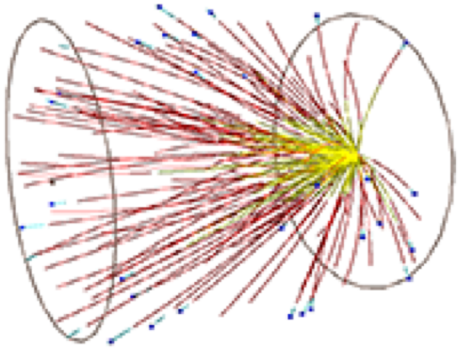
Venezia 2018 Quark Matter



Al+Au $\sqrt{s_{NN}}$ = 4.9 GeV, Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Fixed-Target Collisions at STAR

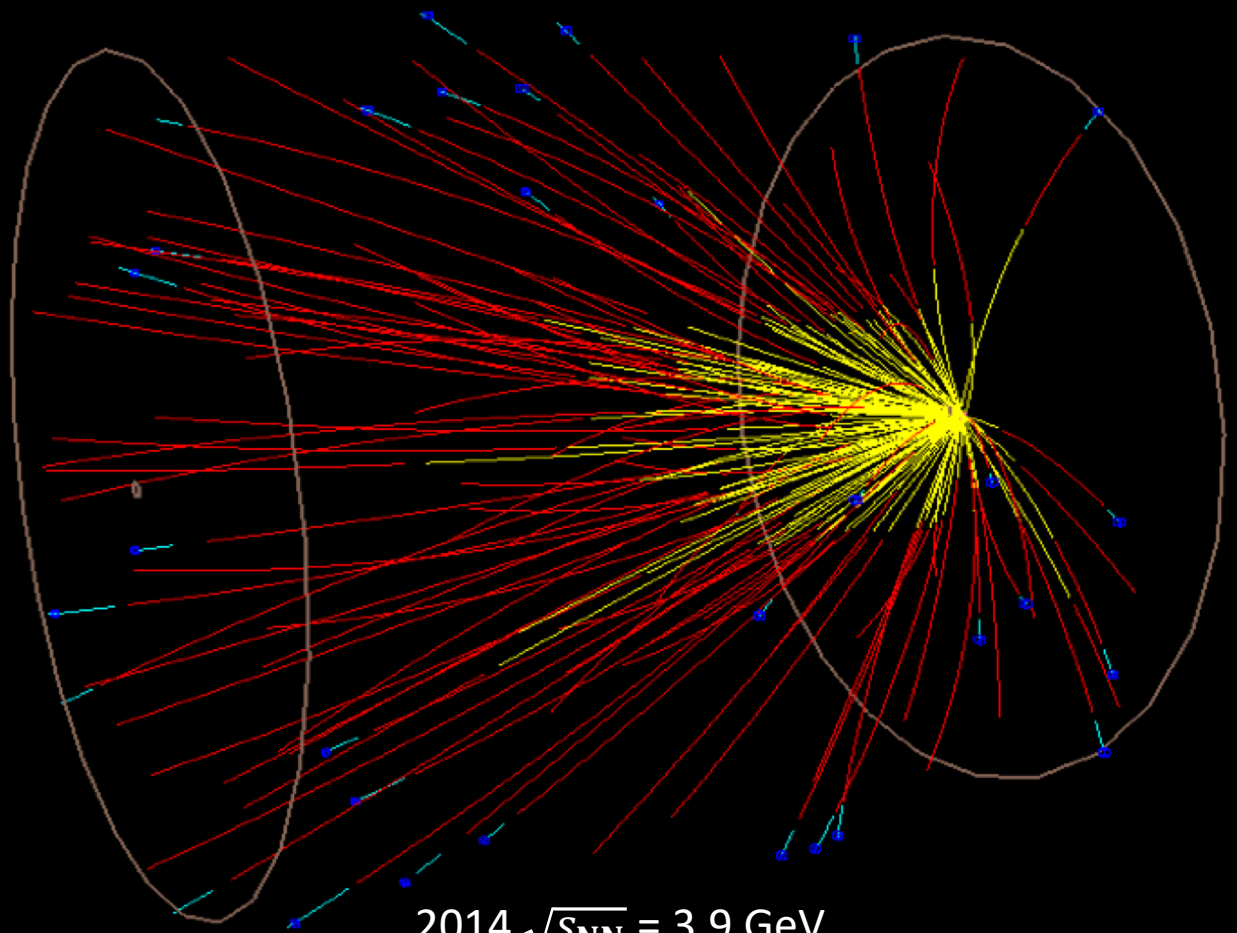
Yang Wu for the STAR Collaboration
Kent State University

KENT STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

STAR

Outline



2014 $\sqrt{s_{NN}}$ = 3.9 GeV

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   - Spectra and yields
   - Directed flow
   - Elliptic flow
   - HBT
   - Fluctuations
4. Summary
5. Future Plan: FXT in Run 18 & BES-II

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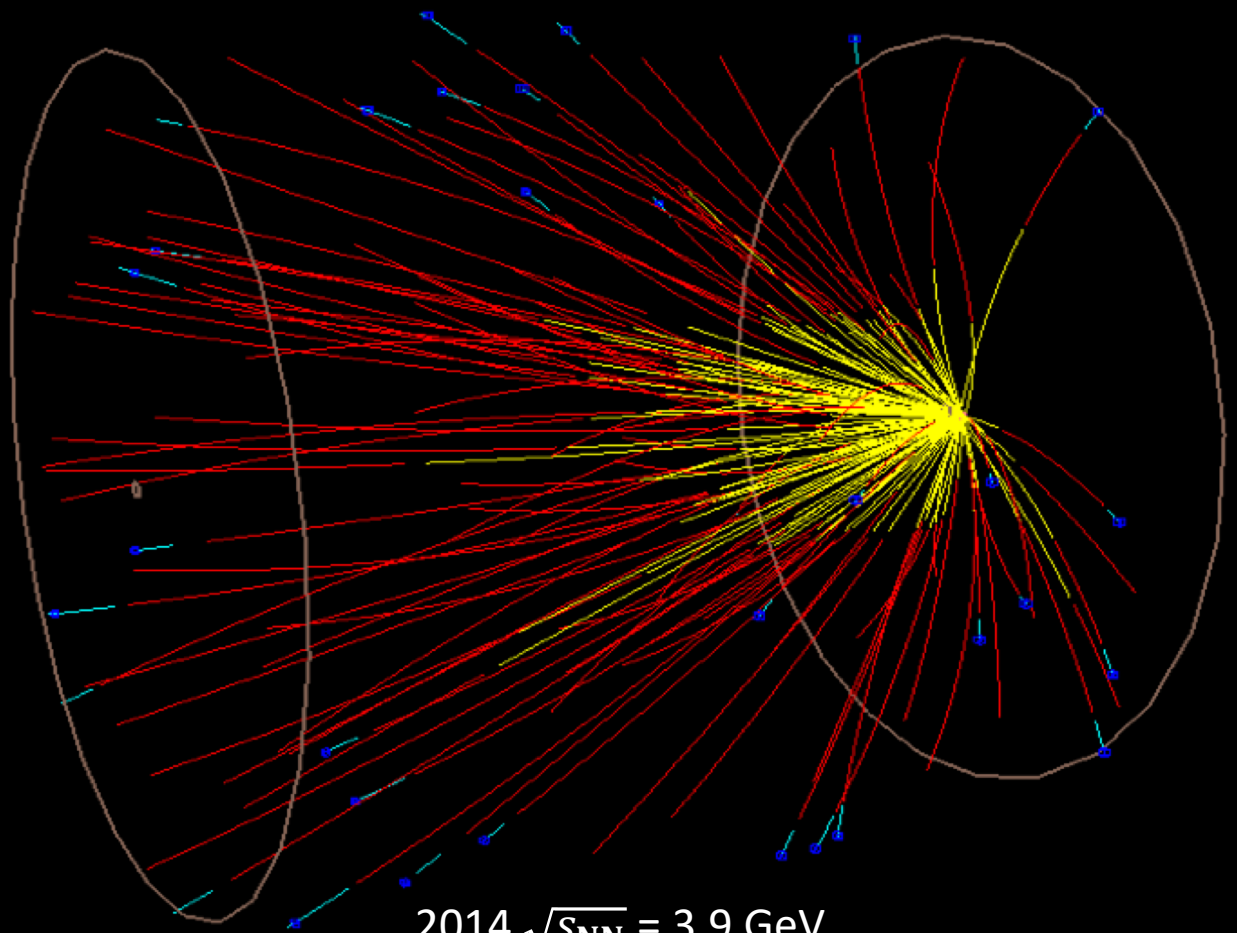

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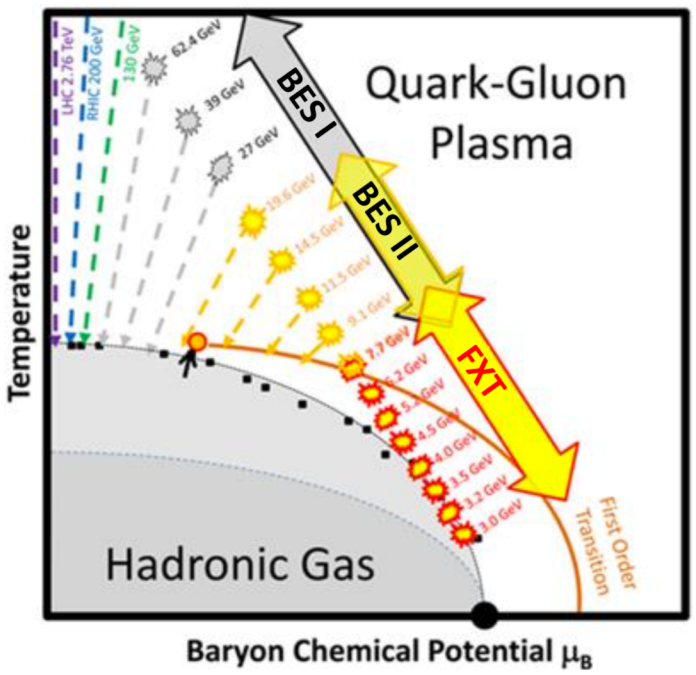
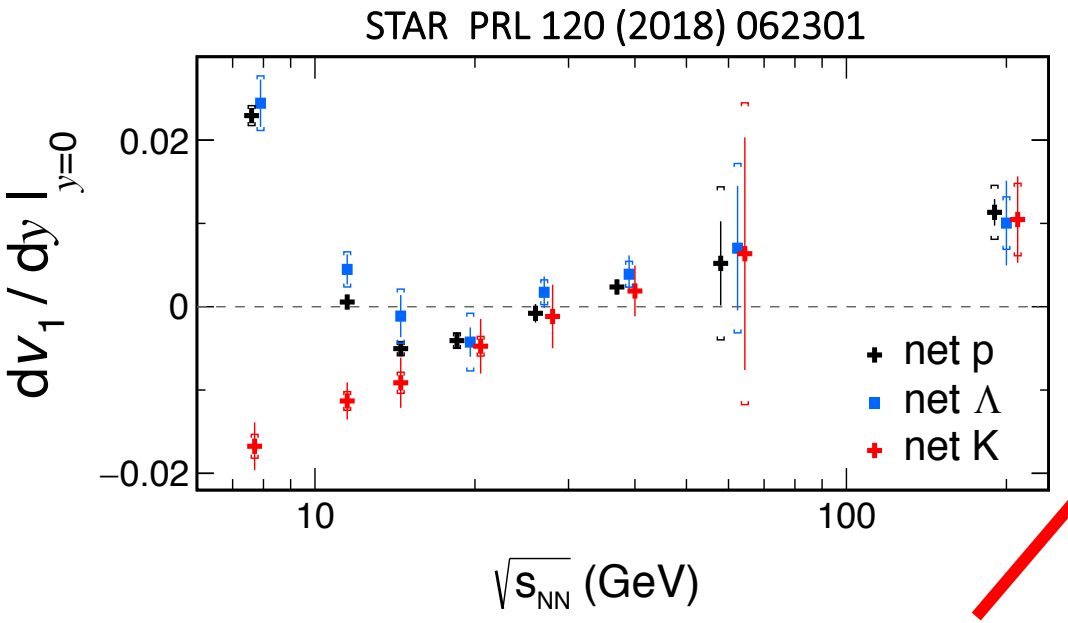
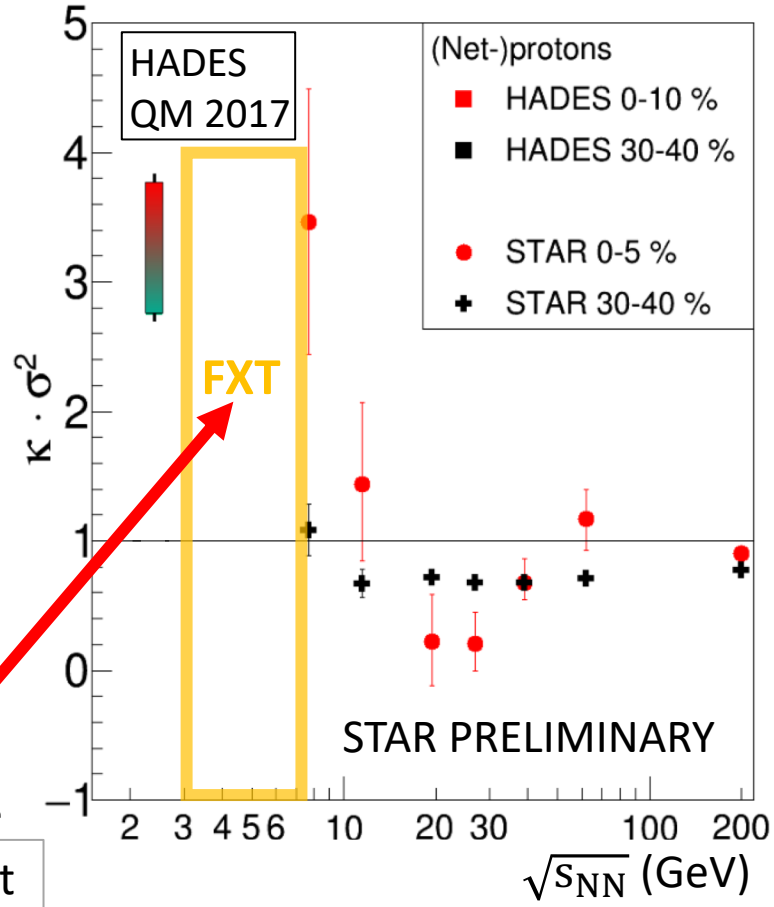
Physics Motivation







