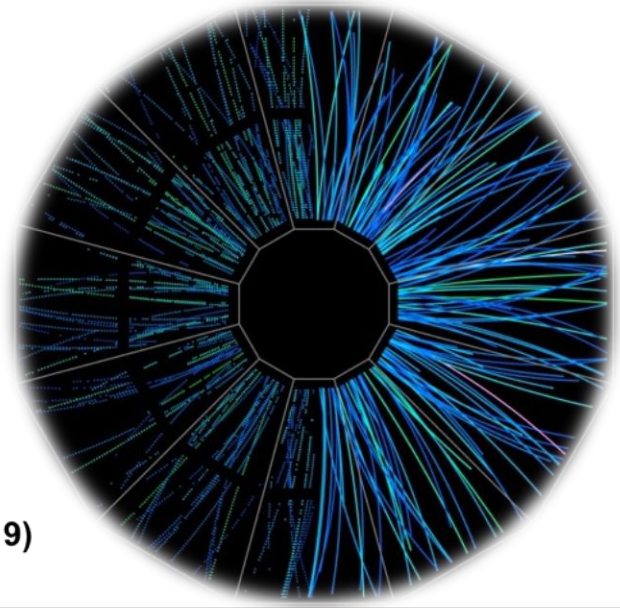
Status and performance of the detector upgrades for STAR in the BES-II and beyond

Florian Seck (TU Darmstadt)

for the STAR Collaboration

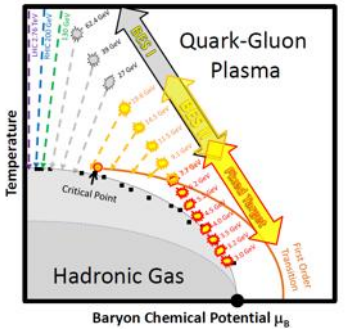
TECHNISCHE UNIVERSITÄT DARMSTADT

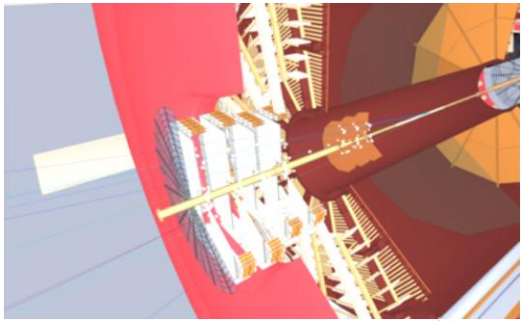


The 18th International Conference on
Strangeness in Quark Matter (SQM 2019)
10-15 June 2019, Bari (Italy)

Outline

- Performance in the Beam Energy Scan phase II (BES-II) program at RHIC
  - Motivation
  - Performance of the new sub-detectors: EPD, iTPC, eTOF
  - Progress with the BES-II
- Opportunities for forward physics at STAR
  - Motivation
  - Status of the forward detector upgrades
- Summary





Motivation: BES-II

- Interesting hints in many observables found in the BES-I program

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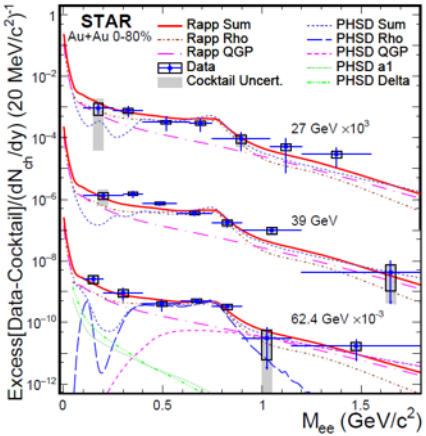
dielectron excess spectra



- Spectral function of ρ meson sensitive to total baryon density and temperature evolution during the collision
- Measure excitation function of low-mass excess
- Link to chiral symmetry restoration?

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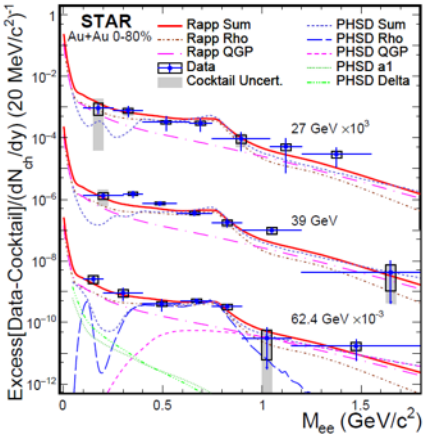

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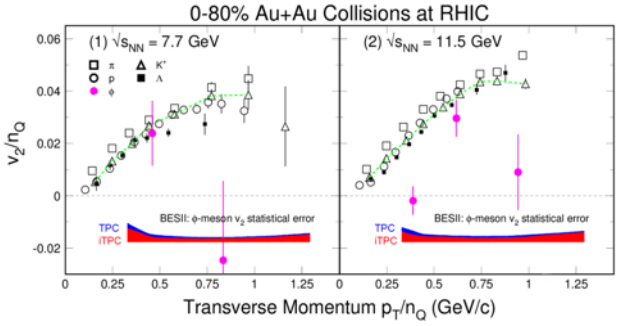

- Very small hadronic cross section of ϕ
- If confirmed, lack of collectivity at low collision energies indicates hadronic-interaction dominates medium
- Onset of Deconfinement?

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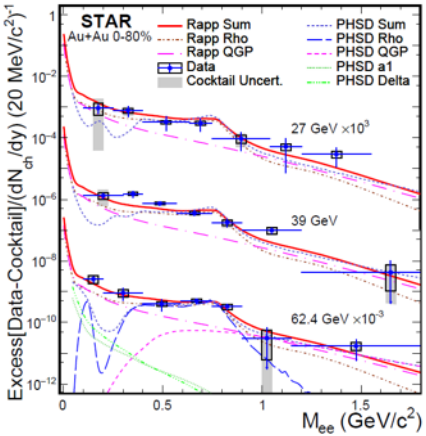

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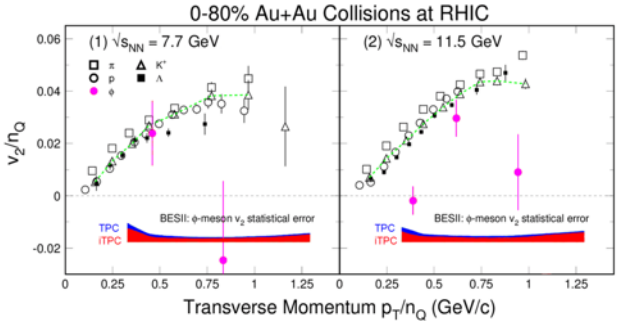

