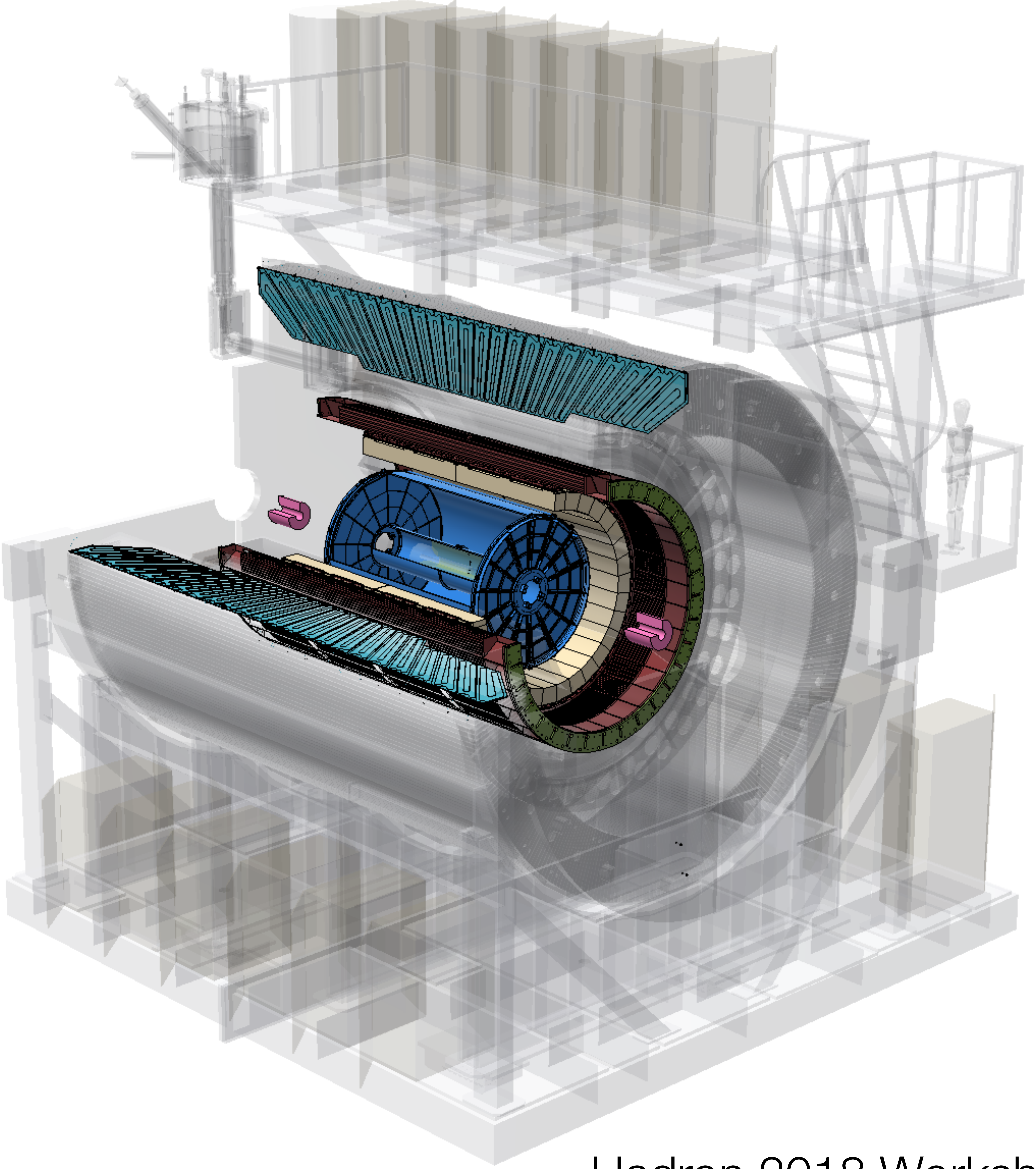


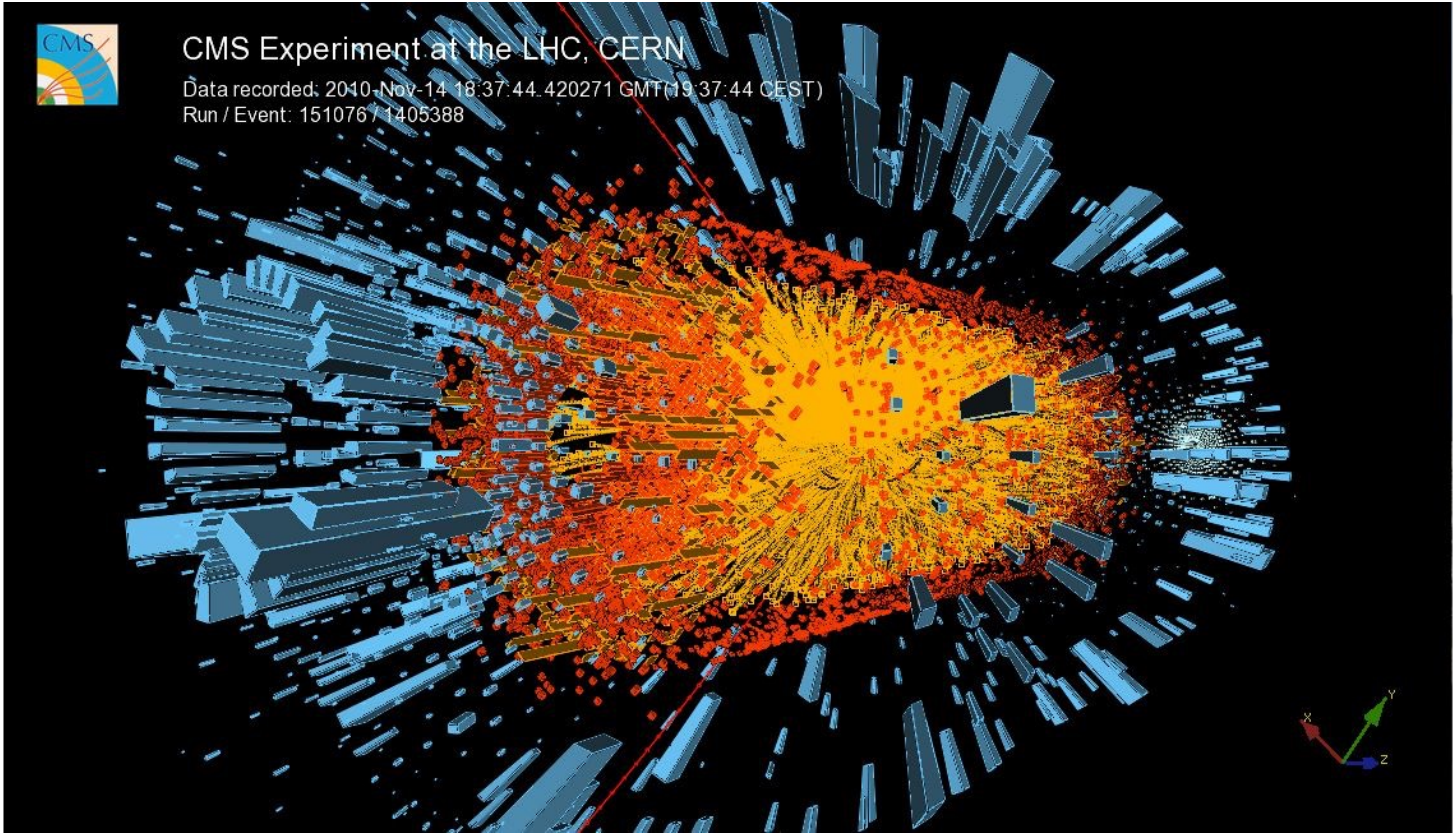
Probing the QGP: Science mission and status of sPHENIX at RHIC

Gunther Roland

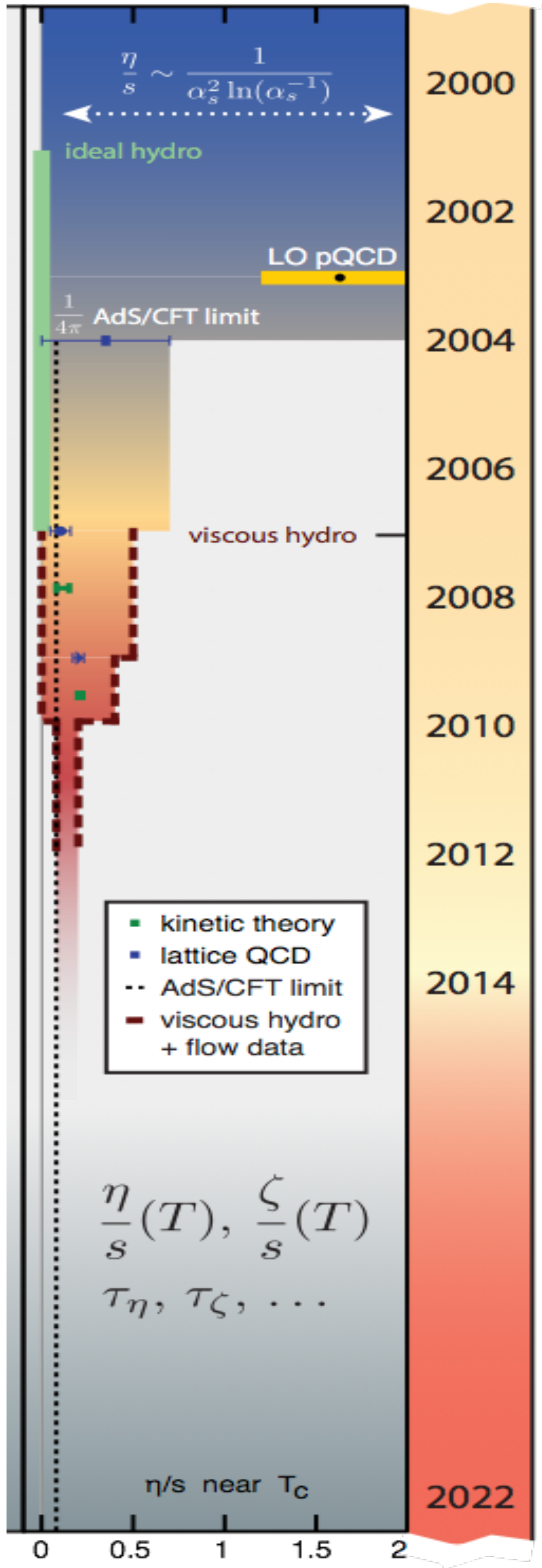
"…worldwide opportunities"

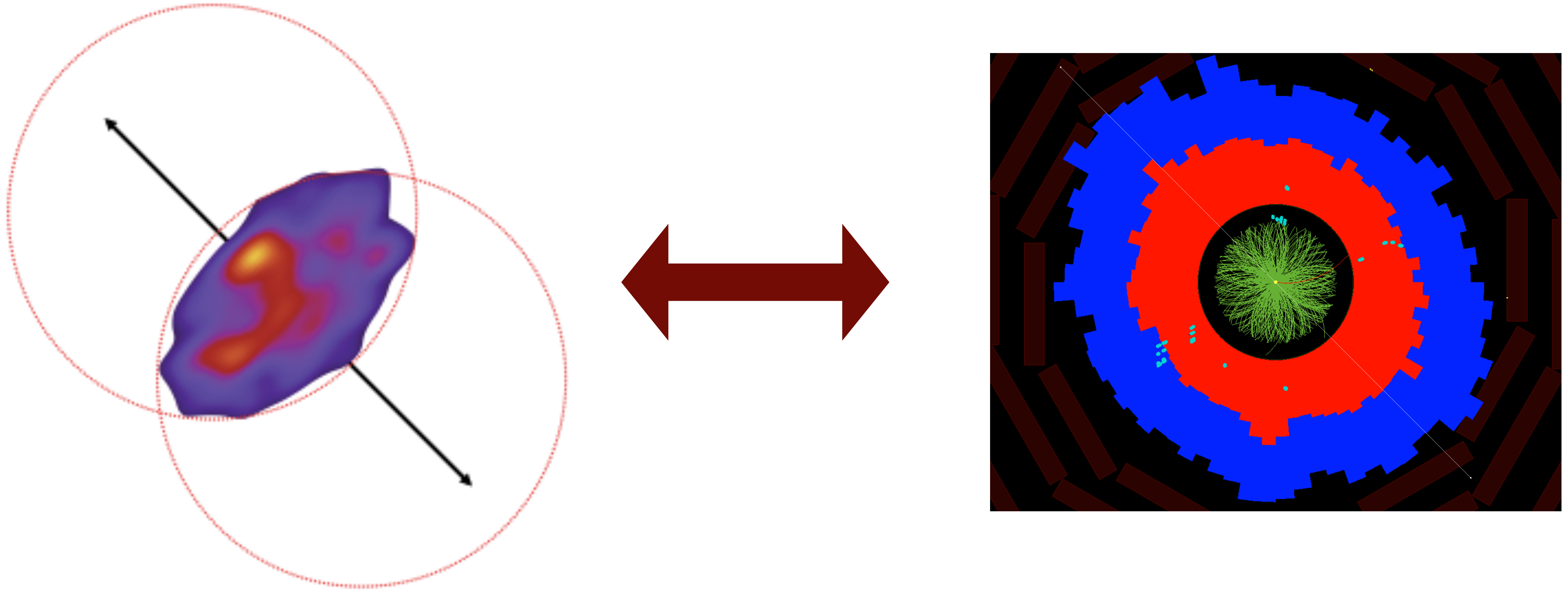
Hadron 2018 Workshop, Weihei, July 26-30

Hot QCD and Heavy-Ion Collisions



Strongly coupled Quark-Gluon Plasma





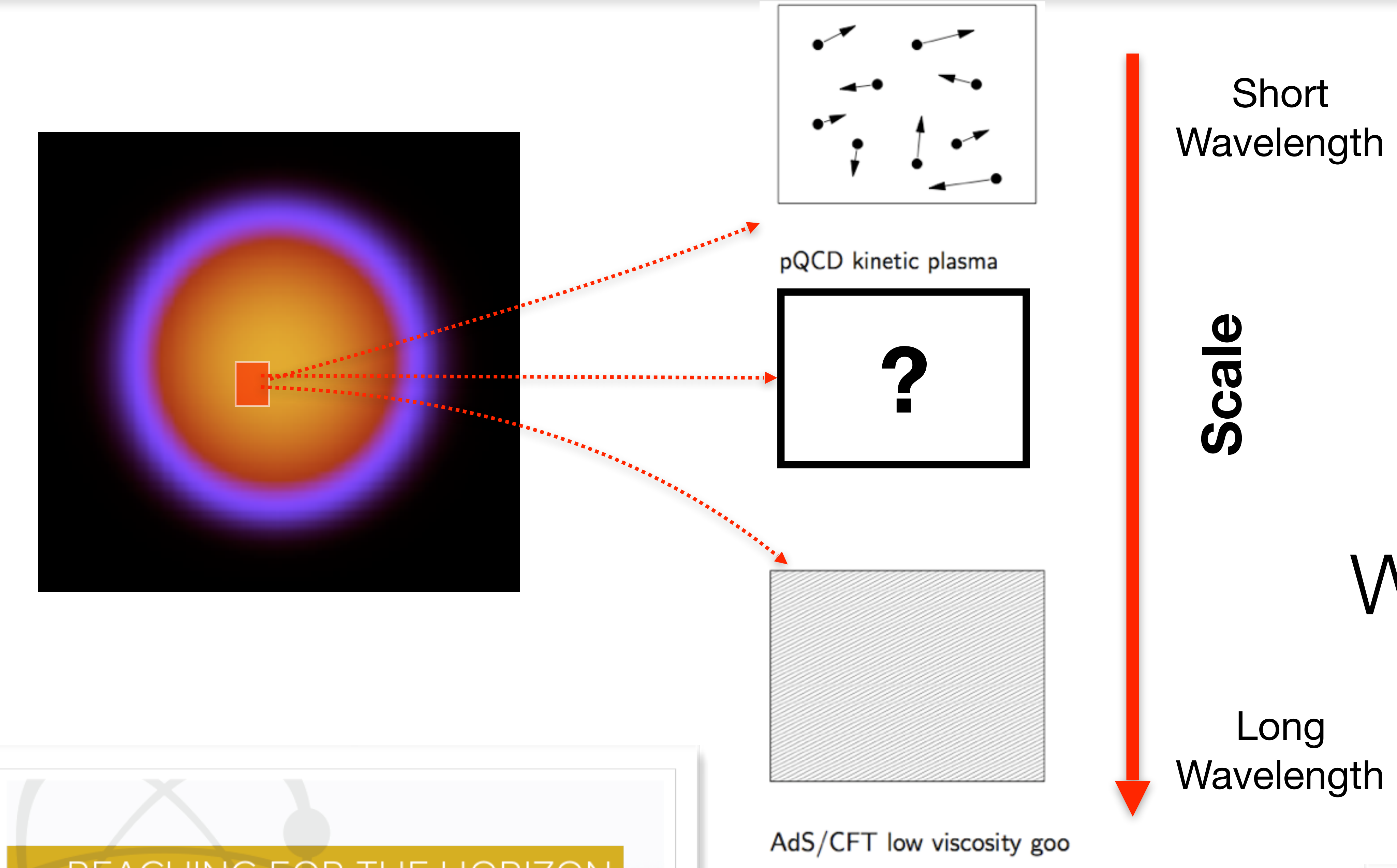
Established **viscous hydrodynamics** as effective theory of long-wavelength dynamics of QGP

Direct connection of final state correlations to structure and fine-structure of **initial state**

Extracted QGP properties quantitatively, most prominently **transport coefficient η/s ~ 1/(4π):** ***most perfect liquid***

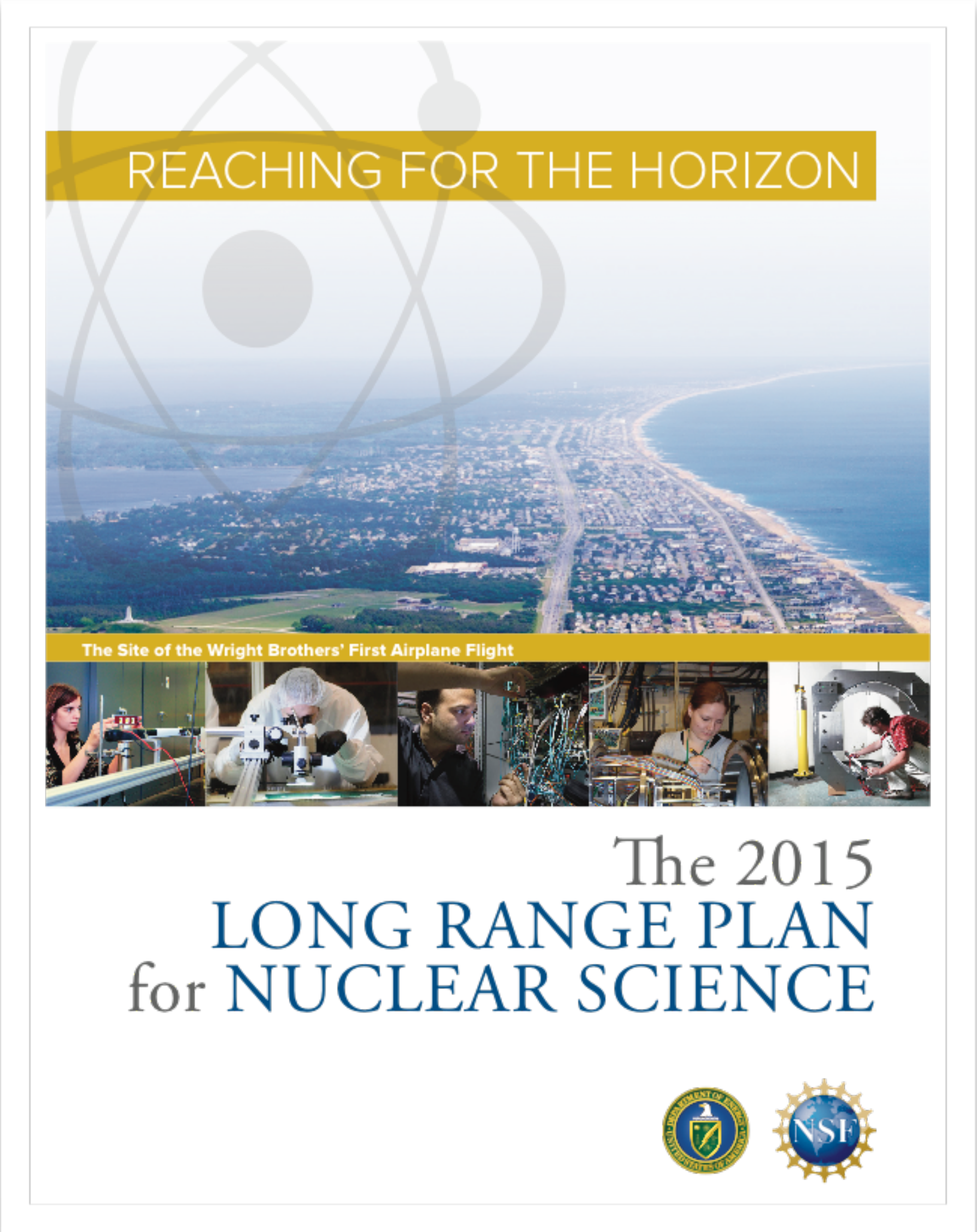
Connections to strong coupled matter in many fields of physics (string theory to cold atoms)

sPHENIX Science Mission

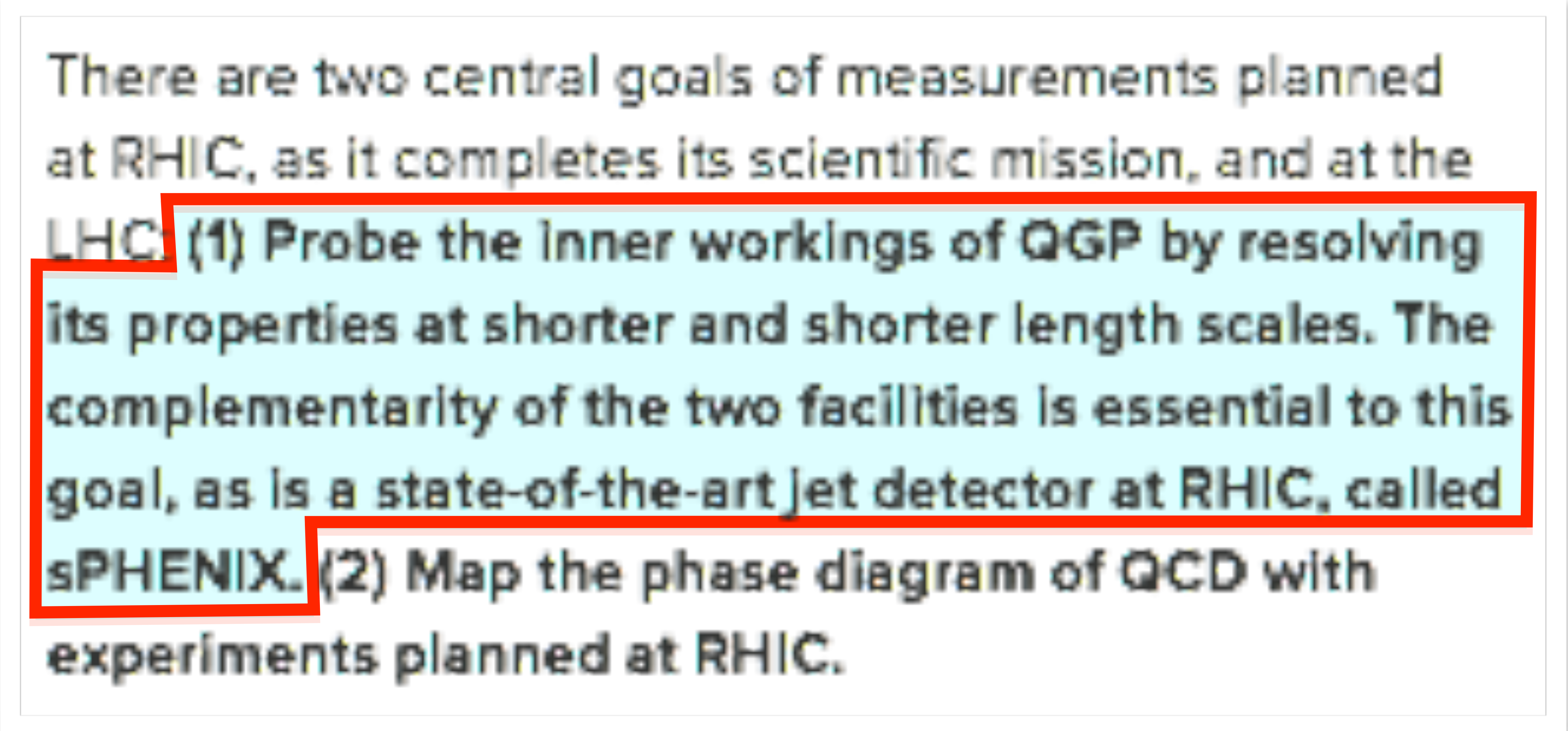


How does QGP work?

