Beyond the phi: the direct K^+K^- contribution

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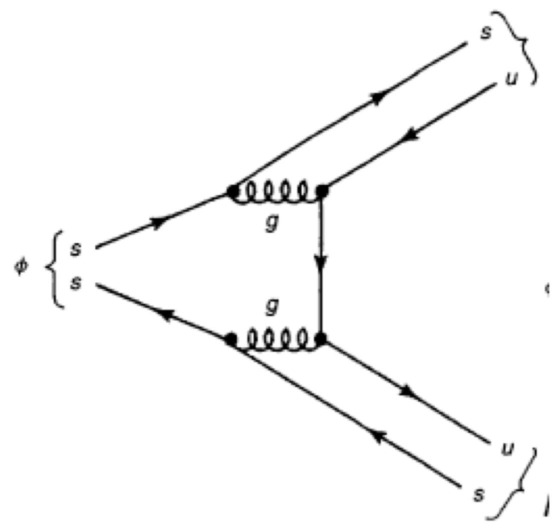
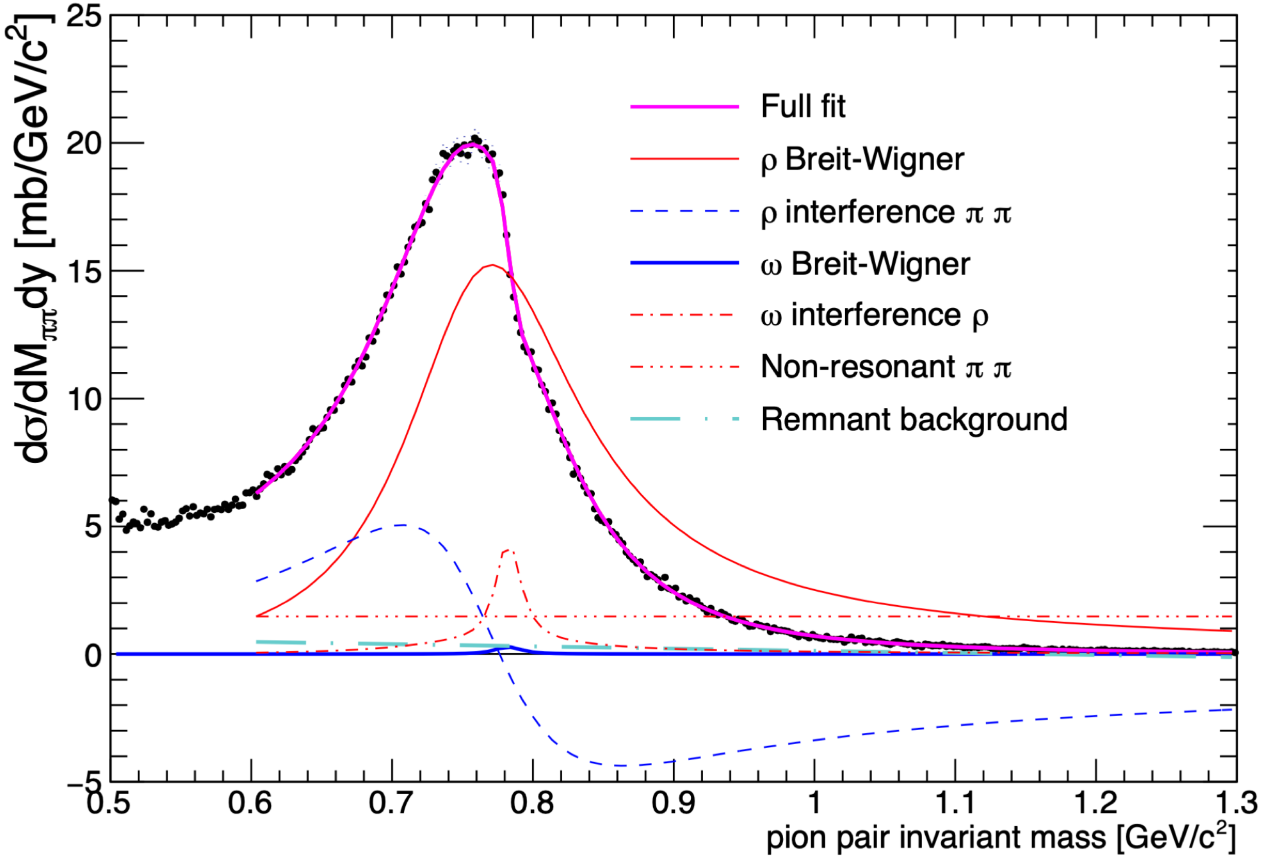
- Review: the ρ
- The ϕ + direct KK
  - ALICE Status
- ePIC implications



Partly based on presentations by Minjung Kim, LBNL, at Hot Quarks 2023 and Nacer Hamdi, LBNL at DIS 2023.