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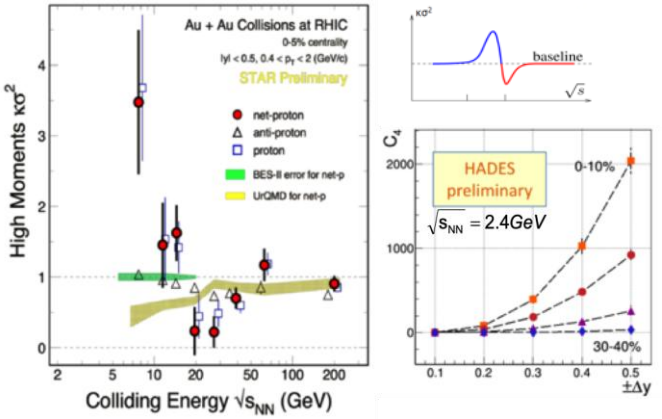
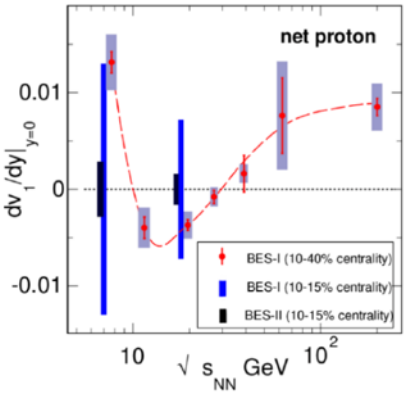


- Non-monotonic behavior indicating vicinity to the QCD critical point?
- Competition with HADES, BM@N, …
- Measure possible return to baseline within the same experiment

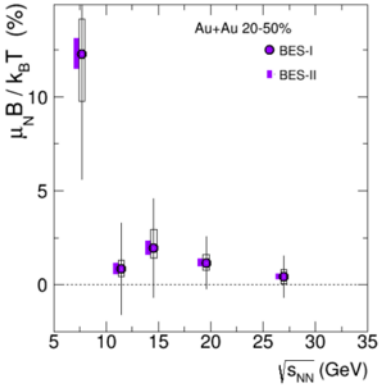
Motivation: BES-II

- Interesting hints in many observables found in the BES-I program
  - Dielectrons, elliptic flow v_2 of the ϕ meson, fluctuations of conserved charges
  - And many other observables

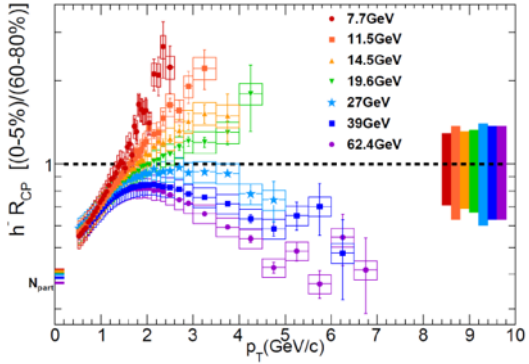
net-proton directed flow



difference of global (anti-)Lambda polarization



nuclear modification factor R_{CP}



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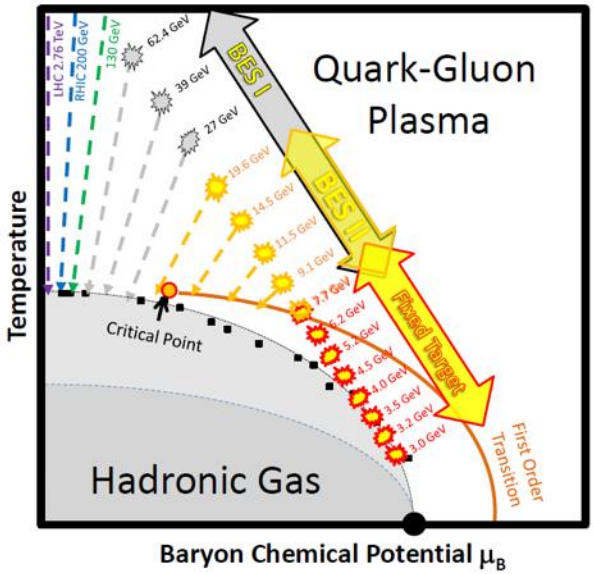
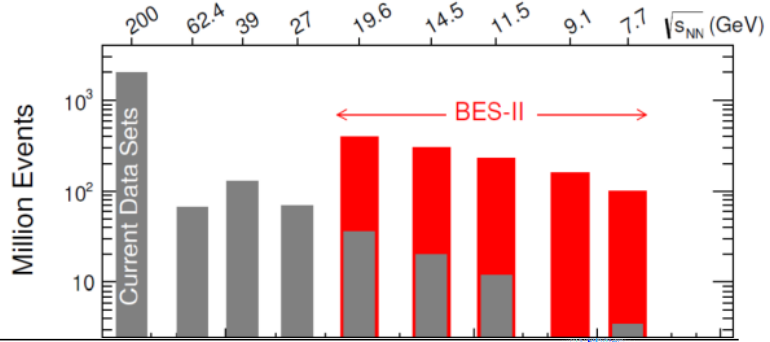
Motivation: BES-II

