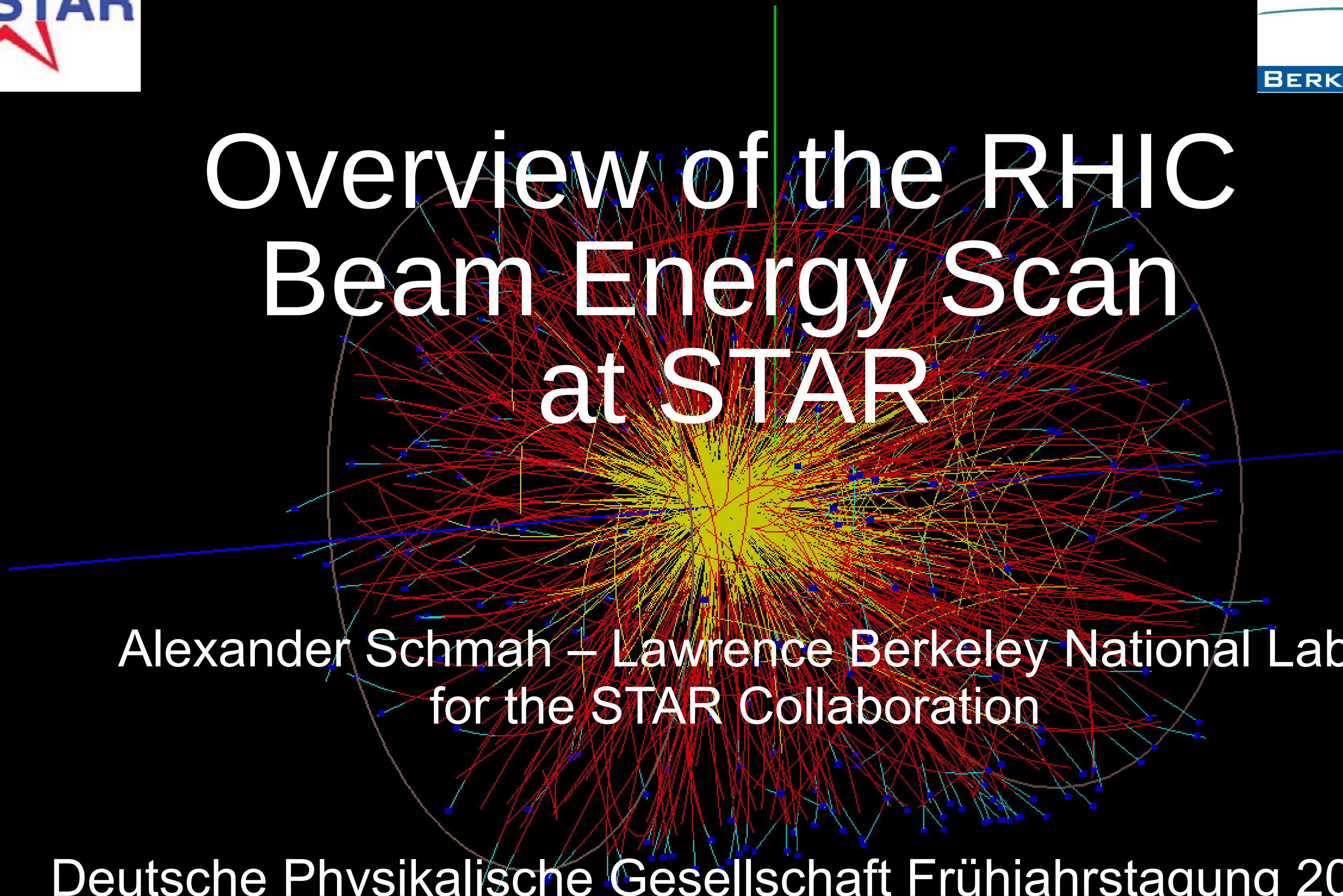
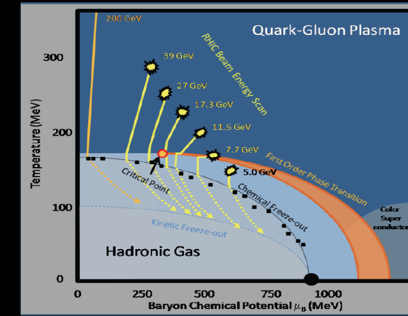
Overview of the RHIC Beam Energy Scan at STAR



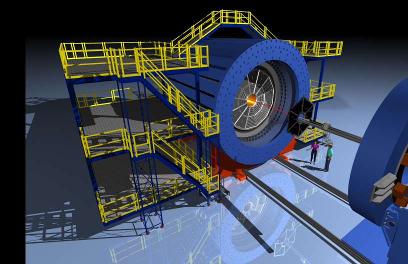
Alexander Schmah – Lawrence Berkeley National Lab
for the STAR Collaboration

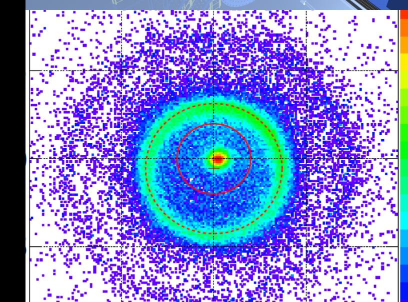
Deutsche Physikalische Gesellschaft Frühjahrstagung 2011
in Münster

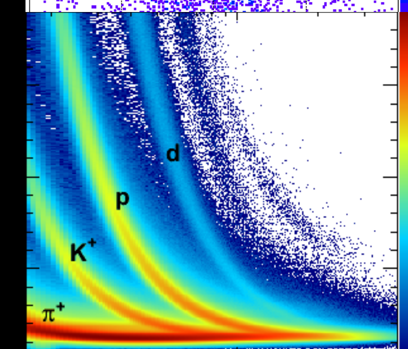


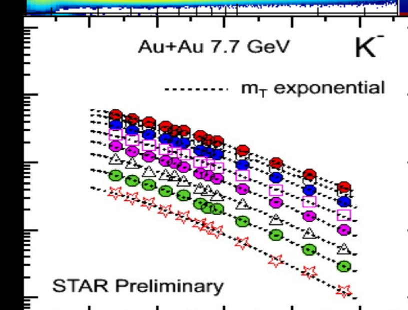
Outline:

- Introduction
- Overview of the BES program
- The STAR experiment at RHIC
- Performance of data taking
- Analysis techniques and first results
- Summary and Outlook







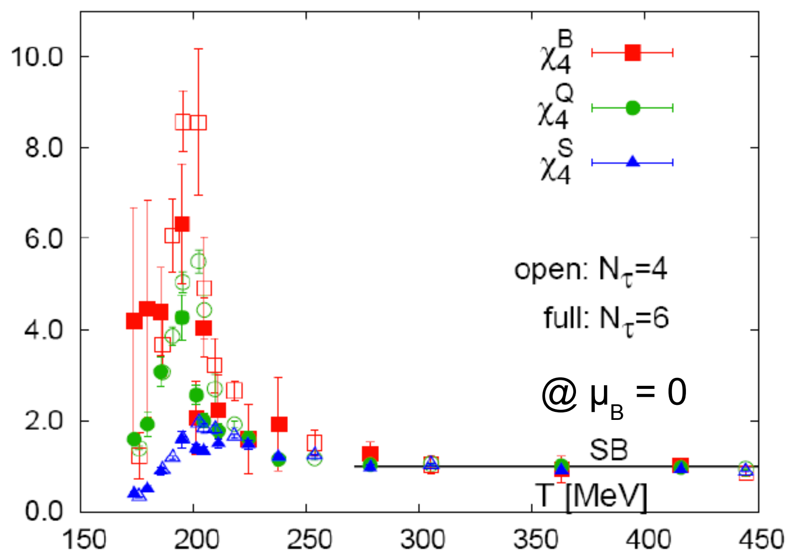


The QCD Phase Diagram

Theory:

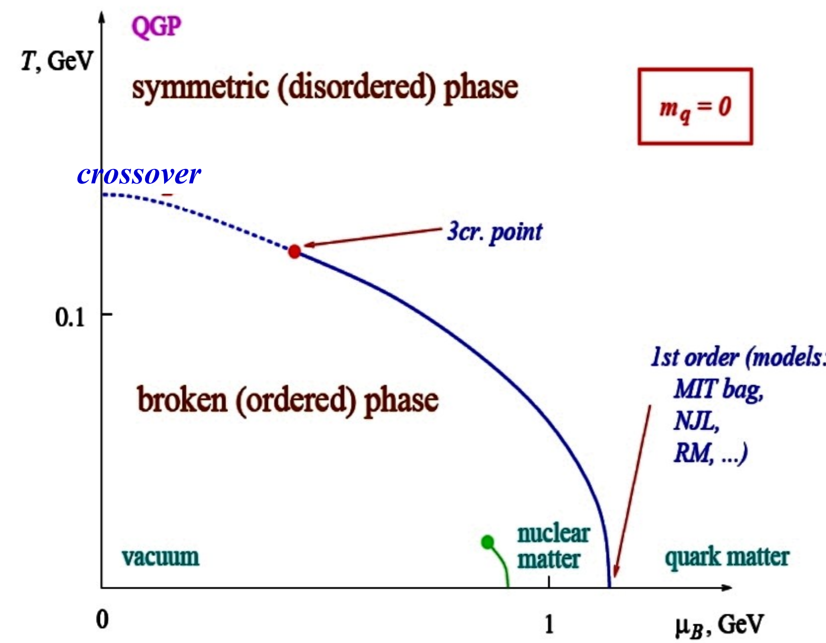
- Lattice QCD finds a smooth crossover at large T and μ_B~0
- Various models find a strong 1st order transition at large μ_B

→ There could be a **critical point**



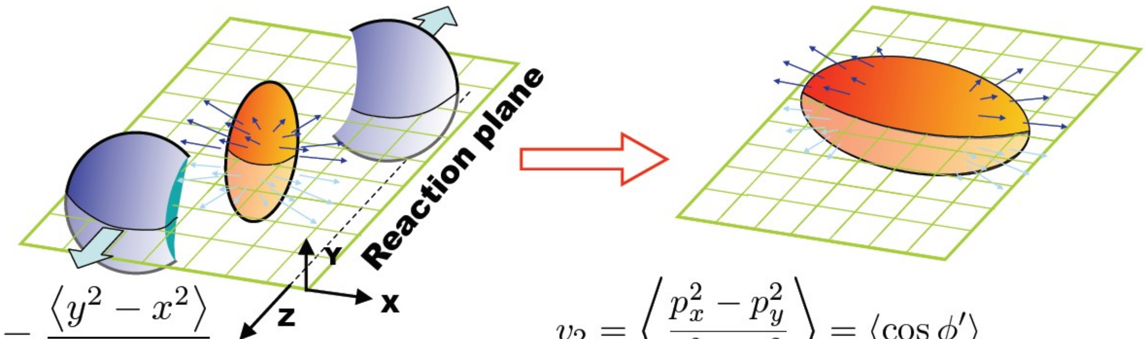
M.Cheng et al, Phys. Rev. D 79, 074505 (2009)

M.Stephanov, hep-ph/0402115v1 (March 2006)



- Fluctuations of conserved quantities indicate nearby singularities

Signatures for a Quark-Gluon Plasma Phase



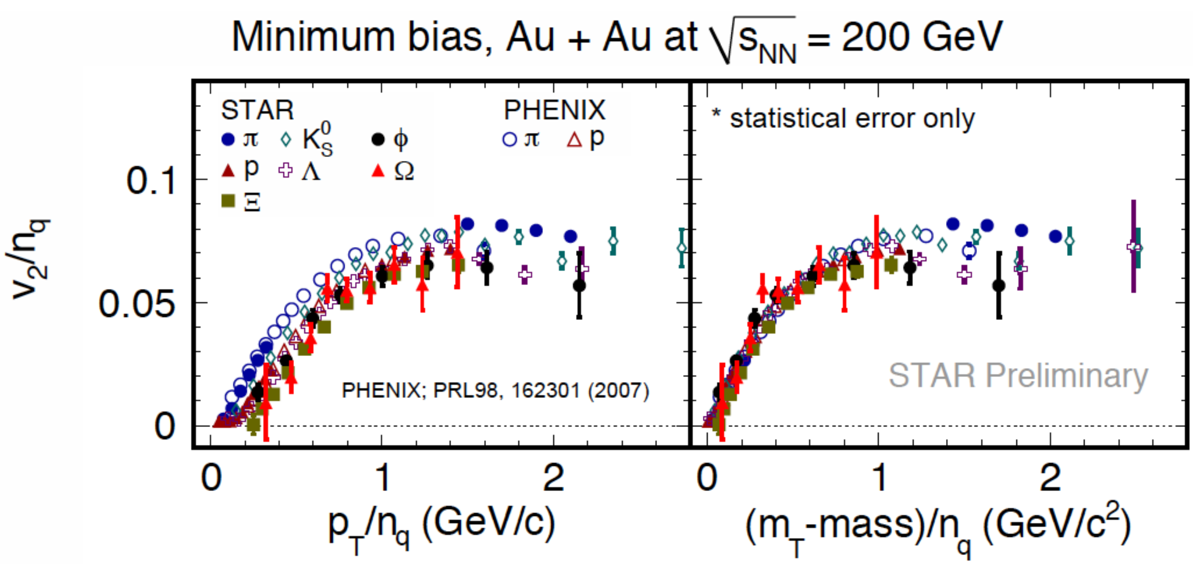
$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

$$v_2 = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle = \langle \cos \phi' \rangle$$

Example elliptic flow v_2:

- Initial asymmetric geometric overlap transforms into an anisotropic momentum distribution
  → different for in- and out-of plane
- Pressure drives the flow
  → partonic freedom (QGP)
- When does the n_q scaling breaks down? → Beam Energy Scan!
  → **Phase transition**

Number of Constituent Quark (NCQ) scaling



NCQ scaling @ STAR:
Phys.Rev.Lett. 92 (2004) 052302
Phys.Rev.Lett. 99 (2007) 112301

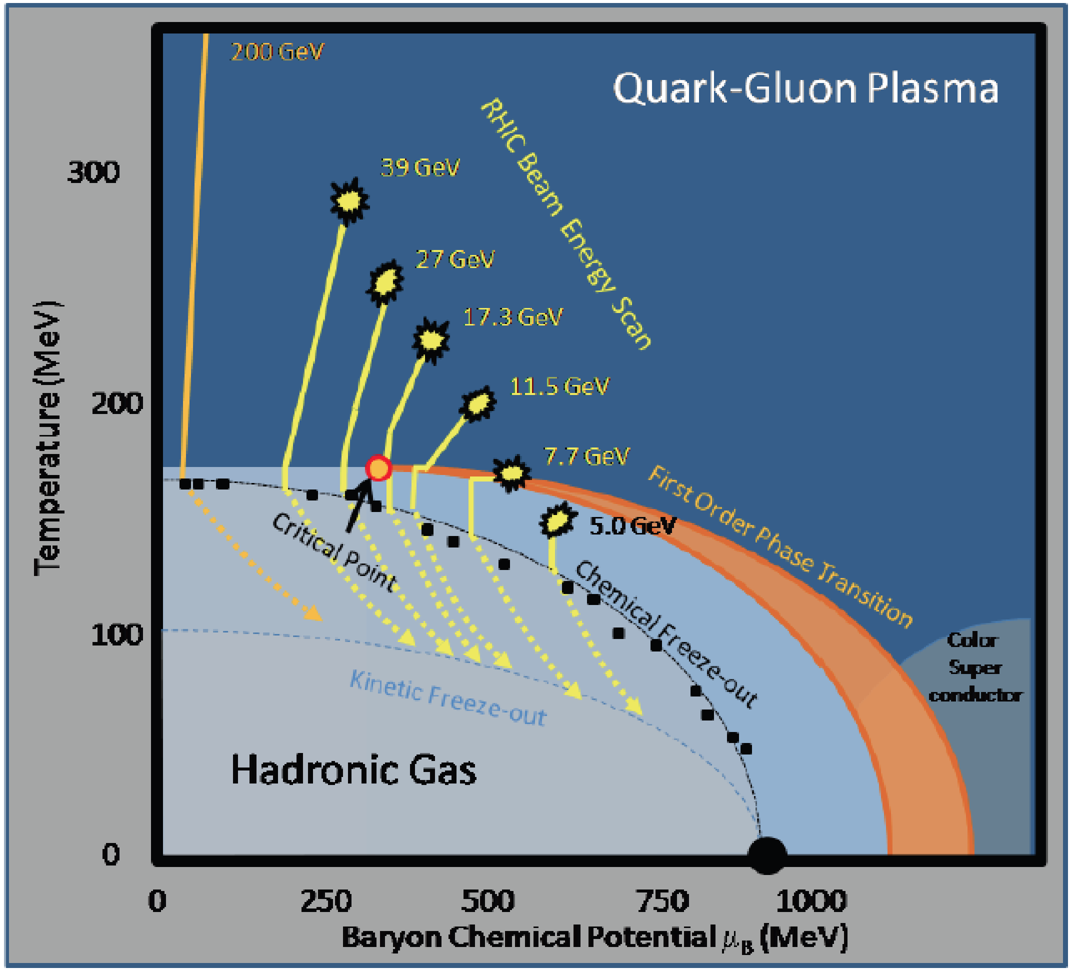
Beam-Energy Scan (BES) Overview

Goal:
- Signatures for a QCD phase transition and/or a critical point by using heavy-ion reactions
- Study the structure of matter with QCD degrees of freedom

