Results from STAR Beam Energy Scan Program

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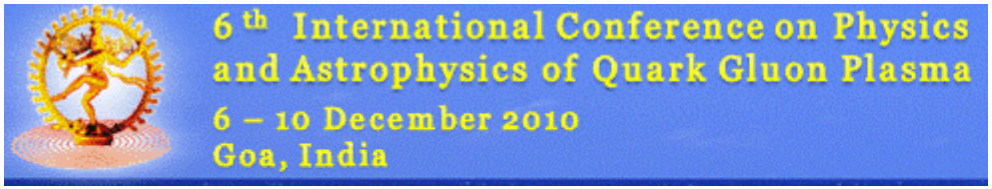
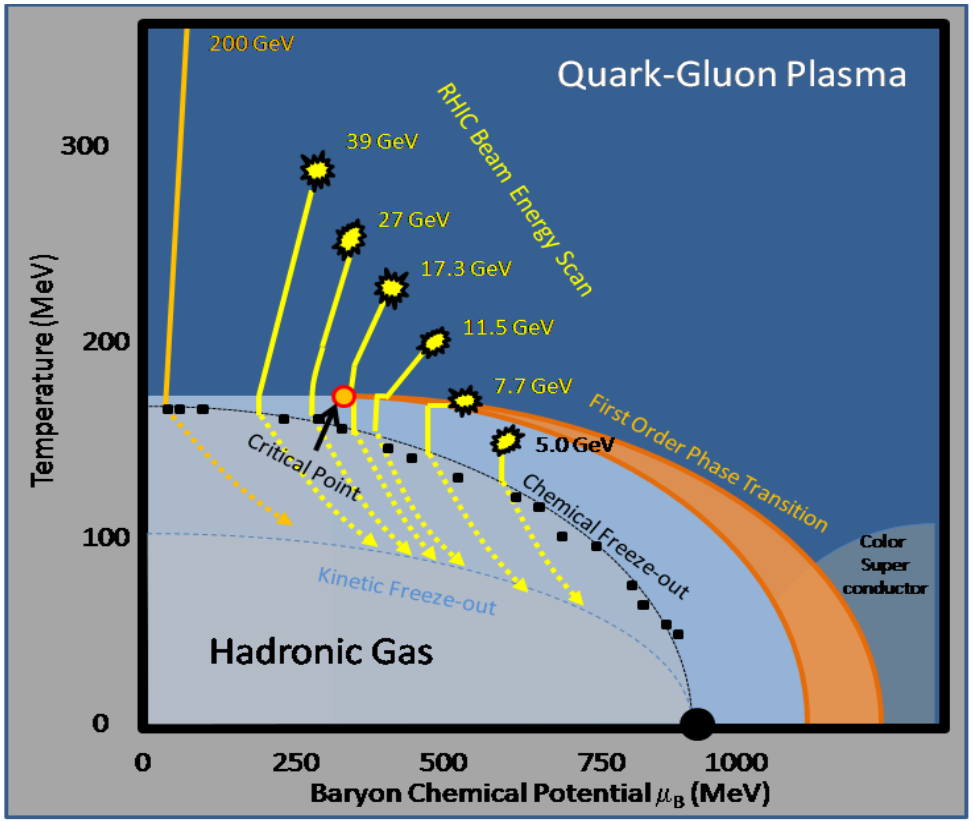


Outline

- Motivation for BES program in STAR
- Status of phase-I data taking
- Results
  - Identified particle production (First results from 7.7 GeV)
  - Azimuthal anisotropy (7.7 GeV to 39 GeV)
  - Fluctuations (First results from 39 GeV)
- Summary and outlook

Motivation

QCD Phase Diagram (Hadrons-Partons):

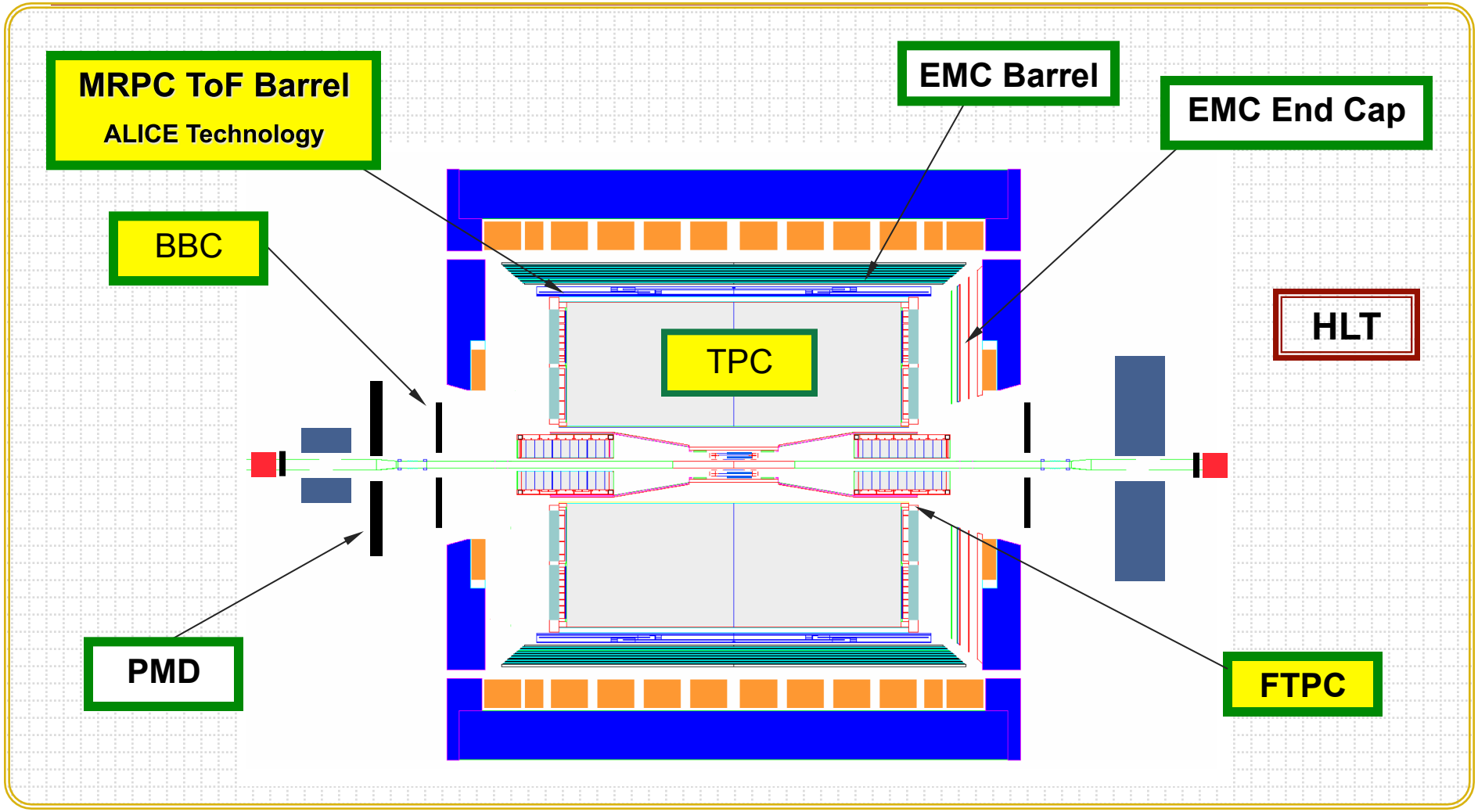


http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493

- QCD Phase diagram:
  T vs. Baryon chemical Potential
- Experimental study: Heavy-ion collisions at varying beam energies
- Phase transition: Look for turn-off of partonic signatures
- Critical Point: Non-monotonic variation of fluctuation observables with beam energy

- Goal of STAR BES program:
  - Search for the phase boundary
  - Search for the possible QCD Critical Point

STAR Detector

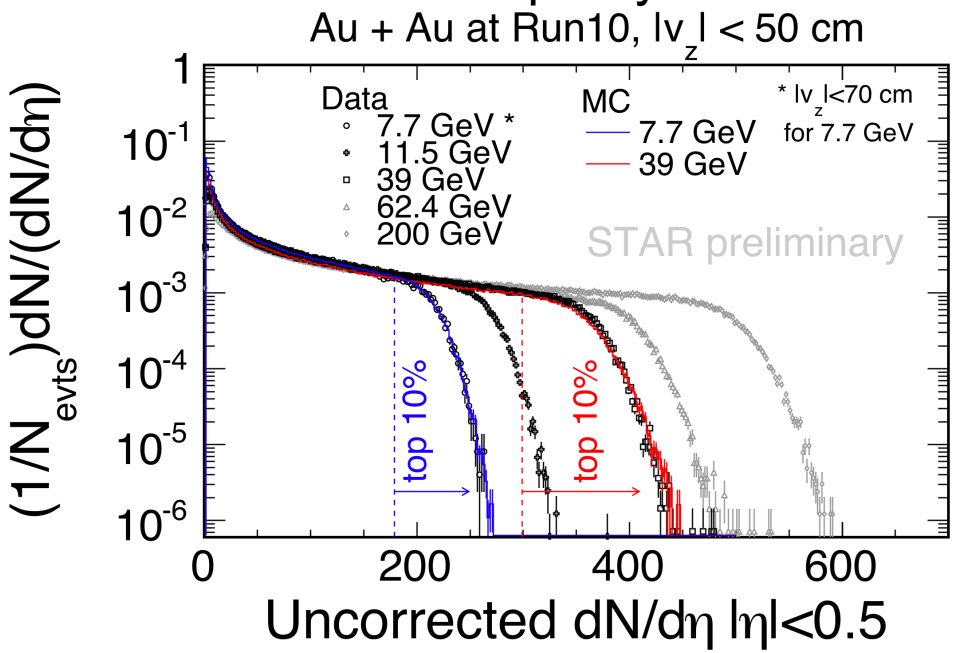


➢ Particle identification over 2π in azimuthal angle and more than two unit in rapidity

Status of Data Taking

$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Events taken (proposed) Million MB
5.0	550	
7.7	410	5(5)
11.5	300	7.5 (5)
18	230	(100 @ 200 Hz)
27	151	(150 @ 400 Hz)
39	112	250 (25)

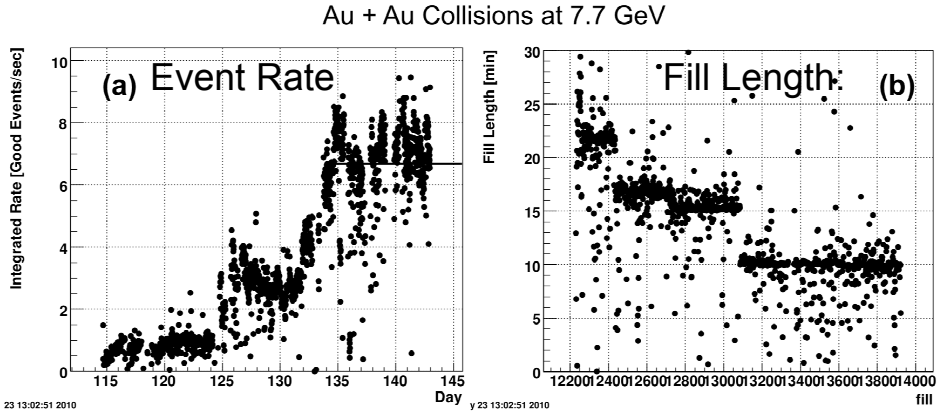
- Uncorrected multiplicity distribution:



