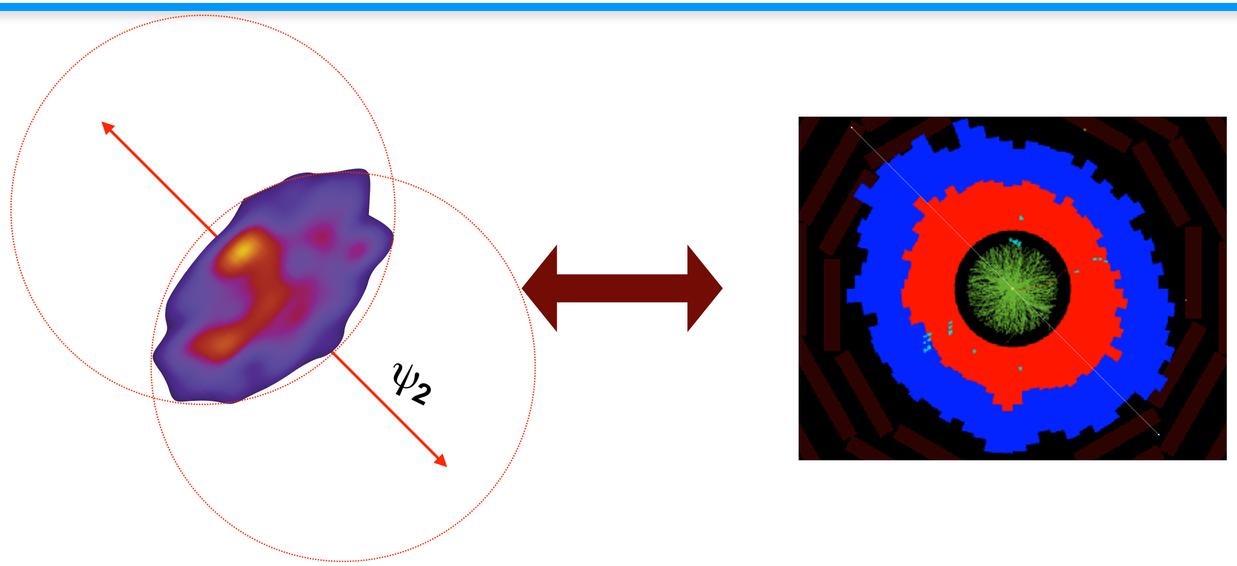
Status and Goals of the sPHENIX Detector

Ross Corliss
for the sPHENIX Collaboration

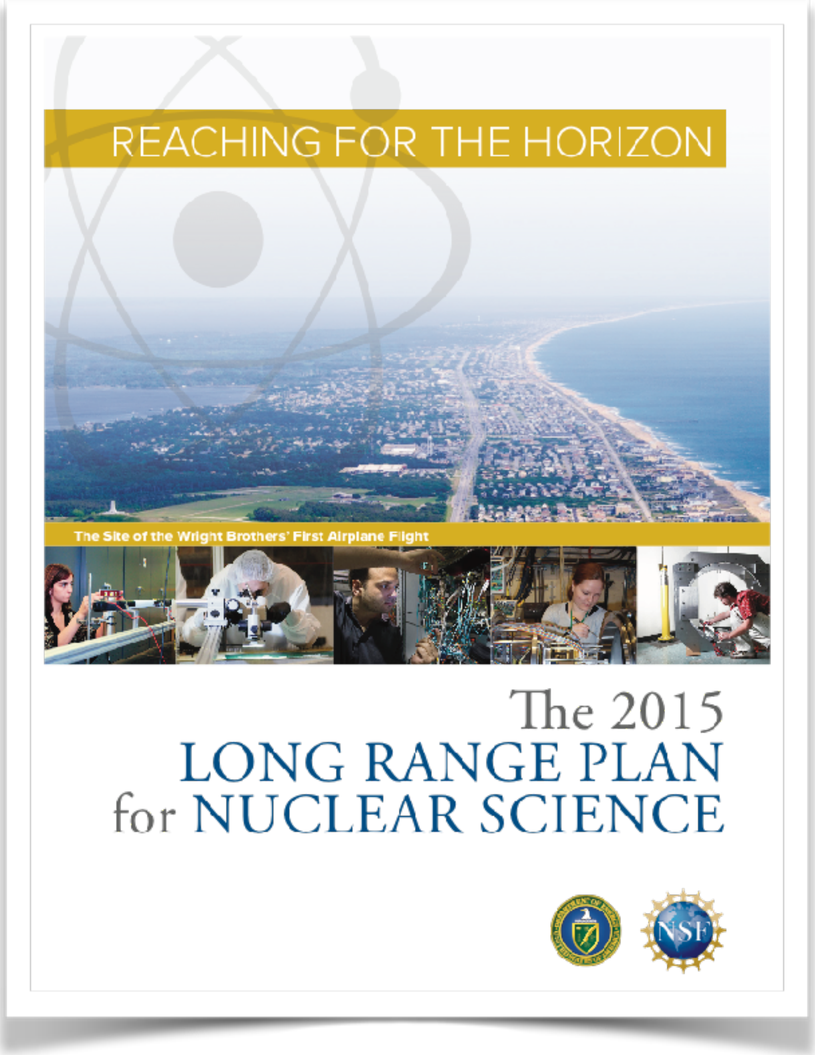
Hot QCD



- First RHIC results demonstrated surprising properties of **Quark-Gluon Plasma** created in **heavy-ion collisions**: near perfect fluidity and extreme opacity
- Precision studies at RHIC and LHC showed that many aspects of final state structure can be understood via relativistic viscous hydrodynamics applied to QGP evolution
- Success of LHC experiments in HI physics demonstrates importance of large acceptance, high resolution tracking, high collision rates and full EM+Hadronic calorimetry
- Coming decade: **Improved instrumentation at RHIC and LHC will help understand how QGP properties emerge from underlying, (asymptotically) weakly coupled interactions**

sPHENIX in the Long Range Plan

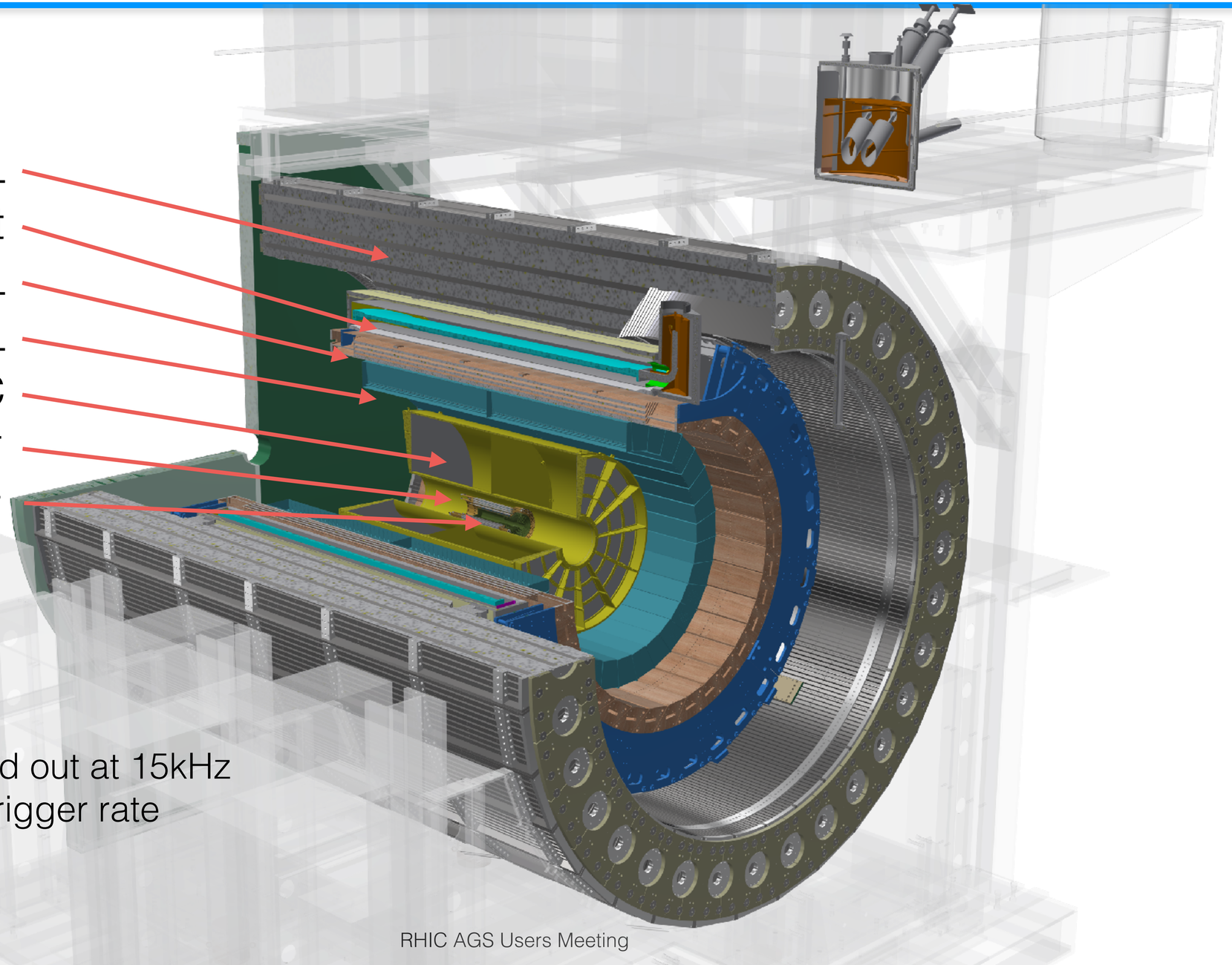
http://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf



Section 2.2, page 22

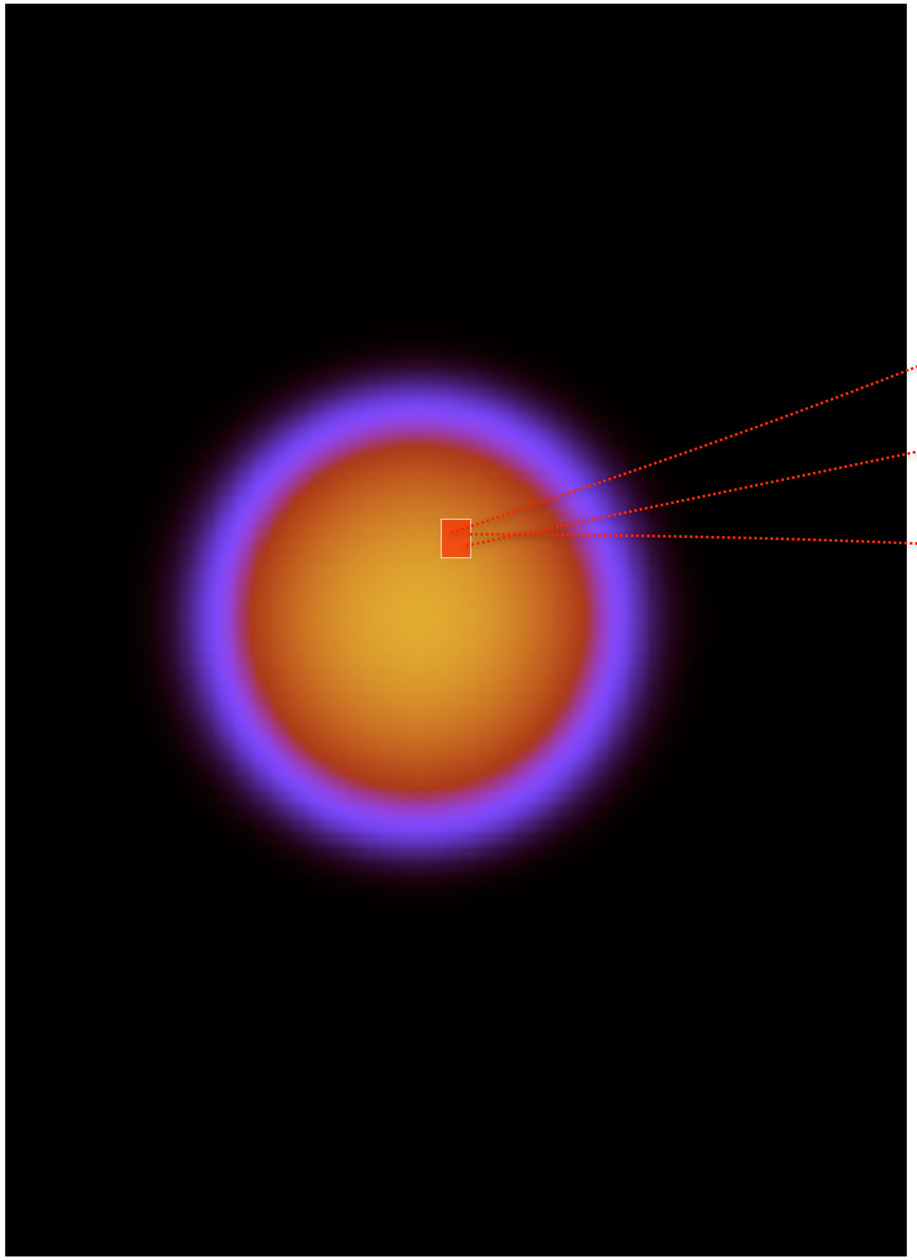
There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.**

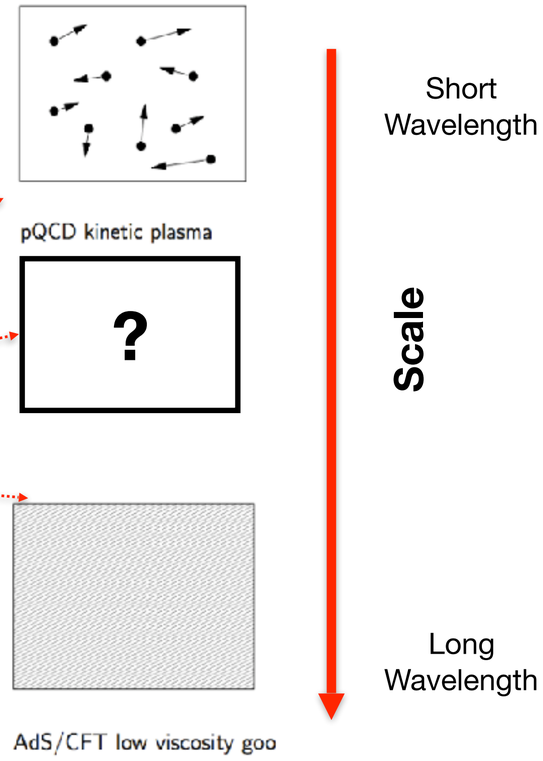
The sPHENIX Detector



- All can read out at 15kHz sPHENIX trigger rate

Probing the QGP





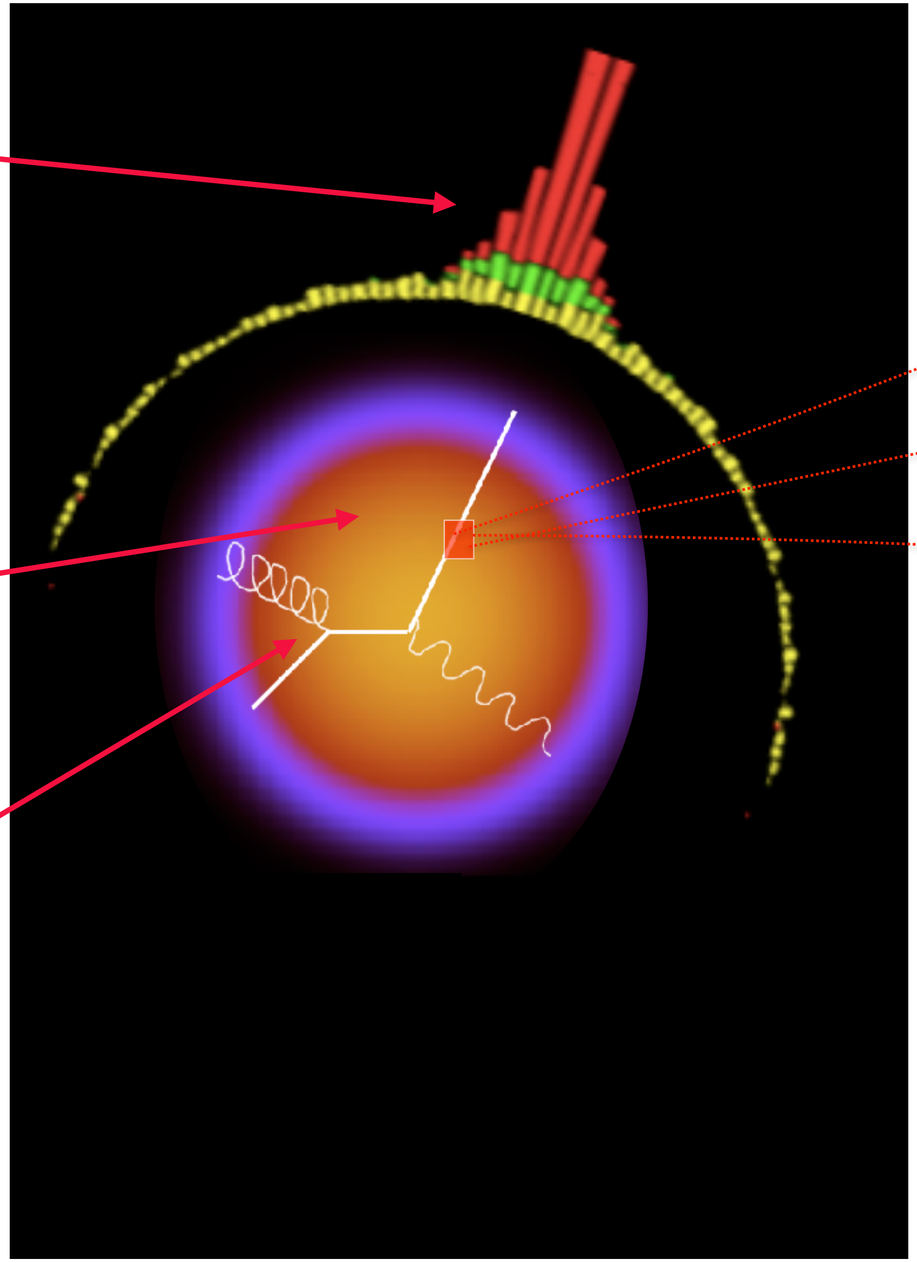
How does long-wavelength physics emerge from underlying gauge theory?

