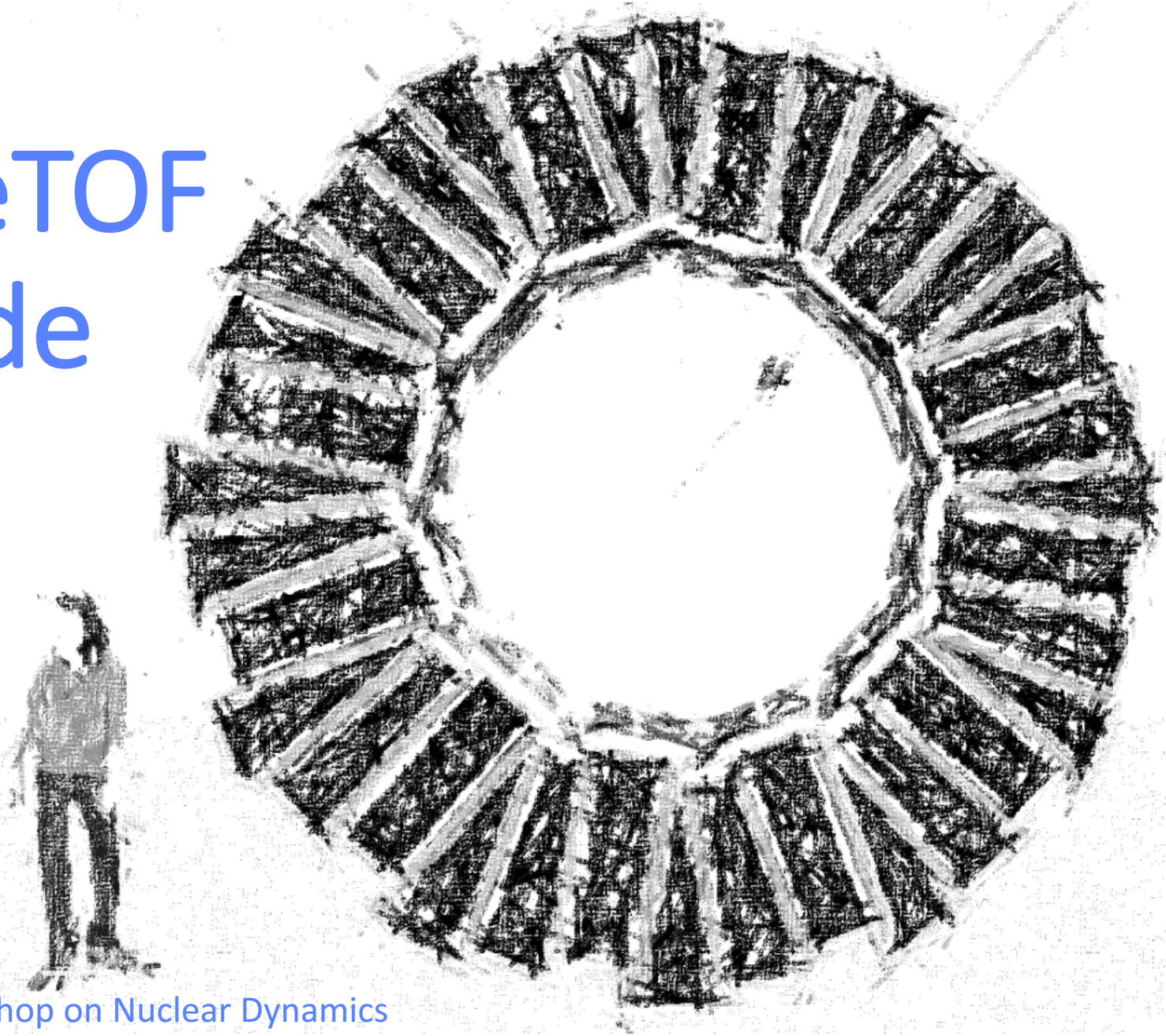
STAR eTOF upgrade



Frank Geurts

for the

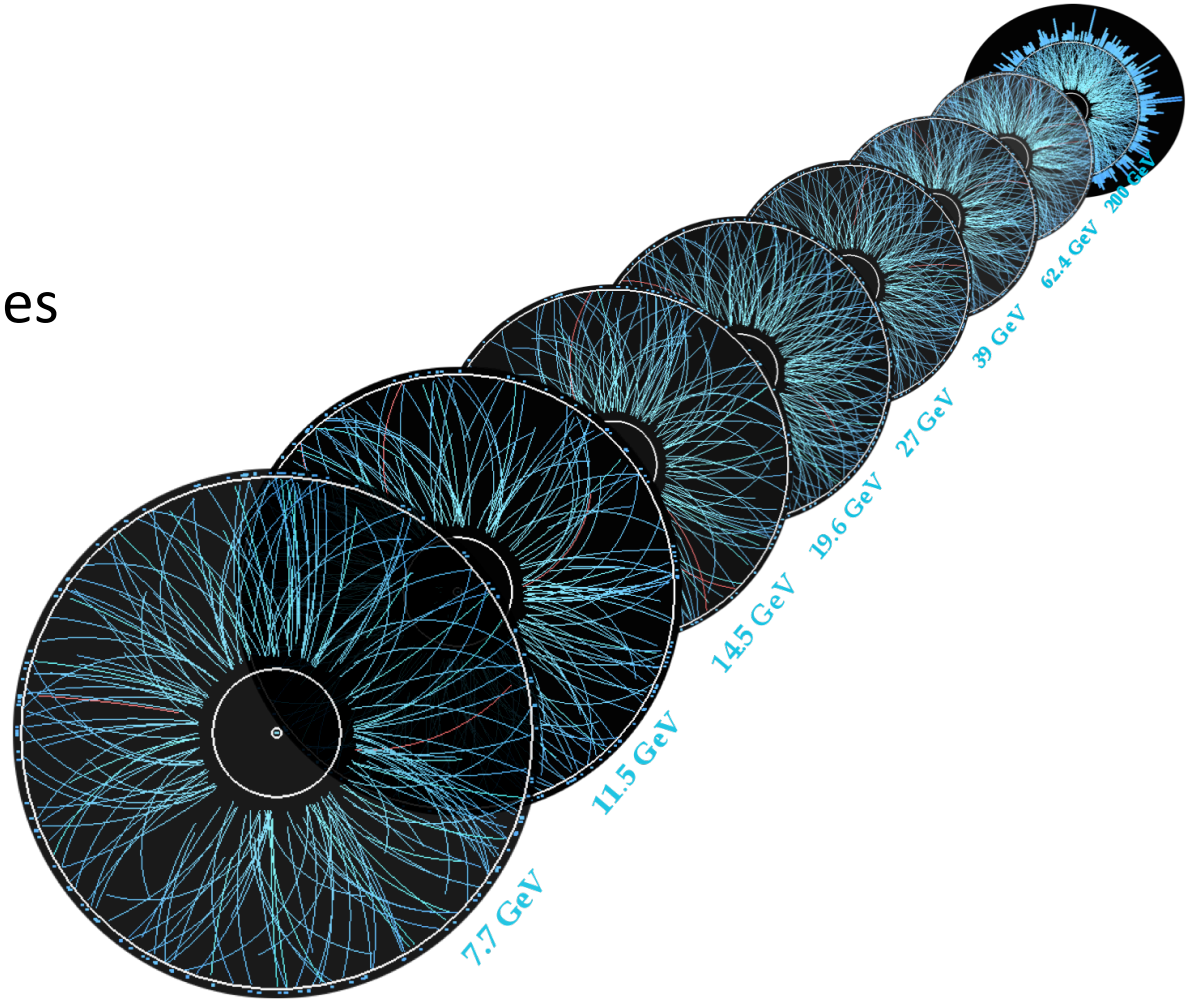
STAR Collaboration

33rd Winter Workshop on Nuclear Dynamics

January 2017 – Snowbird, Utah

Outline

- Beam Energy Scan
  - exploring the QCD Phase Diagram
  - Phase II: proposed detector upgrades
  - improvements to physics program
- STAR eTOF
  - FAIR Phase 0 and opportunities for CBM and STAR
  - layout, plans
  - prototype
- Summary



Exploring the QCD Phase Diagram

Motivation:

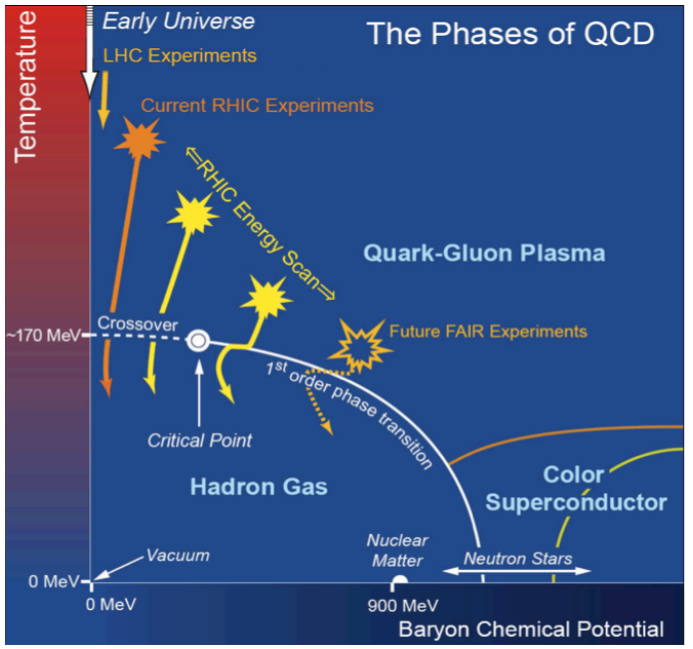
- Hadronic gas phase at low T and μ_B
- Lattice QCD calculations ⇀ expect a cross-over at high energies

➢ Study onset of QGP at high T and μ_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?

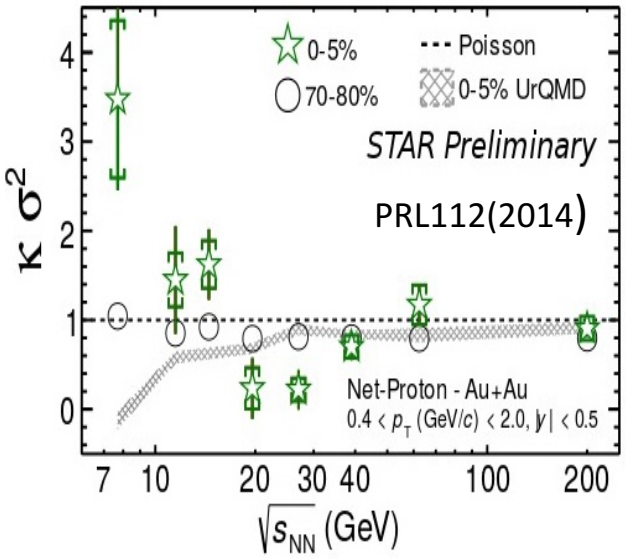
➢ Do we observe chiral symmetry restoration?
  - dielectrons and low-mass vector mesons



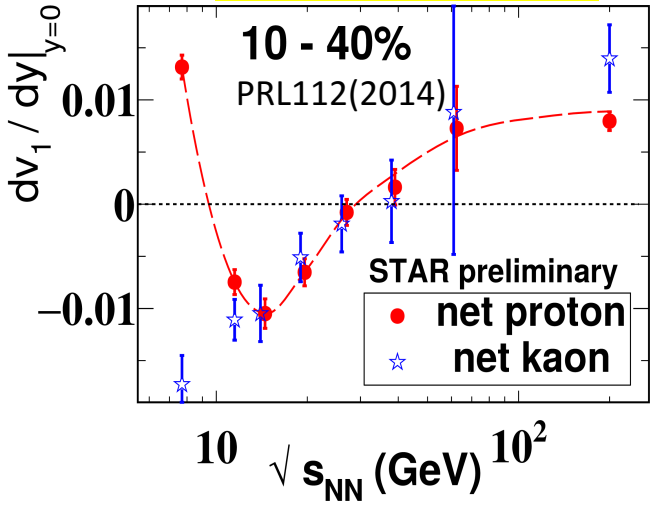
- **RHIC Beam Energy Scan (Phase I)**
  - carried out in 2010-2014
  - covered energies from $\sqrt{s_{NN}}$= 7.7 to 64 GeV
- **STAR has published 16 papers based on BES-I**
  - another half-dozen papers are in preparation or advanced stages of internal review

