9th International Conference on Quarks and Nuclear Physics

sPHENIX Experiment Overview

7 September 2022
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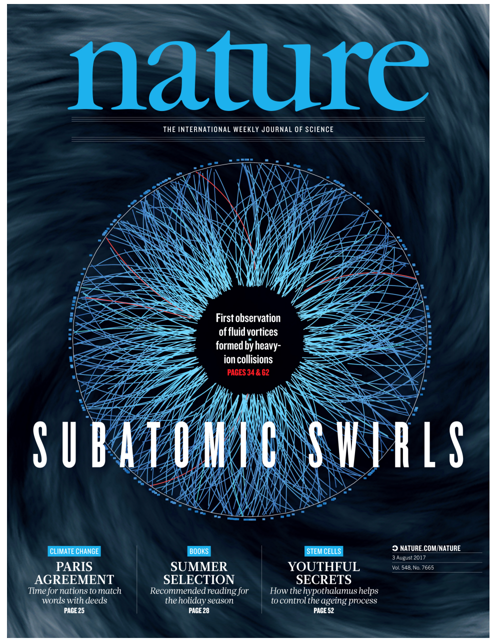
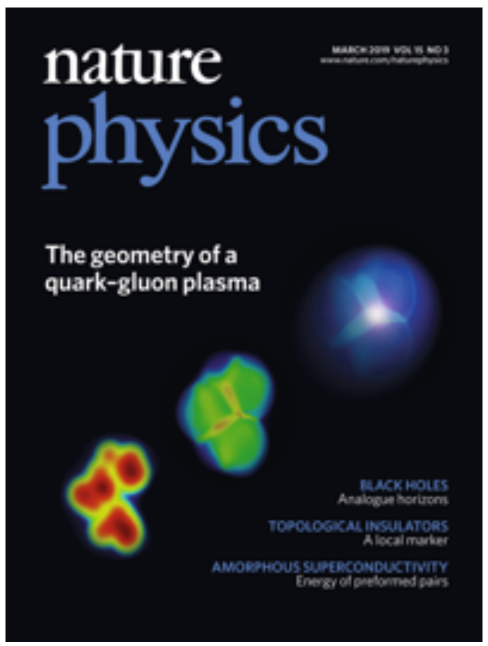
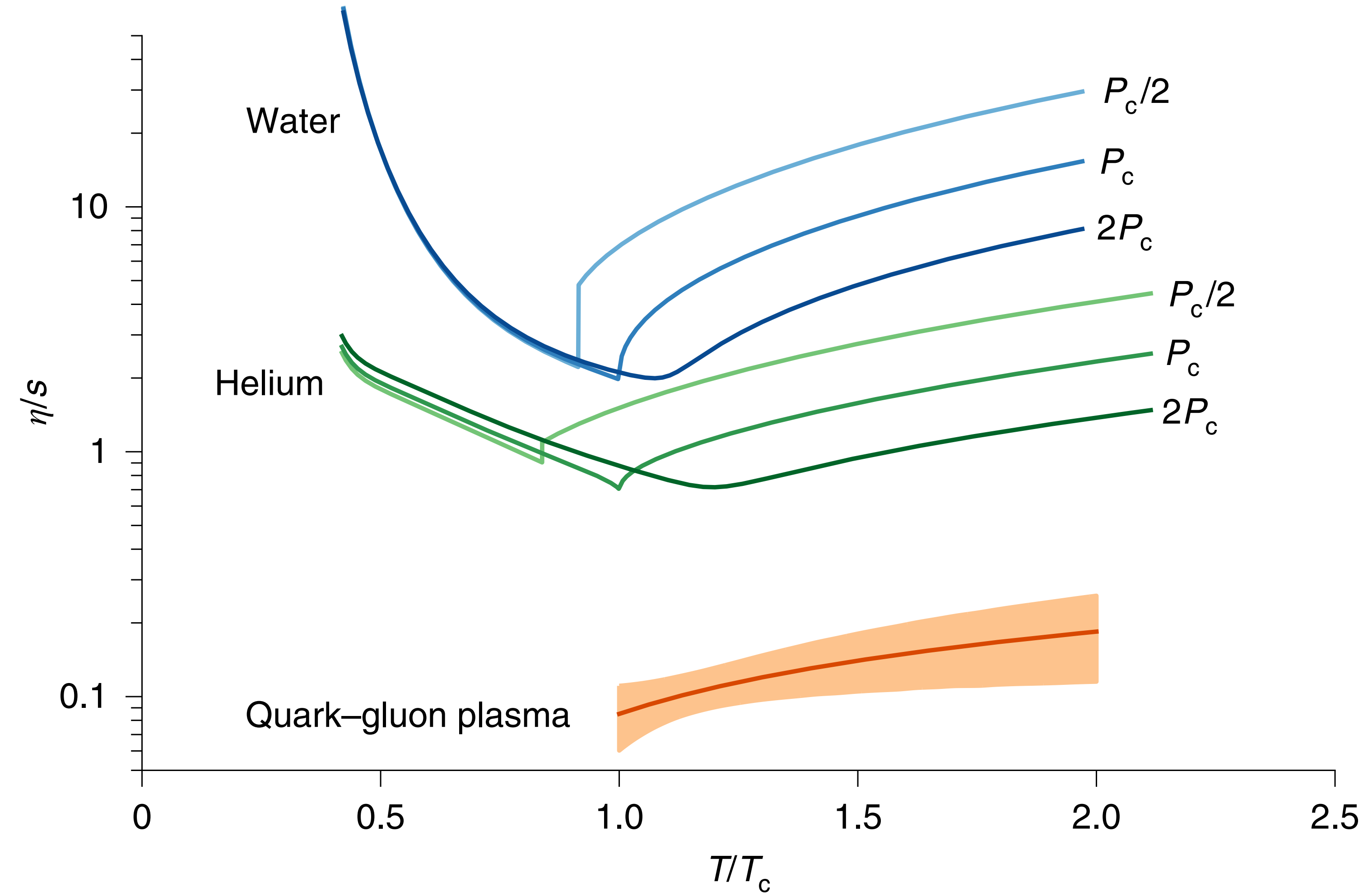
@profdvp

