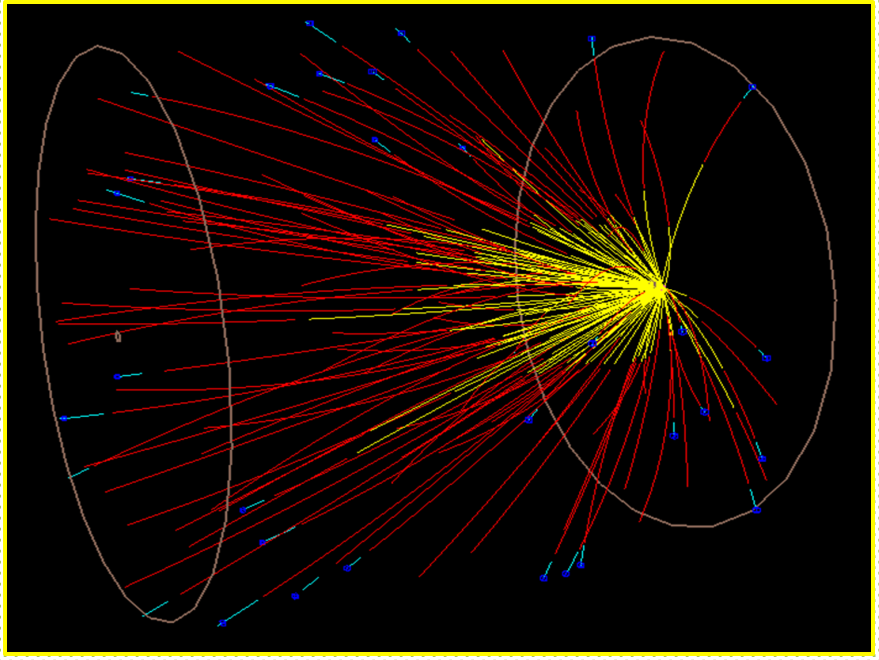
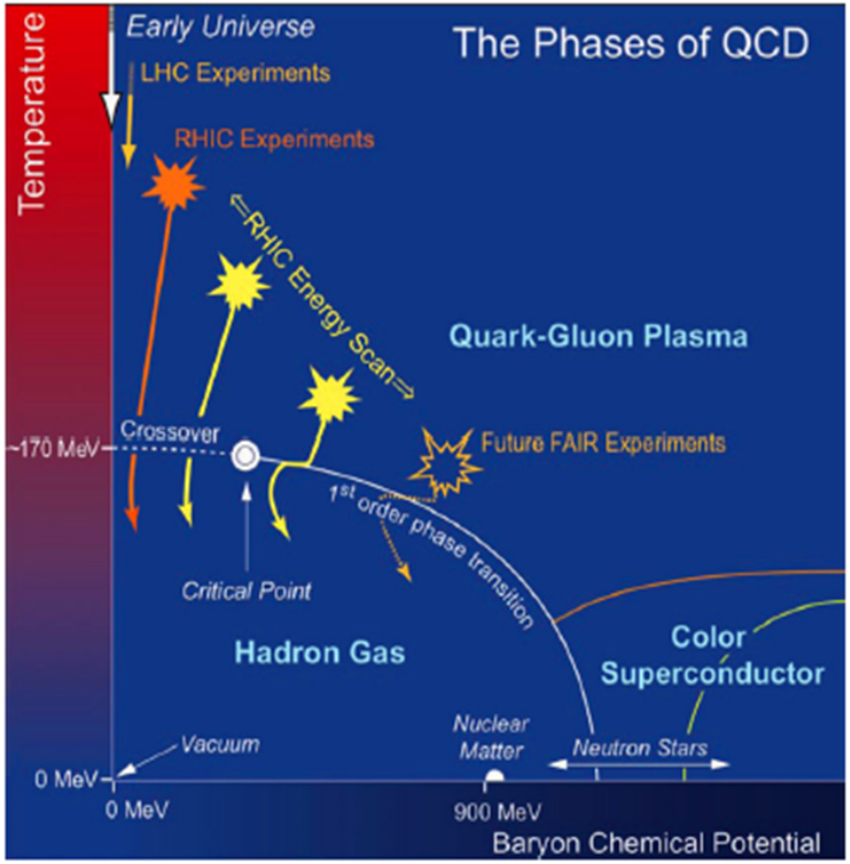
# FXT Program and Physics Topics from Run 18 and Run 19

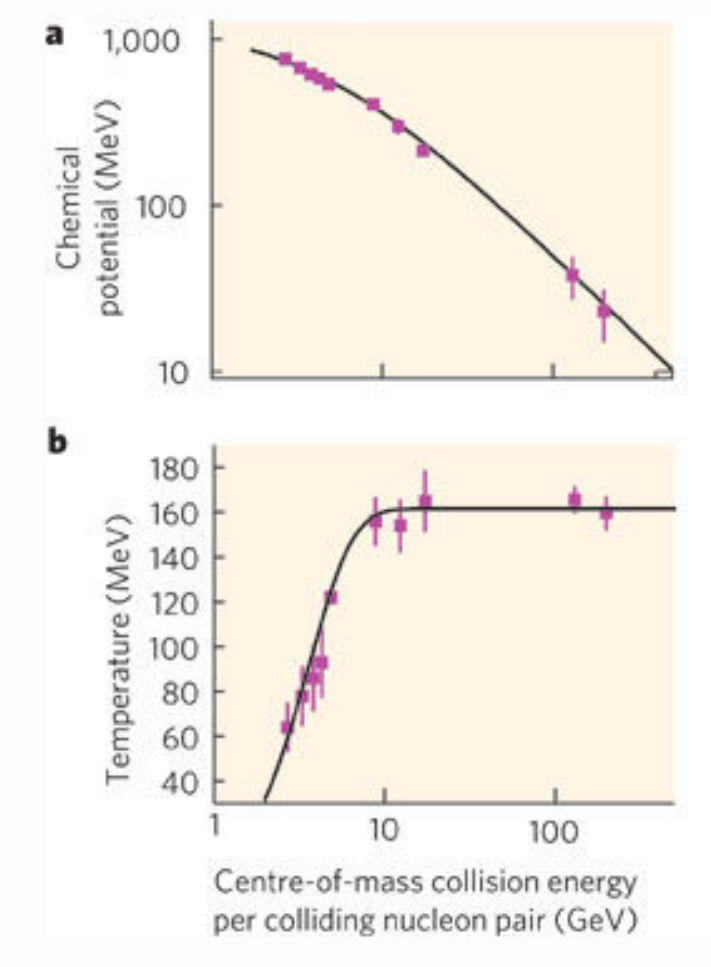


Xiaofeng Luo (罗晓峰)
Central China Normal University

Sept. 23, 2017

# Physics Motivation




Exploring the QCD phase structure

1. Turning off the sQGP signal.
2. Critical Point
3. 1st order phase boundary

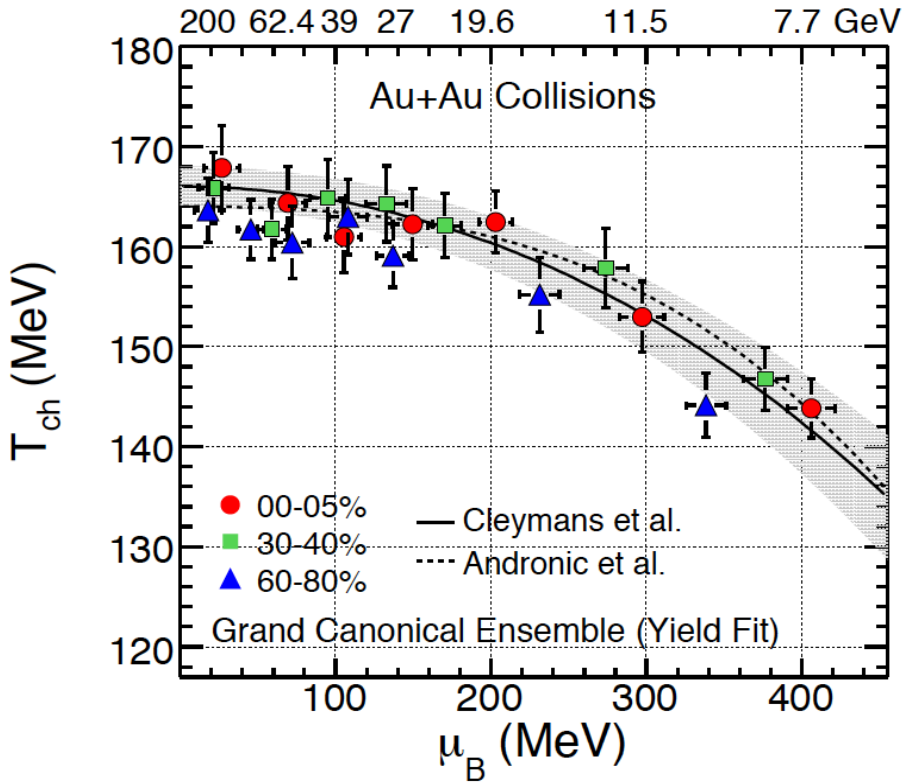
**Scan the QCD phase diagram by tuning the colliding energies in heavy-ion collisions !**

*PBM&Johanna, Nature* **448**, 302-309 (2007)

# Beam Energy Scan - I (2010-2017)

| $\sqrt{s_{NN}}$ (GeV) | Events (X10$^6$) | Year | *$\mu_B$ (MeV) | *$T_{CH}$ (MeV) |
|---|---|---|---|---|
| 200 | 350 | 2010 | 25 | 166 |
| 62.4 | 67 | 2010 | 73 | 165 |
| 54.4 | ~500 | 2017 | 83 | 165 |
| 39 | 39 | 2010 | 112 | 164 |
| 27 | 70 | 2011 | 156 | 162 |
| 19.6 | 36 | 2011 | 206 | 160 |
| 14.5 | 20 | 2014 | 264 | 156 |
| 11.5 | 12 | 2010 | 316 | 152 |
| 7.7 | 4 | 2010 | 422 | 140 |

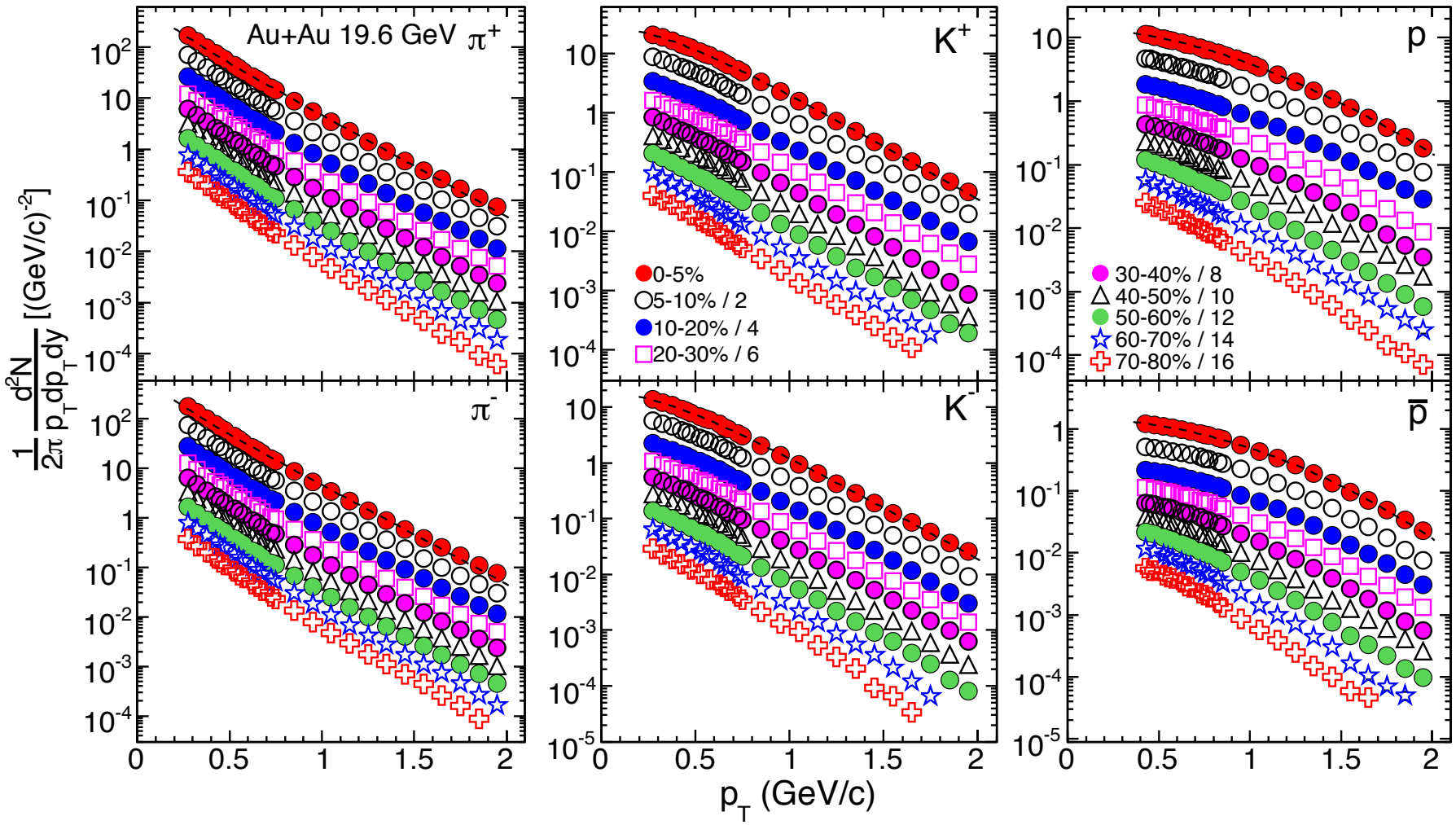
*($\mu_B$, $T_{CH}$) : J. Cleymans et al., PR**C73**, 034905 (2006)