What is its microscopic structure?



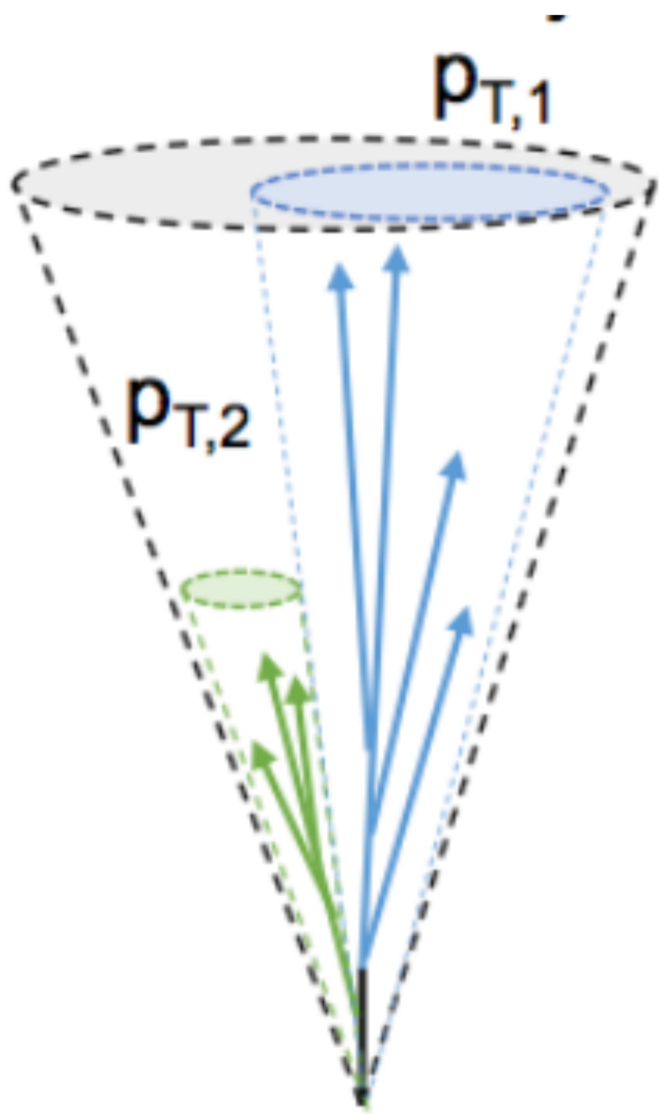
Section 2.2, page 22



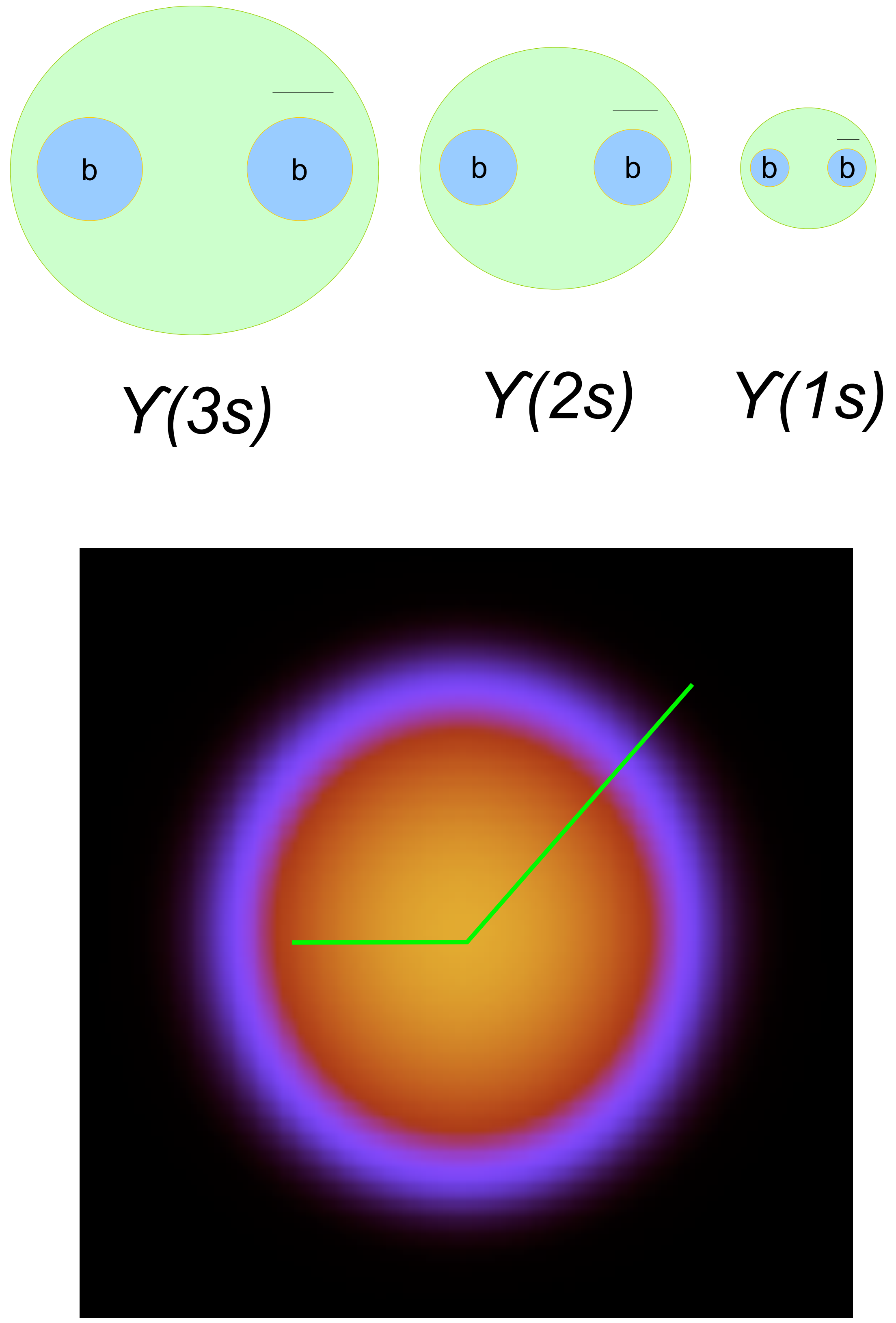
There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: (1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art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

Three key approaches to study
QGP structure at multiple scales

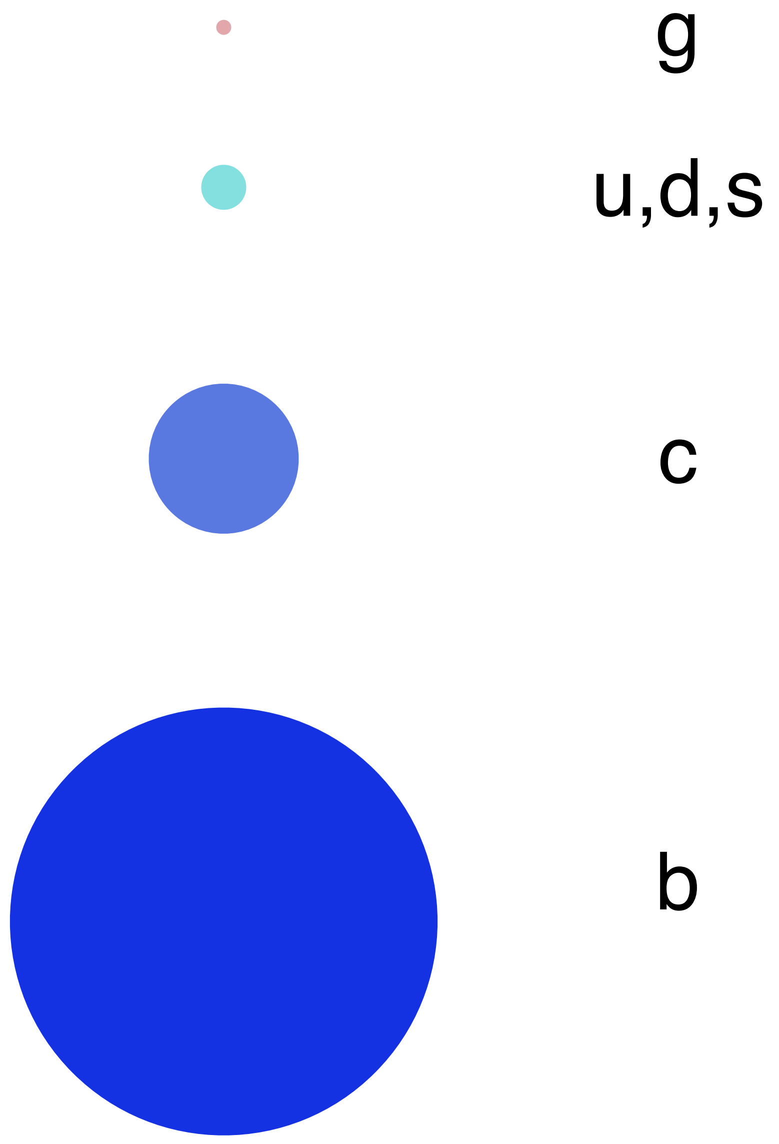
Jet structure
vary momentum/angular scale of probe



Quarkonium spectroscopy
vary size of probe

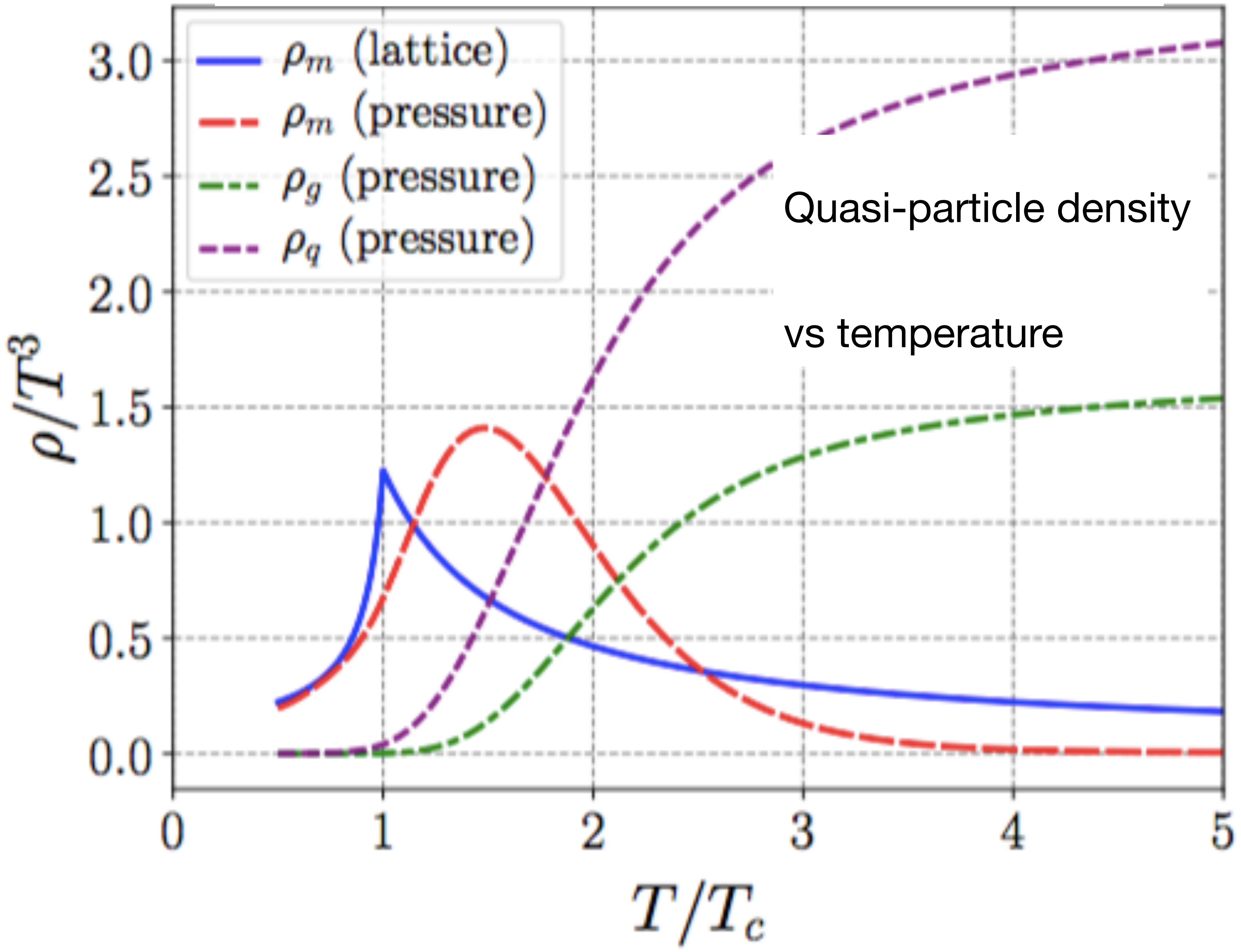


Parton energy loss
vary mass/momentum of probe



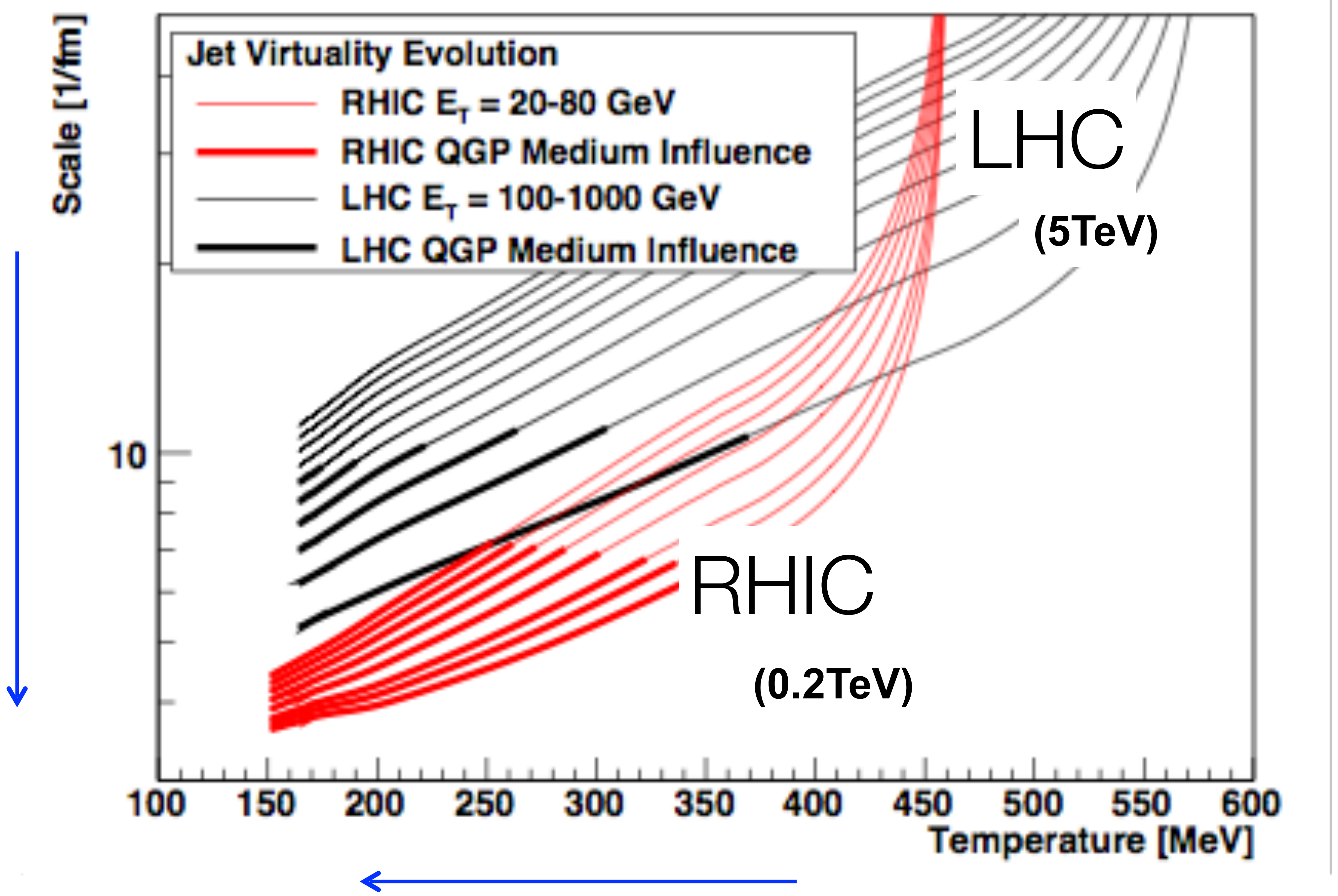
Complementarity: Why RHIC *and* LHC?

A. Ramamurti, E. Shuryak,arXiv:1708.04254



Structure of QGP expected to depend on temperature

M. Habich, J. Nagle, and P. Romatschke, EPJC, 75:15 (2015)

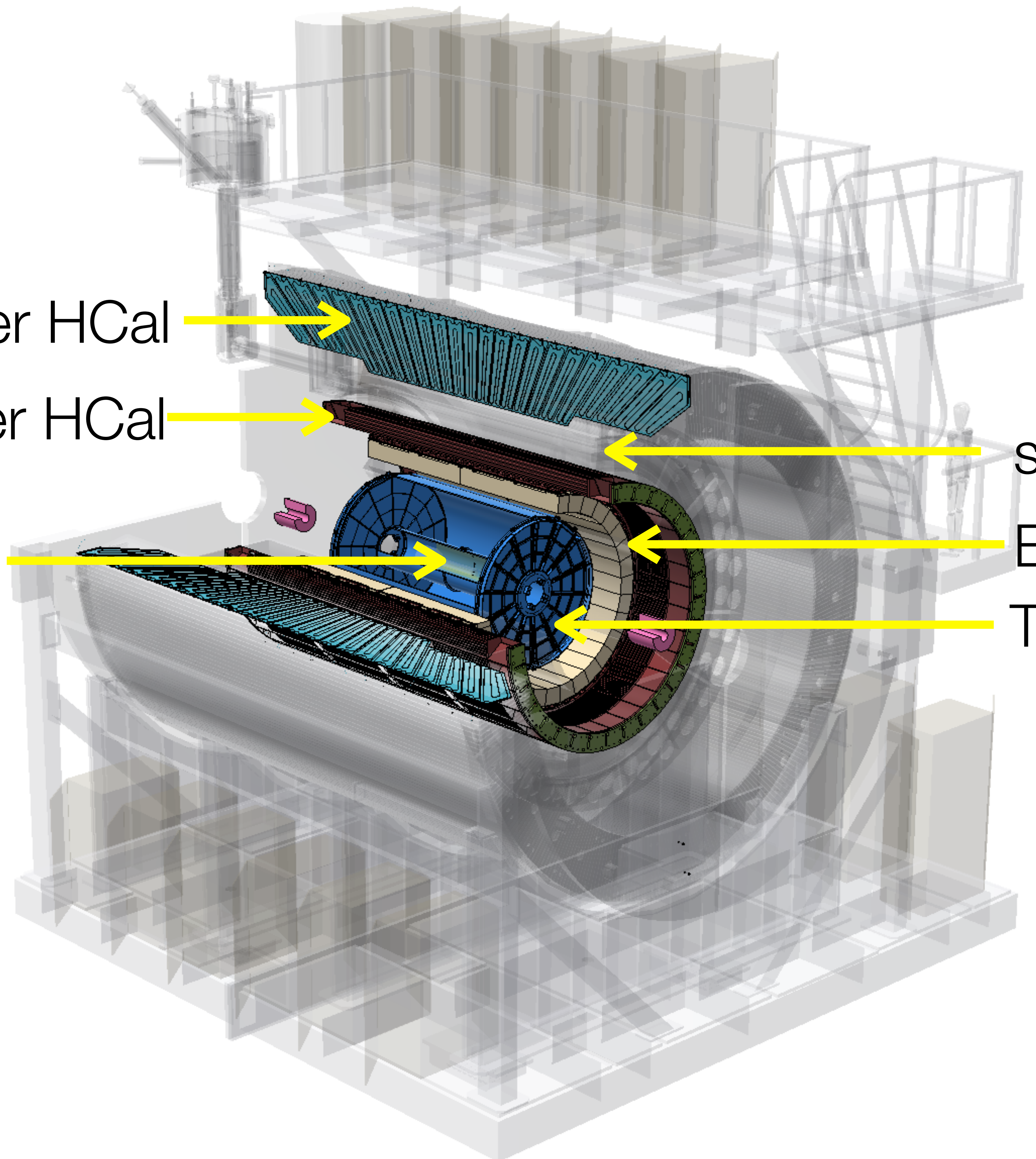


Initial QGP conditions and QGP evolution are different at RHIC vs LHC

RHIC QGP spends more time near T_C

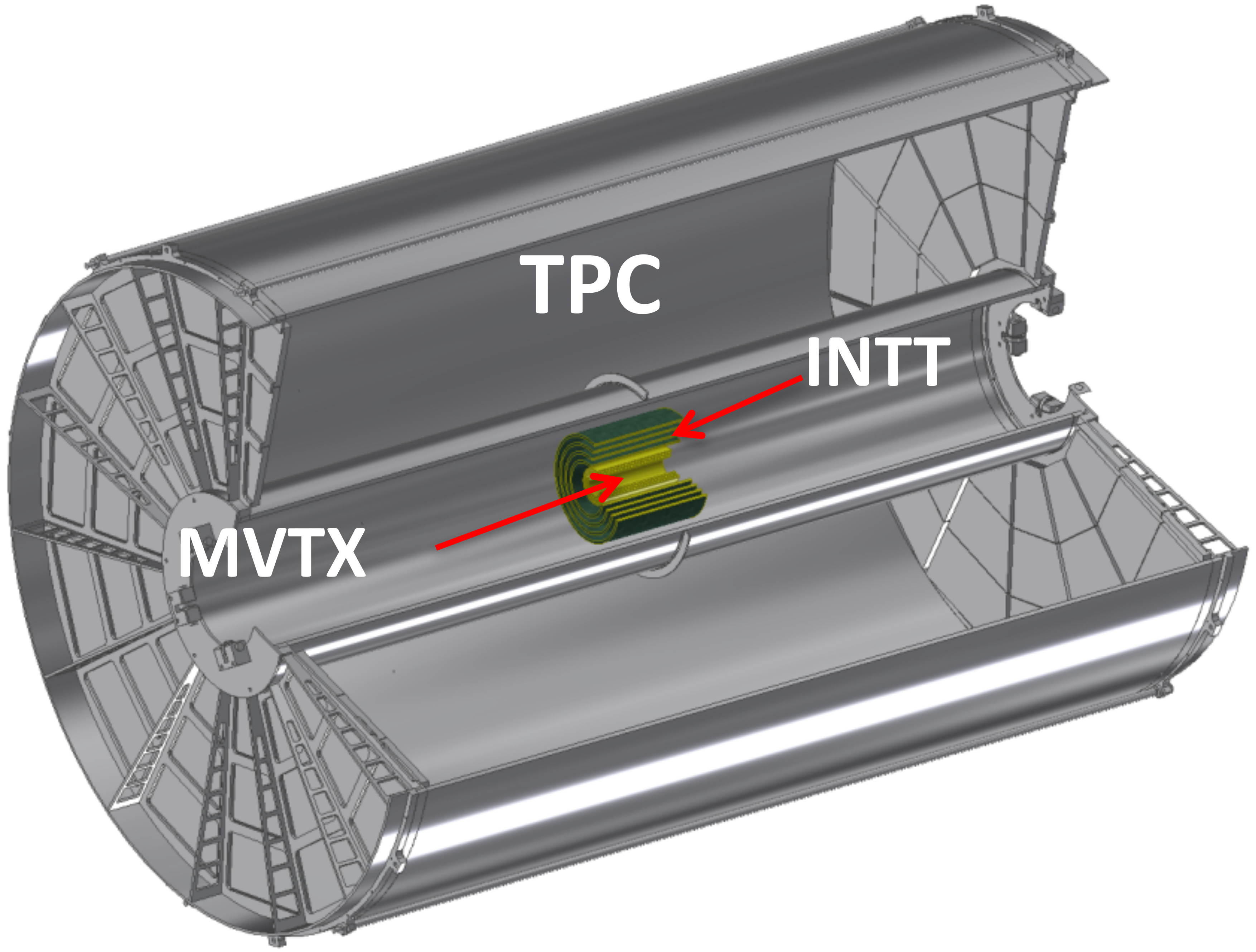
➥ Use **combined RHIC and LHC data** to extract T dependence

