The STAR beam energy scan phase II physics and upgrades

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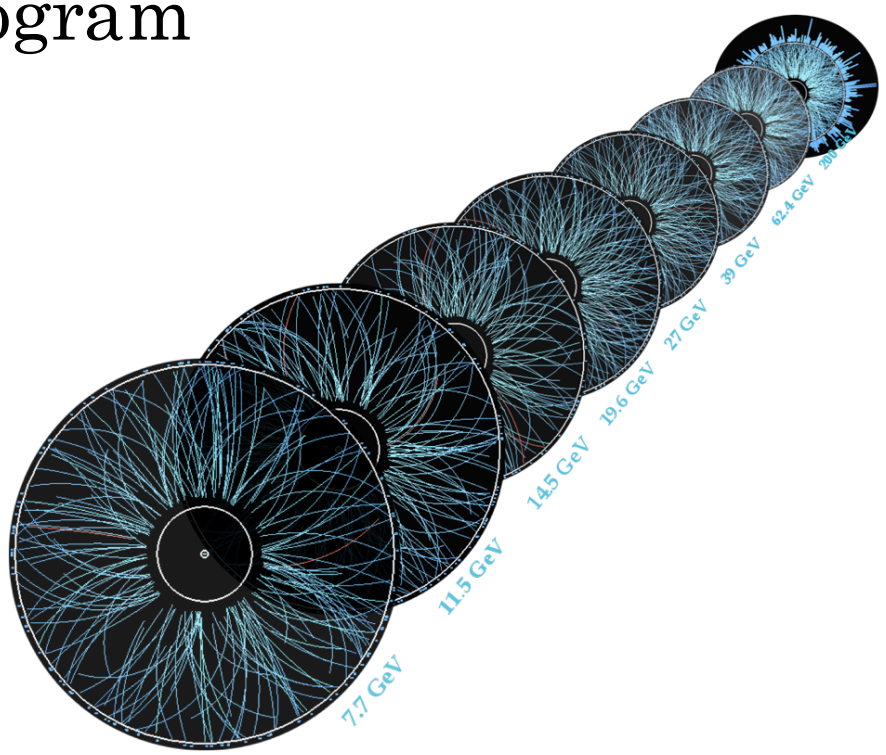
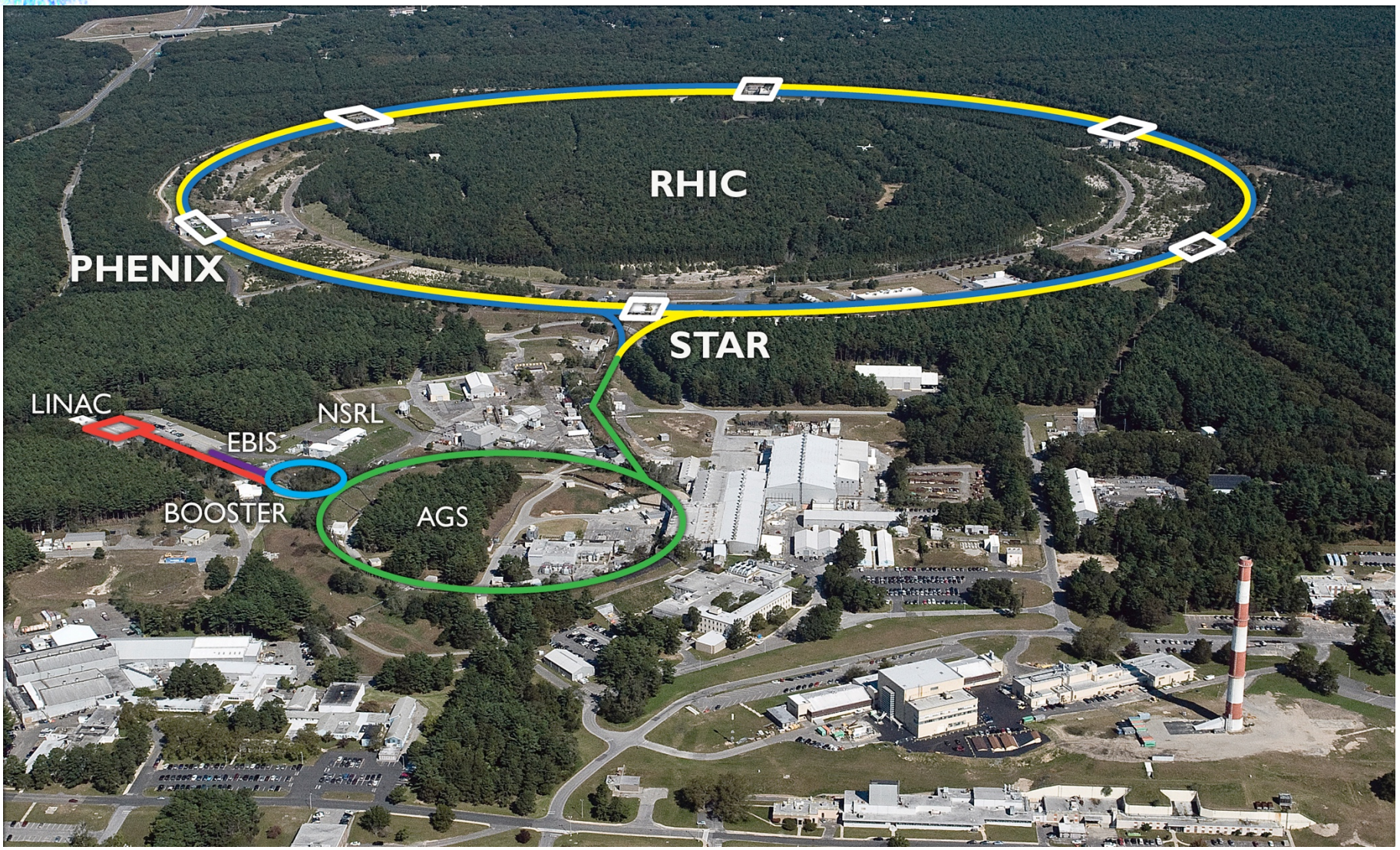
National Natural Science Foundation of China

Outline

- STAR@RHIC
- STAR detector upgrade
- Motivation of the upgrades
- Beam Energy Scan program
- Summary

