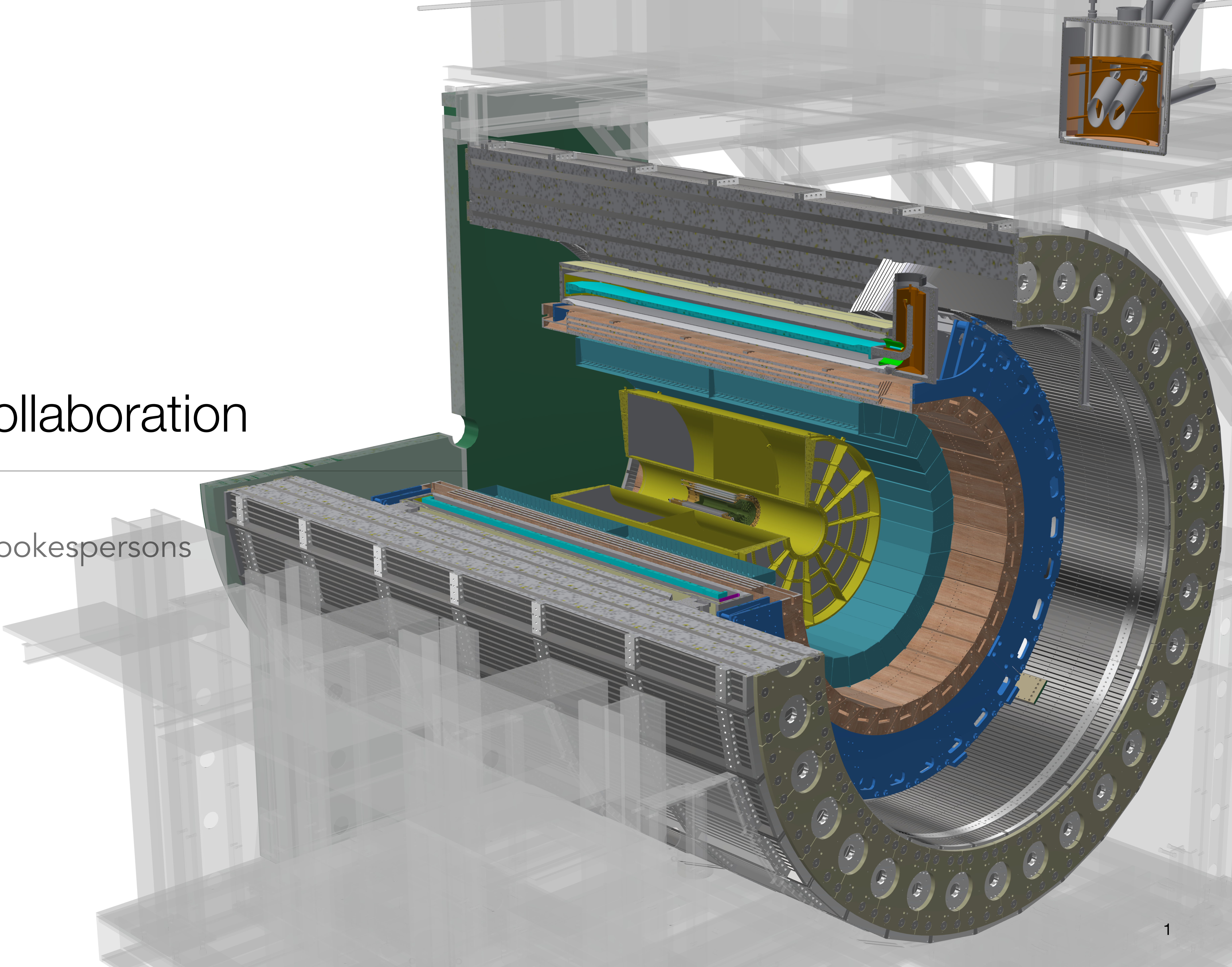
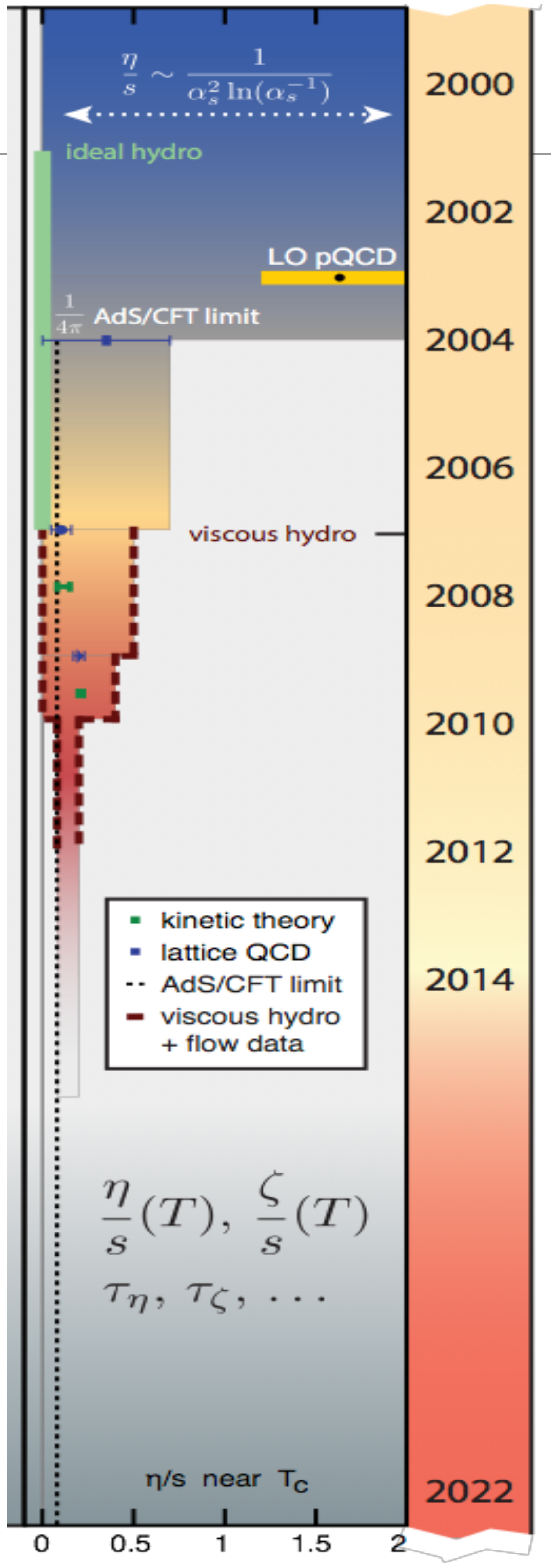
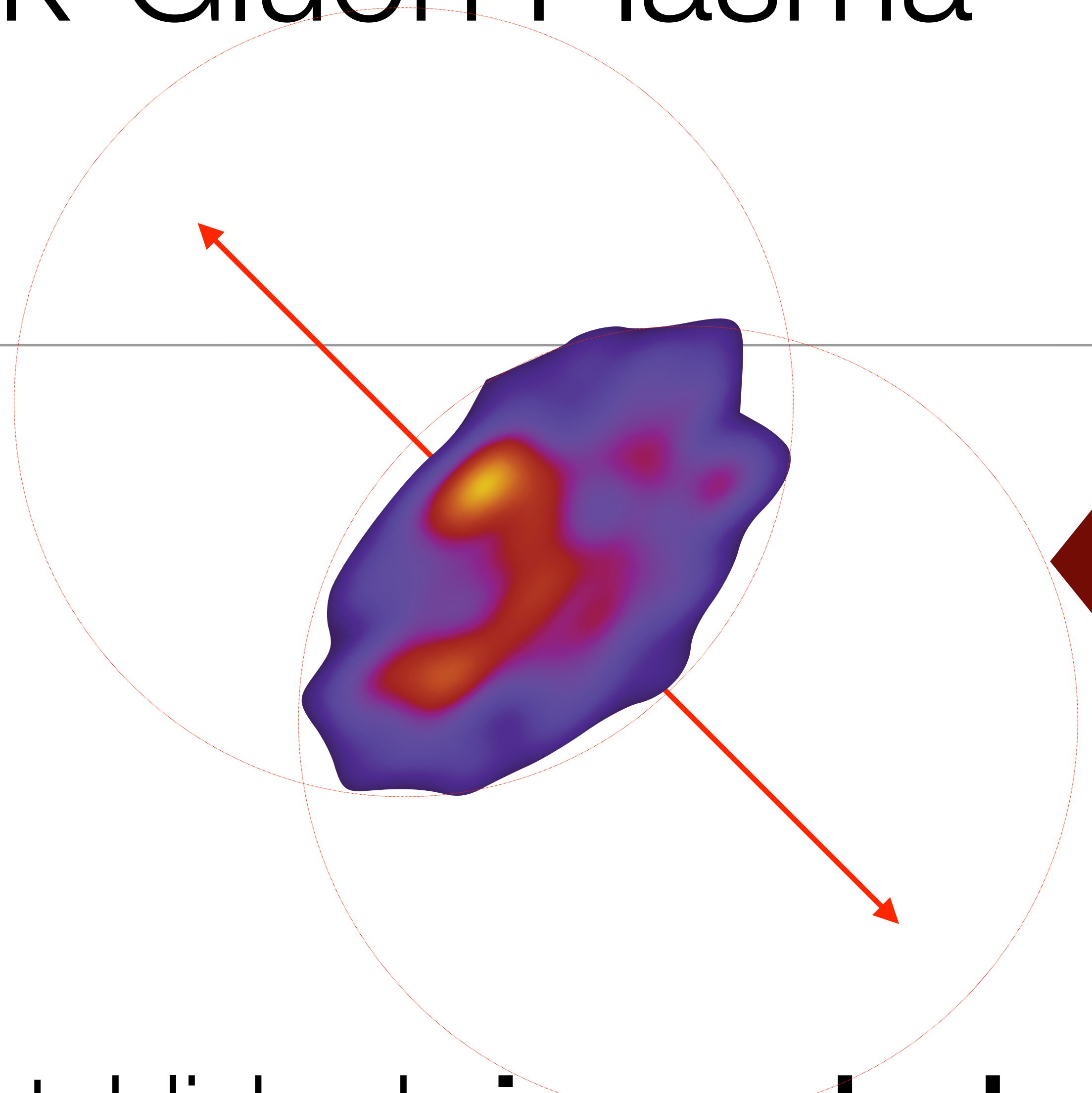
# sPHENIX –
# Science, status, collaboration

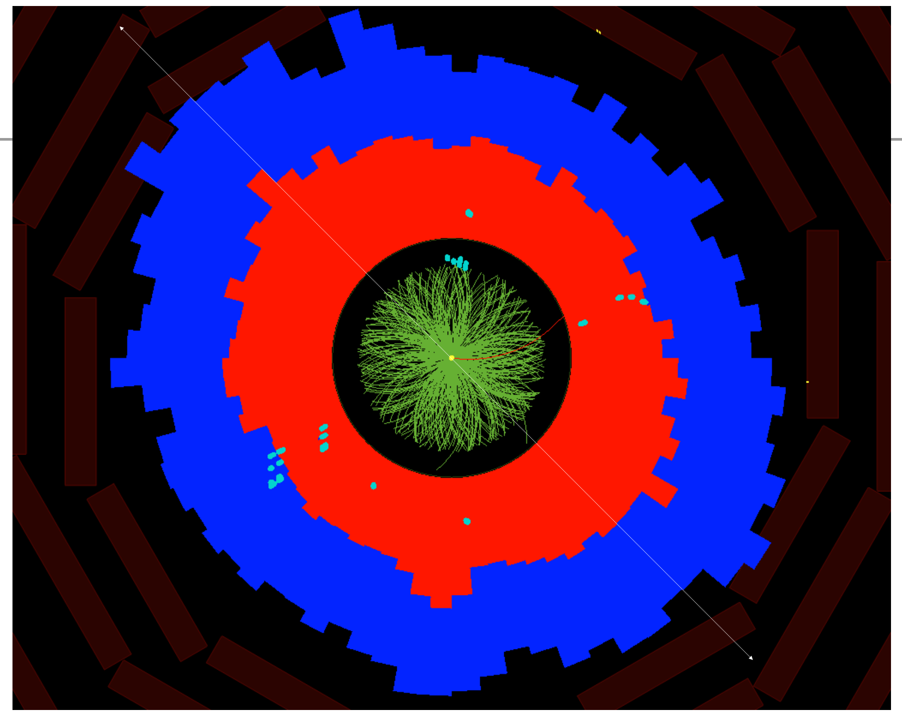
David Morrison (BNL)
Gunther Roland (MIT)
co-spokespersons



# Strongly coupled Quark-Gluon Plasma





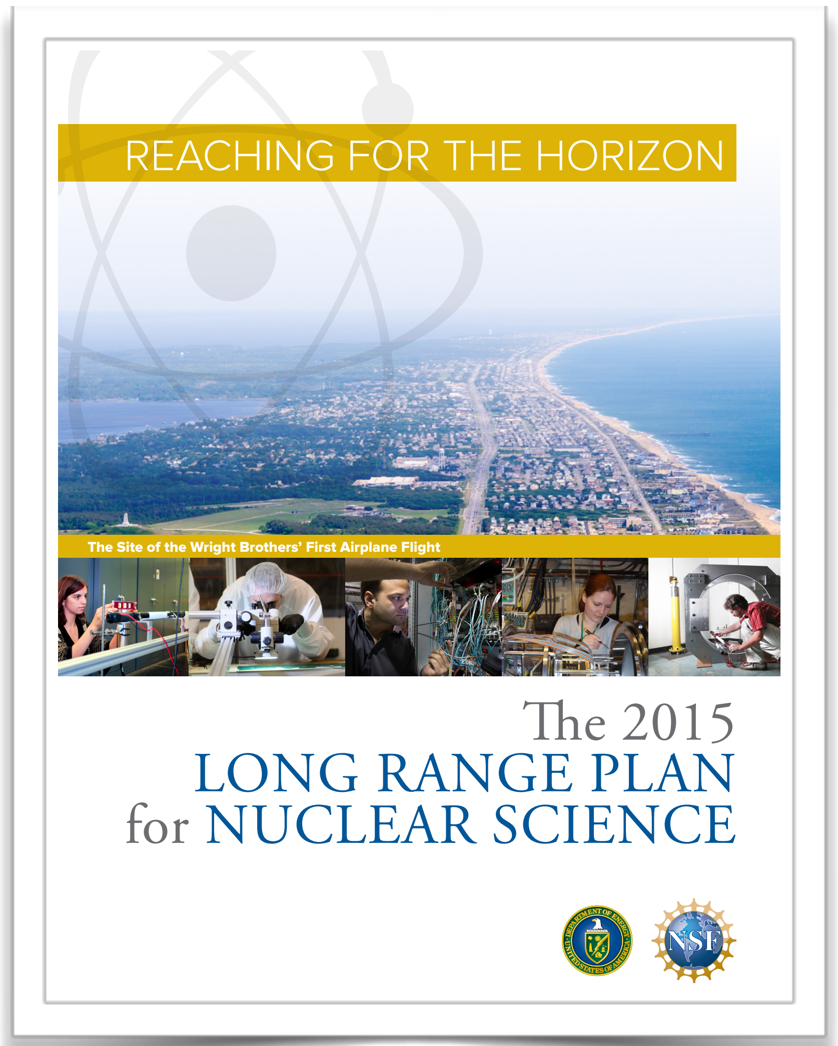
Established **viscous hydrodynamics** as effective theory of long-wavelength dynamics of QGP

**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***

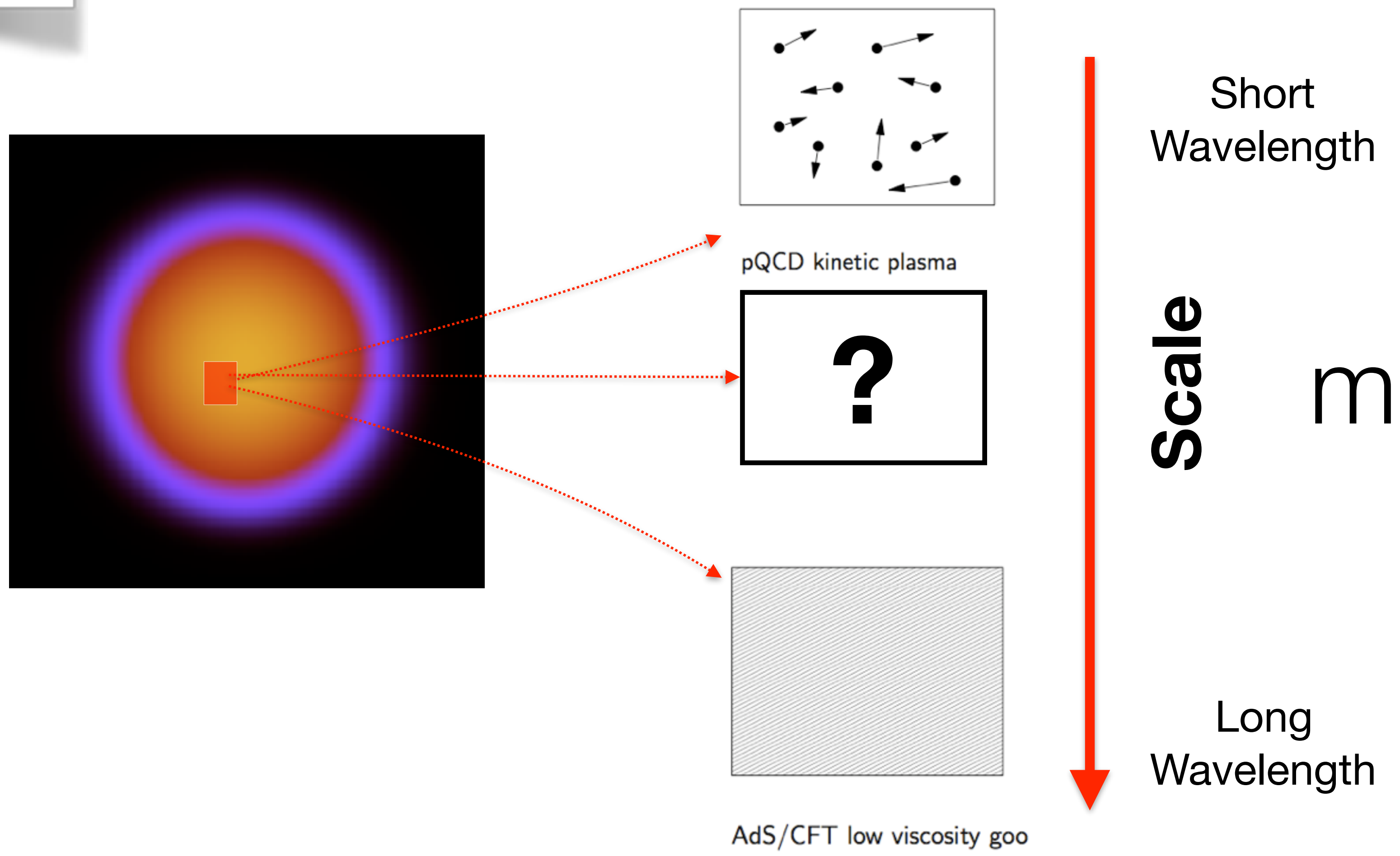
Connections to strong coupled matter in many fields of physics (string theory to cold atoms)

# sPHENIX Science Mission in the DOE/NSF LRP




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.**

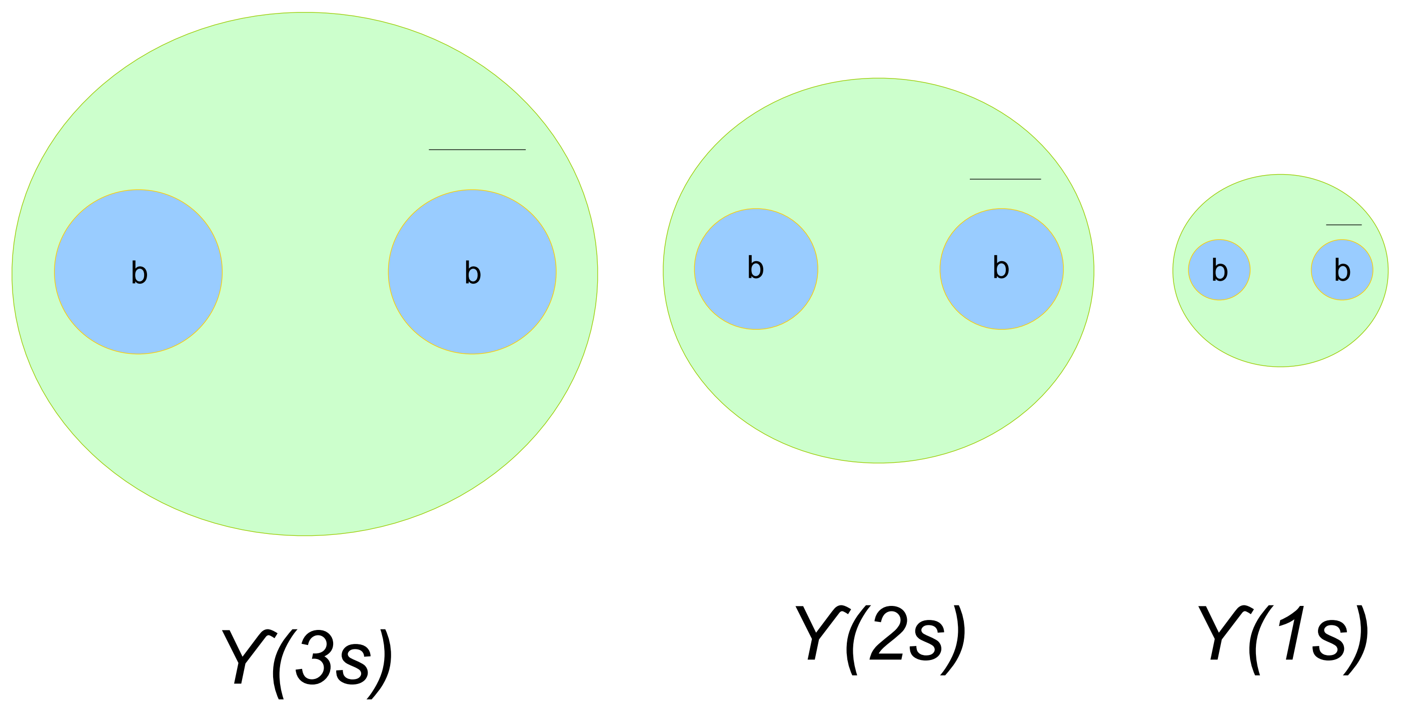



What is the microscopic structure of the QGP?

