STAR Fixed-Target Results from $\sqrt{s_{NN}} = 4.5$ GeV Au + Au Collisions

Kathryn Meehan for the STAR Collaboration

August 11, 2017

CPOD Workshop

NSF
U.S. DEPARTMENT OF ENERGY | Office of Science
UC DAVIS
BERKELEY LAB
Lawrence Berkeley National Laboratory
STAR

Outline

I. Physics Motivation
II. Introduction to STAR FXT and Run 15 Dataset
III. Results from $\sqrt{s_{\mathrm{NN}}}$ = 4.5 GeV Au + Au FXT Collisions
IV. Future Plans: FXT in Run 18 & BES-II
V. Conclusions

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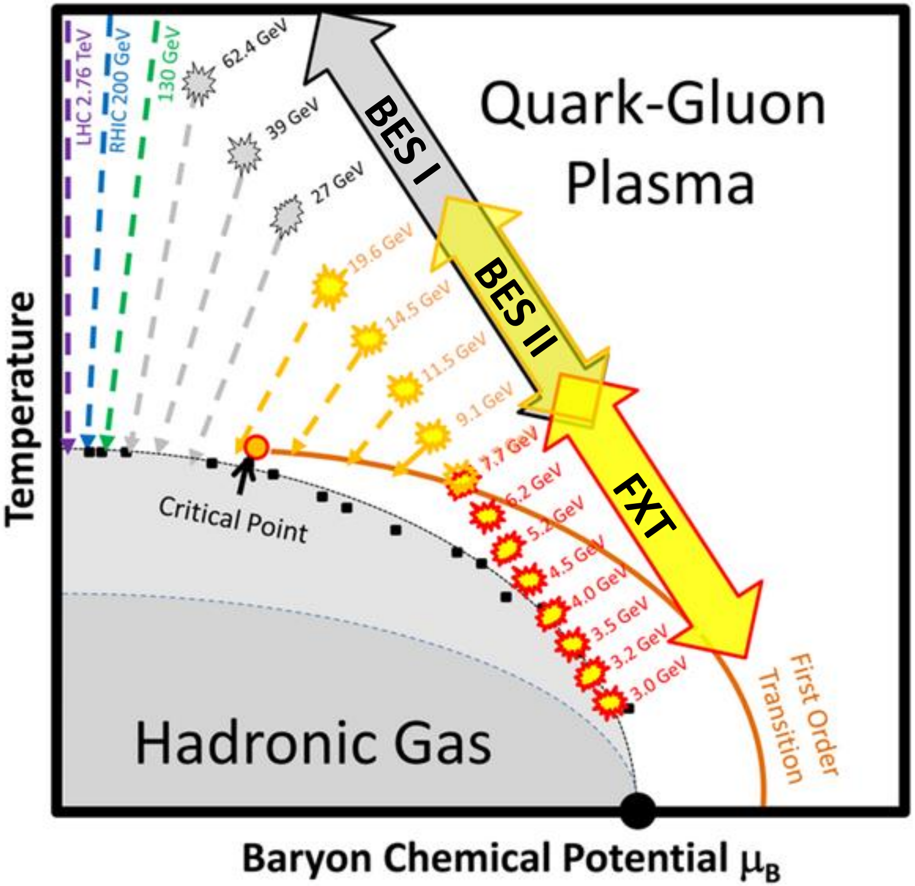
Motivation: Extending RHIC BES to $\mu_B \approx \mathbf{720\ MeV}$



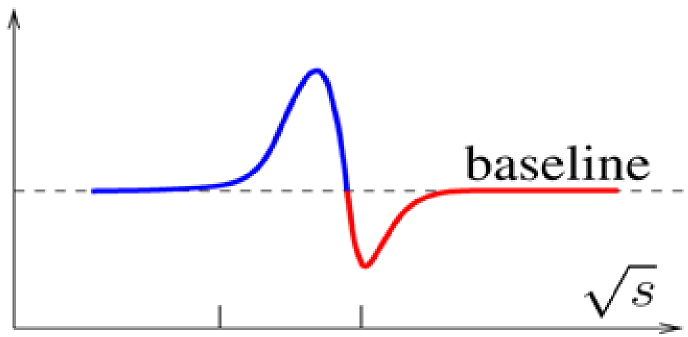
The goals of BES-I:

1) Observe the disappearance of QGP signatures
2) **Find evidence of the possible first-order phase transition**
3) **Find the possible Critical Point**

- Originally BES-I program planned to go down to 5.0 GeV
- Collider luminosity too low at 5 GeV
- FXT collisions allow us to access lower energies (higher μ_B)

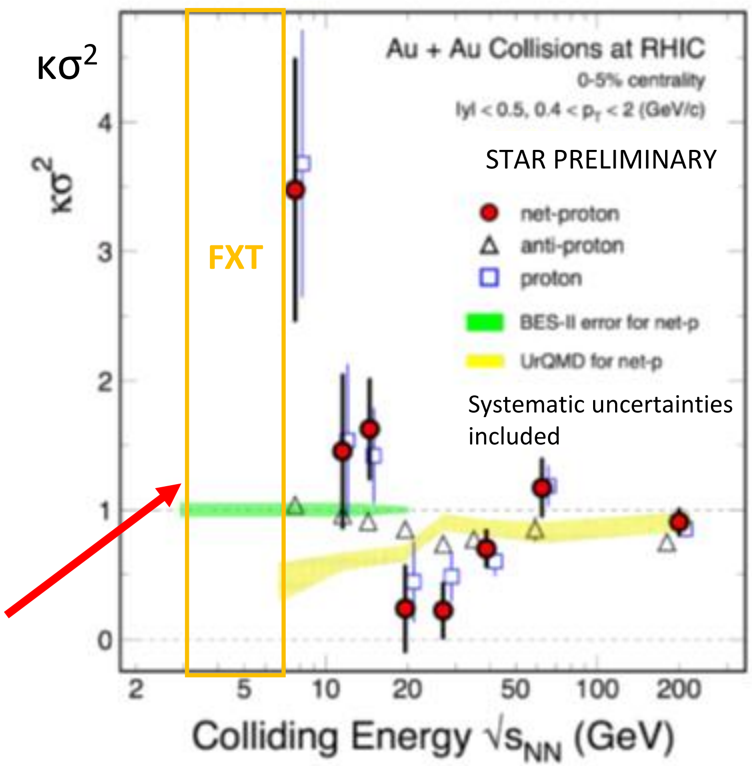
Control Measurements for CEP Signatures

Peak behavior predicted in critical region:



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

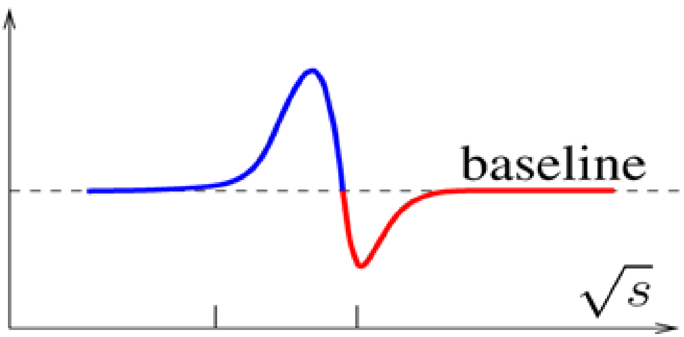
Need data here!



→ FXT measurements needed to determine shape of $\kappa\sigma^2$ observable at lower energies

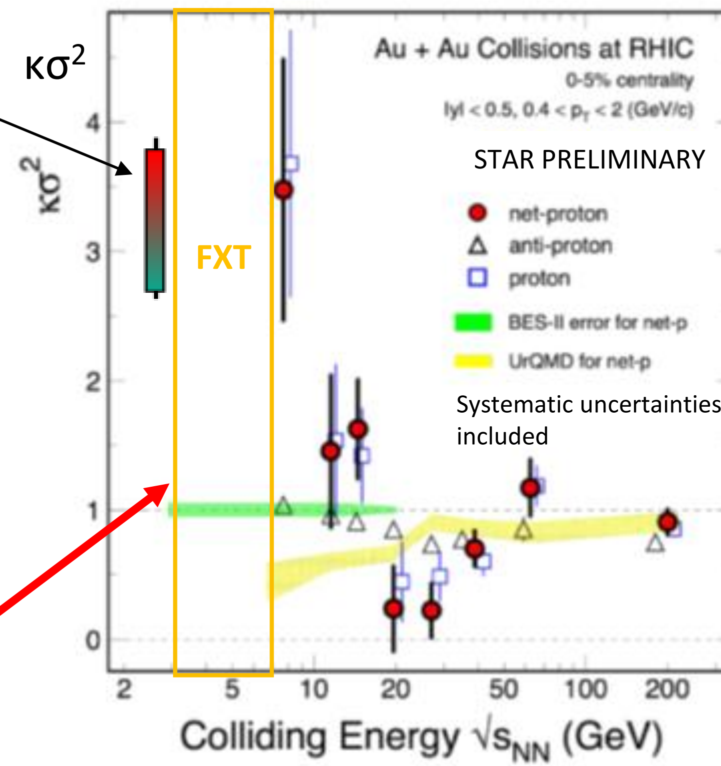
Control Measurements for CEP Signatures

Peak behavior predicted in critical region:



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

Preliminary HADES result, Quark Matter 2017
0-10%
(QM 2017)



Need data here!

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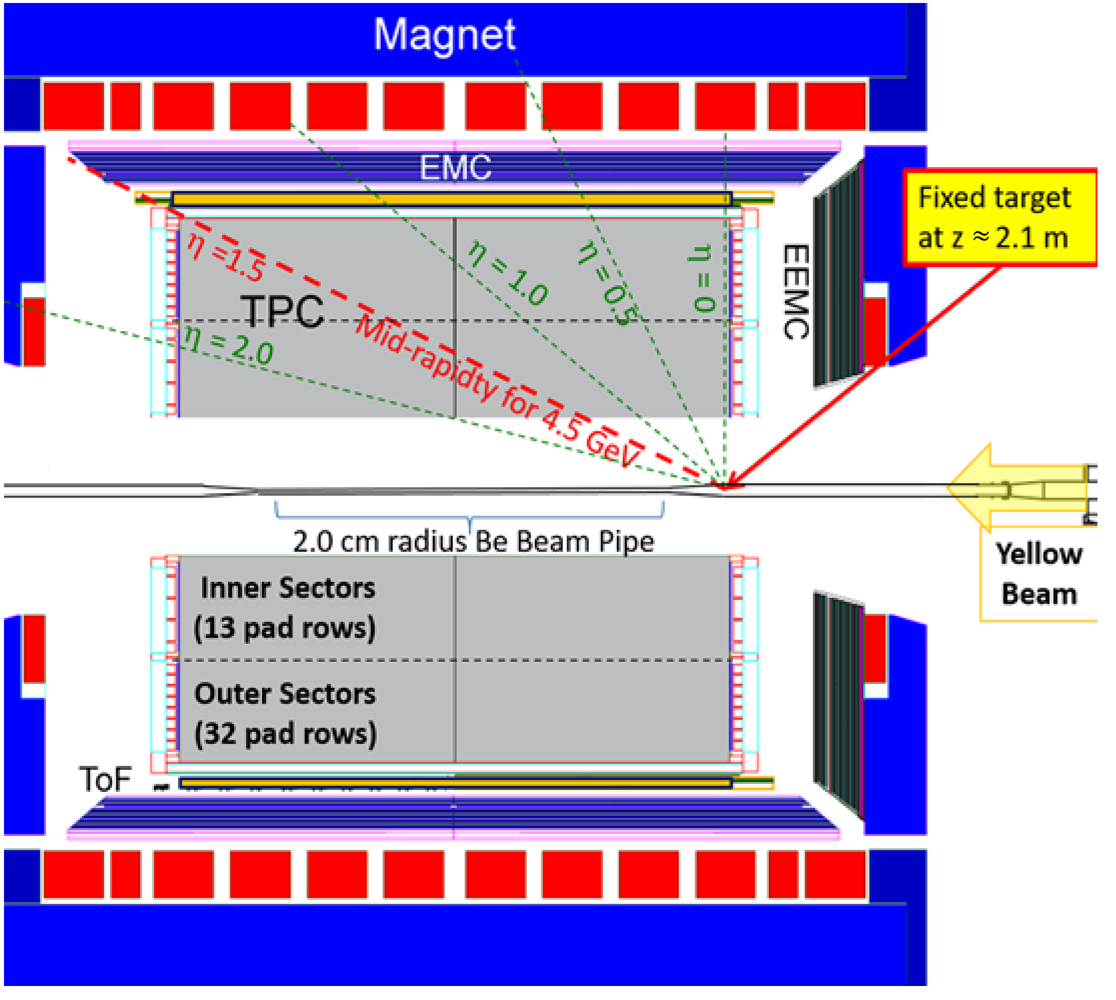
STAR FXT Program

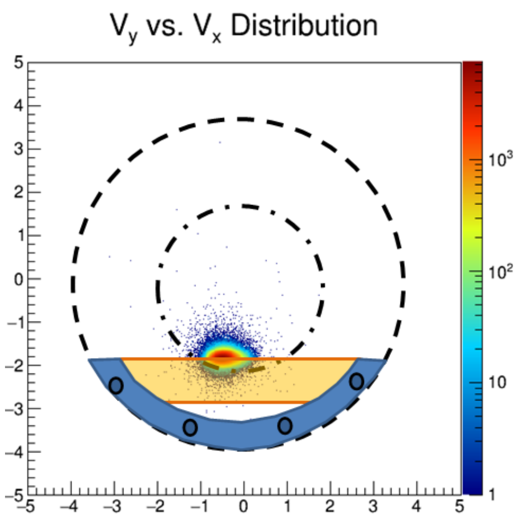
- 1 mm thick (4% interaction probability) gold foil target
- Positioned inside beam pipe at the edge of the TPC, ~211 cm from the interaction region

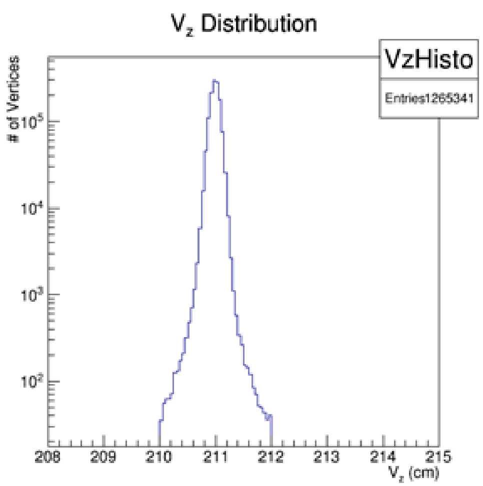
2015: FXT Test Run
2018-2019: FXT Energy Scan

