K+K- photoproduction in ultra-peripheral Pb–Pb collisions with ALICE

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Exclusive K^+K^- photoproduction

- Different physics processes are involved, which cannot be distinguished from and interfere

- Cross section of Exclusive K^+K^- ($\pi^+\pi^-$) photoproduction described by Söding formula

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

mass dependent width and M_K is the kaon mass, while A_ϕ and B_{KK} are the amplitudes for

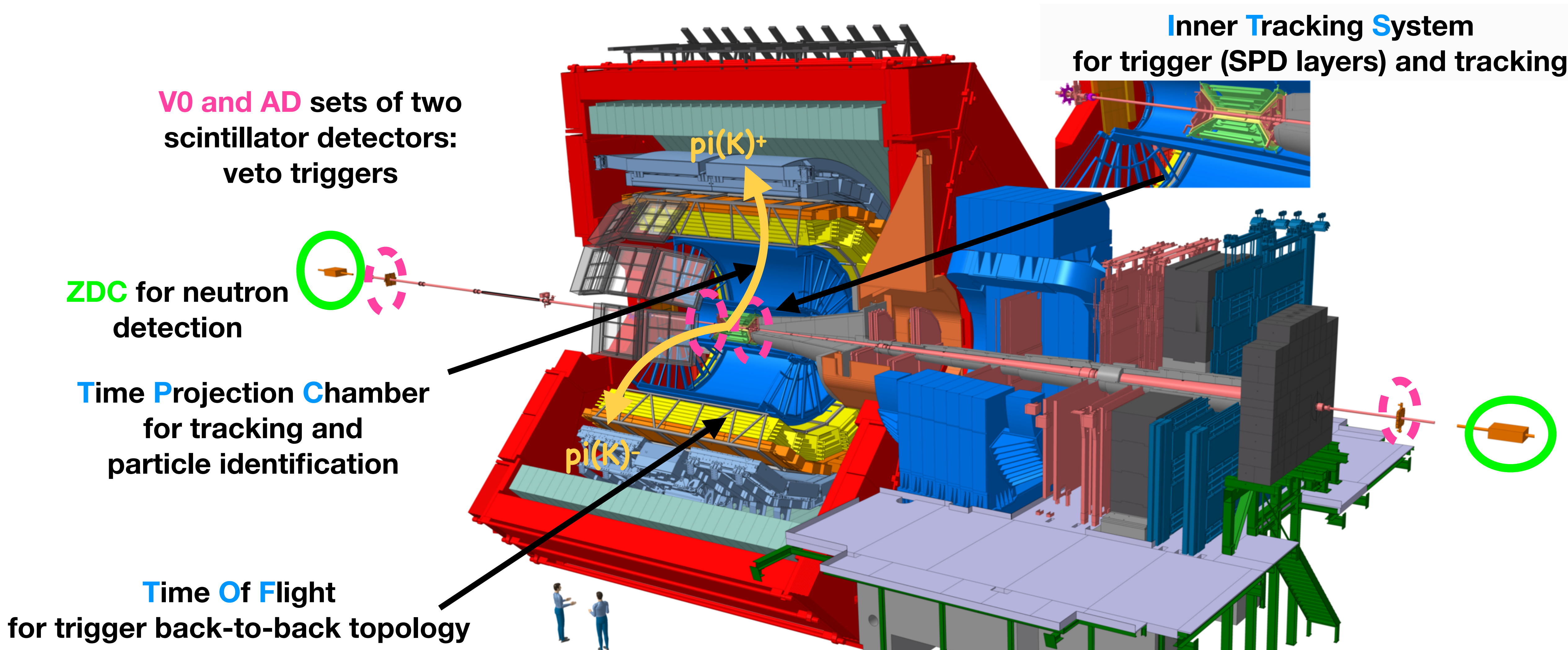$\phi(1020) \rightarrow K^+K^-$ and direct K^+K^- production

