



[arXiv:2311.11792 \[nucl-ex\]](https://arxiv.org/abs/2311.11792)

K⁺K⁻ photoproduction in ultra-peripheral Pb—Pb collisions with ALICE

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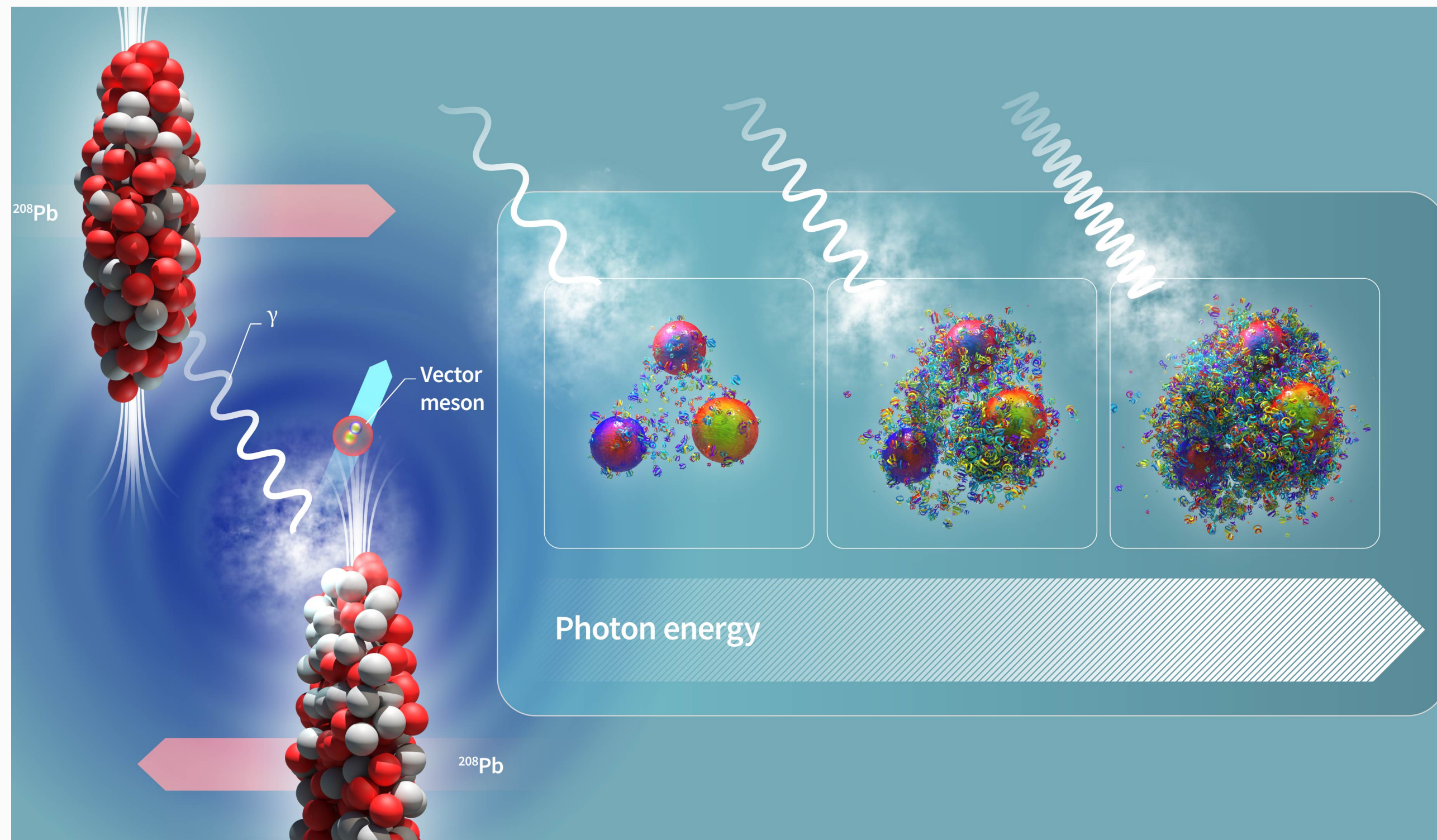
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Vector meson photoproduction in ultra-peripheral collisions



- EM field from ultra-relativistic ions: a beam of quasireal photons (intensity $\approx Z^2$)
- Photon energy frontier: up to ~ 500 TeV in target frame at the LHC energies
- **Ultra-peripheral collisions (UPC):** collisions with an impact parameter greater than the sum of the radii of the nuclei in which hadronic interactions are strongly suppressed
- **Vector meson photoproduction:** photon fluctuates to a dipole which then elastically scatters off the nucleus, emerging as vector meson
- Light vector mesons: sensitive to nuclear shadowing effects and to the approach to the black-disc limit of QCD at a semi-hard scale

Exclusive K^+K^- photoproduction

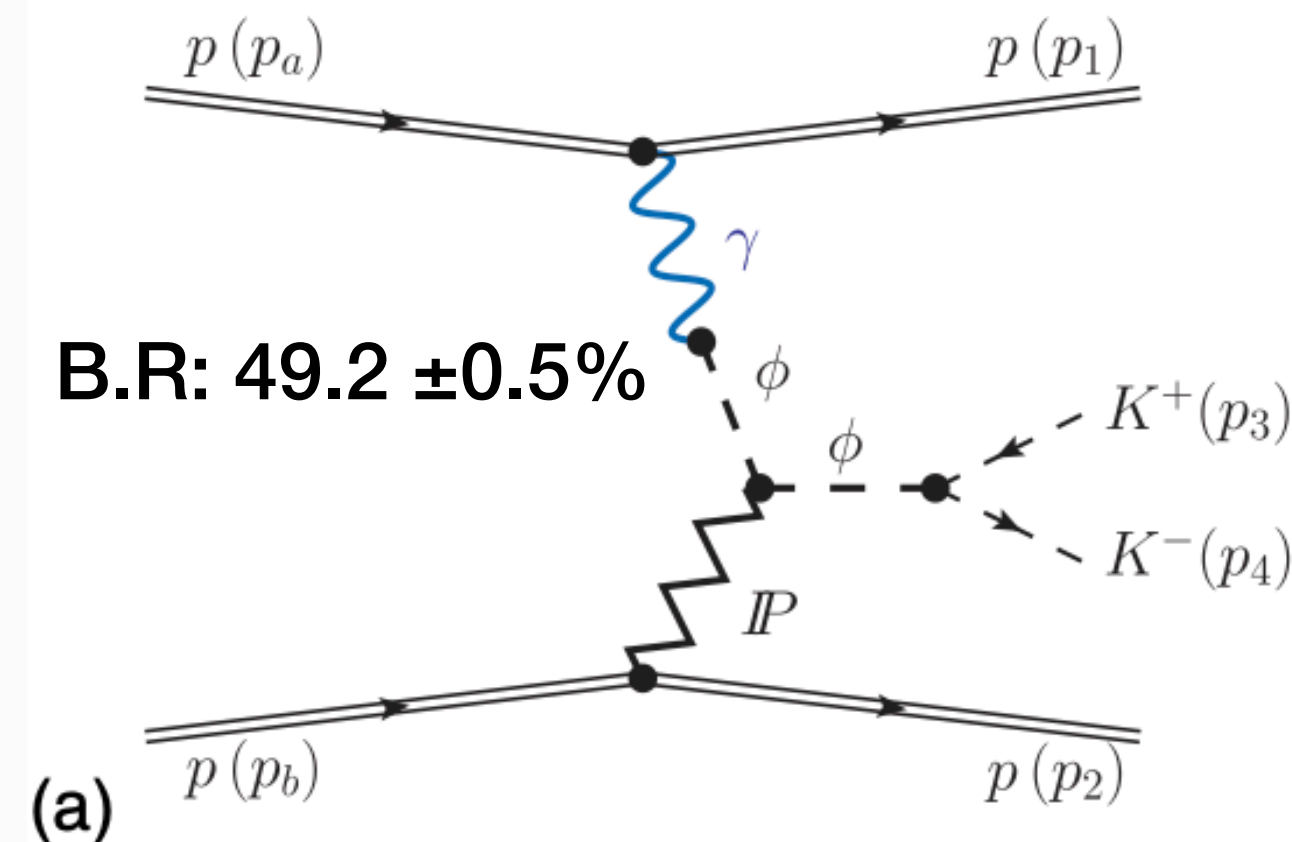
- Different physics processes are involved, which cannot be distinguished from and interfere
- Assumption: Cross section of exclusive K^+K^- photoproduction can be described by Söding formula which describes $\rho(770) \rightarrow \pi^+\pi^-$ and direct $\pi^+\pi^-$ production

$$\frac{d\sigma}{dM_{KK}} = \left| A_\phi \frac{\sqrt{M_{KK} M_\phi \Gamma_\phi}}{M_{KK}^2 - M_\phi^2 + i M_\phi \Gamma_\phi} + B_{KK} \right|^2 \quad \text{where} \quad \Gamma_\phi = \Gamma_0 \frac{M_K}{M_{KK}} \left(\frac{M_{KK}^2 - 4M_K^2}{M_\phi^2 - 4M_K^2} \right)^{3/2}$$

