

# The STAR eTOF Upgrade

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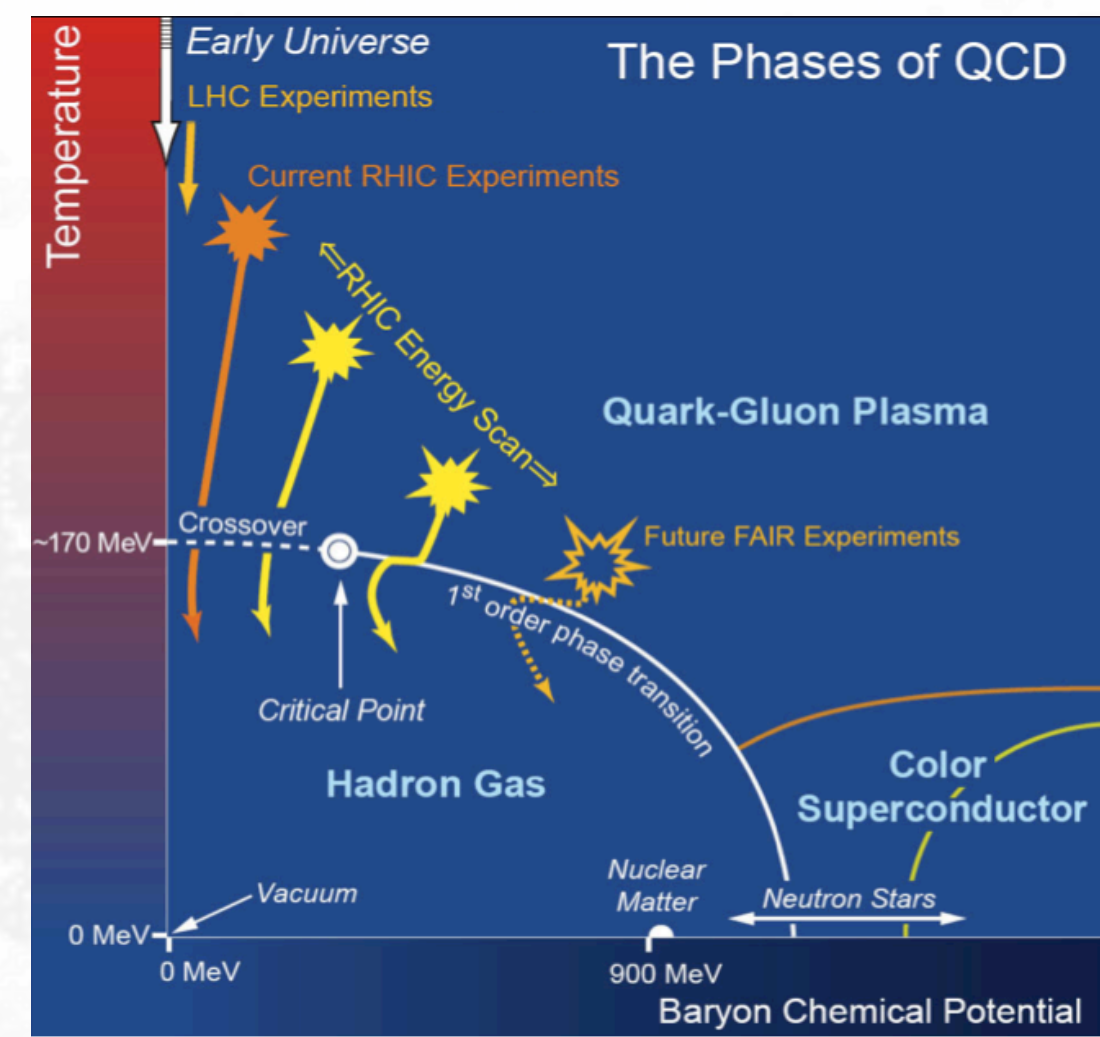
## Abstract

The first RHIC Beam Energy Scan (BES-I) provided an initial survey of the QCD phase diagram by acquiring data from Au+Au collisions from  $\sqrt{s_{NN}} = 7.7$  to 62.4 GeV. Based on those results, a second phase of the BES program, BES-II, has been developed and is scheduled to run in 2019 and 2020. One of the proposed upgrades to STAR for BES-II will be the addition of an end-cap time-of-flight system (eTOF). The eTOF upgrade will employ 36 CBM TOF modules for the duration of BES-II. The eTOF upgrade will extend STAR's particle identification (PID) capabilities to higher momentum in the forward pseudorapidity range provided by the iTPC upgrade. A fixed-target program, enabled by the eTOF upgrade, will extend the energy scan below the 7.7 GeV lowest energy of BES-I. In this poster, we discuss the improvements that the eTOF subsystem will bring to the physics program of BES-II.

