



Dipion & Dikaon Photoproduction in ultra-peripheral Pb-Pb collisions with ALICE

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Ultra-Peripheral Collisions (UPC)

- UPC interactions is where the impact parameter is greater than the sum of nuclear radii
- Hadronic interactions suppressed
- Photon-initiated reactions dominate (photon flux $\propto Z^2$)

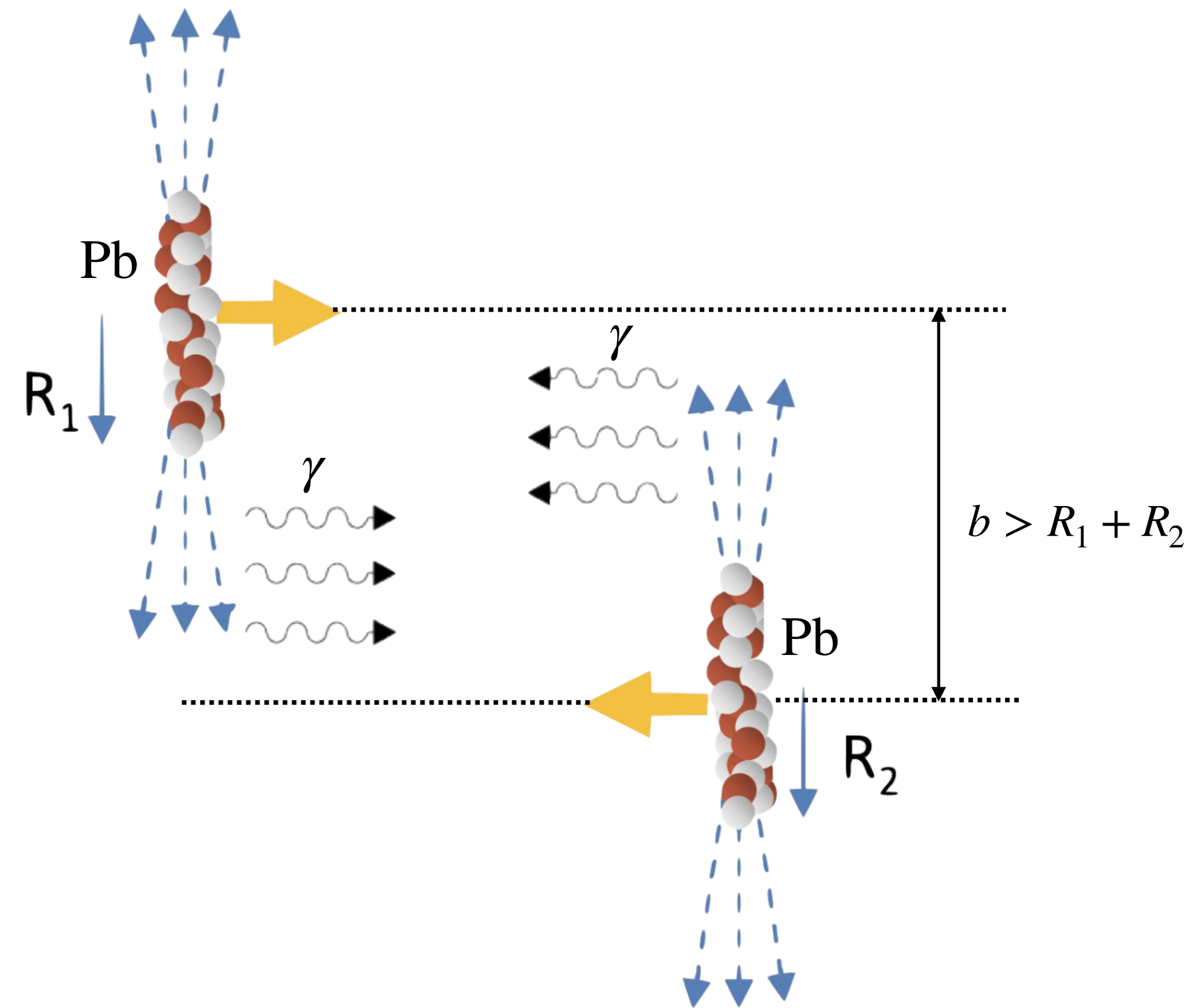
photon-nucleon CM Energy : $W_{\gamma p}^2 = 2EM_{VM}e^{\pm y}$

E : beam energy, per nucleon

M_{VM} : vector meson mass

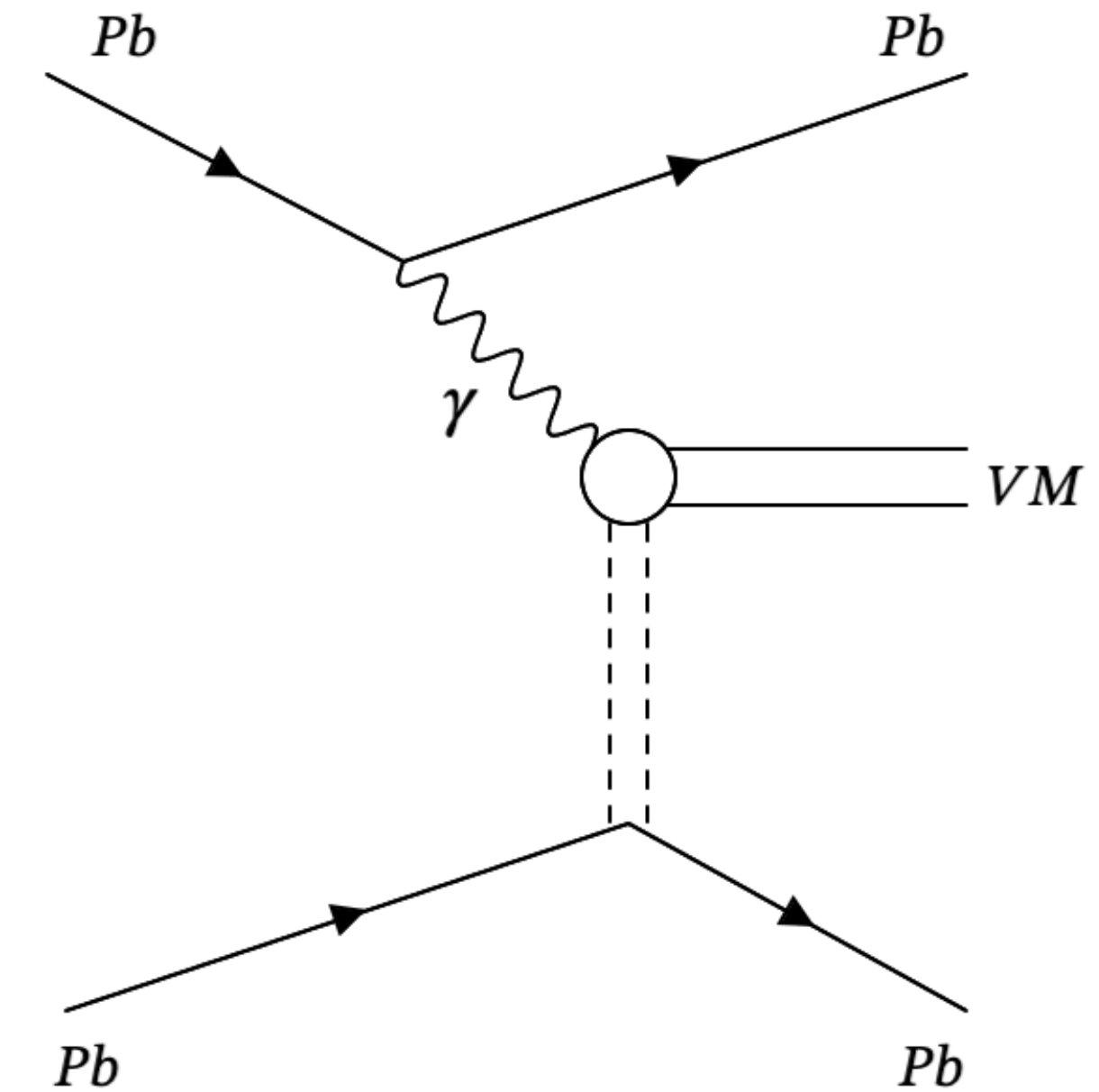
y : vector meson rapidity

- Reaching highest energy photon beams at LHC, up to ~1 TeV



Vector Meson Production in UPC

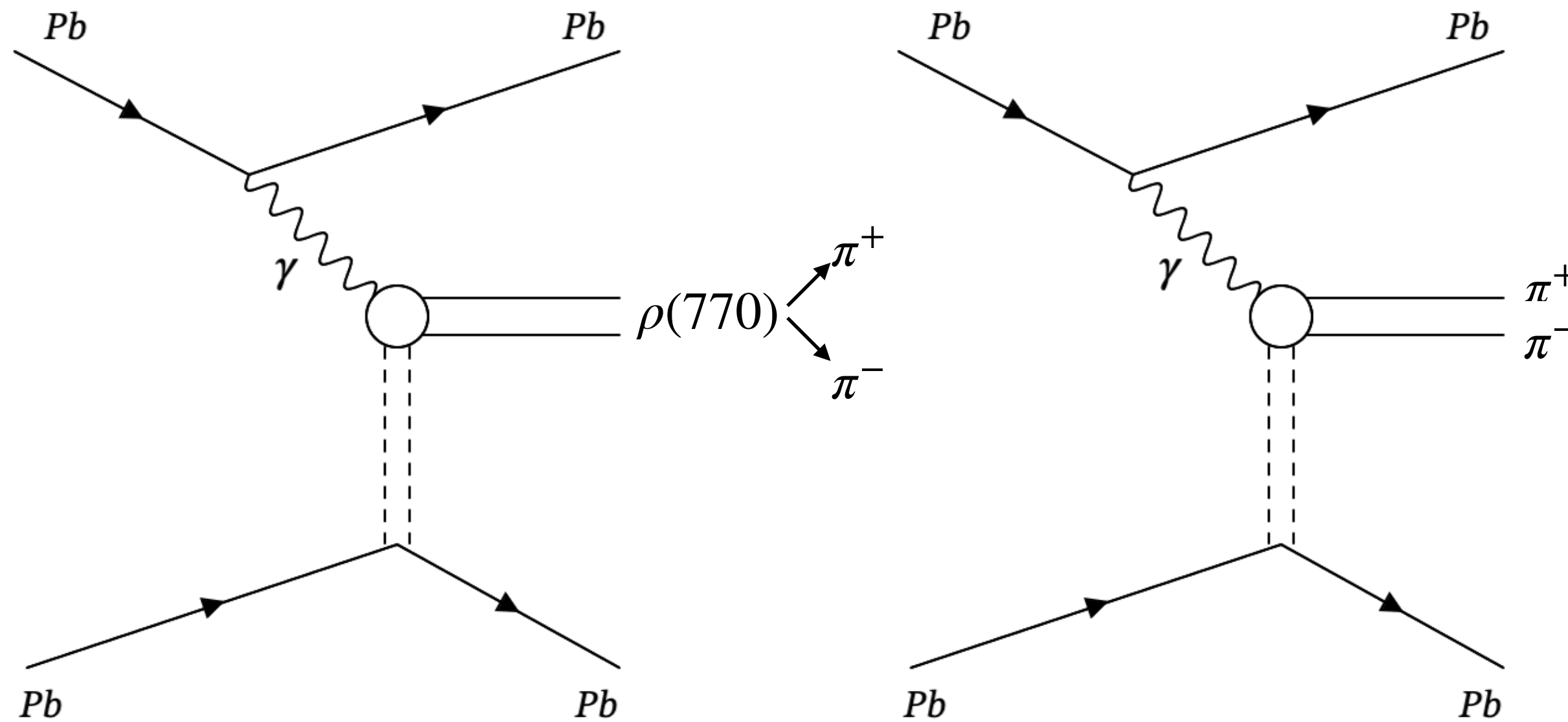
- Photons fluctuate into $q\bar{q}$ pair $J^{PC} = 1^{--}$
- Photons scattering off the target: $\langle p_T \rangle \sim 1/R_{\text{target}}$
 - Coherently (target Pb): $\sim 50 \text{ MeV}/c$
 - Incoherently (target proton): $\sim 400 \text{ MeV}/c$
- Vector Meson photoproduction cross section sensitive to gluon density in nuclei
[Ryskin: Z. Phys. C 57, 89 (1993), K.J. Eskola et. al Phys. Rev. C 106 (2022) 035202]