Data collected (Au+Au):
- BES started in 2010 with:
- 7.7 GeV: ~5 M events
- 11.5 GeV: ~15 M events
- 39 GeV: 169 M events (10%)

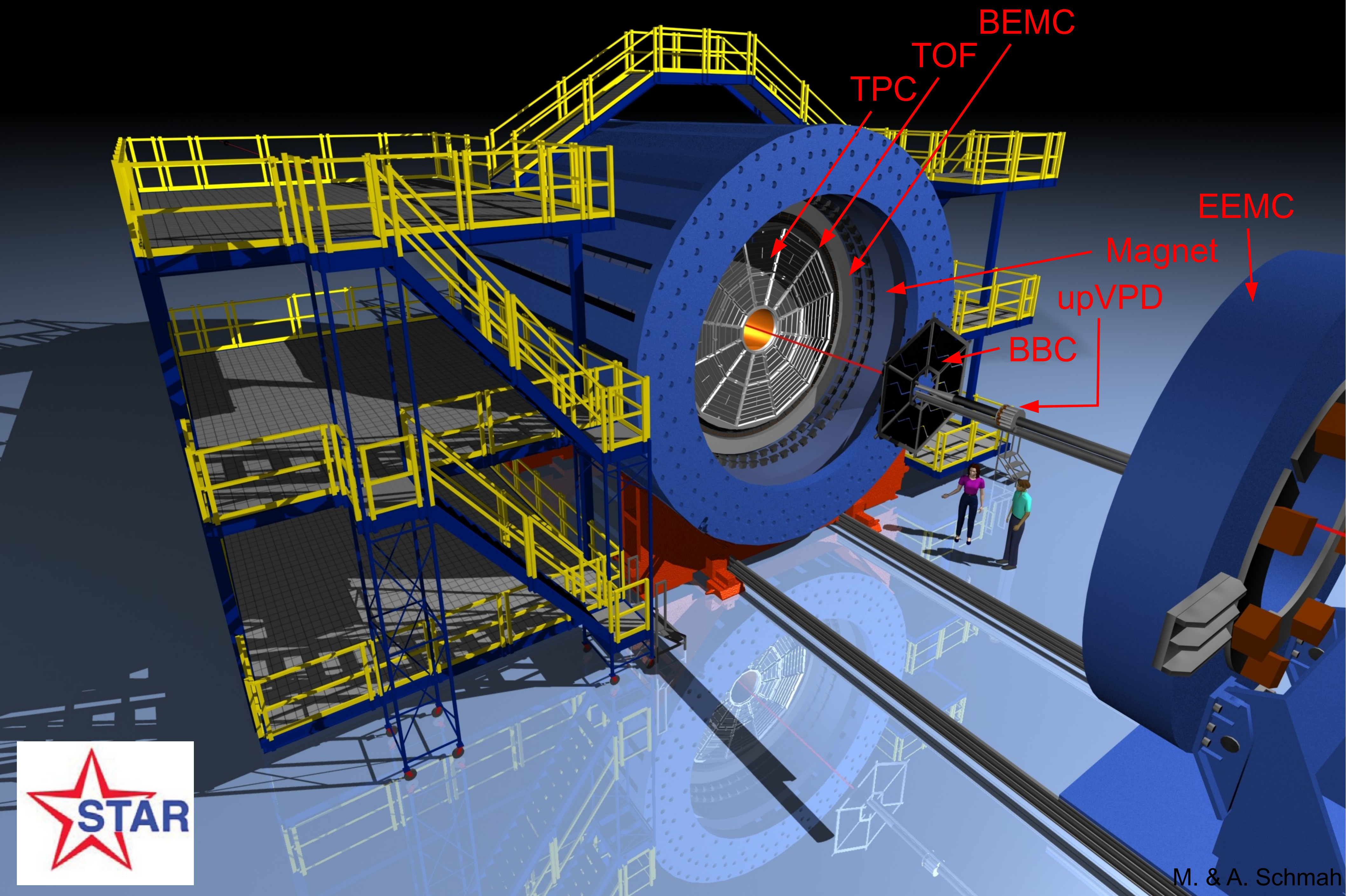
Coming soon (2011):
- 18 GeV + 27 GeV

How?:
- Onset of Quark-Gluon Plasma (e.g. NCQ scaling)
- Signatures of critical point (e.g. fluctuations)

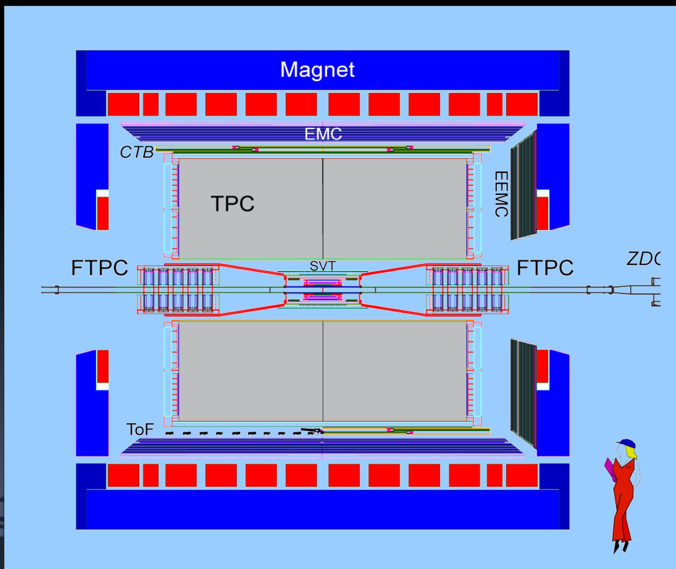


Relativistic Heavy Ion Collider @ Brookhaven National Lab (BNL)/Long Island

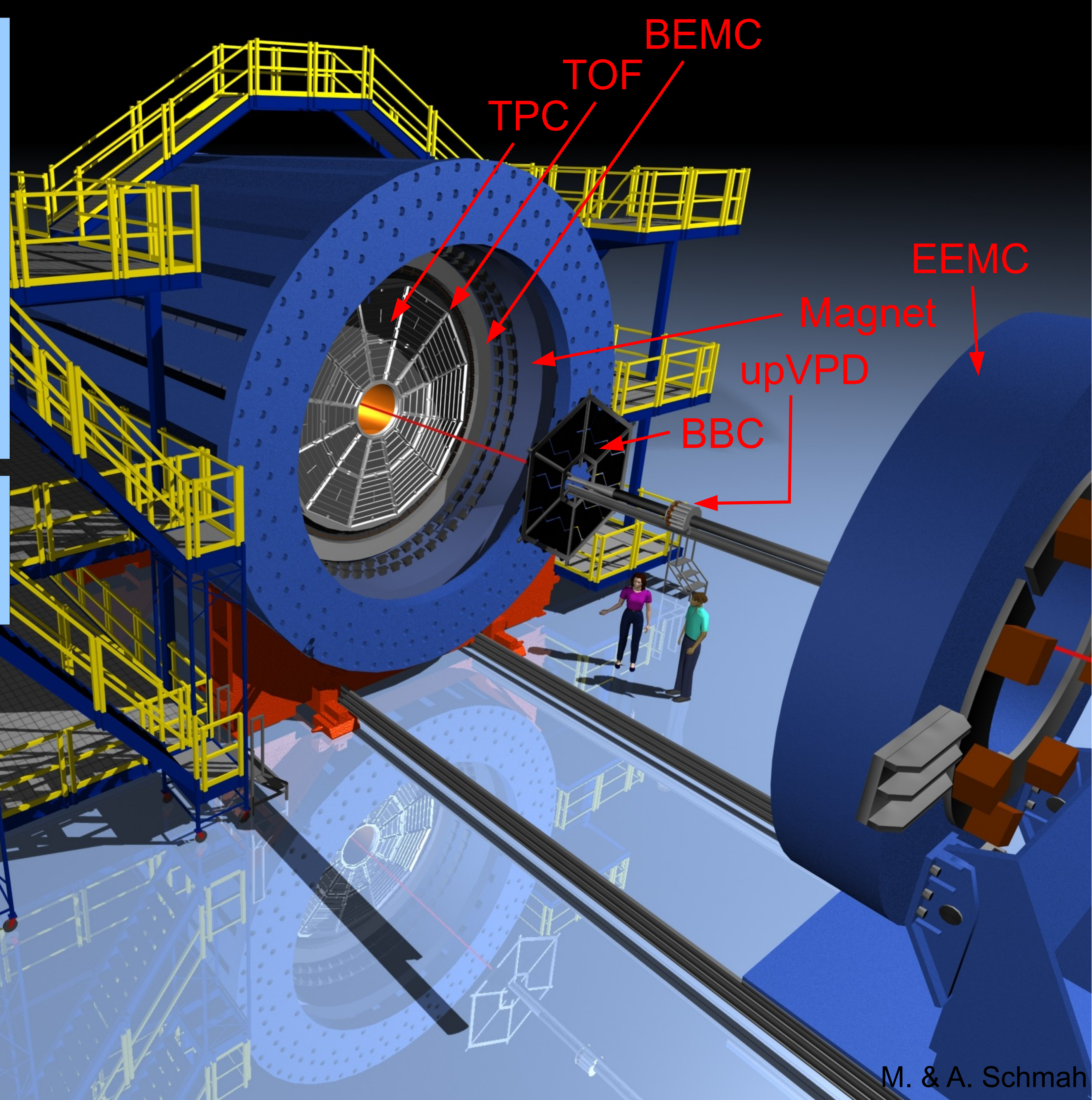
The Solenoid Tracker At RHIC (STAR)



The Solenoid Tracker At RHIC (STAR)

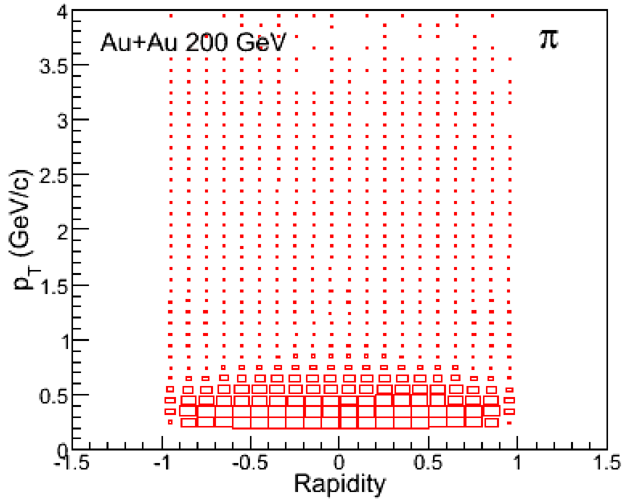


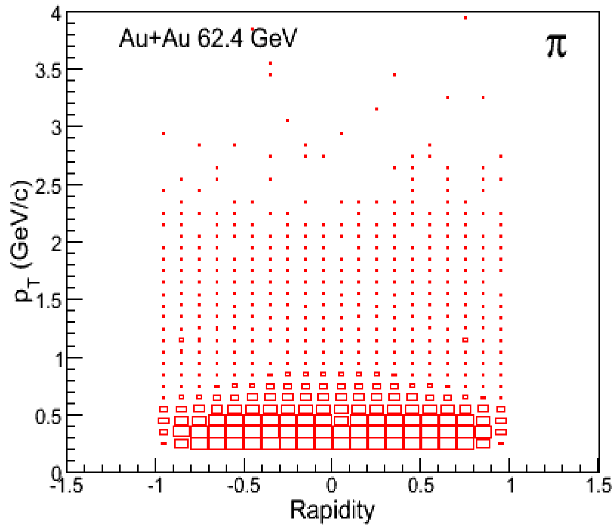
- Full time-of-flight barrel
- No silicon vertex tracker
- FTPC+BBC installed

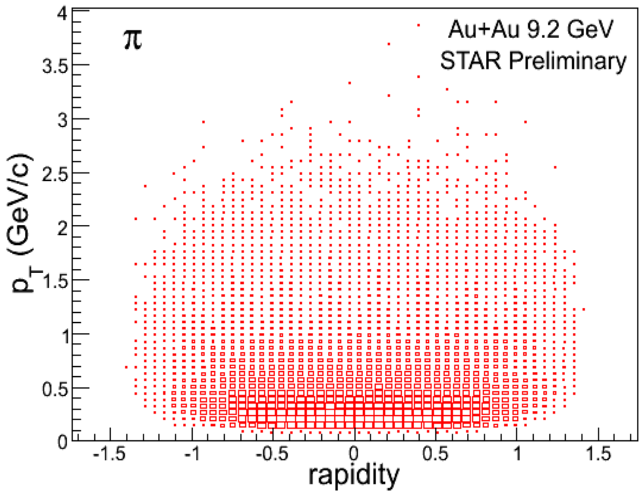


M. & A. Schmah

STAR Acceptance

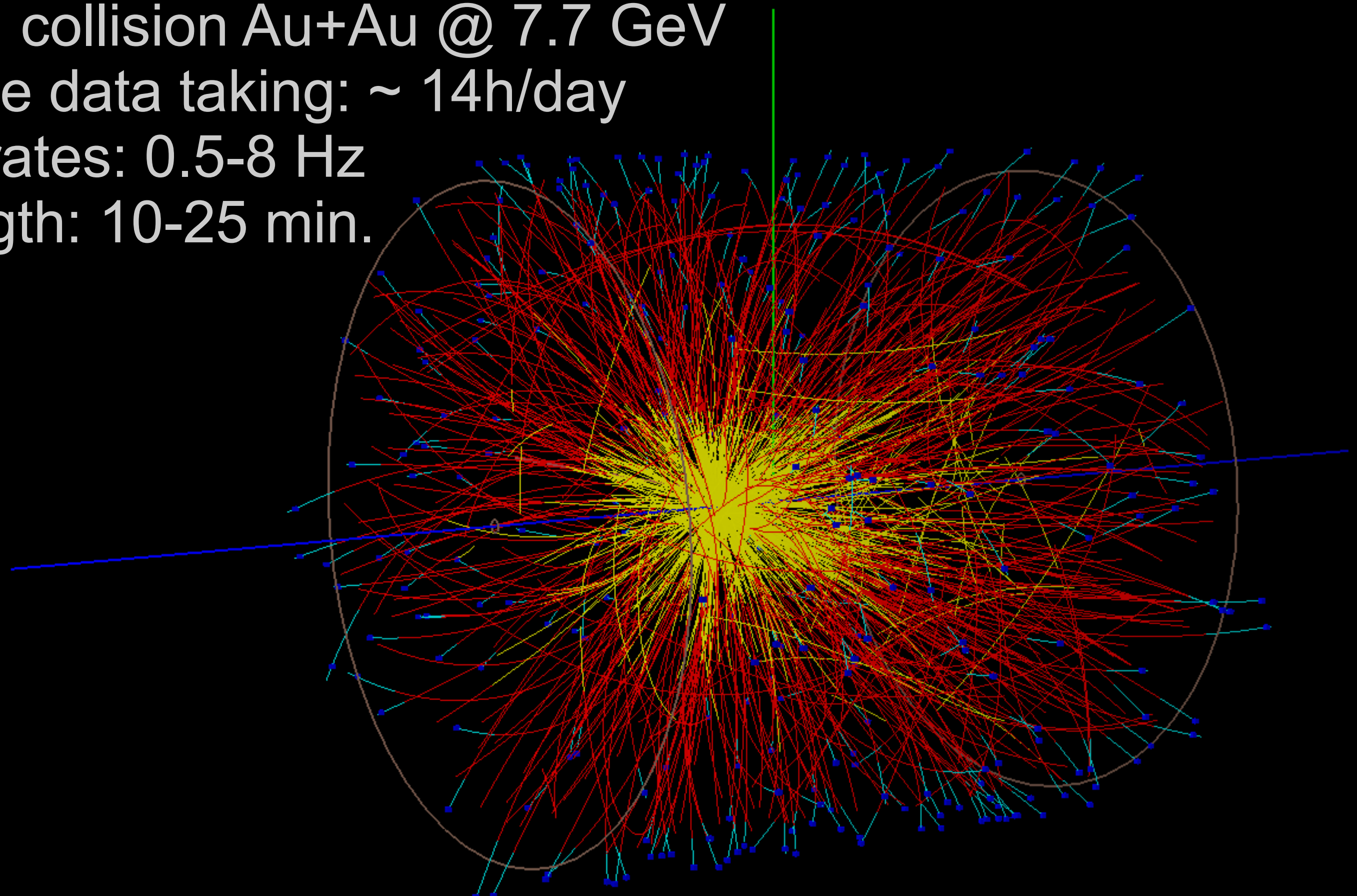


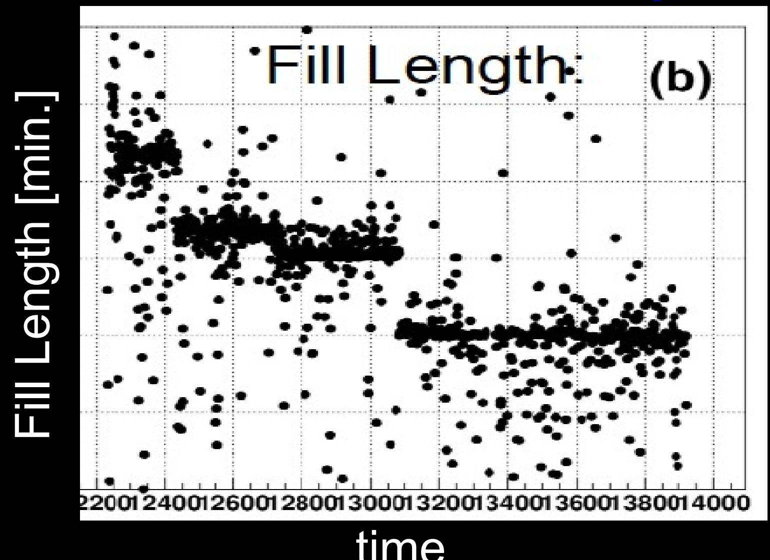


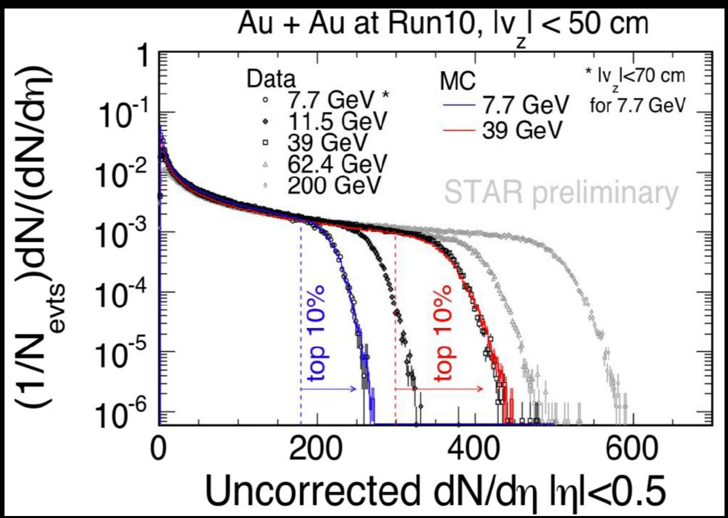


- Acceptance of detectors is independent of beam energy
- Advantage of a collider experiment like STAR and ALICE
- Important for many observables like fluctuations