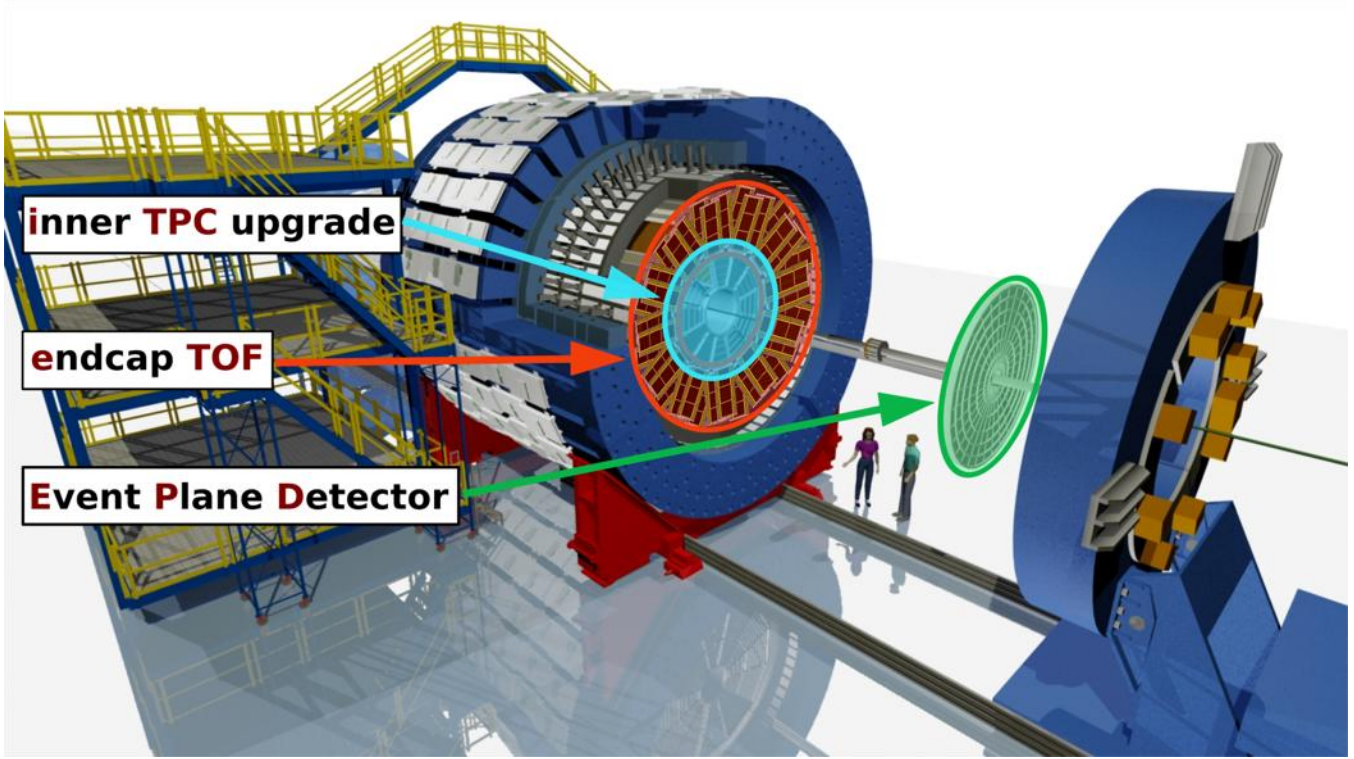
- Revisit the lower energies of BES-I in collider mode
- Fixed target program to reach even further down in $\sqrt{s_{NN}}$
  - Handshake at overlapping energy of 7.7GeV
- Typically 20 times more statistics than in BES-I
  - Low Energy RHIC electron Cooling (LEReC)
  - First RF linac-based electron cooler (bunched beam cooling)
- Significantly improved detector setup
  - Acceptance, efficiency, particle identification
  - EPD, iTPC, eTOF





STAR

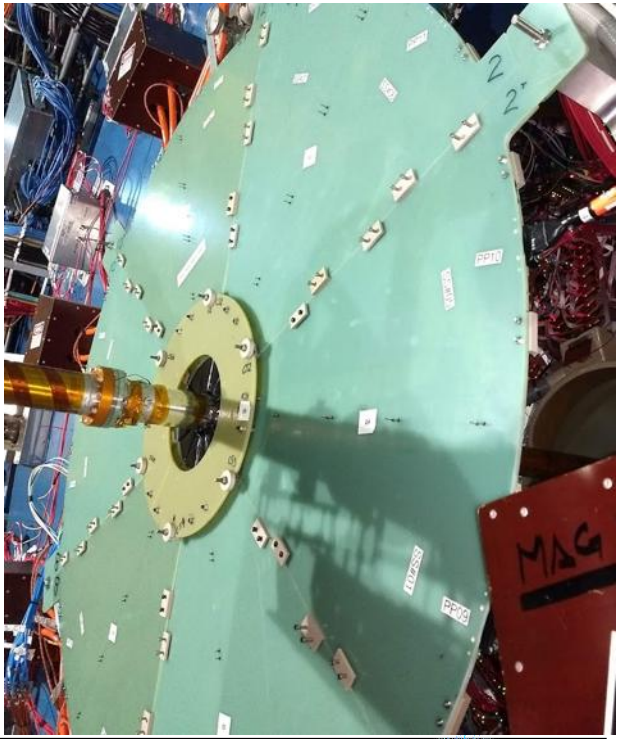
STAR detector upgrades for BES-II



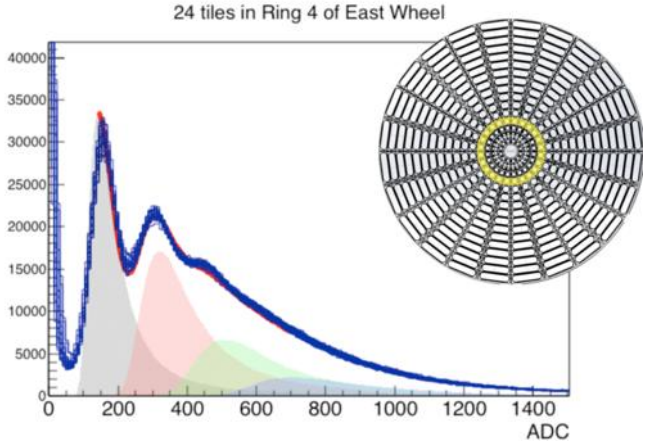
Event Plane Detector

STAR Note 666 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666

- Replaces Beam-Beam-Counters (BBC)
  - Higher granularity: two wheels (East,West) with 16 radial segments and 24 (12 for the innermost ring) azimuthal segments → 744 tiles
  - Larger acceptance: $2.1 < |\eta| < 5.1$ → coverage of ~10 units in η for v_1
- Centrality determination away from mid-rapidity
- Greatly improves event plane resolution
  - Crucial for key measurements in the BES-II: v_n, polarization
- Improved trigger capabilities
  - Asymmetry cut on hits in the East and West wheels can reduce background from beam-pipe collisions
- Already used for physics analysis of 2018 data

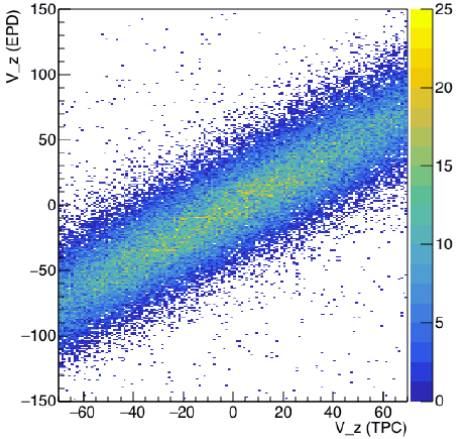


EPD Performance

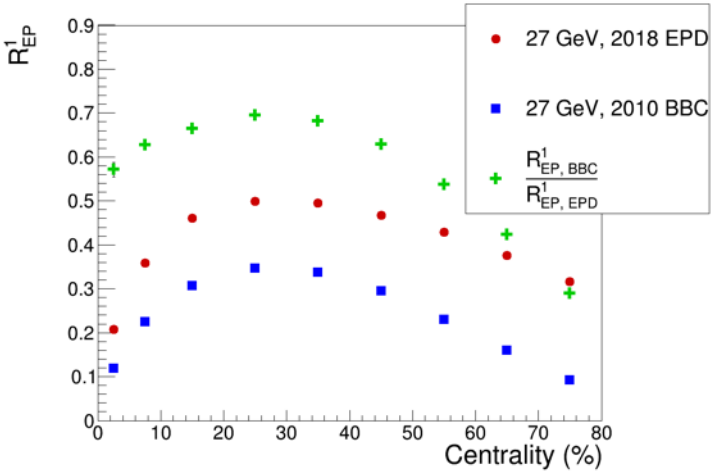


- Clear MIP peak in all 744 tiles
- Very good uniformity

→ identical ADC distributions of the tiles within each ring



- Correlation between offline vertex found by the TPC and the EPD
- EPD timing resolution σ = 0.75ns