ρ^0 + direct $\pi\pi$ data

- Highest statistics modern measurement by STAR, with UPCs
  - 294,000 pairs
- Fit to ρ^0 + direct $\pi\pi + \omega +$ interference between them
  - χ^2/DOF ~ 1



STAR: Phys. Rev. C96, 054904 (2017)

Equations

- $d\sigma/dM_{\pi\pi}$ given by a relativistic Breit-Wigner equation:

$$\frac{d\sigma}{dM_{\pi^+\pi^-}} \propto \left| A_\rho \frac{\sqrt{M_{\pi\pi} M_\rho \Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + iM_\rho \Gamma_\rho} + B_{\pi\pi} + C_\omega e^{i\phi_\omega} \frac{\sqrt{M_{\pi\pi} M_\omega \Gamma_{\omega\to\pi\pi}}}{M_{\pi\pi}^2 - M_\omega^2 + iM_\omega \Gamma_\omega} \right|^2 + f_p$$

- A_ρ, $B_{\pi\pi}$ and C_ω are the amplitudes for the three components
  - All can be complex (C_ω has its separate phase shown explicitly)
    - Relative phases matter
  - ρ:direct $\pi\pi$ quantified by $|B_{\pi\pi}/A_\rho|$, with units $\mathrm{GeV}^{-1/2}$
- f_p is for background (e. g. $\gamma\gamma \to ee$)
- Widths depend on $M_{\pi\pi}$ (phase space)

$$\Gamma_\rho = \Gamma_0 \frac{M_\rho}{M_{\pi\pi}} \left(\frac{M_{\pi\pi}^2 - 4m_\pi^2}{M_\rho^2 - 4m_\pi^2} \right)^{3/2}$$

$$\Gamma_\omega = \Gamma_0 \frac{M_\omega}{M_{\pi\pi}} \left(\frac{M_{\pi\pi}^2 - 9m_\pi^2}{M_\omega^2 - 9m_\pi^2} \right)^{n},$$

The ϕ

- M_ϕ =1019 MeV, Γ_ϕ = 4.4 MeV
  - Narrow
- M_ϕ $2M_{K\pm}$ + 31 MeV
  - Kaons have p ~ 135 MeV/c in ϕ rest frame
- Hard to see ϕ with low p_T, in UPCs or in ePIC
  - In ePIC, higher Q^2 -> higher p_T, but we want to measure exclusive ϕ production over the entire Q^2 range
- Alternative: Look at high-mass ϕ's

$$\frac{d\sigma}{dM_{KK}} = \left| A_\phi \frac{\sqrt{M_{KK} M_\phi \Gamma_\phi}}{M_{KK}^2 - M_\phi^2 + iM_\phi \Gamma_\phi} + B_{KK} \right|^2 \quad (1)$$

