Production yield and azimuthal anisotropy measurements of strange hadrons from BES at STAR

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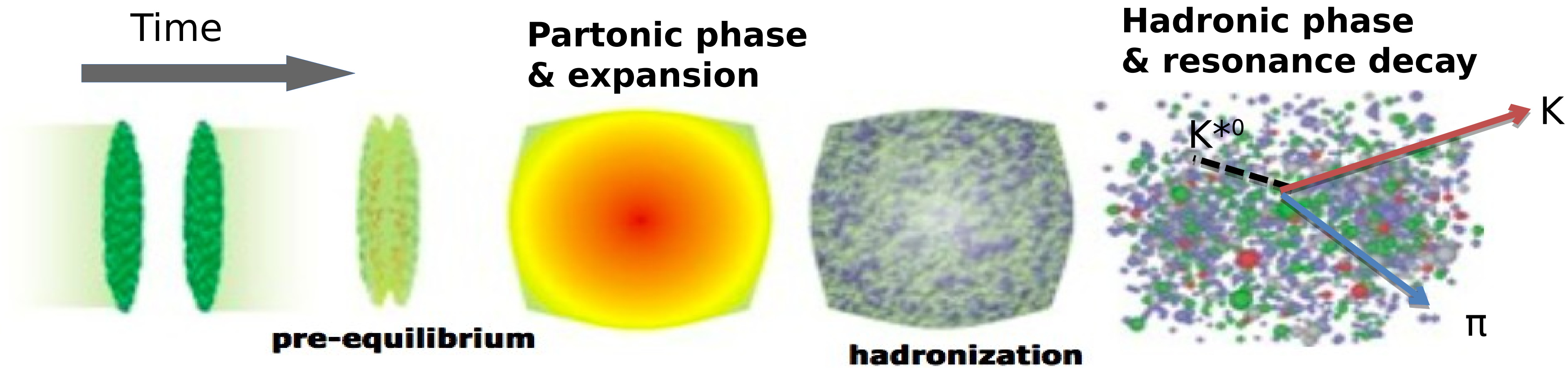
STAR

IISER BERHAMPUR

XXIXth International Conference on Ultra-relativistic Nucleus-Nucleus Collisions, Kraków, Poland, April 4-10,2022

Outline



PART-A

Probing parton dynamics with strange hadrons

Invariant Yield Measurement

a) Particle ratios

Azimuthal Anisotropy

a) Collective flow of K^0_S, ϕ, Λ, Ξ ,Ω

b) NCQ scaling of v_2

PART-B

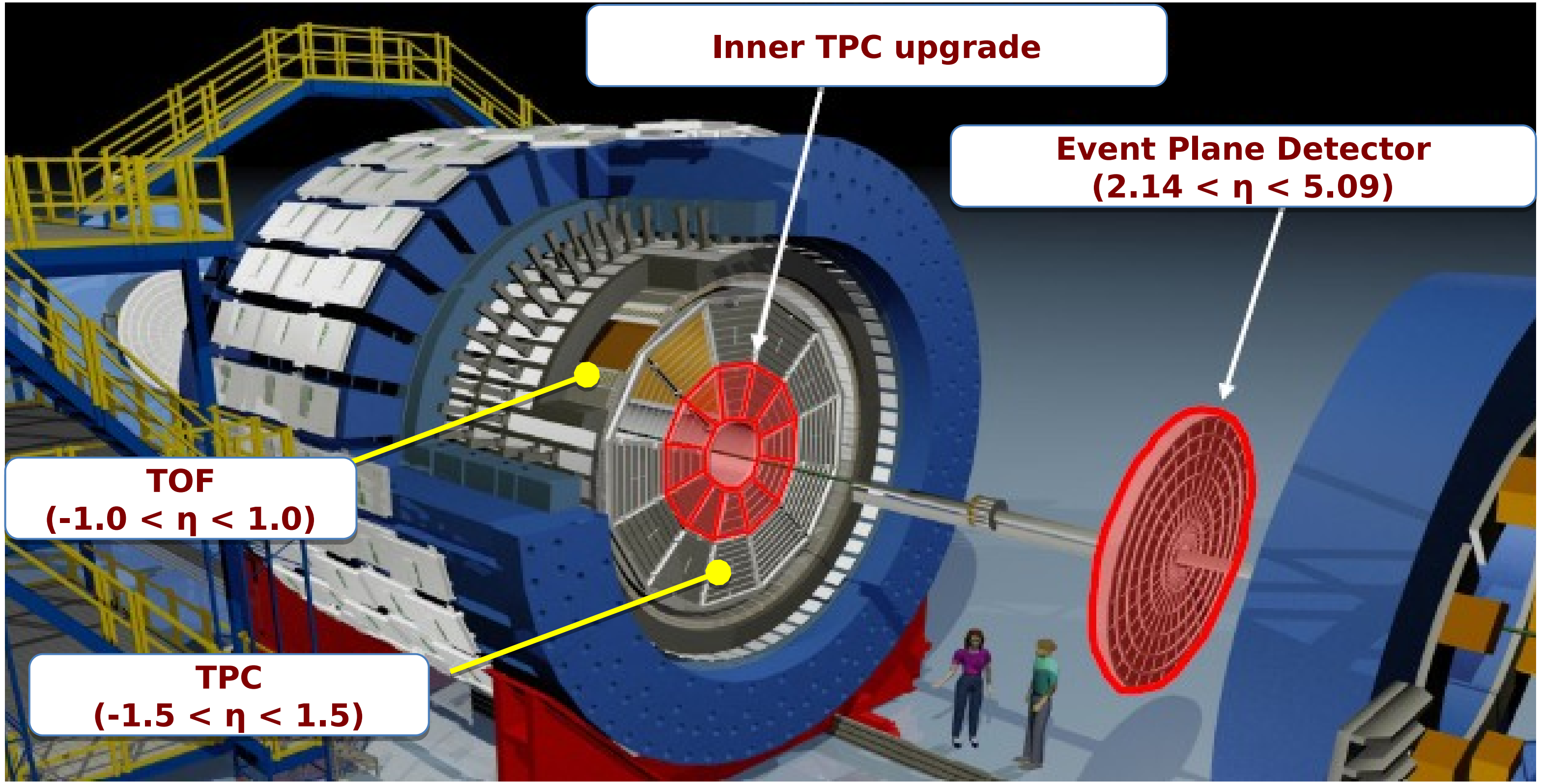
Probing hadronic phase with K^{*0} resonance

Invariant Yield Measurement

a) K^{*0}/K ratios

b) Hadronic phase lifetime

The STAR Detector and Data Sets



Tracking: TPC

Particle Identification: TPC & TOF

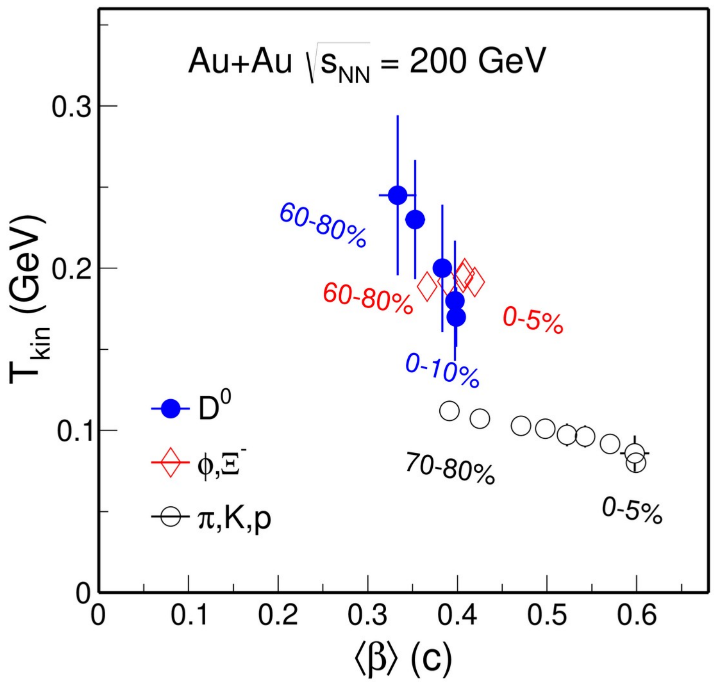
Event Plane: TPC / EPD

Data Sets:

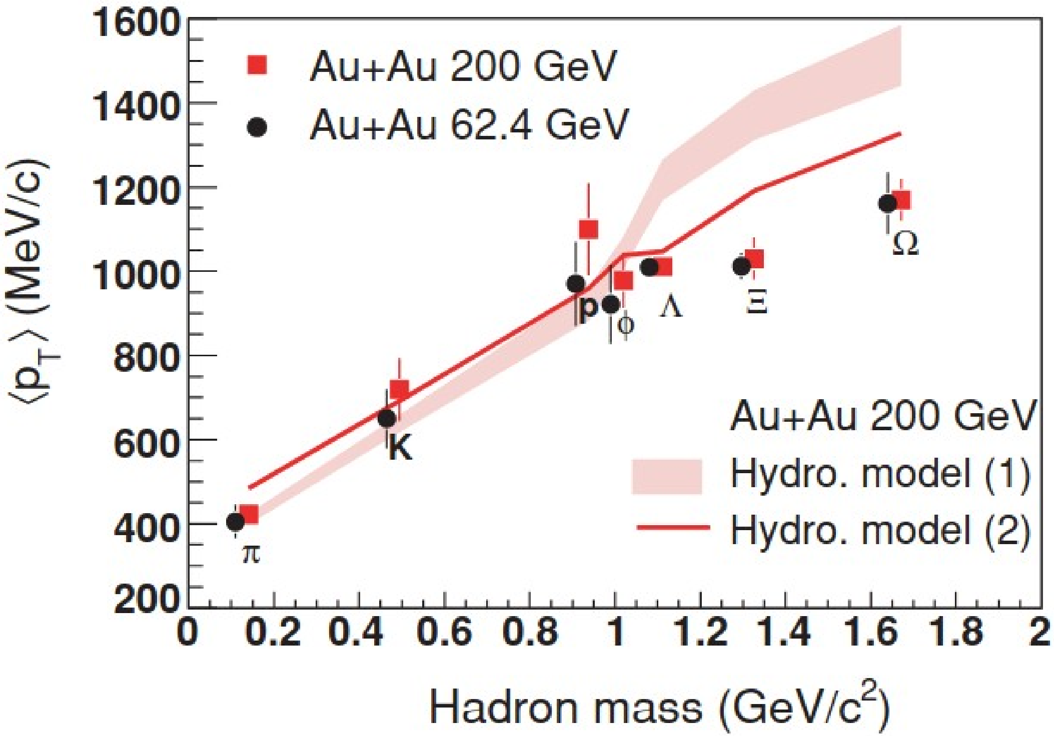
Part A: $\sqrt{s_{NN}}$ = 3 GeV and 19.6 GeV (BES-II) for strange hadrons' (K^0_S, Φ, Λ, Ξ ,Ω) transverse momentum spectra and flow analysis