Need data here

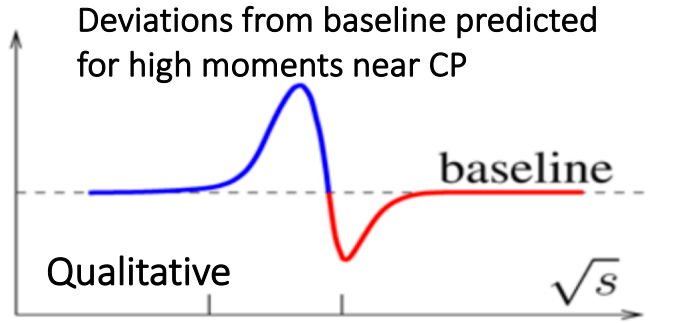
BES Goals:
1. Search for the possible 1st-order phase transition
2. Search for the possible Critical Point
3. Investigate turn-off QGP signatures

RHIC collider-mode luminosity: unusable below 7.7 GeV

FXT can cover 7.7 to 3.0 GeV (μ_B ~400—720 MeV)

Minimum in v_1 for *p*, net *p*, net Λ at $\sqrt{s_{NN}}$ = 10-20 GeV → qualitatively like hydro "softest point"

FXT will extend STAR kurtosis measurements

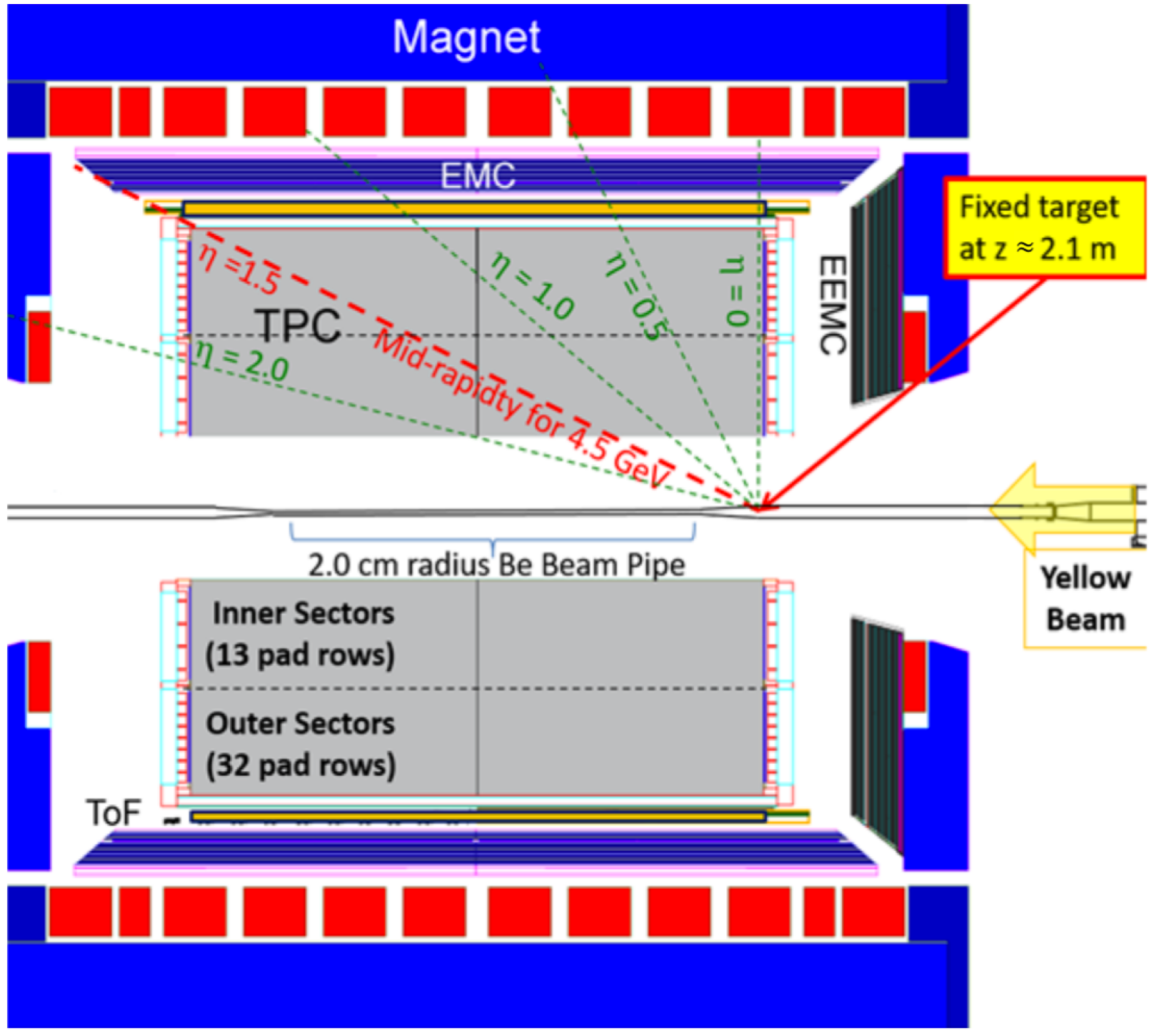


M. Stephanov J Phys G: Nucl Part Phys 38 (2011) 124147

Lattice suggests CP not below $\mu_B \sim 250$ MeV, but crossover could extend much higher in μ_B

O. Kaczmarck *et al*. PRD 83 (2011) 014504 & A. Bazavov *et al*. PRD 85 (2012) 054503

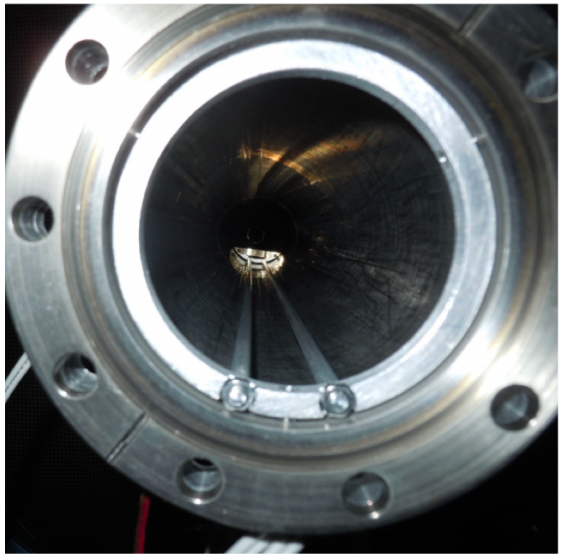
STAR Fixed-Target Program (FXT)

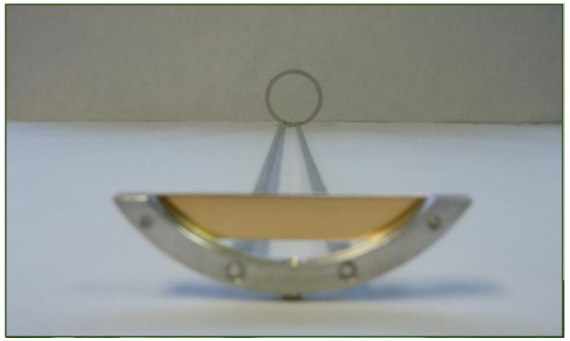


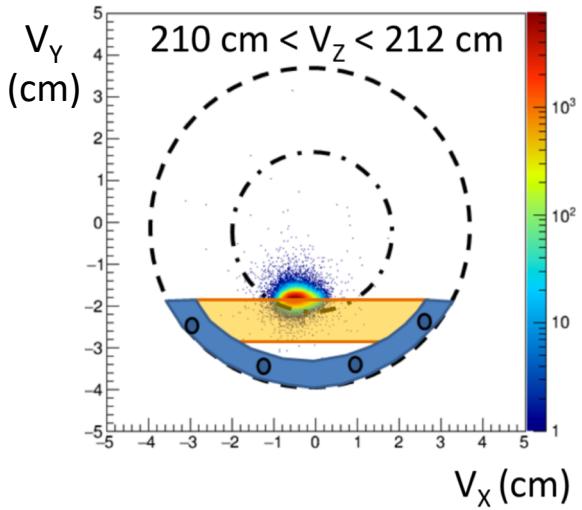
1.3M events from half hour test run, top 30% central trigger, Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV

3.4M events from two hour test run, top 30% central trigger, Al+Au $\sqrt{s_{NN}}$ = 4.9 GeV

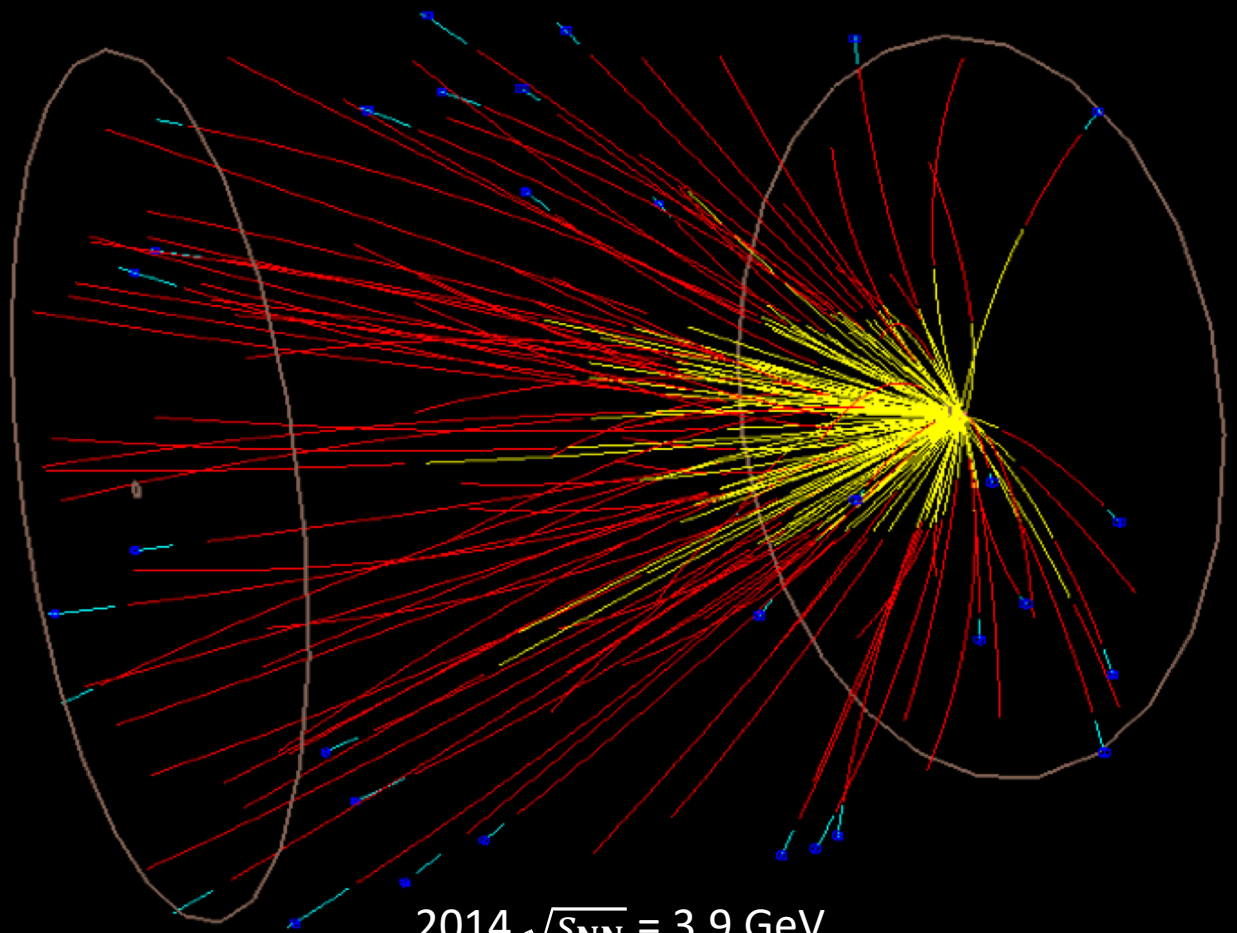
1 mm thick Au target (4% interaction probability)







Outline



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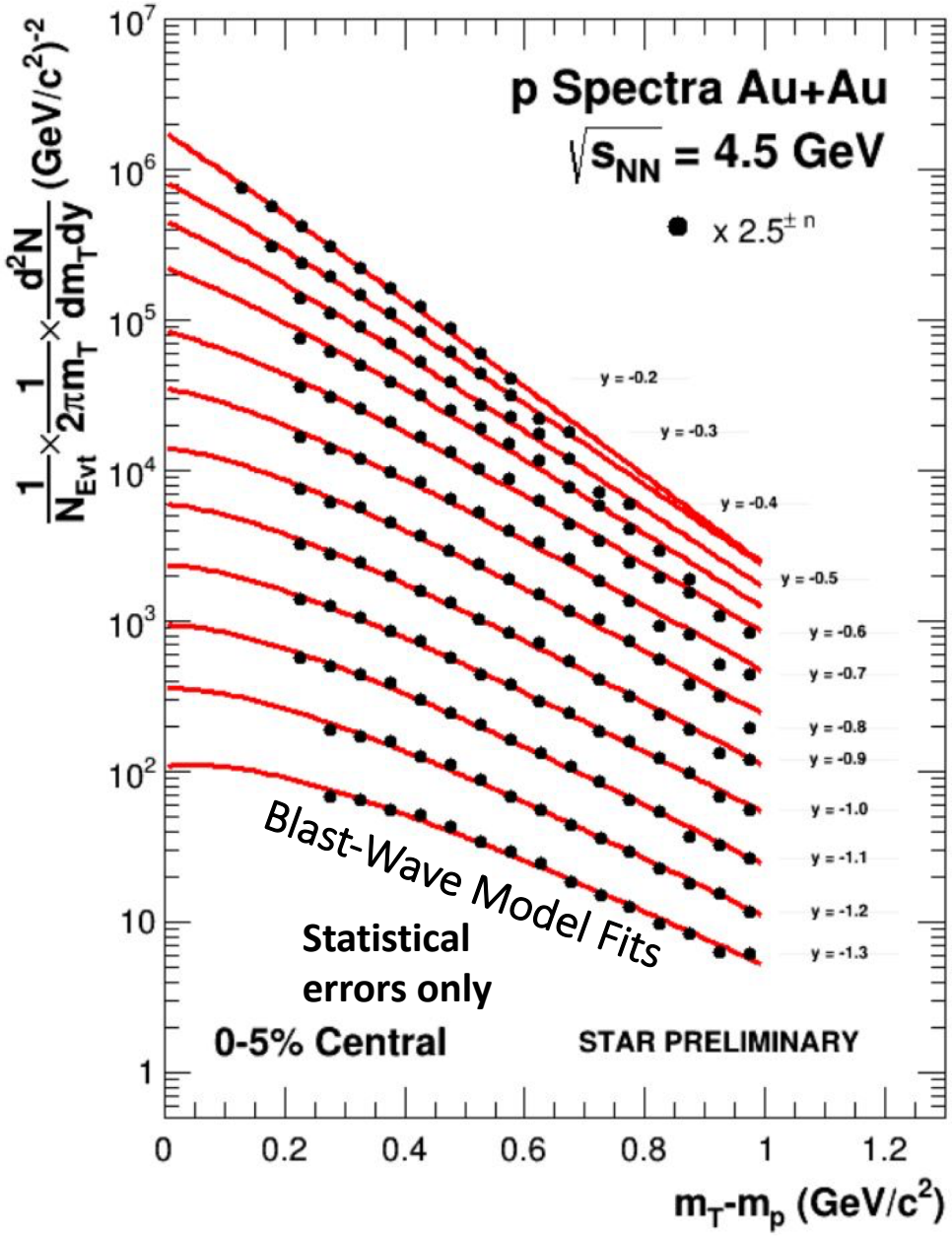
Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Proton Spectra