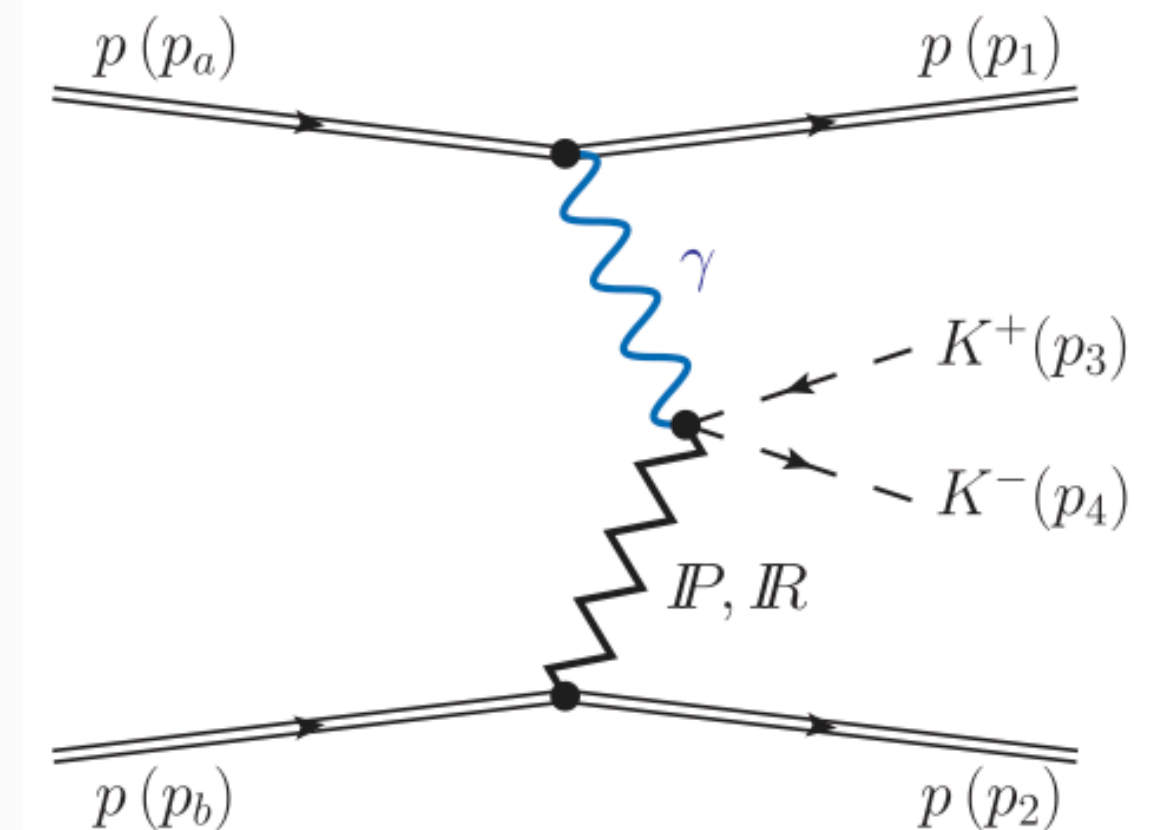
mass dependent width and M_K is the kaon mass, while A_ϕ and B_{KK} are the amplitudes for $\phi(1020) \rightarrow K^+K^-$ and direct K^+K^- production

- Useful tool to access couplings of a $\phi(1020)$ meson and a K^+K^- pair with a photon and a nucleus at extremely high energies

$\phi(1020)$ photoproduction



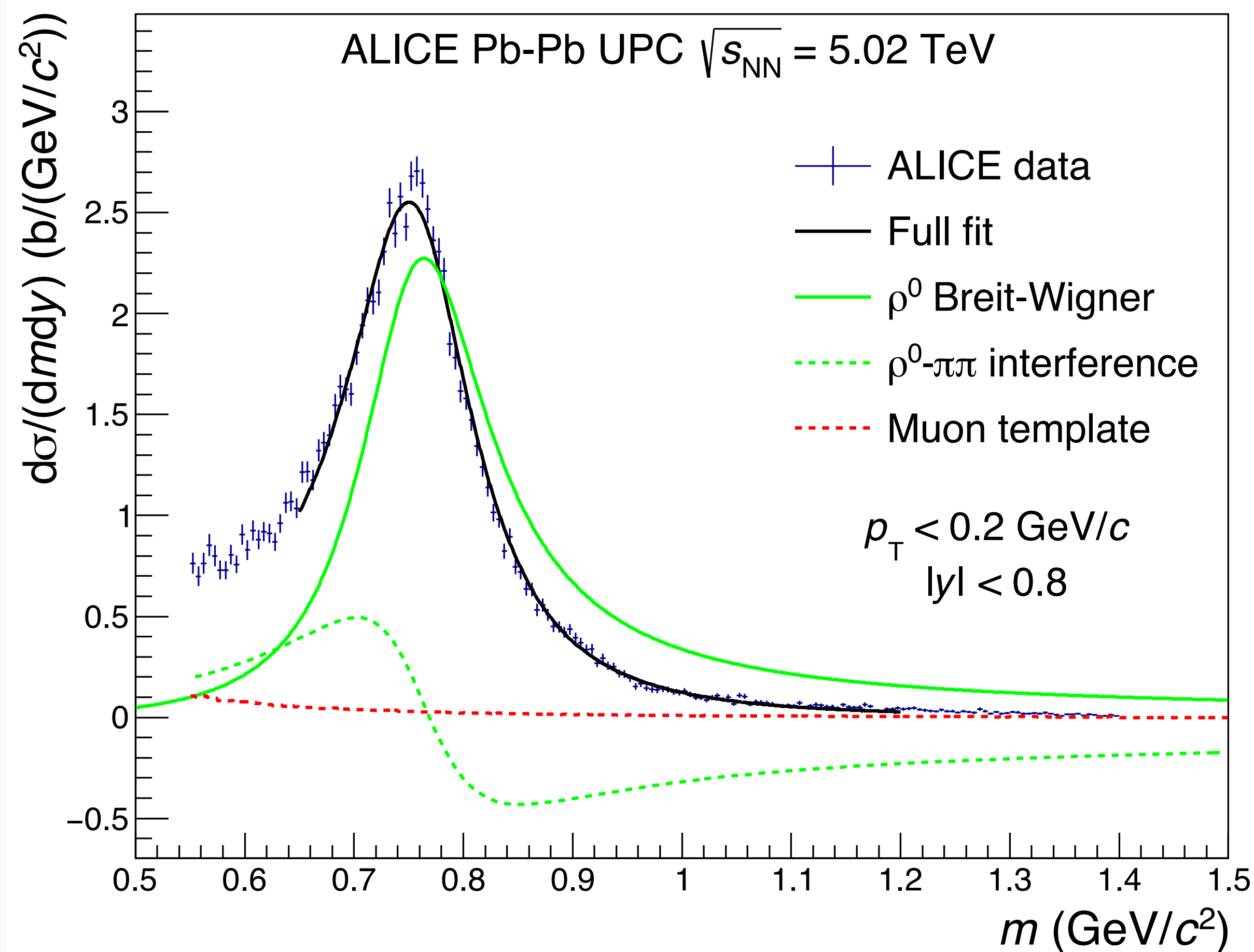
Nonresonant continuum (Drell-Söding) production