Selected Results from BES Phase-I

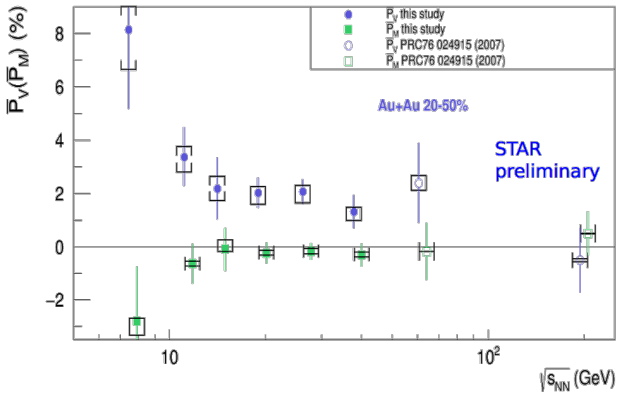
Critical Point



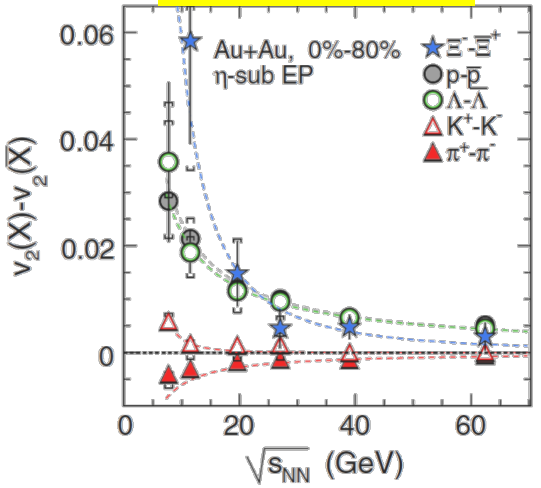
Phase Transition



Chiral Vortical Effect



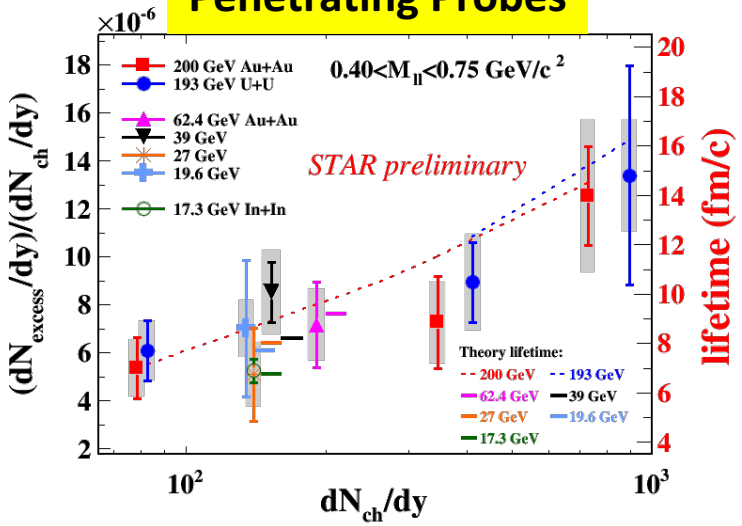
Bulk Behavior



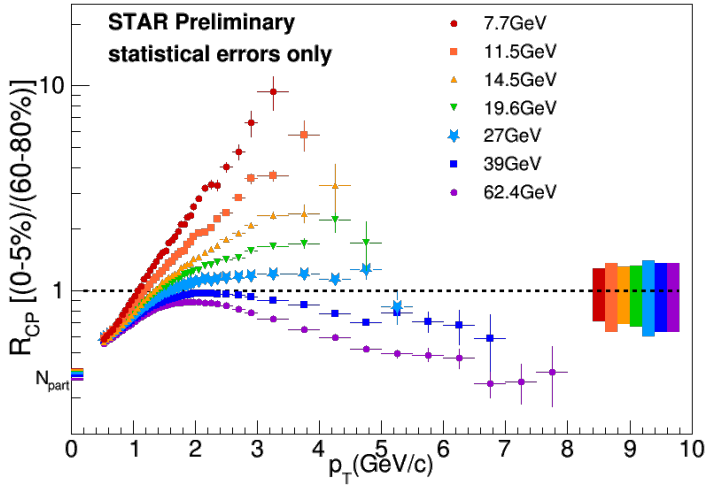
Most measurements limited by statistics and systematics

- Proposal for a BES Phase II with more statistics and new detectors

Penetrating Probes



Energy Loss



Beam Energy Scan Phase-II

Dedicated second phase of the BES program, proposed in 2014

STAR Note 598

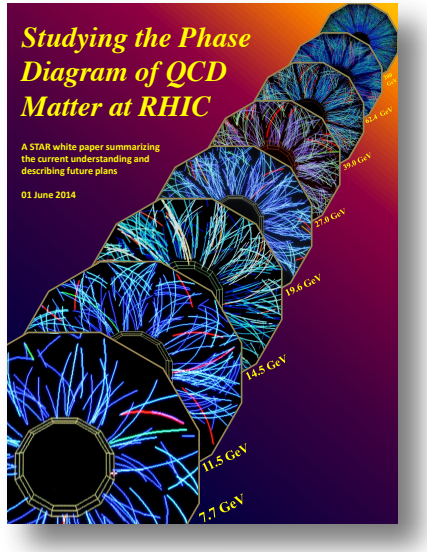


Table 2. Event statistics (in millions) needed for Beam Energy Scan Phase-II for various observables.

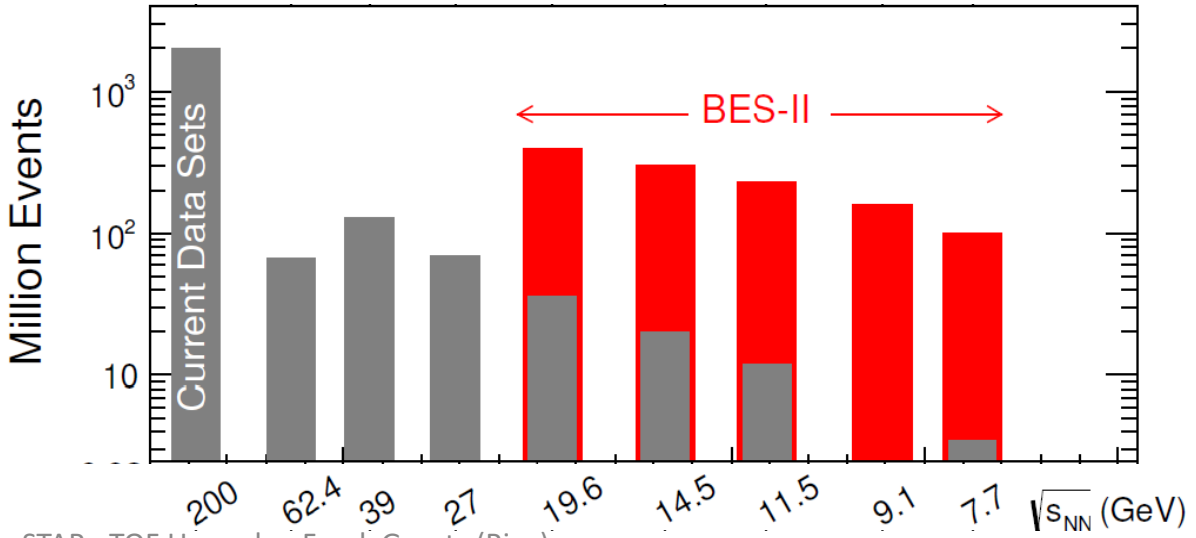
Collision Energy (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV) in 0-5% central collisions	420	370	315	260	205
Observables					
R_{CP} up to p_T = 5 GeV/c	–		160	125	92
Elliptic Flow (ϕ mesons)	100	150	200	200	400
Chiral Magnetic Effect	50	50	50	50	50
Directed Flow (protons)	50	75	100	100	200
Azimuthal Femtoscopy (protons)	35	40	50	65	80
Net-Proton Kurtosis	80	100	120	200	400
Dileptons	100	160	230	300	400
Required Number of Events	**100**	**160**	**230**	**300**	**400**

Strong endorsement by NSAC

Long Range Plan 2015:

- *"Trends and features in BES-I data provide compelling motivation for […] experimental measurements with higher statistical precision from BES-II"*

http://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf



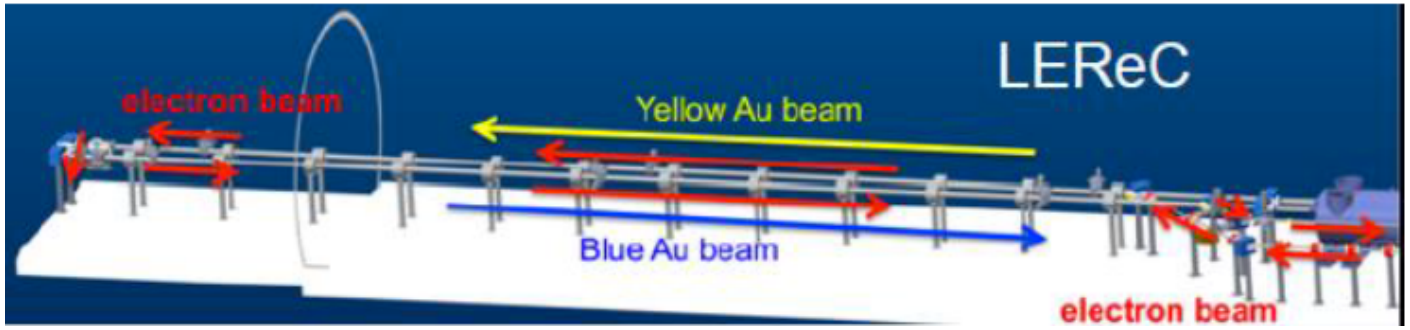
Low Energy RHIC Electron Cooling

BES-II planned for two 24 cryo-weeks in 2019 and 2020

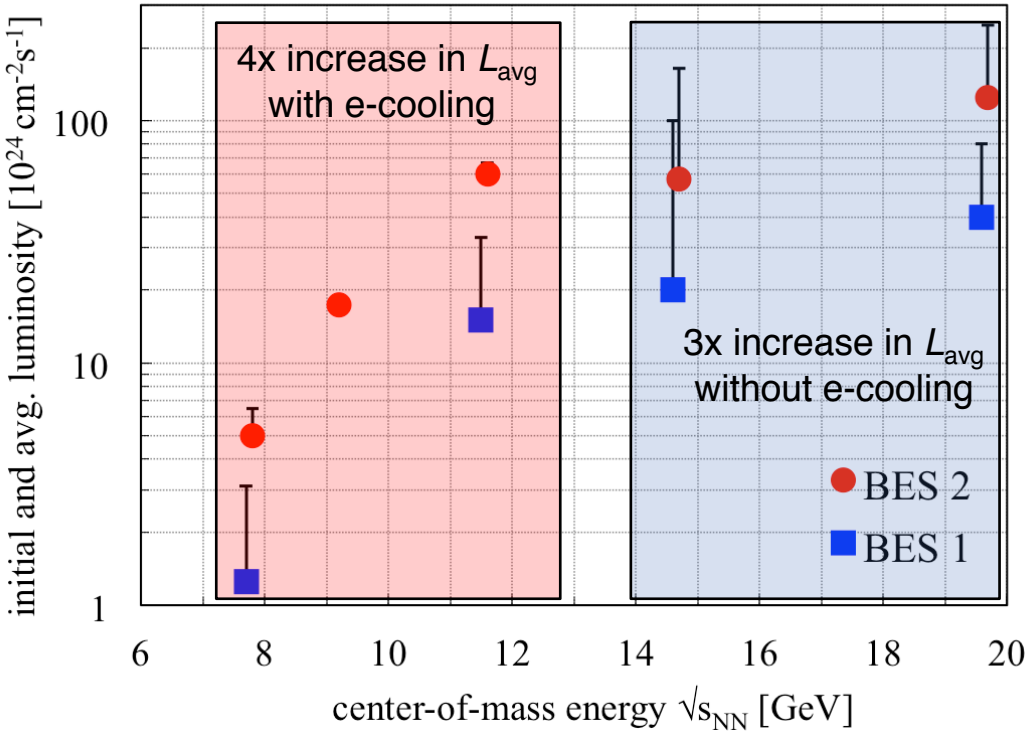
Improve luminosity for low energy beams:

- 2019 (w/o e-cooling): 3× for $\sqrt{s_{NN}}$=14.5 and 19.6 GeV
- 2020 (with e-cooling): 4× for $\sqrt{s_{NN}}$=7.7, 9.1, and 11.5 GeV