- CAD and data taking at 7.7 GeV:

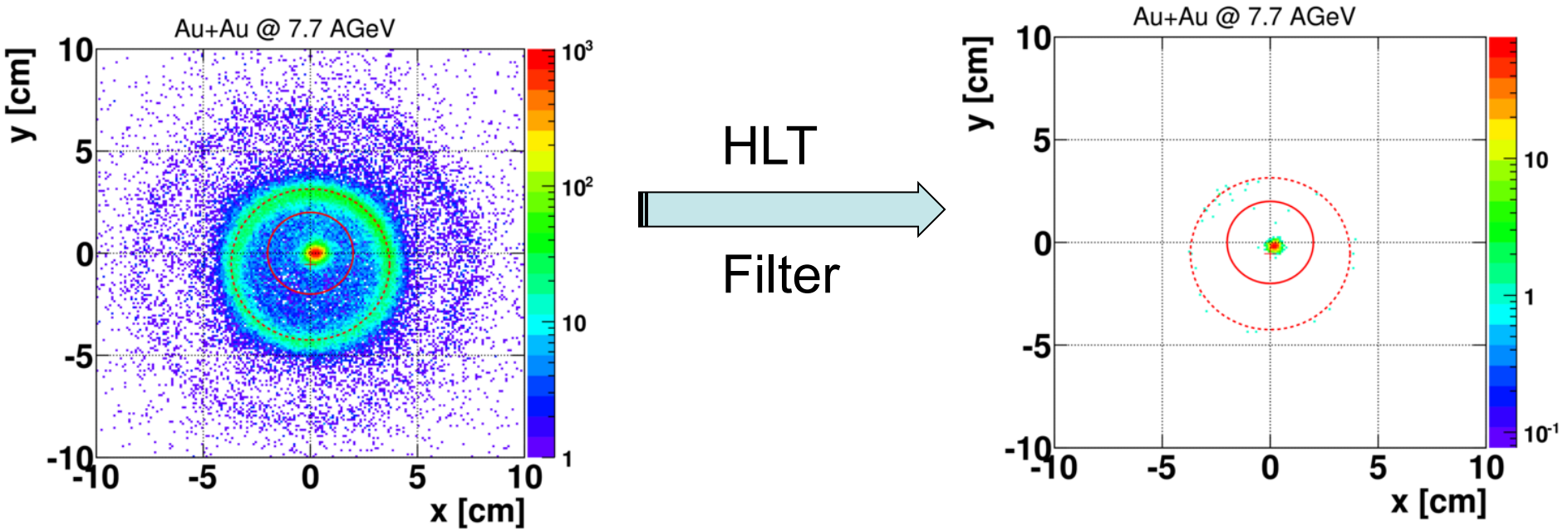
β*(m)	Event rate (Hz)	Fill length (min)
6	~2-3	~15-20
10	~8	~10

Average data taking:14Hrs/day



STAR High Level Trigger and BES

- STAR goal for 7.7 GeV – Good 5M events
- Background events: Predominantly beam-beampipe interactions

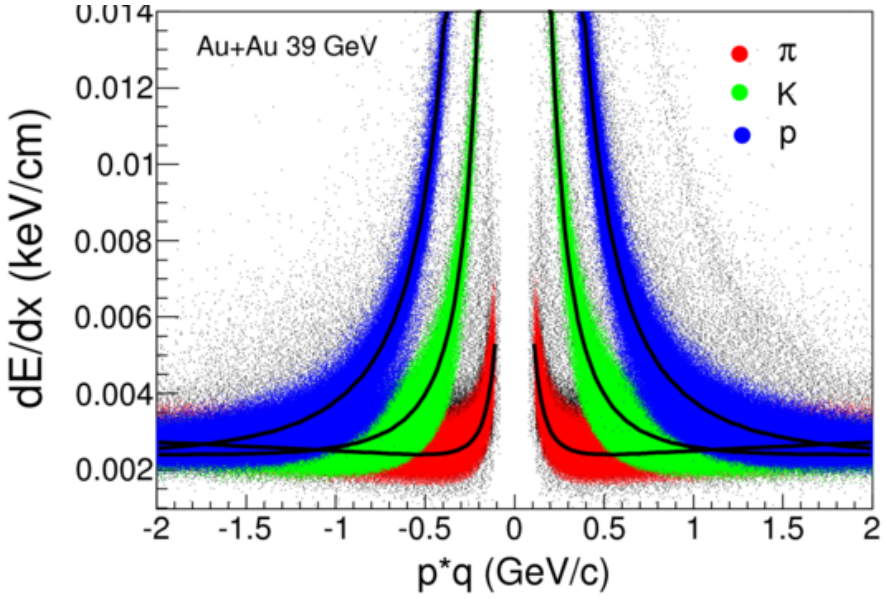


- ✧ HLT used to monitor quality of triggered events online
- ✧ Good events fraction: 3%
- ✧ HLT efficiency (online-offline comparison) : 95%

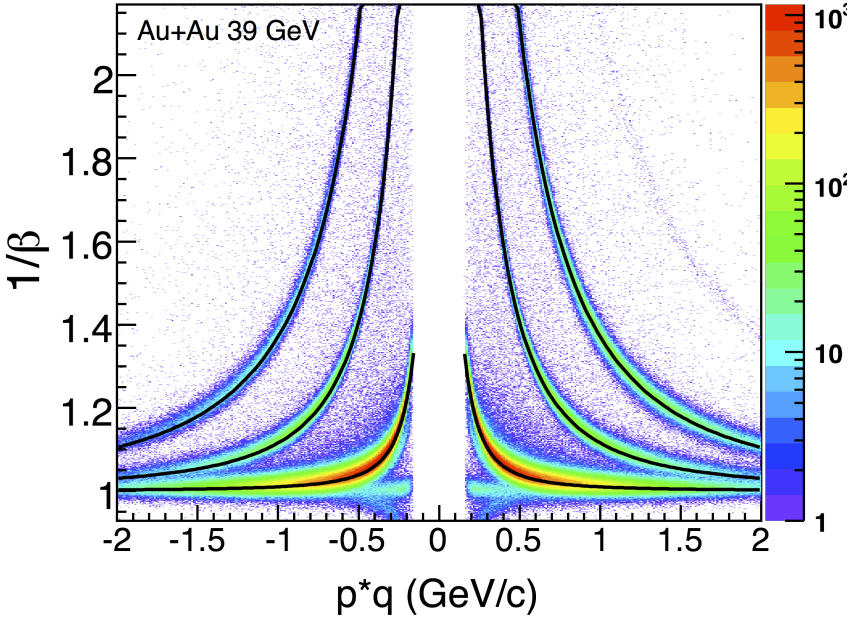
Improved Particle Identification

$\sqrt{s_{NN}}$ = *39* GeV Au + Au Collisions

TPC



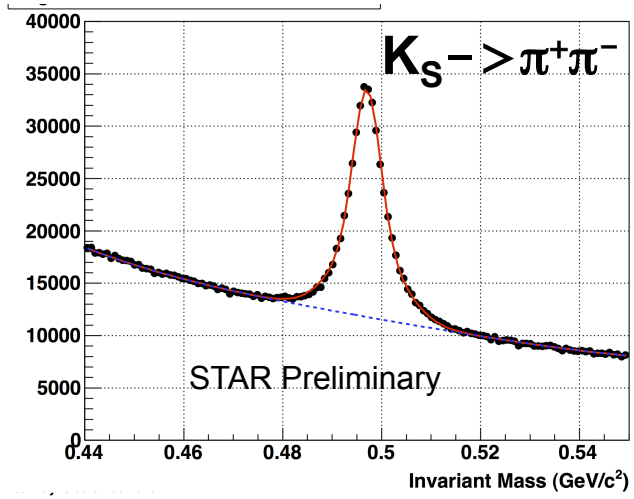
TPC+ToF

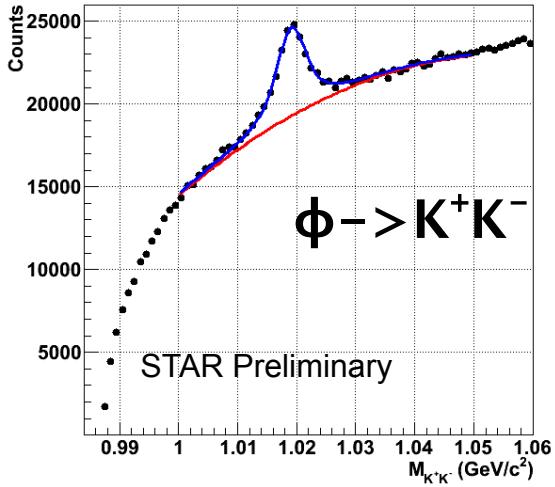


Beam Energy	Timing Resolution	Remarks
200 (GeV)	85 (*ps*)	At 39 GeV, using a new calibration scheme without information of start time from VPD (Vertex Position Detector), 87 *ps* of timing resolution has been achieved.
62.4 (GeV)	90 (*ps*)	
39 (GeV)	85 (*ps*)	
11.5 & 7.7 (GeV)	~ 80 (*ps*)	

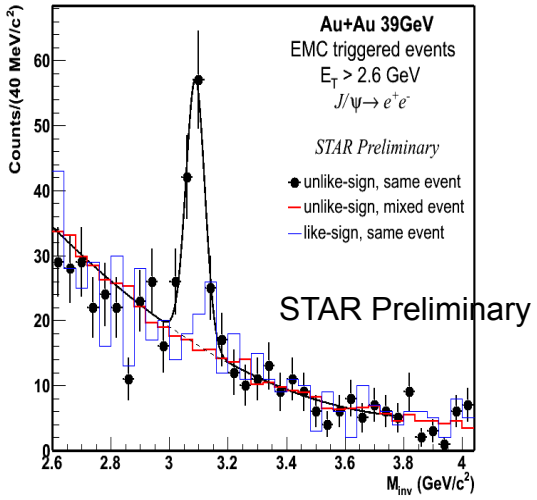
Particle Identification

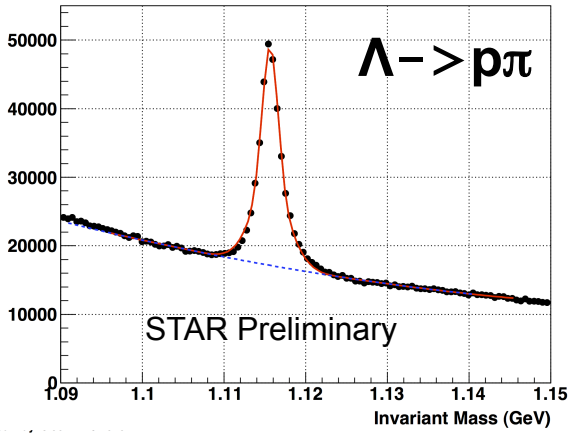
$\sqrt{s_{NN}}$ = 39 GeV Au + Au Collisions

