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전북대학교 JEONBUK NATIONAL UNIVERSITY

ALICE

Understanding the nature of $f_0(980)$ with ALICE at the LHC

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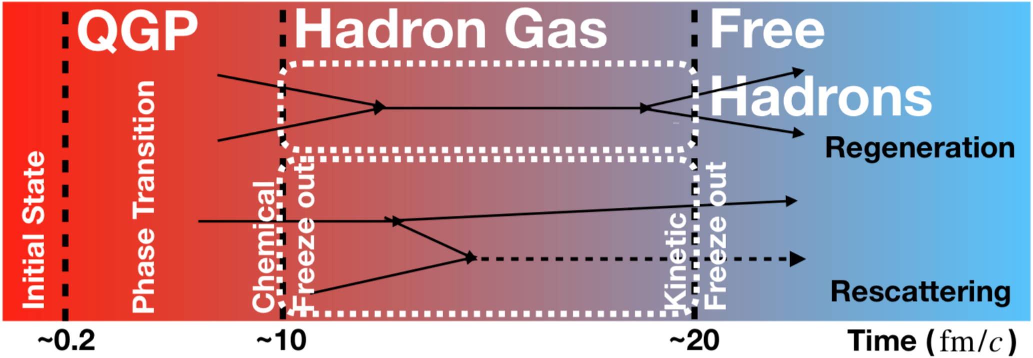
2022 Strangeness in Quark Matter

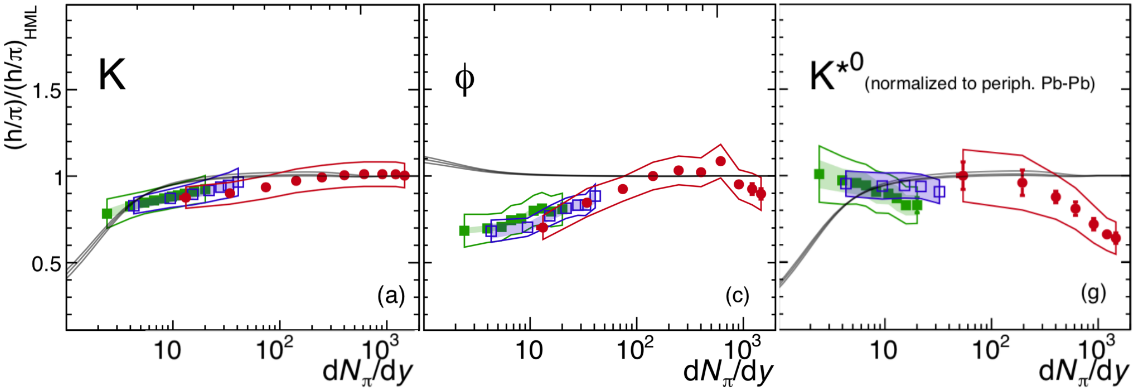


- Resonance yields can be modified in the hadronic gas via regeneration and rescattering.
- Short-lived resonances are powerful probes to study the properties of the hadronic gas.

Particle yield ratio

pp, p–Pb, Pb–Pb

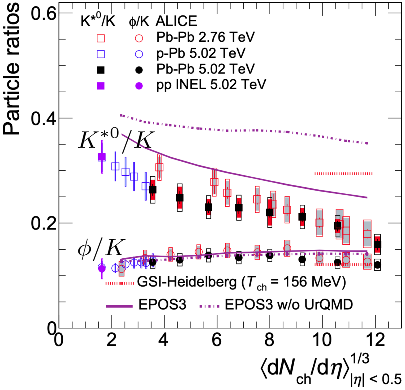
PRC 99, 024906 (2019)

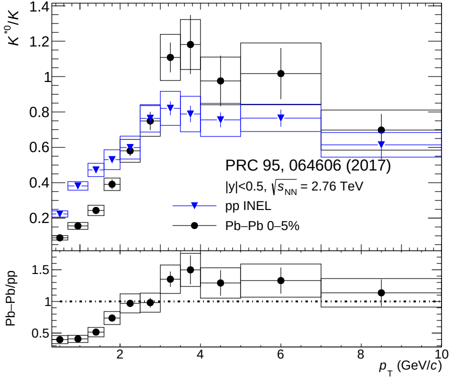


- Strangeness enhancement is seen in the (K/π) and (ϕ/π) ratios.
- (K^{*0}/π) is flat with increasing multiplicity in pp and p–Pb collisions, possibly due to two competing effects.
  - Strangeness enhancement
  - Suppressions due to the short lifetime of K^{*0} ($\tau_{K^{*0}} \sim 4.2$ fm$/c$) $\rightarrow$ **hint for rescattering effects**

