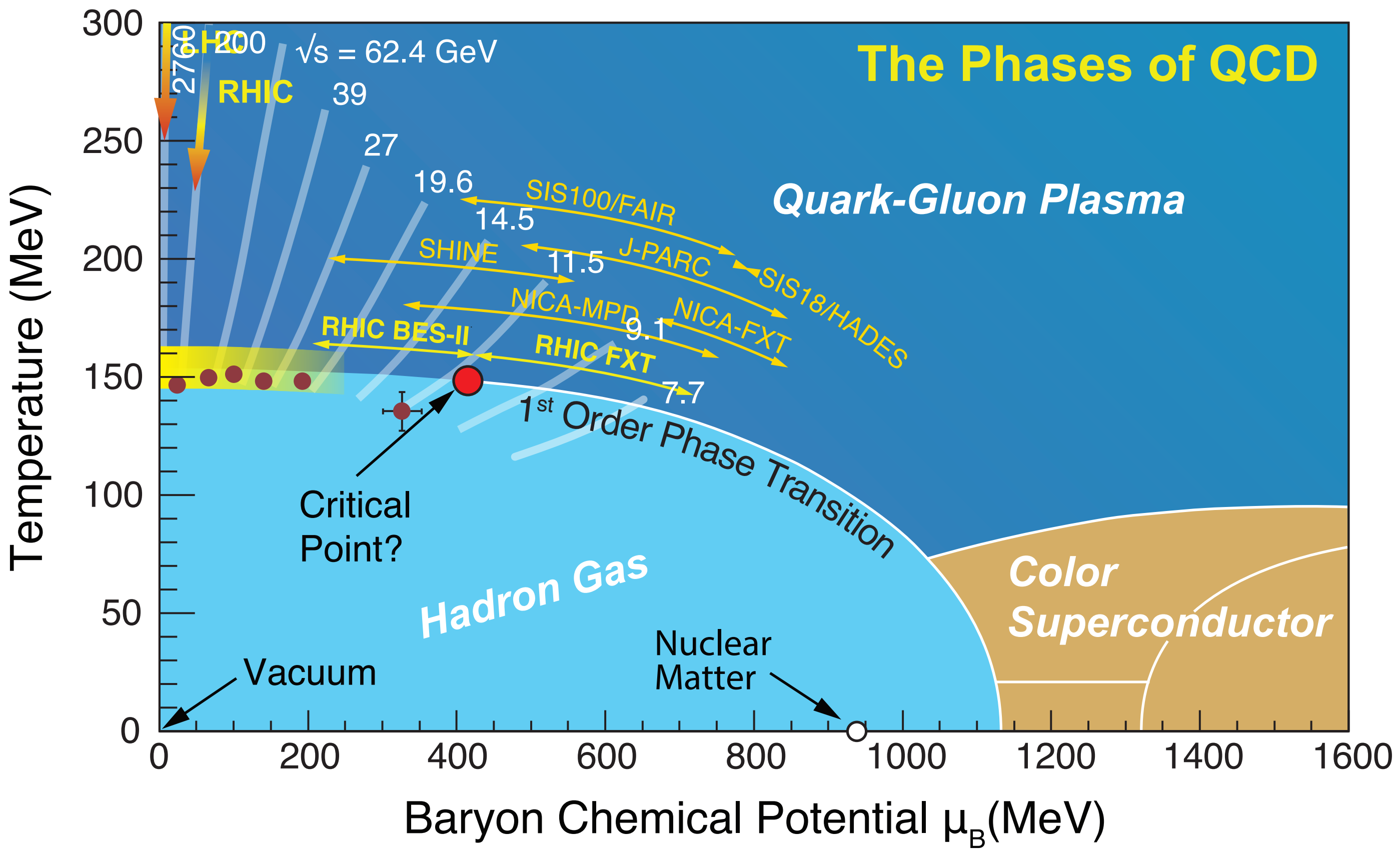
STAR's Beam Use Request for BES-II

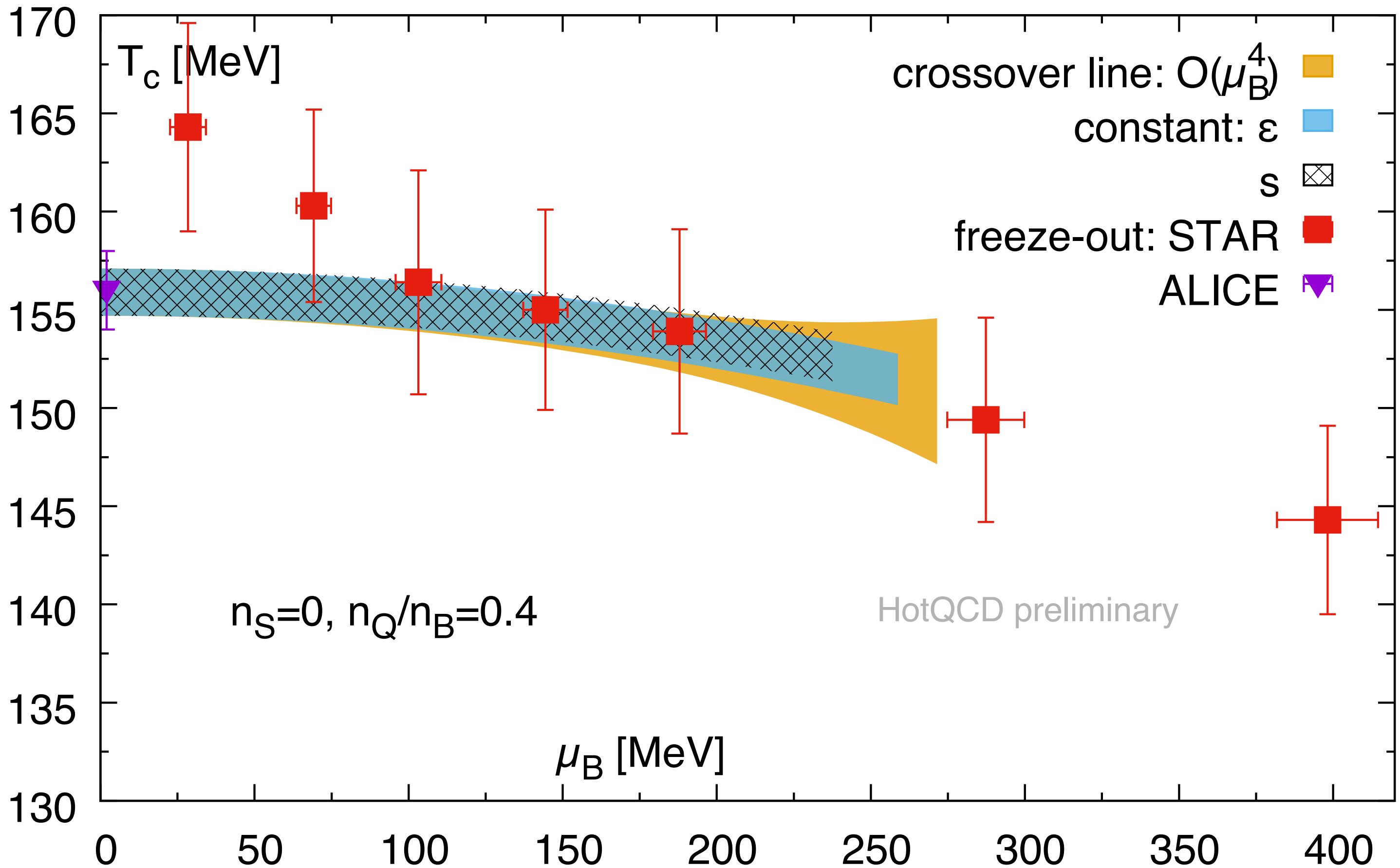


Helen Caines - Yale

on behalf of the STAR Collaboration

Is there a Critical Point?

Latest from the lattice: Cross-over starts at T_0 = 156.5 (1.5) MeV
ε_0 ~ 1 GeV/fm^3



No indication of CP for μ_B < 250 MeV

Patrick Steinbrecher QM18

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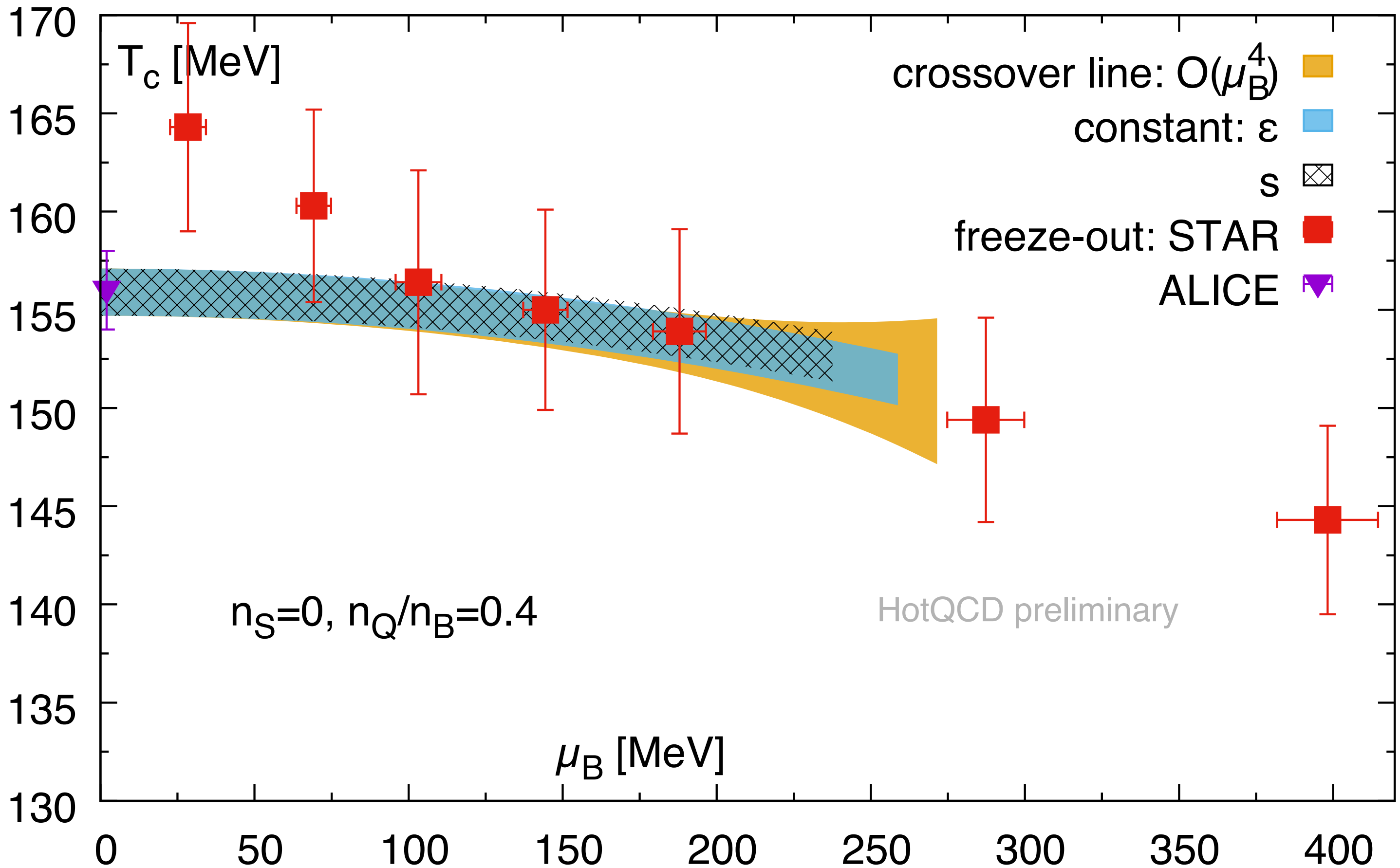

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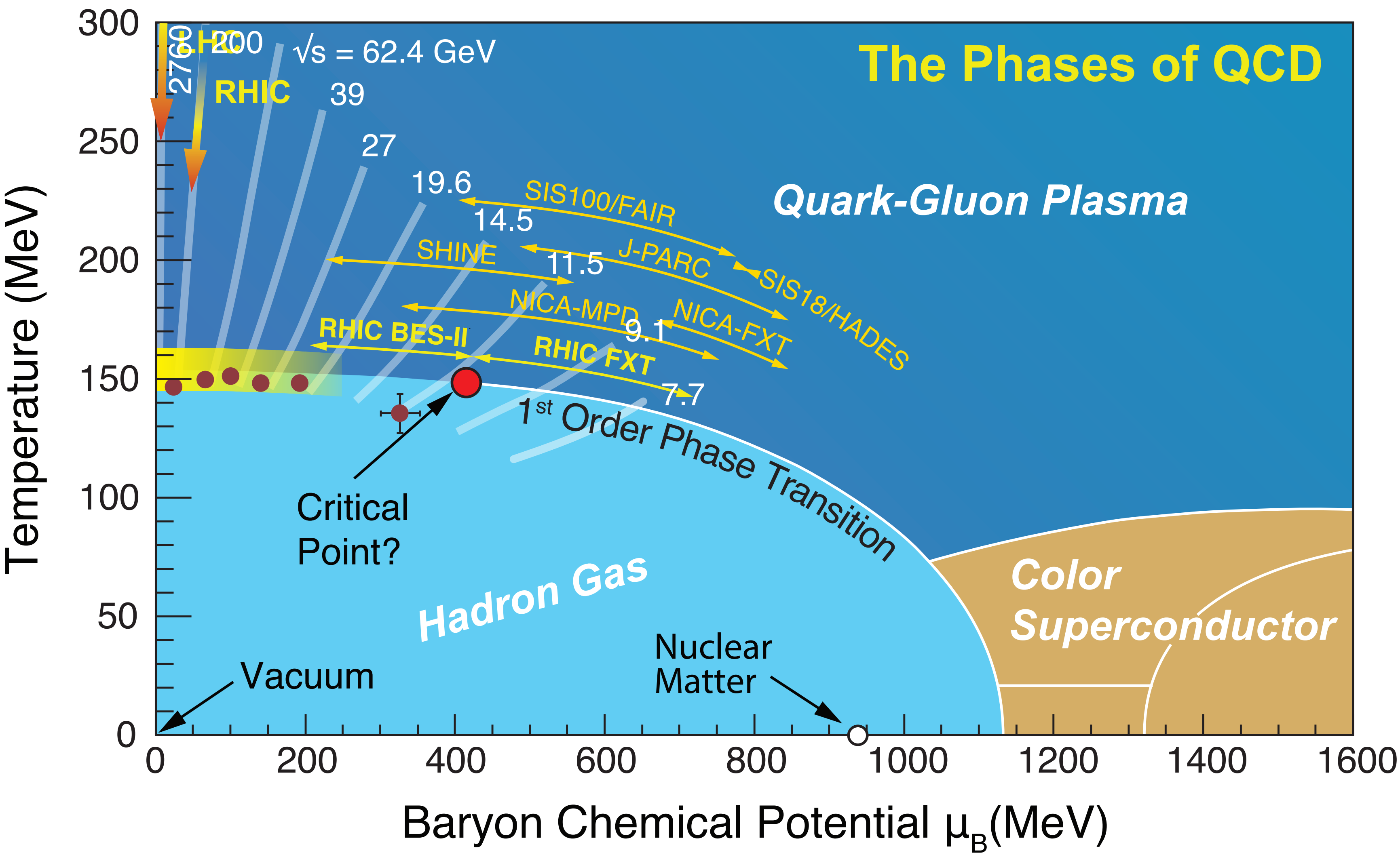
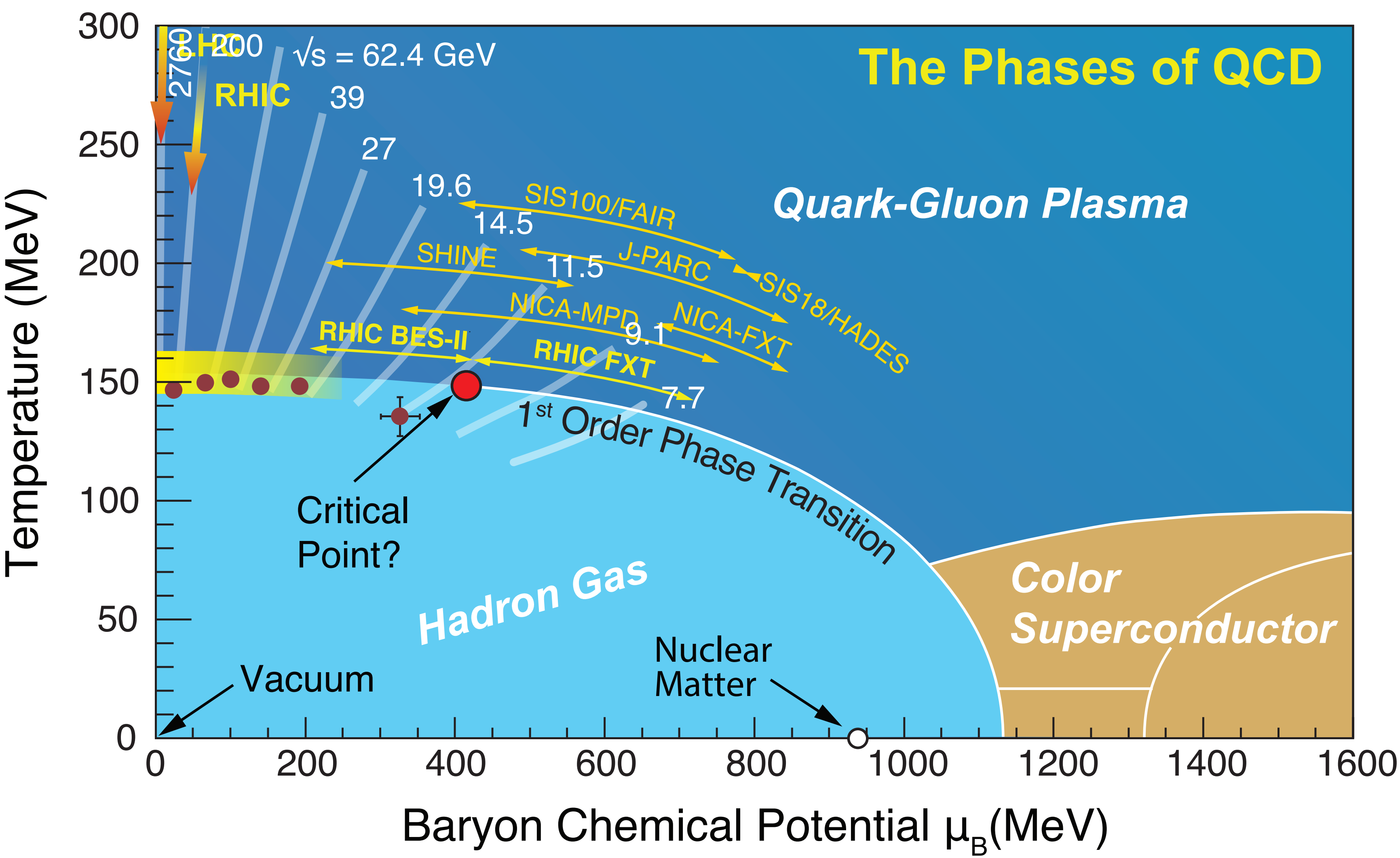
Patrick Steinbrecher QM18