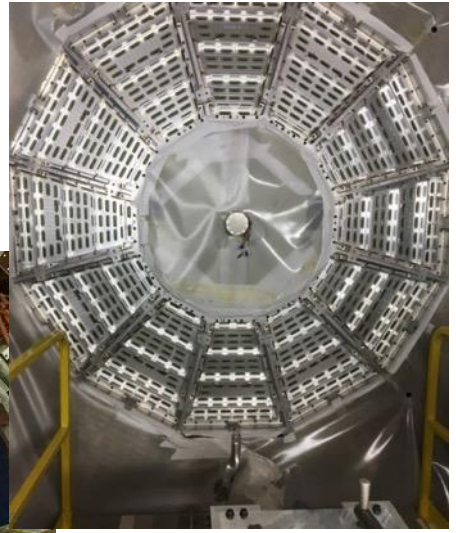


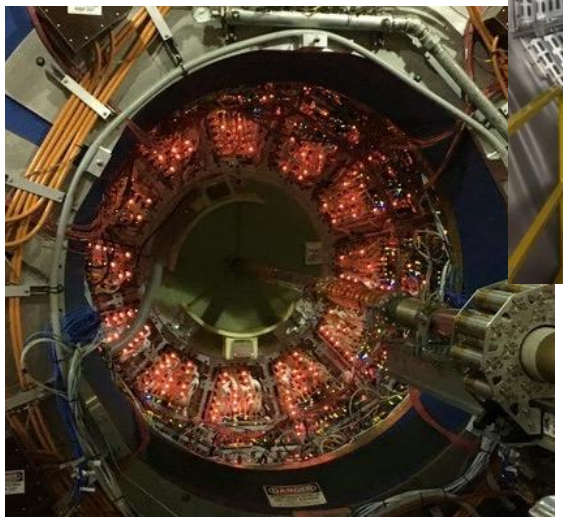
- Significantly improved 1st order event plane resolution across all centralities

Inner Time Projection Chamber Upgrade

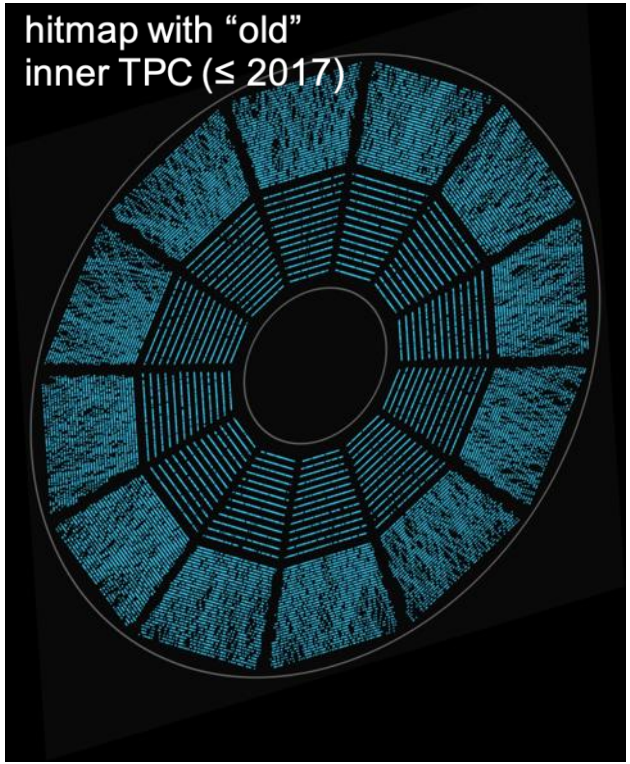
NIM A 896 (2018) 90, STAR Note 644 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0644

- Increase segmentation of the inner pad planes of the TPC
  - Continuous pad rows
  - Doubled the number of readout channels
- Successful commissioning of one sector during 2018 data-taking
- Installation of all 24 sectors completed during 2018 summer shutdown
- Integrated in 2019 data-taking since day-1





Evolution of the TPC



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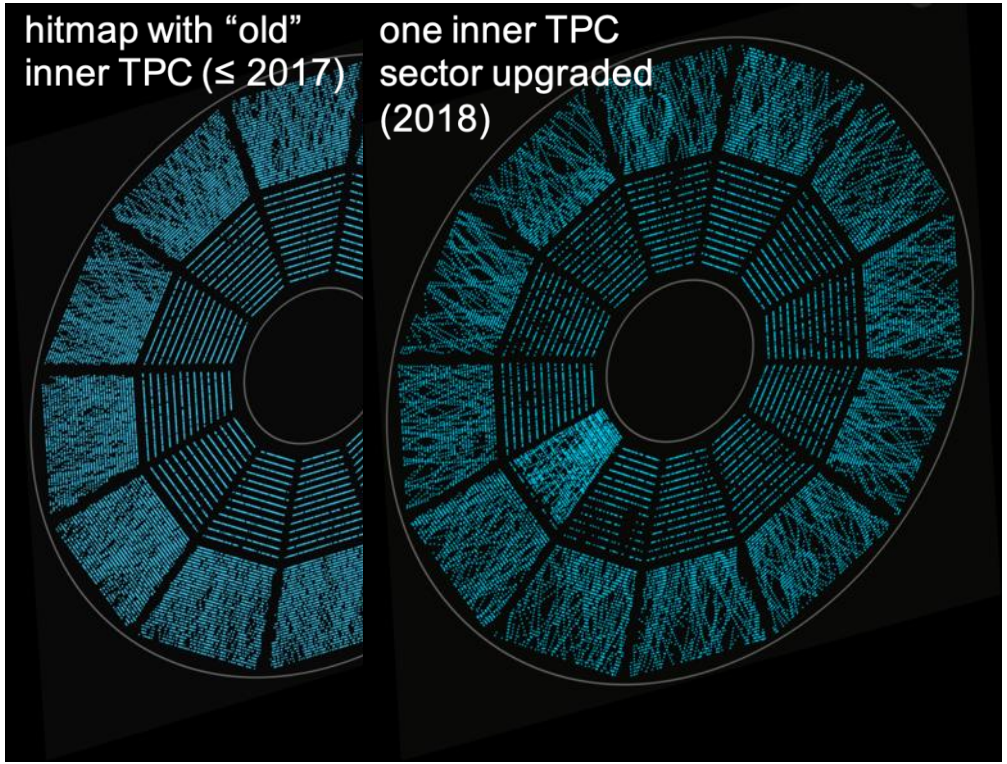