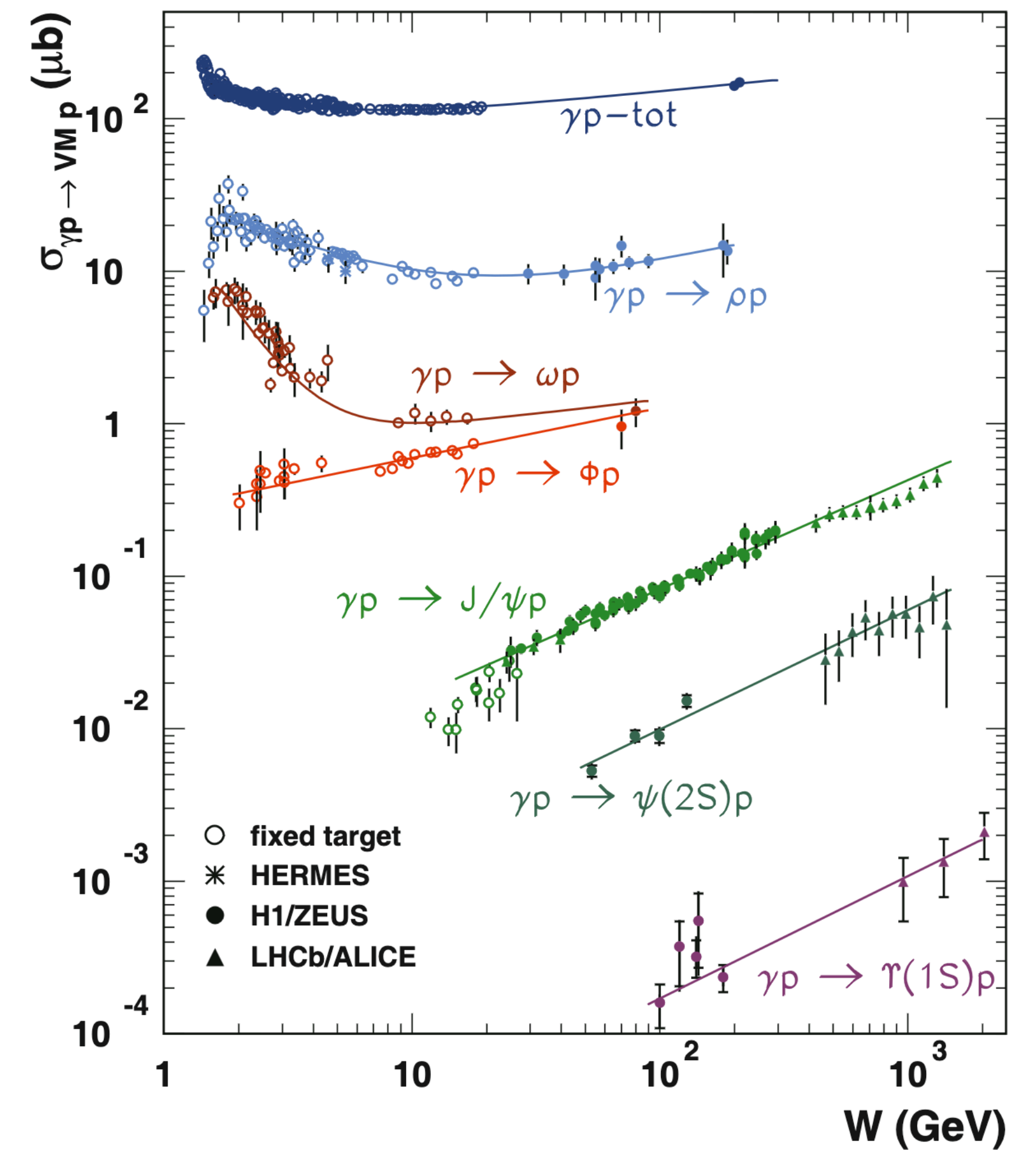
- $x = \frac{M_{VM}^2}{W_{\gamma p}^2}$ @ LHC: $10^{-5} < x < 10^{-2}$
- $Q^2 \sim \frac{M_{VM}^2}{4}$ for : $\rho(770) \sim 0.15 \text{ GeV}^2$, $\phi(1020) \sim 0.26 \text{ GeV}^2$

Exclusive Dipion Photoproduction

- High energy vector meson photoproduction cross section $\sigma \sim W_{\gamma p}^{\delta}$
- $\rho(770)$ dominates the total vector meson production cross section



L. Favart et al. Eur. Phys. J. A 52 (2016) 158

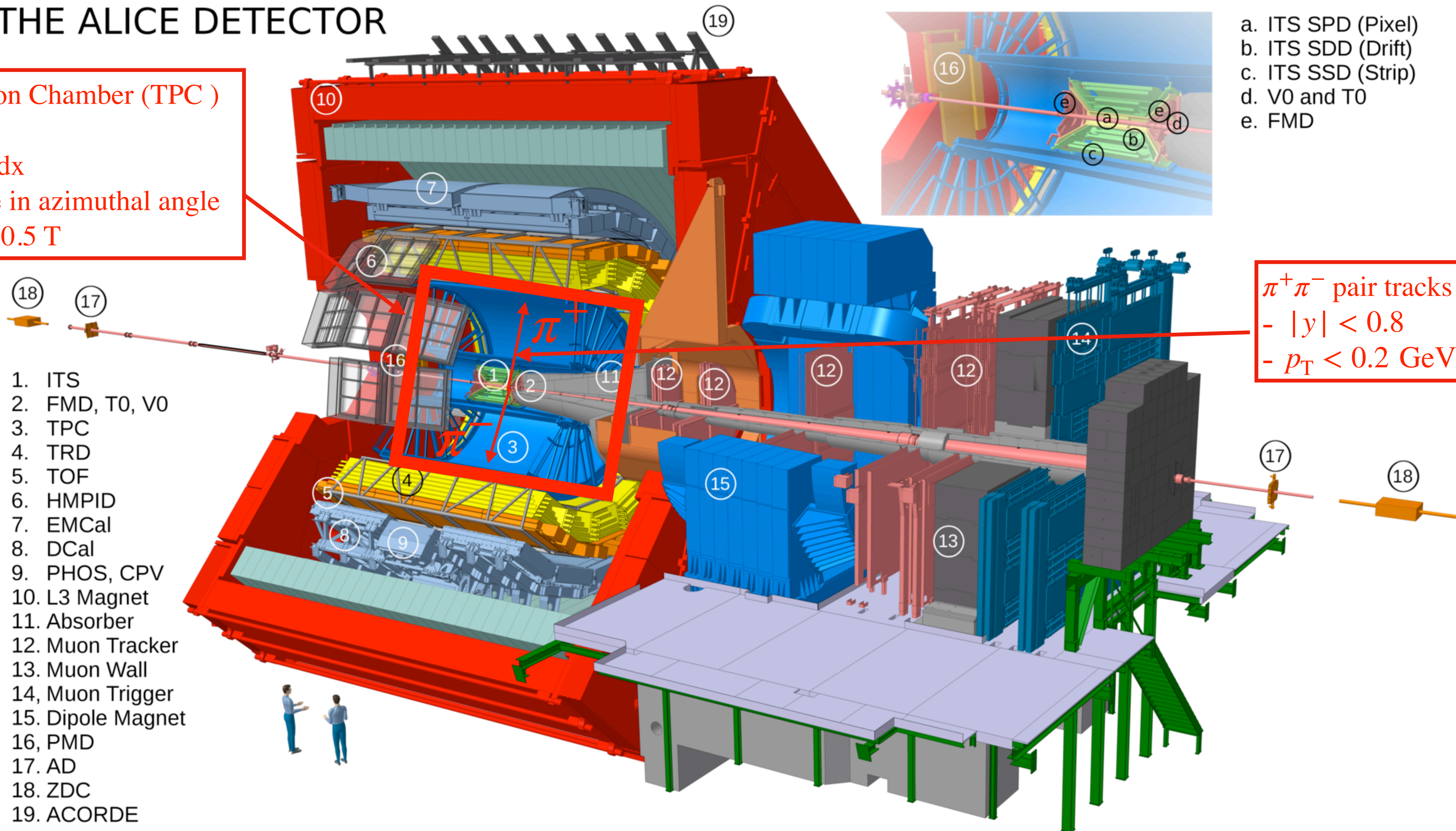


Exclusive Dipion Selection in ALICE Detector

THE ALICE DETECTOR

Time Projection Chamber (TPC)

- $|\eta| < 0.9$
- PID via dE/dx
- 2π coverage in azimuthal angle
- Operated at 0.5 T



Coherent $\rho(770)$ Photoproduction

- Measured mass-dependent differential cross section of ρ^0 in Pb-Pb, and first time in Xe-Xe at UPC

