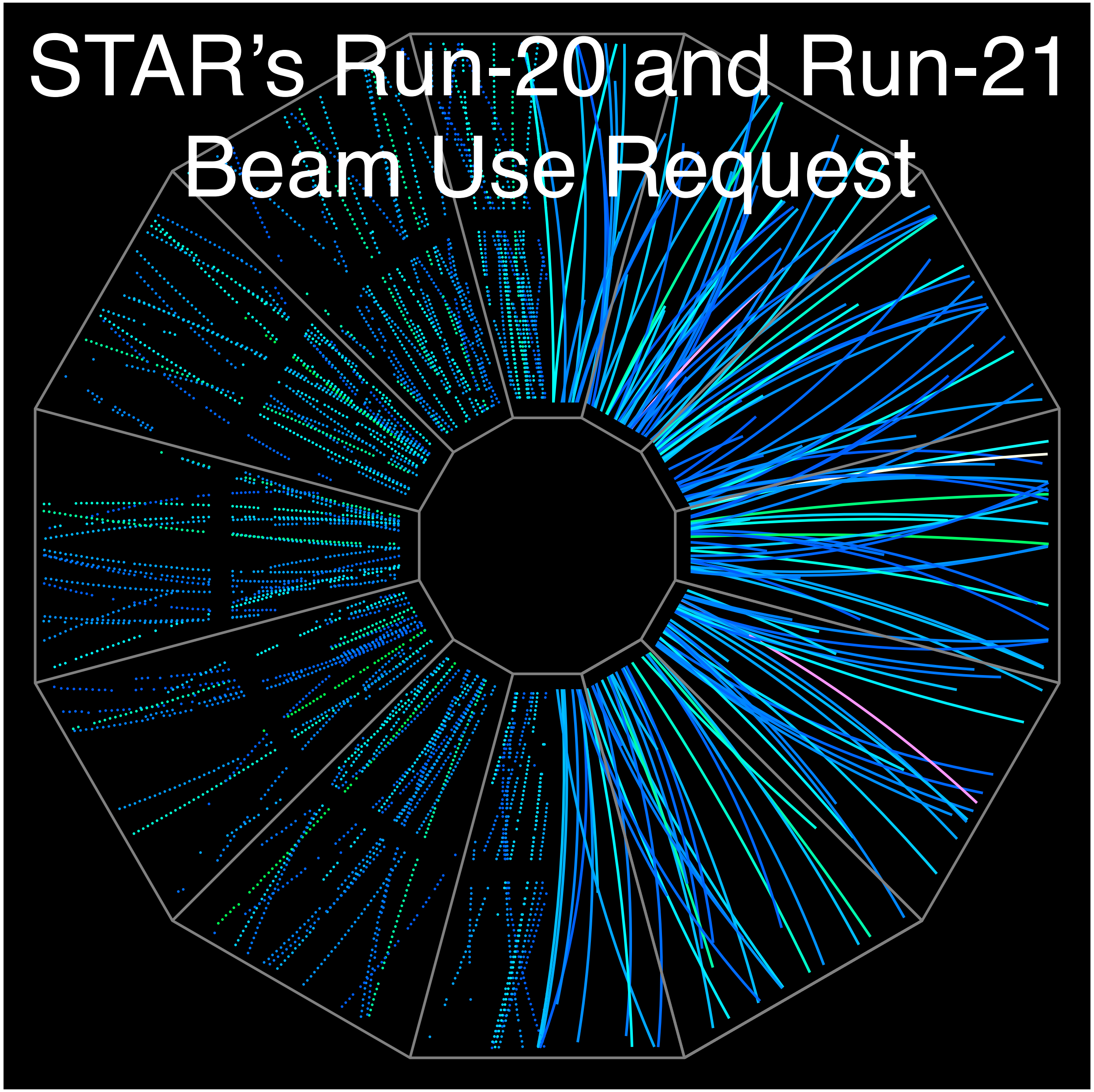
STAR's Run-20 and Run-21 Beam Use Request



Helen Caines - Yale - on behalf of the STAR Collaboration

Executive Summary

STAR's highest priority is the collection of the remaining BES-II data

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events	Status
9.8	19.6	205	4.5 weeks	400M	Run-19 (finished)
7.3	14.6	260	5.5 weeks	300M	Run-19 (finished)
8.35	16.7	235	5 weeks	250M	
5.75	11.5	315	9.5 weeks	230M	LEReC availability?[1]
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	Run-19 (scheduled)
9.8	4.5 (FXT)	589	2 days	100M	Run-19 (scheduled)
7.3	3.9 (FXT)	633	2 days	100M	Run-19 (scheduled)
19.5	6.2 (FXT)	487	2 days	100M	
13.5	5.2 (FXT)	541	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	

[1] At the time of this writing, the availability of LEReC for the 11.5 GeV energy is not clear. Consequently, the run time for this energy is changed from last year's BUR. The new estimate is based on the 14.6 GeV performance in Run-19. A more optimistic estimate, based on the 19.6 GeV performance, would be 7.5 weeks.

Executive Summary

STAR

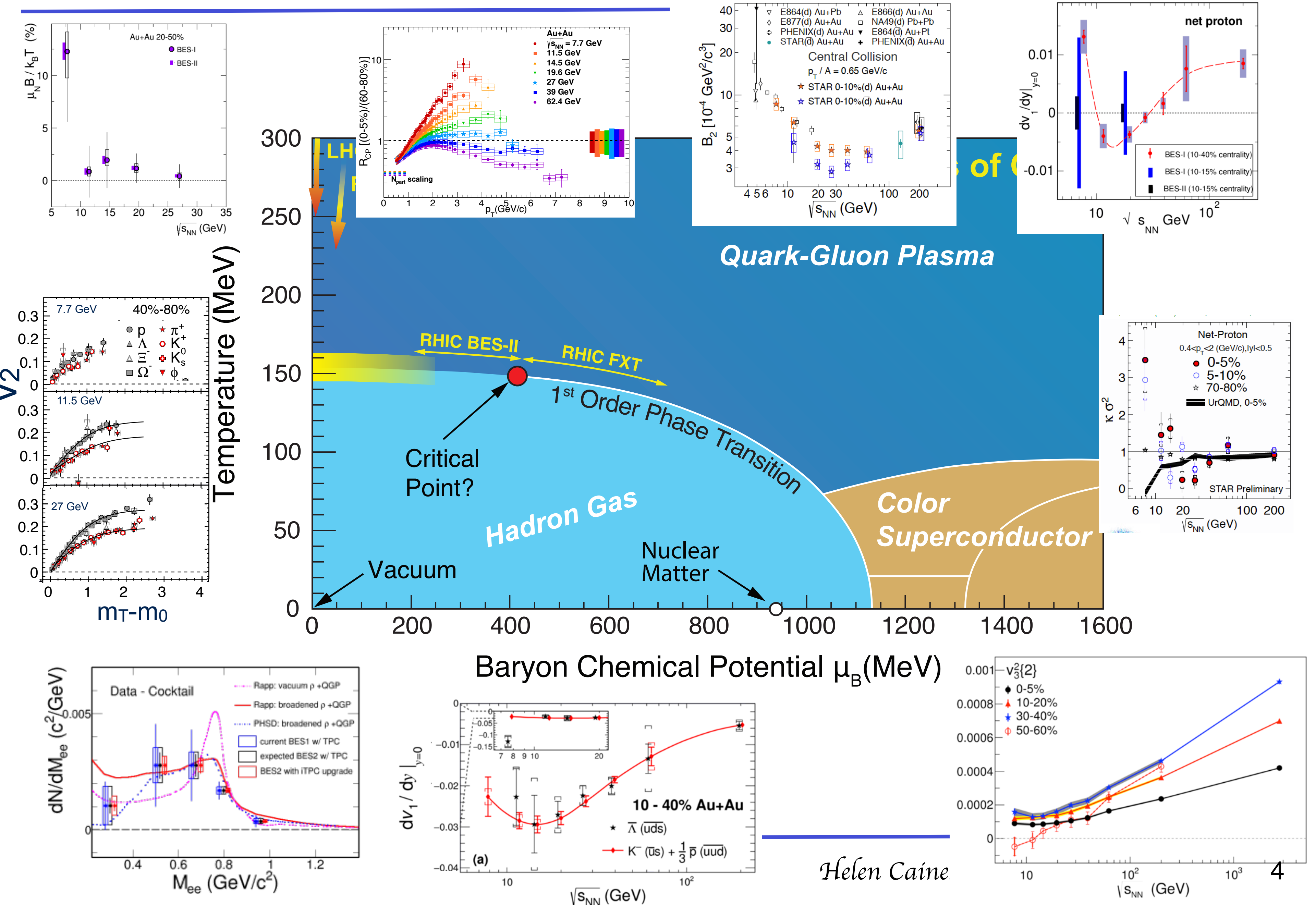
Additionally, the STAR collaboration proposes a small system run to study the emergence of collectivity and the mechanism for early-time *hydrodynamization* in large collisions systems.

BES-II will dramatically enhance our understanding of the QCD phase diagram. The proposed program involves dedicated low beam energy running and high precision measurements of the observables which have been proposed as sensitive to the phase structure of QCD matter. In addition to the five lower collider energies that have been put forward in past BURs, STAR proposes a sixth collider beam energy at $\sqrt{s_{\rm NN}} = 16.7$ GeV. These data will provide for a finer scan in a range where the energy dependence of the net-proton kurtosis and neutron density fluctuations appears to undergo a sudden change.

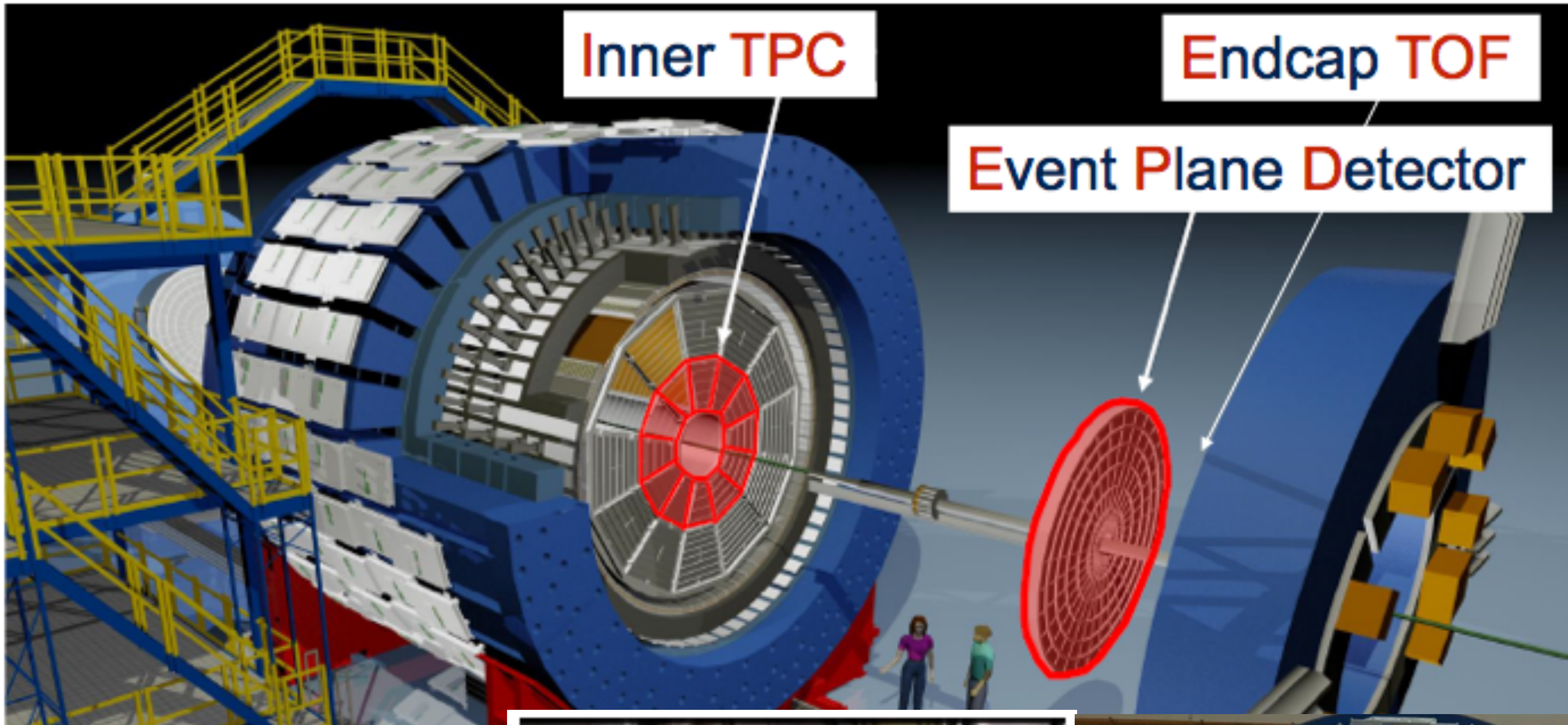
O+O	200 GeV	400 M minbias, 200 M Central	(1 week)
Au+Au	16.7** GeV	250 M minbias	(5 weeks)

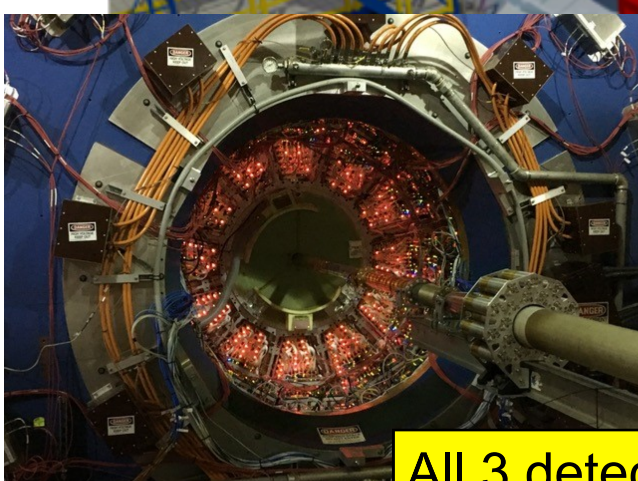
** Discussions with C-AD since BUR submission indicate 17.1 GeV is preferred. This change does not affect STAR's physics goals, so we are changing our request to 17.1 GeV

