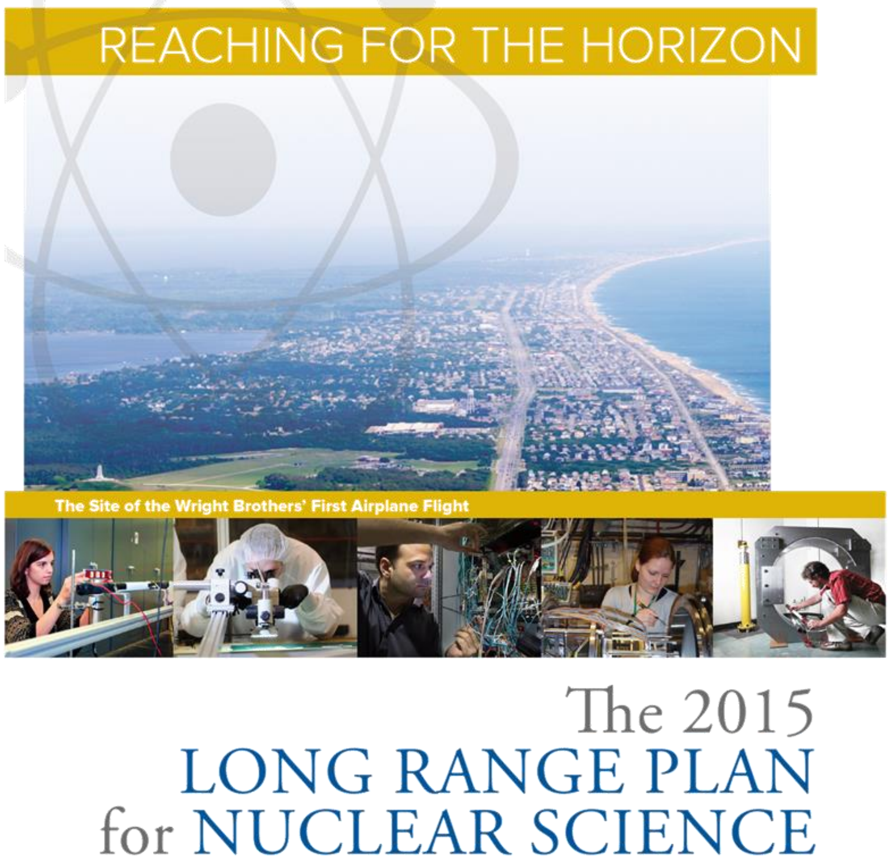
Jets and heavy flavor with sPHENIX

Outline ● Physics Driver ● Performance Projection ● Detector highlights ● Collaboration News

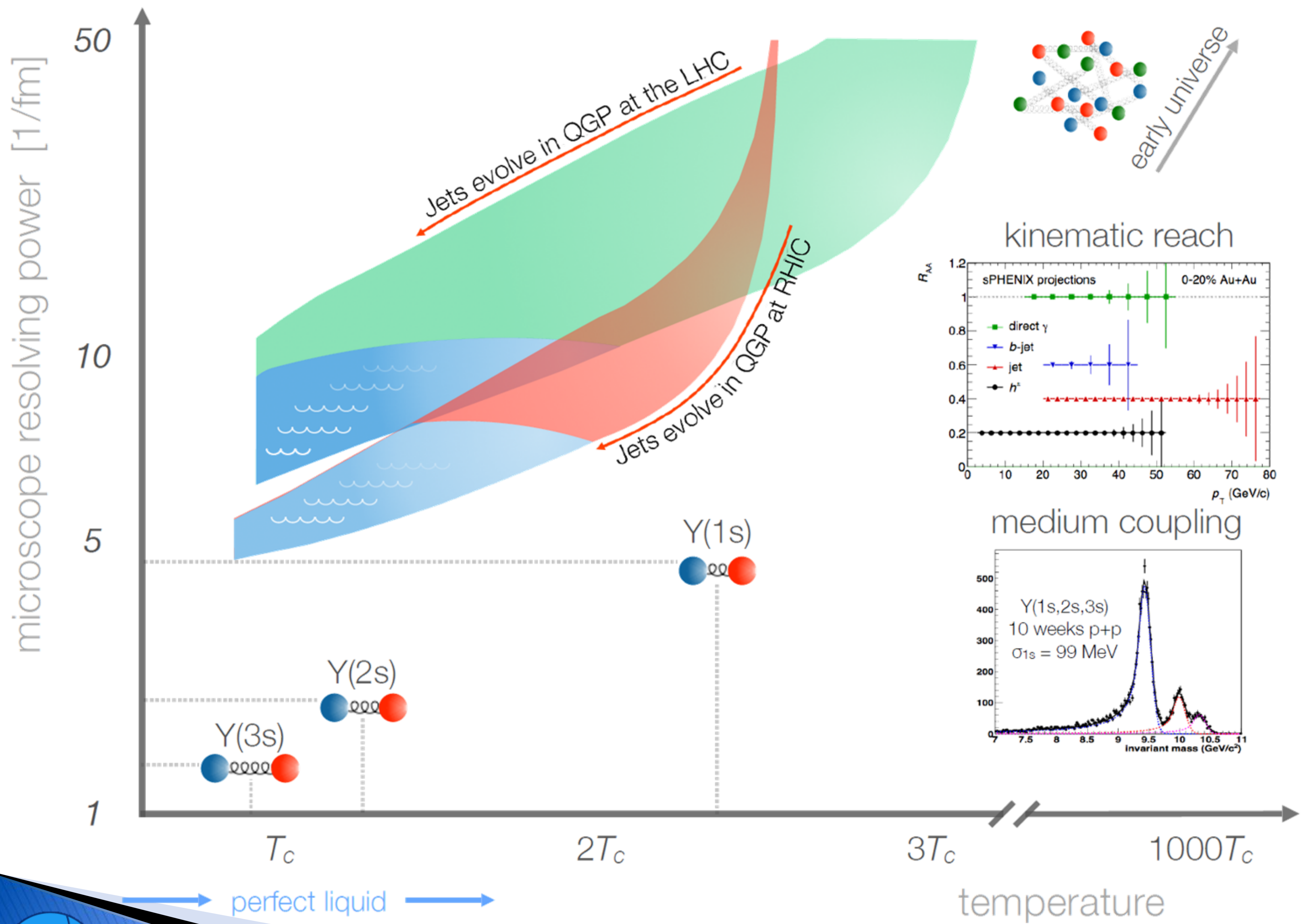
Jin Huang

For the sPHENIX Collaboration

Meeting the grand challenge



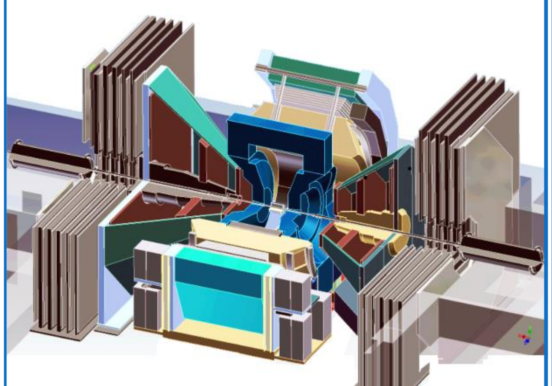
"To understand the workings of the QGP, there is no substitute for microscopy. We know that if we had a sufficiently powerful microscope that could resolve the structure of QGP on length scales, say a thousand times smaller than the size of a proton, what we would see are quarks and gluons interacting 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."**


50
10
5
1
microscope resolving power [1/fm]
Jets evolve in QGP at the LHC
Jets evolve in QGP at RHIC
early universe
kinematic reach
sPHENIX projections
0-20% Au+Au
direct γ
b-jet
jet
$h^{\pm}$
R_{AA}
p_T (GeV/c)
medium coupling
Y(1s,2s,3s)
10 weeks p+p
σ_{1s} = 99 MeV
invariant mass (GeV/c²)
Υ(1s)
Υ(2s)
Υ(3s)
T_c
$2T_c$
$3T_c$
$1000T_c$
perfect liquid
temperature

Evolution of the PHENIX Interaction region

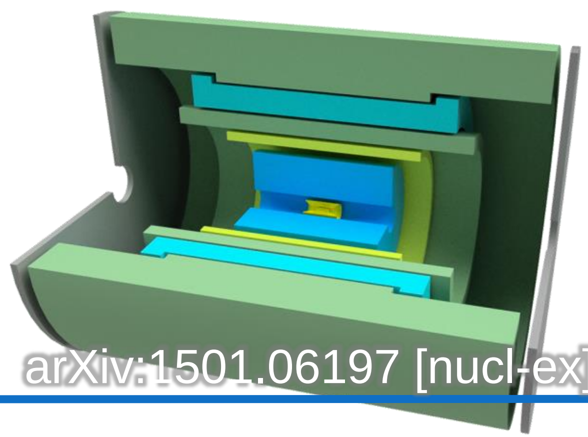
PHENIX experiment

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



sPHENIX

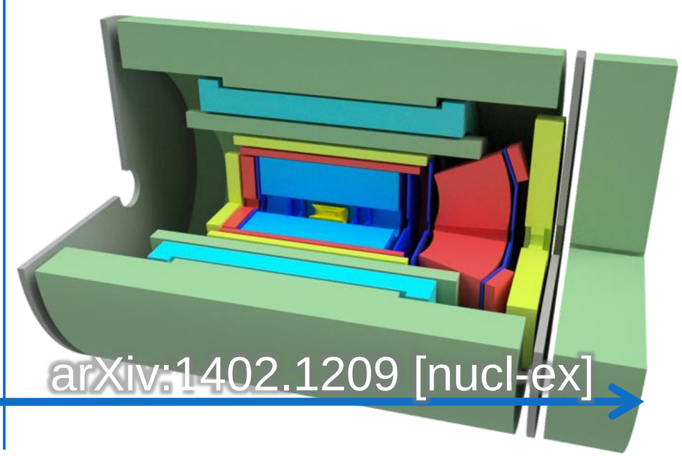
- Comprehensive central upgrade base on BaBar magnet
- Rich jet and HF physics program
  → nature of QGP
- Possible forward tracking, and calorimeter → Spin, CNM



arXiv:1501.06197 [nucl-ex]

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



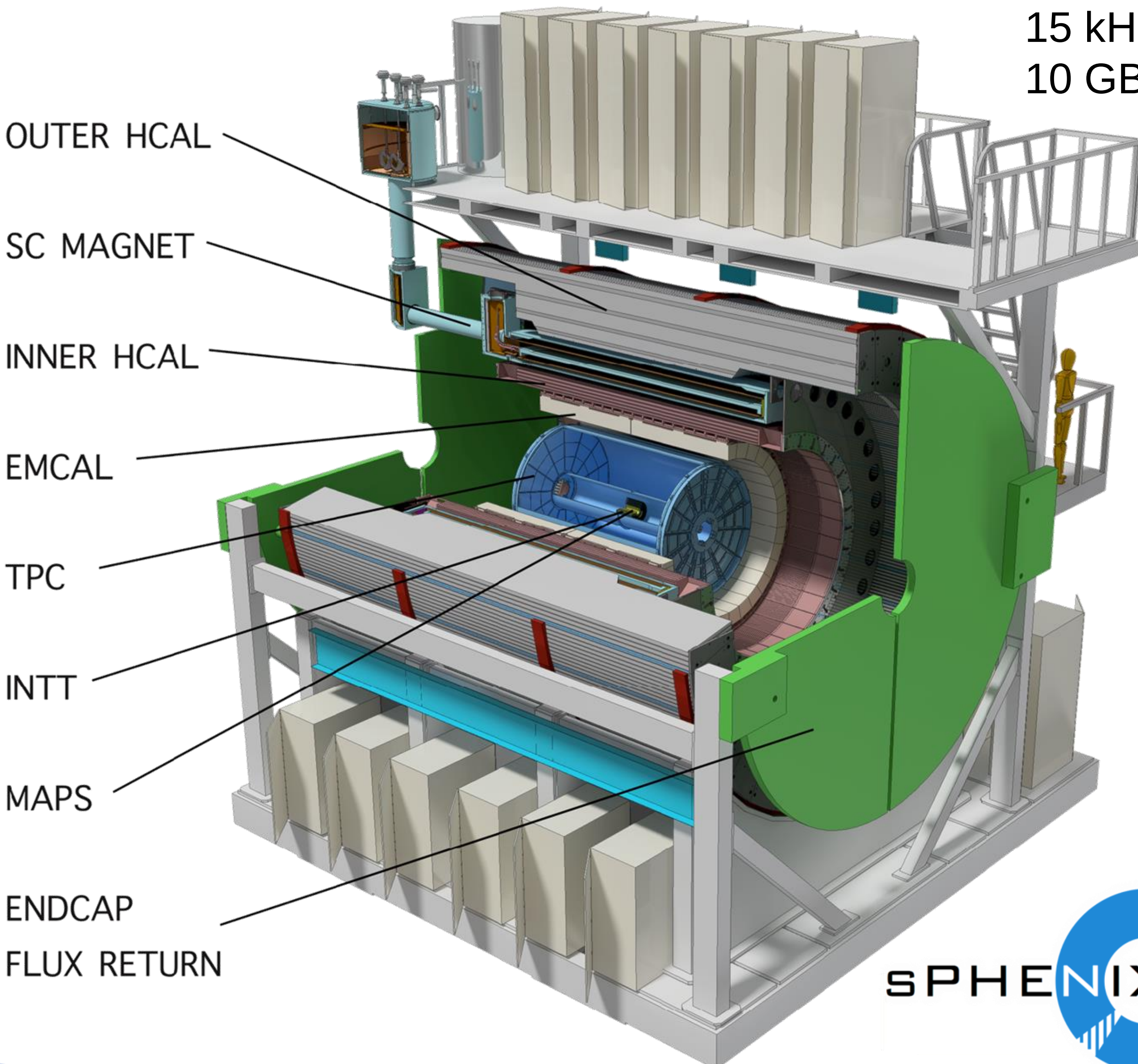
arXiv:1402.1209 [nucl-ex]

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

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

EIC: e+p, e+A

15 kHz MB trigger
10 GB/s data logging



sPHENIX Detector

CD-0	**Sept 2016**
CD-1 review	**May 2018**
Installation complete	**2022**

Possible 5-year run plan for sPHENIX baseline

Multi-year run plan scenario for sPHENIX

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
2022	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
2023	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
2023	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
2024	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
2025	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
2026	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
- Incorporates updated C-AD guidance now officially documented
- Run plan relates to capabilities of full barrel detector
- Incorporates commissioning time in first year

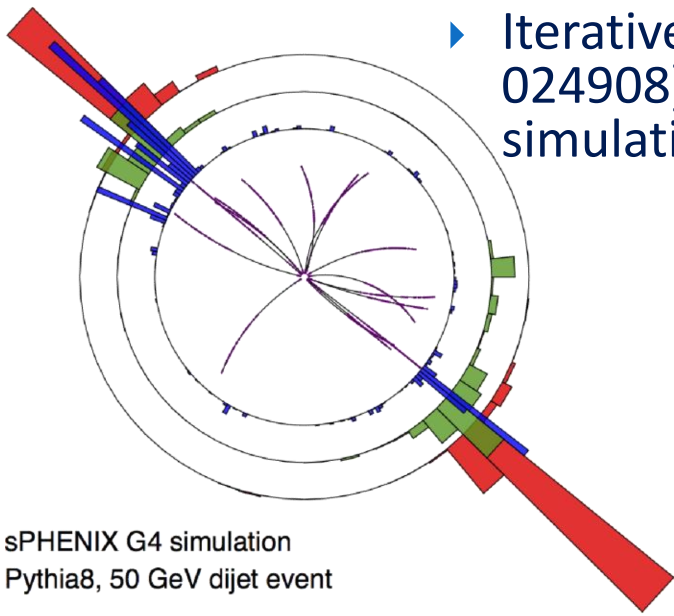
Minimum bias Au+Au at 15 kHz for |z| < 10 cm:
47 billion (2022) + 96 billion (2024) + 96 billion (2026) = Total 239 billion events

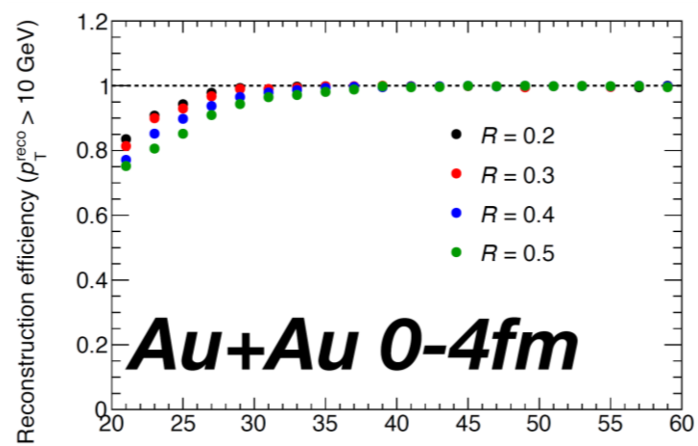
For topics with Level-1 selective trigger (e.g. high p_T photons), one can sample within |z| < 10 cm a total of 550 billion events. One could consider sampling events over a wider z-vertex for calorimeter only measurements, 1.5 trillion events.