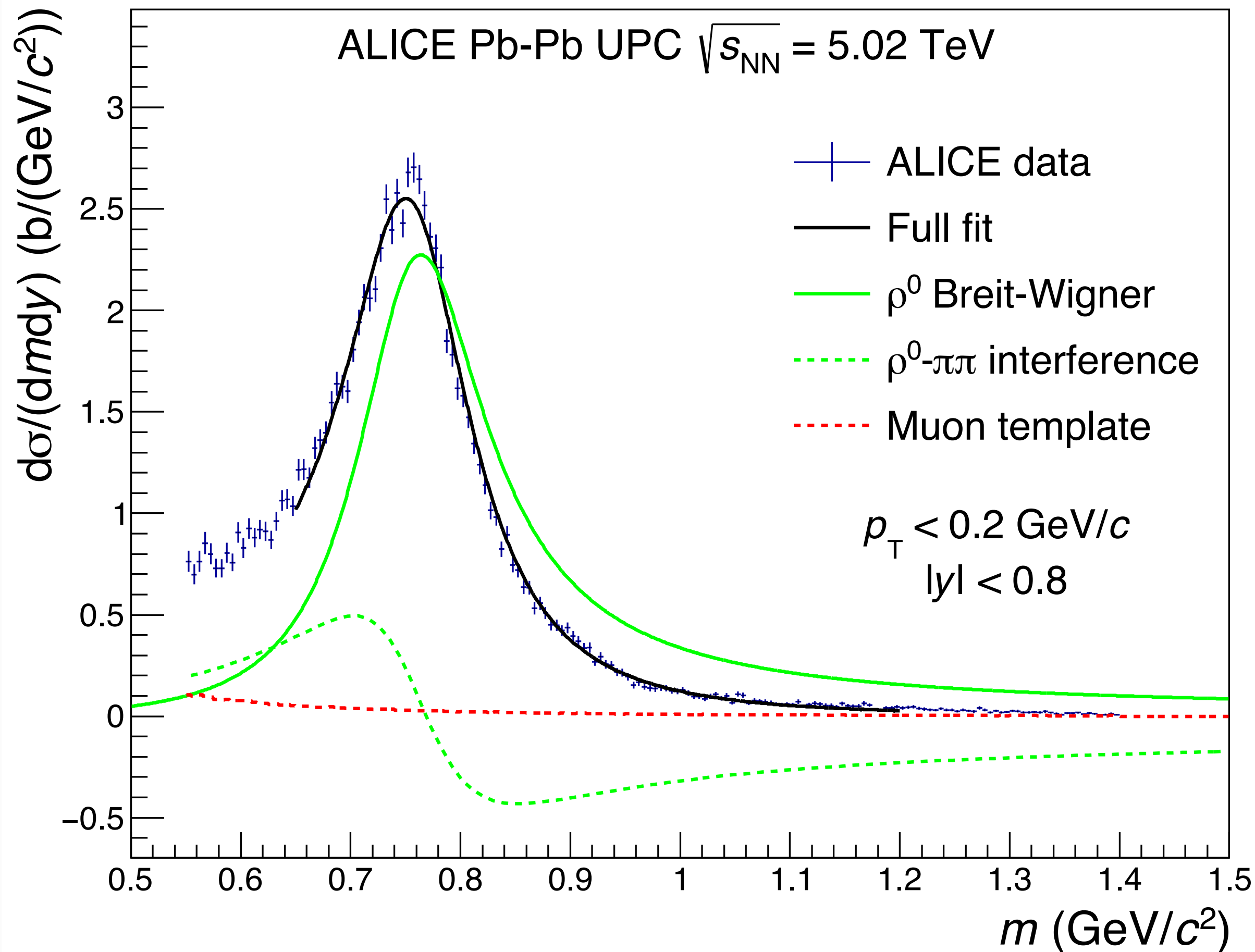**$\phi(1020)$ photoproduction**

Continuum of nonresonant (Drell-Söding)
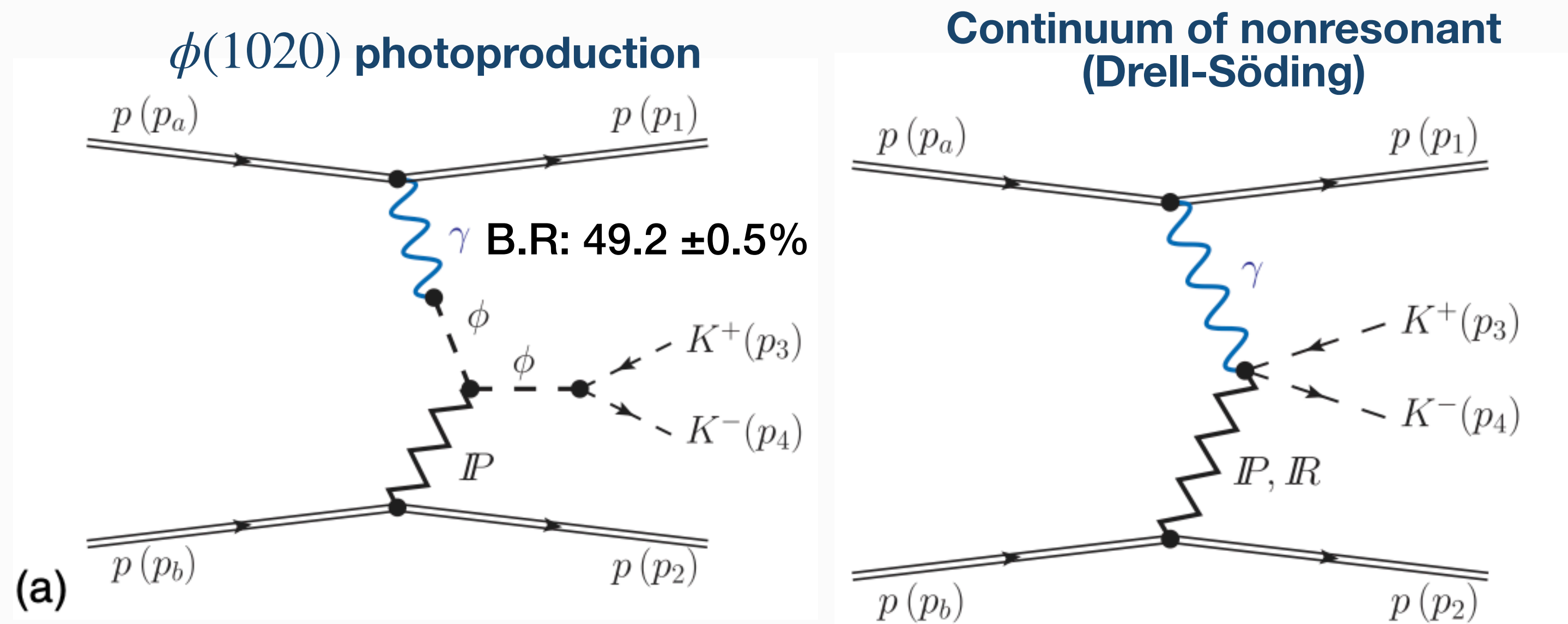
ALICE as photon-hadron collider experiment

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

Inner Tracking System
for trigger (SPD layers) and tracking

V0 and AD sets of two
scintillator detectors:
veto triggers

pi(K)⁺

pi(K)⁻

ZDC for neutron
detection

Time Projection Chamber
for tracking and
particle identification

Time Of Flight
for trigger back-to-back topology

$\rho(770)$ + direct $\pi^+\pi^-$ photoproduction

ALICE Collaboration, JHEP 06 (2020) 035

ALICE Pb-Pb UPC $\sqrt{s_{NN}}$ = 5.02 TeV

- ALICE data
- Full fit
- ρ^0 Breit-Wigner
- ρ^0-$\pi\pi$ interference
- Muon template

