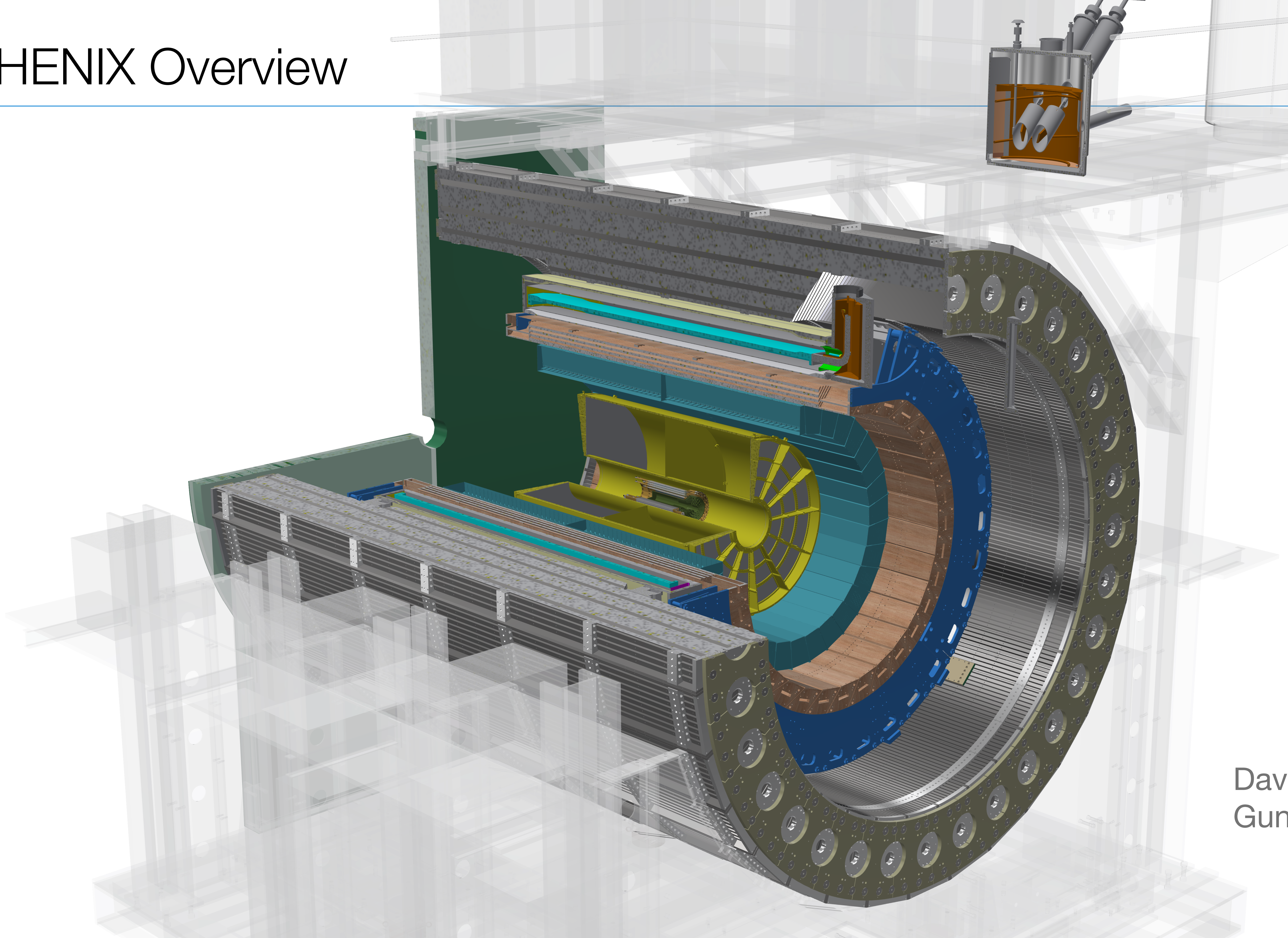
sPHENIX Overview

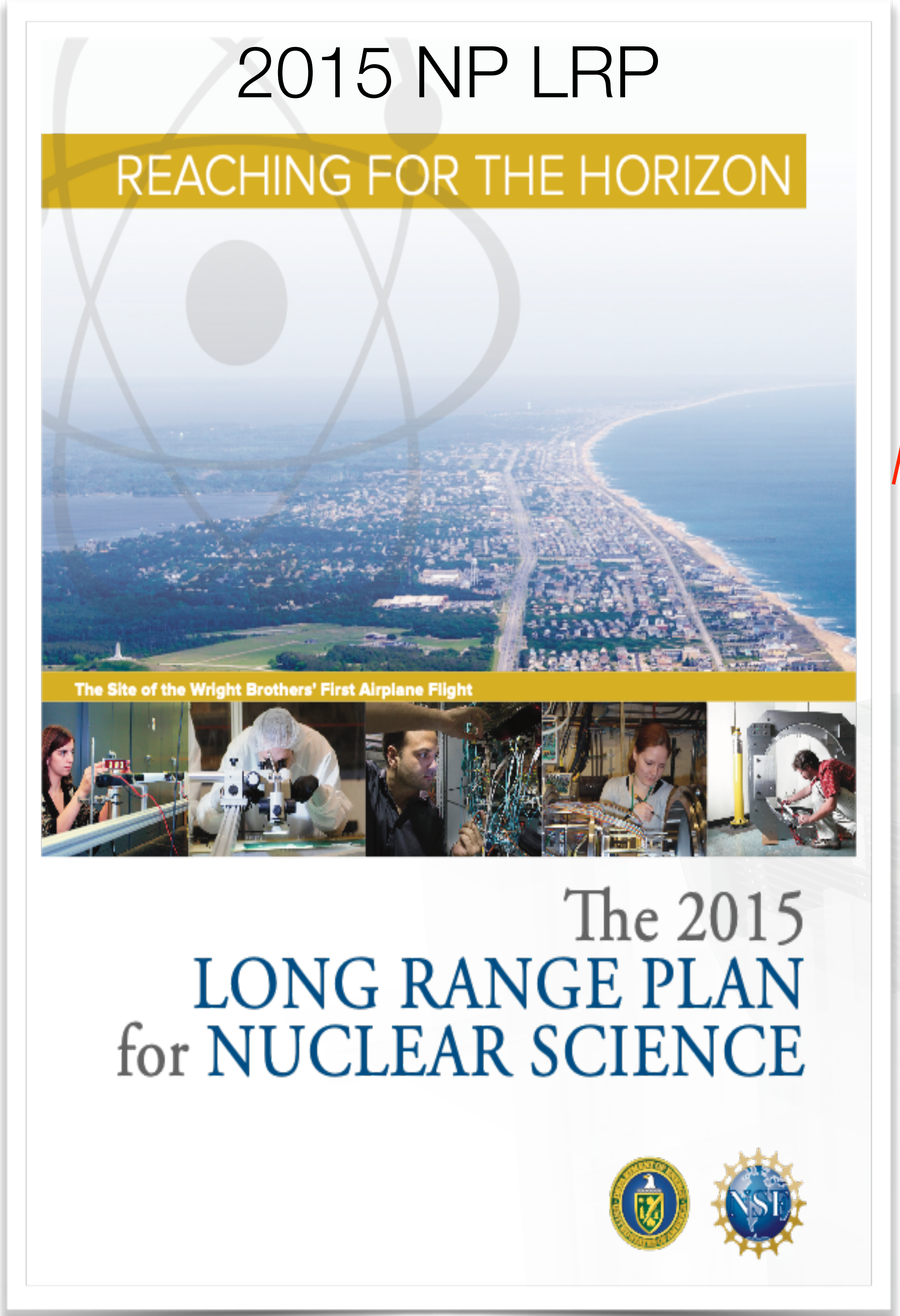


David Morrison (BNL)
Gunther Roland (MIT)
co-spokespersons

sPHENIX Presentations

1. sPHENIX overview (GR,DM)
   - **1st PAC meeting evaluating sPHENIX run plan**
   - **Recall key considerations regarding sPHENIX design, commissioning and operations**
2. sPHENIX run plan (Jamie Nagle)
   - 2023-2025 run plan
   - Commissioning schedule
   - Physics projections
   - Opportunities beyond ’25
3. sPHENIX project status (Ed O’Brien)

sPHENIX Science mission



https://inspirehep.net/literature/1398831

2. Quantum Chromodynamics: The Fundamental Description of the Heart of Visible Matter

describe quark and gluon interactions, the emergent phenomenon that a macroscopic volume of quarks and gluons at extreme temperatures would form a nearly perfect liquid came as a complete surprise and has led to an intriguing puzzle. A perfect liquid would not be expected to have particle excitations, yet QCD is definitive in predicting that a microscope with sufficiently high resolution would reveal quarks and gluons interacting *weakly* at the shortest distance scales within QGP. Nevertheless, the η/s of QGP is so small that there is no sign in its macroscopic motion of any microscopic particlelike constituents; all we can see is a liquid. To this day, nobody understands this dichotomy: how do quarks and gluons conspire to form strongly coupled, nearly perfect liquid QGP?

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.**

This section is organized in three parts: characterization of liquid QGP, mapping the phase diagram of QCD by doping QGP with an excess of quarks over antiquarks, and high-resolution microscopy of QGP to see how quarks and gluons conspire to make a liquid.

EMERGENCE OF NEAR-PERFECT FLUIDITY

The emergent hydrodynamic properties of QGP are not apparent from the underlying QCD theory and were, therefore, largely unanticipated before RHIC. They have been quantified with increasing precision via experiments at both RHIC and the LHC over the last several years. New theoretical tools, including LQCD calculations of the equation-of-state, fully relativistic viscous hydrodynamics, initial quantum fluctuation models, and model calculations done at strong coupling in gauge theories with a dual gravitational description, have allowed us to characterize the degree of fluidity. In the temperature regime created at RHIC, QGP is the most liquidlike liquid known, and comparative analyses of the wealth of bulk observables being measured hint that the hotter QGP created at the LHC has a somewhat larger viscosity. This temperature dependence will be more tightly constrained by upcoming measurements at RHIC and the LHC that will characterize the varying shapes of the sprays of debris produced in different collisions. Analyses to extract this information are analogous to techniques used to learn about the evolution of the universe from tiny fluctuations in the temperature of the cosmic microwave background associated with ripples in the matter density created a short time after the Big Bang (see Sidebar 2.3).