Part B: $\sqrt{s_{NN}}$ =7.7, 11.5, 14.5, 19.6, 27 and 39 GeV (BES-I) for K^{*0} meson spectra analyses

Probing Parton Dynamics with Strange Hadrons



STAR: Phys. Rev. C **99** (2019) 34908



STAR: Phys. Rev. C **79** (2009) 64903

- Small hadronic interaction cross-section

A. Shor. Phys. Rev. Lett. 54, 1122 (1985).

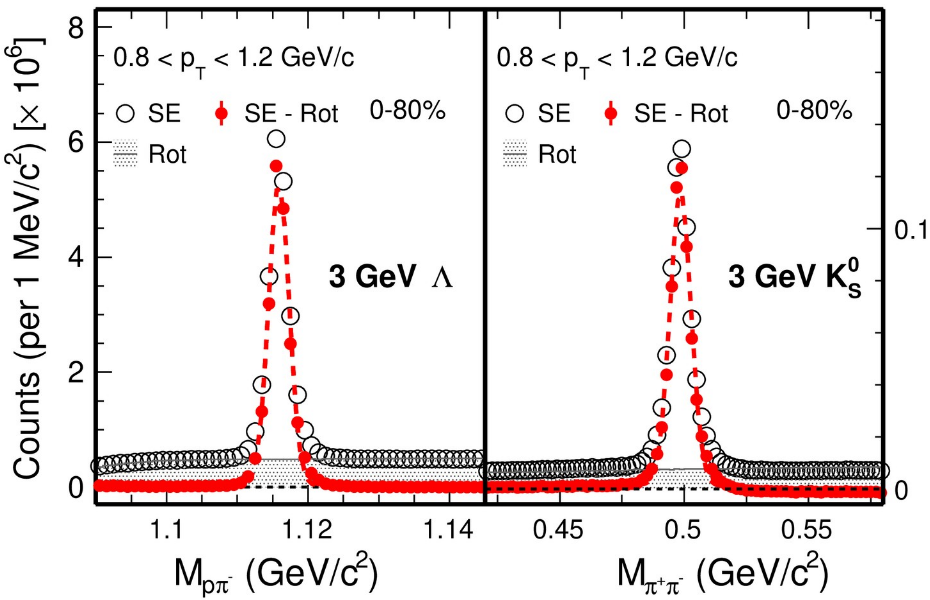
- Early freeze-out

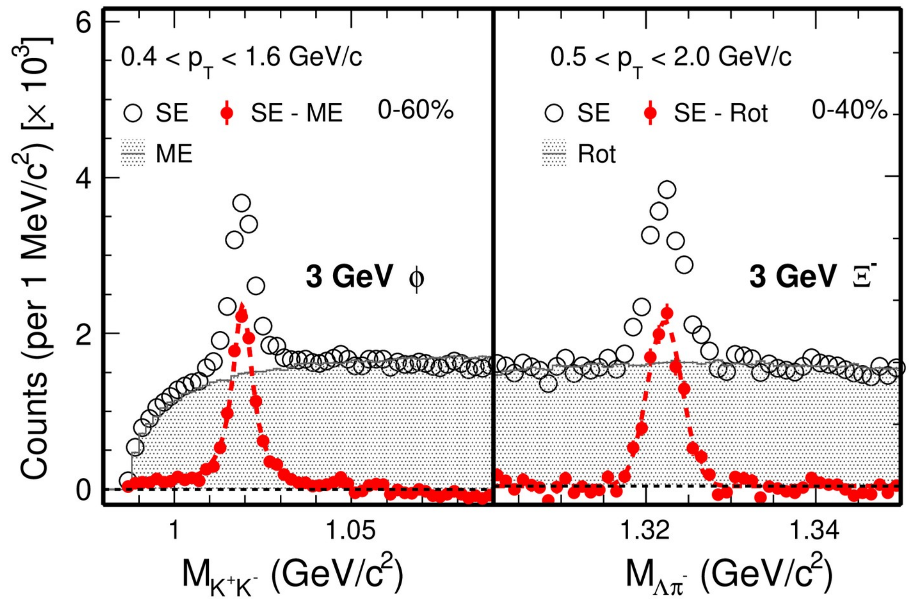
H. van Hecke, H. Sorge, and N. Xu, Phys. Rev. Lett. 81, 5764 (1998)

Excellent probe to study the early stage of the collision

- *Hydro. model (1): Assumes single T_{ch} for all particles*
- *Hydro. model (2): Assumes different T_{ch} for strange and light hadrons (π, k, p)*

Strange Hadrons Reconstruction





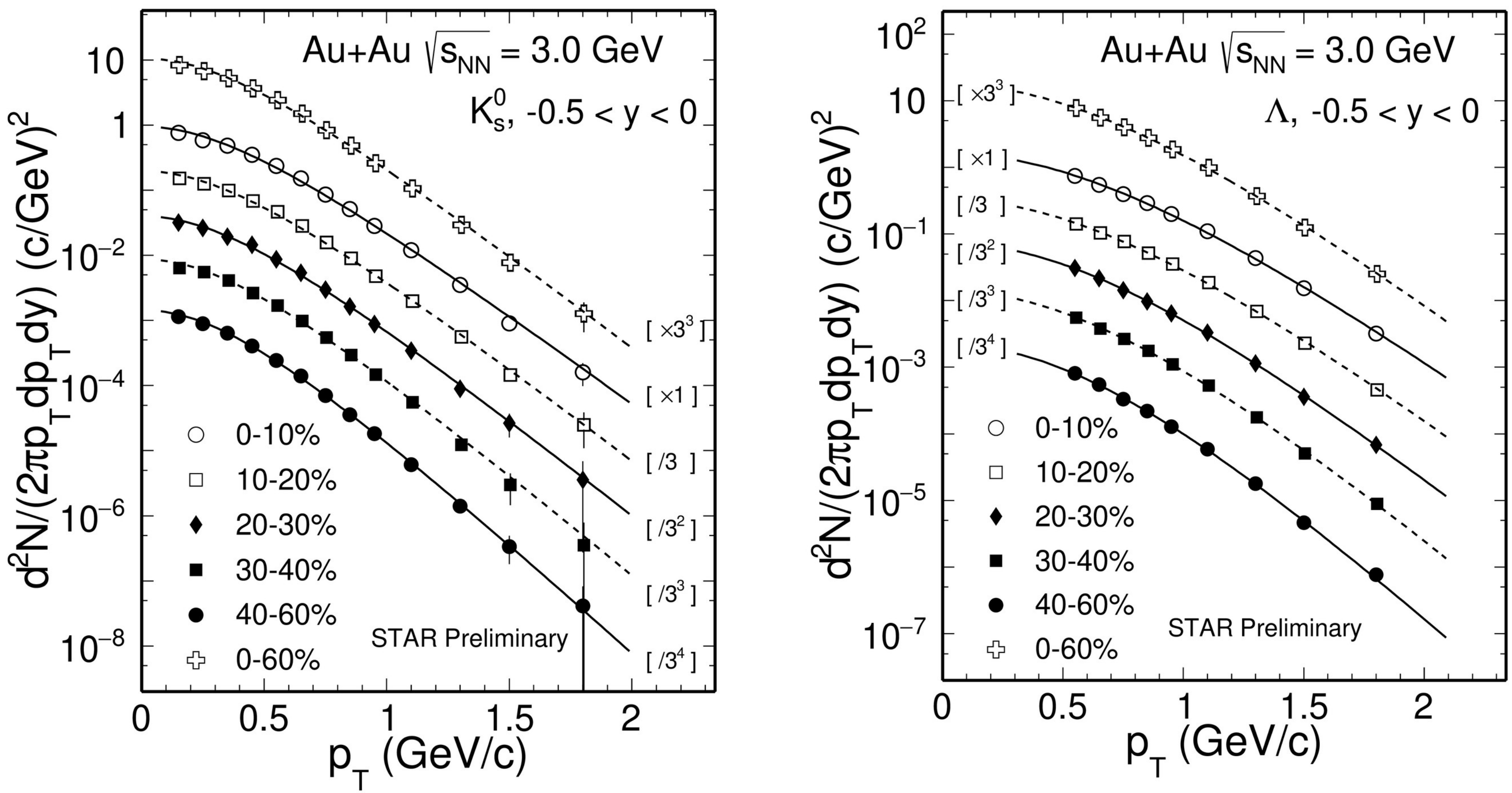
STAR: arXiv:2108.00924

- **<u>Decay channels:</u>**
  $\Lambda \rightarrow p\,\pi^-$
  $K^0_S \rightarrow \pi^+\pi^-$