$p_T < 0.2$ GeV/c
$|y| < 0.8$

- **Invariant mass distribution is fitted to the Söding formula**

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

  → **constant as a function of rapidity, collision energy (vs. 2.76 TeV) and different neutron classes in current precision**

  STAR Collaboration, PRC.96.054904

  → **comparison with STAR result: sensitive to the kinematics of interaction or type of target?**

Kaon identification based on TPC signal
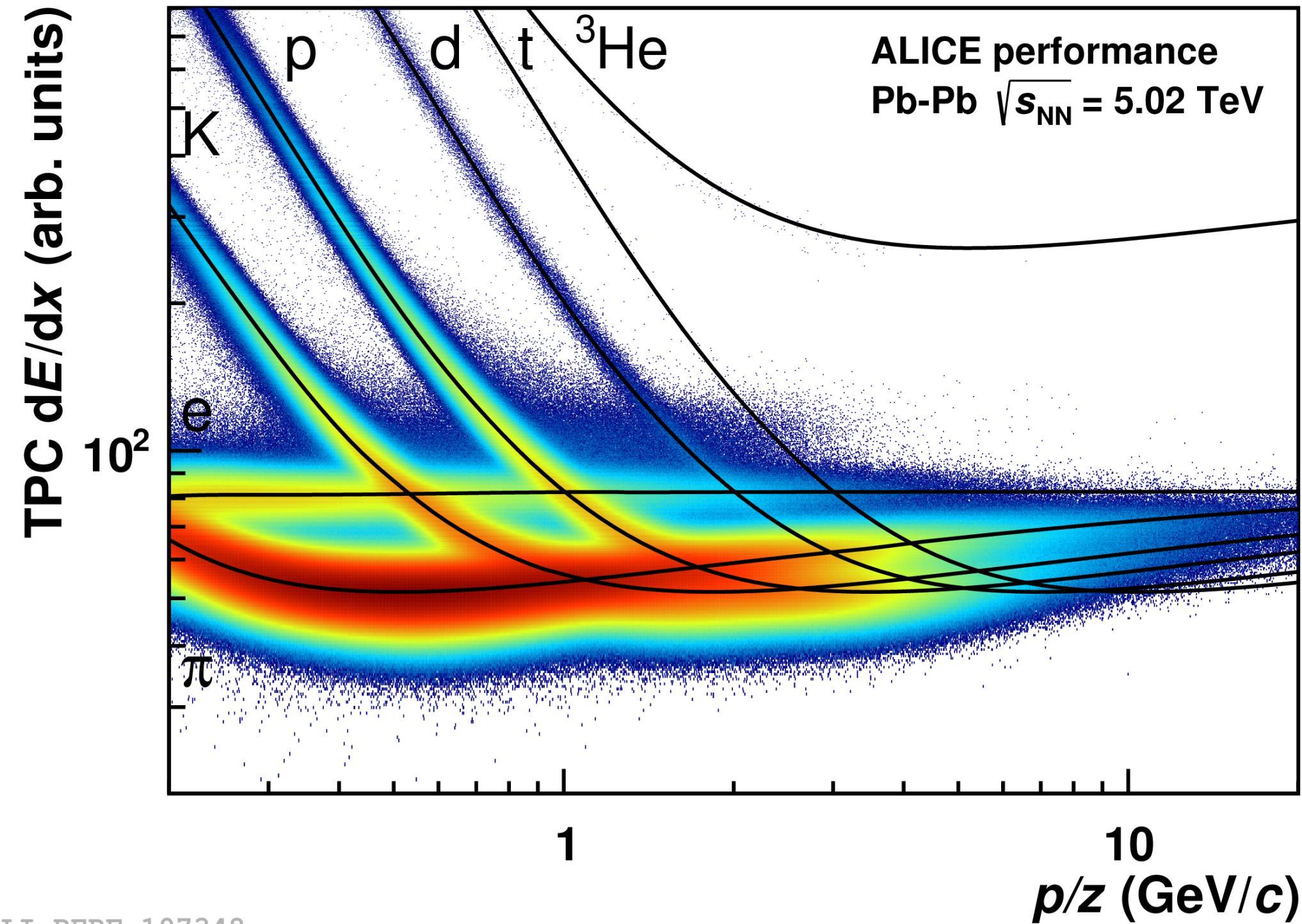
ALI-PERF-107348
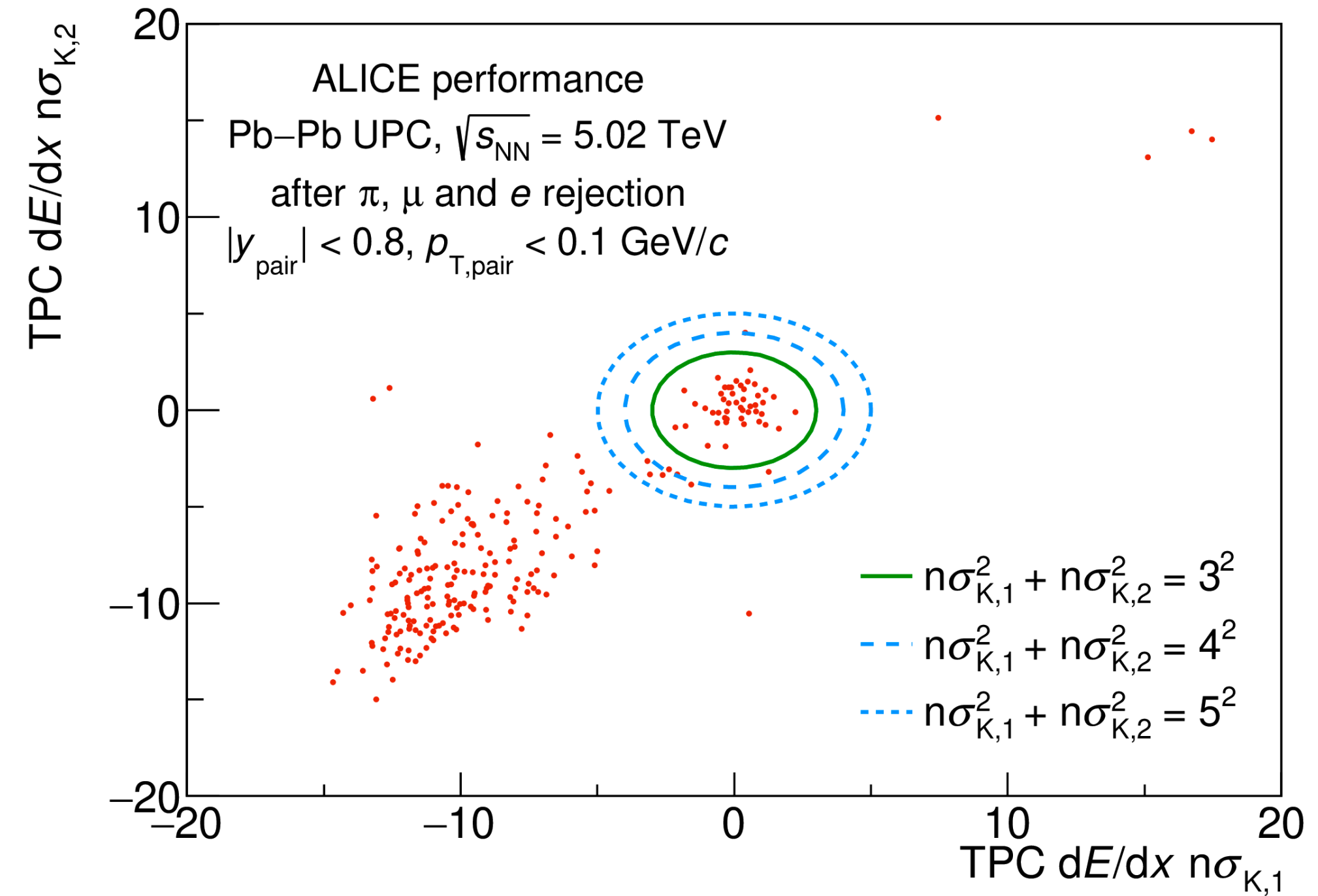
ALI-PERF-537874