University of Colorado Boulder





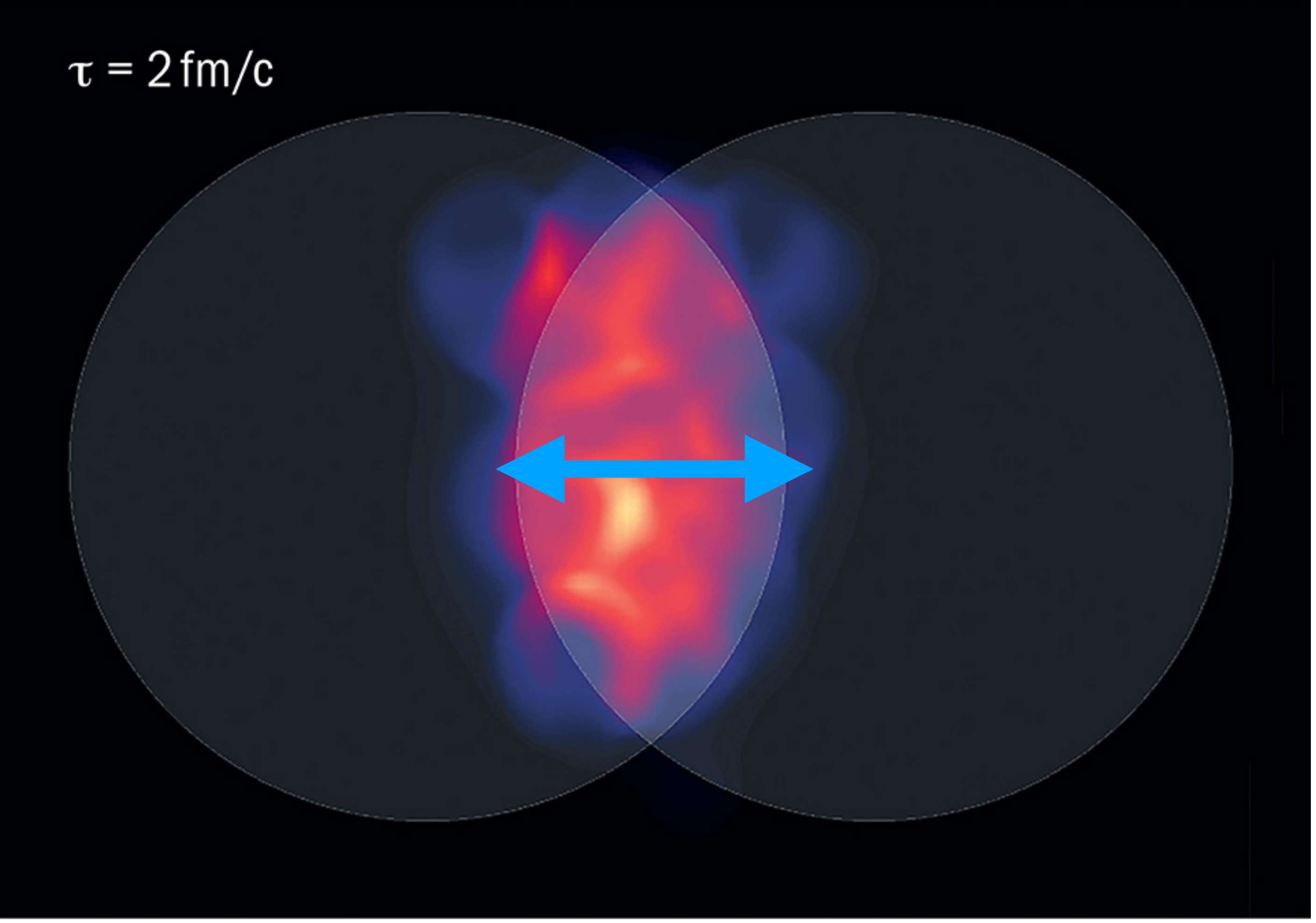
Nature Physics 15 (2019) 1113



Measurements at RHIC & the LHC have shown: Quark-Gluon Plasma (QGP) behaves as an almost perfect fluid

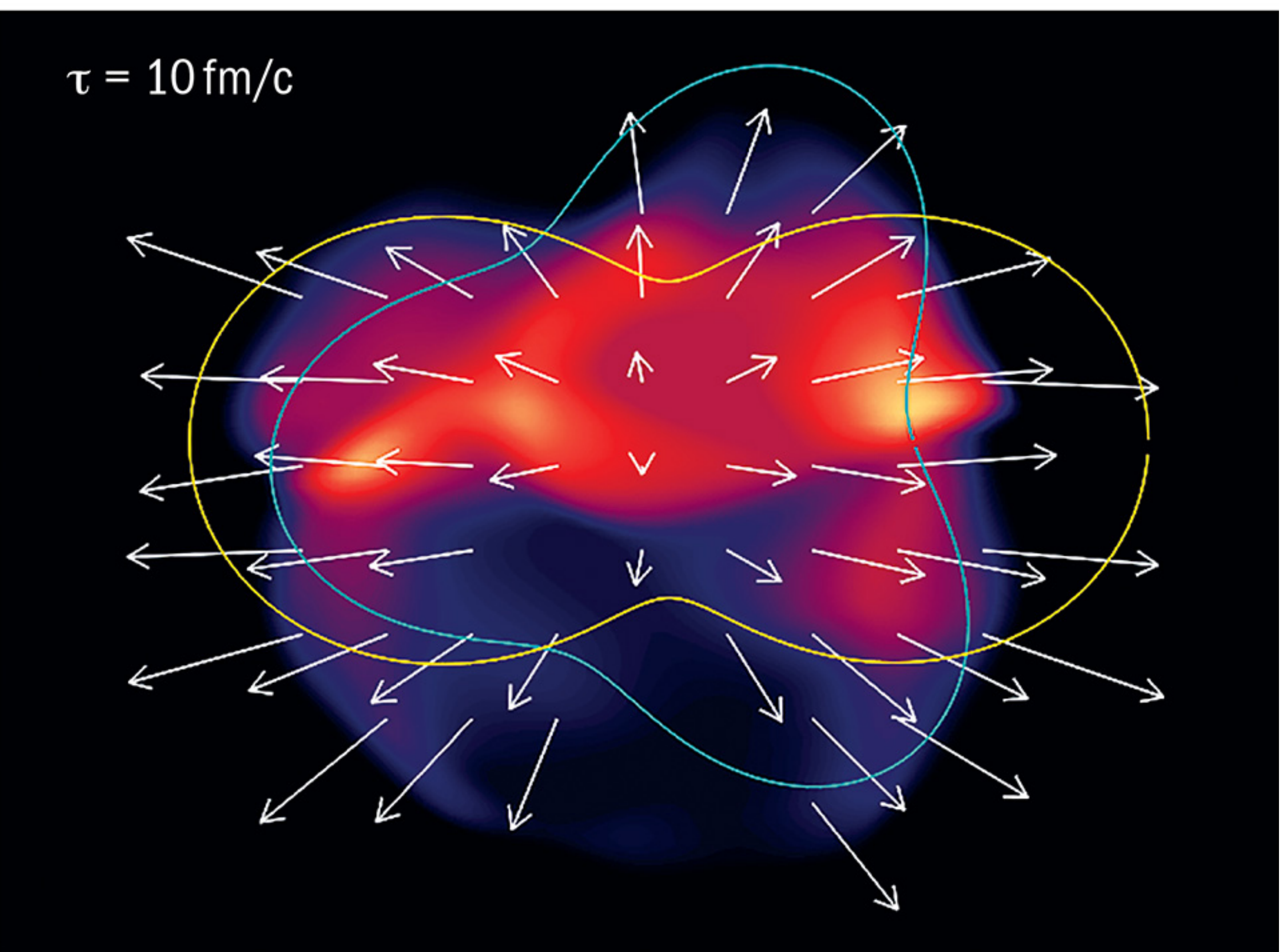
➡ expansion governed by relativistic hydrodynamics