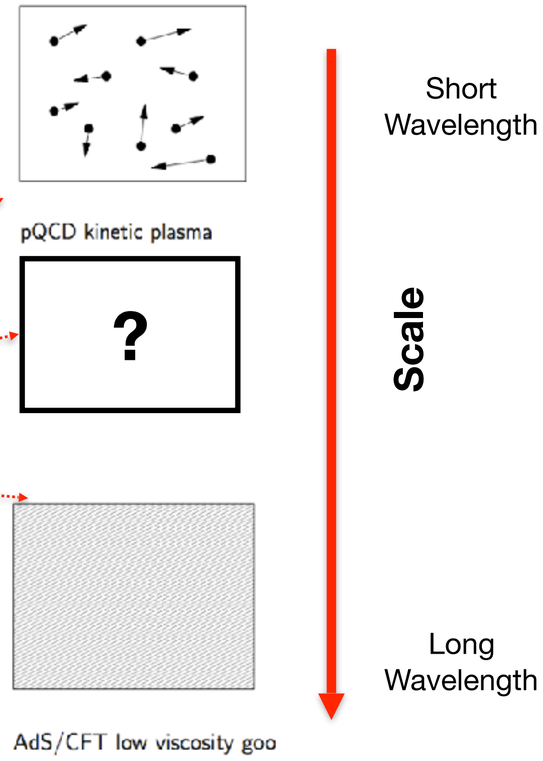
Probing the QGP

Full characterization of final state

Different QGP initial conditions and evolution at RHIC and LHC

Same hard process

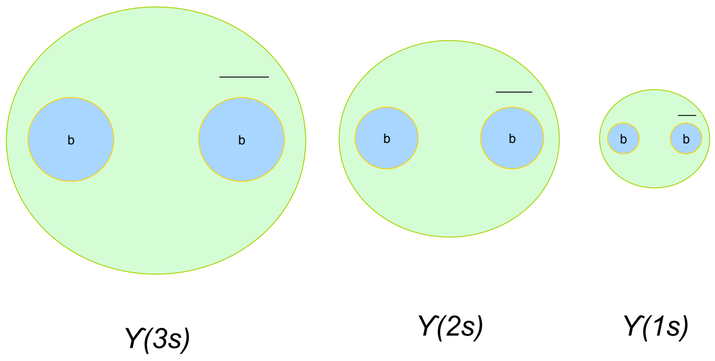




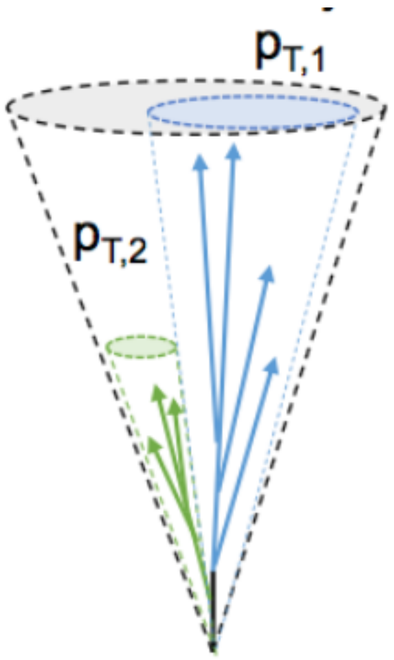
How does long-wavelength physics emerge from underlying gauge theory?

Varying Probes

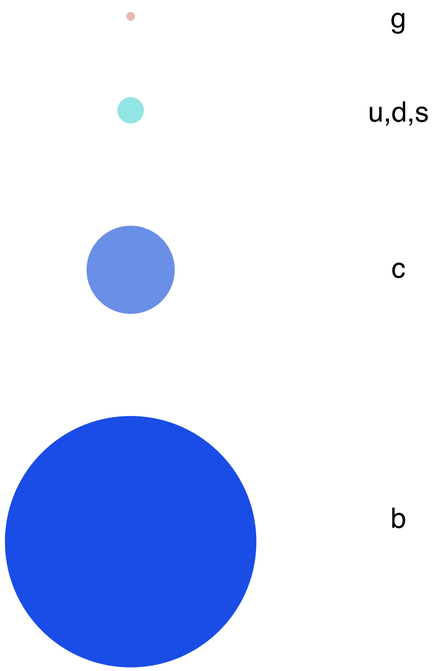
Quarkonium spectroscopy
vary size of probe



Jet structure
vary momentum/angular scale of probe



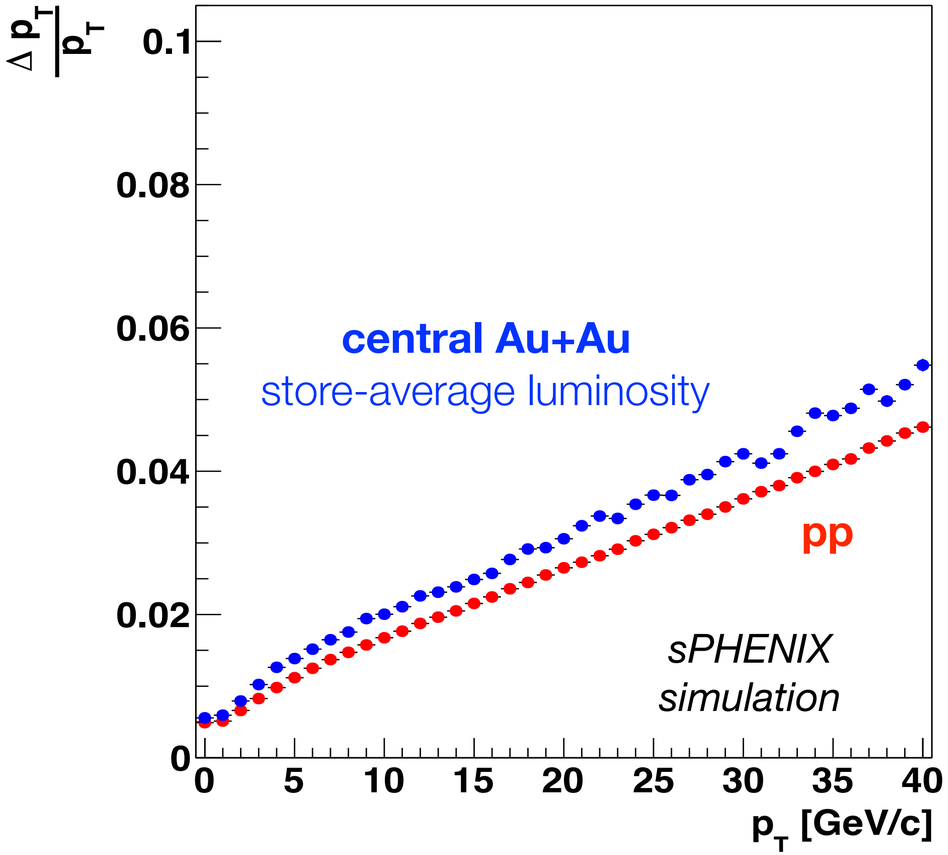
Parton energy loss
vary mass/momentum of probe



- Probe with quarkonia, jets and high-pT hadrons, heavy quarks, high-pT photons
- Continue expanding connections between measurements and underlying physics with theory community
- Use precise tracking and calorimetry capable of high rates to take advantage of high luminosity

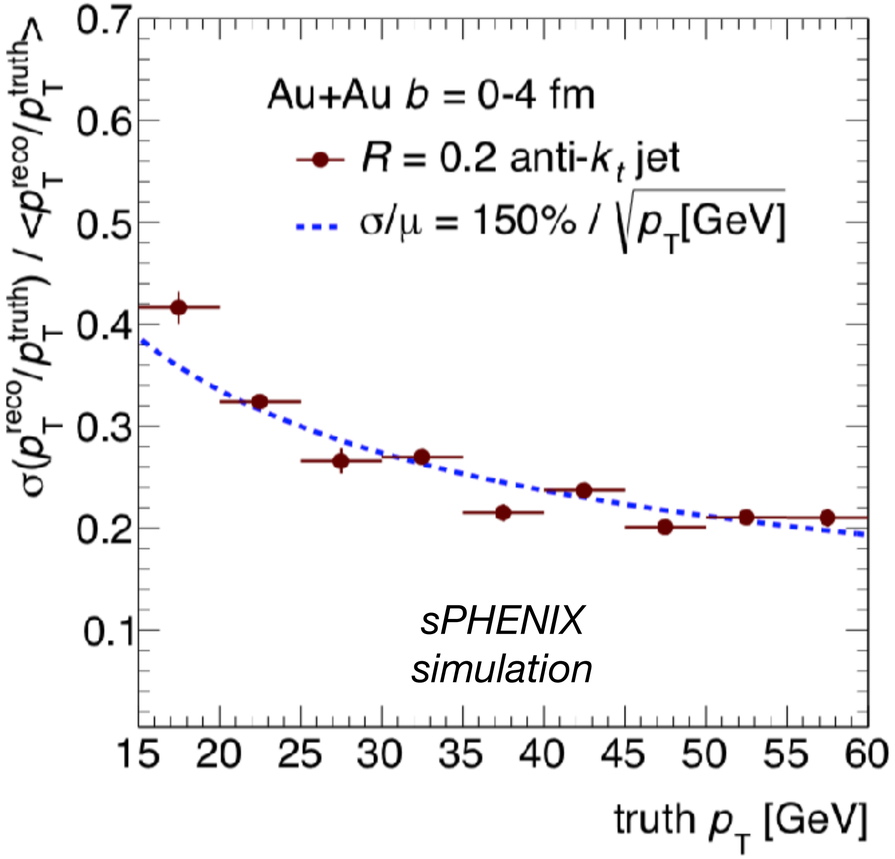
Key Performance Parameters

Track pT resolution (central Au+Au)



High momentum resolution
Simulated tracking efficiency > 90% in high-pileup Au+Au environment

Jet pT resolution (central Au+Au)

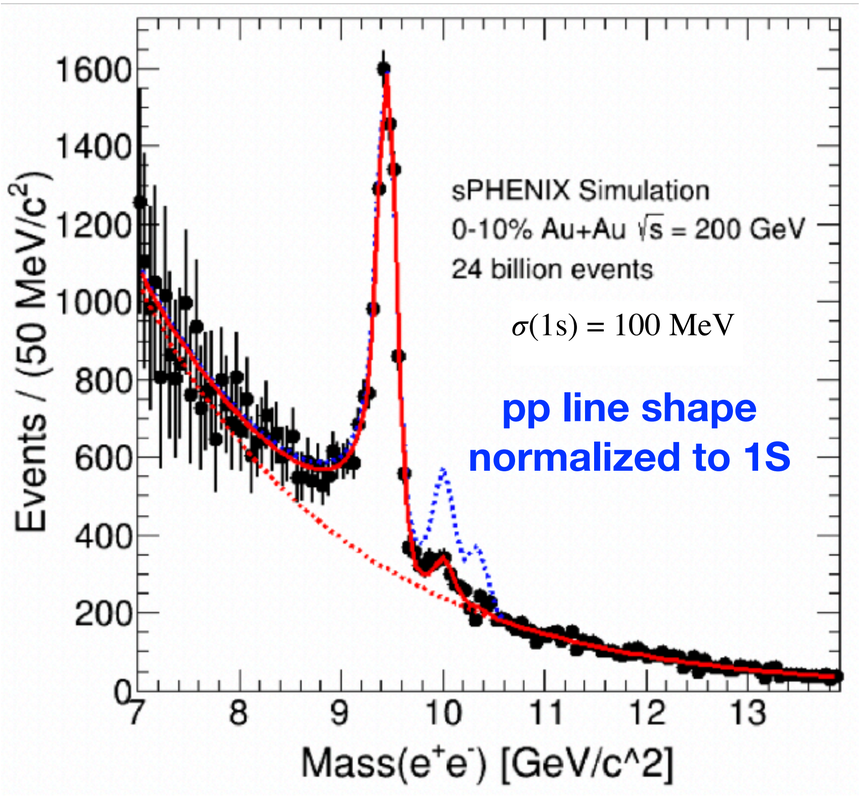


Simulated calorimeter performance verified with **test beam data**

arXiv:1704.01461

Some Observables

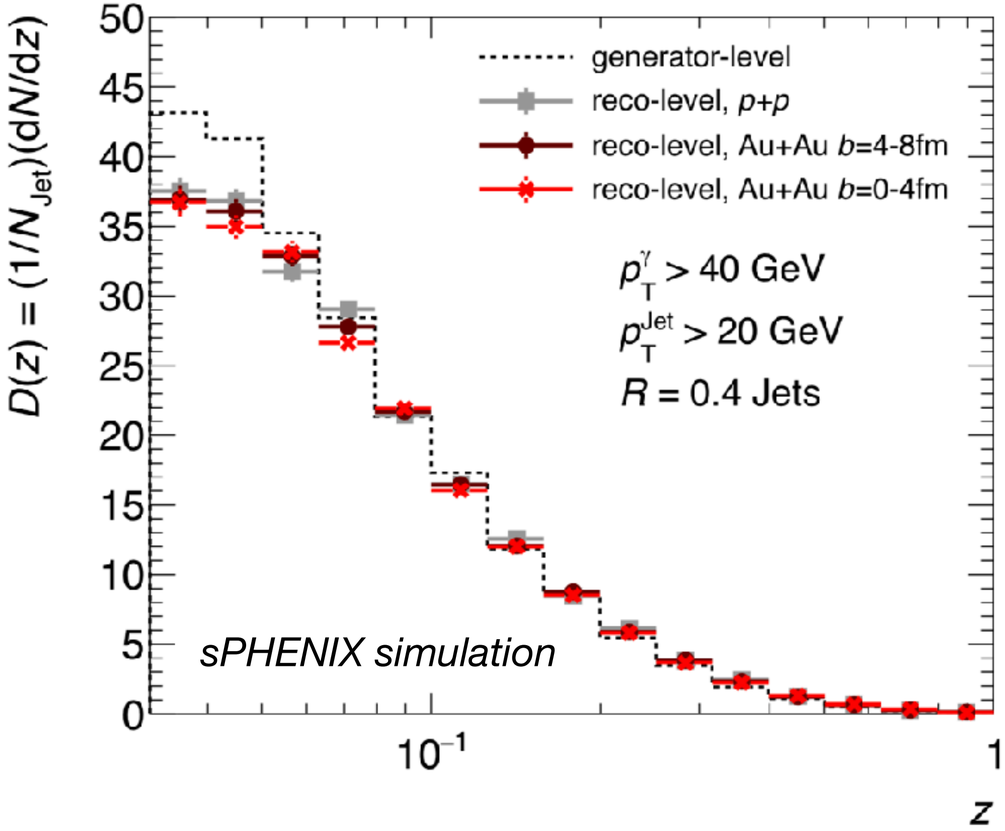
Upsilon invariant mass (central Au+Au)



High resolution Y spectroscopy probes **sequential suppression of Y(nS)** states

(More on observables in Yuanjing Ji's talk)

Jet fragmentation function



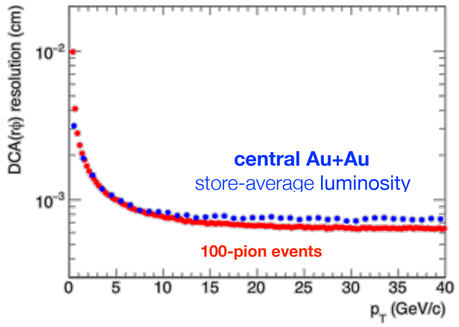
Photon-jet Fragmentation Functions probe **modification of parton shower**

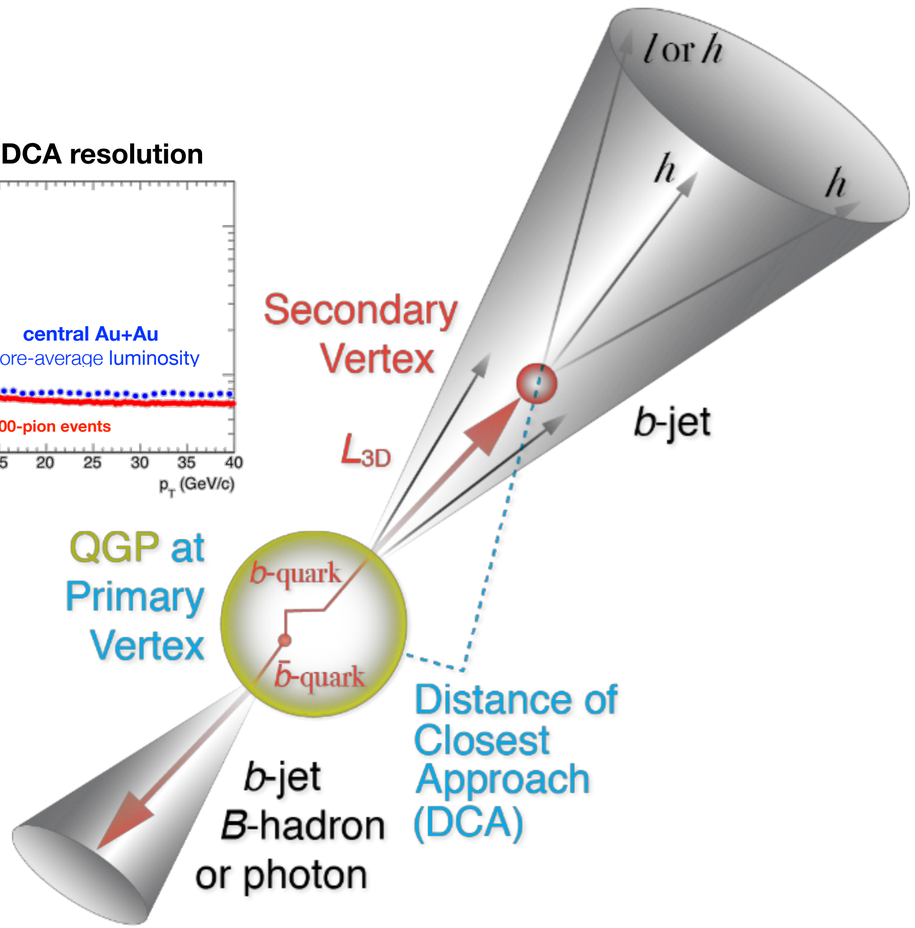
(More on jets in Dennis Perepelitsa's talk)

Heavy Flavor

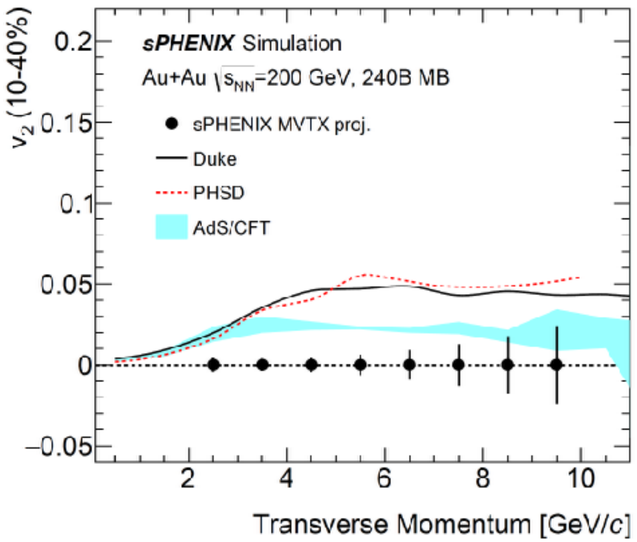
Access Heavy Flavor channels by resolving displaced vertices:

MVTX* DCA resolution

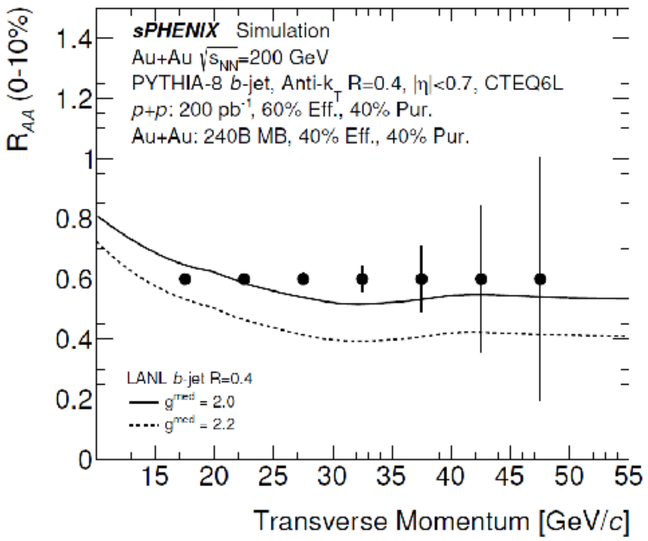




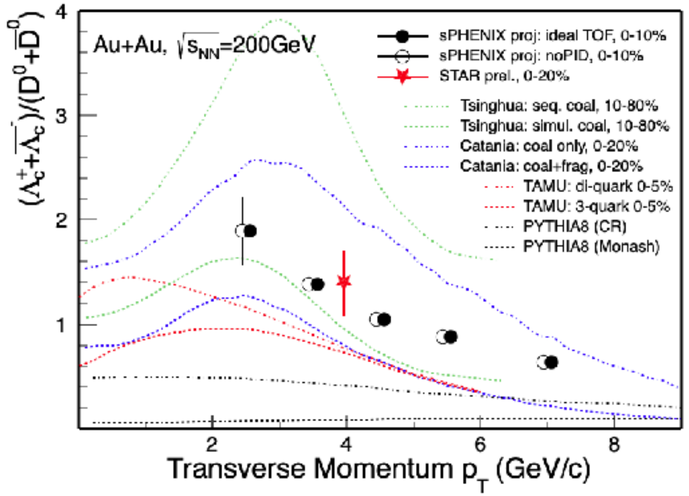
B meson flow



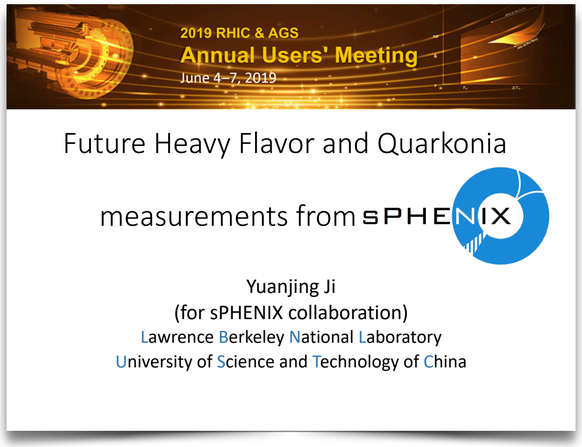
b-jet modification



Λ_c enhancement

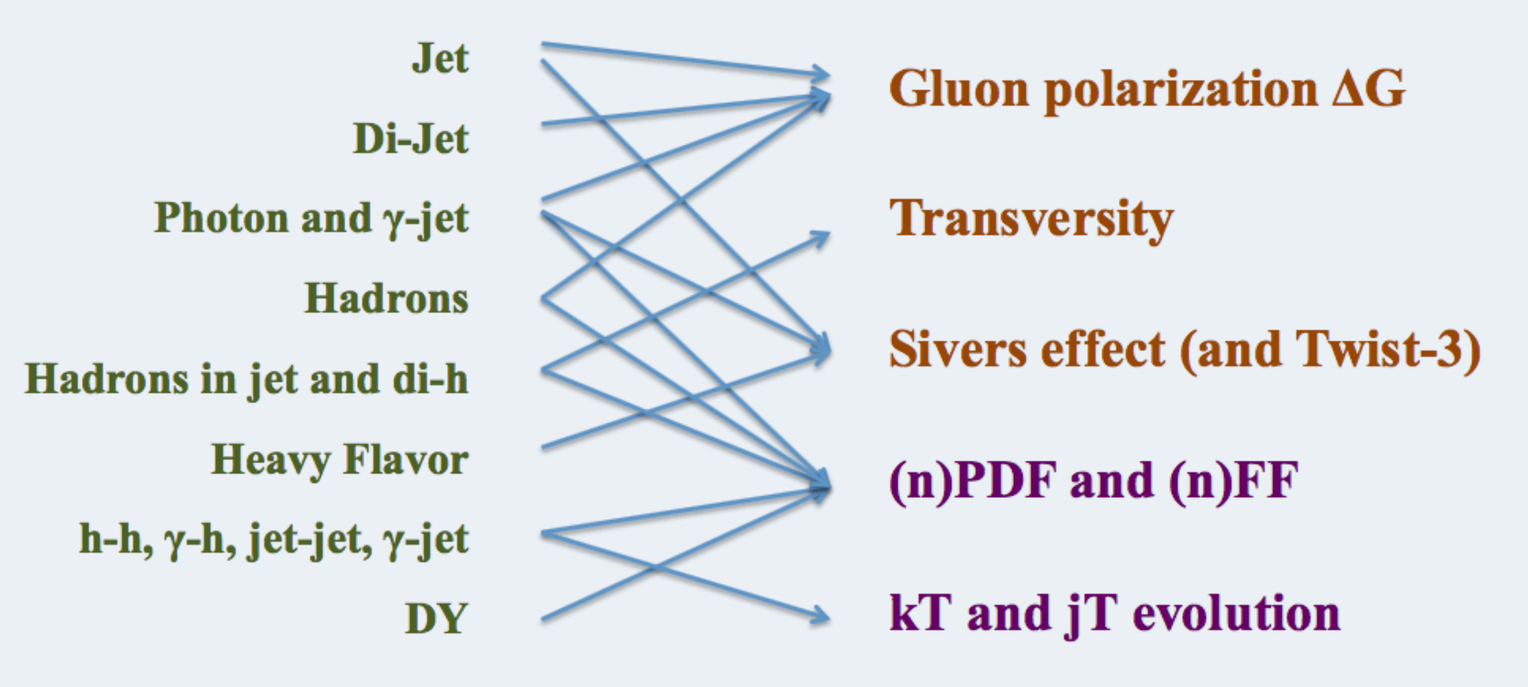


...and more.



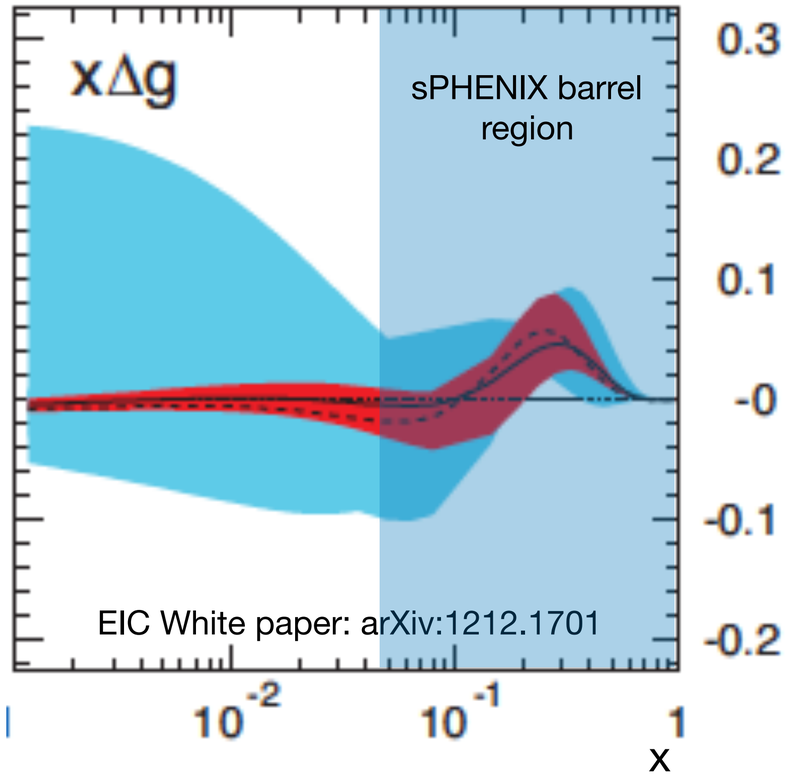
Cold QCD

Cold QCD and Spin Physics measurements also in reach:



(More on these in Sasha Bazilevsky's talk)

Gluon Polarization



Jet and hadron asymmetries in polarized pp are sensitive to **gluon polarization** in high-x region compared to EIC reach

Run Plan

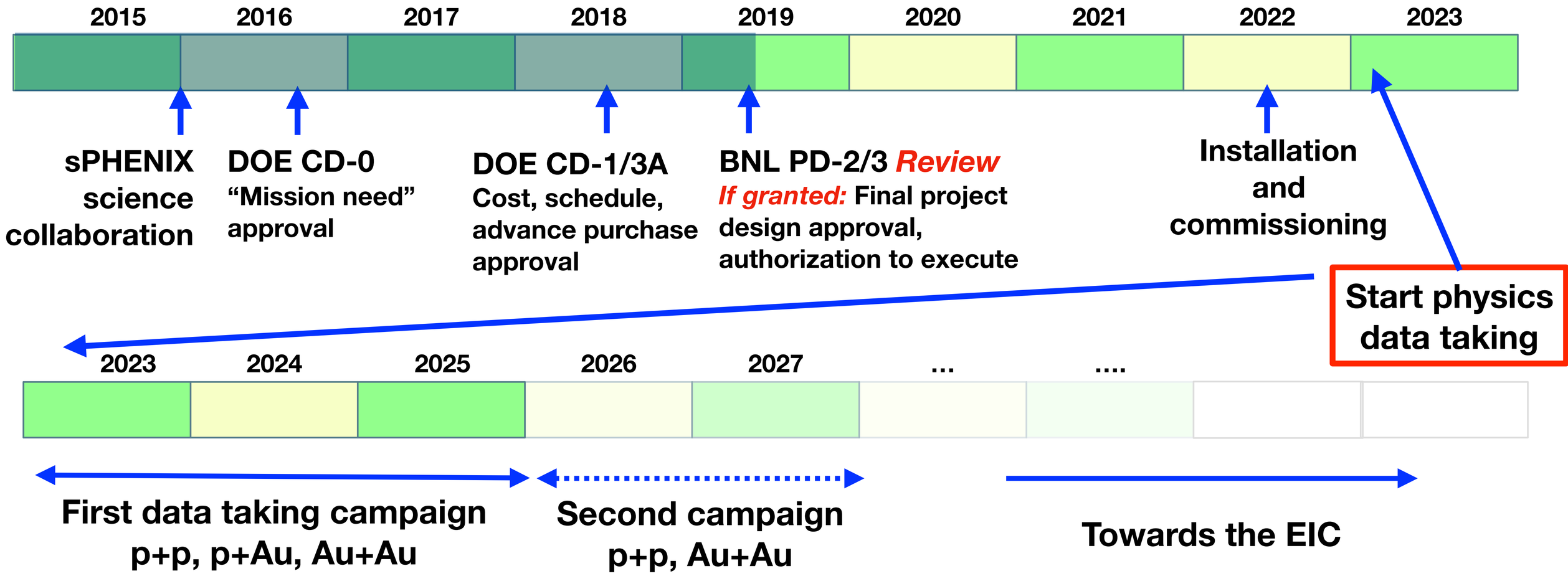
Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
Year-4	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
Year-5	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

Campaign 1

Campaign 2

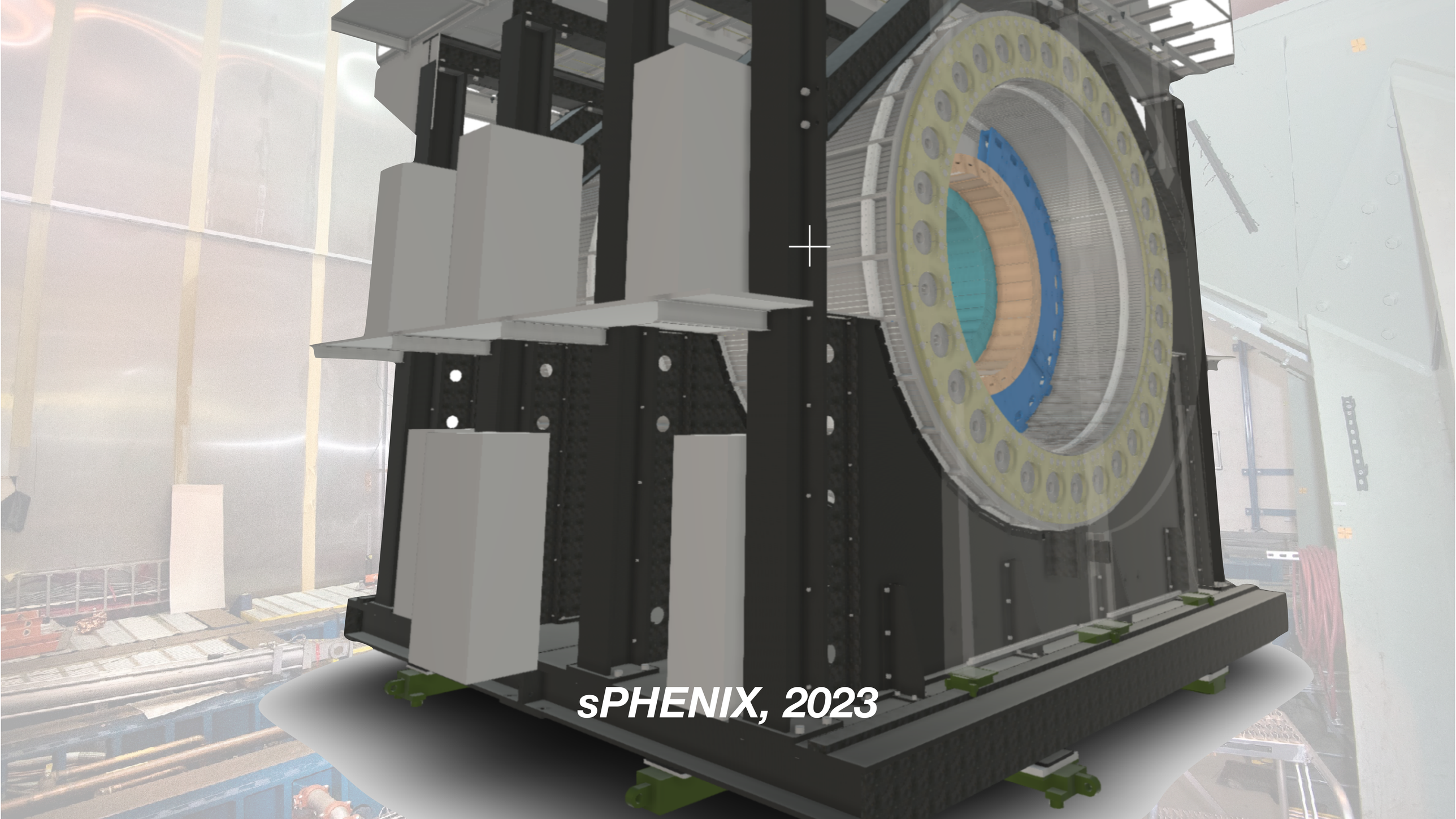
- Minimum bias Au+Au at 15kHz, vertex |z| < 10 cm (in acceptance of Si tracking): **47 billion** (Year-1) + **96 billion** (Year-3) + **96 billion** (Year-5) = Total **239 billion events**
- Topics with Level-1 selective tigger (e.g. high p_T photons), |z|<10cm, can sample **0.5 trillion Au+Au events**

Timeline



https://indico.bnl.gov/event/4788/attachments/19066/24594/sph-trg-000_06142018.pdf

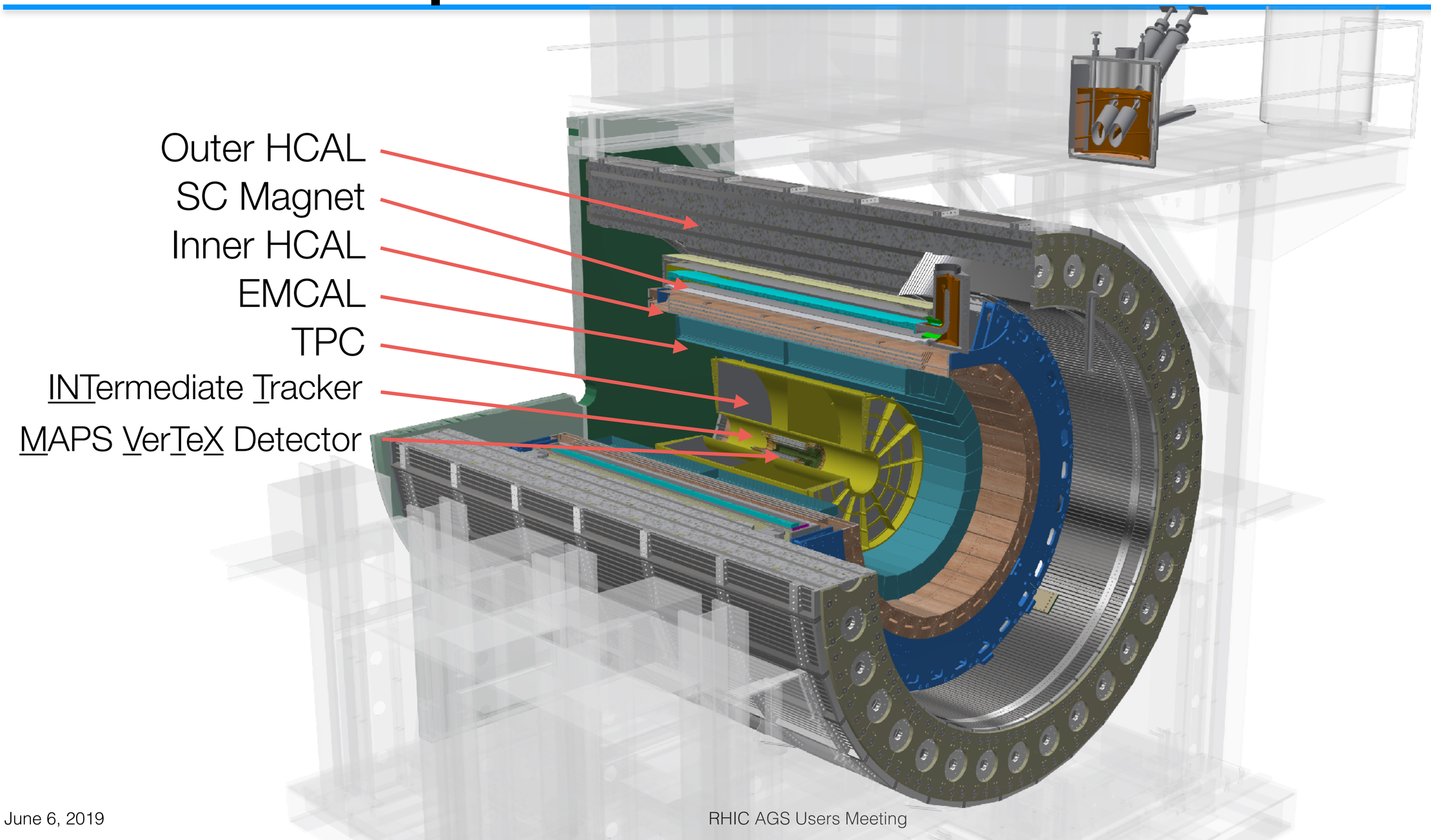
PHENIX, c. 2016


sPHENIX, 2023

77 Institutions and Growing

Augustana University
Banaras Hindu University
Baruch College, CUNY
Brookhaven National Laboratory
China Institute for Atomic Energy
CEA Saclay
Central China Normal University
Chonbuk National University
Columbia University
Eötvös University
Florida State University
Fudan University
Georgia State University
Howard University
Hungarian sPHENIX Consortium
Insititut de physique nucléaire d'Orsay
Institute for High Energy Physics, Protvino
Institute of Nuclear Research,
Russian Academy of Sciences, Moscow
Institute of Physics, University of Tsukuba
Institute of Modern Physics, China
Iowa State University
Japan Atomic Energy Agency
Charles University (CUNI), Prague
Czech Technical University in Prague
Korea University
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
Lehigh University
Los Alamos National Laboratory
Massachusetts Institute of Technology
Muhlenberg College
Nara Women's University
National Central University
National Research Centre
"Kurchatov Institute"
National Research Nuclear University
"MEPhI"
New Mexico State University
Oak Ridge National Laboratory
Ohio University
Peking University
Petersburg Nuclear Physics Institute
Purdue University
Rice University
RIKEN
RIKEN BNL Research Center
Rikkyo University
Rutgers University
Saint-Petersburg Polytechnic University
Sejong University
Shanghai Institute for Applied Physics
Stony Brook University
Sun Yat Sen University
Temple University
Tokyo Institute of Technology
Tsinghua University
Universidad Técnica Federico Santa María
University of California, Berkeley
University of California, Los Angeles
University of California, Riverside
University of Colorado, Boulder
University of Debrecen
University of Houston
University of Illinois, Urbana-Champaign
University of Jammu
University of Maryland
University of Michigan
University of New Mexico
University of North Carolina at Greensboro
University of Sao Paolo
University of Tennessee, Knoxville
University of Texas, Austin
University of Tokyo
University of Science and Technology, China
Vanderbilt University
Wayne State University
Weizmann Institute
Yale University
Yonsei University