Nuclear matter phase diagram

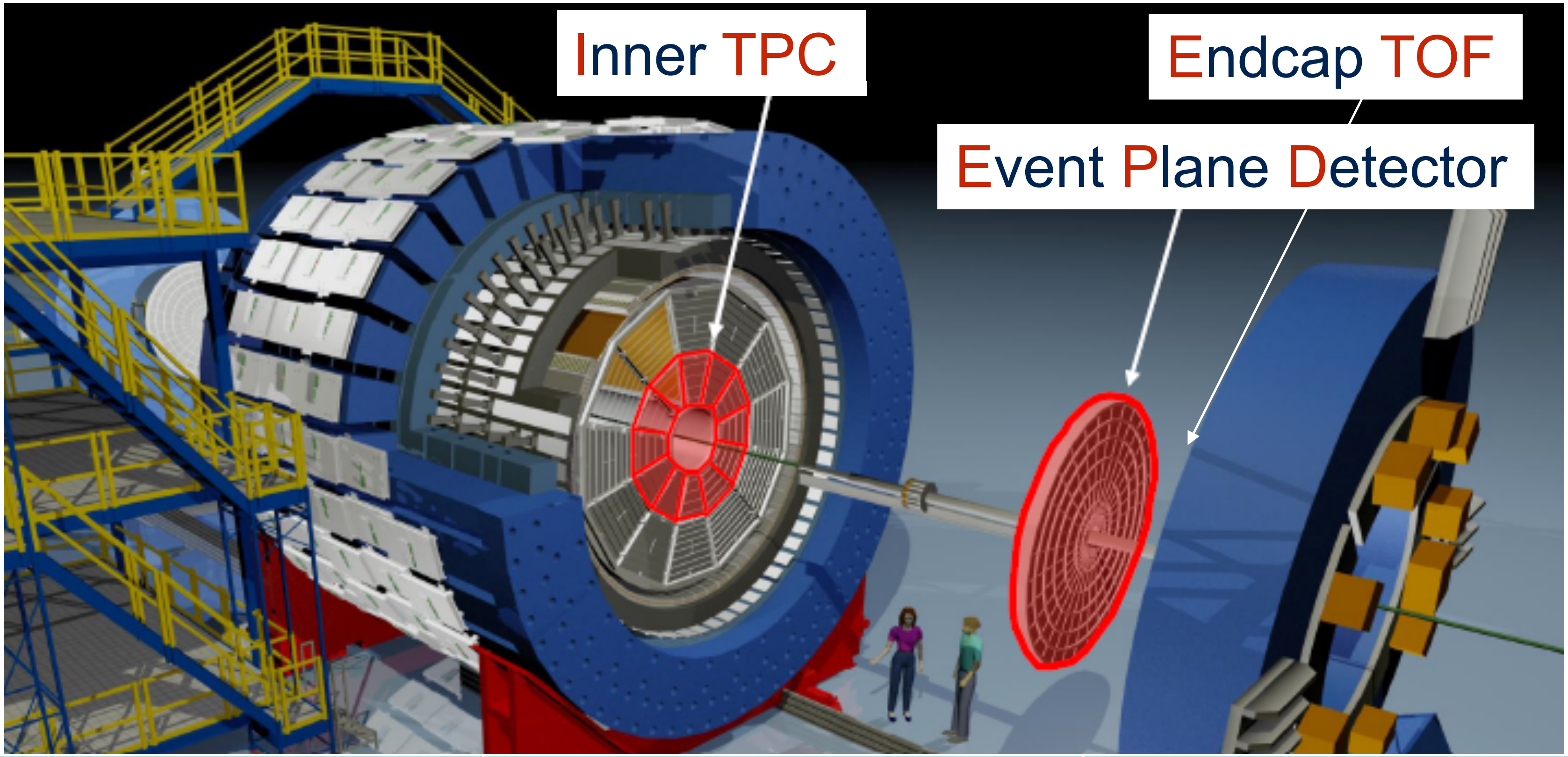


Nuclear matter phase diagram



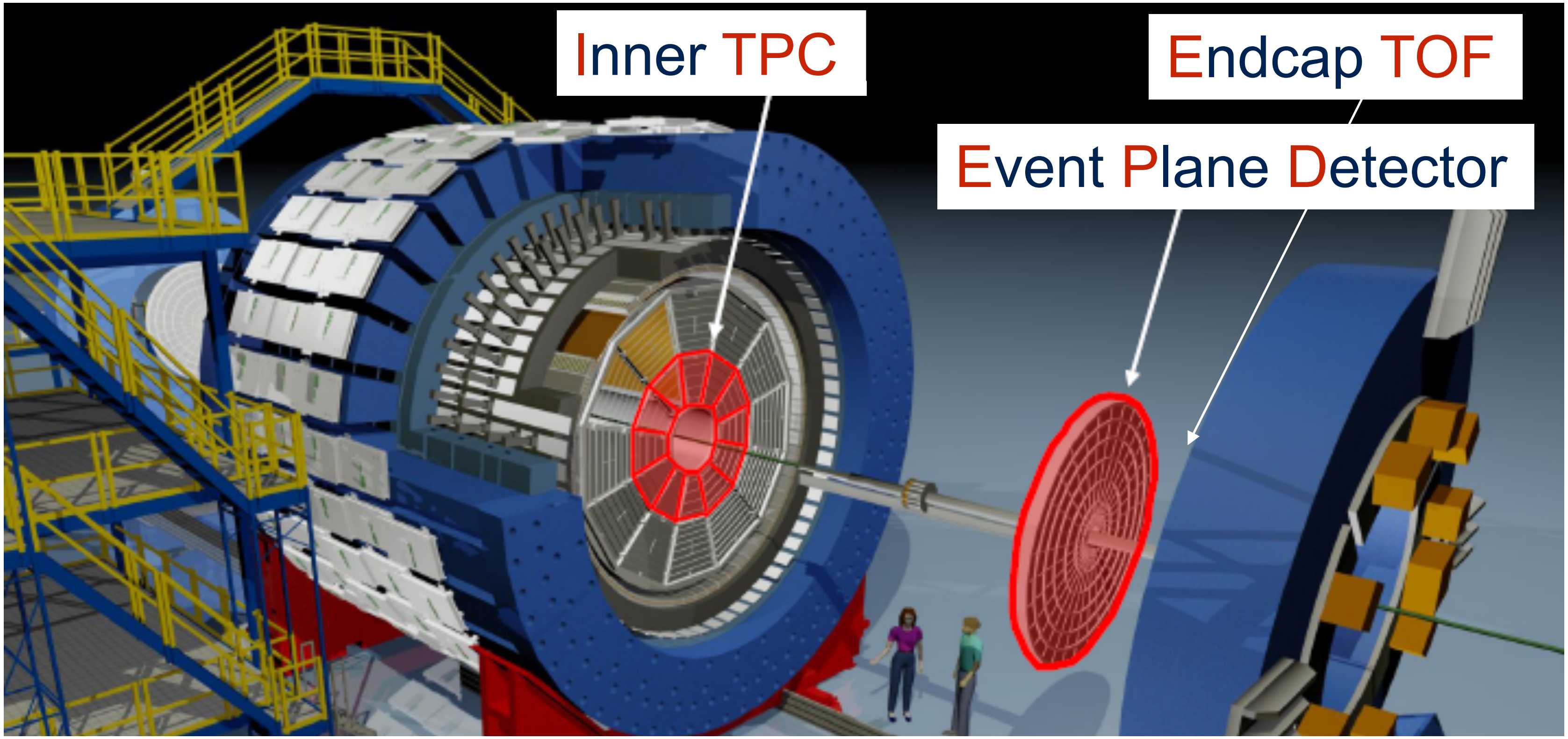
We are focusing in on the right region

The BES-II upgrades



iTPC upgrade	EPD upgrade	eTOF upgrade
Continuous pad rows **Replace all inner TPC sectors**	**Replace Beam Beam Counter**	**Add CBM TOF modules and electronics (FAIR Phase 0)**
$\lvert\eta\rvert<1.5$	**$2.1<\lvert\eta\rvert<5.1$**	**$-1.6<\eta<-1.1$**
p_T > 60 MeV/c	Better trigger & b/g reduction	Extend forward PID capability
Better dE/dx resolution Better momentum resolution	Greatly improved Event Plane info (esp. 1st-order EP)	Allows higher energy range of Fixed Target program

The BES-II upgrades



One iTPC sector has been installed

Full EPD has been installed

3 eTOF modules have been installed

iTPC: enhanced acceptance

Excellent MWPC bench test performance

Gas gain uniformity < 1.5% (RMS)

E resolution < 20% (FWHM)

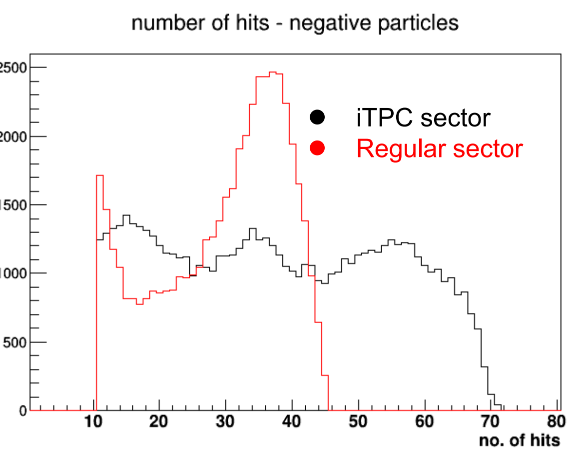
Reasonable stability under X-ray tests

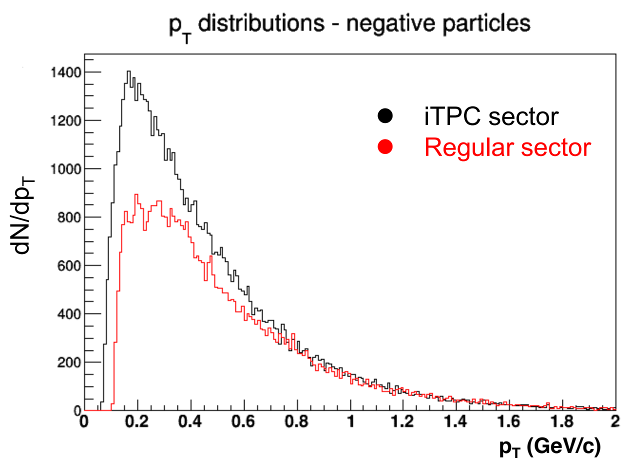
500nA leakage current

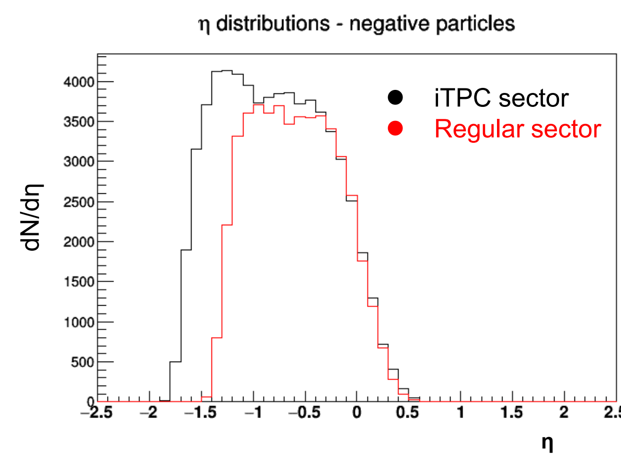
no trips or sparks

One sector has been installed and operated this year

Performance so far reaching expectations







Hits/track 45—> 72

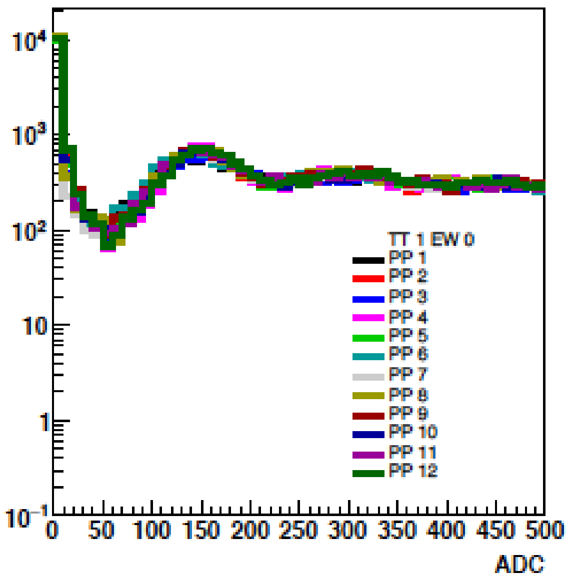
p_T threshold 60 MeV/c

η coverage to 1.7

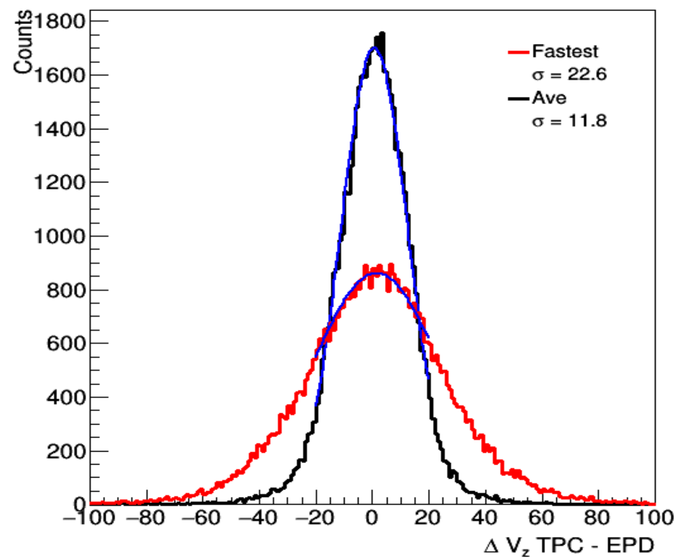
EPD: enhanced event plane resolution

Full EPD installed for Run 18

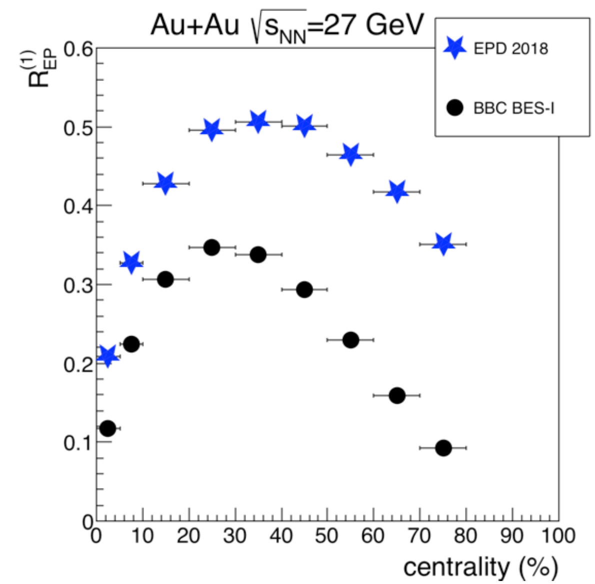
All 744 tiles are good



Extremely uniform tile operation



Average TAC timing resolution 0.35ns

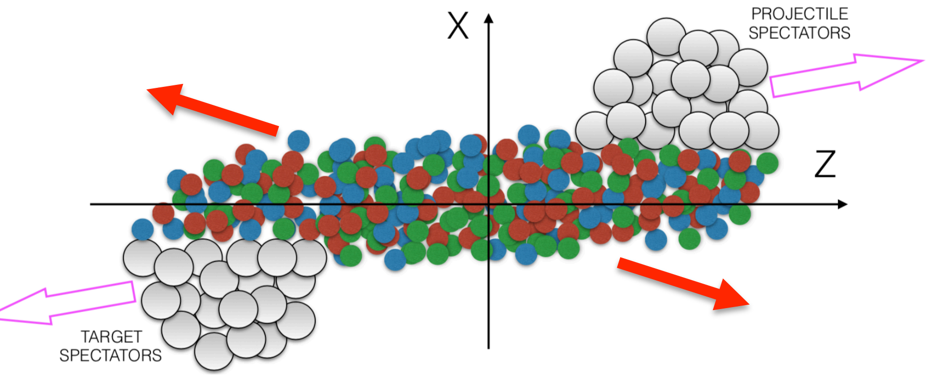


EP resolution better especially in peripheral events

Timed in and operational within first day of operation
EPD in main data stream for whole run

