sPHENIX Update

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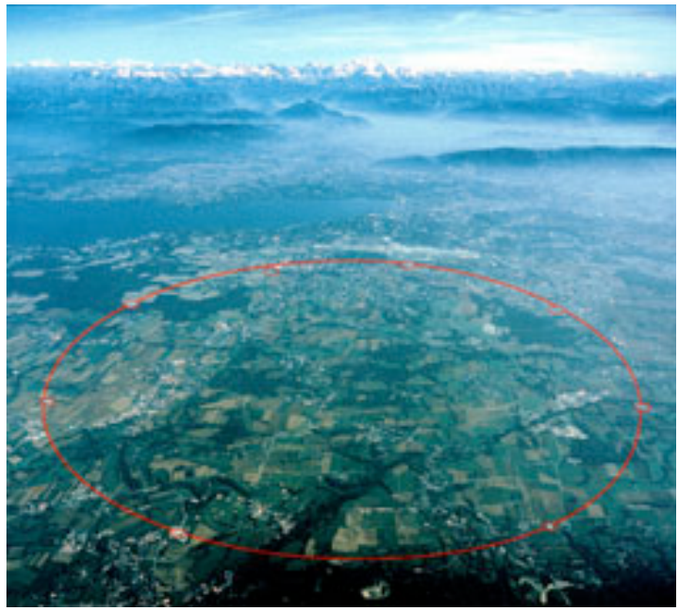
from description to understanding

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."**

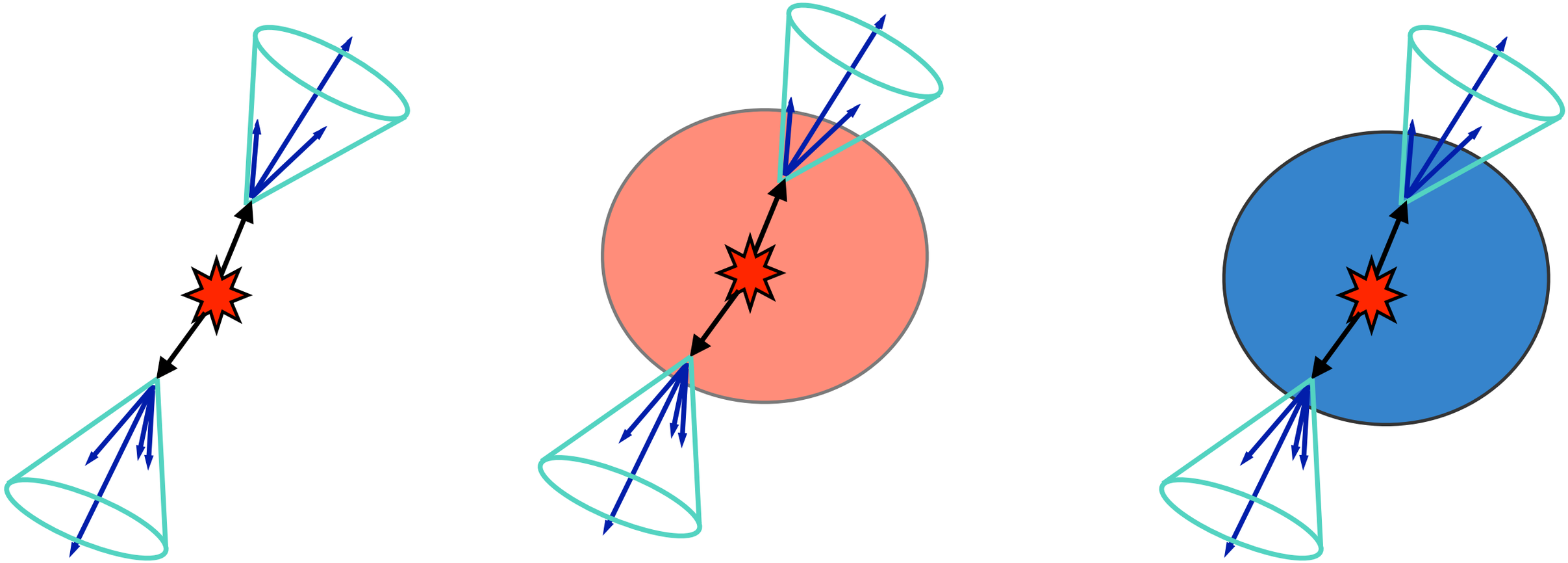
what do we need to measure?

Long Range Plan: "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

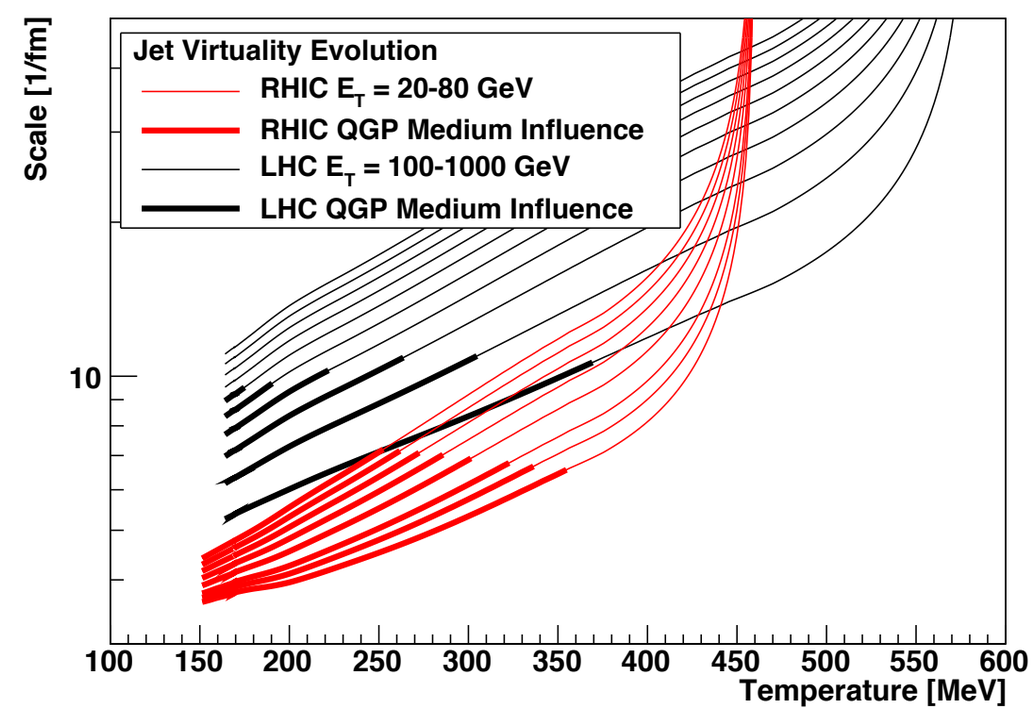


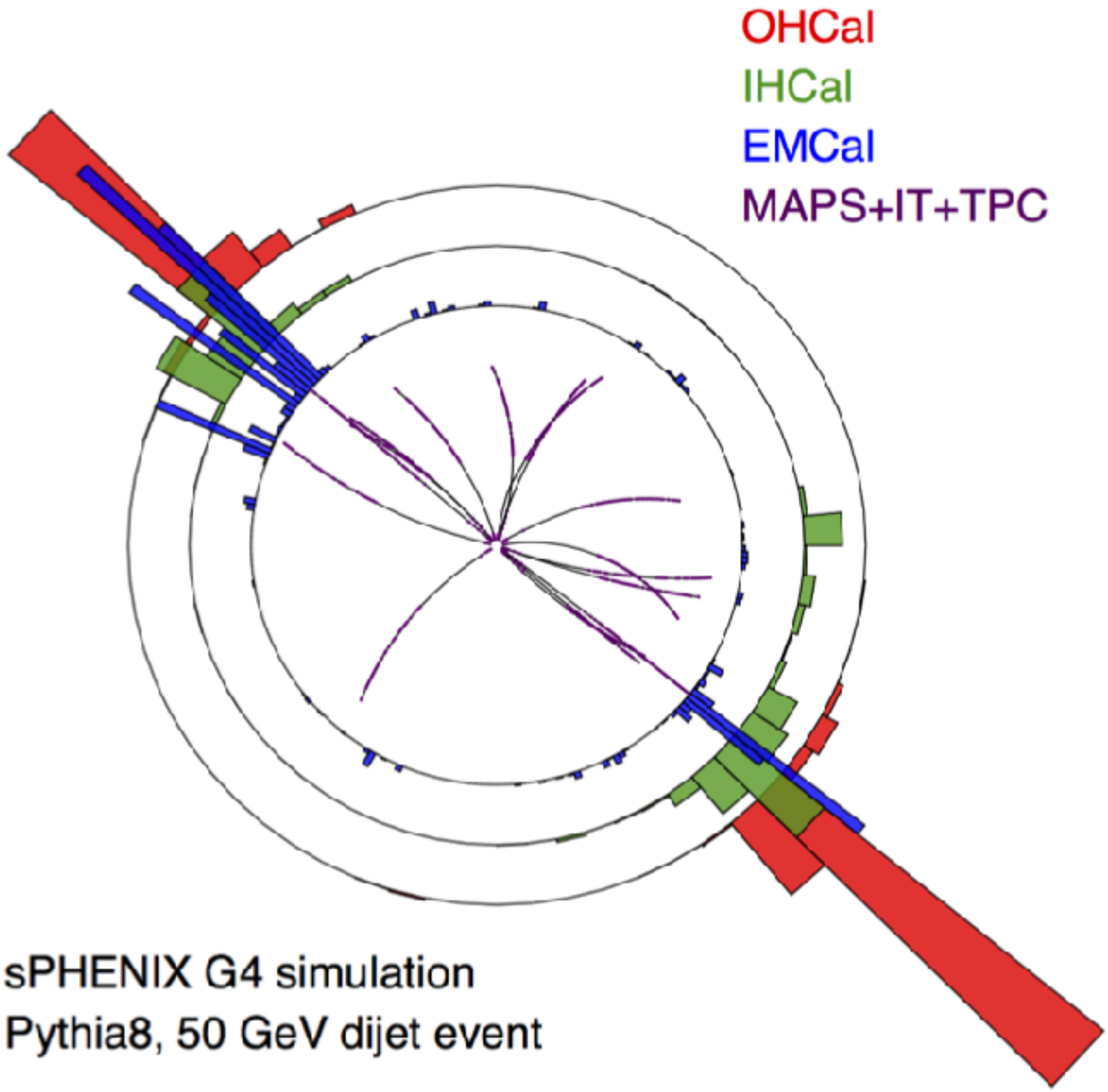
- jets, upsilons and photons with high statistics over a wide kinematic and collision energy range
  - jets from ~20 GeV → 1 TeV
  - collision energy from 200 GeV → 5.5 TeV
  - luminosity for precision measurements at both facilities
  - wide recognition of necessity of both facilities, many groups at sPHENIX and LHC

why two facilities?



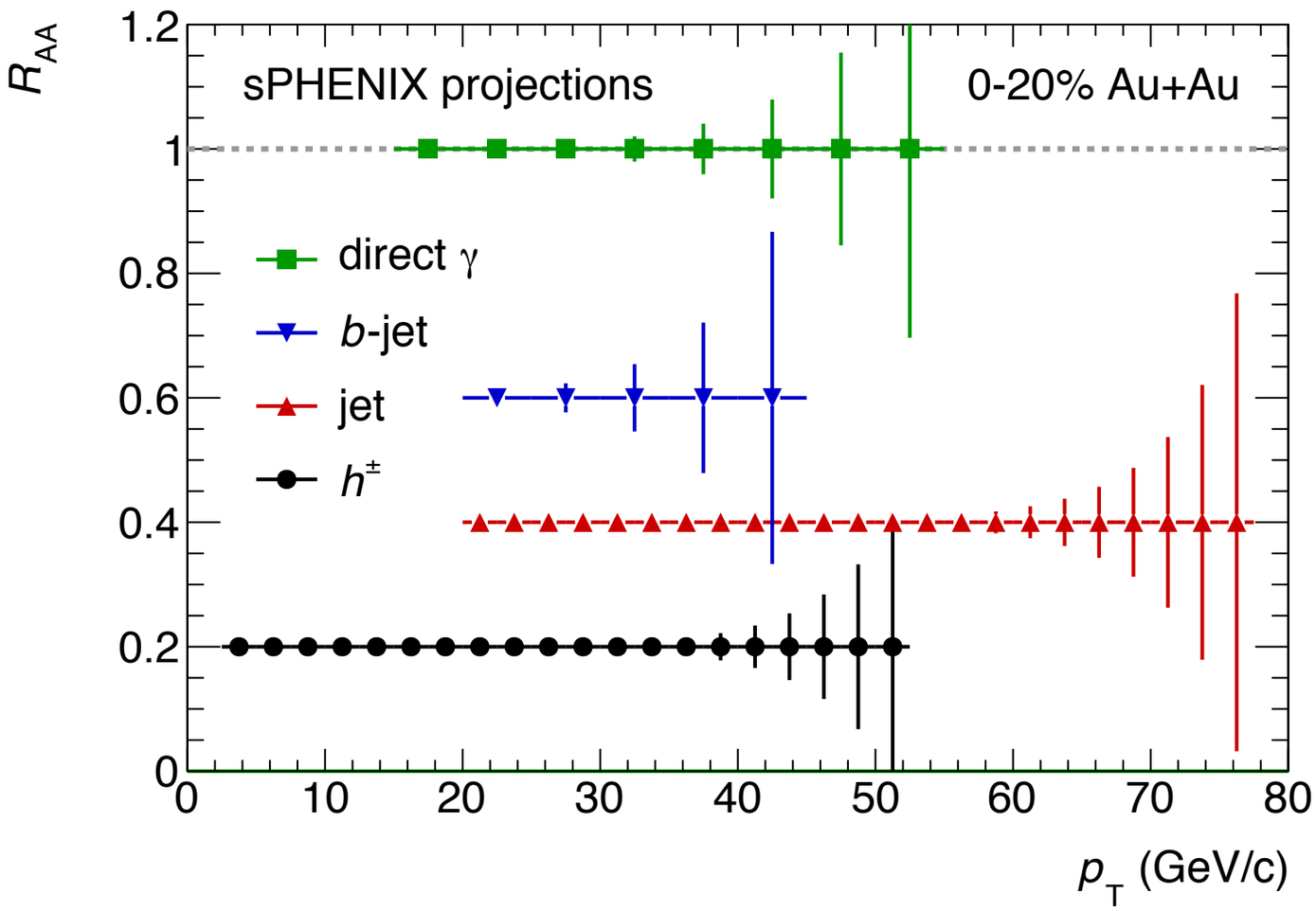
- the QGP itself is different at RHIC and the LHC
- largest range of scales probed is from high energy jets at the LHC to low energy ones at RHIC
- the jets are differently sensitive to the medium through their virtuality evolution