There are still key questions, just as in our universe, about how the rippling liquid is formed initially in a heavy-ion collision. In the short term, this will be addressed using well-understood modeling to run the clock backwards from the debris of the collisions observed in the detectors. Measurements of the gluon distribution and correlations in nuclei at a future EIC together with calculations being developed that relate these quantities to the initial ripples in the QGP will provide a complementary perspective. The key open question here is understanding how a hydrodynamic liquid can form from the matter present at the earliest moments in a nuclear collision as quickly as it does, within a few trillionths of a trillionth of a second.

Geometry and Small Droplets

Connected to the latter question is the question of how large a droplet of matter has to be in order for it to behave like a macroscopic liquid. What is the smallest possible droplet of QGP? Until recently, it was thought that protons or small projectiles impacting large nuclei would not deposit enough energy over a large enough volume to create a droplet of QGP. New measurements, however, have brought surprises about the onset of QGP liquid production.

Measurements in LHC proton-proton collisions, selecting the 0.001% of events that produce the highest particle multiplicity, reveal patterns reminiscent of QGP fluid flow patterns. Data from p+Pb collisions at the LHC give much stronger indications that single small droplets may be formed. The flexibility of RHIC, recently augmented by the EBIS source (a combined NASA and nuclear physics project), is allowing data to be taken for p+Au, d+Au, and ^{3}He+Au collisions, in which energy is deposited initially in one or two or three spots. As these individual droplets expand hydrodynamically, they connect and form interesting QGP geometries as shown in Figure 2.9. If, in fact, tiny liquid droplets are being formed and their geometry can be manipulated, they will provide