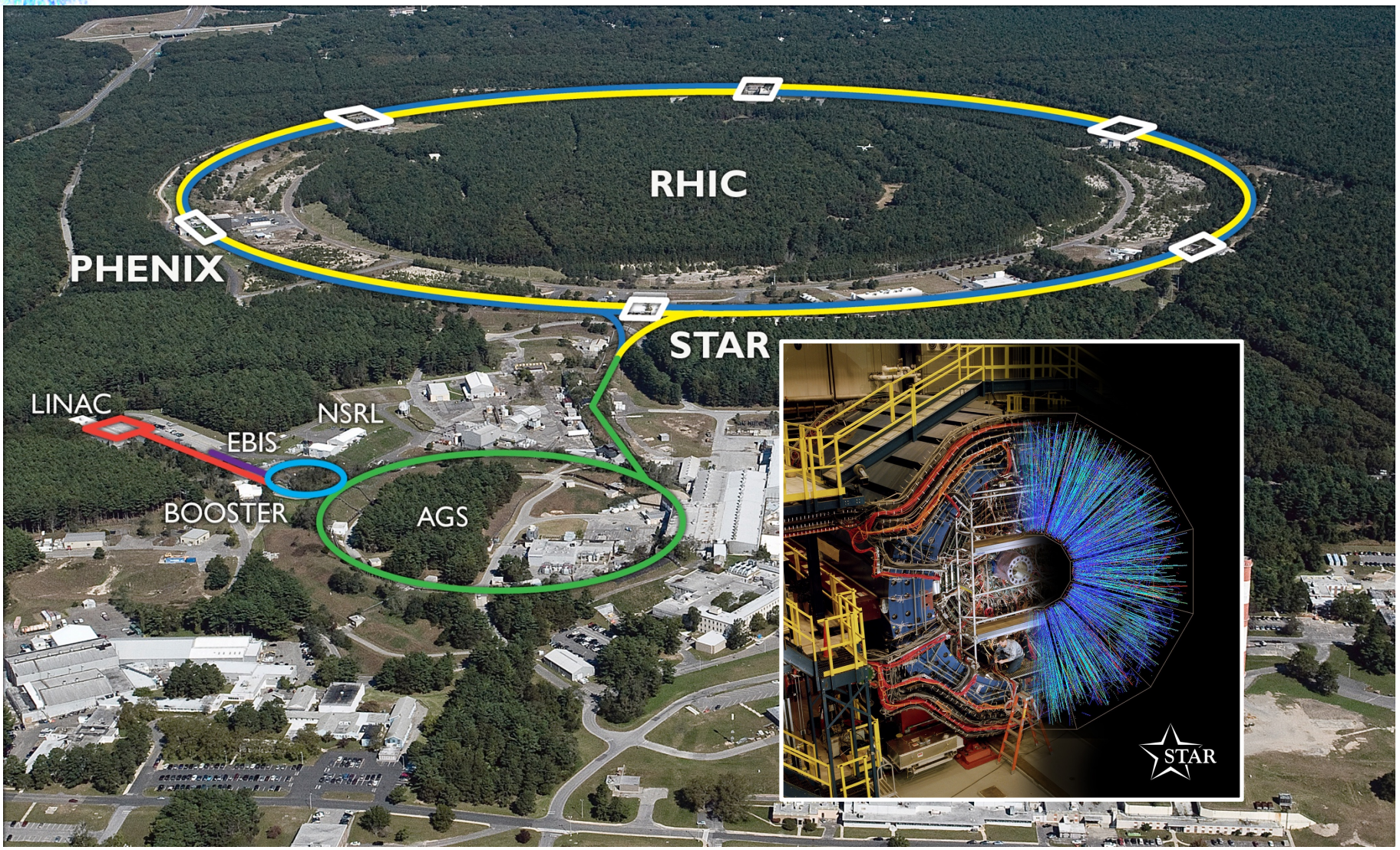


Relativistic Heavy Ion Collider



Located in Brookhaven National Laboratory, Upton, New York, USA

Solenoidal Tracker At RHIC



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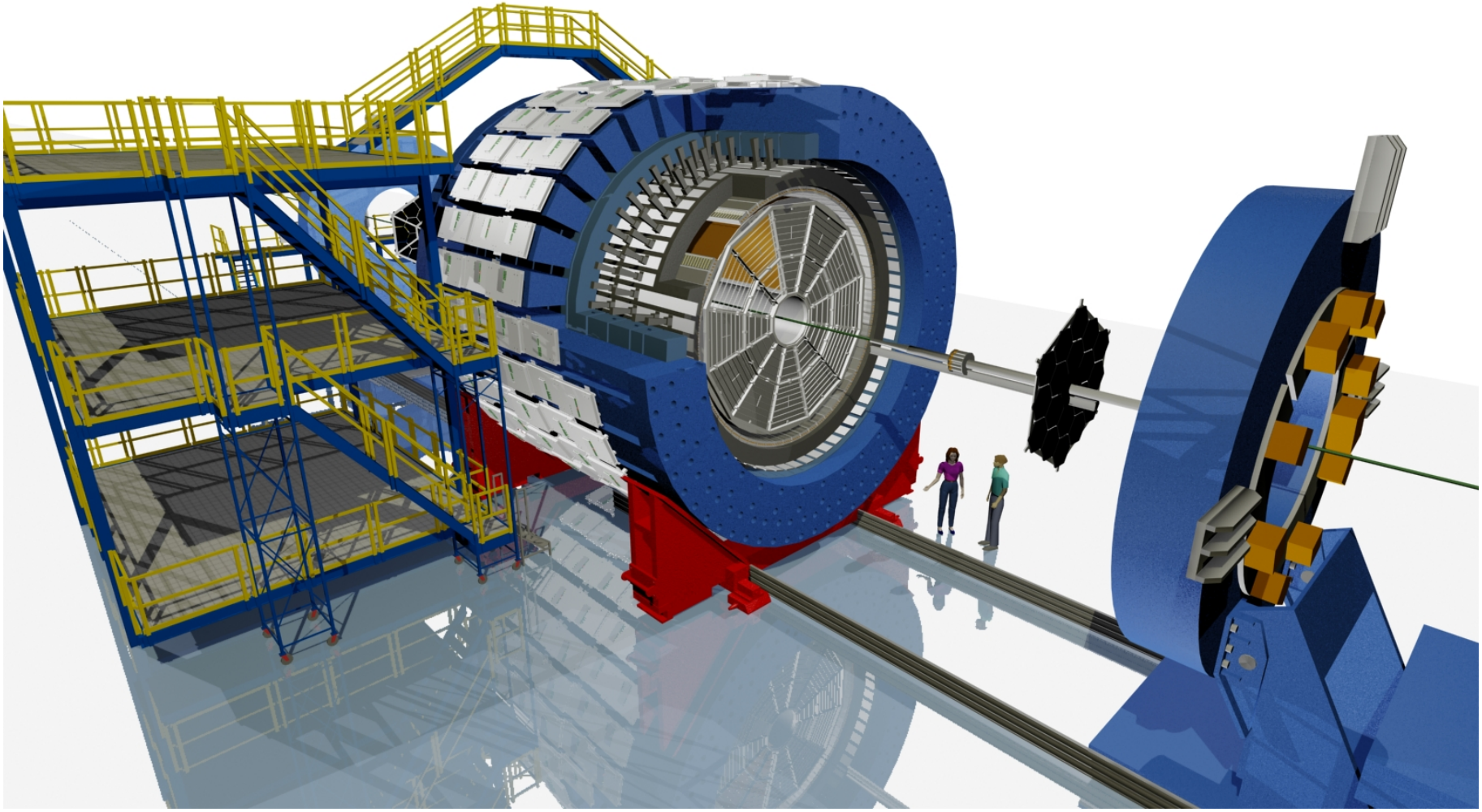
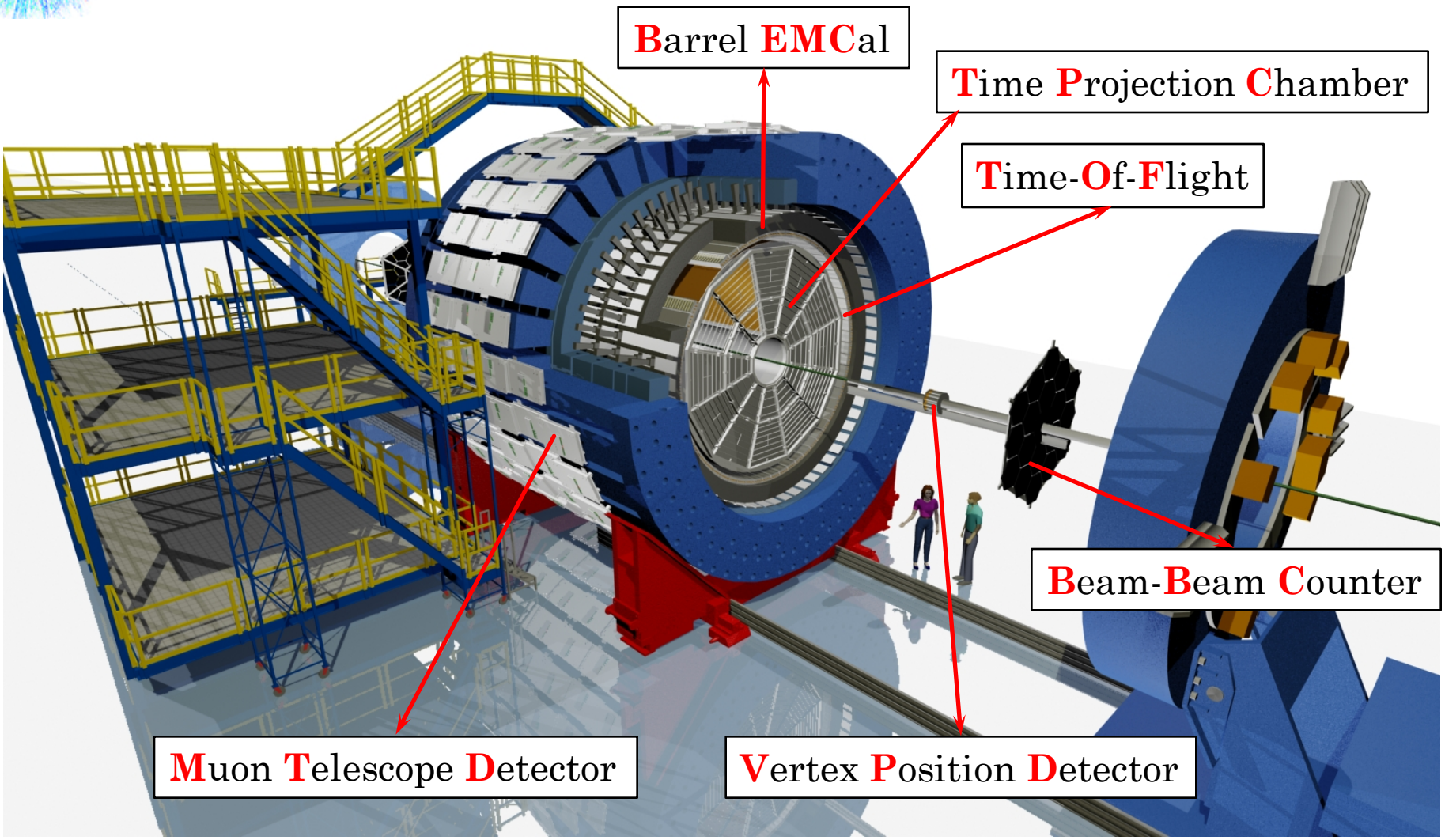
Current STAR detector

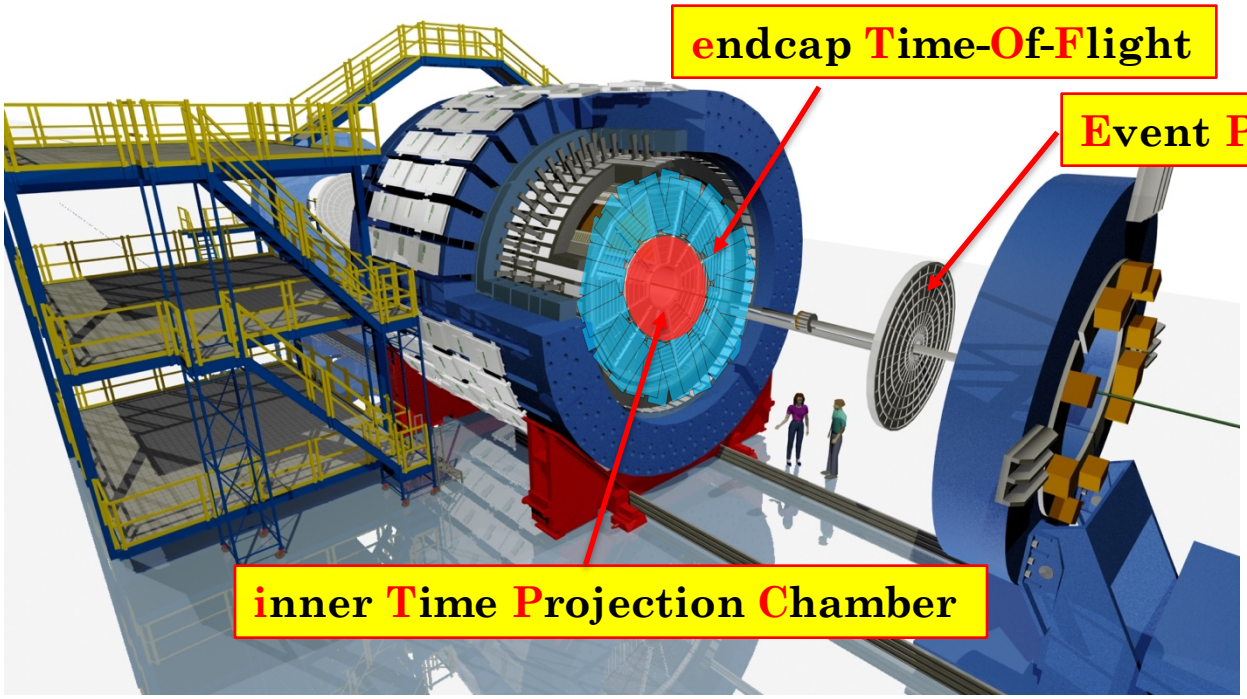


Current STAR detector



Large acceptance, good particle identification
Plenty of interesting physics results over years