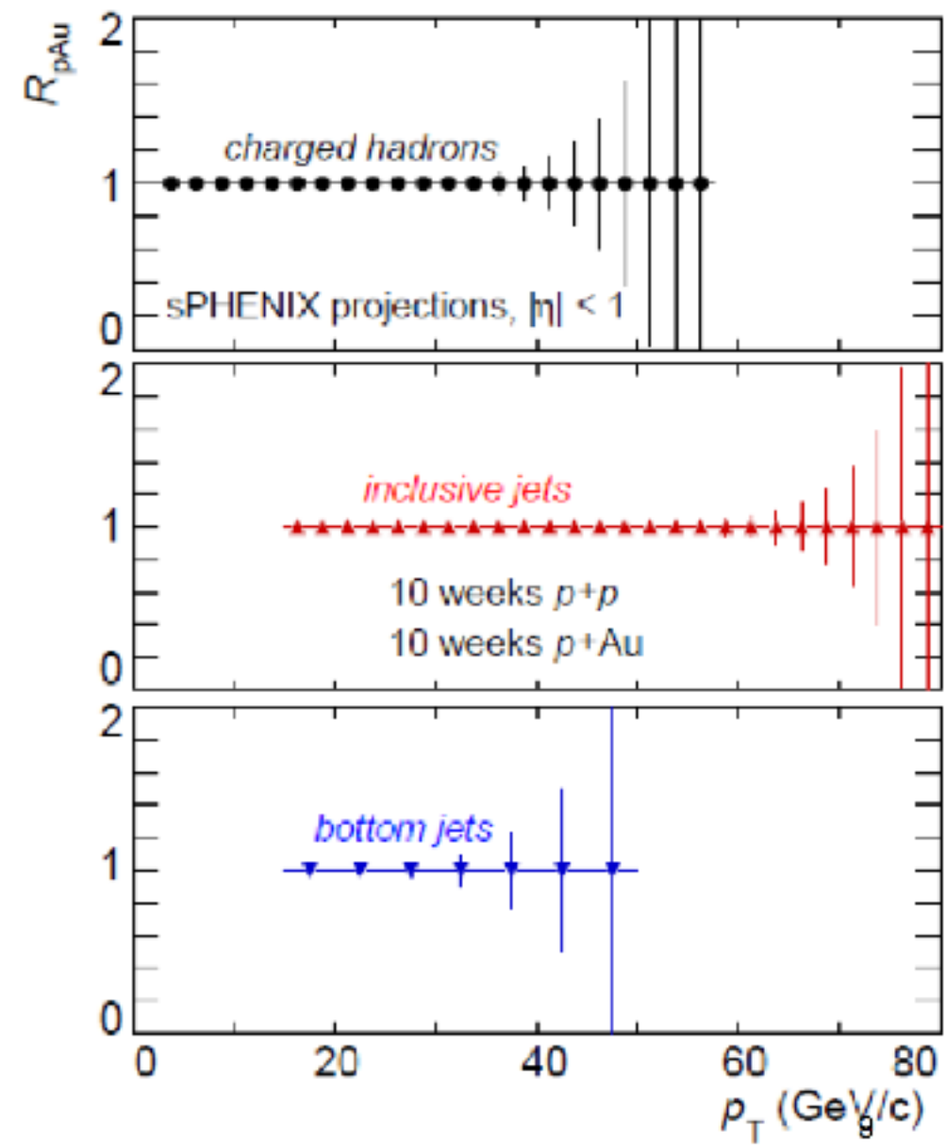

OHCal
IHCal
EMCal
MAPS+IT+TPC
sPHENIX G4 simulation
Pythia8, 50 GeV dijet event

AuAu: high p_T rates

Au+Au projections



p+Au projections



longer running benefits rare channels, especially photons and b-jets!

see Megan Connor's talk Tuesday

Possible 5 year run plan

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}
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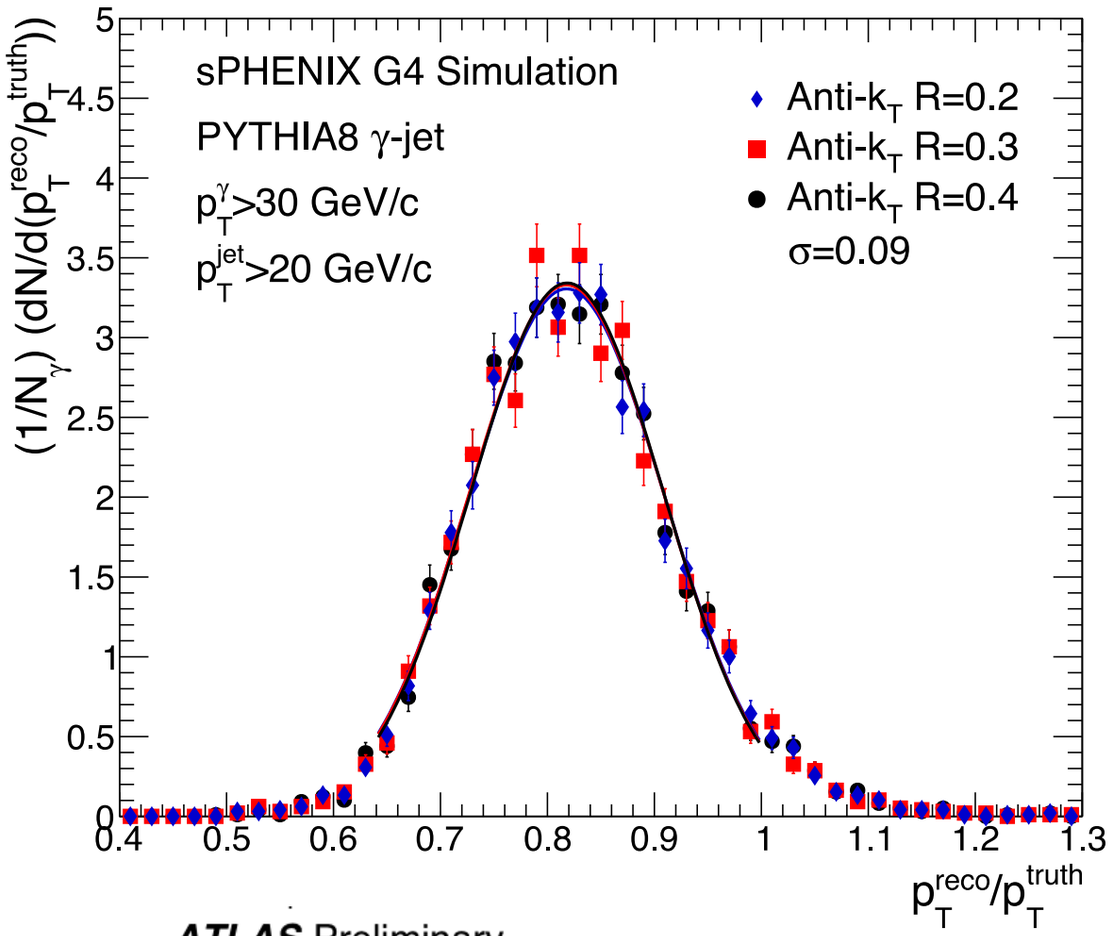
- Guidance from ALD to think in terms of a multi-year run plan
- Consistent with language in DOE CD-0 “mission need” document
- Incorporates updated C-AD guidance now officially documented
- Run plan relates to capabilities of full barrel detector
- Incorporates commissioning time in first year

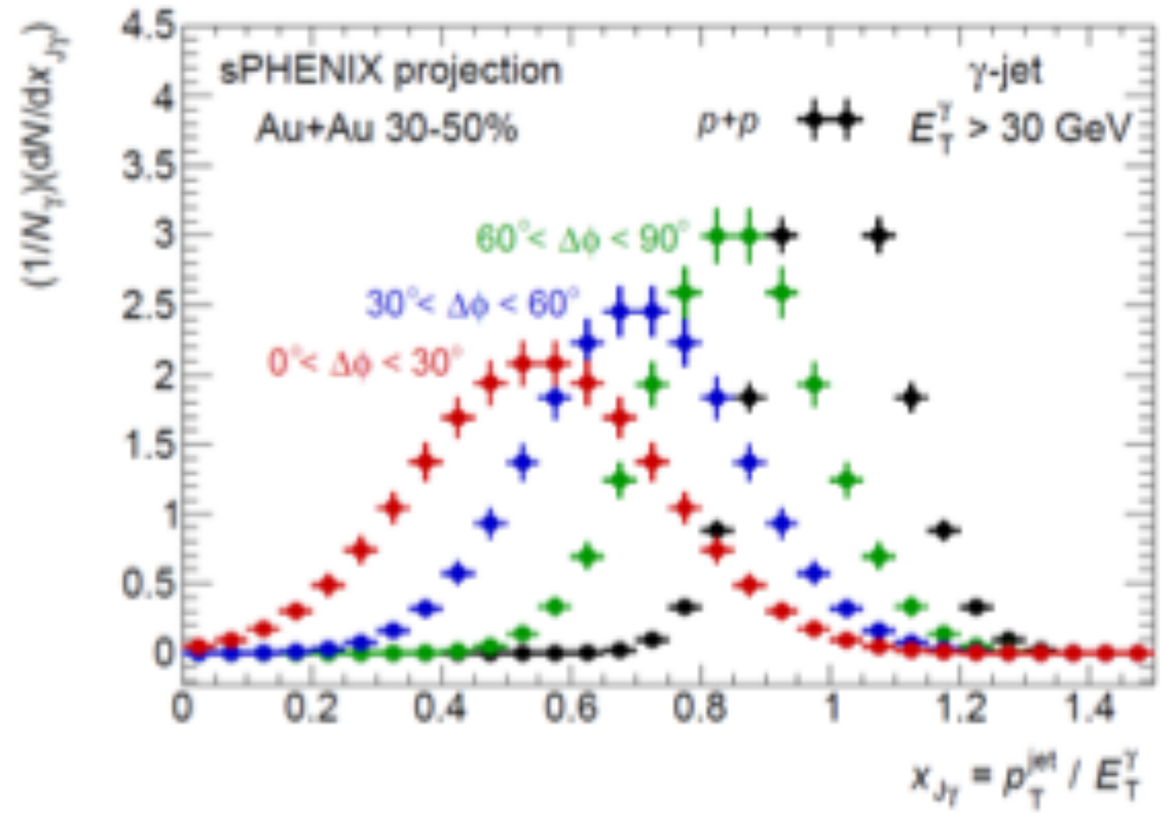
Minimum bias Au+Au at 15 kHz for $|z| < 10$ cm:
47 billion (2022) + 96 billion (2024) + 96 billion (2026) = Total 239 billion events

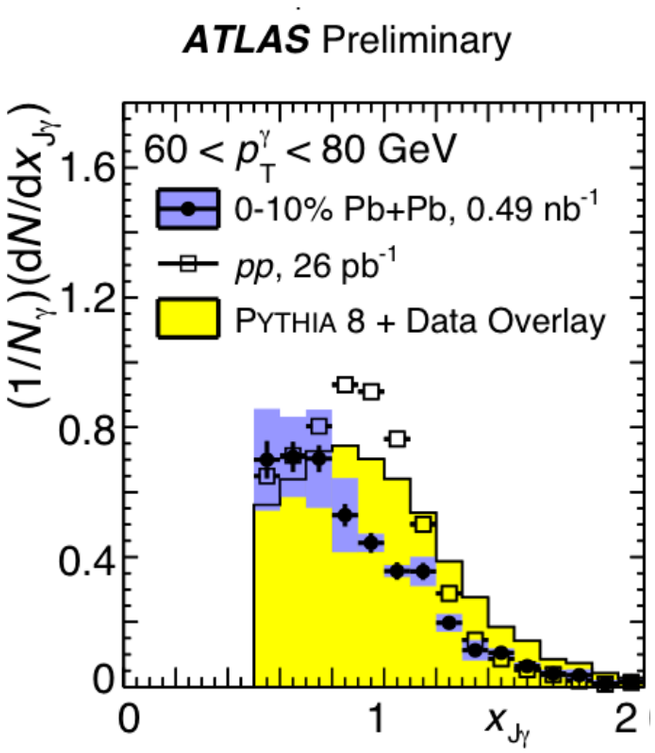
For topics with Level-1 selective trigger (e.g. high p_T photons), one can sample within $|z| < 10$ cm a total of 550 billion events. One could consider sampling events over a wider z-vertex for calorimeter only measurements, 1.5 trillion events.

