Ministry of Science, Technological Development and Innovation of the Republic of Serbia

Exploring the sQGP with sPHENIX

presented at the

The International Workshop
"Exploring Quark-Gluon Plasma Through Soft and Hard Probes"
Serbian Academy of Science and Arts, Belgrade, Serbia
May 31st, 2023

W.A. Zajc
Columbia University
with special thanks to Sebastian Tapia Araya, Anders Knospe, Weihu Ma, J. Nagle and all my sPHENIX colleagues

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April 18, 2005

RHIC
Brookhaven National Laboratory's Relativistic Heavy Ion Collider

Contacts: Karen McNulty Walsh, (631) 344-8350 or Peter Genzer, (631) 344-3174

RHIC Scientists Serve Up 'Perfect' Liquid

New state of matter more remarkable than predicted — raising many new questions

Monday, April 18, 2005

TAMPA, FL — The four detector groups conducting research at the Relativistic Heavy Ion Collider (RHIC) — a giant atom "smasher" located at the U.S. Department of Energy's Brookhaven National Laboratory — say they've created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. In peer-reviewed papers summarizing the first three years of RHIC findings, the scientists say that instead of behaving like a gas of free quarks and gluons, as was expected, the matter created in RHIC's heavy ion collisions appears to be more like a liquid.


Secretary of Energy Samuel Bodman

"Once again, the physics research sponsored by the Department of Energy is producing historic results," said Secretary of Energy Samuel Bodman, a trained chemical engineer. "The DOE is the principal federal funder of basic research in the physical sciences, including nuclear and high-energy physics. With today's announcement we see that investment paying off."

"The truly stunning finding at RHIC that the new state of matter created in the collisions of gold ions is more like a liquid than a gas gives us a profound insight into the earliest moments of the universe," said Dr. Raymond L. Orbach, Director of the DOE Office of Science.

Also of great interest to many following progress at RHIC is the emerging connection between the collider's results and calculations using the methods of string theory, an approach that attempts to explain fundamental properties of the universe using 10 dimensions instead of the usual three spatial dimensions plus time.


Dr. Raymond L. Orbach

"The possibility of a connection between string theory and RHIC collisions is unexpected and exhilarating," Dr. Orbach said. "String theory seeks to unify the two great intellectual achievements of twentieth-century physics, general relativity and quantum mechanics, and it may well have a profound impact on the physics of the twenty-first century."

The papers, which the four RHIC collaborations (BRAHMS, PHENIX, PHOBOS, and STAR) have been working on for nearly a year, will be published simultaneously by the journal *Nuclear Physics A*, and will also be compiled in a special Brookhaven report, the Lab announced at the April 2005 meeting of the American Physical Society in Tampa, Florida.

These summaries indicate that some of the observations at RHIC fit with the theoretical predictions for a quark-gluon plasma (QGP), the type of matter postulated to have existed just microseconds after the Big Bang. Indeed, many theorists have concluded that RHIC has already demonstrated the creation of quark-gluon plasma. However, all four collaborations note that there are discrepancies between the experimental data and early theoretical predictions based on simple models of quark-gluon plasma formation.

Other RHIC News

- Energy Secretary Moniz Announces 2014 Ernest Orlando Lawrence Award Winners
- U.S.-CERN Agreement Paves Way for New Era of Scientific Discovery
- Sergey Belomestnykh Receives Particle Accelerator Science & Technology Award
- Into the Depths of the Electromagnetic Spectrum
- Giant Electromagnet Arrives at Brookhaven Lab to Map Melted Matter
- Explorations of Quarks and Gluons in Scientific American
- Relativistic Heavy Ion Collider Smashes Record for Polarized Proton Luminosity at 200 GeV Collision Energy
- A Tale of Two Colliders, One Thesis, Two Awards—and a Physics Mystery


Sam Aronson

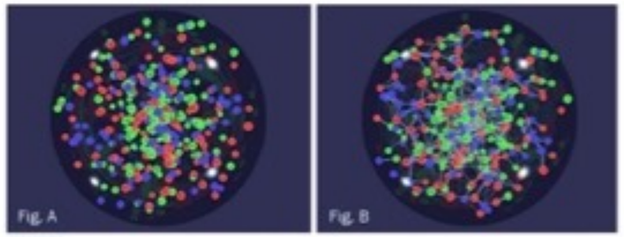
"We know that we've reached the temperature [up to 150,000 times hotter than the center of the sun] and energy density [energy per unit volume] predicted to be necessary for forming such a plasma," said Sam Aronson, Brookhaven's Associate Laboratory Director for High Energy and Nuclear Physics. But analysis of RHIC data from the start of operations in June 2000 through the 2003 physics run reveals that the matter formed in RHIC's head-on collisions of gold ions is more like a liquid than a gas.

That evidence comes from measurements of unexpected patterns in the trajectories taken by the thousands of particles produced in individual collisions. These measurements indicate that the primordial particles produced in the collisions tend to move collectively in response to variations of pressure across the volume formed by the colliding nuclei. Scientists refer to this phenomenon as "flow," since it is analogous to the properties of fluid motion.

However, unlike ordinary liquids, in which individual molecules move about randomly, the hot matter formed at RHIC seems to move in a pattern that exhibits a high degree of coordination among the particles — somewhat like a school of fish that responds as one entity while moving through a changing environment.

"This is fluid motion that is nearly 'perfect,'" Aronson said, meaning it can be explained by equations of hydrodynamics. These equations were developed to describe theoretically "perfect" fluids — those with extremely low viscosity and the ability to reach thermal equilibrium very rapidly due to the high degree of interaction among the particles. While RHIC scientists don't have a direct measure of viscosity, they can infer from the flow pattern that, qualitatively, the viscosity is very low, approaching the quantum mechanical limit.

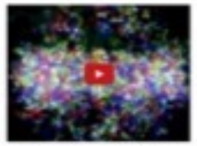
Together, these facts present a compelling case: "In fact, the degree of collective interaction, rapid thermalization, and extremely low viscosity of the matter being formed at RHIC make this the most nearly perfect liquid ever observed," Aronson said.



+ENLARGE These images contrast the degree of interaction and collective motion, or "flow," among quarks in the predicted gaseous quark-gluon plasma state (Figure A, see mpeg animation) vs. the liquid state that has been observed in gold-gold collisions at RHIC (Figure B, see mpeg animation). The green "force lines" and collective motion (visible on the animated version only) show the much higher degree of interaction and flow among the quarks in what is now being described as a nearly "perfect" liquid. (Click images for larger version.) An updated video comparing the expected gas with the observed "perfect" liquid is available.

In results reported earlier, other measurements at RHIC have shown "jets" of high-energy quarks and gluons being dramatically slowed down as they traverse the hot fireball produced in the collisions. This "jet quenching" demonstrates that the energy density in this new form of matter is extraordinarily high — much higher than can be explained by a medium consisting of ordinary nuclear matter.

"The current findings don't rule out the possibility that this new state of matter is in fact a form of the quark-gluon plasma, just different from what had been theorized," Aronson said. Many scientists believe this to be the case, and detailed measurements are now under way at RHIC to resolve this question.


See an updated version of the "perfect" liquid animation.

Theoretical physicists, whose standard calculations cannot incorporate the strong coupling observed between the quarks and gluons at RHIC, are also revisiting some of their early models and predictions. To try to address these issues, they are running massive numerical simulations on some of the world's most powerful computers. Others are attempting to incorporate quantitative measures of viscosity into the equations of motion for fluid moving at nearly the speed of light. One subset of calculations uses the methods of string theory to predict the viscosity of the liquid being created at RHIC and to explain some of the other surprising findings. Such studies will provide a more quantitative understanding of how "nearly perfect" the liquid is.

The unexpected findings also introduce a wide range of opportunity for new scientific discovery regarding the properties of matter at extremes of temperature and density previously inaccessible in a laboratory.

"The finding of a nearly perfect liquid in a laboratory experiment recreating the conditions believed to have existed a few

RHIC Scientists Serve Up 'Perfect' Liquid

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The Papers

- *Quark gluon plasma and color glass condensate at RHIC? The Perspective from the BRAHMS experiment*, Nucl.Phys. **A757** (2005) 1-27, nucl-ex/0410020
- *Formation of dense partonic matter in relativistic nucleus-nucleus collisions at RHIC: Experimental evaluation by the PHENIX collaboration*, Nucl.Phys. **A757** (2005) 184-283, nucl-ex/0410003
- *The PHOBOS perspective on discoveries at RHIC*, Nucl.Phys. **A757** (2005) 28-101, nucl-ex/0410022
- *Experimental and theoretical challenges in the search for the quark gluon plasma: The STAR Collaboration's critical assessment of the evidence from RHIC collisions*, Nucl.Phys. **A757** (2005) 102-183, nucl-ex/0501009

Addressing the nature of QGP discovery

- From the PHENIX "White Paper"
- nucl-ex/0410003
- (4600+ citations)

Q: What is the most relevant *"experimentally observed property"*?

A. *Viscosity* (suitably normalized)

so that concepts such as temperature, chemical potential and flow velocity apply and the system can be characterized by an experimentally determined equation of state. Additionally, experiments eventually should be able to determine the physical characteristics of the transition, for example the critical temperature, the order of the phase transition, and the speed of sound along with the nature of the underlying quasi-particles. While at (currently unobtainable) very high temperatures $T \gg T_c$ the quark-gluon plasma may act as a weakly interacting gas of quarks and gluons, in the transition region near T_c the fundamental degrees of freedom may be considerably more complex. It is therefore appropriate to argue that the quark-gluon plasma must be defined in terms of its unique properties *at a given temperature*. To date the definition is provided by lattice QCD calculations. Ultimately we would expect to validate this by characterizing the quark-gluon plasma in terms of its experimentally observed properties. However, the real discoveries will be of the fascinating properties of high temperature nuclear matter, and not the naming of that matter.

1.2 Experimental Program

The theoretical discussion of the nature of hadronic matter at extreme densities has been greatly stimulated by the realization that such conditions could be studied via relativistic heavy ion collisions [32]. Early investigations at the Berkeley Bevalac (c. 1975–1985), the BNL AGS (c. 1987–1995) and the CERN SPS (c. 1987–present) have reached their culmination with the commissioning of BNL's Relativistic Heavy Ion Collider (RHIC), a dedicated facility for the study of nuclear collisions at ultra-relativistic energies [33].

Also in 2005

- Berndt Müller's Quark Matter 2005 Theoretical Summary: arXiv:nucl-th/0508062

the vicinity of T_c. Turning to physical arguments, it is noteworthy that the perturbative quasiparticles of the effective theory, thermal gluons and plasmons, are short-lived. The collisional width of a gluon/plasmon at rest is given by [109]

$$\Gamma_g(0) \approx \frac{1}{2\pi} g^2 N_c T \approx 1.5\,T. \qquad (6)$$

On the other hand, the effective mass of a gluon/plasmon at rest is $m_g^* = gT\sqrt{N_c/9} \approx T$. Roughly the same relationship holds for thermal quarks [110]. In other words, all slowly moving quasiparticles are strongly damped. The characteristic nature of the temperature region near T_c may thus be that the quasiparticles, gluons and quarks above T_c and hadrons (such as the ρ-meson) below T_c, are strongly collision broadened. Such a property would be indicative of a liquid, which is characterized by the absence of long-lived quasiparticles and long-range order. Because the effective coupling g_E changes only slowly with temperature, it is by no means clear how for above T_c one needs to go before the widths of the plasma quasiparticles become a higher-order effect compared to their masses.

2011 - A Nice Surprise

13
Jul 2011

THE TOPCITED HEP PAPER OF ALL TIME.

by INSPIRE

For as long as the annual topcited papers lists have been around, the all-time champion has been Weinberg's "A model of leptons", the 1967 paper that laid the foundation stone for the Standard Model. 30 years later, in November of 1997, the paper The Large N limit of superconformal field theories and supergravity by Maldacena appeared that established a connection between string theory and quantum field theory. It immediately set of a revolution in HEP and was the most highly cited paper ever since. Remarkably, its highest citation count was in 2010, where it received over 1,000 citations in a single year! One reason for this is the heavy ion results from Brookhaven that drew people to conclude that, based on Maldacena's work, the quark gluon plasma can be modeled using string theory techniques.

Posted in: References and Citations

First RHIC Experimental Paper Quantifying η/s

Welcome to INSPIRE, the High Energy Physics information system. Please direct questions, comments or concerns to feedback@inspirehep.net.

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Energy Loss and Flow of Heavy Quarks in Au+Au Collisions at s(NN)**(1/2) = 200-GeV

PHENIX Collaboration (A. Adare (Colorado U.) *et al.*) *Show all 421 authors*

Nov 2006 - 6 pages

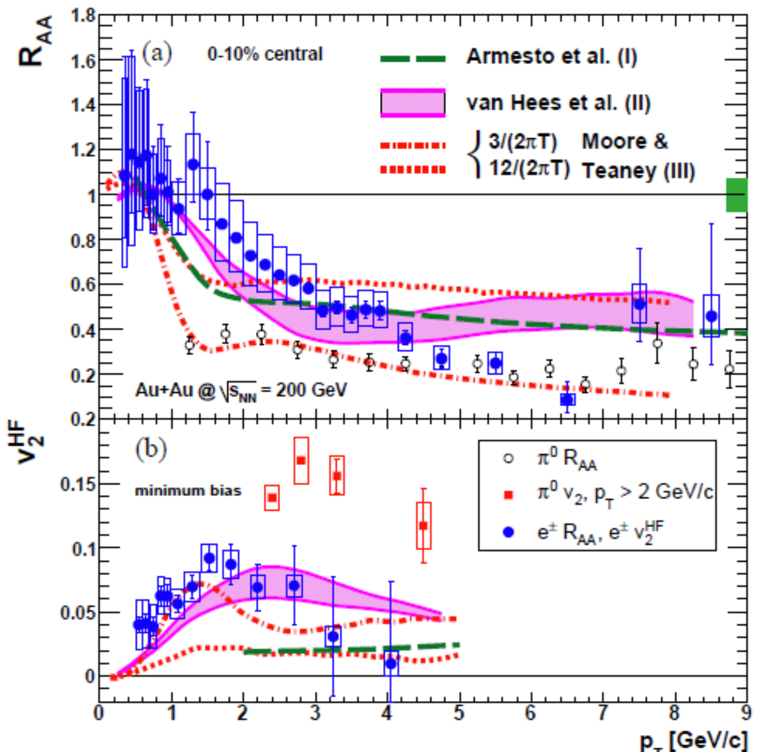
Phys.Rev.Lett. 98 (2007) 172301
DOI: 10.1103/PhysRevLett.98.172301
e-Print: nucl-ex/0611018 | PDF
Experiment: BNL-RHIC-PHENIX

Abstract: The PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) has measured electrons from heavy flavor (charm and bottom) decays for 0.3 < p_T < 9 GeV/c at midrapidity (|y| < 0.35) in Au+Au collisions at sqrt(s_NN) = 200 GeV. The nuclear modification factor R_AA relative to p+p collisions shows a strong suppression in central Au+Au collisions, indicating substantial energy loss of heavy quarks in the medium produced at RHIC. A large azimuthal anisotropy, v_2, with respect to the reaction plane is observed for 0.5 < p_T < 5 GeV/c indicating non-zero heavy flavor elliptic flow. Both R_AA and v_2 show a p_T dependence different from those of neutral pions. A comparison to transport models which simultaneously describe R_AA(p_T) and v_2(p_T) suggests that the viscosity to entropy density ratio is close to the conjectured quantum lower bound, i.e., near a perfect fluid.

PACS: 25.75.Dw
Keyword(s): INSPIRE: nucleus nucleus: colliding beams | scattering: heavy ion | gold | charm | bottom | quark: hadroproduction | quark: decay | electron: yield | elliptic flow | multiple scattering | quark: energy loss | nuclear matter: effect | viscosity | entropy | model: fluid | PHENIX | experimental results | Brookhaven RHIC Coll | 200 GeV-cms/nucleon

Record created 2006-11-13, last modified 2012-10-24

2006 - The Real Surprise



- Heavy quark
  - Energy loss
  - Flow

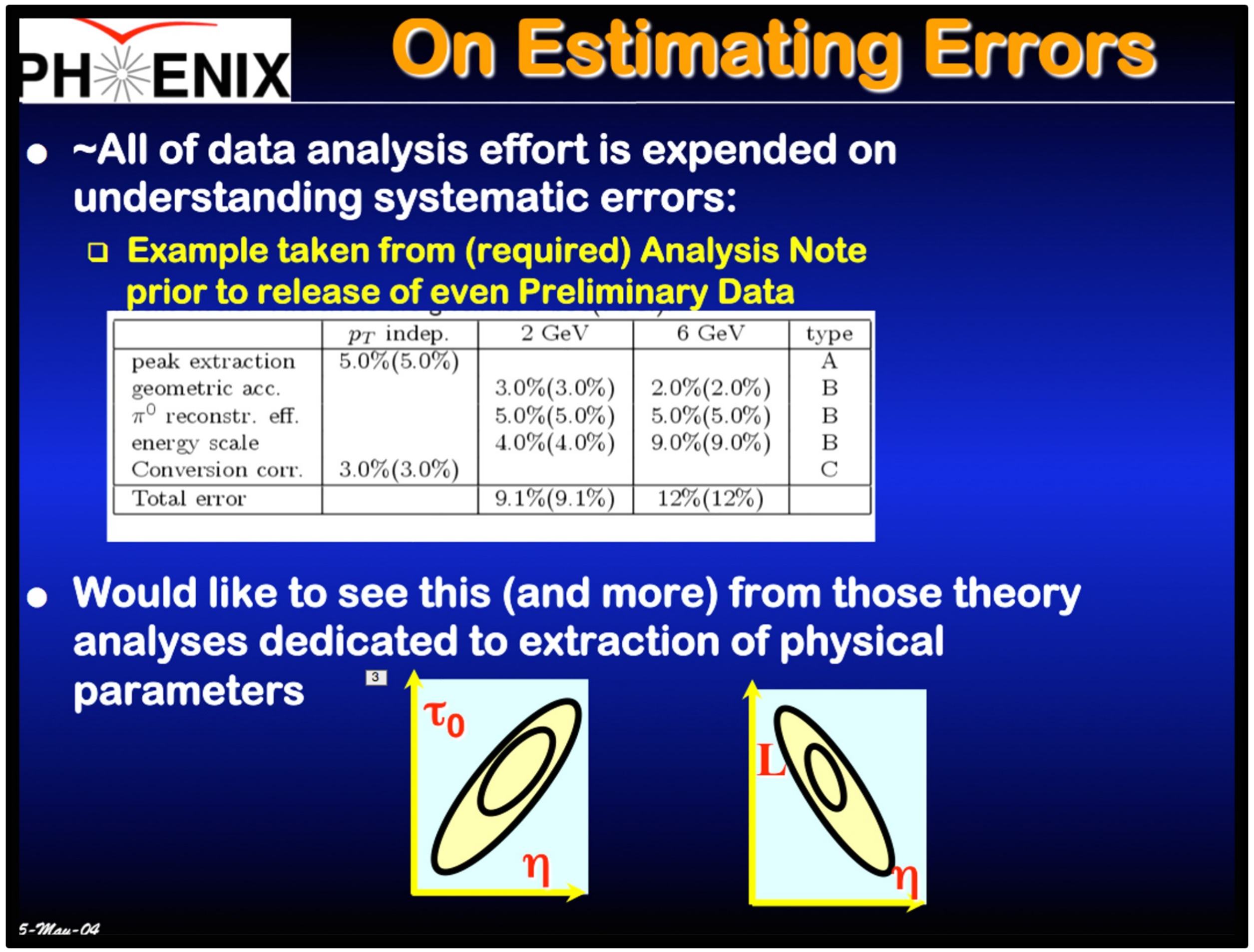
along with

matter's diffusion coefficient D. Using the observation [32] that $D \approx 6 \times \eta/(\epsilon + p)$ with $\epsilon + p = Ts$ at $\mu_B = 0$ provides an estimate for the viscosity to entropy ratio $\eta/s \approx (\frac{4}{3} - 2)/4\pi$, intriguingly close to the conjectured quantum lower bound $1/4\pi$ [33]. This result is consistent with

2004 → 2020

- Extraordinary progress !
- Essential feature: *open source code*

JETSCAPE, Multi-system Bayesian constraints on the transport coefficients of QCD matter, 2011.01430



PHENIX

On Estimating Errors

- ~All of data analysis effort is expended on understanding systematic errors:
  - Example taken from (required) Analysis Note prior to release of even Preliminary Data

	p_T indep.	2 GeV	6 GeV	type
peak extraction	5.0%(5.0%)			A
geometric acc.		3.0%(3.0%)	2.0%(2.0%)	B
π^0 reconstr. eff.		5.0%(5.0%)	5.0%(5.0%)	B
energy scale		4.0%(4.0%)	9.0%(9.0%)	B
Conversion corr.	3.0%(3.0%)			C
Total error		9.1%(9.1%)	12%(12%)	

- Would like to see this (and more) from those theory analyses dedicated to extraction of physical parameters