- **<u>Decay channels:</u>**
  $\phi \rightarrow K^+K^-$
  $\Xi^- \rightarrow \Lambda\,\pi^-$

- Strange hadrons are reconstructed using invariant mass method
- Combinatorial background estimated using mixed event / pair rotation method

Invariant Yield of Strange Hadrons

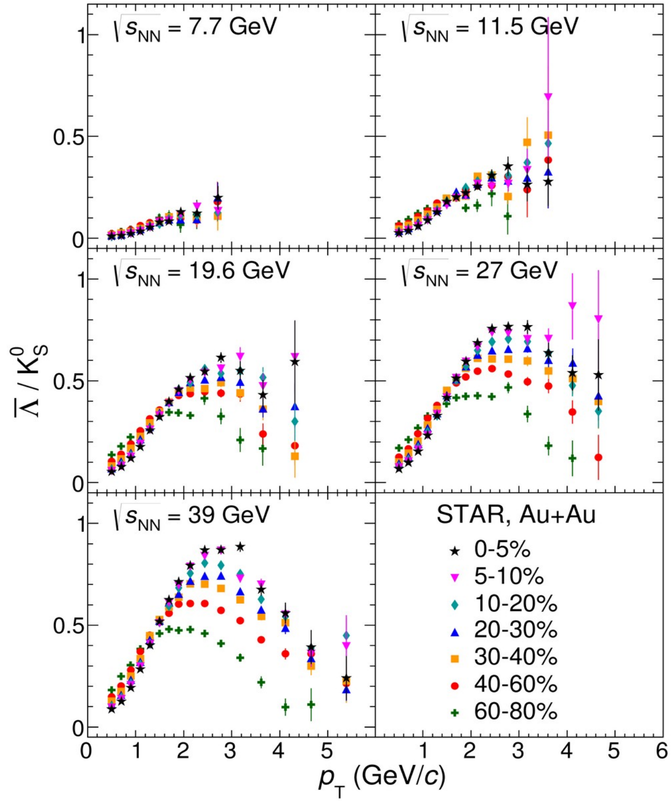


New

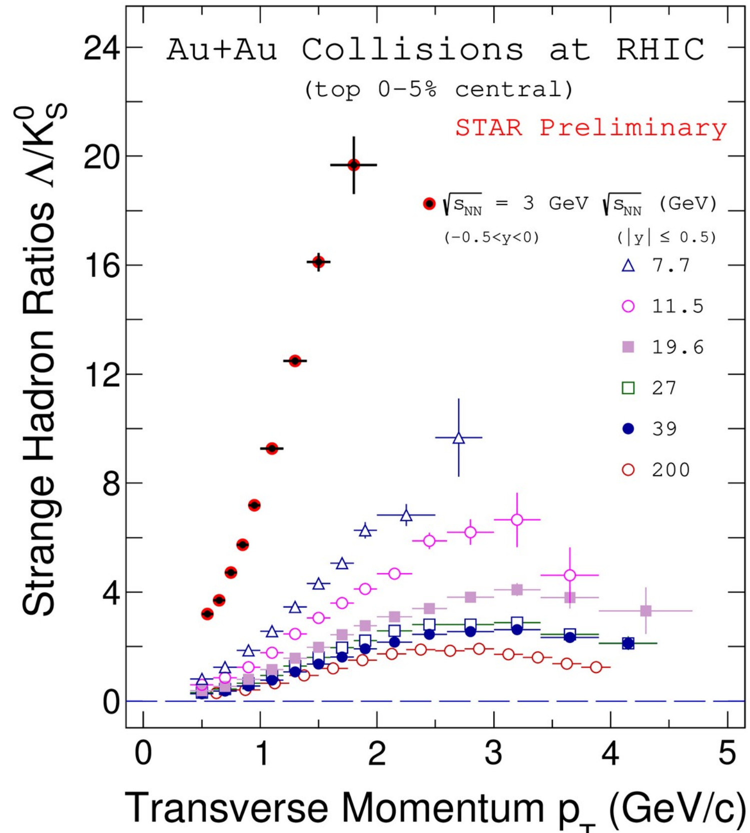
- Blast wave function is used to fit the p_T-spectra

Schnedermann et al:Phys.Rev. C48, 2462 (1993)

Λ/K^0_s Ratio (p_T)



STAR: Phys. Rev. C 102 (2020) 34909



New
3 GeV

See poster by Yingjie Zhou, Apr 8, 2022, T11_2

STAR: Phys. Rev. Lett. 108, 072301 (2012)

According to thermal model:

$$\frac{N(\Lambda)}{N(K_s^0)} \propto \exp\left(\frac{\mu_B(1-\sigma_s)}{T}\right)$$

$$\sigma_s = \frac{\mu_s}{\mu_B}$$

- **Au+Au $\sqrt{s_{NN}} \geq$ 19.6 GeV :** $\bar{\Lambda}/K^0_s$ shows centrality dependence and enhancement at intermediate p_T

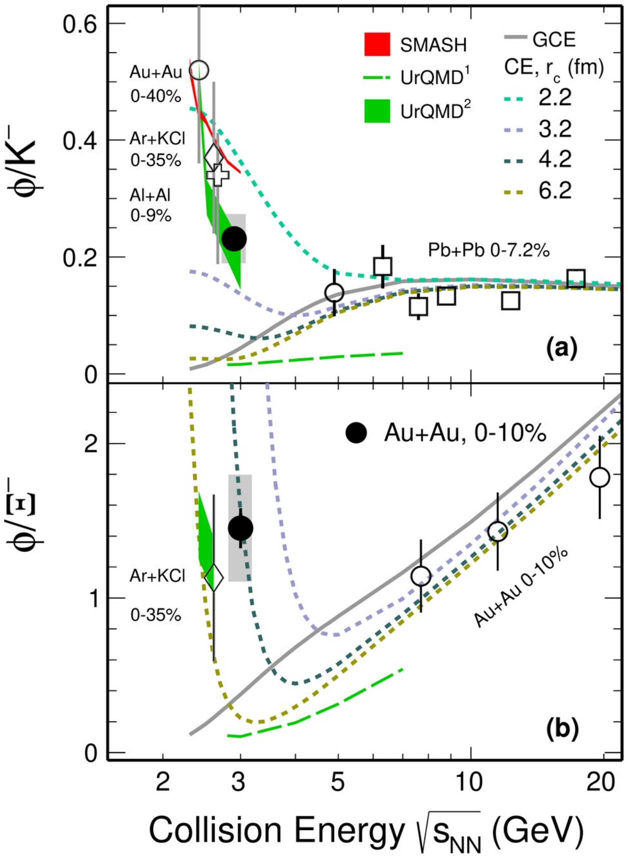
  Consistent with quark coalescence and partonic flow.

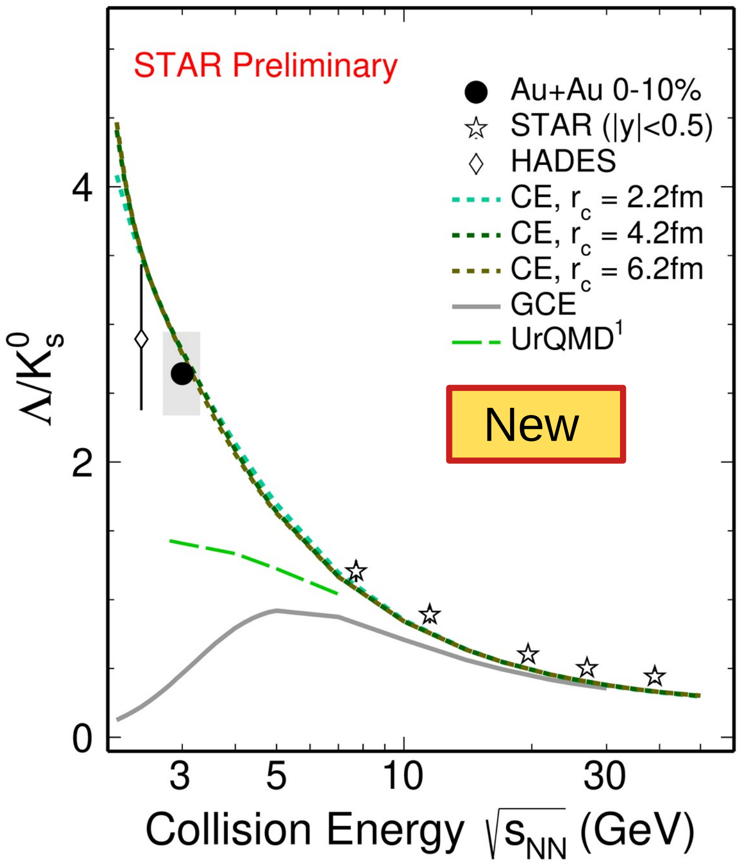
  V. Minissale, F. Scardina, and V. Greco. Phys. Rev. C 92, 054904 (2015)

- **Au+Au $\sqrt{s_{NN}}$ = 3 GeV:** Λ/K^0_s ratio increases faster with p_T compared to higher energies

  Baryon chemical potential driven?