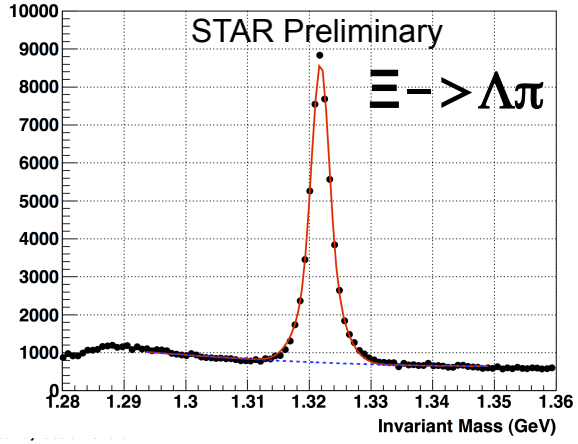


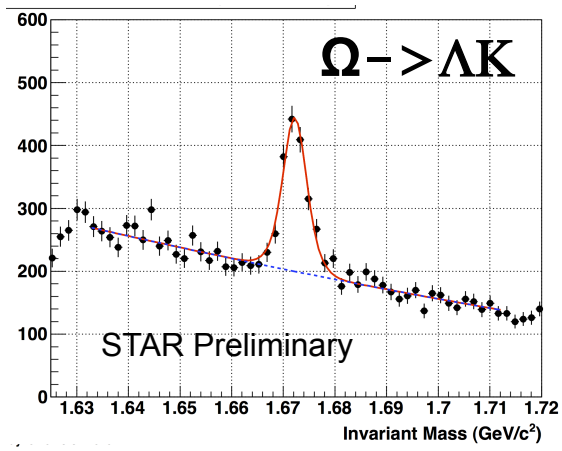


$J/\Psi -> e^+e^-$





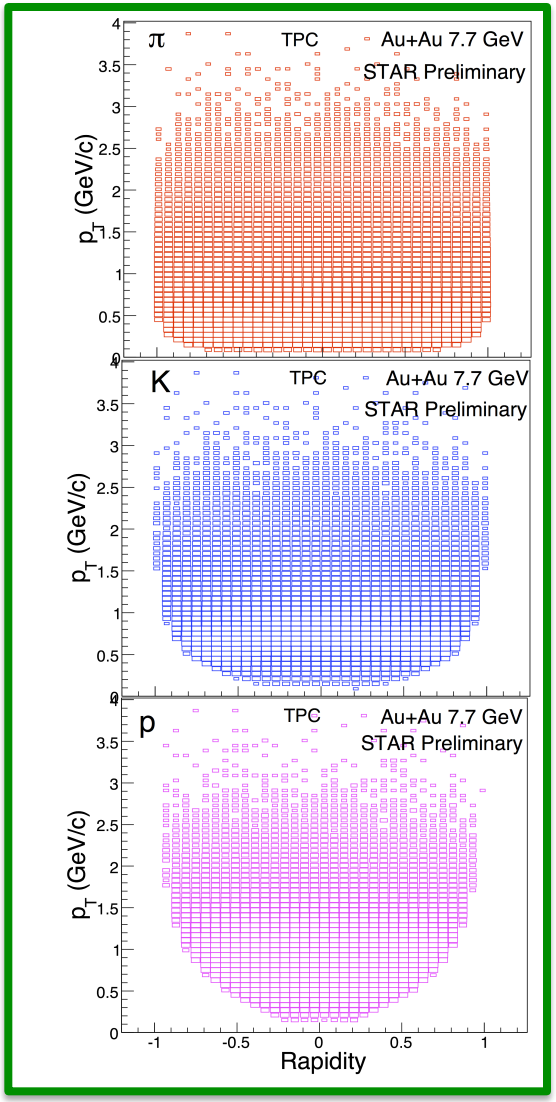




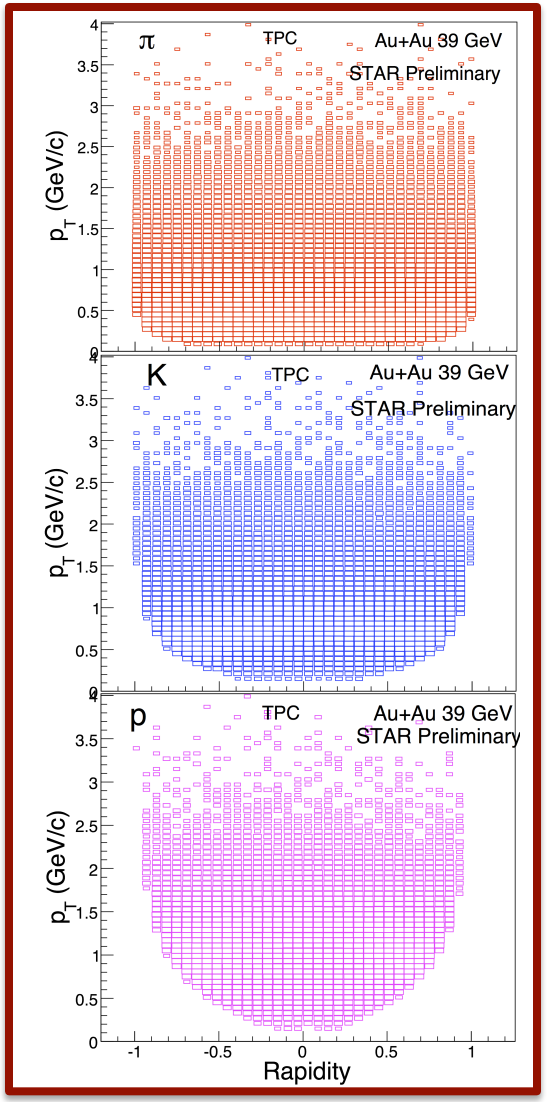
Invariant Mass (GeV)

Large acceptance over all RHIC Energies

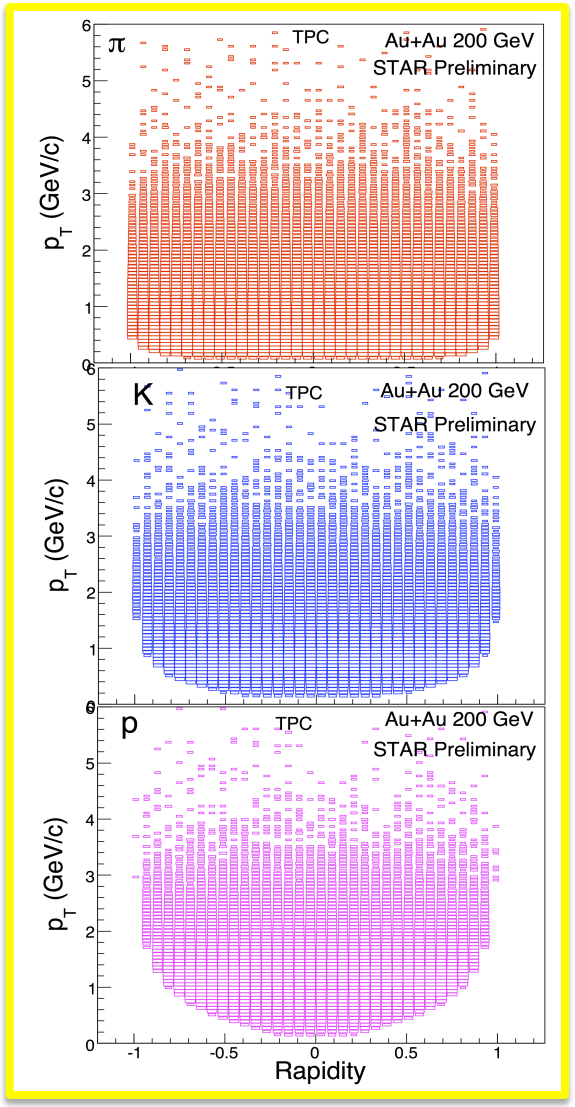
Au+Au at *7.7* GeV



Au+Au at *39* GeV



Au+Au at *200* GeV

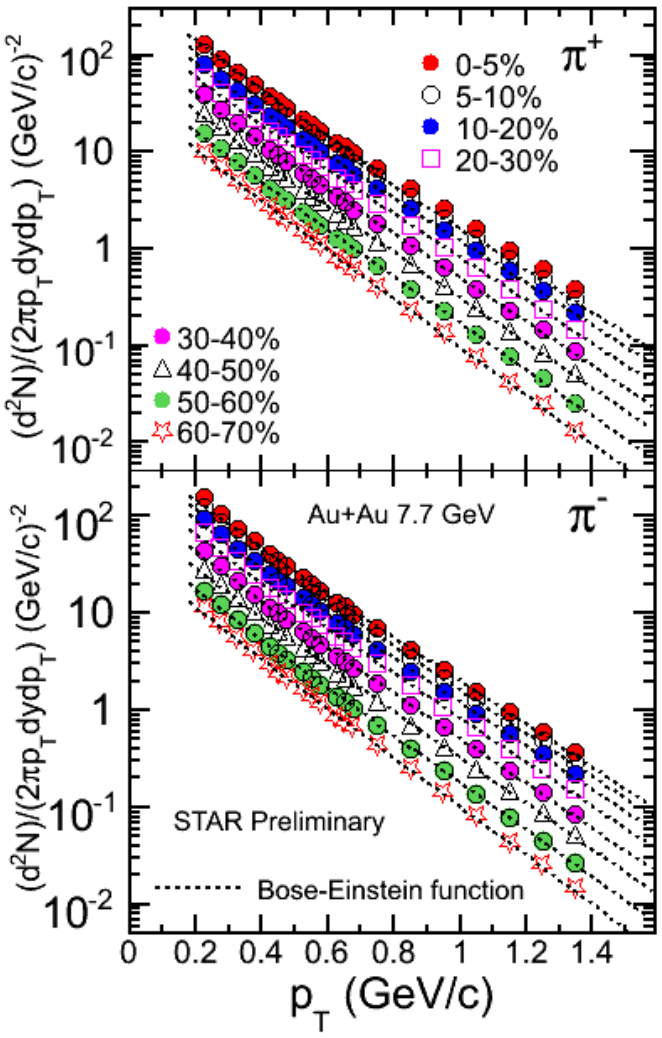


- Similar acceptance at midrapidity - Crucial for all analyses

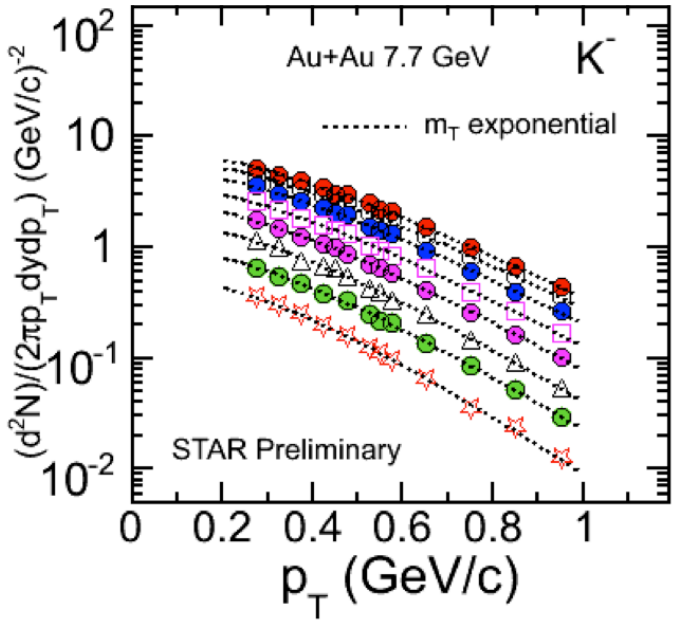
Results from BES

- Identified particle production (First results from 7.7 GeV)
- Azimuthal anisotropy (First results from 7.7 GeV to 39 GeV)
- Fluctuations (First results from 39 GeV)

