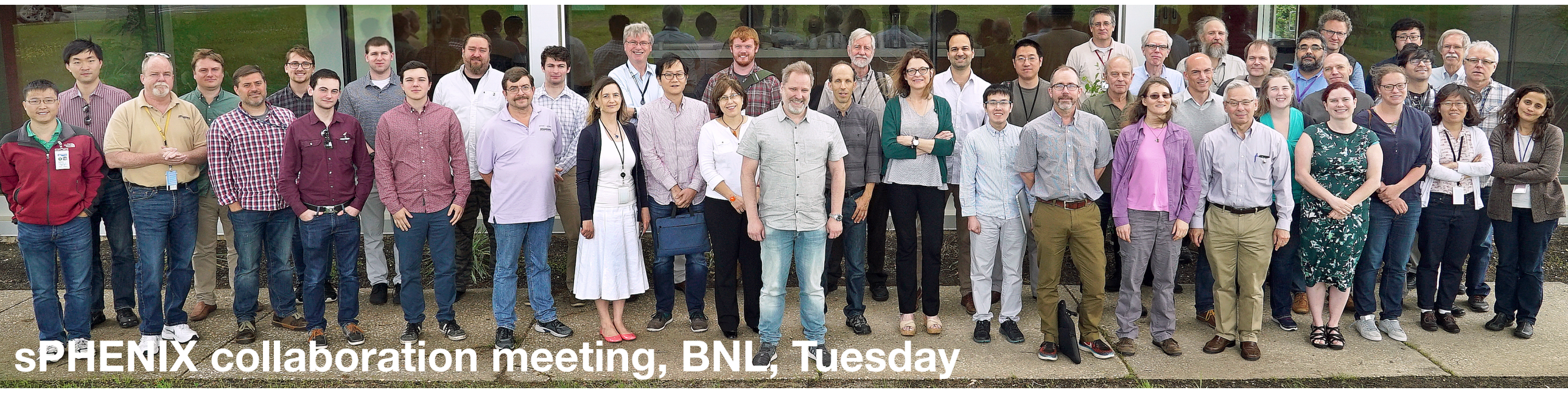
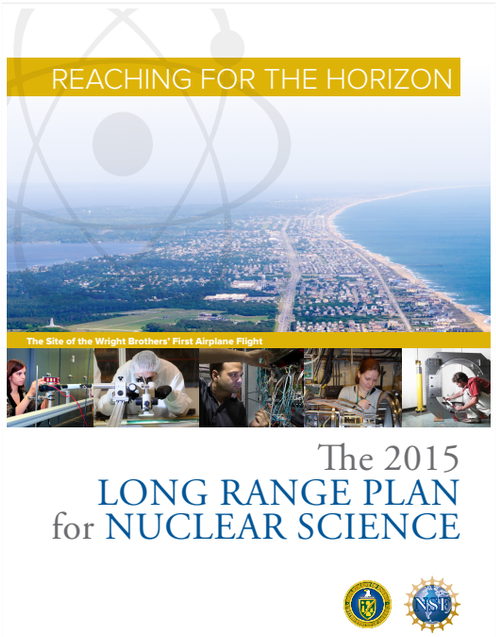
Update on sPHENIX Science Program

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



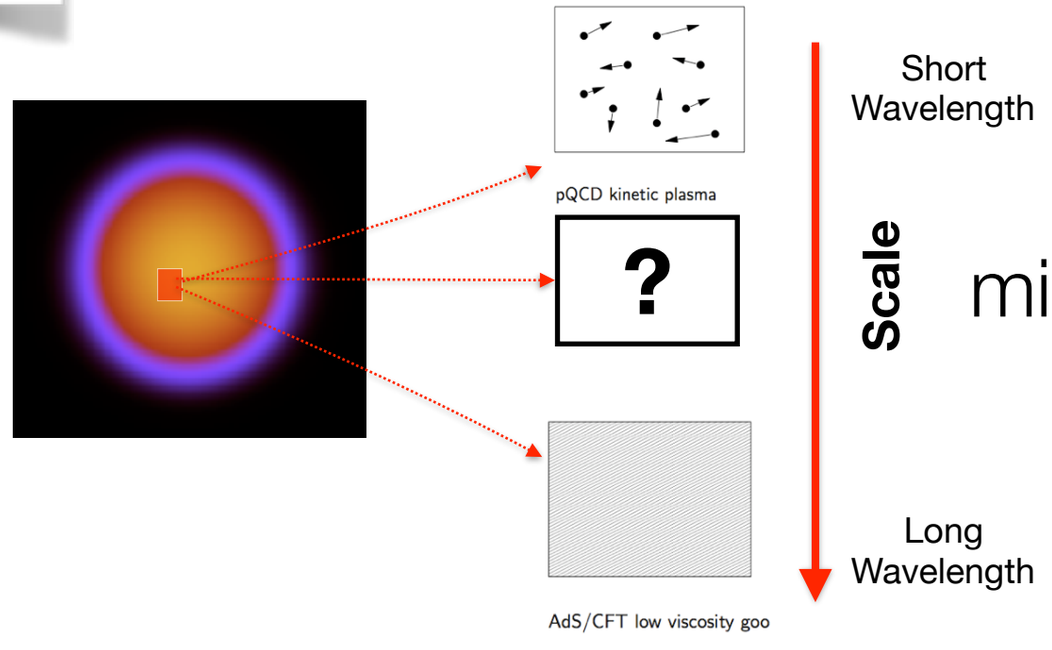
sPHENIX collaboration meeting, BNL, Tuesday

sPHENIX Science Mission



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.**

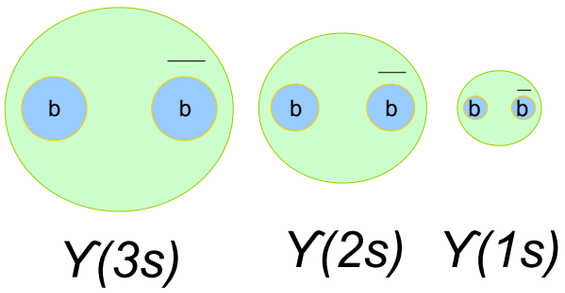


What is the microscopic structure of the QGP?

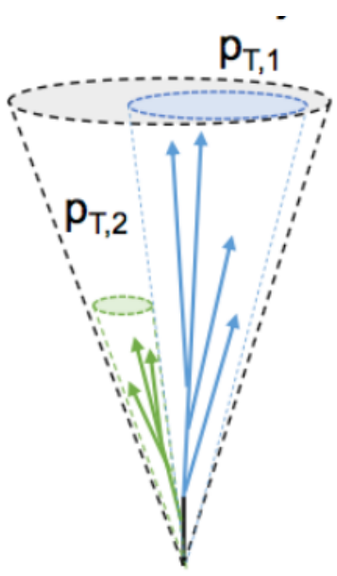
Core sPHENIX science program

Three key approaches to study QGP structure at multiple scales

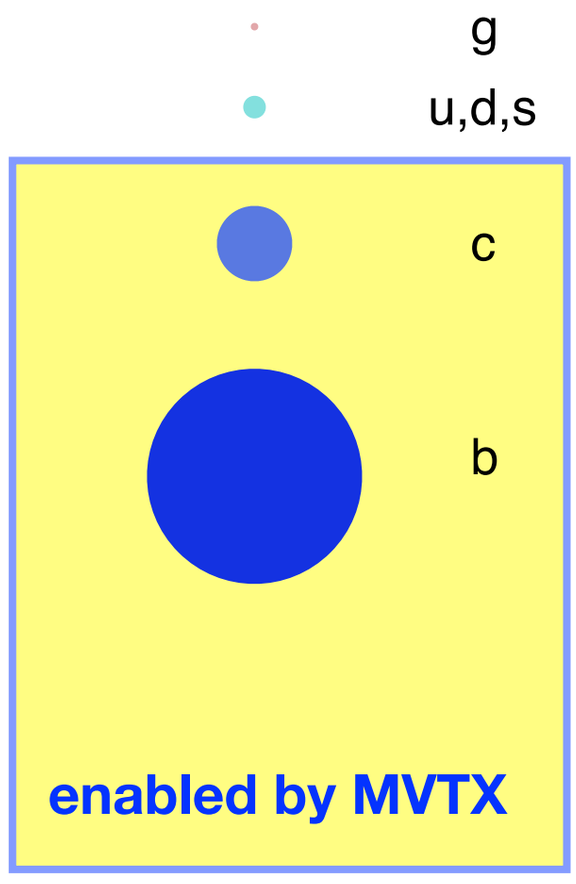
Quarkonium spectroscopy
vary size of probe



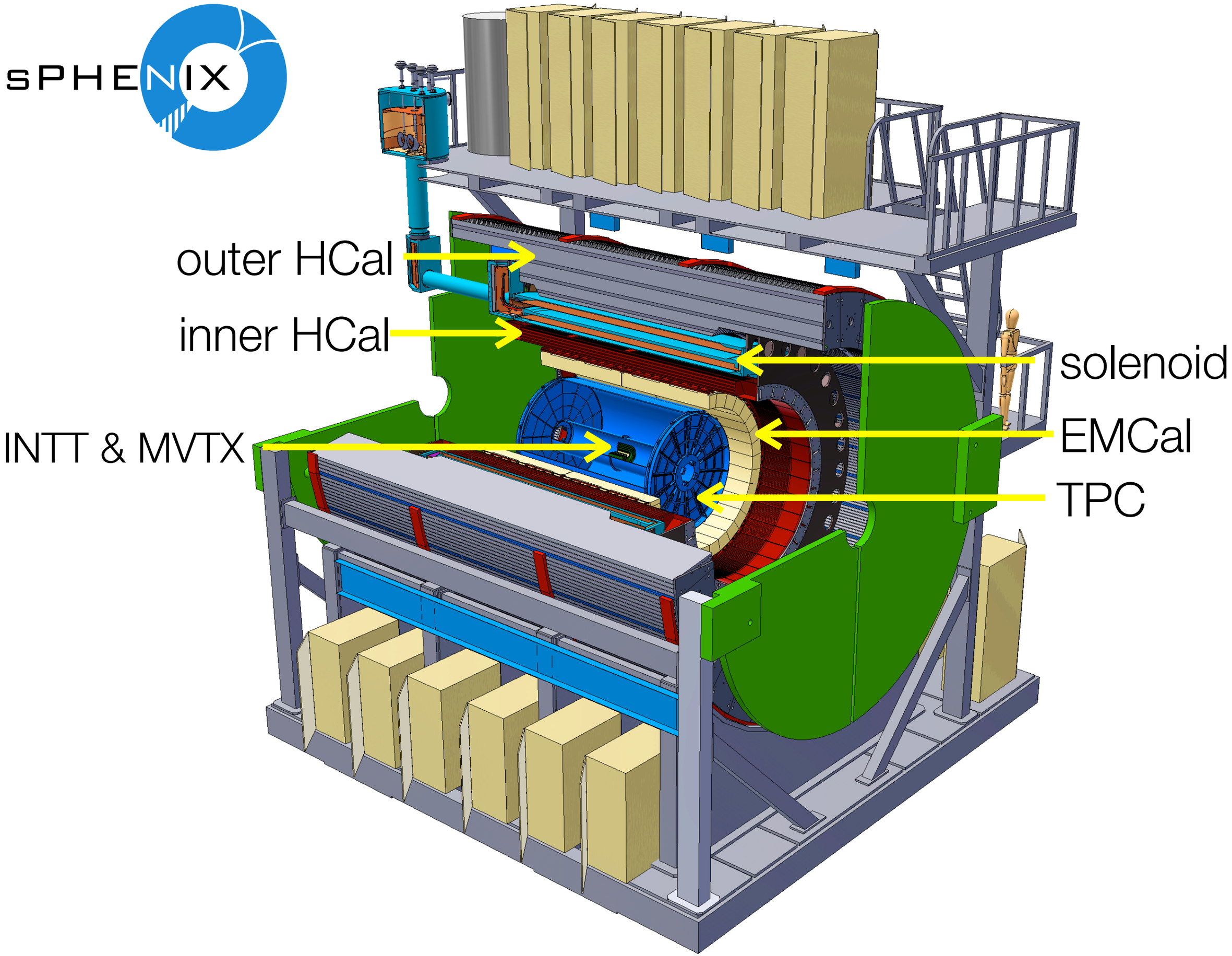
Jet structure
vary momentum/angular scale of probe



Parton energy loss
vary mass/momentum of probe



sPHENIX



Recent timeline and science program

- Responded to two charges from ALD (2016, 2017) to re-scope to fit within cost guidance – collaboration documented in detail the capabilities of reduced scope

- Simulations continue to get more realistic. Detailed vetting against test beam results. More sophisticated consideration of pile-up. All leading to better understanding of the science capabilities of the detector.

- Documented HF (jet tagging, D, B meson) capabilities enabled by MVTX

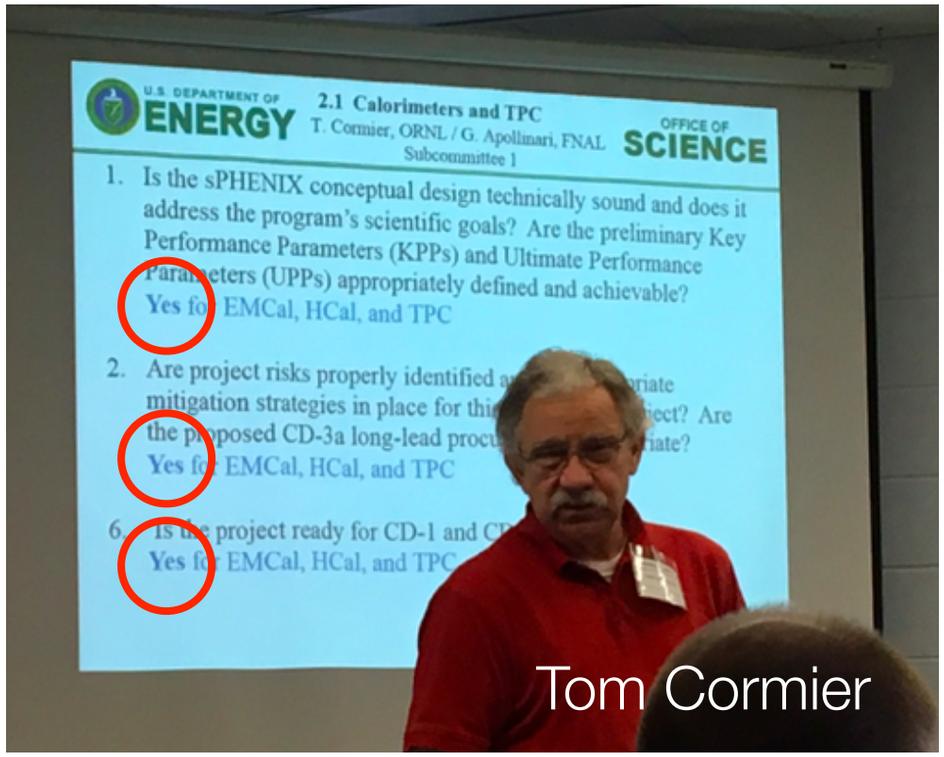
- Document detailing cold QCD capabilities of sPHENIX barrel

- Document detailing cold QCD potential enabled by addition of forward instrumentation to sPHENIX

- Updating LOI detailing sPHENIX connection to EIC (Christine Aidala's talk)

Recent timeline and science program

- Very encouraging DOE OPA CD-1/3A review May 23-25.
  - CD-1: Alternative selection and cost range
  - CD-3A: Long lead time procurements: material for oHCal and EMCal: scintillating tiles, tungsten powder, scintillating fibers, SiPMs

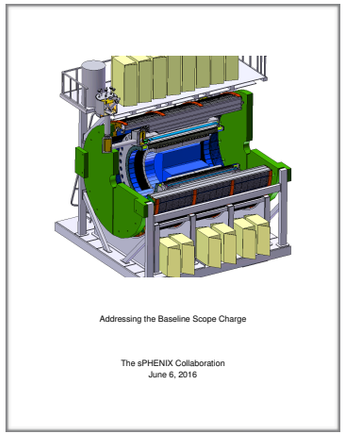


- Focus on cost and schedule of specific sPHENIX scope: full outer HCal, EMCal covering $|\eta| < 0.85$, TPC, INTT (silicon strip), beam-beam detectors, but inner HCal not instrumented and no MVTX (silicon pixels).