Large baryon chemical potential coverage. (20~420 MeV)

# STAR: Hadron Spectra from BES-I

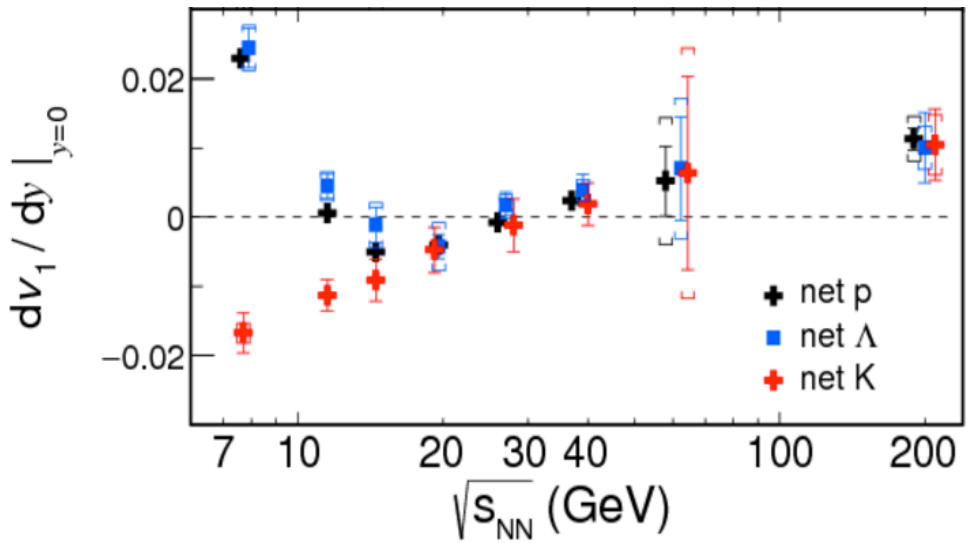
## $\sqrt{s_{NN}} = 19.6$ GeV Au+Au Collisions



