Status report on sPHENIX

Dave Morrison (BNL) | co-spokespersons
Gunther Roland (MIT) |

Ed O'Brien (BNL) | project director

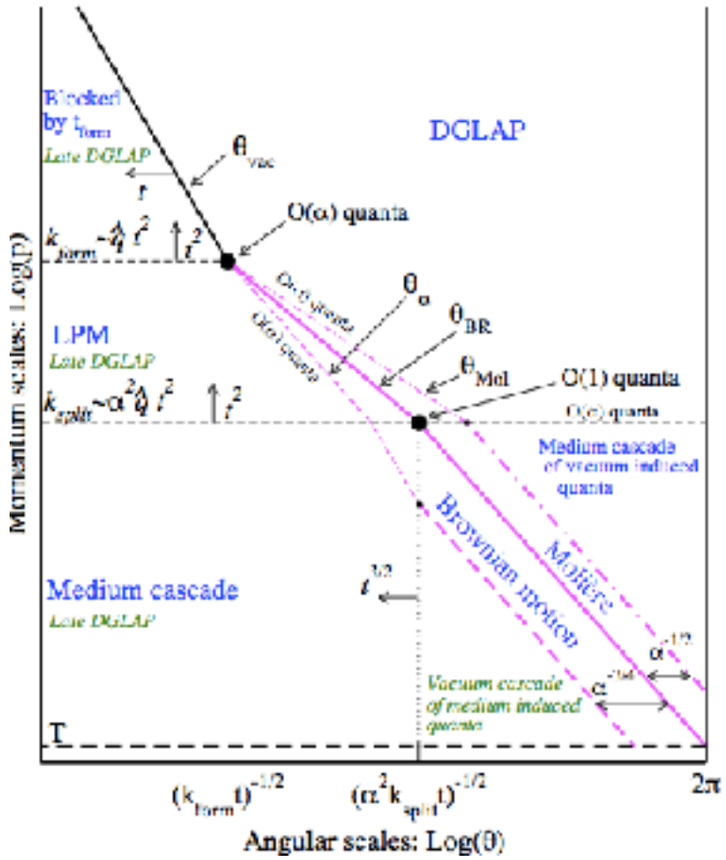
2017 NPP PAC Meeting

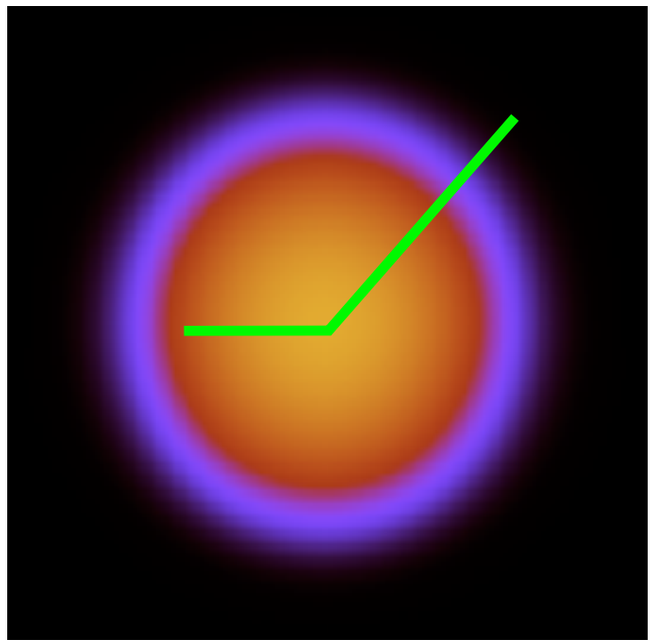
Brief recap of sPHENIX physics

QGP physics with sPHENIX

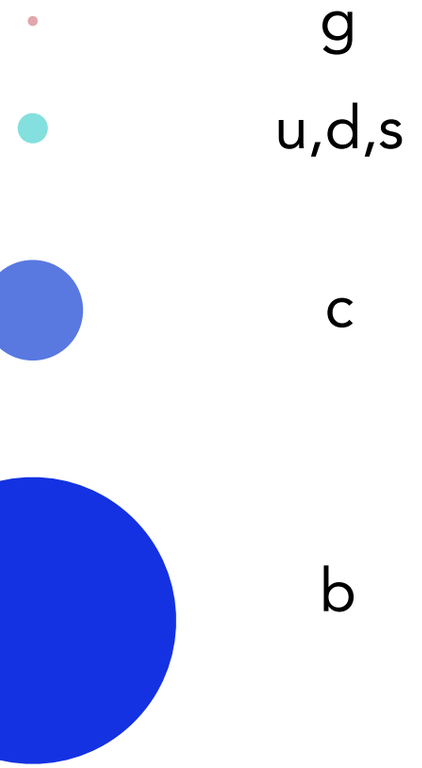
Three key approaches to study
QGP structure at multiple scales

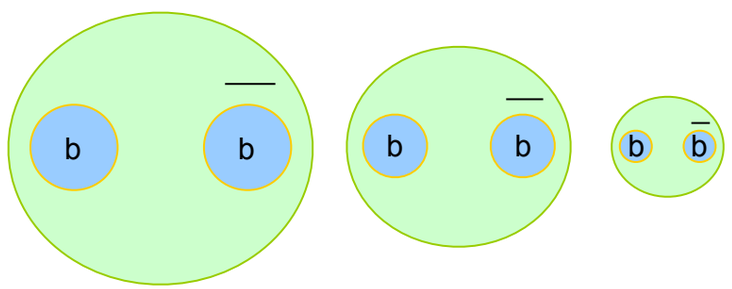
Jets and jet structure





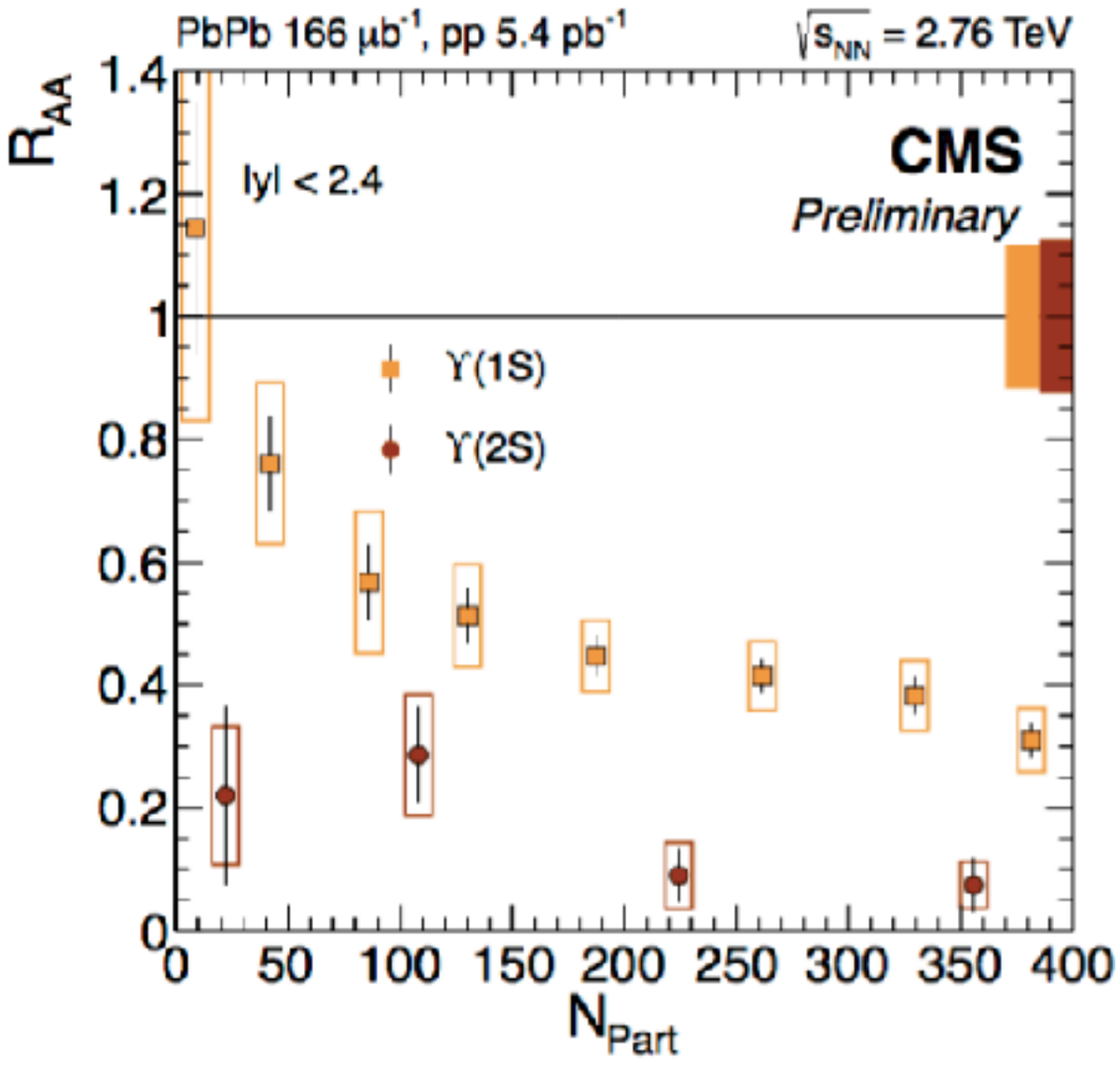
Parton mass/flavor





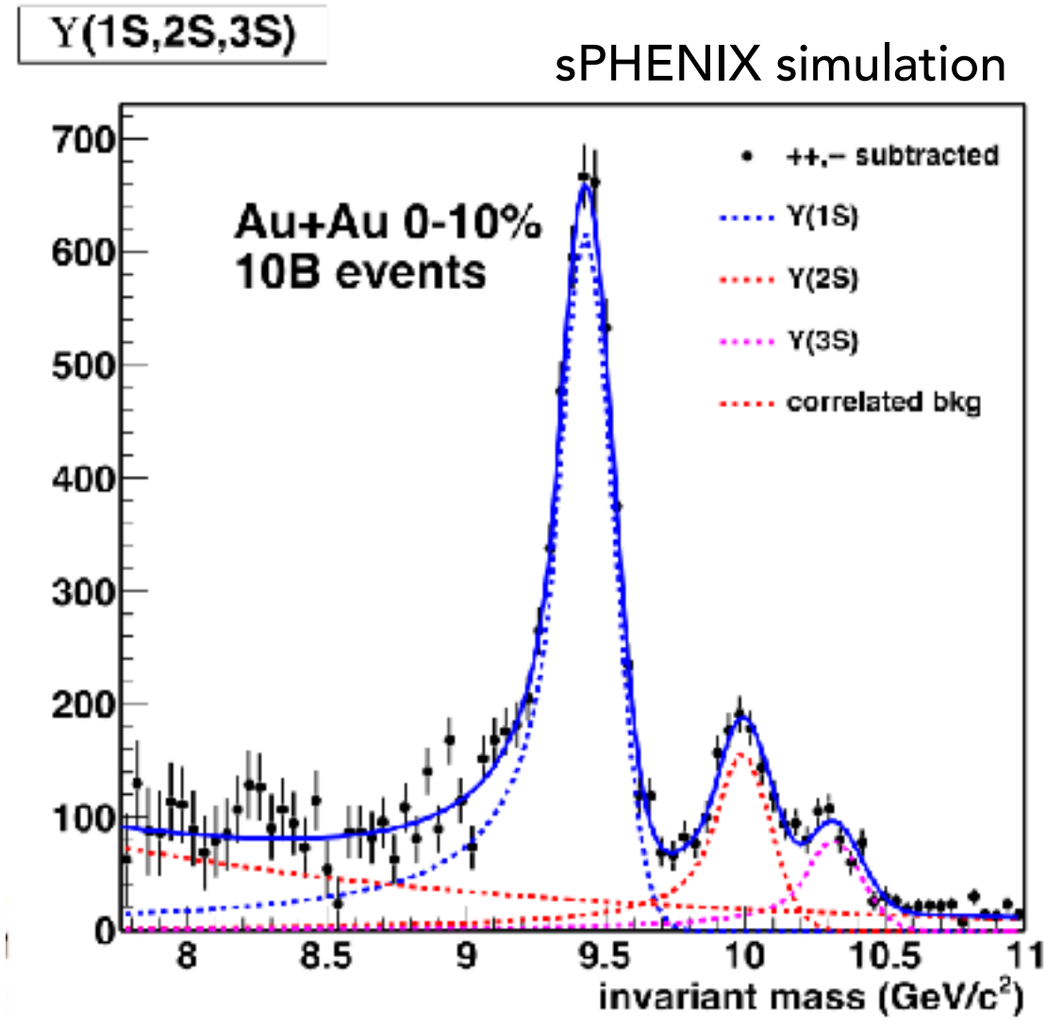
Upsilon spectroscopy

Physics drives detector requirements: Y(ns)



