φ-meson Production in Heavy-Ion Collisions at RHIC

Sarah Blyth
for
The STAR Collaboration

Strangeness in Quark Matter 2006

Motivation

Why the φ-meson?

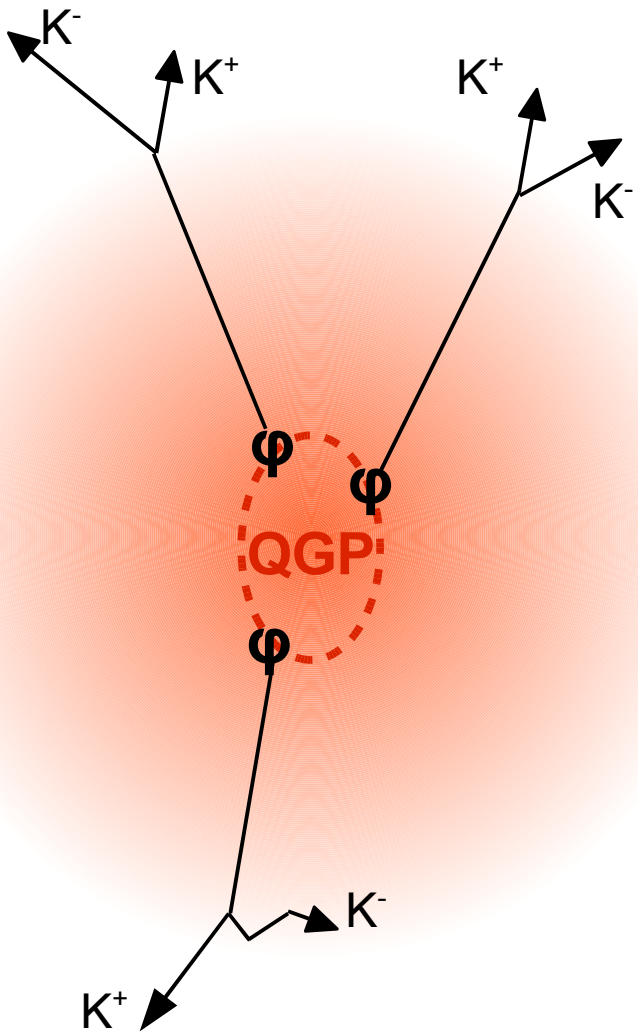
The medium produced in HI collisions is very short-lived → we need probes which carry information from the early stage to find out about the medium constituents:

*The φ-meson ($s\bar{s}$) is a **clean probe** from **early time**:*

- ***Small σ*** *for interactions with non-strange particles[1]*
- *Relatively long-lived (41 fm/c) →decays **outside** the fireball*
- *Previous measurements have **ruled out K+K coalescence** as φ production mechanism[2] → info no "diluted" by hadronic phase*

*The φ can provide info on **particle production** mechanisms / medium constituents:*

- *The φ is a **meson** but as **heavy** as Λ,p baryons*
  - *Differentiate between mass-type or meson/baryon-type dependencies*



[1] A. Shor, Phys. Rev. Lett. 54 (1985) 11
[2] J. Adams *et al.*, Phys. Lett. B 612 (2005) 181

The STAR Experiment

We used the high-statistics 200 GeV Au+Au data to measure the φ observables at STAR:

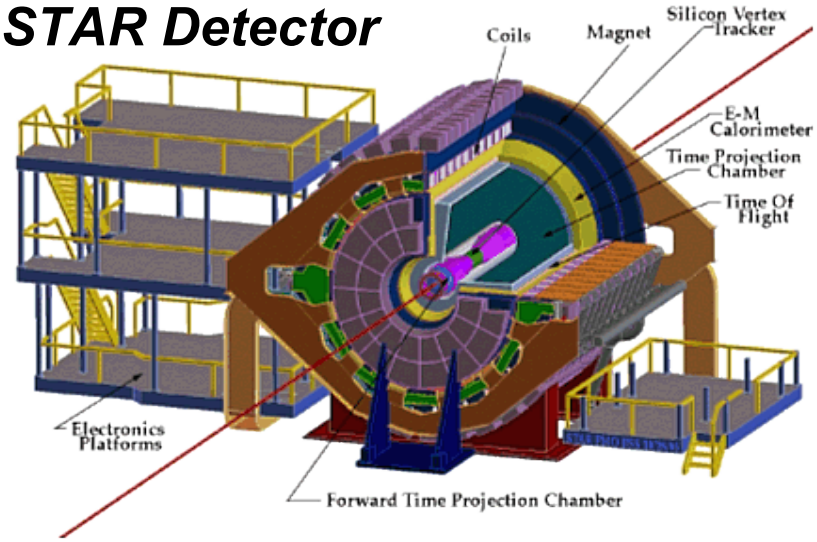
- *~13.5 M minbias (0-80%) events*
- *~13 M central triggered (0-10%) events*