Particle Ratios vs $\sqrt{s_{NN}}$





Data compilation: arXiv: 2108.00924
STAR: Phys. Rev. C 102 (2020) 34909
HADES: Eur. Phys. J. A (2016) 52: 178
UrQMD[1]: Prog. Part. Nucl. Phys. 41 (1998) 225-370
UrQMD[2]: J. Phys. G: Nucl. Part. Phys. 43, 015104 (2015)
SMASH: Phys. Rev. C 99, 064908 (2019).
Thermal CE: Phys. Lett. B 603, 146 (2004)

See poster by Yingjie Zhou, Apr 8, 2022, T11_2

➔ r_c : Correlation length

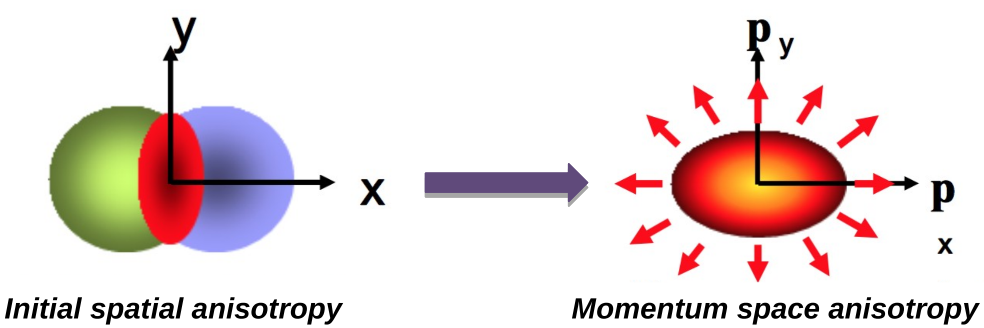
$\sqrt{s_{NN}}$ = 3 GeV : 1) Thermal model with CE explains the data

2) GCE underpredicts the data

- May suggest that local strangeness conservation is important at low energy

Azimuthal Anisotropy

Pressure gradient transfers initial spatial anisotropy to final state momentum space anisotropy

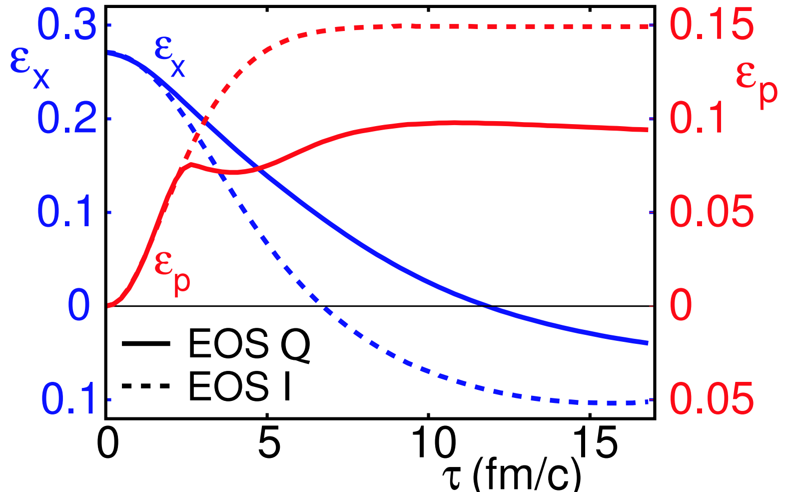


$$E\frac{d^3N}{dp^3}=\frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}[1+2v_1\cos(\phi-\psi_R)+2v_2\cos2(\phi-\psi_R)+.....]$$

v_1 – Directed flow

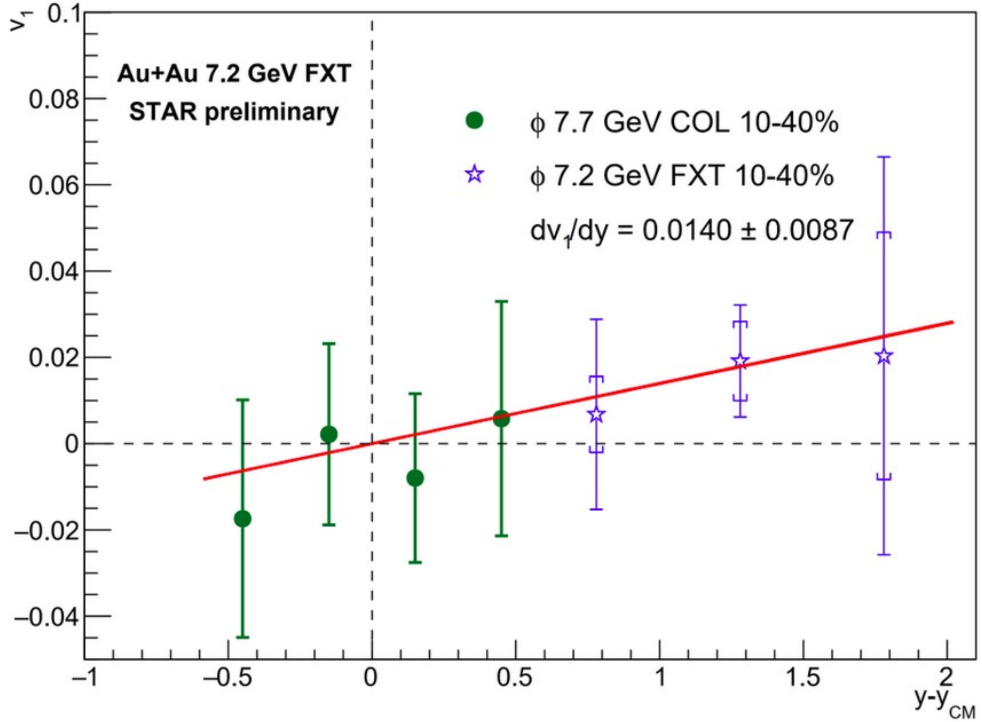
v_2 – Elliptic flow

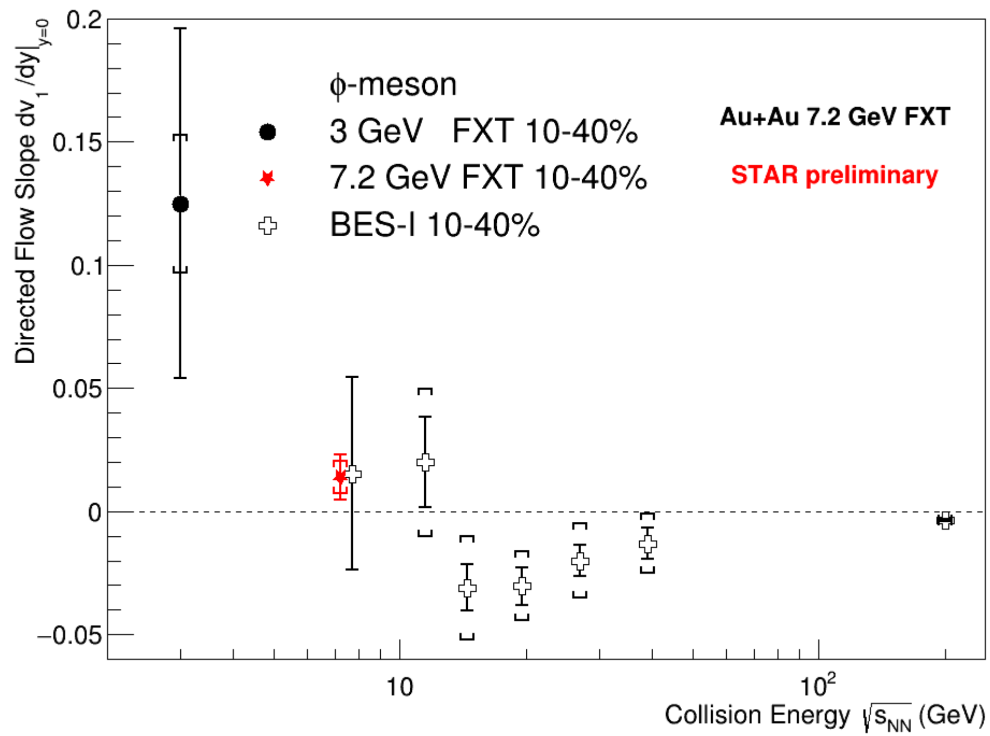
Sensitive to initial dynamics



arXiv:nucl-th/0305084

Directed Flow (v_1)



