# eTOF Scientific Topics Supported by NSFC

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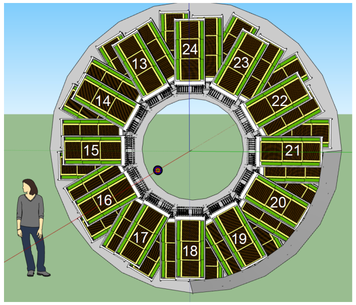


# NSFC International Cooperation Fund

N S F C
National Natural Science Foundation of China

- Funds for International Cooperation and Exchange of NSFC
  - Key International (Regional) Joint Research Project
  - International (Regional) Cooperation and Exchange Programs under Agreements/MOUs between NSFC and foreign partners
  - Research Fund for International Young Scientists

- Key International (Regional) Joint Research Project
  - ~ 100 projects funded per year, success rate ~ 17%
  - 2.5-3 M¥ + ~20% indirect costs, 5-years project, ~100 k$/year
  - Eligibility of Foreign Partners: Independent researchers in charge of research laboratories or key research projects abroad
  - STAR successes: *BTOF*, MTD, HLT, iTPC and eTOF
  - CBM success: TOF

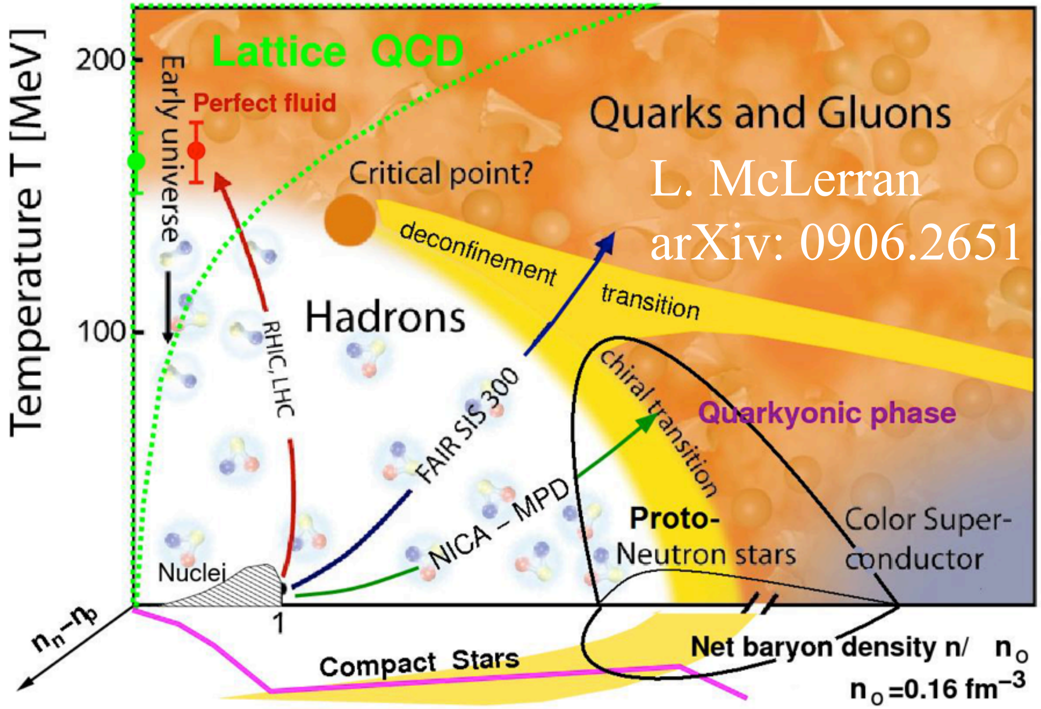
# The eTOF NSFC project

NSFC
National Natural Science Foundation of China

- Dec. 2016: Plan started (initially suggested by Prof. Feng Liu, supported by Zhangbu et al.)
- 3/15/2017: Proposal submitted to NSFC
- 6/8/2017: Passed 1st round review
- 7/7/2017: 2nd round (fact-to-face) review, 4 out 6 projects from the Department of Math. & Phys. Sciences of NSFC passed

- Title: Study of chiral phase transition and QGP properties during RHIC Beam Energy Scan II
- Period of the project: Jan. 2018 – Dec. 2022
- Chinese institutions: USTC and Shandong U.
- Contact of foreign partners: Frank Geurts
- Supported fund: 3M¥ (direct costs) + ~20% (indirect costs)

# Exploring the QCD Phase Diagram




**QCD at high baryonic density:**

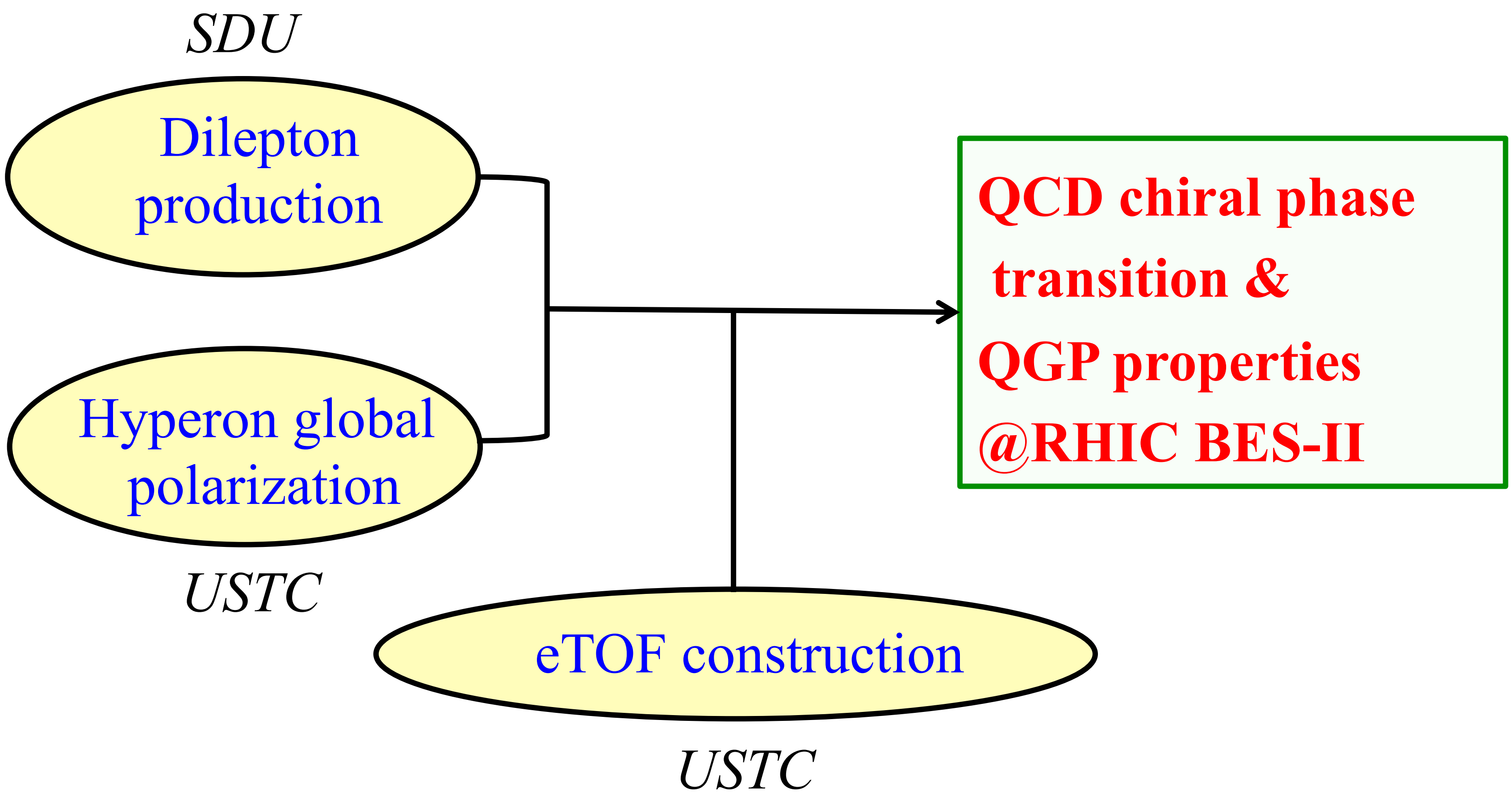
- Onset of QGP
- 1$^{st}$-order phase transition
- Search for Critical Point
- Chiral phase transition
- …

- Collectivity
- Criticality
- Chirality

**LHC and RHIC top energy:**

- Properties of QGP
- *Partonic flow, parton energy loss …*
- *Charm thermalization, quarkonium melting …*

# The eTOF NSFC project



# RHIC-STAR BES II

- BES I measurements important but limited by statistics
- BES II will significantly improved statistics thanks to accelerator and detector upgrades
- The fixed-target program will extend $\mu_B$ coverage to ~720 MeV
- 3 Major detector upgrades (iTPC, EPD, eTOF)

*iTPC: Part. supported by NSFC*
*EPD: Part. supported by CMoST*
*eTOF: Part. supported by CMoST & NSFC*

| Collider Energy | Fixed-Target Energy | Single-beam AGeV | 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 |
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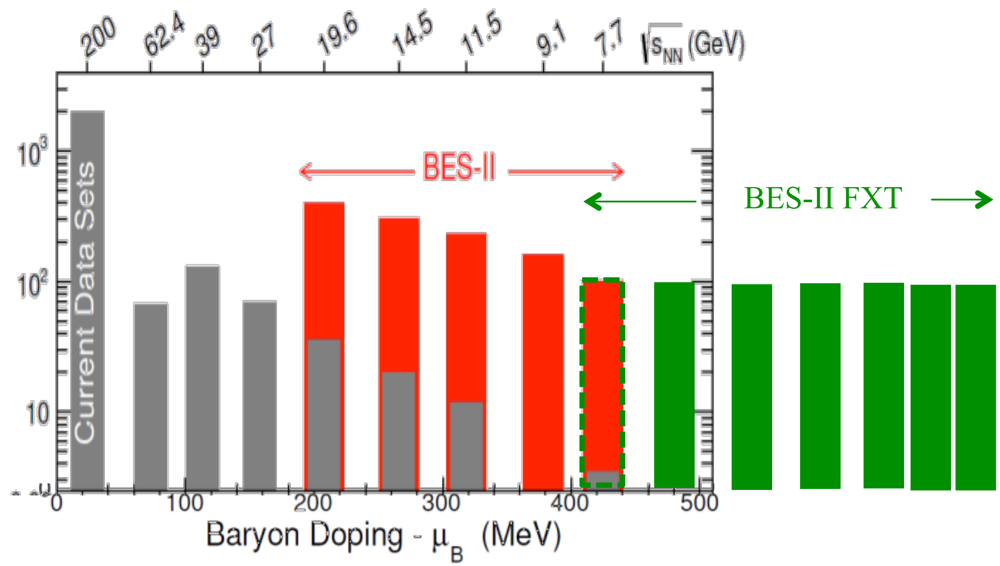
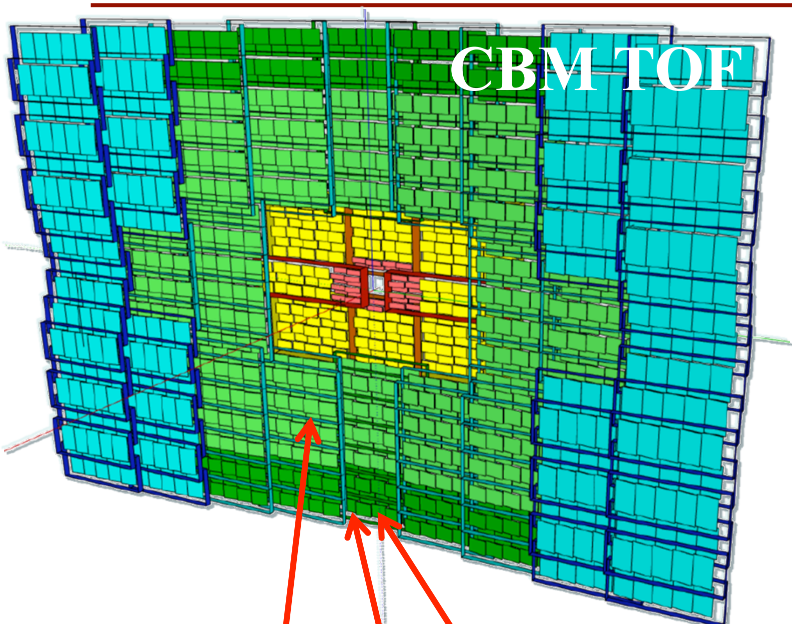


# RHIC-STAR run schedule

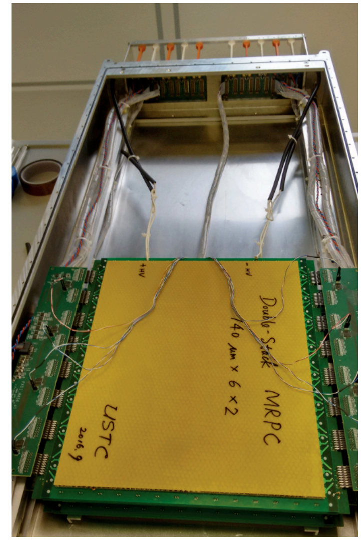
| Run Year | Collision System and Energy | Physics/ Observables | Detector in operation |
|---|---|---|---|
| **2017** | p+p @ 500 GeV | Spin | ***EPD (1/8th)*** ***eTOF prototype*** |
| **2018** | Zr+Zr, Ru+Ru @ 200 GeV<br>Au+Au @ 27 GeV | Dilepton, CME<br>CVE | ***Full EPD*** ***iTPC prototype*** ***eTOF prototype*** |
| **2019** | Au+Au @ 14.5-20 GeV<br>Fixed target | QCD critical point<br>$1^{st}$ phase transition<br>CVE, CME… | ***Full iTPC*** ***Full eTOF*** ***Full EPD*** |
| **2020** | Au+Au @ 7-11 GeV<br>Fixed target | QCD critical point<br>$1^{st}$–order phase transition<br>CVE, CME… | |
| **2020+** | p+Au, p+p, Au+Au @ 200 GeV | Drell-Yan<br>Longitudinal correlations | ***FTS*** ***FCS*** |