- 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 nσ_K distribution → negligible background pairs in $1.1 < M_{KK} < 1.4$ GeV/c^2
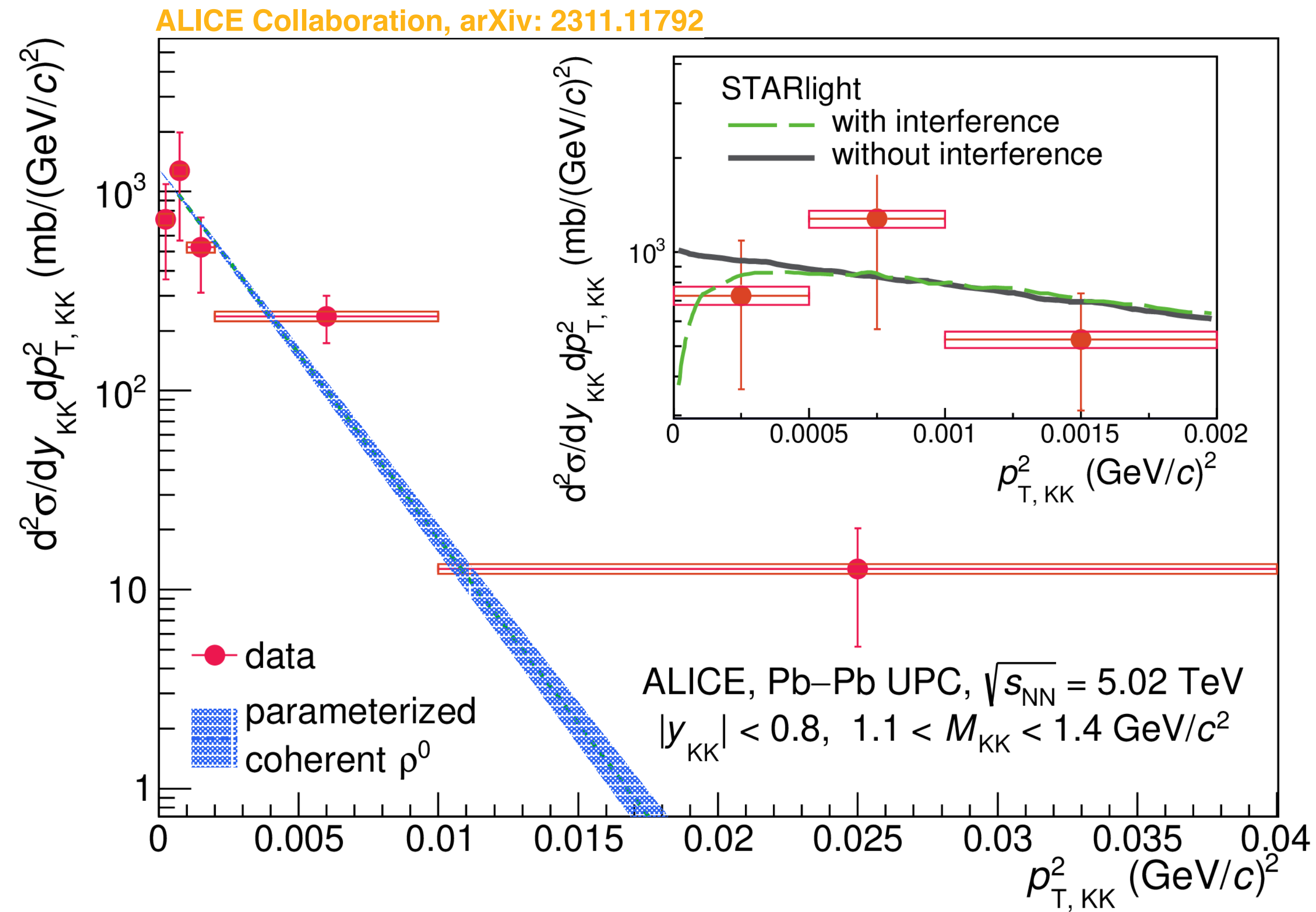
Raw yield of K⁺K⁻ candidates