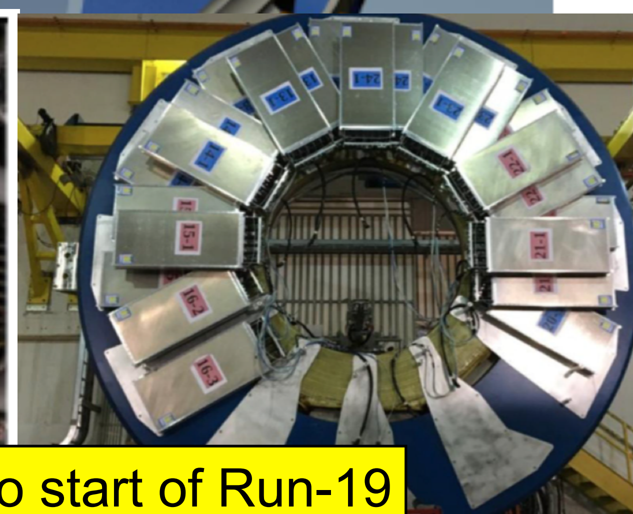
The Case for Continuing BES-II



The BES-II Upgrades

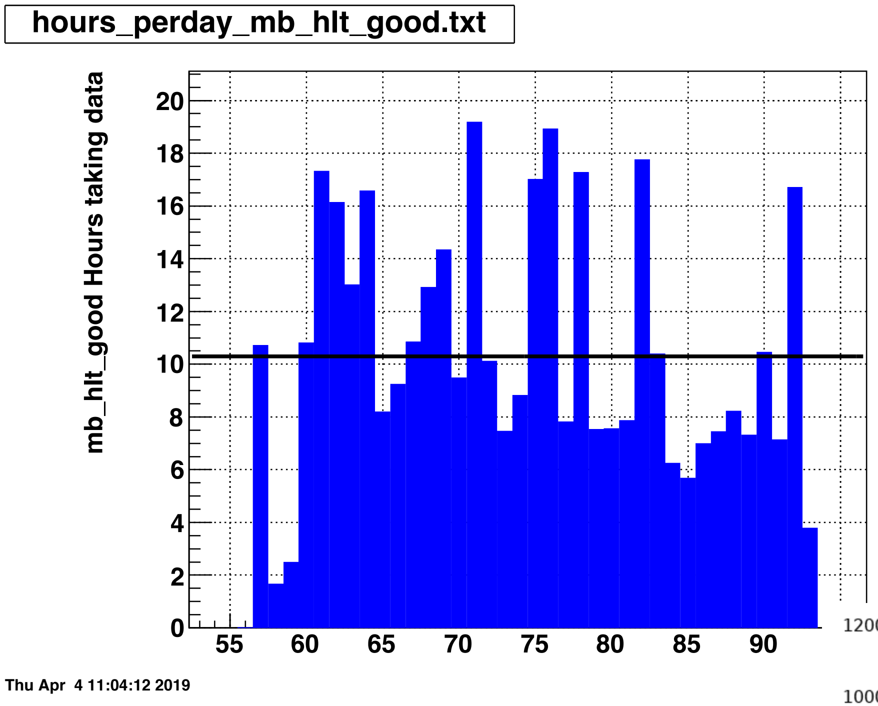






All 3 detectors fully installed prior to start of Run-19

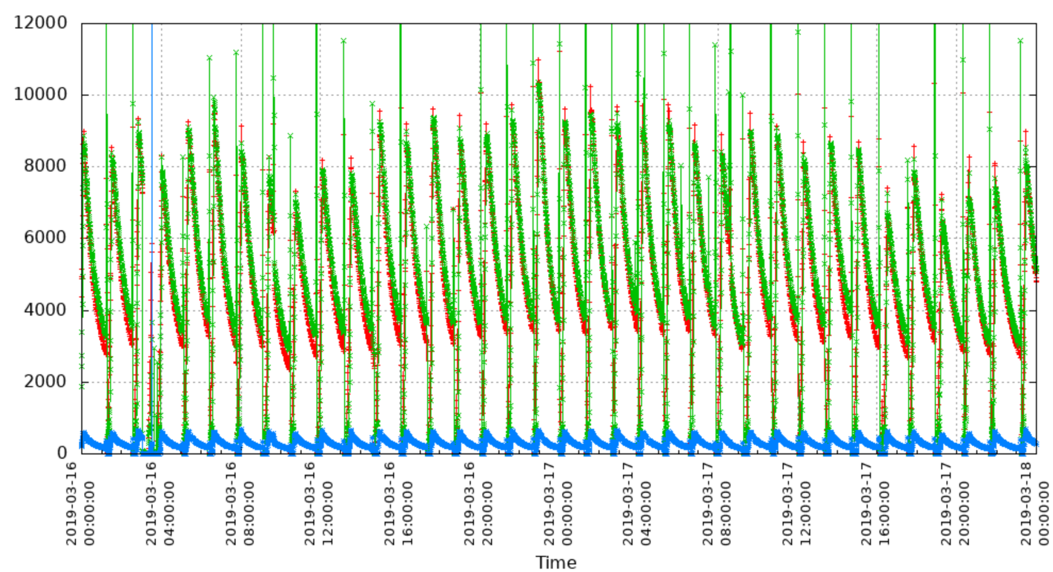
Run-19 Progress Report



STAR running interspersed with LEReC

Averaging ~10 hours/day of collisions at STAR

C-AD provided very stable, low background beam with fast turn-around times



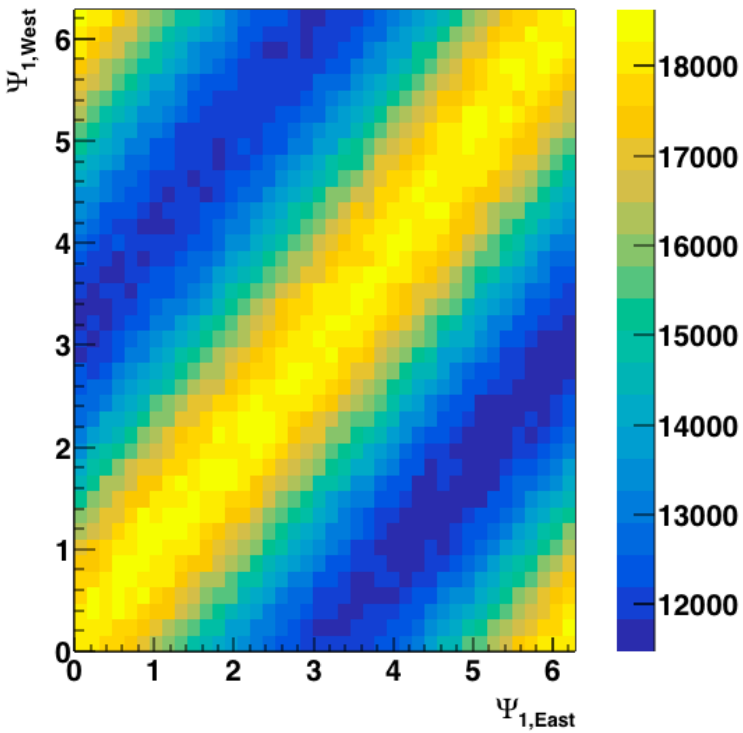
EPD: Enhanced Event Plane Resolution

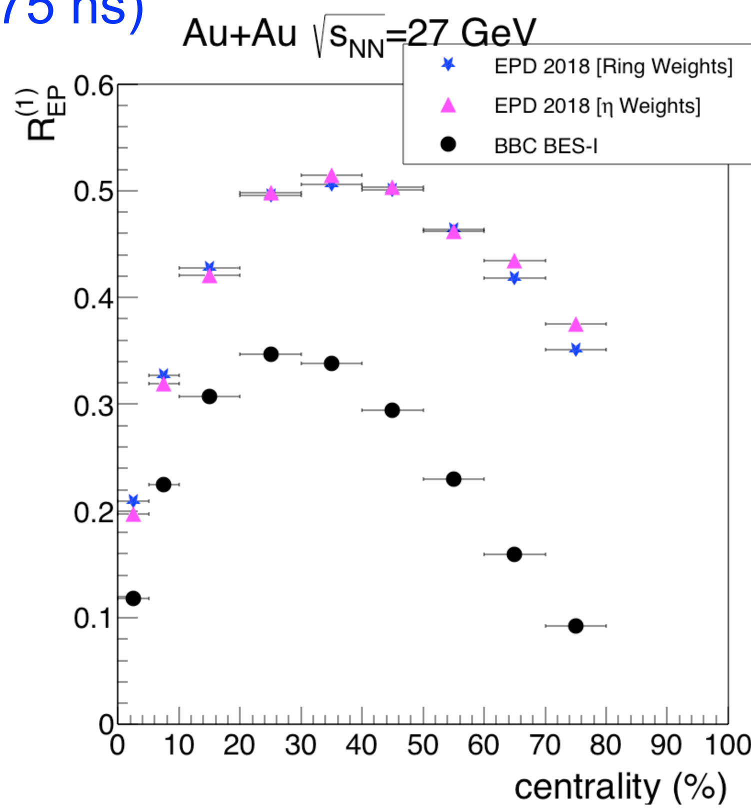
All tiles operational for Run-18 and Run-19 : 2.1 < |η| < 5.1

Run-19: Main trigger detector

Greater acceptance than VPD or ZDC

Better timing resolution than BBC (0.75 ns)





Event plane (and centrality) outside of iTPC acceptance

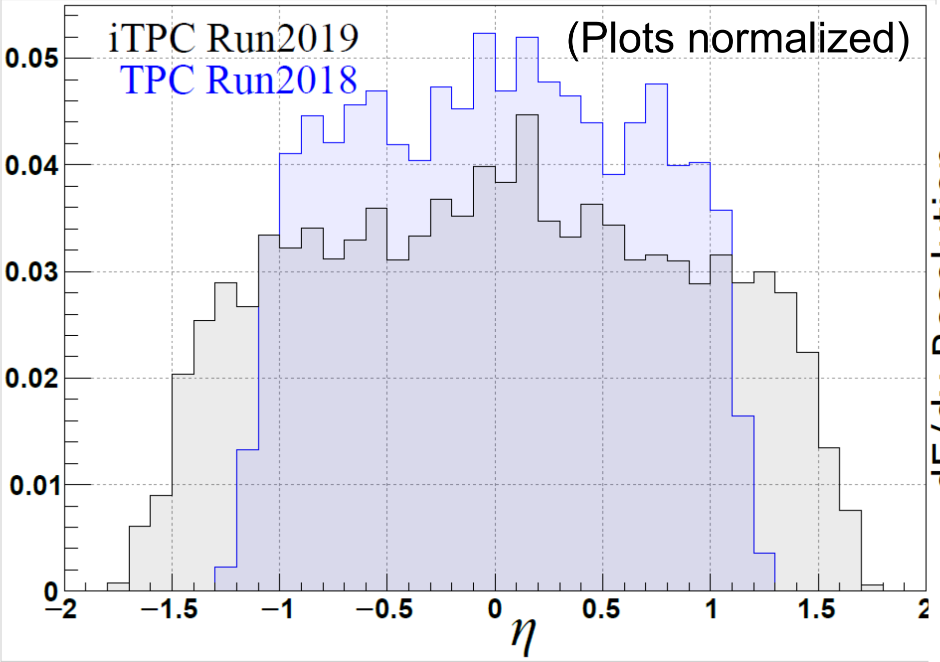
iTPC: Enhanced Acceptance

Successfully integrated into data-taking since day 1 of Run-19

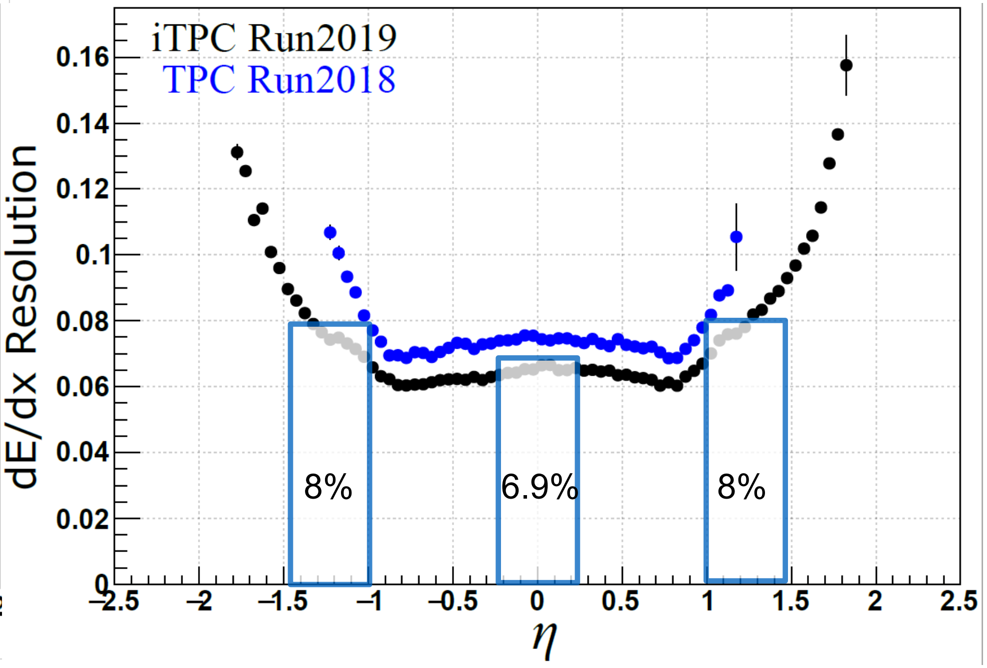
Passed DoE close-out review
All KPP and UPPs met or passed

Demonstrated improvement:

Increased pseudorapidity coverage

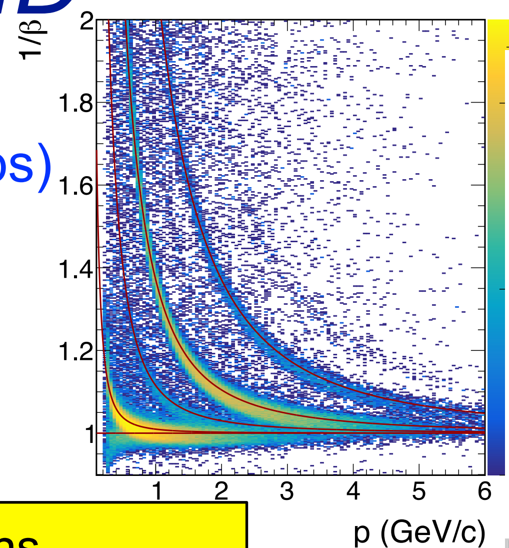


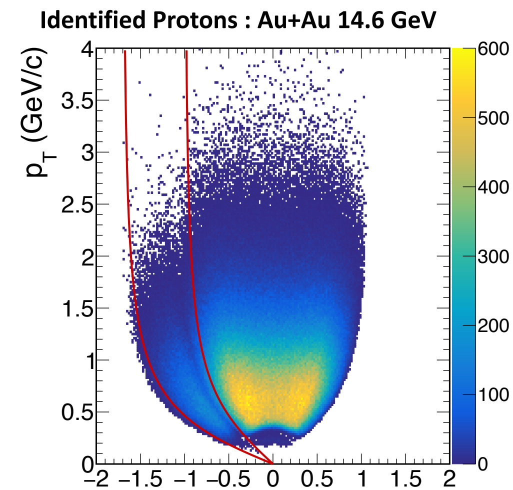
Improved dE/dx resolution



eTOF: Enhanced PID

Initially: Channels 100% working
Good timing resolution (80ps)
Clear PID bands
Extended coverage

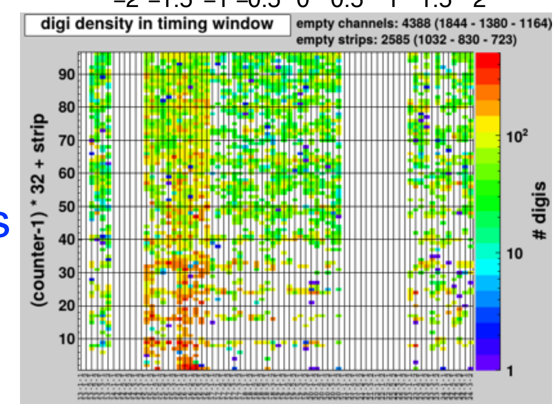




Joint FAIR Phase-0 CBM project

- Operate detector under real conditions
- Challenges integrating into STAR/collider mode

System started to lose performance
Loss of ~50% of readout channels (PADI) - beam related events

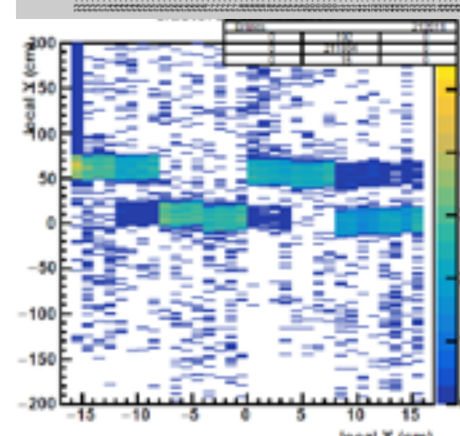


Work ongoing to enhance stability of long term operation:

Occurrence and handling of noisy channels - Gas mixture changed and improved channel masking

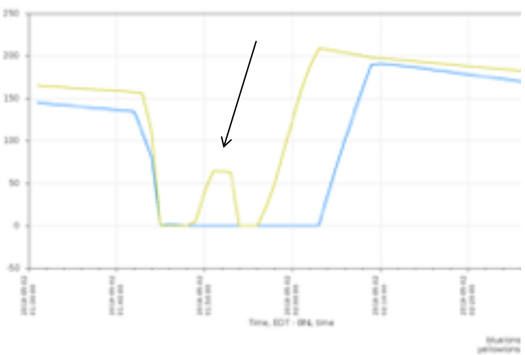
Intermittent failure of GBTx boards configuring - Improvements of eTOF/DAQ code

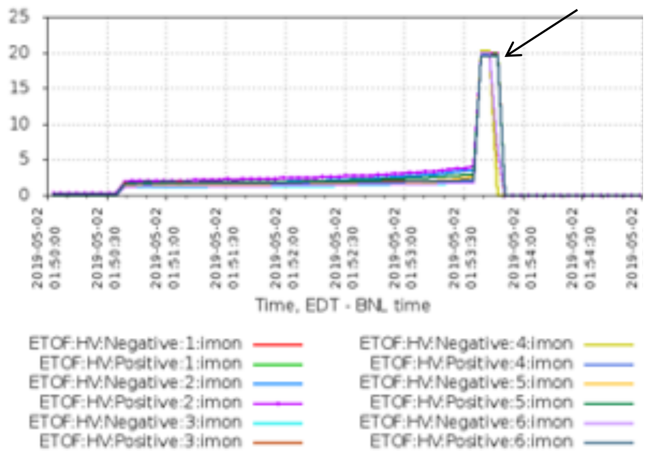
Clock jumps in data occur - Improvement to clock distribution, offline handing of eTOF timing

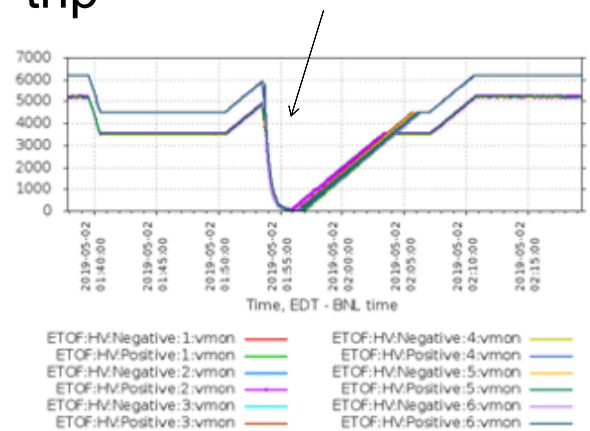


eTOF: Beam Loss Induced Damage

Loss of yellow beam causes instantaneous high current in readout electrode and power supply in turn caused HV trip







Hypothesis: beam loss events → high flux of particles → induced high current in very short time in readout electrodes → damaged PADI input stage