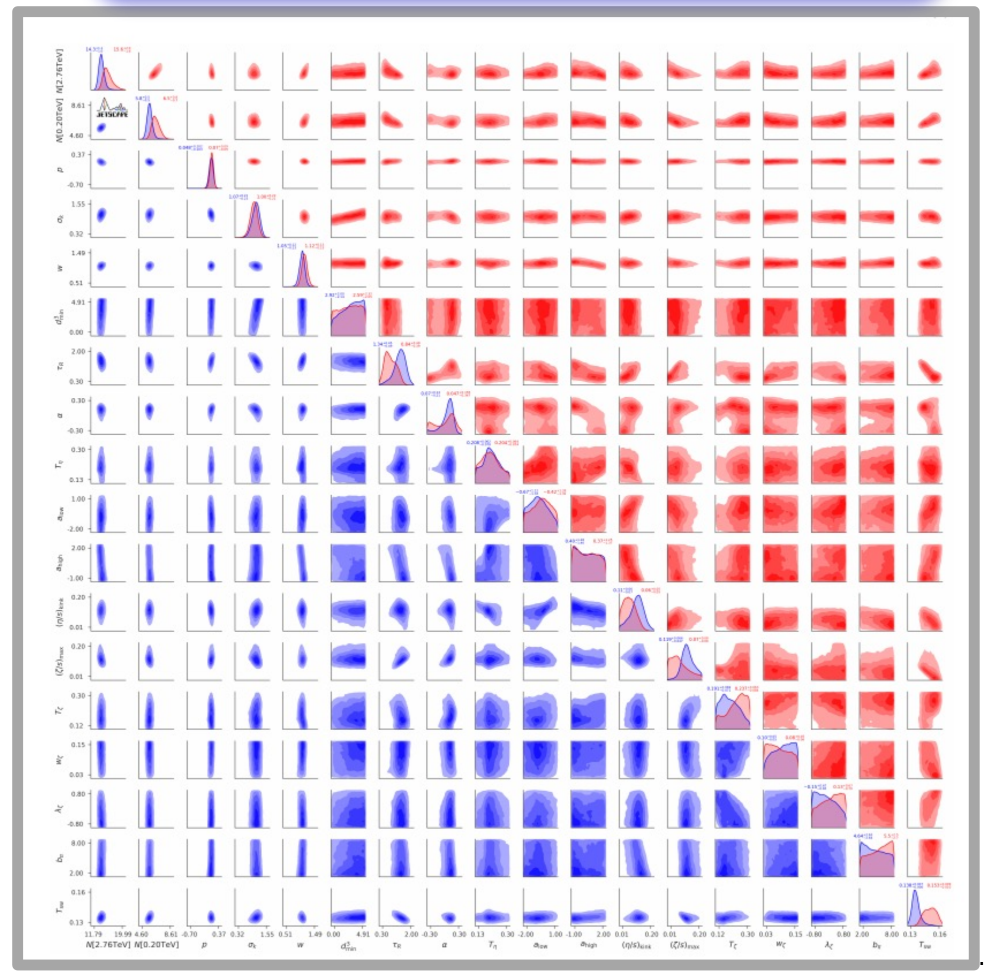
Leadership by

Scott Pratt

Steffen Bass

Abhijit Majumder

→



. Zajc

Two Facilities

RHIC

- First collisions 2000
- p+p, d+Au, ^{3}He+Au, Zr+Zr, Ru+Ru, Cu+Cu, Cu+Au, Au+Au, U+U
- $\sqrt{s_{NN}}$ ~ 7–200 GeV
- Polarized protons

LHC

- First collisions 2010
- p+p, Pb+Pb, p+Pb
- $\sqrt{s_{NN}}$ =2.76 TeV, 5.5 TeV

sPHENIX – The Next Step

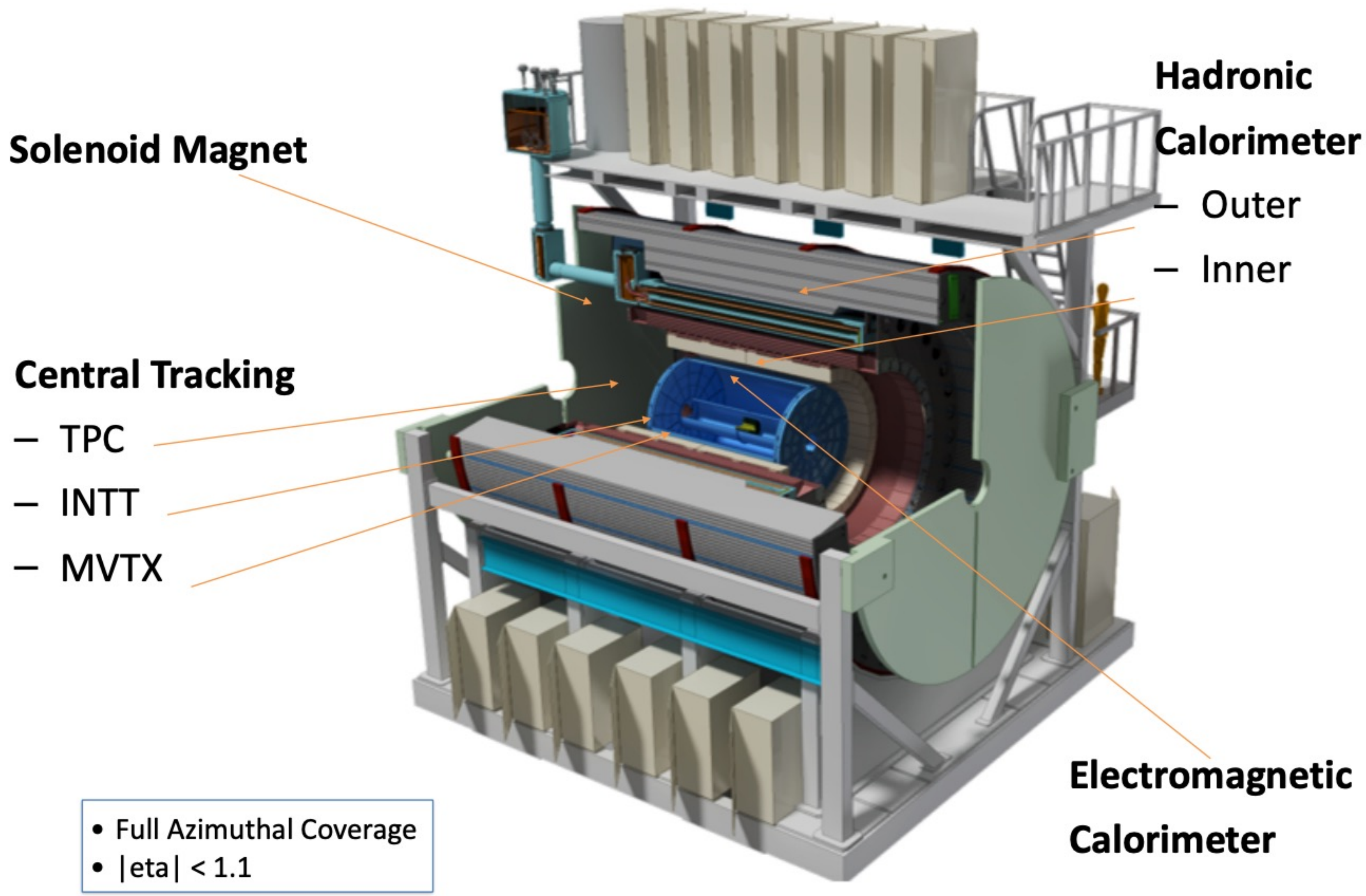
- Open question:

  How do asymptotically free quarks and gluons conspire to form the world's most perfect fluid?

- To answer:

  Probe it on the smallest possible length scales with jets and heavy flavor.

sPHENIX: State-of-the-Art Jet Detector at RHIC



- Full Azimuthal Coverage
- |eta| < 1.1

sPHENIX – The Next Step

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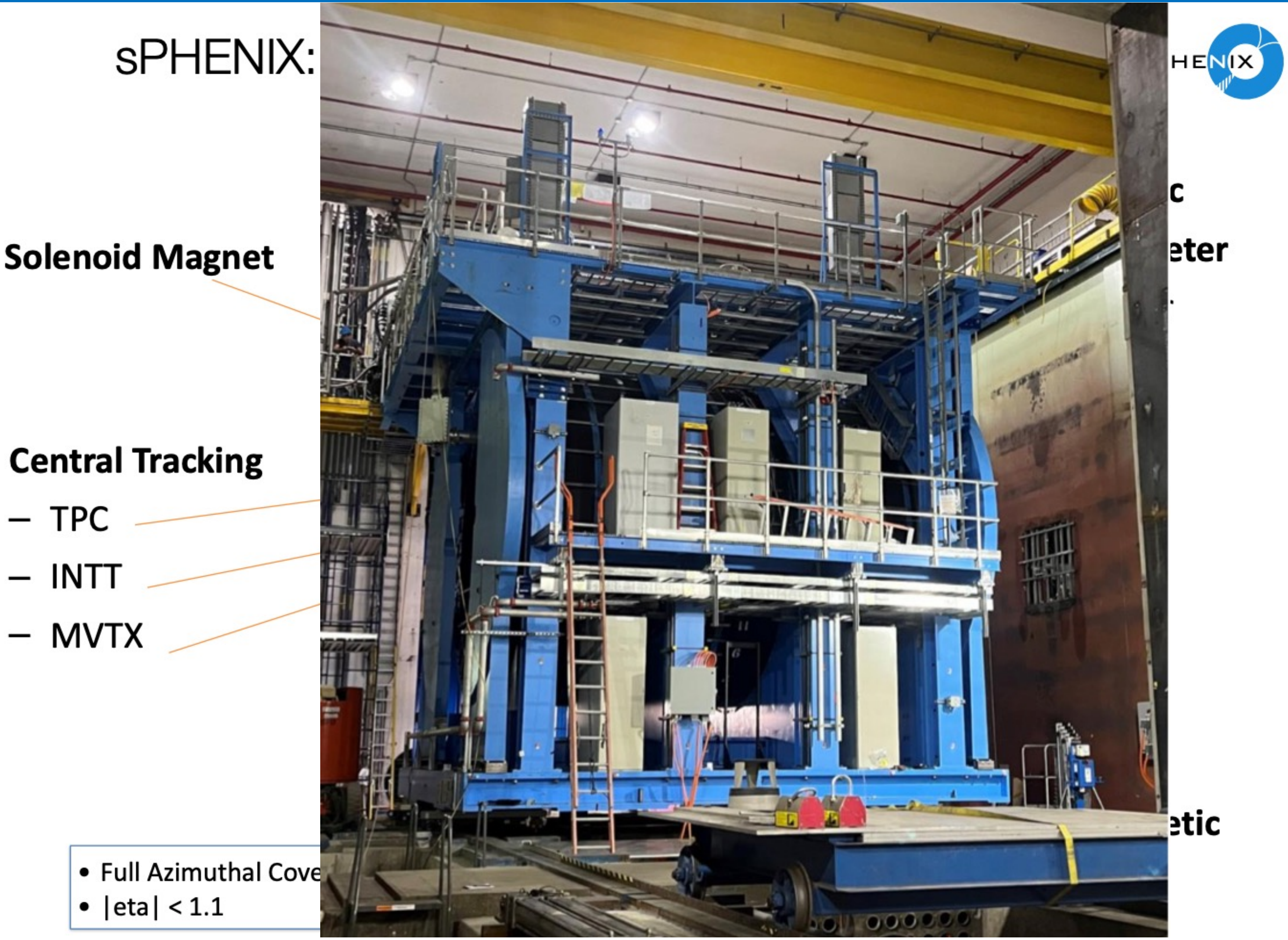

sPHENIX – The Next Step

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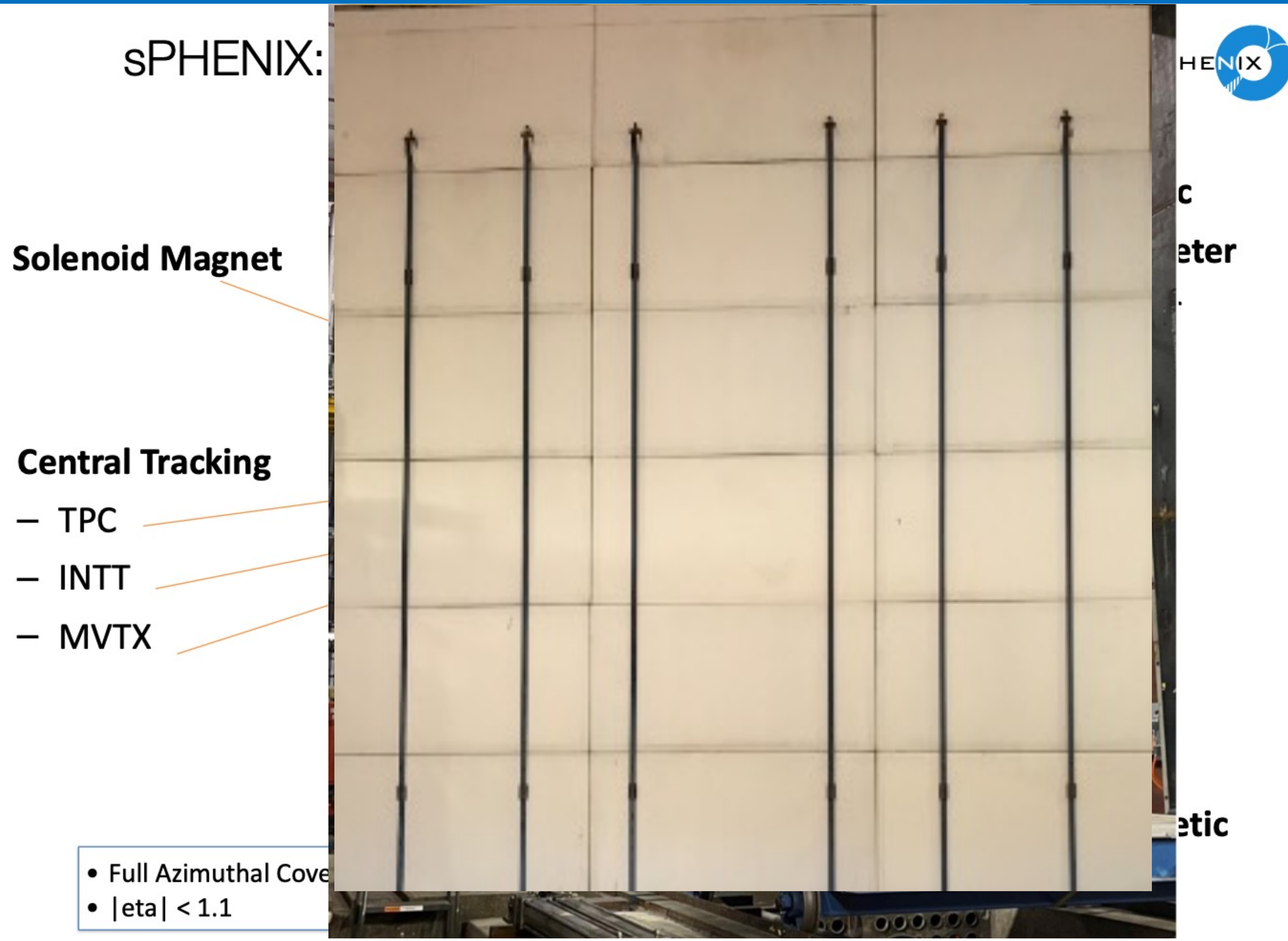
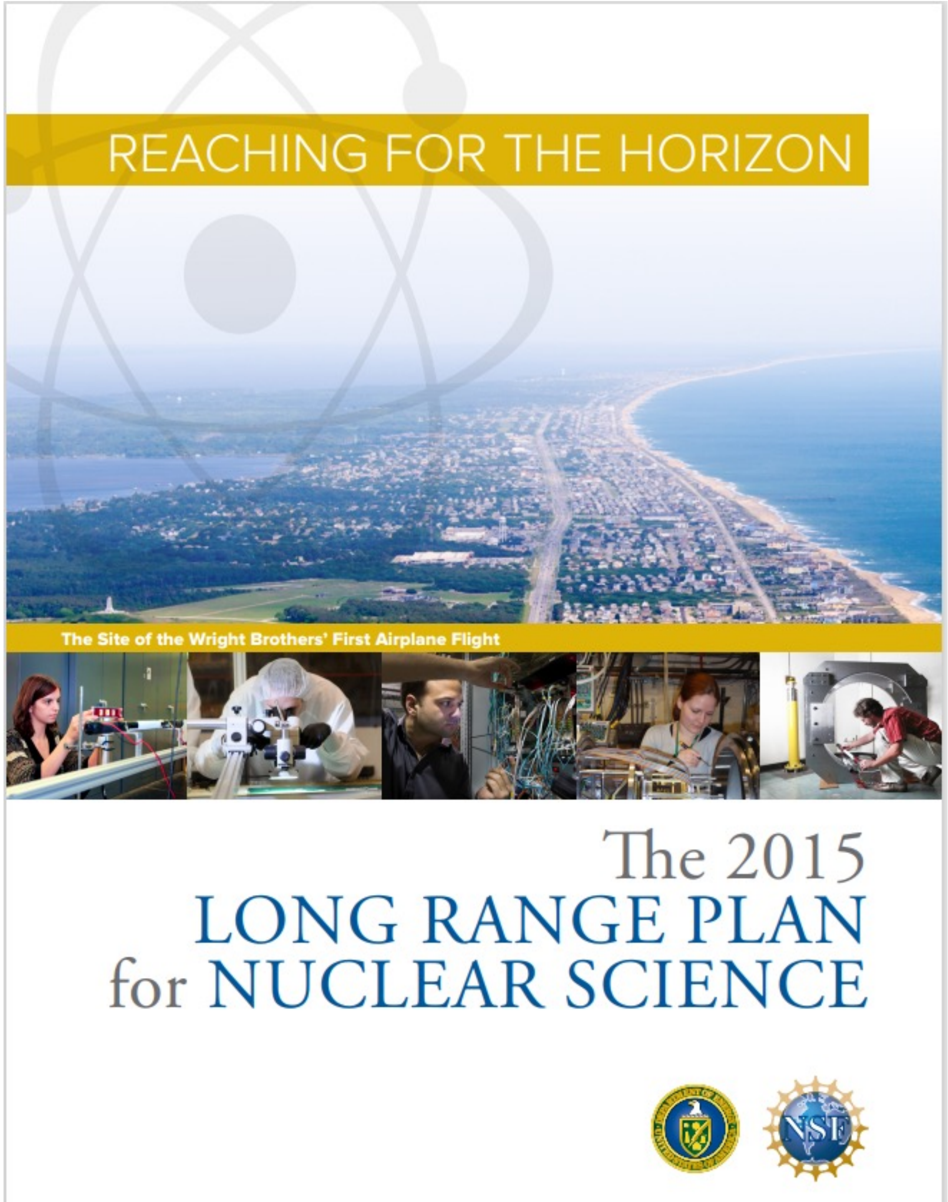


sPHENIX Science Mission



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 will be the first new collider detector in over twenty years (!)*
- ✓ *performing very high precision studies of jet production, jet substructure and open and hidden heavy flavor over an unprecedented kinematic range at RHIC ;*
- ✓ *distinguished by high rate capability and large acceptance, combined with high precision tracking and electromagnetic and hadronic calorimetry.*

Run Schedule

- sPHENIX scientific program consists of 3 years of running:

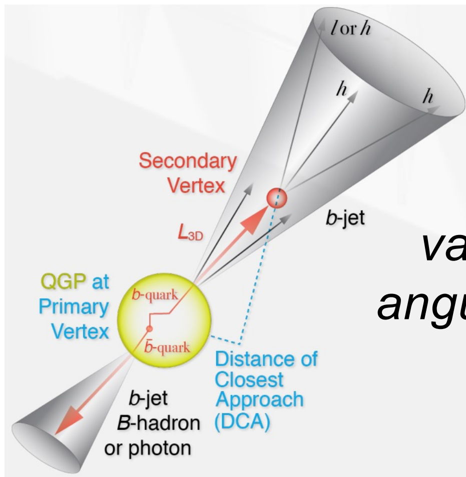
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z \rvert < 10$ cm	Samp. Lum. $\lvert z \rvert < 10$ cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

2023: Au+Au
Commissioning & Calibration, standard candle measurements, first sPHENIX physics

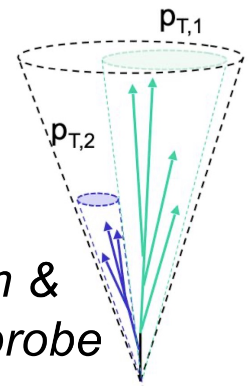
2024: p+p & p+Au
Reference measurements for heavy ions, cold QCD

2025: Au+Au
(high statistics)