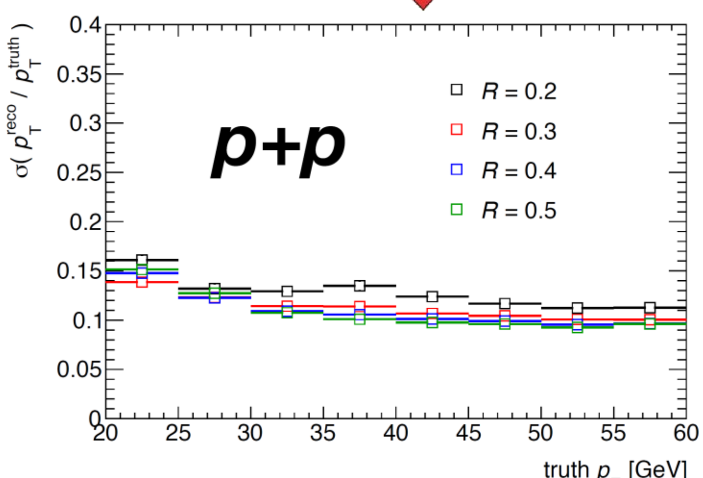
Presented at the PAC Meeting 6/15/17 by D. Morrison

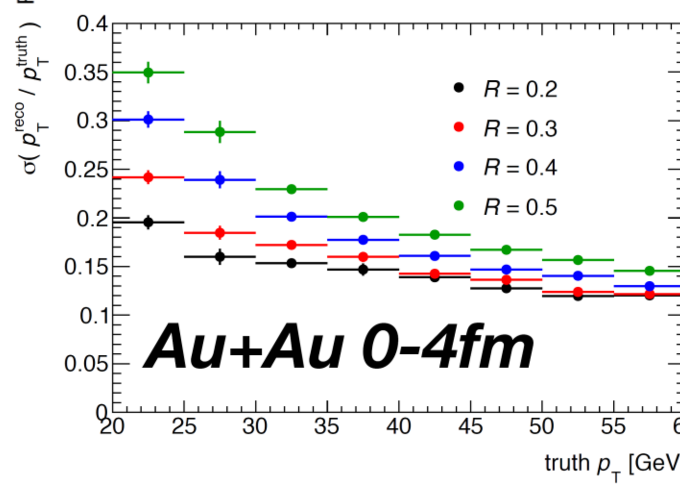
sPHENIX: calorimetry jet at RHIC

- Calorimetric triggering and measurement of jets
- Minimum bias to jet flavor and FF
- Iterative background subtraction [PRC 86 (2012) 024908] demonstrated in sPHENIX full event simulations



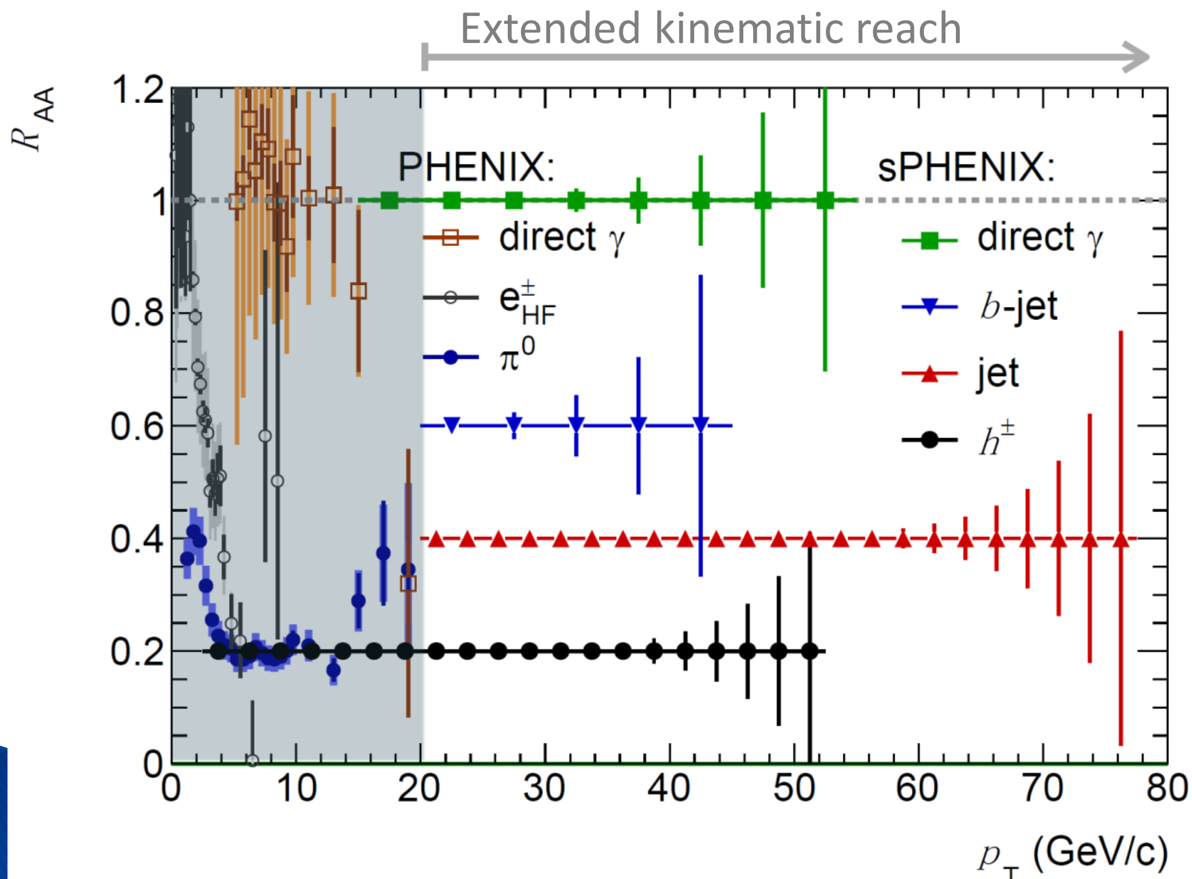


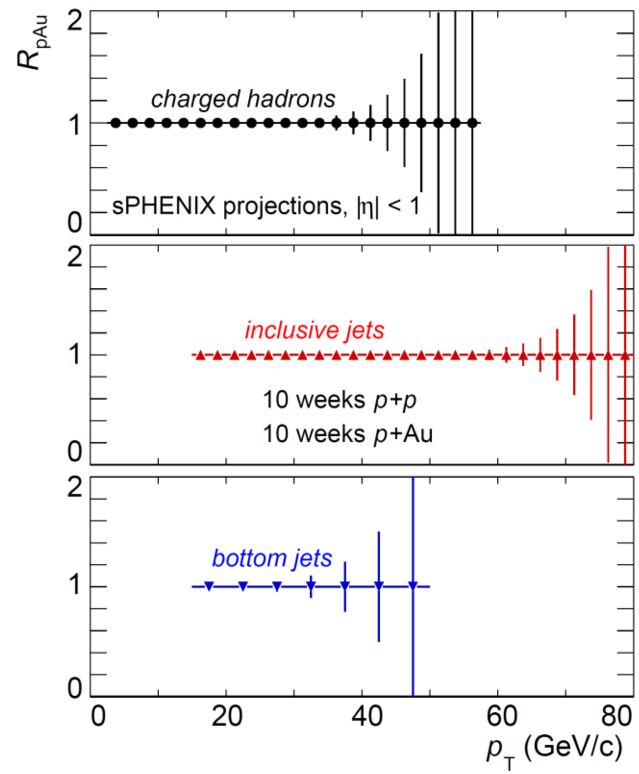




High statistics hard probes

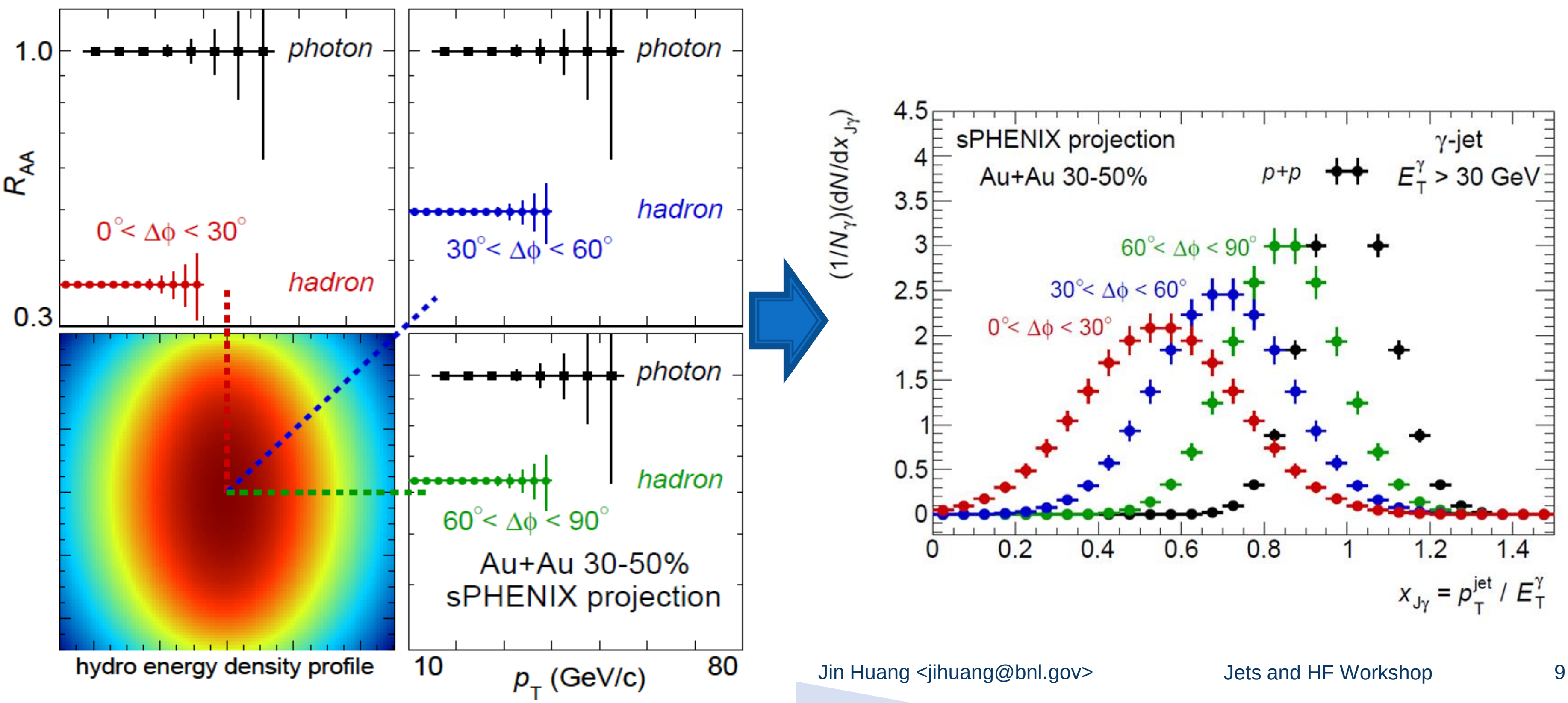
High statistics data represents large extend in hard probes in jets, photon and hadrons



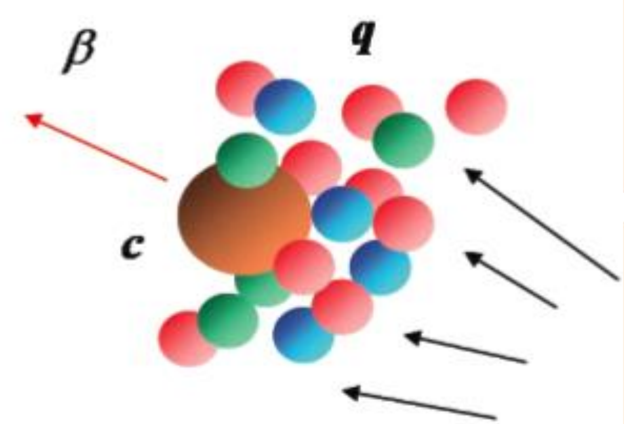


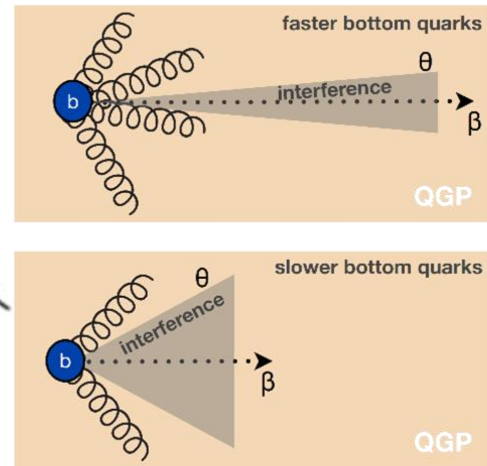
More differential measurement

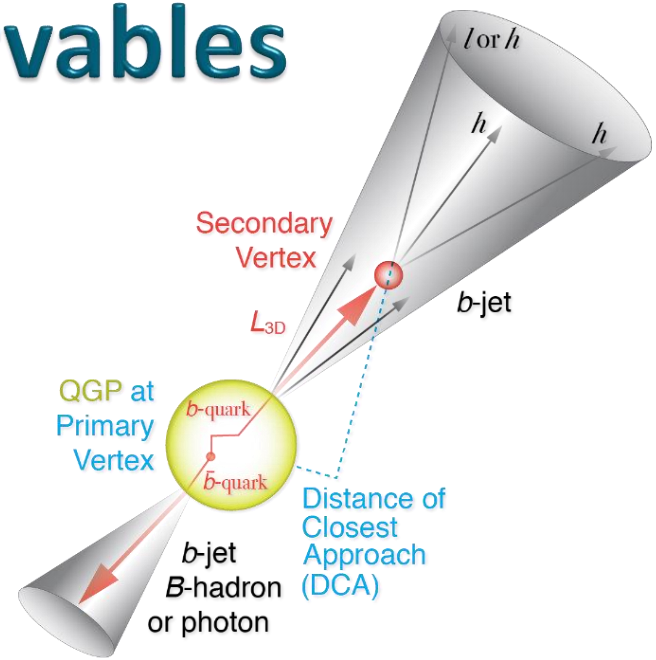
- High statistics also allows more differential measurements
- For example, path-length dependent studies via γ-jet transverse balance in correlation with event plane