State of the art detector for
Jets
Upsilons
Open heavy flavor



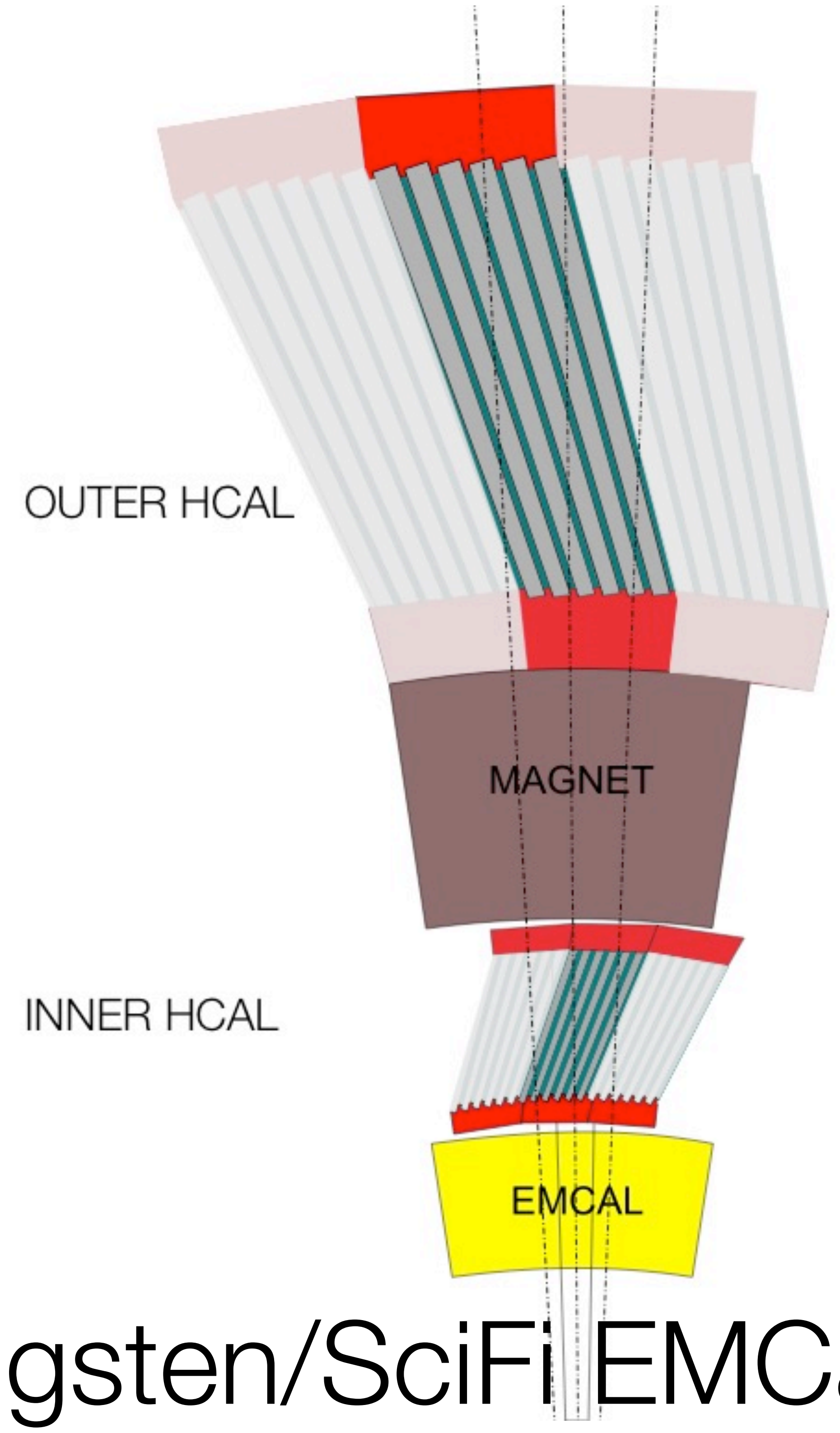
sPHENIX Subdetectors

Tracker



Continuous readout TPC
Si strip intermediate tracker
3-layer MAPS-based μ vertex

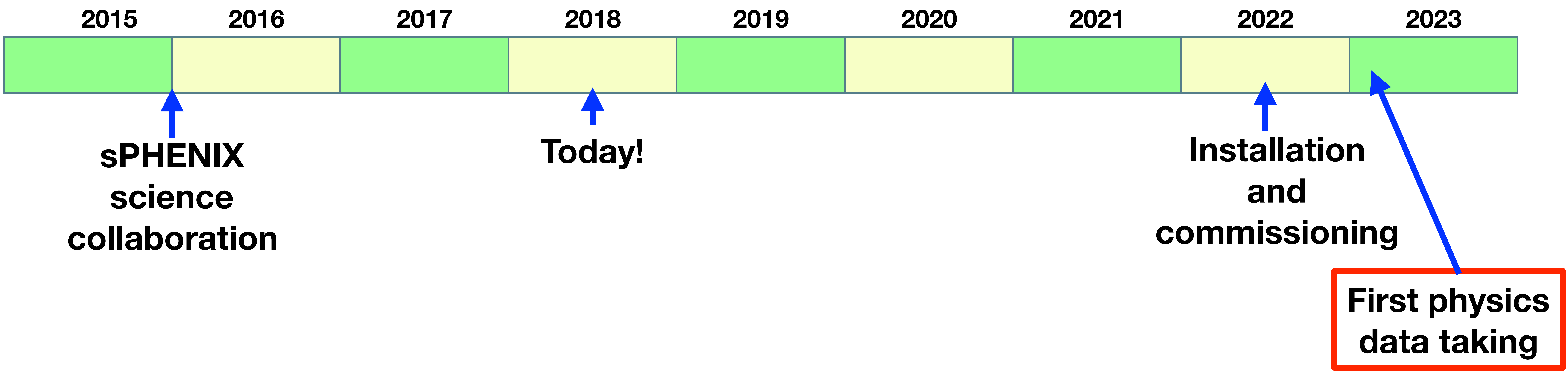
Calorimeter stack



Tungsten/SciFi EMCal
Steel/plastic scintillator HCAL
SiPM readout

15kHz readout in Au+Au to match expected collision rate in $|z| < 10$cm

Realizing sPHENIX

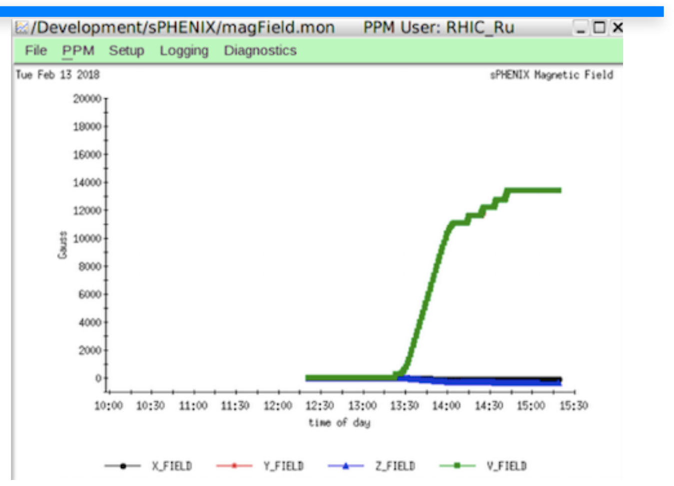


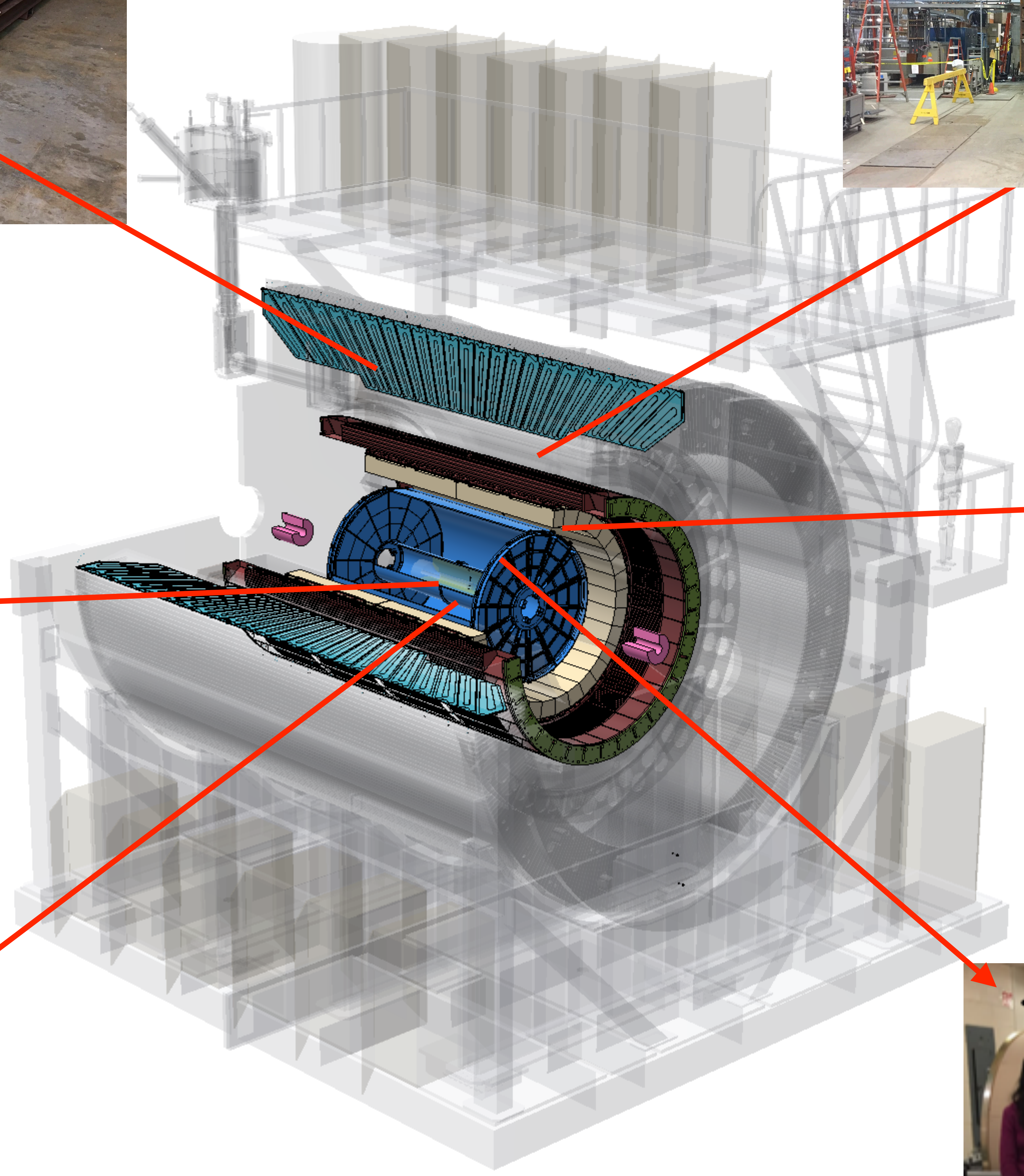
Realizing sPHENIX

Realizing sPHENIX

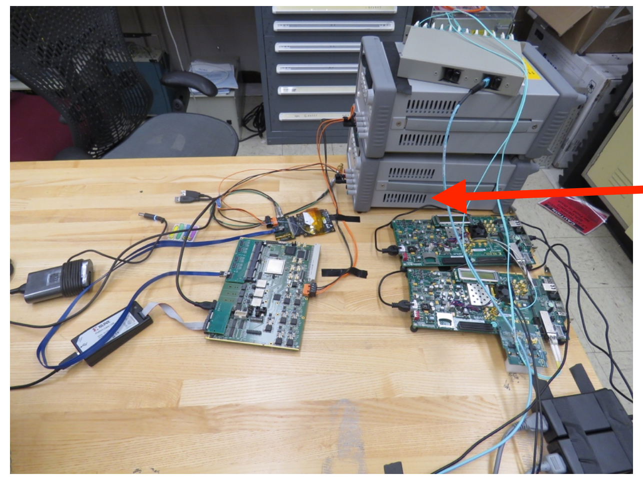
Flux return/**oHCAL** absorber
Production sectors will start arriving September ’18

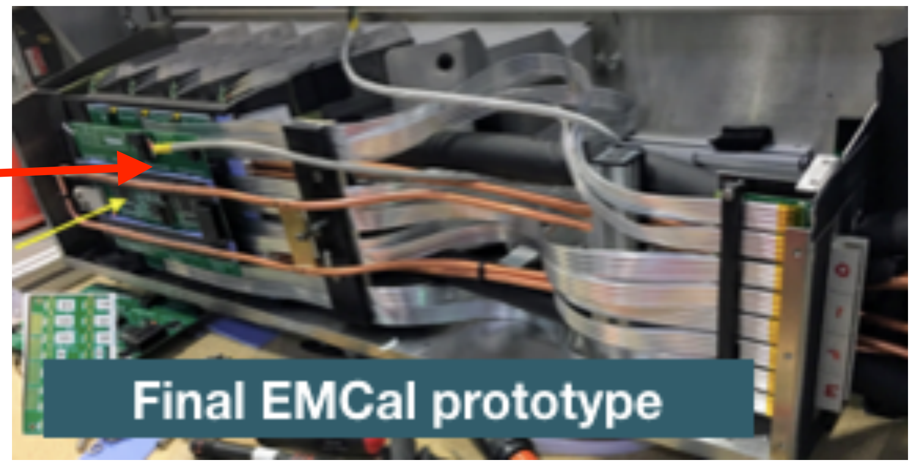
Full field **magnet** test at 1.4T at BNL on 2/13/2018



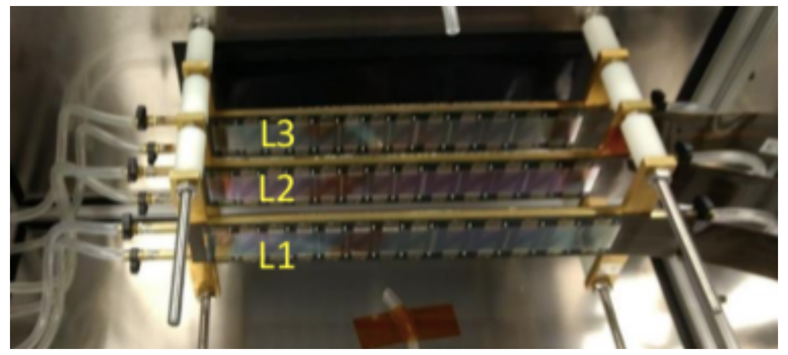


MVTX full chain test and beam test in Spring 2018
Expecting stave procurement in late 2018

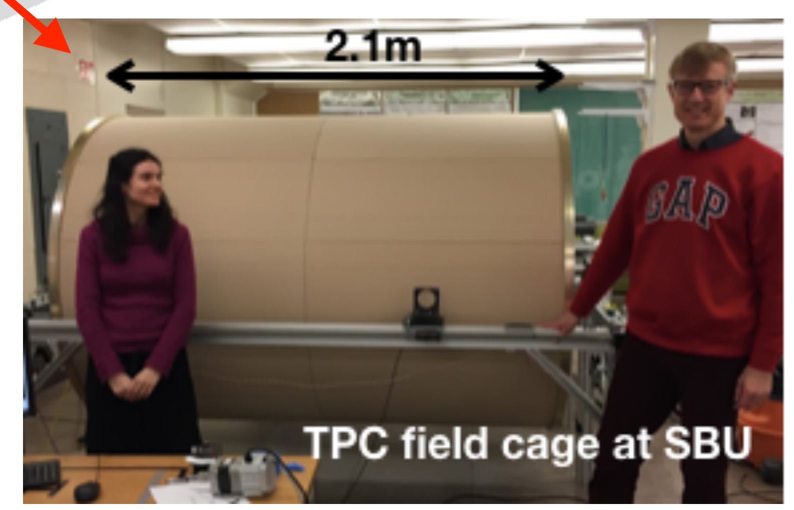




Approval of **EMCAL** materials purchase expected next month
“Sector 0” production starting 2018

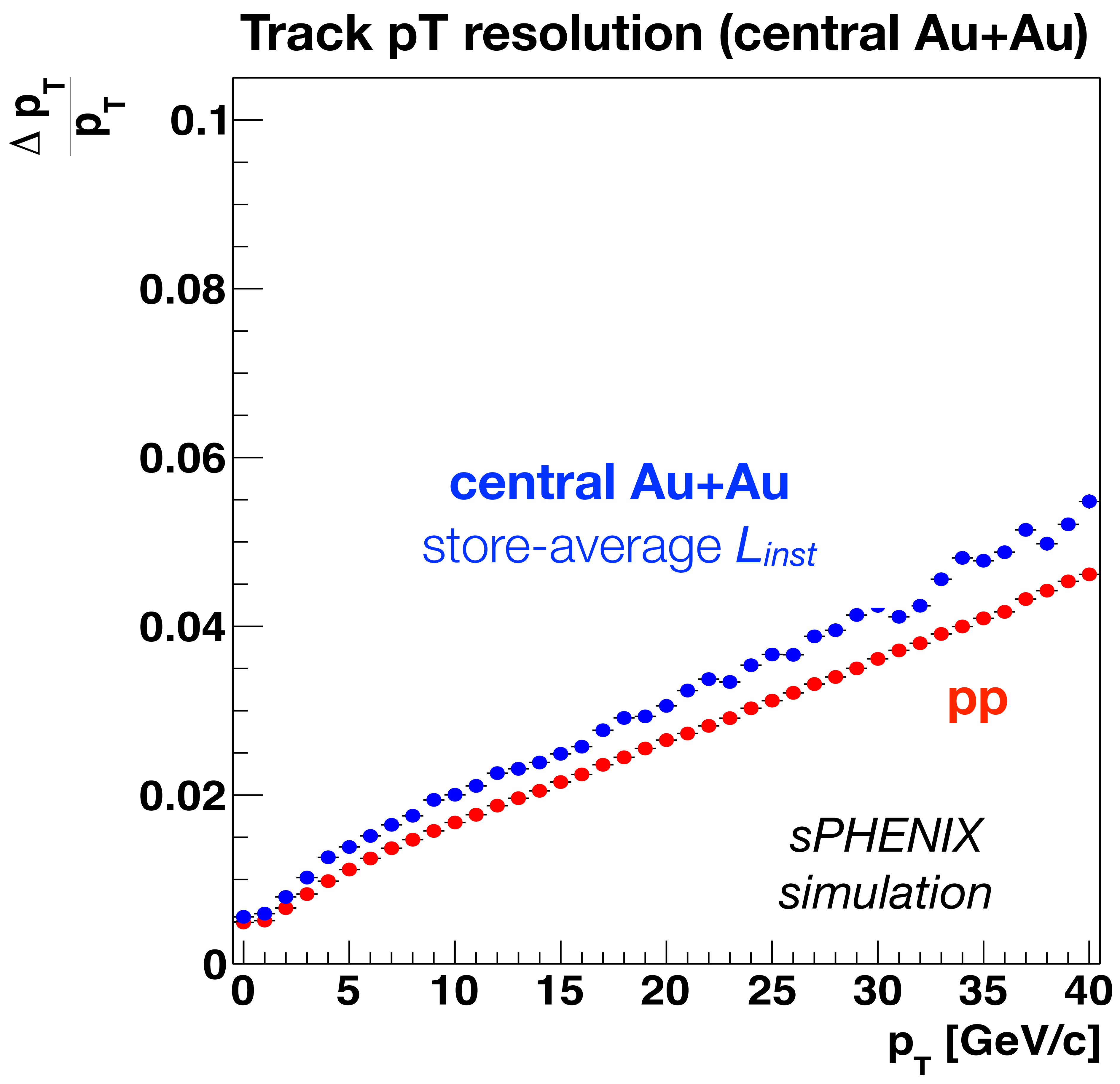


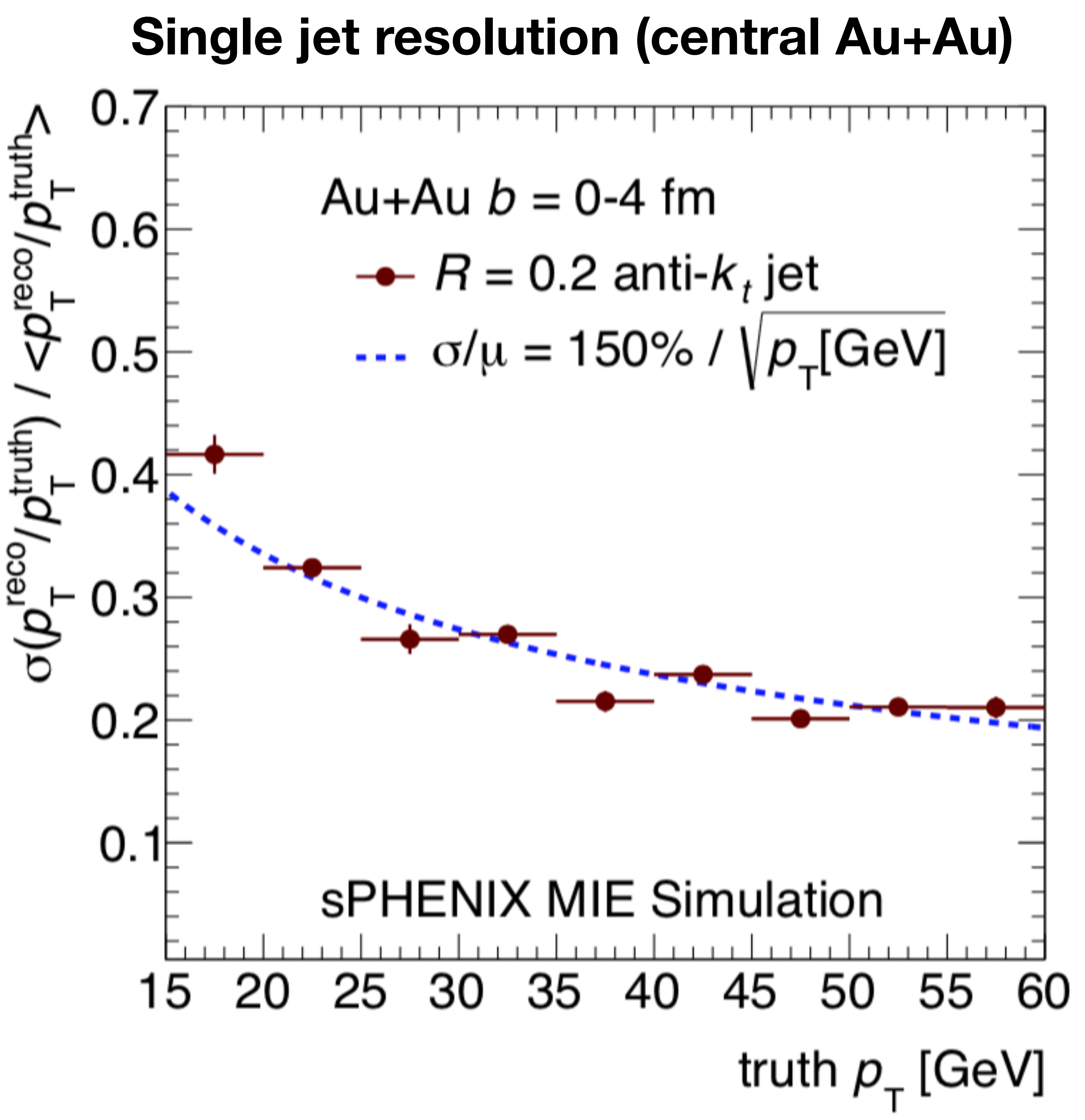
INTT telescope beam test in Spring 2018
Detector will be delivered by Riken



Beam test of **TPC** prototype in June 2018
Ready for producing of full-size field cage “prototype”