Rapid disappearance of Y(2s), Y(3s) in peripheral events is puzzling ➜

Statistics, statistics, statistics…



Count every Y delivered ➜

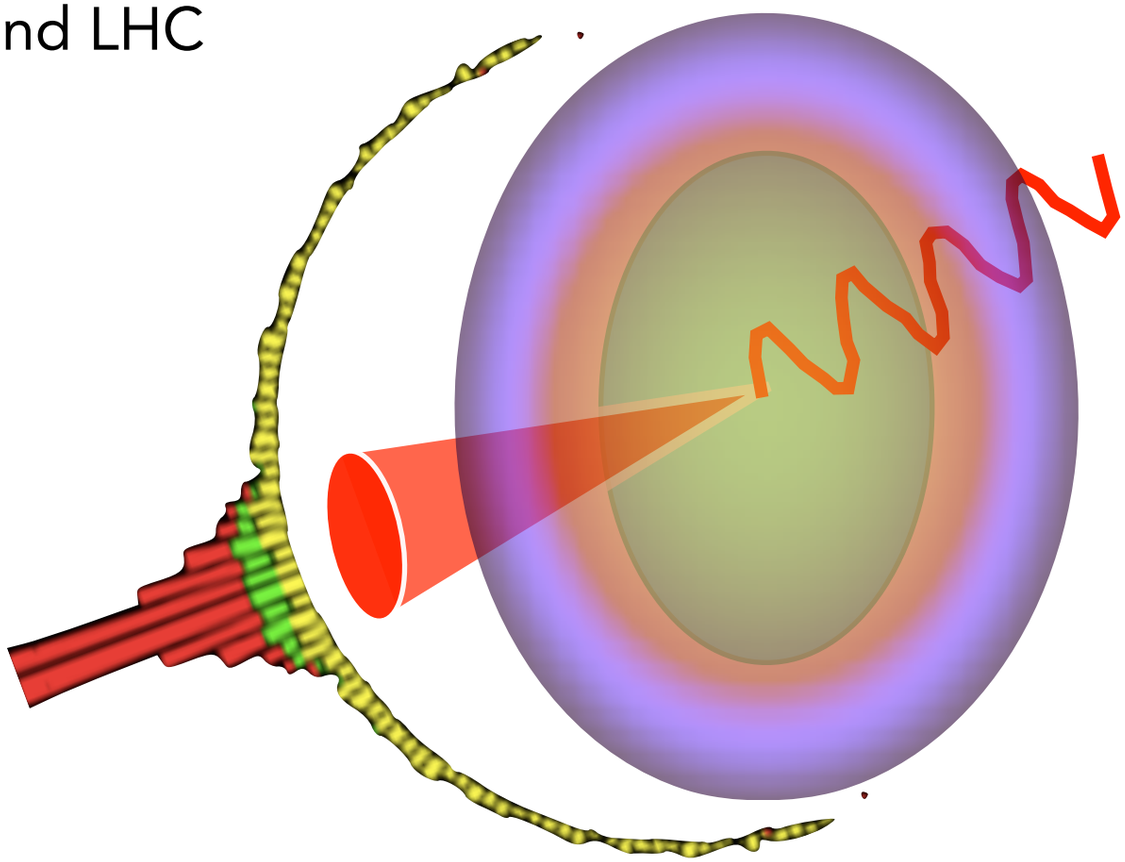
high rate, large acceptance

Make every Y count ➜

excellent momentum resolution

Physics drives detector requirements: Jets and HF

Unified approach to jet physics at RHIC and LHC



Use away- and near-side tags to control initial hard system:

- Parton flavor and mass
- Initial momentum
- Path length
- In-medium evolution
- Initial and final state radiation

➜

Photon and HF tagging

HF meson reconstruction

High rate

Control over jet energy scale

Fully characterize momentum flow near the jet, both "in-cone" and "out-of-cone"➜

Full azimuthal coverage w/ tracking and calorimetry

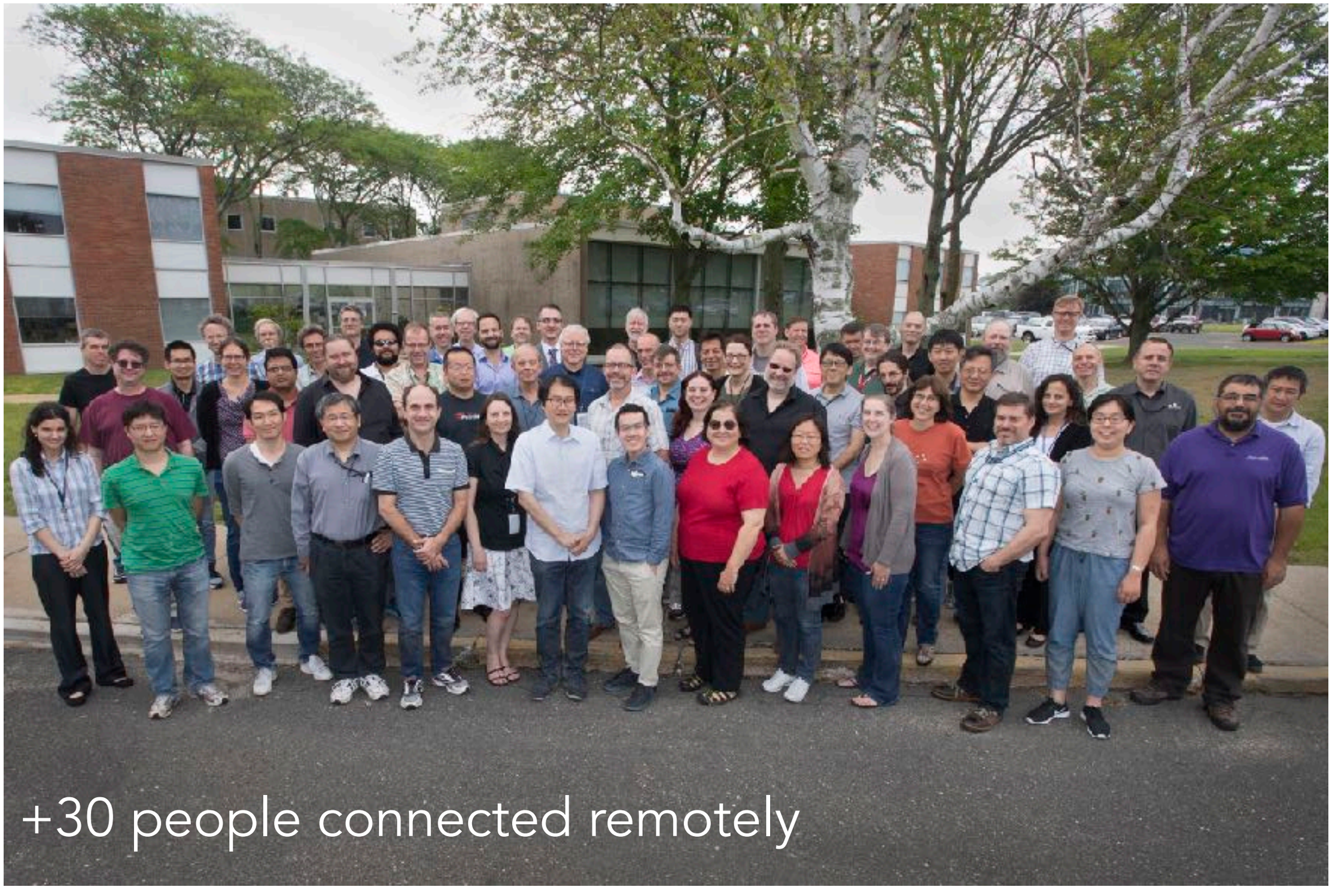
Large acceptance in p_T and rapidity

High tracking efficiency, low fake rate

TOMOGRAPHY
: a method of producing a three-dimensional image of the internal structures of a solid object by the observation and recording of the differences in the effects on the passage of waves of energy impinging on those structures

Who is pushing the sPHENIX program forward?

June 13-14 sPHENIX Collaboration Meeting



Growing the collaboration since last PAC

- Three institutions admitted at December Collaboration meeting
    - LBNL, UC Berkeley, Temple University
- Three institutions applied to join sPHENIX at Collaboration meeting this week
    - Central China Normal University, Purdue University, CEA Saclay
- The new institutions bring world-class expertise on silicon and MAPS technology (LBNL, CCNU, Purdue, UCB) and micro pattern gas detectors (Saclay, Temple), in addition to a strong record in physics
- Discussions with University Sao Paulo and contacts with other international institutions

Major sPHENIX developments since last PAC

A key highlight of 2016: DOE CD-0 approval

Subject: sPHENIX
Date: Thu, 27 Oct 2016 21:04:43 +0000
From: Mueller, Berndt <bmueller@bnl.gov>
To: Morrison, David <morrison@bnl.gov>, Gunther M Roland <rolandg@MIT.EDU>
CC: O'Brien, Edward <eobrien@bnl.gov>, James Nagle <jamie.nagle@colorado.edu>

Dear Dave and Gunther (Cc: Jamie):

I just received word that CD-0 for sPHENIX was approved today. You can go and celebrate (for one evening).

Berndt

Multi-year run plan scenario for sPHENIX

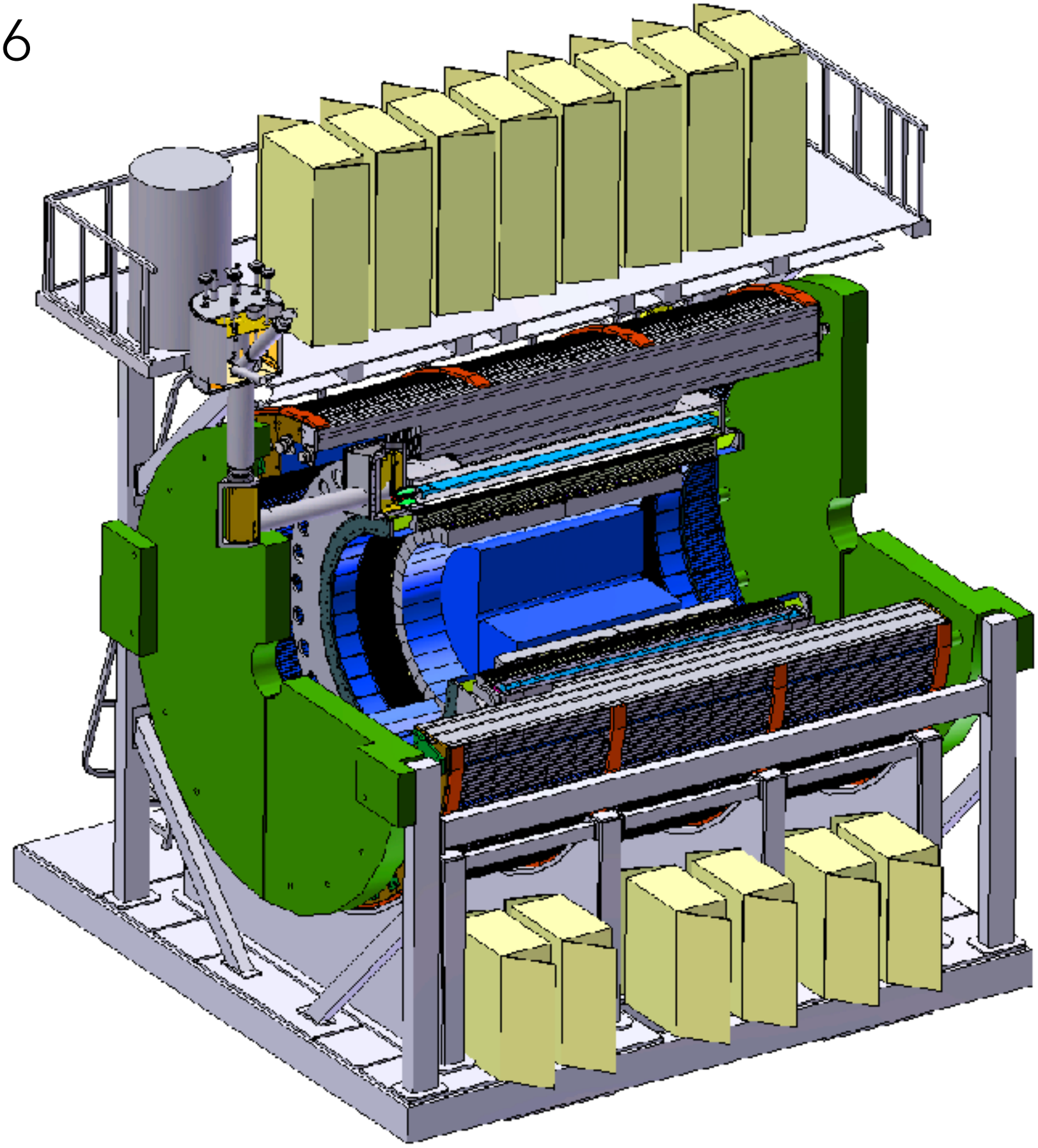
Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
2022	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
2023	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
2023	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
2024	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
2025	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
2026	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