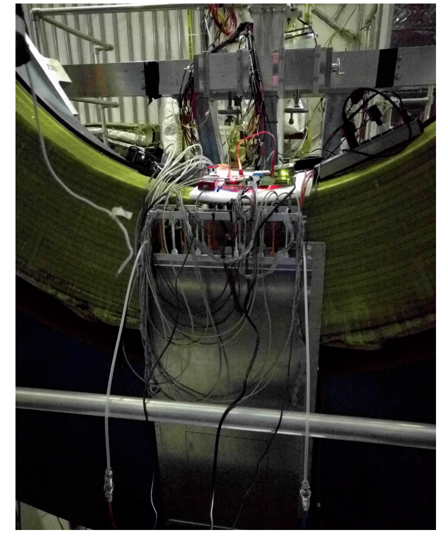
# CBM/STAR eTOF




MRPC 3a

MRPC 3b



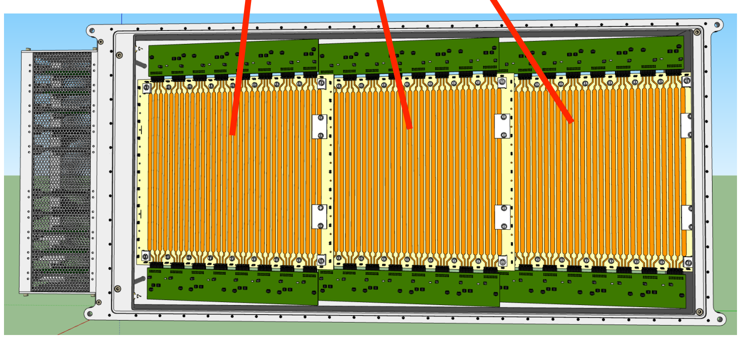


eTOF prototype with MRPC 3b installed to STAR in 2017

USTC:

- Final tuning of MRPC 3b design
- MRPC3b mass production for STAR
- Calibration and performance study

A PhD student sent to Heidelberg



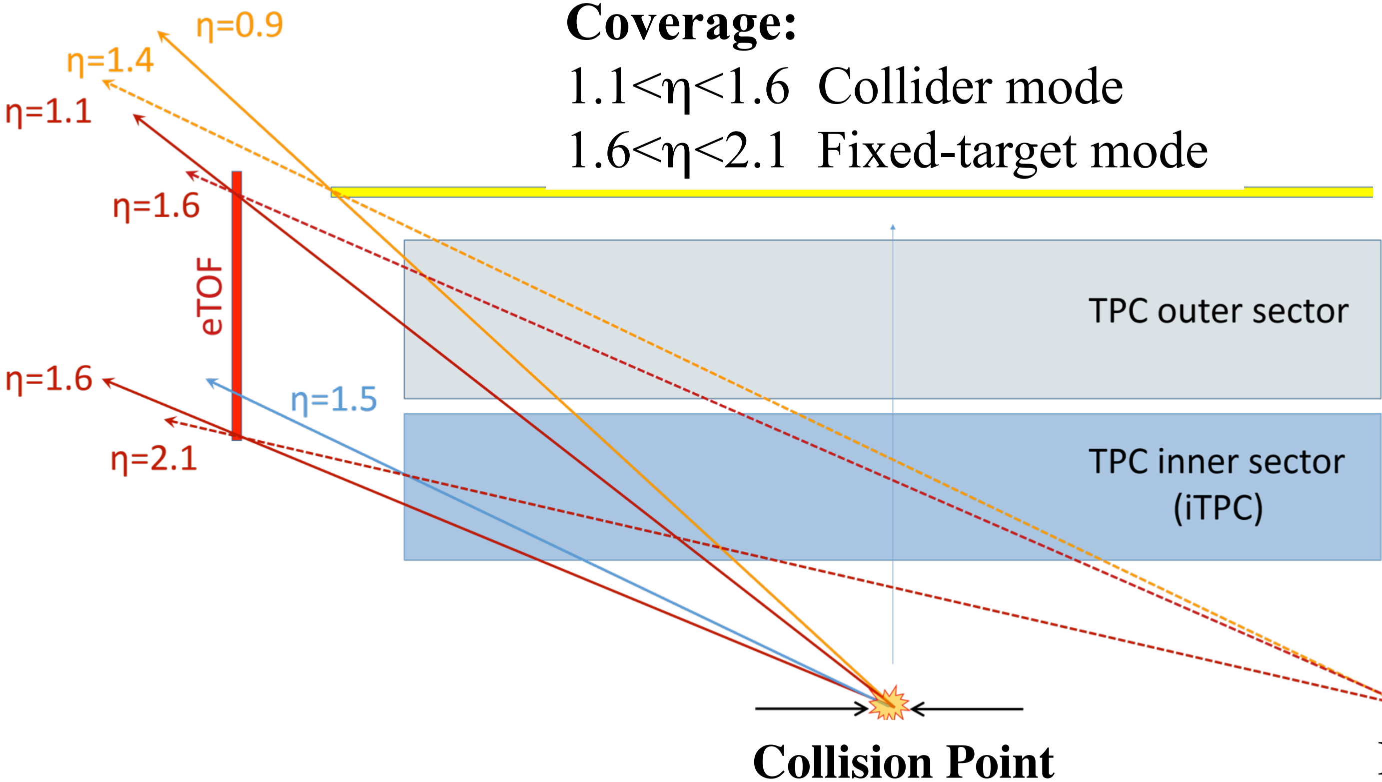
CBM/STAR eTOF module

# eTOF acceptance

**Coverage:**

$1.1<\eta<1.6$ Collider mode

$1.6<\eta<2.1$ Fixed-target mode



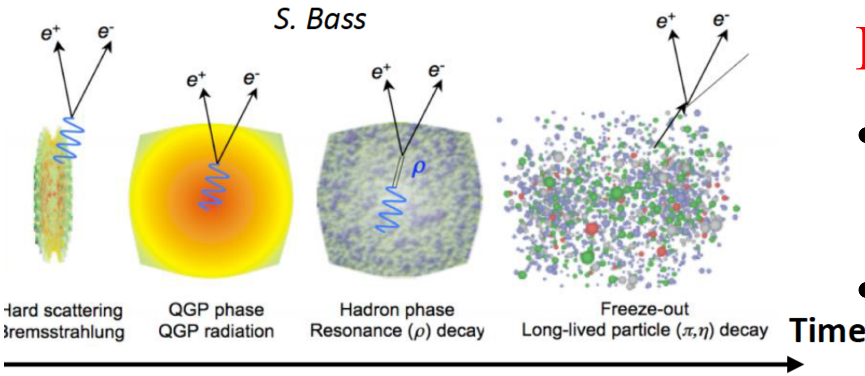

**FXT Experiments**

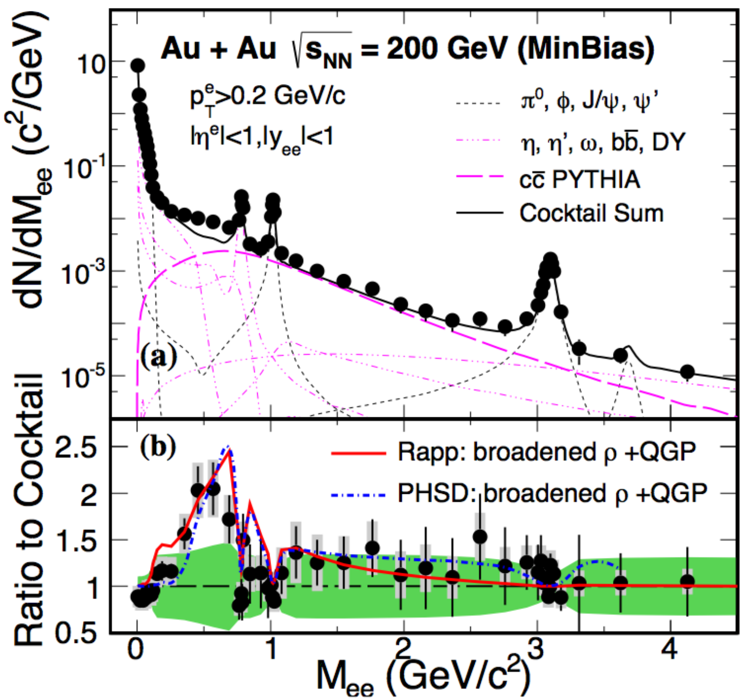
| $\sqrt{s_{NN}}$ (GeV) | $y_{CM}$ | $\mu_B$ (MeV) |
|---|---|---|
| 7.7 | 2.1 | 420 |
| 6.2 | 1.9 | 487 |
| 5.2 | 1.7 | 541 |
| 4.5 | 1.5 | 589 |
| 3.9 | 1.4 | 633 |
| 3.5 | 1.2 | 666 |
| 3.2 | 1.1 | 699 |
| 3 | 1.0 | 720 |

- Collider mode: Extend PID to forward rapidity ($1.1<\eta<1.6$)
- Fixed-target mode: Essential for mid-rapidity measurements

eTOF extends measurements to forward rapidity and lower energy

# Dilepton production in heavy-ion collisions



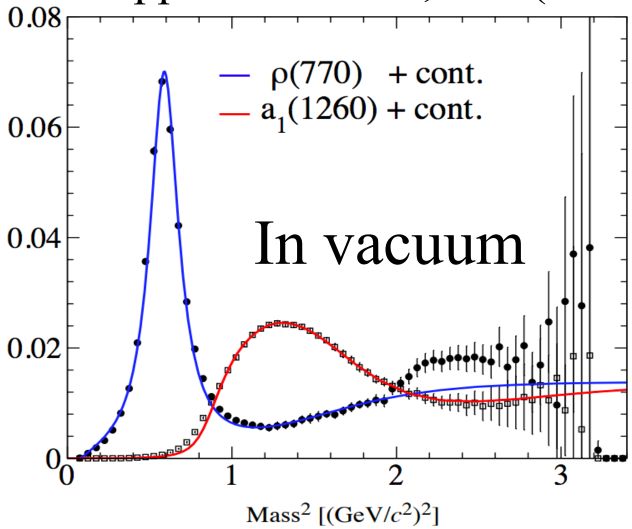

STAR, PRL 113, 022301 (2014)

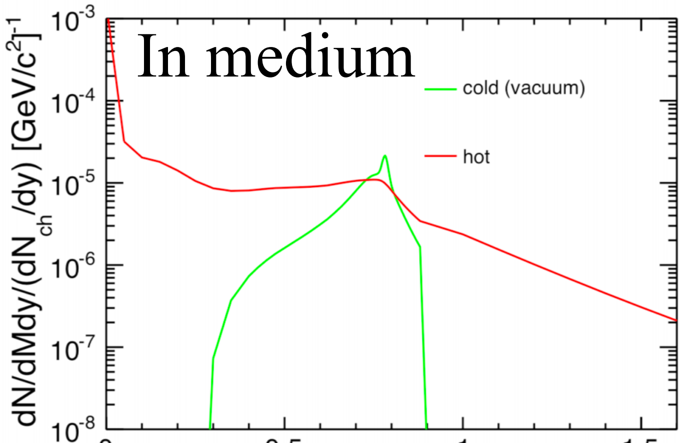
## Dilepton: Penetrating probe

- Provide information deep into system and whole time evolution
- Pairs with different mass have different physics and probes different time scale
  - Low-mass Range (LMR)
    - ✧ *Vector meson modification*
  - Intermediate-mass Range (IMR)
    - ✧ *QGP thermal radiation*
    - ✧ *Correlated heavy quarks*
  - High-mass Range (HMR)
    - ✧ *Quarkonium*
    - ✧ *Drell-Yan process*

# LMR dilepton probes chiral symmetry

ALEPH: EPJC4, 409 (1998)
R. Rapp Pramana 60, 675 (2003)




R. Rapp et al.

Spontaneous chiral symmetry breaking:

Splitting of ρ and $a_1$ (1260)

Is chiral symmetry restored in the hot medium created in heavy-ion collisions?

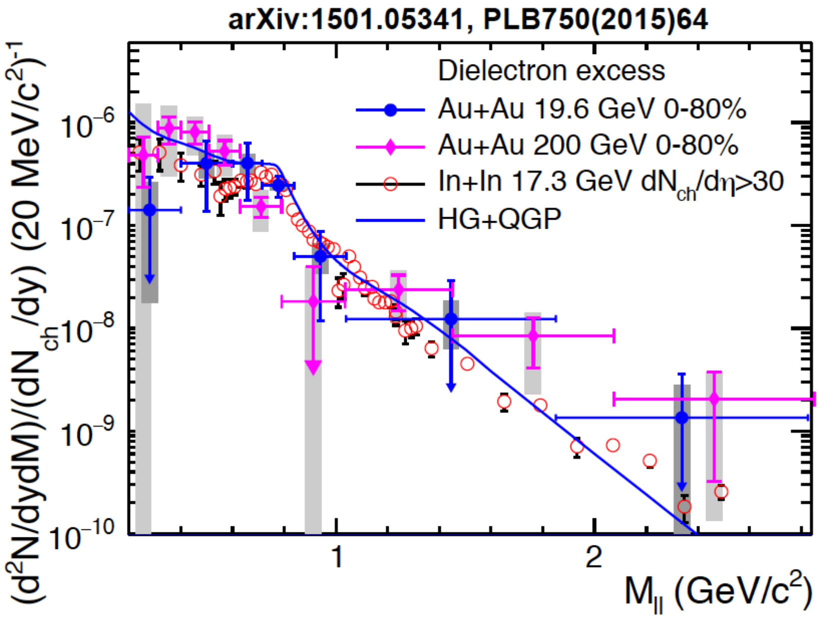
Experimental observable:

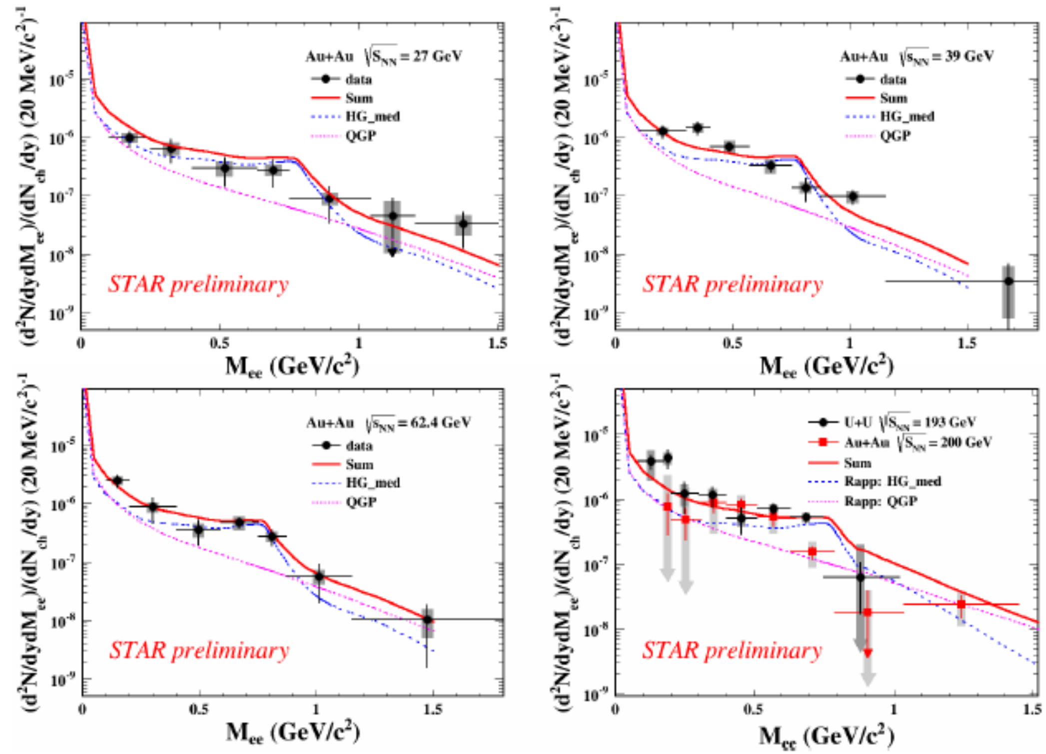
ρ spectral function via dilepton

Chiral symmetry (partially) restoration

→ A broadened ρ spectral function and ultimately the peak structure disappears

# LMR dilepton measurements

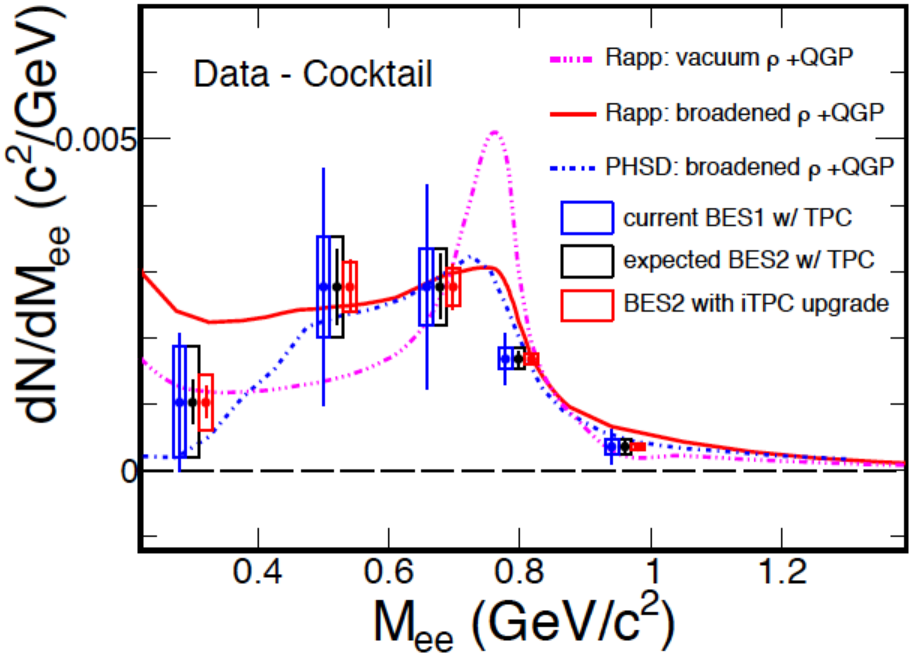



Dilepton excess at LMR observed from SPS to RHIC

Systematically described by model calculations with in-medium broadened ρ spectral function

# Distinguish broadening mechanism



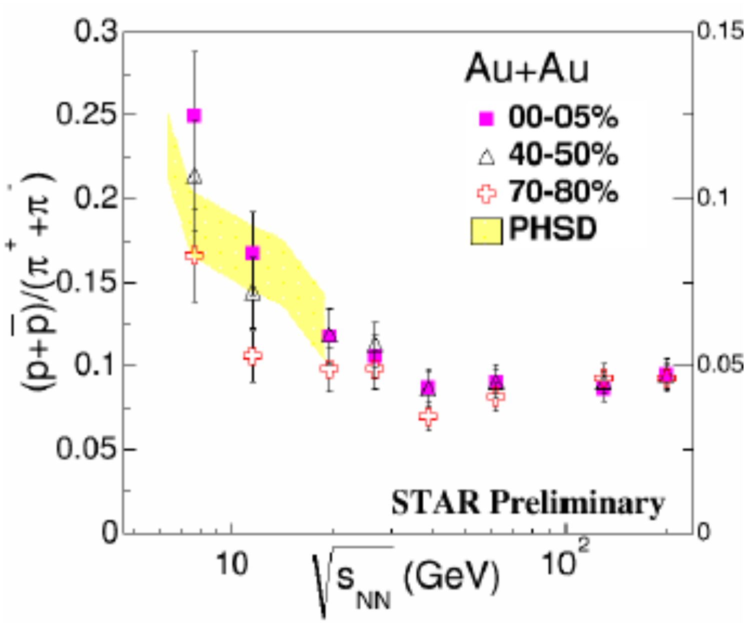

Rapp: Effective many-body theory model
PHSD: Microscopic transport dynamic model

Knowing the mechanism that causes in-medium ρ broadening is fundamental to our understanding and assessment of chiral symmetry restoration in hot QCD matter

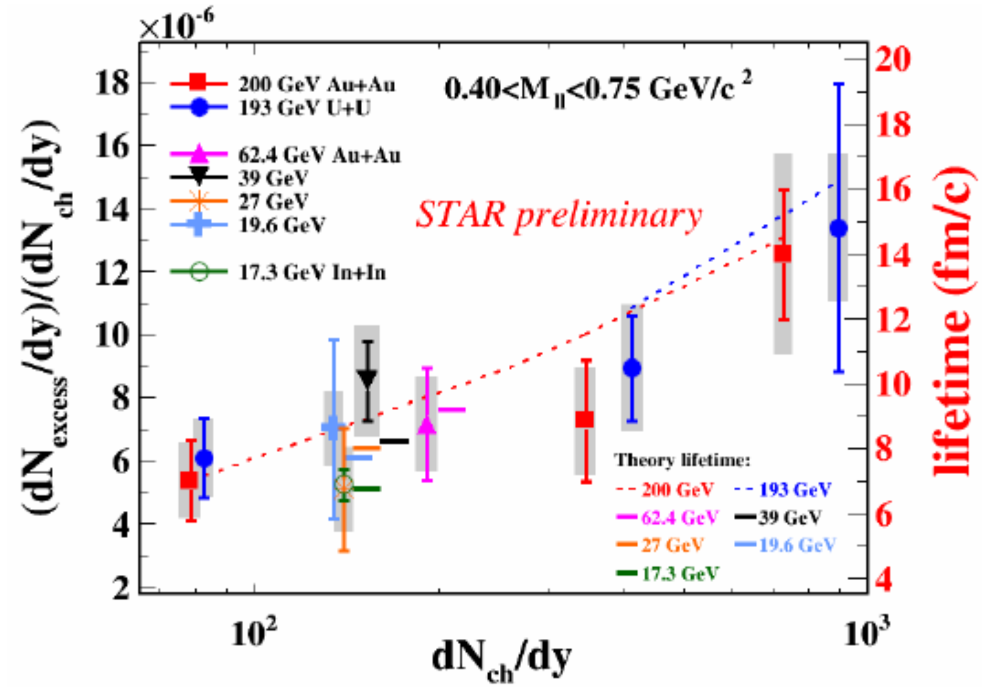
# LMR dilepton yield

LMR dilepton emission rate depends on:

- Temperature
- Total baryon density
- Lifetime

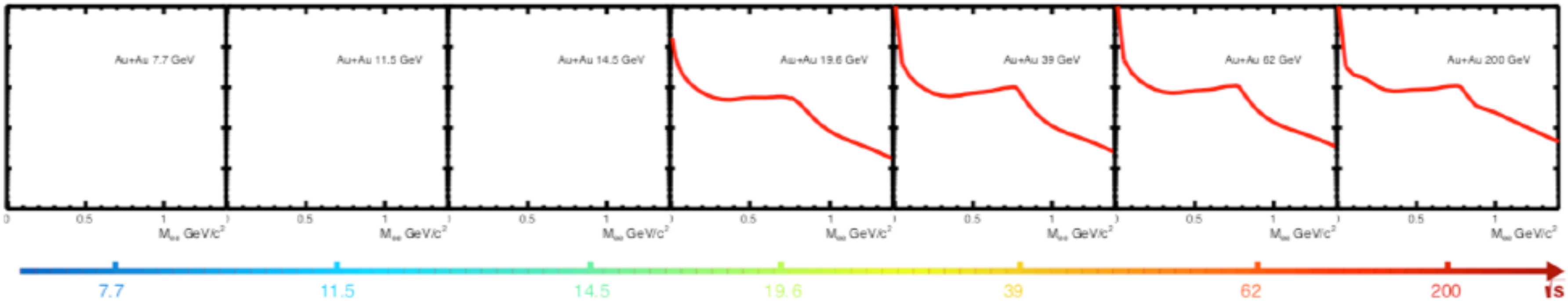


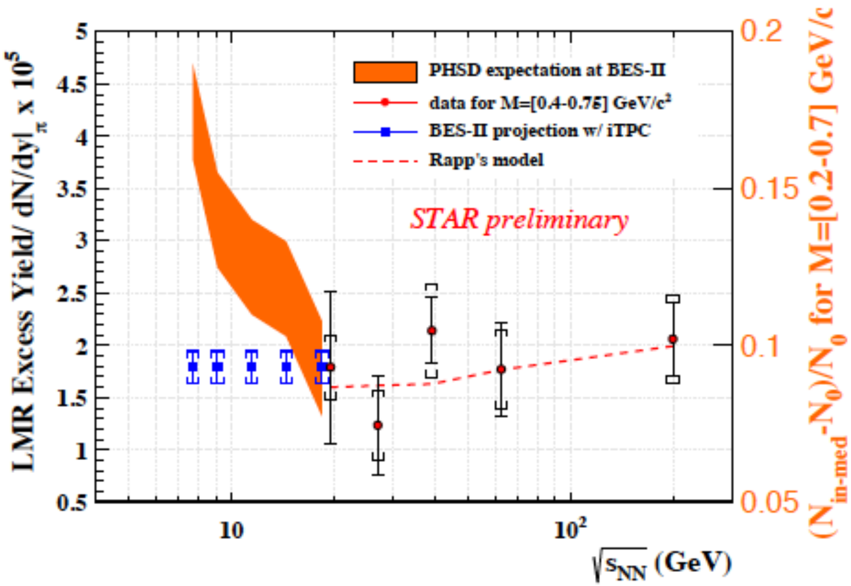

Total baryon density nearly constant above 19.6 GeV




Normalized excess yield proportional to lifetime from 17.3 to 200 GeV

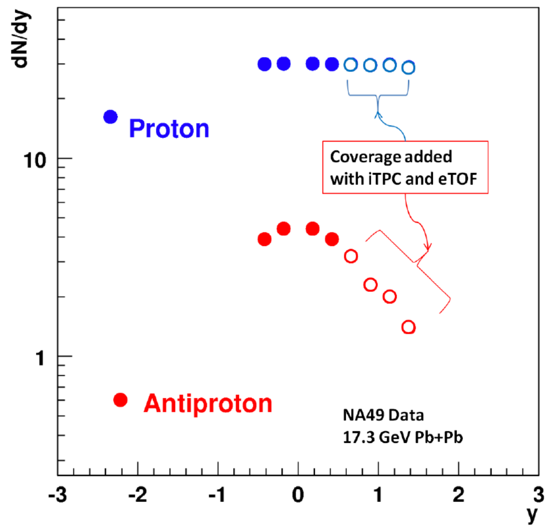
# LMR dilepton at BES II

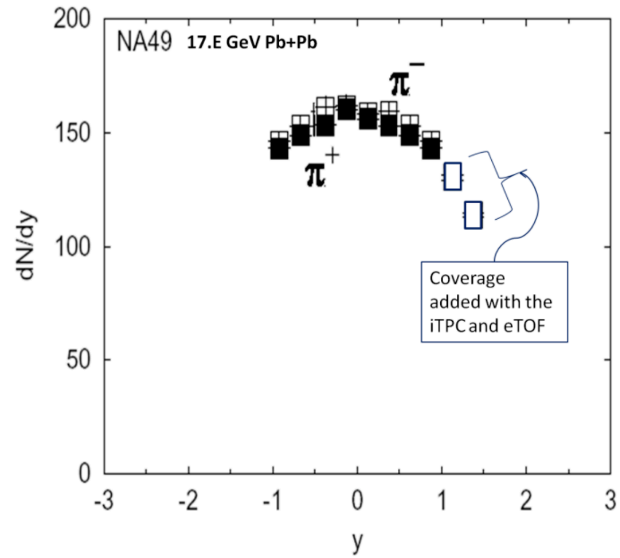



- Broader and more LMR dilepton excess down to 7.7 GeV?
- Structureless mass distribution would form the last piece of evidence of chiral symmetry restoration

# LMR dilepton vs. rapidity



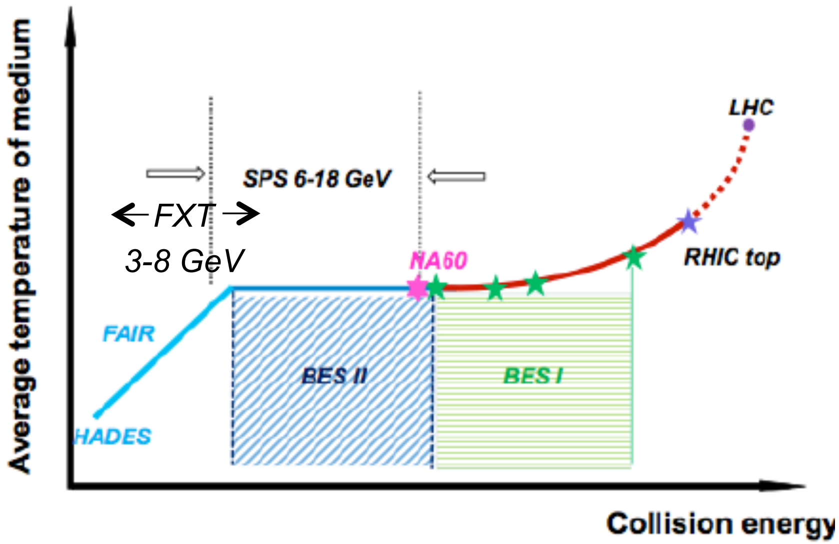



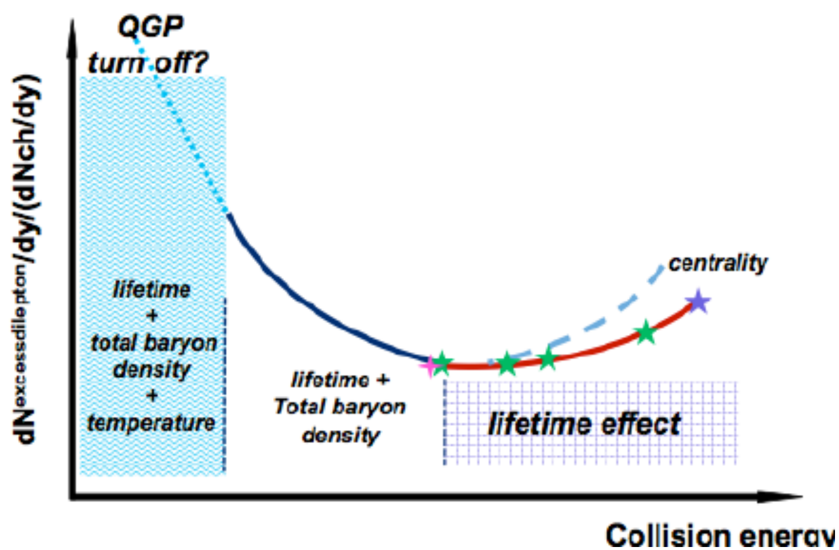

Significant change of (relative) total baryon density from mid-rapidity to forward rapidity

eTOF enable the measurements at forward rapidity

Provides for independent observable to study baryon-density dependence of LMR enhancement

# LMR dilepton vs. energy




BES II fixed-target:

- New data at energy < 7.7 GeV
- Temperature effect?
- QGP turn-off effect?