Results at 7.7 GeV: π, K Spectra

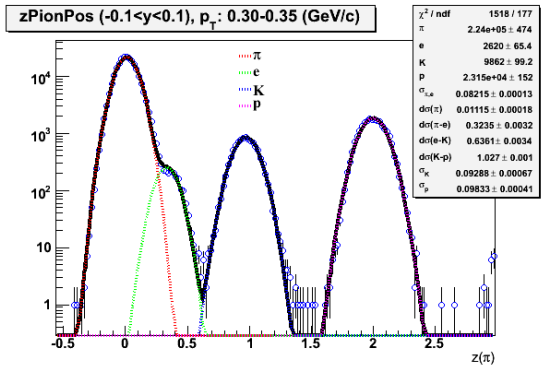


Pion yields are corrected for weak decays

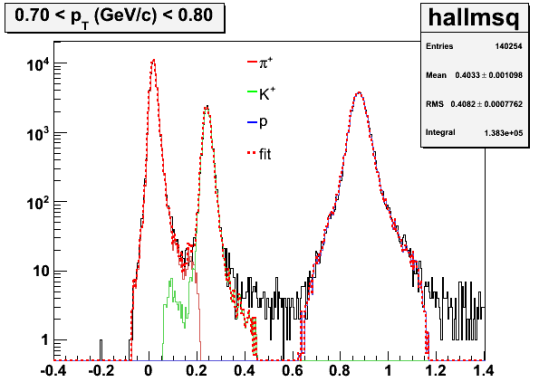


We measure ~ 70% of π, K within our p_T acceptance at mid-rapidity

TPC (dE/dx)

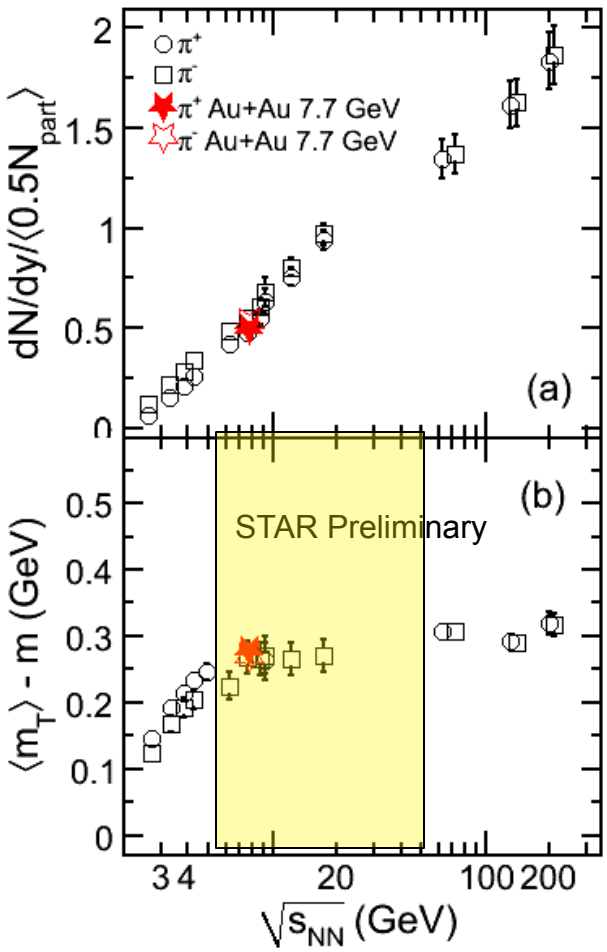


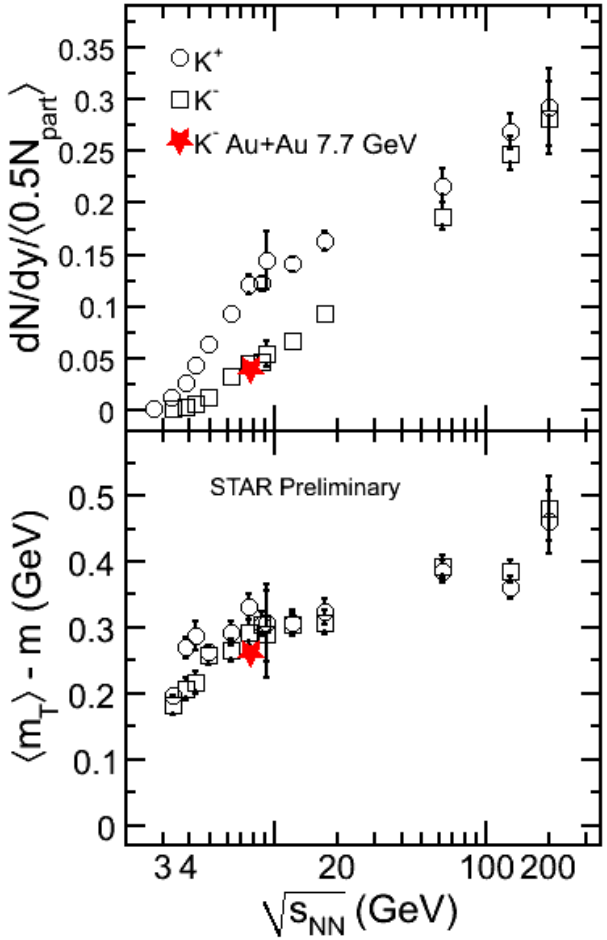
TOF (M^2)



➢ Analyses ongoing for K^+, K^0_s, p, Λ, φ …

Energy dependence: dN/dy and $\langle m_T \rangle$





Errors: statistical
systematic errors in progress

- Assuming a thermodynamic system:

$T \sim \langle m_T \rangle - m$

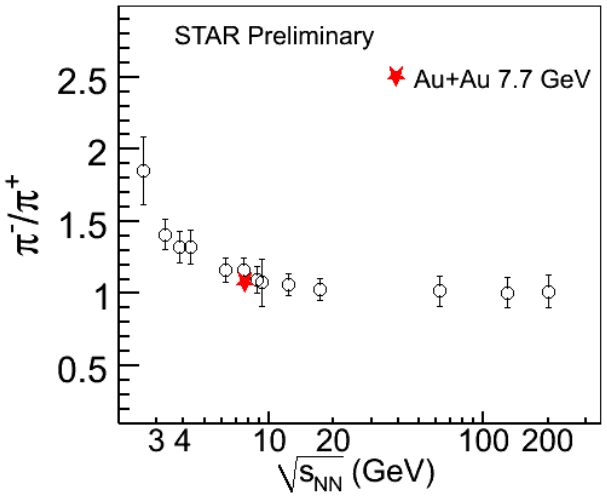
entropy ~ dN/dy α $\log(\sqrt{s_{NN}})$

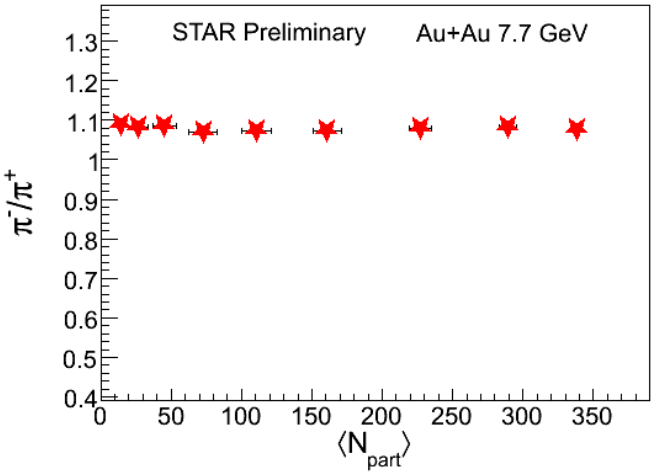
NA49 : PRC 66 (2002) 054902,
PRC 77 (2008) 024903,
PRC 73 (2006) 044910
STAR : PRC 79 (2009) 034909,
arXiv: 0903.4702;
PRC 81 (2010) 024911
E802(AGS) : PRC 58 (1998) 3523,
PRC 60 (1999) 044904
E877(AGS) : PRC 62 (2000) 024901
E895(AGS) : PRC 68 (2003) 054903

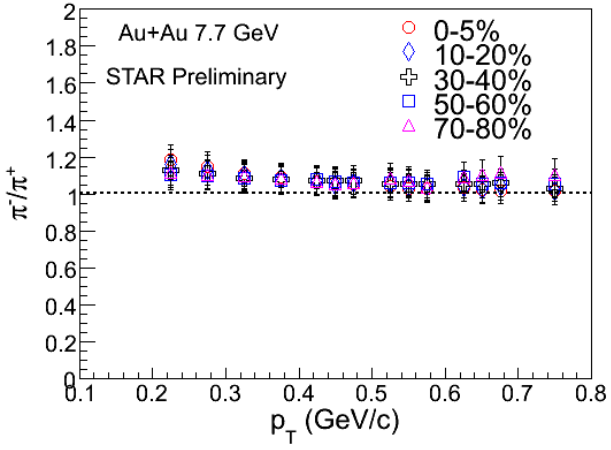
- Results consistent with the published energy dependence
- $\langle m_T \rangle - m$ remains constant for a broad energy range