ALI-PERF-538754
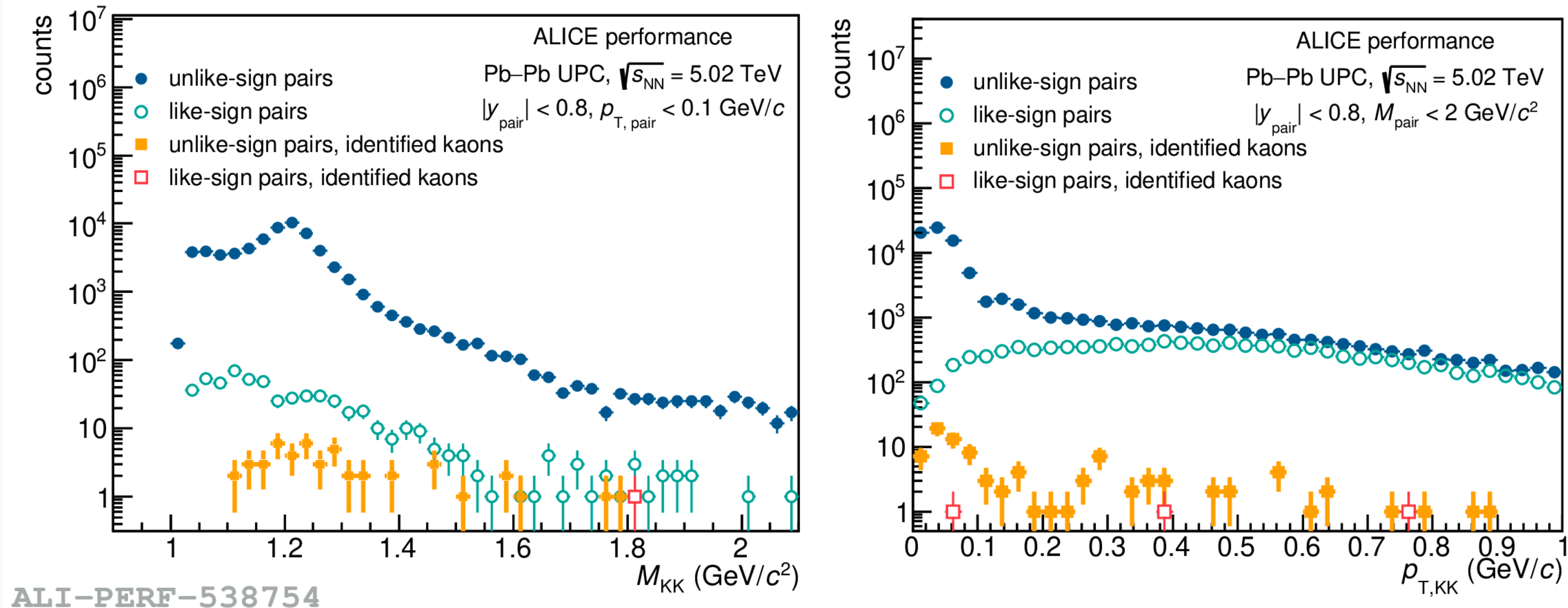
- Small fraction of like-sign pairs: little (negligible) combinatorial background pairs in $p_{\mathrm{T,KK}} < 0.1$ GeV/c in $1.1 < M_{\mathrm{KK}} < 1.4$ GeV/c^2

- Rise of K⁺K⁻ raw yield at low $p_{\mathrm{T,KK}}$ indicating coherent photoproduction

p_T^2 distribution of exclusive K+K⁻ photoproduction
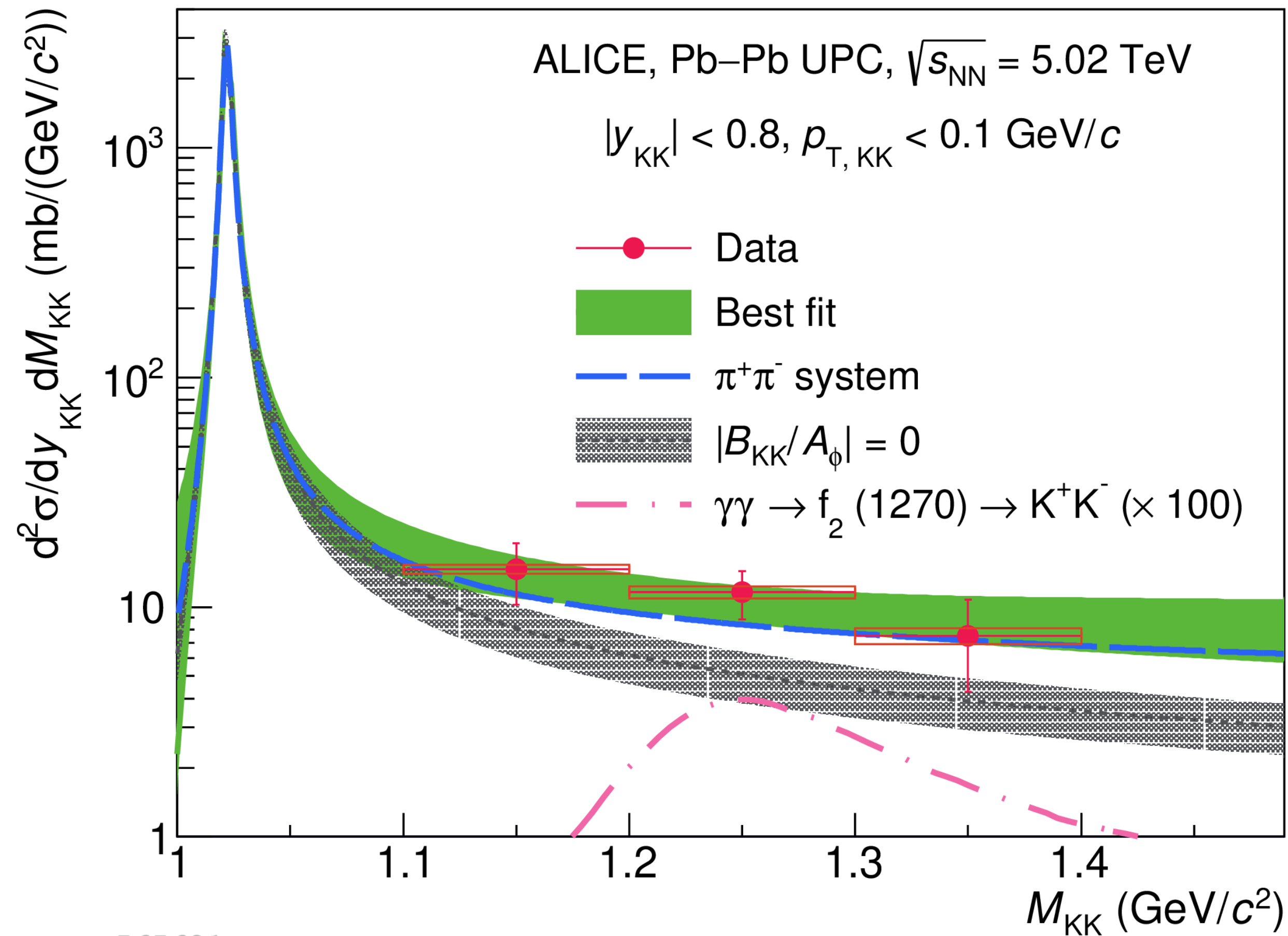

