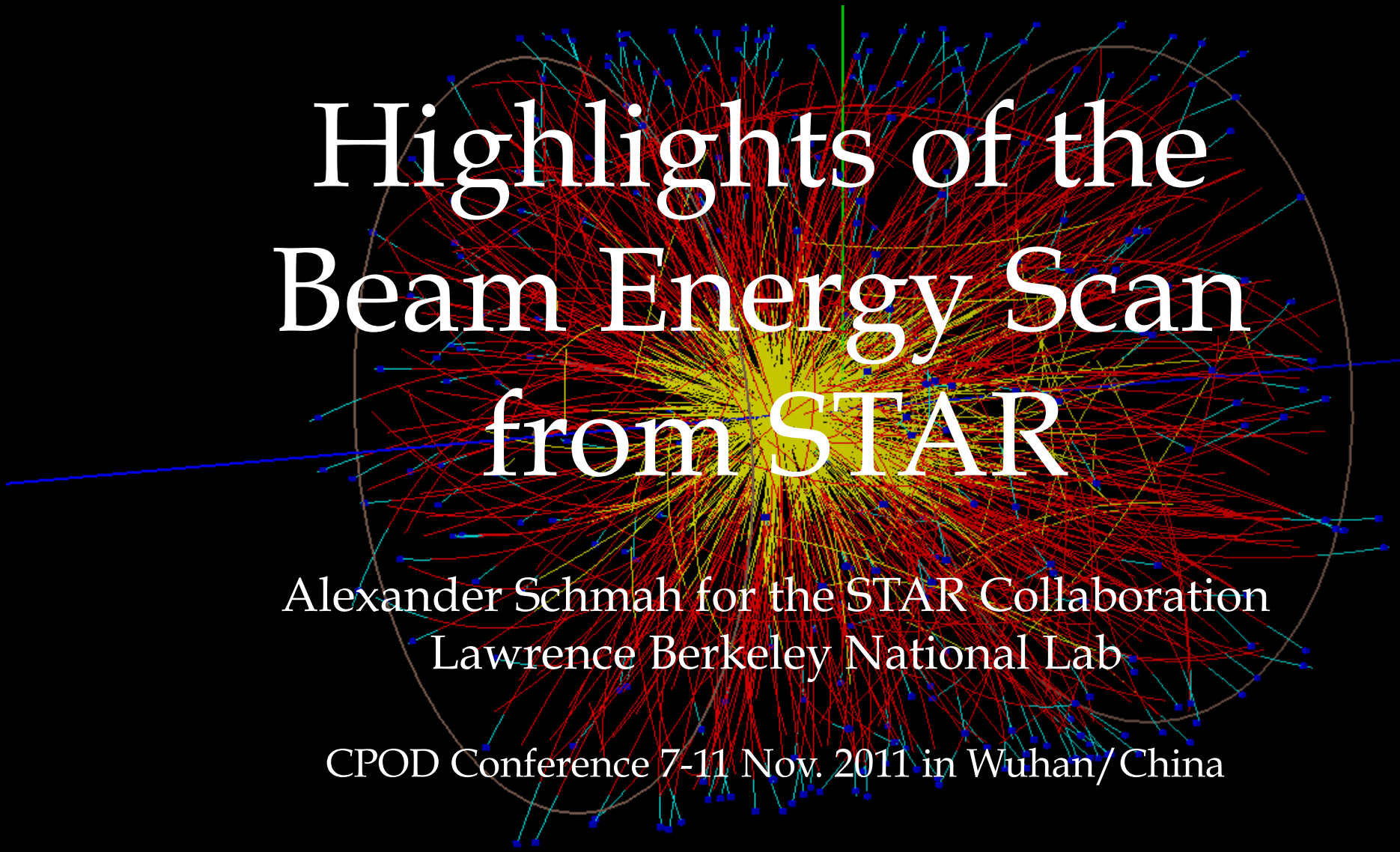


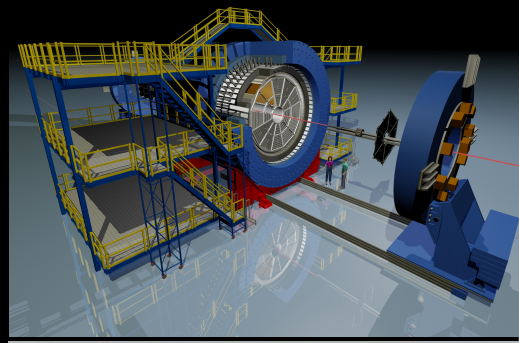
Highlights of the Beam Energy Scan from STAR

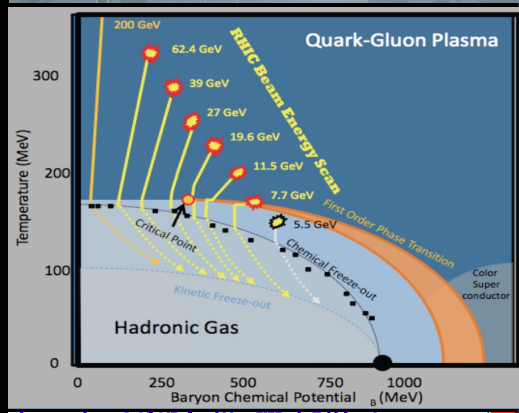
Alexander Schmah for the STAR Collaboration
Lawrence Berkeley National Lab

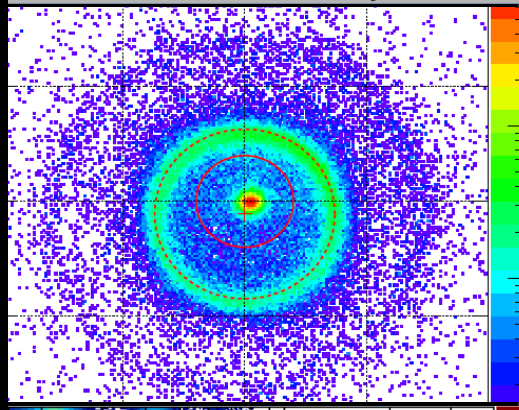
CPOD Conference 7-11 Nov. 2011 in Wuhan/China

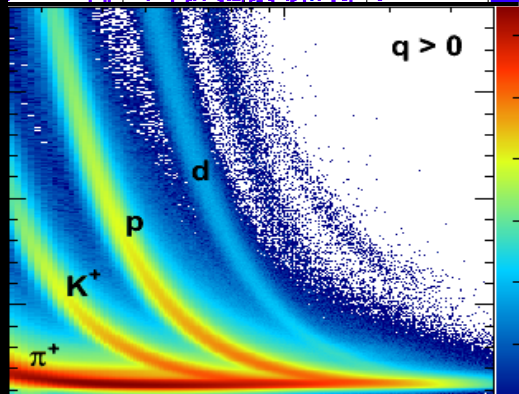
Outline

- Introduction to the Beam Energy Scan program
- Kinematics and freeze-out conditions
- Event anisotropy and number of constituent quark (ncq) scaling
- Dynamical fluctuations and their higher moments
- Summary and outlook

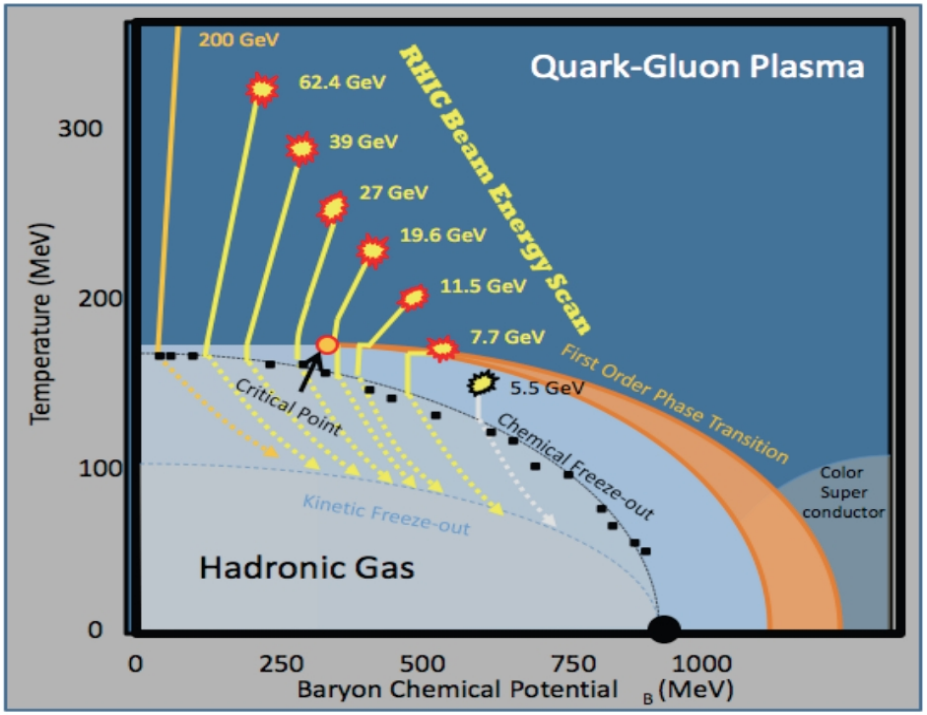








The Beam Energy Scan at RHIC



$\sqrt{s_{NN}}$ (GeV)	MB Events in 10^6
7.7	4.3
11.5	11.7
19.6	35.8
27	70.4
39	130.4
62.4	67.3

*Au+Au minimum bias events at STAR usable for analysis

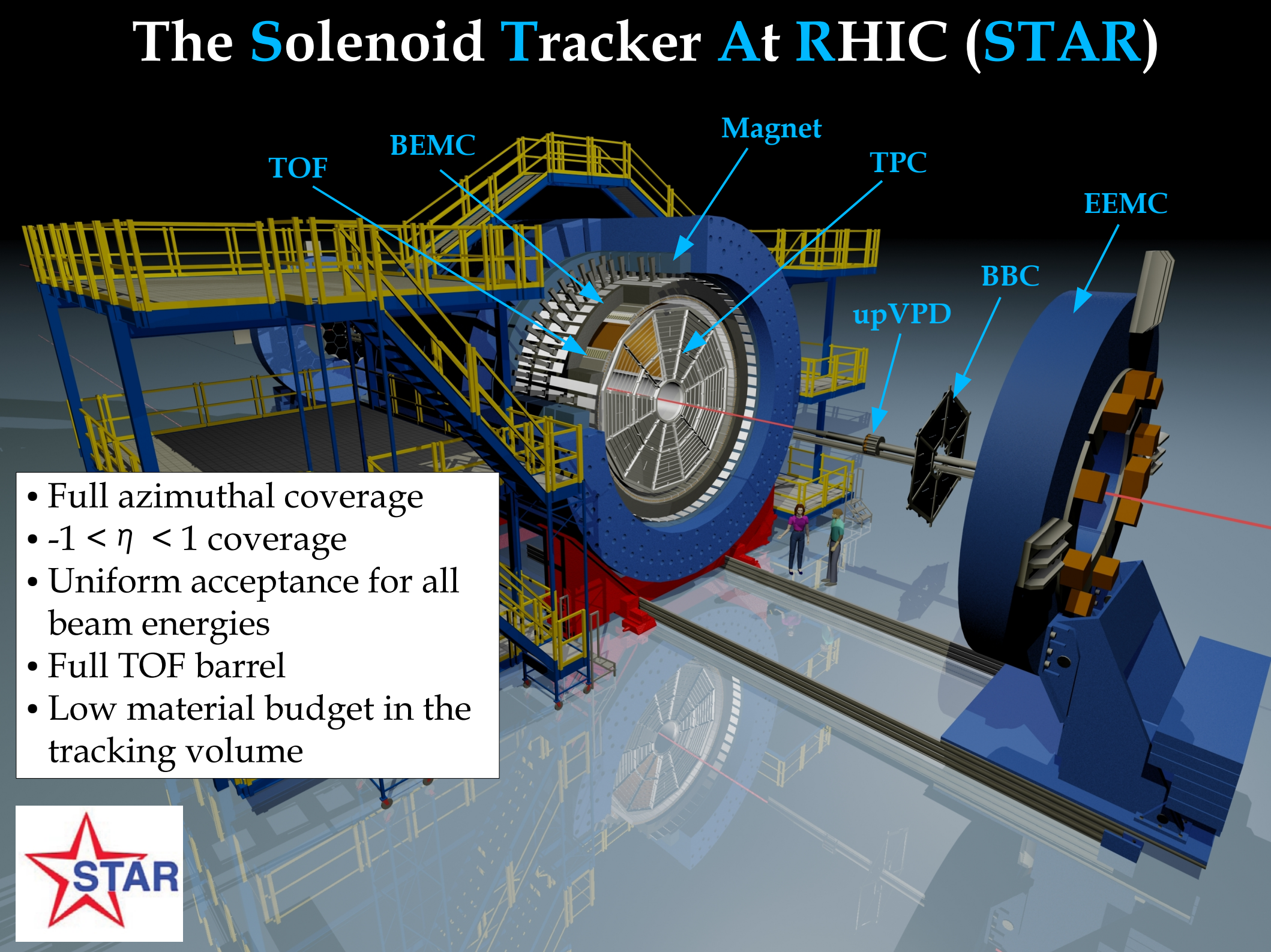
arXiv:1007.2613

Main Goals:
- Signatures for a phase transition
- Signatures for a critical point