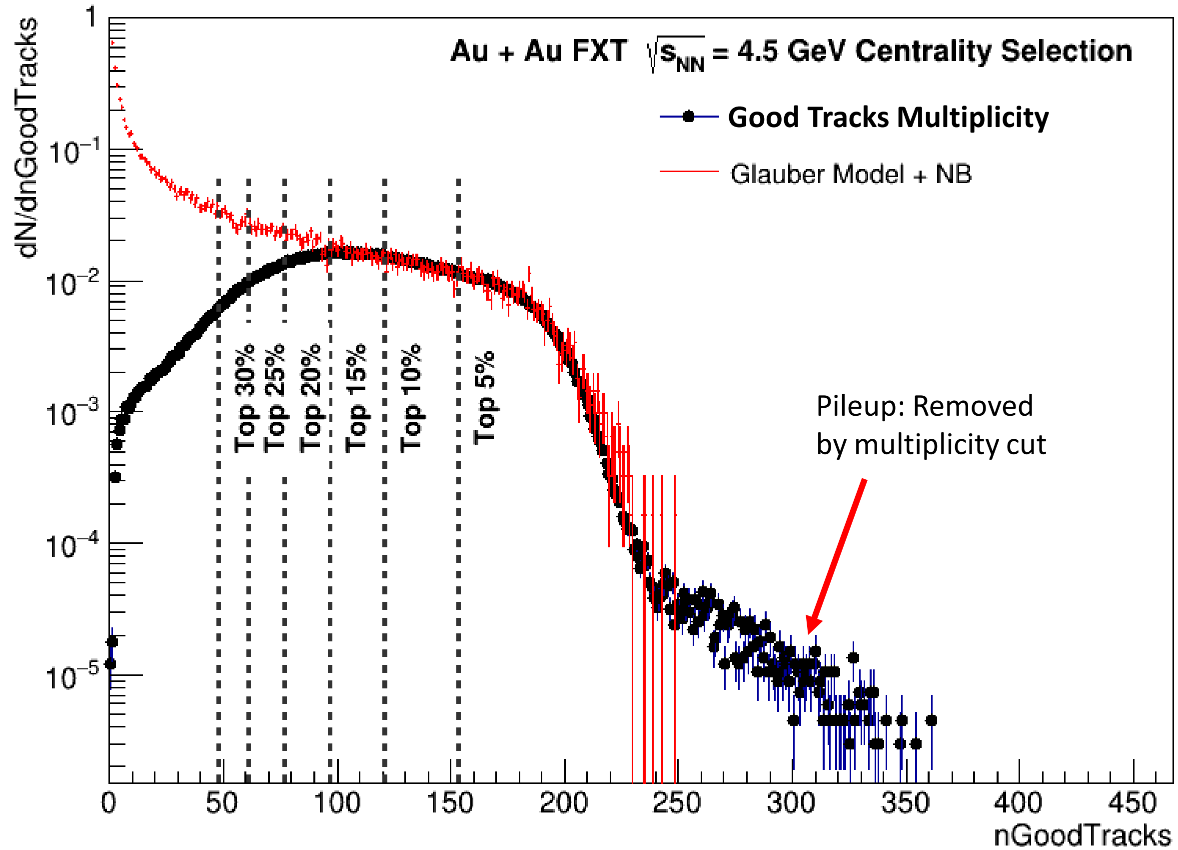


Run 15: $\sqrt{s_{NN}}$ = 4.5 GeV Au + Au FXT Collisions

- 1.3 million events collected with a top ~30% centrality
- Filled trigger bandwidth, DAQ limited







nGoodTracks -> any track that passes basic QA cuts

Pileup Study

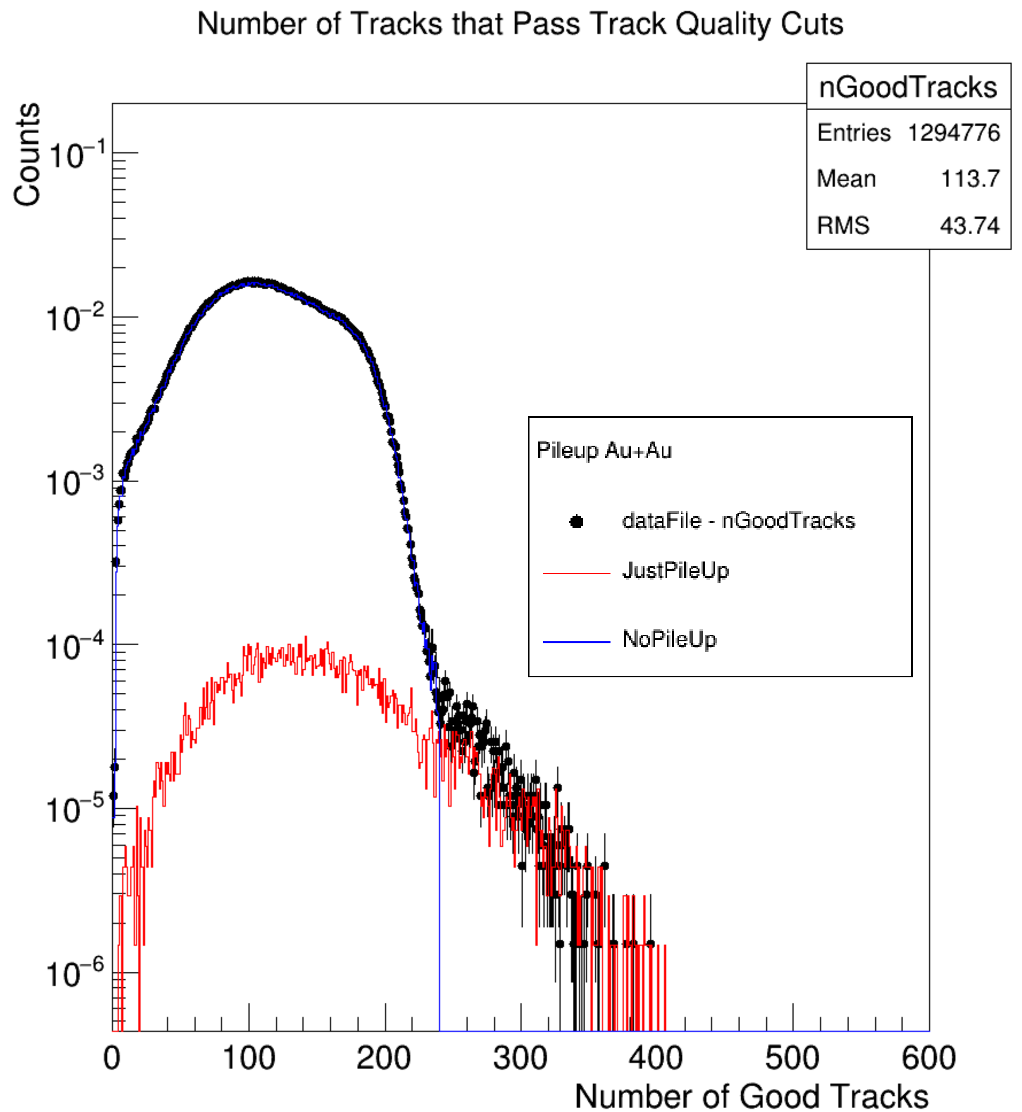
Pileup Simulation Method:

1) Draw events from data histogram
2) For every 0.7% of events, draw a "pileup" event from a minbias Glauber model
3) 0.7% obtained by minimizing chi-2 of a parameter search

Pileup Simulation Conclusions:

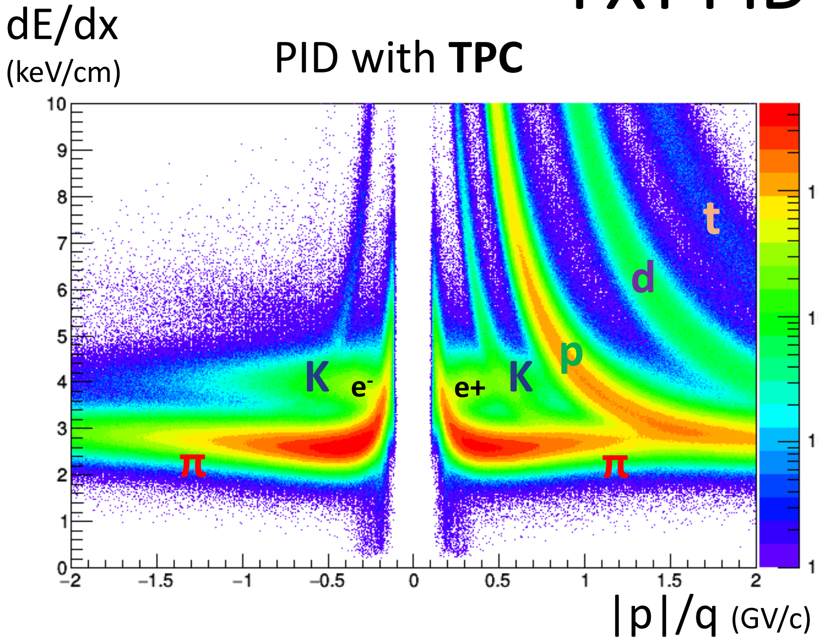
Cut on events with:
 # of accepted tracks > 240