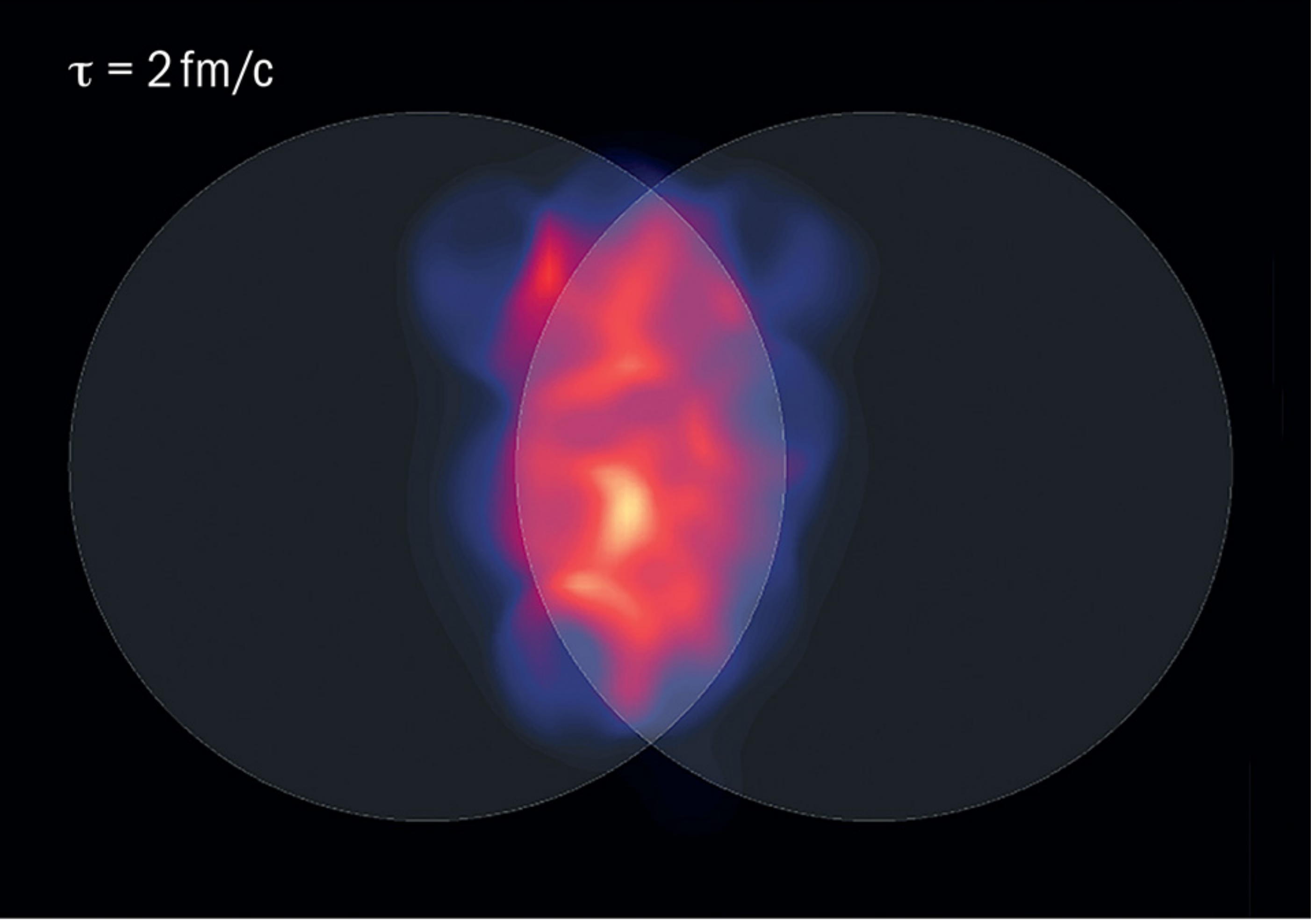
➡ lowest specific viscosity (η/s) of any known material!