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

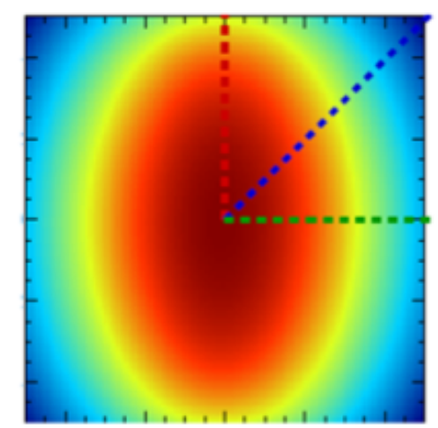
photon-jet correlations







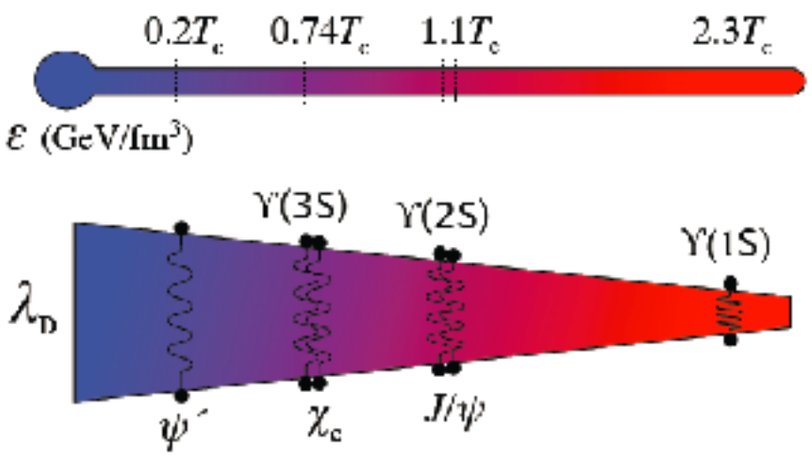
photon-jet correlations are a golden channel for jet quenching, rare probes exploit both running time and large acceptance



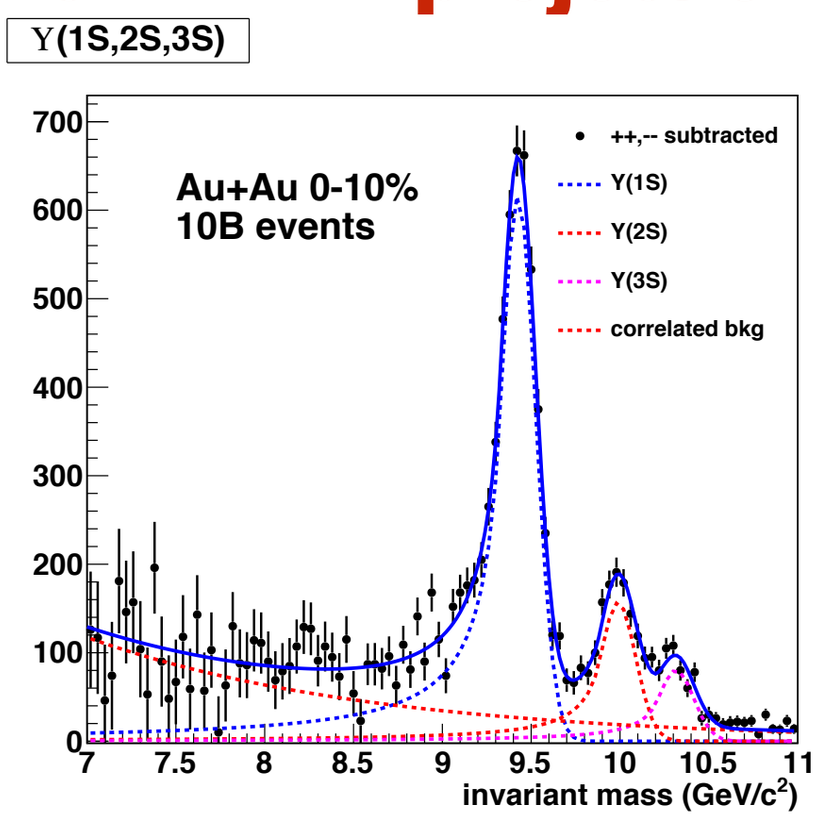
see Megan Connor's talk Tuesday

upsilons

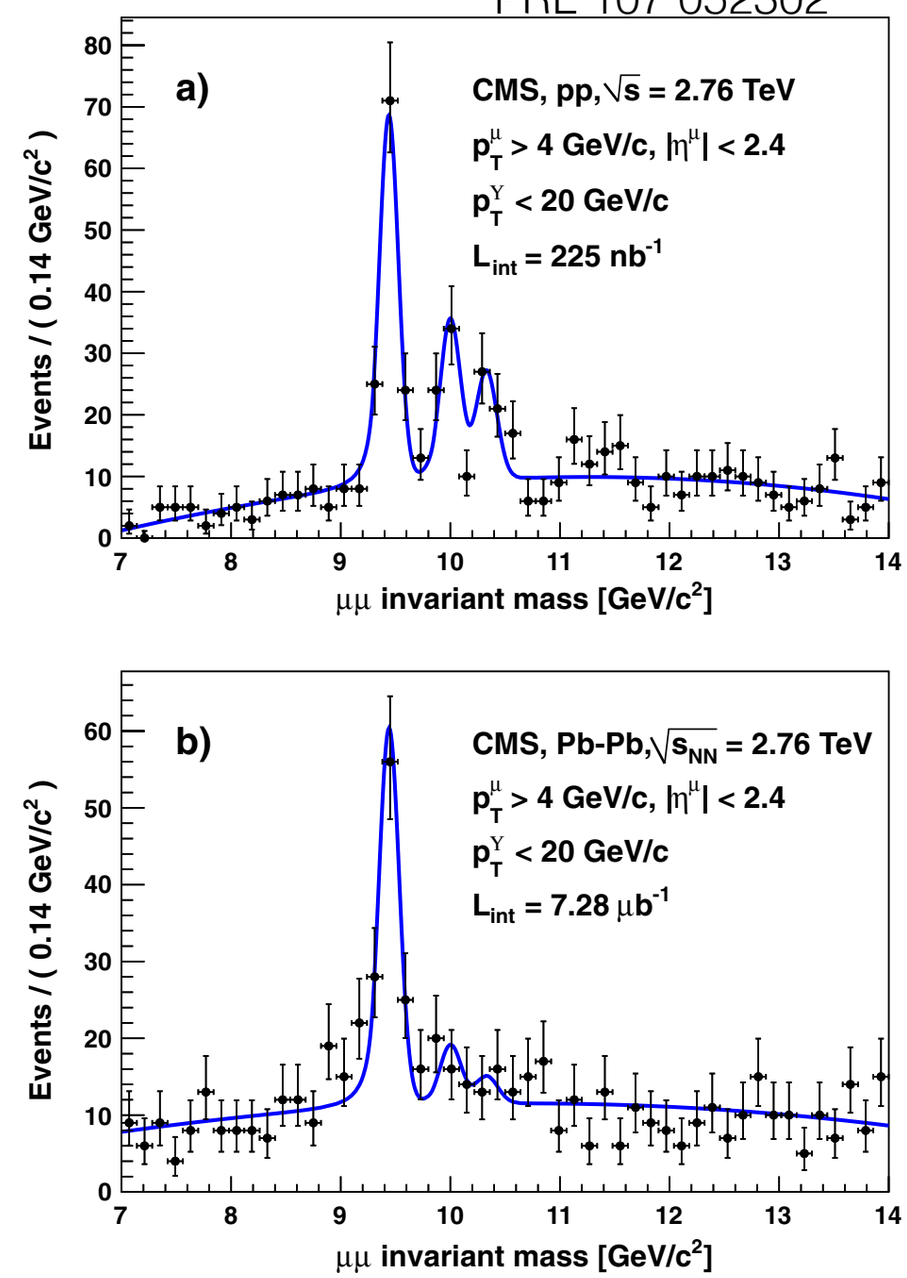
separation of 1S, 2S & 3S states
temperature dependence of screening is key!



sPHENIX projection

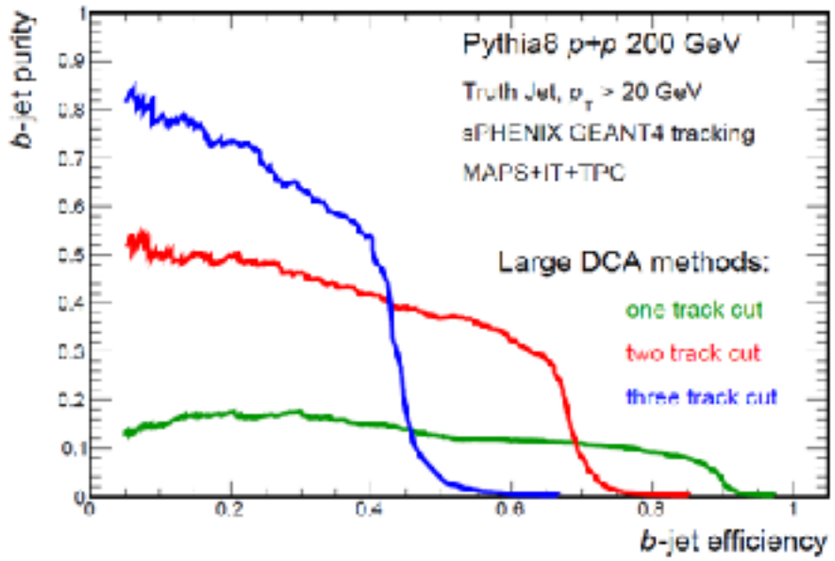


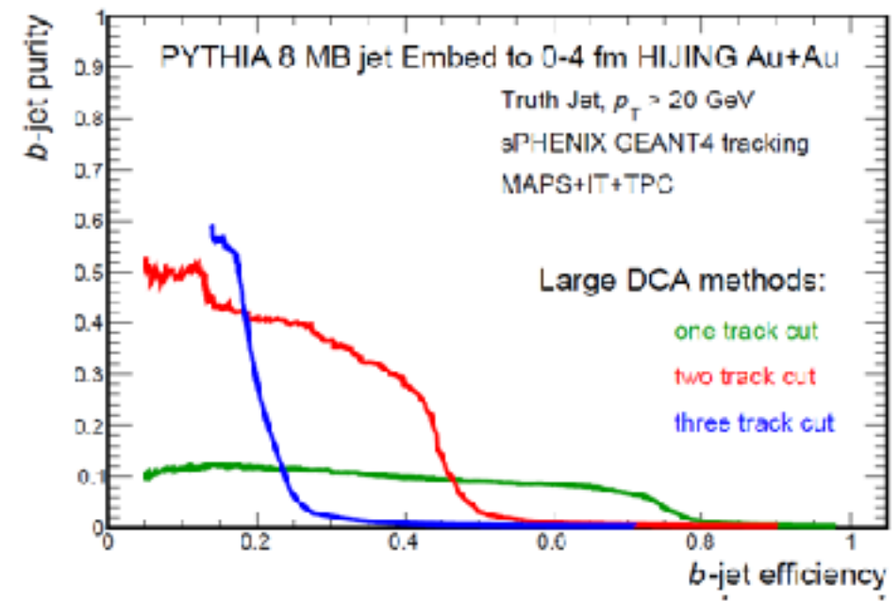
PRL 107 052302



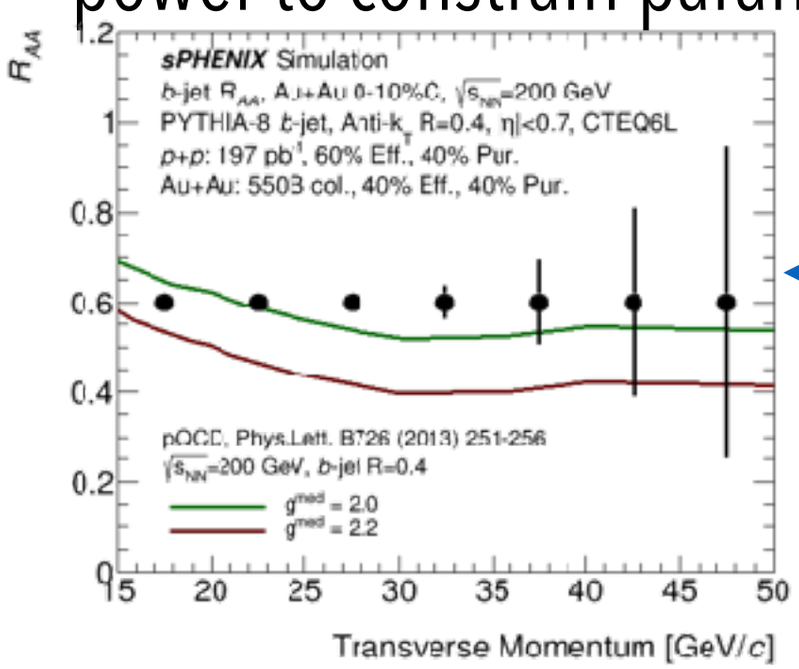
requires excellent tracking & EM calorimetry
for electron ID & mass resolution