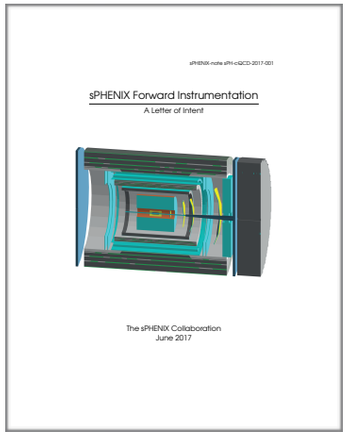
- Committee highlighted importance of restoring full EMCal acceptance ($|\eta| < 1.1$)

Continues long history of development

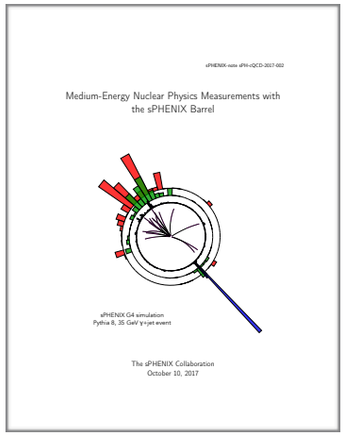
Addressing the baseline scope charge: June 2016



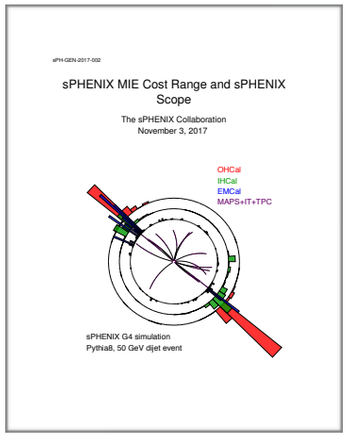
sPHENIX Forward Instrumentation: A Letter of Intent: June 2017



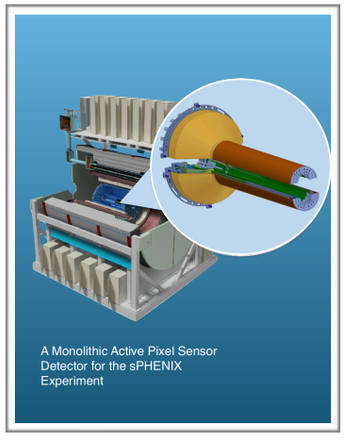
Medium-Energy Nuclear Physics Measurements with the sPHENIX Barrel: October 2017



sPHENIX MIE Cost Range and sPHENIX Scope: November 2017



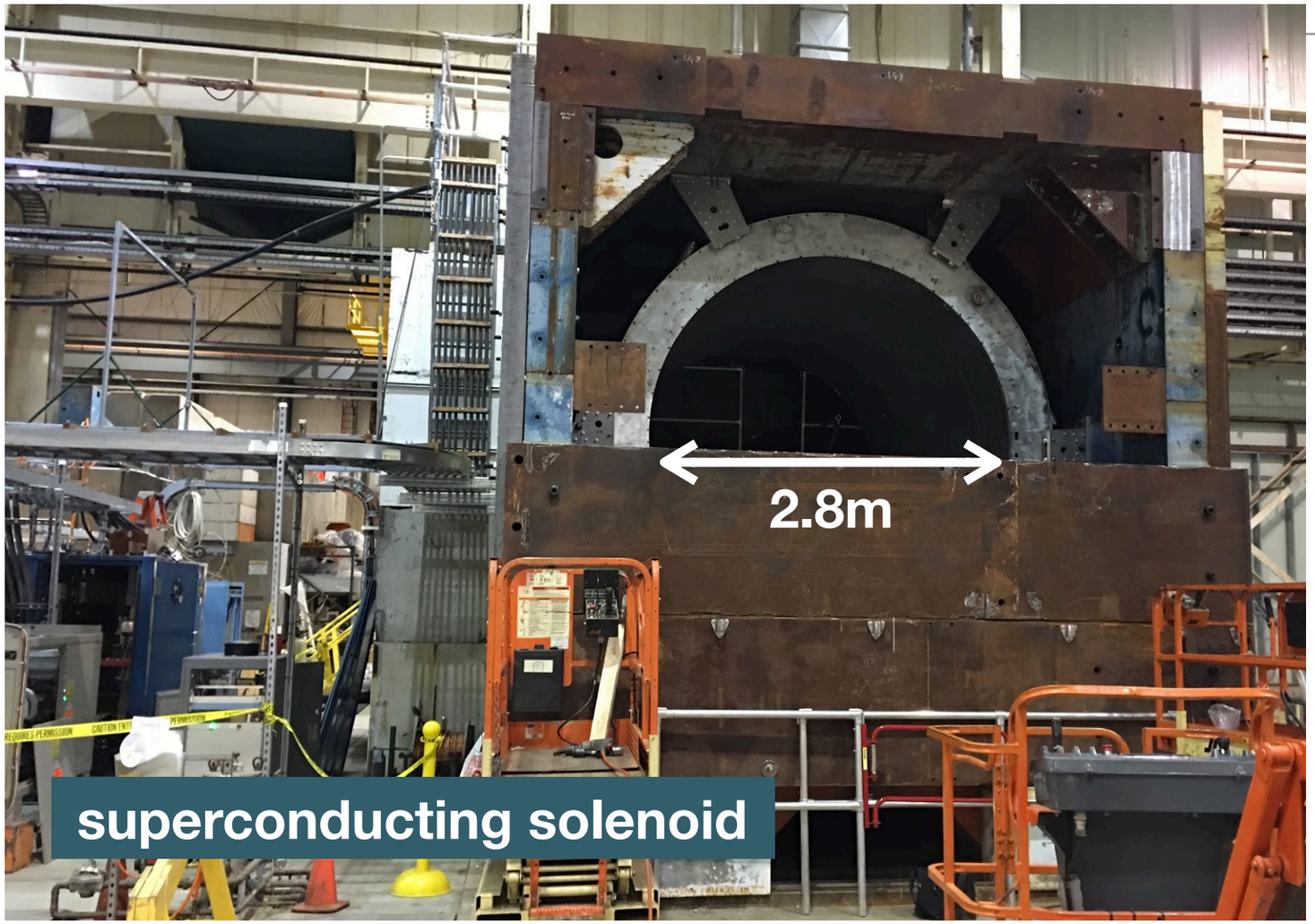
A Monolithic Active Pixel Sensor Detector for the sPHENIX Experiment: February 2018

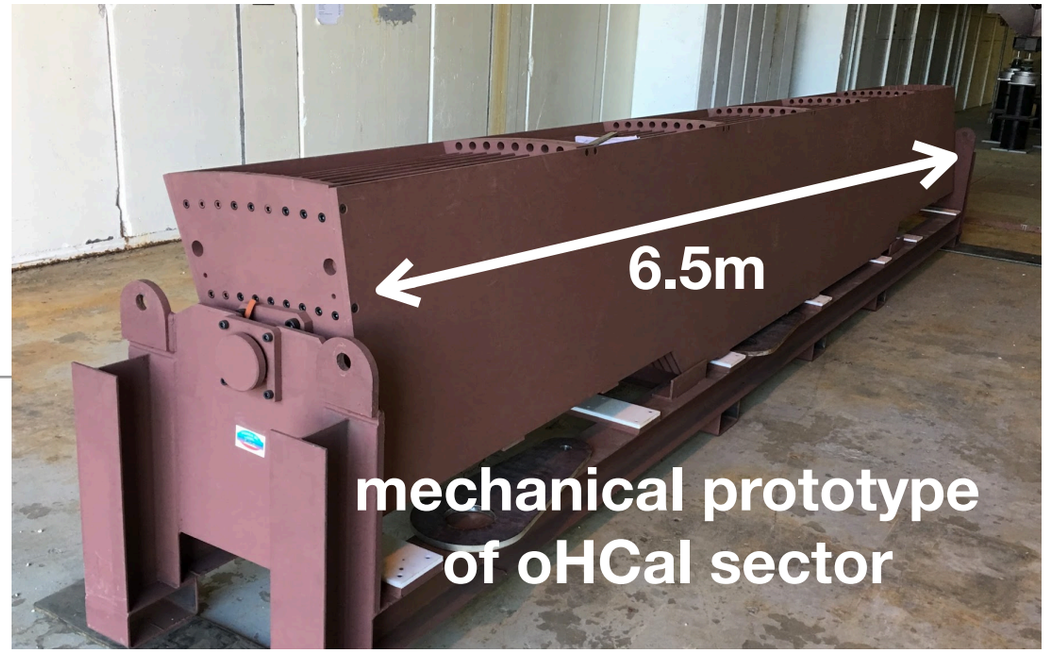


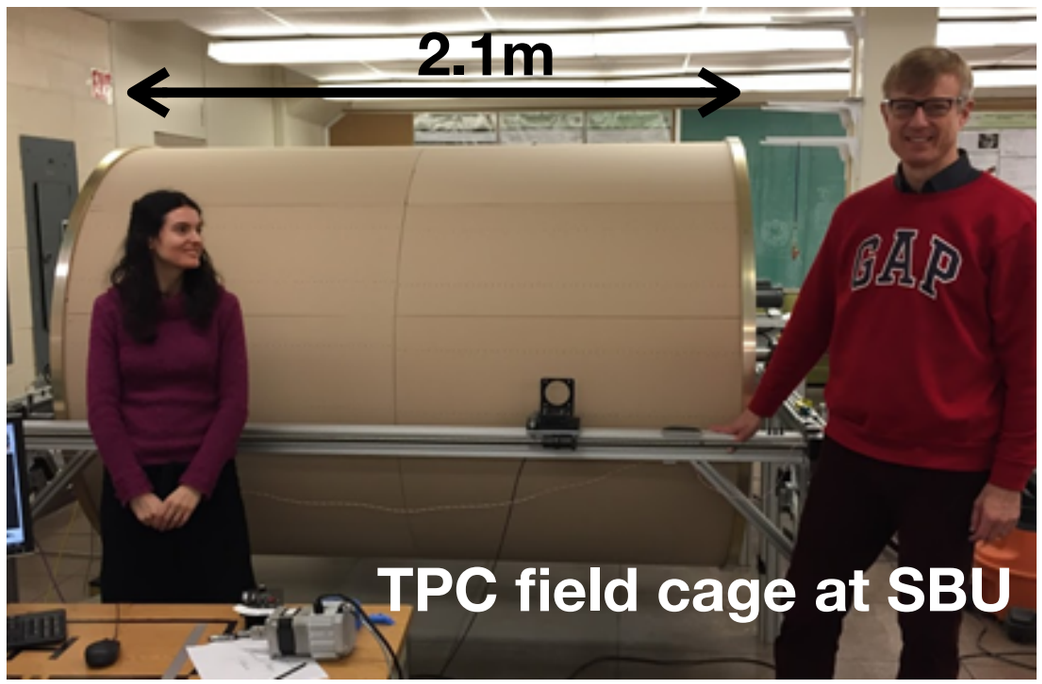
sPHENIX Conceptual Design Report: May 2018

OPA CD-1/3A review of sPHENIX MIE: May 2018

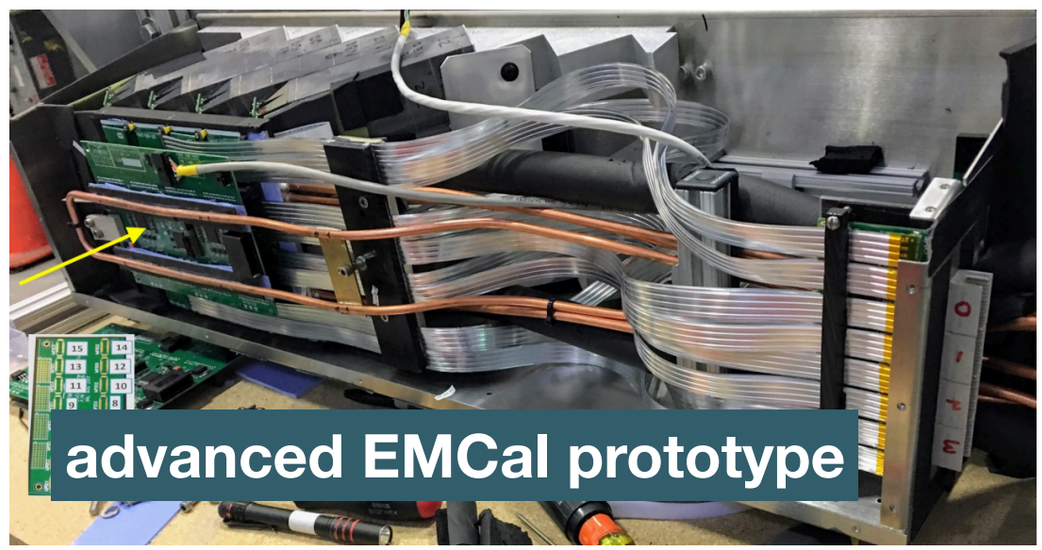
Marching toward reality







- Magnet successfully tested to full current
- Contract awarded for full order of oHCal steel
- Full chain tests of calorimeter stack, MVTX telescope, INTT telescope, readout electronics
- TPC prototype to see test beam next week