Overview:
- Almost equidistant steps in T-μ_B: 7.7-62.4 GeV Au+Au reactions

Methods:
- Disappearance of QGP signals like v_2-ncq scaling, energy loss (R_{CP}),...
- Looking for non-monotonic behavior (eccentricity, yields, slopes,...)
- Comparing to theory predictions
- Fluctuation analyses → critical point

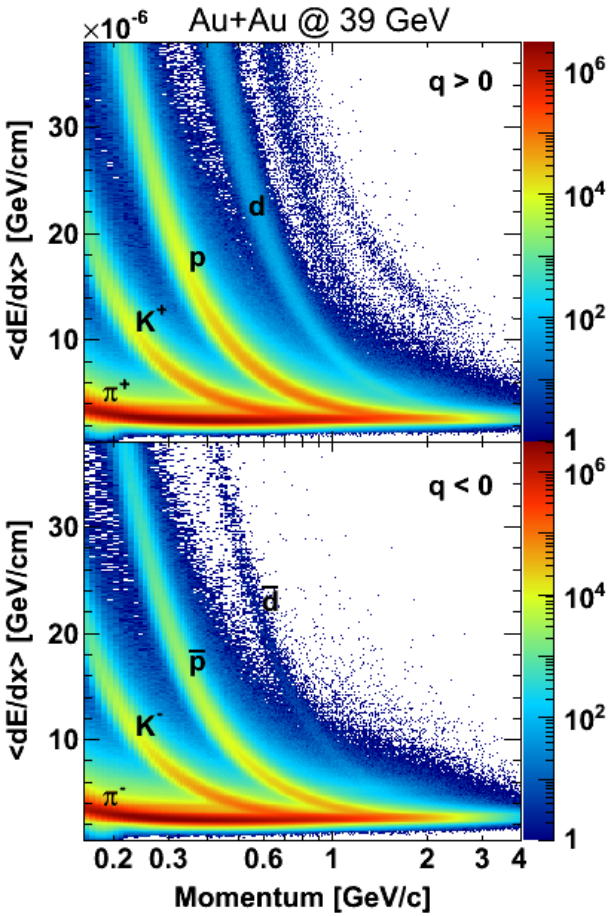
The Solenoid Tracker At RHIC (STAR)



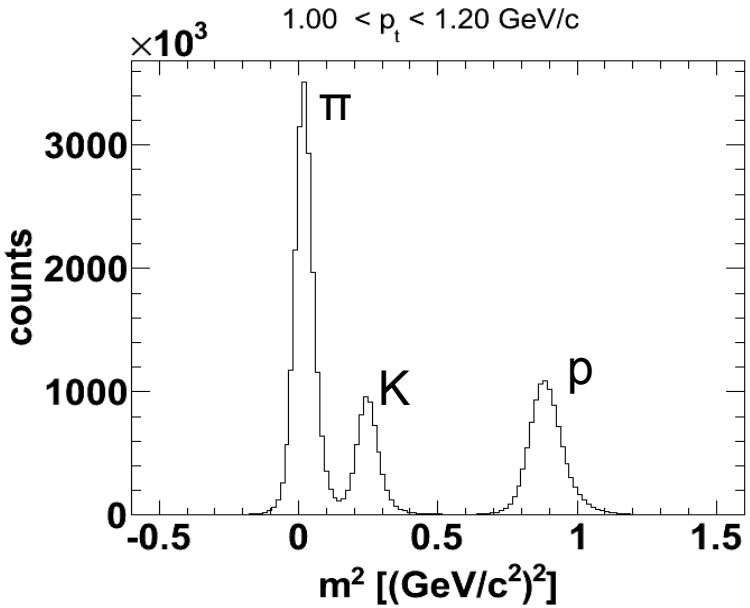
- Full azimuthal coverage
- $-1 < \eta < 1$ coverage
- Uniform acceptance for all beam energies
- Full TOF barrel
- Low material budget in the tracking volume

Particle Identification

dE/dx in the TPC

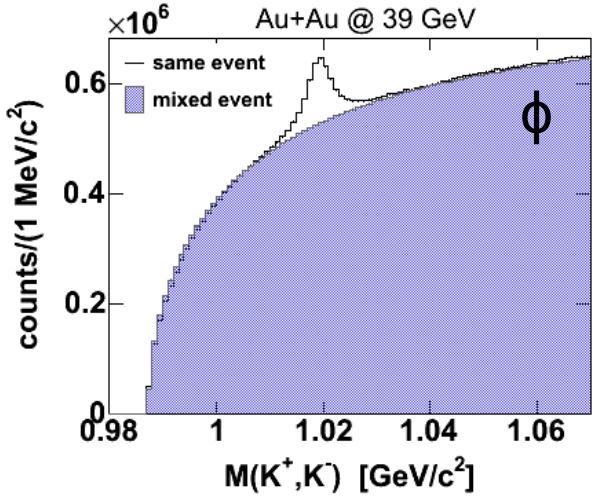


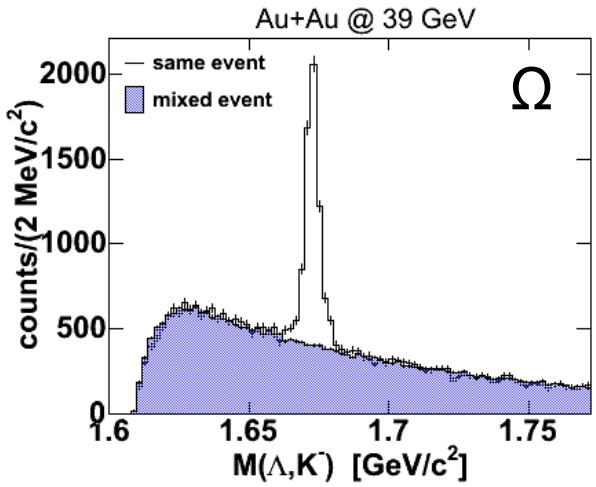
m² from TOF



- Direct (dE/dx + TOF) proton PID up to ~ p = 3 GeV/c
- Kaon, pion and high p_T: statistical signal extraction