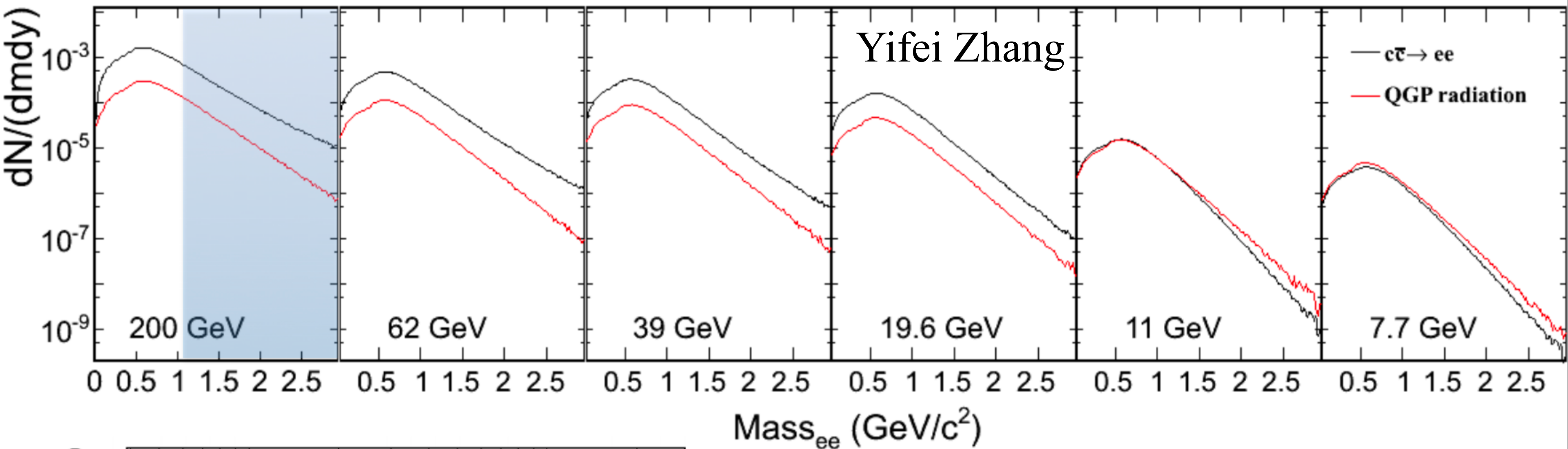
Search for critical point?

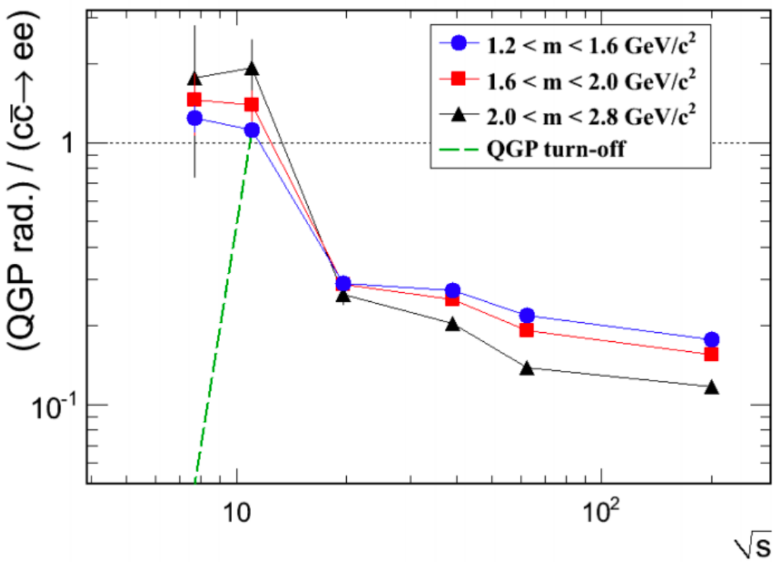
Critical point

→ Increase of lifetime

→ Increase of LMR dilepton yield

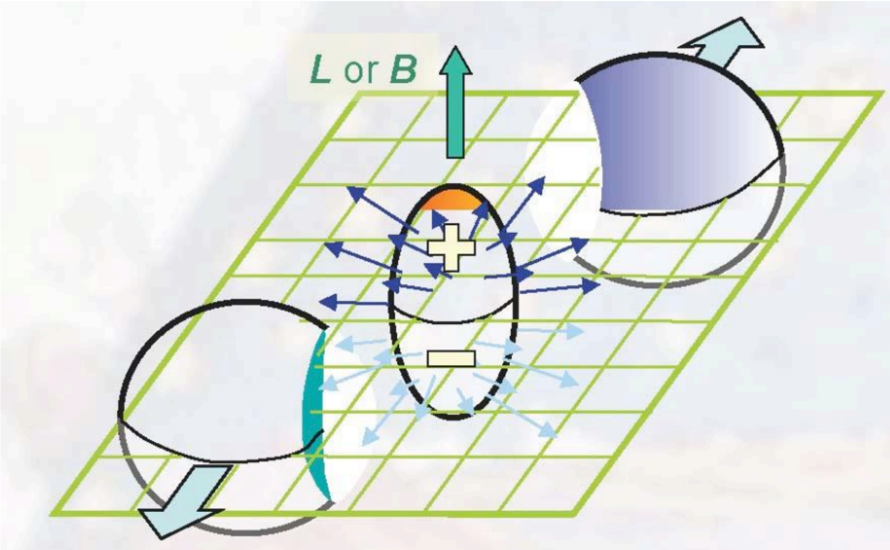
# IMR dilepton: QGP thermometer?




- Charm x-sec. decrease dramatically
- QGP lifetime decrease as well
- Contribution from QGP radiation significant at < 20 GeV
- Way to study QGP radiation?

# Chiral magnetic/vortical effects

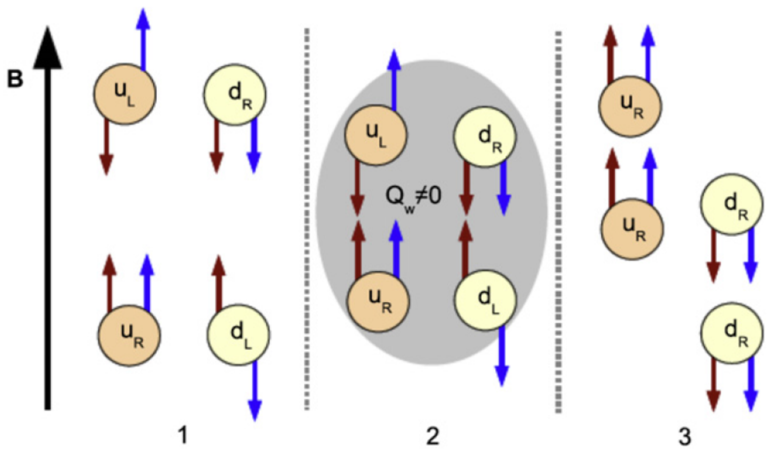



Strong *B* and global *L* in non-central heavy-ion collisions

+ chiral symmetry restoration

+ topological charge fluctuation

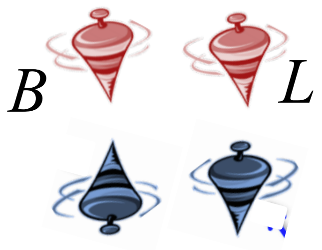
→ CME and CVE



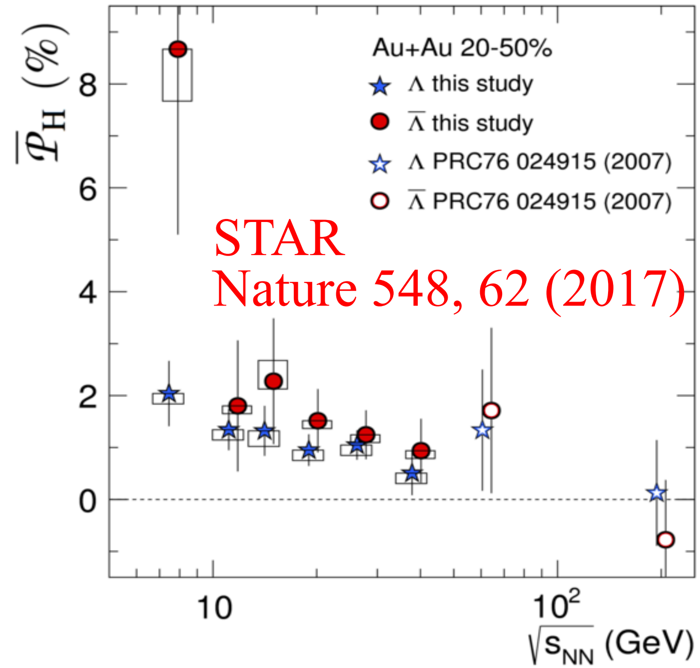

Charge separation due to CME

Similarly, CVE will result in baryon number separation

# Hyperon global polarization

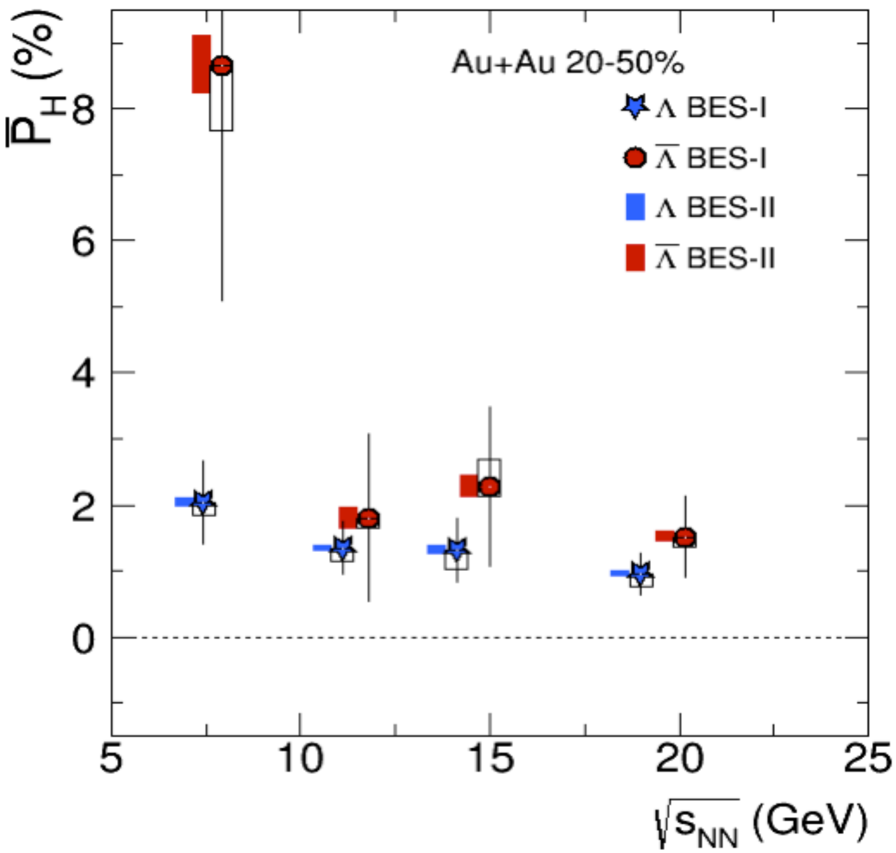



Hyperon global polarization can be used to measure the magnetic field and vortical structure


"Quantitative estimates of extreme vorticity yield a more complete characterization of the system and are crucial input to studies of phenomena related to chiral symmetry restoration that may provide insight into the complex interactions between quarks and gluons."

# Prospective in BES II




Precision will be significantly improved in BES II

- Number of events
- Event Plane Detector (EPD)

Quantifying magnetic field and vorticity of the medium

Will the global polarization keep increasing below 7.7 GeV?