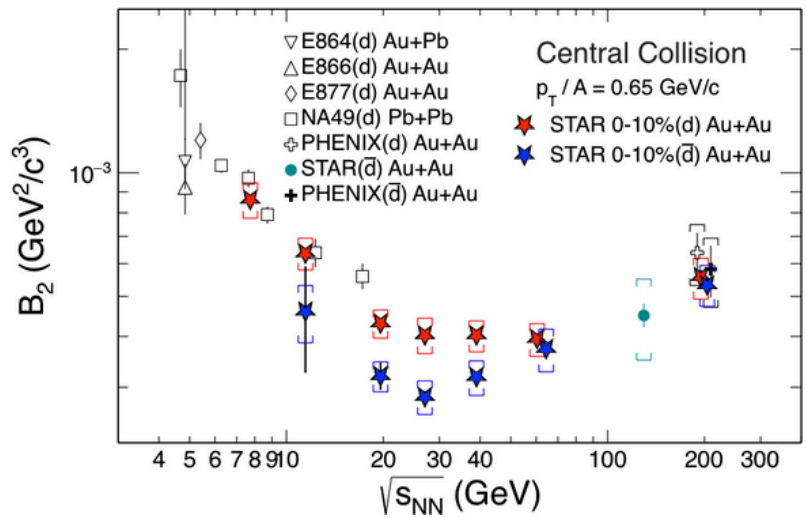

**STAR**: arXiv:1701.07065, to appear in PRC

# Highlights from BES-I

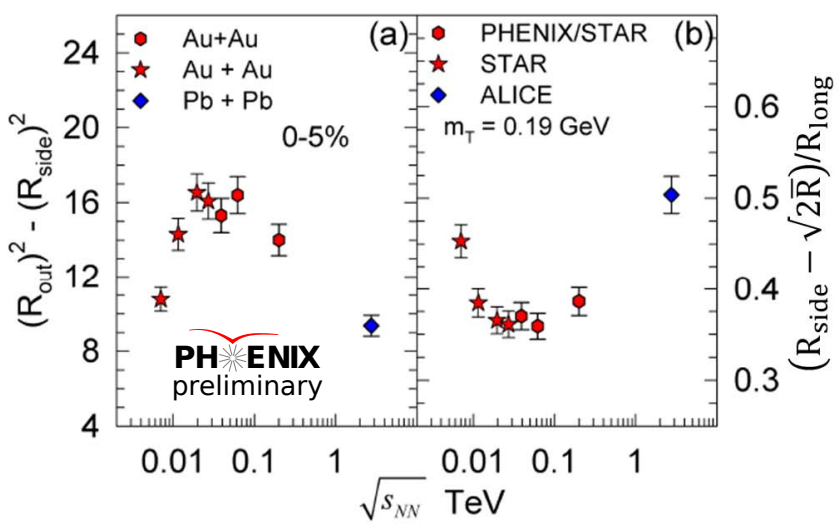
## Directed Flow



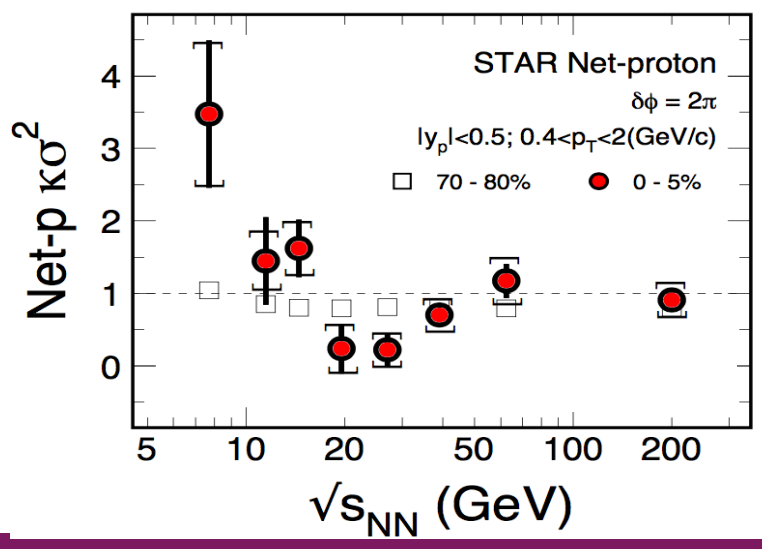

## Deuteron Coalesence Parameter



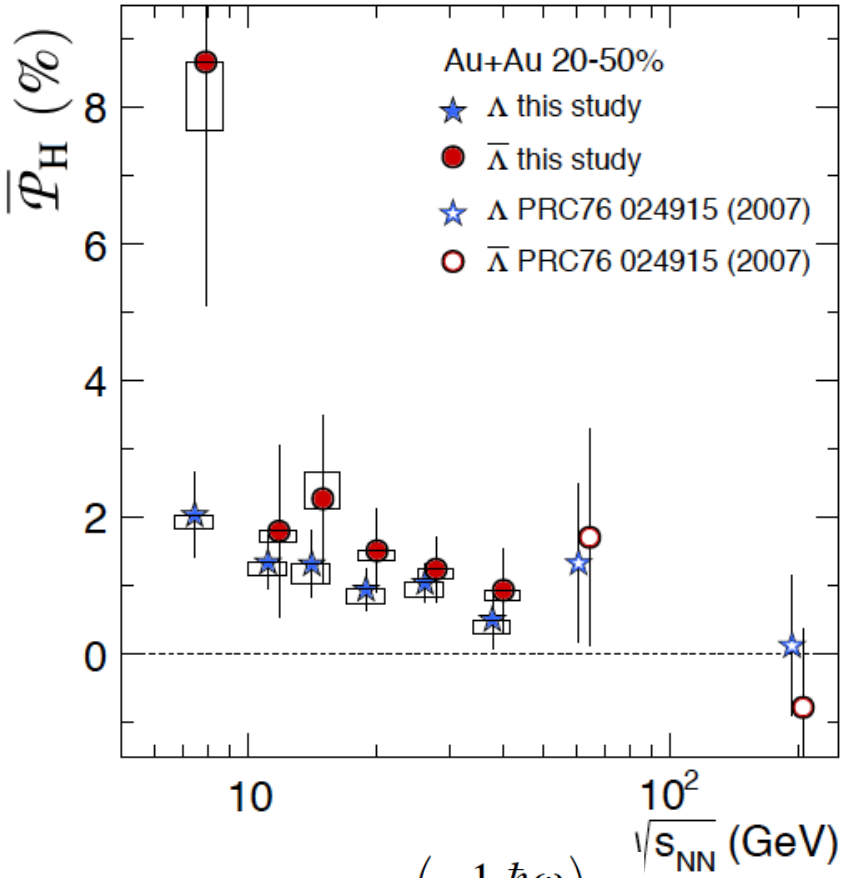

## HBT Radius




## Net-p fluctuations



# Global Hyperon Polarization

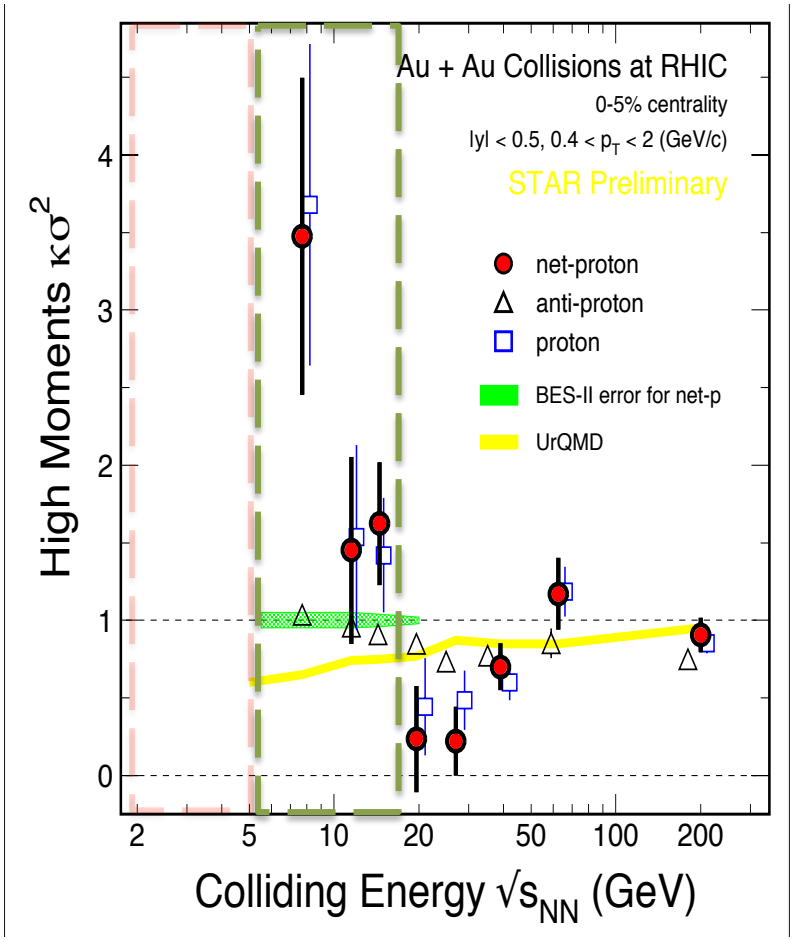



$$P_{\pm} \sim \exp\left(\pm \frac{1}{2}\frac{\hbar\omega}{T}\right)$$

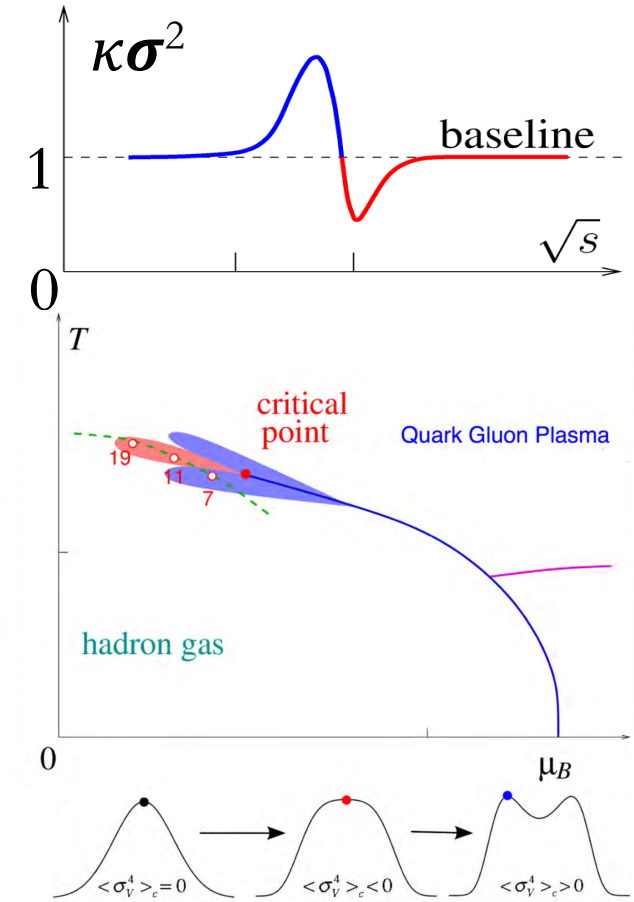
$$\omega \cong (9 \pm 1) * 10^{21} / \text{sec}$$


**STAR: Nature 548, 62 (2017)**

# QCD Critical Point Search



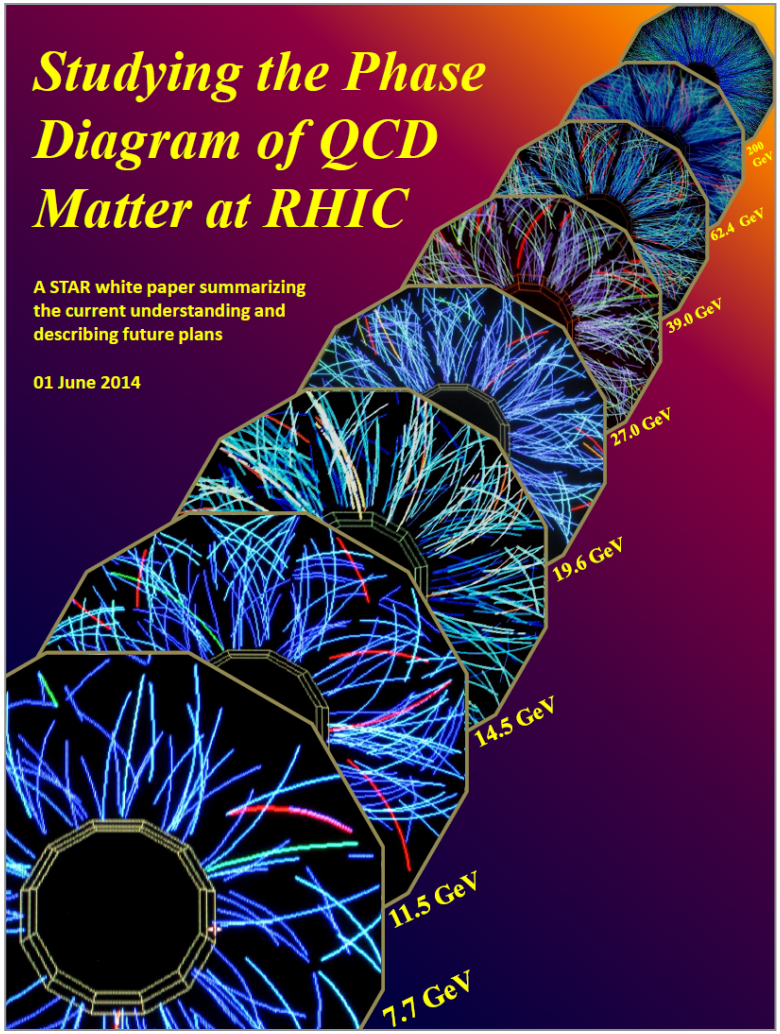

M. A. Stephanov, PRL107, 052301 (2011).




- Lower energies (<7.7 GeV): key step to confirm the signature of QCD critical point

# Beam Energy Scan Phase-II at RHIC (2019-2020)

## BES-II White Paper



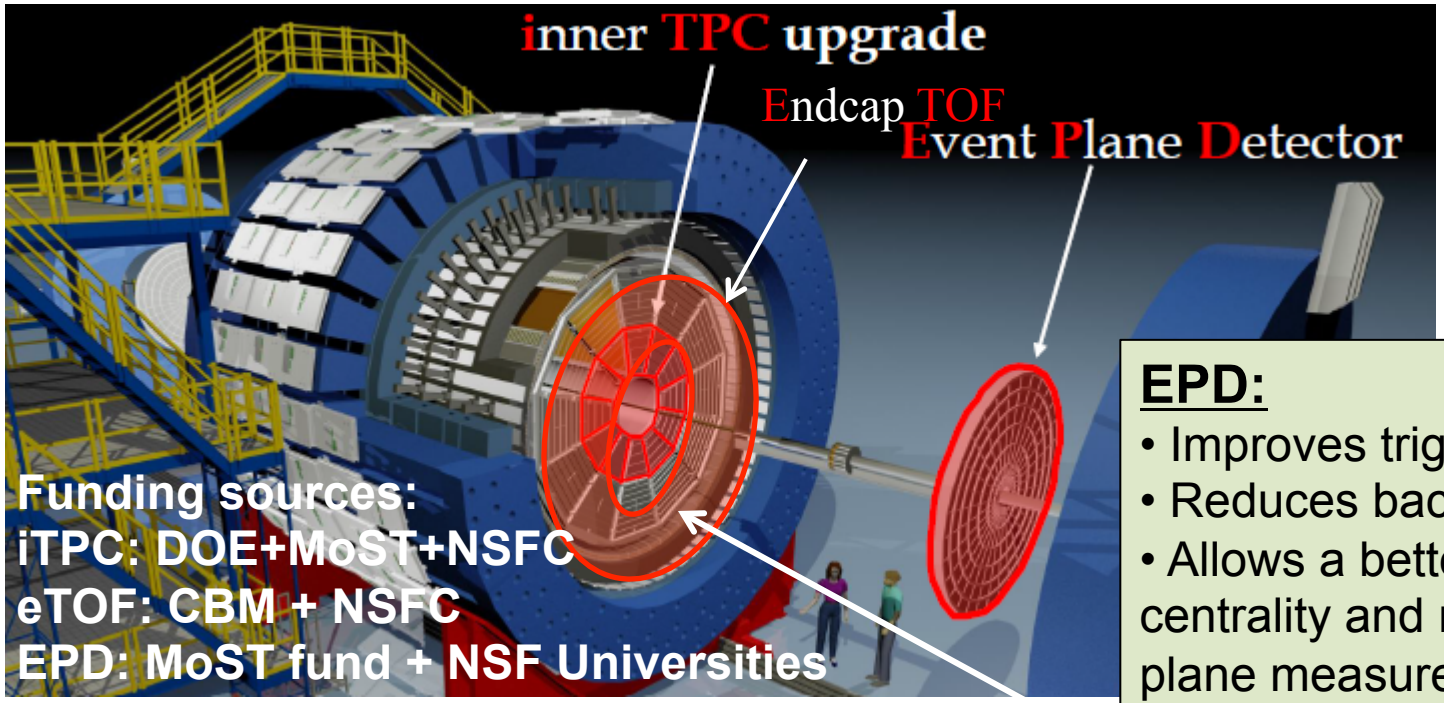

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

Strong Endorsement by the NSAC 2015
http://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf

The trends and features in BES-I data provide compelling motivation for a strong and concerted theoretical response, as well as for the experimental measurements with higher statistical precision from BES-II.

The detector upgrades planned for BES-II focus on maximizing the fraction of the particles in each collision that are measured, which is particularly important for fluctuation observables.

# Major Upgrades for BES-II

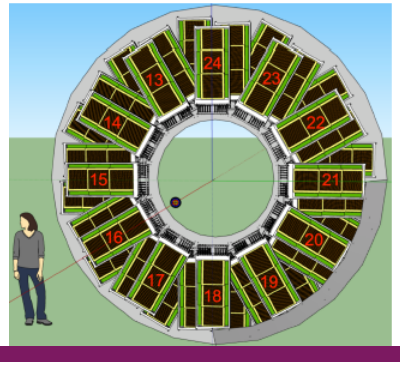



**EPD:**
- Improves trigger
- Reduces background
- Allows a better centrality and reaction plane measurement critical to BES physics
- Ready in 2018

**iTPC:**
- Rebuilds the inner sectors of the TPC
- Improves dE/dx
- Extends h coverage from 1.0 to 1.5
- Lowers $p_T$ cut-in from 125 MeV/c to 60 MeV/c
- Ready in 2019

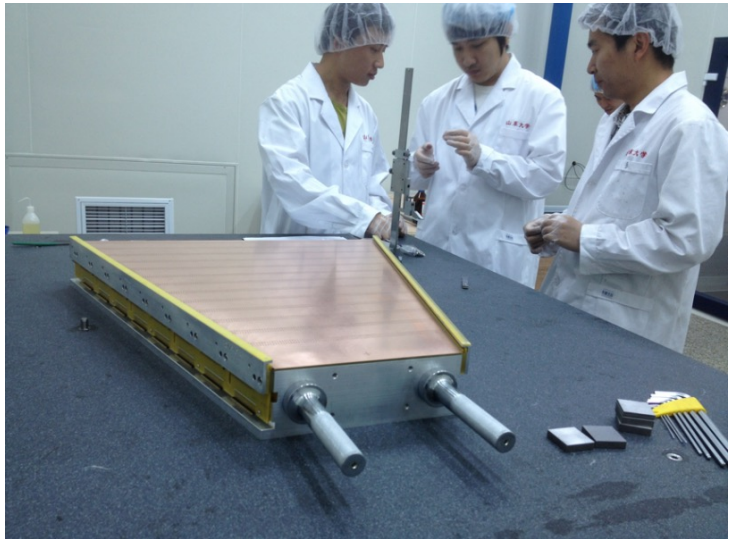
1) Enlarge rapidity acceptance
2) Improve particle identification
3) Enhance centrality/EP resolution

