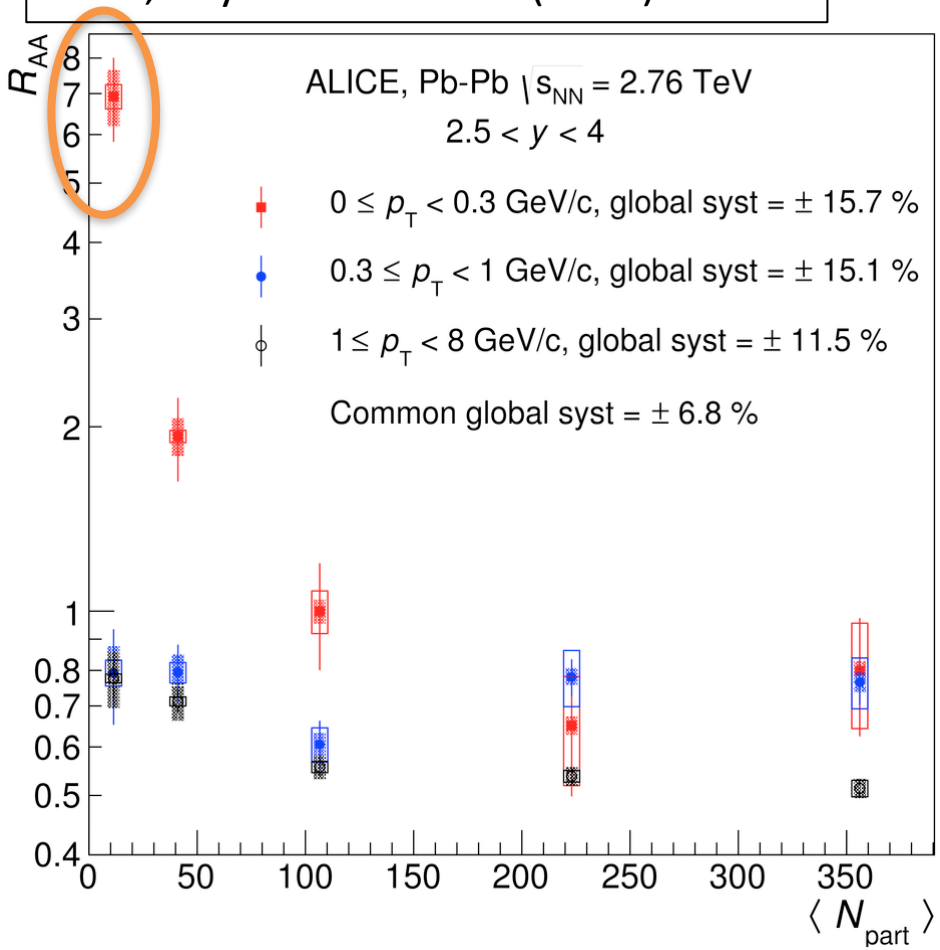


If the excess were from hadronic production, the R_{AA} would reach up to 7!
(Standard expectation is $R_{AA} \sim O(1)$)

Coherent J/ψ production in peripheral collisions

ALICE, Phys.Rev.Lett. 116 (2016) 222301



If photoproduction is assumed as the underlying interaction we obtain

Centrality class	Cross section (μb)
0-10 %	<318
10-30%	<290
30-50%	$73 \pm 44_{-27}^{+26}$
50-70%	$58 \pm 16_{-10}^{+8}$
70-90%	$59 \pm 11_{-10}^{+7}$

No theoretical calculations available for coherent photoproduction in peripheral collisions

(A first try is in PRC93 (2016) 044912)