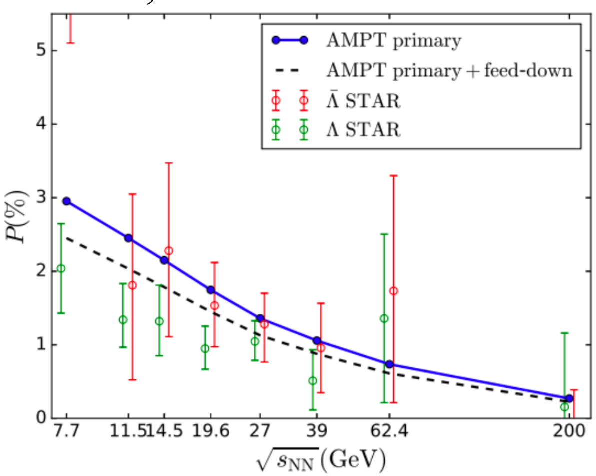
Fixed-target will provide a unique opportunity

# Global polarization vs. rapidity

Theoretical study@USTC:

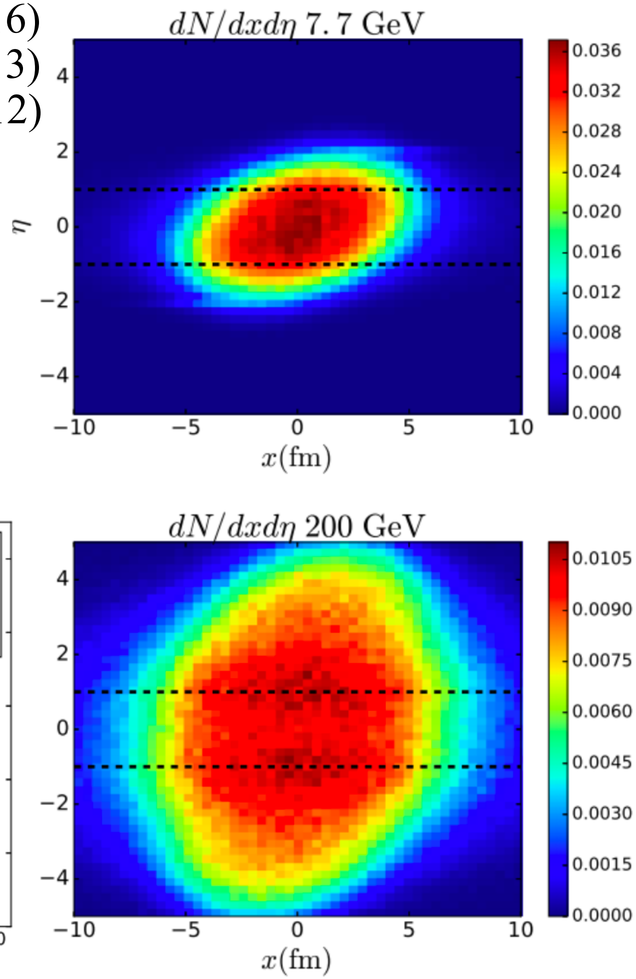
Phys. Rev. Lett. 117, 192301 (2016)
Phys. Rev. Lett. 110, 262301 (2013)
Phys. Rev. Lett. 109, 232301 (2012)
Phys. Lett. B 749, 542 (2015)
arXiv:1704.01507
Phys. Rev. D 95, 014032 (2017)
Phys. Rev. C 94, 024904 (2016)
Phys. Rev. C 94, 044903 (2016)

H. LI, L. Pang, Q. Wang and X. Xia, arXiv:1704:01507

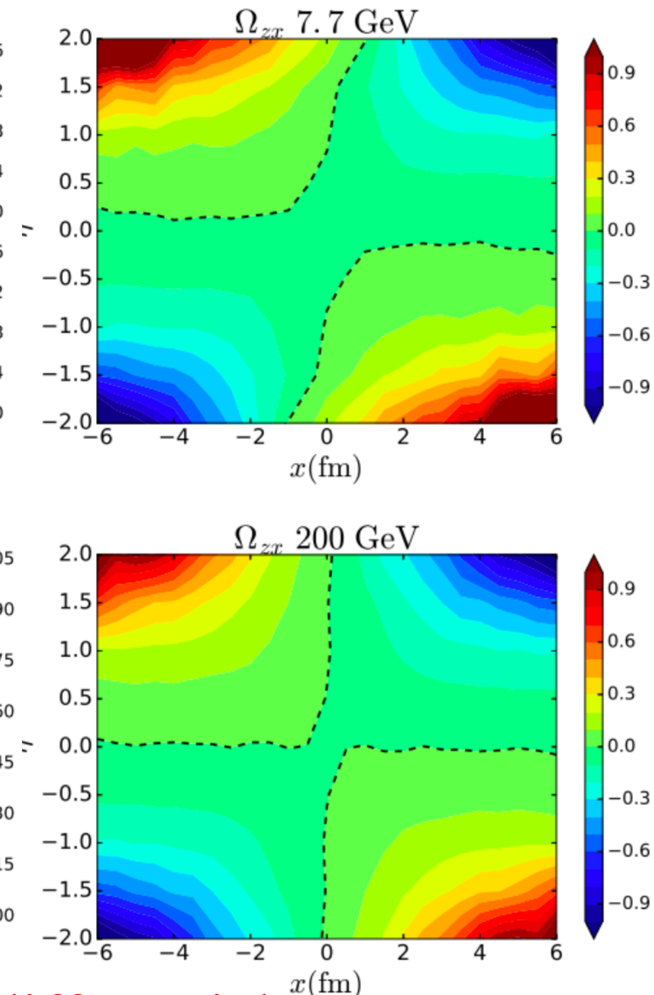



Explains the trend

## Λ freeze-out position




## Vorticity




May be checked with differential measurements

# Summary

- The NSFC project will support eTOF construction and experimental and theoretical study of dilepton production and hyperon global polarization at BES II

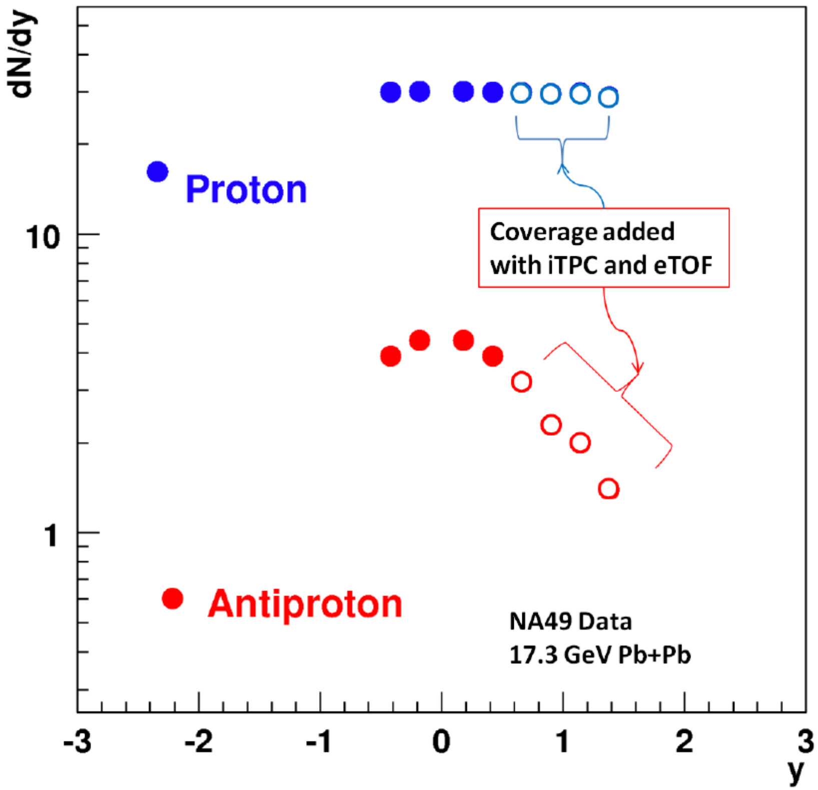
- eTOF will significantly improve the precision of these two measurements
- And extend the measurements to forward rapidity and lower energy (together with Fixed-target)

- Money will be there, let's get our jobs done.

Thanks!

# Backup slides

# Rapidity dependent $\mu_B$



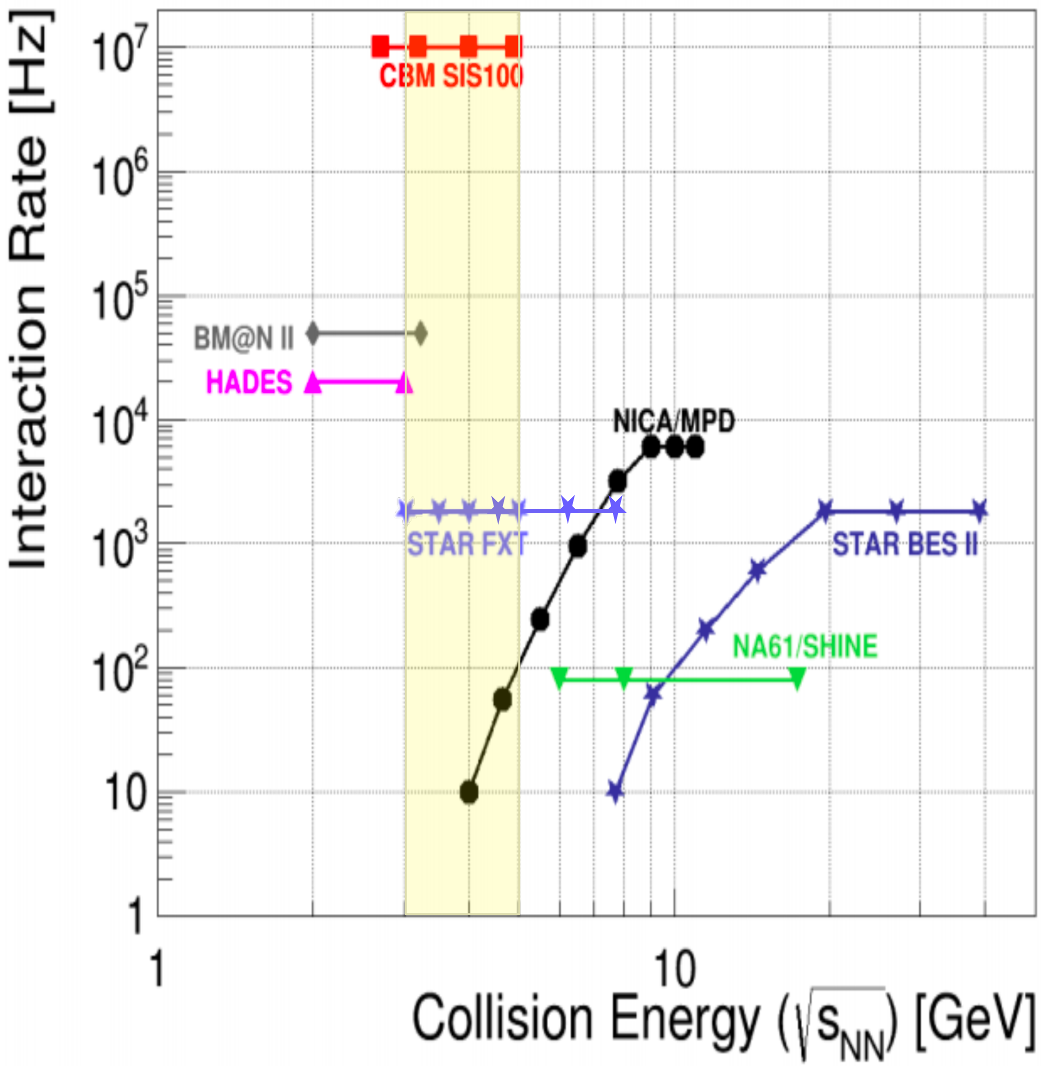

Proton: flat rapidity distribution

Anti-proton: decreasing rapidly

$\mu_B$ increases with rapidity

~50 MeV from mid- to forward rapidity

# Experiments for dense baryonic matter




**STAR BES I:** *2010-2017*

7.7-200 GeV

**STAR BES II:** *2019-2020*

Collider: 7.7-19.6 GeV

Fixed-target: 3.0-7.7 GeV

**CBM SIS100:** *2025-????*

2.7-4.9 GeV

BES III?

# Observables for dense baryonic matter

Onset of Deconfinement:

- NCQ scaling of elliptic flow
- High-$p_T$ suppression
- Strangeness enhancement

Criticality:

- Higher moments
- Particle ratio fluctuation

$1^{st}$ order phase transition:

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

Chirality:

- Dilepton studies
- CME, CMW, CVE etc

# BES II

- Most BES I measurements limited by statistics and systematics
- BES II will significantly improved statistics via upgraded accelerator and detectors
- The fixed-target program will extend $\mu_B$ coverage to ~720 MeV
- 3 Major detector upgrades (iTPC, EPD, eTOF)