Multi-year sPHENIX run plan

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}

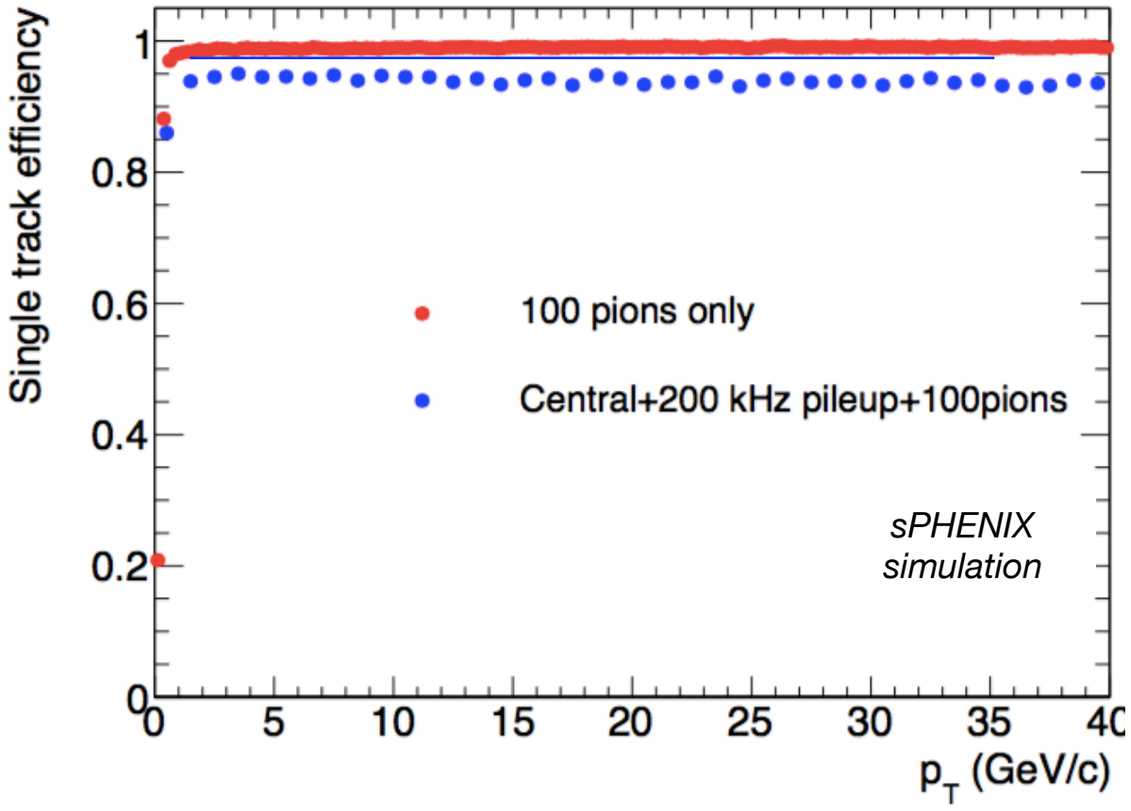
- Guidance from ALD to think in terms of a multi-year run plan
- Consistent with language in DOE CD-0 “mission need” document
- Based on BNL C-AD guidance on projected luminosity
- Incorporates commissioning time in first year
- Structured so that first three years delivers at least minimum science program

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**

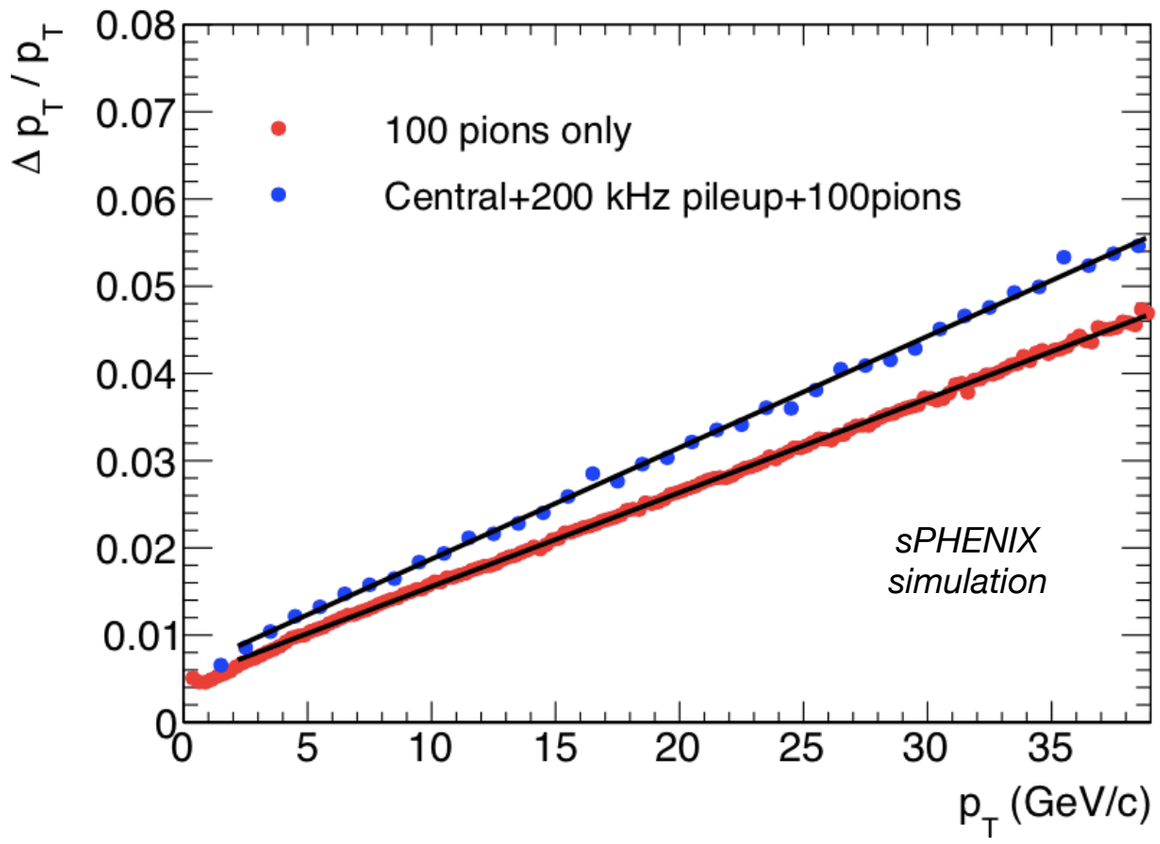
For topics with Level-1 selective trigger (e.g. high p_T photons), one can sample within |z| < 10 cm a total of 550 billion events. One could sample events over a wider z-vertex for calorimeter only measurements, 1.5 trillion events.

Performance simulation: tracking efficiency and resolution

Tracking efficiency (central Au+Au)



Track pT resolution (central Au+Au)

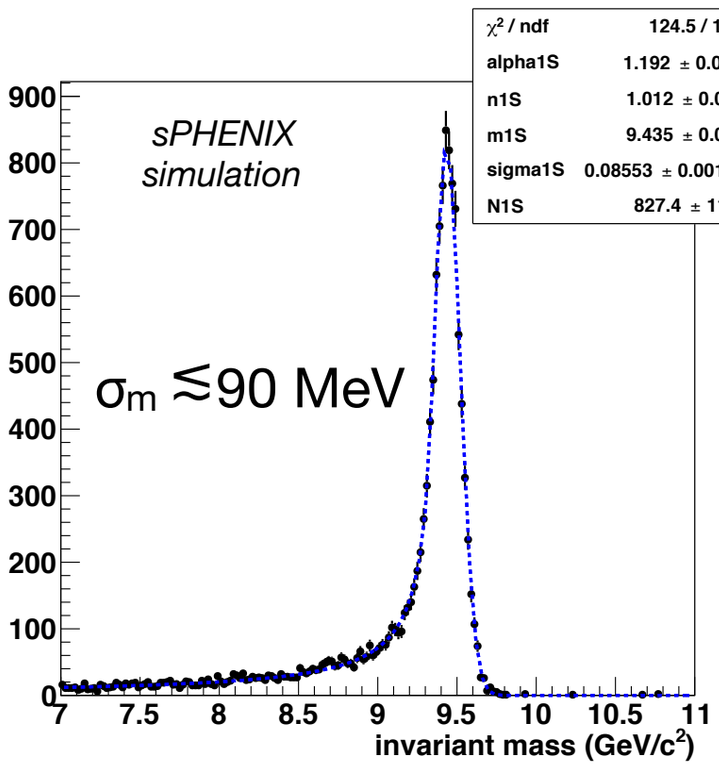


Excellent tracking performance in full GEANT simulations including pileup

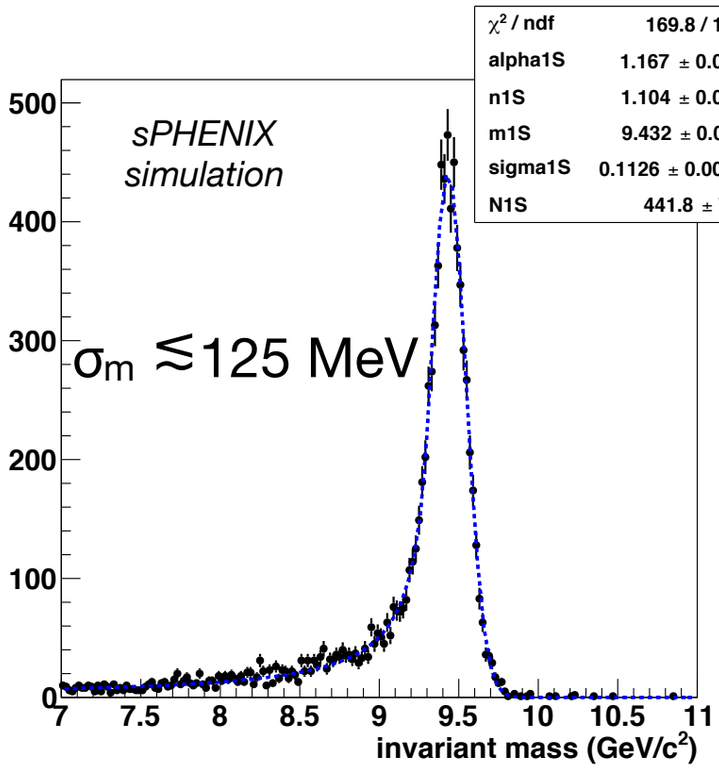
Recent improvements in reconstruction speed; ALICE, ATLAS experience indicate significant further improvements possible.

Performance simulation: Upsilon mass resolution

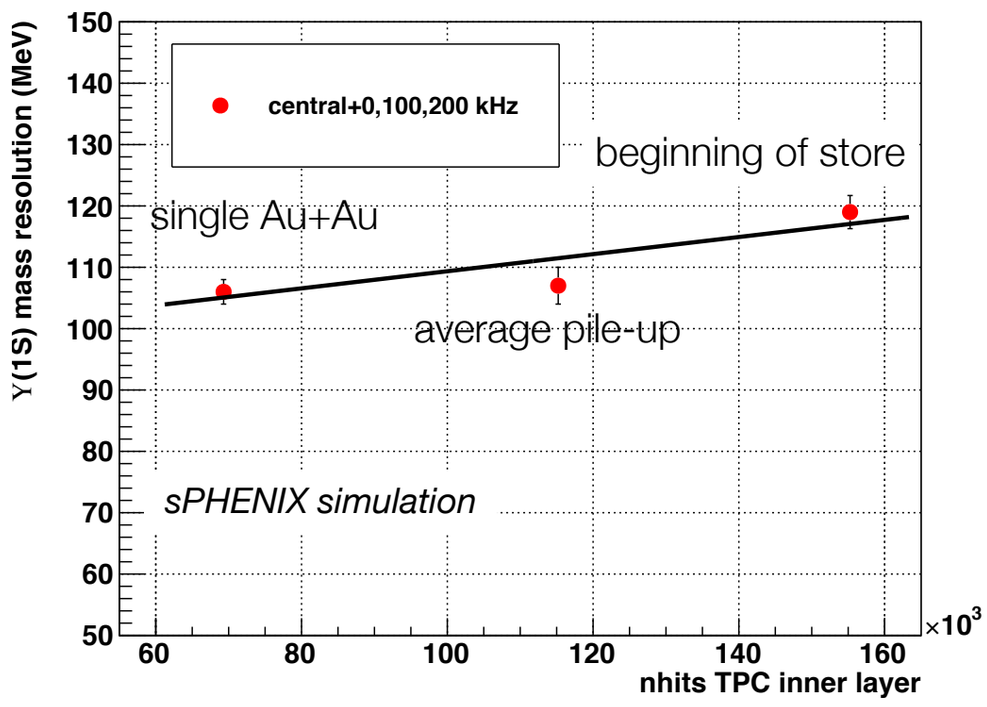
p+p √s = 200GeV



Au+Au + pileup √s = 200GeV



Y(1s) mass resolution vs multiplicity (instantaneous luminosity)



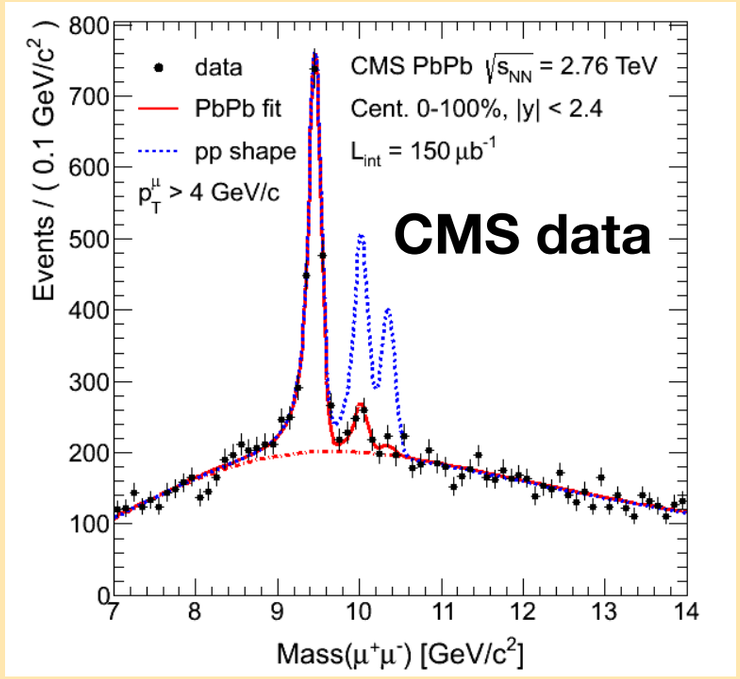
Mass resolution sufficient to resolve Υ(nS).

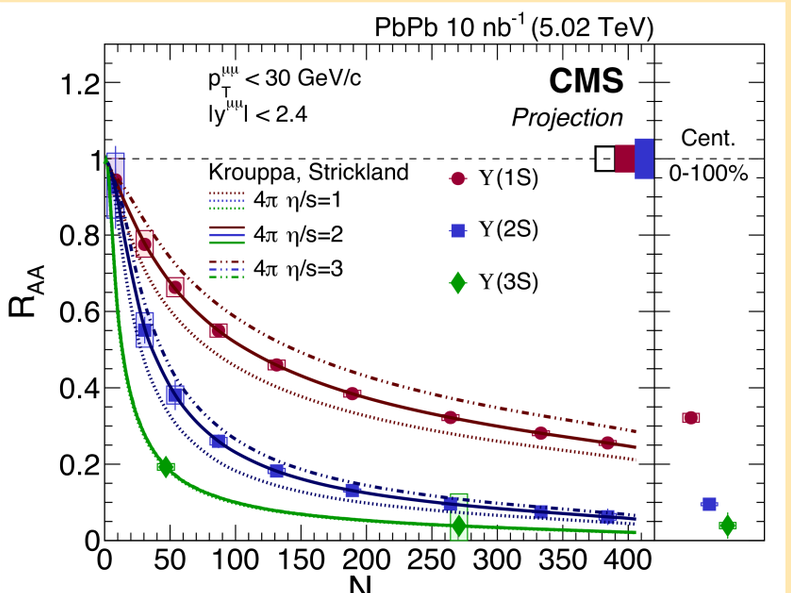
Current TPC cluster finder does not include deconvolution of overlapping clusters → multiplicity dependence

Simulations indicate Υ(1s) mass resolution better than 125 MeV

(averaged over in-store luminosity evolution)