Diagrams from O. Nachtmann et. al., PRD 98, 014001 (2018)

Lessons from exclusive $\pi^+\pi^-$ photoproduction

ALICE Collaboration, JHEP 06 (2020) 035



- Multiple measurements from LHC and RHIC in UPCs:

- Interference of $\rho(770) \rightarrow \pi\pi$ and continuum of direct $\pi\pi$

Contribution from continuum, $|B/A|$:

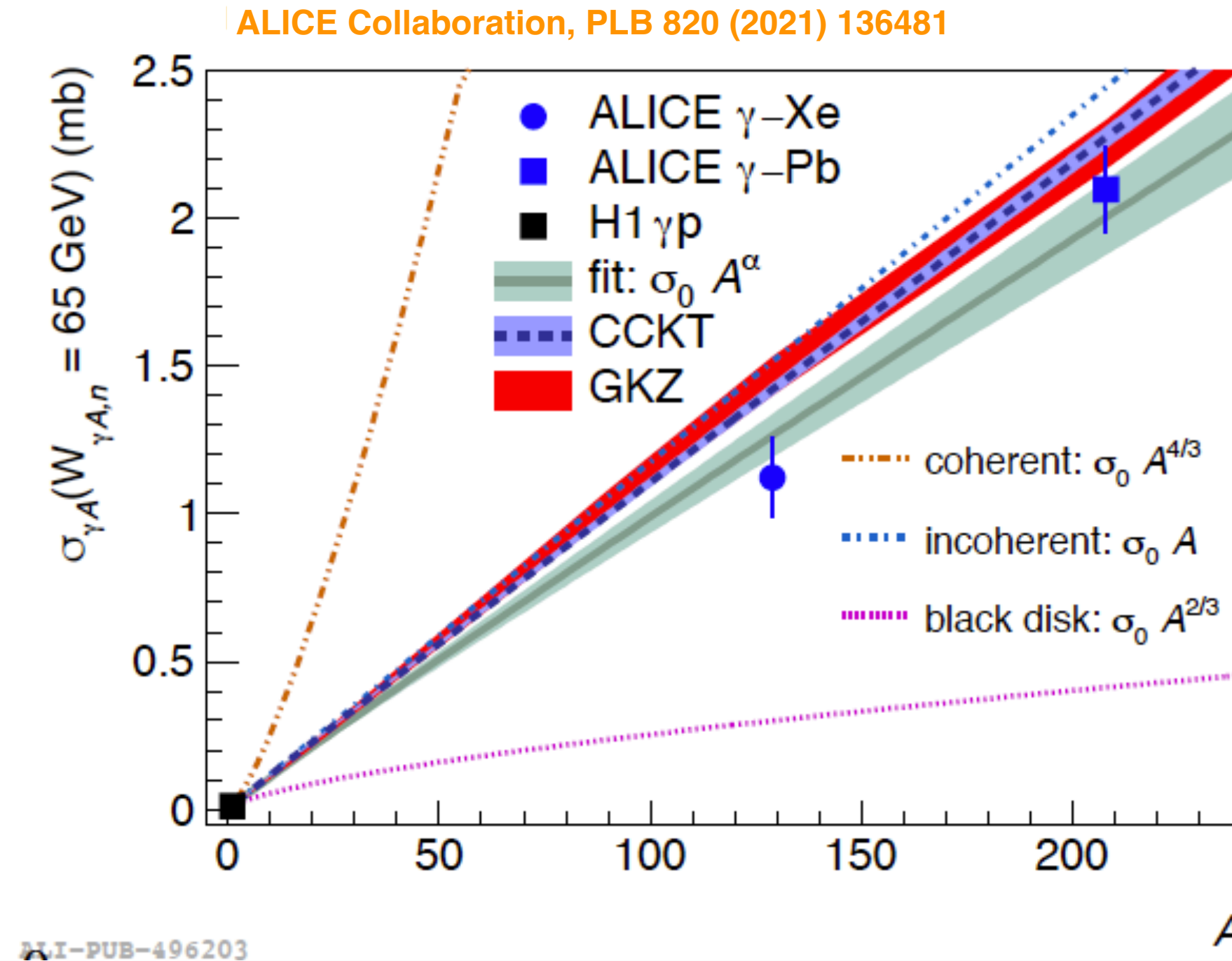
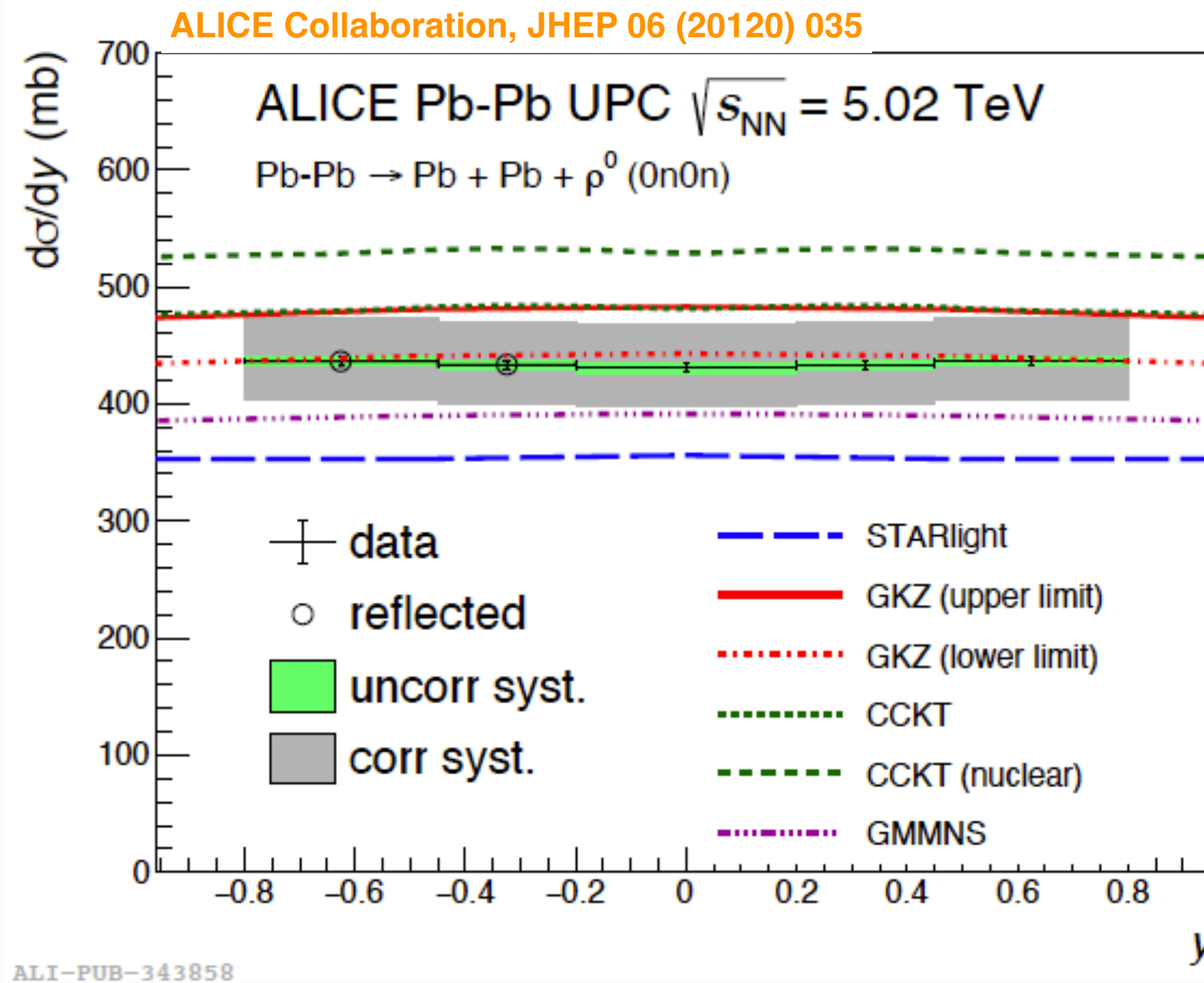
- constant as a function of rapidity, collision energies (5.02 TeV vs. 2.76 TeV) and different neutron classes in current precision seen in

ALICE

STAR Collaboration, PRC.96.054904

- discrepancy between ALICE and STAR :
 ~30% smaller than Au-Au UPCs at
 $\sqrt{s_{NN}} = 200$ GeV. Is it sensitive to the kinematics of interaction or type of target?

