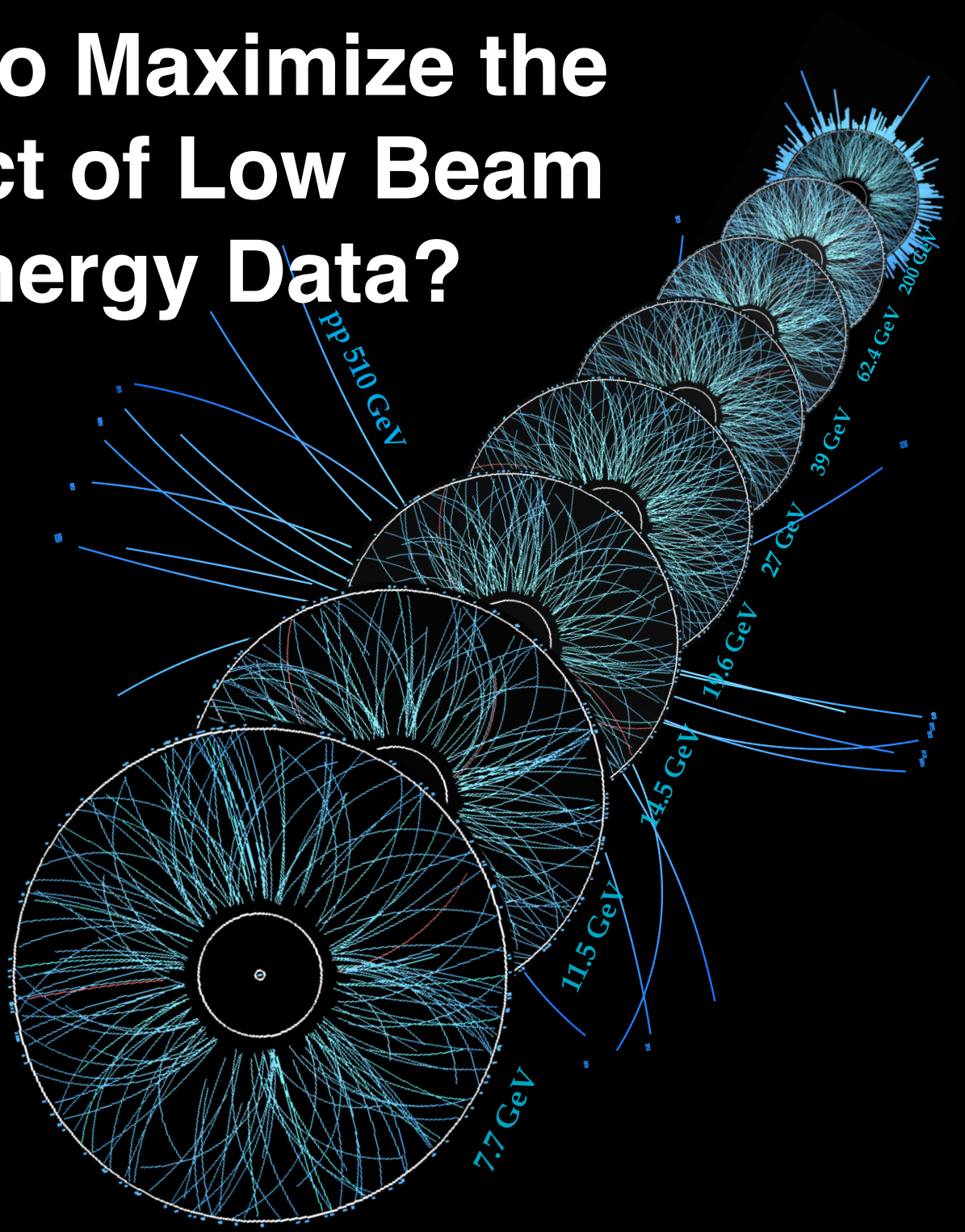
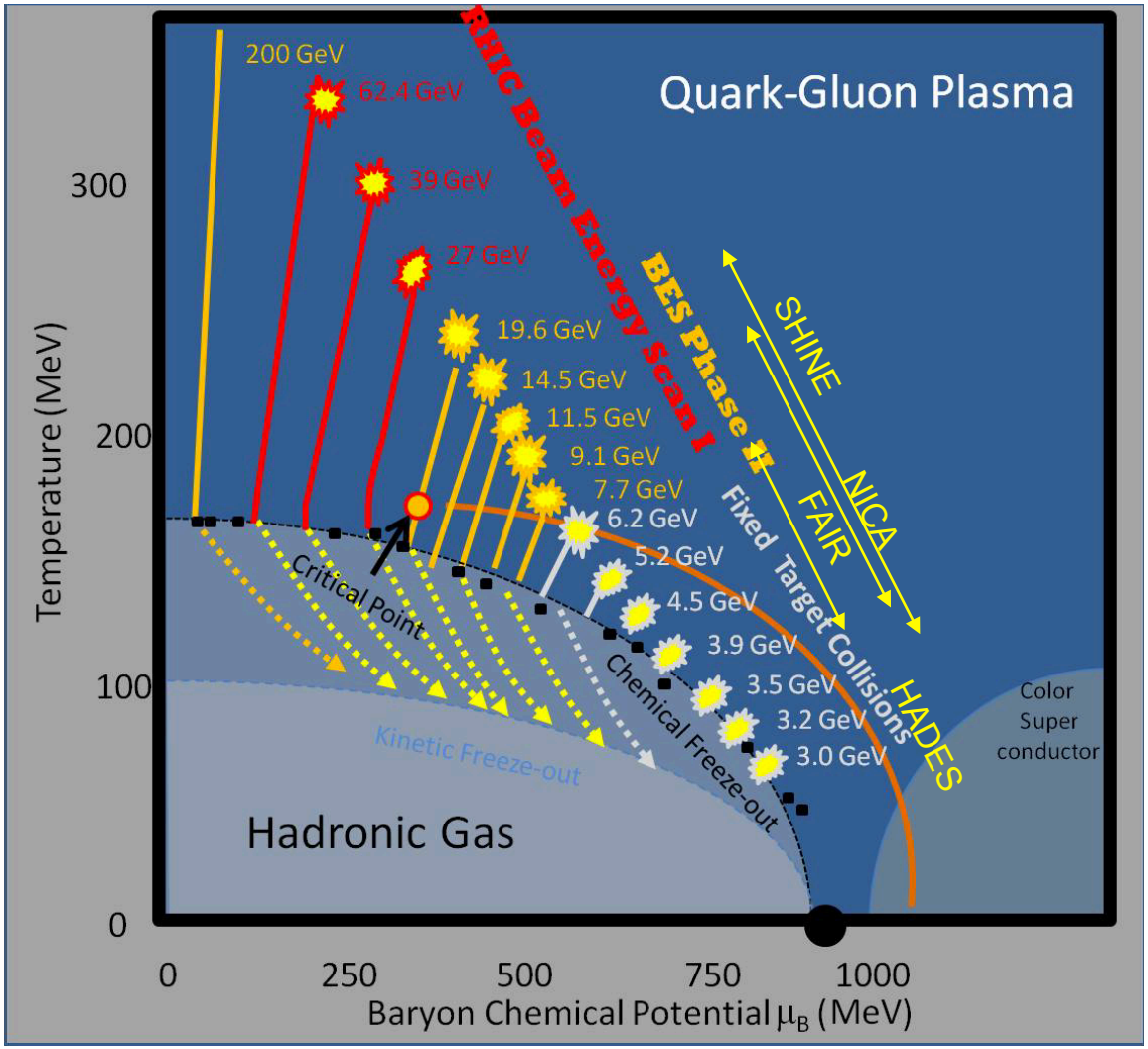
How to Maximize the Impact of Low Beam Energy Data?



Helen Caines
Yale

INT-BES
October 2016

Current and expected data



Wealth of data in hand and more coming soon

RHIC: BES-I

BES-II - Fixed target

(2.5 - 19.6)

d+Au - (200, 62, 38, 20)

Cu+Au (200, 62)

SPS: NA49/NA61: (5.1-17.3)

Lighter ions

HADES: (2.6)

FAIR: 2.7-8.2

NICA/BM@N: 2-11

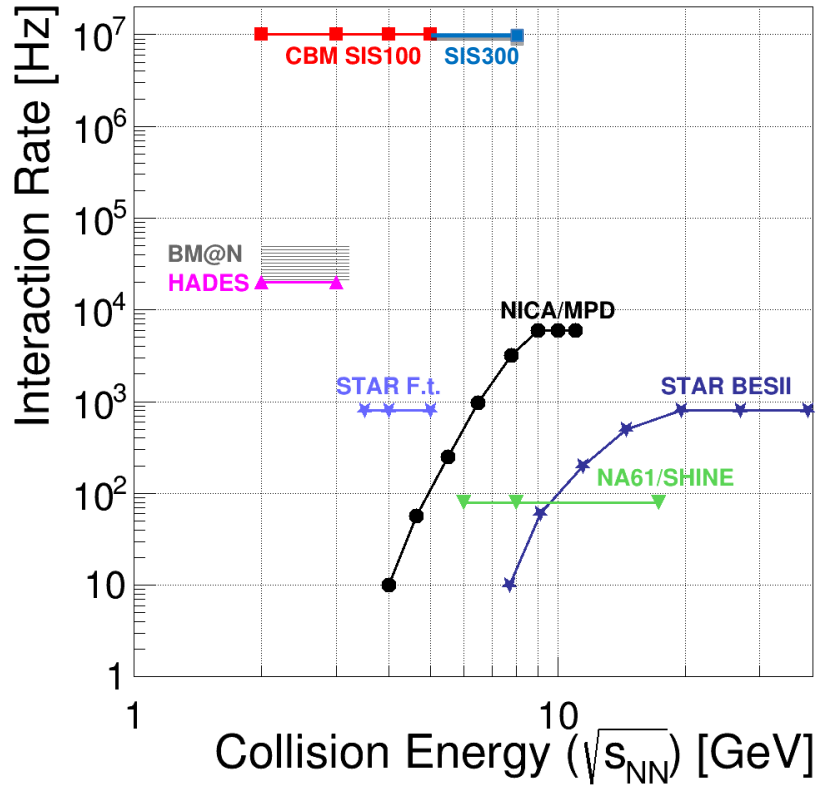
J-PARC: 2-6.2

Improving on current data

Current low energy data:

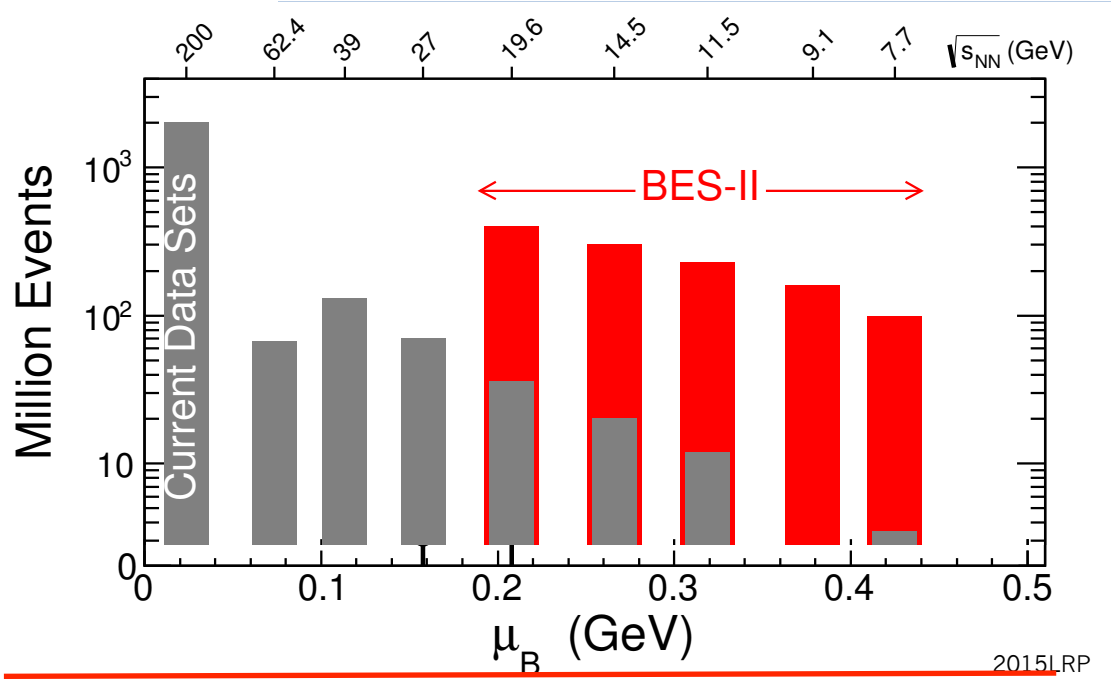
Hints that at low √s

- QGP turns off
- 1st order phase transition
- Critical Point
- Chiral symmetry restoration



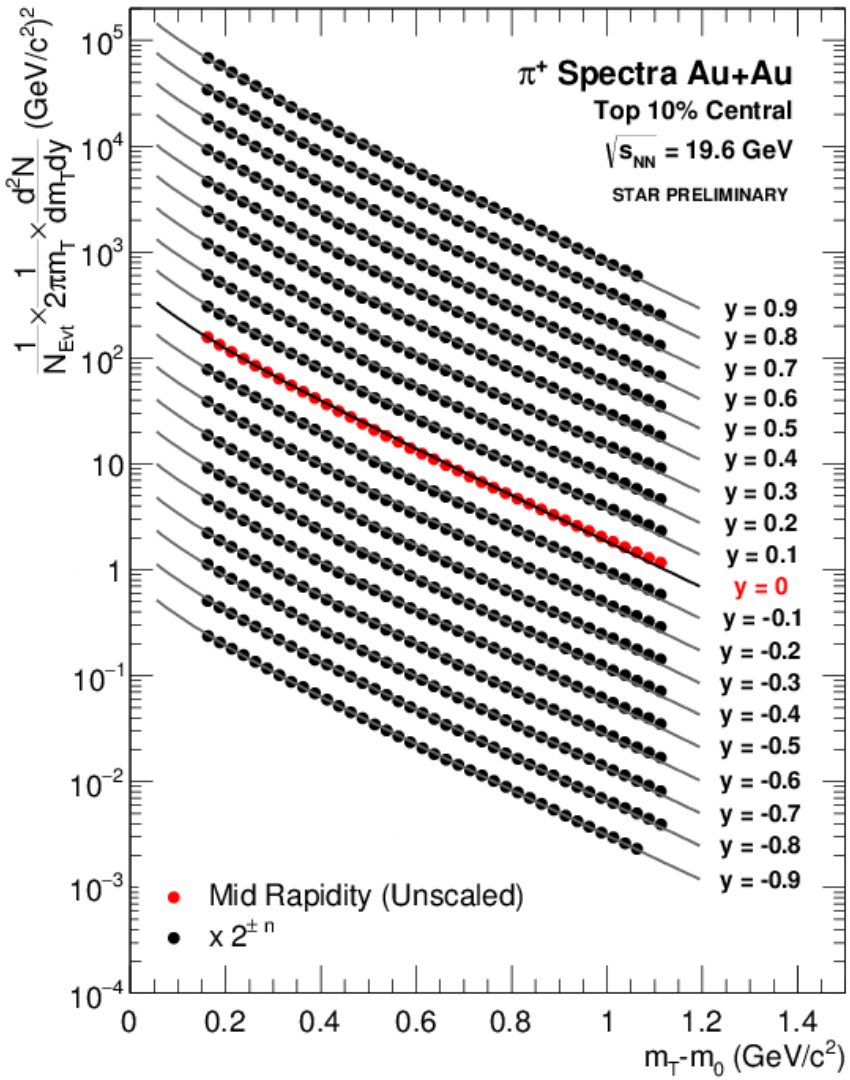
Future data:

- Examine regions of interest
- Maximizing fraction particles measured
- Probe lower √s
- High(er) luminosities