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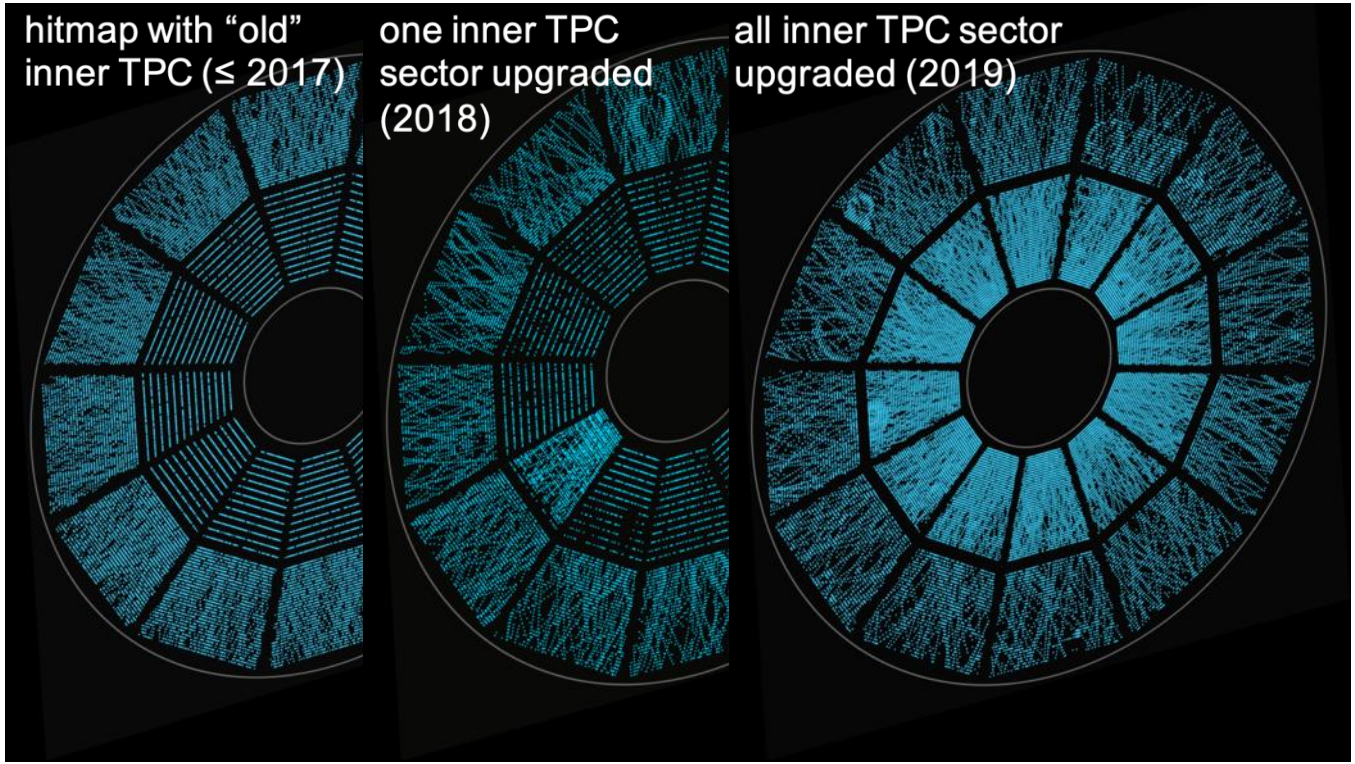

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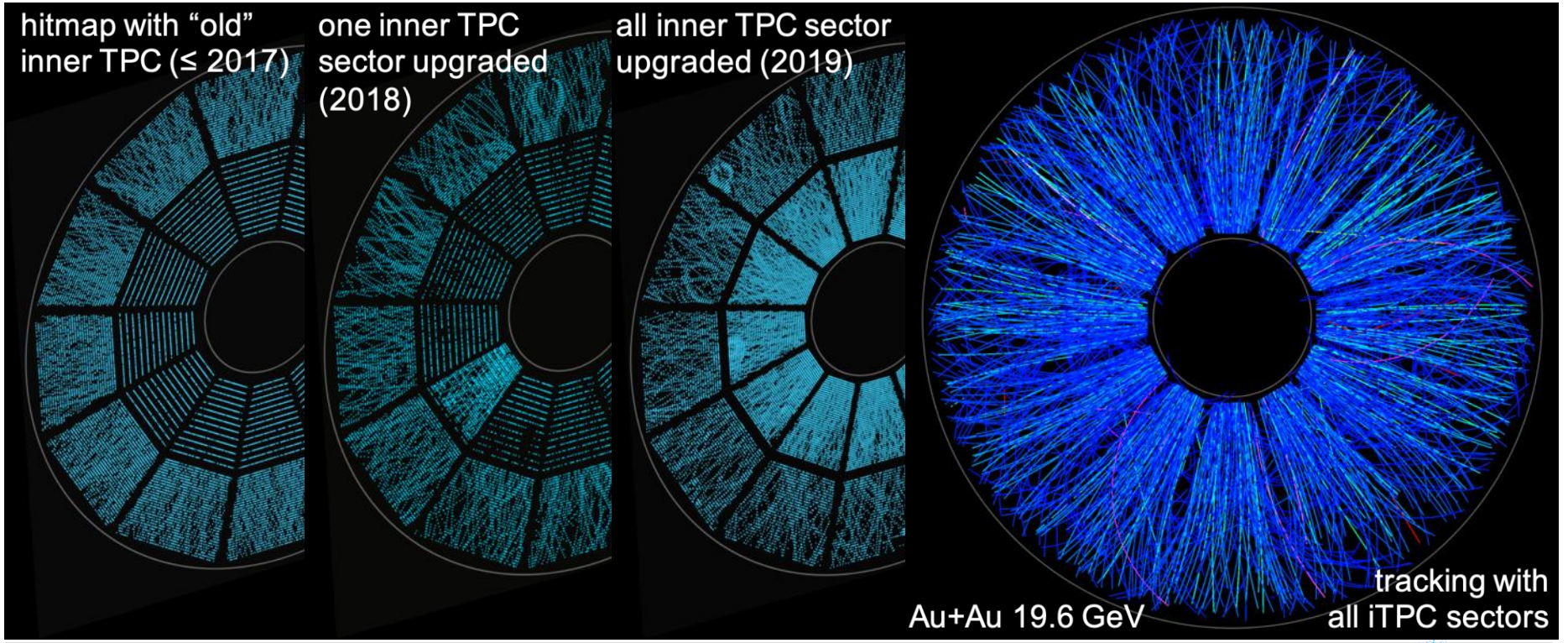
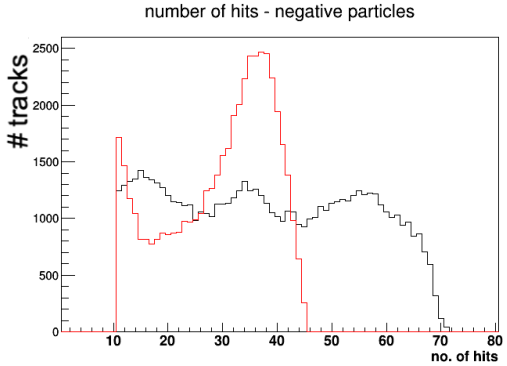
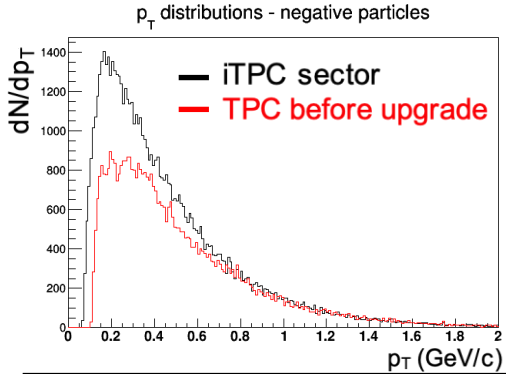
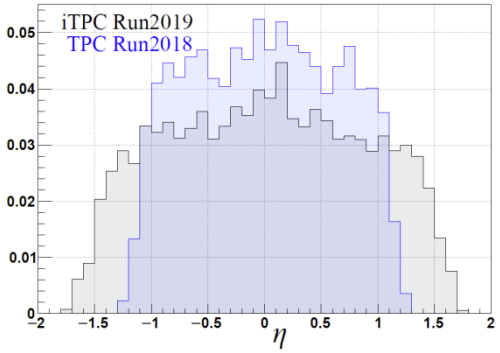