b-jets





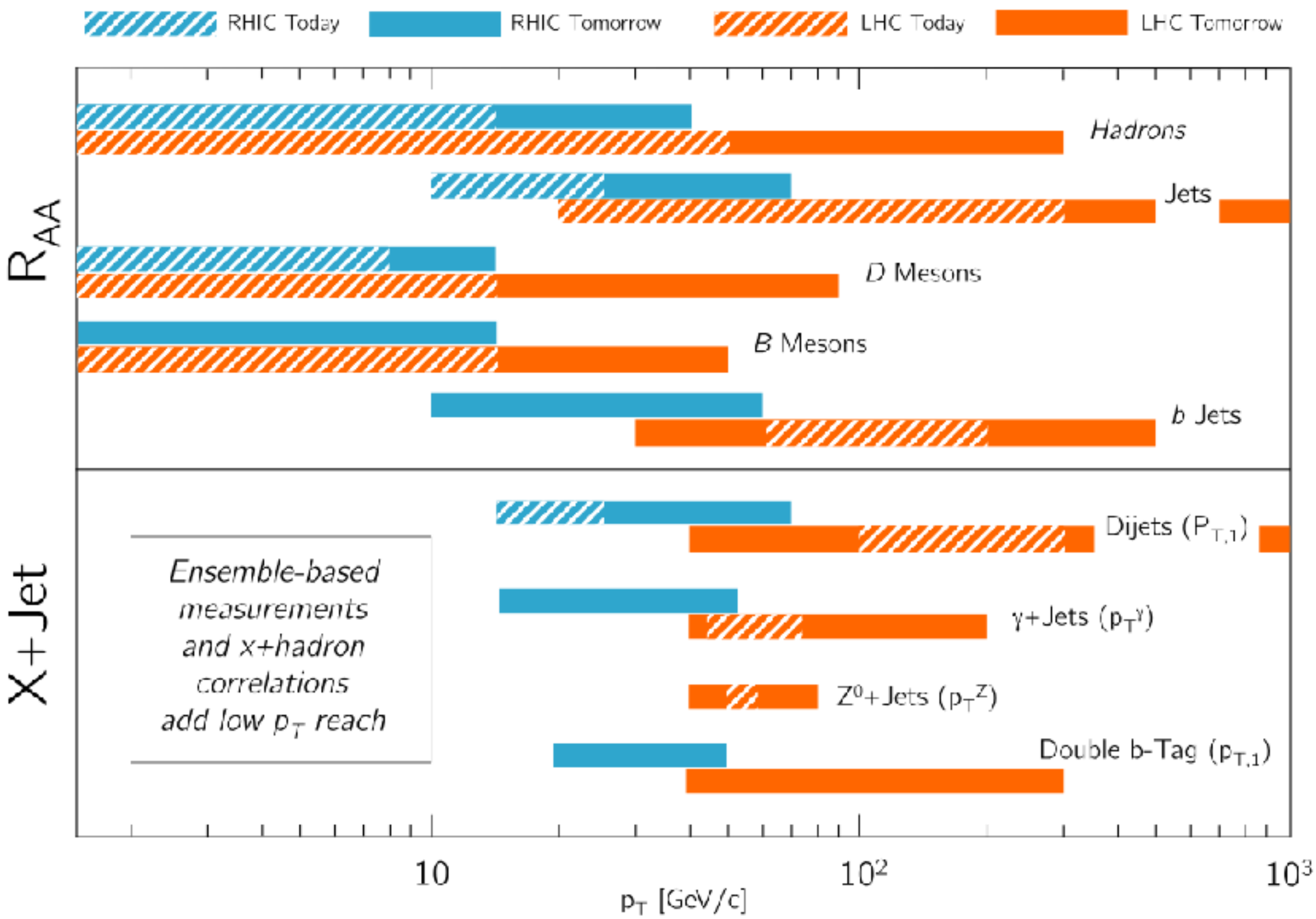
- tracking system provides good b-jet identification capabilities in pp & AuAu collisions
- resulting uncertainties provide kinematic range and descriminating power to constrain parameters in Vitev, et al's calculation!



based on the luminosities from the 5 Year Run Plan

see Megan Connor's talk Tuesday

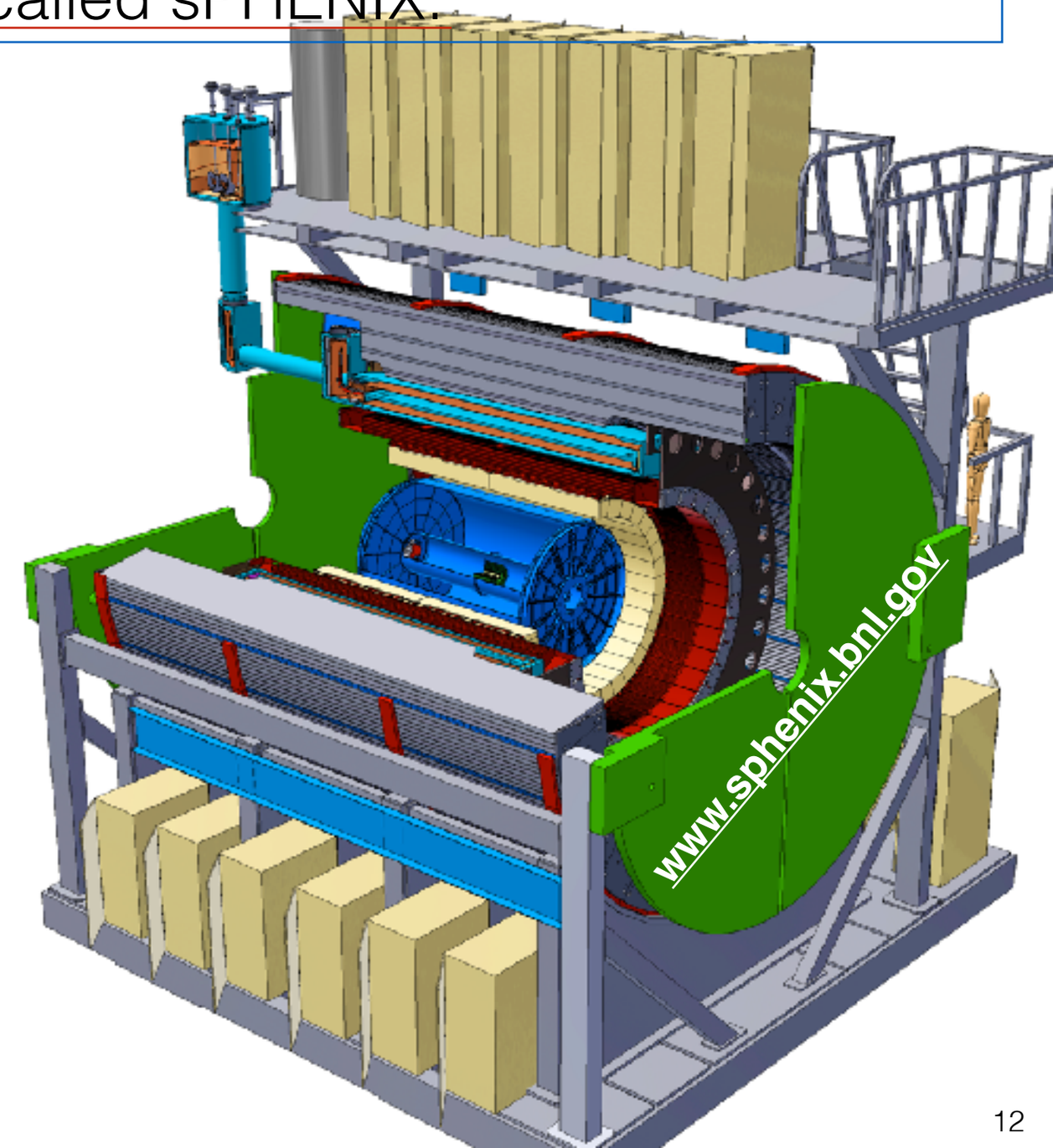
LHC & RHIC


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]

what detector do we need?

Long Range Plan: "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."

- high rate, record 15kHz
- excellent tracking
- large uniform acceptance for jets, photons and upsilons
- full hadronic and electromagnetic calorimetry

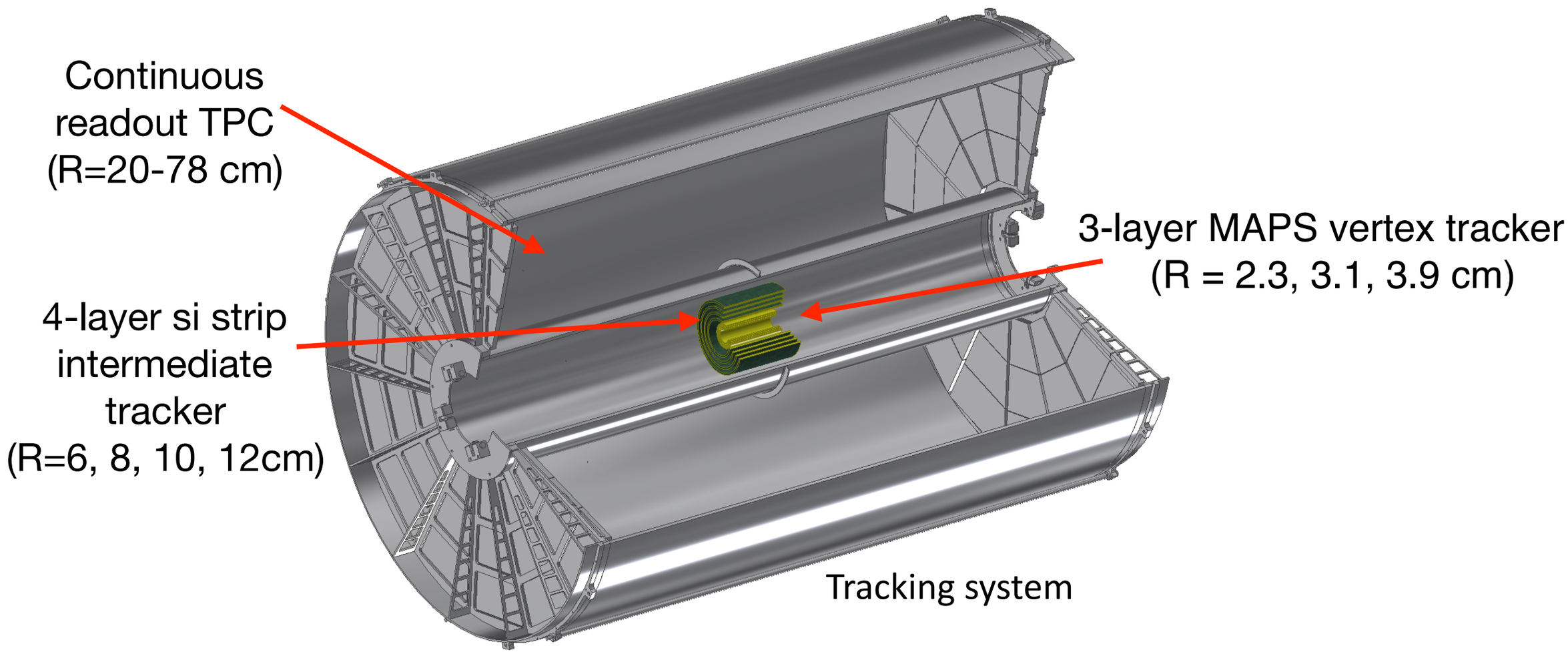


the former Babar solenoid

- 1.5 T solenoid
- low power cold tests have been successful
- preparation underway for full field tests

sPHENIX tracking

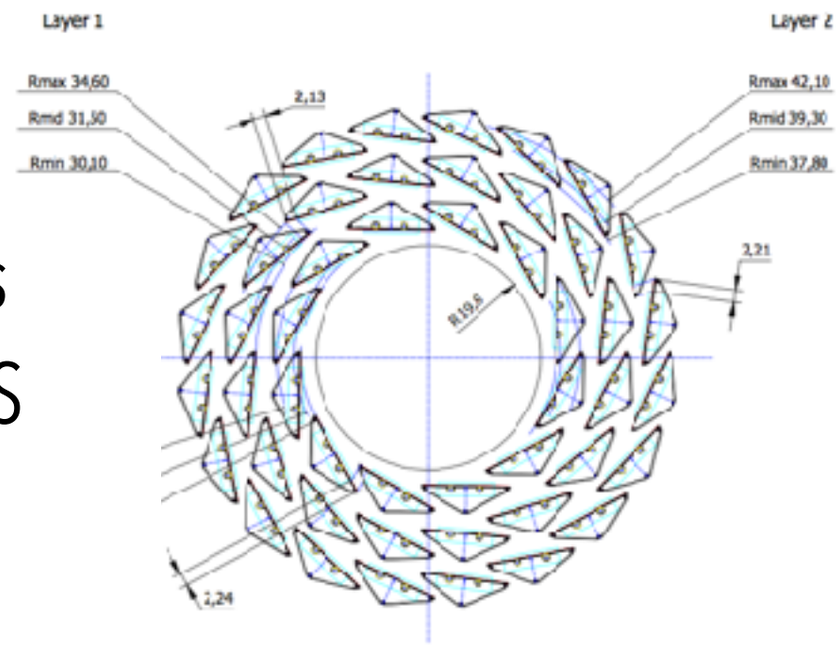
- **tracker design:**
  - 3 layers MAPS, using ALICE stave design
  - 4 layer intermediate silicon tracker
  - outer TPC

