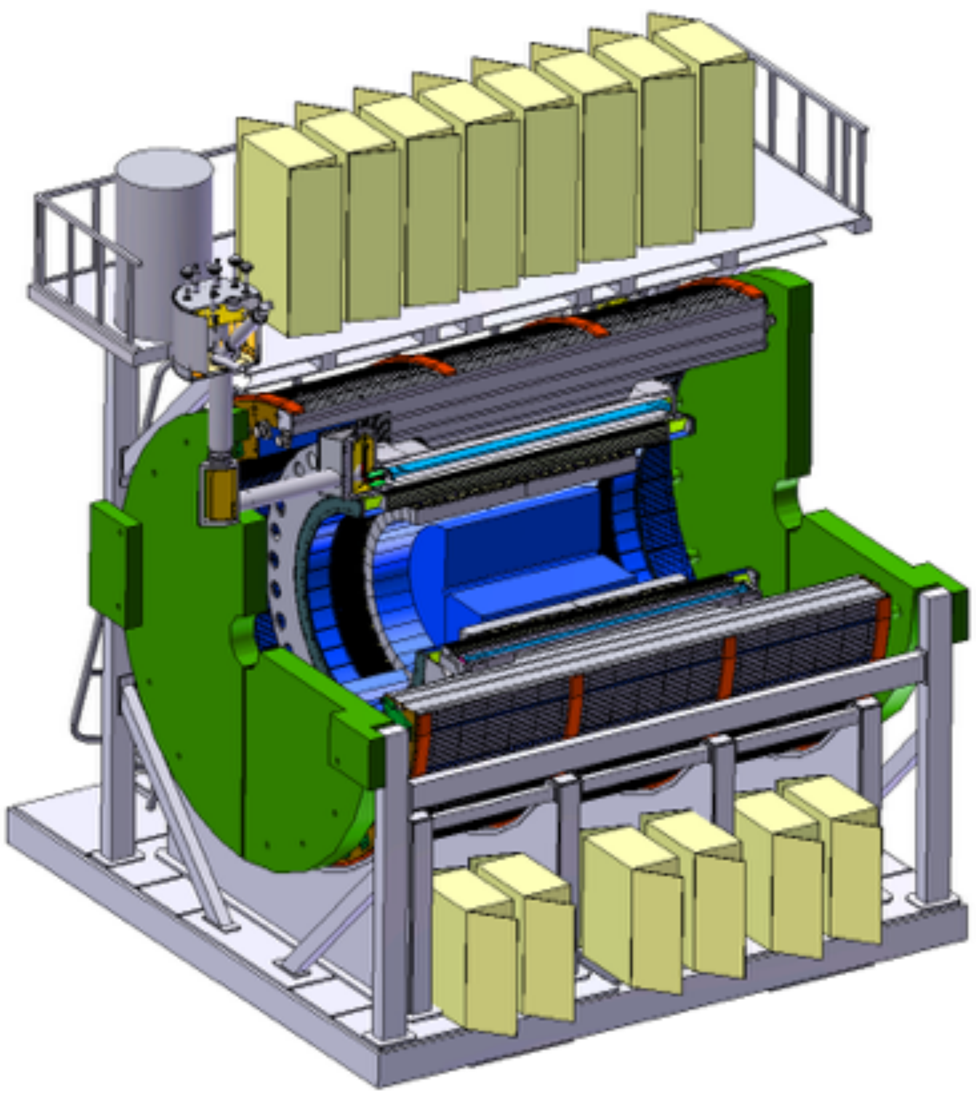
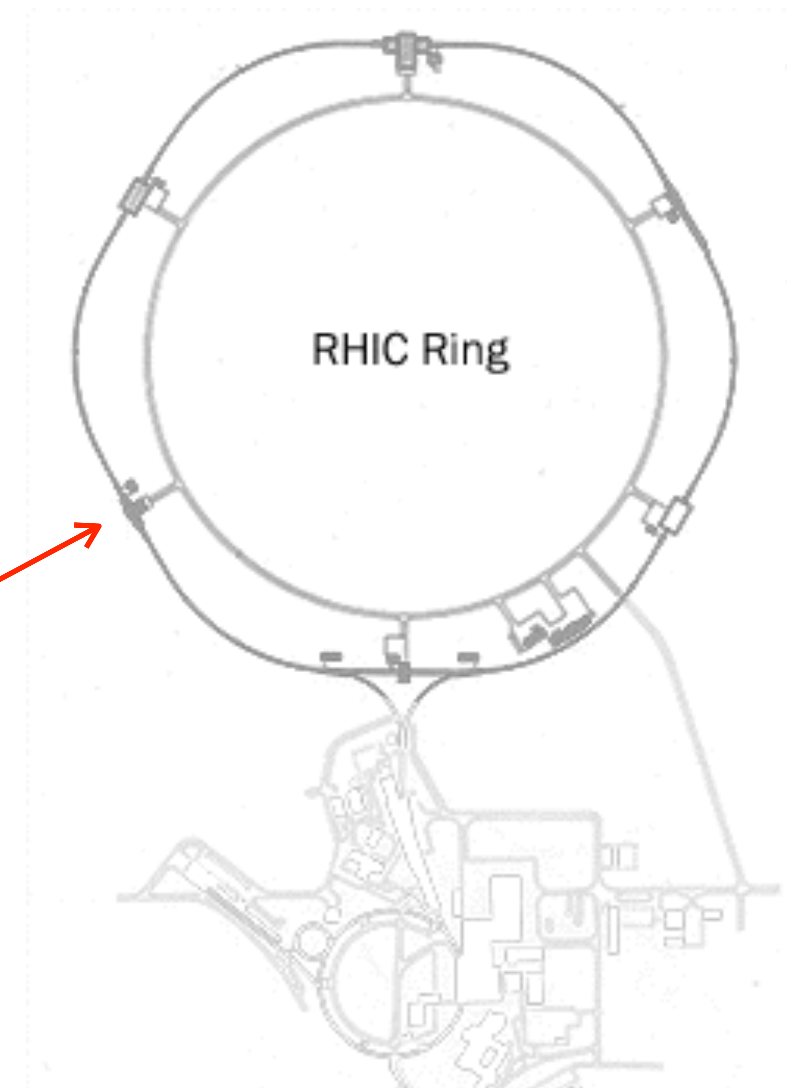
sPHENIX

Dave Morrison (BNL)
Gunther Roland (MIT)

Co-spokespersons

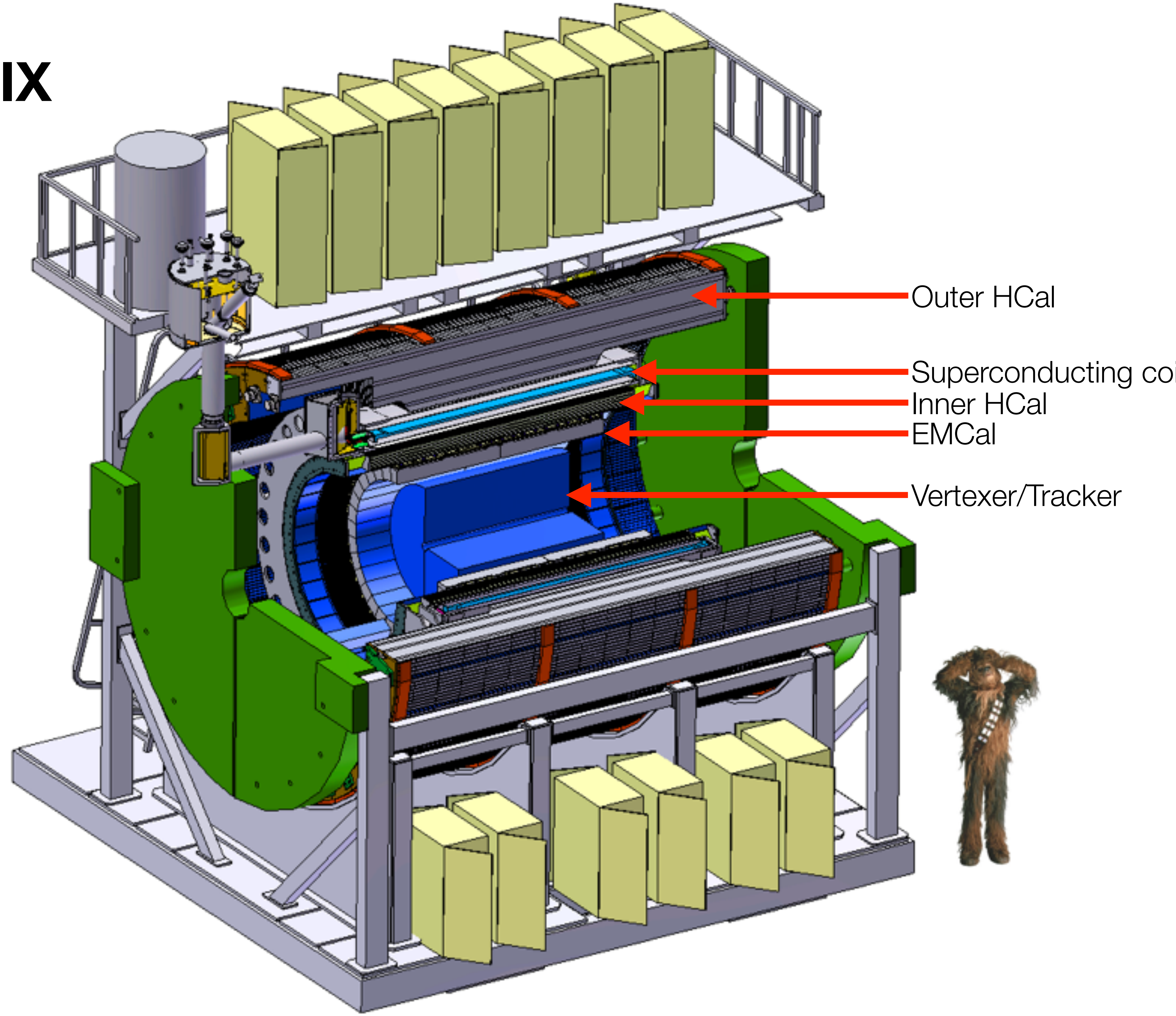
sPHENIX: A fantastic* high-rate capable detector at RHIC IP8, built around the former BaBar 1.5 T superconducting solenoid, with full electromagnetic and hadronic calorimetry and precision tracking and vertexing, with a core physics program focused on light and heavy-flavor jets, direct photons, Upsilons and their correlations in p+p, p+A, and A+A to study the underlying dynamics of the QGP – physics delivered by 22 weeks of Au+Au, 10 weeks each of p+p and p+A (@ 200 GeV).





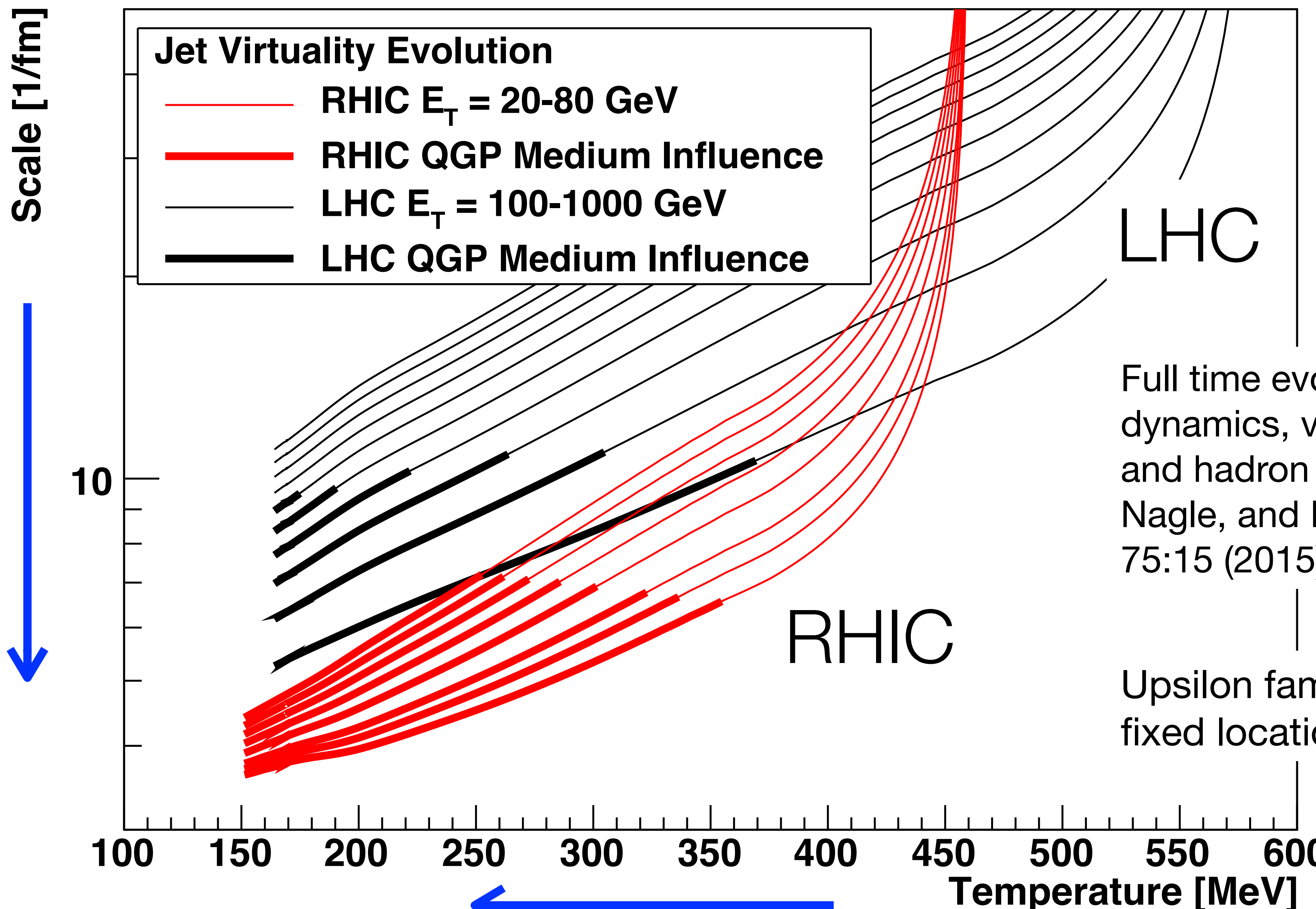
**full disclosure:* co-spokespersons G. Roland, D. Morrison

sPHENIX


Outer HCal
Superconducting coil
Inner HCal
EMCal
Vertexer/Tracker

sPHENIX in one plot

Initial hard scattered parton virtuality in units of 1/fm as a function of the local temperature of the QGP medium

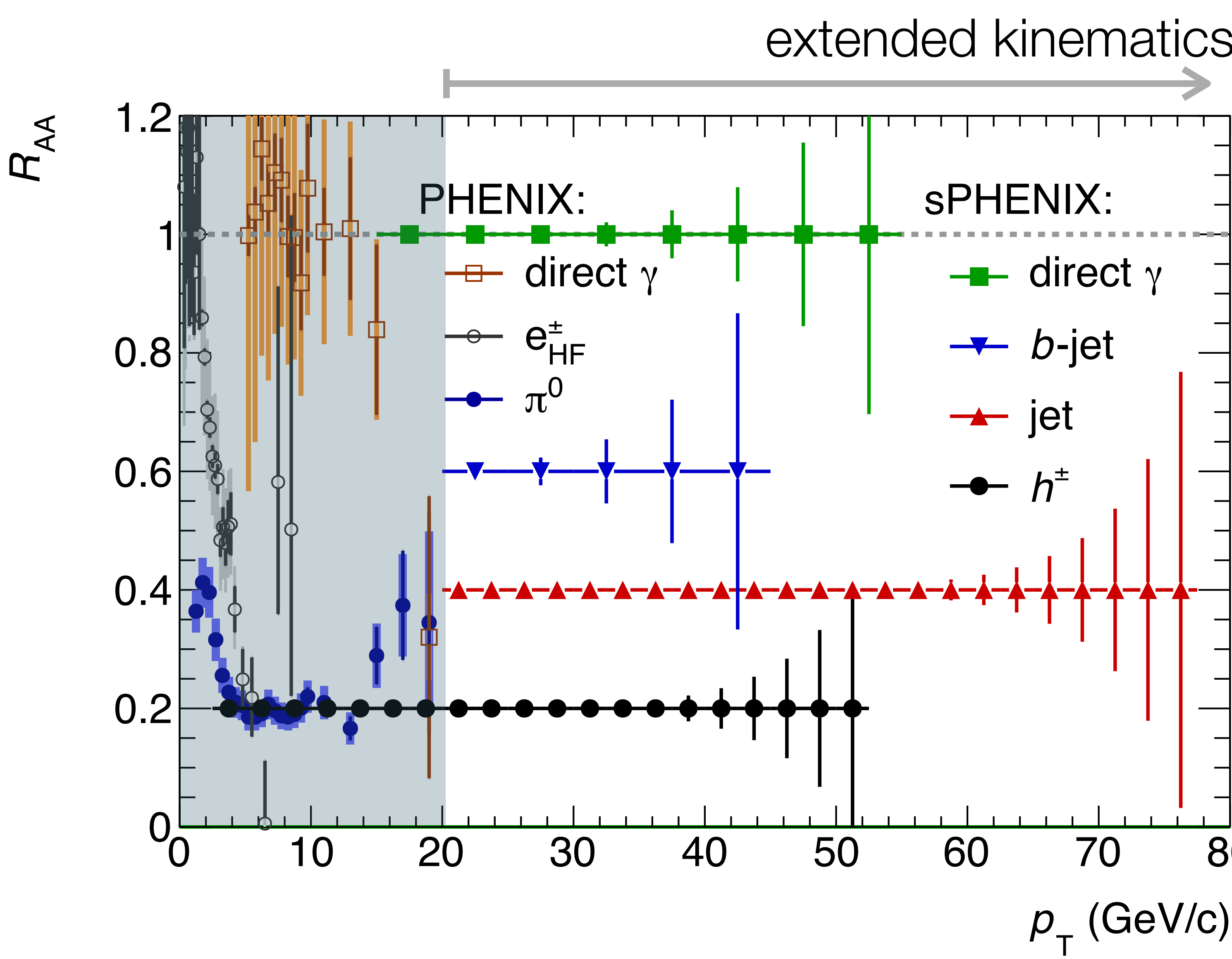


Full time evolution of pre-equilibrium dynamics, viscous hydrodynamics, and hadron cascade M. Habich, J. Nagle, and P. Romatschke, EPJC, 75:15 (2015)