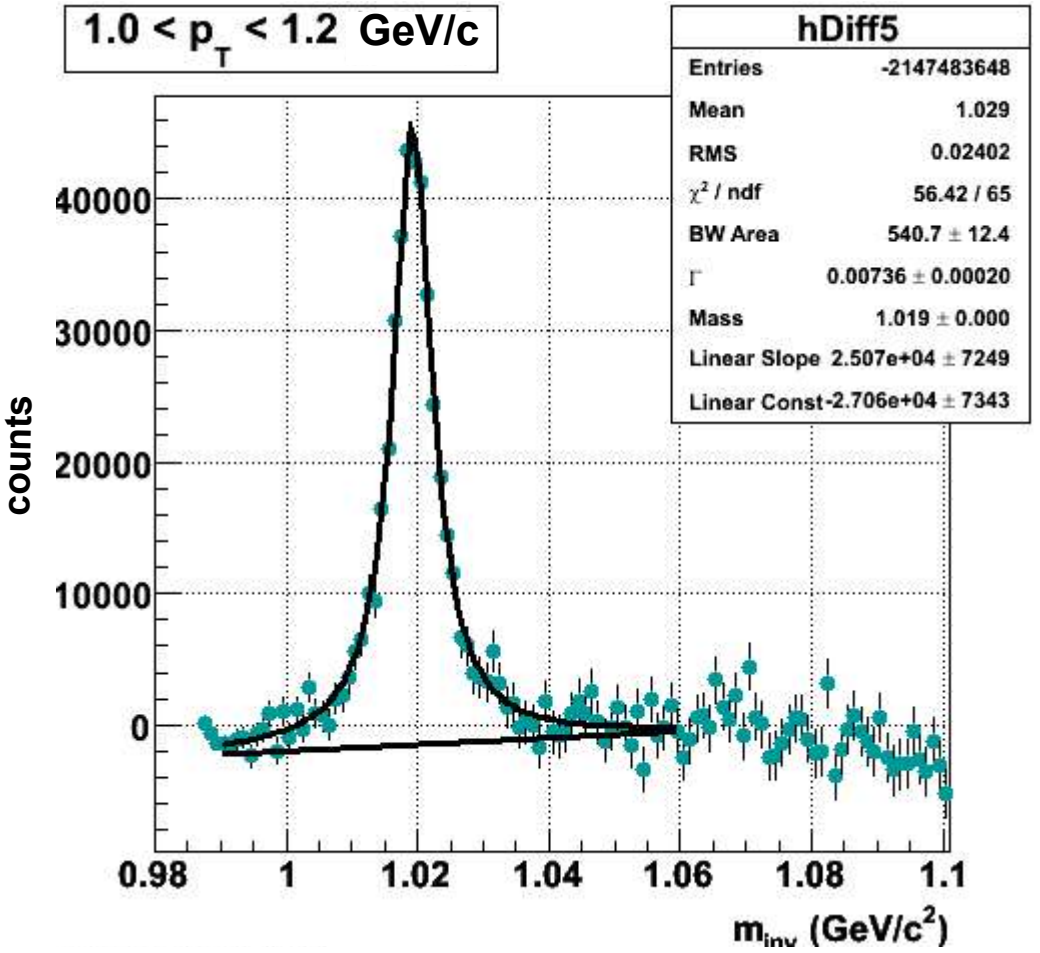
Measured decay channel:

$$\varphi \rightarrow K^+ + K^- \ (BR = 49.1\%)$$

- *STAR TPC used to identify K via dE/dx in TPC gas*

STAR Detector



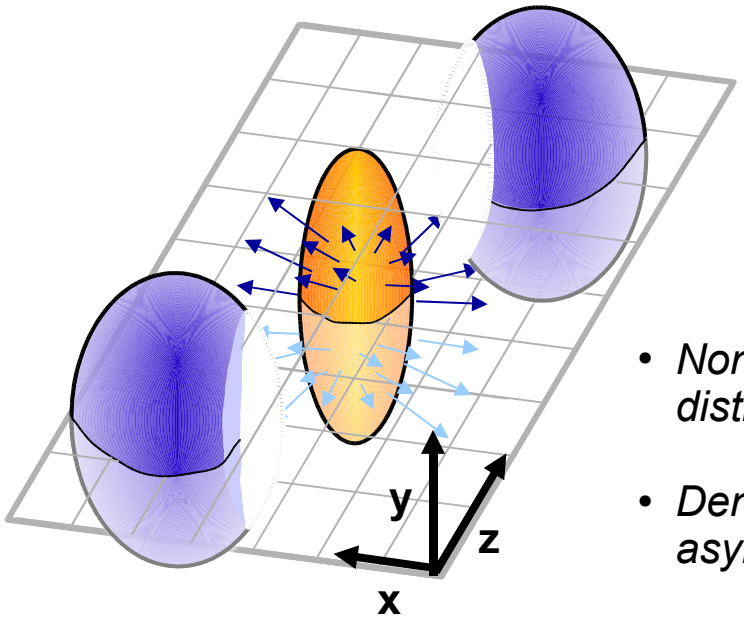


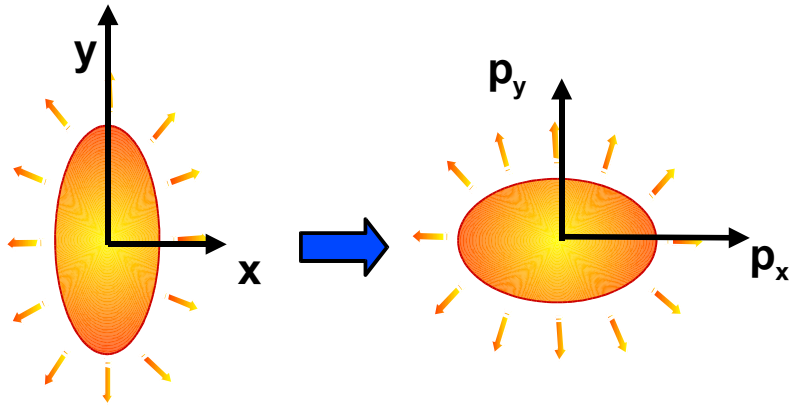
- *Event-mixing method used to estimate background from uncorrelated K^+K^- pairs*
- *Final subtracted m_{inv} distribution fitted with Breit-Wigner + straight line*

Elliptic Flow

Signal from the early stage

Elliptic flow provides early time information on the collectivity of particles from heavy-ion collisions:





- *Non-central A+A collisions result in an azimuthally anisotropic distribution of particles in **coordinate-space***
- *Density gradients and **interactions** between the particles lead to an asymmetry in momentum-space*
- *Signal is **self-quenching** with time – **EARLY TIME OBSERVABLE!***