## Exploring the QCD Phase Diagram

### Motivation:

- Hadronic gas phase at low T and  $\mu_B$
- Lattice QCD calculations  $\rightarrow$  expect a cross-over at high energies
- Study onset of QGP at high T and  $\mu_B$ 
  - nuclear modification ( $R_{CP}$ )
  - NCQ scaling of elliptic flow
- Do we observe a phase transition as we lower the beam energy? What type of phase transition?
  - directed flow
  - femtoscopy
- Do we observe a critical point?
  - fluctuation analyses
  - dielectrons?
- Do we observe chiral symmetry restoration?
  - dielectrons and low-mass vector mesons

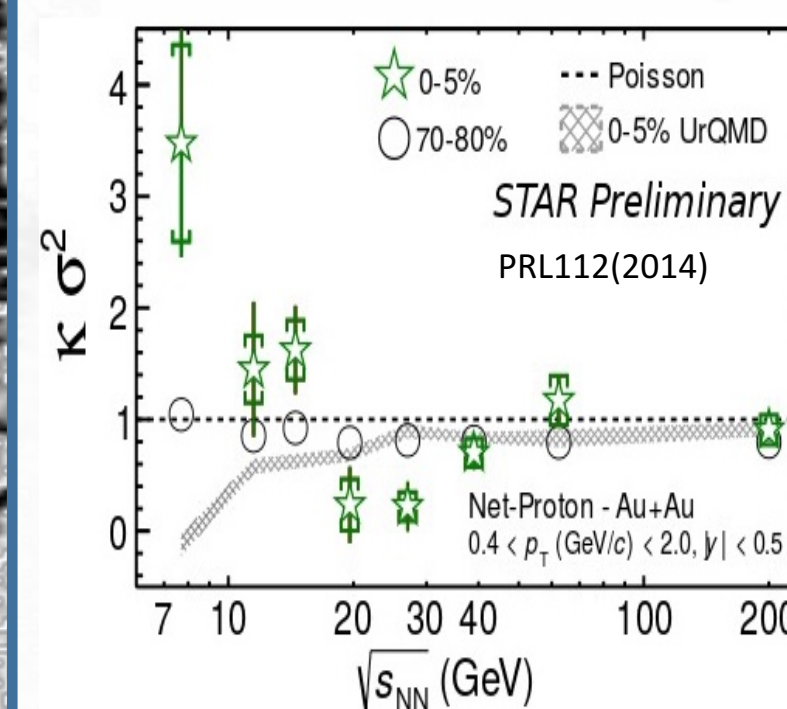


### RHIC Beam Energy Scan (Phase I)

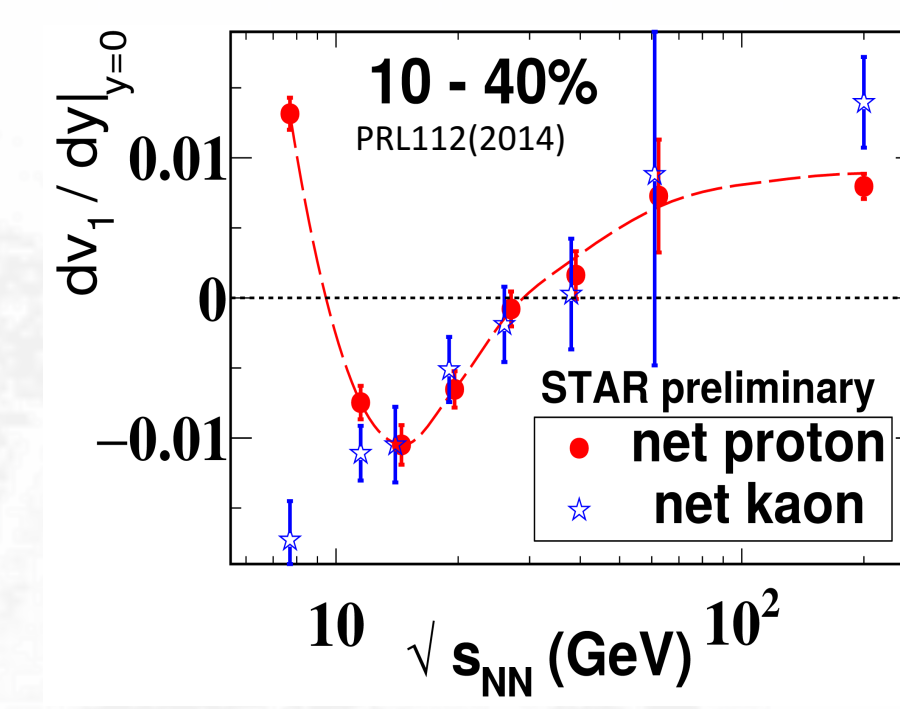
- carried out in 2010-2014
- covered energies from  $\sqrt{s_{NN}} = 7.7$  to 64 GeV