K^{*0}/K

PLB 802 (2020) 135225





- Strangeness enhancement effect is not expected in (K^{*0}/K) ratio.
- Rescattering effects dominate the decreasing trend.
  - EPOS+UrQMD can qualitatively reproduce the (K^{*0}/K) ratio from small to large collision systems.
  - Strong suppression at low p_{T} + no suppression at high p_{T}

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- Scalar meson whose quark content and structure are still unresolved.
  - $q\bar{q}$ state: PRD 67, 094011 (2003)
  - Tetraquark ($q\bar{q}s\bar{s}$) state: PRD 103, 014010 (2021)
  - $K\overline{K}$ molecule state: PRD 101 094034 (2020)
- Measured $f_0(980)$ yield in hadron-hadron collisions can be largely modified because of its short lifetime ($\tau_{f_0} \sim$ 2–20 fm/c).
- Particle yield ratios and nuclear modification factor ($Q_{\rm pPb}$) of $f_0(980)$ allow to
  - Study the hadronic gas
  - Explore internal structure of $f_0(980)$

	ρ^0	K^*	$f_0(980)$	ϕ
Mass (MeV/c^2)	775	892	990	1020
J^P	1^-	1^-	0^+	1^-
Contents	$\frac{u\bar{u}+dd}{\sqrt{2}}$	$d\bar{s}$	???	$s\bar{s}$
lifetime (fm/c)	1.3	4.2	$\sim$ 2–20	46.2

$$Q_{\rm pPb}(p_{\rm T},{\rm cent}) = \frac{{\rm d}^2 N^{\rm cent}_{\rm pPb}/{\rm d}y{\rm d}p_{\rm T}}{< T^{\rm cent}_{\rm pPb} > {\rm d}^2\sigma^{\rm INEL}_{\rm pp}/{\rm d}y{\rm d}p_{\rm T}},$$

where $< T^{\rm cent}_{\rm pPb} >= N^{\rm cent}_{\rm coll}/\sigma_{\rm NN}$

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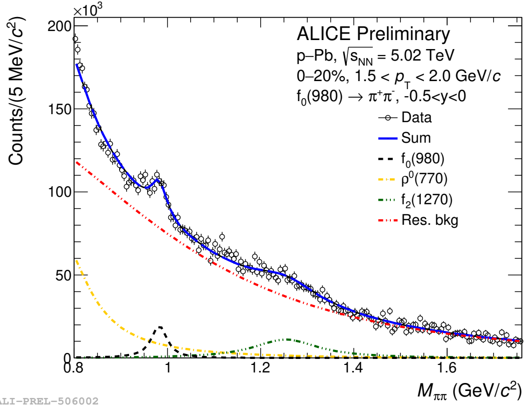
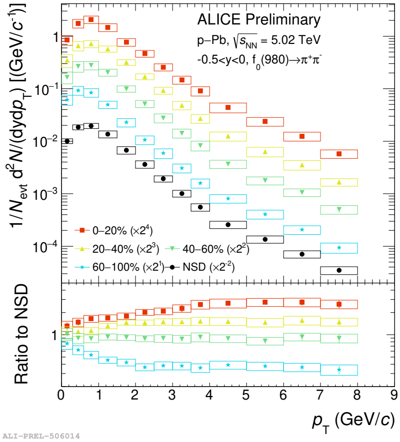
- The position of each resonance is corrected by the phase space correction,
  $PS(M_{\pi\pi}) = \frac{M_{\pi\pi}}{\sqrt{M_{\pi\pi}^2 + p_T^2}} \exp(-\sqrt{M_{\pi\pi}^2 + p_T^2}/T)$.
- After the combinatorial background subtraction, the residual background can be described by
  $f_{BG}(M_{\pi\pi}) = (M_{\pi\pi} - 2m_\pi)^n A\exp(BM_{\pi\pi} + CM_{\pi\pi}^2)$.
- In total,
  $f(M_{\pi\pi}) = (N_\rho \mathrm{rBW}_{\rho^0}(M_{\pi\pi}) + N_{f_0}\mathrm{rBW}_{f_0}(M_{\pi\pi}) + N_{f_2}\mathrm{rBW}_{f_2}(M_{\pi\pi})) \times PS(M_{\pi\pi}) + f_{BG}(M_{\pi\pi})$
- **The estimated $f_0(980)$ width is 55 MeV/c^2 ($\sim$ 4 fm/c)**