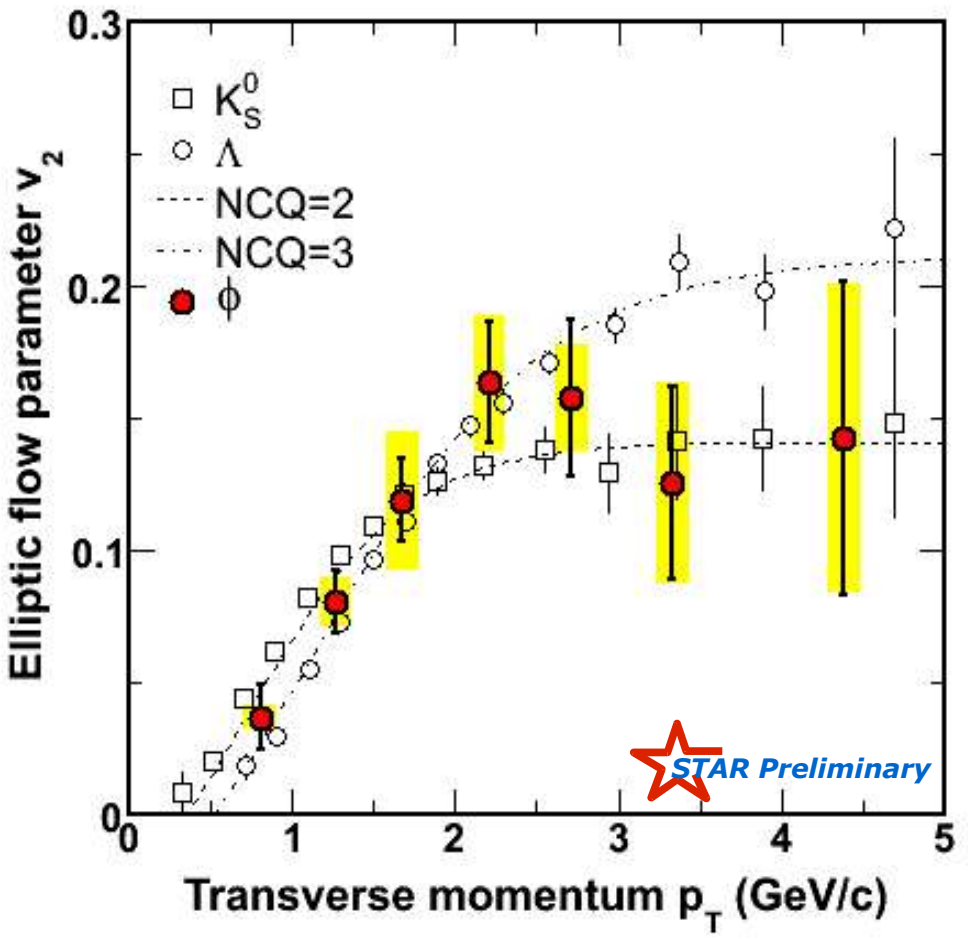
- *Expanding in a Fourier series:*

$$E\frac{d^3N}{d^3p}=\frac{1}{\pi}d^2\frac{N}{dp_T^2\,dy}\left[1+2v_1\cos(\phi)+2v_2\cos(2\phi)+\ldots\right] \quad \Rightarrow \quad v_2=\langle\cos(2\phi)\rangle$$

Early time information

The φ experiences significant elliptic flow! (result is mean of 2 different, but consistent methods):

v_2 vs. p_T



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- *For p_T<2 GeV/c, φ flows as much as other ID'd particles, consistent with hydro. mass-ordering*
- *For p_T>2 GeV/c, φ v_2 is more consistent with K^0_S than Λ (favors NCQ[1]=2)*
- *Consistent with v_2 of other multi-strange hadrons (Ξ, Ω)[2] i.e. s-quarks flow!*

Particle production mechanisms:

- *Further evidence of species-type dependence of v_2 at intermediate p_T (described by recombination/ coalescence models[3])*

[1] X. Dong *et al*., Phys. Lett. B, 597 (2004) 328
[2] STAR Collab. Phys. Rev. Lett. 95 (2005) 122301
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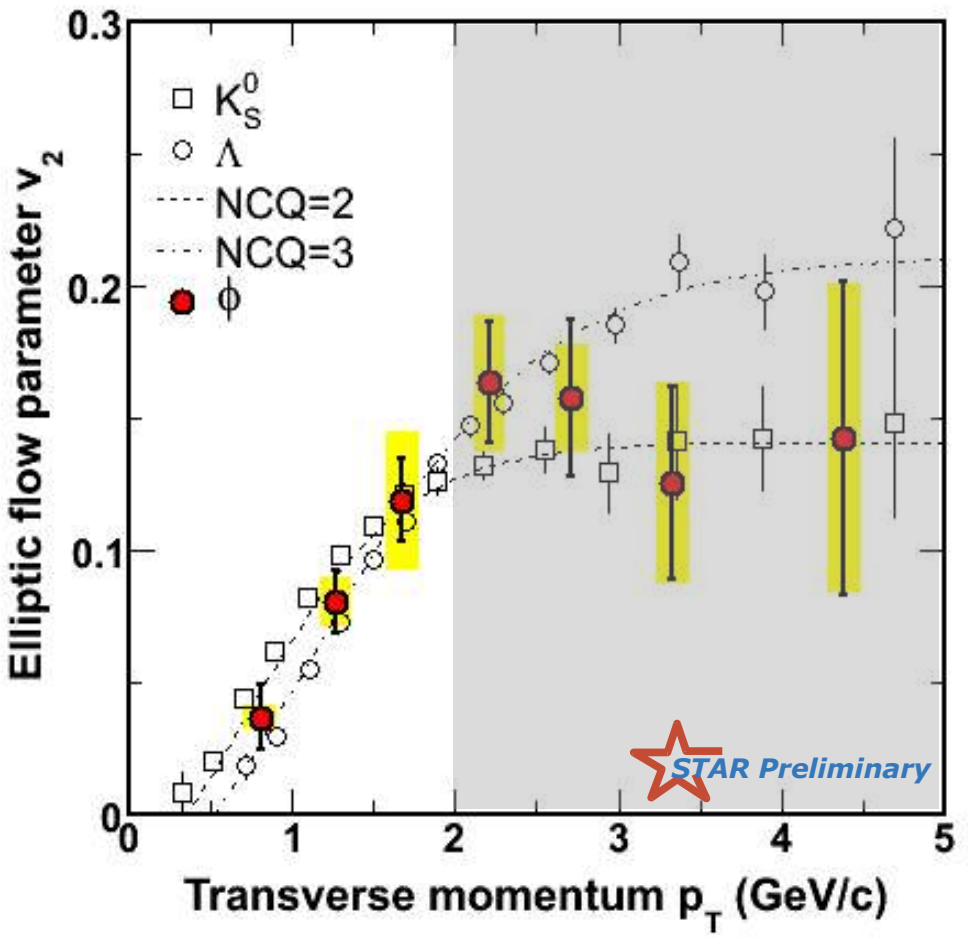