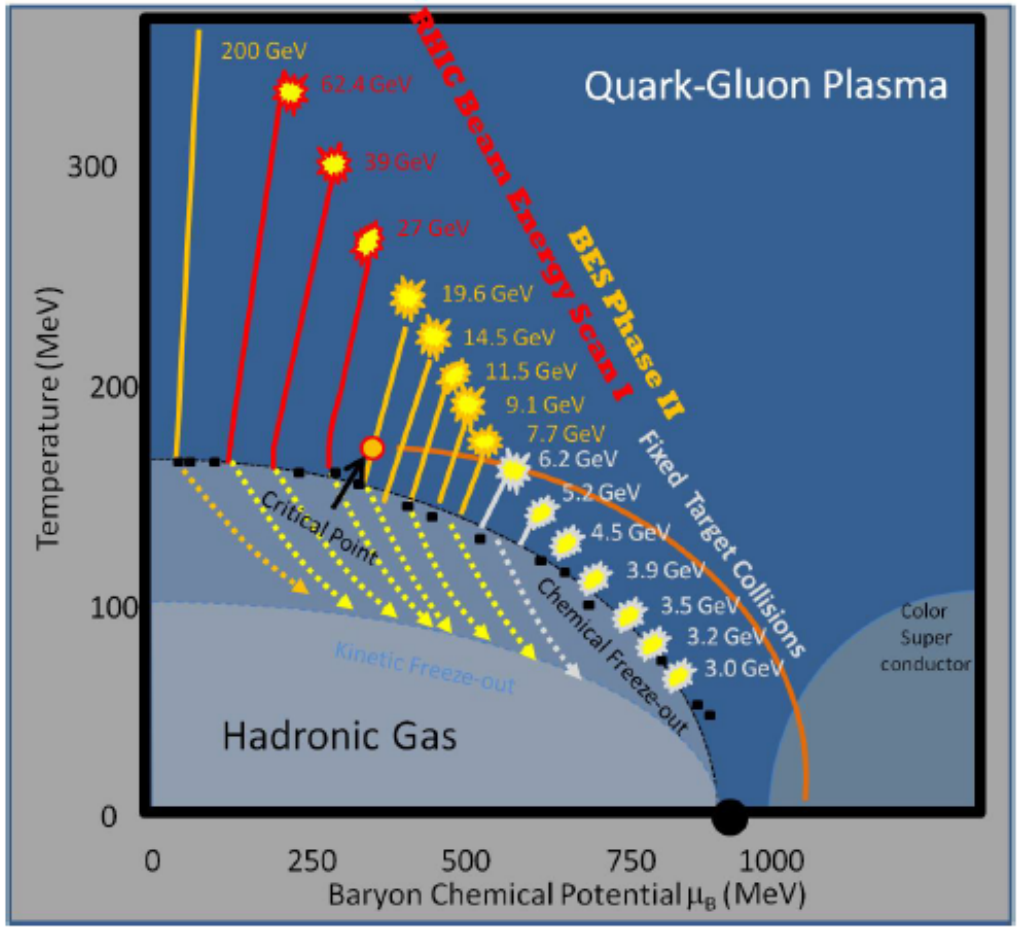
➢ *e*-Cooling: a critical machine upgrade



Increased luminosity



BES II Fixed Target Mode



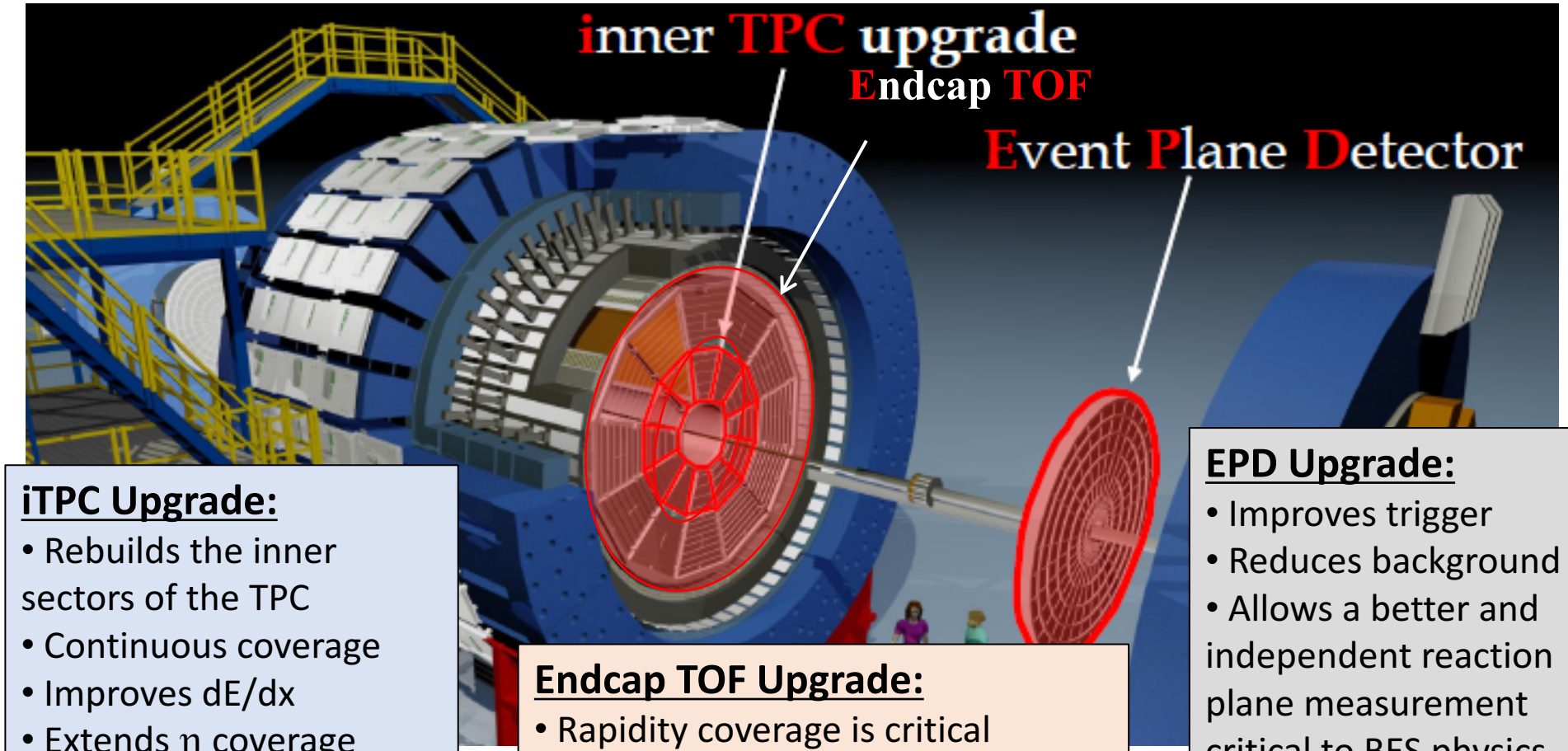
Proposal to extend CMS energy range from 7.7 down to 3 GeV

➢ increase μ_B range from 420 MeV to 720MeV

Collider Energy	Fixed-Target Energy	Single beam AGeV	Center-of-mass Rapidity	μ_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

The STAR Upgrades and BES Phase II

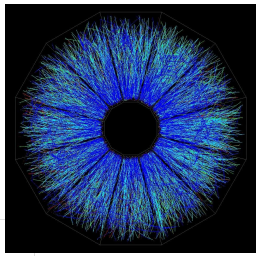


iTPC Upgrade:
- Rebuilds the inner sectors of the TPC
- Continuous coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut-off from 125 MeV/c to 60 MeV/c

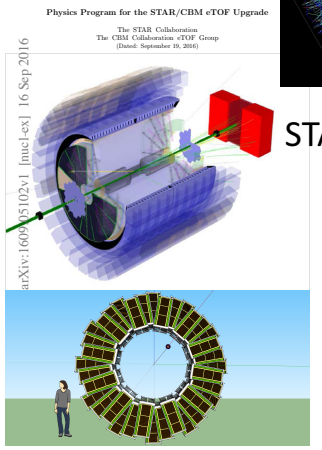
Endcap TOF Upgrade:
- Rapidity coverage is critical
- PID at η = 1.1 to 1.5
- Improves the fixed target program
- Provided by CBM at FAIR

EPD Upgrade:
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

A Proposal for STAR Inner TPC Sector Upgrade (iTPC)
The STAR Collaboration
June 9th, 2015



STAR Note 619



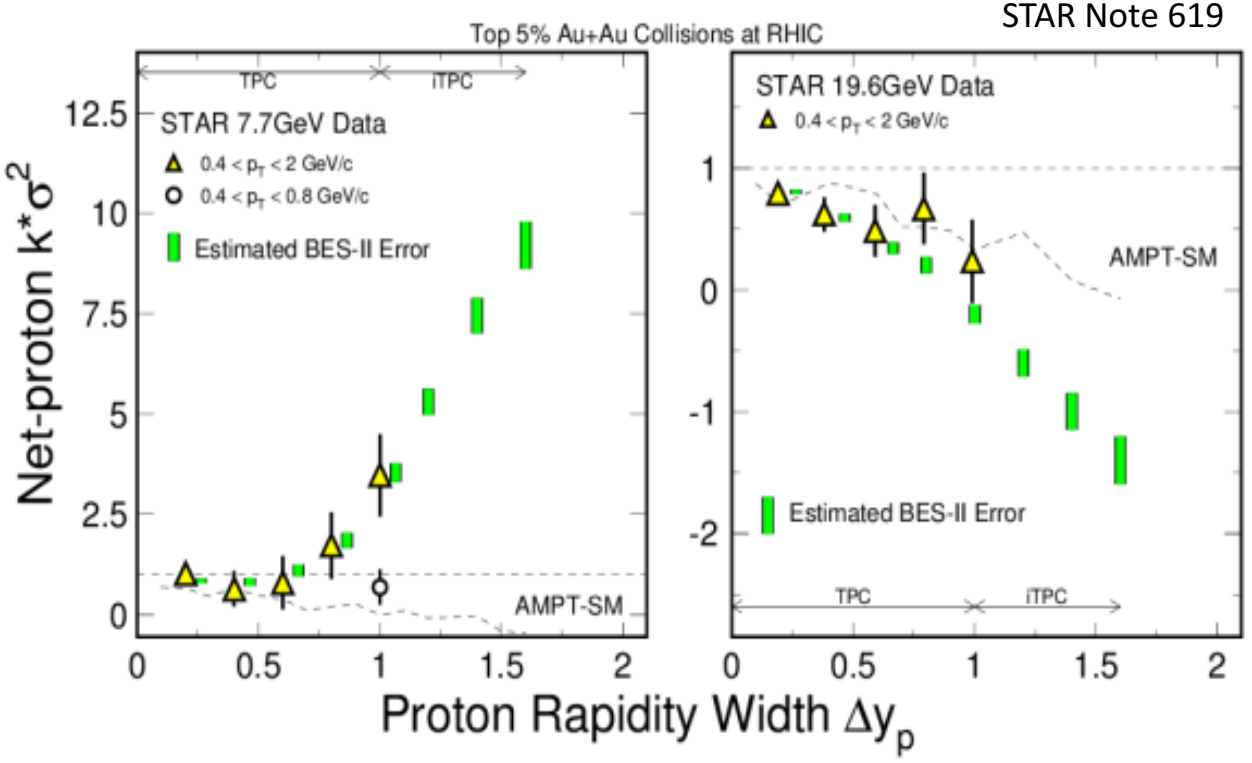
arXiv:1609.05102v1

iTPC Impact on Net-Proton Kurtosis

- Kurtosis represents fluctuations of the distributions
  - $K\sigma^2$ related to ratios of cumulants (C_4/C_2) which are expected to reflect divergence of susceptibilities (χ) and correlation lengths (ξ)

- Measure multiplicity distributions of net-protons in a larger rapidity range
  - ➢ reach the necessary rapidity width of the correlation

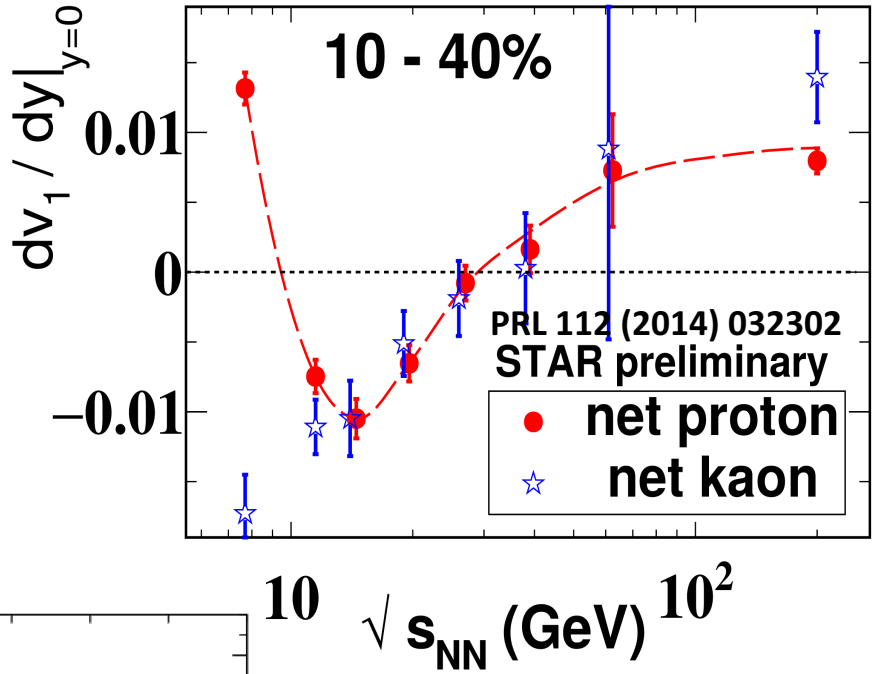
STAR Note 619



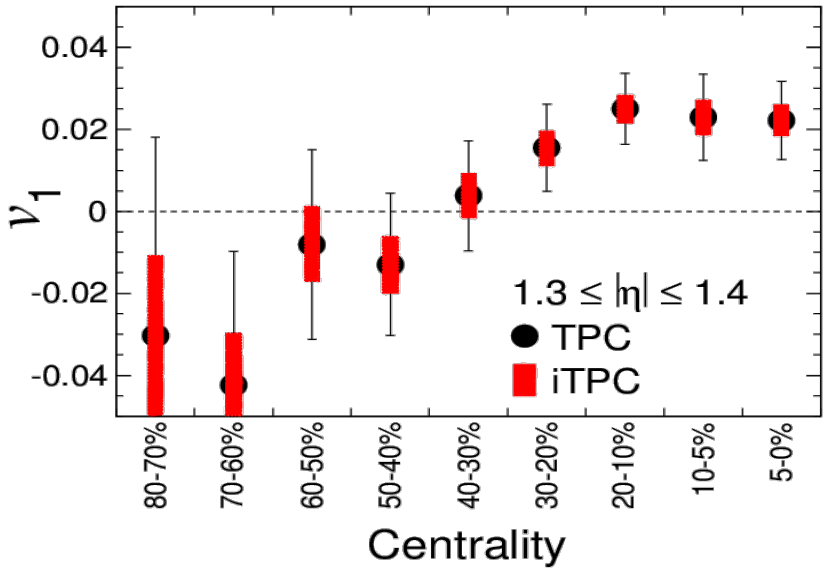
➢ Ling & Stephanov (PRC 93 (2016) 034915) : *"extension of rapidity coverage […] should significantly increase the magnitude of the critical point fluctuation signatures"*