Turn trends and features into definitive conclusions

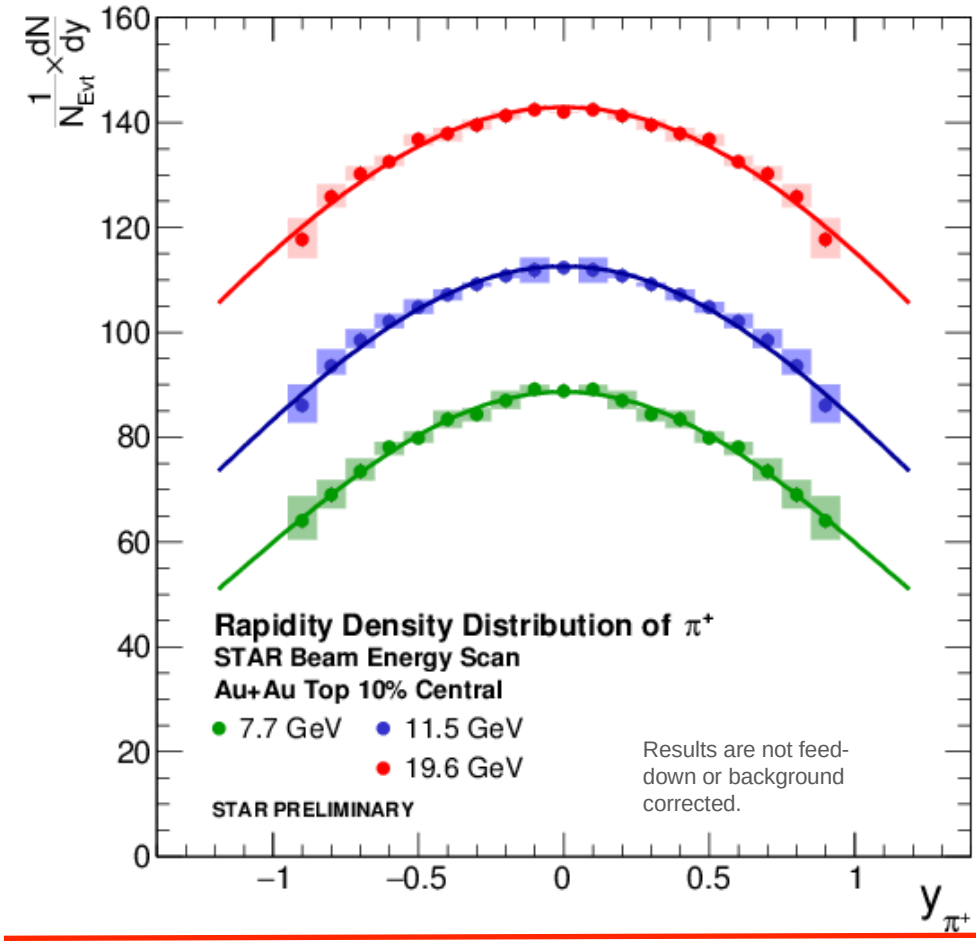
Establishing the "basics": Yields and spectra



STAR can measure forward and backwards

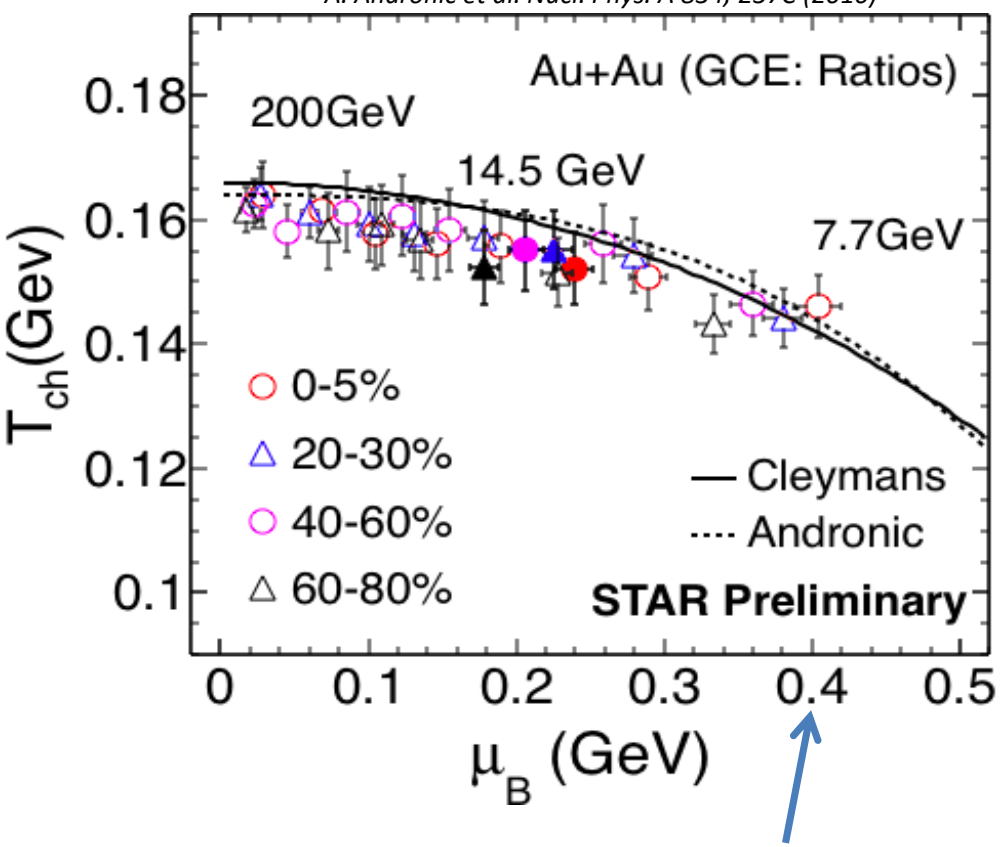
Inching towards full phase space measurements

(preliminary pions at QM2015
preliminary protons at DNP,
Kaons coming soon C.Flores)



Establishing the "basics": Hadro chemistry

D. Mishra, QM 2015, Kobe, Japan
- J. Cleymans et al. Phys. Rev. C 73, 034905 (2006)
- A. Andronic et al. Nucl. Phys. A 834, 237C (2010)



Thermal fits work at $\sqrt{s}$ = 2.6 GeV

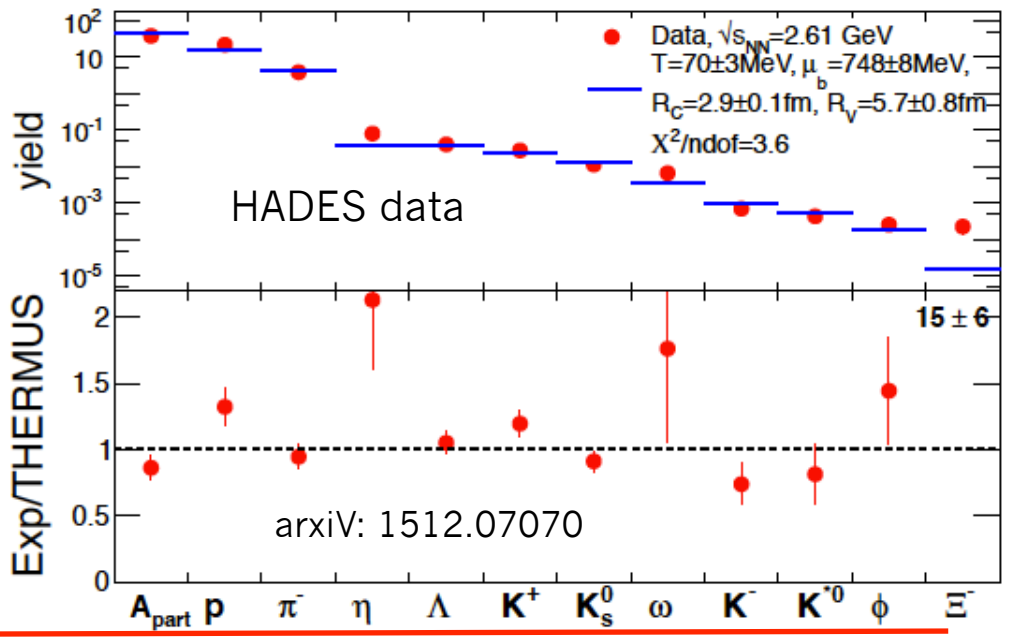
All data fit smoothly into model expectations

Results need "ALL" strange hadrons included

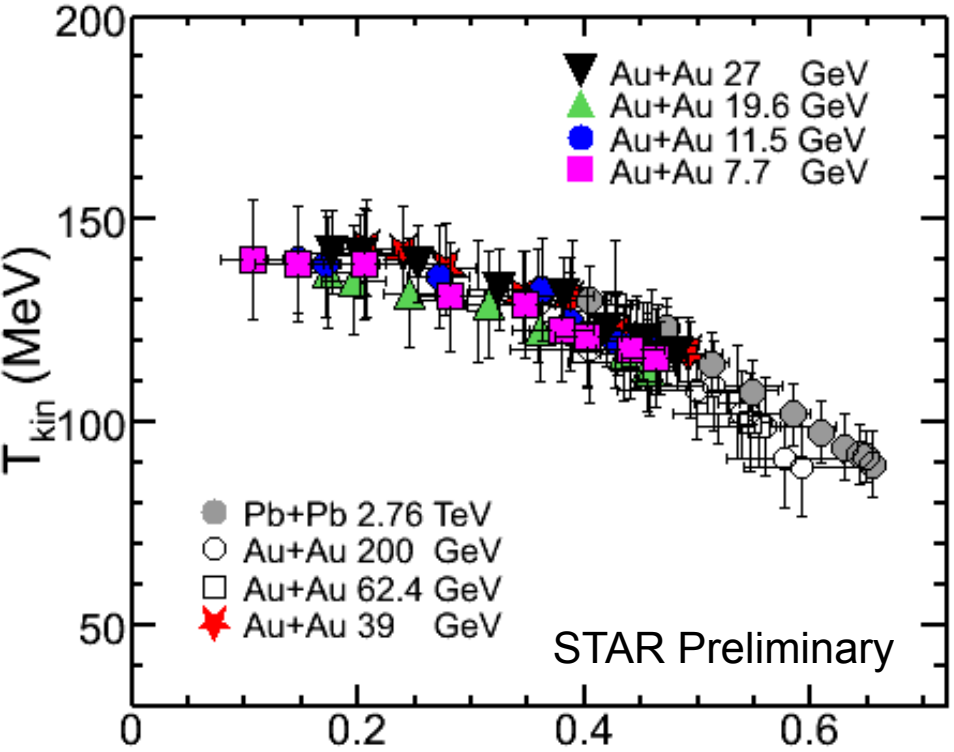
No significant difference seen in BES energies using GCE or SCE

PHENIX results using Lattice in approximate agreement (arXiv:1506.07834)

THERMUS V3.0: S. Wheaton, J.Cleymans: Comput.Phys.Commun.180:84-106,2009



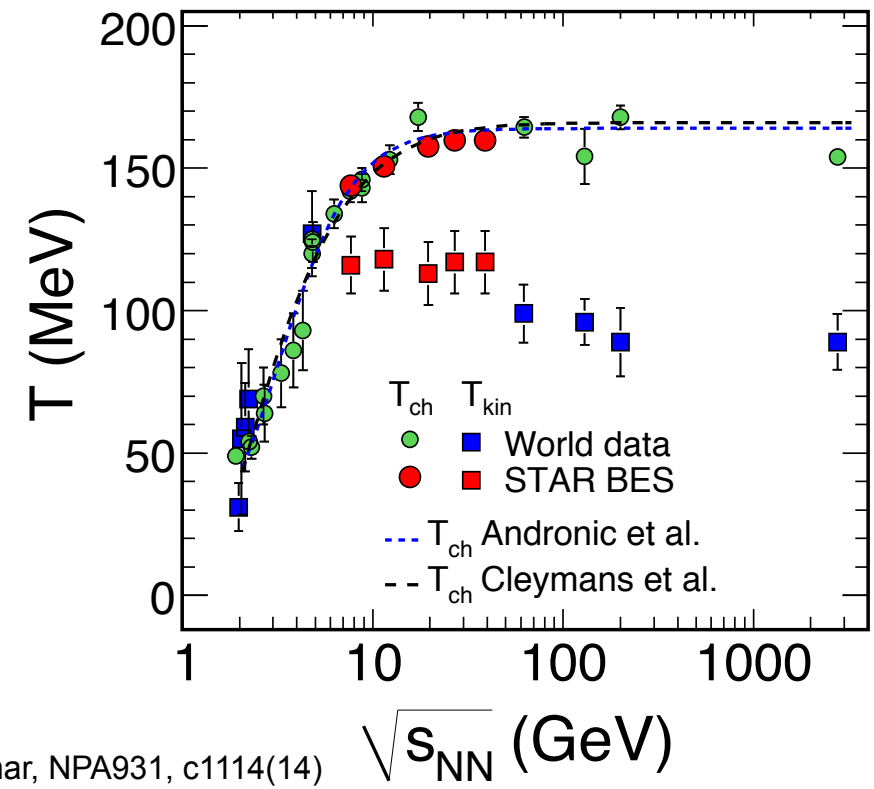
Establishing the "basics": Kinetic freeze-out



Stronger collectivity at higher √s

Central collisions:

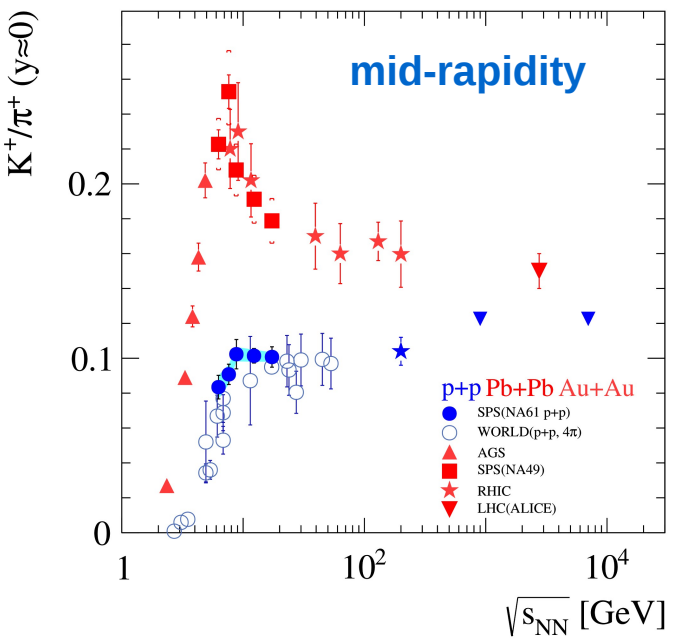
Lower T→ higher β

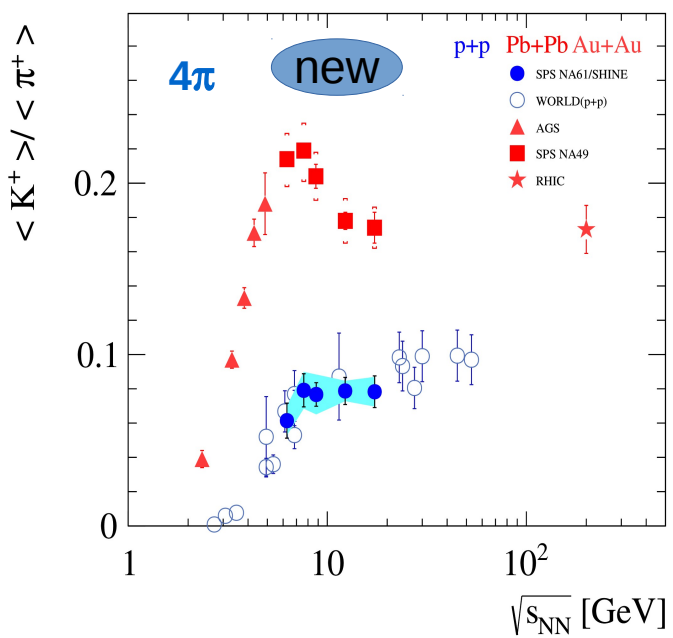


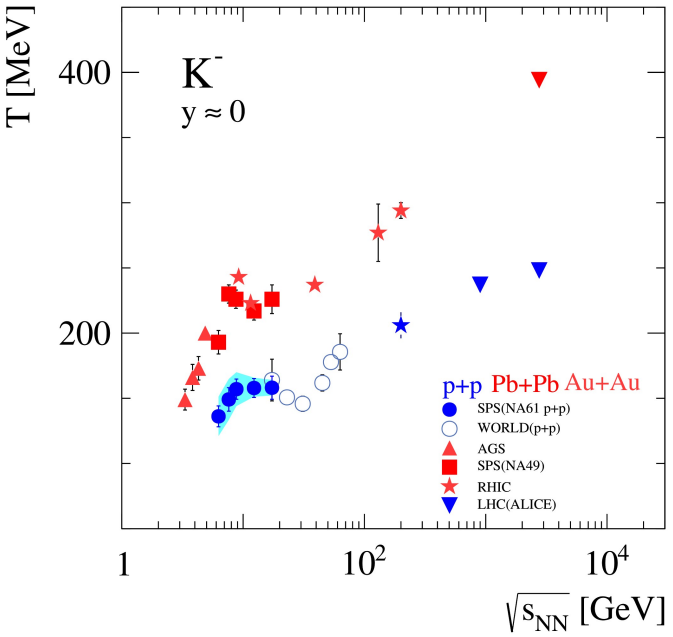
$T_{kin} \sim T_{ch}$ below √s ~ 7 GeV

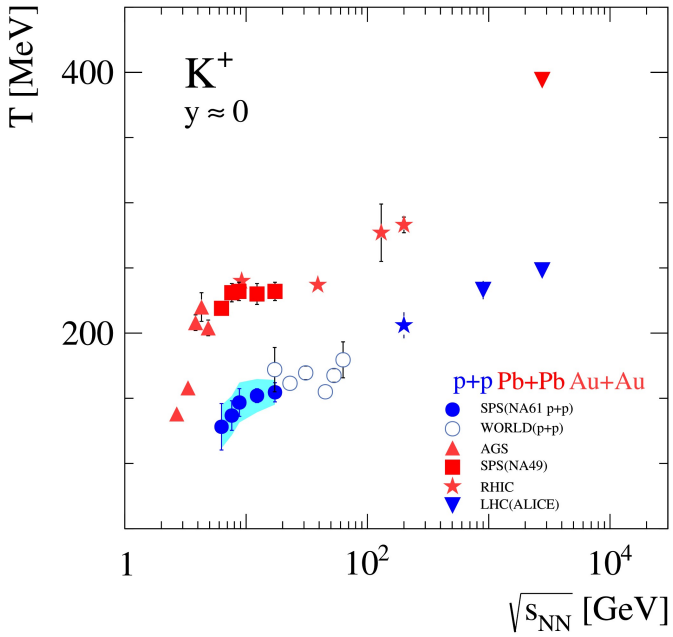
ALICE: B.Abelev et al., PRL109, 252301(12); PRC88, 044910(2013).
STAR: J. Adams, et al., NPA757, 102(05); X.L. Zhu, NPA931, c1098(14); L. Kumar, NPA931, c1114(14)