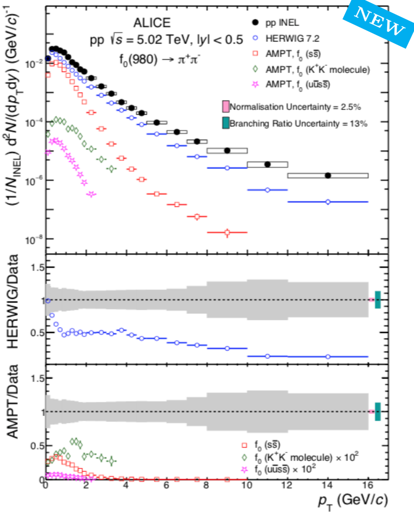


ALI-PREL-506002

- Fully corrected p_T spectra for $f_0(980)$ down to $p_T = 0$ in different multiplicity classes
- $f_0(980)$ p_T spectra cannot be reproduced by HERWIG 7.2 model and AMPT+coalescence model in three configurations ($s\bar{s}$, $u\bar{u}s\bar{s}$, and $K\overline{K}$ molecule).

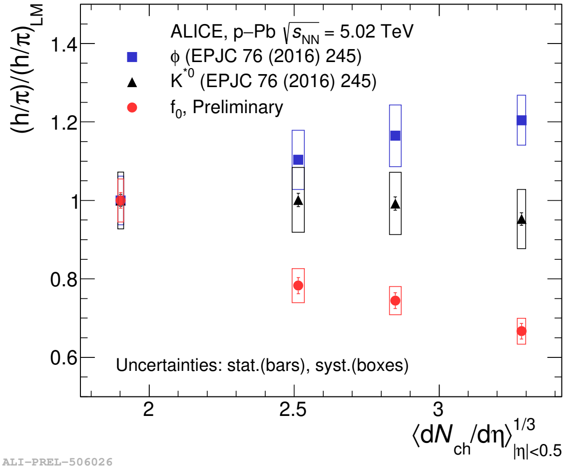


arXiv:2206.06216



- (f_0/π) ratio decreases with increasing $\langle dN/d\eta \rangle$.
  - Similar trend as observed for (K^{*0}/K) but larger decrease with the multiplicity
  - Larger rescattering effects or smaller regeneration effects for $f_0(980)$?

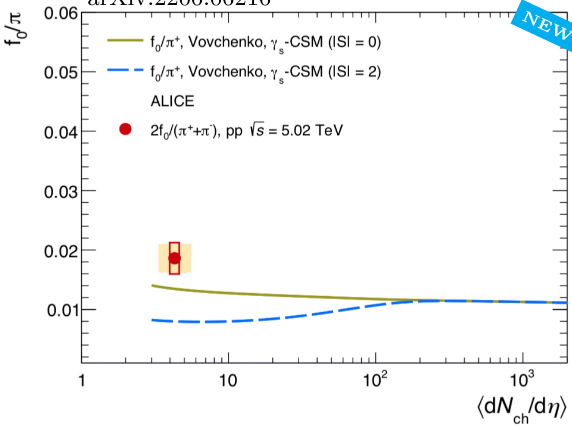
	K^*	$f_0(980)$	ϕ
lifetime (fm/c)	4.2	$\sim$4	46.2



Particle yield ratios: model comparison

- Canonical statistical model (CSM) with multiplicity dependent $\gamma_s \leq 1$ [1] is used to predict (f_0/π) ratio for strangeness content hypotheses.
- $|S| = 2$: Increasing trend predicted
- $|S| = 0$: Decreasing trend predicted
  - [1] V. Vovchenko et al, PRC 100 (2019) 5, 054906