More damaged channels on USTC counters than Tsinghua counters

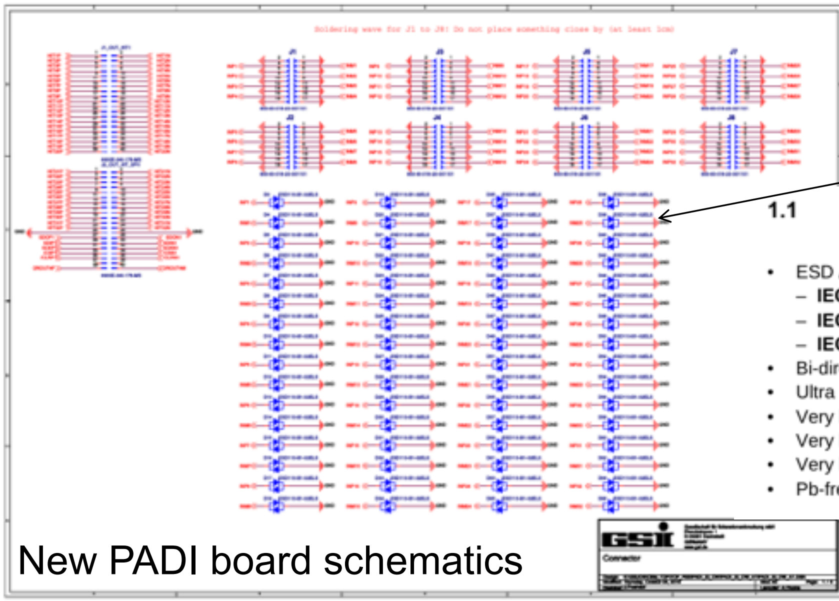
- due to larger E-field energy (~30% more at operating voltage)

- Threshold behavior in channel destruction

- Distinct pattern of damaged channels is visible on USTC counters
- Not all beam loss events caused damage

eTOF: Avoiding Future Damage

- Replace all PADI preamplifier boards
  - New preamplifier boards have protection diode (ESD 113-B1)
  - Prototype boards exist and are being tested



New PADI board schematics

Protection Device

TVS (Transient Voltage Suppressor)

ESD113-B1 Series

1.1 Features

- ESD / transient protection of high speed data lines according to:
  - **IEC61000-4-2 (ESD): ±20 kV (air / contact)**
  - **IEC61000-4-4 (EFT): ±2.5 kV / ±50 A (5/50 ns)**
  - **IEC61000-4-5 (surge): ±3 A (8/20 µs)**
- Bi-directional, working voltage up to: V_{RWM} **= ±3.6 V**
- Ultra low capacitance C_L **= 0.20 pF (typical) at** f **= 1 GHz**
- Very low clamping voltage: V_{CL} **= 14 V (typical) at** I_{TLP} **= 16 A**
- Very low reverse current. I_R **< 1 nA (typical)**
- Very low dynamic resistance: R_{DYN} **= 0.45 Ω (typical)**
- Pb-free and halogen-free package (RoHS compliant)

Mitigation plans in place

- Change gas mixture to include 1% SF6
- Ramp to full voltage only after both beams are stable
- Lower standby voltage

eTOF: Preparing for Run-20 and Run-21

Run-19 commissioning highlighted critical issues with stable collider operations

Hardware → exchange all PADI boards and GBTx back-planes in Fall 2019
- improved overload protection
- improved clocking scheme with more flexibility
- extended slow control features (temp, on board voltages)

Firmware → development ongoing based on experience gained from eTOF and miniTOF during run 2019
- improve DAQ stability (noisy channel handling)
- eliminate data losses under high local rate conditions

Software → improve and test with Run-18 and Run-19 data
- handling of clock cycle jumps on data calibration level
- usage of pulser data for phase stability monitoring and correction

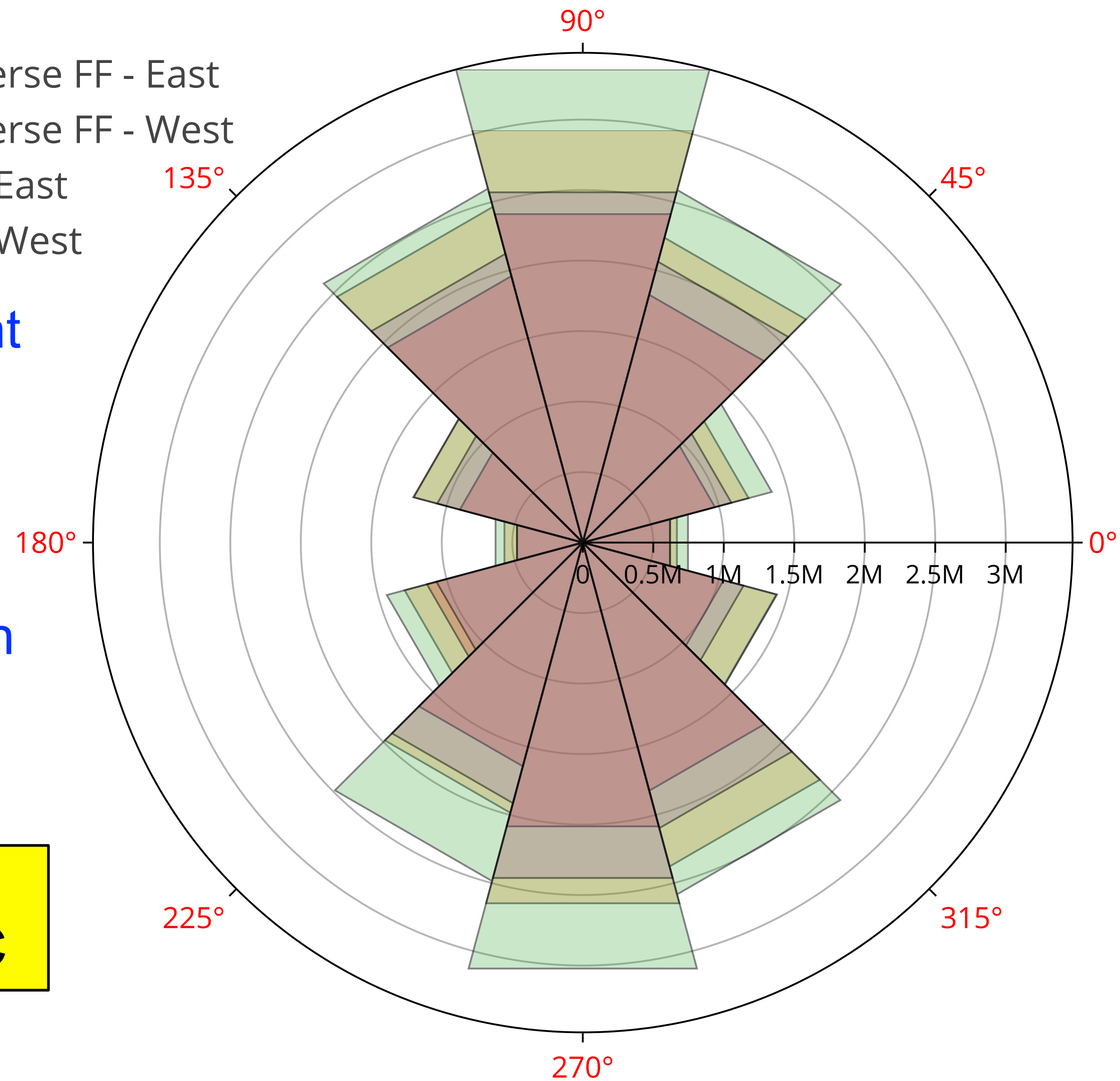
Time line

now	- PADI boards ordered
End of July	- Return of module 18.1 to Heidelberg
End of Sept	- PADI boards available and tested
Beg of Oct	- New GBTx back-planes available and tested
Oct/ Nov	- Maintenance work at BNL (~3 weeks on-site)
afterwards	- Commissioning

eTOF can provide expected timing and PID

Cosmic Commissioning

Fully commissioned iTPC prior to BES-II data taking

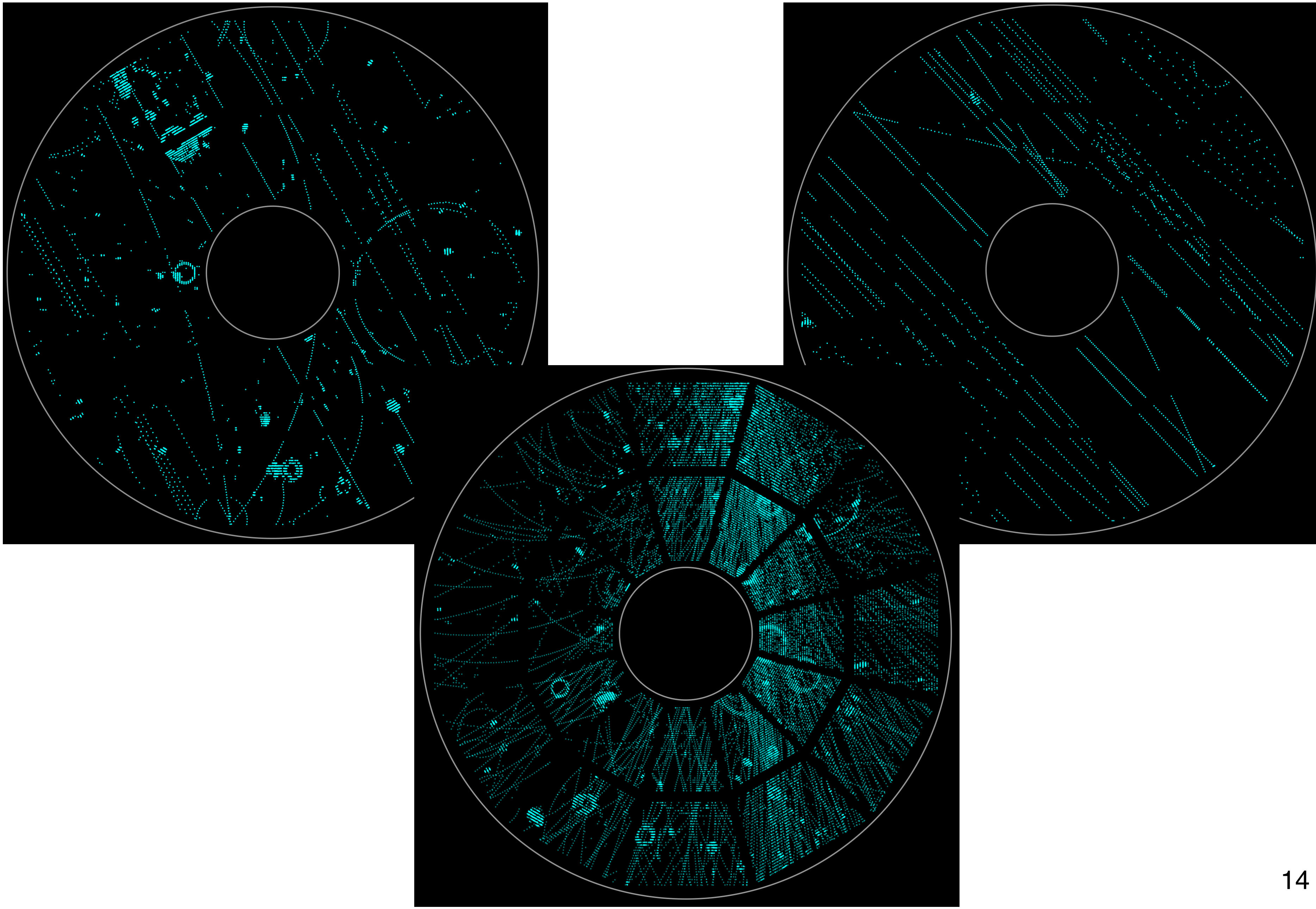


To eliminate B-field dependent effects both field polarities used

Collected >0.5M cosmic events in each sector for each field

Enables alignment of new inner sectors with outer TPC

Cosmic Examples

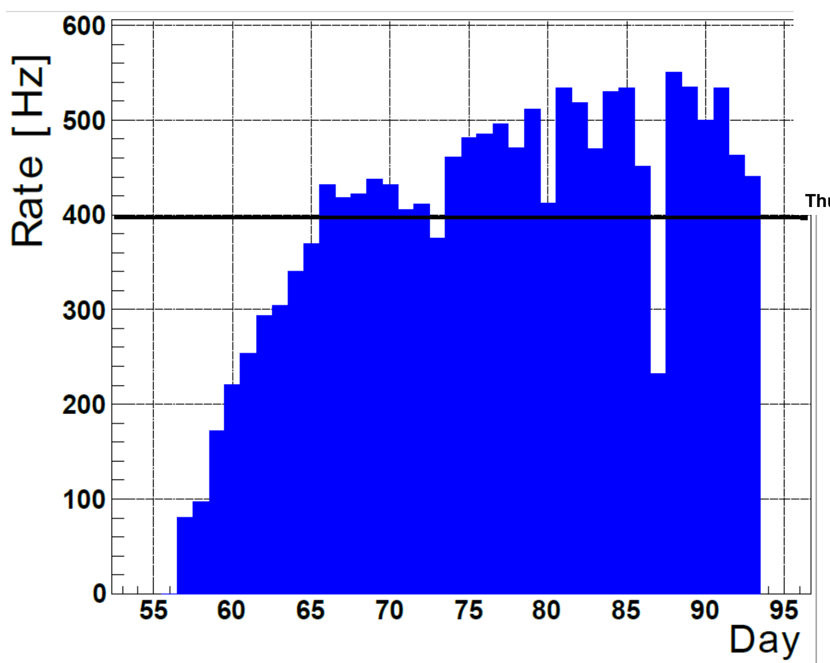


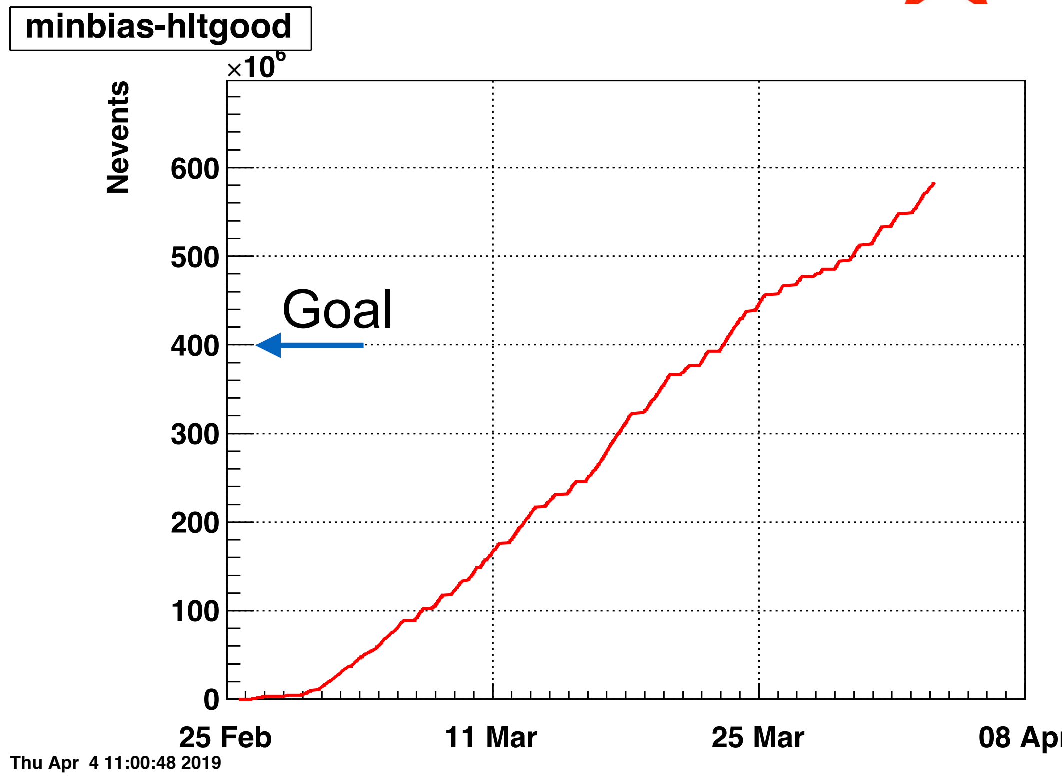
Au+Au $\sqrt{s_{NN}}$ = 19.6 GeV

Efficient data-taking and high quality stable beams

~60 min fills,
turn around ~20mins

Good event fraction 40-55%





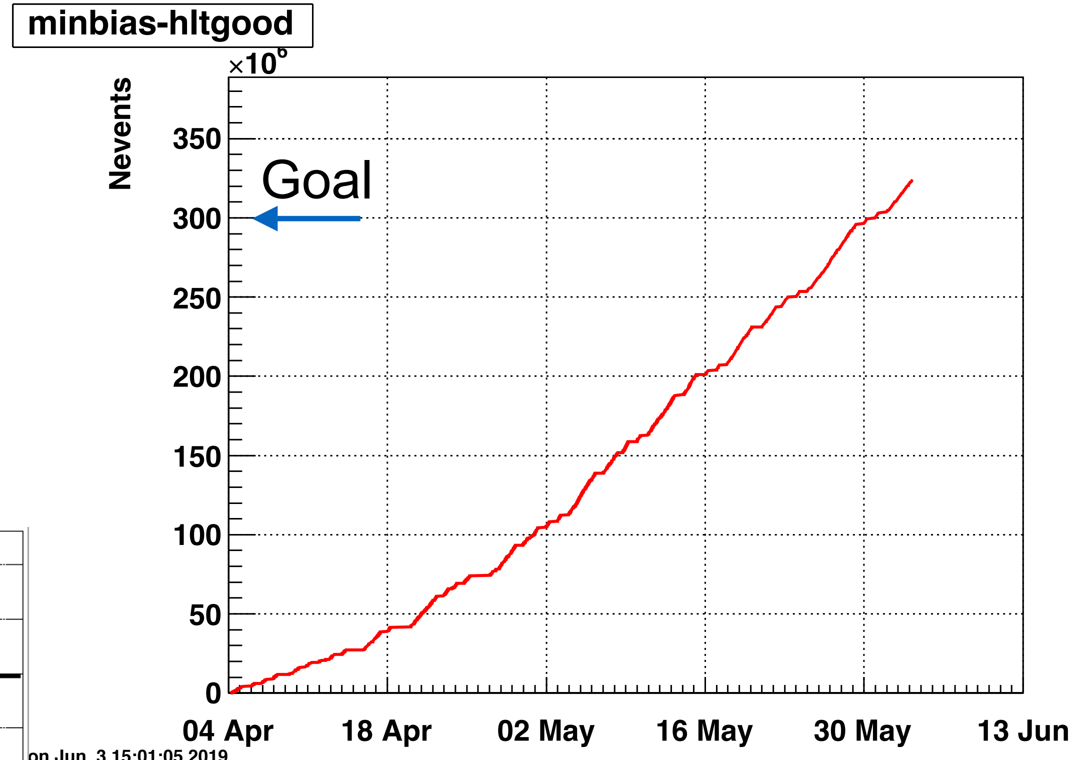
Concluded on April 4th
580 M minbias "good" events collected