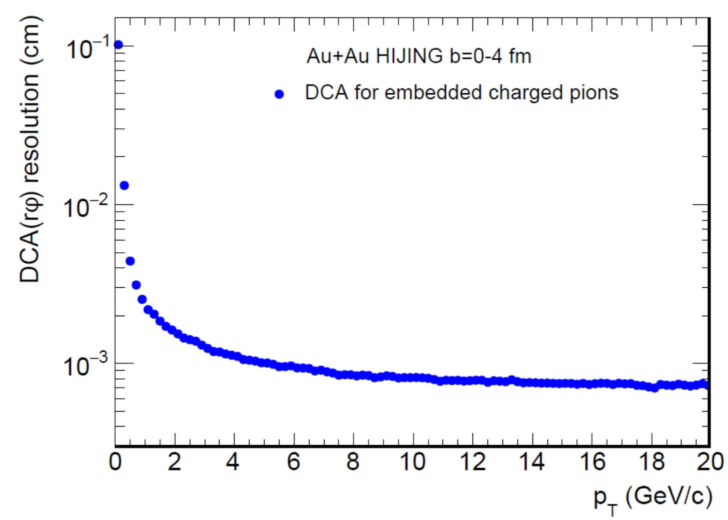
Open heavy flavor observables





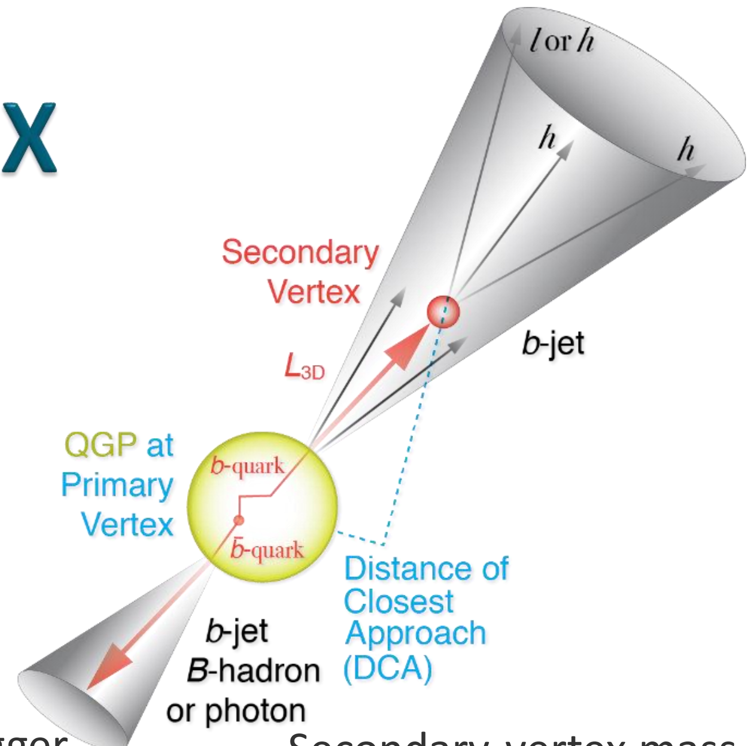


- Precision vertex tracker + High rate → Precision bottom observables
- *B*-meson @ Low p_T : diffusion of HF quark in QGP
- *b*-jet @ Higher p_T: differentiate collision VS radiative energy loss

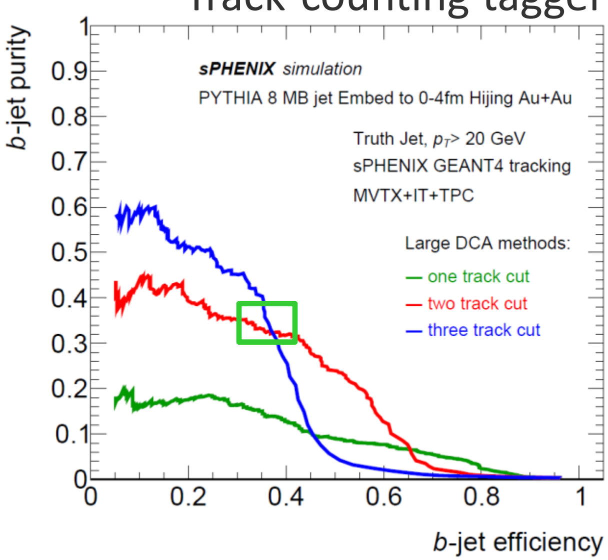


b-jet tagging @ sPHENIX

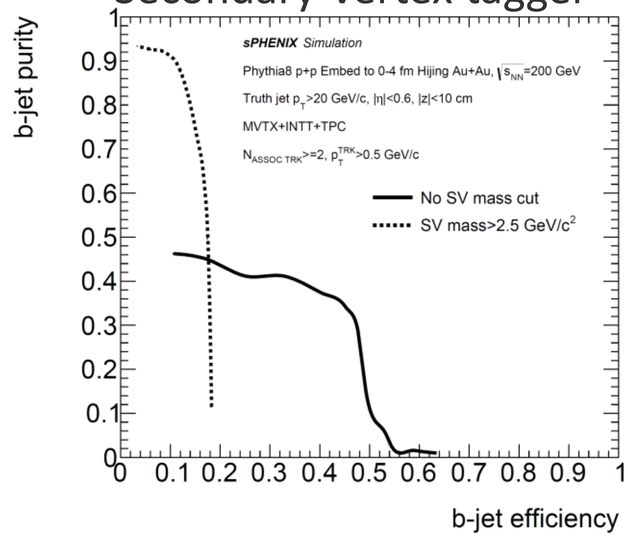
- Demonstrate b-jet capability: tagging algorithms evaluated using full detector HI simulation
- Reaching a promising working point in central Au+Au collisions



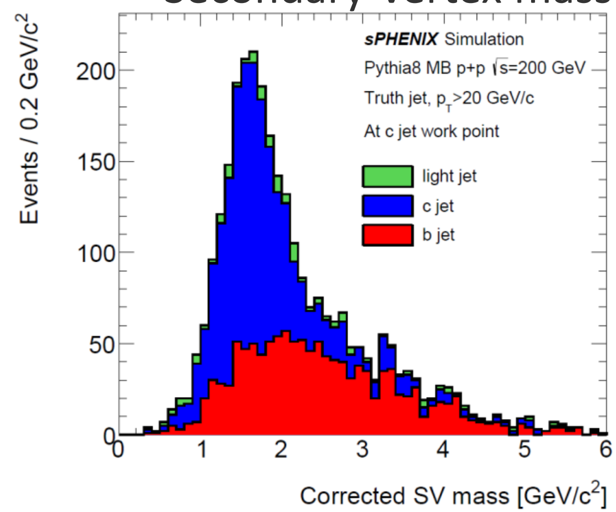
Track-counting tagger



Secondary-vertex tagger

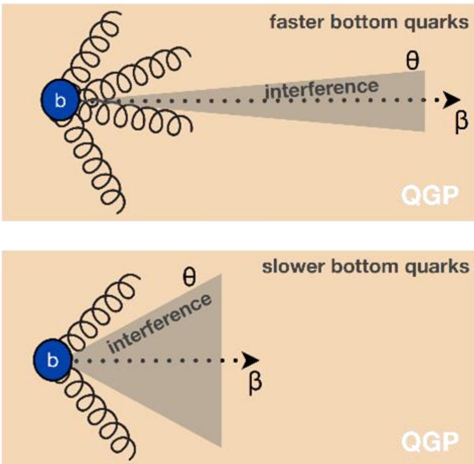


Secondary-vertex mass

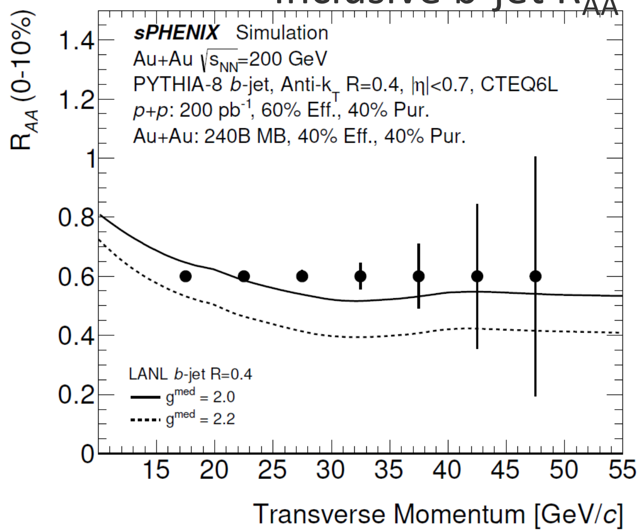


CMS work-point, Phys. Rev. Lett. 113, 132301 (2014)

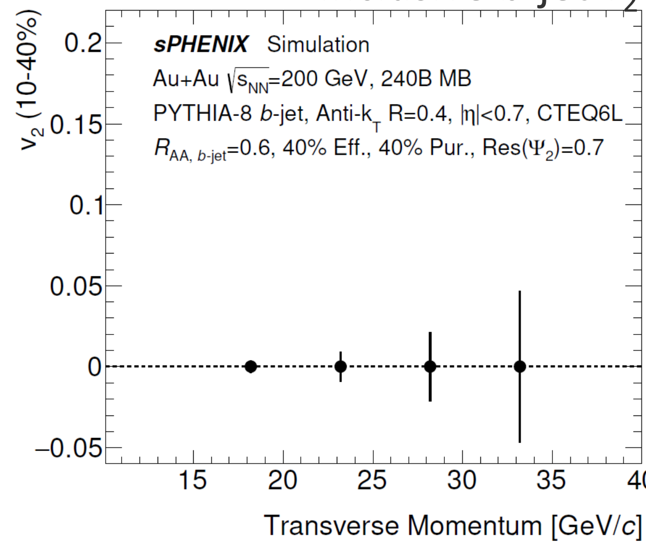
b-jet projection



Inclusive b-jet R_{AA}

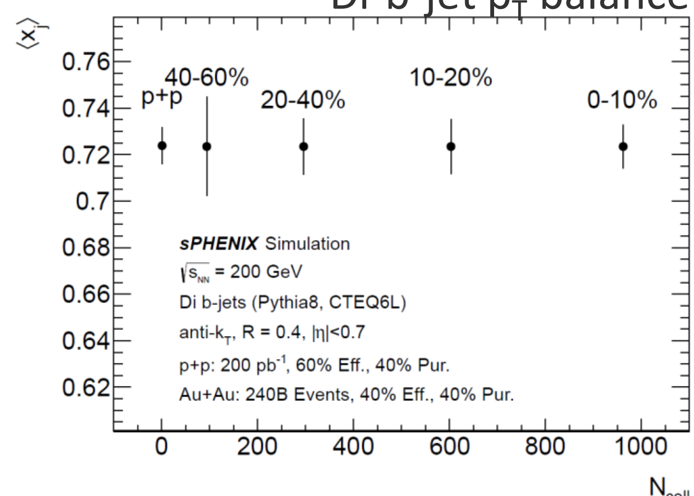


Inclusive b-jet v_2



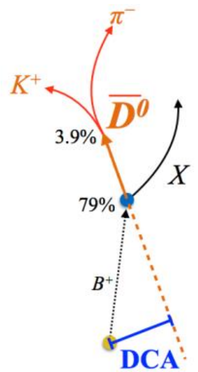
- Bring inclusive b-jet suppression and v_2 to RHIC
  - Covering jet p_T = 15-35 GeV/c
  - Strong constraints of high energy probe in QGP
- Broader opportunities on more differentiating observables
  - Di-*b*-jet and *b*-jet-*B*-meson correlations
  - *b*-jet substructures