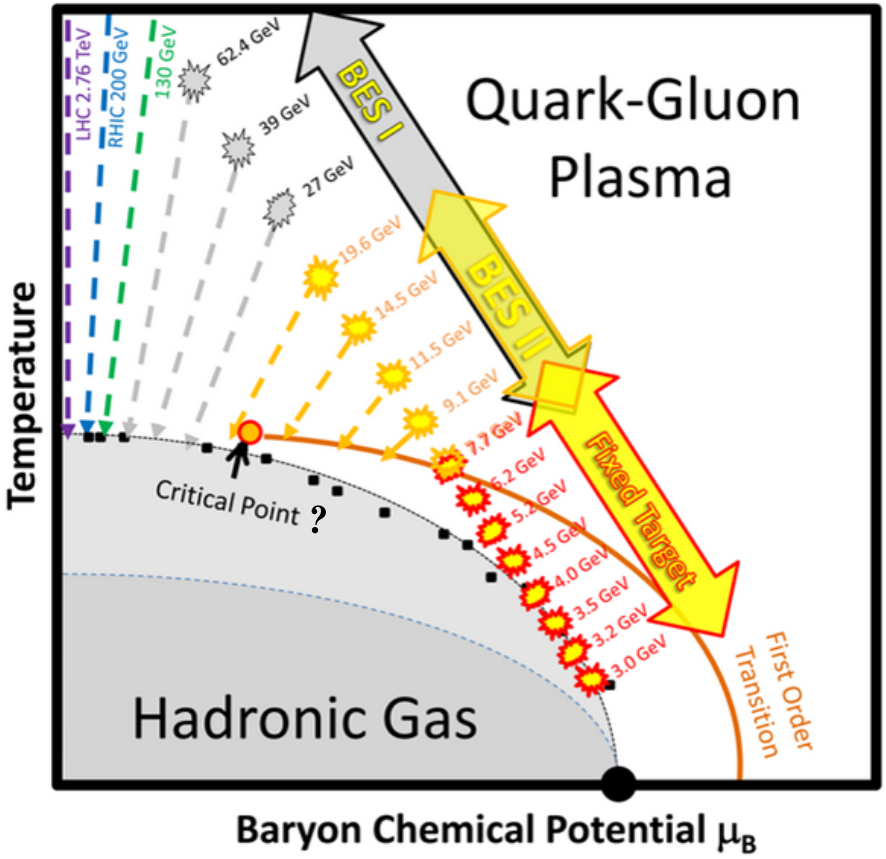
Ongoing detector upgrade



iTPC upgrade	EPD upgrade	eTOF upgrade
Continuous pad rows Replace all inner TPC sectors	**Replace Beam Beam Counter**	**Add CBM TOF modules and electronics (FAIR Phase 0)**
$\|\eta\|<1.5$ (was 1.0)	**$2.1<\|\eta\|<5.1$**	**$-1.6<\eta<-1.1$**
p_T >60 MeV/c (was 150MeV/c)	Better trigger & b/g reduction	Extend forward PID capability
Better dE/dx resolution Better momentum resolution	Greatly improved Event Plane info (esp. 1st-order EP)	Allows higher energy range of Fixed Target program
Fully operational in 2019	**Fully operational in 2018**	**Fully operational in 2019**

Why do we need to upgrade these subsystems?

Physics motivation for Beam Energy Scan program



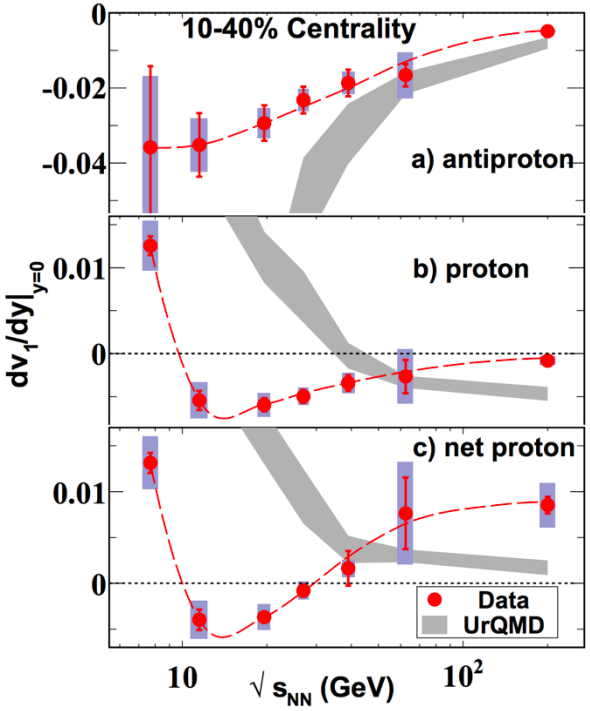
Explore the QCD phase diagram

- Signs of 1st order phase transition ⟹ HBT, v_1 analyses
- QCD critical point. ⟹ Fluctuation analyses (net-proton kurtosis)
- Chiral symmetry restoration ⟹ Dilepton analyses
- Signature on QGP turn-off. ⟹ R_{cp}, CME, ϕ v_2

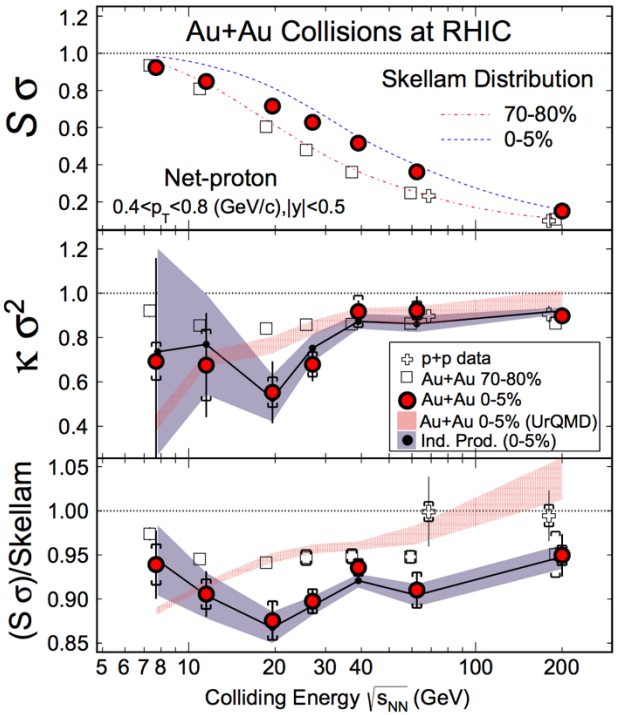
RHIC Beam Energy Scan Phase I

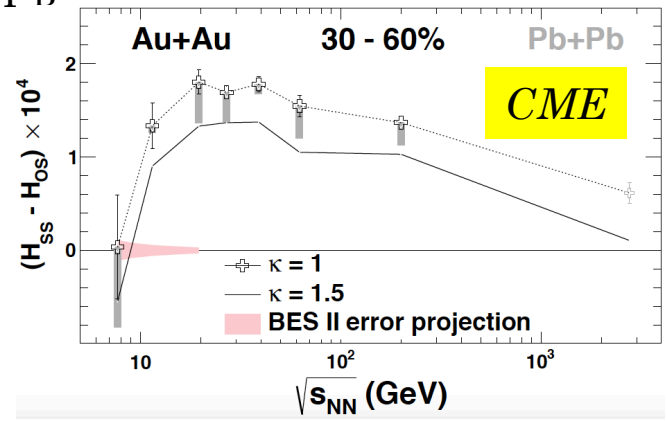
- From 2010 to 2014
- 8 collision energies 200, 62, 39, 27, 19.6, 14.5, 11.5 and 7.7 GeV
- Vary temperature T and baryon chemical potential μ_B

Direct flow

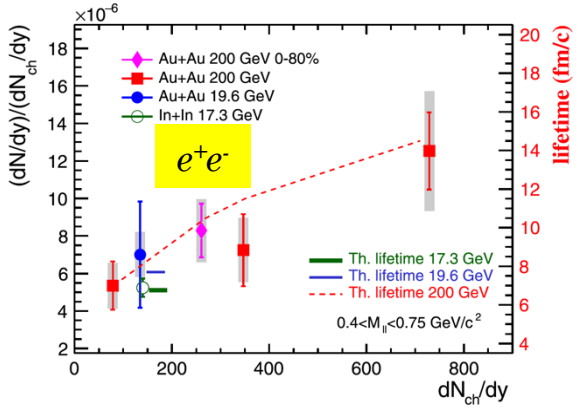


Net-proton cumulants





[*Phys. Rev. Lett. 113 (2014) 52302*]