BES-II Directed Flow Measurements

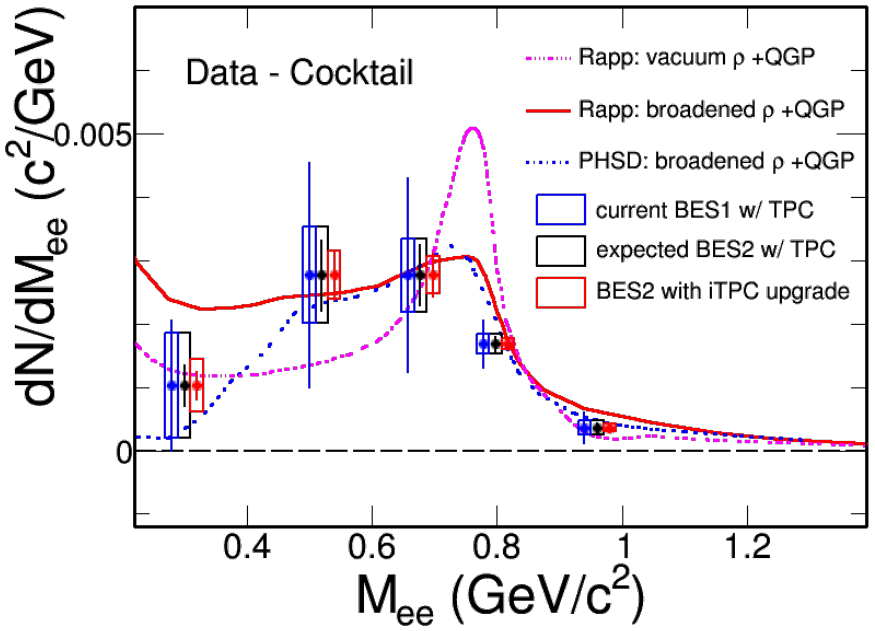
- Minimum in net-proton v_1 slope
  - interplay between baryon stopping and soft EOS
  - ➢ BES-II: improved event-plane resolution from EPD

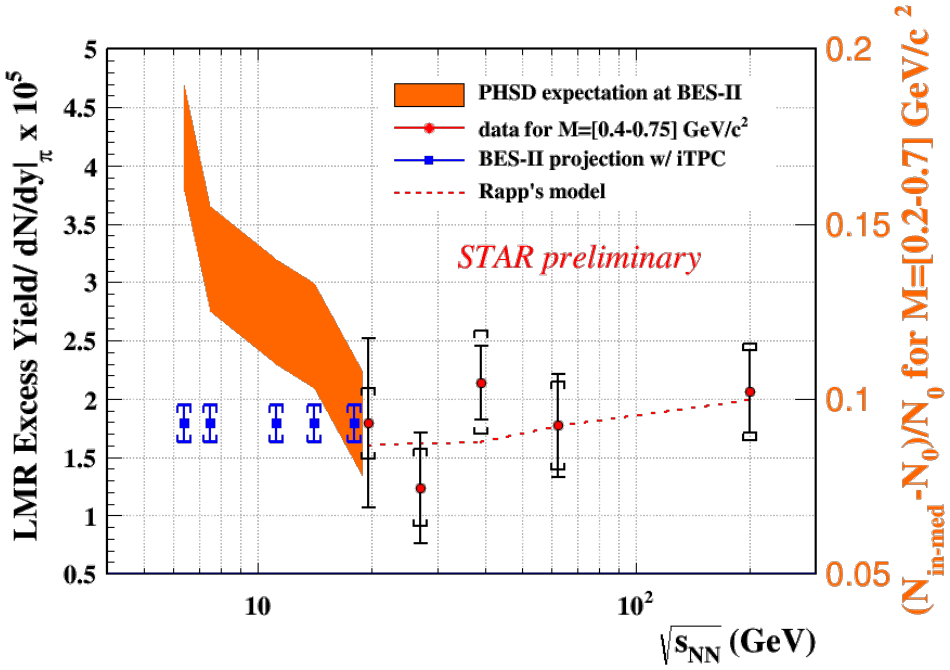


- Forward v_1 measurements as a function of centrality
  - ➢ BES-II: improvements due to extended iTPC coverage



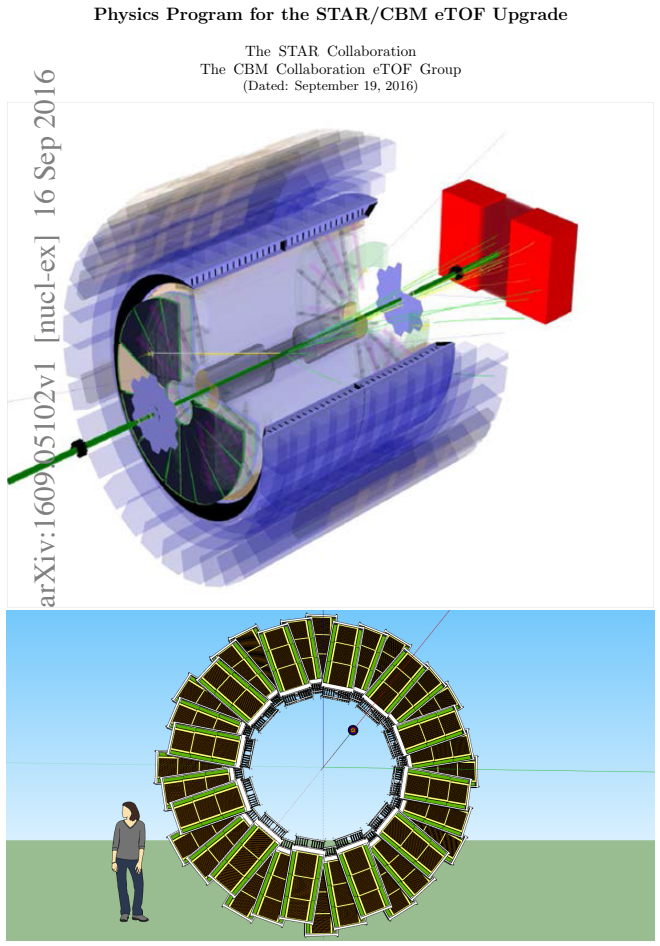
BES-II Dielectron Measurements





- Systematically study dielectron continuum from $\sqrt{s_{NN}}$ = 7.7 – 19.6 GeV
  - ➢ BES-II: iTPC upgrade: reduce systematic *and* statistical uncertainties
- Distinguish models with different ρ-meson broadening mechanisms
  - Rapp's model *vs.* PHSD
  - ➢ BES-II: Study the total baryon density effect on LMR excess yield in BES-II

The STAR eTOF Upgrade



arXiv:1609.05102v1

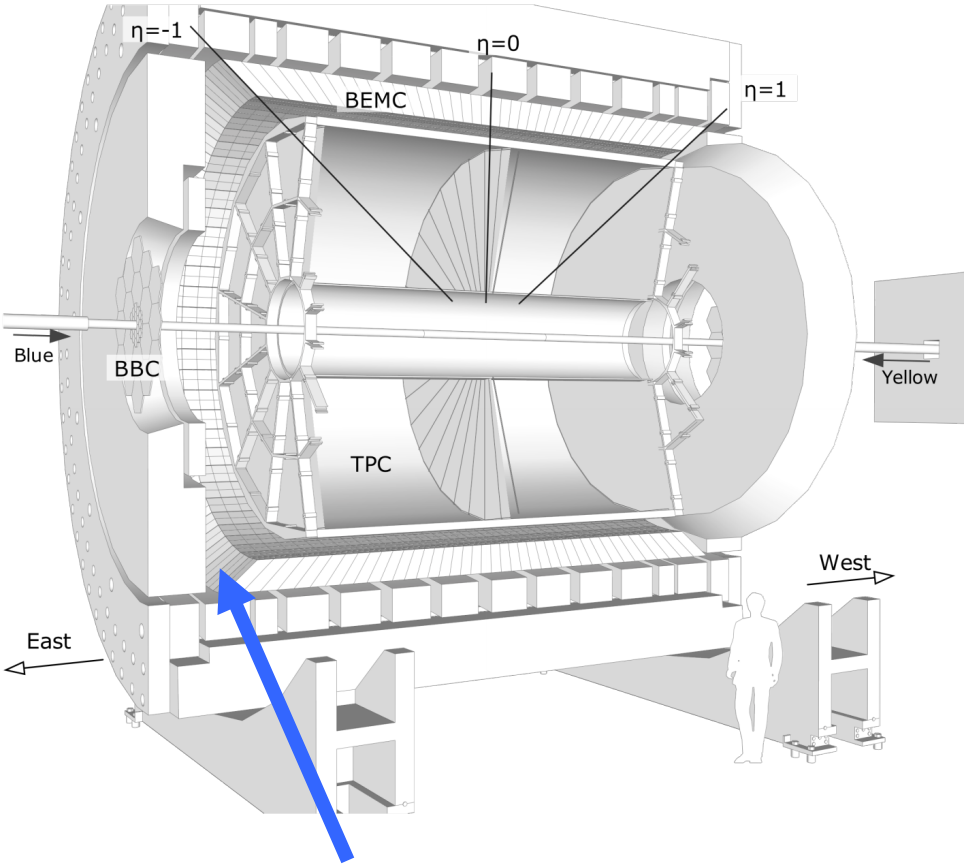
- Proposal by STAR Collaboration and several CBM institutions

  CBM: Heidelberg, Darmstadt, CCNU, Tsinghua, USTC

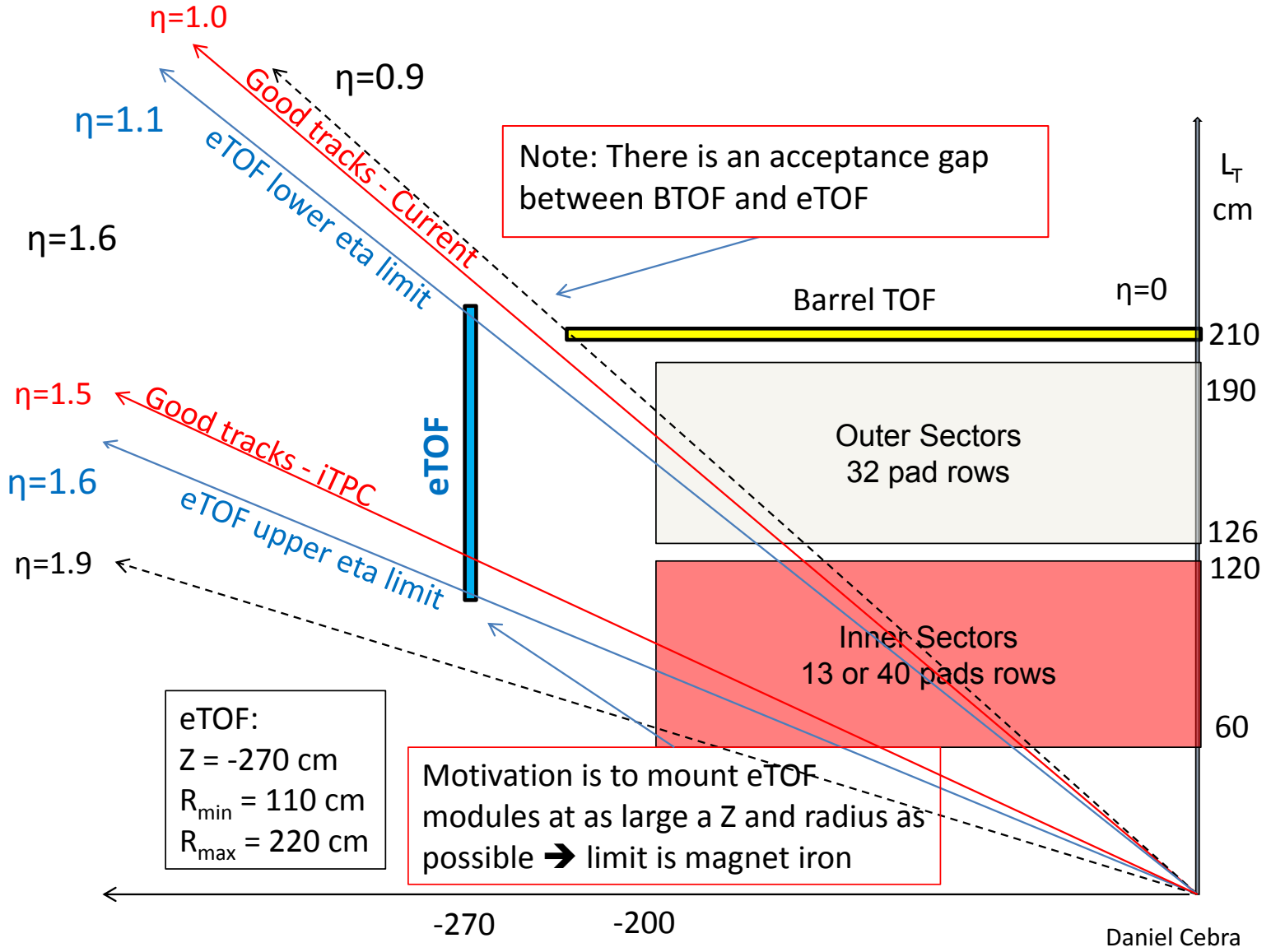
  - extend STAR's particle ID capabilities for π, K, p
    - complement the improved reach of the iTPC to η≈1.5 (0.9 if no eTOF)
  - essential for mid-rapidity PID in Fixed-Target mode
    - for $\sqrt{s_{NN}}$= 4.5 – 7.7 GeV