EPD: directed flow over 10 units

27 GeV y_{beam}=3.4
EPD 2.1< $|\eta|$ < 5.1



Directed flow changes sign in EPD

Spectators (η > 3.4) positive v_1
Participants ((η < 3.4) negative v_1

Deflections in EPD in opposite direction

Congratulations to the EPD team

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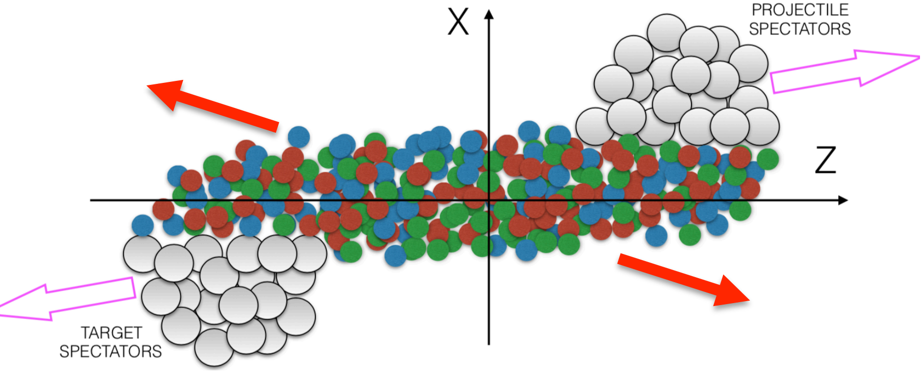

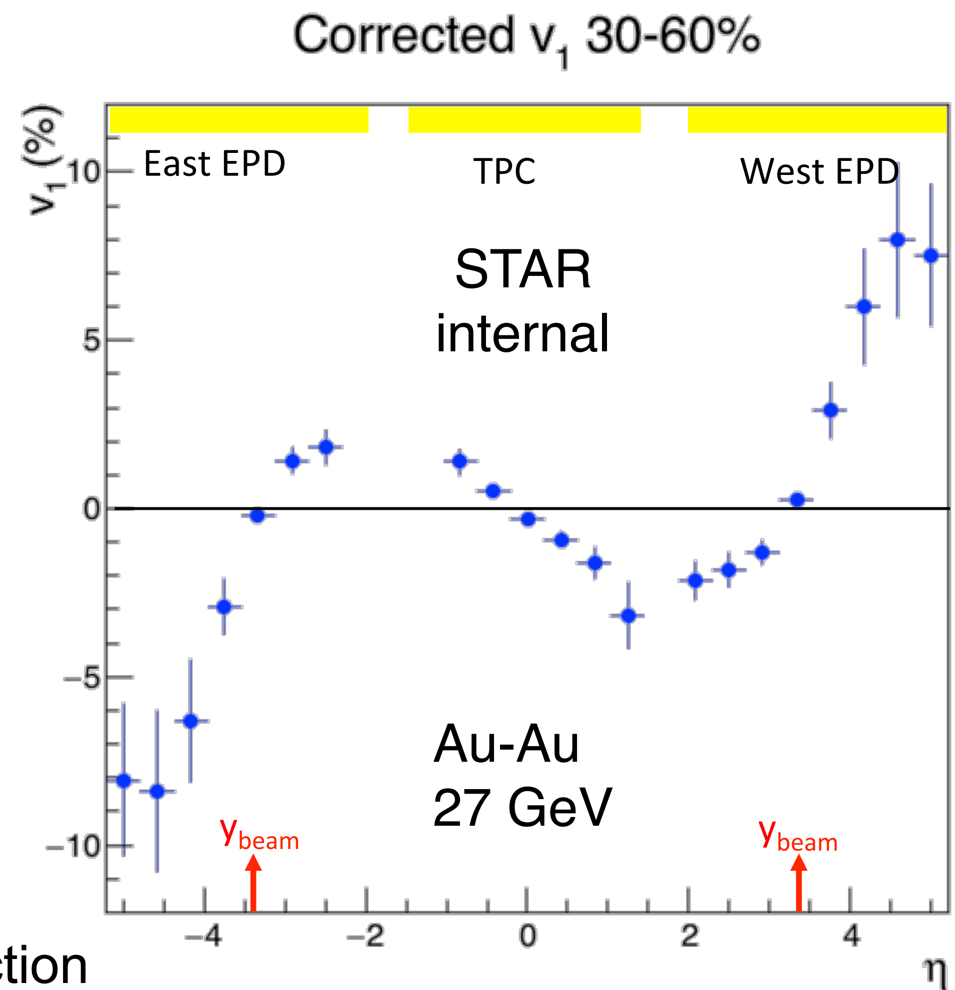

Directed flow changes sign in EPD

Spectators (η > 3.4) positive v_1
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Deflections in EPD in opposite direction

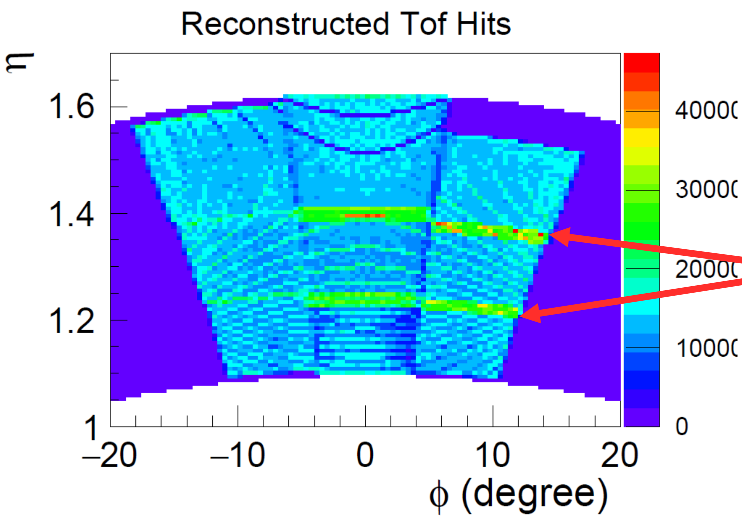
Congratulations to the EPD team

eTOF: enhanced forward PID

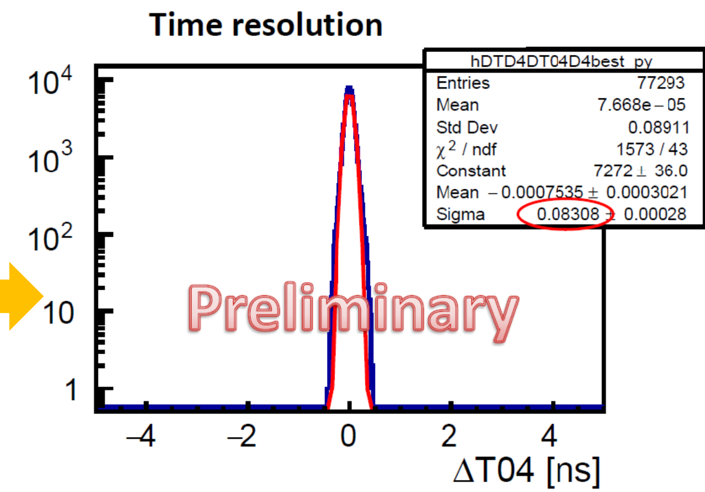
Run 17 commissioning

- Interface to STAR data completed
- Engineering design completed

Participating 3 modules in data taking in Run 18



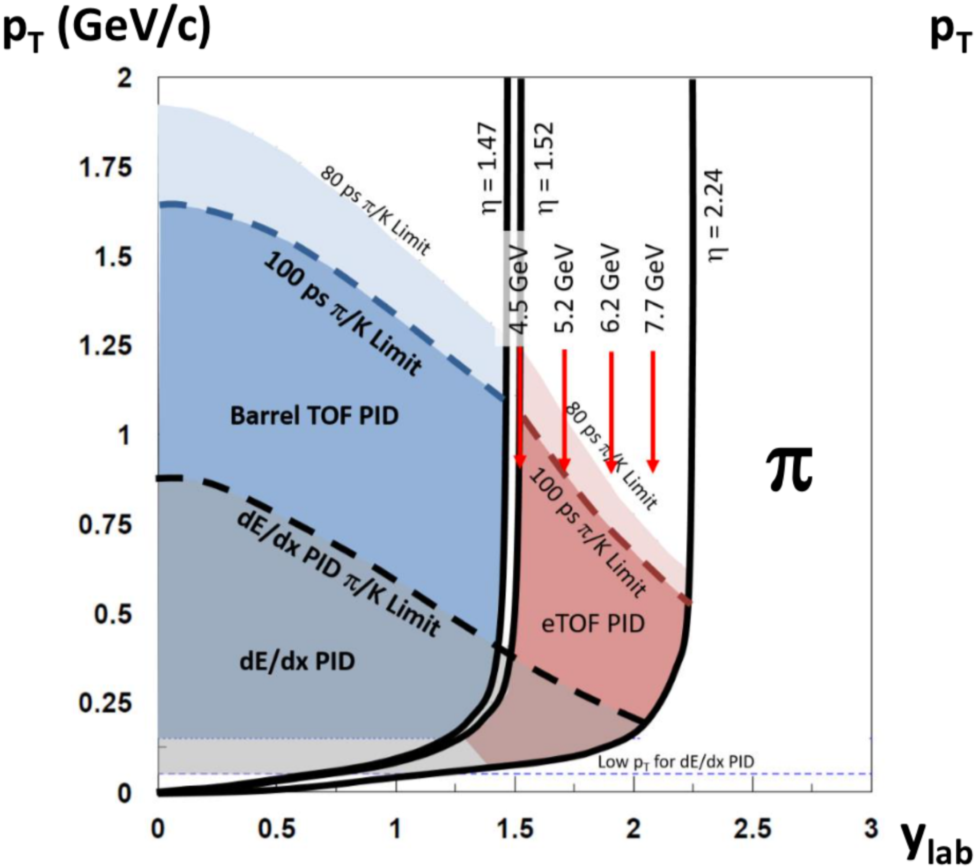
Overlap range of two MRPCs

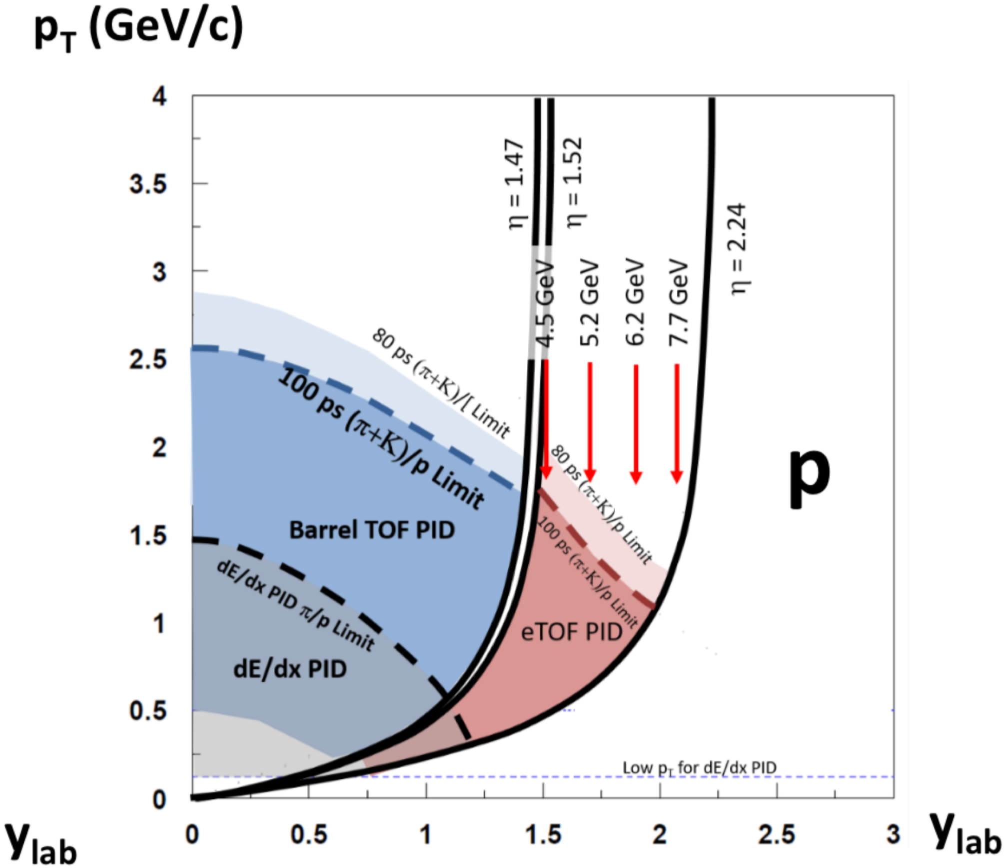


- ✓ System time resolution: 83 ps
- ✓ Counter time resolution: 59 ps

59 ps timing resolution established

FXT: energy "upgrade"





Current Acceptance	Acceptance with upgrades	Current Acceptance	Acceptance with upgrades

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

Executive summary

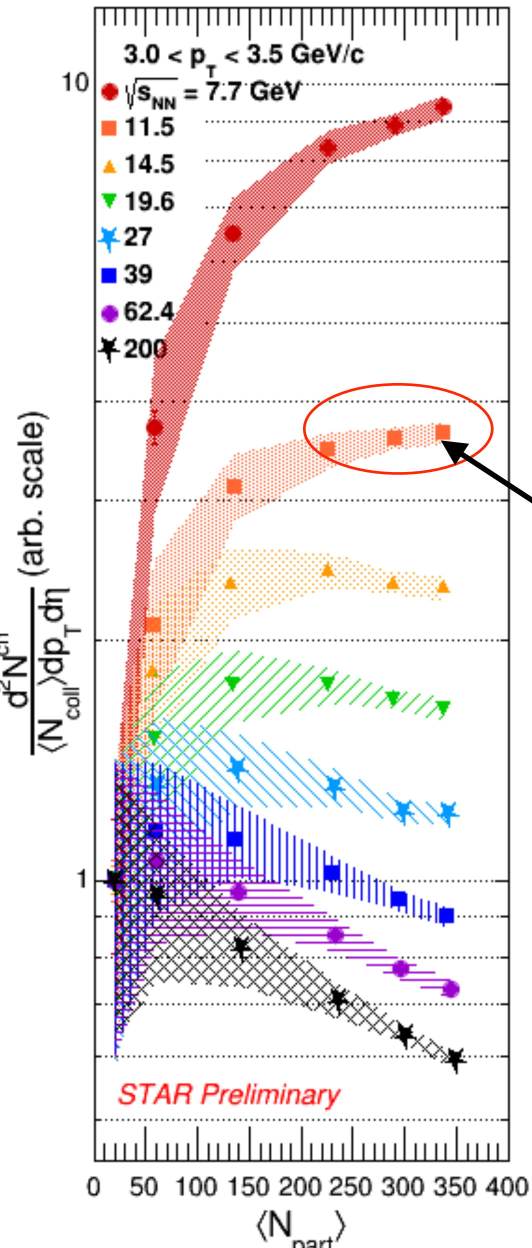
STAR's goal is the collection of **all** the data outlined below

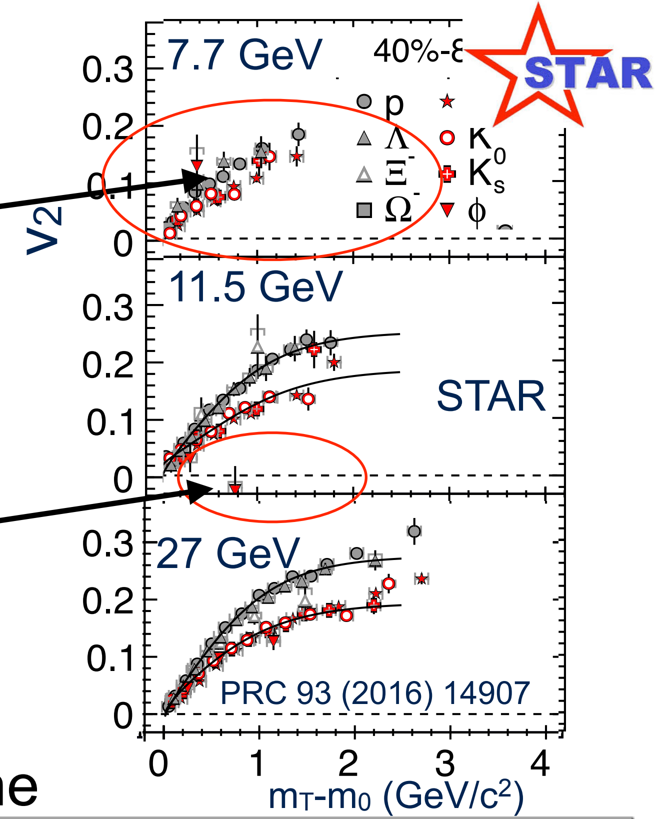
Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events
9.8	19.6	205	4.5 weeks	400M
7.3	14.5	260	5.5 weeks	300M
5.75	11.5	315	5 weeks	230M
4.55	9.1	370	9.5 weeks	160M
3.85	7.7	420	12 weeks	100M
31.2	7.7 (FXT)	420	2 days	100M
19.5	6.2 (FXT)	487	2 days	100M
13.5	5.2 (FXT)	541	2 days	100M
9.8	4.5 (FXT)	589	2 days	100M
7.3	3.9 (FXT)	633	2 days	100M
5.75	3.5 (FXT)	666	2 days	100M
4.55	3.2 (FXT)	699	2 days	100M
3.85	3.0 (FXT)	721	2 days	100M

Roughly equal spacing in μ_B given energies RHIC can circulate
Measure 7.7 in both collider and FXT mode

Numbers updated from white paper given upgrades

Disappearance of QGP?