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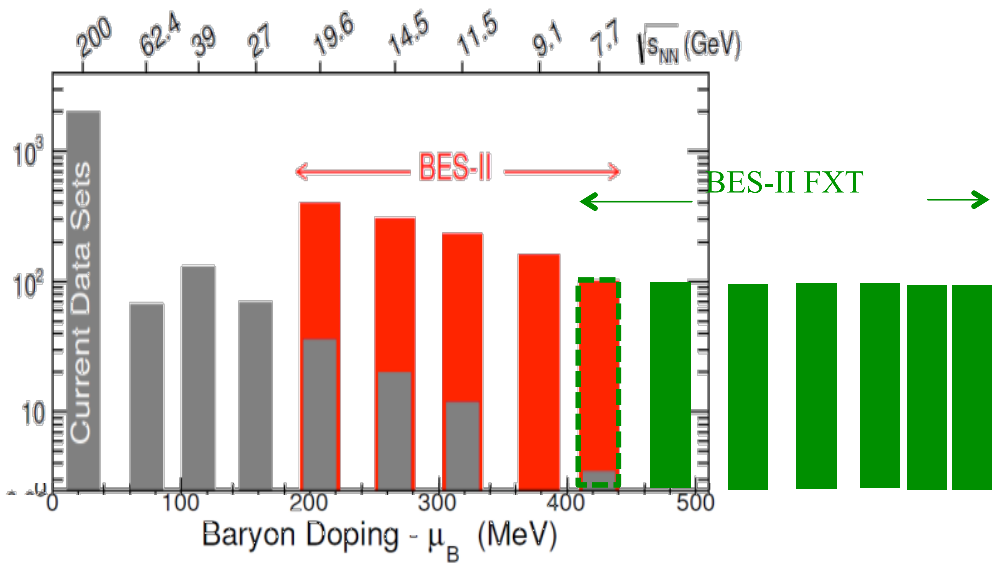
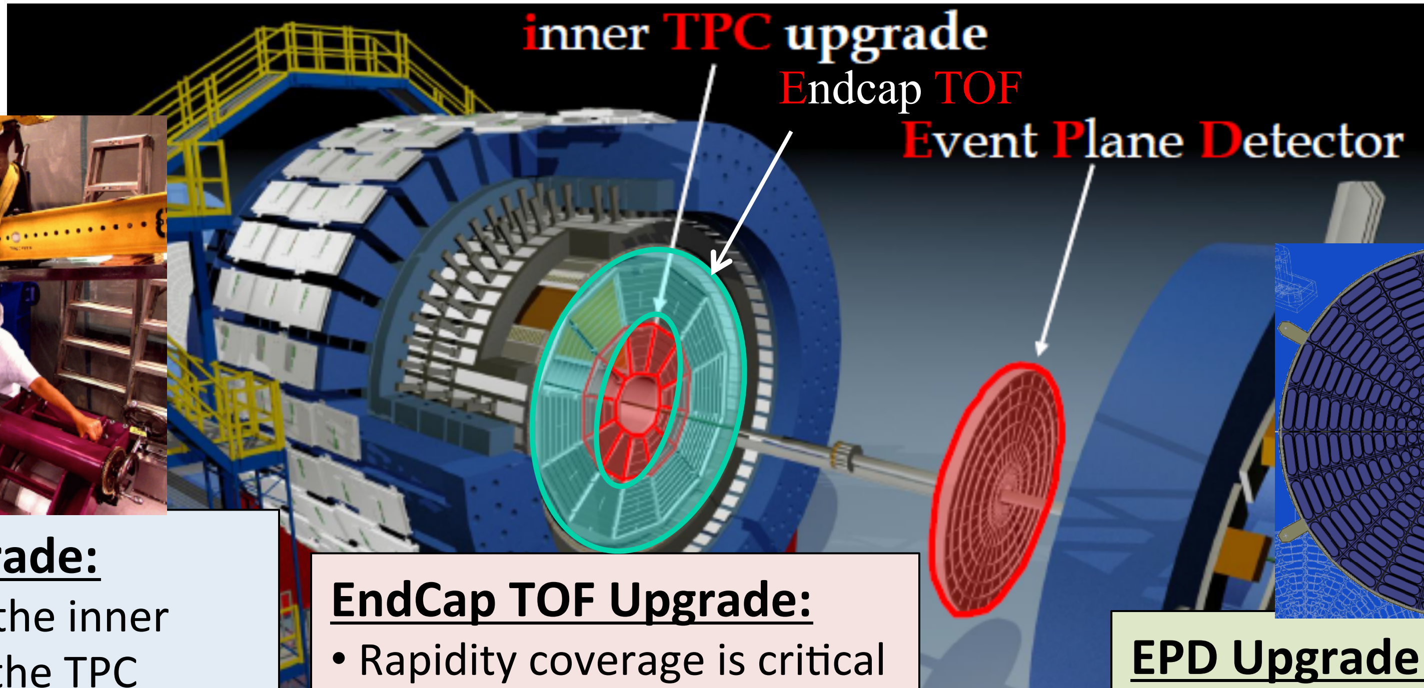
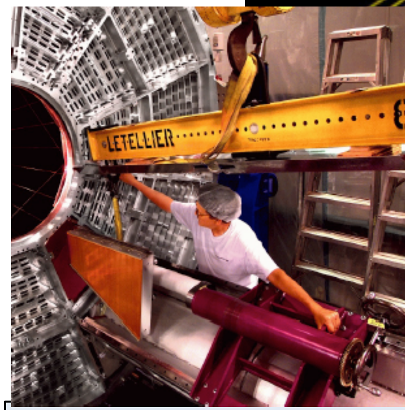
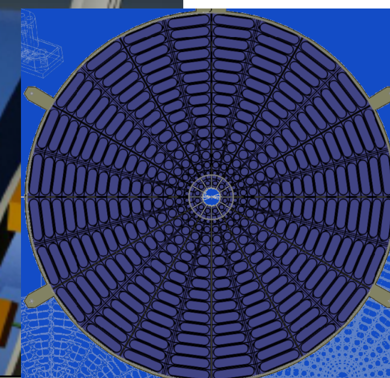


# STAR detector upgrade



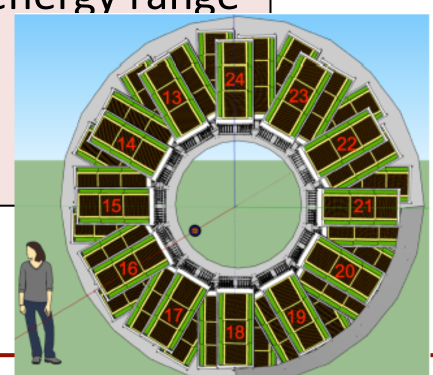



**iTPC Upgrade:**

- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends $\eta$ coverage to 1.5 (2.2 for FXT)
- Lowers $p_T$ cut-in from 125 MeV/c to 60 MeV/c
- Ready in 2019

**EndCap TOF Upgrade:**

- Rapidity coverage is critical
- PID at forward rapidity
- Allows higher energy range of FXT program
- **CBM/STAR**
- Ready 2019

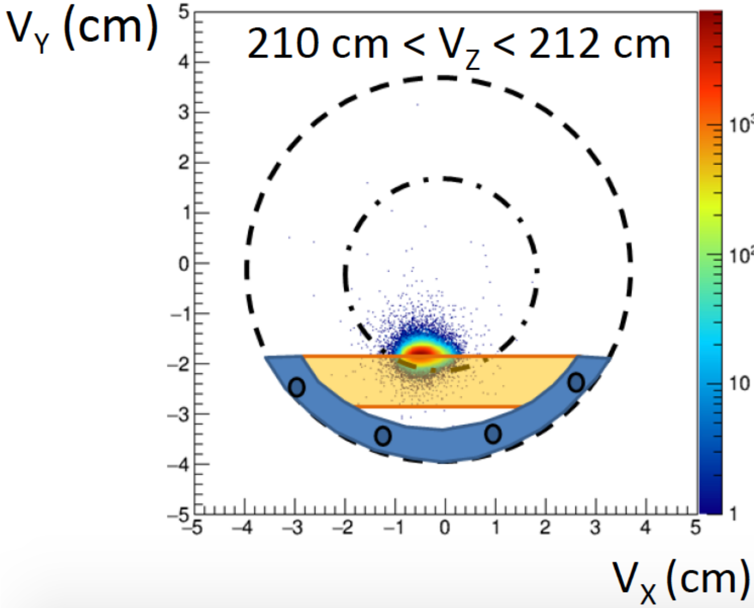


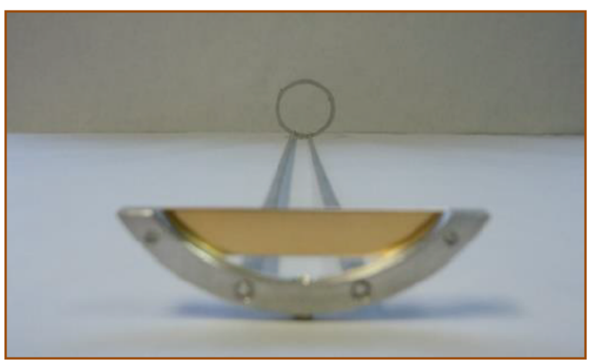

**EPD Upgrade:**

- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES and FXT
- Ready 2018

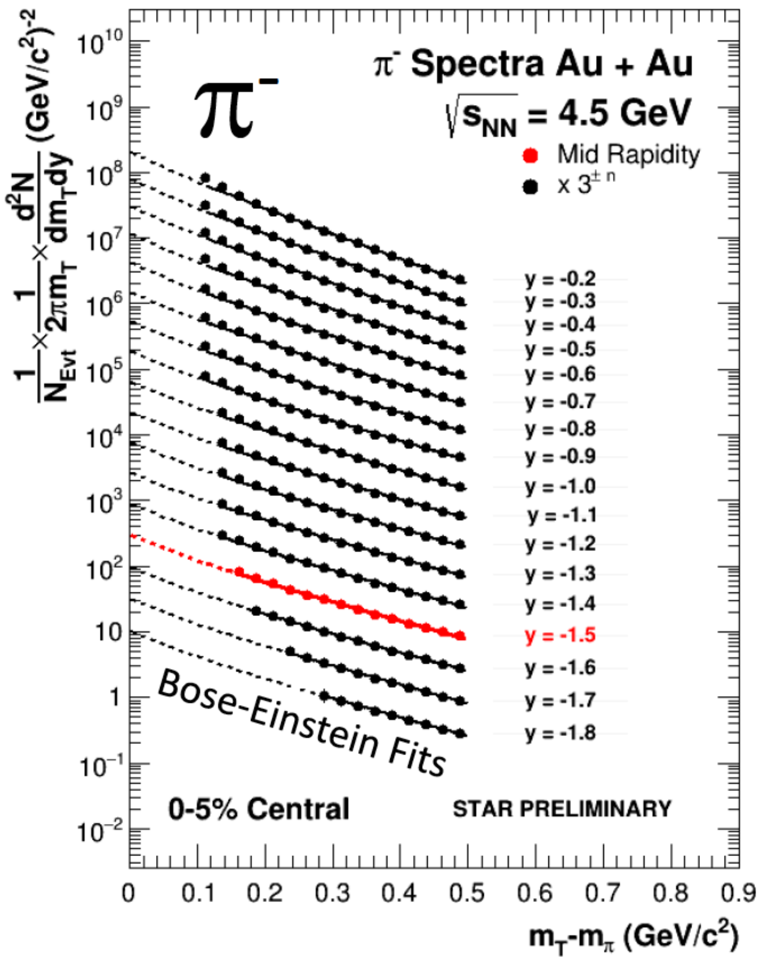
# Fixed-target test run

1.3 M events taken in 2015



1 mm thick gold foil

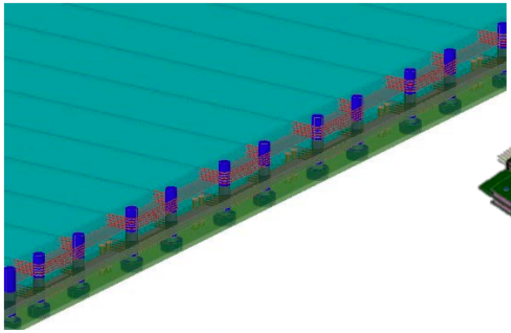


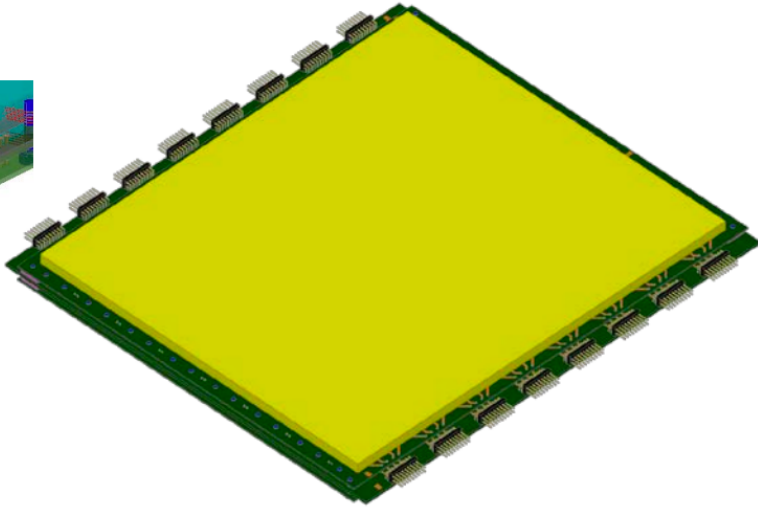

Data rate limited by DAQ

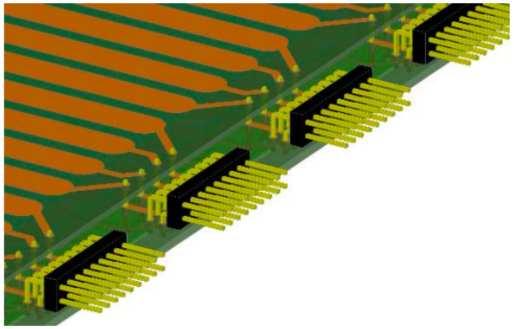
50 M/day expected for BES-II

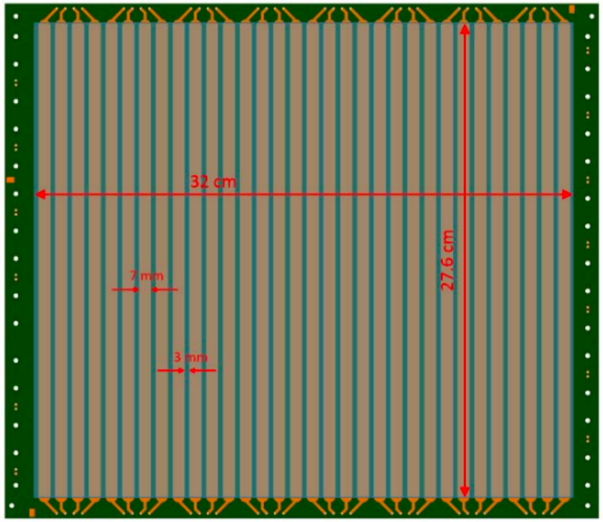
# eTOF MRPC prototypes

- Thin float glass electrodes
  - 0.28 mm
- Impedance matching
  - 50 Ω
- Double-end strip readout
  - 7 mm strip + 3 mm gap = 1 cm pitch
- Differential signals to PADI
- Active area
  - 32 cm × 27.6 cm
- Detector size
  - 354 × 324 × 22 mm
- Double stacks





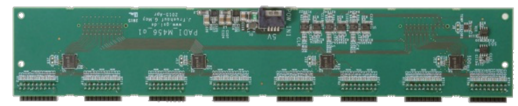




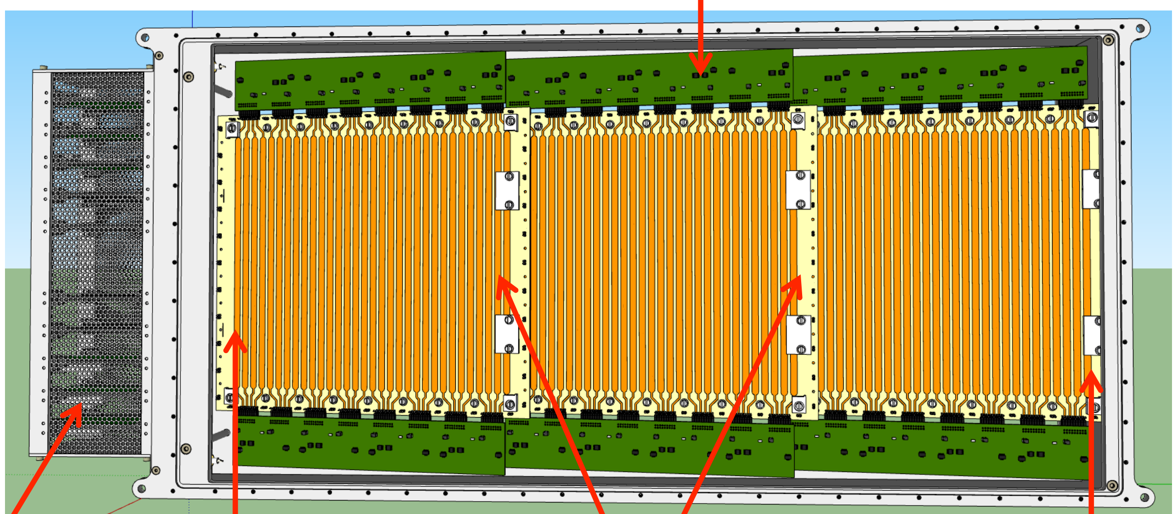
# STAR eTOF module

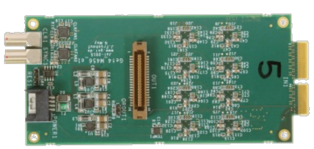
- 3 MRPCs (MRPC3a/b) – tilted by ≈7°
- 32 strips/MRPC with a pitch of 1 cm
- 27 cm strip length
- Active area about 92 cm × 27 cm
- 192 read out channels