Results in ~1% pileup in top 5% central bin

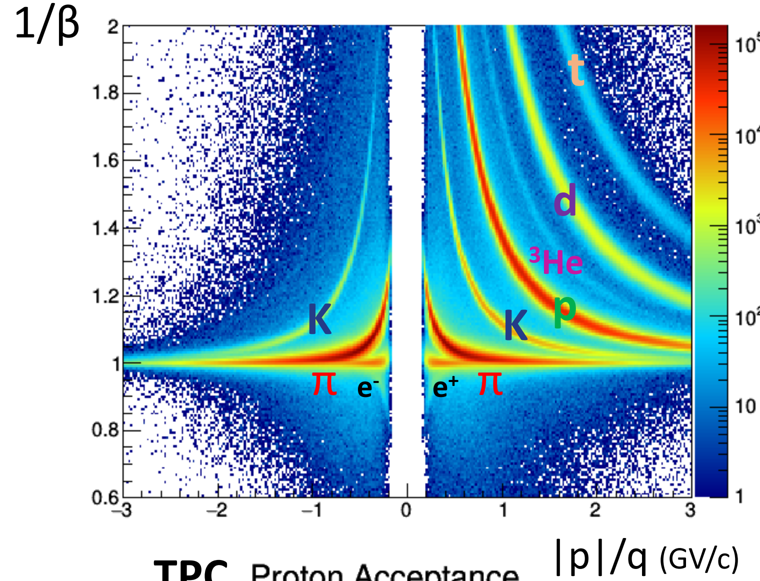


FXT PID & Acceptance

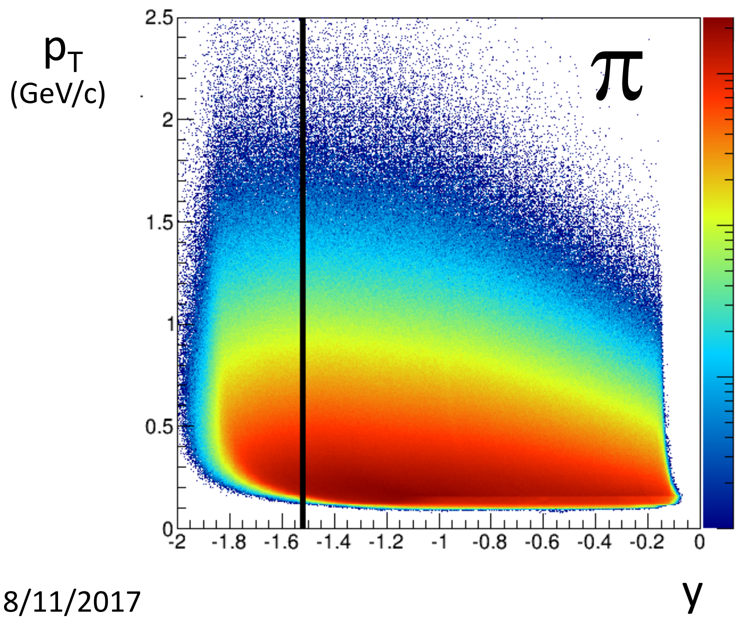
PID with **TPC**



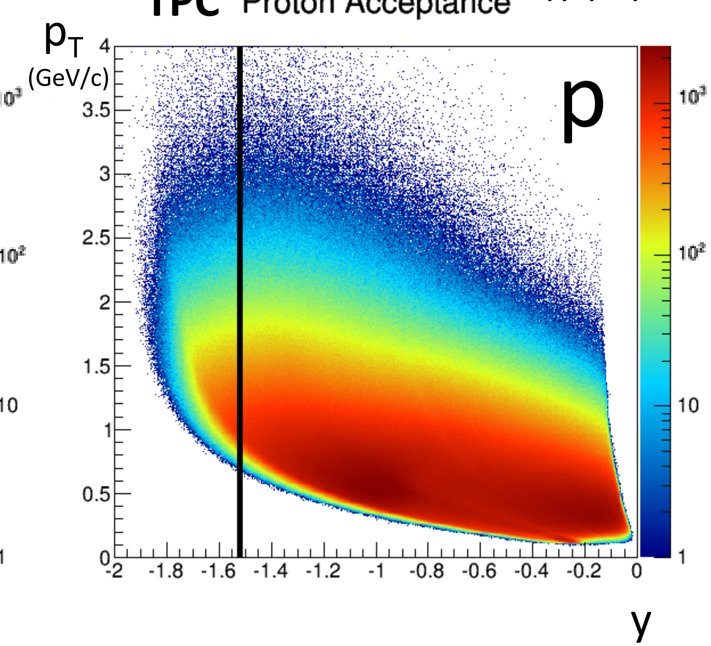
PID with **Time-of-Flight** Detector



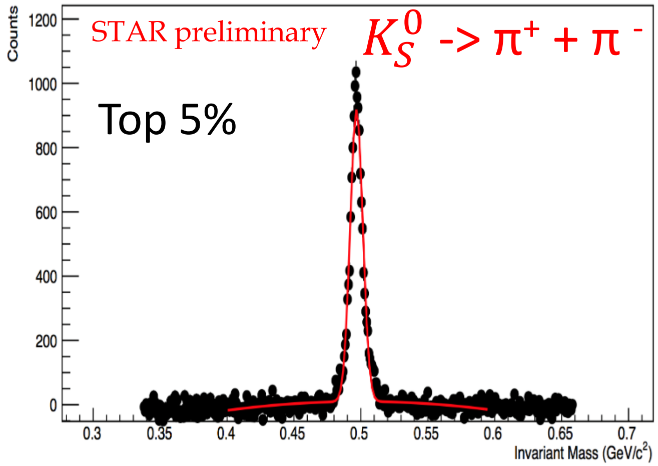
TPC π- Acceptance

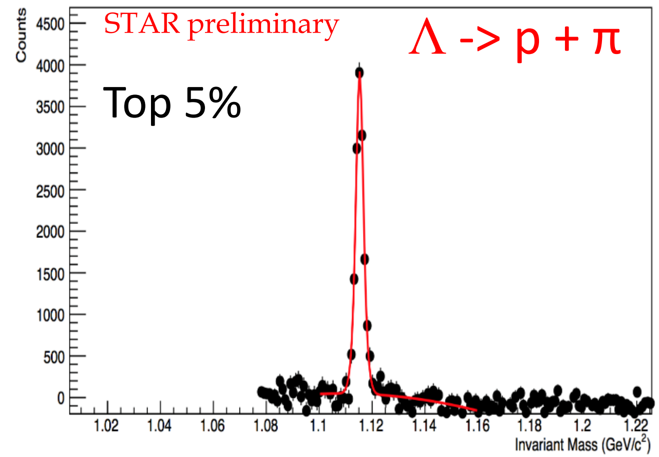


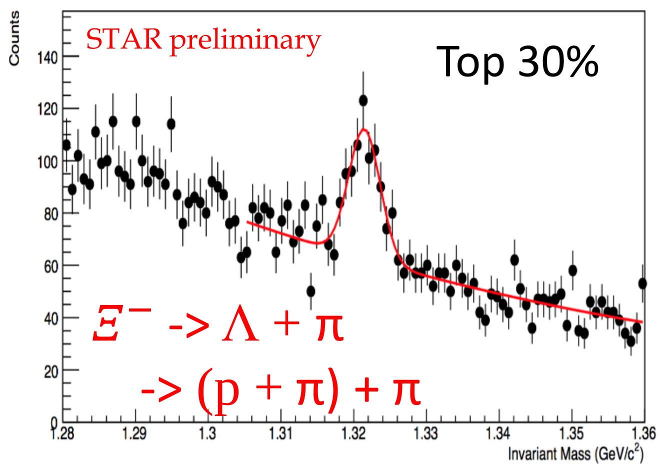
TPC Proton Acceptance

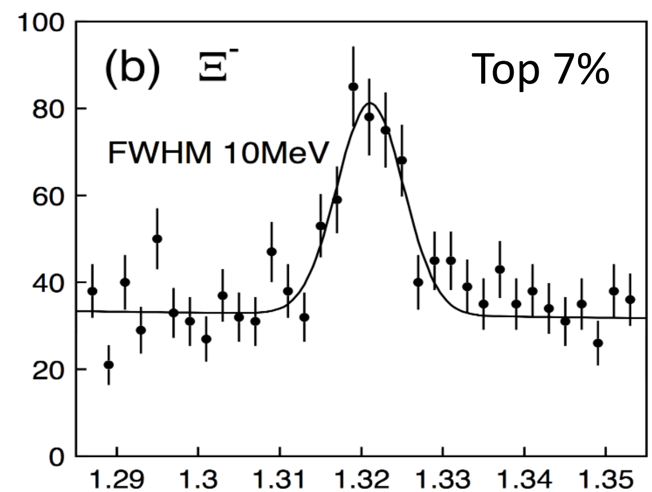


FXT Particle Reconstruction









E895: Phys. Rev. Lett. 91 (2003) 202301

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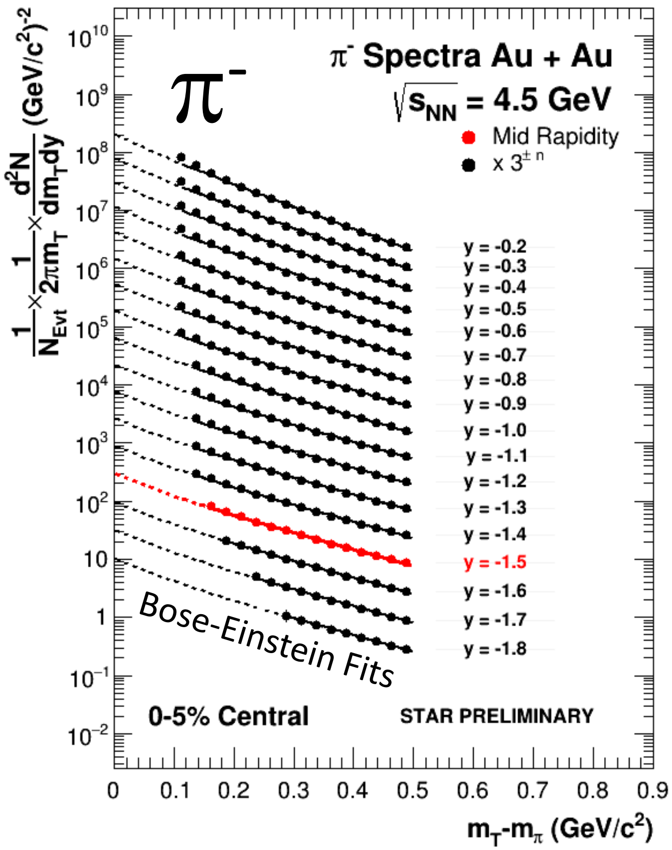
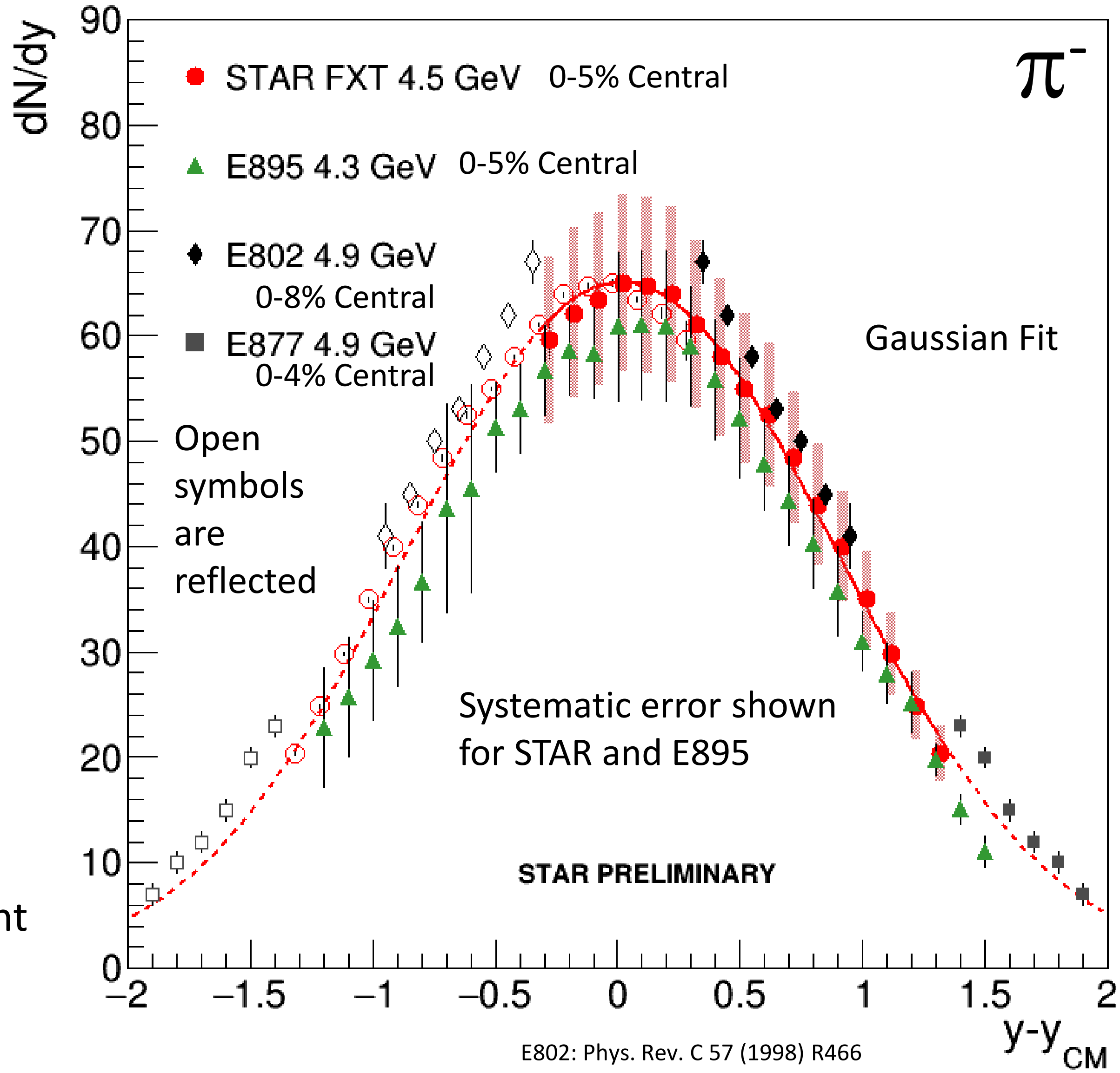
TPC Pion Spectra and dN/dy



π⁻ Rapidity Density



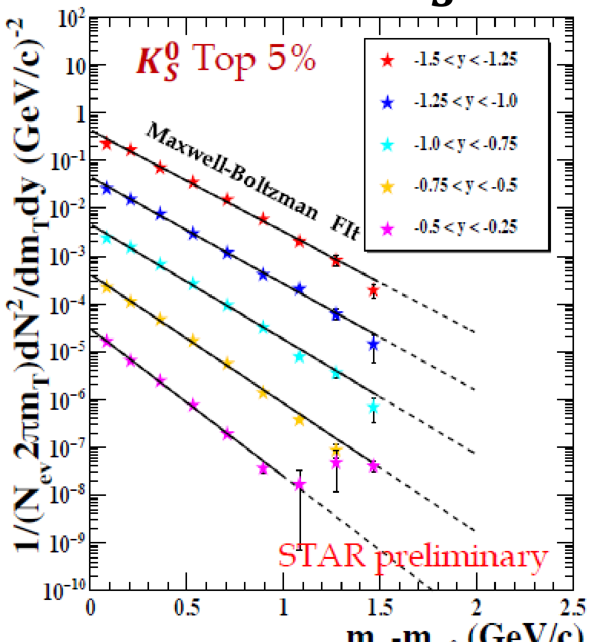
E802: Phys. Rev. C 57 (1998) R466

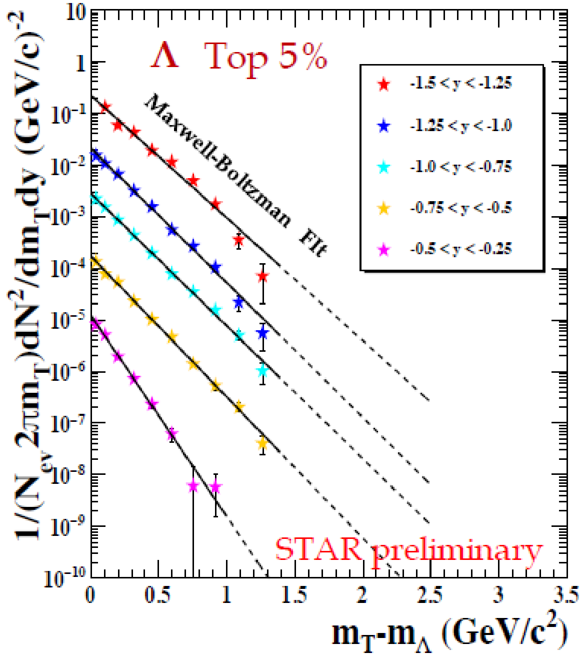
E877: Phys. Rev. C 62 (2000) 024901

E895: Phys. Rev. C 68 (2003) 054905

- Amplitudes and widths of the rapidity densities are consistent with results from the AGS experiments

K_S^0 and Lambda Spectra and dN/dy



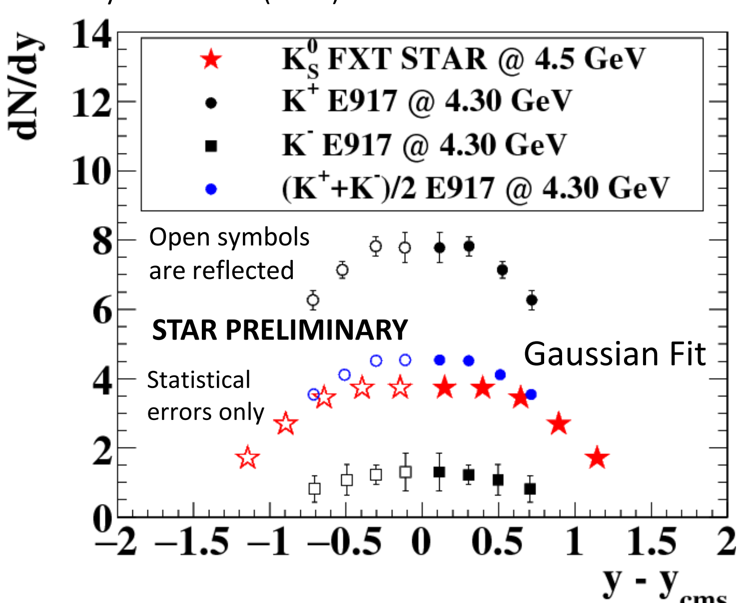


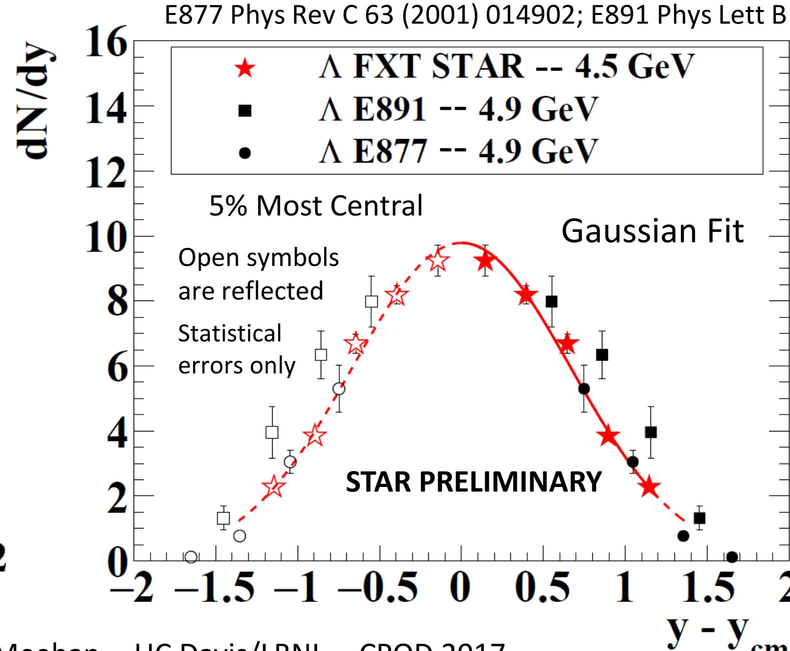
Centralities:
STAR FXT- 5% central
E917 – 5% central
E891 – 5% central
E877 – 4% central