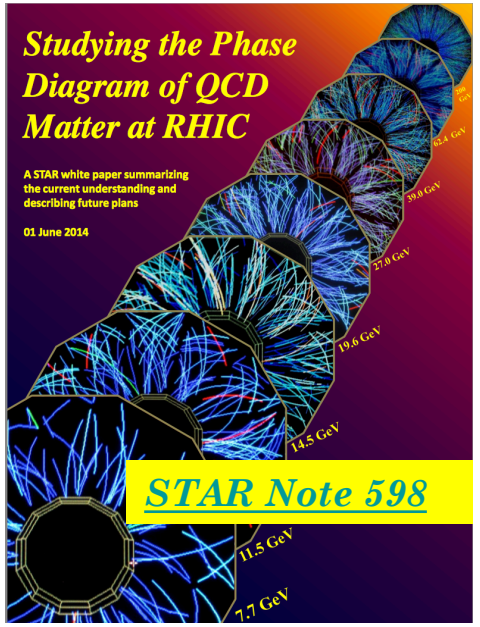


[*Phys. Rev. Lett. 112 (2014)162301*] [*Phys.Rev.Lett. 112 (2014) 032302*] [*Phys.Lett.B, 750 (2015) 64-71*]

Beam Energy Scan Phase II (BES-II)

- ✓ In *2019 & 2020*
- ✓ *7.7, 9.1, 11.5, 14.5* and *19.6* GeV
- ✓ μ_B from *205* to *420* MeV
- ✓ *10 -- 25* times more statistics
- ✓ Detector upgrades
- ✓ Low Energy Electron Cooling at RHIC

Collision Energies (GeV)	Proposed Event Goals (M)	BES-I Event (M)
7.7	100	4
9.1	160	N/A
11.5	230	12
14.5	300	20
19.6	400	36



Physics impact for the detector upgrade in BES-II

Low Energy Electron Cooling at RHIC:

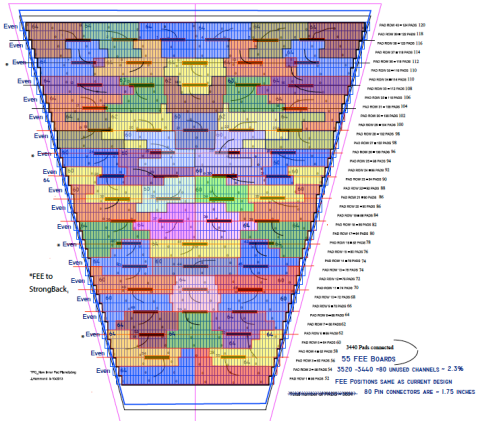
- ✓ Electron Cooling can raise the luminosity by a factor of 3-10 in the range from 5 – 20 GeV (will be applied to 7.7 – 15 GeV data taking)
- ✓ Long Bunches increase luminosity by factor of 2-5

The upgrades for BES-II will improve many of the STAR analyses

- ✓ Better statistics
- ✓ Better resolution
- ✓ Smaller systematic uncertainty
- ✓ Wider rapidity range
- ✓ Wider p_T coverage

Only some selected physics topics will be discussed in this presentation

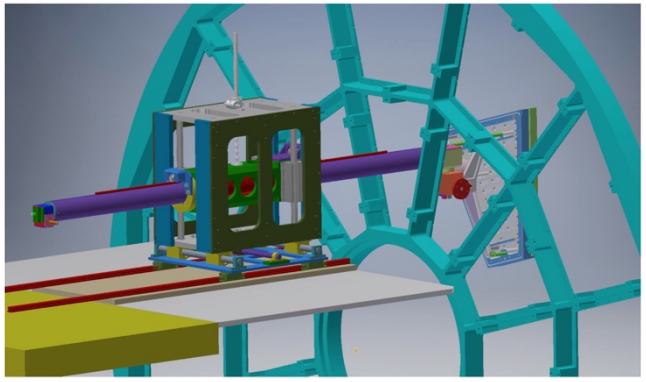
The inner TPC upgrade



Replace all 24 inner sectors including:

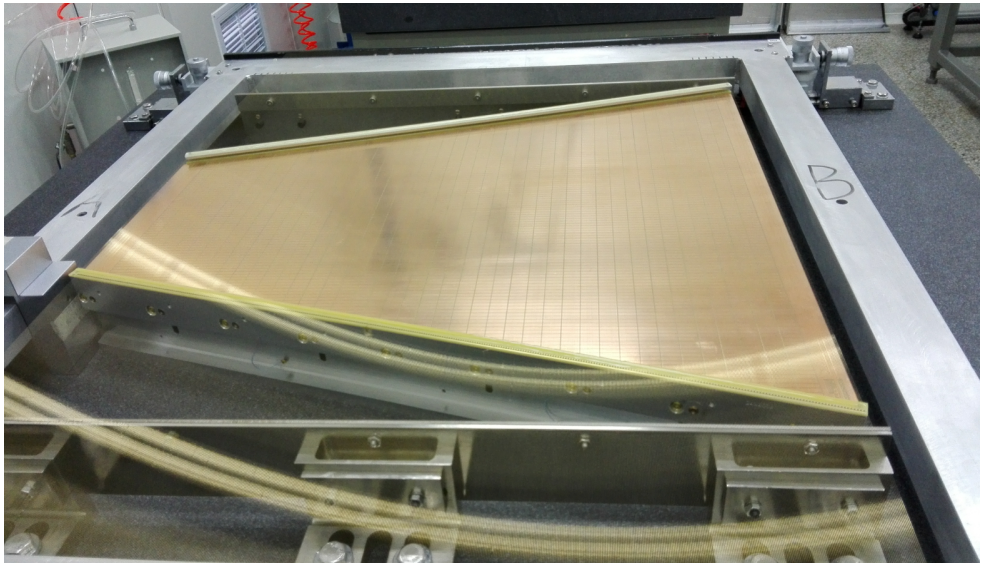
- ✓ Increase readout pad rows from 13 to 40
  -- *20% -> ~100% readout pads coverage*
- ✓ Renew all three wire frames
  -- *Replace ageing wires, MWPC building in Shandong University*
- ✓ New electronics for inner sectors
  -- *Double # of readout channels per FEE, use ALICE SAMPA chip*
- ✓ New designed insertion tools
  -- *Install and replace sectors, STAR operations*
- ✓ New designed strongback
  -- *Ongoing in LBL*

STAR Note 619
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0619

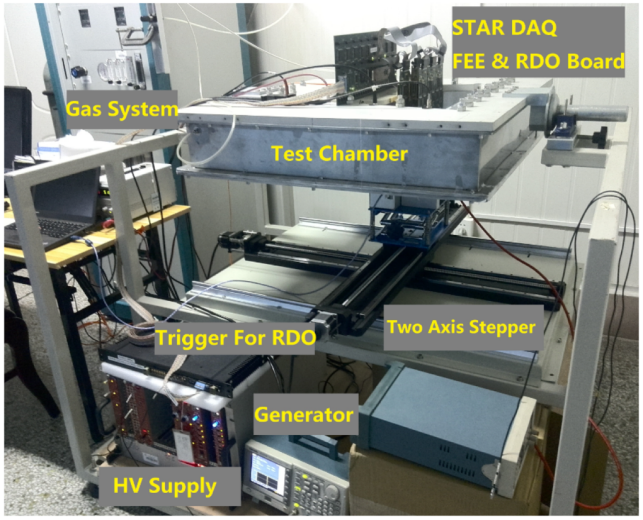


MWPC production for iTPC

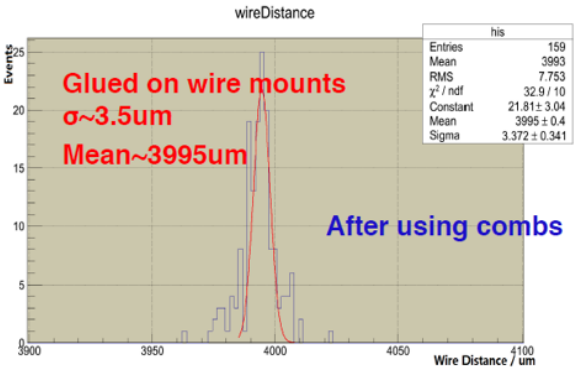
- ✓ MWPC mass production started
- ✓ Qualified wire tension, pitch, height
- ✓ Qualified gas gain uniformity (~1% RMS)