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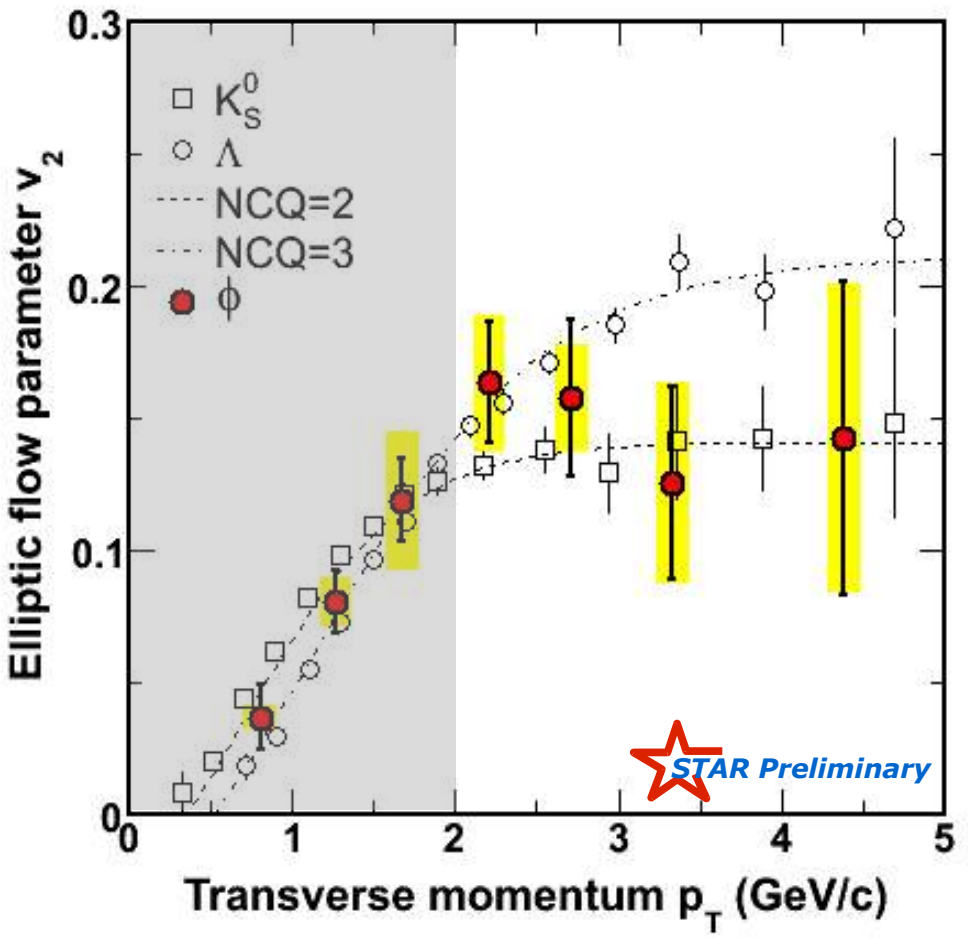

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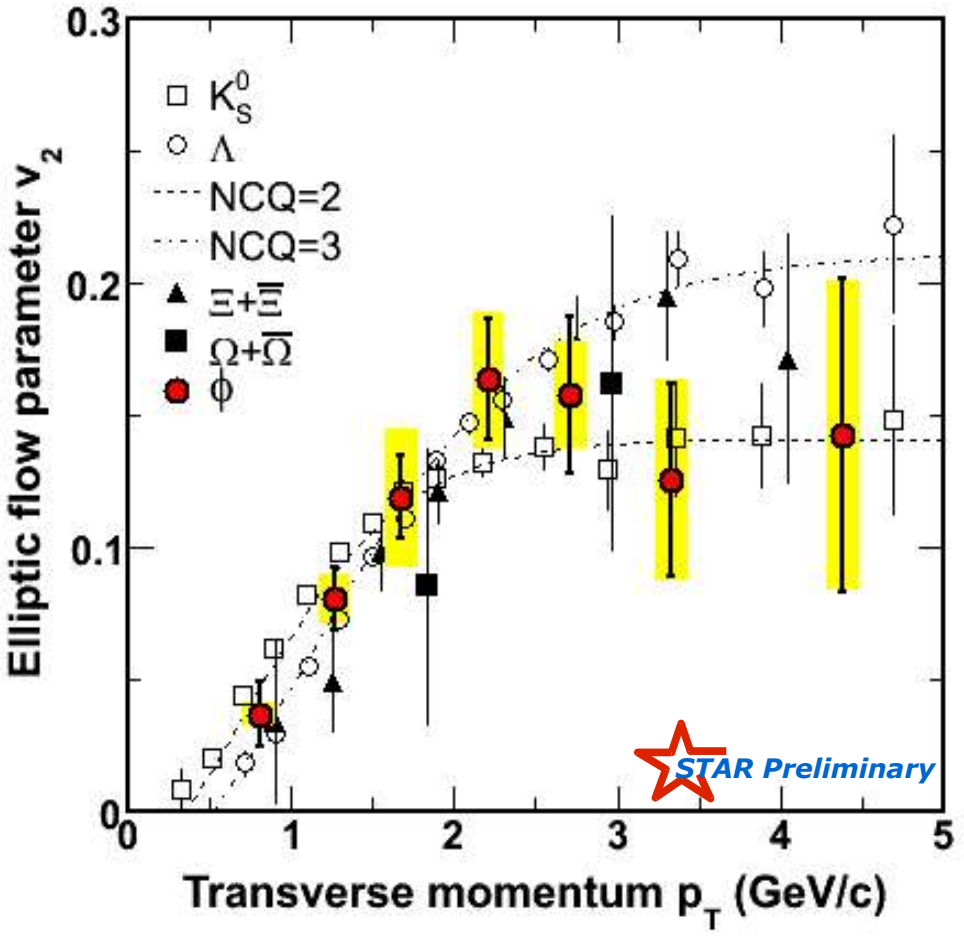