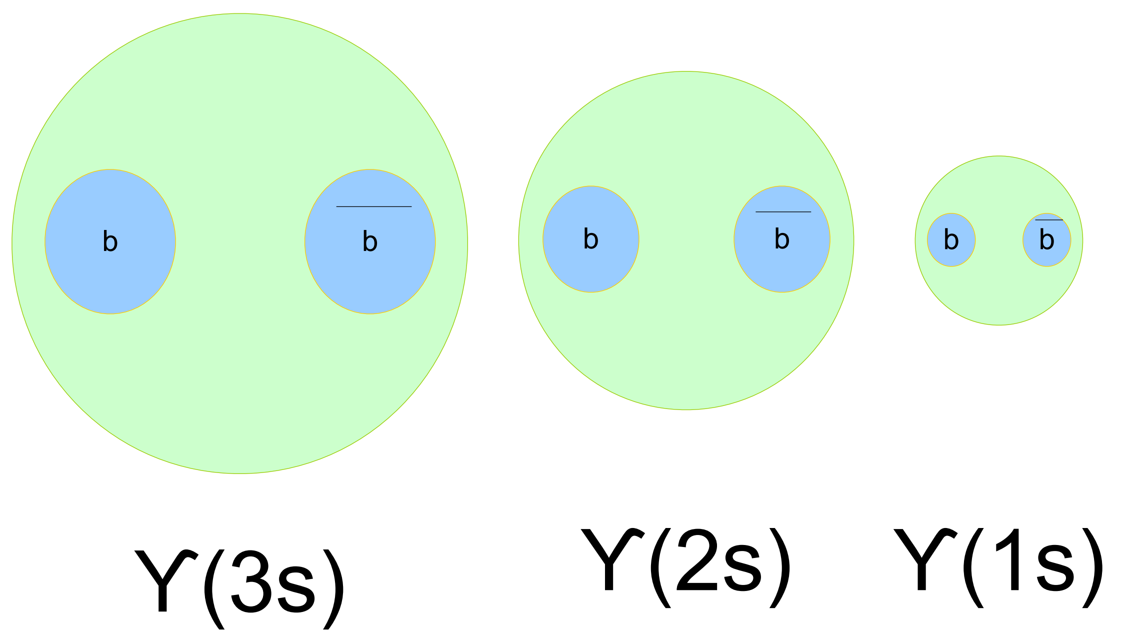
22

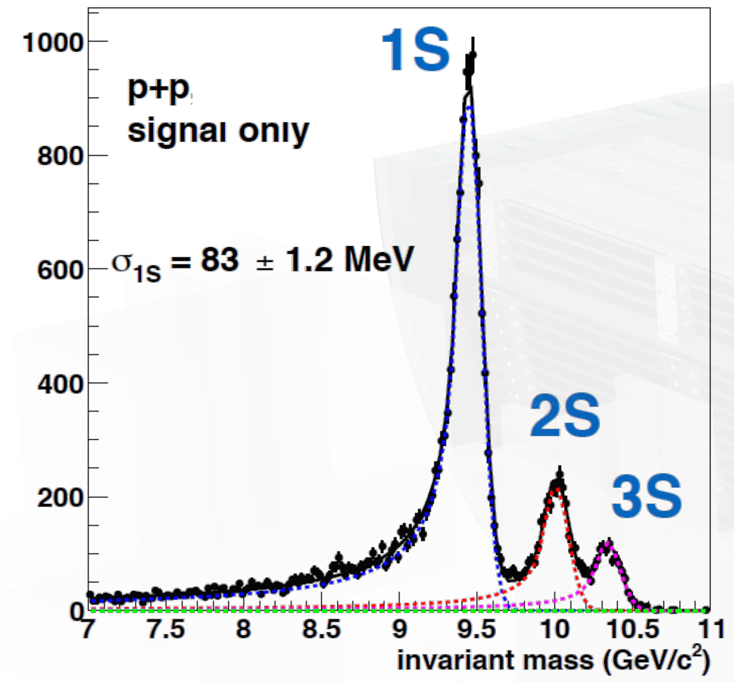
page 22

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.**

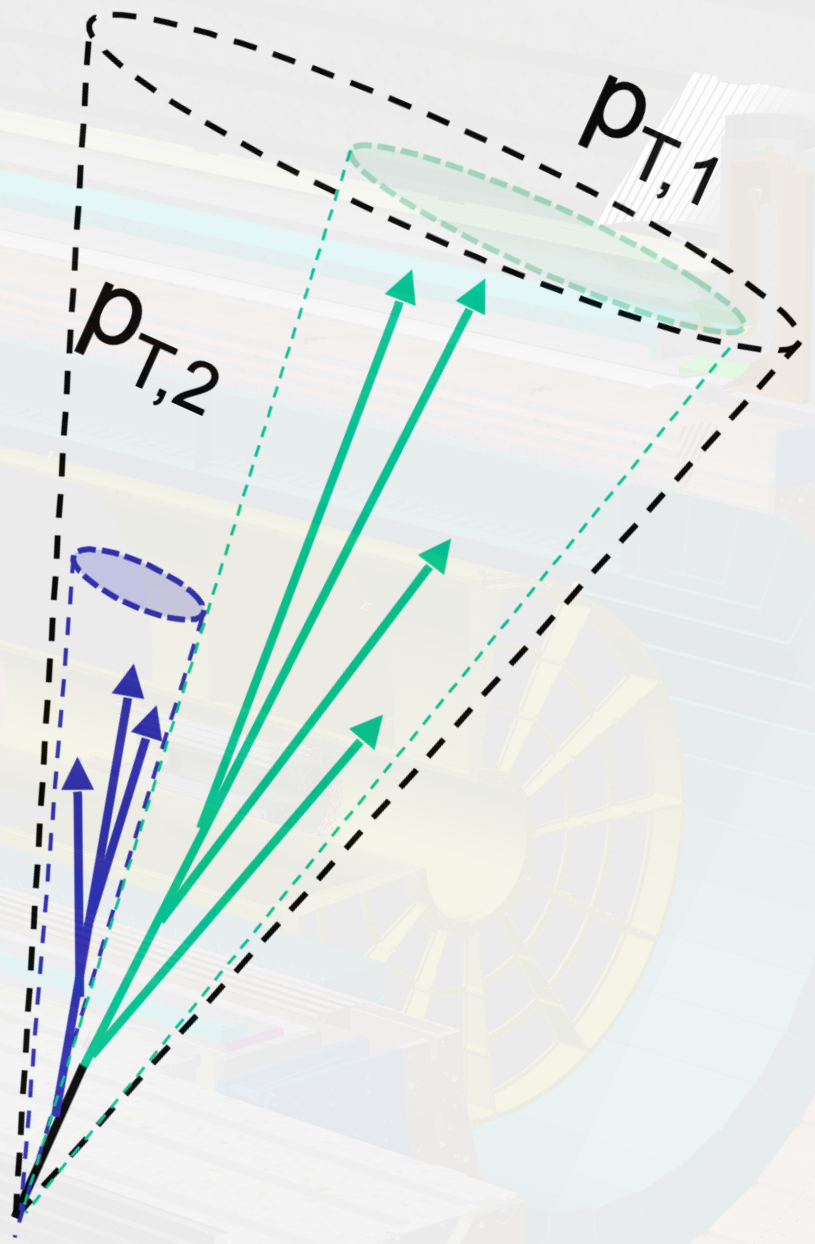
sPHENIX toolbox for QGP studies

Quarkonium spectroscopy
vary size of probe

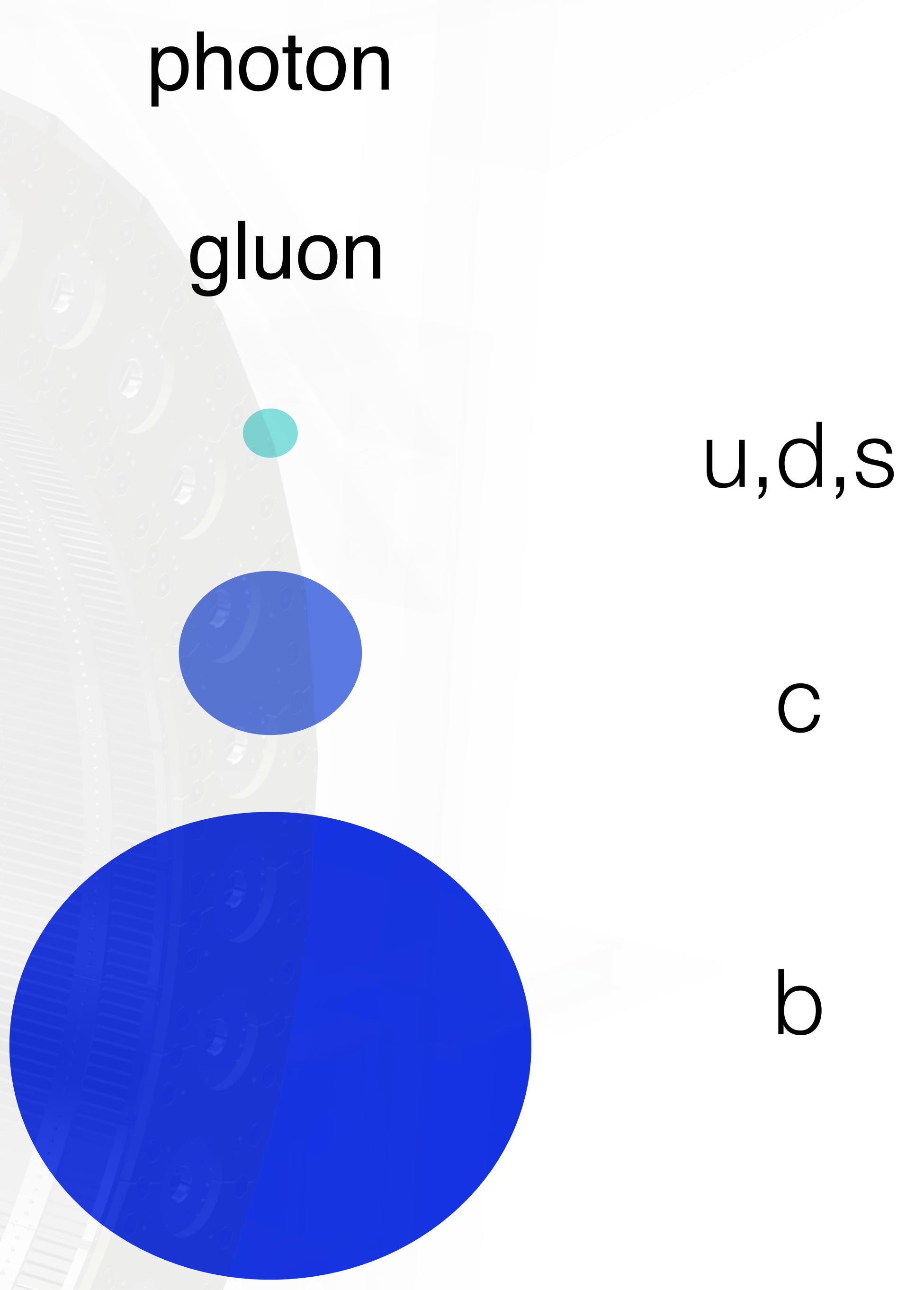




Jet structure
vary momentum/angular scale of probe



Parton energy loss
vary mass/momentum of probe



sPHENIX optimized for high precision studies of jet and heavy flavor probes

Also enables rich bulk QGP and cold QCD program

sPHENIX collaboration growth

2016 | 2017 | 2018

2019

U. Sao Paolo

NCU, Taiwan

Florida AMU

- Steady growth after CD-0
  - 20 new institutions (7 in 2019, 80 total)
    - world-class expertise in relevant physics, silicon, TPCs, calorimetry, electronics, computing
  - about 25% non-US institutions
  - ≈ 300 participants (➔ 400-500 by 2023)
- Steady evolution of collaboration organization
  - Added speaker's bureau (M. Rosati), Diversity committee (V. Greene)
    - regular reports in fortnightly meting, consultation of D,E&I on appointments

sPHENIX organization

sPHENIX Key Considerations

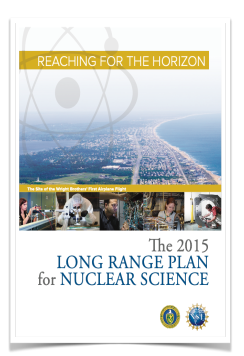
- **’15 LRP recommended installation of a new detector at existing collider**
  - this is unusual (vs LEP, Tevatron, LHC,…)
  - realized as upgrade to PHENIX
  - needs to significantly advance HI physics compared to prior 20 years of data taking
  - **guides detector design and detector/collider operations**
- **’15 LRP, NAS recommend EIC as major NP construction project**
  - EIC @BNL reference schedule implies end of RHIC operations after 2025 run
  - this is unusual (vs prior colliders)
  - **guides construction, commissioning and running schedule**
  - **success of science mission depends on schedule decisions taken now**
    - IP8 infrastructure work needs to be coordinated with RHIC operations
    - **sPHENIX requires 40 weeks of IP8 access to guarantee readiness for 2023 run**

Proposed sPHENIX runs 2023-2025

- 2023 - commissioning of detector, RHIC and data operations with Au+Au
- 2024 - high statistics p+p and p+A reference/cold QCD data
- 2025 - high statistics Au+Au data
- **Each of three runs has distinct, critical role for sPHENIX science mission**
- Collaboration sees this as minimal “safe” schedule, in particular wrt 2023 run
  - ensure safe combined operation of detector and collider
  - provide development time for calibration and reconstruction to ensure timely completion of science mission before EIC
  - key consideration wrt shortening/compressing schedule is increase in **risk**

sPHENIX Schedule

2015	2016	2017	2018	2019	2020	2021	2022	2023



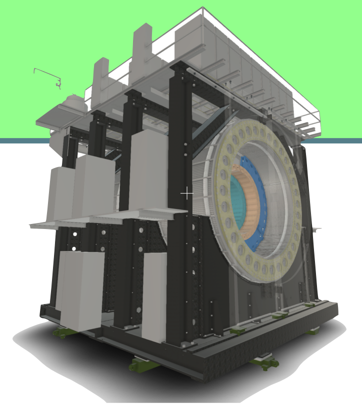
sPHENIX science collaboration

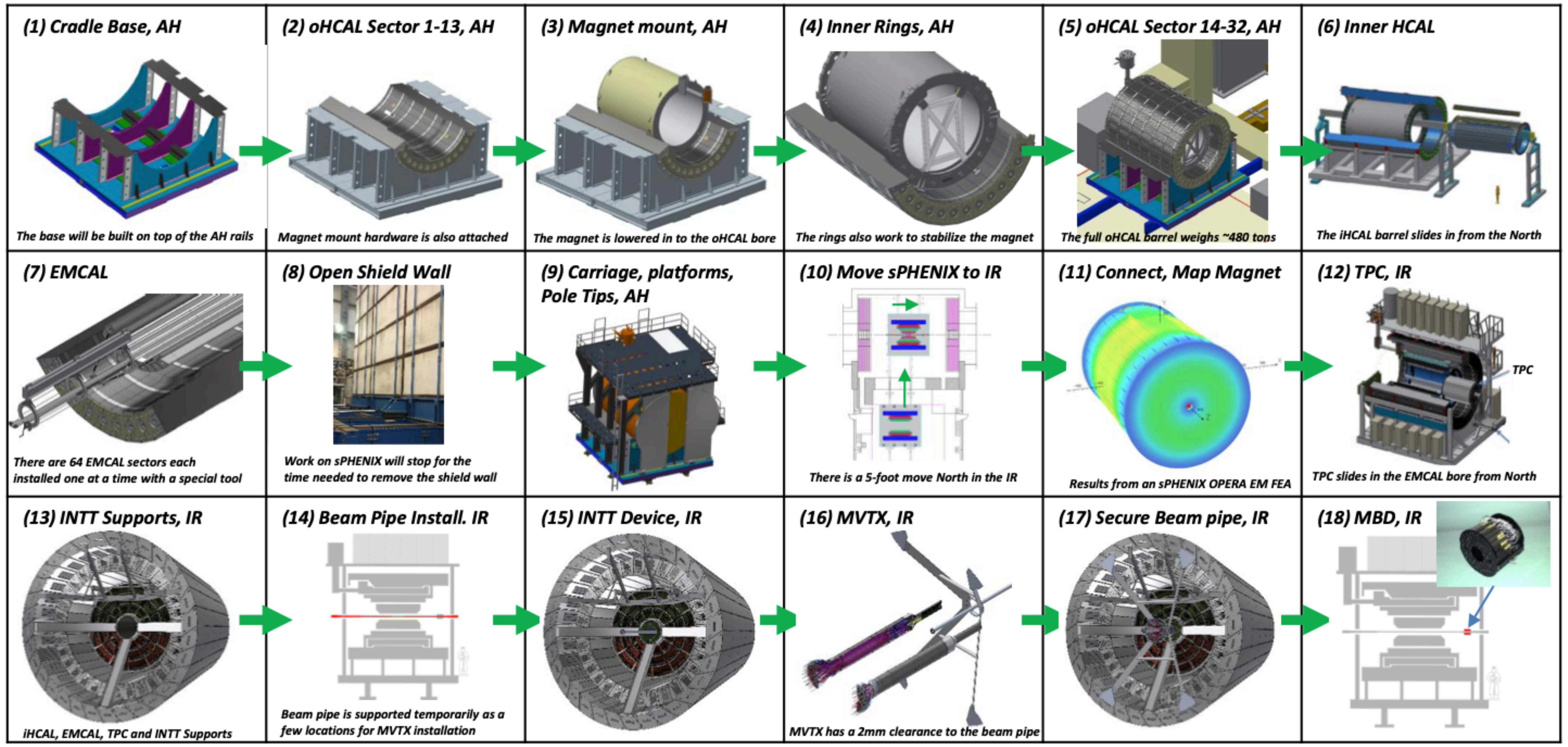
DOE CD-0
"Mission need" approval

DOE CD-1/3A
Cost, schedule, advance purchase approval

BNL PD-2/3
: Final project design approval, authorization to execute

Installation & commissioning





Collaboration and project are committed to sPHENIX being ready for data taking in early 2023