Upsilon family 1S, 2S, 3S establish fixed locations in this space

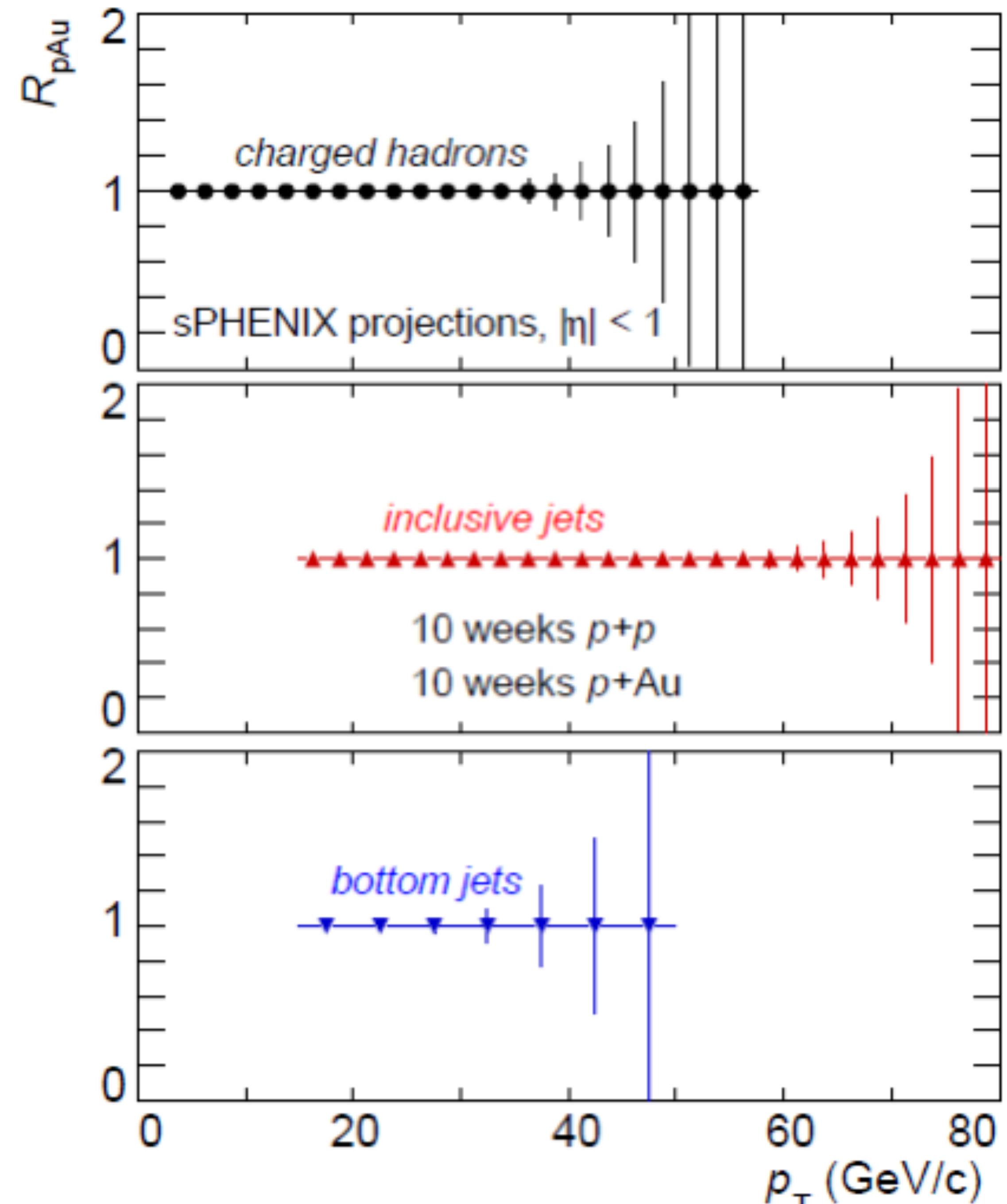
Vacuum virtuality evolution initially, with medium influence becoming significant as virtuality of parton shower and medium become comparable

sPHENIX reach exploits RHIC luminosity



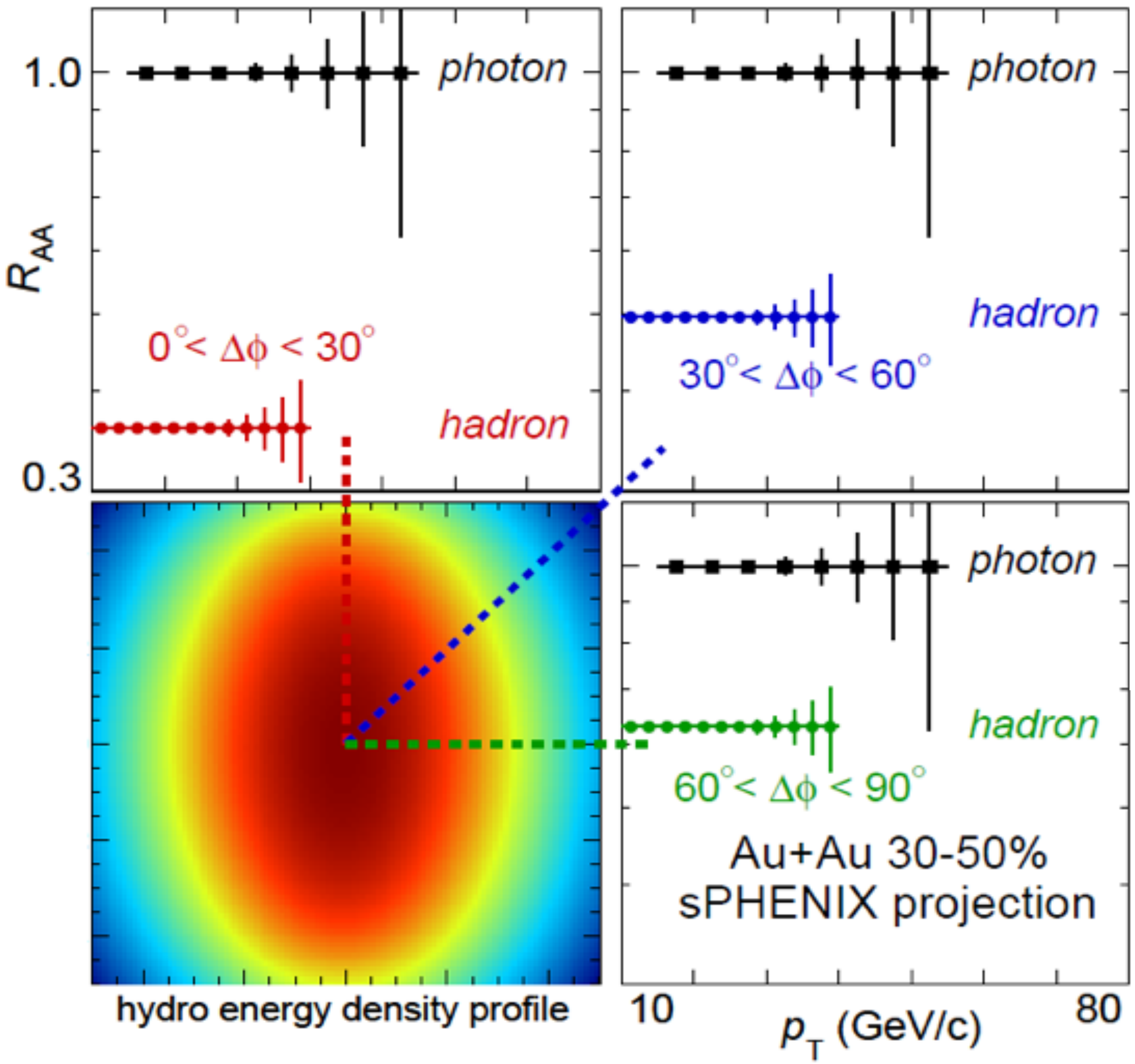
for measurements able to use full vertex range
– can sample 0.6 trillion events