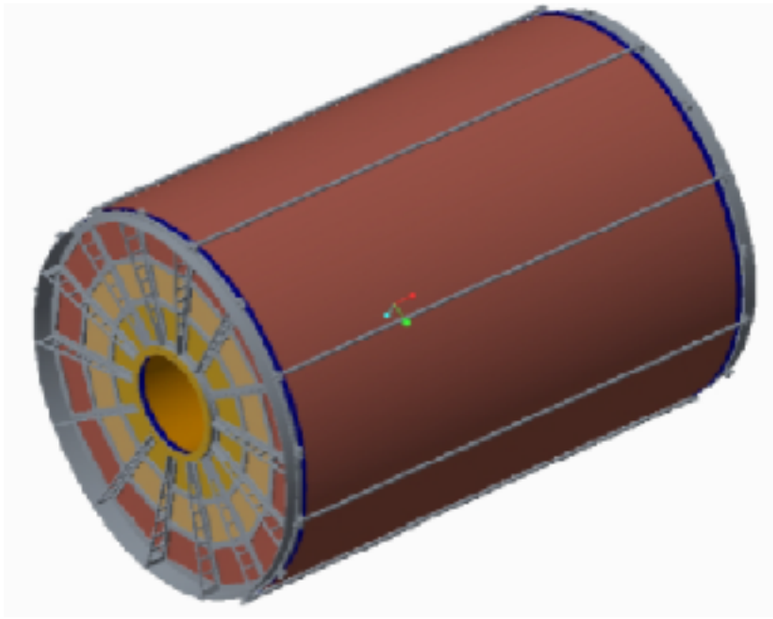


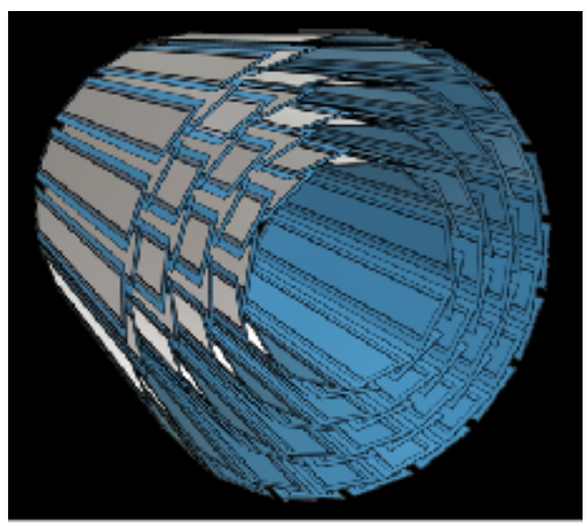
tracking components

MVTX

- 3 layers Si sensors
- Based on ALICE ITS upgrade
- $DCA_{xy} < 70\ \mu m$
- $|z_{vtx}| < 10$ cm







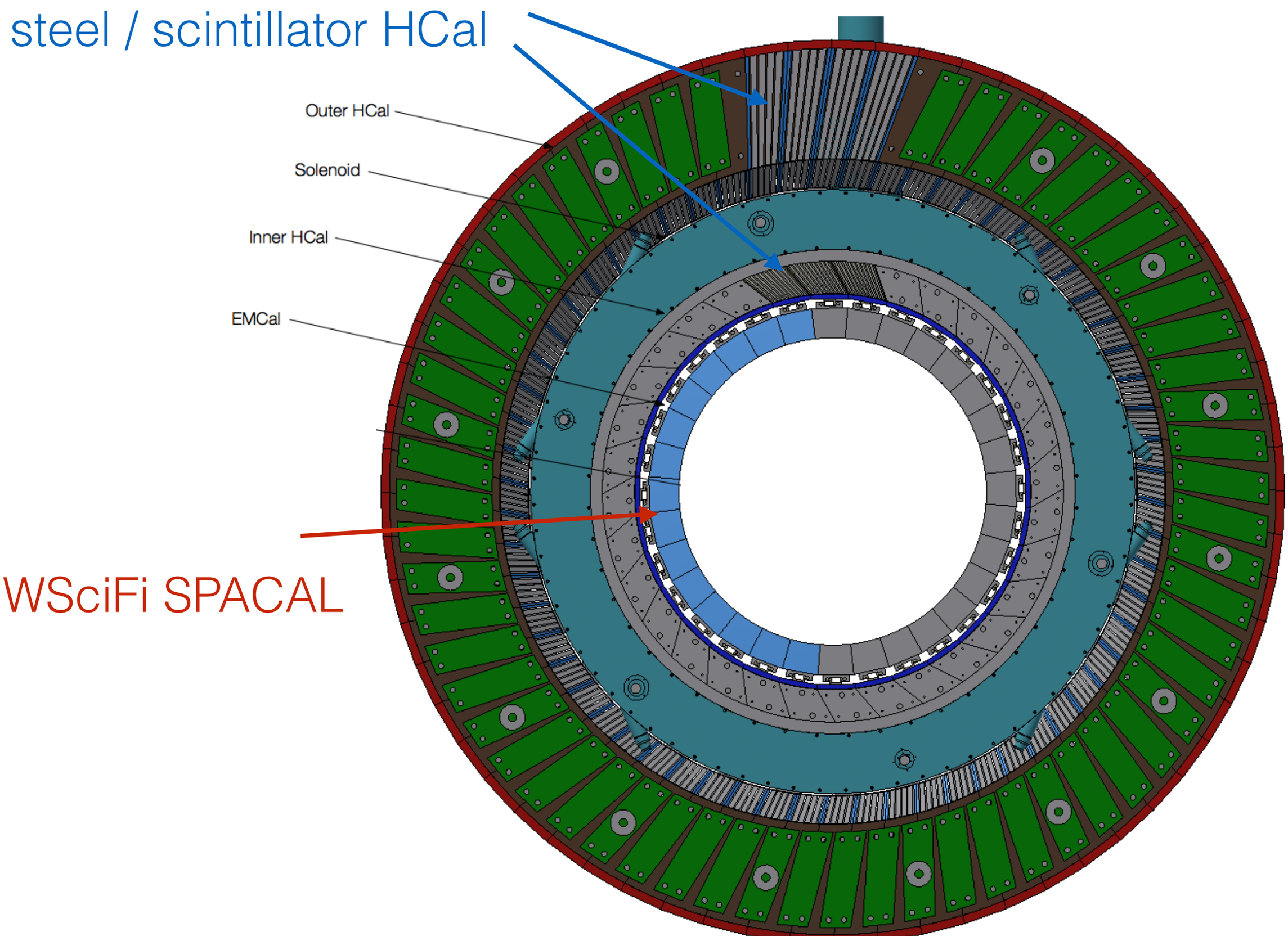
INTT

- 4 layers Si strips
- Pattern recognition, DCA, connect tracking systems, reject pile-up

TPC

- Radius 20–78 cm
- ~250 μm effective hit resolution
- Continuous (non-gated) readout
- Pattern recognition, momentum resolution, p_T 0.2-40 GeV/c