Shorten for eTOF



Preamplifier PADI boards





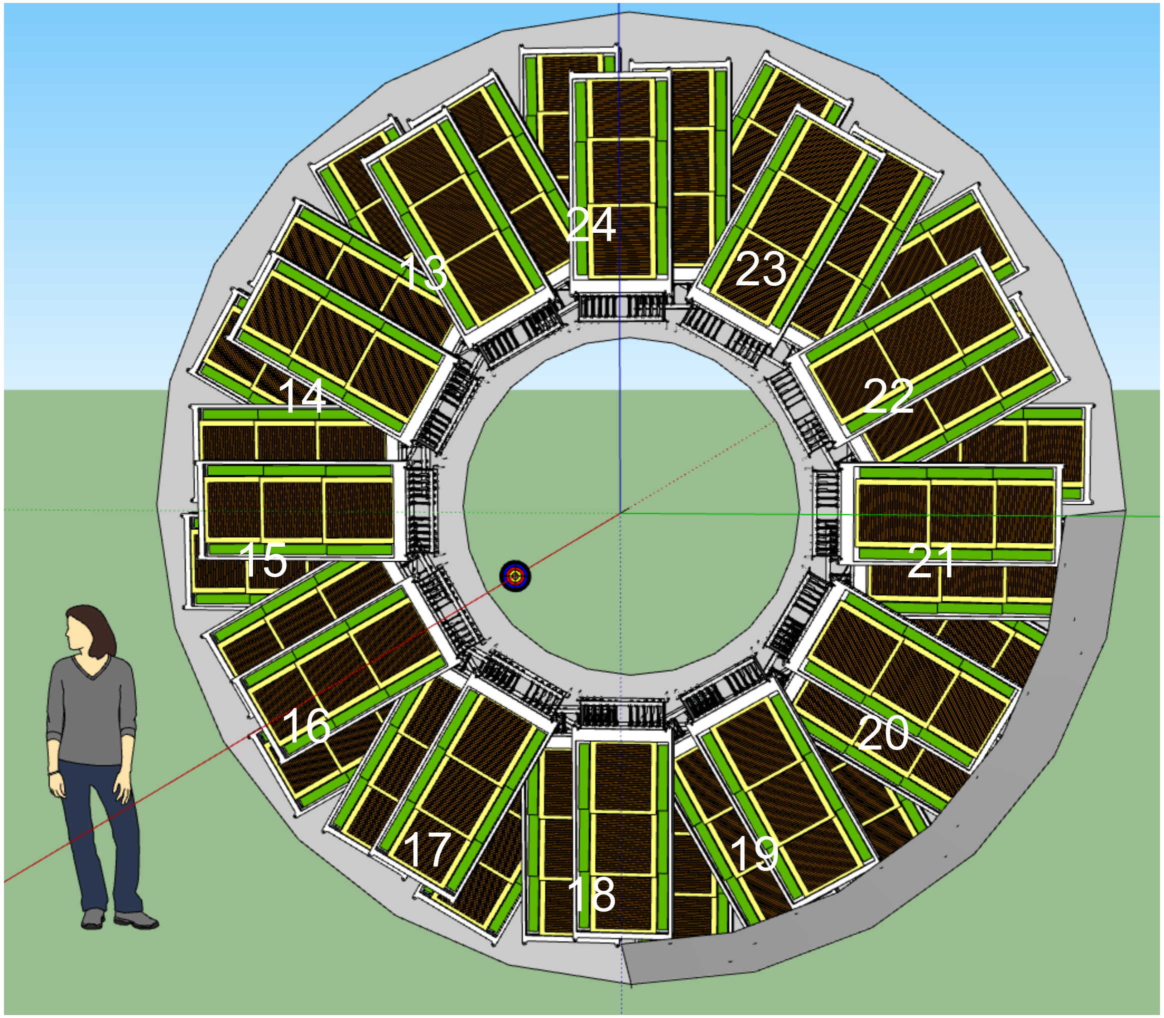
TDC GET4 boards

Strip 1

overlapping strips

Strip 96

# STAR eTOF Wheel




**A conceptual design**

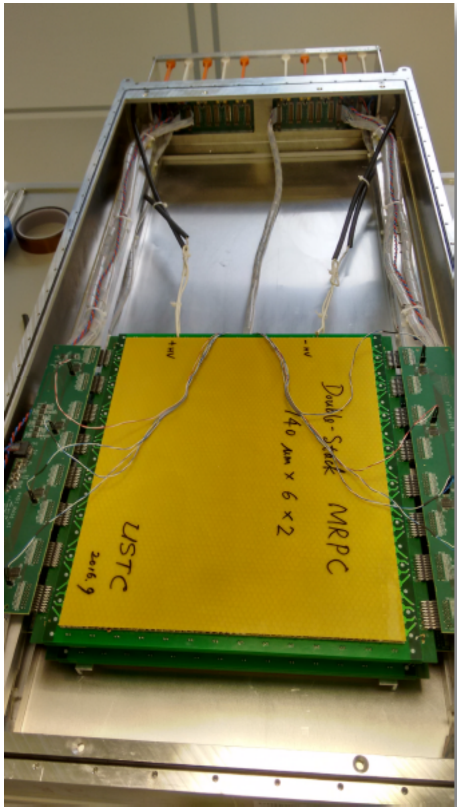
- 36 modules
- 3 layers
- 12 sectors
- 6912 channels

- Sector counting matches the TPC sectors

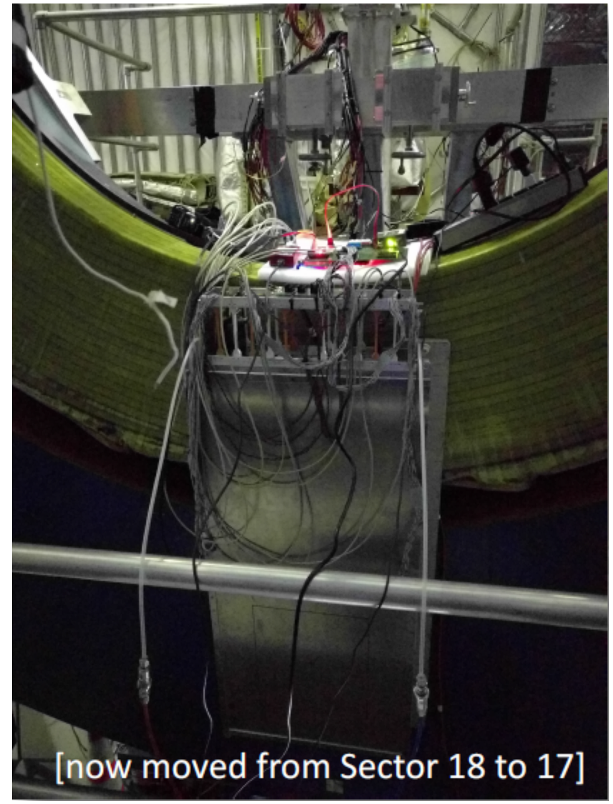
- Total depth about 14.2” (36 cm)

# eTOF prototype installed in STAR

Open module



Module fixed at the pole-tip

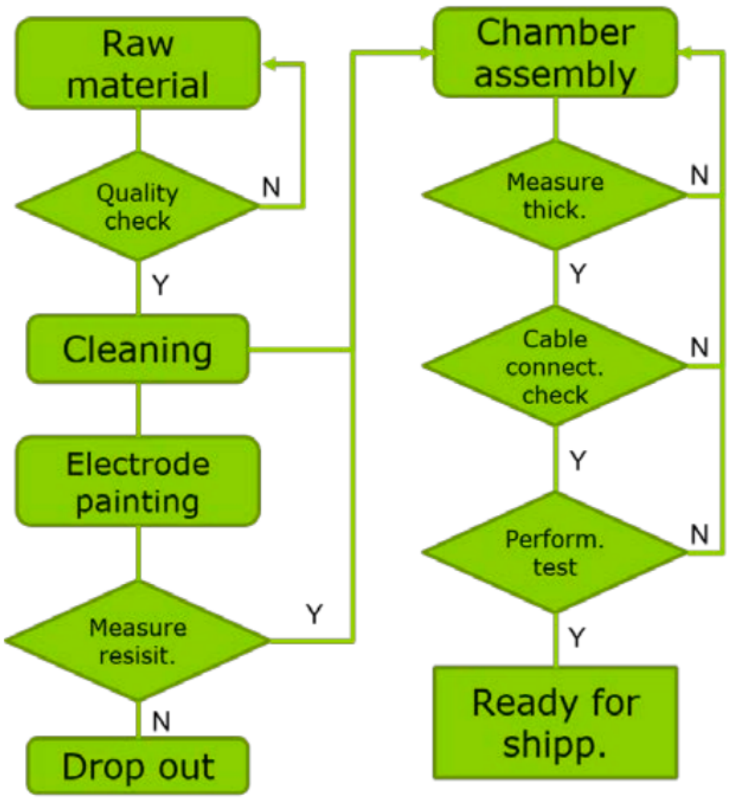



Integrated in STAR system (gas, mechanical, electronics, software)

Data taken in run 2017 (~100M)