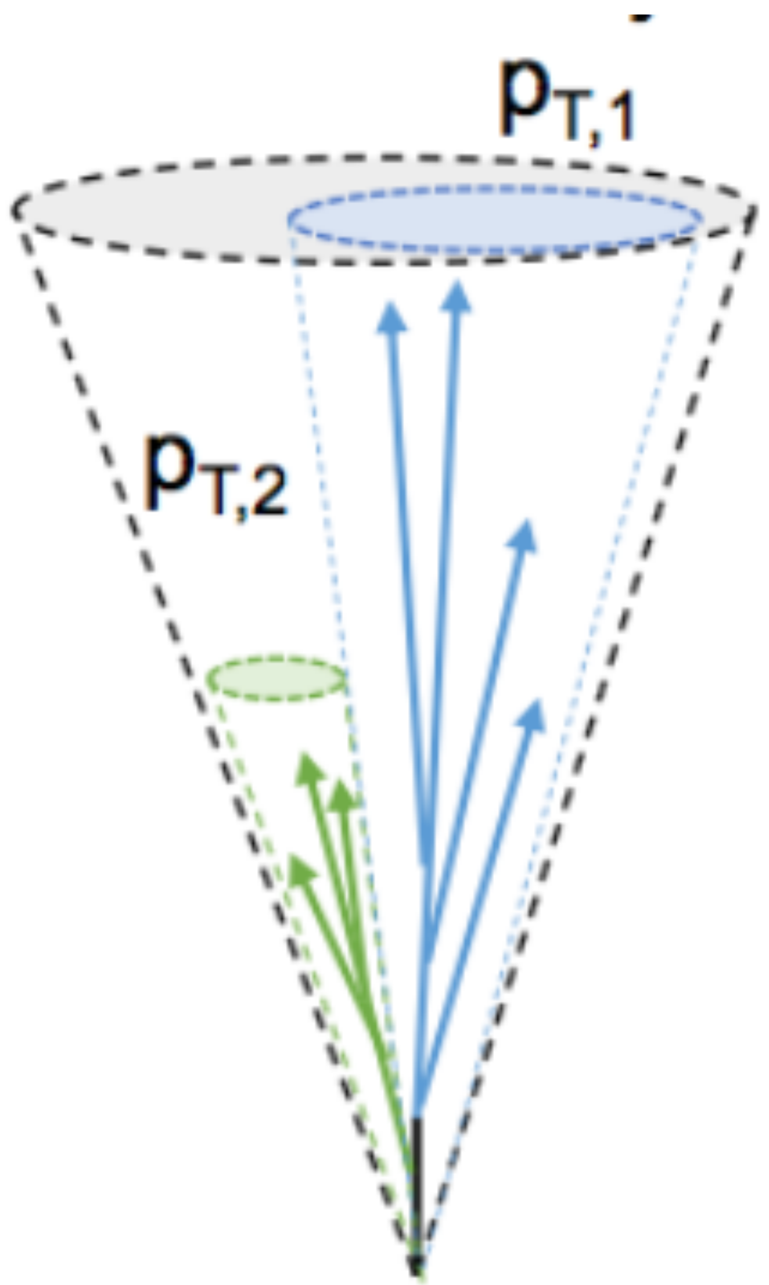
# Core sPHENIX science program

Key approaches to study QGP structure at multiple scales with sPHENIX

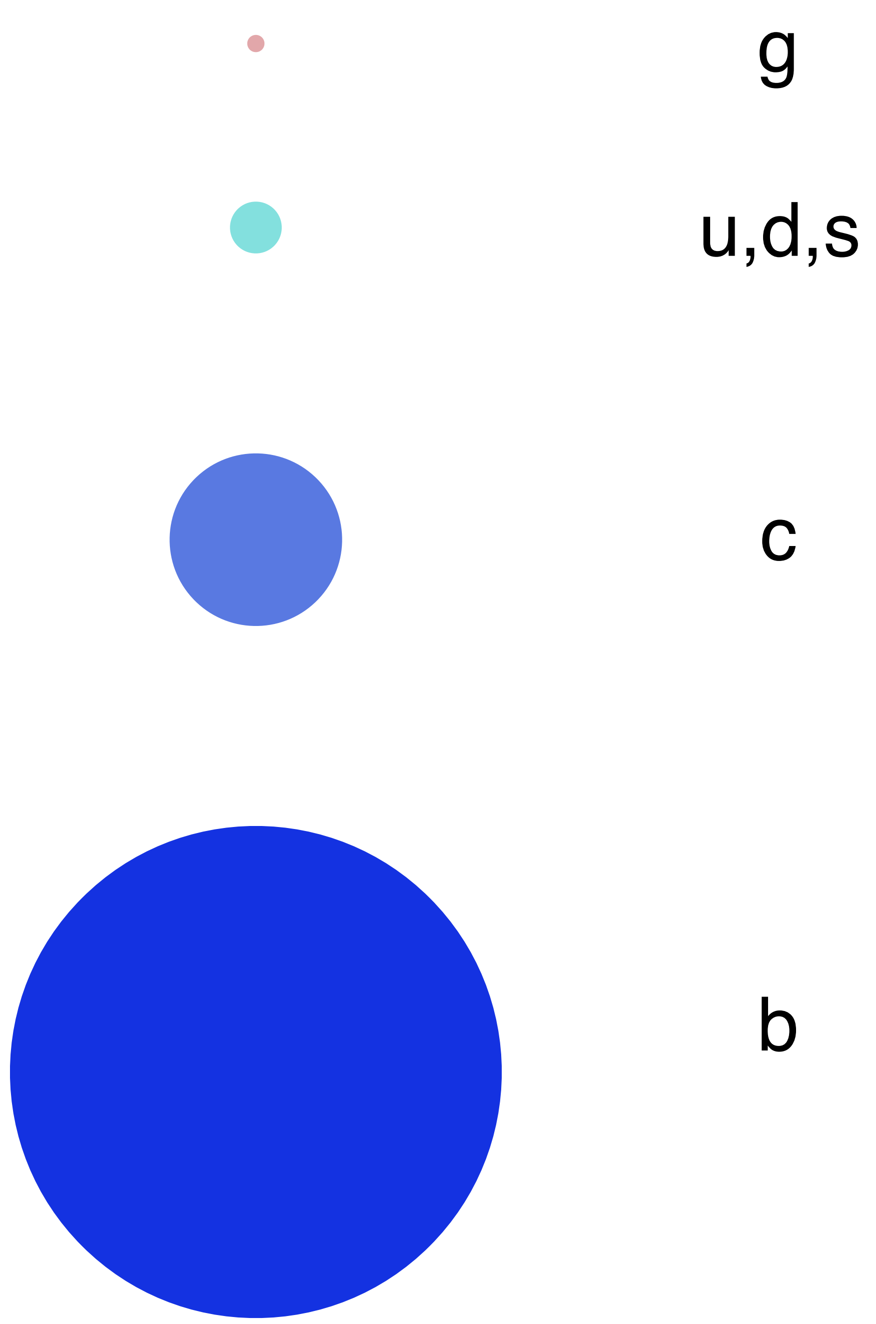
**Quarkonium spectroscopy**
vary size of probe



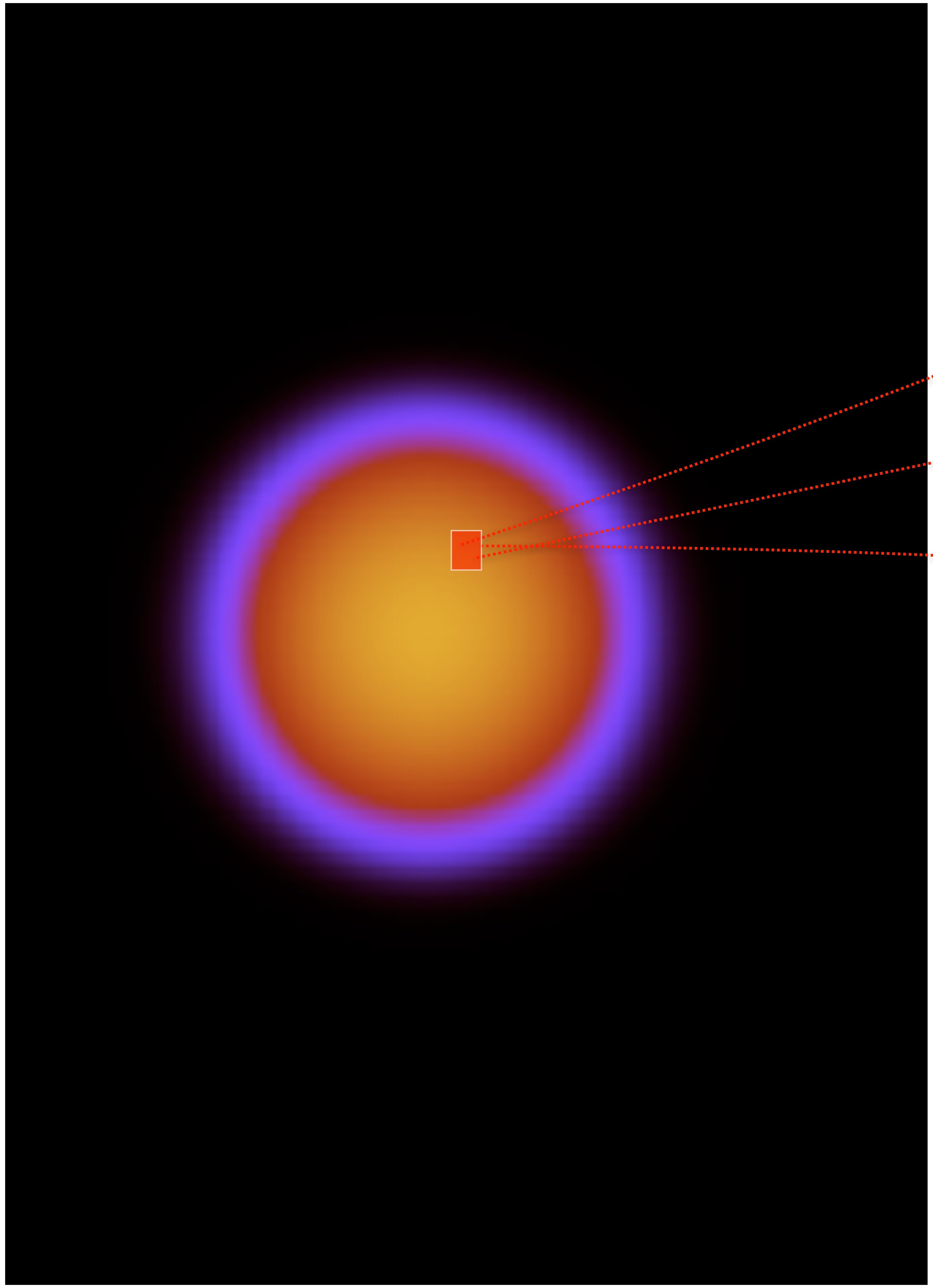

**Jet structure**
vary momentum/angular scale of probe

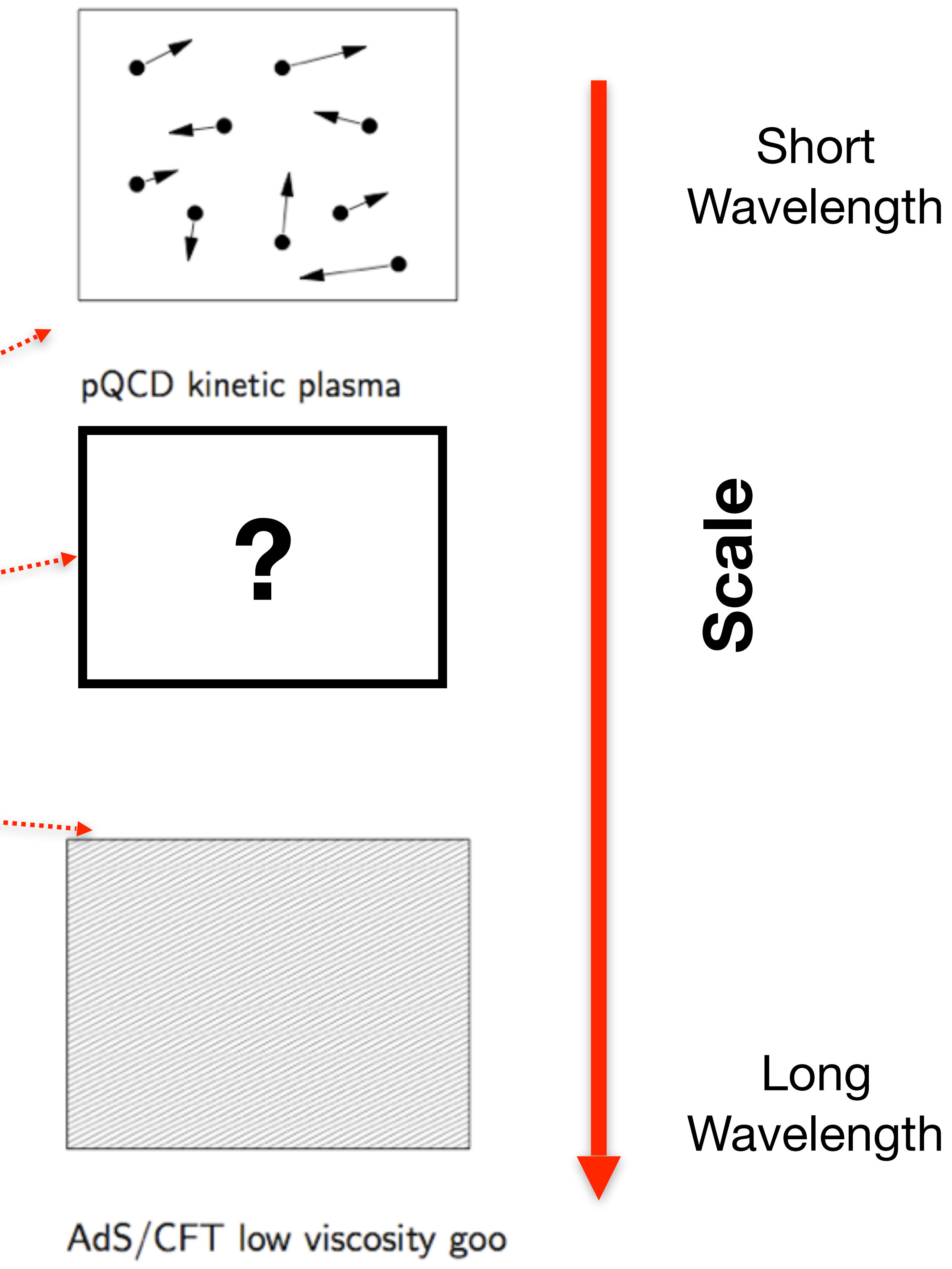



**Parton energy loss**
vary mass/momentum of probe



# Experimental approach



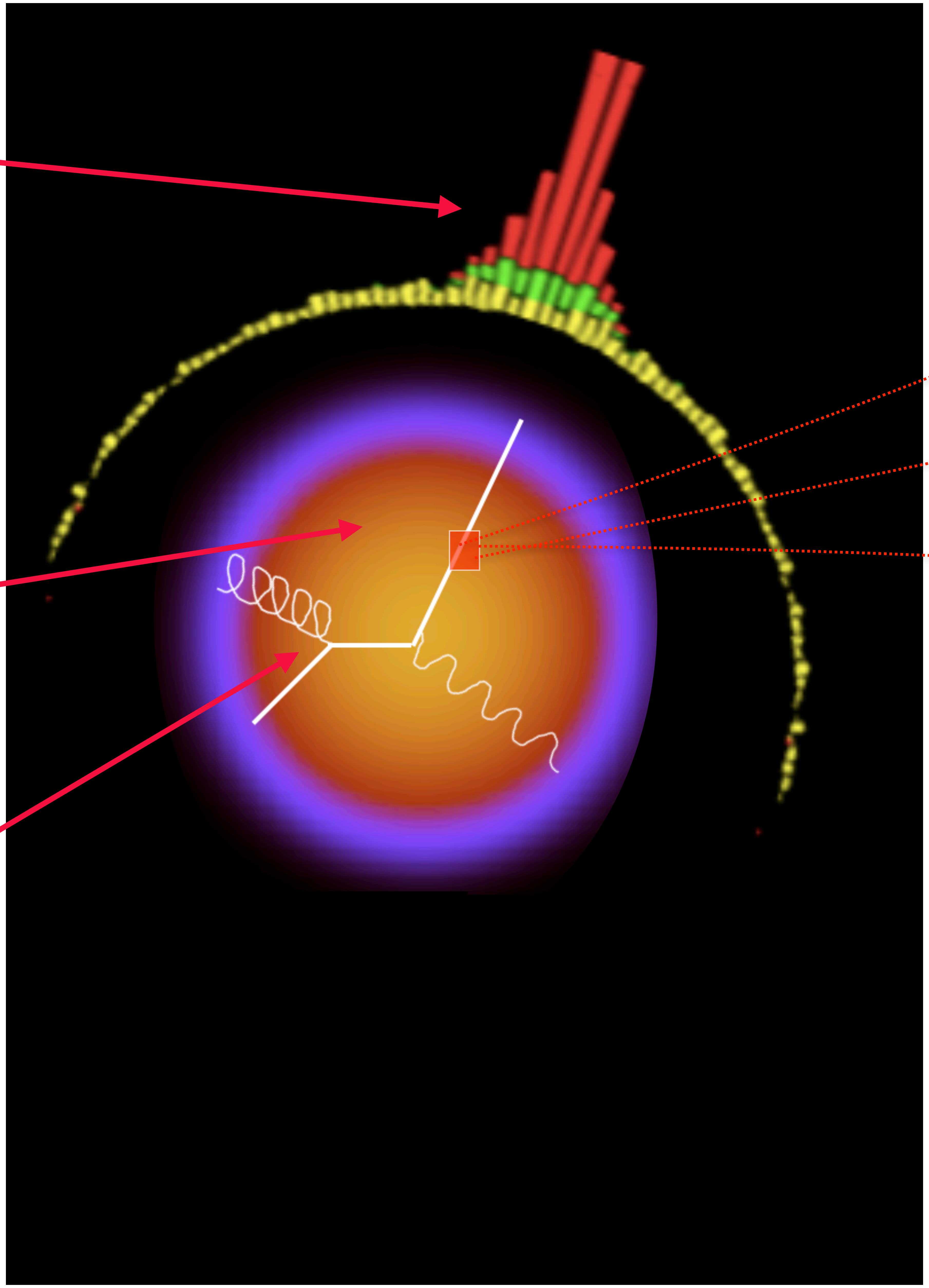


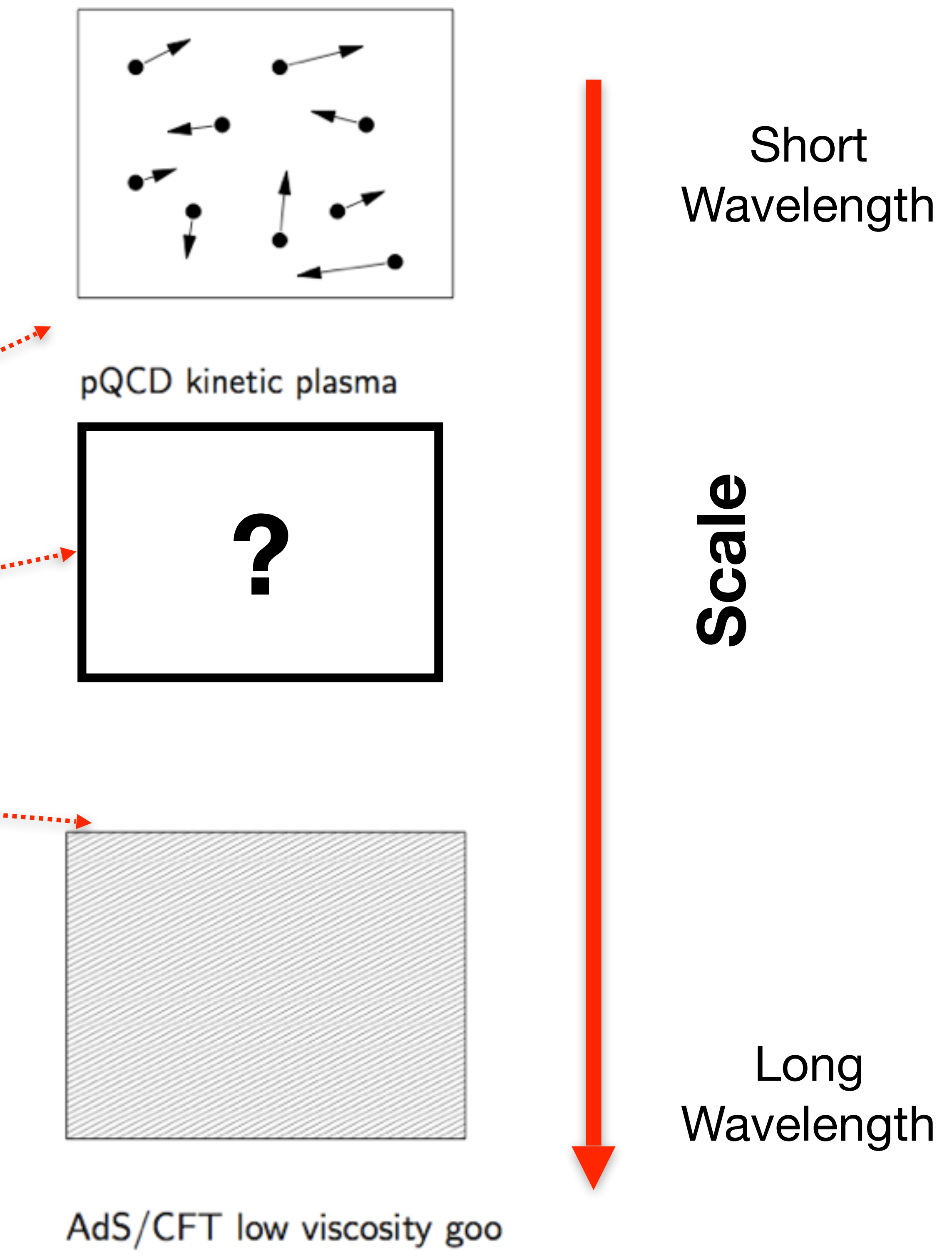

How does long-wavelength physics emerge from underlying gauge theory?