Performance simulation: Track and jet resolution

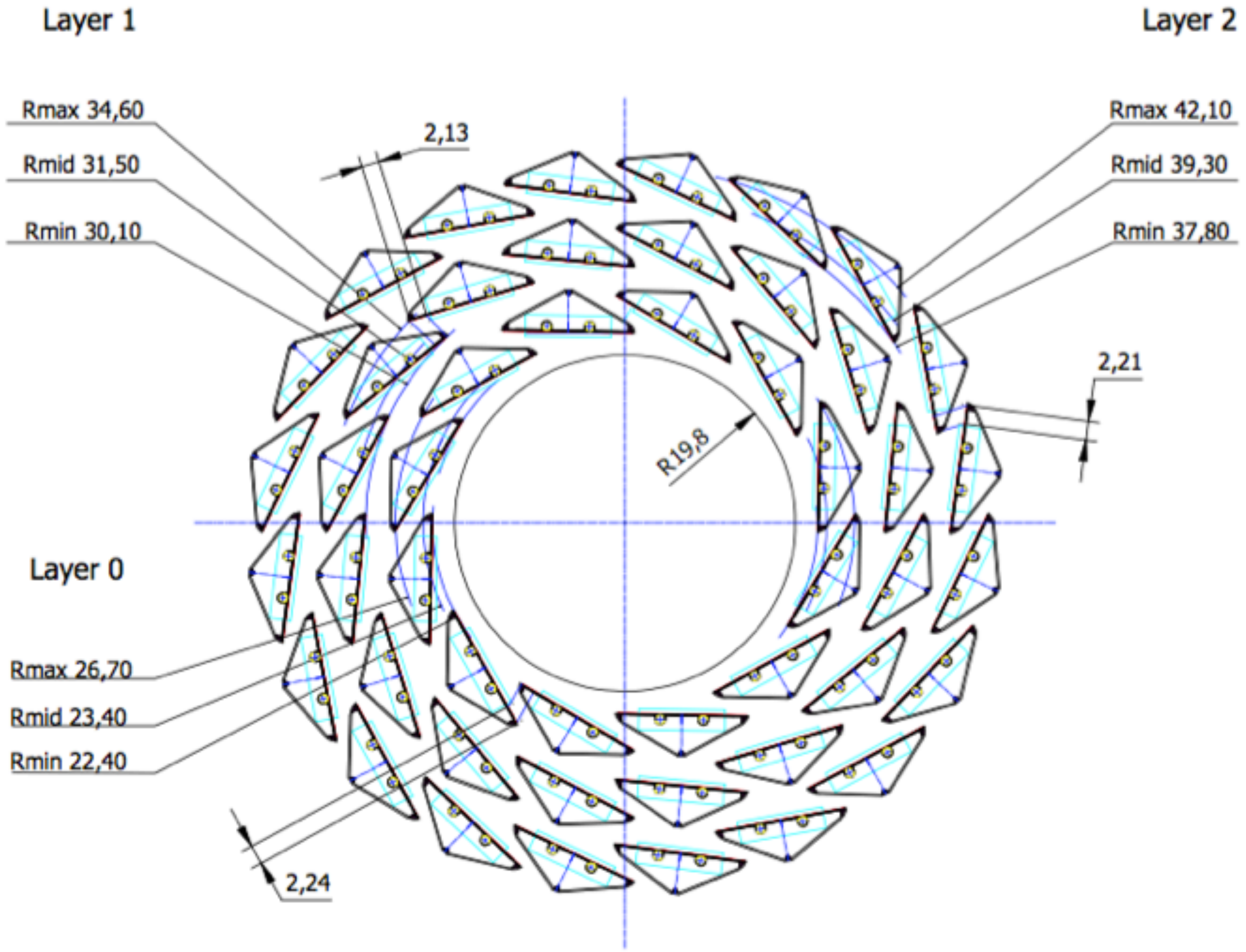




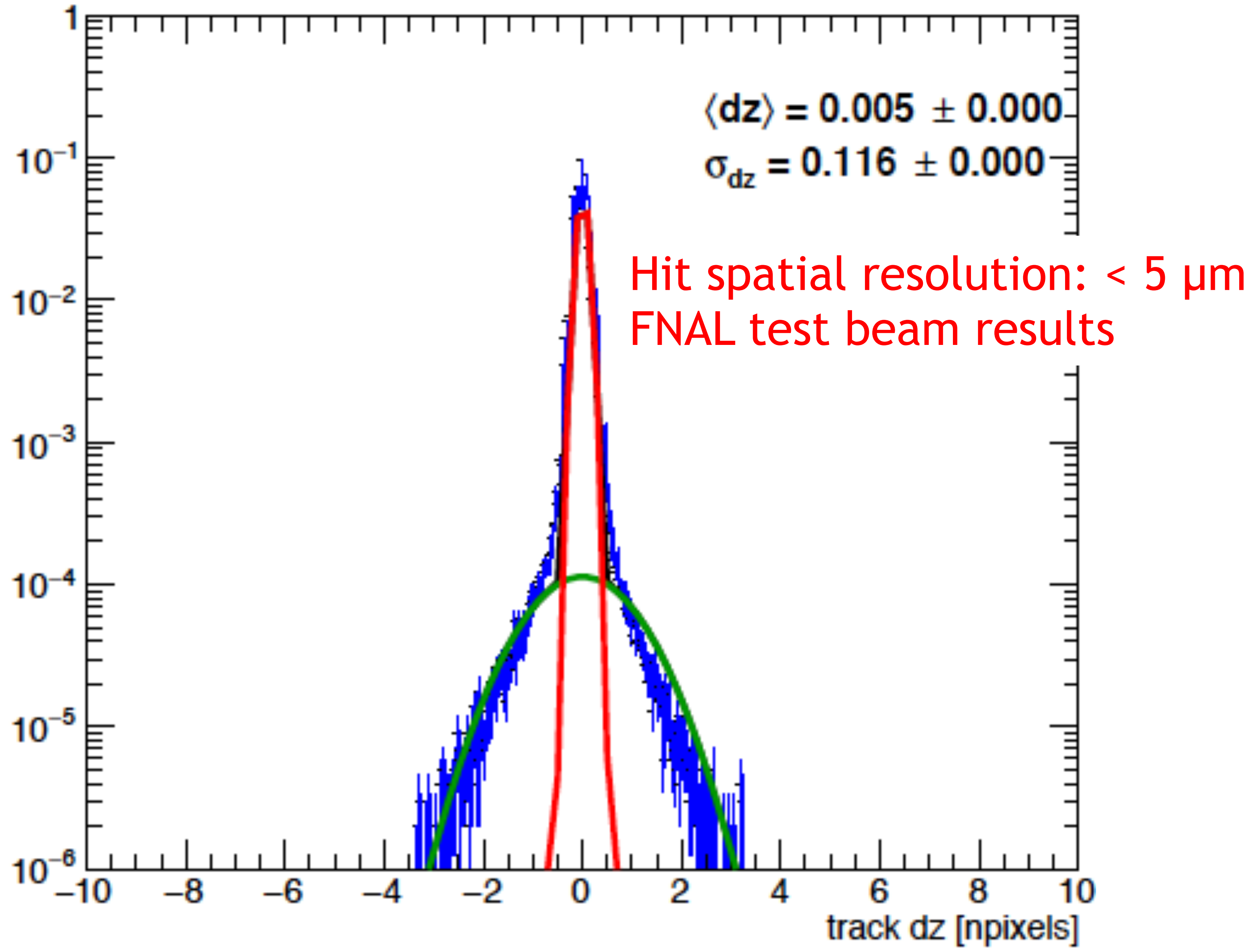
Calorimeter-related performance studied using GEANT simulations verified with **test beam data**

MVTX enables world-class HF science program

Stave layout beam view

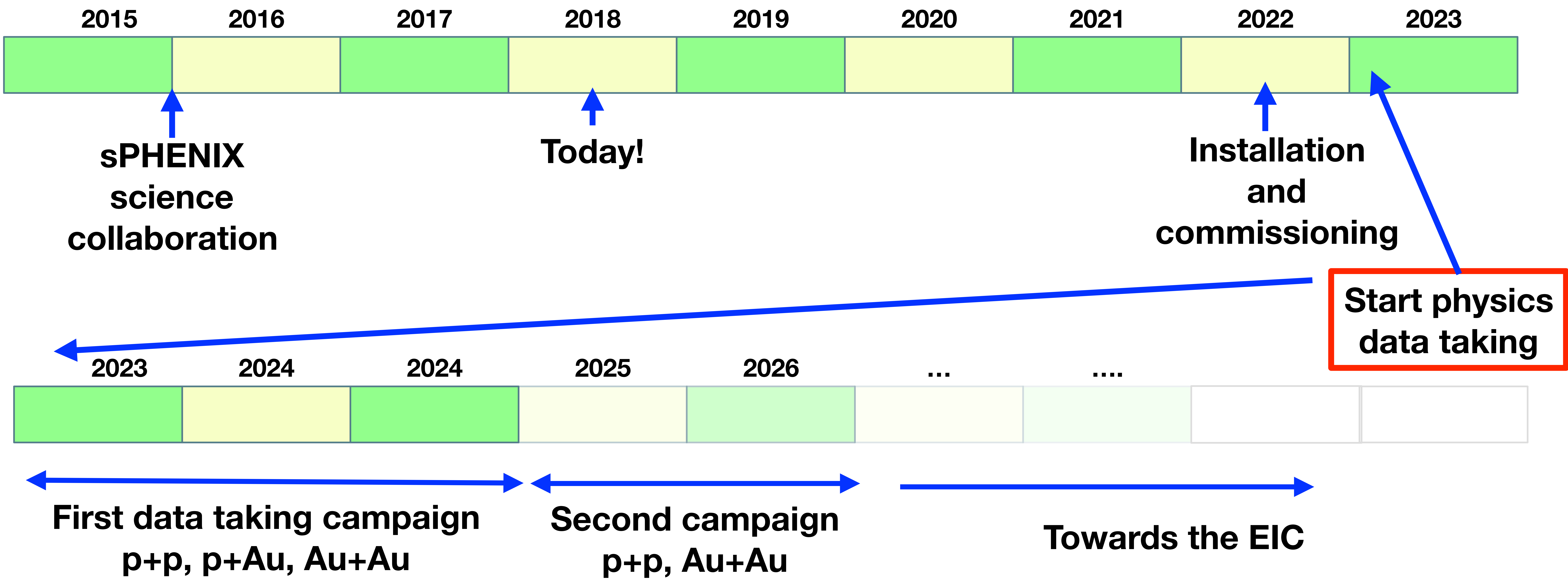


MVTX spatial resolution



MVTX based on copy of ALICE staves with support structure modified for sPHENIX

Realizing and running sPHENIX



Multi-year run plan for sPHENIX

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}

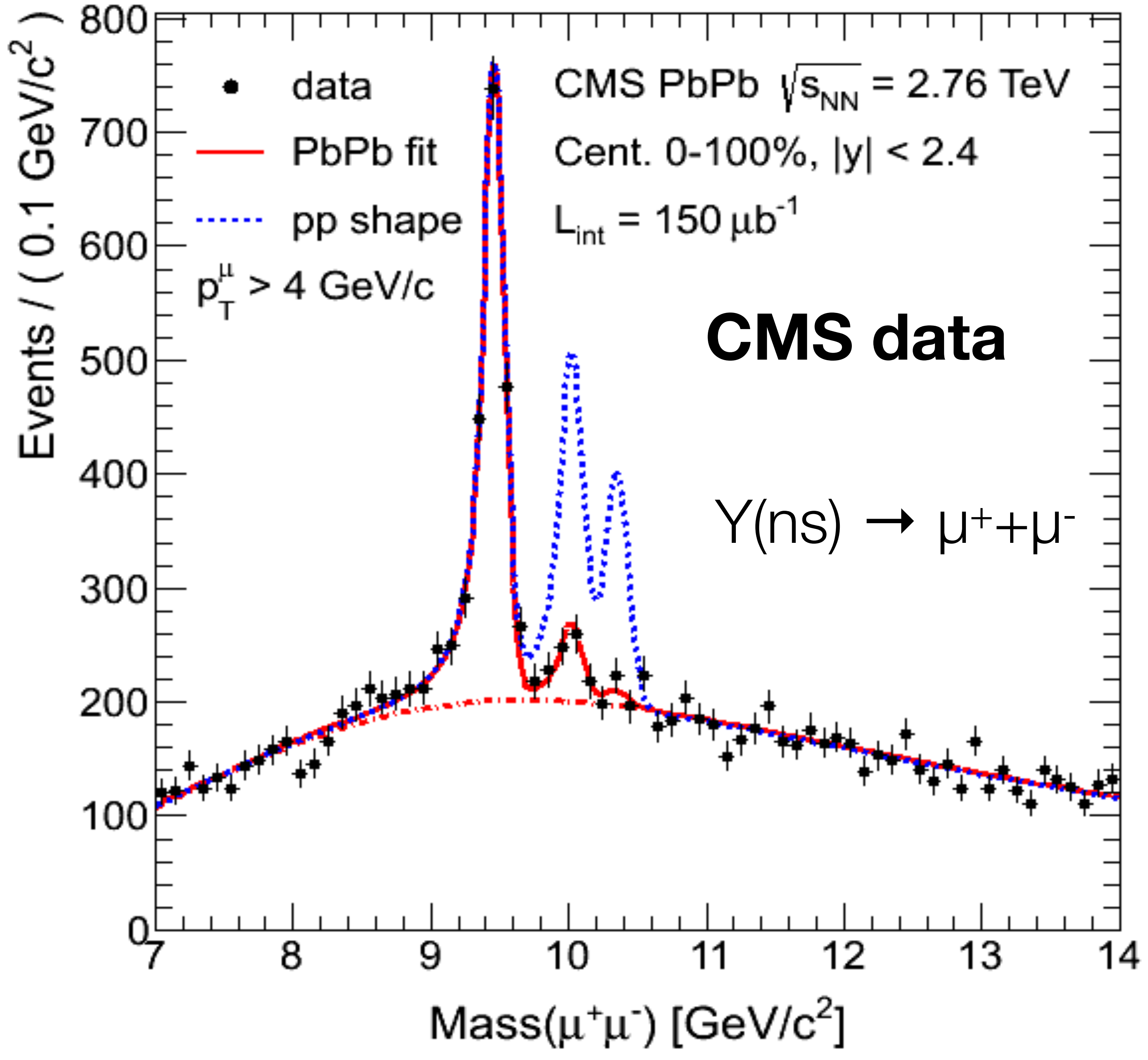
- Consistent with DOE CD-0 “mission need” document
- Incorporates BNL C-AD guidance on luminosity evolution
- Incorporates commissioning time in first year

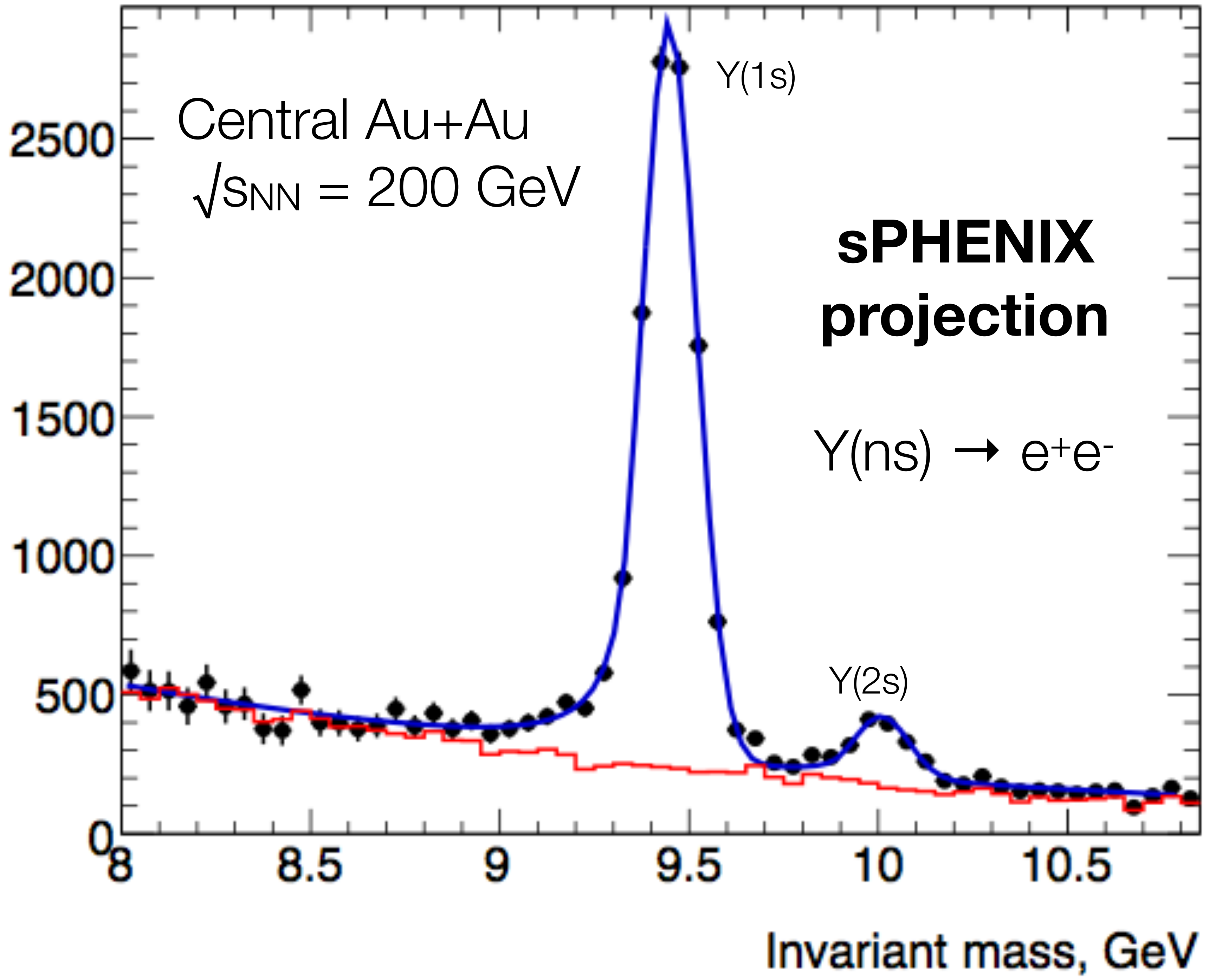
Minimum bias Au+Au at 15 kHz for |z| < 10 cm:

47 billion (Year-1) + **96 billion** (Year-2) + **96 billion** (Year-3) = 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.

Physics projection: Upsilons at sPHENIX vs LHC



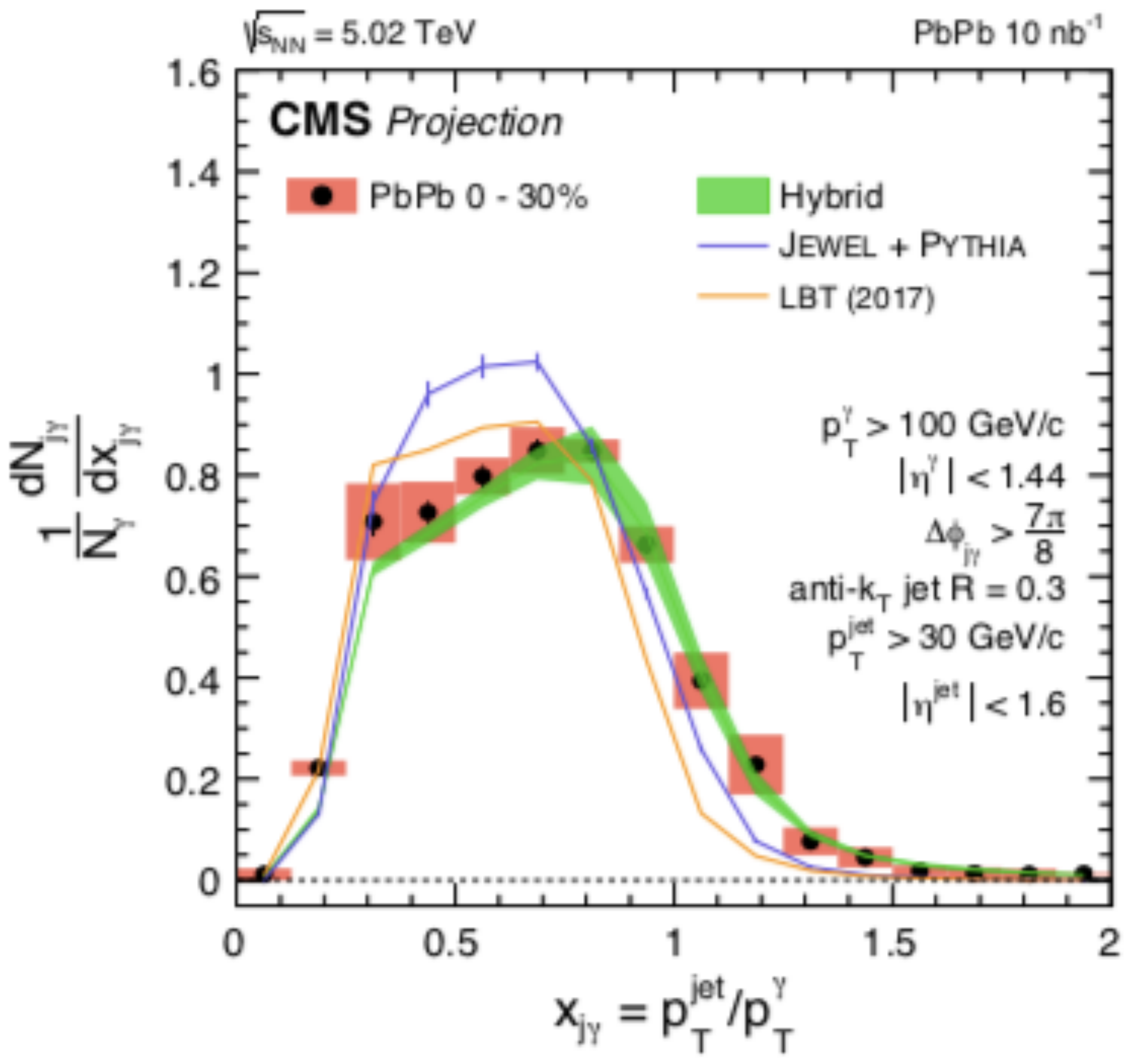


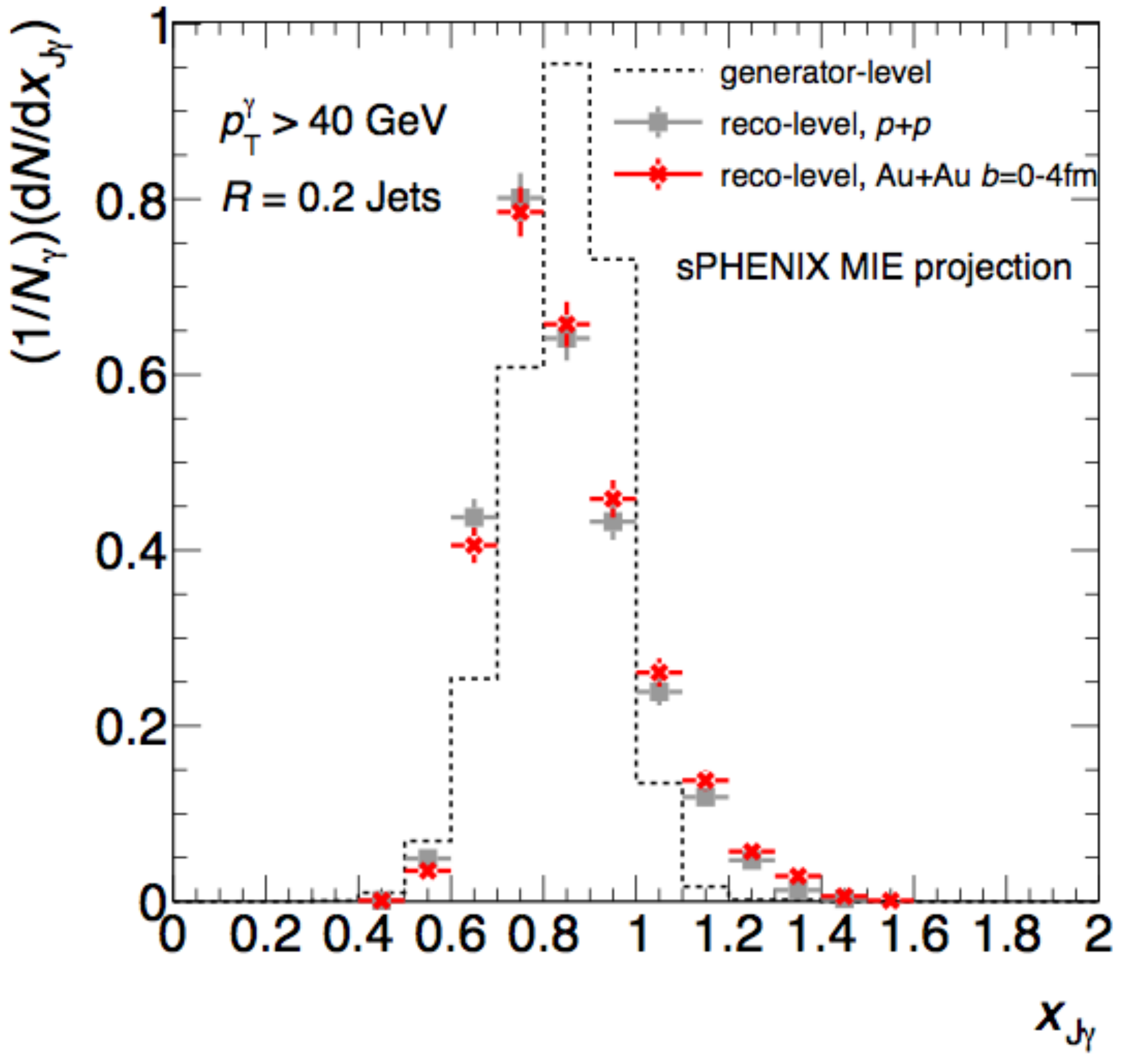
Sequential suppression of Υ(nS) states reveals QGP Debye screening length