extended reach in p+Au

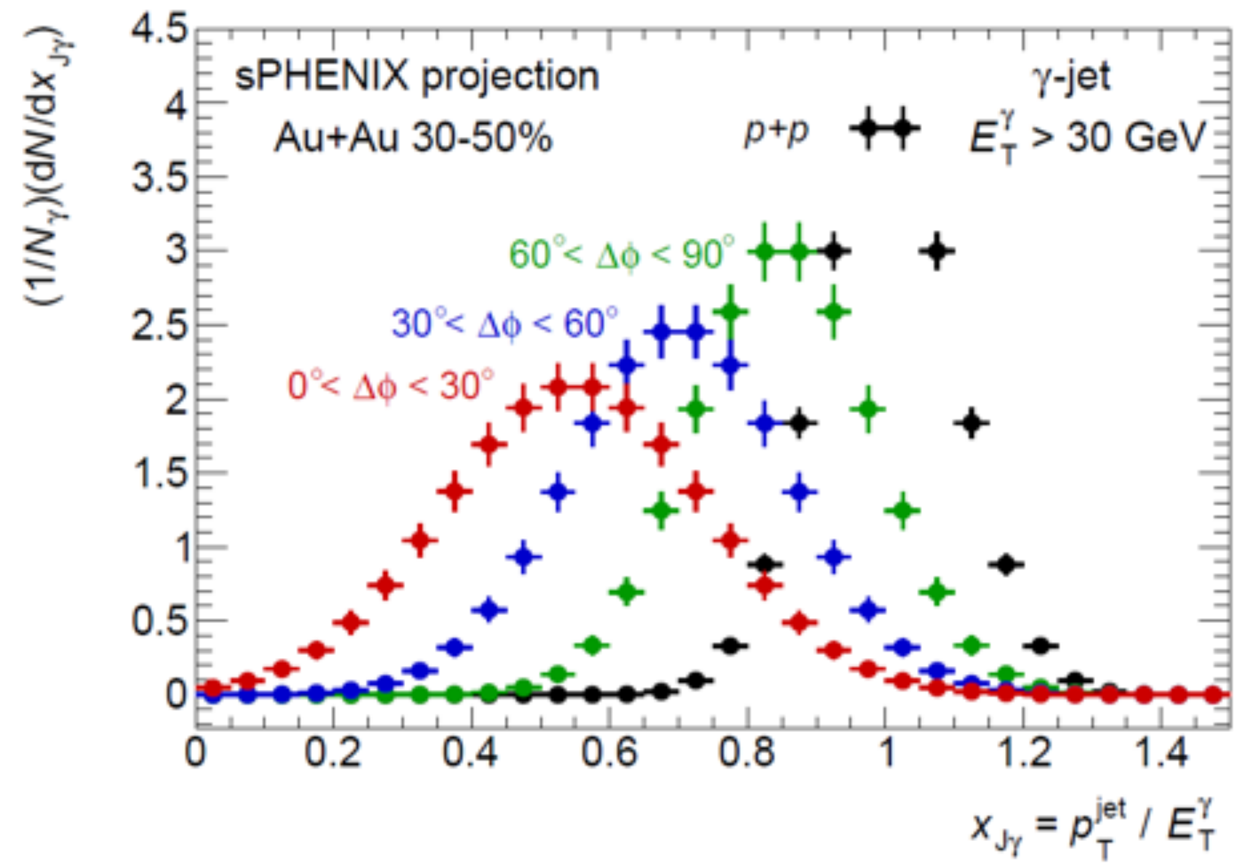


RHIC luminosity: more differential measurements

direct photons, charged hadrons

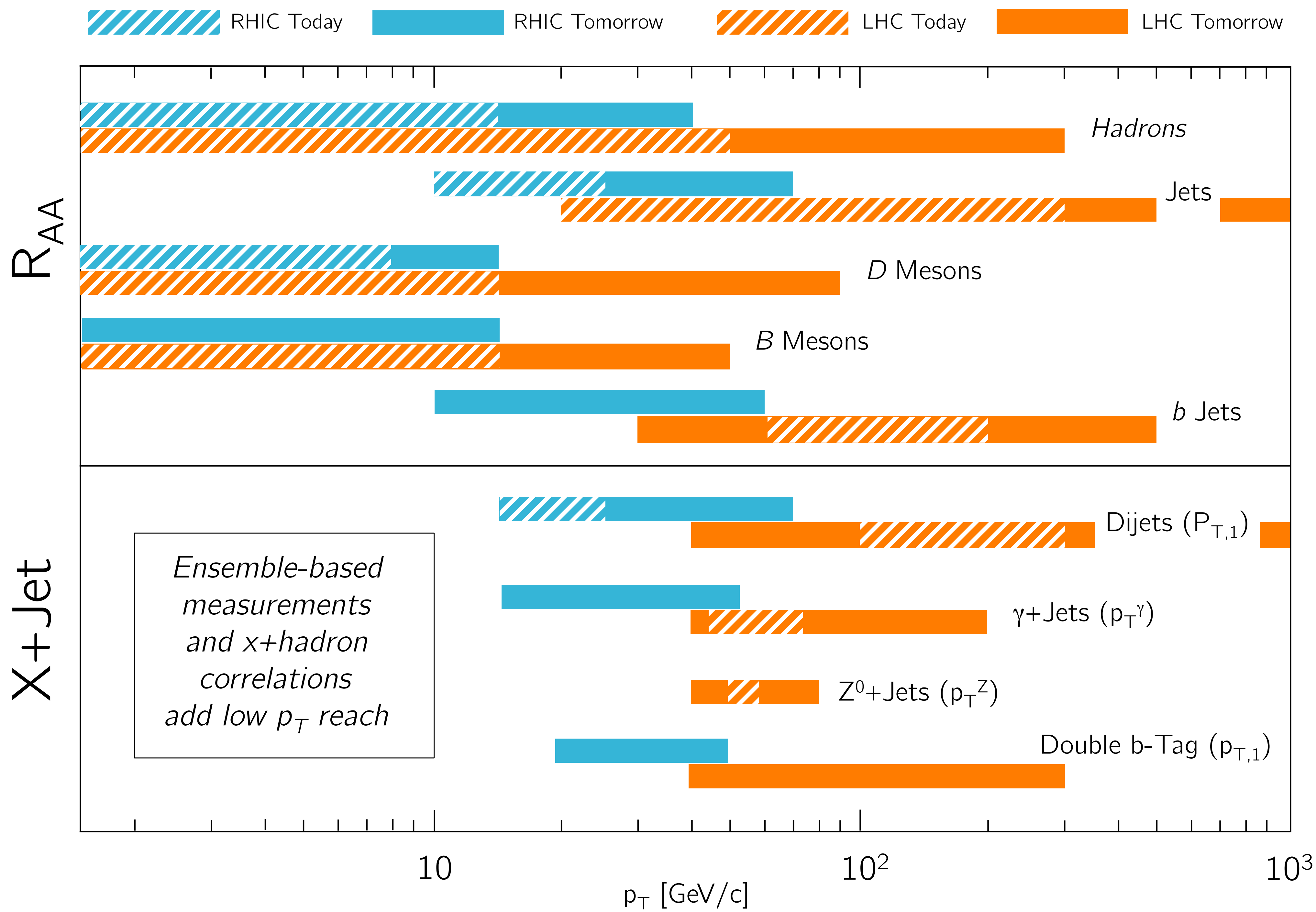


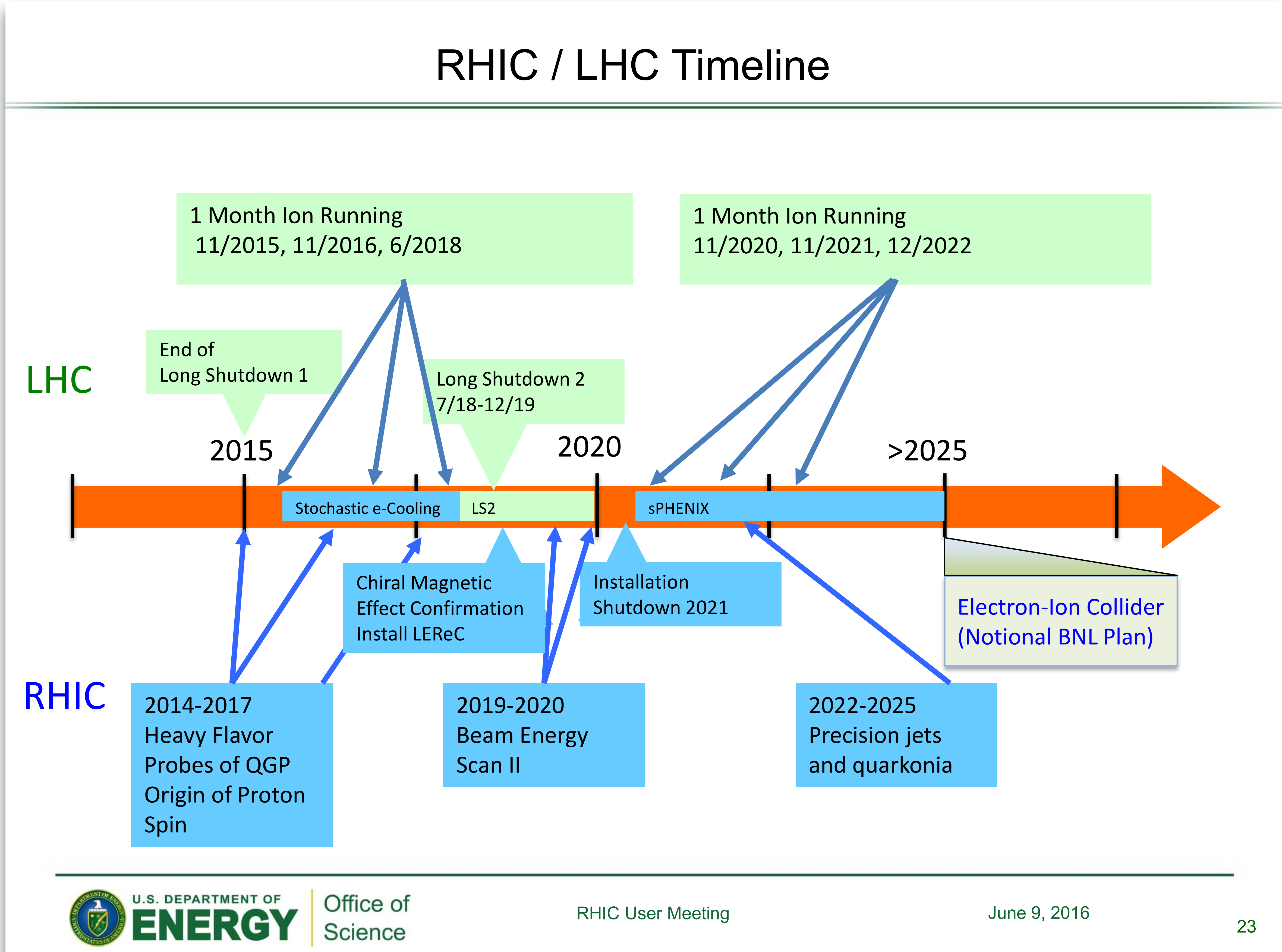
γ-jet



statistical uncertainties based on sPHENIX run plan

RHIC/LHC measurements in 2020s





Slide from Tim Hallman's talk at RHIC Users' Meeting, June 2016

Many sPHENIX developments since last PAC

- DOE NP long-range plan
- sPHENIX Project
- sPHENIX Scientific Collaboration

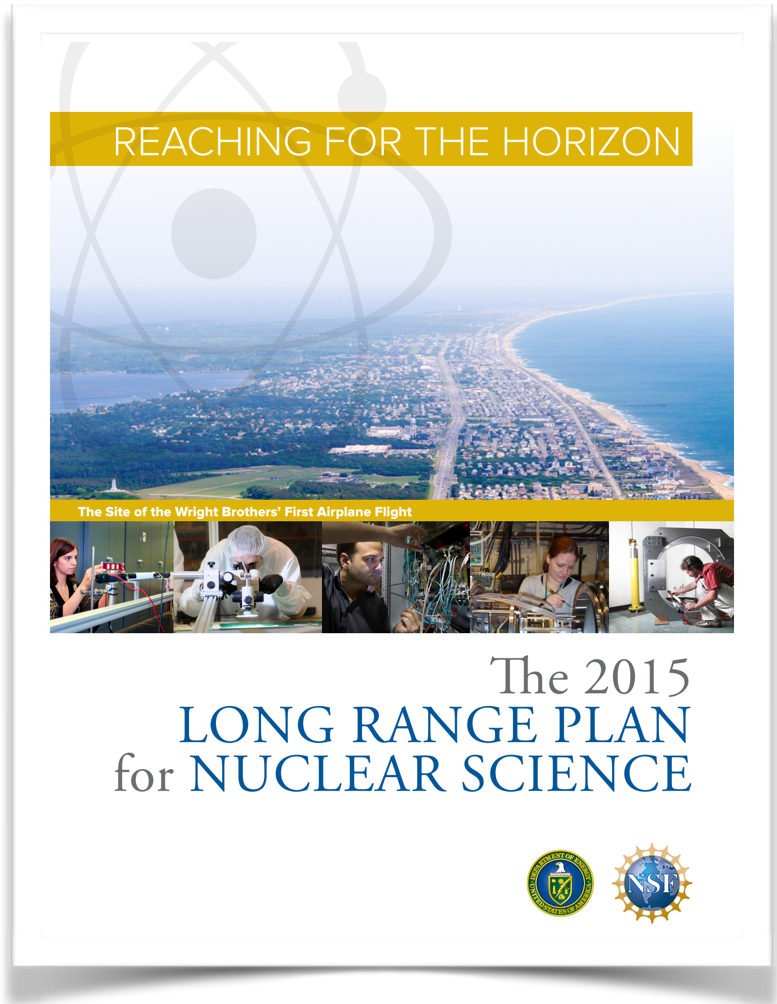
RECOMMENDATION I

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

- *With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model must be realized.*
- *Expeditiously completing the Facility for Rare Isotope Beams (FRIB) construction is essential. Initiating its scientific program will revolutionize our understanding of nuclei and their role in the cosmos.*
- *The targeted program of fundamental symmetries and neutrino research that opens new doors to physics beyond the Standard Model must be sustained.*
- *The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.*

RECOMMENDATION IV

We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.



RECOMMENDATION III

Gluons, the carriers of the strong force, bind the quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleons and nuclei. These questions can only be answered with a powerful new electron ion collider (EIC), providing unprecedented precision and versatility. The realization of this instrument is enabled by recent advances in accelerator technology.

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

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.**

New instrumentation at RHIC in the form of a state-of-the-art jet detector (referred to as sPHENIX) is required to provide the highest statistics for imaging the QGP right in the region of strongest coupling (most perfect fluidity) while also extending the kinematic reach at RHIC (as illustrated in Figure 2.13) to overlap that for jets at LHC energies. Upgrades to the LHC luminosities and detector and measurement capabilities are keys to providing a complete picture, as are new experimental techniques being developed to compare how light quark jets, heavy quark jets, and gluon jets "see" QGP. In general, using common, well-calibrated, jet shape observables in suitably tagged fully reconstructed jets at RHIC and the LHC will be critical to using the leverage in resolution and temperature that the two facilities provide in concert (see Sidebar 2.5) to relate observed modifications of jets to the inner workings of QGP.

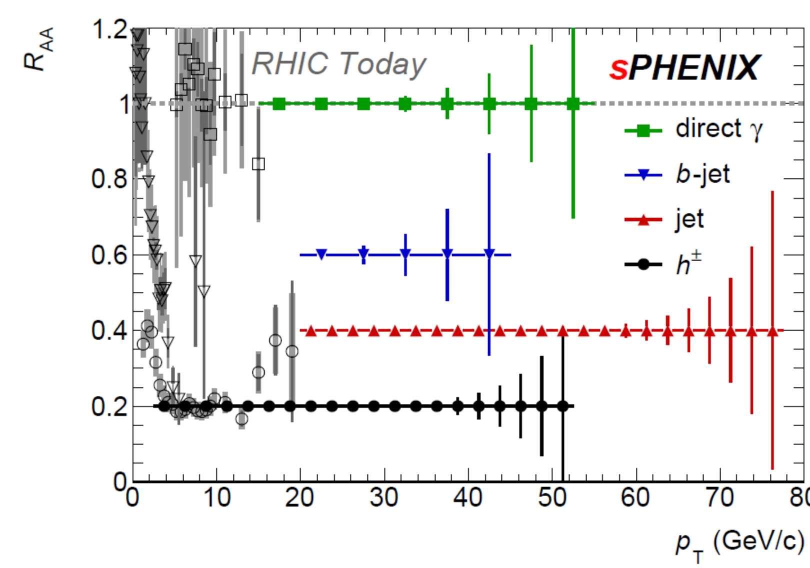


Figure 2.13: *Future reach of four precision measurements via jets for probing the most strongly coupled liquid with sPHENIX, in color, compared to current measurements from RHIC where available, in grey.*

Immediately before last year’s PAC meeting

John Harris as acting IB chair, institutions were asked to indicate their potential interest in the collaboration, leading to a first collaboration meeting at Rutgers in December 2015

Continues six-year history of development

sPHENIX Concept in the PHENIX Decadal Plan (charged by ALD Steve Vigdor):
October 2010

Original proposal http://arxiv.org/abs/1207.6378: July 2012
(new superconducting solenoid & optional additional tracking)

BNL Review (chaired by Tom Ludlam) of sPHENIX proposal: October 2012

Updated sPHENIX proposal: October 2013

BNL Review (chaired by Sam Aronson) of “ePHENIX” LOI: January 2014

“ePHENIX” White Paper (http://arxiv.org/abs/1402.1209): February 2014

Future Opportunities in p+p and p+A with the Forward sPHENIX Detector
(http://www.phenix.bnl.gov/phenix/WWW/publish/dave/sPHENIX/pp_pA_whitepaper.pdf): April 2014

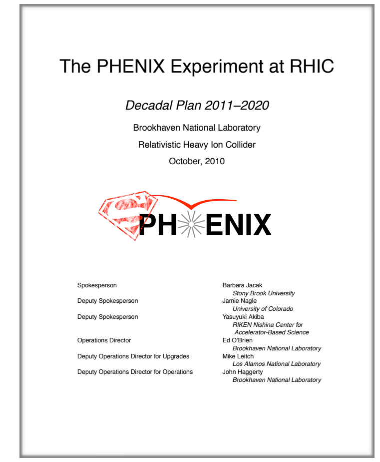
Updated proposal, submitted to DOE: June 2014 (incorporation of Babar
magnet and tracking)

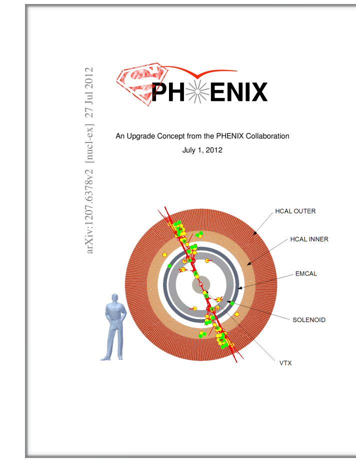
DOE Science Review: July 2014

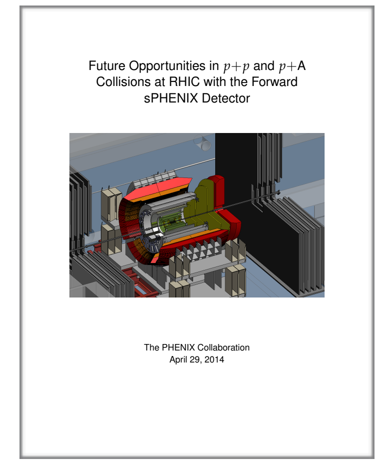
Updated Proposal http://arxiv.org/abs/1501.06197 : November 2014

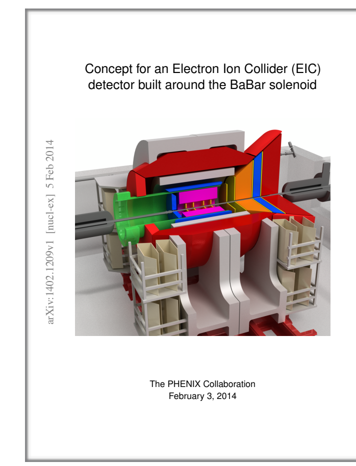
DOE Science Review (chaired by Tim Hallman): April 2015 – successful science
review with no tracked recommendations

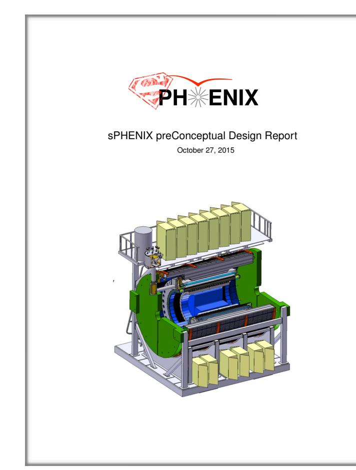
sPHENIX pCDR: November 2015











Institutions by the time of the Rutgers meeting

57 institutions signed up: Abilene Christian, Augustana College, Banaras Hindu University (India), Baruch College, CUNY, BNL and BNL (PHENIX), UC-Davis, UCLA, UCR, Chonbuk National University (South Korea), Colorado, Columbia, Joint Czech Group (Charles University): Prague Czech Technical University, Prague Institute of Physics, Czech Academy of Sciences – Prague; University of Debrecen, Florida State, Georgia State, Howard University, Houston, sPHENIX (Hungary), Illinois – U.C., Institute of Nuclear Research, Russian Academy of Sciences, Moscow, Iowa State, University of Jammu (India), JAEA (Japan Atomic Energy Agency), Korea University, National Research Centre “Kurchatov Institute”, Lehigh, LLNL, LANL, Maryland, MIT, Michigan, National Research Nuclear University (Moscow Engineering Physics Institute), Muhlenberg College, Nara Women’s University (Japan), New Mexico State, University of New Mexico, ORNL, Ohio University, Insititut de Physique Nucléaire d’Orsay, Petersburg Nuclear Physics Institute (National Research Centre “Kurchatev Institute”), IHEP (Protvino), RIKEN/RBRC, Rikkyo University, Rutgers, Stony Brook, Saint-Petersburg Polytechnic University, Tennessee - Knoxville, Texas - Austin, Tokyo Institute of Technology (Tokyo Tech, TITech), University of Tokyo (Center for Nuclear Study), Institute of Physics - University of Tsukuba, Universidad Técnica Federico Santa María - Valparaíso (Chile), Vanderbilt, Wayne State, Weizmann Institute, Yale, Yonsei University (Korea).

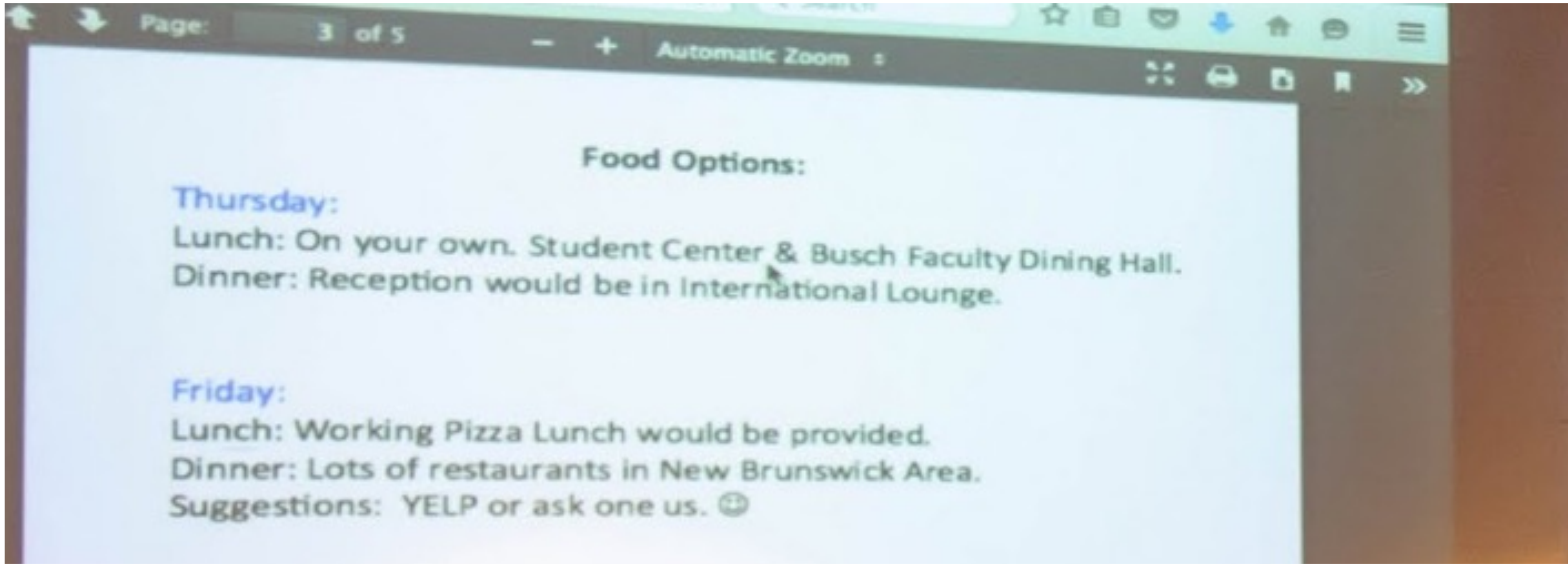
Inaugural sPHENIX collaboration meeting

Inaugural sPHENIX collaboration meeting

Rosi Reed (Lehigh)

Sevil Salur (Rutgers)