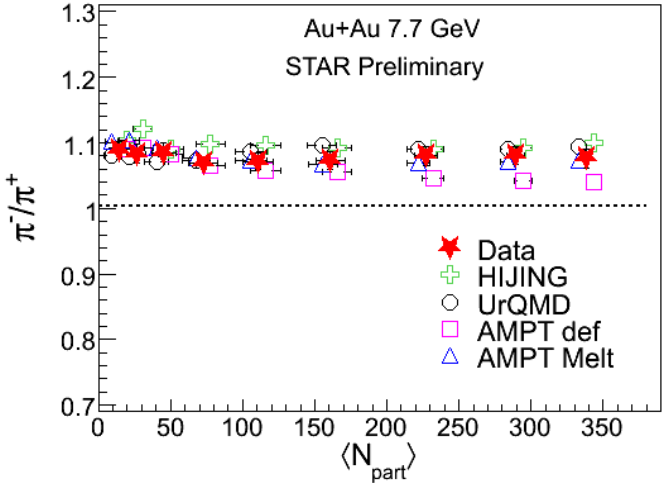
K^+ yields and other beam energy analyses ongoing

Pion Ratio







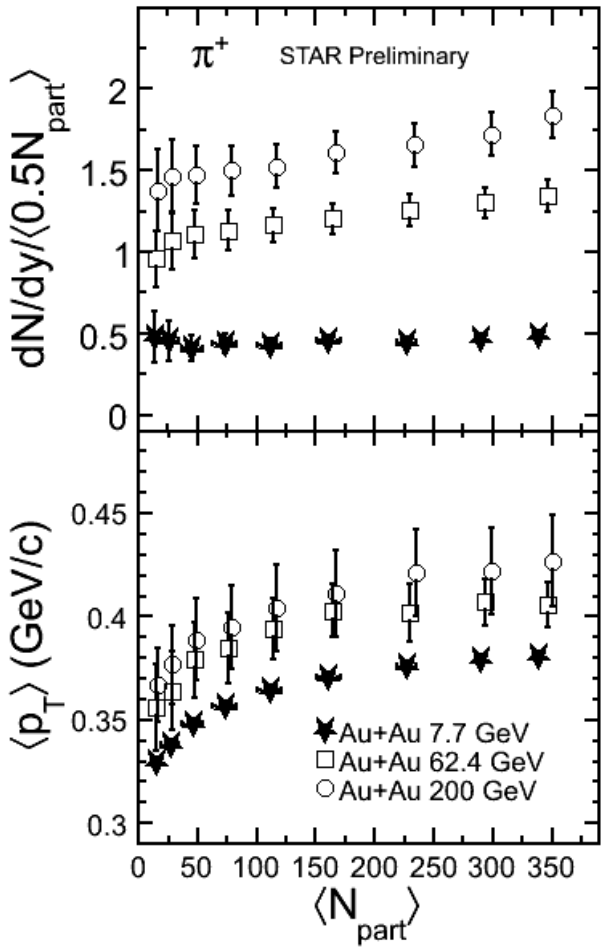


Errors: statistical systematic errors in progress

- Results consistent with the published energy dependence
- π^-/π^+ ratio ~ 1.1
- Ratio > 1 at low p_T
- Most models give similar values

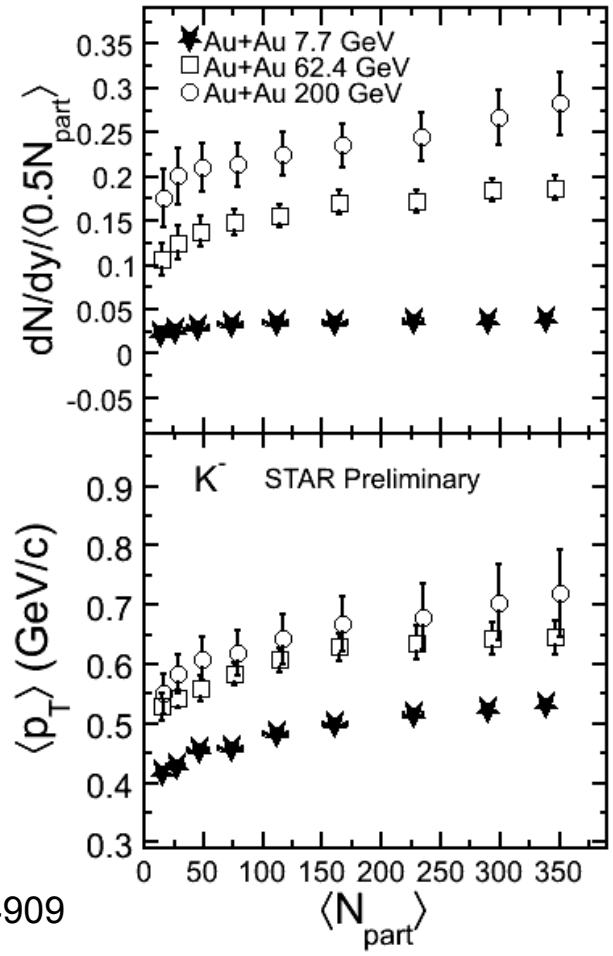
NA49 : PRC 66 (2002) 054902, PRC 77 (2008) 024903, PRC 73 (2006) 044910
STAR : PRC 79 (2009) 034909, arXiv: 0903.4702;PRC 81 (2010) 024911
E802(AGS) : PRC 58 (1998) 3523, PRC 60 (1999) 044904
E877(AGS) : PRC 62 (2000) 024901
E895(AGS) : PRC 68 (2003) 054903

Centrality Dependence: dN/dy and $\langle p_T \rangle$



Errors: statistical
systematic errors
in progress

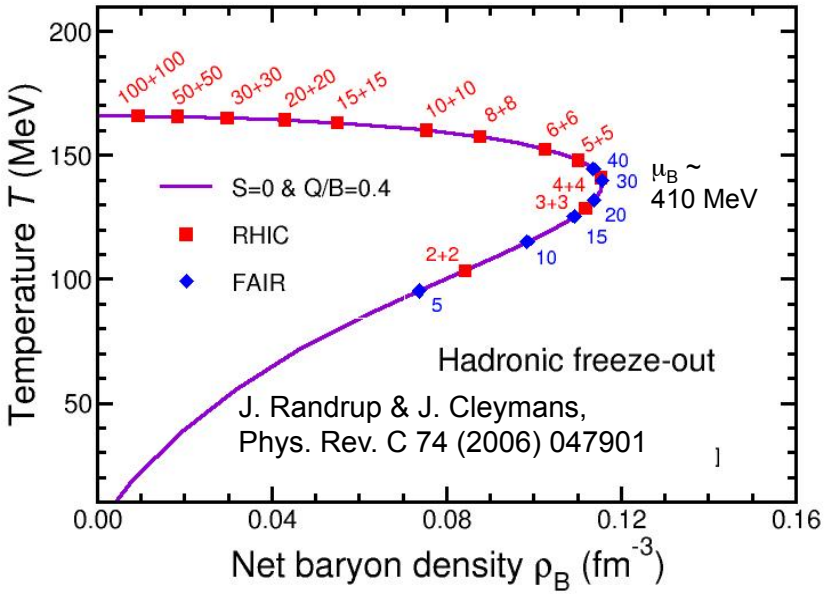
STAR :
PRC 79 (2009) 034909



- dN/dy/<0.5Npart> ~ constant with centrality at 7.7 GeV
- $\langle p_T \rangle$ increases from peripheral to central collisions
  Indicates collectivity increases with collision centrality

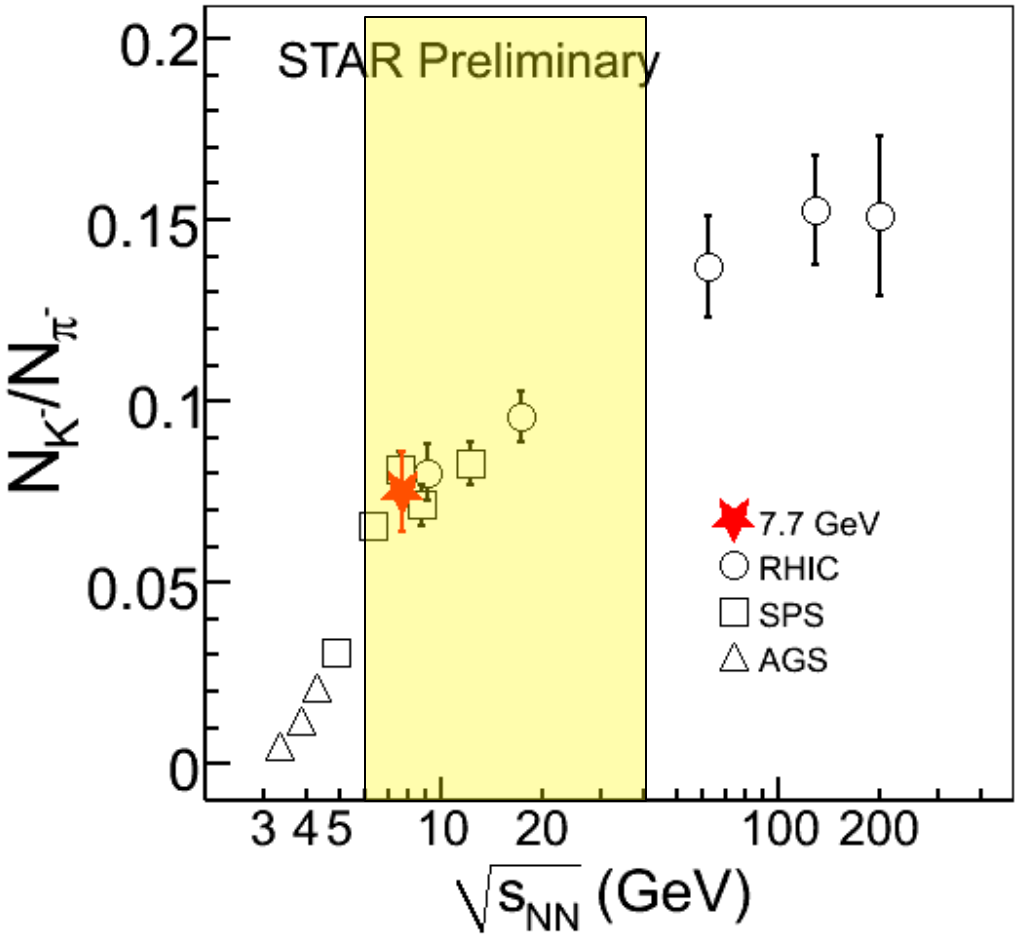
Energy dependence: K/π ratio and models

The maximum baryon density at freeze-out: $\sqrt{s_{NN}}$ ~ 8 GeV



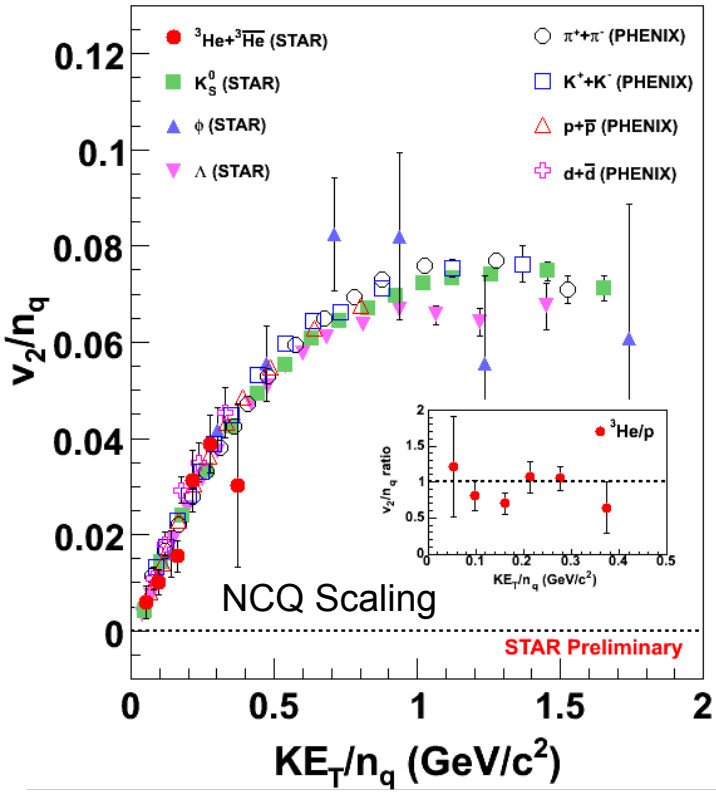
J. Cleymans et al., Eur. Phys. J. A 29, 119 (2006);
J. Rafelski et al., J. Phys. G 35, 044011 (2008);
A. Andronic et al., Phys. Lett B 673, 142 (2009);
B. Tomasik et al., Eur. Phys. J. C 49, 115 (2007)
S. Chatterjee et al. arXiv:0906.2523v1