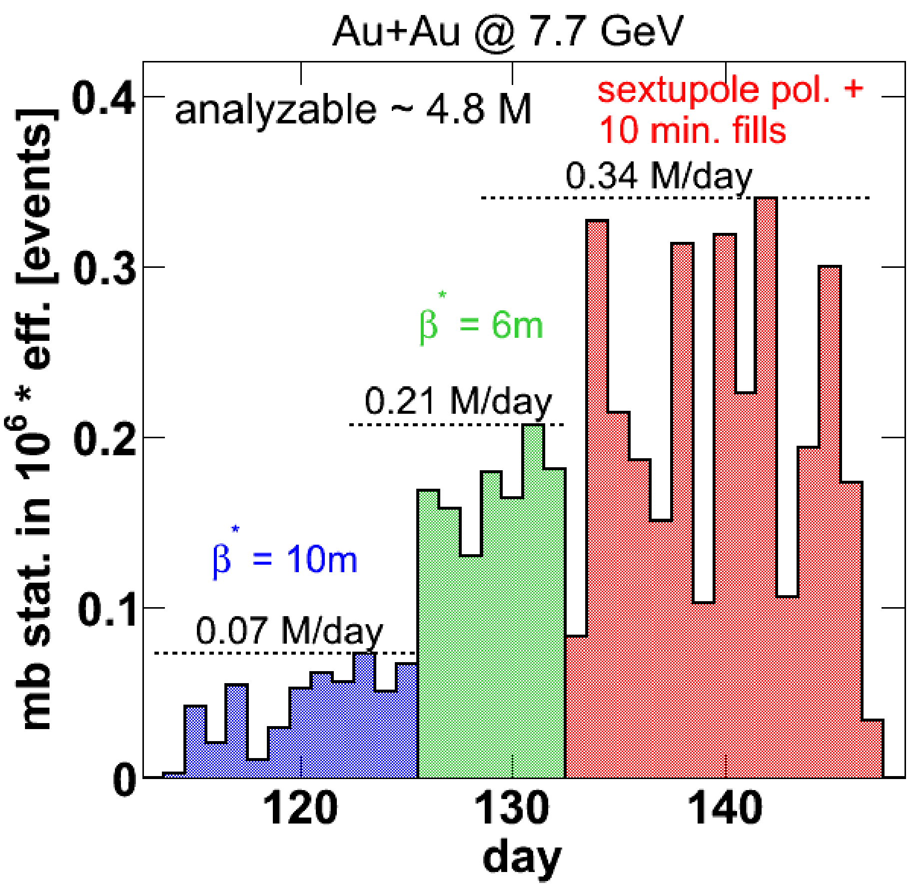
Central collision Au+Au @ 7.7 GeV
Average data taking: ~ 14h/day
Event rates: 0.5-8 Hz
Fill length: 10-25 min.

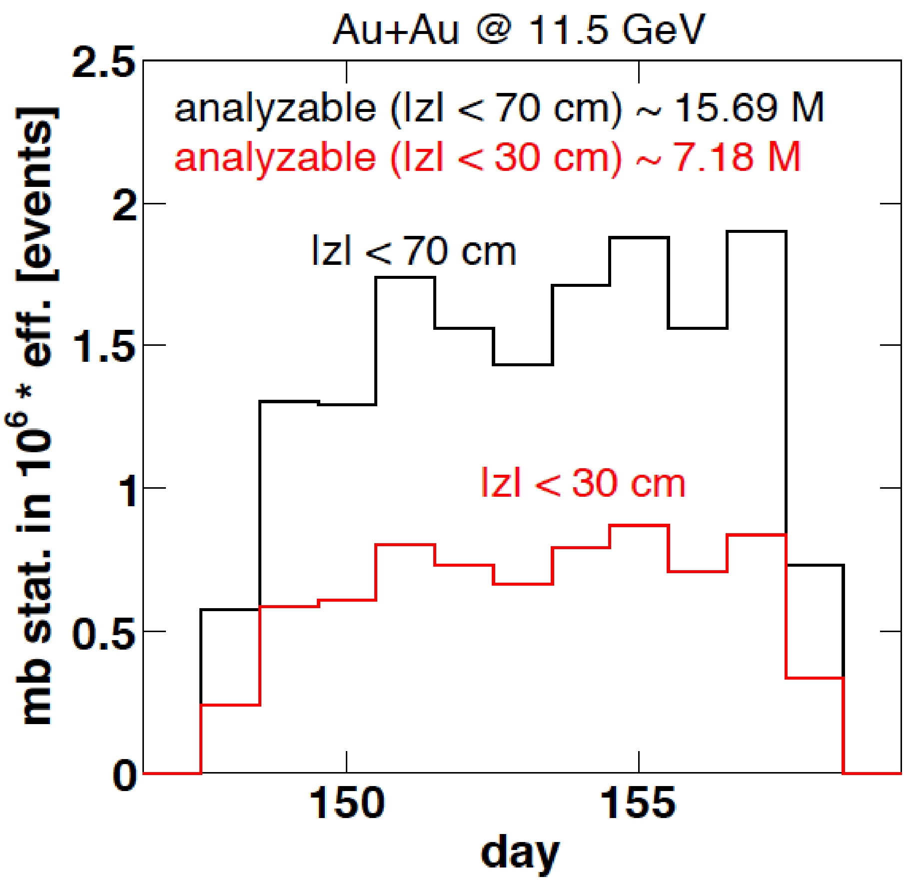






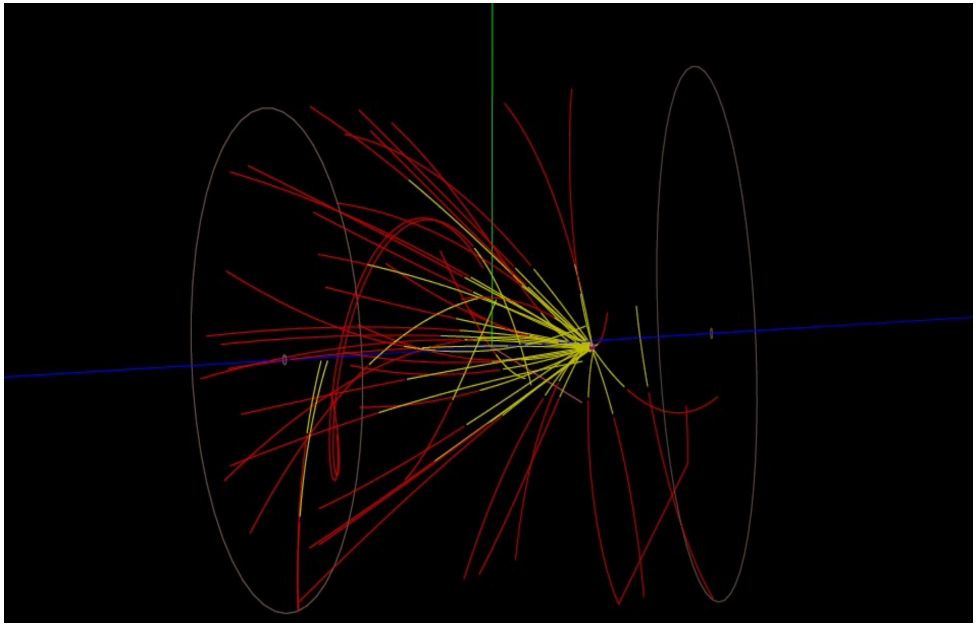
Performance of Data Taking

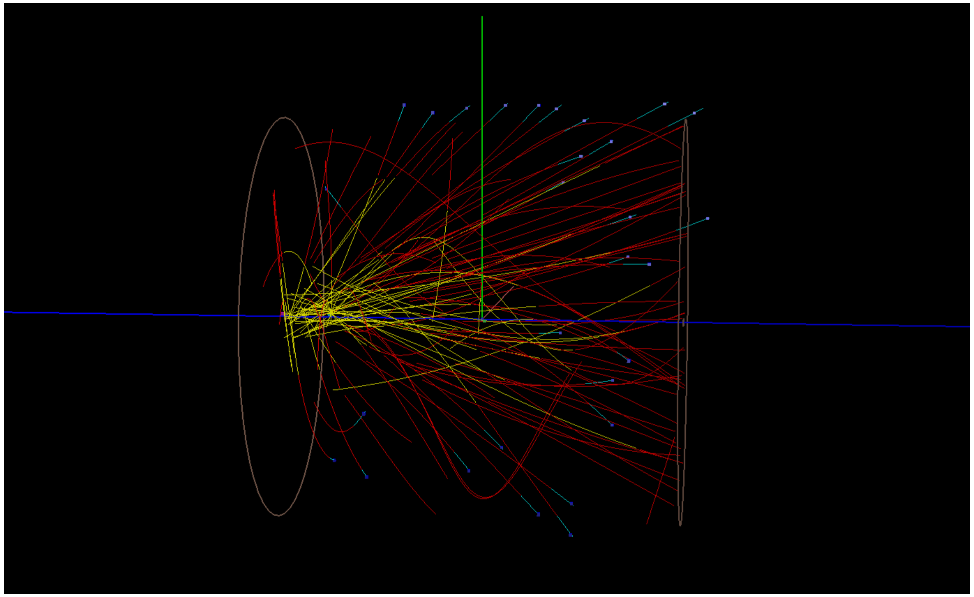


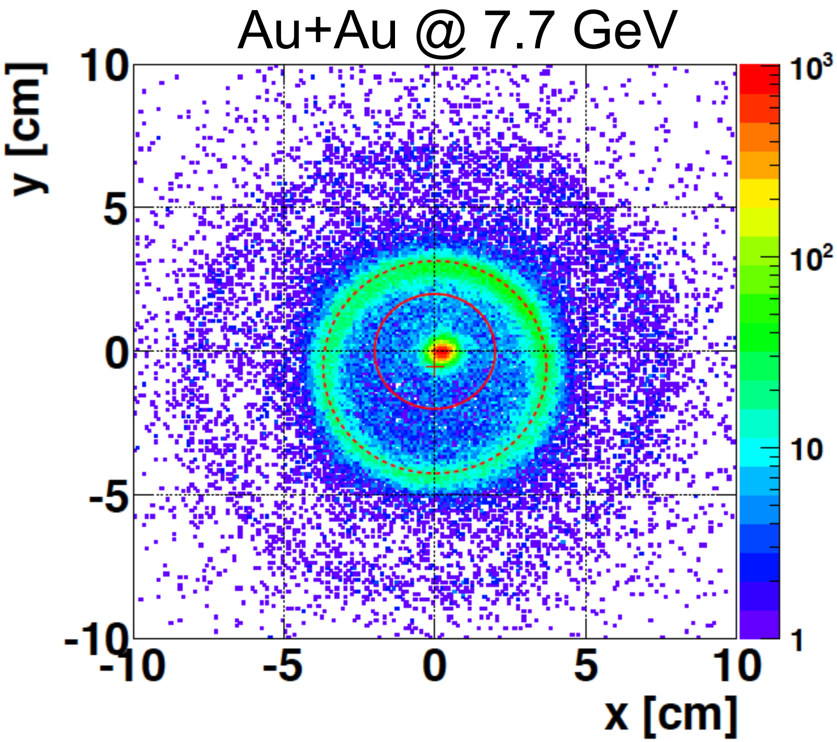


- The RHIC experts tuned the beams and optimized the fill procedures over several weeks → **huge increase in performance** to the end of the 7.7 GeV run
- For 7.7 and 11.5 GeV we reached our goals (~5M and ~15M events)
- 39 GeV was stable and STAR collected 169M events (25M proposed)