Spectra corrected for: detector efficiency, acceptance in each rapidity bin, energy loss and hadronic background

Spectra fit with Blast-Wave Model

$m_T - m_0$ range will be extended by eTOF & iTPC upgrade

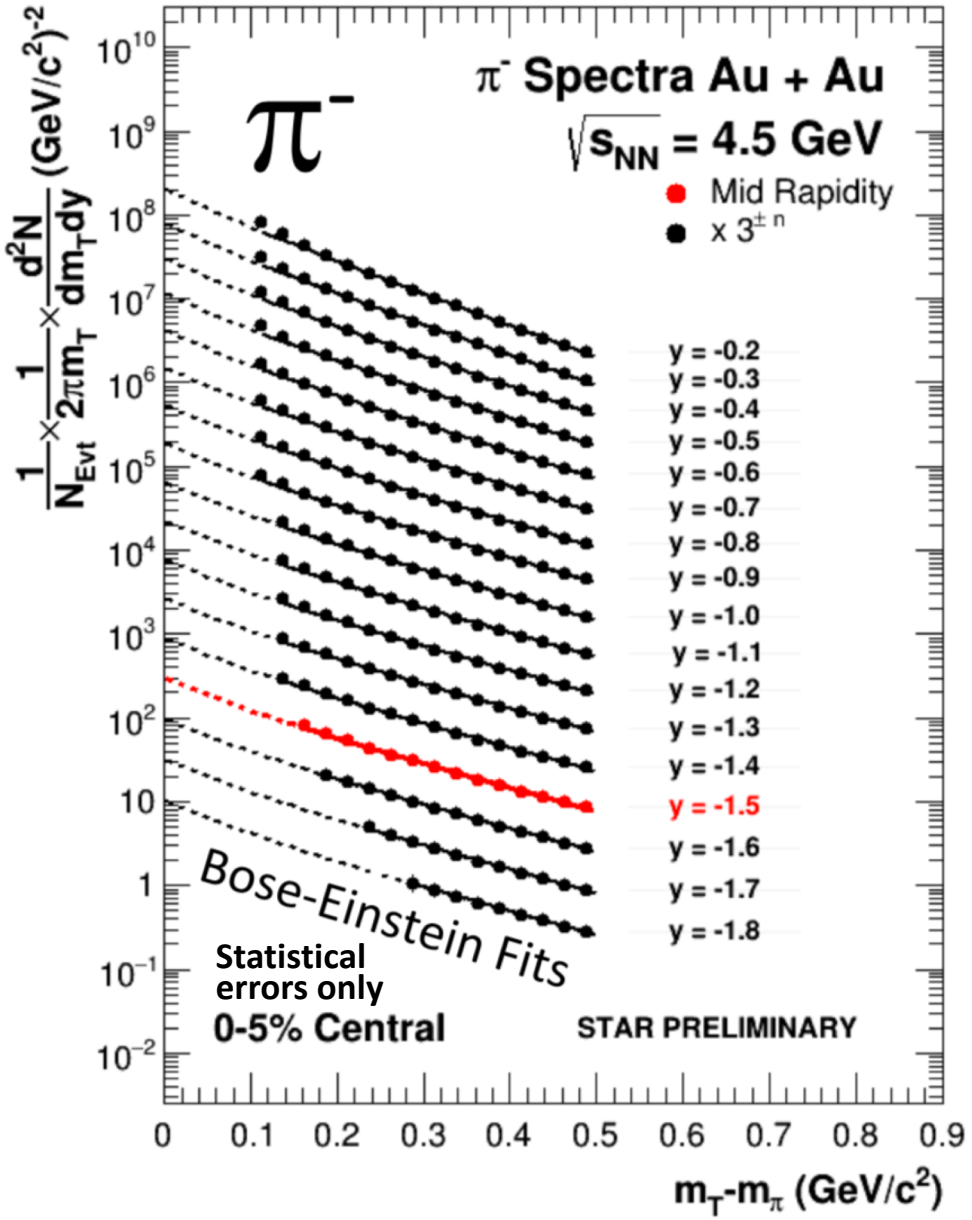
See Qian Yang's talk
15/05/2018, 10:00

$$\frac{d^2N}{m_T dm_T dy} = A\int_0^R r dr m_T \times I_0\left(\frac{p_T \sinh\rho(r)}{T_{kin}}\right) K_1\left(\frac{m_T \cosh\rho(r)}{T_{kin}}\right)$$

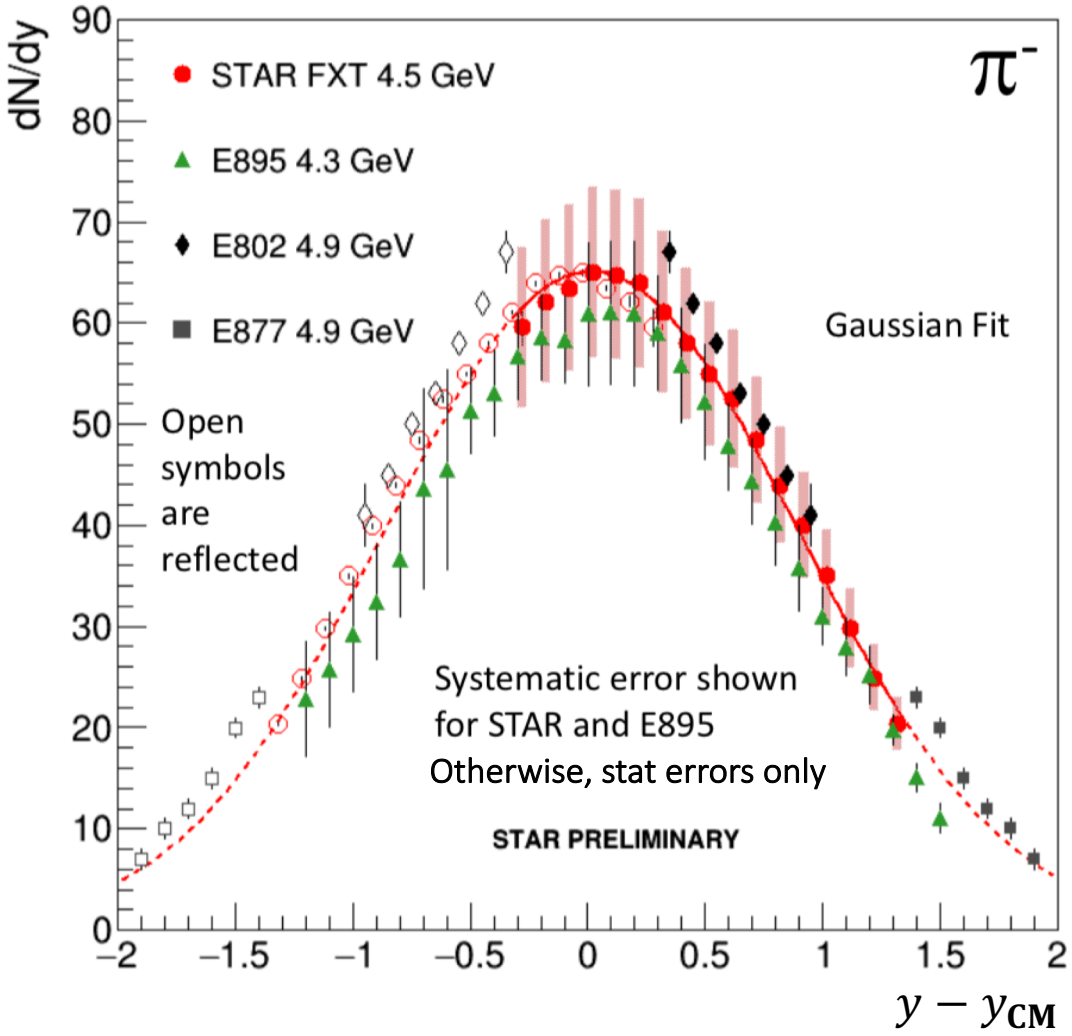
$$\rho(r) = \tanh^{-1}\beta_T(r) \quad \beta_T(r) = \beta_s\left(\frac{r}{R}\right)^n$$

A is normalization, β_s is surface velocity, both free fit parameters
n is fixed to ½ and R is fixed to 1. Fit range 0.2 to 1 GeV/c^2.

Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Pion Spectra and *dN/dy*



E895 PRC 68 (2003) 054905
E802 PRC 57 (1998) R466
E877 PRC 62 (2000) 024901

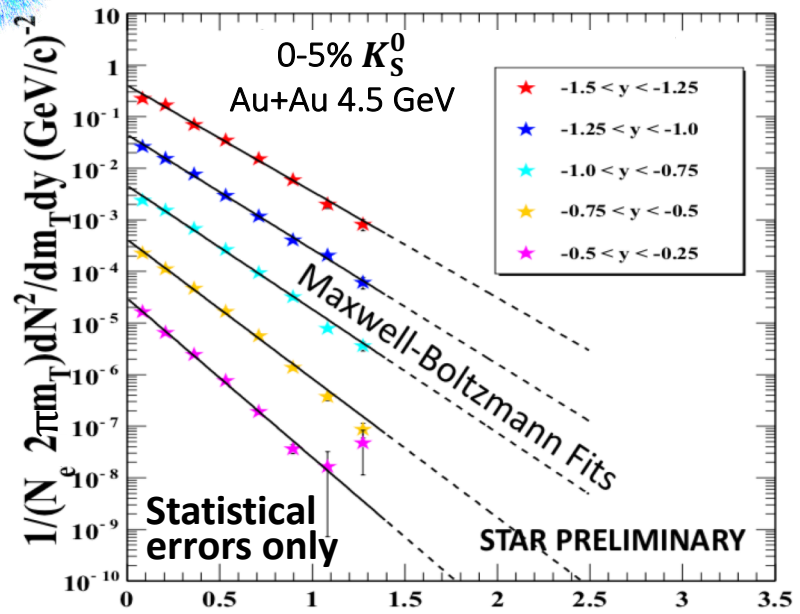


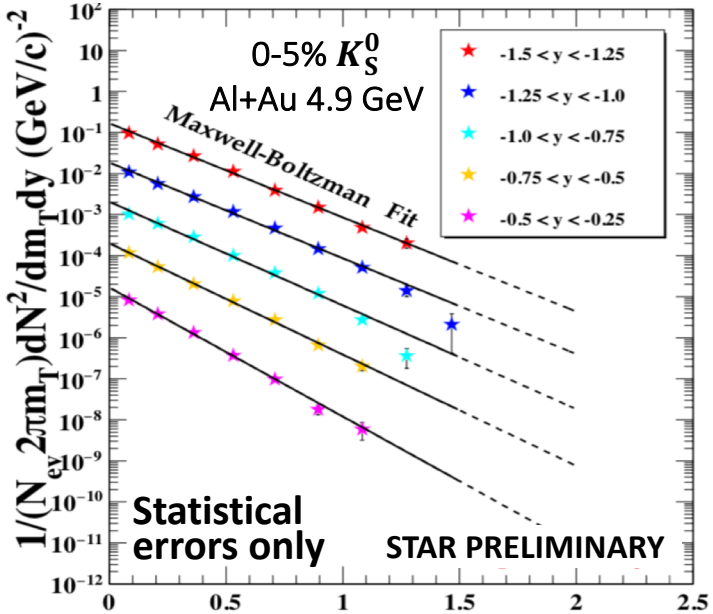
Amplitudes & widths of rapidity densities are consistent with AGS experiments

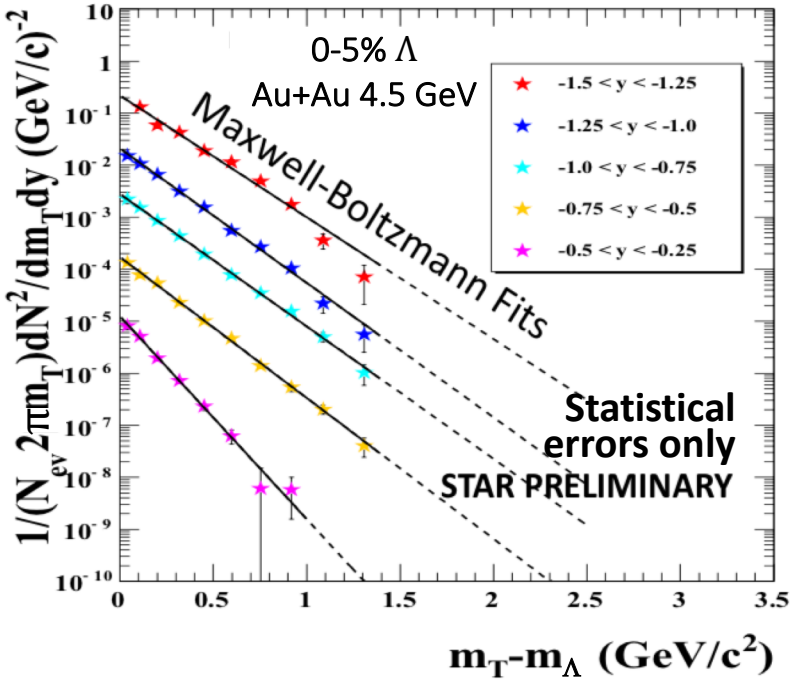
$m_T - m_0$ and y range will be extended by eTOF & iTPC upgrade