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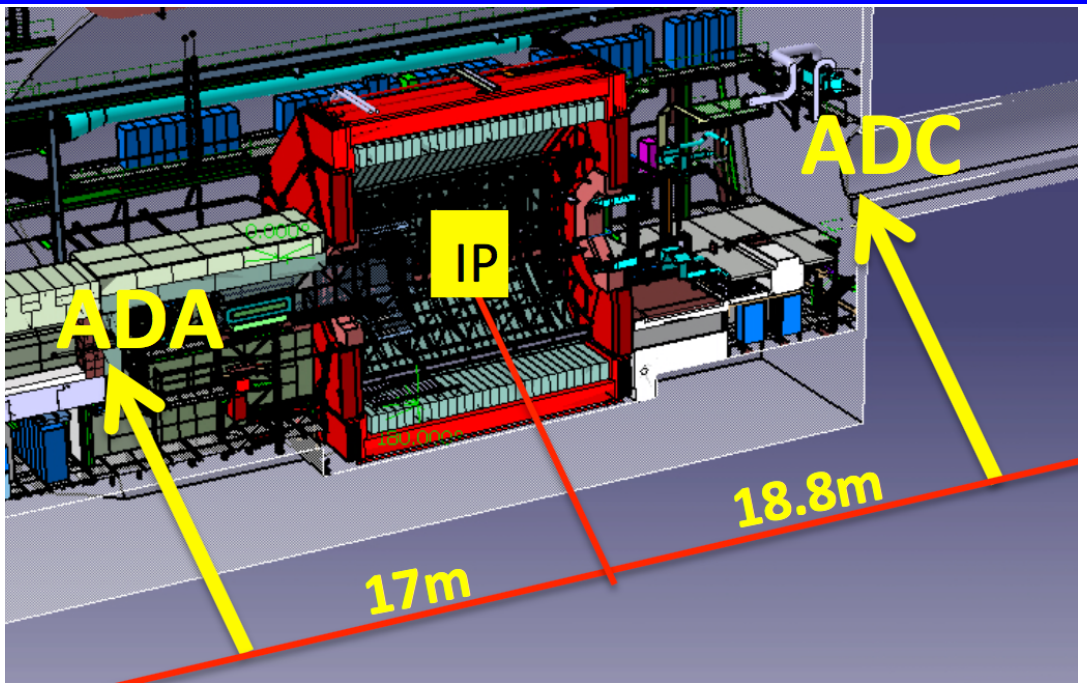
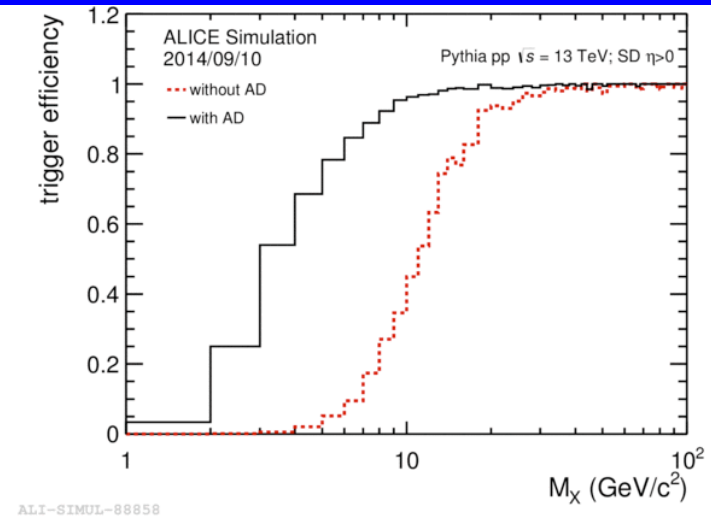
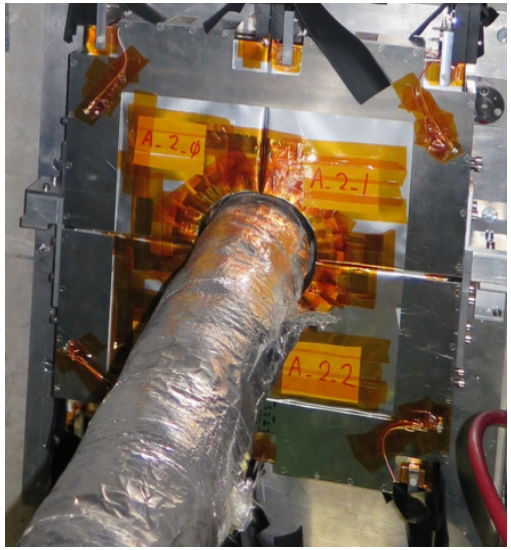
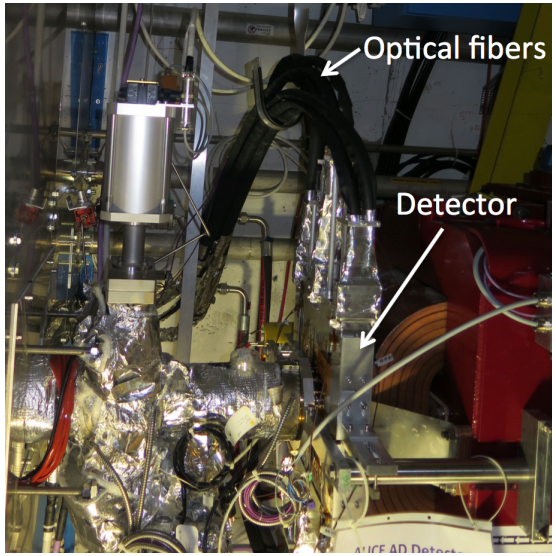
Some comments on Run 2 plans

New for Run2: The AD detector









- ✓ Modules of plastic scintillator read out with PMTs
- ✓ Time resolution 300 (500) ps in C (A) side, allows one 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 on extra activity for exclusive processes in UPC