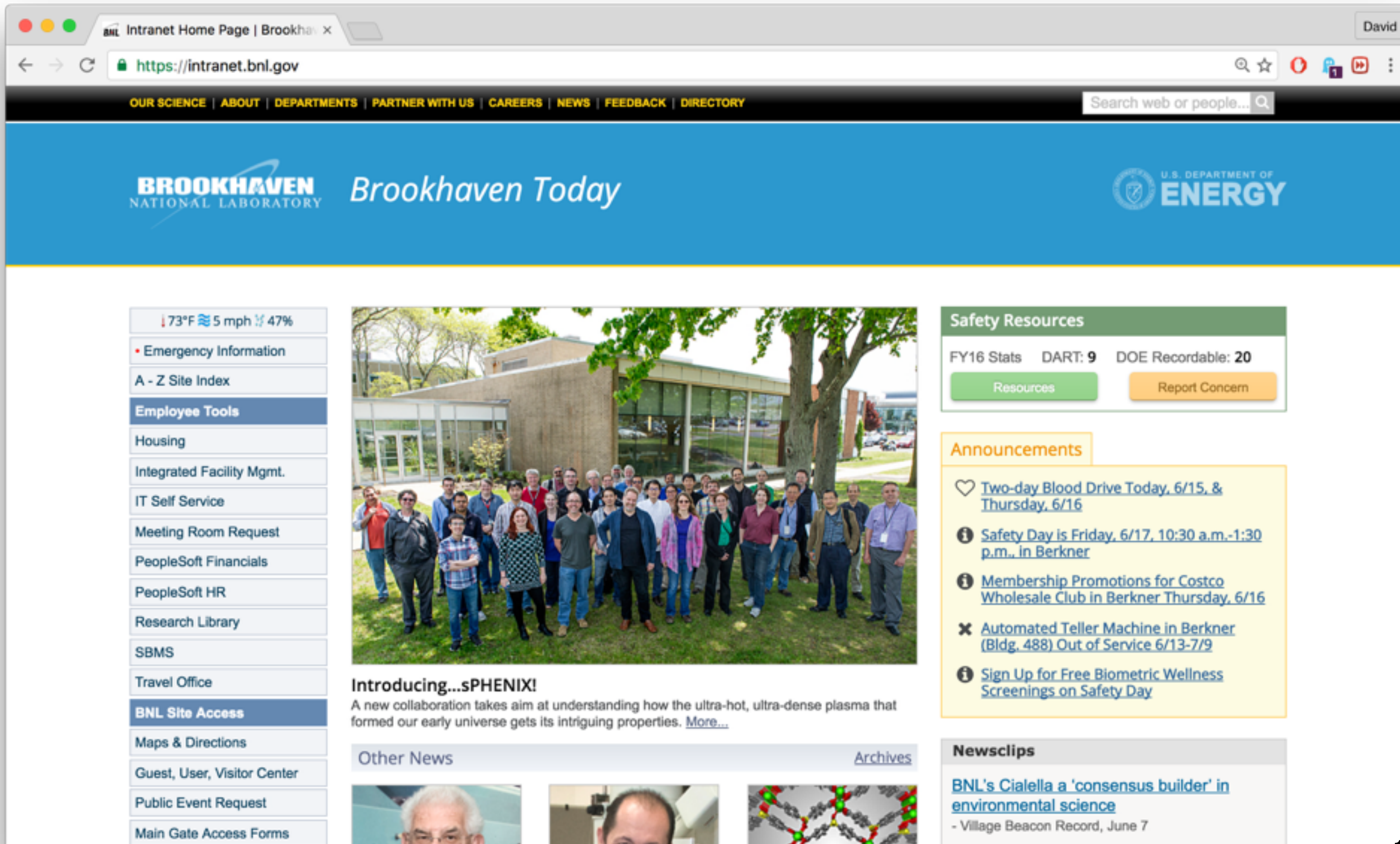
Hosts

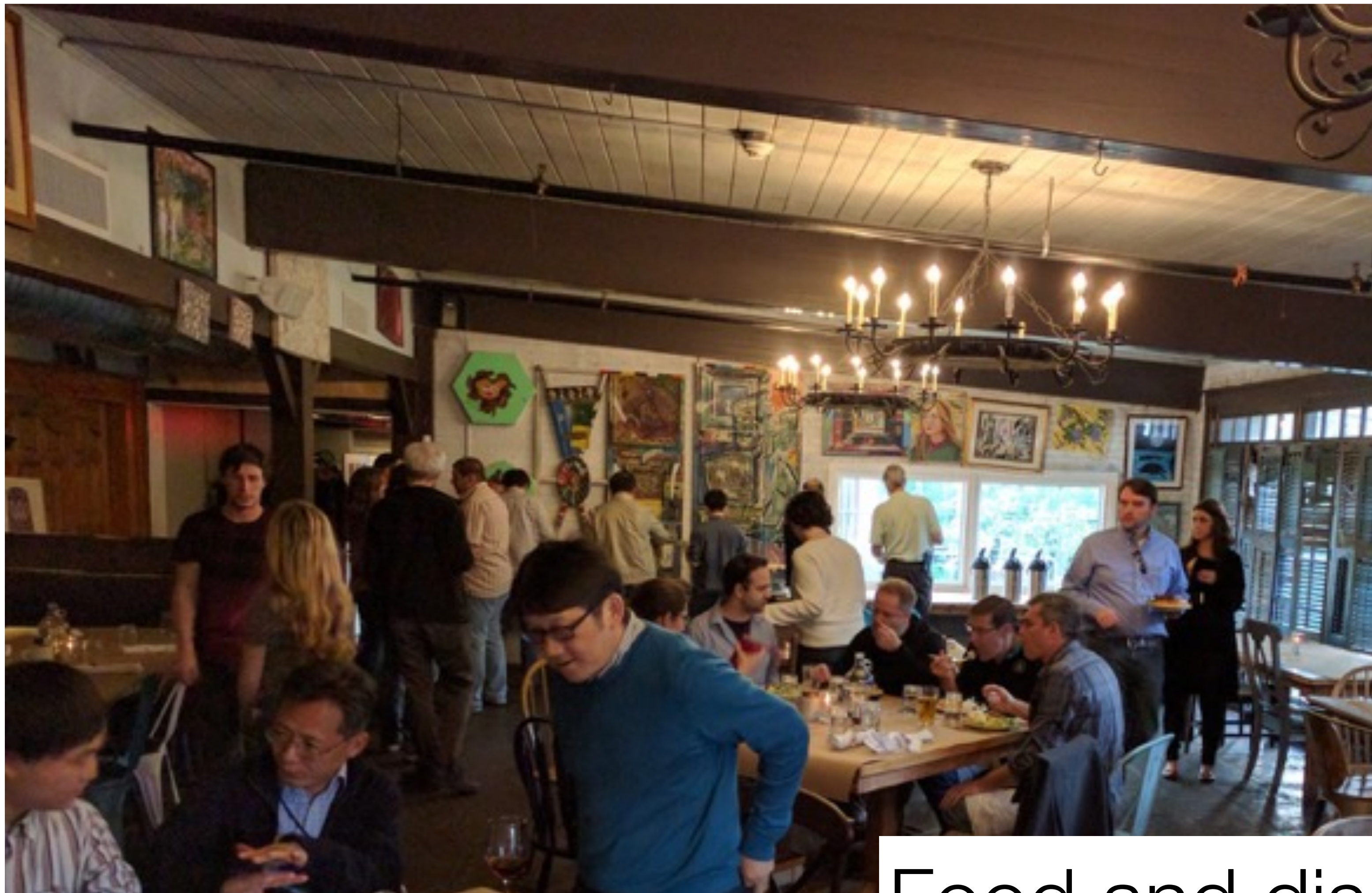




Rutgers Univ.
December 2015

Second sPHENIX collaboration meeting May 2016





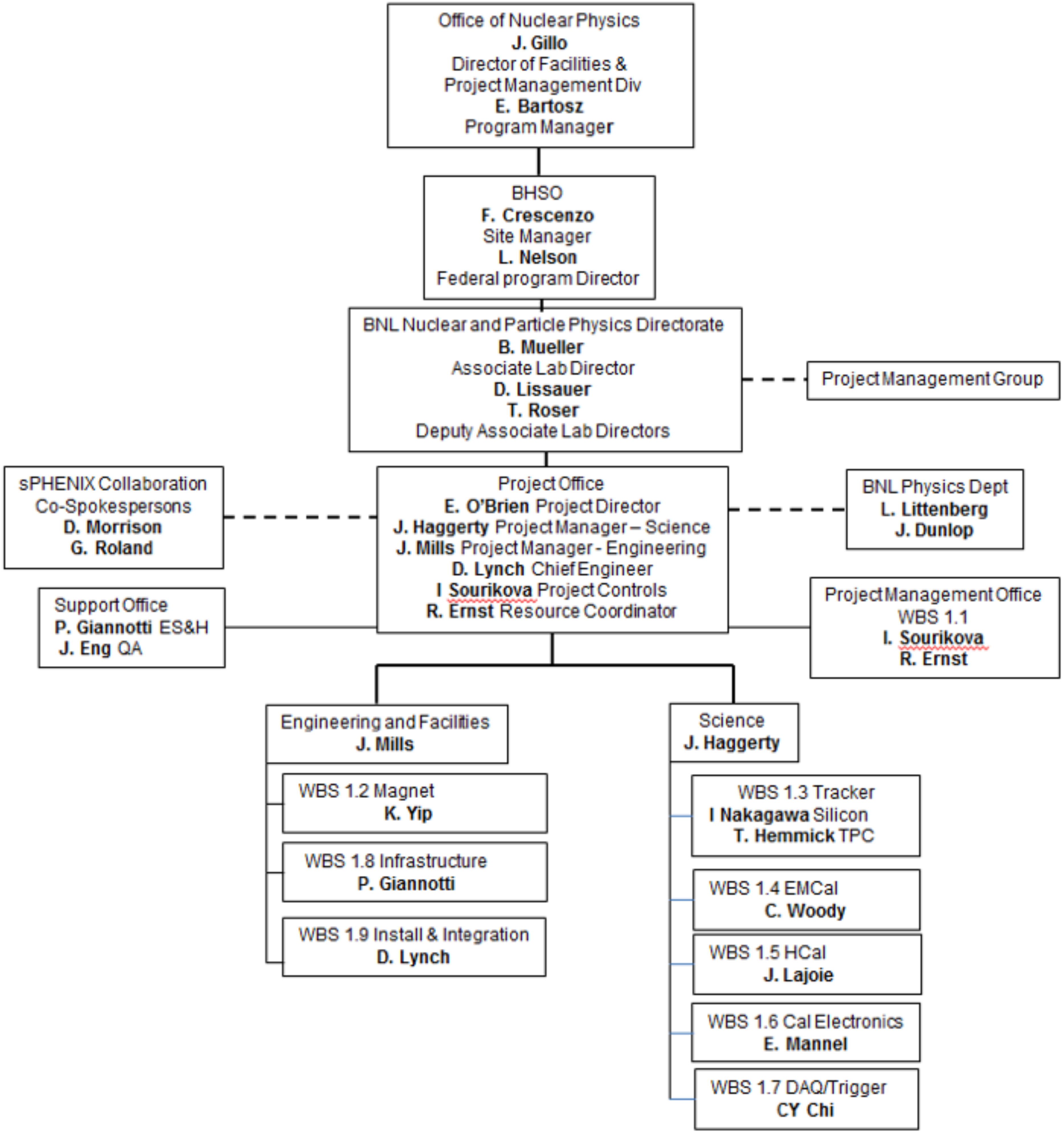
Food and discussion

Structure of the scientific collaboration

- Co-spokespersons (Roland, Morrison)
- Institutional Board (58 institutions)
- Executive Council – elections, appointments complete by late April
- Topical groups – focus on specific observables to drive simulations
    - Jet structure (Dennis Perepelitsa (BNL), Rosi Reed (Lehigh))
    - Heavy-flavor tagged jets (Jin Huang (BNL), Mike McCumber (LANL))
    - Upsilon spectroscopy (Tony Frawley (Florida), Marzia Rosati (Iowa))

Executive Council

- Ed O’Brien (BNL) (ex officio)
- Megan Connors (GSU) (junior)
- Sarah Campbell (Columbia) (junior)
- Tom Hemmick (Stony Brook)
- John Lajoie (Iowa State)
- Anne Sickles (UIUC)
- Bill Zajc (Columbia)
- Joern Putschke (Wayne State)
- Jamie Nagle (Boulder)
- Huan Huang (UCLA)
- Itaru Nakagawa (RIKEN)
- Christine Aidala (Michigan)


Office of Nuclear Physics
J. Gillo
Director of Facilities &
Project Management Div
E. Bartosz
Program Manager
BHSO
F. Crescenzo
Site Manager
L. Nelson
Federal program Director
BNL Nuclear and Particle Physics Directorate
B. Mueller
Associate Lab Director
D. Lissauer
T. Roser
Deputy Associate Lab Directors
Project Management Group
sPHENIX Collaboration
Co-Spokespersons
D. Morrison
G. Roland
Project Office
E. O'Brien Project Director
J. Haggerty Project Manager – Science
J. Mills Project Manager - Engineering
D. Lynch Chief Engineer
I Sourikova Project Controls
R. Ernst Resource Coordinator
BNL Physics Dept
L. Littenberg
J. Dunlop
Support Office
P. Giannotti ES&H
J. Eng QA
Project Management Office
WBS 1.1
I. Sourikova
R. Ernst
Engineering and Facilities
J. Mills
Science
J. Haggerty
WBS 1.2 Magnet
K. Yip
WBS 1.8 Infrastructure
P. Giannotti
WBS 1.9 Install & Integration
D. Lynch
WBS 1.3 Tracker
I Nakagawa Silicon
T. Hemmick TPC
WBS 1.4 EMCal
C. Woody
WBS 1.5 HCal
J. Lajoie
WBS 1.6 Cal Electronics
E. Mannel
WBS 1.7 DAQ/Trigger
CY Chi

Director's Review of sPHENIX Cost and Schedule

- November 9-10, 2015, committee includes BNL and outside experts
- Based on information in the pCDR
  - HCal and EMCal unchanged
  - Reuse PHENIX silicon vertex pixel detector
  - Tracker assumed to come from outside funds
- Base cost estimate reasonable; increase overall project contingency to 40%; bring tracker into project with its own $5M contingency

There are many exciting challenges ahead for sPHENIX. A new collaboration is under development, with the first collaboration meeting planned for December 2015. We believe that a highly engaged and robust scientific collaboration is a vital component of the sPHENIX project and physics program, and that all effort should be made to develop this collaboration, and its integration with the sPHENIX project, as quickly as possible.

Jon Kotcher, Chair

Project Management

Dmitri Denisov - Fermilab
John Hobbs – Stony Brook*

Cost and Schedule

Bill Freeman - Fermilab
Xiaofeng Guo – BNL*
Penka Novakova – BNL

Magnet, Installation, Integration and Decommissioning

George Ganetis - BNL
George Ginther - Fermilab
Phil Pile – BNL*

Calorimetry

Michael Begel – BNL*
Hong Ma – BNL
Mike Tuts – Columbia

Tracking

Graham Smith – BNL*
Gerritt Van Nieuwenhuizen – BNL

Electronics/Trigger/DAQ

Chris Bee – Stony Brook*
Hucheng Chen -- BNL

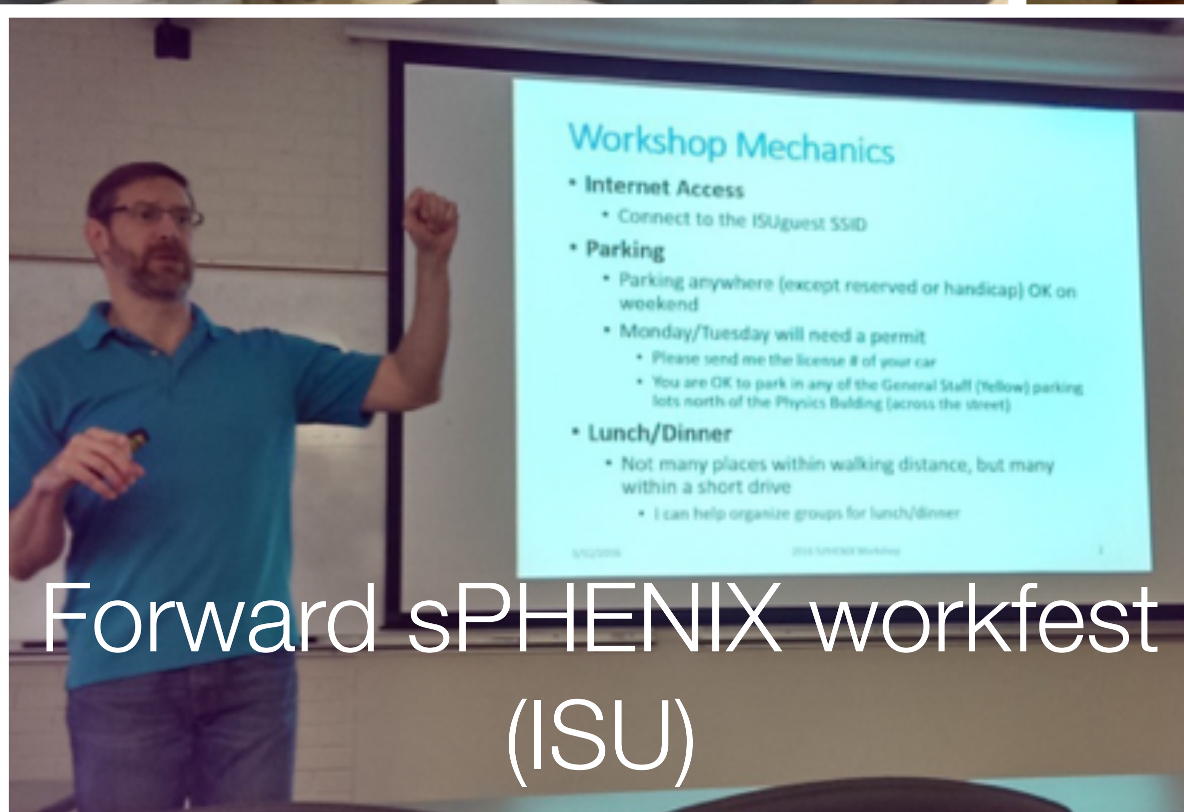
Extensive pre-conceptual R&D relevant to sPHENIX

- EIC R&D:
  - eRD1 (calorimetry consortium – W/Sci-Fi EMCal) BNL, Caltech, JLab, IU, UIUC, IPN Orsay, Penn. St., TAMU, UCLA, Yerevan PI
  - eRD6 (tracking consortium – TPC) BNL, FIT, Stony Brook University, UVA, Yale
- Current BNL program development funds targeted at tilted plate HCal
- Current BNL LDRD targeted at SiPMs, TPCs
- Anticipating news in July on LANL LDRD targeted at MAPS
- Supporting efforts to obtain other funding – e.g. JSPS tracking proposal

Focused “workfests” and other events


MAPS cost and schedule workfest (LANL)

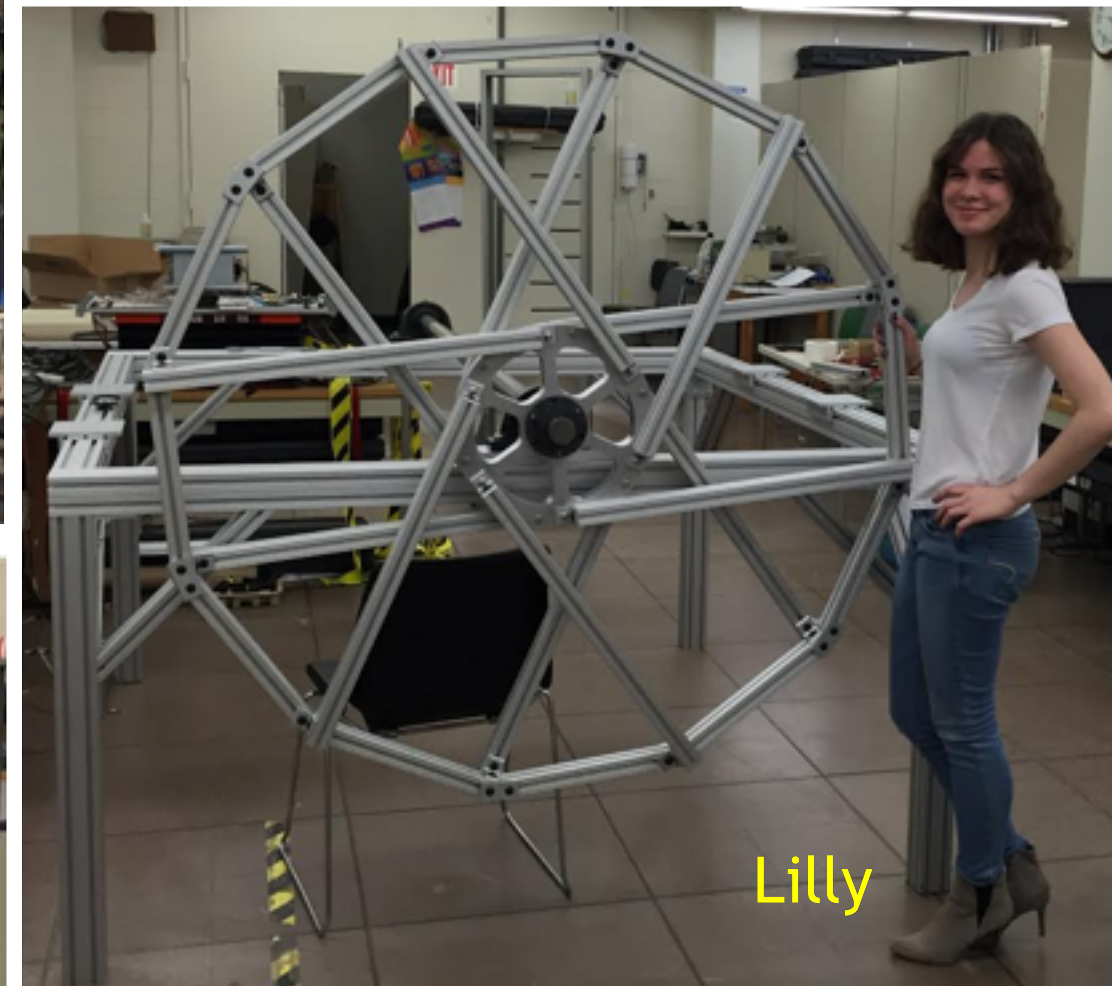

HF tagged jets workfest (BNL)