**Full** characterization
of final state

**Different** QGP
initial conditions
and evolution
at RHIC and LHC

**Same** hard process



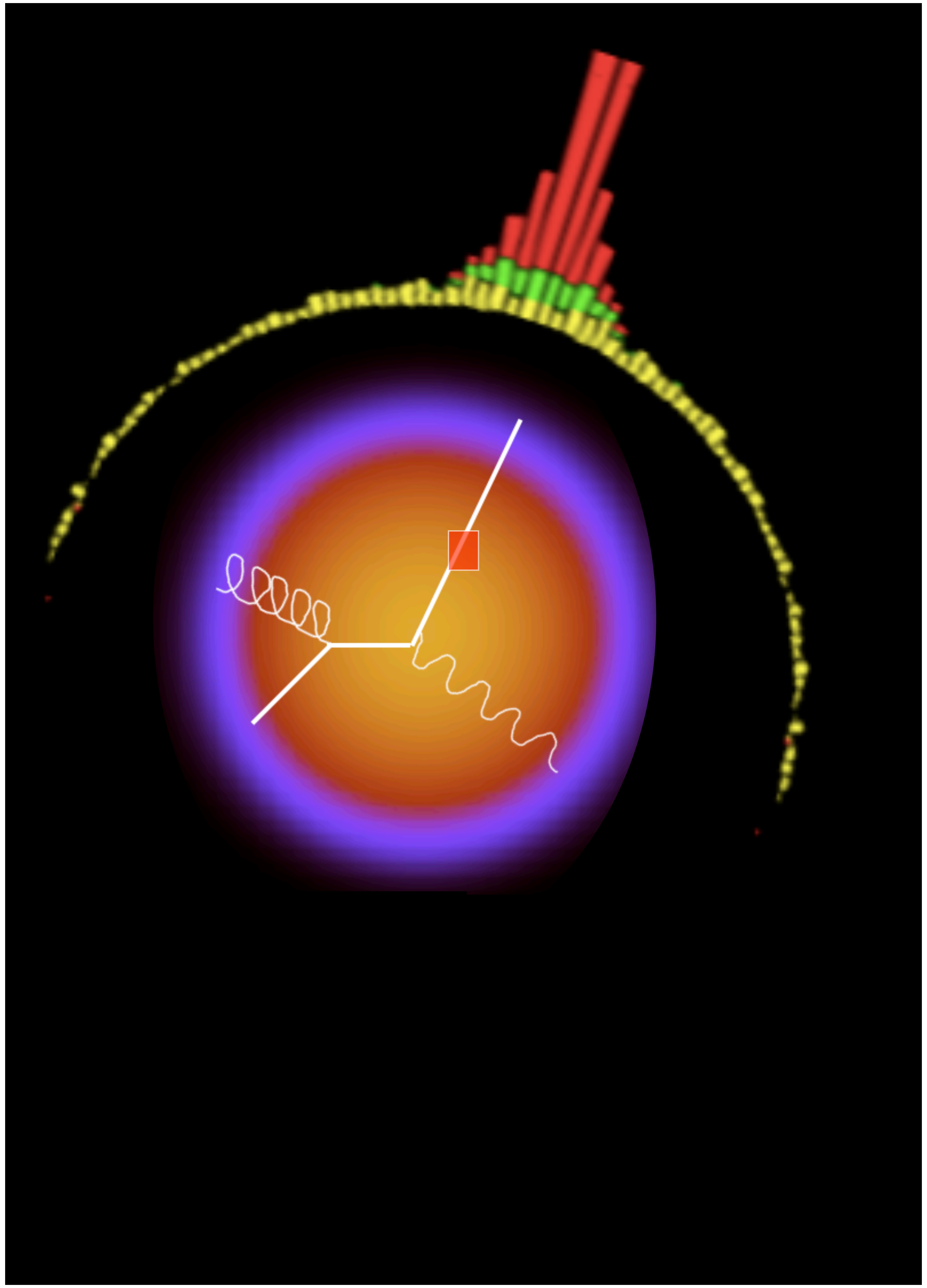



How does long-wavelength
physics emerge from
underlying gauge theory?

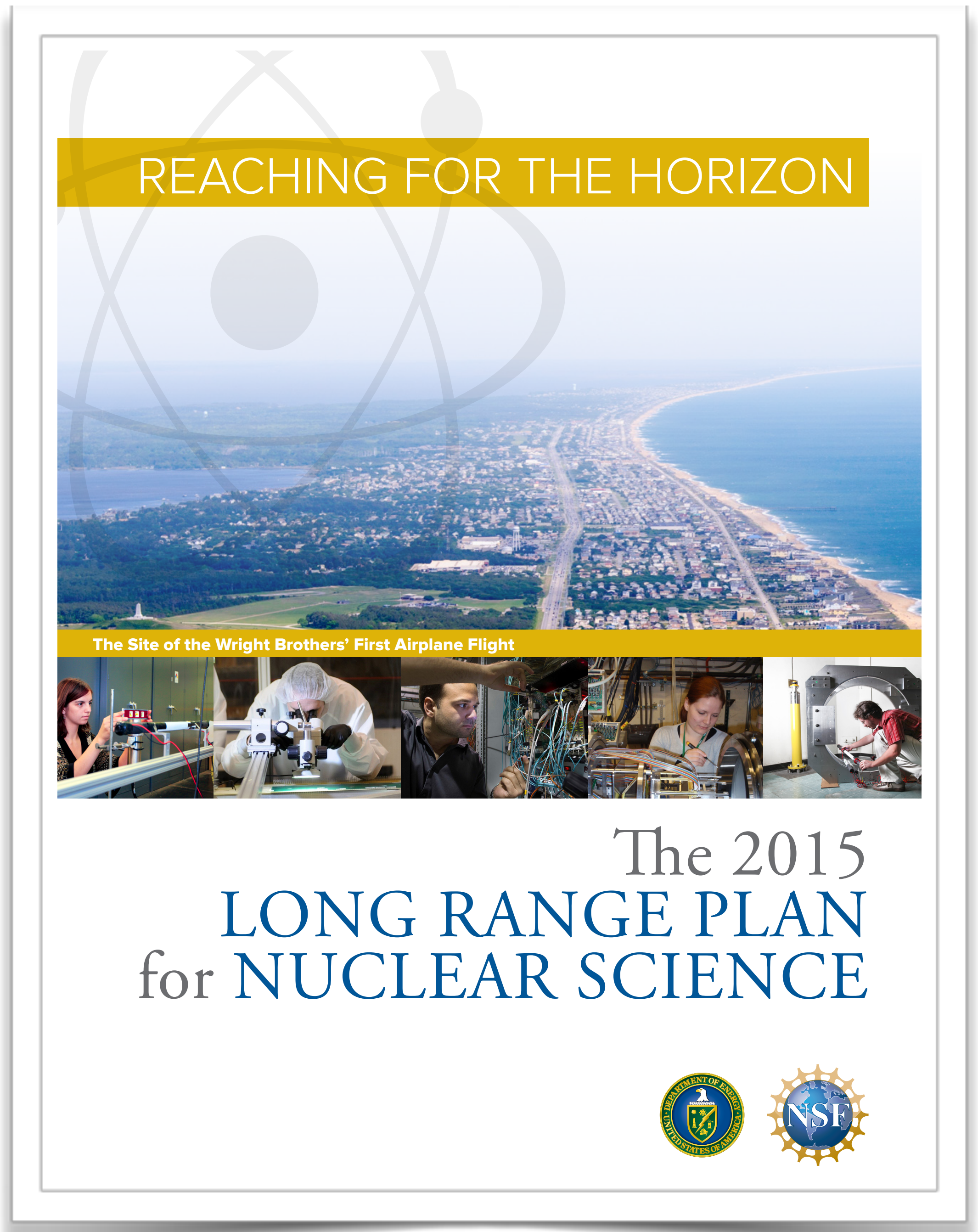
**Full** characterization of final state

Ability to tag initial state and to fully characterize final state drives sPHENIX detector design

**Same** hard process



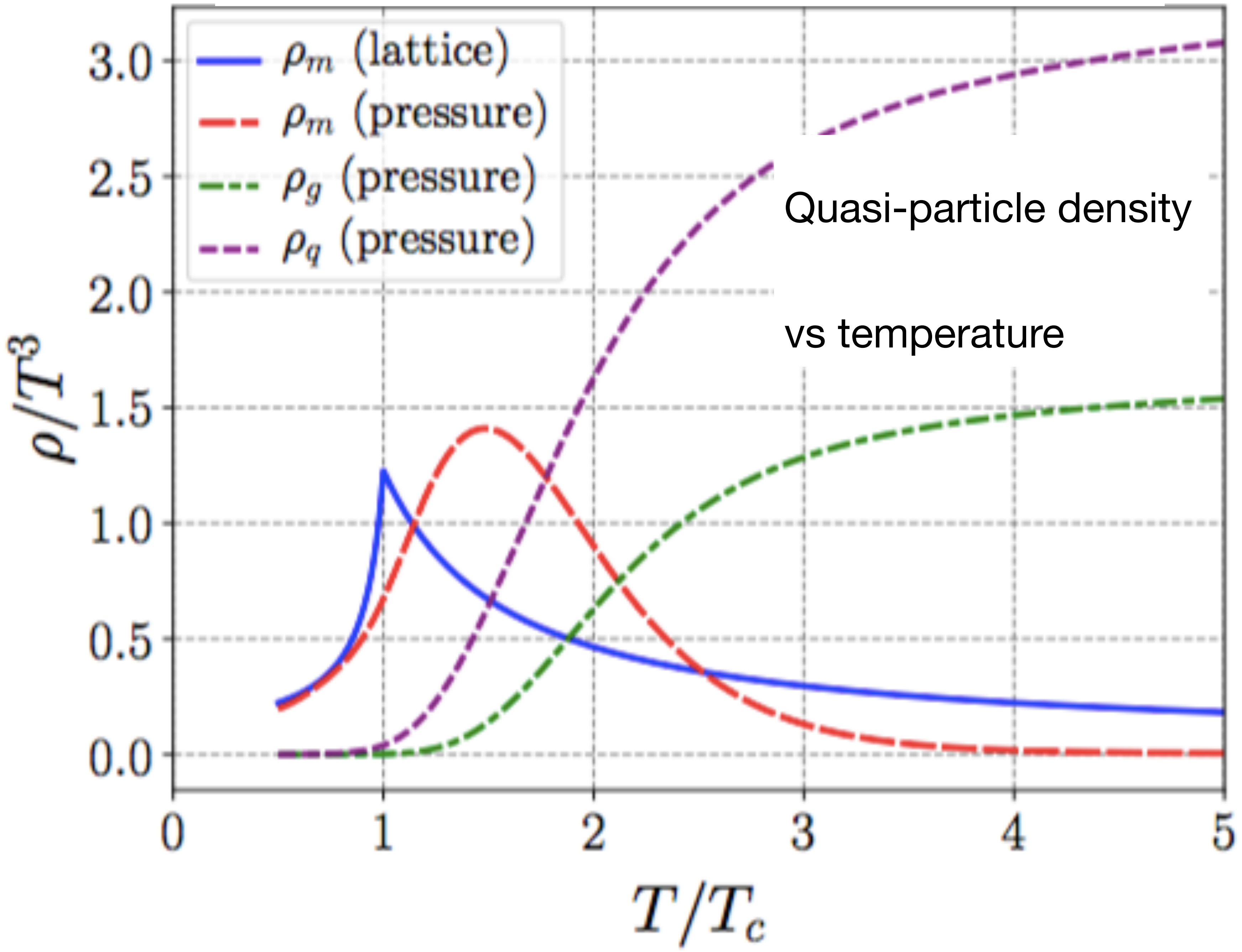
# sPHENIX and complementarity in the Long Range Plan




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.**

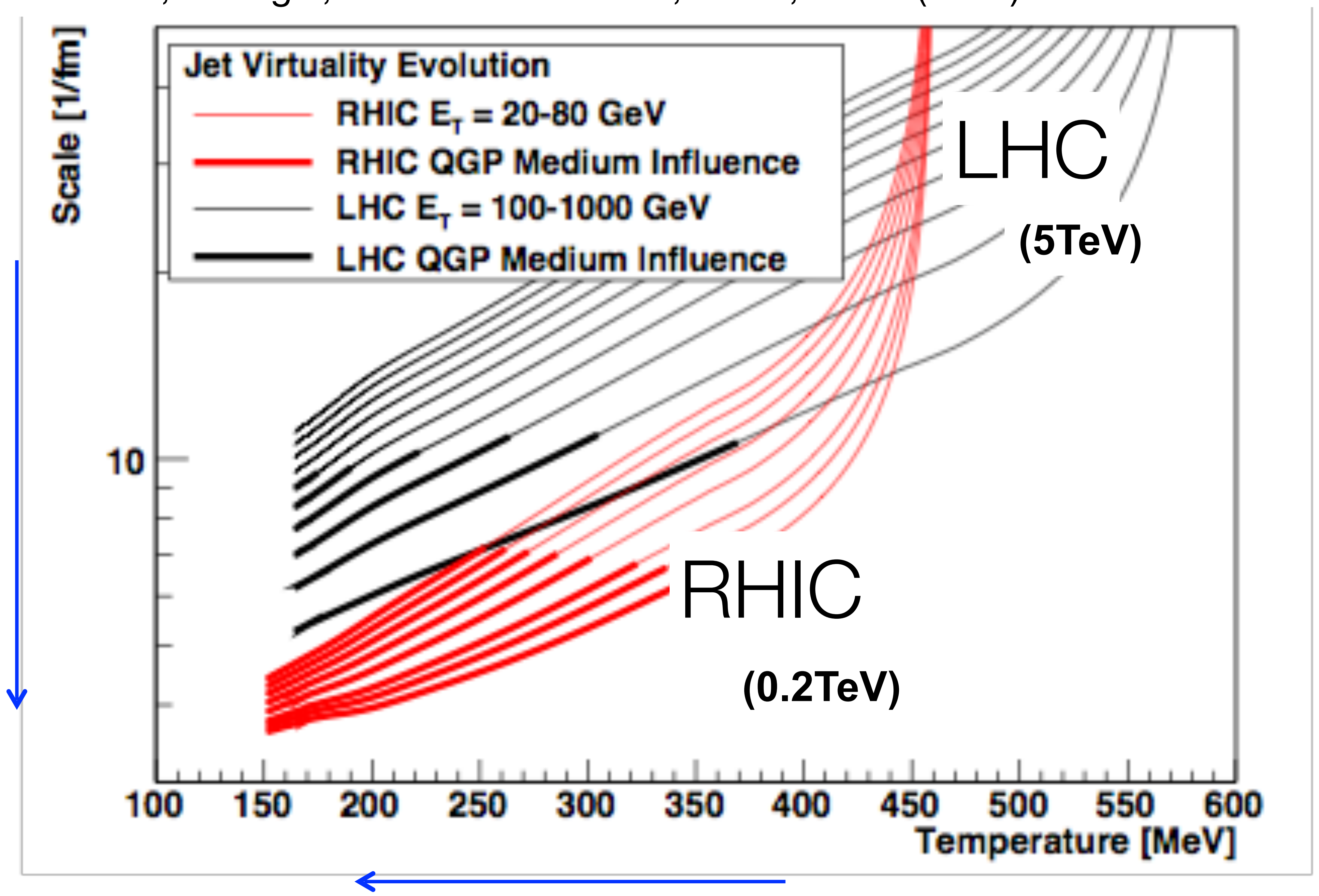
# Complementarity: Why RHIC *and* LHC?

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)



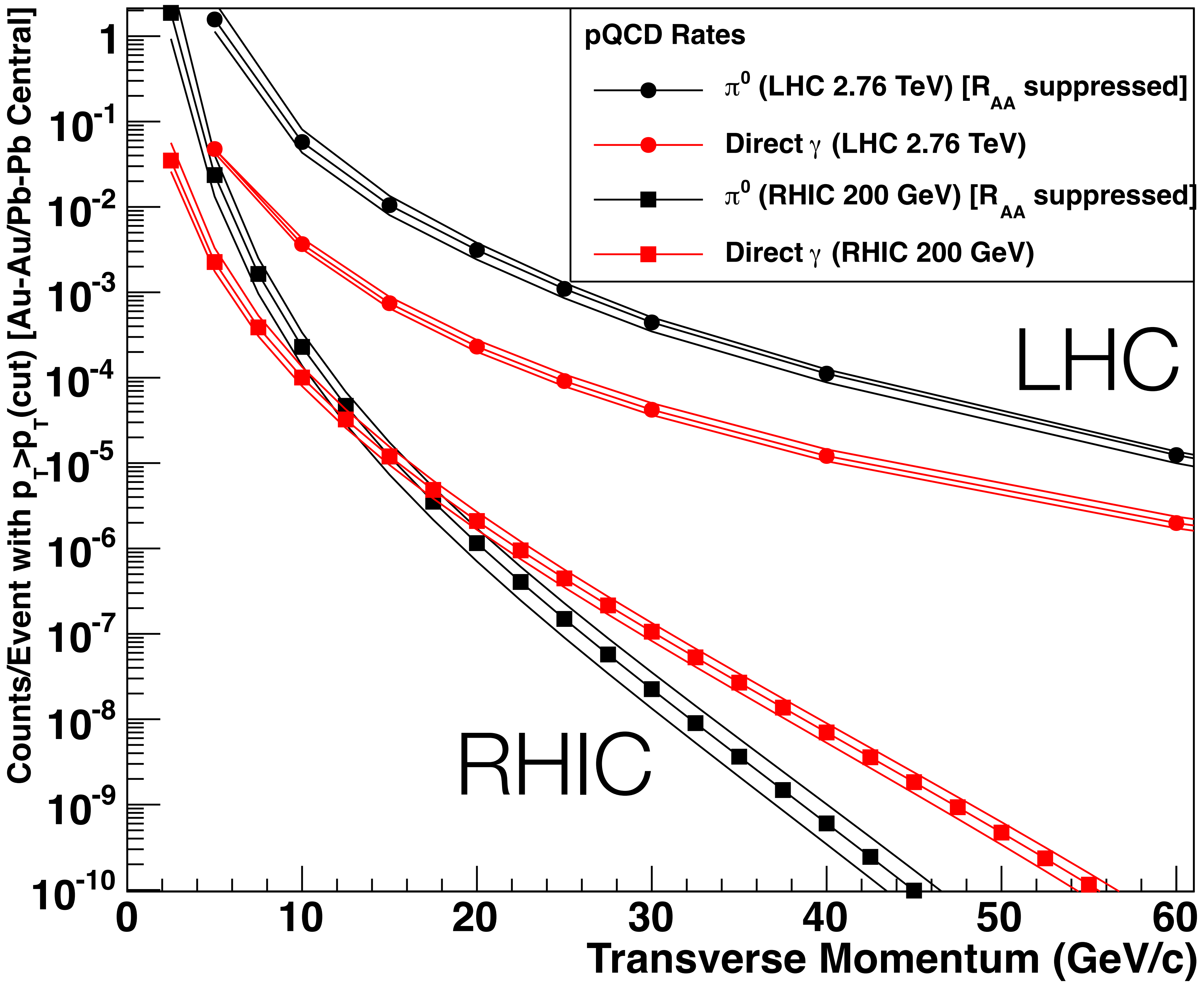

Initial QGP conditions and QGP evolution are different at RHIC vs LHC

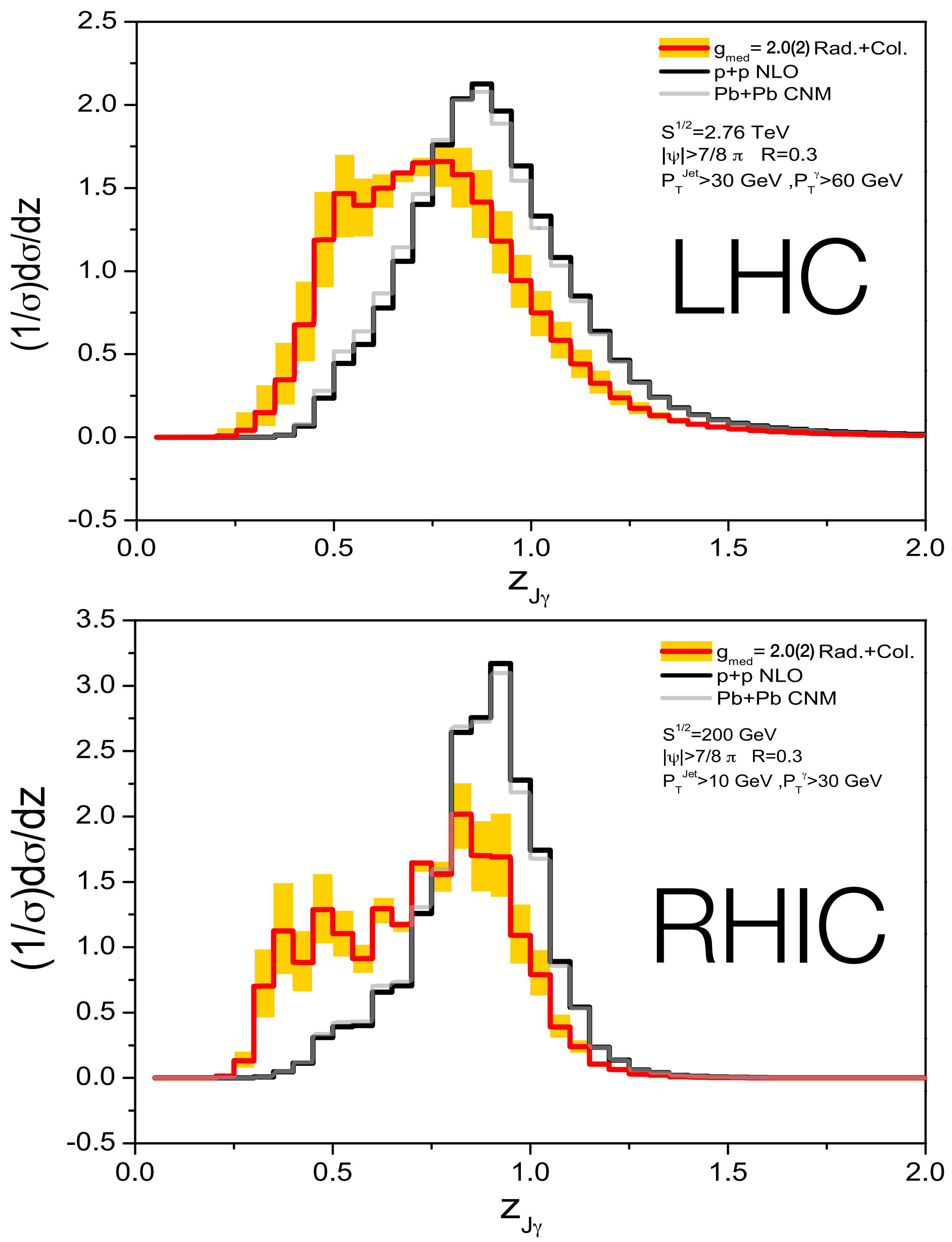
RHIC QGP spends more time near $T_C$

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

# Direct photons and photon triggered jets

Dai, Vitev, Zhang, PRL 110 (2013) 14, 142001




For γ (@ E = 20 GeV), S/B is 20x larger at RHIC; underlying event 2.5x smaller

"The steeper falling cross sections at RHIC energies lead not only to a narrower $z_{J\gamma}$ distribution in p+p collisions but also to larger broadening and shift in the $\langle z_{J\gamma} \rangle$. "