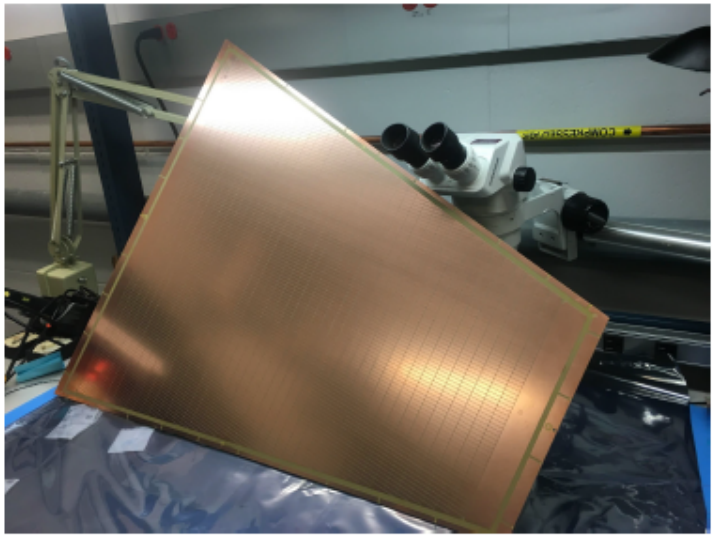
**EndCap TOF:**
- Rapidity coverage is critical
- PID at h = 0.9 to 1.5
- Improves the fixed target program
- Provided by CBM-FAIR
- Ready in 2019



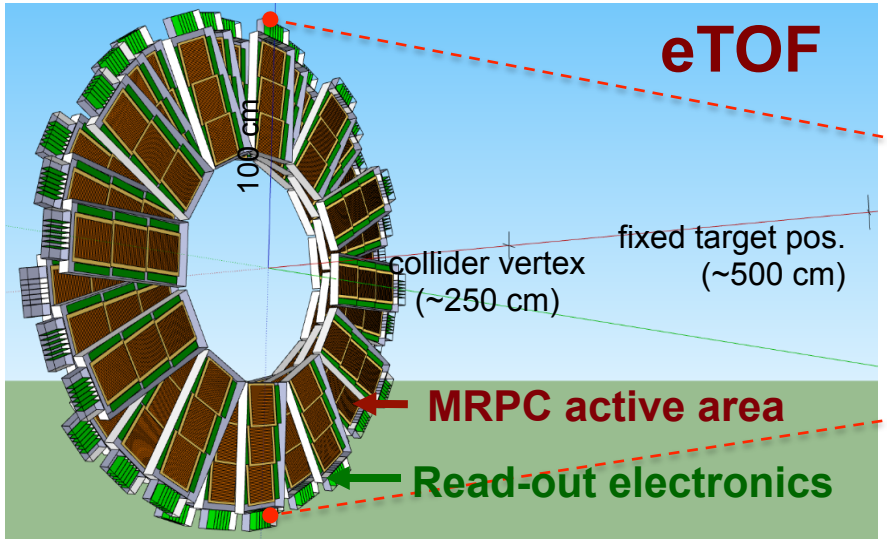
# iTPC Project Status

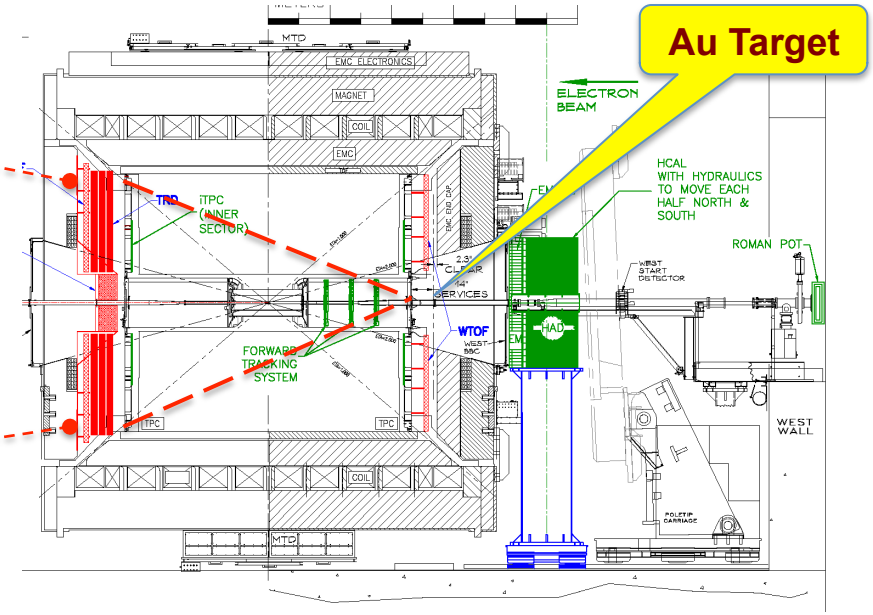
- SAMPA FEE (WMP2)
  - 2FEEs and RDO installed on one inner most row of TPC
  - Running through USB port with beam
  - 200 chips for a sector this summer
  - ALICE MWP3 pre-production ~September 2017; 4000 chips afterward
- Sectors (strongback+padplane+WMPC)
  - First two sectors completed at LBL and arrived at SDU in June 5
  - Complete in August and back to BNL
- Insertion tool
  - Completed at UIC and arrived at BNL in May 12
- Reviews and Reports
  - DOE TCSM review 09/12/2017
  - MWPC readiness review at SDU 12/05/2017
  - LBL and SDU conducted local multiple reviews
  - Monthly Phone calls with DOE since 01/2017
  - Quarterly reports to DOE





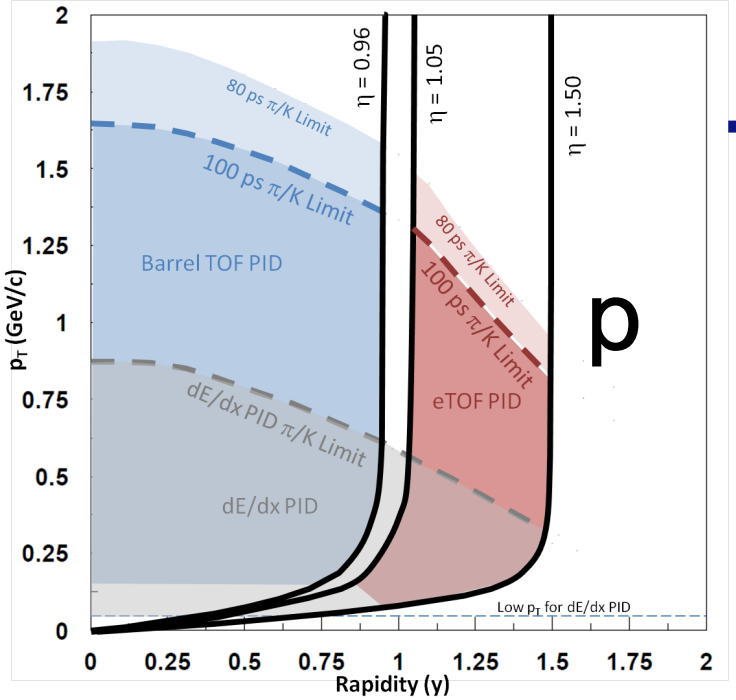
# CBM Phase-0 Exp: eTOF at STAR

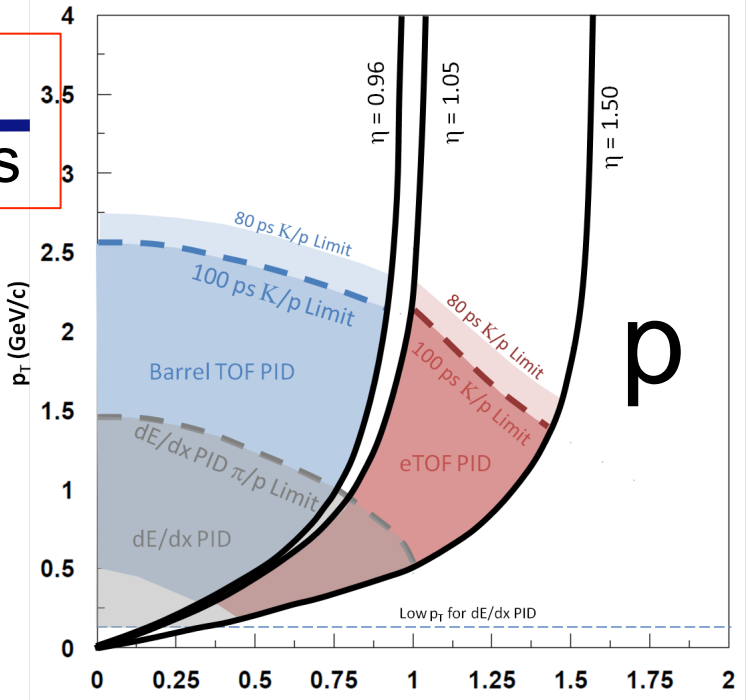


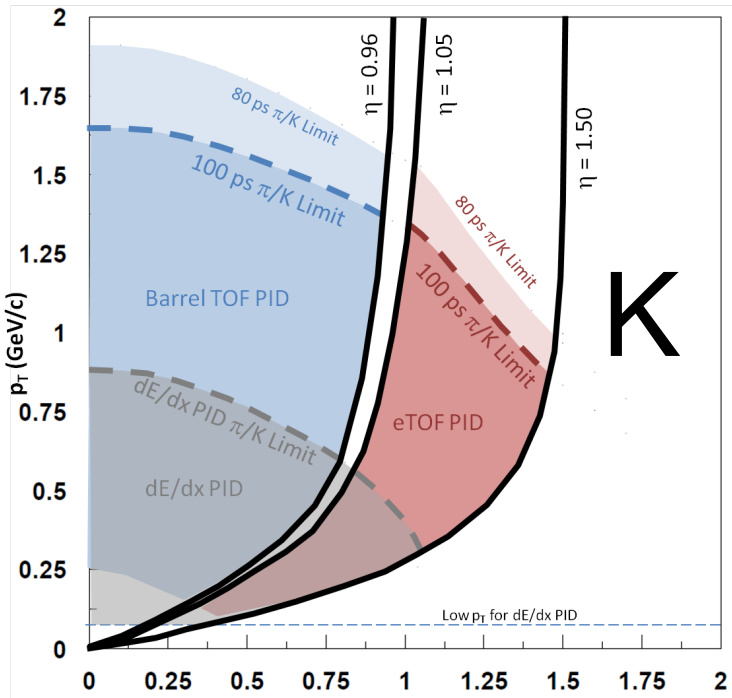

- Two prototype modules with readout installed in run 17
  - CBM Triggerless Electronics interface with STAR DAQ/TRG systems
  - Provides performance for final design choices
- Run 18 plans on one full Sector
  - 3x32-strip MRPC with final readout electonics
  - Installation: 10-11/2017
- Complete installation in 11/2018
- Complete BES-II program with full eTOF coverage