See Usman Ashraf's Thursday parallel talk on strange hadron production in FXT

E917 Phys Lett B 476 (2000) 1

E877 Phys Rev C 63 (2001) 014902; E891 Phys Lett B 382 (1996) p. 35

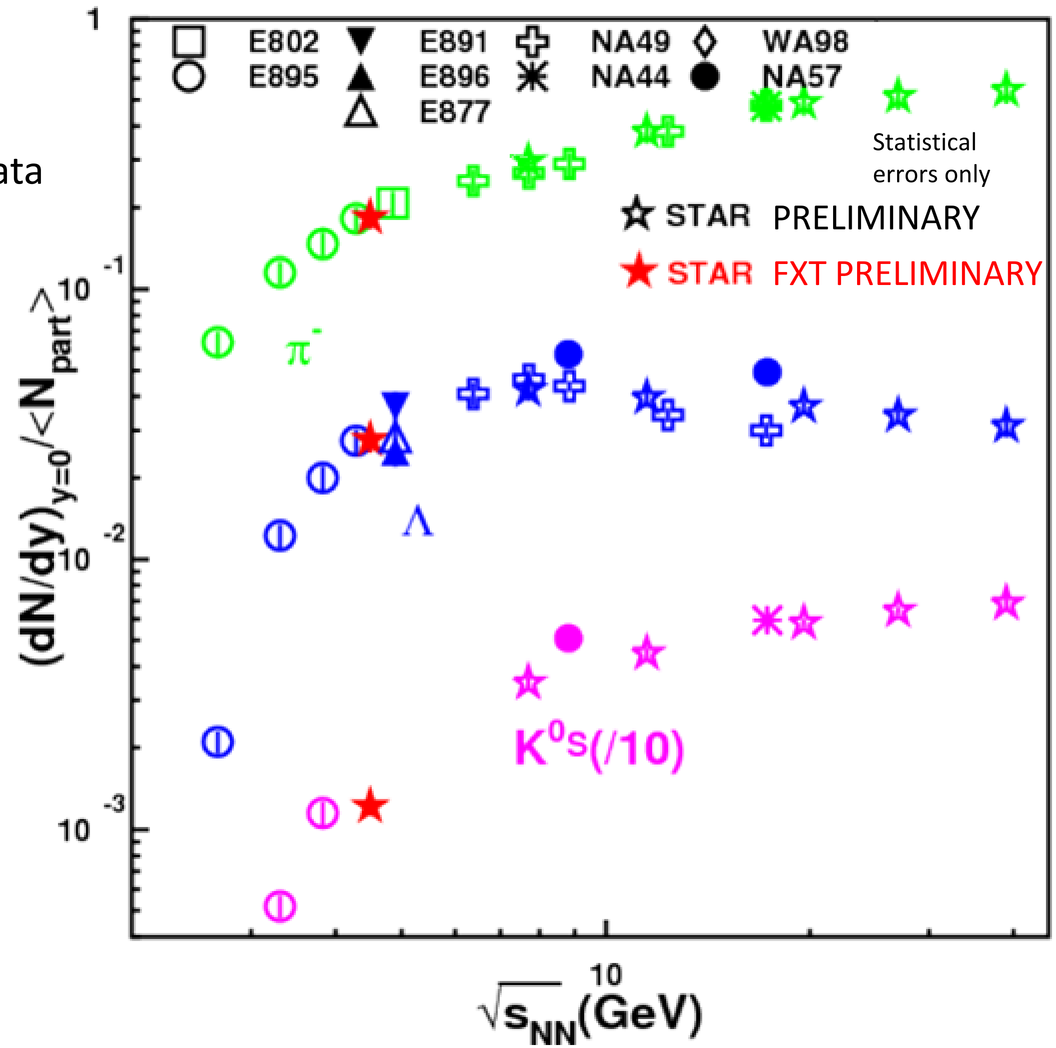




Amplitudes and widths comparable with results from the AGS experiments

Central dN/dy Yields For Pions, Lambdas and $\mathbf{K_s^0}$ Mesons

All error bars are similar in size to or smaller than the data symbol.



E895: Phys. Rev. C 68 (2003) 054905

E895: NPA 698 (2002) 495c

E802: NPA 610 (1996) 139c

E877: Phys. Rev. C 63 (2001) 014902

E891: PLB 382 (1996) 35

E896: Phys. Rev. Lett. 88, 062301

NA44: Phys. Rev. C 66 (2002) 044907

NA49: JPG 30 (2004) S701

NA49: Phys. Rev. Lett. 93 (2004) 022302

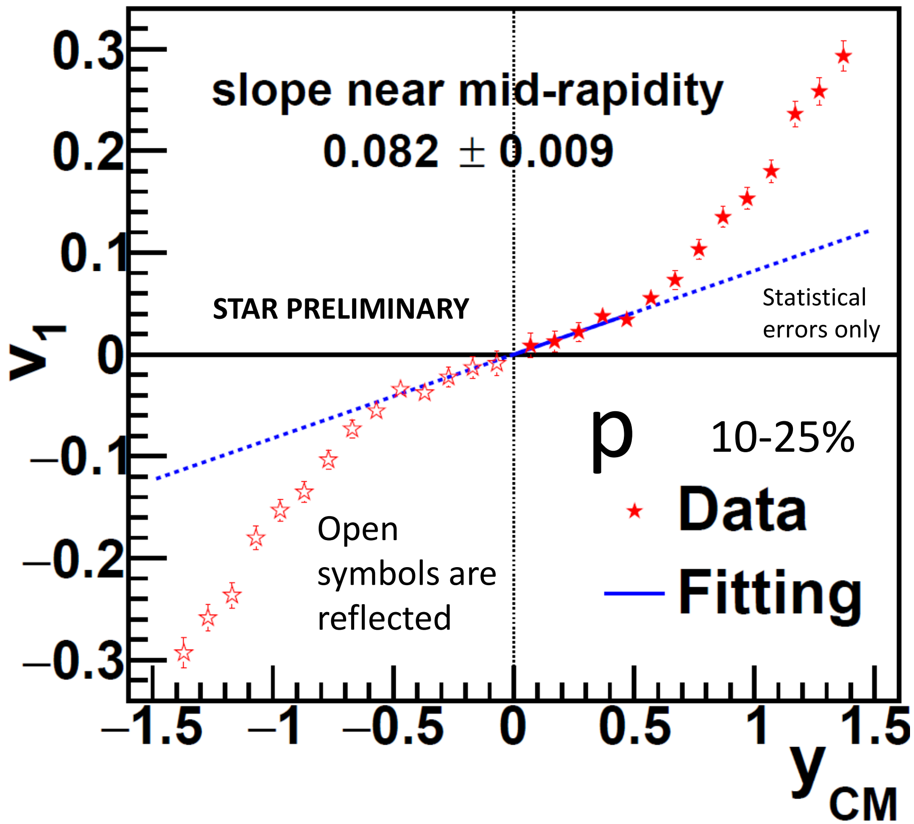
Phys. Rev. Lett. 93 (2004) 022302

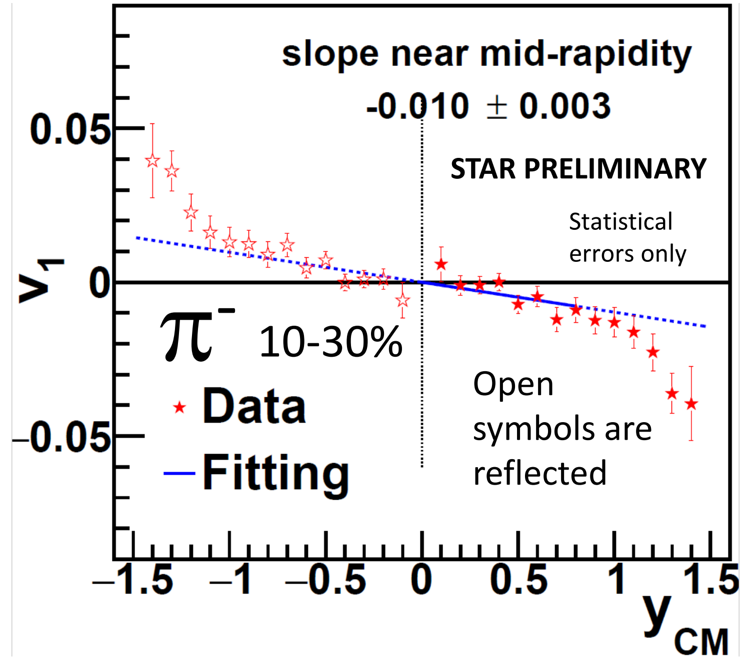
NA57: JPG:NPP32 (2006) 2065

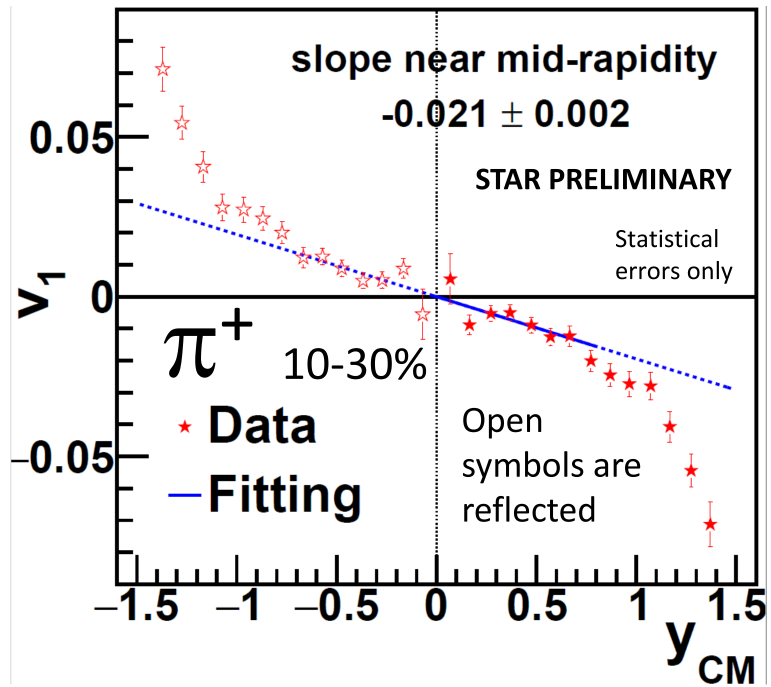
WA98: Phys. Rev. C 67 (2003) 014906

STAR FXT dN/dy measurements are consistent with the excitation function data from other experiments.

Directed flow of protons and pions at $\sqrt{s_{NN}}$ = 4.5 GeV



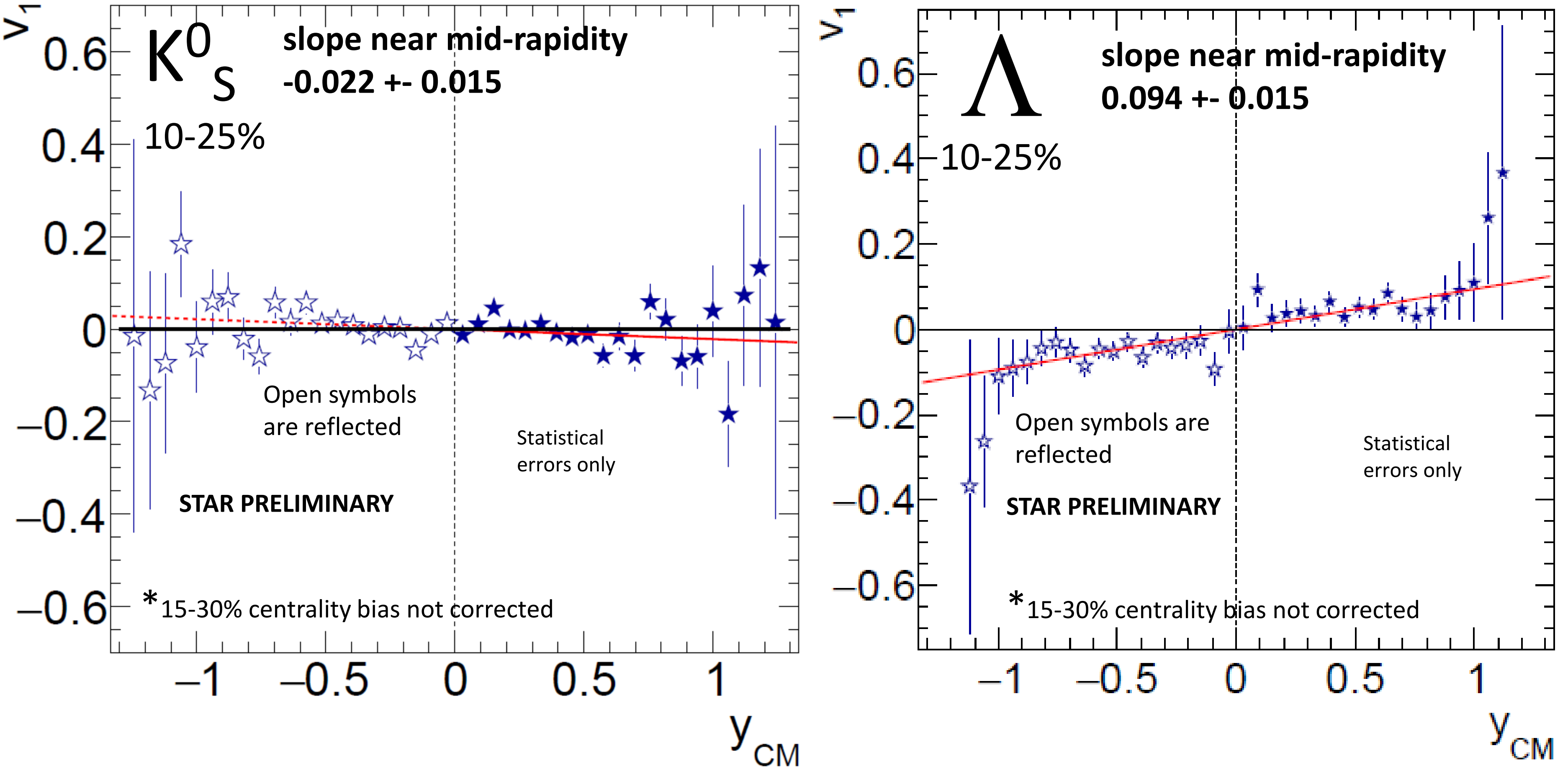




- Proton flow is "positive"
- Pion flow is "negative"
- π^+ flow is twice that of π^- flow