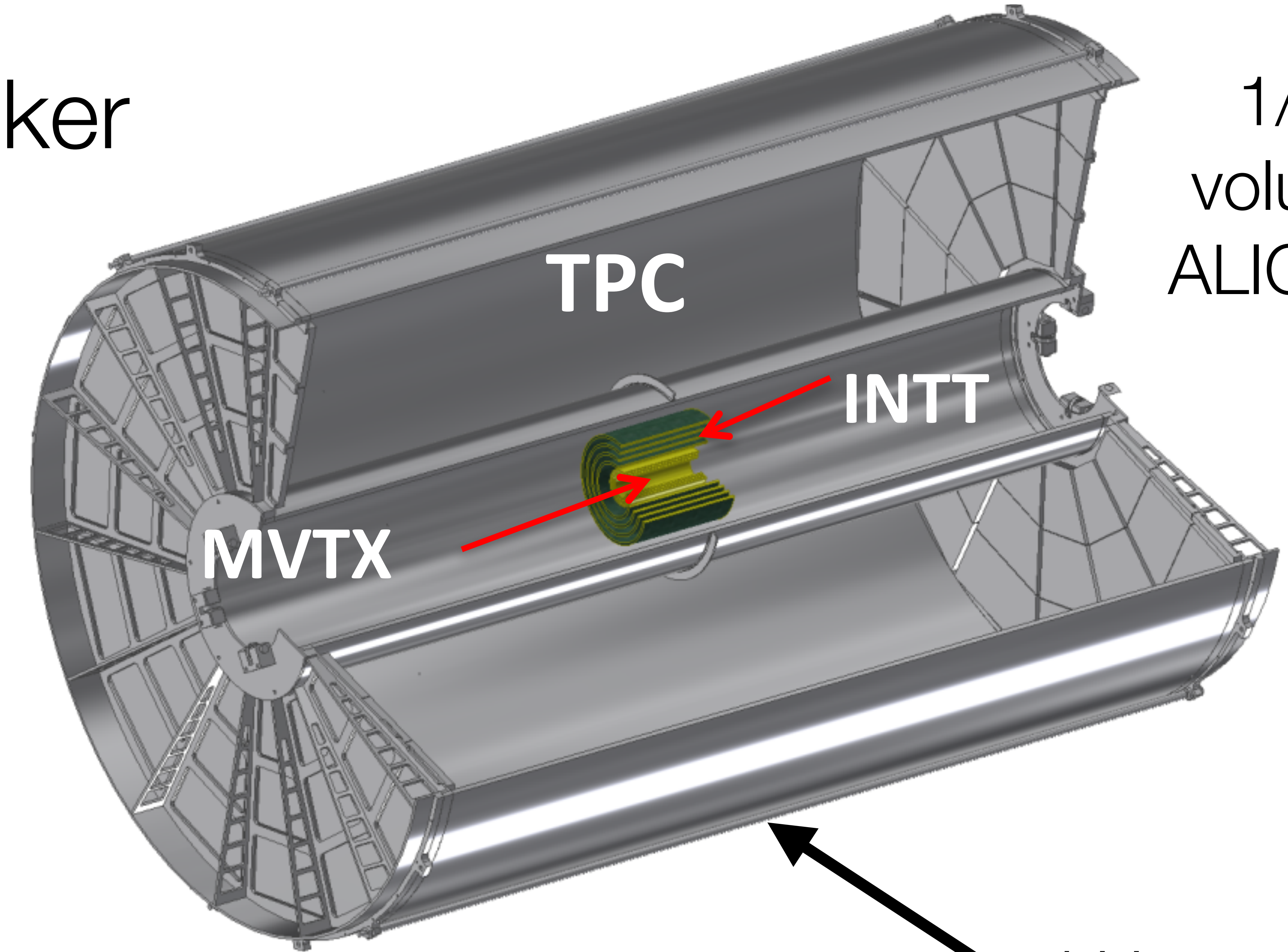

From PHENIX...
2016


...to...
CAUTION - ENTRY REQUIRES PERMISSION
2018


...sPHENIX

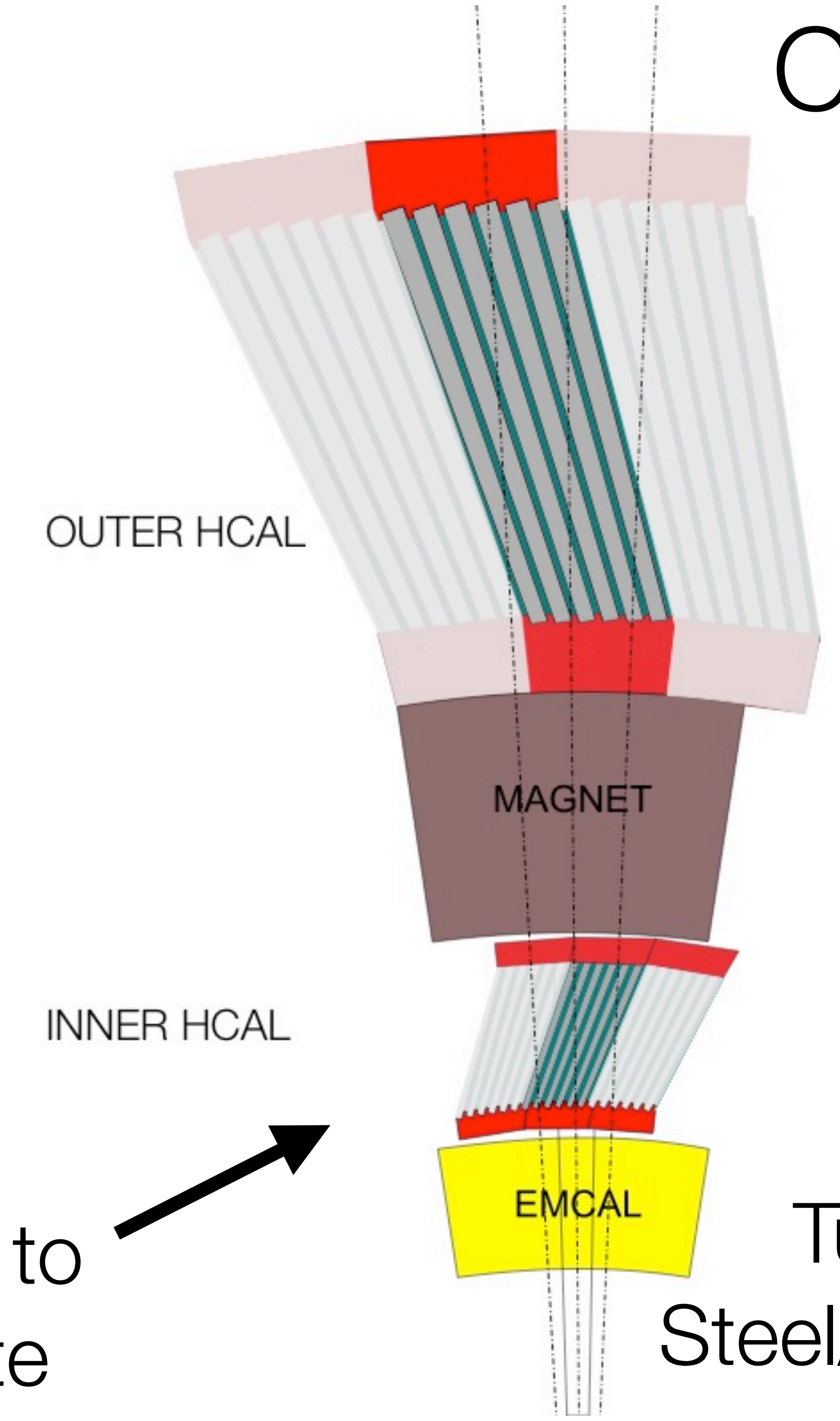
# sPHENIX detector systems

Tracker




1/30th volume of ALICE TPC

Calorimeter stack




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

15kHz readout in Au+Au to match RHIC collision rate

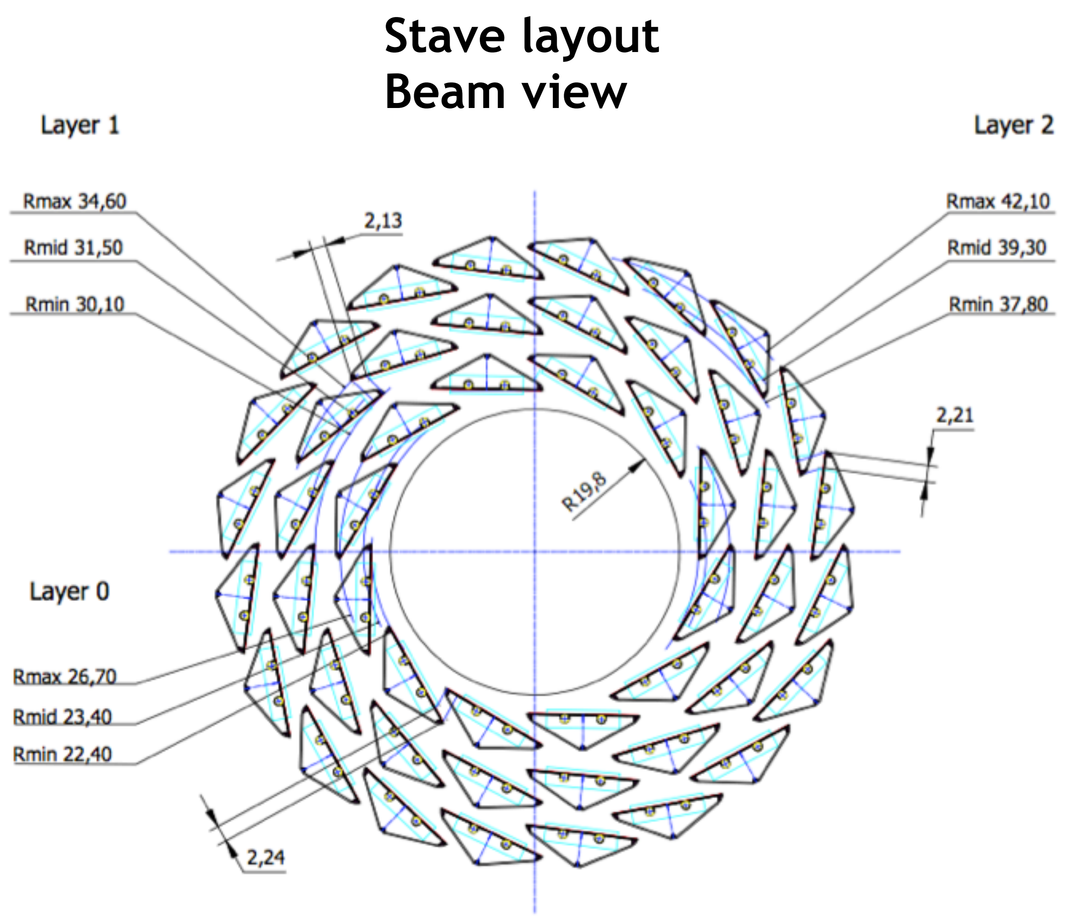
Tungsten/SciFi EMCal
Steel/plastic scintillator HCAL
SiPM readout

**Qualitative** improvement on 20 years of studies at RHIC through higher statistics (x10+), full calorimetry and higher precision tracking



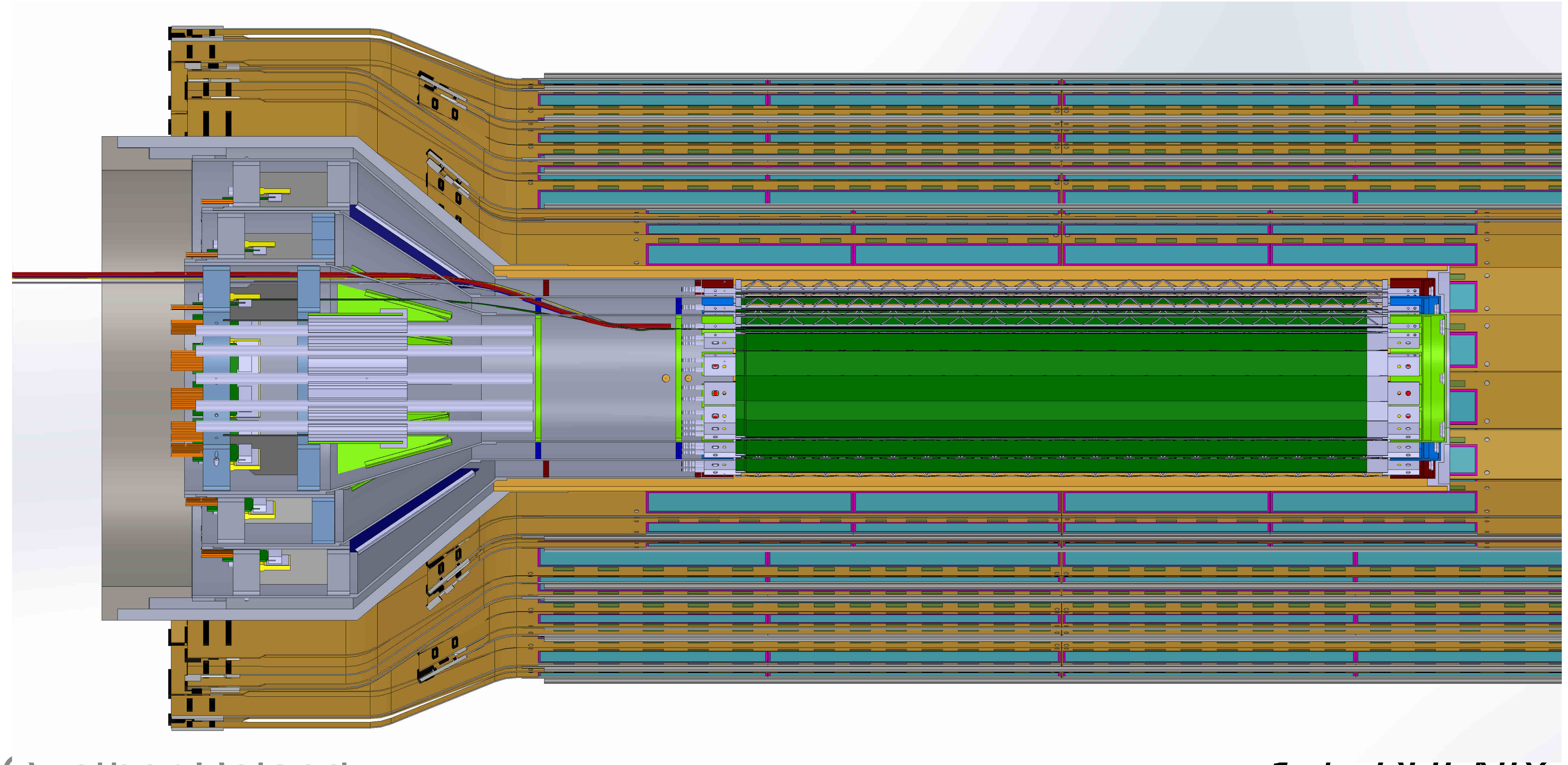
https://indico.bnl.gov/event/4640/attachments/18495/23200/sphenix-conceptual-design.pdf

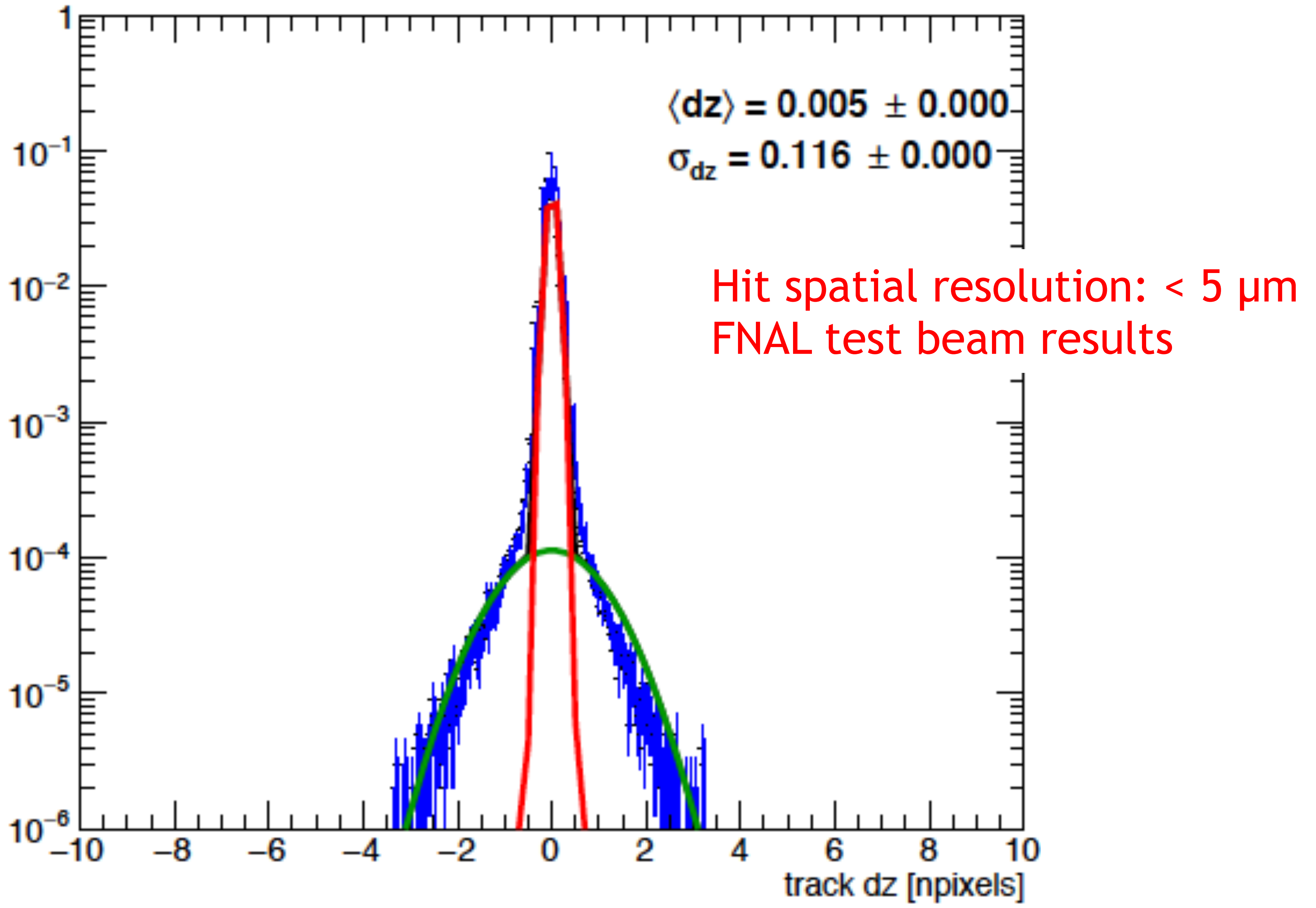
# MVTX enables world-class HF science program




MVTX based on copy of ALICE staves with support structure modified for sPHENIX – integrate with silicon strip (INTT) and all fit inside TPC inner field cage.

LANL LDRD addressing key questions –demonstrating successful read-out chain test and stave performance in FNAL test beam





# When will sPHENIX take data?


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

# 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 $\text{nb}^{-1}$ | 8.7 $\text{nb}^{-1}$ | 34 $\text{nb}^{-1}$ |
| Year-2 | p+p | 200 | 11.5 | — | 48 $\text{pb}^{-1}$ | 267 $\text{pb}^{-1}$ |
| Year-2 | p+Au | 200 | 11.5 | — | 0.33 $\text{pb}^{-1}$ | 1.46 $\text{pb}^{-1}$ |
| Year-3 | Au+Au | 200 | 23.5 | 14 $\text{nb}^{-1}$ | 26 $\text{nb}^{-1}$ | 88 $\text{nb}^{-1}$ |
| Year-4 | p+p | 200 | 23.5 | — | 149 $\text{pb}^{-1}$ | 783 $\text{pb}^{-1}$ |
| Year-5 | Au+Au | 200 | 23.5 | 14 $\text{nb}^{-1}$ | 48 $\text{nb}^{-1}$ | 92 $\text{nb}^{-1}$ |

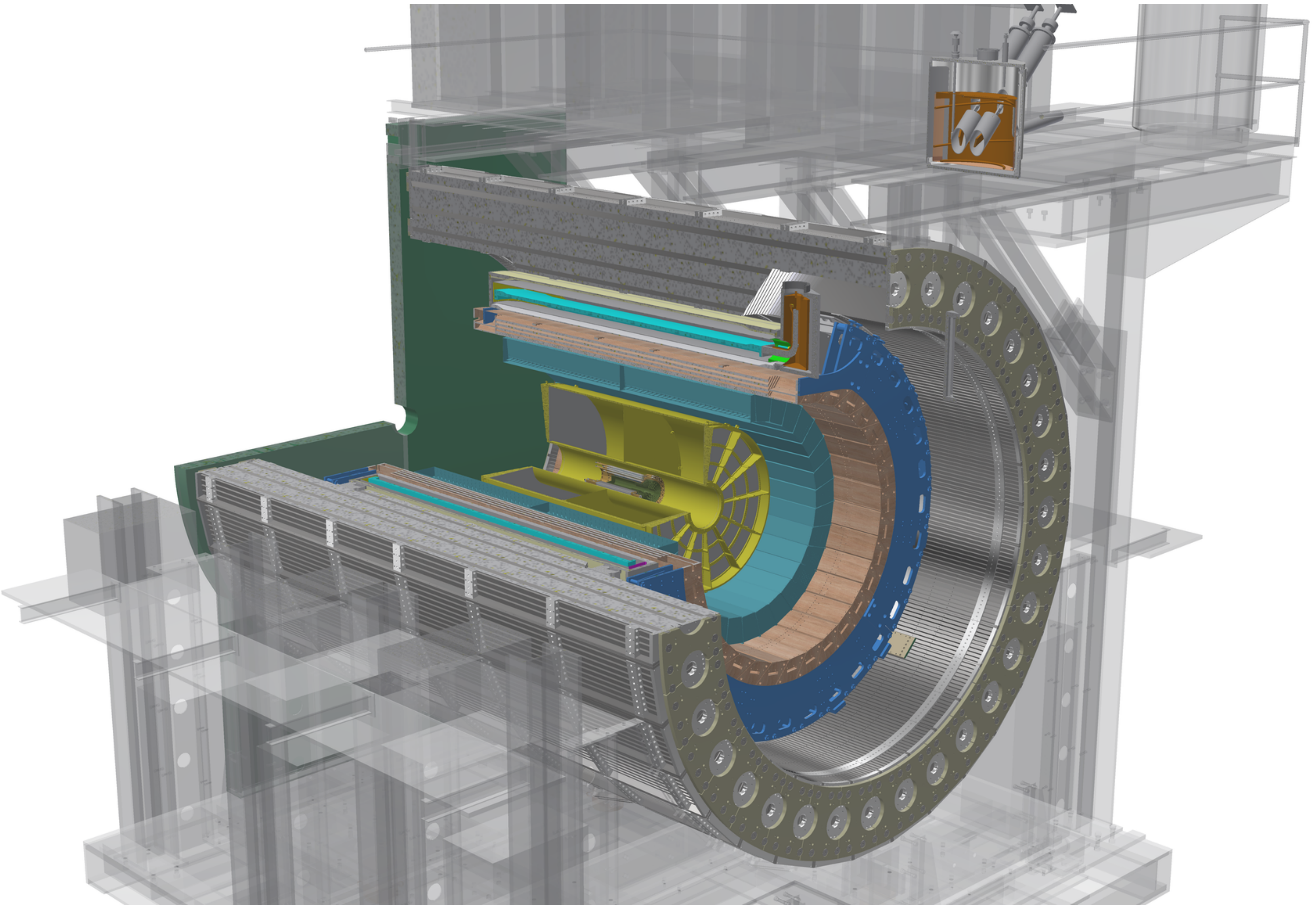
- Consistent with DOE CD-0 “mission need” document
- Incorporates BNL C-AD guidance on luminosity evolution
- Incorporates commissioning time in first year

**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 pT photons) one can sample within |z| < 10 cm a total of 550 billion events.

