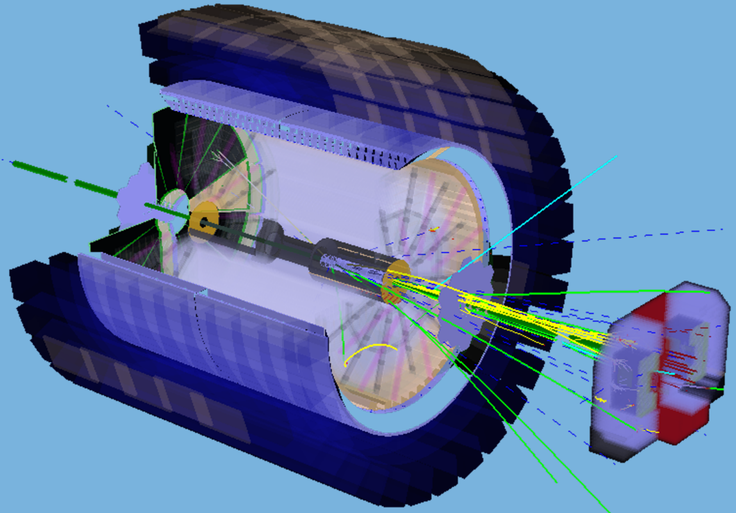
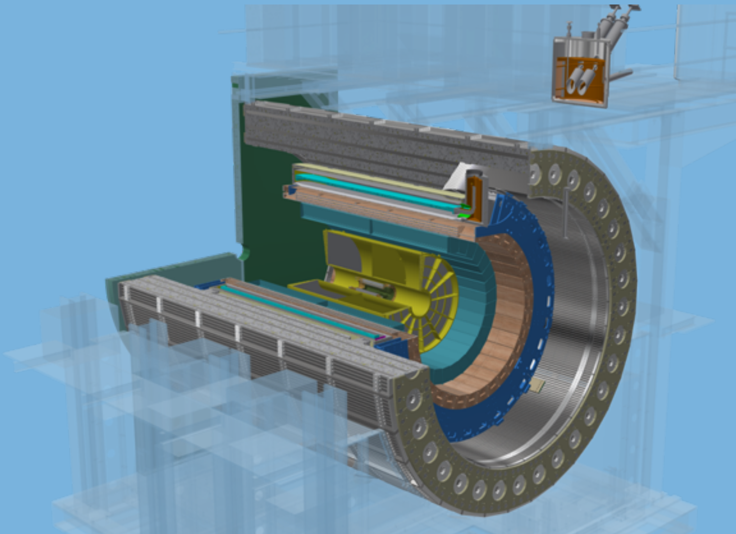
Future Facilities: RHIC Plans



Rosi Reed

Lehigh University



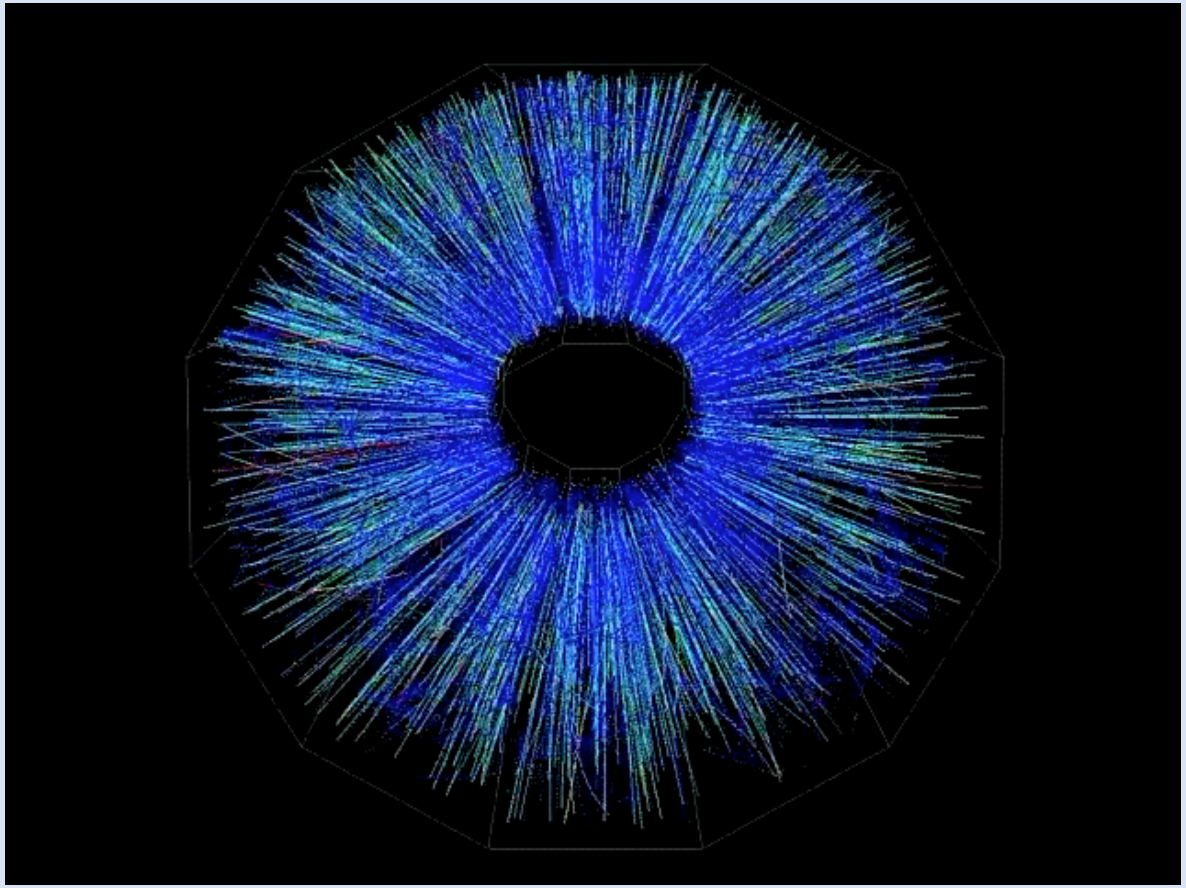
20 Years of RHIC!

At 9:15pm on **Monday, June 12, 2000** the first collisions at RHIC occurred

- Short online commemoration **3pm (EST) on Friday, June 12, 2020**
  - 20 years of the RHIC machine
  - 20 years of the cold QCD program at RHIC
  - 20 years of the heavy ion program at RHIC

Details can be found at:

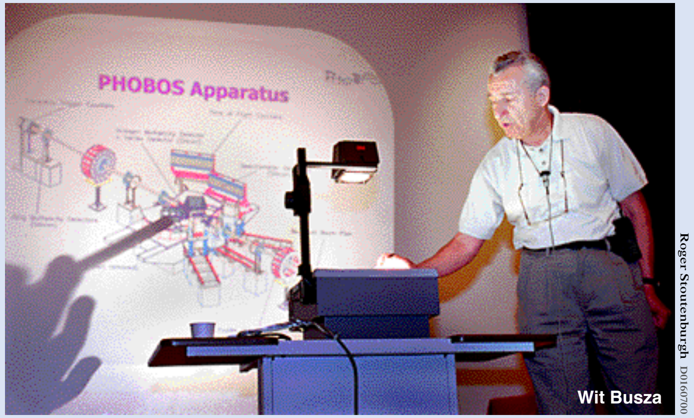
- https://indico.bnl.gov/event/8575/



From acetate slides to Zoom!

The technology has changed, but we are still pondering the nature of QCD

PHOBOS Collaboration Presents First Physics Results From RHIC



The Big Picture: QCD @ RHIC

We have gone from asking, “Does the QGP exist?” to “Precisely how does QCD lead to the emergent phenomena we observe?”

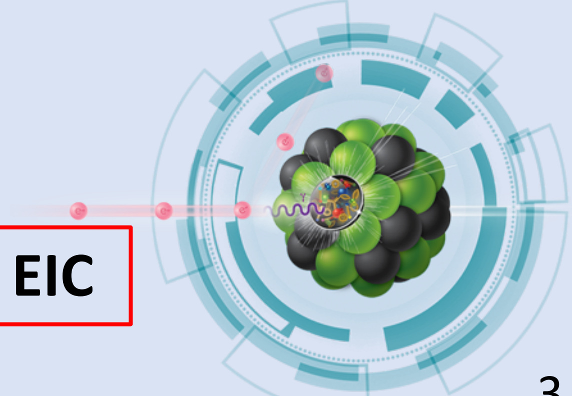
- **Qualitative** observations (jets are quenched, nearly ideal fluid, fluctuations are important) to **quantitative** descriptions (qhat, η/S, σ, S, κ)

Major **upgrades** to the accelerator, **STAR** experiment and the new **sPHENIX** experiment allow us to capitalize on this versatile machine and answer fundamental questions about QCD

- How do quarks and gluons form a strongly coupled, nearly perfect liquid?
  - What are its properties?
- How do the proton constituents lead to its spin?
- What is the initial state in nuclear collisions?

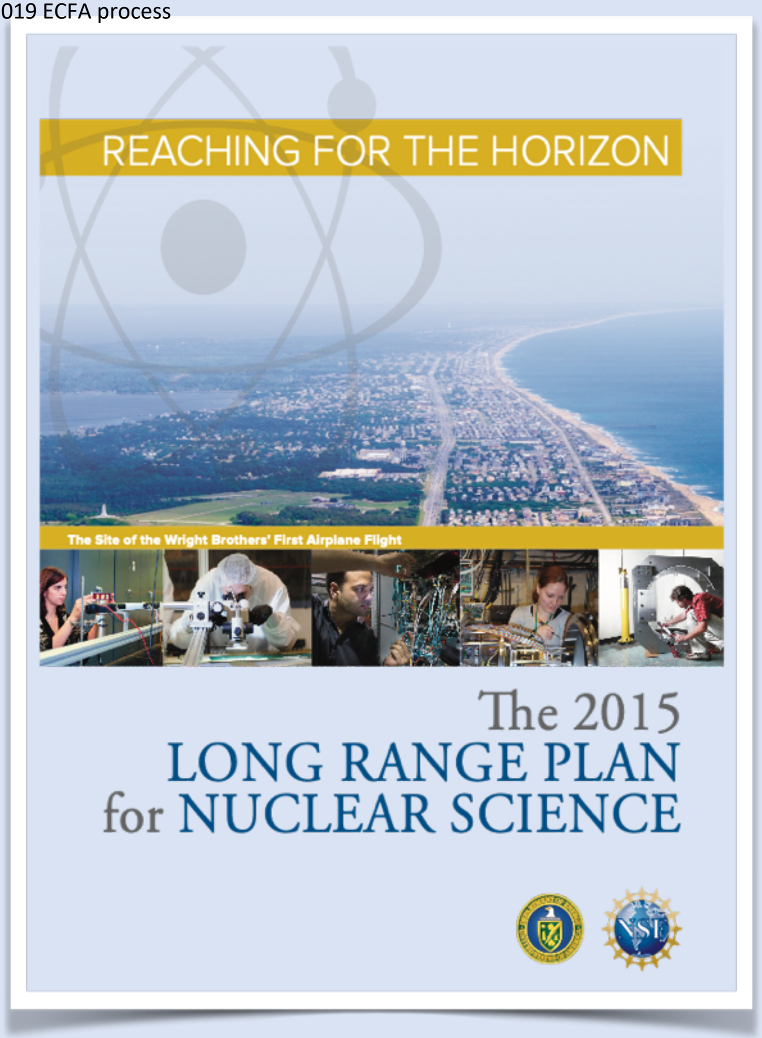
Next era: **Electron Ion Collider (EIC)**

E. Aschenauer F - 9:15 EIC



Nuclear Physics Science Mission

WG5 for 2019 ECFA process



REACHING FOR THE HORIZON

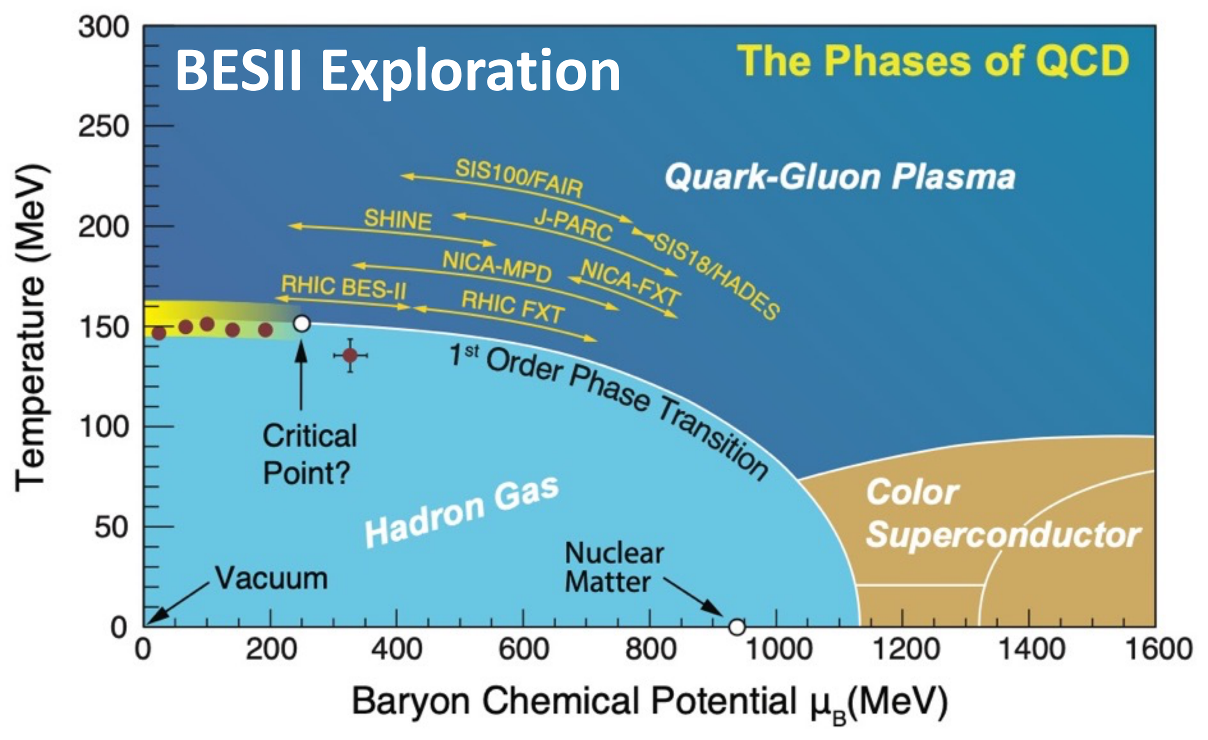
The Site of the Wright Brothers' First Airplane Flight