Background from Beampipe Interactions

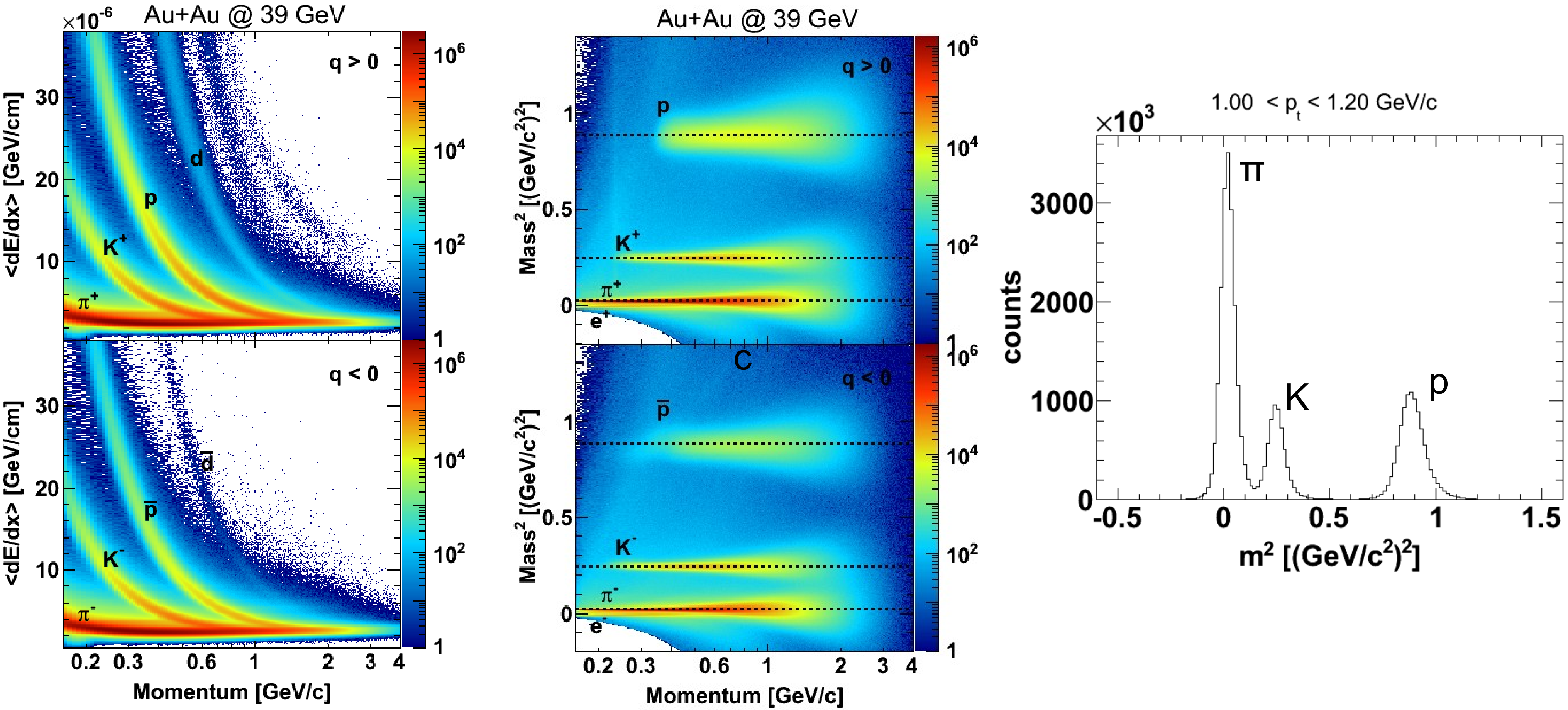






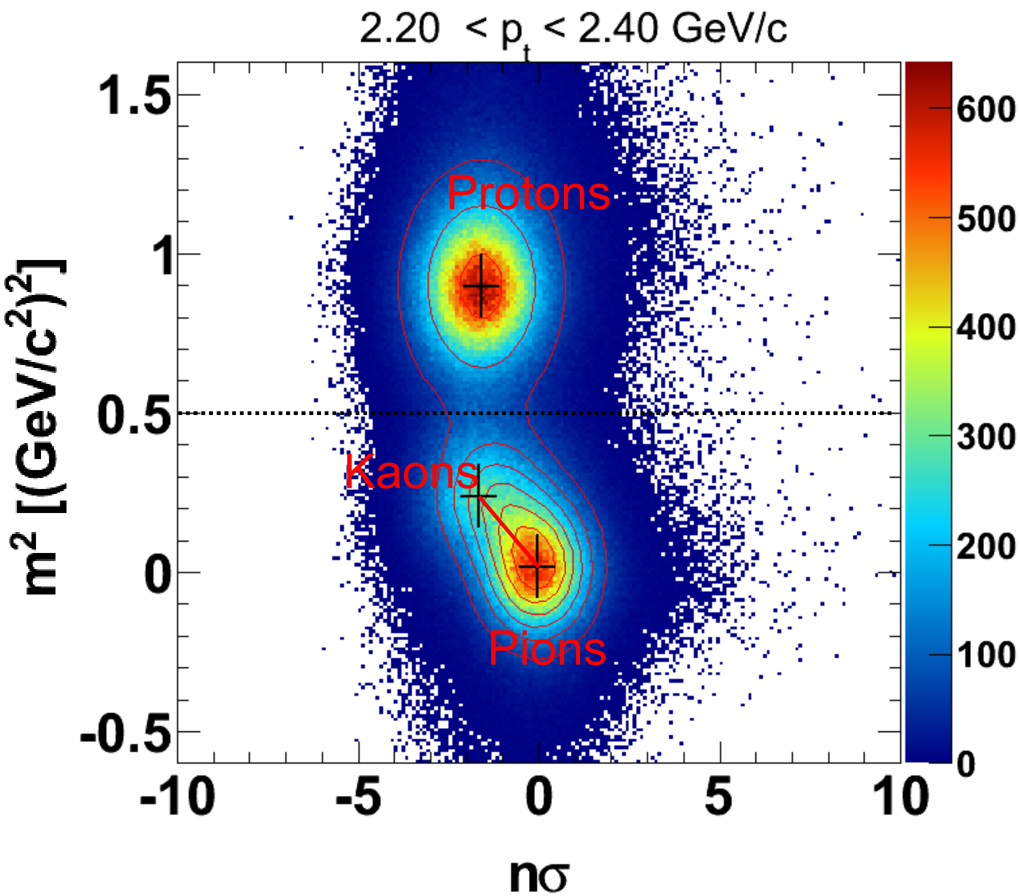
- Much larger beam width compared to 200 GeV
- Expected situation from year 2009 test run @ 9.2 GeV
- Continuously online (High Level Trigger) and offline (fast offline DST production) monitoring of the background
- Background well under control for analysis

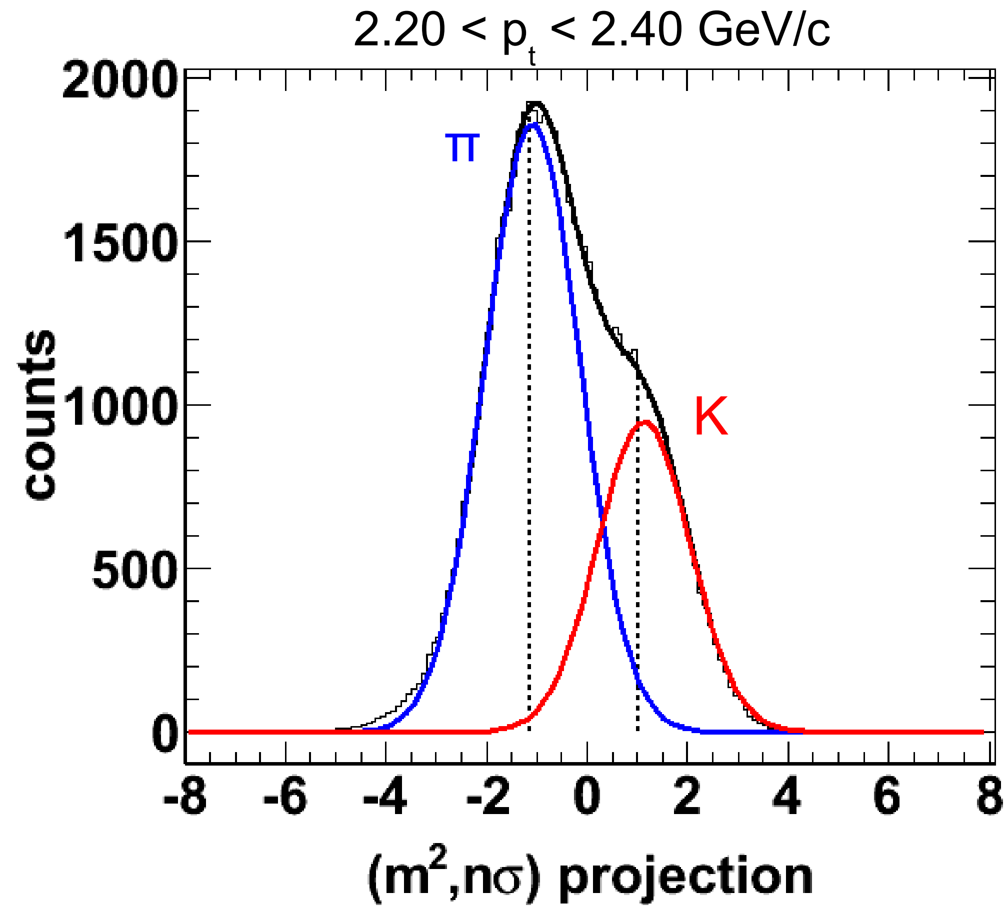
Particle Identification via TPC and TOF



- dE/dx can separate the particles up to 1 GeV/c
- First beam time period with full RPC TOF system
  → Clean particle separation up to 1.6 GeV/c

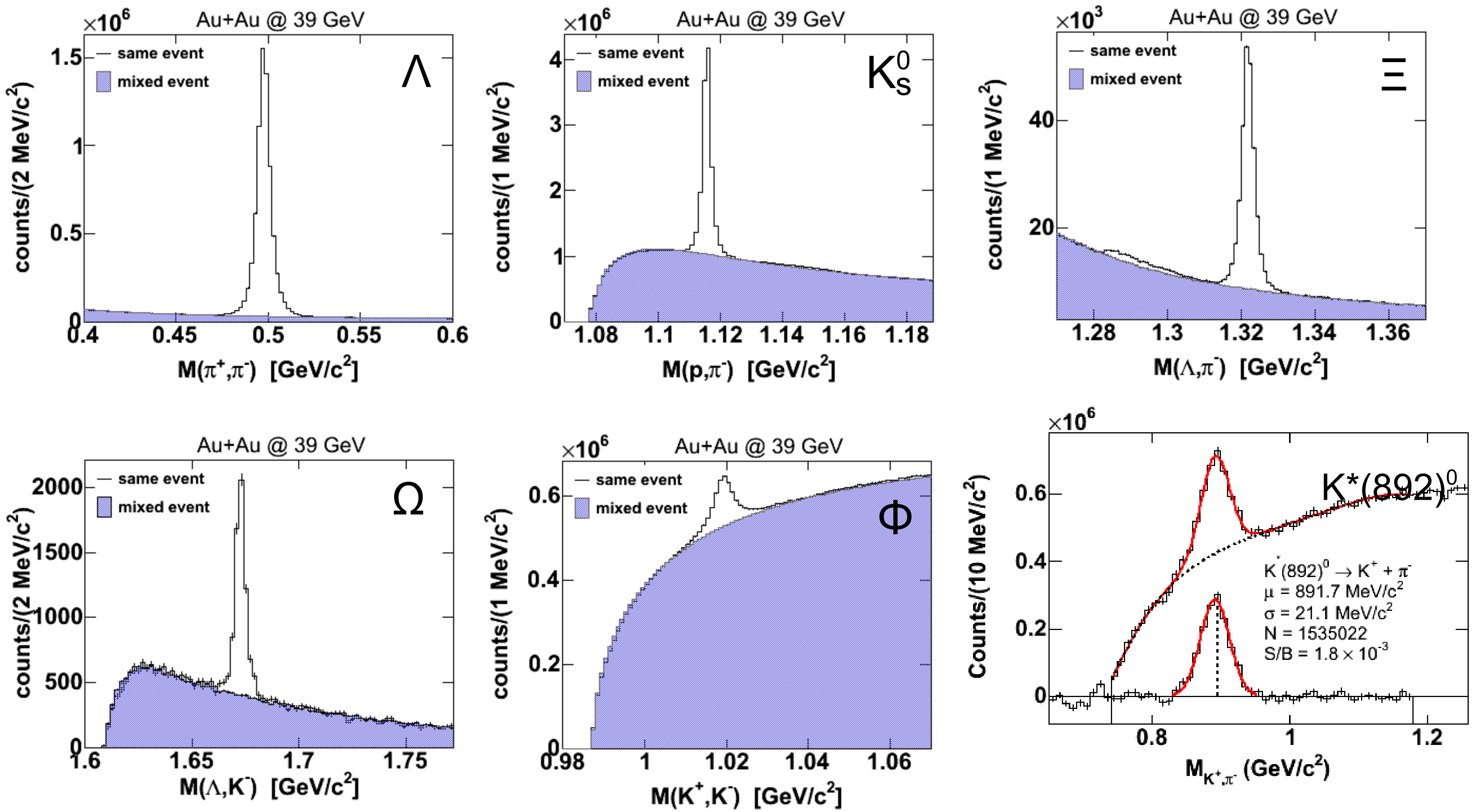
Combined TPC and TOF PID





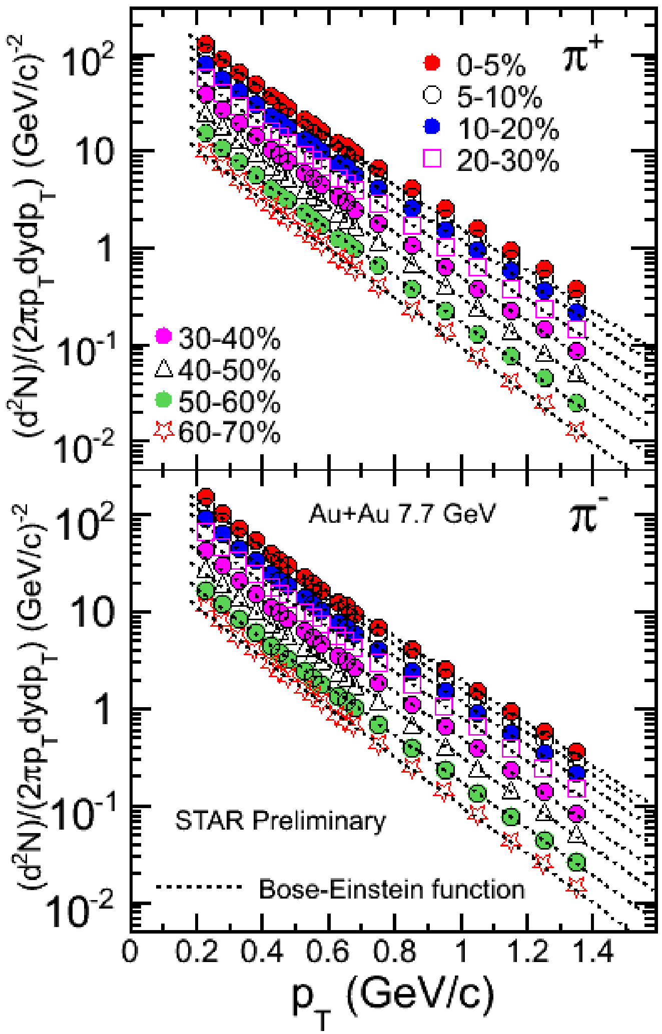
- Combined TPC and TOF PID at high momenta
- Best separation of Kaons and Pions for the shown projection axis
  → Particle identification at high p_t

Reconstructed Particles

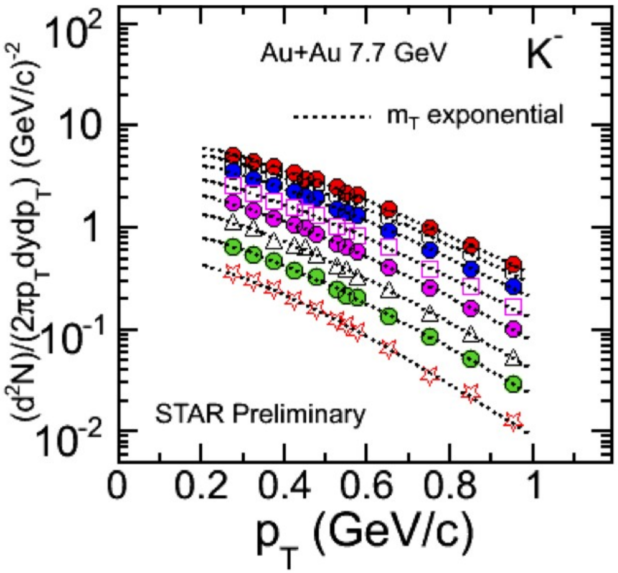


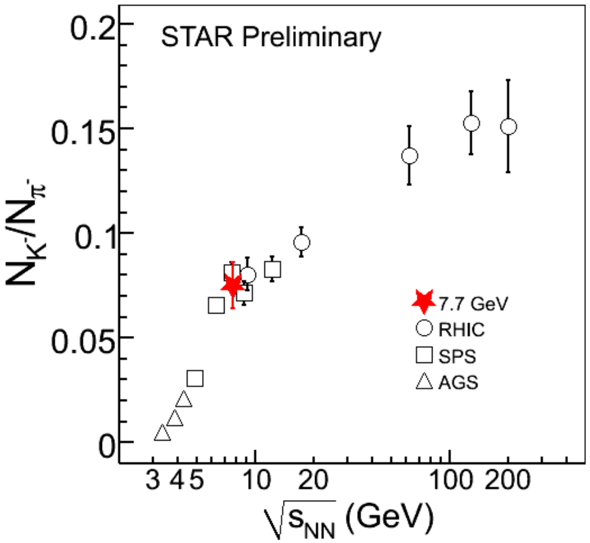
- Improved S/B ratio compared to previous results due to additional time-of-flight PID

Particle Spectra



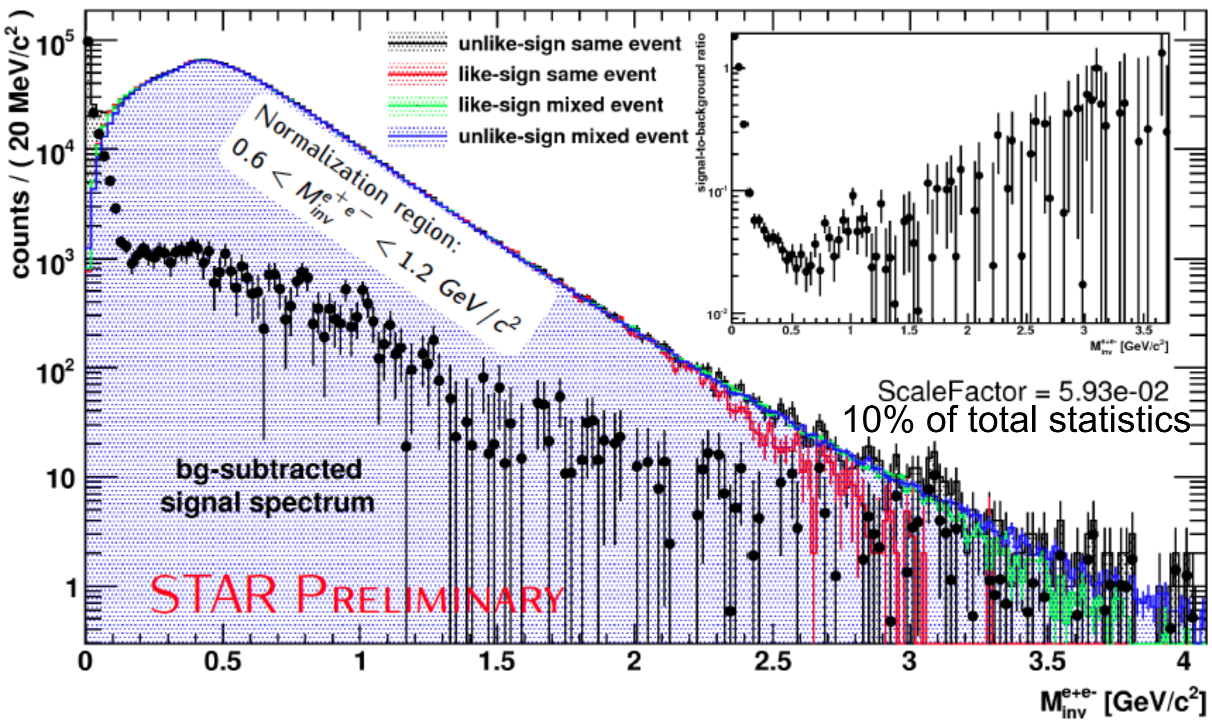
Lokesh Kumar ICPAQGP 2010

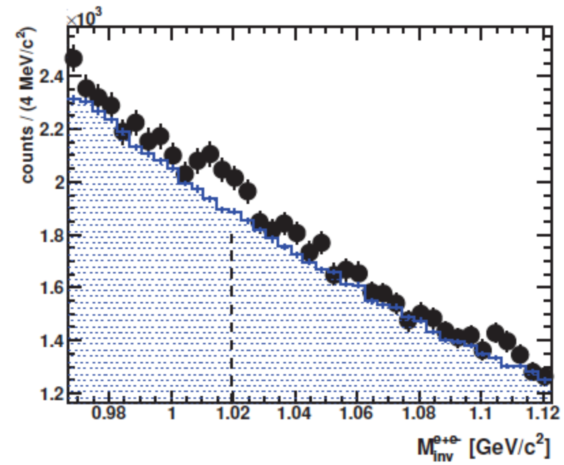


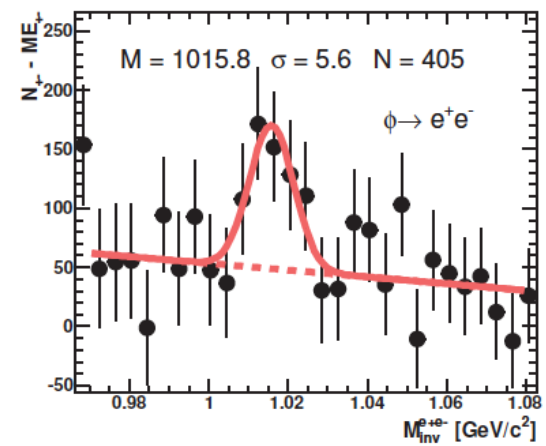


- First efficiency and acceptance corrected particle spectra @ 7.7 GeV
- 70% of π, K are measured within our p_t acceptance at mid rapidity
- Transverse momentum range will be extended
- K^-/π^- ratio fits into the systematics
- Other spectra in preparation (p,Φ,Λ,Ξ,Ω,J/Ψ)