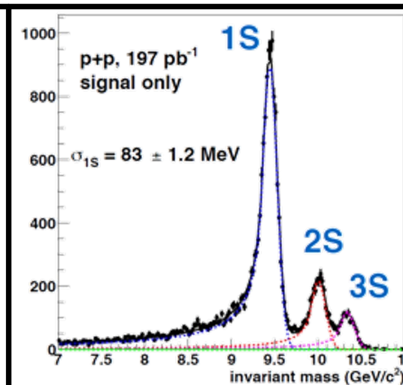
The Core sPHENIX Physics Program

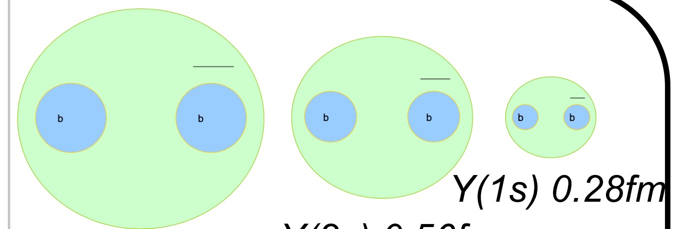


vary momentum & angular scale of probe



- **Jet physics**

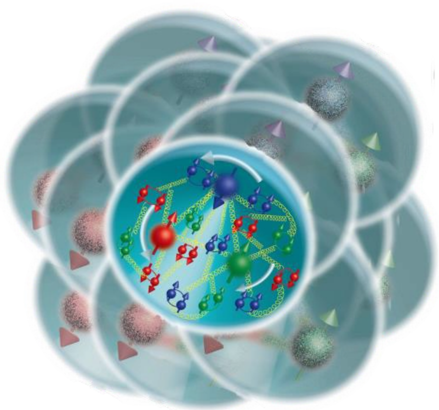




Υ(3s) 0.78fm Υ(2s) 0.56fm Υ(1s) 0.28fm

vary size of probe

- **Quarkonium spectroscopy**



- **Cold QCD**

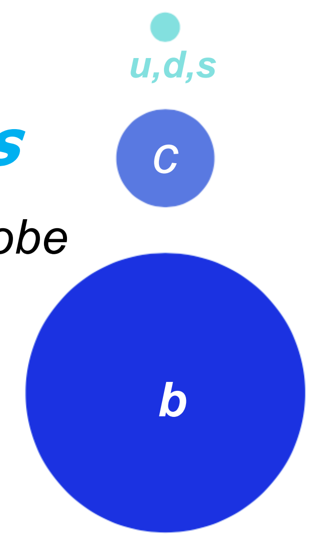
vary temperature of QCD matter

study proton spin, transverse-momentum, and cold nuclear effects

- **Parton energy loss**

vary mass & momentum of probe

photon
gluon



W.A. Zajc

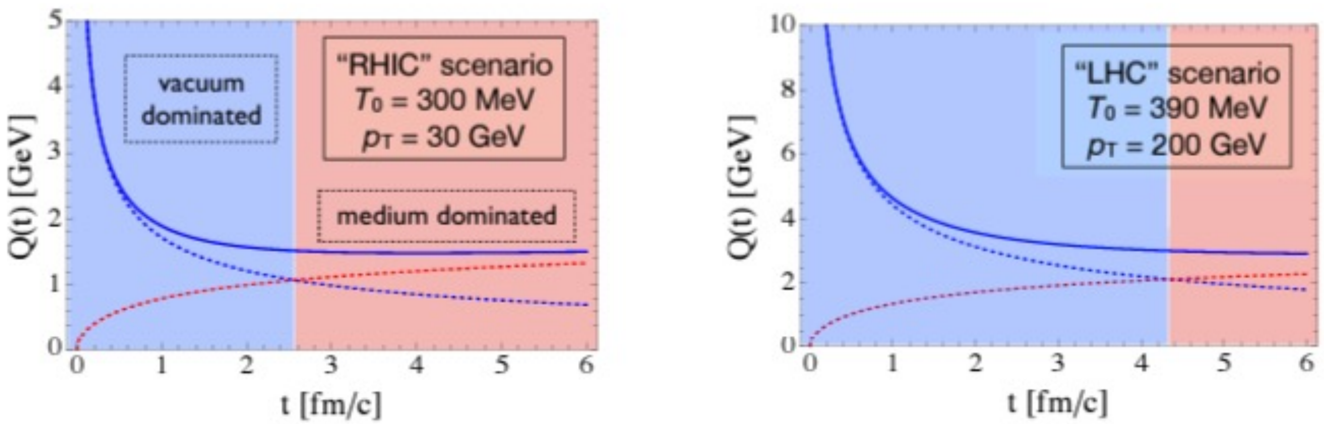
The sPHENIX raison d'être

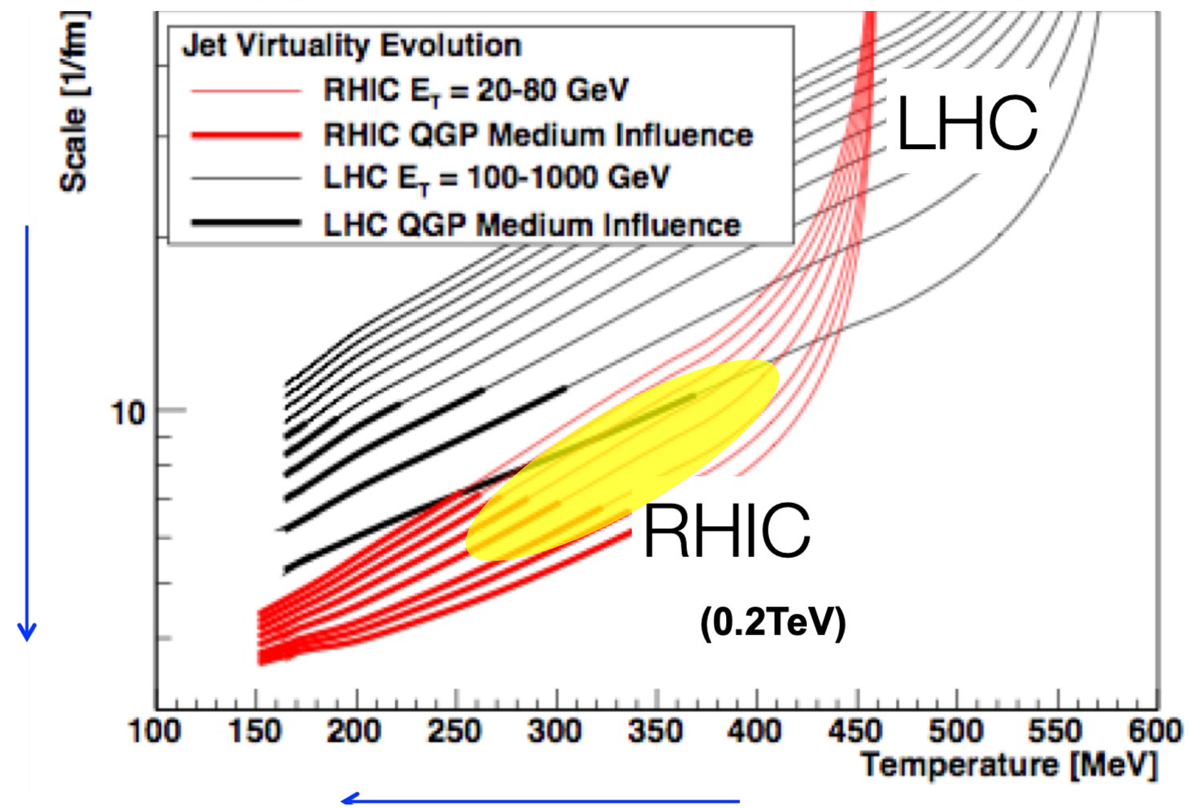
From the sPHENIX proposal arXiv:1501.06197:

Spanning the largest possible range of virtuality (initial hard process Q^2) is very important, but complementary measurements at both RHIC and LHC of produced jets at the same virtuality (around 50 GeV) will test the interplay between the vacuum shower and medium scattering contributions . . .

It is notable that highest energy partons at the LHC, of order 1 TeV, are always dominated by the initial vacuum virtuality evolution (for more than 10 fm/c). In contrast, the lower energy jets and the RHIC medium evolution have the largest influence and map out a unique part of the microscope resolving power and temperature of the quark-gluon plasma.

$$Q^2 = Q^2_{vac} + Q^2_{med} = \langle z \rangle (1 - \langle z \rangle) \frac{E}{L} + \hat{q}\ L$$





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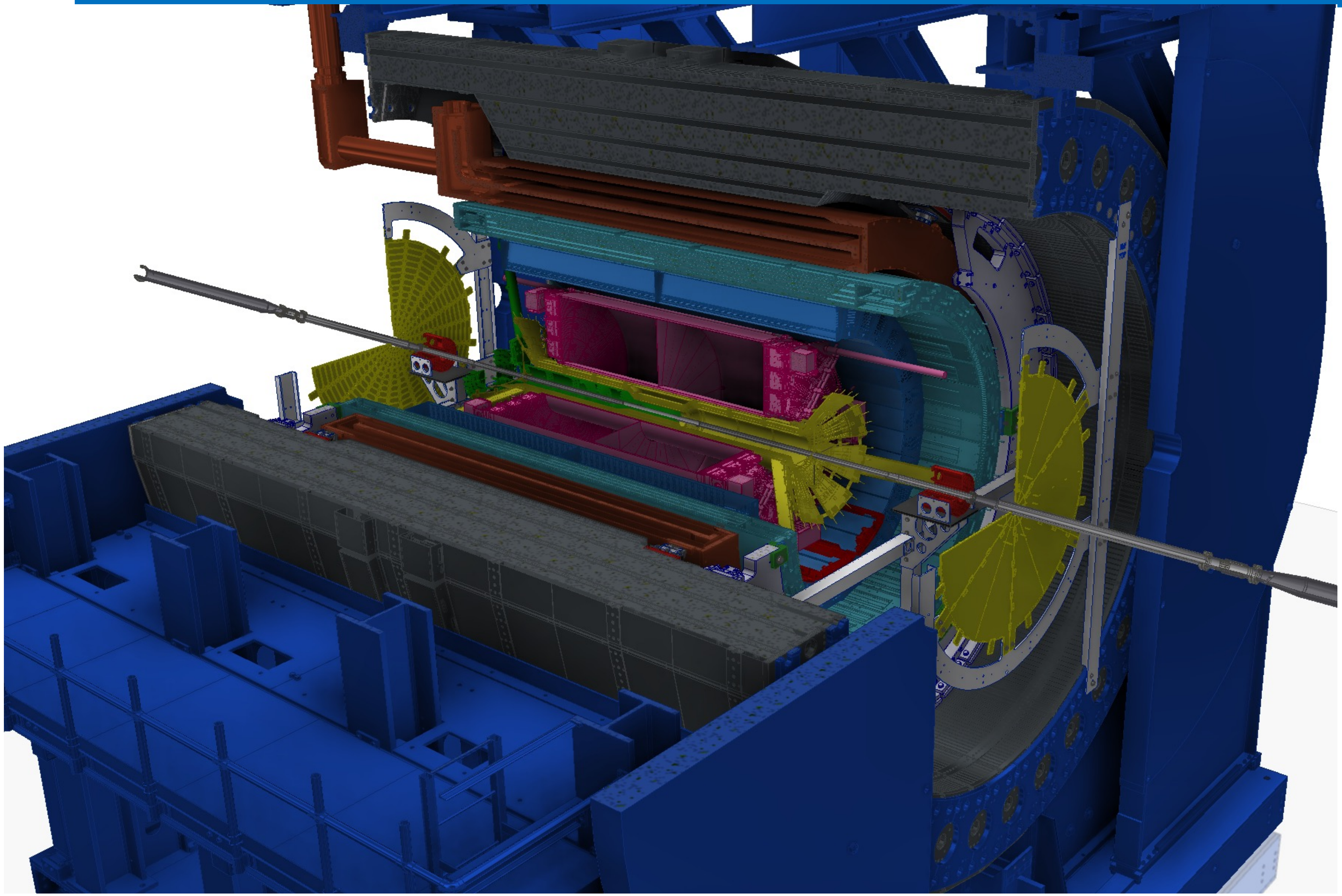
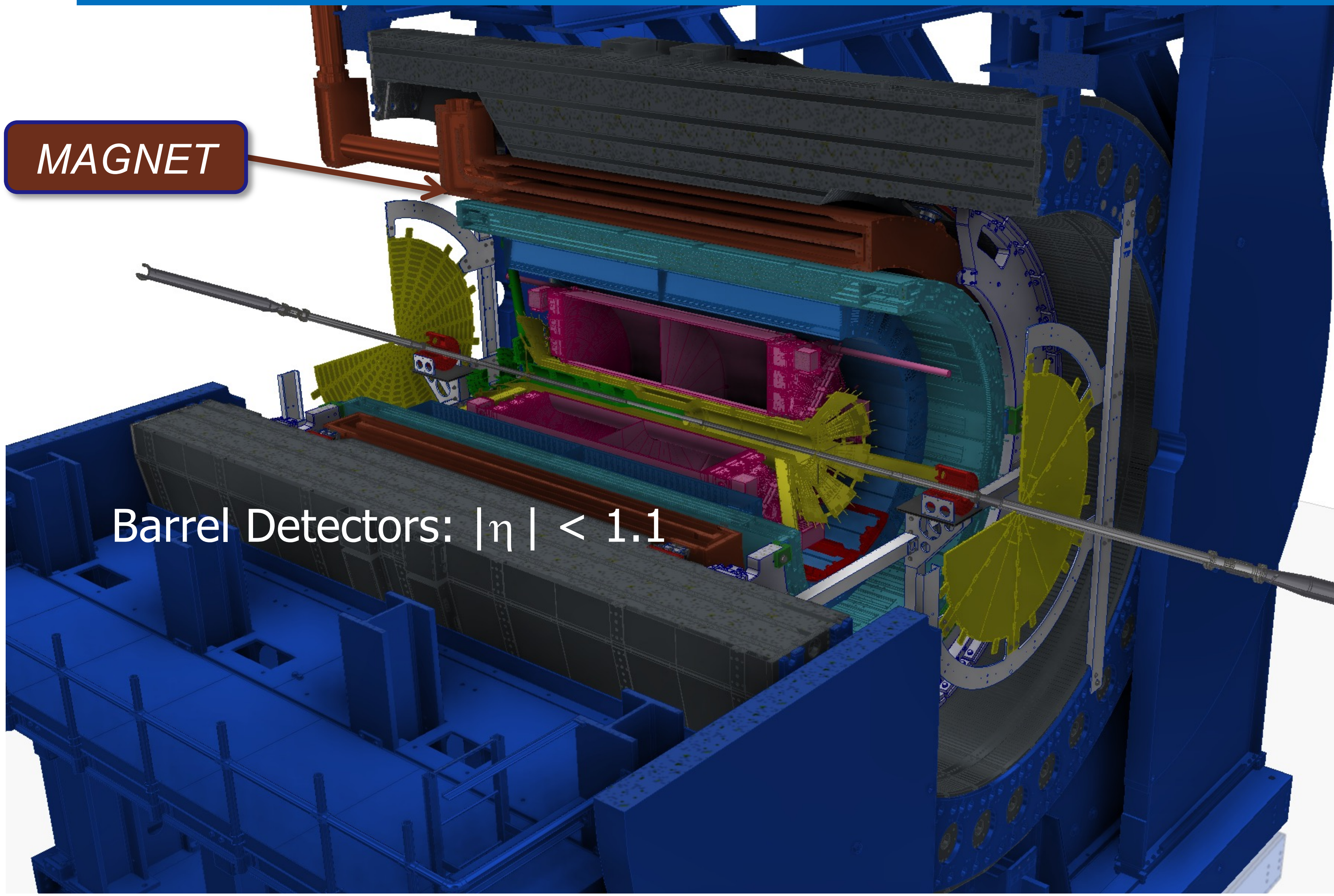
sPHENIX Detector



sPHENIX Detector



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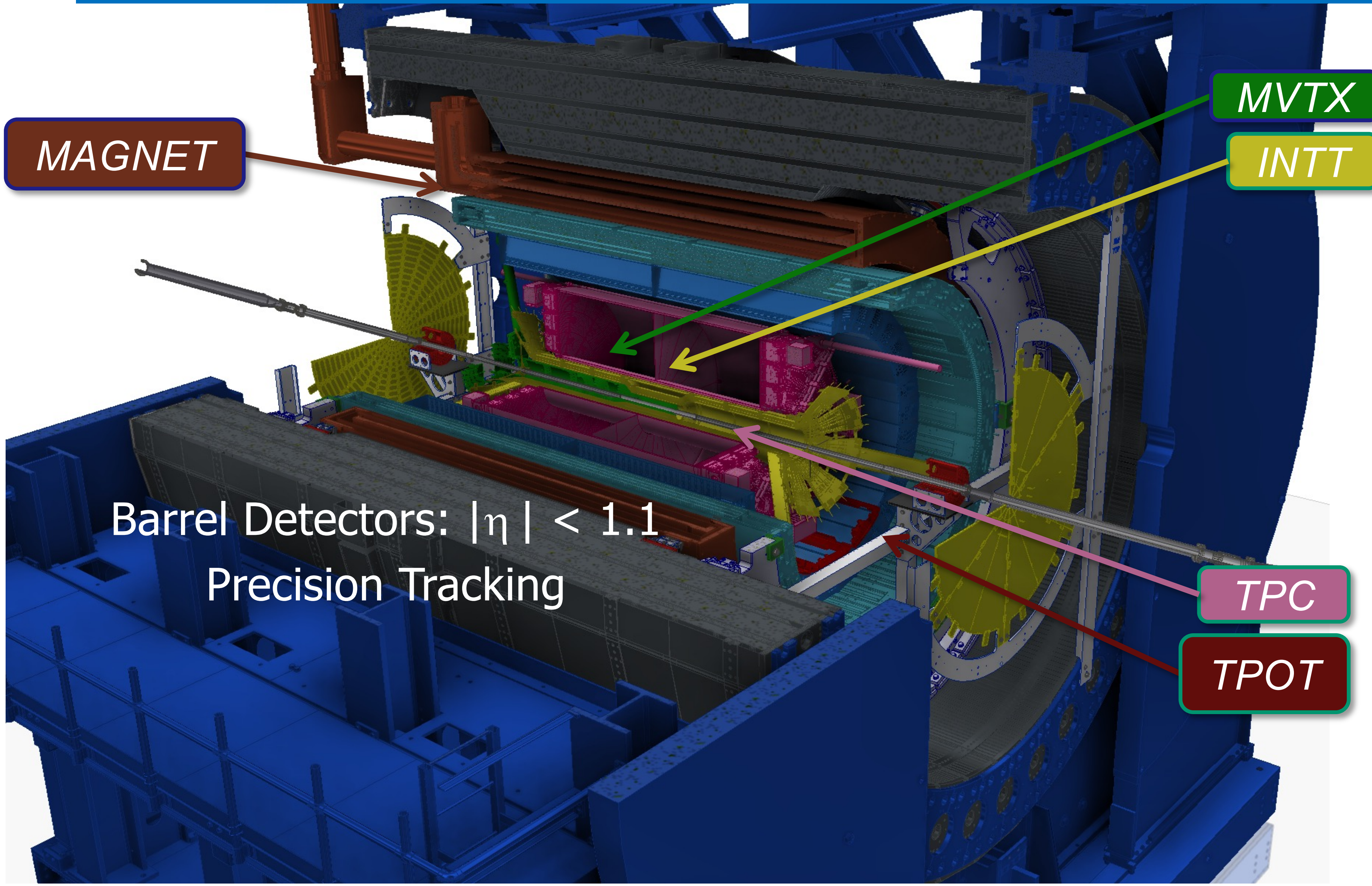
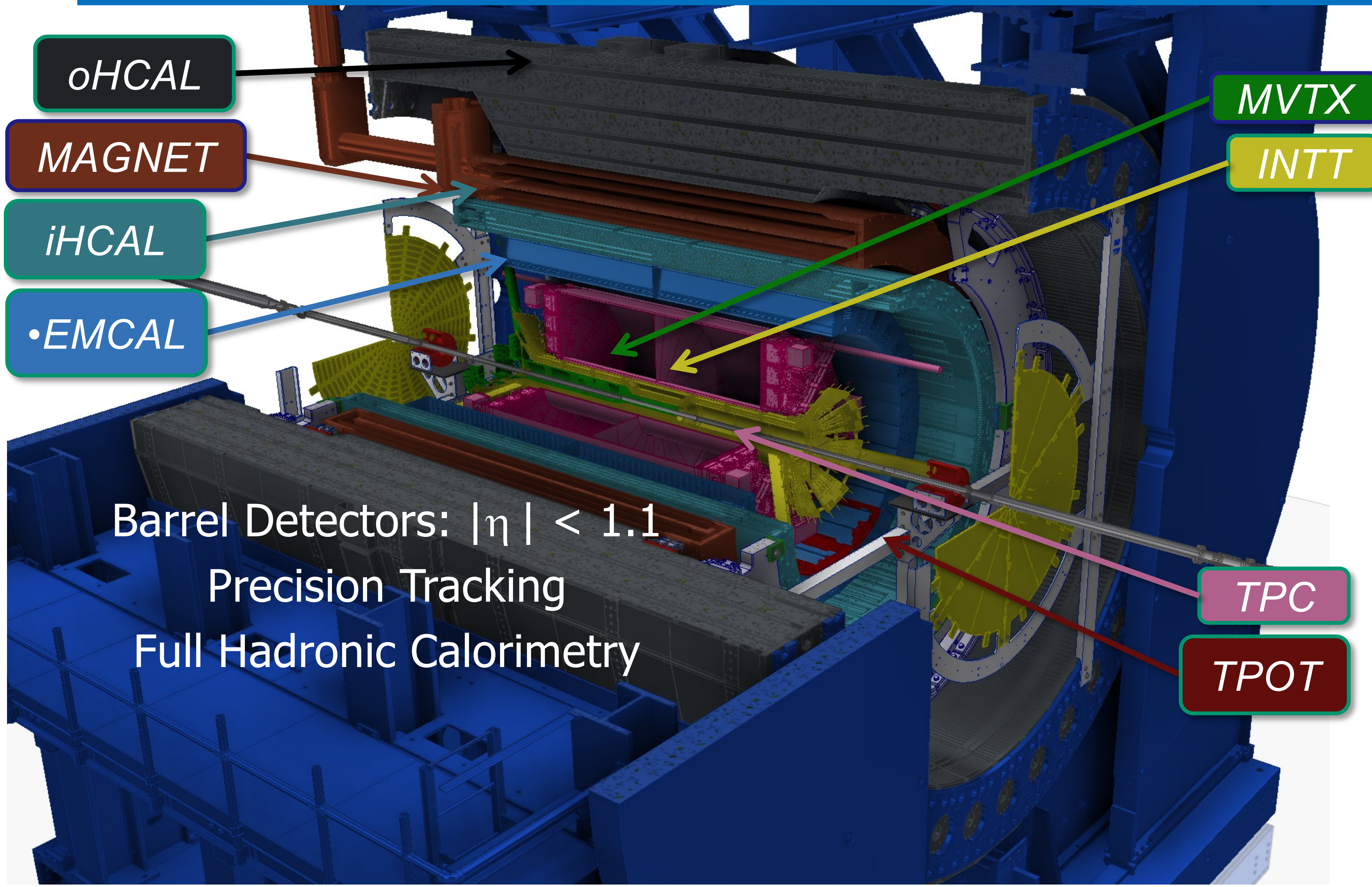
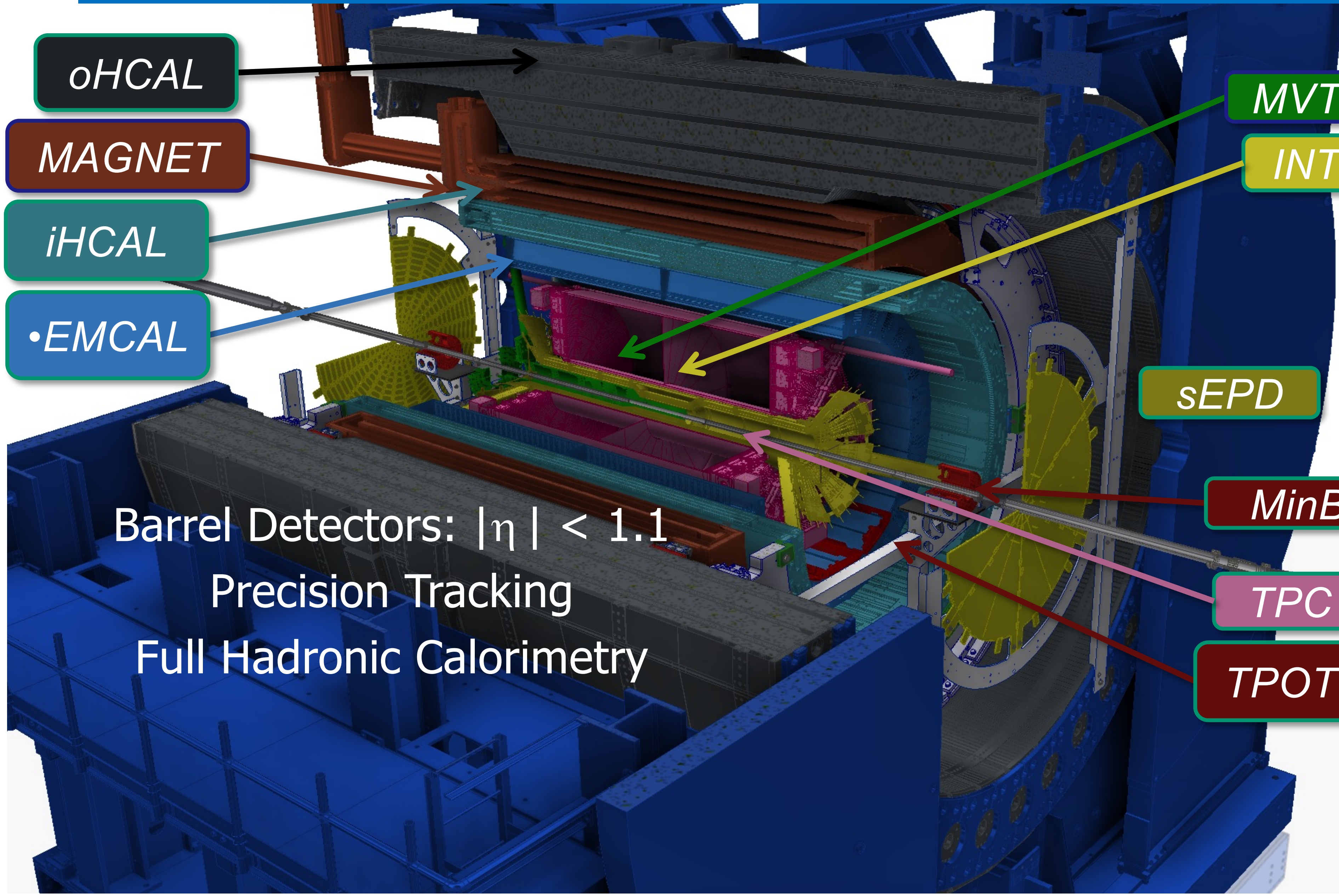