## Selected Results from BES Phase I

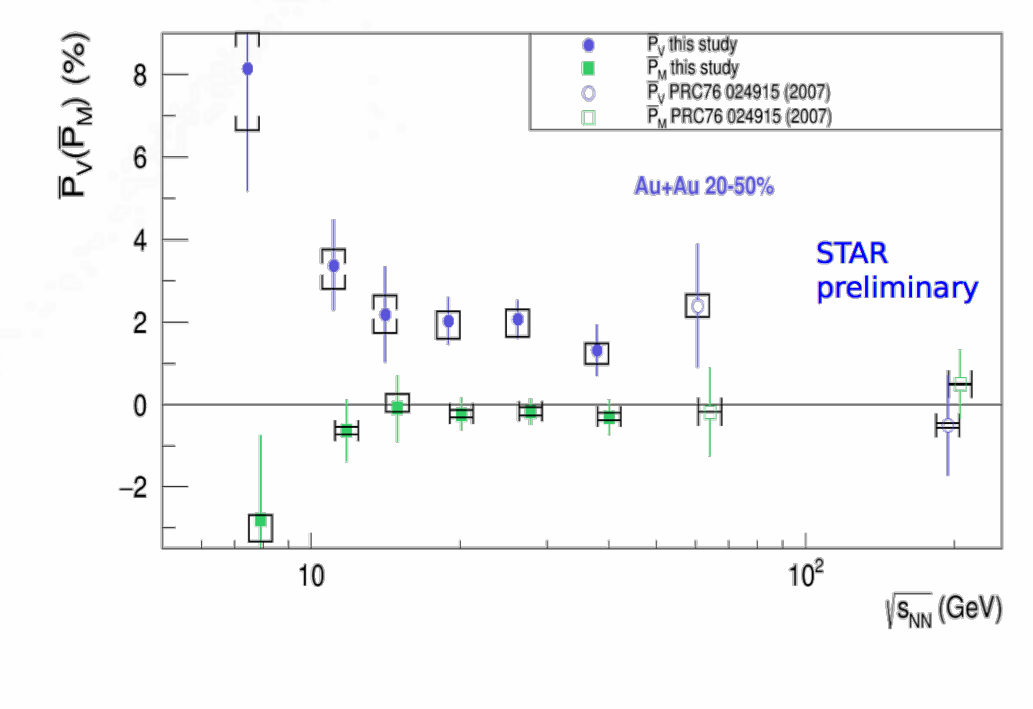
### Critical Point



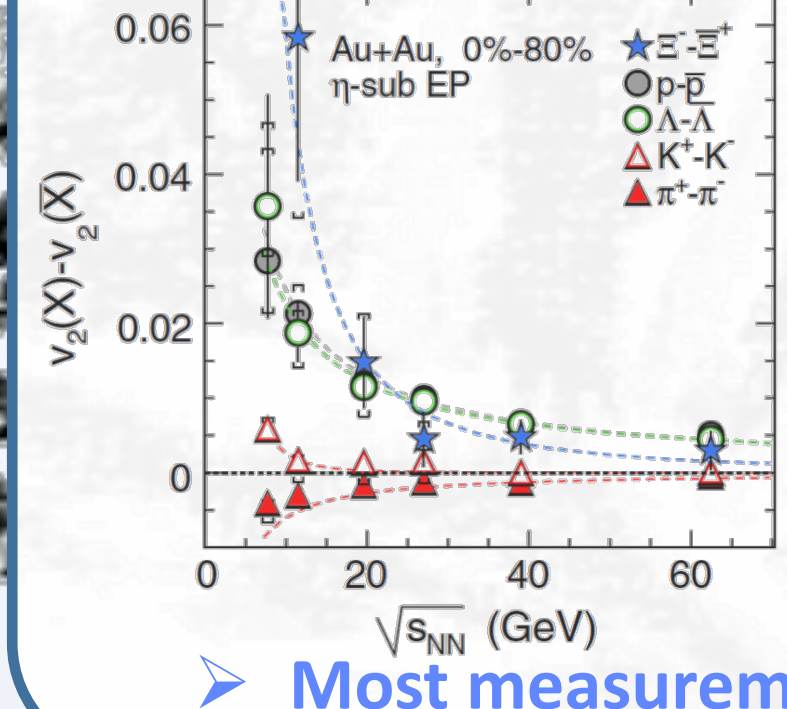
### Phase Transition



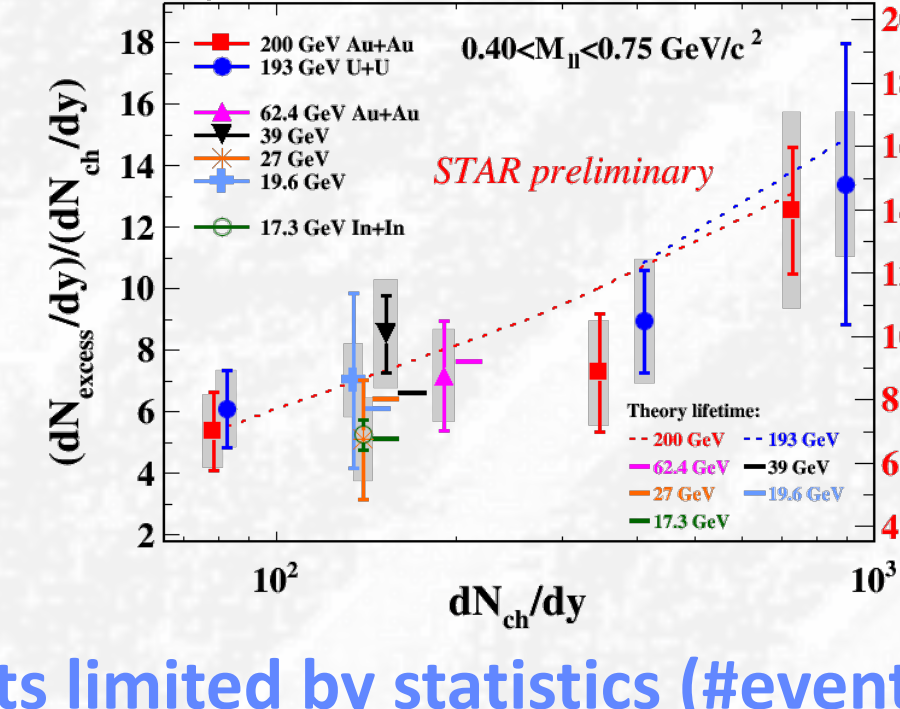
### Chiral Vortical Effect



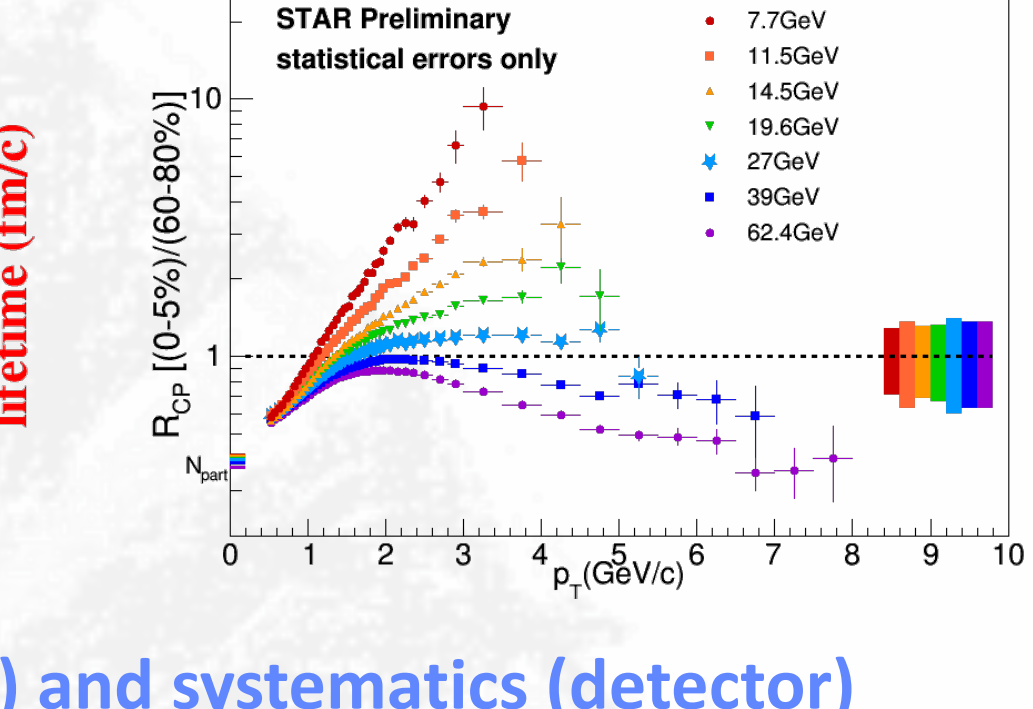
