PHENIX and forward upgrade

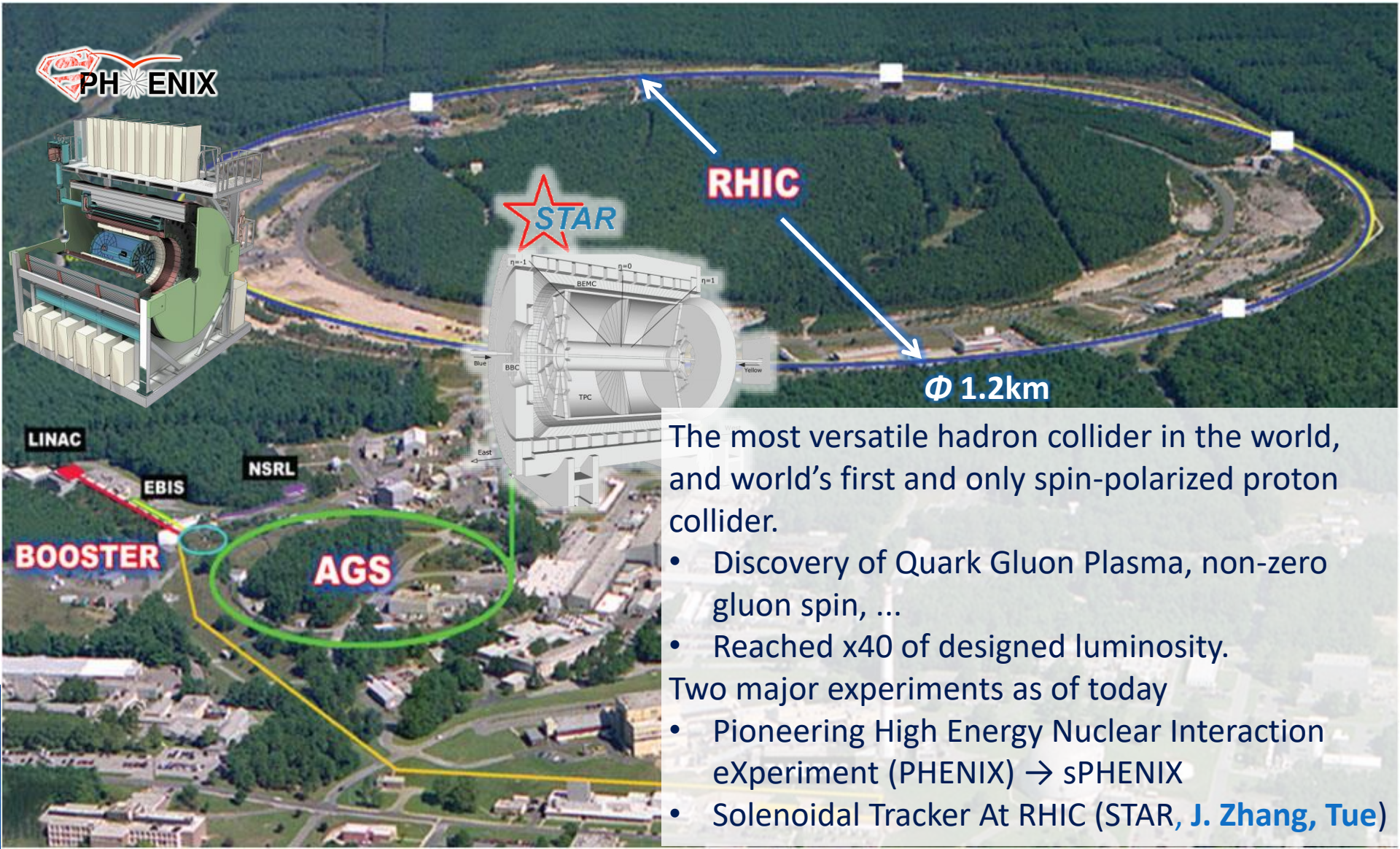
Outline: ● Physics Driver ● Detector Design ● Collaboration News ● Summary

Jin Huang (黄进)

Brookhaven National Lab, NY, USA

Relativistic Heavy Ion Collider, NY, USA
Bird's eye view

See also: **B. Mueller, Mon**



The most versatile hadron collider in the world, and world's first and only spin-polarized proton collider.

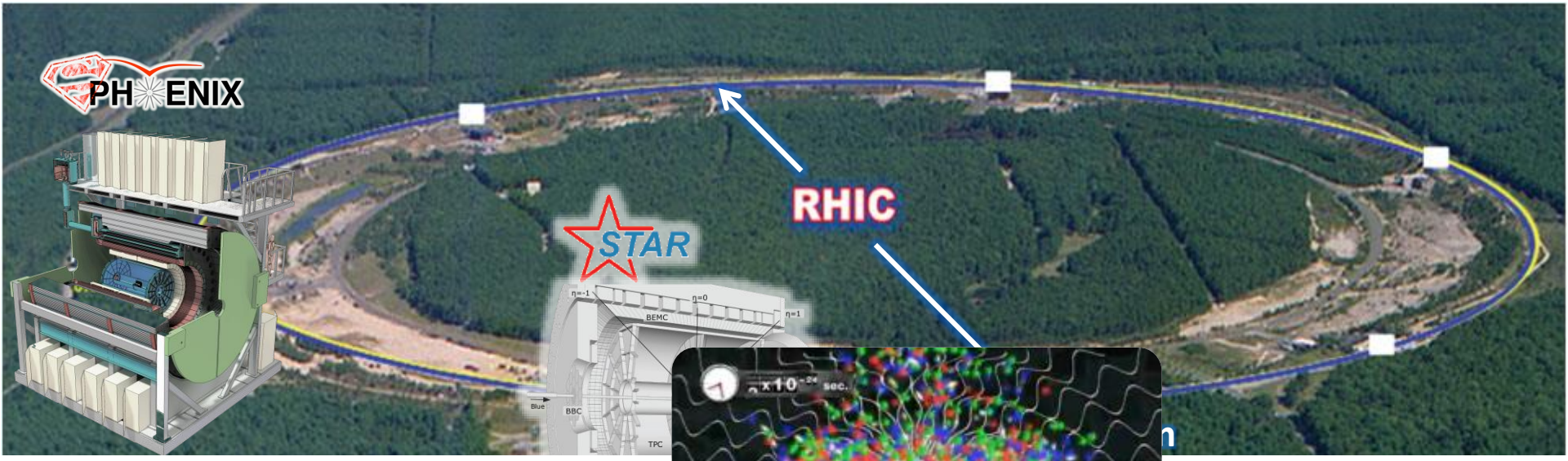
- Discovery of Quark Gluon Plasma, non-zero gluon spin, ...
- Reached x40 of designed luminosity.

Two major experiments as of today

- Pioneering High Energy Nuclear Interaction eXperiment (PHENIX) → sPHENIX
- Solenoidal Tracker At RHIC (STAR, **J. Zhang, Tue**)

Relativistic Heavy Ion Collider, NY, USA
Bird's eye view

See also: **B. Mueller, Mon**



APS NEWS

Mar 2010

RHIC Sets Temperature Record

More

At the "April" meeting, physicists from Brookhaven National Lab announced that they measured the hottest temperature ever recorded, thus recreating an exotic form of matter that hasn't existed since microseconds after the Big Bang. This is the first time that physicists were able to positively confirm the creation of the much sought after quark-gluon plasma.

"The RHIC at Brookhaven created matter that seems to be at a temperature of 4 trillion degrees Celsius. This is the hottest matter ever created in a laboratory," said Steven Vigdor, Associate Laboratory Director for Nuclear Particle Physics at the Lab, "We're talking about the highest temperature in the known universe,"

PHENIX, Phys. Rev. Lett. 104, 132301

Under standing inner working of QGP

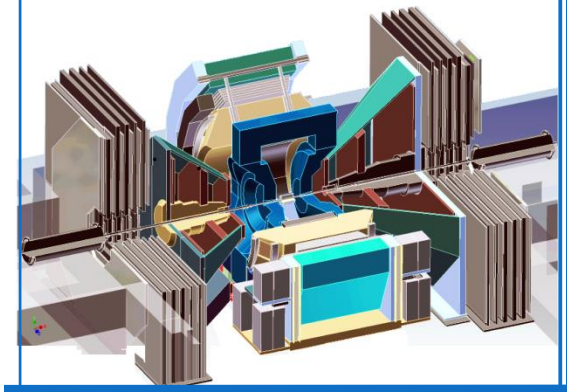
The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE

"To understand the workings of the QGP, there is no substitute for microscopy. We know that if we had a sufficiently powerful microscope that could resolve the structure of QGP on length scales, say a thousand times smaller than the size of a proton, what we would see are quarks and gluons interacting only weakly with each other. **The grand challenge for this field in the decade to come is to understand how these quarks and gluons conspire to form a nearly perfect liquid."**

Evolution of the PHENIX Interaction region

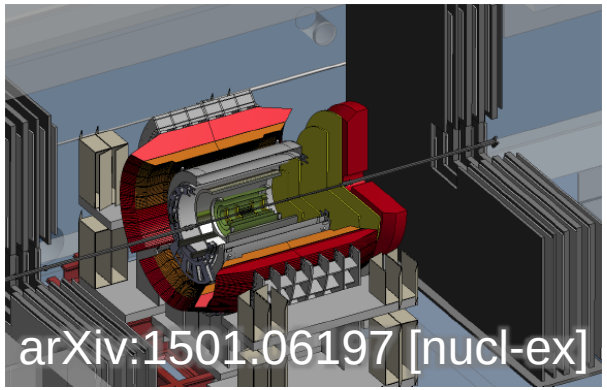
PHENIX experiment

- 16y+ operation
- Broad spectrum of physics (QGP, Hadron Physics, DM)
- 170+ physics papers with 24k citations
- Last run in this form 2016



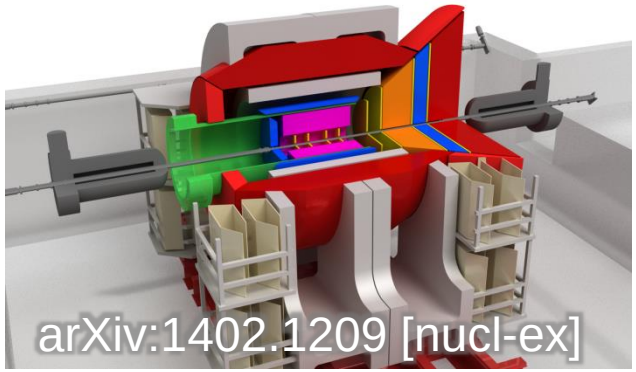
PHENIX

- Comprehensive central upgrade base on BaBar magnet
- Rich jet and beauty quarkonia physics program → nature of QGP
- Possible forward tracking, and calorimeter → Spin, CNM



An EIC detector

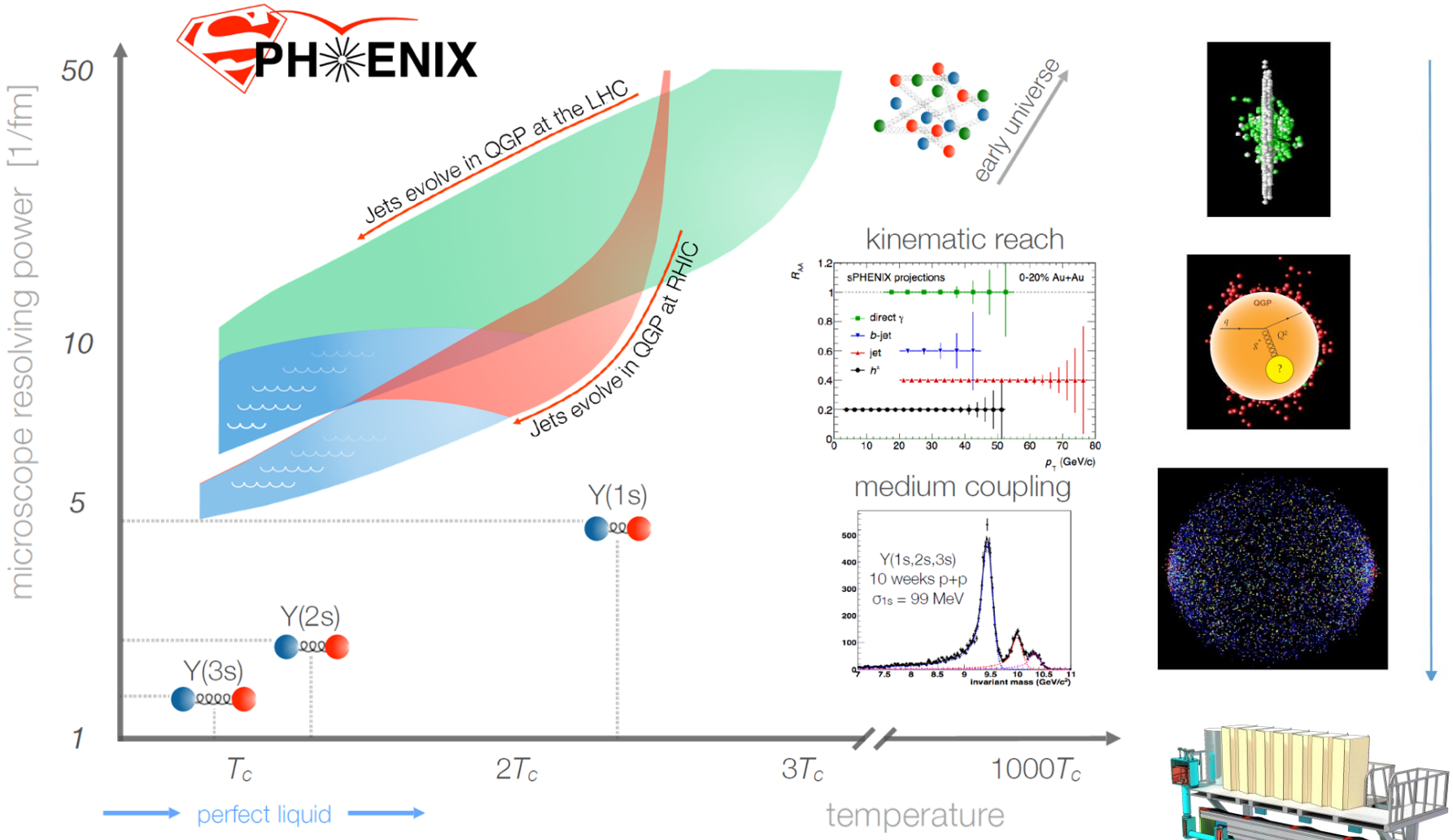
- Path of PHENIX upgrade leads to a capable EIC detector
- Large coverage of tracking, calorimetry and PID
- Open for new collaboration/new ideas