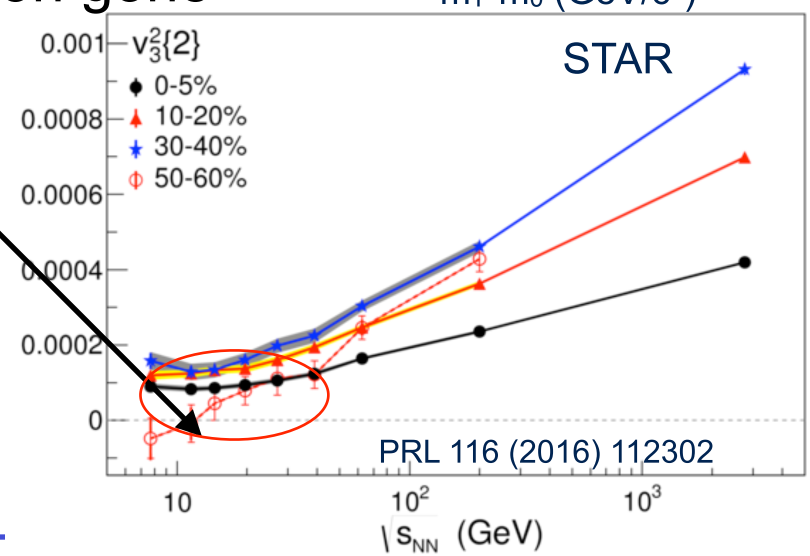


B-M v_2 separation gone

ϕ $v_2 \sim 0$

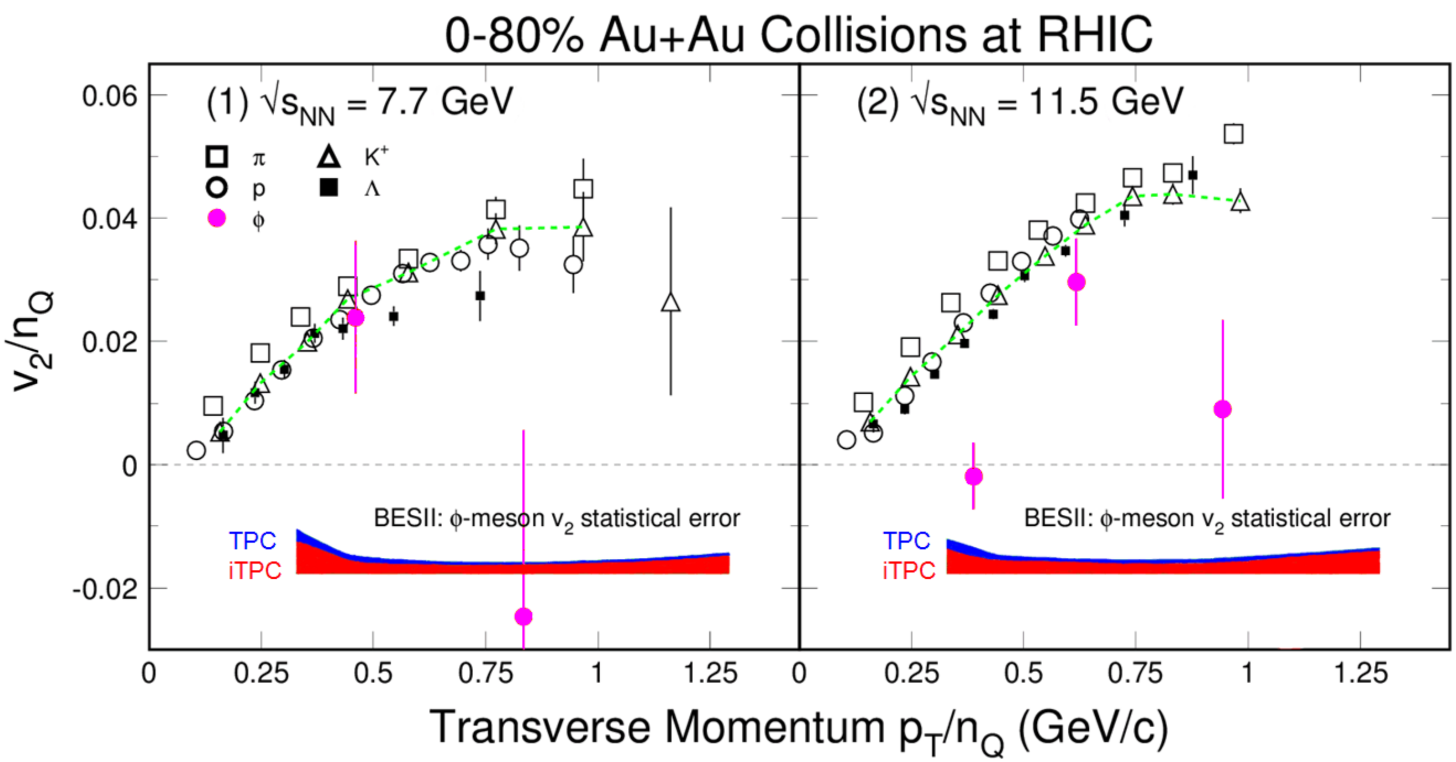
High p_T suppression gone

$v_3 \sim 0$



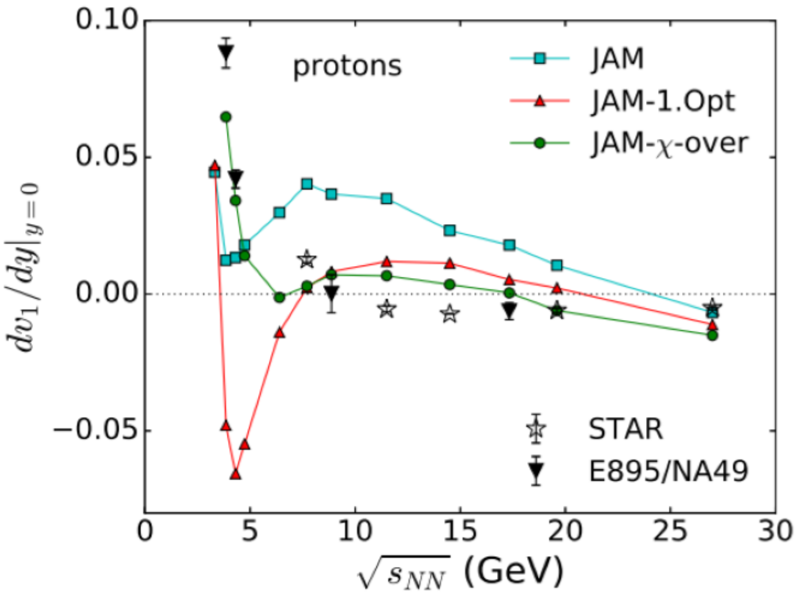
Several standard signals disappear at $\sqrt{s}$ < 15 GeV

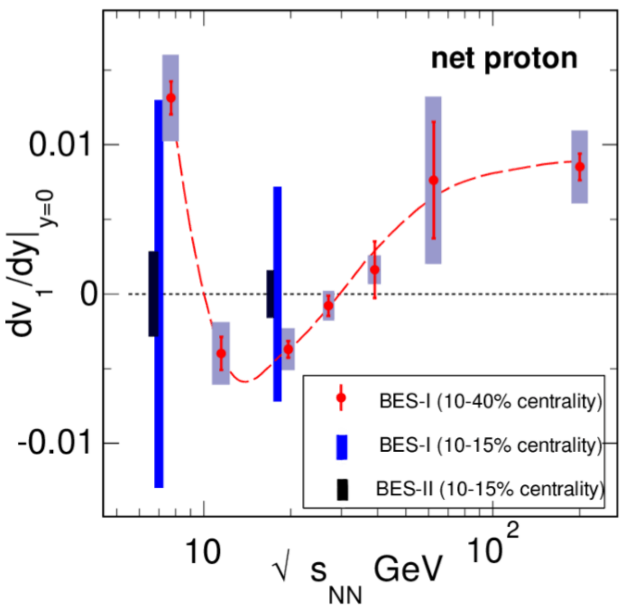
BES-II: quark elliptic flow



Precision measurement of the ϕ (and other) flow

Softest point in EOS





net-proton directed flow

Recent calculations consistent with original 2005 prediction

JAM 1.0pt: First order phase transition
strong "wiggle"

JAM X-over - Cross over
weaker "wiggle"

JAM - No transition
no "wiggle"

Theoretical calculations do not yet match data

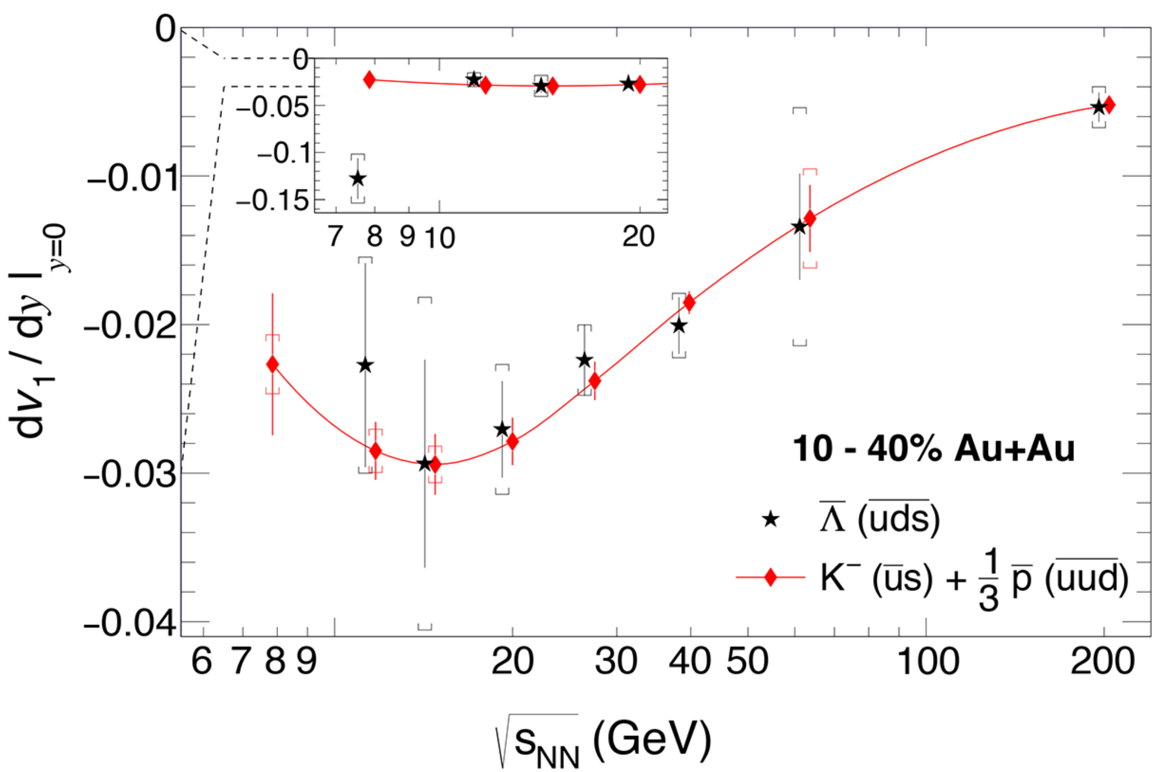
Fine centrality binning possible with BES-II data

Y.Nara et al. Phys. Lett. B769 (2017) 543

Coalescence of "produced" particles

Assumptions:

- v_1 is developed in prehadronic stage
- Hadrons are formed via coalescence: $(v_n)_{hadron} = \Sigma(v_n)_{constituent\ quarks}$
- $(v_1)_{\bar{u}} = (v_1)_{\bar{d}}$ and $(v_1)_s = (v_1)_{\bar{s}}$



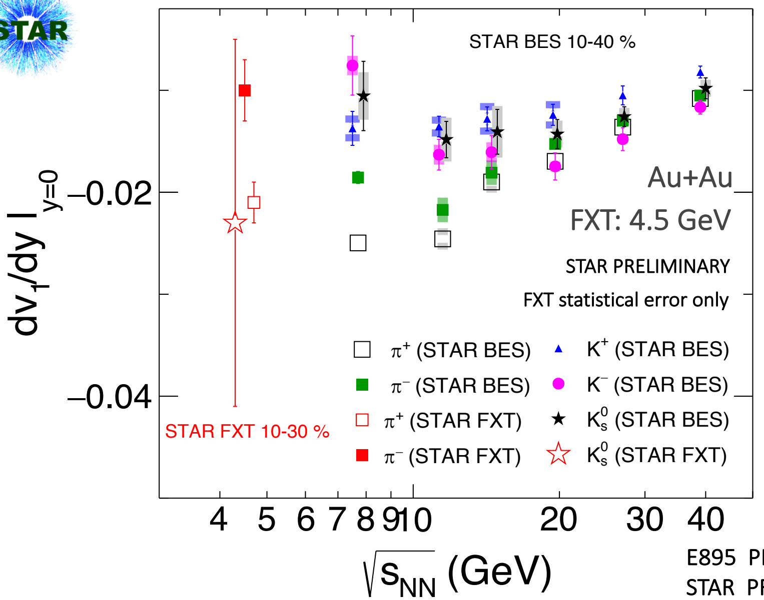
anti-Λ predicted from quark values deduced from K and p

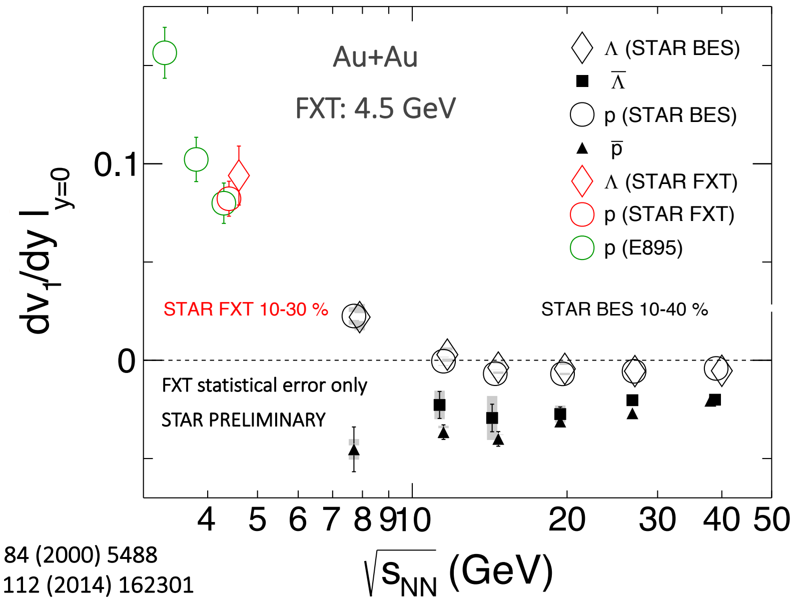
Fails for 7.7 GeV -
At least one assumption incorrect

What happens at lower √s?
Finer centrality bins?