### Bulk Behavior



### Penetrating Probes



### Energy Loss



➢ Most measurements limited by statistics (#events) and systematics (detector)

## Next: Beam Energy Scan Phase II

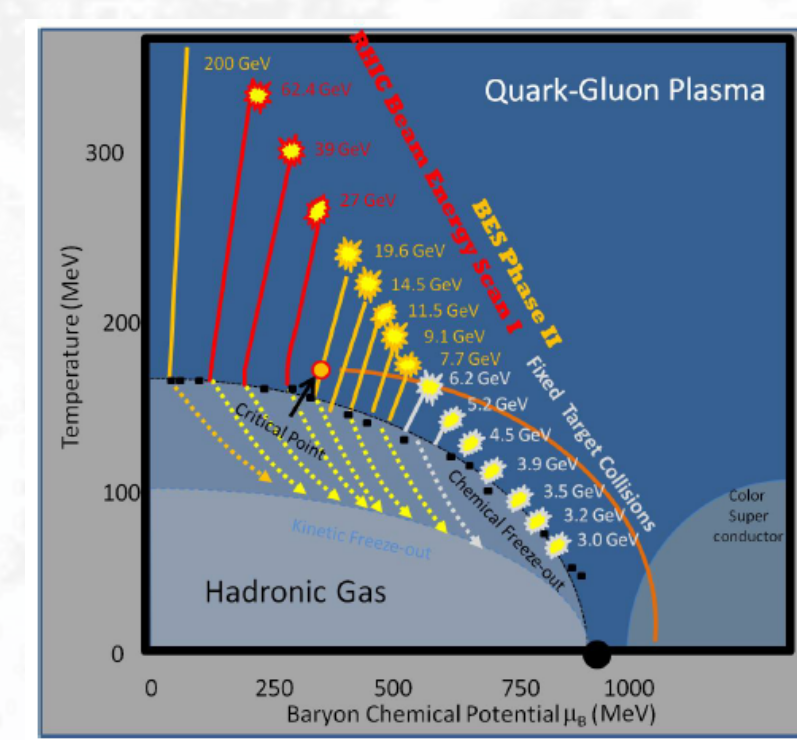
Table 2. Event statistics (in millions) needed for Beam Energy Scan Phase-II for various observables.