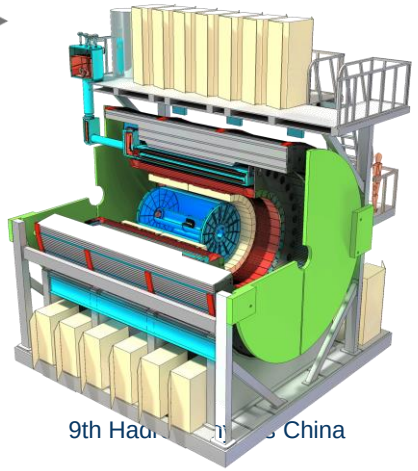


~2000 | 2017→2022, CD-0 @ 2016 | >2025 | Time

RHIC: A+A, spin-polarized p+p, spin-polarized p+A

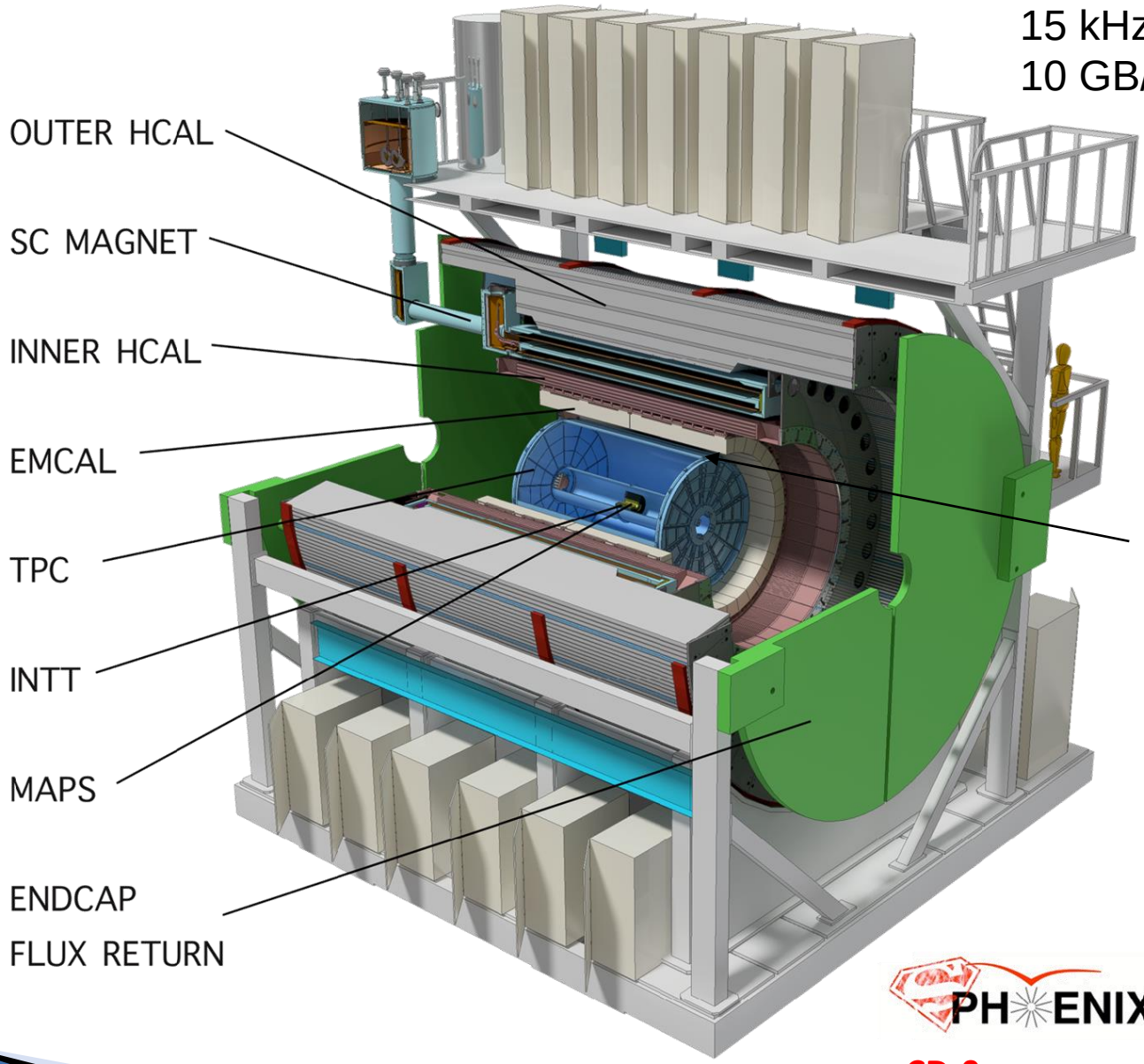
EIC: e+p, e+A





CD-0 Granted Sept 2016, Preparation for CD-1

15 kHz trigger
10 GB/s data logging

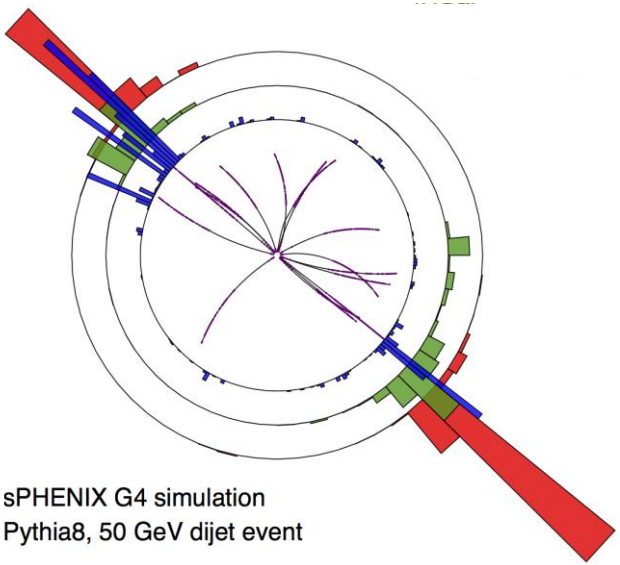


Space preserve for
Particle ID
See **M. Chiu, Friday**

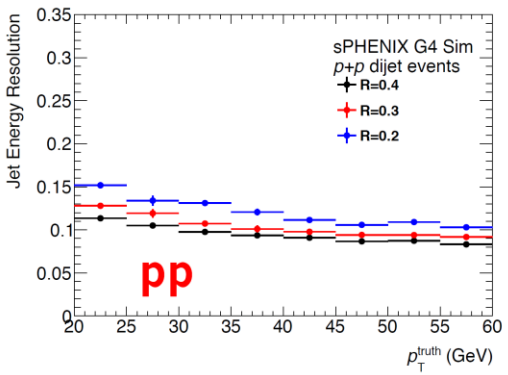
PHENIX Detector

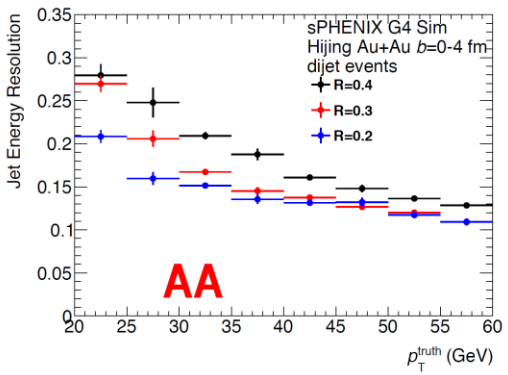
CD-0	**Sept 2016**
Construction Phase	**Jul 2018**
Ready for Beam	**Jan 2022**