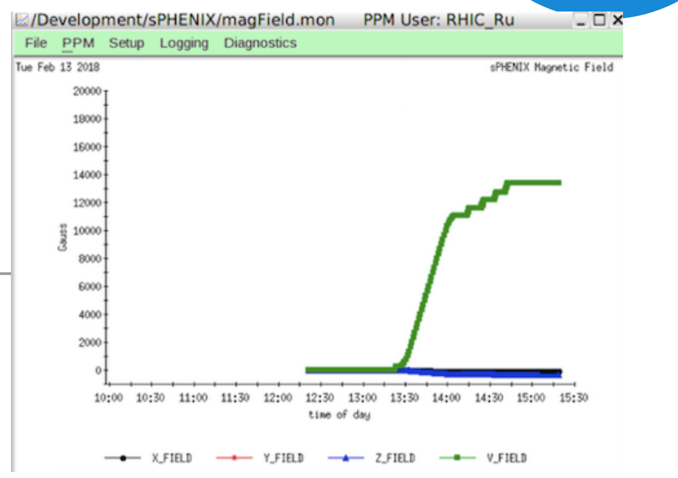
# sPHENIX *today*

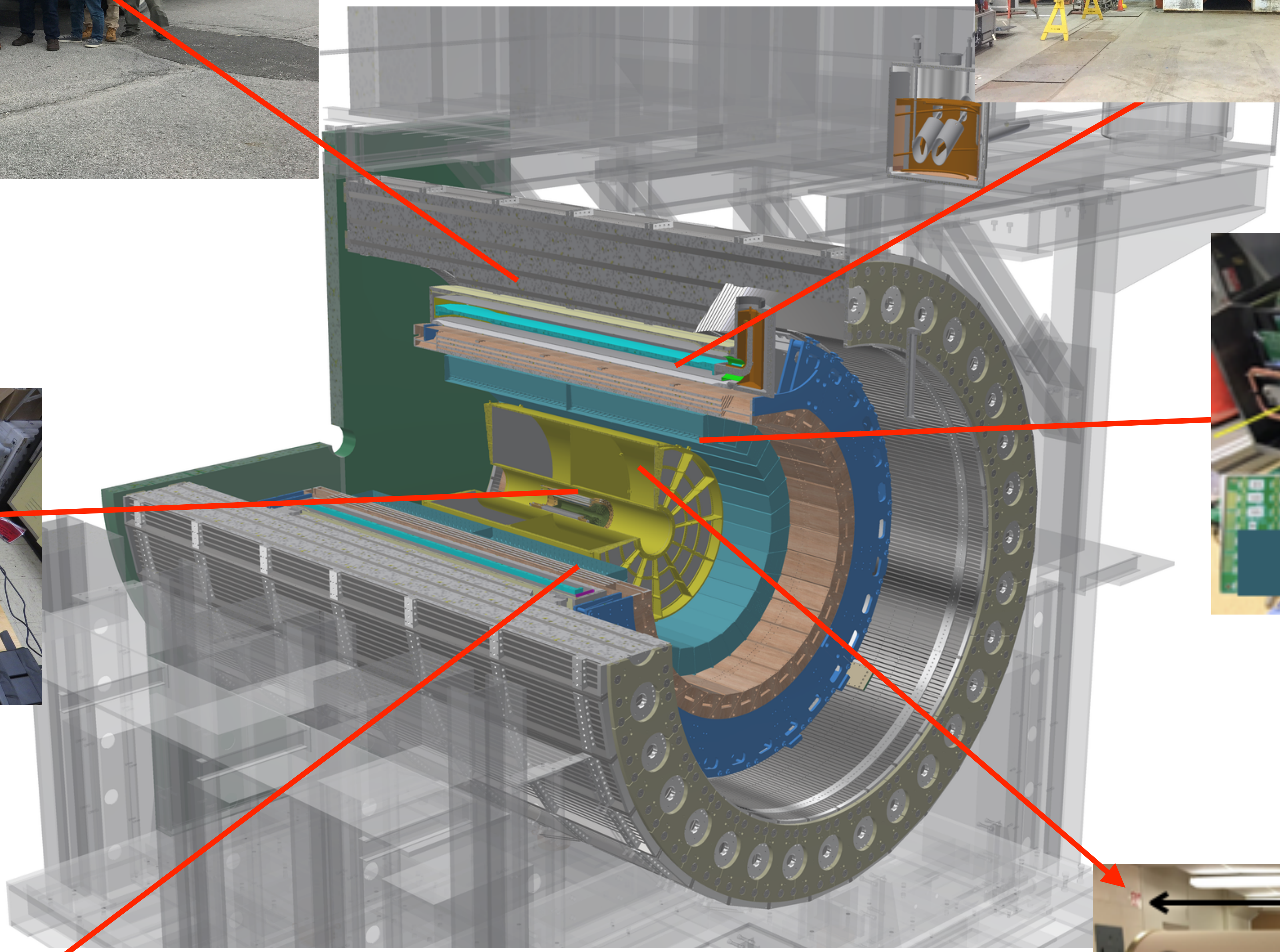


# sPHENIX *today*

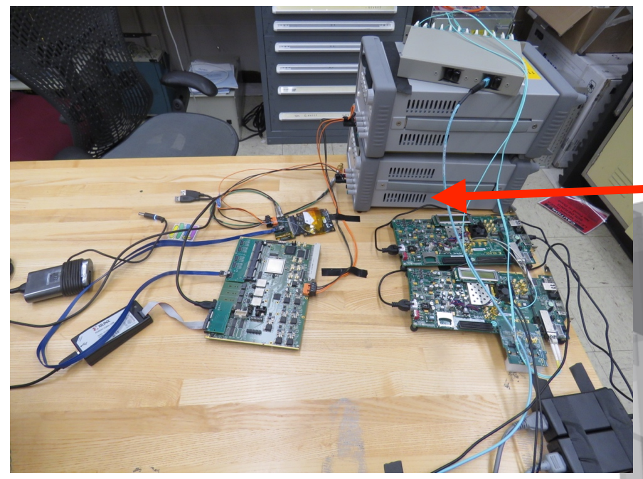
Flux return/**oHCAL** absorber
First production sectors
**arrived two weeks ago**

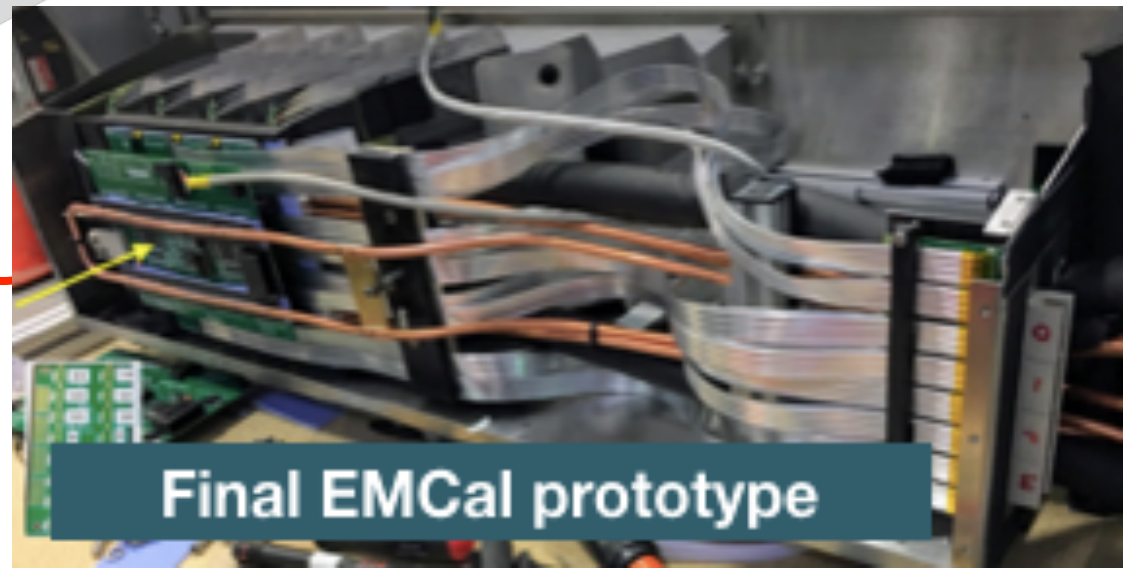
Full field **magnet** test
at 1.4T at BNL on
**2/13/2018**



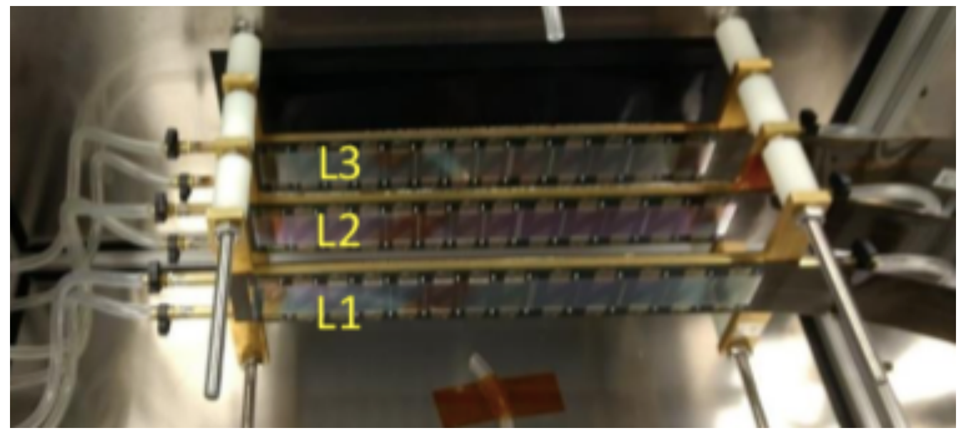


**MVTX** full chain test and beam test in **Spring 2018**
Expecting stave procurement in **late 2018**

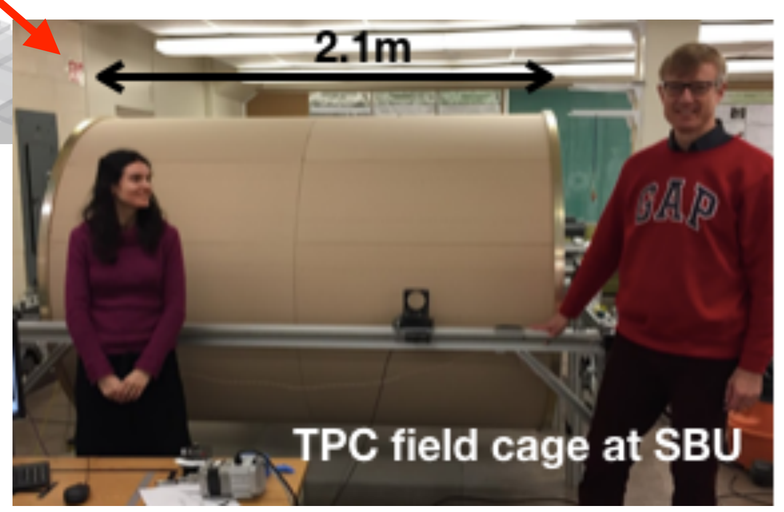





Approval of **EMCAL** materials purchase received in **August ’18**
**“Sector 0” production starting 2018**




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

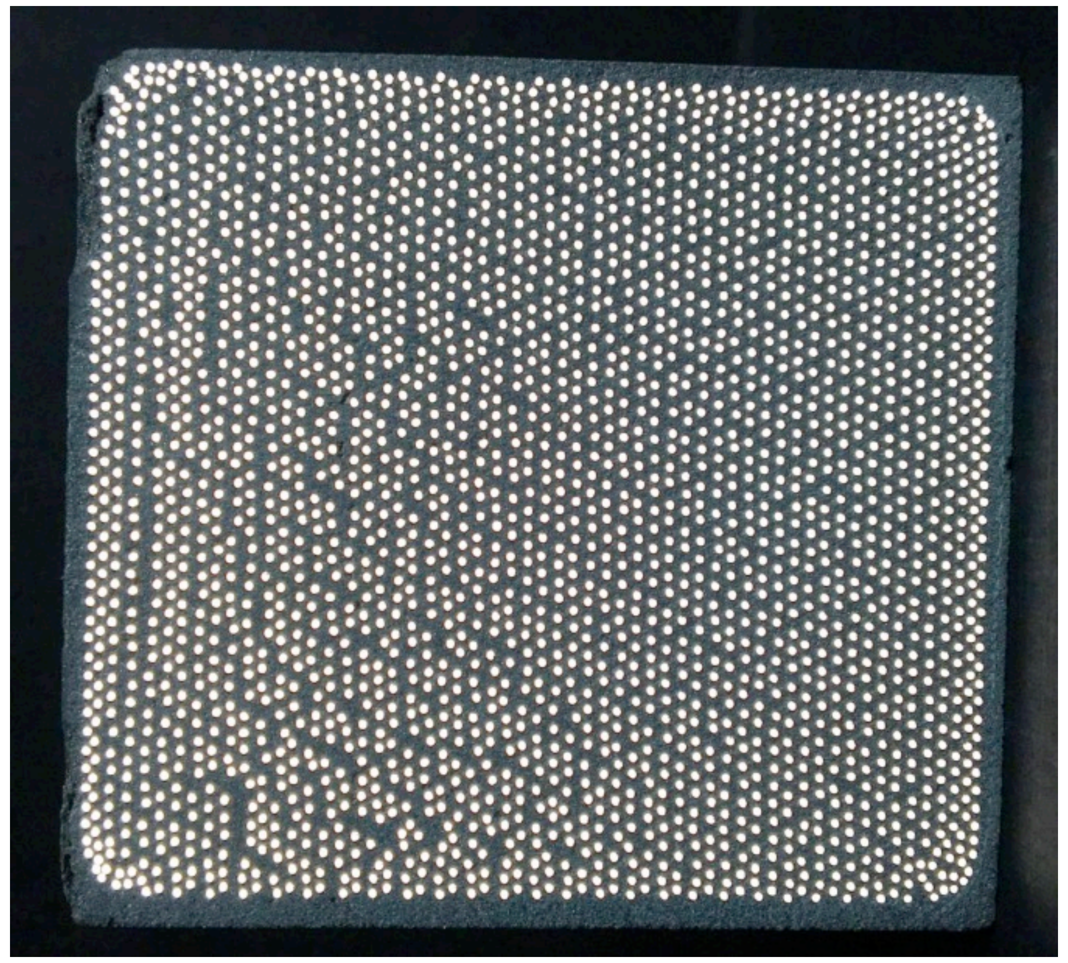



Beam test of **TPC** prototype in **June 2018**
Ready for producing of full-size field cage “prototype”


Slots for scintillating tiles, read-out using SiPMs
6.4 meters long, |η| < 1.1
32 modules form flux return
instrumented to be outer HCal
First production module delivered to BNL one month ago
Second module arrives on Friday
After that, they'll arrive at a rate of about one per week

# Tungsten SciFi EMCal moving from R&D to pre-production

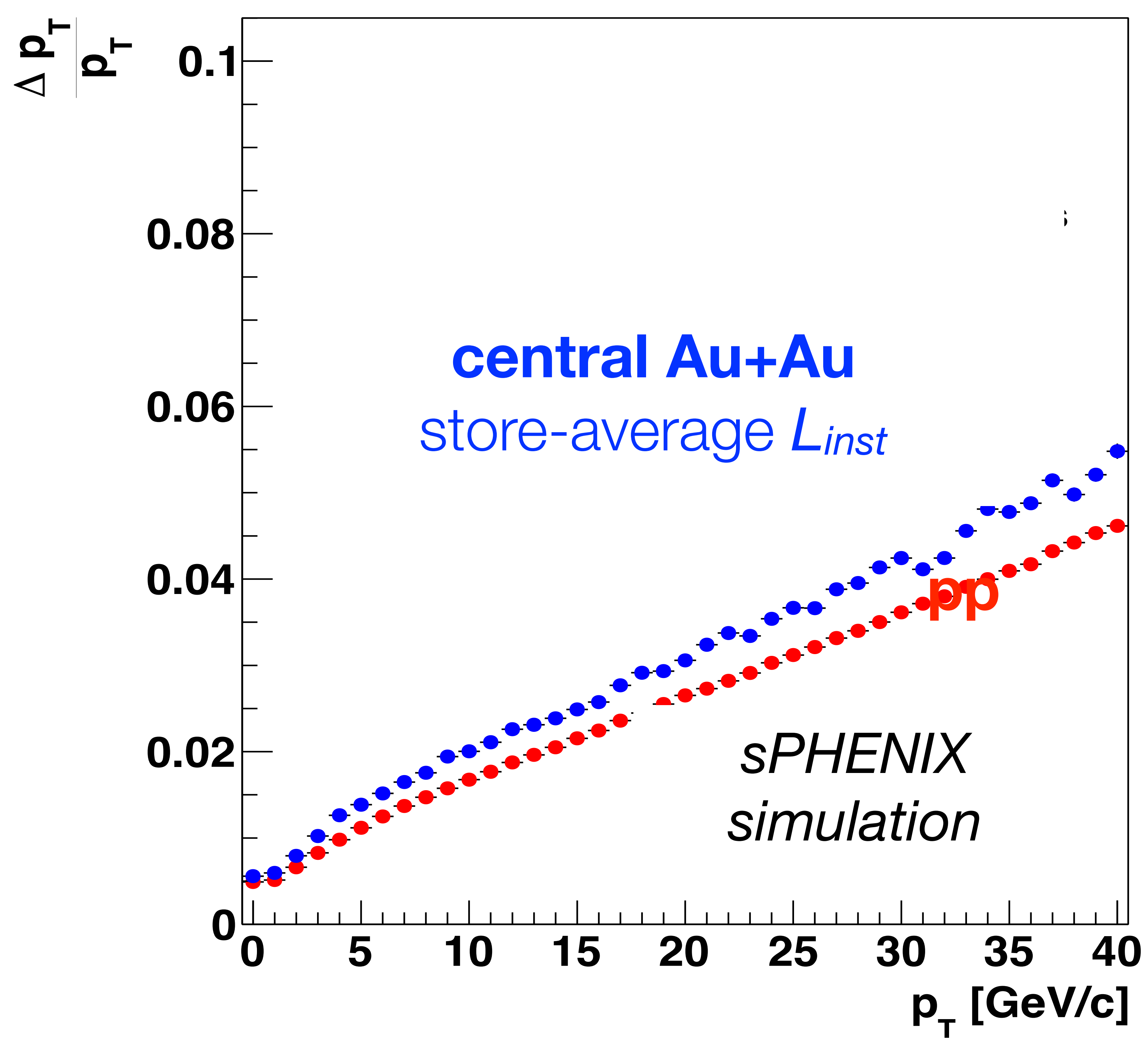

- First 12 blocks for Sector 0 (all Type 1) have arrived at BNL.



technology pioneered by UCLA group
now 2D projective, to be read out by SiPMs
same electronics (up to form factor) as HCal
production techniques advanced by UIUC group
discussions with Chinese institutions about

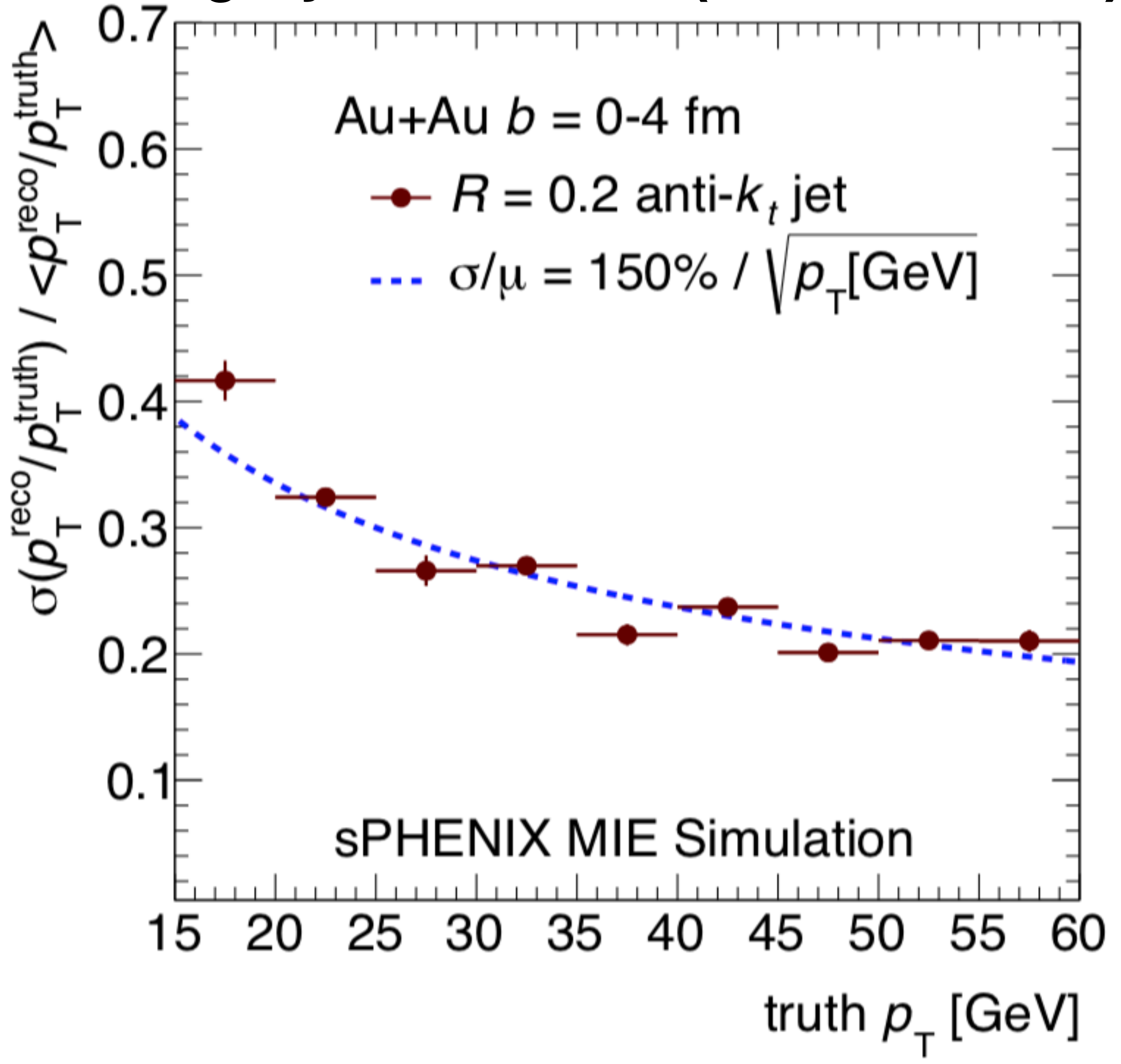
# Performance simulation: Track and jet resolution