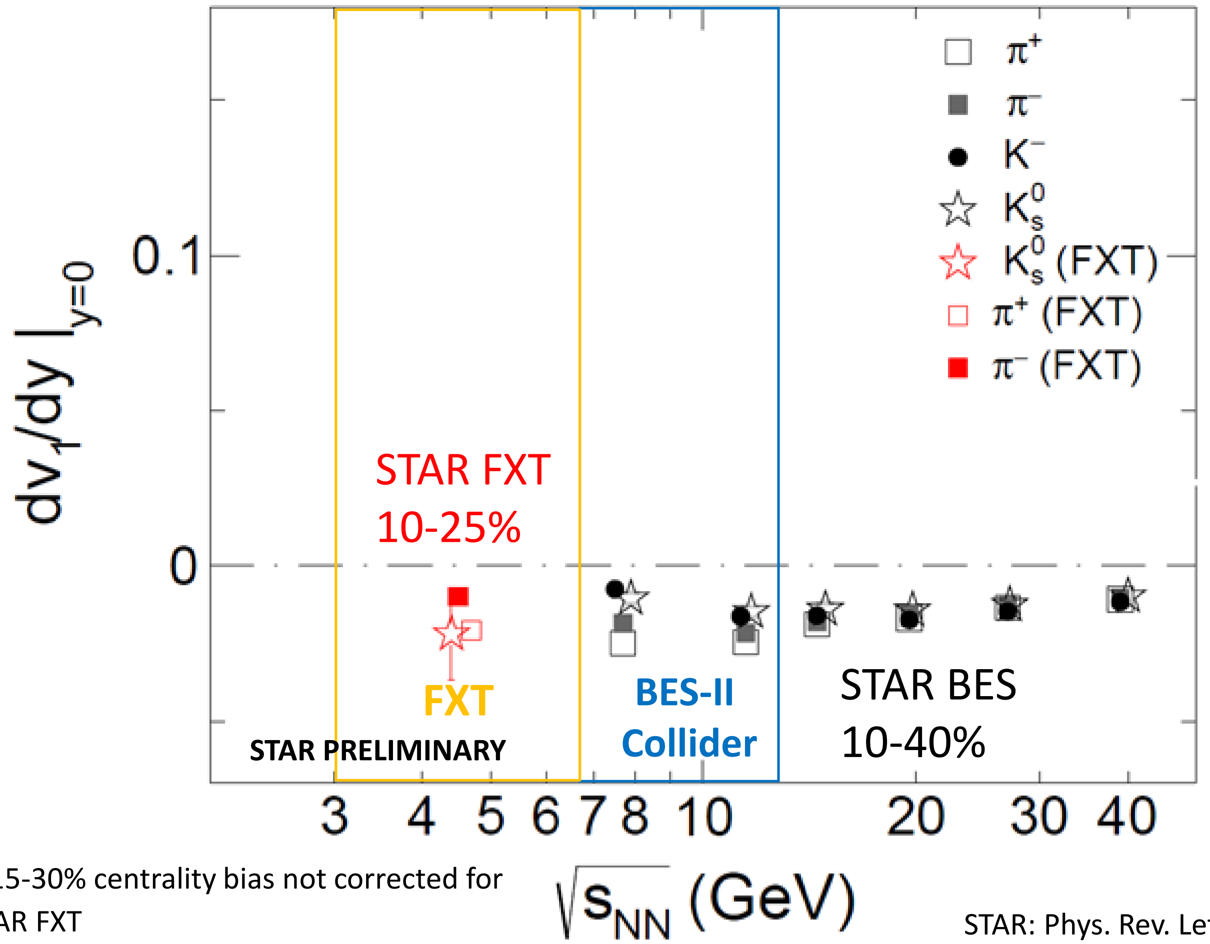
*15-30% centrality bias not corrected

Directed flow of kaons and lambdas at $\sqrt{s_{NN}}$ = 4.5 GeV



- $dv_1/dy|_{y=0}$ of kaons (mesons) is negative.
- $dv_1/dy|_{y=0}$ of lambdas (baryons) is positive.

Directed Flow Comparison Across Experiments and Energies

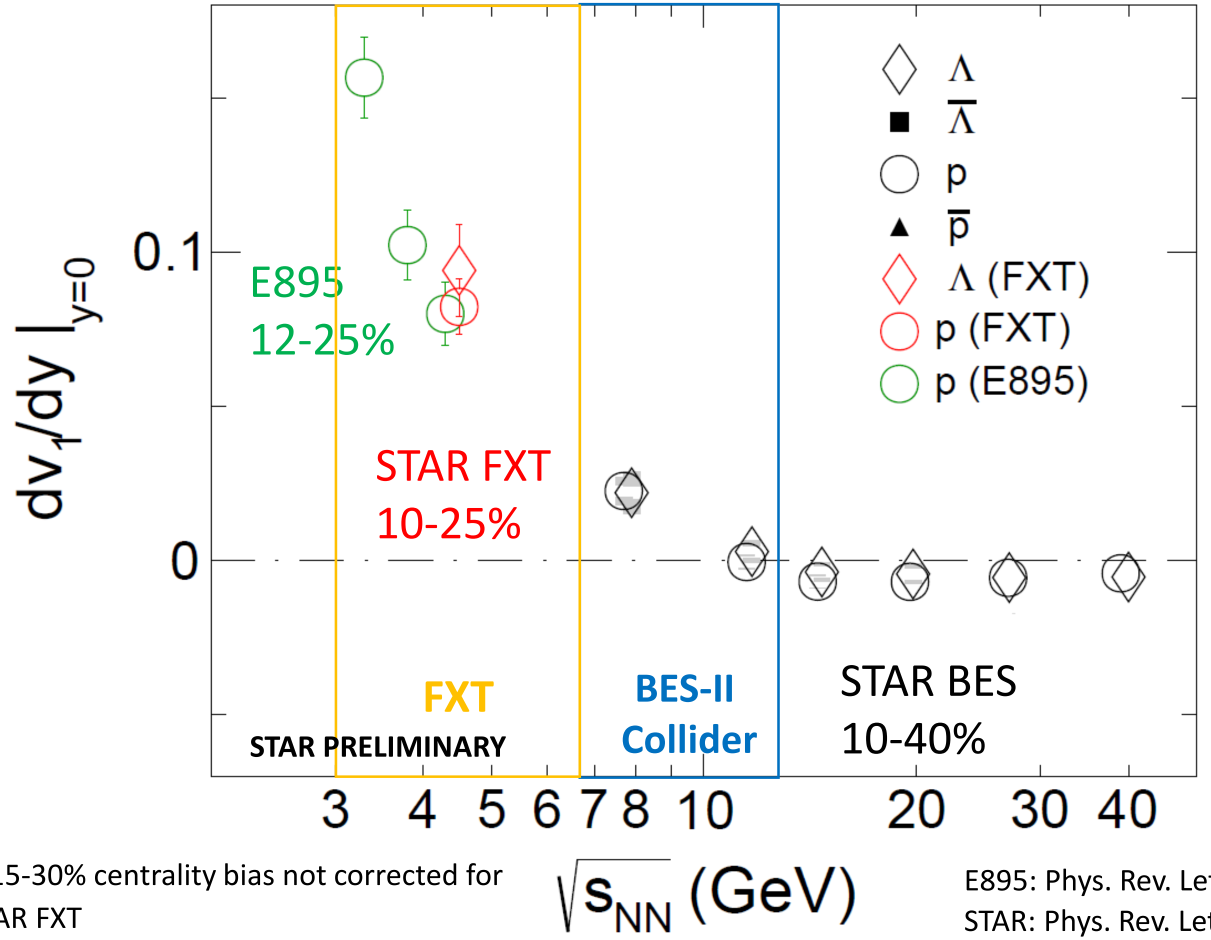


*15-30% centrality bias not corrected for STAR FXT

STAR: Phys. Rev. Lett. **112** (2014) 162301

- First π results shown for this energy range.
- The mesons continue the trend of negative flow seen at higher energies.

Directed Flow Comparison Across Experiments and Energies

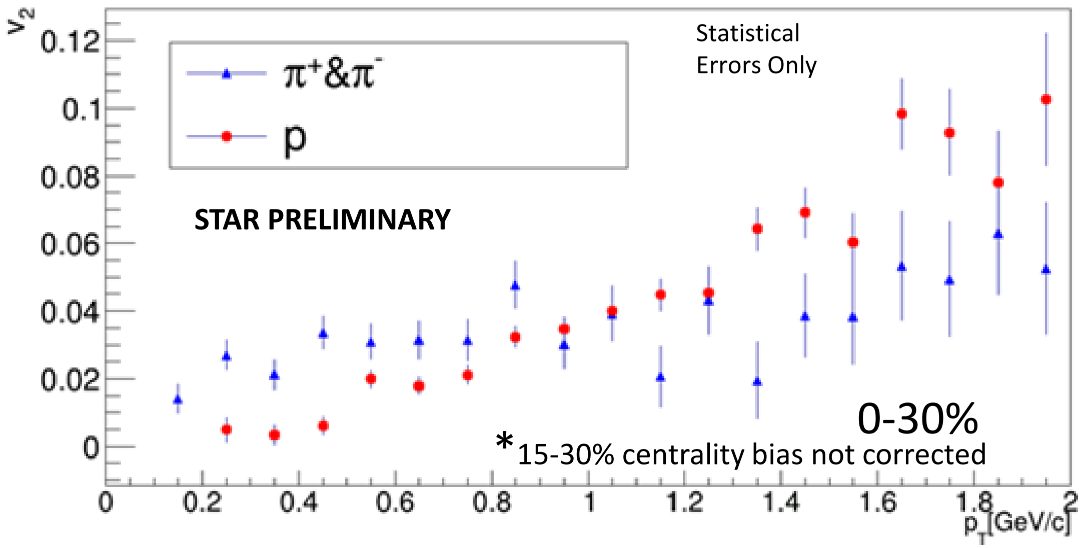


*15-30% centrality bias not corrected for STAR FXT

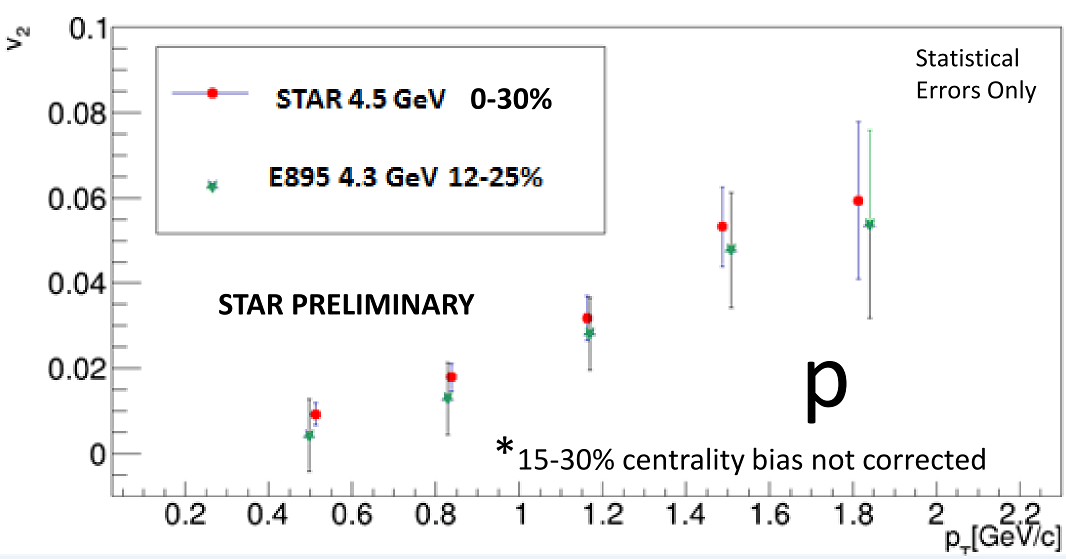
E895: Phys. Rev. Lett. 84 (2000) 5488
STAR: Phys. Rev. Lett. **112** (2014) 162301

- Protons and lambdas are consistent with positive flow indicative of compression.