- Guidance from ALD to think in terms of a multi-year run plan
- Consistent with language in DOE CD-0 “mission need” document
- Incorporates updated C-AD guidance now officially documented
- Run plan relates to capabilities of full barrel detector
- Incorporates commissioning time in first year

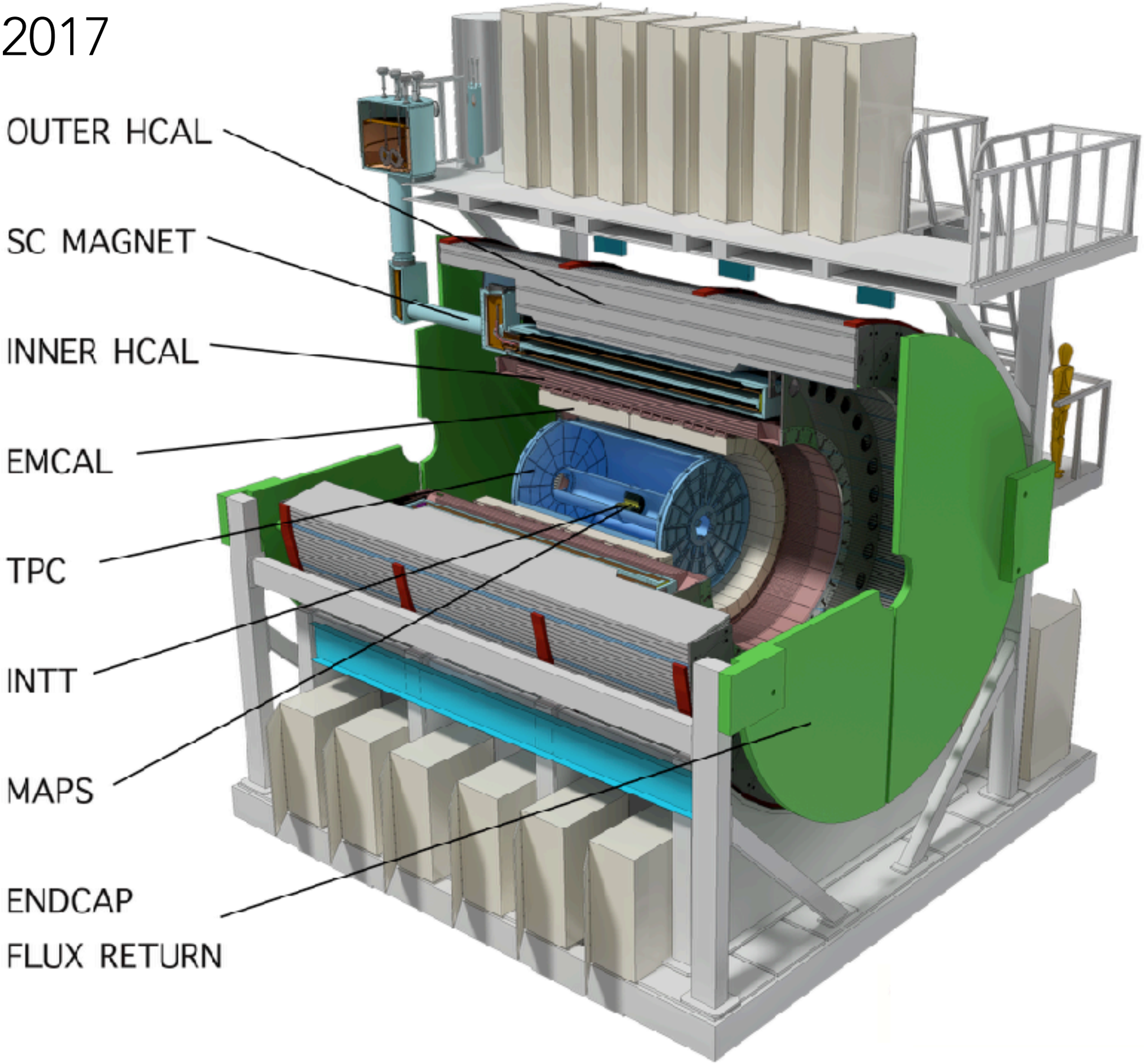
Minimum bias Au+Au at 15 kHz for |z| < 10 cm:
47 billion (2022) + **96 billion** (2024) + **96 billion** (2026) = Total **239 billion events**

For topics with Level-1 selective trigger (e.g. high p_T photons), one can sample within |z| < 10 cm a total of 550 billion events. One could consider sampling events over a wider z-vertex for calorimeter only measurements, 1.5 trillion events.

early 2016



early 2017

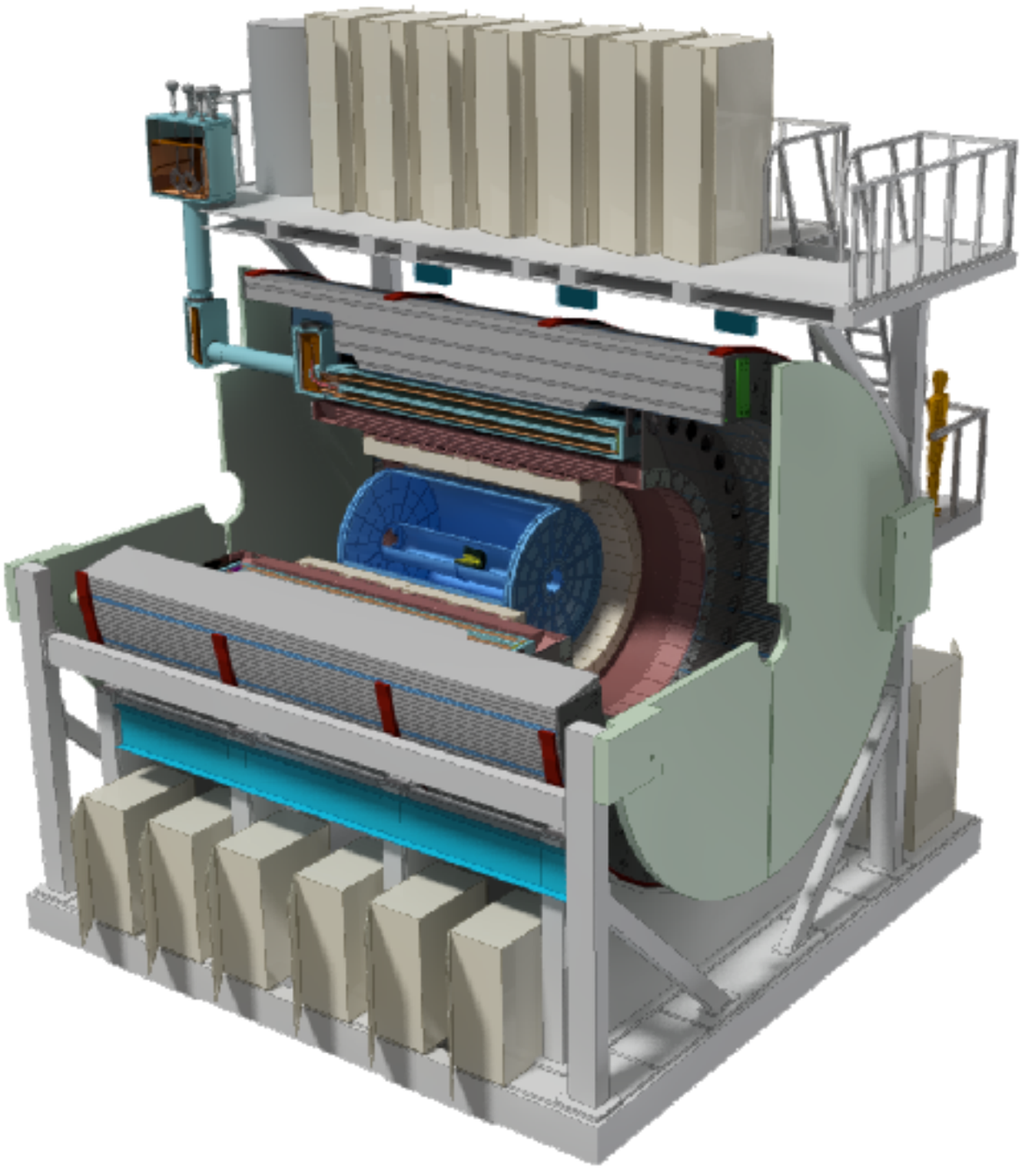

OUTER HCAL
SC MAGNET
INNER HCAL
EMCAL
TPC
INTT
MAPS
ENDCAP
FLUX RETURN

Situation at the time of the 2016 PAC meeting –

Collaboration approach to baseline scope charge

- Focus on three main science drivers: jet structure, HF jets, Upsilon spectroscopy – established three corresponding Topical Groups
- Cost reductions are relative to the pCDR detector, but with further simulation of VTX pixel performance, including known dead areas, and the operational experience with the VTX detector in the 2016 RHIC run, this configuration is not expected to provide acceptable performance for the sPHENIX science program.
- Defined a reference configuration we believe would address physics in sPHENIX proposal (3-layer MAPS inner tracker, TPC, full calorimeter stack) to provide a performance target for buy-back discussion.
- Strong consensus to prioritize tracking; consider effects of calorimeter acceptance and granularity; consider risk to schedule; potential for buying back capability (e.g., possible use of contingency, LDRD, or non-DOE funds)