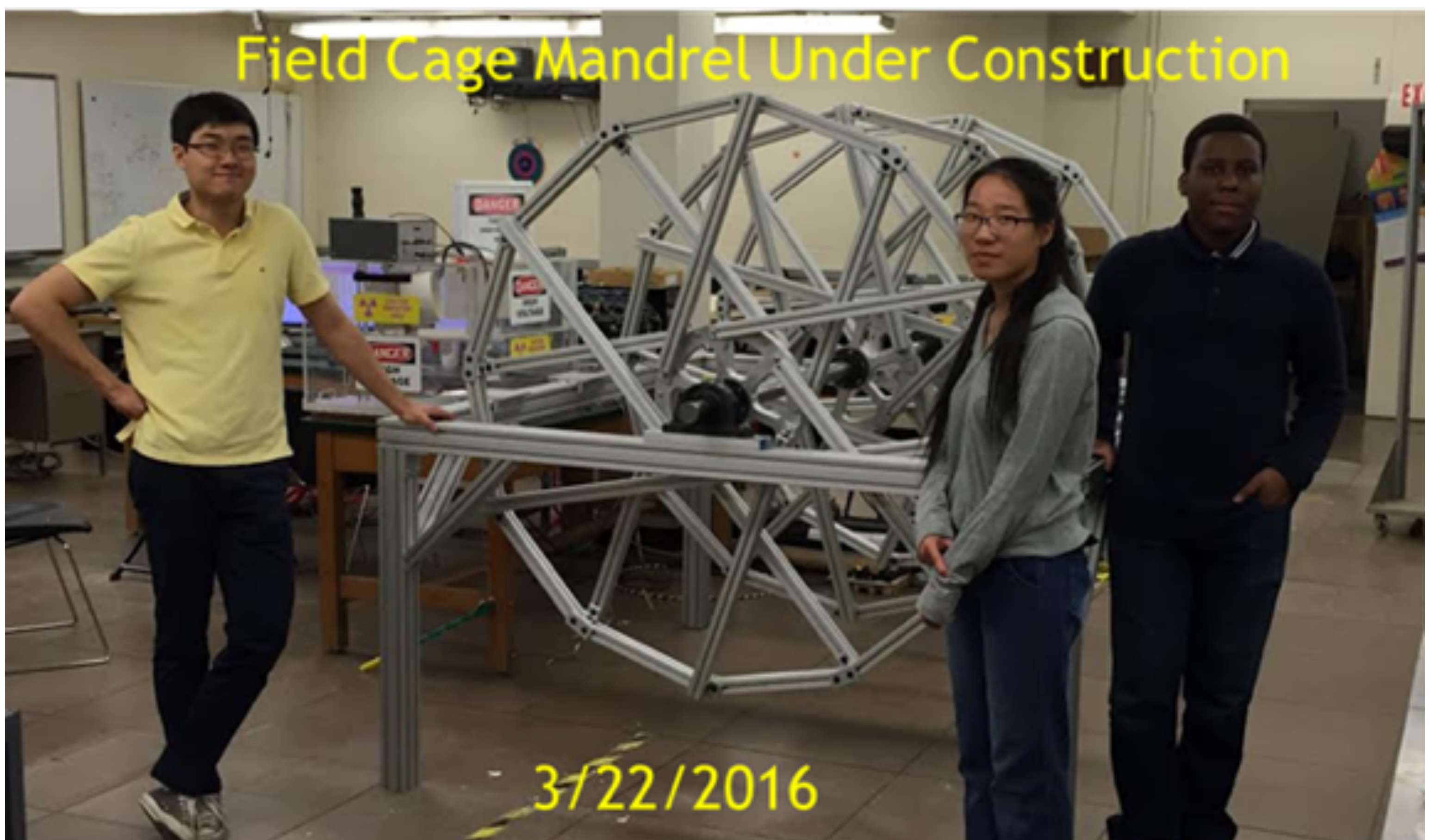


Forward sPHENIX workfest (ISU)

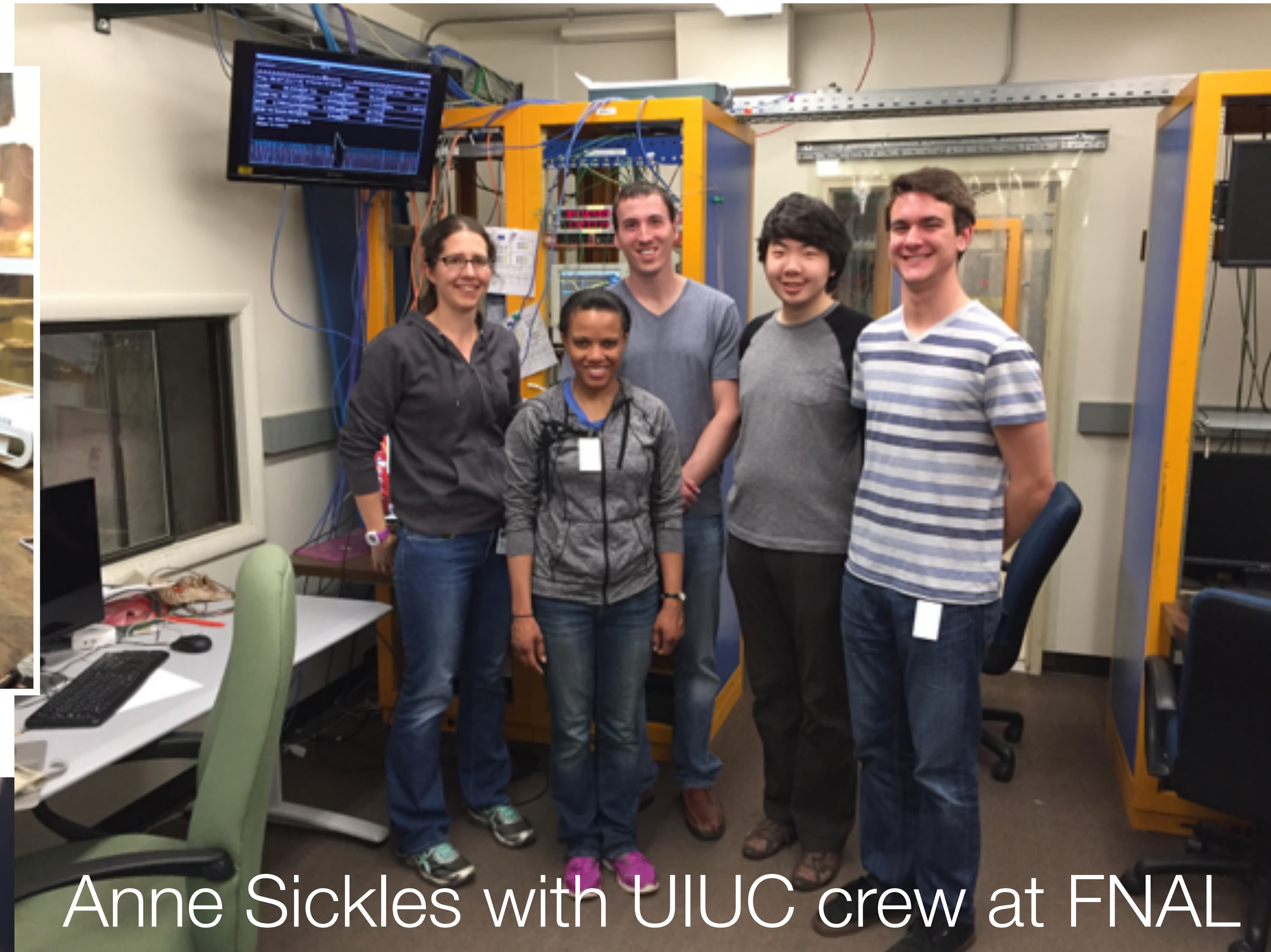
- Continues practice that was very productive in developing sPHENIX proposals
- Invite outside experts when appropriate – e.g., discussion with ALICE & STAR experts on space charge distortion in TPC
- Upcoming plans: two-day EMCal workfest in August, two-day test beam paper writing workshop, discussion with ALICE to gauge needs of sPHENIX TPC readout

SBU Machine Shop making parts for TPC

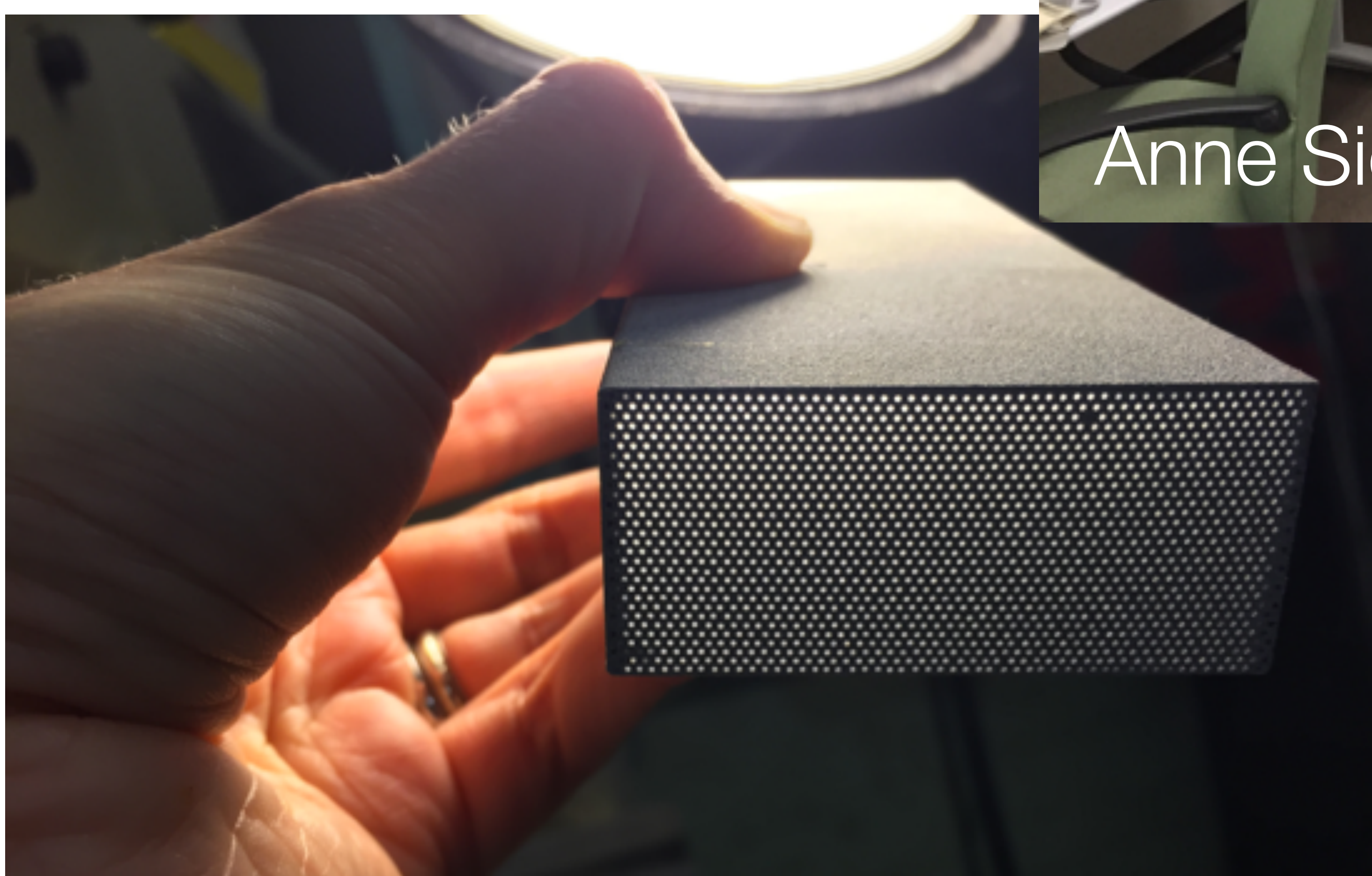




Vera Loggins (UIUC)



Anne Sickles with UIUC crew at FNAL



scintillating fibers embedded in tungsten/ epoxy matrix

MAPS for precision microvertexing

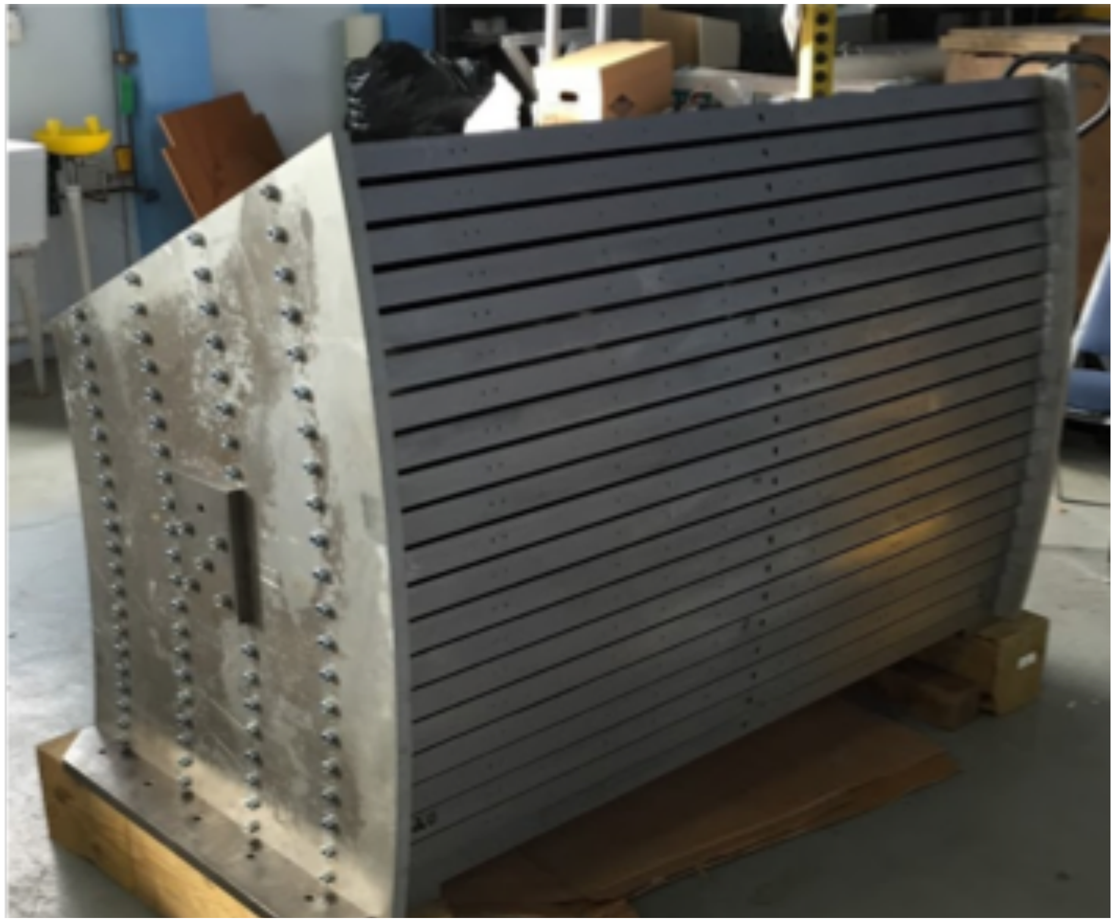
Following ALICE ITS upgrade developments closely, learning from real-world experience of STAR HFT – very useful discussions with Luciano Musa (CERN), Leo Greiner (LBNL), Flemming Videbaek (BNL).

Mike McCumber (LANL)

Low-field test of sPHENIX (née BaBar) solenoid

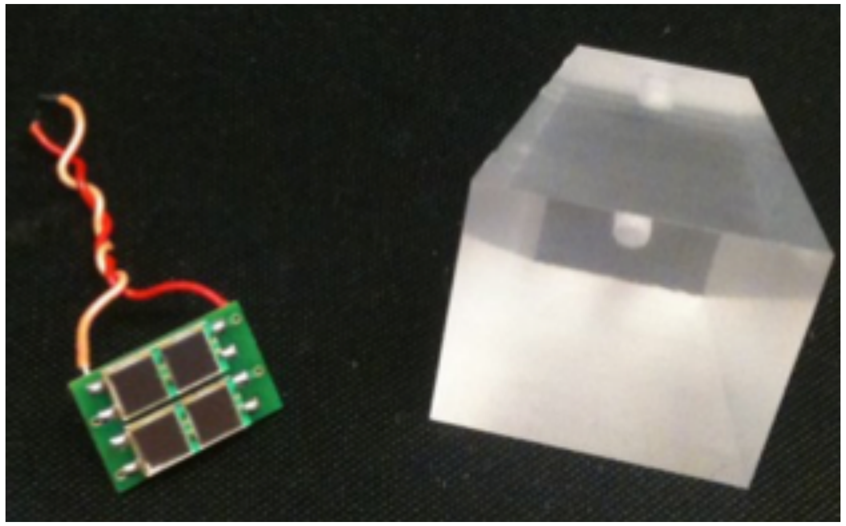
Cooled to 4K, verified superconducting, 100 A = 260 G
Preparations underway for high-field test (4600A)