sPHENIX Components

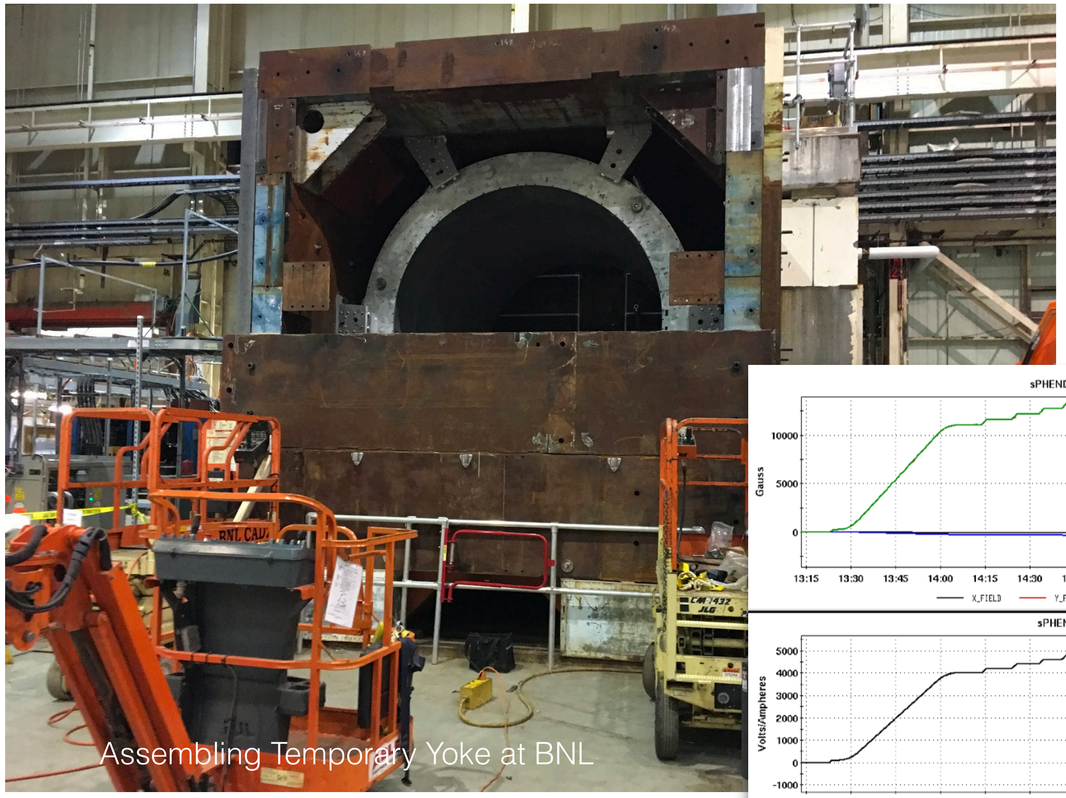


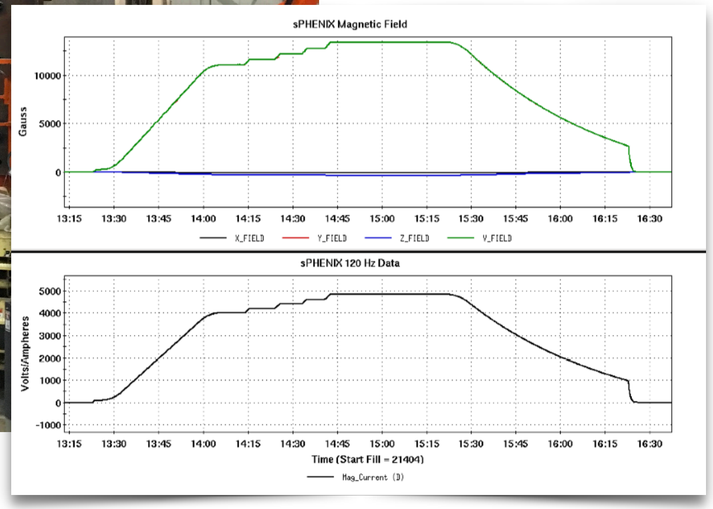
Superconducting Magnet

- Superconducting magnet from Babar, 1998-2008
- Inner radius 140cm, desired field 1.4T
- Moved to BNL in 2015

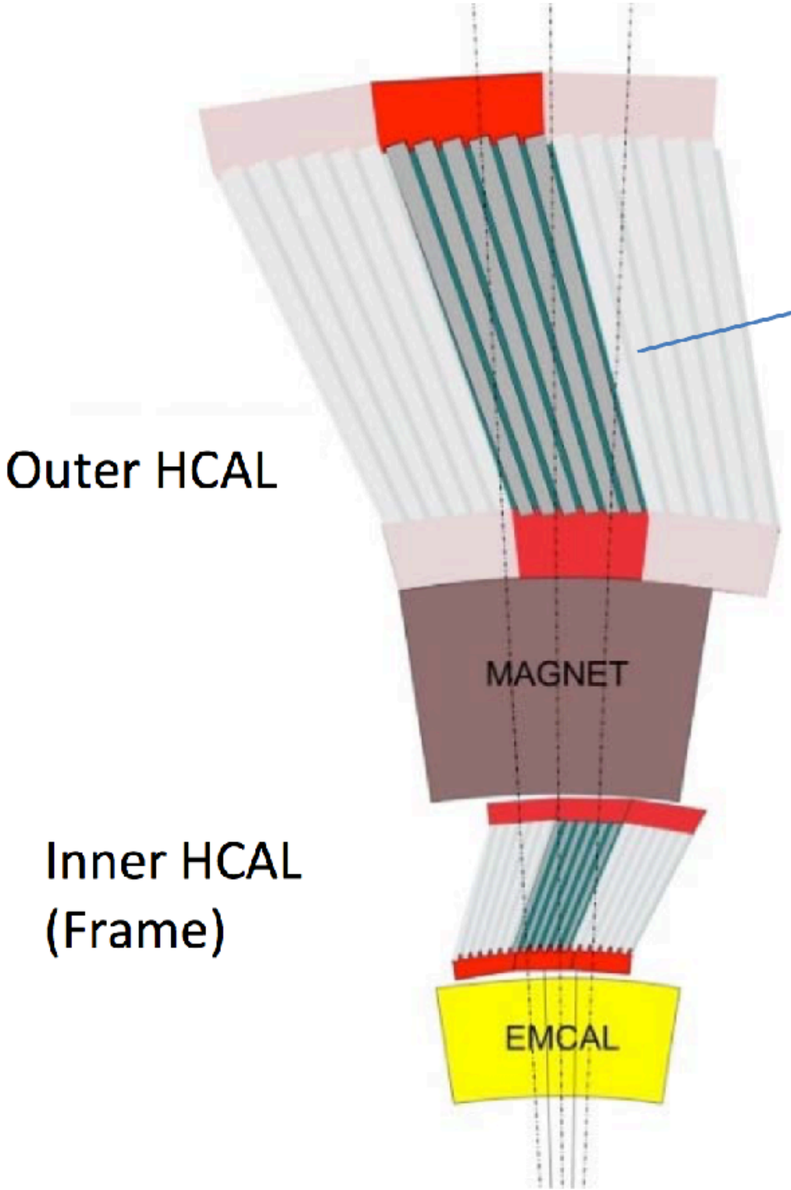
- Tested at 100A in 2016
- Tested to 105% of operating current, 4596A in 2018

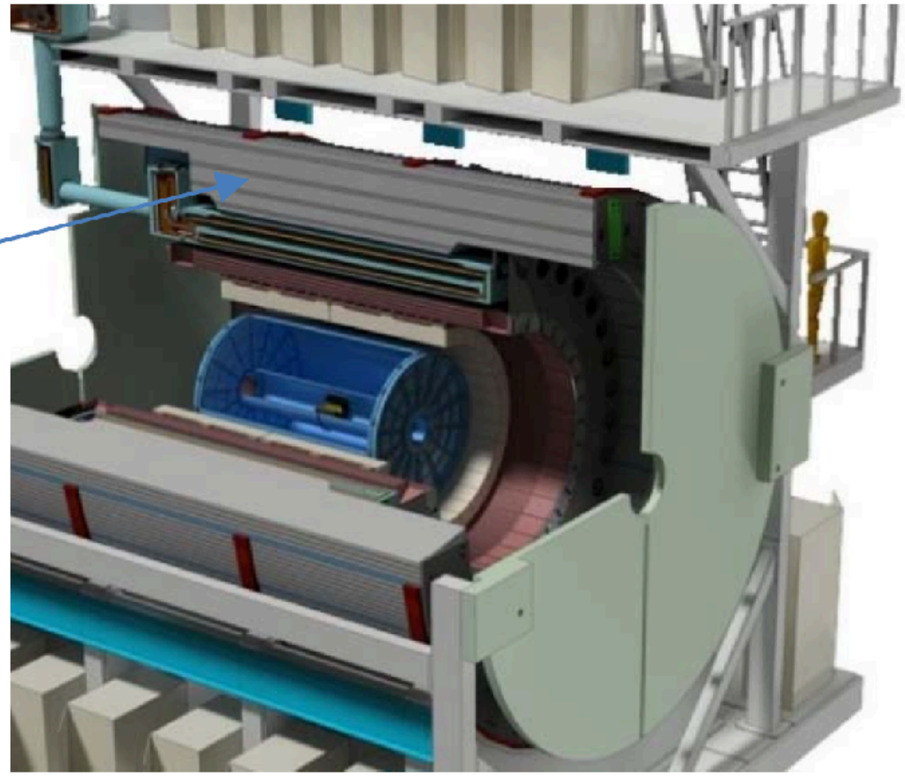
Magnet leaving SLAC


Assembling Temporary Yoke at BNL



Calorimeters

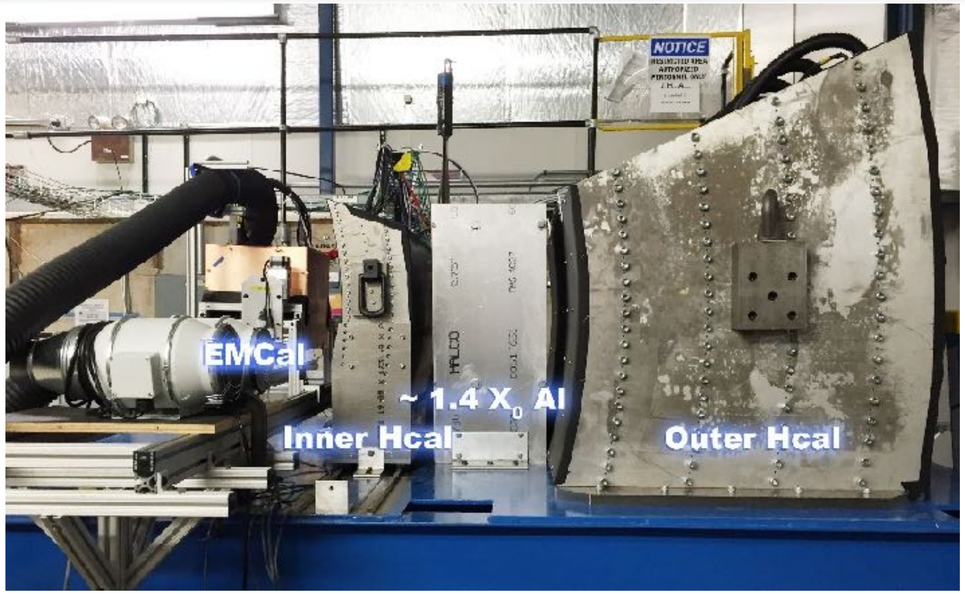


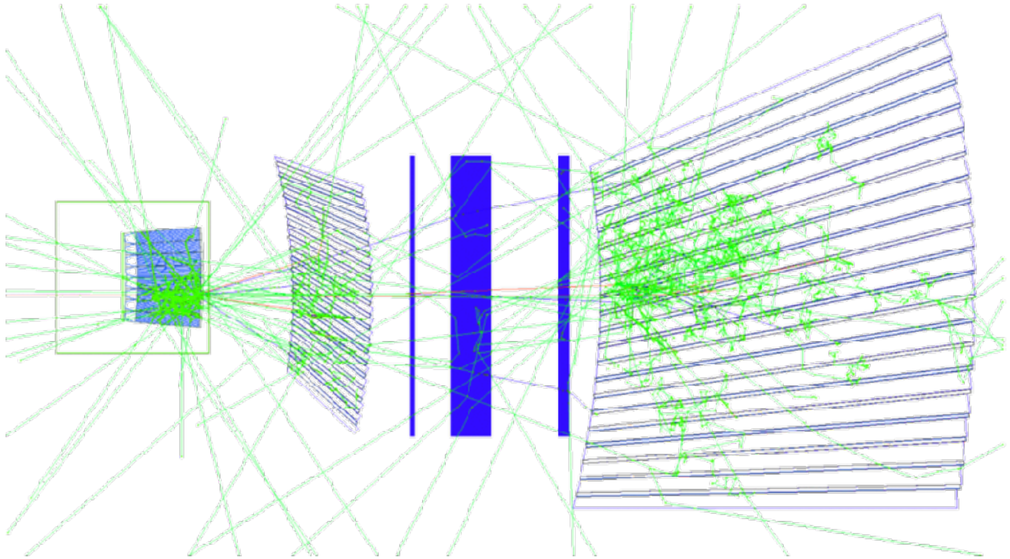


Covering $-1.1<\eta<1.1$:

- Outer HCAL ~$3.5\lambda_I$
- Magnet ~$1.4X_0$
- Frame ~$0.25\lambda_I$
- EMCAL ~$18X_0 \approx 0.7\lambda_I$

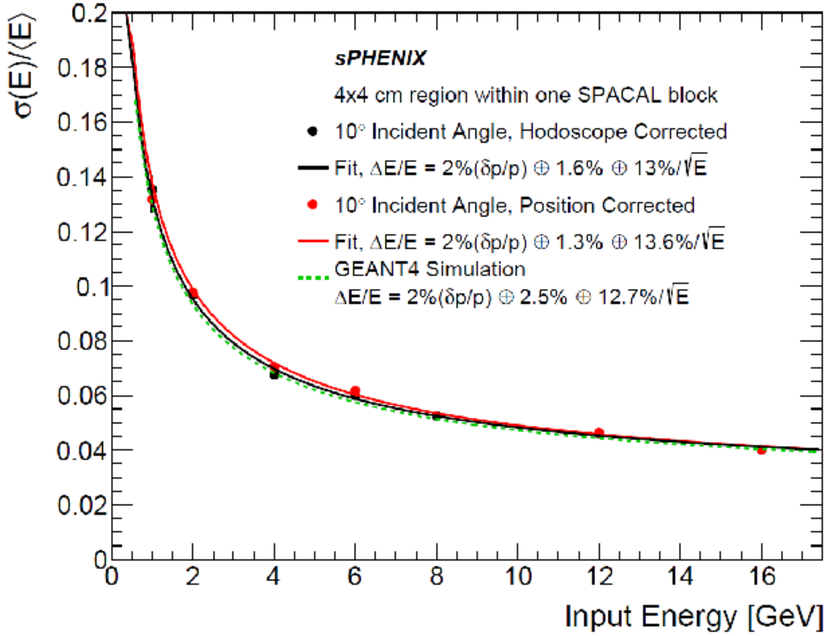
Calorimetry Beam Test





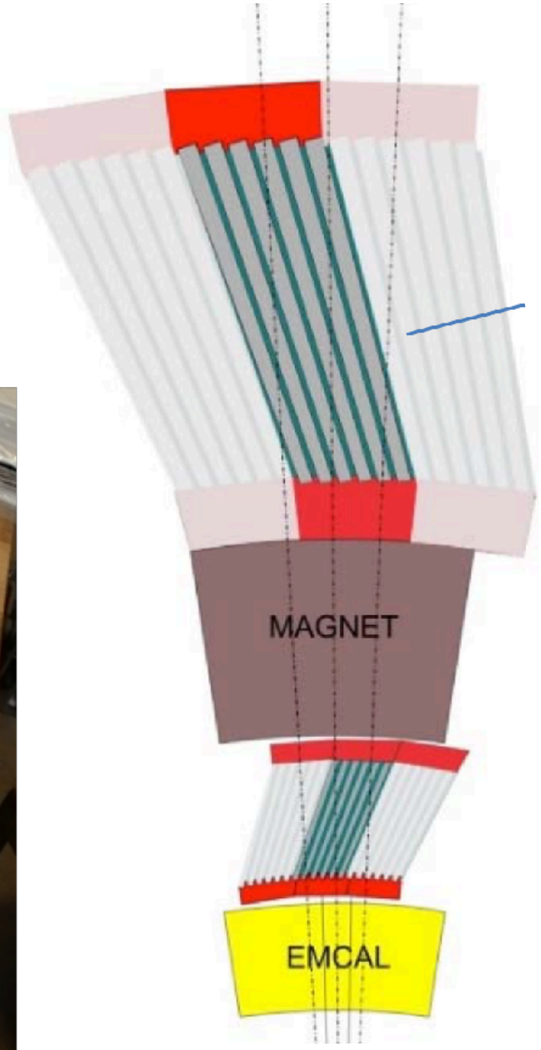
- EMCAL (sim and test) for photons $\Delta E_T/E_T < 8\%$ at 15 GeV pT
- HCAL (sim) for jets $\Delta E_T/E_T < 150\%/\sqrt{E_T}$
- In all configurations, meets sPHENIX spec