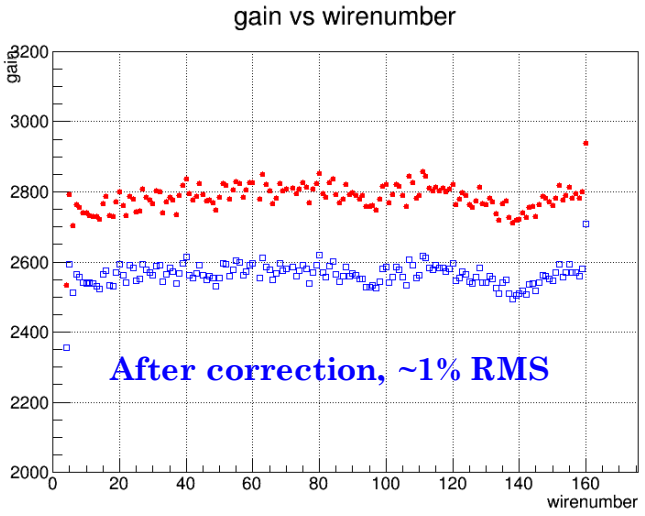


MWPC testing system

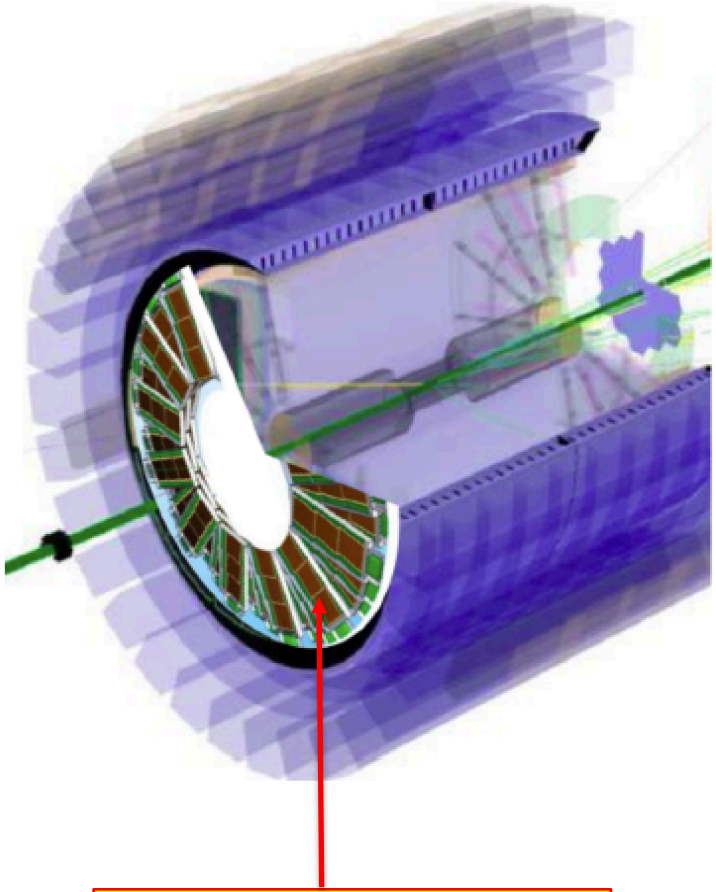


MWPC anode wire pitch





The endcap Time-Of-Flight upgrade

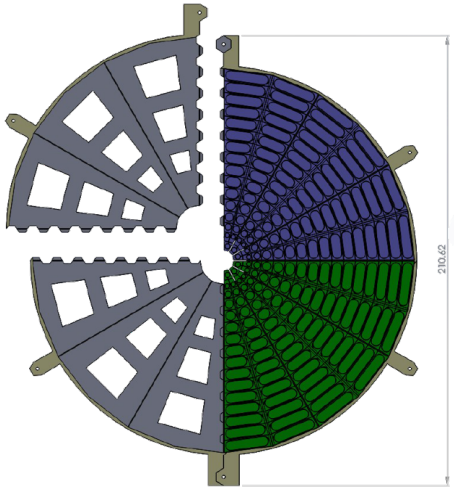


CBM and STAR collaborate and agree to install 10% of the full CBM TOF system at STAR (FAIR Phase 0)

- ✓Provides STAR with an endcap TOF for BES-II
- ✓Provides CBM a test of the CBM TOF system with large data samples (both in events and the scale of the system)
- ✓Provides PID in forward direction
- ✓Essential to STAR Fixed Target program at BES-II

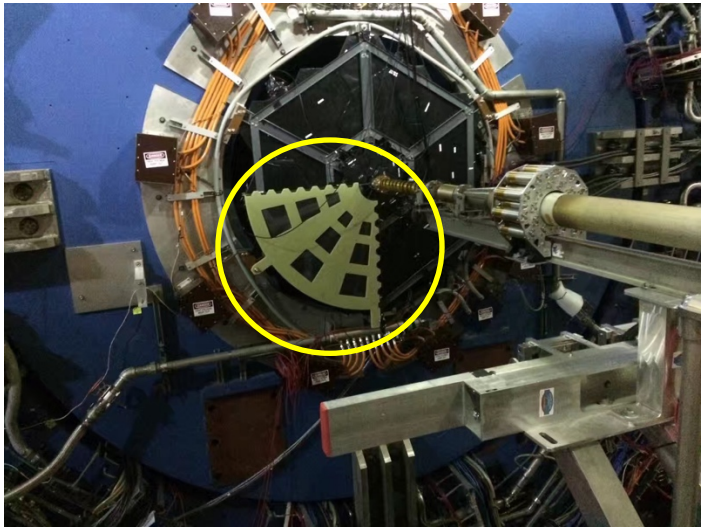
The Event Plane Detector upgrade

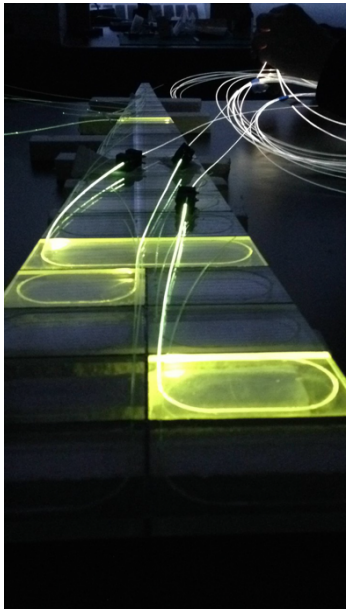
Centrality definition and event plane resolution are important for BES-II



For examples:

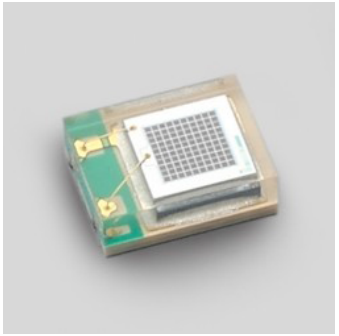
- ✓ Net-proton higher moments
- ✓ dv_1/dy for net protons
- ✓ v_2 of identified particles



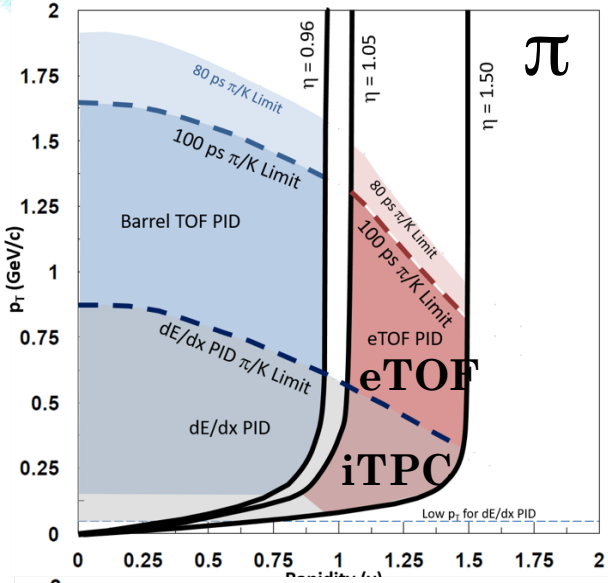


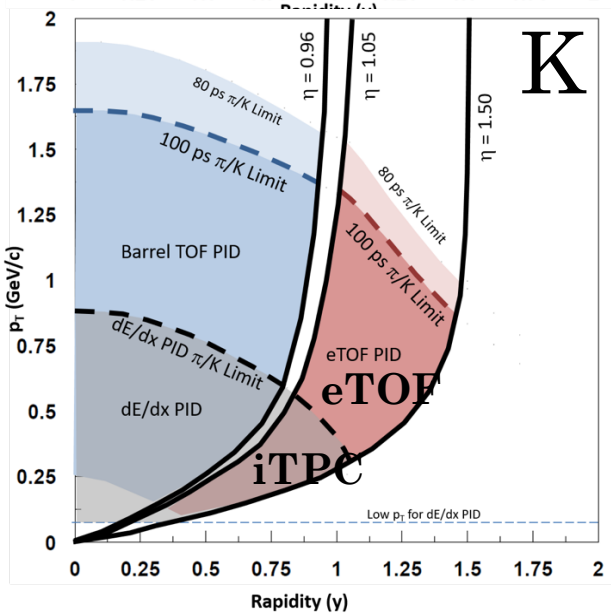
Wave Length Shifting fibers + scintillator + Silicon Photon Multiplier

- ✓Large forward eta coverage $2.1<|\eta|<5.1$
- ✓Installed at z position +/- 375 cm
- ✓24 azimuthal segments – better event plane resolution
- ✓16 radial segments – centrality independent with TPC
- ✓Good timing resolution (~ 1 ns)



