Heavy vector meson photoproduction measured by ALICE in ultraperipheral Pb-Pb collisions

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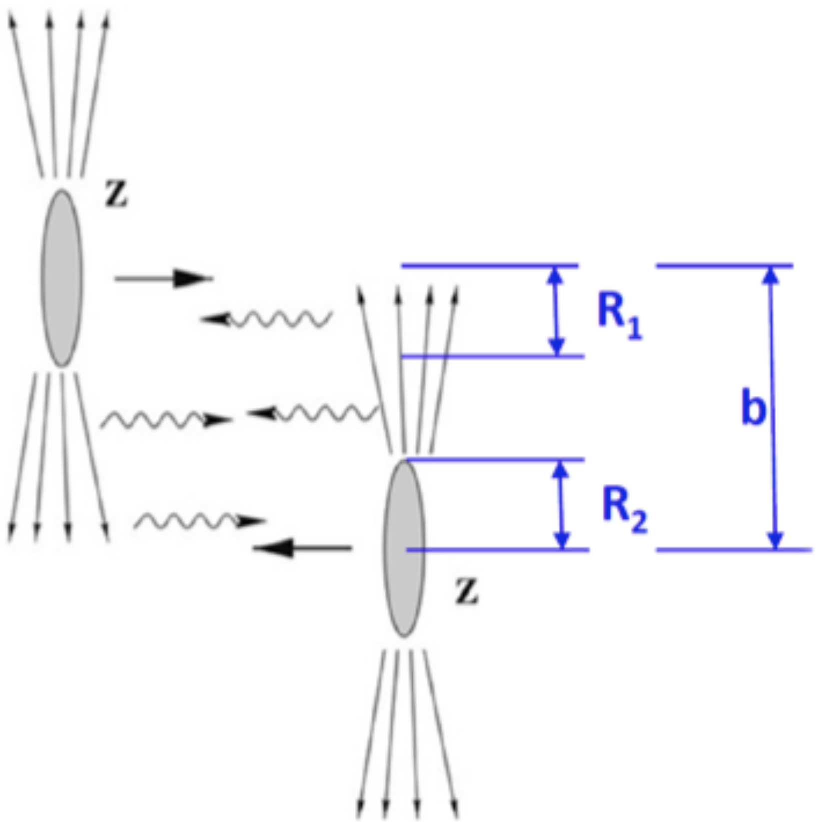
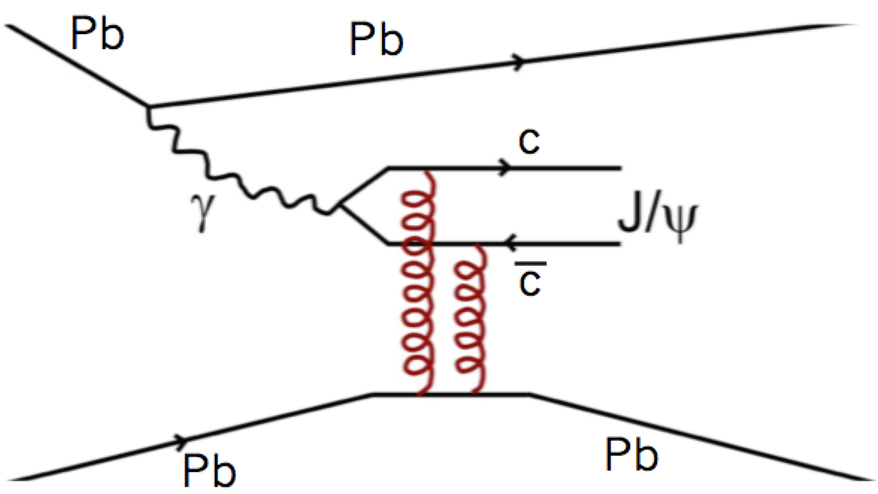
Ultraperipheral Pb-Pb Collisions



- In ultraperipheral collisions (UPC) the impact parameter is greater than the sum of the projectile radii ($b > R_1+R_2$)
- This greatly suppresses hadronic interactions
- Heavy ions give a very high flux of quasi-real photons
- Photon flux proportional to Z^2

J/ψ photoproduction in UPC

$$\frac{d\sigma_{\gamma^* p/Pb}(t=0)}{dt} = \frac{16\Gamma_{ee}\pi^3}{3\alpha_{em}M^5_{J/\psi}}\left\{\alpha_s\left(Q^2\right)G_{p/Pb}\left(x,Q^2\right)\right\}^2$$

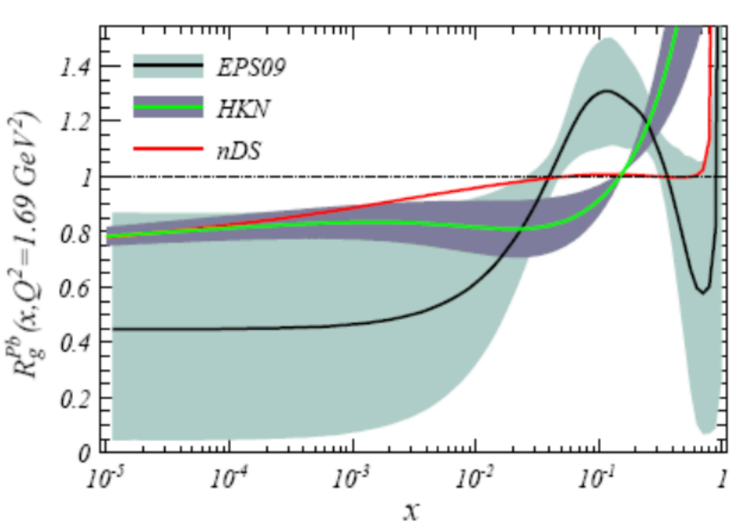


$$x = \frac{M_{J/\psi}}{\sqrt{s_{NN}}}\exp(\pm y) \approx 10^{-2} - 10^{-5}$$

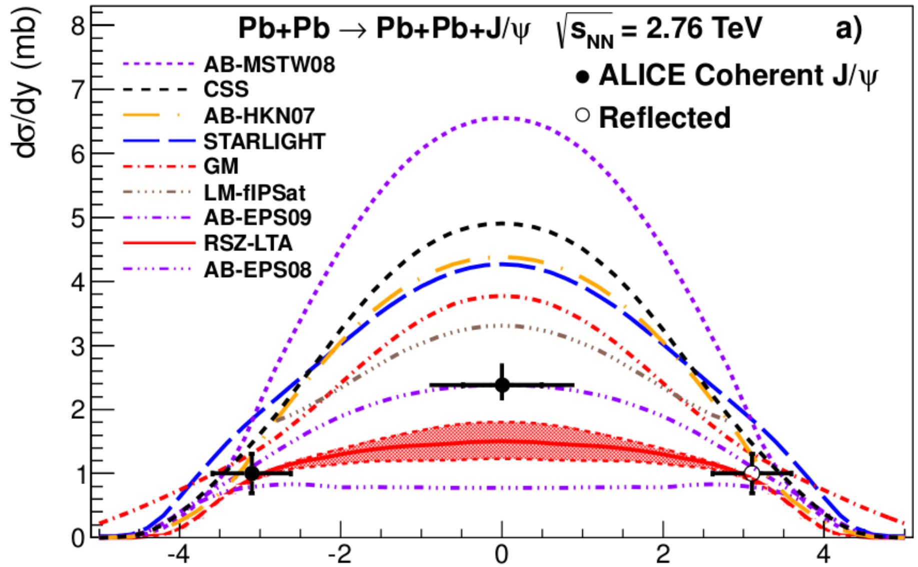
$$R_g^A(x,Q^2) = \frac{g_A(x,Q^2)}{Ag_p(x,Q^2)}$$