Collision Energy (GeV)	7.7	9.1	11.5	14.5	19.6
$\mu_B$ (MeV) with 5% central collisions	420	370	315	260	205

Observables

Observable	7.7	9.1	11.5	14.5	19.6
$R_{CP}$ up to $p_T = 5$ GeV/c	100	150	200	200	400
Elliptic Flow ( $v_2$ mesons)	50	50	50	50	50
Chiral Magnetic Effect	50	50	100	100	200
Directed Flow (protons)	25	40	50	65	80
Antinuclear Femtoscopy (protons)	80	100	120	200	400
Net-Proton Kurtosis	100	160	230	300	400
Dileptons	100	160	230	300	400
Required Number of Events	100	160	230	300	400

Million Events

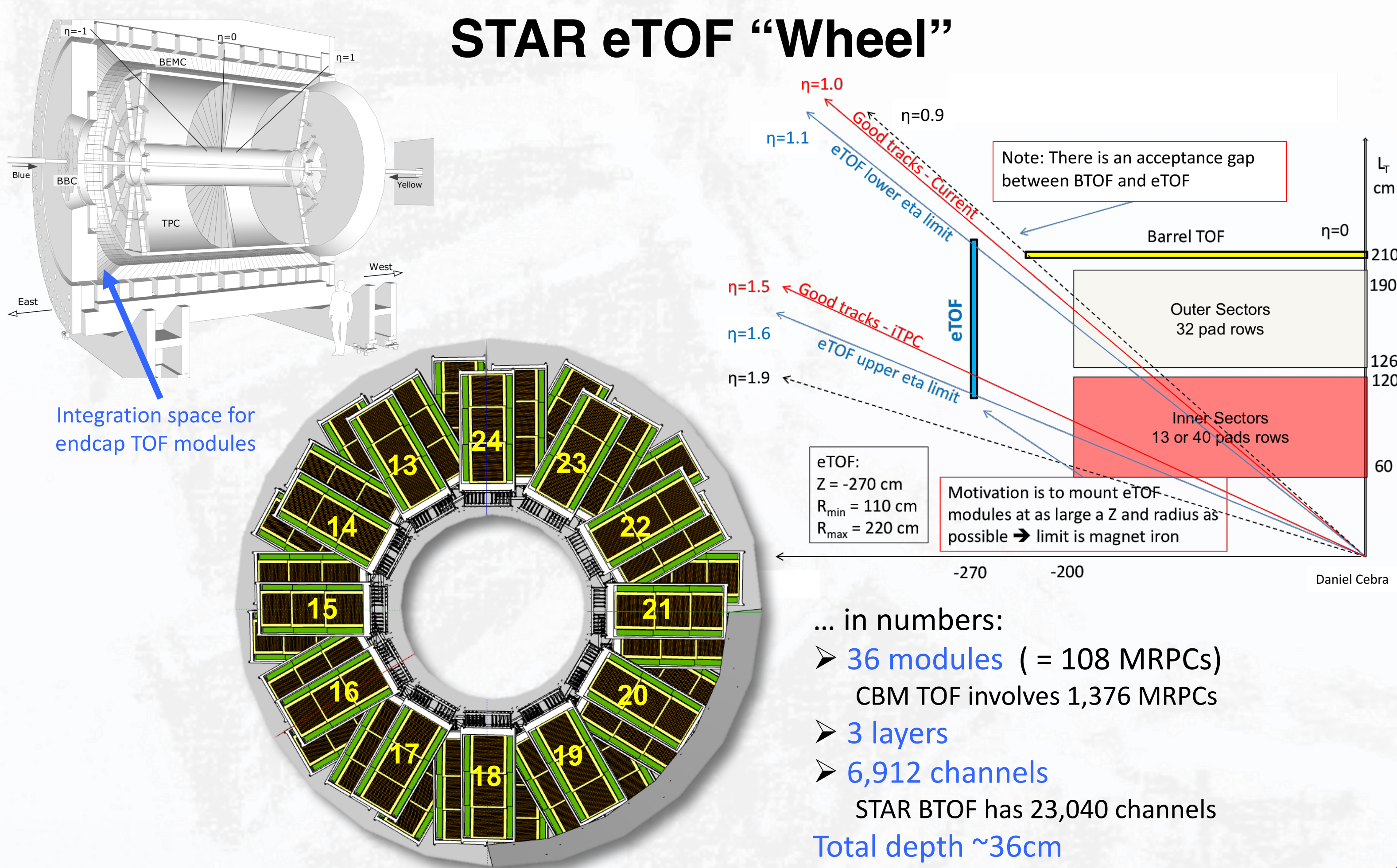


### Fixed Target Mode

Collision Energy	Fixed-Target Energy	Single Beam Energy	Center-of-Mass Rapidity	$\mu_B$ (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