Maps of Acceptance



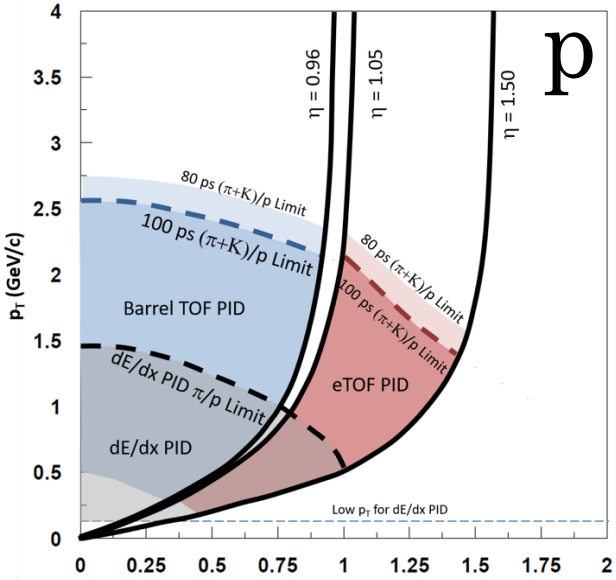


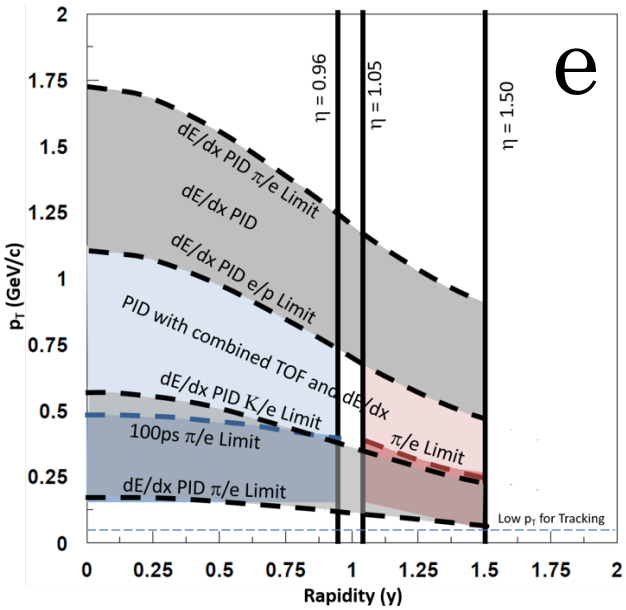
Collider mode

Extends rapidity coverage
➔ allows a change in μ_B

Improves yields of protons
➔ better kurtosis

Improves coverage for electrons
➔ better di-electron studies

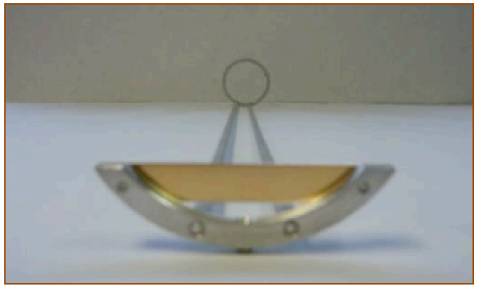




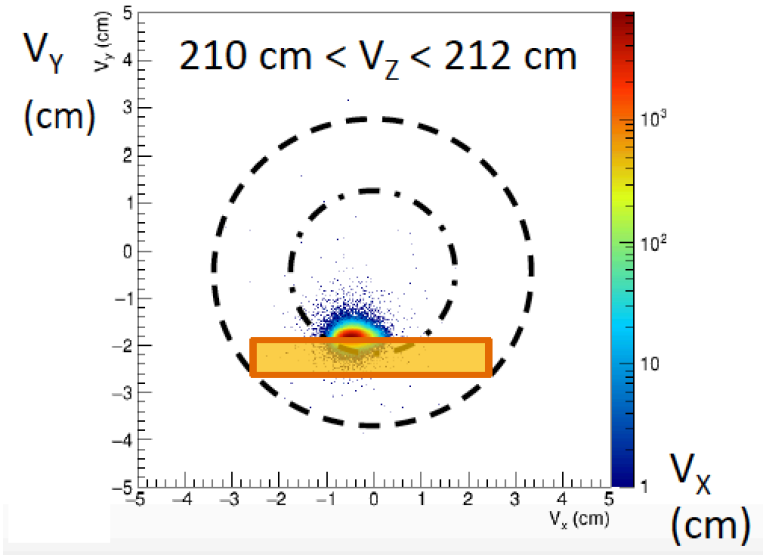
FiXed Target program

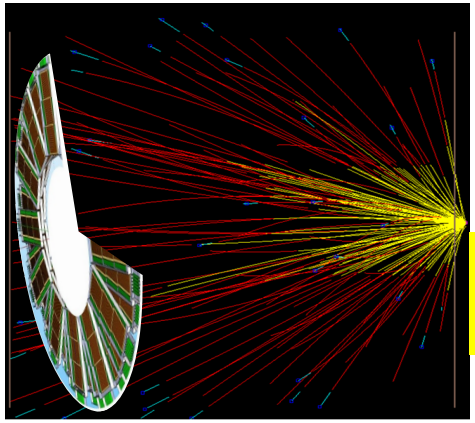
Fixed target program proposed during RHIC BES-II will extend the energy down to $\sqrt{s_{NN}}$ = 3.0 GeV (μ_B=721MeV)

- ✓ The fixed target is outside the STAR TPC at 211 cm
- ✓ Only single beam is used
- ✓ $\sqrt{s_{NN}}$ = 3.0 -- 7.7 GeV
- ✓ ~100M events needed per energy (2 days, DAQ rate limited)