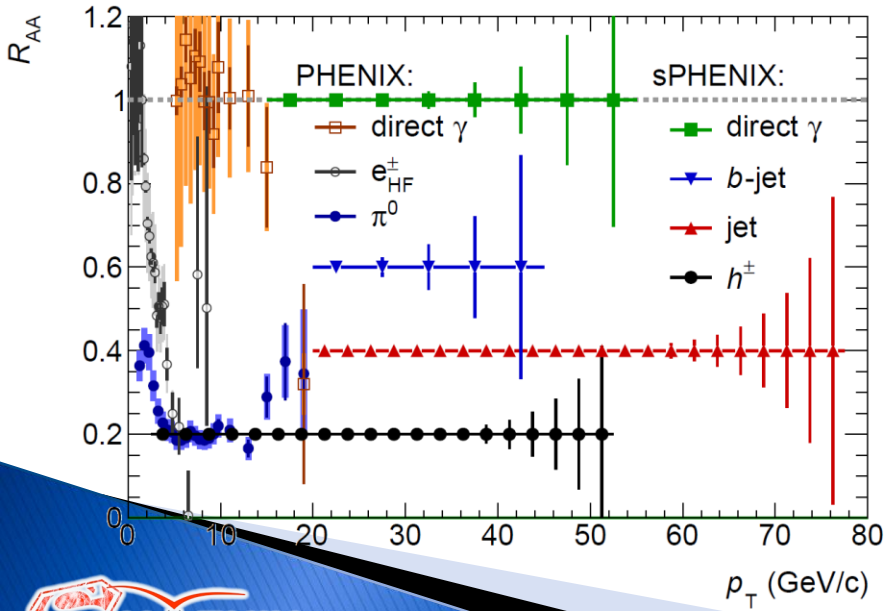
Precision calorimetry jet and photon

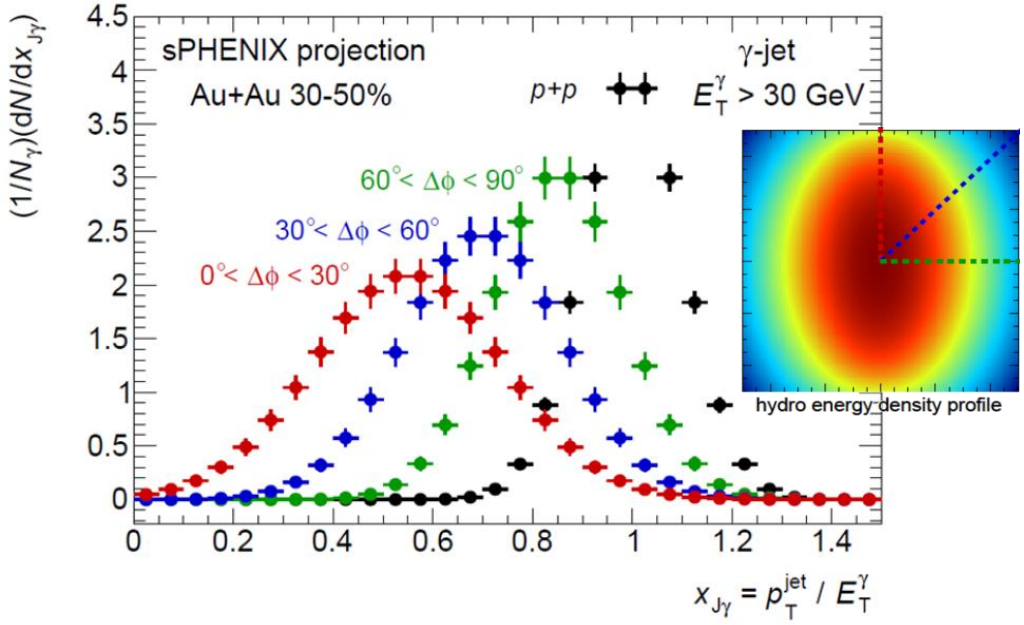


sPHENIX G4 simulation
Pythia8, 50 GeV dijet event

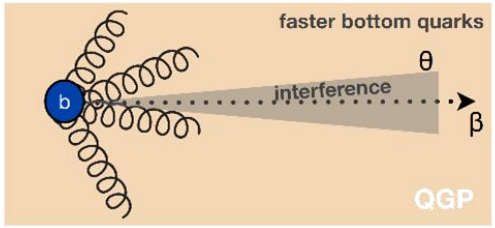


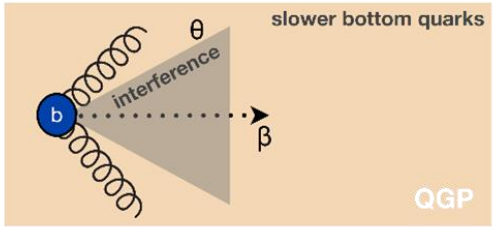


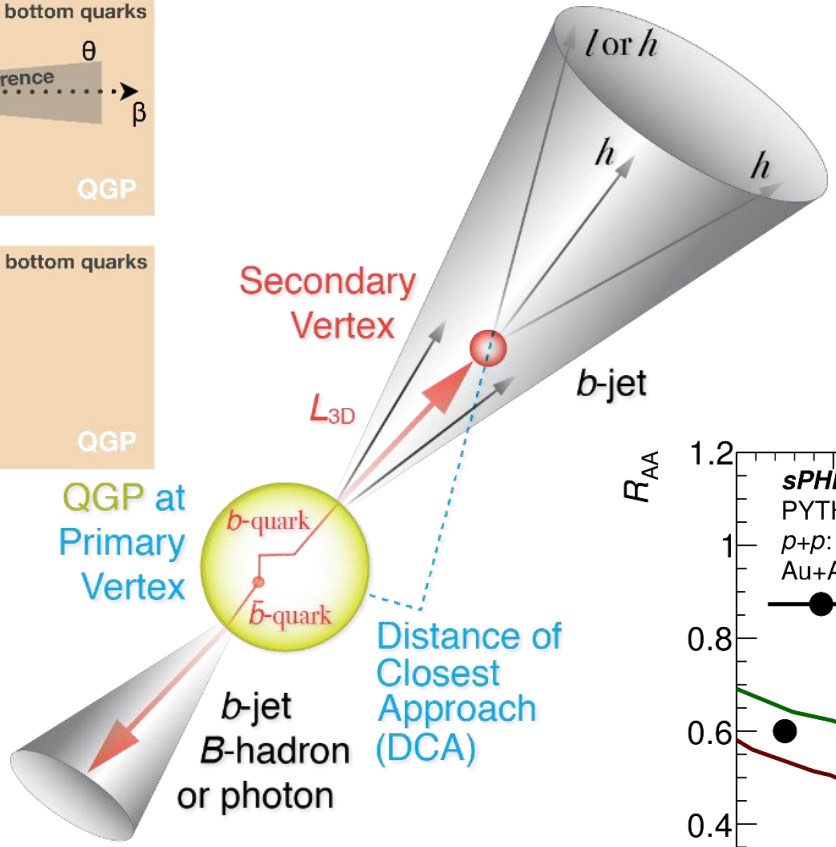


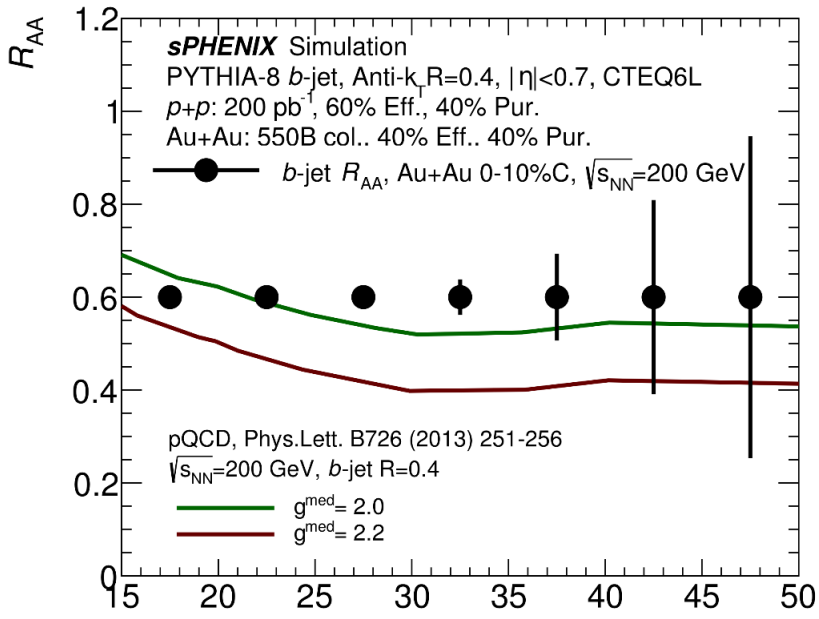


b-quark jet as probe of QGP







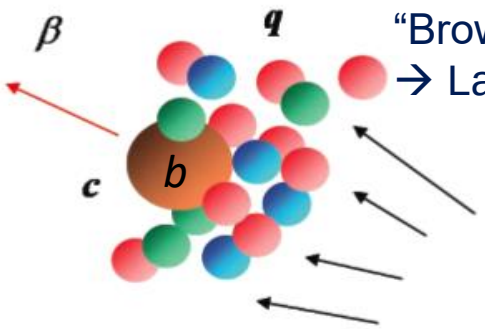


b-jet + light jet:

differential sensitivity to radiative energy loss

VS collisional energy loss.

Precision open bottom meson



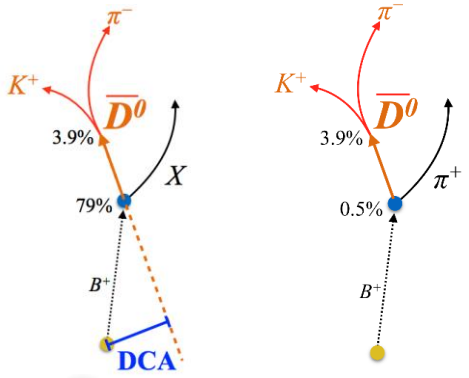
"Brownian" motion
→ Langevin simu.

$$\frac{dp^i}{dt} = -\eta_D p^i + \xi^i(t)$$

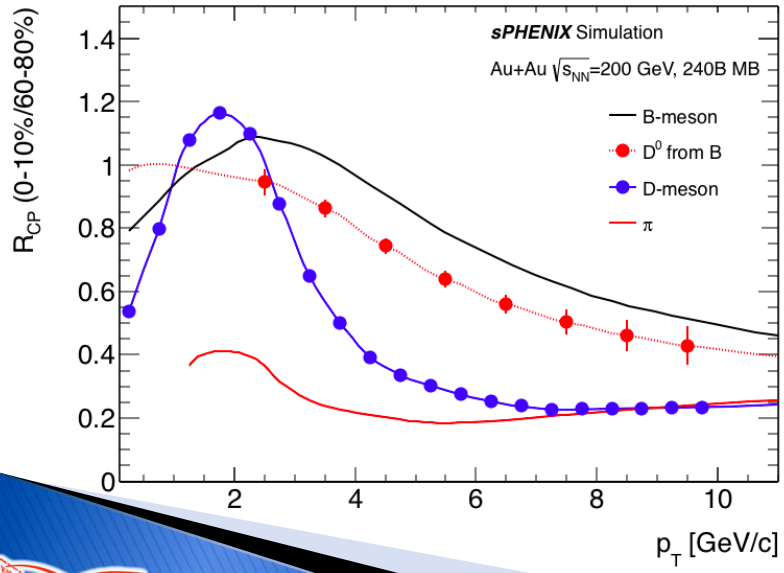
drag | fluctuations

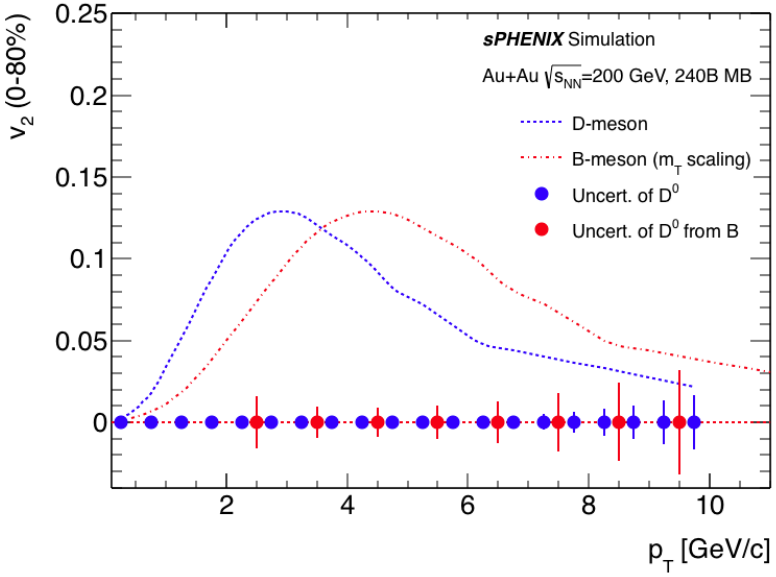
Diffusion coefficient D_{HQ}

$B \to \bar{D}^0 + X$ $\quad B^+ \to \bar{D}^0 \pi^+$

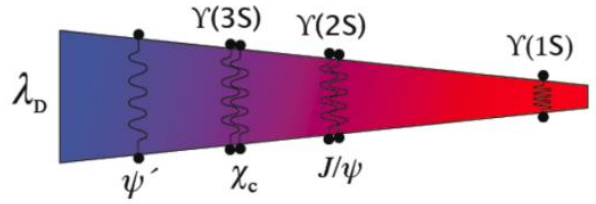


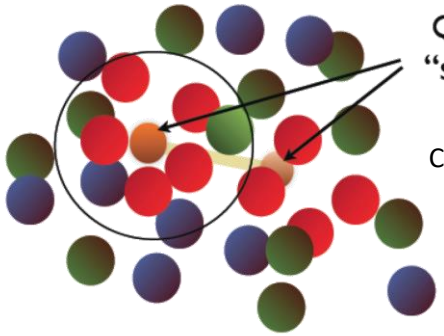
B-meson program: p_T 2-10 GeV/*c*, precisely determine the bottom quark collectivity → clean access to D_{HQ}