Calorimeter energy resolution

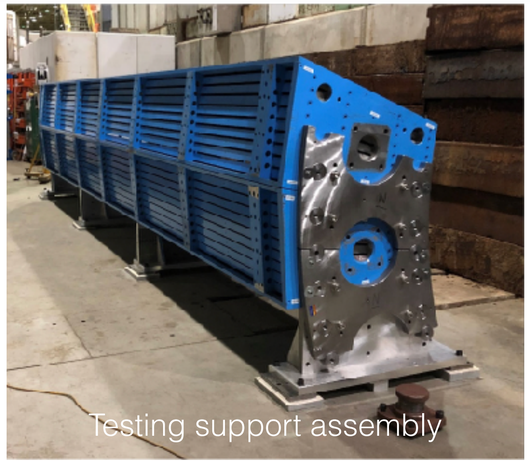


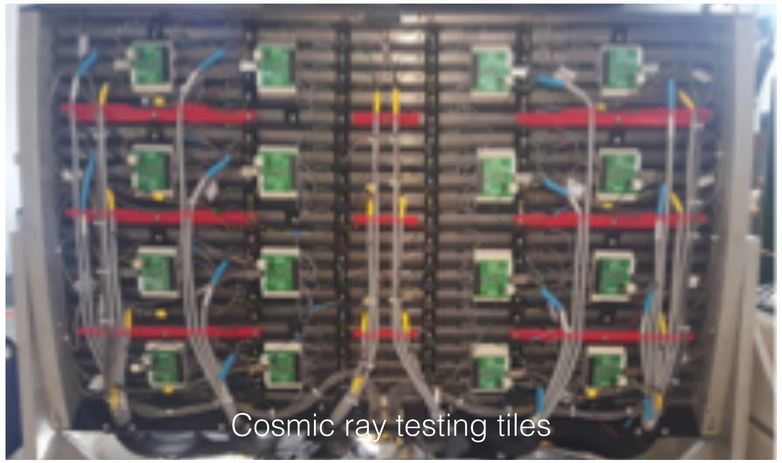
Hadronic Calorimeter (HCAL)

- Provides energy resolution for hadrons and jets
- Scintillating tiles interleaved in steel magnetic flux return
- Analog SiPM signals from 5 tiles combined into one tower
- 48 towers ($\Delta\eta \times \Delta\phi = 0.1 \times 0.1$) per sector
- 32 azimuthal sectors 6.3m x 0.7m, 13.5 tons each

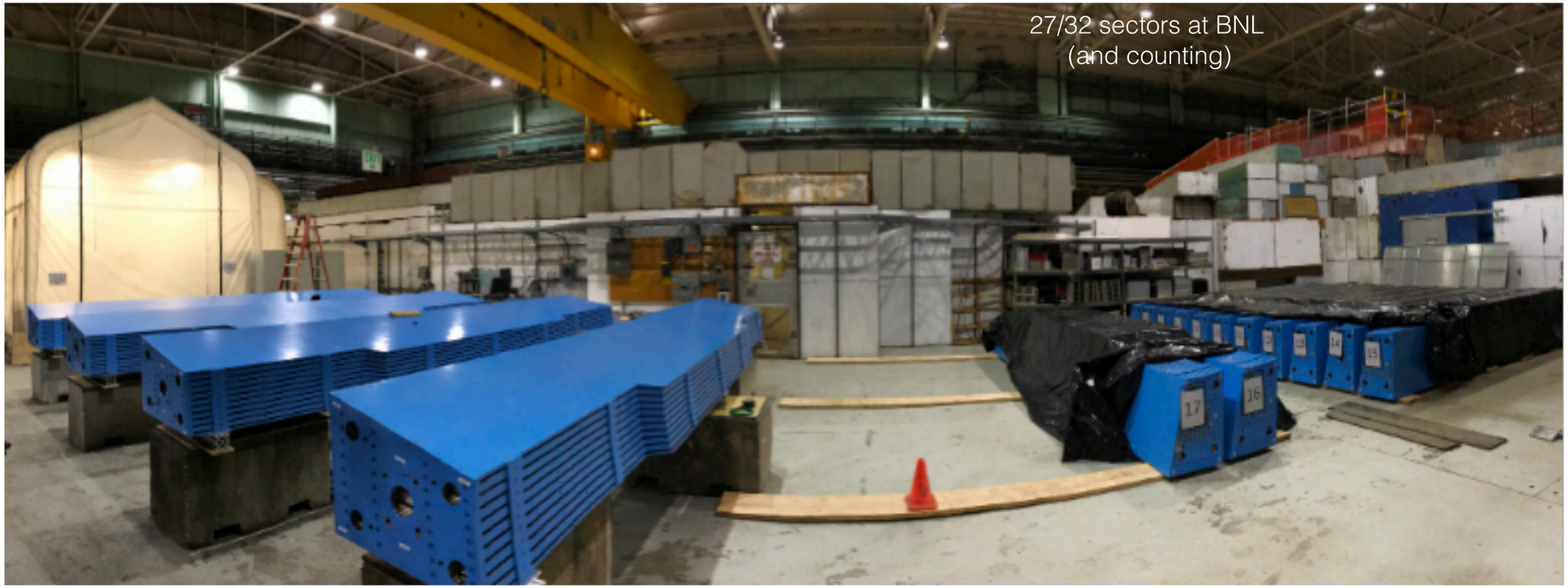


Hadronic Calorimeter Status


Testing support assembly

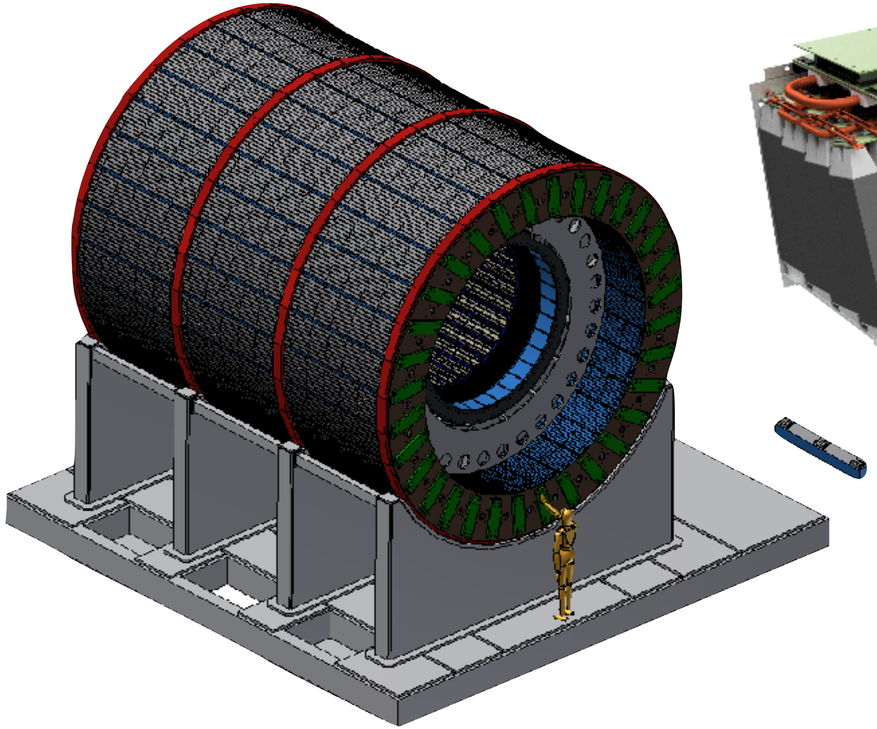

Cosmic ray testing tiles

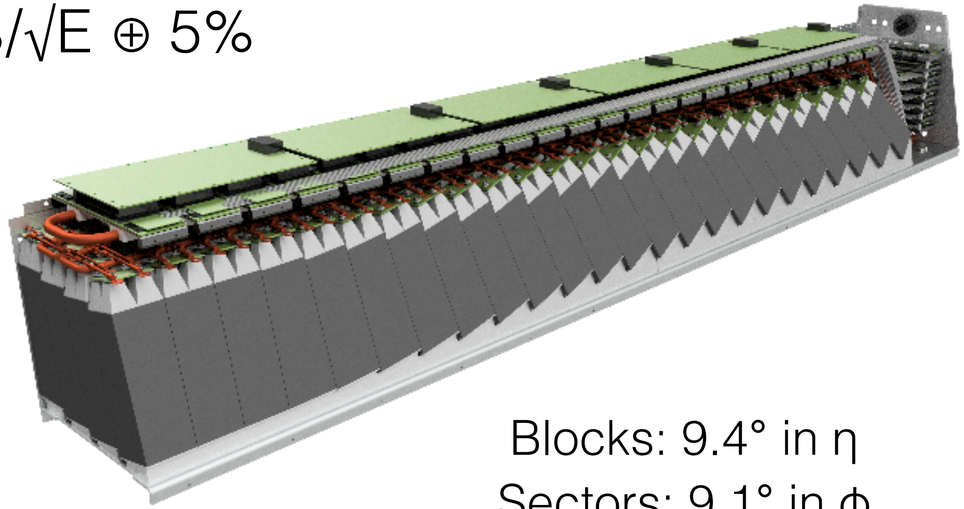
Testing cable routing

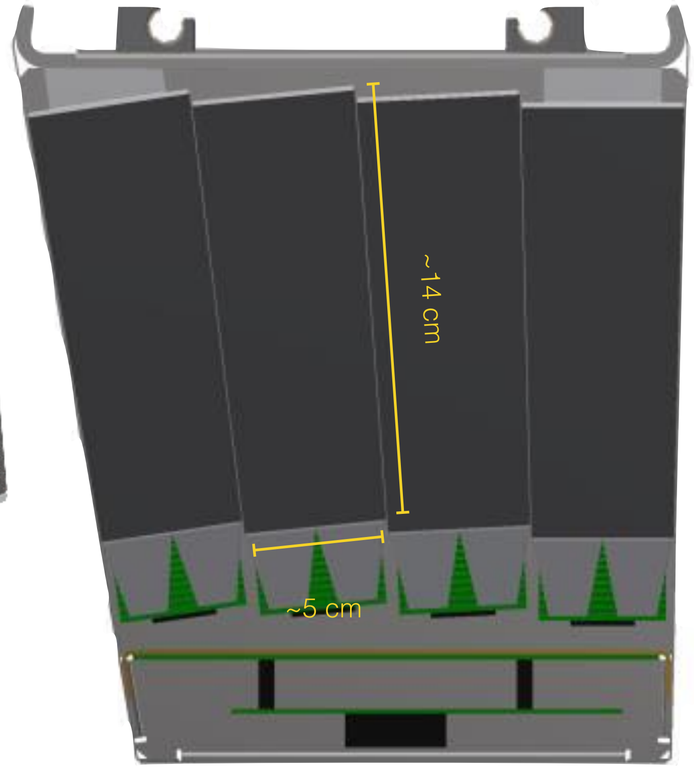

27/32 sectors at BNL
(and counting)

Electromagnetic Calorimeter (EMCAL)

- Provides energy resolution for EM particles and jets
- W/SciFi SPACAL design for compactness
- Segmentation: $\Delta\eta \times \Delta\phi \approx 0.025 \times 0.025$
- Channels: 96 x 256 = 24576 2-D projective towers
- Energy resolution: $< 16\%/\sqrt{E} \oplus 5\%$

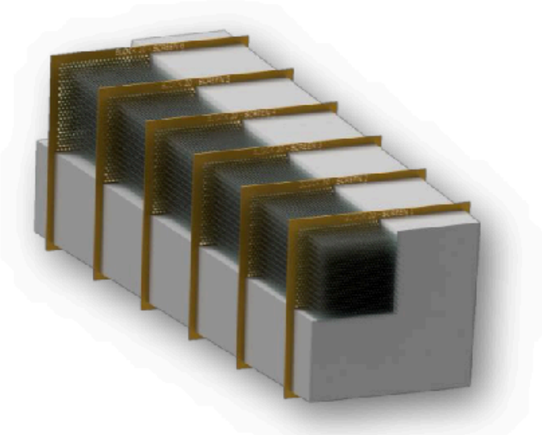




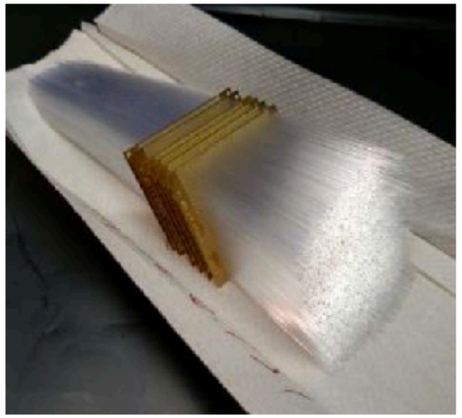


Blocks: 9.4° in η
Sectors: 9.1° in ϕ

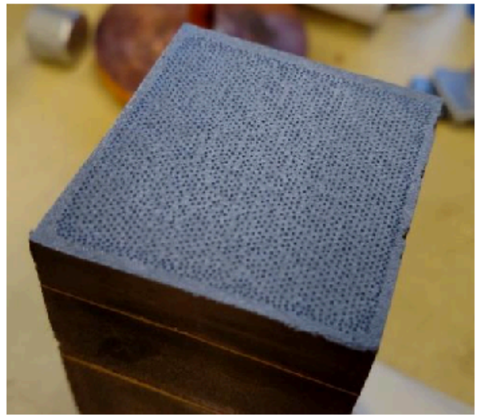
Electromagnetic Calorimeter Status



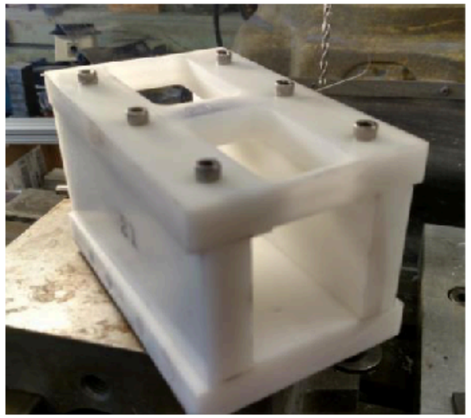
2D Projective Block with Screens



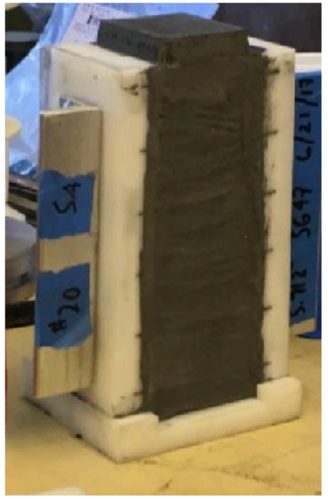
Fiber Assembly



Fibers are tapered inward at readout end to improve light collection



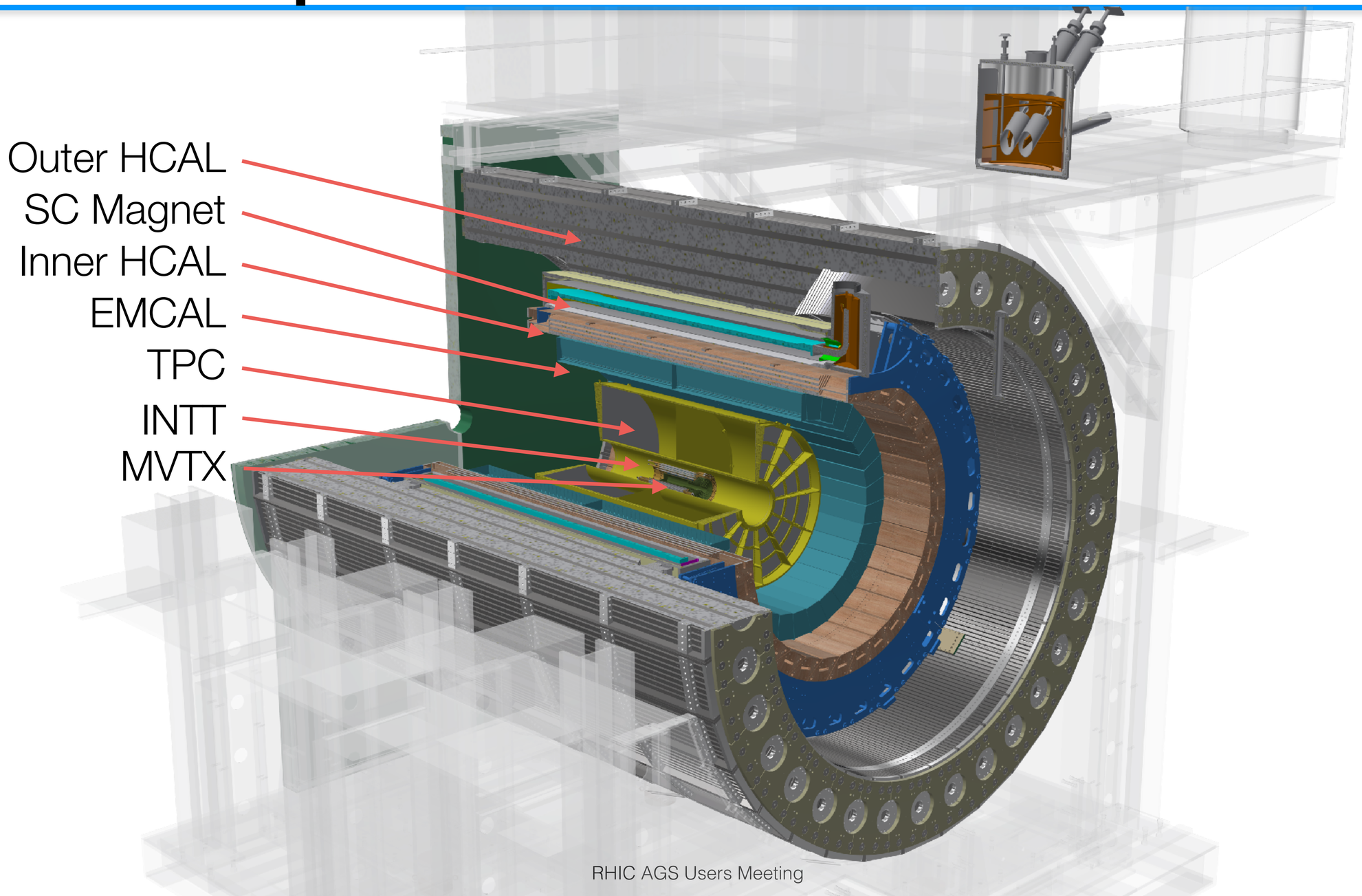
Mold for casting blocks



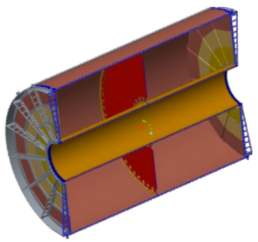
Finished 2D projective block

- Prototype Sector 0 assembly underway at BNL:

sPHENIX Components

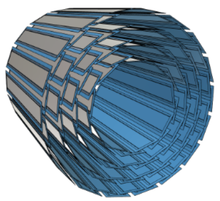


Tracking Detectors



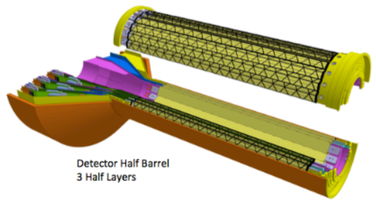
TPC

- 48 layer continuous readout TPC
- Main tracking device
- Provides momentum resolution