gluon shadowing factor

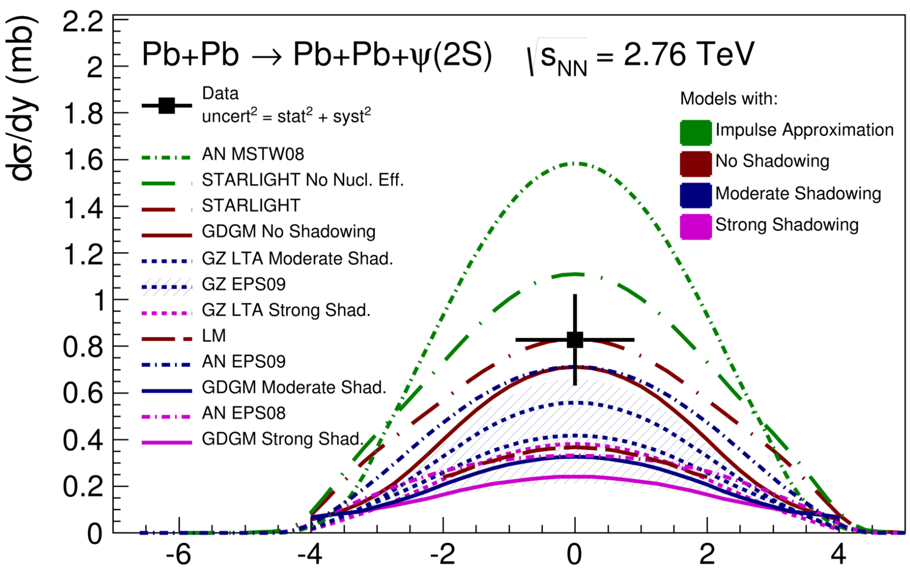
- The photon emitted by one nucleus couples to a vector meson
- At LO, the cross-section is proportional to the gluon PDF squared
- Hard scale for the J/ψ of $Q^2 \sim (M_{J/\psi}{}^2/4) \approx 2.5\ GeV^2$
- Can give information on nuclear gluon shadowing at low x



Run 1 results



Phys. Lett. B718 (2013) 1273, Eur. Phys. J. C73 (2013) 2617

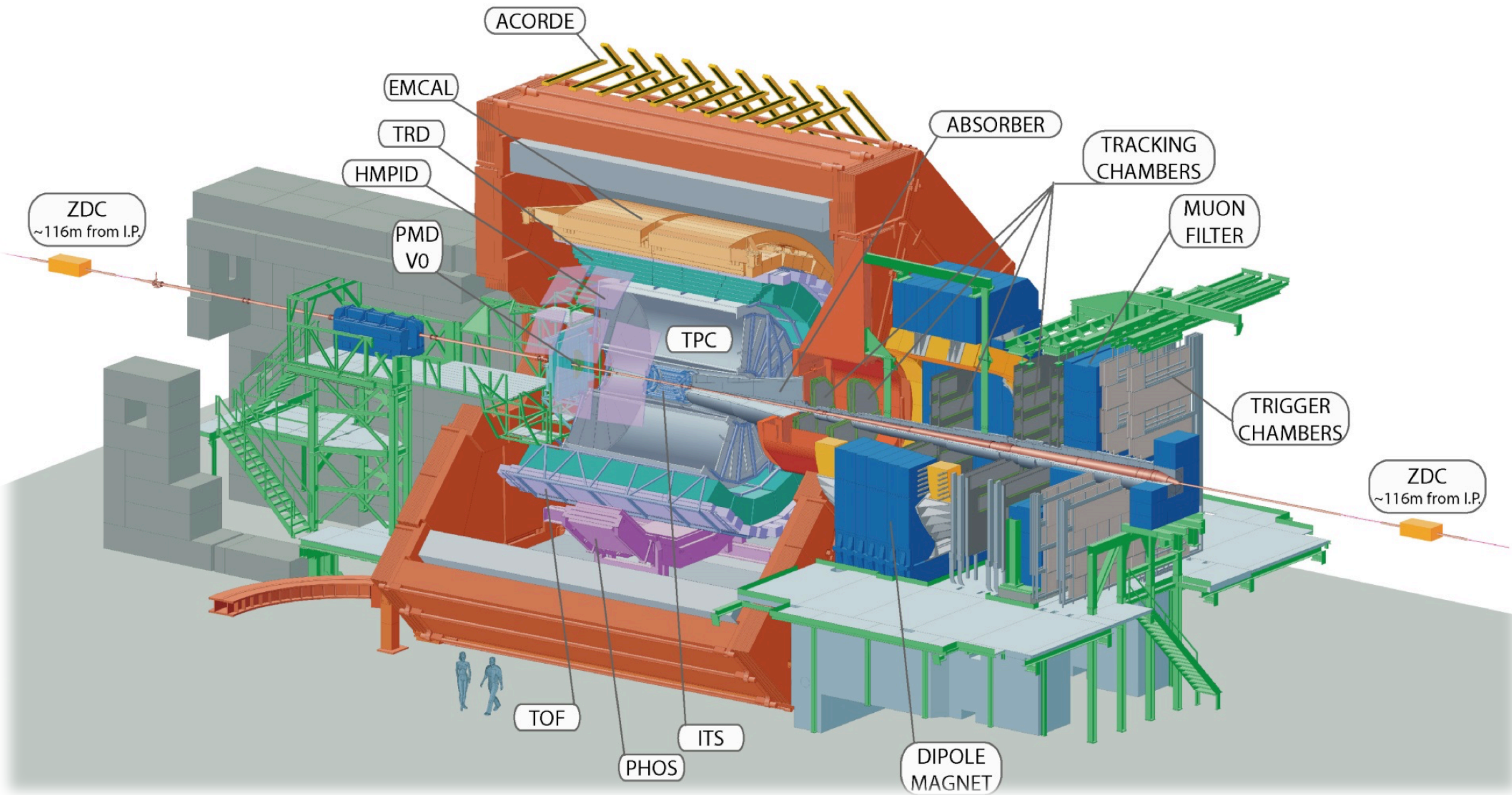


Phys.Lett. B751 (2015) 358

- J/ψ and ψ(2s) in Pb-Pb at 2.76 TeV
- Forward and mid-rapidity J/ψ data points agree best with moderate shadowing based on EPS09 model: R_g^{Pb} (x ≈10^{-3}, Q^2 ≈ 2.4 GeV^2) ≈ 0.6
- Mid-rapidity ψ(2s) data point consistent with moderate gluon shadowing
- σ(ψ(2s))/σ(J/ψ) ≈ 0.34 ± 0.08 (stat +syst), higher than the expected < 0.20

The ALICE detector

To look for UPC in the forward direction we require ALICE to be empty except for just two tracks, using:



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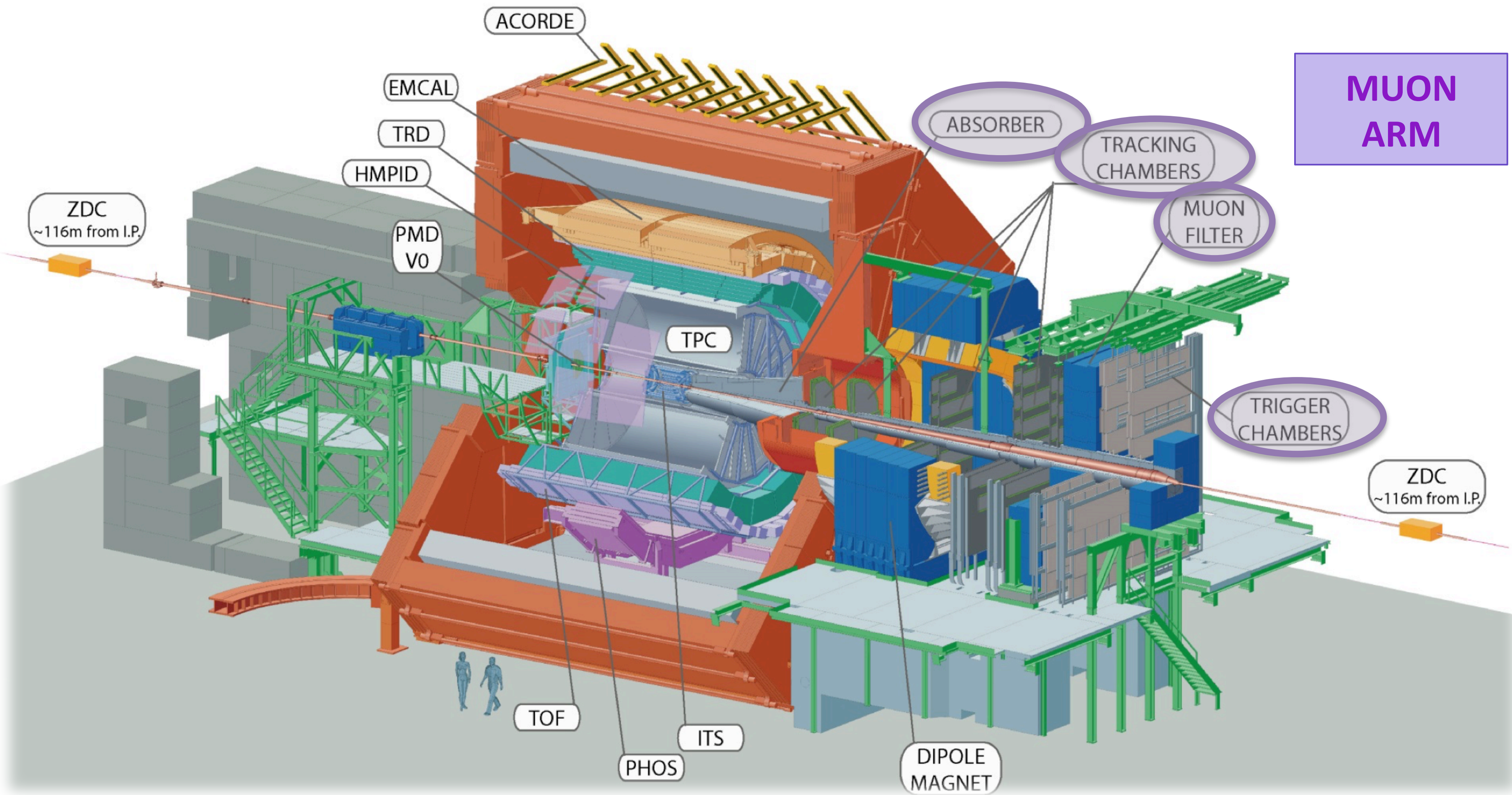