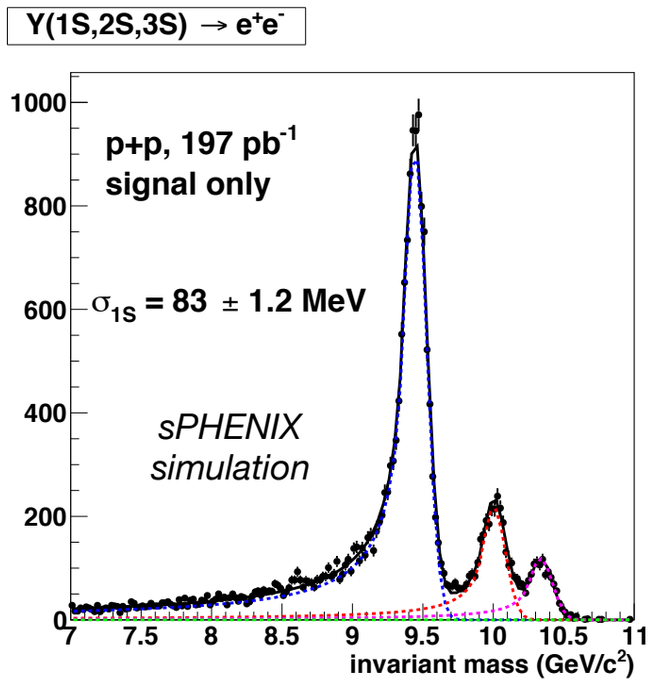
Physics projection: Upsilons at sPHENIX cf. LHC

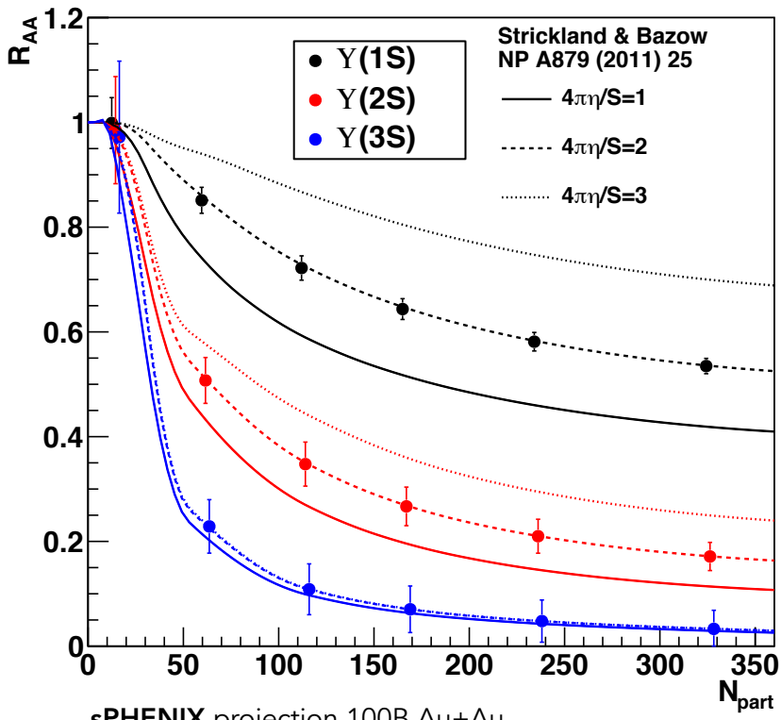




LHC projection for Run III+IV

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



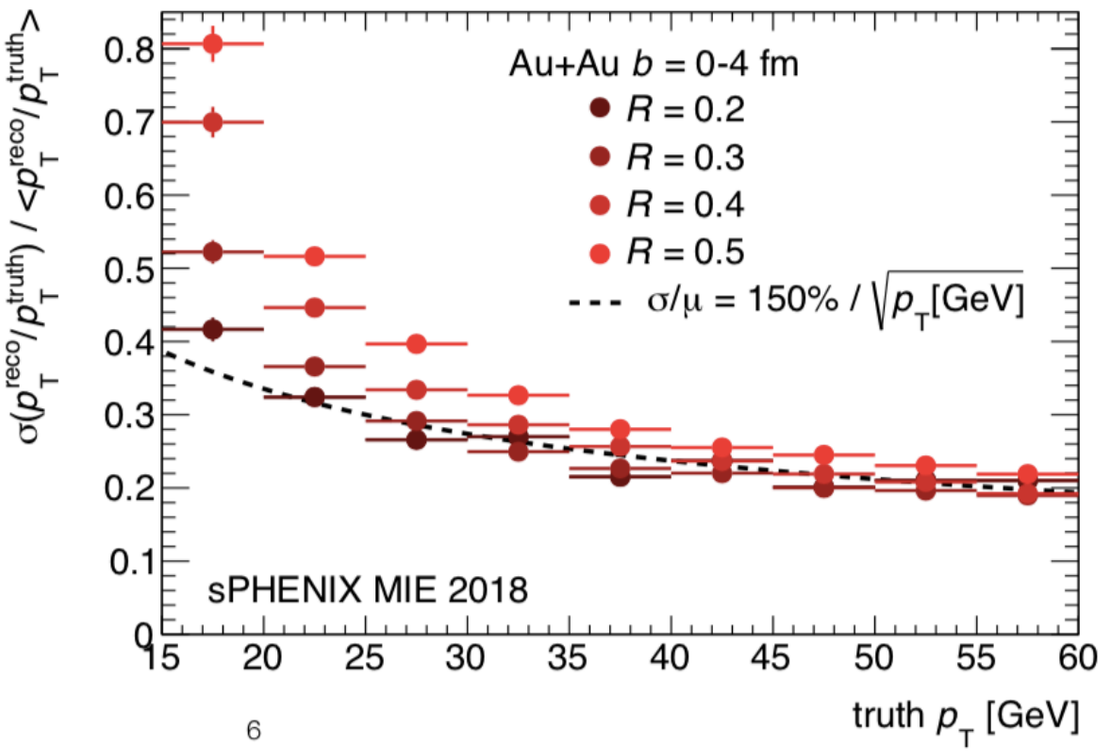


sPHENIX projection 100B Au+Au

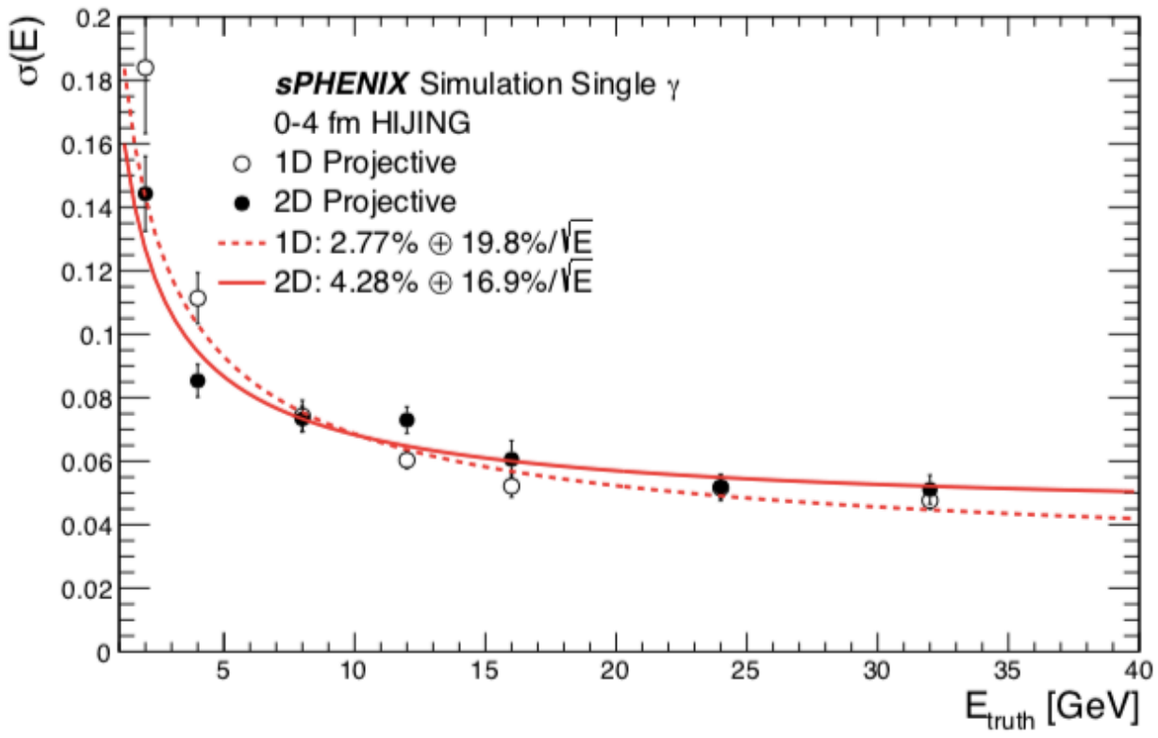
sPHENIX projection

Performance simulation: Jet and γ resolution

Single jet resolution (central Au+Au)



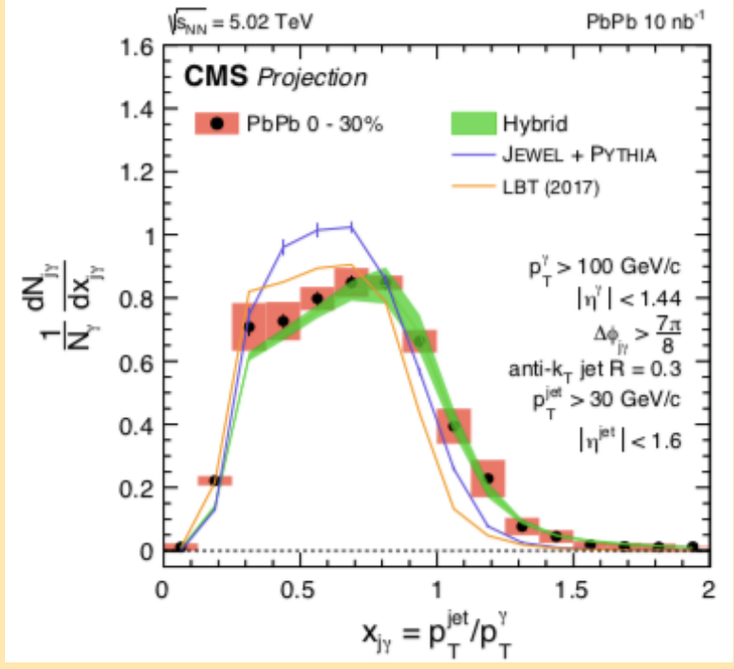
Single photon resolution (central Au+Au)



Calorimeter-related performance studied using GEANT simulations verified with test beam data – meets performance needed for science program

Physics projections: Jets in sPHENIX cf. LHC

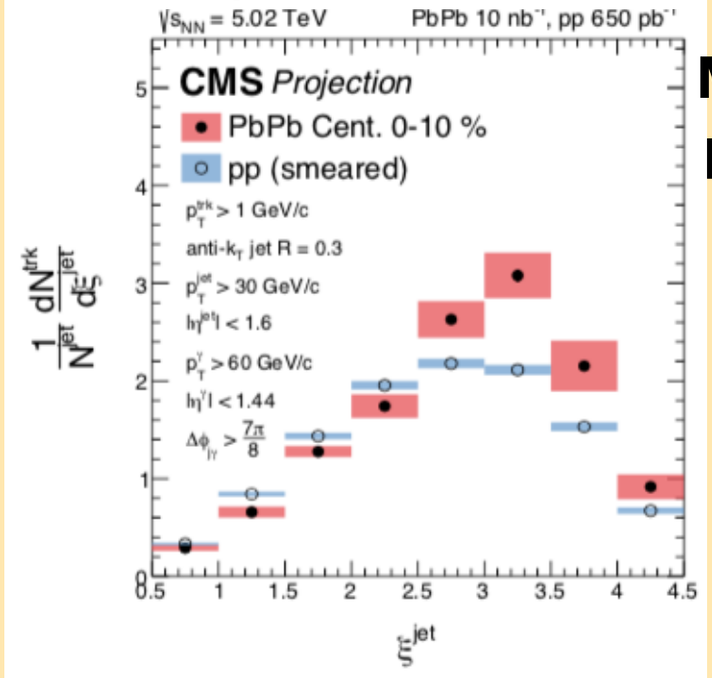
γ+Jet momentum balance



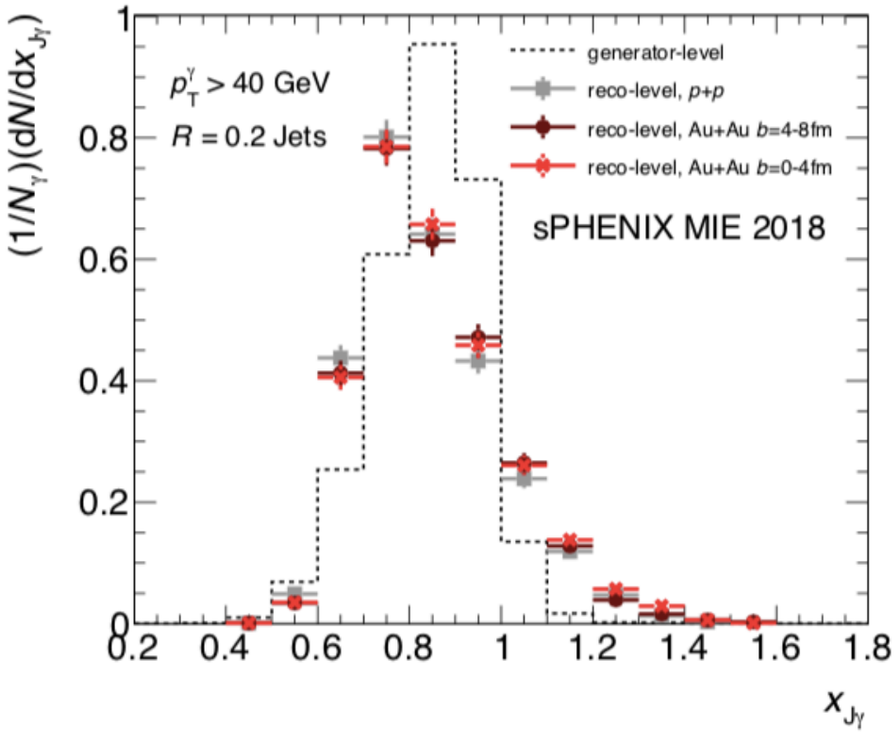
Direct measurement of parton energy loss in the QGP