INTT

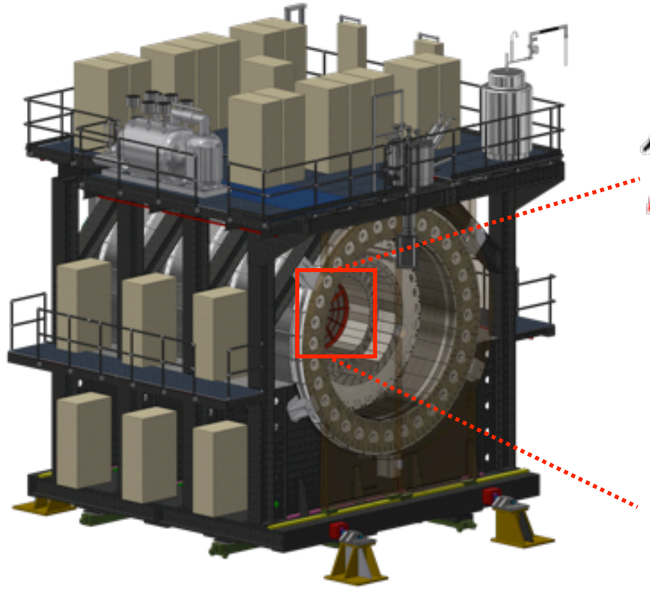
- 2 layers of silicon strip detectors
- Fast response time for pileup disambiguation

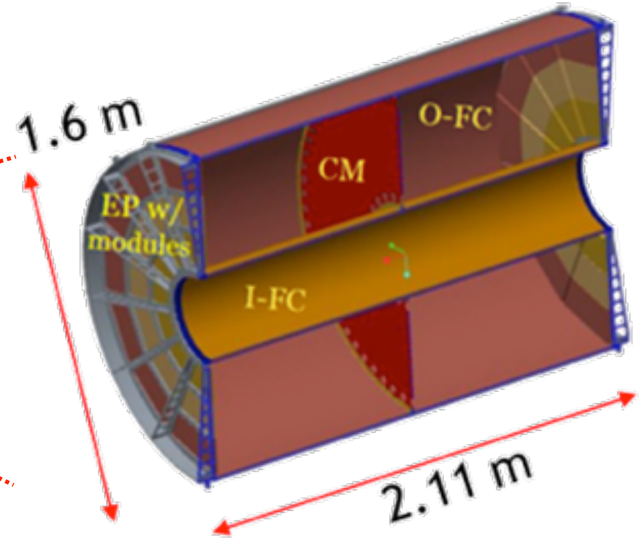


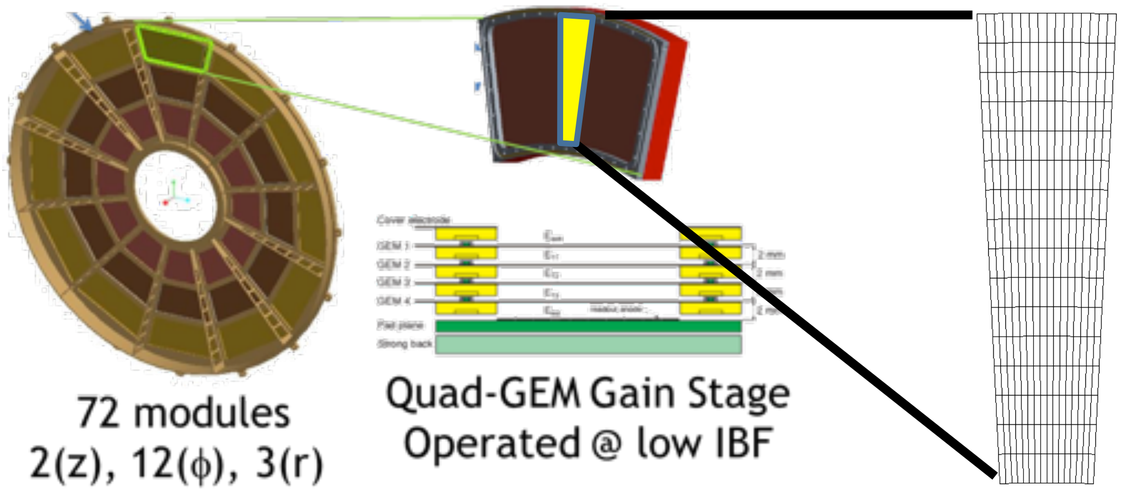
MVTX

- 3 layers of Monolithic Active Pixel Sensors
- Provides impact parameter resolution

Time Projection Chamber (TPC)

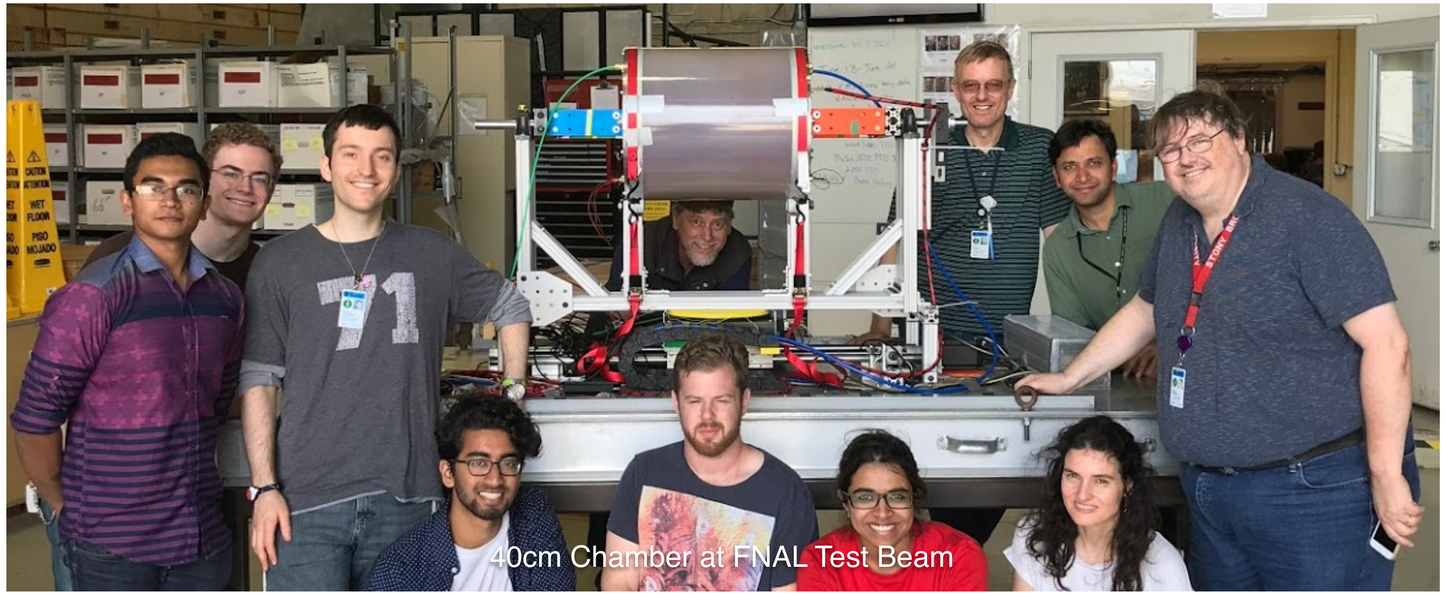




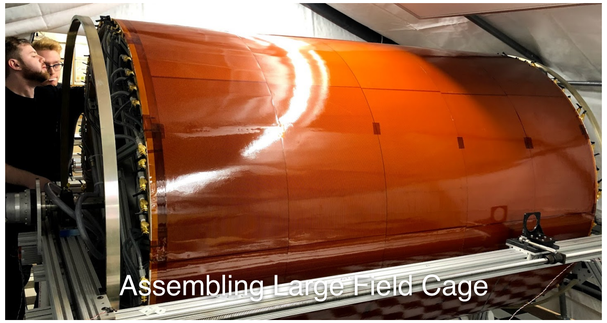


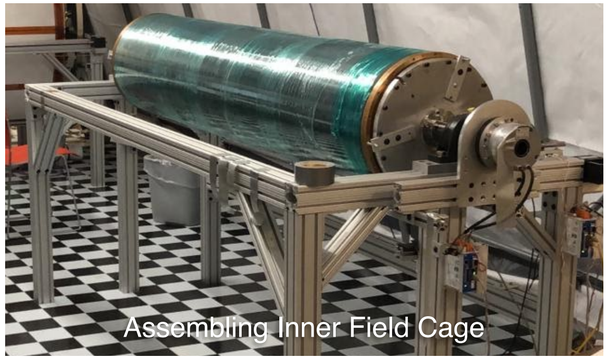
- Provides momentum reconstruction
- Operates in continuous readout mode
- Gas-Electron Multiplier (GEM) avalanche for low Ion Back Flow (IBF)
- FEE, Data Aggregation from ALICE and ATLAS

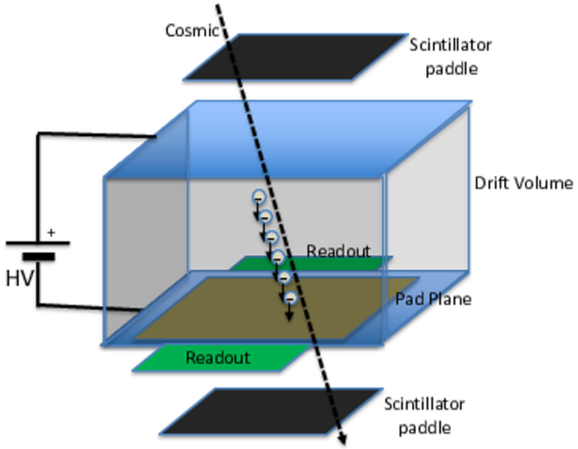
TPC Status

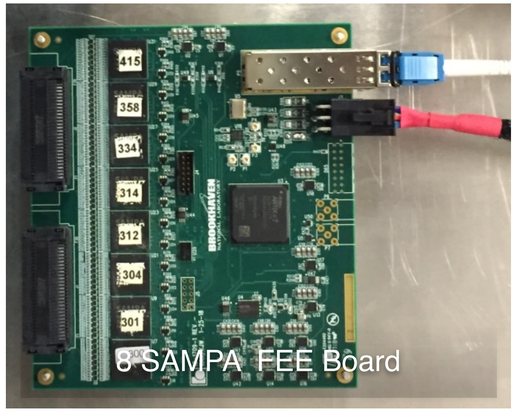

40cm Chamber at FNAL Test Beam

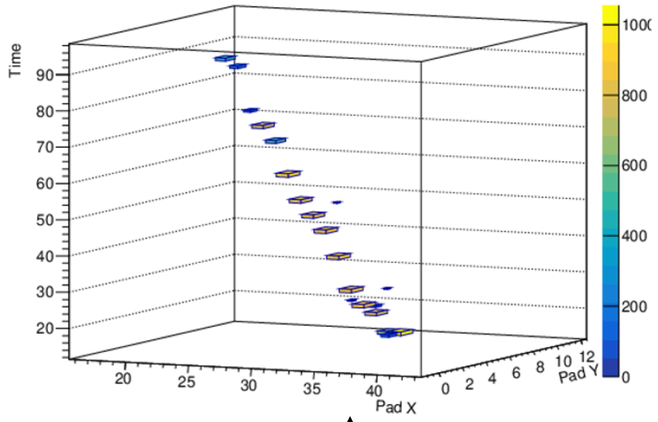
Wagon Wheels Delivered


Assembling Large Field Cage


Assembling Inner Field Cage

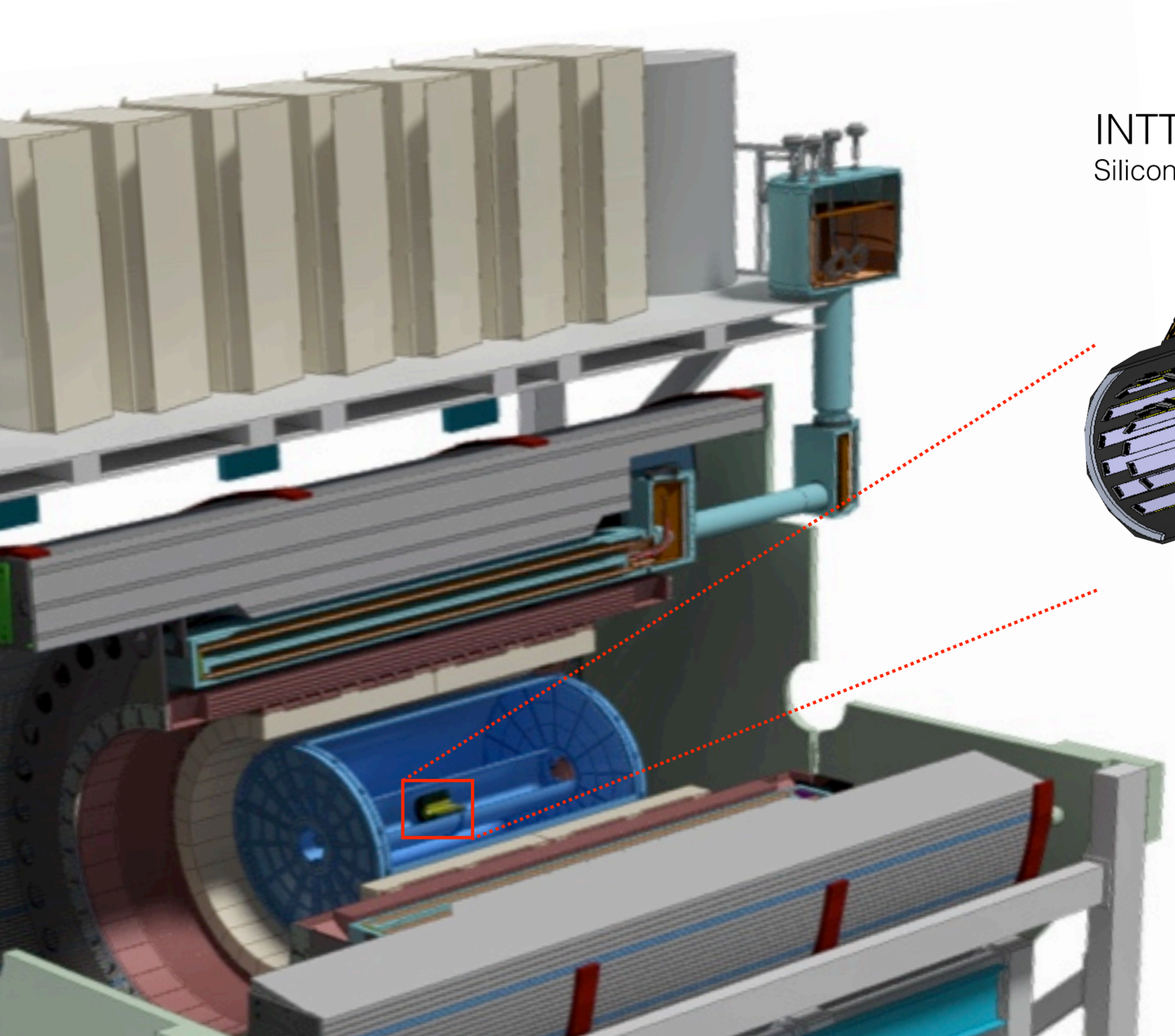



8 SAMPA FEE Board

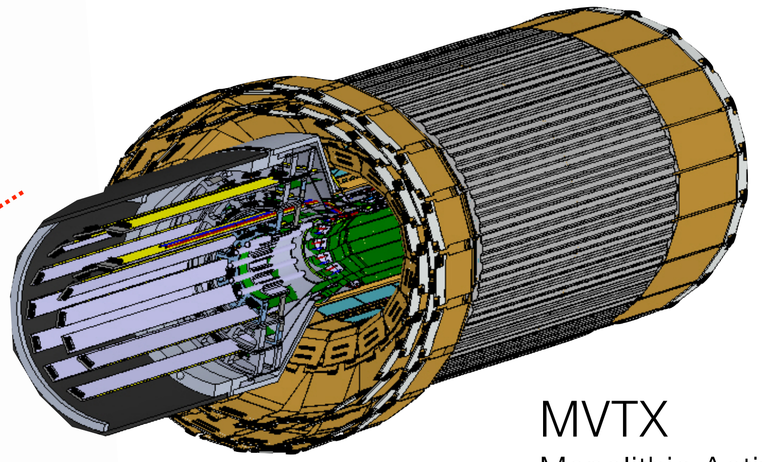


Full chain readout

Inner Tracking



INTT
Silicon strips, 2 layers

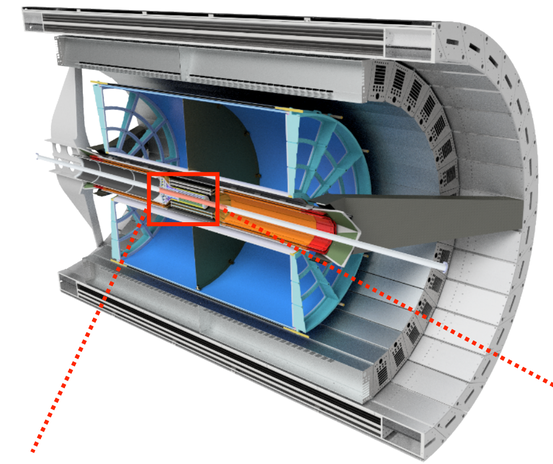


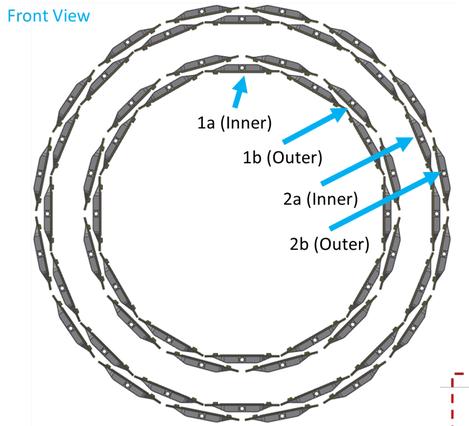
MVTX
Monolithic Active Pixel Sensors (MAPS),
3 layers, based on ALICE ITS detector

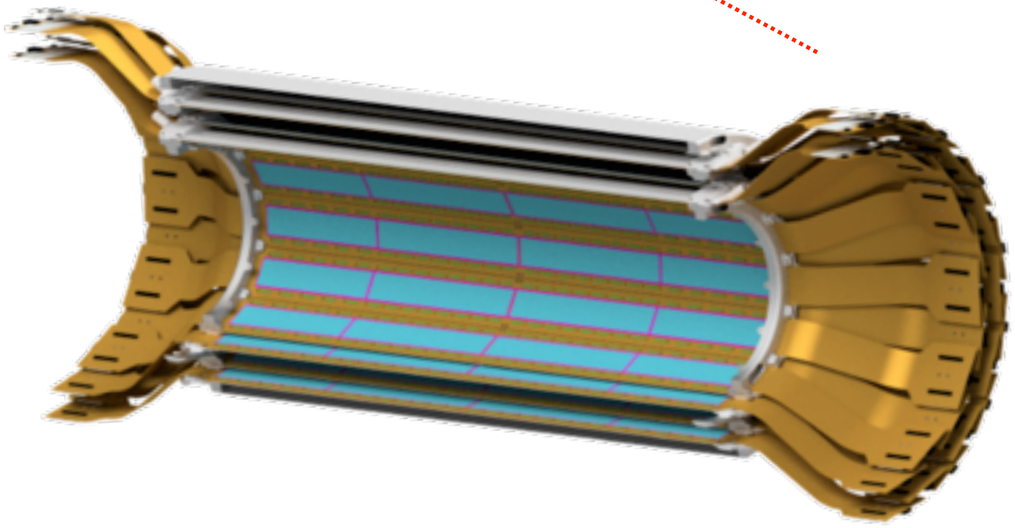
Upgrade to sPHENIX baseline adds:

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

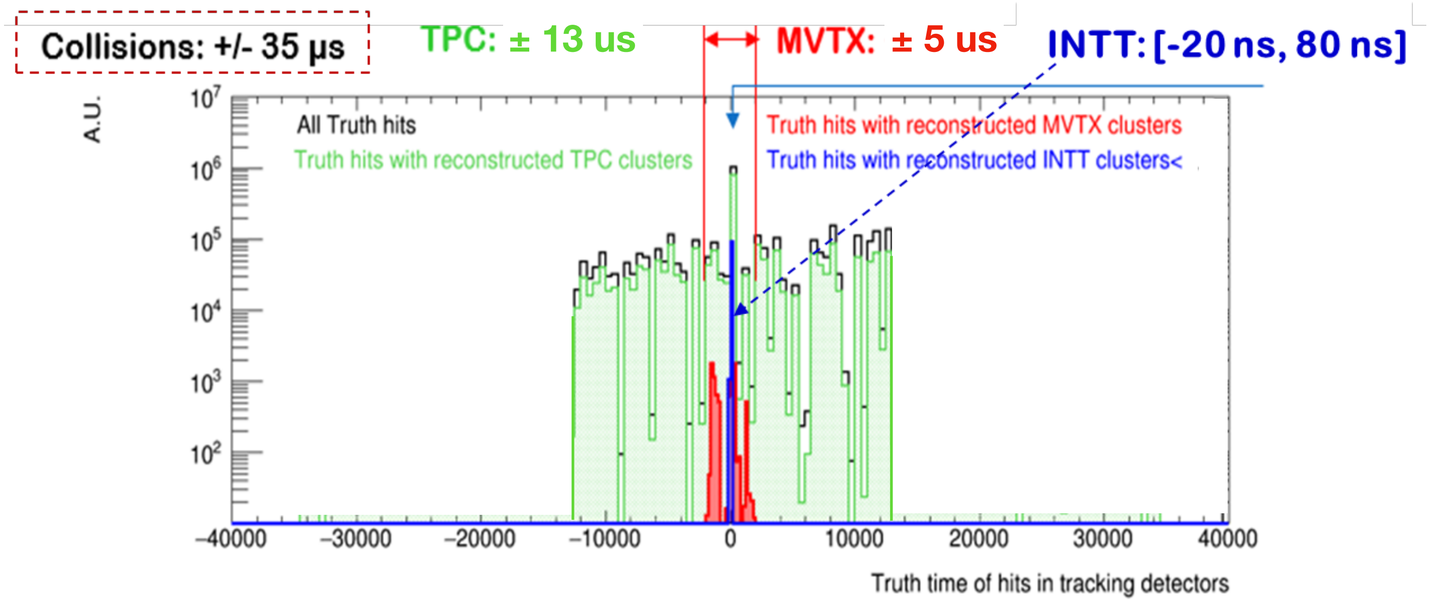
Intermediate Tracker (INTT)



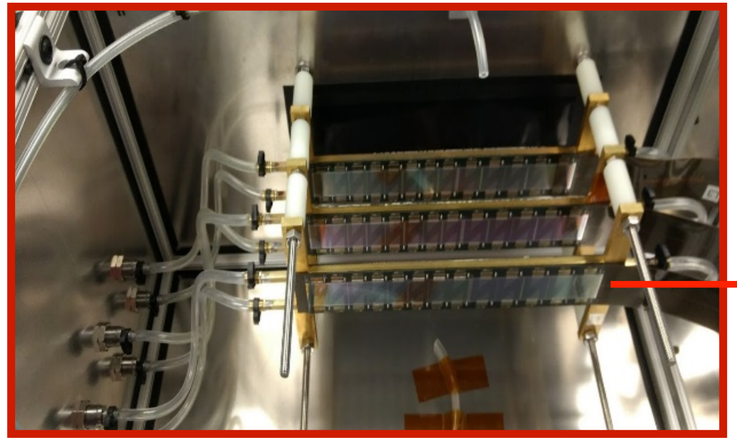


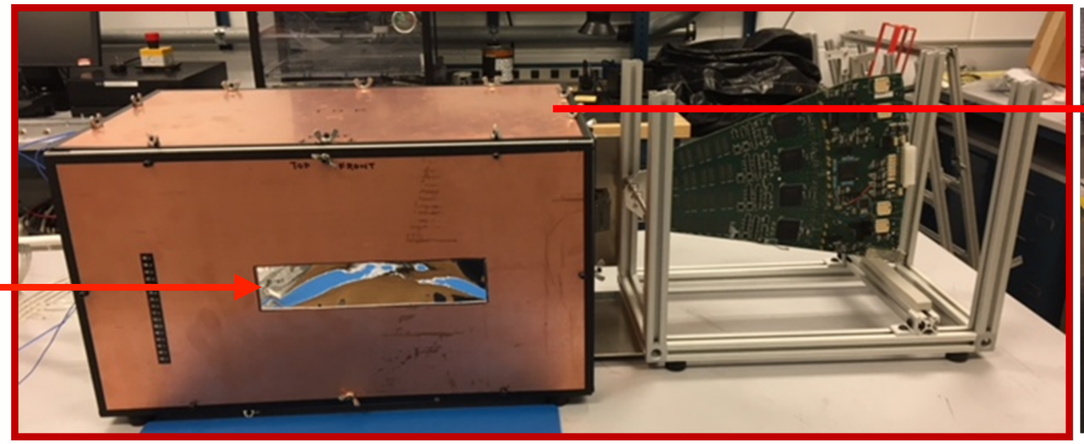


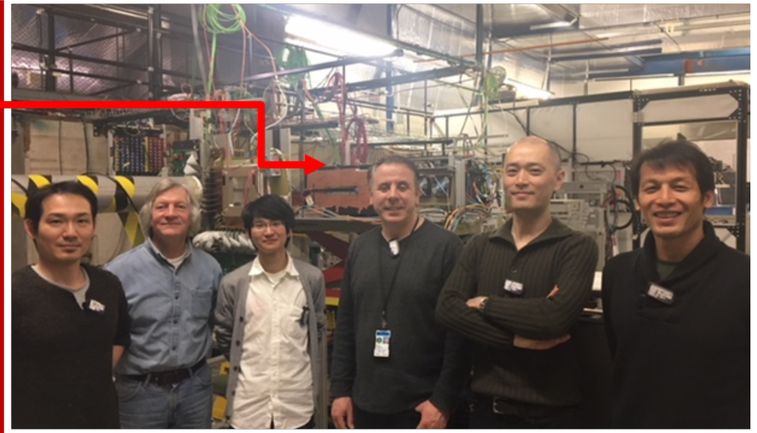
- Provides time resolution to associate individual tracks and events
- Two hermetic double-layers of Si strip detectors
- Contributed by RIKEN

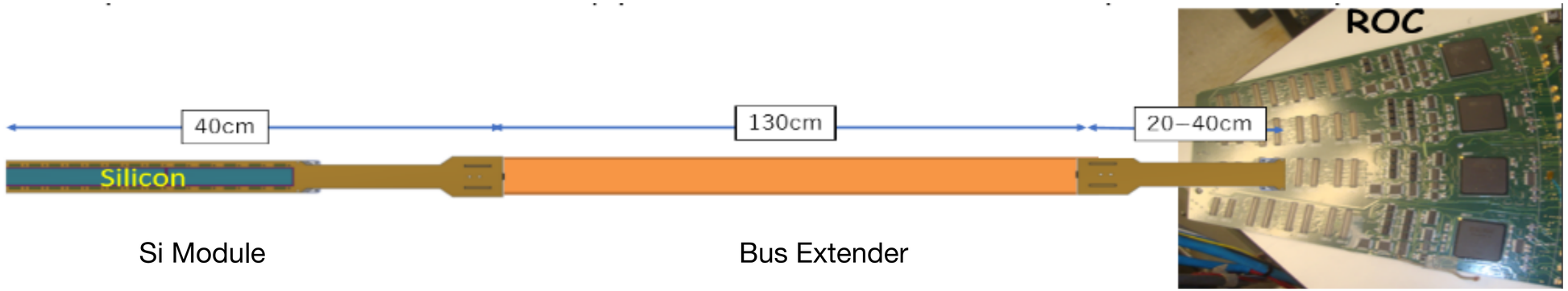


INTT Test Beam



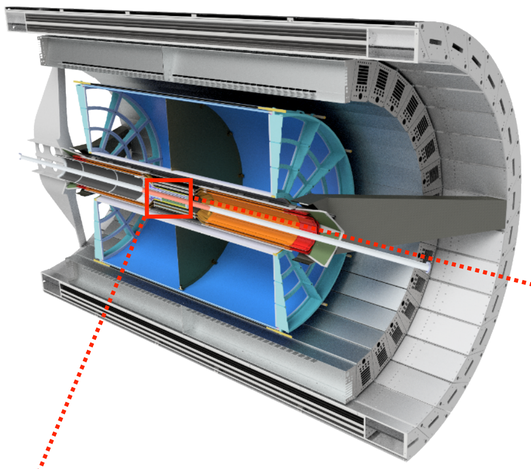


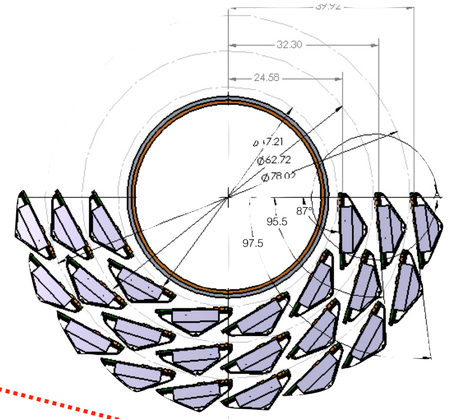


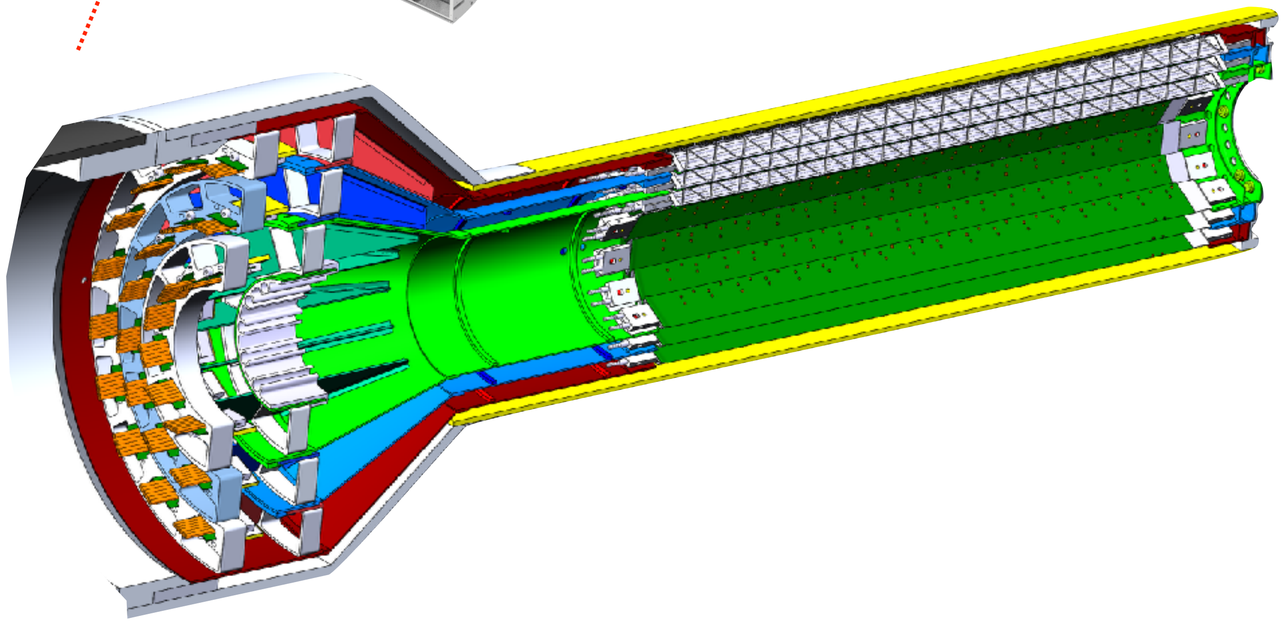


- Si Modules tested in 2018
- Track resolution measurements and full readout chain test planned this month
- Includes multi-layer Flexible Printed Circuit bus extender from sensor to Readout Cards

MAPS Vertex Detector (MVTX)

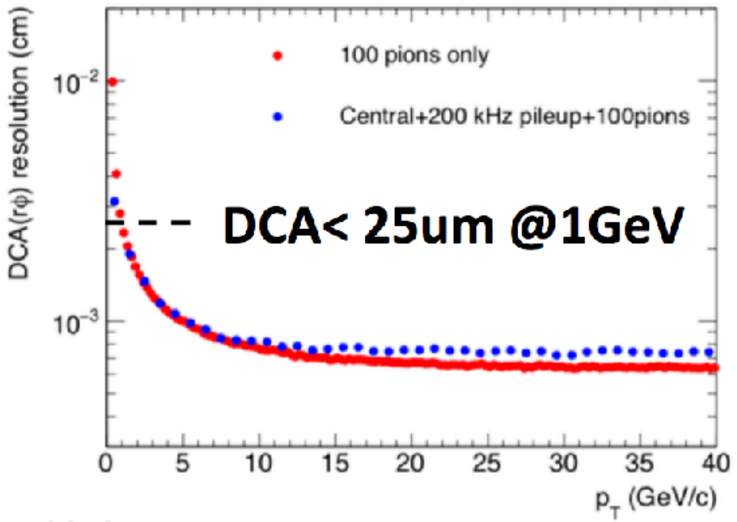




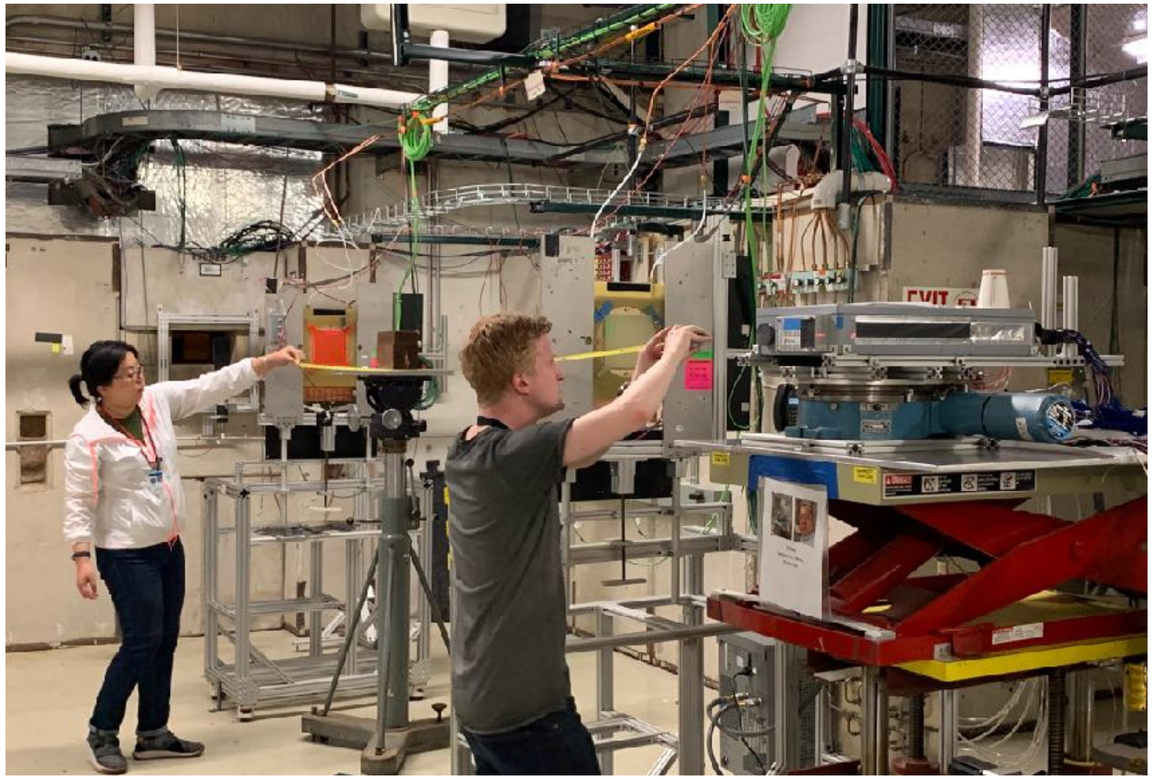


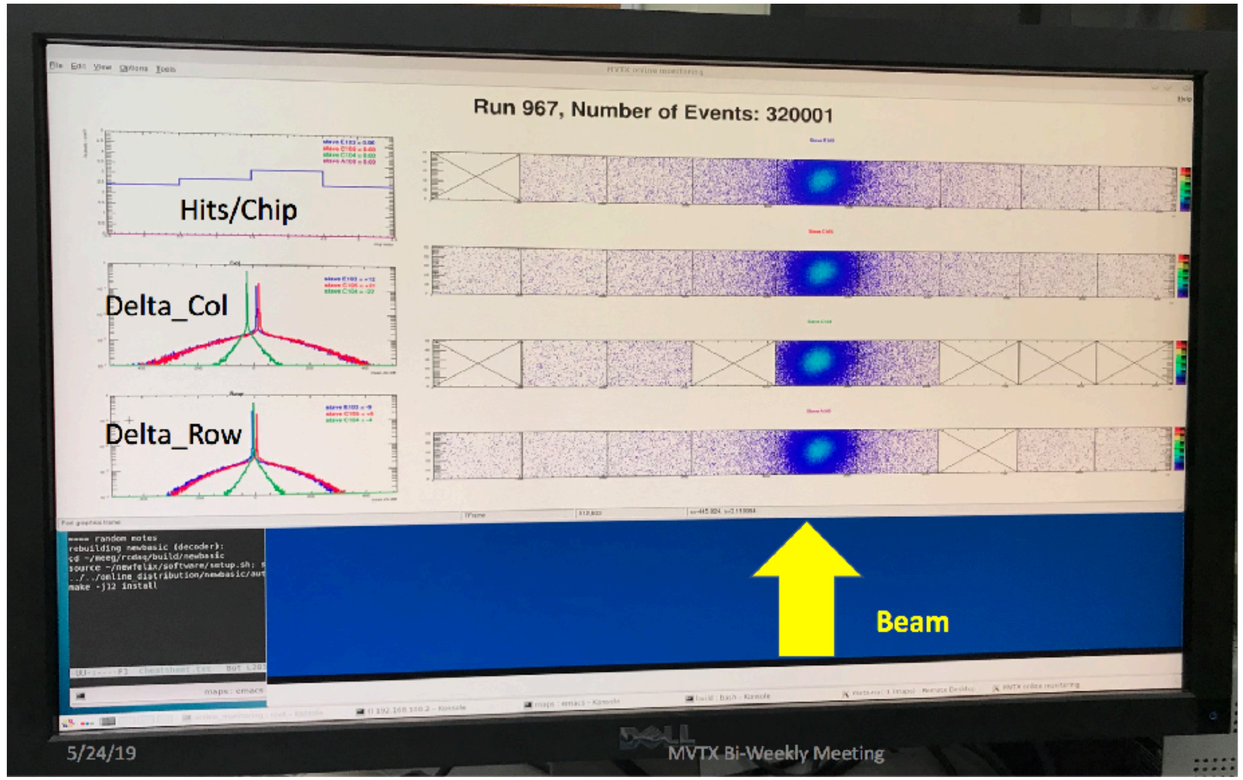
- Provides spatial resolution for displaced vertices
- 3 layers of hermetic Monolithic Active Pixel sensors
- ALICE ITS design modified to fit sPHENIX envelope