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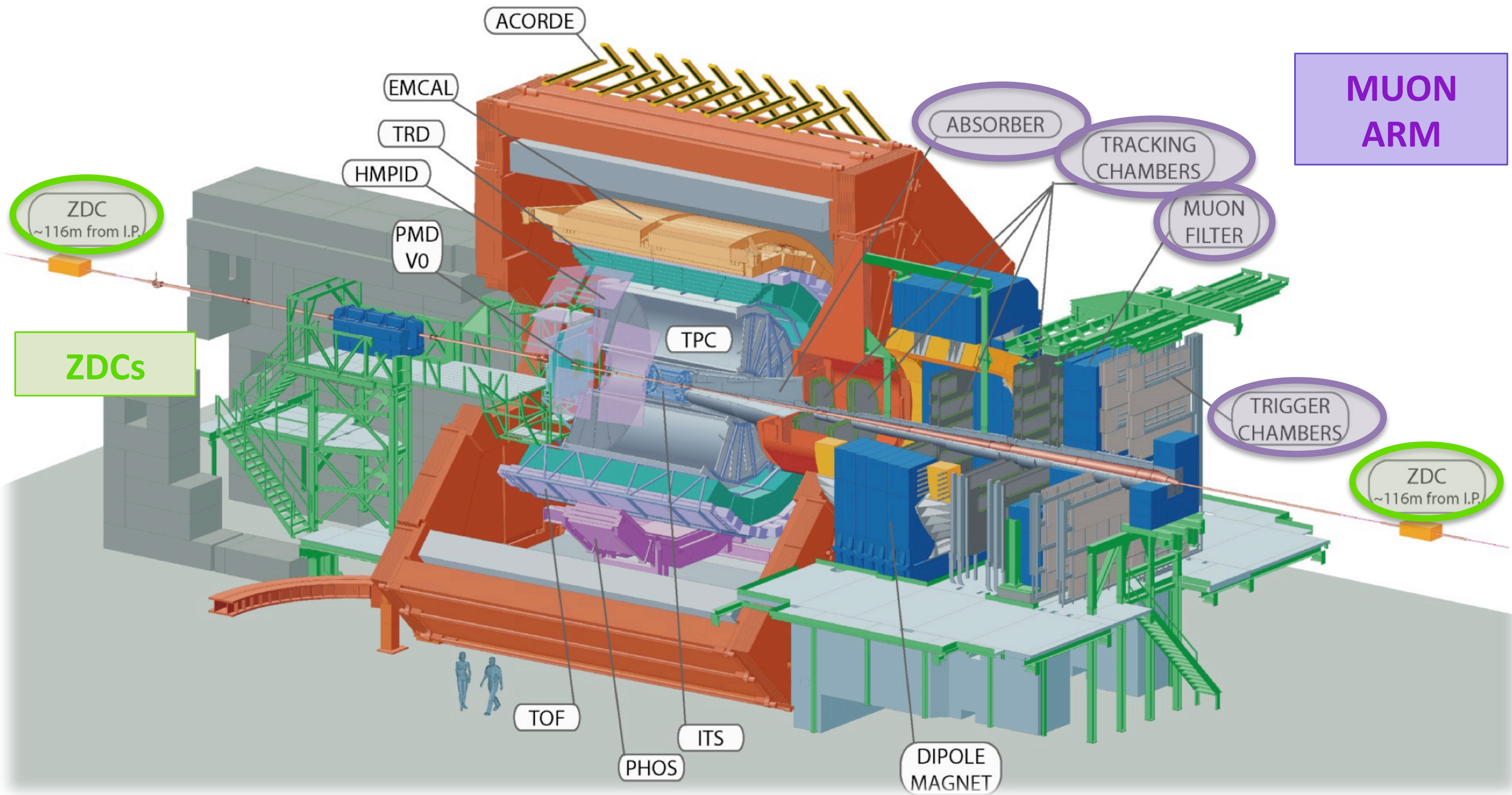

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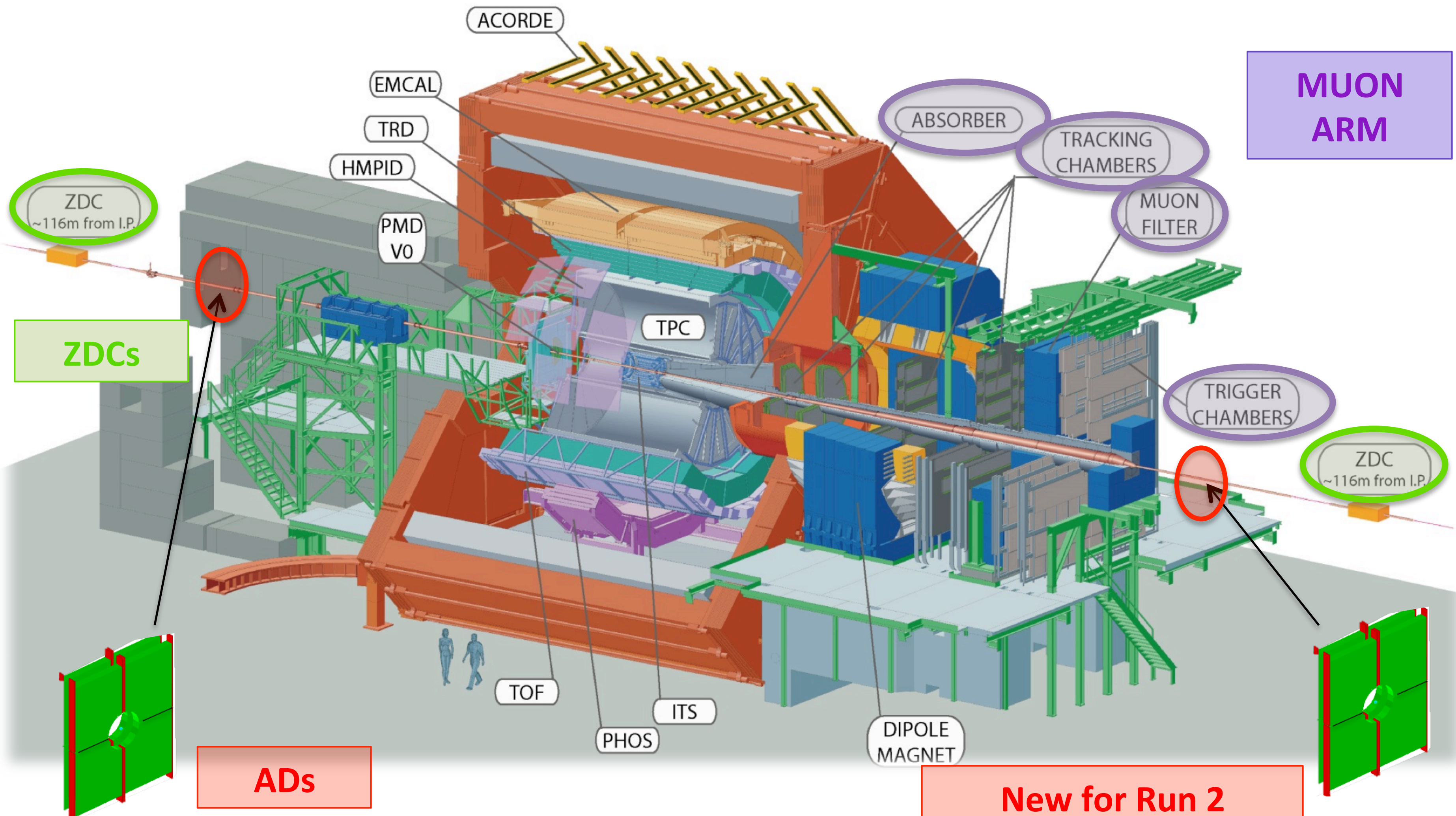