- eTOF upgrade allows for a complete and "gap free" scan in combined fixed-target & collider program of BES-II
  - covering $\sqrt{s_{NN}}$ = 3.0 – 7.7 GeV

TOF Acceptance Considerations



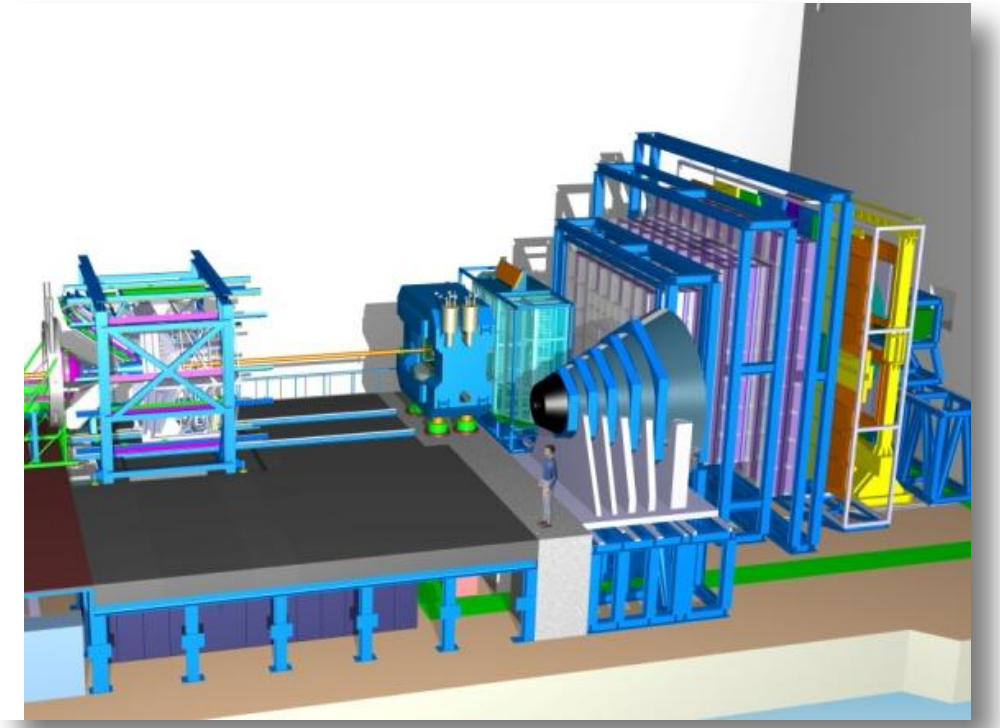
space for
endcap TOF modules

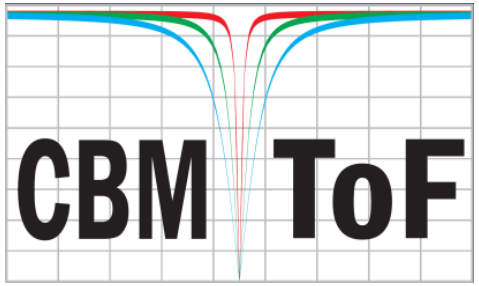


Opportunities: FAIR Phase 0 and CBM TOF

FAIR at GSI is delayed and CBM plans to embed some prototype subsystems into running experiments

- FAIR Phase 0
  - commissioning of detectors under real experimental conditions
  - train teams
  - physics measurements!



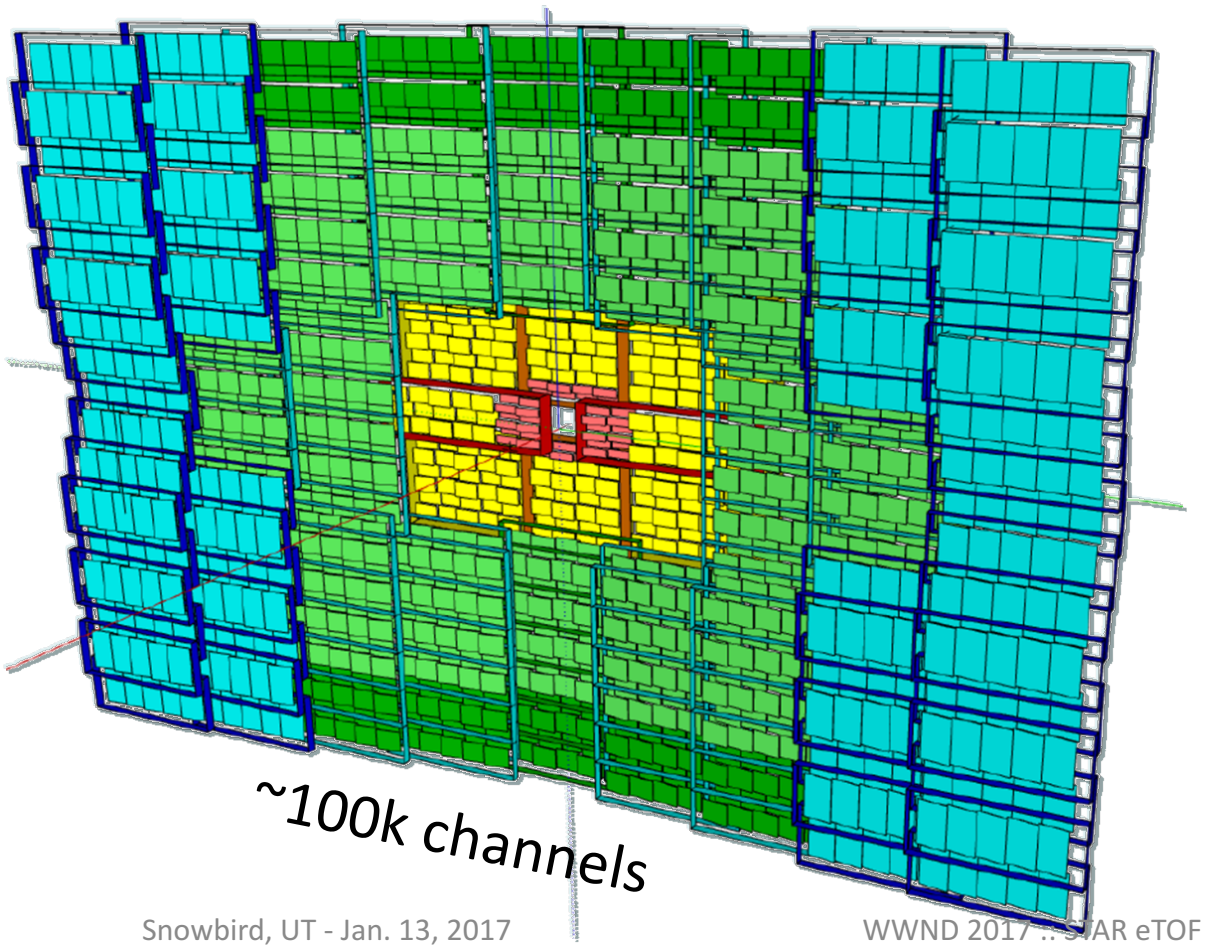


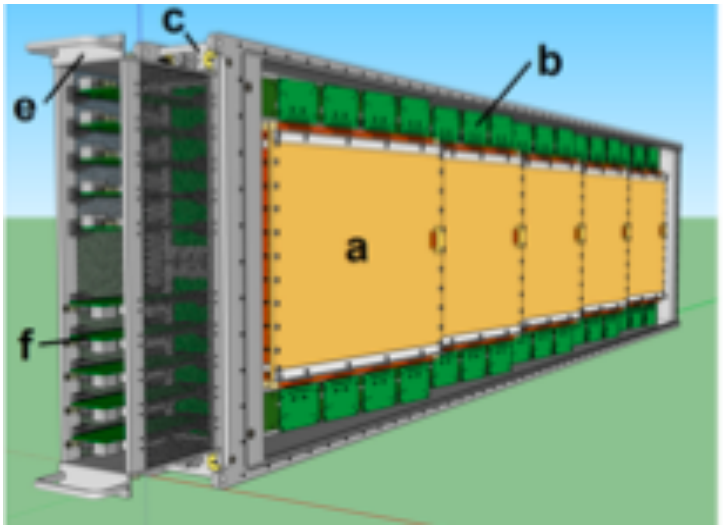
TOF: ***in STAR experiment at RHIC/BNL***
RICH: *in HADES experiment at SIS-18/GSI*
STS: *in BM@N experiment at Nuclotron/JINR*
DAQ/FLES: *in mCBM set-up at SIS-18 (MVD,STS,TRD,TOF)*

➢ STAR eTOF is part of FAIR Phase 0

CBM TOF Wall

12 x 9 m^2 - MRPCs designed for the light green area in the CBM wall slated for STAR use.

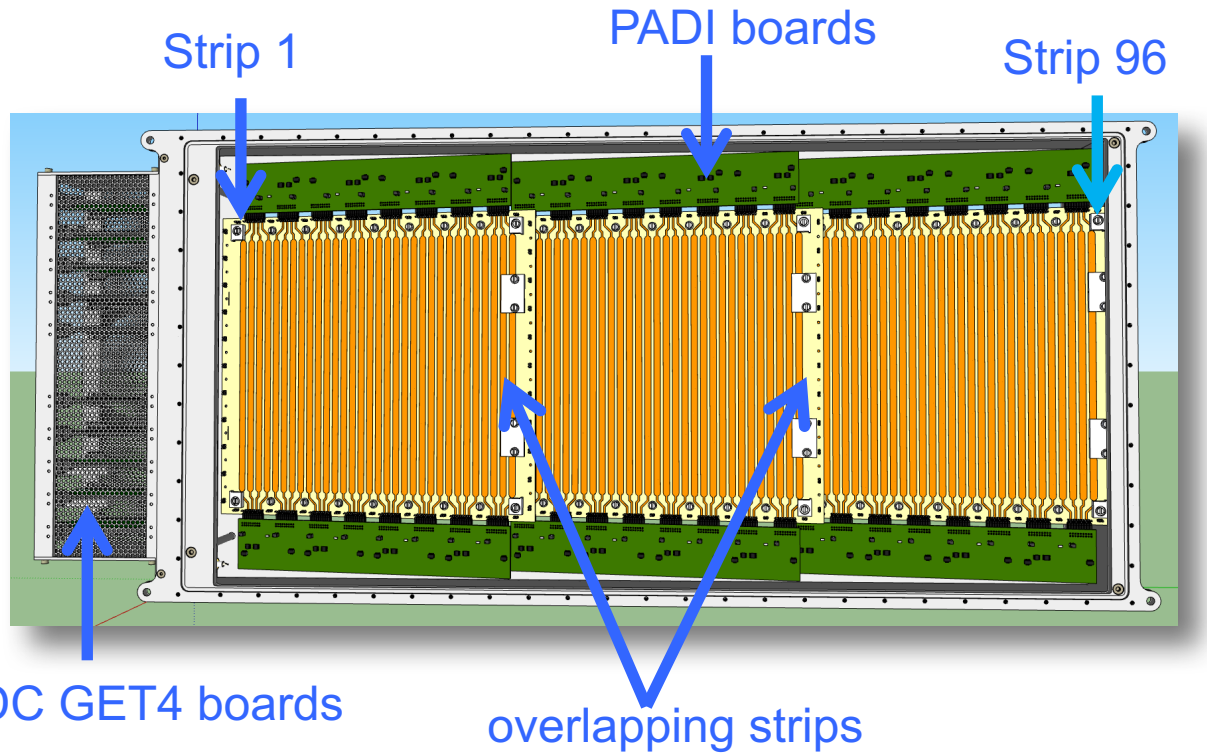




STAR modules based on CBM type M5

- M5 will be shortened for use in STAR

CBM TOF Module for STAR

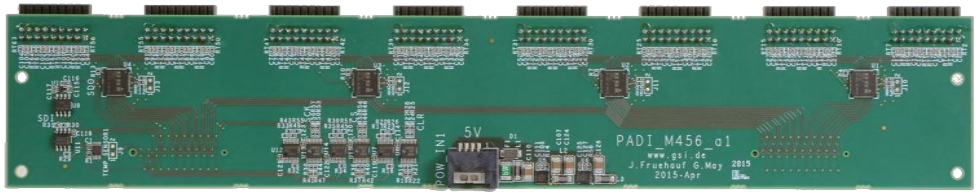


3 MRPCs

- 32 strips/MRPC with of pitch 1 cm
- 27 cm strip length
- active area about 92 cm x 27 cm
- 192 read-out channels