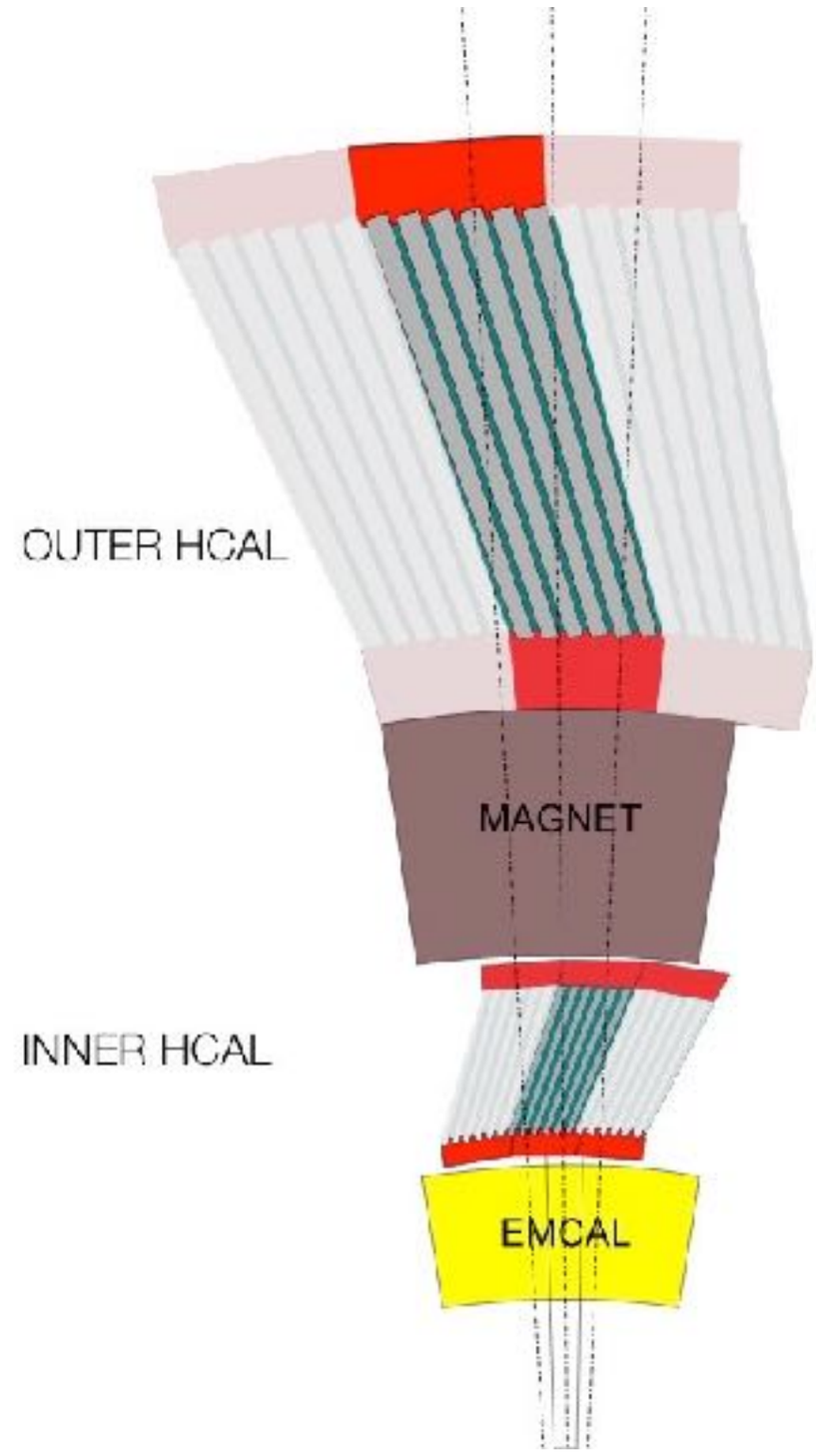
sPHENIX: calorimeters



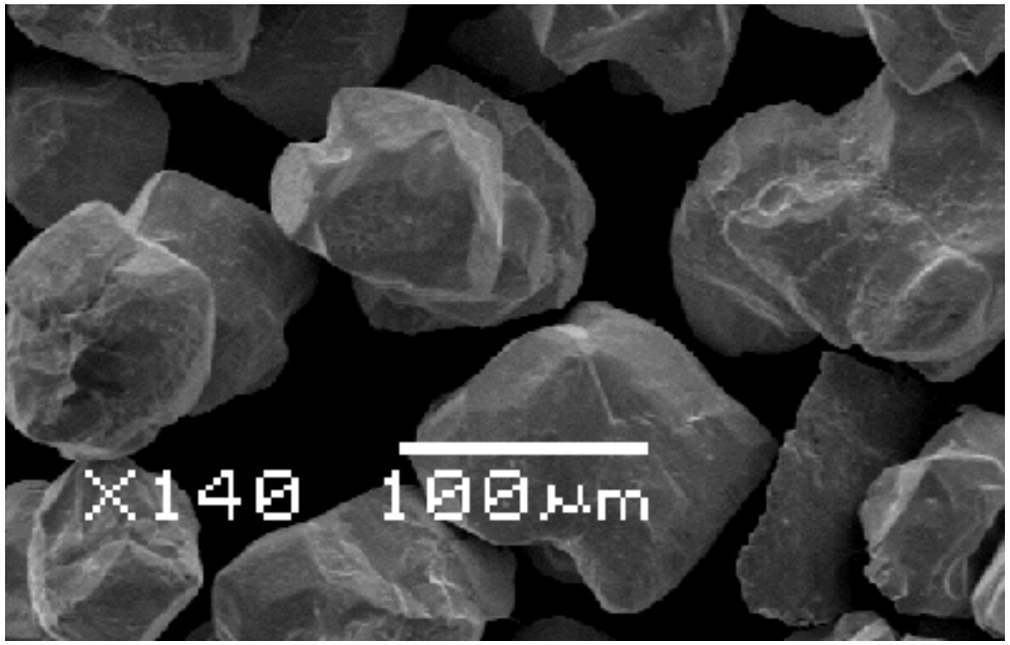
hadronic calorimeter

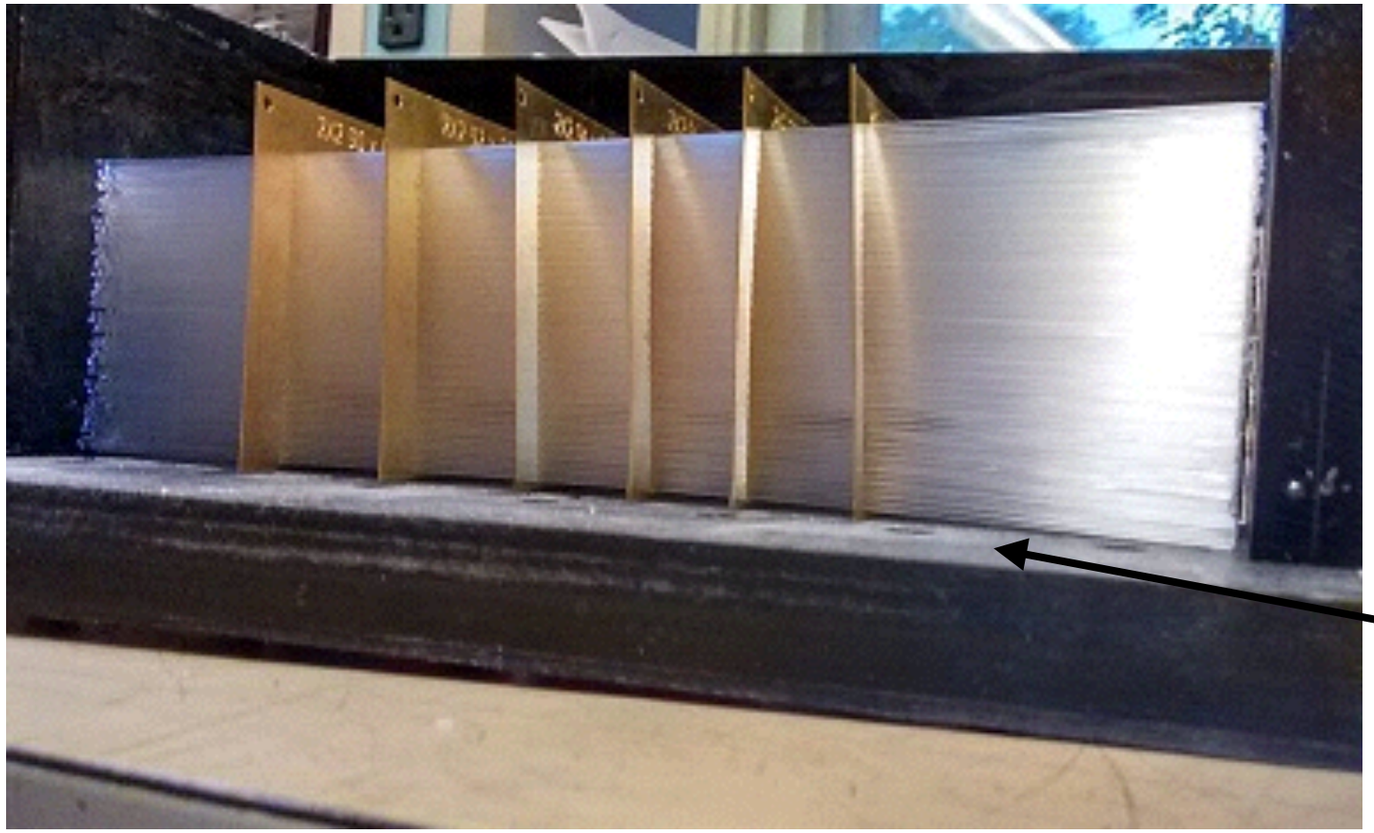
alternating steel/scintillator plates

prototype assembled at BNL



sPHENIX EMCal

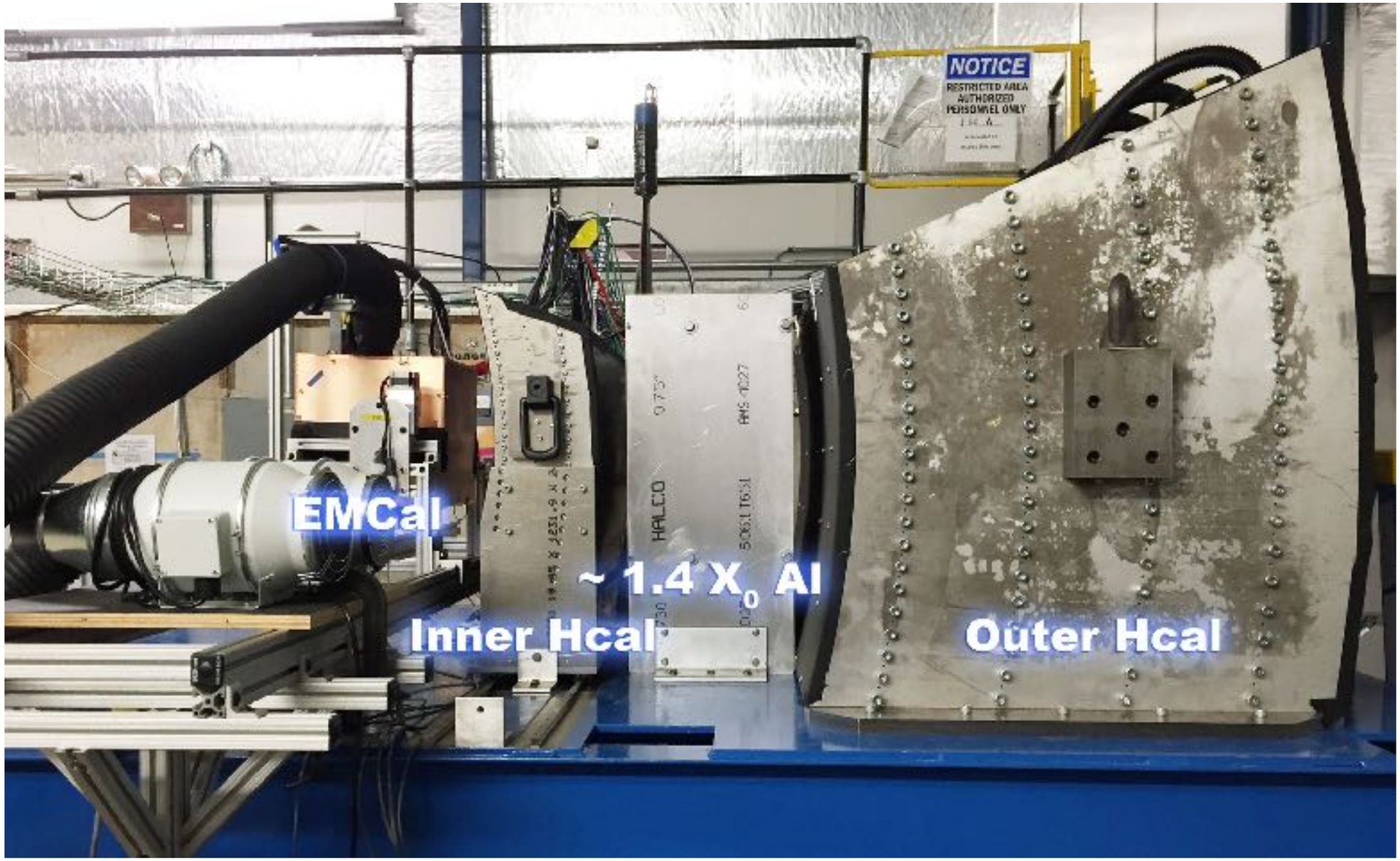




scintillating fibers embedded in tungsten powder

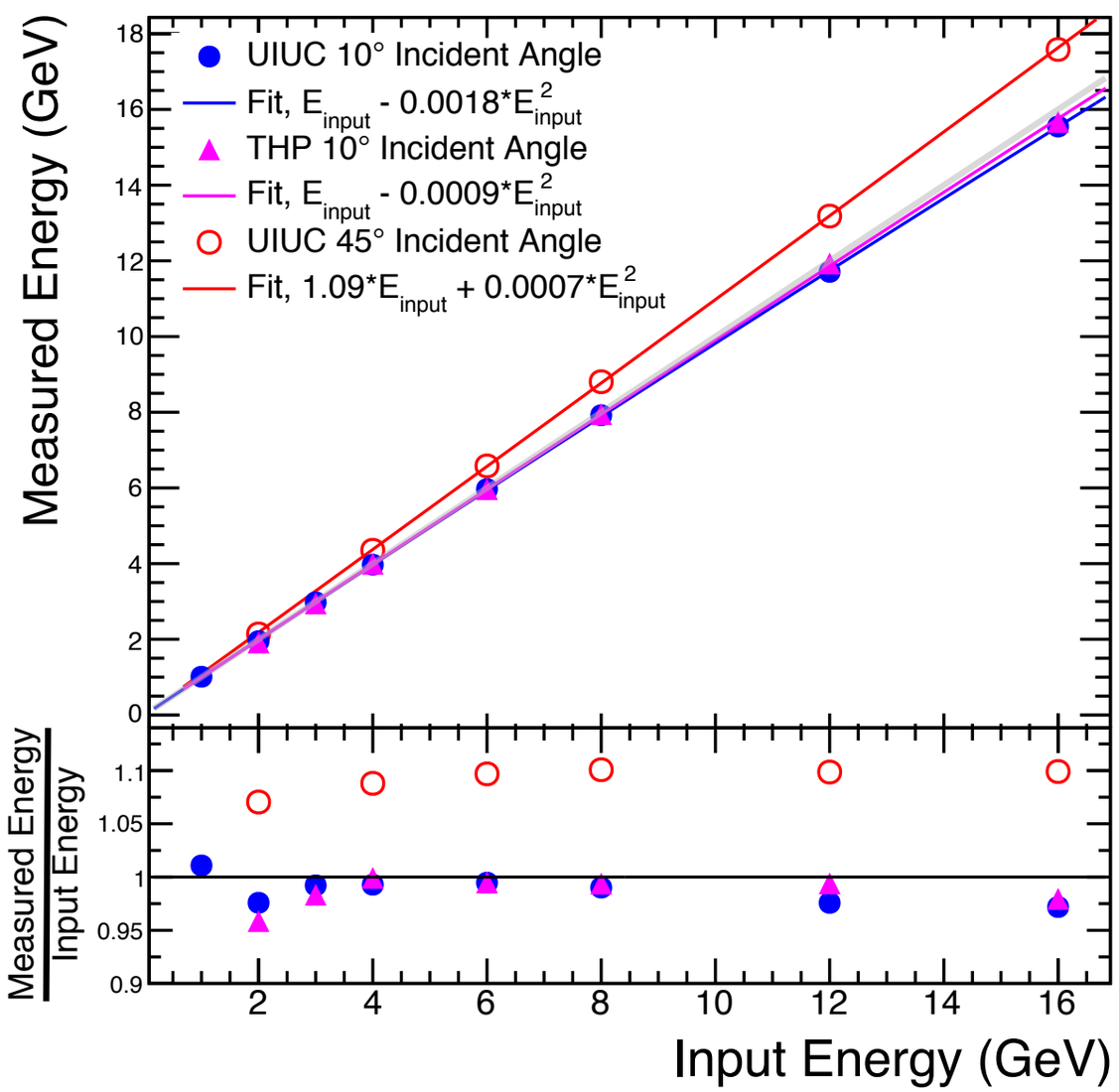
first 2D projective tungsten SPACALs produced at Illinois

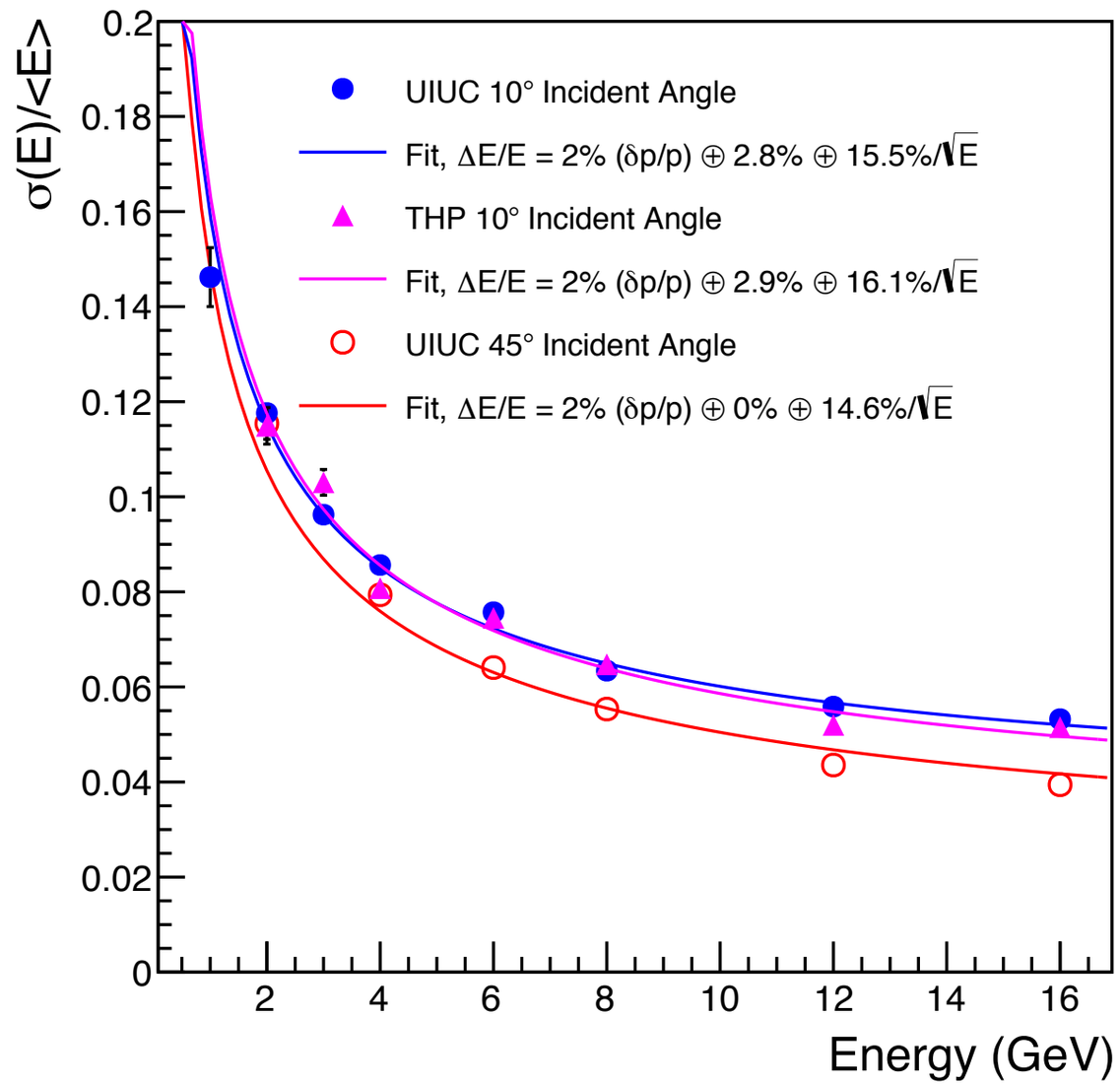
tests of the calorimeter system



- February 2016: $\eta \sim 0$ configuration, submitted for publication: 1704.01461
- April 2017: $|\eta| \sim 1$ configuration, analysis in progress
- (planned) February 2018: final design and electronics