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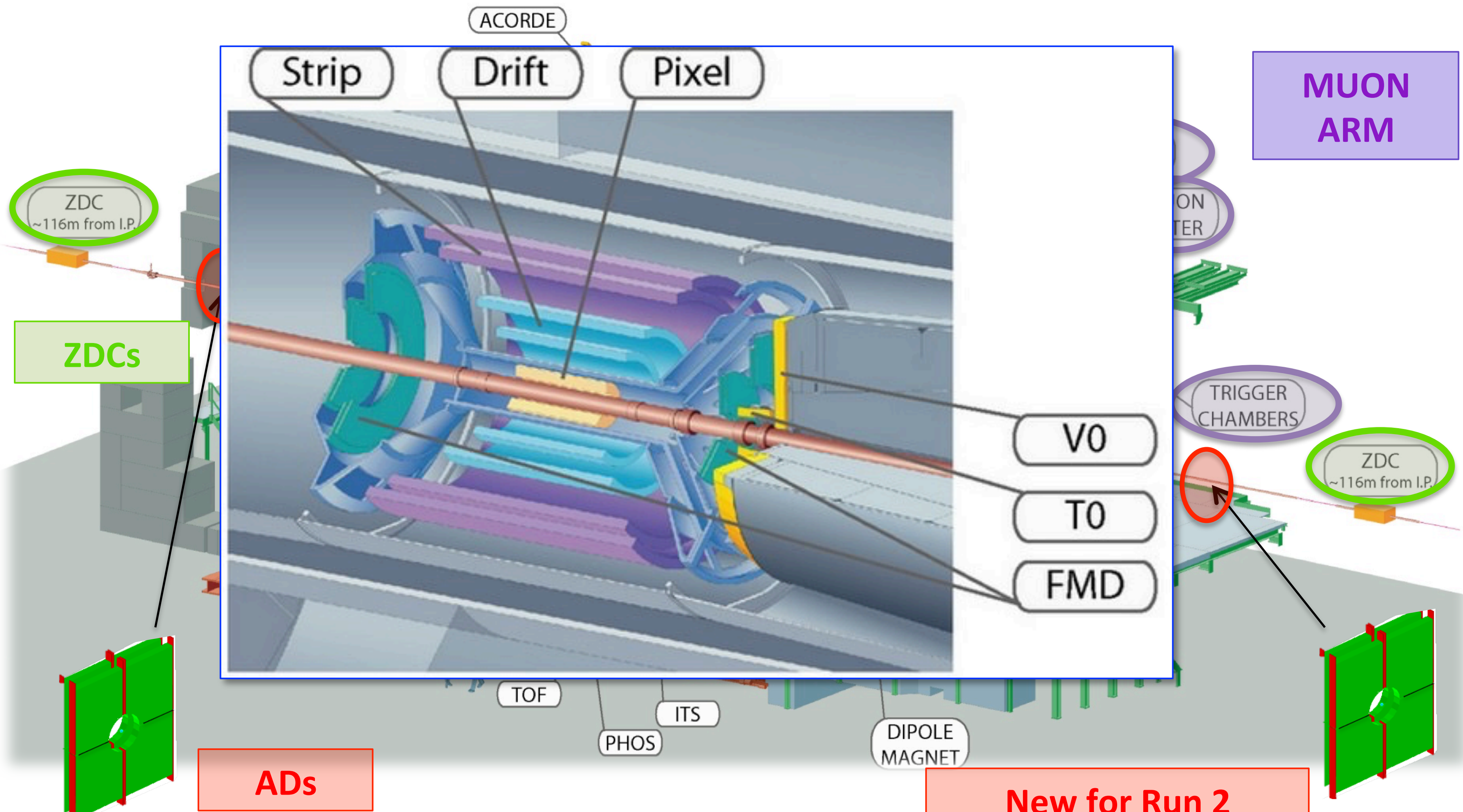

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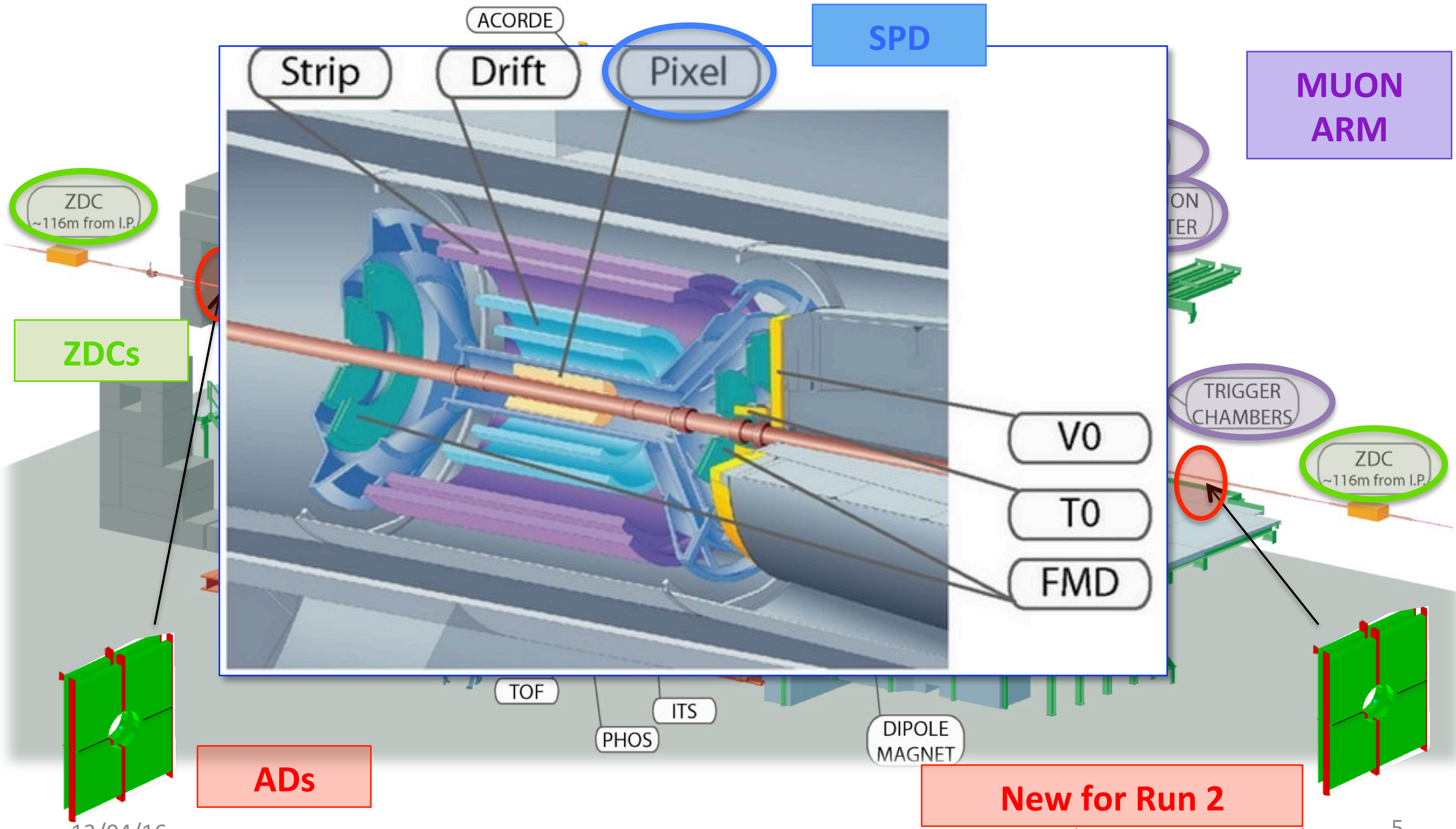