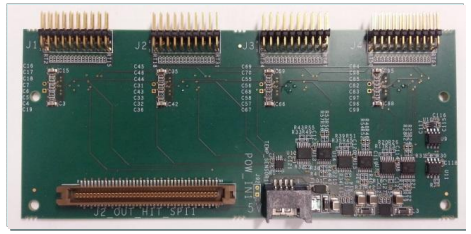
GET = GSI Event-driven TDC

PADI = PreAmplifier/DIscriminator



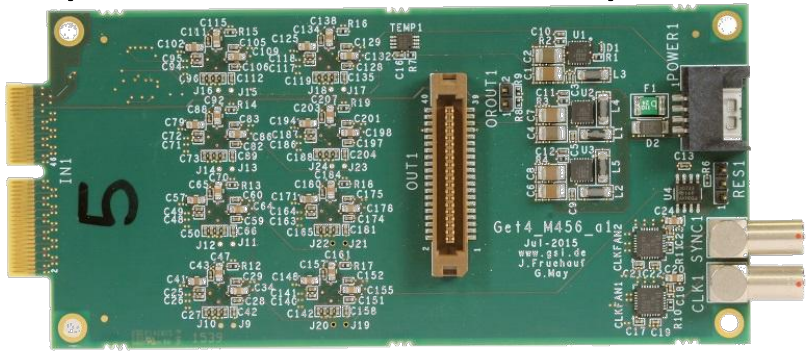
PADI FEE Outer Wall

FEE for STAR



PADI FEE Inner Wall

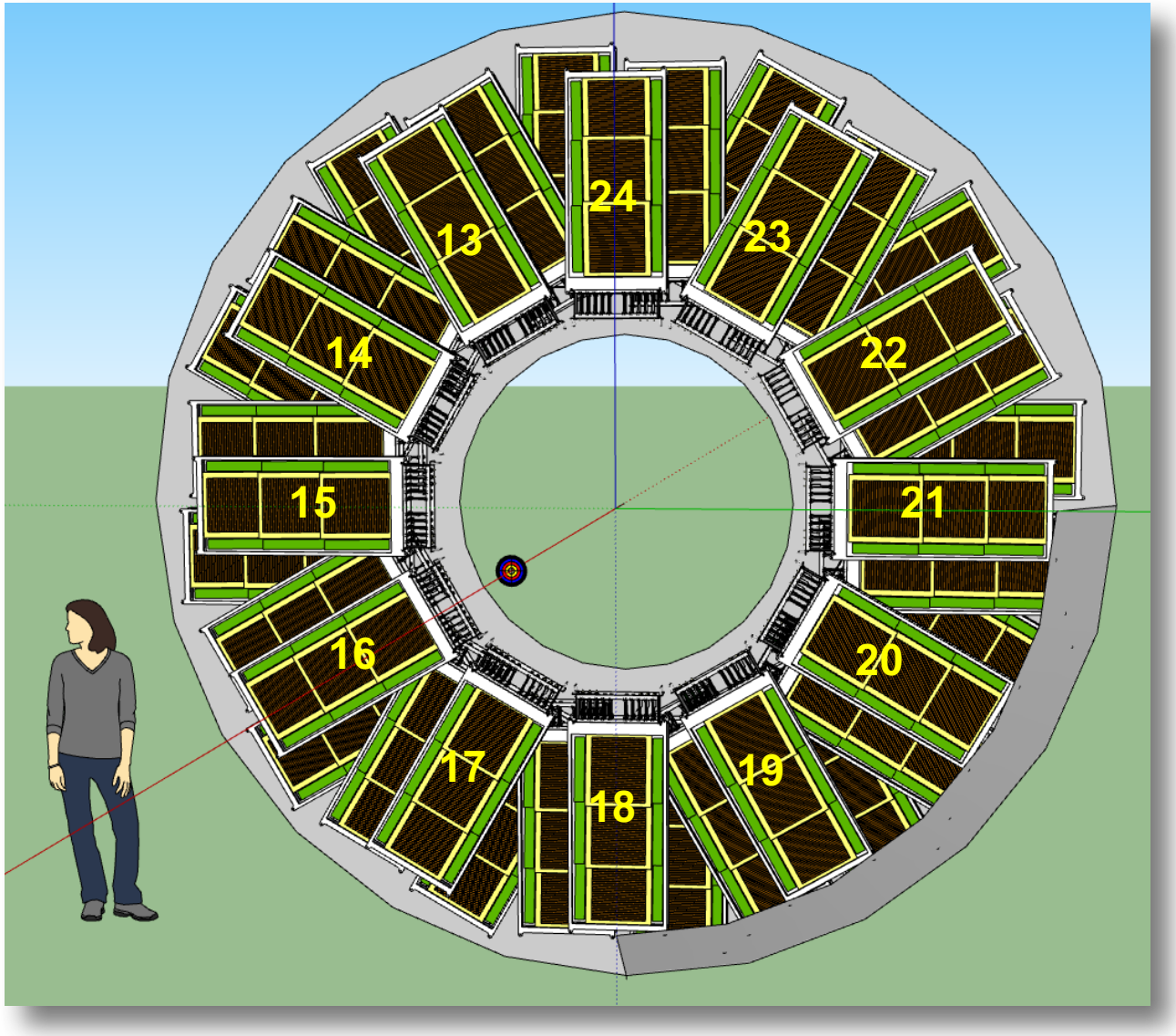
GET4 FEE for STAR
(backplane CLK/SYNC and power distr.)



GET4 FEE (Top View)

Frühauf (GSI) CBM Collaboration meeting (2016)

STAR eTOF “Wheel”

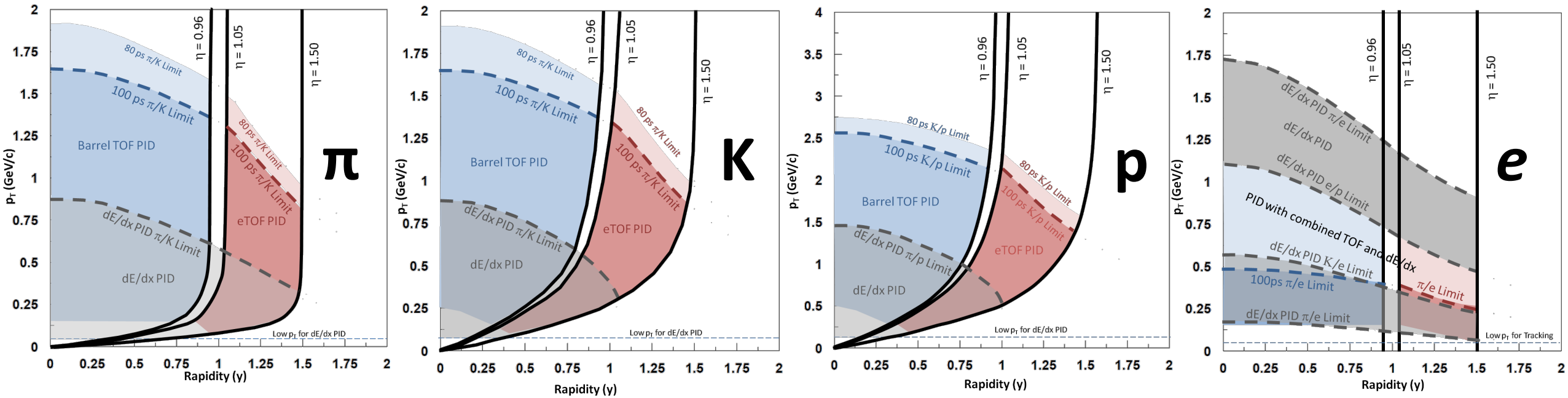


… in numbers:

- 36 modules (= 108 MRPCs)
  CBM TOF involves 1,376 MRPCs
- 3 layers
- 6,912 channels
  STARBTOF has 23,040 channels

Total depth ~36cm

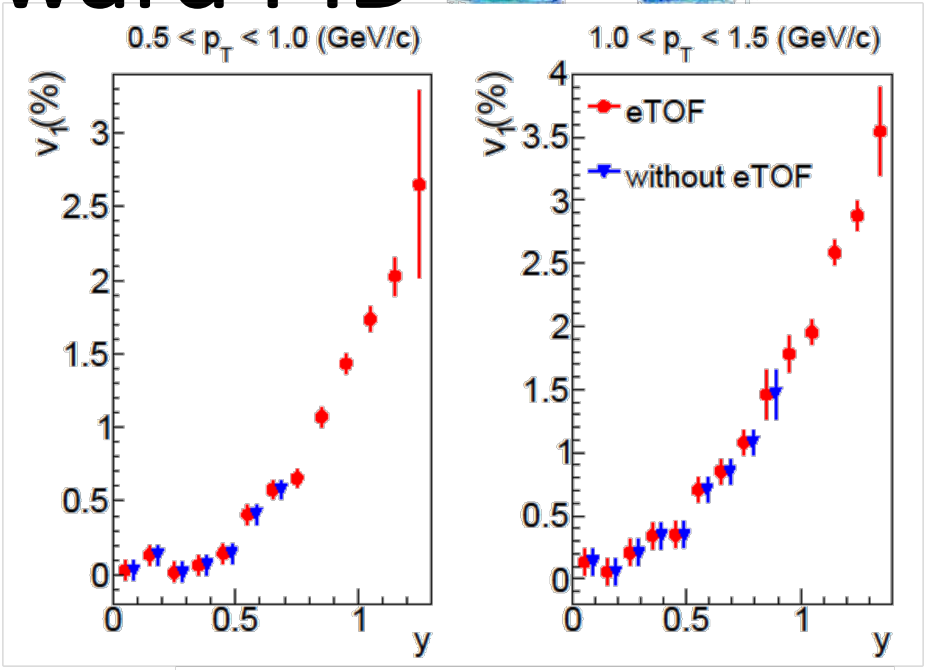
TOF Acceptance: PID in Collider Mode



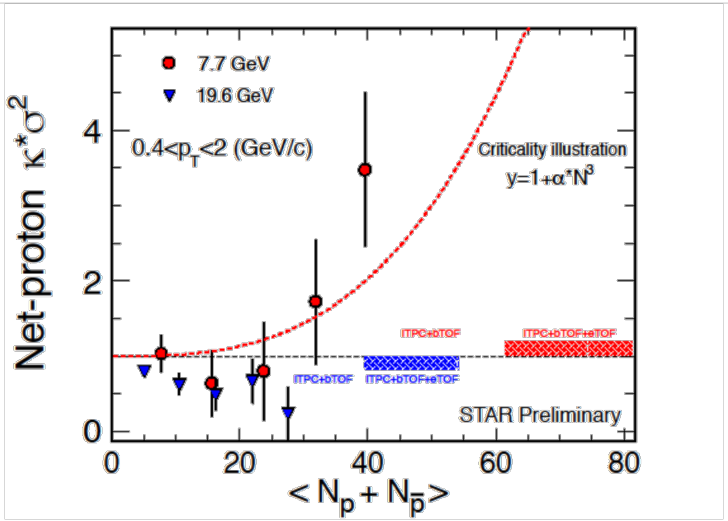
- Lower p_T limit – from track length of the TPC (multiple scattering);
  - for BTOF lower p_T limit from minimal track rigidity
- High p_T limit – from the TOF time resolution (σ_{TOF} = 100 and 80 ps ranges)

Physics Benefits from Enabling Forward PID

- Precision studies of y dependence of key bulk property observables
  - BES-II range characterized by partial stopping → wider rapidity interval helps disentangle dynamic from thermodynamic effects