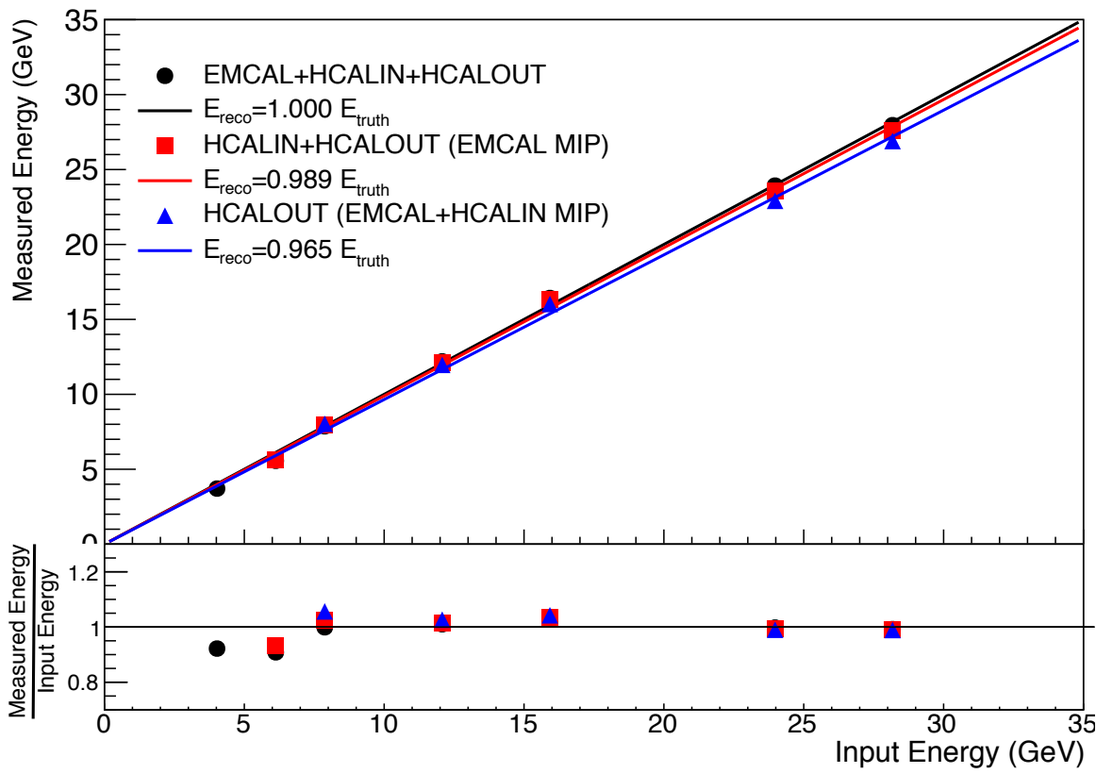
EMCal energy resolution & linearity

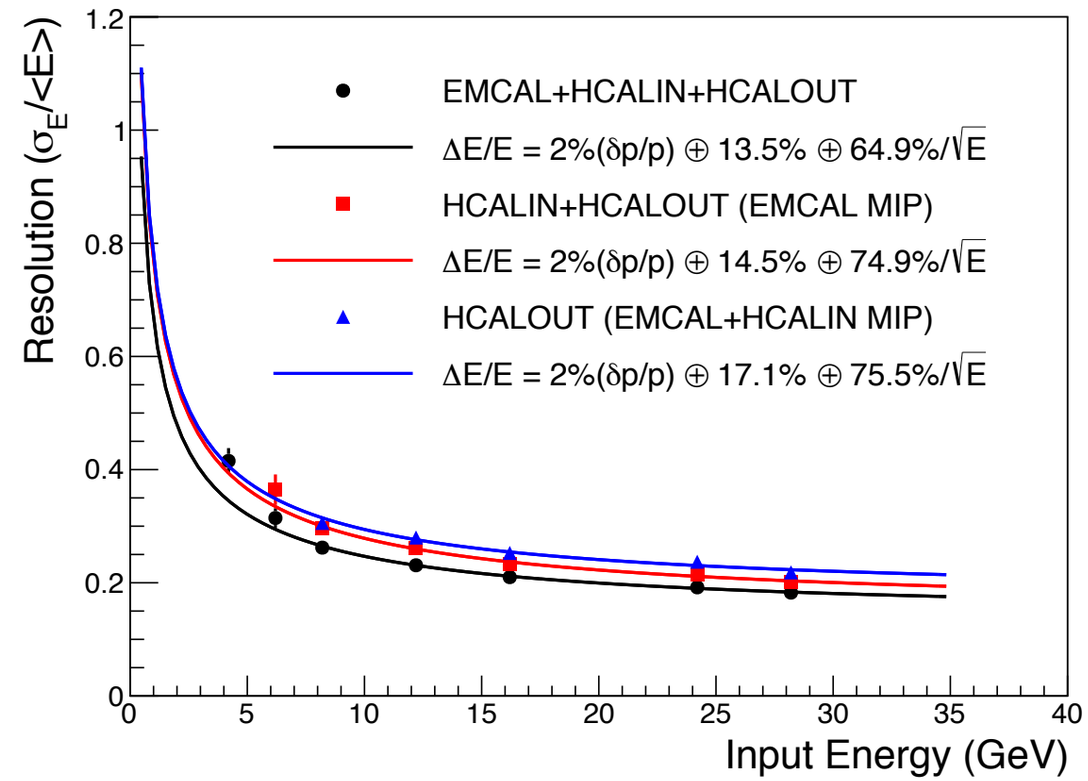


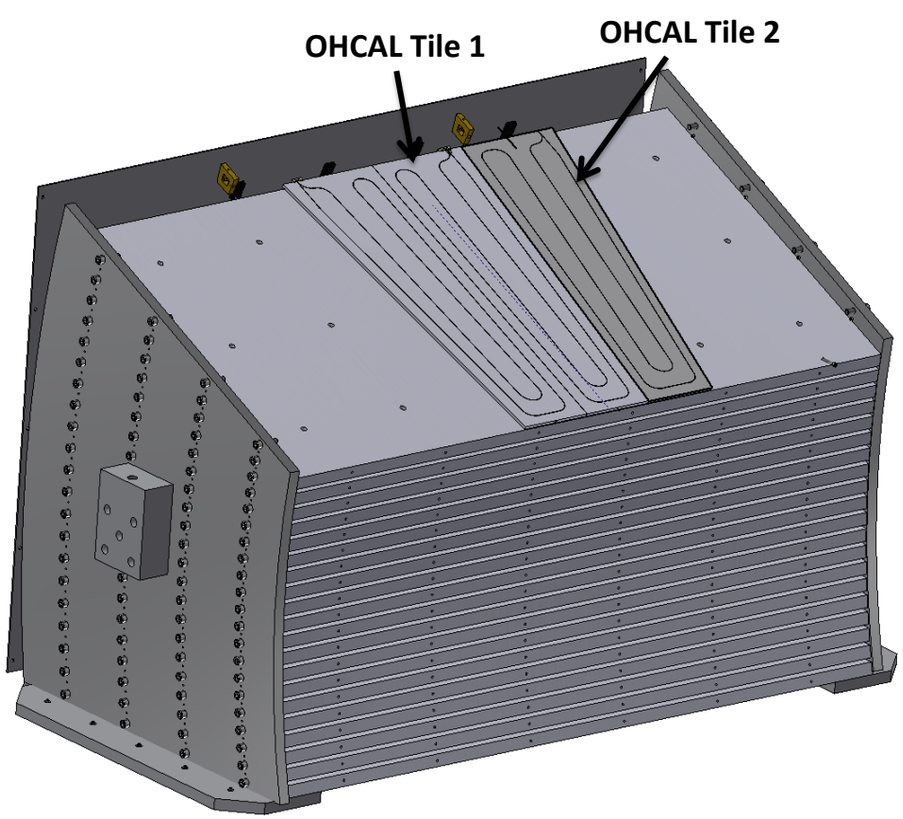


1D projective blocks energy resolution ~15% / √E for **Illinois blocks,** consistent with our specs

HCal resolution







- energy resolution for single particles in combined EMCal + HCal $13.5\% \oplus 64.9\%/\sqrt{E}$
- significantly better than our specs

EMCal 2017 prototype

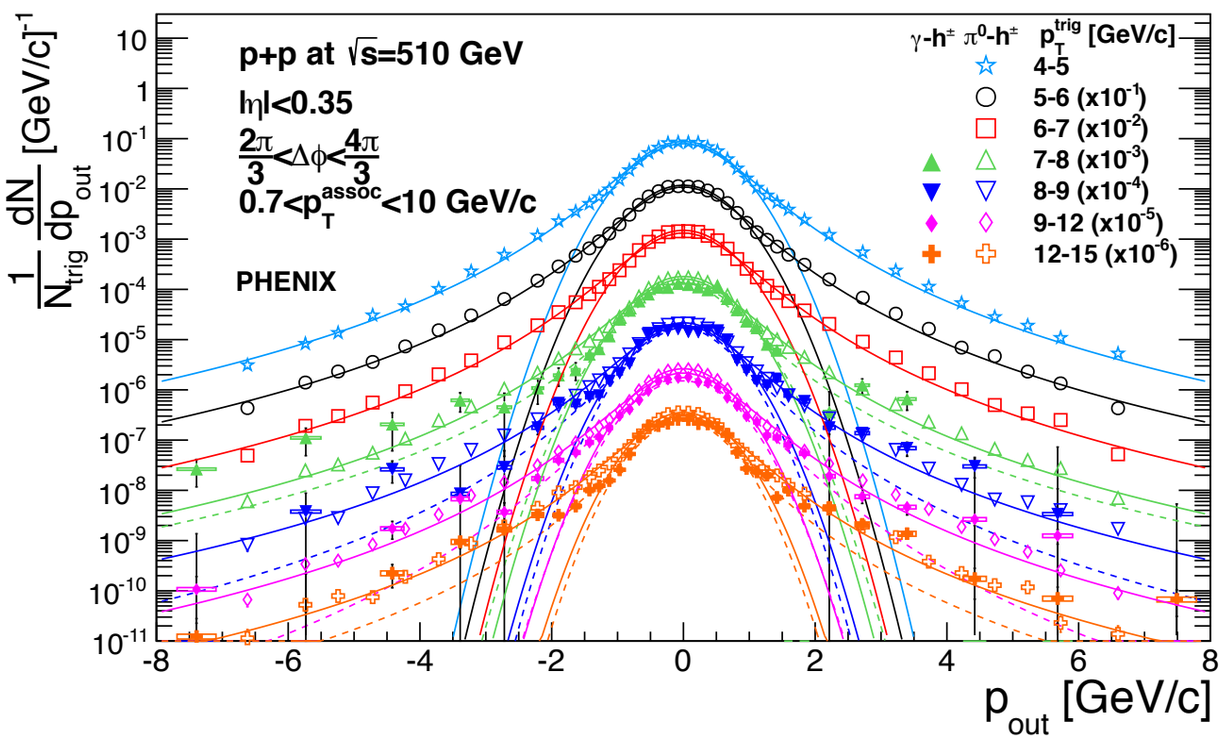
- what was new?
  - 2D projectivity, close to the final design
  - blocks are 2x2 towers → ~twice as large as in 2016 prototype
- longest step is filling the fibers into meshes
  - holes don't line up because of the projectivity so we developed a 3D printed spacer setup to funnel the fibers through; supported with a solo cup and filled by Illinois undergraduates
  - 3D printed molds to cast the blocks

photon-jets in pp

PHENIX: γ-hadron p_{out}

PHYSICAL REVIEW D **95,** 072002 (2017)

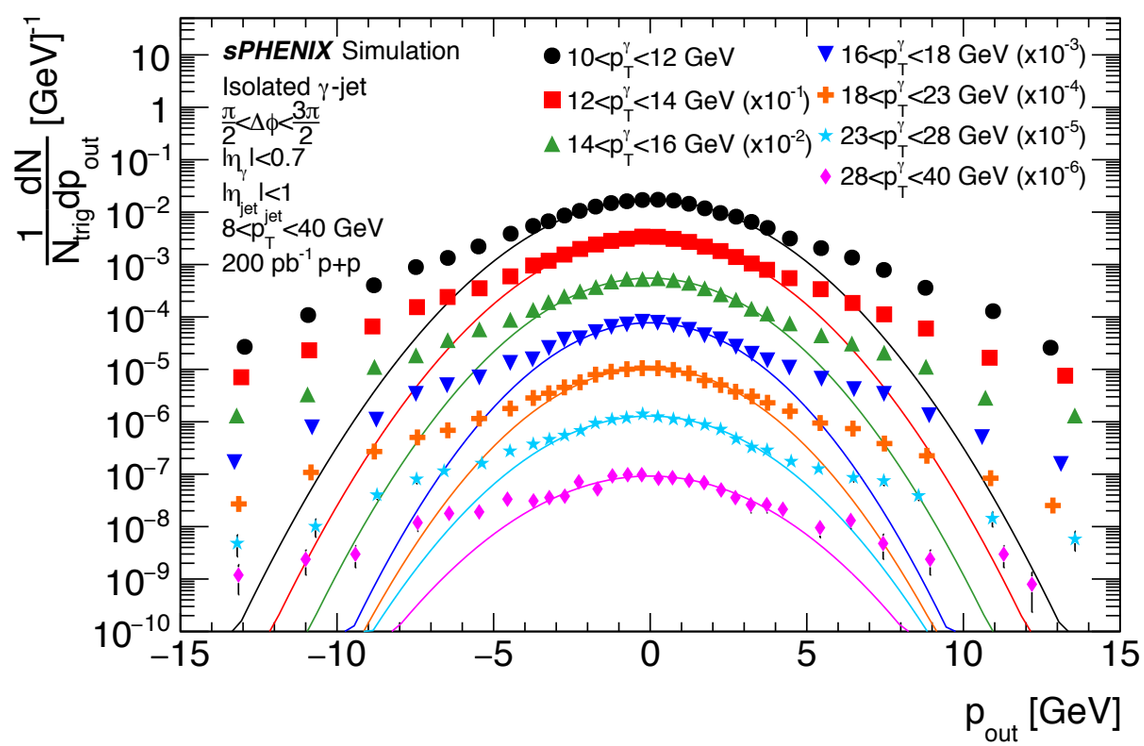
Nonperturbative-transverse-momentum effects and evolution in dihadron and direct photon-hadron angular correlations in $p+p$ collisions at $\sqrt{s}=510$ GeV