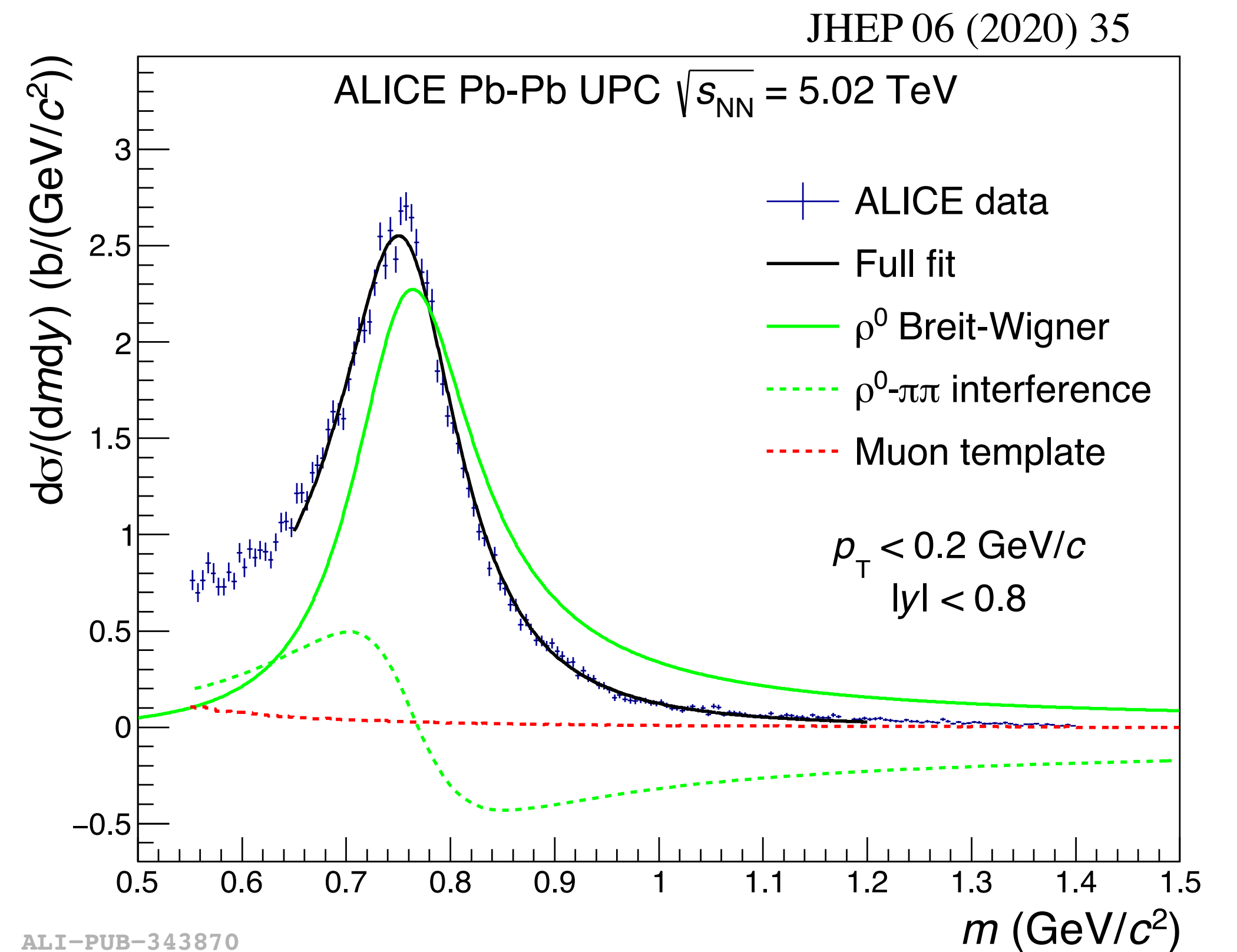
- ρ^0 resonance + direct $\pi^+\pi^-$ well described by Söding formula:

$$\frac{d\sigma}{dm dy} = \left| A \frac{\sqrt{m m_\rho \Gamma(m)}}{m^2 - m_\rho^2 + i m_\rho \Gamma(m)} + B \right|^2 + M,$$

$$\Gamma(m) = \Gamma(m_{\rho^0}) \frac{m_{\rho^0}}{m} \left(\frac{m - 4m_\pi^2}{m_{\rho^0} - m_\pi^2} \right)^{3/2}$$

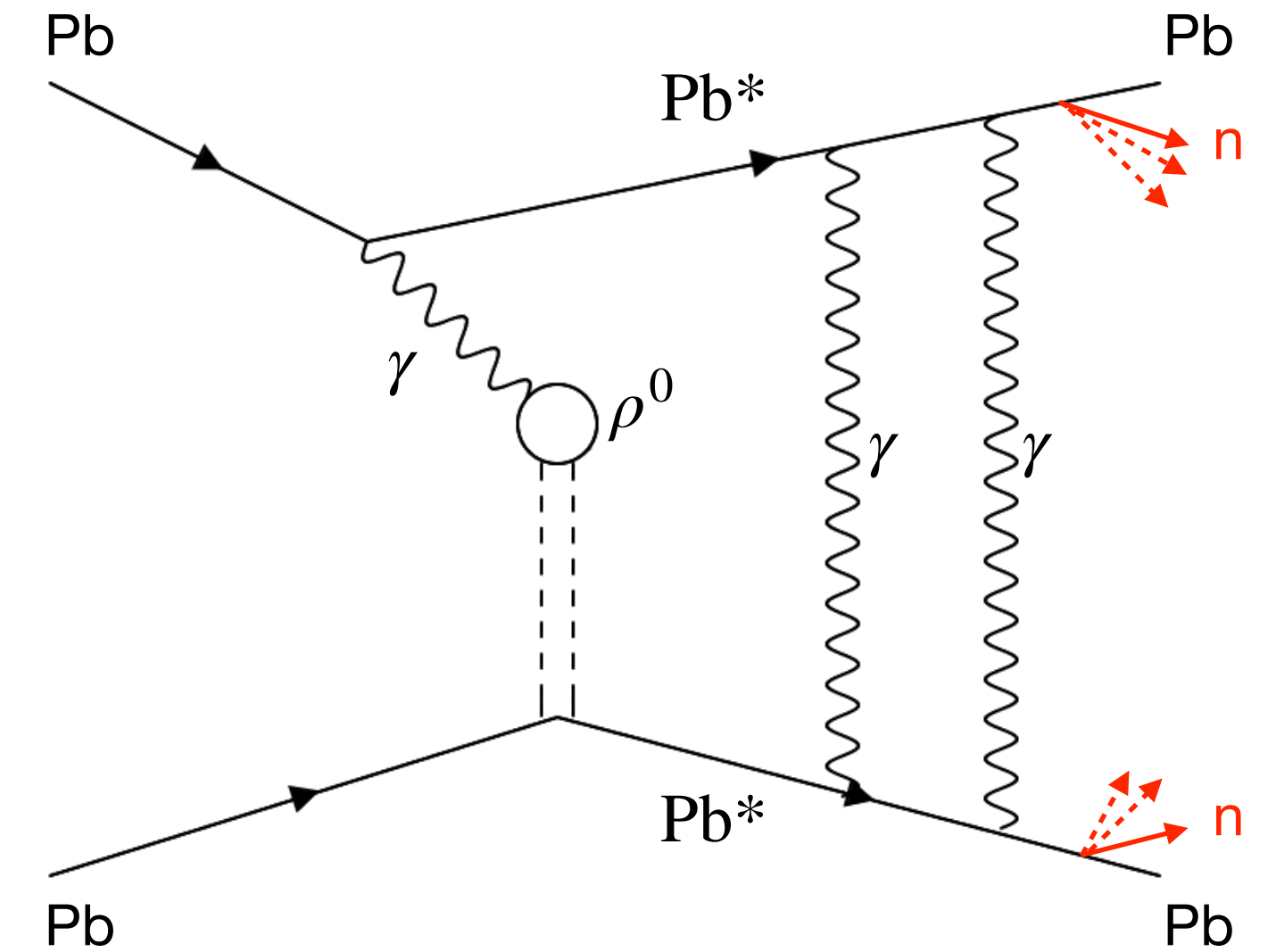
M : accounts for $\gamma\gamma \rightarrow \mu^+\mu^-$ contribution