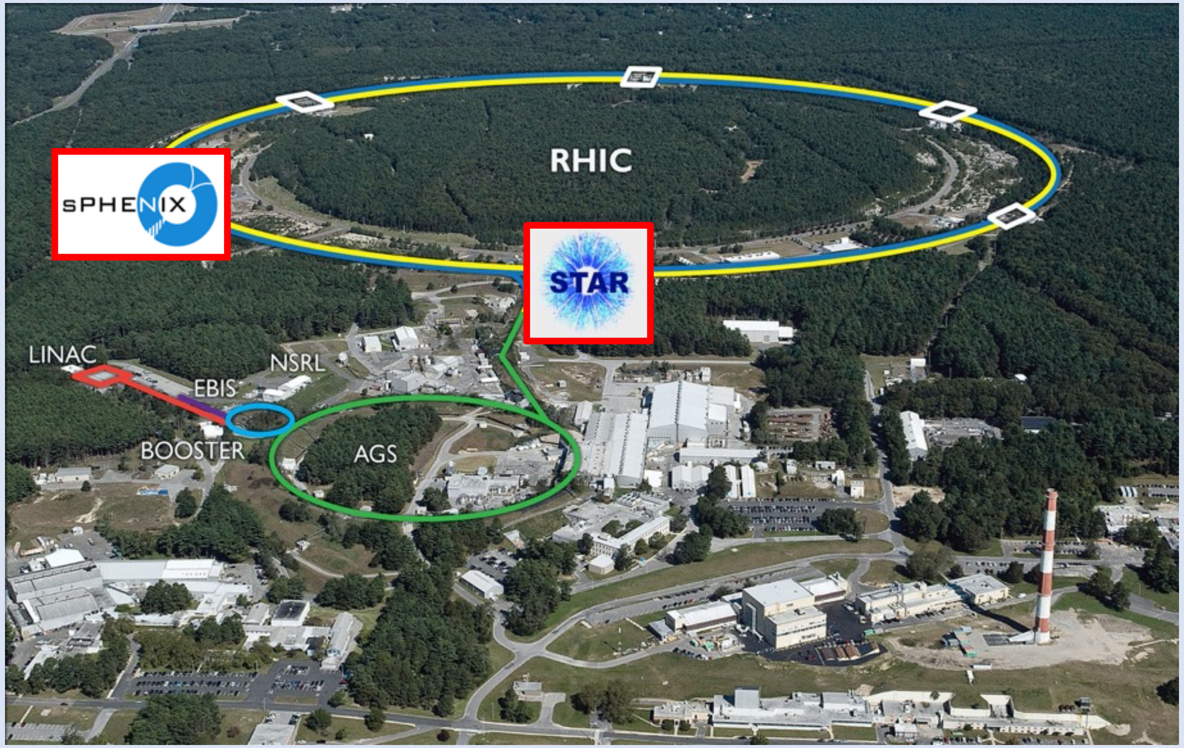
The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE

"There are **two central goals** of measurements planned at RHIC, as it **completes its scientific mission**":

- Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a **state-of-the-art jet detector at RHIC, called sPHENIX**.
- **Map the phase diagram** of QCD with experiments planned at RHIC."

RHIC Beyond BESII

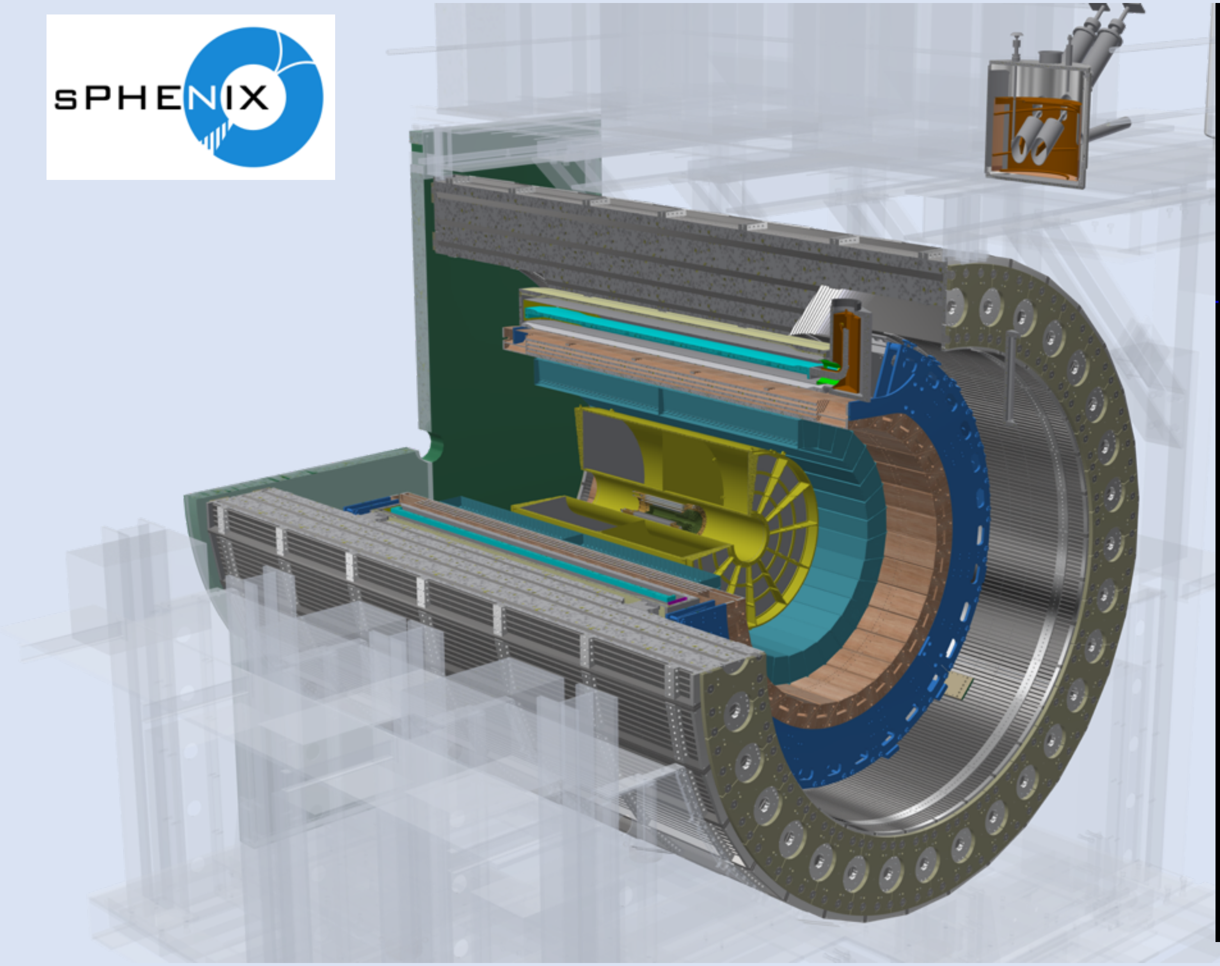


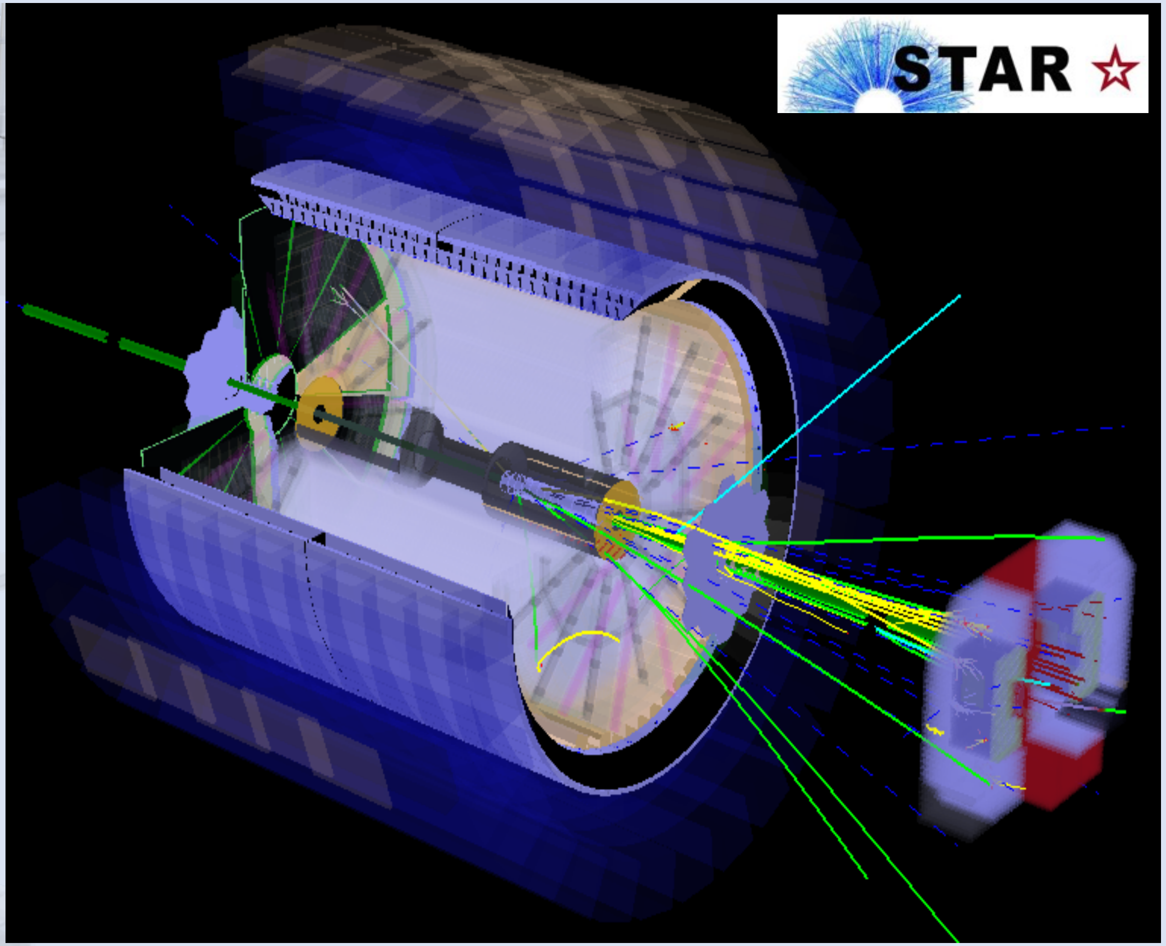


RHIC is an amazingly versatile machine, colliding **p+p, p+Al, p+Au, d+Au, He^3+Au, Cu+Cu, Cu+Au, Zr+Zr, Ru+Ru, Au+Au, U+U** from $\sqrt{s_{NN}}$ = 7.7 - 510 GeV

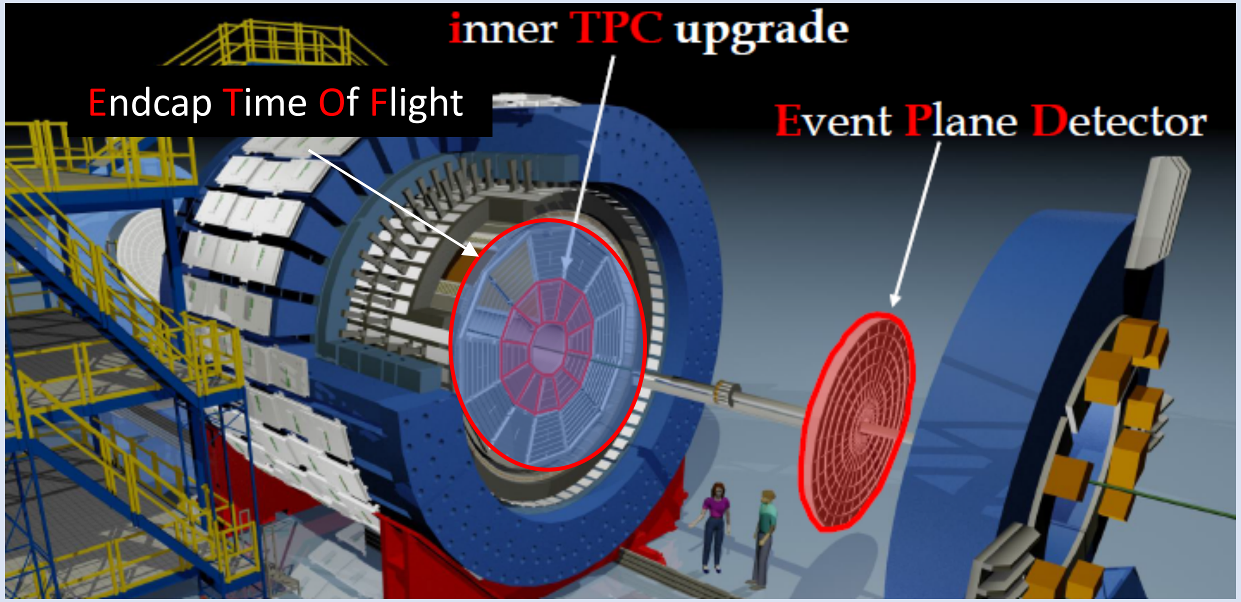
2 Detectors in the 2020+ era: STAR, sPHENIX