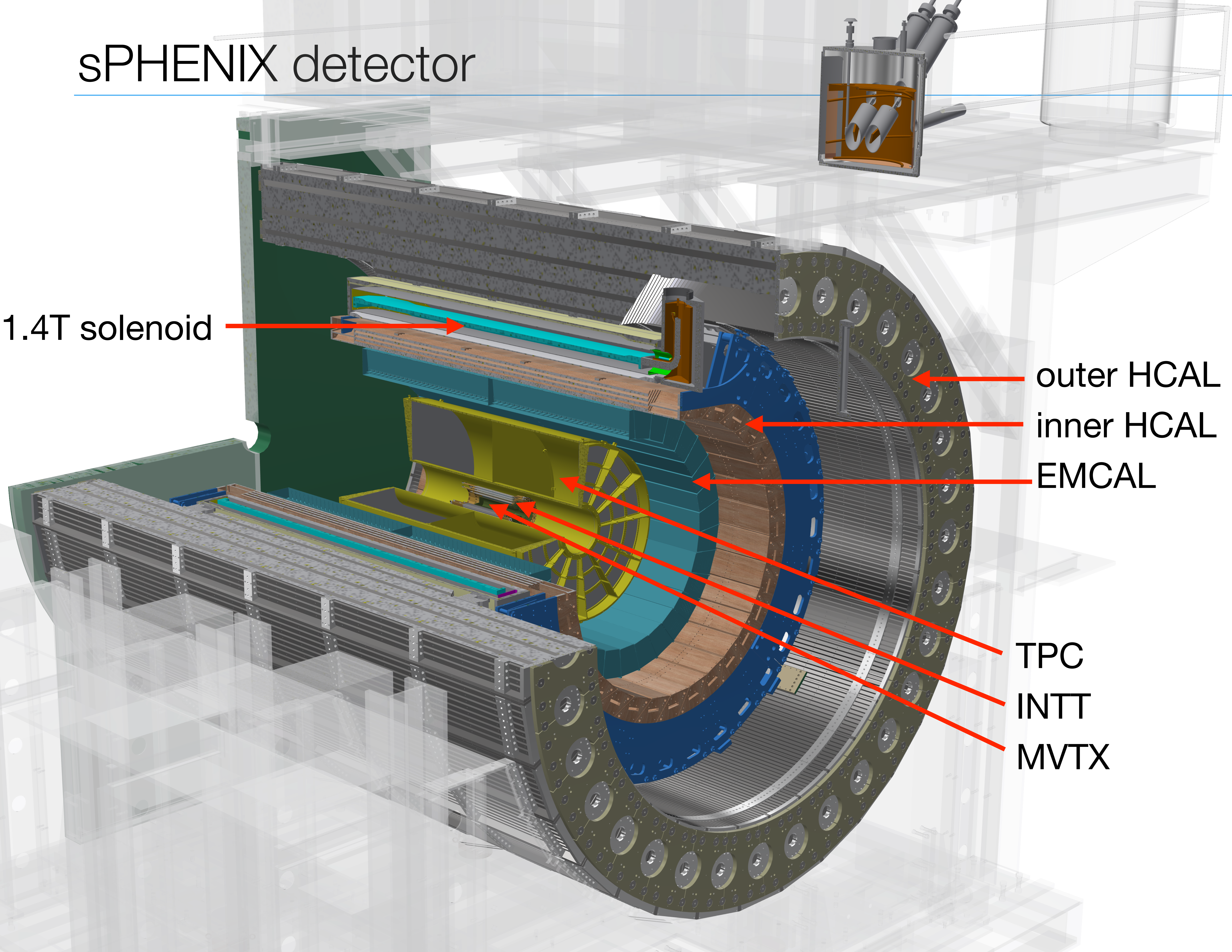
Schedule for IP8 infrastructure work is critical consideration

Physics goals → Detector design and performance

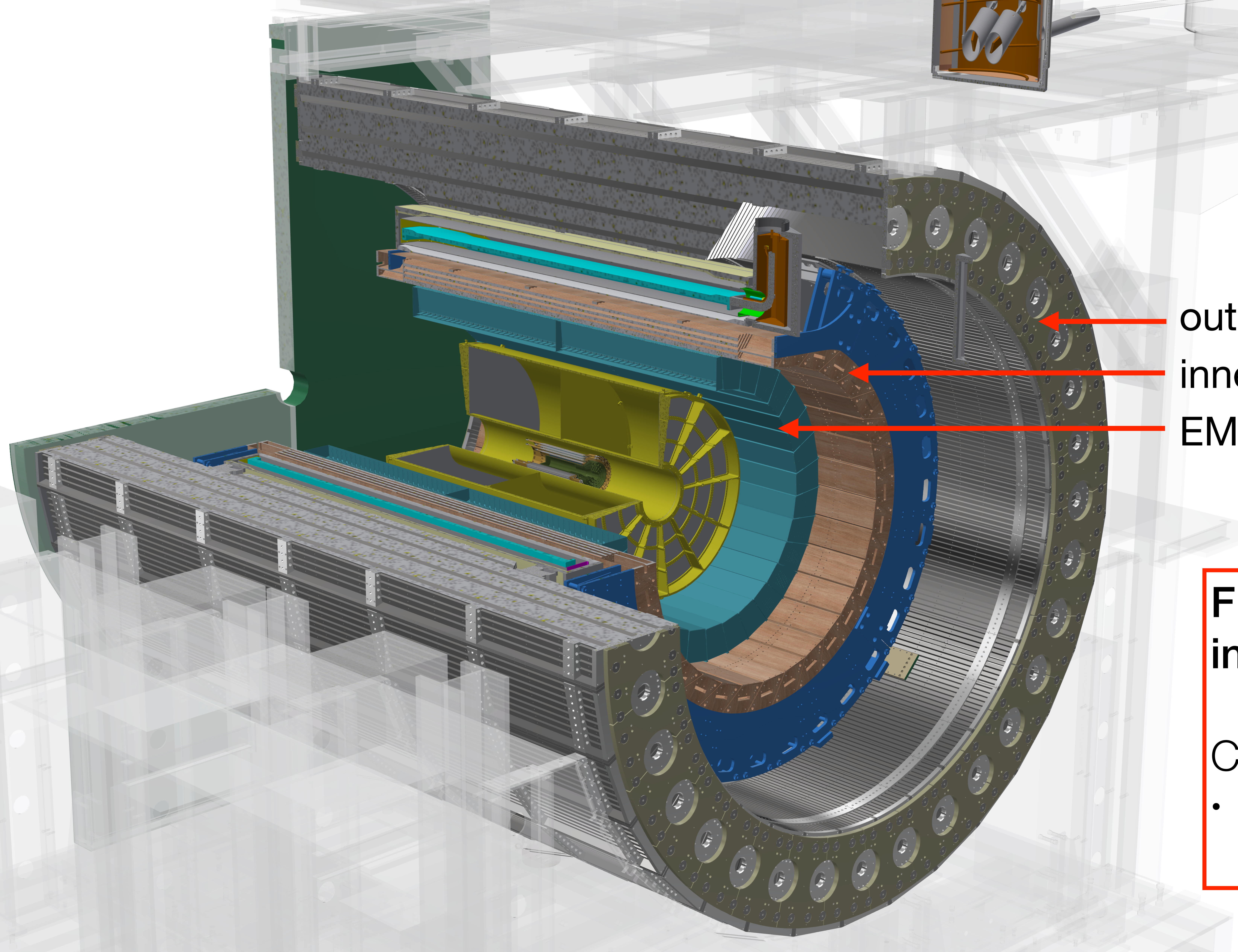
Physics Goal	Analysis Requirement	Performance Goal
Maximize statistics for rare probes	Accept/sample full delivered luminosity	**Data taking rate of 15kHz for Au+Au**
Precision Upsilon spectroscopy	Resolve Y(1s), Y(2s), (Y3s) states	**Y(1s) mass resolution ≤ 125MeV in central Au+Au**
High jet efficiency and resolution	Full hadron and EM calorimetry Jet resolution dominated by irreducible background fluctuations	**$\sigma/\mu \leq 150\%/\sqrt{p_{Tjet}}$ in central Au+Au for R=0.2 jets**
Full characterization of jet final state	High efficiency tracking for $0.2 < p_T < 40$GeV	**Tracking efficiency ≥ 90% in central Au+Au** **Momentum resolution ≤ 10% for p_T = 40 GeV**
Control over initial parton p_T w/ photon tag	Photon energy resolution dominated by irreducible higher order effects	**Single photon resolution ≤ 8% for p_T = 15 GeV in central Au+Au**
Control over initial parton p_T	Topological identification of heavy flavor hadron decays	**High resolution secondary vertex identification (DCA < 30μm @ 1GeV)**

Success of LHC multi-purpose experiments in HI physics demonstrates importance of large acceptance, high resolution tracking, high collision rates and full EM+Hadronic calorimetry