As at LHC, Υ(3s) will be challenging to see in Au+Au

Physics projection: Jets in sPHENIX vs LHC

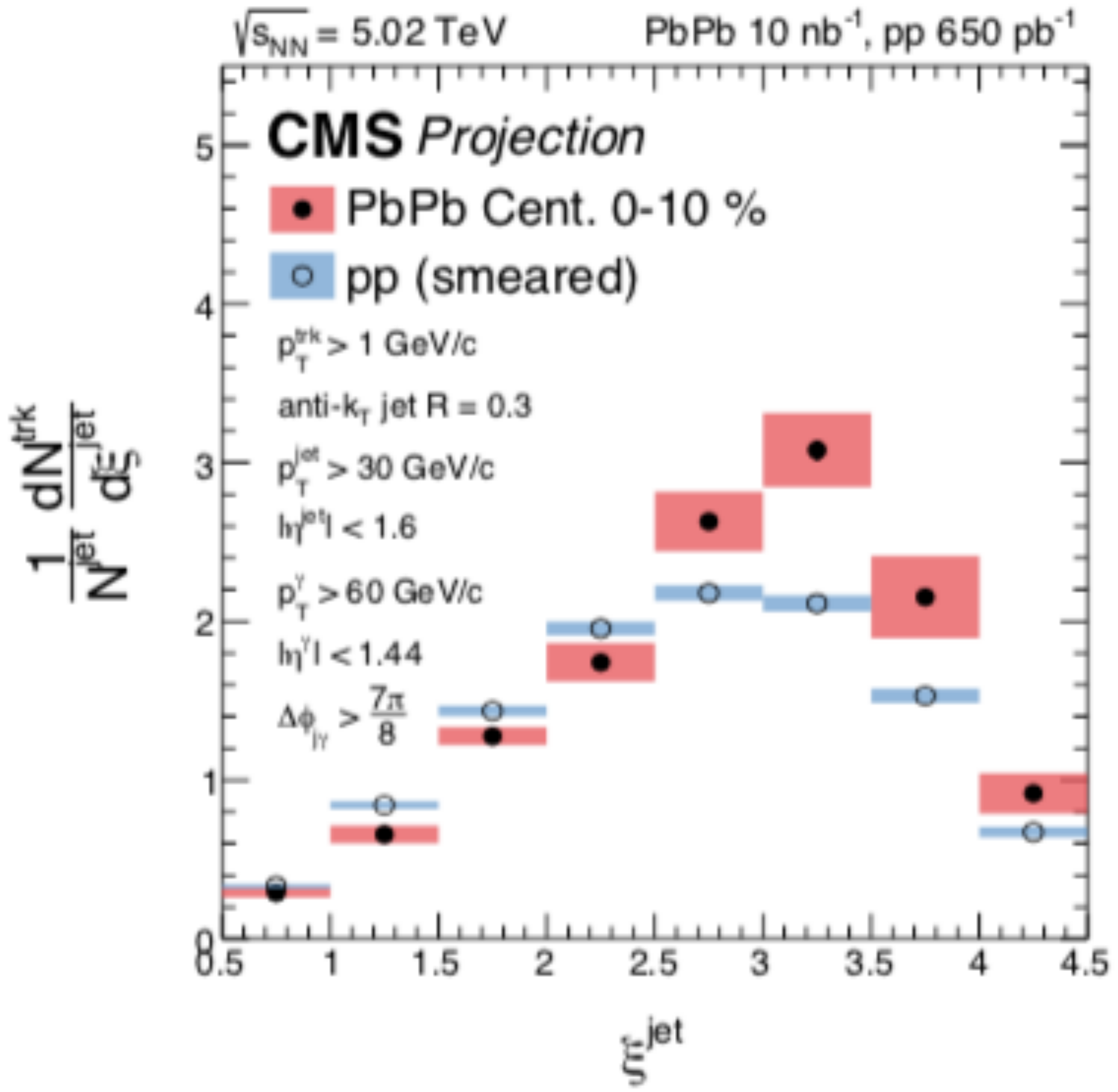
γ+Jet momentum balance



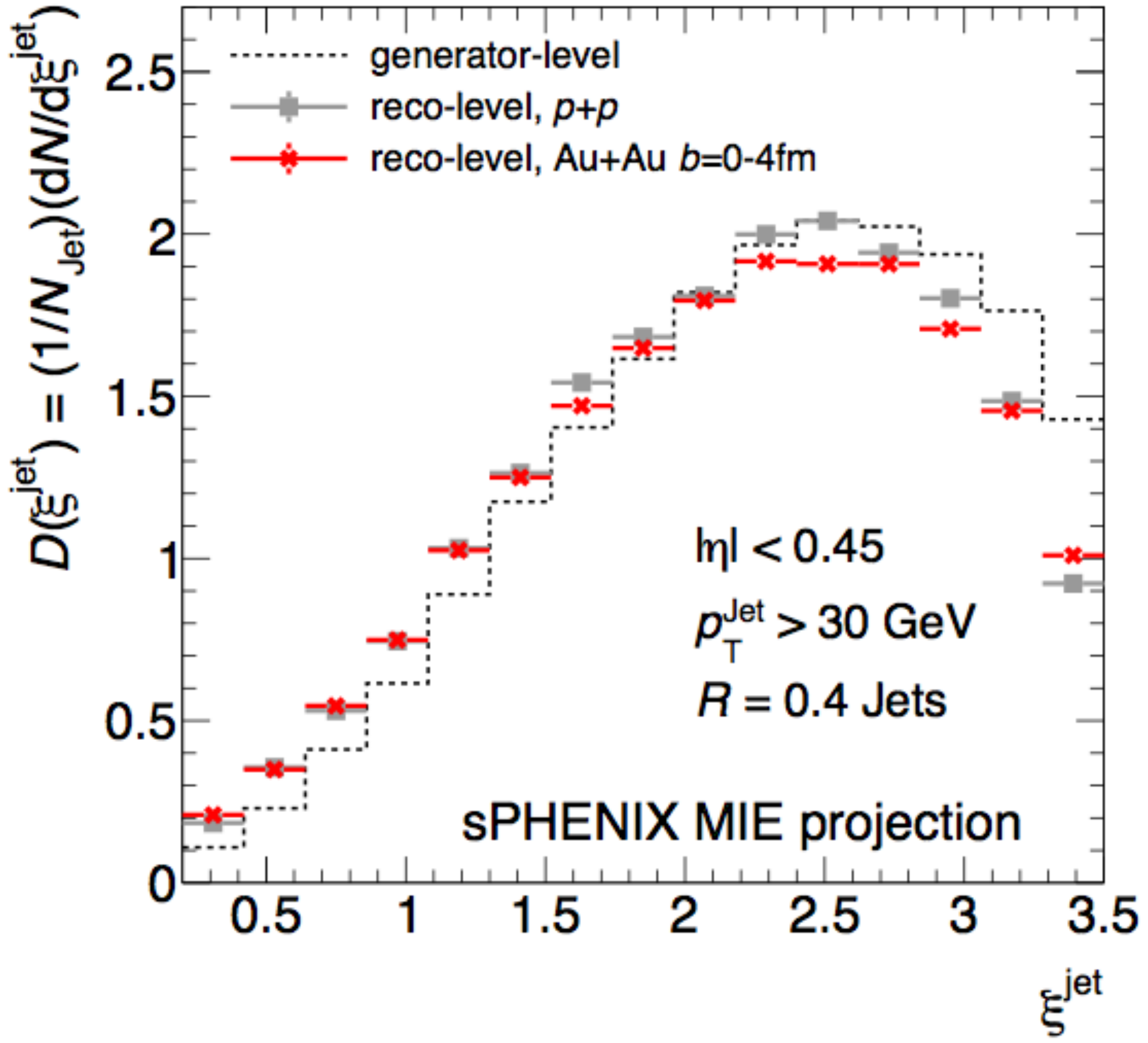


Direct measurement of parton energy loss in QGP

γ+Jet fragmentation function



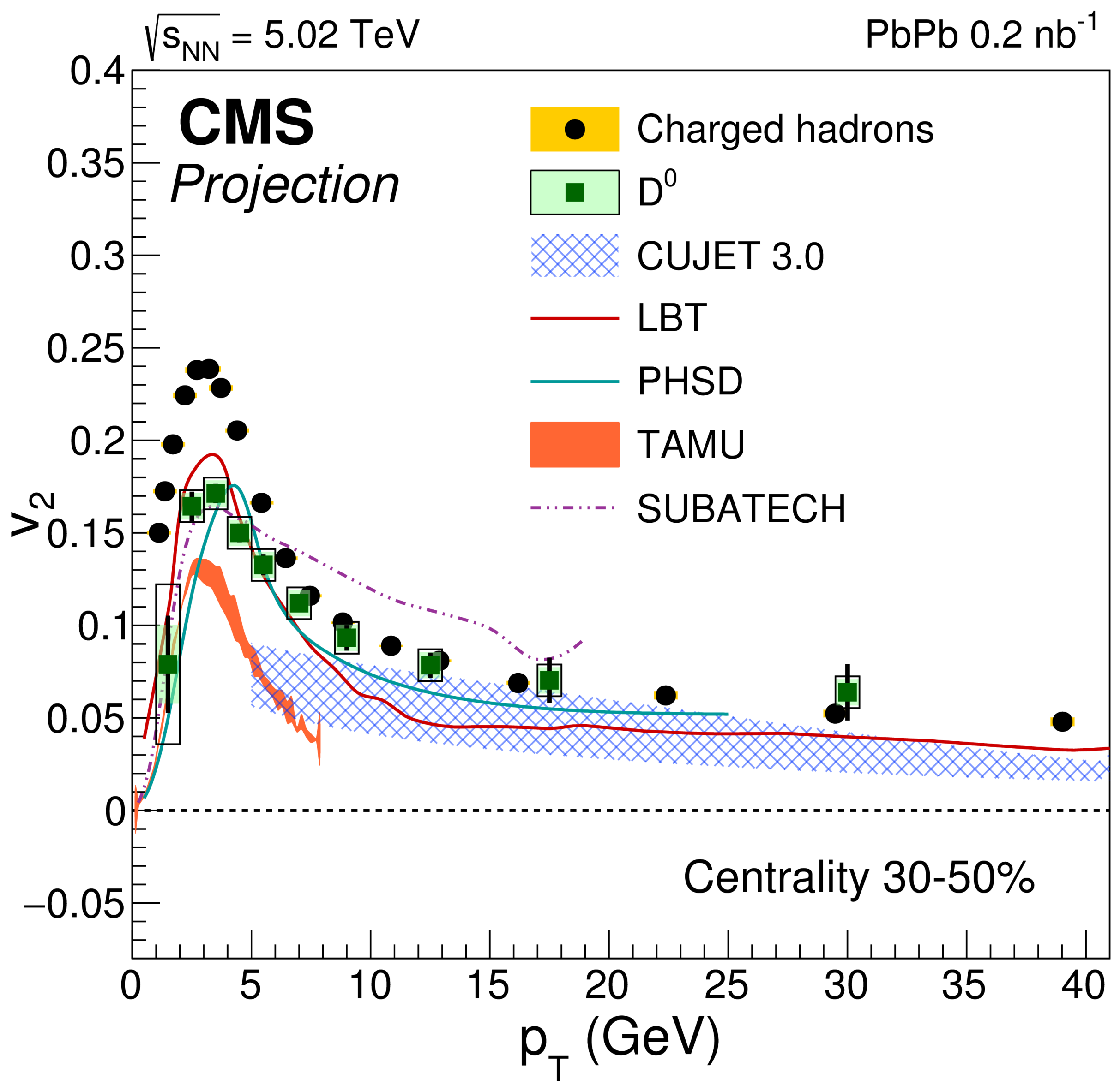
LHC projections for Run III+IV

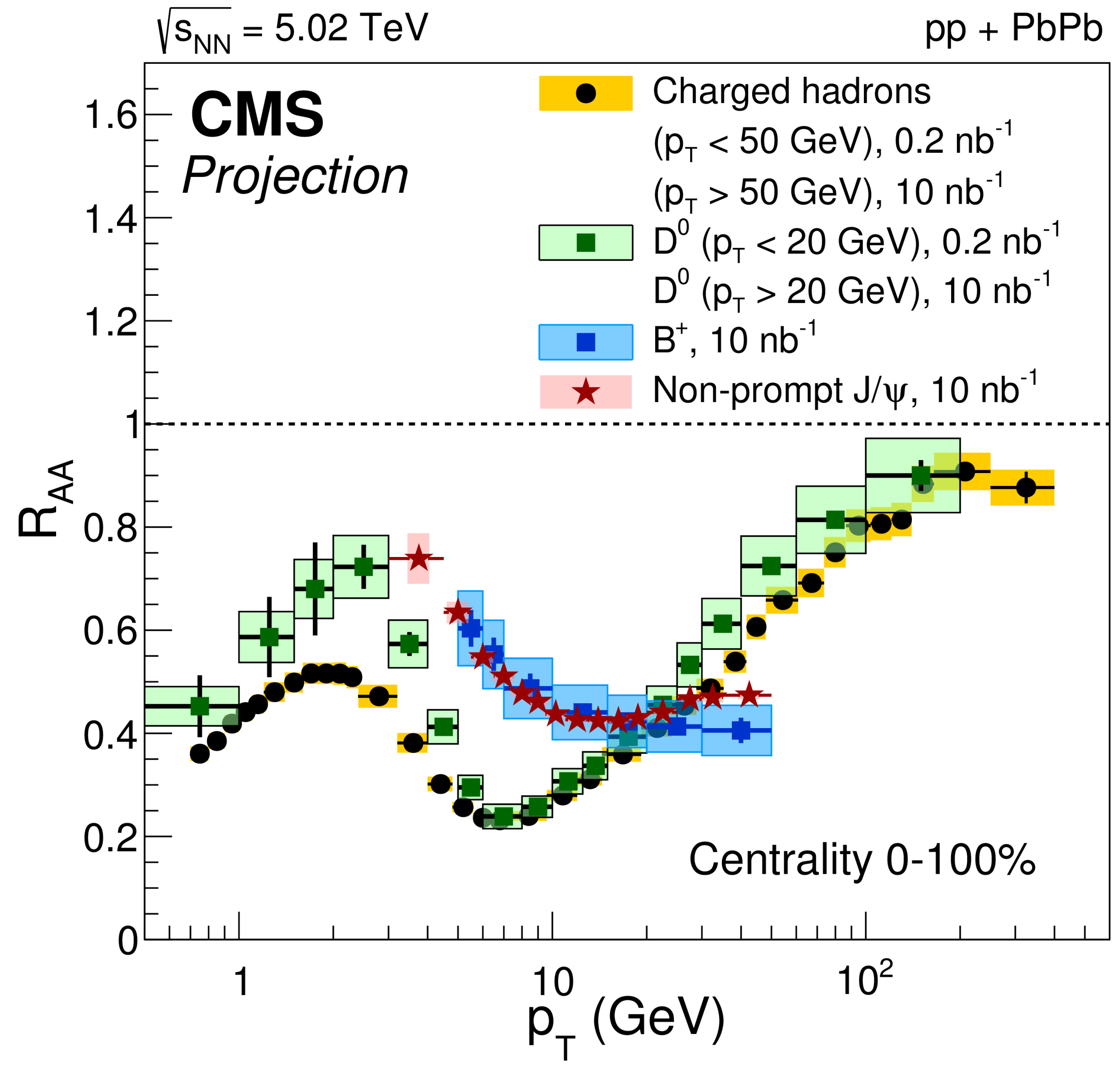


Modification of parton shower in QGP

sPHENIX projection

Physics projection: Heavy flavor at sPHENIX vs LHC

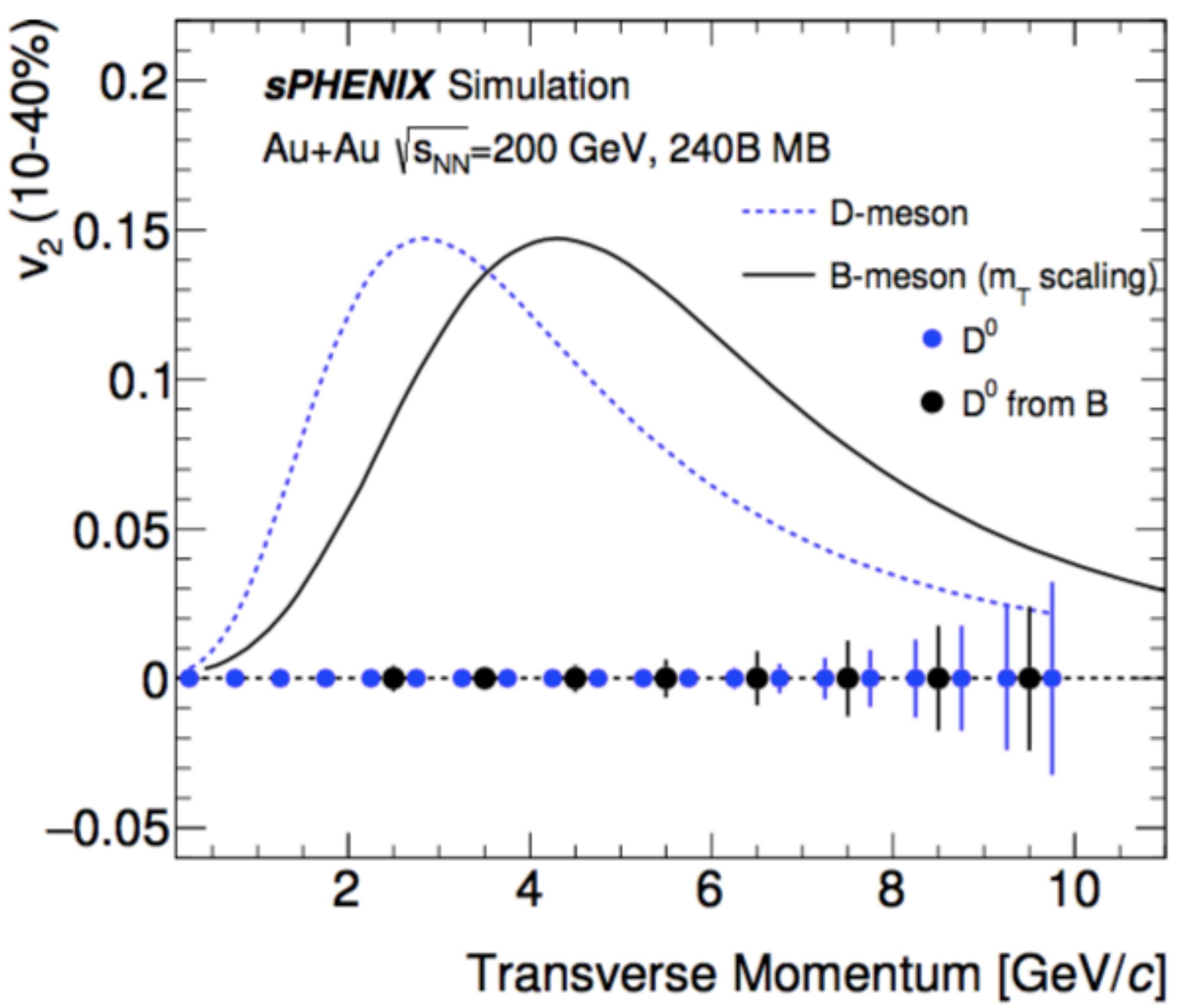


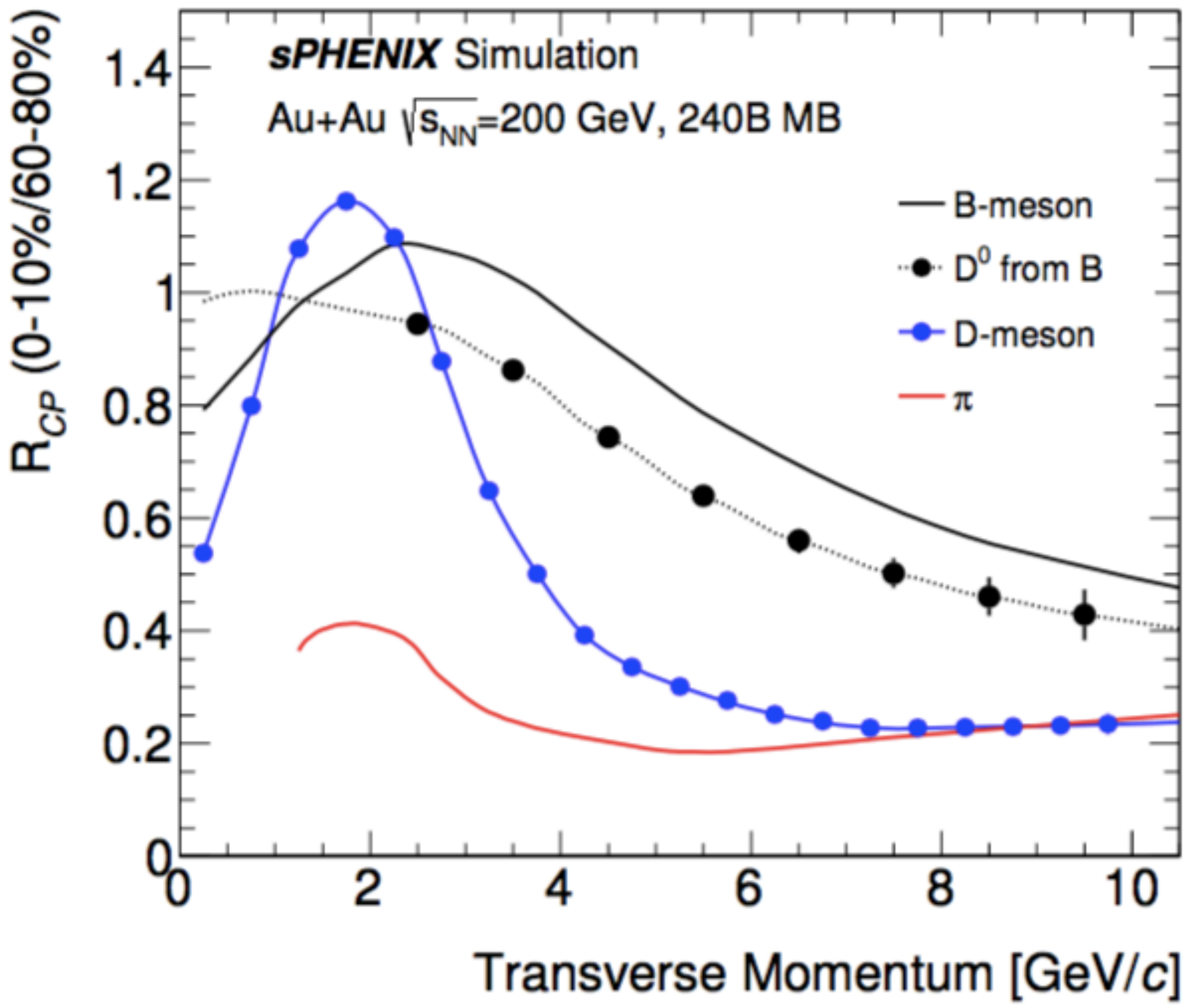


LHC projections for Run III+IV

“Elliptic flow” measures c and b quark thermalization in medium

Open heavy flavor suppression probes flavor dependence of energy loss



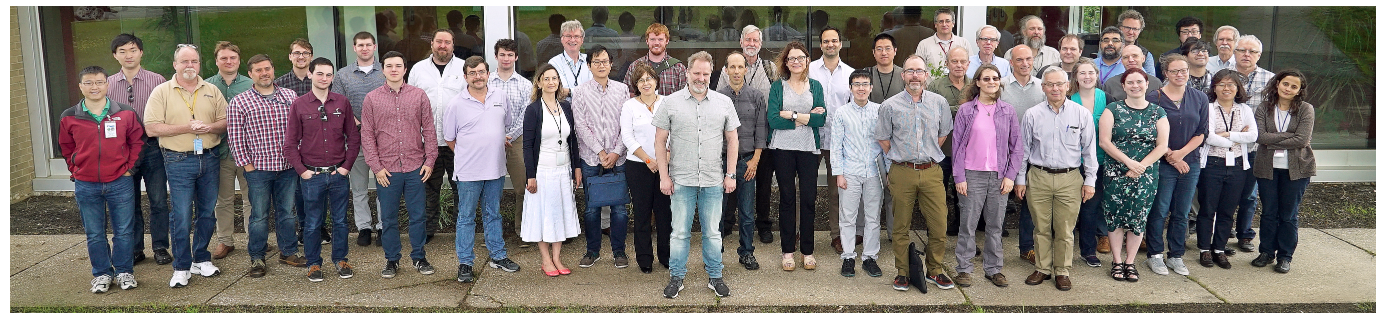


sPHENIX projections

sPHENIX collaboration: 70 institutions and counting

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
Joint Czech Group
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 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
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 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