A, B : Amplitudes of the ρ^0 and direct $\pi^+\pi^-$, respectively

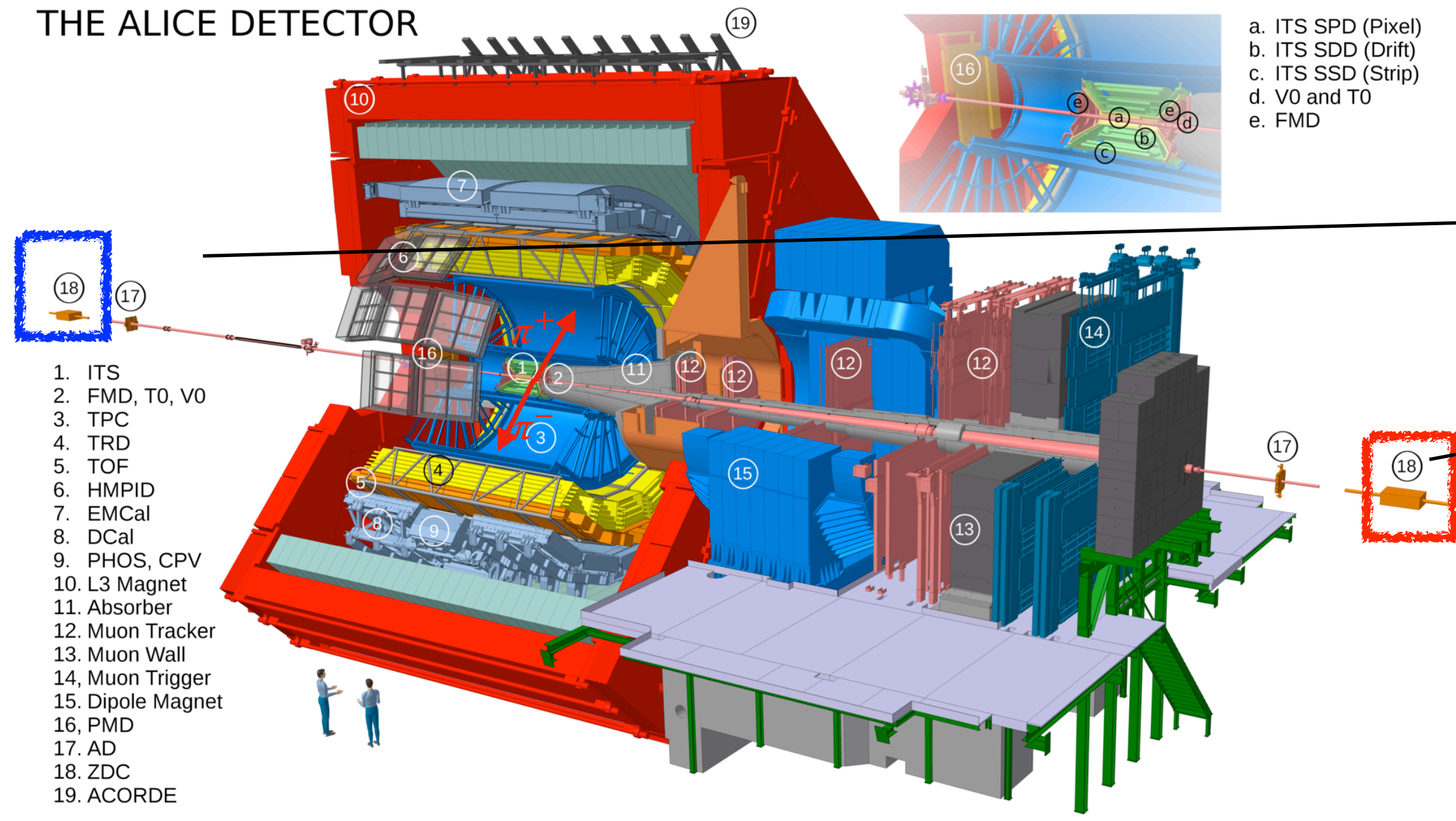


Nuclear Dissociation

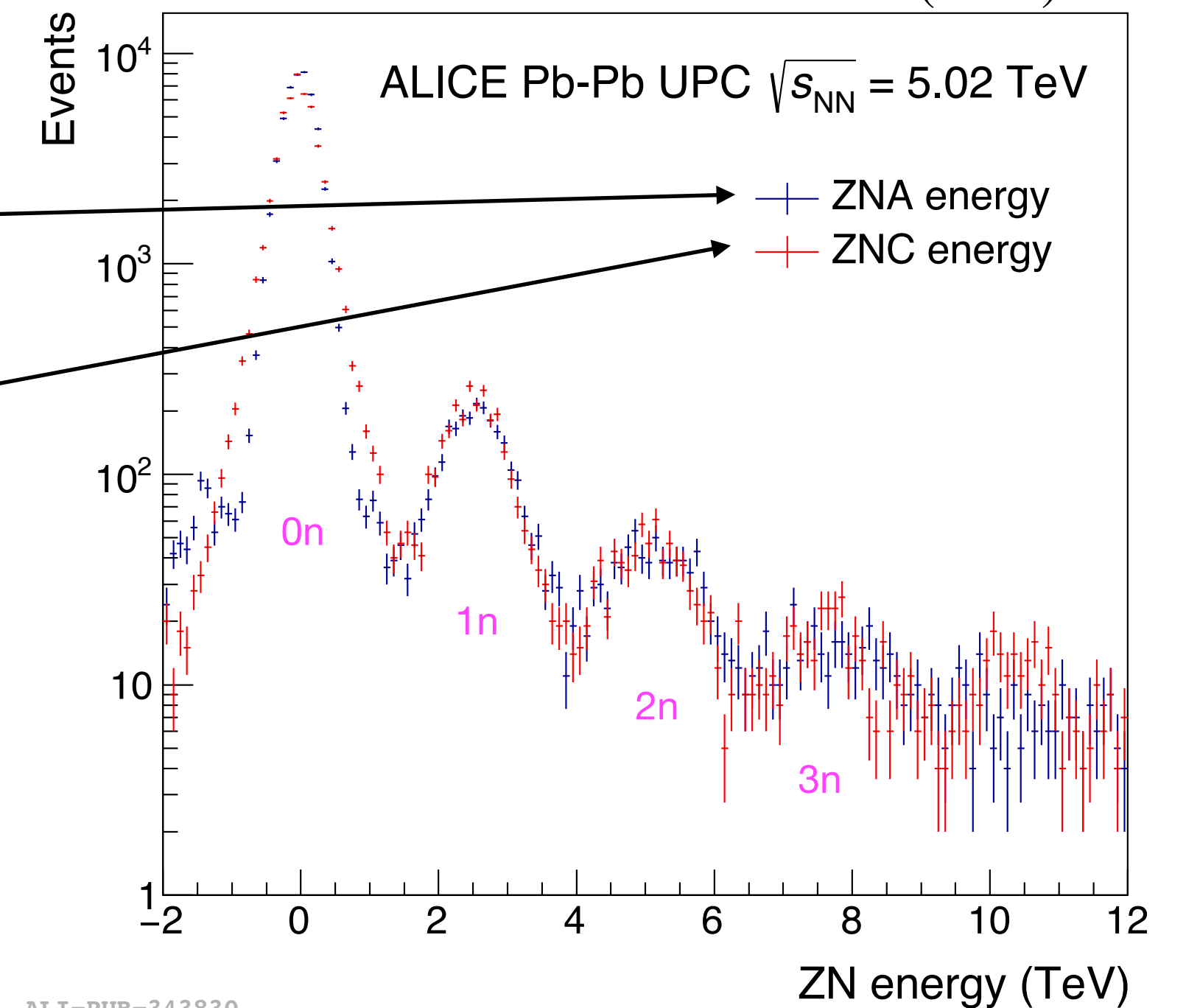
- Neutrons are occasionally emitted from excited ions
- Neutrons measured in Zero Degree Calorimeters (ZDC)
 - $\pm 112.5\text{m}$ from interaction point
 - Efficient neutron detection at $|y| > 8.8$
 - Neutron energy resolution : 20 %



THE ALICE DETECTOR



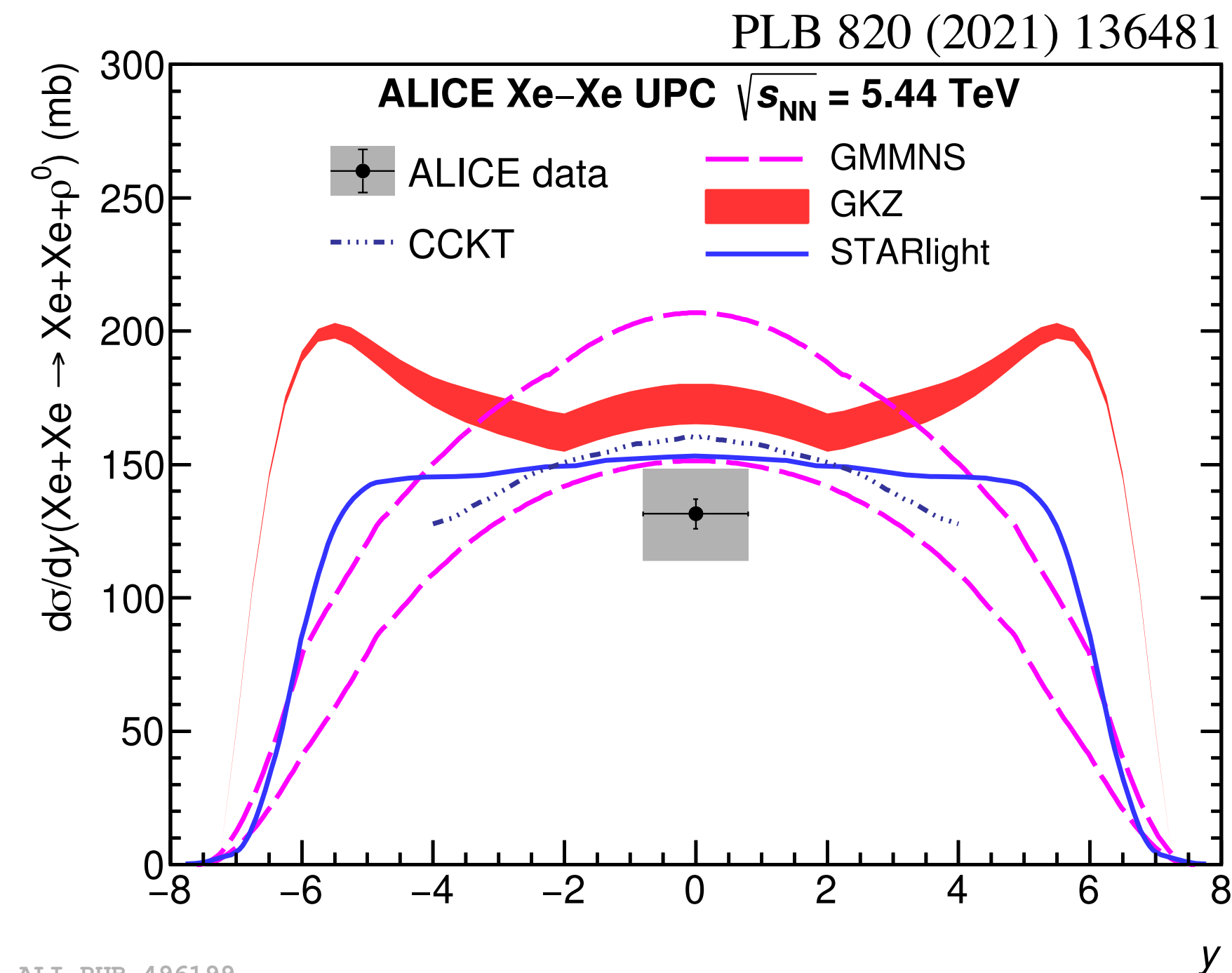
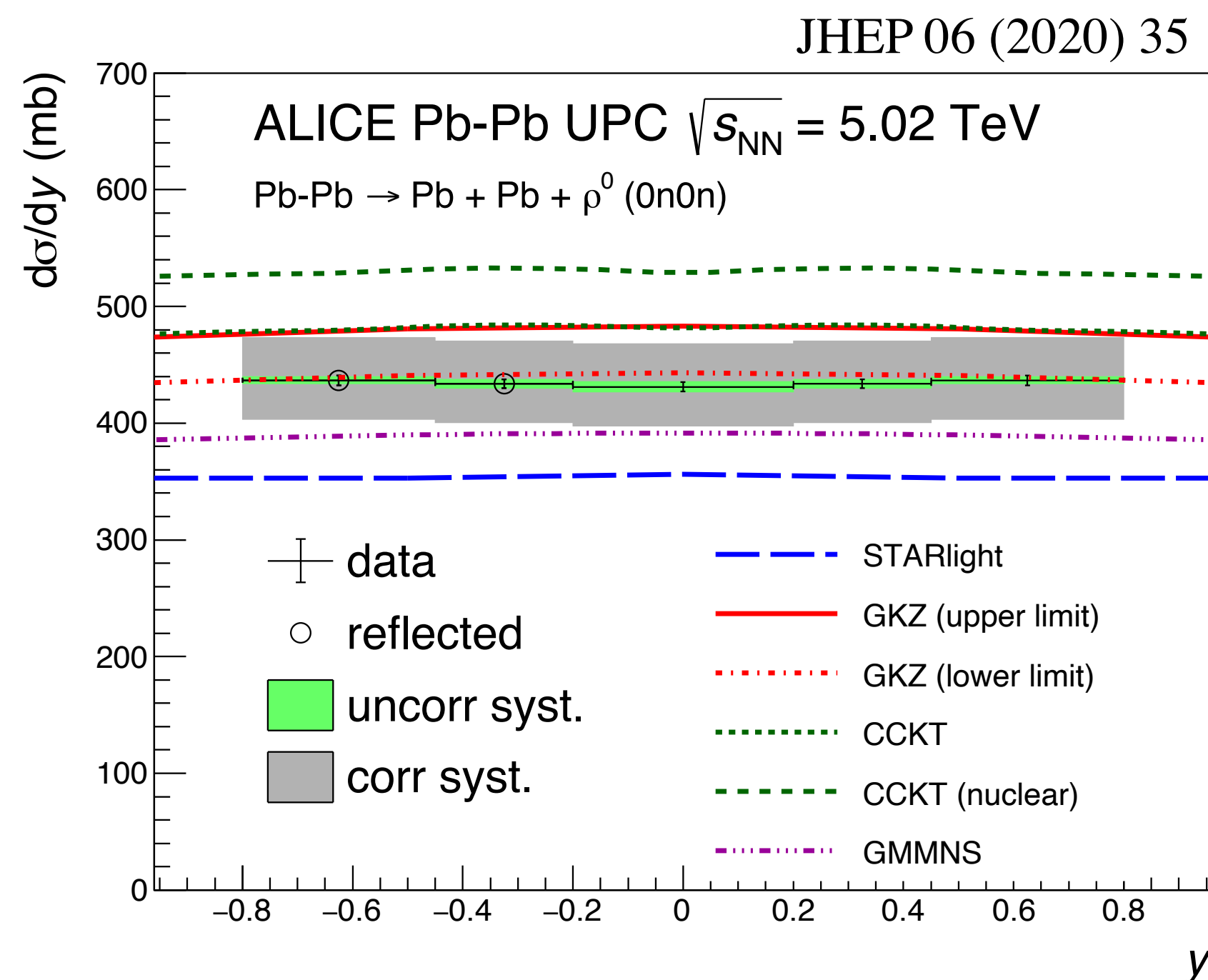
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$\rho(770)$ Photoproduction Cross Section