LHC projections for Run III+IV

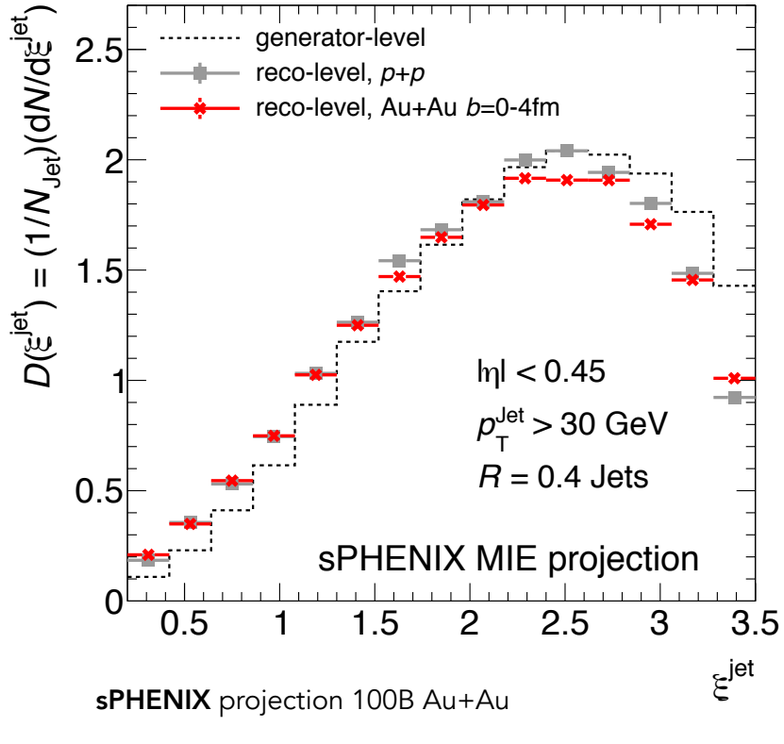
γ+Jet fragmentation function



Modification of parton shower in the QGP

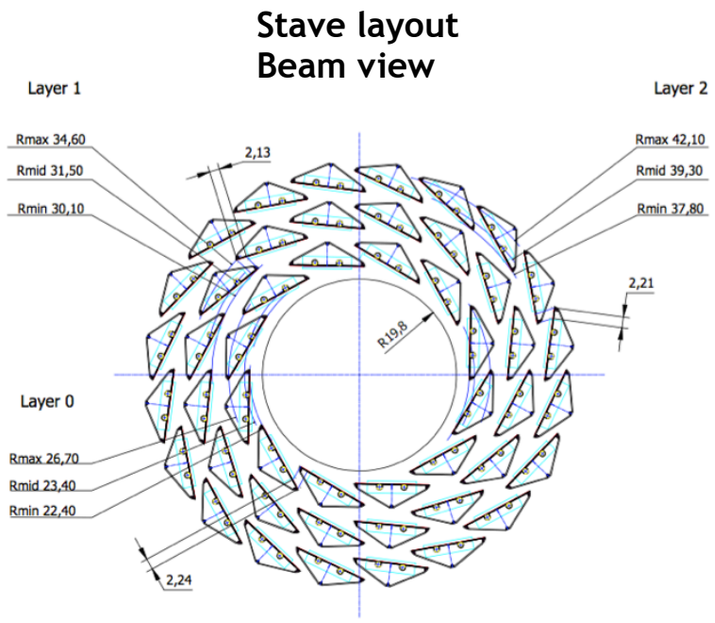


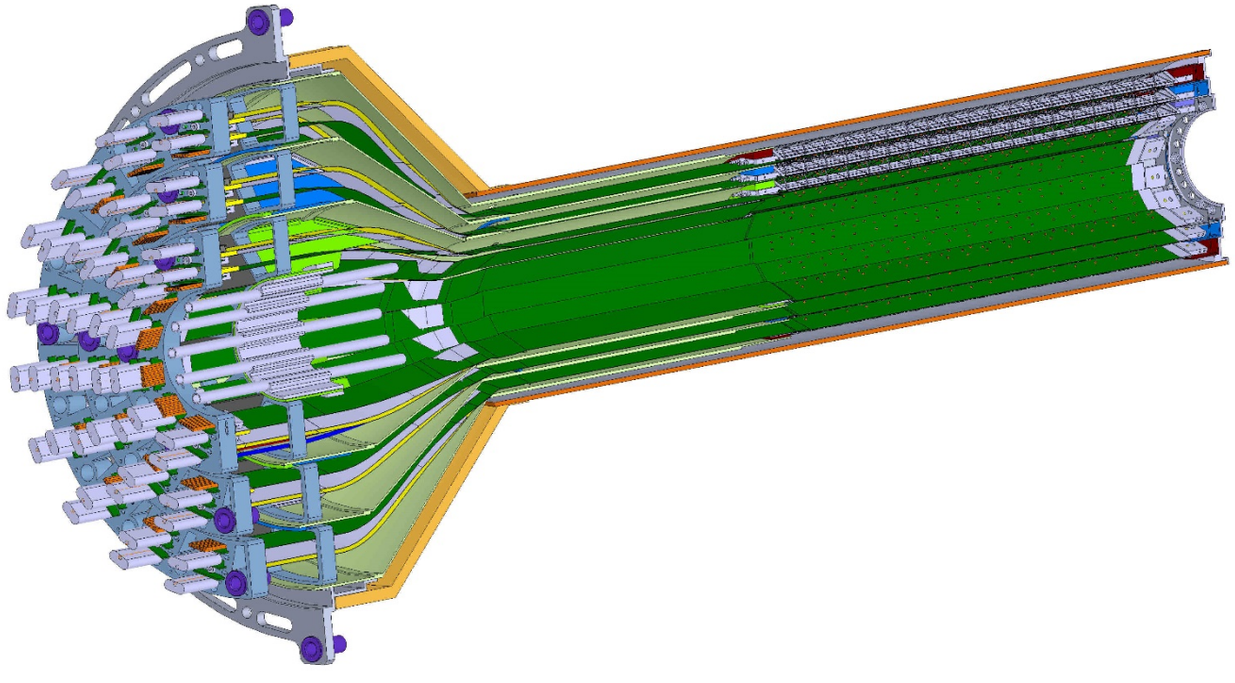
sPHENIX projections



sPHENIX projection 100B Au+Au

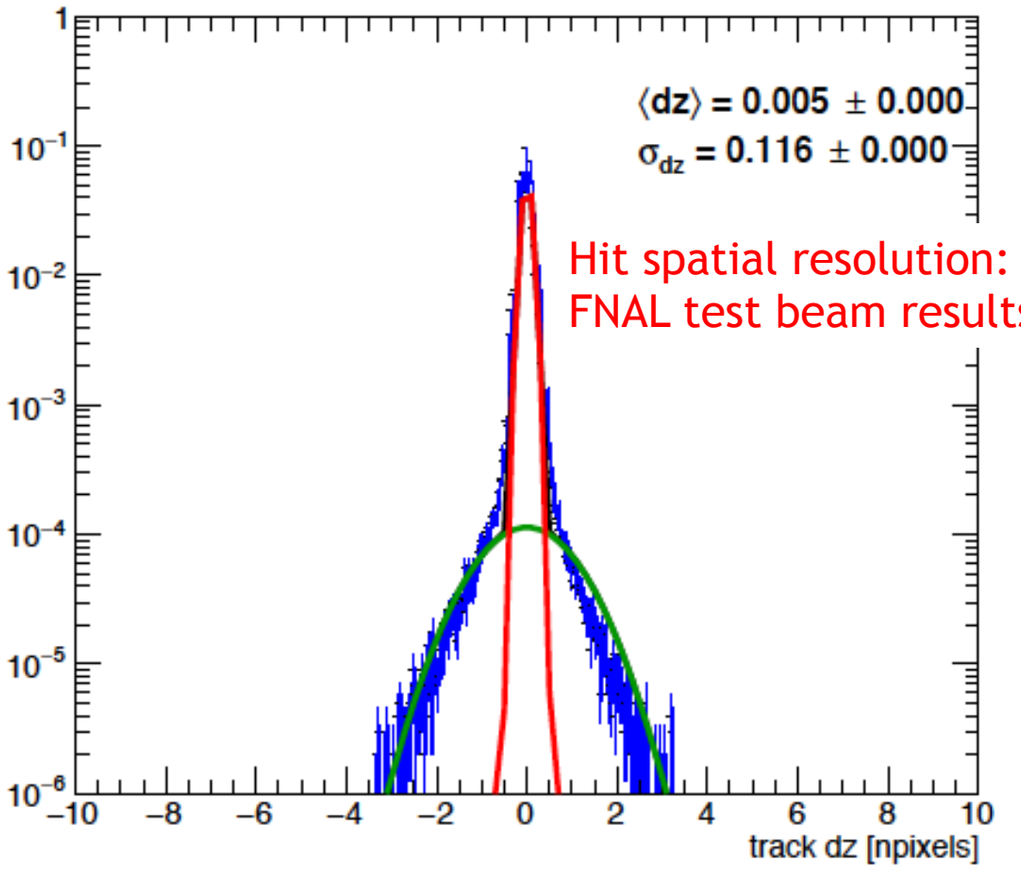
MVTX enables world-class HF science program





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

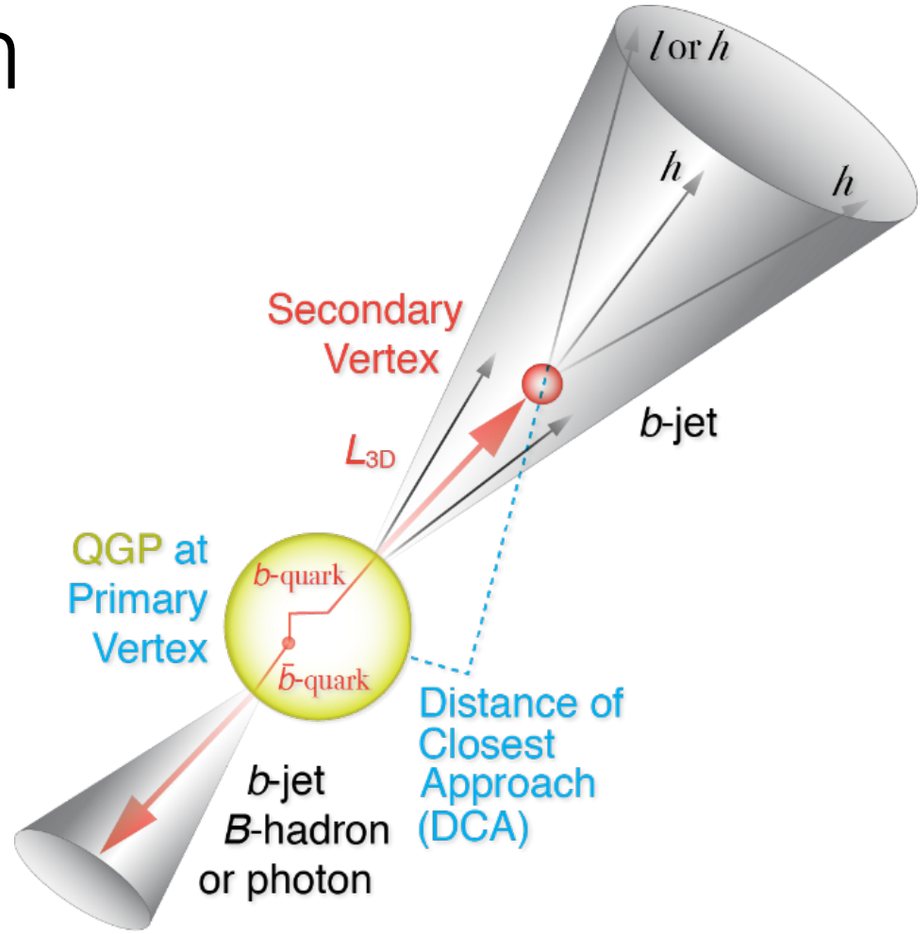
LANL LDRD addressing key questions – demonstrating successful read-out chain test and stave performance in FNAL test beam



Hit spatial resolution: < 5 μm
FNAL test beam results

Heavy flavor science program

Hadron	Abundance	cτ (μm)
D^0	61%	123
D^+	24%	312
D_s	8%	150
Λ_c	6%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435



b-tagged jet and cor. p_T>15 GeV

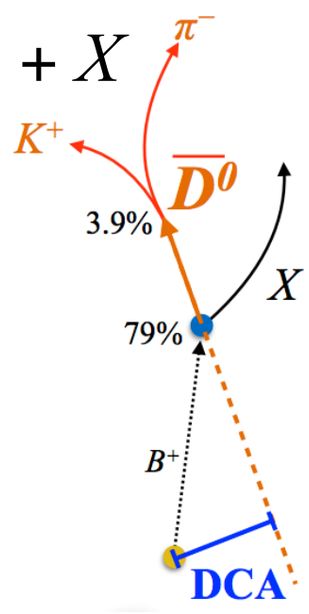
$B \rightarrow \overline{D}^0 + X$ 60%

$B^+ \rightarrow \overline{D}^0 \pi^+$ 0.5%

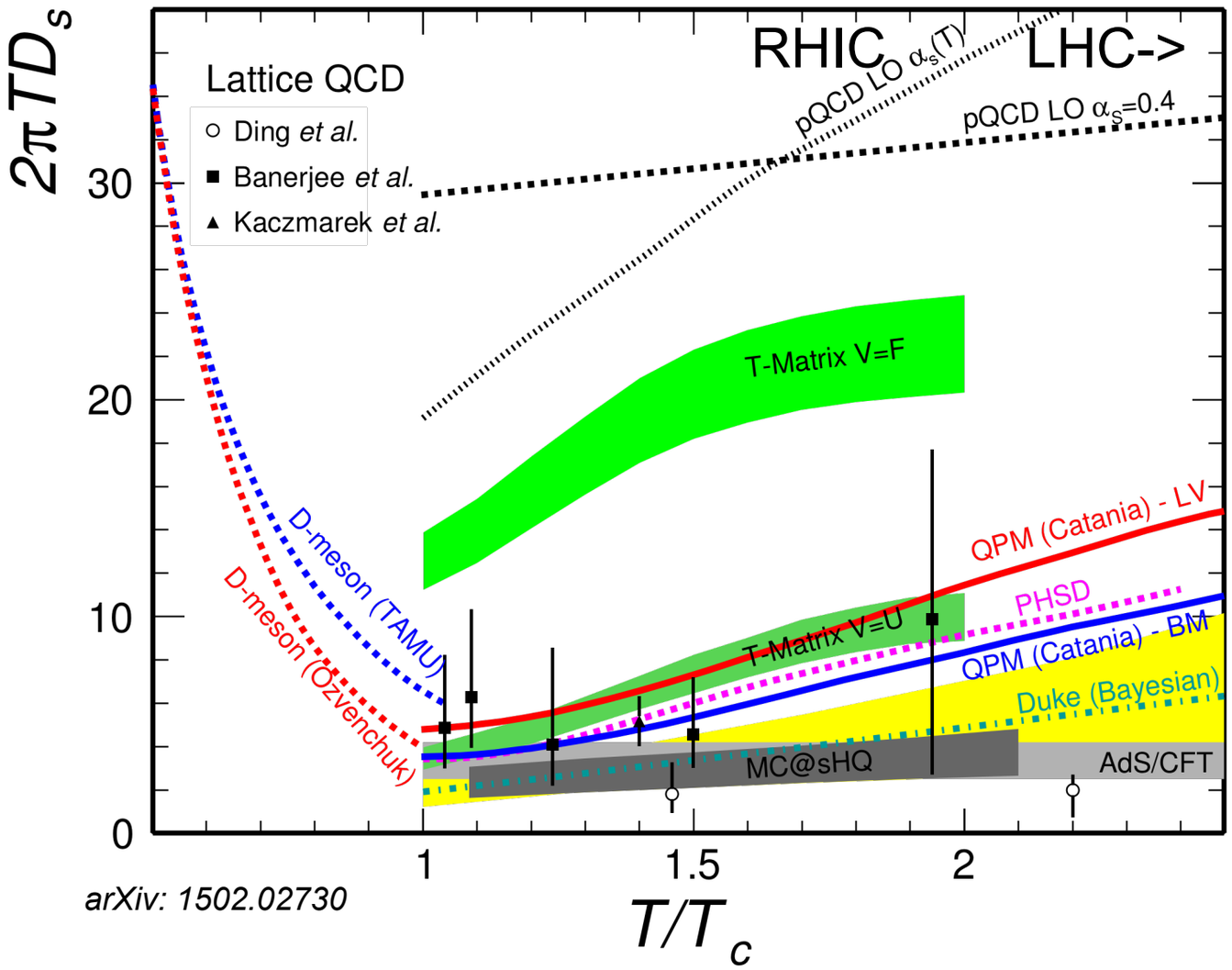
p_T<15 GeV

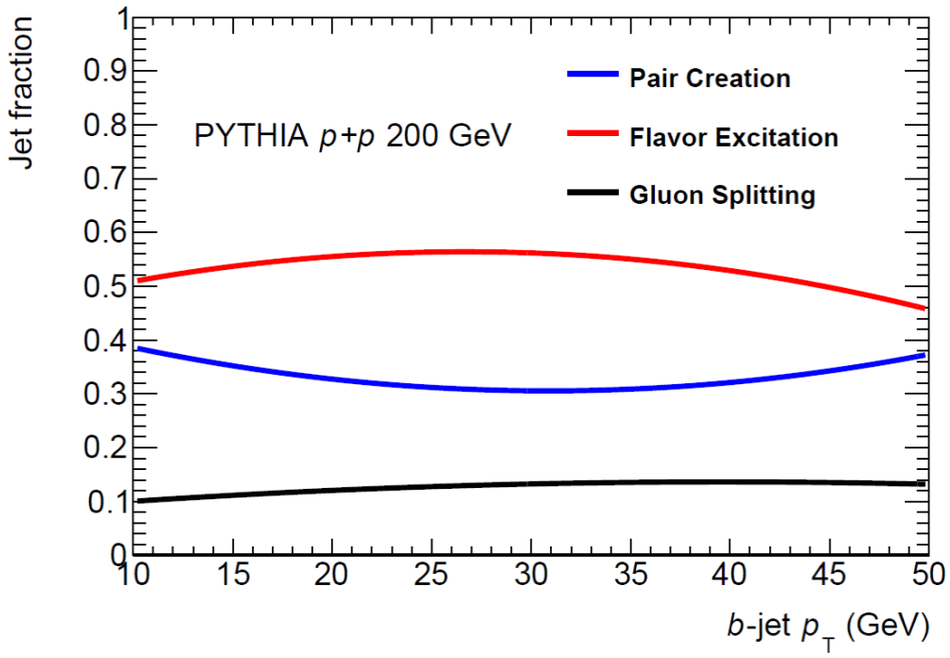
Exploring $B \rightarrow J/\psi + X$ and more