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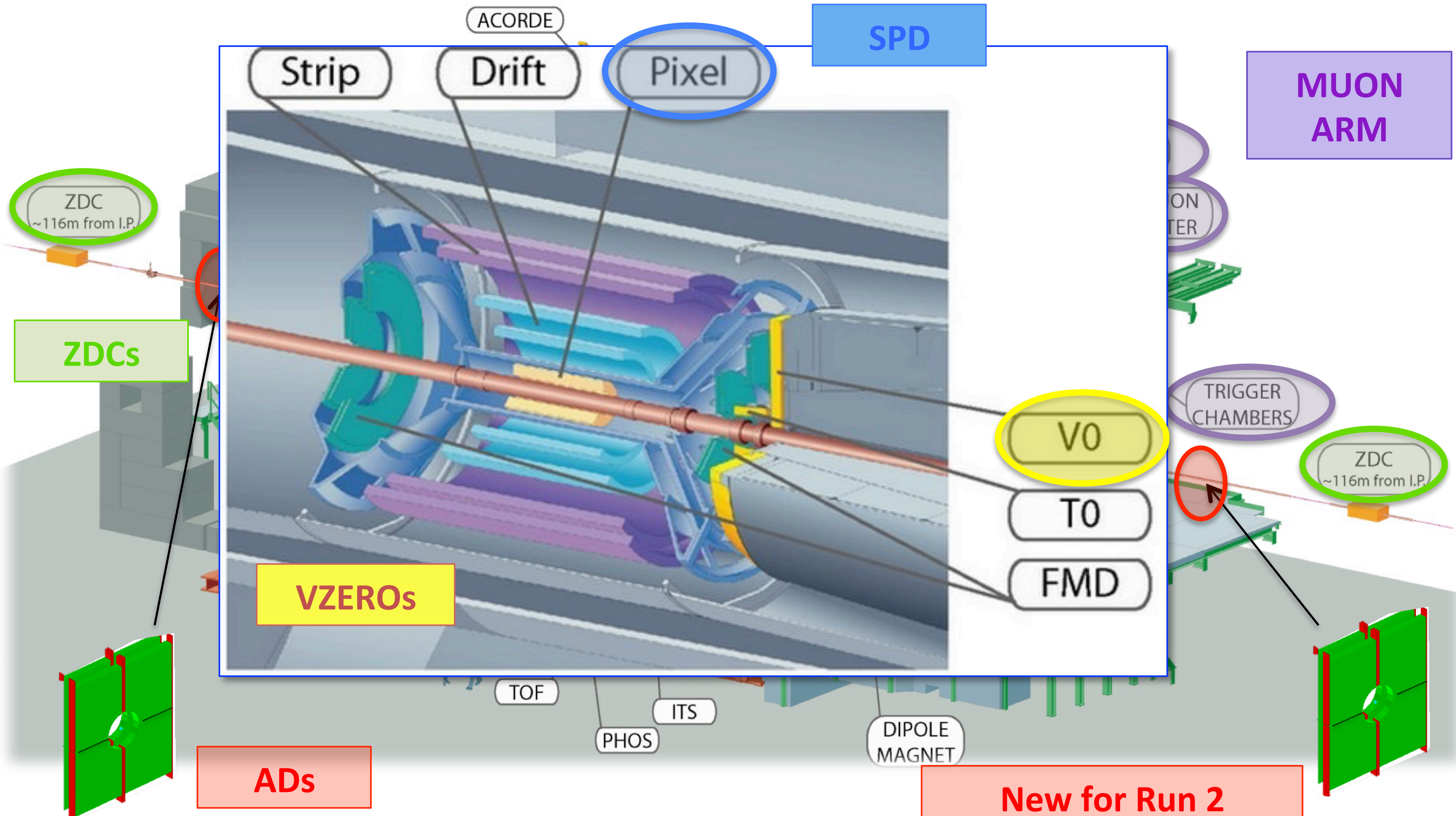
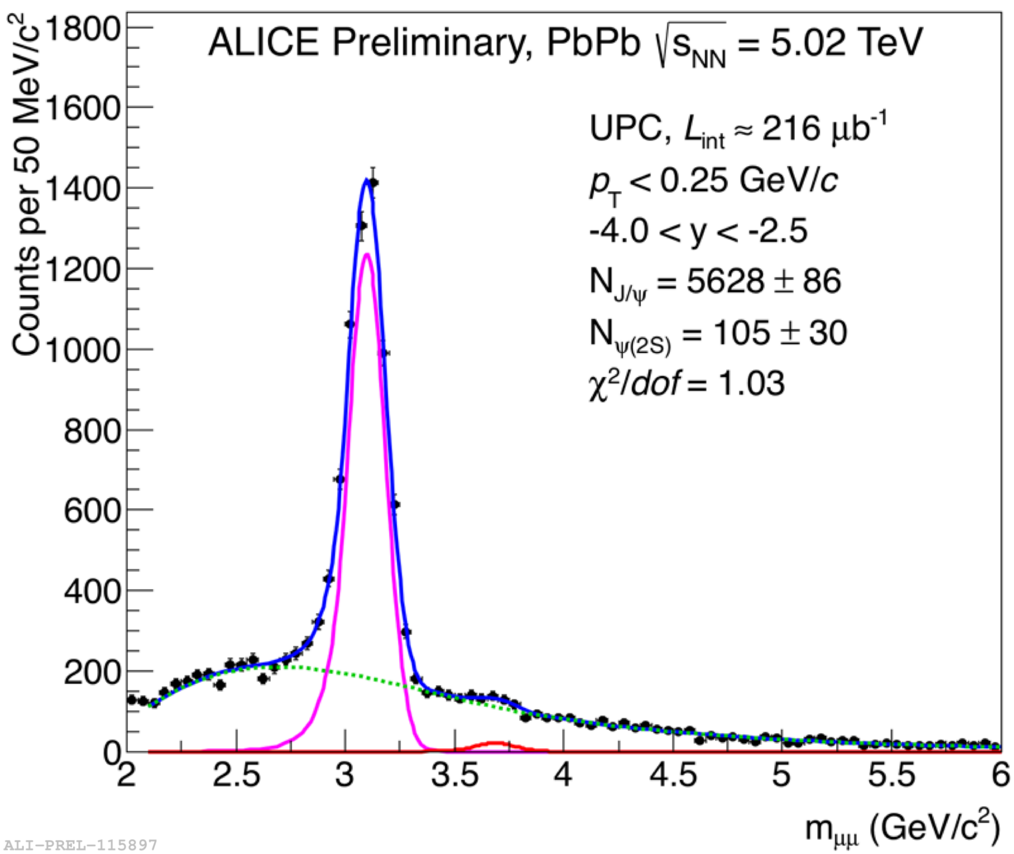
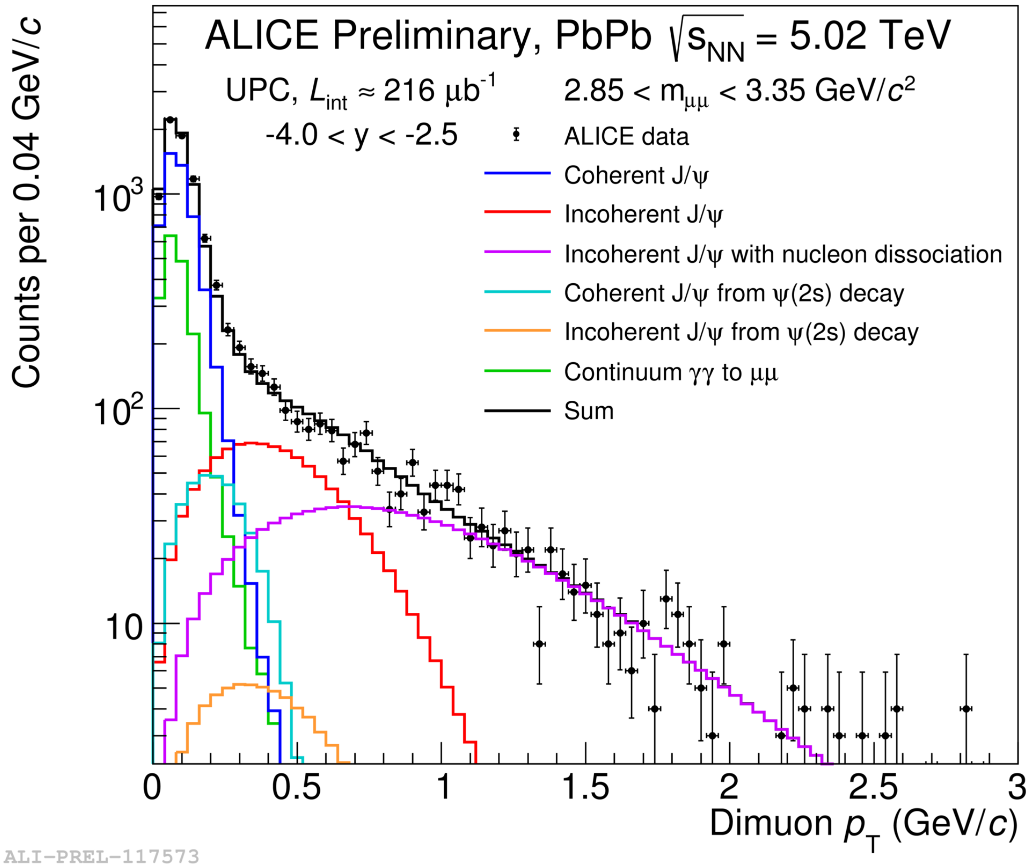