Scope of sPHENIX MIE



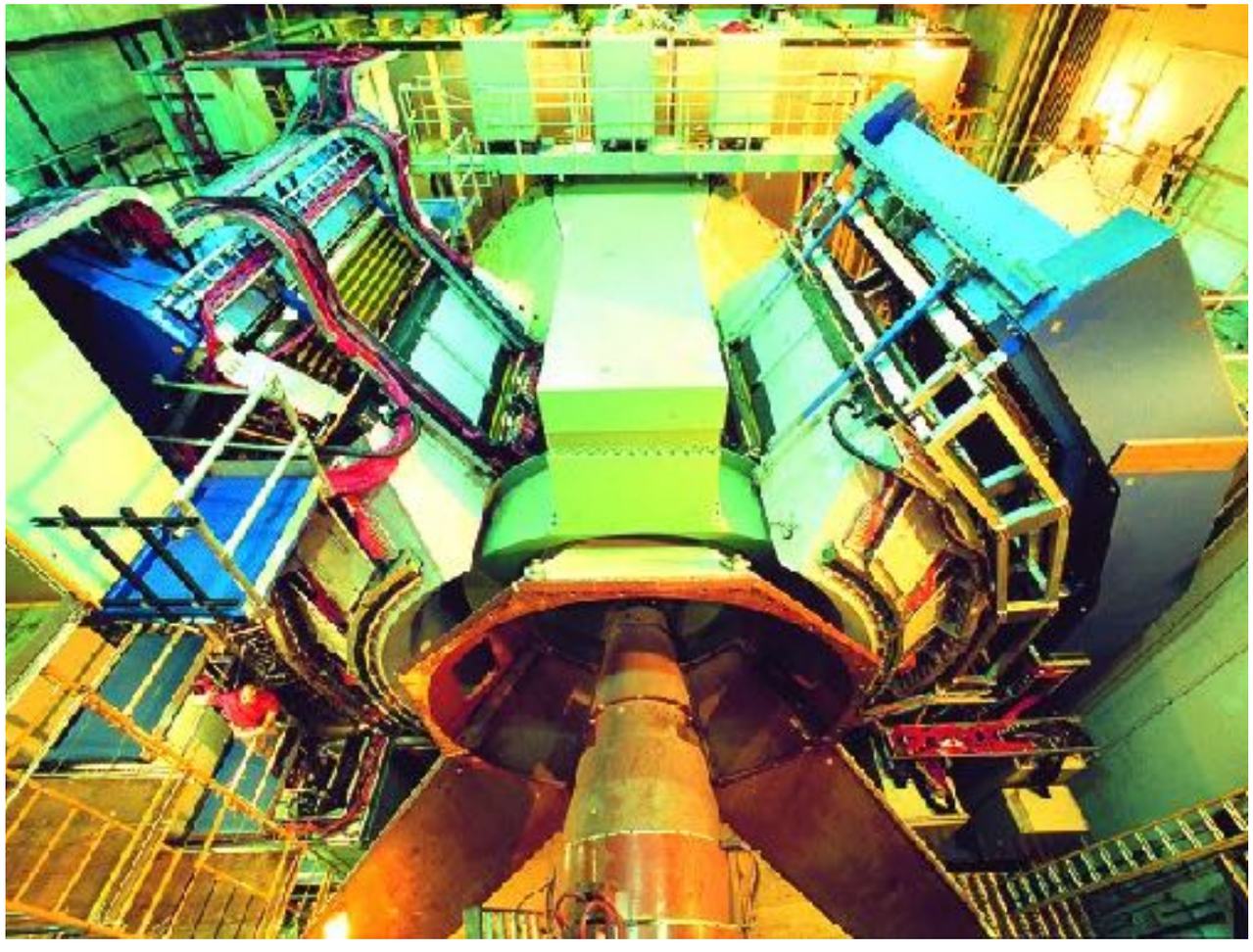
WBS	sPHENIX MIE Project Elements
1.1	Project Management
1.2	Time Projection Chamber
1.3	Electromagnetic Calorimeter
1.4	Hadron Calorimeter
1.5	Calorimeter Electronics
1.6	DAQ-Trigger
1.7	Minimum Bias Trigger Detector

WBS	Infrastructure & Facility Upgrade
1.8	SC-Magnet
1.9	Infrastructure
1.10	Installation-Integration

WBS	Parallel Activities
1.11	Intermediate Silicon Strip Tracker
1.12	Monolithic Active Pixel Sensors

Clearing the 1008 IR to get ready for sPHENIX

2001



2017

beam pipe

sPHENIX Solenoid

- High resolution tracking translates to high field
  - 1.5 T
  - 2.8 m bore
  - 3.8 m long
- BaBar solenoid arrived at BNL in February 2015
  - Low field test March 2016
  - High field test → September 2017
- Cryo, power supply, and quench protection for 1008 under development

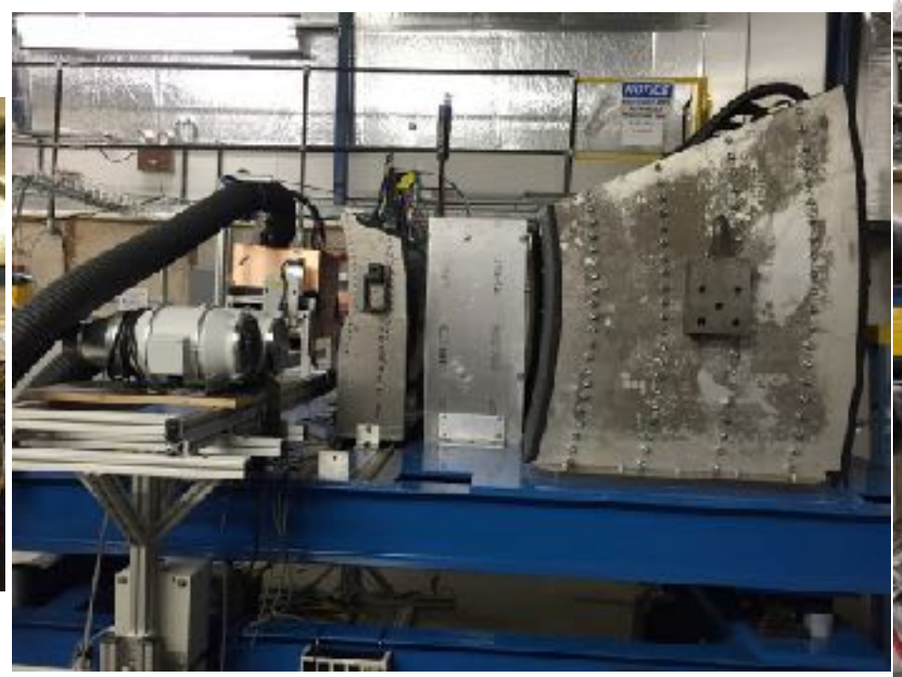
Magnet testing

- Side and front/back wall nearly complete.
- The roof will be tested for fit, after which the solenoid will be placed inside the flux return “box”.
- Field test scheduled for early September 2017

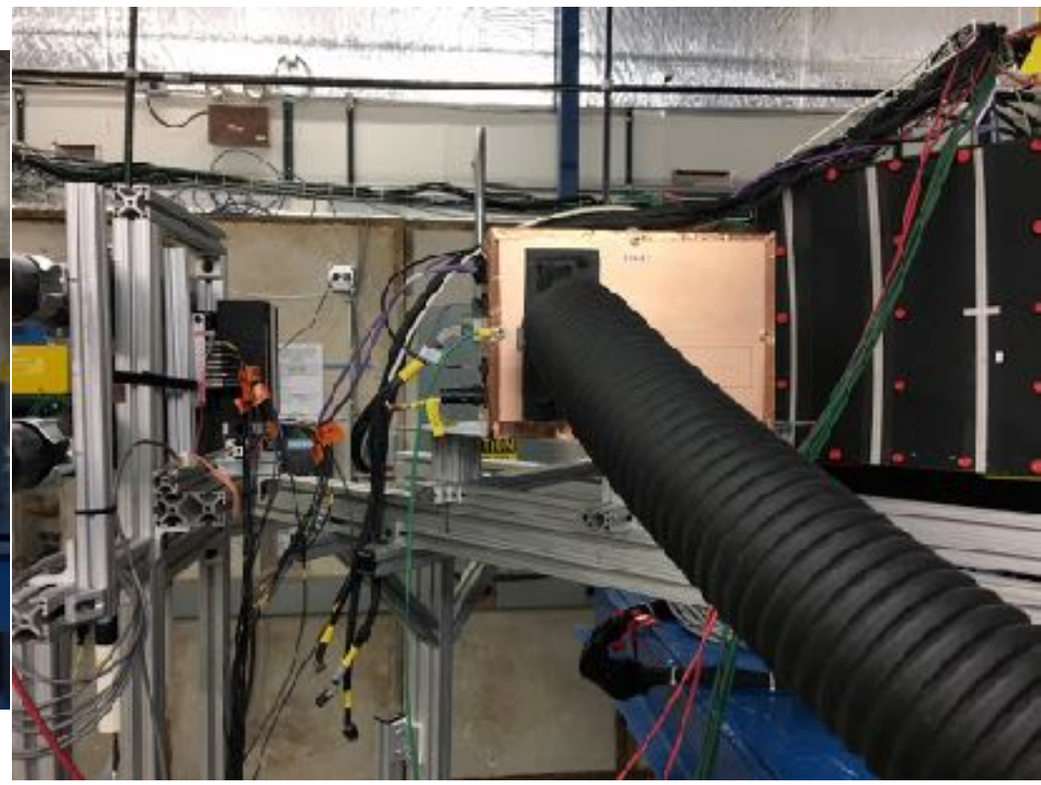
FTBF T-1044

Calorimeter beam tests

February 2014
Proof of principle



April 2016
η~0
sPHENIX geometry



February 2017
η~0.9

First publication

Design and Beam Test Results for the sPHENIX Electromagnetic and Hadronic Calorimeter Prototypes

C.A. Aidala, V. Bailey, S. Beckman, R. Belmont, C. Biggs, J. Blackburn, S. Boose, M. Chiu, M. Connors, A. Franz, J.S. Haggerty, X. He, M.M. Higdon, J. Huang, K. Kauder, E. Kistenev, J. LaBounty, J.G. Lajoie, M. Lenz, W. Lenz, S. Li, V.R. Loggins, E.J. Mannel, T. Majoros, M.P. McCumber, J.L. Nagle, M. Phipps, C. Pinkenburg, S. Polizzo, C. Pontieri, M.L. Purschke, J. Putschke, M. Sarsour, T. Rinn, R. Ruggiero, A. Sen, A.M. Sickles, M.J. Skoby, J. Smiga, P. Sobel, P. Stankus, S. Stoll, A. Sukhanov, E. Thorsland, F. Toldo, R.S. Towell, B. Ujvari, S. Vazquez-Carson, C.L. Woody

***Abstract*—The sPHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) will perform high precision measurements of jets and heavy flavor observables for a wide selection of nuclear collision systems, elucidating the microscopic nature of strongly interacting matter ranging from nucleons to the strongly coupled quark-gluon plasma. A prototype of the sPHENIX calorimeter system was tested at the Fermilab Test Beam Facility as experiment T-1044 in the spring of 2016. The electromagnetic calorimeter (EMCal) prototype is composed of scintillating fibers embedded in a mixture of tungsten powder and epoxy. The hadronic calorimeter (HCal) prototype is composed of tilted steel plates alternating with plastic scintillator. Results of the test beam reveal the energy resolution for electrons in the EMCal is $2.8\% \oplus 15.5\%/\sqrt{E}$ and the energy resolution for hadrons in the combined EMCal plus HCal system is $13.5\% \oplus 64.9\%/\sqrt{E}$. These results demonstrate that the performance of the proposed calorimeter system is consistent with GEANT4 simulations and satisfies the sPHENIX specifications.**

The electromagnetic calorimeter will be used for identifying photons and electrons. Photons can be used to tag the energy of opposing jets traversing the QGP, and electrons will be used to study quarkonia suppression and to tag heavy flavor jets. The combined EMCal and HCal are used to measure the hadronic energy of jets. sPHENIX will be the first detector at RHIC to employ hadronic calorimetry to enable full jet reconstruction at mid-rapidity.

The electromagnetic calorimeter (EMCal) design is based on both mechanical constraints and physics requirements. The principal mechanical constraint for the EMCal is that it must be compact, i.e. both the EMCal and the inner HCal must fit inside the solenoid magnet with enough space remaining for a tracking system. One major physics requirement is that it needs to have a large solid angle with minimal inactive area to

https://arxiv.org/abs/1704.01461

Submitted to IEEE Trans. Nucl. Sci.