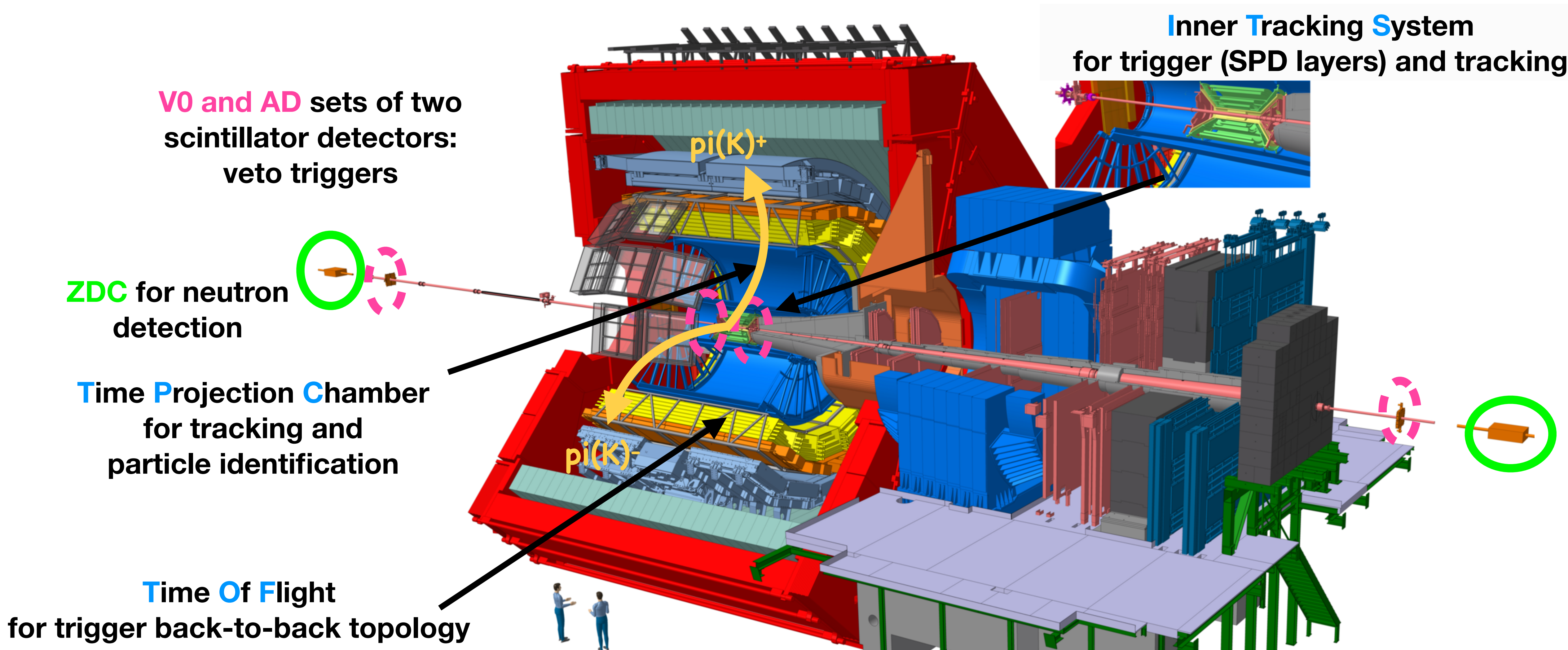
Lessons from exclusive $\pi^+\pi^-$ photoproduction