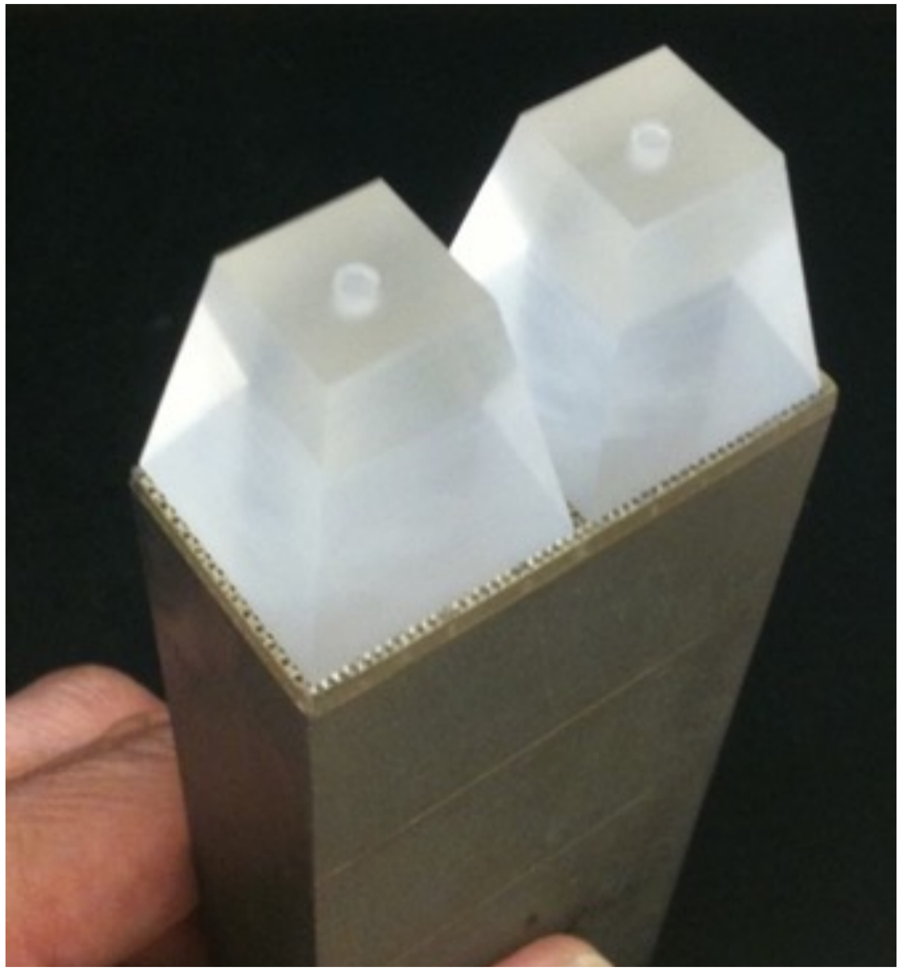
HCal



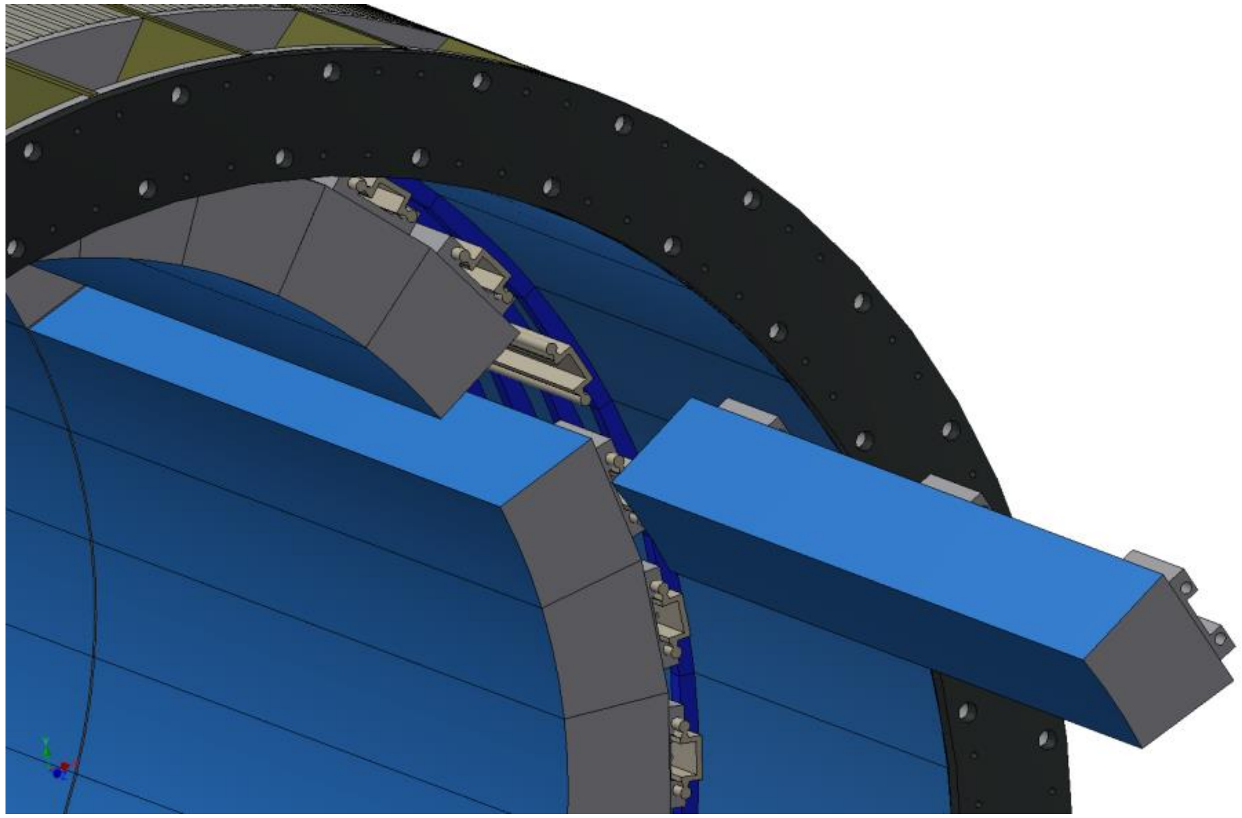
steel plates, tilted with respect to beam axis
polystyrene with embedded wavelength shifting fiber
SiPM readout

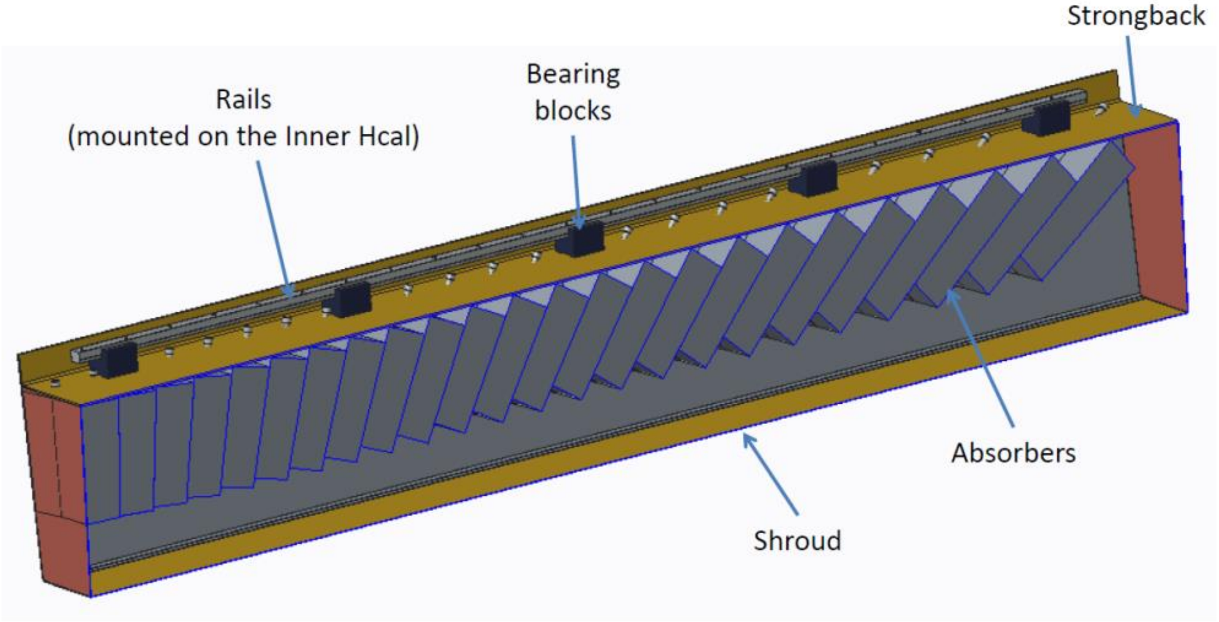
EMCal



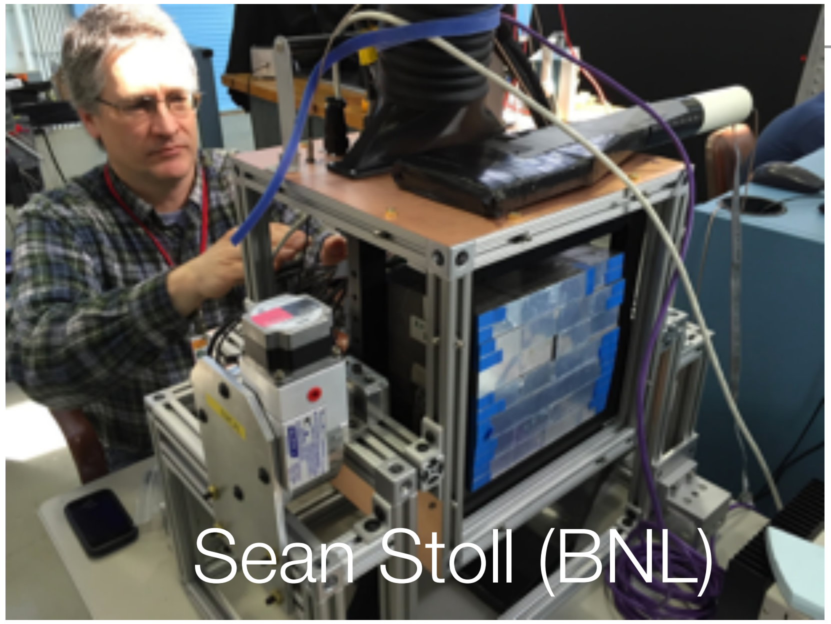


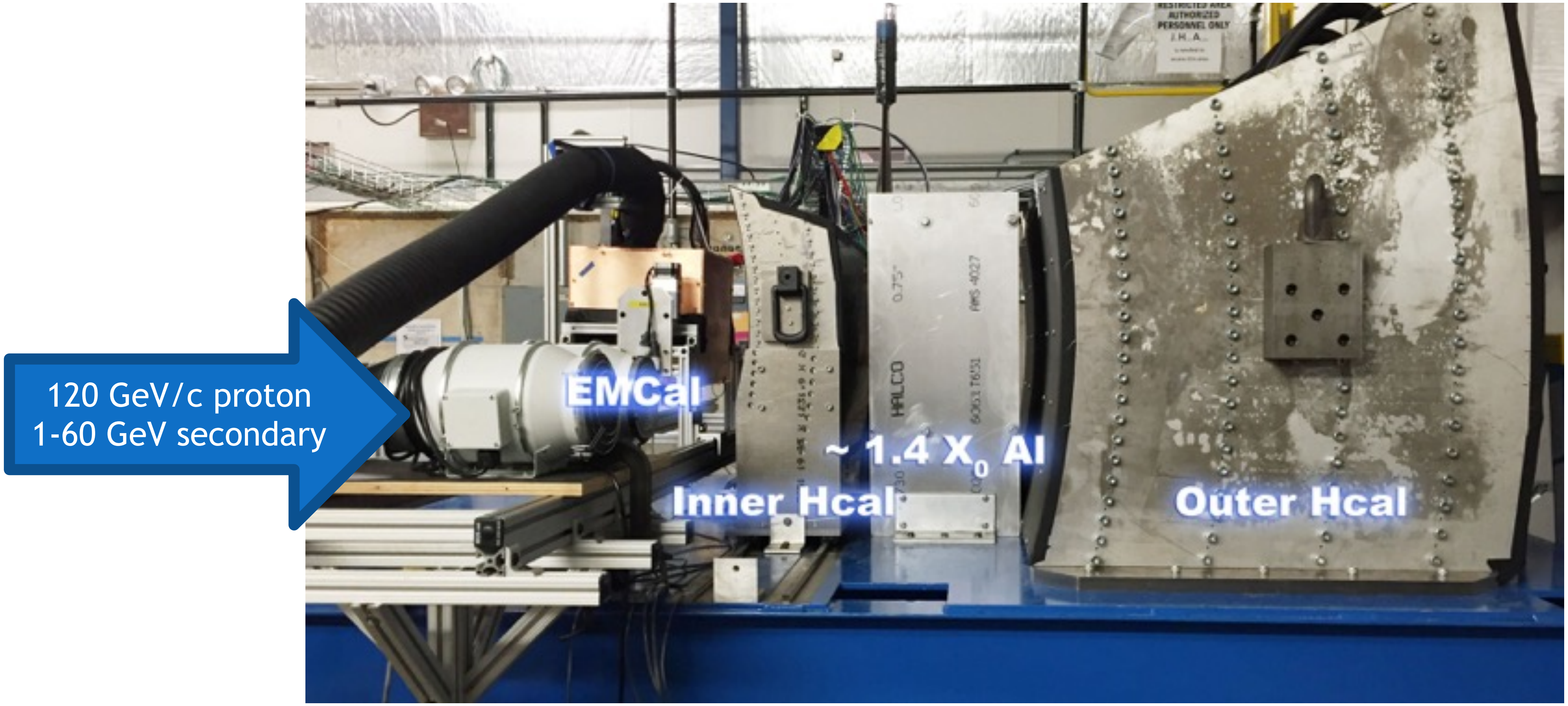
- Fibers threaded through screens
- Filled with Tungsten powder and epoxy
- Attach light guide
- Moliere radius ~2.3 cm
- 1D and 2D Projective modules being explored



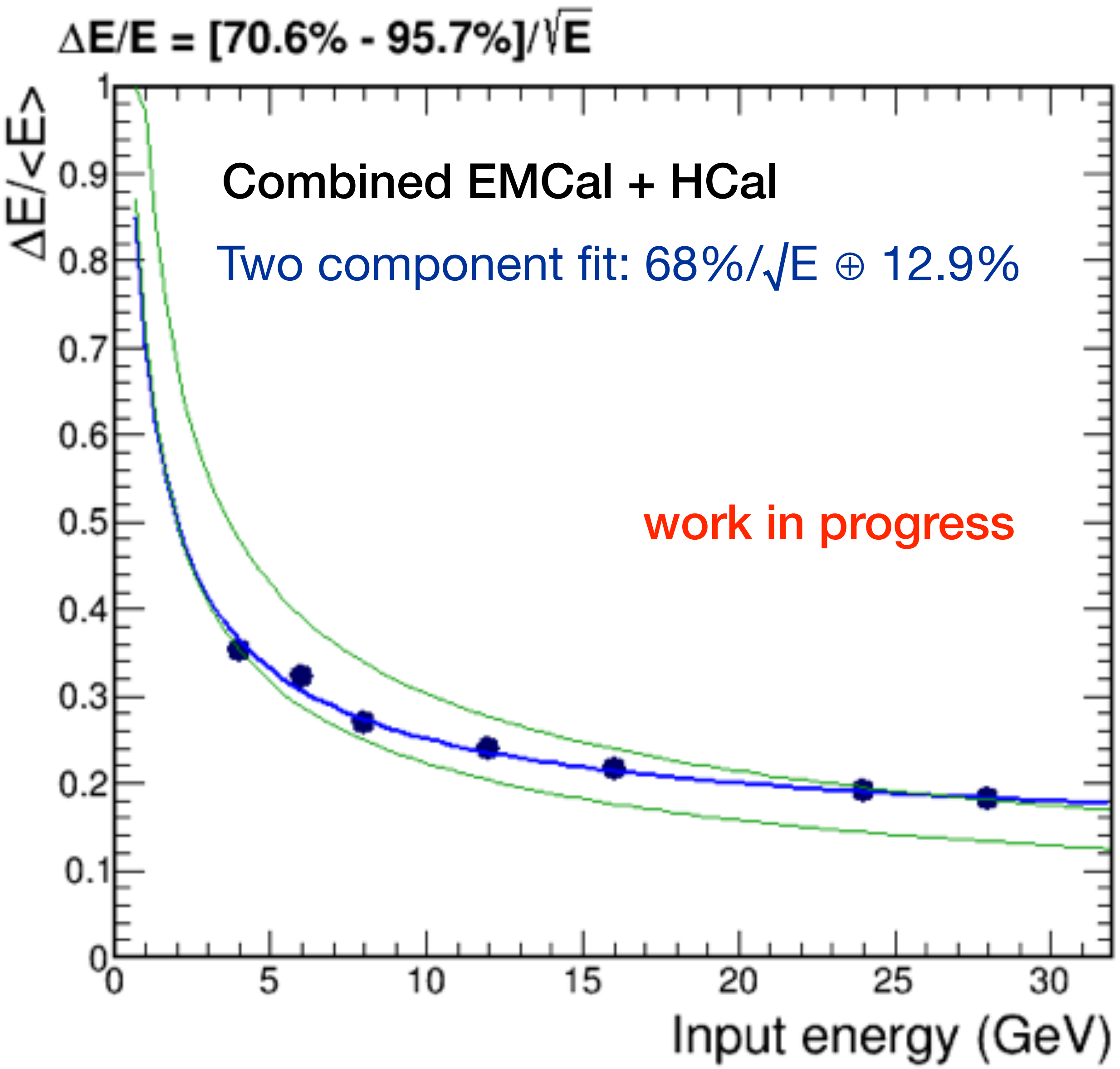


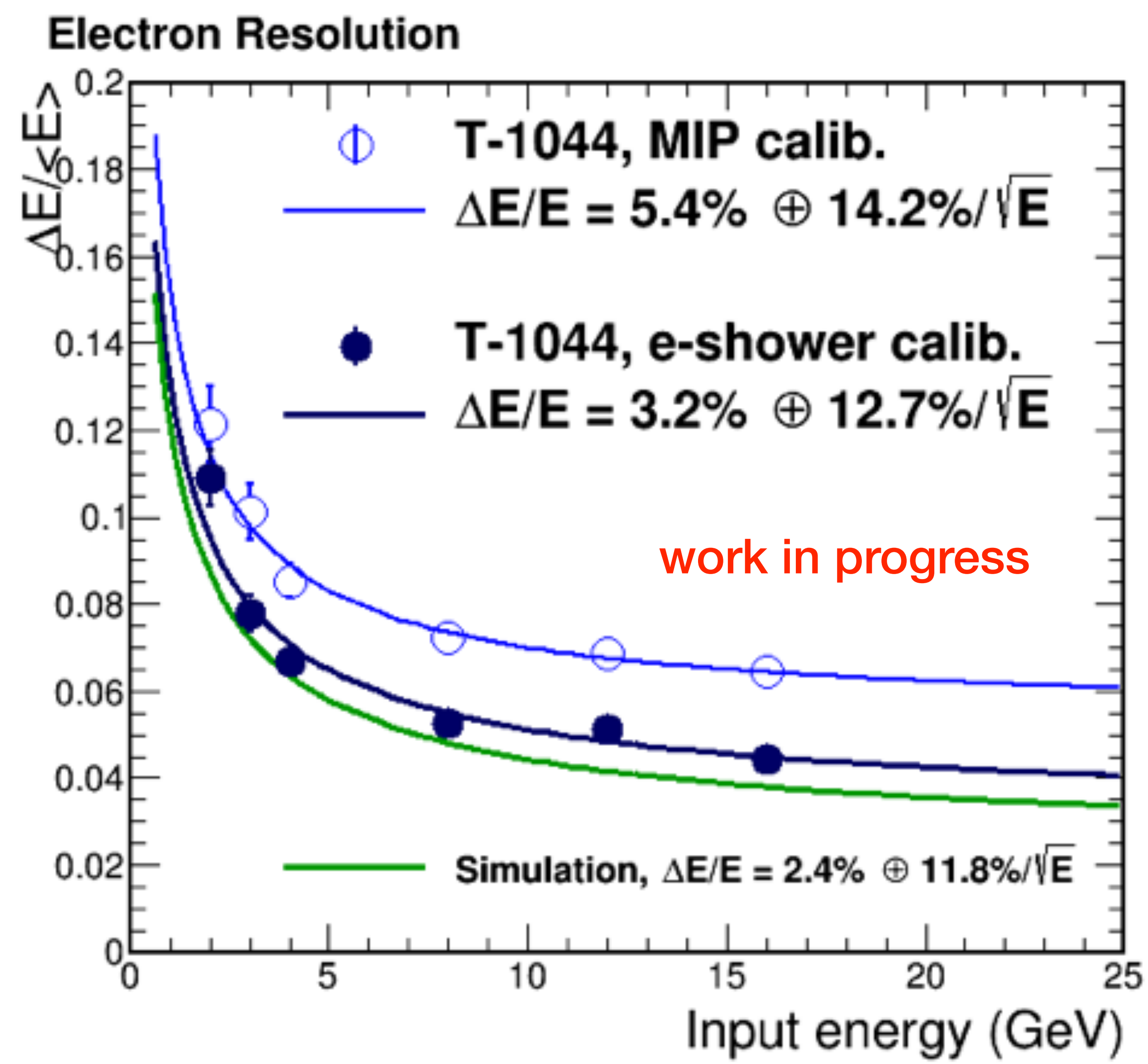
Calorimeter system test at FNAL





Early analysis of FNAL test beam results





Test beam momentum spread (3%) not yet unfolded in these results

Expect additional improvements as detailed tower-to-tower calibrations are finalized

Satisfies performance requirements

Simulation agrees well with early data results – enables refinement of design via simulation

Baseline scope, cost, and schedule charge to Collaboration from ALD

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Nuclear and Particle Physics Directorate

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Upton, NY 11973-5000
Phone 631 344-5397
Fax 631 344-5820
bmueller@bnl.gov

Managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memorandum

From: *Berndt Mueller*
To: *David Morrison, Gunther Roland*
Cc: *Ed O'Brien, James Dunlop*
Date: *March 30, 2016*

Dear Dave and Gunther:

In discussions since the November 2015 Cost and Schedule Review for sPHENIX, it has become clear that further work is needed to develop a plan for the construction of the sPHENIX detector within the constraints of possible DOE funding redirected from RHIC Operations.