sPHENIX and STAR

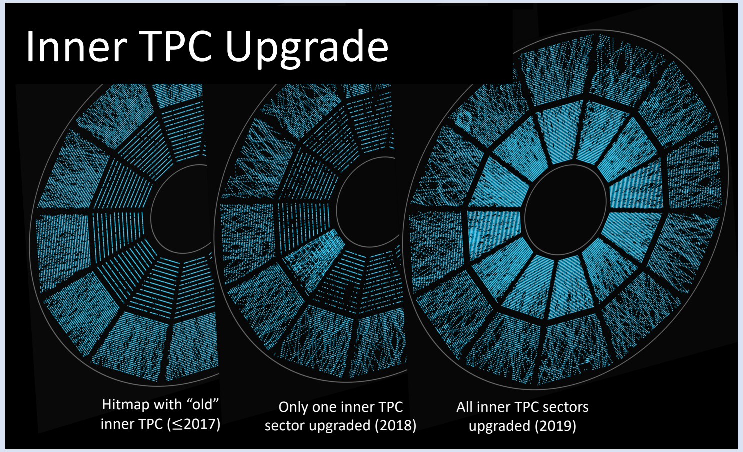


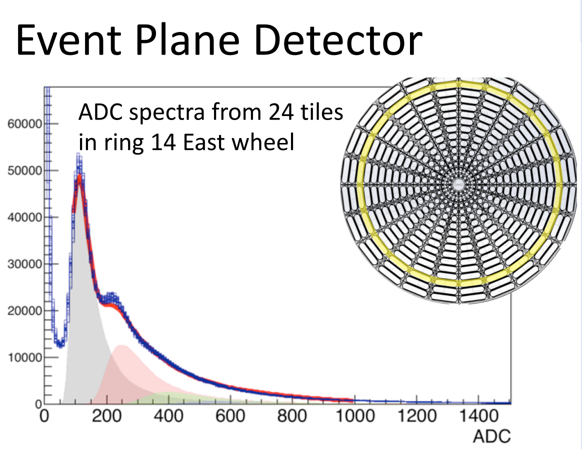


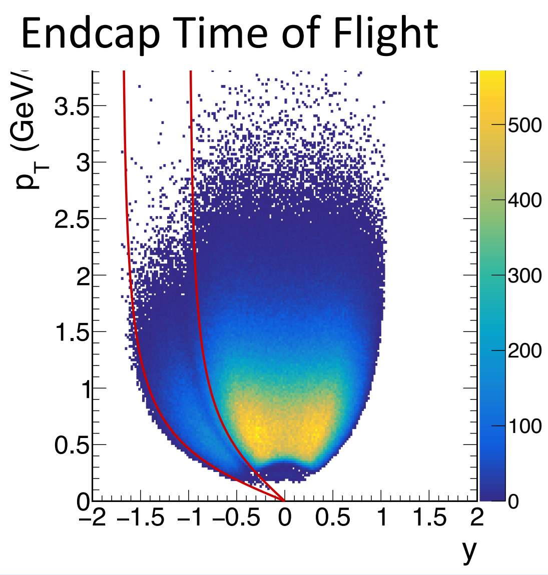
STAR Upgrades pre-2020



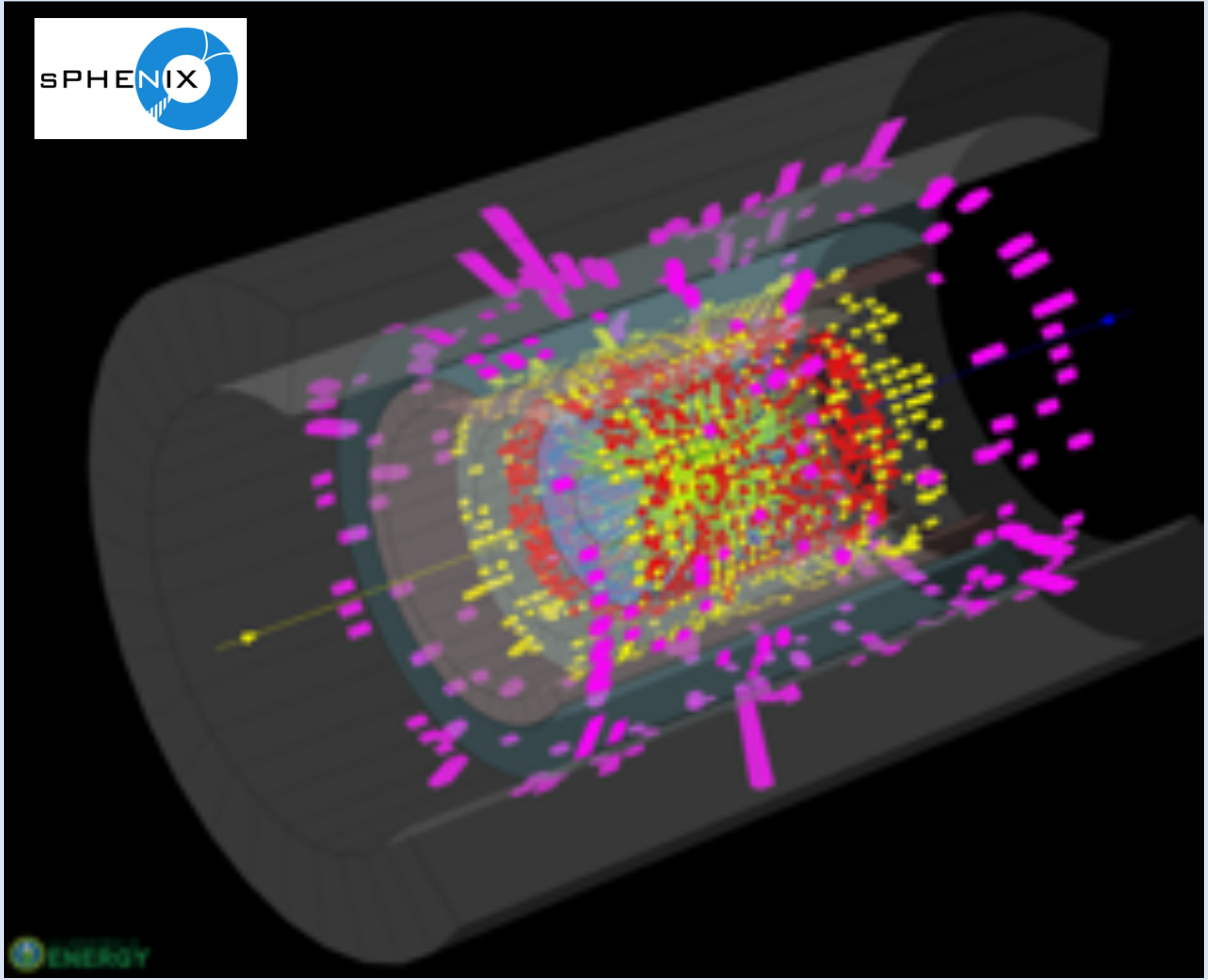
- Upgraded detectors for BESII era **expanded acceptance**, **improved momentum** resolution and **expanded PID**
  - Not only useful for BES, but also for hard probes


Inner TPC Upgrade


Event Plane Detector

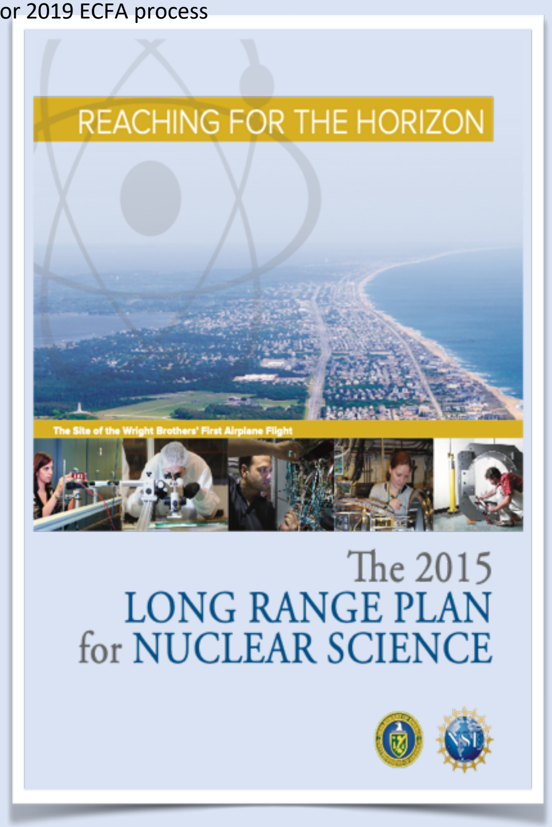

Endcap Time of Flight

Look for results from Isobar (Zr+Zr/Ru+Ru) coming soon!


sPHENIX
ENERGY

sPHENIX Science Mission

WG5 for 2019 ECFA process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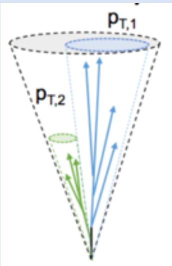
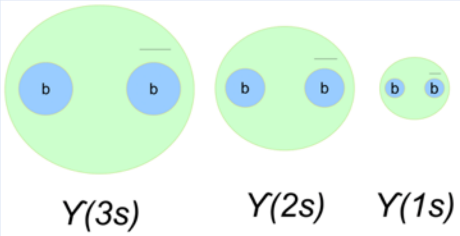
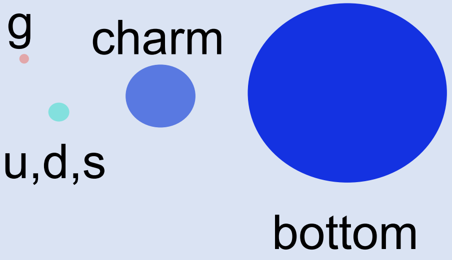
> "Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of [RHIC and the LHC] is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX."



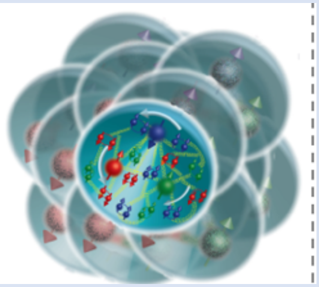
Jet structure
Vary momentum/angular scale of probe



Quarkonium spectroscopy
vary size of probe

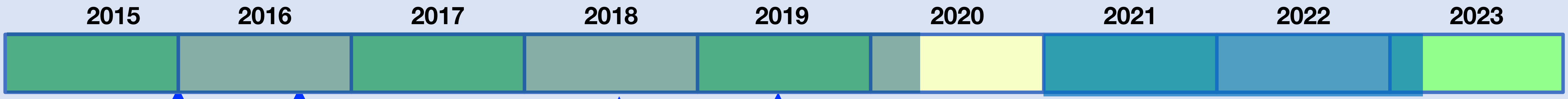


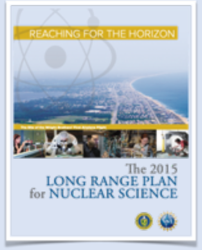
Parton energy loss
vary mass/momentum of probe



Cold QCD
vary temperature of QCD Matter

sPHENIX Timeline





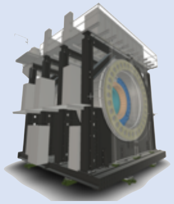
sPHENIX science collaboration

DOE CD-0 “Mission need” approval

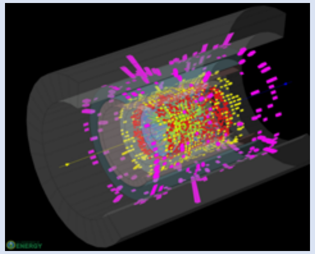
DOE CD-1/3A Cost, schedule, advance purchase approval

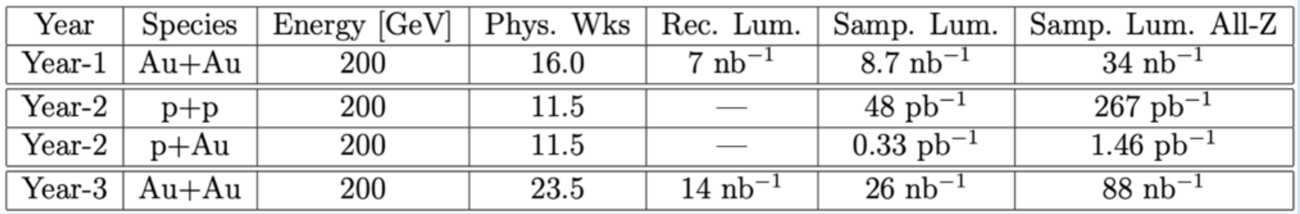
BNL PD-2/3 Final project design approval