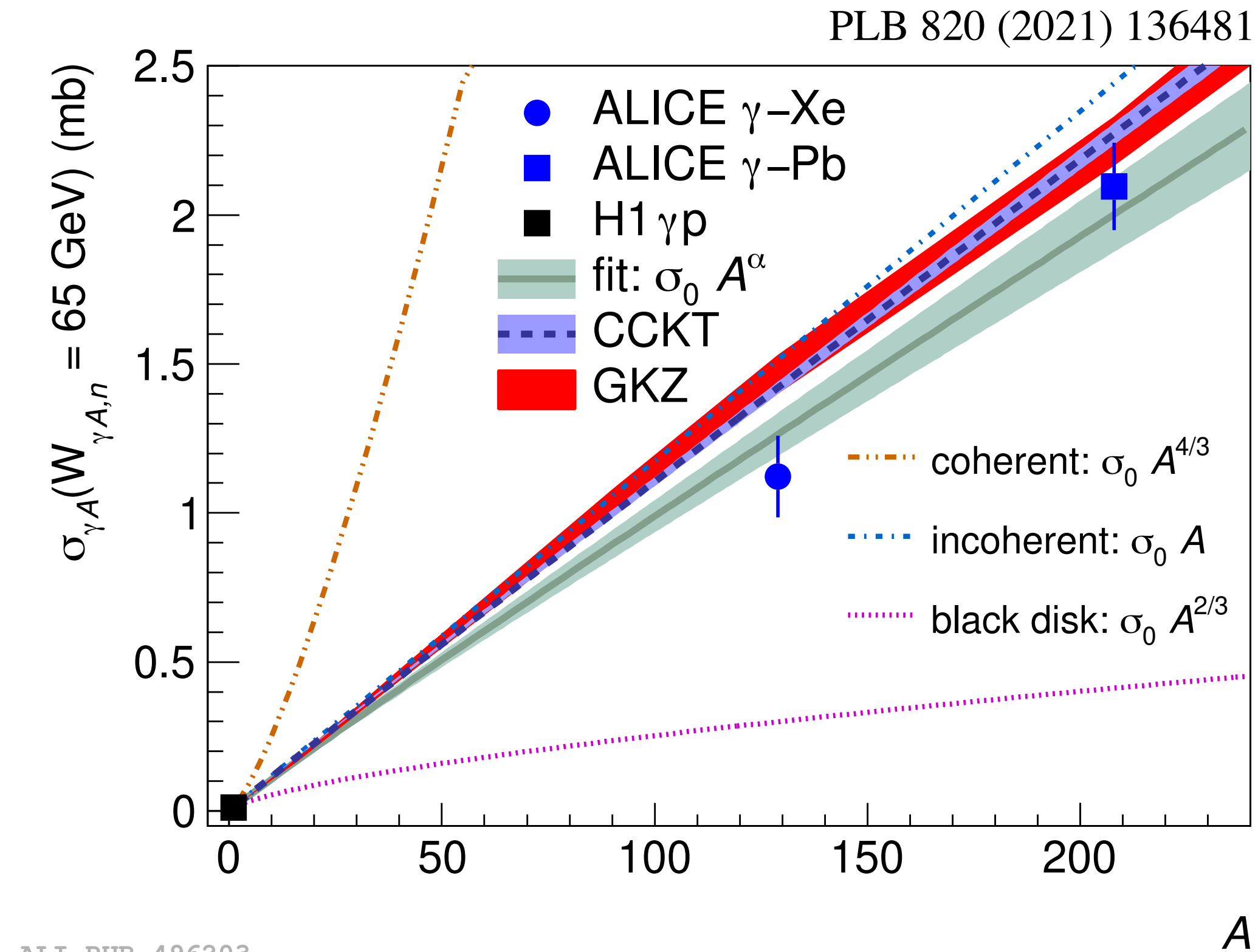
- Neutron emission sensitive to impact parameter (b)
 - no neutron emitted (0n0n) \rightarrow large b
 - neutron emitted in one beam side \rightarrow medium b
 - neutron emitted in both sides (XnXn) \rightarrow small b
- Tool to disentangle low- & high-energy photon interactions

- Data in good agreement with models
 - Shadowing: **GKZ**
 - Saturation : **CCKT**
- Xe-Xe data well described by the forward neutrons generator in UPC ($n_0^0 n$)
[Broz et. al.: CPC 253 (2020) 107181]



Photoproduction Cross Section vs. Atomic Number

- Dependence of the atomic number (A) on ρ^0 photoproduction cross section at $W_{\gamma p} = 65$ GeV is consistent with power-law behavior $\sigma(A) = \sigma_0 A^\alpha$ with a slope of $\alpha = 0.96 \pm 0.02$.
- The slope found in data is significantly different from a purely coherent process expectation \rightarrow shadowing effect