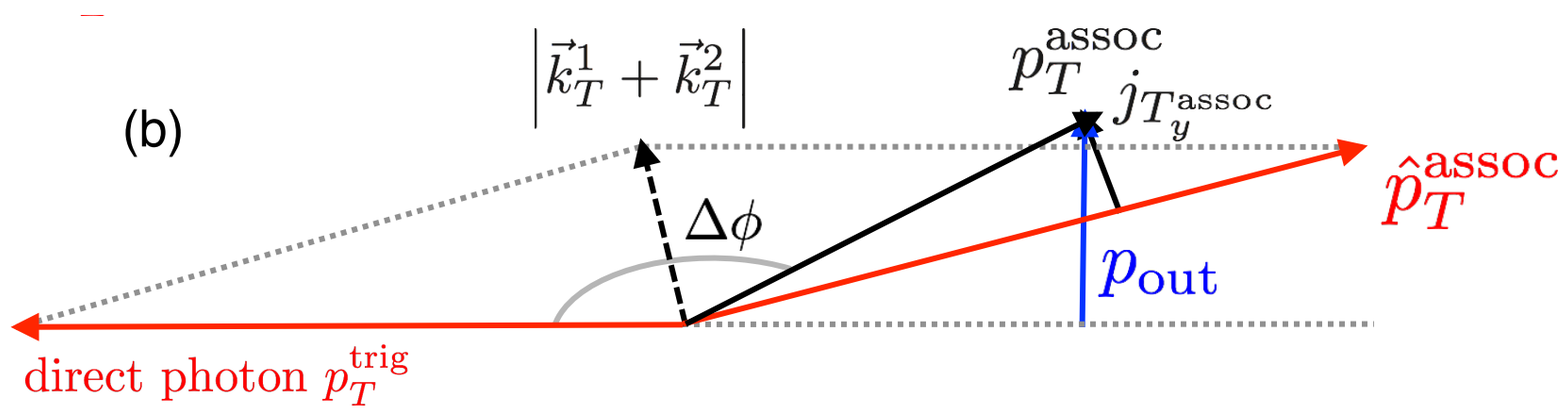


sPHENIX: γ-jet p_{out}

midrapidity

200 pb^{-1} 200 GeV pp





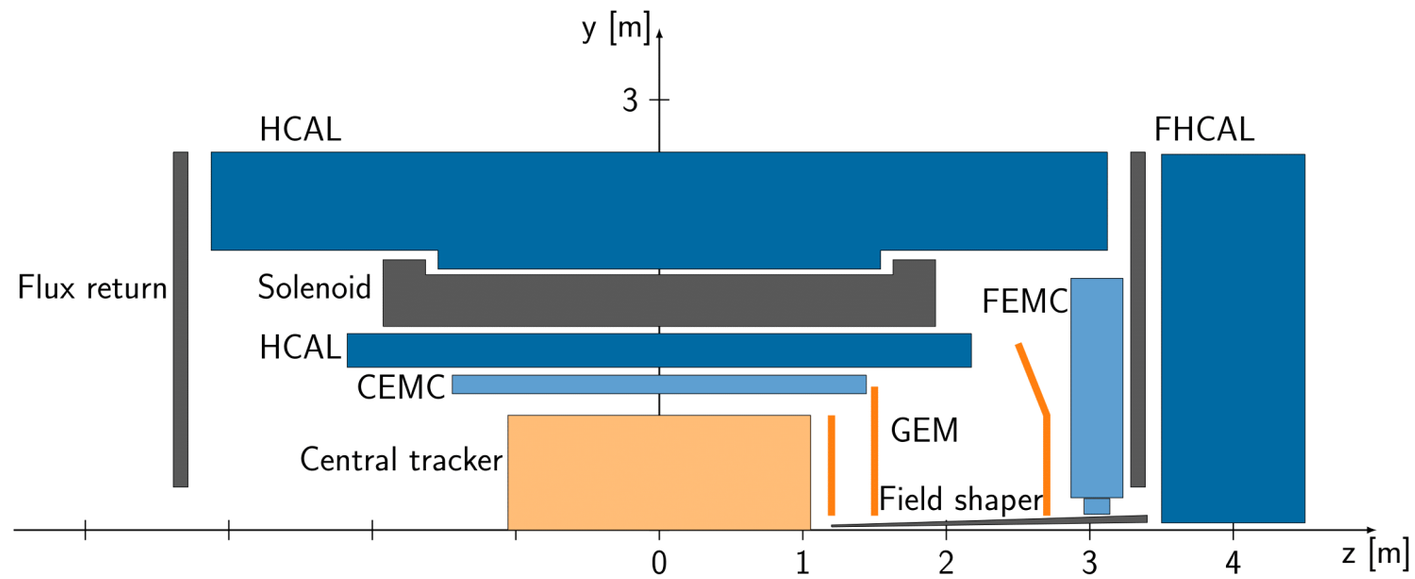
see Joe Osborn's talk Tuesday

sPHENIX Forward Upgrade

Colliding Species and Energy	Scientific Objective	Observable
Au+Au @ 200 GeV	T, μ_B dependence on η	Fourier moments (v_2, etc.) vs. η
	HI initial conditions, early times	rapidity-separated correlations
	energy loss in the QGP	dijets and γ+jet
p↑+Au @ 200 GeV	nuclear PDFs	R_{pAu} for Drell-Yan inclusive jets, dijets $\gamma+$jet
	sea quark dynamics in nuclei medium in small systems	Drell-Yan p_T spectrum rapidity-separated correlations
	quark energy loss proton structure at large x	Drell-Yan and inclusive jets
p↑+p↑ @ 200 GeV	nuclear PDF reference data	Drell-Yan inclusive jets, dijets
	sea quark dynamics spin-momentum correlators	Drell-Yan p_T spectrum hadron A_N
	factorization breaking	$\gamma+$jet, dijets
p↑+p↑ @ 510 GeV	origin of large hadron A_N at high x_F	A_N for flavor-enhanced jets
	transversity at high x, Collins FF	$\gamma+$jet, dijets with hadron in jet hadron asymmetries in jets
	factorization breaking	$\gamma+$jet, dijets

see Joe Osborn's talk Tuesday

sPHENIX-note sPH-cQCD-2017-001



tracking and calorimetry extended to $\eta = 4$

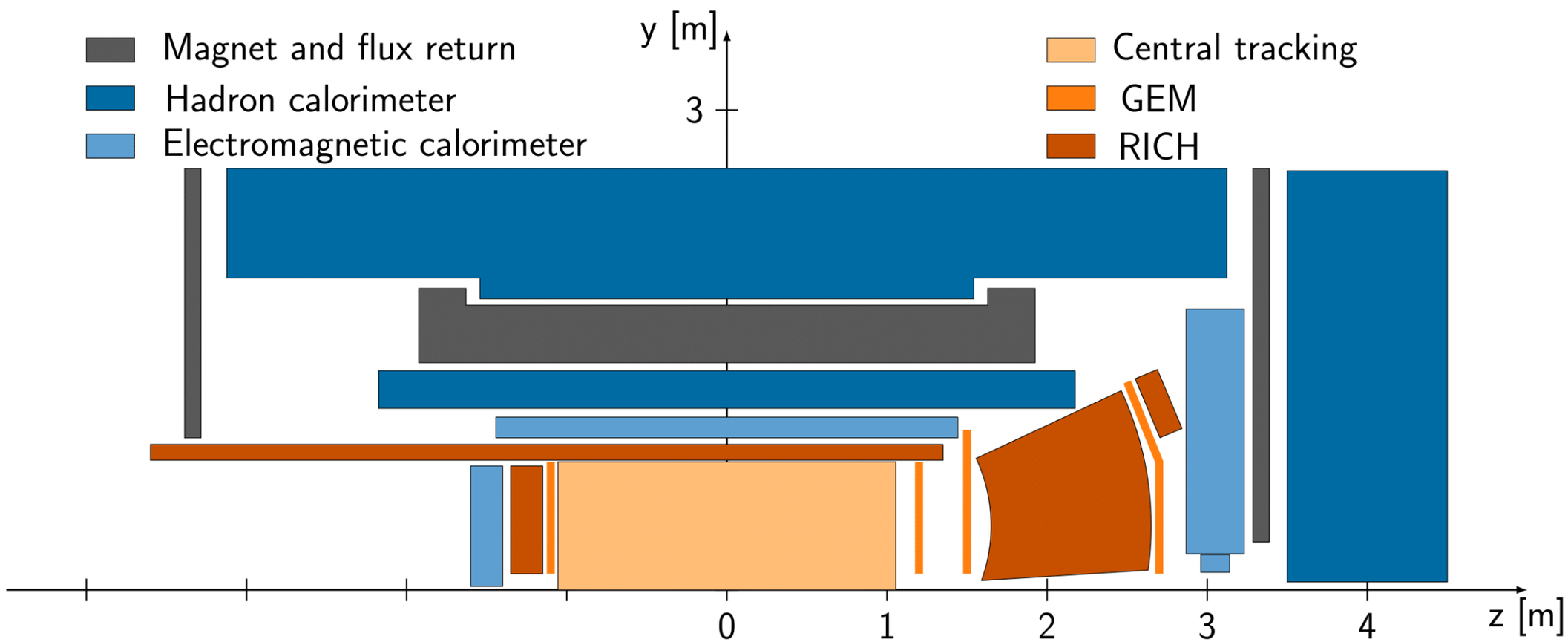
tracking: GEMs

EMCal: refurbished PHENIX EMCal

HCal: PbSc

transition to an EIC detector

- forward upgrades augmented with additional particle ID and detectors in electron going direction is suitable for much of the EIC physics program



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timeline

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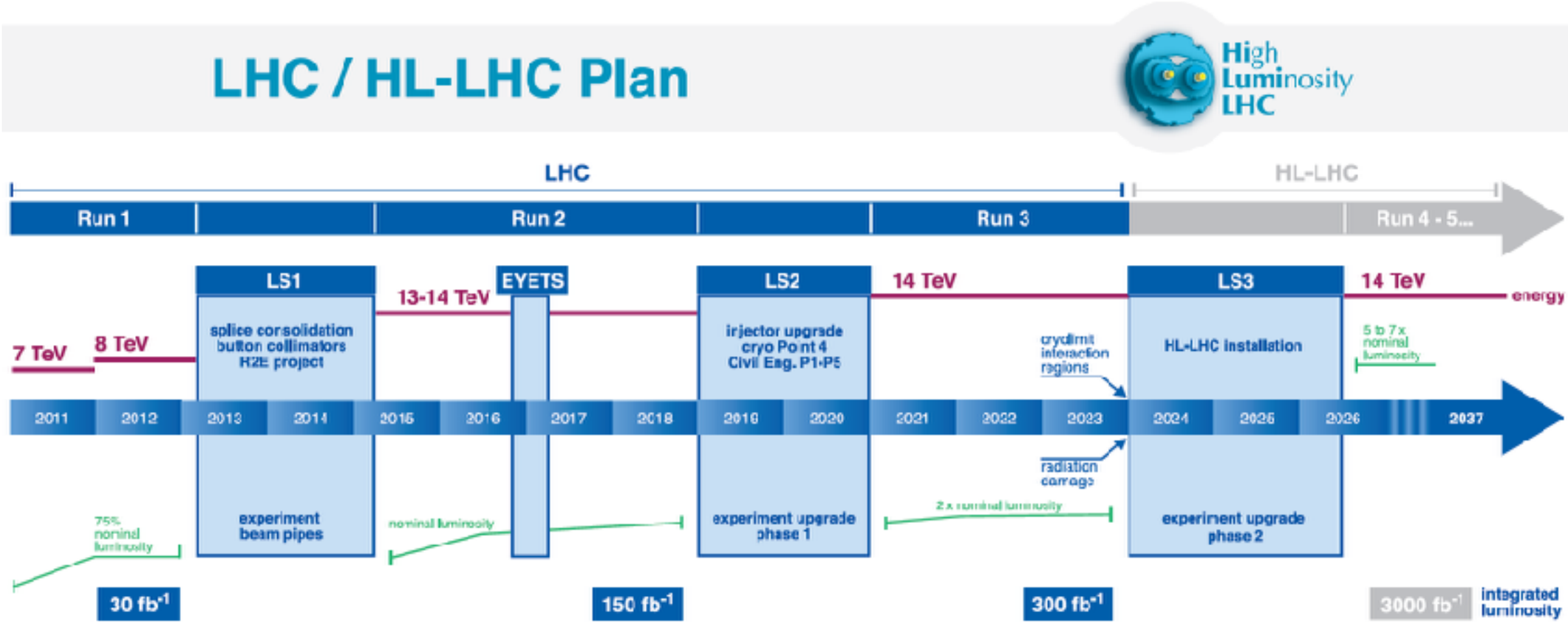

sPHENIX and LHC Run 3 ~coincident

collaboration

Rutgers, 12/15

BNL, 6/16

Georgia State, 12/16

BNL, 5/17

summary

- **a growing collaboration**
  - over the last year, Berkeley, LBNL & Temple joined in December
  - Saclay, CCNU & Purdue made requests to join in May
- **an advanced detector design**
  - validation of calorimeter design in test beams
- **a sophisticated simulation framework**
  - more simulation studies ongoing, realistic detector modeling
  - this list is not exhaustive (of course!)
- **a diverse physics case**
  - *combination of sPHENIX & LHC Run 3 will provide the best opportunity to understand the inner workings of the quark gluon plasma*
  - *rich cold QCD program with the core sPHENIX, interest in forward extensions leading*