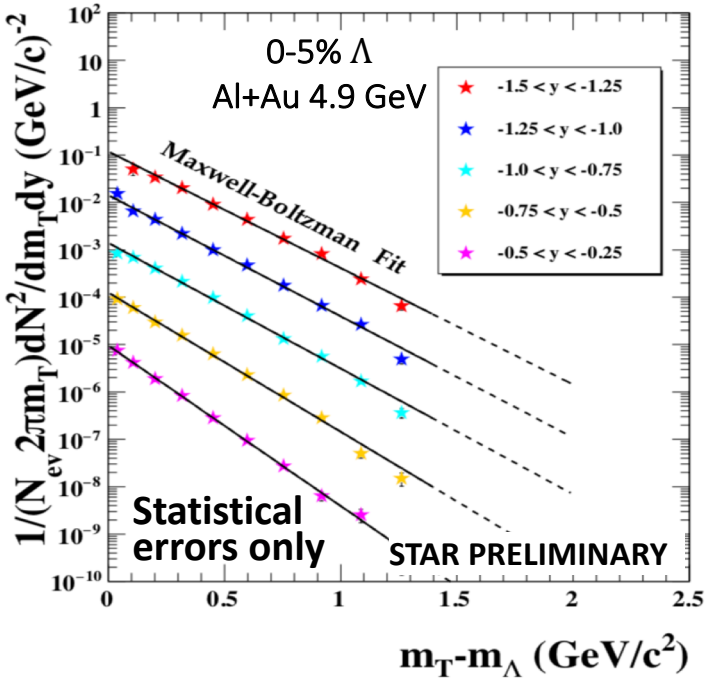
Yang Wu, Quark Matter 2018, Venice

STAR FXT Kaon and Λ Spectra and *dN/dy*



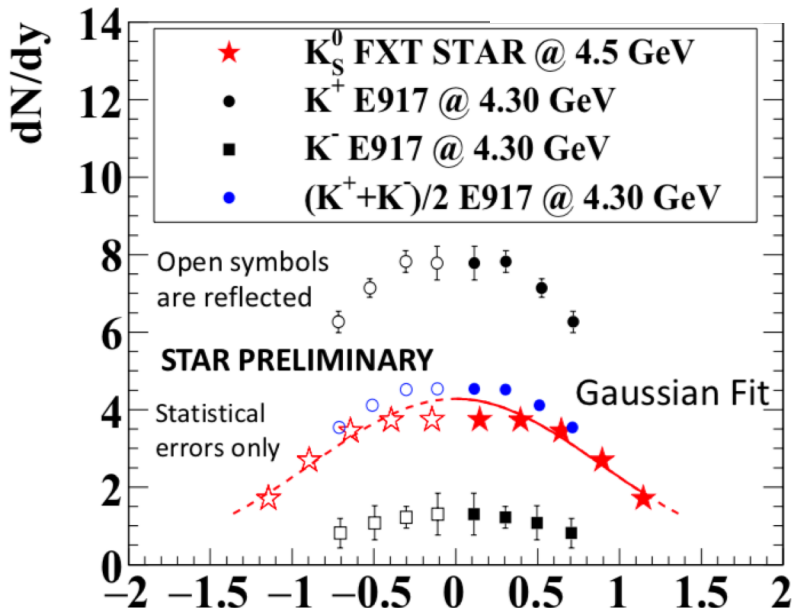


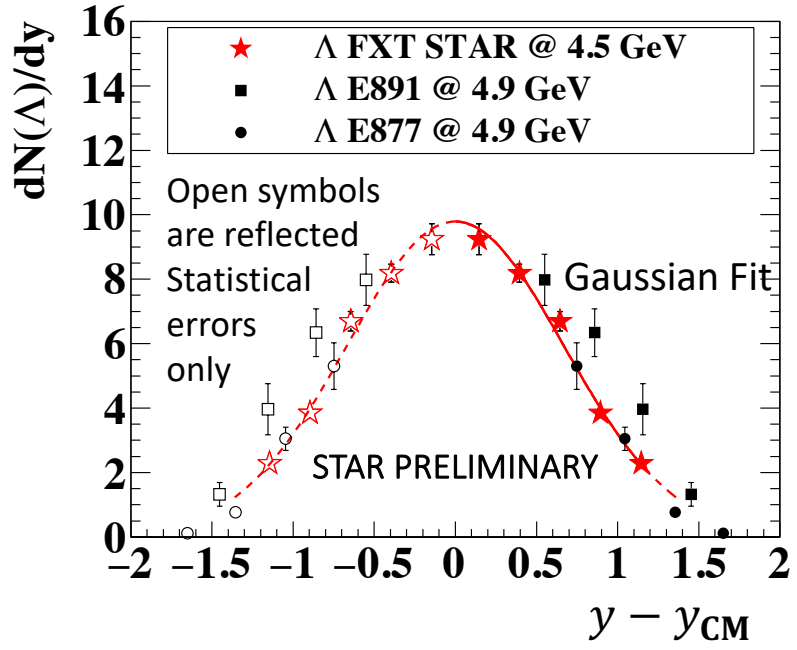


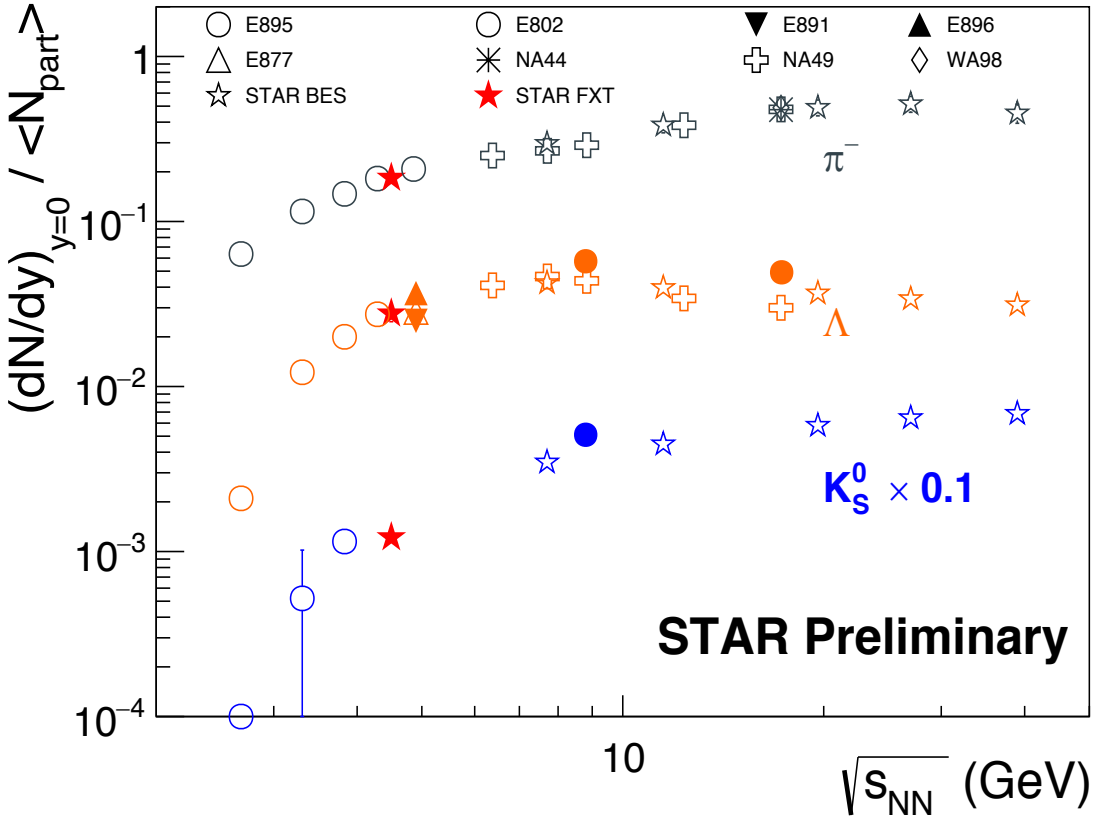


m_T - m_0 spectra in different rapidity bins for Au+Au 4.5 GeV & Al+Au 4.9 GeV

Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Kaon and Λ *dN/dy*





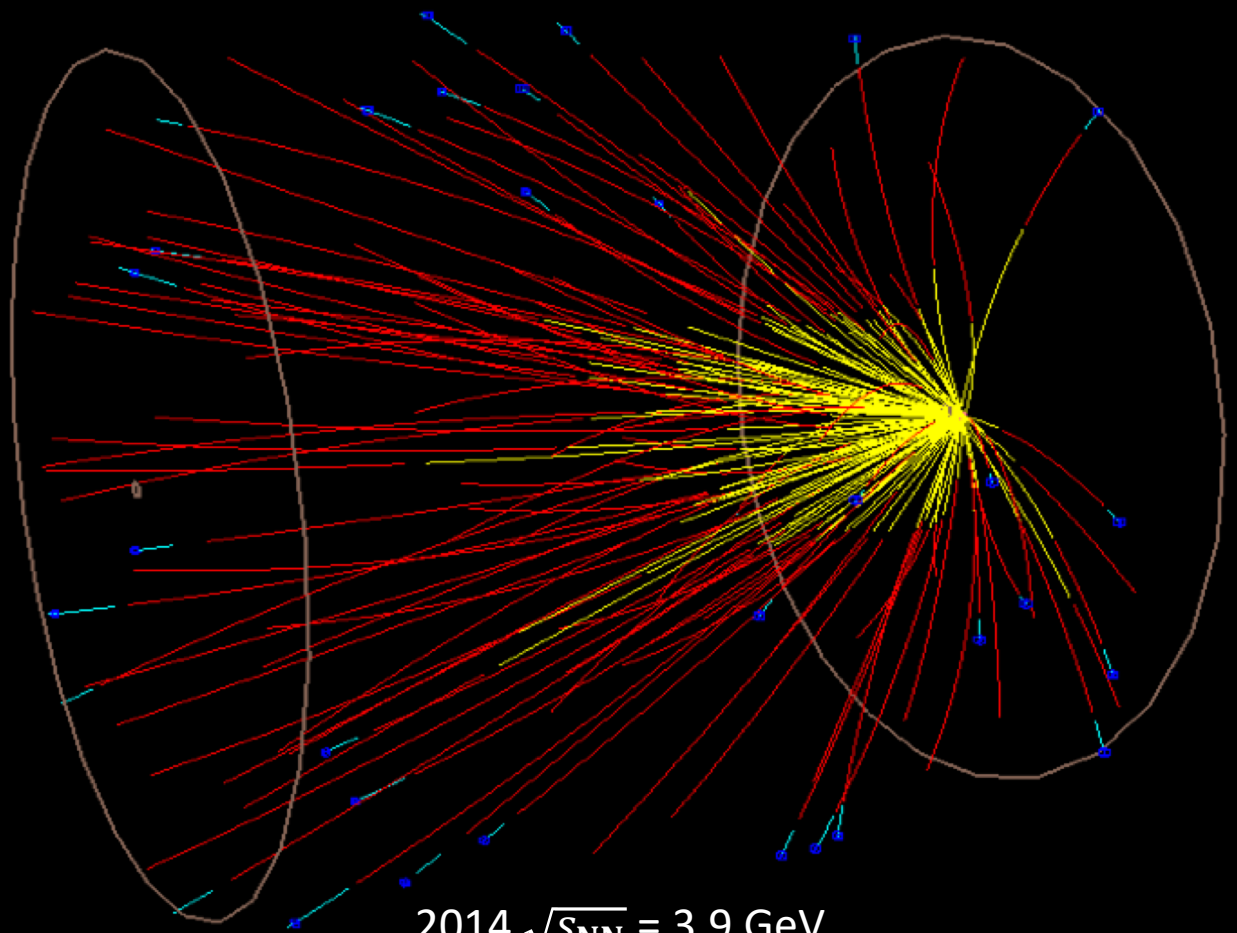


E896 PRL 88 (2002) 062301
NA44 PRC 66 (2002) 044907
NA49 JPG 30 (2004) S701
NA49 PRL 93 (2004) 022302
NA57 JPG:NPP 32 (2006) 2065
WA98 PRC 67 (2003) 014906
E895 RPC 68 (2003) 054905
E895 NPA 698 (2002) 495c
E917 PLB 476 (2000) 1
E802 NPA 610 (1996) 139c
E877 PRC 63 (2001) 014902
E891 PLB 382 (1996) 35