sPHENIX Detector



sPHENIX Detector



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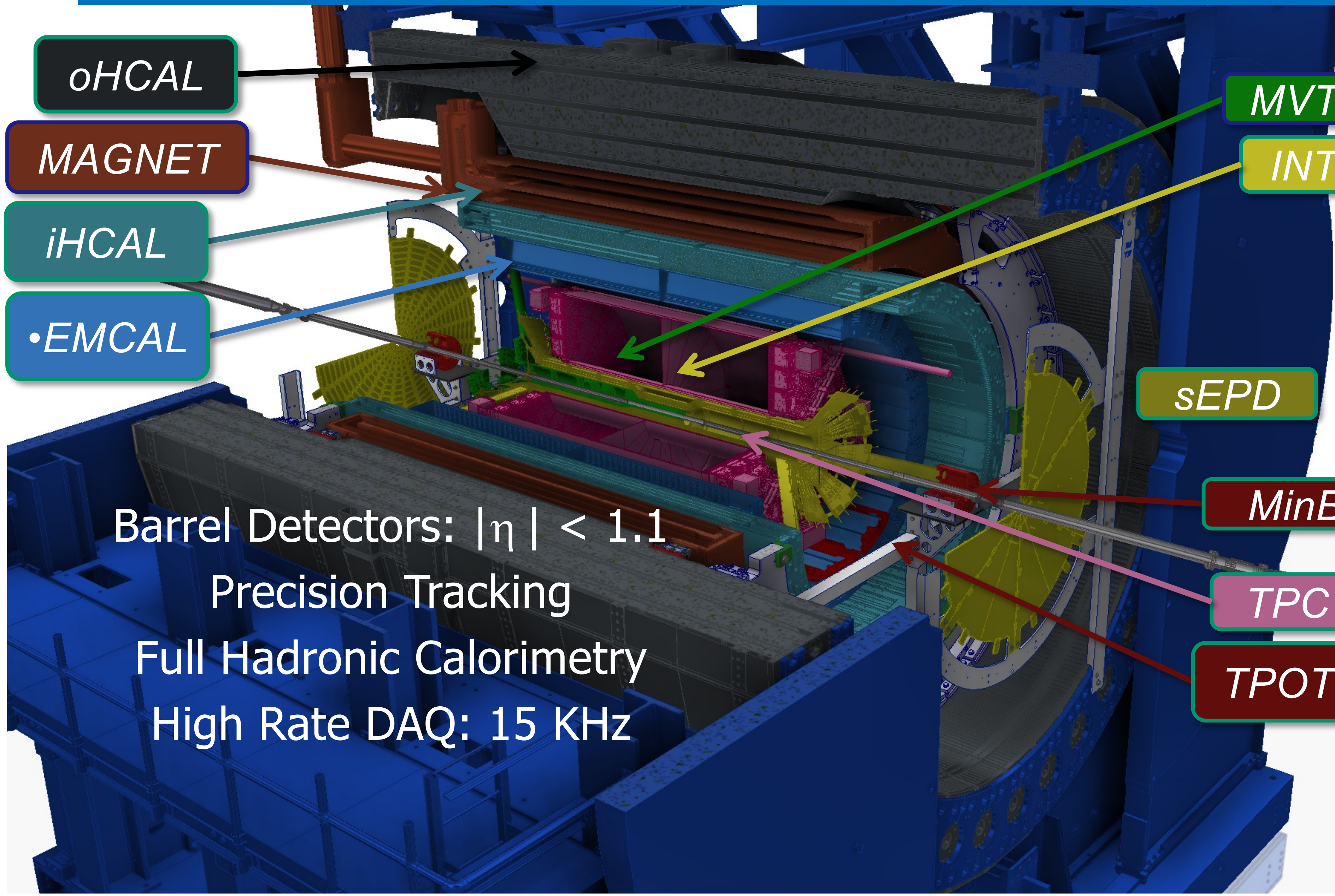

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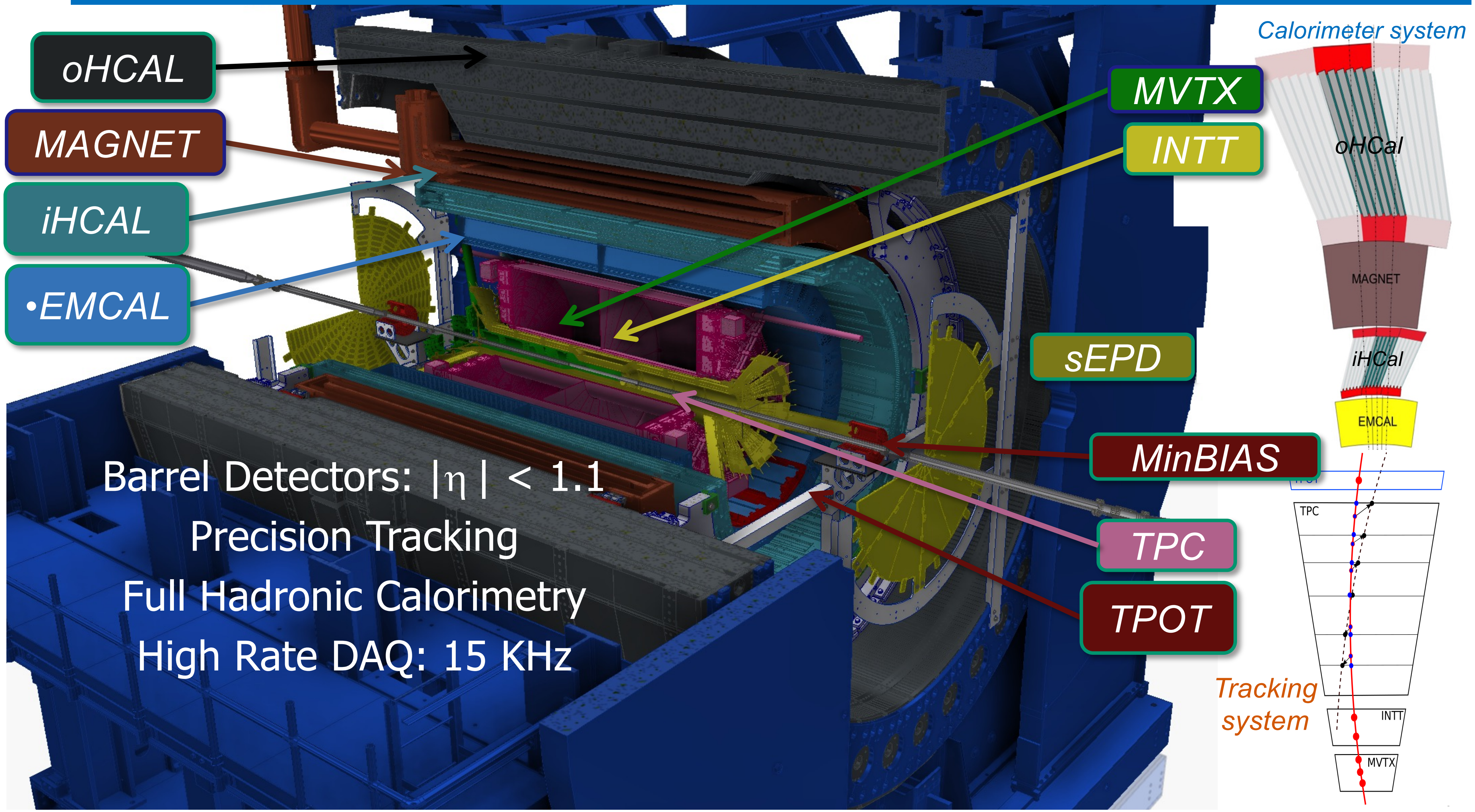
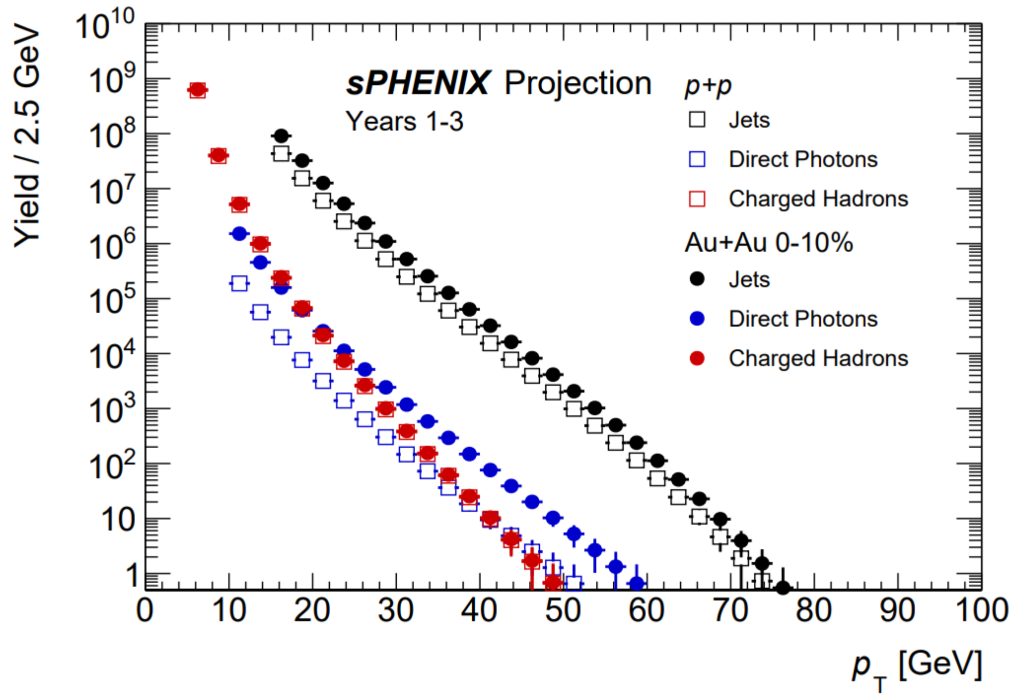
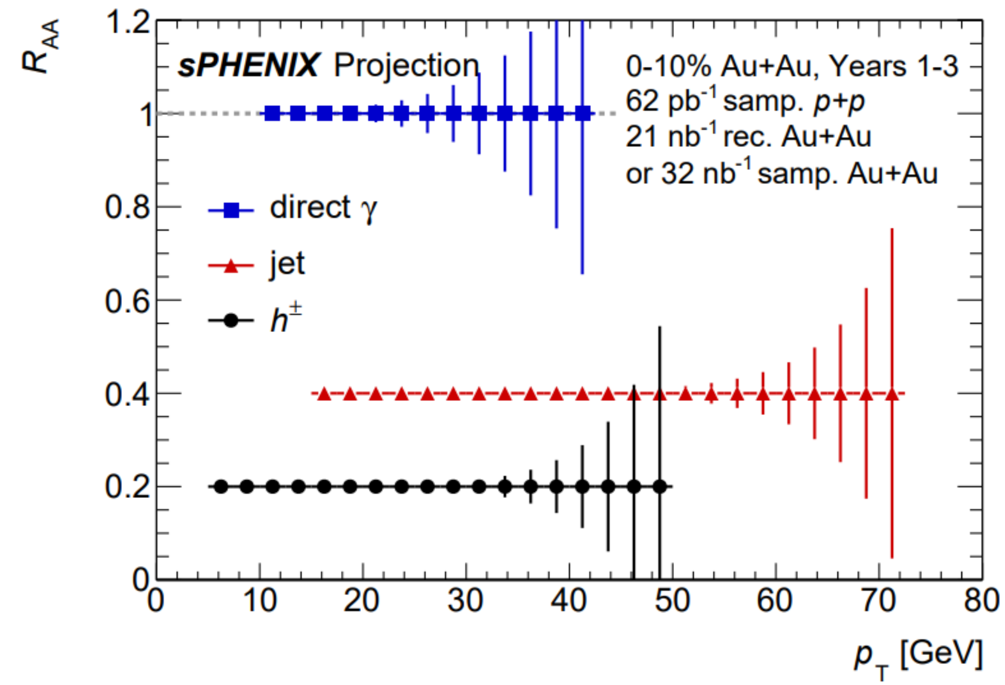


High-p_T Probes

Probing the QGP with precise jet, direct photon, and hadron measurements





✓High data rates & 2π EMCal+HCal offer wide p_T range for jet reconstruction.

✓sPHENIX can precisely measure the low p_T region, which is challenging at the LHC.

✓sPHENIX will have kinematic reach out to ~70 GeV for jets, kinematic overlap with the LHC.

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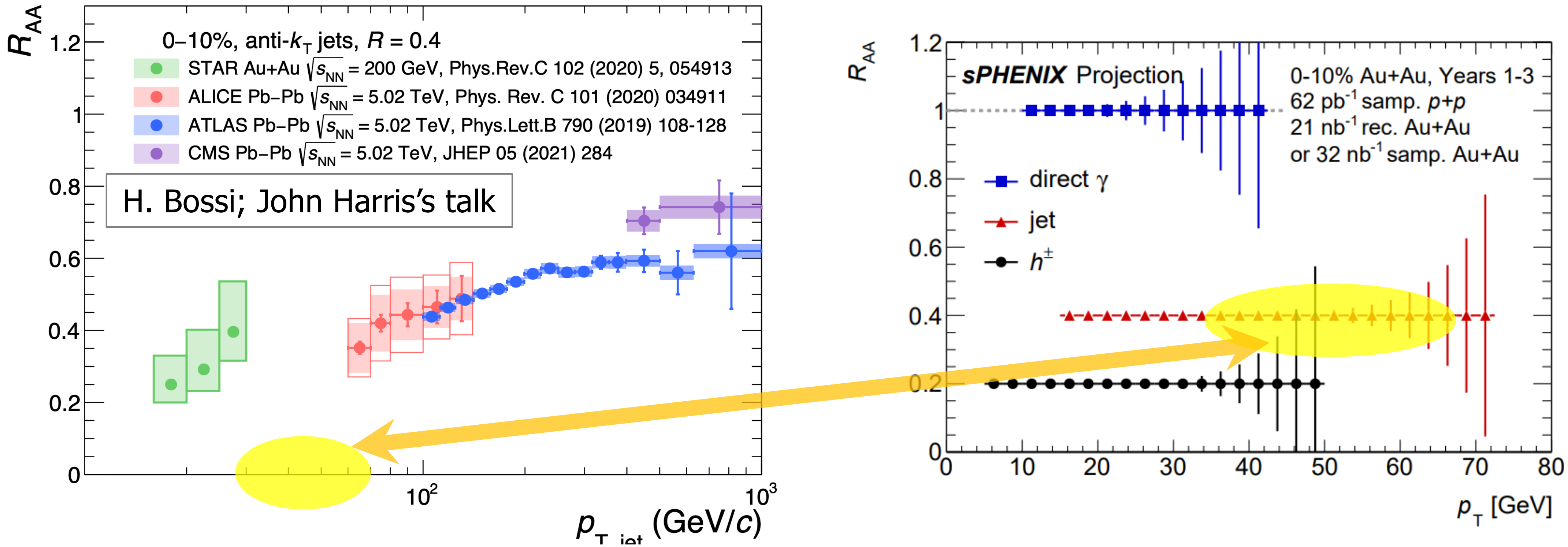

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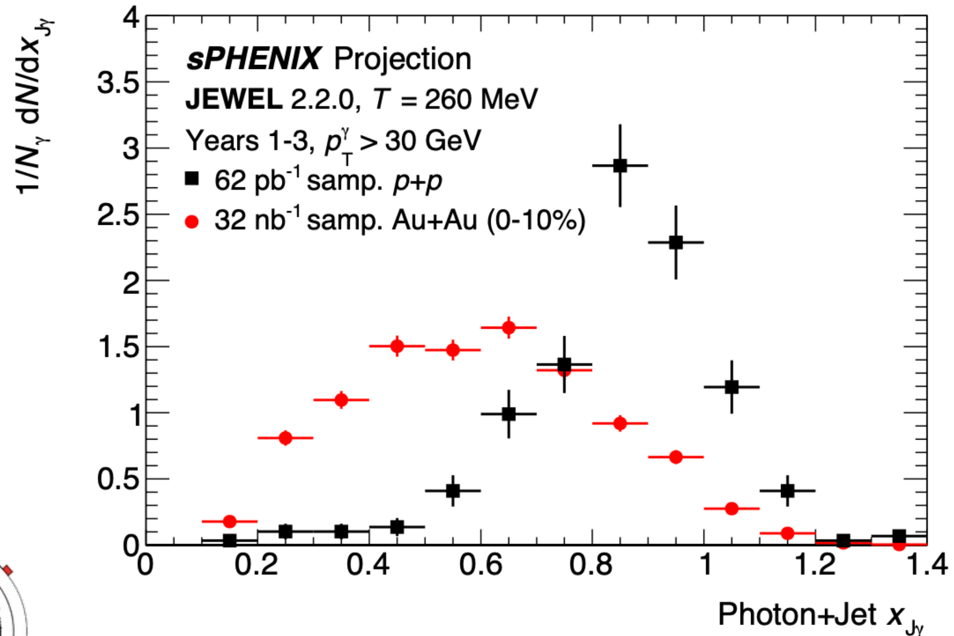
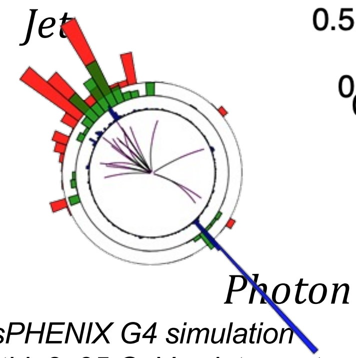
Jet Physics