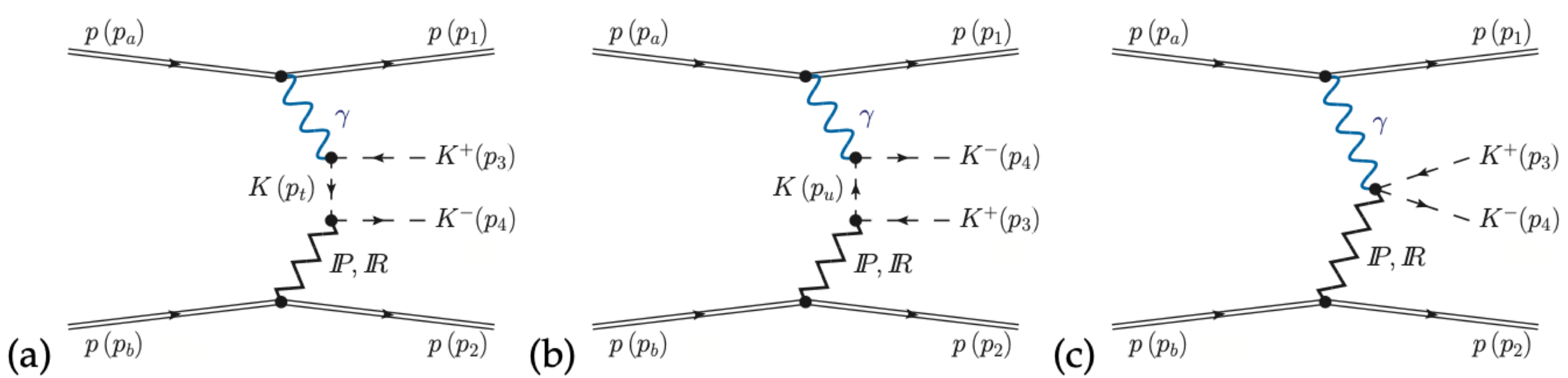
where $M_\phi = 1019.416 \pm 0.016$MeV [10] and Γ_ϕ are the ϕ mass and mass-dependent width, respectively, with

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

- Because of the mass-dependent width, drop-off is slower than it might be, even with B_{KK}=0

Direct KK

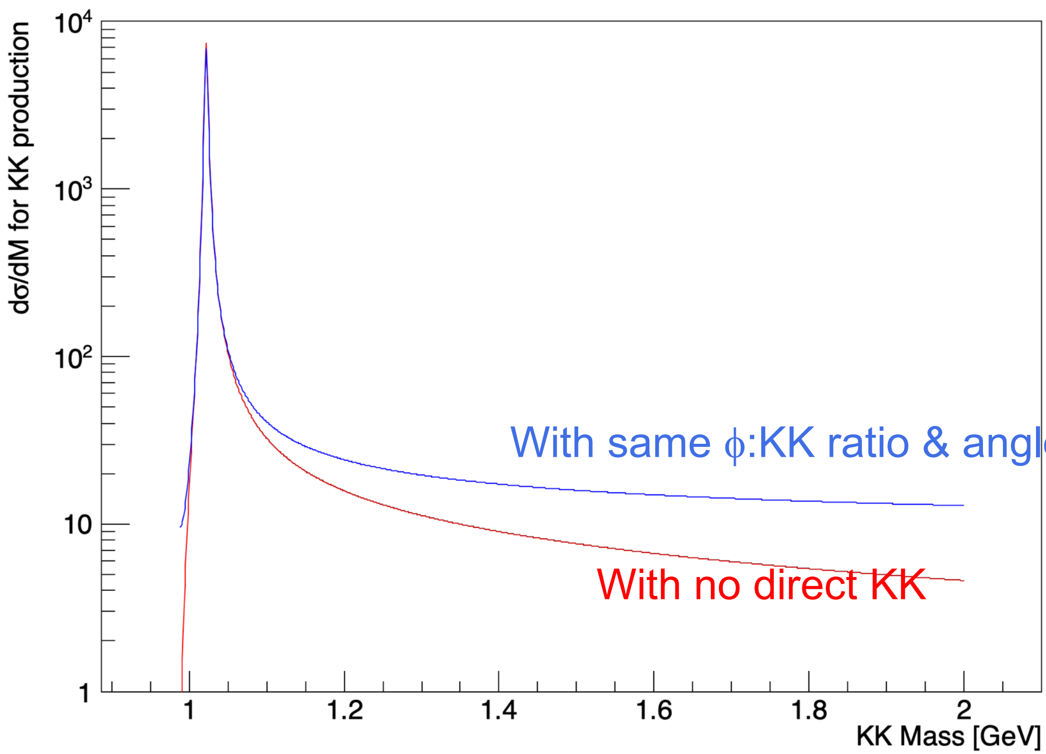
- Not yet seen
- We expect direct KK production along with the ϕ, with the same mechanism - just like the ρ + direct $\pi\pi$
- Roughly similar relative amplitudes and relative phase (?)
  - Constructive interference(?)
- Higher masses than the ϕ, so easier to see