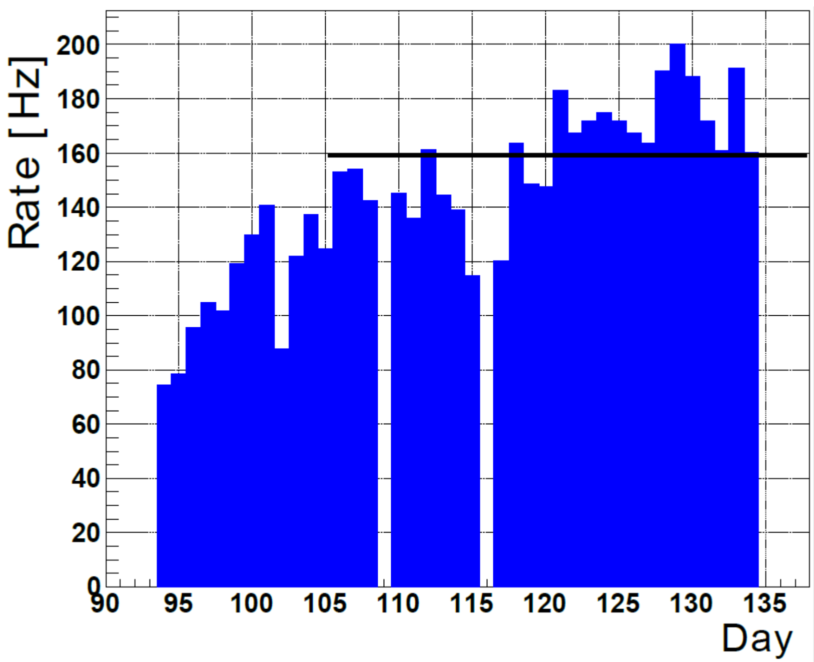
Au+Au $\sqrt{s_{NN}}$ = 14.6 GeV

Ever-increasing collision rate as C-AD enhanced beam

~45 min fills,
turn around ~20mins

Good event fraction 35-40%



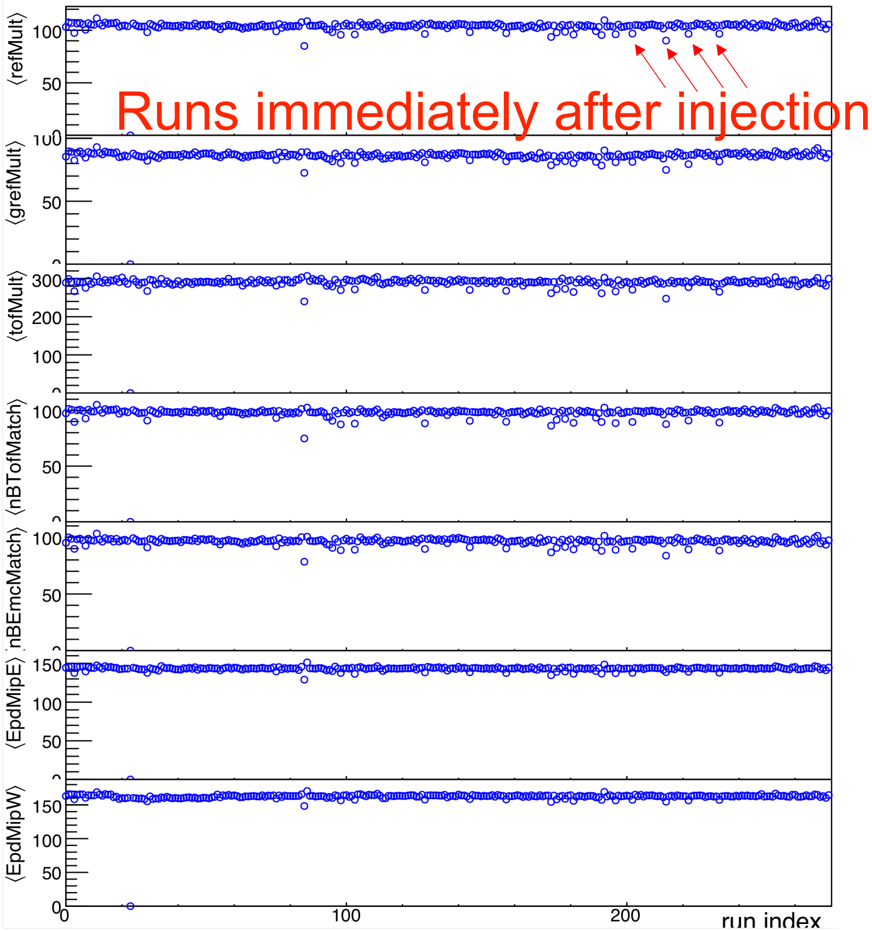


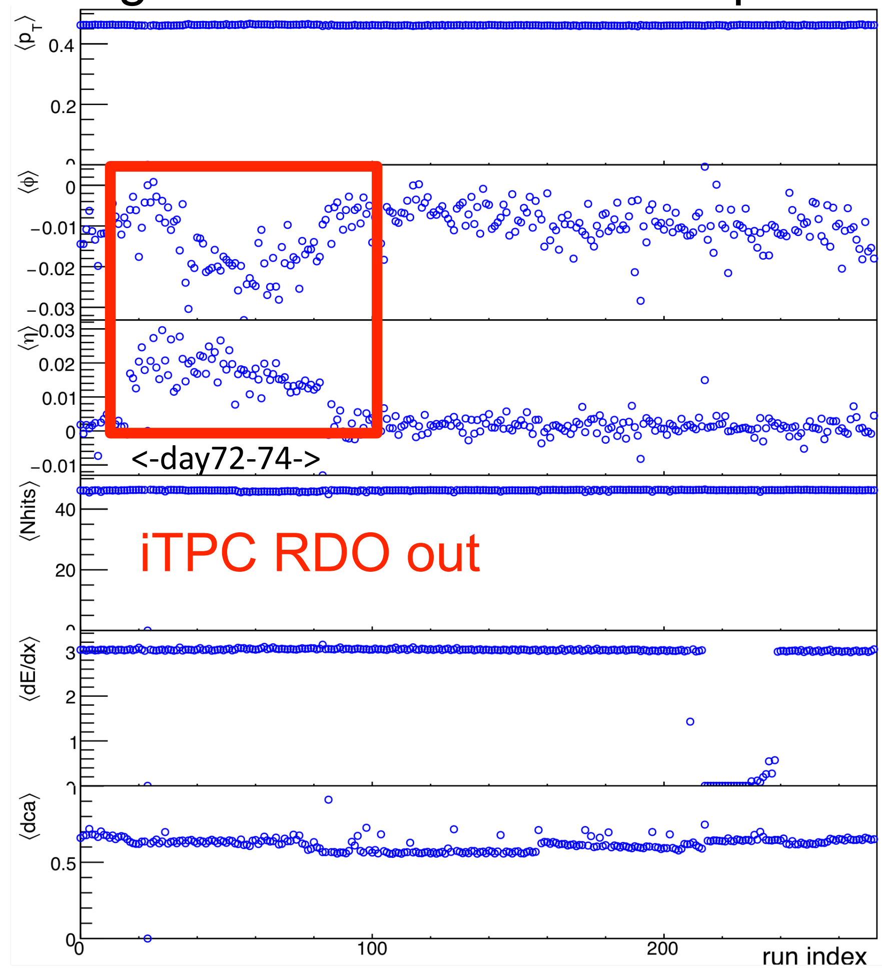
Concluded on June 3rd
324 M minbias "good" events collected

[1]In 2014, collisions were run at a collider energy of 14.546 GeV, which was rounded to 14.5 GeV. This year, we are running at a slightly different energy, 14.618 GeV, which is rounded to 14.6 GeV.

Continuous Data QA

Data QA occurs: On shift while data being taken, via fast offline reconstruction QA shift, HLT monitoring and weekly meeting of detector and PWG experts





Issues rapidly identified, fast feedback to C-AD and/or shift crew

2 plots from a weekly QA meeting

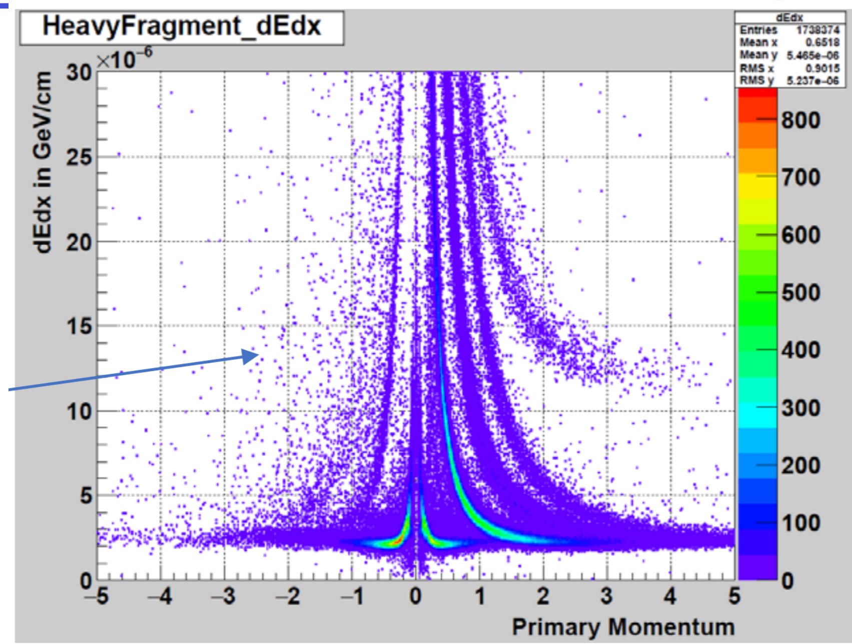
Au+Au $\sqrt{s_{NN}}$ = 3.9 GeV: FXT test

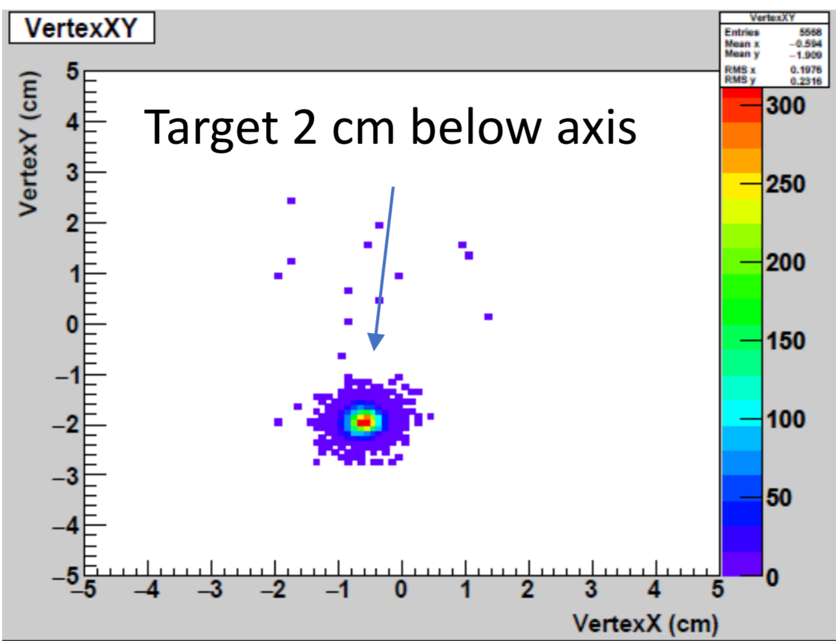
Quick test during LEReC operations

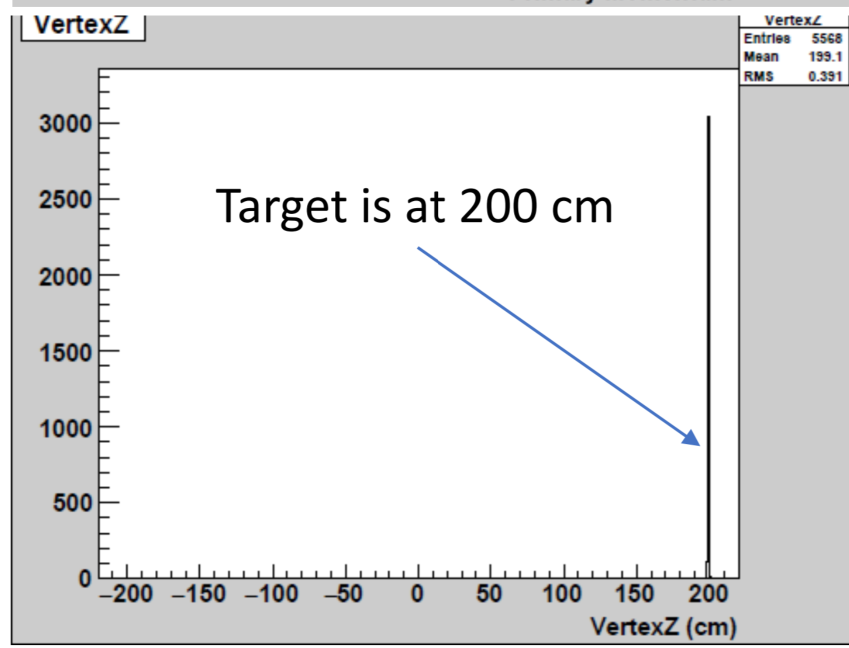
Data taking for 1 hr
recorded ~4M good events
Trigger effic. 90%

Clear PID, including heavy fragments

Confident can trigger and collect data requested





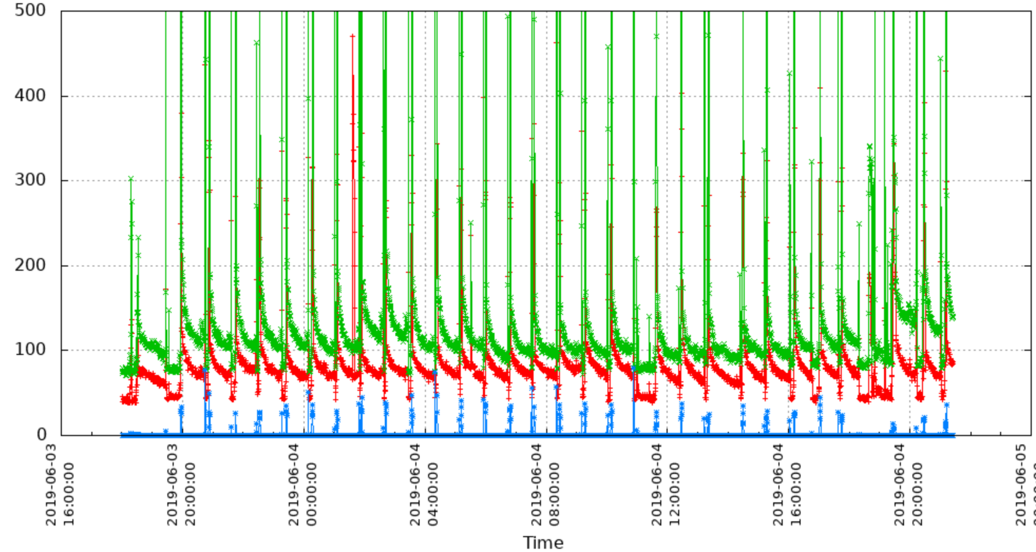


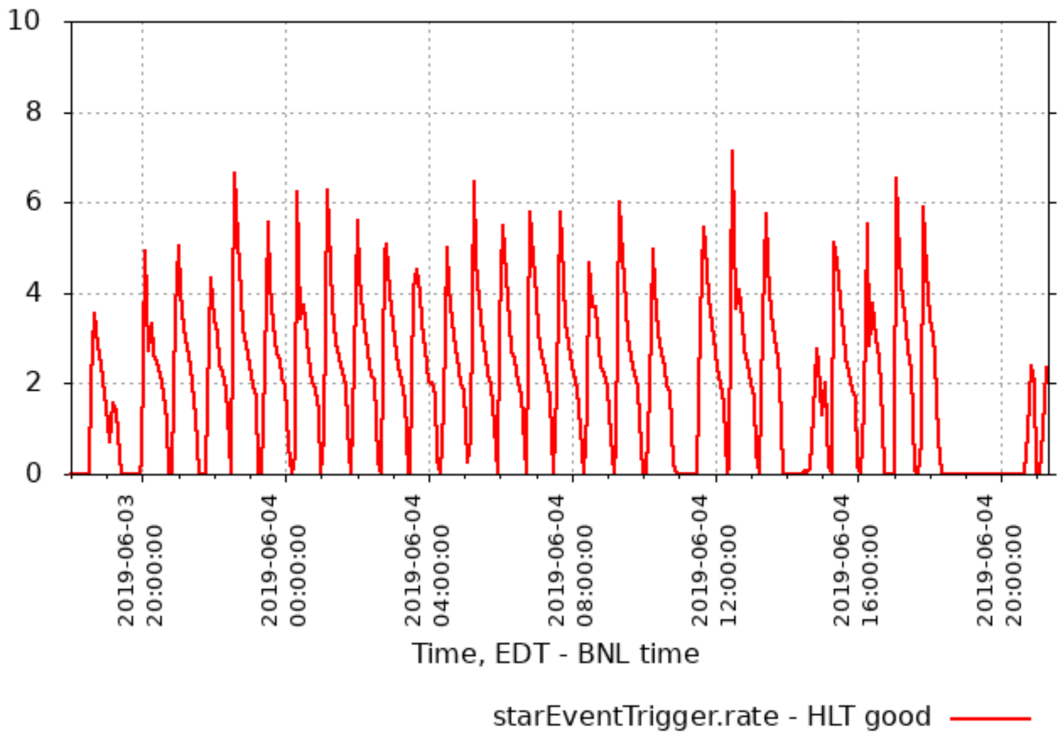
Remainder of Run-19

Au+Au 7.7 GeV (collider mode)

STAR: Commissioning for Run-20
LEReC: commissioning during real physics running

Run until ~June 20th





Remainder of this year's run:

FXT at 3.85, 4.55, 7.3, and 31.2 GeV

Au+Au 200 GeV collider during RHIC APEX

STAR BES-II (projected) Performance

Table 9: Achieved and projected experiment performance criteria for the BES-II collider program.