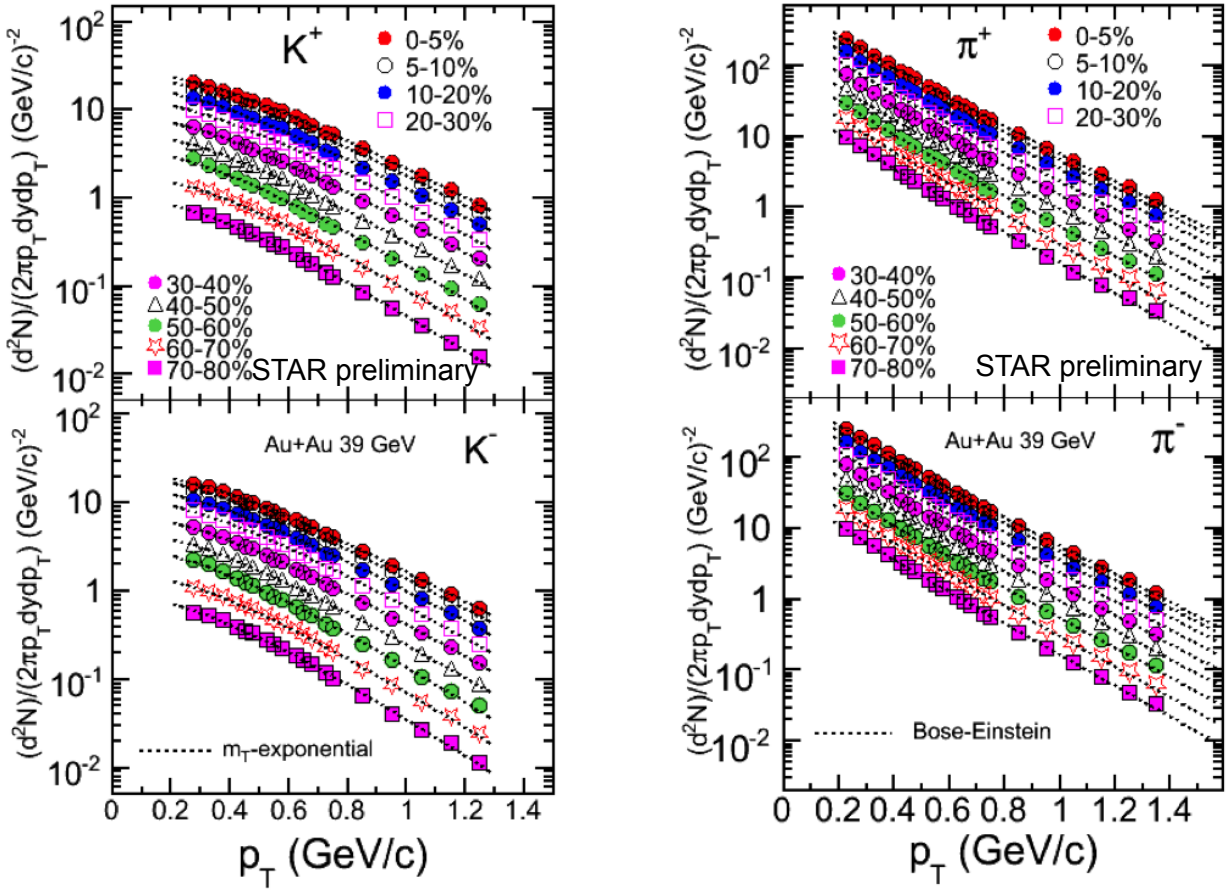
Invariant mass and topological PID

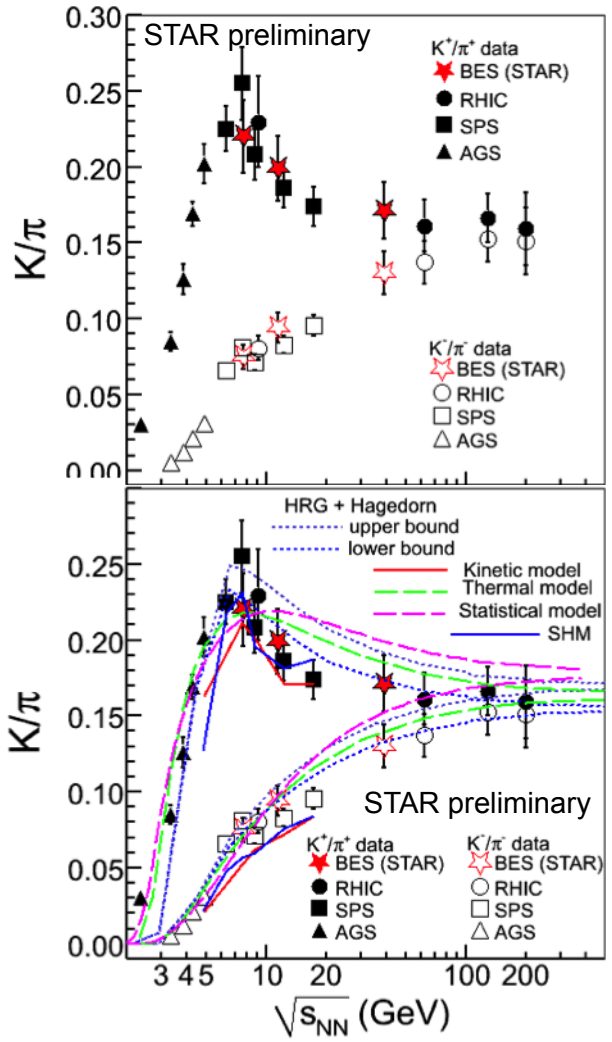




Charged Meson Spectra

Tue. 11:50: Lokesh Kumar



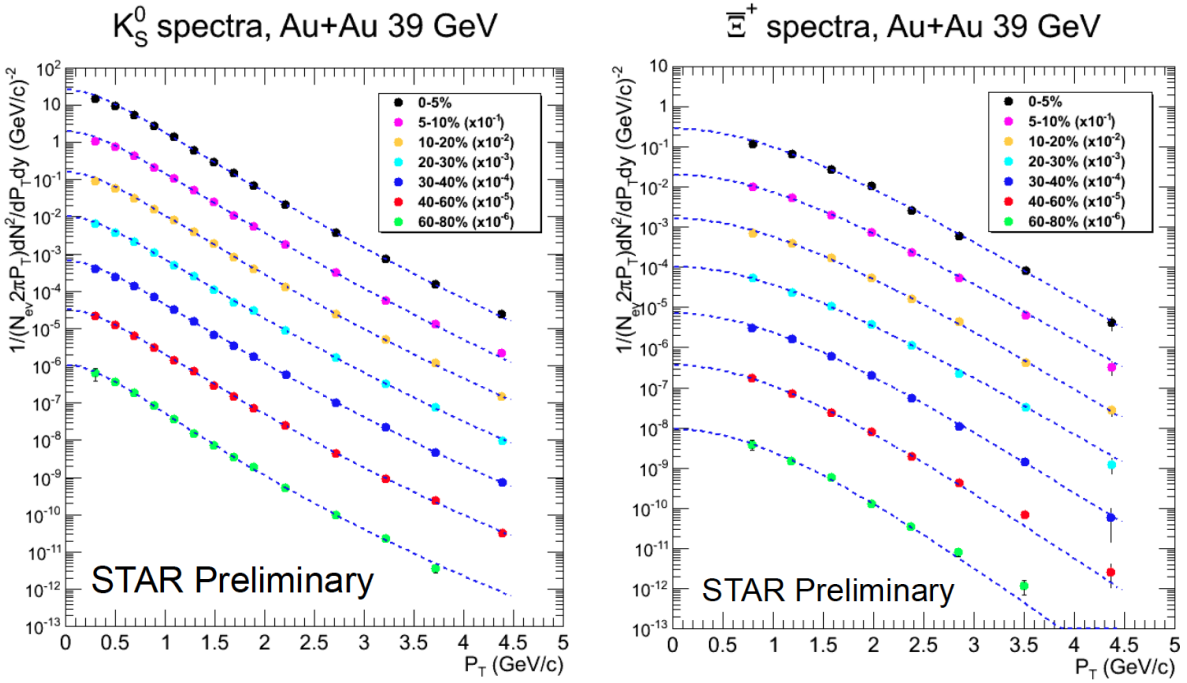


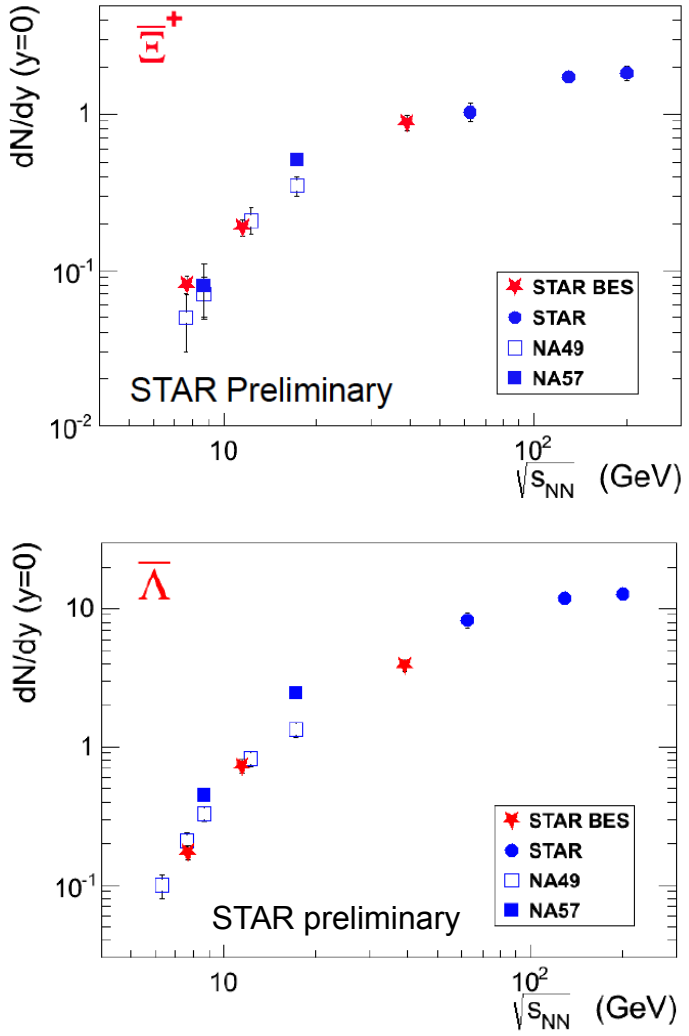
- Corrected for weak decay feed down
- K/π and other ratios fit into published systematics
- p_T range will be extended in the future

J. Cleymans et al., A. Andronic et al., J. Rafelski et al., B. Tomasik et al., S. Chatterjee et al.

Spectra of Weak Decay Particles

Tue. 15:30: Xianglei Zhu



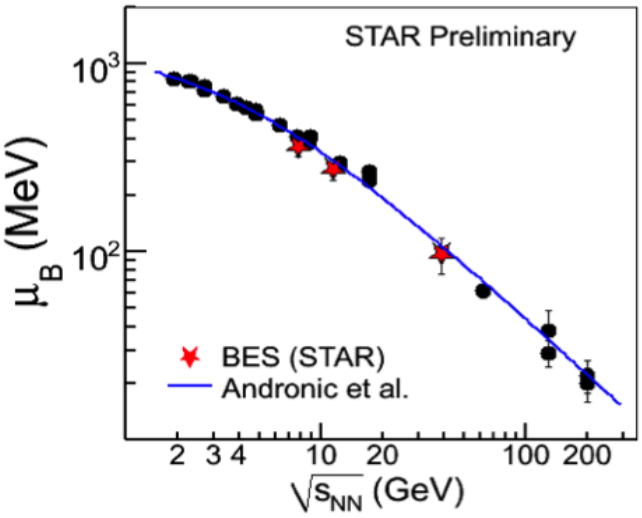


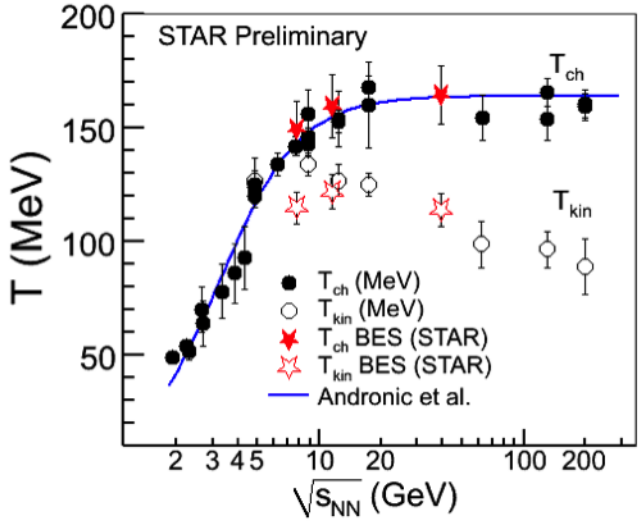
- K^0, Λ, $\bar{\Lambda}$, $\Xi^{+/-}$, $\Omega^{+/-}$ spectra up to p_T = 4.5 GeV/c
- Corrected for feed down
- Yields agree well with published results
- R_{CP}, $\langle m_T \rangle - m_0$, statistical model comparison,... follow soon

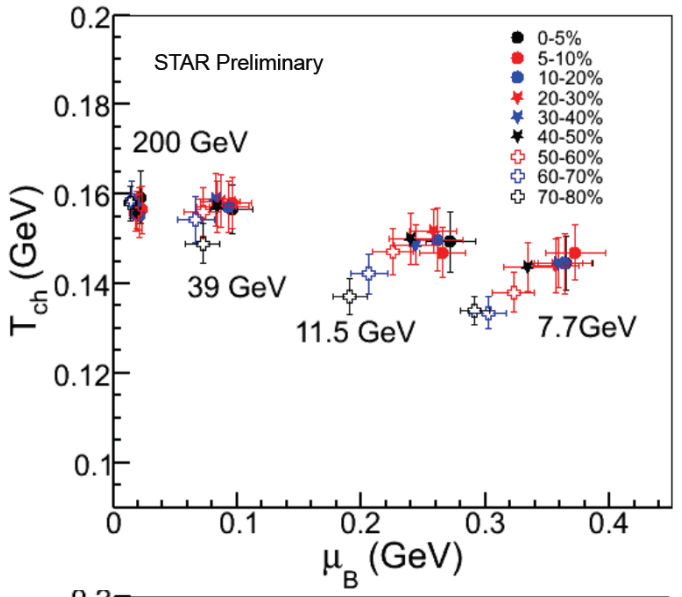
Freeze Out Conditions

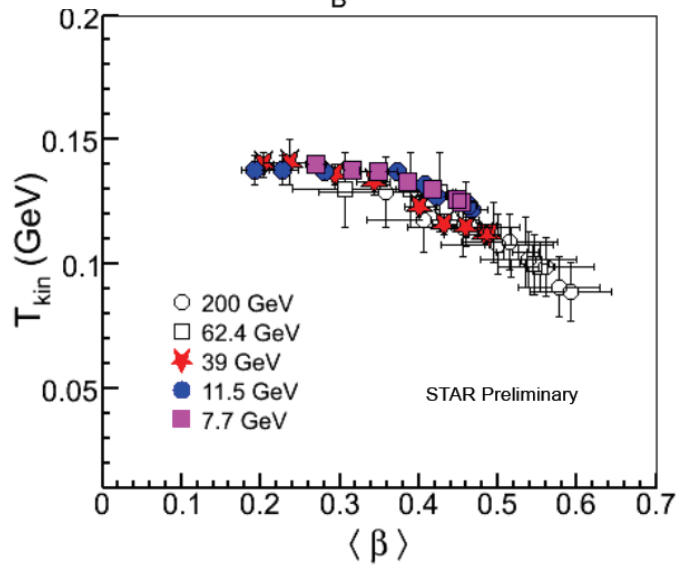
Tue. 11:50: Lokesh Kumar

STAR : PRC 79 (2009) 034909 and references therein
STAR : NPA 757 (2005) 102
Model: Andronic et al. NPA 834 (2010) 237