Testing sPHENIX calorimeter electronics

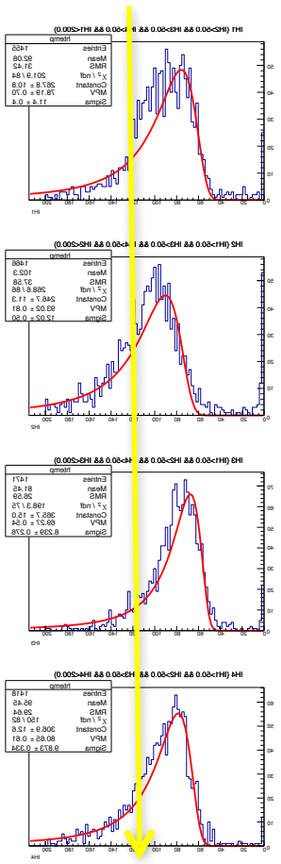
DCM II

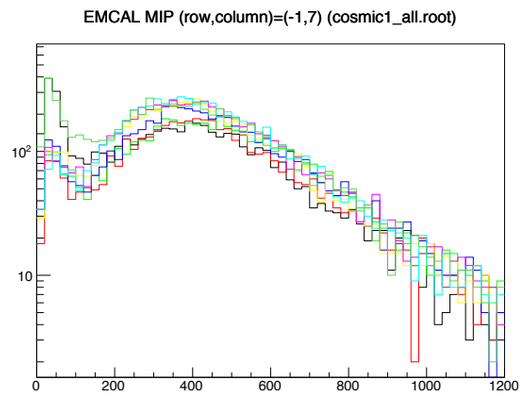
CALADC

EMCAL

IHCAL

HCAL Lab





Outer HCal steel

- Engineers visited vendor last week
- Saw-cut absorber plates for the OHCal Module 0
- Module 0 will be assembled at vendor
- Ship to BNL early August.
- We have a signed contract to deliver all 32 modules if BNL wants to exercise that option by Apr 2018

Refining EMCal design for production, more uniform response

2017 prototype

- 2D projectivity, close to the final design
- blocks are 2x2 towers → ~twice as large as in 2016 prototype
- longest step is filling the fibers into meshes
  - holes don't line up because of the projectivity so we developed a 3D printed spacer setup to funnel the fibers through; supported with a solo cup
  - 3D printed molds to cast the blocks

11

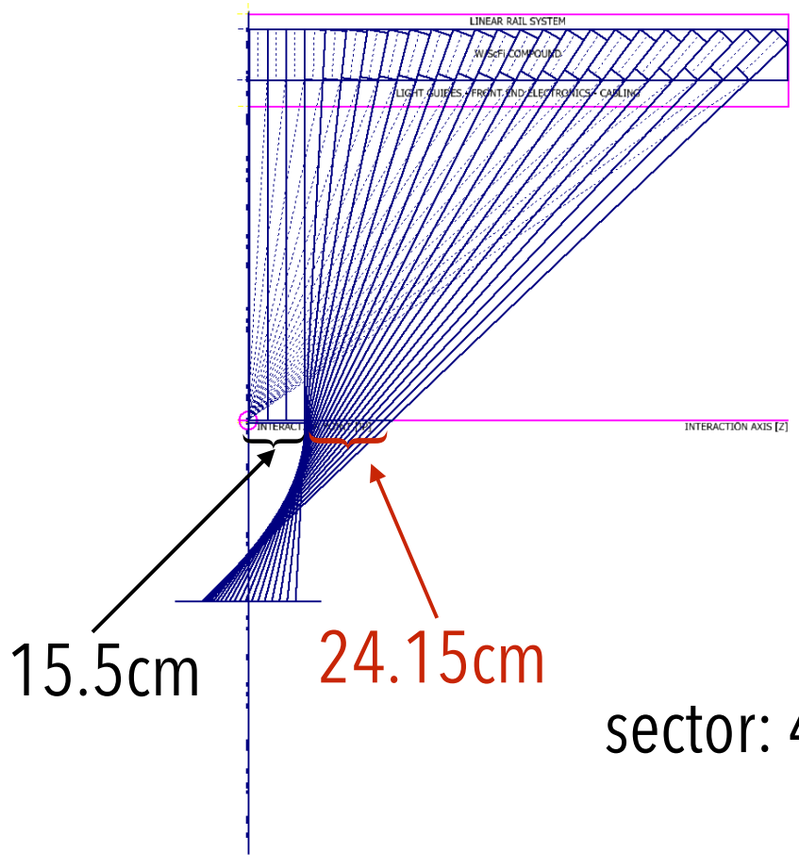
4th generation prototypes

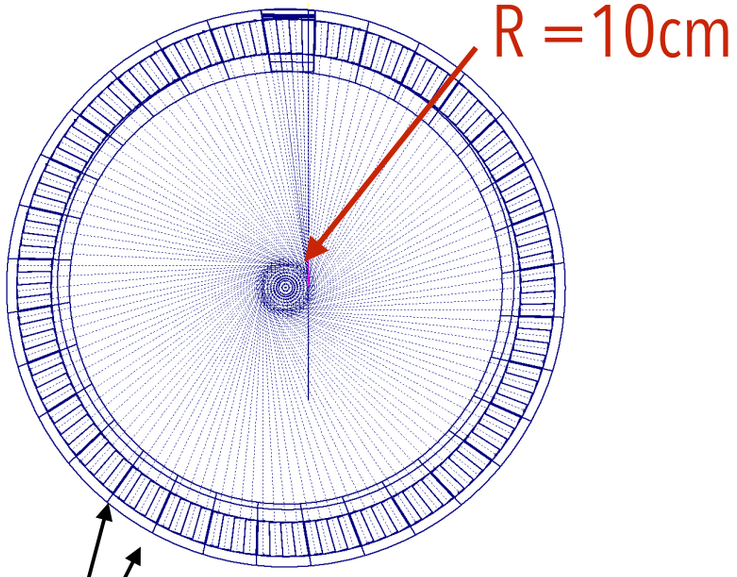
Refining EMCal structure to reduce "channeling"

non-projectivity

total width is 48 blocks in η, six blocks around η = 0 have the same shape → 22 different block shapes

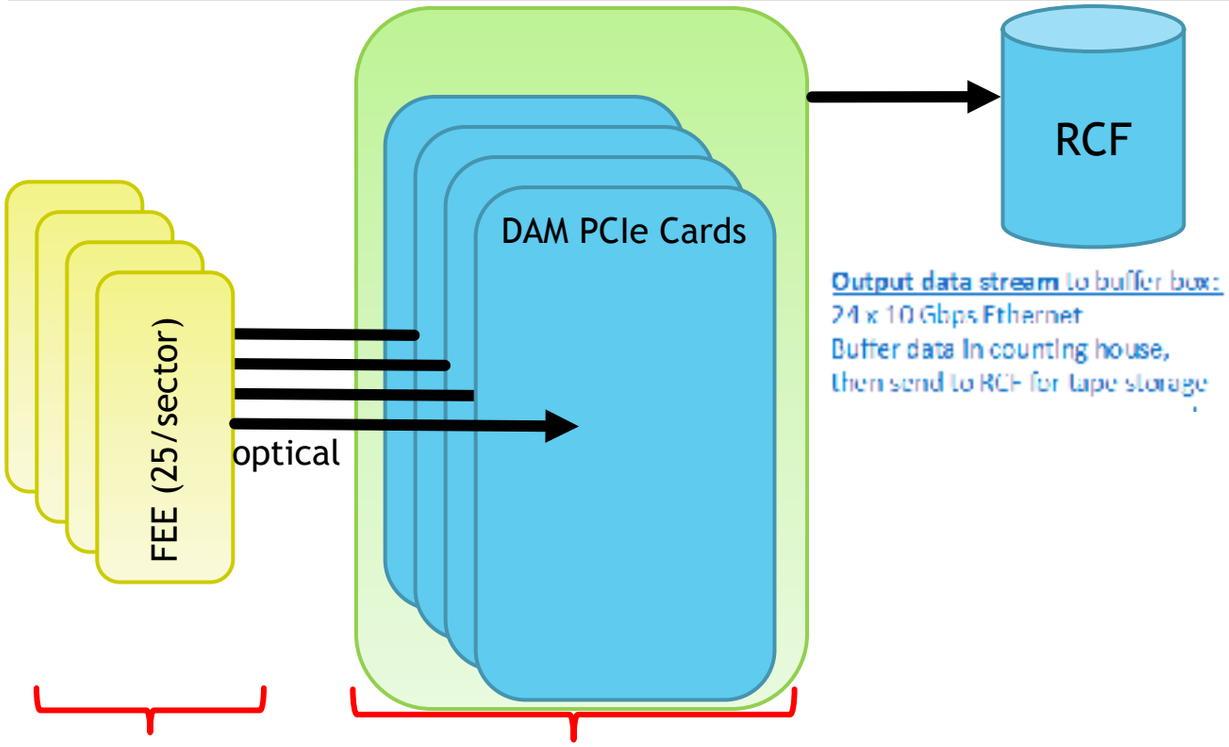
slight non-projectivity: 100mrad in azimuth and 150mrad in η