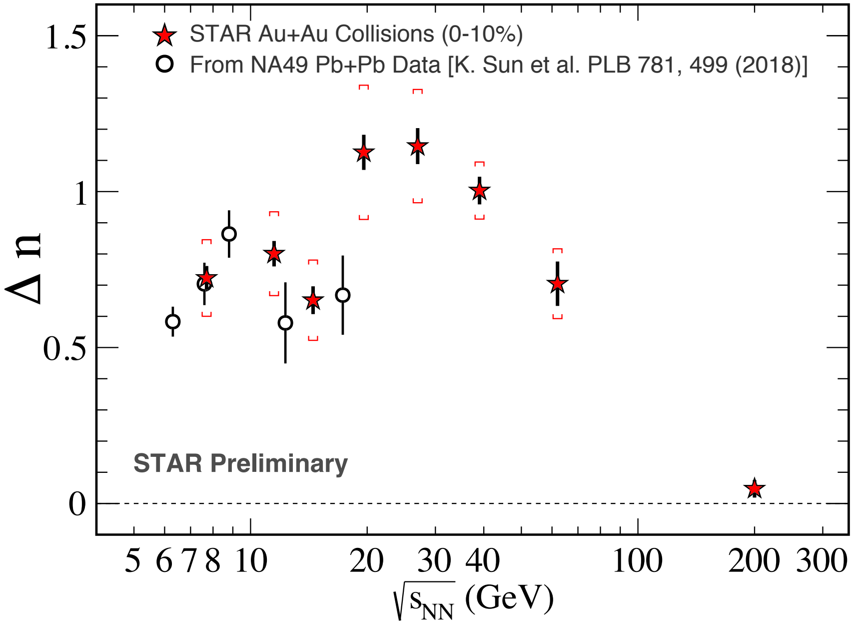
Collision Energy (GeV)	7.7	9.1	11.5	14.5	16.7 **	19.6	27
Performance in BES-I							
Good Events (M)	4.3	NA	11.7	12.6	NA	36	70
Days running	19	NA	10	21	NA	9	8
Data Hours per day	11	NA	12	10	NA	9	10
Fill Length (min)	10	NA	20	60	NA	30	60
Good Event Rate (Hz)	7	NA	30	17	NA	100	190
Max DAQ Rate (Hz)	80	NA	140	1000	NA	500	1200
Performance in BES-II (**achieved** or projected)							
Required Number of Events	100	160	230	300	250	400	NA
Achieved Number of Events	TBD	TBD	TBD	**324**	TBD	**580**	**560**
fill length (min)	20	30	40	**45**	50	**60**	**120**
Good Event Rate (Hz)	20-33	33-53	60-80	**160**	245	**400**	**620**
Max DAQ rate (Hz)	125	160	250	**800**	1300	**1800**	**2200**
Data Hours per day	12	14	15	**10**	15	**11**	**9**
weeks to reach goals	16-10	14-8.5	10.2-7.6	9.5	2.7	**5.3**	**4.0**

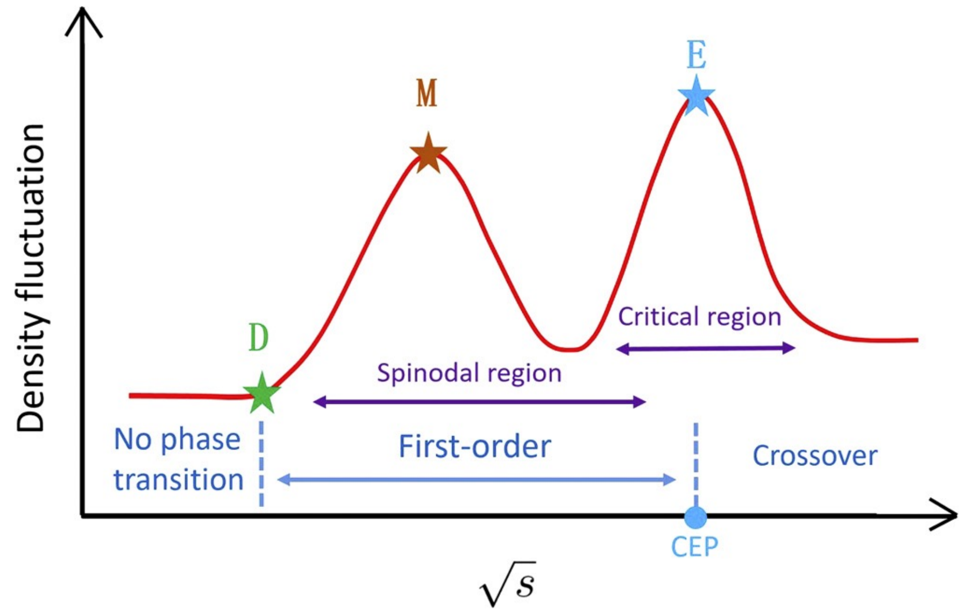
Projection ranges from optimistic/pessimistic assumptions

Below injection energy luminosity scales with γ^3

**17.1 GeV

Case for Au+Au $\sqrt{s_{NN}}$ = 17.1 GeV





Ratio of light nuclei yields sensitive to neutron relative density fluctuations
Neutron relative density fluctuations increase near CP and/or 1st order PT

$$\Delta(n) = \langle(\delta n)^2\rangle / \langle n\rangle^2 = \frac{1}{g}\frac{N_t \times N_p}{N_d^2} - 1$$

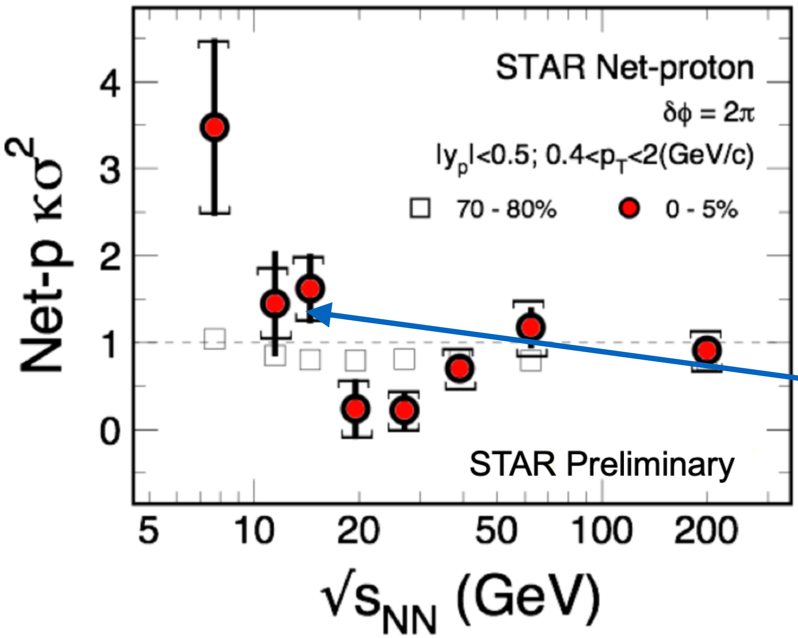
Clear non-monotonic energy dependence

Sudden drop below 19.6 GeV
- Consistent with NA49

Second peak?

Note: 14.5 GeV and triton data are new

Case for Au+Au $\sqrt{s_{NN}}$ = 17.1 GeV



First order phase transition could also cause large increase in net-p kurtosis

Entering spinoidal region (mixed phase)

Therefore propose a 17.1 GeV (μ_B = 235 MeV) run

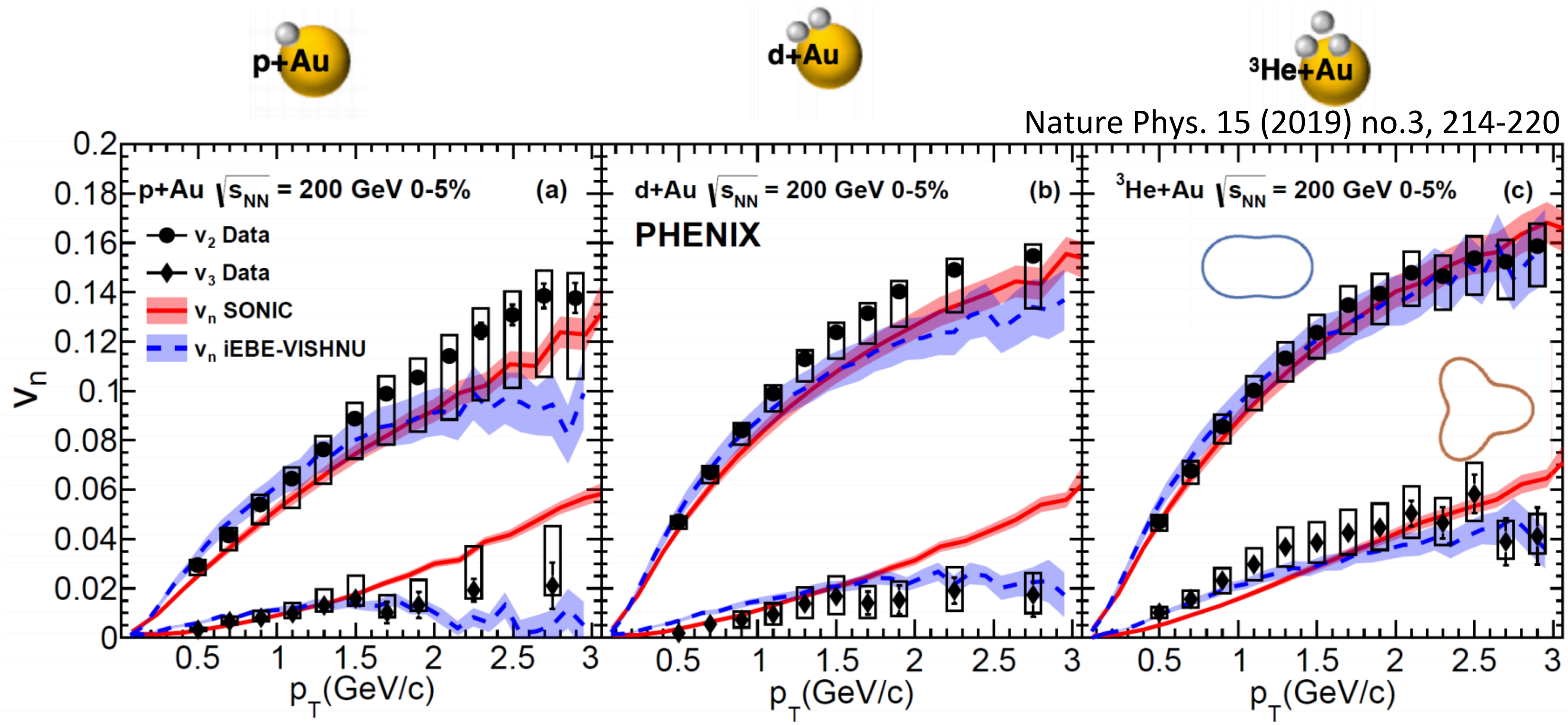
Equal spacing in μ_B

Table 10: Event statistics (in millions) needed in a Au+Au run at $\sqrt{s_{NN}}$ = 16.7 GeV for fourth order net-proton fluctuations ($\kappa\sigma^2$) and neutron density fluctuation (Δn) measurements.

Triggers	Minimum Bias	Net-proton $\kappa\sigma^2$ (0-5% Cent.)	Δn (0-10% Cent.)
Number of events	250 M	6% error level	3.6% error level

Estimate 3-5 weeks of data collecting

Studying Small Systems



Hydro calculations reproduce v_n measurements

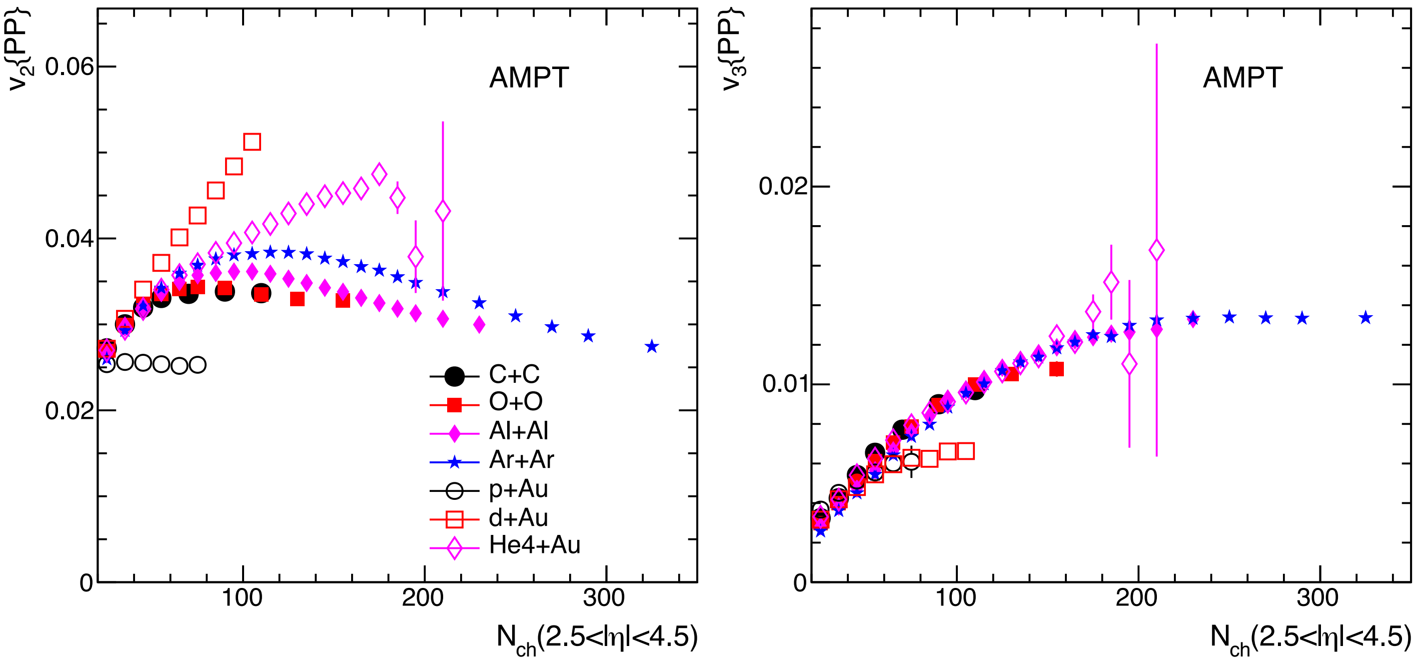
Effect of pre-equlibrium flow?

Initial State Correlations (ISM) or Final State Interaction (FSM) in p+A?

If FSM: is collectivity fluid-like or off-equilibrium few scatterings?