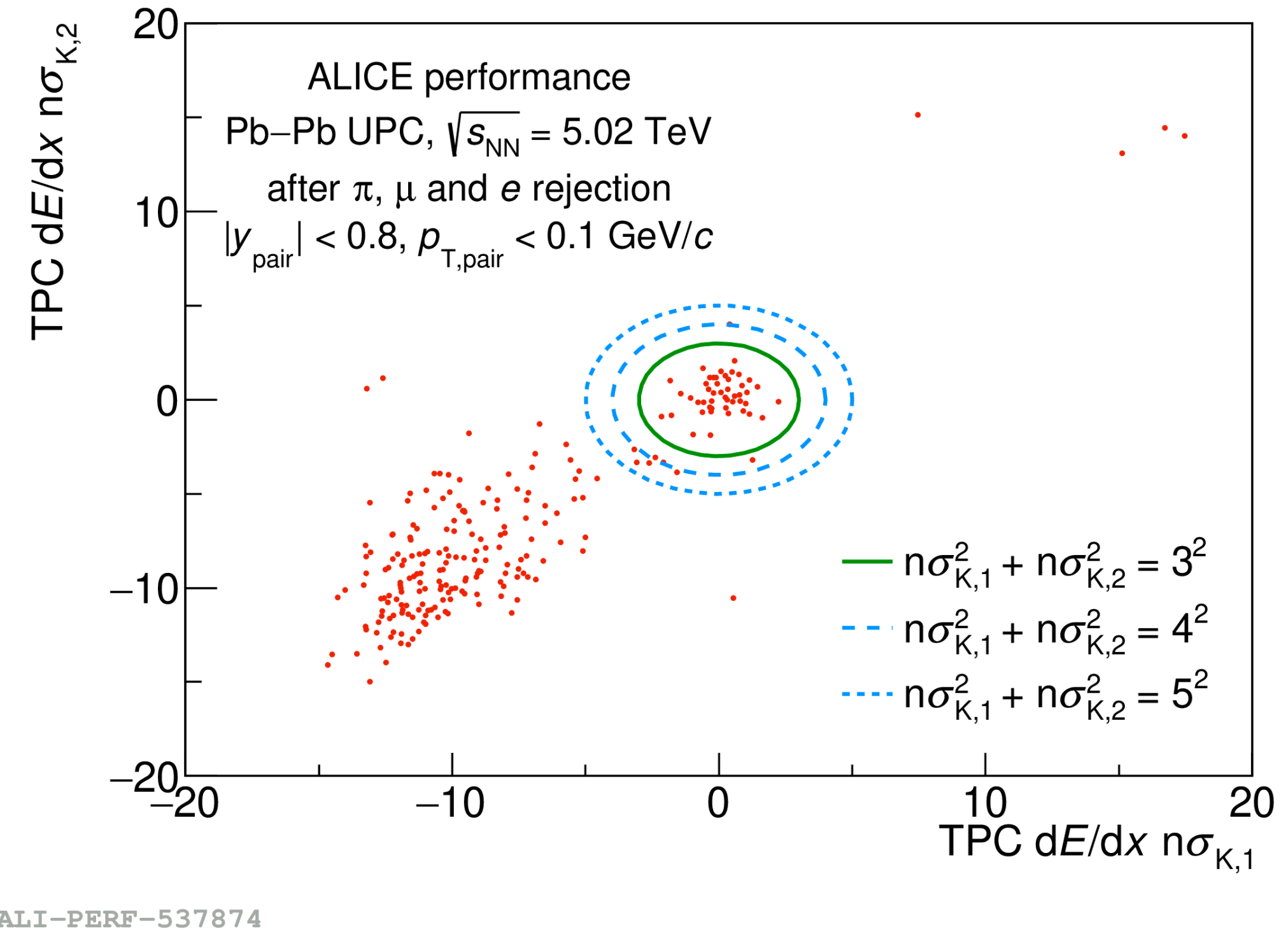
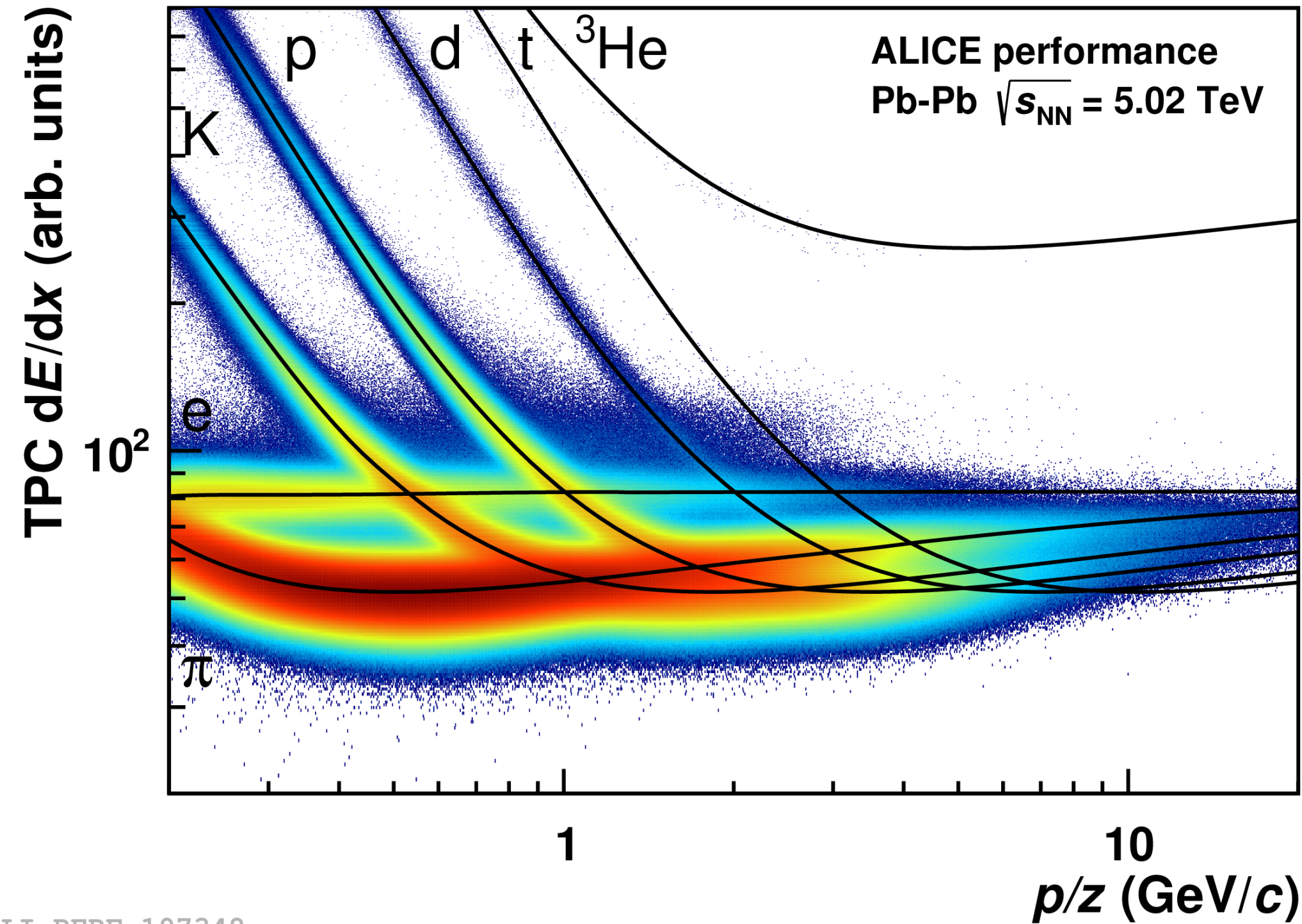
- Measured cross section of coherent photoproduction shows good agreement with model predictions for different neutron emission classes
 - similarly favored in colour-dipole approach with gluon saturation/hot spots or Gribov-Glauber shadowing approach
- Atomic number (A) dependent γA cross section, $\sigma(\gamma A \rightarrow \rho^0 A) \propto A^\alpha$ with $\alpha = 0.96 \pm 0.02$
 - substantial nuclear effects, yet considerably above black-disk limit

ALICE as photon-hadron collider experiment

- Trigger events having two back-to-back tracks in the transverse plane in central barrel

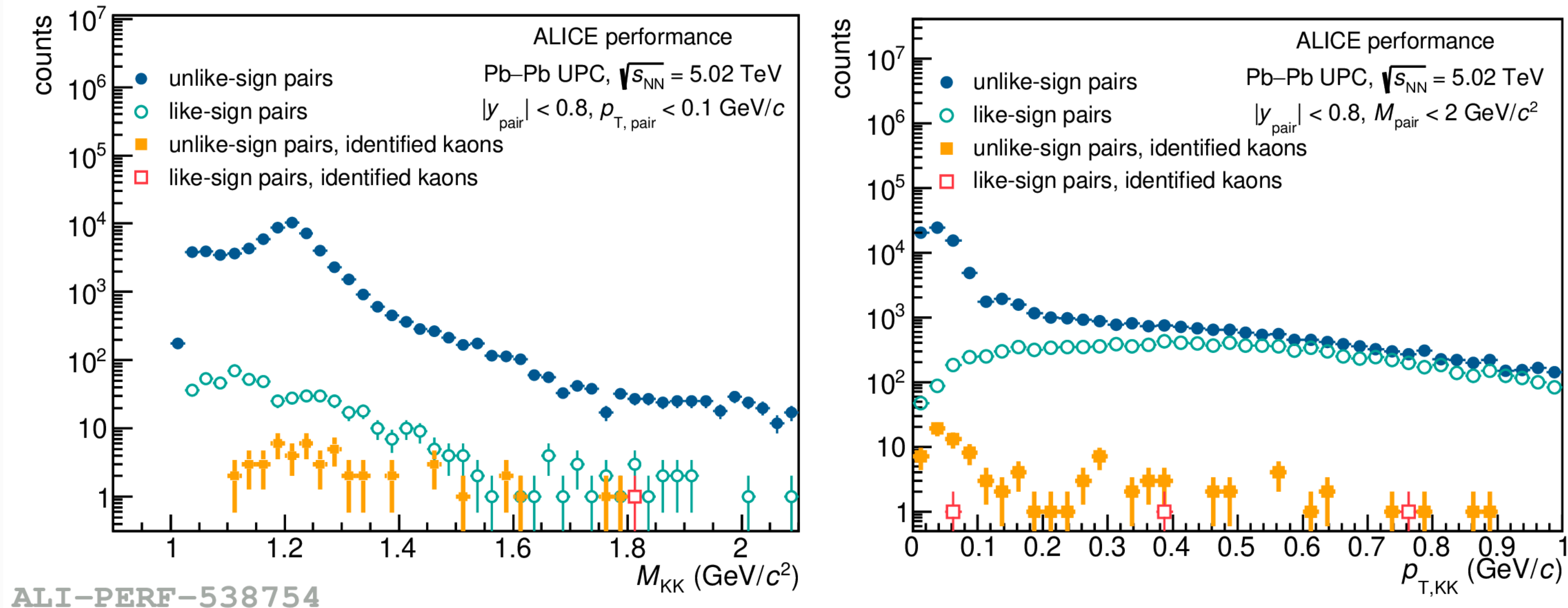


Kaon identification based on TPC signal



- Kaon identification with specific energy loss measured in TPC: stringent PID requirements to reject pion, muon and electron
- Contamination from misidentified particles estimated based on the 2-dimensional TPC dE/dx $n\sigma_K$ distribution \rightarrow negligible background pairs in $1.1 < M_{KK} < 1.4$ GeV/c²