Horns and plateaus









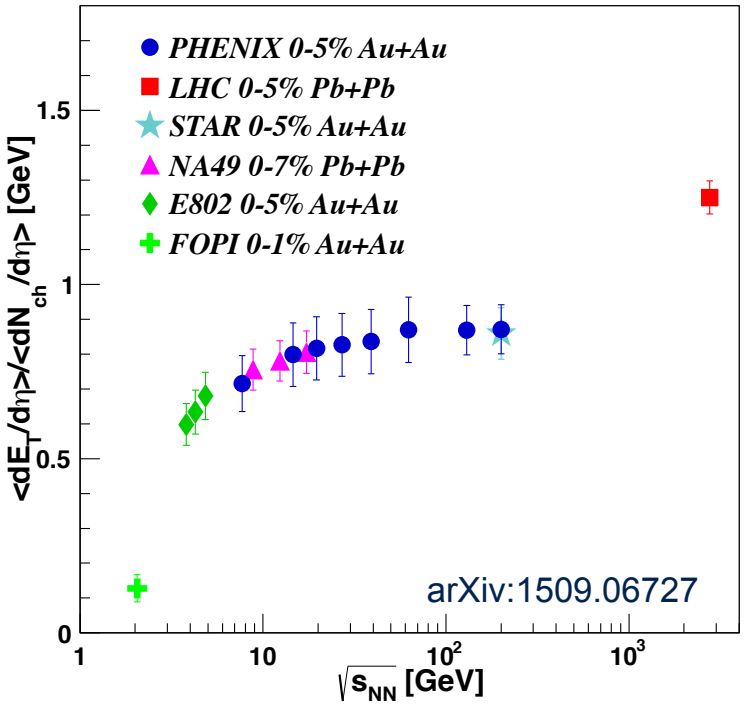
RHIC data suggests horn less pronounced

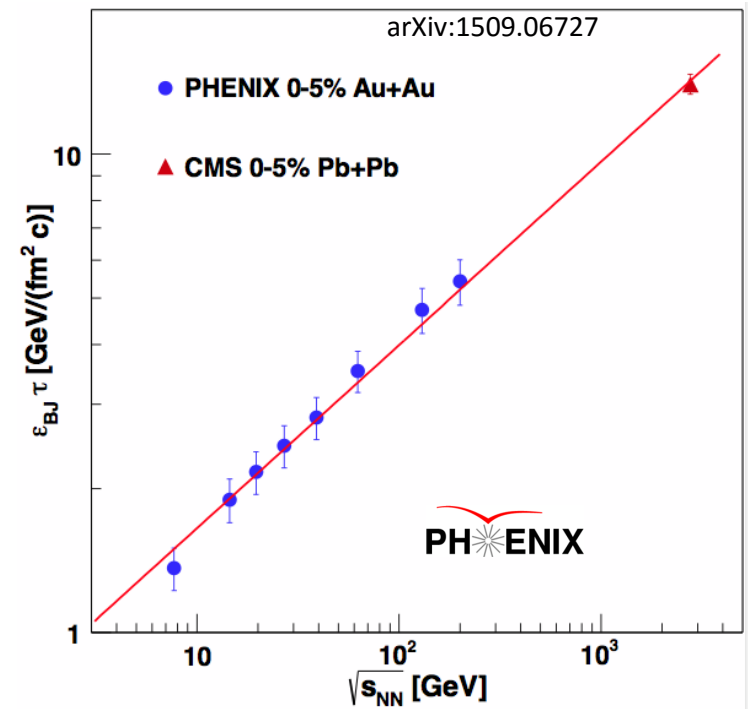
Same result for mid-rapidity as total yield

Models show baryon density also peaks $\sqrt{s}$ ~7 GeV

Similar plateau in T_{kin} for pp

Establishing the "basics": Energy density





E_T/N_{ch} relates to average transverse mass of produced particles

rises, plateaus, rises again

constant as function of N_{part}

Leveling off starts around $\sqrt{s}$ ~ 7 GeV

For central events:

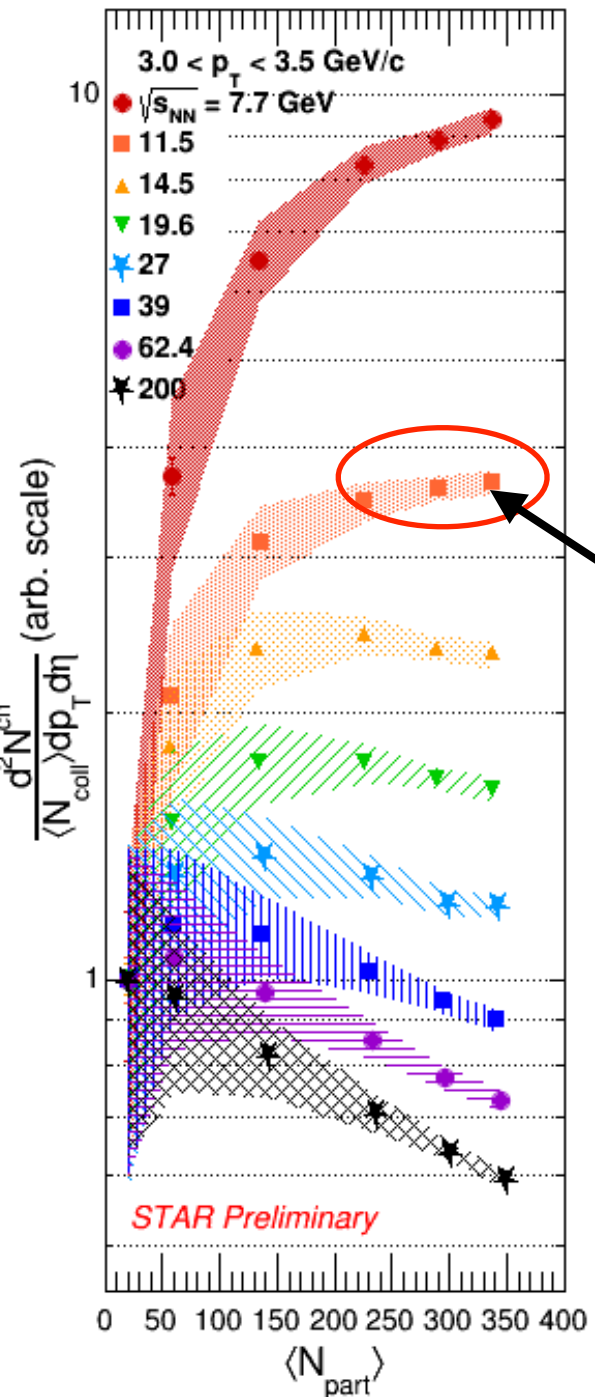
Bjorken energy density*τ > 1 GeV/fm^{2}c

$\varepsilon_{BJ}\tau \propto e^{b\times\log(\sqrt{s_{NN}})}$; (b = 0.422 ± 0.035)

$\varepsilon_{BJ}\tau$ < 1 for low energy peripheral events

Can we establish τ?

Disappearance of QGP?

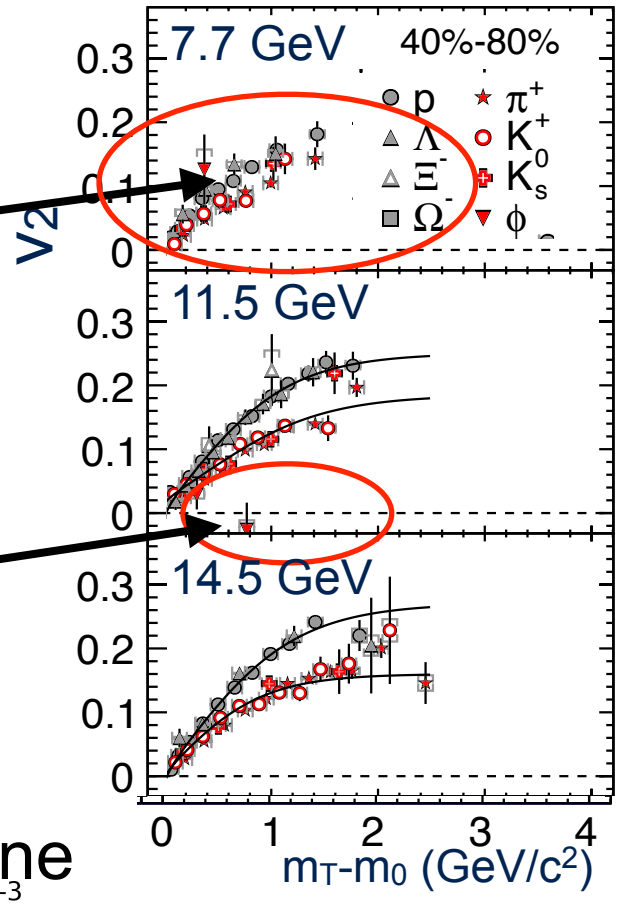


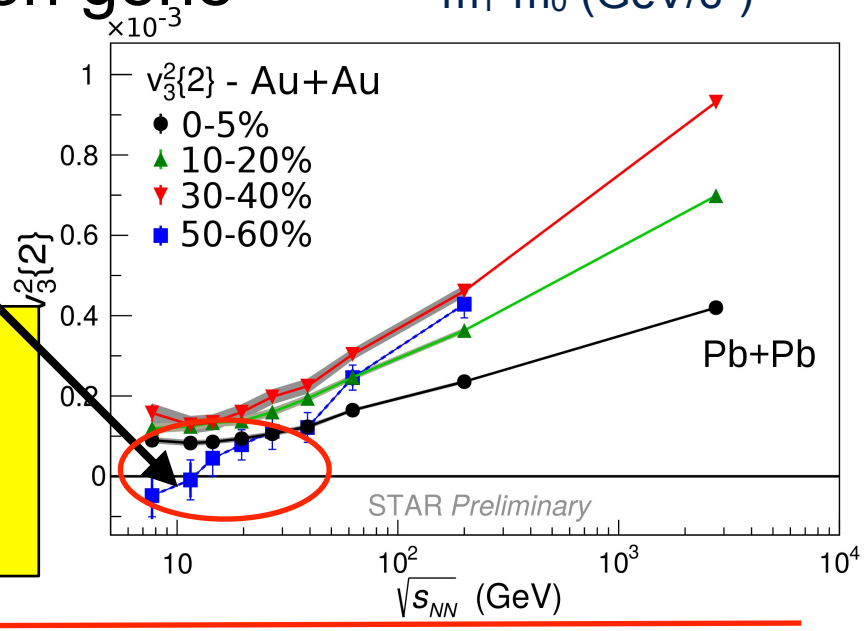
B-M v_2 separation gone

ϕ v_2 ~ 0

High p_T suppression gone

v_3 ~ 0





Several standard signals disappear at $\sqrt{s} < 15$ GeV

First order phase transition?

Beam energy baryon dv_1/dy trend complex

interplay of:

- v_1 baryons transported from beam
- v_1 from pair production

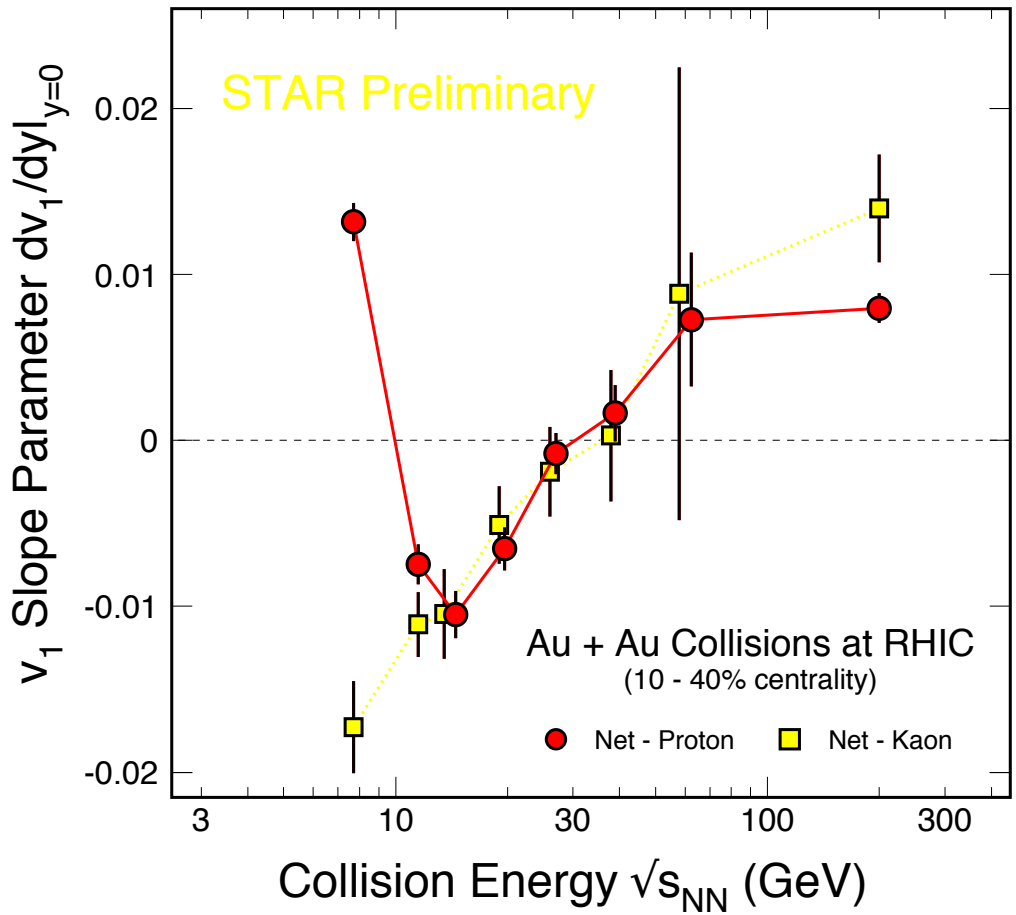
Net-proton isolates directed flow of transported:

- Double sign change in dv_1/dy
- 14.5 GeV in published trend

Not seen in kaons

Many transport models have monotonic trend

PRL 112,162301 (2014)



Softening of EoS ?