[1] http://www.int.washington.edu/talks/WorkShops/int_19_1b/People/Mace_M/Mace.pdf
[2] https://indico.cern.ch/event/771998/contributions/3339235/subcontributions/276910/attachments/1813022/2961981/talk_smallsystems_SHEN.pdf

Case for O+O $\sqrt{s_{NN}}$ = 200 GeV



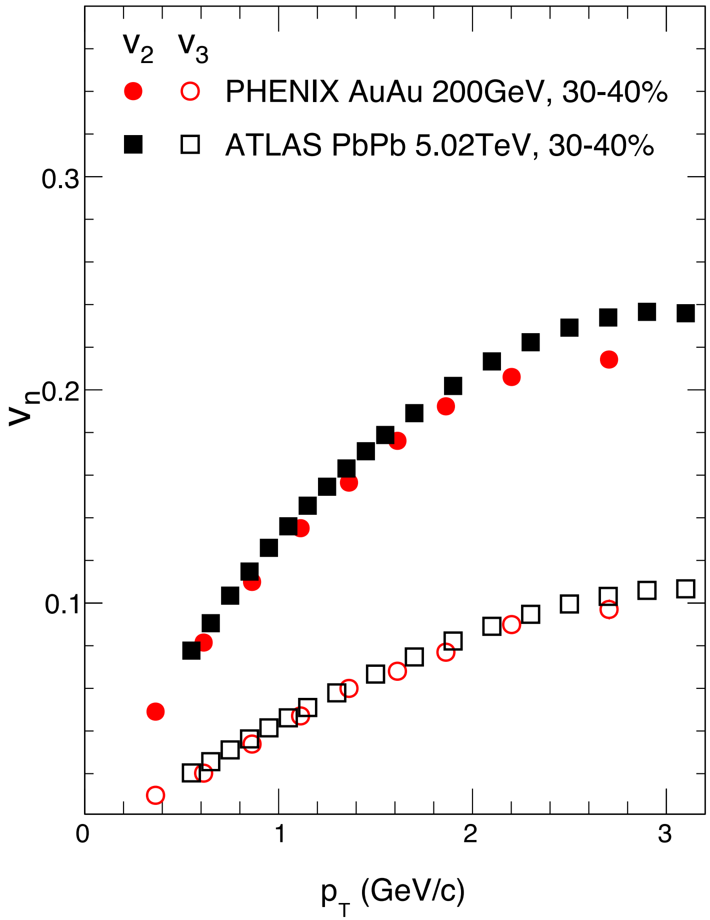
AMPT (FSM): v_n from geometry:

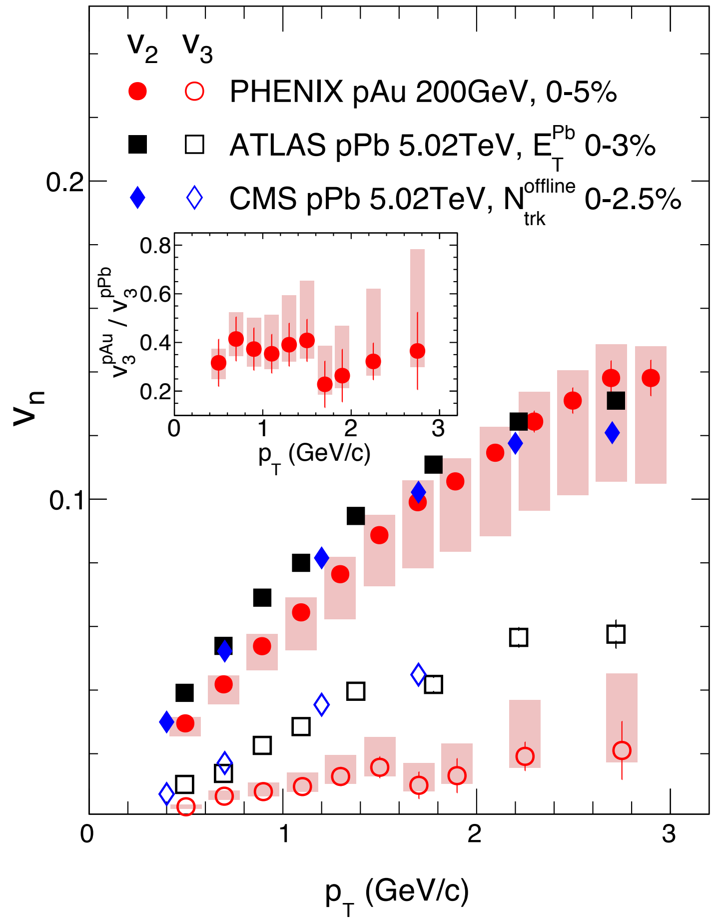
v_2: asymmetric systems behave differently to symmetric systems
v_3: all systems behave similarly

If system driven by ISM: signals smaller with increasing system size

Potential to constrain transport vs hydro

Case for O+O $\sqrt{s_{NN}}$ = 200 GeV



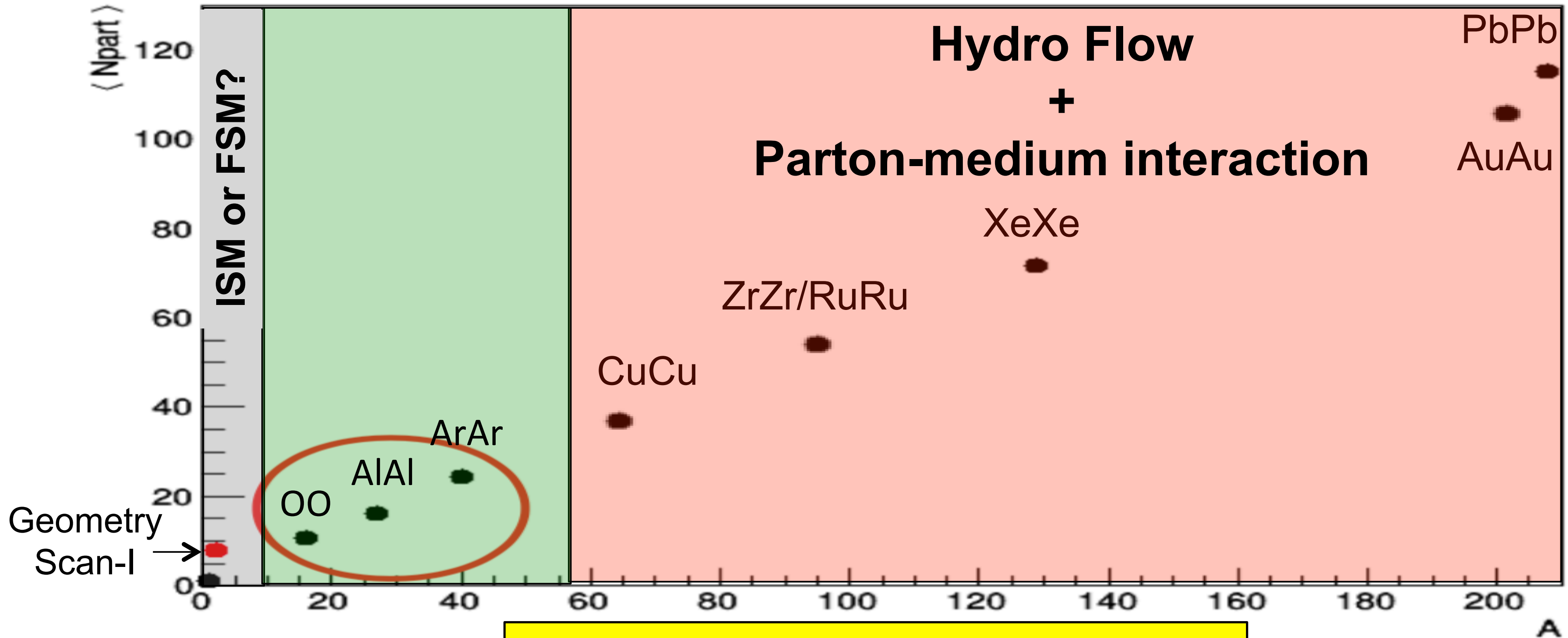


v_3: Energy invariance for symmetric heavy systems

v_3: Energy dependence for asymmetric systems

What about small symmetric systems?

Mind the Gap



Propose O+O:
400M MB, 200M Central (1-2 weeks)

Why Oxygen and why now?:

Better control of N_{part} and ε_n than in peripheral Au+Au

Larger acceptance from BES-II upgrades, better control of non-flow

Synergy with LHC

Evidence of jet quenching?

Run-20: 28 Cryo-weeks

Table 2: Proposed Run-20 assuming 28 cryo-weeks, including five weeks of LEReC commissioning, an initial one week of cool-down and a one week set-up time for each collider energy.

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority	Sequence
5.75	11.5	9.5 weeks	Au+Au	230M	1	1
4.55	9.1	9.5 weeks	Au+Au	160M	1	3
19.5	6.2 (FXT)	2 days	Au+Au	100M	2	5
13.5	5.2 (FXT)	2 days	Au+Au	100M	2	6
5.75	3.5 (FXT)	2 days	Au+Au	100M	2	2
4.55	3.2 (FXT)	2 days	Au+Au	100M	2	4
3.85	3.0 (FXT)	2 days	Au+Au	100M	2	7
100	200	1 week[2]	O+O	400M 200M (central)	3	8

[2] Available run time for the proposed small system run using O+O will directly depend on the the run time for the 11.5 GeV system. In the case the combined performance of C-AD and STAR resembles that of last year's 19.6 GeV data set, then approximately 2 cryo-weeks would be available to complete the small system program.

Top priority: Collider program and commissioning of LEReC (5 weeks) - impact on yet to come 7.7 GeV running

Run-20: 24 Cryo-weeks

Table 3: Proposed Run-20 assuming 24 cryo-weeks, including three to four weeks of LEReC commissioning, an initial one week of cool-down and less than one week set-up time for each collider energy.

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority	Sequence
5.75	11.5	7.5 weeks[3]	Au+Au	230M	1	1
4.55	9.1	9.5 weeks	Au+Au	160M	1	3
19.5	6.2 (FXT)	2 days	Au+Au	100M	3	5
13.5	5.2 (FXT)	2 days	Au+Au	100M	3	6
5.75	3.5 (FXT)	2 days	Au+Au	100M	2	2
4.55	3.2 (FXT)	2 days	Au+Au	100M	2	4
3.85	3.0 (FXT)	2 days	Au+Au	100M	3	7

[3] In this 24 cryo-week scenario an optimistic view on the performance of the 11.5 GeV run is presumed, based on combined performance of C-AD and STAR resembling that of last year's 19.6 GeV run.

Top priority: Collider program and commissioning of LEReC (3-4 weeks) - impact on yet to come 7.7 GeV running

Optimistic projection for the non-cooled 11.5 GeV and e-cooled 9.1 GeV - FXT could be finished in Run-21 along with O+O running

Run-21: 20 Cryo-weeks

Single-Beam Energy (GeV/n)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority	Sequence
3.85 8.35	7.7 16.7	12 weeks 5 weeks	Au+Au Au+Au	100M 250M	1 2	1 2
100	200**	1 week[4]	O+O	400M 200M (central)	2	3

[4] In the case the proposed small system run can not take place in Run-20, the cryo-week budget for Run-21 could potentially permit this run to take place depending on the Run-20 LEReC performance.

Top priority: Completion of BES-II

Bulk of running dedicated to 7.7 GeV
Time estimate will be refined as Run-19 and Run-20 continue

New Requests: Au+Au at 17.1 GeV (collider data)
O+O at 200 GeV

**17.1 GeV

Summary

STAR's highest priority requests
Run-20 & Run-21: completion of BES-II
Run-22: p+p 500 GeV - next talk by Jim D

Significant progress towards this goal made in Run-19
- iTPC and EPD working beyond expectations
- eTOF commissioning progressing, improvements planned for Run-20

Request to add Au+Au at 17.1 GeV to BES-II program
- Probing potential "double bump" signals

Request for short O+O (small system) run at 200 GeV
- Good control of geometry for comparison to p+A data

Beyond BES-II
- Run-22: p+p 500 GeV
- Co-running with sPHENIX

Depending on pending results:
- Further Isobar, BES, small system running

BACK UP

Event statistics requirements: Collider

Table 7: Event statistics (in millions) needed in the collider part of the BES-II program for various observables. This table updates estimates originally documented in STAR Note 598.

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

Typically factor 20 more than for BES-I

dileptons drive the event request

Event statistics requirements: FXT

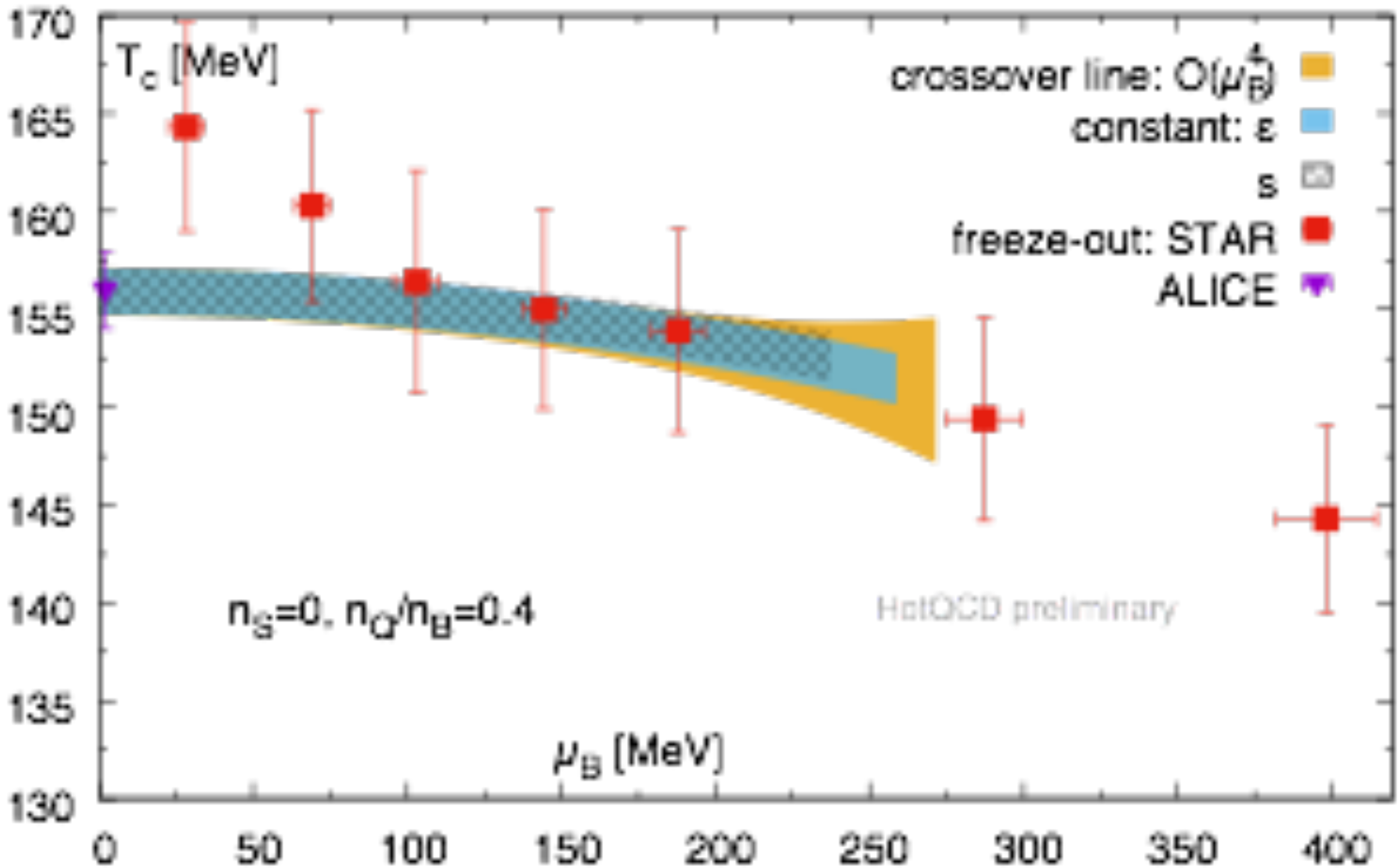
Table 8: Event statistics (in millions) needed in the fixed-target part of the BES-II program for various observables.

$\sqrt{s_{NN}}$ (GeV)	3.0	3.2	3.5	3.9	4.5	5.2	6.2	7.7
Single Beam Energy (GeV)	3.85	4.55	5.75	7.3	9.8	13.5	19.5	31.2
μ_{B} (MeV)	721	699	666	633	589	541	487	420
Rapidity y_{CM}	1.06	1.13	1.25	1.37	1.52	1.68	1.87	2.10
Observables								
Elliptic Flow (kaons)	300	150	80	40	20	40	60	80
Chiral Magnetic Effect	70	60	50	50	50	70	80	100
Directed Flow (protons)	20	30	35	45	50	60	70	90
Femtoscopy (tilt angle)	60	50	40	50	65	70	80	100
Net-Proton Kurtosis	36	50	75	125	200	400	950	NA
Multi-strange baryons	300	100	60	40	25	30	50	100
Hypertritons	200	100	80	50	50	60	70	100
Requested Number of Events	300	100	100	100	100	100	100	100

Is there a Critical Point?