Installation & commissioning



2023	2024	2025
Au+Au	p+p/p+Au	Au+Au



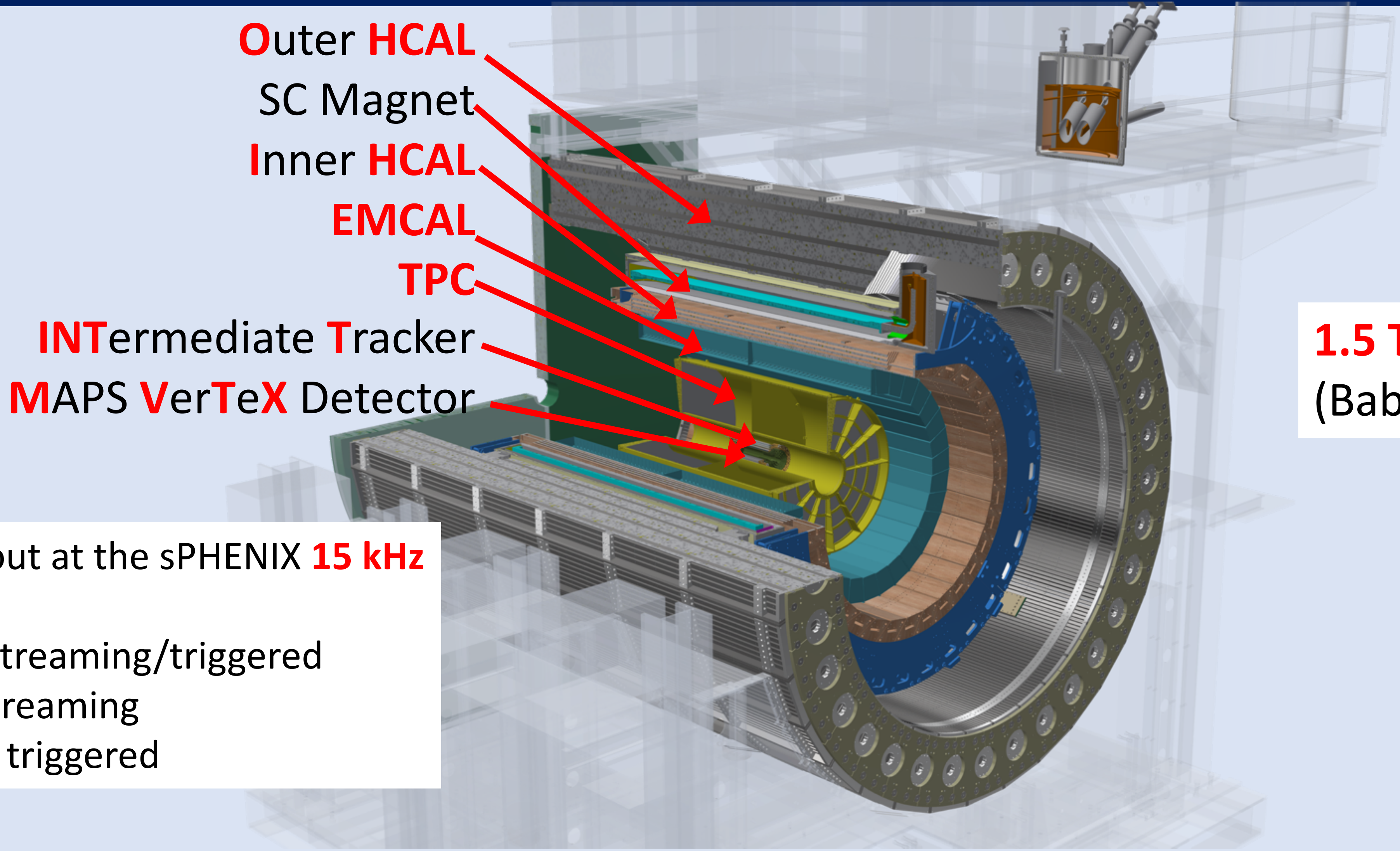


Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}

145B (240B) MB Au+Au (5 yr plan)→
~1.5 orders of magnitude more Au+Au events than taken at RHIC to date

sPHENIX → data taking in early 2023

sPHENIX Design



Outer **HCAL**

SC Magnet

Inner **HCAL**

EMCAL

TPC

INTermediate **T**racker

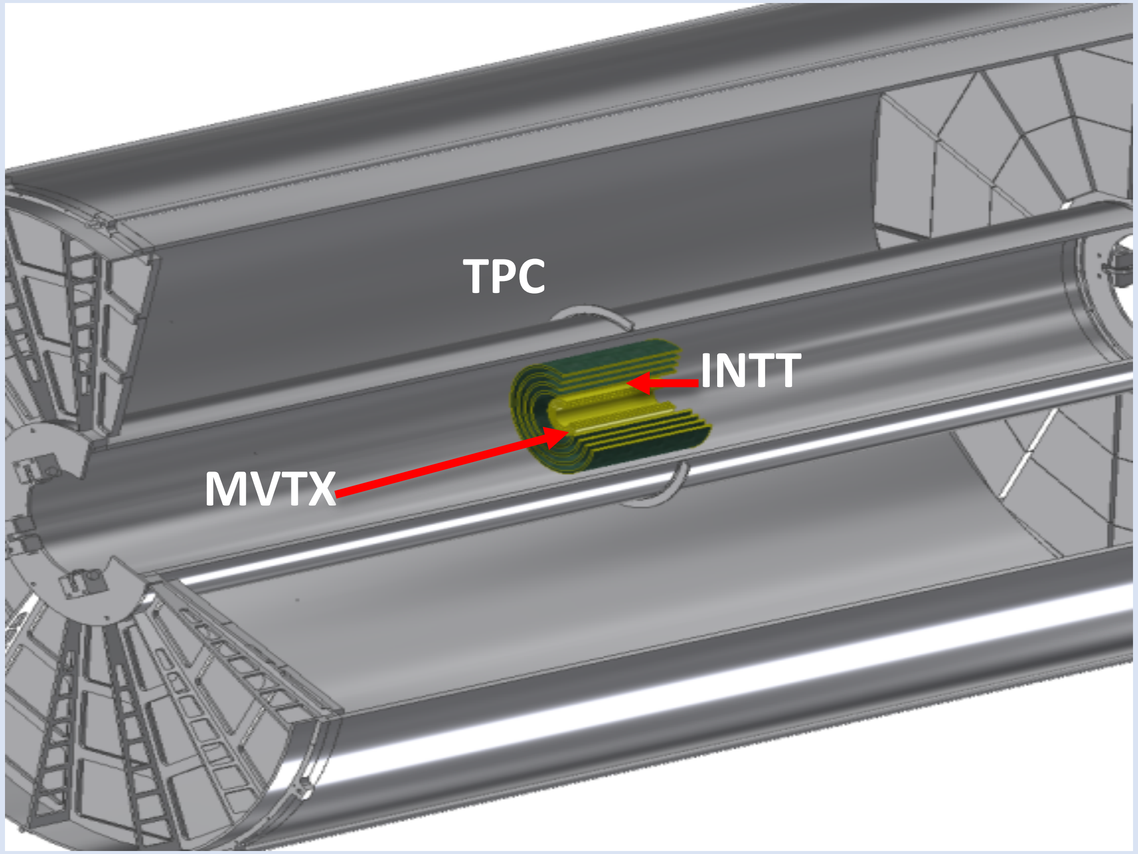
MAPS **V**er**T**e**X** Detector

1.5 Tesla B field
(Babar Magnet)

All can be read out at the sPHENIX **15 kHz trigger rate**

- DAQ hybrid streaming/triggered
- TPC/MVTX streaming
- Calorimeters triggered

sPHENIX Tracking



1/30th volume
ALICE TPC

MVTX (based on ALICE ITS):

- 3-layer MAPS vertex tracker
- Excellent 2-D DCA resolution, < 10 µm, $p_T > 2$ GeV/c

INTT:

- 2-layer Si strip

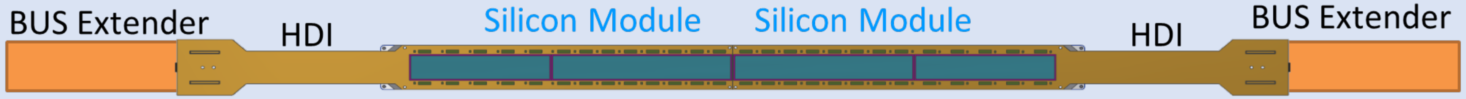
TPC:

- 48 layers, continuous readout, R = 20-78 cm
- Momentum resolution $\sigma_{p_T}/p_T < 0.2\% \times p$ for p_T = 0.2-40 GeV/c

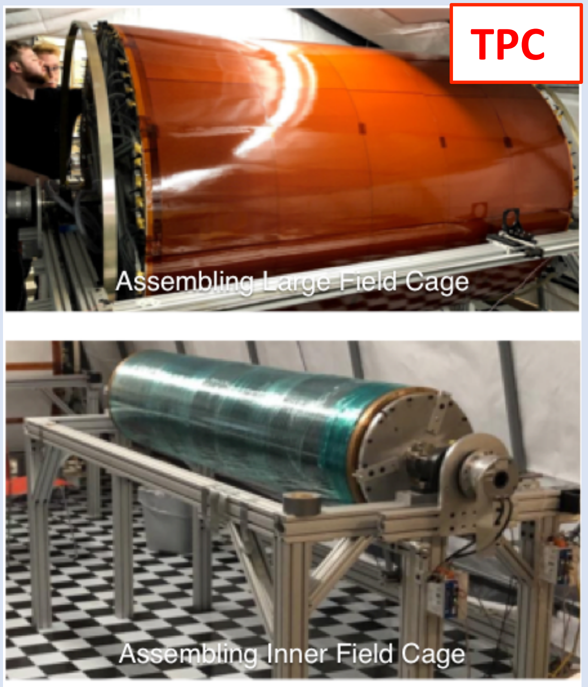
sPHENIX MTVX + INTT + TPC

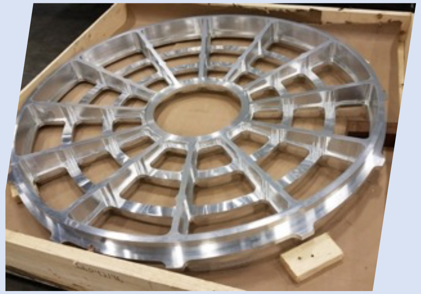
Inner Tracking System adds:

- **Out-of-time pileup** track rejection
- Outward pointing resolution for TPC calibration
- Inward pointing resolution for **displaced vertices**

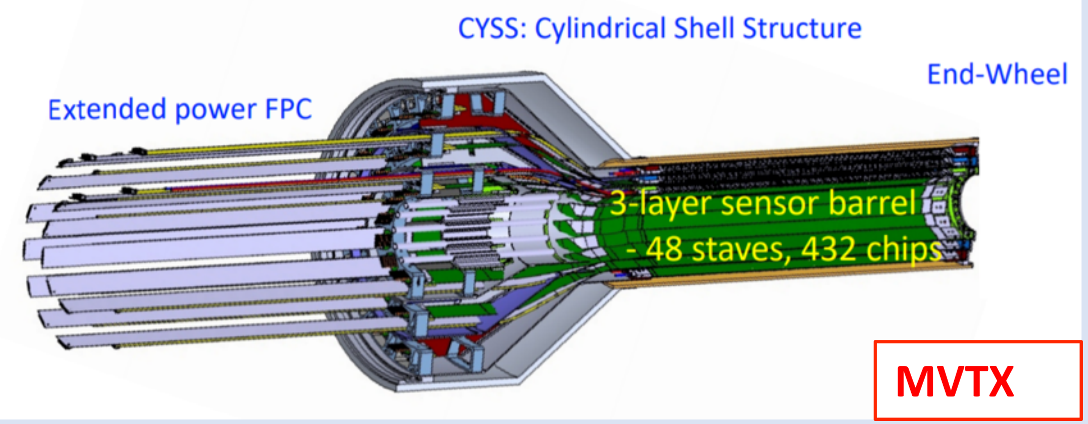


INTT





TPC position resolution in the r-ϕ (bend) direction measured at 114 μm averaged over full drift length

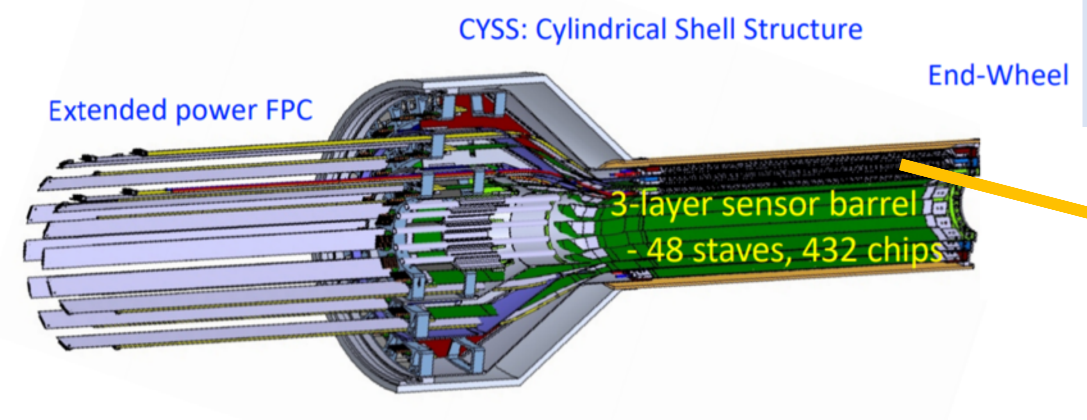


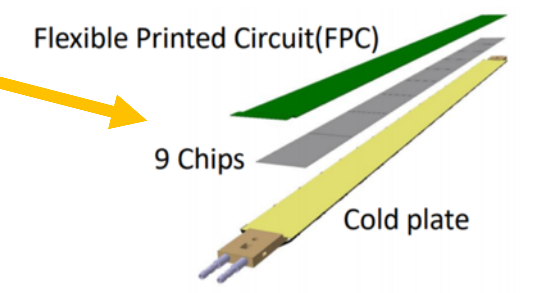
MVTX

- Hit spatial resolution of < 10 μm
- Contributes **high-performance vertexing** to integrated tracking program

sPHENIX MVTX

Monolithic Active Pixel Sensor (MAPS)-based detector



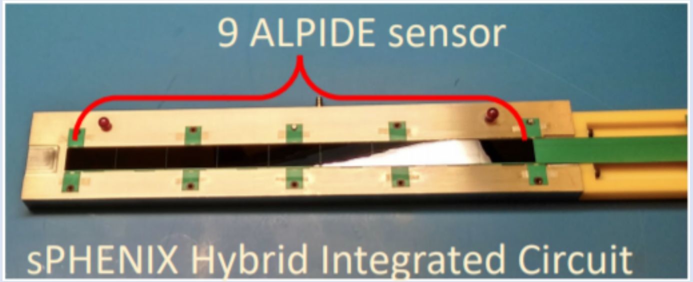


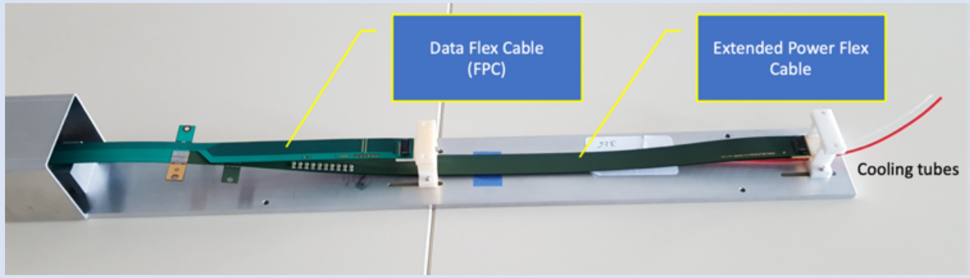
Staves identical to ALICE inner barrel staves (except for leads)