STAR, Phys. Rev. Lett. **120** (2018) 62301

FXT directed flow





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

v_1 at 4.5 GeV:

- p and Λ similar values
- First identified π results
- Suggestion of difference between π^+ and π^-
  - Transported quarks have stronger effect on π^-

Run 18 (with EPD):

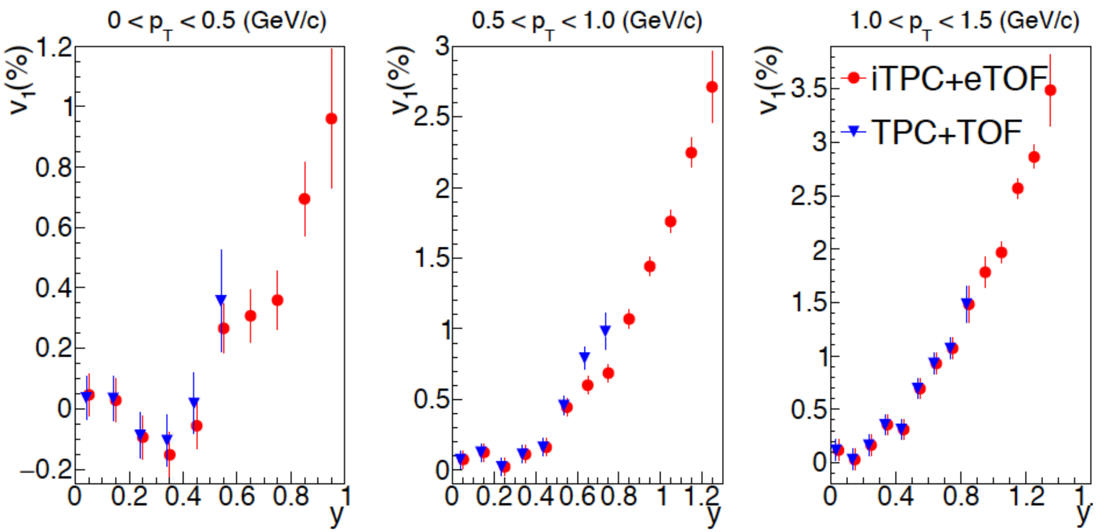
- 1 B events at 7.2 GeV
- 100 M events at 3.0 GeV

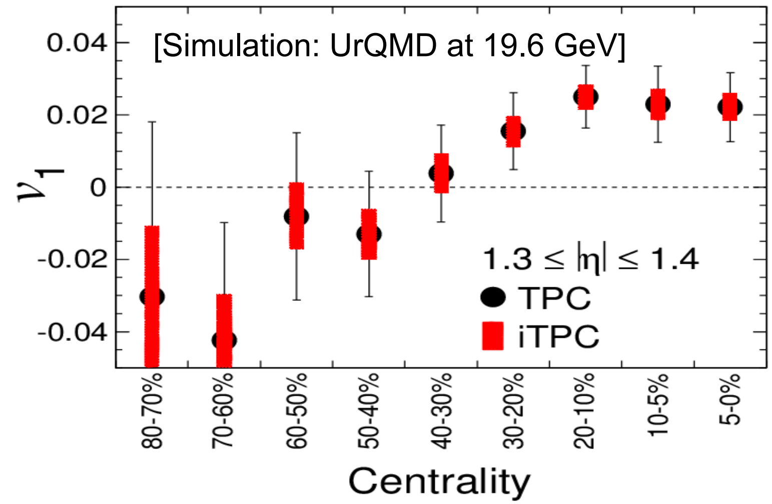
Fluctuation measurements below 7 GeV

BES-II: directed flow improvements

Current data: 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

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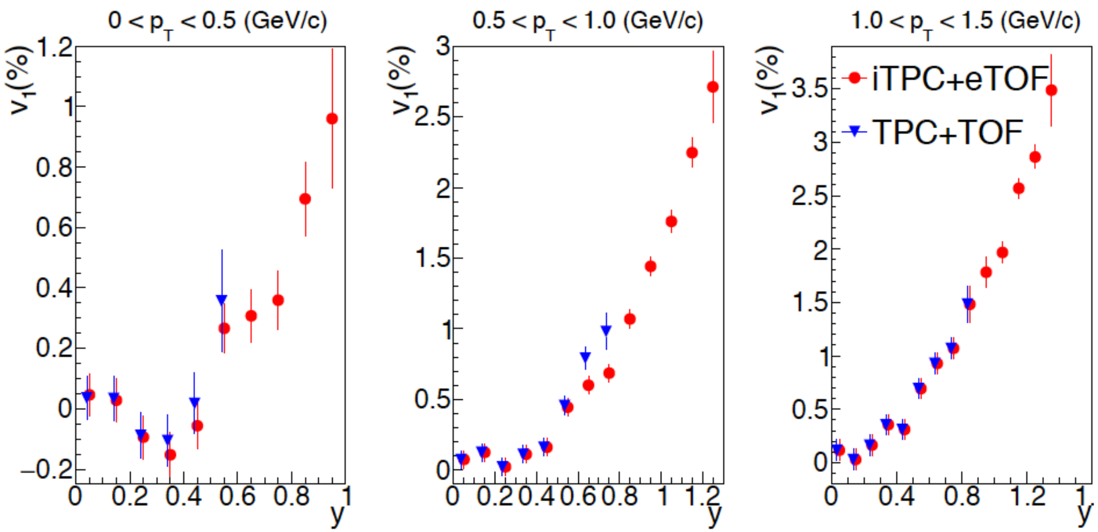
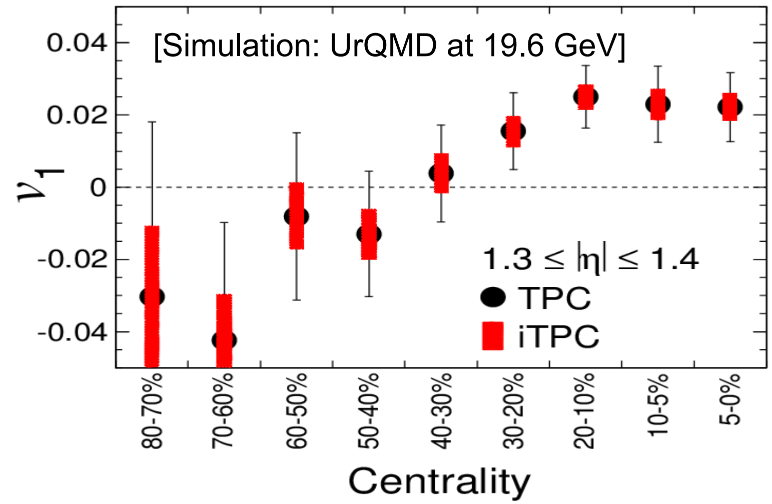
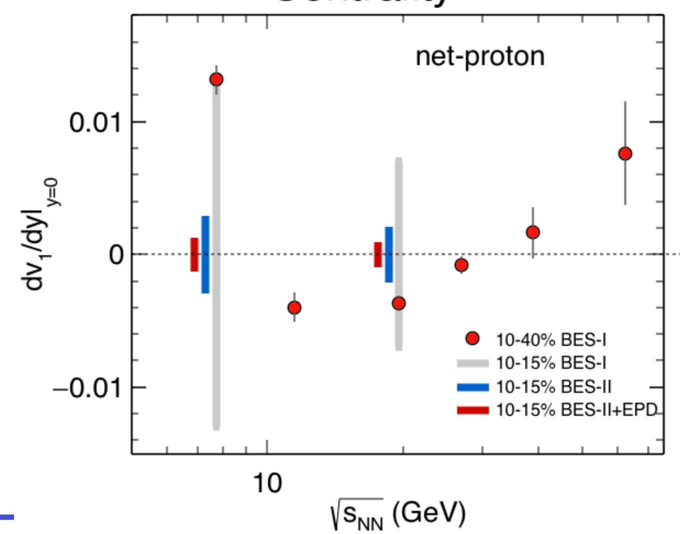






iTPC+ eTOF:

Enhanced coverage at forward y

Signal larger - role of baryon stopping

EPD:

Enhanced 1st order EP resolution

Reduced systematics

Presence of Critical Point?

Critical Points:

divergence of susceptibilities

e.g. magnetism transitions

divergence of correlation lengths

e.g. critical opalescence

Top 5% central collisions:

Non-monotonic behavior

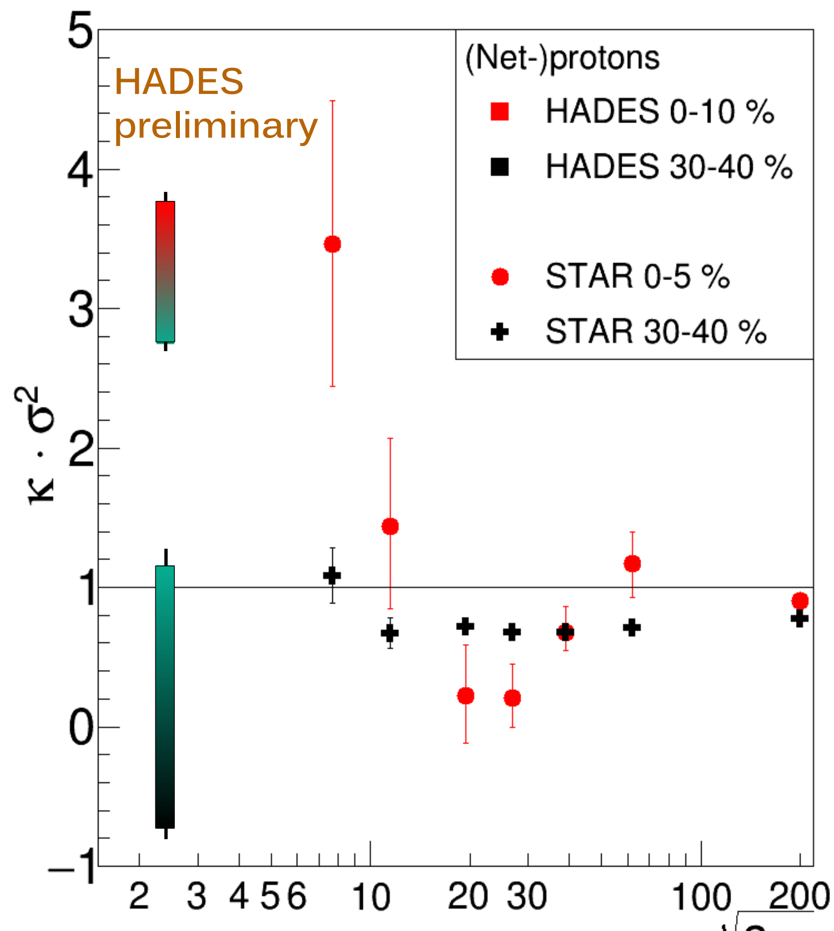
Peripheral collisions:

smooth trend

Hints of Critical fluctuations

Correlation lengths diverge →

Net-p $\kappa\sigma^2$ diverge



NB: Different y and p_T ranges

R. Holzmann QM2017

BES-II: Critical fluctuations

Current data: Suggestive of non-trivial √s dependence of net proton cumulant ratios

iTPC:

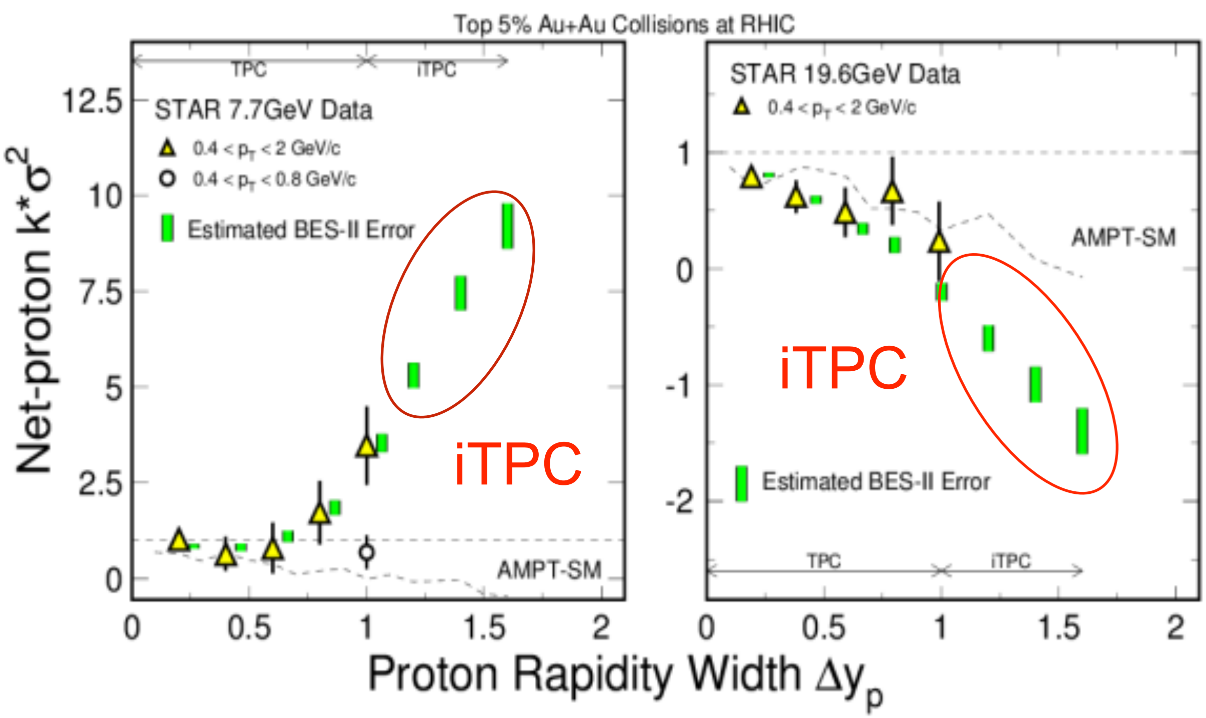
Increase Δy_p acceptance

$\Delta y_p > \Delta y$ correlation

EPD:

Improved centrality selection

Use all TPC for measurement



Establish true nature of correlation

Subject actively pursued theoretically

Light-ion FXT target?

Question:

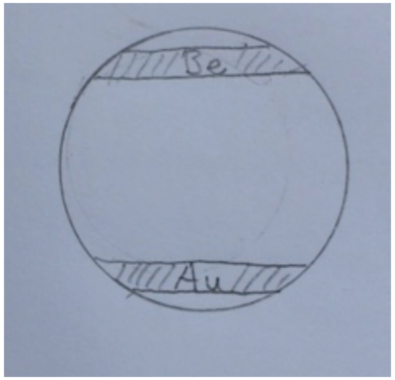
Does baryon stopping dominate net-proton fluctuation measurements?

Proposed Test:

Au+light ion collisions
  No QGP created but significant baryon stopping
  If stopping is poisson in nature - correlation random

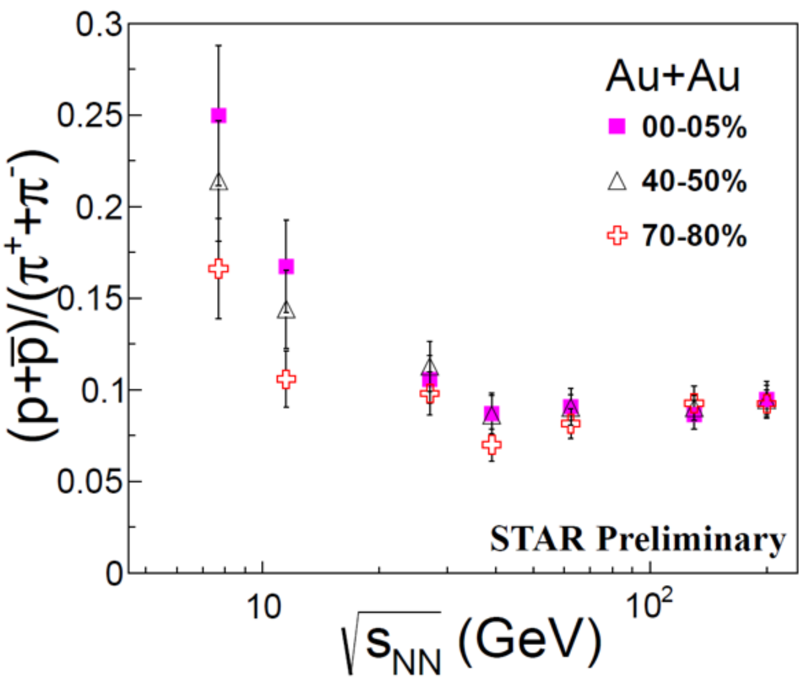
Under discussion:

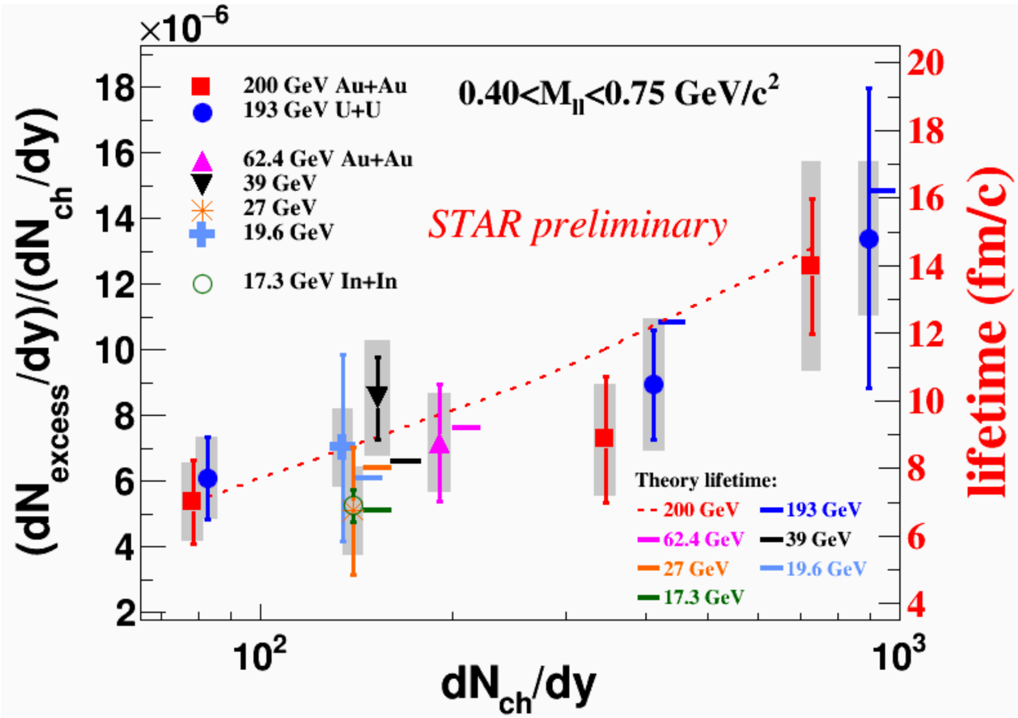
Insert a Be target above the current FXT Au target
  - needs more detailed discussion with CAD
Can measure fluctuations in the target rapidity region