I have therefore requested that sPHENIX Project Management, in close collaboration with the sPHENIX Collaboration, develops a credible plan encompassing an option of baseline design scope, cost, and schedule that will allow the detector to be completed on schedule for data taking in the FY2022 RHIC run within the presently foreseen DOE funding profile, and that the sPHENIX Project Management present this plan to BNL management no later than May 31, 2016. The plan should maintain the 40% contingency requested by the cost and schedule review. This plan should not assume the availability of additional funding from non-DOE sources, but may describe which elements would be added to the baseline scope of sPHENIX if additional funding became available.

I am aware that design scope choices will likely require making priority choices with respect to the scientific scope of the sPHENIX physics program. The sPHENIX collaboration and project management team should work closely in establishing these priority choices as needed. I trust that you understand that the sole purpose of my request is to ensure the success of sPHENIX and its future science program. I will be happy to answer any questions you may have at our bi-weekly sPHENIX spokespersons meetings.

Baseline scope, cost, and schedule charge to Collaboration from ALD

BROOKHAVEN NATIONAL LABORATORY
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Dear Dave and Gunther:

In discussions since the November 2015 Cost and Schedule Review for sPHENIX, it has become clear that further work is needed to develop a plan for the construction of the sPHENIX detector within the constraints of possible DOE funding redirected from RHIC Operations.

I have therefore requested that sPHENIX Project Management, in close collaboration with the sPHENIX Collaboration, develops a credible plan encompassing an option of baseline design scope, cost, and schedule that will allow the detector to be completed on schedule for data taking in the FY2022 RHIC run within the presently foreseen DOE funding profile, and that the sPHENIX Project Management present this plan to BNL management no later than May 31, 2016. The plan should maintain the 40% contingency requested by the cost and schedule review. This plan should not assume the availability of additional funding from non-DOE sources, but may describe which elements would be added to the baseline scope of sPHENIX if additional funding became available.

I am aware that design scope choices will likely require making priority choices with respect to the scientific scope of the sPHENIX physics program. The sPHENIX collaboration and project management team should work closely in establishing these priority choices as needed. I trust that you understand that the sole purpose of my request is to ensure the success of sPHENIX and its future science program. I will be happy to answer any questions you may have at our bi-weekly sPHENIX spokespersons meetings.

Process to address baseline scope charge

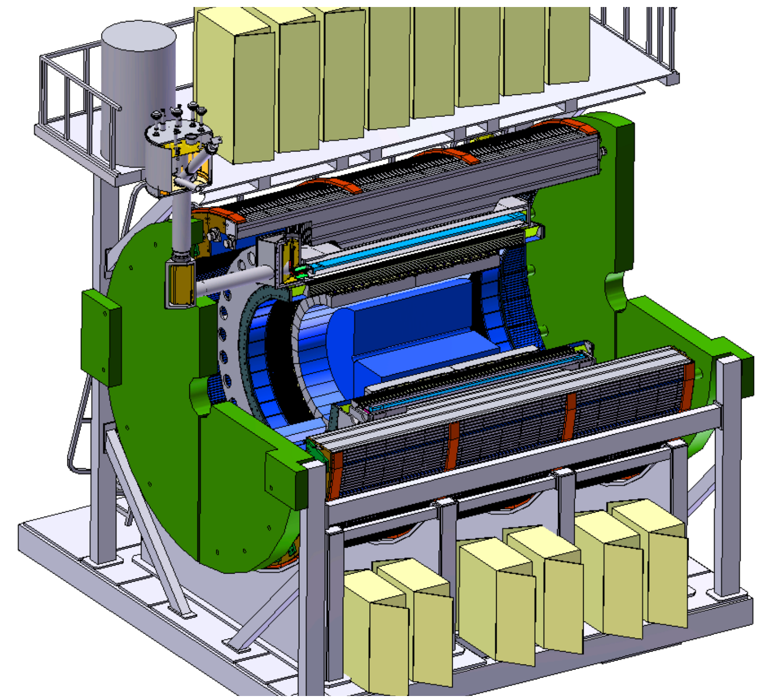
- Worked with Project Management to translate funding constraint in charge into something Collaboration could reason effectively about:
- Reduce total project cost (TPC) by $6M to $75M
  - many elements in TPC – redirected BNL labor, contingency, overhead, escalation to AY$, and M&S (e.g., purchased items or non-BNL labor) – focus of charge is effectively M&S
  - equivalent to reducing $20M "discretionary" M&S by nearly $4M (FY16$, before contingency) – verified this understanding with ALD
- Engaged collaboration to identify the compelling physics addressable within this constraint scenario. Topical groups organized simulations of physics performance. Extensive discussion at 2nd sPHENIX Collaboration meeting May 2016.
- Project Management worked up cost estimates for response document.

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)

Collaboration used input from Topical Groups and Project Management to weigh pros and cons of many options and identify the “best worst-case” configuration.

- reducing the depth of the outer HCal by one λ_{int}
- reduce eta coverage of inner and outer HCal
- don’t build inner HCal
- larger EMCal towers
- gang together 2x2 towers of EMCal
- reduce eta coverage of EMCal
- reduce TPC readout channels
- reduce DAQ refresh
- reuse existing beam-beam counter
- don’t reuse VTX pixels
- introduce 1- or 2-layer MAPS vertex detector



Addressing the Baseline Scope Charge

The sPHENIX Collaboration
June 6, 2016

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reduce eta coverage of inner and outer HCal

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gang together 2x2 towers of EMCal

reduce eta coverage of EMCal

reduce TPC readout channels

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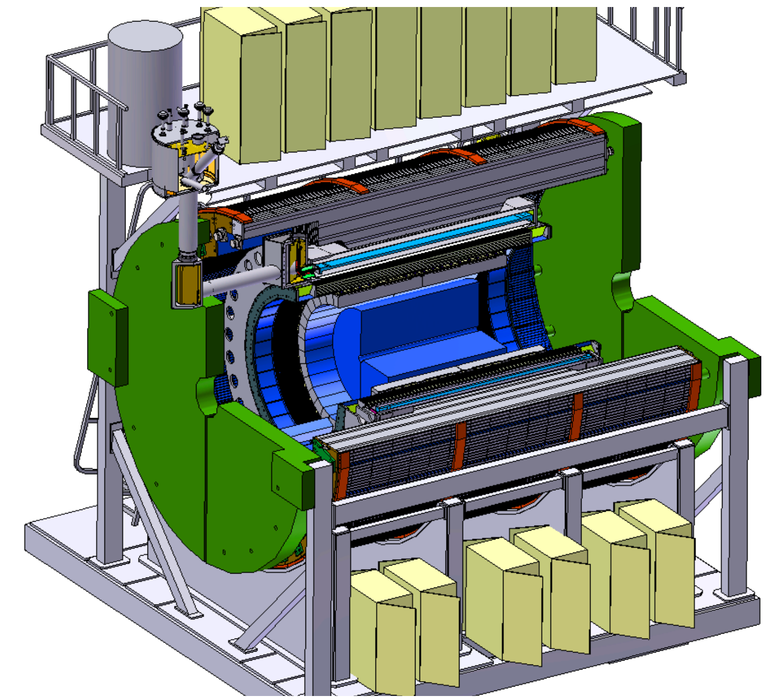


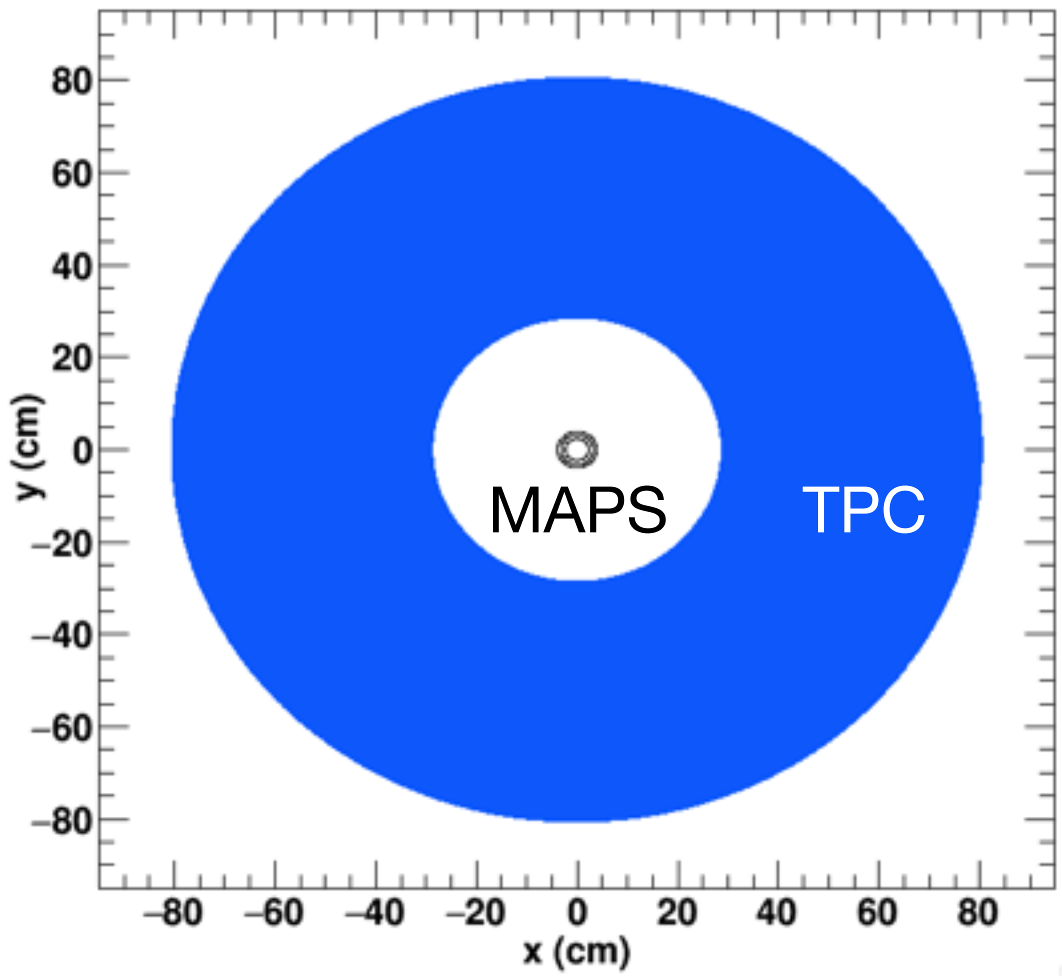
Addressing the Baseline Scope Charge

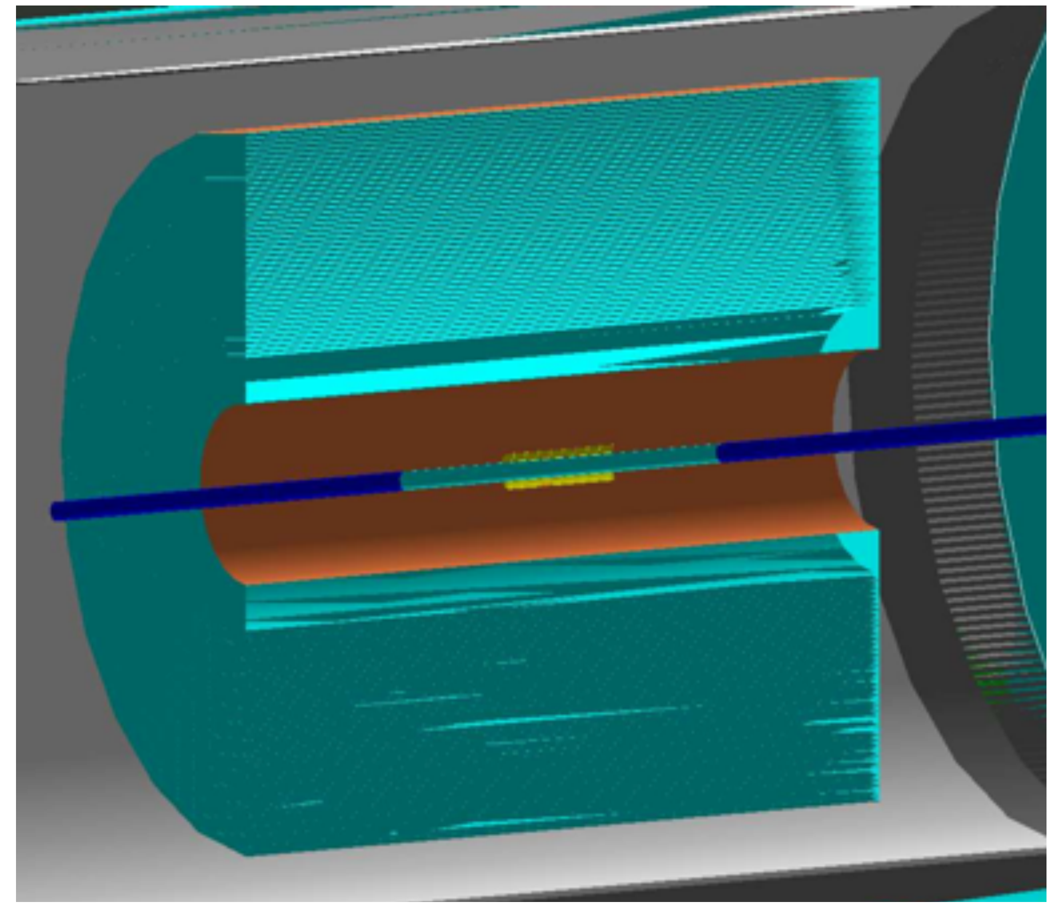
The sPHENIX Collaboration
June 6, 2016

Scenario A	Δ	Scenario B	Δ
two-layer MAPS inner barrel	+3.0	one-layer MAPS inner barrel	+2.1
no reuse of VTX	−0.2	no reuse of VTX	−0.2
reduce TPC readout	−0.5	reduce TPC readout	−0.5
reduce EMCal segmentation	−1.8	reduce EMCal segmentation	−1.8
reduce EMCal η acceptance	−2.0	further reduce EMCal η acceptance	−2.2
reduce DAQ refresh	−0.5	reduce DAQ refresh	−0.5
reuse beam-beam trigger counter	−0.5	reuse beam-beam trigger counter	−0.5
Total	−2.5	Total	−3.6

(in $M)

Focus on tracking





comparative TPC radii

ALICE:	60-250 cm
STAR:	50-200 cm
sPHENIX:	30-80 cm

MAPS cf. VTX

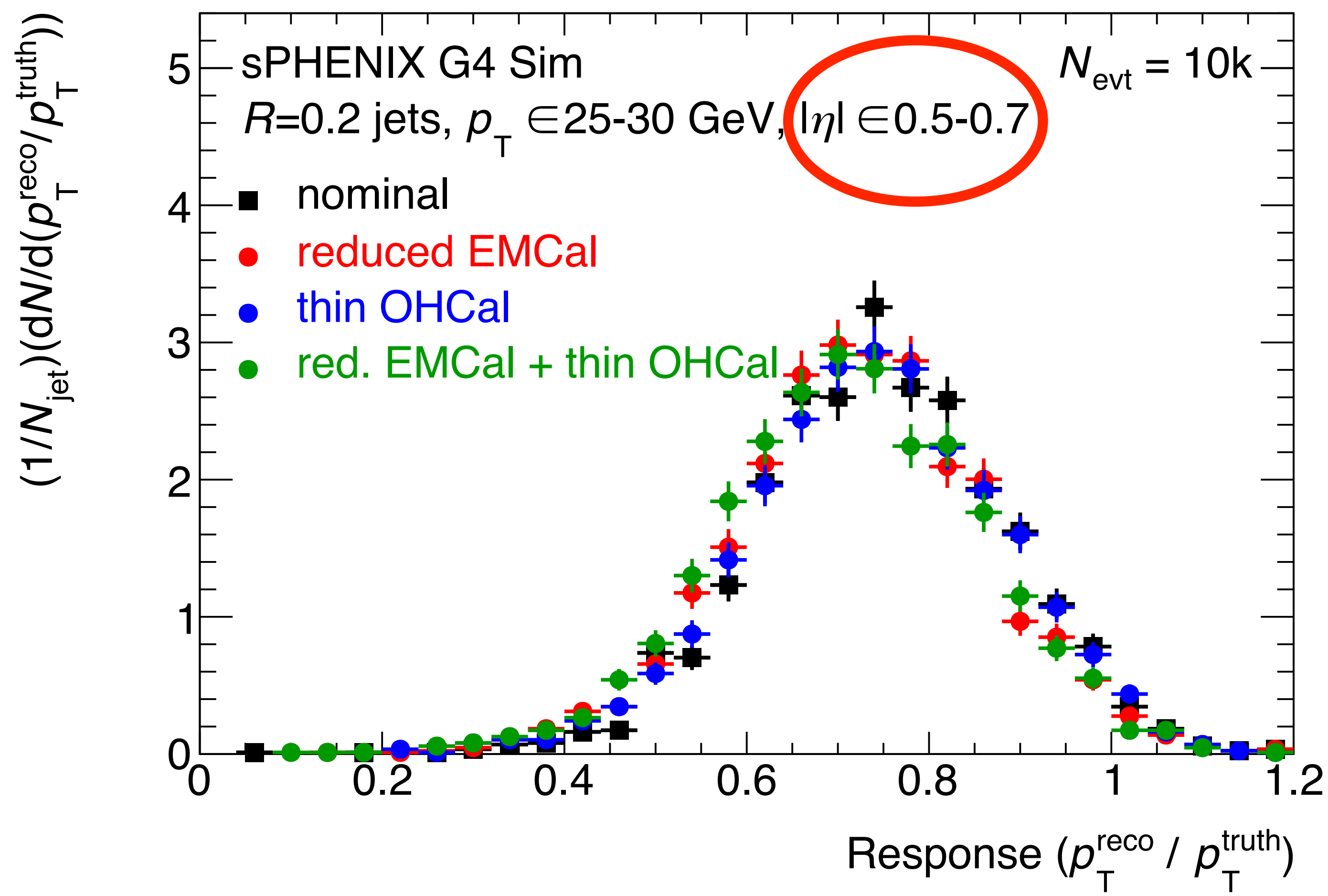
higher efficiency (98% vs 70-94%)
longer staves (27cm vs 20cm)
10+ year old silicon
benefit by ALICE commissioning