P. Lebiedowicz et al., PRD 98, 014001 (2018)

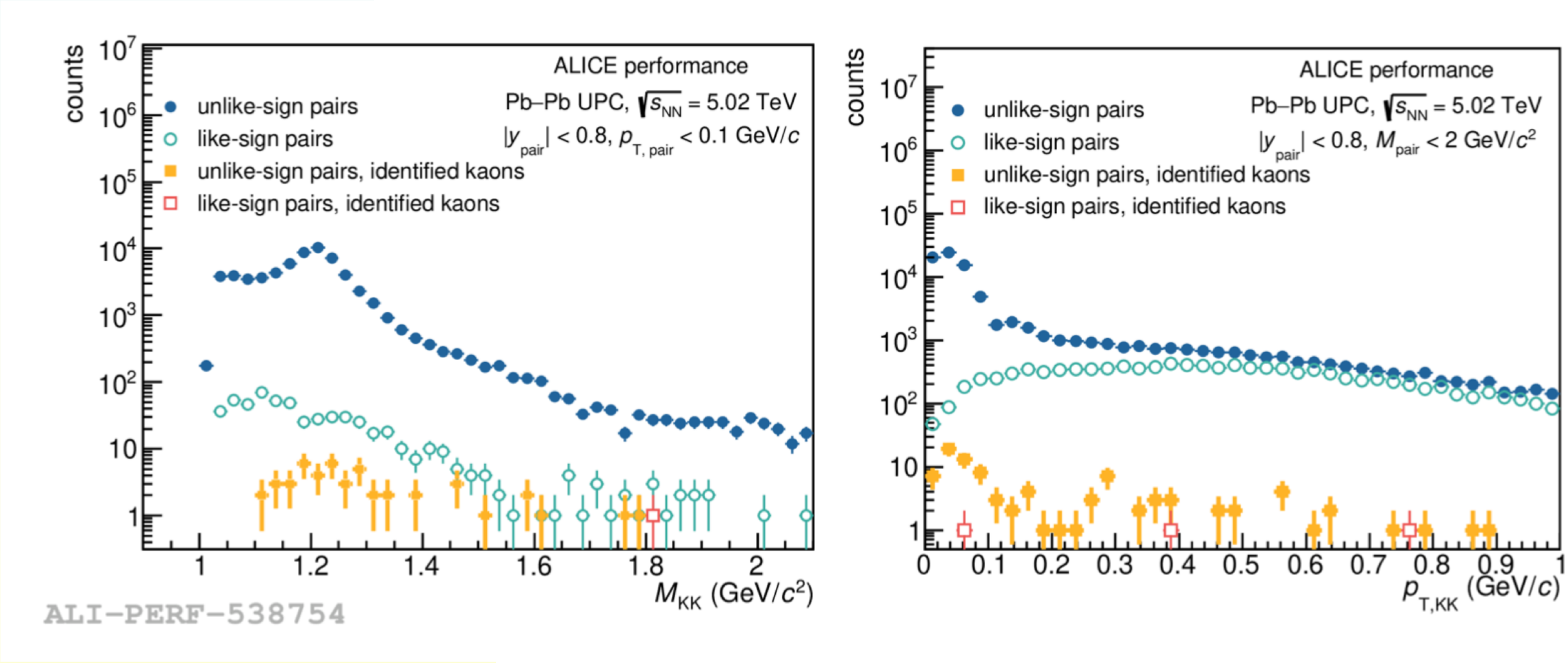
Mass spectrum

- KK mass spectrum, assuming the same ϕ:KK ratio as $\rho:\pi\pi$
  - Somewhat counterintuitive behavior:
    - Far above M_ϕ, for very small R= $|B_{KK}/A_\phi|$, destructive interference means σ drops as R rises from 0
      - Different phase angle -> possibly different behavior
    - As R rises further, direct KK dominates, and σ rises with a further increase in R