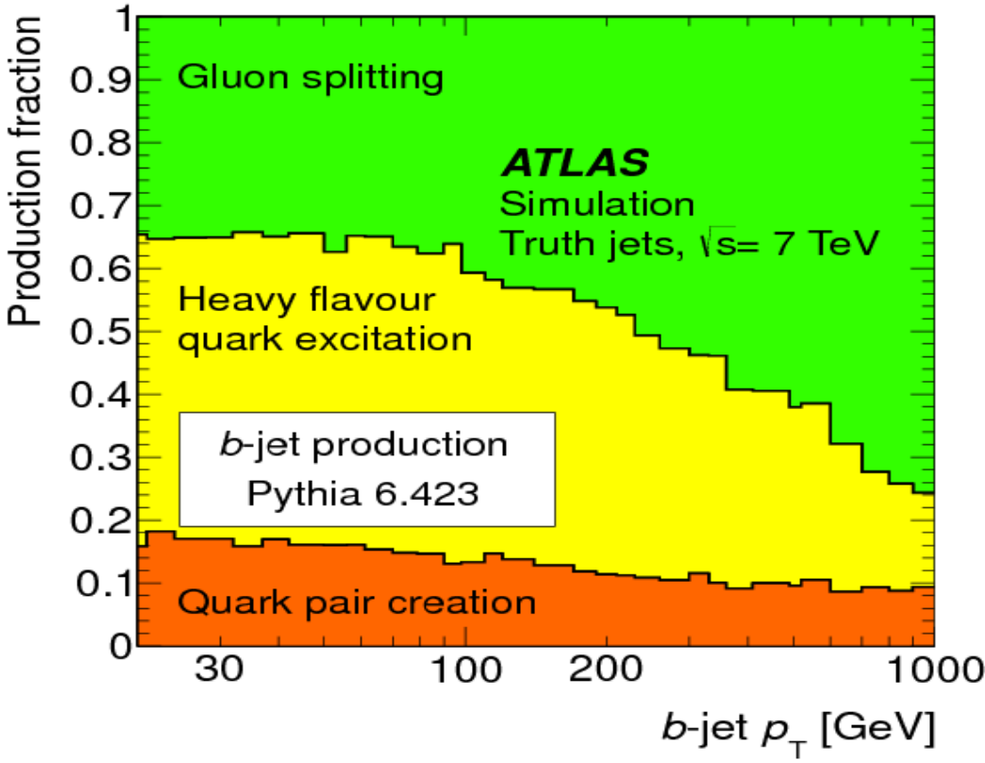
$B \rightarrow \overline{D}^0 + X$



Heavy flavor at RHIC and the LHC



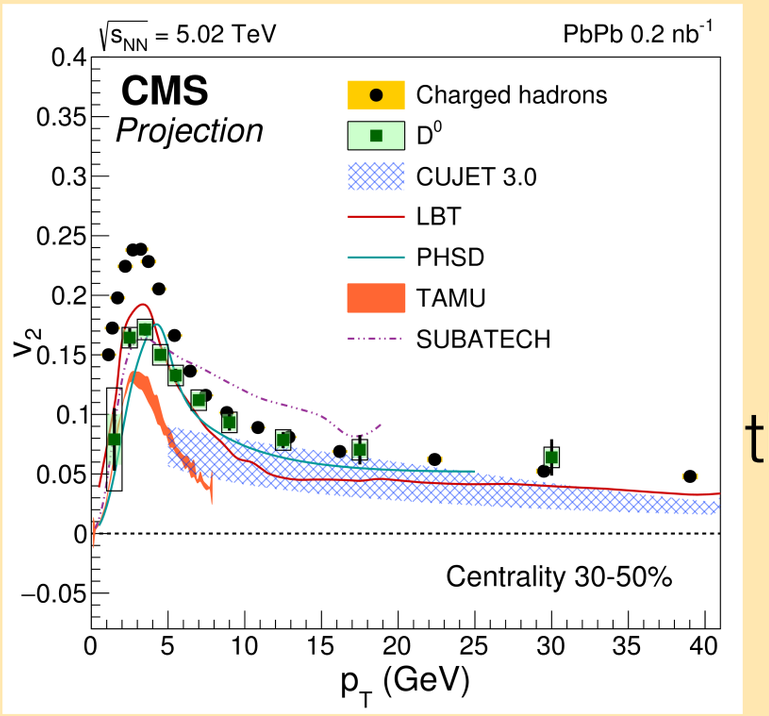




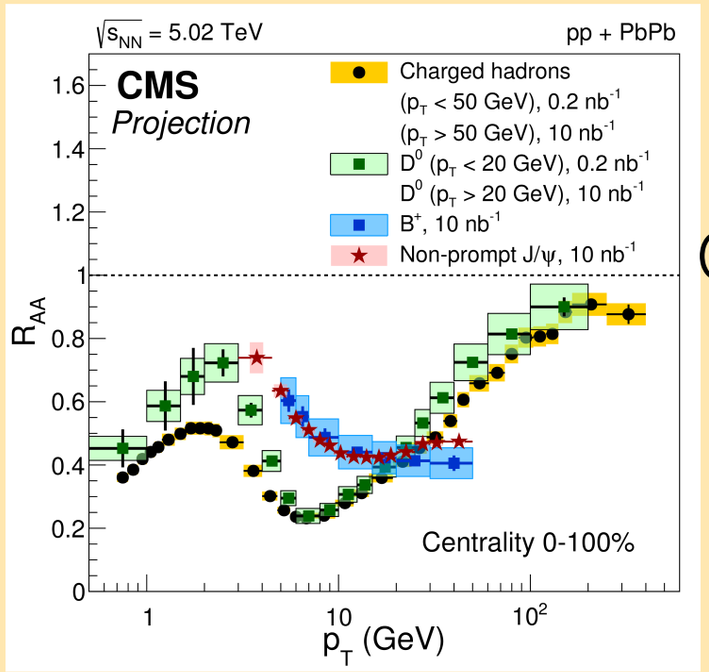
Complementarity: RHIC vs. LHC
- Sensitive to different temperature regions

Uniqueness at RHIC (vs. LHC)
- Gluon splitting contribution is much less (~10%)

Heavy flavor at sPHENIX cf. LHC

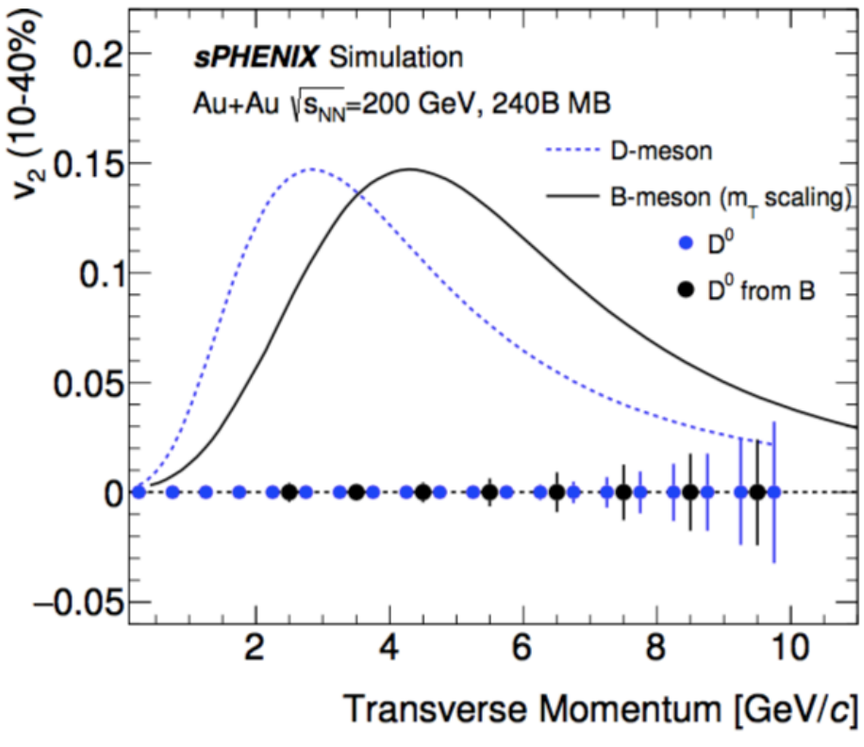


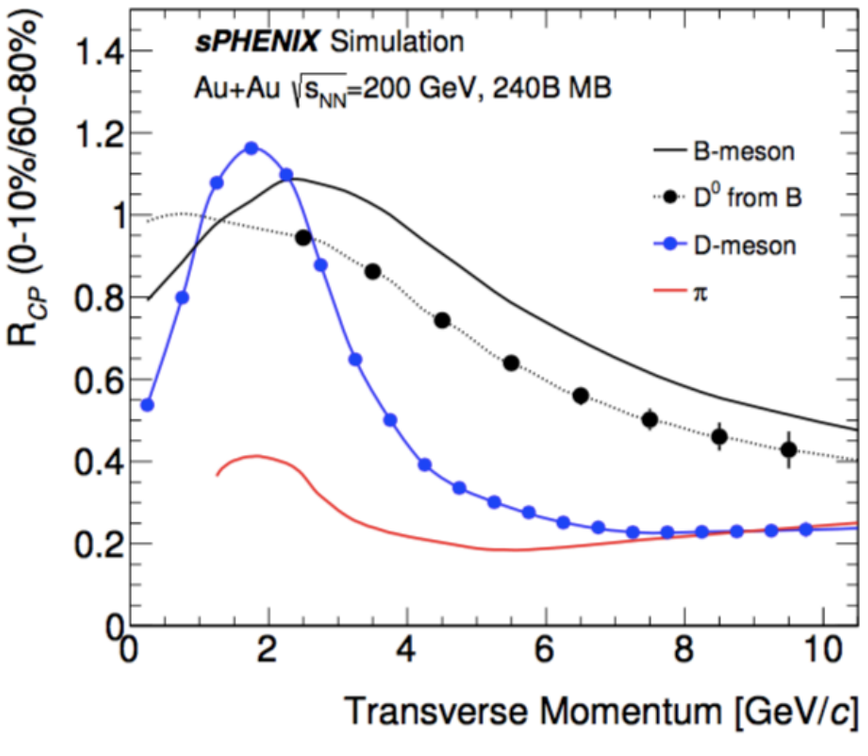
Elliptic flow measures *c* and *b* quark thermalization in medium