**Track pT resolution (central Au+Au)**




High momentum resolution
Tracking efficiency > 90% in high pileup Au+Au environment

**Single jet resolution (central Au+Au)**

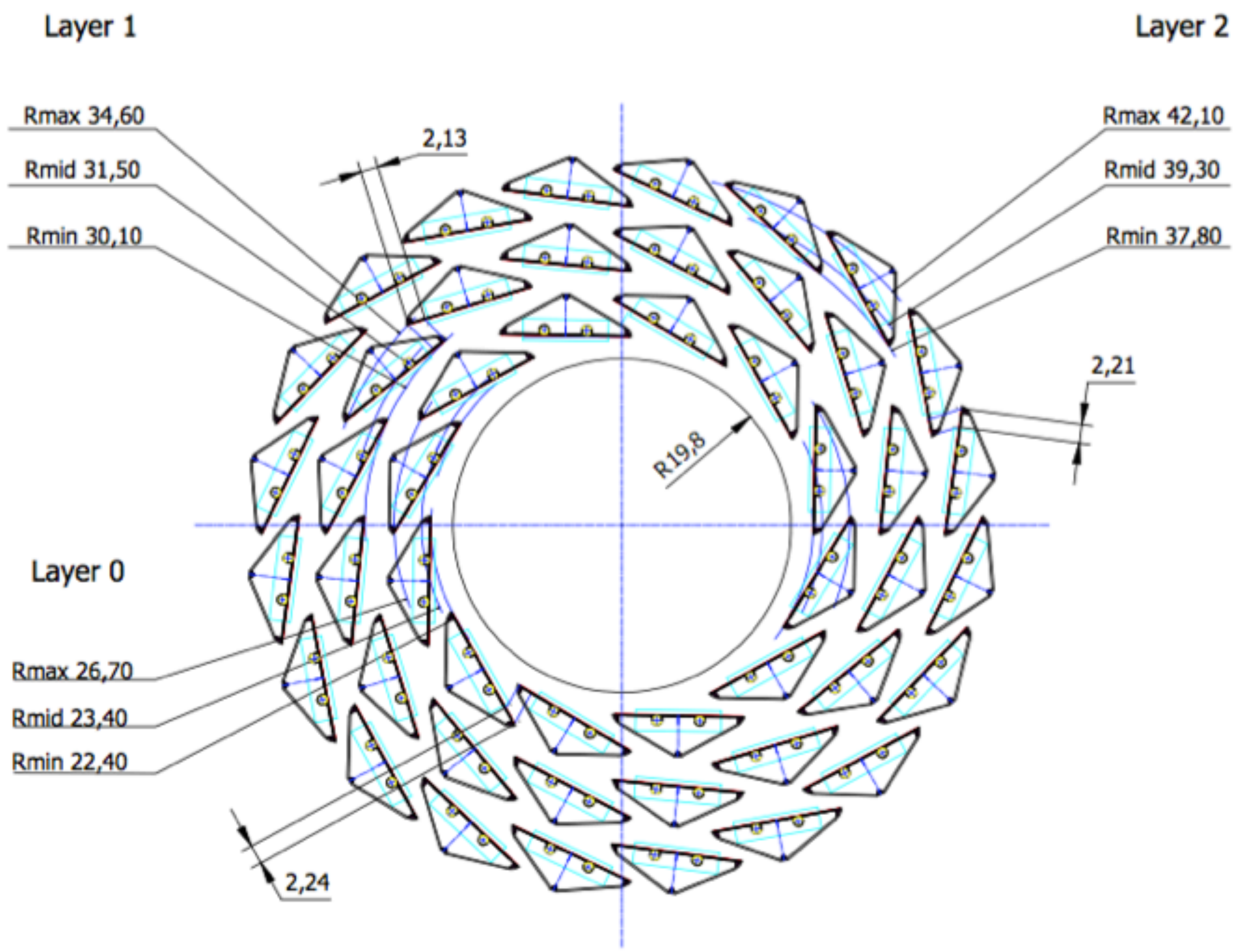



Calorimeter-related performance studied using GEANT simulations verified with **test beam data**

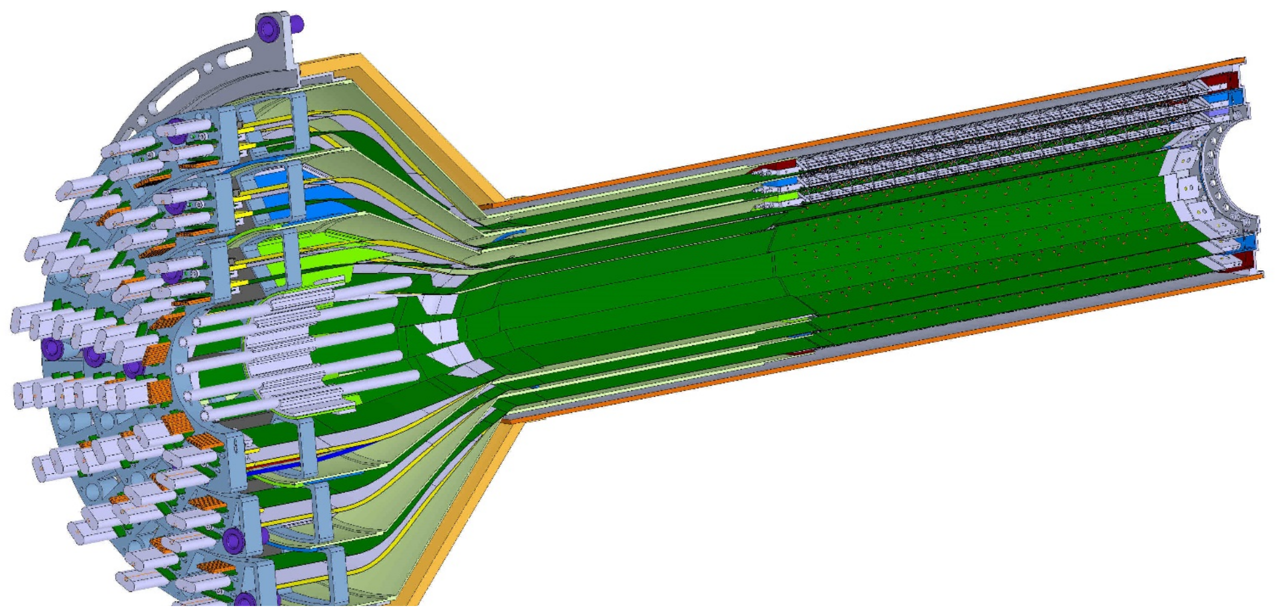
arXiv:1704.01461

# Microvertex tracker performance

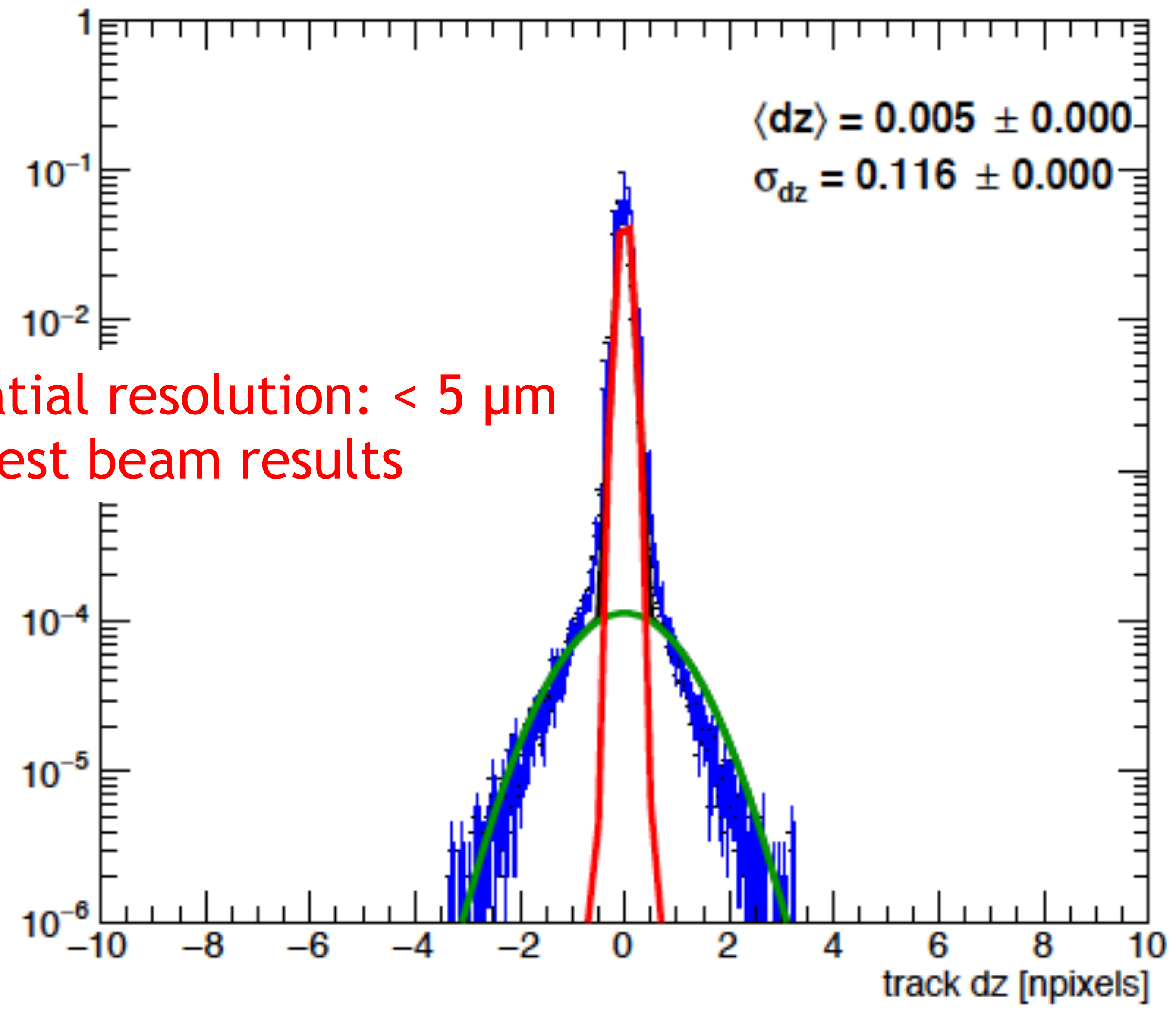
**Stave layout beam view**




MVTX based on copy of ALICE Inner Barrel staves

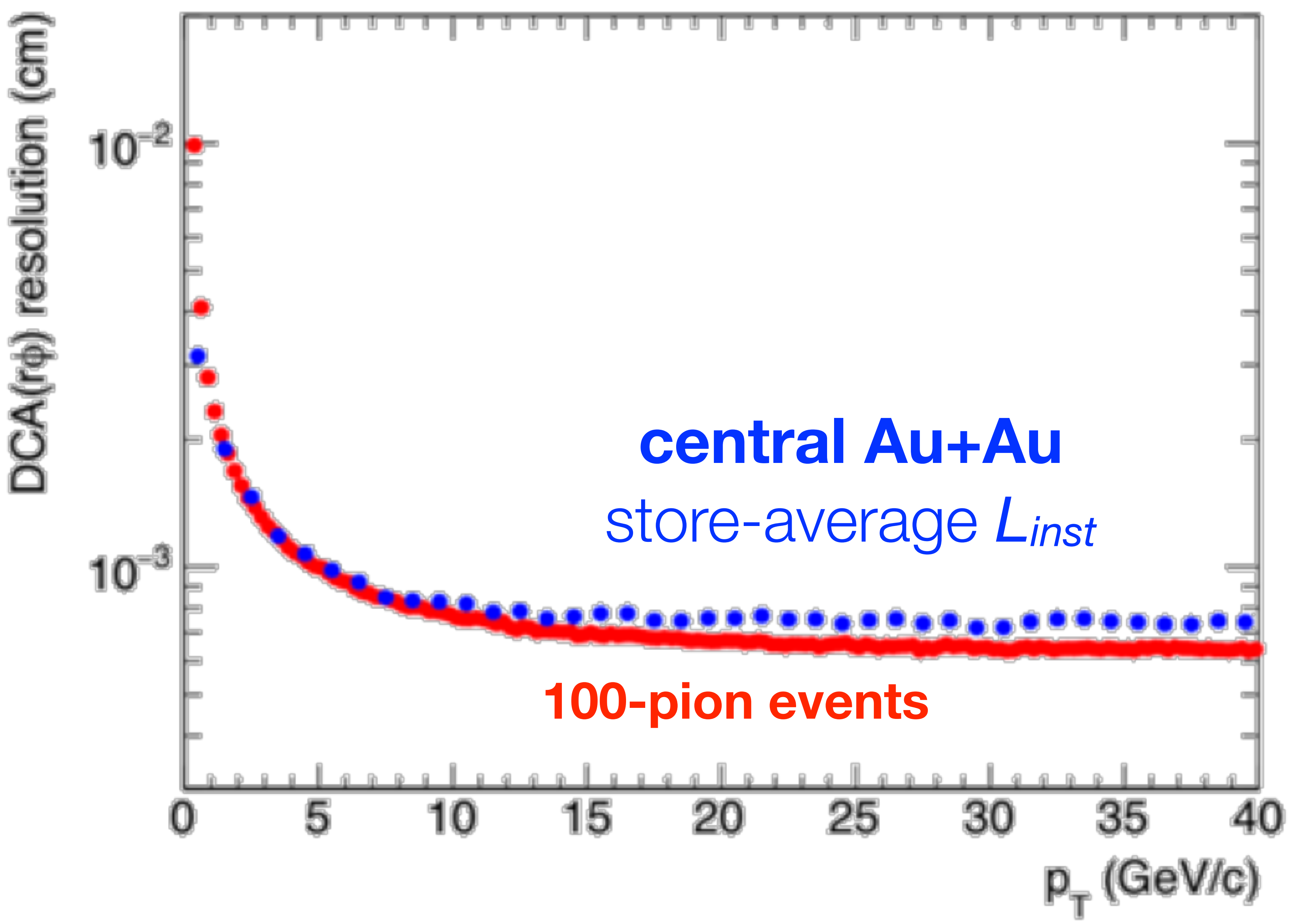


**MVTX spatial resolution**




Spatial resolution verified in full chain **test beam** at FNAL

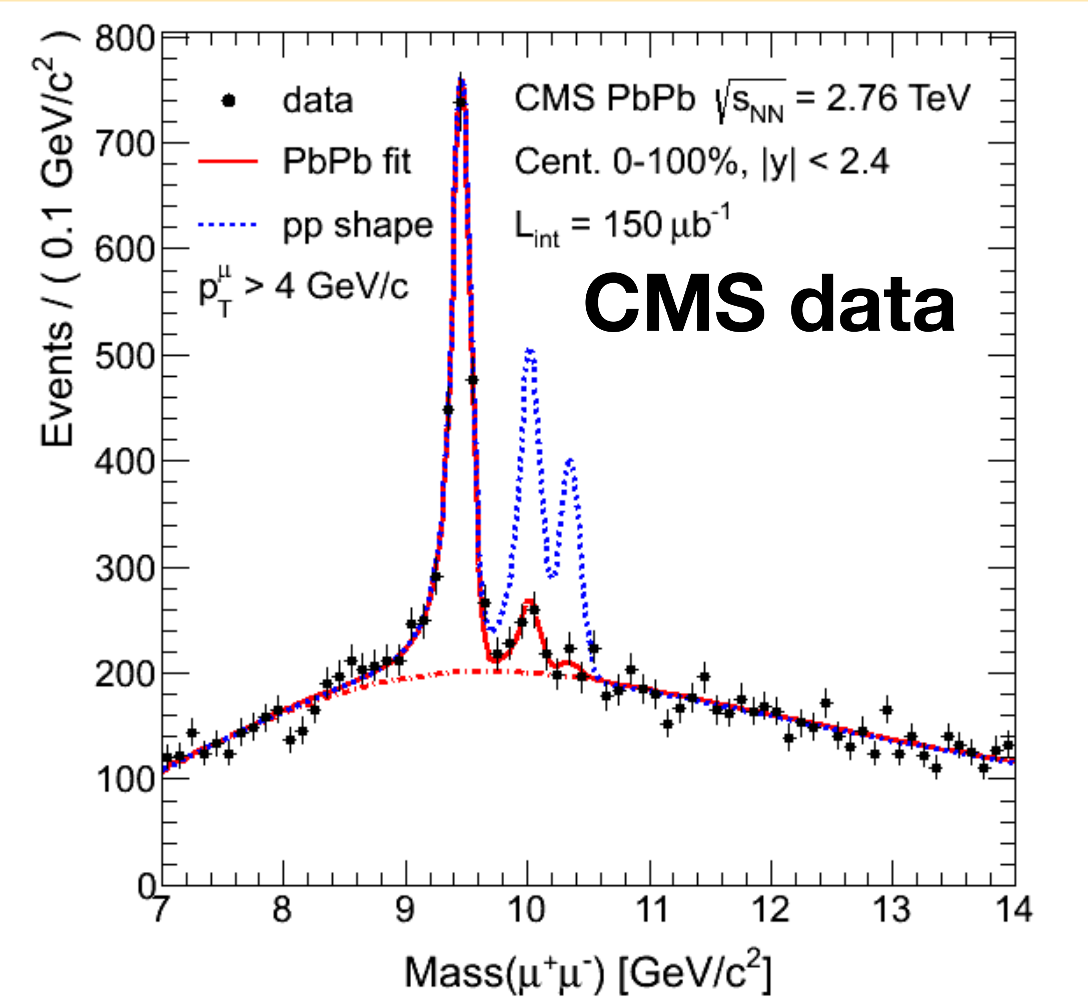
**MVTX DCA resolution**

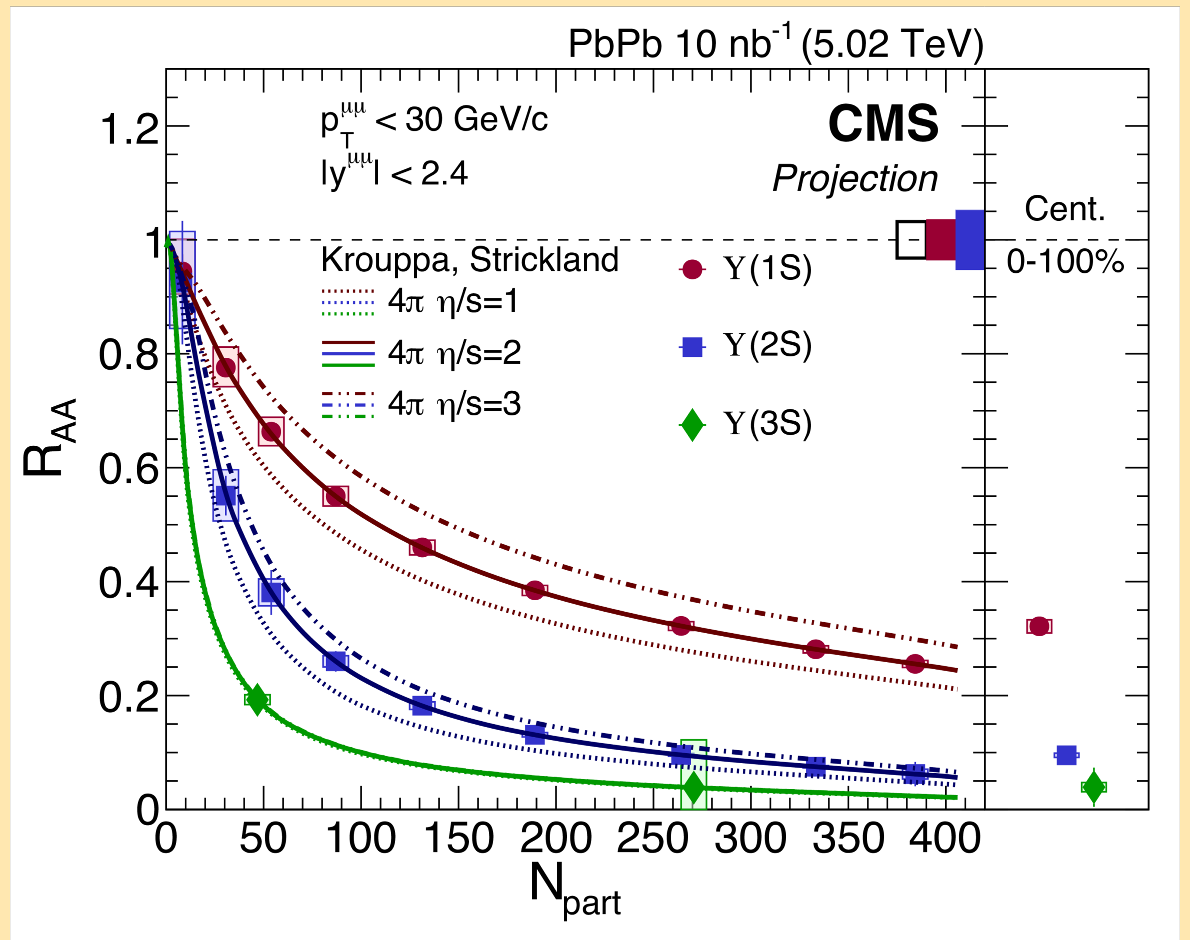



b-jet tagging and open HF hadrons through secondary vertexing

https://indico.bnl.gov/event/4072/attachments/11335/13816/sPH-HF-2018-001-final.pdf