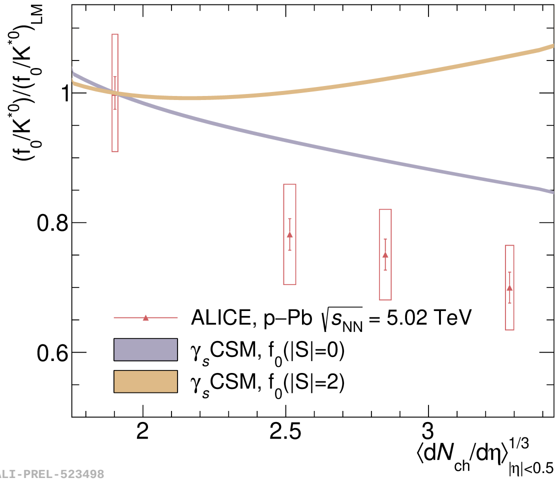
arXiv:2206.06216



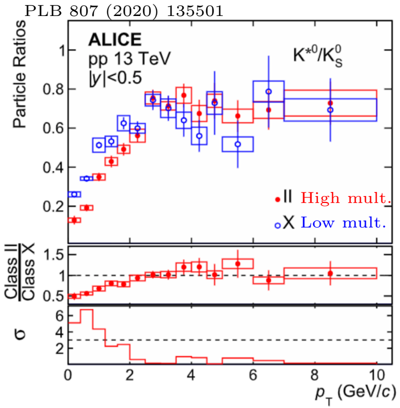
Particle yield ratios: model comparison

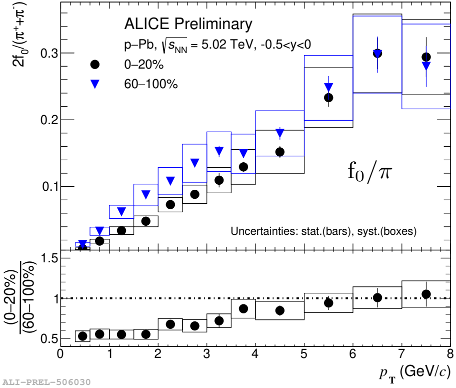
- Canonical statistical model (CSM) with multiplicity dependent $\gamma_s \leq 1$ [1] is used to predict (f_0/K^{*0}) ratio for strangeness content hypotheses.
- CSM predicts a flat behavior for $|S| = \mathbf{2}$ while a decreasing trend (qualitatively similar to what seen in data) is expected for $|S| = \mathbf{0}$.
    - N.B.: No rescattering effects in CSM
    - [1] V. Vovchenko et al, PRC 100 (2019) 5, 054906

	K^*	$f_0(980)$	ϕ
lifetime (fm/c)	4.2	$\sim$4	46.2



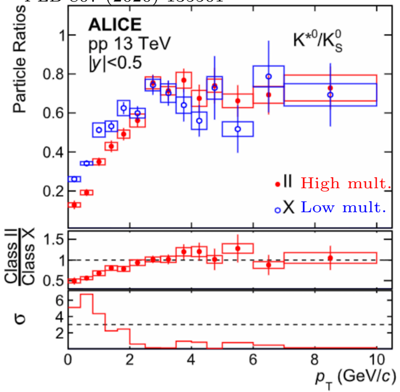
p_T-differential yield ratios of $f_0(980)$ to π