Upsilon spectroscopy

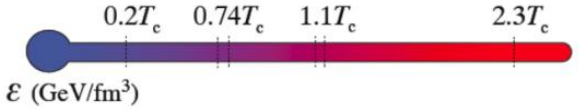




Q and $\bar{Q}$ cannot "see" each other

$r_D < r_{Q\bar{Q}}$

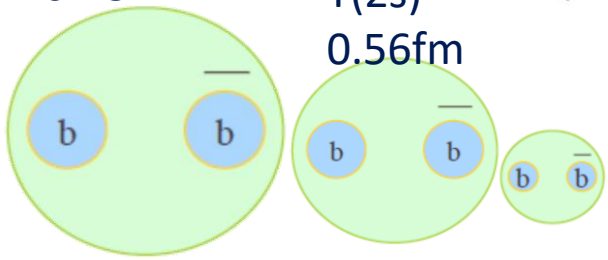
Courtesy from A. Mocsy



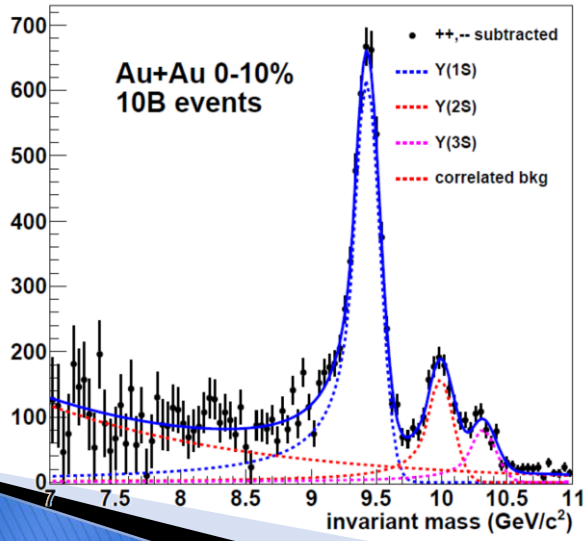
Υ(3s)-0.78fm

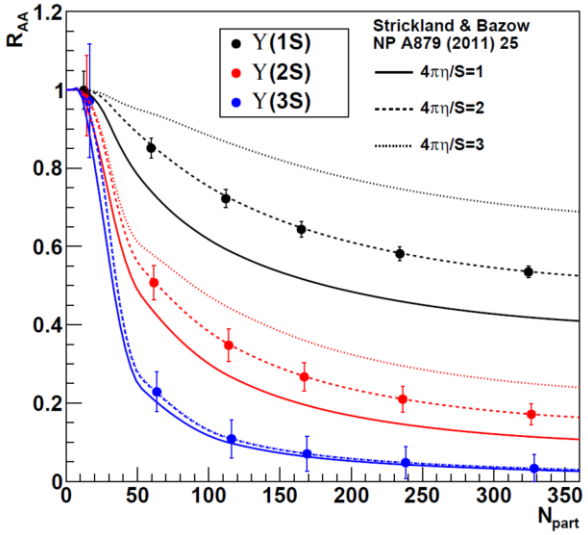
Υ(2s) – 0.56fm

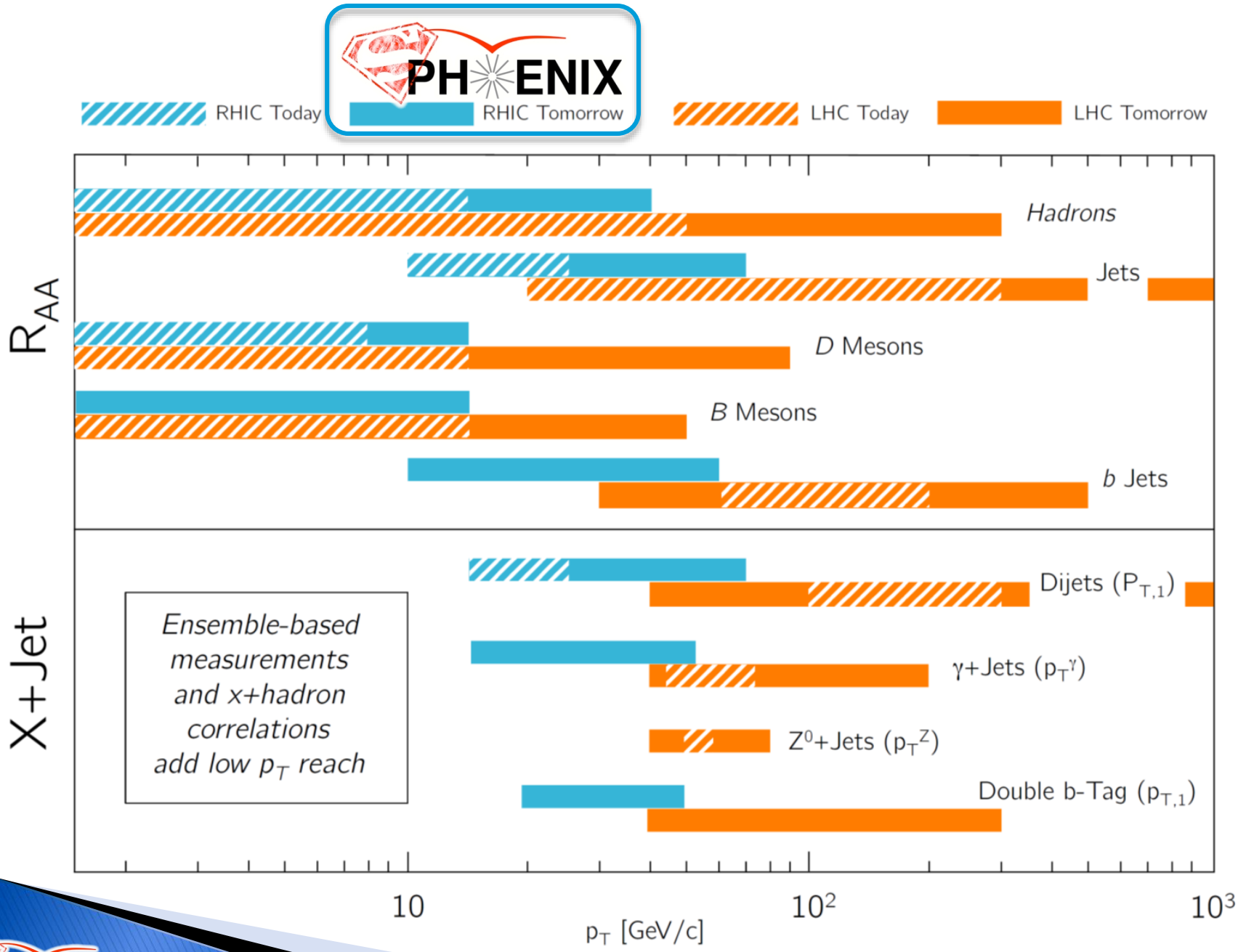
Υ(1s) – 0.28fm



Thermometer of QGP via clean separation of three Upsilon states (M_{ee} < 100 MeV/c^2)



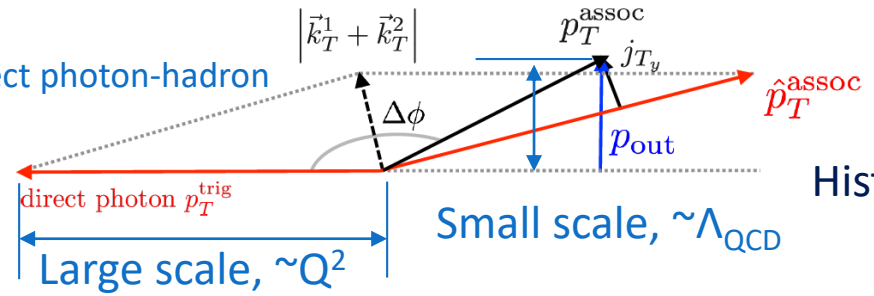



PHENIX
RHIC Today
RHIC Tomorrow
LHC Today
LHC Tomorrow
R_AA
Hadrons
Jets
D Mesons
B Mesons
b Jets
X+Jet
Ensemble-based measurements and x+hadron correlations add low p_T reach
Dijets (P_T,1)
γ+Jets (p_T^γ)
Z^0+Jets (p_T^Z)
Double b-Tag (p_T,1)
10
10^2
10^3
p_T [GeV/c]

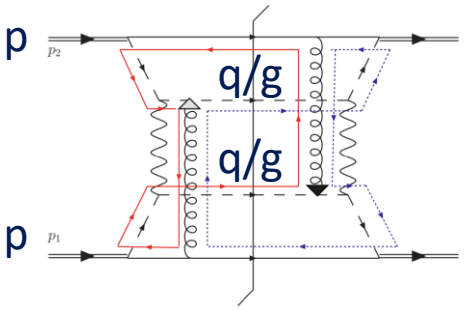
Hadronic physics opportunities with sPHENIX

- Hadron final states in p+p *not* factorized in TMD framework: non-Abelian nature of gluon field
- Exploring the size of this effect in p+p → γ+h in PHENIX. Extending to p+p → γ+jet in sPHENIX.
- What will be the scale-dependence? Spin dependence?

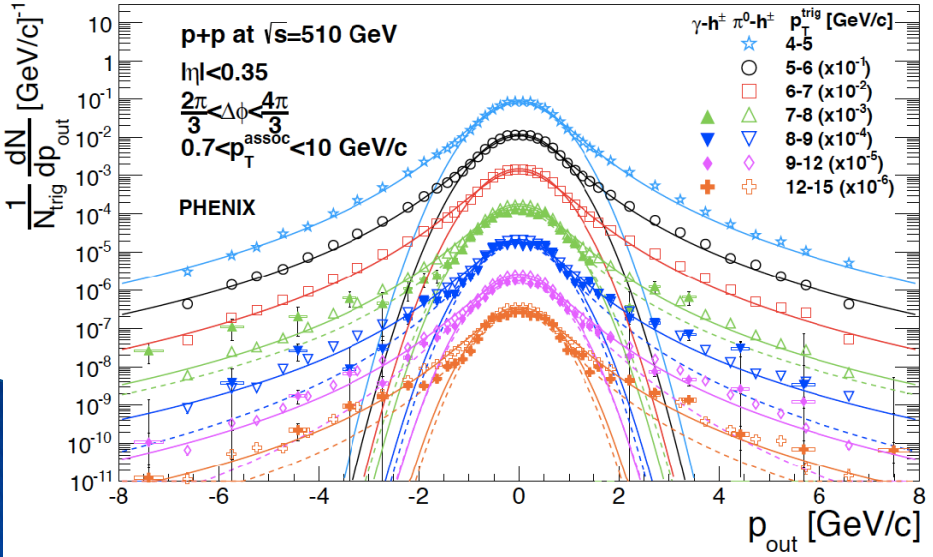
Direct photon-hadron



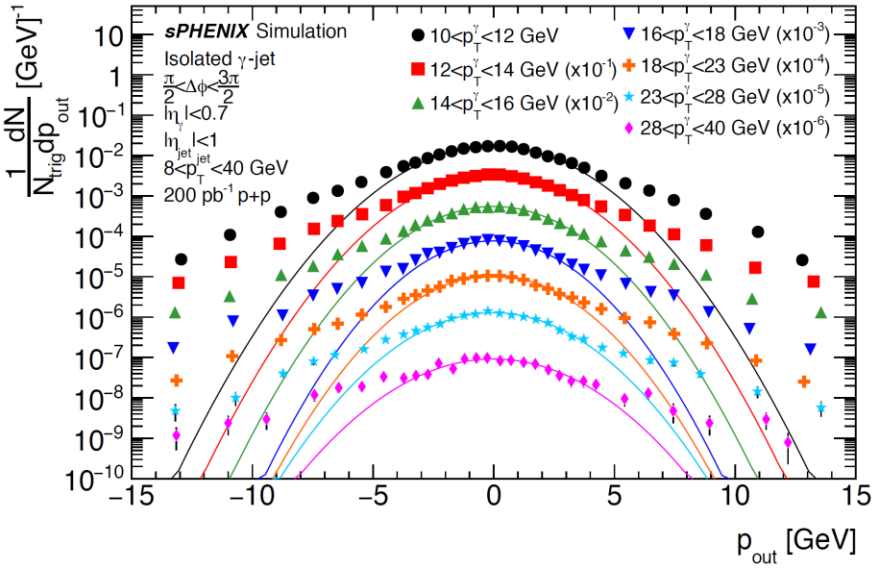
Histogram $p_{\rm out}$



PHENIX Data, Phys.Rev. D95 (2017) no.7, 072002



sPHENIX Projection, γ+jet



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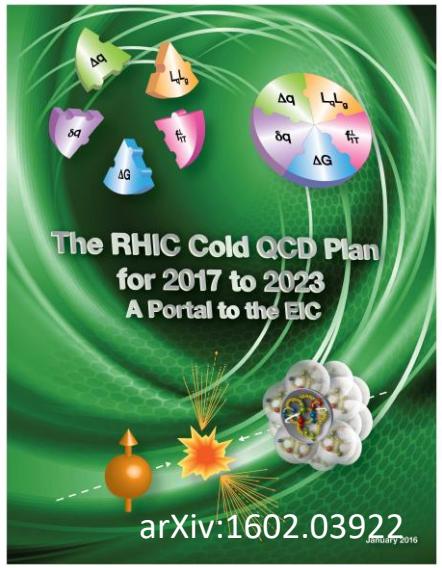
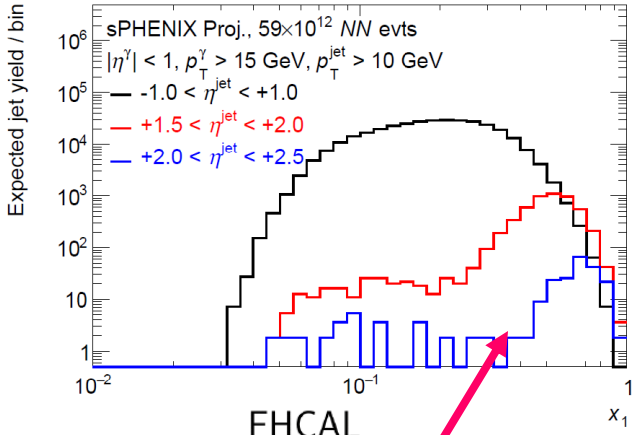
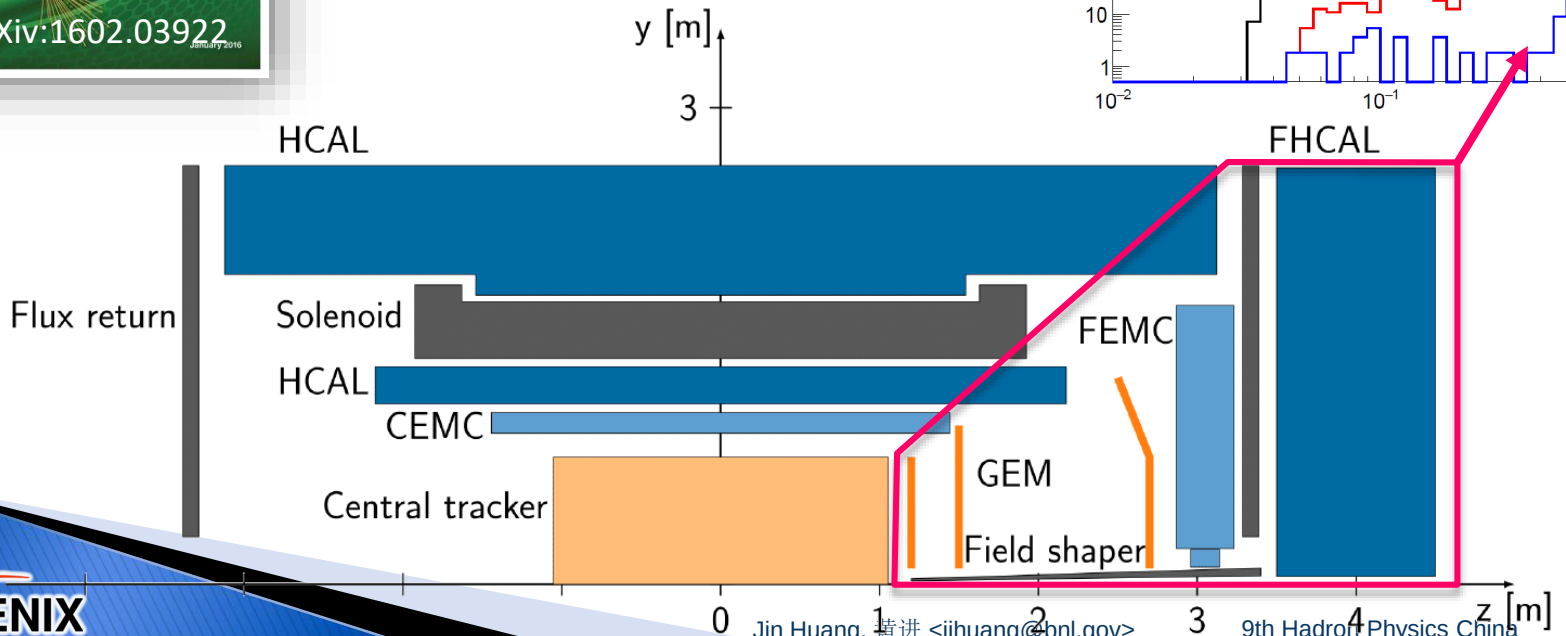
Forward upgrade for sPHENIX