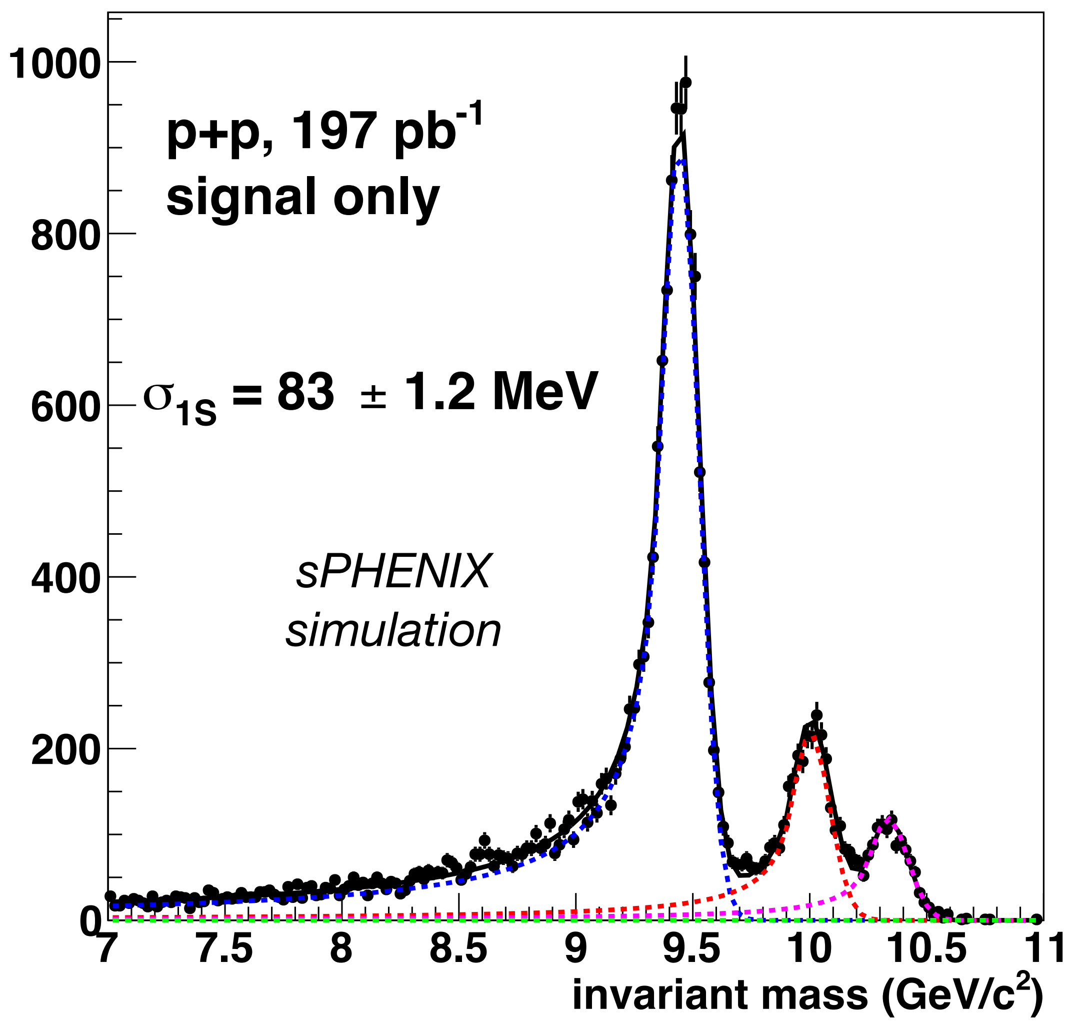
# Physics projection: Upsilons at sPHENIX cf. LHC

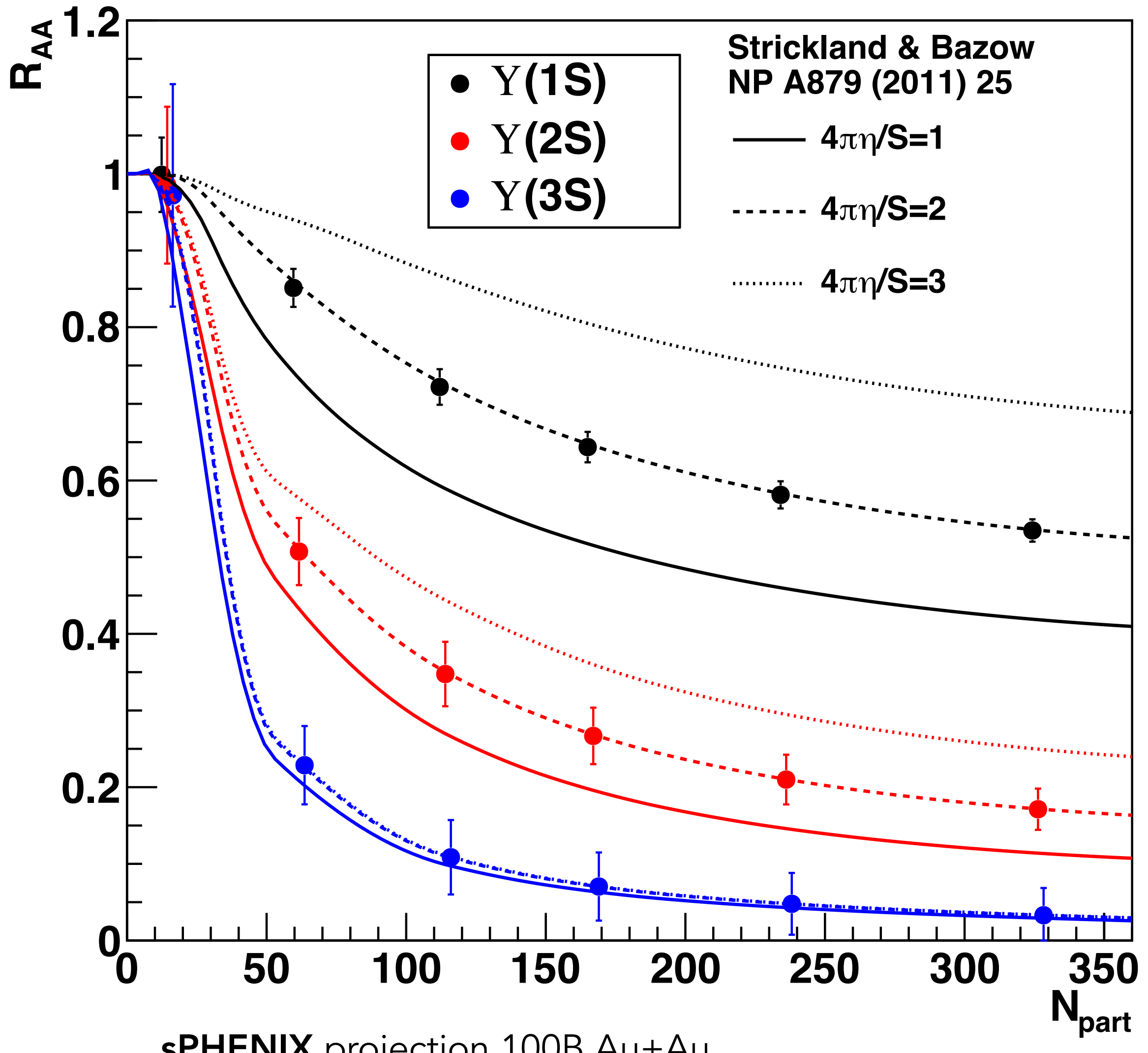



## CMS projection for Run III+IV

Differential suppression of Y(nS) states depends on QGP Debye screening length



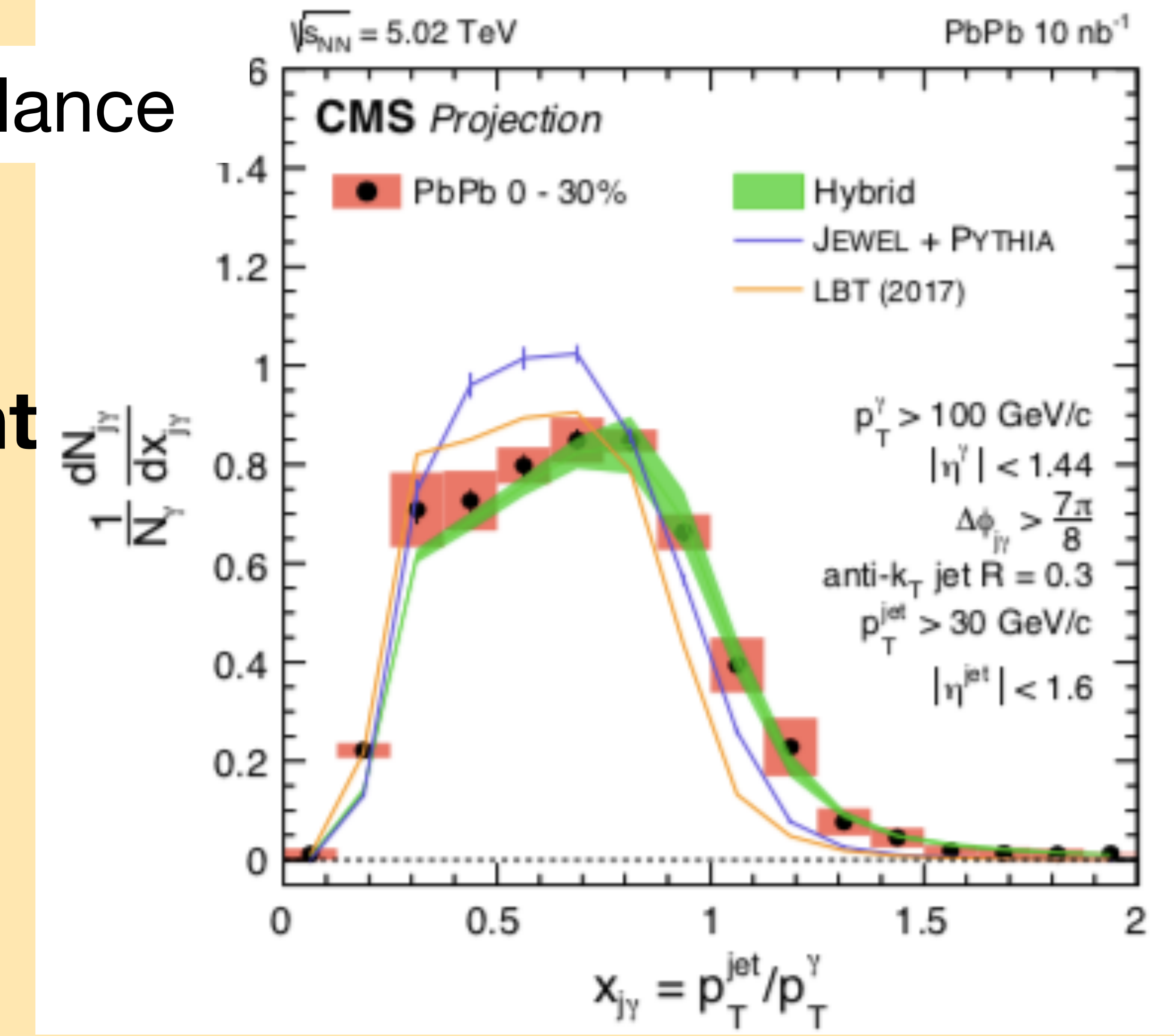




## sPHENIX projection

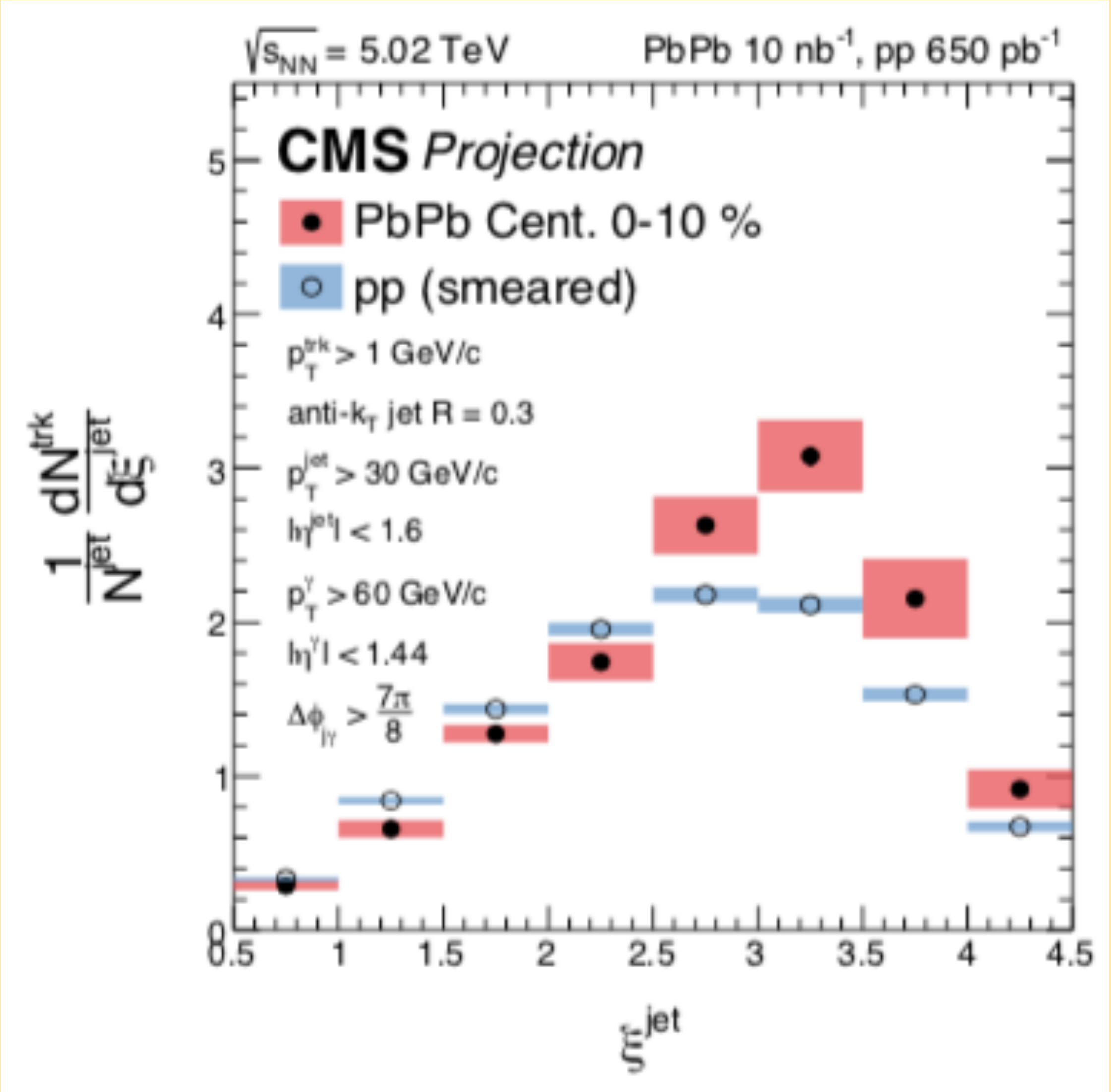
# Physics projections: Jets in sPHENIX cf. LHC