Amplitudes & widths of rapidity densities are consistent with AGS experiments

STAR FXT dN/dy consistent with trends demonstrated by published data

Outline



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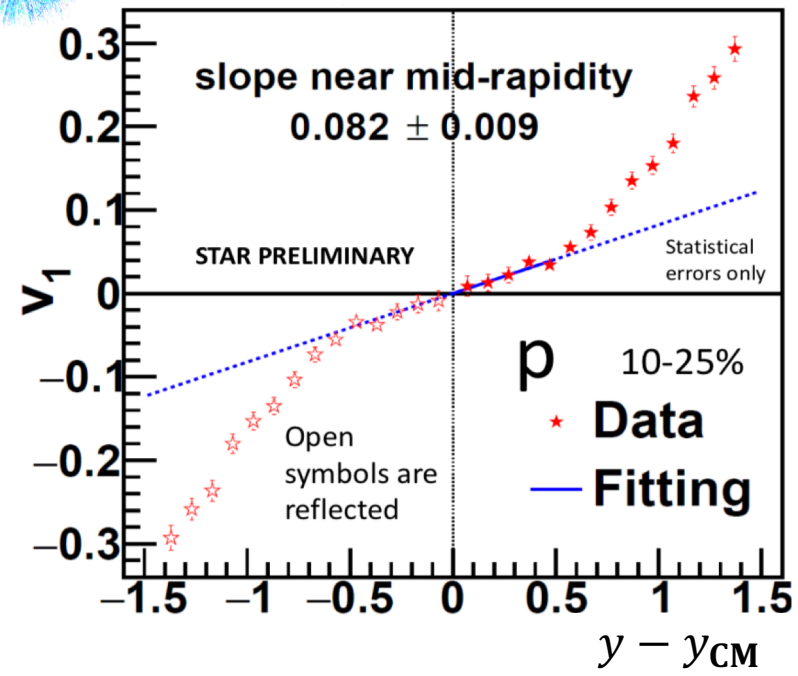
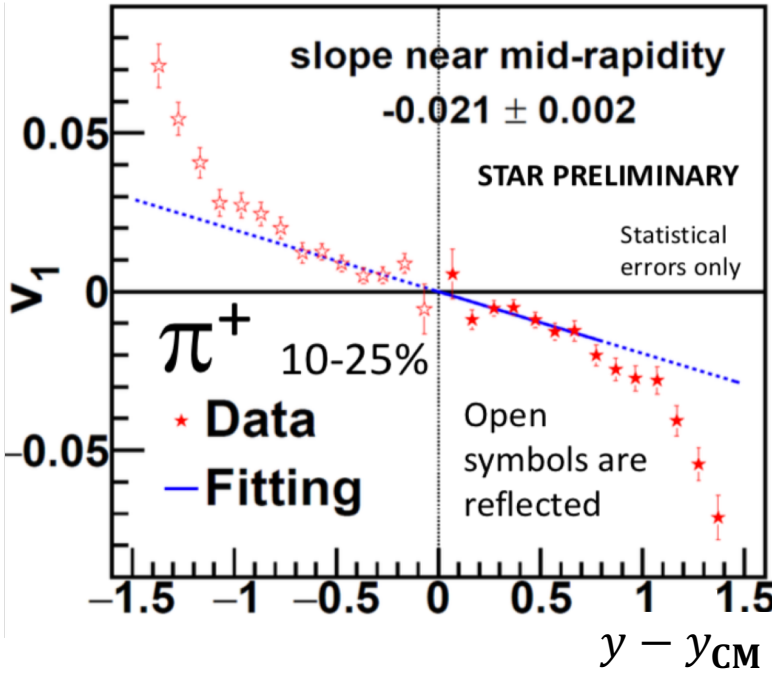
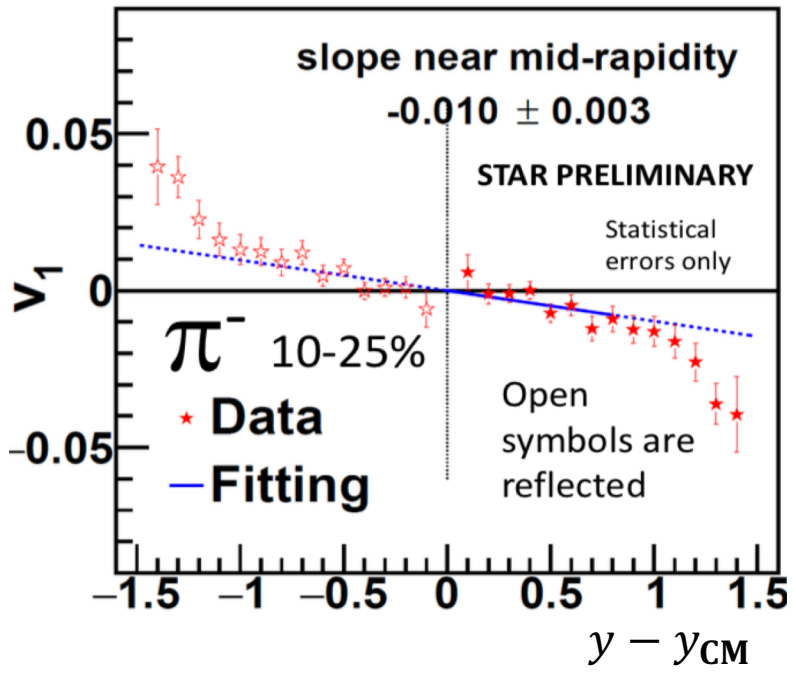
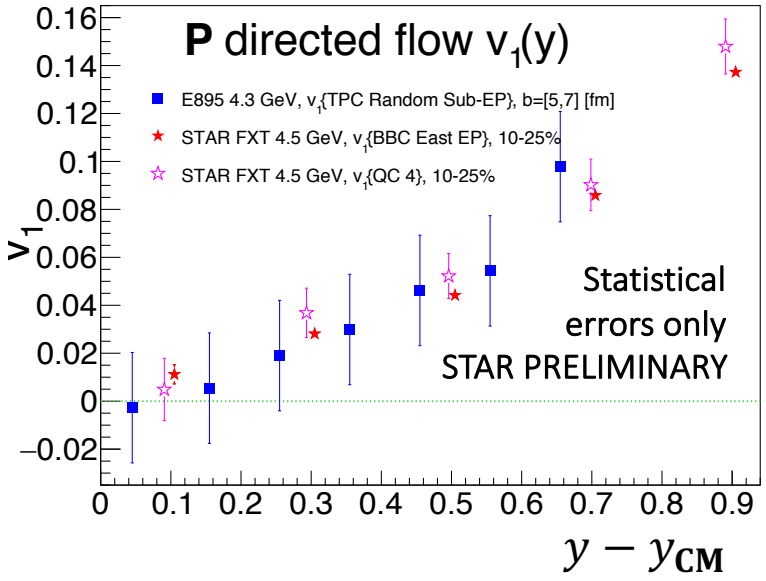
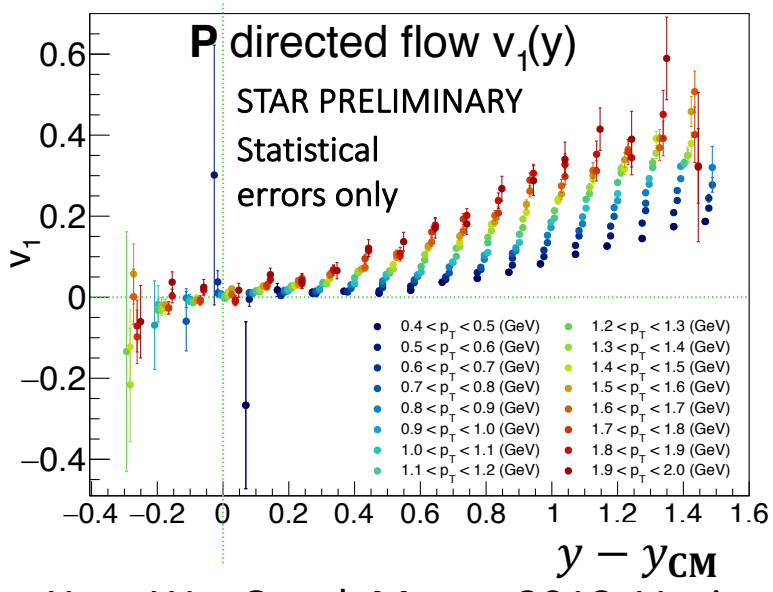
Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Directed Flow of Protons and Pions









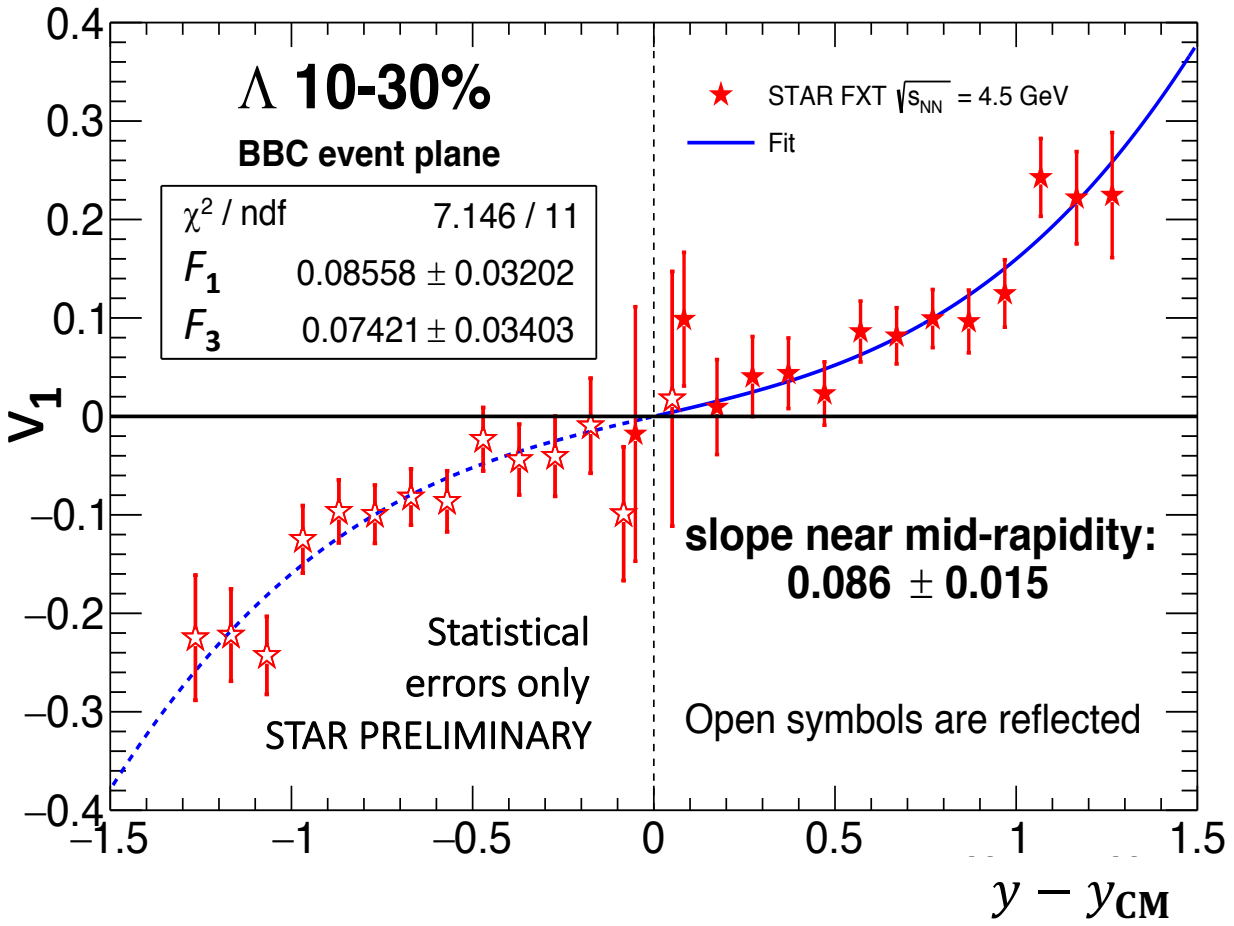


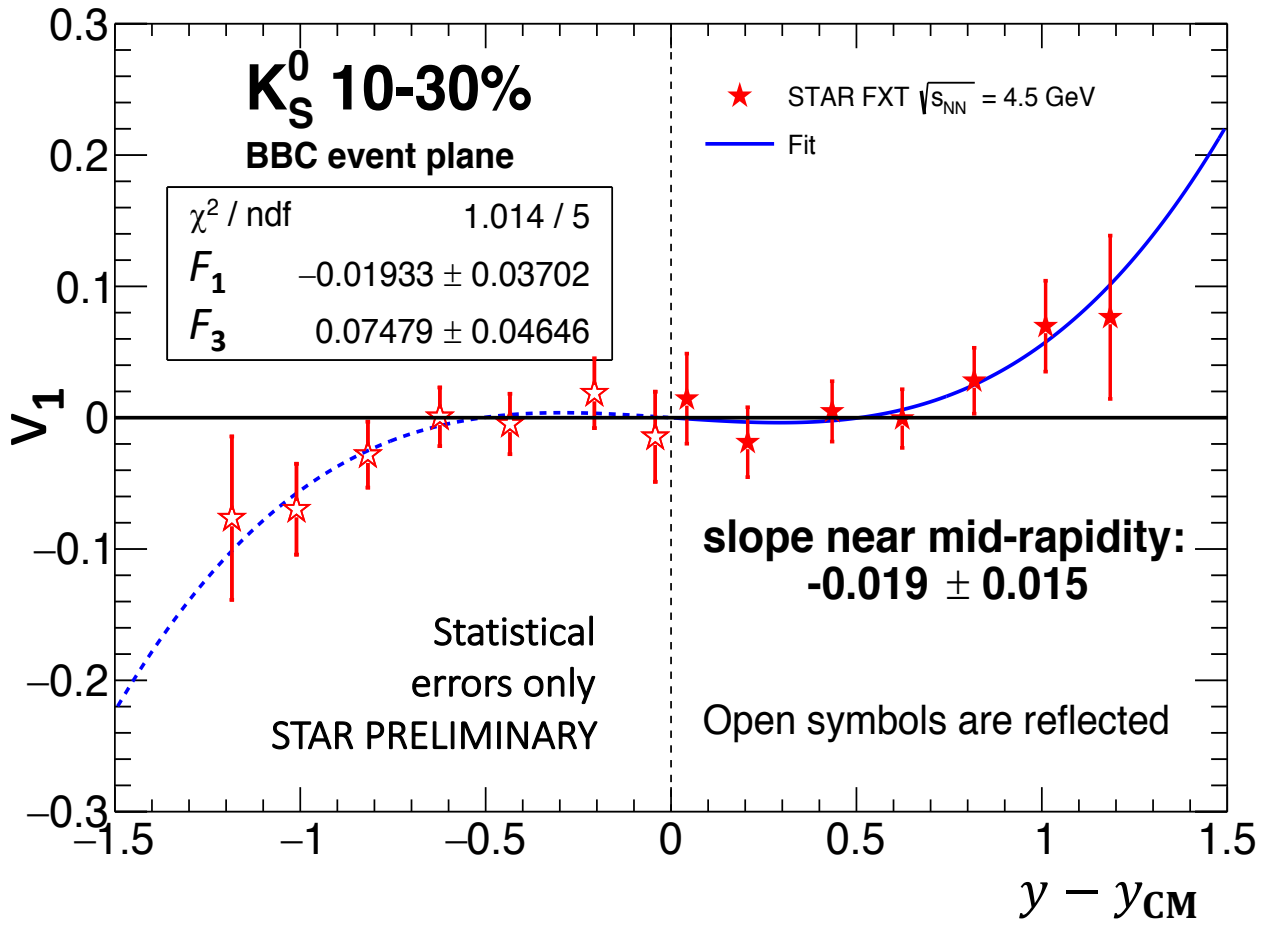
Proton v_1 has positive slope & agrees with E895