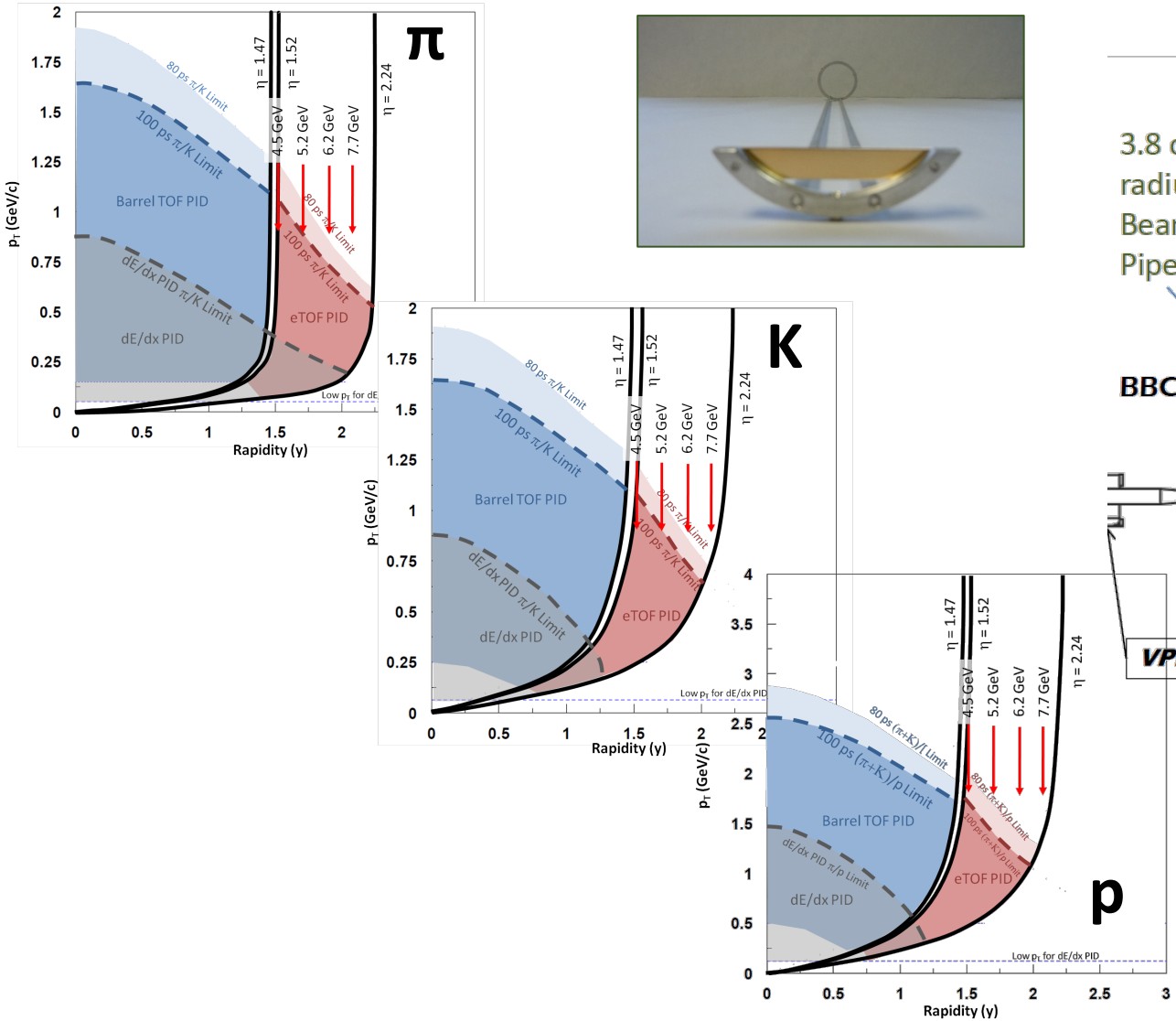


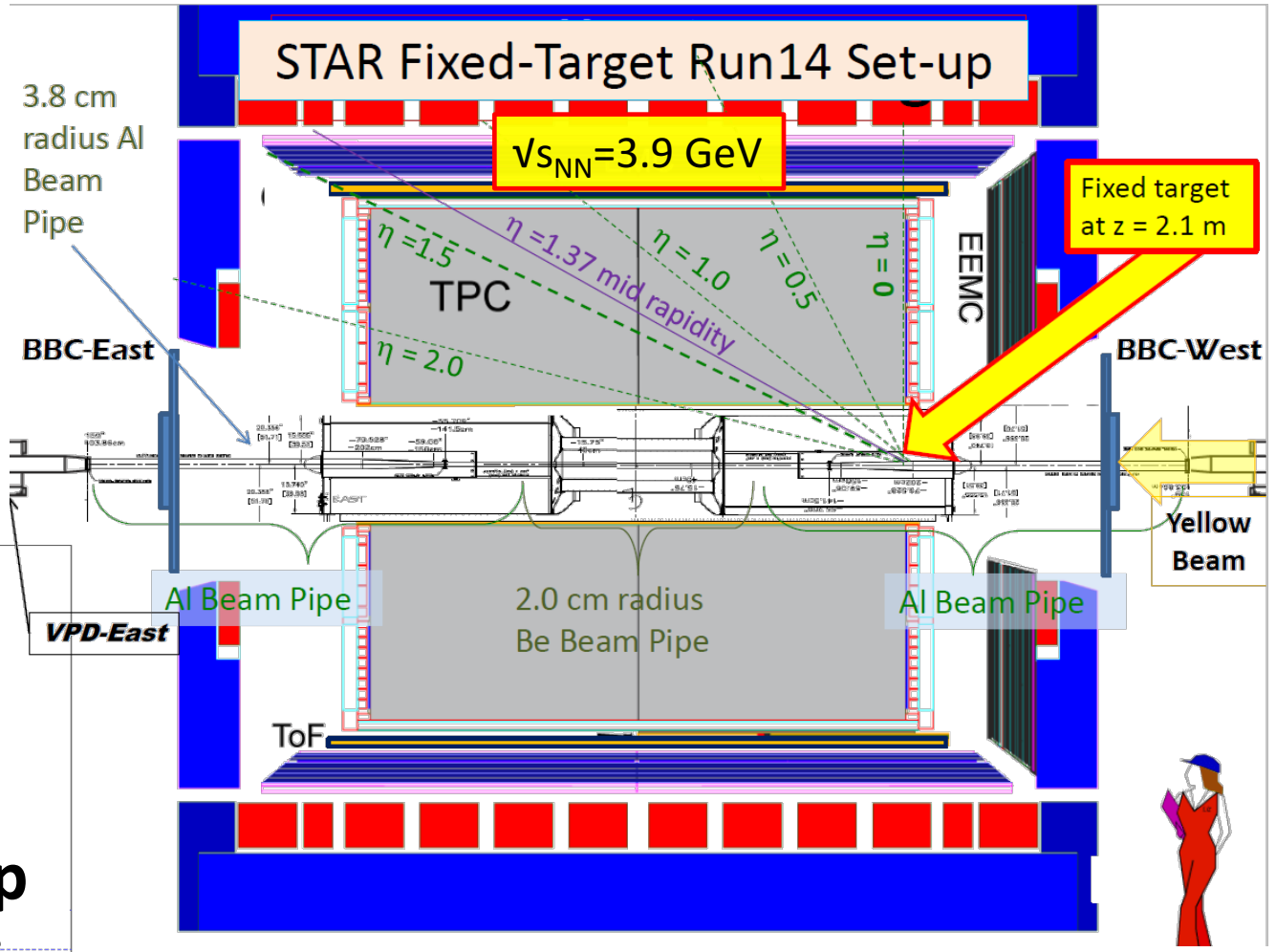
- **Dileptons**: forward measurements provide for independent observable to study LMR baryon-density dependence
  - quantifying the effect on the ρ meson broadening
- **Directed Flow**: extending PID to y=1.2 opens a new rapidity region that may help confirm EOS softening
- **Elliptic Flow**: y-dependent v_2
- **Fluctuations**: enhanced fluctuation signals are expected to provide a cleaner and more significant indication of critical behavior



TOF Acceptance: Fixed Target Mode

Fixed Target located at Z=+210cm (“west”)





Physics Goals of the FXT Program

Onset of Deconfinement

- High-p_T suppression
- NCQ scaling of elliptic flow
- LPV through 3-particle correlators
- Balance functions
- Strangeness enhancement

Compressibility →1st order phase transition

- Directed flow
- Volume and tilt angle of HBT source
- Width of pion rapidity distributions
- Zero-crossing of elliptic flow
- Volume measures from Coulomb potential

Criticality

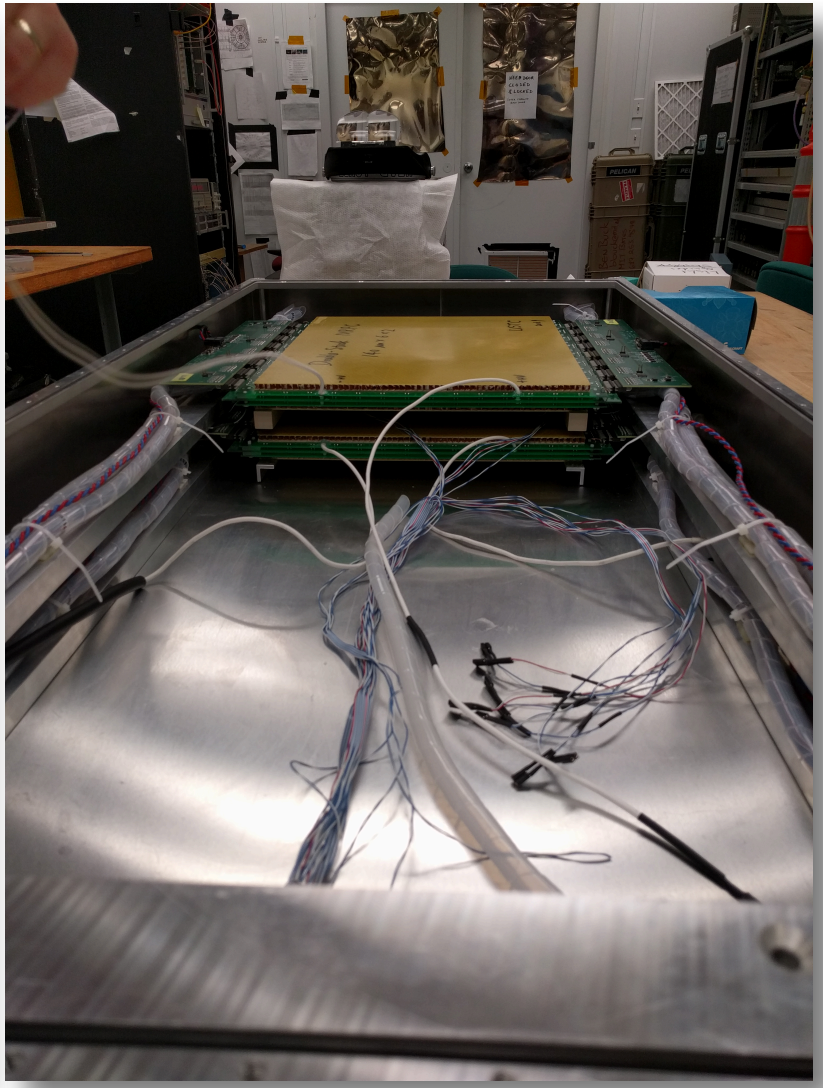
- Higher moments
- Particle ratio fluctuations