Expect 1-2 days dedicated beam time per energy = 50M events/day

## STAR eTOF "Wheel"



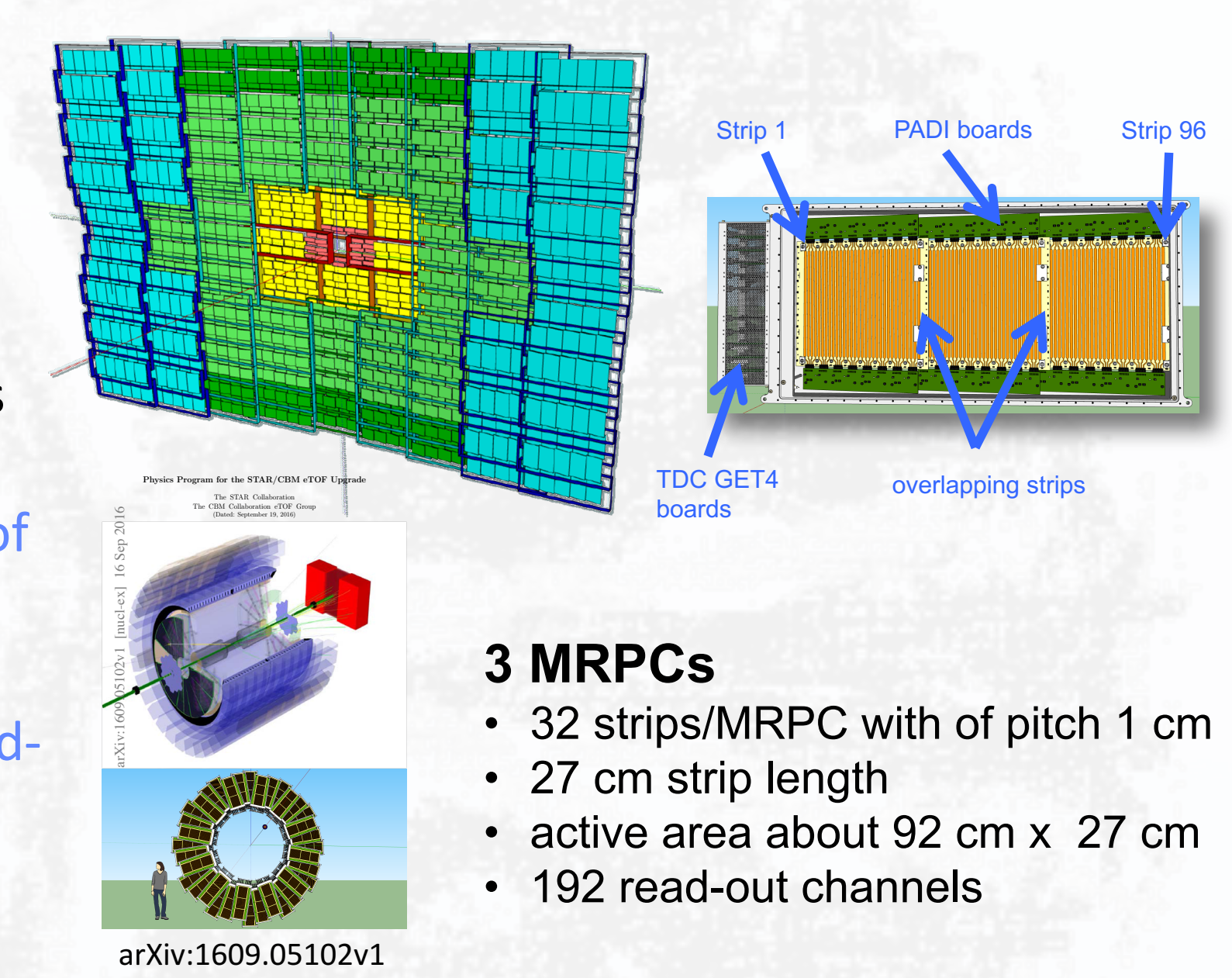
## Opportunities: FAIR PHYS 0 and CBM TOF