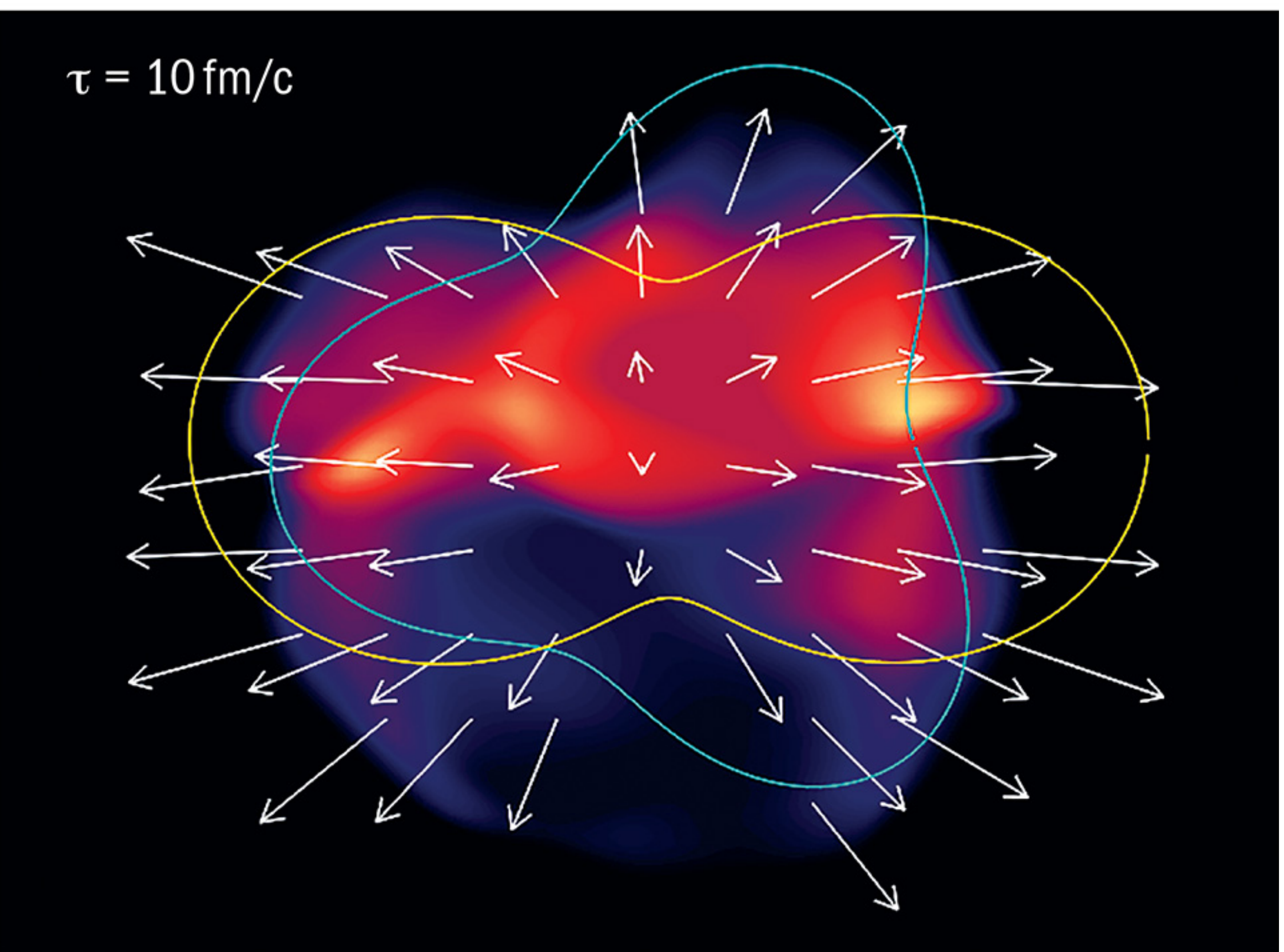


larger pressure gradients in this direction

nearly frictionless expansion



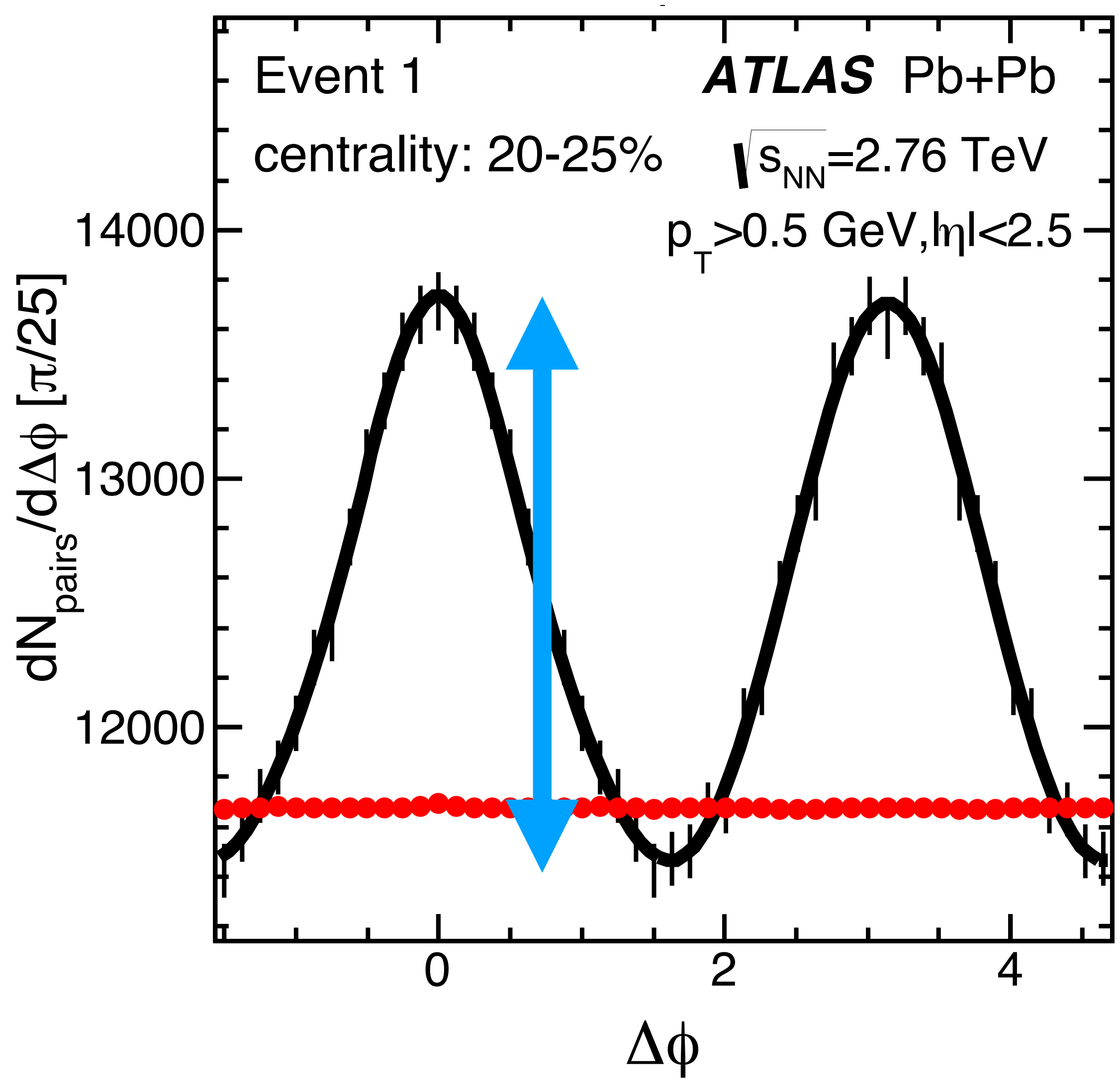




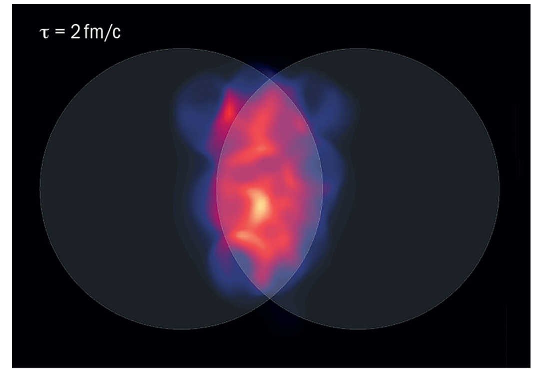
Spatial anisotropies at time of QGP creation…

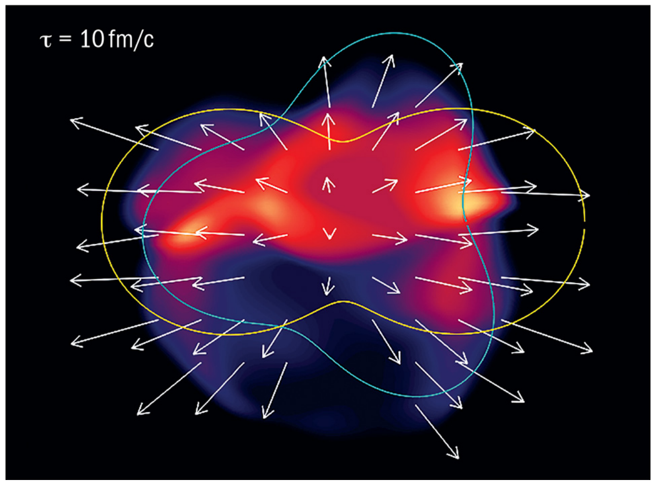
…momentum-space anisotropy in the final state