Determine if fluctuations all due to stopping

Low mass di-lepton excess





Above 20 GeV
Total baryon density ~ constant

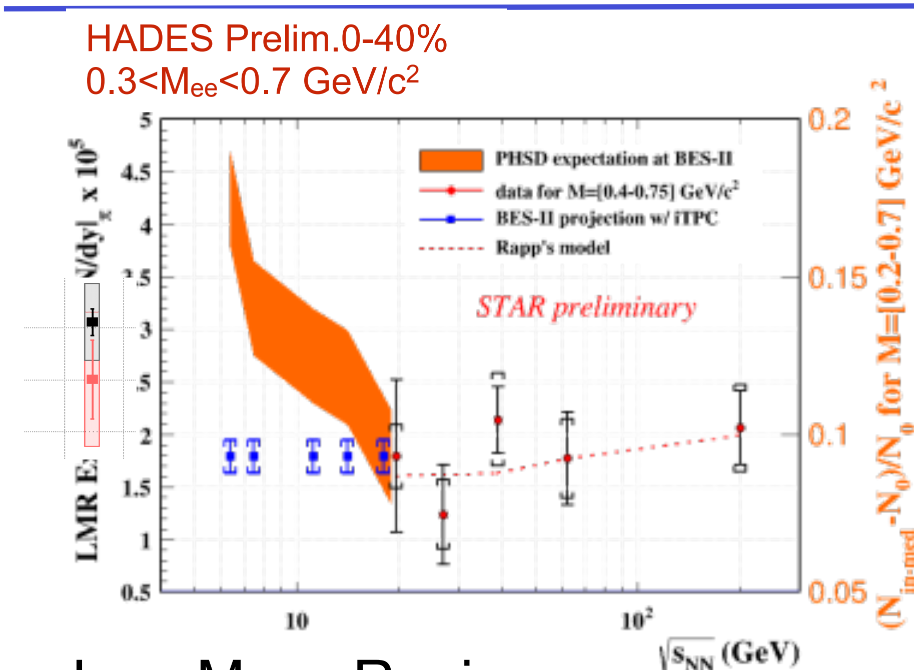
Low mass excess ∝ fireball lifetime

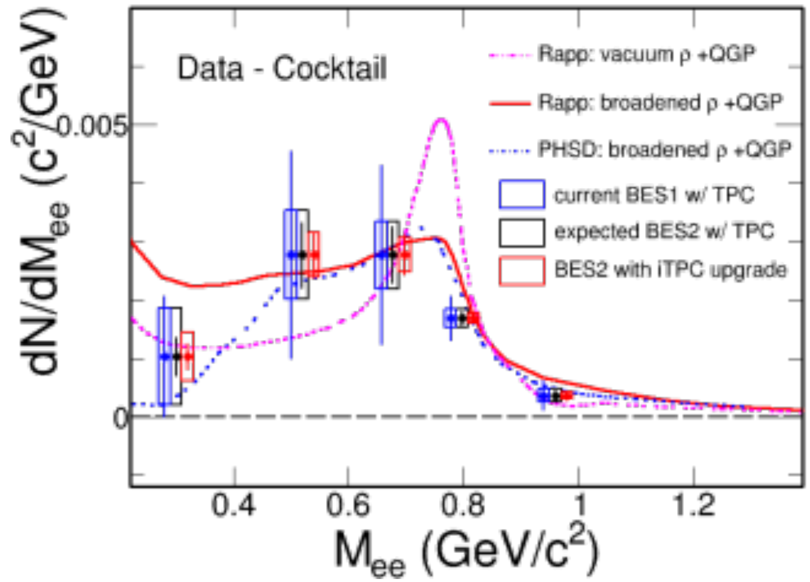
for large range of beam energies and centralities

Excess driven by convolution of **total baryon** density, **hot dense** medium effects and the medium's **lifetime**

Need to add more low energy data

BES-II: change total baryon number





Low Mass Region:

iTPC: Significant reduction in sys. and stat. uncertainties

Disentangle total baryon density effects

ρ-meson broadening:

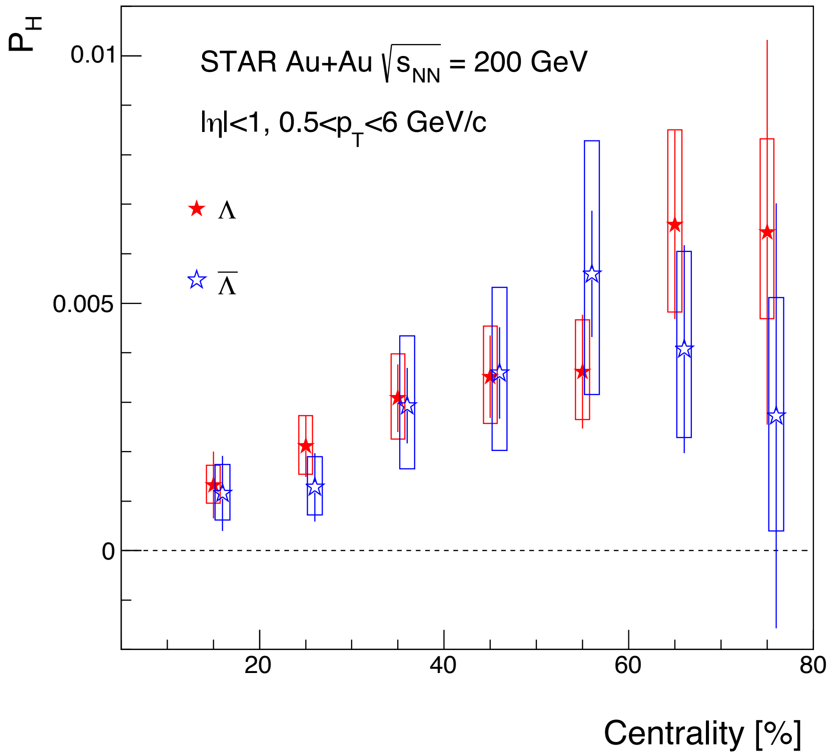
different predictions for di-electron continuum (Rapp vs PHSD)

iTPC: Significant reduction in sys. and stat. uncertainties

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

T. Galatyuk, QM2017

Global Λ polarization



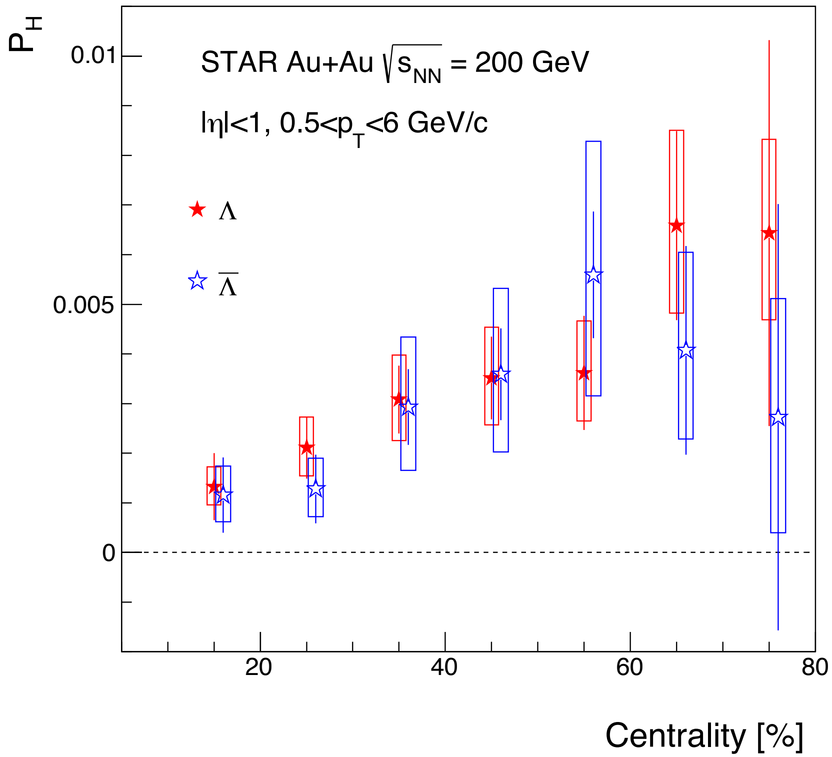
Non-zero measurement now demonstrated 200 GeV

Also as function of centrality

Consistent polarization for particle and anti-particle (within statistical precision)

STAR, arXiv:1805.04400

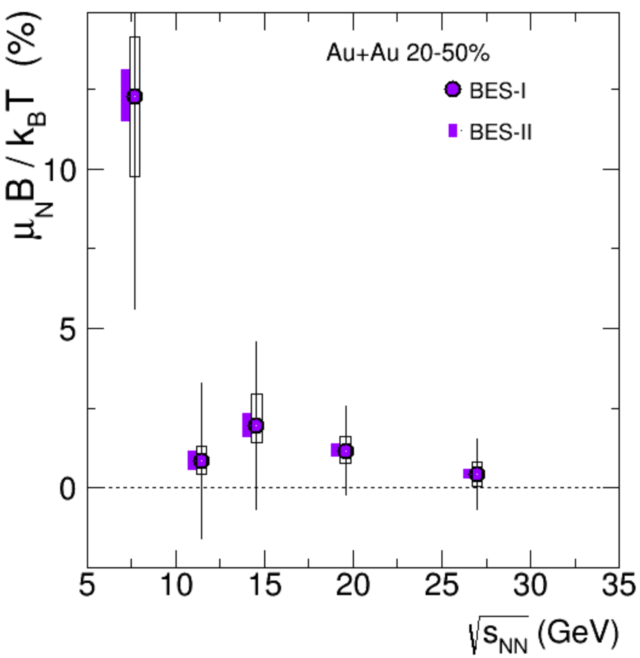
BES-II: Magnetic field determination



Non-zero measurement now demonstrated 200 GeV

Also as function of centrality

Consistent polarization for particle and anti-particle (within statistical precision)



Difference ∝ B-field/T

10% on y axis corresponds to 8×10^{14} T

BES-II resolve >5σ difference

STAR, arXiv:1805.04400

Updated event statistics requirements

STAR

Table 8: Event statistics (in millions) needed in BES-II for various observables. This table updates estimates originally documented in Ref. [45].

Collision Energy (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV) in 0-5% central collisions	420	370	315	260	205
Observables					
R_{CP} up to $p_T = 5$ GeV/c	-		160	125	92
Elliptic Flow (ϕ mesons)	80	120	160	160	320
Chiral Magnetic Effect	50	50	50	50	50
Directed Flow (protons)	20	30	35	45	50
Azimuthal Femtoscopy (protons)	35	40	50	65	80
Net-Proton Kurtosis	70	85	100	170	340
Dileptons	100	160	230	300	400
$>5\sigma$ Magnetic Field Significance	50	80	110	150	200
Required Number of Events	100	160	230	300	400

+100M for each FXT energy

Typically factor 20 more than for BES-I

dileptons drive the event request

BES-II extension into 2021

With guidance from the Collider-Accelerator Department, each scenario has cryo-weeks assigned to commissioning of Low-Energy RHIC electron Cooling (LEReC): six weeks in Run 19 and five weeks in Run 20. For all scenarios we have to assume a third year of RHIC running to follow, in order to allow the completion of the BES-II physics mission. Specifically, the request of twelve weeks for $\sqrt{s_{NN}} = 7.7$ GeV will need to be collected in a third year of BES-II. Moreover, some scenarios necessitate this third run to address parts of the requests for the $\sqrt{s_{NN}} = 9.1$ GeV. Run 21 would thus combine the remainder of BES-II with the start of STAR's forward physics program which would see a $\sqrt{s}$ =500 GeV polarized *pp* run that year as proposed in [2, 3].

For more details about running at 500 GeV see Elke's talk

Run 19

Table 2: Scenarios 1, 2, 3, and 4 -Run 19 assuming nineteen cryo-weeks of running, including six weeks of LEReC commissioning, and two weeks of cool-down/set-up time

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events	Priority	Sequence
9.8	19.6	4.5 weeks	Au+Au	400M	1	1
9.8	4.5 (FXT)	2 days	Au+Au	100M	2	2
7.3	14.5	5.5 weeks	Au+Au	300M	1	3
7.3	3.9 (FXT)	2 days	Au+Au	100M	2	4
31.2	7.7 (FXT)	2 days	Au+Au	100M	3	5

Expect installation and commissioning of upgrades to last until Feb 27th

See Flemming's talk for more details

Run 20

STAR

Table 3: Scenario 1 - Run 20 assuming twenty-four cryo-weeks of running, including five weeks of LEReC commissioning, and two weeks of cool-down/set-up time.[1]

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events	Priority	Sequence Spring 2020
5.75	11.5	5 weeks	Au+Au	230M	1	1
5.75	3.5 (FXT)	2 days	Au+Au	100M	2	2
4.55	9.1	7 weeks[2]	Au+Au	118M[2]	1	3
4.55	3.2 (FXT)	2 days	Au+Au	100M	3	4
19.5	6.2 (FXT)	2 days	Au+Au	100M	3	5
13.5	5.2 (FXT)	2 days	Au+Au	100M	3	6
3.85	3.0 (FXT)	2 days	Au+Au	100M	4	7

[1] The BES-II request includes a 7.7 GeV run which requires 12 cryo-weeks. This data set will need to be collected in a third year of BES-II.

[2] The complete request is for 160M MB events and will take 9.5 cryo-weeks to collect assuming design cooling performance. The remainder of the data will be collected in a third year of BES-II.

Table 4: Scenario 2 - Run 20 assuming nineteen cryo-weeks of running, including five weeks of LEReC commissioning, and two weeks of cool-down/set-up time.[1]

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events	Priority	Sequence Spring 2020
4.55	9.1	9.5 weeks	Au+Au	160M	1	1
4.55	3.2 (FXT)	2 days	Au+Au	100M	2	2
5.75	3.5 (FXT)	2 days	Au+Au	100M	3	3
7.3	3.9 (FXT)	2 days	Au+Au	100M	3	4
19.5	6.2 (FXT)	2 days	Au+Au	100M	3	5
13.5	5.2 (FXT)	2 days	Au+Au	100M	3	6
3.85	3.0 (FXT)	2 days	Au+Au	100M	4	7

[1] The BES-II request includes an 11.5 GeV and 7.7 GeV run which require 5 and 12 cryo-weeks, respectively. These data sets will need to be collected in a third year of BES-II.

Running in Fall of 2019

STAR

Table 5: Scenario 3 - combined Fall '19 run with five cryo-weeks from Run 19 and nine cryo-weeks from Run 20 assuming twenty-four cryo-weeks of running, including five weeks of LEReC commissioning, and two weeks of cool-down/set-up time. Followed by a Spring '20 run of the remaining thirteen cryo-weeks.[1]

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events	Priority	Sequence Fall 2019
5.75	11.5	5 weeks	Au+Au	230M	1	1
5.75	3.5 (FXT)	2 days	Au+Au	100M	2	2
19.5	6.2 (FXT)	2 days	Au+Au	100M	3	3
13.5	5.2 (FXT)	2 days	Au+Au	100M	3	4
3.85	3.0 (FXT)	2 days	Au+Au	100M	4	5
						Spring 2020
4.55	9.1	9.5 weeks	Au+Au	160M	1	1
4.55	3.2 (FXT)	2 days	Au+Au	100M	2	2

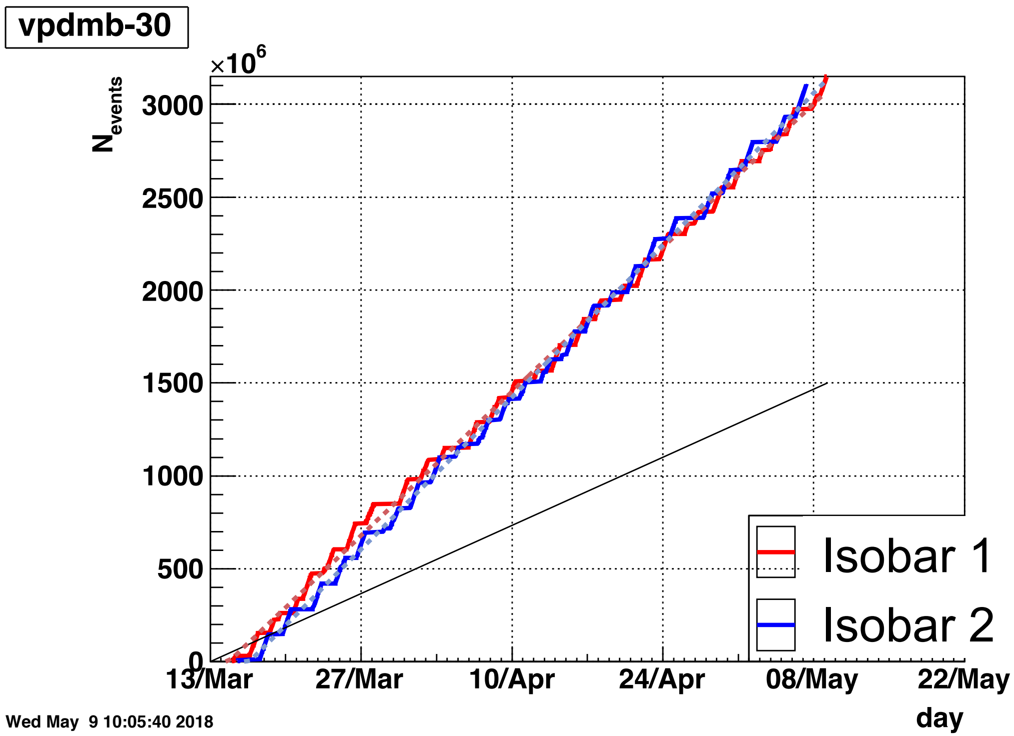
[1] The BES-II request includes a 7.7 GeV run which requires 12 cryo-weeks. This data set will need to be collected in a third year of BES-II.