"Dale" in longitudinal expansion

Probe expansion dynamics:

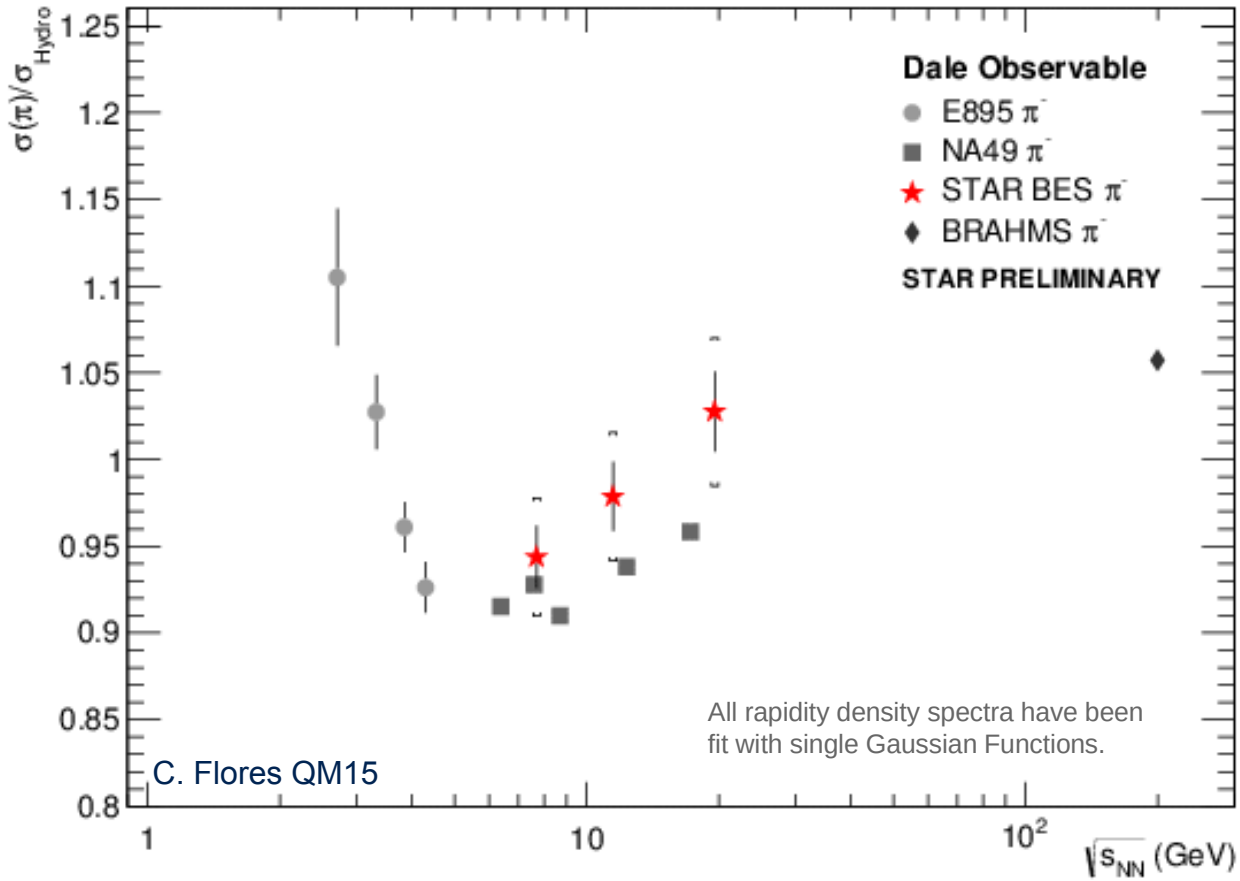
Width of rapidity distribution compared to Landau hydro. expansion predictions

Minimum observed at $\sqrt{s}$ = ~7 GeV

Minimum in the speed of sound?

$c_s^2 \sim 0.26$

Another indication of softening of EoS?



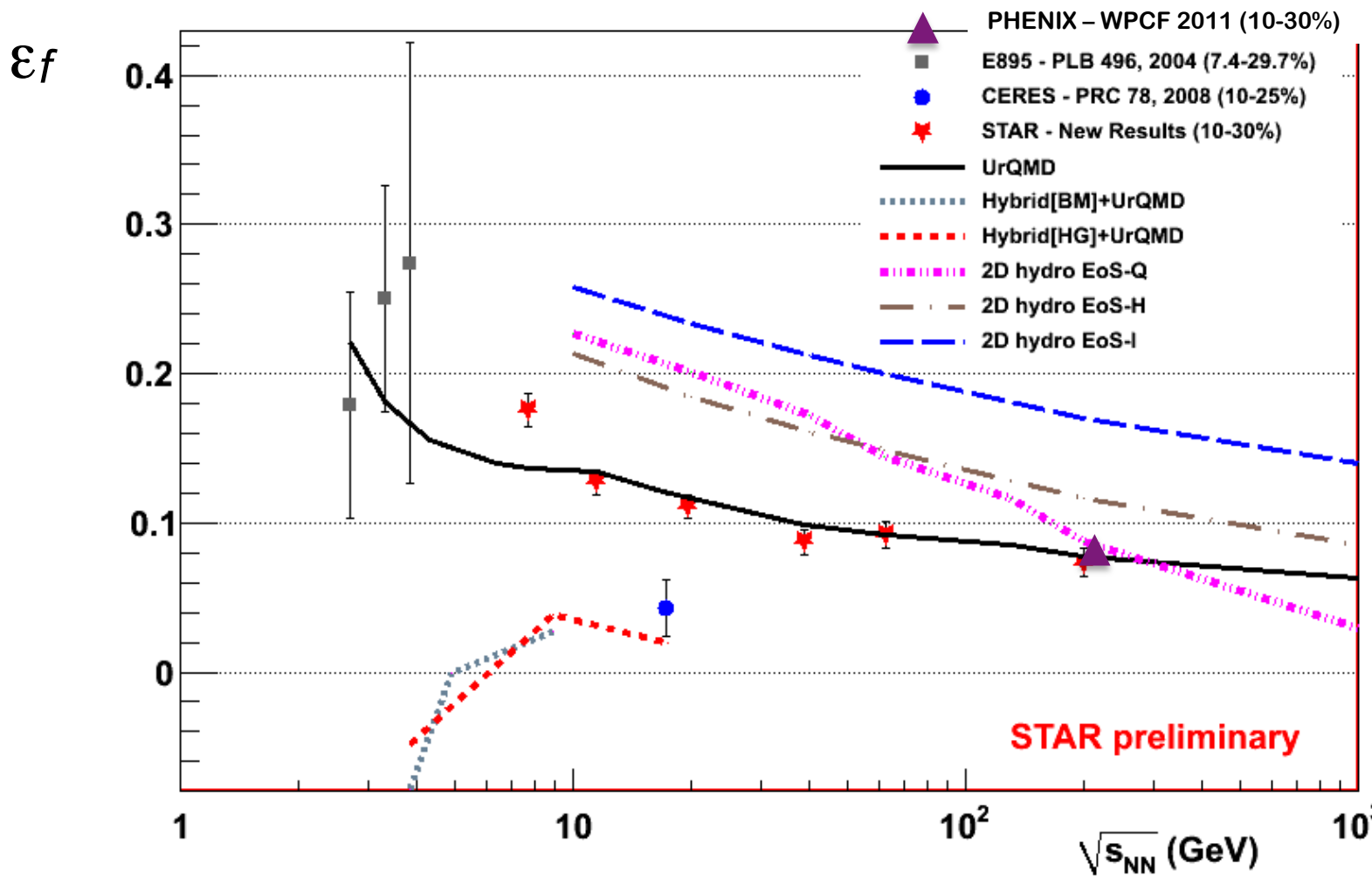
E895: J. L. Klay et al, PRC 68, 05495 (2003)
NA49: S. V. Afanasiev et al. PRC 66, 054902 (2002)
BRAHMS: I.G. Bearden et al., PRL 94, 162301

SHINE see minima in similar place for pp data

BES results for π^+ and π^-

Eccentricity at freeze-out

Accessed via azimuthal HBT



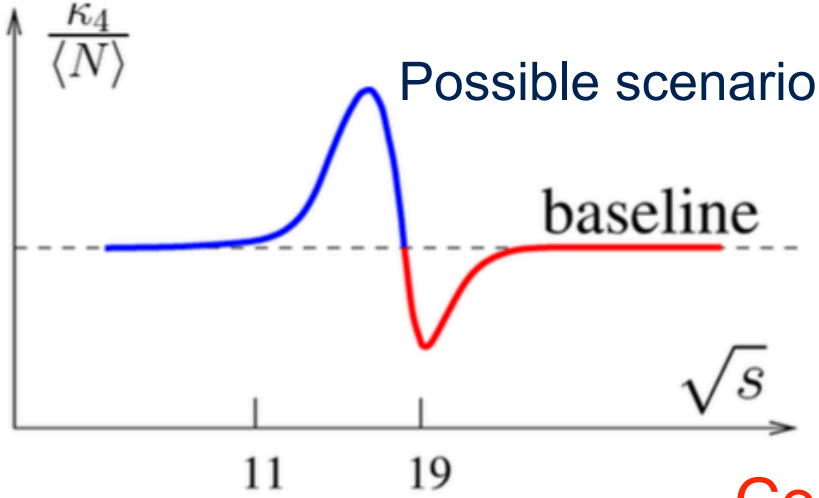
Sensitivity to the EoS

trend smooth over all √s

STAR data does not confirm CERES data

No evidence of change in EoS

Presence of Critical Point?



Critical Points:

divergence of susceptibilities

e.g. magnetism transitions

divergence of correlation lengths

e.g. critical opalescence

Correlation lengths diverge → Net-p $\kappa\sigma^2$ diverge

Top 5% central collisions:

Non-monotonic behavior

Enhanced p_T range → enhanced signal

Peripheral collisions:

smooth trend

5-10% central collisions:

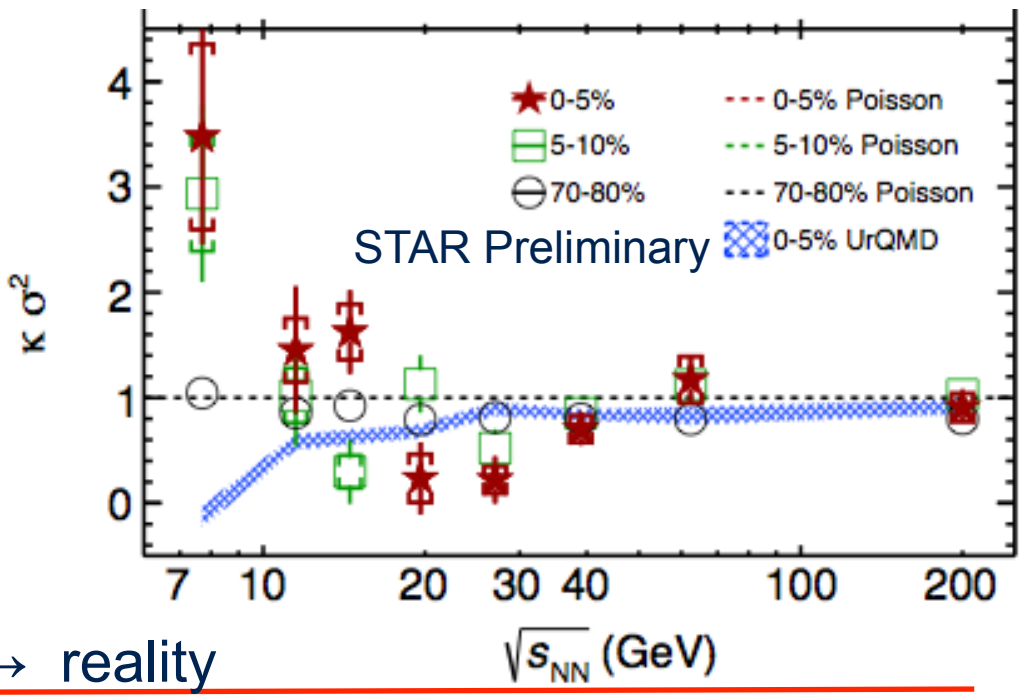
in between

UrQMD (no Critical Point):

shows suppression at lower energies

- due to baryon number conservation

Hints of Critical fluctuations



HADES and Fixed target data: sketch → reality

STAR PRL 112 (2014) 32302

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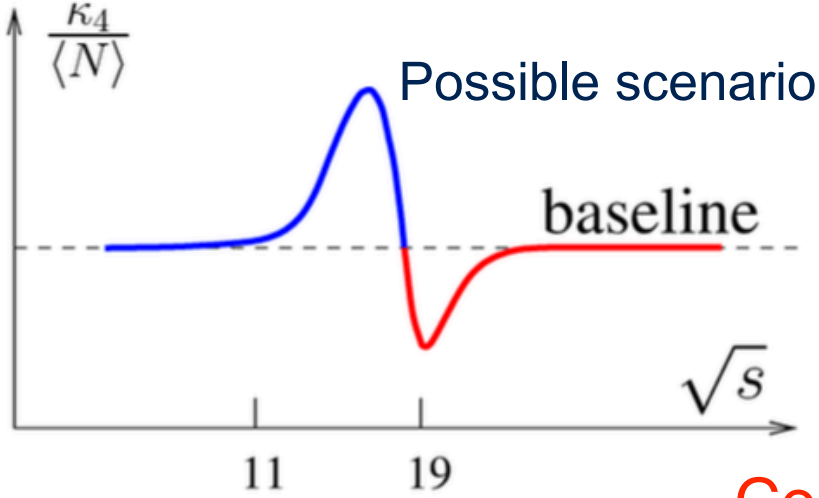

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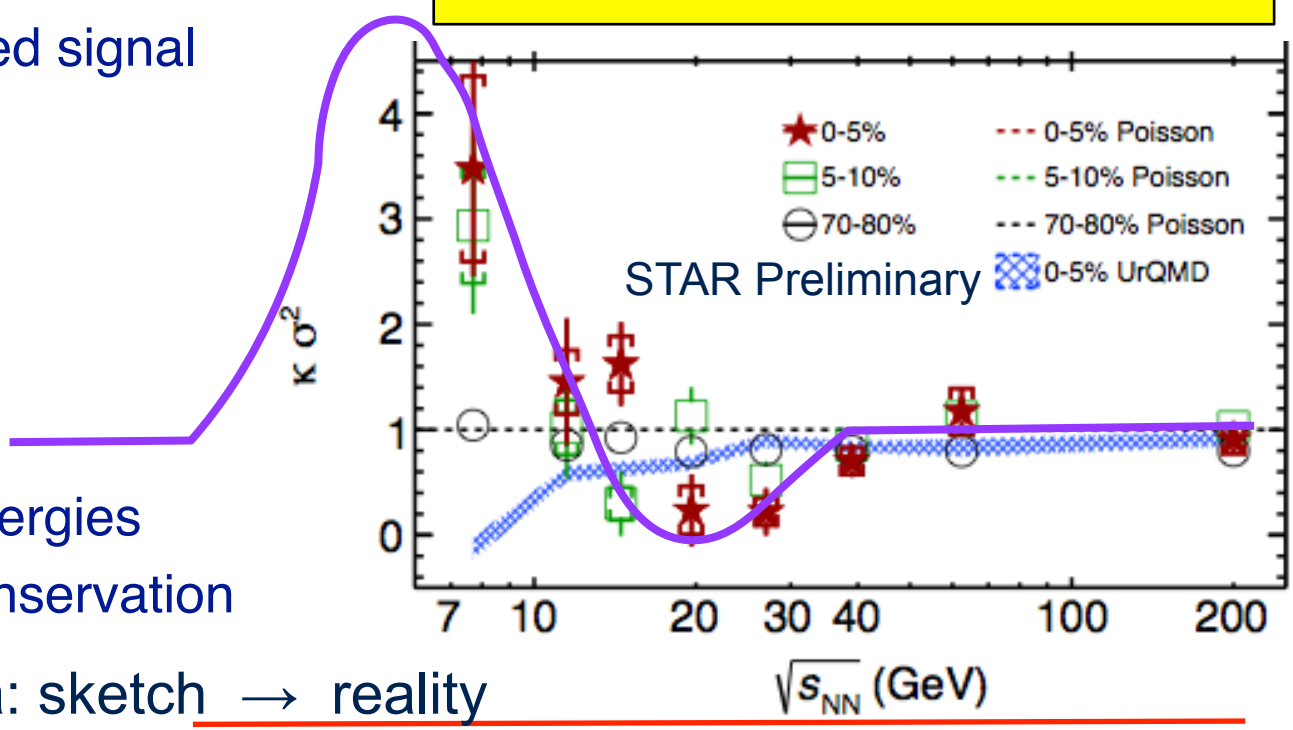


HADES and Fixed target data: sketch → reality

STAR PRL 112 (2014) 32302

HBT and the CP

$(R^2_{out} - R^2_{side})$ sensitive to emission duration

If softening of EoS:

Non-monotonic pattern as function of $\sqrt{s_{NN}}$

Finite size scaling effects can be used to extract location of deconfinement transition

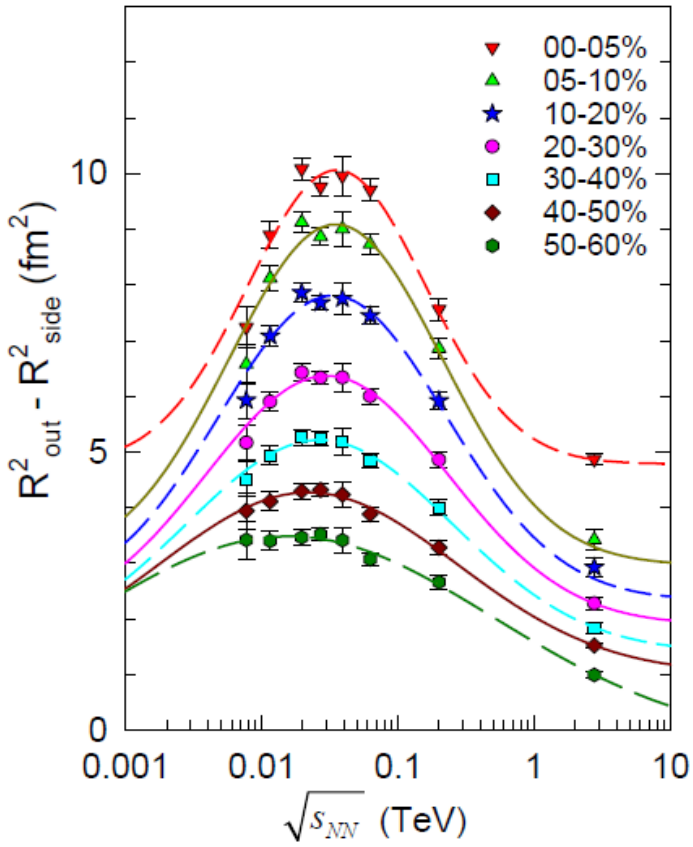
Plot of $(R^2_{out} - R^2_{side})$ as function of initial transverse size of the system