Flow magnitude



emergent near-perfect fluidity



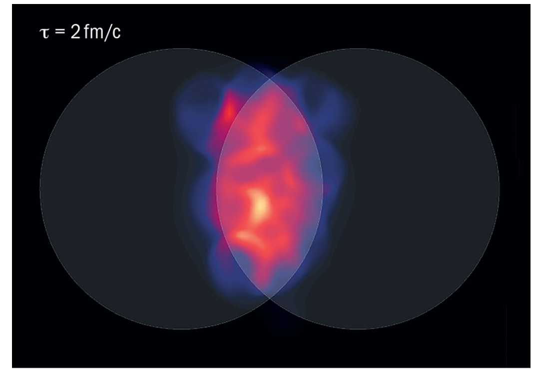


strongly-coupled*,*
long-distance behavior

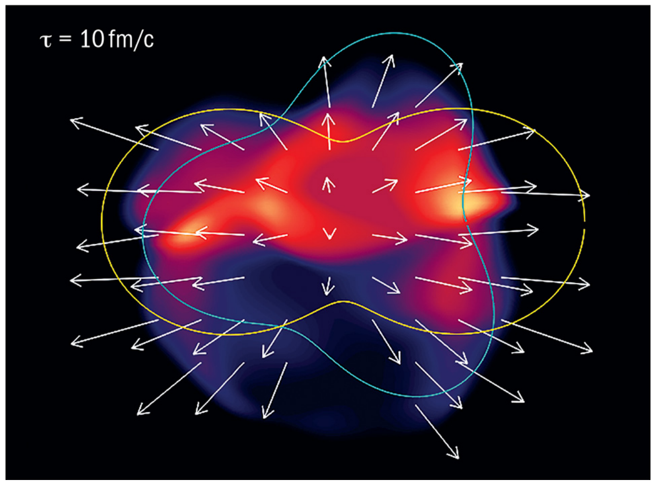
?

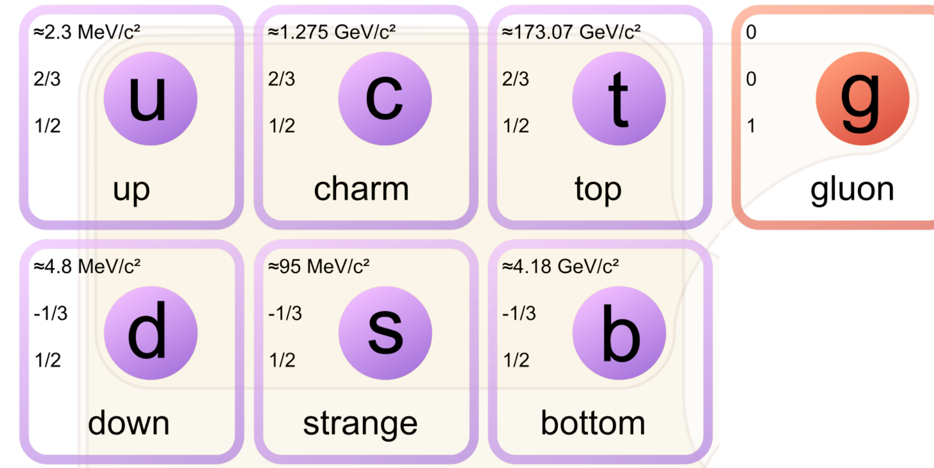
QGP

emergent near-perfect fluidity



fundamental interaction & degrees of freedom exactly known





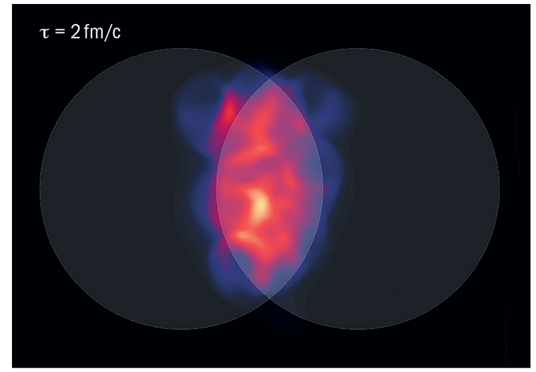
?

QGP

strongly-coupled, *long-distance behavior*

short-distance, ***asymptotically free*** *quarks and gluons*

emergent near-perfect fluidity



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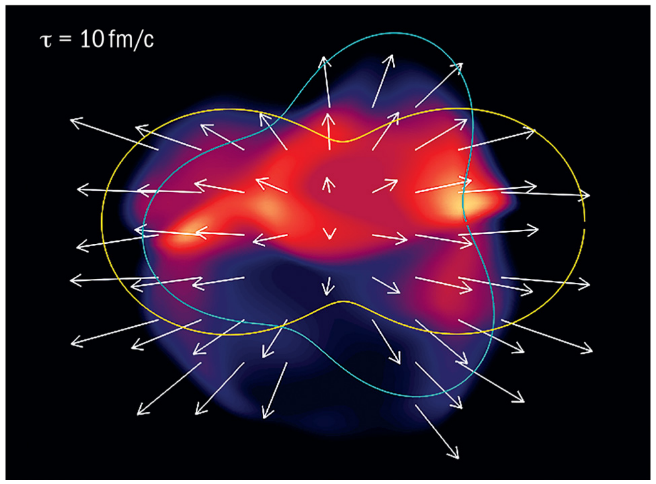
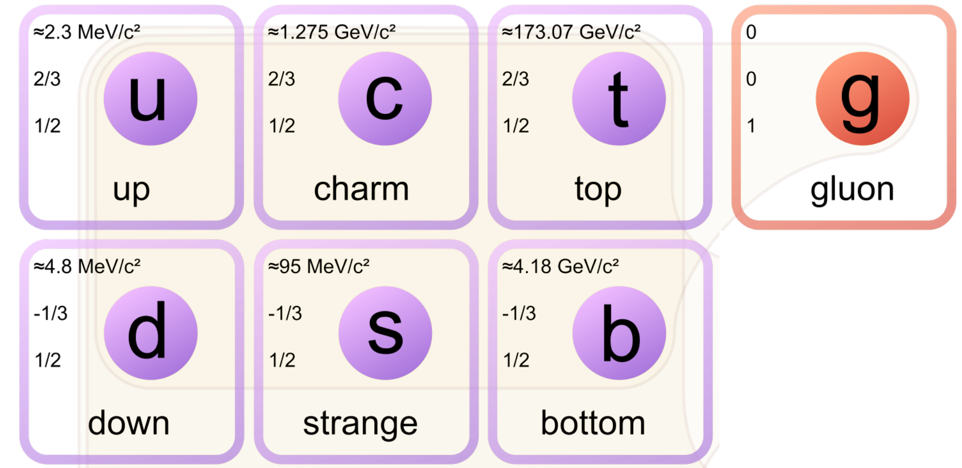