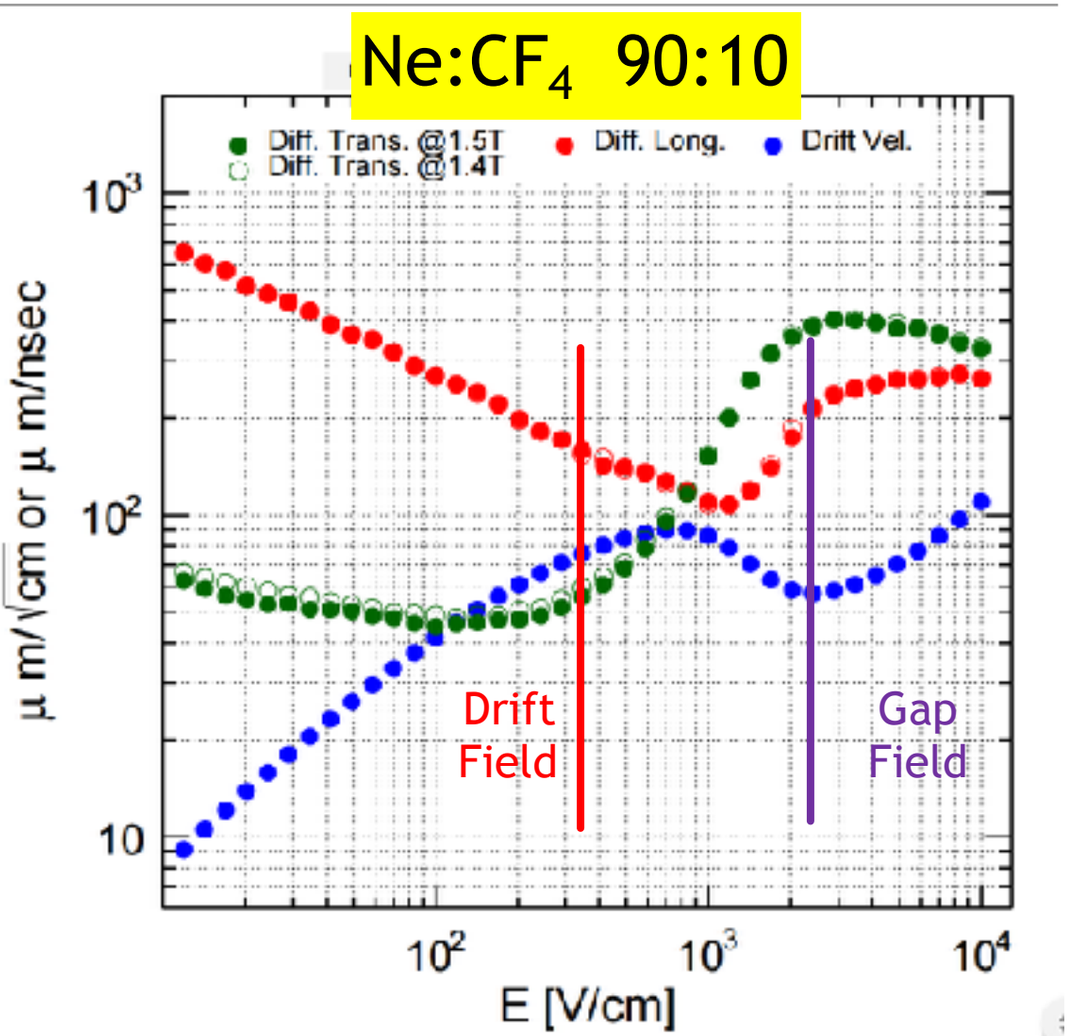


sector: 4 blocks wide in Φ, 32 sectors around

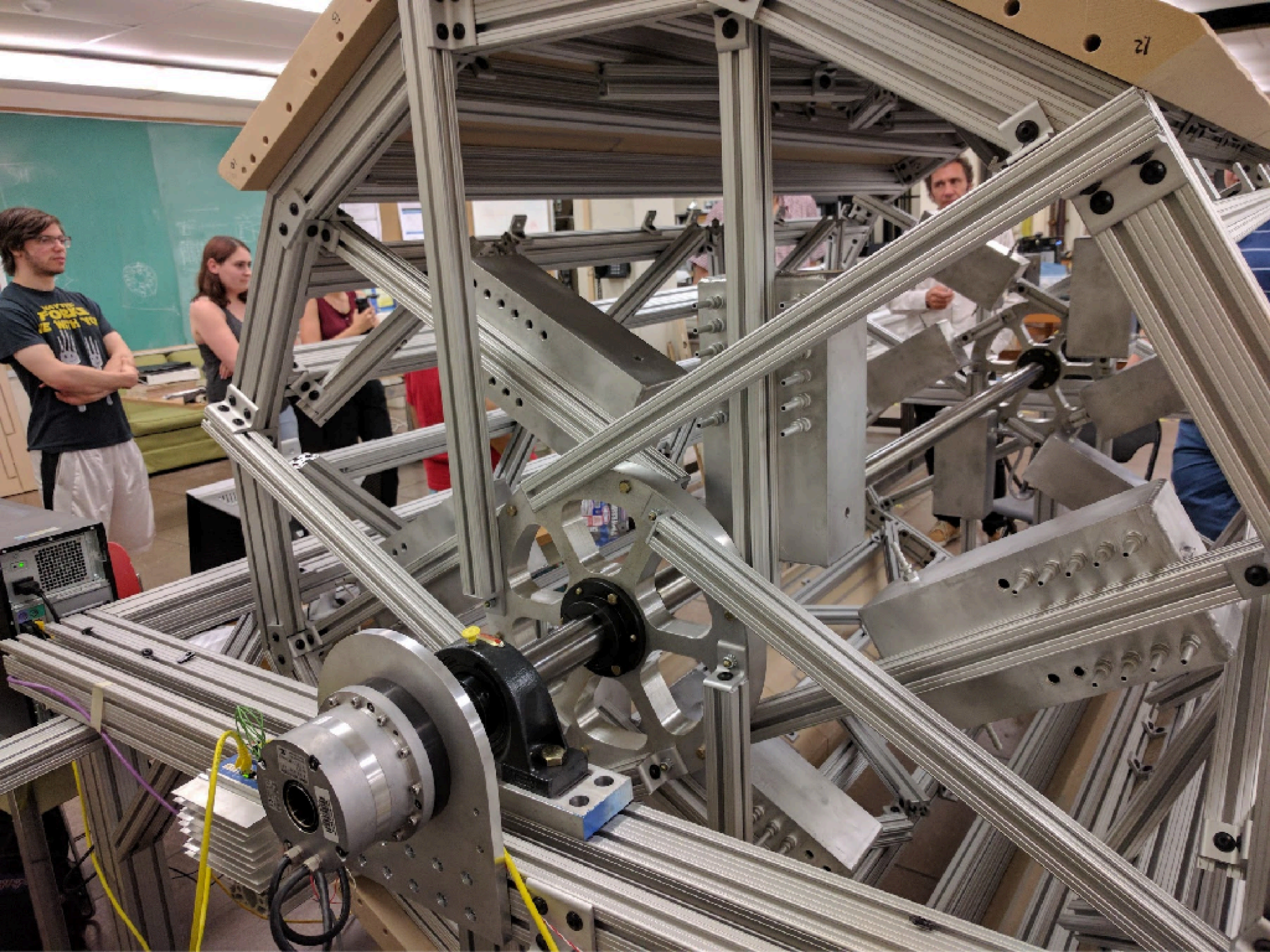
Many TPC developments - electronics, gas, more



- FEE (sPHENIX Development)
  - 256 channel SAMPA→optical (no processing)
- DAM (use e.g. BNL/ATLAS FELIX board)
  - Data Aggregation Module.
  - Aligns, Clusters, Compresses (Triggers?) Data.
- EBDC (purchase commodity PC)
  - Commodity PC, houses one sector of DAM cards.



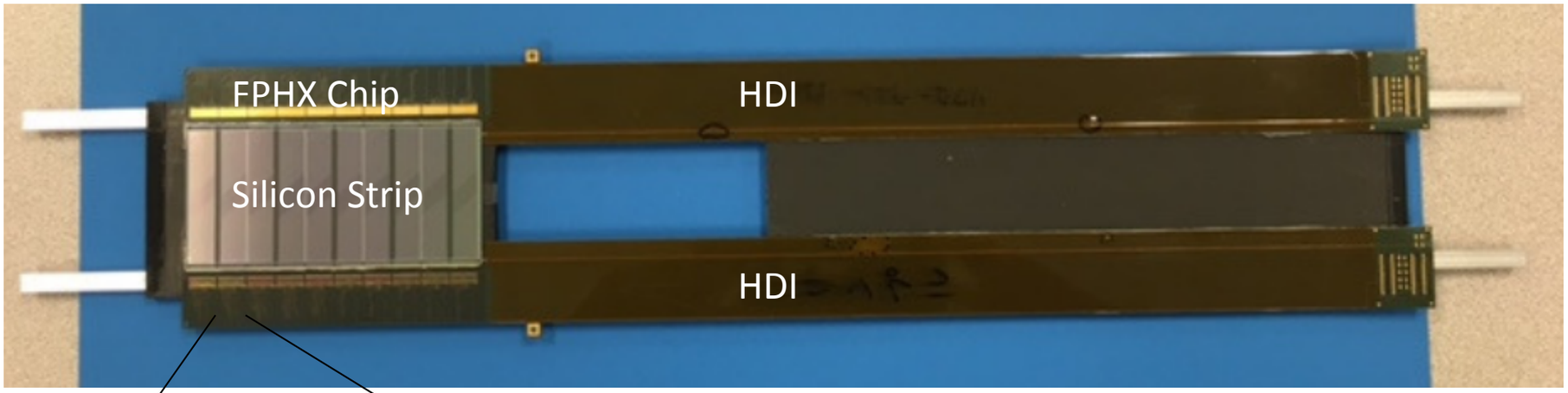
Best of Both Worlds!
- Position Resolution:
  Small Transverse Diffusion
- Pad Plane:
  Large Transverse Diffusion
- Ideal:
  - Low D during TPC drift
  - High D during avalanche

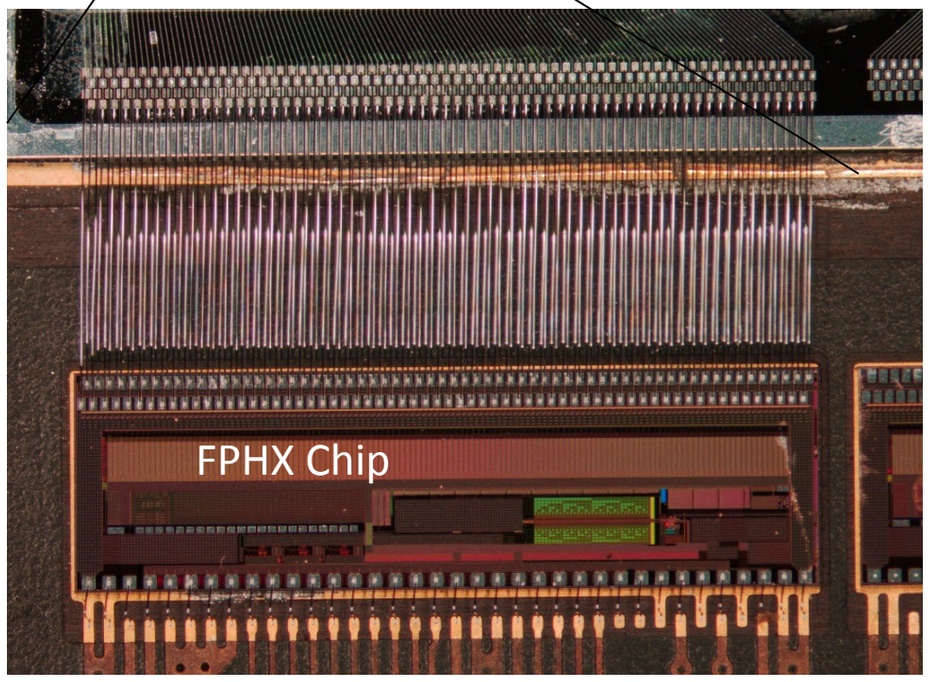


Progress on parallel projects (outside MIE)

Intermediate silicon strip tracker (INTT) – RIKEN

Ladder Prototype-0 Assembly

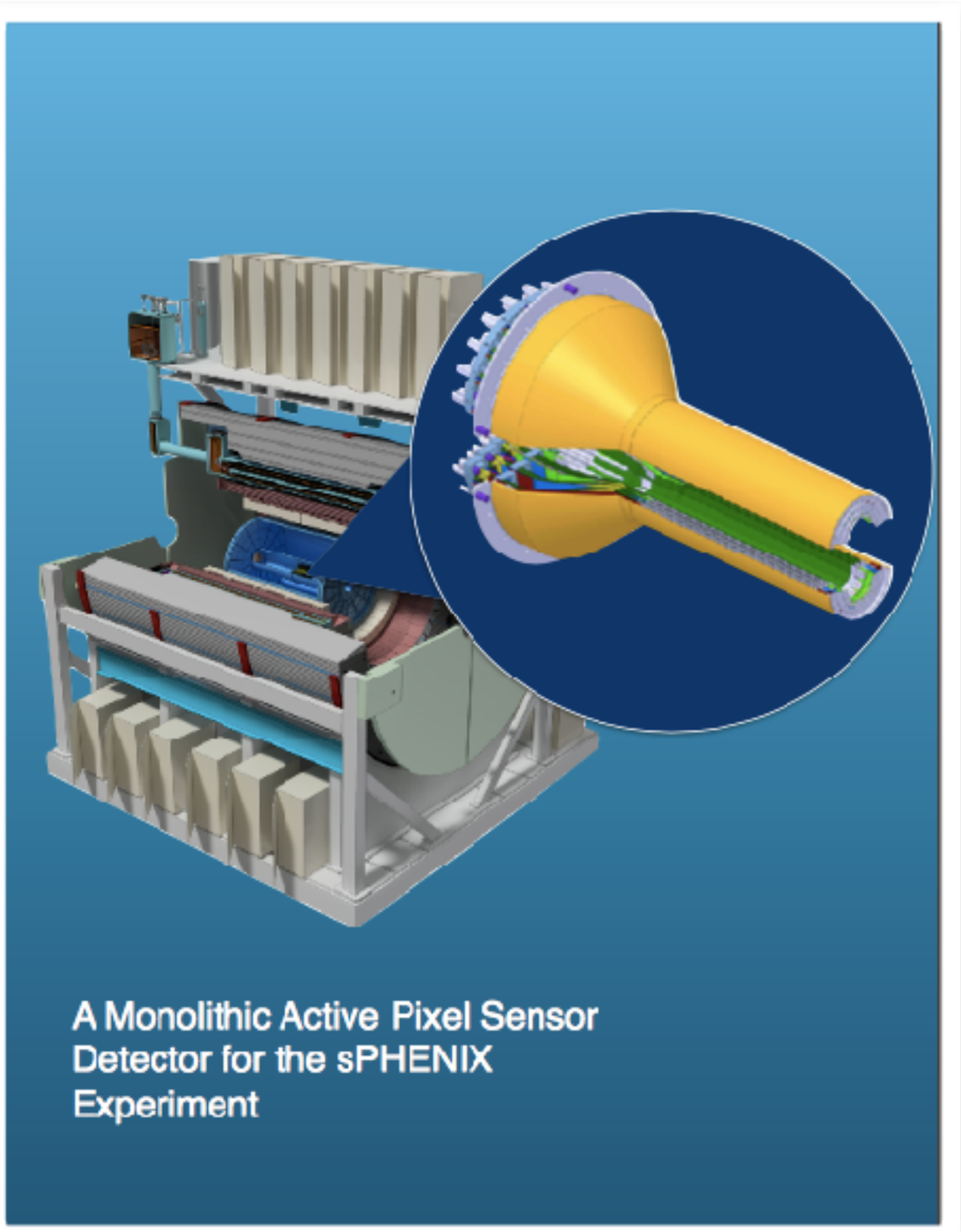




Wire-bondig of the FPHX chip was done at Inst. Div. BNL

Ongoing optimization of innermost layer geometry, sensor layout, sensor thinning, HDI connection

MVTX pre-proposal and beyond



- Fall 2016 project plan: MVTX as separate project outside of, but pursued in parallel to, baseline MIE detector
- MVTX consortium developed MVTX pre-proposal
- Sent to DOE in February 2017
- DOE response indicates concerns regarding sequencing, i.e. sPHENIX CD-1 should come before consideration of “upgrades”
- Director’s review at BNL on July 10-12

sPHENIX MVTX consortium

Los Alamos National Lab (LANL) : Readout electronics and mechanics integration.