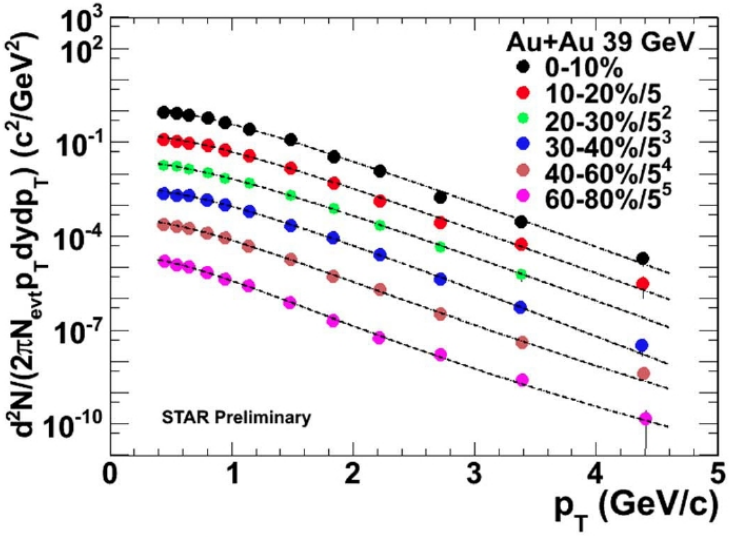


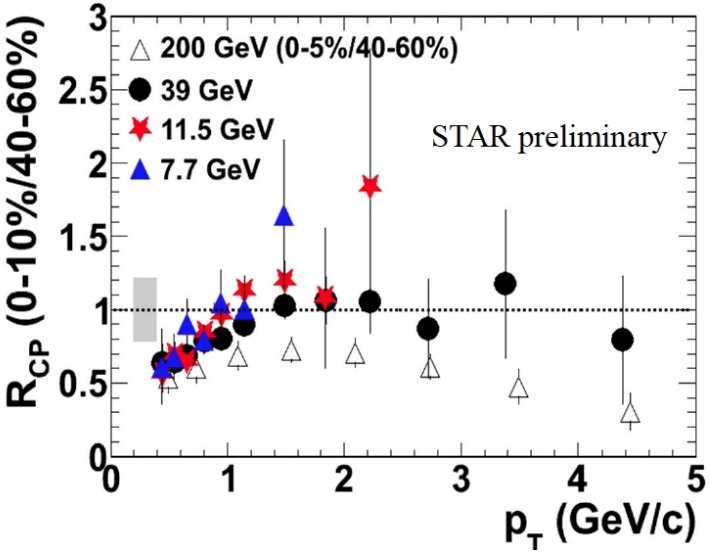


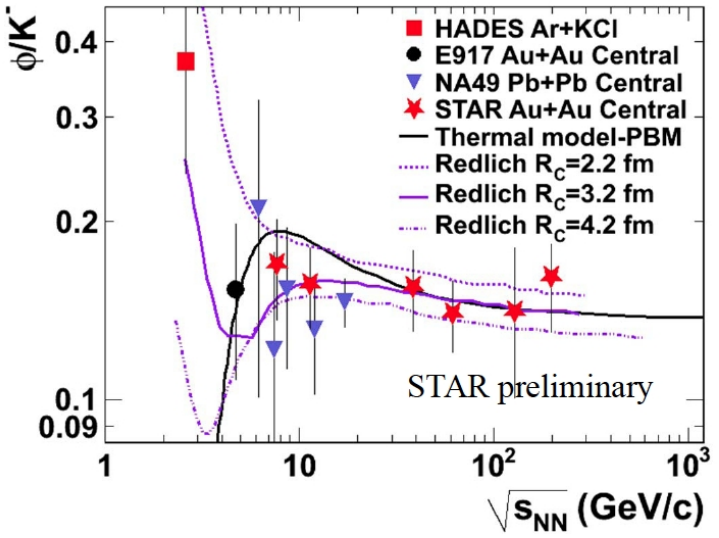
- Statistical model fit to $\pi^{+/-}$, $K^{+/-}$, p and $\bar{p}$
- Other particles will be included soon to improve the validity of the fits
- New results are in good agreement with published data
- Clear centrality dependence of T and μ_B

ϕ-Meson Spectra from $\phi \rightarrow K^+K^-$

Thu. 17:00: Xiaoping Zhang





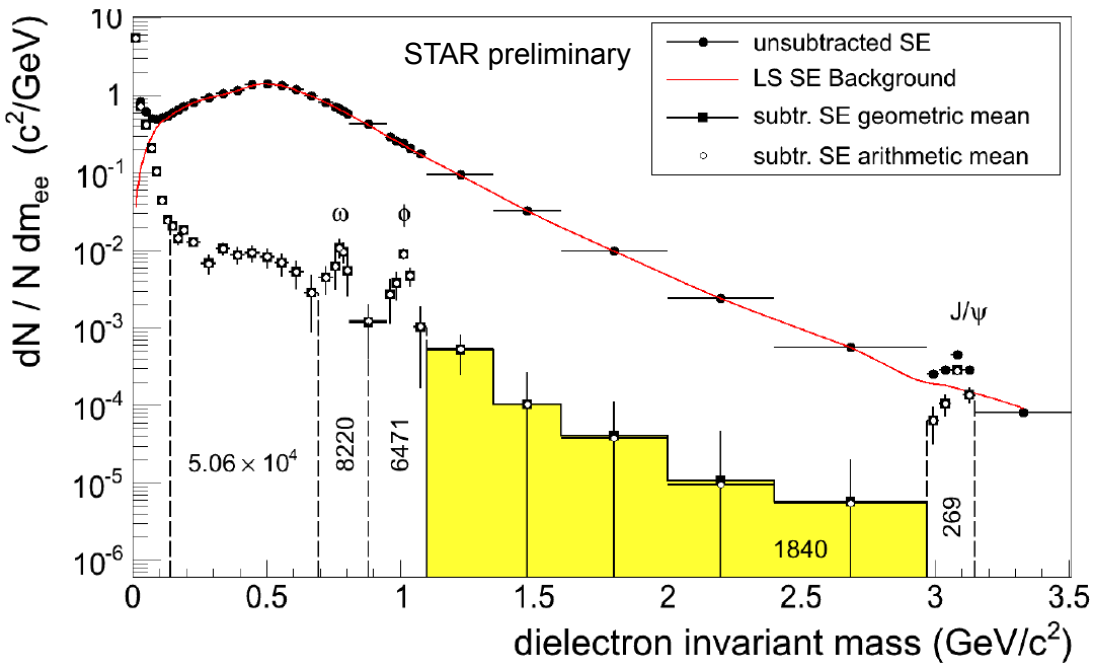


- Reconstruction up to 4.5 GeV in p_T
- ϕ/K^- ratio is used to test strangeness production mechanism
- R_{CP} at 39 GeV is consistent with unity at $p_T > 1$ GeV/c

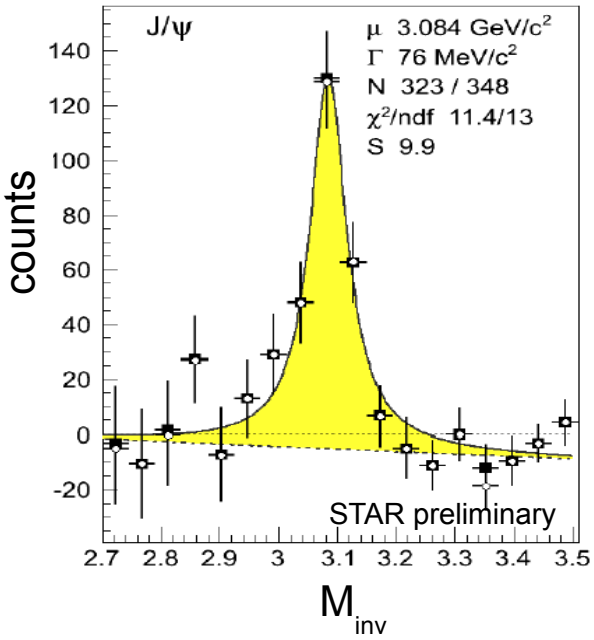
*error bars are combined stat. + syst.

Di-Lepton Spectroscopy at 39 GeV

Thu. 16:30: Patrick Huck



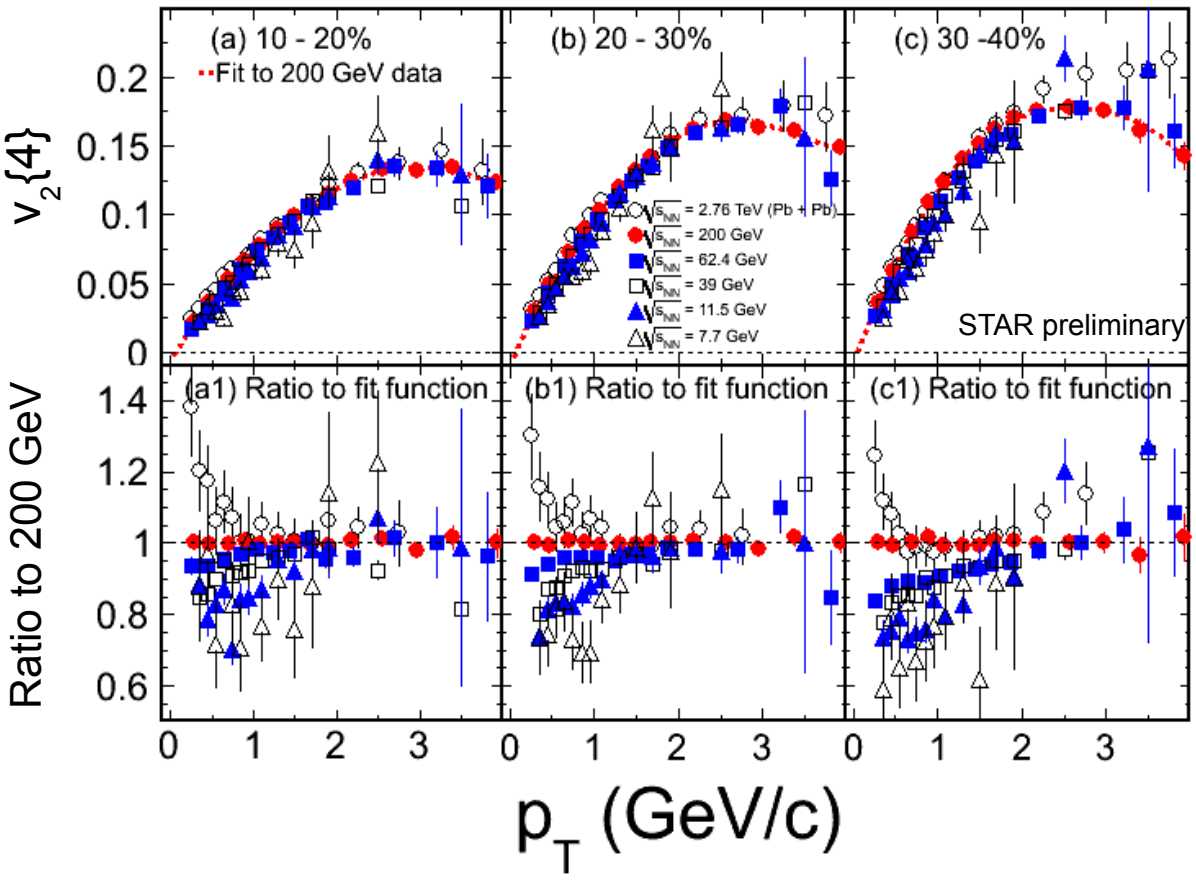
*only statistical errors
** uncorrected for efficiency



- Direct probes from the early stage, almost undisturbed by strong interactions
- High statistics di-lepton spectrum: ~67k entries above π^0
- Prominent peaks for ϕ, ω and J/Ψ
- Enough statistics for differential p_T and v_2 analysis!
- 27 GeV and 62.4 GeV spectra in preparation

Flow from Charged Hadrons

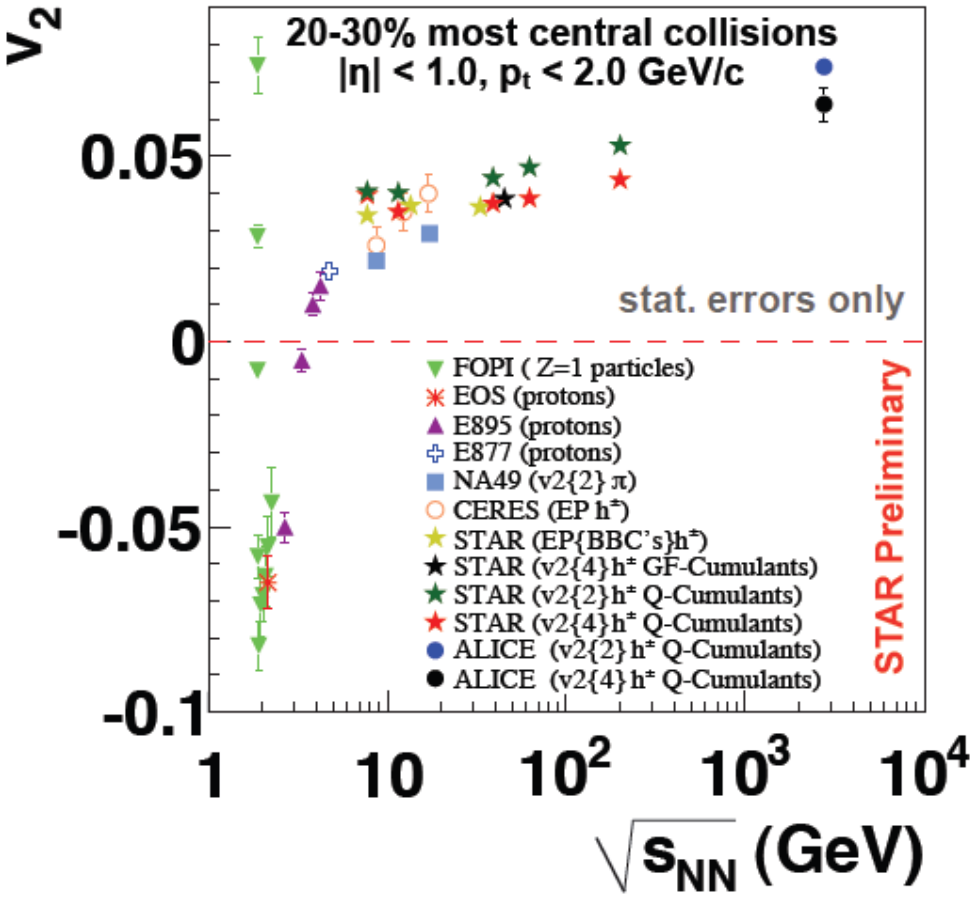
Thu. 10:10: Shusu Shi



ALICE data: Phys. Rev. Lett. 105, 252302 (2010)