strongly-coupled, *long-distance behavior*

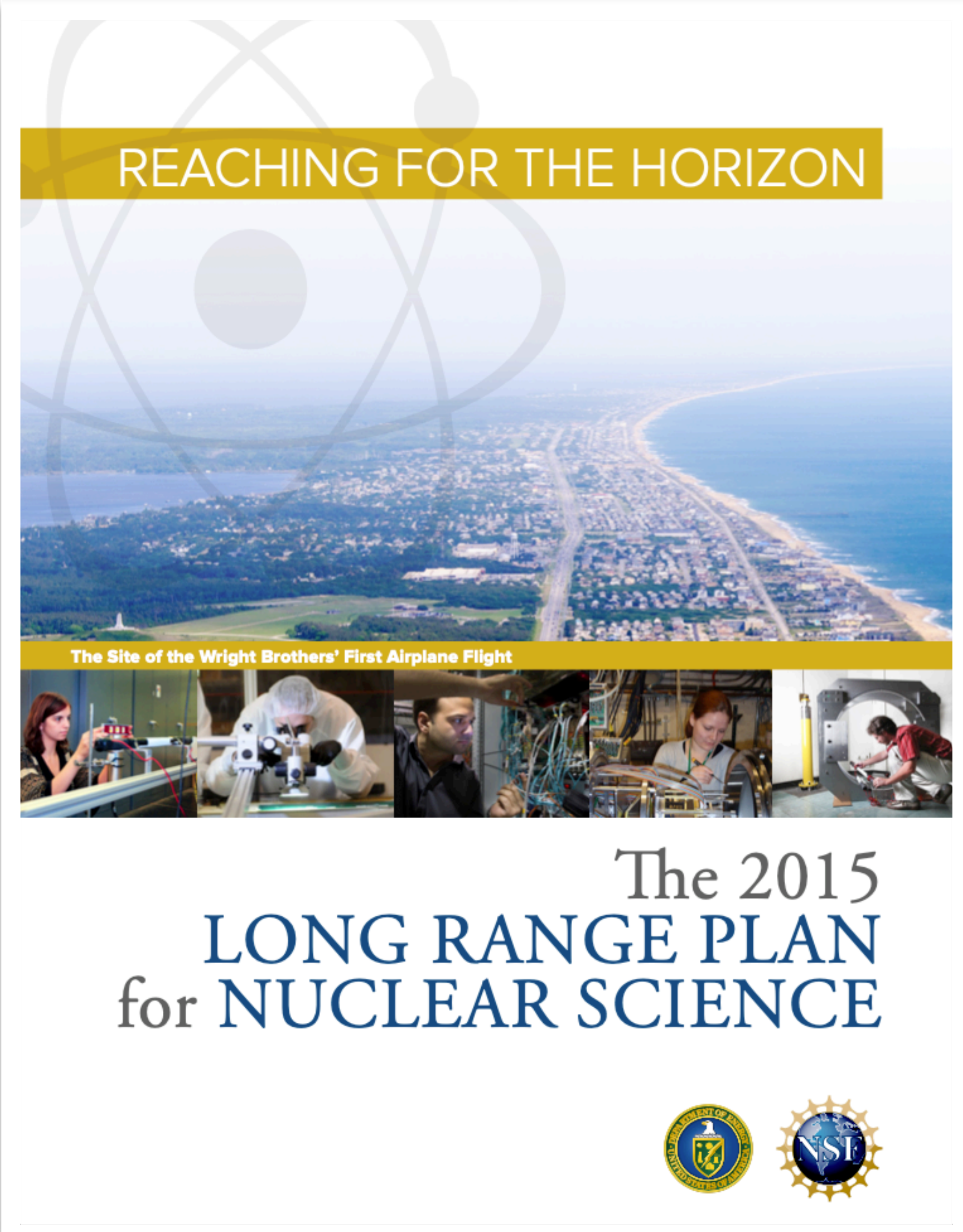
?

QGP

short-distance, ***asymptotically free*** *quarks and gluons*

How does the behavior of Quark-Gluon Plasma emerge from the microscopic QCD theory?