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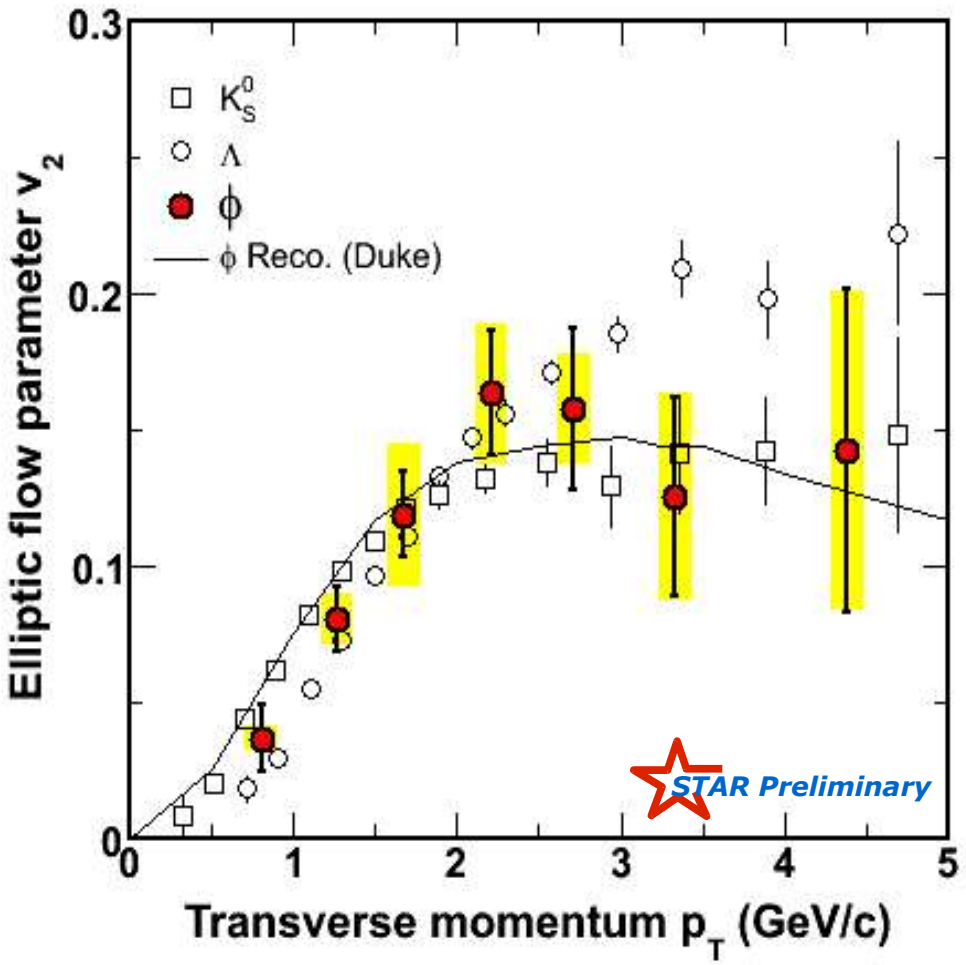

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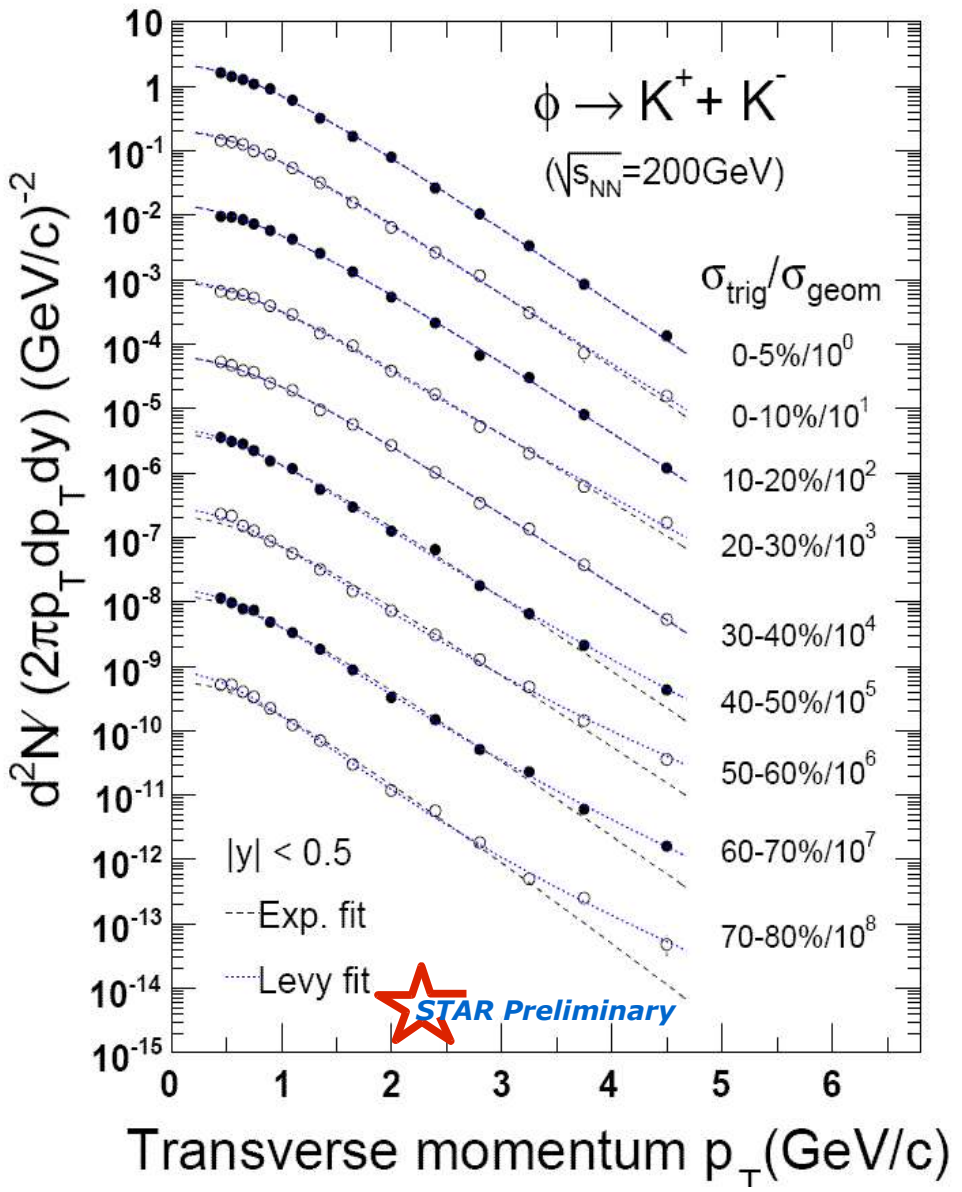
Particle Production I