Di-b-jet p_T balance

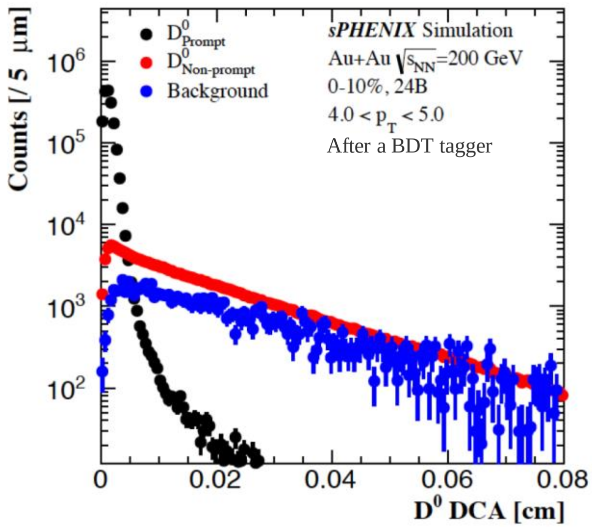


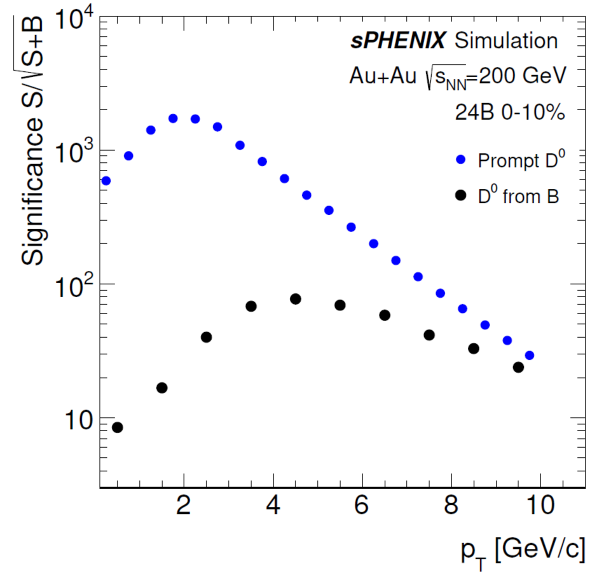
Precision open bottom meson

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



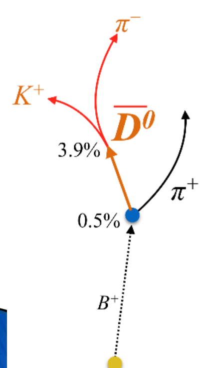
Prompt and non-prompt D-meson

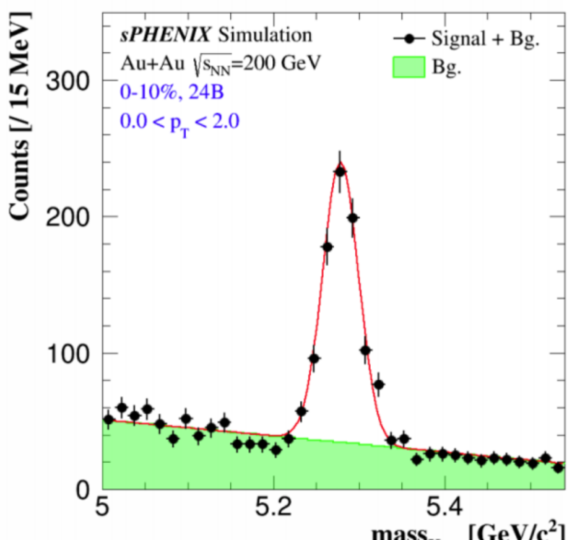




Exclusive $B^{\pm}$

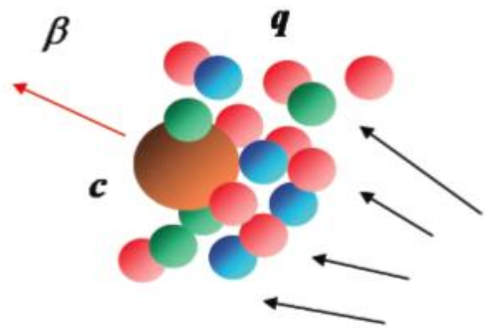
$B^+ \rightarrow \overline{D}^0 \pi^+$



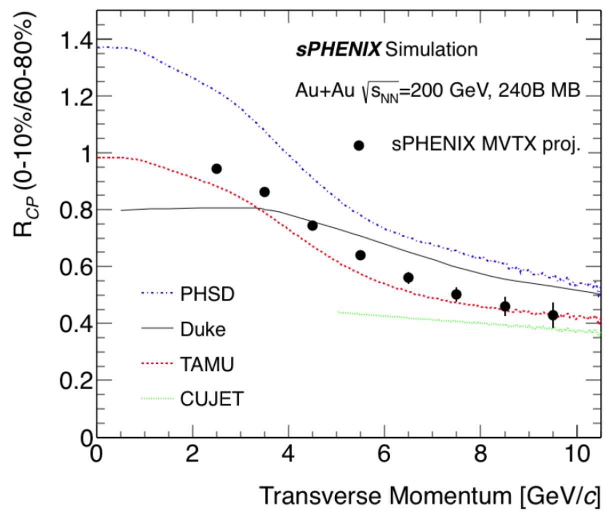


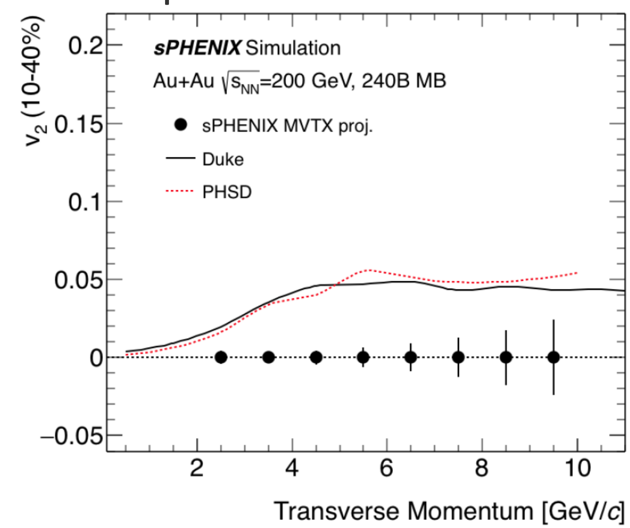
- 240 MB Au+Au collisions and high precision tracking allow accumulate high significance of HF-meson signals
- Measuring high statistics *B* meson via non-prompt D decay channel
- Exclusive *B* reconstruction too!

B-meson projections



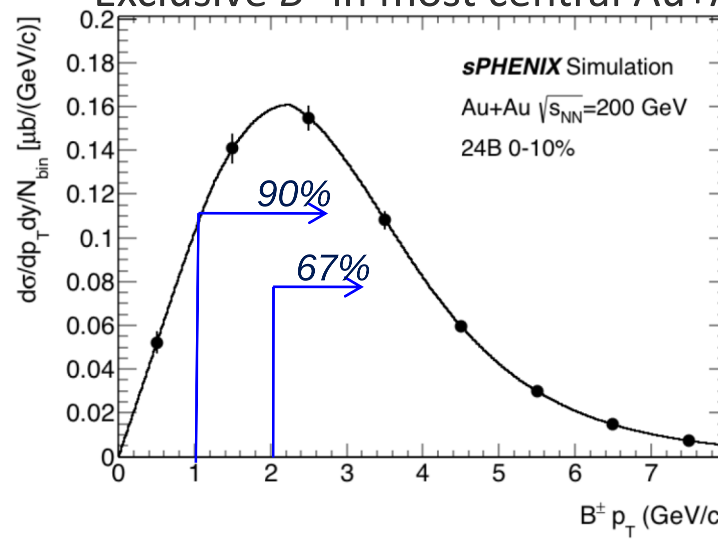
non-prompt *D*-meson and predictions for sPHENIX



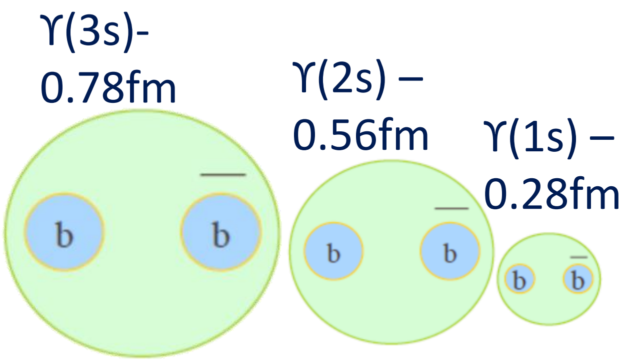


- Bring high precision non-prompt-*D* suppression and flow to RHIC
- Determine the bottom quark collectivity → clean access to D_{HQ} at RHIC energy
- Broader program:
  - Total *b*-cross section for Upsilon program
  - Charm chemistry and HF hadronization
  - *D* fragmentation function with Jets

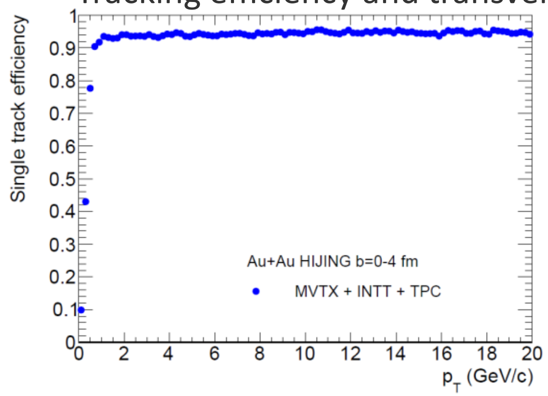
Exclusive $B^{\pm}$ in most central Au+Au

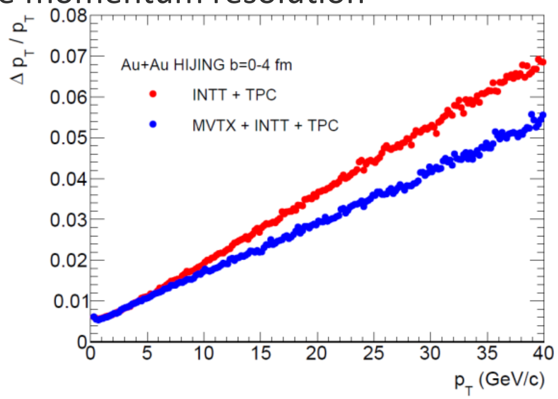


Upsilon spectroscopy

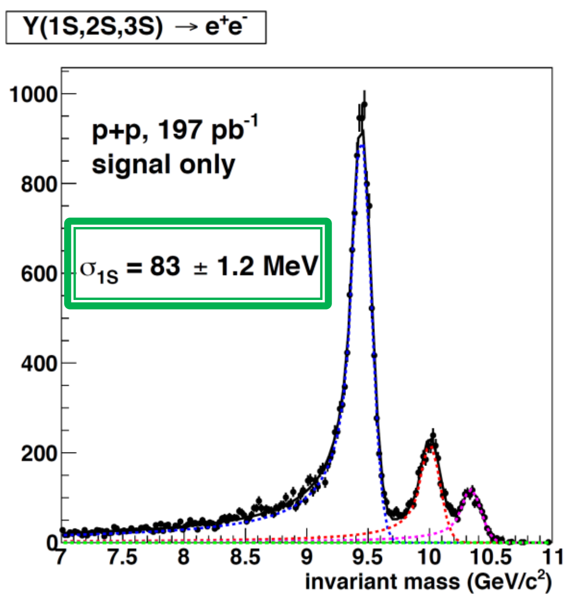


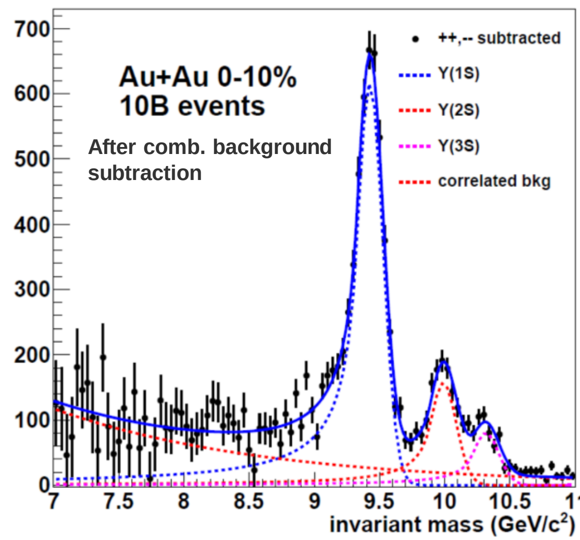
Tracking efficiency and transverse momentum resolution

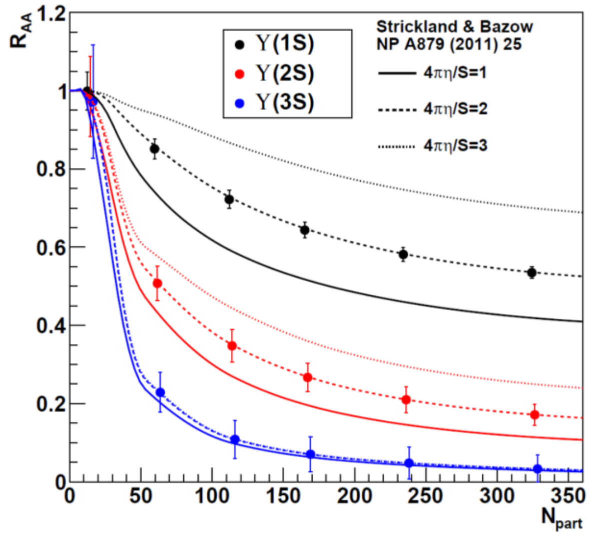




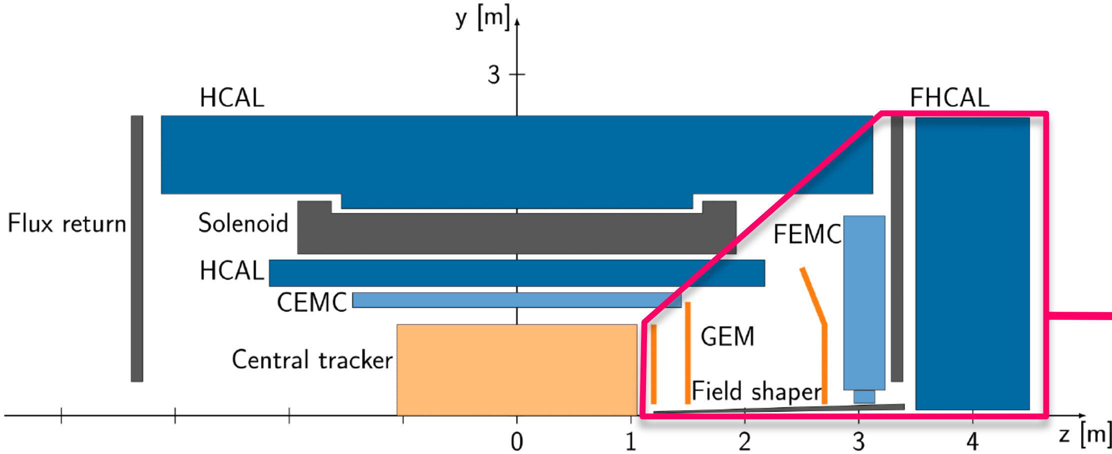
Precision tracking → Separated Upsilon states at RHIC → Probe of the QGP at distinct length scales.

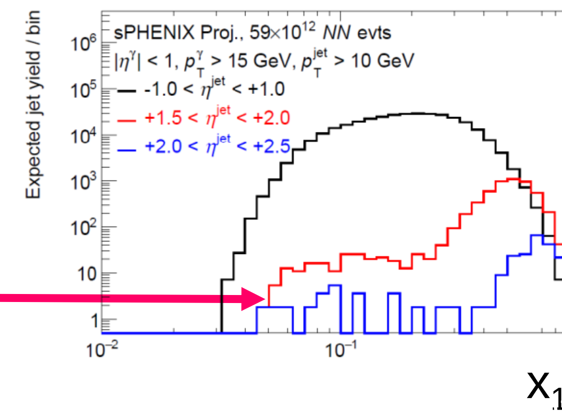


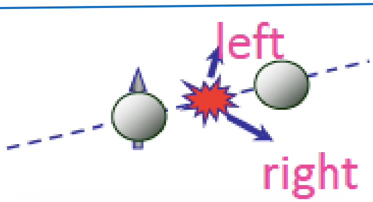


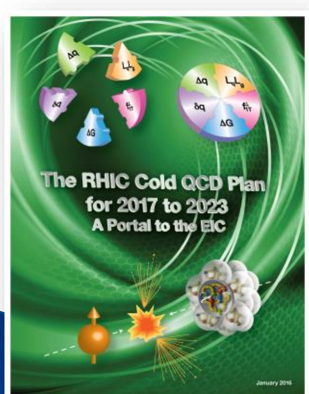


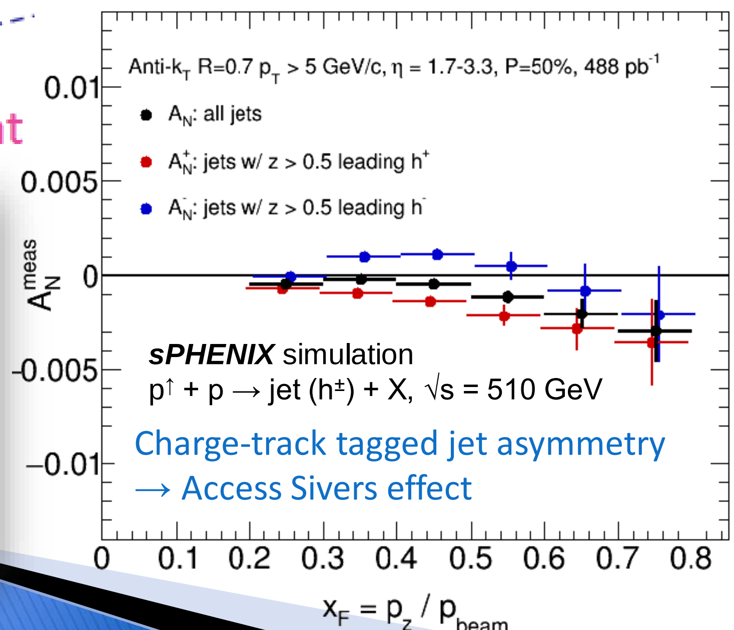
Jets in forward upgrades – Portal to EIC