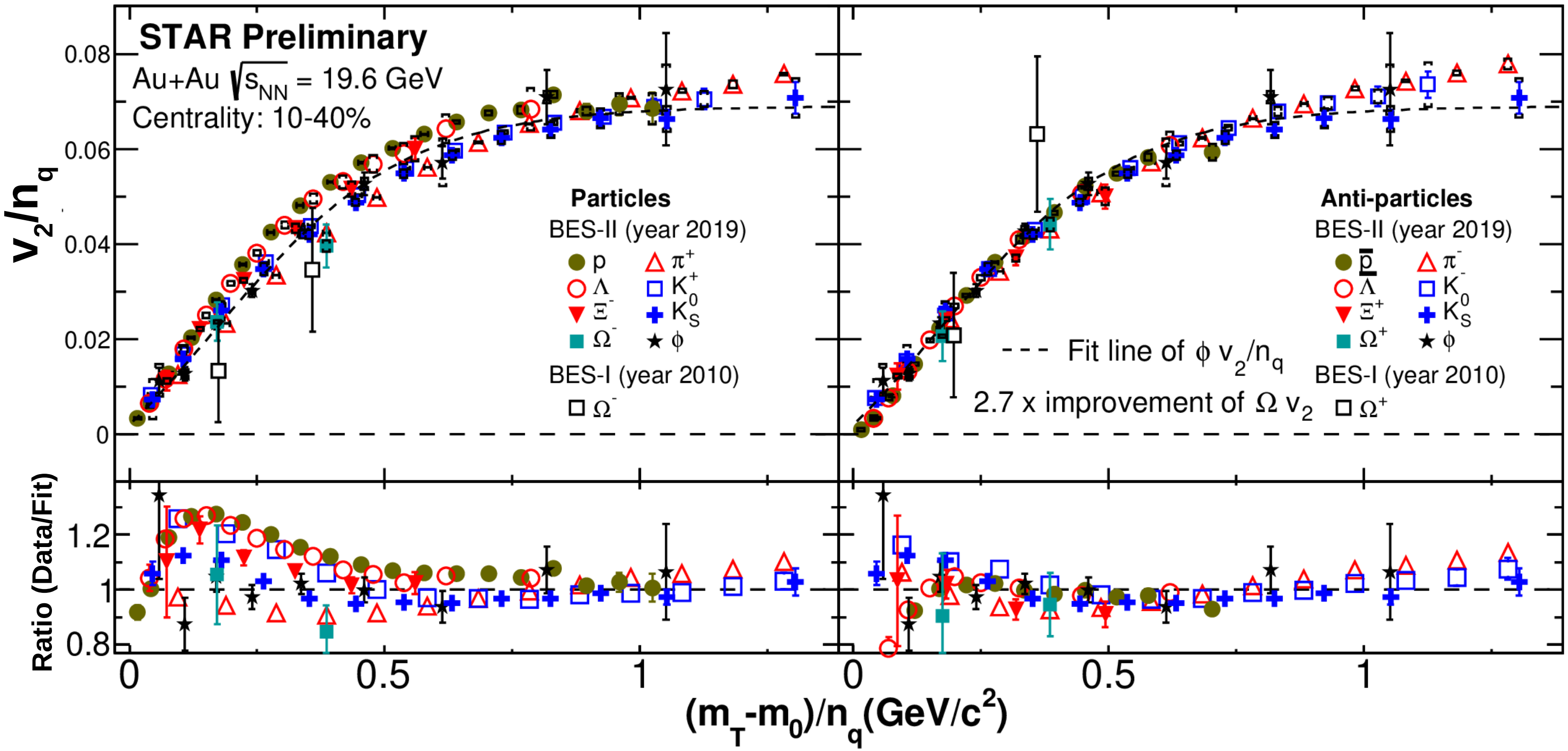


- With decreasing $\sqrt{s_{NN}}$, ϕ-meson v_1 slope shows a trend of turning from negative to positive
  - *This may indicate a change of equation of state at low energy*

STAR: Phys.Lett.B. 827(2022) 137003.

See poster by Ding Chen, Apr 8, 2022, T11_4

NCQ Scaling of v_2



New

See poster by Li-Ke Liu, Apr 8, 2022, T11_4

$v_2(\Omega)$: Statistical errors are reduced by a factor of 2.7 in BES-II

- NCQ scaling holds within 20% for particles and corresponding anti-particles: *Evidence of partonic collectivity*
- NCQ scaling holds better for anti-particles than for particles: *Transported quark effect*

Part A: Summary

Au+Au, $\sqrt{s_{NN}} \geq 19.6$ GeV :

- $\overline{\Lambda}/K^0_s$ ratio shows centrality dependence and enhancement at intermediate p_T
- Number of constituent quark scaling holds within 20%

Suggest the formation of deconfined quark matter

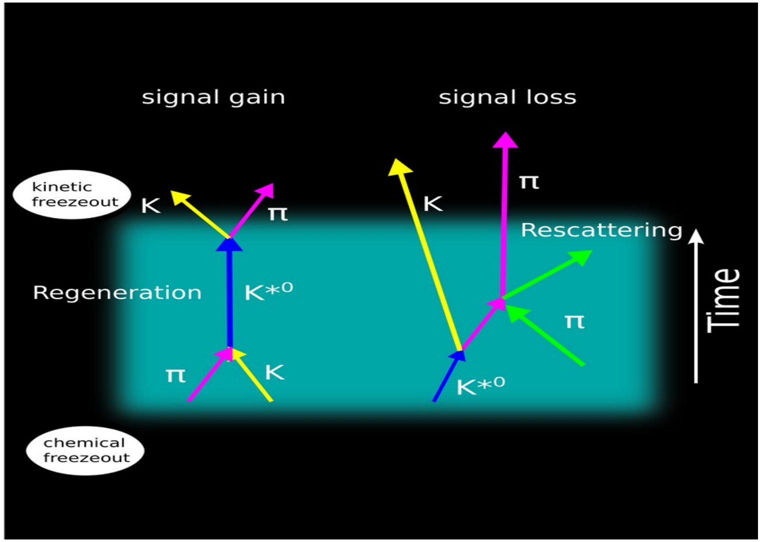
Au+Au, $\sqrt{s_{NN}} = 3$ GeV :

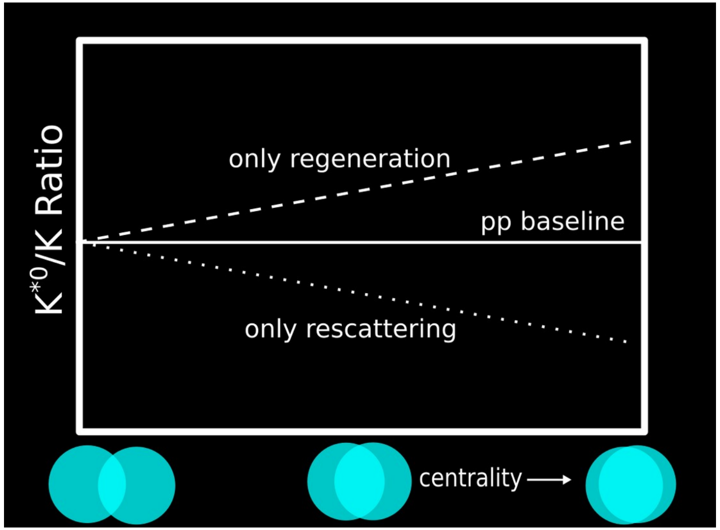
- Thermal model with CE explains measured particle ratios, whereas GCE fails
- ϕ-meson dv_1/dy hints at a sign change

Medium created is likely hadronic interaction dominated

Probing Hadronic Phase Using K^{*0} Resonance

Rescattering and Regeneration:



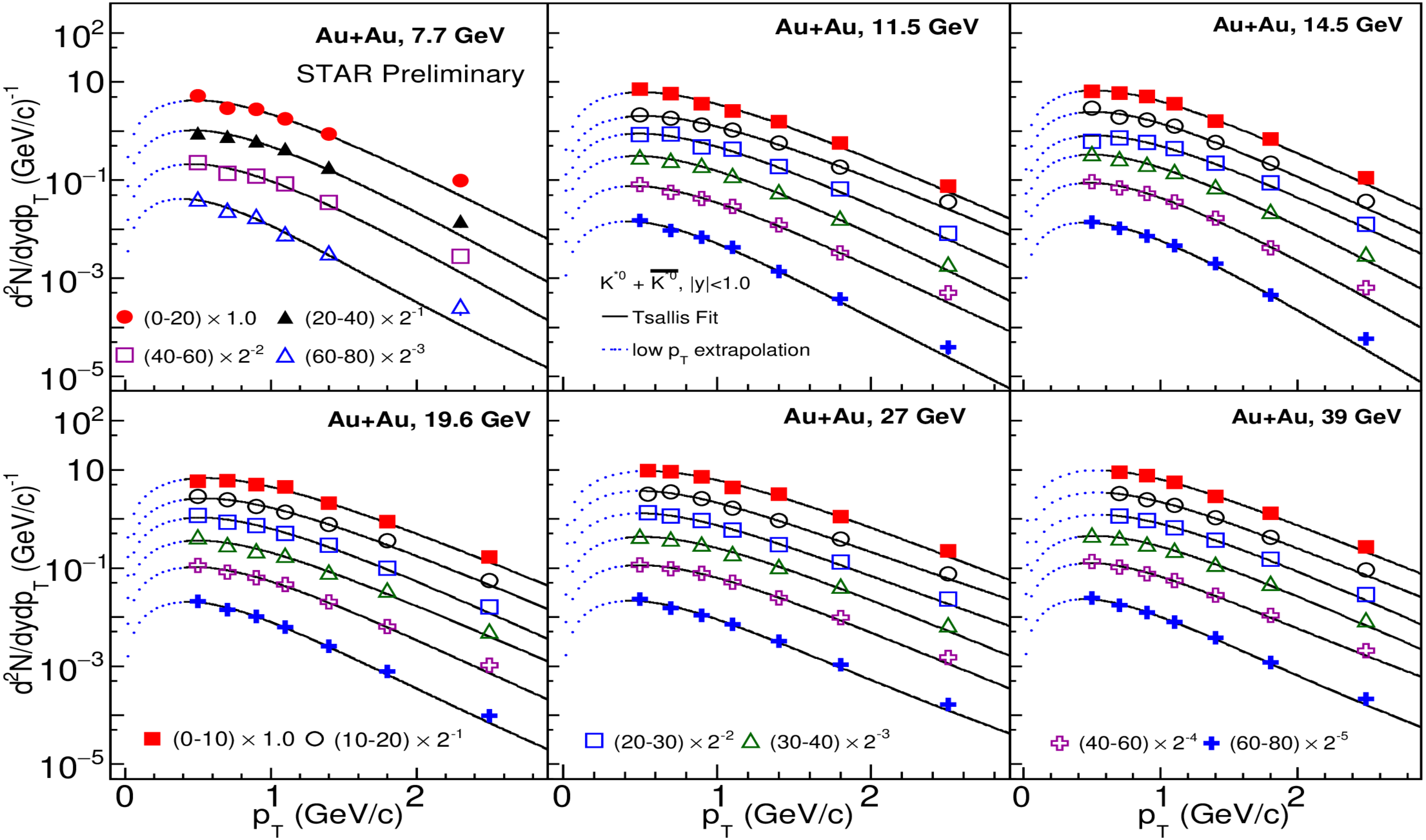


Resonances	t(fm/c)
Φ (1020)	45
K^{*0} (896)	4

Resonances are good probe to study the hadronic phase of the collision

STAR. Phys. Rev. C 66 (2002) 61901

Transverse Momentum Spectra of K*⁰

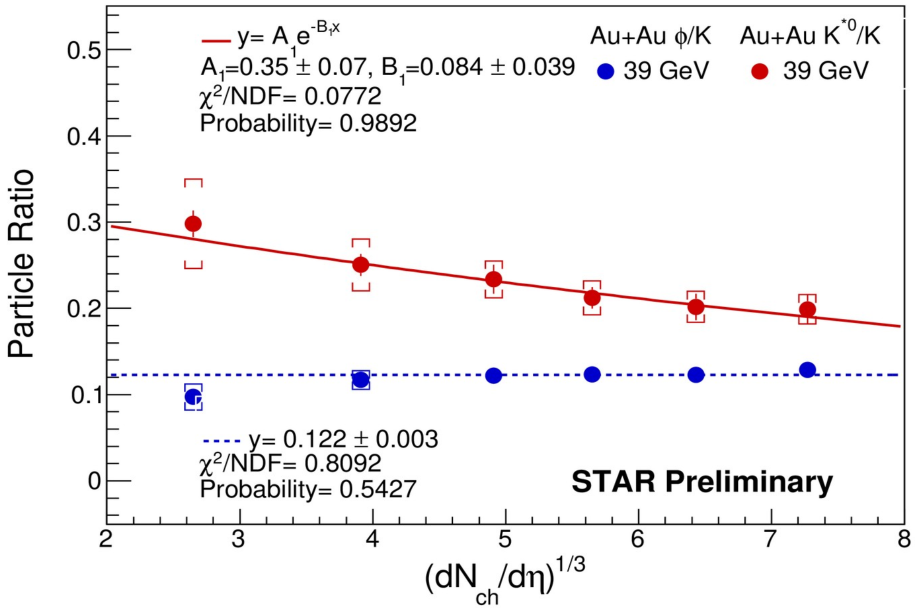


New

- Levy Tsallis function is used to extrapolate yield at low p_T region

J. Statist. Phys., 52:479–487, 1988

K^{*0}/K Ratio



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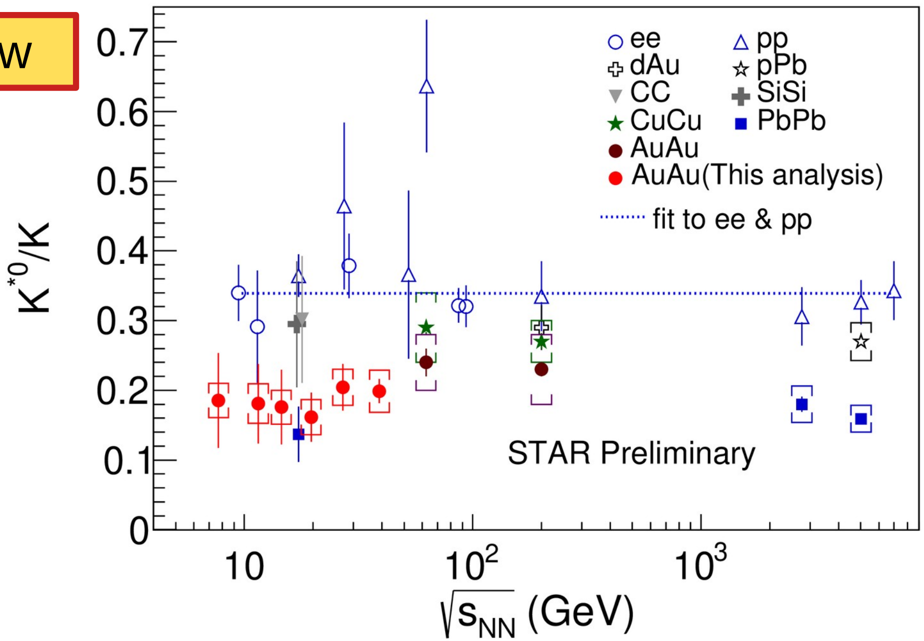

- Here K^{*0} denotes $K^{*0} + \overline{K^{*0}}$ and K denotes $K^{+}+K^{-}$

- The K^{*0}/K ratio for A+A collisions are for most central collision

- $(K^{*0}/K)_{central} < (K^{*0}/K)_{peripheral}$
- $(K^{*0}/K)_{central} < (K^{*0}/K)_{pp/ee\text{-}reference}$
- (φ/K): independent of centrality

Favors dominant hadronic re-scattering in central A+A collisions

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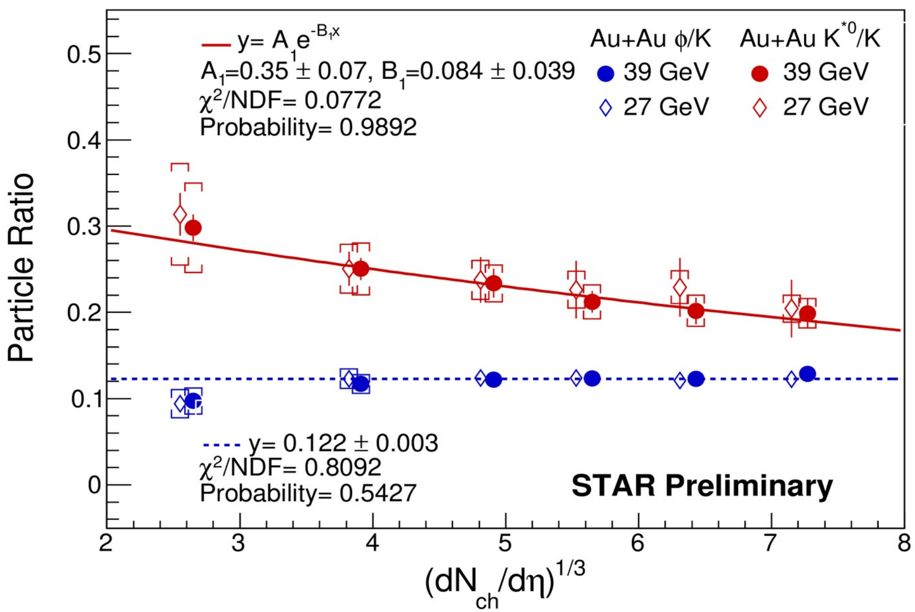
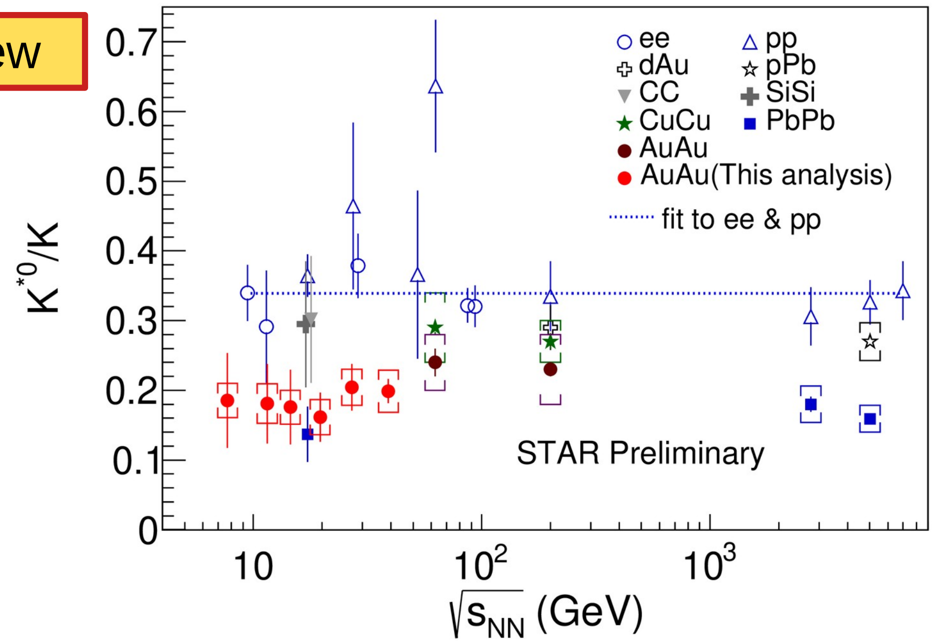
K*⁰/K Ratio



New



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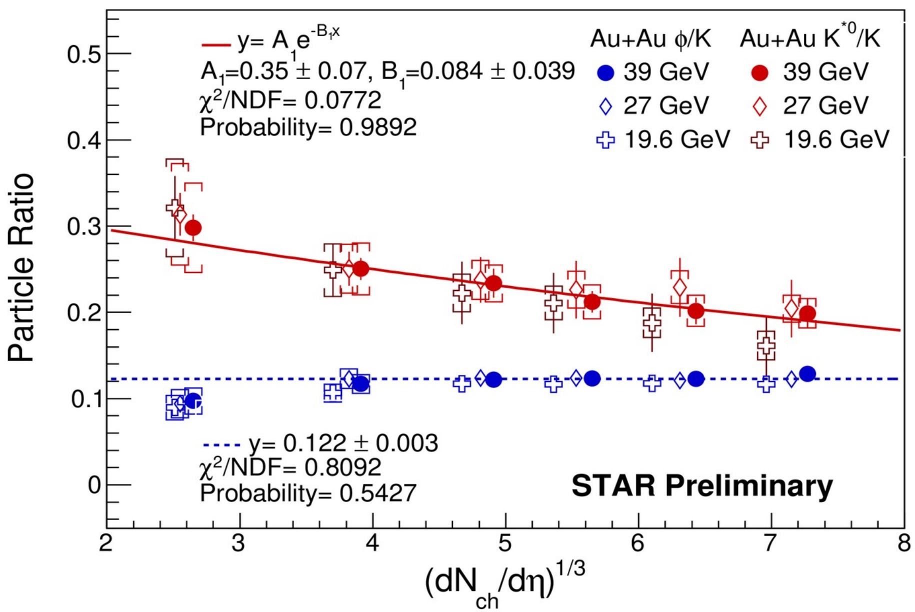