φ Spectra

The shape of the φ p_T spectra provide information on the mechanisms of particle production:

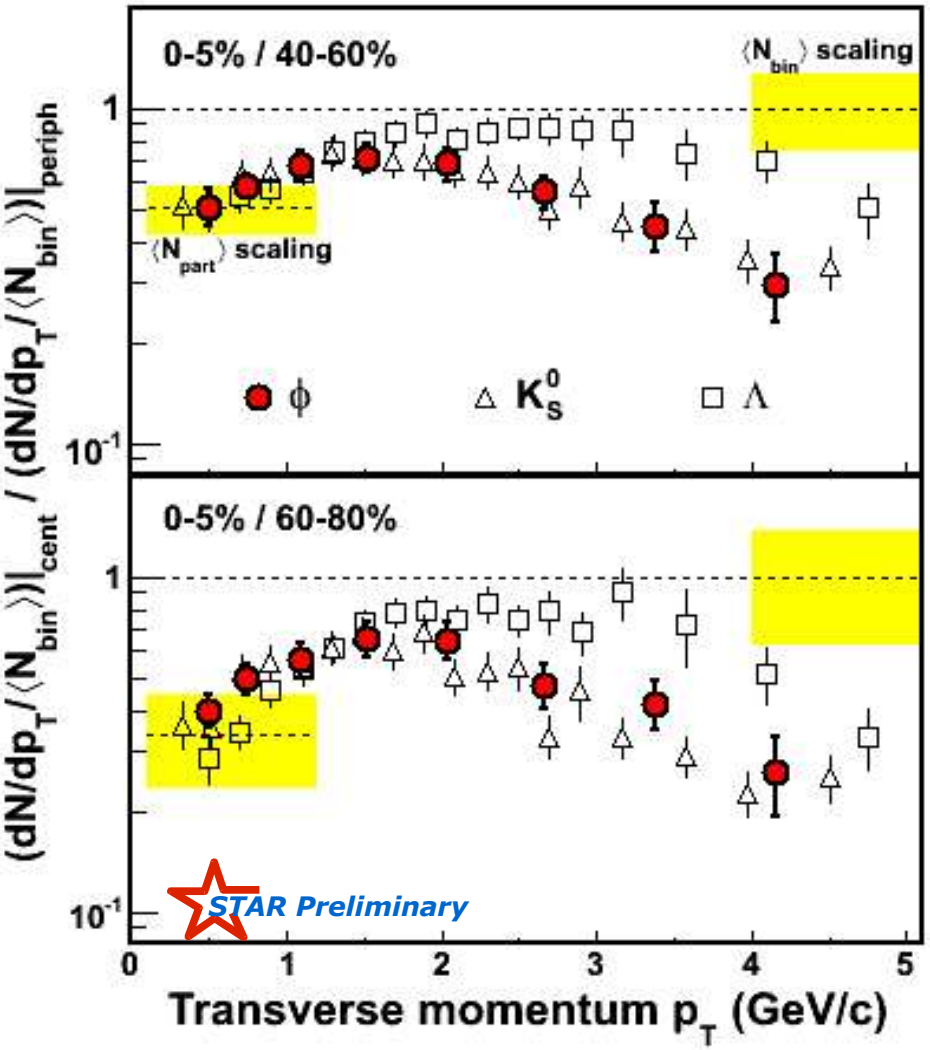
- *φ p_T spectra show a systematic centrality-dependent evolution in shape*
- *For **peripheral collisions**, a pQCD power-law tail is evident*
  - ➔ *Peripheral spectra favor a Levy function description*
- *For **central collisions**, exponential and Levy functions fit spectra equally well*
  - *The **power-law tail is suppressed** by the medium produced in central collisions*



Particle Production II

Nuclear Modification Factor

For both centrality groupings, R_{CP} of φ < 1 : φ yield suppressed in central compared to peripheral collisions:



Particle grouping behaviour:

- *Like for v_2, φ follows same trend as K^0_S and K* [1] in R_{CP}*
- *Confirmation of **meson-baryon dependence** of R_{CP} rather than mass-type dependence*
- *Described by recombination/ coalescence models[2]*

[1] STAR Collab., Phys. Rev. C 71 (2005) 064902
[2] R. J. Fries *et al.*, Phys. Rev. C 68 (2003) 044902