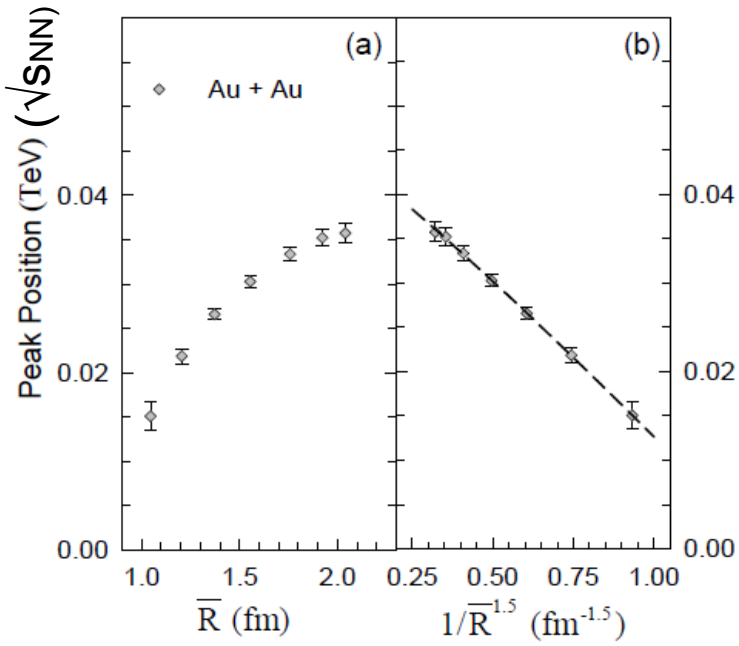
Slope and intercept give information on the location of CP at infinite volume and the critical exponents

Infinite volume $\sqrt{s_{NN}}$ =47 GeV

T^{cep} : 165 MeV, μ_B^{cep} : 95 MeV

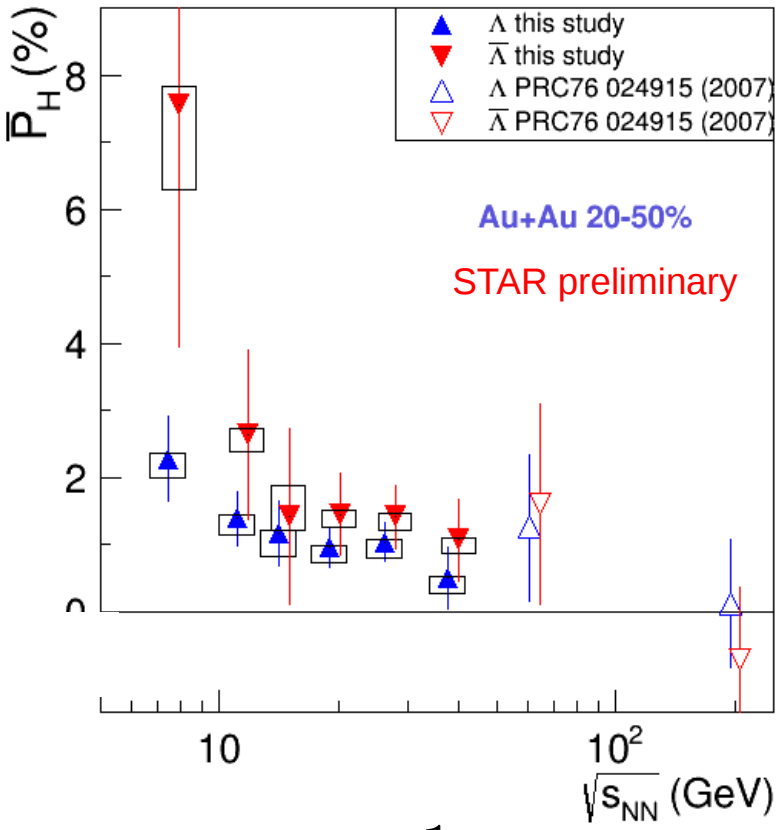
2nd order phase transition





The spinning QGP

Feeddown corrected



$$P_{vortical} = \frac{1}{2}(P_\Lambda + P_{\bar{\Lambda}})$$

$$P_{EM} = \frac{1}{2}(P_\Lambda - P_{\bar{\Lambda}})$$

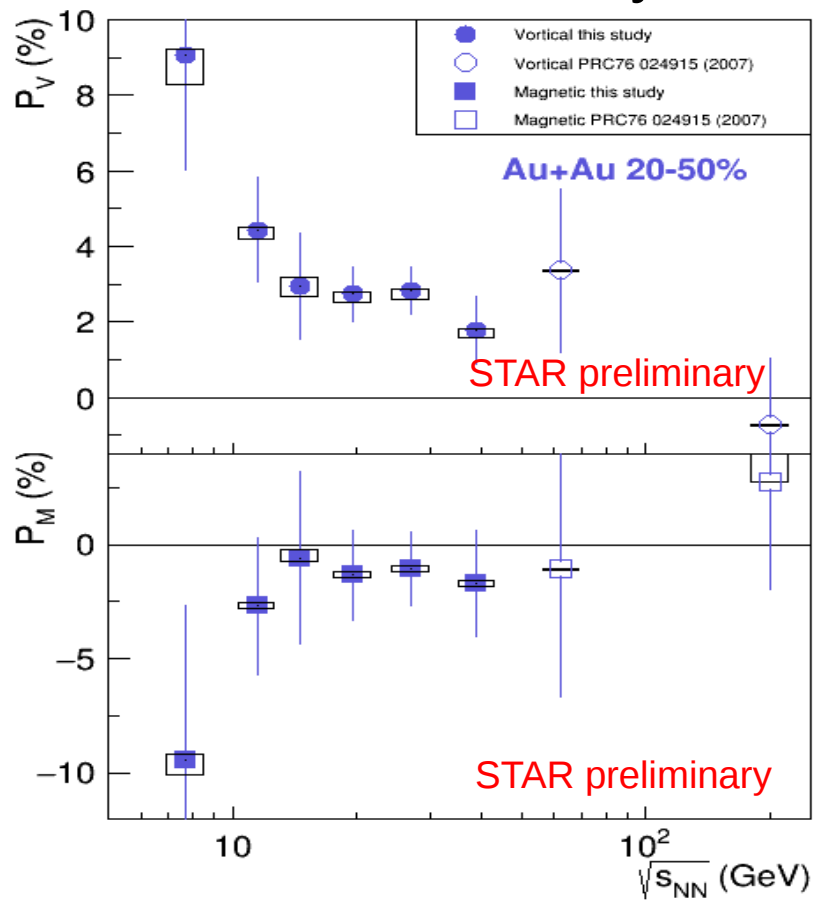
First observation of global hyperon polarization

Marginal significance for each energy

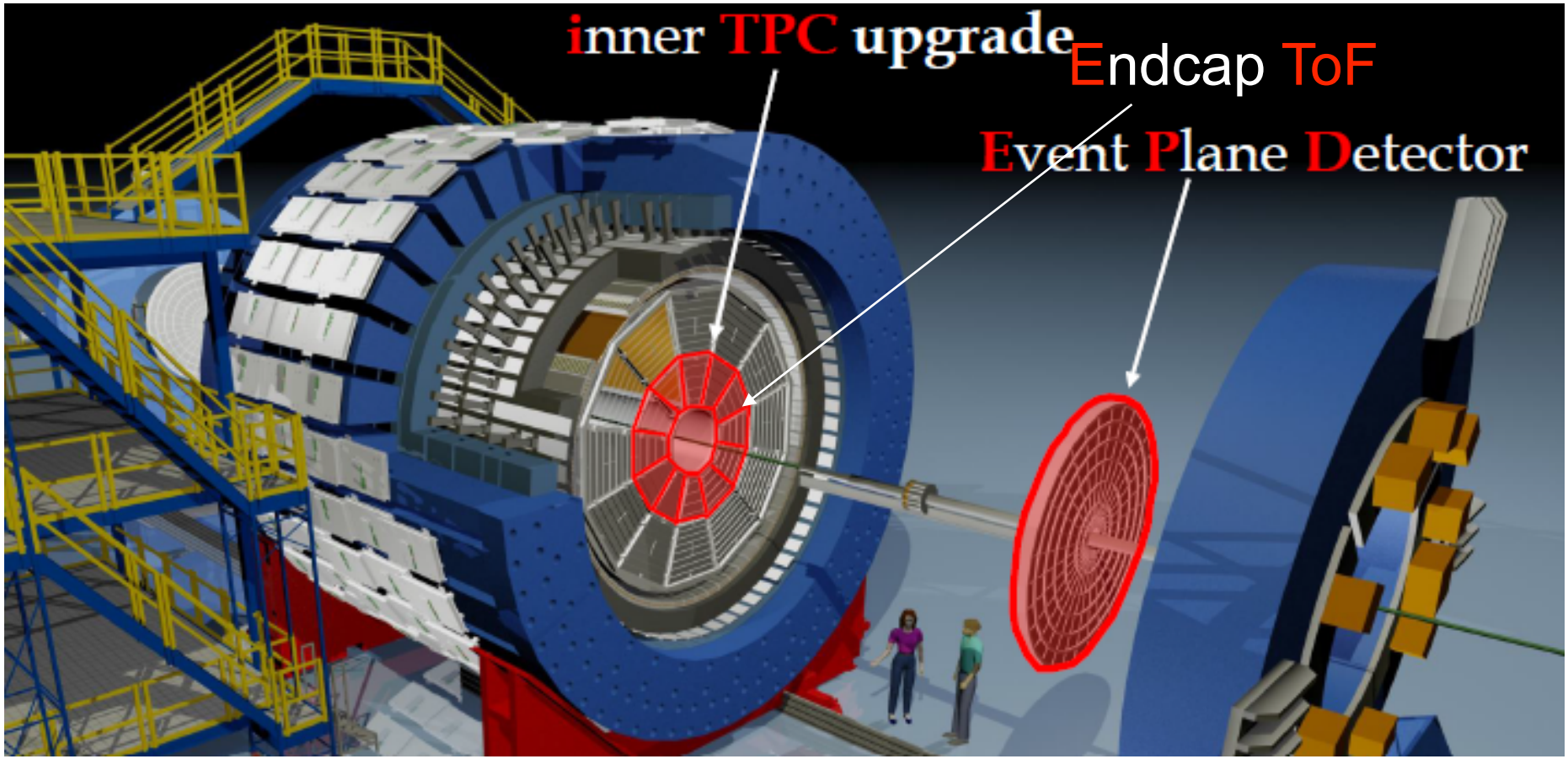
Ensemble and trend add confidence

anti-Λ > Λ

Both EM and vorticity



STAR upgrades for BES-II



Enhanced Acceptance
Enhanced PID
Enhanced Event Plane Resolution
Enhanced Centrality Definition

⟺ iTPC, EPD, eTOF

iTPC

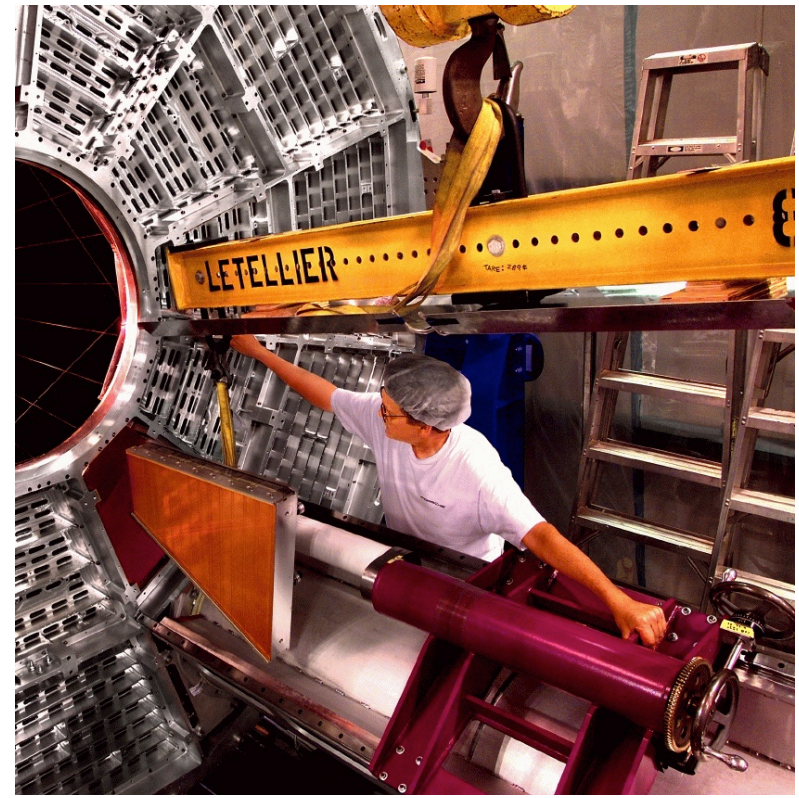
Increase in #channels in 24 inner sectors by ~factor 2

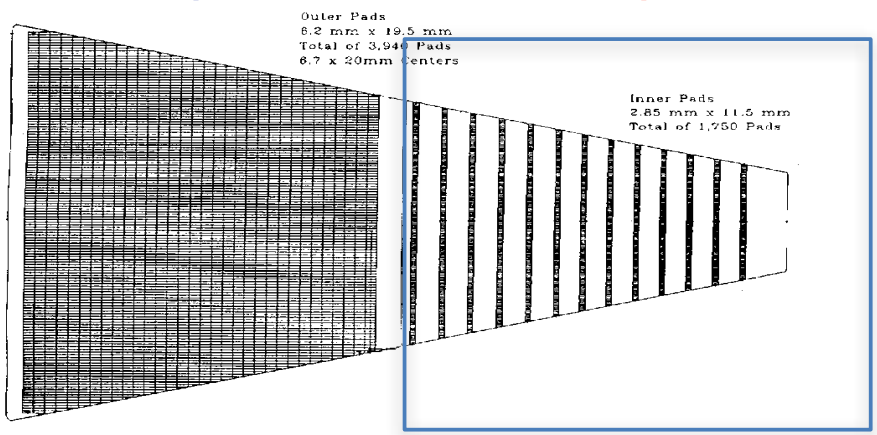
Provides near complete coverage

New electronics for inner sectors

Enhanced rapidity coverage

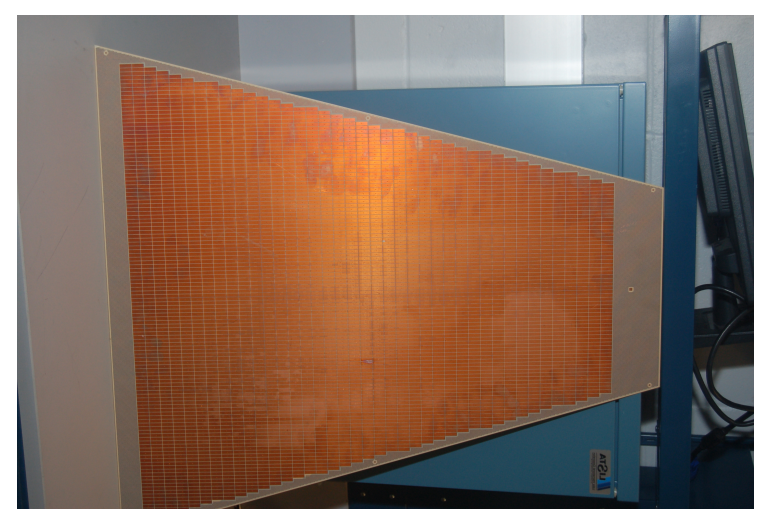
Old	New
	better *dE/dx*;
$-1 < \eta < 1$	$-1.5 < \eta < 1.5$;
$p_T > 125$ MeV/*c*	$p_T > 60$ MeV/*c*.