sPHENIX science

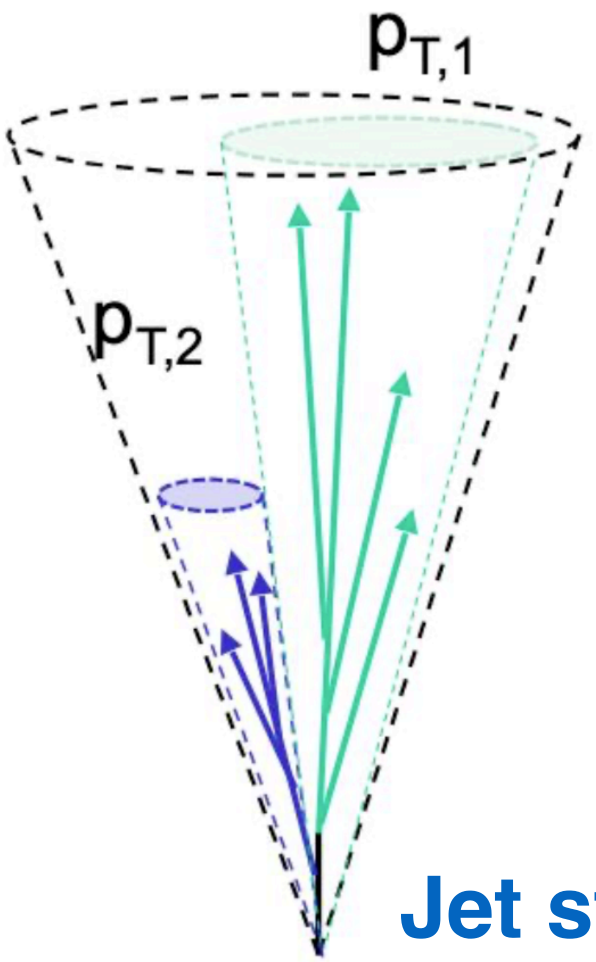


> There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.**

2015 US NP LRP

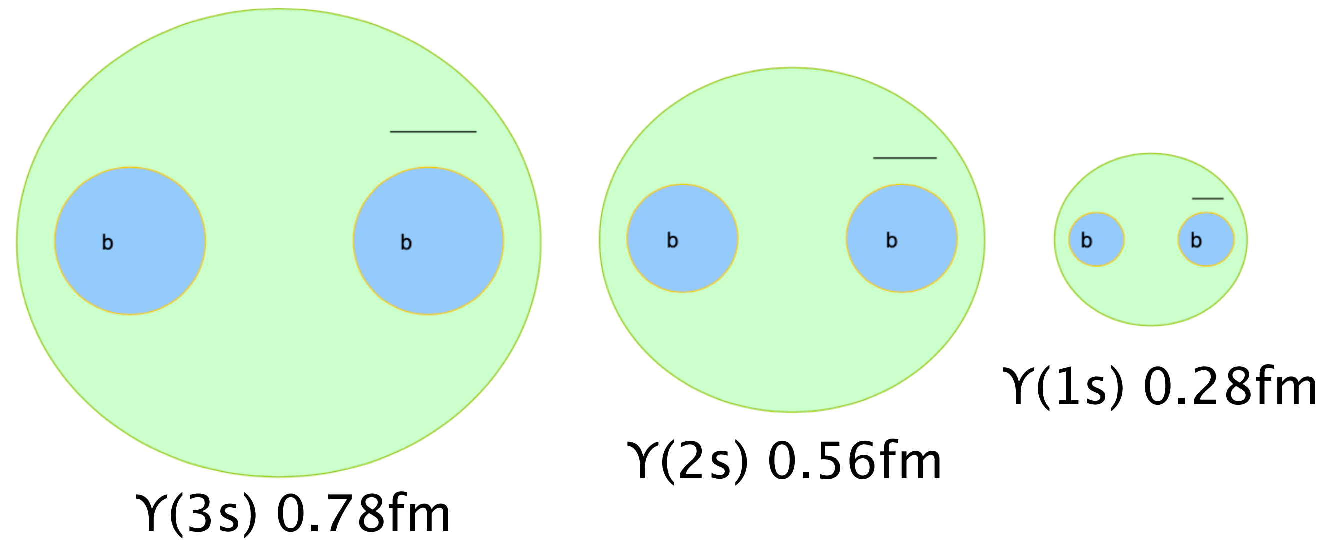
sPHENIX recognized by the U.S. Nuclear Physics community as an *essential* tool for QGP microscopy

➡ new, unique capabilities not used before at RHIC!