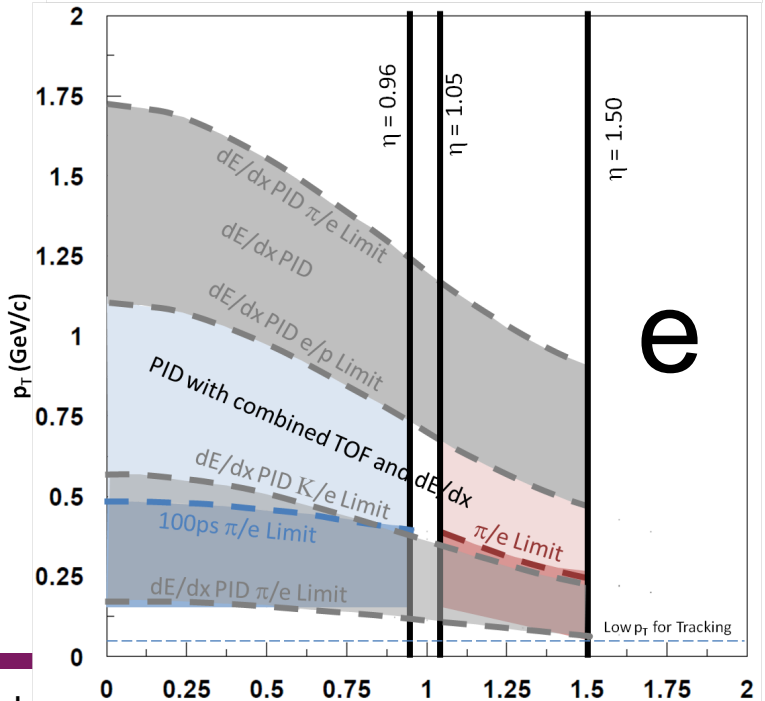
# Acceptance Improvements



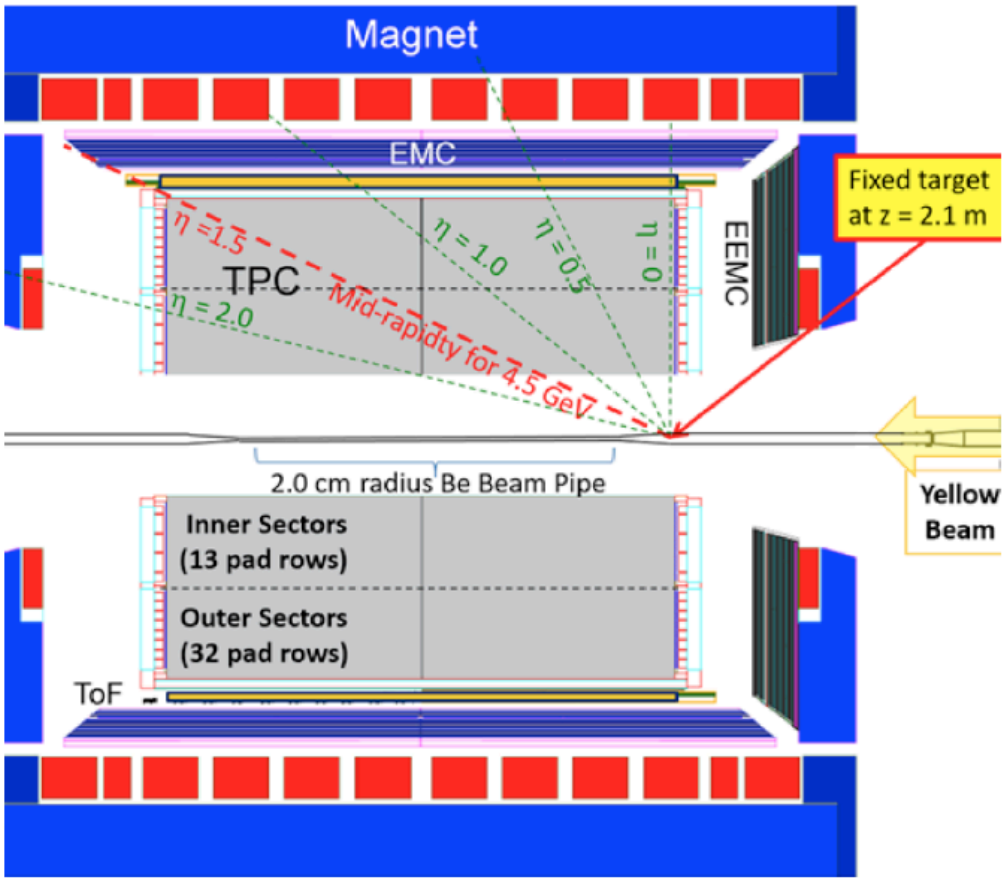



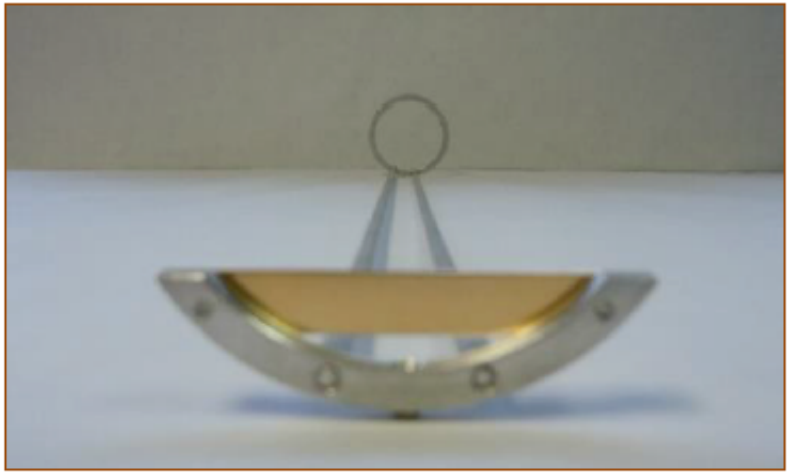

- Extends rapidity coverage ➔ allows a change in $m_B$
- Improves yields of protons ➔ better kurtosis
- Improves coverage for electrons ➔ better di-electron studies



# FXT Experiments at STAR (2018-2019)



Target design:

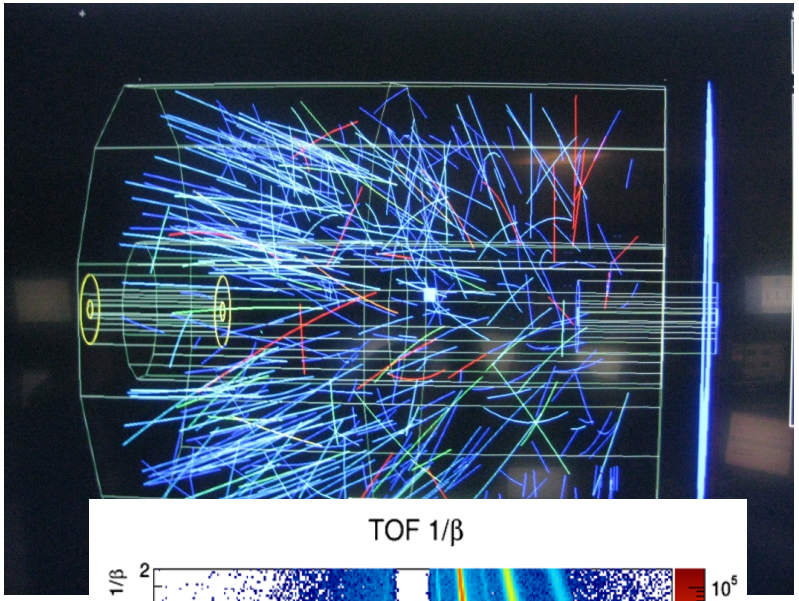
**Gold foil**
**1 mm Thick**
**~1 cm High**
**~4 cm Wide**
**210 cm from IR**

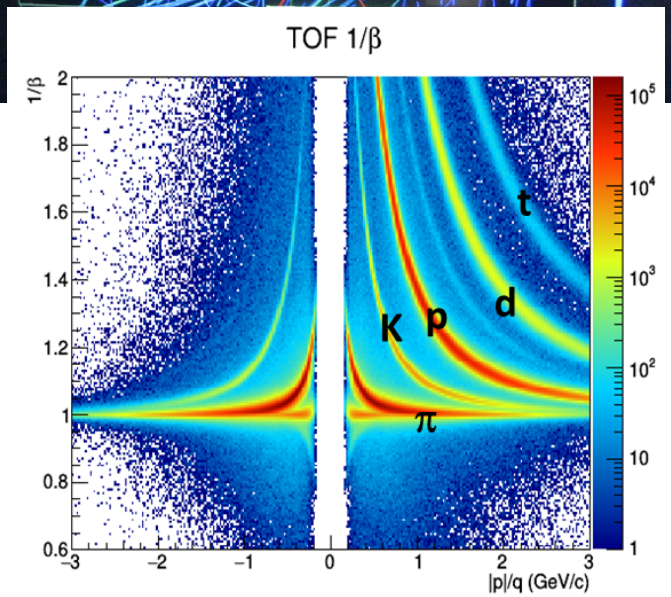
FXT Data Taking Plan：
2015: Au+Au: 4.5 GeV (test Run)
2018: Au+Au :3 GeV (100 million events)
2019-2020: Au+Au: 6.2, 5, 4.5, 4, 3.5 GeV

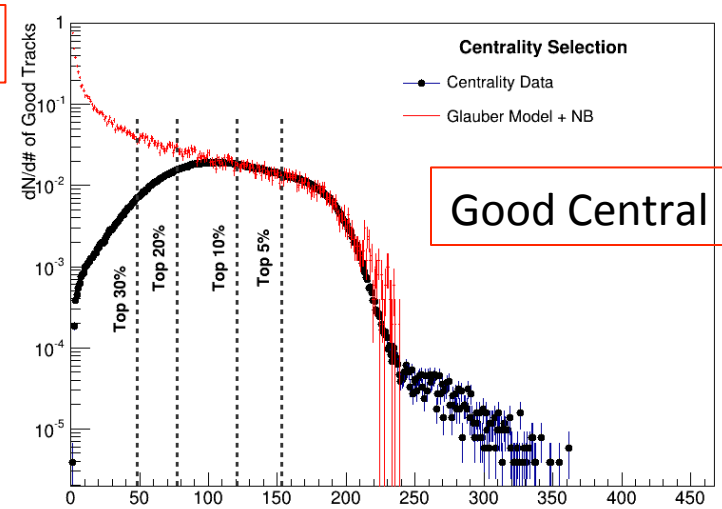
# FXT Pilot Runs were Successful

Trigger was effective

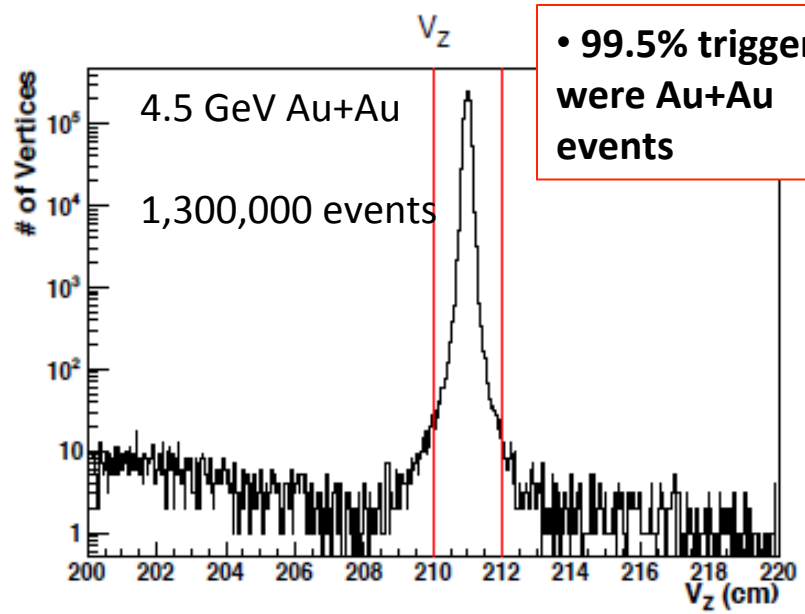
May 20th, 2015





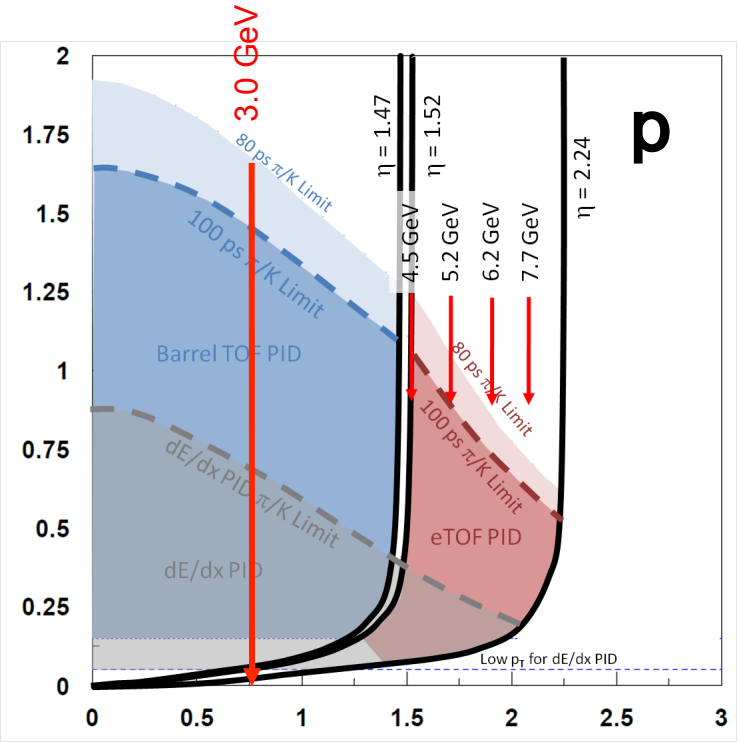

Good Central Events




- **99.5% triggers were Au+Au events**

# FXT Program in 2018-2020

| Collider Energy | Fixed-Target Energy | Single beam AGeV | CM Rapidity | $m_B$ (MeV) |
|---|---|---|---|---|
| 62.4 | 7.7 | 30.3 | 2.10 | 420 |
| 39 | 6.2 | 18.6 | 1.87 | 487 |
| 27 | 5.2 | 12.6 | 1.68 | 541 |
| 19.6 | 4.5 | 8.9 | 1.52 | 589 |
| 14.5 | 3.9 | 6.3 | 1.37 | 633 |
| 11.5 | 3.5 | 4.8 | 1.25 | 666 |
| 9.1 | 3.2 | 3.6 | 1.13 | 699 |
| 7.7 | 3.0 | 2.9 | 1.05 | 721 |