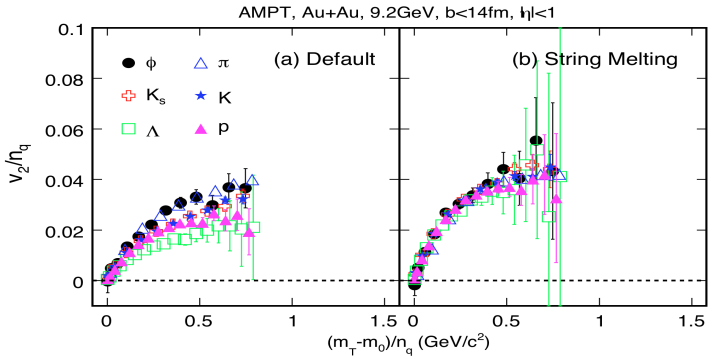
STAR K^+/π^+ analysis at 7.7 GeV ongoing



- K^+/π^+ vs. $\sqrt{s_{NN}}$ is best explained using HRG+Hagedorn model
- K^-/π^- at 7.7 GeV consistent with published energy dependence

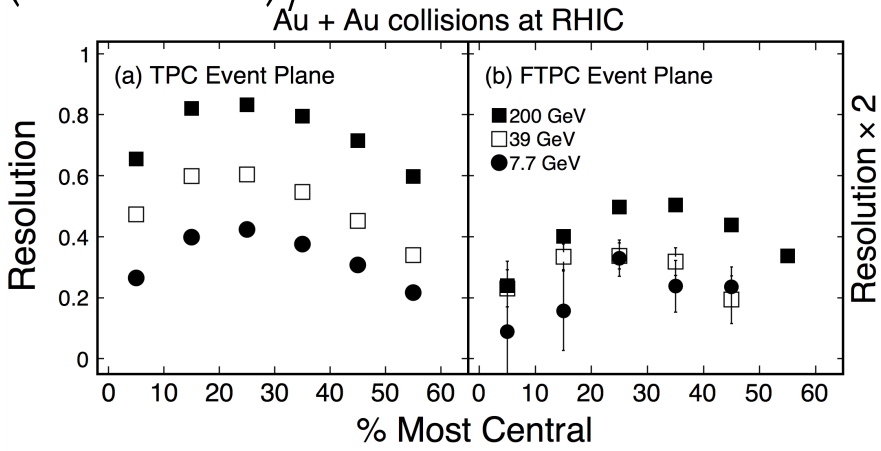
Azimuthal Anisotropy v_2 - Motivation





$$v_2 = \left\langle \cos\left(2\left(\phi - \psi_2\right)\right)\right\rangle$$

See Talks: C. Jena, S. Shi
Session # 7



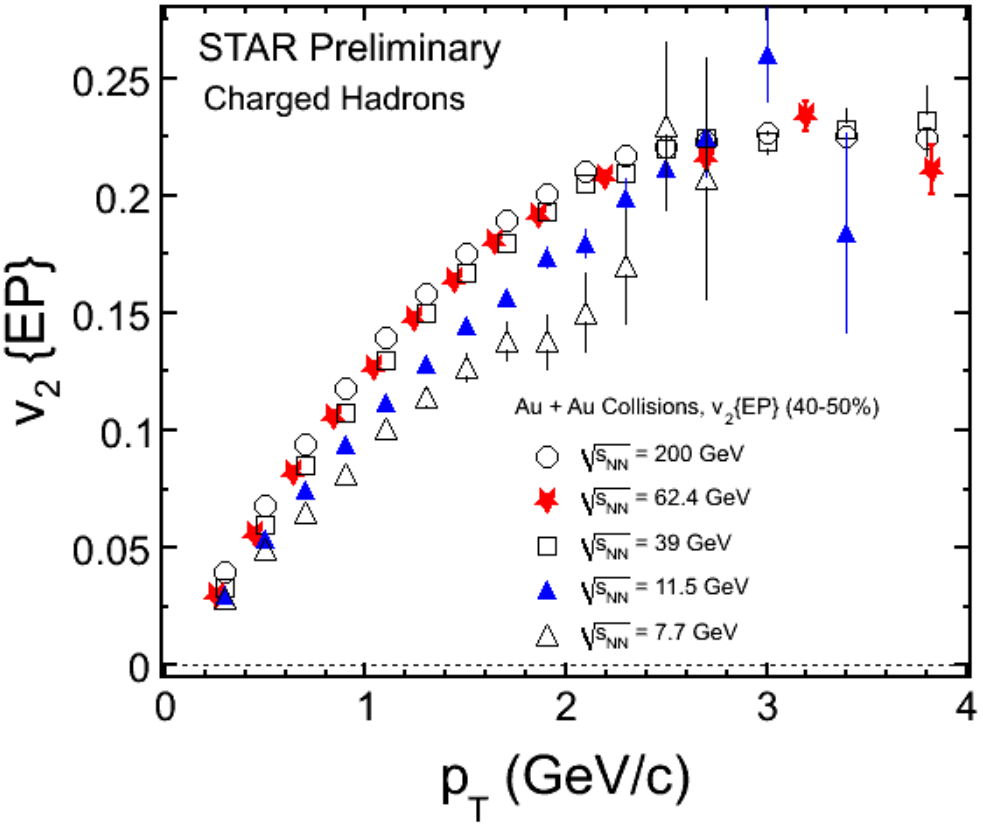
- Event plane measurements at STAR:
  - (1) TPC ($|\eta| \le 1$)
  - (2) FTPC ($2.5 \le |\eta| \le 4.2$)
  - (3) BBC ($3.8 \le |\eta| \le 5.2$)
- In this talk only inclusive charged hadron v_2 are presented
- In the hadronic case:
  - (i) No number of quark scaling
  - (ii) Very small value of φ v_2

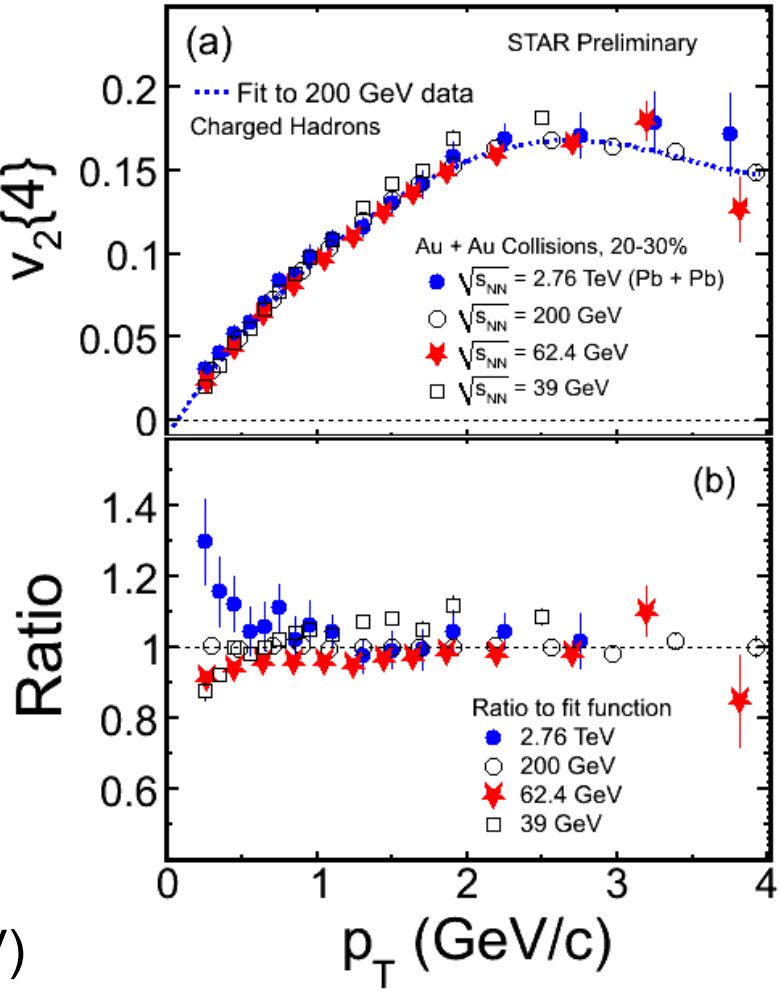
K.J. Wu et al., J.Phys.G37:094029,2010
J. Tian et al., Phys. Rev. C79:067901, 2009

Azimuthal Anisotropy: v_2

ALICE:arXiv 1011.3914
STAR: PRC 77 (2008) 054901; PRC 75 (2007) 054906

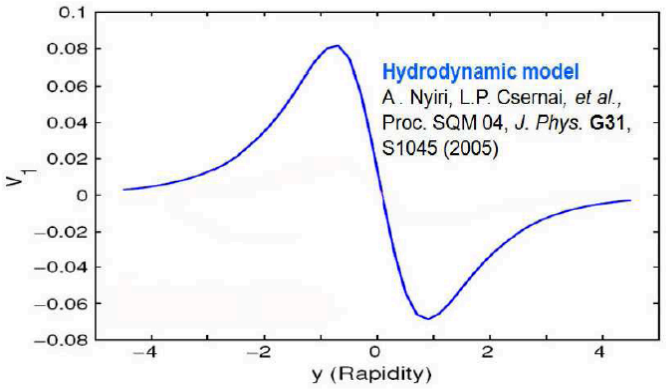
Compilation by S. Shi





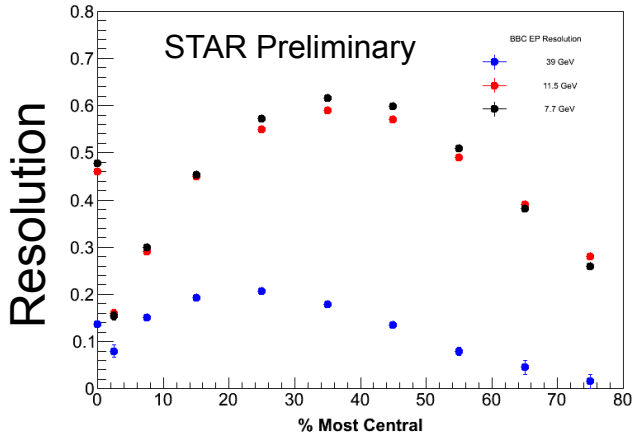
- v_2 (7.7 GeV) < v_2 (11.5 GeV) < v_2 (39 GeV)
- v_2 (39 GeV) ~ v_2 (62.4 GeV) ~ v_2 (200 GeV) ~ v_2 (2.76 TeV)