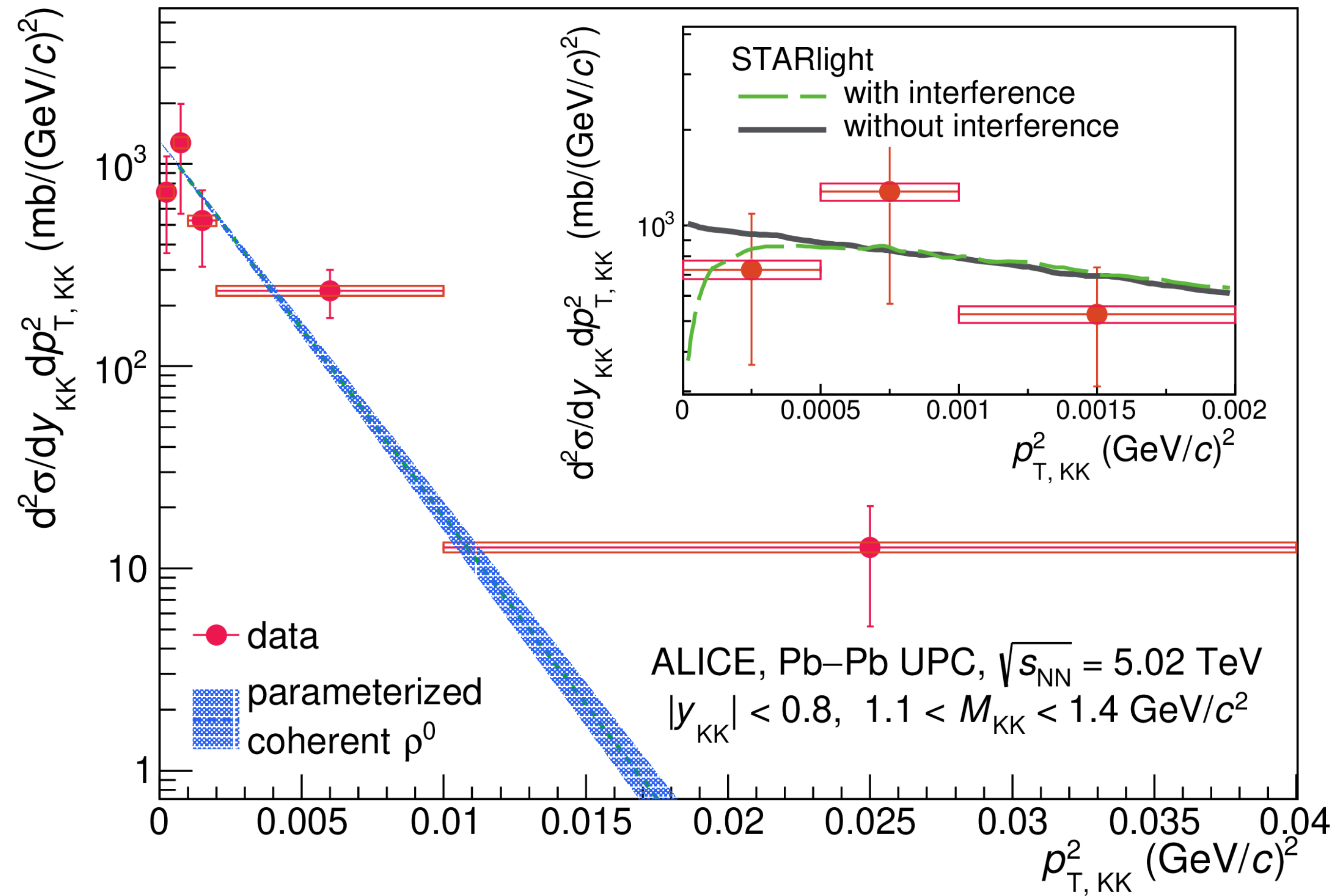
Raw yield of K^+K^- candidates



- Small fraction of like-sign pairs: little (negligible) combinatorial background pairs in $p_{T, KK} < 0.1$ GeV/c in $1.1 < M_{KK} < 1.4$ GeV/c²
- Rise of K^+K^- raw yield at low $p_{T, KK}$ indicating coherent photoproduction

p_T^2 distribution of exclusive K^+K^- photoproduction

ALICE Collaboration, arXiv:2311.11792 [nucl-ex]

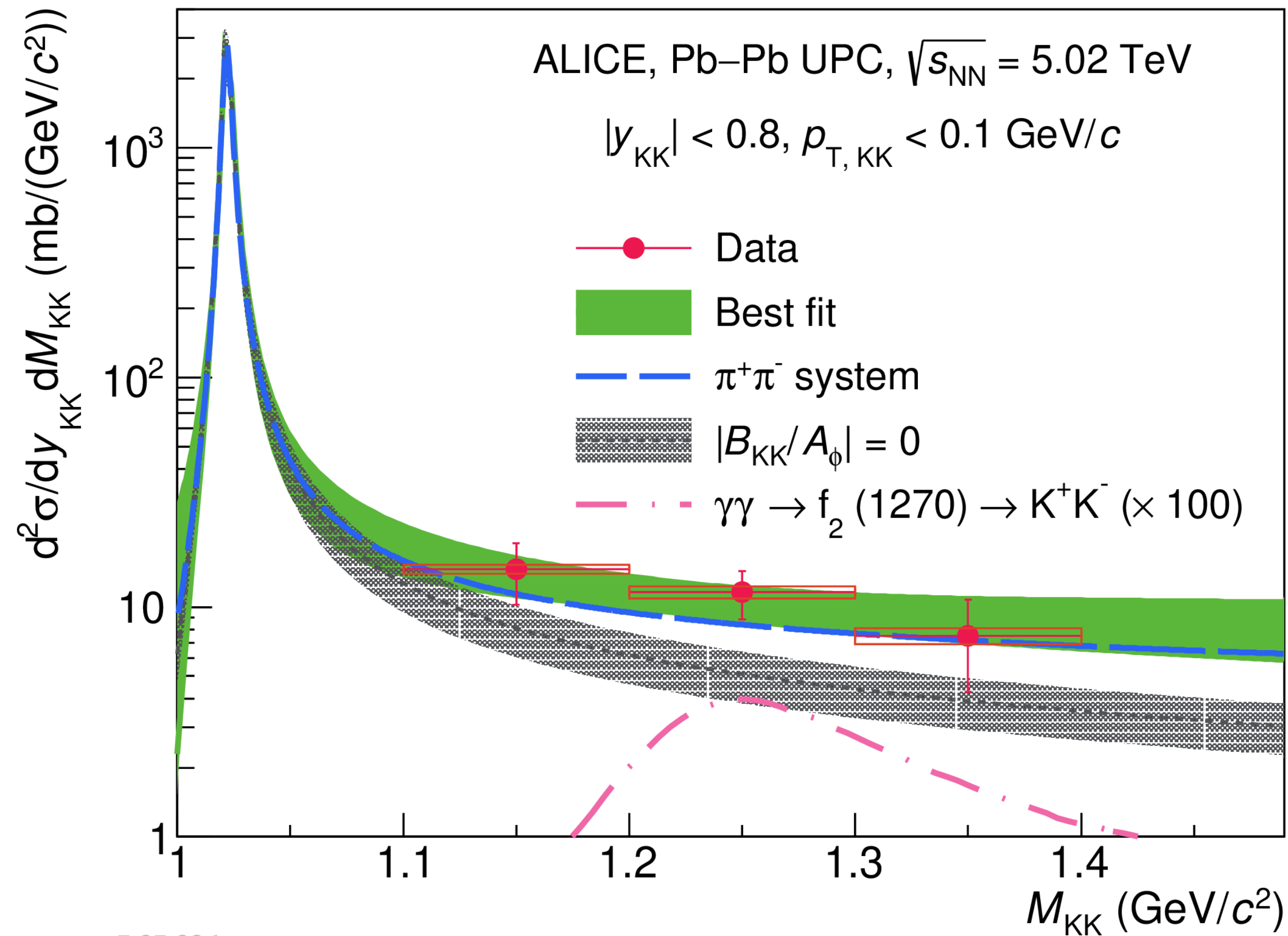


- Exclusive K^+K^- photoproduction as a function of $p_T^2 \approx |t|$
- Exponential function: $ae^{-b \times p_T^2}$ with slope parameter $b = 428 \pm 6(\text{stat.}) \pm 15(\text{syst.}) \text{ GeV}^{-2}$ taken from ALICE $\rho(770) \rightarrow \pi\pi$ measurement fairly well describes the data [ALICE Collaboration, JHEP 09 \(2015\) 095](#)
- The cross section at low p_T^2 seems in slight favor of photoproduction with destructive interference (as both nuclei can be either the photon source or scattering target)