BNL, June '18



Santa Fe, Dec '17

BNL, June '17

GSU (Atlanta), Dec '16

BNL, June '16

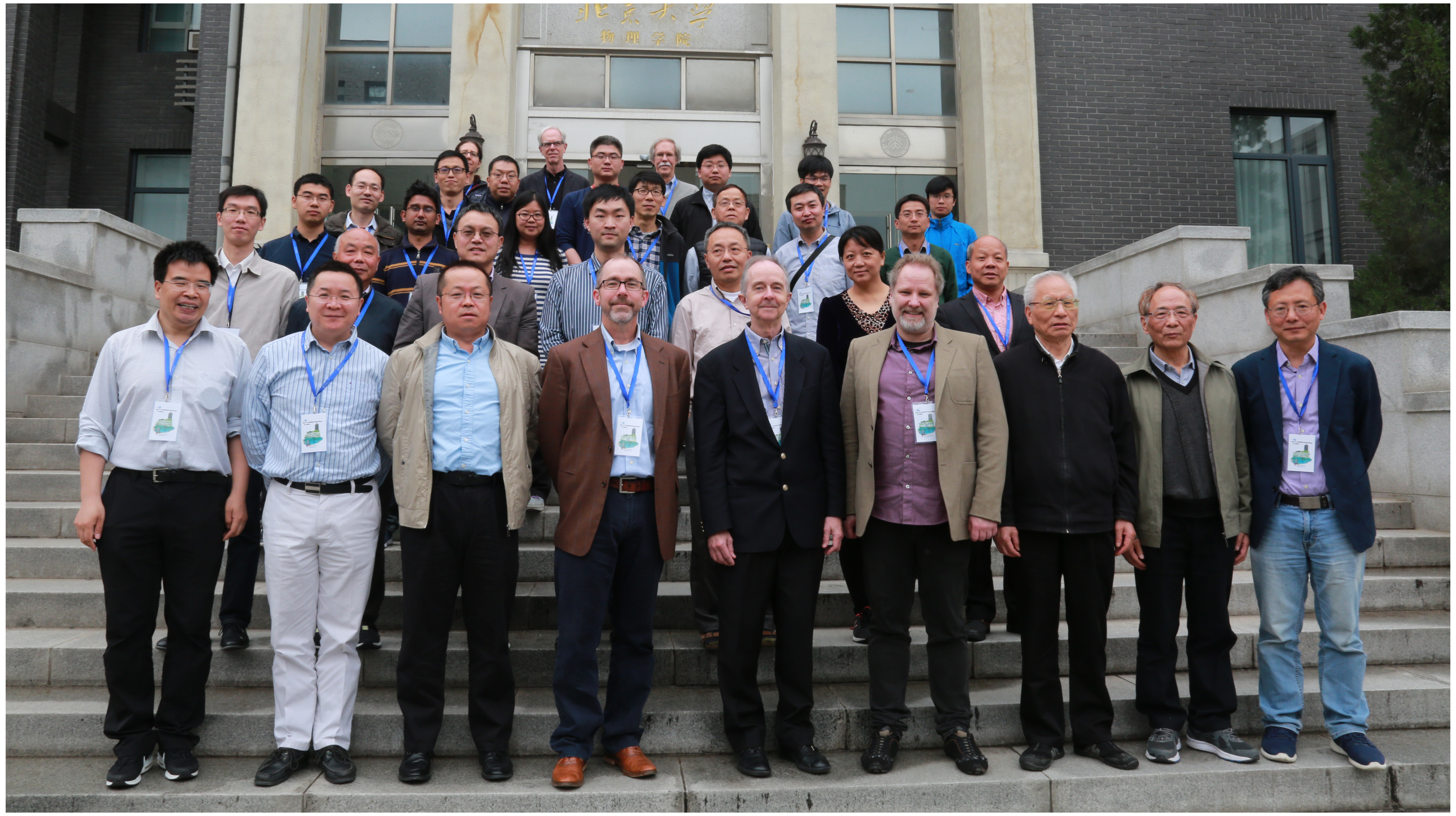
Rutgers, Dec'15

Growth of collaboration since CD-0

2016	2017	2018
Berkeley, University of California	Purdue University	University of Science and Technology of China; Fudan University
Temple University	CEA	Tsinghua University; Sun Yat-sen University
Berkeley Lab (Lawrence Berkeley National Laboratory)	Central China Normal University	IMP; SINAP
		Peking University; IAE

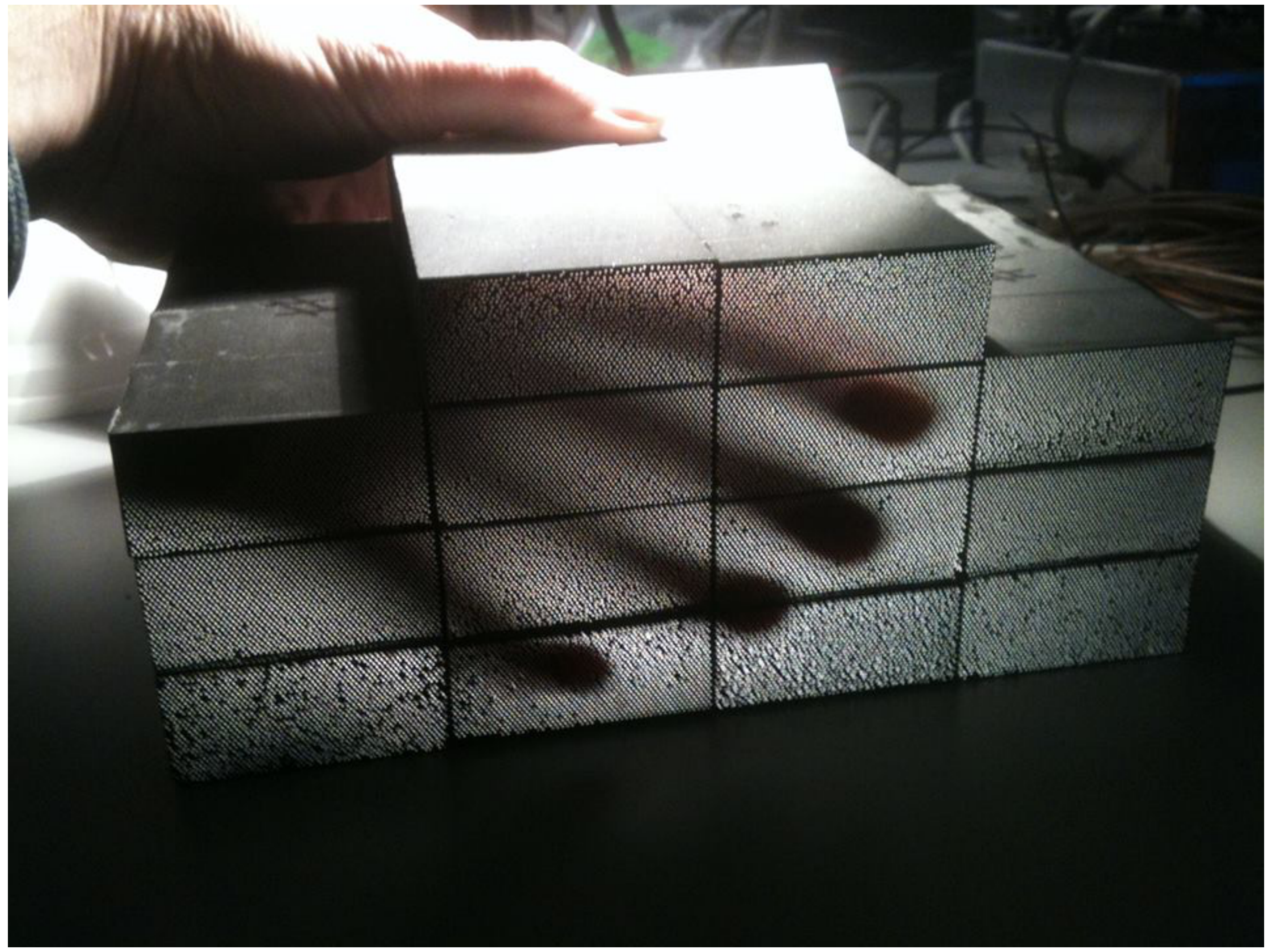
Broad expertise in relevant physics, silicon, TPCs, calorimetry

First sPHENIX Workshop in China

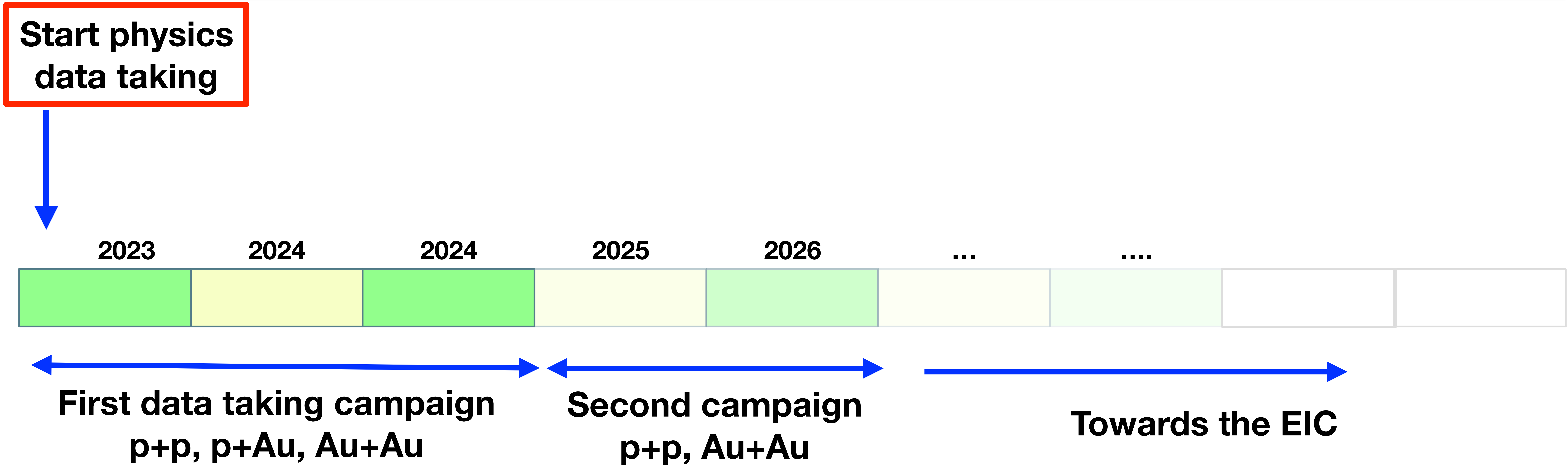


Peking University, April 22-23, 2018

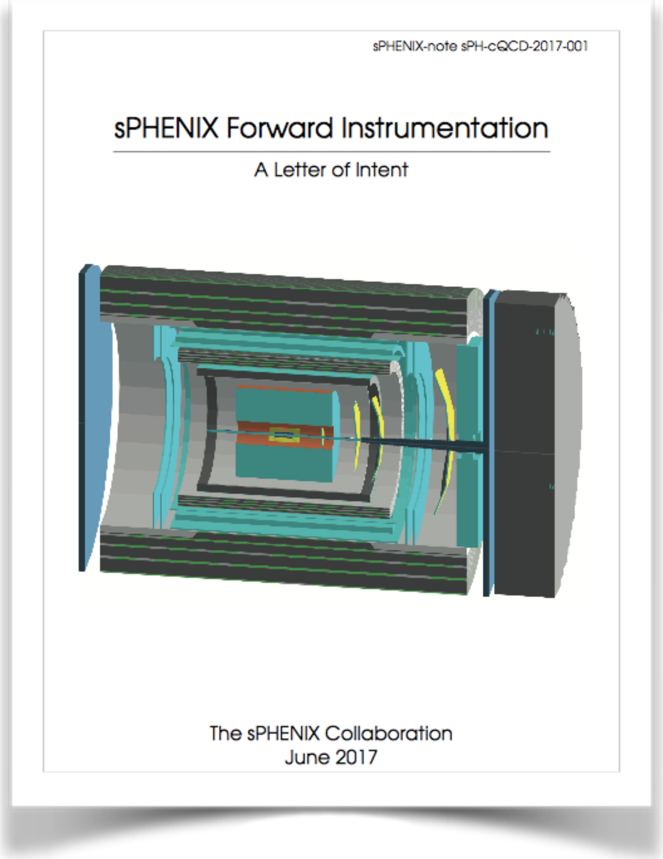
Consortium of Chinese institutions planning to establish EMCAL block production facility



sPHENIX in the 2020's and beyond



Strong interest in Cold QCD with sPHENIX

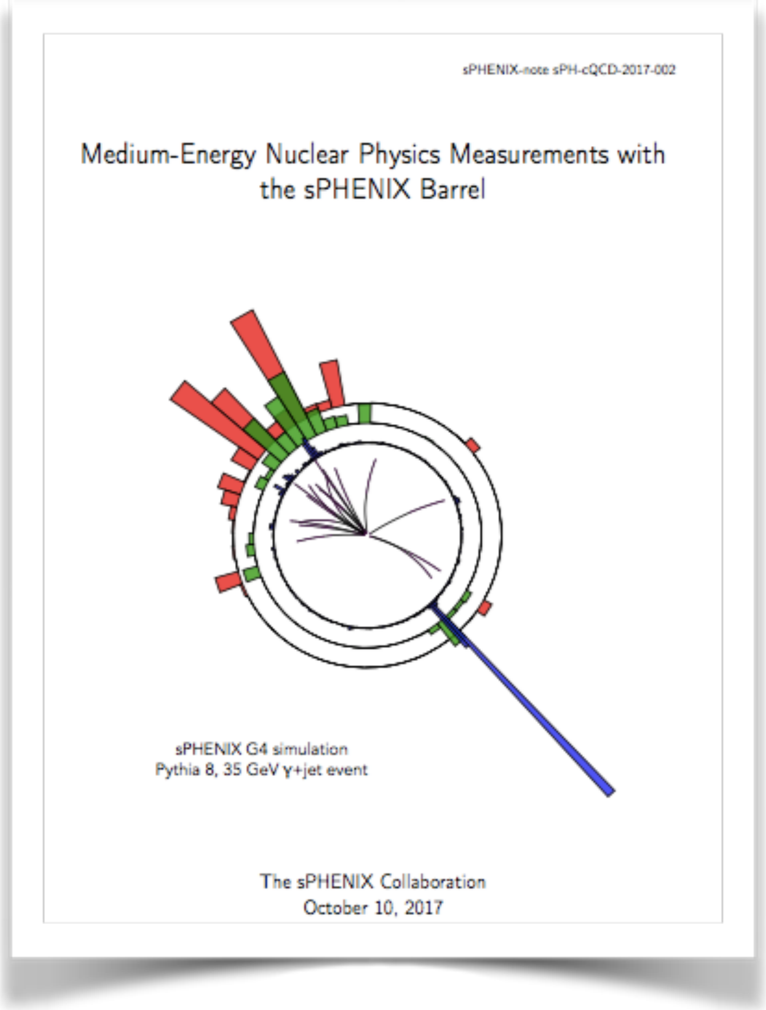


June '17: Modest forward upgrade, following invitation by ALD to STAR and sPHENIX.

Exciting p+p and p+A program, but also strengthening of core sPHENIX program through high-rate, high resolution, large acceptance calorimetry and tracking

Oct '17: Medium-energy physics with sPHENIX Barrel

Demonstrates wide range of physics opportunities with MIE detector



Charged to produce Letter of Intent for EIC detector based on sPHENIX

April 5, 2018

Dear Dave and Gunther

As you know, the eRHIC design team is close to completing the pre-conceptual design report, the NAS Study Panel is expected to publish its assessment of the value of a US based EIC in the May time frame, and DOE may declare CD-0 for an EIC sometime in the second half of 2018. In this context it will be important that we have a clear and up-to-date understanding of the value of sPHENIX as the basis of a Day-1 eRHIC detector. **The ePHENIX Letter of Intent now is four years old and urgently requires an update** that takes into account the developments in detector technology and interaction region design.

I am therefore asking you to **establish a detector study group consisting of members of the sPHENIX Collaboration and other individuals interested in EIC science from outside the sPHENIX Collaboration to update the Letter of Intent for an EIC detector built around the BaBar solenoid** in the context of the eRHIC pre-CDR. The Letter of Intent should contain an outline of the expected physics program for the detector in the first five years of running, using estimates of the luminosity development anticipated for initial EIC operation.

In parallel, I am asking you to perform a cost estimate of the construction costs in FY2018 dollars. This estimate should be performed with the methodology that the NPP Director for Project Planning and Oversight of Accelerator Projects, Diane Hatton, has developed for the EIC and that Elke Aschenauer and her group are using to develop a cost estimate for a generic EIC detector in conjunction with the ongoing pre-CDR cost estimation process. Please, do not include the cost estimate in the updated Letter of Intent, but transmit it as a separate document.

A brief presentation on the physics capabilities of the detector should be prepared for the PAC meeting in June 2018. After receiving comments from the PAC, I expect to be able to provide feedback and further guidance with respect to the process and goals of developing the updated LoI. The final versions of the revised LoI and the associated cost estimate should be submitted to me by September 30, 2018. The NPP Director for Project Planning and Oversight of Detector Projects, Maria Chamizo Llatas, will then convene a review with external experts, as appropriate.

These are exciting times for all those interested in the physics of an EIC. The facility is finally at the doorstep from concept onto the path toward realization. I hope that this request will build on and further strengthen the excitement of all those within the sPHENIX collaboration who are looking forward to participation in a future EIC physics program.

Best regards

Berndt

sPHENIX @ EIC

Timely: US National Academies of Science recommend construction of EIC


The National Academies of | SCIENCES ENGINEERING MEDICINE THE NATIONAL ACADEMIES PRESS

This PDF is available at http://nap.edu/25171 SHARE

An Assessment of U.S.-Based Electron-Ion Collider Science

DETAILS

114 pages | 7 x 10 | PAPERBACK
ISBN 978-0-309-47856-4 | DOI 10.17226/25171

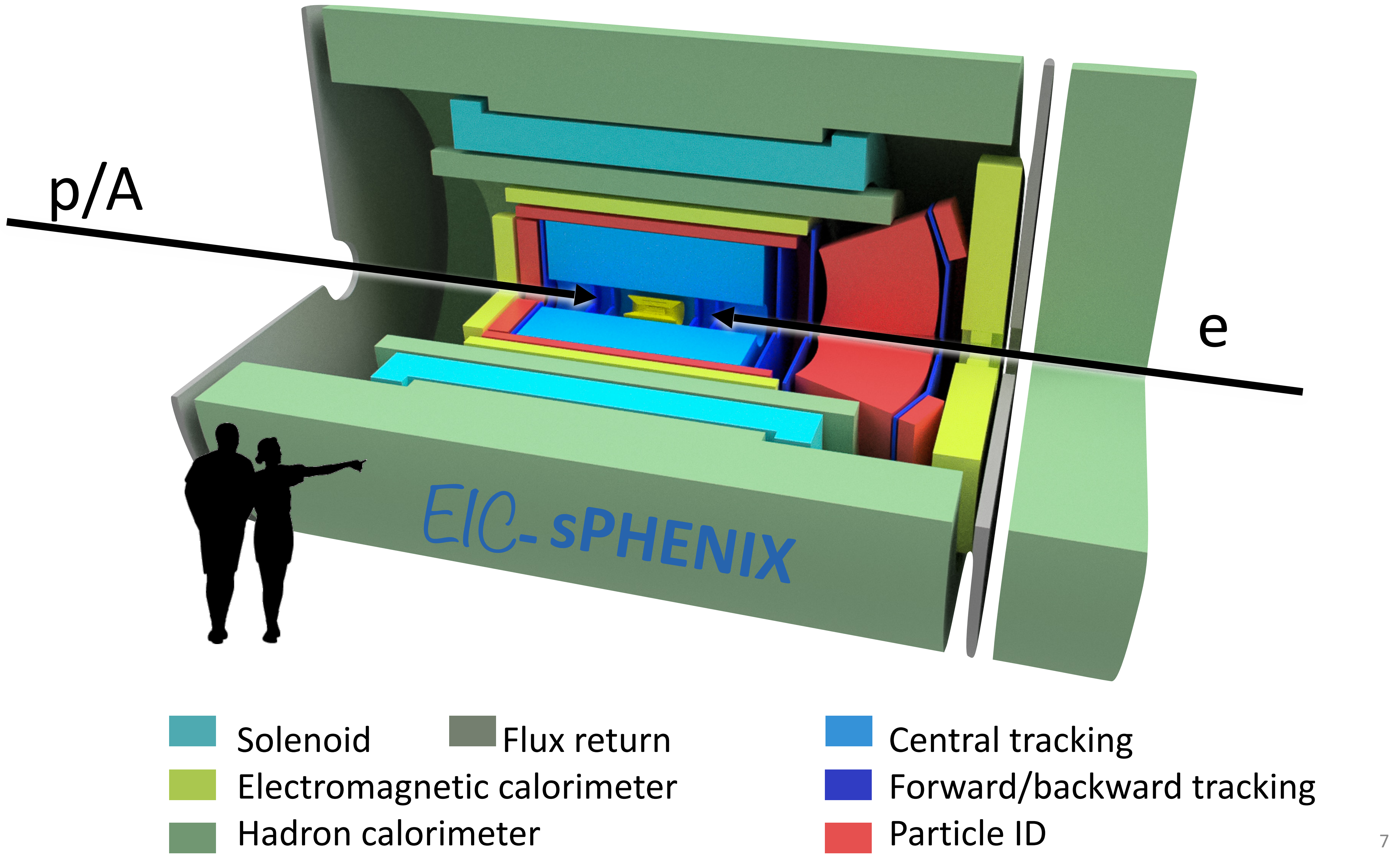
GET THIS BOOK

FIND RELATED TITLES

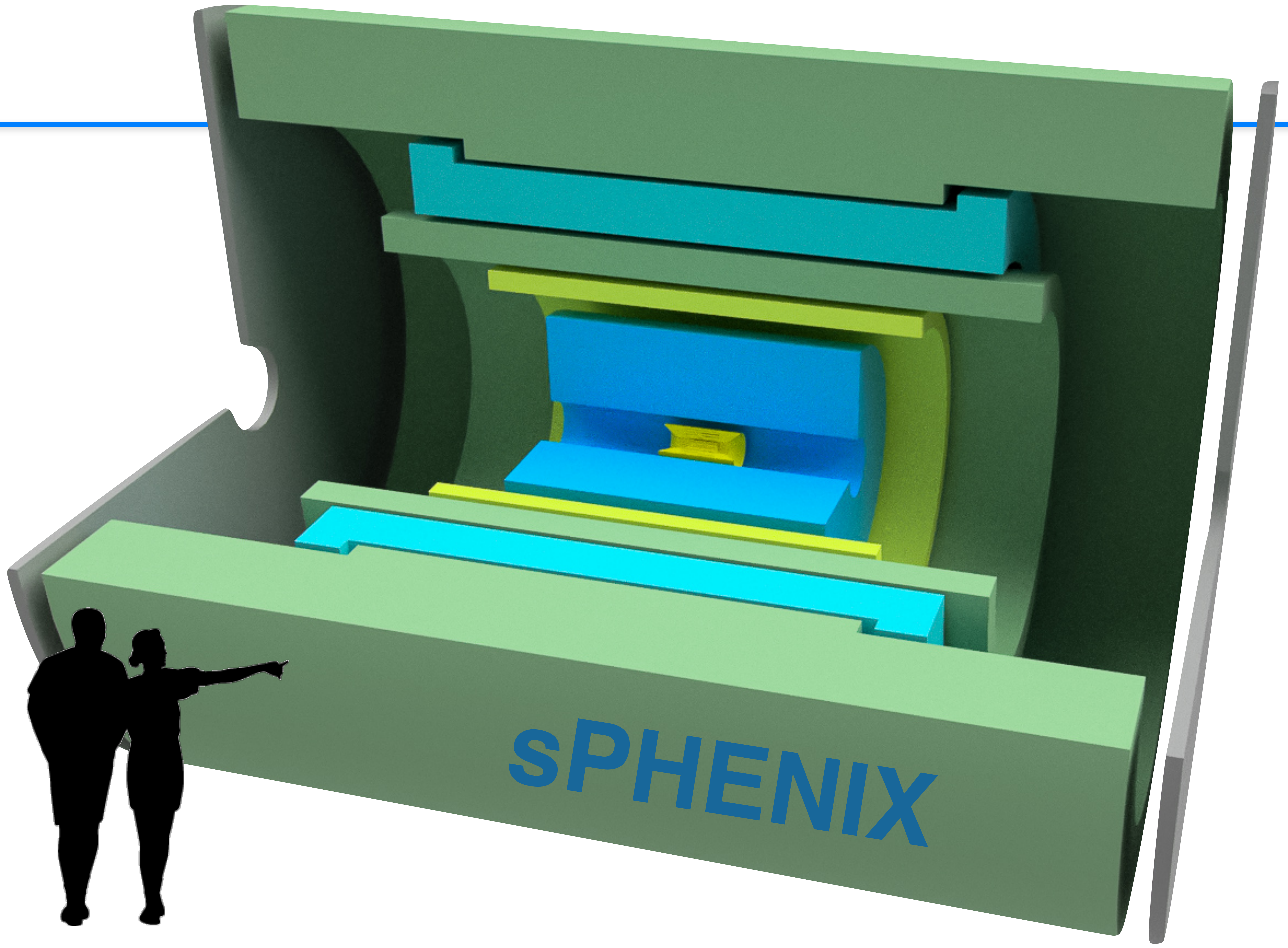
CONTRIBUTORS

Committee on U.S.-Based Electron-Ion Collider Science Assessment; Board on Physics and Astronomy; Division on Engineering and Physical Sciences; National Academies of Sciences, Engineering, and Medicine