V_y vs. V_x Distribution

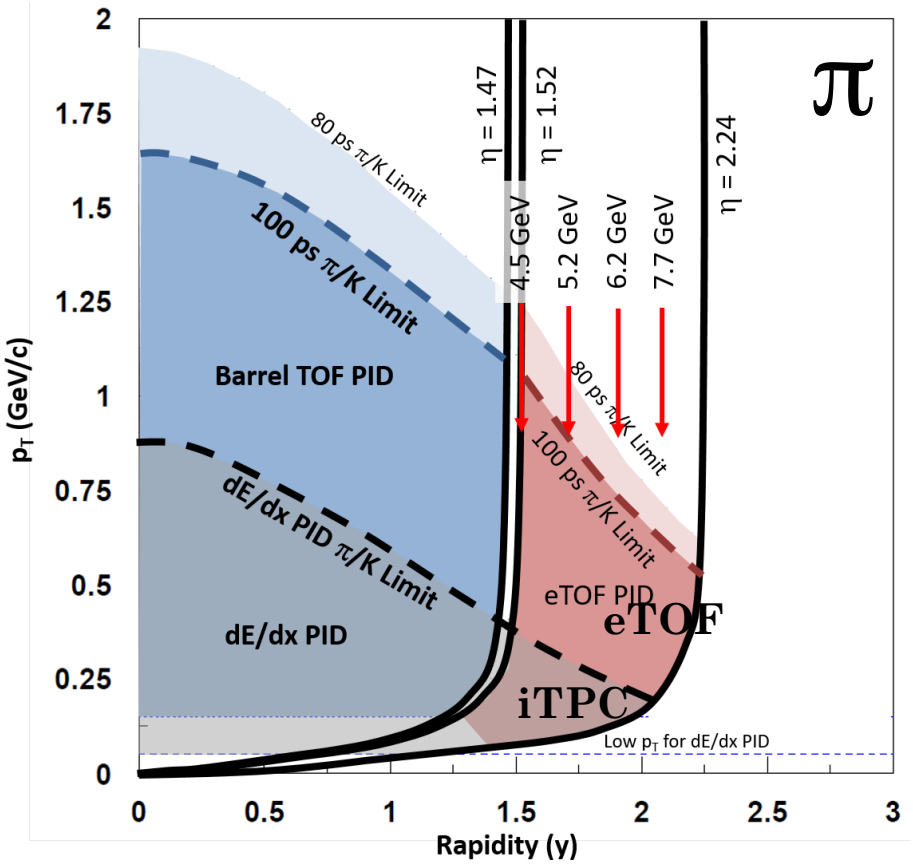


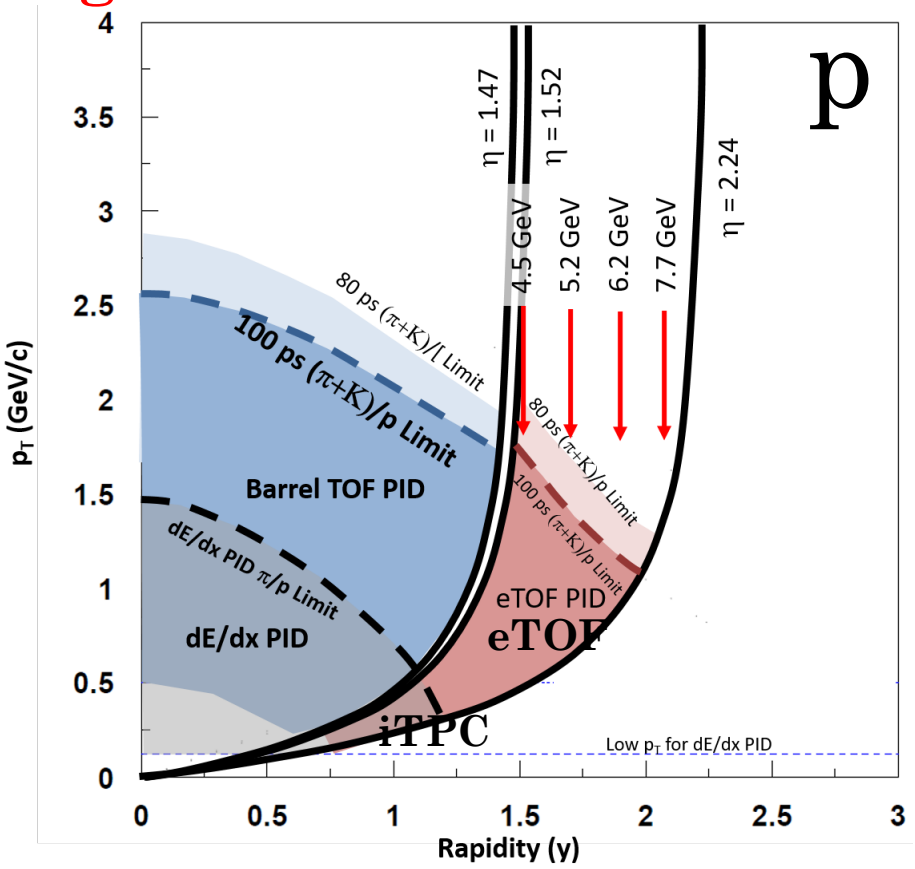


Reconstructed 3.9 GeV Au+Au event

Maps of Acceptance

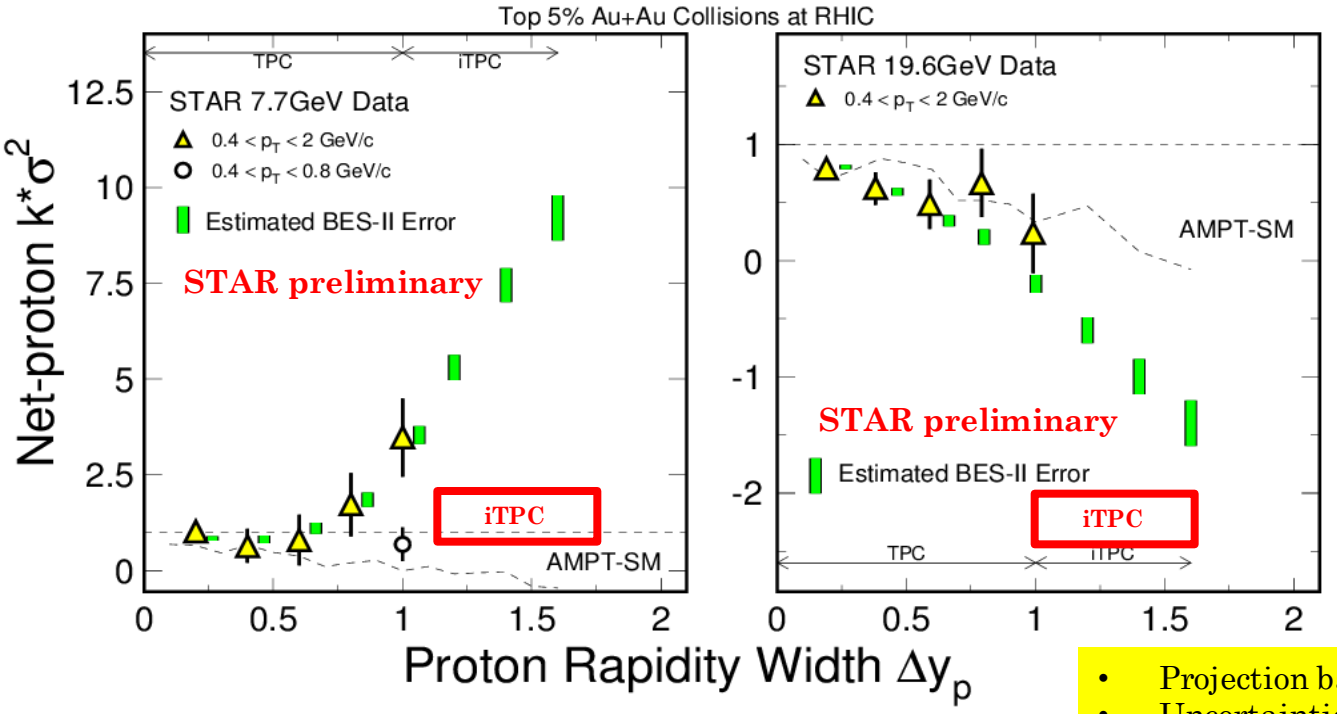
Fixed Target mode





- ✓ Only for rapidity > 0
- ✓ Overlap at 7.7 GeV with collider mode

Net-proton cumulants in BES-II with iTPC

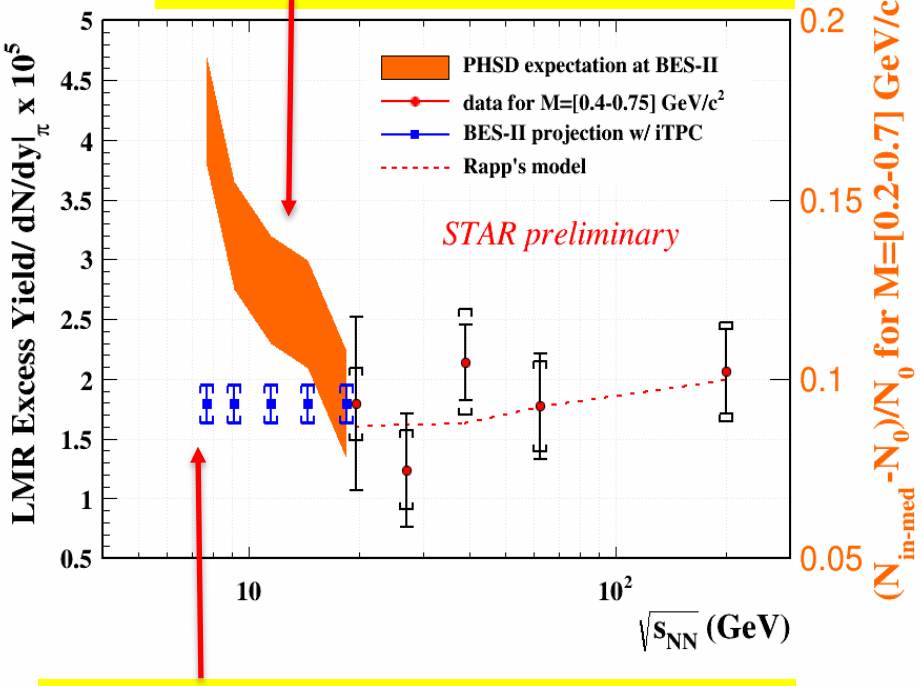


- Projection based on data trend
- Uncertainties are coming from the LEReC enhanced luminosity

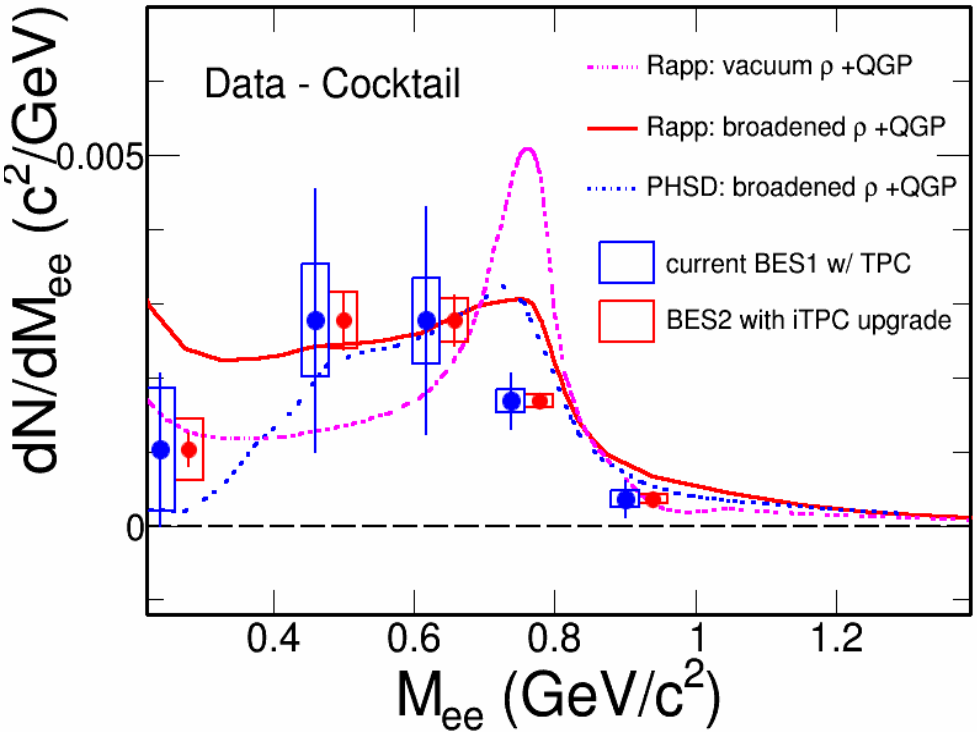
- ✓ BES-I has revealed non-trivial energy dependence
- ✓ Rapidity length of correlation is important
- ✓ Measure as fct. of Δy_p in wide range is needed to establish true nature of correlation
- ✓ iTPC upgrade will enable this measurement in wider range

e^+e^- measurements in BES-II with iTPC

PHSD model expects "raising"



Uncertainty projection with iTPC

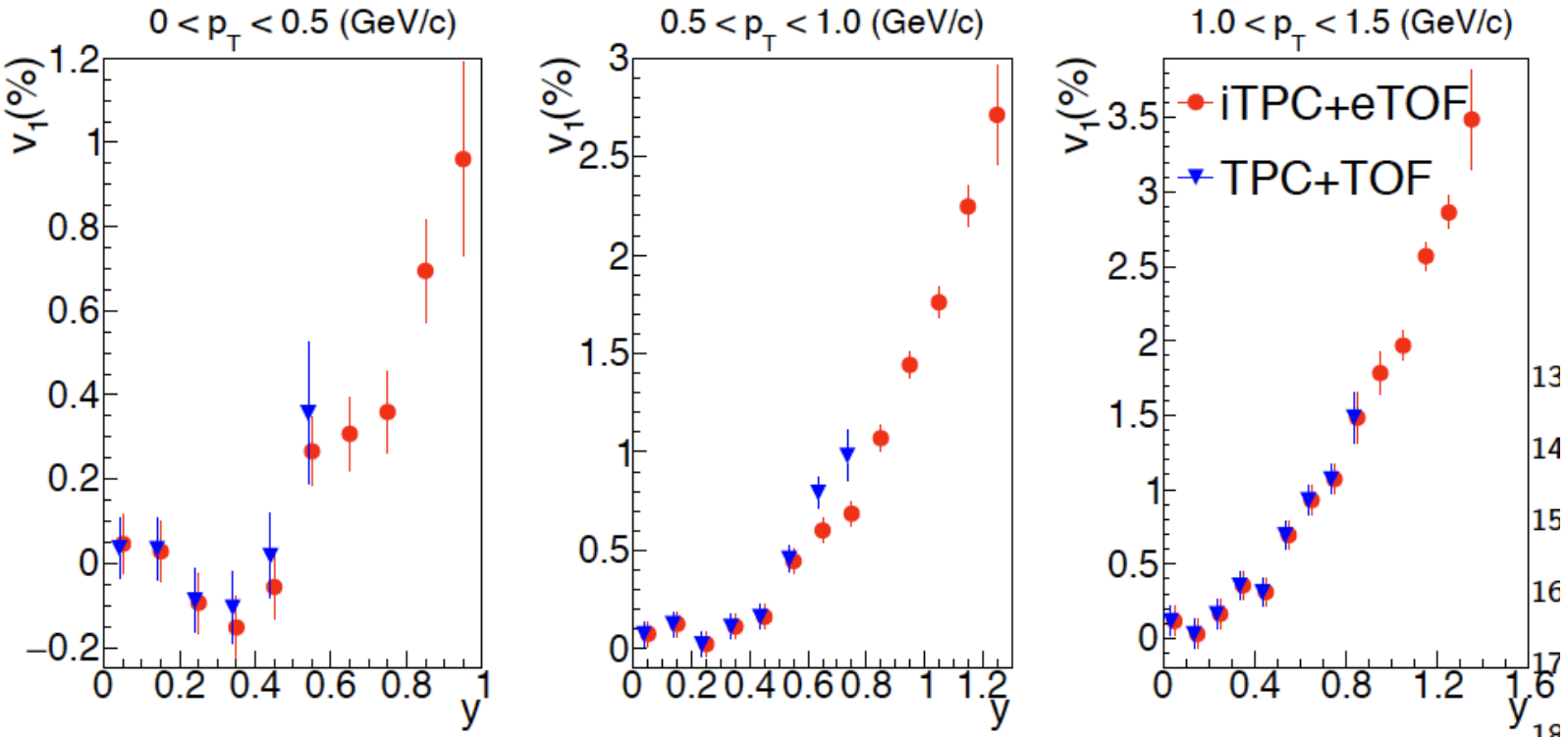


[*Phys. Rev. Lett. 113 (2014) 022301*]