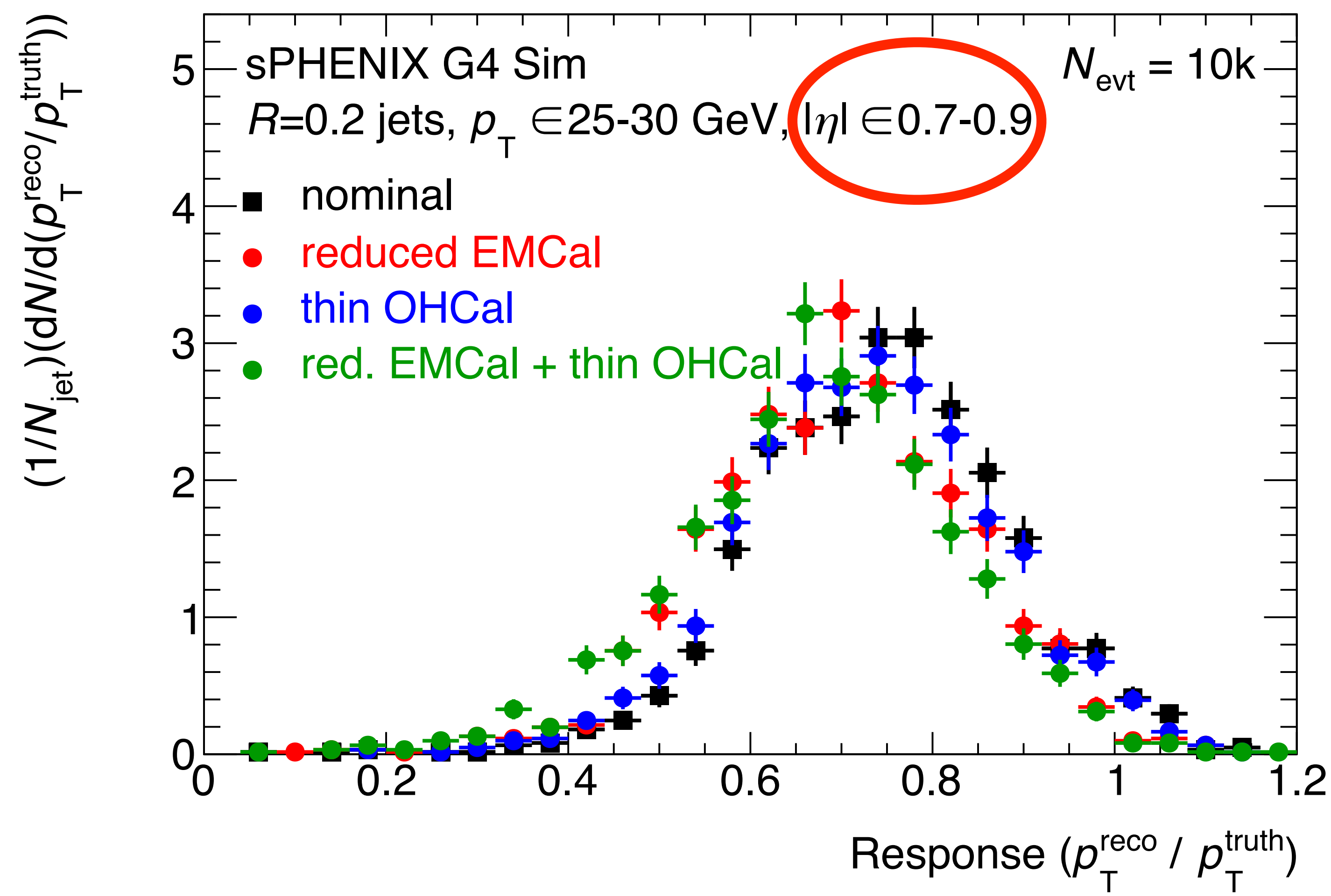
reduced EMCal: |η| < 0.6
thin OHCal: thinner by one λ_{int}

each change shifts mean low appearance of low-side tail

effects become pronounced with both changes

LHC experience: dealing with jets that span substantial changes in detector material subject to large systematic uncertainties





Jet fragmentation bias

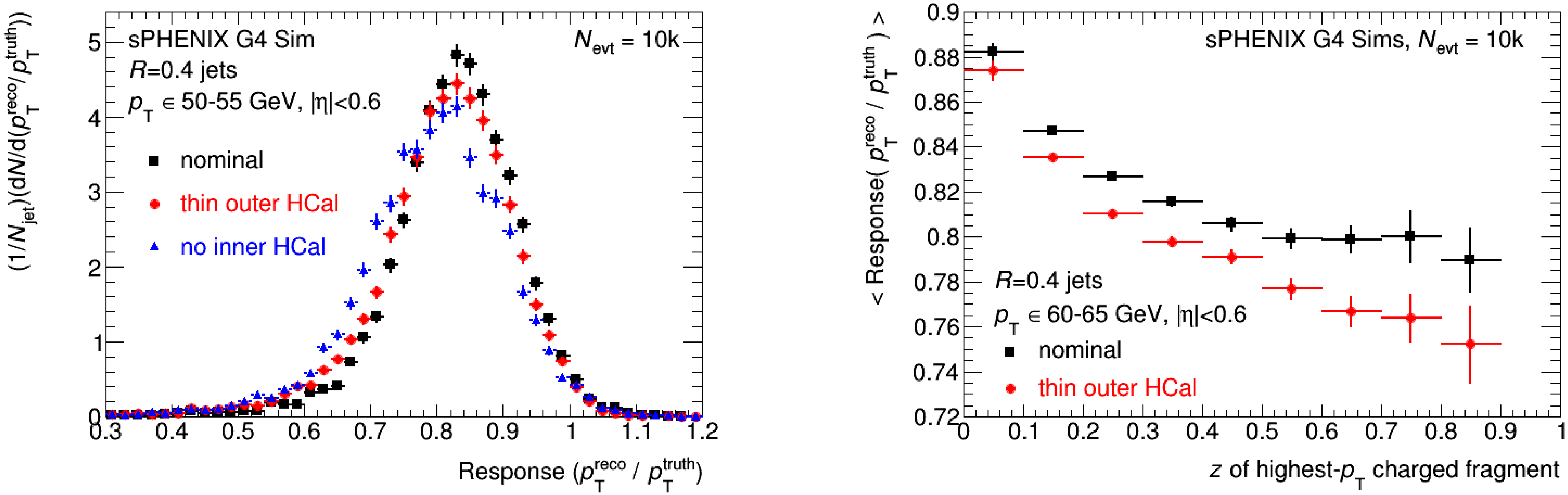
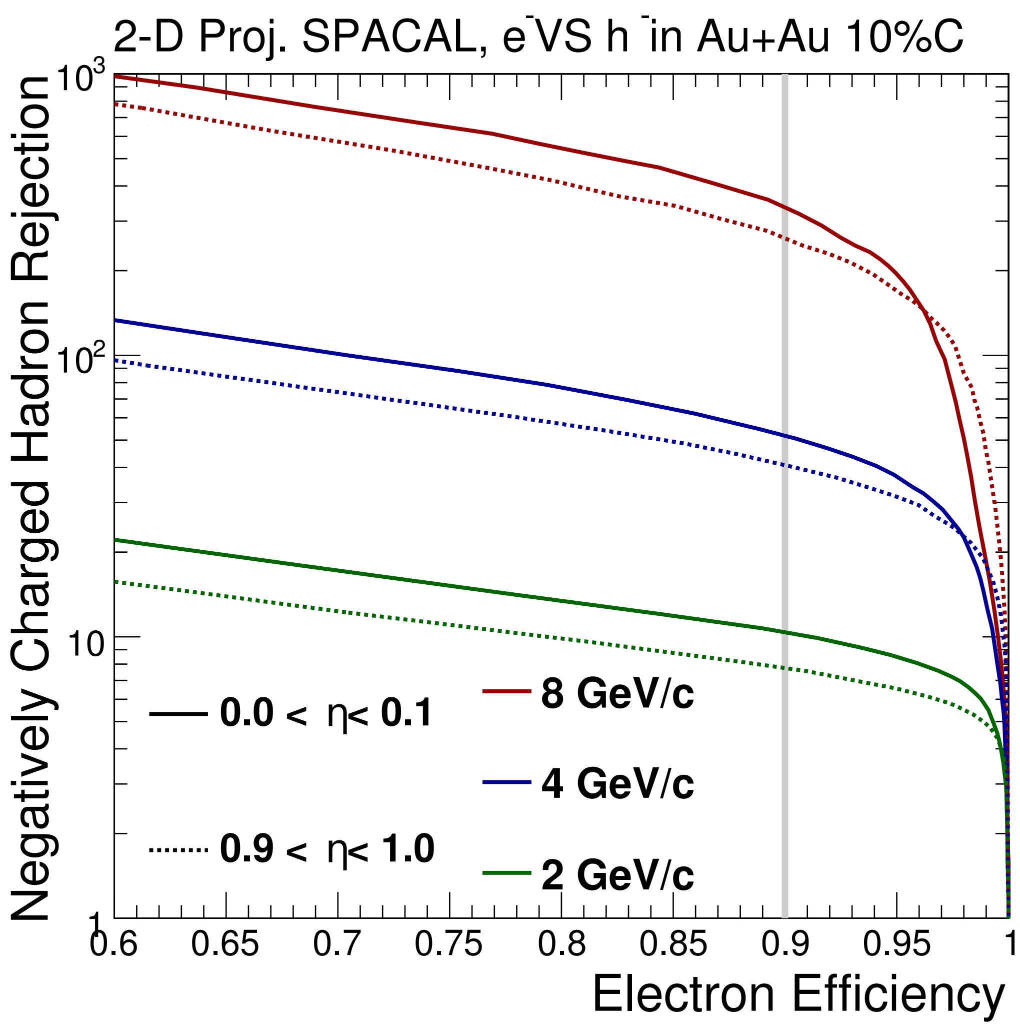
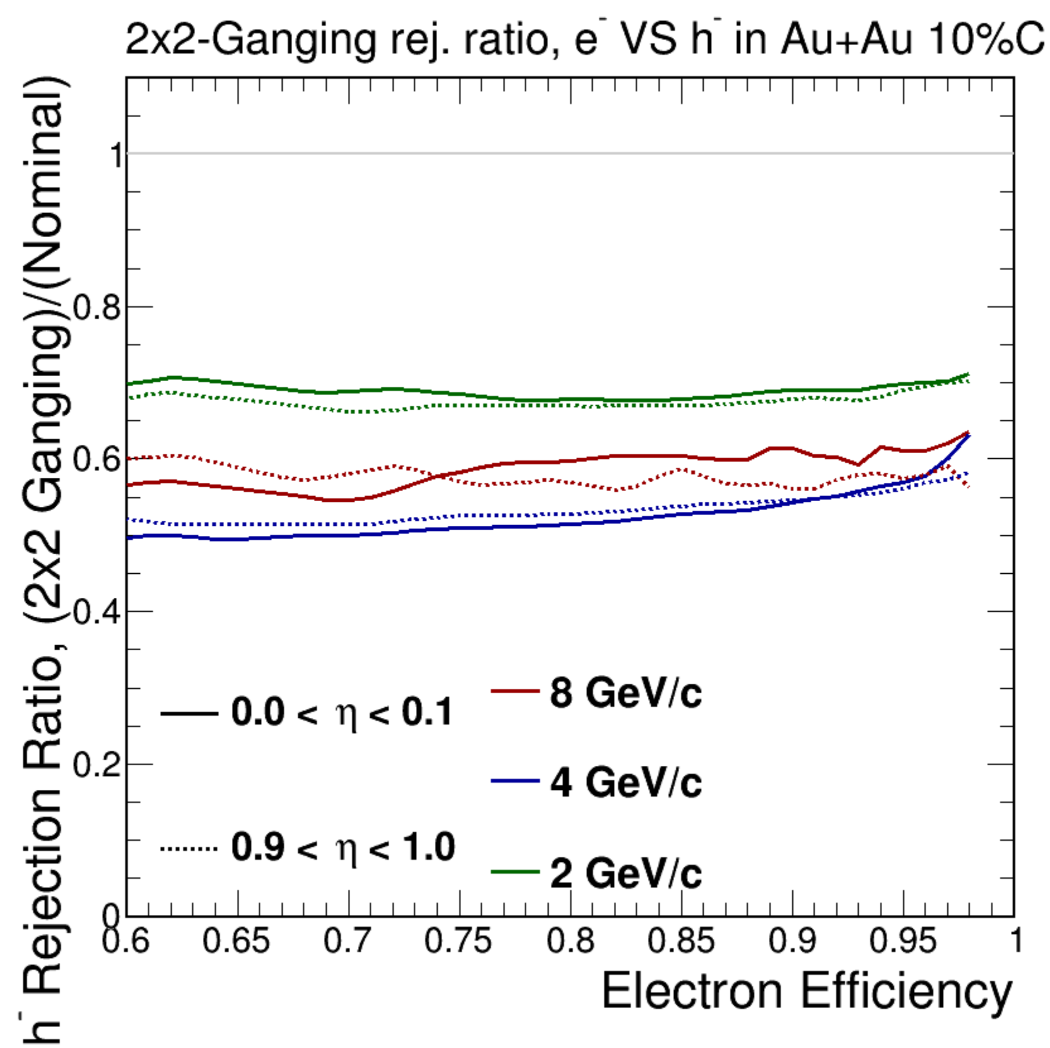
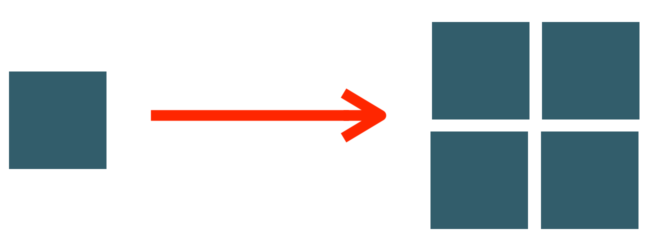


Figure B.1: (Left) Comparison of the jet response for three different HCal configurations: Nominal outer HCal (black markers), outer HCal thinned by 20 cm (red markers) and no inner HCal (blue markers). (Right) Comparison of the jet fragmentation bias for nominal (black markers) and thinned outer HCal (240 cm outer radius, red markers).

Effect of reduced segmentation in EMCal







e/π lower by ~2x in 2x2 ganged EMCal

Reduced Υ acceptance with |η| < 0.6 EMCal

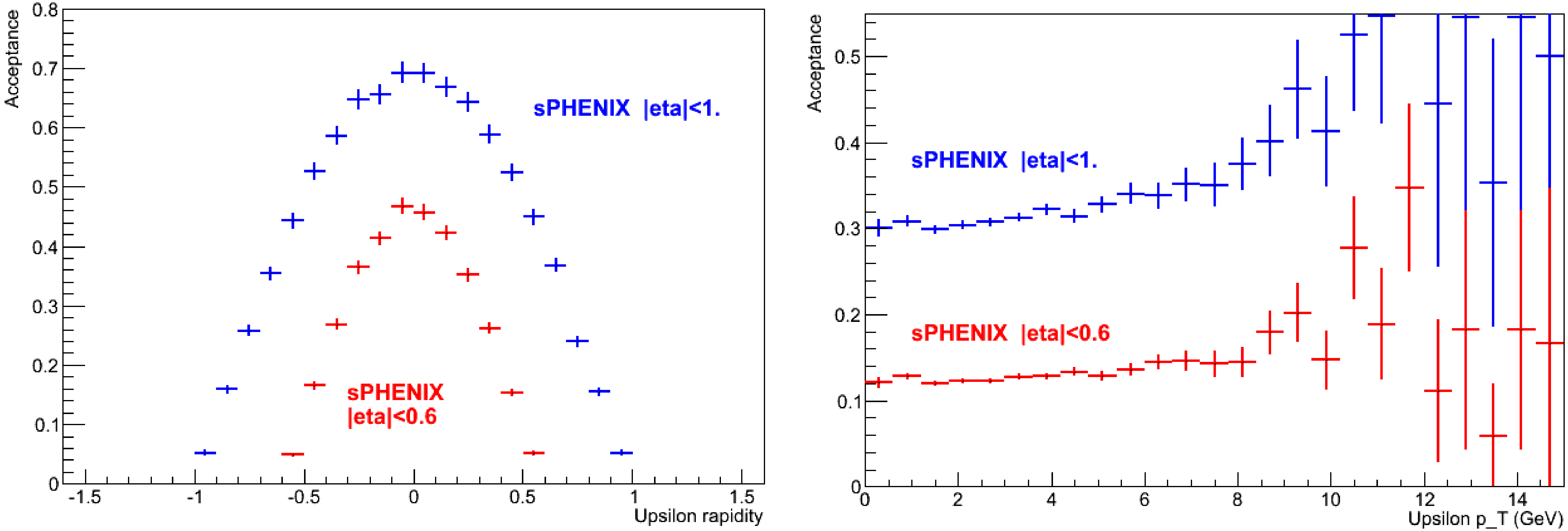


Figure B.5: (Left) Υ to e^+e^- acceptance as a function of rapidity for the nominal (blue markers) and $|\eta| < 0.6$ configurations, averaged over Υ p_T. (Right) Υ to e^+e^- acceptance as a function of p_T for the nominal (blue markers) and $|\eta| < 0.6$ configurations, averaged over η.

Looking forward with the Project

Project Schedule and Budget based on Review committee recommendations:

Tracker review	Sept 2016
CD-0	Sept-Oct 2016
Director's Cost and Schedule Review	Late Fall 2016
Test Beam at FNAL (2nd round prototyping)	Jan 2017
OPA-CD-1/CD-3a Reviews	May-Jun 2017
CD-1/CD-3a authorization	Nov 2017
Preproduction R&D and Design complete	May-Jun 2018
OPA-CD-2/CD-3b review	May-Jun 2018
CD-2/CD-3b authorization	Jul 2018
sPHENIX Installed, cabled, ready to commission	Apr 2021
First RHIC beam for sPHENIX	Jan 2022

Outlook

- sPHENIX scientific collaboration now exists officially – organizing efforts to provide guidance on physics questions – topical groups were instrumental in developing response to recent ALD charge
- Organizing a new “cold QCD” topical group to provide a target for current collaborators and potential new groups with interests in spin, forward and future EIC physics
- sPHENIX project continues excellent progress – pCDR, advanced prototypes, test beam, preparations for high-field magnet test, tracking review, updated cost and schedule review
- Collaboration is committed to building a world-class experiment with the capabilities needed to deliver the full suite of sPHENIX physics – the scientific questions remain extremely relevant