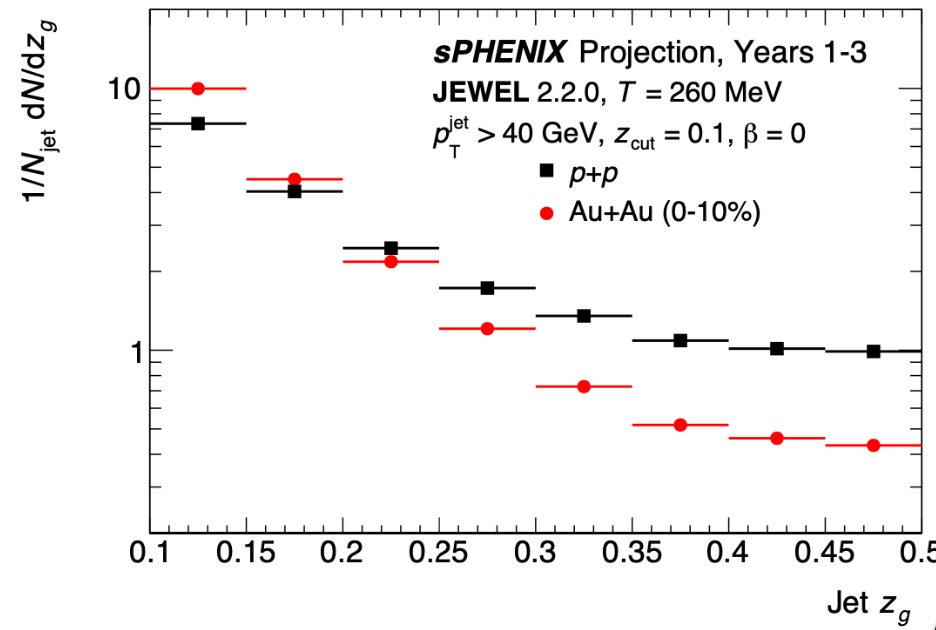


Jet-to-photon momentum balance

$$X_{J\gamma} = p_T^{jet}/p_T^{\gamma}$$

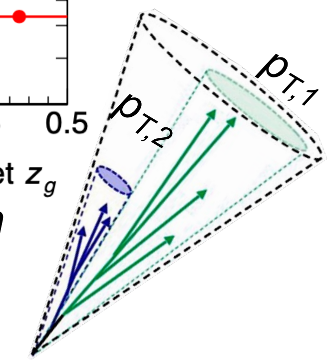


sPHENIX G4 simulation
Pythia8, 35 GeV γ+jet event



Groomed momentum fraction

$$z_g = \frac{\min(p_{\perp,1}, p_{\perp,2})}{p_{\perp,1} + p_{\perp,2}}$$

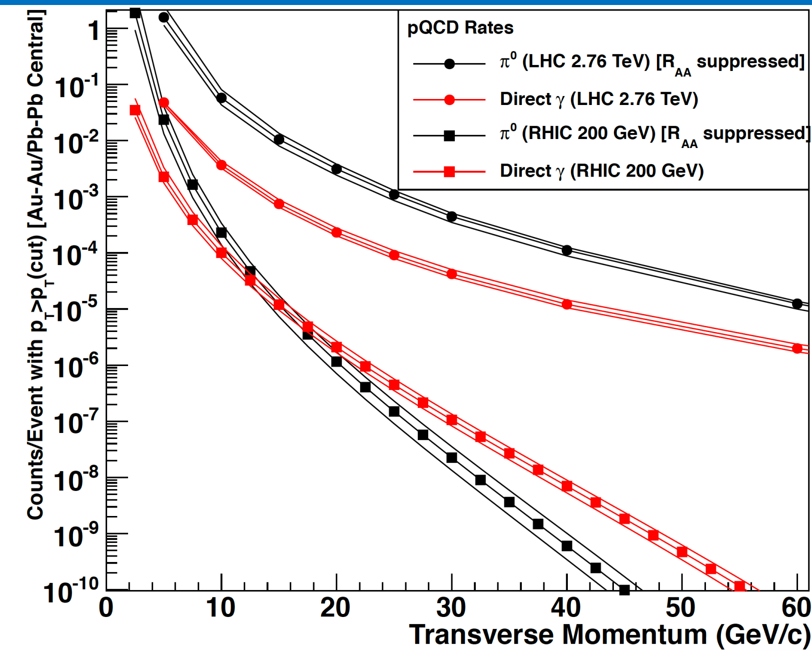


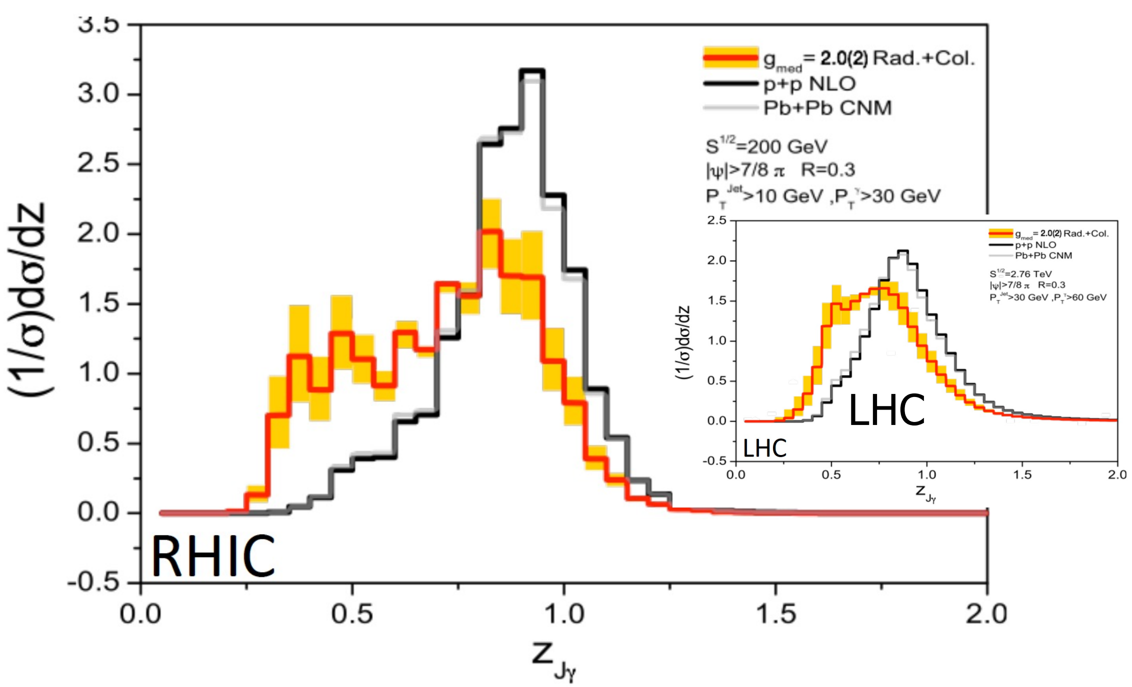
- ✓ A “flagship” measurement.
- ✓ Photon+jet measurements with high statistics.
- ✓ A direct measure of the jet energy loss.

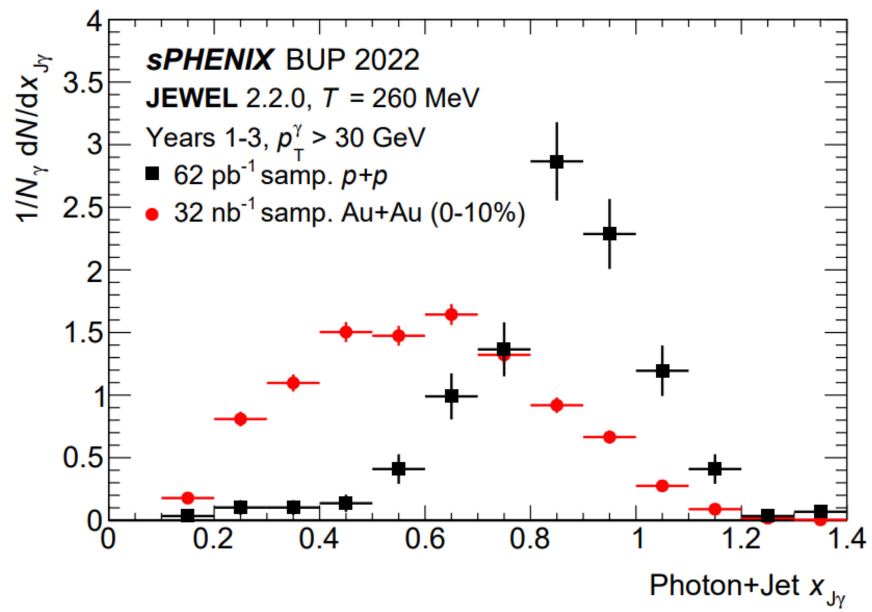
- ✓ Jet substructure measurements enabled by fine segmentation of calorimeter + good tracking resolution.
- ✓ Providing a glimpse into fundamental splittings at parton level.

Photon-Tagged Jets

- ✓ Key measurement in sPHENIX physics program.
- ✓ RHIC is ideal for measuring direct photons.
- ✓ Measurements of $z_{J\gamma}$ may be more sensitive at RHIC.







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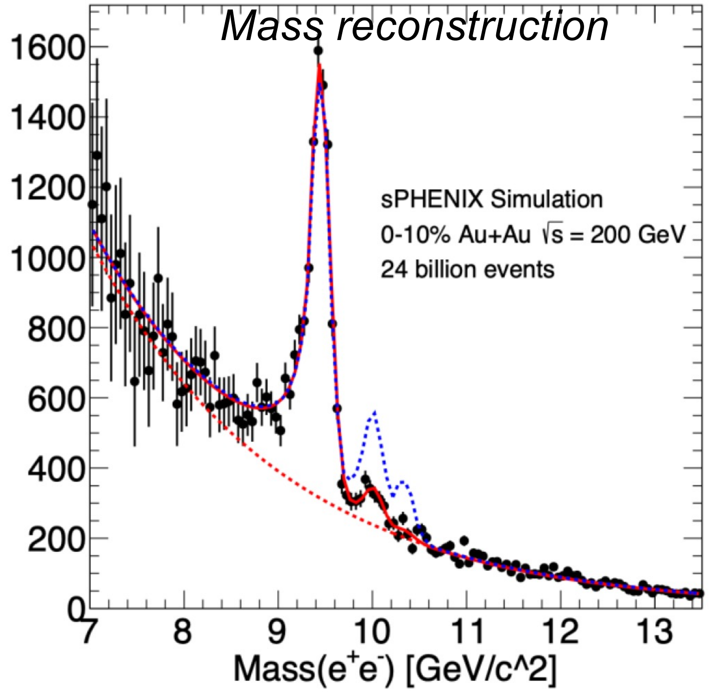
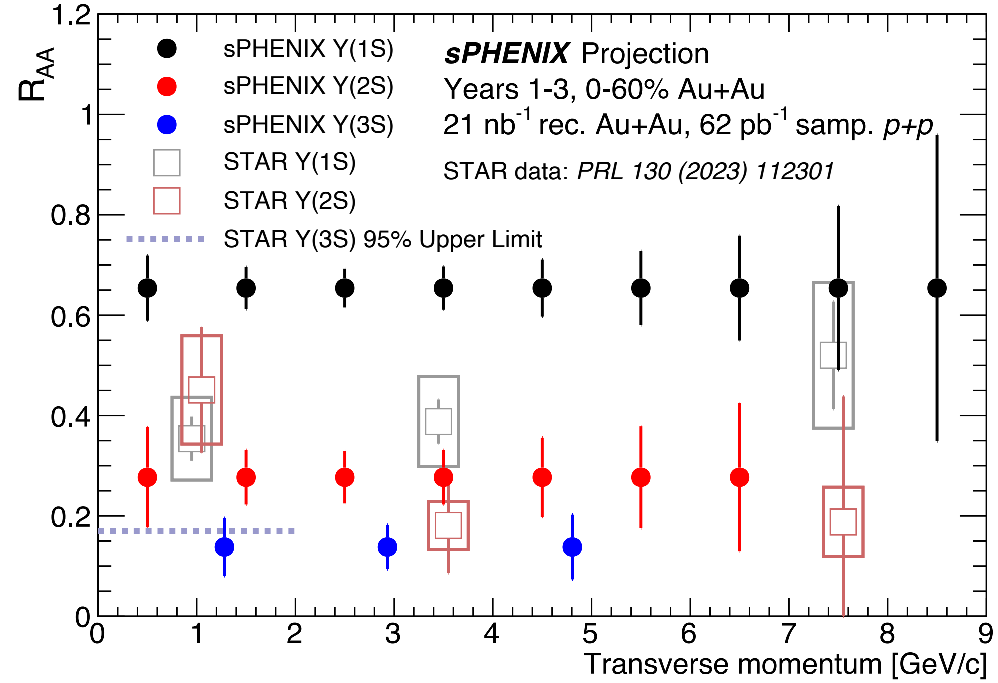
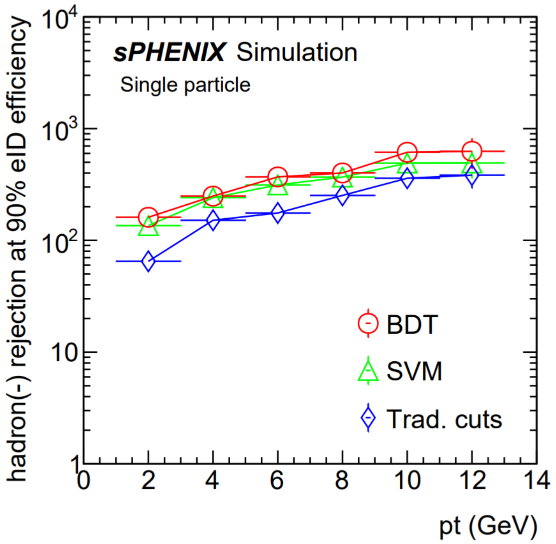
Upsilon R_{AA}

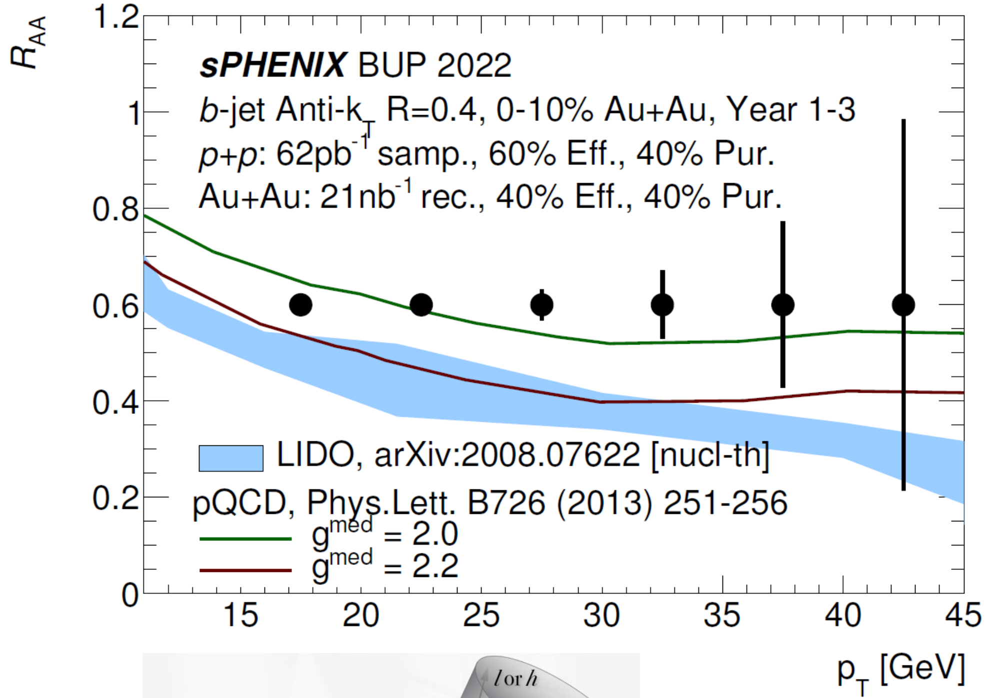


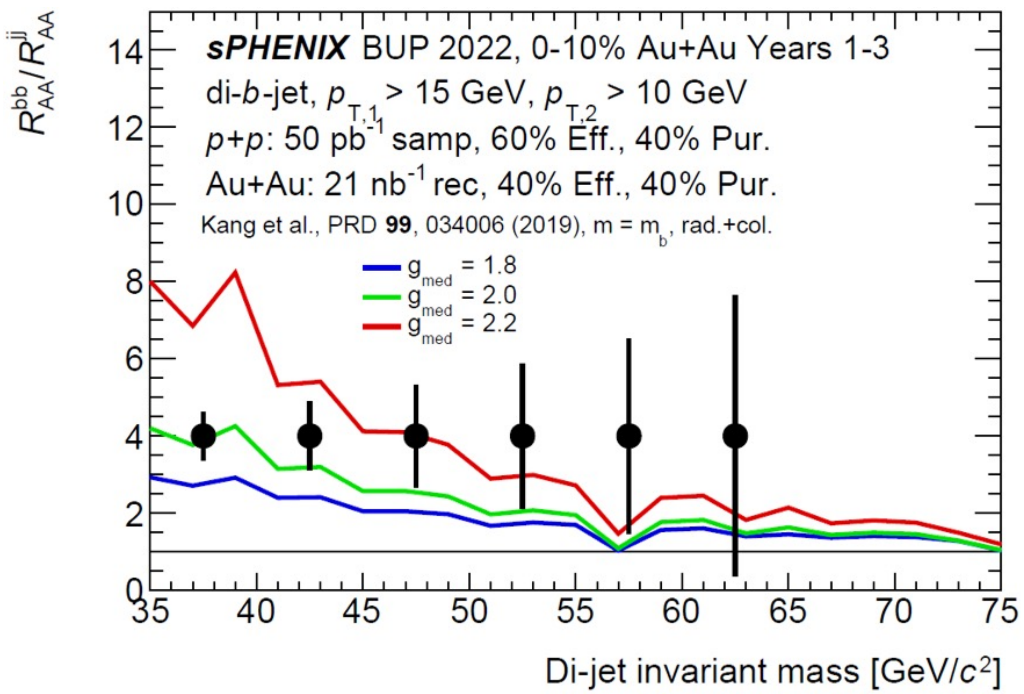


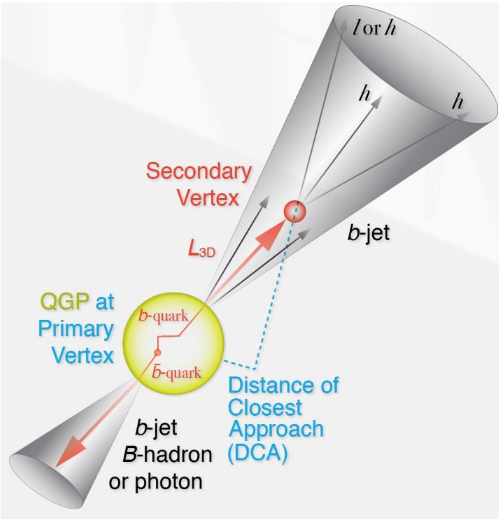


- ✓ Suppression with clear distinction of three Upsilon states. Color dipoles probing the QGP at three different length scales.
- ✓ The centrality dependence and particularly the p_T dependence are critical measurements for comparison between RHIC and the LHC.
- ✓ Signal enhancement with ML tools (BDT) is expected.

b-Jet Physics

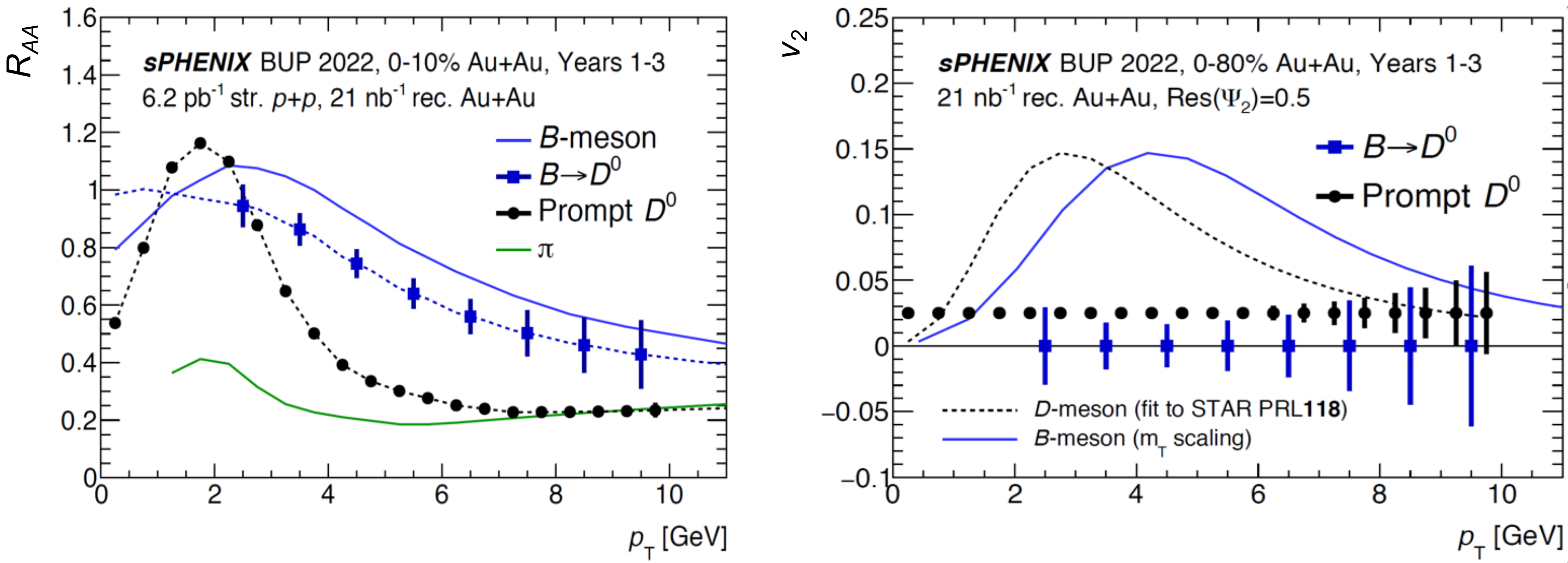






- ✓ First b-jet tagging at RHIC using precision-DCA (Distance of Closest Approach) track and secondary vertices tagger.
- ✓ sPHENIX data will place stringent constraints on the b-quark coupling to the QGP.
- ✓ Back-to-back heavy-flavor jet pairs studying the propagation of quarks in the QGP.

Open Heavy Flavor



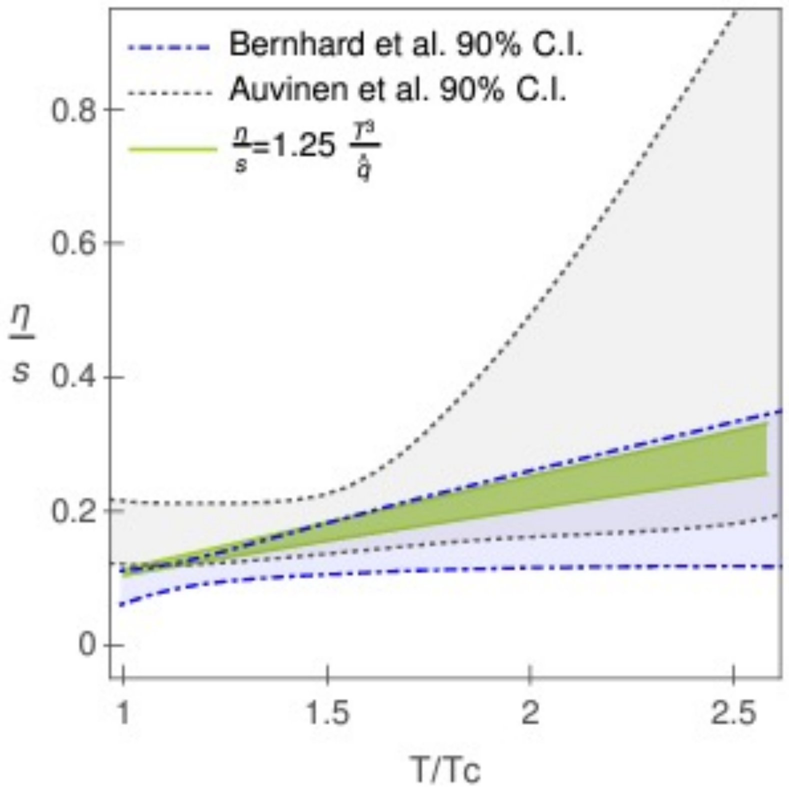
- ✓ Cleanly separate open bottom via DCA.
- ✓ Study mass dependence of energy loss and collectivity.
- ✓ Bottom quarks and light quarks are expected to be different for R_{AA} and v_2 for $p_T \lesssim 15$ GeV
- ✓ Will access b-quark R_{AA} & v_2 via non-prompt D^0, full b-hadron reconstruction

Two Examples (out of many) from This Workshop

Bithika Karmakar:

Constraining η/s Through High-p_T Tomography

Study of $T^3/\hat{q}$ as valid proxy for η/s

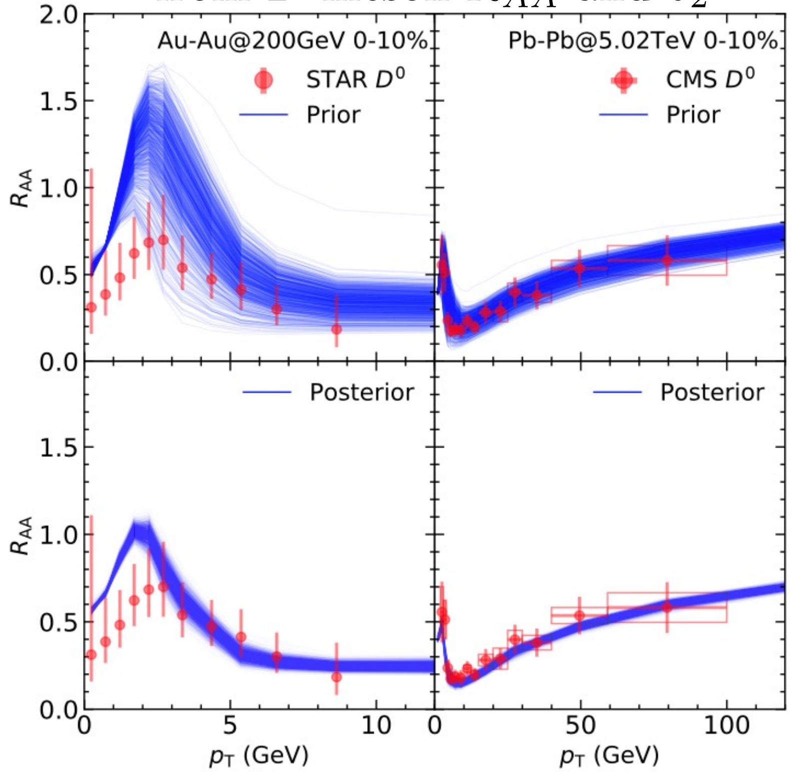


https://arxiv.org/abs/2305.11318

Shanshan Cao:

Constraining the QGP Properties Using Heavy Quarks

Bayesian determination of D_s and η/s from D-meson R_{AA} and v_2



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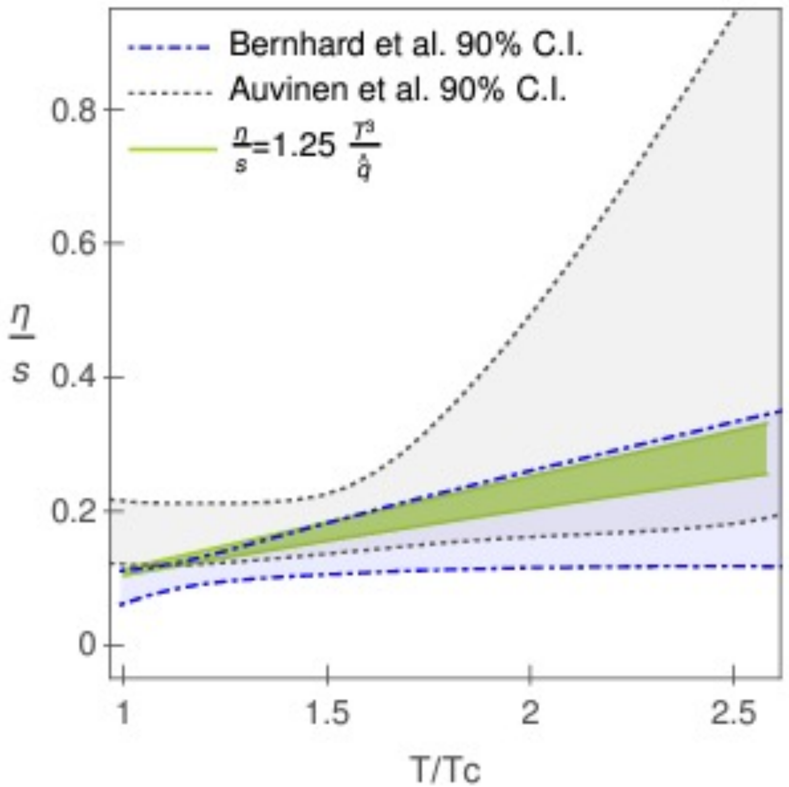

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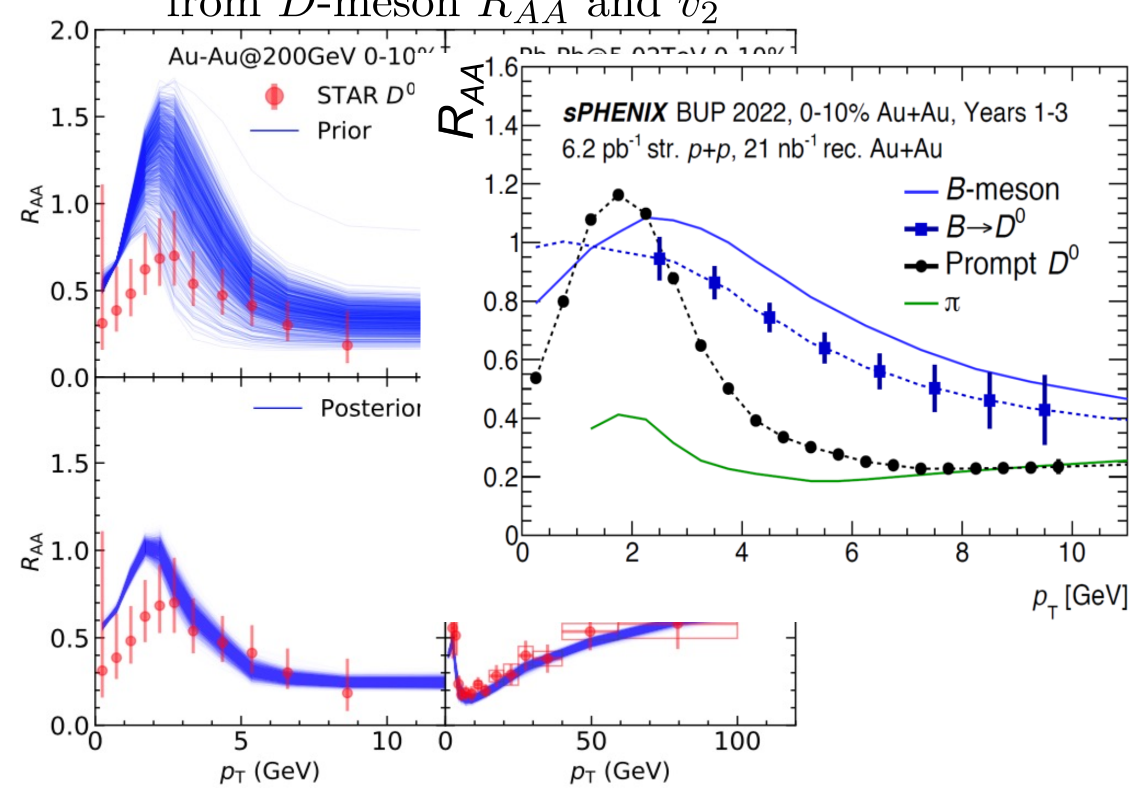

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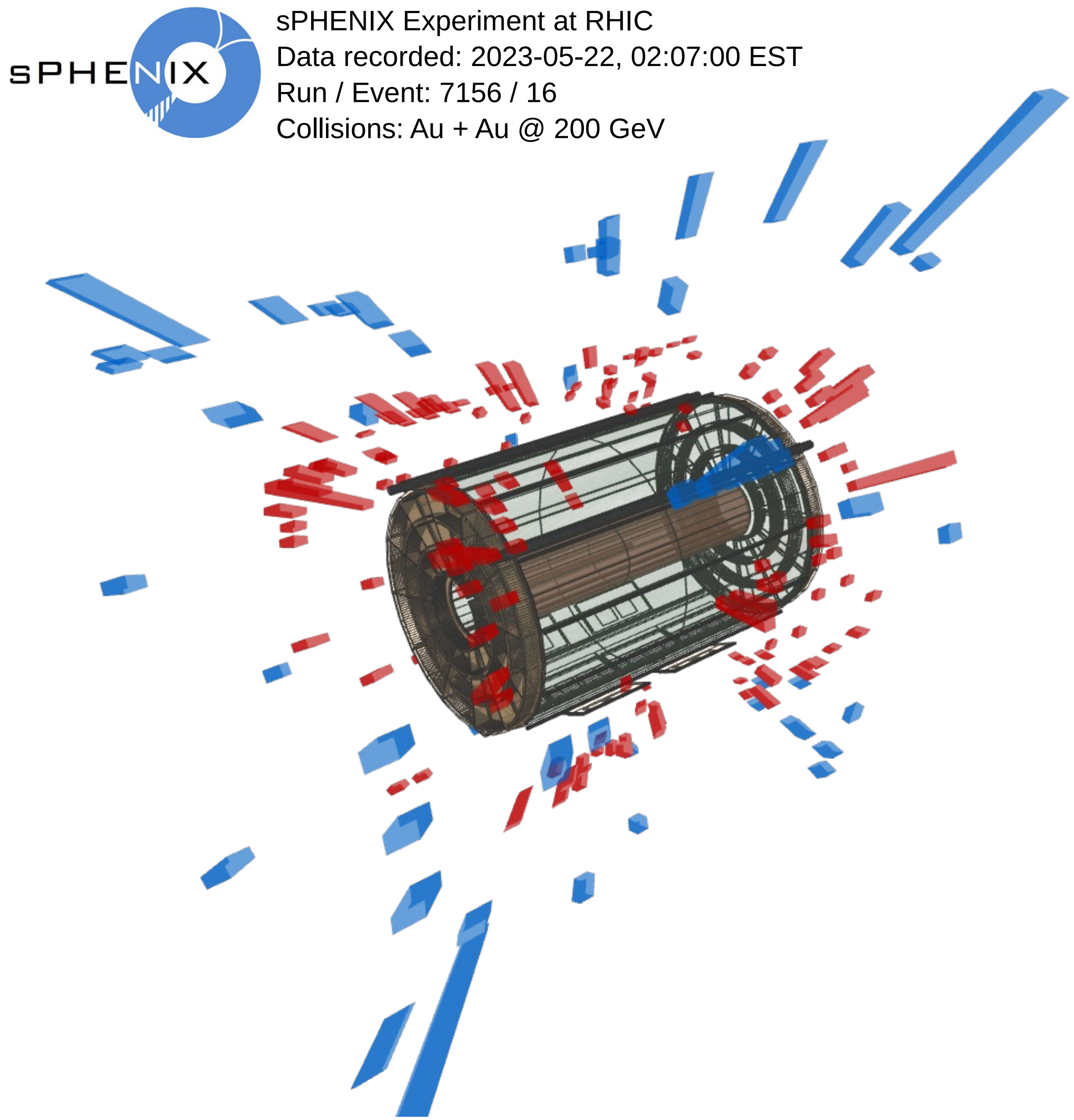
Current sPHENIX Status

- Commissioning!
  - 200 GeV Au+Au



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- Commissioning!
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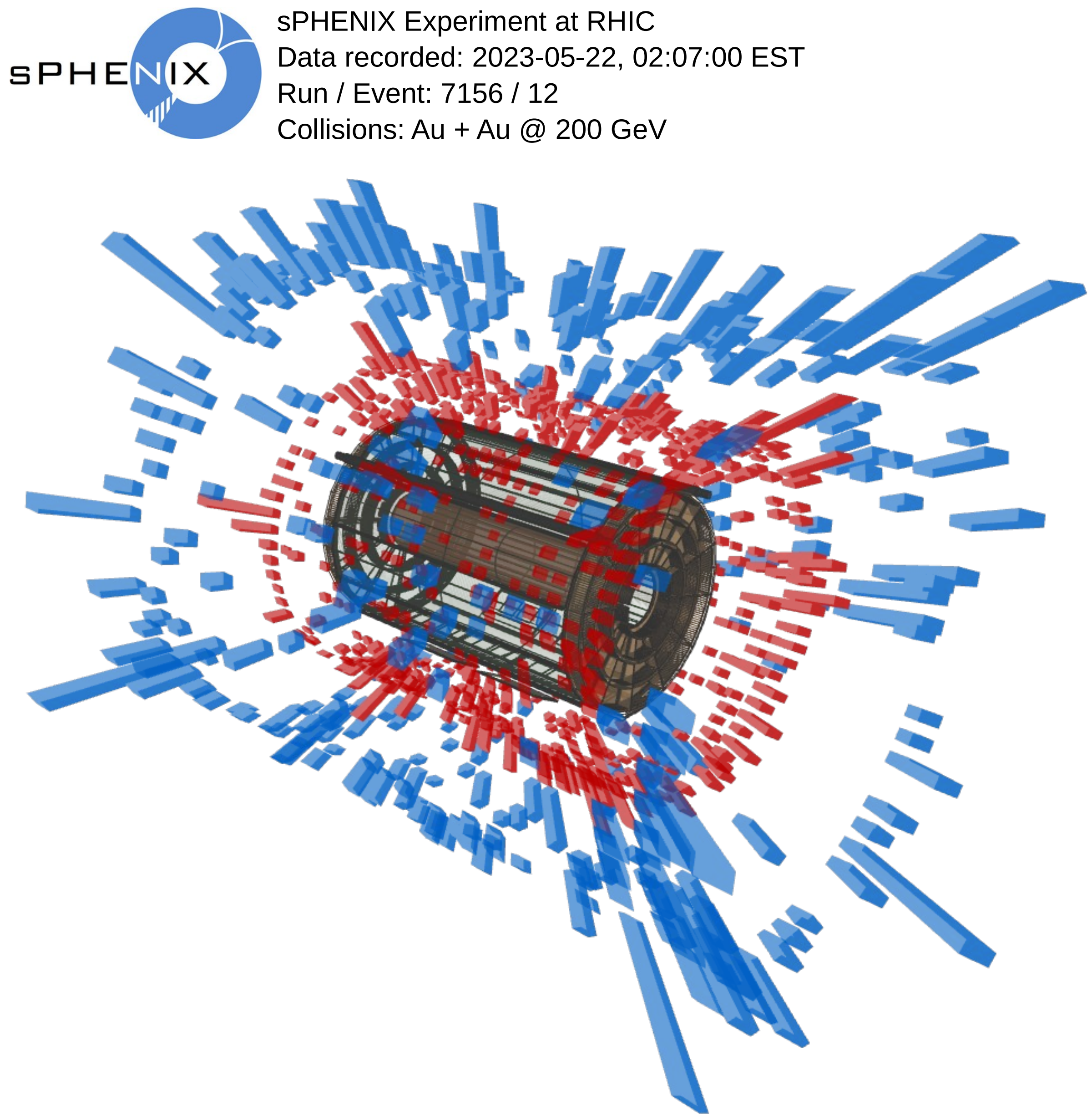
- Events!



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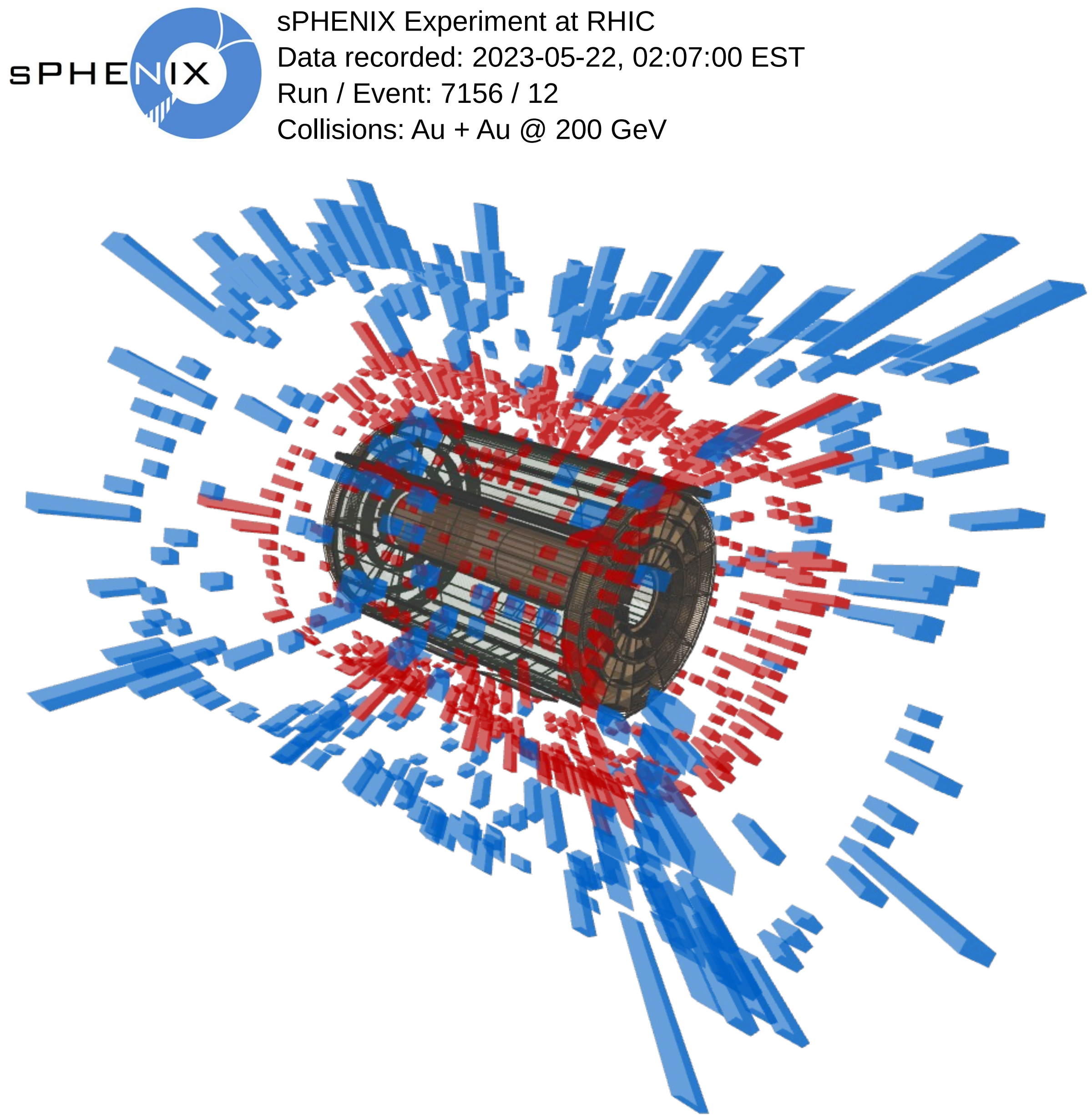
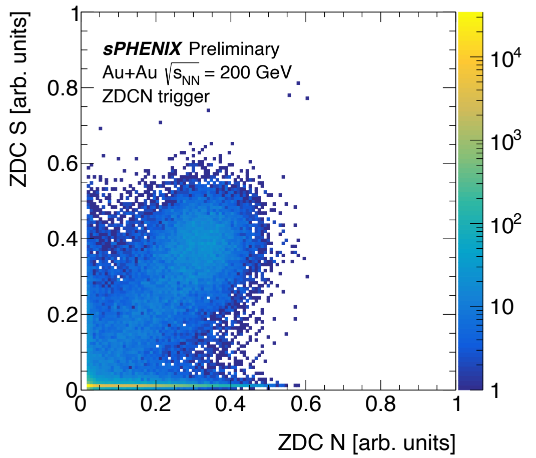
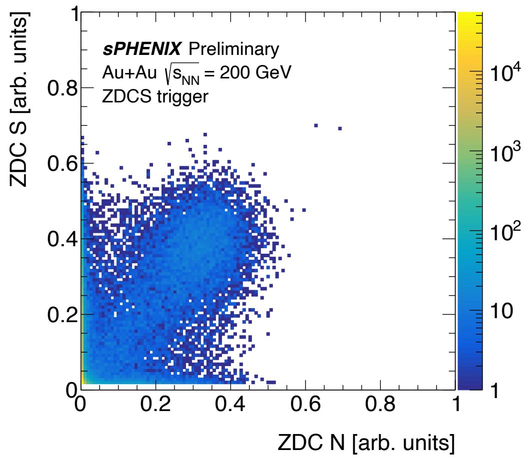


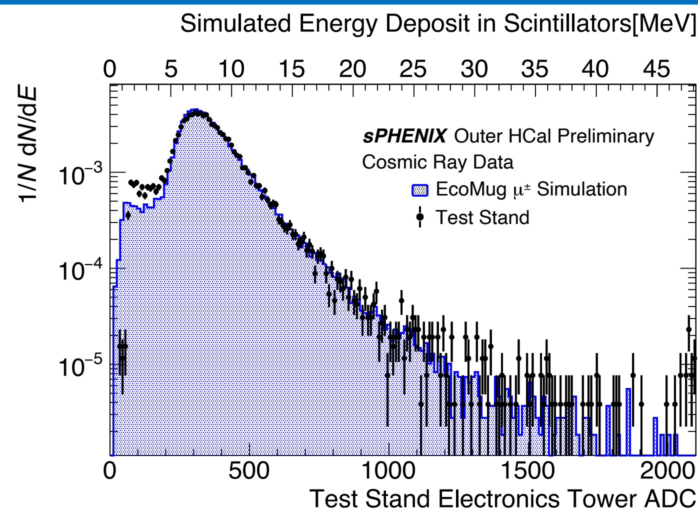
- Events!

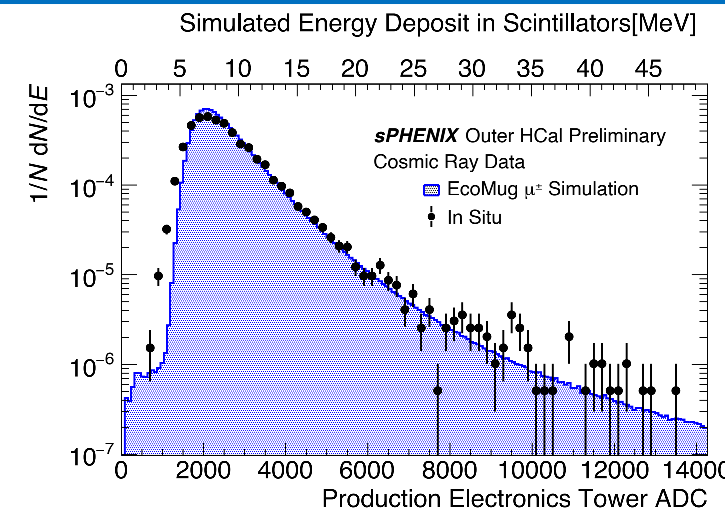
- So much more to come!