Di-Lepton Spectroscopy @ 39 GeV



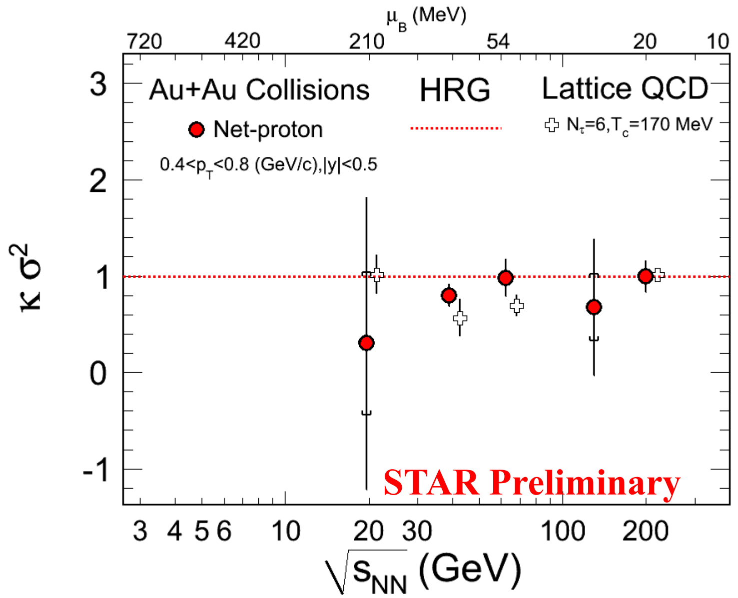


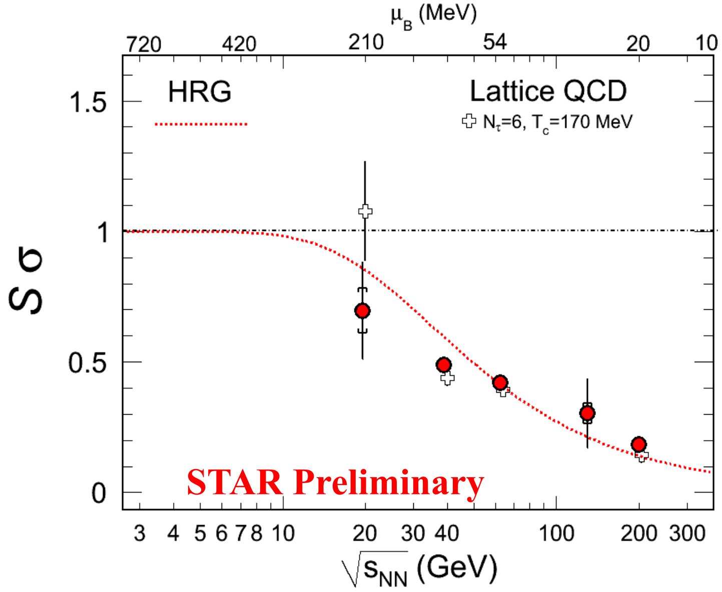


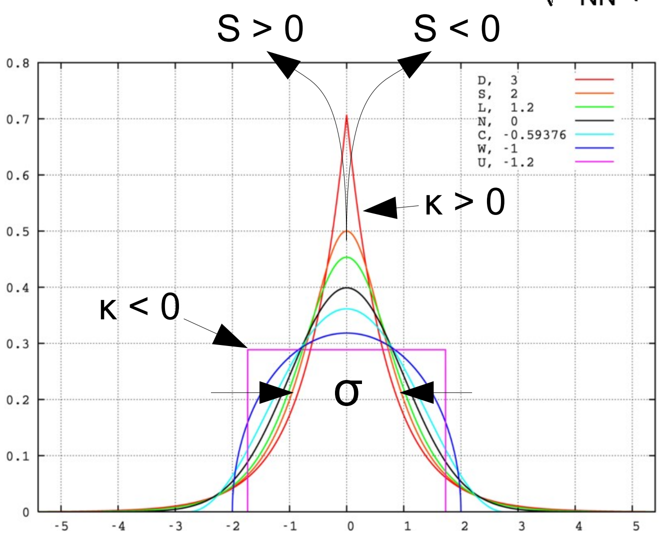
- Motivation: Low mass enhancement, p_t-spectra from hot and dense phase
- Not efficiency and acceptance corrected
- Time-of-flight information + dE/dx was used for particle identification
- Result is based on only 10% of the total statistics

Patrick Huck HK 15.5

Higher Moments of Net-Proton Multiplicity





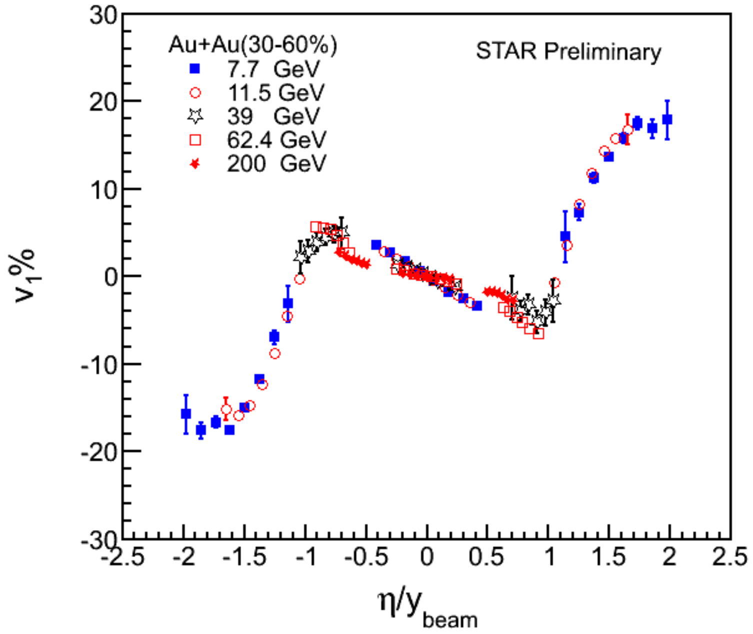


Lattice: R. Gavai and S. Gupta, Phys. Lett. B 696, 459 (2011)
HRG: F. Karsch and K. Redlich, Phys. Lett. B 695, 136 (2011)

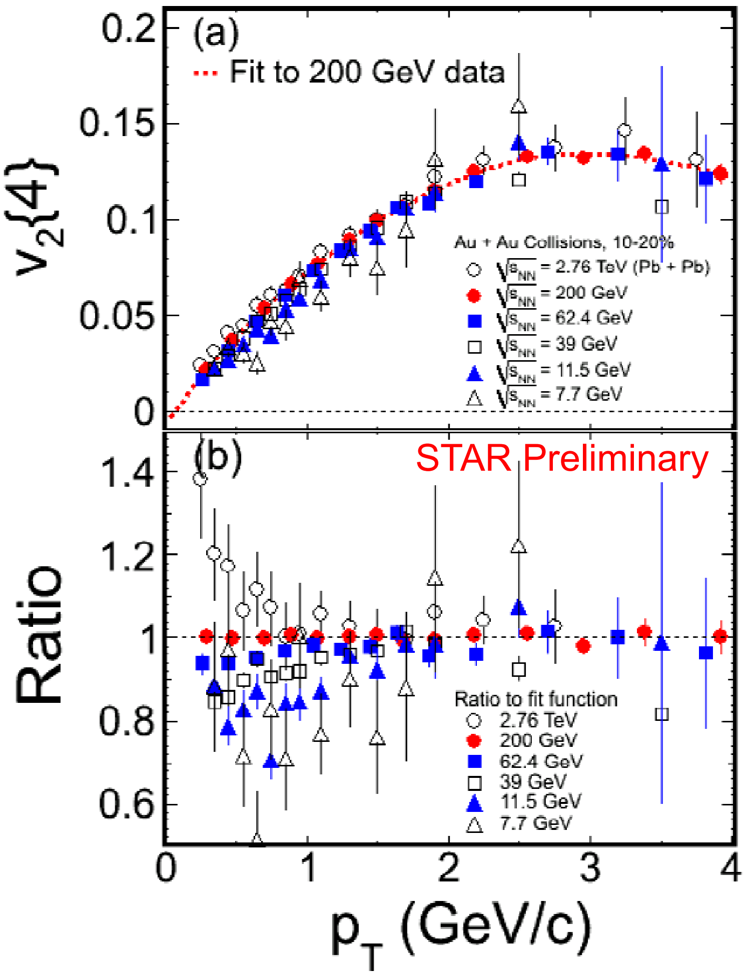
- High order correlation function → sensitive
- Direct comparison with lattice QCD!
- Non monotonic behavior at critical point expected
- 62.4, 130 and 200 GeV results consistent with models
- At 39 GeV data slightly deviates from the HRG model

Flow: v_1 and v_2 of Charged Hadrons

$$v_1 = \langle \cos(\psi - \phi) \rangle$$

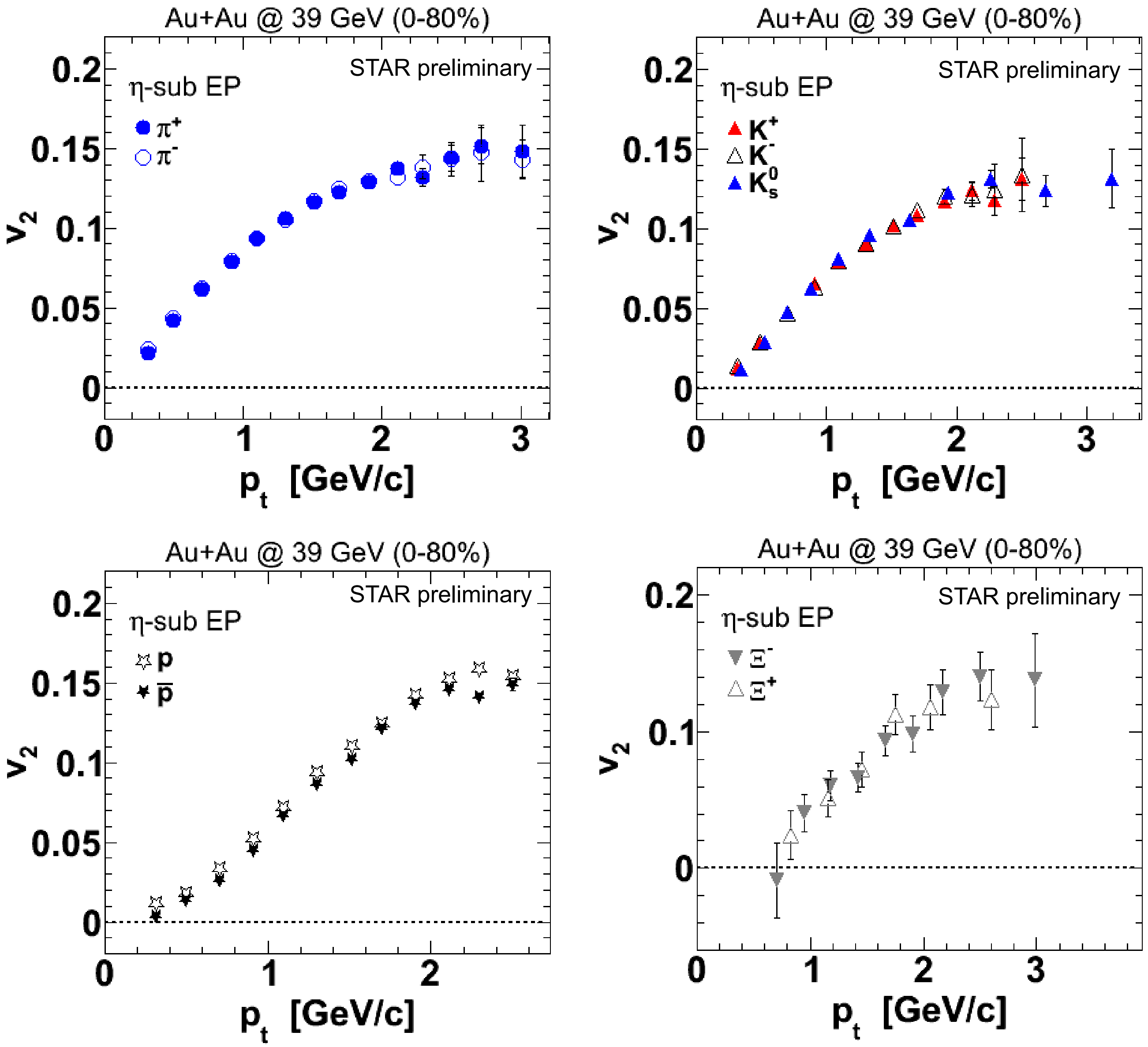


$$v_2 = \langle \cos(2(\psi - \phi)) \rangle$$



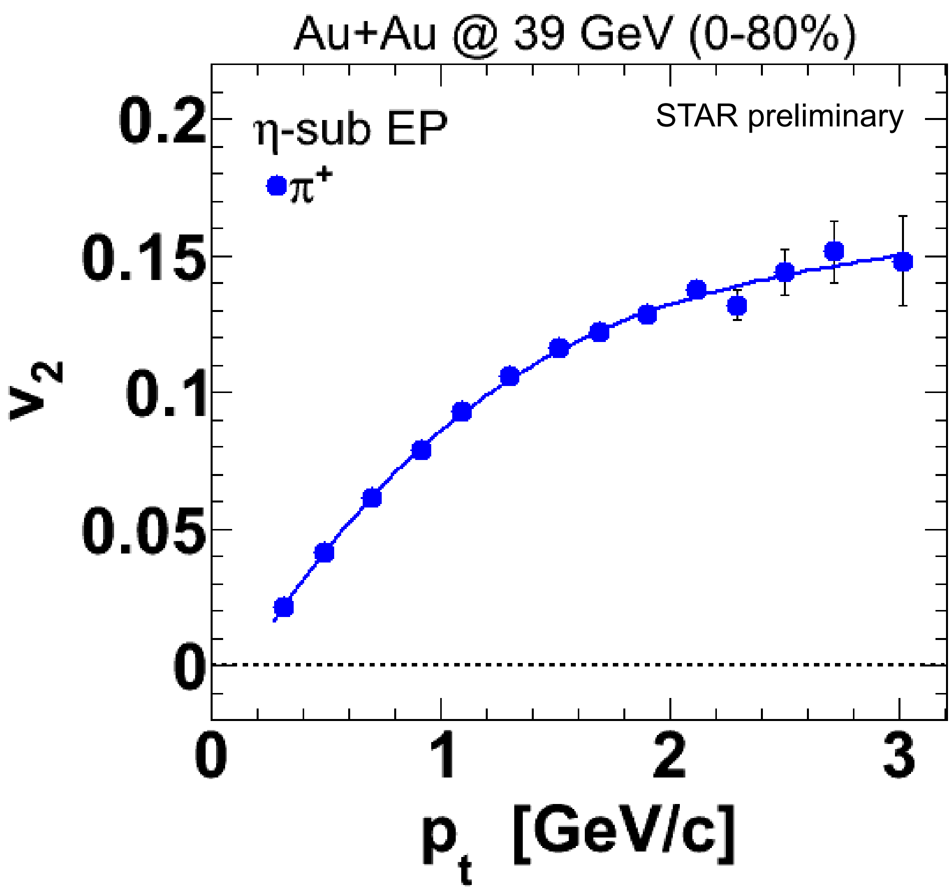
- Scaling of v_1 with η/y_{beam}
- v_2 increases with decreasing centrality and increasing energy
- $v_2\{4\}$ increases only slightly from 39 GeV to 200 GeV at low transverse momenta