- Produced at CERN

Basic unit: ALPIDE sensors

- Good time resolution
- High efficiency
- Low fake rate





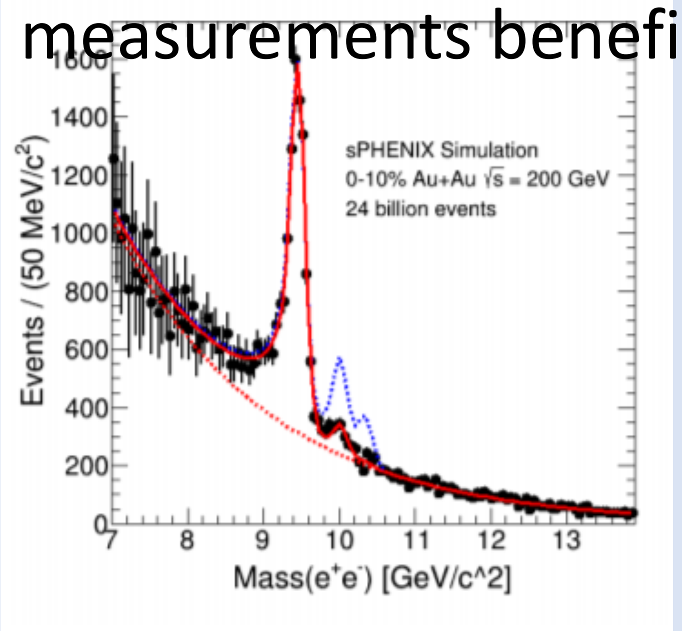
Hardware requires dedicated software to maximize its performance

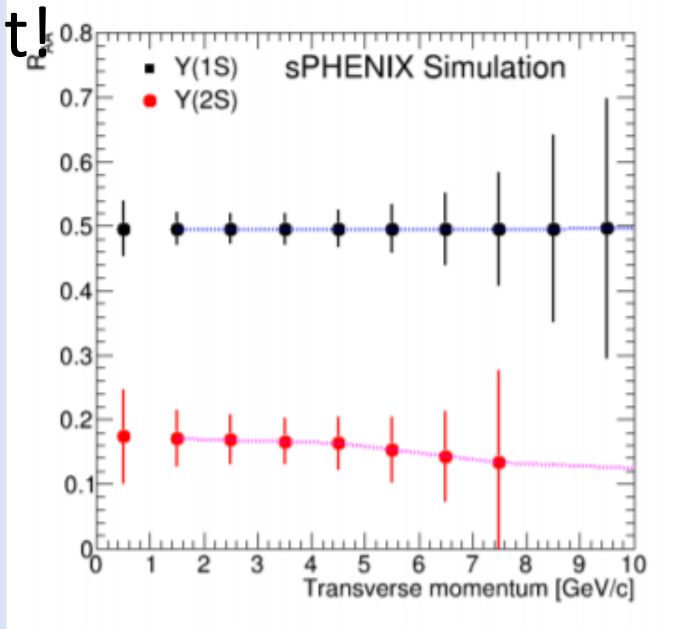
- Kalman filter-based decay reconstruction software

M. Peters D3 T 13:35

Upsilons at sPHENIX

ϒ + heavy flavor jet physics drive tracking requirements → Jet structure measurements benefit!



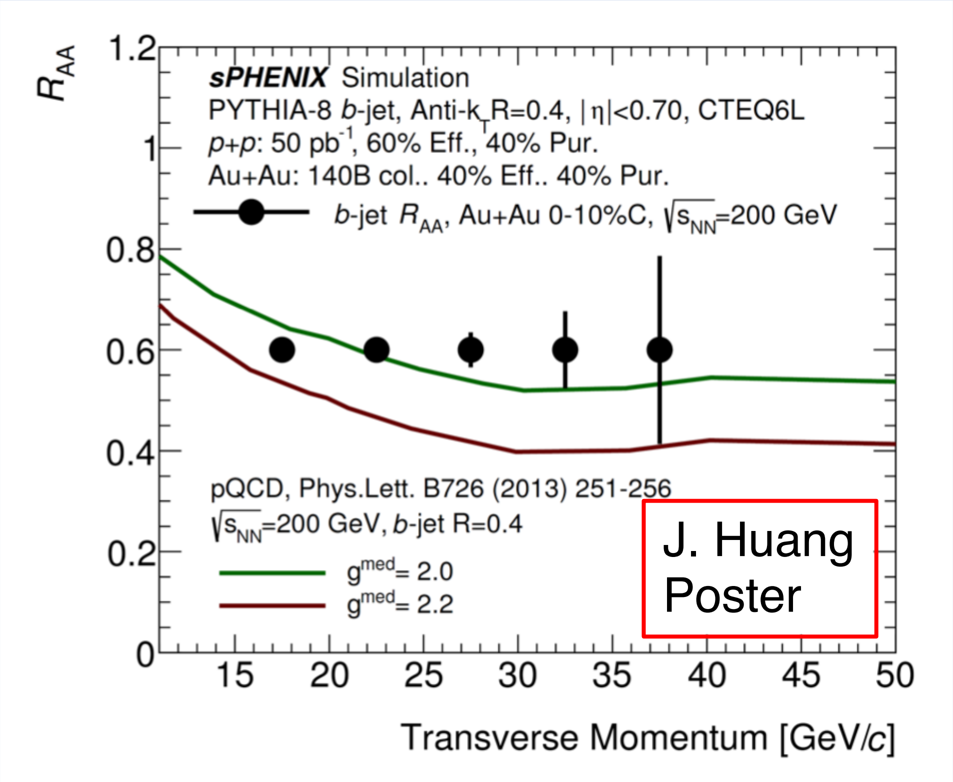


- Differential suppression of Y(nS) → T dependence of QGP Debye screening length
- **Y(1S) width key FOM** in INTT configuration

- Mass resolution of precision tracking allows **clear separation of ϒ states**!
- Precision measurements of ϒ(1S) and ϒ(2S) R_{AA}
  - Upsilon melting observations for $0<p_T<7$ GeV

Heavy Flavor at sPHENIX

b-tagged jet R_{AA}

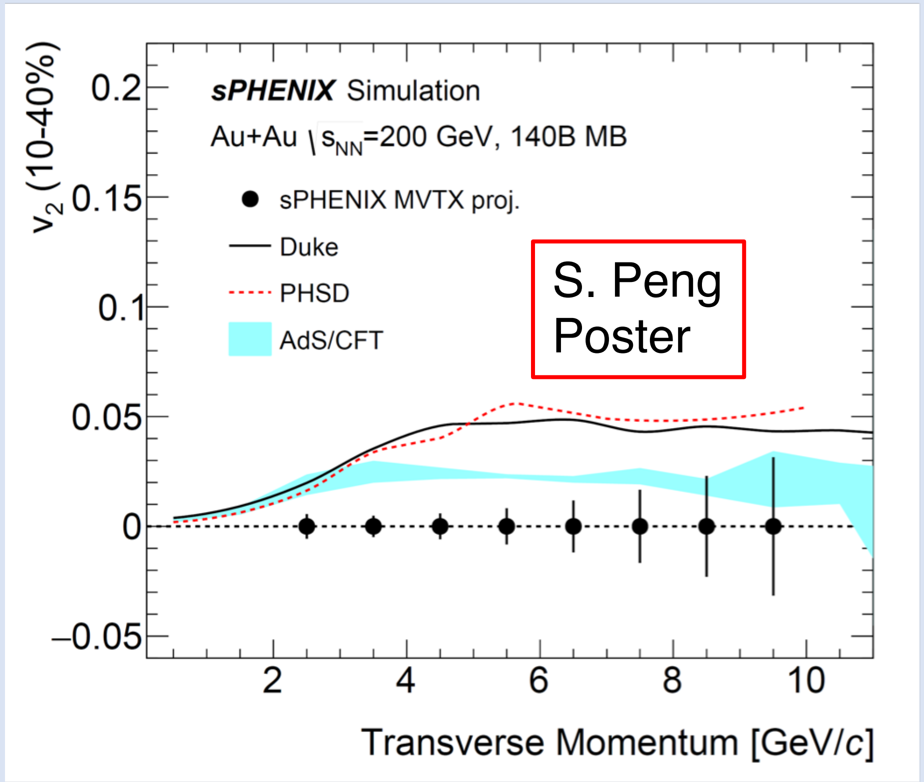


J. Huang Poster

2 b-jet finding methodologies:

- High-DCA track tagger
- Secondary vertices tagger

B-meson v_2



S. Peng Poster

Non-Prompt B → D^0

Moving outward, Tracking → Calorimetry

sPHENIX Calorimetry

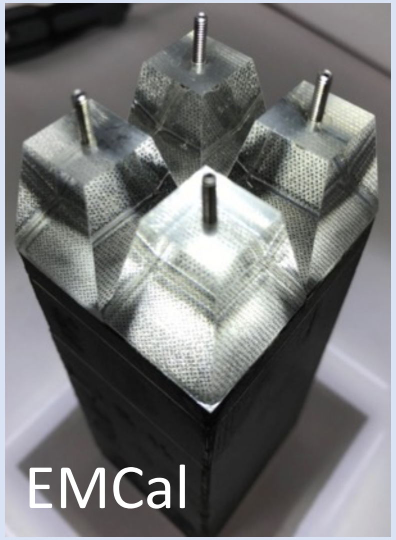
EMCal: Scintillating fibers embedded in W powder

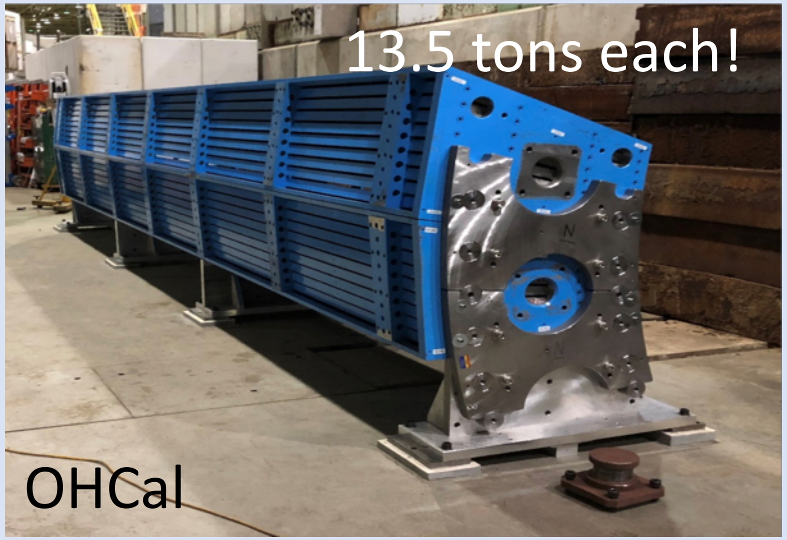
- $\Delta\eta\times\Delta\phi = 0.024\times0.024$ → 24,576 2-D projective towers
- $\sigma_E/E < 15\%/\sqrt{E} \oplus 5\%$

HCal: Plastic scintillating tiles + tilted Steel/Al plates

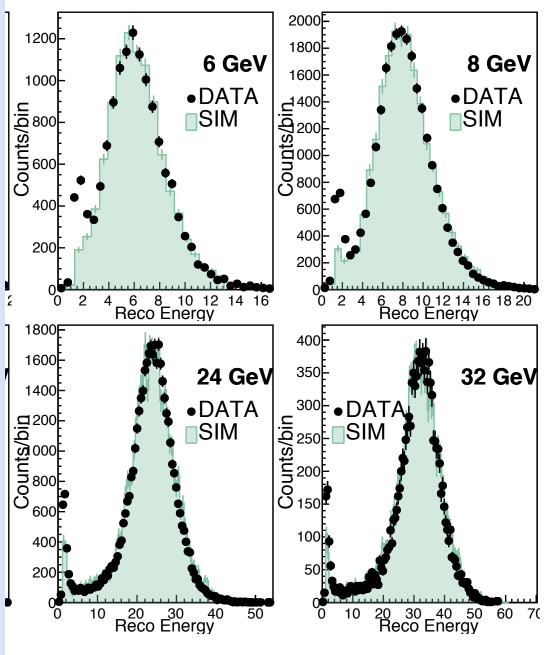
- $\Delta\eta\times\Delta\phi = 0.1\times0.1$ → 1,536 towers
- $\sigma_E/E < 100\%/\sqrt{E}$

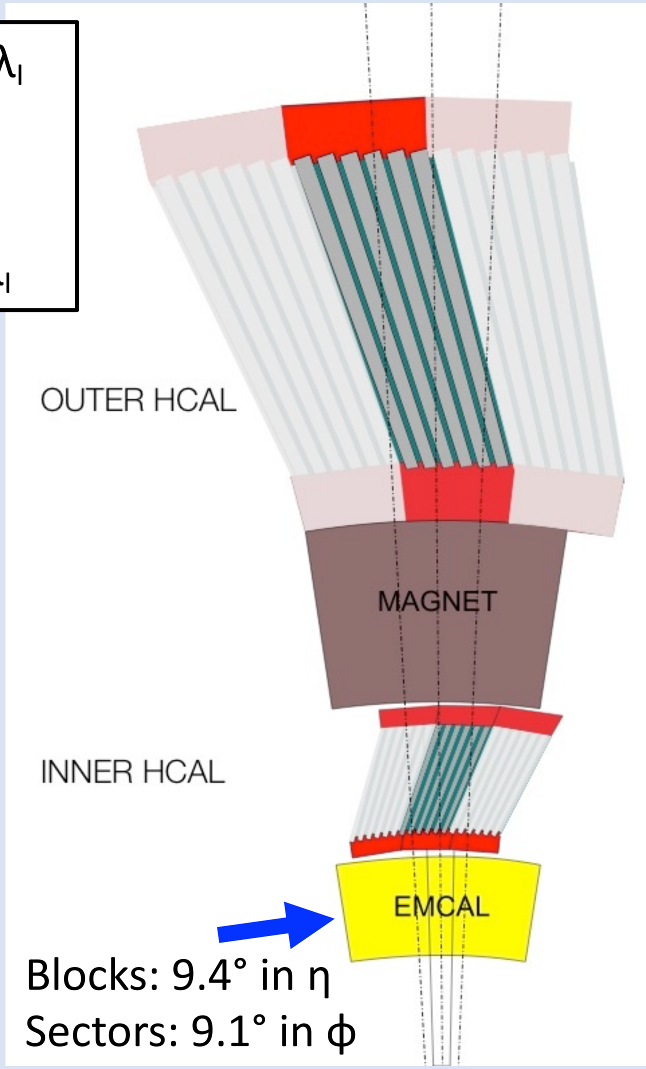
- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- Inner HCAL $\approx 1\lambda_I$
- EMCAL $\approx 18X_0 \approx 1\lambda_I$