Forward J/ψ and ψ(2s) in Pb-Pb



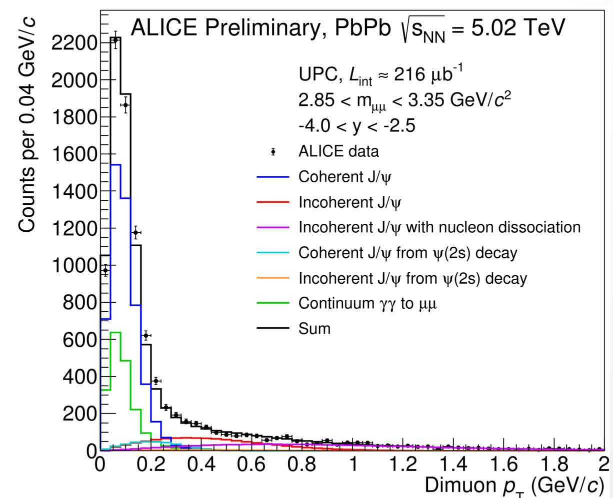
- p_T cut applied to select coherent J/ψ
- Continuum background very well described by Starlight MC
- Around 50 times as many J/ψ as in Run 1
- ψ(2s) seen with 3σ significance
- σ(ψ(2s))/σ(J/ψ) ≈0.166 ± 0.011 fits well with H1 data: 0.166 ± 0.007 (stat) ± 0.008 (syst) ± 0.007 (BR) [Phys.Lett.B541:251-264,2002]

p_T distribution of forward J/ψ

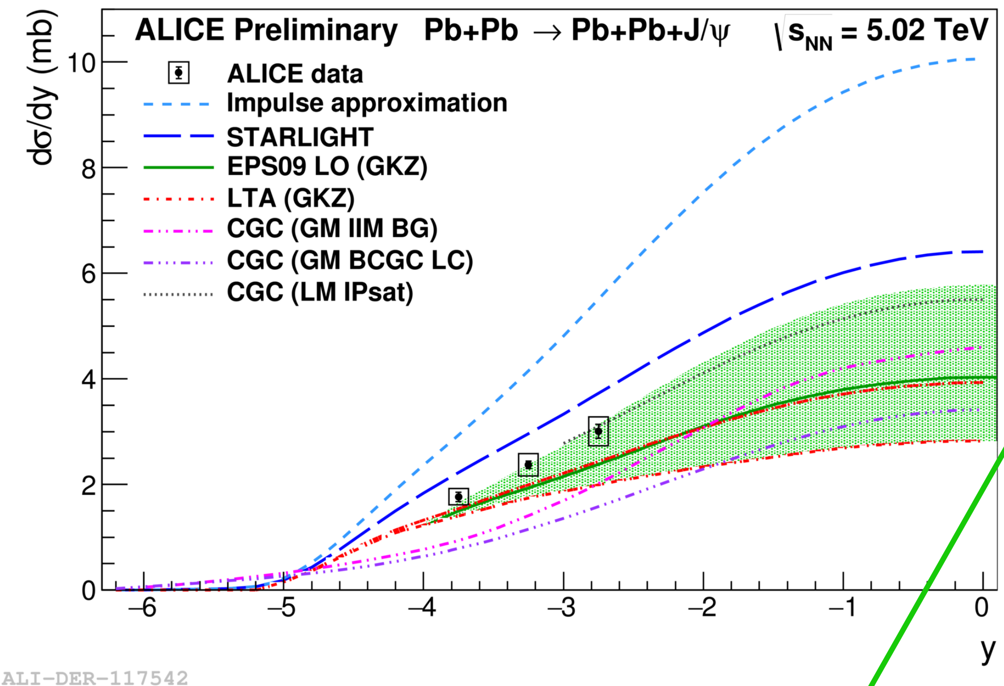


p_T templates from Starlight MC

- Coherent J/ψ (photon couples coherently to whole nucleus)
- Incoherent J/ψ (photon couples to single nucleon)
- Nucleon dissociation shape comes from HERA data
- Sizes of templates for coherent and incoherent J/ψ from feed-down fixed as fractions of direct J/ψ
- Continuum template size fixed to yield under mass peak



Coherent J/ψ forward cross section



Cross section consistent with moderate nuclear gluon shadowing

- Impulse approximation: no nuclear effects
- STARLIGHT: VDM + Glauber (Klein, Nystrand *et al* Comput. Phys. Commun. 212 (2017) 258)
- EPS09 LO: EPS09 shadowing (Guzey, Kryshen, Zhalov, PRC93 (2016) 055206)
- LTA: Leading Twist Approximation (Guzey, Kryshen, Zhalov, PRC93 (2016) 055206)
- CGC GM: color dipole model + IIM/BCGC (Goncalves, Machado *et al*, PRC 90 (2014) 015203, JPG 42 (2015) 105001)
- CGC LM: Color dipole model + IPSat (Lappi, H. Mäntysaari, PRC 83 (2011) 065202; 87 (2013) 032201)

Two photon energies

$$\omega = \frac{M_{J/\psi}}{2} \exp(\pm y)$$

$$x = \frac{M_{J/\psi}}{\sqrt{s_{NN}}} \exp(\pm y)$$

$$\frac{d\sigma_{UPC}}{dy} = n(\omega_1)\sigma_{\gamma T}(\omega_1) + n(\omega_2)\sigma_{\gamma T}(\omega_2)$$

Low energy (high-x)

High energy (low-x)

For forward rapidity (y<0):