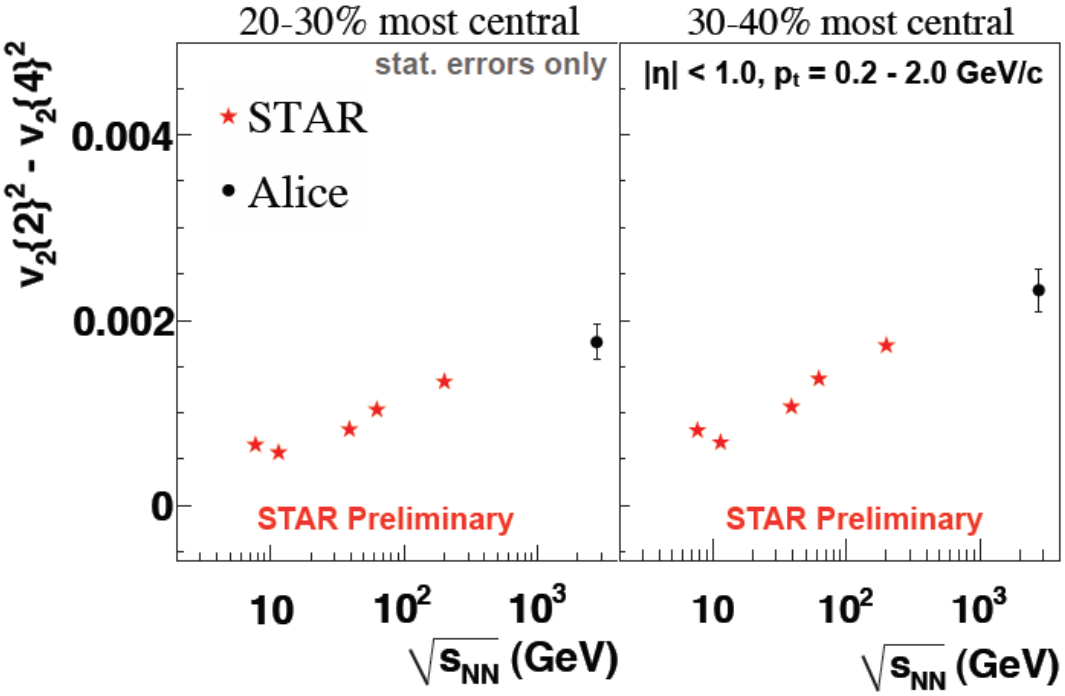
- $v_2\{4\}$ cumulant method
  → reduces non-flow
- General shape and magnitude of $v_2\{4\}(p_T)$ is similar for all energies between 7.7 GeV – 2.76 TeV
- In detail: at $p_T < 2$ GeV/c the
- $v_2\{4\}$ increases with increasing $\sqrt{s_{NN}}$
- Baseline measurement for identified particle v_2

Integrated v_2 and Non-Flow + Fluctuations



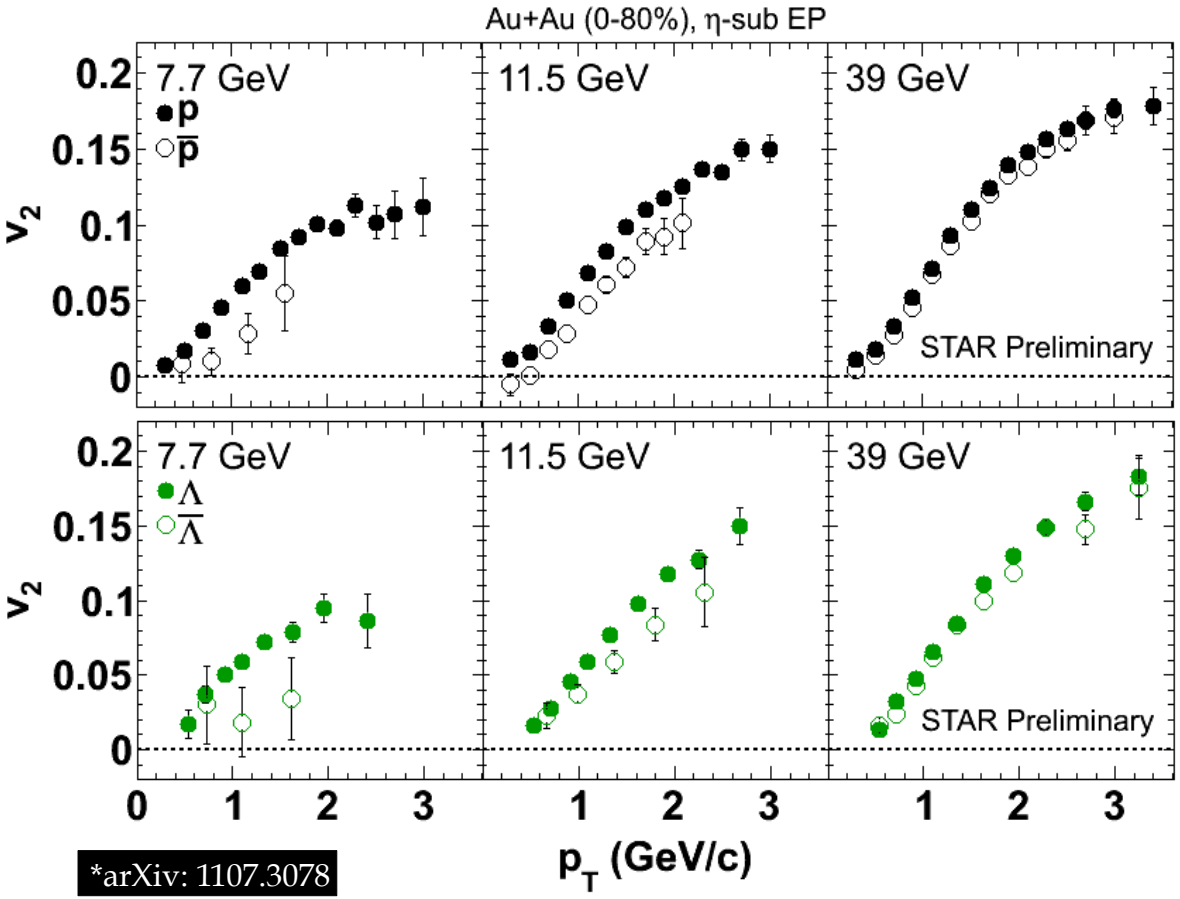
STAR: QM2011

$v_2\{2\}^2 - v_2\{4\}^2 \approx \delta_2 + 2\sigma^2$



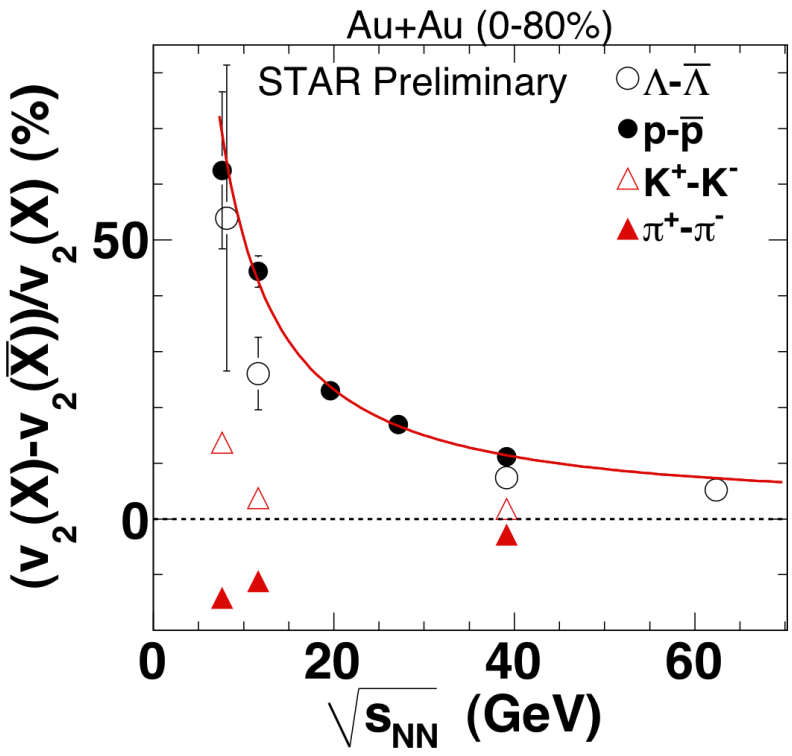
- BES data fill gap between NA49 and 200 GeV RHIC results
- Non-flow + v_2 fluctuations increase with increasing beam energy

Particle ↔ Anti-Particle Difference in v_2



*arXiv: 1107.3078

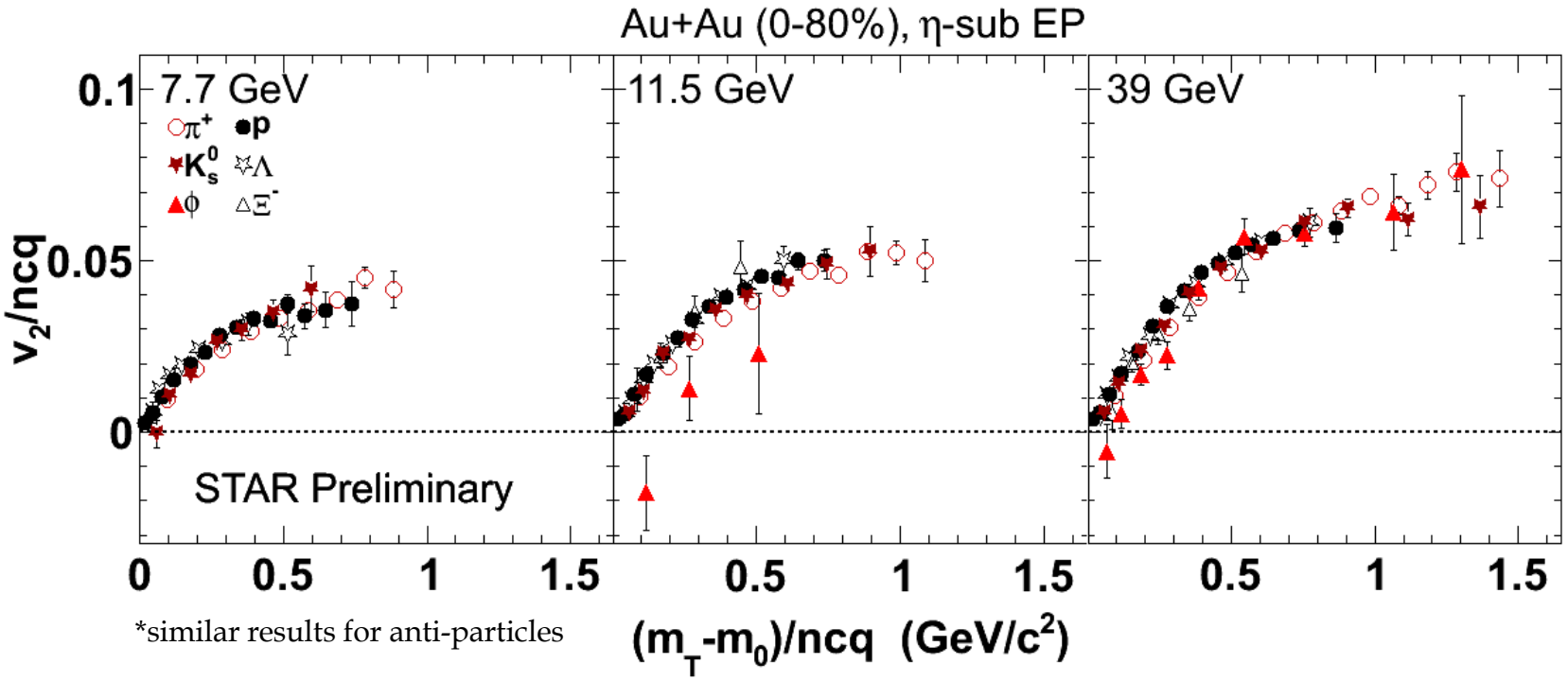
Thu. 10:10: Shusu Shi



- Difference in v_2 between X and $\overline{X}$ for all particle species at lower energies
  → break down of ncq-scaling between X and $\overline{X}$
- Difference increases with decreasing $\sqrt{s_{NN}}$
  → baryon transport to mid-rapidity?* Absorption in hadronic environment?