Pion v_1 has negative slope

π^+ v_1 is twice that of π^-

Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Directed Flow of Kaon and Λ



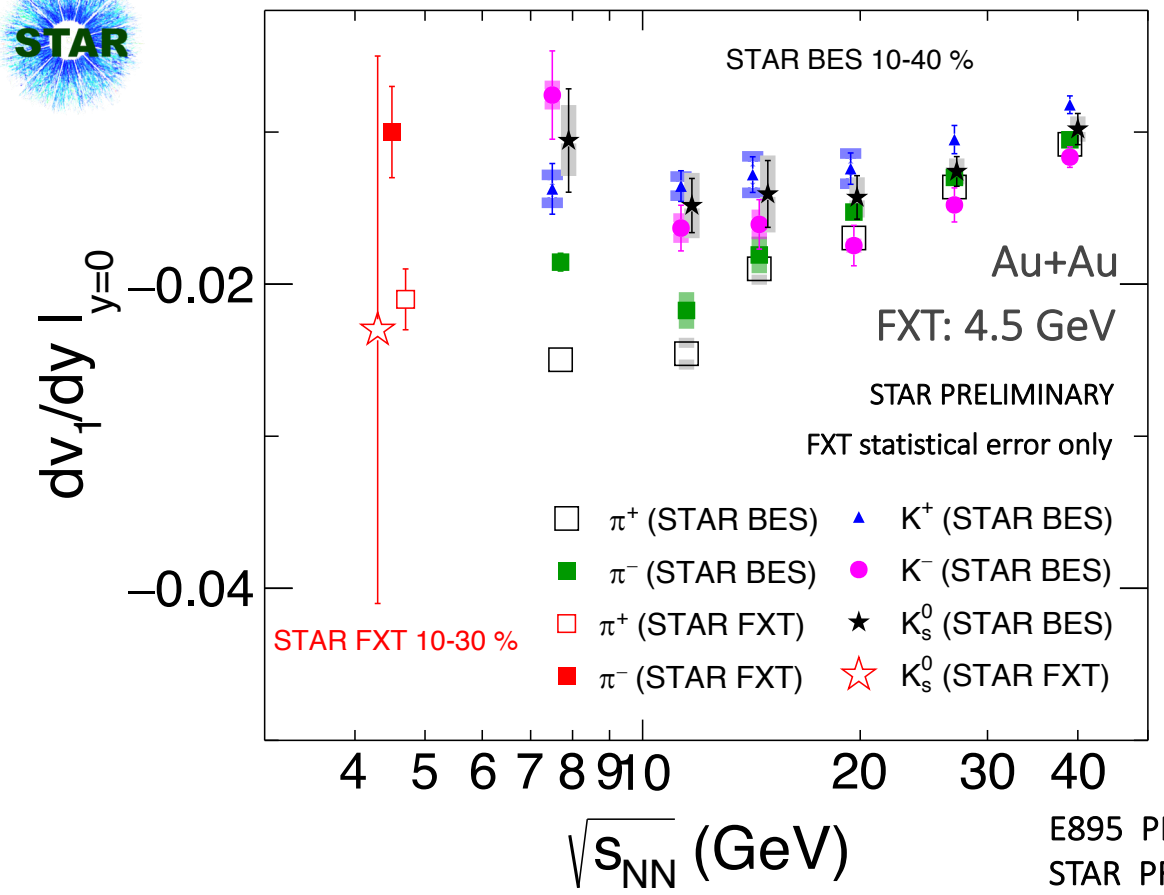


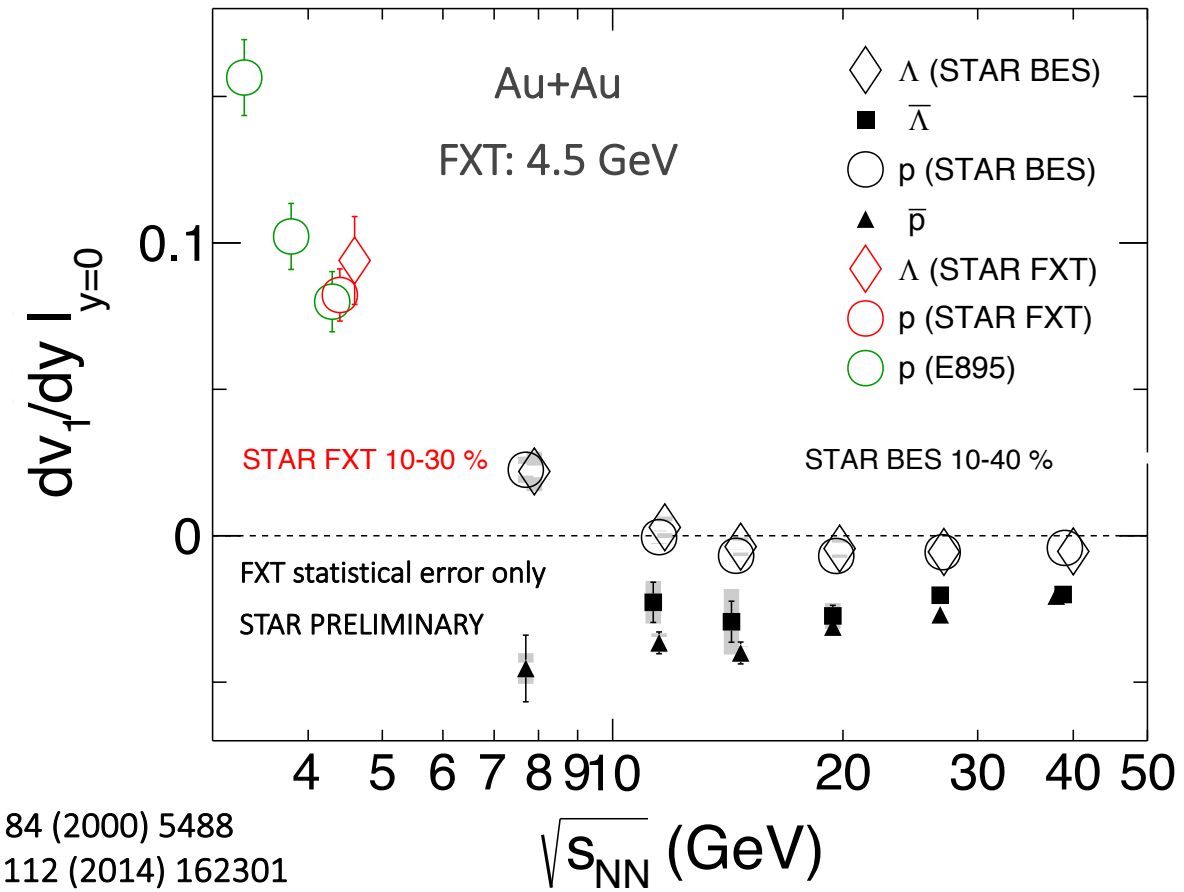
Mid-rapidity v_1 slope of K_S^0: close to zero

Mid-rapidity v_1 slope of Λ: positive

Cubic fit function used: $F_1\, y + F_3\, y^3$

Directed Flow Comparison Across Experiments & Energies





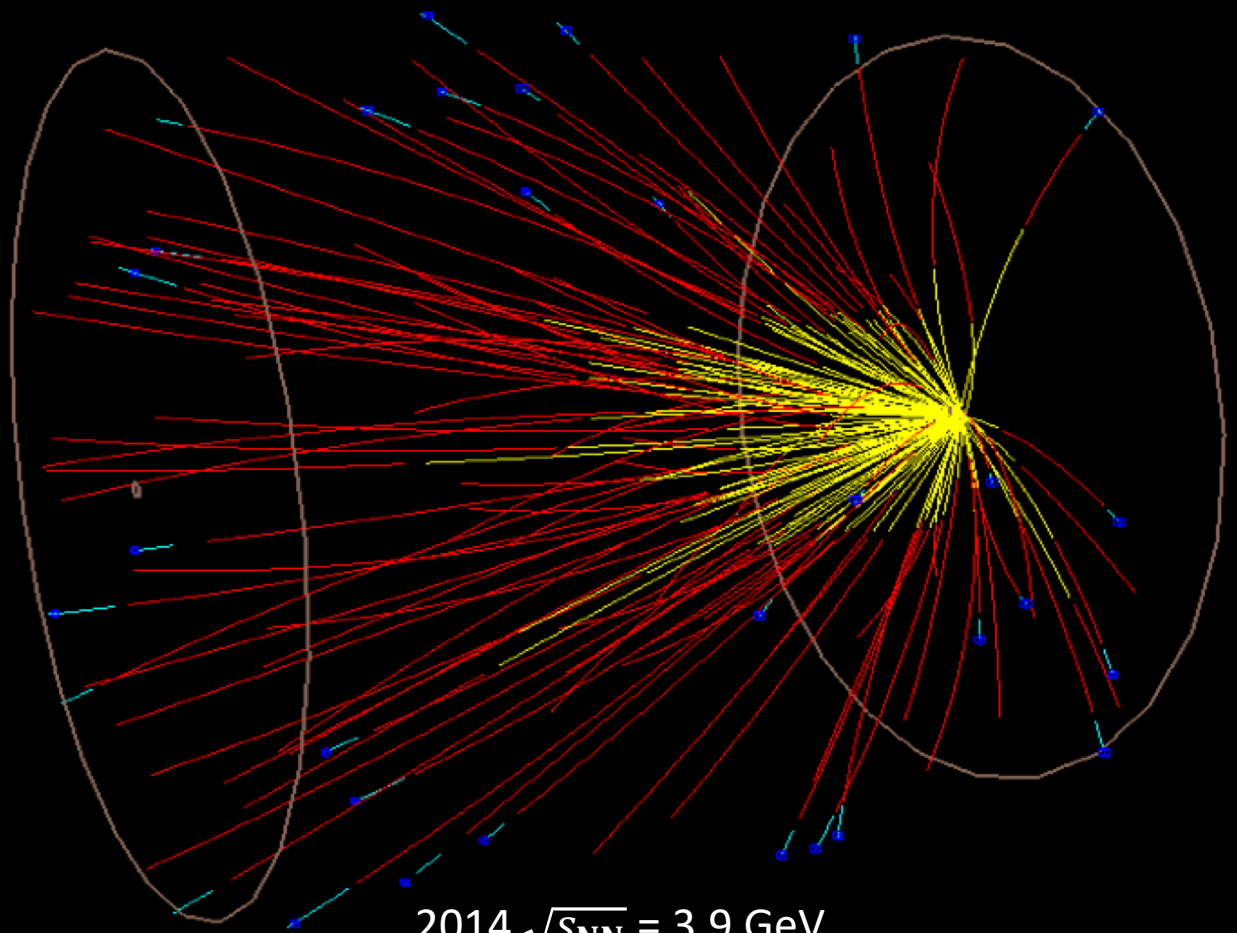
E895 PRL 84 (2000) 5488
STAR PRL 112 (2014) 162301

Proton v_1 agrees with E895; Λ is close to proton

First π results shown for this energy range

π^+, π^- ordering supports idea that transported quarks have bigger effect on π^- (See Gang Wang's talk, May 16, 11:50)

Outline



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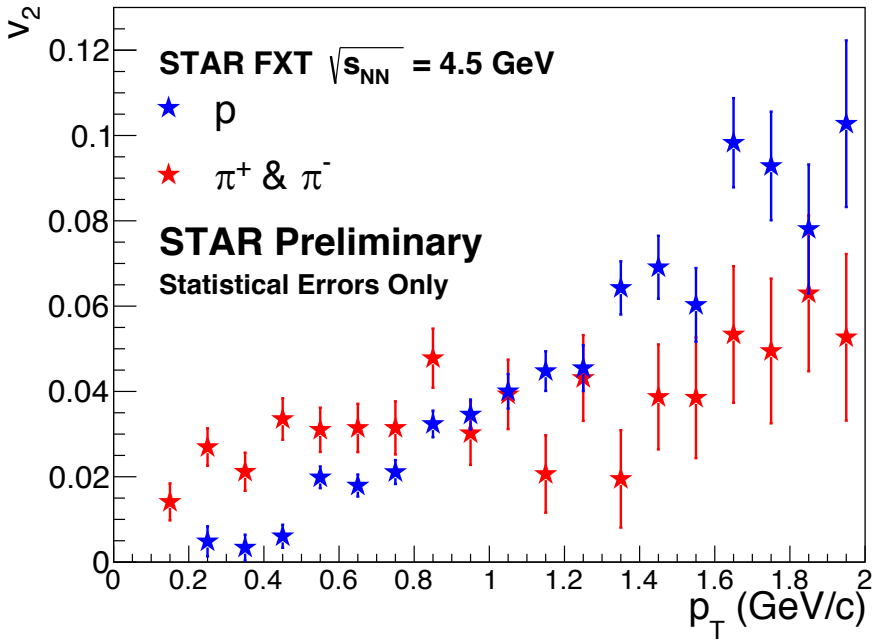
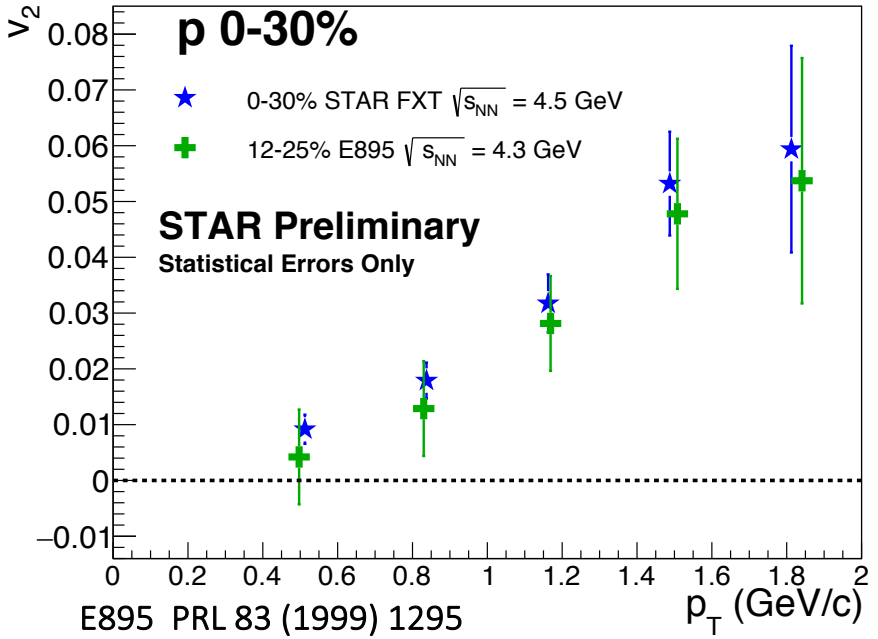
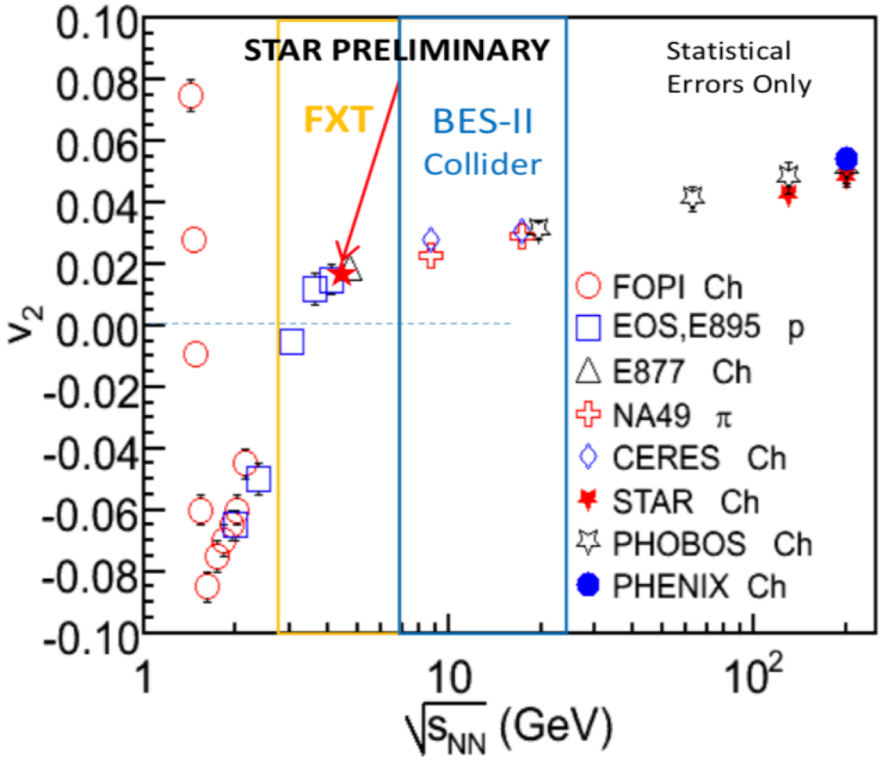
Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Elliptic Flow of Protons and Pions