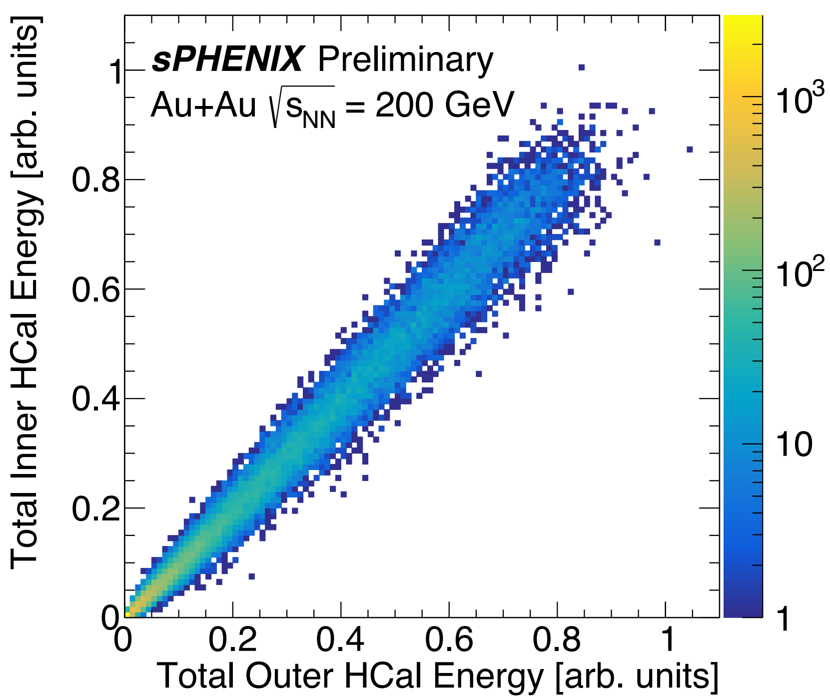
Preliminary Performance Plots

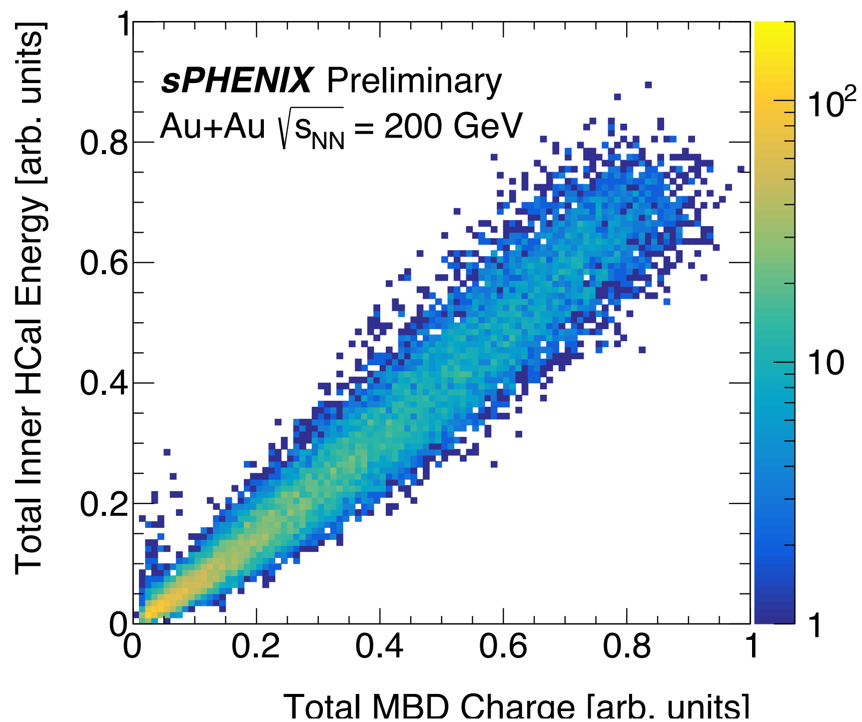


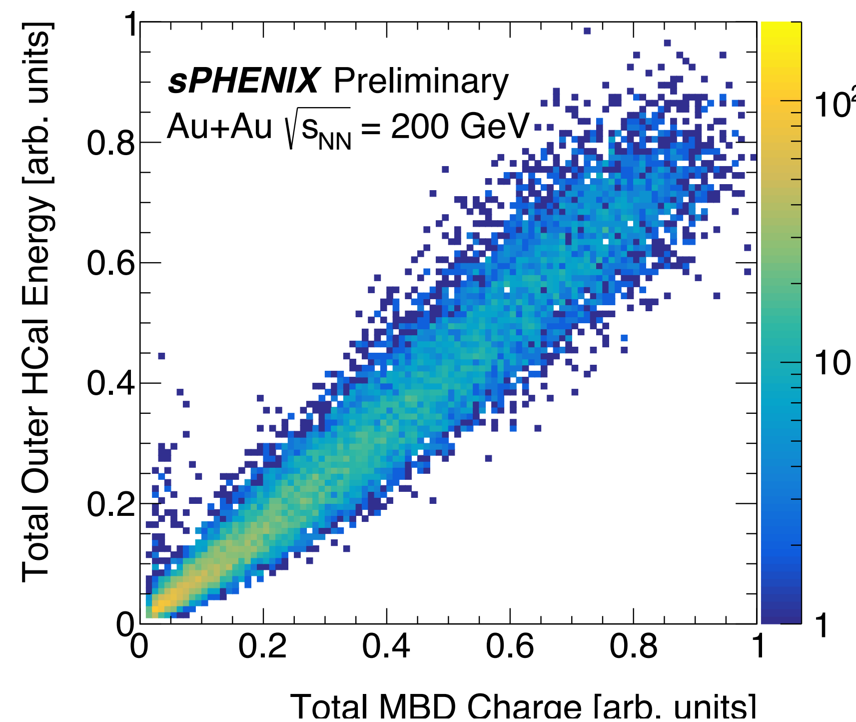




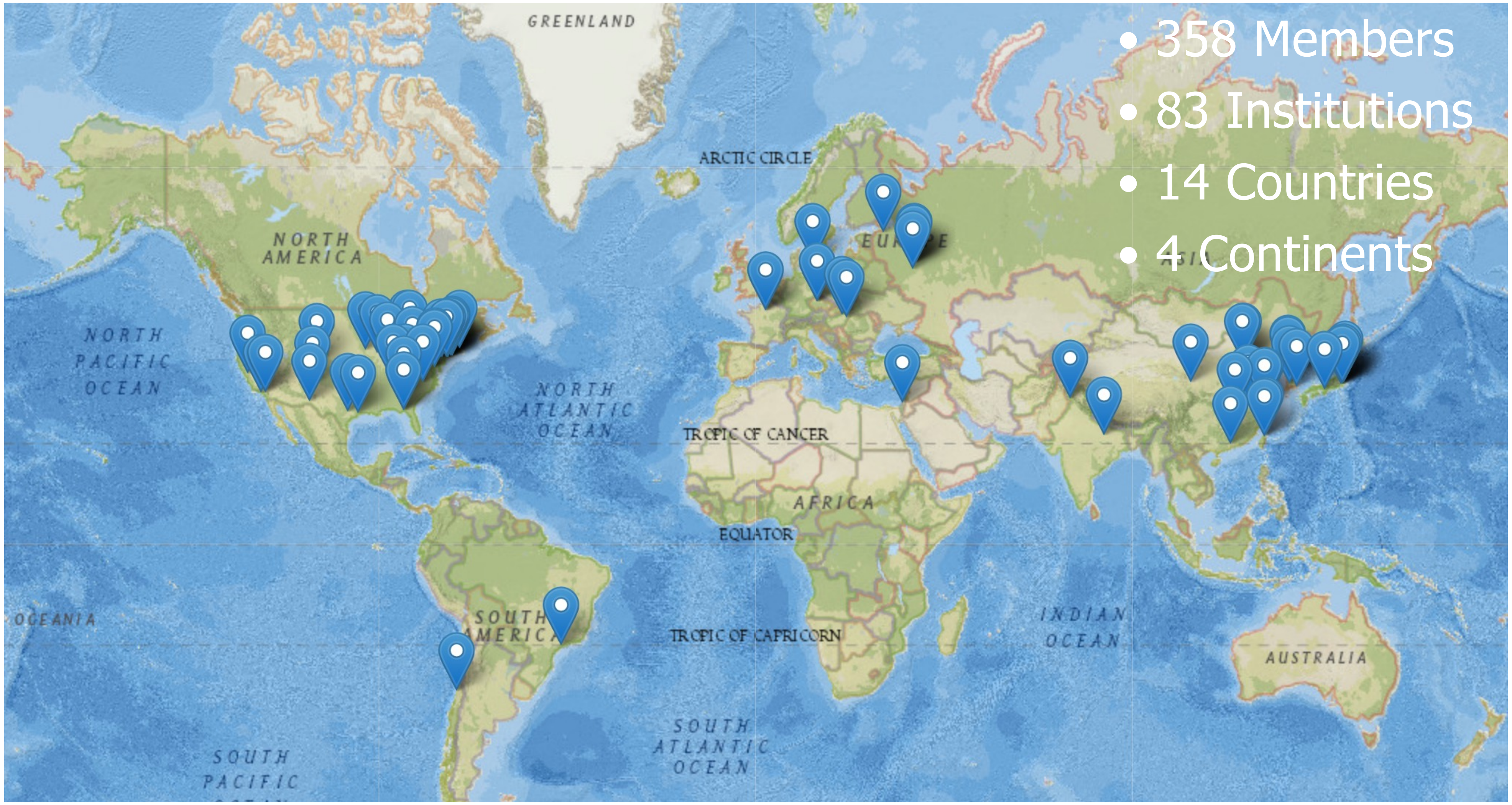








sPHENIX Collaboration



- 358 Members
- 83 Institutions
- 14 Countries
- 4 Continents

- Encouraging diversity is a priority for our collaboration.
  - Diversity, Equity, & Inclusion training is a requirement for being an sPHENIX author.

Ministry of Science, Technological Development and Innovation of the Republic of Serbia

Thank You!

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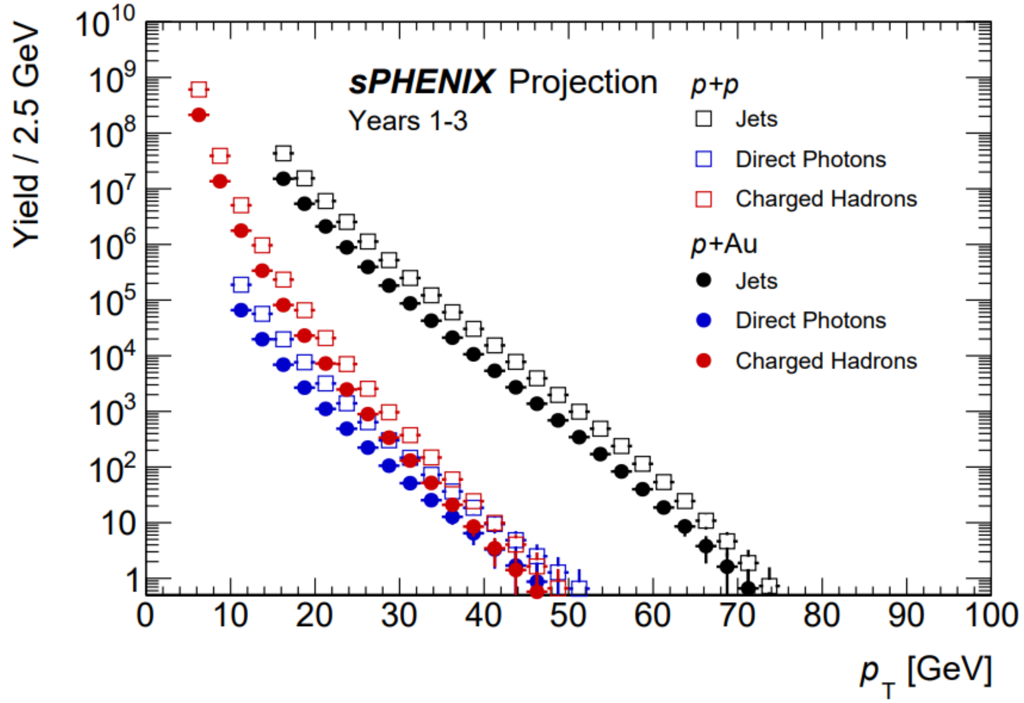
Back-up Material

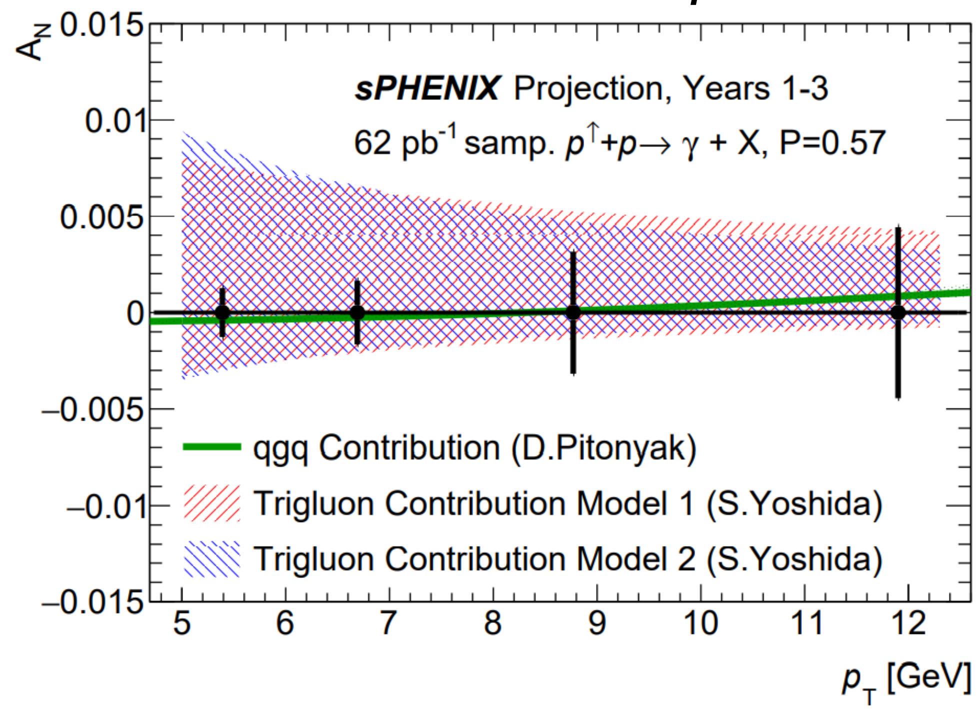
This work was supported by the United States Department of Energy Grant DOE-FG02-86ER-40281

Cold QCD

Hard probes in p+Au



TSSA for direct photon

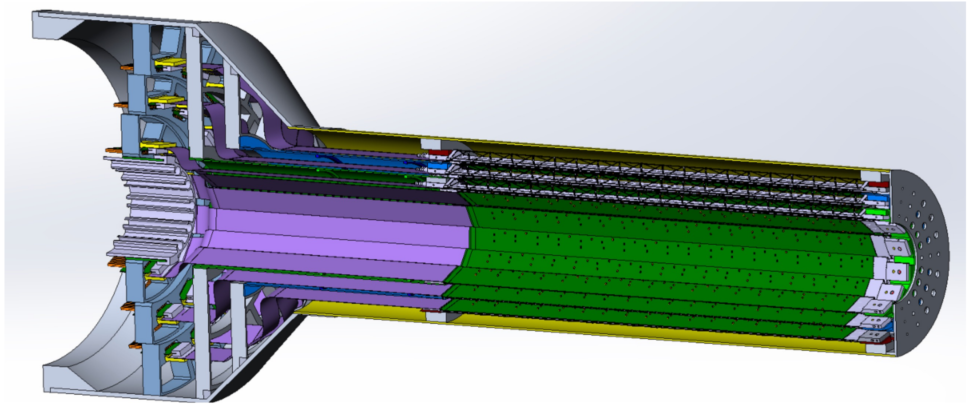


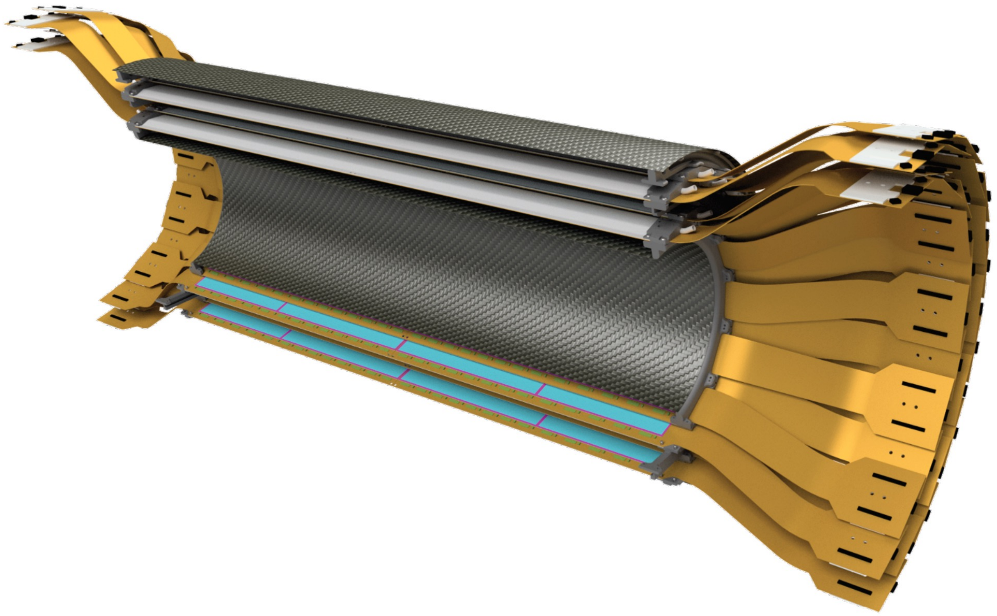
- ✓ Study of nuclear modifications using unpolarized p+Au measurements.
- ✓ Provide information on the nuclear modification of hadronization processes.
- ✓ Sensitive to the CNM effects.

- ✓ Spin measurements such as transverse single spin asymmetry (TSSA) will be done using polarized beams.
- ✓ Study the nucleon spin structure and parton dynamics.

Inner Tracking

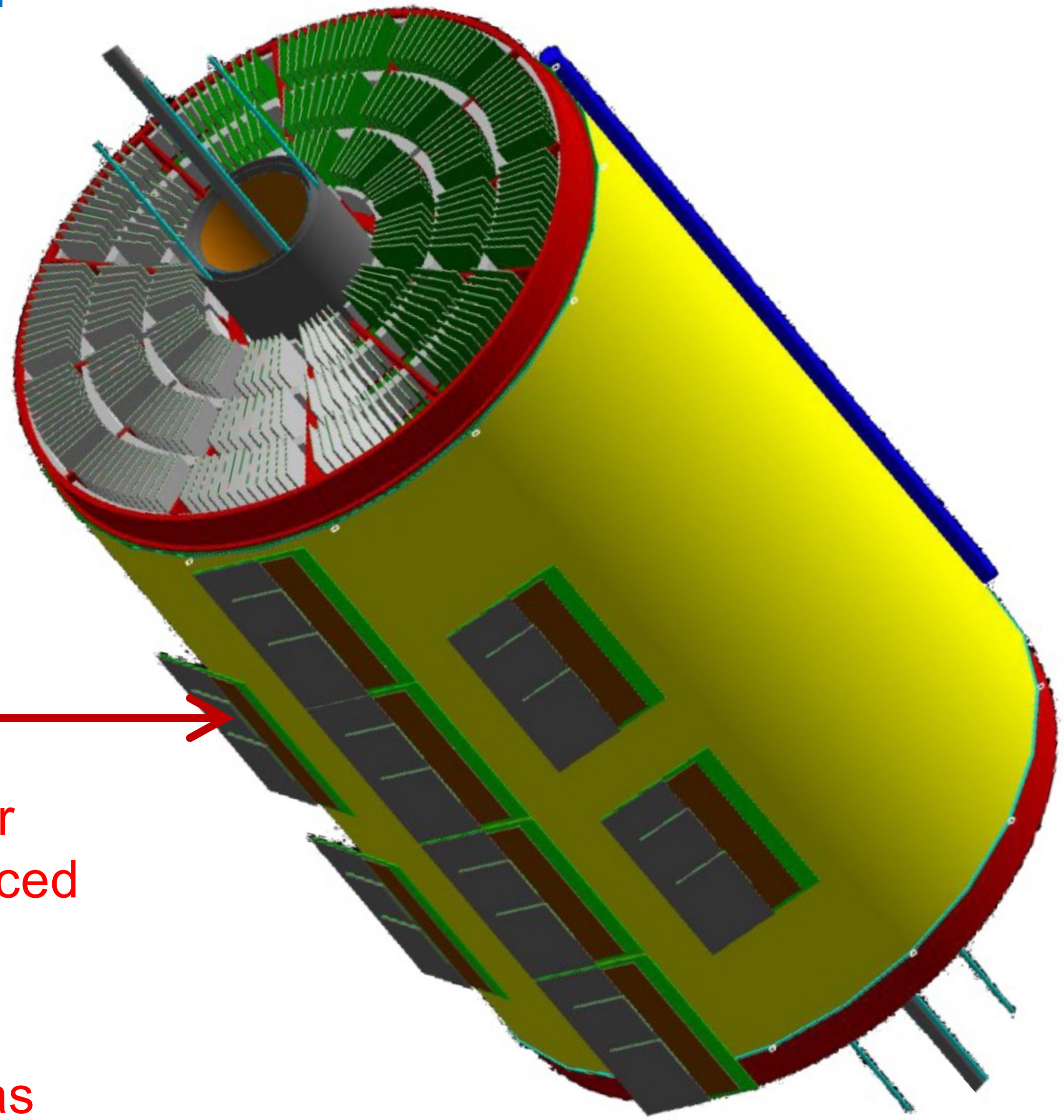
- **MVTX**
  - Precision vertexing
  - Position: 2.3 < r < 3.9 cm
  - 3 layers of Monolithic Active Pixel Sensors
  - Based on new ALICE ITS
  - Pixel size: 29×27 μm
  - Position resolution: 5 μm (tracks w/ p_T > 1 GeV/c)
- **INTT**
  - Position: 7 < r < 12 cm
  - 2 layers of Si strips
  - Pitch: 86 μm
  - Single-beam-crossing timing resolution





TPC & TPOT

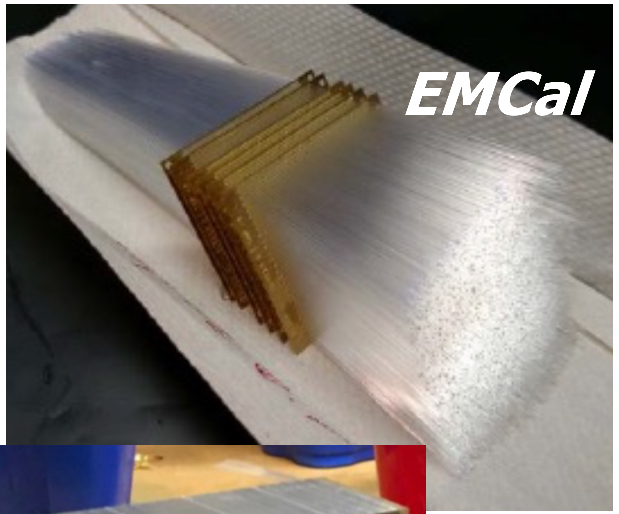
- **TPC**
  - Tracking
  - Position: 20 < *r* < 78 cm
  - Compact, GEM-based
  - Effective hit resolution: ~250 μm
  - Continuous (non-gated) readout
- **TPOT**
  - Additional information for calibration of beam-induced space charge distortions
  - Position: outside TPC
  - 8 modules of Micromegas