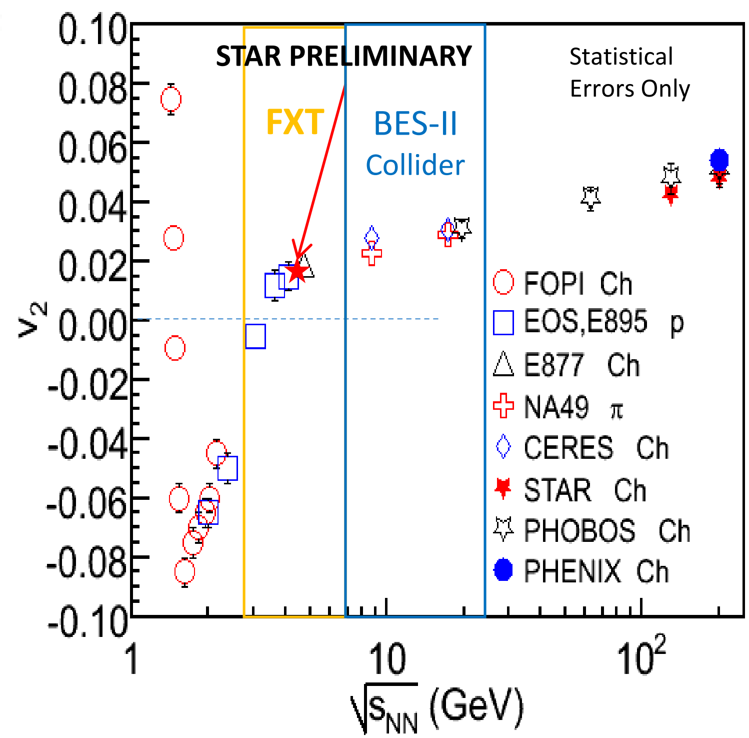
Elliptic Flow of Pions and Protons



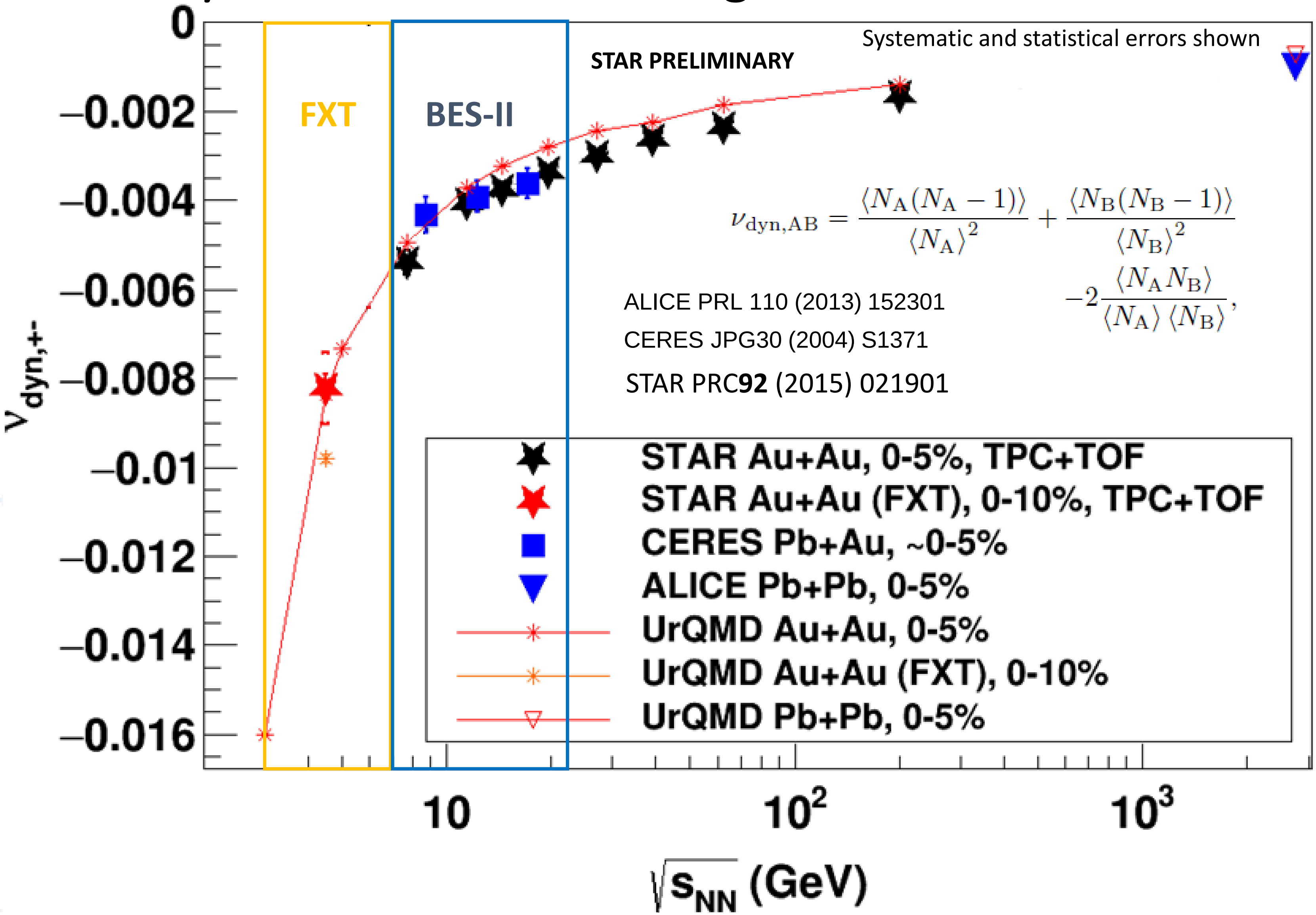
E895: Phys. Rev. Lett. 83 (1999) 1295



- First measurement of pion elliptic flow for this energy range
- Good agreement with E895

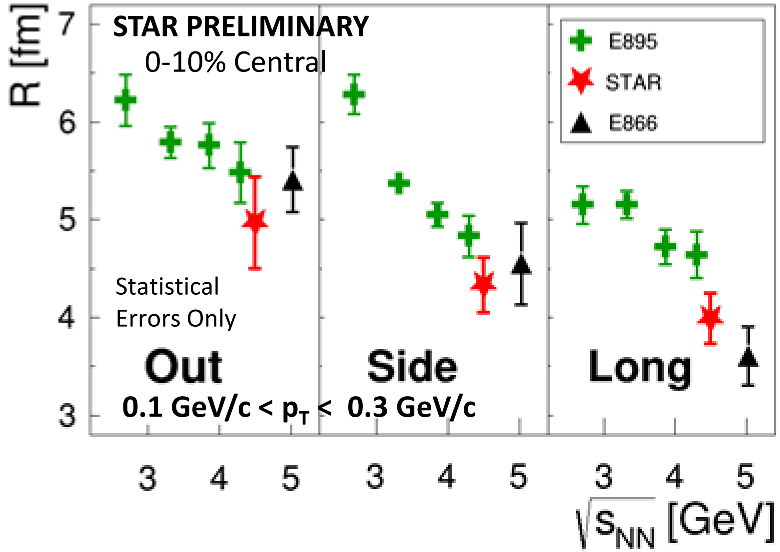


Dynamical Relative Charge Number Fluctuations

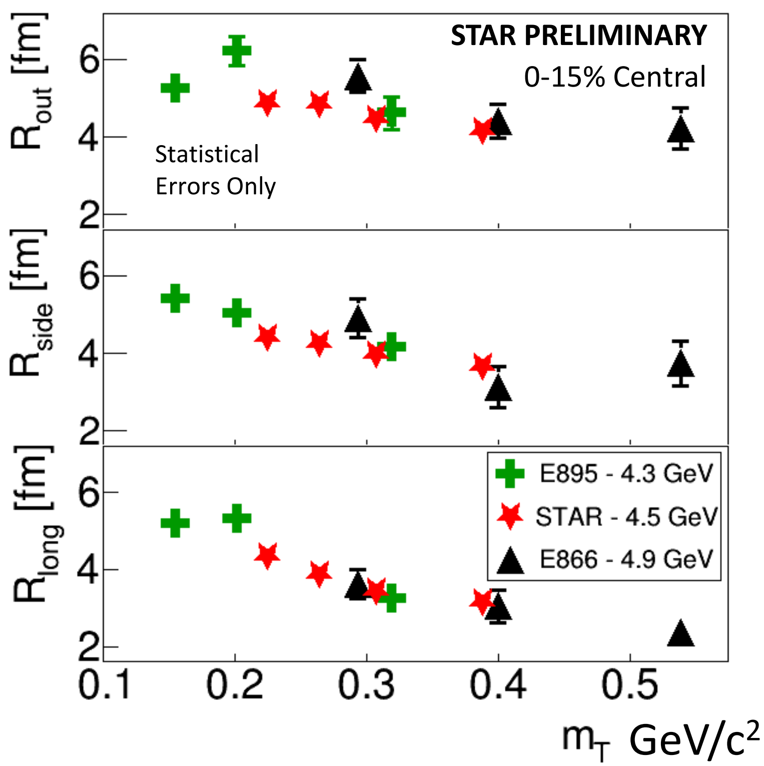


FXT measurement continues the decreasing trend with lower energies and is in good agreement with UrQMD

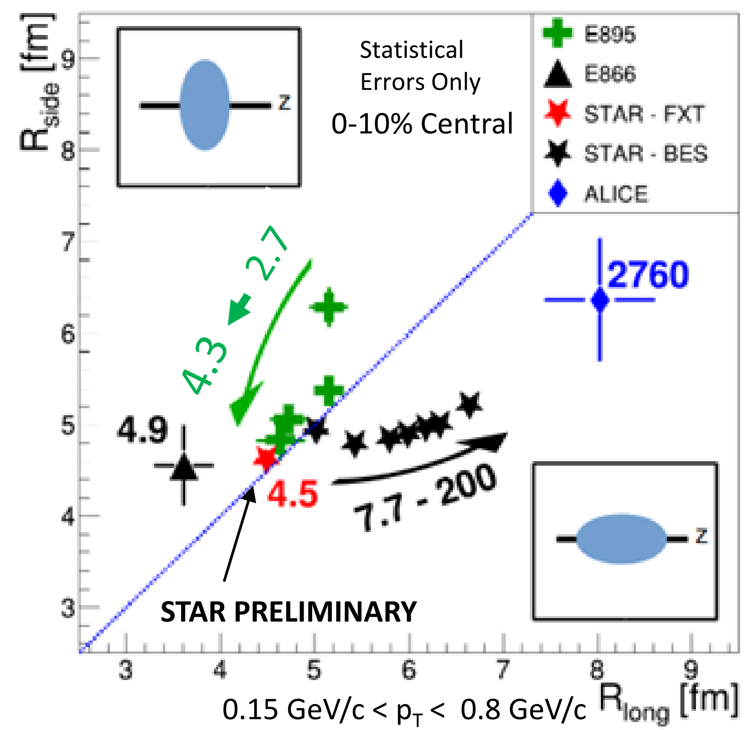
Pion HBT Results



- Consistency with results from AGS experiments
- In the FXT regime, as the collision energy rises, compression reduces the source size and increases the baryon density
- The BES collider regime shows increased longitudinal expansion



E866: Phys. Rev. C 66 (2002) 054096 ALICE: Phys. Lett. B 696 (2011) 328
E895: Phys. Rev. Lett. 84 (2000) 2798 STAR BES: Phys. Rev. C **92** (2015) 14904



E895: Phys. Rev. Lett. 84 (2000) 2798
E866: Phys. Rev. C 66 (2002) 054096

Conclusions from First FXT Run

1) First pion dv_1/dy results obtained for this energy range. They continue the trend of negative flow for mesons.

2) First pion v_2 results obtained for this energy.

3) First ν_{dyn} result obtained for this energy range

4) Spectra and yields, HBT radii, proton dv_1/dy, and proton v_2 results are consistent with results from AGS experiments

→ STAR operates well in FXT mode!

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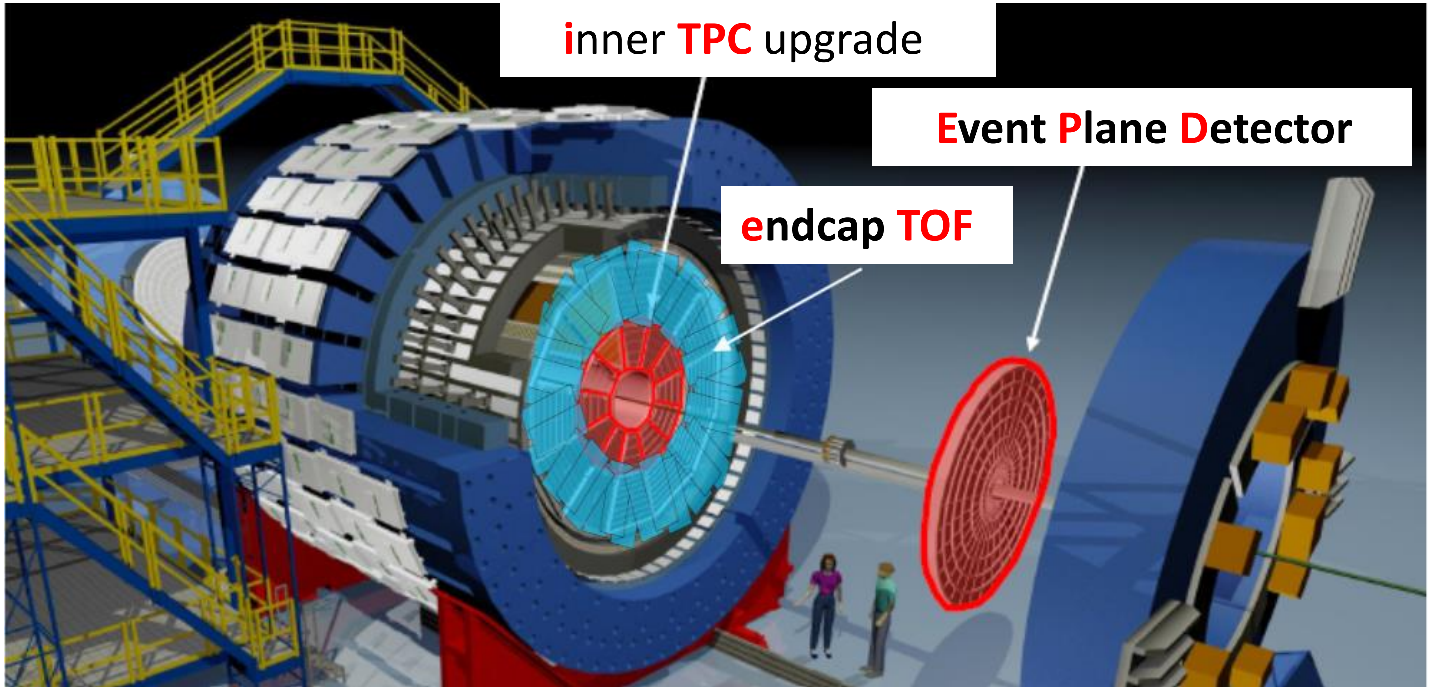
The STAR Upgrades and the FXT program