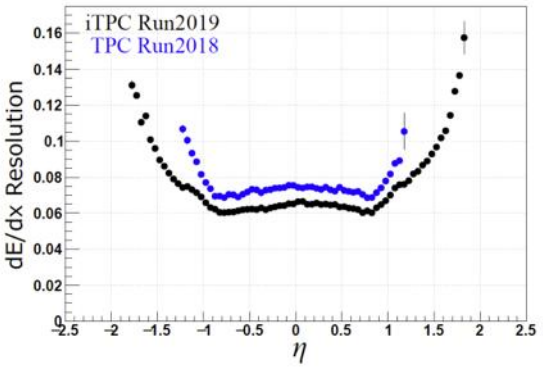
iTPC Performance





- Increased maximum number of hits per track from 45 to 72
- Improved momentum resolution
- Decreased minimum transverse momentum threshold from $p_T > 125$ MeV/c to $p_T > 60$ MeV/c
- Increased mid-rapidity coverage from $|\eta|<1.0$ to $|\eta|<1.5$
- Improved dE/dx resolution (15%-30%)

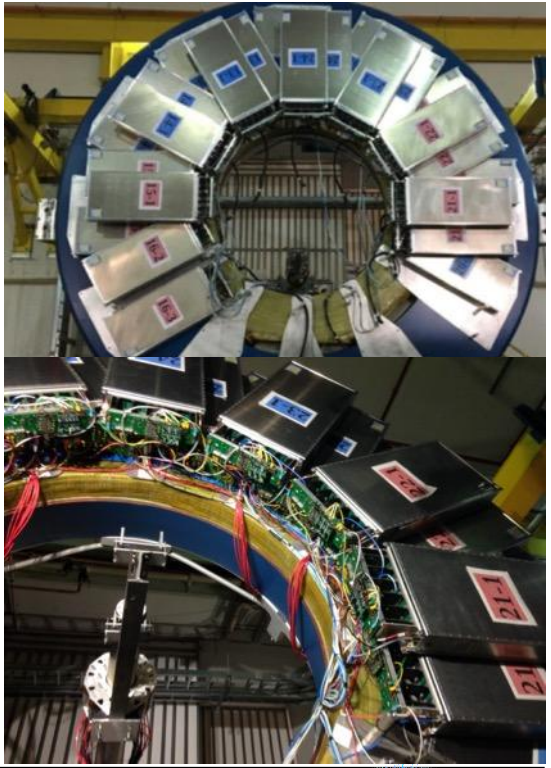




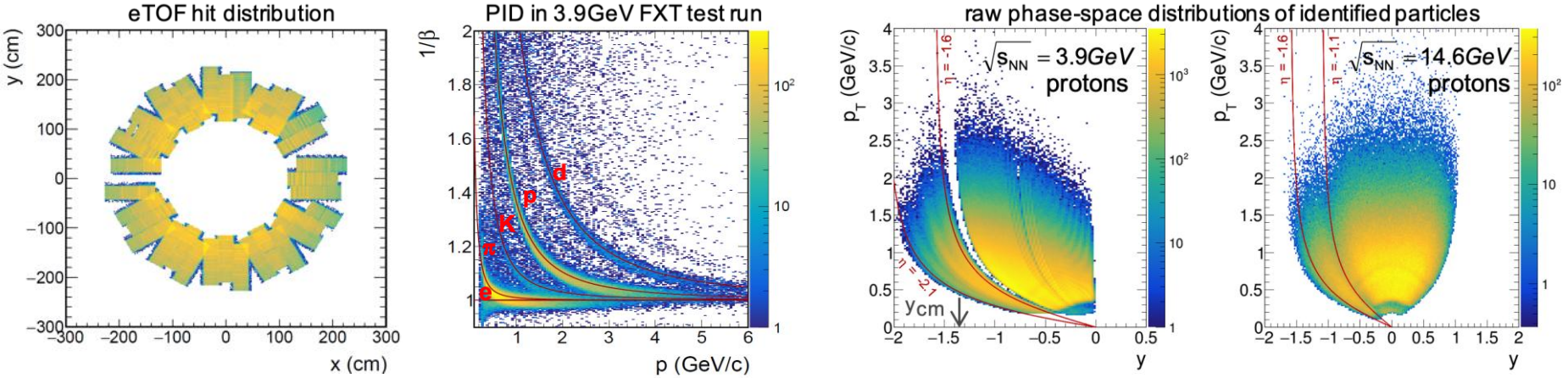
Endcap Time of Flight Detector

STAR Note 665 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0665

- East poletip of STAR equipped with 36 modules of MRPCs
  - 3 MPRCs with 32 strips per module: 6912 channels in total
  - Installation completed end of November 2018
- Extends particle identification capabilities and enables gapless scan of the QCD phase diagram in collider and fixed-target mode
  - Complements increased iTPC coverage $|\eta|<1.5$
  - Provides mid-rapidity PID in fixed-target program
    - Essential for fluctuation measurements
  - Exploration of rapidity dependence of key BES-II observables
- Synergy project with CBM collaboration as part of FAIR Phase-0
  - Operational experience via large-scale integration test of future CBM TOF