Elliptic Flow from Identified Hadrons

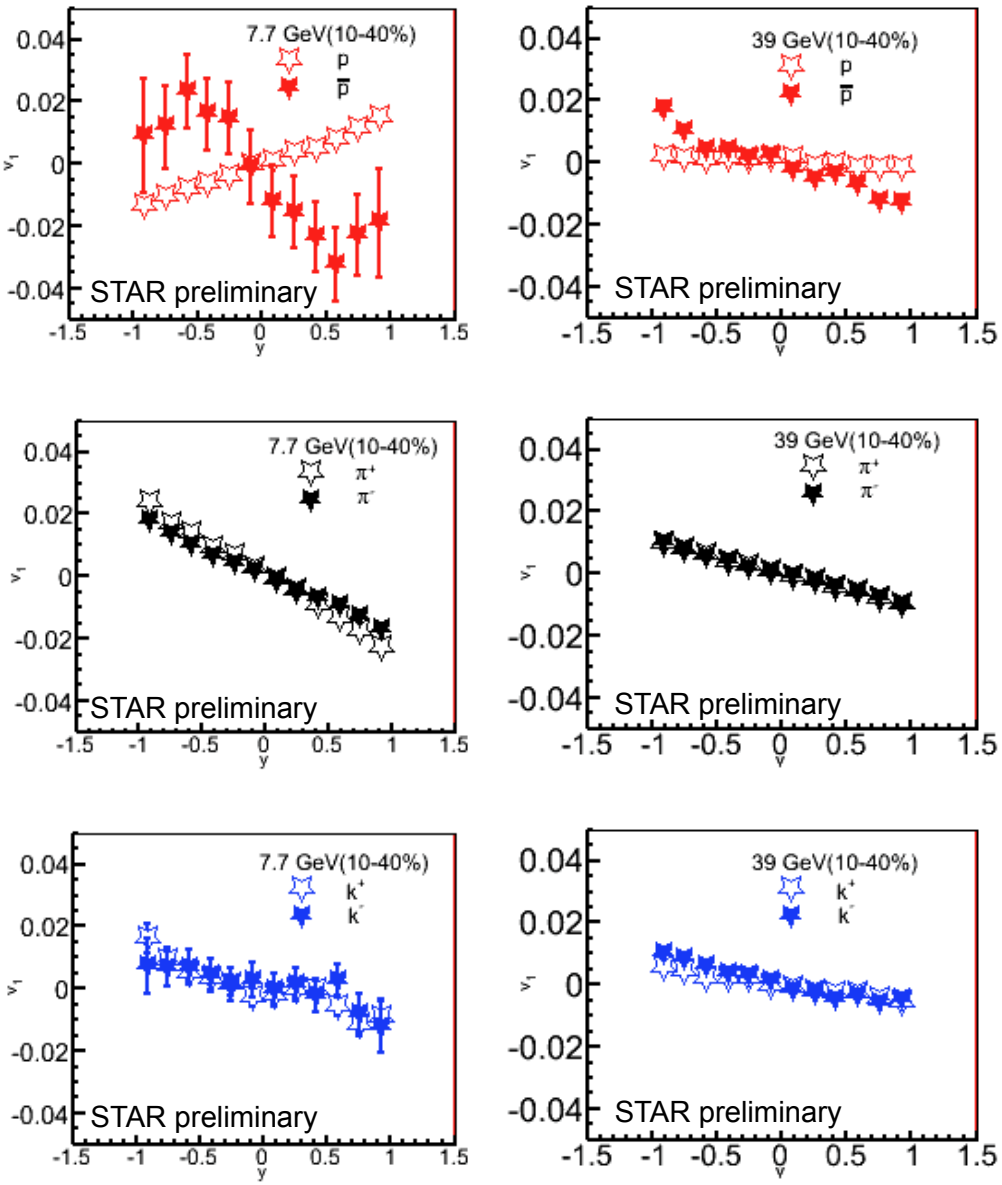
Thu. 10:10: Shusu Shi **Thu. 17:00: Xiaoping Zhang**



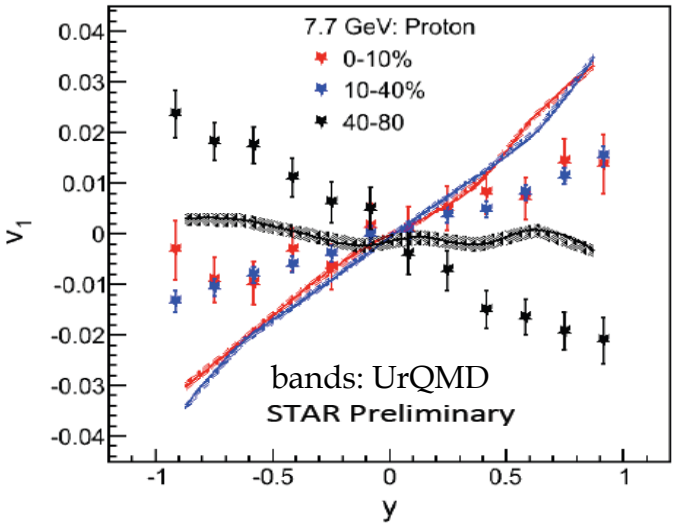
*similar results for anti-particles

- ncq-scaling for all particles holds at 39 GeV → similar to 200 GeV
- 2.6σ deviation of ϕ-meson $v_2(p_T)$ from pion $v_2(p_T)$ at 11.5 GeV in measured p_T range
- ncq scaling seems to hold for the rest of the particles

Directed Flow from Identified Hadrons



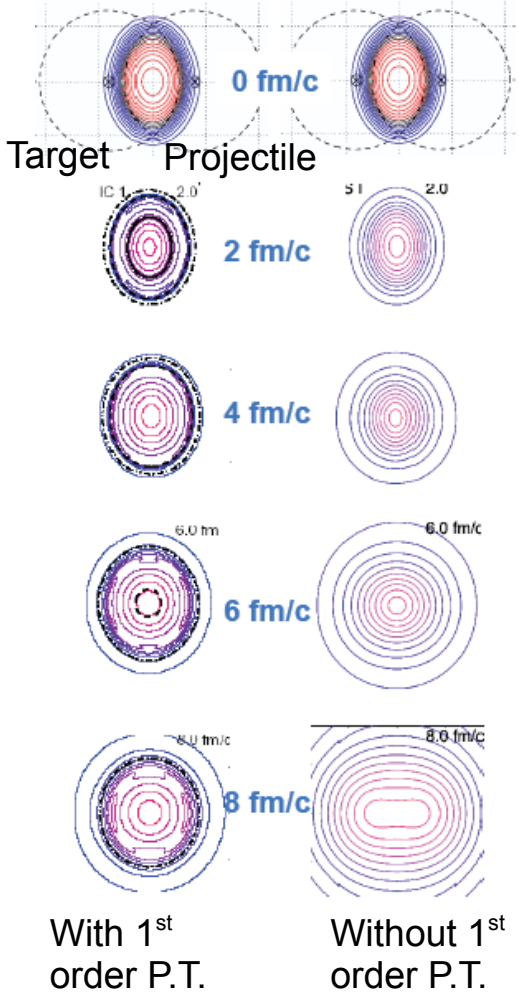
STAR: SQM2011



- $0.2 < p_T < 2.8$ for protons
- $0.2 < p_T < 1.6$ for pions and kaons
- Change of the proton dv_1/dy from 39 to 7.7 GeV at mid-central collisions
  → maybe due to transported protons to mid-rapidity
- No change in the slope for other particle species
- UrQMD predicts the right trend

Freeze out Eccentricity from Azimuthal HBT

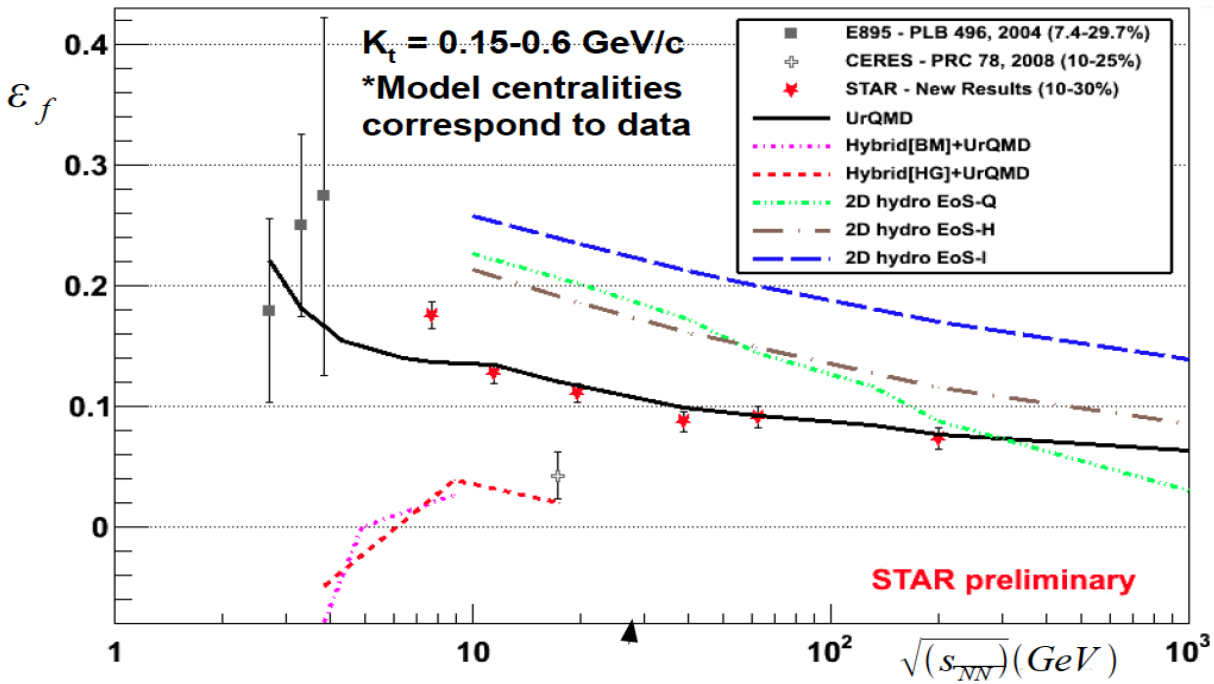
Spatial eccentricity: $\varepsilon_F = \frac{R_y^2 - R_x^2}{R_y^2 + R_x^2}$