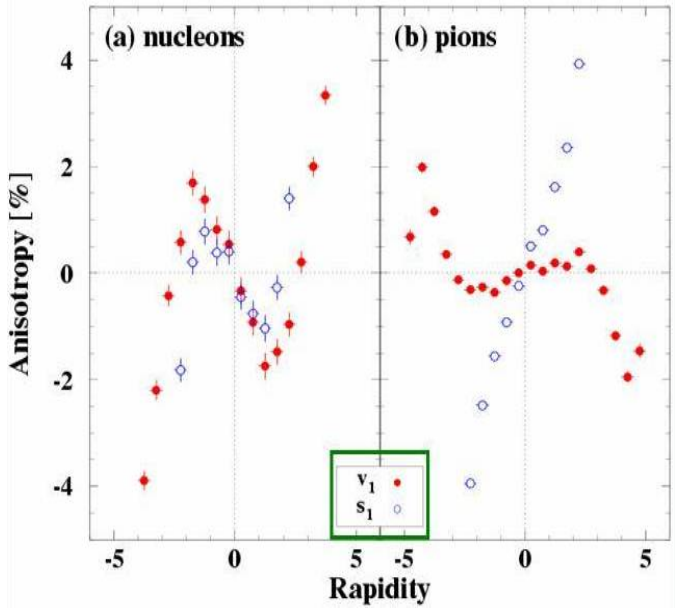
Directed Flow: v_1



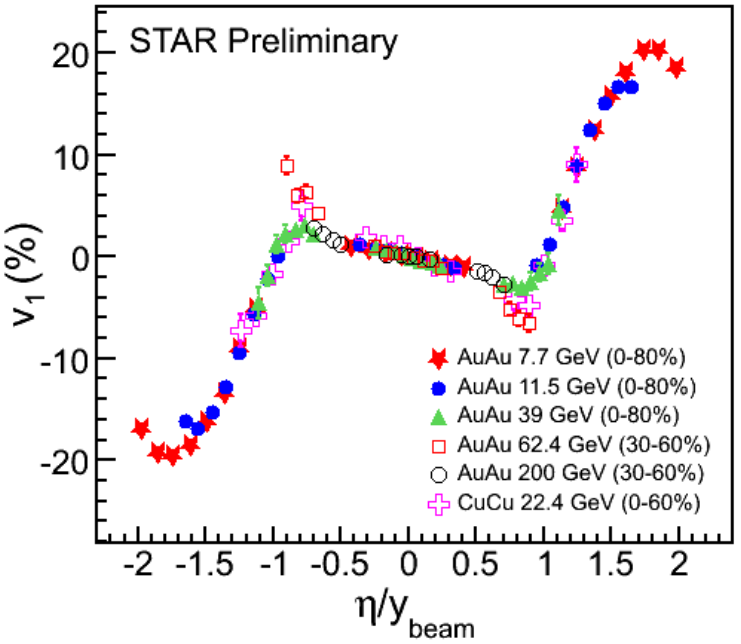
$$v_1 = \left\langle \cos(\phi - \Psi_r) \right\rangle$$

$$\phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$





R. Snellings et al. PRL 84, 2803 (2000);H. Liu et al., PRC 59, 348 (1999).

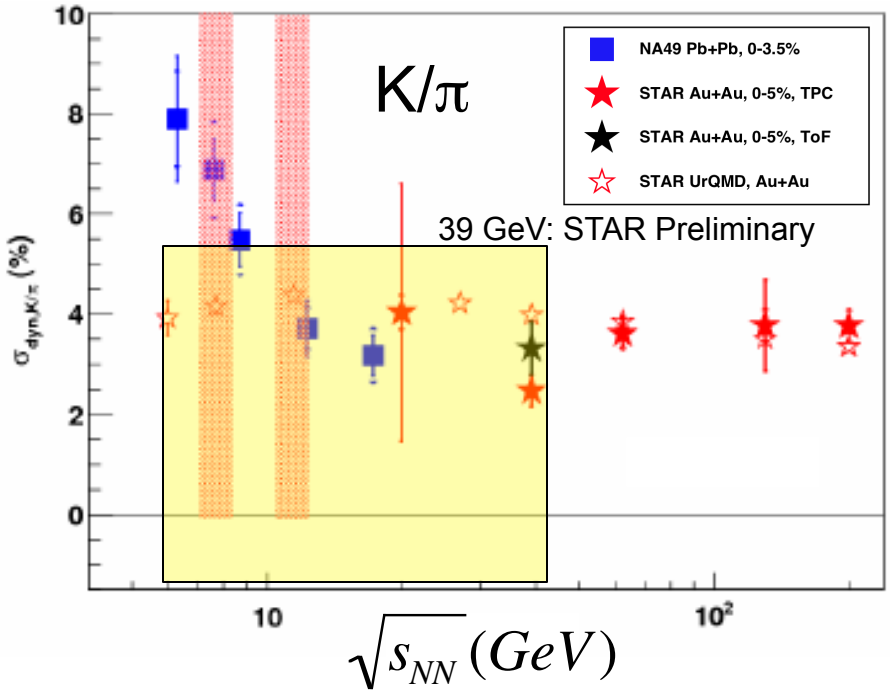


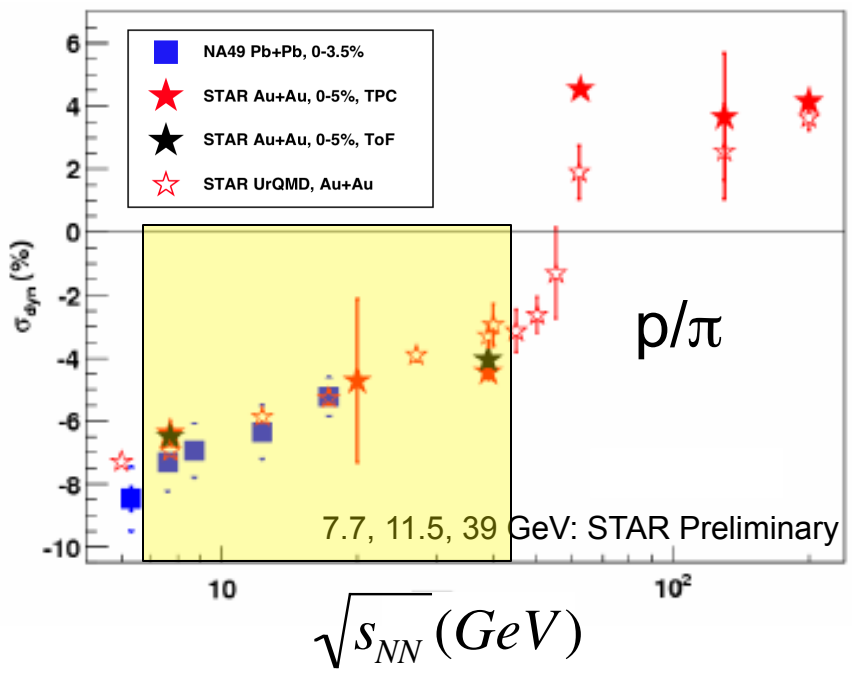
- v_1(y) could be sensitive to baryon transport, space momentum correlations and QGP formation

Fluctuations: Particle Ratios

STAR CPOD 2010

$$\sigma_{dyn} = sign(\sigma^2_{data} - \sigma^2_{mixed})\sqrt{|\sigma^2_{data} - \sigma^2_{mixed}|} \qquad \sigma^2_{dyn} \approx \nu_{dyn}$$



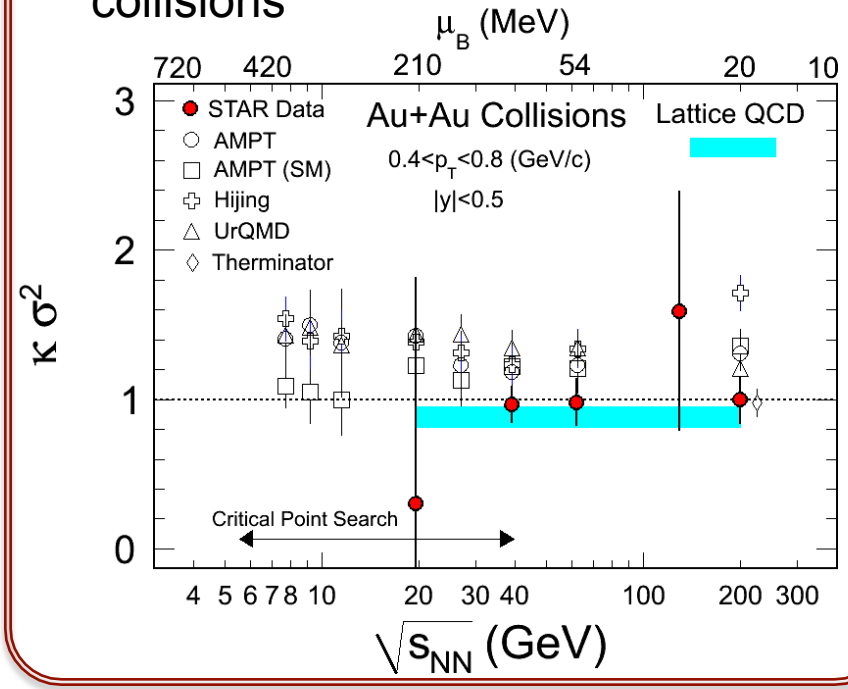


- K/π fluctuations: ~constant from 19.6 to 200 GeV
- p/π fluctuations at 7.7 GeV similar to SPS fixed target experiment

Fluctuations: Higher Moments - Net Protons

Critical Point Search

- Measure conserved quantities, ***B, s, Q***, for example.
- Higher moments sensitive to the critical point.
- Net-p Kurtosis central Au+Au collisions