Latest from the lattice:

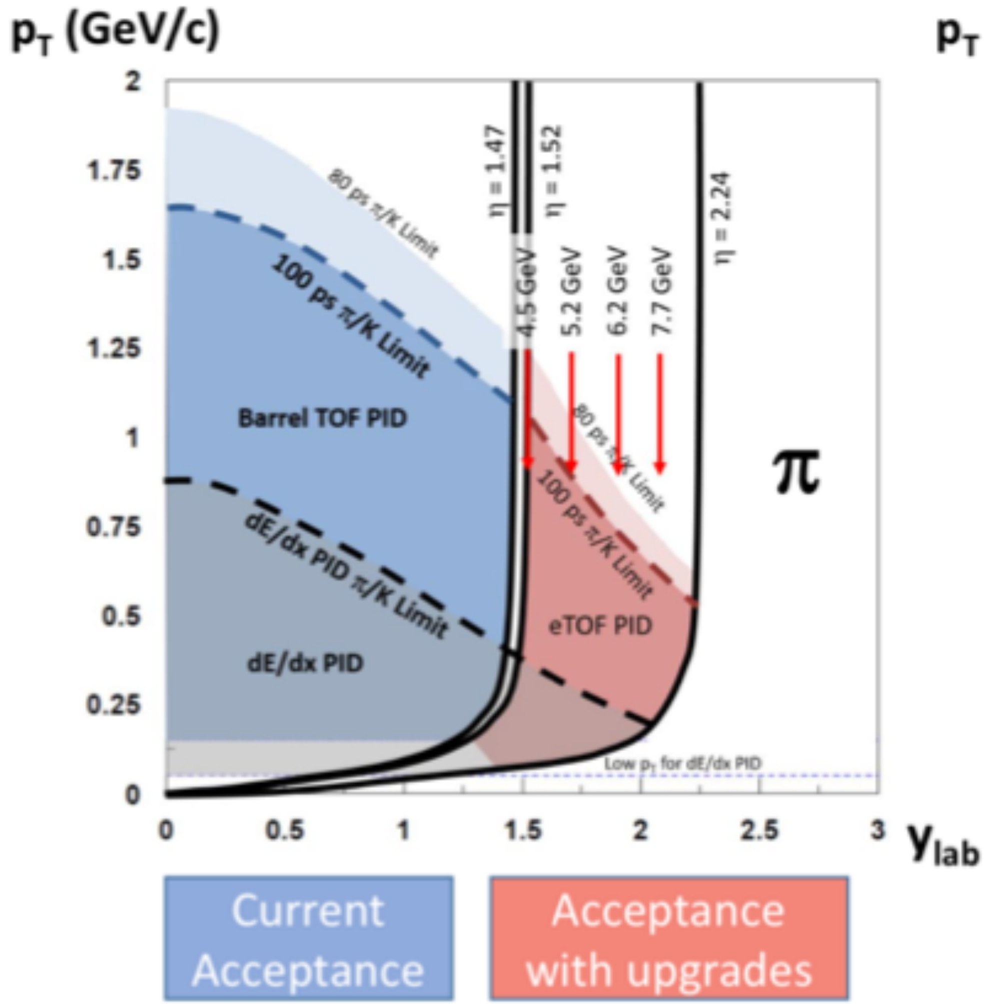
Cross-over starts at T_0 = 156.5 (1.5) MeV
ε_0 ~ 1 GeV/fm^3

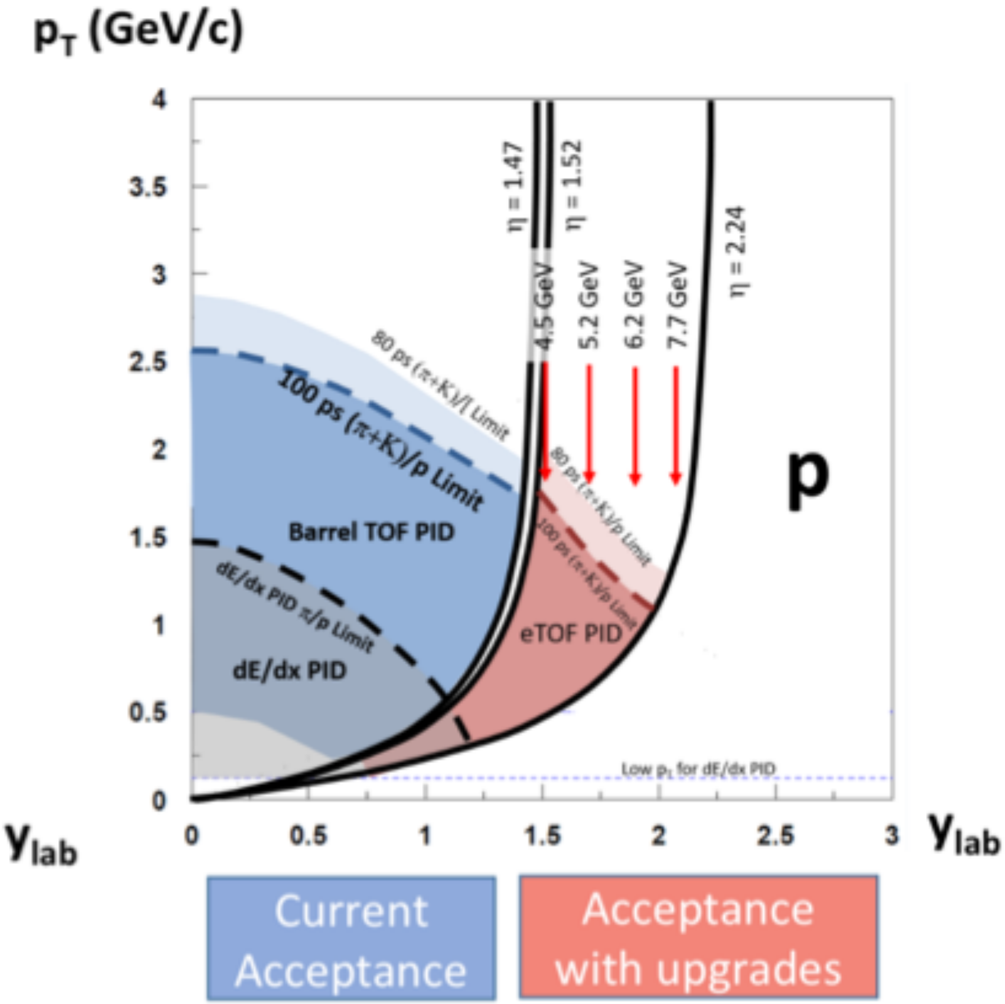


No indication of CP for μ_B < 250 MeV

Patrick Steinbrecher QM18

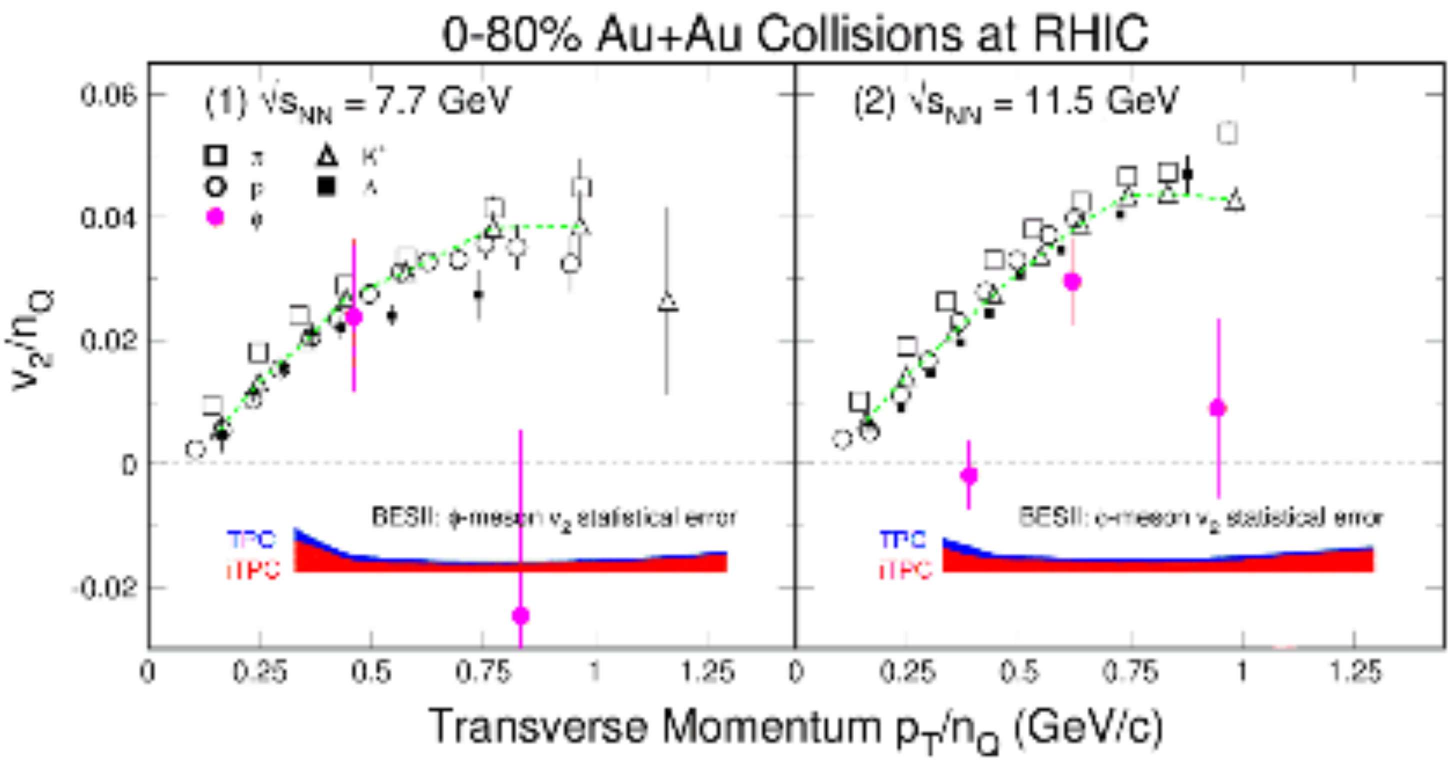
FXT: energy "upgrade"





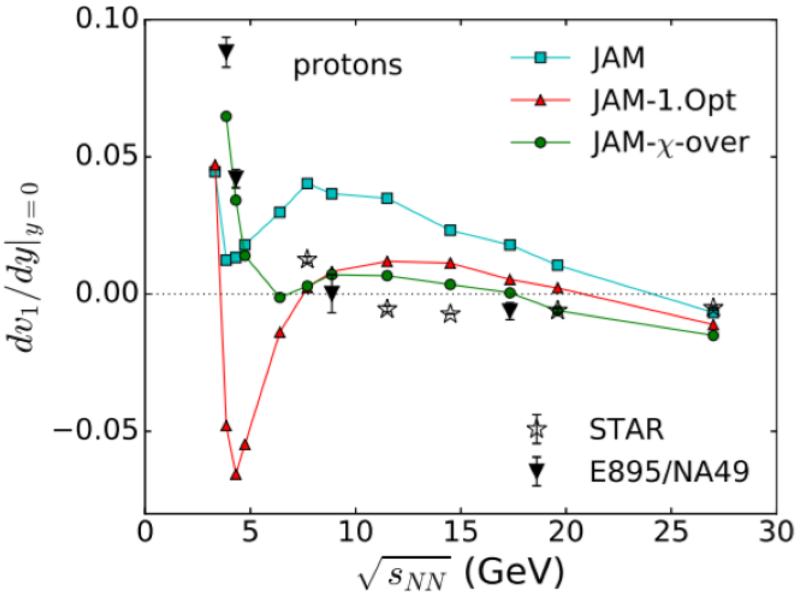
Detector upgrades improve STAR PID and acceptance performance, for FXT energies up to 7.7 GeV, overlap energy with the collider mode

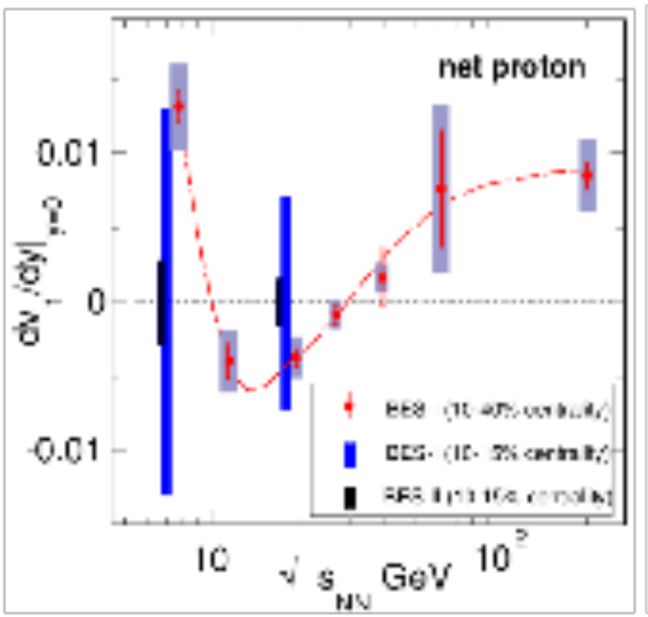
BES-II: quark elliptic flow



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

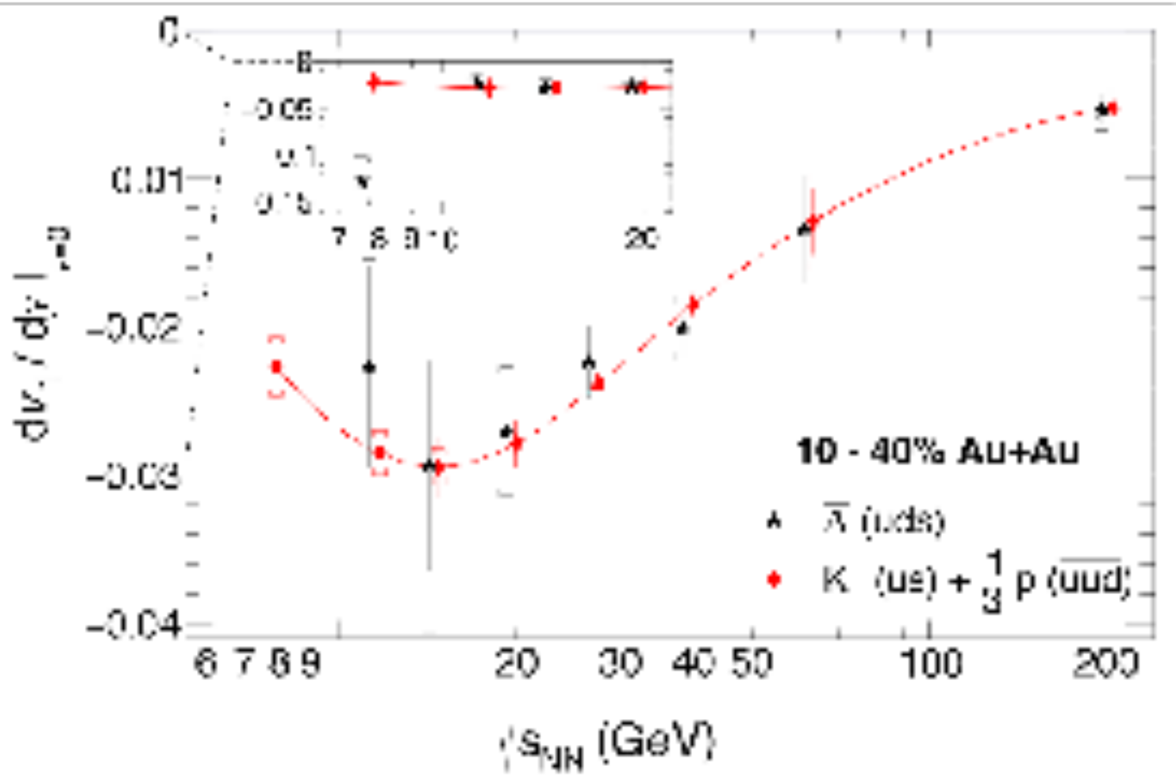
Fine centrality binning possible with BES-II data

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 $(v_1)_s = (v_1)_{\bar{s}}$



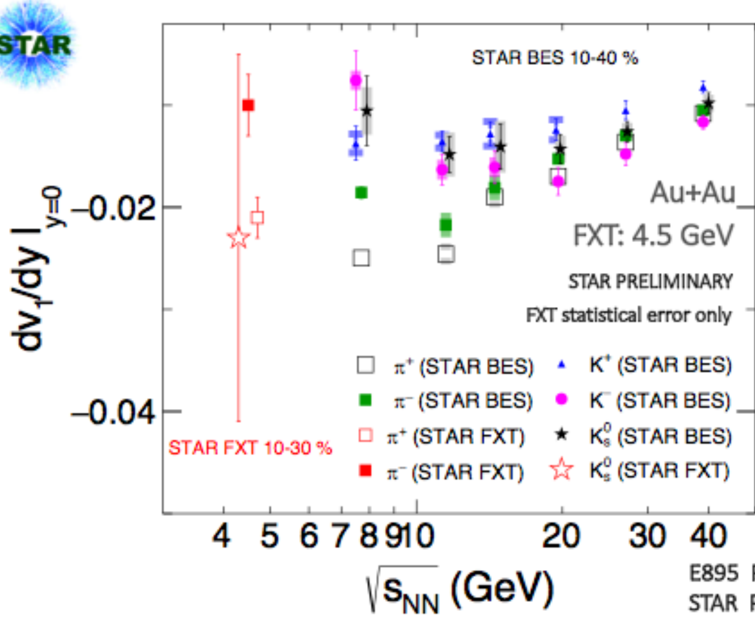
anti-Λ predicted from quark values deduced from K and p

Fails for 7.7 GeV - At least one assumption incorrect

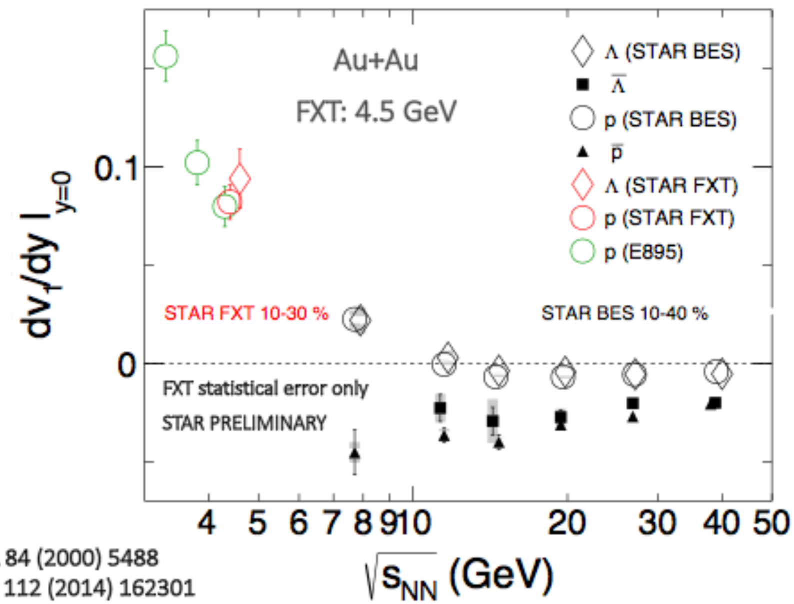
What happens at lower √s?
Finer centrality bins?