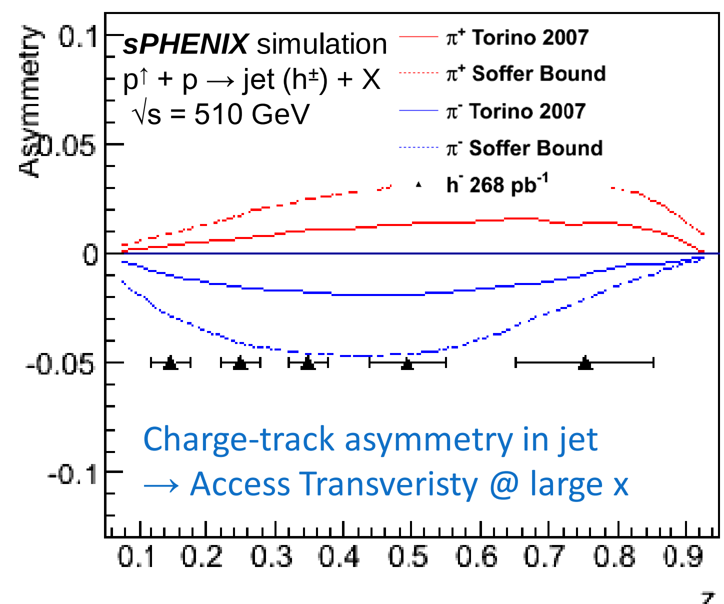


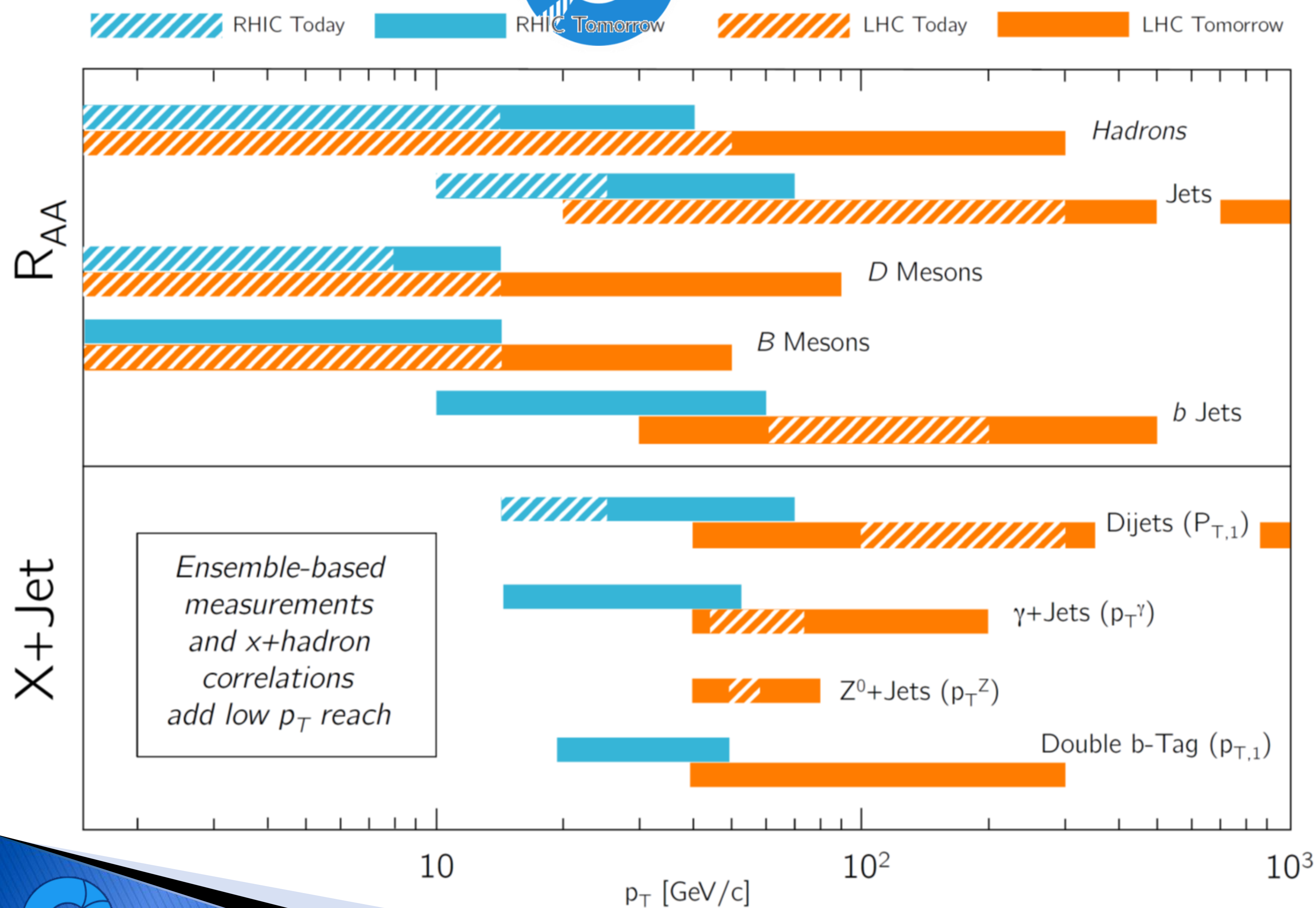




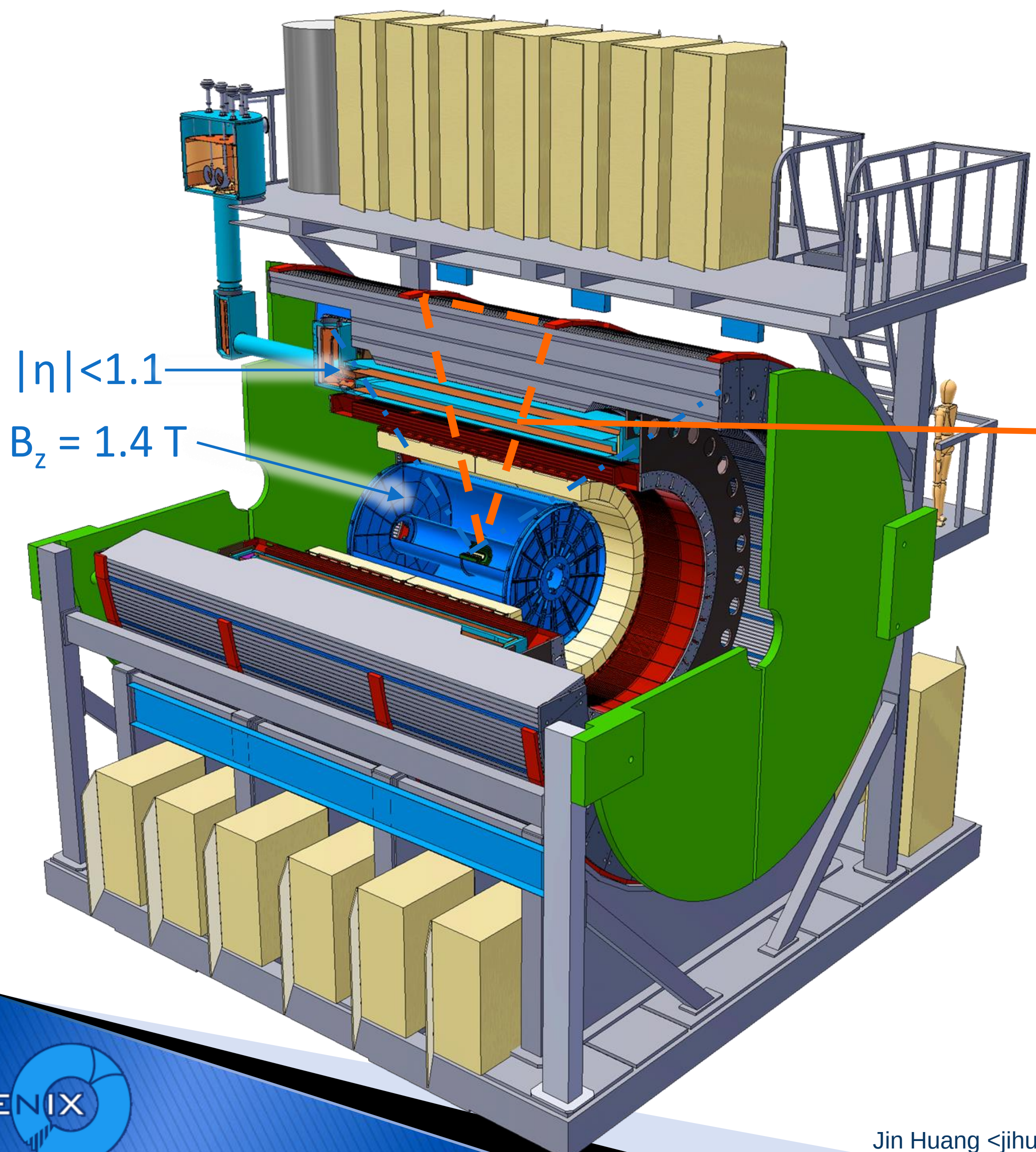


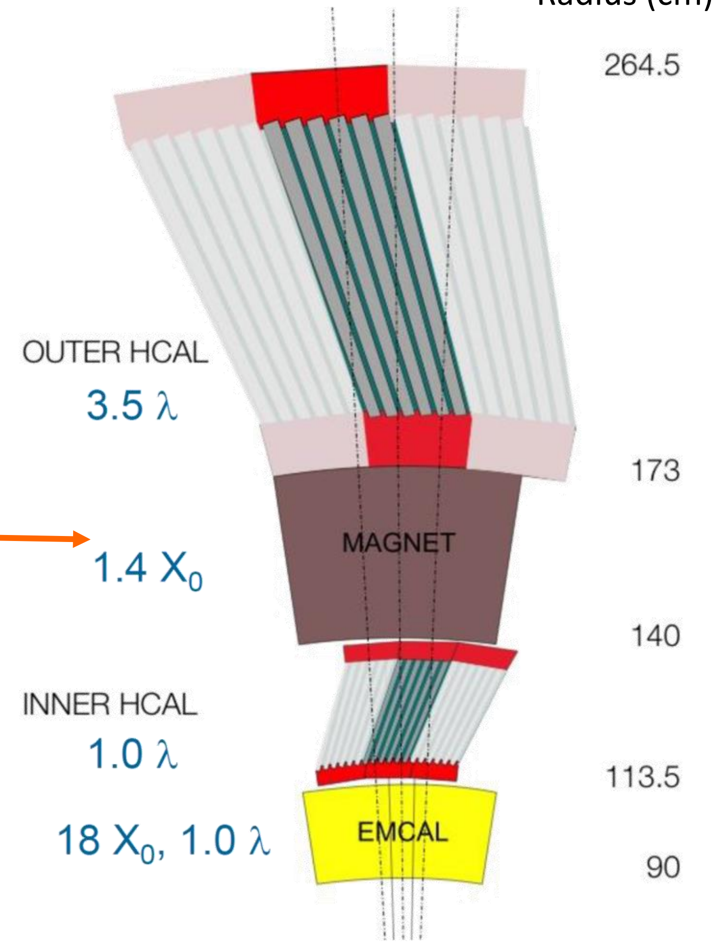


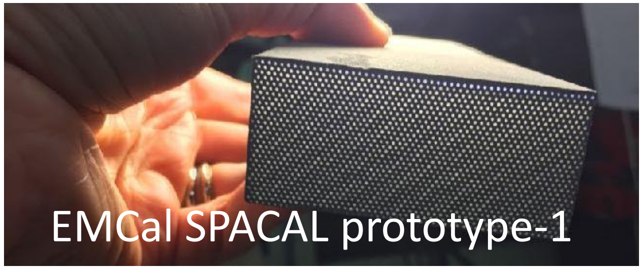



RHIC Today
RHIC Tomorrow
LHC Today
LHC Tomorrow
R_AA
X+Jet
Hadrons
Jets
D Mesons
B Mesons
b Jets
Dijets (P_T,1)
γ+Jets (p_T^γ)
Z^0+Jets (p_T^Z)
Double b-Tag (p_T,1)
Ensemble-based measurements and x+hadron correlations add low p_T reach
10
10^2
10^3
p_T [GeV/c]

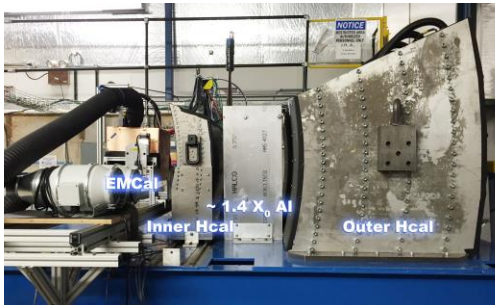
Detector highlights

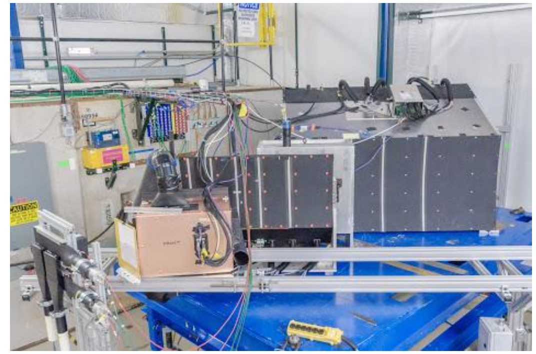


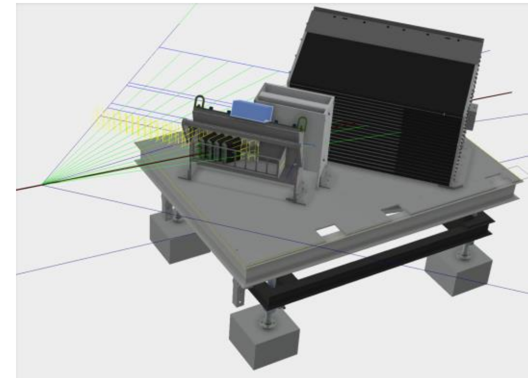




Calorimeters beam tests

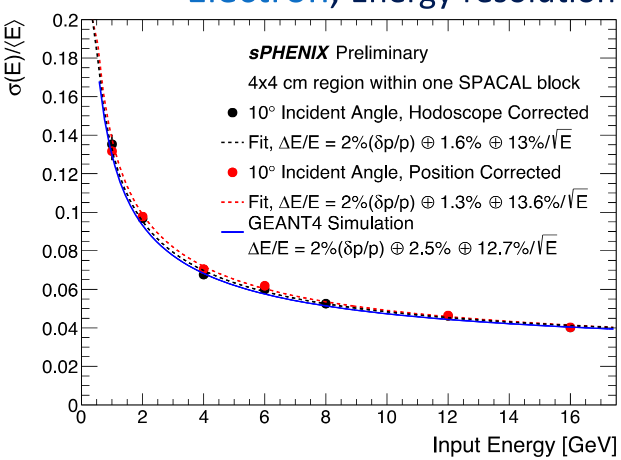




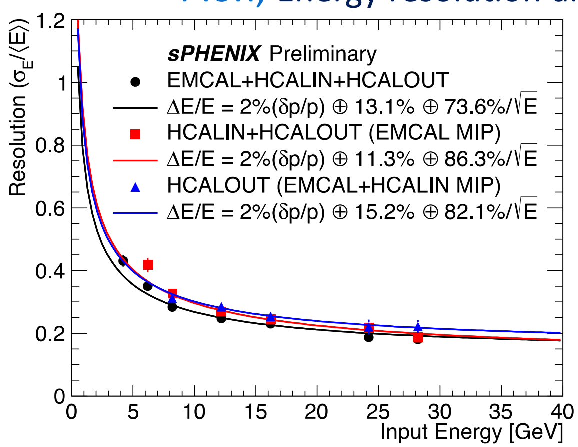


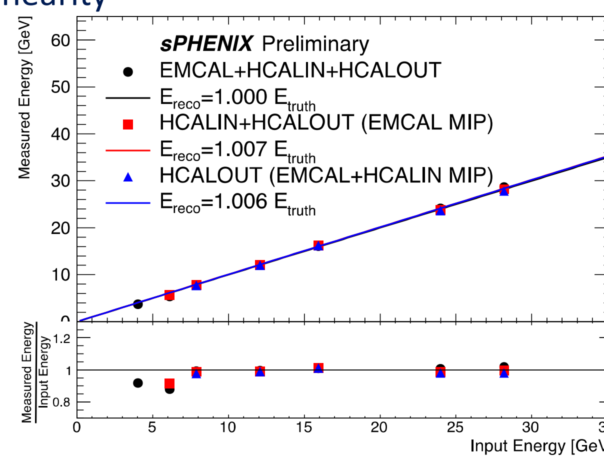
February 2014	February 2016	February 2017	Next Month!
Proof of principle	η~0 prototype	η~0.9 prototype	Final η~0.9 prototype