Kolb and Heinz, 2003, nucl-th/0305084

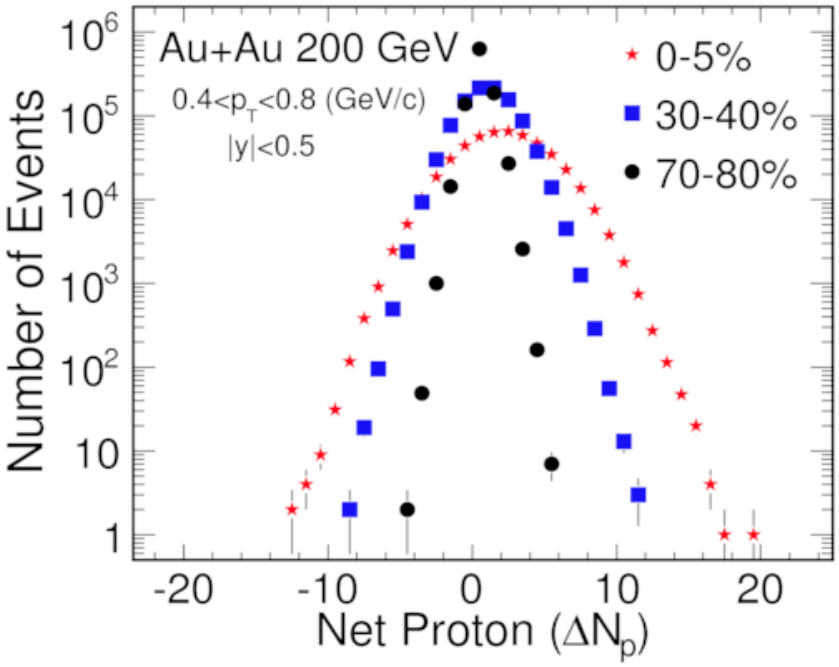
STAR: DNP2011

Lisa, Frodermann, Graef, Mitrovski, Mount, Petersen, Bleicher, *New J. Phys.* 2011, arxiv: 1104.5267



- Models predict different final state eccentricities (ε_f) with and w/o 1st order phase transition included
- Monotonic decrease of ε_f from 7.7 to 200 GeV
- UrQMD appears to predict the STAR data most closely

Higher Moments of Net-Proton Distributions



Mean: $M = < N >$

Sigma: $\sigma = \sqrt{< (N - < N >)^2 >}$

Skewness: $s = \dfrac{< (N - < N >)^3 >}{\sigma^3}$

Kurtosis: $\kappa = \dfrac{< (N - < N >)^4 >}{\sigma^4} - 3$

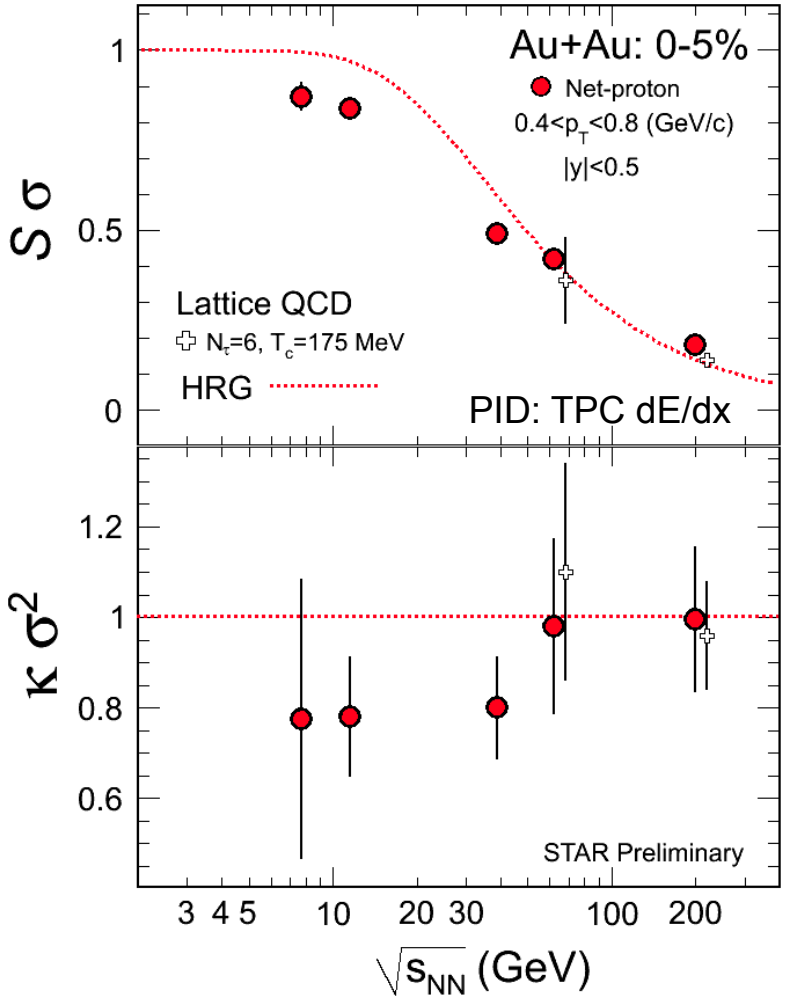
$$\chi_B^{(n)} = \left. \frac{\partial^n (P/T^4)}{\partial (\mu_B/T)^n} \right|_T$$

$$\chi_B^4 / \chi_B^2 = (\kappa\sigma^2)_B$$
$$\chi_B^3 / \chi_B^2 = (S\sigma)_B$$

F. Karsch et al, Phys. Lett. B 695, 136 (2011)
M.Cheng et al, Phys. Rev. D 79, 074505 (2009)

- Link between susceptibilities (e.g. from lattice QCD) and products of higher moments
- Volume effect cancels out
- Net-proton number fluctuations can reflect baryon number fluctuations
- High fluctuations predicted close to the critical point

Higher Moments of Net-Proton Distributions



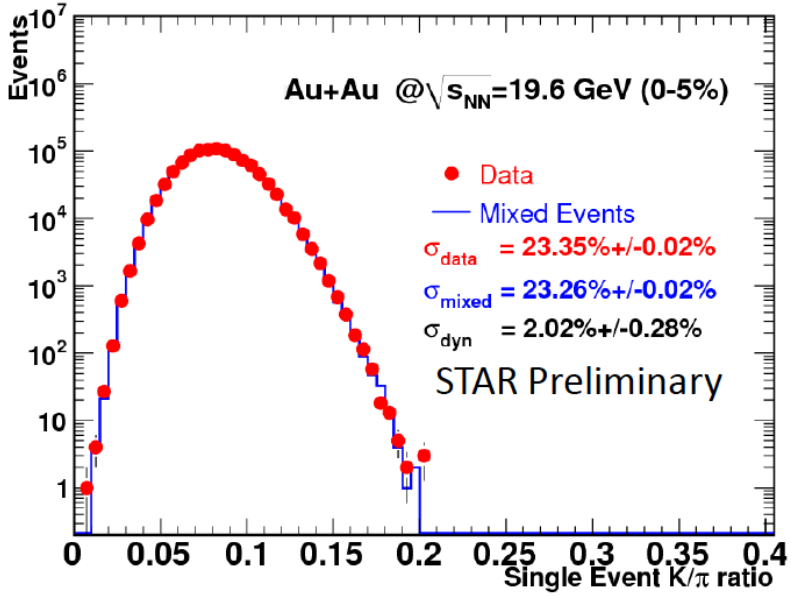
The 62.4 and 200 GeV data are published in PRL 105 (2010) 022302

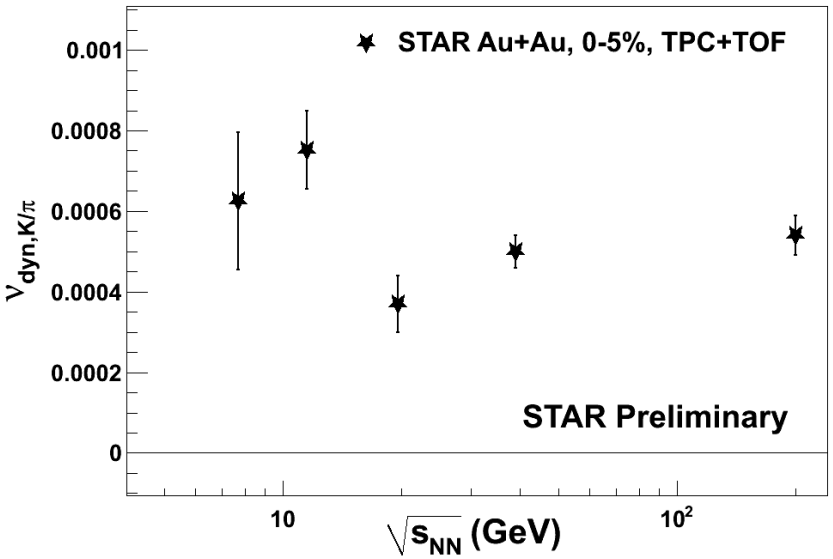
F. Karsch and K. Redlich, Phys. Lett. B 695, 136 (2011)

Wed. 10:00: Xiaofeng Luo

- Data are consistent with HRG model at high energies
- No indication for a non-monotonic behavior so far
- Analysis for 19.6 and 27 GeV is ongoing
- Autocorrelation between centrality definition window and analysis window is being studied → more important at the lower energies!
- PID methodology (rapidity, p_T cuts, PID method) studies are ongoing
- More accurate statistical error propagation is ongoing

K/π Event-by-Event Fluctuations





STAR: DNP2011

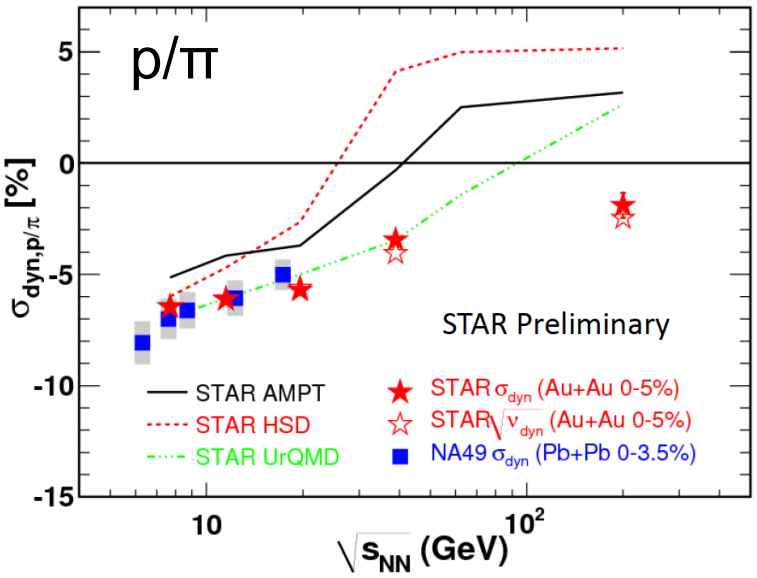
- Fluctuations in particle numbers can be related to critical behavior such as an increase in susceptibility
- Non monotonic behavior ($\sqrt{s_{NN}}$) of event-by-event particle ratios → critical point

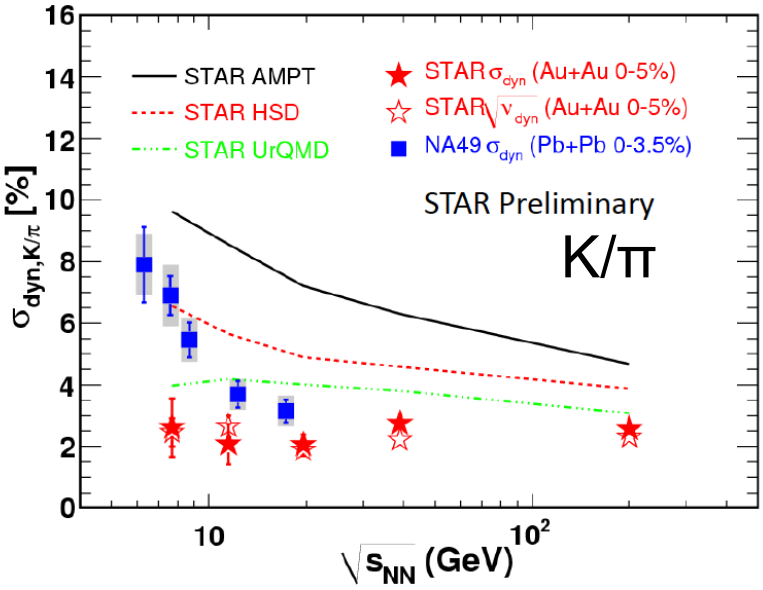
$$\sigma_{\mathrm{dyn}} = sign\left(\sigma^2_{\mathrm{data}} - \sigma^2_{\mathrm{mixed}}\right)\sqrt{\left|\sigma^2_{\mathrm{data}} - \sigma^2_{\mathrm{mixed}}\right|}$$

$$\nu_{\mathrm{dyn},K\pi} = \frac{\langle N_K(N_K-1)\rangle}{\langle N_K\rangle^2} + \frac{\langle N_\pi(N_\pi-1)\rangle}{\langle N_\pi\rangle^2} - 2\frac{\langle N_K N_\pi\rangle}{\langle N_K\rangle\langle N_\pi\rangle}$$

$$\sigma^2_{dyn} \approx \nu_{dyn}$$

K(p)/π Event-by-Event Fluctuations





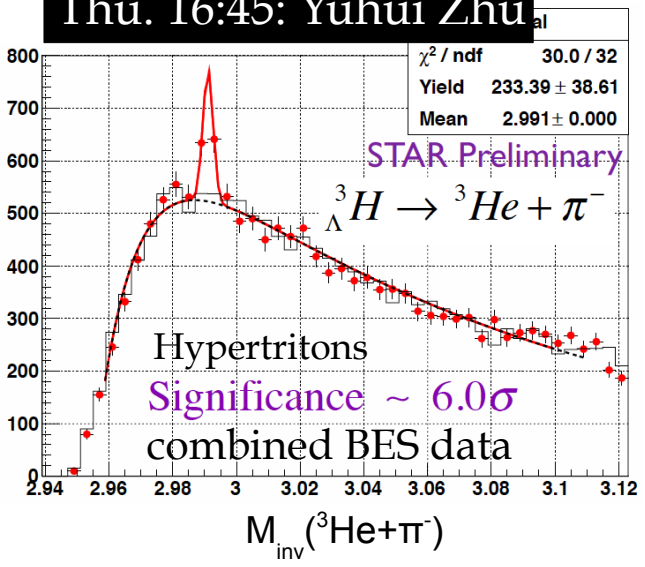
Wed. 12:10: Jian Tian
Thu. 15:15: Hui Wang