γ+Jet momentum balance

**Direct measurement of parton energy loss in the QGP**

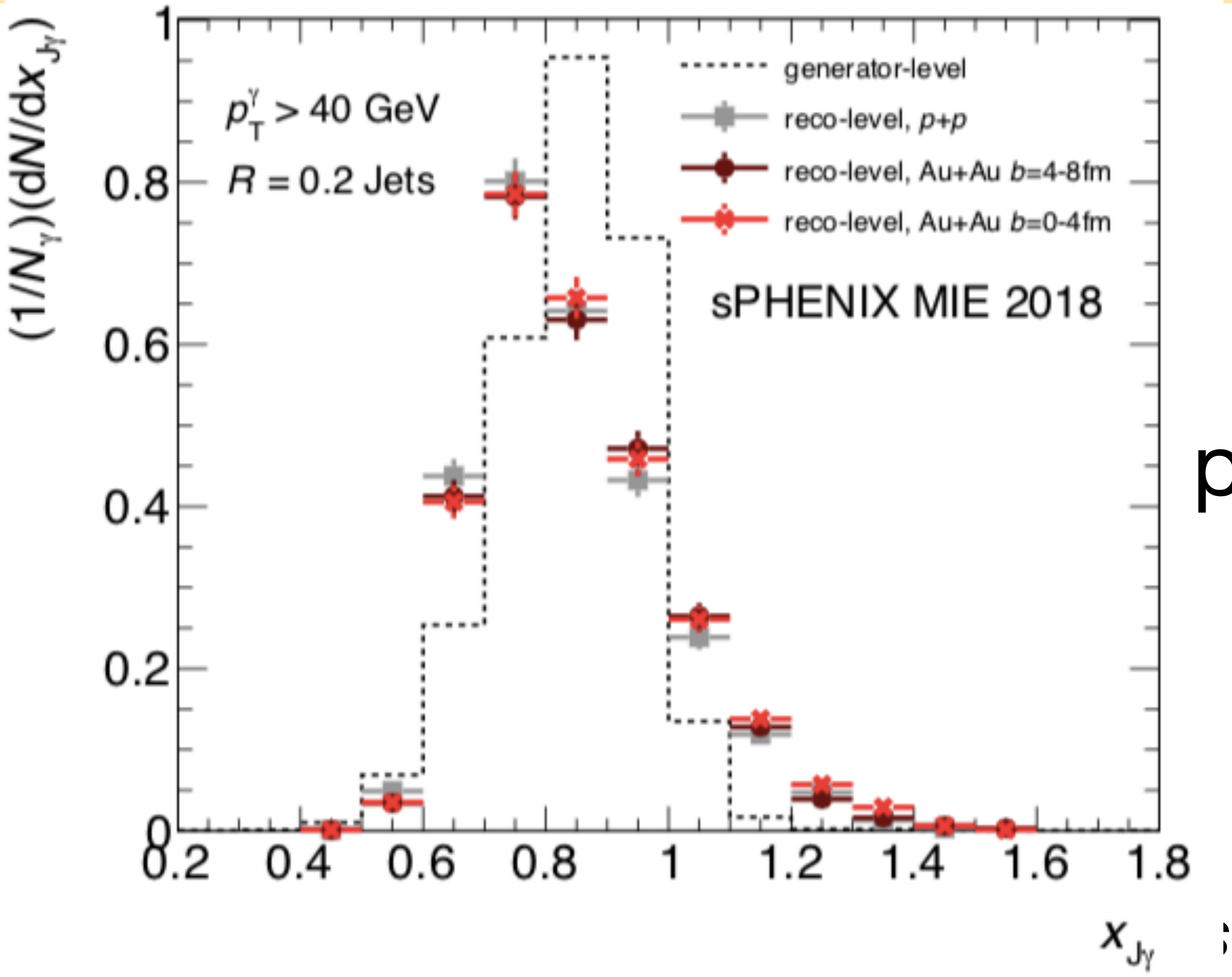



CMS projections for Run III+IV



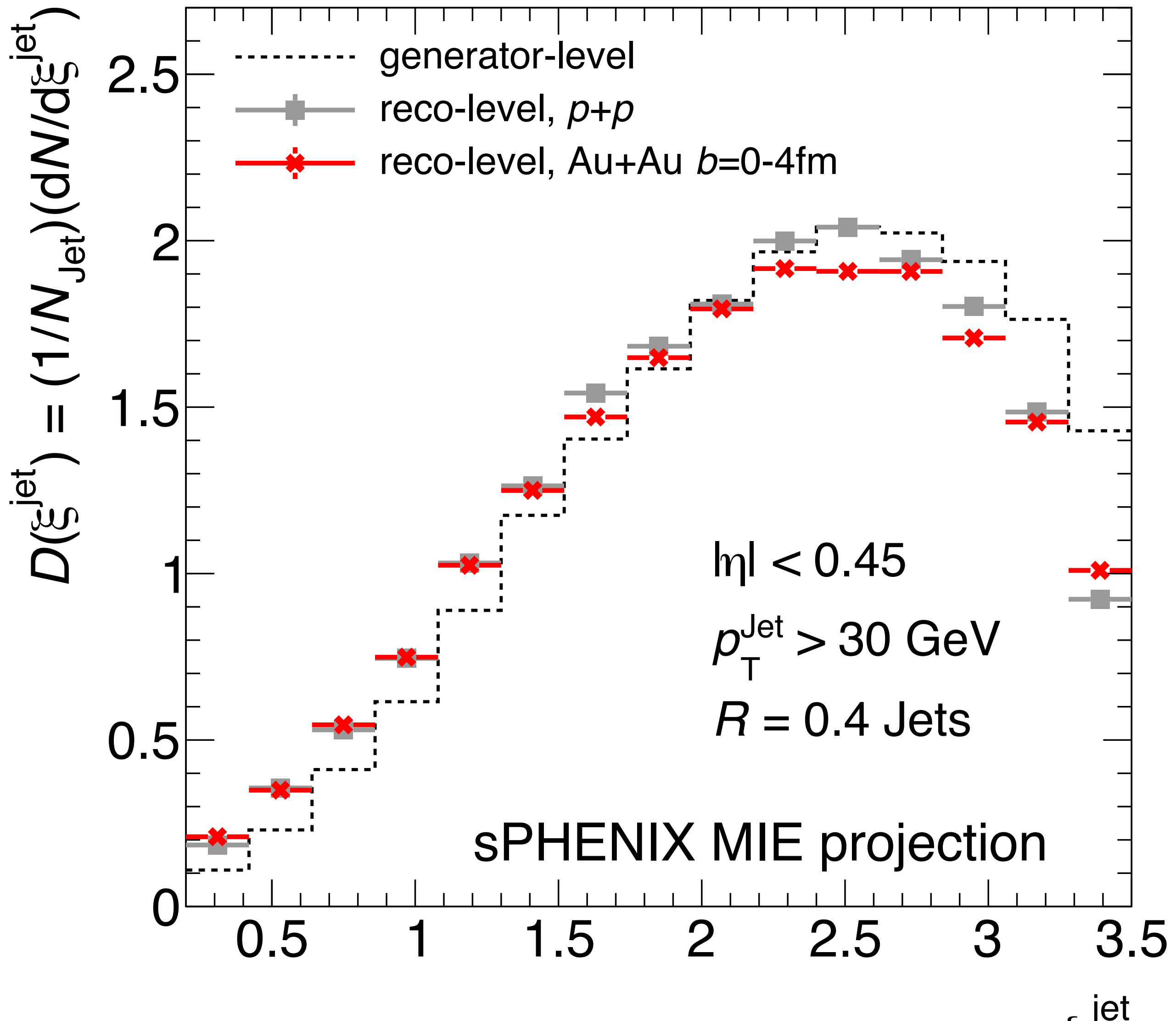

γ+Jet fragmentation function

**Modification of parton shower in the QGP**




sPHENIX projections

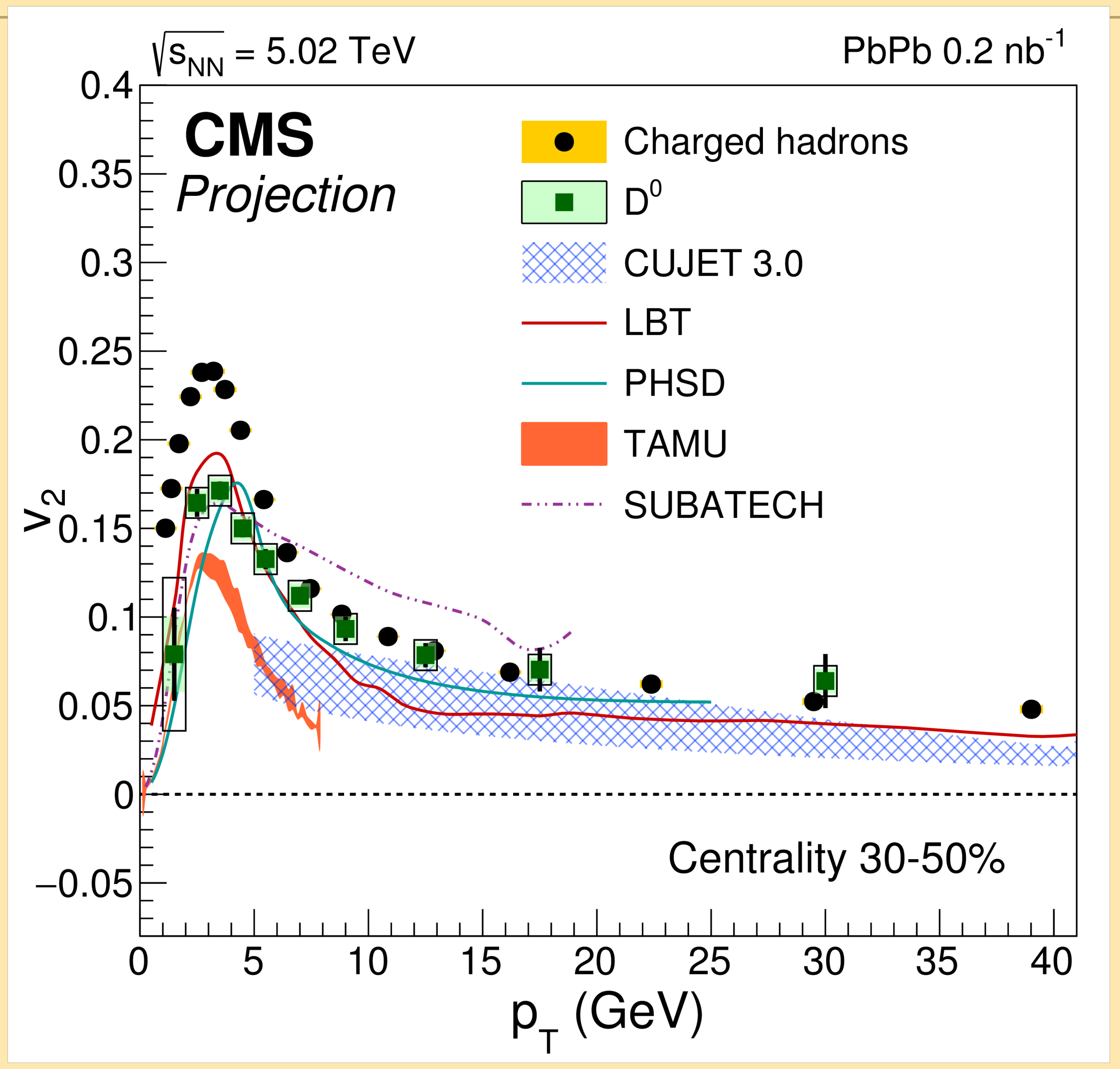
t sPHENIX Ru



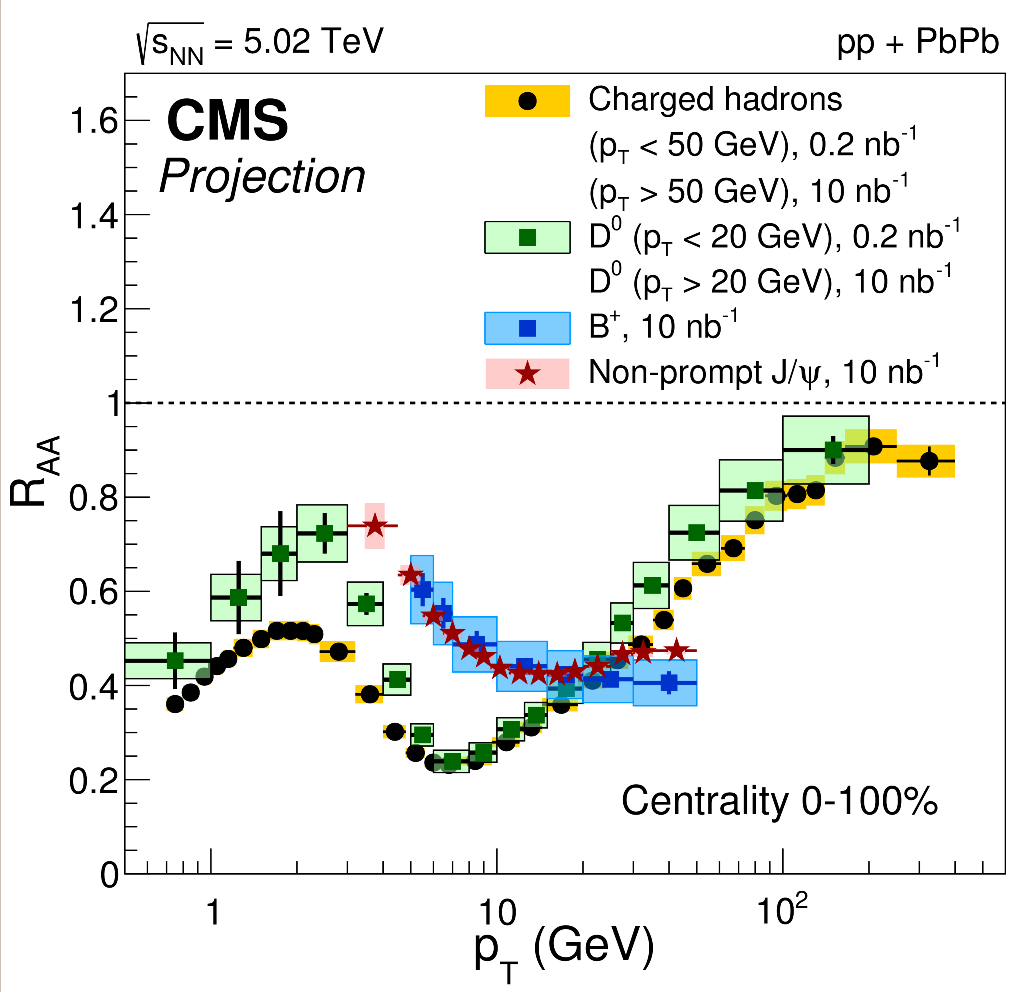

**sPHENIX** projection 100B Au+Au

# Heavy flavor at sPHENIX cf. LHC

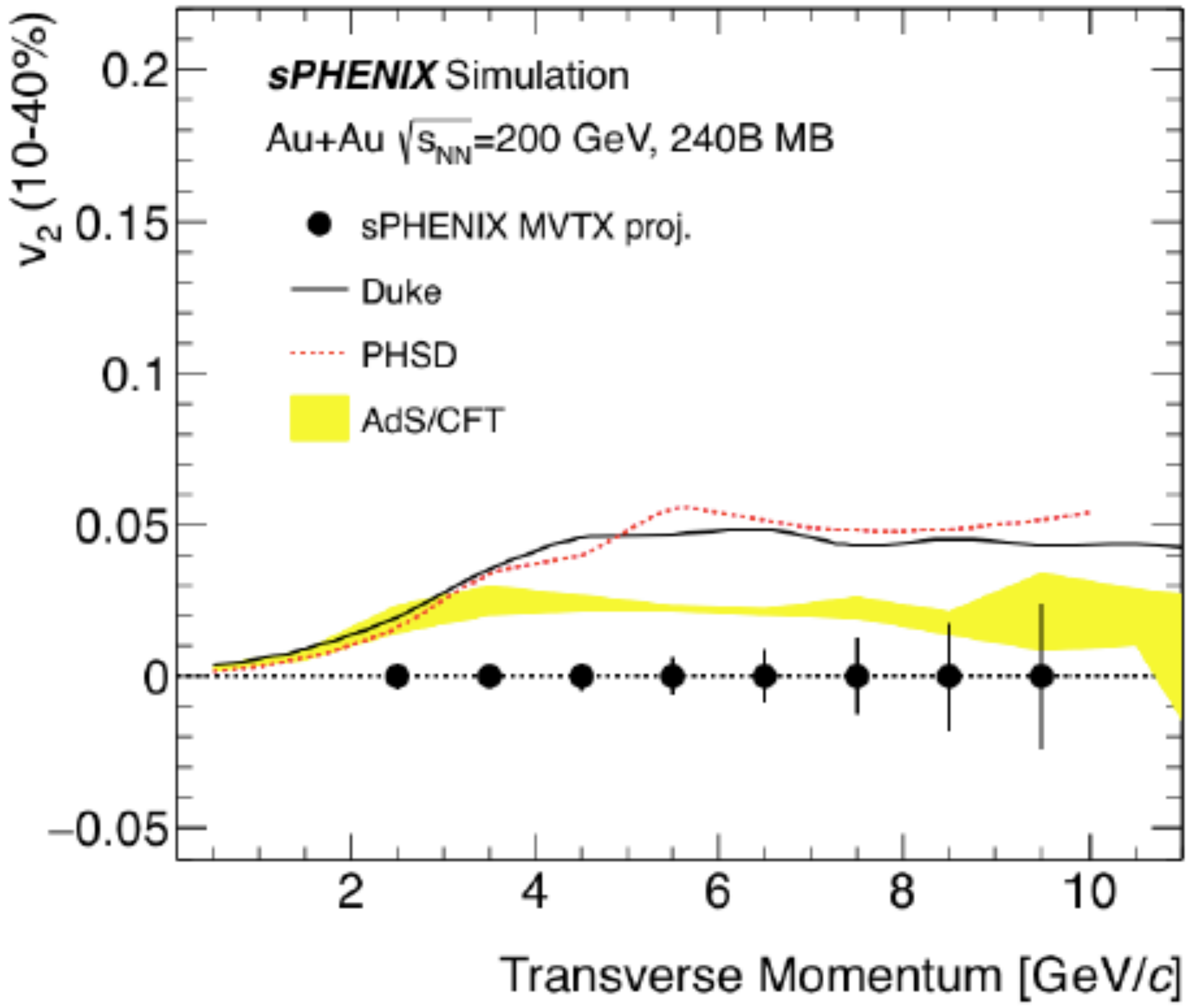
Elliptic flow measures *c* and *b* quark thermalization in medium



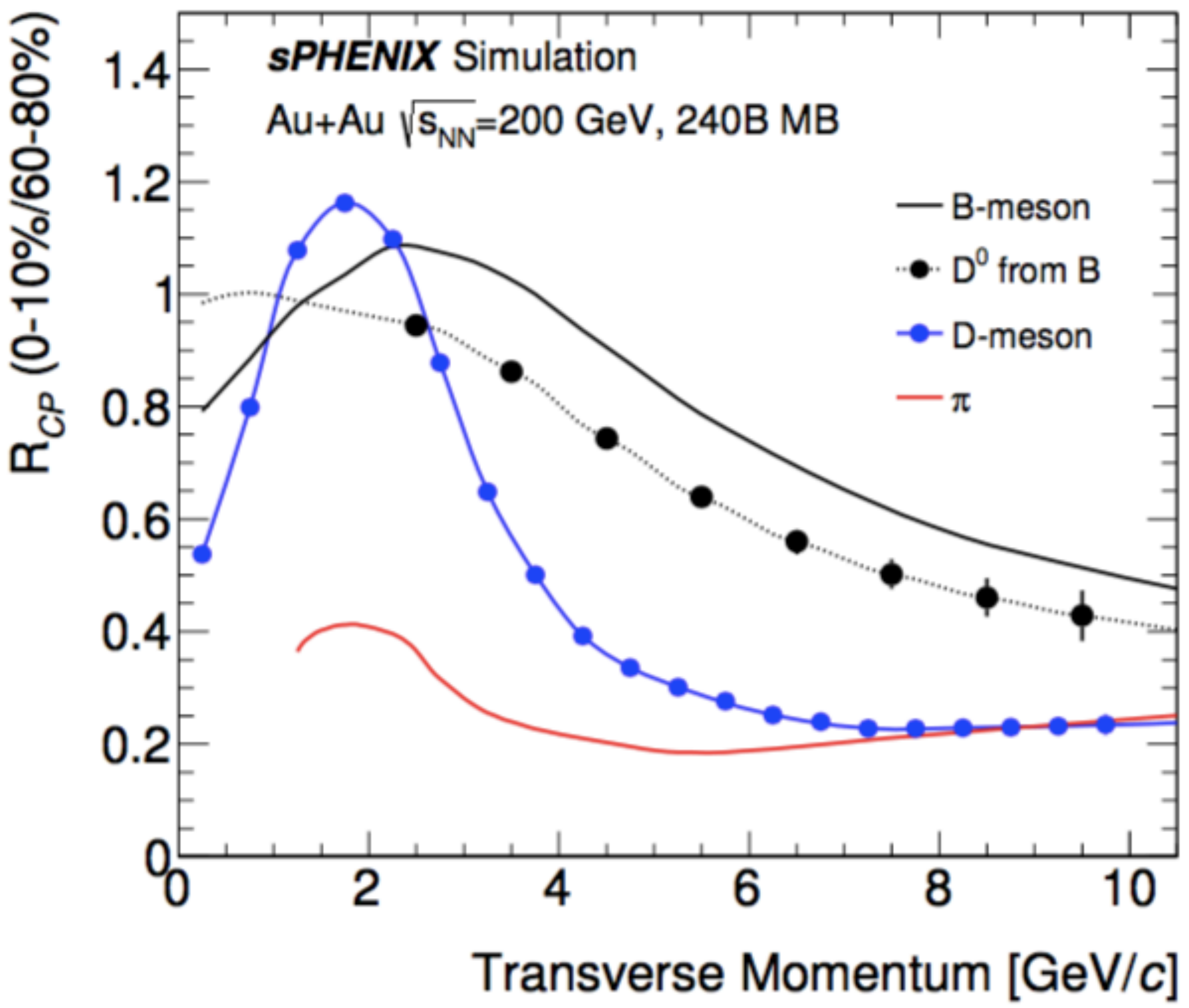

CMS projections for Run III+IV




Open heavy flavor suppression probes flavor dependence of energy loss




PHENIX projections




*1st sPHENIX Russ*

# The sPHENIX collaboration – formed December 2015

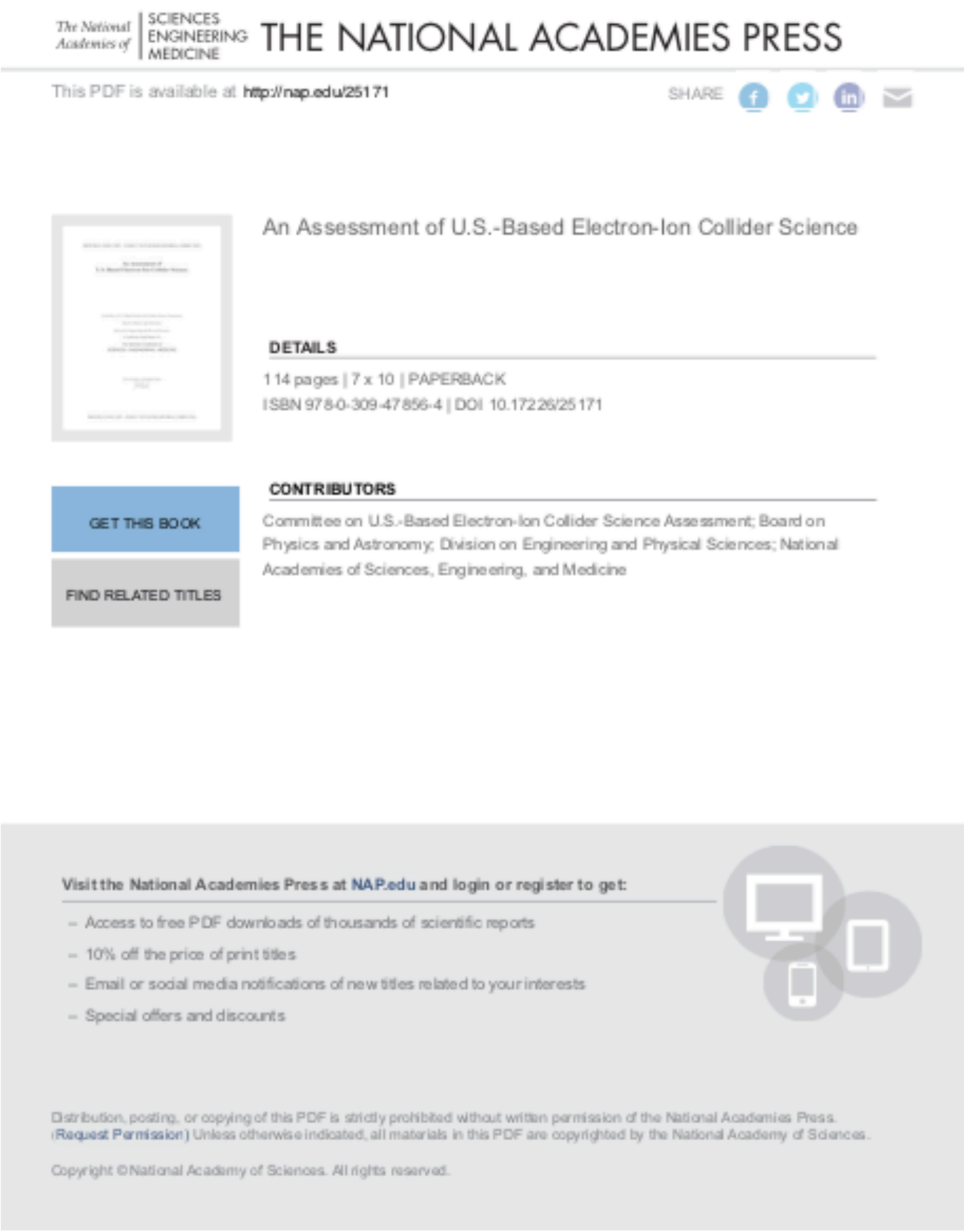
## More than 70 institutions currently, significant growth since formation

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 (CTU)
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 UniversityOak 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

2016 2017 2018

# 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**

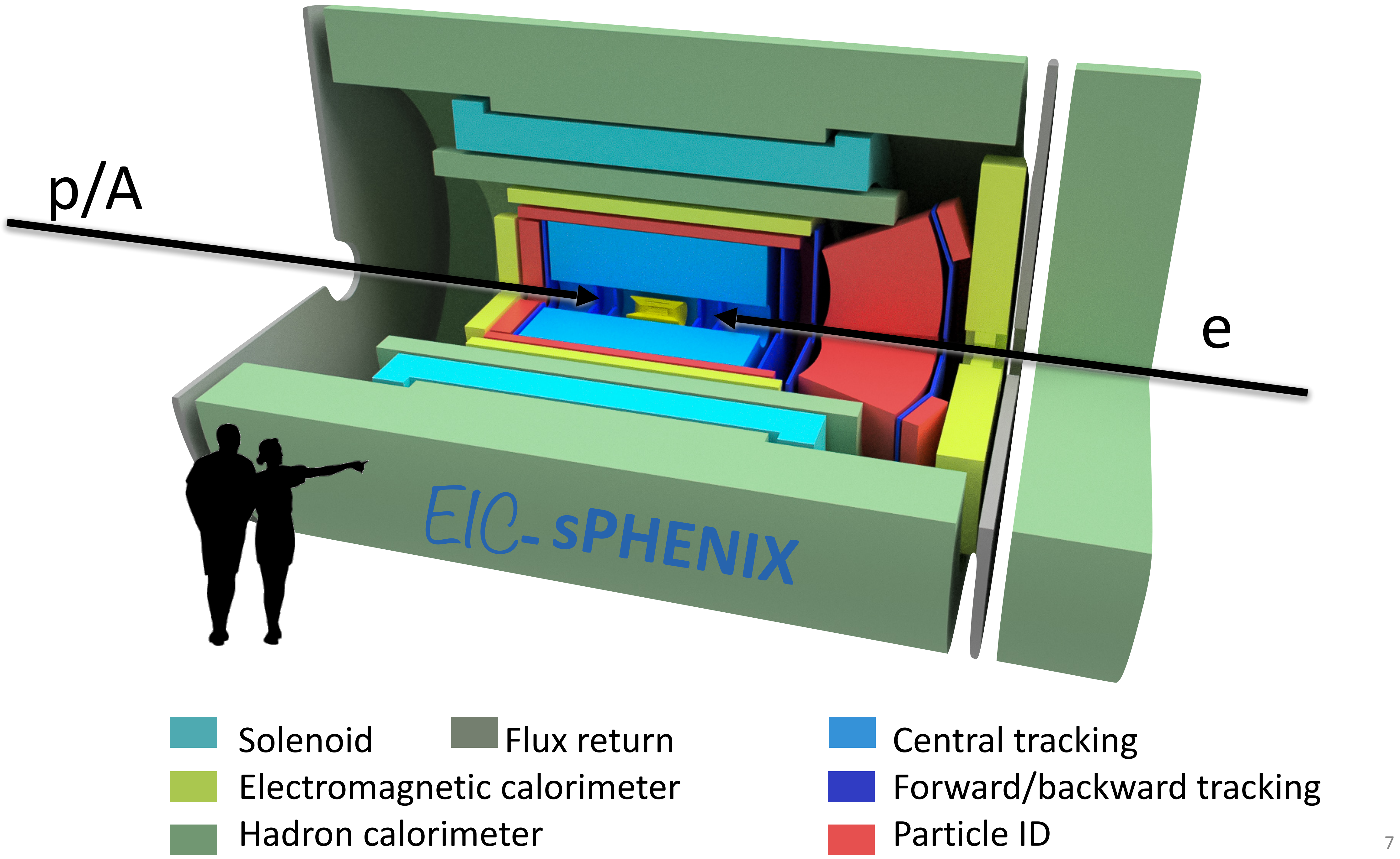
Committee on U.S.-Based Electron-Ion Collider Science Assessment; Board on Physics and Astronomy; Division on Engineering and Physical Sciences; National Academies of Sciences, Engineering, and Medicine

**Visit the National Academies Press at NAP.edu and login or register to get:**

- Access to free PDF downloads of thousands of scientific reports
- 10% off the price of print titles
- Email or social media notifications of new titles related to your interests
- Special offers and discounts



Study group (incl. non-sPHENIX members) working on EIC detector design based on sPHENIX/Babar magnet - Design Study Report in final review



# Outlook

- sPHENIX will probe microscopic structure of strongly coupled QGP
- New state of the art detector at RHIC, complementing capabilities of LHC
  - Upsilon spectroscopy
  - Jet suppression and substructure
  - Open heavy flavor over full kinematic range
- Growing international collaboration
- Work on sPHENIX is in full swing
- Exciting physics program at RHIC starting in 2023

From June 2017
RHIC Users' Meeting talk
by
BNL ALD Berndt Mueller

# sPHENIX $\sqrt{s_{NN}}$ = 200 GeV tentative run plan

campaign 1

campaign 2

| Year | Species | Goals |
|---|---|---|
| 2022* | Au+Au | Commissioning<br>Single jet, di-jet, photon-tagged jet, b-tagged jet spectra<br>D-jet asymmetry<br>IUpsilon spectra |
| 2023 | p+p<br>p+Au | Reference data for modification of jets, di-jets, b-tagged jets<br>Jet $A_{LL}$<br>Reference data for cold nuclear matter effects |
| 2024 | Au+Au | Direct photon measurement<br>Study of flavor dependence of jet observables<br>Modification of jet fragmentation functions, jet splitting functions, other complex jet observables |
| 2025 | p+p | High statistics data for Upsilon modifications<br>High statistics data for jet $A_{LL}$ |
| 2026 | Au+Au | High statistics data for b-tagged jets and photon-tagged jets<br>High statistics data for jet fragmentation functions, jet splitting functions, other complex jet observables<br>High statistics data for high $p_T$ direct photons<br>High statistics data for Upsilon modifications, including Y(3S)<br>Collective flow of b-quarks (B hadron elliptic flow) |

*operations start now planned for 2023