Electron, Energy resolution



Pion, Energy resolution and linearity

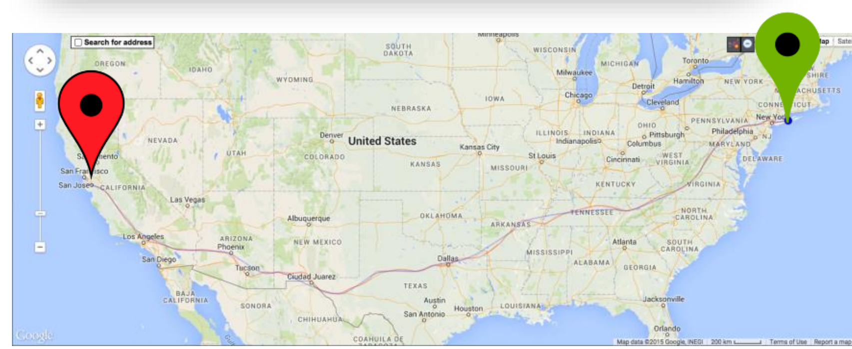




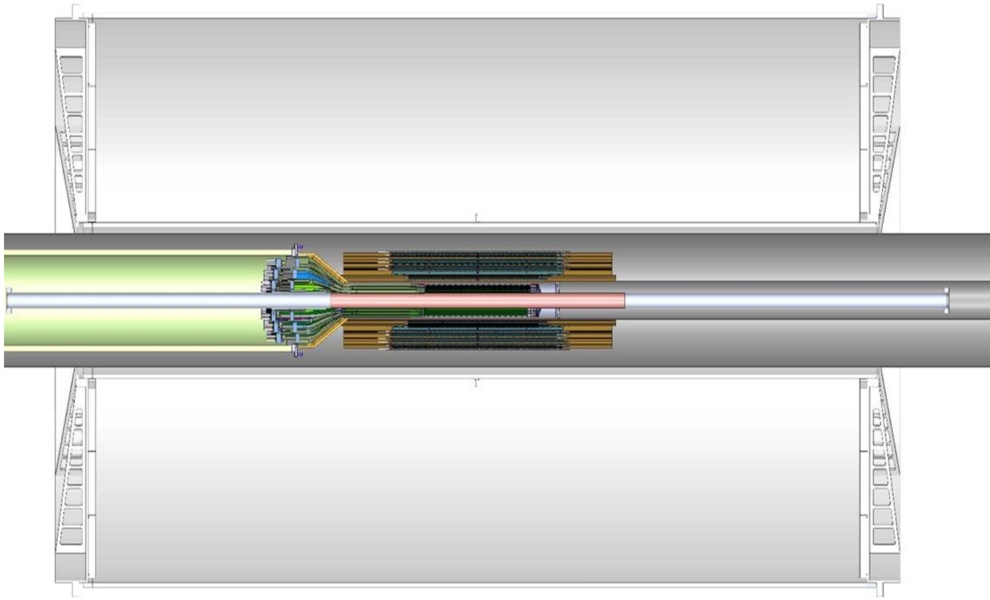
Super conducting magnet

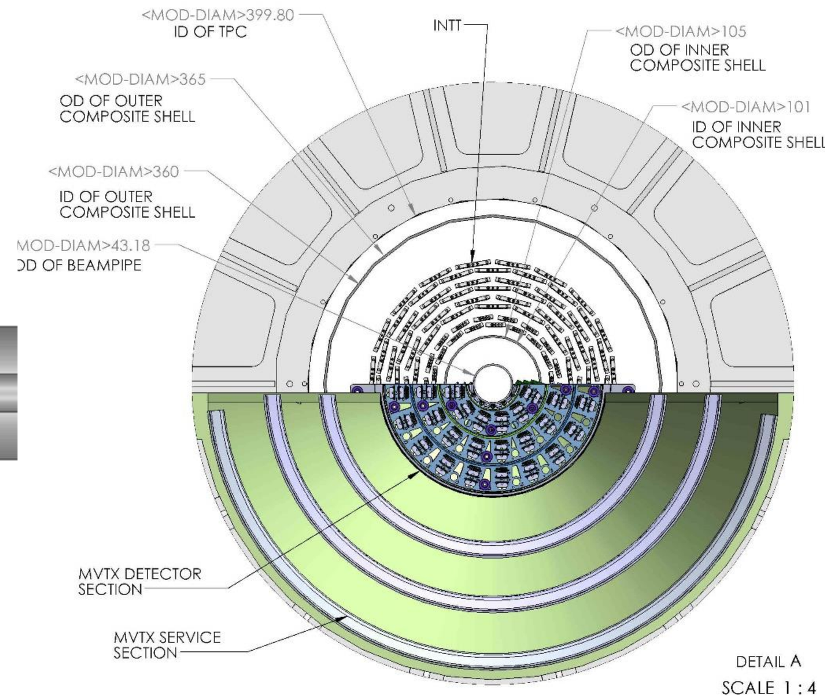
- 1.4 Tesla magnet, Φ = 2.8 m, L = 3.8 m
  Previously used in BaBar @ SLAC
- Moved to BNL in Feb 2015
- Successful cold low field test in 2016
- On-going full field test as we are speaking.


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 detectors





Inner tracking:

- **MVTX**: 30-um-pitch MAPS pixel sensors (3-layer)
  - Precision vertexing
- **INTT**: strip silicon sensors (4-layer)
  - Pattern recognition, timing
- DCA^{π}< 50um for p_T>1 GeV/c, <10 um for p_T>10 GeV/c

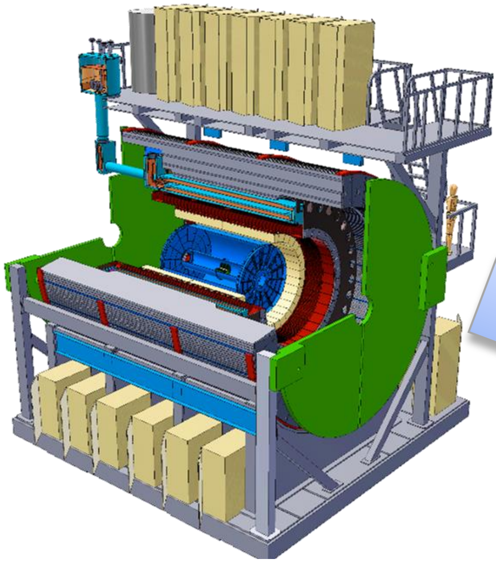
Outer tracking:

- **TPC**: gateless and continuous readout
- Low diffusion, high ion mobility Ne-CF_4 gas + Quad GEM + mini pads
- 1 Tbps DAQ, FPGA-based reduction, 100 Gbps data file rate
- $R\delta\Phi$ < 200 um
- $\delta p/p$ < 2% for p_T<10 GeV/c

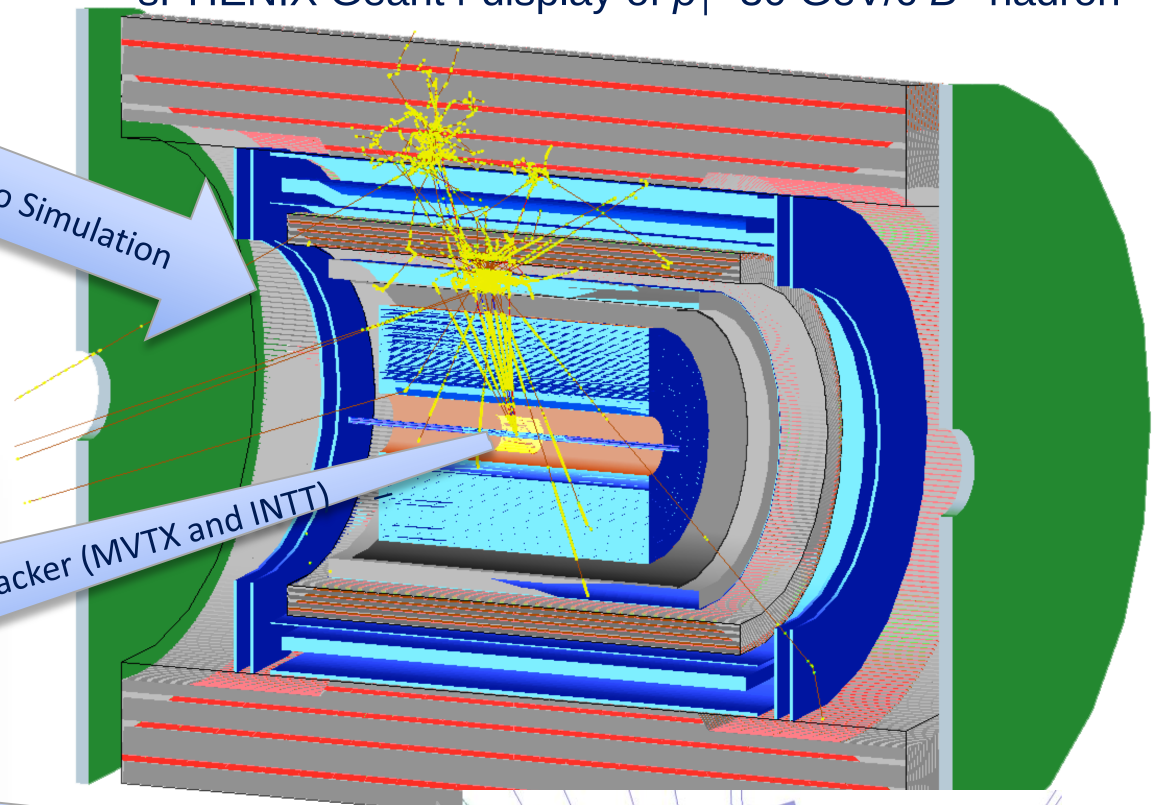
Full detector simulation + reconstruction

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

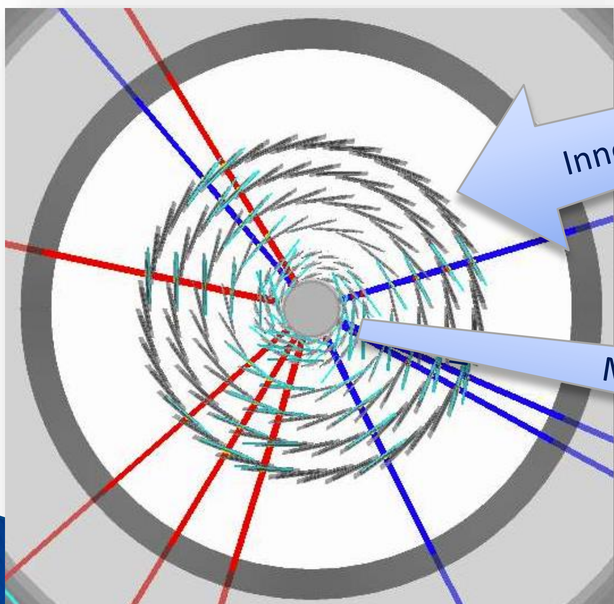
sPHENIX Geant4 display of p_T=30 GeV/c B^+-hadron



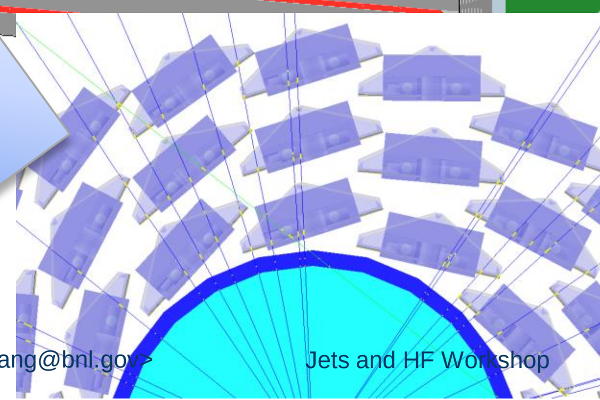
Design to Simulation



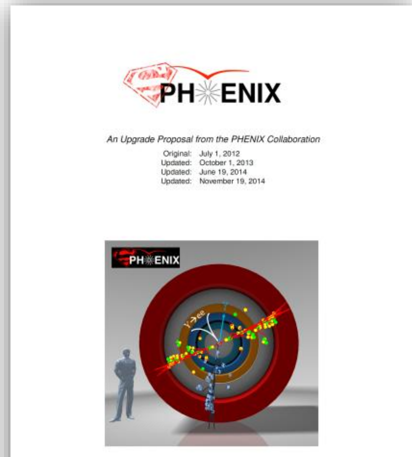
Inner tracker (MVTX and INTT)