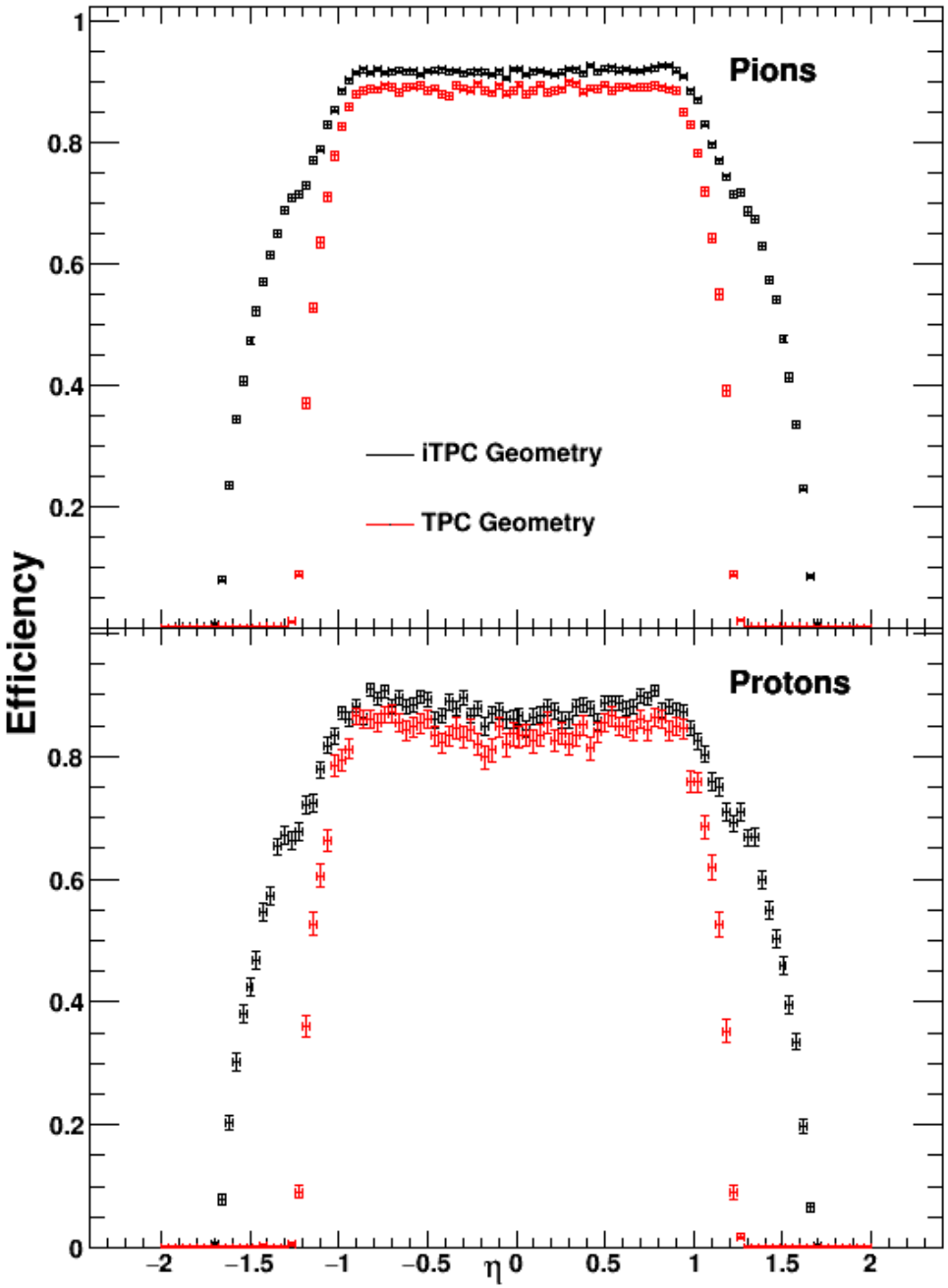


Outer

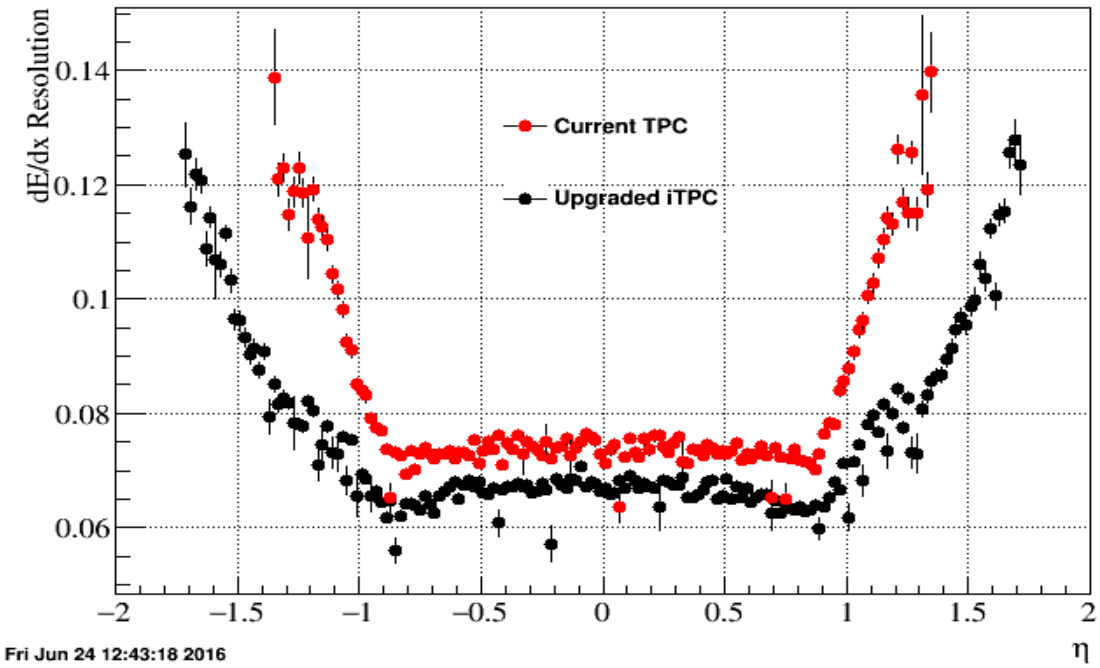
Inner



Enhanced tracking and dE/dx performance



Increased coverage, efficiency and dE/dx resolution out to $|\eta| < 1.5$

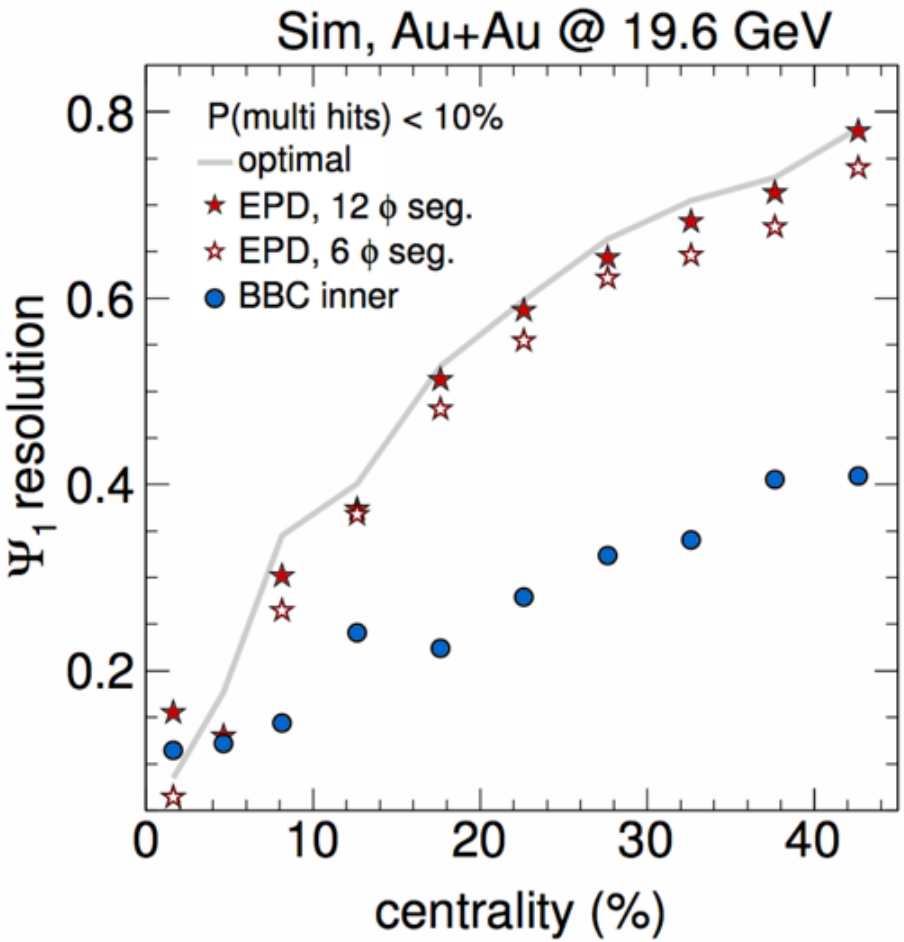


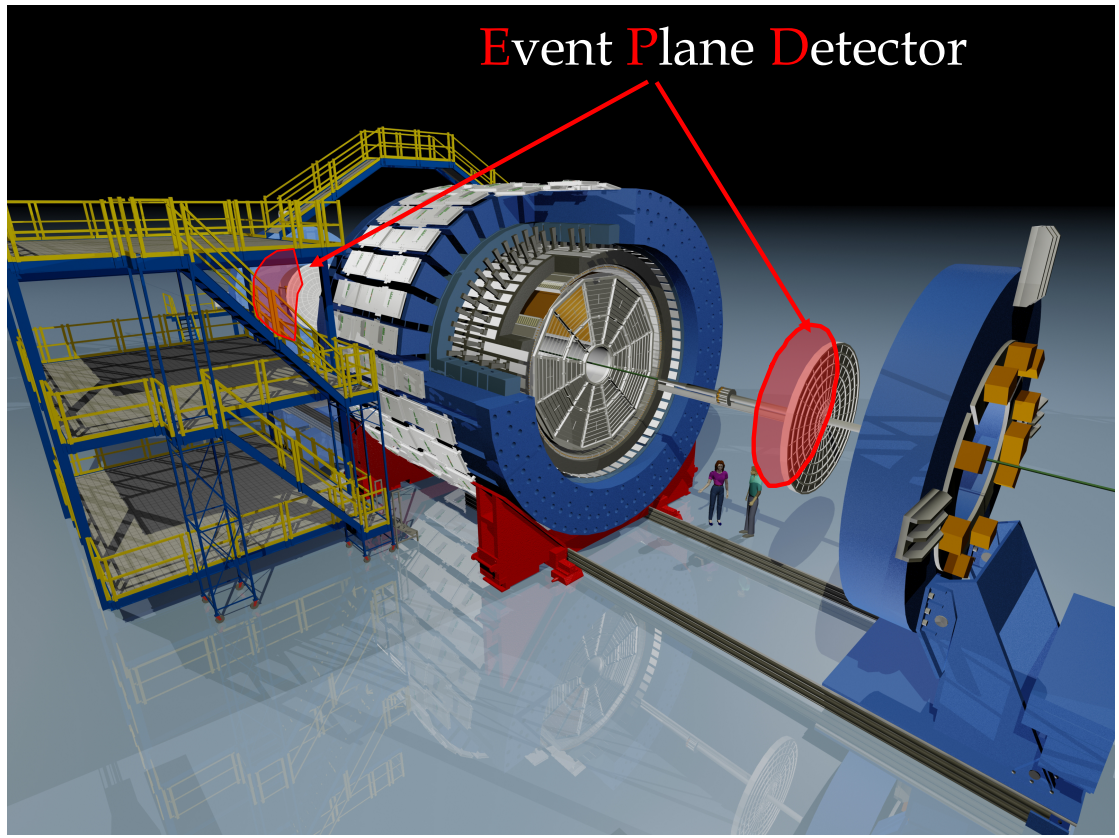
Event Plane Detector: EPD

$2.1 < |\eta| < 5.0$

Replacing BBCs

16 radial and 24 azimuthal sections





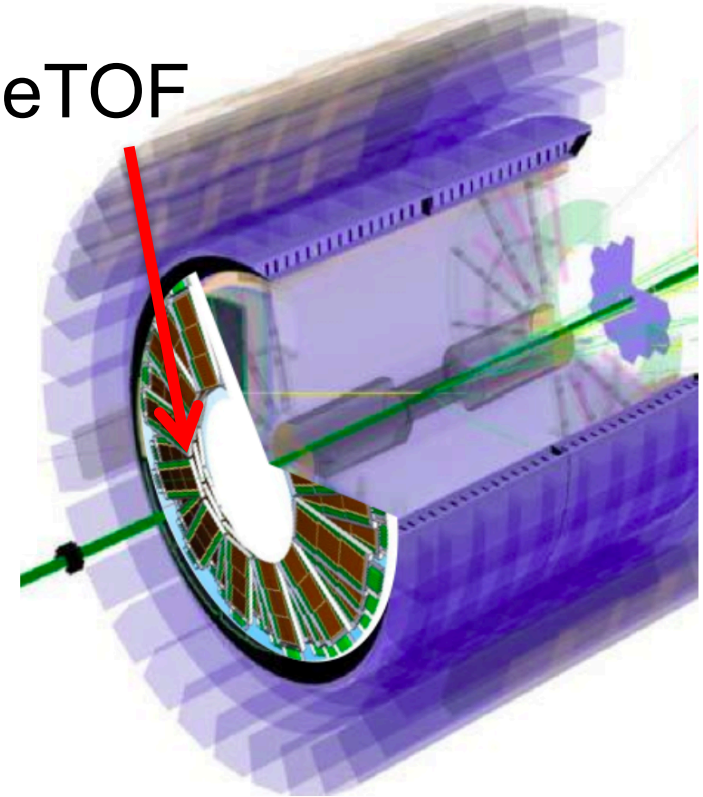
Greatly improved Event Plane Resolution

especially 1st-order EP

Determine Centrality away from mid-rapidity

Better trigger & background reduction

Endcap Time-Of-Flight: eTOF



Forward PID over iTPC η range

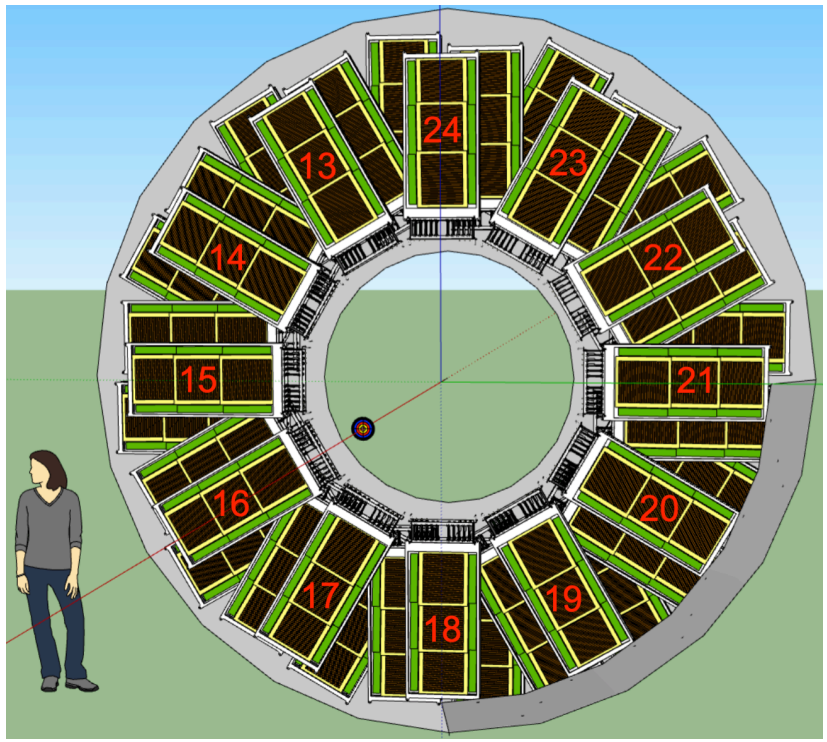
$-1.6 < \eta < -1.1$

TPC dE/dx effic. drops rapidly in this range due to p_z boost

Compressed Baryonic Matter Experiment (CBM)

- 1/10th TOF modules installed inside East pole-tip
- Large-scale integration test of system for CBM