ALICE Collaboration, arXiv: 2311.11792

ALI-PUB-565617

- 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±6(stat.)±15(syst.) GeV^{-2} taken from ALICE $\rho(770) \to \pi\pi$ measurement fairly well describes the data ALICE Collaboration, JHEP 09 (2015) 095,

- The cross section at low p_T^2 is in favor of photoproduction with destructive interference (as both nuclei can be either the photon source or scattering target)

Invariant mass spectrum

ALICE Collaboration, arXiv: 2311.11792

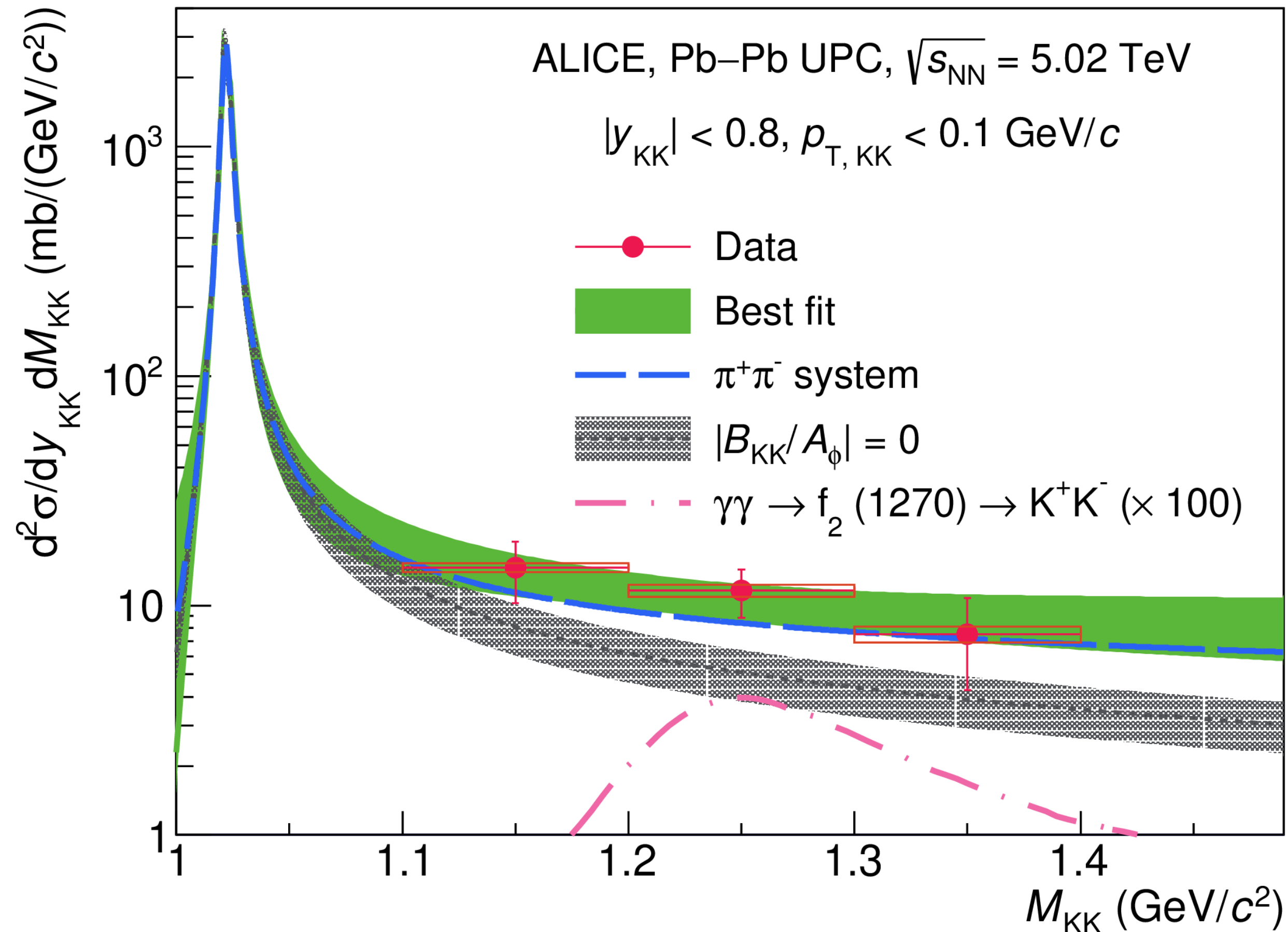ALI-PUB-565621

- First measurement of coherent photoproduction of K⁺K⁻ pairs in ultra-peripheral heavy-ion collisions