HCal E response to π^-

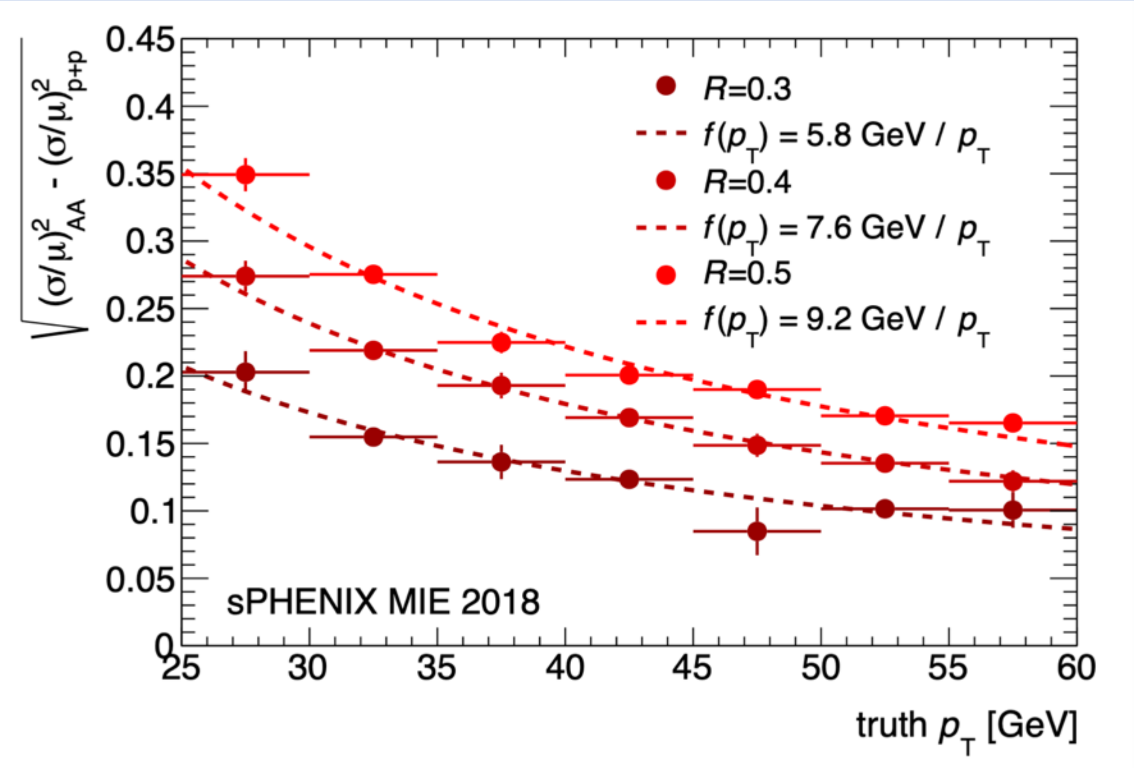




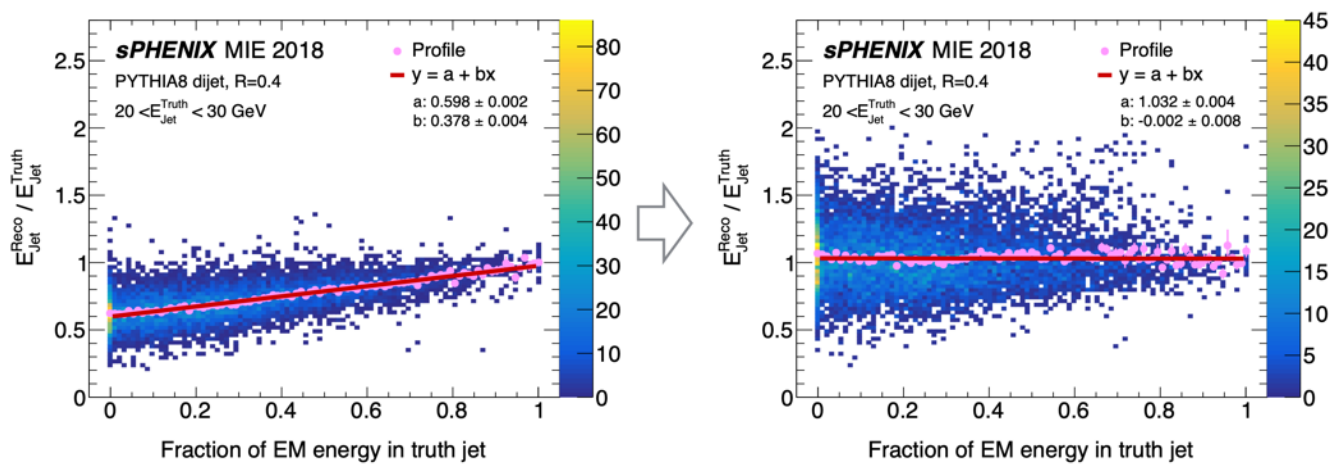
Blocks: 9.4° in η
Sectors: 9.1° in φ

IEEE Trans. Nucl. Analysis of 2018 data underway Sci. 65 (2018) 2901

sPHENIX Calorimeter Jet performance



Calibration of Jet Energy Scale



Au+Au response as pp response ⊗ UE

- Identical sensitivity to fragmentation in both systems

Can the resolution be further improved?

Particle Flow

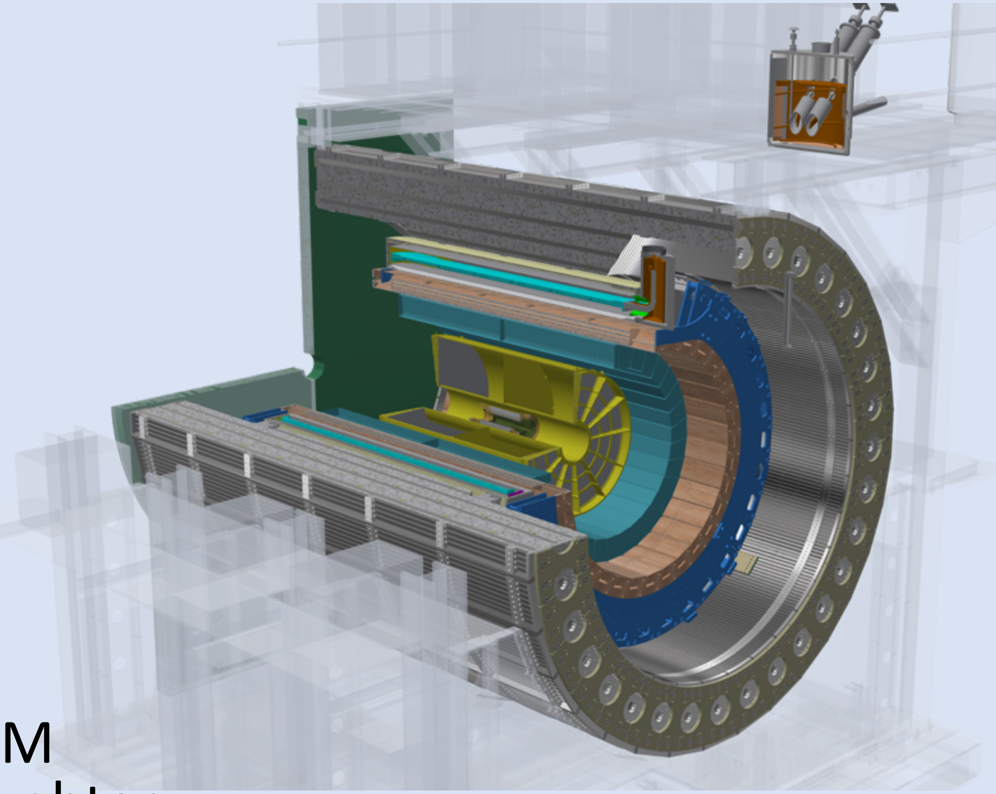
D. Perepelitsa Poster

Deconvolution of Underlying Event (UE) term in Au+Au response

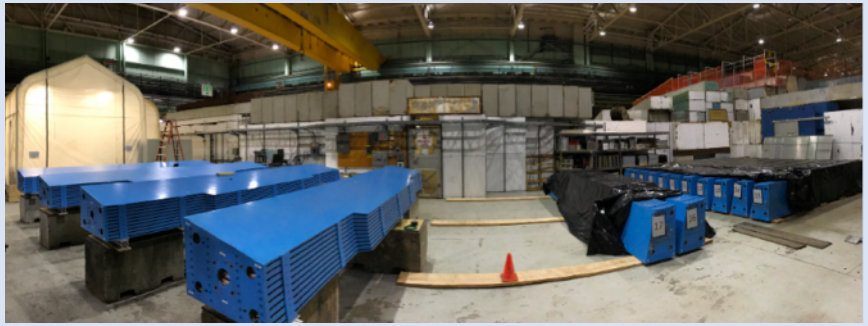
$$\frac{\sigma_{p_T}}{p_T} = \underset{\text{Noise}}{\frac{n}{p_T}} \oplus \underset{\text{Stochastic}}{\frac{s}{\sqrt{p_T}}} \oplus \underset{\text{Constant}}{c}$$

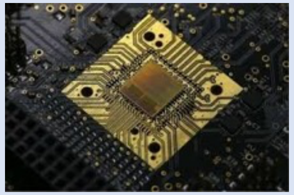
sPHENIX Construction Proceeding!

EMCAL "sector 0" prototype produced



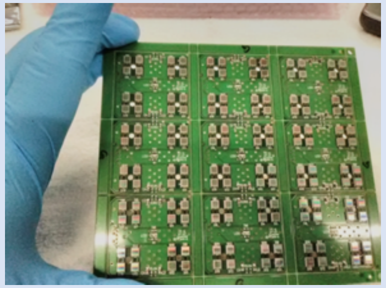
All oHCAL sectors at BNL



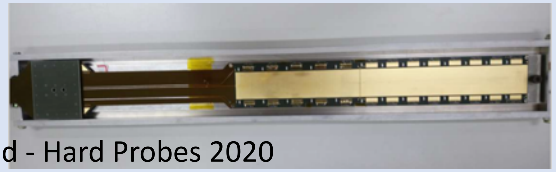


SAMPA v5 TPC FE chip successfully produced and qualified

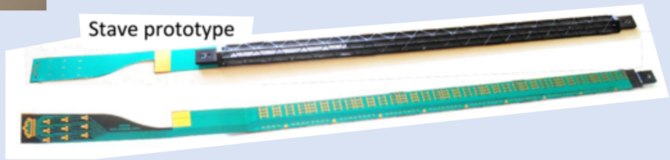
GEM factories



SiPM daughter boards



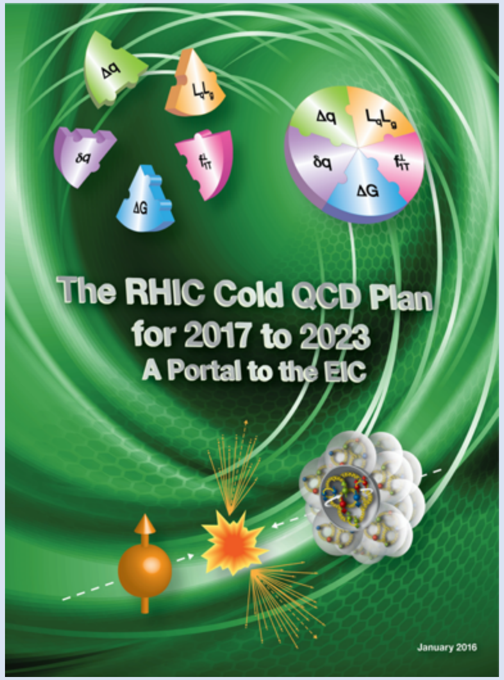
First INTT module assembled

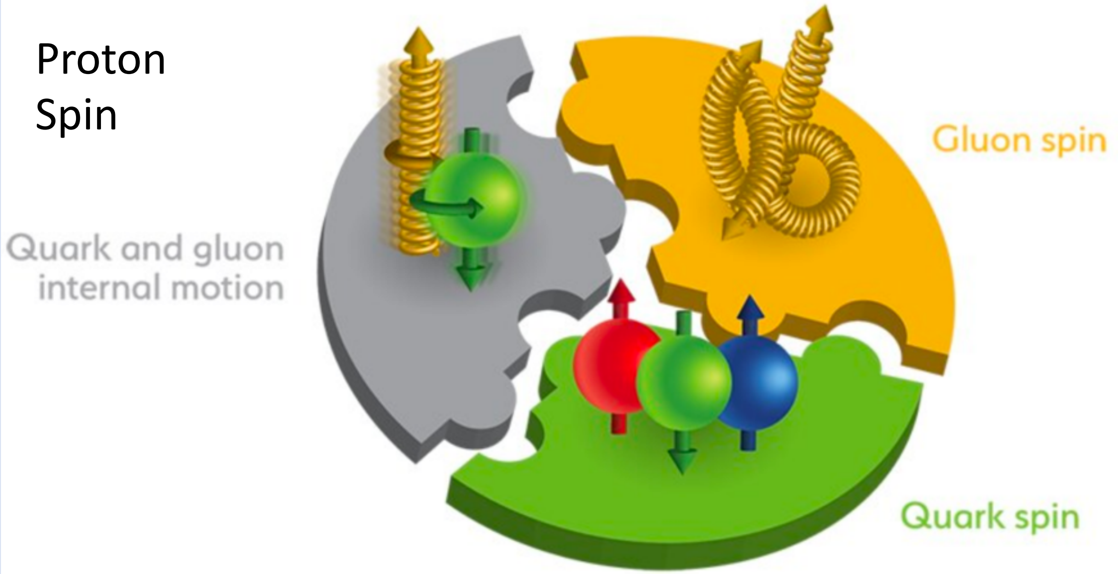


First sPHENIX MVTX staves produced

STAR Forward Upgrade Plan

Arxiv:1602.03922





The exploration of the fundamental structure of strongly interacting matter has always thrived on the complementarity of lepton scattering and purely hadronic probes… an outstanding scientific opportunity remains to complete "must-do" measurements in p+p and p+A physics in the years preceding the EIC.