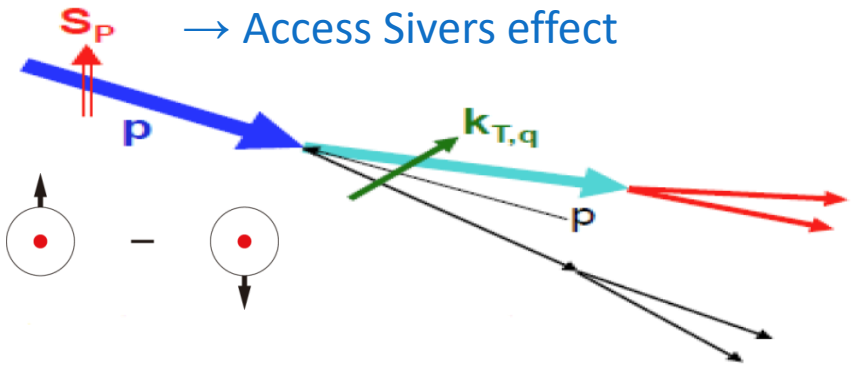
- RHIC cold-QCD community is also pushing for an forward tracking + calorimetry upgrade @ sPHENIX or STAR (J. Zhang, Tue)
- LOI for forward upgrade was submitted to RHIC PAC 2017
  Tracking + Calorimetry leads to joint coverage of $-1<\eta<4$
- sPHENIX forward upgrade:
  - Transverse spin
  - Cold nuclear matter
  - Longitudinal evolution of QGP
  - And more ...



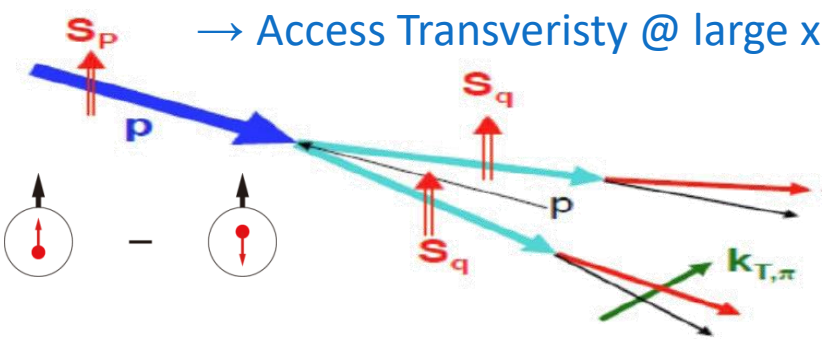


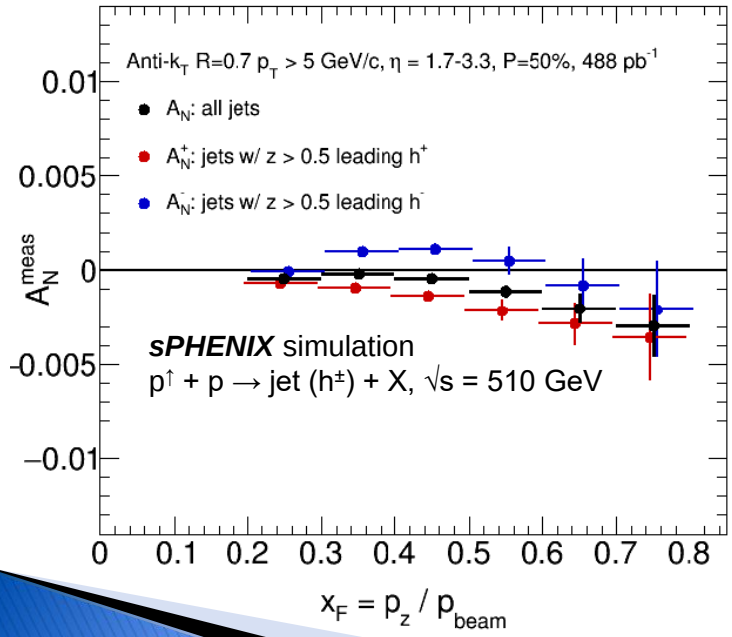
Forward jet → origin of transverse A_N

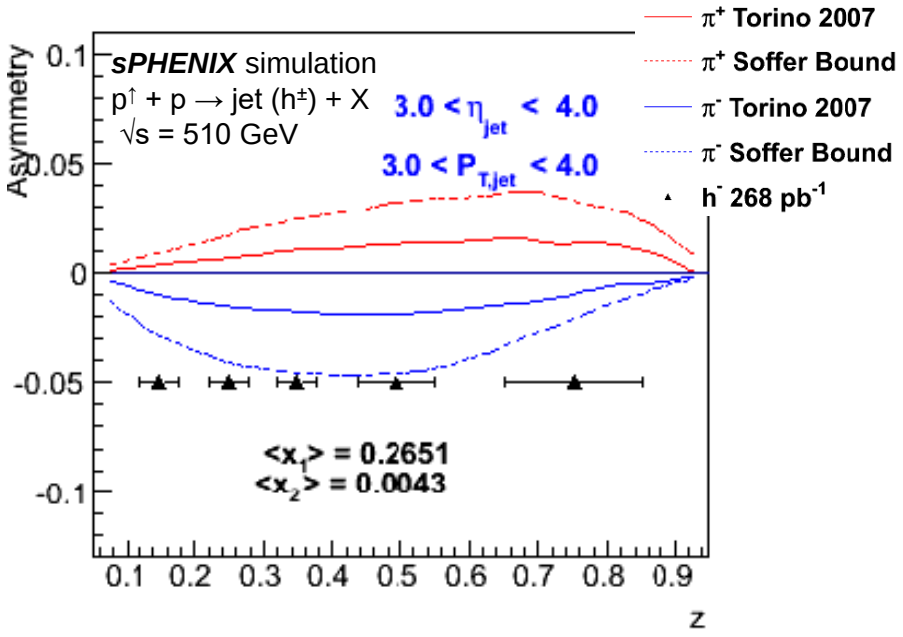
Charge-track tagged jet asymmetry
→ Access Sivers effect



Charge-track asymmetry in jet
→ Access Transveristy @ large x





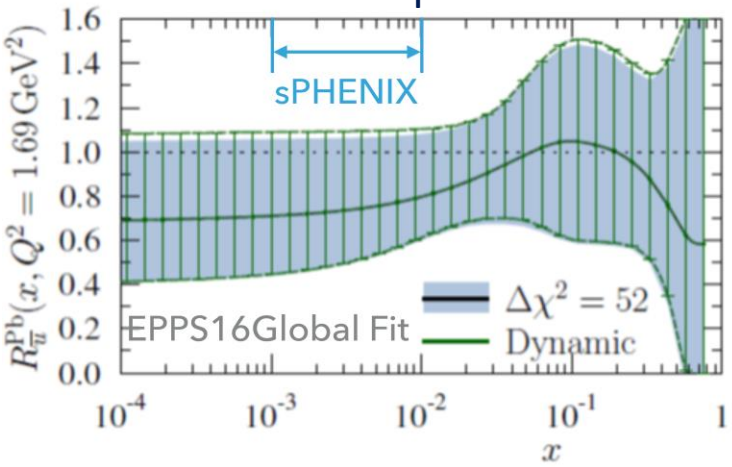


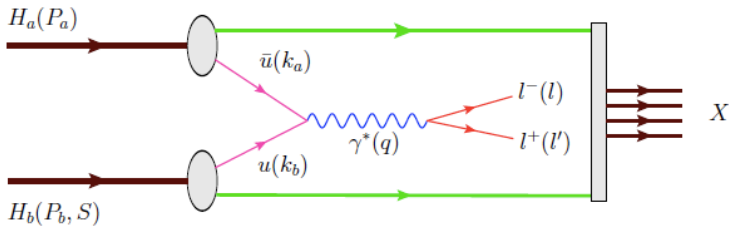
Check universality of Transversity @ SIDIS

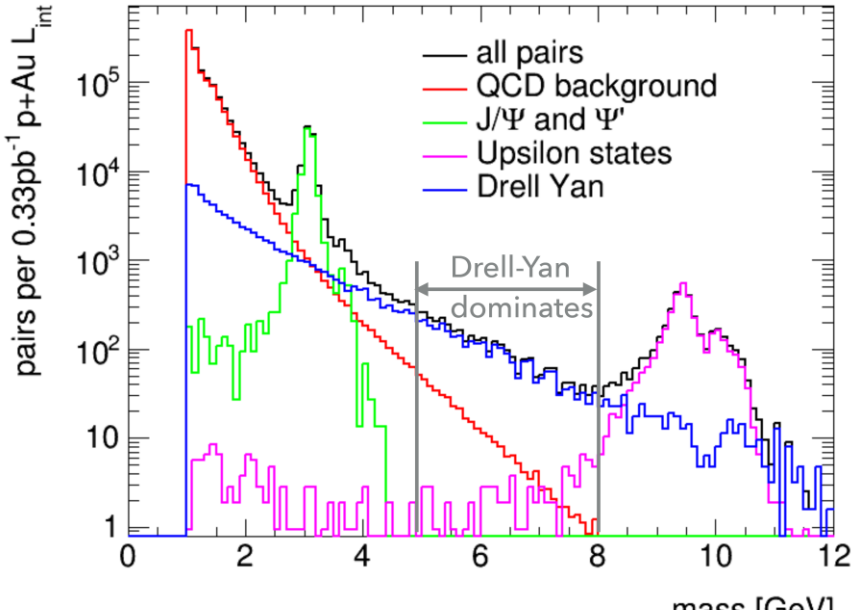
Forward DY

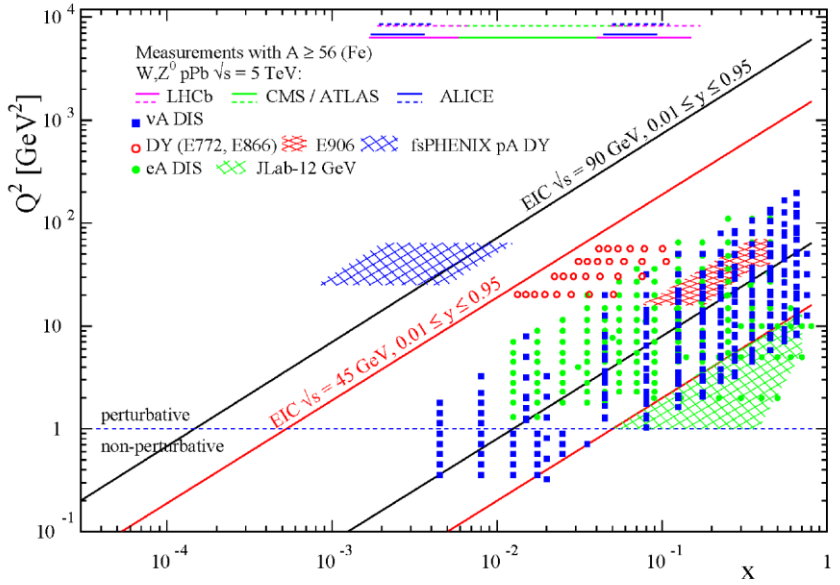
- DY in p+A provides clean access to sea quark distribution
  → gluon in nuclei
- fsPHENIX measure DY via di-electron final states
- Benefit from continuous and large calorimetry + tracking coverages

u-bar quark in nuclear









An EIC detector based on sPHENIX

- -1<η<+1 (barrel) : sPHENIX + DIRC/TOF
- -4<η<-1 (e-going) :
  High resolution calorimeter + Aerogel RICH
- +1<η<+4 (h-going) :
  - 1<η<4 : GEM tracker + Gas RICH
  - 1<η<2 : Aerogel RICH
  - 1<η<5 : EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: ZDC and roman pots