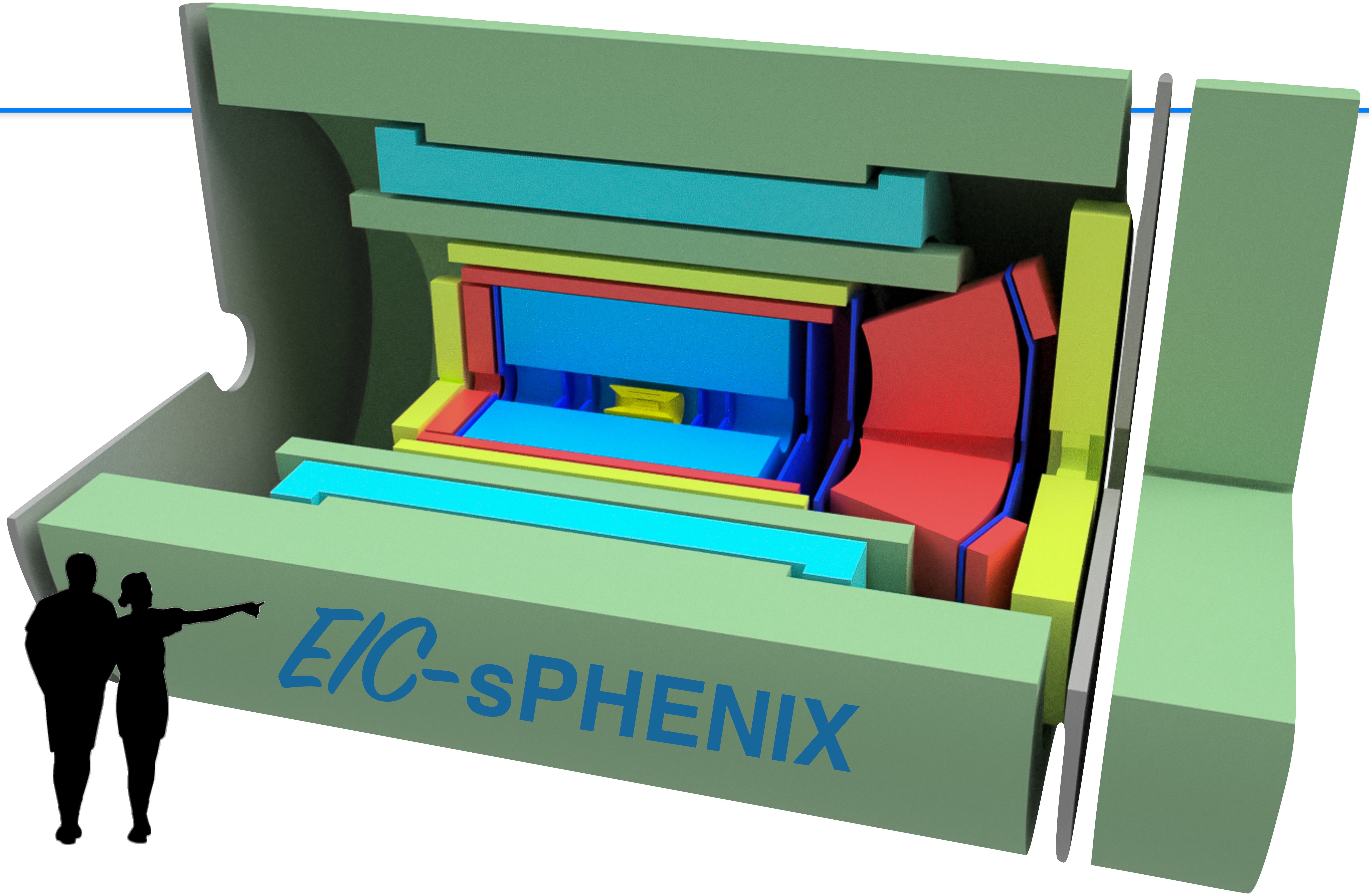
Study group (incl. non-sPHENIX members) working on EIC detector design based on sPHENIX



Deliver LOI by end of September ‘18



Solenoid
Flux return
Central tracking
Electromagnetic calorimeter
Hadron calorimeter


EIC-sPHENIX

Solenoid
Flux return
Central tracking
Electromagnetic calorimeter
Forward tracking
Hadron calorimeter
Particle ID

Outlook

- sPHENIX will probe microscopic structure of strongly coupled QGP
- New state of the art detector at RHIC, complementing capabilities of LHC
  - Jet suppression and substructure
  - Upsilon spectroscopy
  - Open heavy flavor over full kinematic range
- International collaboration, including many Chinese institutions
- Work on sPHENIX is in full swing
- Exciting physics program at RHIC in 2020's, and possibly beyond at EIC

Backup

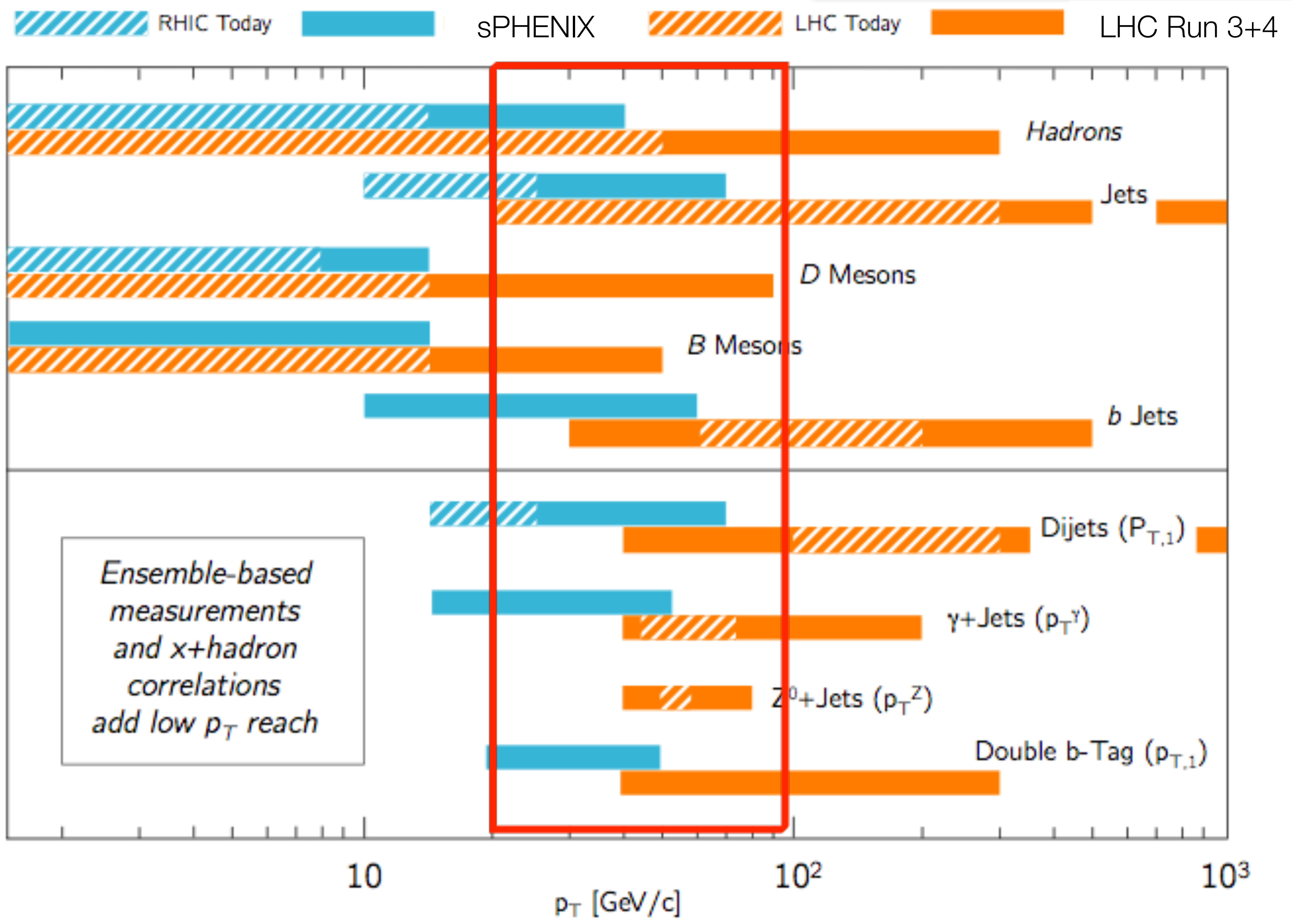
Complementarity of RHIC and LHC: Three regimes

Low p_T @RHIC:
Extend kinematic reach vs LHC
Lower background fluctuations

High p_T @LHC:
Extend kinematic reach vs RHIC
Add new probes

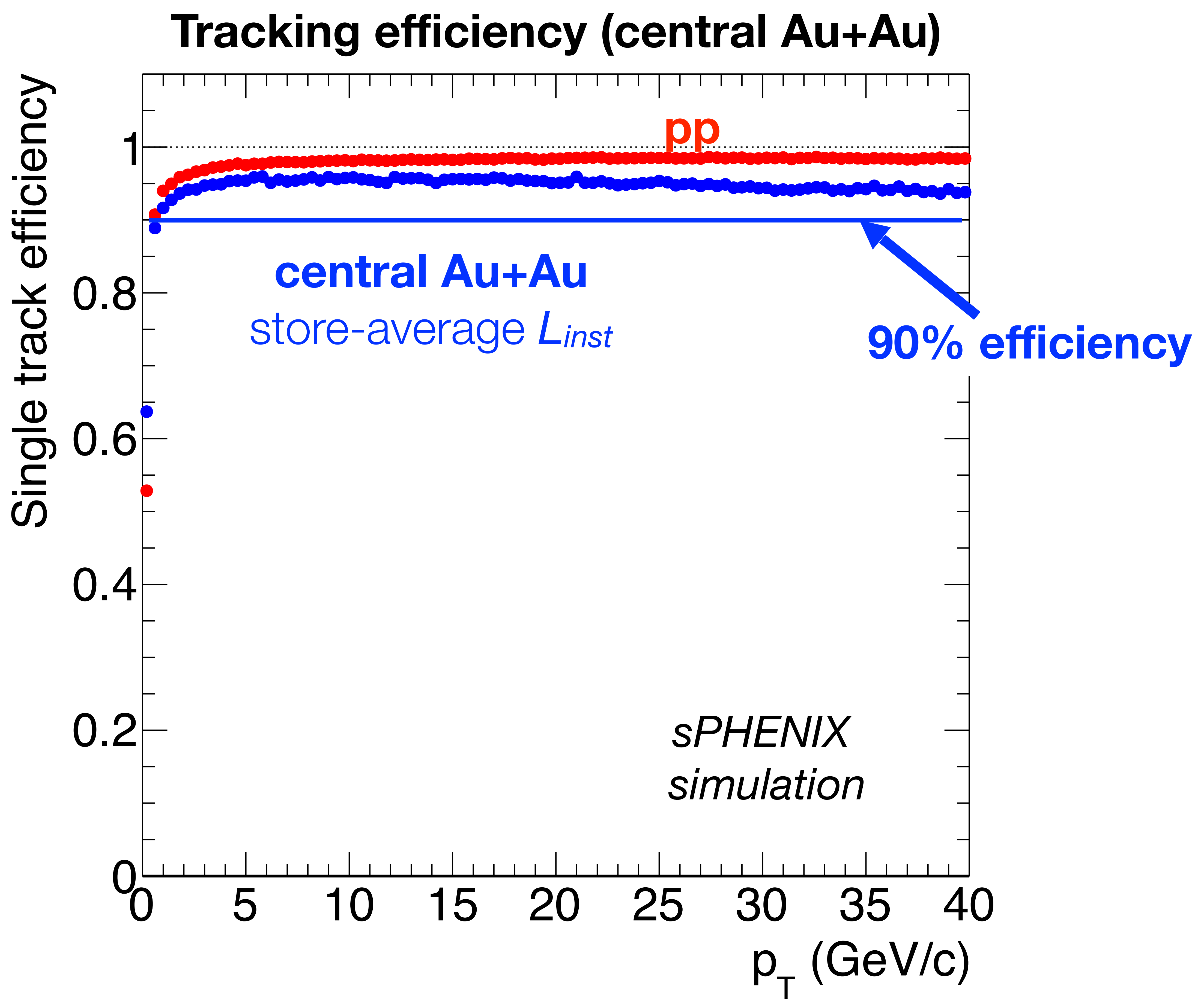
Single Hadrons and Jets

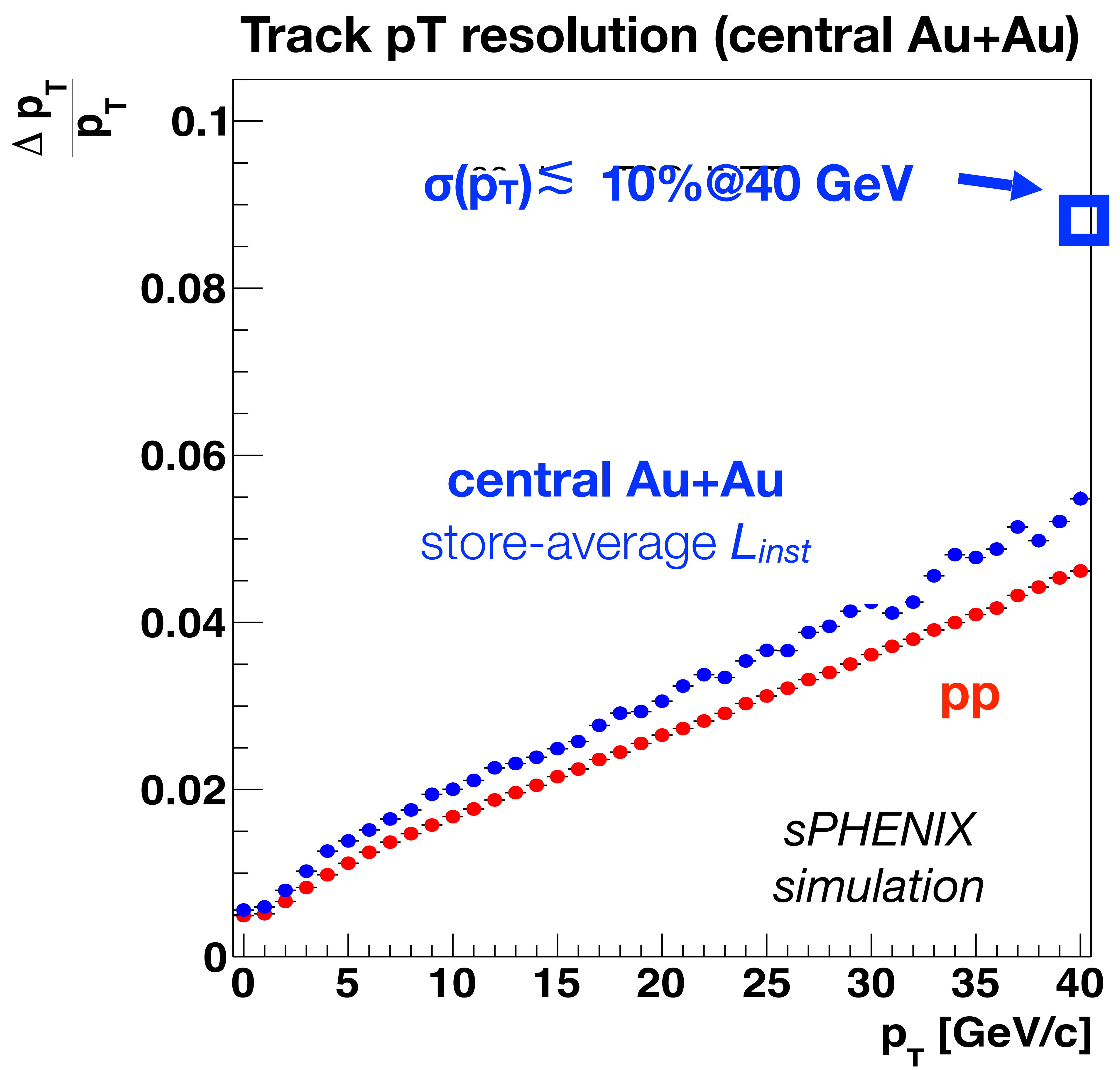
Jet+jet and photon+jet correlations



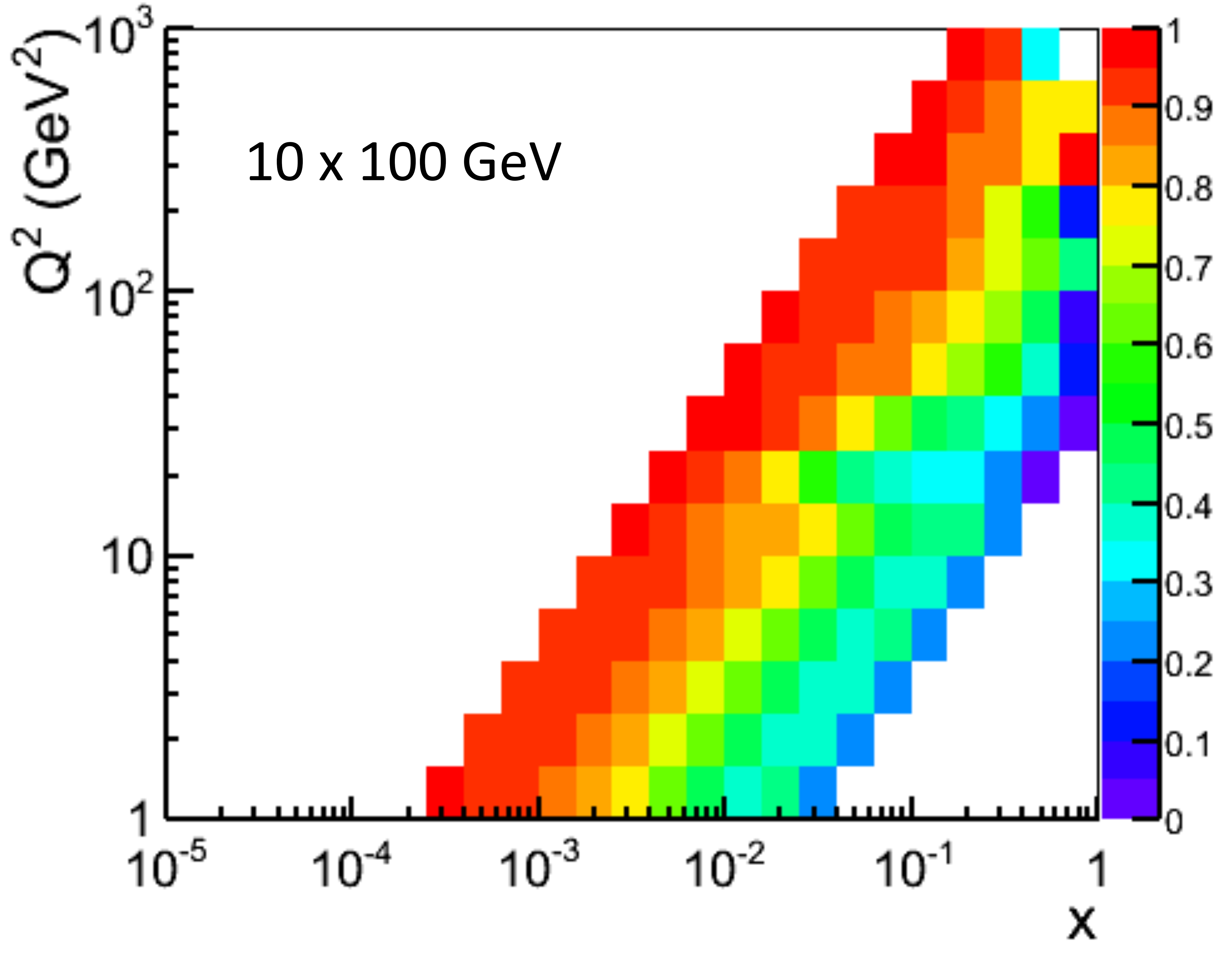
Overlap in kinematic reach:
Study the ***same*** probe for ***different*** QGP evolution

Performance simulation: Tracking efficiency and resolution





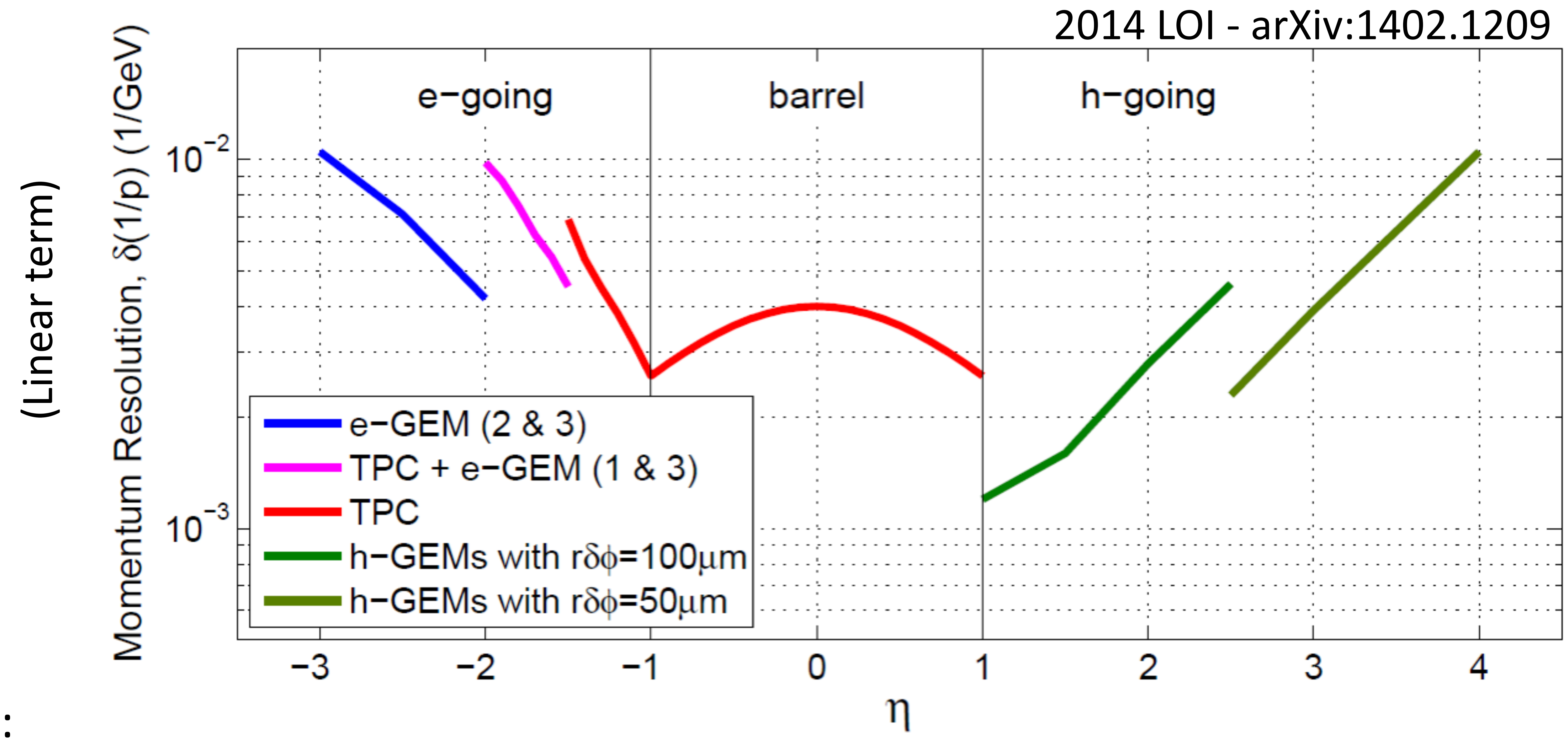
Inclusive DIS: x, Q^2 resolution based on scattered electron detection sufficient for EIC science program



Fraction of events reconstructed in correct x, Q^2 bin

Precise recovery of event kinematics from smearing effects possible using unfolding.