LHC projections for Run III+IV

Open heavy flavor suppression probes flavor dependence of energy loss

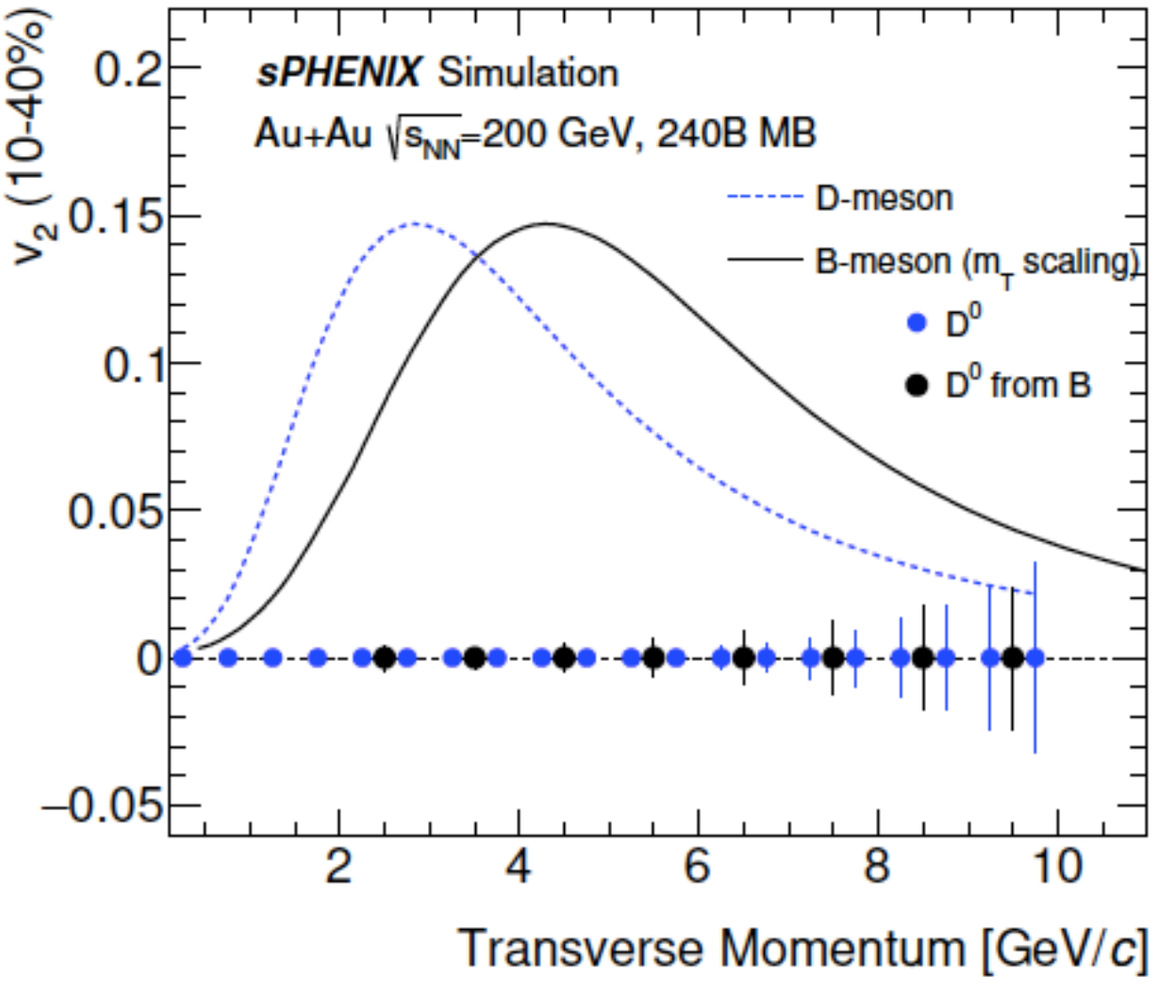


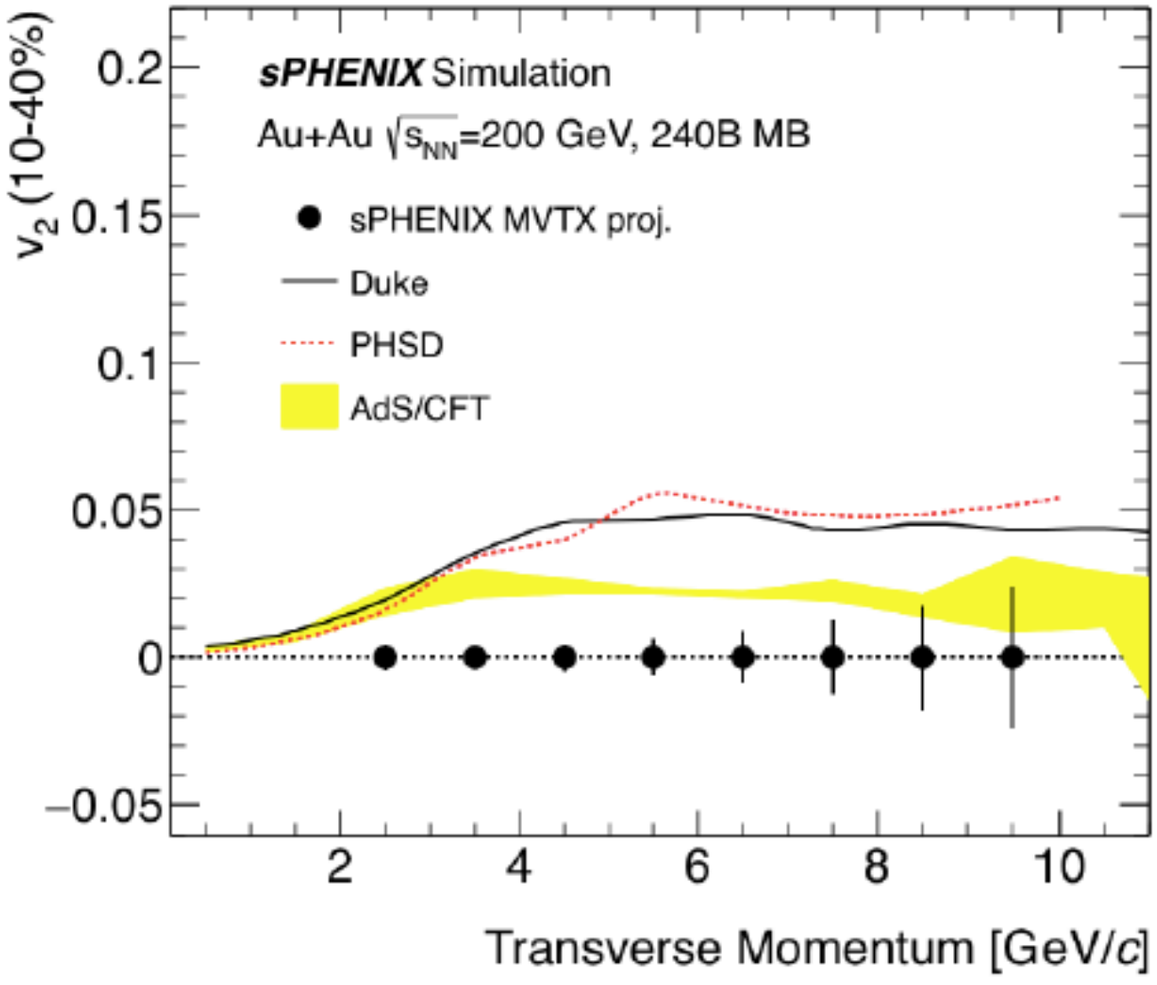


sPHENIX projections

Projection for v_2 of non-prompt D^0

- Excellent statistical precision enables study of bottom collectivity
  - sensitive to heavy quark diffusion coefficient
  - strong constraints on model calculations





Broader relevance of sPHENIX science program

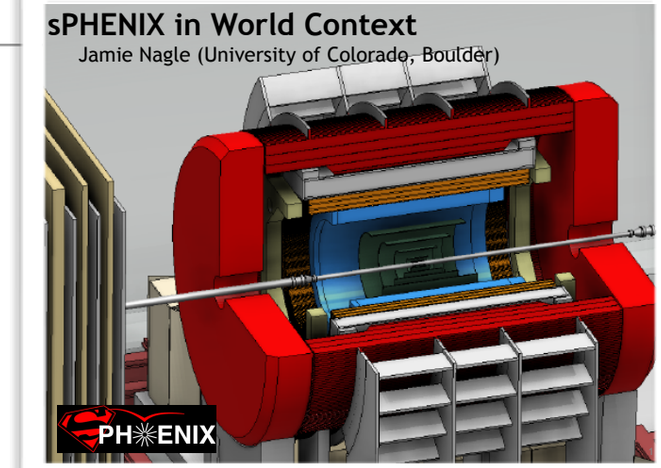
Asked to present world context for sPHENIX science program at successful 2014 DOE CD-0 review of science proposal.

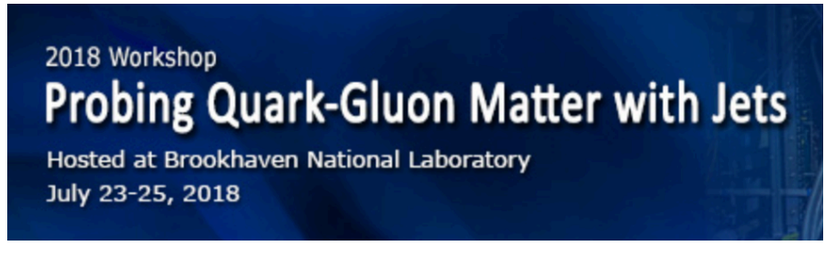
Topical workshops, international conferences. e.g., “Recent RHIC and LHC results and their implications for heavy ion physics in the 2020s” MIT 2016; “Precision Spectroscopy of QGP Properties with Jets and Heavy Quarks” INT 2017; programs for QM, HP, IS, etc.

Upcoming BNL and RBRC workshops focused on questions aligned with sPHENIX program.

Benefit from theory/modeling tools relevant to questions targeted by sPHENIX program: e.g. jet quenching framework developed by NSF’s JETSCAPE collaboration (includes a number of sPHENIX collaborators).

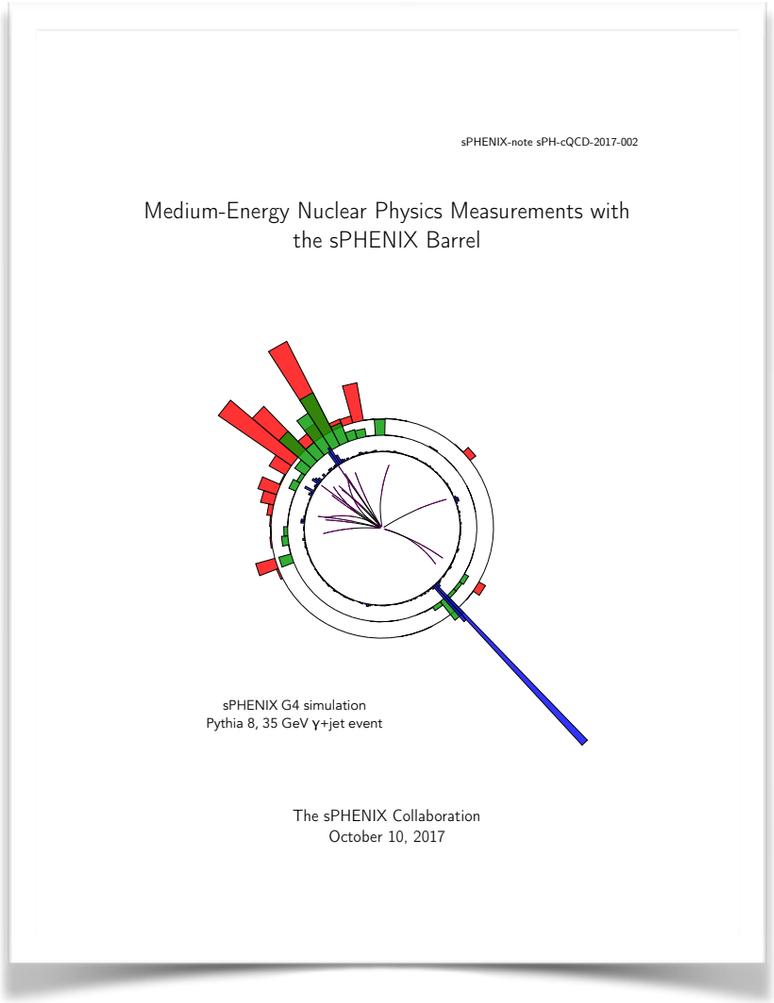
Three-year LANL LDRD advances MAPS for sPHENIX and supports a significant, related theory activity.





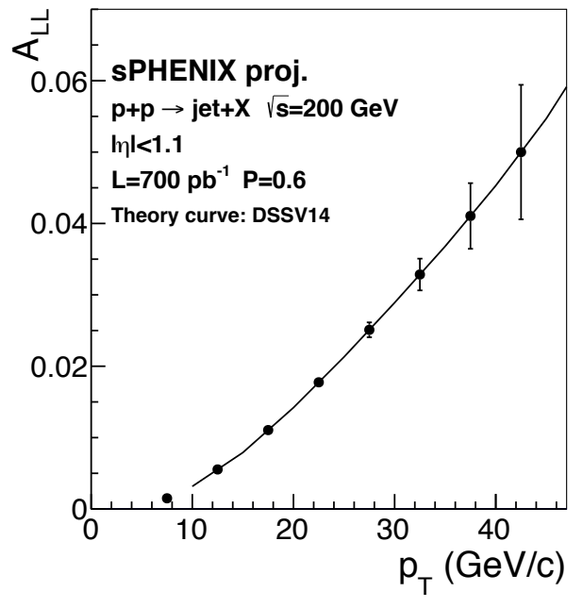
Cold QCD with sPHENIX barrel

Charge from ALD, delivered 10/2017

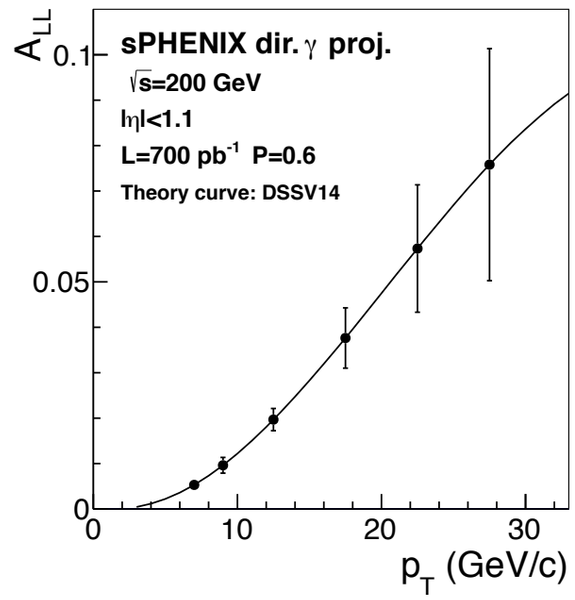


Projected capabilities for observables in longitudinally, transversely polarized collisions, nPDFs