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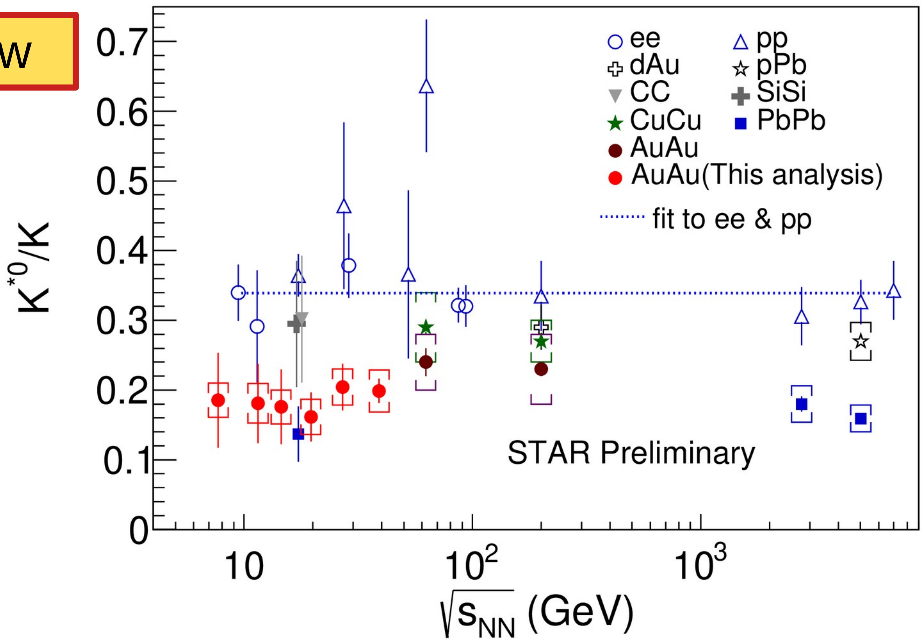

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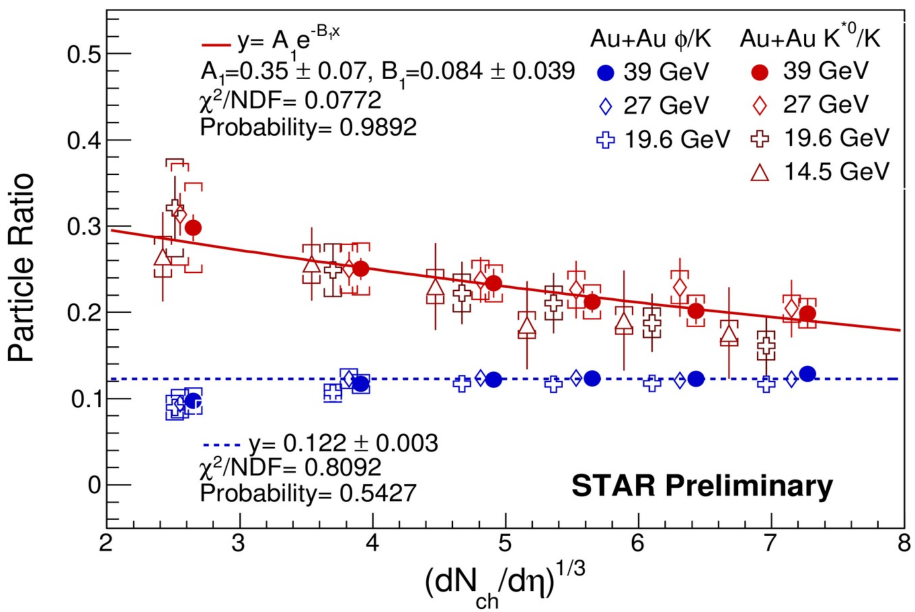

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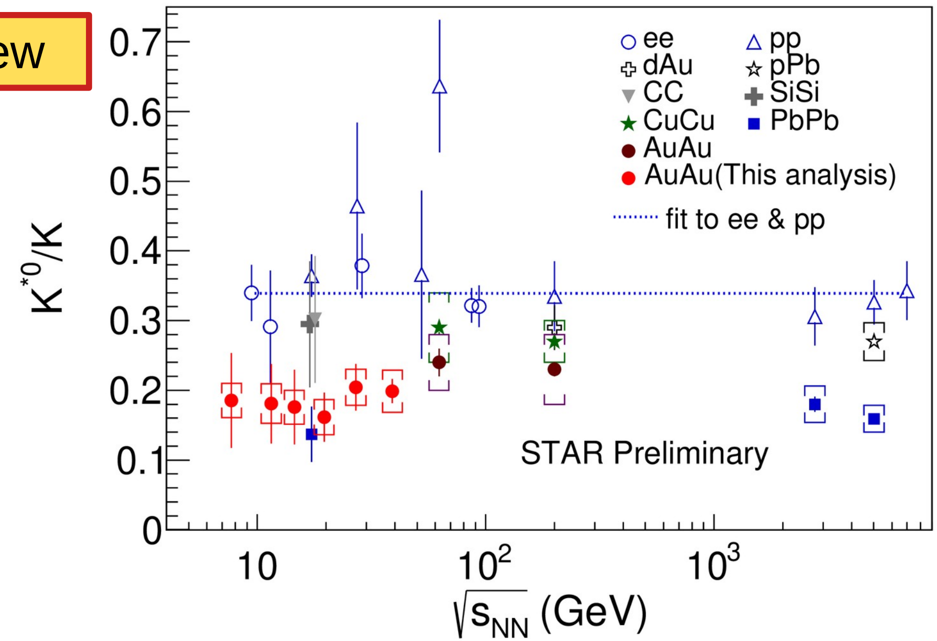

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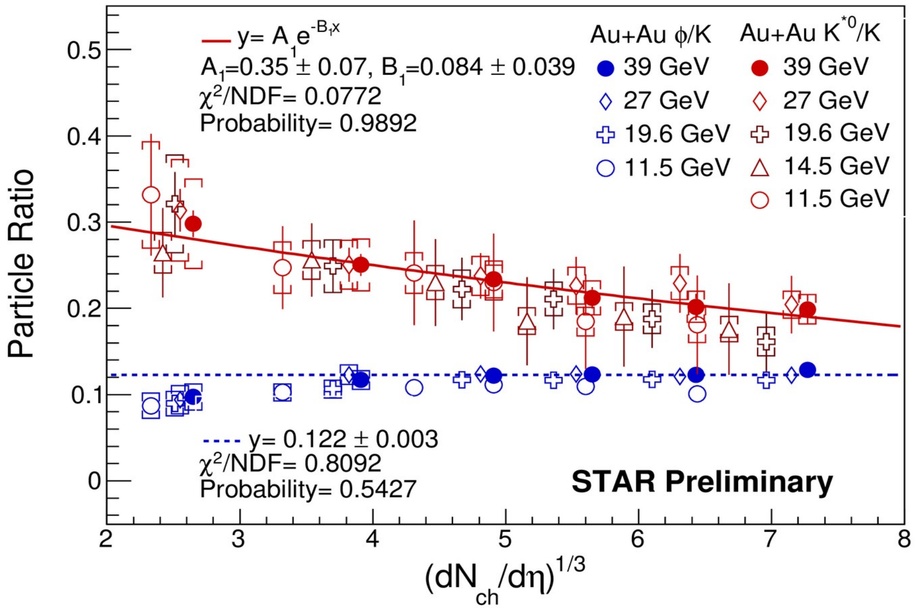

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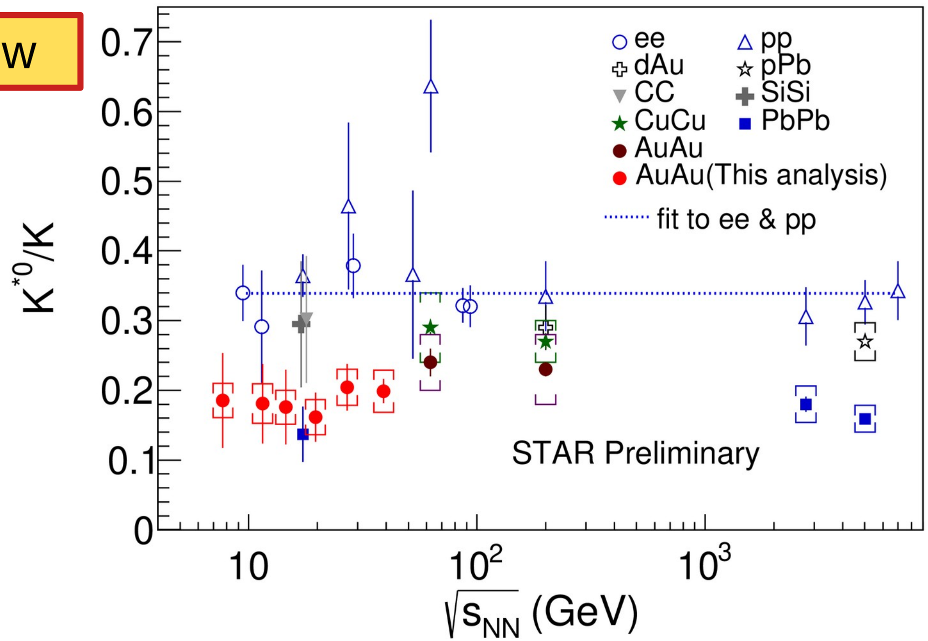