CBM plans to embed some prototype subsystems into running experiments

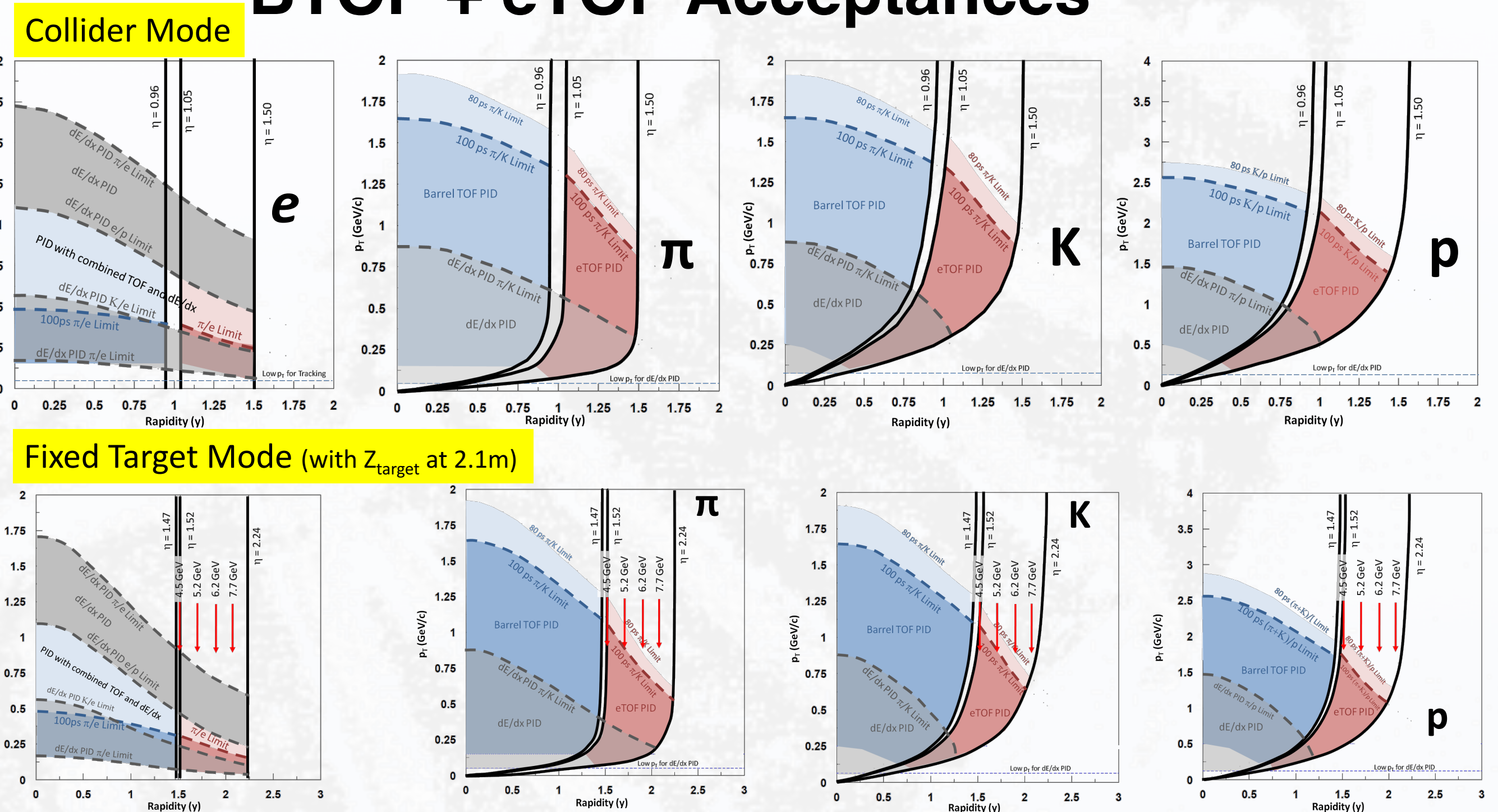
➢ STAR eTOF is part of FAIR Phase 0

Proposal by STAR/CBM Collaboration:

- extend STAR's particle ID capabilities for  $\pi, K, p$ 
  - complement the improved reach of the iTPC to  $\eta \approx 1.5$
  - if no eTOF:  $\eta \approx 0.9$
- essential for mid-rapidity PID in Fixed-Target mode
  - for  $\sqrt{s_{NN}} = 4.5 - 7.7$  GeV



## BTOF + eTOF Acceptances



## Physics Benefits from Enabling Forward PID

Precision studies of  $y$  dependence of key bulk property observables

BES-II range characterized by partial stopping  $\rightarrow$  wider rapidity interval helps disentangle dynamic from thermodynamic effects