Hadron in jets ($|\eta| > 1$)
TMDs (low/high x)

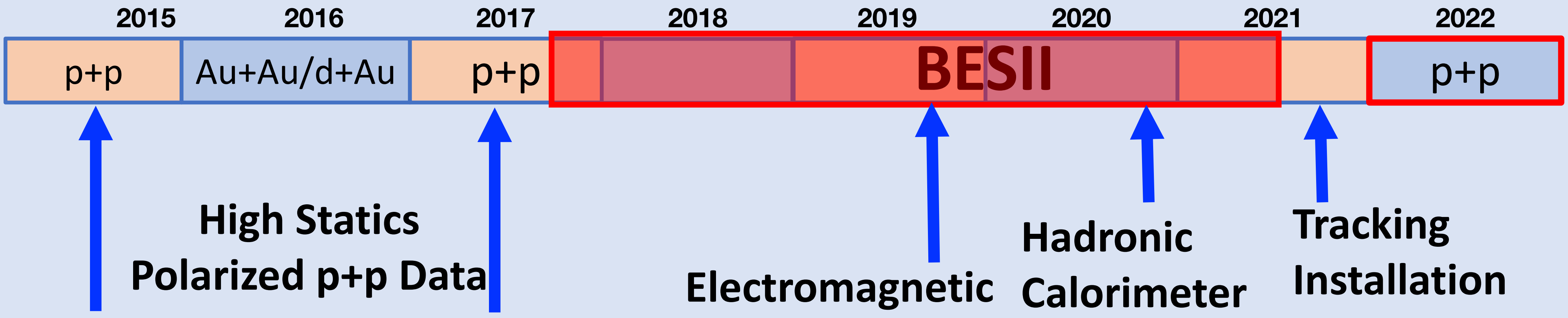
Dijets, h/γ-jets ($|\eta| > 1$)
Constrain gluon contribution at small x

Direct photons/DY
Initial state, hadronization in nuclear collisions, nPDF

Dihadrons, h/γ-jets
Saturation

E. Aschenauer F - 9:15 EIC

STAR Timeline

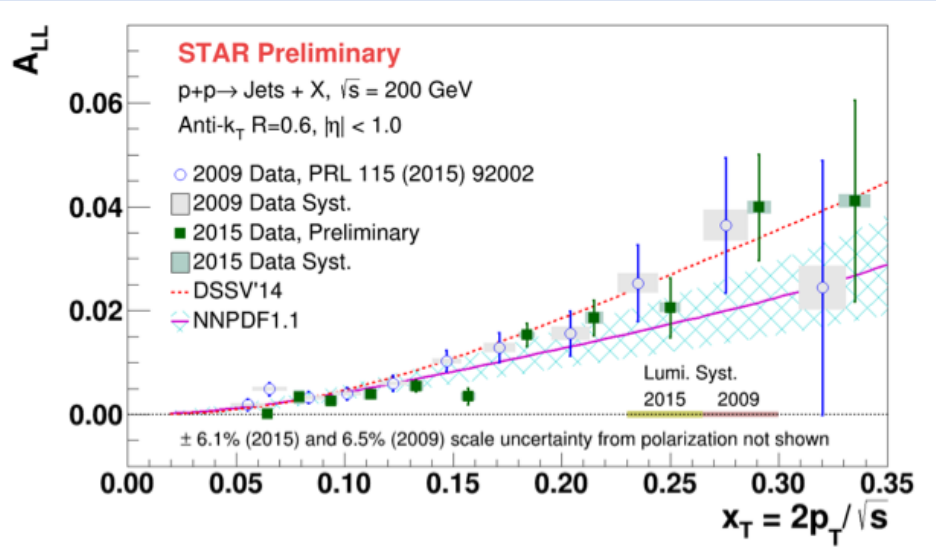


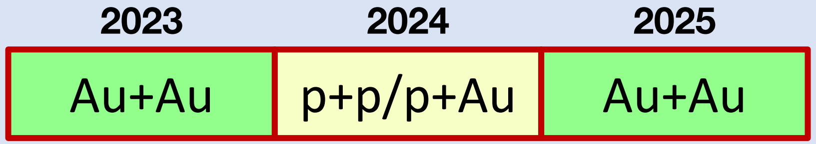
High Statics Polarized p+p Data

Electromagnetic Calorimeter Installed

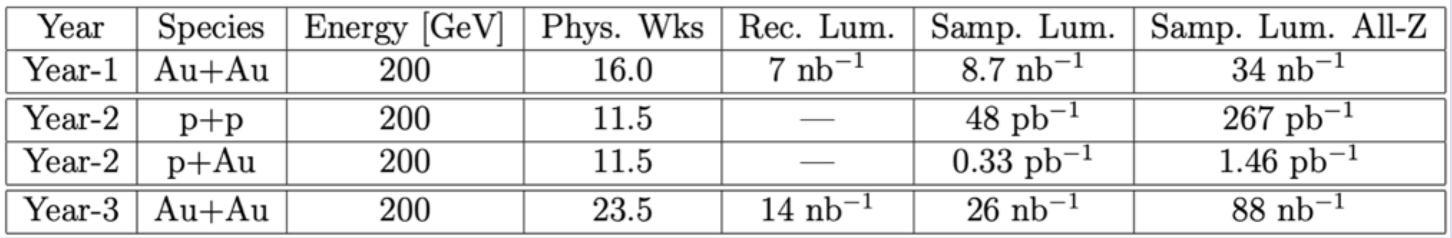
Hadronic Calorimeter Installation

Tracking Installation



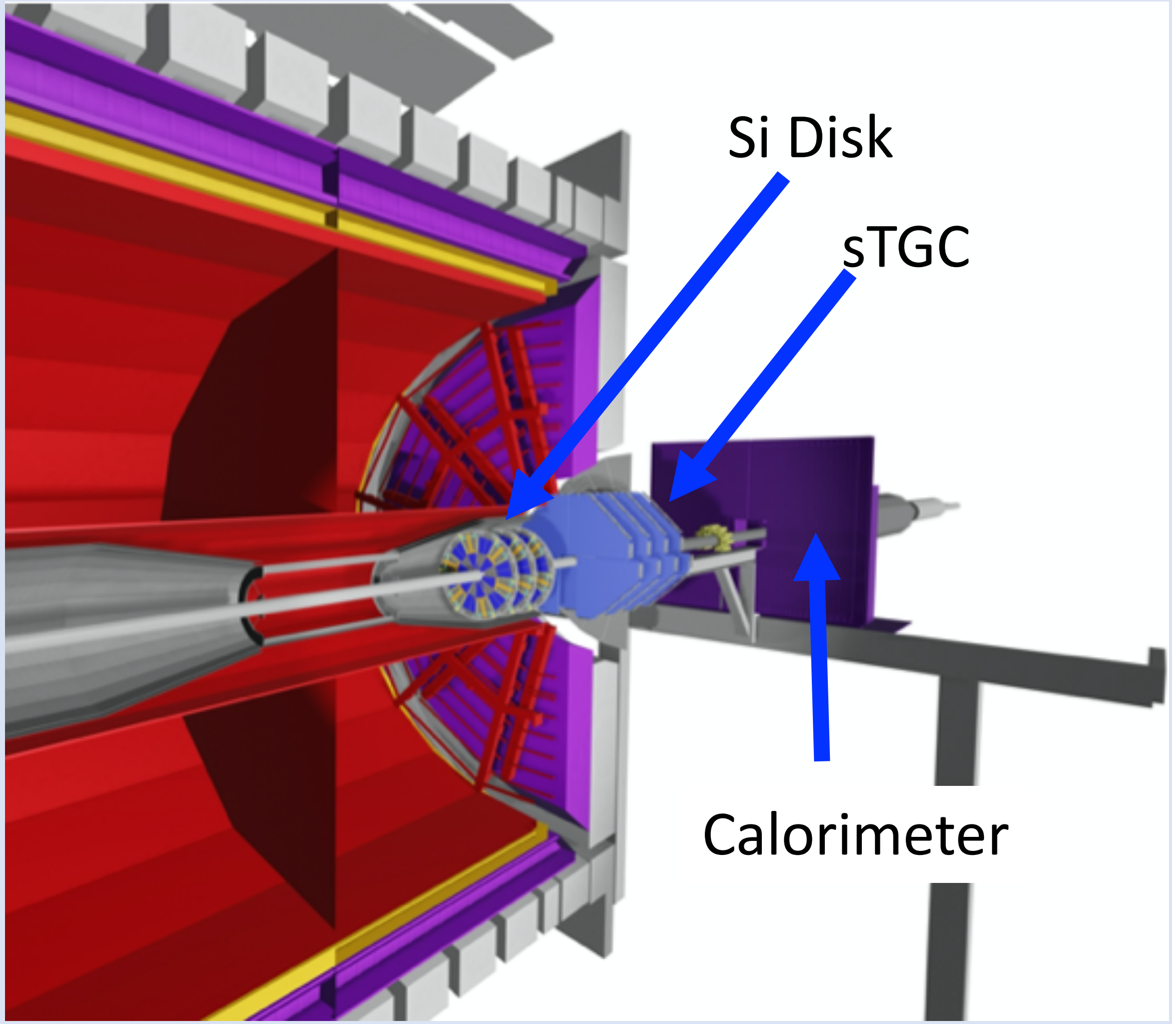


sPHENIX Run plan → Parallel running



Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}

STAR Forward Upgrade



Coverage: $2.5 < \eta < 4.0$

- Mid-rapidity Emcal/Tracking coverage $|\eta| < 1.2$

Forward Tracking System (FTS)

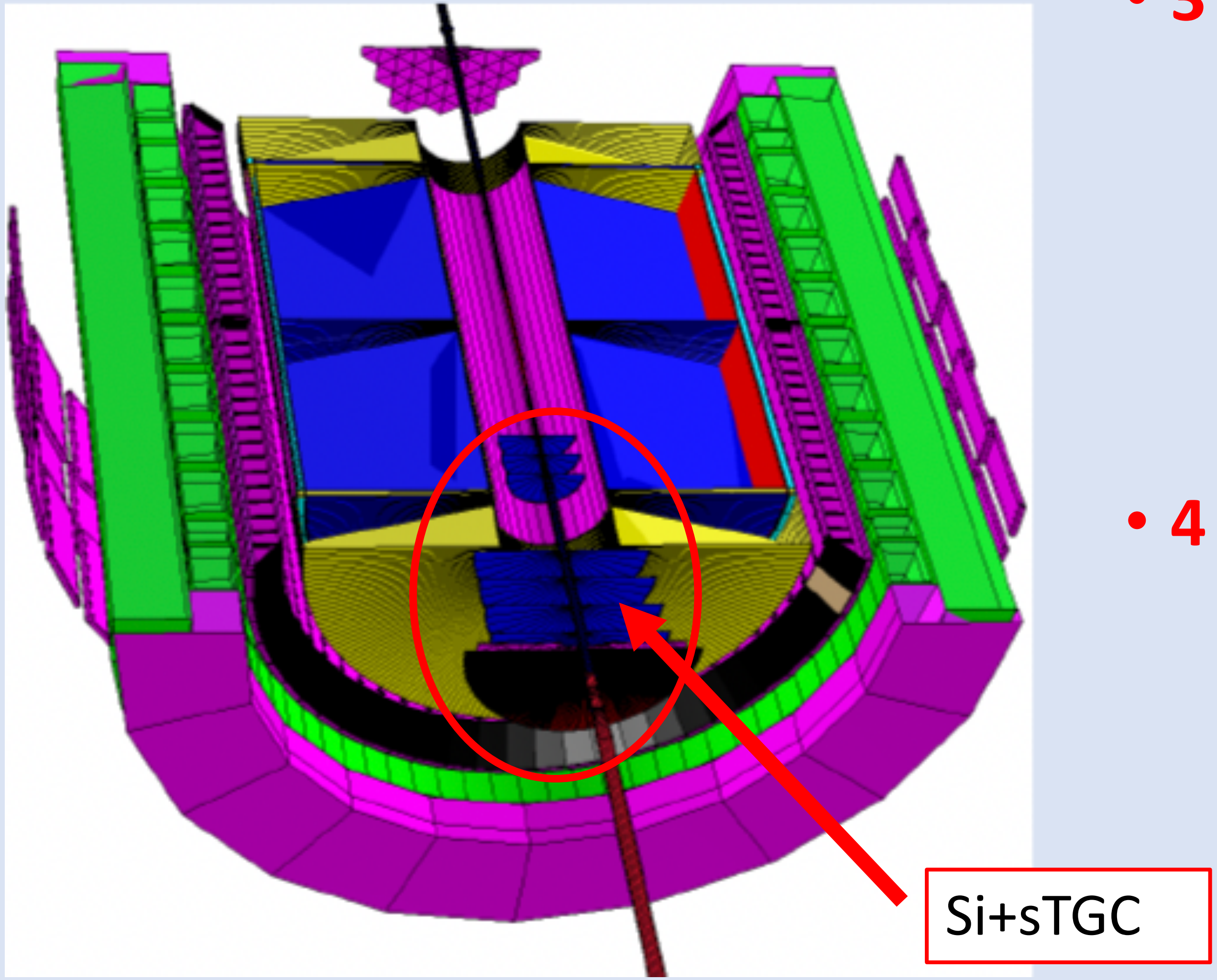
- Silicon microstrip sensors
- Small-Strip Thin Gap Chambers (sTGC)
- Momentum Resolution **< 30%**
- Tracking **Efficiency > 80%** @ 100 tracks / evt