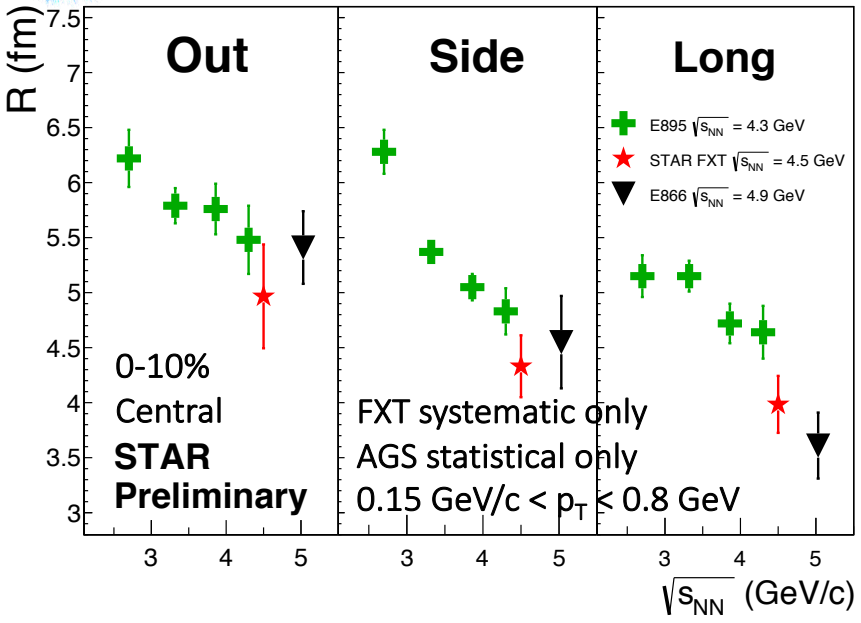


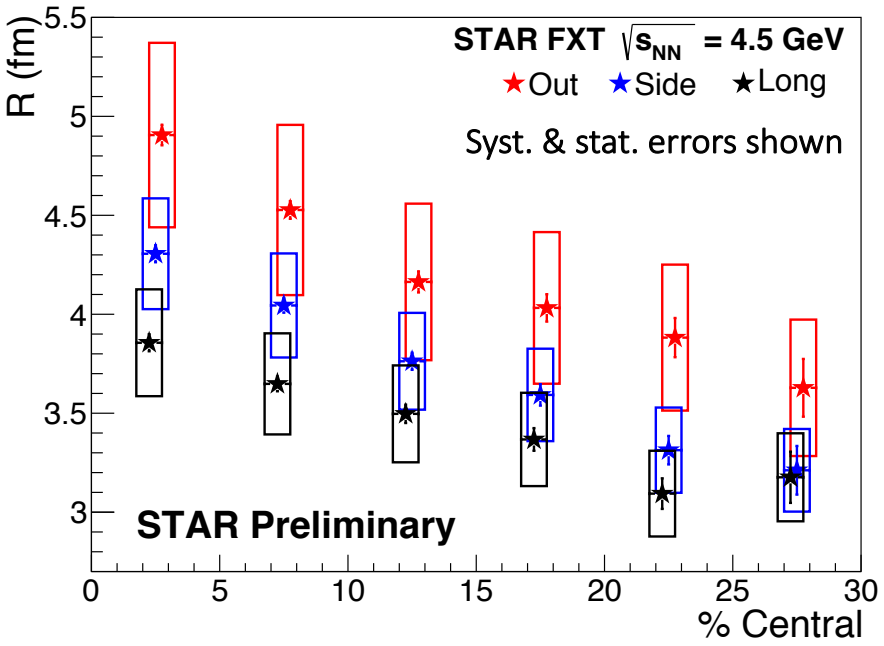


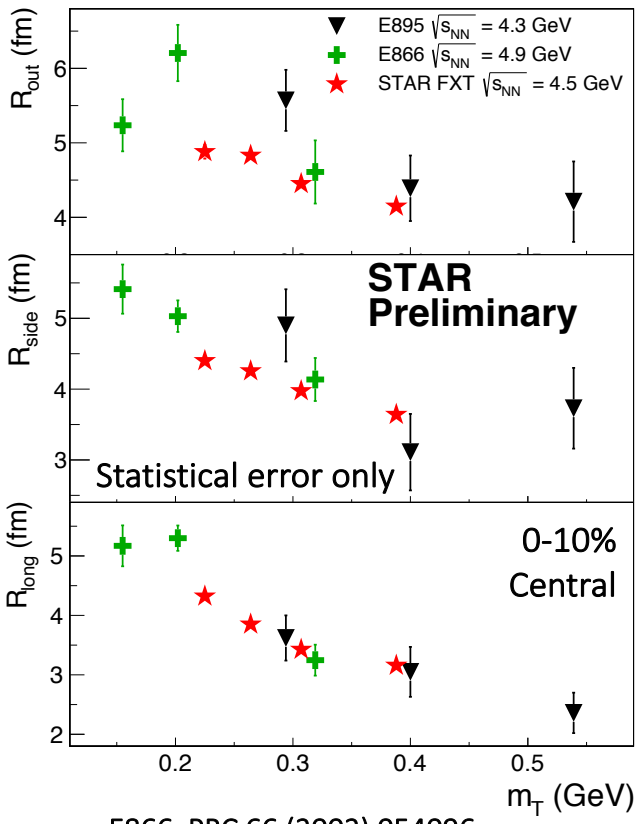
First measurement of pion elliptic flow for this energy range

Good agreement with world data in region where energy dependence changes

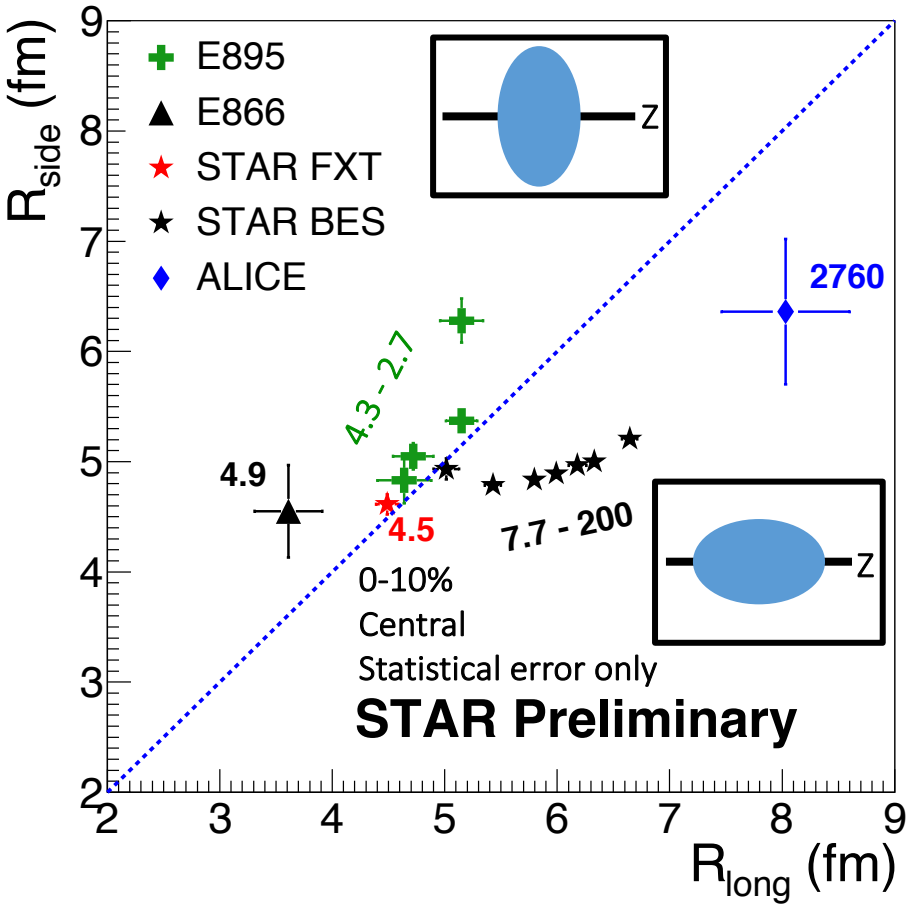
Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Pion HBT Results







E866 PRC 66 (2002) 054096
E895 PRL 84 (2000) 2798
ALICE PRB 696 (2011) 328
STAR PRC 92 (2015) 14904

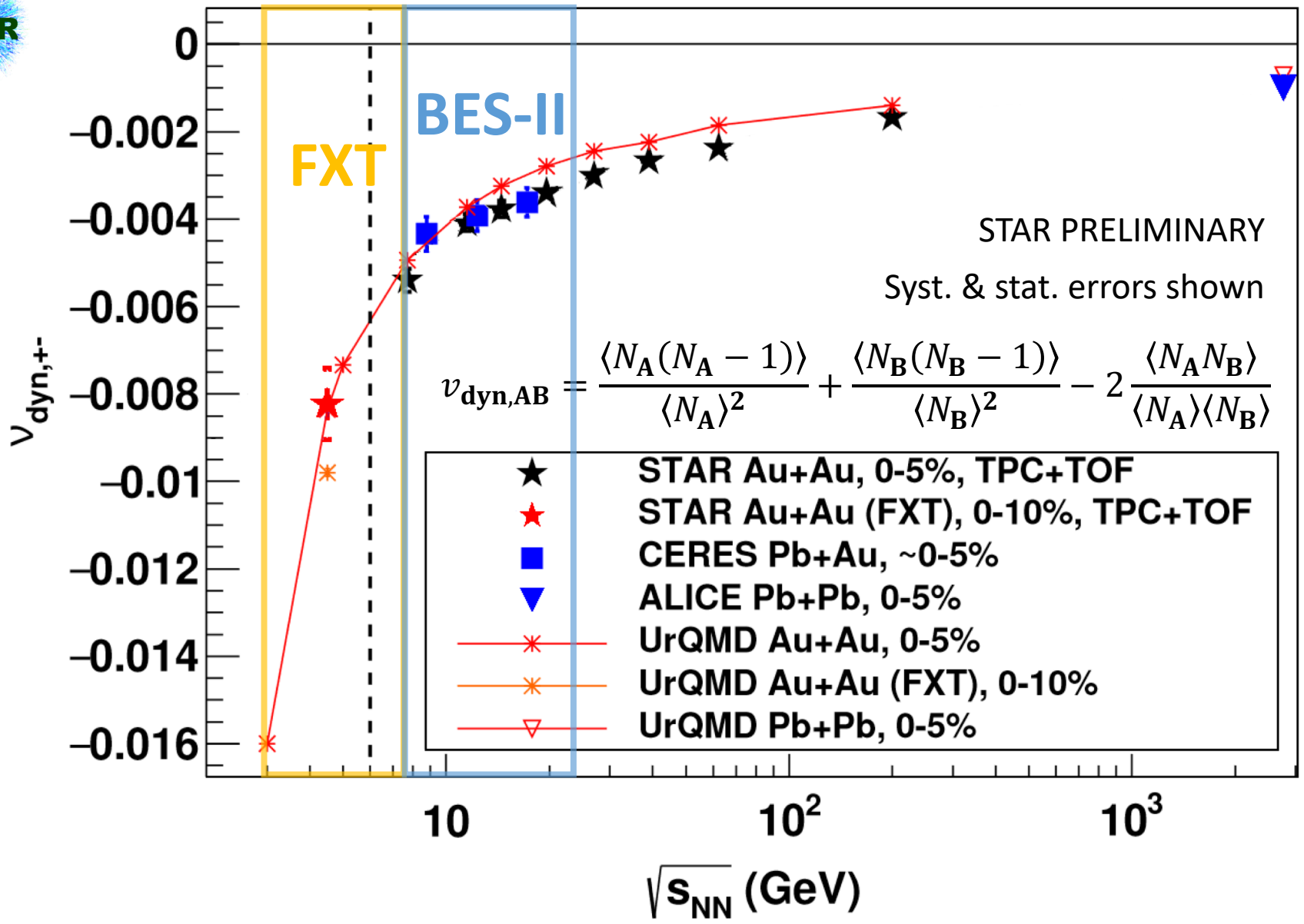


Consistent with results from AGS experiments, with smaller stat. errors

Apparent source shape evolves from oblate to prolate, as energy increases

Increased longitudinal expansion above FXT energy

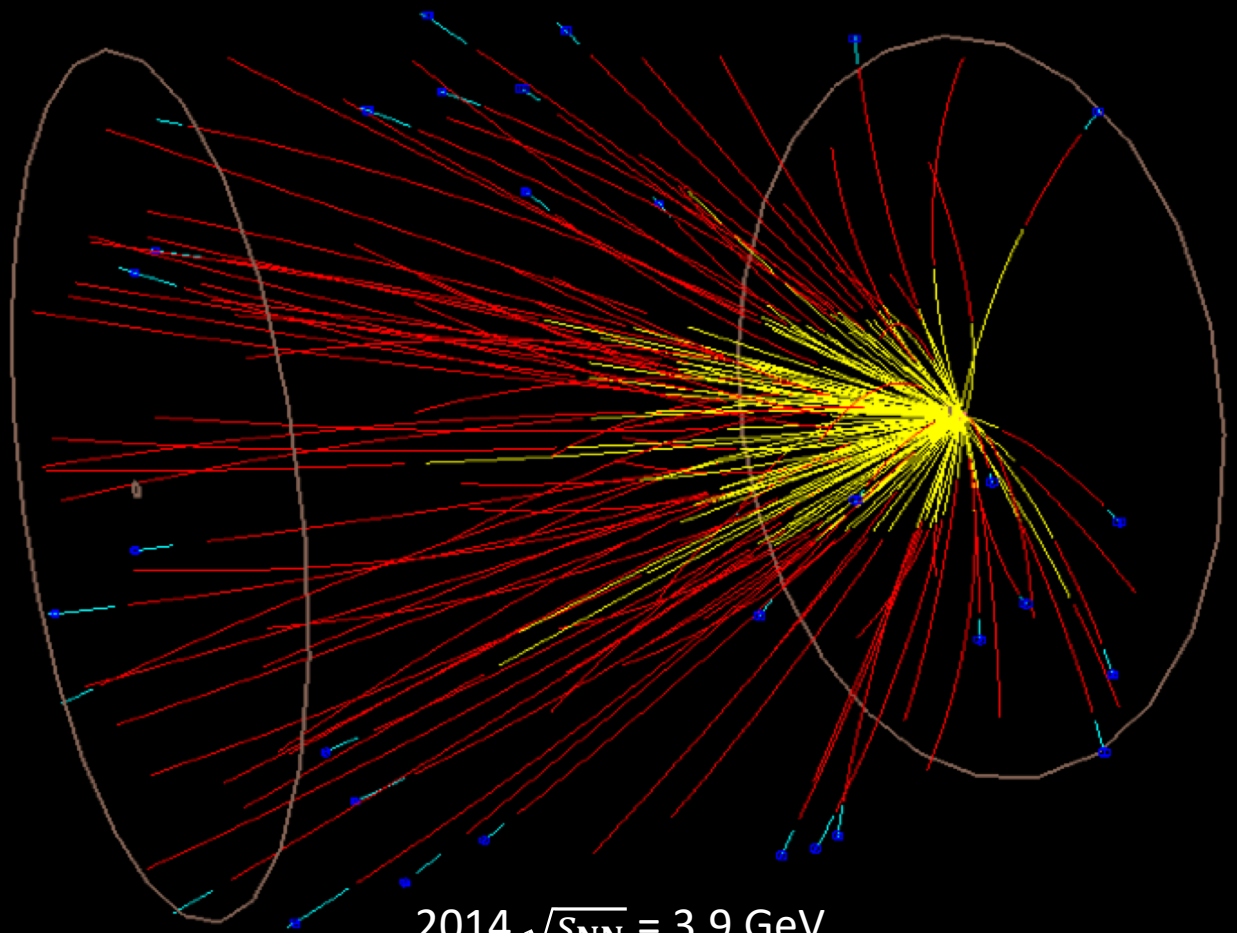
Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV Dynamical Relative Charge Number Fluctuations