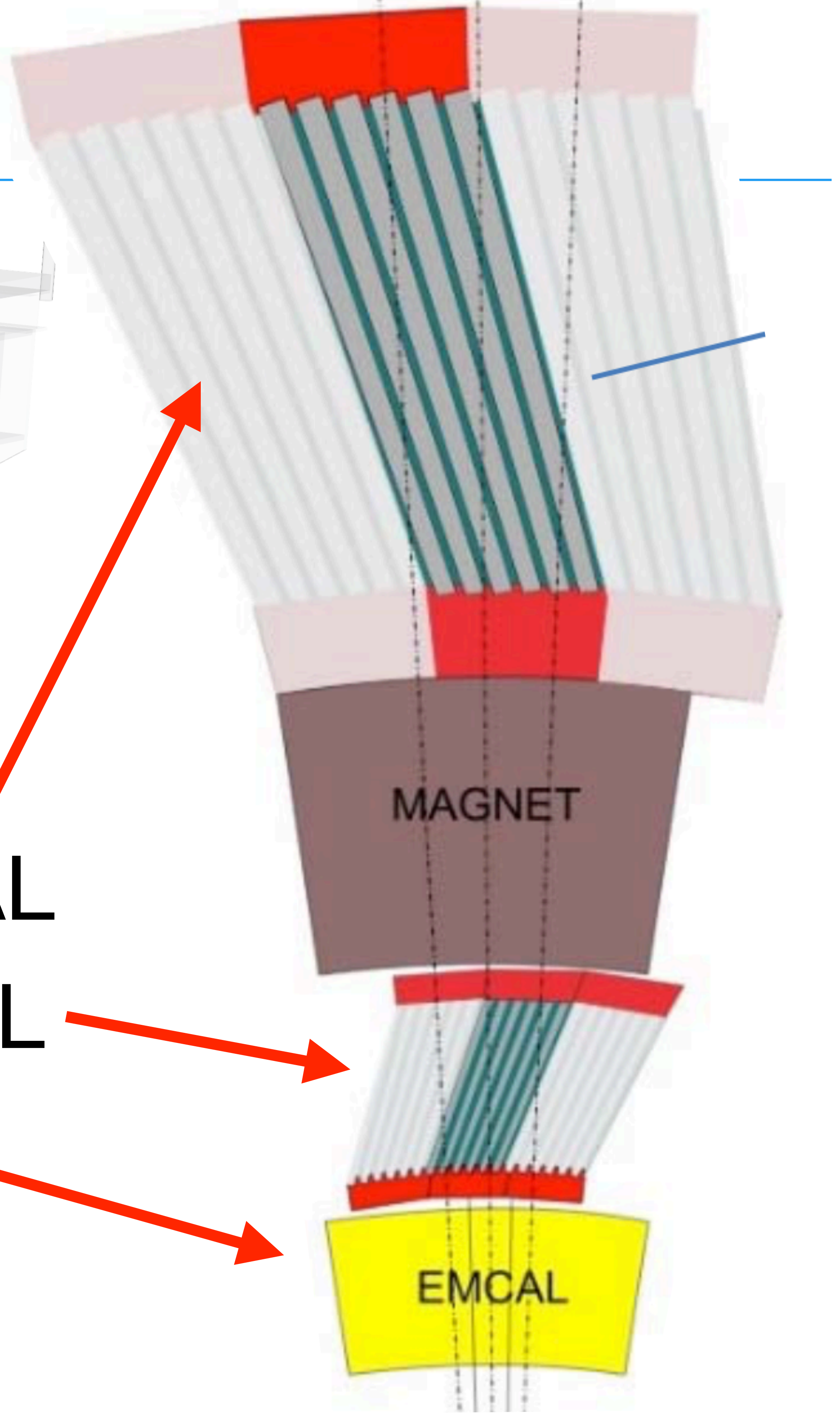
sPHENIX detector



sPHENIX calorimeters



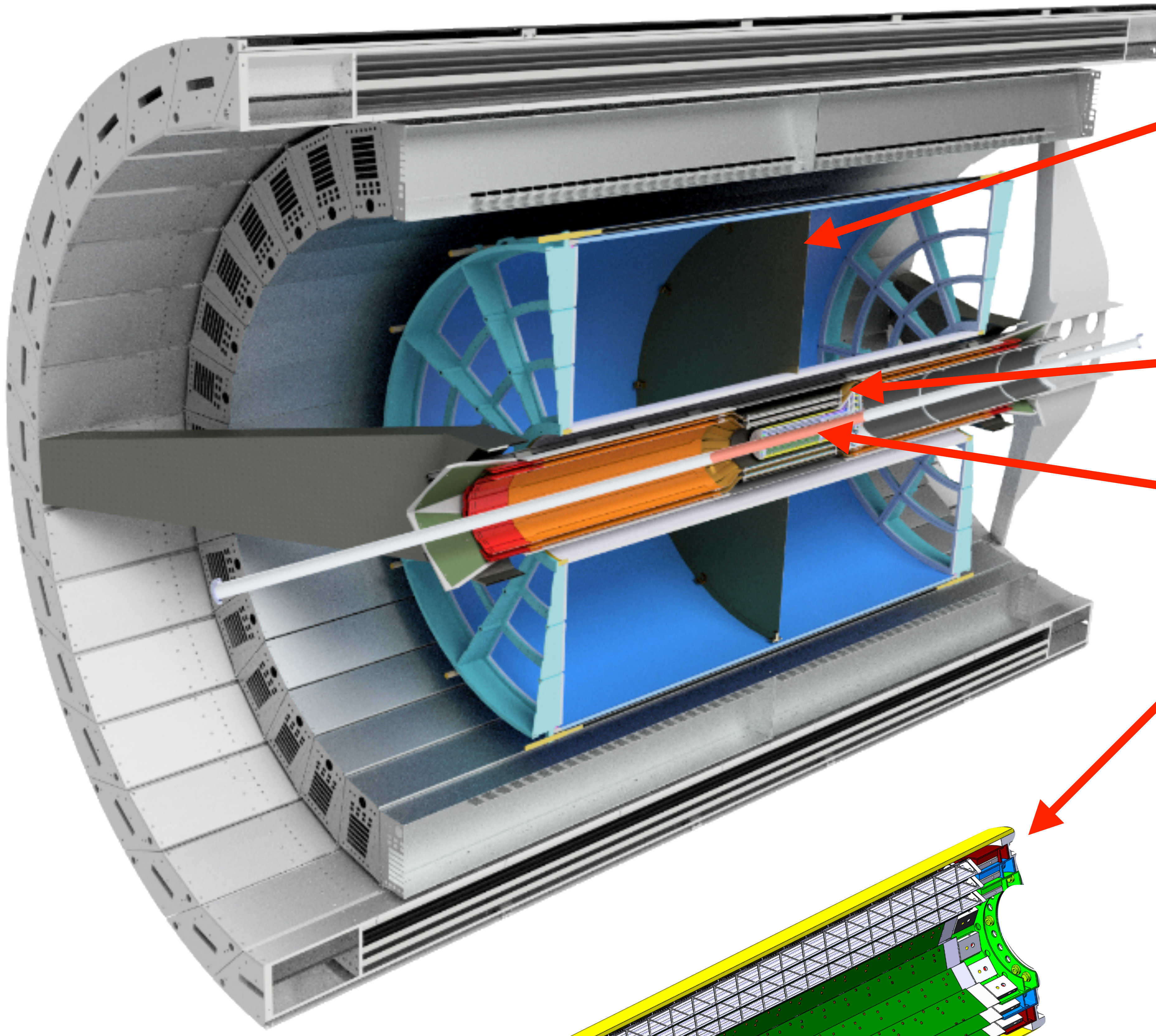
outer HCAL
inner HCAL
EMCAL



First @ RHIC: Full calorimeter stack incl. hadronic calo

Challenge:
- Absolute calibration of jet response (JES, JER)

sPHENIX Tracking detectors



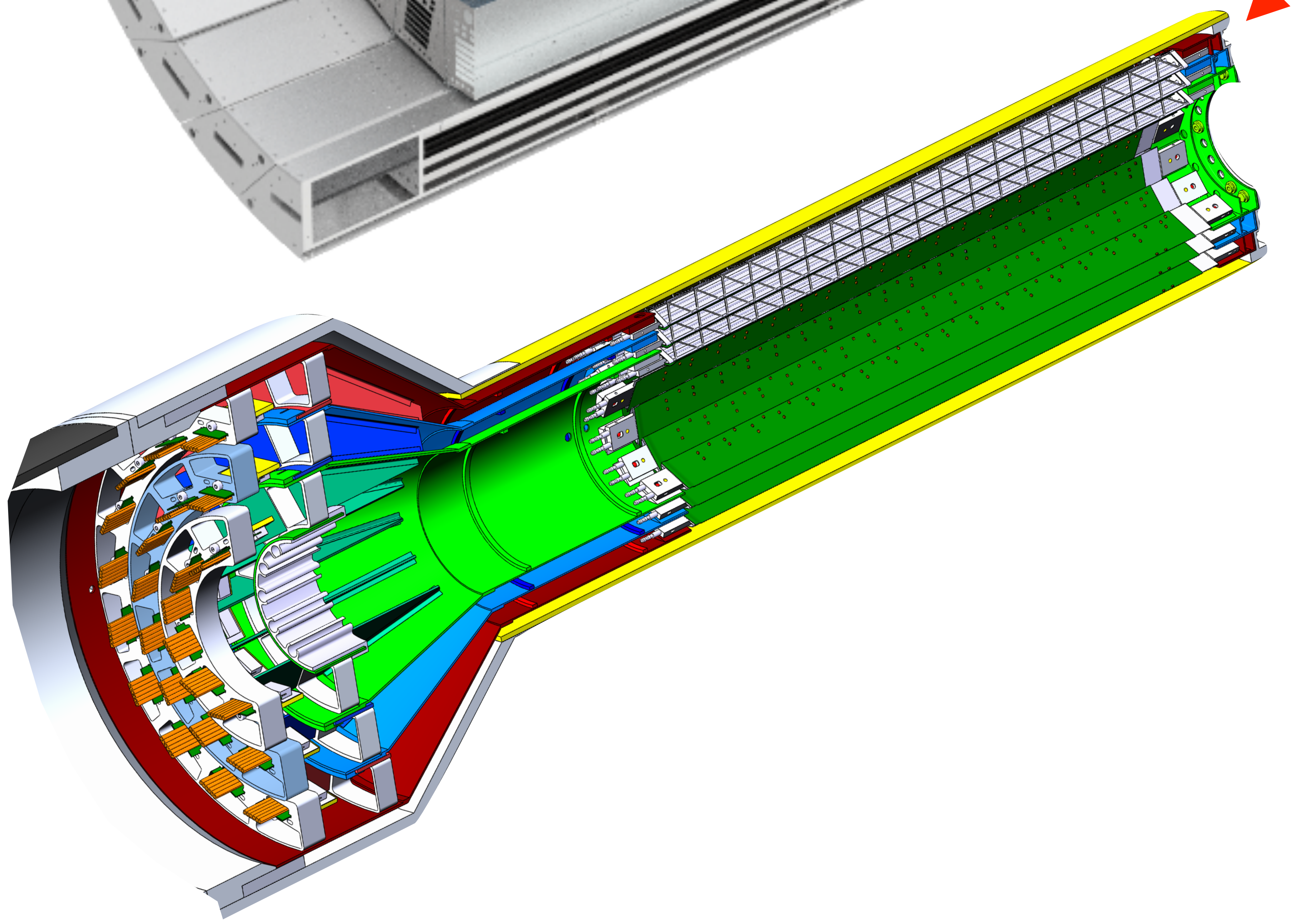
Continuous readout TPC (R = 20-78cm)

- shares many concepts with ALICE TPC upgrade

Si strip intermediate tracker (INTT, R = 6-12cm)

3 layer MVTX vertex tracker (R = 2.3, 3.1, 3.9cm)