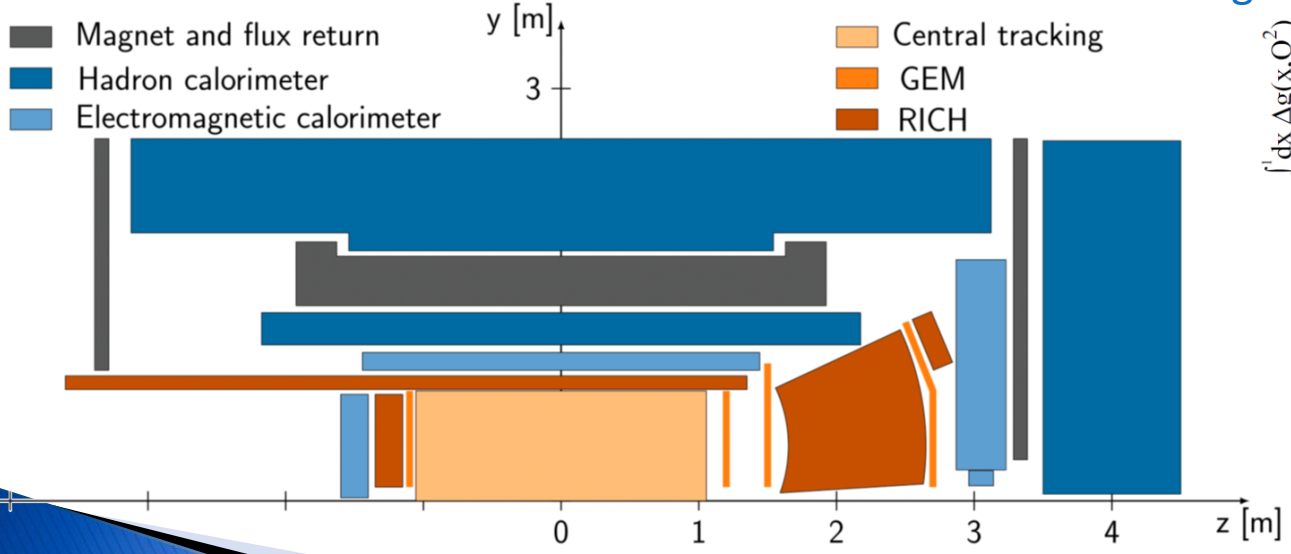
Working title: "ePHENIX"

LOI: arXiv:1402.1209

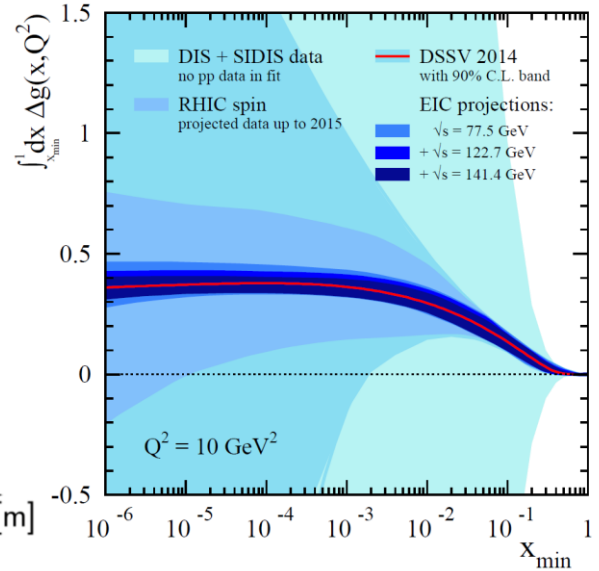
Cost: 75 M$ including contingency

This is an evolving concept

Updating concept as sPHENIX and detector R&D refines

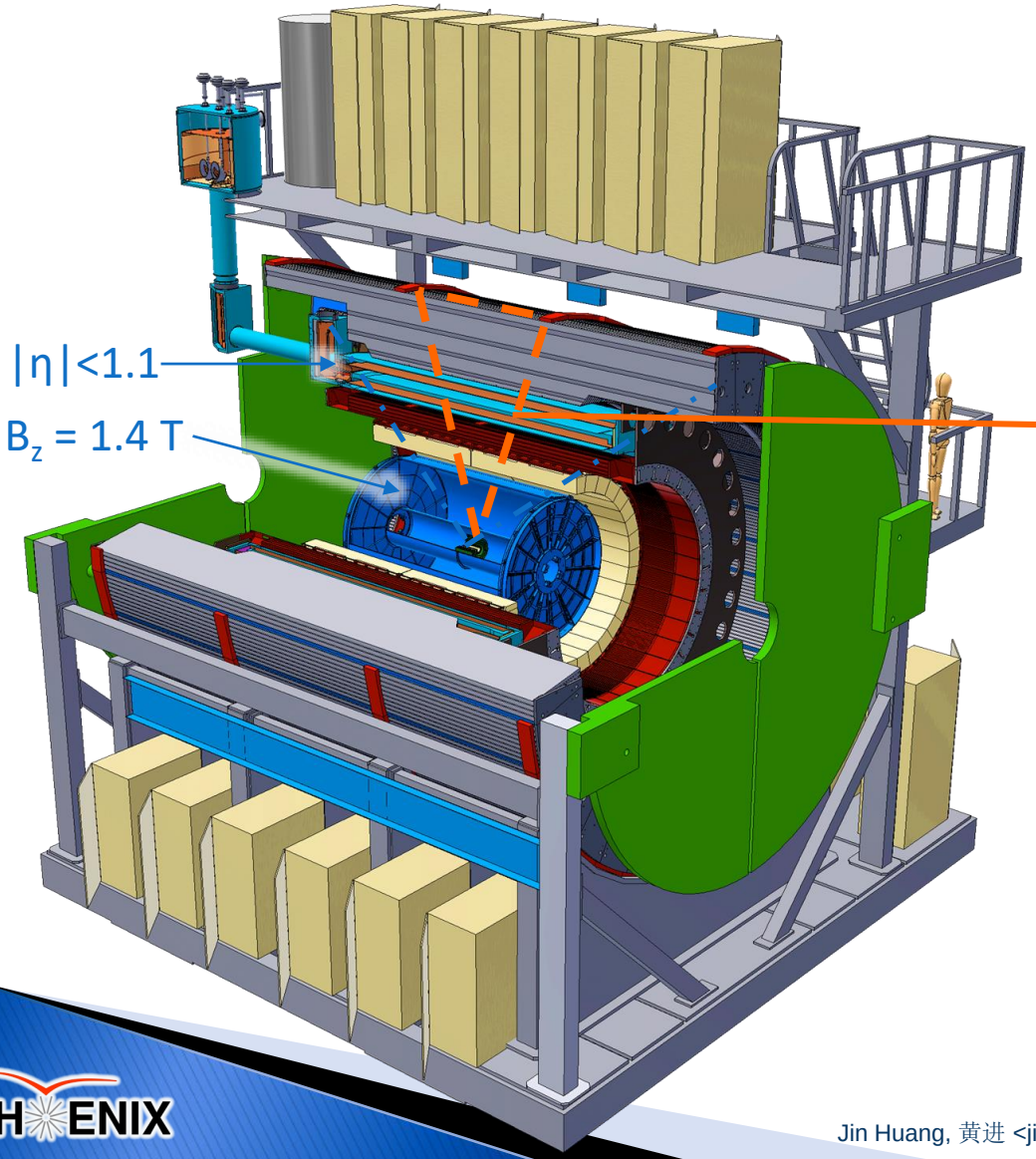


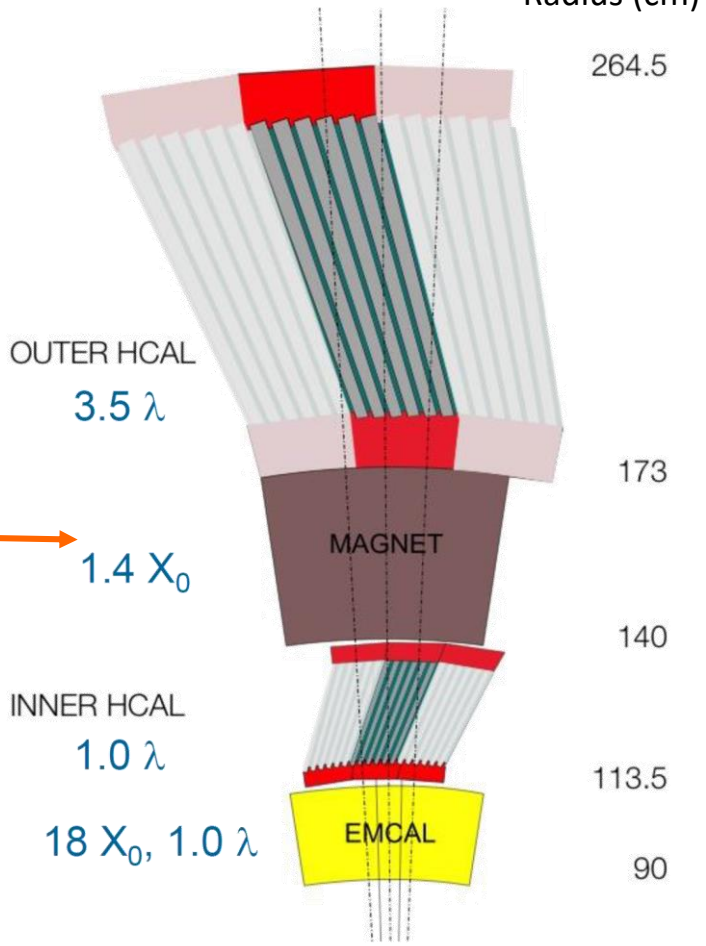
Ping down landscape of gluon spin



US-EIC physics: **Z. Meziani, Mon Afternoon**

Detector highlights

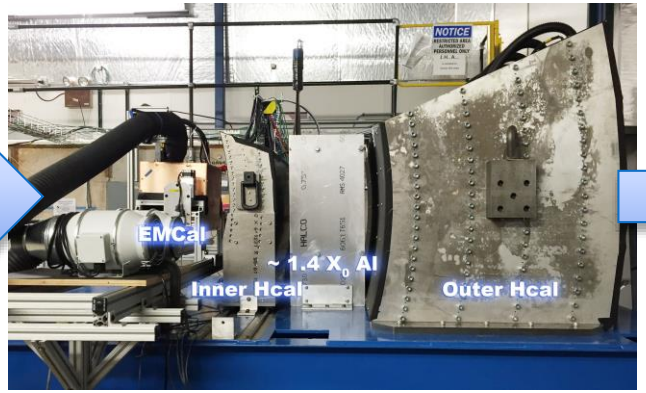




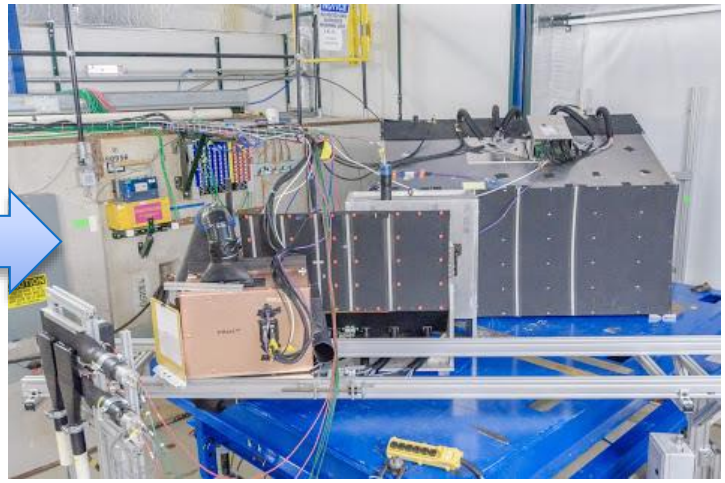
Calorimeters beam tests

February 2014

Proof of principle



February 2016: η~0 prototype

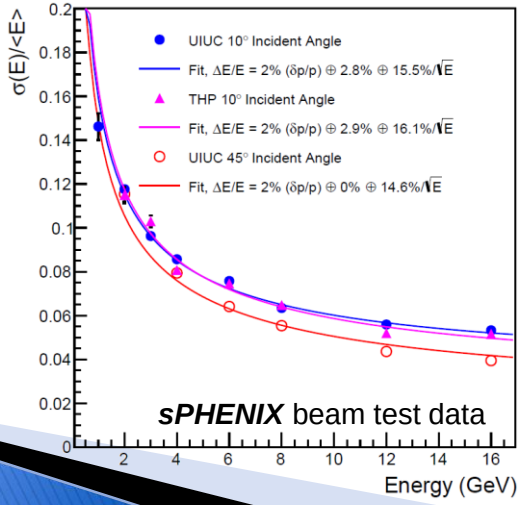


February 2017: η~0.9 prototype

Electron

Energy resolution

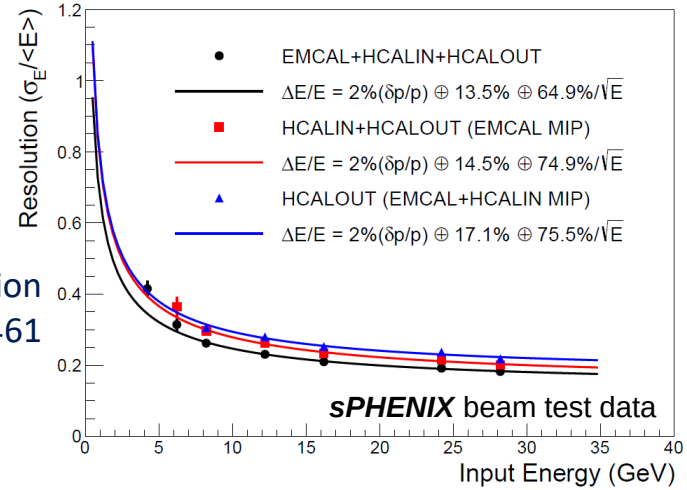
arXiv:1704.01461



Pion

Energy resolution

arXiv:1704.01461



Super conducting magnet

- 1.4 Tesla magnet, Φ = 2.8 m, L = 3.8 m Previously used in BaBar @ SLAC
- Moved to BNL in Feb 2015
- Successful cold low field test in 2016
- On-going full field test