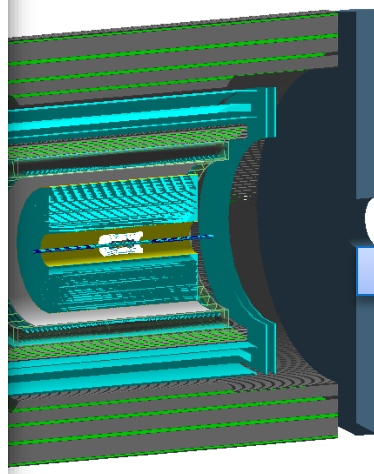


MVTX Ladders modeled in details



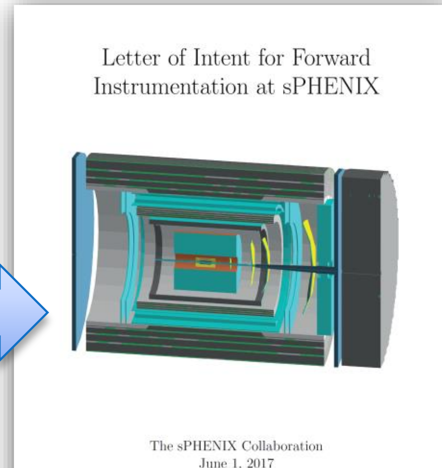
Evolving upgrade concepts

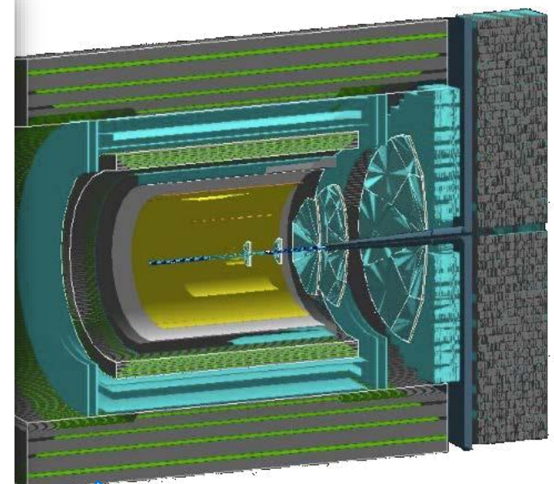




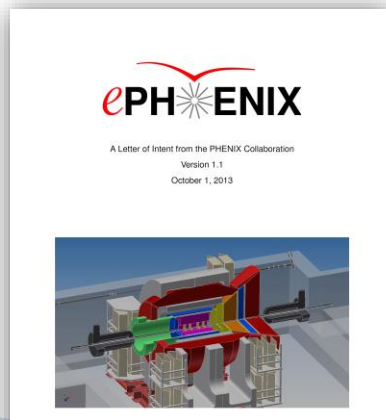
arXiv:1501.06197

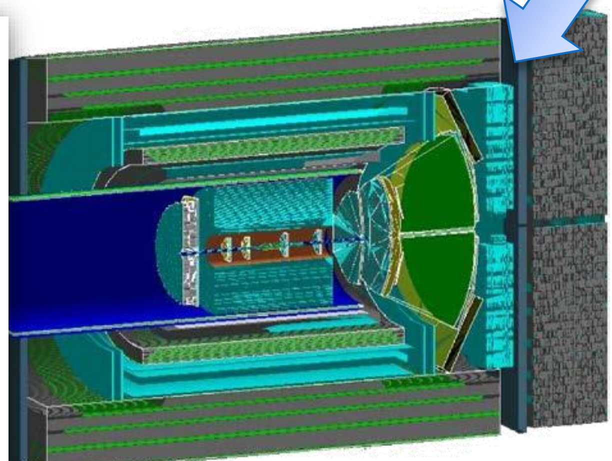
CDR in preparation





To RHIC PAC 2017





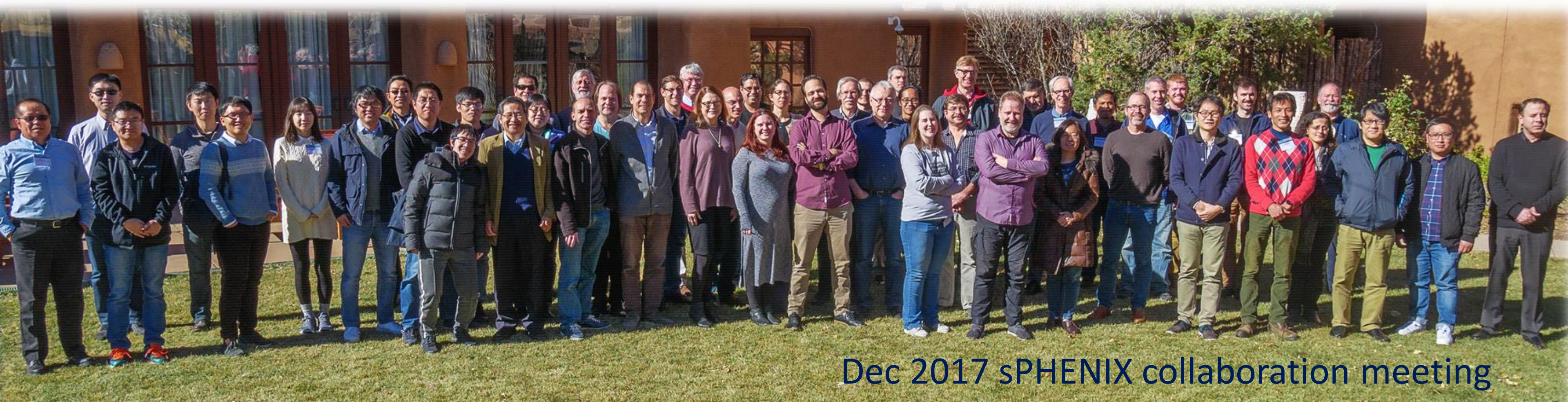
LOI/arXiv:1402.1209

Evolving sPHENIX collaboration

- Established in Dec 2015
- ~70 institutions and growing
- Most recent: 7 Chinese institution joined in Dec 2017 as consortium with interesting of construction and analysis

Summary

- Rich physics cases
  - Precision jet and HF @ RHIC, probes inner working of QGP when combined with LHC
  - Predictions on sPHENIX observables welcomed!
  - Completing scientific RHIC mission and connect to EIC
- Advanced design and many progress in detector R&D
  - CD-0 approved, in preparation for CD-1.
  - Planned data taking start 2023
- Growing collaboration
  - ~70 institutions with 9 new in the past year
  - Abundant opportunities to contribute



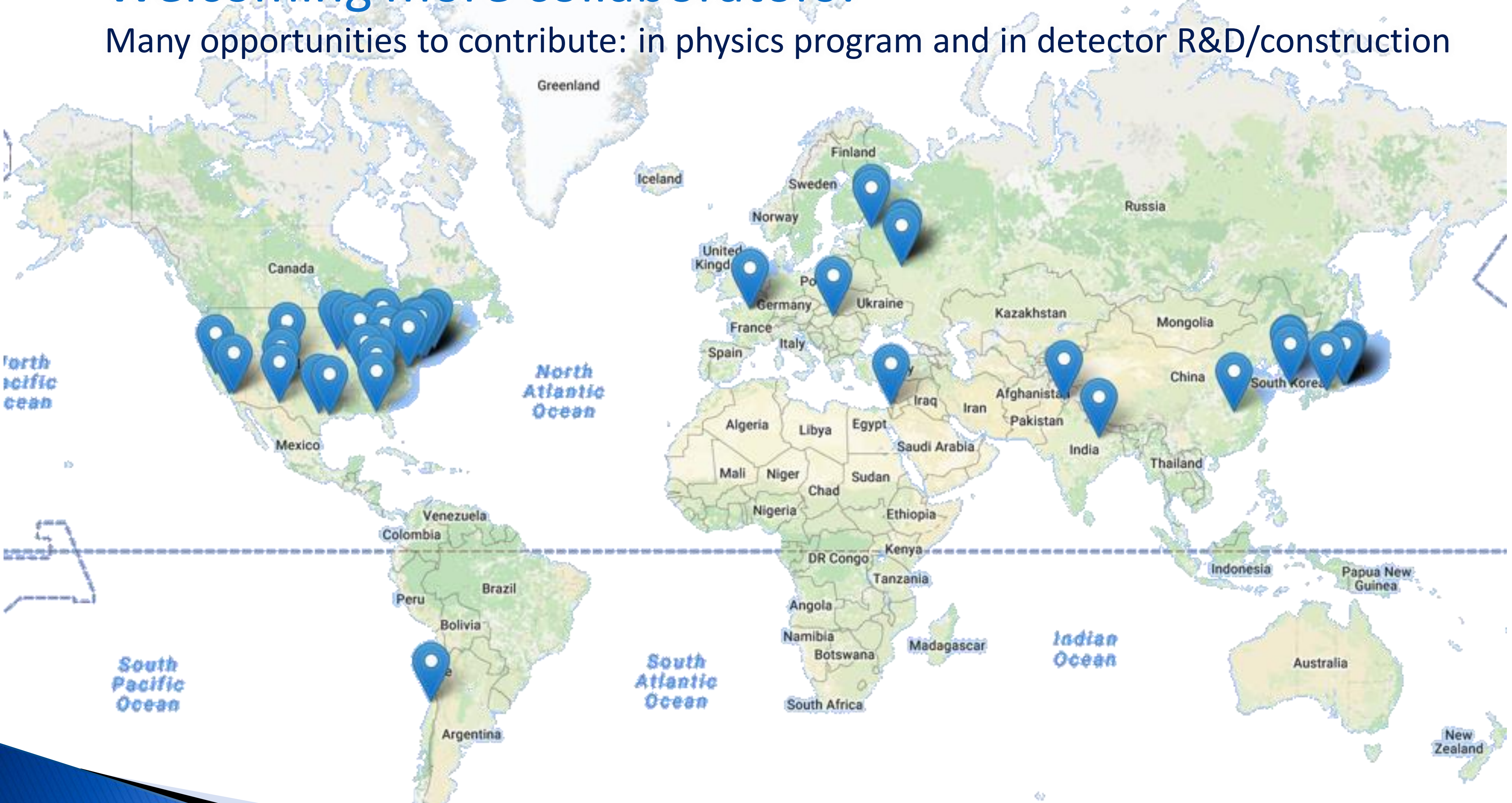
Dec 2017 sPHENIX collaboration meeting

Extra Information

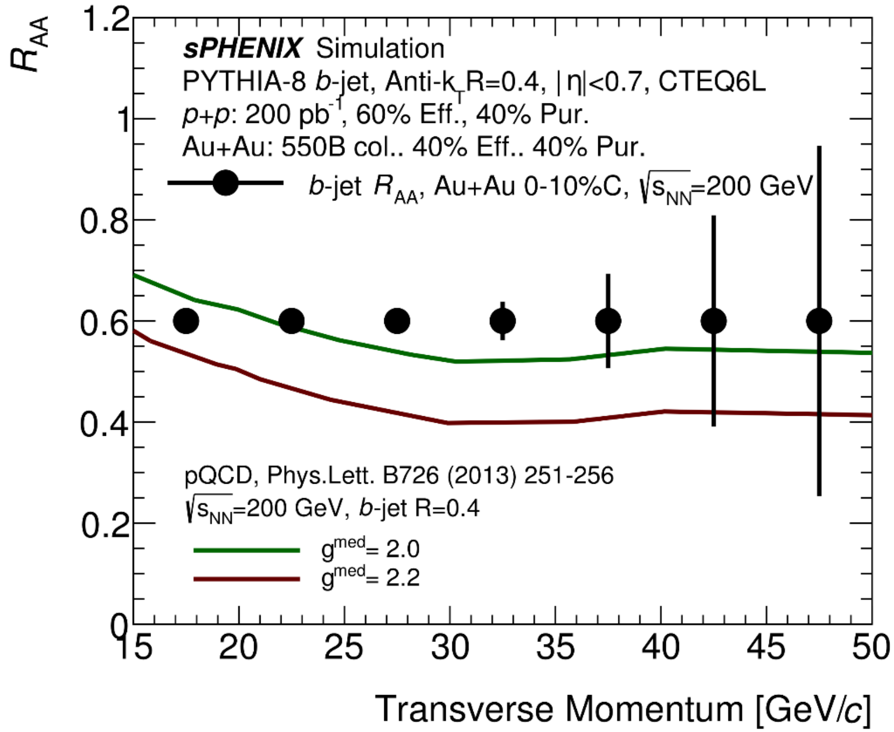
Welcome to join the collaboration

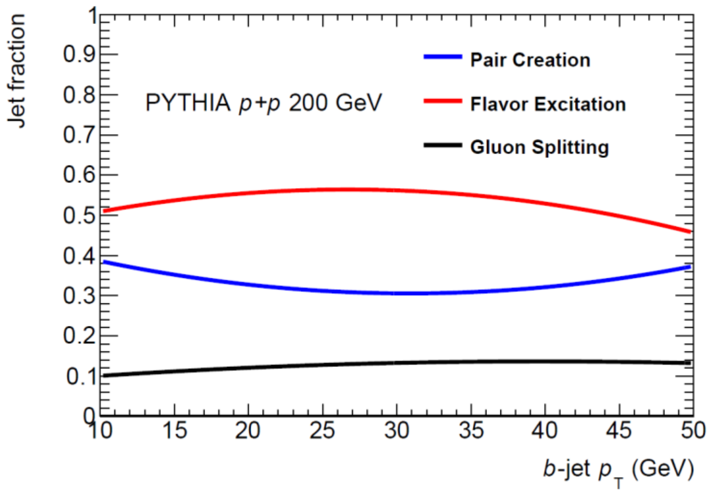
Welcoming more collaborators!

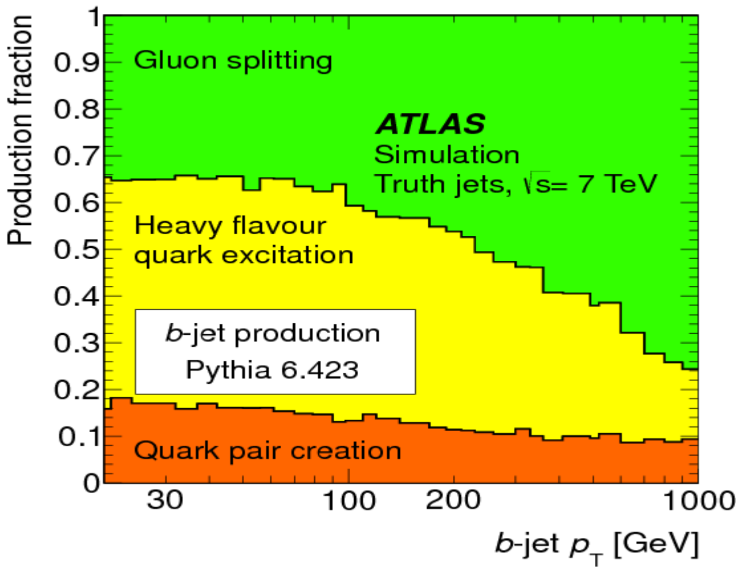
Many opportunities to contribute: in physics program and in detector R&D/construction