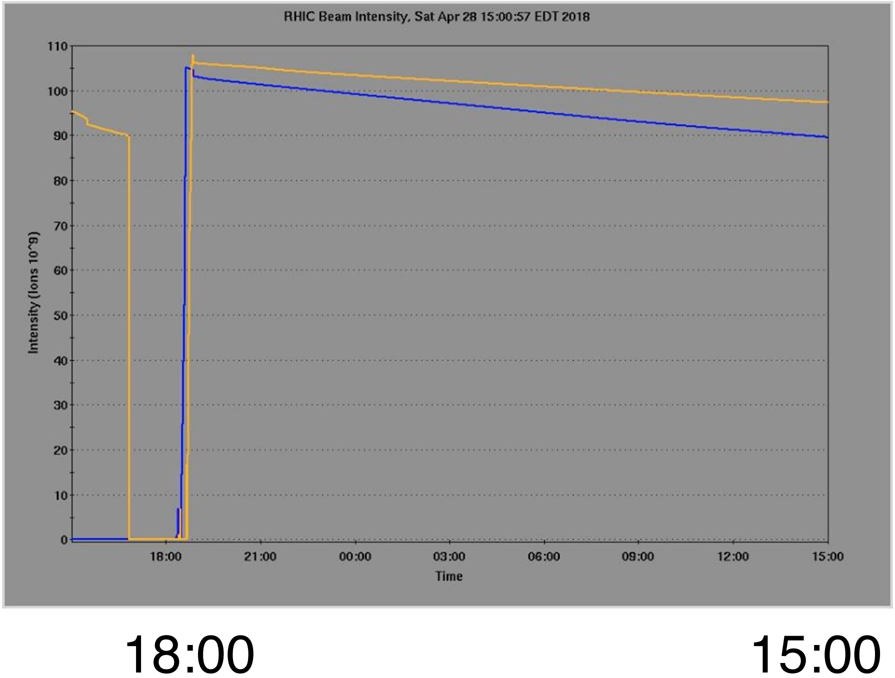
Table 6: Scenario 4 - combined Fall '19 run with five cryo-weeks from Run 19 and eight cryo-weeks from Run 20 assuming nineteen cryo-weeks of running, including five weeks of LEReC commissioning, and two weeks of cool-down/set-up time. Followed by a Fall '20 run which combines the remaining eleven cryo-weeks with those of a third year of BES-II[1]

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events	Priority	Sequence Fall 2019
5.75	11.5	5 weeks	Au+Au	230M	1	1
5.75	3.5 (FXT)	2 days	Au+Au	100M	2	2
19.5	6.2 (FXT)	2 days	Au+Au	100M	3	3
13.5	5.2 (FXT)	2 days	Au+Au	100M	3	4
3.85	3.0 (FXT)	2 days	Au+Au	100M	4	5
						Fall 2020
4.55	9.1	9.5 weeks	Au+Au	160M	1	1
4.55	3.2 (FXT)	2 days	Au+Au	100M	2	2

[1] The BES-II request includes a 7.7 GeV run which requires 12 cryo-weeks. This data set will also need to be collected in a third year of BES-II, extending into Spring '21.

Run 18 brief report: Isobars





Very smooth running - fills lasted many hours with close to flat luminosity thanks CAD

Exceeded data taking goals for both isobars

Blind analysis procedures in place and data QA underway

Run 18 brief report: FXT

√s = 3.85 GeV:
~300 M events with EPD

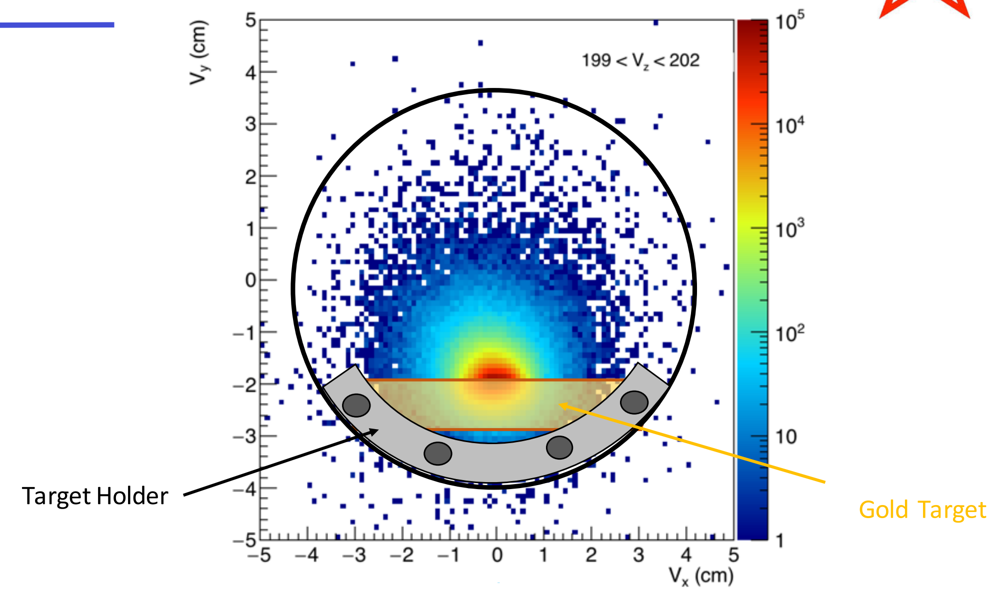
Fast offline:

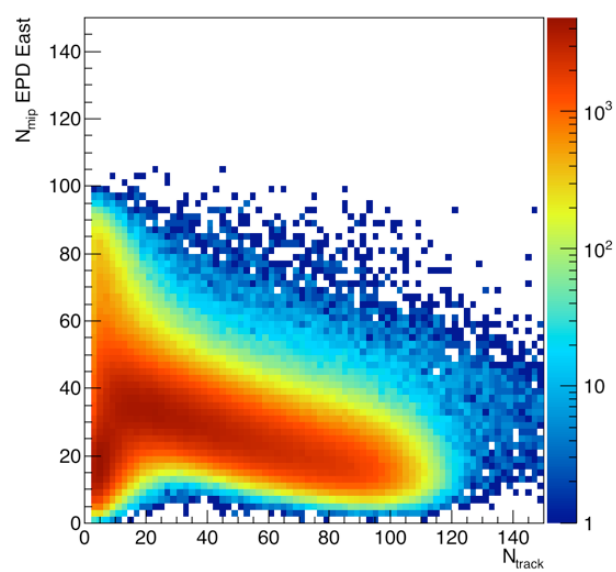
FXT location clear

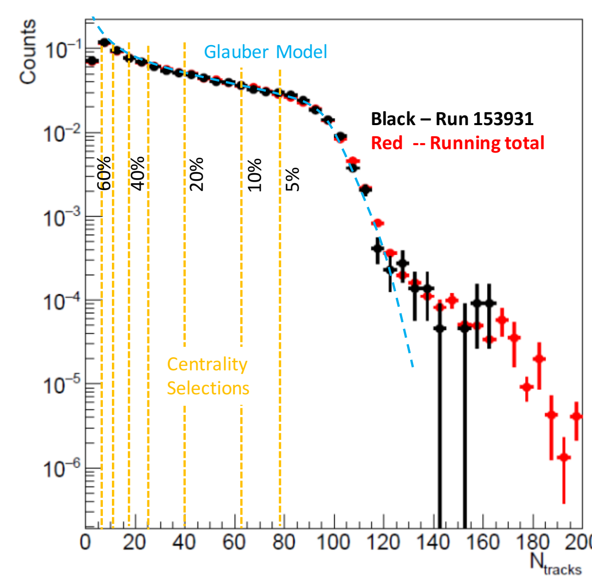
Good EPD - TPC correlations

Nice agreement with Glauber centrality estimates

(√s =7.2 GeV Recorded during CEC commissioning - ~15M events)







Run 18 brief report: Au+Au 27 GeV

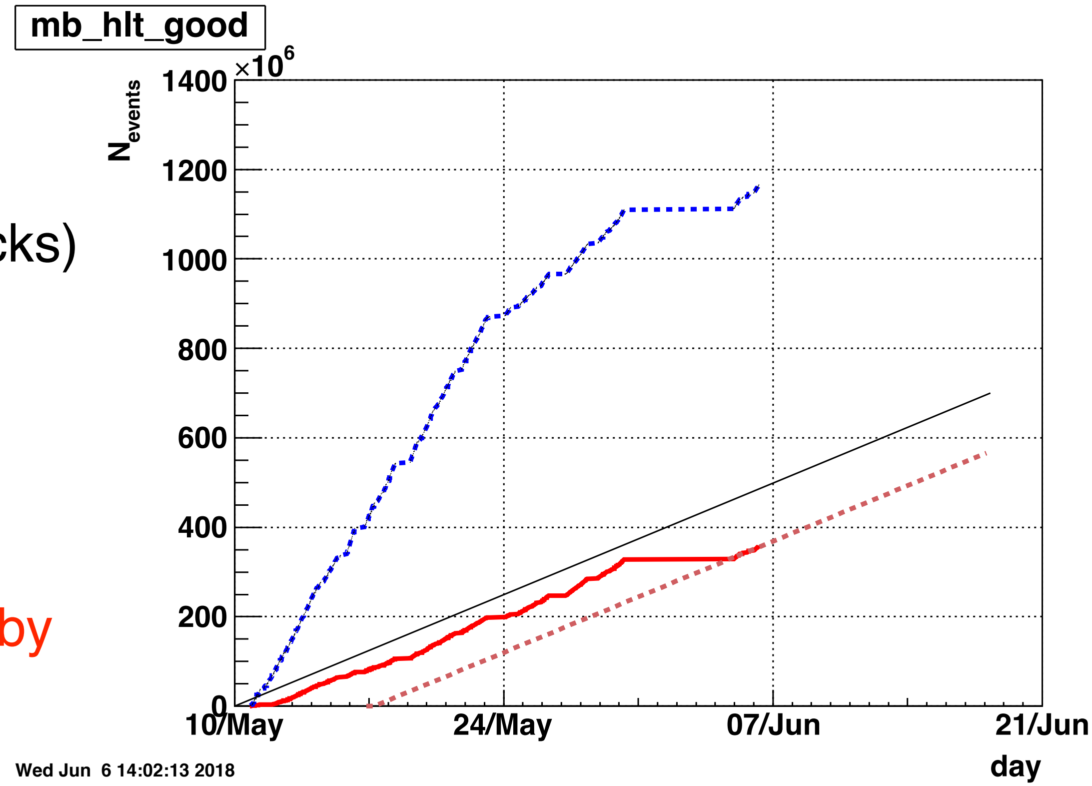
Goal is 700M “Good” events.
(NB: Run 11 68M events
|vz| < 70 cm && >1 primary tracks)

MB trigger very open

Only ~50% are actual events

Only ~50% of those are flagged by HLT as good

|vz| < 50 cm && >4 primary tracks



Currently have ~350M events (as of Wed)
Hope to reach 500—550M good events by end of run

Summary

Data taking during Run 18 very successful

Upgrades performing at or beyond expectations

BES-I 24 papers published (1 nature, 9 PRL)
2 submitted
5 advanced stages

BES-II will likely run into 2021

Ready for BES-II

BACK UP

PAC recommendation for Run 18

The PAC recommends for Run 18 the following:

- $\sqrt{s_{NN}}$ = 200 GeV ^{96}Ru+^{96}Ru and ^{96}Zr+^{96}Zr, 1.2 billion minimum bias events in each system. This program has the potential to clarify a question of major significance in the field – can a signal of the chiral magnetic field be extracted from charge separation measurements in two isobaric systems. This is the highest priority for Run 18.

- 3 weeks of $\sqrt{s_{NN}}$ = 27 GeV Au+Au collisions accumulating 1 billion events to measure effects of global polarization of Lambdas and anti-Lambdas with high statistics, assuming RHIC operates with 15 weeks of cryogenic running in 2018.

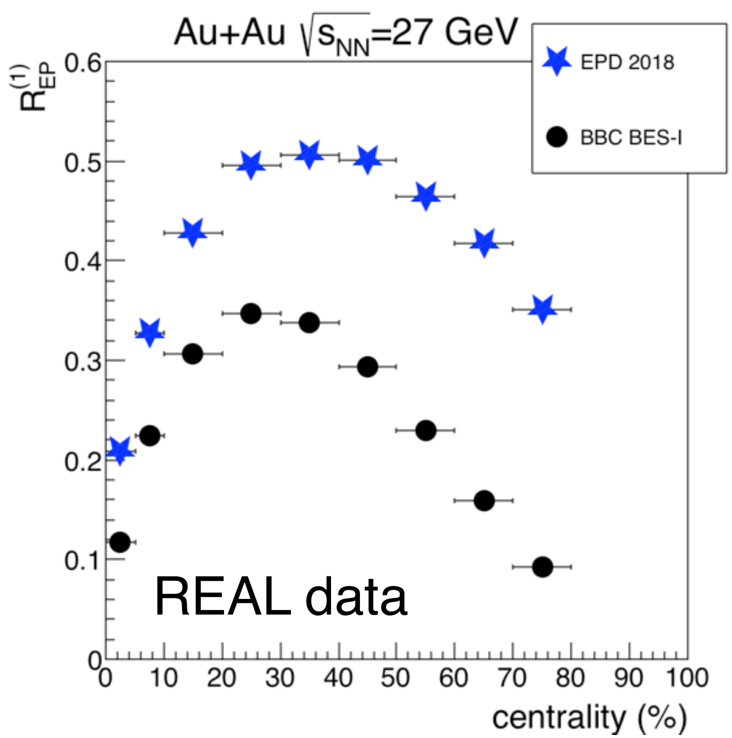
- 2 days of $\sqrt{s_{NN}}$ = 3 GeV Au+Au collisions in fixed-target mode to accumulate approximately 100 million events in order to investigate net proton fluctuations at an energy between its BES I run and the lower energy HADES runs.