Continuous tracking from -4 < η < 4

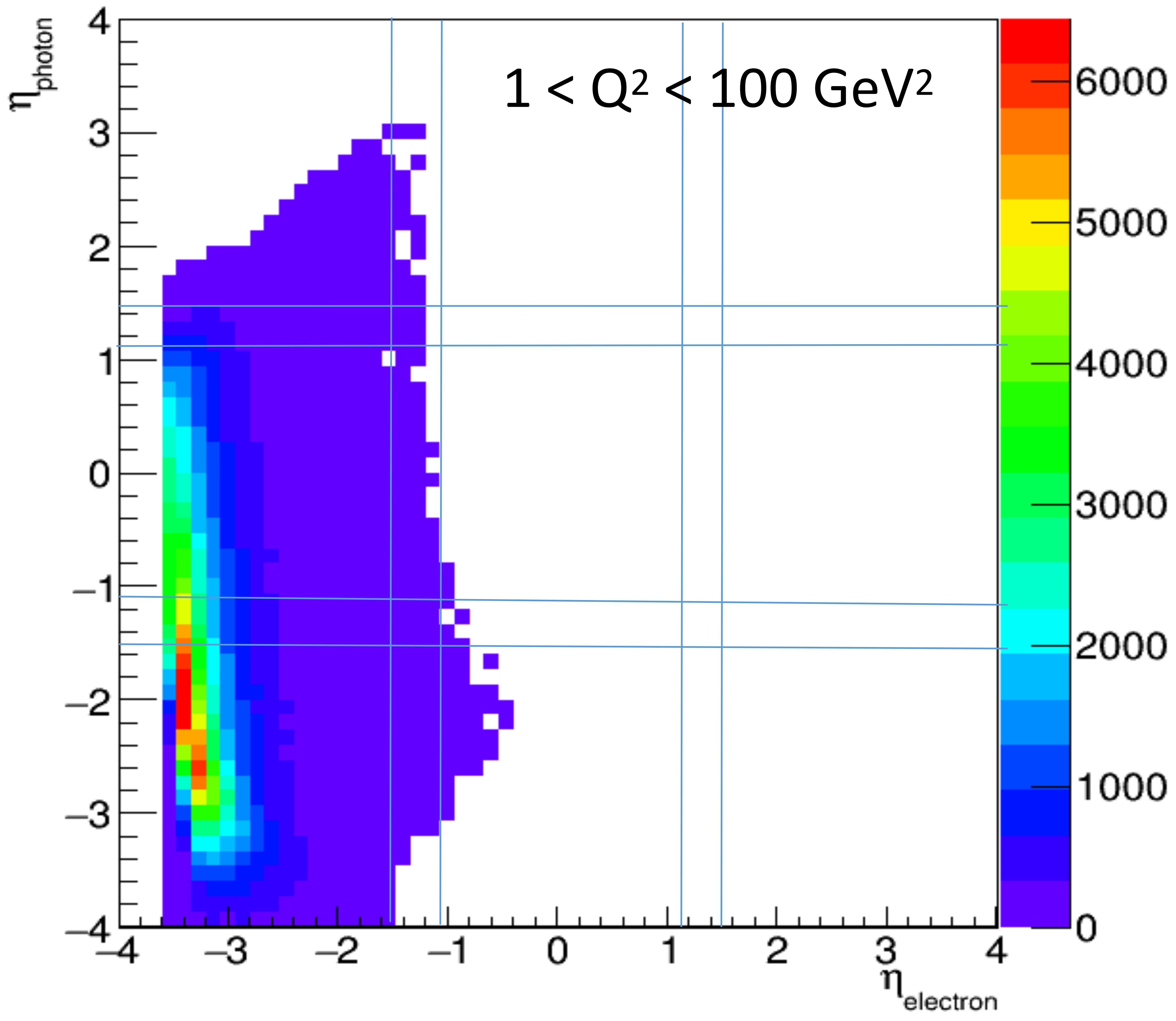


Since 2014 LOI:

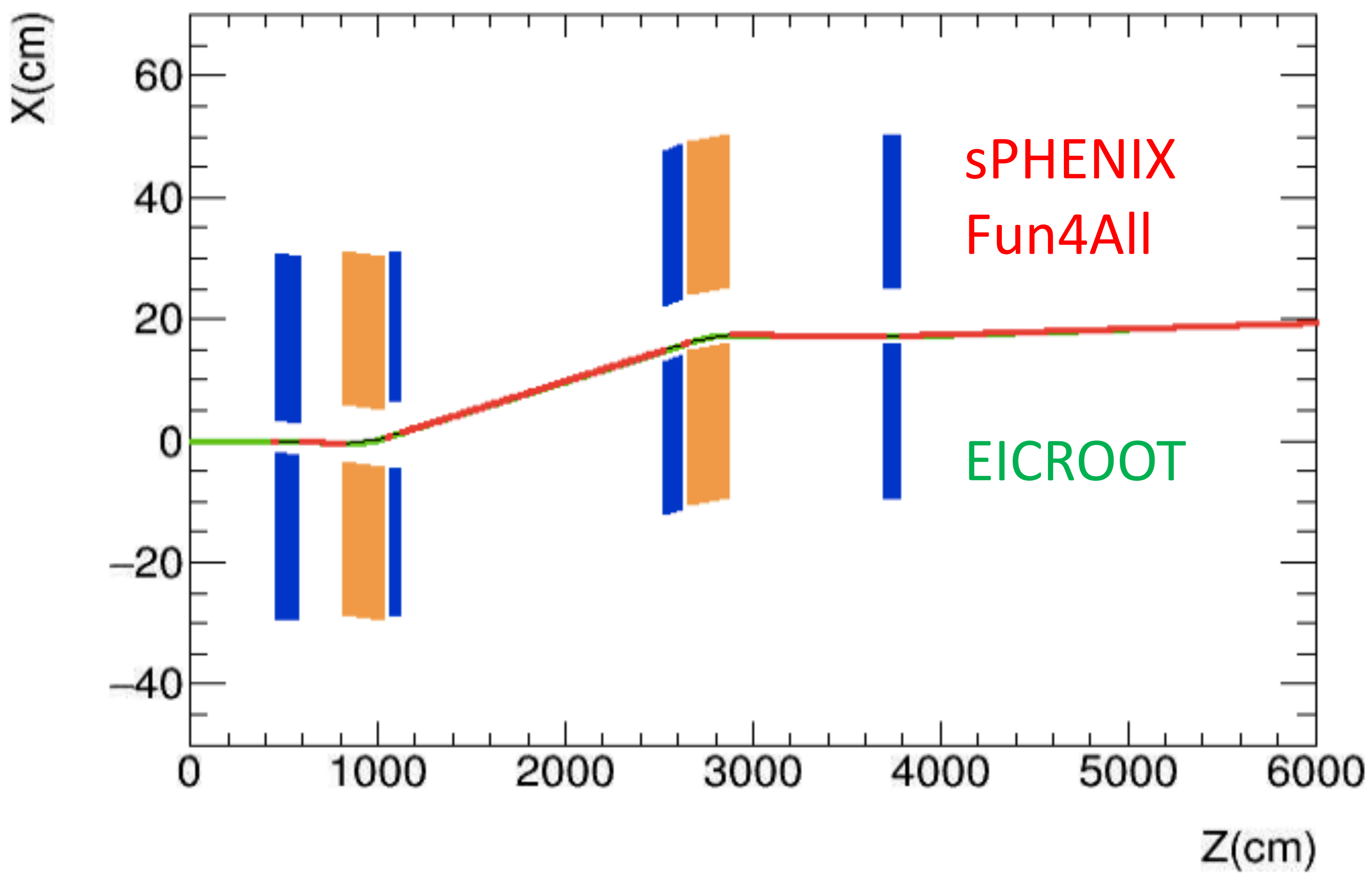
- Full GEANT4 simulations now
  - Forward/backward pattern recognition from truth hits, then Kalman filter for fitting
- Extended backward tracking to $\eta = -4$
- Improved TPC resolution based on sPHENIX design
- MVTX added
- 5 forward GEM stations now rather than 3

Calorimeter coverage to η= -4 captures all DVCS photons

18 x 275 GeV



Gap in EMCal coverage in electron-going direction would impact photon detection in particular



Detection of scattered (intact) proton

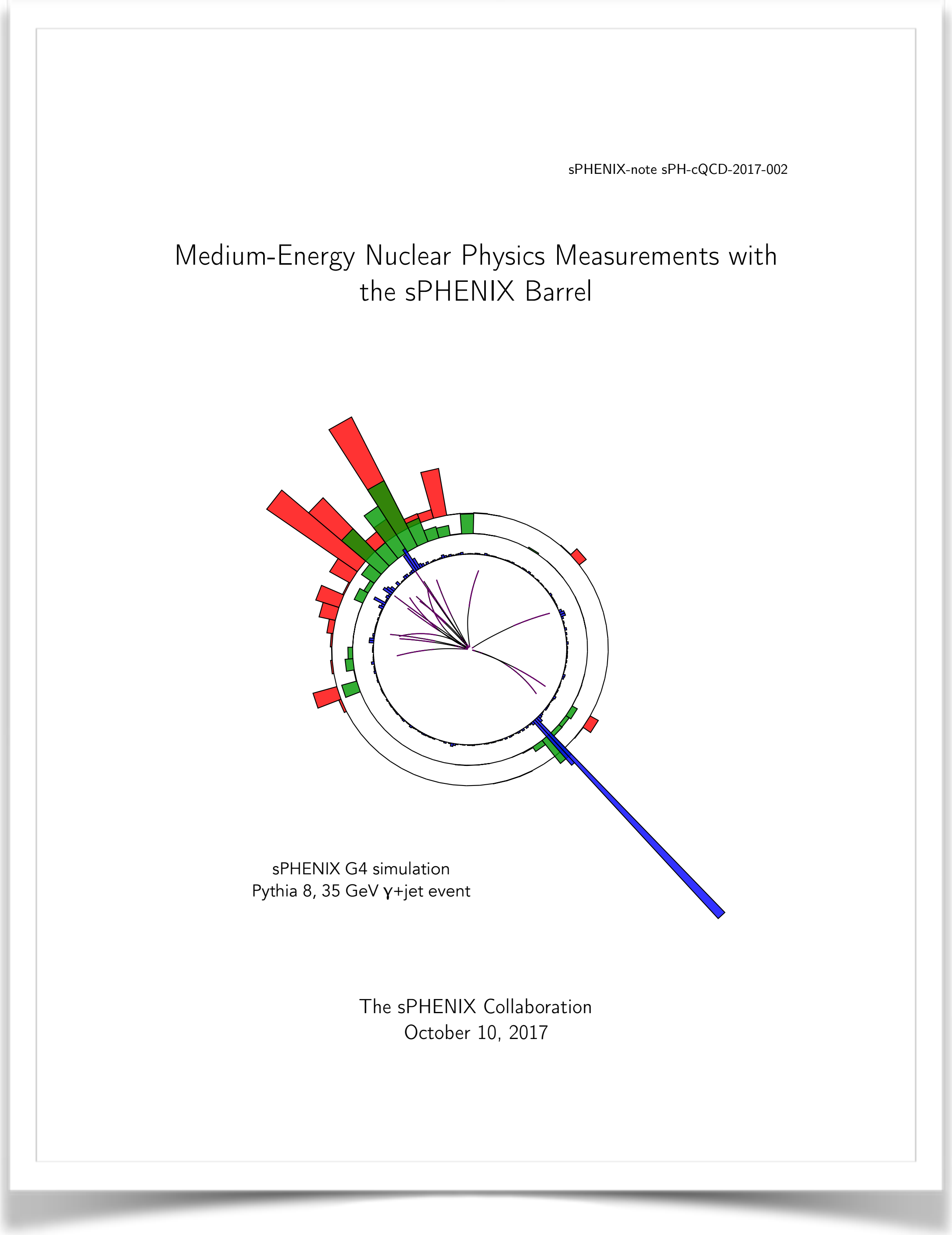
- Beam line dipoles and quadrupoles included in GEANT

Calorimeter coverage $-4 < \eta < 4$

$-4 < \eta < -1.55$	$PbWO_4$	2 cm x 2 cm	$\frac{2.5\%}{\sqrt{E}} \oplus 1\%$
$-1.55 < \eta < 1.24$	W-SciFi	0.025 x 0.025	$\frac{16\%}{\sqrt{E}} \oplus 5\%$
$1.24 < \eta < 3.3$	PbScint	5.5 cm x 5.5 cm	$\frac{8\%}{\sqrt{E}} \oplus 2\%$
$3.3 < \eta < 4$	$PbWO_4$	2.2 cm x 2.2 cm	$\frac{12\%}{\sqrt{E}}$
$-1.1 < \eta < 1.1$	Fe Scint + Steel Scint	0.1 x 0.1	$\frac{81\%}{\sqrt{E}} \oplus 12\%$
$-1.24 < \eta < 5$	Fe Scint	10 cm x 10 cm	$\frac{70\%}{\sqrt{E}}$

Cold QCD with sPHENIX barrel

Charge from ALD, delivered 10/2017


sPHENIX-note sPH-cQCD-2017-002

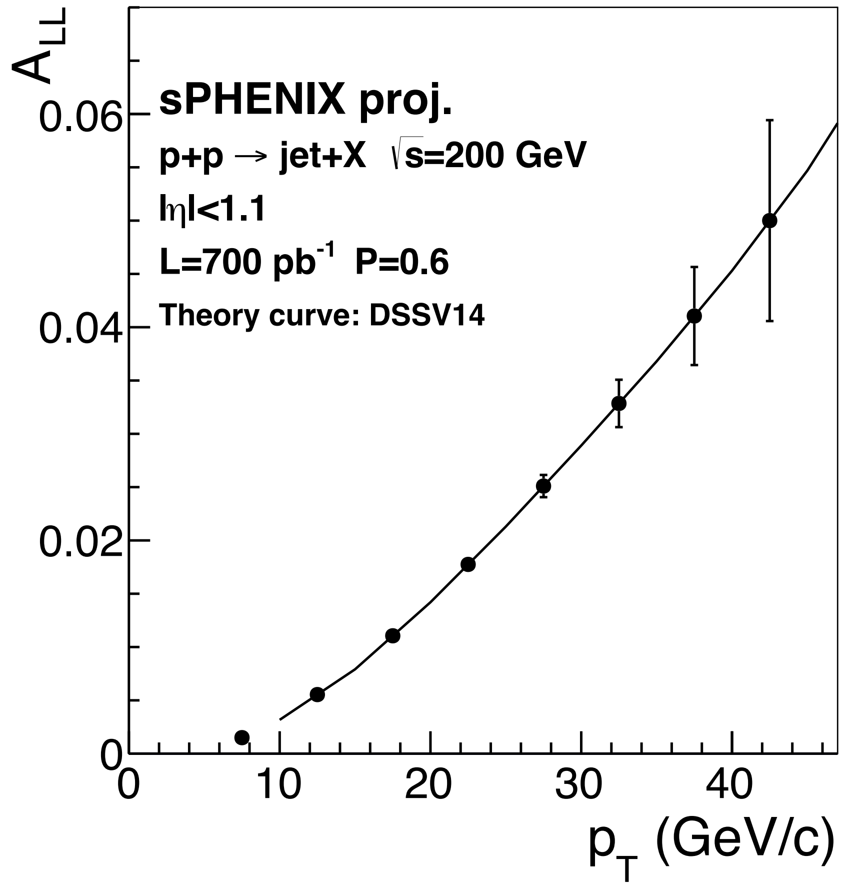
Medium-Energy Nuclear Physics Measurements with the sPHENIX Barrel

sPHENIX G4 simulation
Pythia 8, 35 GeV γ+jet event

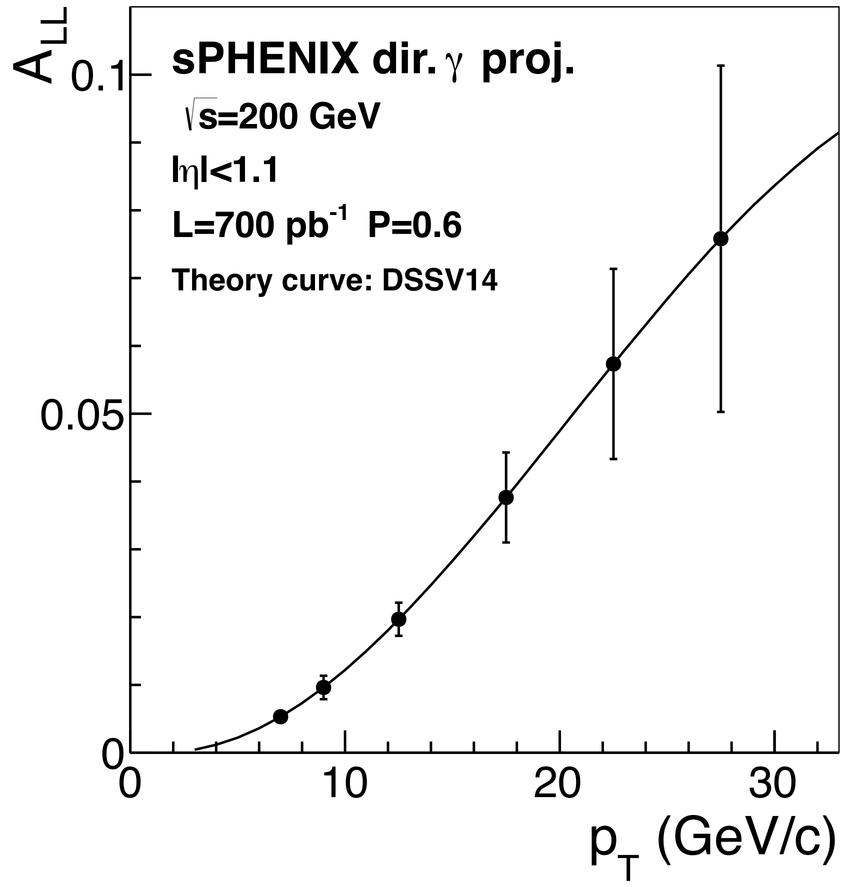
The sPHENIX Collaboration
October 10, 2017

Projected capabilities for observables in longitudinally, transversely polarized collisions, nPDFs

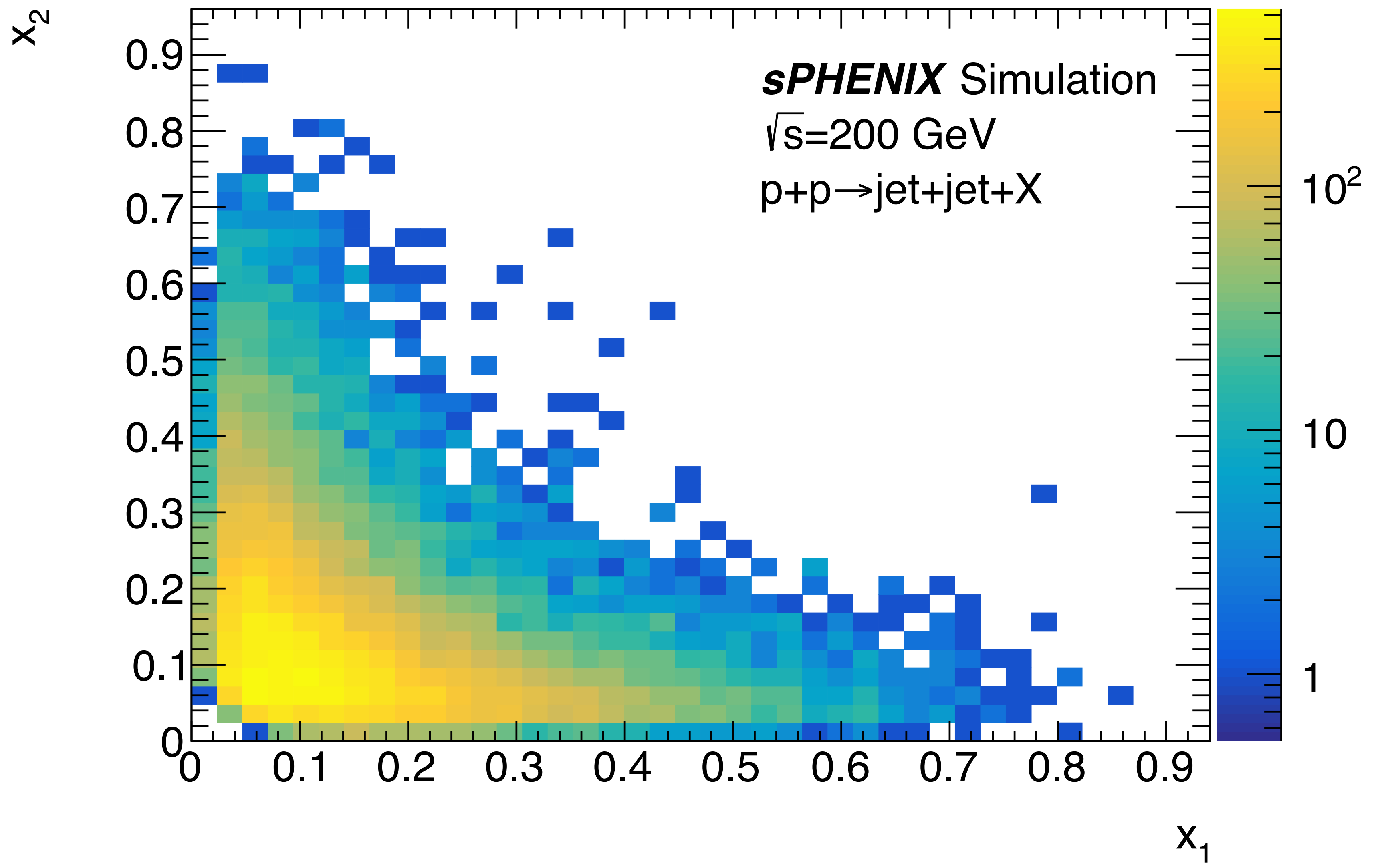
jet A_{LL}



direct γ A_{LL}



dijet kinematics in sPHENIX barrel



Additional studies are underway

- Fully integrated tracking with appropriate resolutions for combined TPC + forward/backward tracking stations
- Impact of projective geometry for electron-direction EMCal
- Reconstruction of kinematics based on hadronic activity
  - Complements kinematics reconstruction based on scattered electron
  - Necessary to measure charged-current DIS events (unmeasured outgoing neutrino)
- Charm tagging in low-multiplicity environment of EIC
- Exclusive J/Psi production
- Spectator tagging in collisions between electrons and light and heavy ions