Inclusive b-jet R_{AA} Performance







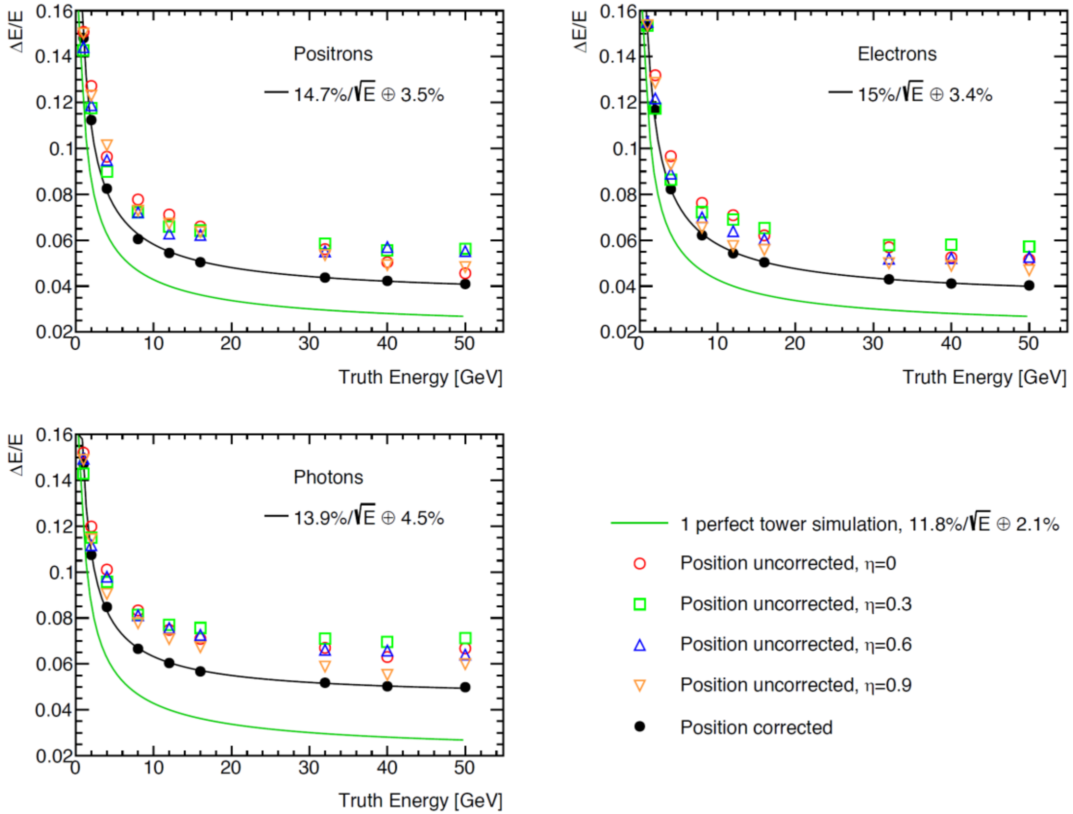
MVTX aiming first b-jet nuclear modification factor @ RHIC, covering ~15-40 GeV/c

- Mass dependence of parton energy loss
- Cleaner access to partonic kinematics

Uniqueness at RHIC (vs. LHC)

- Gluon splitting contribution is much less (~10%)

EMCal: EM-shower energy resolution



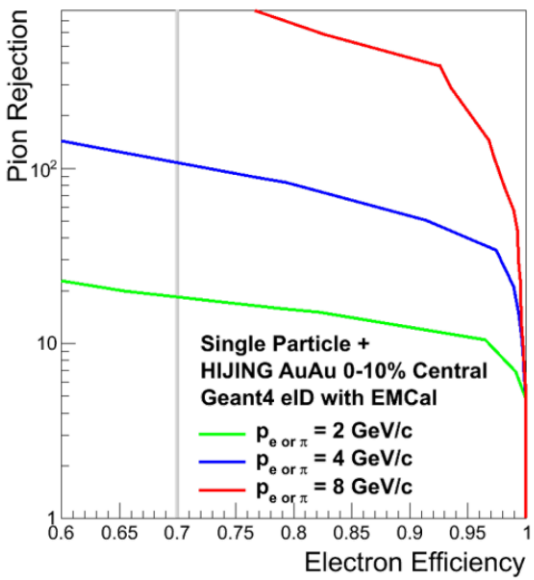
Joe Osborn (UMich),
June 13 Sim meeting

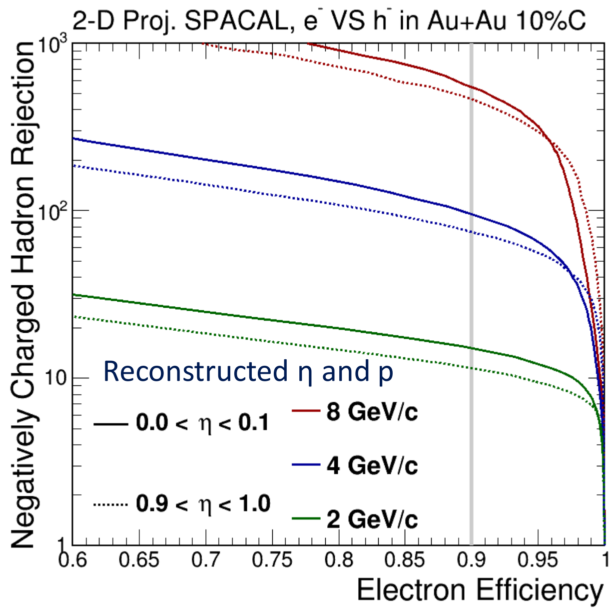
Request:

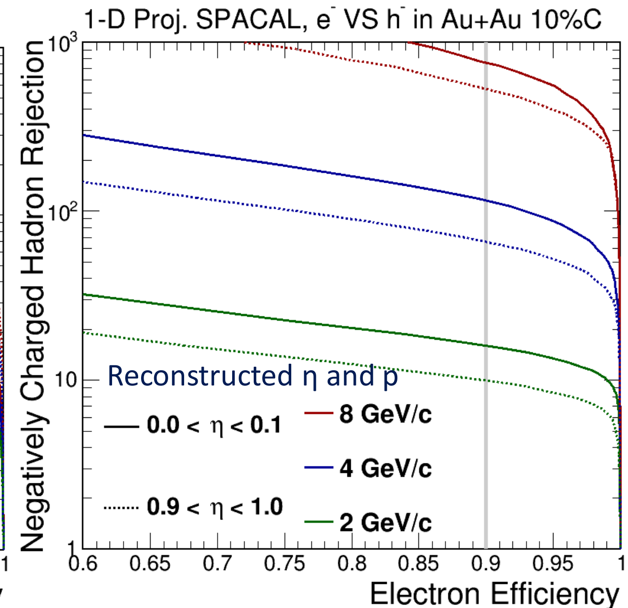
- Update with EMCal tower-by-tower calibration
- Apply sPHENIX style

Performance : electron-ID in Au+Au

Updated and more detailed simulation show good safety margin on electron-ID performance on top of the baseline design (as required to reach Upsilon program physics goal)







Baseline performance,
design goals

- Sum all scintillator energy
- 1D SPACAL material with hits grouped into 2D SPACAL towers

2D projective SPACAL

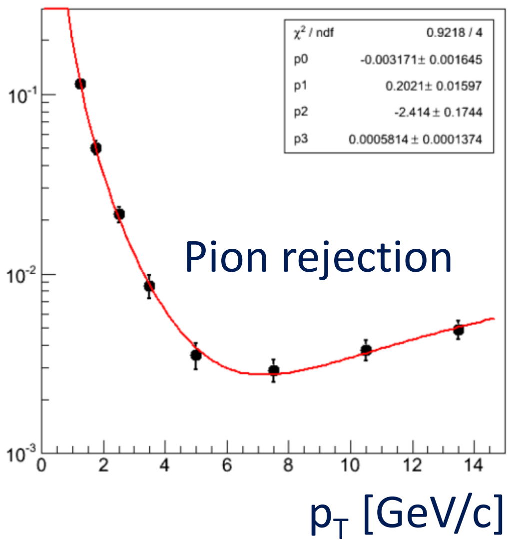
- Updated studies (Preliminary)
- Sum all hadron taking account of hadron ratio
- Full digitization (w/ Birk corrections)
- Full tracking with silicon opt.
- Fully implemented 2D SPACAL (tower/support structure)

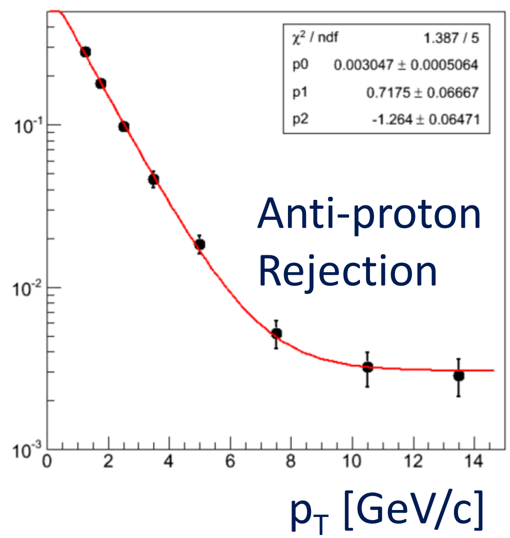
1D projective SPACAL

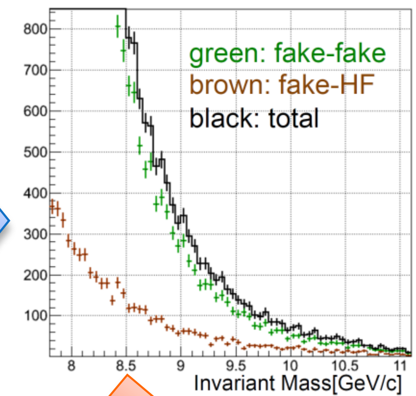
- Updated studies (Preliminary)
- Sum all hadron taking account of hadron ratio
- Full digitization (w/ Birk corrections)
- Full tracking with silicon opt.
- Ideally towering (no-tower boarder, no enclosure structure)

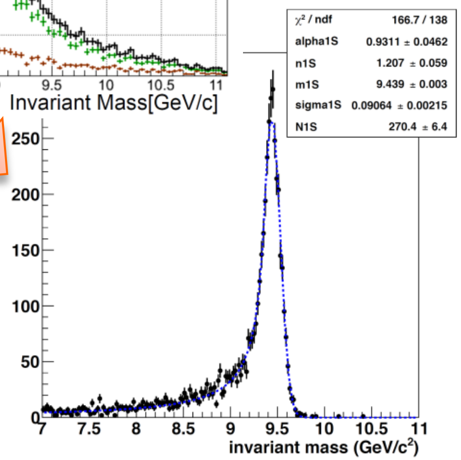
EMCal: Hadron rejection

Hadron rejection @ 90% electron eff. for embedded particle in 0-4.4 fm Au+Au collision
Work by Sasha Lebedev (ISU), quoted from Quarkonium-TG wiki, June-2017 Col. meeting









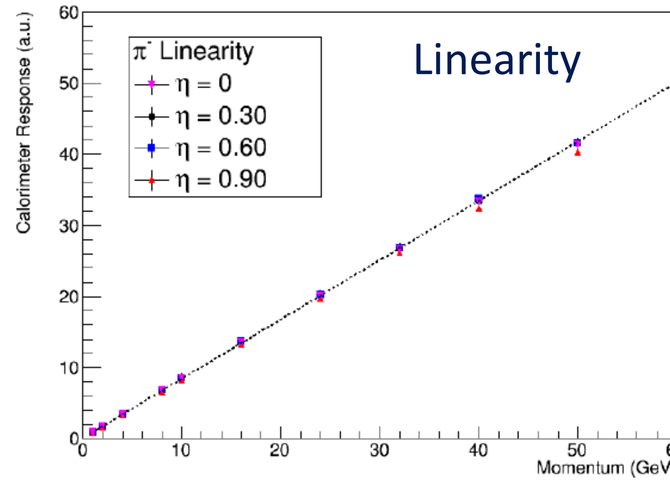
Requests in priorities:

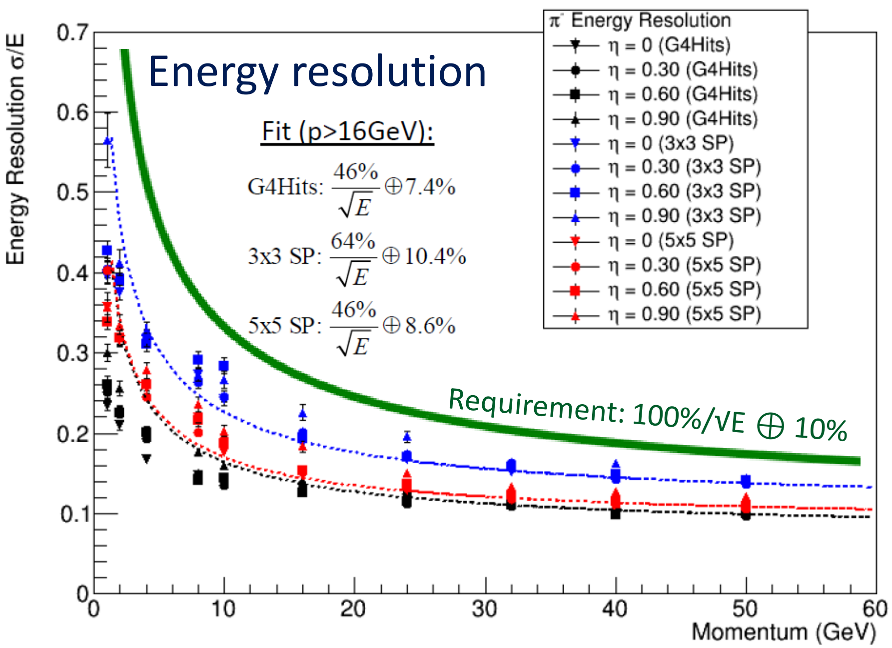
1. Update to sPHENIX plotting style
2. Produce Upsilon spectrum update with updated background
3. Use 2017 EMCal design and tracking simulations. Help on running?
4. Finalizing Upsilon R_AA projection?

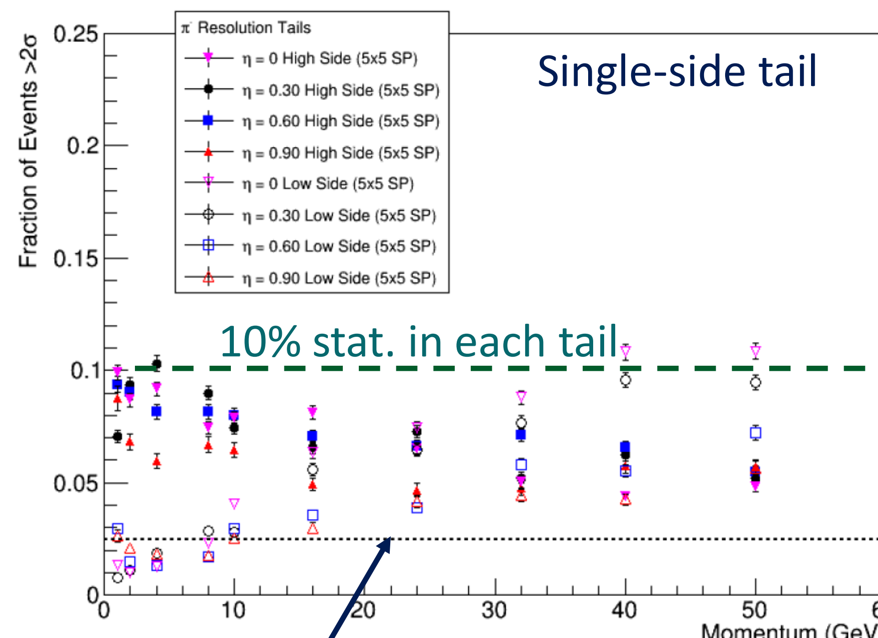
More in Sasha's talk today.

Performance : Single Hadron showers

- Single pion shower studied with clusters of digitized towers (3x3 and 5x5 clusters), which is compared with ideal sum of Geant4 hit in scintillator (label G4Hits)
- Energy resolution satisfied design goal.
  Tails <= 10%
- Refinement underway: time cut-off and light collection variations







2.5% stat. in tails as expected from Gauss shape

Occupancy in central Au+Au

- sPHENIX are designed to handle large background environment of central AuAu collisions
- Such background is simulated with HIJING → full detector in Geant4 → full analysis chain
- Folded into electron ID and jet projections via embedding