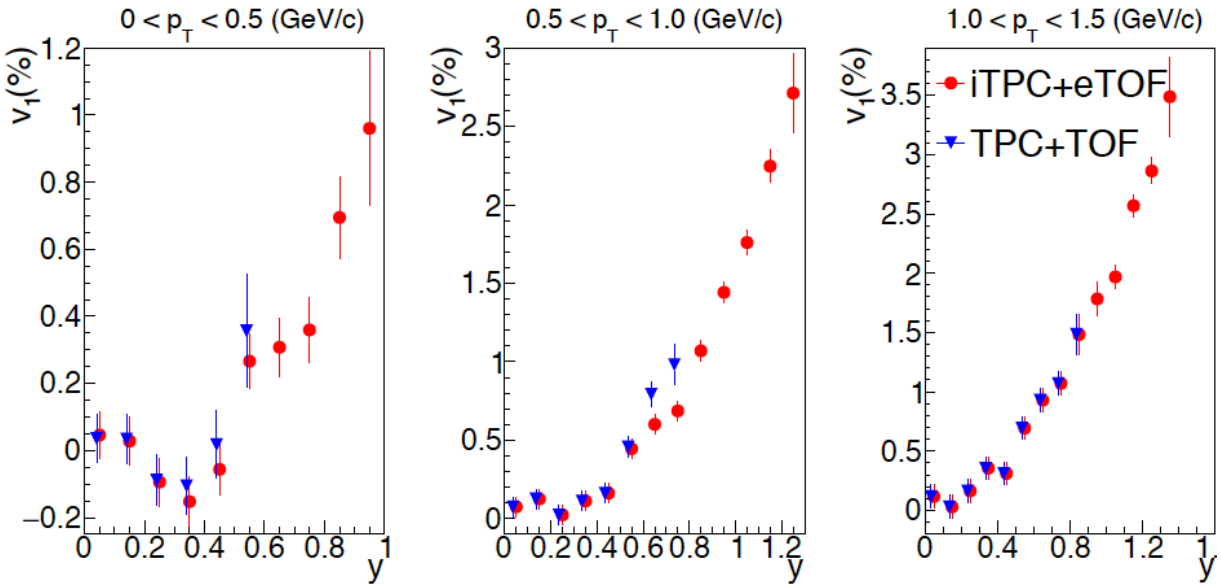
Single TOF module for Run-17
- integration test

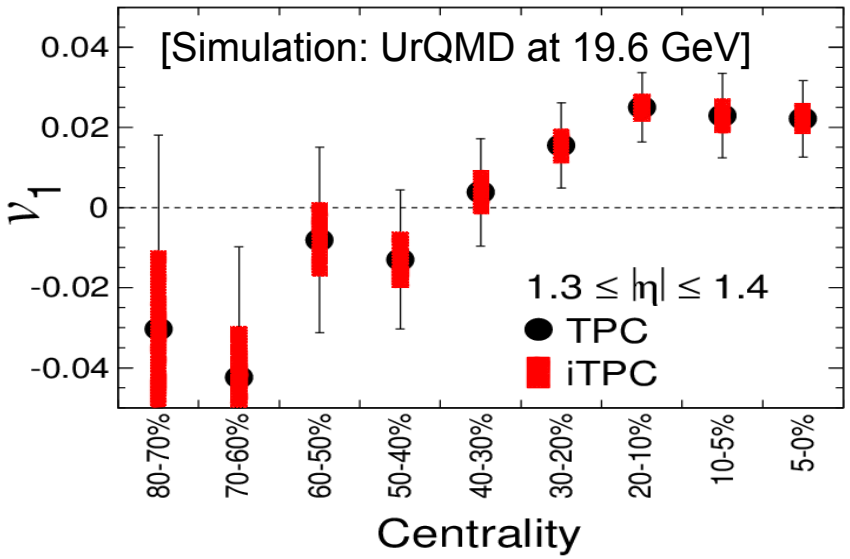


BES-II: Softening of EoS

BES-I: Double sign change of v_1

Precision measurement of dv_1/dy as function of centrality





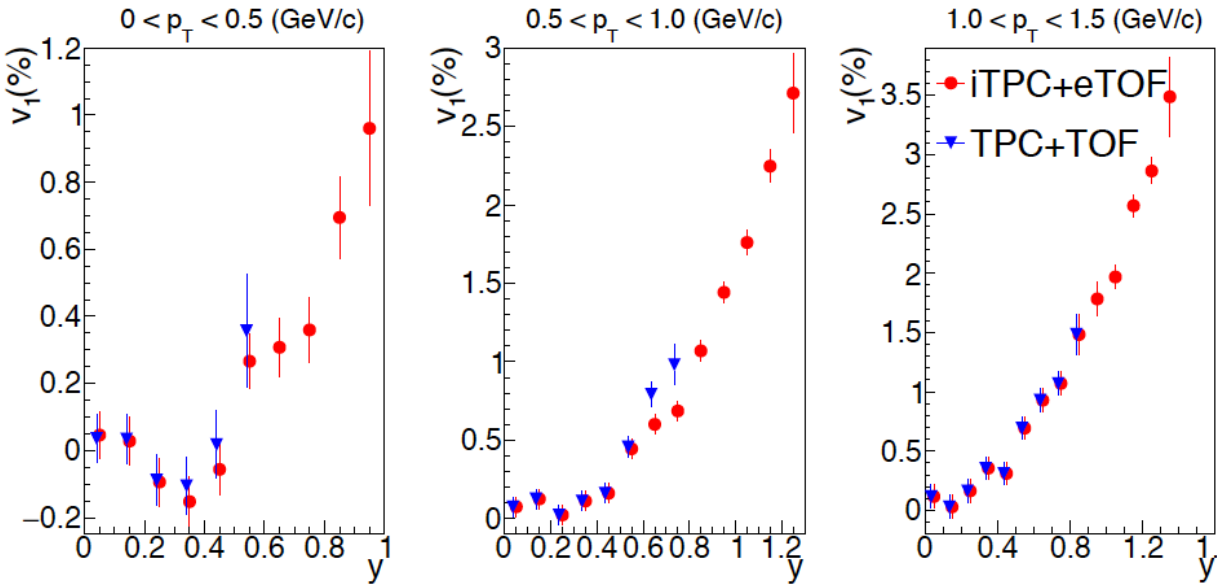
iTPC+ eTOF:

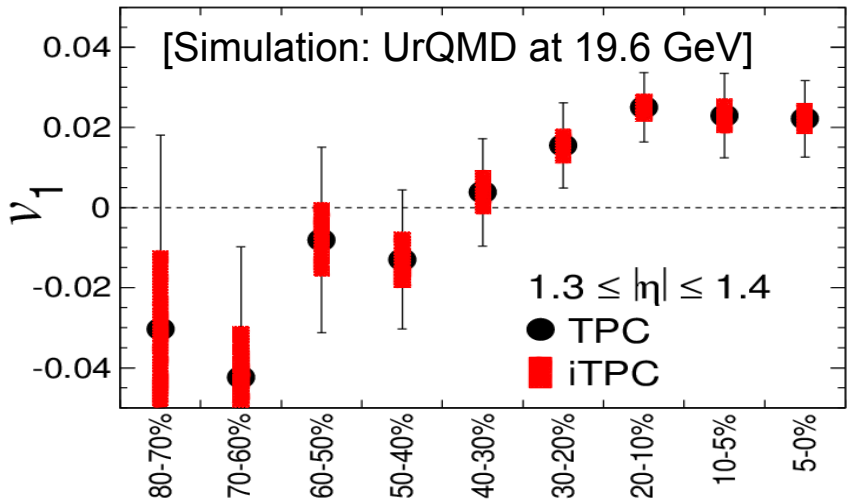
- Enhanced coverage at forward y
  - Signal larger - role of baryon stopping

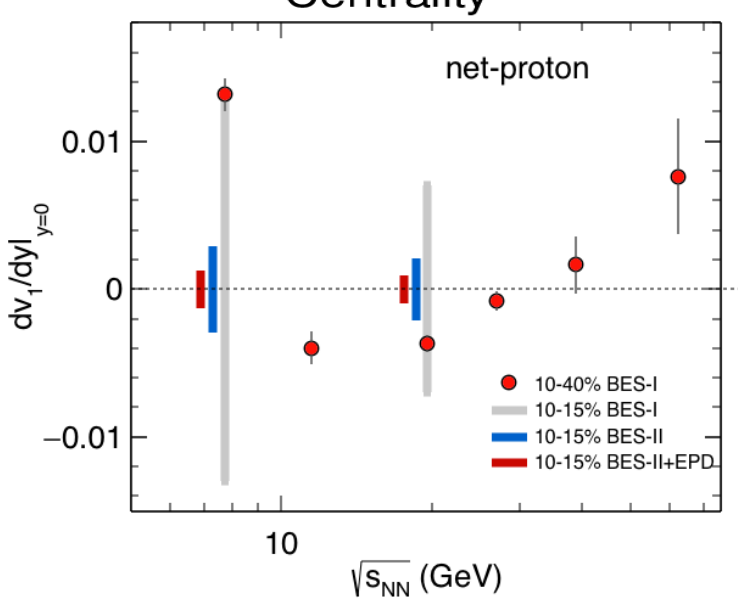
BES-II: Softening of EoS

BES-I: Double sign change of v_1

Precision measurement of dv_1/dy as function of centrality







iTPC+ eTOF:

- Enhanced coverage at forward y
  - Signal larger - role of baryon stopping

EPD:

- Enhanced 1st order EP resolution
  - Reduced systematics

BES-II: Critical fluctuations

BES-I: Suggestive of non-trivial √s dependence of net proton cumulant ratios

iTPC:

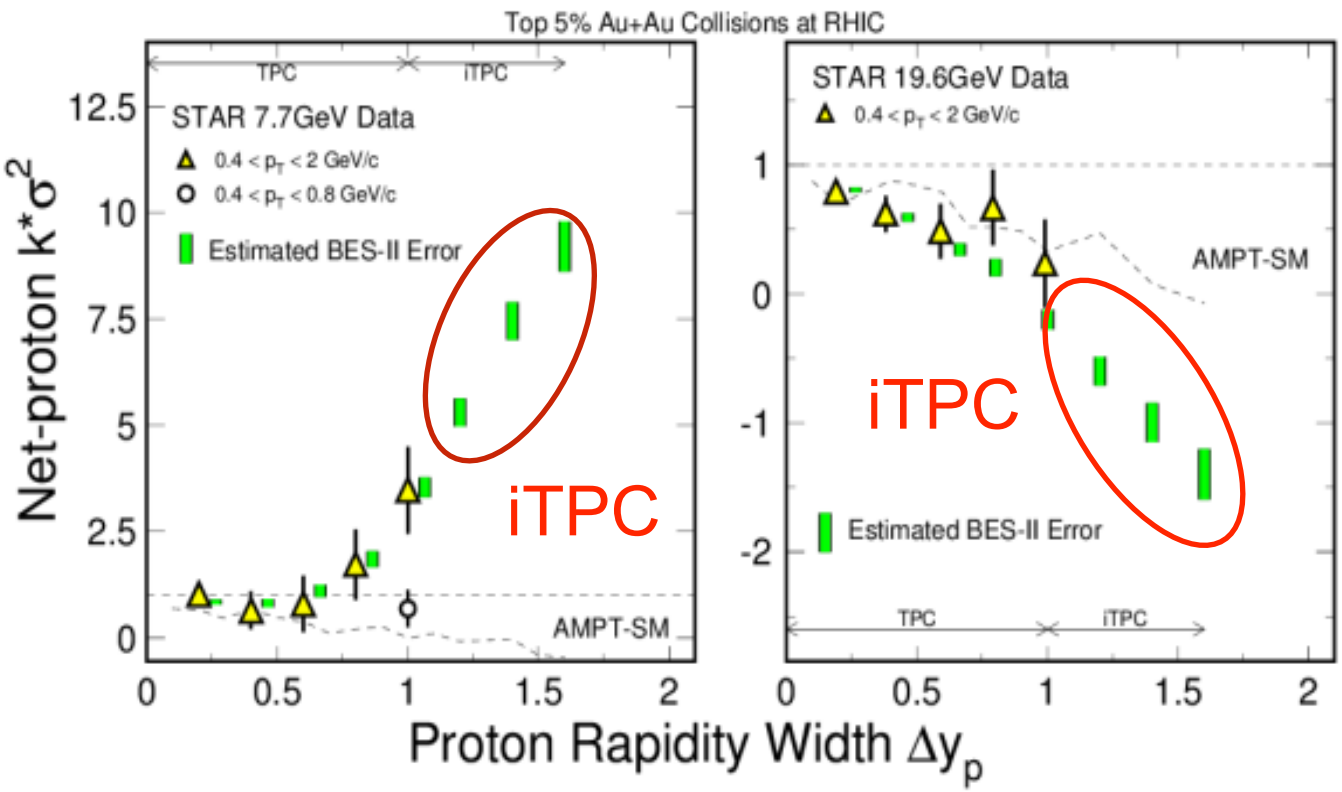
Increase Δy_p acceptance

$\Delta y_p > \Delta y$ correlation

EPD:

Improved centrality selection

Use all TPC for measurement

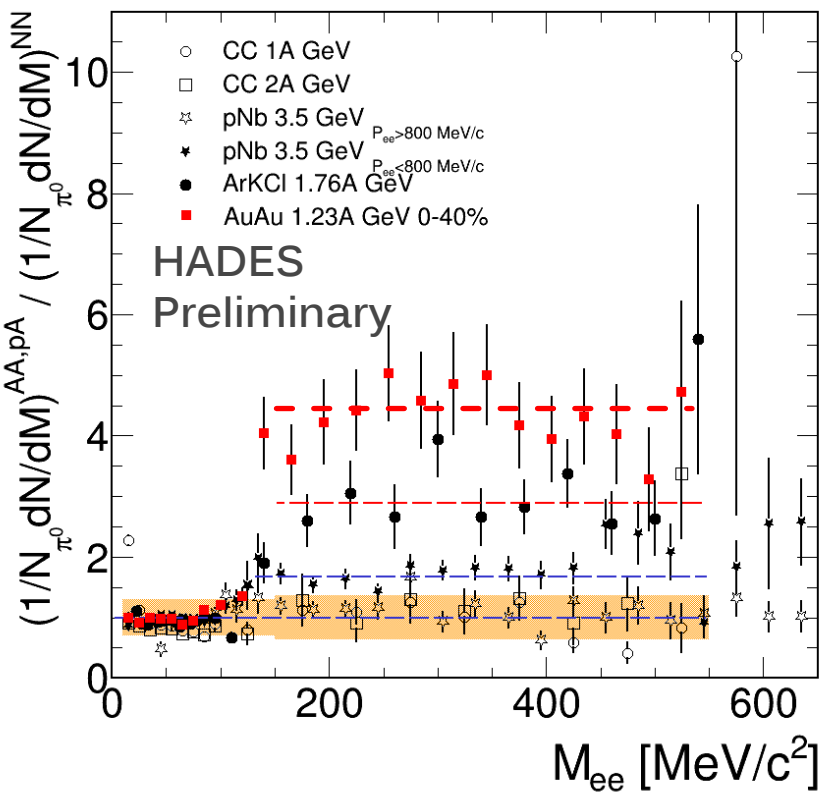


Establish true nature of correlation

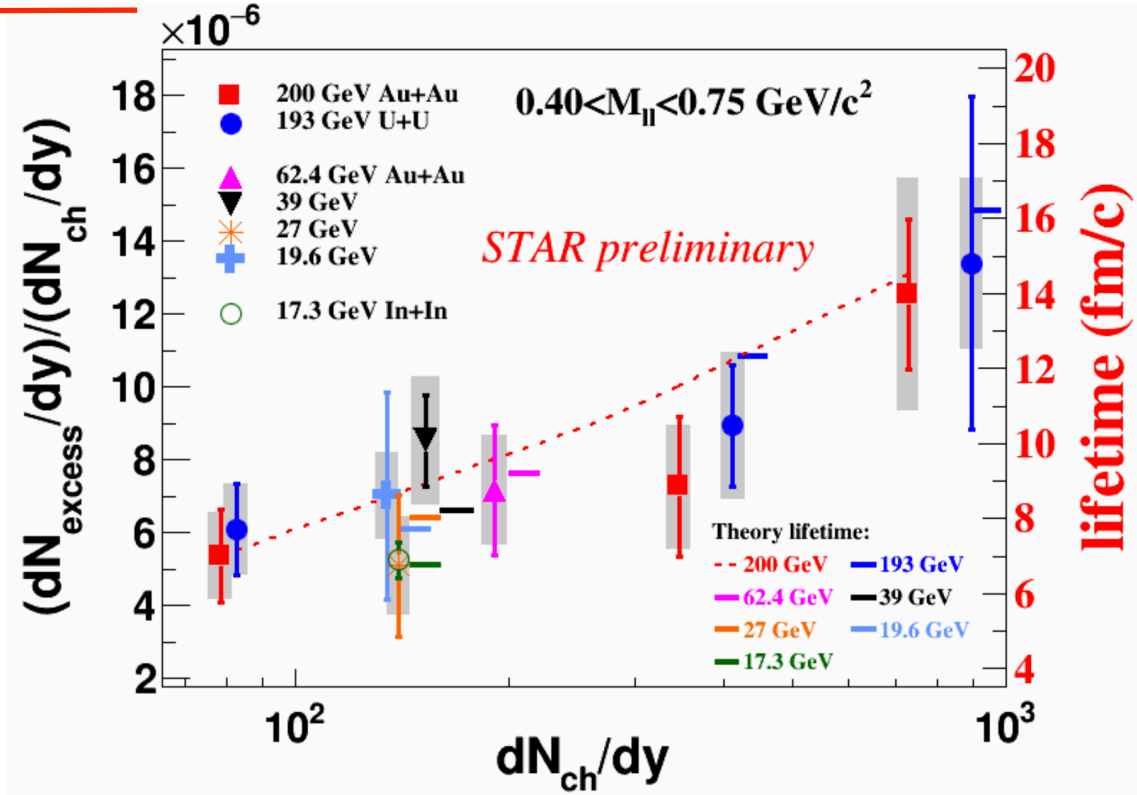
Subject actively pursued theoretically

Low mass di-lepton excess

HP2016 J. Butterworth (STAR) P. Sellheim (HADES)