iTPC Upgrade:
- Improves tracking and acceptance
- Ready in 2019

EndCap TOF Upgrade:
- Improves PID and acceptance
- Ready in 2019

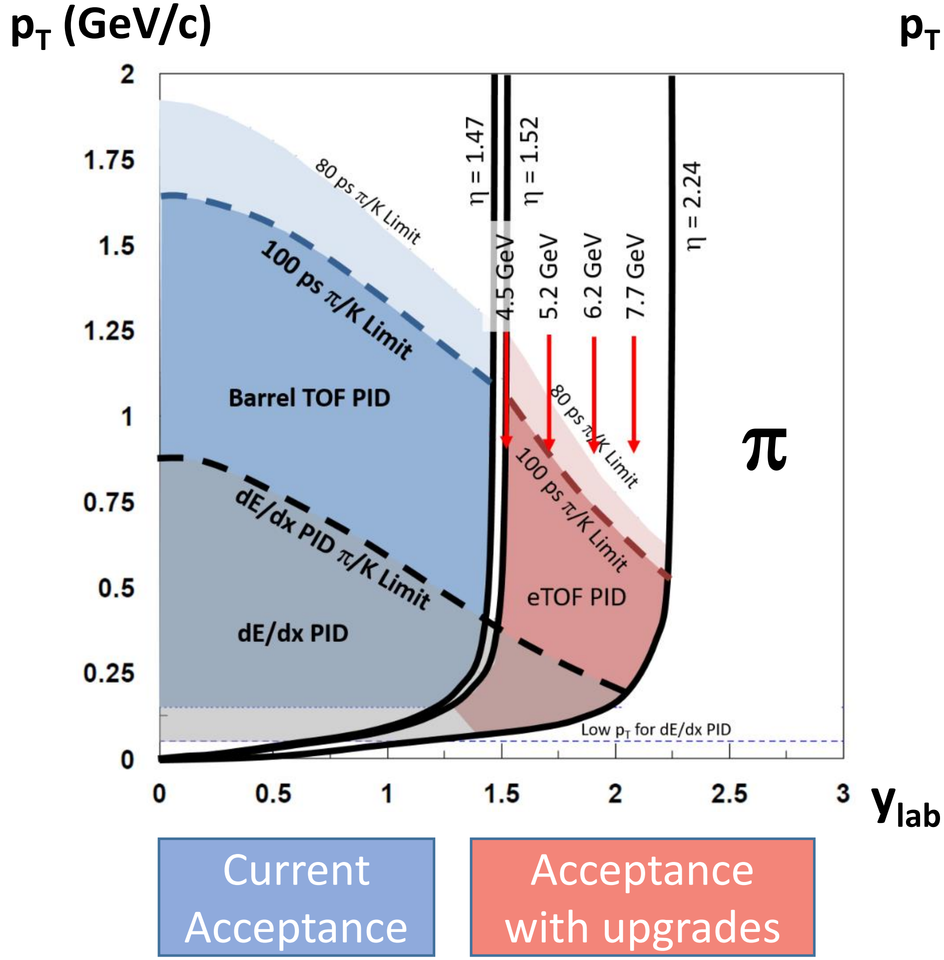
EPD Upgrade:
- Improves event plane resolution and centrality definition
- Ready in 2018

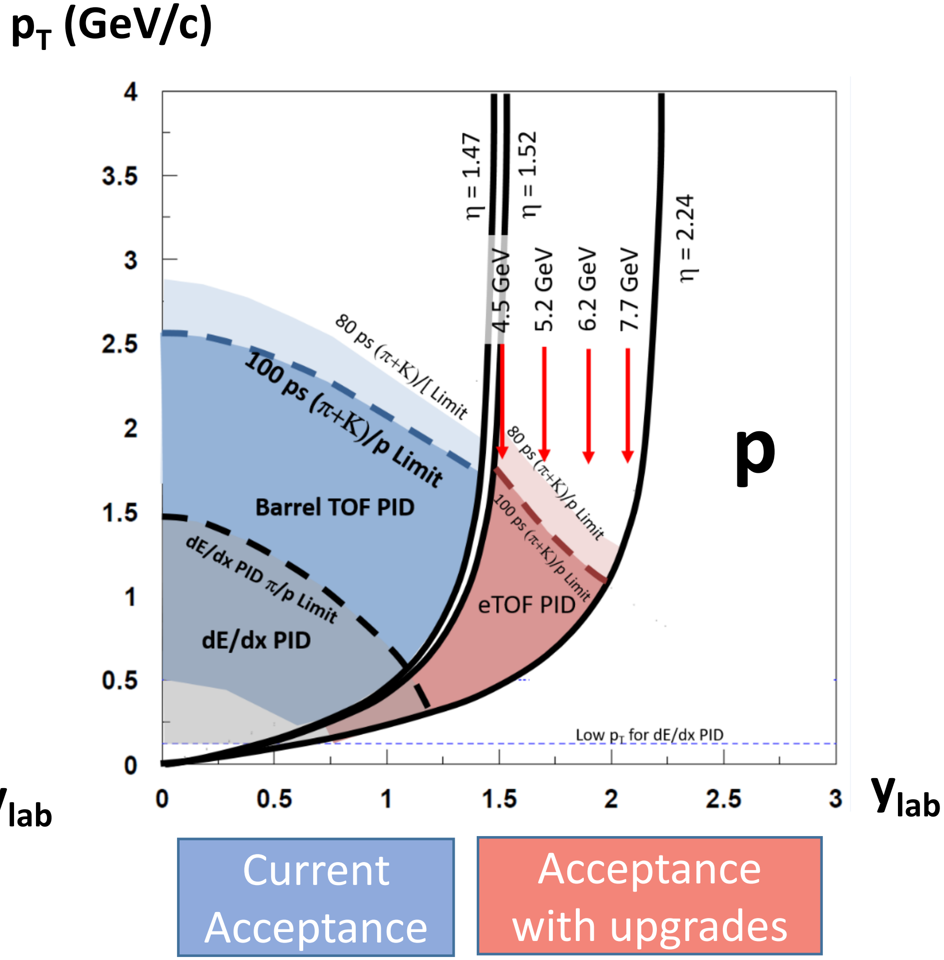
Star Note 0644 : Technical Design Report for the iTPC Upgrade

https://arxiv.org/pdf/1609.05102.pdf

Star Note 0666 : An Event Plane Detector for STAR

FXT Energy Reach With Upgrades



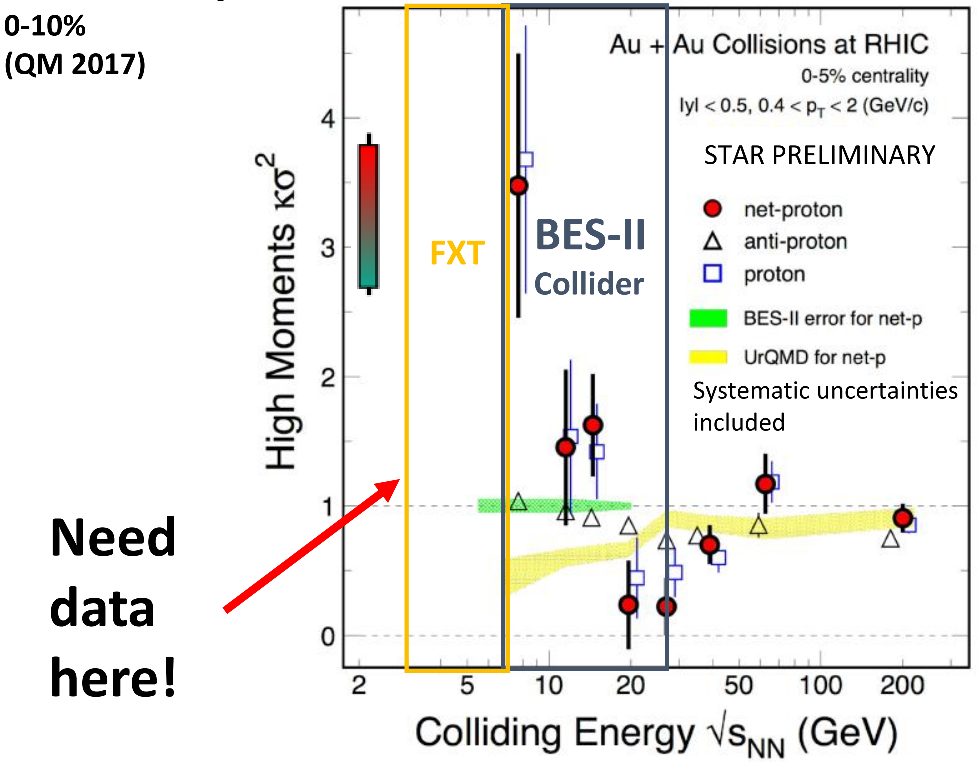


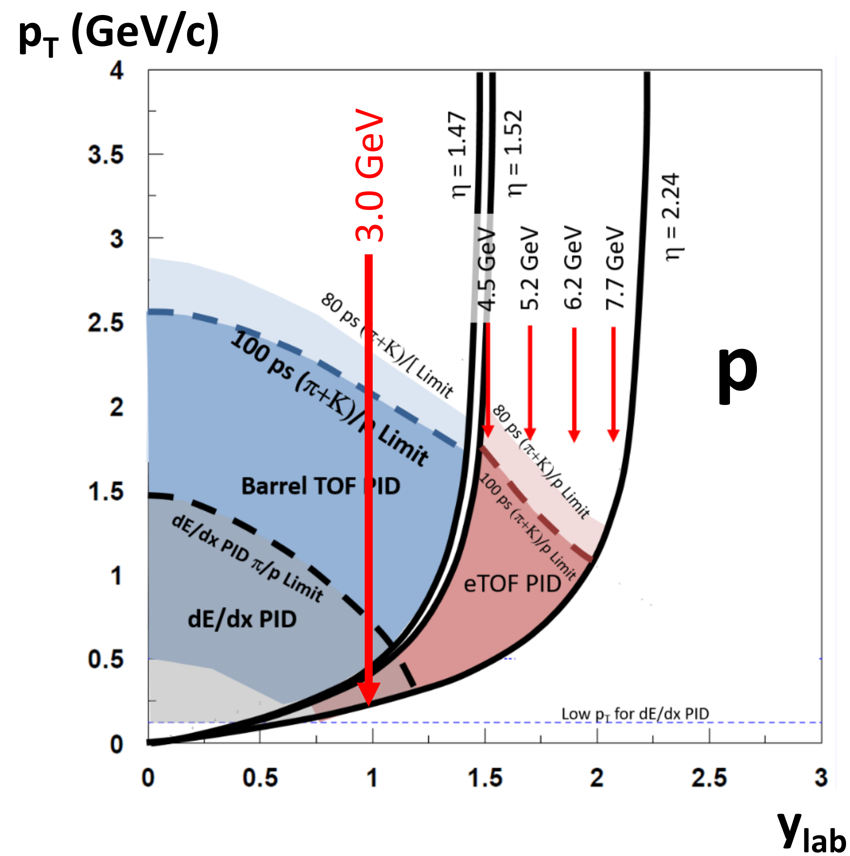
Detector upgrades required to extend STAR FXT up to 7.7 GeV, an overlap energy with the collider

FXT in Run 18

- 100 M (~2 days) of $\sqrt{s_{NN}}$ = 3.0 GeV Au + Au collisions
- Event Plane Detector will be ready and available for flow analyses
- Can obtain a fluctuation measurement at energies below BES-I

Preliminary HADES result, Quark Matter 2017



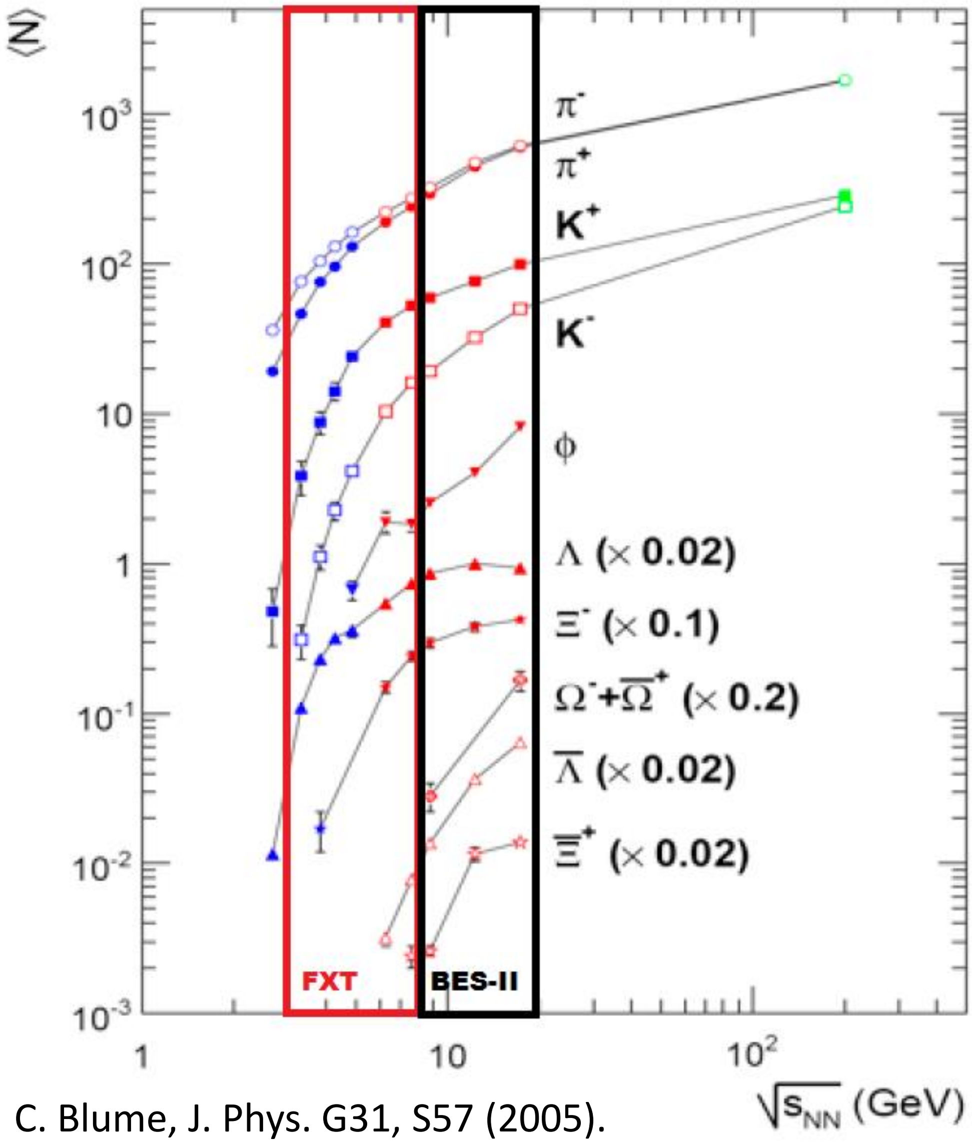


FXT in BES-II: Run 19

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

- iTPC and eTOF upgrades will be available
- Would need 100 Million Events at each energy to make the sensitivity of BES-II, 2 days per energy (3.5 GeV – 7.7 GeV)
- Data rate is DAQ limited
- Data at 7.7 GeV would provide an overlap energy with the collider mode