Displaced Vertex Resolution

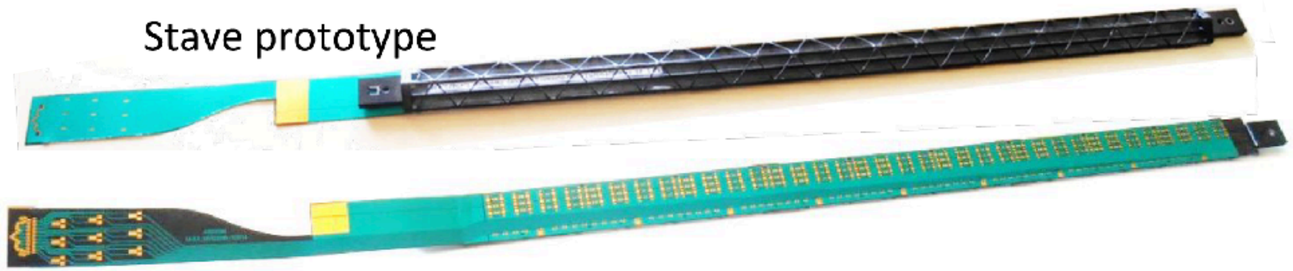


MVTX Test Beam





- 2019 test of telescope with full readout and cables just completed (May 25)
- Readout tested up to 300kHz with p beam and p-on-Pb sprays (sPHENIX requirement 15kHz)



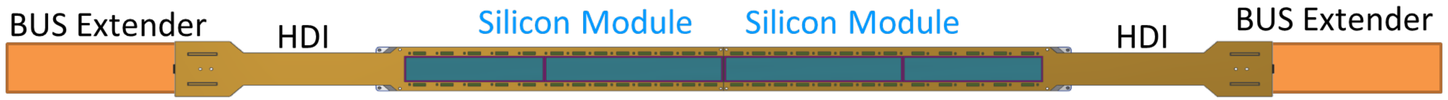
sPHENIX Outlook

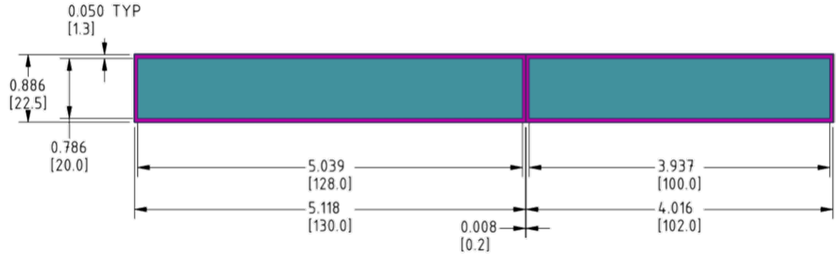
- sPHENIX will have precision tracking and calorimetry, all capable of high rate operation
- This enables rich QGP and QCD physics at RHIC: Jets, upsilons, open heavy flavor
- Lots of progress occurring now:
  - PD-2/3 review very positive
  - Barrel magnet steel sectors arriving 1/week
  - 35,000 calorimeter SiPMs now at U.Mich
  - EMCAL block and HCAL tile production in full swing
  - ...and more
- INTT and MVTX expected to be available day-1

- On track for exciting physics in 2023!

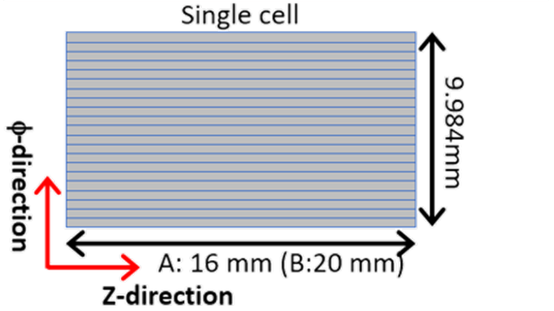
INTT Details

- Sensors from HPK
  - **78 μ pitch**
  - **single-sided**
  - **AC coupled**
  - **320 μ thick**
- Two sizes of sensors
  - **128x20 mm**
  - **100x20 mm**
- FPHX ASIC (developed for PHENIX)
  - **128 channels**
  - **3 bit ADC**
  - **64 mW/chip**
  - **200 MHz data port**
- Near detector Readout Cards (ROC's) from PHENIX FVTX
- Data acquisition by FVTX FEM + DCM II/JSEB II
  - **Alternative under consideration**





L1, L2, L3 Sensor design: better seg in ϕ



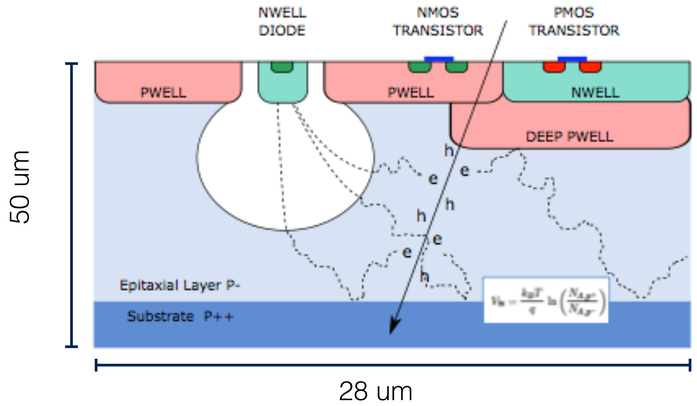
Type A: Single sensor = 8 x 2 cells
Type B: Single sensor = 5 x 2 cells

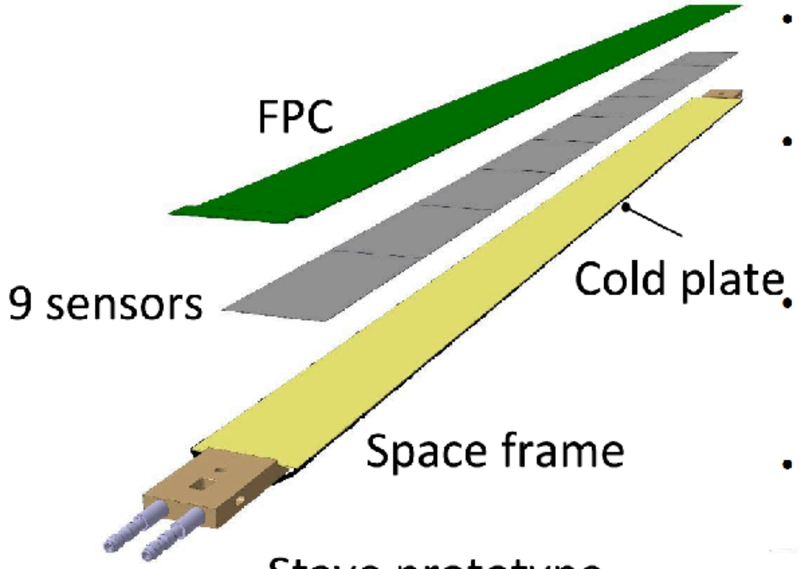
Thickness: 320 um
Pitch: 9.984 mm/128 = 78 um
Φ-length (single sensor) = 22.5 mm
F-length (active area) = 20.0 mm
Z-length type-A (single sensor) = 130.0 mm
Z-length type-A (active area) = 128.0 mm
Z-length type-B (single sensor) = 102.0 mm
Z-length type-B (active area) = 100.0 mm

MVTX Details

ALICE Pixel Detector

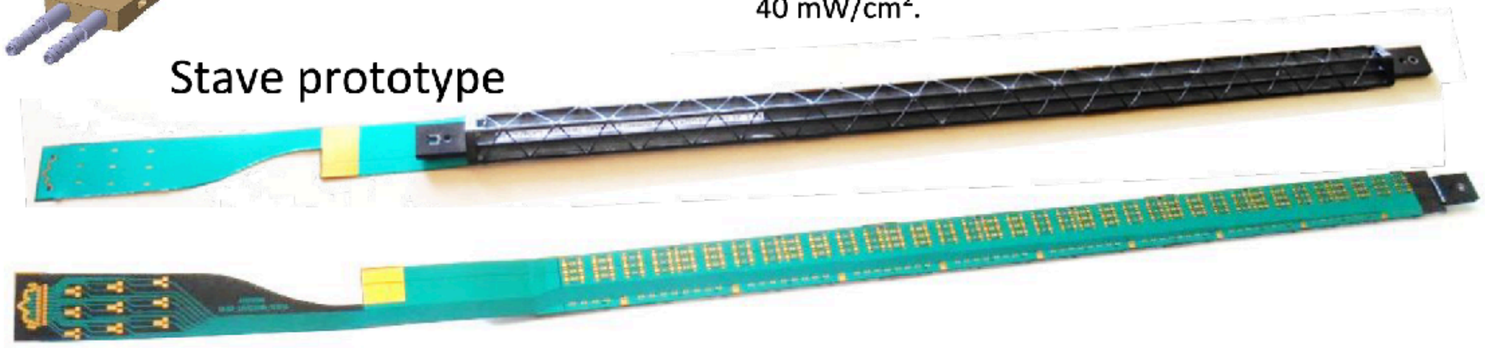
- Very fine pitch (27μm x 29μm), for superb spatial resolution
- High efficiency (>99%) and low noise ($<10^{-6}$), for excellent tracking
- Time resolution, as low as ~5 μs, for less pileup
- Ultra-thin/low mass, 50μm (~0.3% X_0), for less multiple scattering
- 0.5M channels with on-pixel digitization, for zero-suppression and fast readout
- Low power dissipation, 40mW/cm^2, for minimal service materials





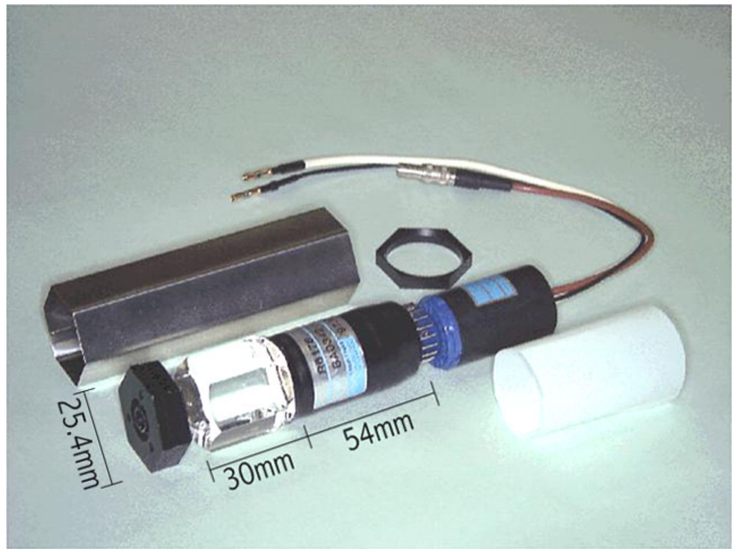
- **Staves:** detector modules consisting of a Hybrid Integrated Circuit (HIC) mounted on carbon fiber mechanical support structure
- **HIC:** a row of 9 ALPIDE sensors wire-bonded to a Flexible Printed Circuit (FPC). Area covered by the chips: 15x271.2 mm^2, including a gap of 150 μm between adjacent chips.
- **Mechanical support:** single light structure composed of a Space Frame, providing the required stiffness, and a Cold Plate, high-thermal conductivity carbon fiber sheet with embedded polyamide cooling pipes.
- **Heat Dissipation** – The ALPIDE sensors dissipate only 40 mW/cm^2.

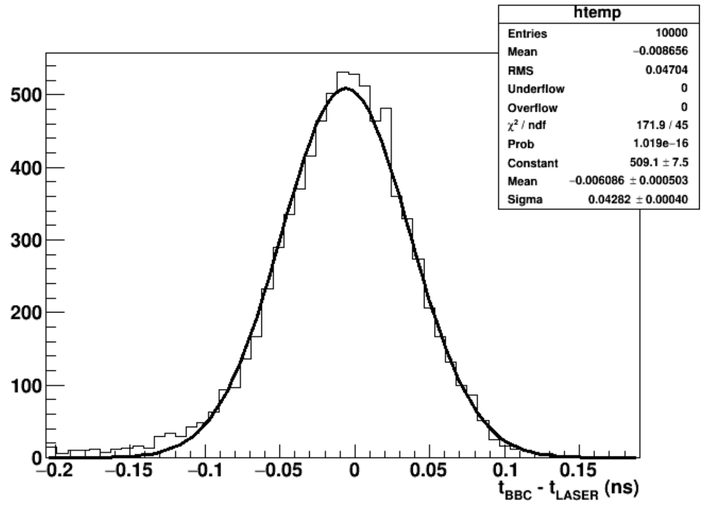
Stave prototype



MBD

- Min Bias Detector
- Same 128 channel quartz radiators as current PHENIX BB
- New electronics based on E/HCal digitizers
- Tests demonstrate 120 ps trigger timing achievable

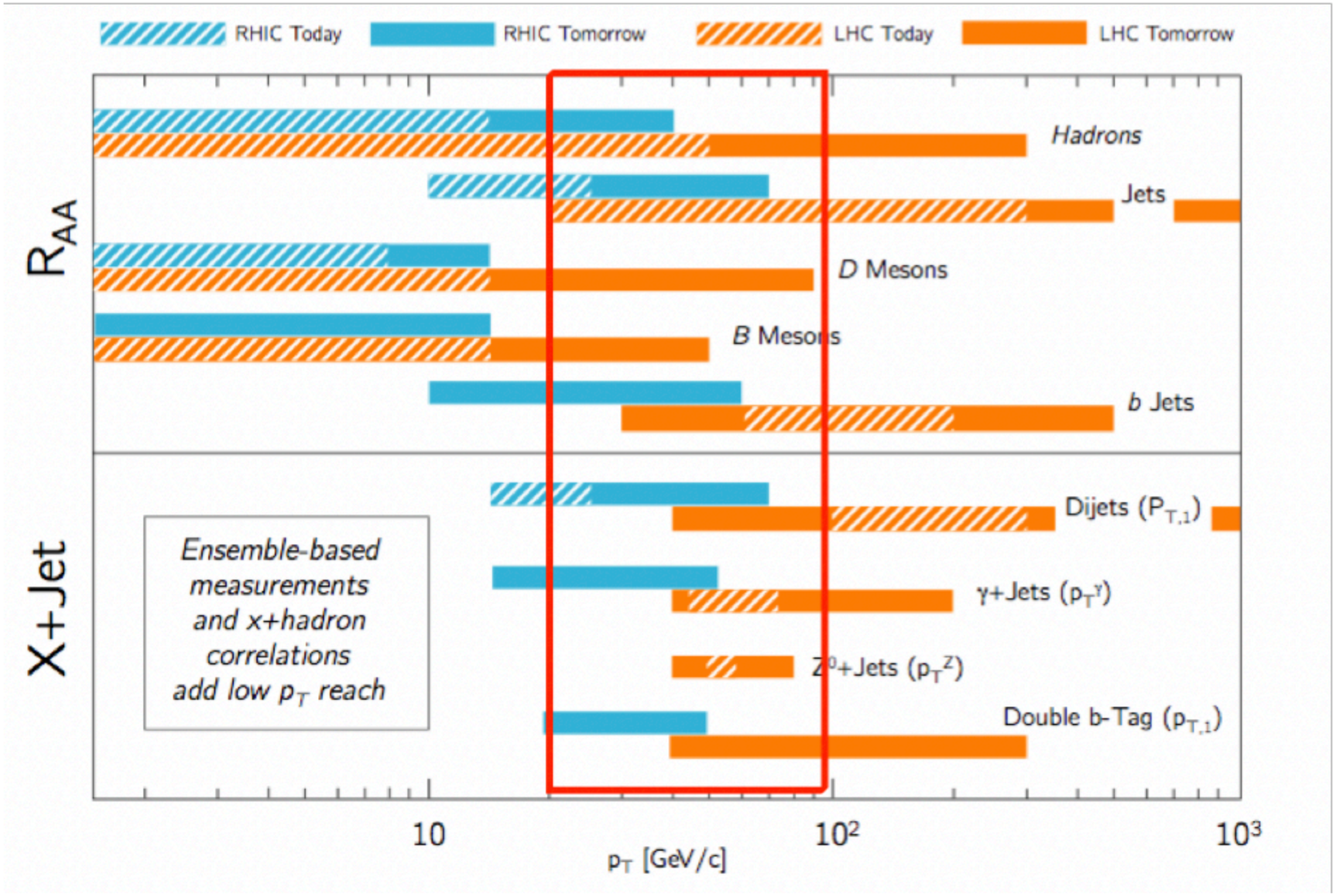




Core Physics Goals

Physics Goal	Analysis Requirement	Ultimate Performance Parameter
Maximize statistics for rare probes	Accept/sample full delivered luminosity	**Data taking rate of 15kHz for Au+Au**
Precision Upsilon spectroscopy	Resolve Y(1s), Y(2s), (Y3s) states	**Y(1s) mass resolution ≤ 125MeV in central Au+Au**
High jet efficiency and resolution	Full hadron and EM calorimetry Jet resolution dominated by irreducible background fluctuations	**$\sigma/\mu \leq 150\%/\sqrt{p_{Tjet}}$ in central Au+Au for R=0.2 jets**
Full characterization of jet final state	High efficiency tracking for $0.2 < p_T < 40$GeV	**Tracking efficiency ≥ 90% in central Au+Au** **Momentum resolution ≤ 10% for p_T = 40 GeV**
Control over initial parton p_T	Photon tagging with energy resolution dominated by irreducible higher order processes	**Single photon resolution ≤ 8% for p_T = 15 GeV in central Au+Au**

Overlapping Observables, Different Mediums



sPHENIX Talks at the Users Meeting

- **Cold QCD Plans with sPHENIX**,
  Sasha Bazilevsky (Tuesday / Cold QCD)
- **Future Heavy Flavor and Quarkonia Measurements from sPHENIX**,
  Yuanjing Ji (Tuesday / Heavy Flavor)
- **sPHENIX and its Capabilities on Jet Substructure at RHIC Energies**,
  Dennis Perepelitsa (Wednesday / High p_T/Jets)