eToF Performance



- System time resolution of <85ps demonstrated with one test sector in 2018 data-taking
- Clearly distinguished particle bands over a large momentum range
- Extended phase-space coverage with eTOF PID in collider mode and fixed-targed collisions

Run-19 Progress

- 19.6 and 14.6GeV runs finished with surplus of recorded events
- 3.0GeV FXT data already taken 2018
- Currently commissioning 7.7GeV collider data-taking with LEReC to get a heads up for next year's production runs

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events	
9.8	19.6	205	4.5 weeks	400M	✓
7.3	14.5	260	5.5 weeks	300M	✓
5.75	11.5	315	5 weeks	230M	
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	
19.5	6.2 (FXT)	487	2 days	100M	
13.5	5.2 (FXT)	541	2 days	100M	
9.8	4.5 (FXT)	589	2 days	100M	
7.3	3.9 (FXT)	633	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	✓

Motivation: STAR Physics Program after BES-II

STAR Note 648 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648, STAR Note 669 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0669

- Unique opportunities at mid-rapidity in high energy A+A, p+A, and p+p collisions
  - Deep look into the QGP with e^+e^- pairs
  - Lower momentum π, K, p spectra
  - Hypertriton lifetime measurement
  - Precise direct photon yields and v_n
- Address fundamental questions in QCD at forward rapidity $2.5 < \eta < 4$ with the forward detector upgrade
  - Portal towards the Elector Ion Collider (EIC)

Beam:
200 GeV: Au+Au

Physics topics:
- Temperature dependence of viscosity through flow harmonics up to η~4
- Longitudinal decorrelation up to η~4
- Global Lambda polarization → strong rapidity dependence

Beam:
500 GeV: p+p
200 GeV: p+p and p+A

Physics topics:
- TMD measurements at high x
- transversity → tensor charge
- Improve statistical precision for Sivers through DY
- $\Delta g(x,Q^2)$ at low x through di-jets
- Gluon PDFs for nuclei → R_{pA} for direct photons & DY
- Test of saturation predictions through di-hadrons, γ-jets

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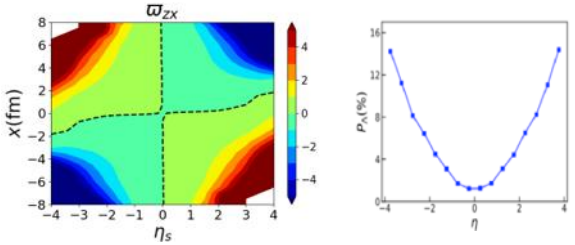
- Global Lambda polarization
  - Predicted to depend on viscosity
  - Viscous hydrodynamic evolution introduces strong trend with rapidity
  - Measurements at forward rapidity are key



Li, Pang, Wang & Xia, PRC 96 (2017) 054908; (private comm.)
F. Beccattini et al. EPJ C 75 (2015) 406

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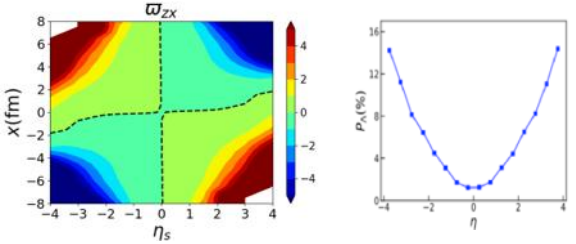

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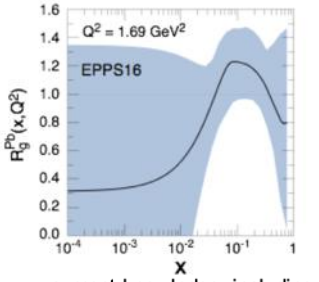
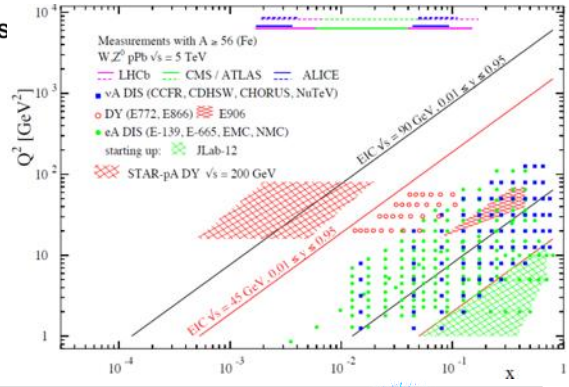
F. Beccattini et al. EPJ C 75 (2015) 406

- Probing the initial state
  - Nuclear PDFs poorly constrained at low-x
  - Unique kinematic coverage by STAR forward upgrade
  - Measure nPDFs in a x-Q^2 region where nuclear effects are large
  - Observables free of final state effects
    - Direct photons → gluon PDF
    - Drell-Yan process → sea quarks