Additional Physics Goals & Capabilities:



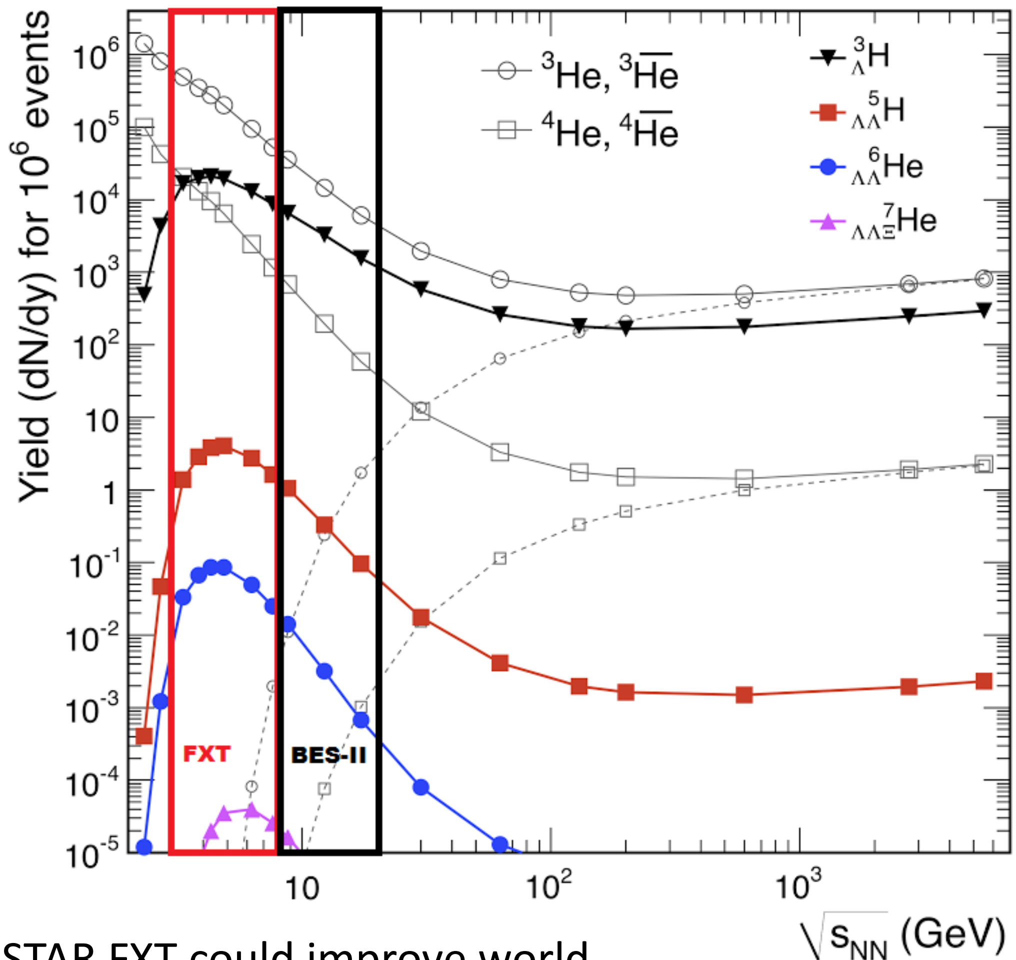
C. Blume, J. Phys. G31, S57 (2005).

Hyperons in FXT

- "Turn-on" occurs in FXT energy range
- Expect to be able to measure turn-on of lambdas and cascades
- Might be able to measure omegas and anti-lambdas

Hypernuclei in FXT

Predicted Hyperon Yields for
Mid-rapidity Central Collisions



STAR FXT could improve world hypertriton lifetime measurement

A. Andronic, P. Braun-Munzinger, J. Stachel, and H. Stocker, Phys. Lett. B697, 203 (2011), arXiv:1010.2995 [nucl-th].

Summary

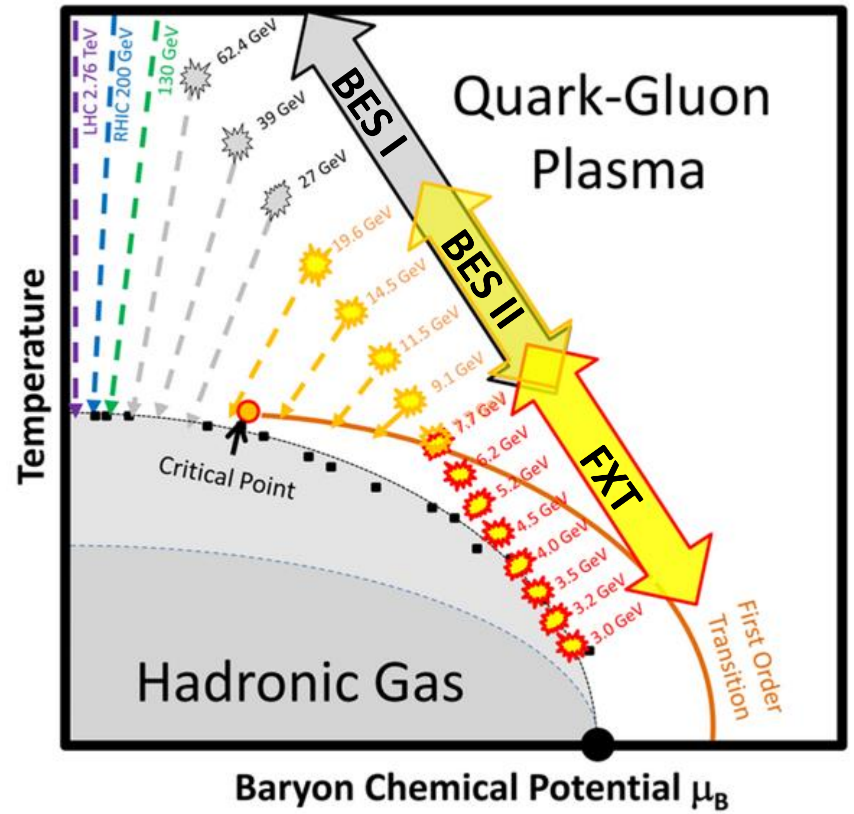
1) First FXT run results demonstrate STAR works well in FXT configuration

2) Higher statistics FXT run in 2018 will allow a kurtosis measurement at 3 GeV

- EPD installation in run 18 will allow improved flow measurements

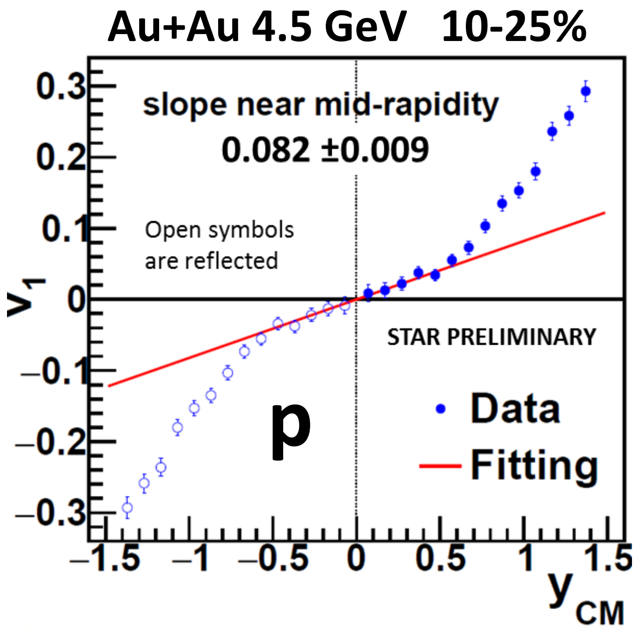
3) A FXT energy scan will extend BES-II down tc 3.0 GeV

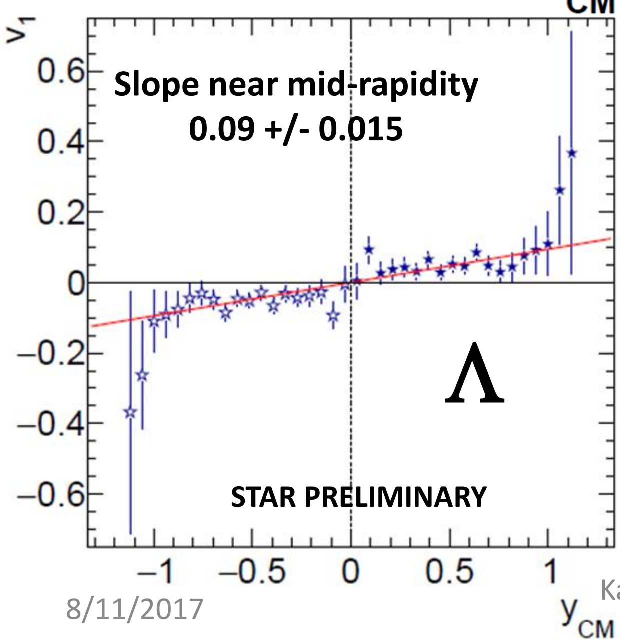
- iTPC and eTOF detector upgrades for BES-II will extend energy reach up to 7.7 GeV, an overlap energy with collider analyses

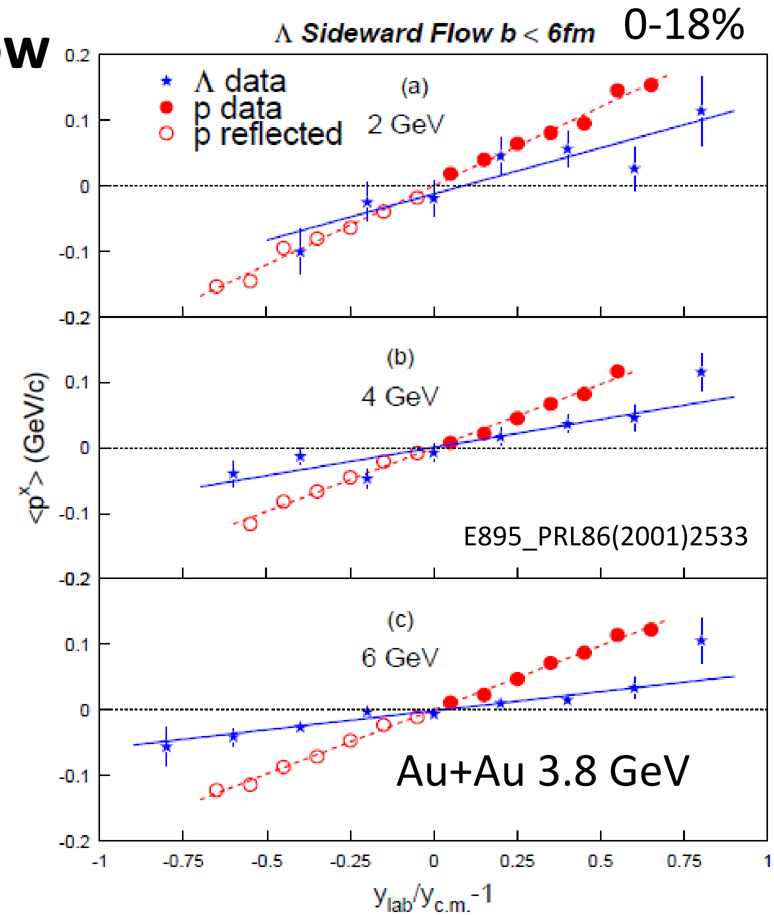


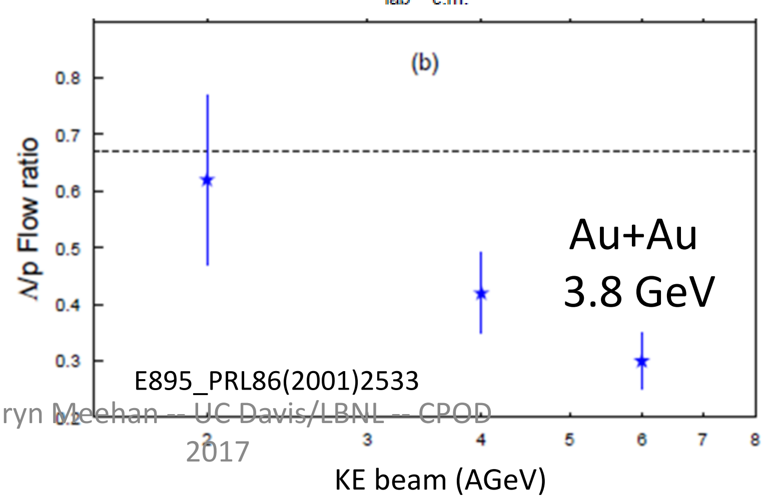
Backup Slides

Comparison to E895 Λ Flow









Differences:

E895 -- $<p^x>$

STAR-FXT – v_1

E895 – 0-18%

STAR-FXT 10-25%

E895 *trend*:

Λ/p flow ratio at 4.5 GeV ➔ 0.2

STAR FXT:

Λ/p flow ratio at 4.5 GeV ➔ 1.1

Relation between centrality bins and <nPart>

Centrality	# of Events	<Npart> +/- stat +/- sys
0-5%	~267k	335.9 +/- 0.51 +/- 0.97
5-10%	~287k	285.9 +/- 0.56 +/- 0.88
10-15%	~259k	242.4 +/- 0.53 +/- 0.37
15-20%	~204k	203.9 +/- 0.48 +/- 0.85
20-25%	~126k	170.3 +/- 0.44 +/- 0.46
25-30%	~69k	142.2 +/- 0.43 +/- 0.50