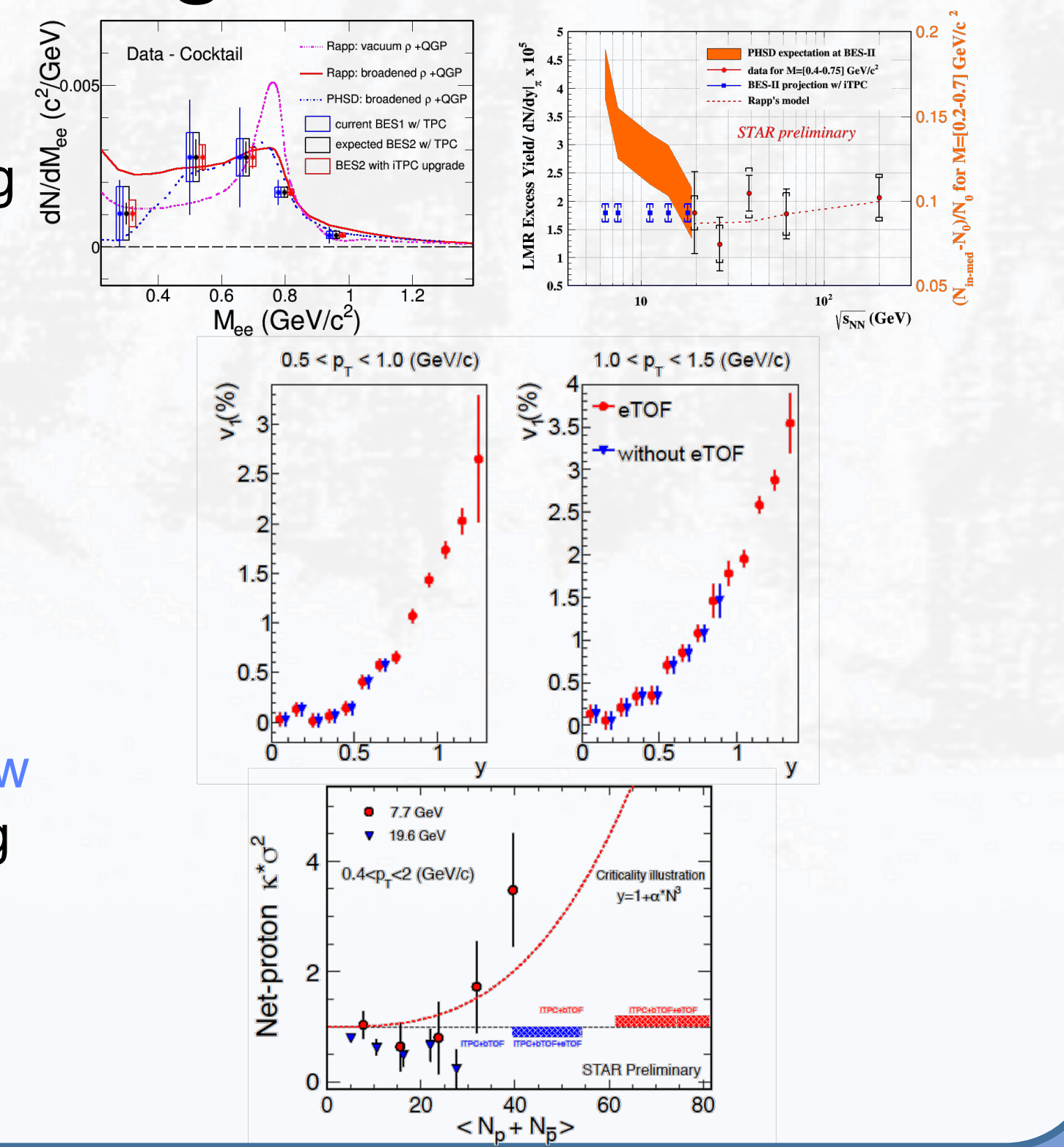
**Dileptons:** forward measurements provide for independent observable to study LMR baryon-density dependence

quantifying the effect on the  $\rho$  meson broadening

**Directed Flow:** extending PID to  $y=1.2$  opens a new rapidity region that may help confirm EOS softening

**Elliptic Flow:**  $y$ -dependent  $v_2$

**Fluctuations:** enhanced fluctuation signals are expected to provide a cleaner and more significant indication of critical behavior



## Summary

STAR proposed Phase II of Beam Energy Scan

➢ slated for 2019-2020

Preparations for proposed detector upgrades well underway

➢ proposed eTOF complements iTPC upgrade,

➢ essential for mid-rapidity PID in fixed-target mode

FAIR Phase-0 presents opportunities to embed prototype CBM TOF in STAR

➢ Letter of Interest between participating CBM TOF institutes and STAR; blessed by CBM

eTOF wheel with 36 CBM modules

➢ based on CBM M5 but instead with 3 MRPCs

➢ outer-wall based PADI FEES and GET4 electronics

➢ mounted inside, on the east poletip

First single-unit installation and cosmics test successfully completed in Oct. '16

➢ ready for first integration test in the RHIC 2017 run

Looking forward to successful installation ahead of BES Phase II!

References

- ✓ Studying the Phase Diagram of QCD Matter at RHIC – STAR Note 598
- ✓ Physics Program for the STAR/CBM eTOF Upgrade – arXiv:1609.05102v1
- ✓ A Proposal for STAR Inner TPC Sector Upgrade – STAR Note 619



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The STAR Collaboration  
drupal.star.bnl.gov/STAR/presentations