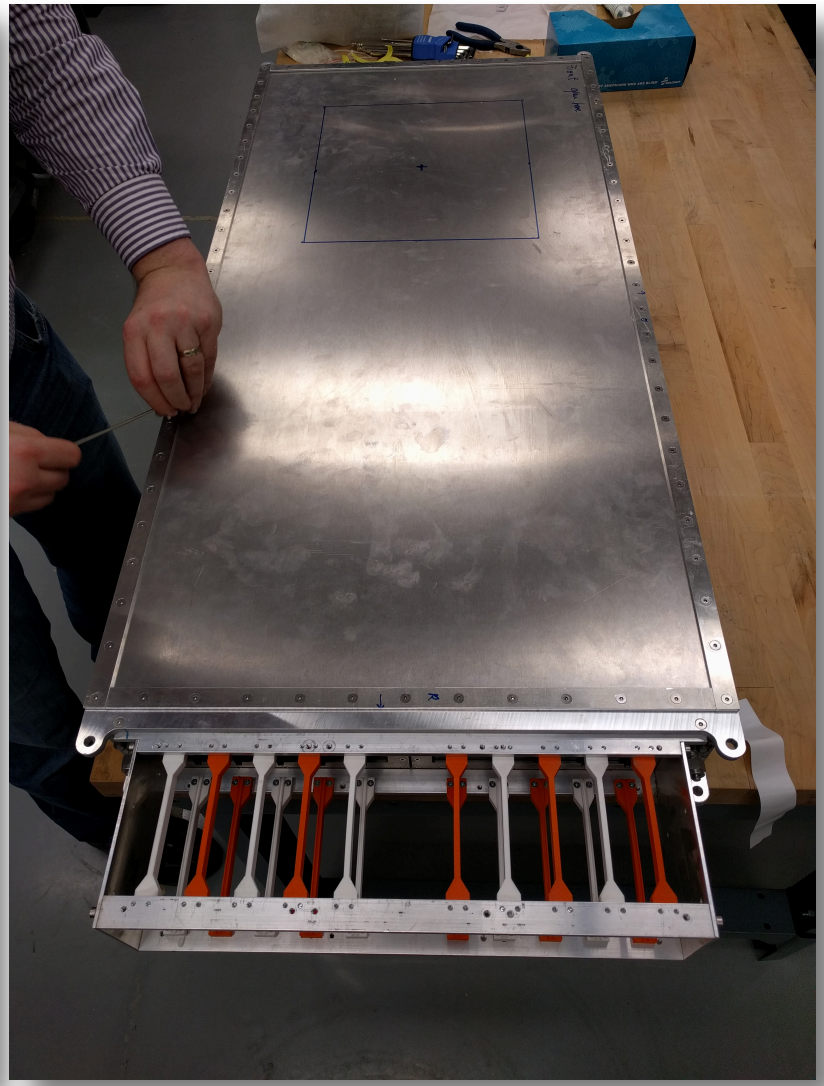
Chirality

- Dilepton studies

no measurements in this energy range

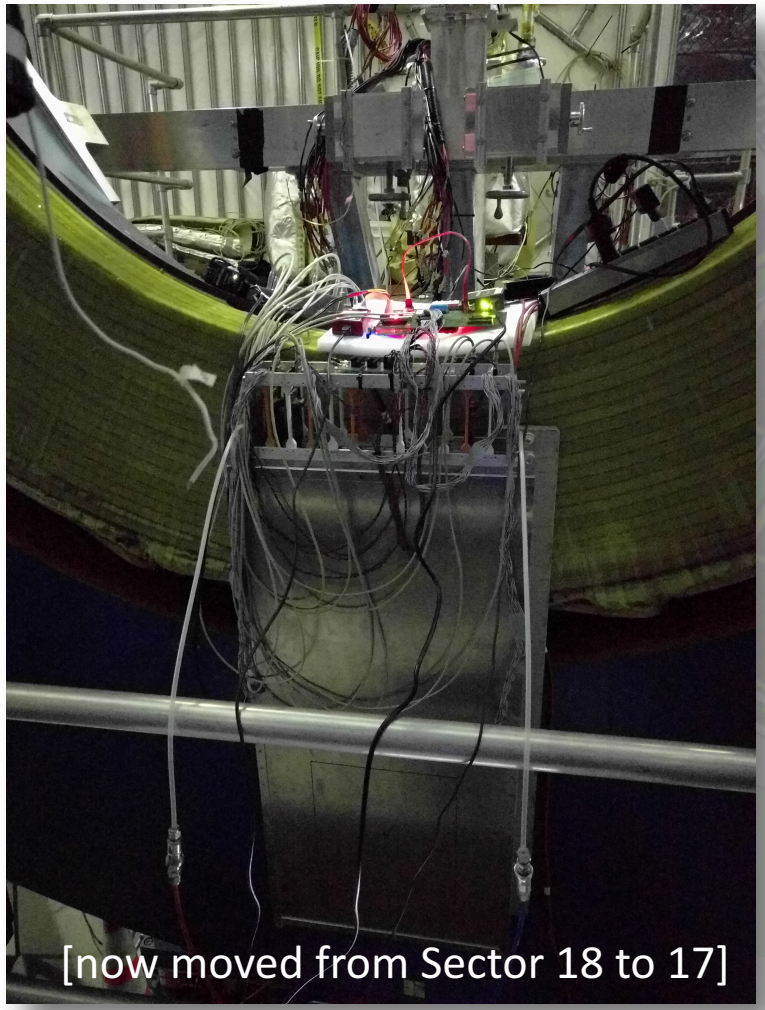
Run-17 Double-Stack Prototype

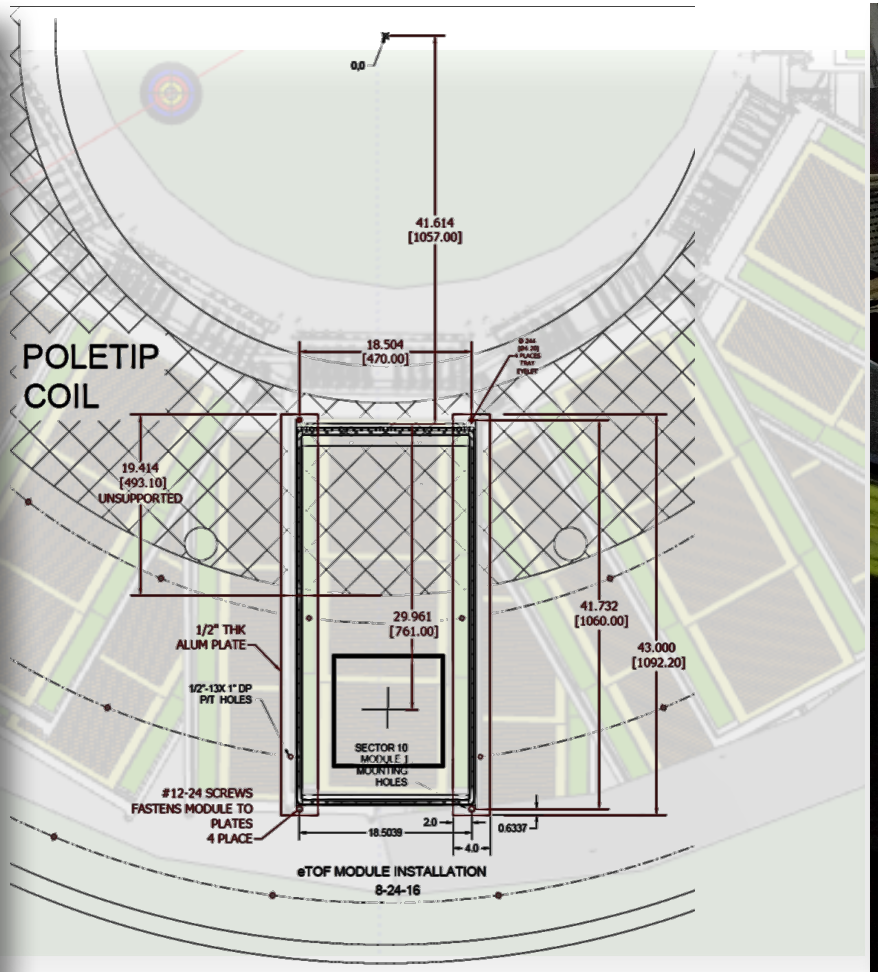


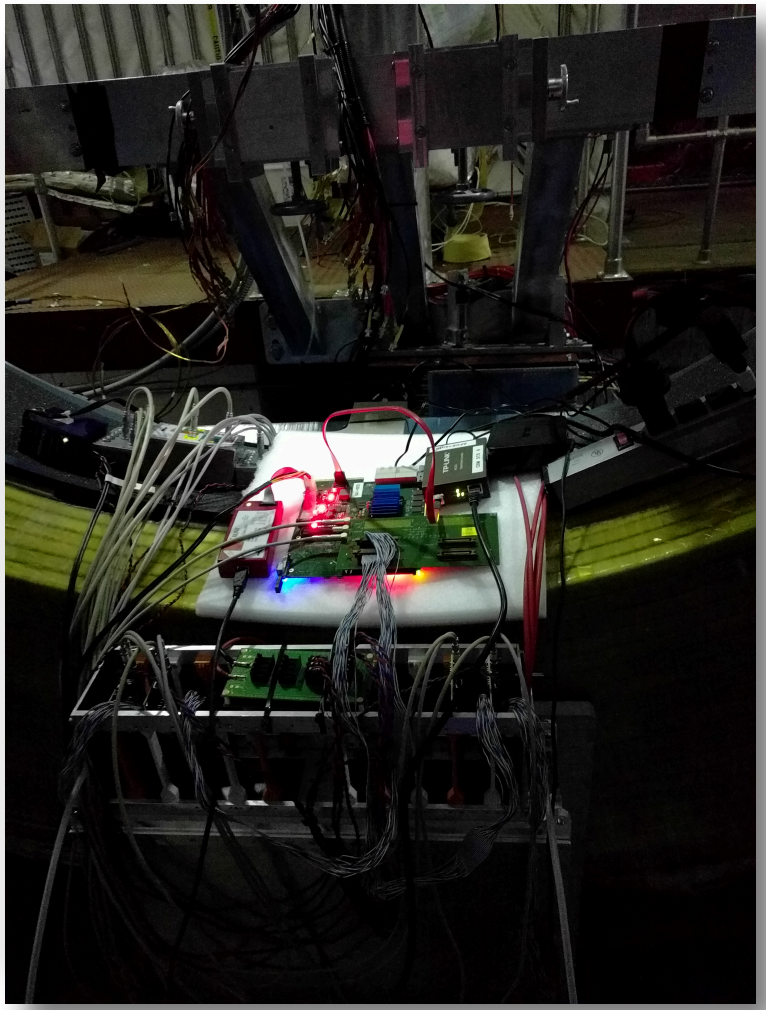


Courtesy David Tlusty

Run-17 Prototype Installation (Oct. 2016)







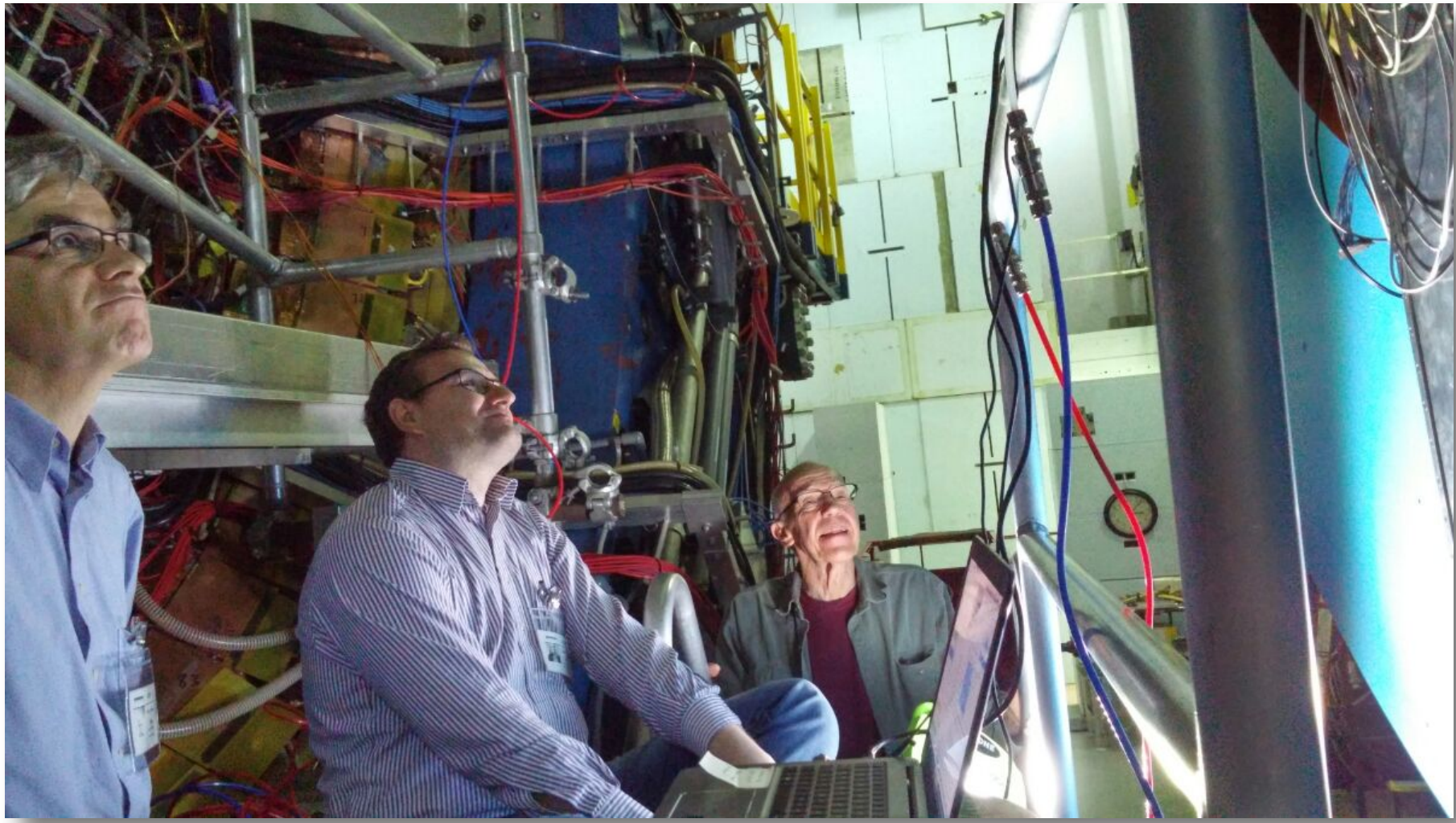
Courtesy David Tlusty

Successful Test ⇒ Happy People

October 2016:

First Test Program at STAR

(High Voltage Scan using cosmics)



Courtesy Zhangbu Xu

Left to right: Norbert Herrmann, Ingo Deppner, Geary Eppley

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 October 2016
  - readying for first integration test in the RHIC 2017 run
- Looking forward to successful installation ahead of BES Phase II !