High Mass Dipion Photoproduction

- Observation of resonance-like structure in coherent $\pi^+\pi^-$ mass

- Mass: $1725 \pm 17 \text{ MeV}/c^2$

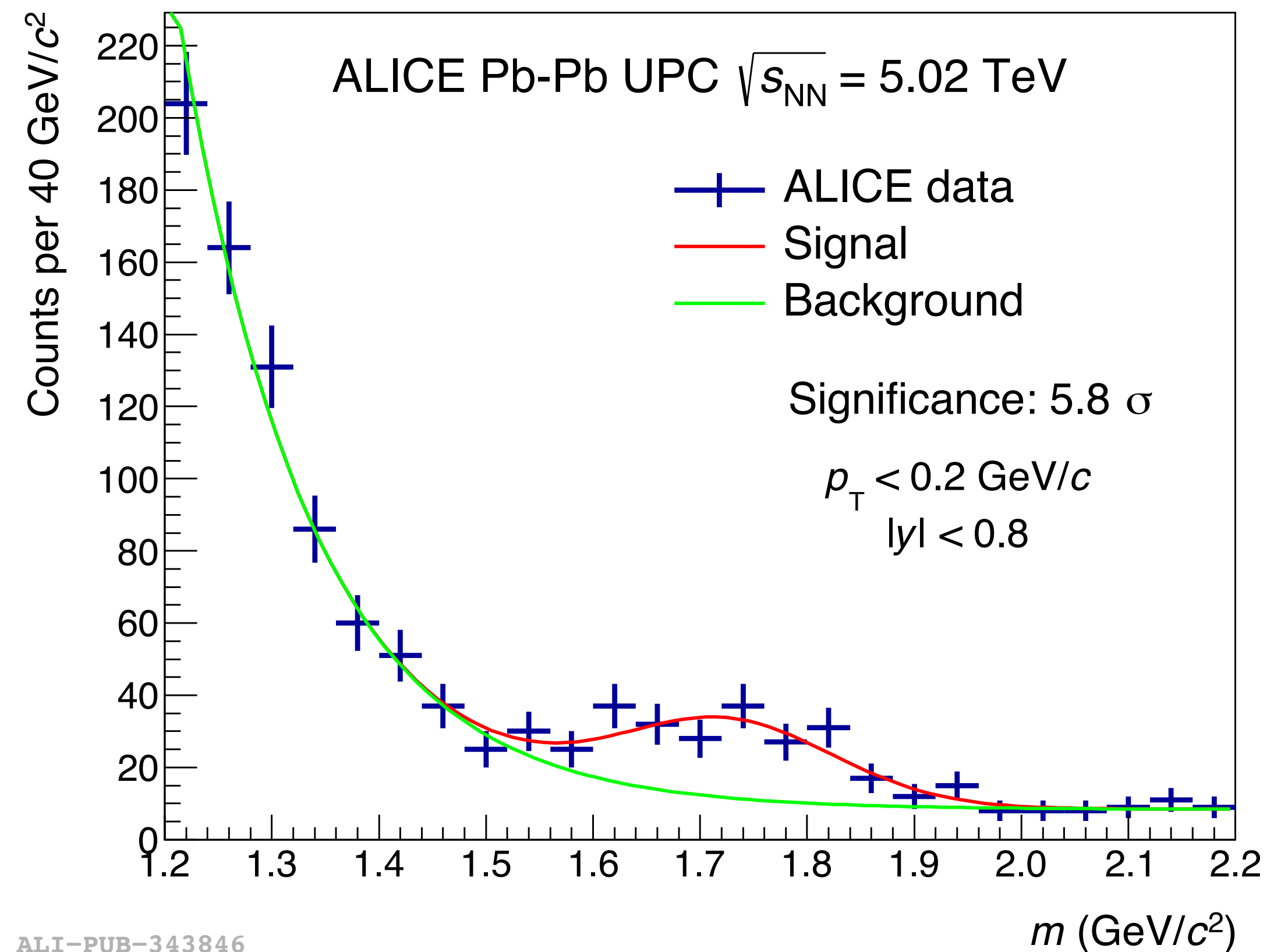
- Width: $143 \pm 21 \text{ MeV}/c^2$

- Resonance consistent with $\rho_3(1690)$ listed in PDG

- $J^{PC} = 3^{--}$

- Observed in coherent-production process

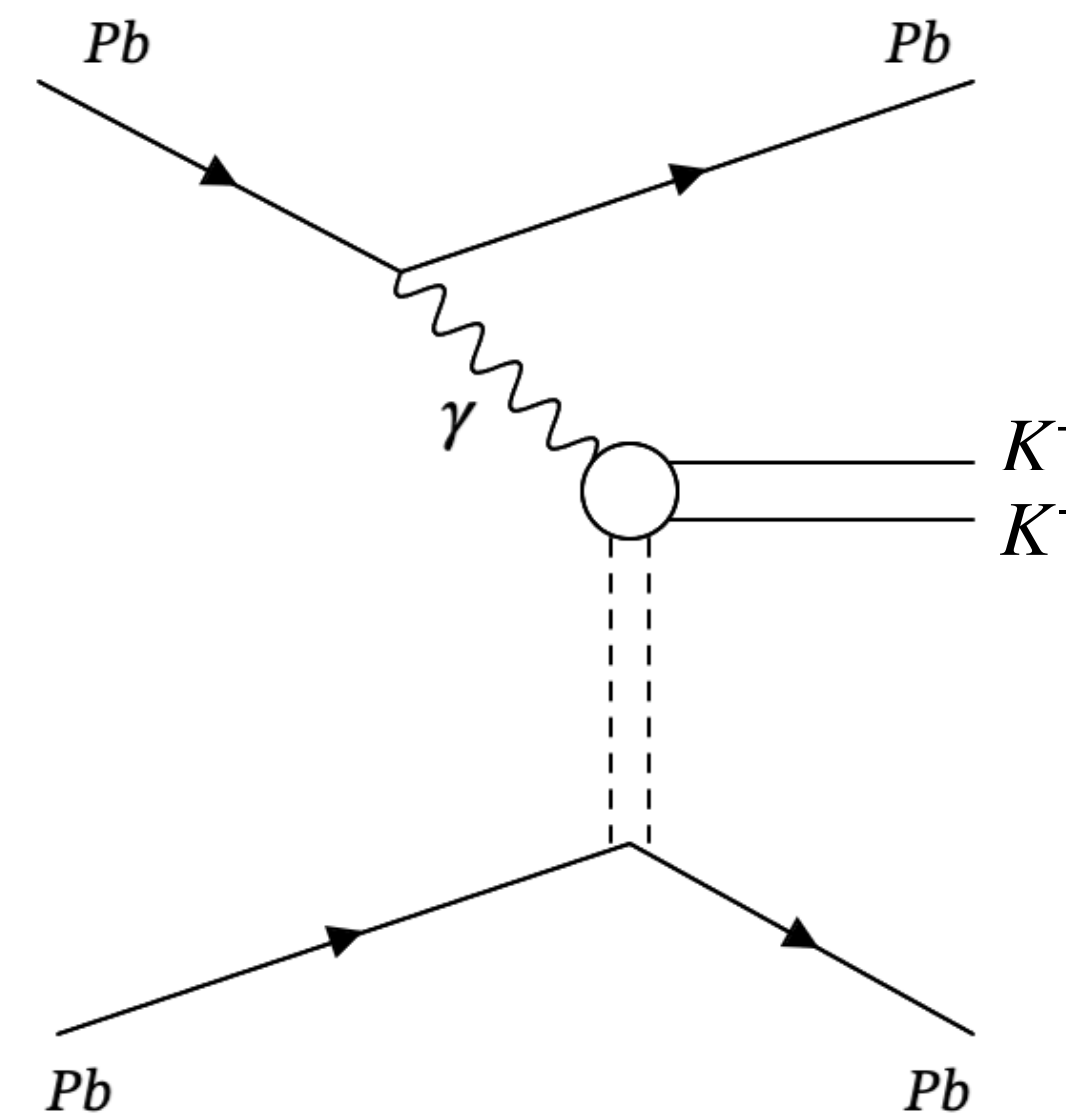
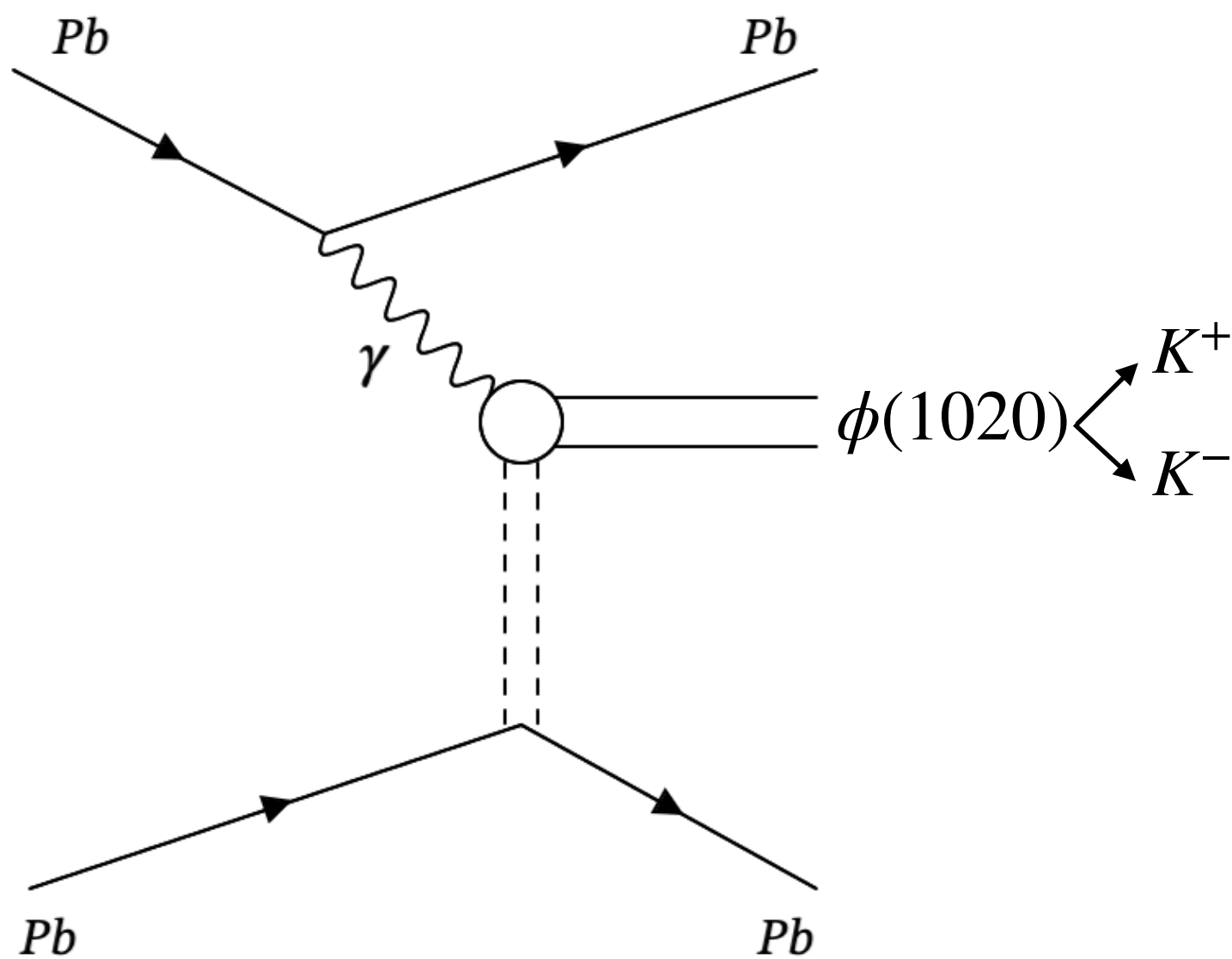
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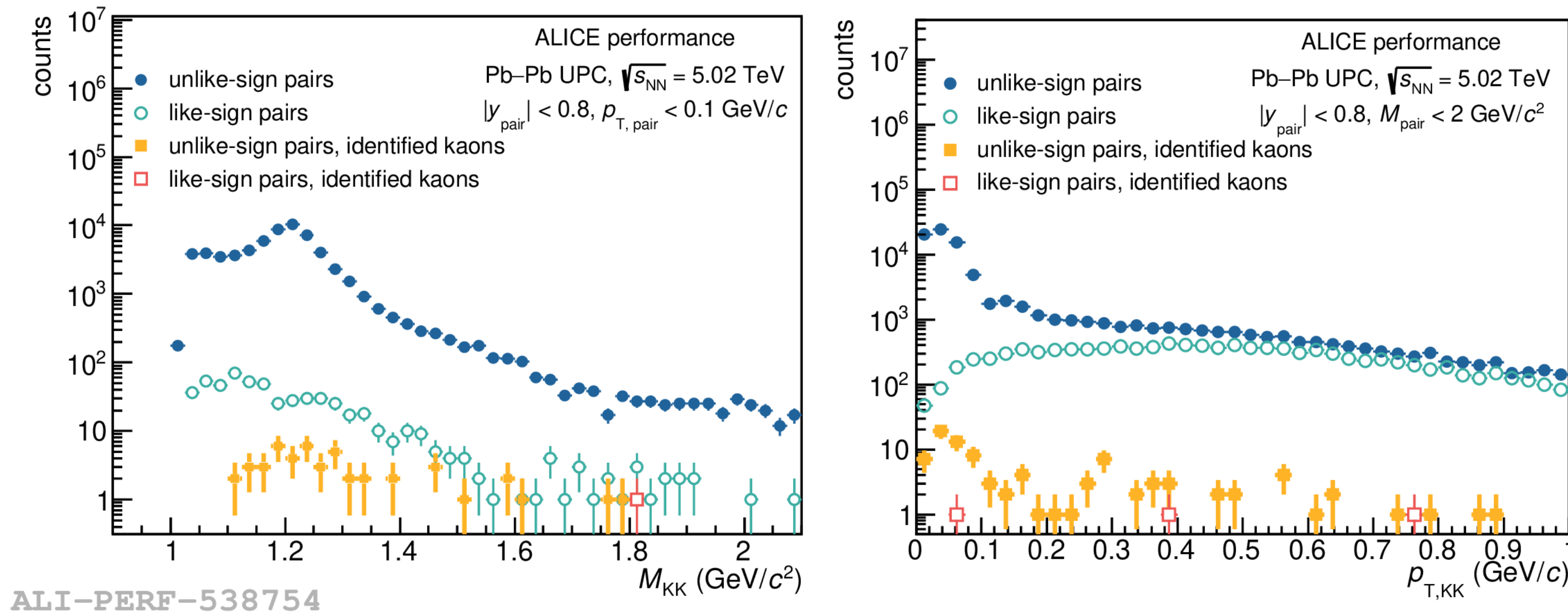
Dikaon Photoproduction in UPC

- First look into dikaon photoproduction in UPC
- Very challenging signal, competes with the background from the dipion final state
- Study exclusive K^+K^- events in UPC, produced through $\phi(1020)$ decay or direct production
- Similar event selection and data runs as the ALICE dipion analysis [*JHEP* 06 (2020) 35]