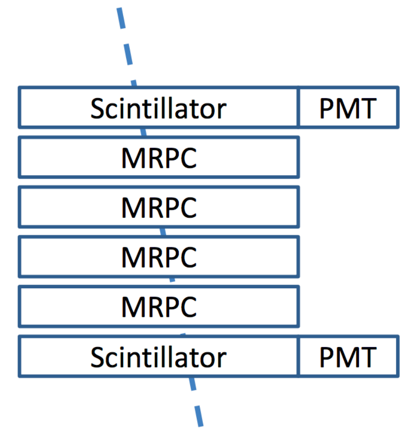
# Mass production procedure at USTC

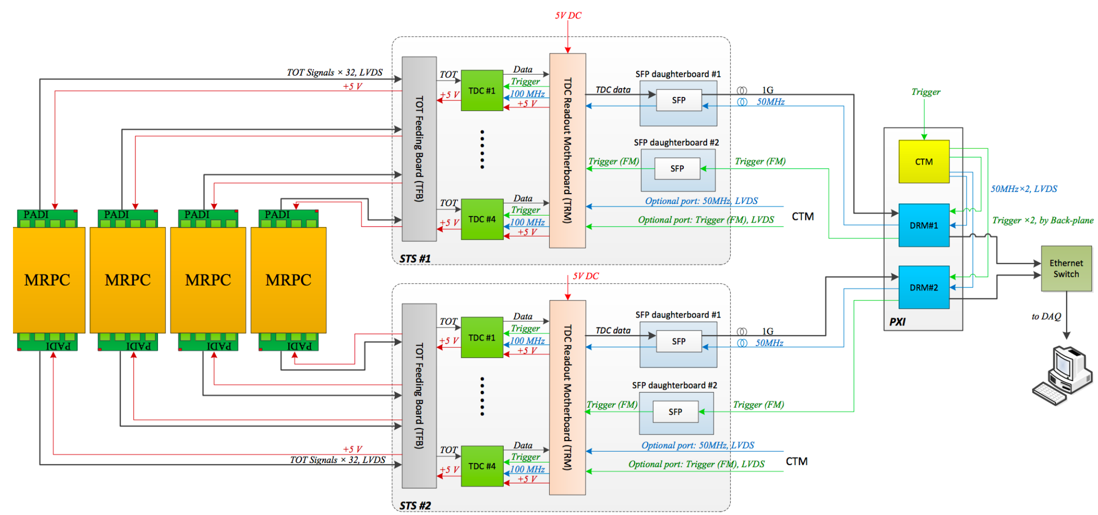
QC & QA




Cosmic ray

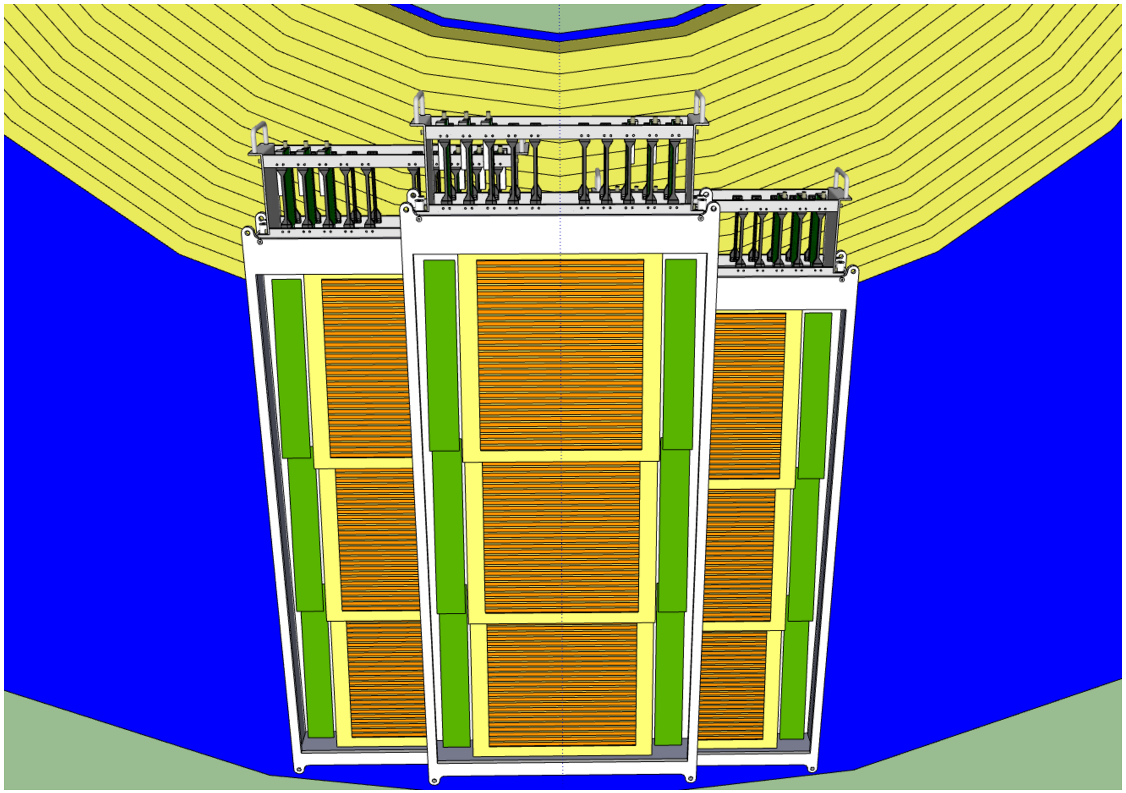
Test system



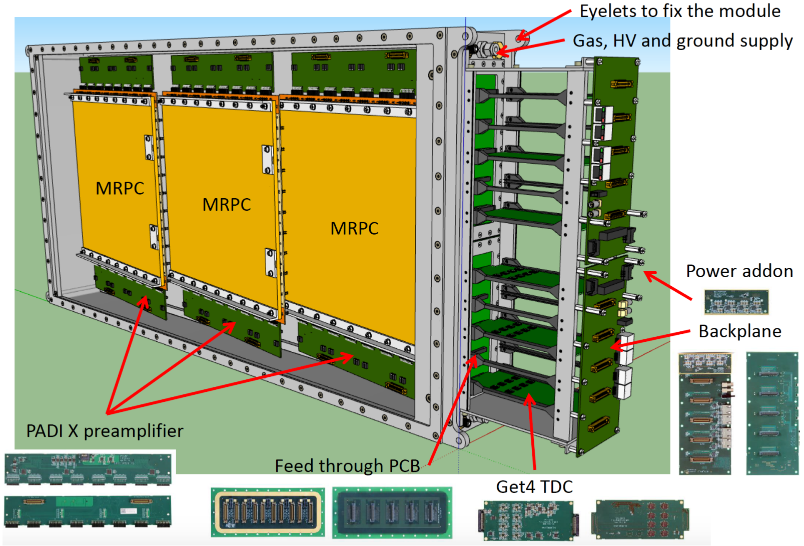
# Setup in 2018

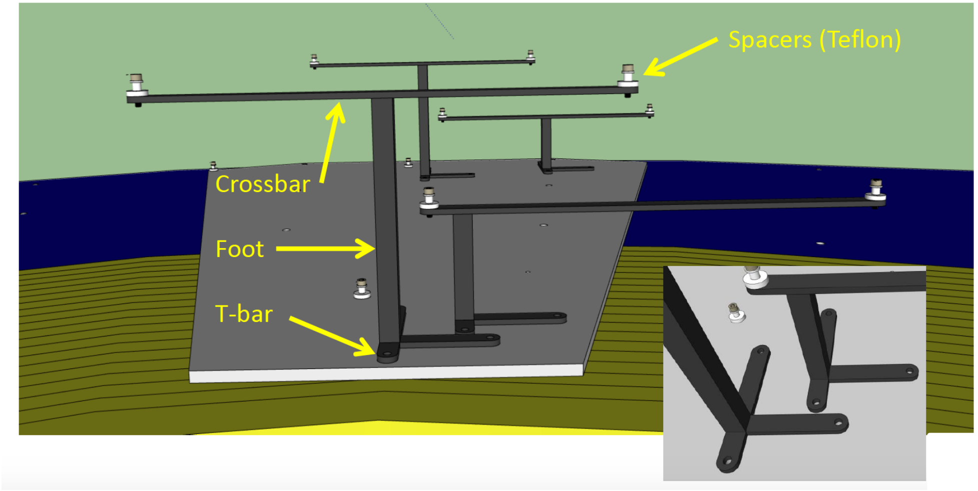
One full sector



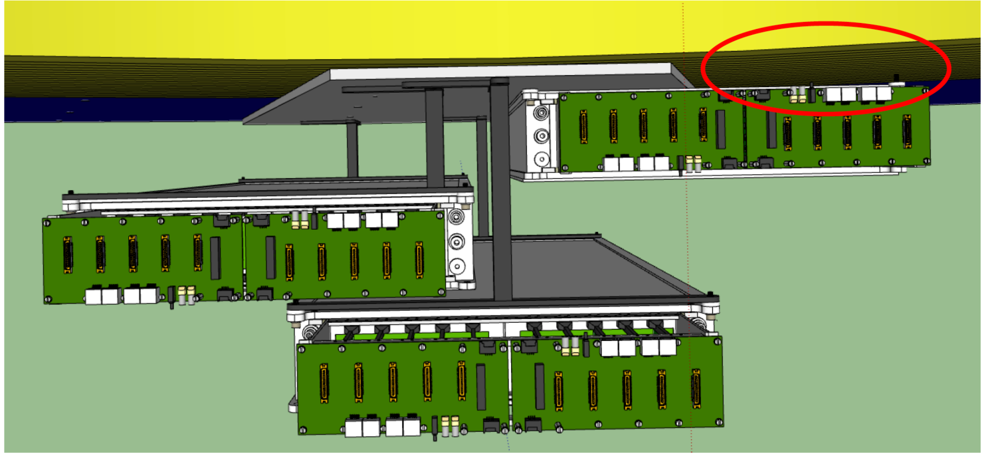
- 10 module produced @USTC
  as pre-mass production
- Cosmic ray test @USTC ongoing
- 1 PhD student sent to Heidelberg

# eTOF support structure

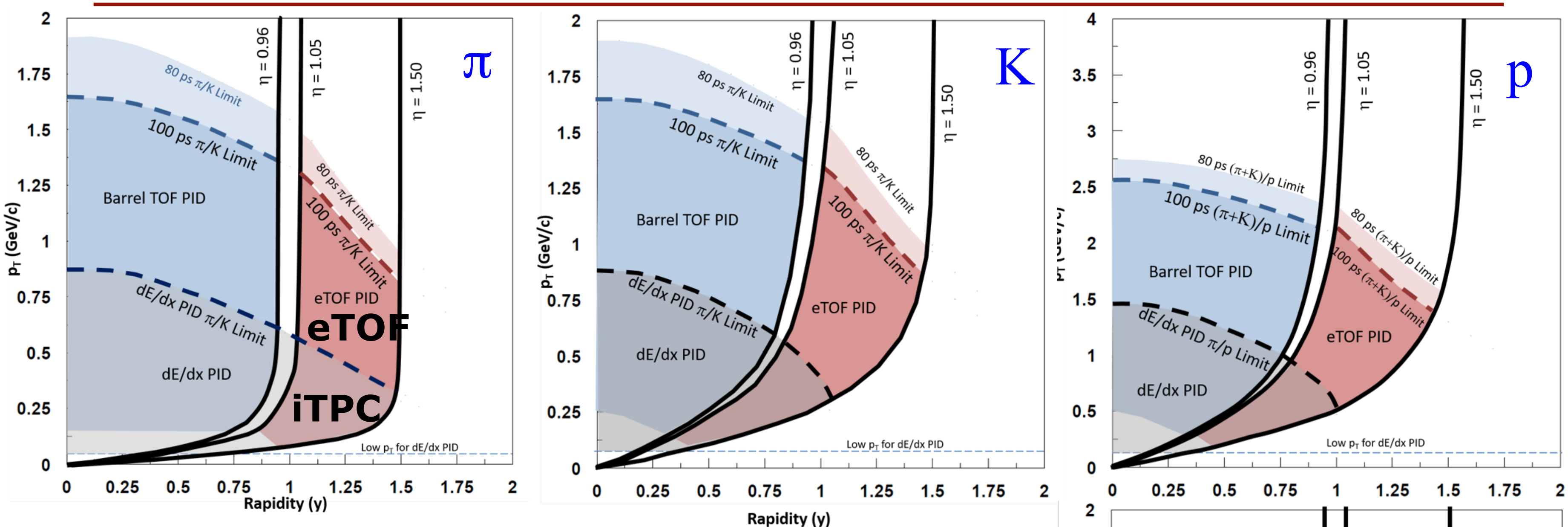



Pre-final review of the eTOF support structure on July 13, 2017



# PID capability @ Collider mode

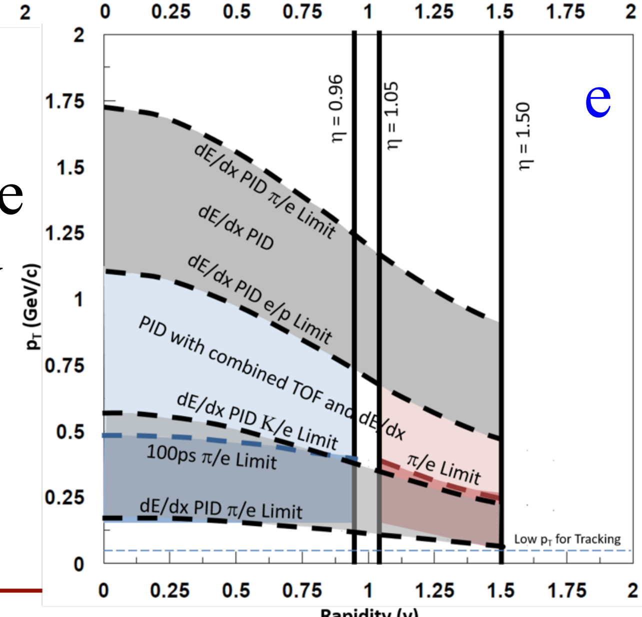



Collider Mode

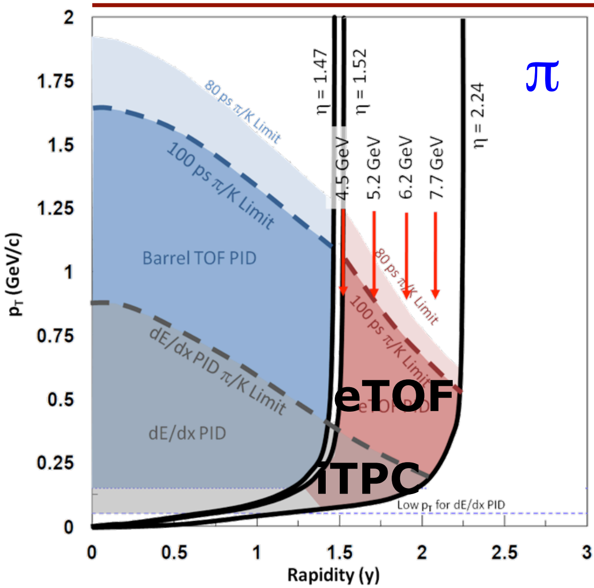
An important complementary to iTPC upgrade

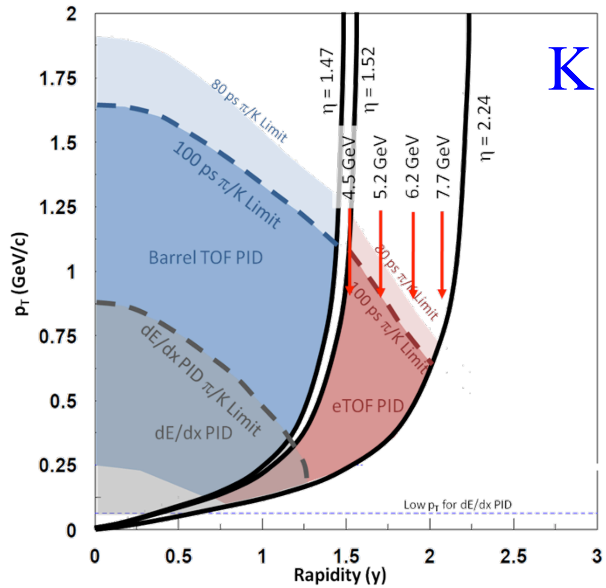
Significantly improve PID at forward rapidity

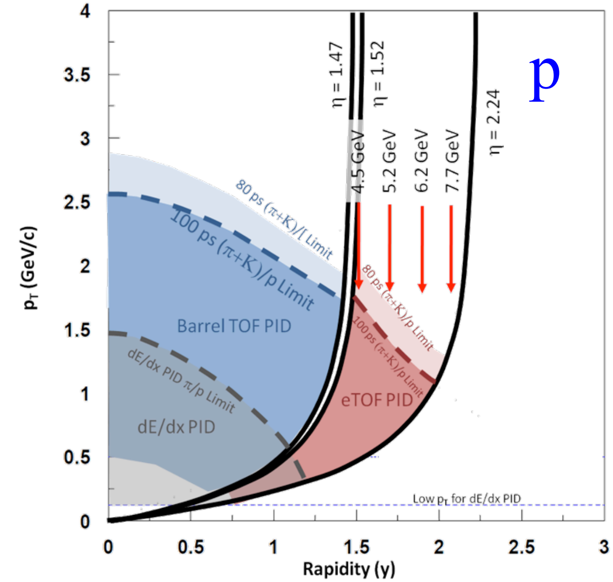
- iTPC+eTOF: 1.05<η<1.50
- TPC+BTOF: -0.96<η<0.96

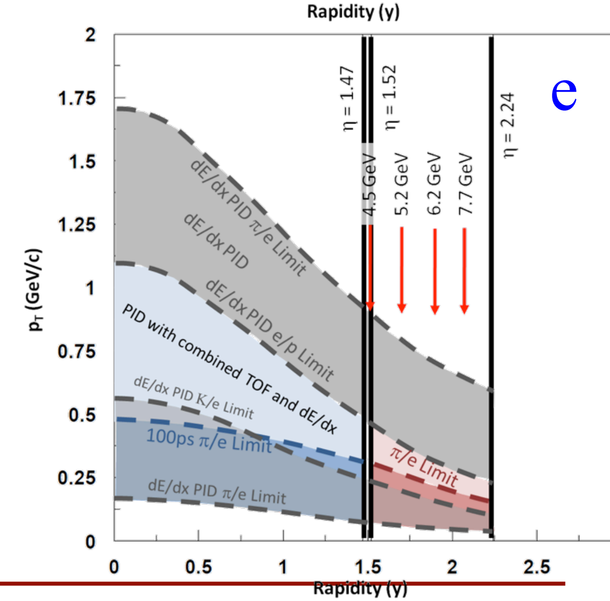


# PID capability @ Fixed-target mode




Fixed-target Mode

Covers mid-rapidity at fixed-target mode

- iTPC+eTOF: 1.52<η<2.24
- TPC+BTOF: 0<η<1.47

Overlap with collide mode at 7.7 GeV