- Possible physics background of $\gamma\gamma \to X \to K^+K^-$ seems small: signal is likely the composition of $\phi(1020) \to K^+K^-$ and direct K^+K^-

Invariant mass spectrum

ALICE, Pb–Pb UPC, $\sqrt{s_{NN}}$ = 5.02 TeV

$|y_{KK}| < 0.8$, $p_{T, KK} < 0.1$ GeV/c

- Data
- Best fit
- $\pi^+\pi^-$ system
- $|B_{KK}/A_\phi| = 0$
- $\gamma\gamma \to f_2 (1270) \to K^+K^- (\times 100)$

ALI-PUB-565621

- Söding formula has 3 free parameters:
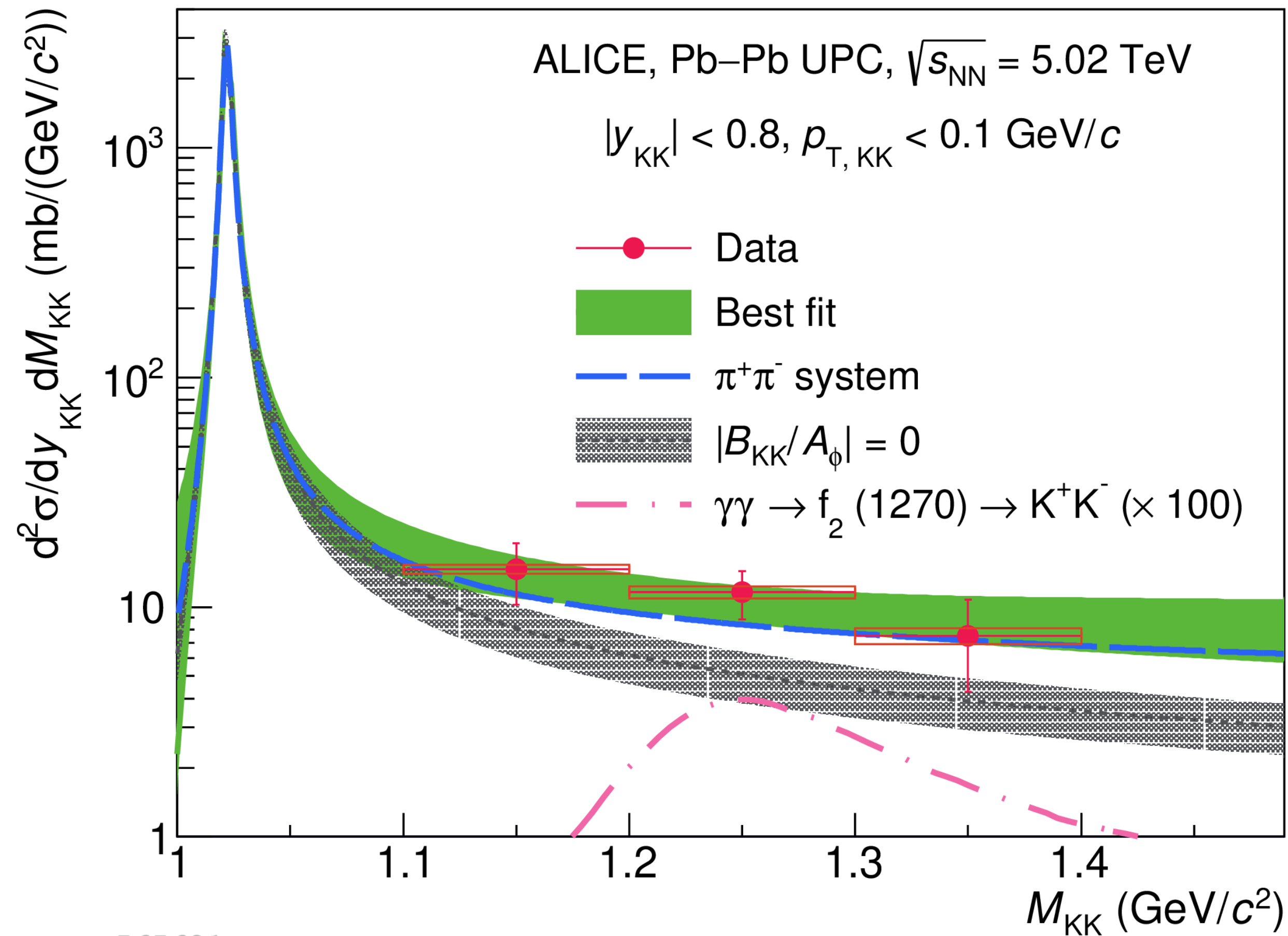
$$\frac{d\sigma}{dM_{KK}} = \left| A_\phi \frac{\sqrt{M_{KK}M_\phi\Gamma_\phi}}{M_{KK}^2 - M_\phi^2 + iM_\phi\Gamma_\phi} + B_{KK} \right|^2$$

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

- ϕ meson cross section:
  fixed by HERA measurement + Glauber model with 25% uncertainty including BR

- $|B/A|$: ratio between non-resonant contribution and $\phi \to KK$

- Φ: relative phase angle between non-resonant contribution and $\phi \to KK$

- Best fit: fit data points with 2 free parameters, $|B/A|$ and Φ considering measured uncertainties