Flow: v_2 of Identified Hadrons @ 39 GeV



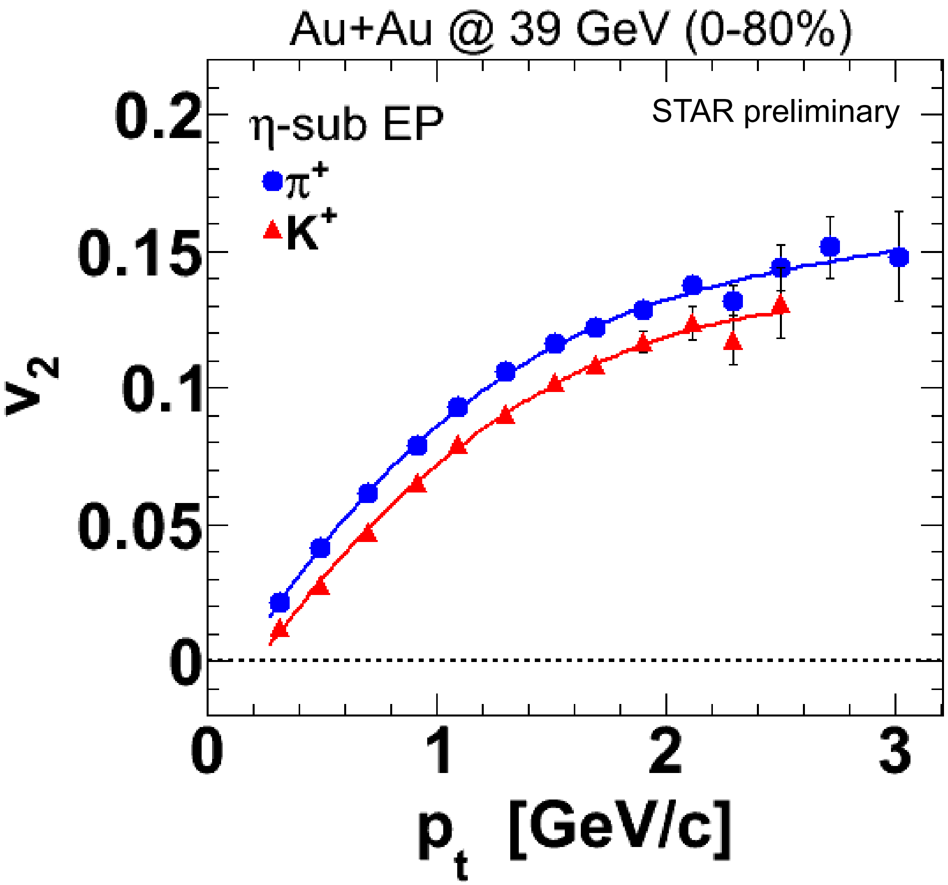
- Different charge states of Pions, Kaons and Cascades have identical v_2
- Proton and anti-Proton v_2 is slightly different
- Already observed at higher energies

Flow: v_2 of Identified Hadrons @ 39 GeV



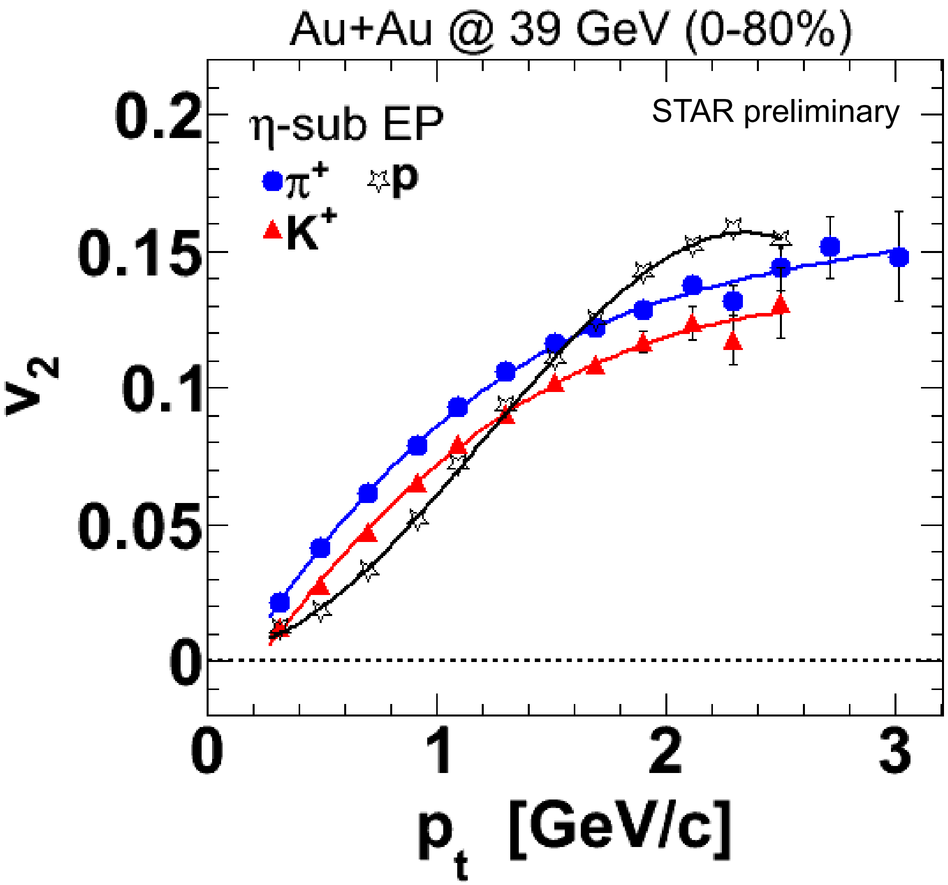
- 3 GeV/c in p_t for Pions with 10% statistics

Flow: v_2 of Identified Hadrons @ 39 GeV



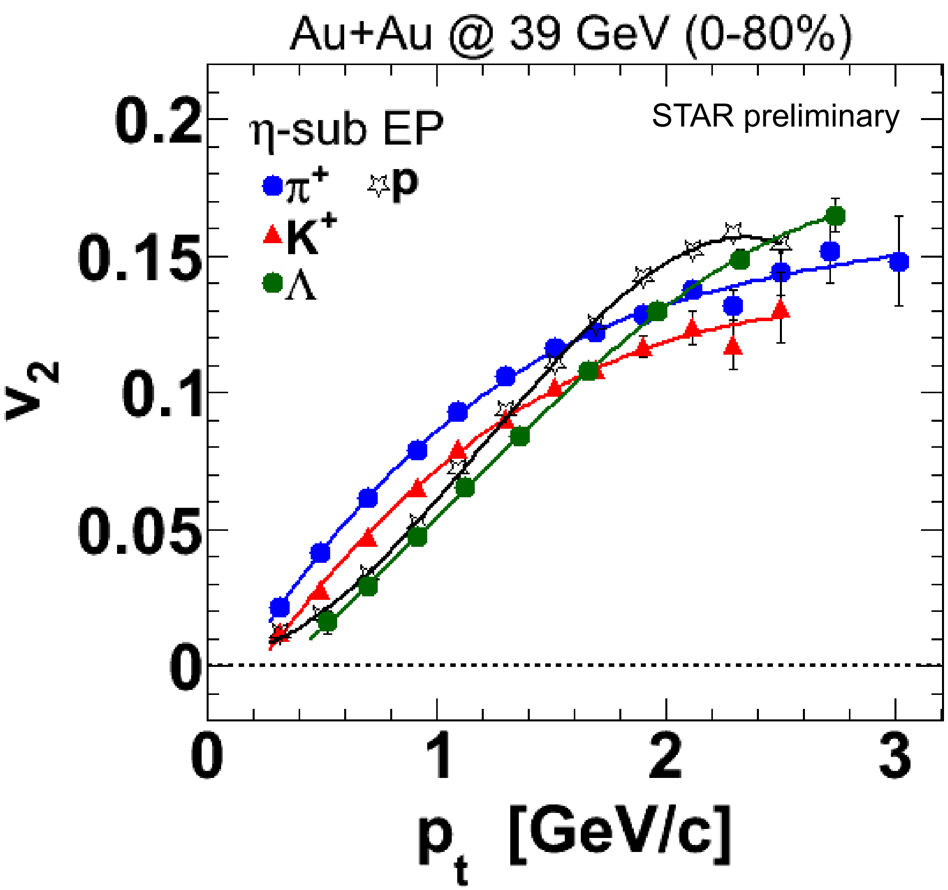
- 3 GeV/c in p_t for Pions with 10% statistics
- Kaons are below Pions in this p_t range

Flow: v_2 of Identified Hadrons @ 39 GeV



- 3 GeV/c in p_t for Pions with 10% statistics
- Kaons are below Pions in this p_t range
- Mass ordering at low p_t

Flow: v_2 of Identified Hadrons @ 39 GeV



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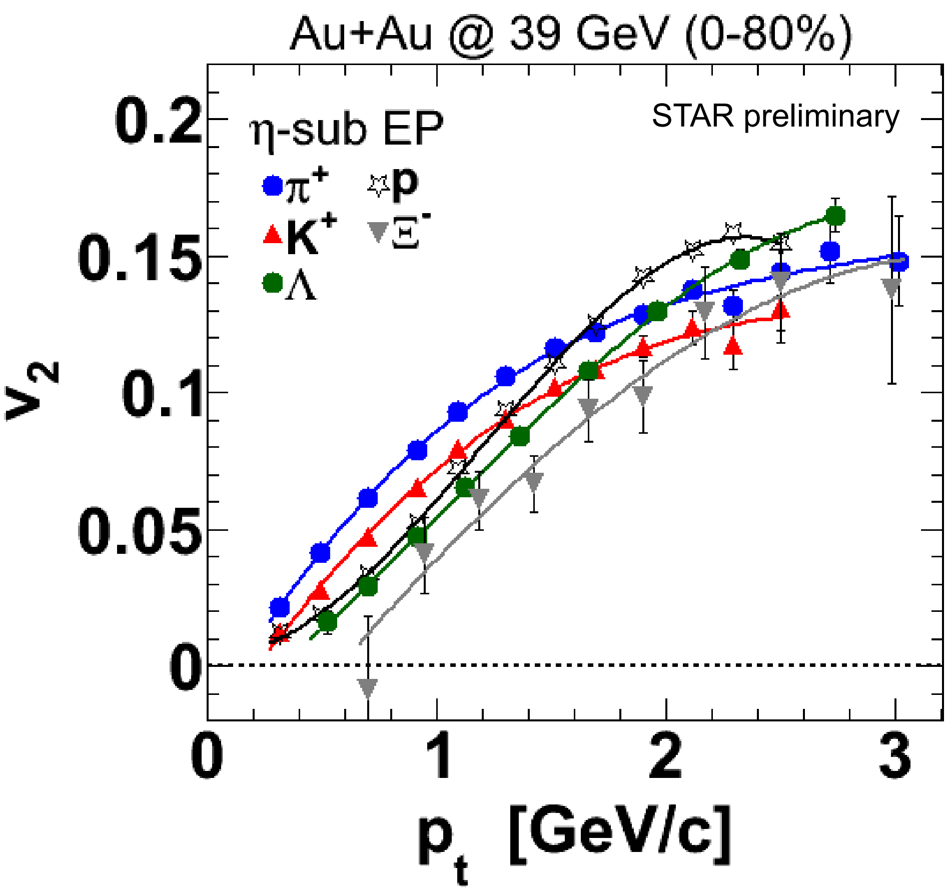
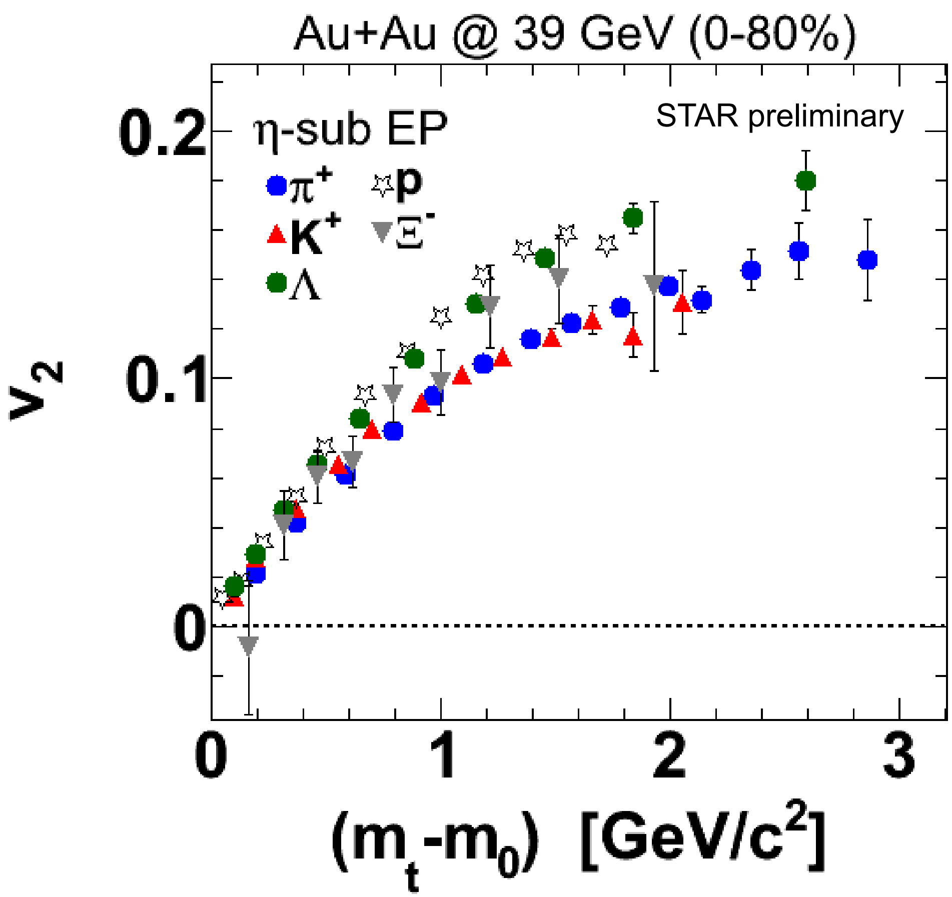


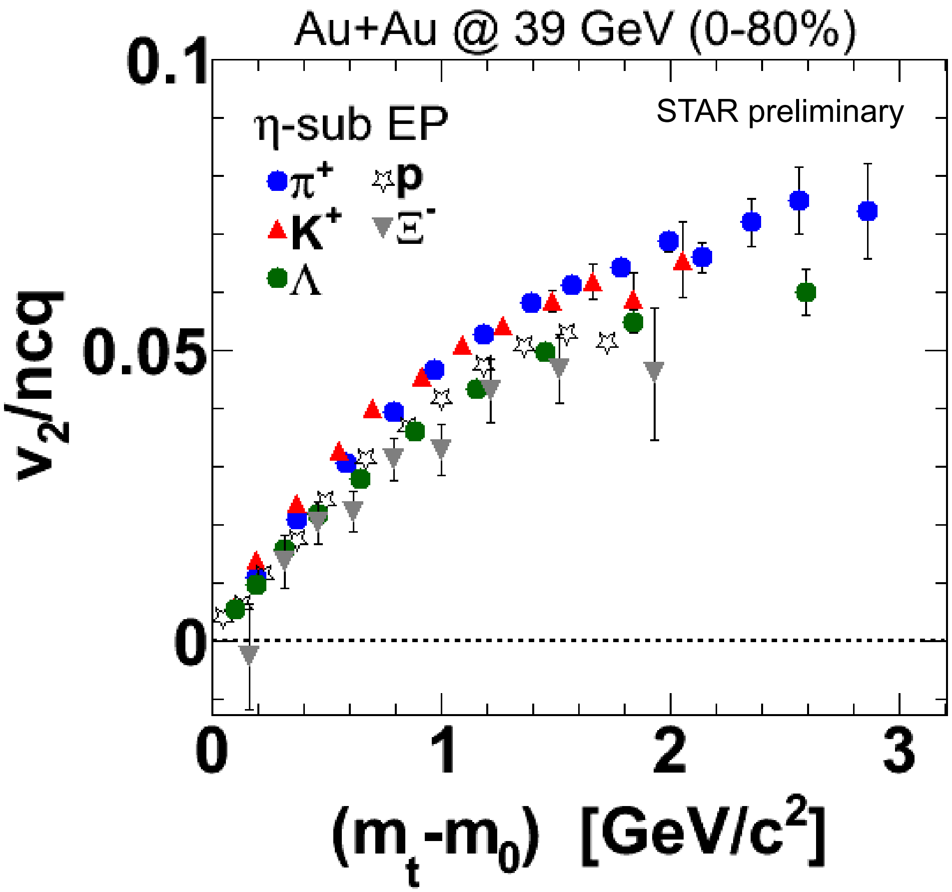
- 3 GeV/c in p_t for Pions with 10% statistics
- Kaons are below Pions in this p_t range
- Mass ordering at low p_t