Particle Production III

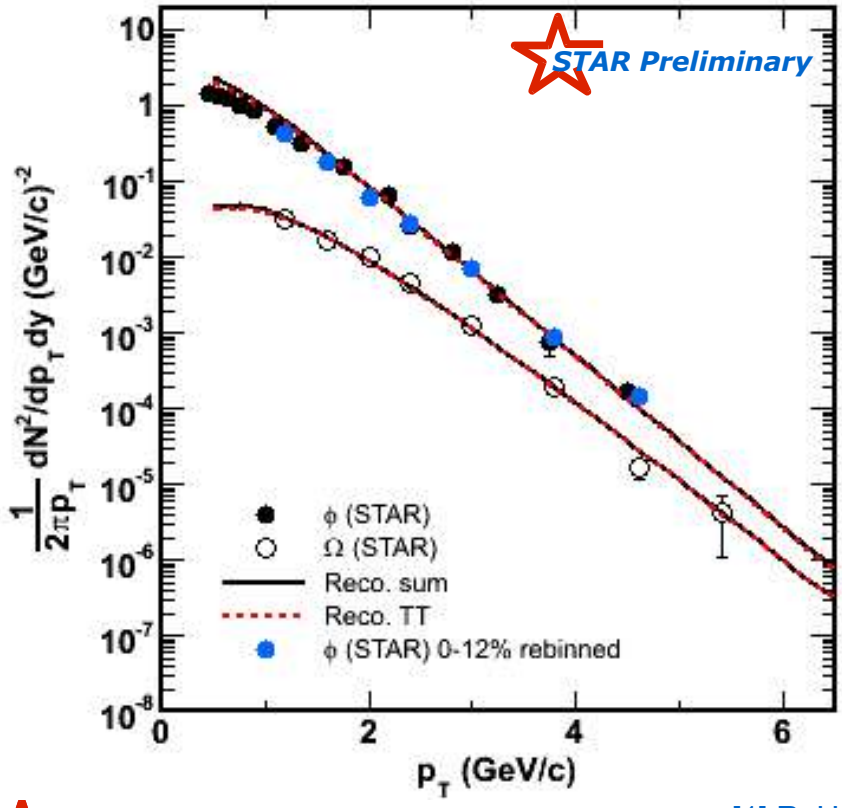
Model Predictions

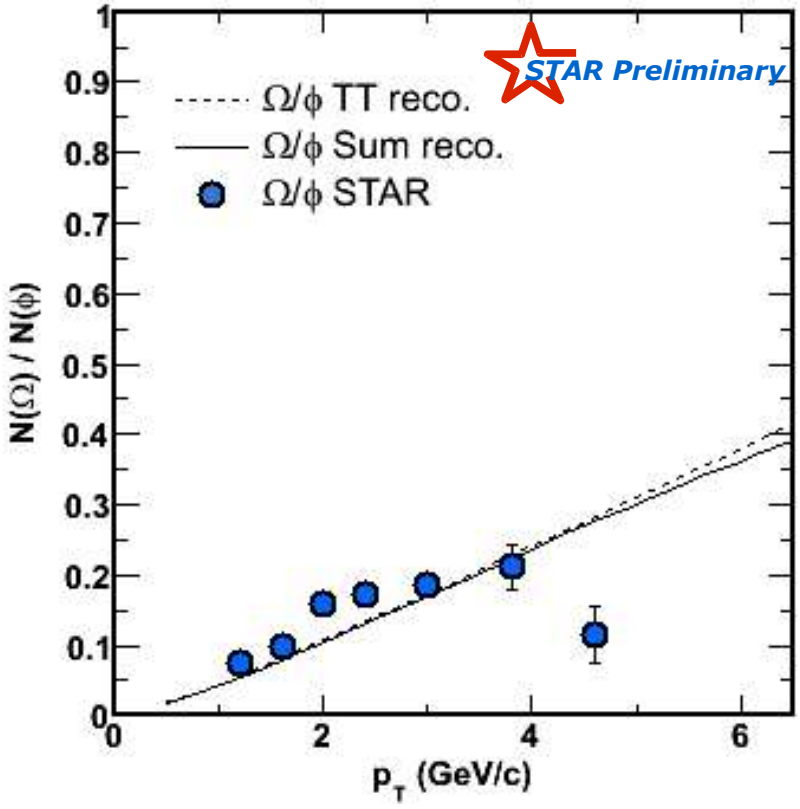
Comparison with model expectations on particle production can give insight on the constituents of the medium produced in heavy-ion collisions:

R. Hwa's recombination model[1]:

- *φ and Ω (sss) spectra (p_T<8GeV/c) mainly due to recombination of thermal quarks (TT)*
- *Seems to match data well*

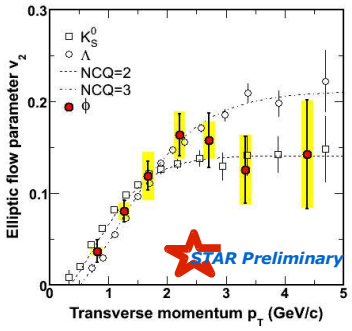
- ***BUT**... Ω/φ ratio has similar shape to other baryon/meson measurements*
- *Model matches data for p_T < 4 GeV/c*





[1] R. Hwa & C-B Yang, nucl-th/0602024

Conclusions



- ***Large elliptic flow*** *(despite small σ) at low p_T*
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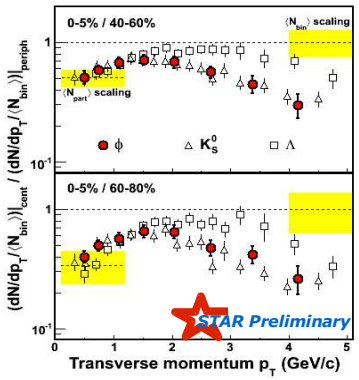
- *Reco. models describe data well*[1]



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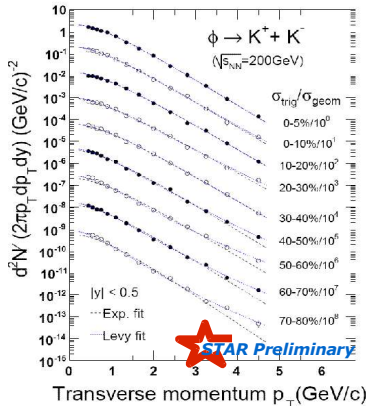

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- *pQCD power-law tails suppressed in central compared to peripheral spectra*
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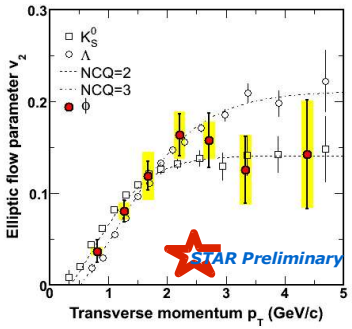