ALI-PUB-565617

Invariant mass spectrum

ALICE Collaboration, [arXiv:2311.11792 \[nucl-ex\]](https://arxiv.org/abs/2311.11792)

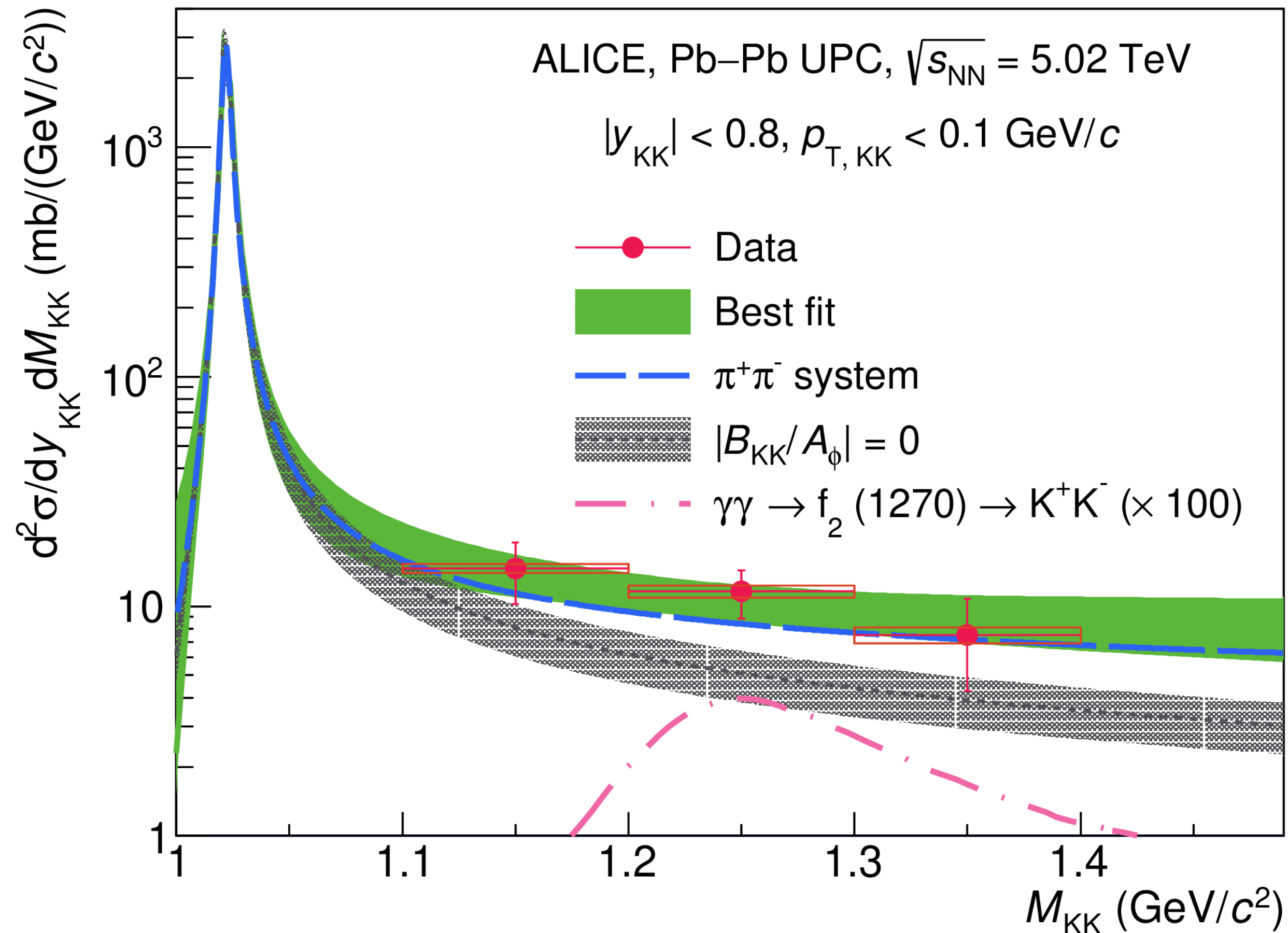


ALI-PUB-565621

- First measurement of coherent photoproduction of K^+K^- pairs in ultra-peripheral heavy-ion collisions
- Possible physics background of $\gamma\gamma \rightarrow X \rightarrow K^+K^-$ seems small: signal is likely the composition of $\phi(1020) \rightarrow K^+K^-$ and direct K^+K^-

Invariant mass spectrum

ALICE Collaboration, arXiv:2311.11792 [nucl-ex]



ALI-PUB-565621

- Söding formula has 3 free parameters:

$$\frac{d\sigma}{dM_{KK}} = \left| A_\phi \frac{\sqrt{M_{KK} M_\phi \Gamma_\phi}}{M_{KK}^2 - M_\phi^2 + i M_\phi \Gamma_\phi} + B_{KK} \right|^2$$

where $\Gamma_\phi = \Gamma_0 \frac{M_K}{M_{KK}} \left(\frac{M_{KK}^2 - 4M_K^2}{M_\phi^2 - 4M_K^2} \right)^{3/2}$