Lawrence Berkeley National Lab (LBNL) : Carbon structure, production, LV and HV power system, full detector assembly and test.

Brookhaven National Lab (BNL) : System integration and services, safety and monitoring.

Massachusetts Institute of Technology (MIT/Bates) : Mechanical system integration and cooling.

Massachusetts Institute of Technology (MIT) : Stave assembly and testing at CERN.

University of Texas at Austin (UT Austin) : MVTX readout electronics integration and testing.

University of Colorado : *b*-jet simulations and future hardware.

Iowa State University (ISU) : Detector assembly and testing, simulations.

Florida State University (FSU) : Offline and simulations.

University of New Mexico (UNM) : LV cabling & connectors.

New Mexico State University (NMSU) : Tracking algorithm and physics simulations.

Georgia State University (GSU) : Online software and trigger development.

University of California at Los Angeles (UCLA) : Simulation and readout testing.

University of California at Riverside (UCR) : Detector assembly and testing, simulations.

Yonsei University (Korea) : MAPS chips QA and readout, simulations

RIKEN/RBRC (Japan) : Mechanical integration, cooling, cabling, simulation, patter recognition.

Purdue: Detector assembly and testing, analysis. Silicon lab available.

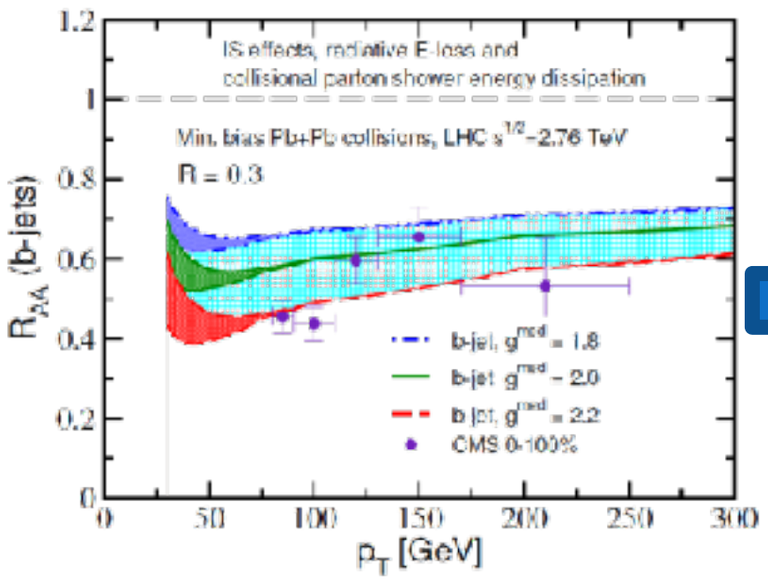
Central China Normal University (CCNU/China): MAPS chip and stave test at CERN and/or CCNU.

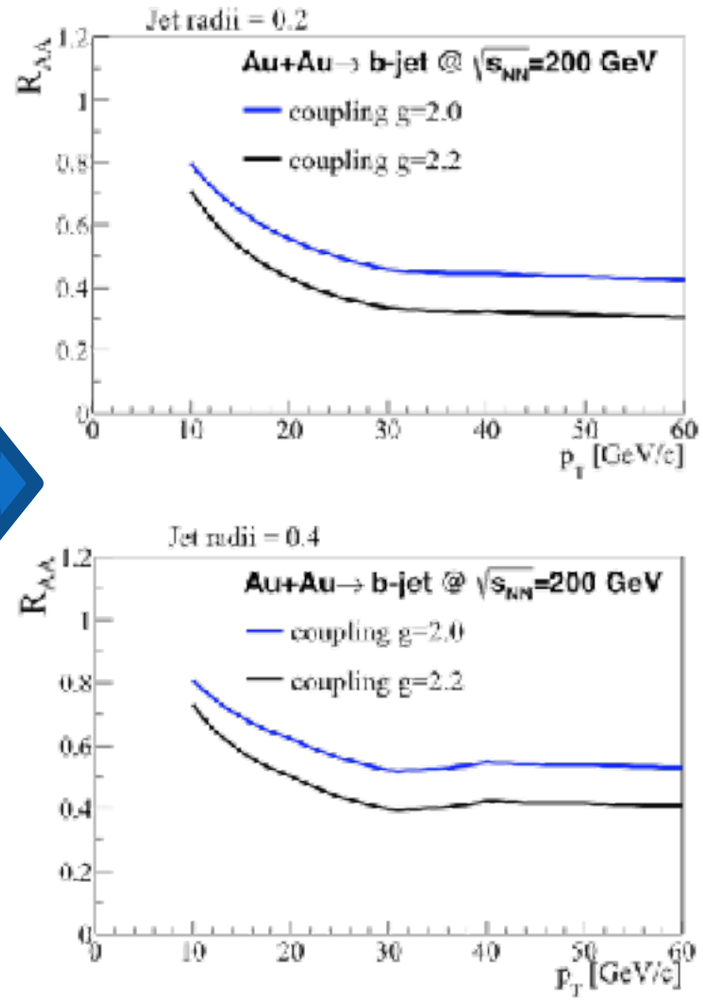
Univ. of Science and Technology of China (USTC/China): MAPS chip and stave test, simulations.

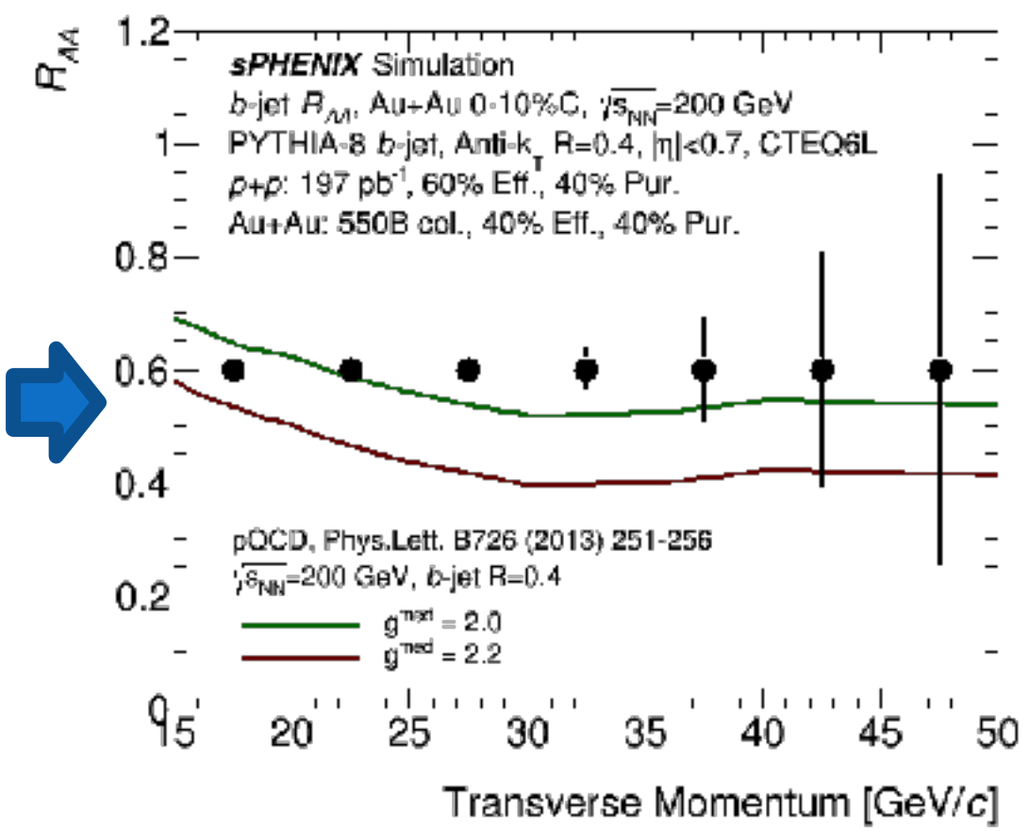
b-jet theory updates for sPHENIX

Cesar da Silva (LANL) working with Ivan Vitev's group updating pQCD calculation of [Phys.Lett. B726 (2013) 251-256] to sPHENIX kinematics