STAR FXT measurement follows a monotonic trend for all energies

ALICE PRL 110 (2013) 152301
CERES JPG 30 (2004) s1371
STAR PRC 92 (2015) 21901

Outline



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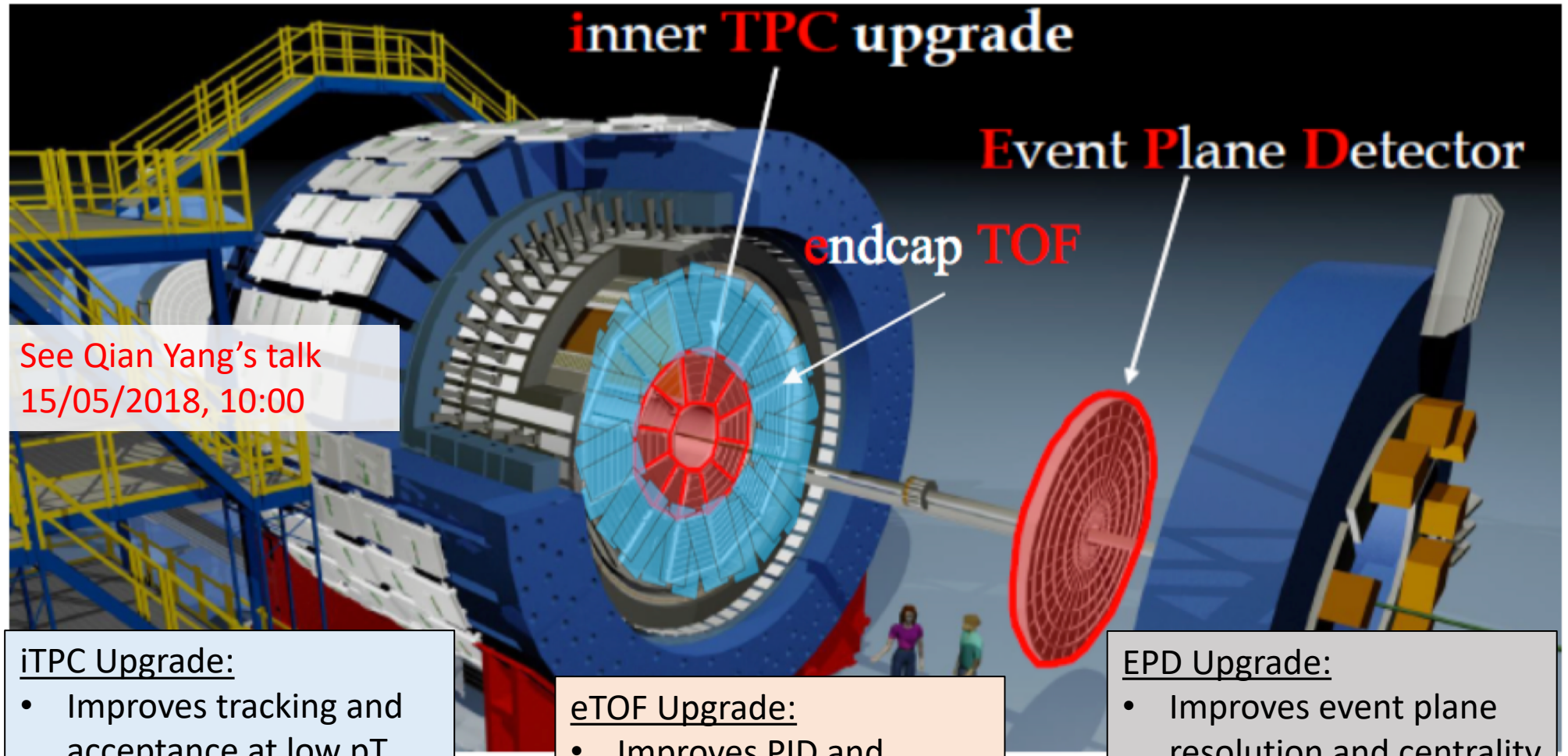
Summary

- ✓STAR continues to operate successfully in FXT mode.
- ✓Spectra & yields agree with results from AGS experiments for Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV & Al+Au $\sqrt{s_{NN}}$ = 4.9 GeV.
- ✓Proton directed flow measurement agrees with results from AGS experiments. The first measurement of pion directed flow in this energy range; trend of negative v_1 for mesons continues.
- ✓Proton elliptic flow measurement agrees with results from AGS experiments. FXT v_2 follows the trend across energies. The first measurement of pion v_2. Mass ordering seen as at higher energies.
- ✓HBT radii agree with results of AGS experiments.
- ✓First dynamical fluctuation measurement (ν_{dyn}) at this energy range, follows trend across energies, and agrees with UrQMD.
- ✓FXT energy scan approved & ongoing. Will extend the reach of BES-II down to $\sqrt{s_{NN}}$ = 3.0 GeV ($\mu_B \approx 720$ MeV) – high baryon density regime!

The STAR Upgrades and the FXT program



See Qian Yang's talk
15/05/2018, 10:00

iTPC Upgrade:
- Improves tracking and acceptance at low pT and extra y acceptance
- Ready in 2019

STAR Note 0644: Technical Design Report for the iTPC Upgrade

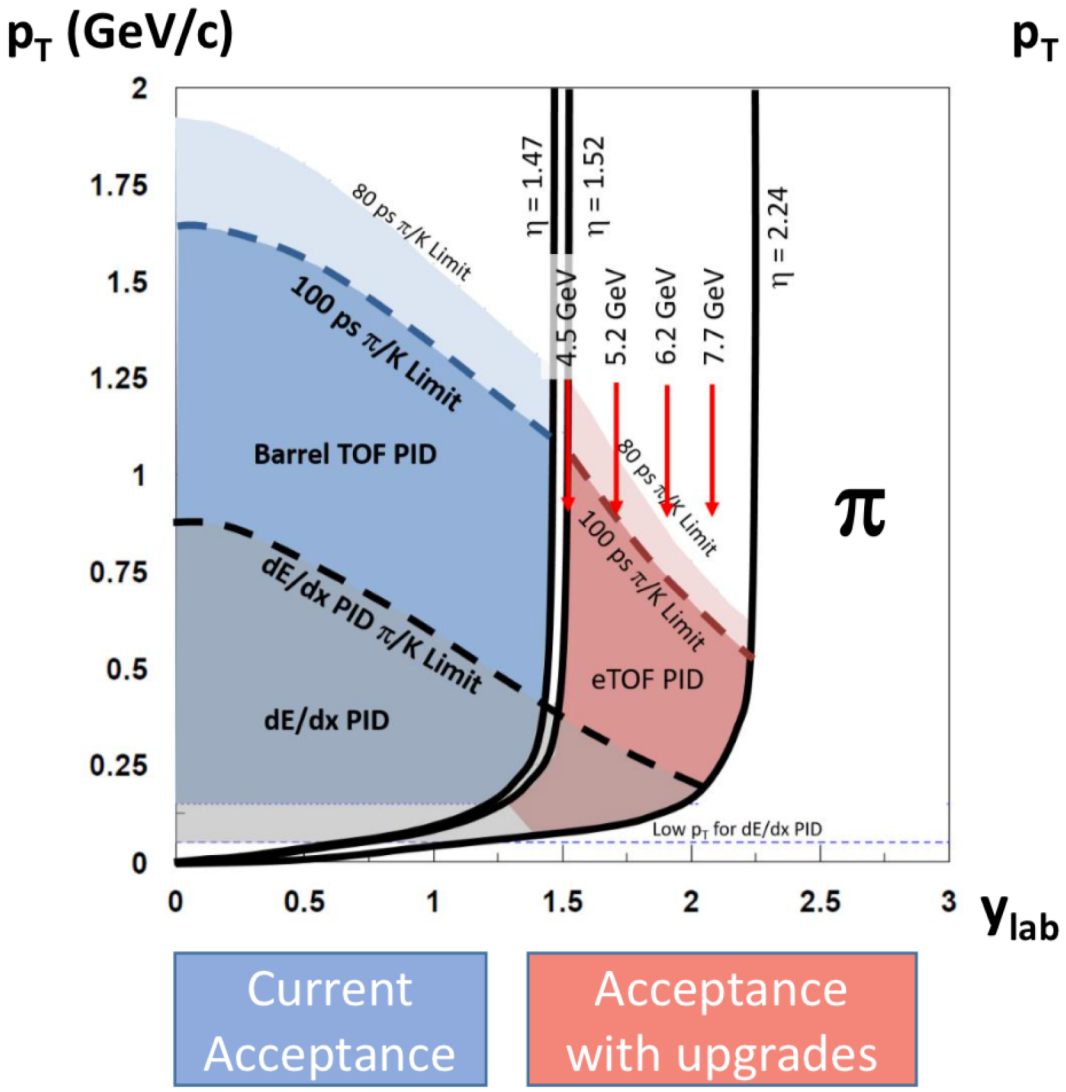
eTOF Upgrade:
- Improves PID and acceptance
- Ready in 2019

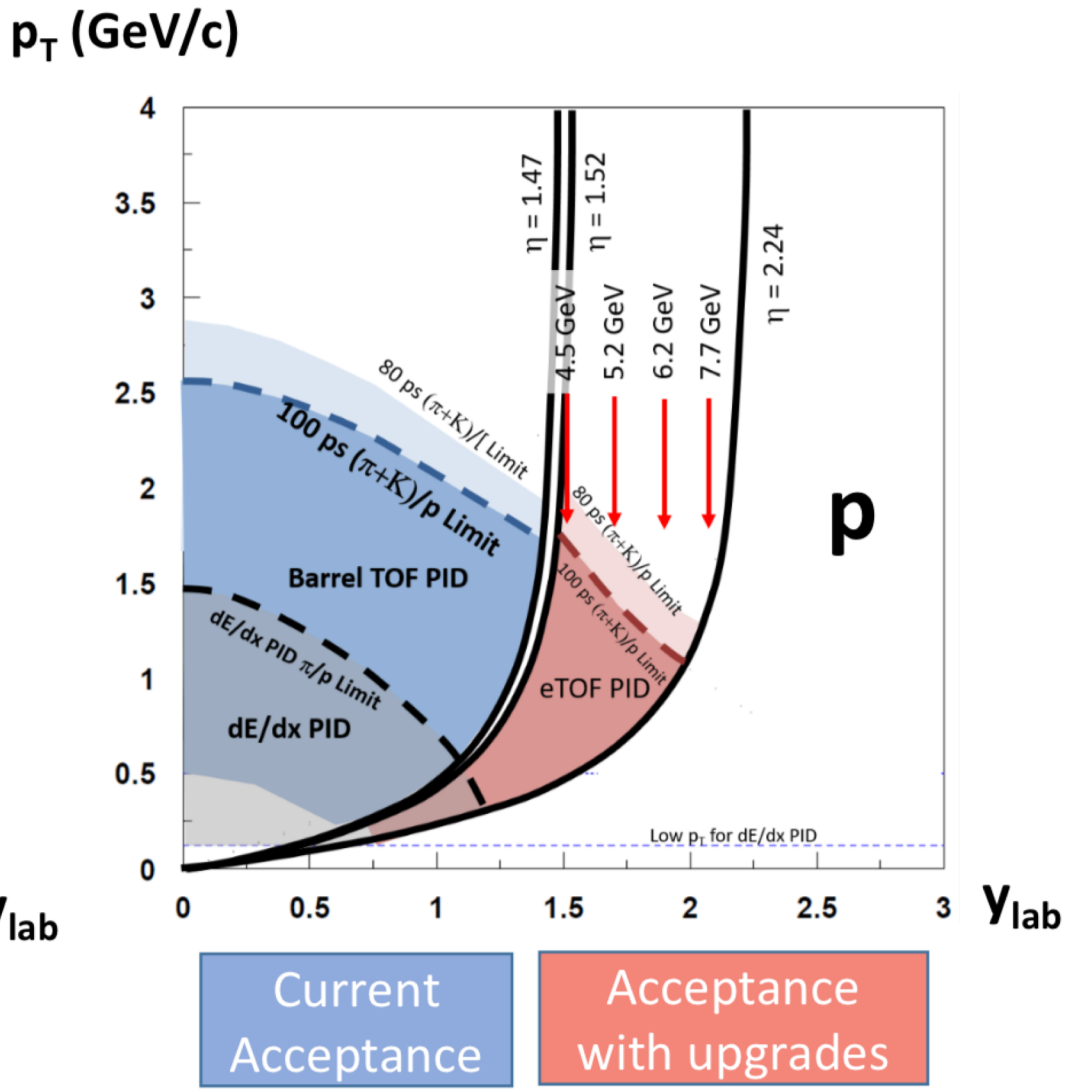
arXiv:1609.05102v1 [nucl-ex]

EPD Upgrade:
- Improves event plane resolution and centrality definition
- Taking data in 2018 run

STAR Note 0666: An Event Plane Detector for STAR

FXT Energy Reach With Upgrades





Detector upgrades improve STAR PID and acceptance performance, for FXT energies up to 7.7 GeV, overlap energy with the collider mode

BES-II FXT Program: Run 19+

STAR Note 0696: STAR Collaboration Beam Use Request for Run 19+ (Scenario 1)

Single Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	Run Year	Run Time	Species	Min-Bias Events Number
5.75	3.5 (FXT)	2020	2 days	Au+Au	100M
7.3	3.9 (FXT)	2019	2 days	Au+Au	100M
9.8	4.5 (FXT)	2019	2 days	Au+Au	100M
13.5	5.2 (FXT)	2020	2 days	Au+Au	100M
19.5	6.2 (FXT)	2020	2 days	Au+Au	100M
31.2	7.7 (FXT)	2019	2 days	Au+Au	100M

- iTPC & eTOF upgrades will be available
- Need 100M events at each energy to match sensitivity of BES-II:
  2 days per energy (3.5 GeV – 7.7 GeV)
- Data rate is DAQ limited
- Data at 7.7 GeV will provide an overlap energy with collider mode

FXT in Run 18

Trigger commissioning occurring now

1 Billion events at 7.2 GeV

100 Million events at 3.0 GeV

EPD ready and available for flow analyses

Can obtain fluctuation measurement at energies below BES-I

Yang Wu, Quark Matter 2018, Venice