- STAR observes a monotonic increase for the p/π dyn. fluctuations and an almost constant value for K/π vs. $\sqrt{s_{NN}}$
  → No indication so far for the critical point
- UrQMD can describe the trend for the STAR results
- Good agreement between STAR and NA49 results for $\sigma_{dyn,p/\pi}$
- Significant difference for $\sigma_{dyn,K/\pi}$, especially at 7.7 GeV
- Different acceptance was ruled out to be the reason for the difference

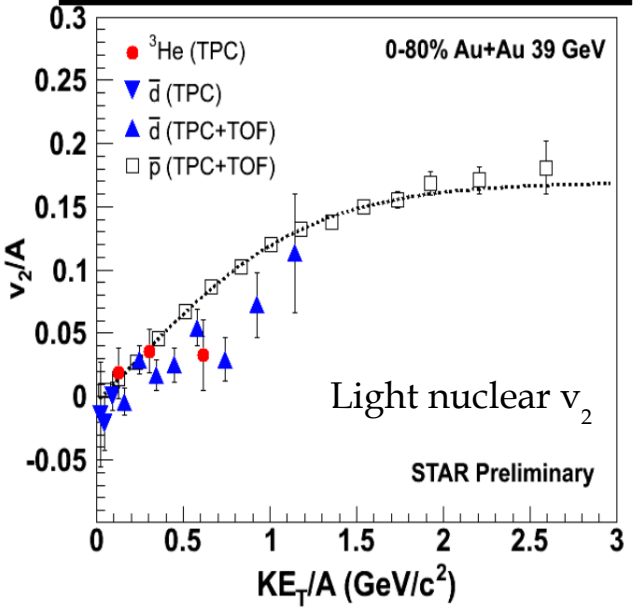
NA49: Phys.Rev.C79 044910 (2009)

… more interesting results are coming soon:

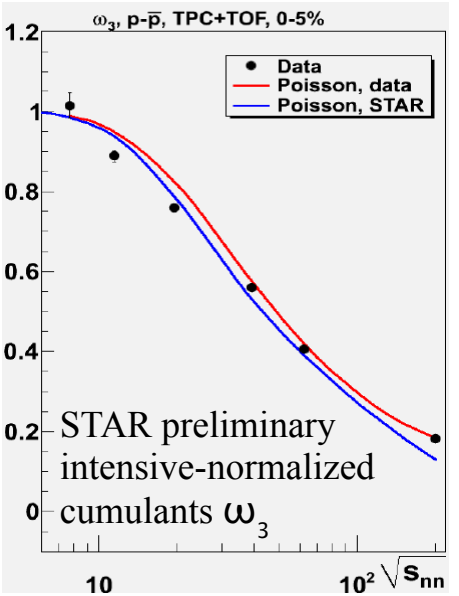
Thu. 16:45: Yuhui Zhu



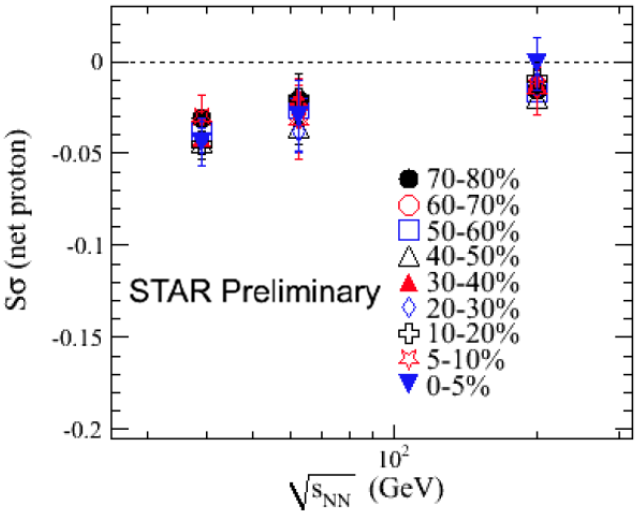
Thu. 14:30: Chitrasen Jena



STAR: DNP2011



Thu. 14:45: Zhiming Li



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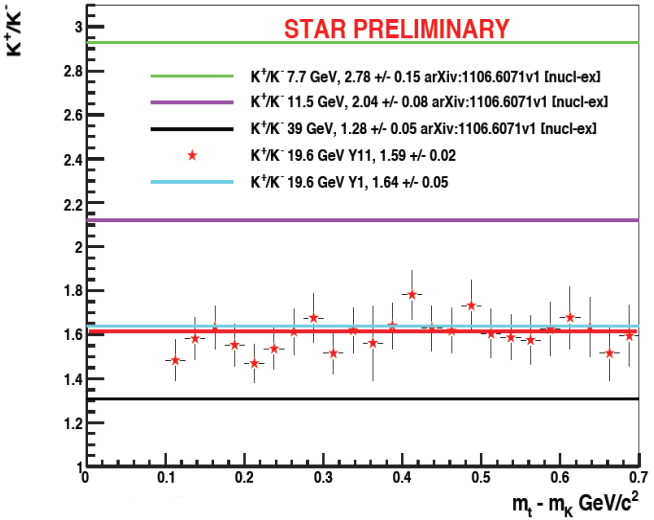

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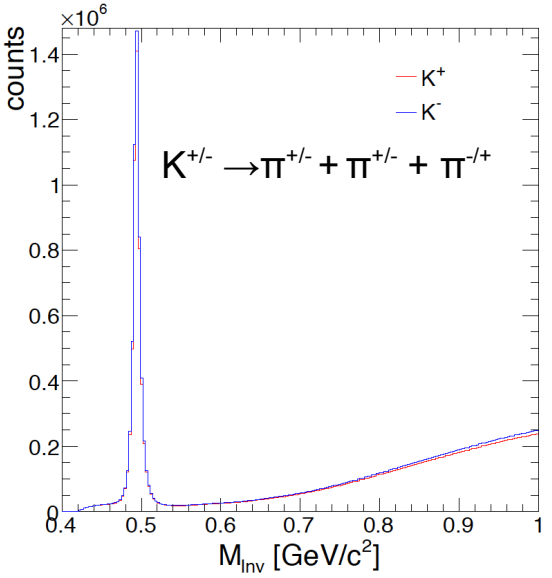


Summary and Outlook

Spectra results: Excellent agreement with published results

Event anisotropy: -Difference between particles and corresponding anti-particles in v_1 and v_2

-ϕ-meson v_2 deviates from other hadrons at 11.5 GeV

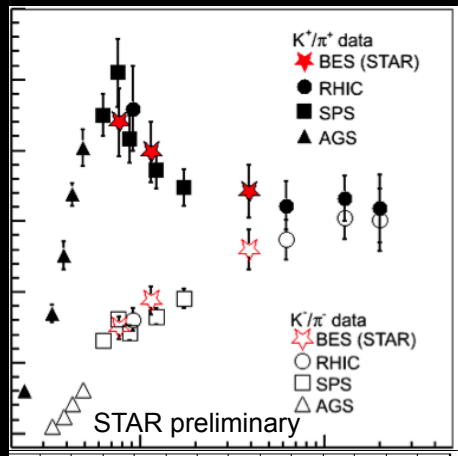
→ hadronic interactions might become more important at lower energies

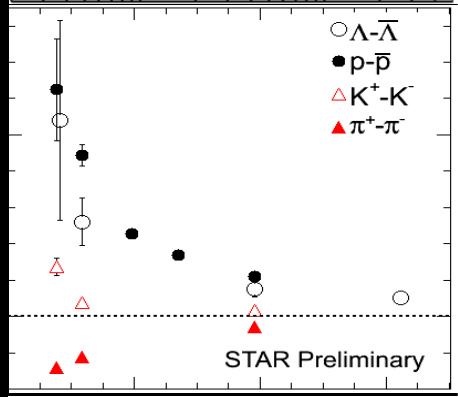
Azimuthal HBT: Possible dip at 17 GeV is ruled out

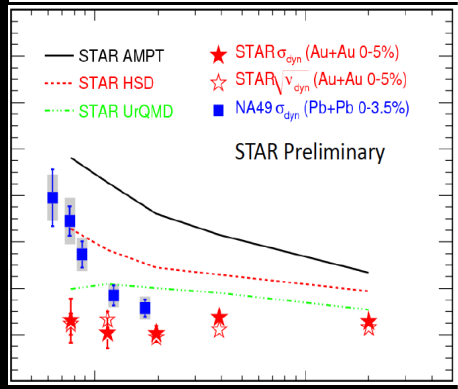
K/π fluctuations: Flat as a function of $\sqrt{s_{NN}}$, discrepancy at lower energies with NA49 results

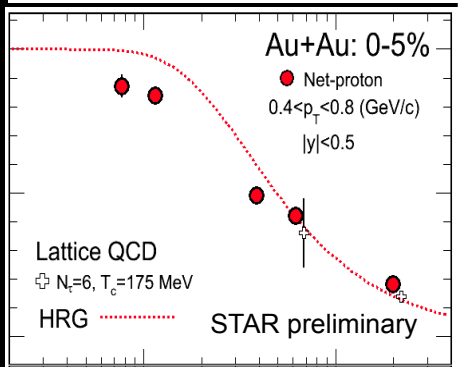
Higher moments: In agreement with HRG model at higher energies. No indications for a critical point so far

Outlook: 19.6 and 27 GeV results are coming soon for all analyses!









List of STAR Presentations at CPOD

Lokesh Kumar:	Centrality Dependence of Freeze-out Parameters from Au+Au Collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, and 39 GeV
Gang Wang:	STAR Highlights on Heavy Flavor and Di-electron Program
Xianglei Zhu:	Measurements of Strange Hadrons K0S, Λ and Ξ from Au+Au Collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5 and 39 GeV in STAR
Xiaofeng Luo:	Probing the QCD Critical Point by Higher Moments of Net-proton Multiplicity Distributions at STAR
Zhiming Li:	Energy Dependence of Dynamical Net- and Total-proton Cumulants at STAR
Jian Tian:	Event-by-Event Hadron Ratio Fluctuations from Au+Au Collisions at STAR
Shusu Shi:	Probe the QCD Phase Boundary with Elliptic Flow in Relativistic Heavy Ion Collisions at STAR
Chitrasen Jena:	Elliptic flow of light nuclei in heavy ion collisions at STAR
Lizhu Chen:	The sixth and fourth order cumulants of net-proton multiplicity distribution at STAR
Hui Wang:	Particle Ratio Fluctuations and Charge Balance Functions in Heavy Ion Collisions at RHIC
Yuhui Zhu:	Beam Energy Dependence of Hypertriton Production and Lifetime Measurement
Xiaoping Zhang:	Probe the QCD phase diagram with ϕ-meson production in relativistic nuclear collisions at STAR
Patrick Huck:	Dielectron production in Au+Au collisions at $\sqrt{s_{NN}}$ = 39 GeV at STAR