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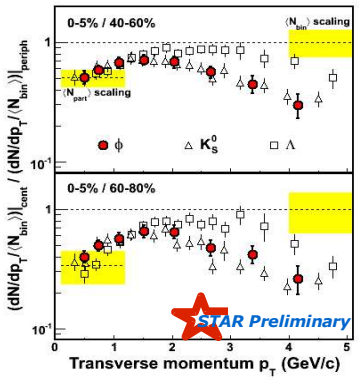

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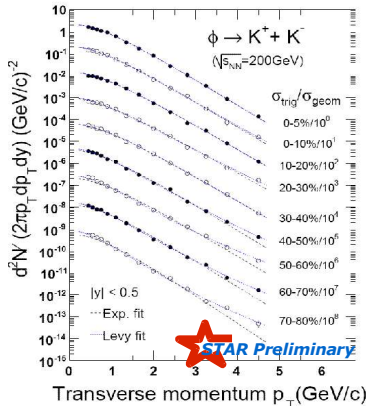

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PARTONIC COLLECTIVITY & DECONFINEMENT

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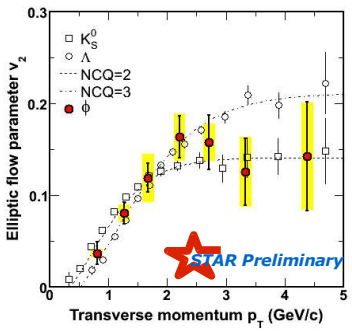

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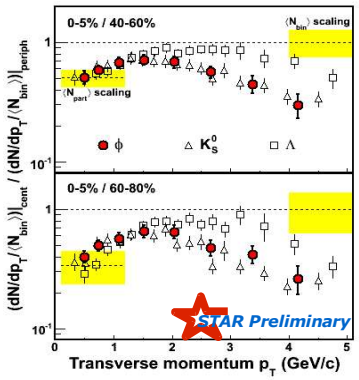

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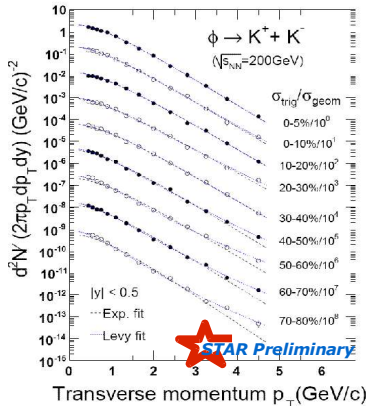

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PARTONIC COLLECTIVITY & DECONFINEMENT

...hints of THERMALIZATION?

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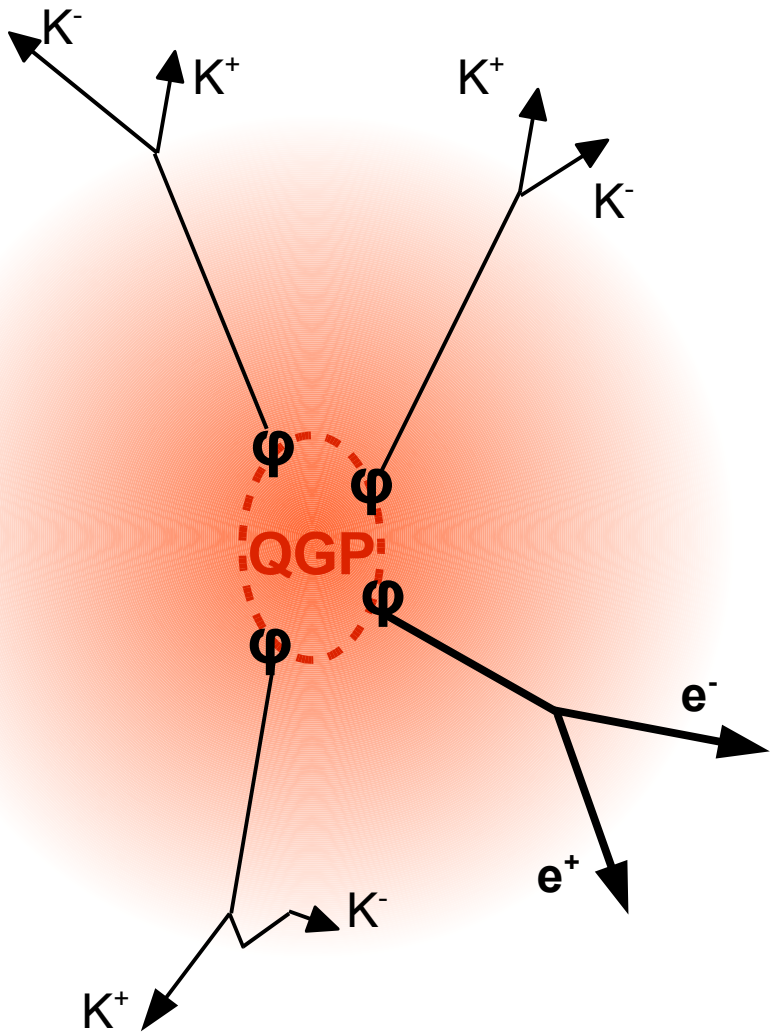
The Future...

Further interesting predictions can be investigated using φ-meson observables:



- *Measurement of angular correlations with respect to a φ-meson trigger particle[1]:*
  - *Investigates particle production mechanism*

- *φ **di-lepton decay** channel is a **very clean probe** from the early stage (e^{+-} do not interact strongly)*

$$\varphi \rightarrow e^+ + e^-$$

  - *Good channel to search for modifications of hadron properties due to the hot medium[2]*
  - *Will be a challenge: $\varphi \rightarrow e^+ + e^-$ ($BR \sim 10^{-4}$)*
  - *STAR Full barrel Time Of Flight (TOF) detector (installed by 2008) will be a huge asset in making this measurement!*

[1] R. Hwa & C-B Yang, nucl-th/0602024
[2] M. Asakawa & C.M. Ko, Phys. Rev. C50 (1994) 3064