Event Plane Detector: EPD

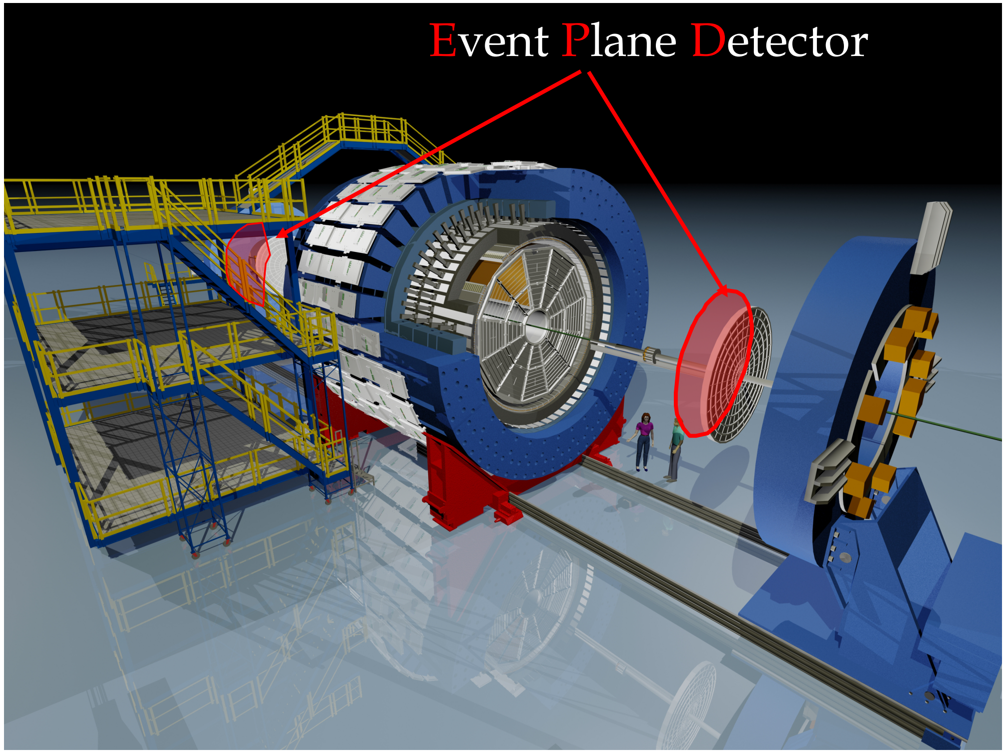
2.1 < |η| < 5.0

Replacing BBCs

16 radial and 24 azimuthal sections



Note EP resolution much better in peripheral events



Greatly improved Event Plane Resolution

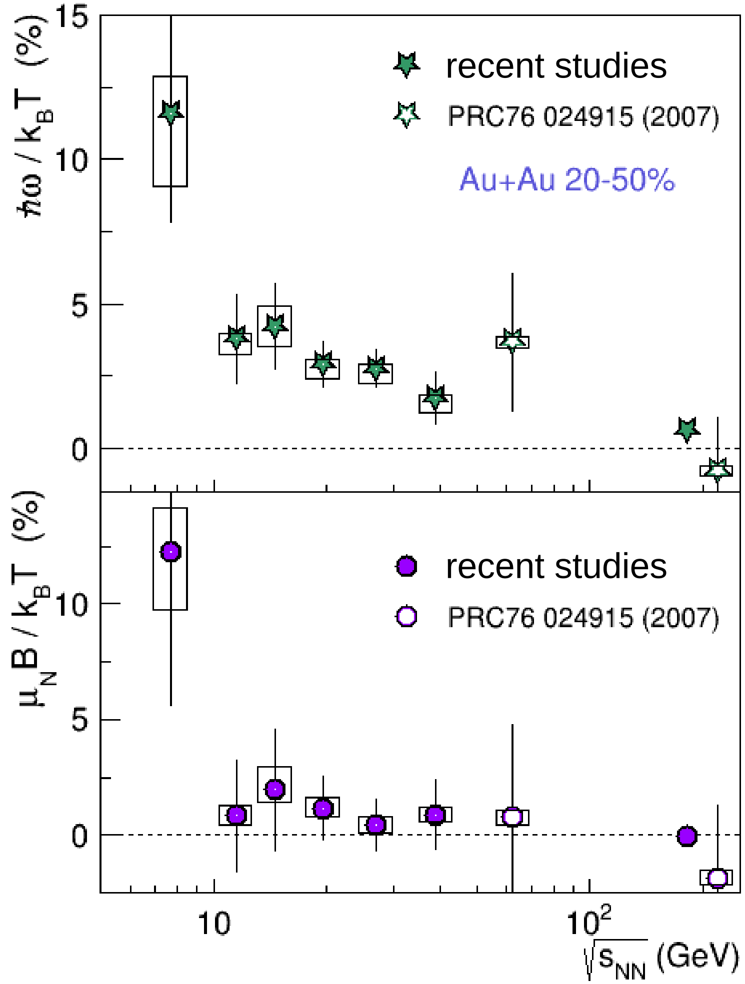
especially 1st-order EP

Determine Centrality away from mid-rapidity

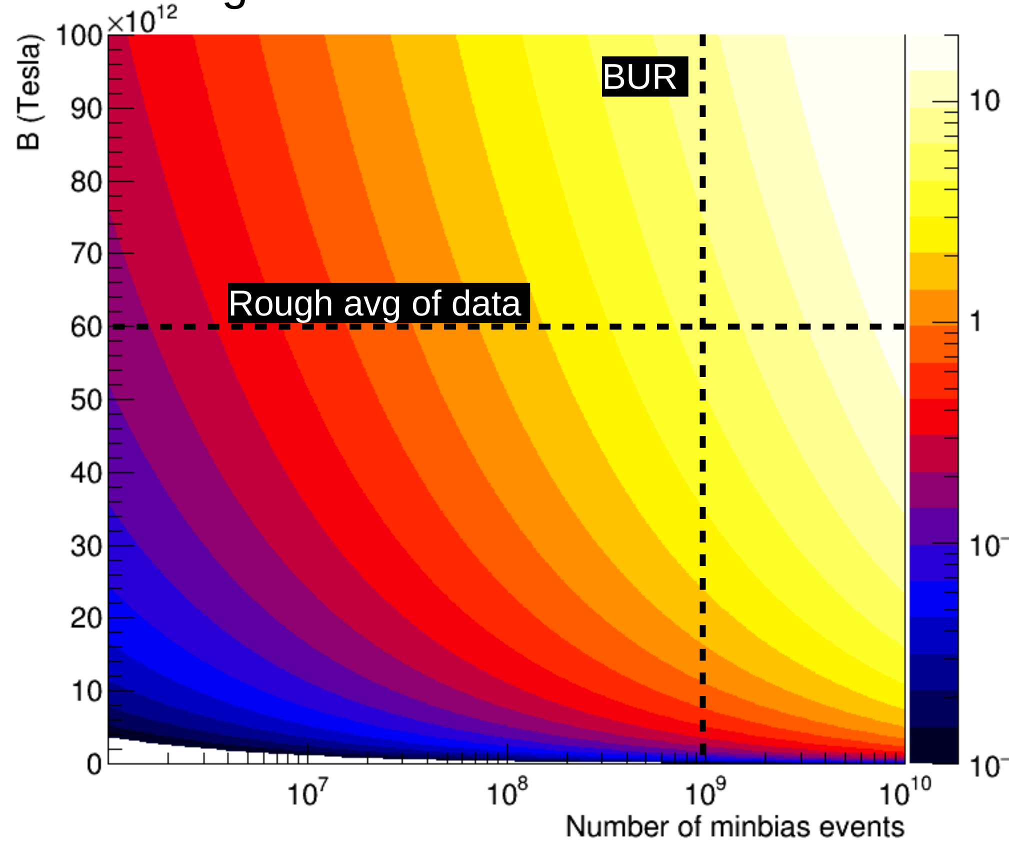
Better trigger & background reduction

Lambda polarization statistics

Clearly, very exciting development
Signal and BES dependence need more data
Au+Au 27GeV in run 18 with EPD
    To establish if there is a difference
Result will guide BES-II studies

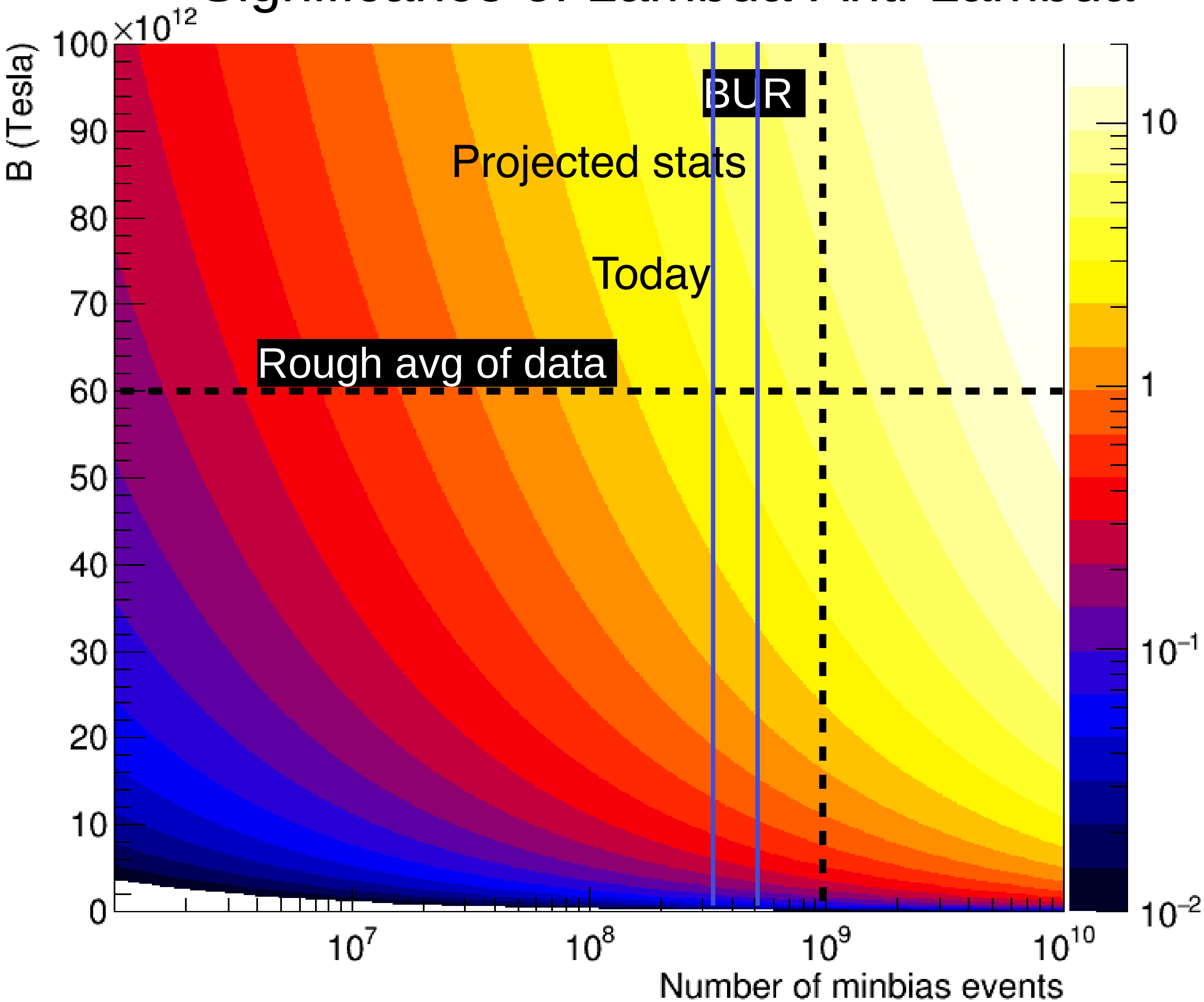


Significance of Lambda-Anti-Lambda



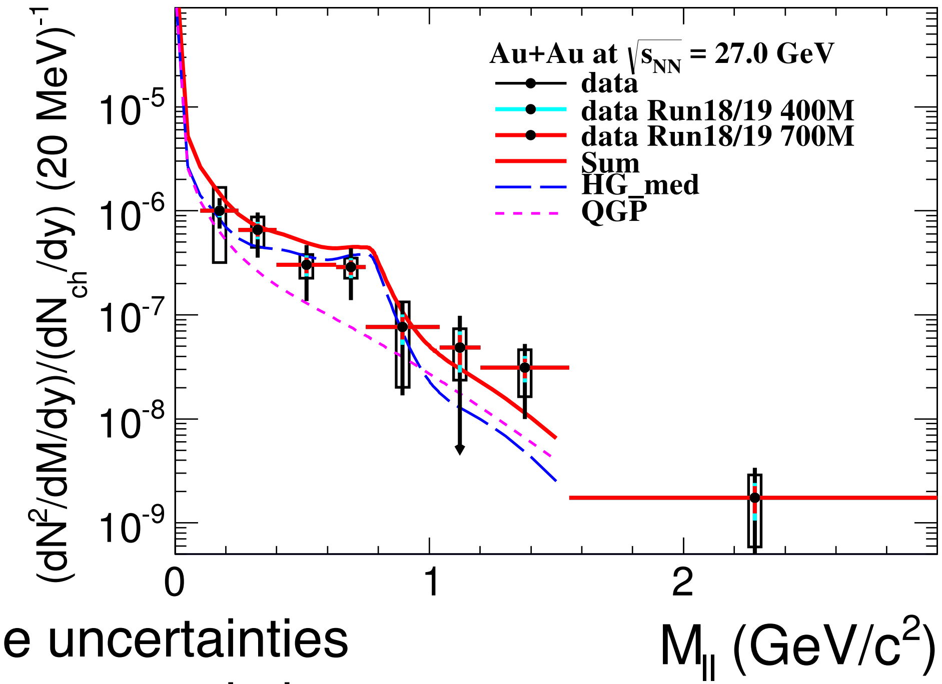
Hint of Bfield:
1.5sigma average for 7.7-39GeV

Significance of Lambda-Anti-Lambda



dilepton 27 GeV

Above phi mass QGP dominated



400 M factor 2.4 reduction in average uncertainties

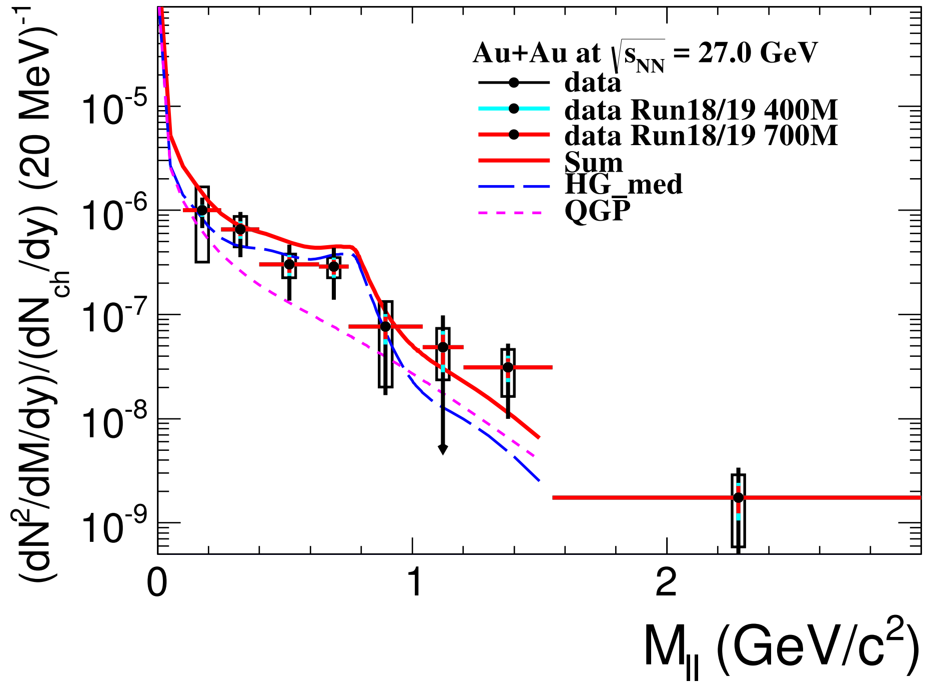
700 M factor 3.2 reduction in average uncertainties

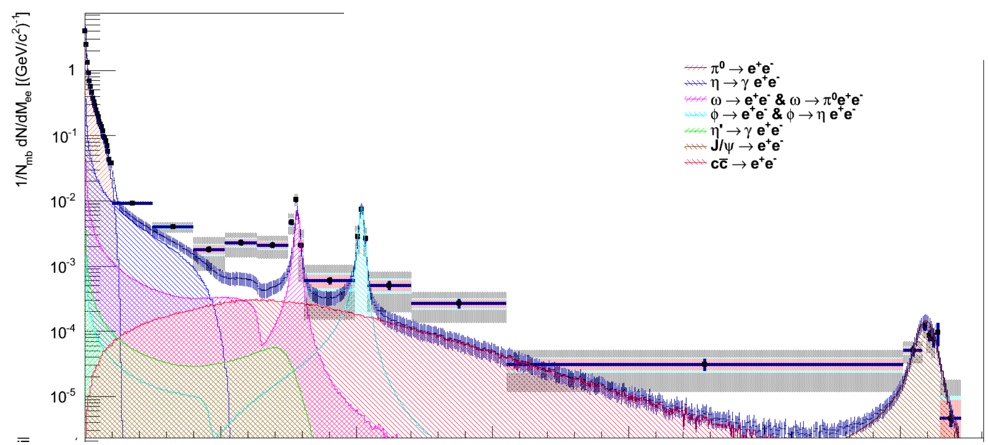
First measurement of T at this energy

Di-lepton error estimates - 27 GeV

Error Bars

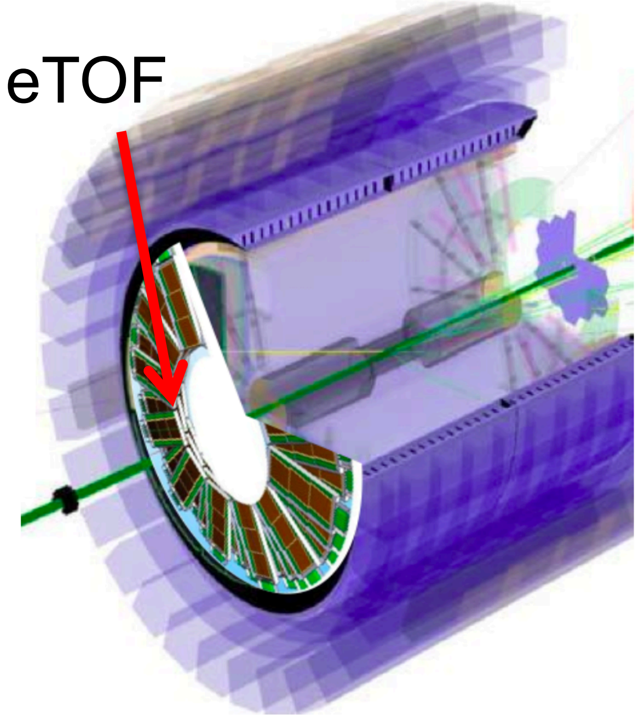
- How much will they shrink?
  - Run 11: 68M
  - 390 M 2.4x(cyan)
  - 700 M 3.2x(red)
- (dN/dy)/(dN$_{ch}$/dy) [M:0.4-0.75GeVc^{-2}]
  - Run11: 5.21552e-06 ± 2.13466e-06(stat) ± 9.84061e-07(sy
  - 2Weeks(2.4) : ±8.89e-07
  - 3Weeks(3.2) : ±6.67e-07





(500M —> 2.7x)

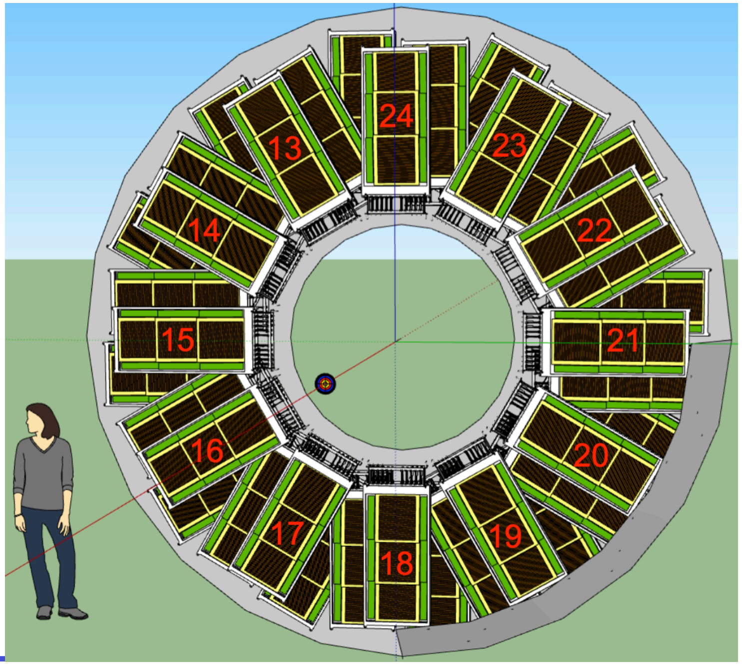
Endcap Time-Of-Flight: eTOF



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

iTPC

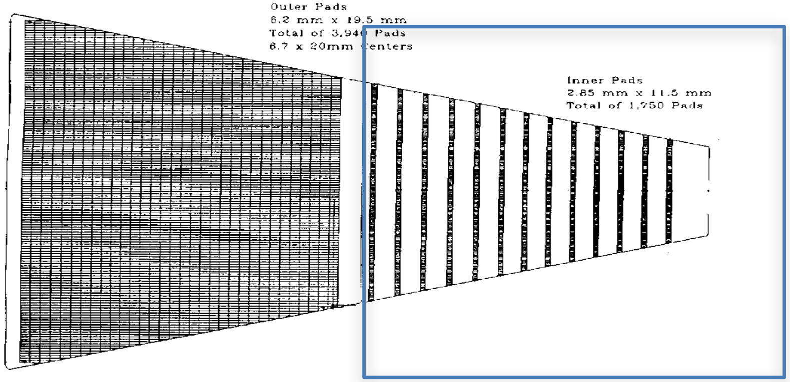
Increase in #channels in 24 inner sectors by ~factor 2

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*.



Inner

Outer