Phys. Lett. B726 (2013) 251-256
Phys.Rev.Lett. 113 (2014) no.13, 132301





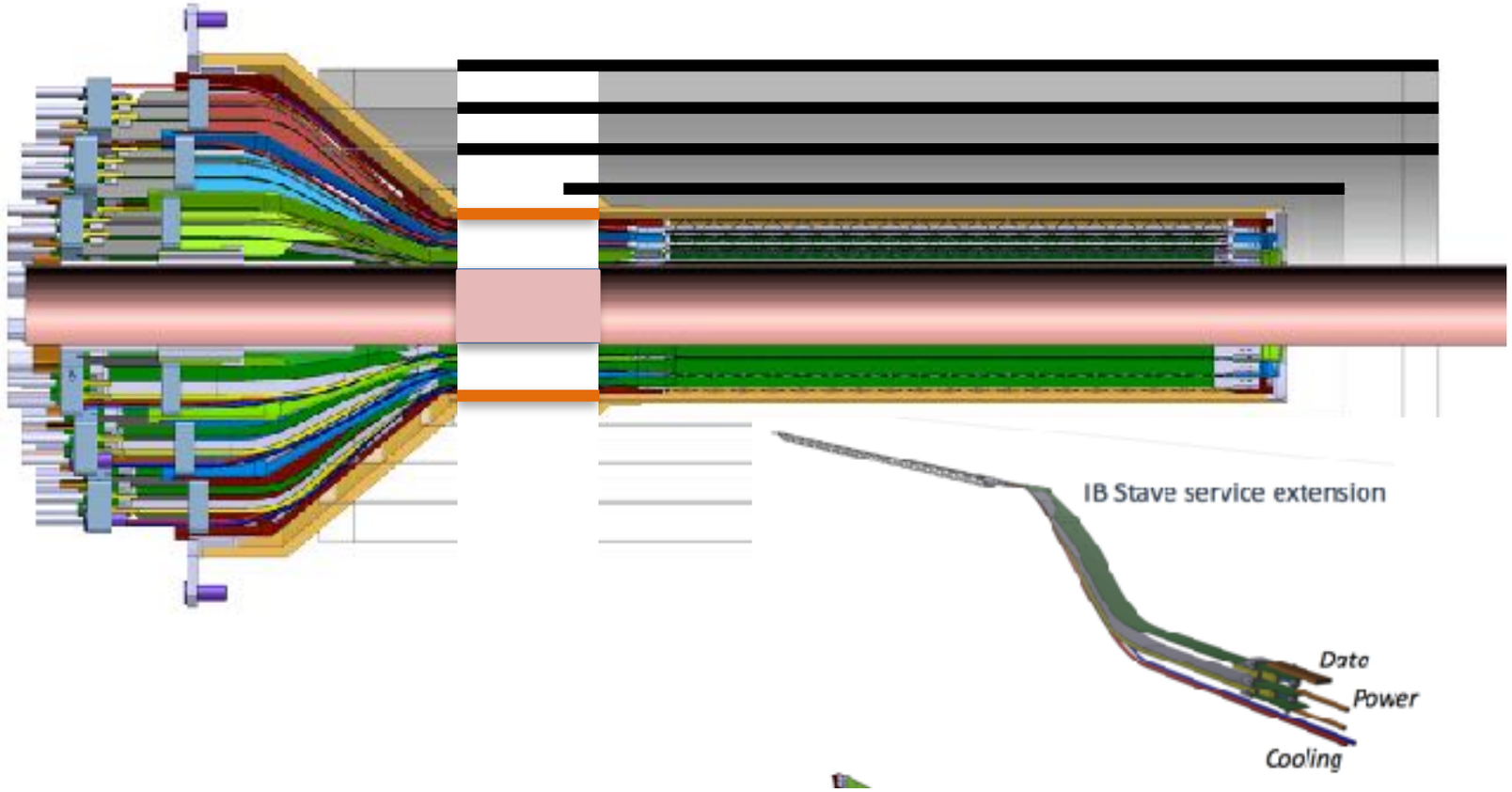


LANL LDRD has technology R&D and theory components

Integration task force

- Collect Information on what is required for the four inner detectors
  - Cables, Racks, Cooling, Power, Boards, Detector outline and location, etc
- Determine how to best provide all of those services
  - In a way that minimizes impact on physics
  - Minimizes cost and maximizes efficiency and ease of maintenance
- Establish exclusion zones for each detector
- Written report submitted to project

example: detailed consideration of scheme for how INTT and MVTX could coexist



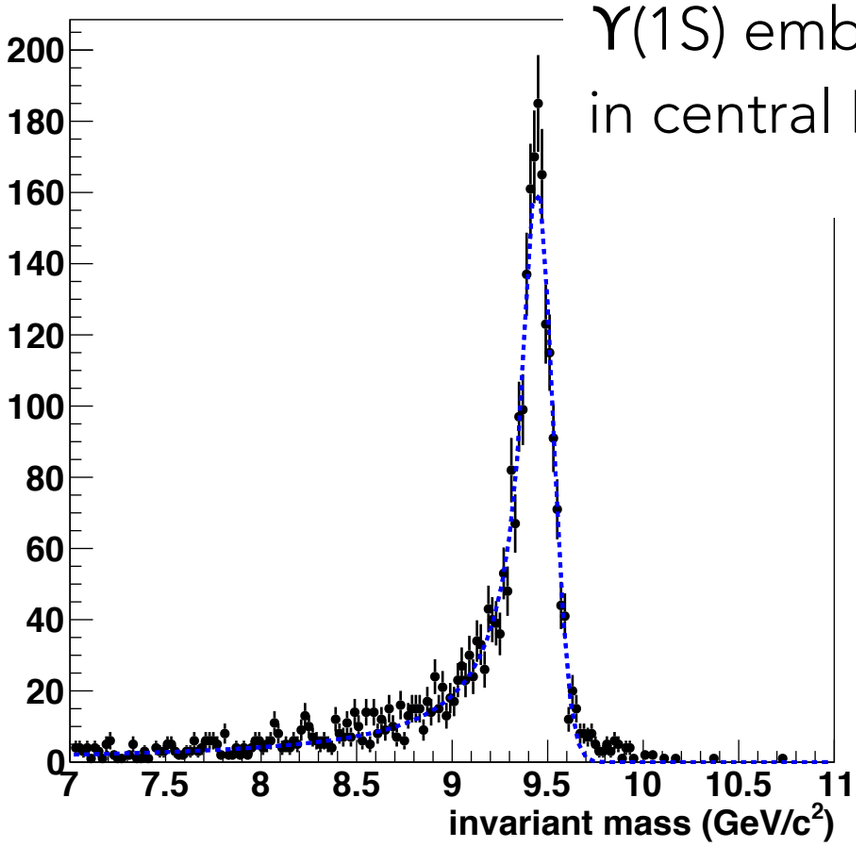
Excellent tracking software progress

Major new developments in the reconstruction software through the topical groups. Learning from the CERN experiments where we can (tracking approach adapted from CMS/CERN experiments, jet background subtractions from ATLAS/STAR/ALICE, HF tagging a la CMS/ATLAS, HF mesons like STAR/CMS, photons, upsilons a la PHENIX

Code implements the MVTX ladders using the GEANT4 model provided by ALICE. The INTT ladder geometry is implemented in GEANT4 as it is presently envisioned by the RIKEN group.

State of the art Kalman filter package (GENFIT) and primary/secondary vertex fitter (RAVE)

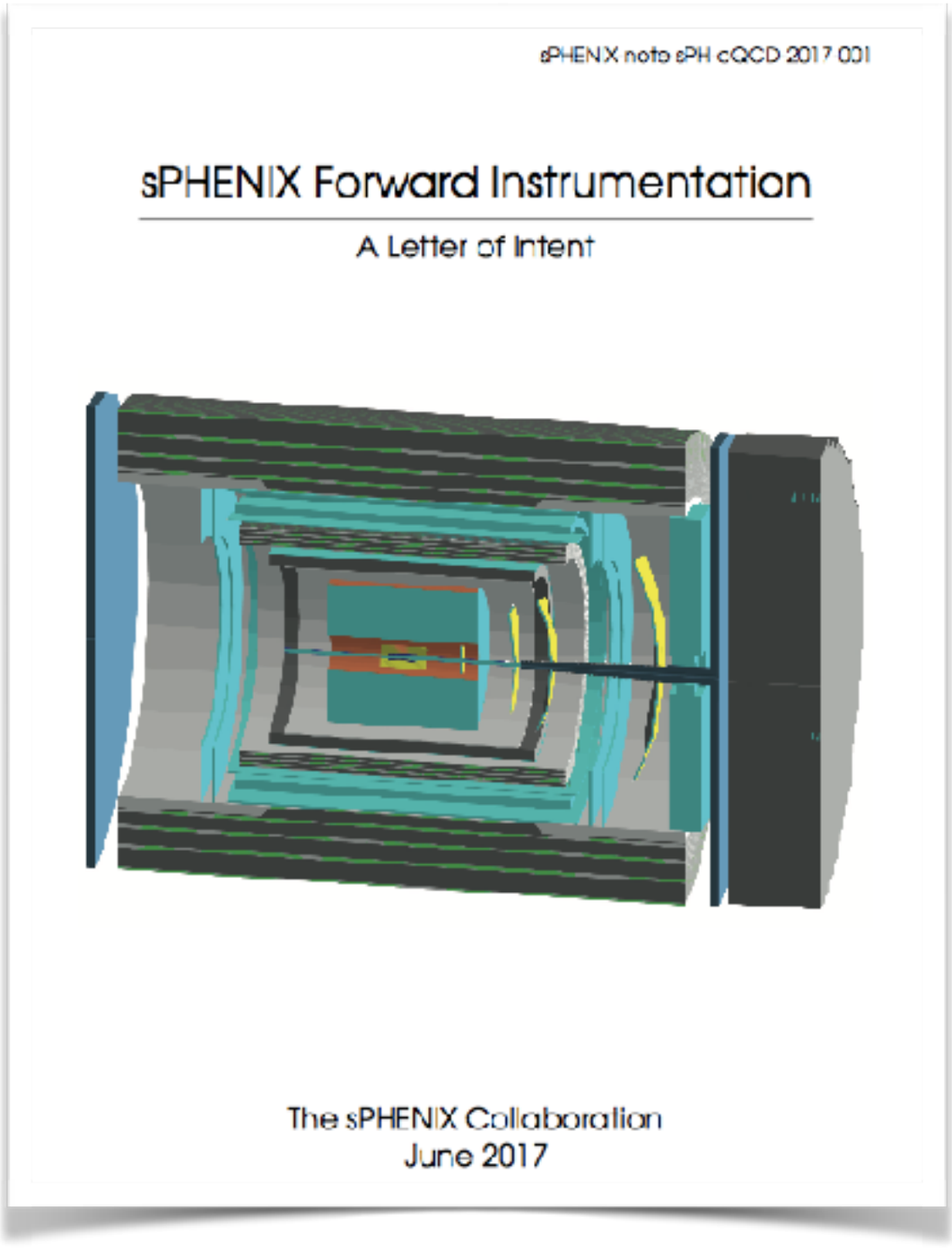
More properly accounts for material and multiple scattering – meets spec in central Au+Au



ϒ(1S) embedded in central HIJING

- effort is benefitting from influx of additional people, experience
- updates to many physics projections keyed on updated tracking

Modest Forward Upgrade LOI



- Invitation by ALD to STAR and sPHENIX on February 22. Submitted to ALD on June 3

- Contributions across collaboration, led by cold QCD topical group. First exercise of "CMS lite" process for producing and archiving official Collaboration notes.

- In addition to p+p and p+A program, collaboration excited by strengthening of core sPHENIX program from adding forward instrumentation to high-rate, deep calorimetry, high resolution tracking, precise vertexing of barrel.

  - E.g., dijets and (central-forward) gamma+jet over extended rapidity range $-1 < \eta < 4$

Project timetable

- Very useful and very positive internal sPHENIX “Document Review” June 5-6, convened by Deputy Director Bob Tribble – awaiting final review report
    - B. Wahl, J. Keister, M. Begel, F. Videbaek, M. Pleier, R. Gutta, P. Novakova, H. Turbush and G. Woods – mix of physicists, engineers, project experts
- MVTX BNL review July 10-12
- sPHENIX “Director’s Review” August 2-4 to be chaired by Jay Marx
- DOE OPA CD-1 review will likely **not** be Nov 7-9
    - Present guidance is that there would not be a CD-1 review/approval until after the FY18 budget clarifies, the timescale for that is after March 2018

Strengthening the science case for sPHENIX

- sPHENIX future rests on LRP science case – and we recognize that this is a task that is never finished

- The Collaboration is in a strong position to help drive the discussion of how to extract the "microscopic nature" of QGP from proposed measurements – cf. interactions with JET topical collaboration.

- Number of recent meetings have highlighted topics relevant to sPHENIX program: "Recent RHIC and LHC results and their implications for heavy ion physics in the 2020's" at MIT, October 2016

- Workshops this year – e.g., INT program May/June, CERN Jet Workshop (August)

- Would be good to organize a workshop at BNL – synergy with new NT hire

- Opportunities to engage with theorists (e.g., JETSCAPE)

Issues and concerns

- Semi-infinite review recursion – each official DOE review spawns several pre-reviews.
    - To be effective, feedback from pre-reviews needs to be strongly correlated with expectations of final panel
- Budget uncertainty leading to delay in CD-1. Don't want to squander momentum of growing collaboration, or have multi-year run plan compete with community interest in EIC coming as early as possible, or complicate potential availability of resources/ facilities at CERN and elsewhere.
- With CD-0 having been granted, we are hearing from collaboration that ME funding for sPHENIX participation is problematic – a real concern for upcoming grant renewals
- Local group is supporting two distinct multi-hundred person collaborations – support from Department has been very welcome, still challenging

Outstanding progress since last PAC

- CD-0 approval with a strong and growing collaboration
- extensive revamp of tracking software with much improved performance – key to updating physics performance plots
- all detector subsystems making excellent progress
- MIE project would be on track for CD-1 as scheduled
- progress toward parallel projects: MVTX and INTT
- physics case looks ever more relevant