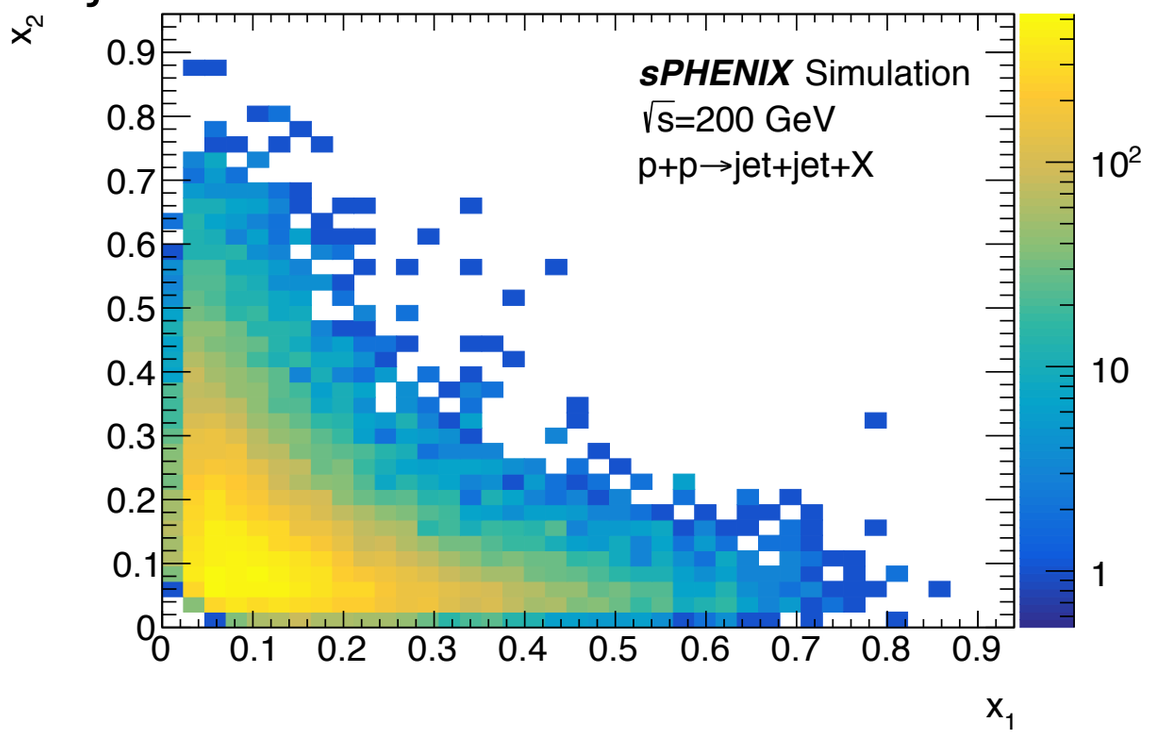
jet A_{LL}



direct γ A_{LL}



dijet kinematics in sPHENIX barrel



Growth of collaboration since CD-0

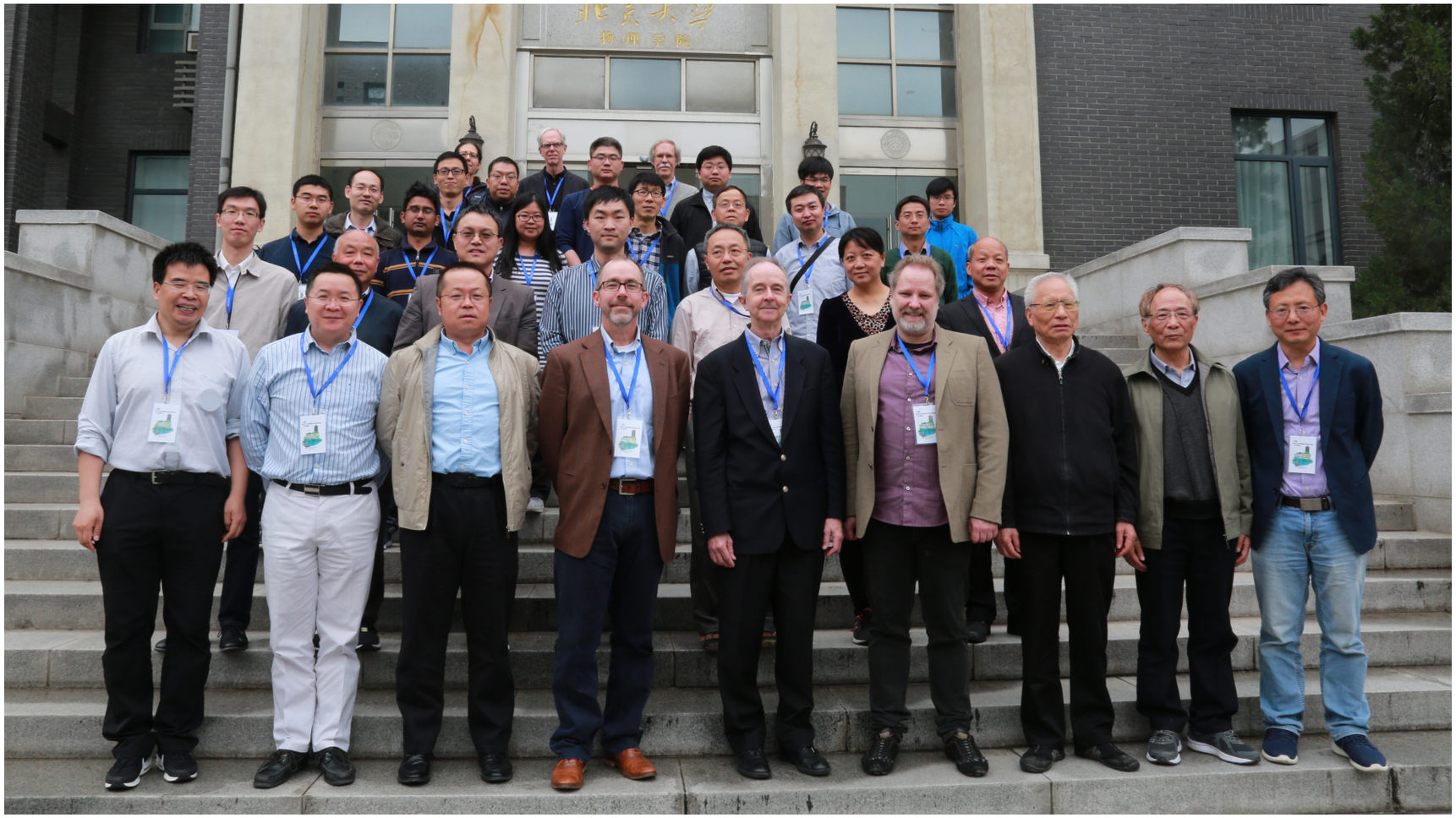
2016

2017

2018

Continuing to add strong institutions with expertise in sPHENIX science program and key technologies. Additional applications to join sPHENIX presented at collaboration meeting yesterday (June 6).

Meeting with new sPHENIX collaborators



“The First sPHENIX Workshop in China,” at Peking University, Beijing, April 22-23, 2018

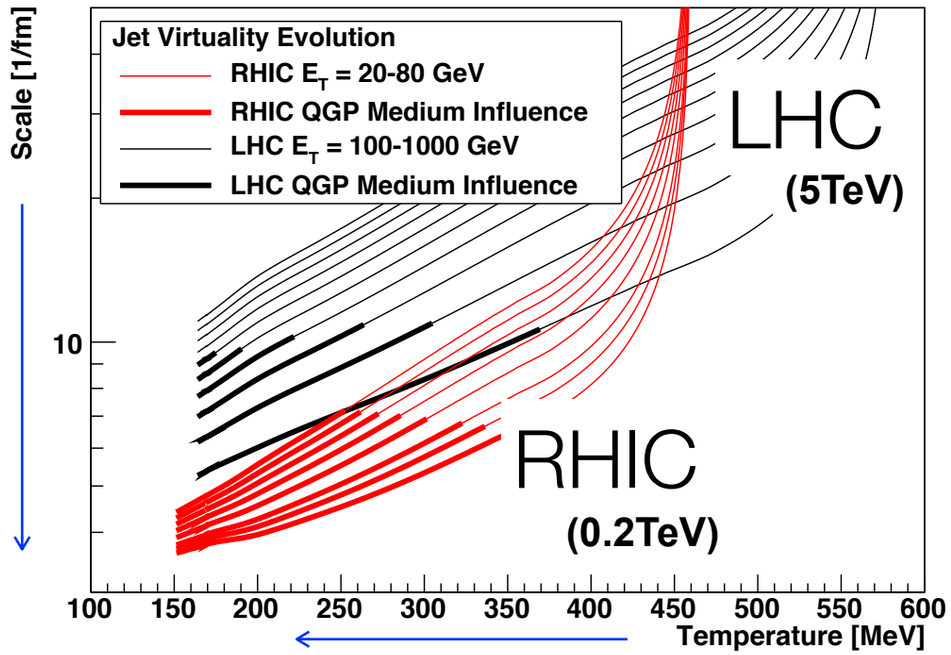
Summary

- Progress toward detector as detailed in OPA CD-1/3A review is proceeding extremely well – capable of addressing core jet and Upsilon science program.
  - Review committee noted the importance of restoring the full η acceptance of the EMCal.
  - Collaboration also investigating ways to restore instrumented inner HCal.
- Acknowledged that MVTX enables a very rich science program including HF-tagged jets, low p_T open HF. Detailed funding considerations frame ongoing discussions about realizing MVTX.
- Excellent cold QCD capabilities of sPHENIX barrel and the physics potential of forward augmentation extensively studied and documented.
- The sPHENIX science program is in excellent shape. First data expected in 2023 – only five years away!

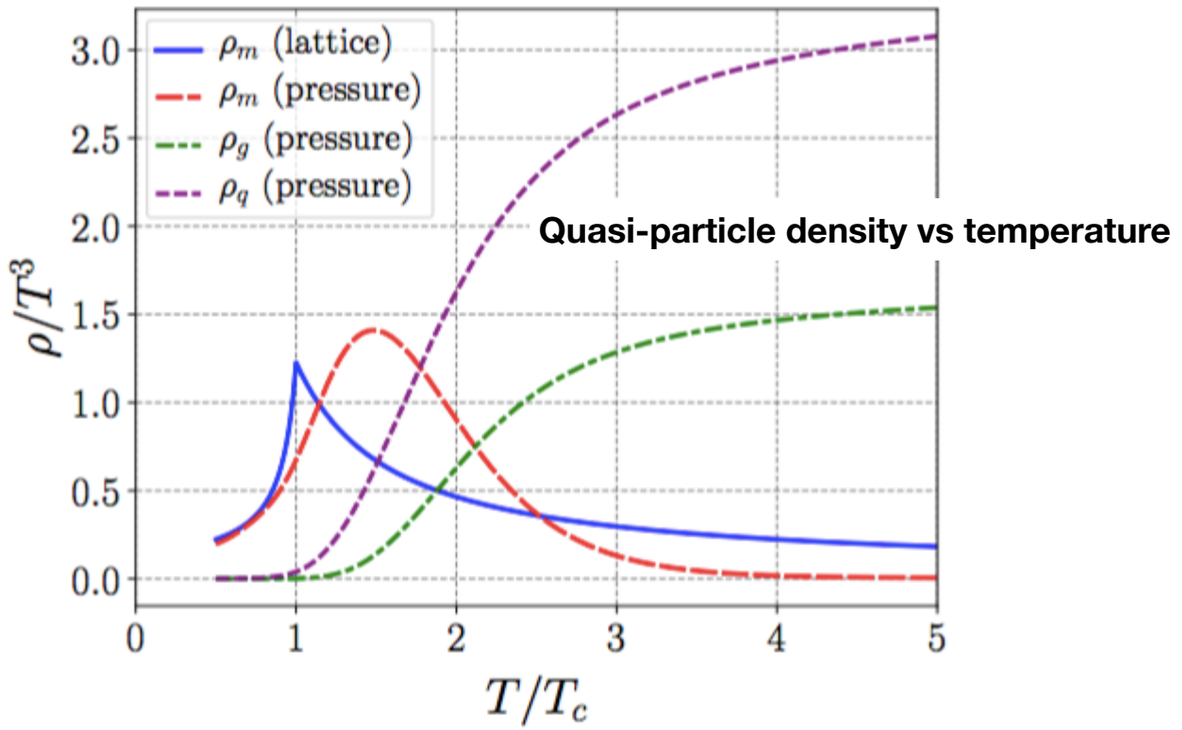
extra slides

Complementarity of RHIC and LHC

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



A. Ramamurti, E. Shuryak, Phys. Rev. D 97, 016010 (2018)

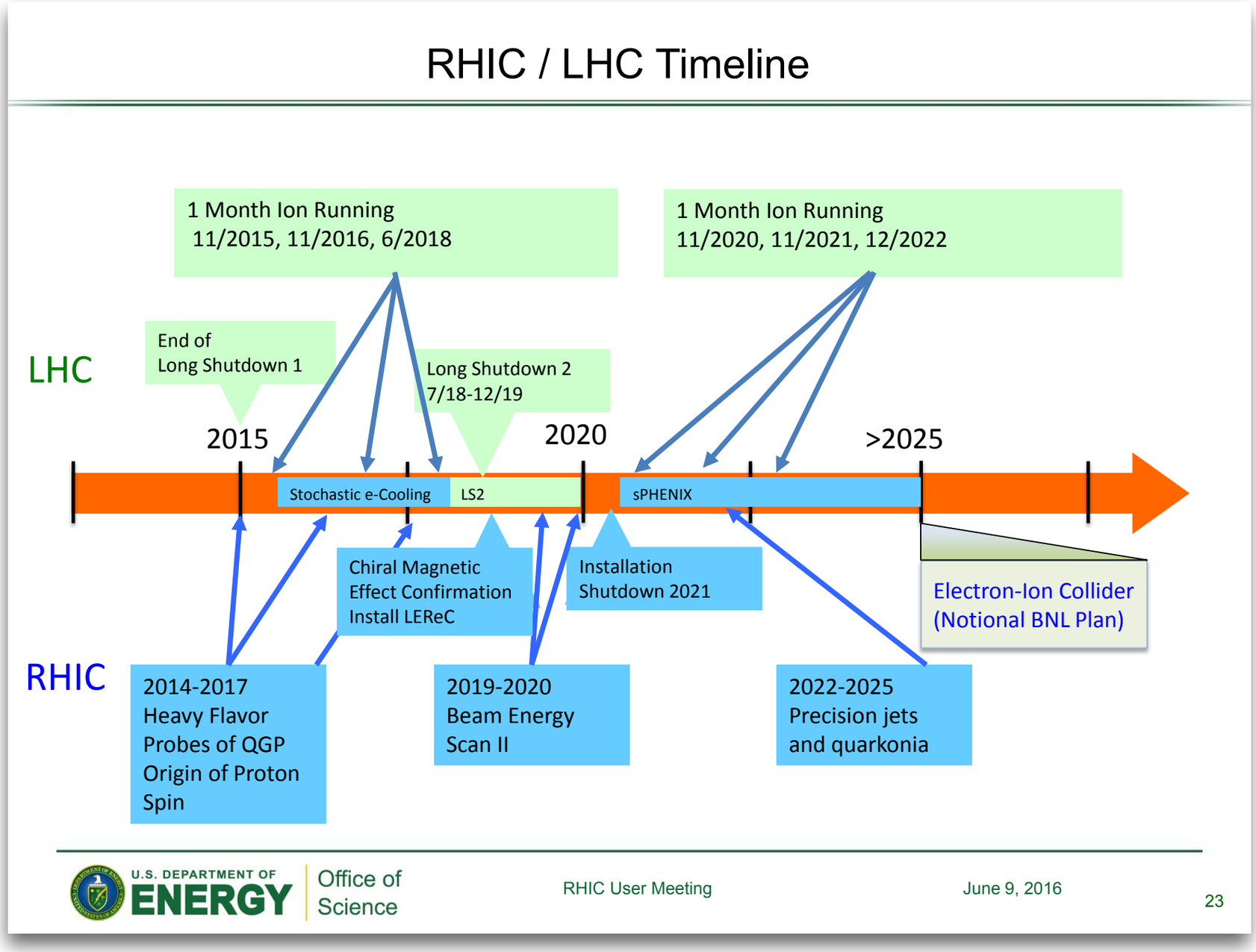


Initial QGP conditions and QGP evolution are different at RHIC vs LHC

Structure of QGP is temperature dependent

RHIC QGP spends significant time near T_c

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



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

A comment from CD-1/3A review closeout

Due to the limited EMCal eta coverage after de-scoping, the jet acceptance/fiducial region will be restricted. For one of the premier detector in Ion Physics in the next decade this does not appear a wise choice. We invite the collaboration to pursue every means to extend EMCal to the full HCal eta coverage to insure full depth for jets studies. This decision must be made in a timely fashion because it becomes irreversible once full commitment to sector assembly is made.

Continues ~~six~~ eight-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)

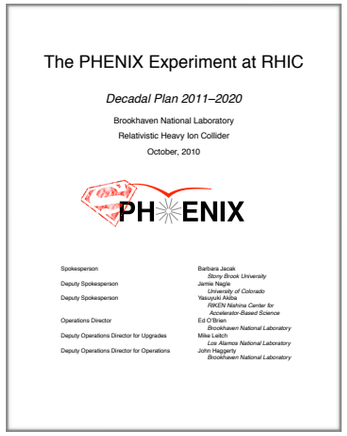
DOE Science Review: July 2014

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

(from 2016 PAC presentation)

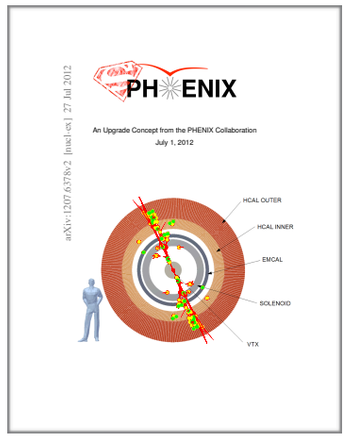

The PHENIX Experiment at RHIC

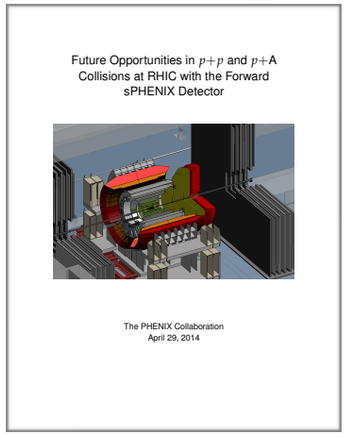
Decadal Plan 2011–2020

Brookhaven National Laboratory
Relativistic Heavy Ion Collider
October, 2010

PHENIX

Spokesperson — Barbara Jacak, *Stony Brook University*
Deputy Spokesperson — Jamie Nagle, *University of Colorado*
Deputy Spokesperson — Yasuyuki Akiba, *RIKEN Nishina Center for Accelerator-Based Science*
Operations Director — Ed O'Brien, *Brookhaven National Laboratory*
Deputy Operations Director for Upgrades — Mike Leitch, *Los Alamos National Laboratory*
Deputy Operations Director for Operations — John Haggerty, *Brookhaven National Laboratory*




Future Opportunities in $p+p$ and $p+$A Collisions at RHIC with the Forward sPHENIX Detector

The PHENIX Collaboration
April 29, 2014