Flow: v_2 in Transverse Mass Representation



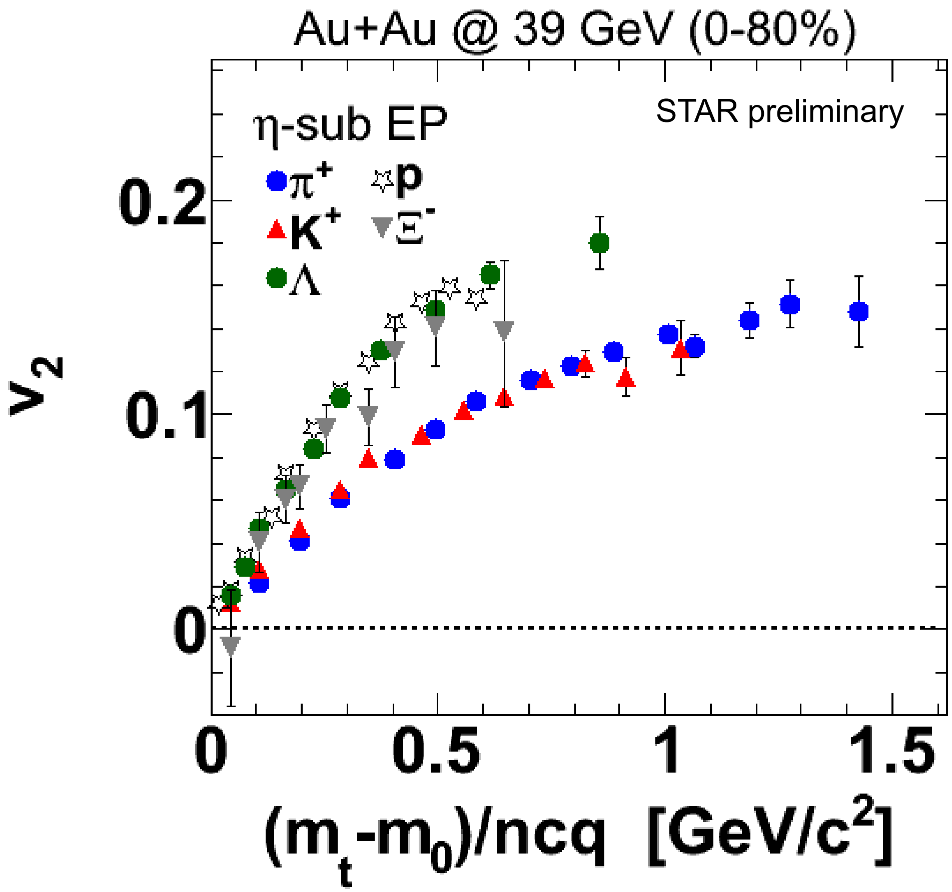
- Clear separation between baryons and mesons at large (m_t-m_0)

Flow: v_2 in Transverse Mass Representation



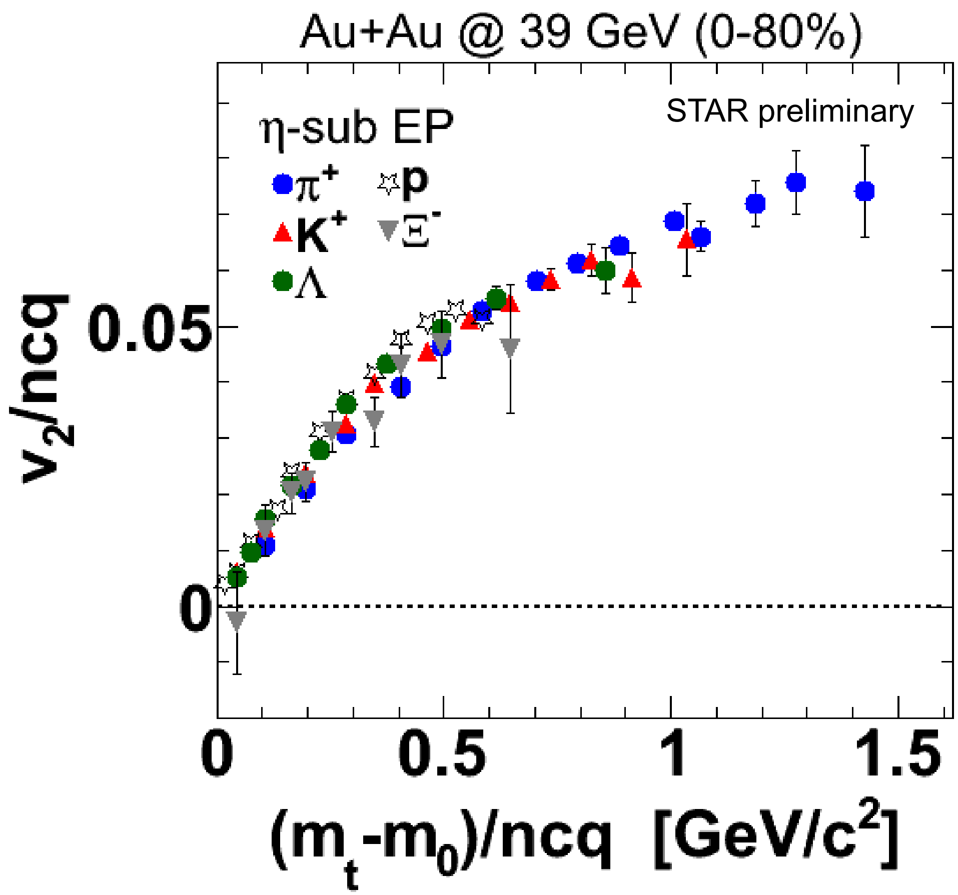
- Clear separation between baryons and mesons at large (m_t-m_0)
- Separation holds after $v_2 \rightarrow v_2$/ncq

Flow: v_2 in Transverse Mass Representation



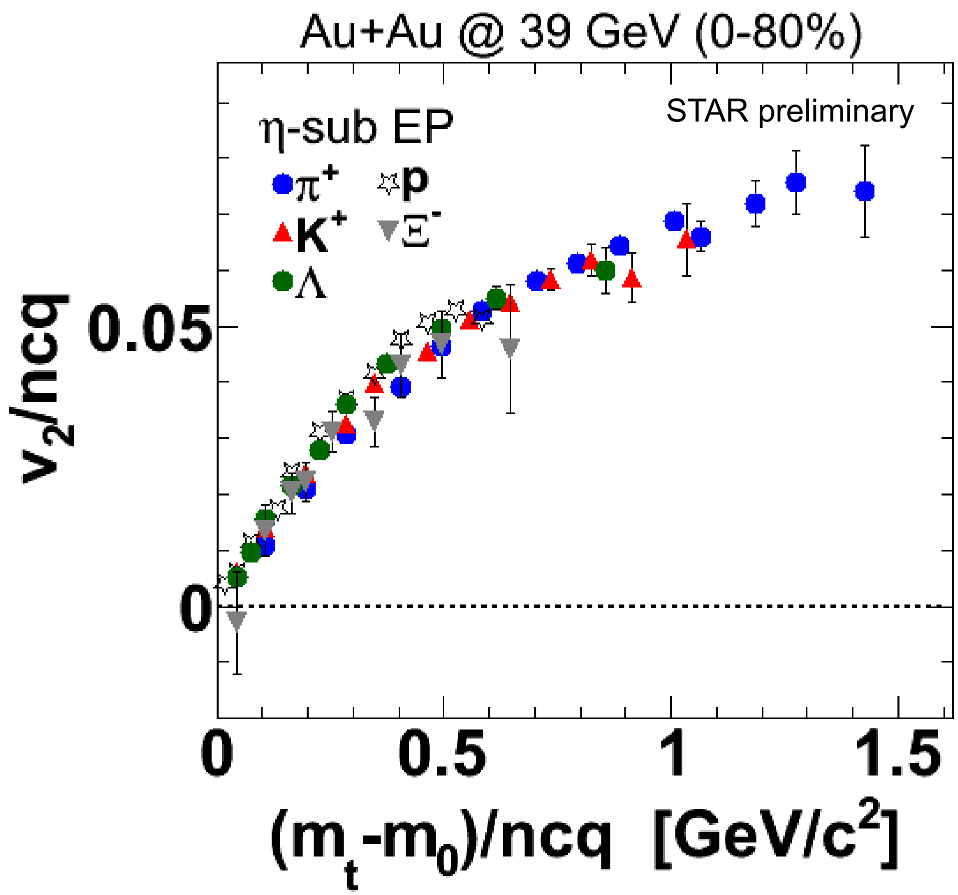
- Clear separation between baryons and mesons at large (m_t-m_0)
- Separation holds after $v_2 \rightarrow v_2/ncq$
- Separation holds after $(m_t-m_0) \rightarrow (m_t-m_0)/ncq$

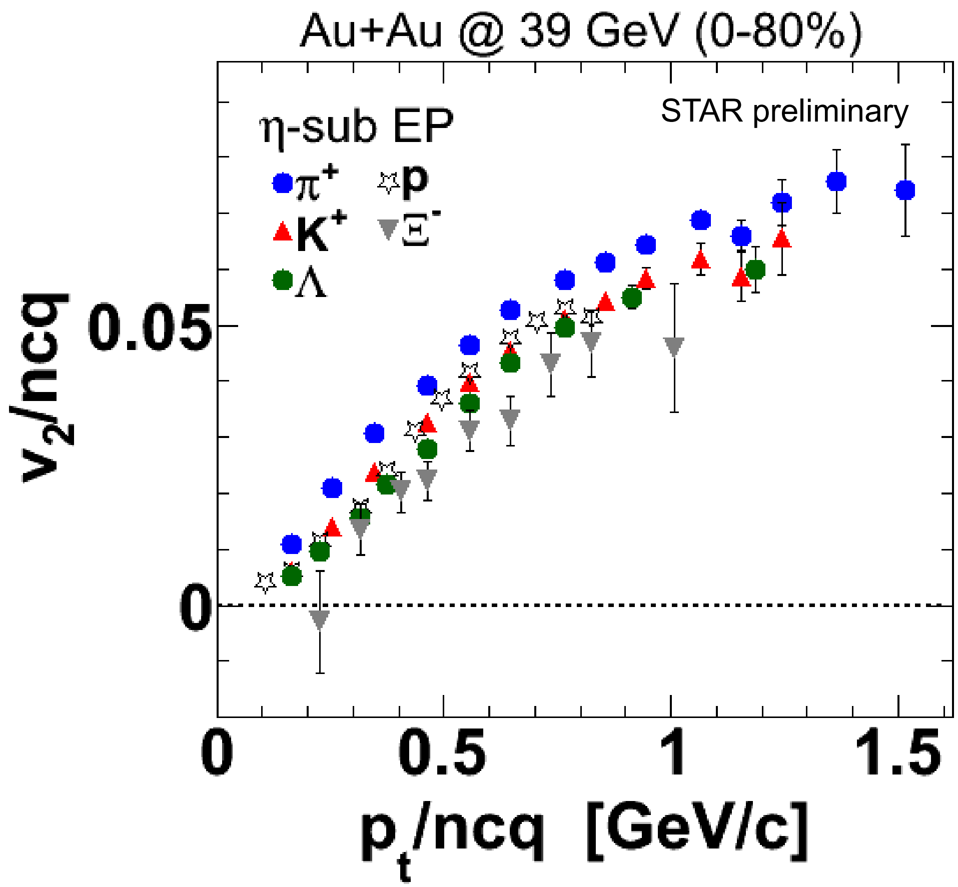
NCQ scaling @ 39 GeV



- The $(m_t\text{-}m_0)$/ncq looks similar to 200 GeV

NCQ scaling @ 39 GeV





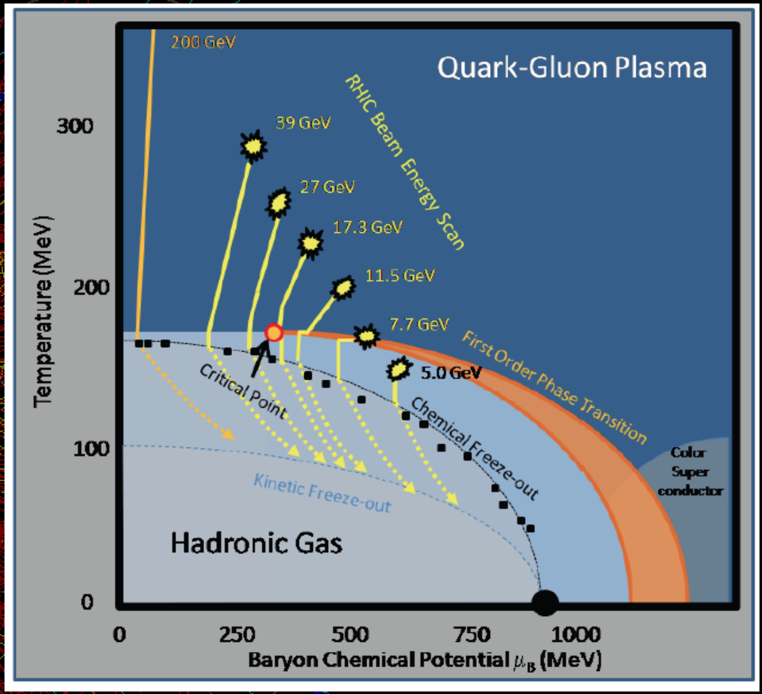
- The $(m_t - m_0)/ncq$ looks similar to 200 GeV

- At p_t/ncq ~ 1 GeV/c we see a similar v_2/ncq of the particles ~ as in 200 GeV

Summary and Outlook

Summary:

- First data taking period of BES program was very successful → stable beams from RHIC
- All goals concerning collected data reached
- Di-Leptons spectroscopy @ STAR @ 39 GeV
- First spectra, higher moments, v1 and v2 results



Outlook:

- Full statistics @ 39, results @ 11.5 and 7.7 GeV
- 18 and 27 GeV is scheduled for 2011 or 2012

One QCD, two different views

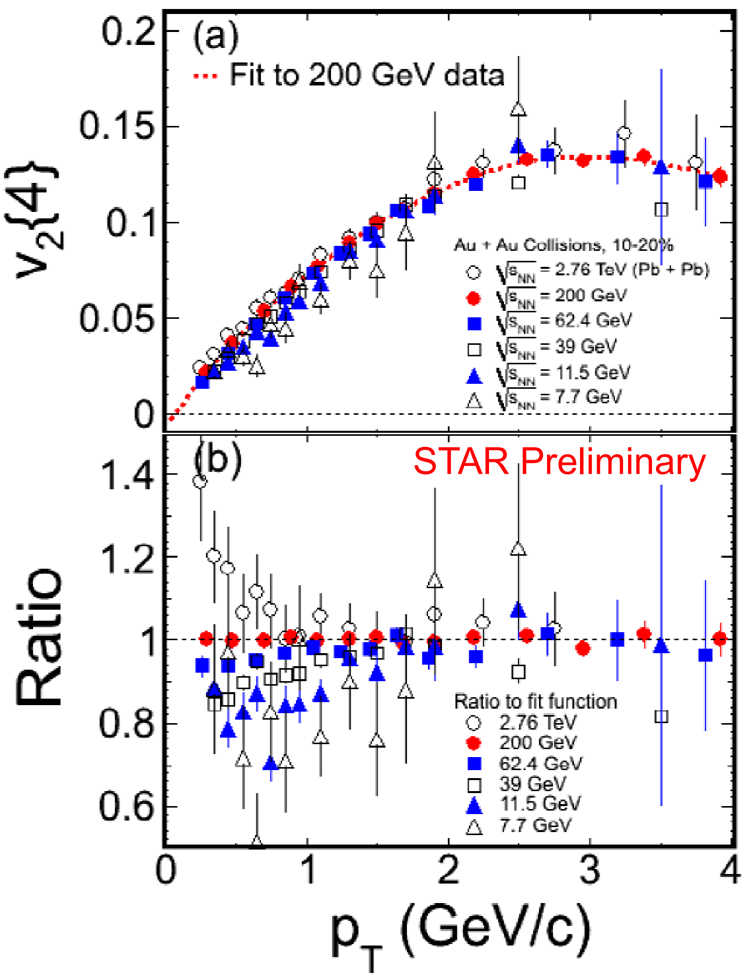
ALICE: I am in wonderland

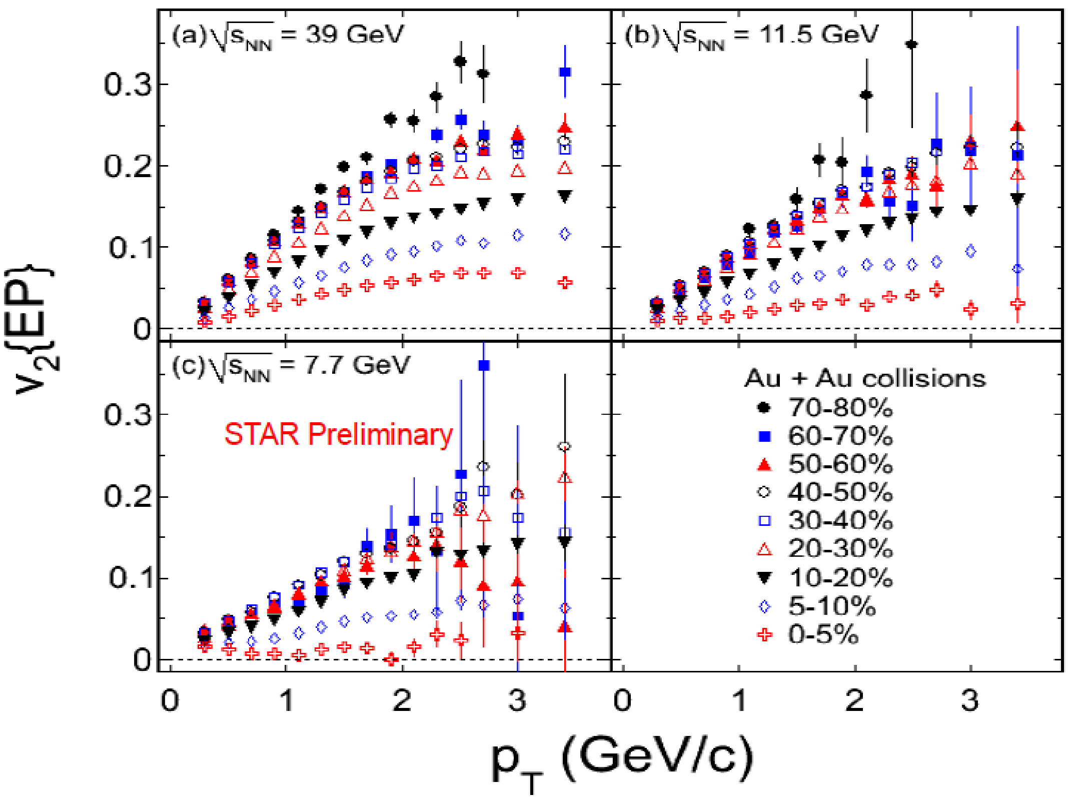
Dorothy: I've a feeling we're not in Kansas any more