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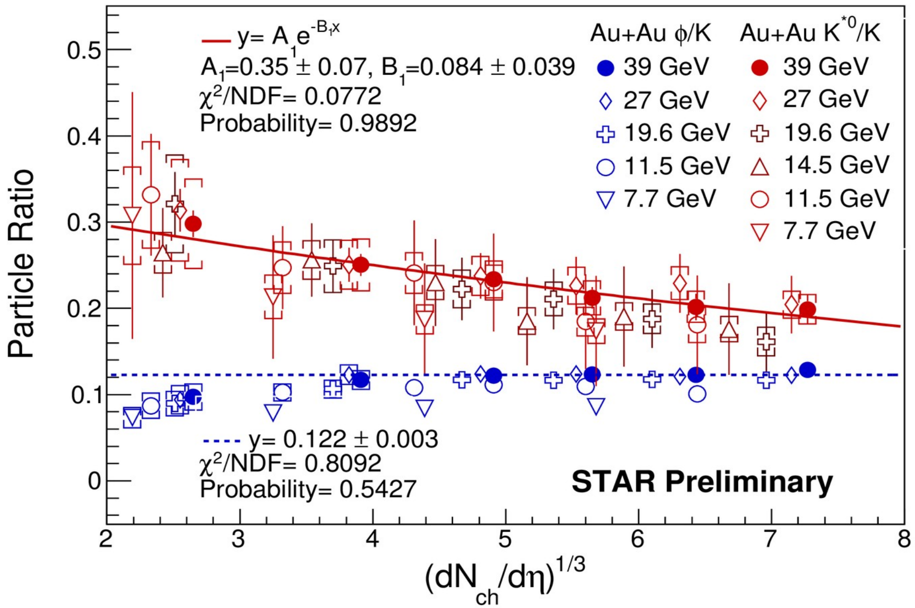

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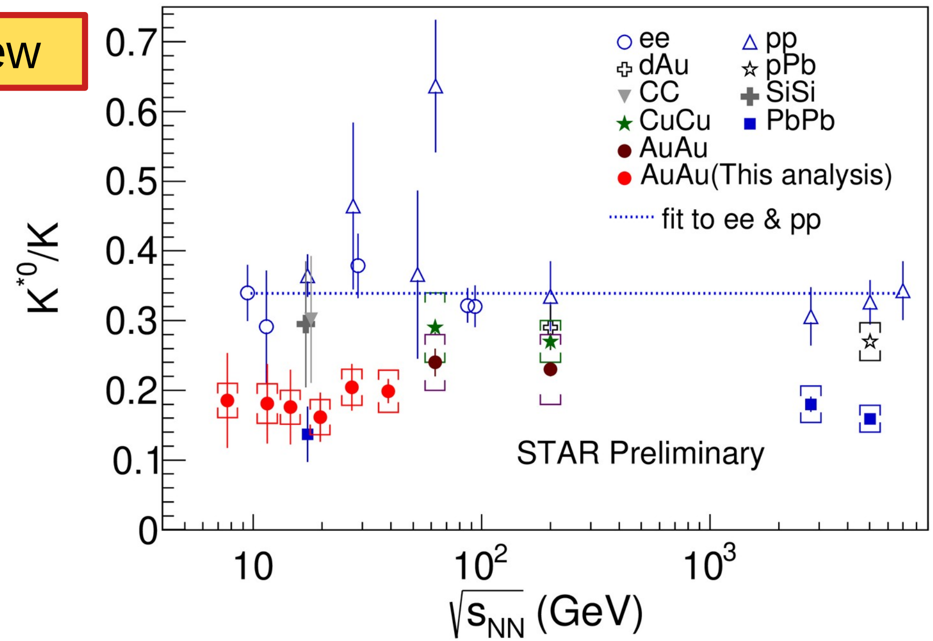

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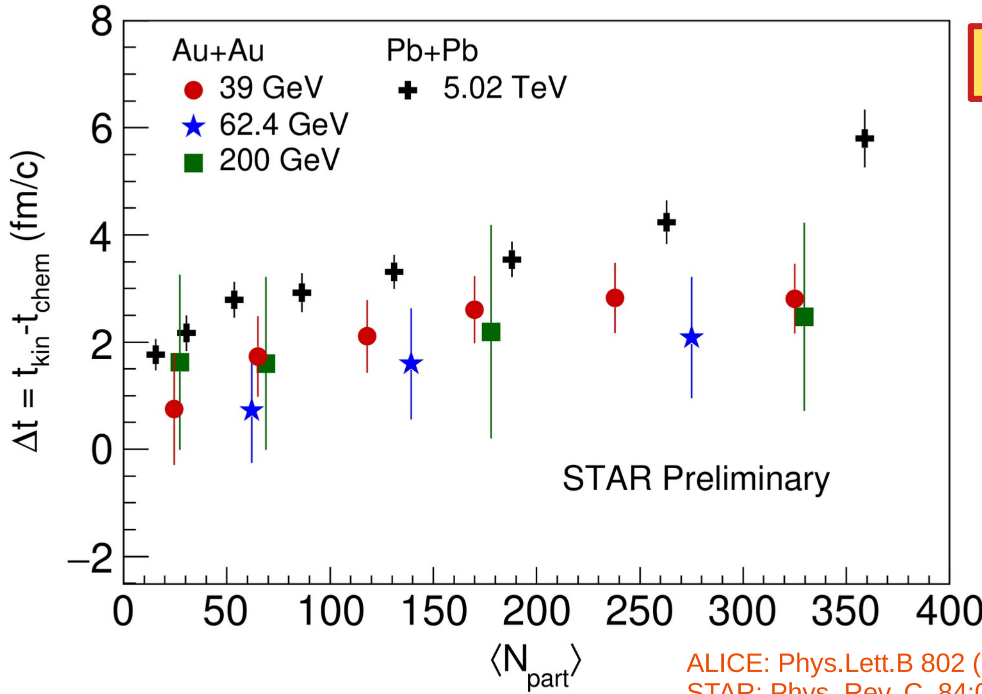
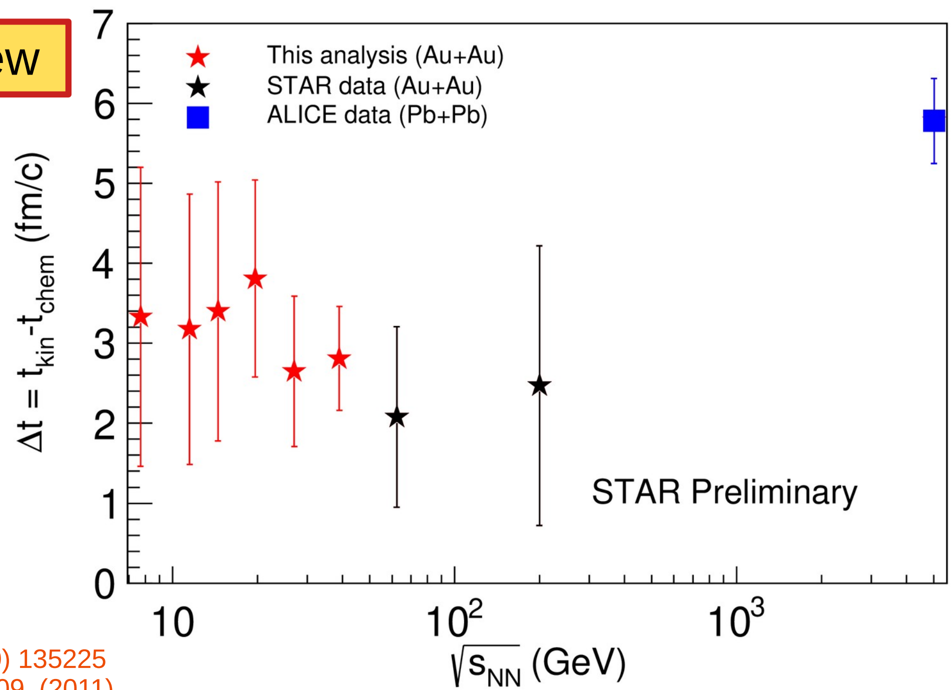
Hadronic-Phase Lifetime



New



ALICE: Phys.Lett.B 802 (2020) 135225
STAR: Phys. Rev. C, 84:034909, (2011)

- $(K^{*0}/K)_{kin} = (K^{*0}/K)_{chem} \times e^{-\Delta t/\tau}$
  where, Δt = Hadronic phase lifetime ($t_{kin} - t_{chem}$)
  τ = Lifetime of K^{*0}

- Here we can take
  $(K^{*0}/K)_{kin} \approx (K^{*0}/K)_{AA}$
  $(K^{*0}/K)_{chem} \approx (K^{*0}/K)_{pp}$

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➔ errors are quadratic sum of statitical and systematic errors

- ***Hadronic phase lifetime at RHIC seems to be smaller than LHC (more statistics is needed for confirmation)***

Part B: Summary

- Production of K^{*0} in BES-I Au+Au collisions at 7.7-39 GeV is presented
- K^{*0}/K ratio suggests dominance of hadronic rescattering over regeneration in central Au+Au collisions
- Energy dependence of hadronic phase ($t_{kin} - t_{chem}$) lifetime (using toy model) is reported

Thank you ......