Forward Calorimetry System (FCS)

- Hadronic Calorimeter
  - Resolution **$\sim 50\%/\sqrt{E}+10\%$**
- Electromagnetic Calorimeter
  - Resolution **$\sim 10\%/\sqrt{E}$ p+p vs $\sim 20\%/\sqrt{E}$ A+A**

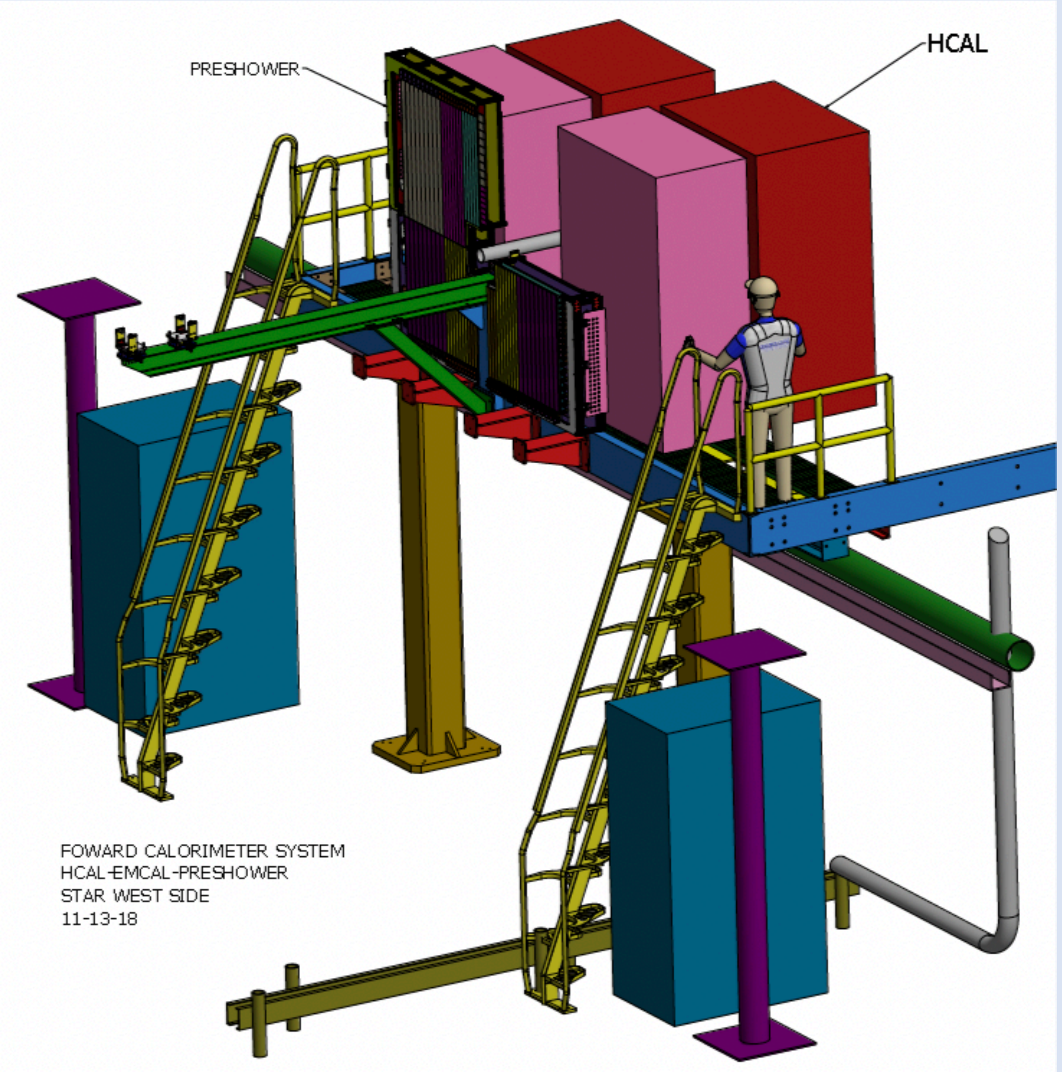
D. Brandenburg, 4 June, 11:55, G4

STAR Silicon and sTGC



- **3 Silicon disks**
  - Z = 139.9, 163.2, 186.5 cm (from IP)
  - Built on successful experience w/STAR Inner Silicon Tracker (IST)
  - Reuse IST DAQ system (FTS) + cooling system
- **4 sTGC disks**
  - Z = 273, 303, 333, 363 cm (from IP)
  - Inside Magnet pole tip opening Position resolution: ~100 µm
  - Material budget: ~0.5% per layer
  - 24,000 channels

STAR ECal & HCal

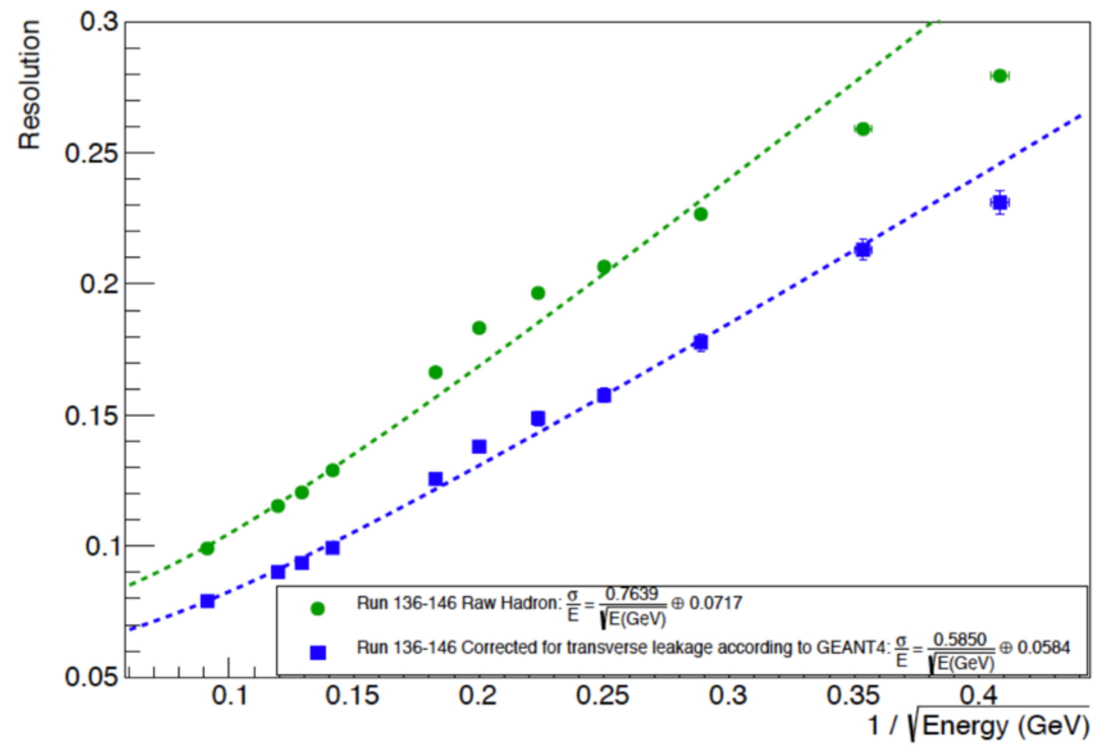


- Location: Z = 7 m (from IP)
  - Readout: SiPMs
  - Will be used in the Trigger
  - Slightly projective
- **Ecal** (Already Installed)
  - Reuse PHENIX PbSC calorimeter with new readout → 1496 channels
  - ~18 X_0
- **Hcal**
  - First use of a hadronic calorimeter @ STAR!
  - Fe/Sc (20mm/3 mm) sandwich
  - 520 readout channels
  - Lateral tower size 10 x 10 cm^2
  - ~ 4.5λ
- STAR event plane detector → Electron ID w/Calorimeter

STAR Forward Upgrade Performance

Performance of HCAL @ FNAL

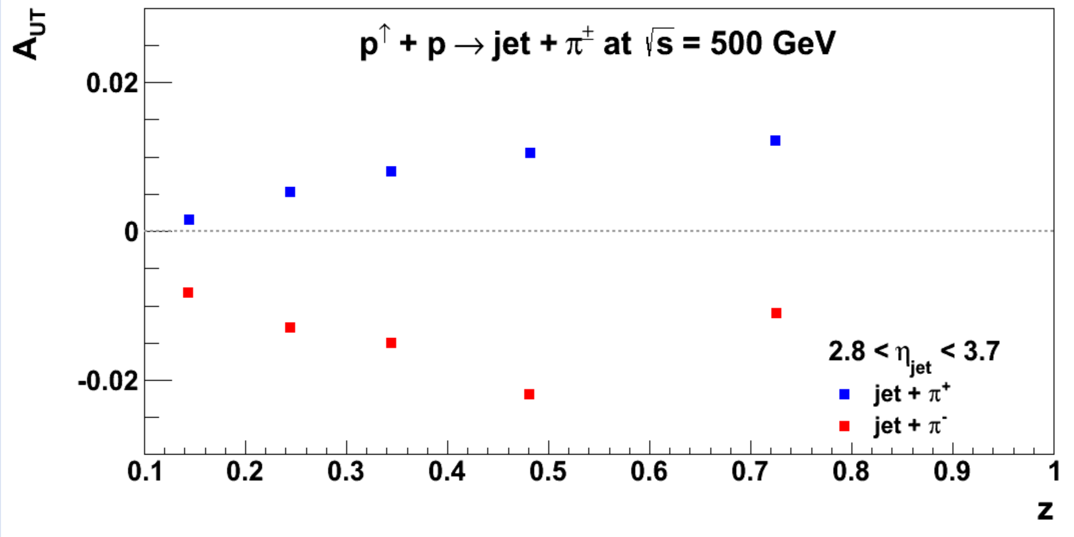
- ECAL+HCAL performance near requirements
- ~50%/$\sqrt{E}$+10%



Expected Collins asymmetries

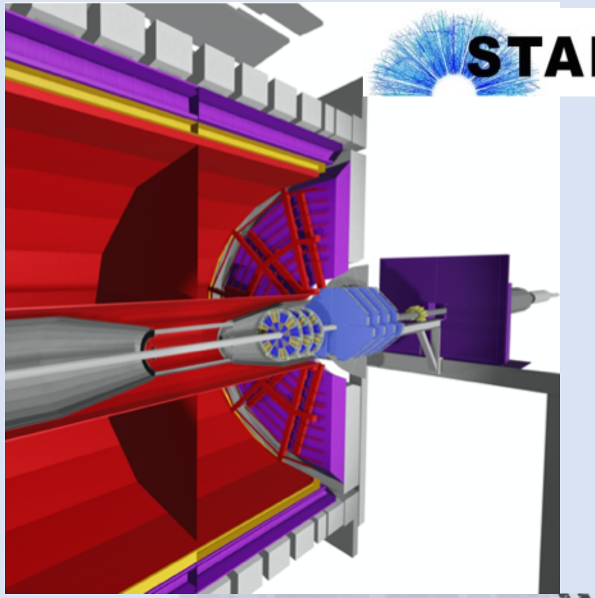
- Describes a transversely polarized quark fragmenting into an unpolarized hadron
- Single spin asymmetry (AUT) → Asymmetry ~2% expected for both flavors of pion

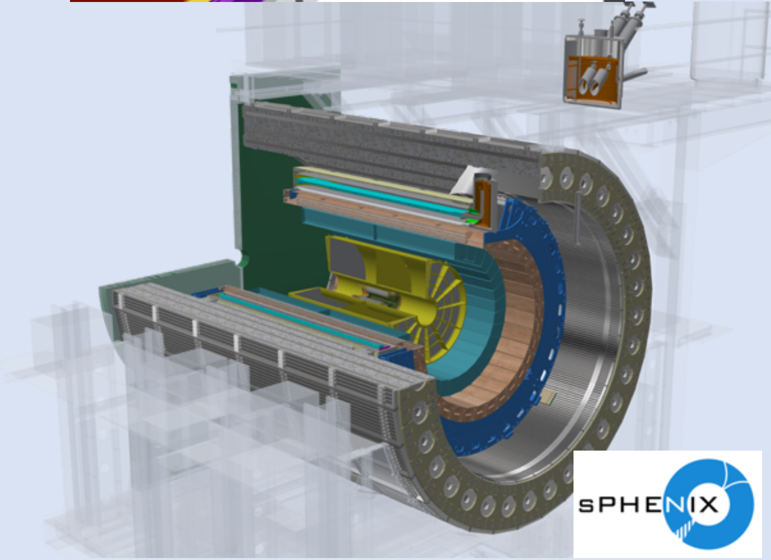
$p_{T,jet} > 3$ GeV/c
$\mathcal{L} = 1\ \text{fb}^{-1}$ w/ 60% polarization



Conclusions

- RHIC is carrying out the priorities of the LRP
- Improved capabilities from STAR upgrades, accelerator upgrades + sPHENIX will result in an exciting post-BESII Era!
  - **Improved tracking, calorimetry** (including hadronic)
  - Increased **kinematic reach** + improved statistics
- STAR forward program will be a bridge to the EIC
  - Probes allow separation of interaction dependent phenomena from intrinsic nuclear properties
  - Complementarity between RHIC Cold QCD program/EIC and STAR/sPHENIX
- sPHENIX will probe the QGP structure at a variety of scales
  - On track for data taking in **2023!**
  - Complementary to HI LHC measurements in 2020s
  - Allow new observables to be measured at RHIC → rich QGP and QCD physics (b-jets, b-dijet, D-D correlations + others)
  - Motivated by HEP experience





Conclusions

- RHIC is carrying out the priorities of the LRP
  - Precisely how does QCD lead to the emergent phenomena we observe?
- Improved capabilities from **STAR** upgrades, accelerator upgrades + **sPHENIX** will result in an exciting post-BESII Era!
- How do quarks and gluons form a strongly coupled, nearly perfect liquid?
  - What are its properties?
- How do the proton constituents lead to its spin?