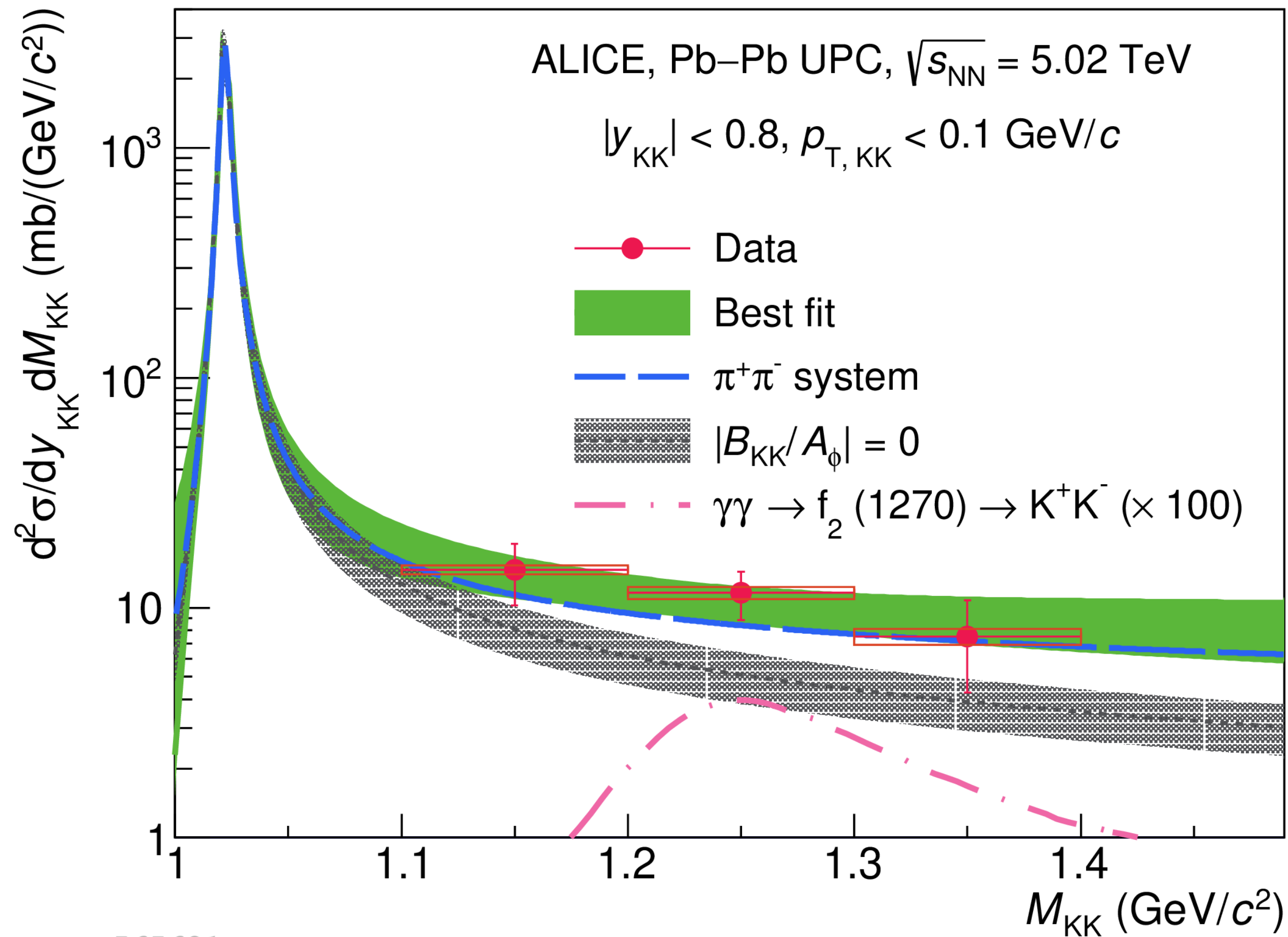
R. M. Egloff et al., PRL.43.657

ZEUS Collaboration Phys. Lett. B 377 (1996) 259–272

- ϕ meson cross section (fixed):
fixed target experiments + HERA
measurement + Glauber model
- $|B/A|$: ratio between non-resonant contribution
and $\phi \rightarrow KK$
- Φ : relative phase angle between non-resonant
contribution and $\phi \rightarrow KK$
- Best fit: fit data points with 2 free parameters,
 $|B/A|$ and Φ considering measured uncertainties

Invariant mass spectrum

ALICE Collaboration, arXiv:2311.11792 [nucl-ex]

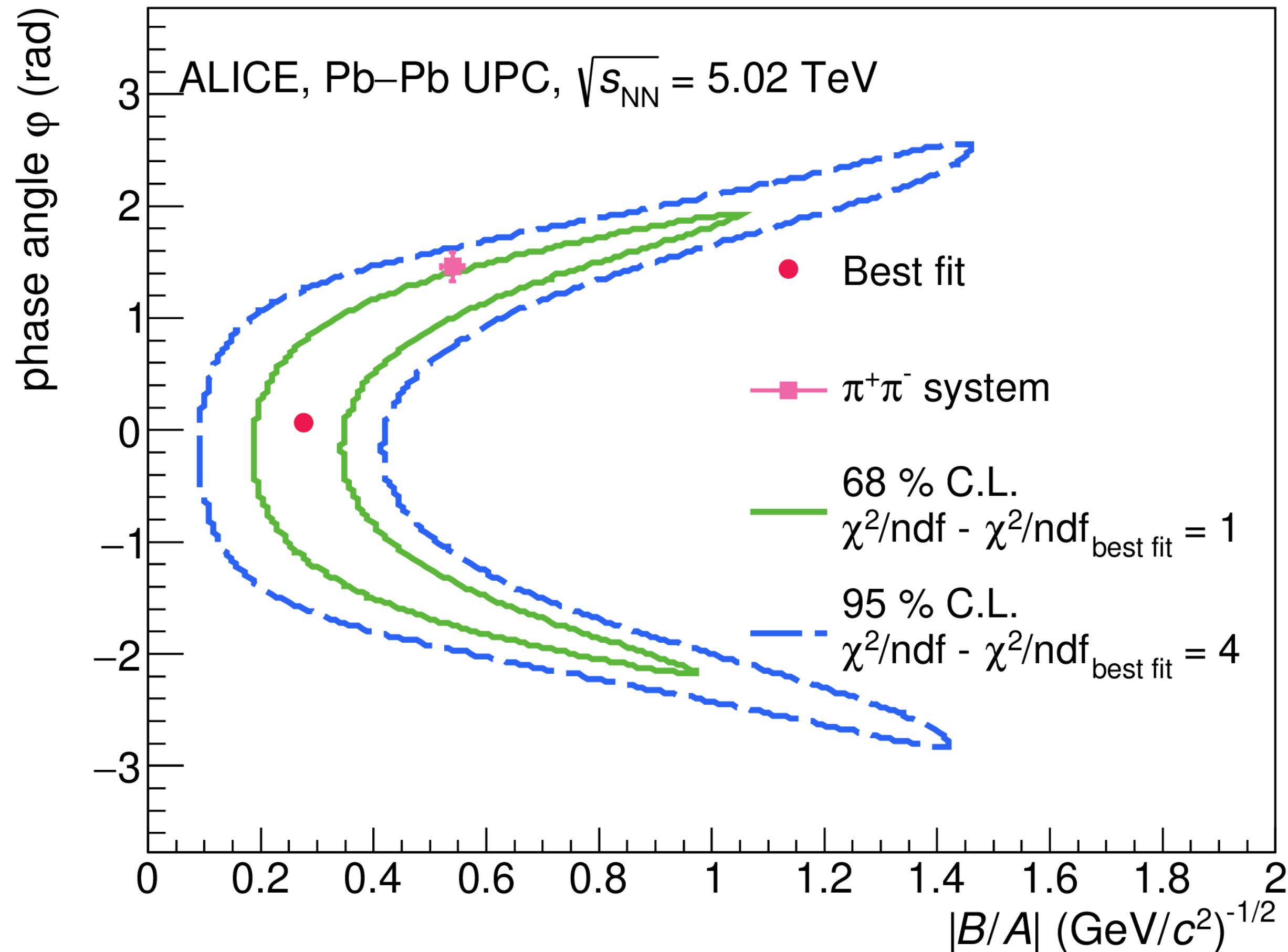


ALI-PUB-565621

- $|B/A|=0$:
 - Independent from phase angle Φ
 - Band reflects the 25% systematic uncertainty of $\phi(1020)$ cross section
 - More than 2 sigma away from the measurements, suggesting non-negligible non-resonant contribution
- $\pi\pi$ system:
 - All 3 parameters fixed from previous measurements:
 - ALICE Collaboration, JHEP 06 (2020) 035
 - $|B/A|$ from ALICE
 - STAR Collaboration, PRC.96.054904
 - Phase angle Φ from STAR
 - Lower edge of fit uncertainty

Uncertainty and confidence level

ALICE Collaboration, arXiv:2311.11792 [nucl-ex]



- χ^2/ndf scanned over $-\pi < \phi < \pi$ and $0 < |B/A| < 2$ to determine confidence level
- $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ contour as 68% and 95% confidence level
- As seen in invariant mass spectrum, the parameters are consistent with those in $\pi\pi$ system in 1σ

ALI-PUB-565625

Summary

- First measurement of coherent photoproduction of K^+K^- pairs in ultra-peripheral heavy-ion collisions
- Access the dynamics and couplings of a $\phi(1020)$ meson and a K^+K^- pair with a photon and a nucleus at high energies, as well as complimentary to exclusive $\pi^+\pi^-$ photoproduction
- The measured cross section for coherent photoproduction of K^+K^- in the mass range $1.1 < M_{KK} < 1.4 \text{ GeV}/c^2$ consistent with a mixture of $\phi(1020)$ and non-resonant K^+K^- photoproduction and their interference
- Ratio of each component and the relative phase angle between $\phi(1020)$ and non-resonant K^+K^- are similar to those seen for the $\rho(770)$ and direct $\pi^+\pi^-$ production

Backup