- Data rate is DAQ limited.
- Need100 Million Events at each energy.
- ~ 2 days per energy

# BUR for Run 18 and Run 19

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0670


**Two Highest Priorities for the next two RHIC runs ( run 18 and 19) focus on two compelling programs key to RHIC mission**

**Run 18: isobar collisions at 200 GeV**
Decisive test of role of magnetic field in charge separation measurements

**PAC Recommendation :**
**Double blind Analysis !**
**Fill-by-fill switch or Weekly switch ?**
**Under discussion in the STAR Coll.**

**Run 19: Initiating the BES-II**
Higher BES energies +
Fixed Target (FXT) program

# Run 18 BUR Executive Summary

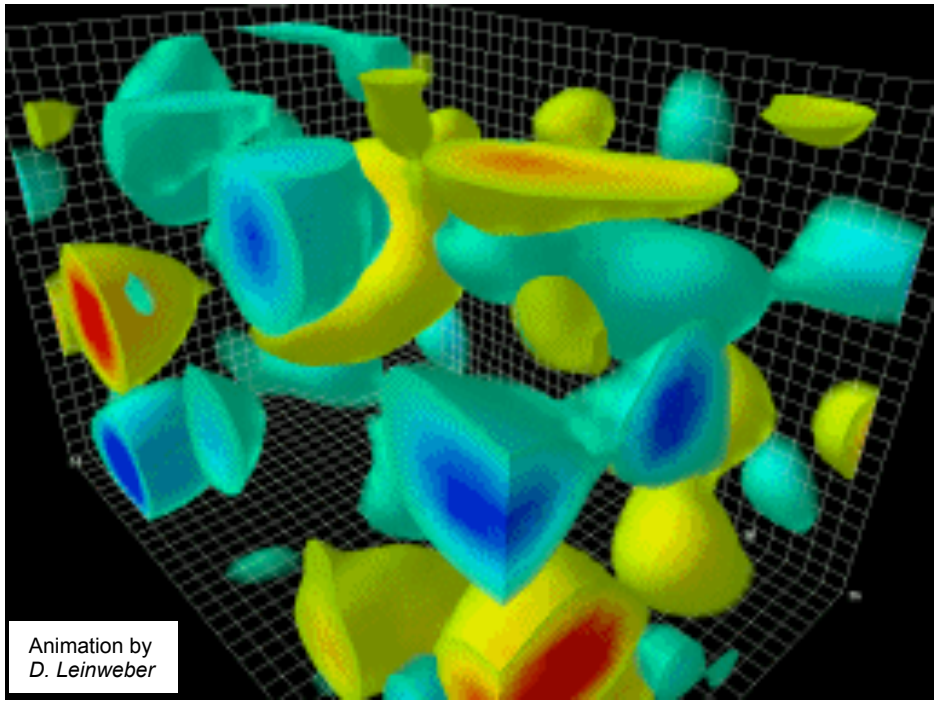
| Run | Energy | Duration | System | Goals | priority | Sequence |
|---|---|---|---|---|---|---|
| 18 | ?$s_{NN}$=200 GeV | 3.5-wk | Zr+Zr | 1.2B minbias | 1 | 1 |
| | | 3.5-wk | Ru+Ru | 1.2B minbias | 1 | 2 |
| | ?$s_{NN}$=27 GeV | 3-wk | Au+Au | 1B minbias | 2 | 3 |
| | ?$s_{NN}$=3 GeV(FXT) | 2 days | Au+Au | 100M minbias | 3 | 4 |

1. **Isobar collisions:**
   Study the CME contribution to charge separation,
   **Ru+Ru (44, 96) and Zr+Zr (40, 96)**
   charge different by 10% (44 vs 40), everything else the "same"

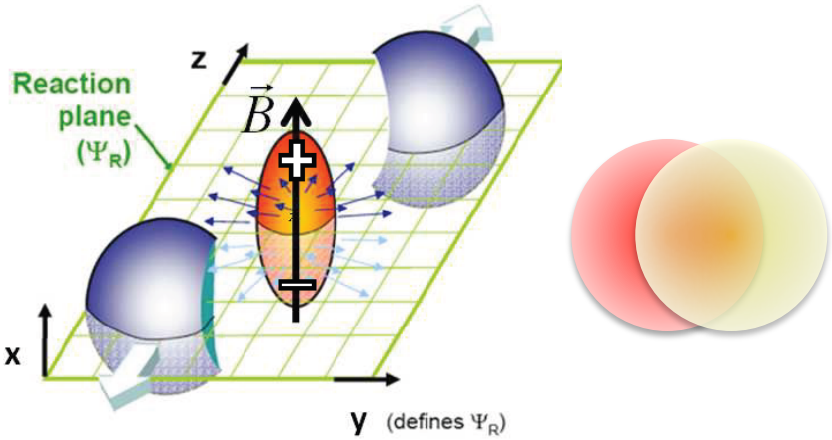
2. **Au+Au @ 27 GeV:**
   High Statistics L and $L$ Global Polarization Measurement
   Event-Plane Detector (EPD) presence important

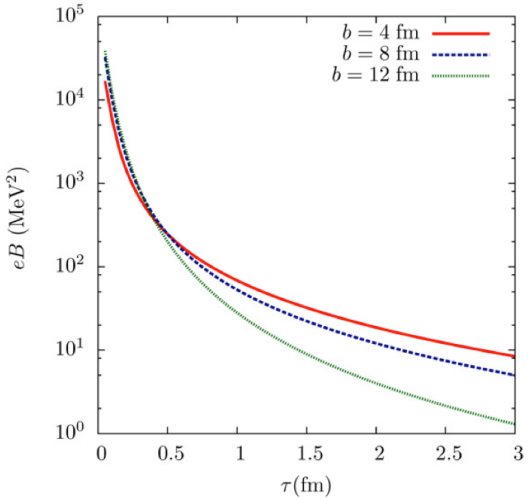
3. **Au+Au @ 3 GeV:**
   Fluctuation measurement at energies between HADES and BES-I
   Significant statistics in FXT mode with large acceptance

# Search for CME in HIC




**The topological charge density**



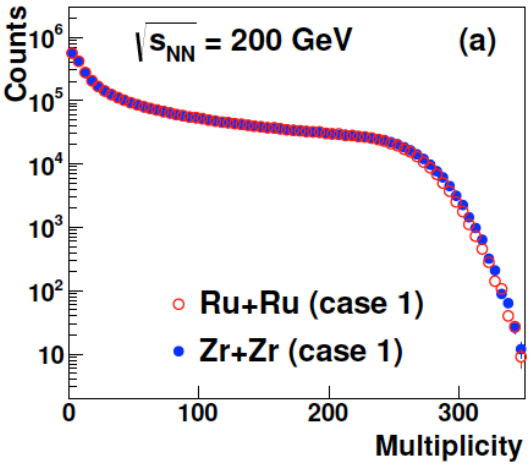

Chiral Magnetic Effects :

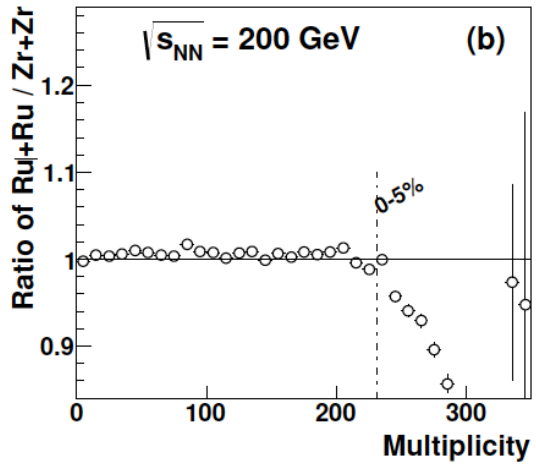
1. Nonzero Topological Charge + LPV
2. Chiral Symmetry Restoration
3. Strong Magnetic Field

Observing : Charge Separation along B field. Measuring 2-particle correlation WRT Reaction Plan.