- ✓ Systematically study continuum from 7.7-19.6 GeV
- ✓ Distinguish model with different rho-meson broadening
- ✓ Study effect of total baryon density and lifetime on LMR excess
- ✓ ~10 times more statistics
- ✓ ~1/3 systematic uncertainties (better PID from improved TPC dE/dx)

Directed flow v_1 in BES II

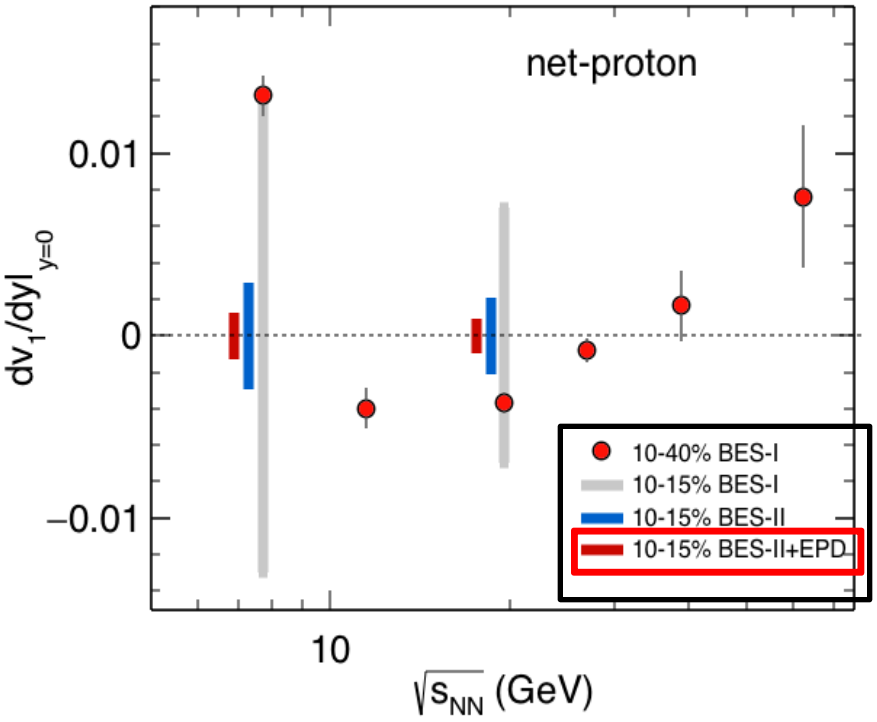
Based on 19.6 GeV UrQMD model events



- ✓ Proton v_1 measures early compression
- ✓ The drop in proton and net proton dv_1/dy at 11.5 GeV indicate softening of EOS
- ✓ Possible signature of a 1st-order phase transition
- ✓ Softening would occur at different energies for forward rapidities

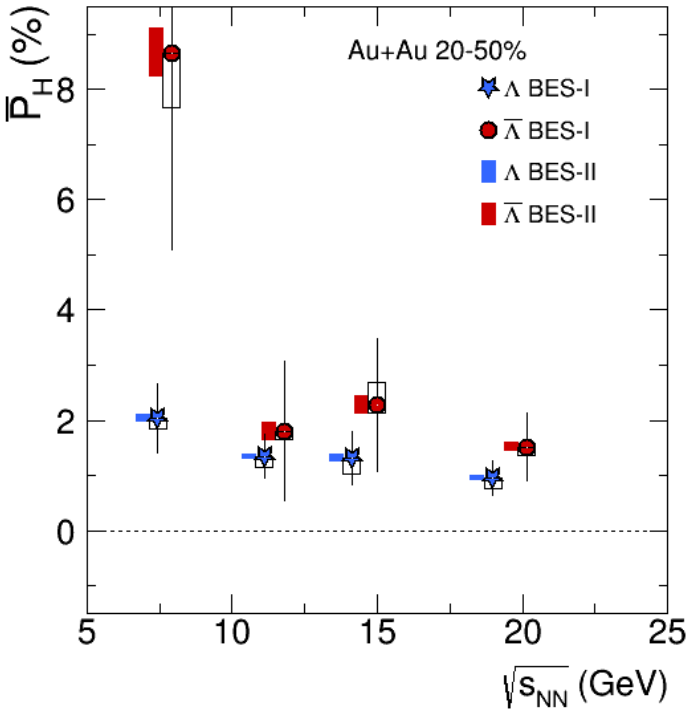
Physics impact of EPD upgrade

Direct flow



[*Phys. Rev. Lett. 112 (2014)162301*]

Global Λ polarization



[*Nature 548 (2017) 62*]

- ✓ EPD is going to reduce the auto-correlations to mid-rapidity measurements: net-protons, v_2
- ✓ The statistics (resolution) improvement is significant: global Λ polarization

STAR 2020+

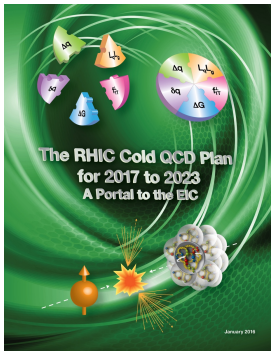
Physics topics of the forward upgrades:

Cold QCD:

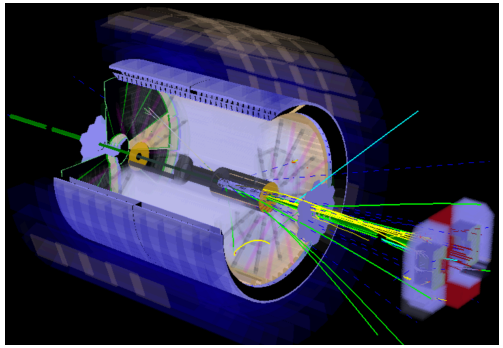
- What are the nPDFs at low-x?
- How saturated is the initial state of the nucleus?
- Constrain the 3d momentum structure of the proton --> TMDs
- Unravel the helicity structure of the proton --> Delta G at low x

Hot QCD:

- What is the longitudinal structure of initial condition
- Constraining the temperature dependence profile of transport parameters



Cold QCD plan:
[*arXiv:1602.03922*]



Forward **C**alorimeter **S**ystem
Forward **T**racking **S**ystem

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

Physics program

Run Year	Collision System and Energy	Physics/ Observables	Detector in operation
2017	p+p @ 500 GeV Au+Au @ 54 GeV	Spin	***EPD (1/8th)*** ***eTOF prototype***
2018	Zr+Zr, Ru+Ru @ 200 GeV Au+Au @ 27 GeV	e^+e^-, CME CVE	***Full EPD*** ***iTPC prototype*** ***eTOF prototype***
2019	Au+Au @ 14.5-20 GeV Fixed target	QCD critical point 1st phase transition CVE, CME…	***Full iTPC*** ***Full eTOF*** ***Full EPD***
2020	Au+Au @ 7-11 GeV Fixed target	QCD critical point 1st–order phase transition CVE, CME…	
2020+	p+Au, p+p, Au+Au @ 200 GeV	Drell-Yan Longitudinal correlations	***FTS*** ***FCS***

Summary

- STAR is well prepared for *Beam Energy Scan Phase II in 2019&2020*
- Many interesting topics will be further studied in BES-II including net-proton cumulants, dilepton, direct flow and v_2
- With *iTPC, eTOF* and *EPD upgrades*, many *physics* potential *will be* significantly *improved* in
  - ✓ *Statistics & Systematics*
  - ✓ *p_T & rapidity coverage*
  - ✓ *Particle identification*
- Fixed Target program enables high statistics studies below 7.7 GeV

backup

Beam Energy Scan Phase II

Collision Energies (GeV)	7.7	9.1	11.5	14.5	19.6	*Related to*
Chemical Potential (MeV)	420	370	315	260	205	
Observables	Millions of Events Needed					
R_{cp} up to p_T 5 GeV	N/A	N/A	160	125	92	*Turn-off of QGP signature*
Elliptic Flow of ϕ meson (v_2)	100	150	200	300	400	
Local Parity Violation (CME)	50	50	50	50	50	
Directed Flow studies(v_1)	50	75	100	100	200	*1st order phase transition*
asHBT (proton-proton)	35	40	50	65	80	
Net-proton kurtosis	80	100	120	200	300	*Critical point*
Dileptons	100	160	230	300	400	*Chiral*
Proposed Event Goals	100	160	230	300	400	
BES I Event	4	N/A	12	20	36	

Only part of physics topics in BES II are shown here!

FiXed Target program energies

Collider Energy	Fixed-Target Energy	Single beam A GeV	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*