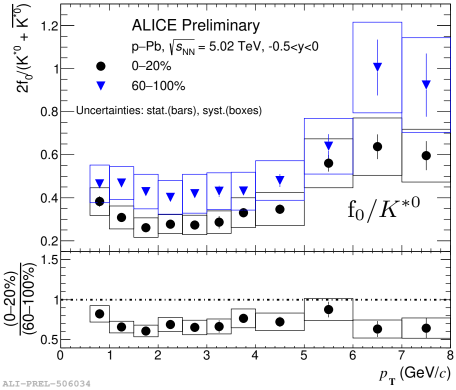




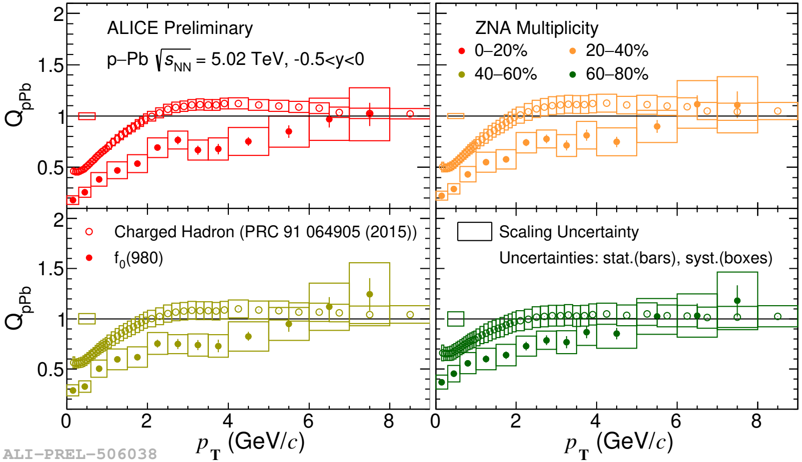
- (f_0/π): Significant modification at low p_T (< 3 GeV/c) and no modification at high p_T (> 4 GeV/c)
  - Similar p_T dependence between (pp_{high}/pp_{low}) and (Pb–Pb/pp) for (K^{*0}/K)
  - Similar p_T dependence between double ratio of (K^{*0}/K) and (f_0/π)

PLB 807 (2020) 135501





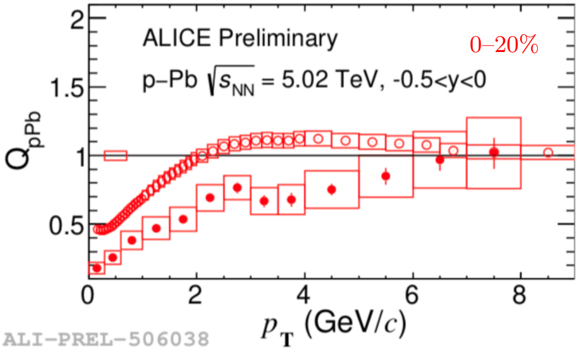
- Rescattering effects should be comparable between $f_0(980)$ and K^{*0} as they have comparable lifetime.
- Different behavior between (K^{*0}/K) and (f_0/K^{*0}) in the full measured p_T interval
- (f_0/K^{*0}): Modification in the entire p_T range.
  $\rightarrow$ due to different quark content for the two particles?



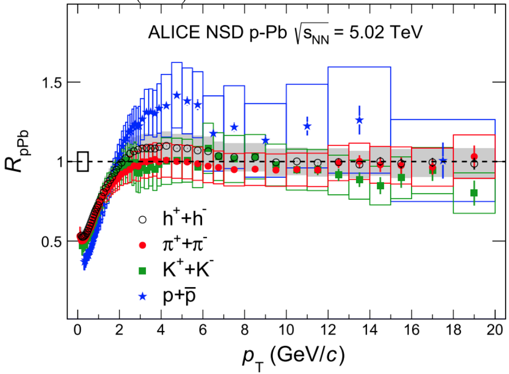
$$Q_{\mathrm{pPb}}(p_{\mathrm{T}}, \mathrm{cent}) = \frac{\mathrm{d}^2 N^{\mathrm{cent}}_{\mathrm{pPb}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{< T^{\mathrm{cent}}_{\mathrm{pPb}} > \mathrm{d}^2\sigma^{\mathrm{INEL}}_{\mathrm{pp}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}},$$

where $< T^{\mathrm{cent}}_{\mathrm{pPb}} >= N^{\mathrm{cent}}_{\mathrm{coll}}/\sigma_{\mathrm{NN}}$

- Multiplicity dependent suppression for $f_0(980)$ at the low $p_{\mathrm{T}}(< 4\ \mathrm{GeV}/c)$
- Rescattering effects observed in all the centrality intervals



PLB 760 (2016) 720



- No Cronin peak is observed for $f_0(980)$ in contrast to what is observed for baryons.

- Multiplicity dependence of $f_0(980)$ in pp and p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV has been measured to understand the nature of $f_0(980)$.
  - Particle yield ratios and nuclear modification factor in different multiplicity classes to study hadronic gas and $f_0(980)$ structure.
- Decreasing (f_0/π) at low p_T
  - **Evidence of rescattering-like effects for the f_0(980)**
- Decreasing (f_0/K^{*0}) in the full measured p_T range
  - **due to different quark content for f_0(980) and K^{*0}?**
- Multiplicity dependence of Q_{pPb} of $f_0(980)$
  - **Stronger suppression of f_0(980) at low p_T: rescattering effects**
  - **No Cronin peak for Q_{pPb} of f_0(980) in high-multiplicity events.**
- Models with different quark contents or structures are needed to shed light on $f_0(980)$ structure.

BACKUP