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):

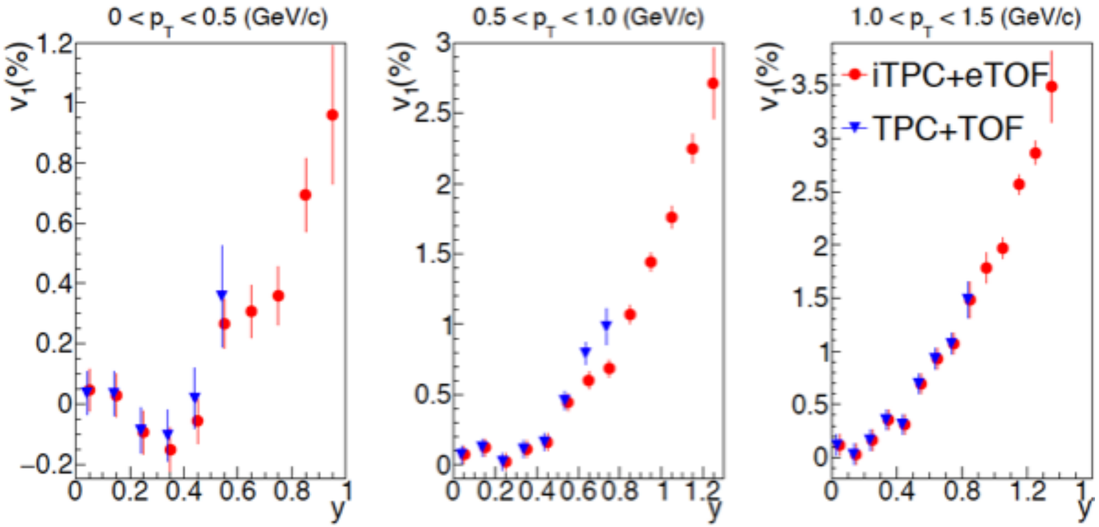
- 1 B events at 7.2 GeV
- 100 M events at 3.0 GeV

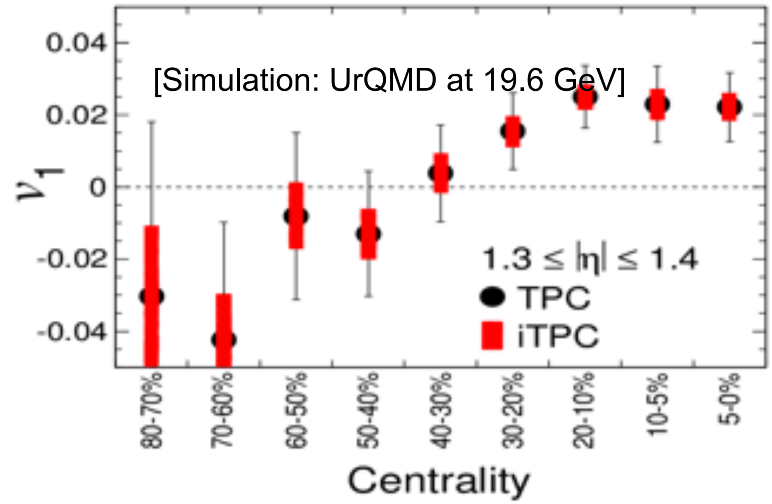
Fluctuation measurements below 7 GeV

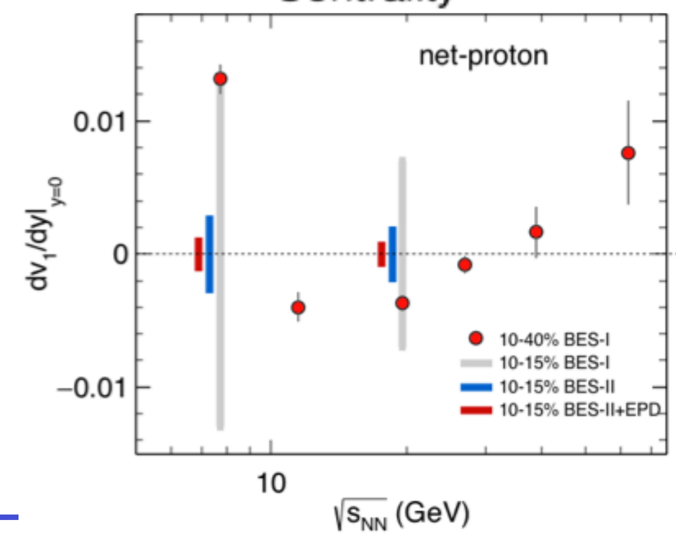
BES-II: directed flow improvements

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

EPD:

Enhanced 1st order EP resolution

Reduced systematics

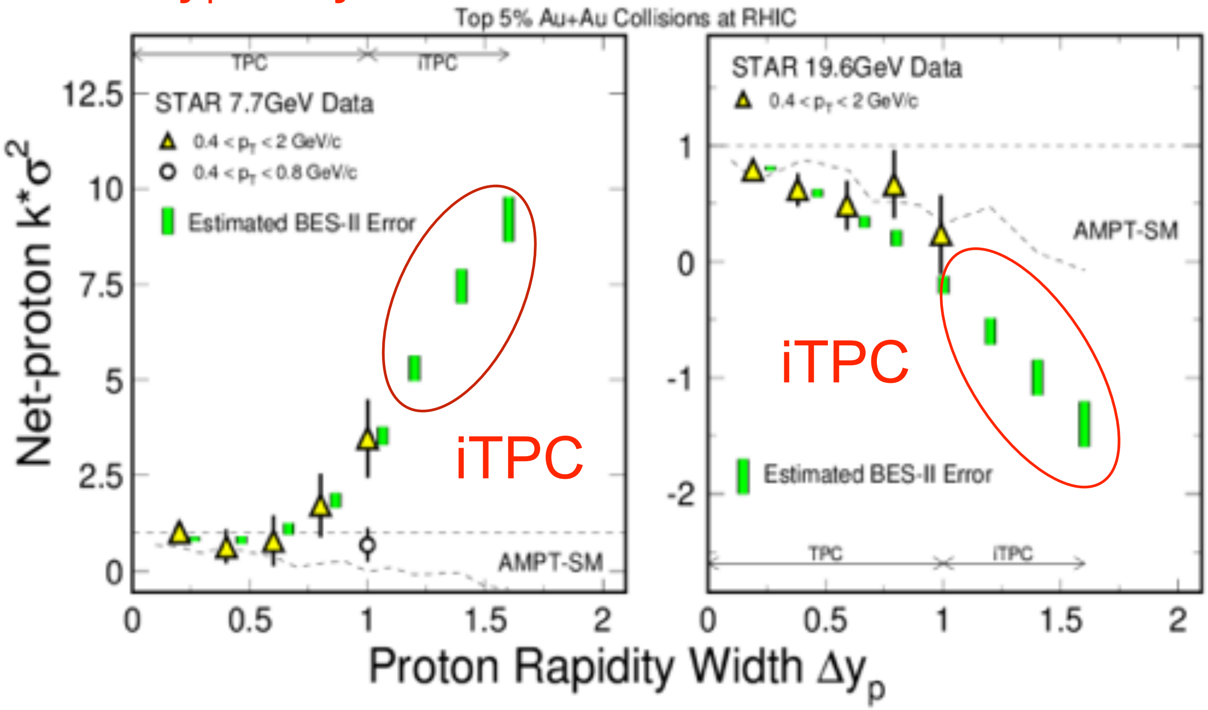
BES-II: Critical fluctuations

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

iTPC:
Increase Δy_p acceptance

EPD:
Improved centrality selection
Use all TPC for measurement

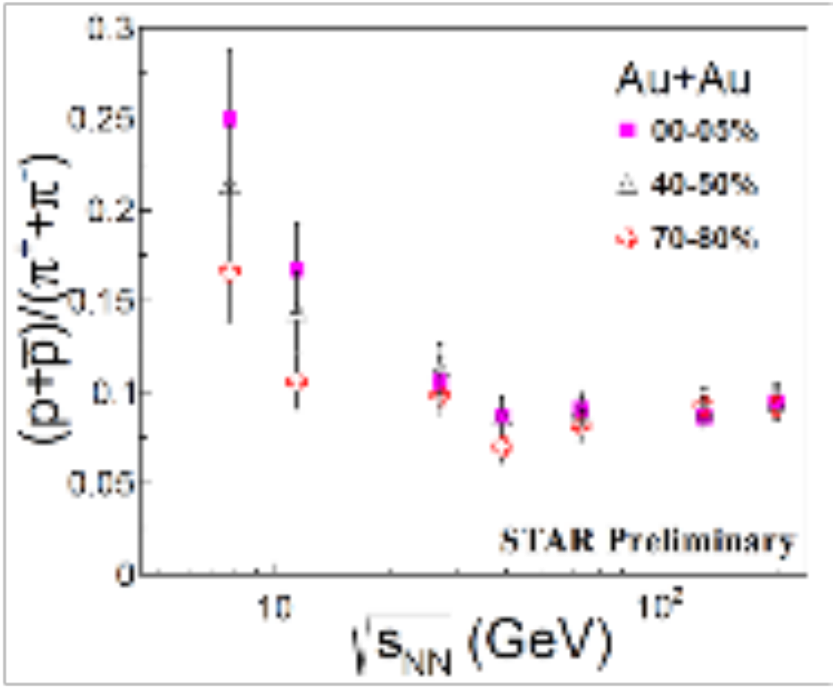
$\Delta y_p > \Delta y$ correlation

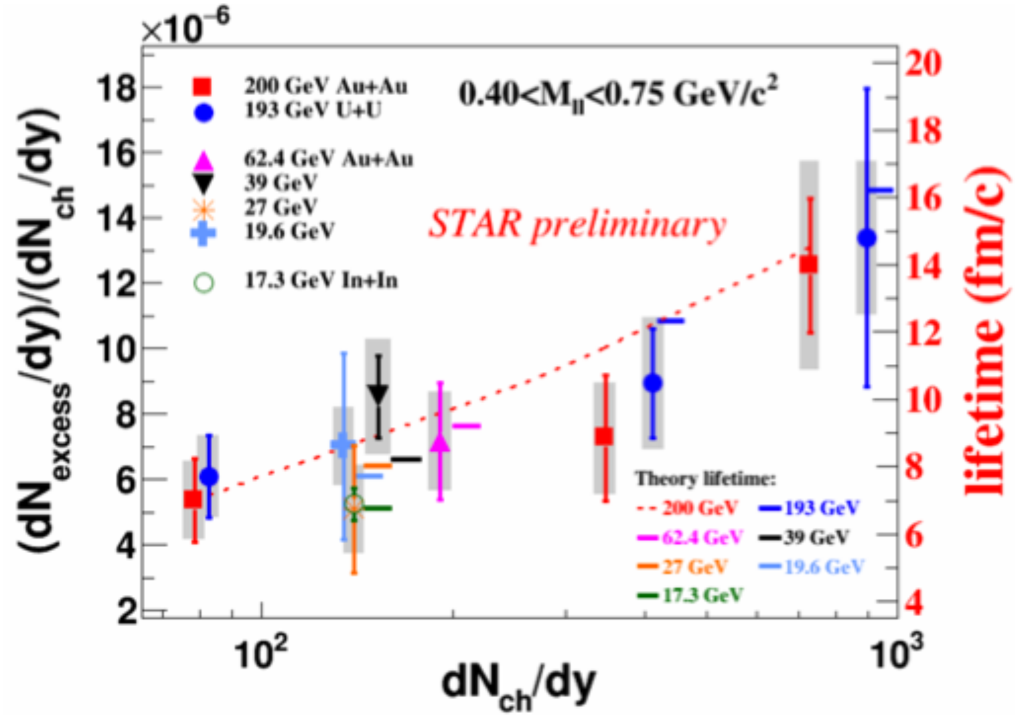


Establish true nature of correlation

Subject actively pursued theoretically

Low mass di-lepton excess





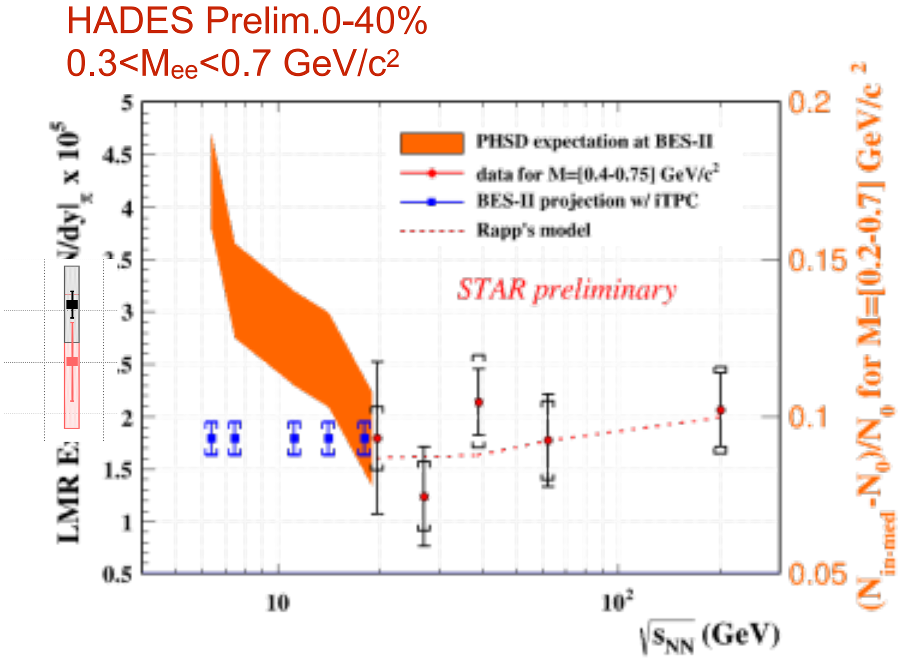
Above 20 GeV
Total baryon density ~ constant

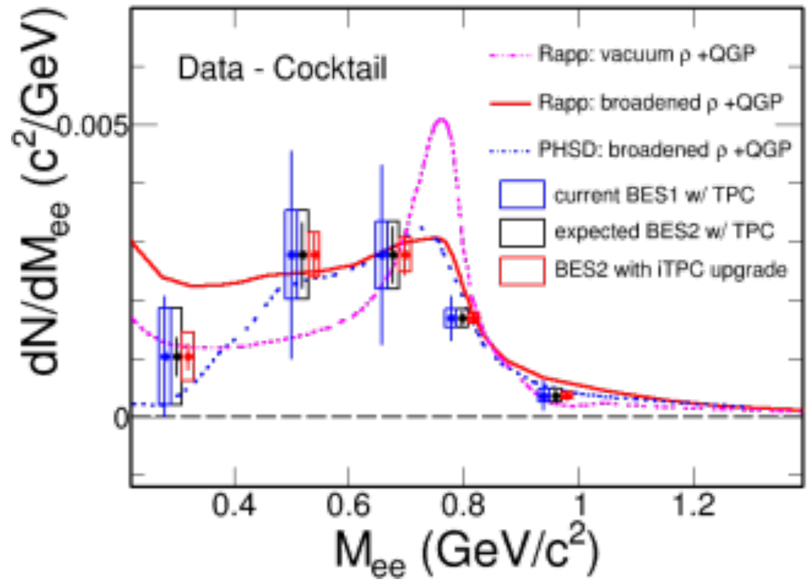
Low mass excess ∝ fireball lifetime
for large range of beam energies and centralities

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