$\omega_1 << \omega_2$

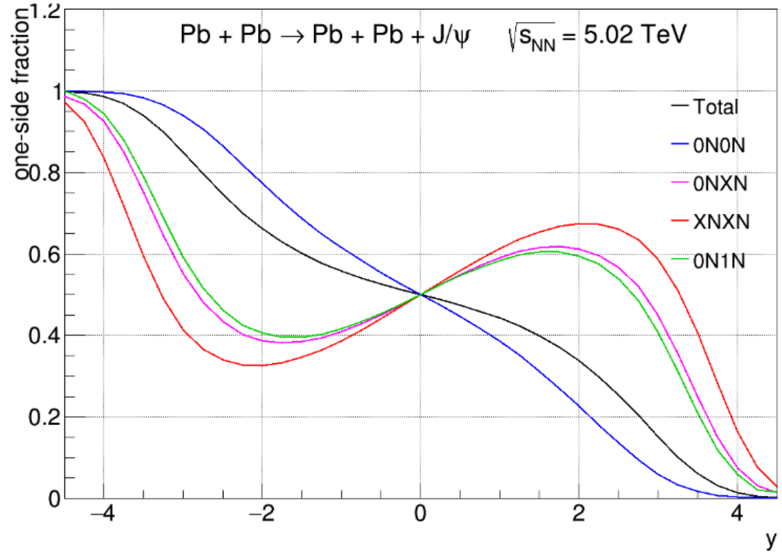
$n(\omega_1) >> n(\omega_2)$

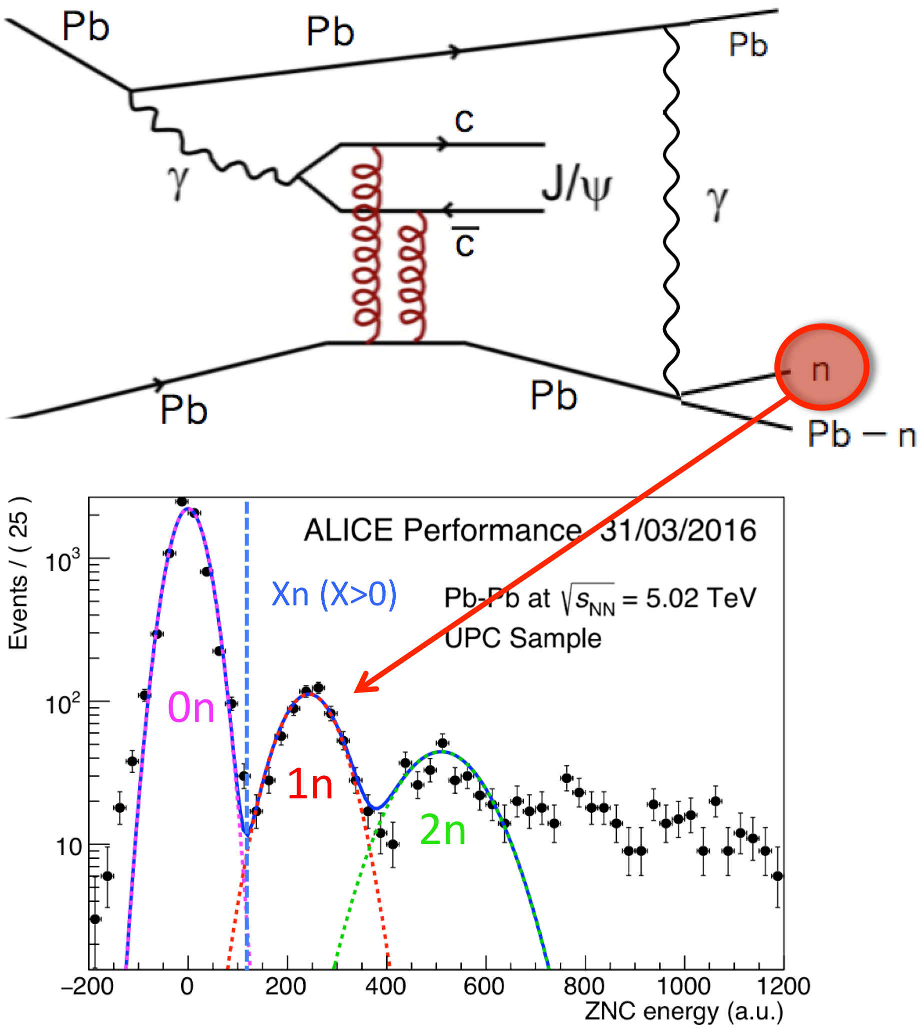
$\sigma_{\gamma T}(\omega_1) < \sigma_{\gamma T}(\omega_2)$

- There are two possible photon energies depending on which direction the emitting nucleus was travelling
- 90-95% contribution of high-*x*: $(0.7\text{-}3)\times10^{-2}$
- 5-10% contribution of low-x: $\approx10^{-5}$
- Difficult to disentangle

Forward neutron production

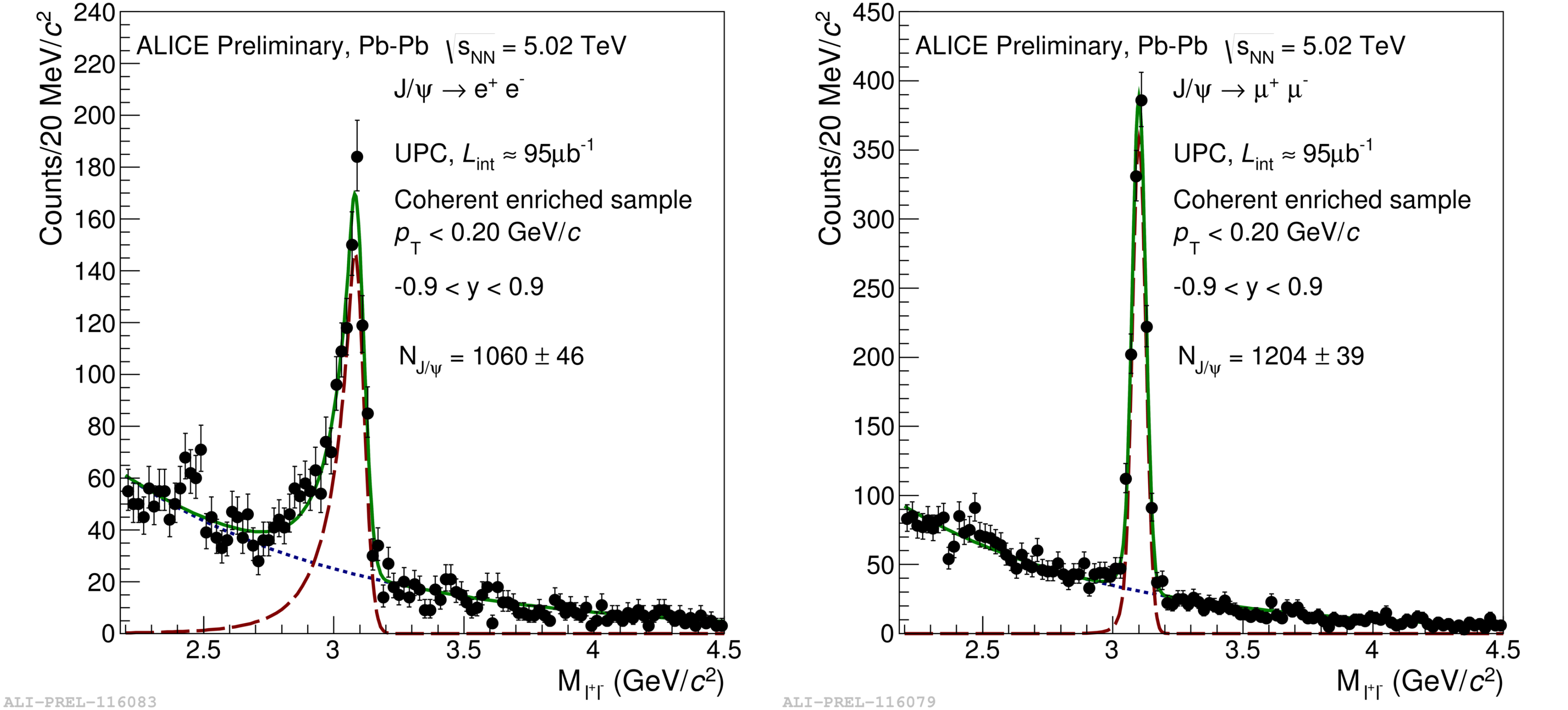
Guzey, Kryshen, Zhalov, PRC93 (2016), 055206