current knowledge including first LHC p+A data

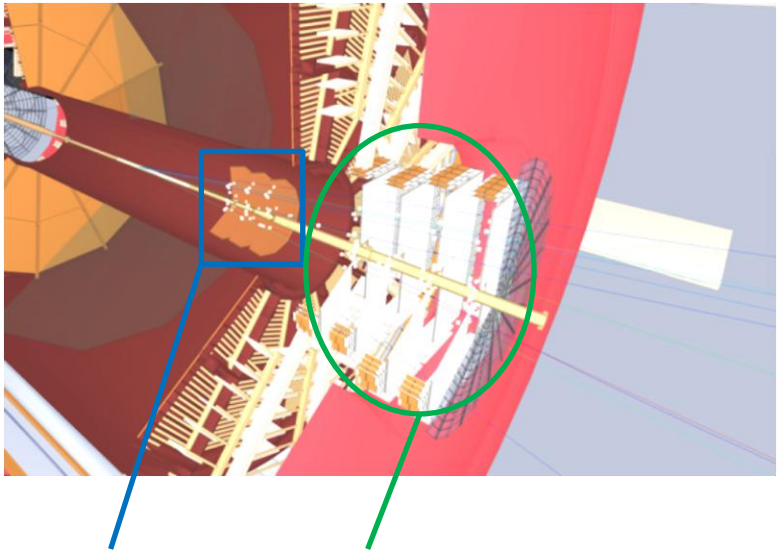
pA@RHIC: unique kinematics



STAR Forward Detectors: FTS + FCS

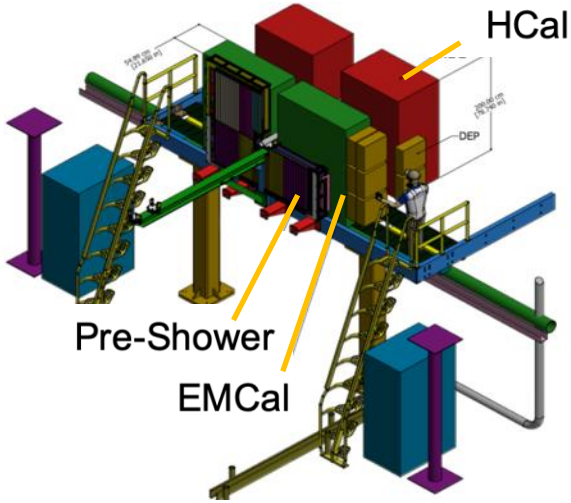
Forward Tracking System

- Located at the West side of STAR
- Coverage: $2.5 < \eta < 4$
- Reuse existing equipment as much as possible



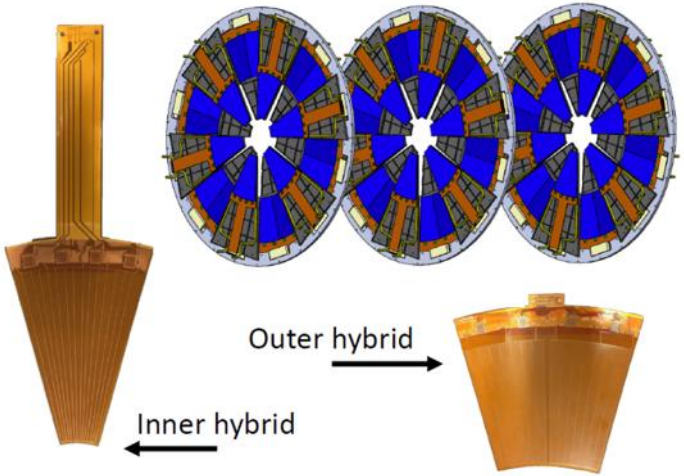
Silicon + small-Strip Thin Gap Chambers (sTGC)

Forward Calorimeter System



Forward Tracking System

- Requirements
  - Momentum resolution < 30% in 0.2 < pT < 2 GeV/c (A+A)
  - Tracking efficiency of 80% at 100 tracks per event (A+A)
  - Charge separation (p+p / p+A)
- Silicon mini-strip disks: 3 layers
  - Location from interaction point: z = 139.9, 163.2, 186.5 cm
  - Build on STAR experience with IST detector (part of HFT)
  - Detector module design and prototyping in progress
  - First complete prototype ready for test in Fall/Winter 2019



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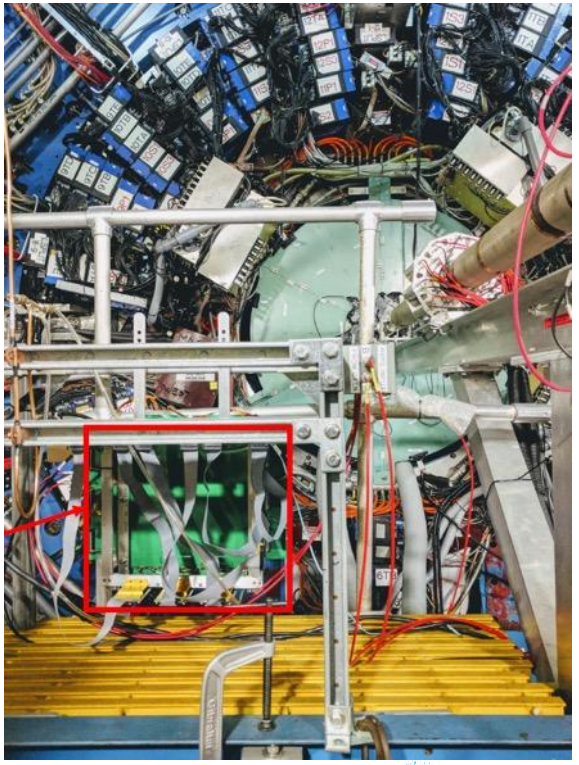
  - Tracking efficiency of 80% at 100 tracks per event (A+A)
  - Charge separation (p+p / p+A)
- Small-Strip Thin Gap Chamber (sTGC): 4 layers
  - Location z = 270, 300, 330, 360 cm
  - Significant reduction in cost
  - 30x30 cm prototype delivered to BNL in January
  - Module tested with cosmic rays and commissioned with STAR DAQ
  - Installed in STAR on June 5, 2019
  - Full size 60x60 cm prototype in production



Forward Calorimeter System

- Requirements

Detector	p+p and p+A	A+A
EMCal	~10% / √E	~20% / √E
HCal	~50% / √E + 10%	-

- Electronic Calorimeter
  - Use PHENIX PbSc
  - New readout SiPM + FEE

- Hadronic Calorimeter
  - Sampling iron-scintillator

- Large scale test run at Fermilab in April 2019
  - 16 channels of HCal and EMCal each
  - Promising results: resolution requirement met
- Installation and in-situ testing at STAR
  - 64 (8x8) EMCal installed, 16 (4x4) HCal installed
  - 1 layer (9 slats) Pre-Shower (former FMS Post-Shower)
  - New generation of digitizer/trigger boards
- Currently commissioning in STAR with beam
- 10-20 hours of Au+Au 200 GeV collisions planed in July (parasitic to APEX running)
  - Test readout of calorimeters at ~10kHz rate

Summary

Upgrades for BES-II

- EPD, iTPC, eTOF successfully commissioned and integrated into data-taking
- BES-II in full swing: first two collider energies already finished with statistics goals exceeded
- Many exciting results to be deduced from the data on tape

STAR Forward Rapidity Upgrade

- Unique program addressing several fundamental questions in QCD paving the way towards an EIC
- Design of all sub-detectors components finalized: HCal + EMCal + tracking(Si + sTGCs)
- Prototypes are tested at STAR right now
- Ready for data-taking after the BES-II in 2021