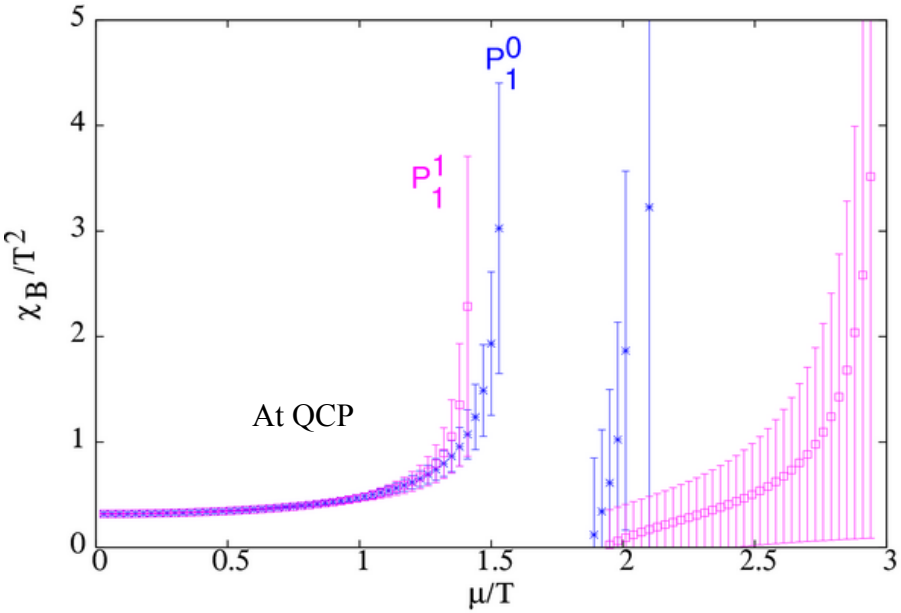
$$\sigma = \sqrt{< (N - < N >)^2 >} \qquad s = \frac{< (N - < N >)^3 >}{\sigma^3}$$

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

$$S\sigma \sim \chi_B^{(3)}/\chi_B^{(2)}$$

$$\kappa\sigma^2 \sim \chi_B^{(4)}/\chi_B^{(2)}$$

R. Gavai & S. Gupta PRD 78, 114503 (2008)



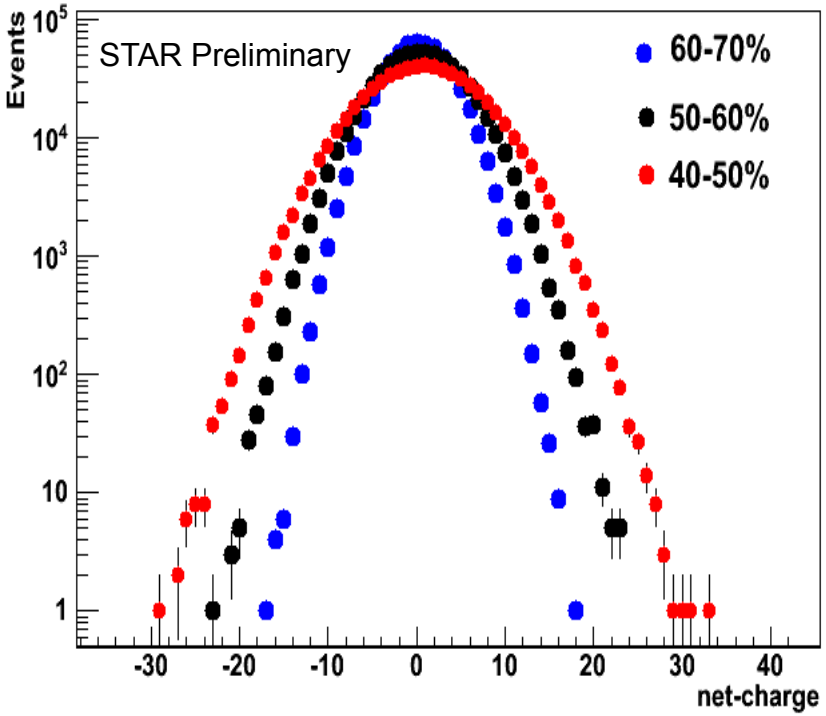
- $\kappa\sigma^2 \sim 1$ for the beam energies studied

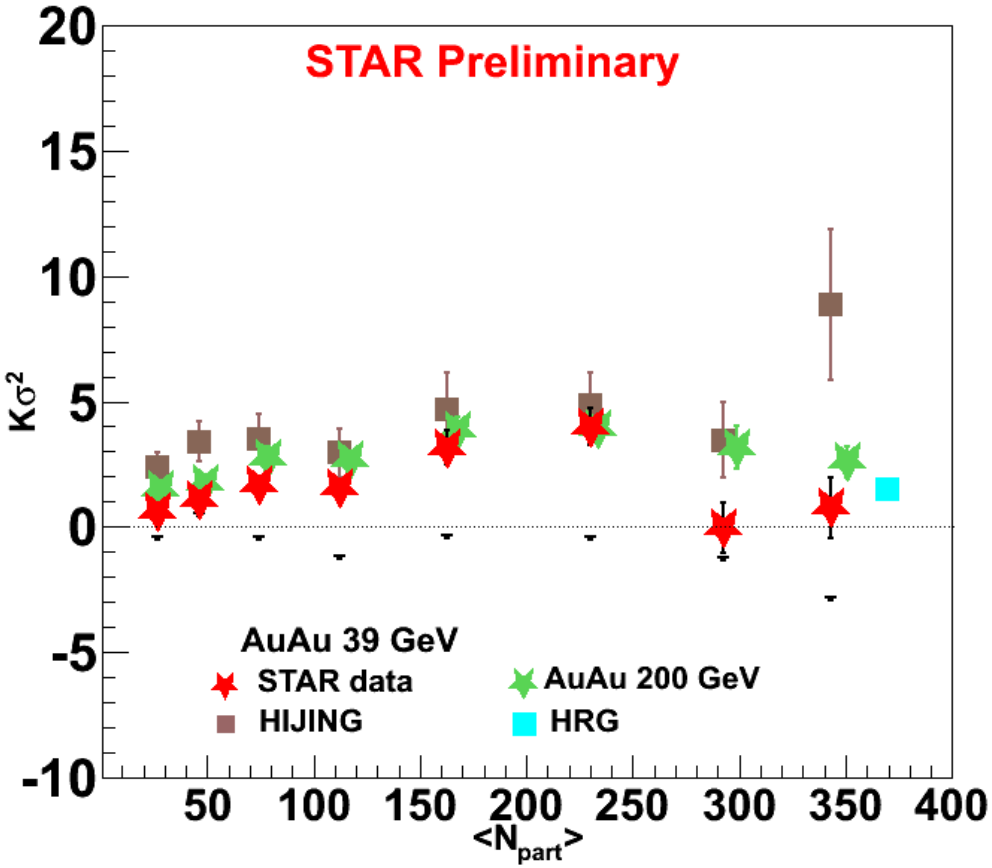
See Talk by H. G. Ritter
Session# 15

Fluctuations: Higher Moments - net charge

STAR Data Au+Au 39 GeV:
$0.15 < p_T < 1.0$ (GeV/c)
$-0.5 < \eta < 0.5$

See Talk by N. R. Sahoo
Session# 15





- $K\sigma^2$ similar for 39 and 200 GeV Au+Au collisions
- Central collision results consistent with Hadron Resonance Gas model
- These observations are similar to those from net-proton study

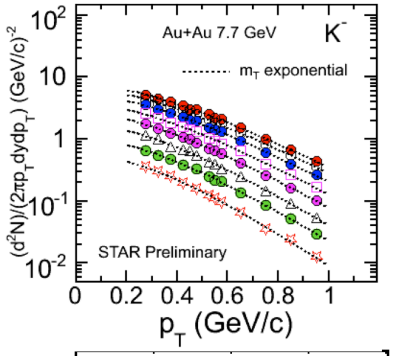
Summary

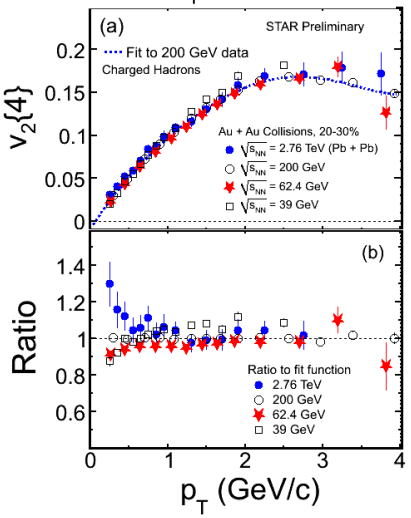
- RHIC beam energy scan program has started

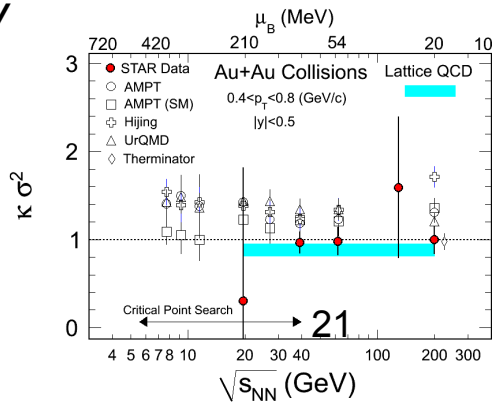
  Aim: - Establish the possible QCD phase boundary
  - Locate the possible QCD critical point

  Status: - Very successful operation of RHIC
  - Successful data taking in STAR
  - All event statistics (7.7, 11.5, and 39 GeV) goals are met

- First results from BES program at RHIC presented
  - Identified particle production at 7.7 GeV
    - -- *Particle production scales with N_{part}*
    - -- *Collectivity increases with centrality*
  - Azimuthal anisotropy at 7.7, 11.5 and 39 GeV
    - -- *$v_2(p_T)$ saturates beyond 39 GeV above p_T = 500 MeV*
  - Fluctuations at 39 GeV
    - -- *Net-proton and Net-charge results consistent with expectations from Hadron Resonance Gas Model (HRG model assumes thermal equilibrium)*







Lokesh Kumar ICPAQGP 2010

Outlook

Physics	Experimental Measurements	Detectors
A. Critical Point	**(i) Net-p σ, S, κ, fluctuations** **(ii) <K/π>, <p/π>,** $\langle p_T \rangle$, $\langle N_{ch} \rangle$ (iii) Light nuclei cluster multiplicity distributions	TPC, FTPC, TOF
B. Phase Transition	(i) Heavy flavor collectivity + J/ψ v_2 (ii) Di-lepton spectra and v_2 **(iii) The n_q-v_2 scaling** **(iv) v_1 rapidity dependence** (v) Net-p & net-K: *σ, S, κ* (vi) LPV	TPC, FTPC, TOF, HFT, MTD

Runs	$\sqrt{s_{NN}}$ (GeV)	Detectors
Run10	7.7, 11.5, 39, 62.4, 200	TPC, FTPC, TOF, BBC, PMD
Run11	6.1(?), 18, 27, 200	TPC, FTPC, TOF, BBC, PMD
Run14-15 (DM11)	Finer steps in beam energy (?)	TPC, TOF, BBC, FGT

Thanks

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