ALICE studies

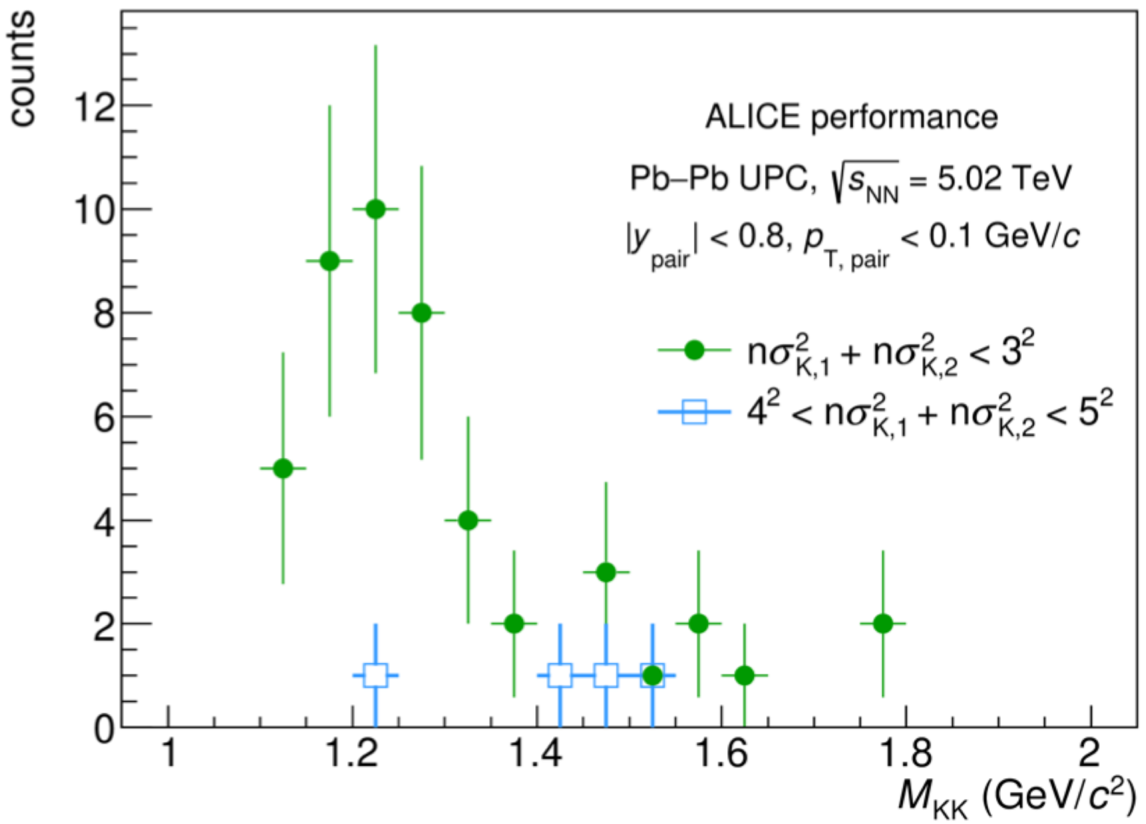
- Parallels UPC ρ+direct $\pi\pi$ photoproduction analysis, but with tight PID cuts to select a clean KK sample (above the ϕ)
  - N(KK) ~ 1/1000 N($\pi\pi$)
- 1.1 GeV < M_{KK} < 1.4 GeV
  - Sweet spot with OK acceptance and good PID $\pi\pi$ rejection



Minjung Kim at Hot Quarks 2023 and Nacer Hamdi at DIS 2023.

ALICE mass spectrum

- Clean sample in chosen mass range



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Some implications for ePIC (in lieu of conclusions)

- With high enough rates (which ePIC has), we can use high mass KK pairs as a proxy for the ϕ
- For measurements at M_{KK} > 1.1 GeV, the amplitude ratio $|B_{KK}/A_\phi|$ and its phase angle are correlateted. If $|B_{KK}/A_\phi|$ is large, then it will increase σ, but a smaller R may decrease σ through destructive interference with the ϕ.
  - Measurements nearer the ϕ peak are needed to resolve this.
    - ePIC can do this at higher Q^2, and then assume that the phase angle does not change much as Q^2 decreases.
      - Theoretical justification is needed.
- The ϕ is narrow, so any measurement will include a significant direct KK component. This will complicate any attempt to measure the ϕ cross-section by itself.
- Direct KK have a different wave function from the ϕ, so will complicate efforts to interpret ϕ data in terms of dipole-model parton densities.