- based on ALICE ITS IB detector



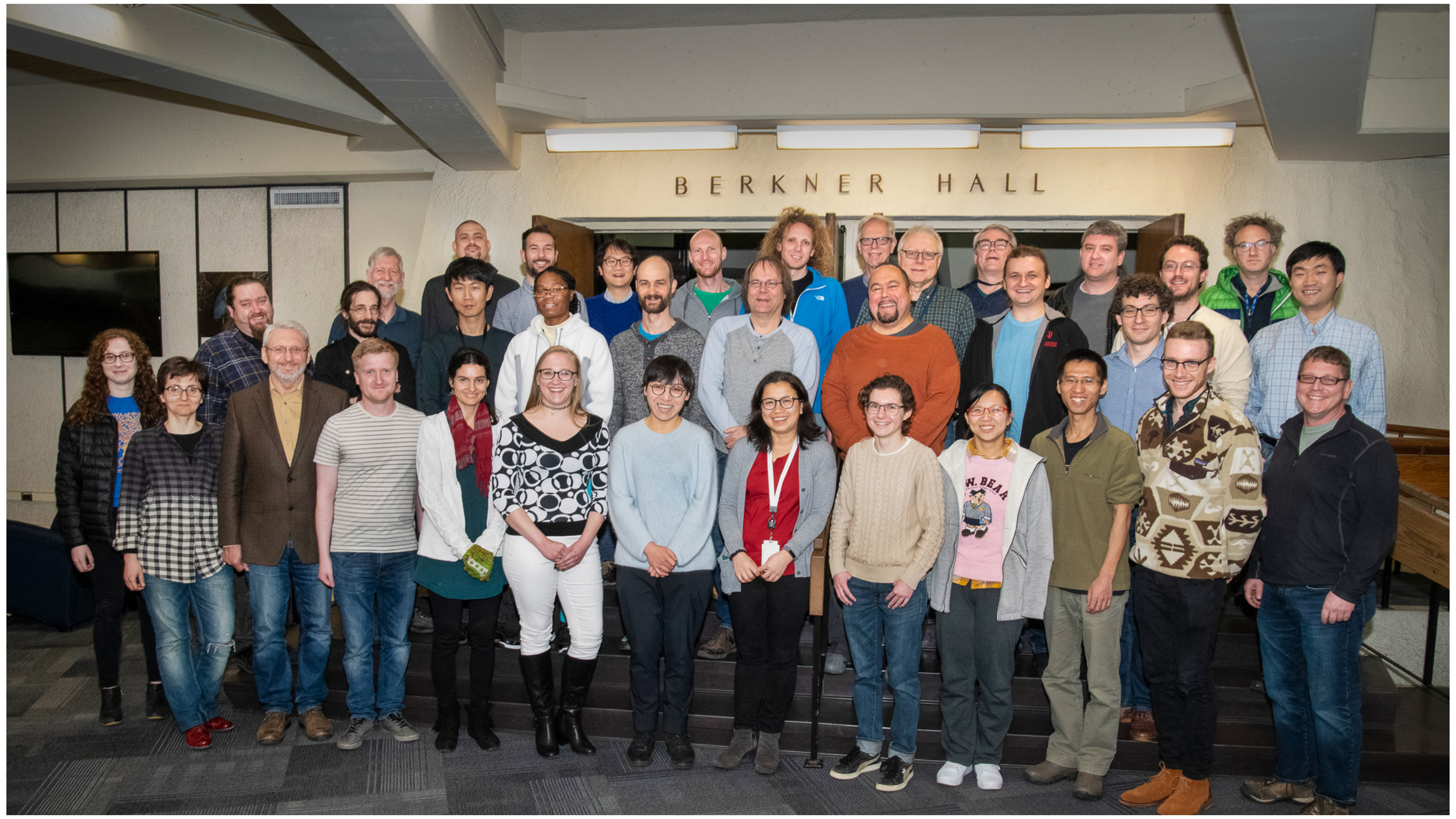
First @ RHIC: Large acceptance high-rate tracking

Challenges:

- track reconstruction CPU time
- TPC distortion correction
  - n.b., with delayed LHC schedule, first HI operation of ALICE TPC only in Nov '22

Software/Computing

- **Key principle: Reconstruction with fixed, short latency**
  - Rapid diagnosis of rare failures
  - Timely completion of science program
  - → Reconstruction time budget of 5s/event
- **Challenges**
  - TPC distortion correction
  - Jet energy calibration
- **Collaboration on common software:**
  - Workfest w/ ALICE/STAR (July ’19)
  - Workfest w/ ALICE/STAR/CBM/ATLAS (Jan ’20)
- **Main efforts:**
  - ACTS tracking, CA seeding (ATLAS, ALICE, STAR)
  - TPC distortion correction (ALICE)
  - Particle flow jet reconstruction (CMS/ATLAS)



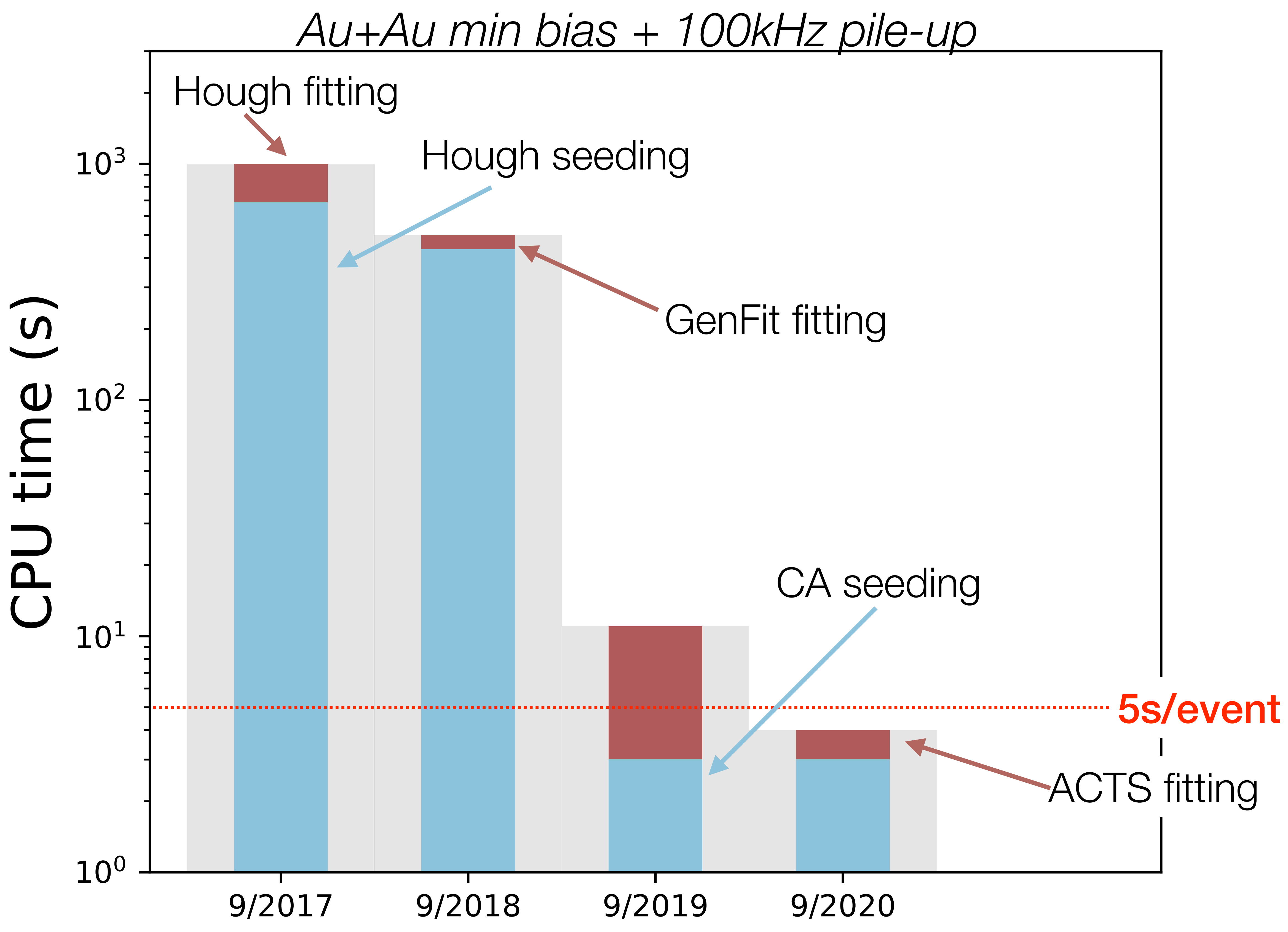
Charged particle reconstruction

Main principle is reconstruction with fixed, short latency

- e.g., latency for CMS “prompt reco” is 72h

Consequence (sPHENIX S&C reviews in ’18, ’19):

- Reconstruction time budget of 5s/event → speed-up of tracking by 200x required



Speed-up:

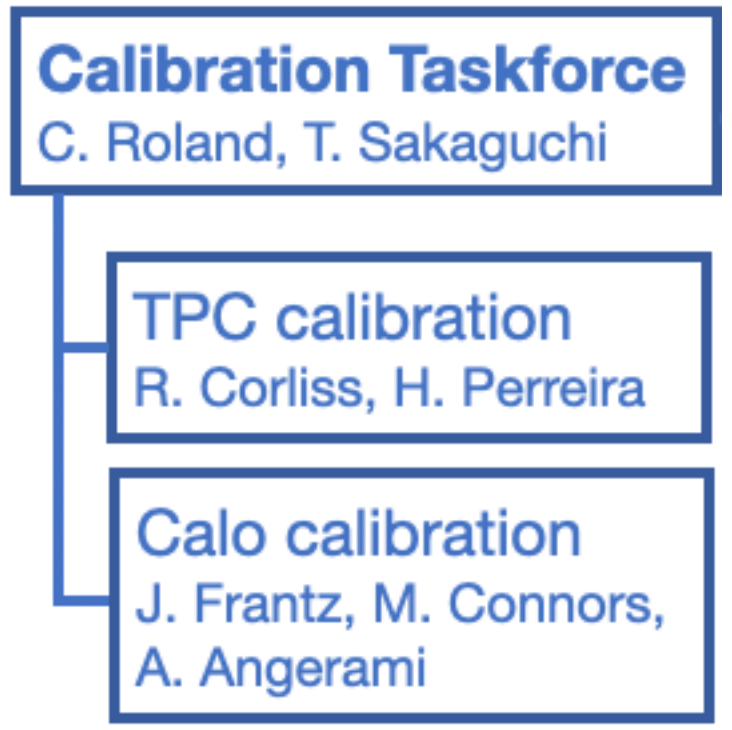
- Cellular Automaton track seeding (ALICE/STAR)
  - time/event: **460s (Hough) to 3s (CA)**
- ATLAS ACTS package track propagator/fitter
  - time/track: **40ms (GenFit) to < 1ms (ACTS)**
- Work continuing on integration and tuning
- 5s/event goal (nearly) reached
- Mock data challenge in late 2020

n.b., CA seeding is 1.6s for 80% eff., 3s for 95% eff.