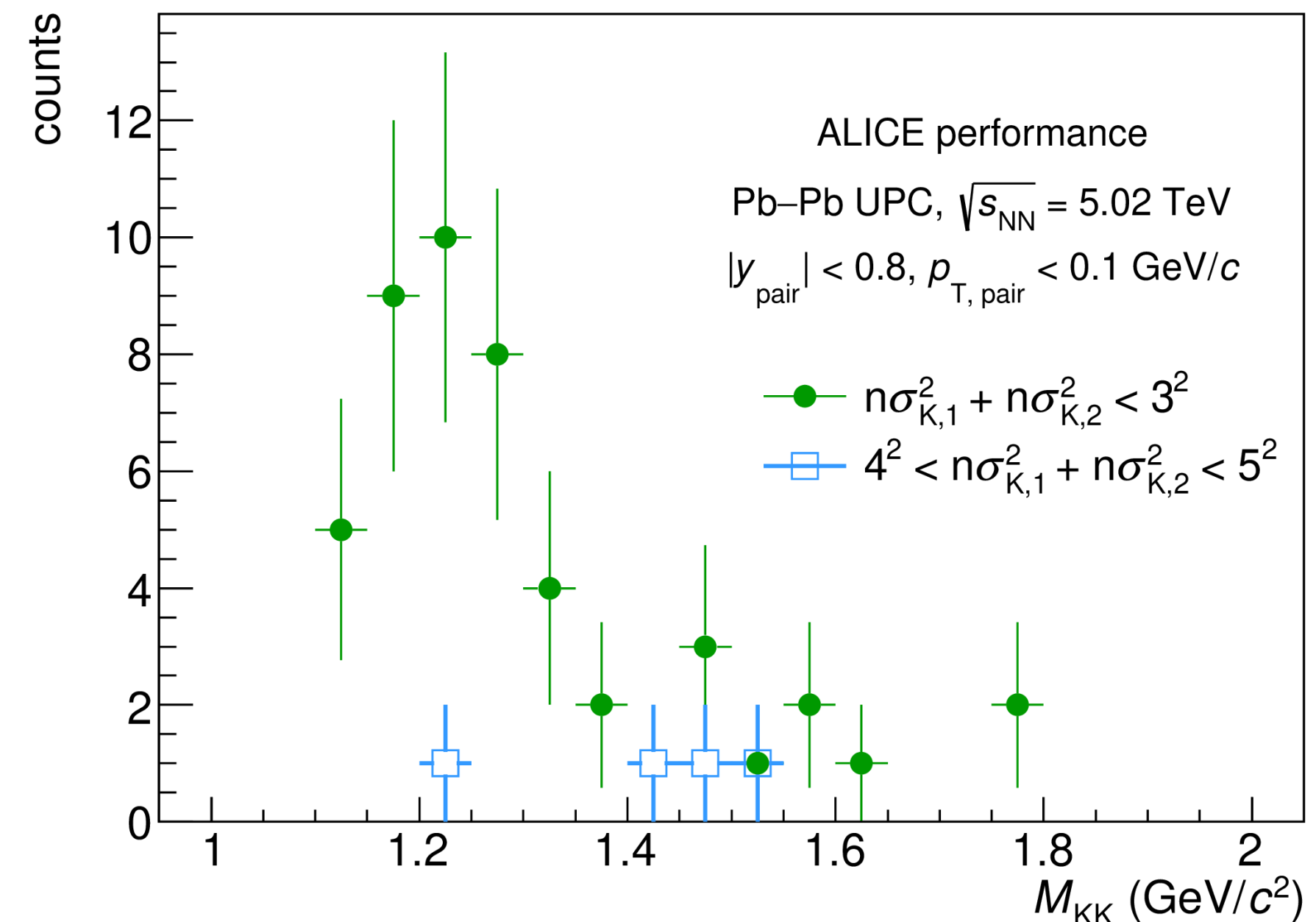
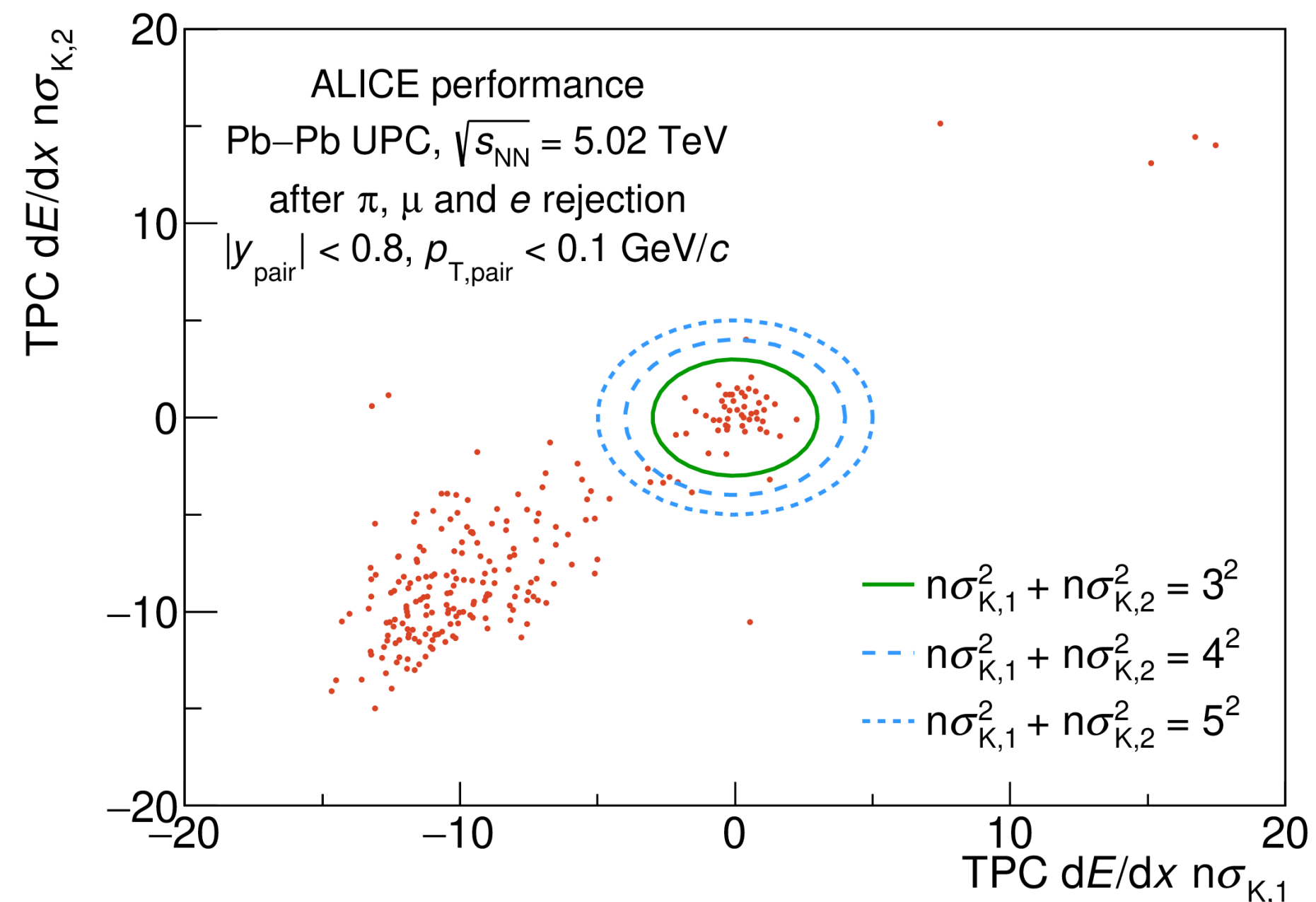
High Mass Dikaon Photoproduction

- Characteristic coherent photoproduction at low pair transverse momenta $p_T < 0.1 \text{ GeV}/c$
- Continuum at high momenta corresponds to incoherent productions
- Pair tracks with Kaon mass hypothesis
 - Before kaon selection \rightarrow mis-identified $\rho(770)$ at $\sim 1.2 \text{ GeV}/c^2$
 - Very soft kaons \rightarrow suppressed $\phi(1020)$



Kaon Selection

- Rejecting π^\pm , μ^\pm , e^\pm contamination from both tracks using the TPC dE/dx defined in number of SD from the model ($n\sigma$)
 - $|n\sigma_{\pi^\pm}| > 2$
 - $|n\sigma_{\mu^\pm}| > 2$
 - $|n\sigma_{e^\pm}| > 2$
- Kaon selection $|n\sigma_{K^\pm}| < 3$ for both tracks \rightarrow clean K^+K^- pairs achieved in the mass range $[1.1, 1.4 \text{ GeV}/c^2]$



Summary

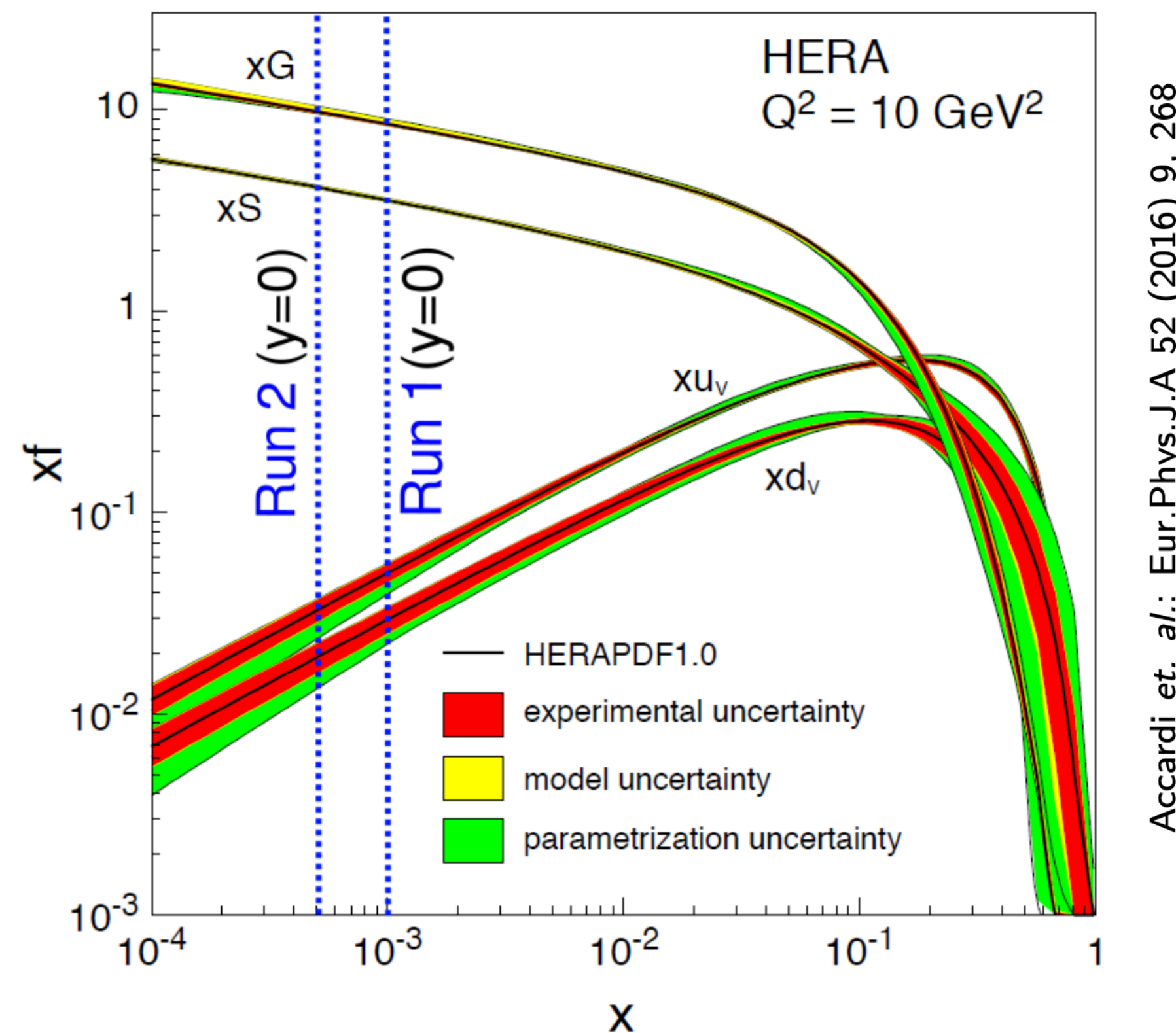
- Vector meson photoproduction in UPC is an important tool to probe the dynamics of photonuclear interaction and gluon distribution in nuclei
- Measured ρ^0 photoproduction cross section in Pb-Pb and for first time in Xe-Xe at UPC, at different neutron emission classes
- ρ^0 cross section well described by models based on shadowing and saturation
- Atomic number dependence on ρ^0 coherent photonuclear cross section signals important shadowing effects
- Resonance-like structure found at dipion mass of $1.7 \text{ GeV}/c^2$ and a width of about $140 \text{ MeV}/c^2$ in Pb-Pb UPC
- ALICE has great potential to study dikaon photoproduction in UPCs
- Expecting large increase in statistics and data collection efficiency with new ALICE data ($\sim \times 13$ in luminosity)