# Isobar Collisions : only B-Field changes

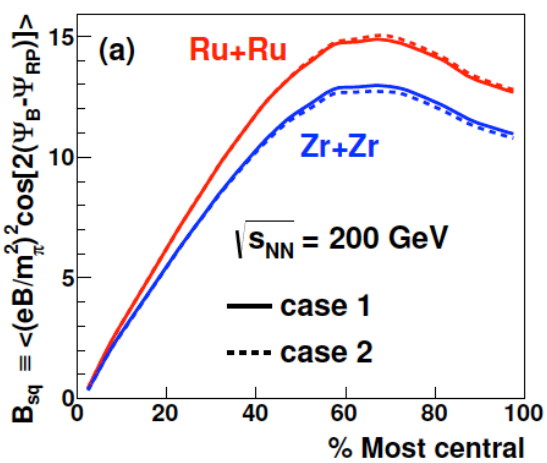
## Controlled measurement

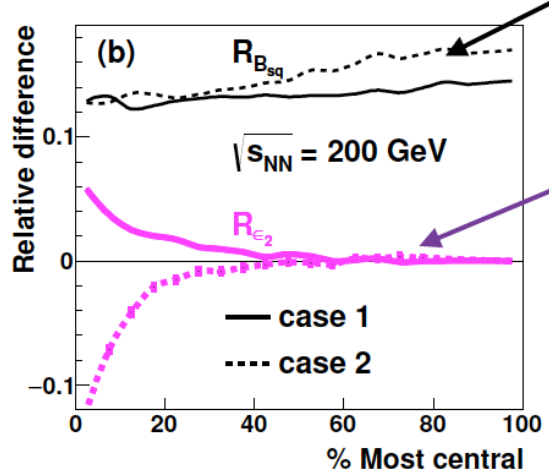



Except for most central data mult. distribution the same

Initial B-field ~10% different

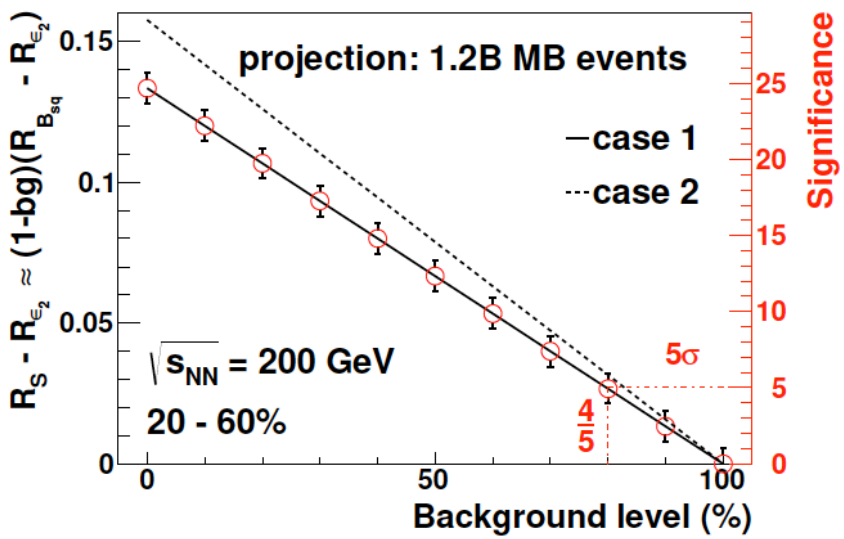


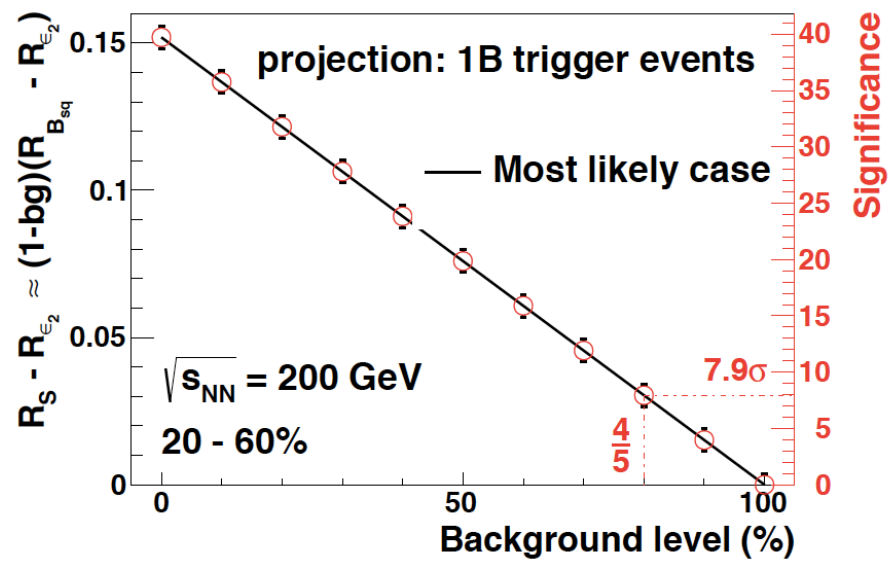




Eccentricity similar except for most peripheral events

Solid/dashed curves range in knowledge shape of isobar

# Projections for Isobar



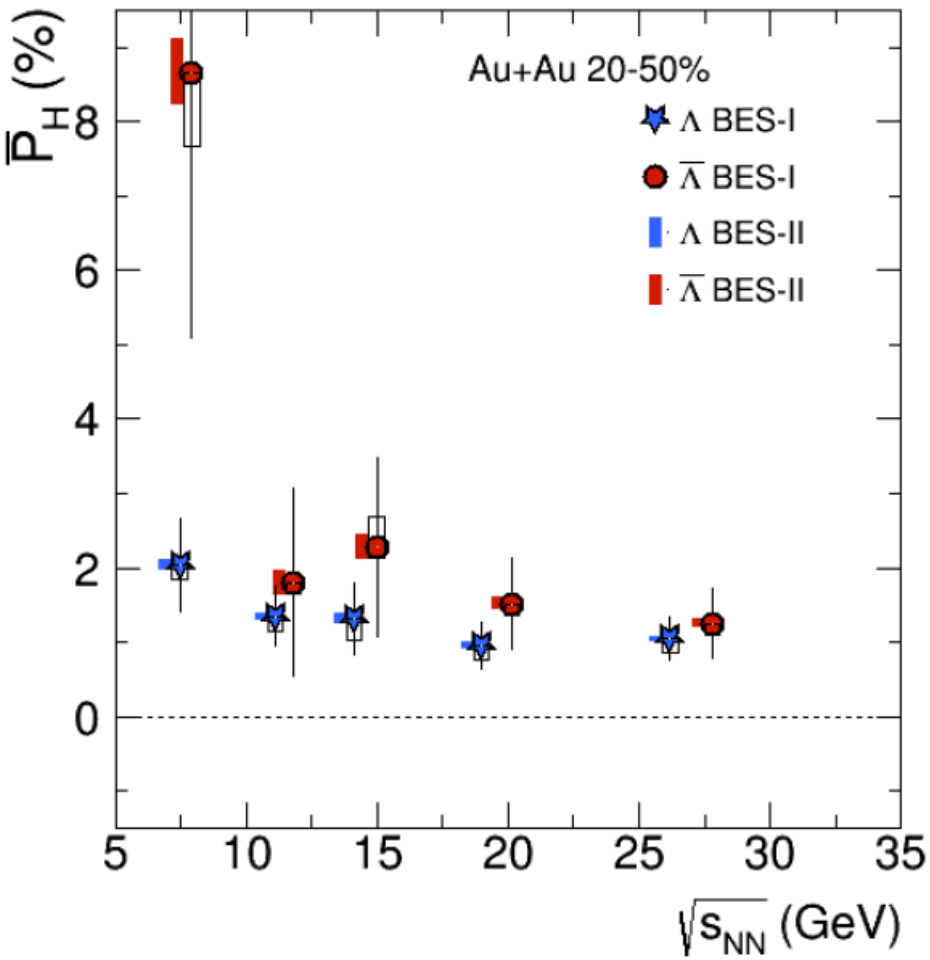

Depending on background level different statistical significance

Proposal is to take 1.2B MB events

CME studies focus on 20-60% -

- propose to trigger in this range, factor 2 in statistics
  Take ~200M MB events for baseline cross-checks

# Au+Au 27 GeV: Priority II




**1B MB events**

Confirm the difference between Lambda and (anti)Lambda Polarization

----Strong Magnetic Field

Other observables affected by MF: Coherent photo-production of J/Ψ and low-mass di-lepton in non-central A+A collisions

# Run 19 BUR Executive Summary

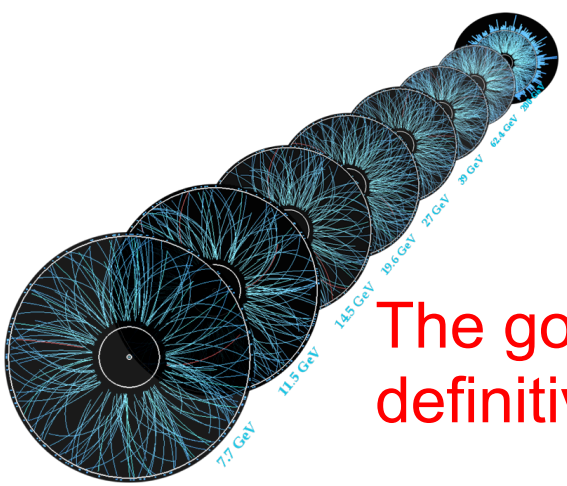
| Beam Energy (GeV/nucleon) | $\sqrt{s_{NN}}$ (GeV) | Run Time | Species | Number Events | Priority | Sequence |
|---|---|---|---|---|---|---|
| 9.8 | 19.6 | 4.5 weeks | Au+Au | 400M MB | 1 | 1 |
| 7.3 | 14.5 | 5.5 weeks | Au+Au | 300M MB | 1 | 3 |
| 5.75 | 11.5 | 5 weeks | Au+Au | 230M MB | 1 | 5 |
| 4.6 | 9.1 [1] | 4 weeks | Au+Au | 160M MB | 1 | 7 |
| 9.8 | 4.5 ( FXT) | 2 days | Au+Au | 100M MB | 2 | 2 |
| 7.3 | 3.9 (FXT) | 2 days | Au+Au | 100M MB | 2 | 4 |
| 5.75 | 3.5 (FXT) | 2 days | Au+Au | 100M MB | 2 | 6 |
| 31.2 | 7.7 (FXT) | 2 days | Au+Au | 100M MB | 2 | 8 |
| 19.5 | 6.2 (FXT) | 2 days | Au+Au | 100M MB | 2 | 9 |
| 13.5 | 5.2 (FXT) | 2 days | Au+Au | 100M MB | 2 | 10 |

1. **Au+Au @ 11.5 – 19.6 GeV:**
   Assume low-energy electron cooling ready mid-way through run & performs at design for 11.5 & 9.1 GeV running

2. **Au+Au FXT:**
   Multiple measurements at energies between
   World FXT programs and BES-II
   Significant statistics in FXT mode with large acceptance

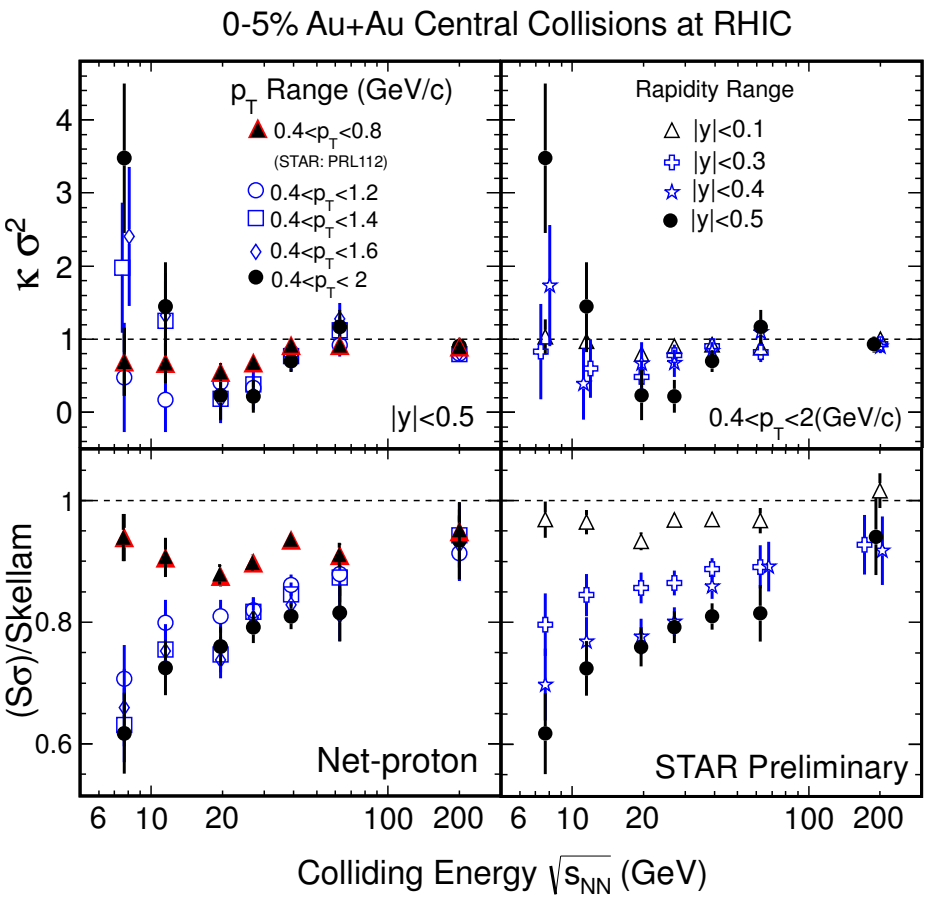
# Physics Analysis Plan in Run 19

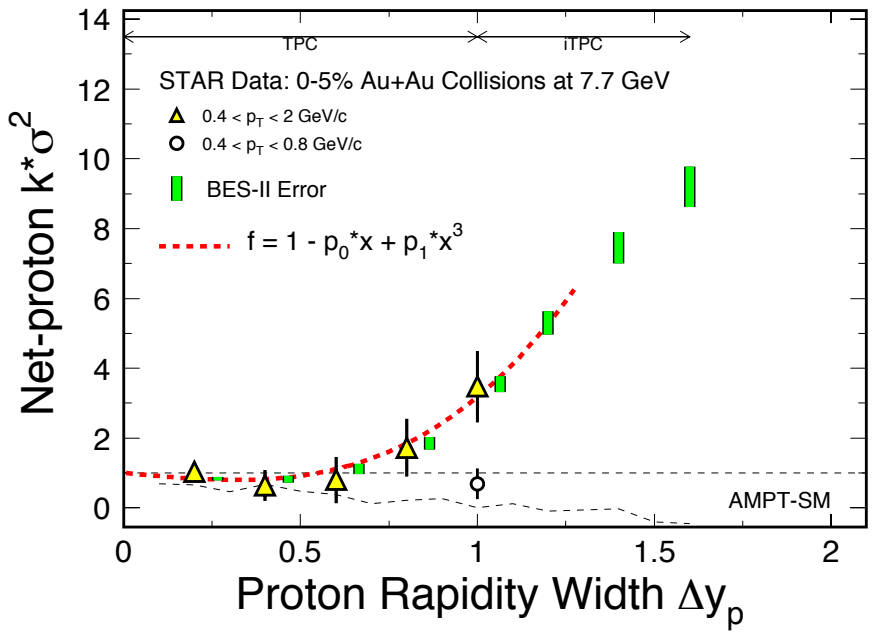
- $R_{CP}$ of high $p_T$ hadrons (up to 4.5 GeV), rapidity dependence
- Elliptic Flow of the phi meson, multi-strange baryon.
- Local Parity Violation studies (CME)
- Directed flow for identified particles()
- Net proton higher moments ($ks^2$)
- Di-lepton production.
- Global Hyperon Polarization
- Multi-strange baryon and Light nuclei production




The goal of BES-II is to turn trends and features into definitive conclusions and new understanding.