Photo by Andy Freeberg, SLAC National Accelerator Laboratory

breaking

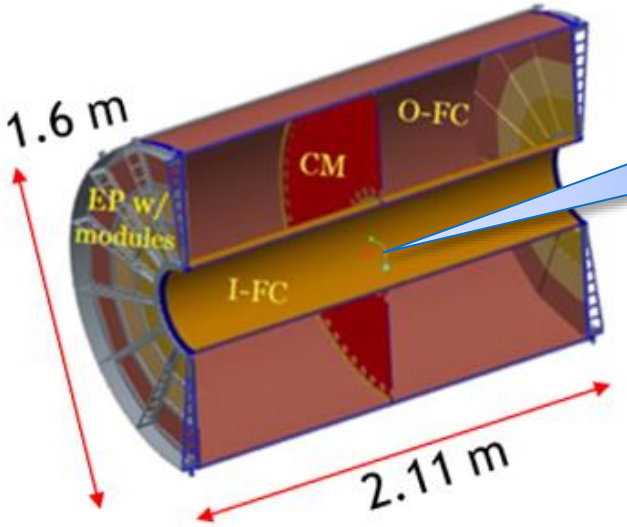
January 16, 2015

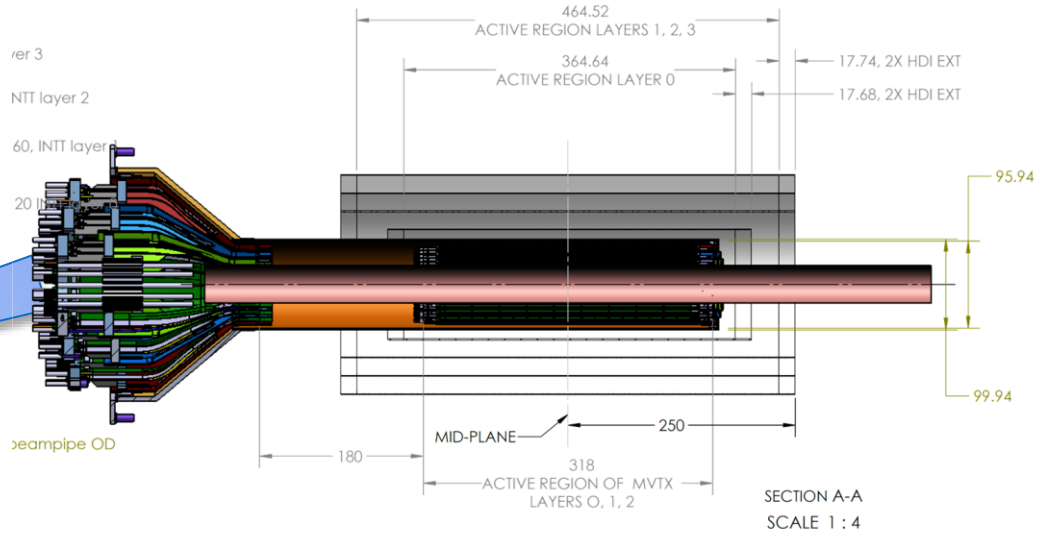
20-ton magnet heads to New York

A superconducting magnet begins its journey from SLAC laboratory in California to Brookhaven Lab in New York.

By Justin Eure

Tracking



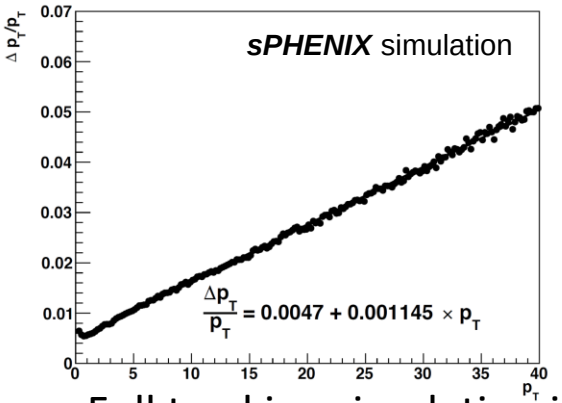


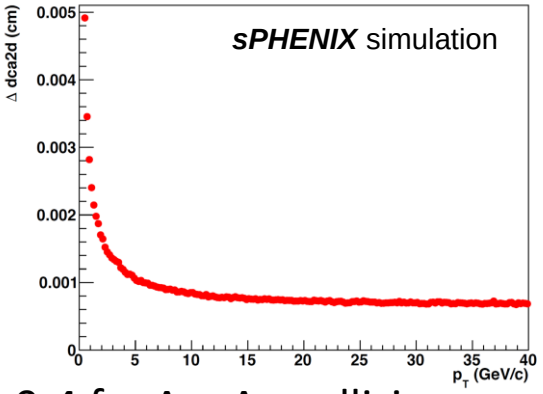
Outer tracking:

- Continues readout TPC @ 1 Tbps, FPGA based data reduction
- Low diffusion, high ion mobility Ne-CF_4 gas + Quad GEM + mini pads
- $R\delta\Phi$< 200 um
- $\delta p/p$ < 2% for p_T<10 GeV/c

Inner tracking:

- MAPS pixel (3-layer) + strip silicon (4-layer)
- DCA< 50um for p_T>1 GeV/c, <10 um for p_T>10 GeV/c
- Possible stave production @ CCNU

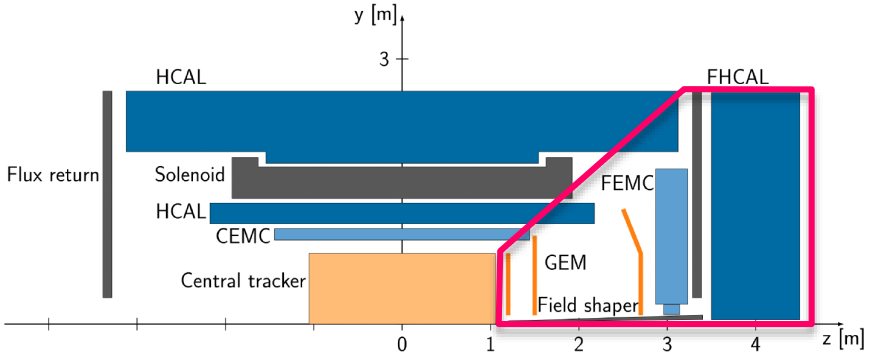




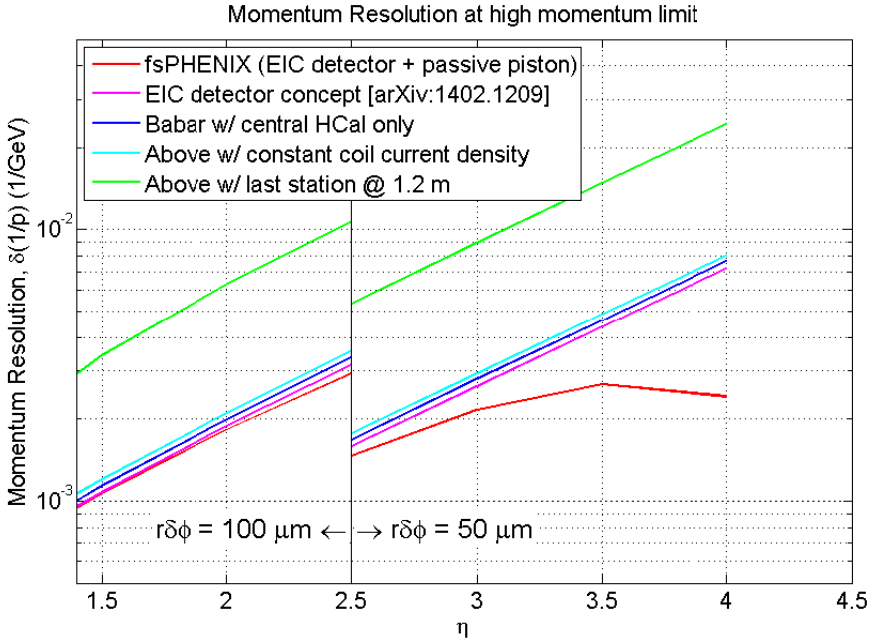
Full tracking simulation in 0-4 fm Au+Au collisions

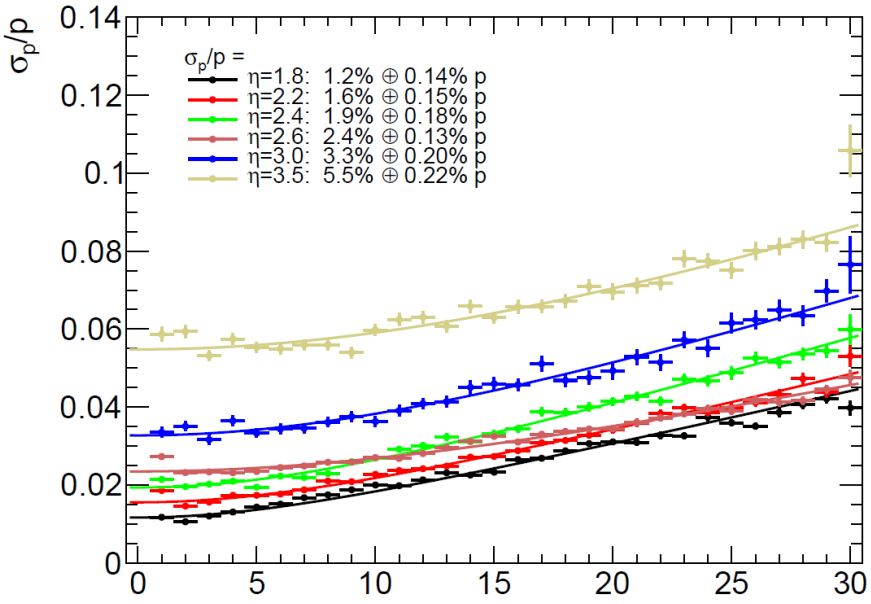
Forward tracking

- Forward tracking by shaping central field for forward use
- Inner tracking (η = 3-4):
  - High rate and resolution requirement
  - COMPASS-like GEM (R<30 cm) RδΦ= 50-70 μm
- Outer tracking (η = 1-3):
  - Segments & vertex via central tracker
  - SoLID-like GEM (R~100 cm) RδΦ= 100 μm.
  - Alternative: MicroMegas or sTGC



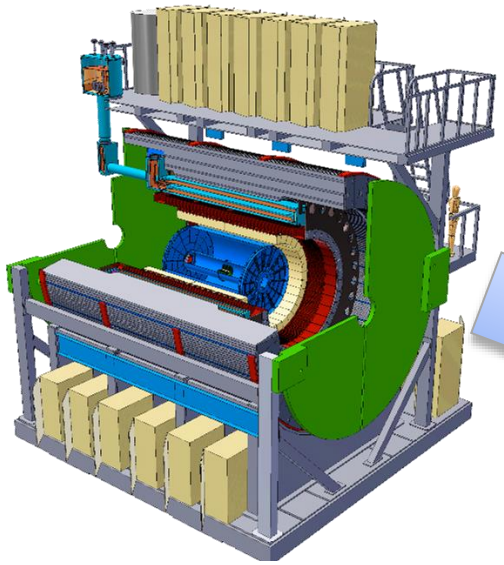
Design tracking in analytical estimation → confirmation with full Geant4 simulation