In Au+Au excess scales as $A^{1.3}_{part}$



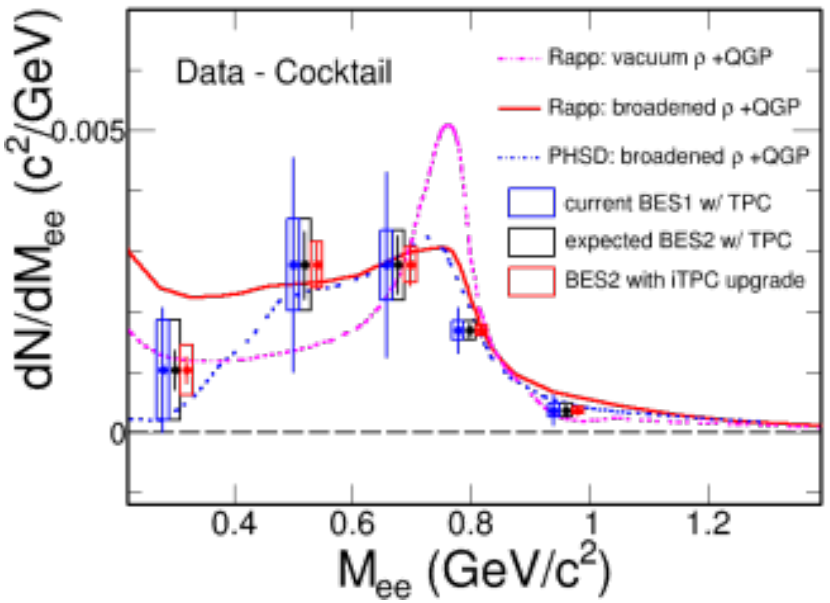
Low mass excess ∝ fireball lifetime

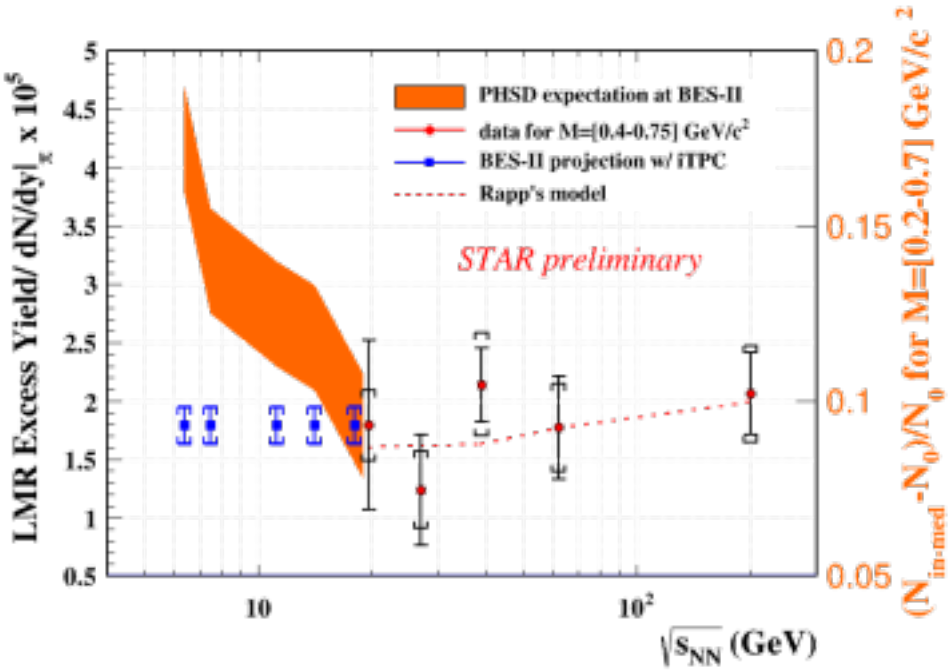
for large range of beam energies and centralities

Results suggest excess from total baryon driven hot dense medium effects and the medium's lifetime

Looking forward to adding HADES, BES-II and LHC data into trend plots

BES-II: Change the total baryon number





ρ-meson broadening:

different predictions for di-electron continuum (Rapp vs PHSD)

iTPC: Significant reduction in sys. and stat. uncertainties

Enables to distinguish between models for √s =7.7-19.6 GeV

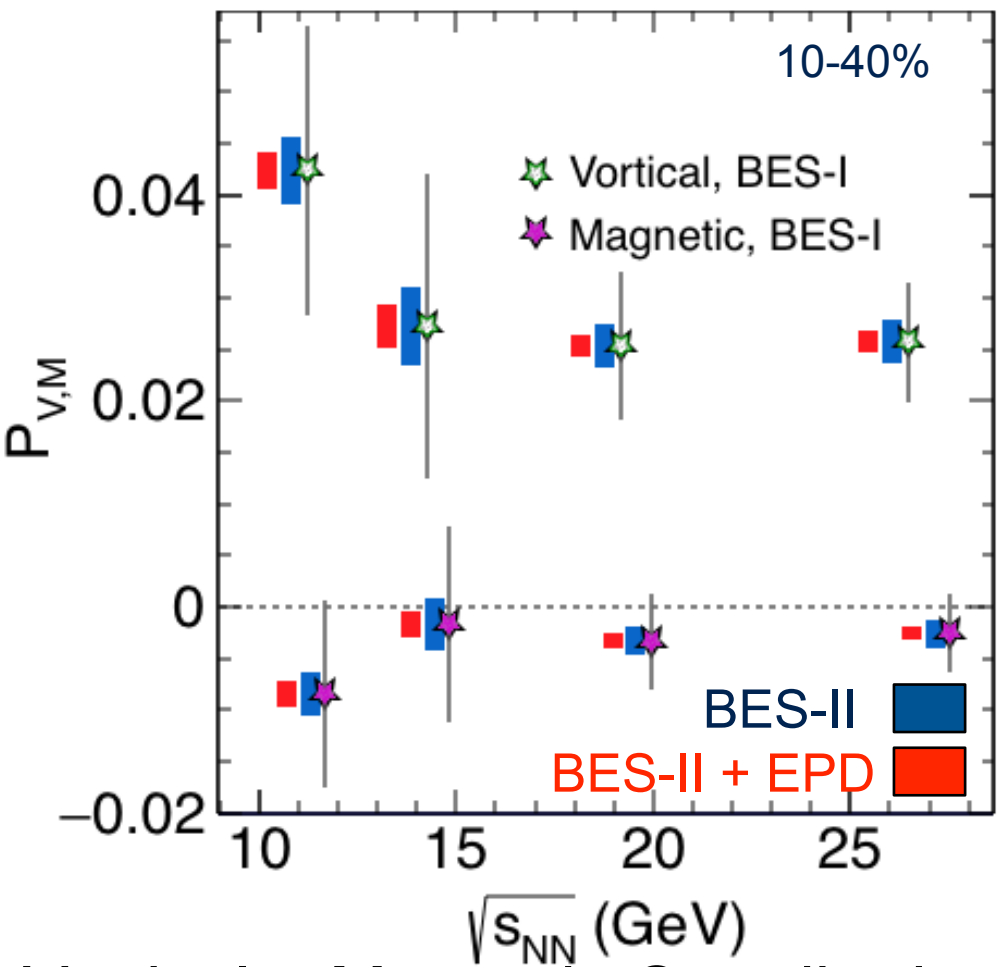
Low Mass Region:

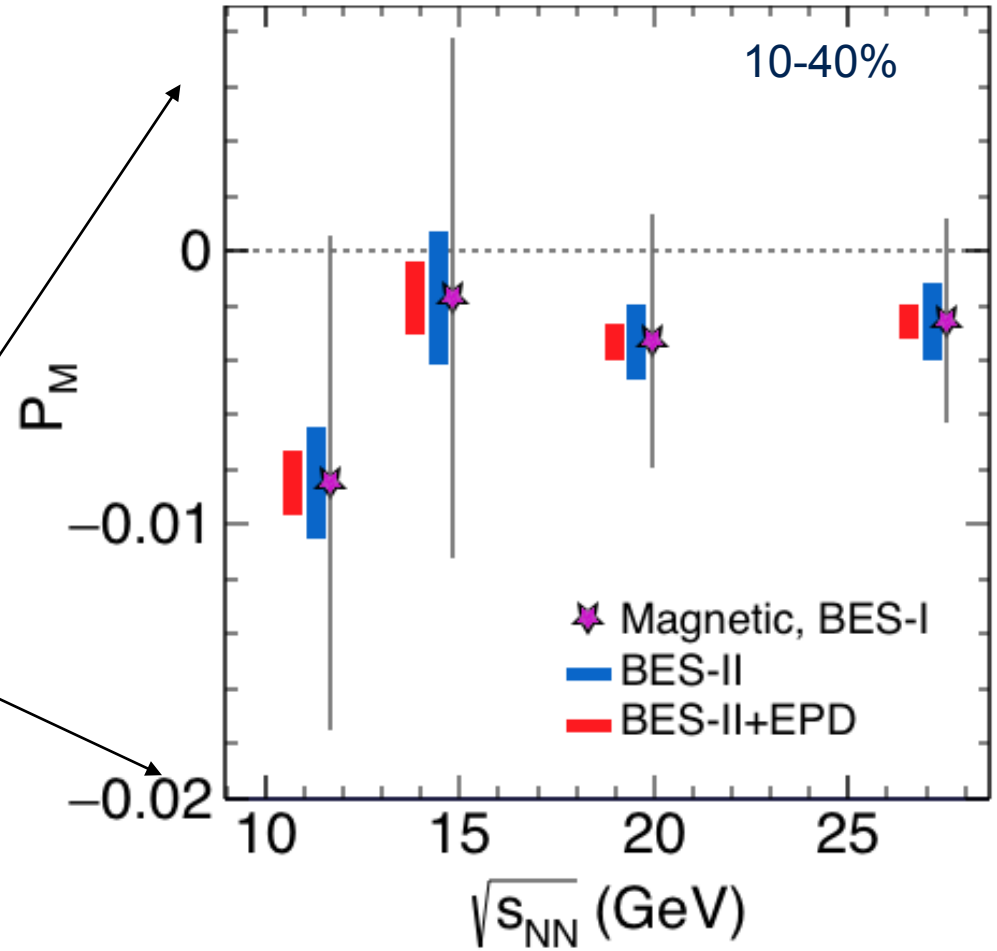
iTPC: Significant reduction in sys. and stat. uncertainties

Disentangle total baryon density effects

BES-II: Vorticity and Initial B-field

*BES-I: First measurement of Λ **Global** Polarization*





Vortical + Magnetic Contributions:

Current data barely stat. significant

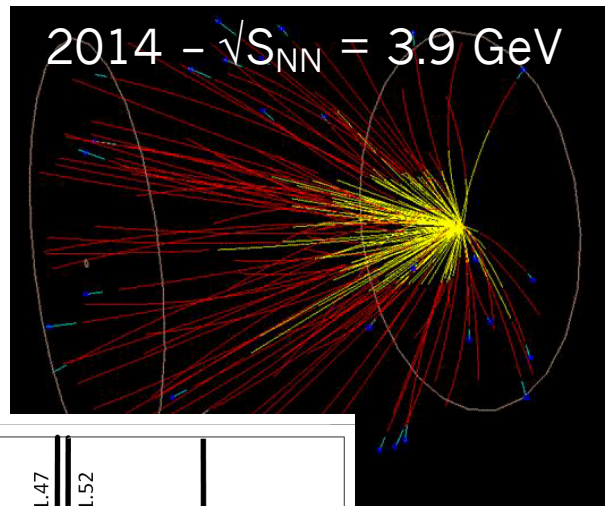
EPD:

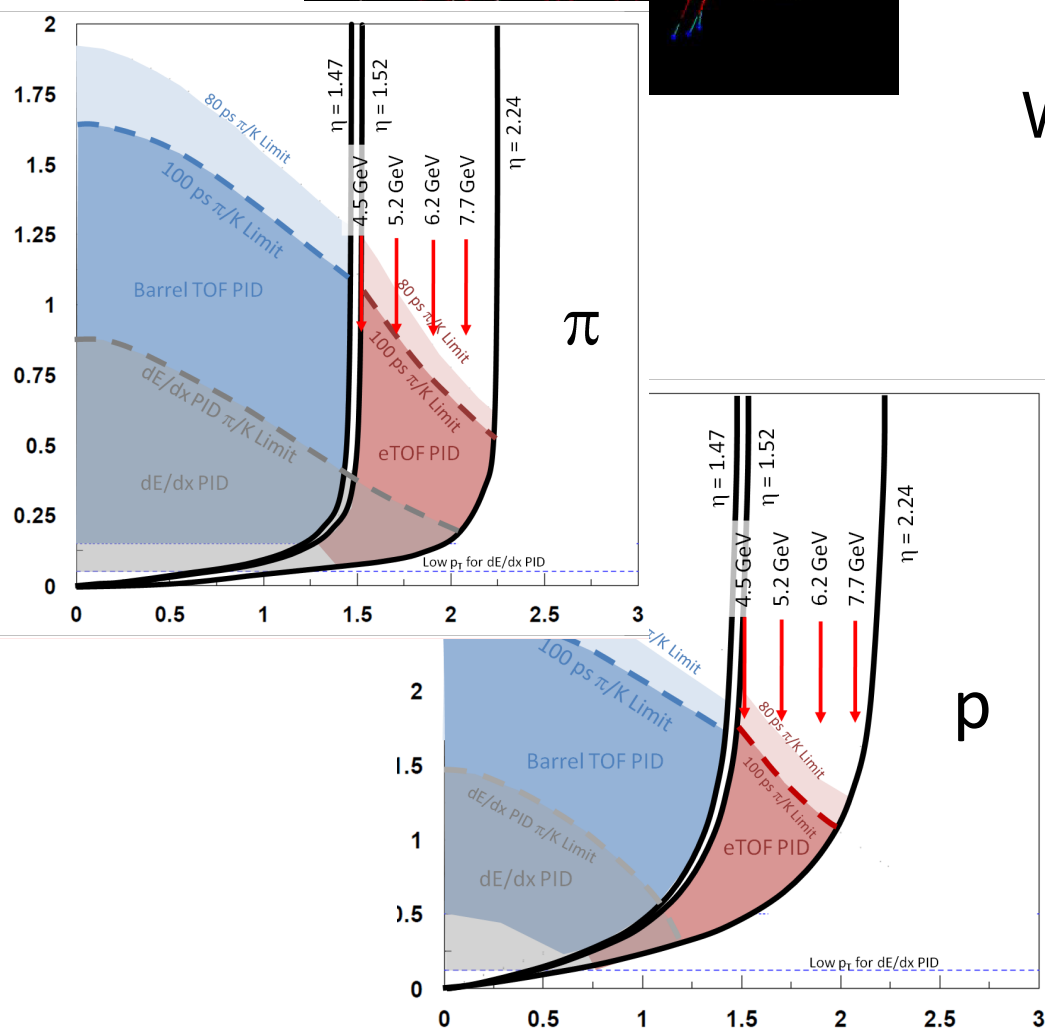
Improved EP resolution

BES-II: 3σ effect

Unique measurement of B
Significant input to CME/CVE interpretations

BES-II: Onset of deconfinement





NA49 - onset of deconfinement at $\sqrt{s}$ = 7.7 GeV

Fixed target program

- Collider can't run below 7.7GeV
- Target in beam pipe at z=210cm

Will perform dedicated short runs

- More efficient
- Successful tests completed

TOF+iTPC:

- Forward acceptance in fixed target mid-rapidity range
  - Reach 7.7 GeV for fixed target too

Precision investigation with new techniques and same detector

Summary

High statistics exploration of QCD phase diagram and its key features

Significantly extended detection capabilities

iTPC → enhanced y- p_T acceptance - Project en route to success

EPD → crucially improved EP resolution - Hopeful support will be found

eTOF → significant improvement to PID - Hopeful support will be found

eCooling → higher beam luminosities, better statistics

Also new data from SPS, FAIR and NICA on the horizon

In conjunction: Turn trends and features into definitive conclusions

Strong theoretical interest: BEST Collaboration & this Workshop