# BES-II Physics highlights (I): net-proton fluctuations



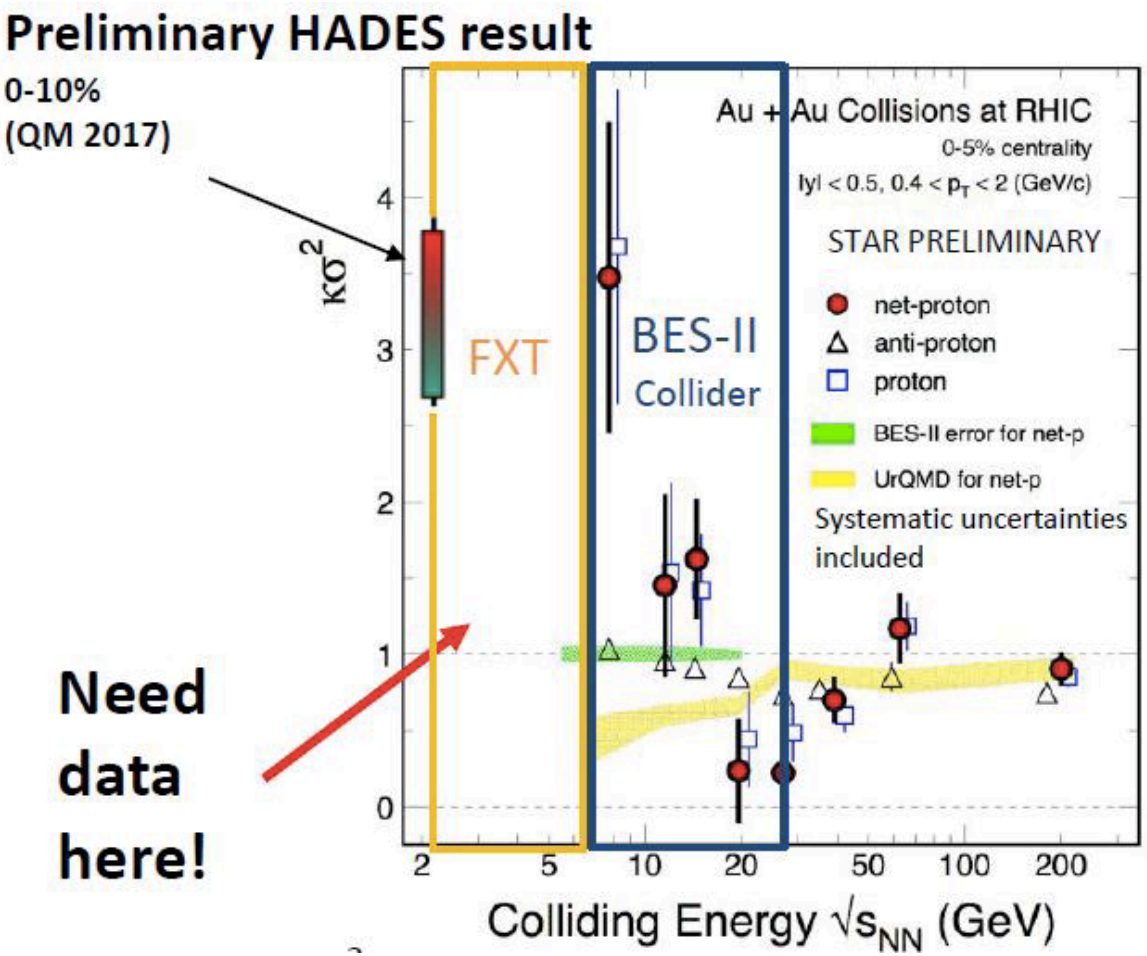



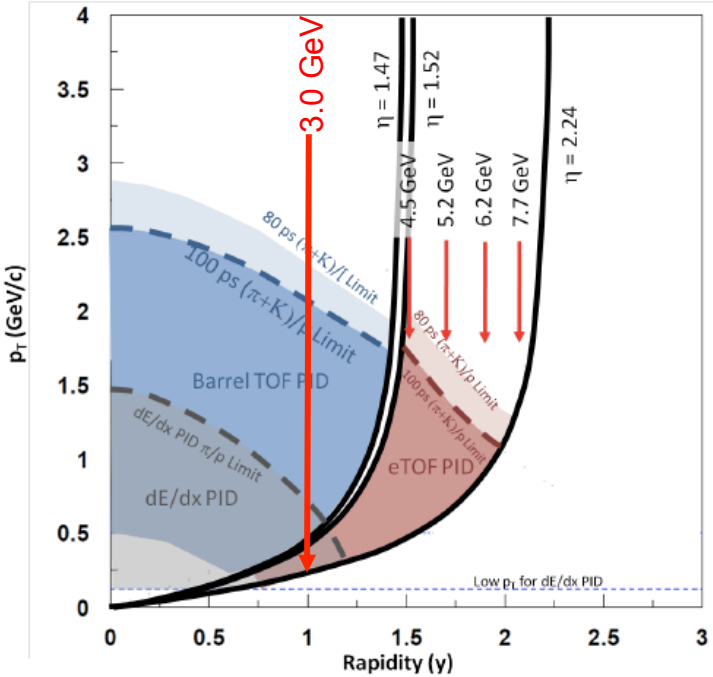

Enhance the fluctuation signals by enlarge the acceptance.

- System size limits the increase of the correlation length.
- The acceptance needs to be large enough to capture the critical fluctuations. (1-2 units)

B. Ling and M. Stephanov, Phys.Rev. C93 (2016) 034915

# Net-proton Fluctuation at low energies

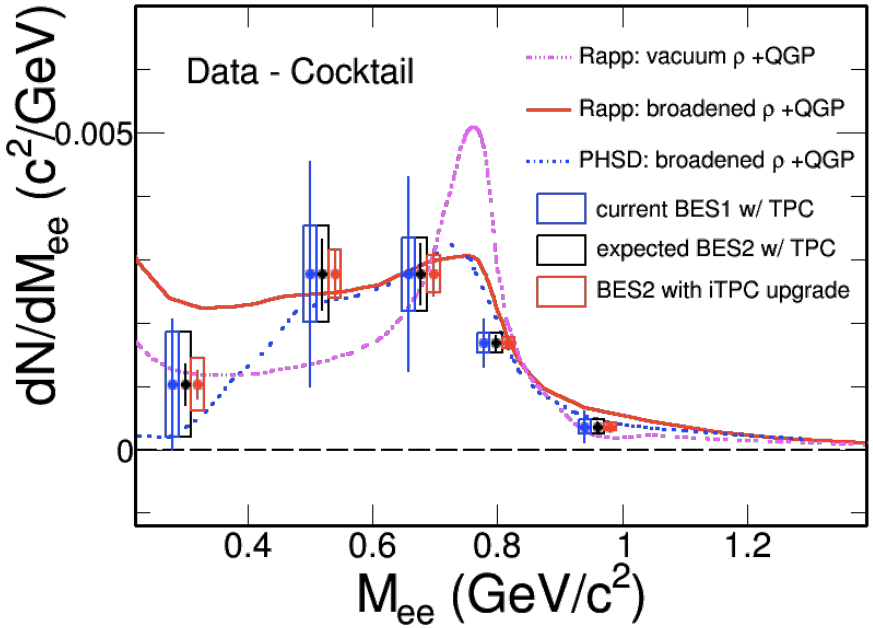


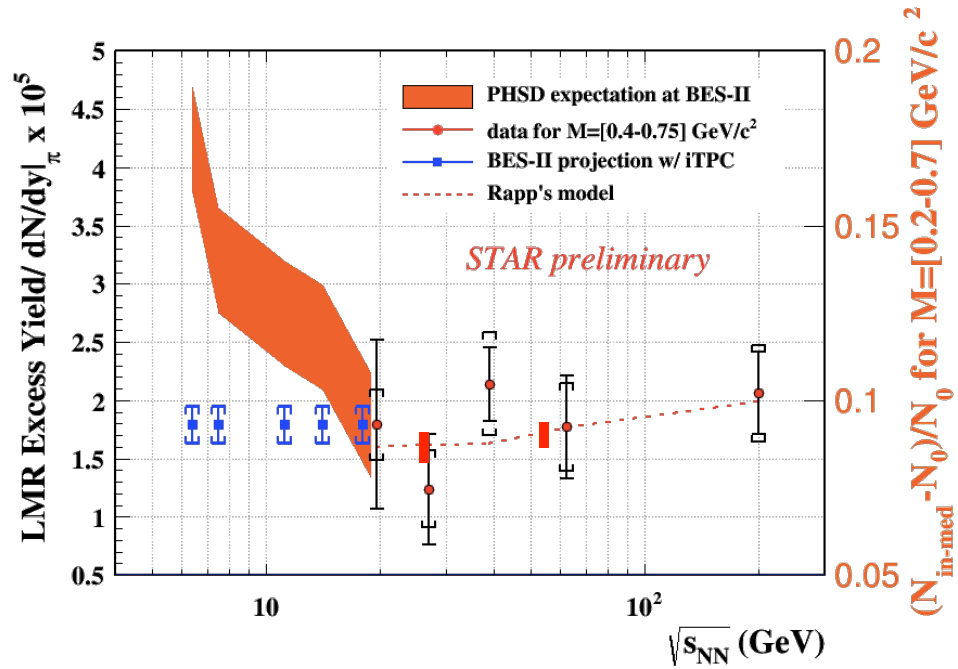




Au+Au at 3 GeV:
mid-rapidity well within current TPC

With high statistics, establish a bridge between BES and world program at fixed target (HADES/CBM/NICA/JPARC)

# BES-II Physics highlights (II): Di-electron measurements




- Systematically study di-electron continuum from $\sqrt{S_{NN}}$ = 7.7 – 19.6 GeV
- Inner Time Projection Chamber (iTPC) upgrade: reduce systematic and statistical uncertainties
- Distinguish models with different ρ-meson broadening mechanisms (Rapp's method vs. PHSD)
- Study the total baryon density effect on LMR excess yield.

# Summary

- Results from the first Beam Energy Scan at RHIC built the case and defined the best search range for BES-II（2019-2020)

- Key measurements need more data (net-proton fluctuations, $v_2$ of phi, di-leptons etc.)

- Detector upgrades in progress will extend coverage . Upgrades are on schedule - tight but we can make it.

- FXT program will extend the reach of BES program at high baryon density region.

**Run 18-19 well defined and set to produce exciting and definitive results. Stay Tune !**

# Acknowledgement:

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***Thank you !***