Thank you

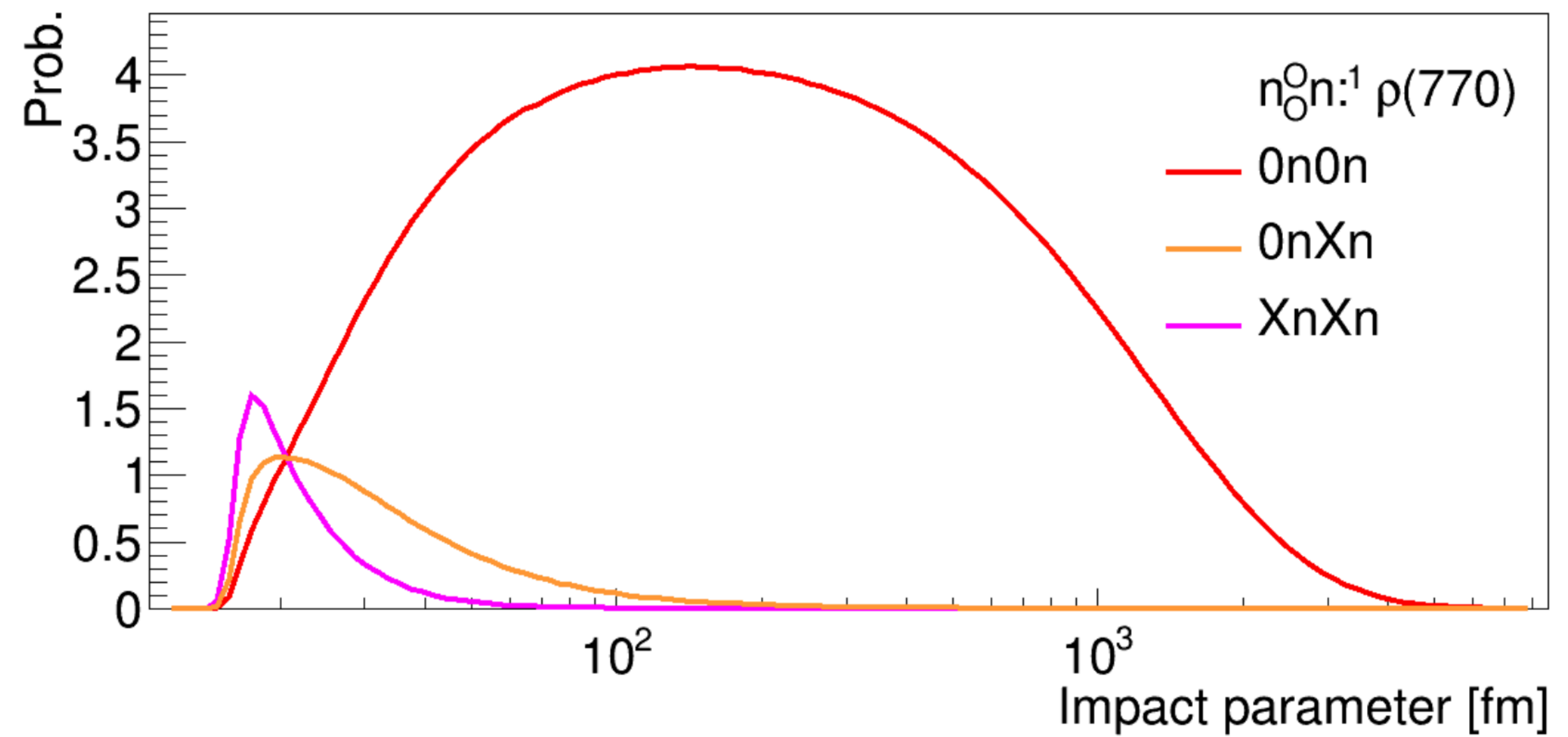
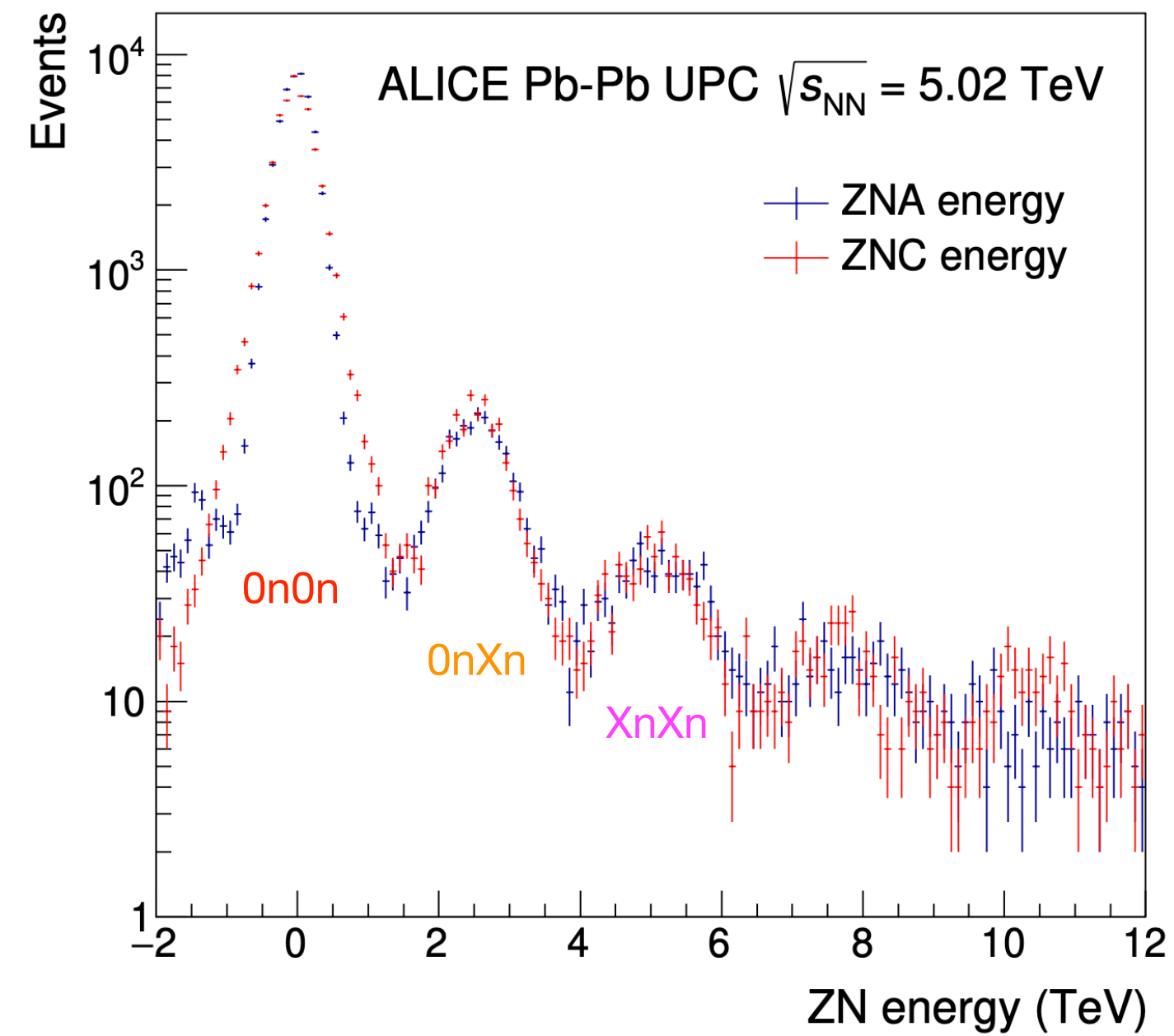
VM cross section vs. nuclear gluon distribution

- The cross section for the exclusive elastic photoproduction of a vector meson V on nucleon A

$$\left. \frac{d\sigma^{\gamma A \rightarrow VA}}{dt} \right|_{t=0} = \zeta_V \frac{16\pi^3 \alpha_s^2 \Gamma_{ee}}{3\alpha_{em} M_V^5} [xg_A(x, Q^2)]^2$$



Neutron emission vs. impact parameter



¹Broz et. al.: CPC 253 (2020) 107181

Models description

- **GKZ** : VDM + Gribov-Glauber model of nuclear shadowing accounting for photon fluctuations into intermediate diffractive states, [V. Guzey, E. Kryshen and M. Zhalov, *Phys. Rev. C*93 (2016) 055206]
- **CCKT**: colour-dipole model + gluon “hot spots” in the structure of the nucleon in the transverse plane + Glauber model for nuclear effects, [J. Cepila, J. G. Contreras, M. Krelina, and J. Tapia Takaki, *Nucl. Phys. B*934 (2018) 330–340]
- **GMMNS**: Iancu-Itakura-Munier (IIM) approach for gluon saturation + colour-dipole model, [Goncalves, Machado, Morerira, Navarra and dos Santos, *Phys. Rev. D*96 (2017) 094027]
- **STARLight**: $\gamma + p \rightarrow VM + p$ cross section + the optical theorem + Glauber-like eikonal formalism, [S. Klein, J. Nystrand et al. *Comp. Phys. Comm.* 212 (2017) 258]