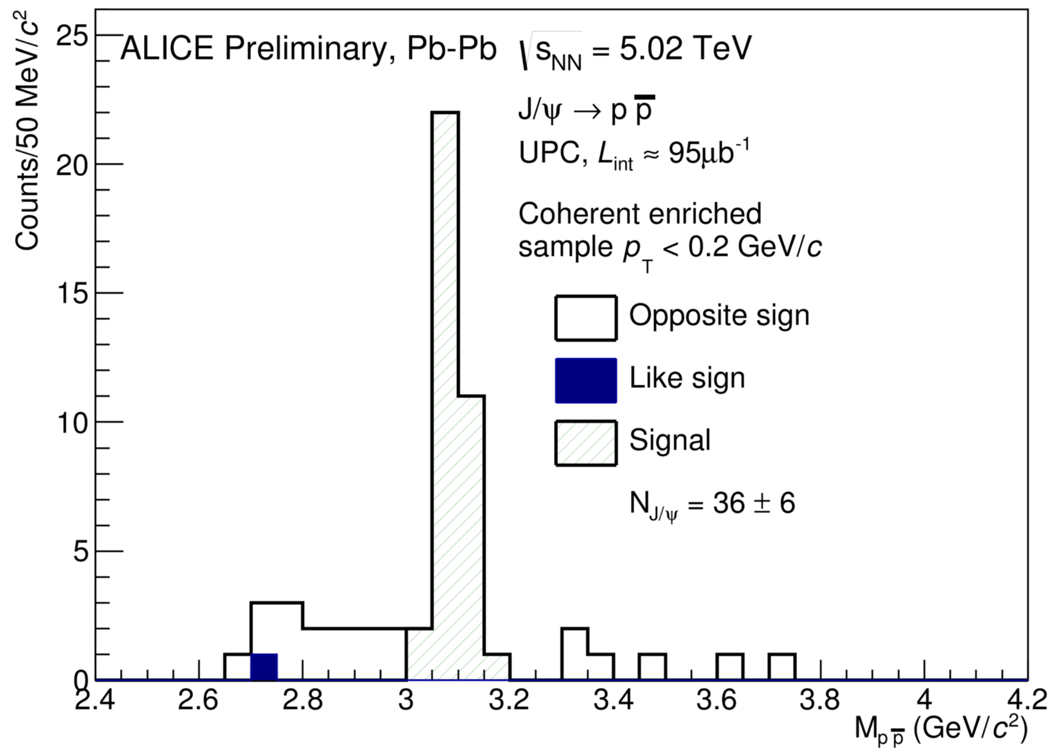
- Separately from the coherent J/ψ production, the nuclei can photodissociate resulting in neutron emission
- Using the ZDCs we have another method of separating events with 0n0n, 0nXn and XnXn
- These three categories have different proportions of low-x and high-x production, from which the two components can be separated
- See Baltz, Klein & Nystrand, PRL **89** (2002) 012301; Guzey, Kryshen & Zhalov, PRC93 (2016) 055206 for more detailed explanations

Mid-rapidity J/ψ→ℓ⁺ℓ⁻



- Four times more statistics with respect to Run 1
- Access to $x \approx 0.5 \times 10^{-3}$

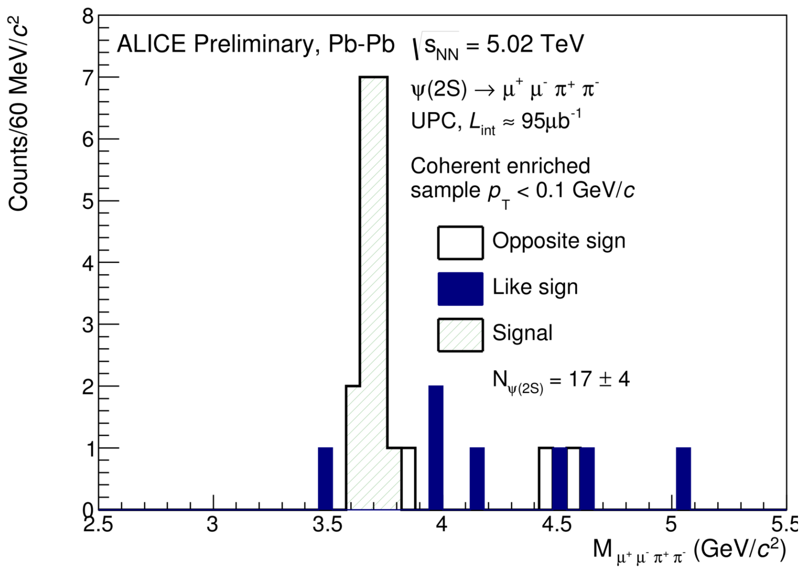
First observation of J/ψ→$p\bar{p}$ in UPC



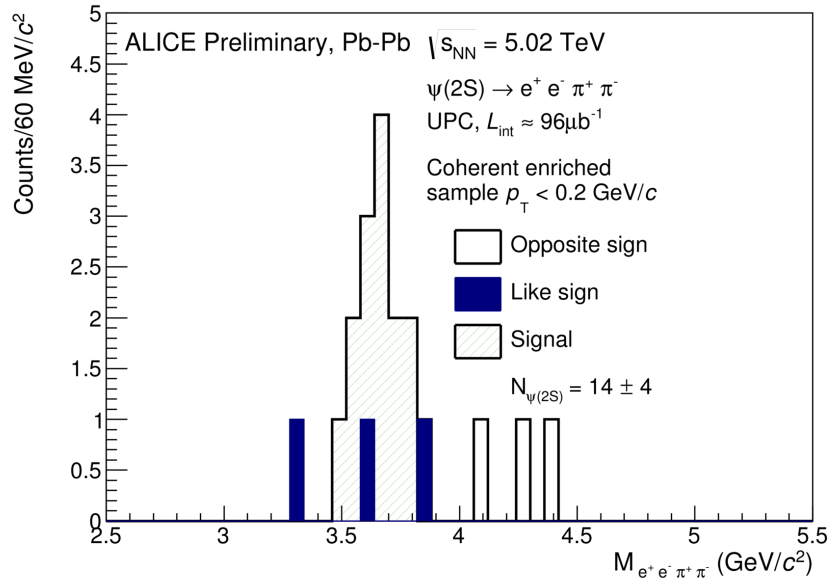
ALI-PREL-117138

- First measurement of J/ψ→$p\bar{p}$ in UPC at the LHC
- Can be seen due to ALICE's excellent PID capabilities
- Much smaller radiative losses due to Bremsstrahlung compared to e^+e^-, $\mu^+\mu^-$

Mid-rapidity ψ(2S) → J/ψπ⁺π⁻



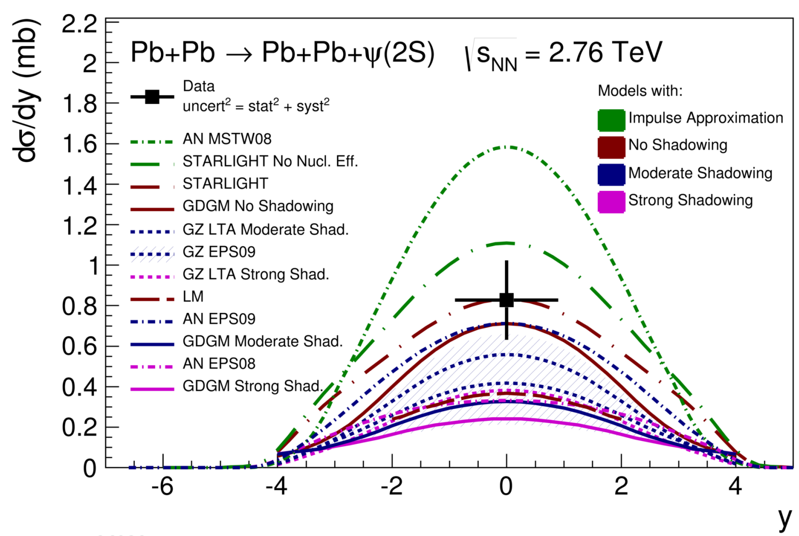
ALI-PREL-116095



ALI-PREL-116091

- Will have comparable errors to the result at 2.76 TeV (0.83 ± 0.19 (stat+syst) mb) for -0.9 < y < 0.9

Phys. Lett. B 751 (2015) 358-370



ALI-PUB-96039

Summary

- Run 1 main point: the forward cross section for coherent J/ψ photoproduction in ultraperipheral collisions is consistent with a moderate amount of nuclear gluon shadowing
- This is confirmed with much better statistics in Run 2
- Coming soon for Run 2:
  - The ZDC-differential cross section, incoherent cross section and polarisation of the forward J/ψ
  - The J/ψ and ψ(2s) photoproduction cross sections at mid-rapidity

Separation of low-x and high-x contributions using the ZDC

- The flux of high-energy photons (low-x) decreases faster with b than the flux of low-energy photons
- Probability of photodissociation also decreases with b
- Selecting events with neutrons in the ZDC (where photodissociation has taken place) thus gives a sample with lower b and so a larger ratio of low-x to high-x photon events than the sample with no neutrons
- See Baltz, Klein & Nystrand, PRL **89** (2002) 012301; Guzey, Kryshen & Zhalov, arXiv:1602.01456 (2016) for more detailed explanations