BACKUP

Elliptic Flow v_2 of Charged Hadrons

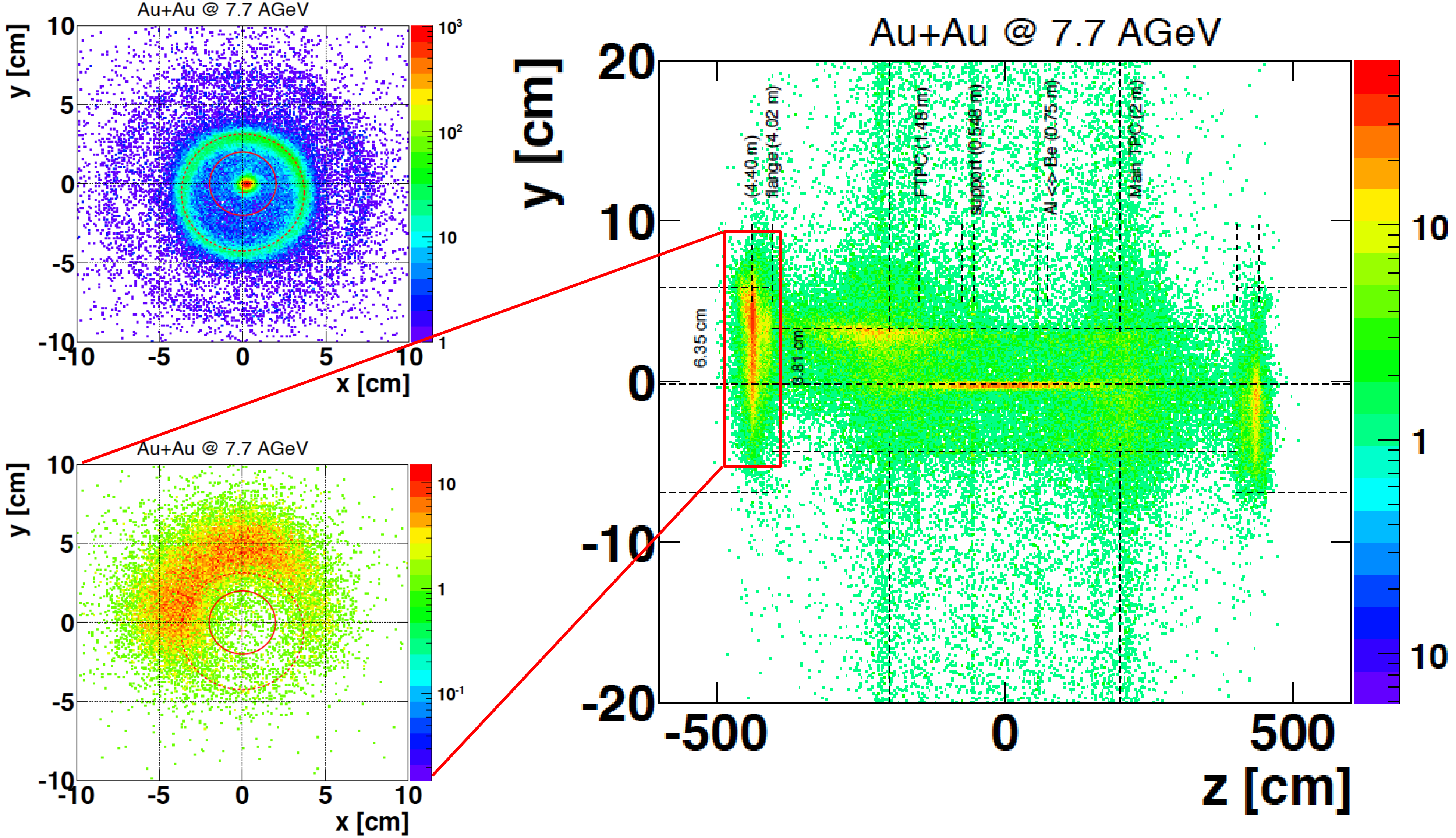
$$v_2 = \langle \cos(2(Psi - \phi)) \rangle$$



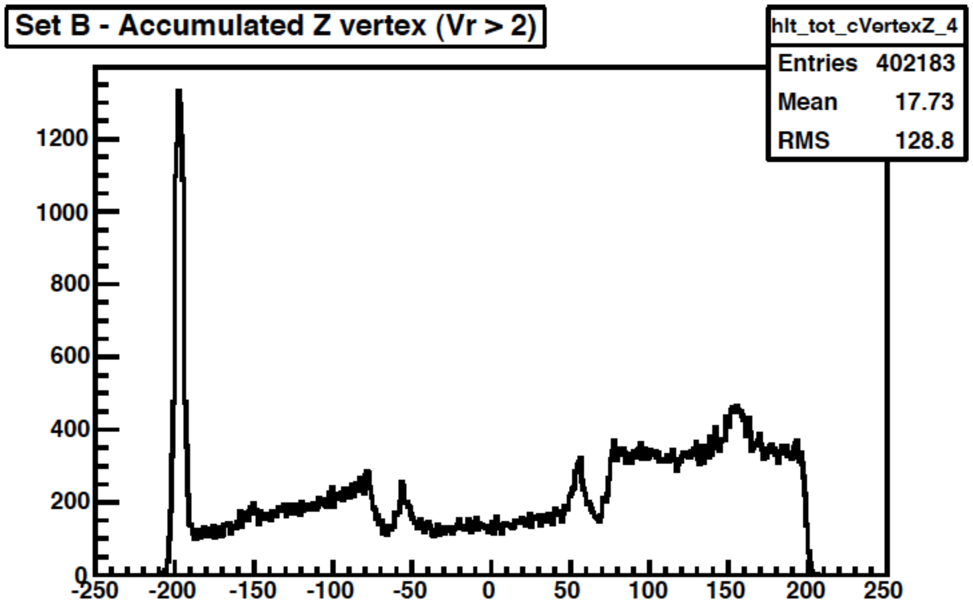


- v_2 increases with decreasing centrality and increasing energy
- $v_2\{4\}$ increases only slightly from 39 GeV to 200 GeV

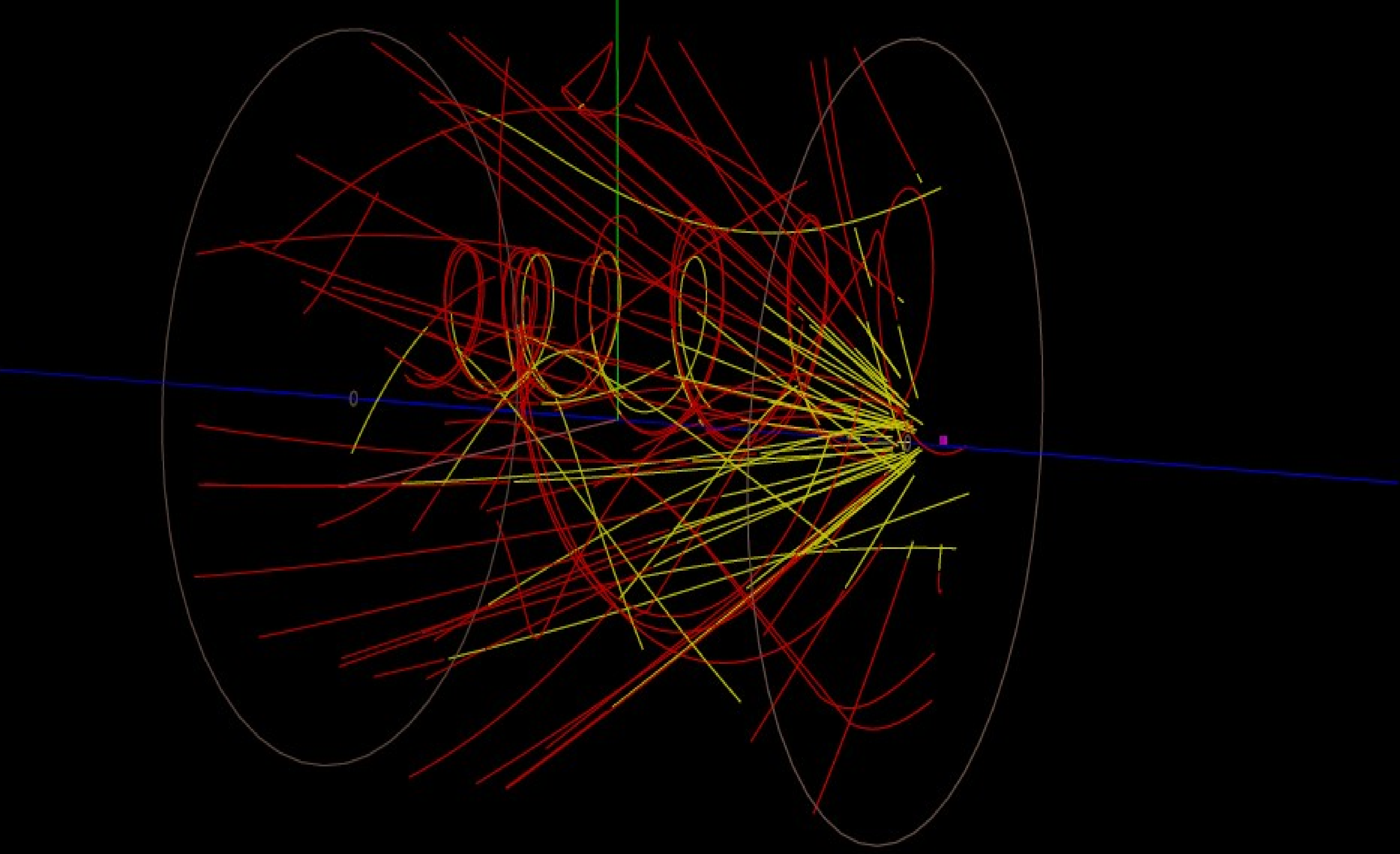
Beampipe Interactions



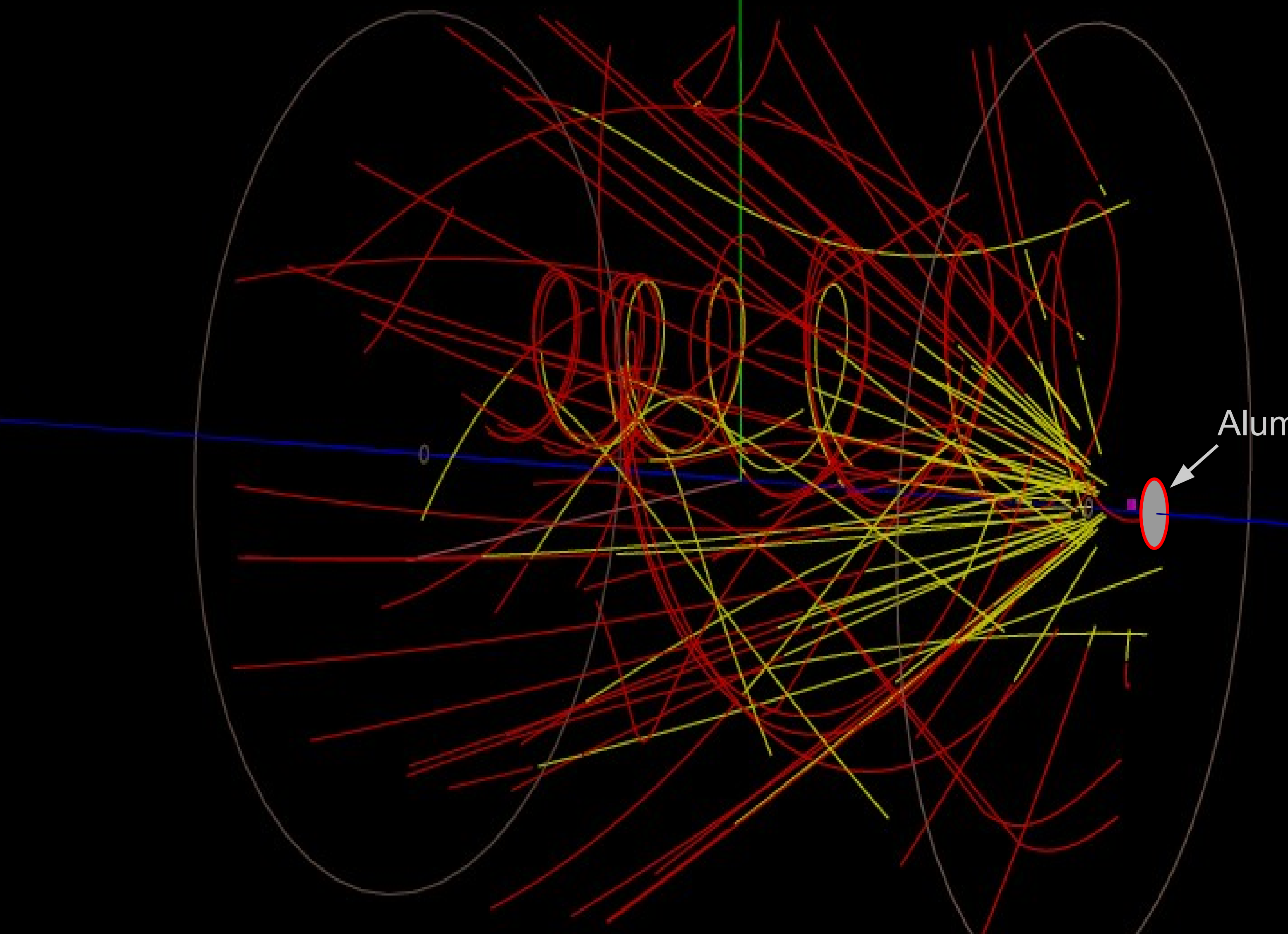
High Level Trigger Vertex

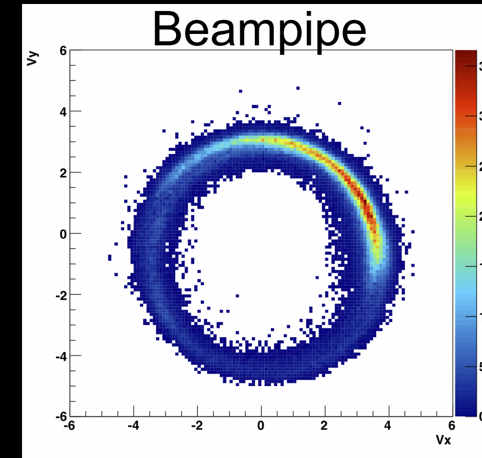


Au+Al @ 2.8 AGeV outside TPC → Fixed target experiment @ RHIC:
Not only background...



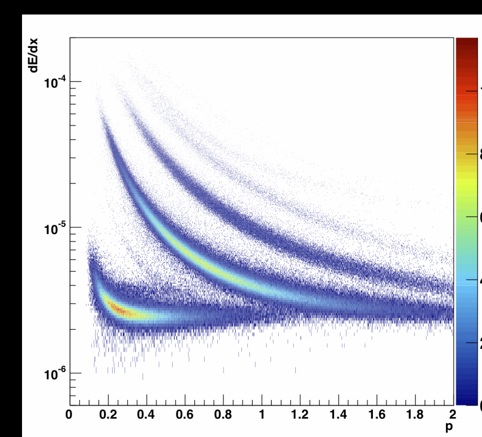
Au+Al @ 2.8 AGeV outside TPC → Fixed target experiment @ RHIC: Feasibility study





Vertex selection

dE/dx PID



Motivation: We can dramatically go down in energy!

Advantage: Cross check of our data at 7.7 GeV with the 62.4 GeV data set (same c.m. energy)