Run2 expectations for Pb-Pb UPC

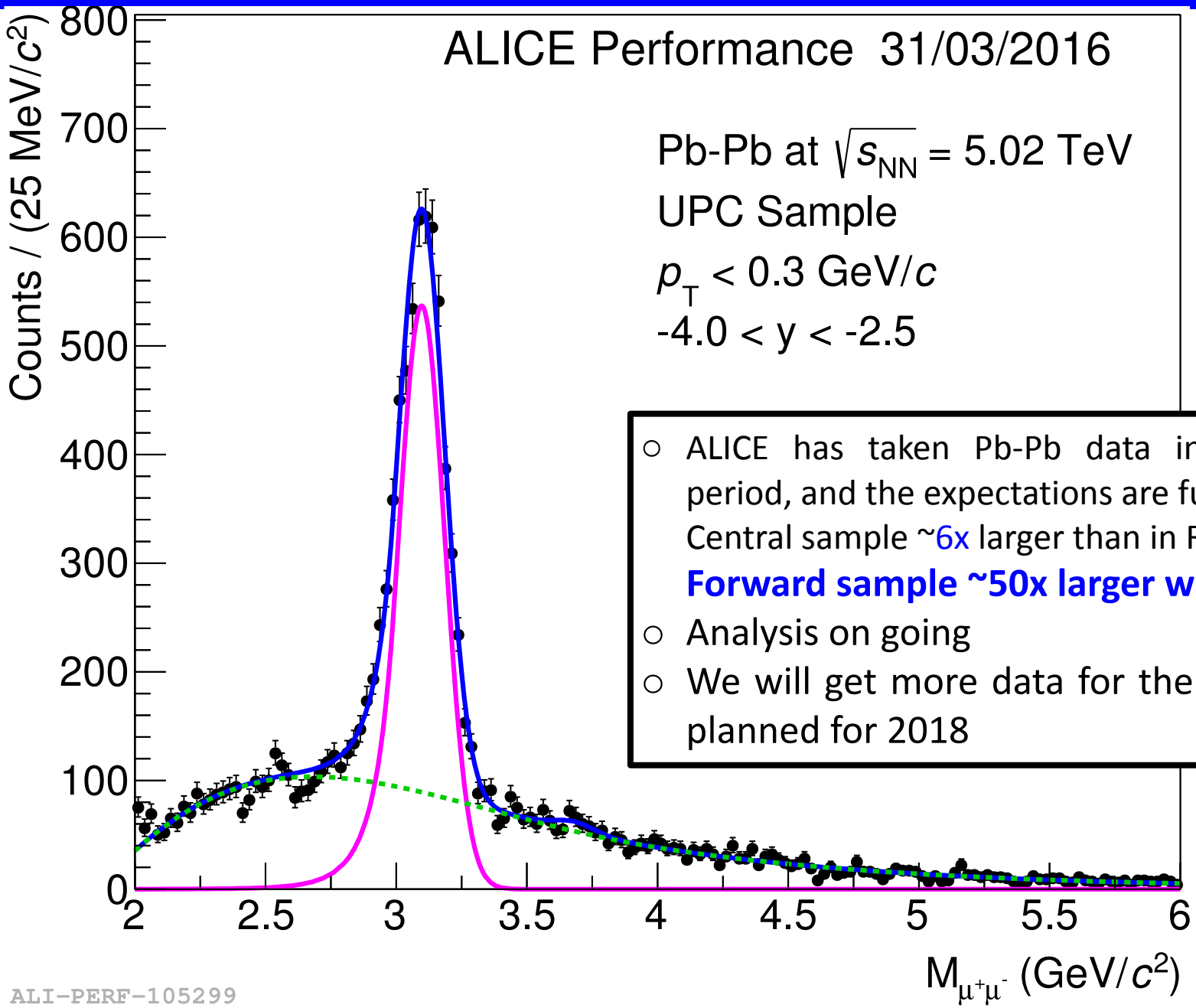
- Factor of two increase on the Pb-Pb centre-of-mass energy
  - Increase in the cross section, mainly due to an increase in the photon flux
  - Increase in the kinematic reach: a factor of two lower values of Bjorken x will be accessible

- 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
  - Depending on accelerator and detector conditions we expect a large increase in luminosity

- CMS and ATLAS are joining the party !

Pb-Pb Run2 data



- ALICE has taken Pb-Pb data in the 2015 period, and the expectations are fulfilled Central sample ~6x larger than in Run1, and **Forward sample ~50x larger wrt Run 1!**
- Analysis on going
- We will get more data for the Pb-Pb run planned for 2018

ALI-PERF-105299

Summary and outlook

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

Exciting times are ahead of us, so stay tuned!

References

References for ALICE UPC papers

Coherent J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV
Phys.Lett. B718 (2013) 1273-1283
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Phys.Lett. B751 (2015) 358-370
http://inspirehep.net/record/1388730?ln=en

Coherent ρ^{0} photoproduction in ultra-peripheral Pb-Pb collisions at $ \sqrt{s_{\mathrm{NN}}}=2.76 $ TeV
JHEP 1509 (2015) 095
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Measurement of an excess in the yield of J/ψ at very low $p_{\rm T}$ in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV
Accepted by PRL
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Phys.Lett. B710 (2012) 647-653
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Vector Meson Production in Coherent Hadronic Interactions: An update on predictions for RHIC and LHC
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