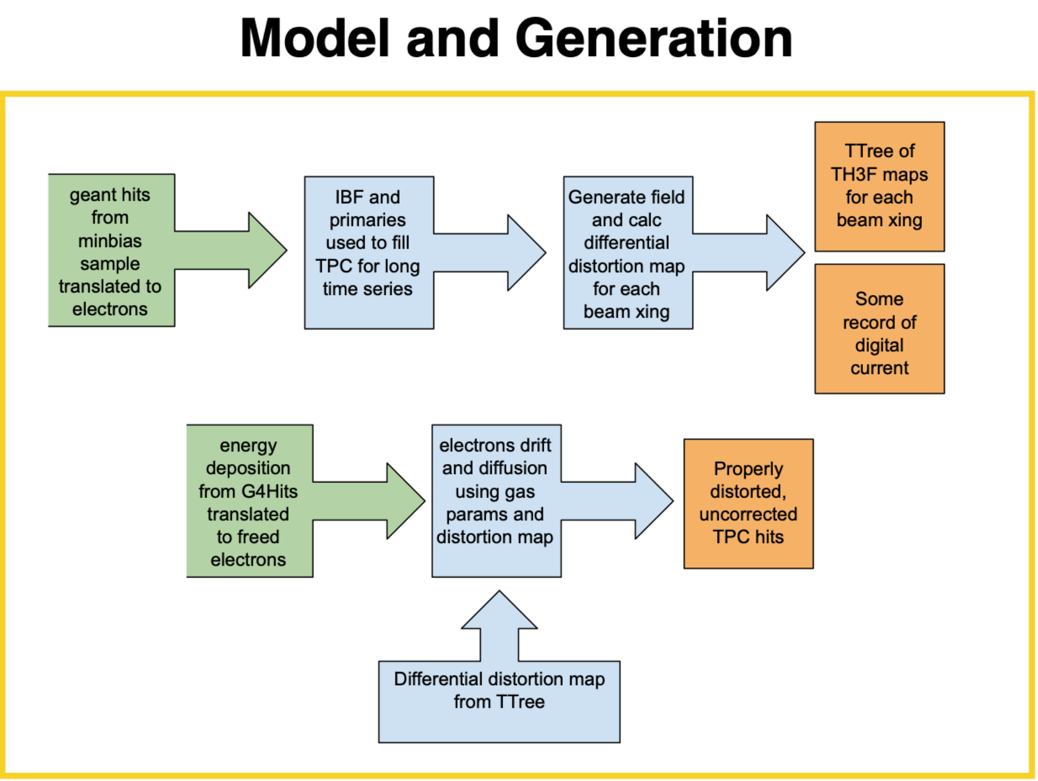
TPC distortion corrections

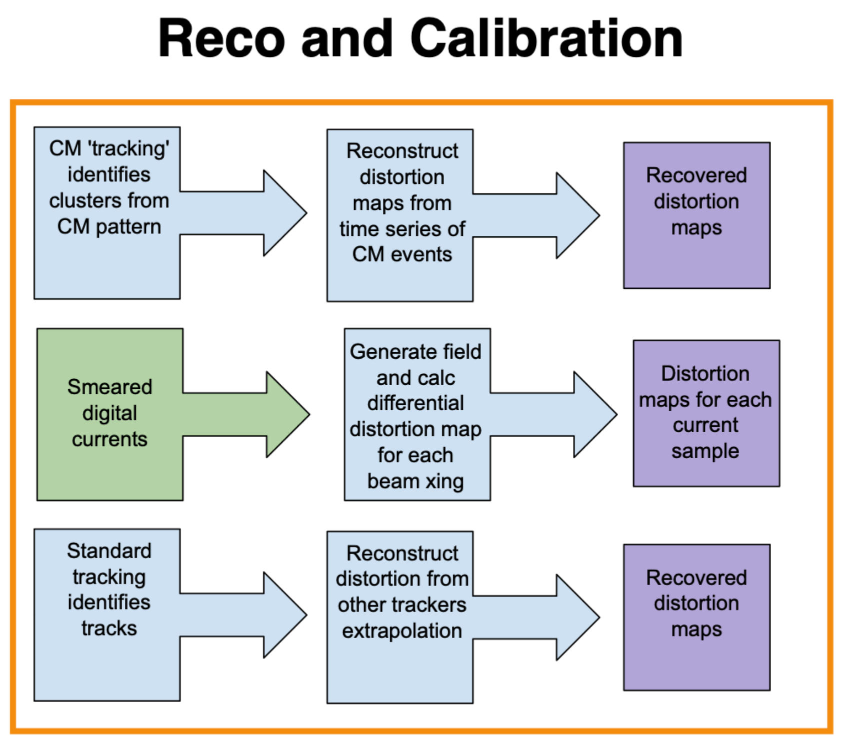
Key benchmarks:

- Upsilon mass resolution < 125MeV
- $\Delta p_T / p_T < 10\%$ for $p_T \approx 40$ GeV/c
- requires 150µm hit resolution → TPC distortion corrections



+ many students, postdocs

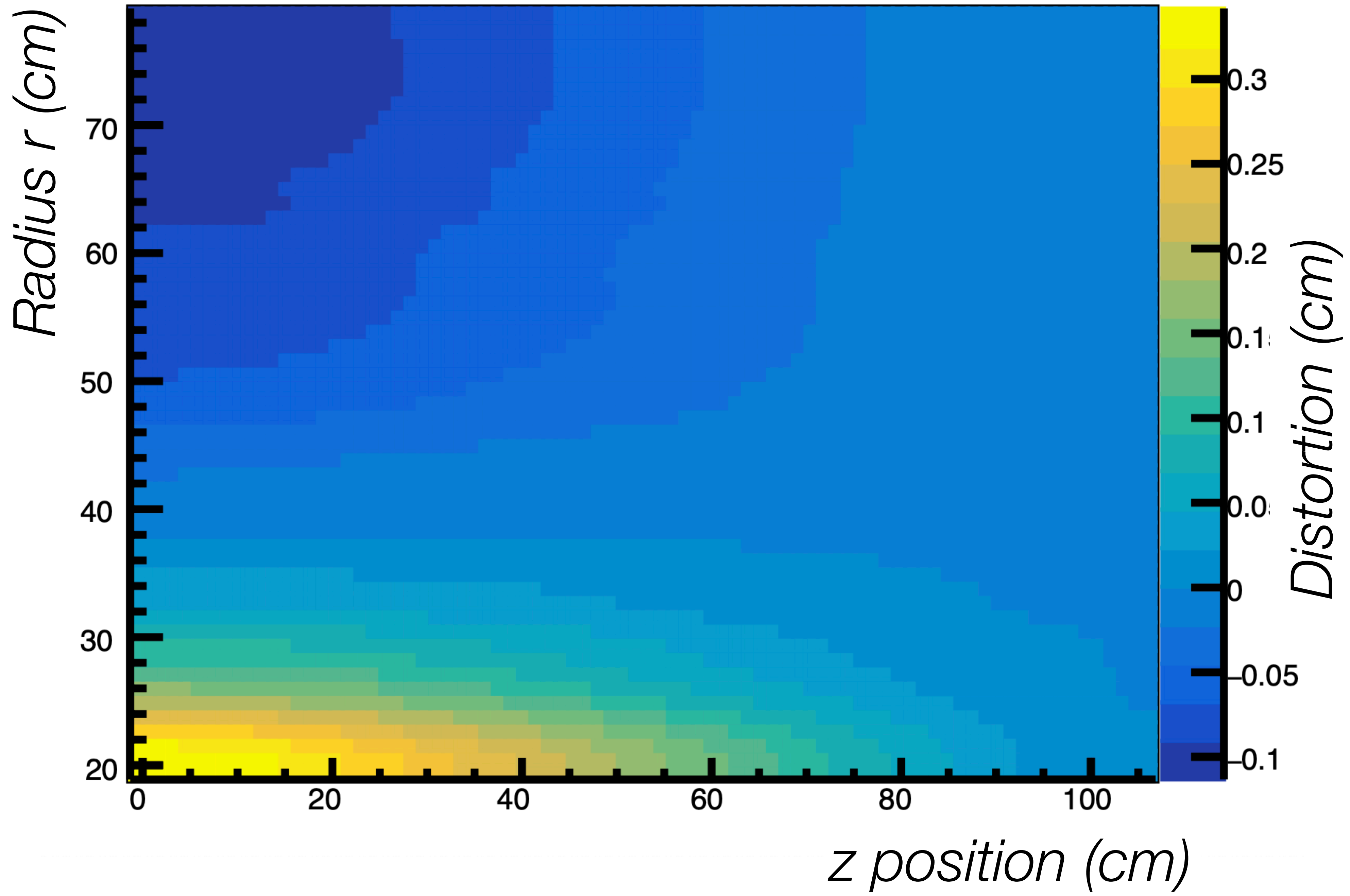




Distortion corrections:

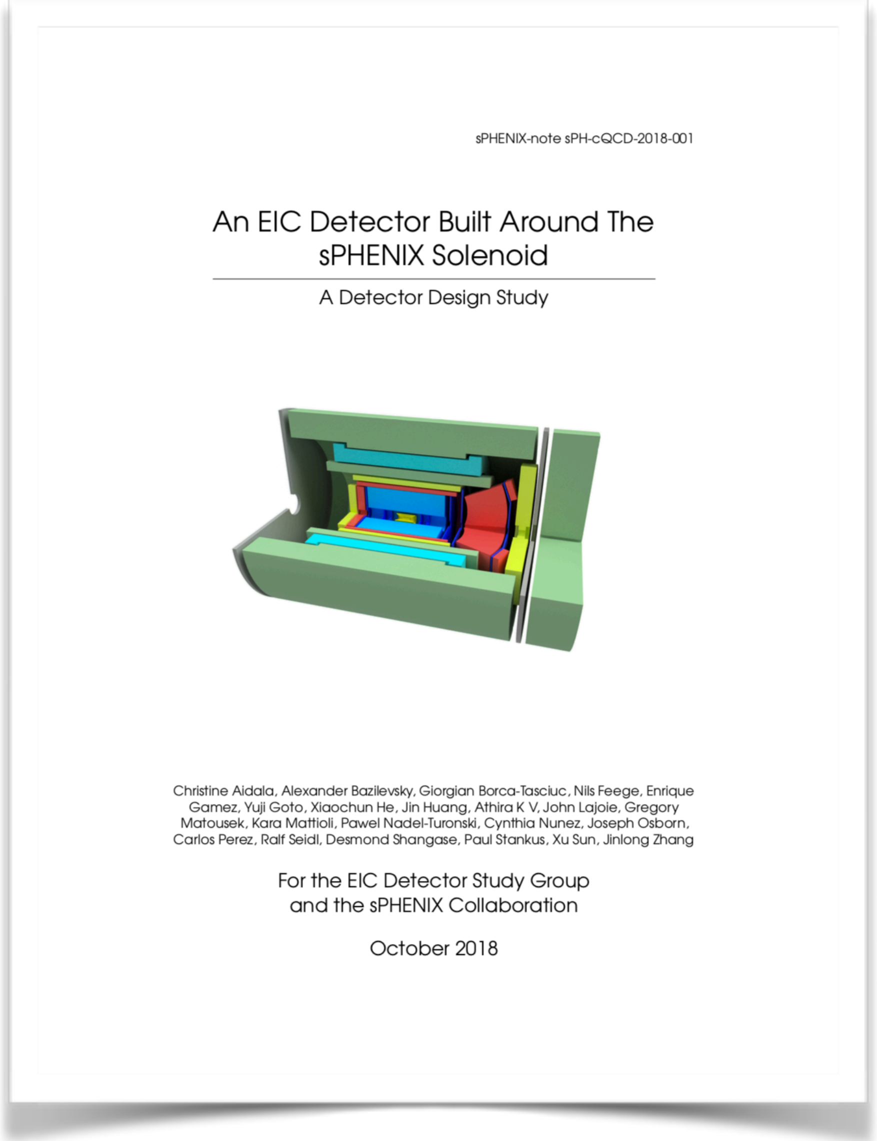
- **Established calibration taskforce**
- Workfests with ALICE/STAR experts (@CERN, @BNL)
- Work is proceeding on distortion map, simulations, correction algorithms and verification
- Diffuse laser system will play key role
- **Critical item for ’23 commissioning**

r distortion simulations vs (r,z)



Connection to EIC

2018 design study on EIC detector based on sPHENIX solenoid, led by C. Aidala and N. Feege



sPHENIX-note sPH-cQCD-2018-001

An EIC Detector Built Around The sPHENIX Solenoid

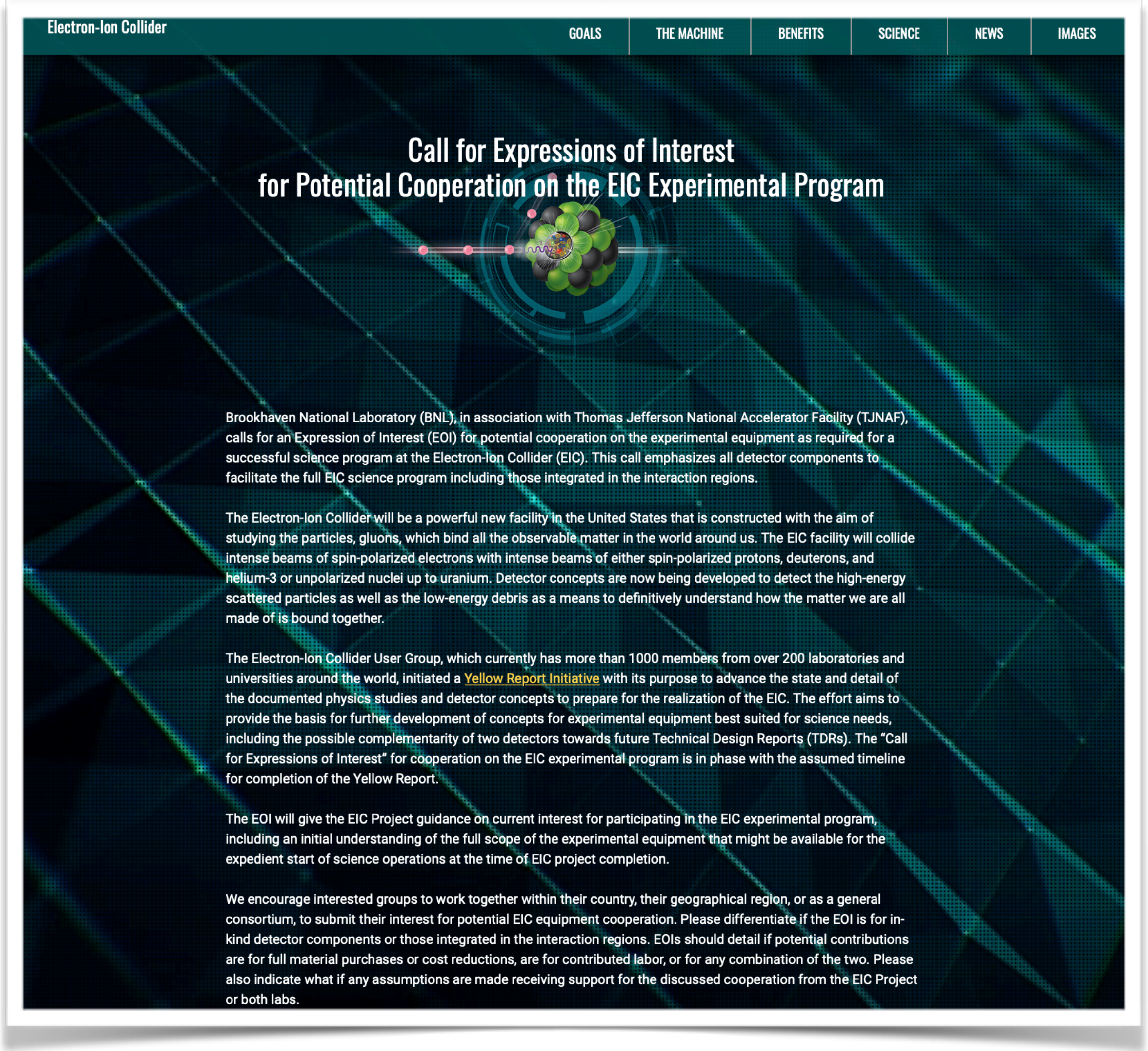
A Detector Design Study

Christine Aidala, Alexander Bazilevsky, Giorgian Borca-Tasciuc, Nils Feege, Enrique Gamez, Yuji Goto, Xiaochun He, Jin Huang, Athira K V, John Lajoie, Gregory Matousek, Kara Mattioli, Pawel Nadel-Turonski, Cynthia Nunez, Joseph Osborn, Carlos Perez, Ralf Seidl, Desmond Shangase, Paul Stankus, Xu Sun, Jinlong Zhang

For the EIC Detector Study Group and the sPHENIX Collaboration

October 2018

Large number of collaborators involved in EICUG, EIC YR and related activities



Electron-Ion Collider

GOALS | THE MACHINE | BENEFITS | SCIENCE | NEWS | IMAGES

Call for Expressions of Interest
for Potential Cooperation on the EIC Experimental Program

Brookhaven National Laboratory (BNL), in association with Thomas Jefferson National Accelerator Facility (TJNAF), calls for an Expression of Interest (EOI) for potential cooperation on the experimental equipment as required for a successful science program at the Electron-Ion Collider (EIC). This call emphasizes all detector components to facilitate the full EIC science program including those integrated in the interaction regions.

The Electron-Ion Collider will be a powerful new facility in the United States that is constructed with the aim of studying the particles, gluons, which bind all the observable matter in the world around us. The EIC facility will collide intense beams of spin-polarized electrons with intense beams of either spin-polarized protons, deuterons, and helium-3 or unpolarized nuclei up to uranium. Detector concepts are now being developed to detect the high-energy scattered particles as well as the low-energy debris as a means to definitively understand how the matter we are all made of is bound together.

The Electron-Ion Collider User Group, which currently has more than 1000 members from over 200 laboratories and universities around the world, initiated a Yellow Report Initiative with its purpose to advance the state and detail of the documented physics studies and detector concepts to prepare for the realization of the EIC. The effort aims to provide the basis for further development of concepts for experimental equipment best suited for science needs, including the possible complementarity of two detectors towards future Technical Design Reports (TDRs). The "Call for Expressions of Interest" for cooperation on the EIC experimental program is in phase with the assumed timeline for completion of the Yellow Report.

The EOI will give the EIC Project guidance on current interest for participating in the EIC experimental program, including an initial understanding of the full scope of the experimental equipment that might be available for the expedient start of science operations at the time of EIC project completion.

We encourage interested groups to work together within their country, their geographical region, or as a general consortium, to submit their interest for potential EIC equipment cooperation. Please differentiate if the EOI is for in-kind detector components or those integrated in the interaction regions. EOIs should detail if potential contributions are for full material purchases or cost reductions, are for contributed labor, or for any combination of the two. Please also indicate what if any assumptions are made receiving support for the discussed cooperation from the EIC Project or both labs.

- Many institutions preparing EoIs, typically as part of consortia
- Forming consortium with interests in number of technologies and exploring re-use of IP-8 infrastructure
- RHIC and non-RHIC institutions
- Editorial board for EoI: Or Hen (MIT), Tanja Horn (CUA), John Lajoie (Iowa)

Summary

- sPHENIX collaboration and project are committed to realize priority (1) of the NP LRP with first data taking in early 2023
  - Construction of full sPHENIX baseline detector and infrastructure are underway
  - Major progress on key software challenges
    - Continued support by BNL (NPPS, CIS) essential
  - Developed BUR to meet essential commissions and data taking needs of sPHENIX science mission
  - Continued enthusiasm for cold QCD studies with sPHENIX barrel; forming consortium of sPHENIX/RHIC/non-RHIC institutions to respond to EoI call
- **Key concern is RHIC schedule; sPHENIX requires 40 weeks of access for IP8 infrastructure work**