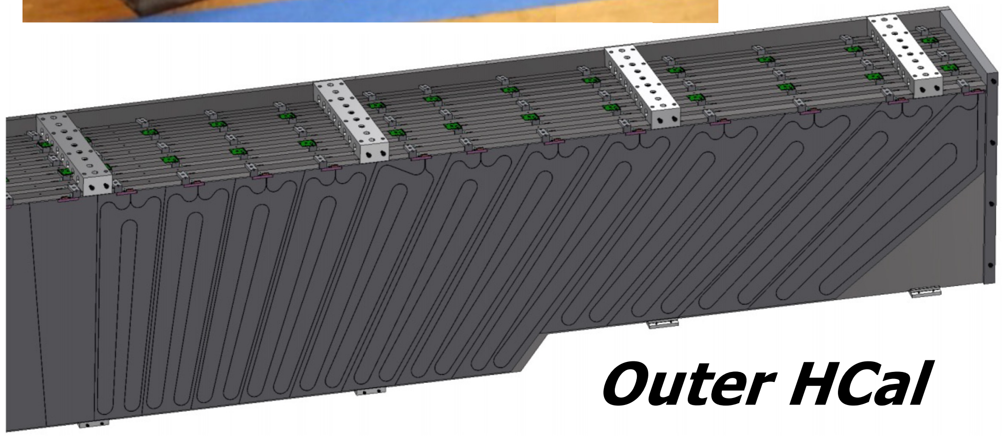


Calorimeters

- **EMCal**
  - Tungsten-Scintillating Fiber sampling calorimeter
  - Material: 20.1 X_0, 0.83 λ_{int}
  - Resolution: $16\%/\sqrt{E} \oplus 5\%$
- **HCal**
  - Inner & Outer HCals w/ magnet in between
  - Al (inner) & steel (outer) absorber plates
  - Scintillating tiles w/ embedded WLS fibers
  - Resolution: $88\%/\sqrt{E} \oplus 12\%$ (single particle)
- Total 5 λ_{int} for both calorimeters combined

$\Delta\eta \times \Delta\phi =$ 0.025×0.025

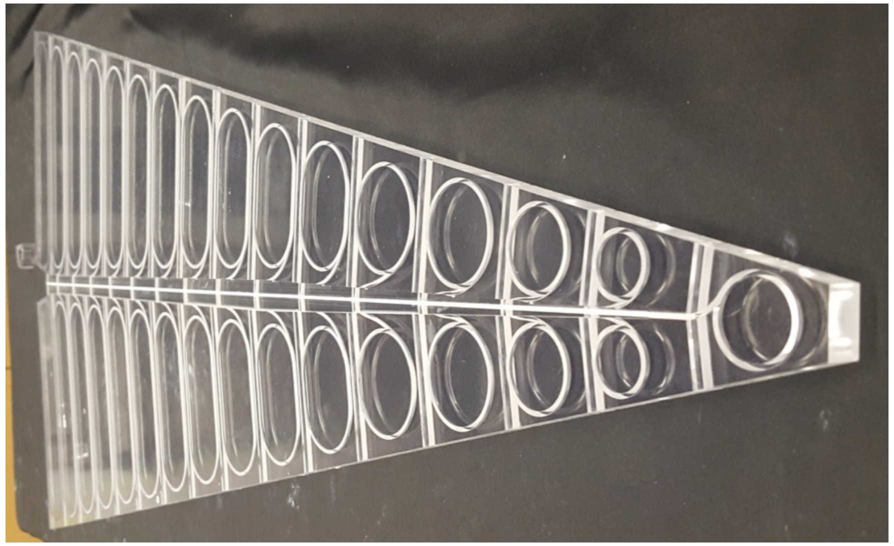




W.A. Zajc

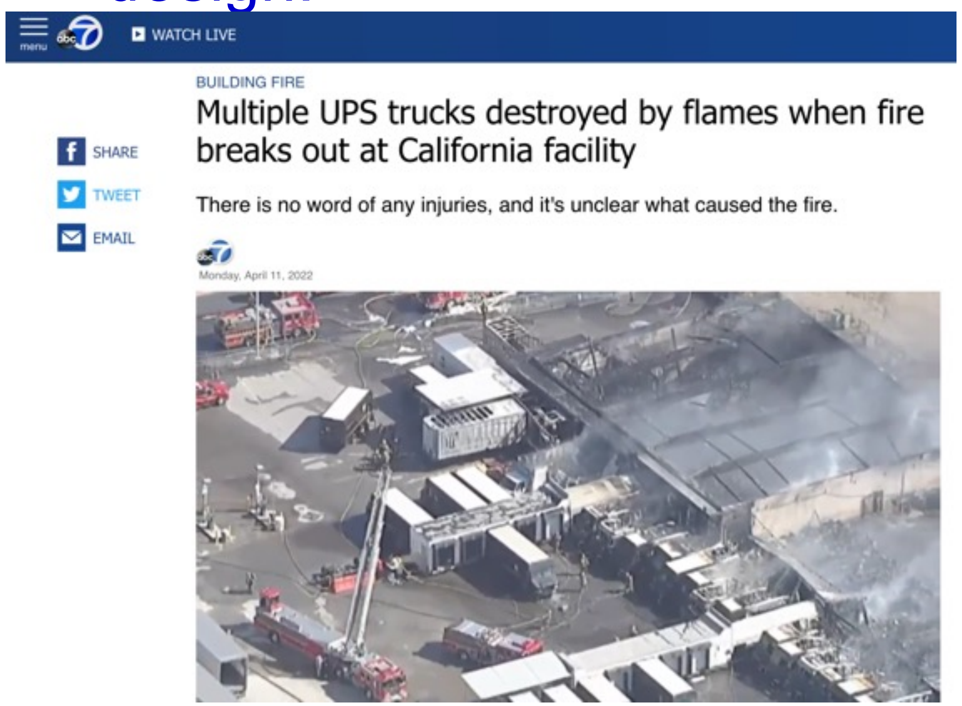
Event Characterization

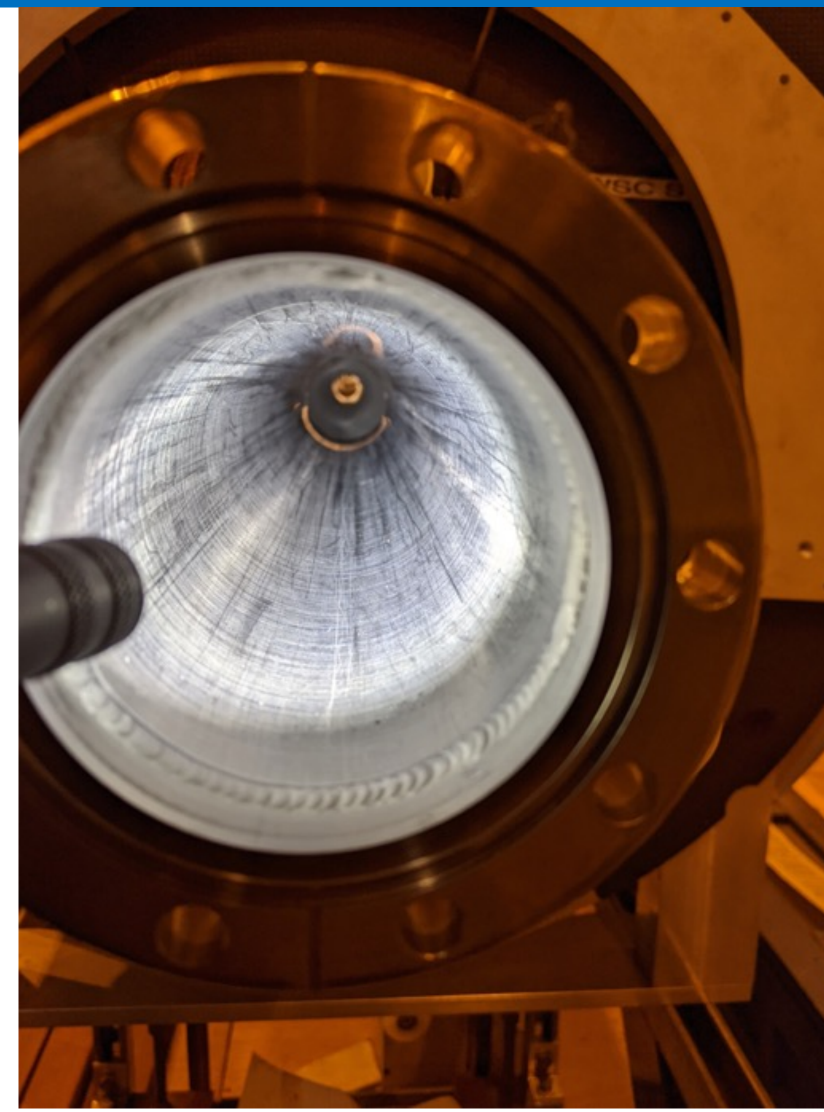
- **Min. Bias Detector (MBD)**
  - Covers $3.51 < |\eta| < 4.61$
  - Reuse PHENIX Beam-Beam Counter
  - 128 channels of 3 cm thick quartz radiator on mesh dynode PMT
  - Timing resolution: 120 ps
- **sPHENIX Event Plane Detector (sEPD)**
  - 2 wheels; $2.0 < |\eta| < 4.9$
  - Scintillator plastic (1.2 cm thick), embedded WLS fibers
  - Significant improvement of event plane resolution
  - Closely based on STAR EPD



Beampipe

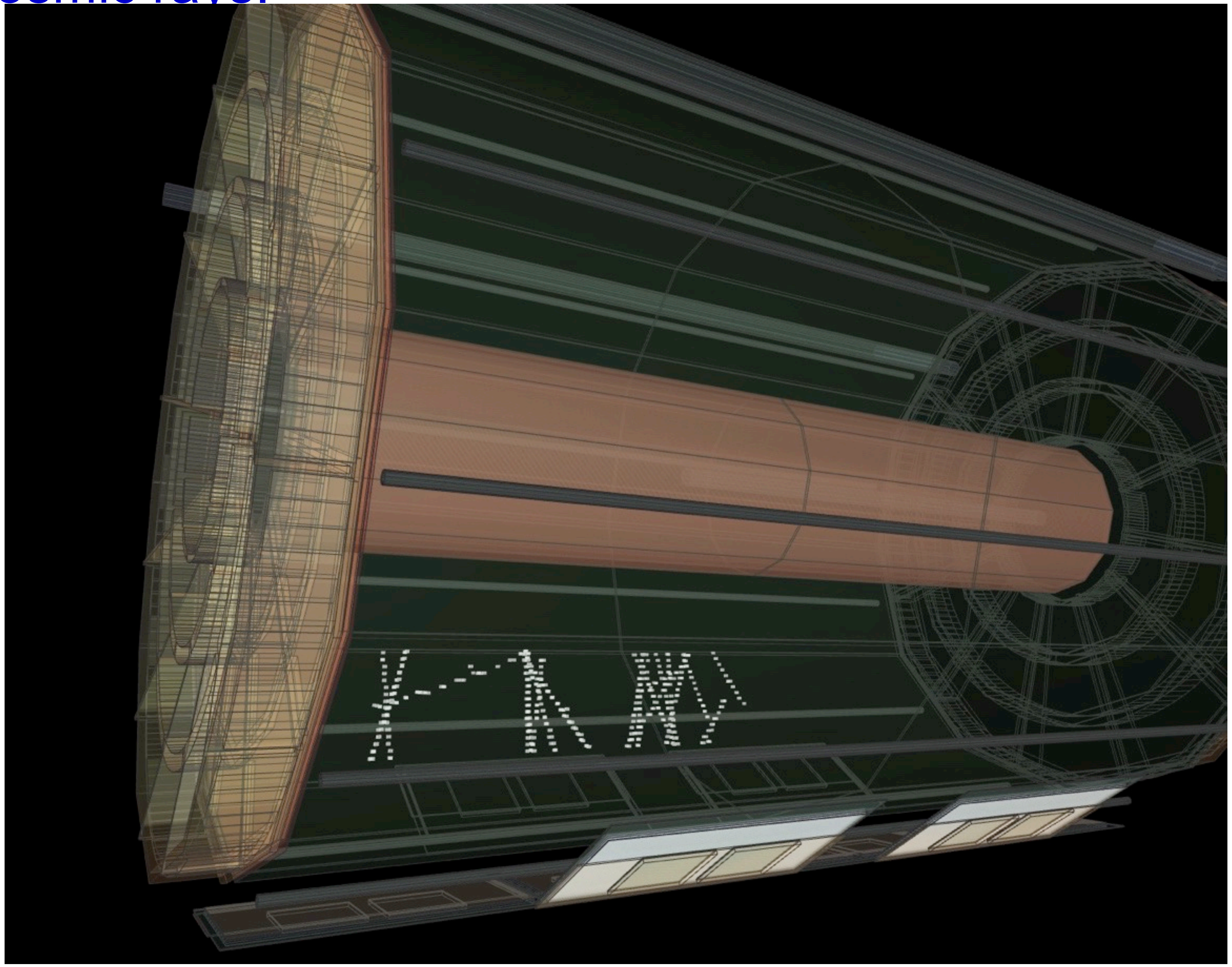
- sPHENIX beampipe shipped to California for work
- Lost in warehouse fire in 2022!
- STAR had a spare beampipe that is in good condition and is compatible with sPHENIX design.


menu
WATCH LIVE
BUILDING FIRE
Multiple UPS trucks destroyed by flames when fire breaks out at California facility
SHARE
TWEET
EMAIL
There is no word of any injuries, and it's unclear what caused the fire.
Monday, April 11, 2022



Cosmic Rays

- The TPC sees cosmic rays.



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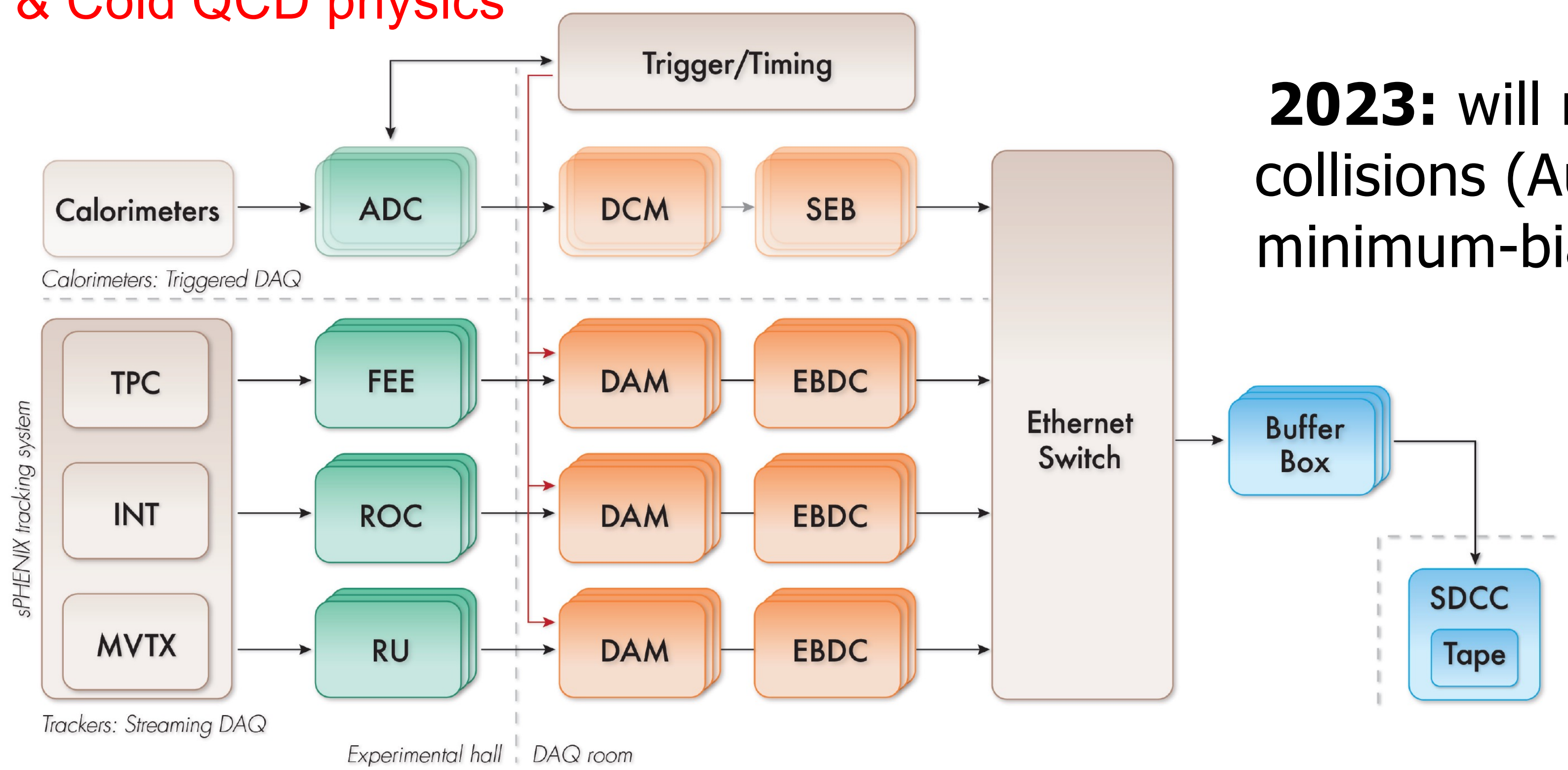
Data Acquisition

- Hybrid DAQ
- Triggered readout for calorimeters
- Streaming (triggerless) readout for tracking detectors
  - Records ~10% of all collisions
  - Key to get full *p+p* statistics in 2024
  - Crucial for HF & Cold QCD physics



2023: will record all collisions (Au+Au) w/ minimum-bias trigger

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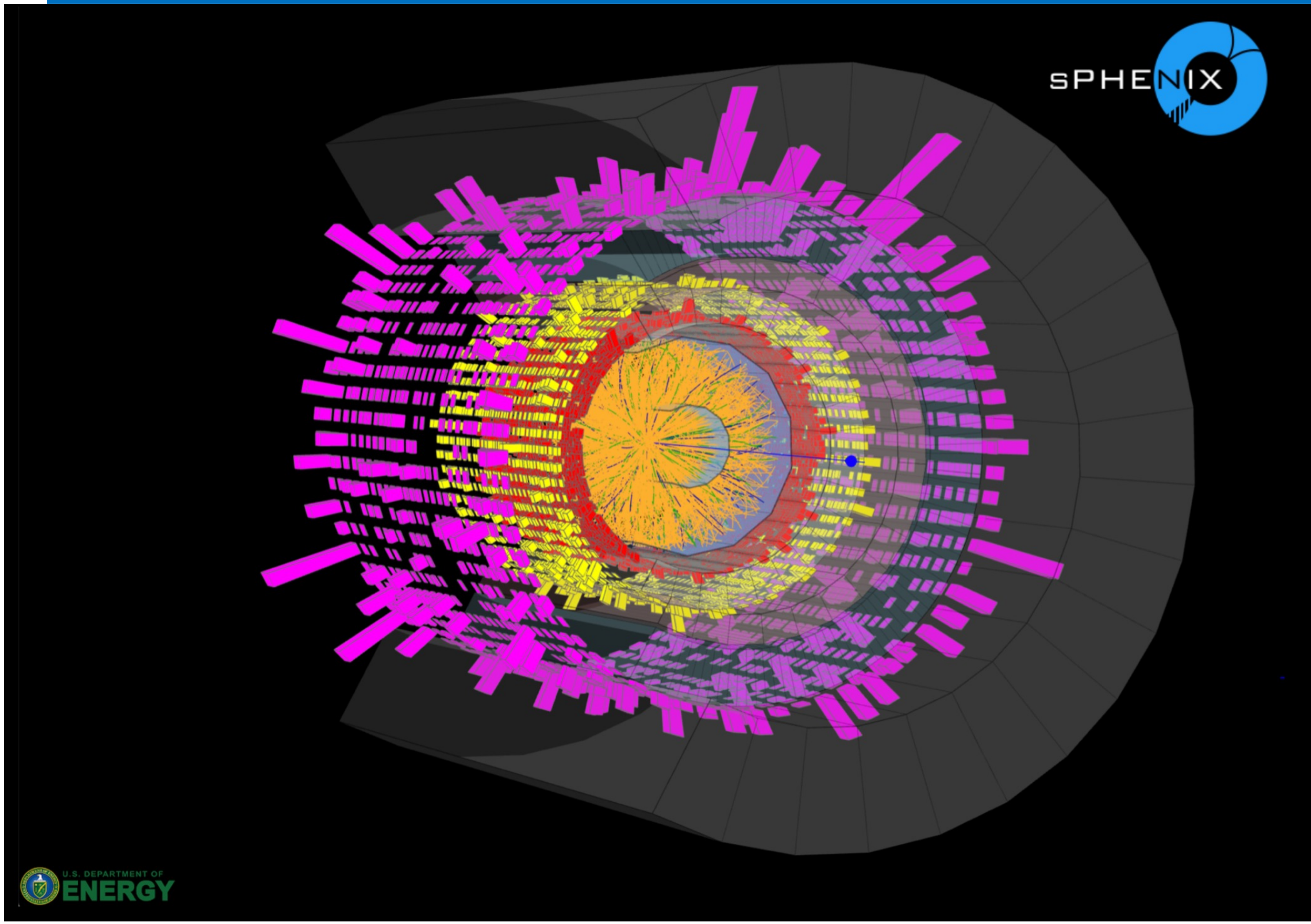
(MC) Event Display



RHIC = Relativistic Heavy Ion Collider

RHIC

- First collisions 2000
- p+p, d+Au, ^{3}He+Au, Zr+Zr, Ru+Ru, Cu+Cu, Cu+Au, Au+Au, U+U
- $\sqrt{s_{NN}}$ ~ 7–200 GeV
- Polarized protons

W.A. Zajc