Invariant mass spectrum

ALICE Collaboration, arXiv: 2311.11792

ALICE, Pb–Pb UPC, $\sqrt{s_{NN}}$ = 5.02 TeV

$|y_{KK}|$ < 0.8, $p_{T, KK}$ < 0.1 GeV/c

- ● Data
- ▬ Best fit
- ▬ ▬ $\pi^+\pi^-$ system
- ▨ $|B_{KK}/A_\phi|$ = 0
- —·— $\gamma\gamma \to f_2$ (1270) $\to$ K$^+$K$^-$ ($\times$ 100)

ALI-PUB-565621

- ● $\pi\pi$ system:

  - ● All 3 parameters fixed:
    - **R. M. Egloff et al., PRL.43.657**
    - **ZEUS Collaboration Phys. Lett. B 377 (1996) 259–272**
    - ϕ(1020) meson cross section

    - **ALICE Collaboration, JHEP 06 (2020) 035**
    - $|B/A|$ from <u>ALICE</u>

    - **STAR Collaboration, PRC.96.054904**
    - Phase angle Φ from <u>STAR</u>

  - ● Lower edge of fit uncertainty

- ● $|B/A|$=0:
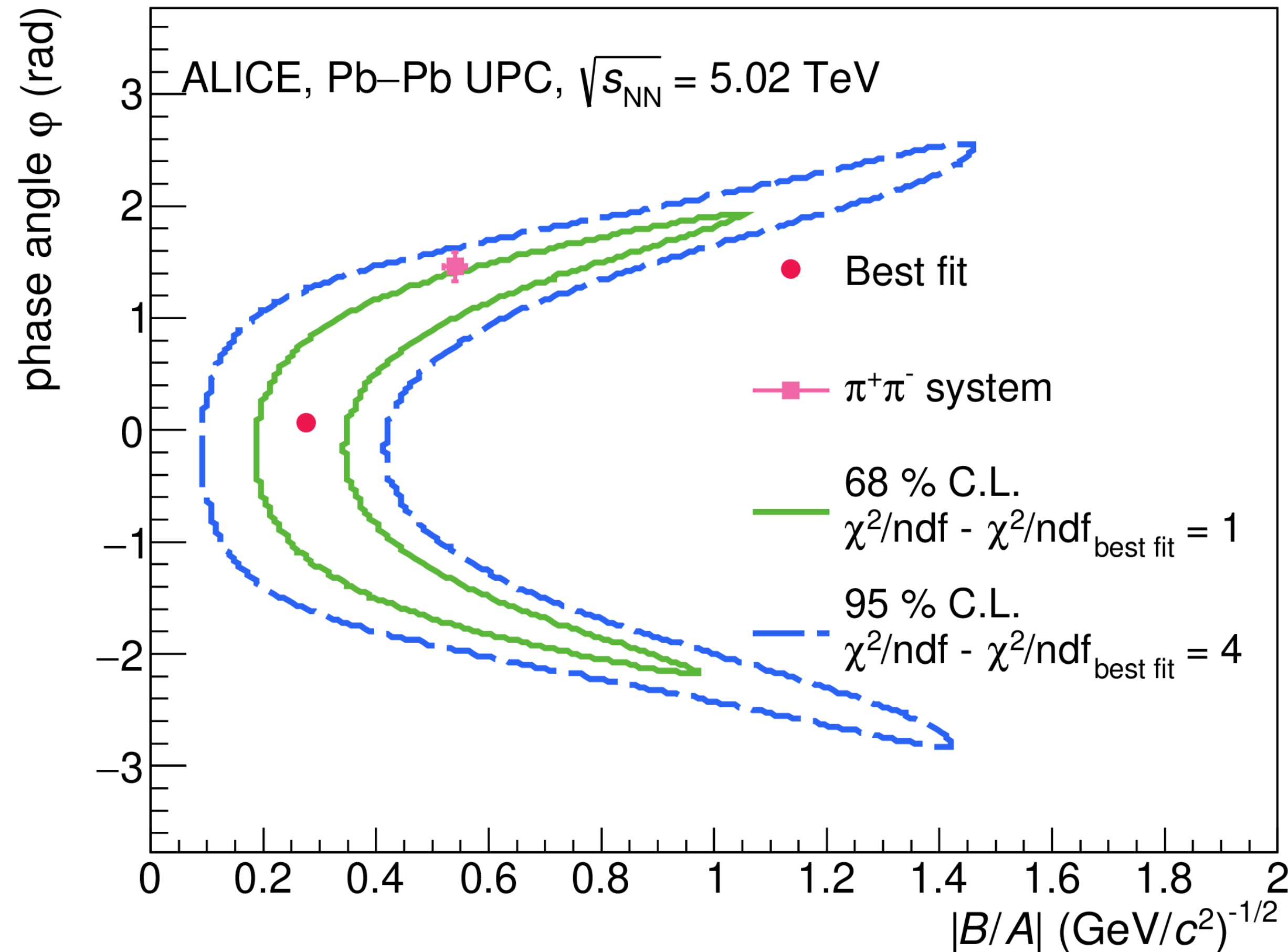
  - ● Independent from phase angle Φ

  - ● Band reflects the 25% systematic uncertainty of ϕ(1020) cross section

  - ● More than 2 sigma away from the measurements, suggesting non-negligible non-resonant contribution

Uncertainty and confidence level

ALICE, Pb–Pb UPC, $\sqrt{s_{NN}}$ = 5.02 TeV

ALI-PUB-565625

- 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

Summary and outlook

- First measurement of coherent photoproduction of K+K− pairs in ultra-peripheral heavy-ion collisions

- The measured cross section for coherent photoproduction of K+K− in the mass range $1.1 < M_{\mathrm{KK}} < 1.4~\mathrm{GeV}/c^2$ consistent with a mixture of ϕ(1020) and non-resonant K+K− photoproduction and their interference

- Ratio of each component and the relative phase angle between ϕ(1020) and non-resonant K+K− are similar to those seen for the ρ(770) and direct $\pi^+\pi^-$ production

- Improved precision measurement expected based on large data collected in Run 3