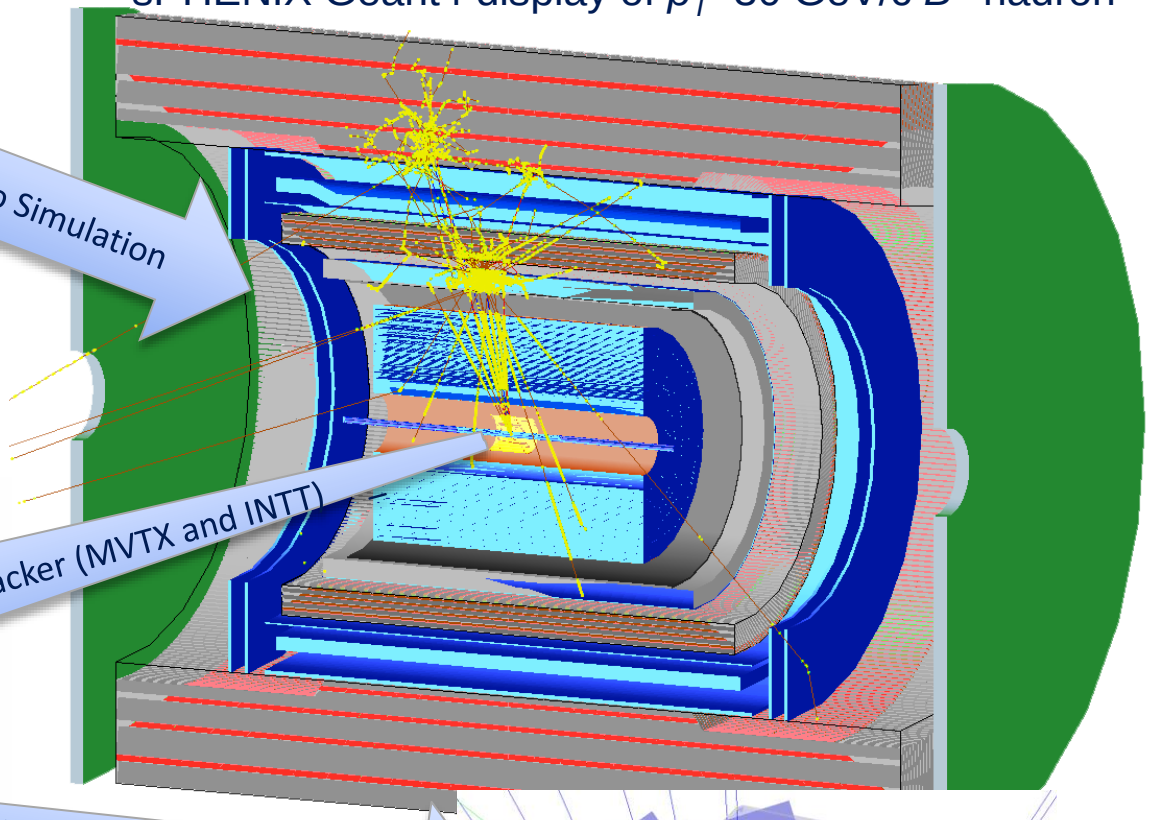


Full detector simulation + reconstruction

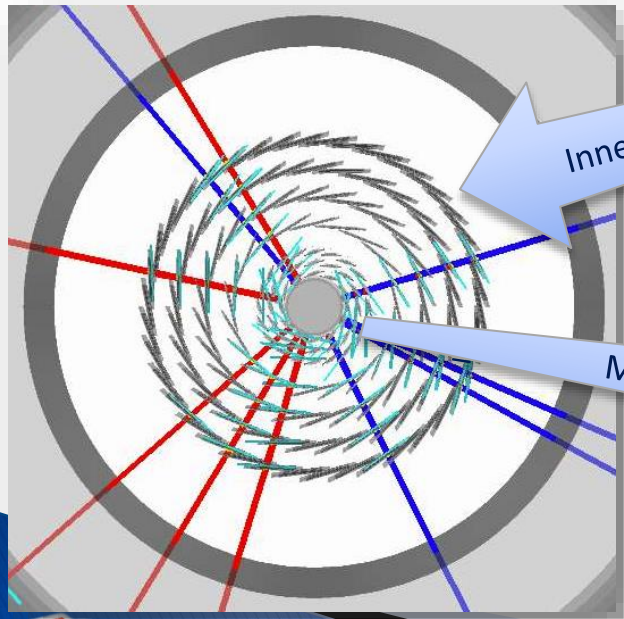
Open source @ GitHub : https://github.com/sPHENIX-Collaboration/



sPHENIX Geant4 display of p_T=30 GeV/c B^+-hadron

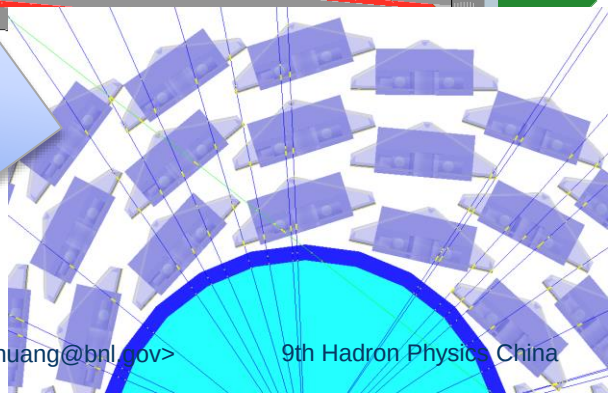


Design to Simulation



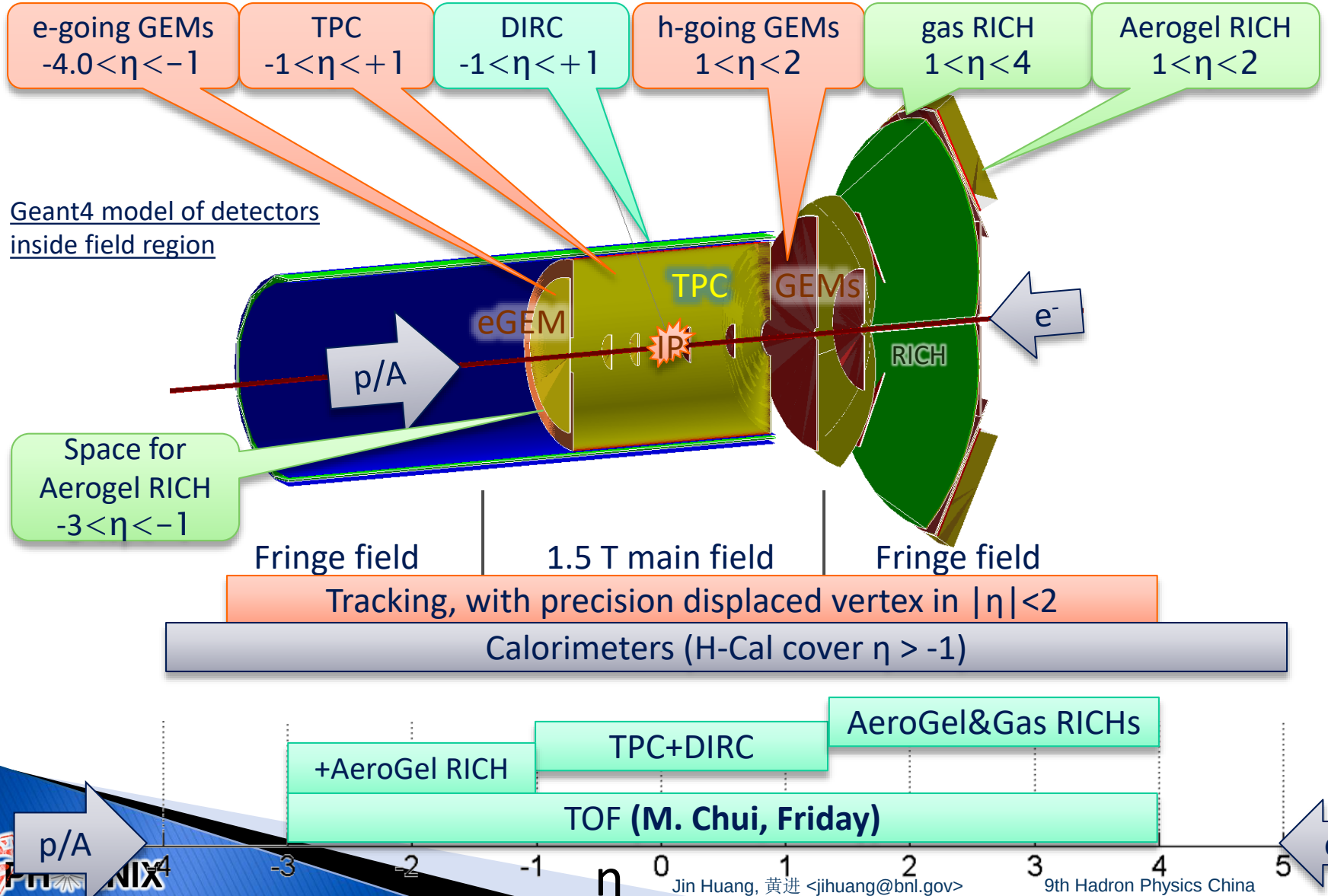
Inner tracker (MVTX and INTT)

MVTX Ladders modeled in details

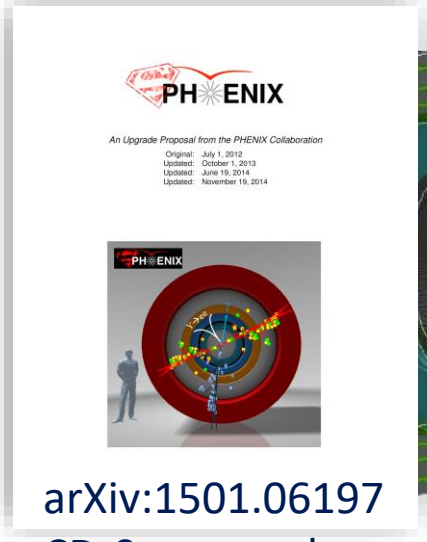


Simulation of EIC detector addition to sPHENIX

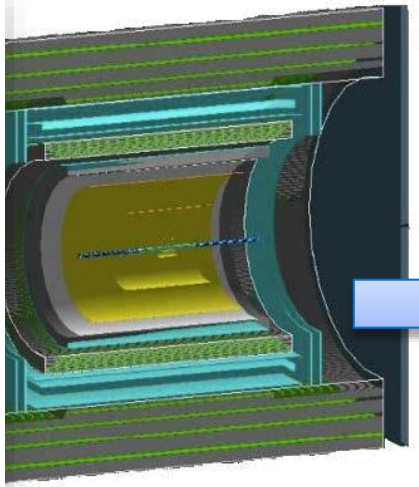
US-EIC physics: **Z. Meziani, Mon Afternoon**



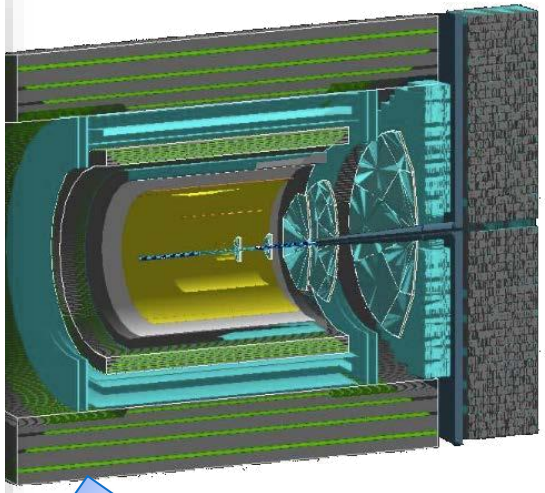
Evolving upgrade concepts

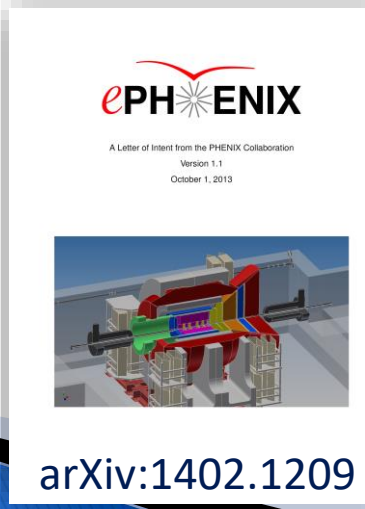


arXiv:1501.06197
CD-0 approval
CDR in preparation

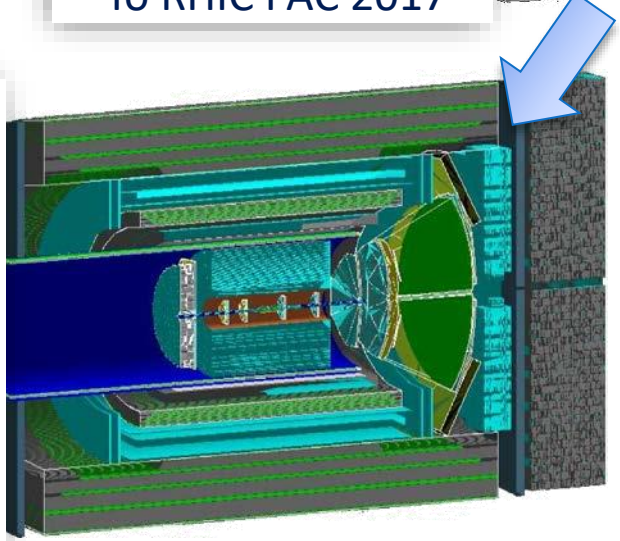


To RHIC PAC 2017





arXiv:1402.1209



Evolving sPHENIX collaboration

sPHENIX collaboration is a new scientific collaboration. Four collaboration meetings.

Rutgers, 12/15

BNL, 6/16

Georgia State, 12/16

BNL, 5/17

& 30+ people via phone bridge

Welcome to join the collaboration

Growing collaboration, 64 institutions as of today

Welcoming more Chinese collaborators!

Many opportunities to contribute: in physics program and in detector R&D/construction

Summary

- sPHENIX: Study QGP with precision jet and beauty quarkonia @ RHIC
  - Completing scientific mission @ RHIC
- Hadronic physics opportunities in sPHENIX and proposed forward detector upgrade
  - Complementarity of hadronic collisions and DIS, e.g. JLab, COMPASS, EIC
- sPHENIX received CD-0 approved, in preparation for CD-1.
  Planned data taking start 2022.
- sPHENIX detector has advanced design.
  - Forward upgrade and EIC: many opportunities for joint detector R&D
- Growing collaboration
- Welcome more Chinese institutions to join the sPHENIX collaboration

Thank you for your attention!
Credit to sPHENIX collaboration:

Augustana University
Banaras Hindu University
Baruch College, CUNY
Brookhaven National Laboratory
CEA Saclay
Central China Normal University
Chonbuk National University
Columbia University
Eötvös University
Florida State 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
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
Petersburg Nuclear Physics Institute
Purdue University
Rice University
RIKEN
RIKEN BNL Research Center
Rikkyo University
Rutgers University
Saint-Petersburg Polytechnic University
Stony Brook University
Temple University
Tokyo Institute of Technology
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
Vanderbilt University
Wayne State University
Weizmann Institute
Yale University
Yonsei University