Jet structure

vary momentum/angular scale of probe

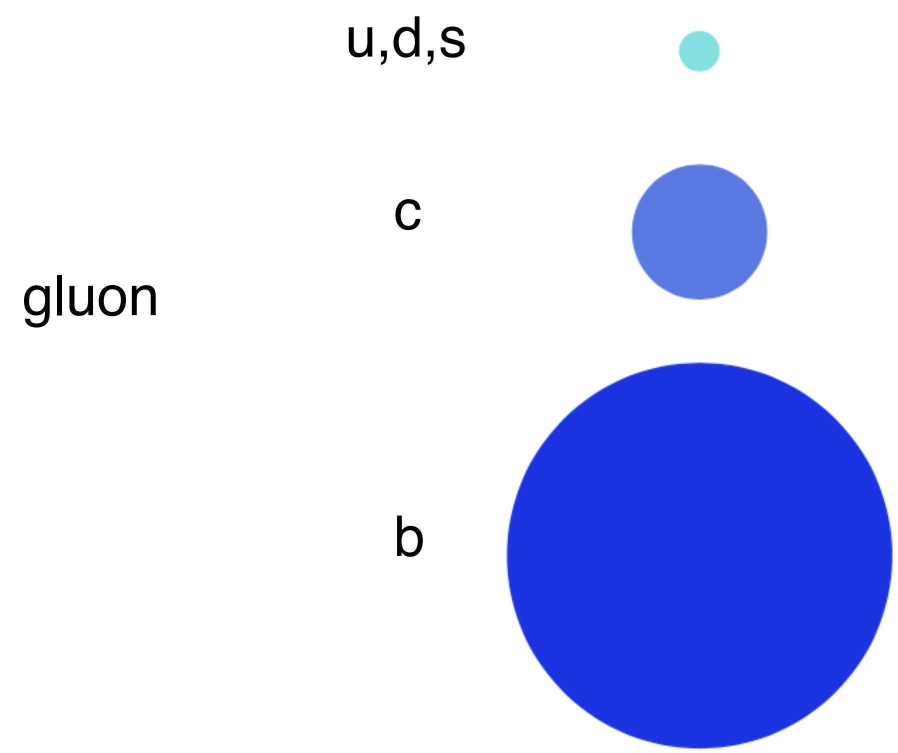


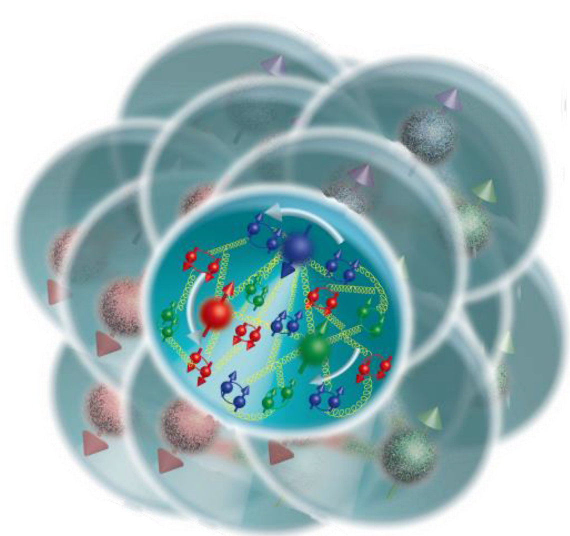
Quarkonium spectroscopy

vary size of probe

Parton energy loss

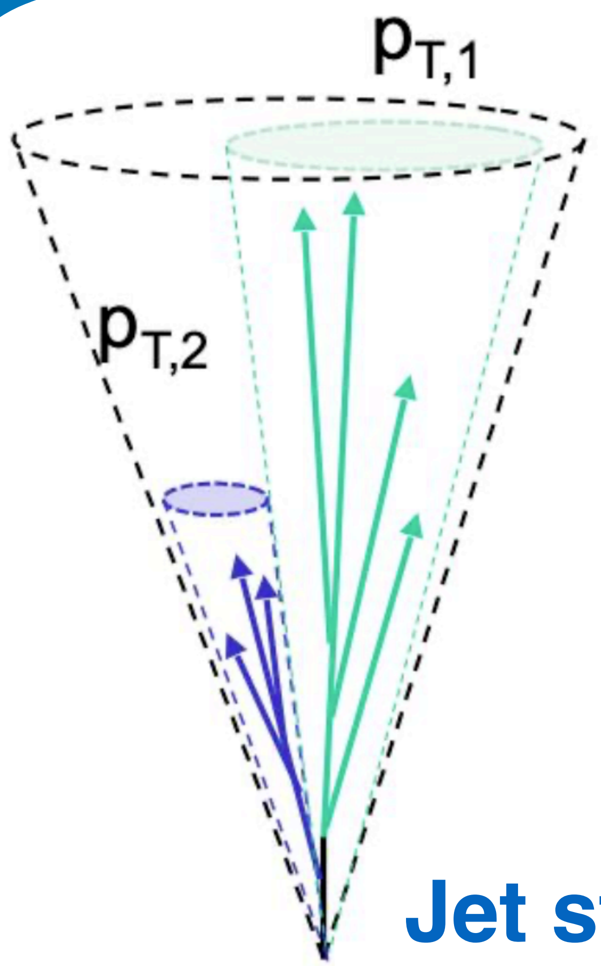
vary mass/momentum of probe





Cold QCD

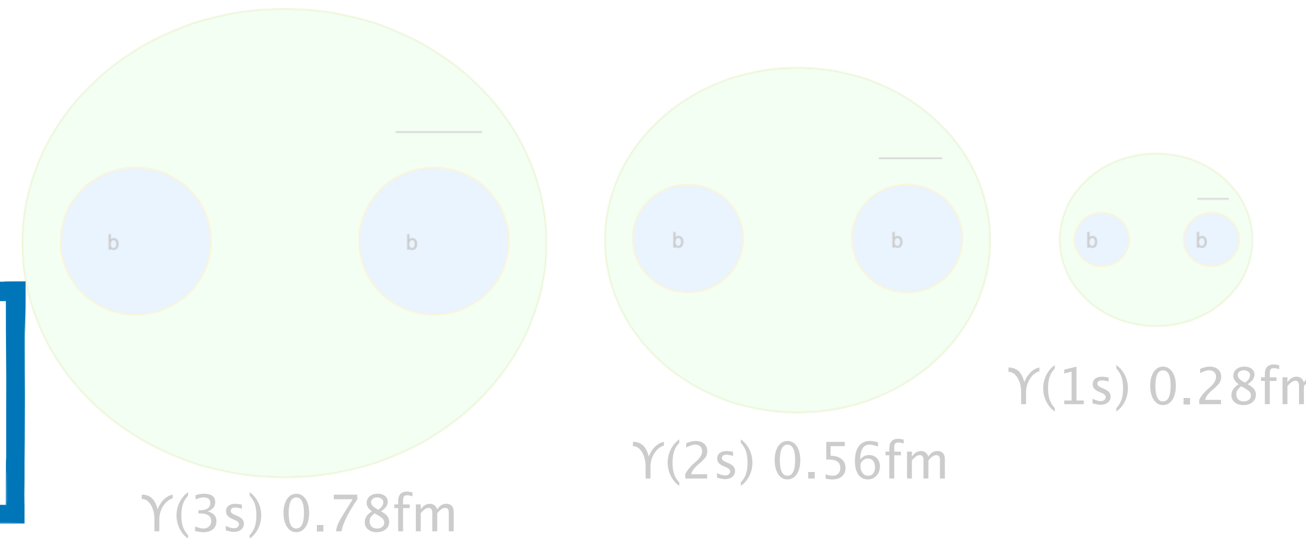
study proton spin, transverse-momentum, and cold nuclear effects



Jet structure

vary momentum/angular scale of probe

Ejiro Umaka,
9/7, 1pm



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sPHENIX

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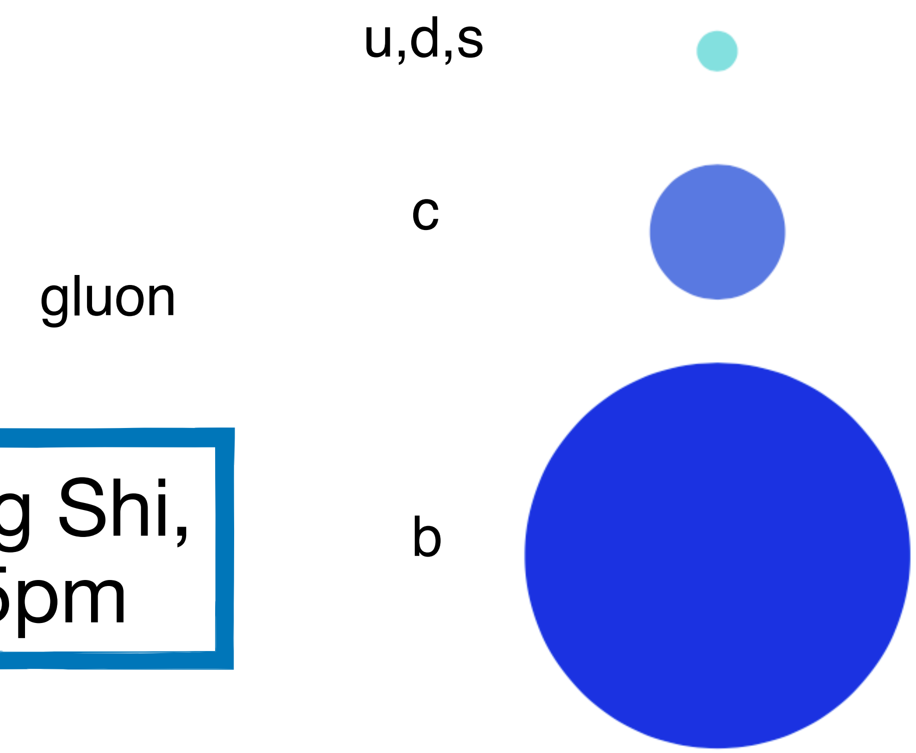


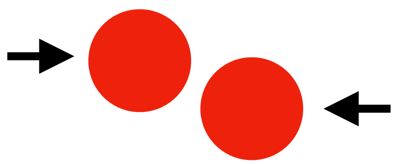
Cold QCD

study proton spin
transverse-mome
and cold nuclear e

Zhaozhong Shi,
9/8, 3:25pm

sPHENIX run plan (2023-2025)

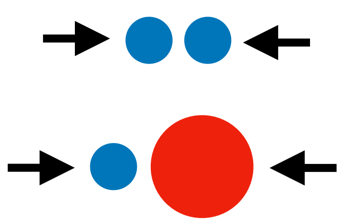
Year-1



Commissioning the detector

First Au+Au collisions for physics!

Year-2



Transversely polarized *p+p* and *p*+Au collisions:

vacuum baseline & reference for Au+Au physics

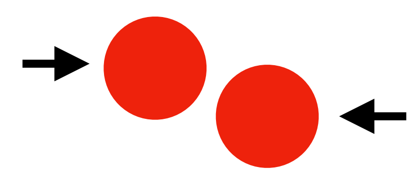
spin & "cold QCD" physics in their own right

from the sPHENIX Beam Use Proposal 2022

Table 1: Summary of the sPHENIX Beam Use Proposal for years 2023–2025, as requested in the charge. The values correspond to 24 cryo-week scenarios, while those in parentheses correspond to 28 cryo-week scenarios. The 10%-*str* values correspond to the modest streaming readout upgrade of the tracking detectors. Full details are provided in Chapter 2.

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\|z\|$ <10 cm	Samp. Lum. $\|z\|$ <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}

Year-3

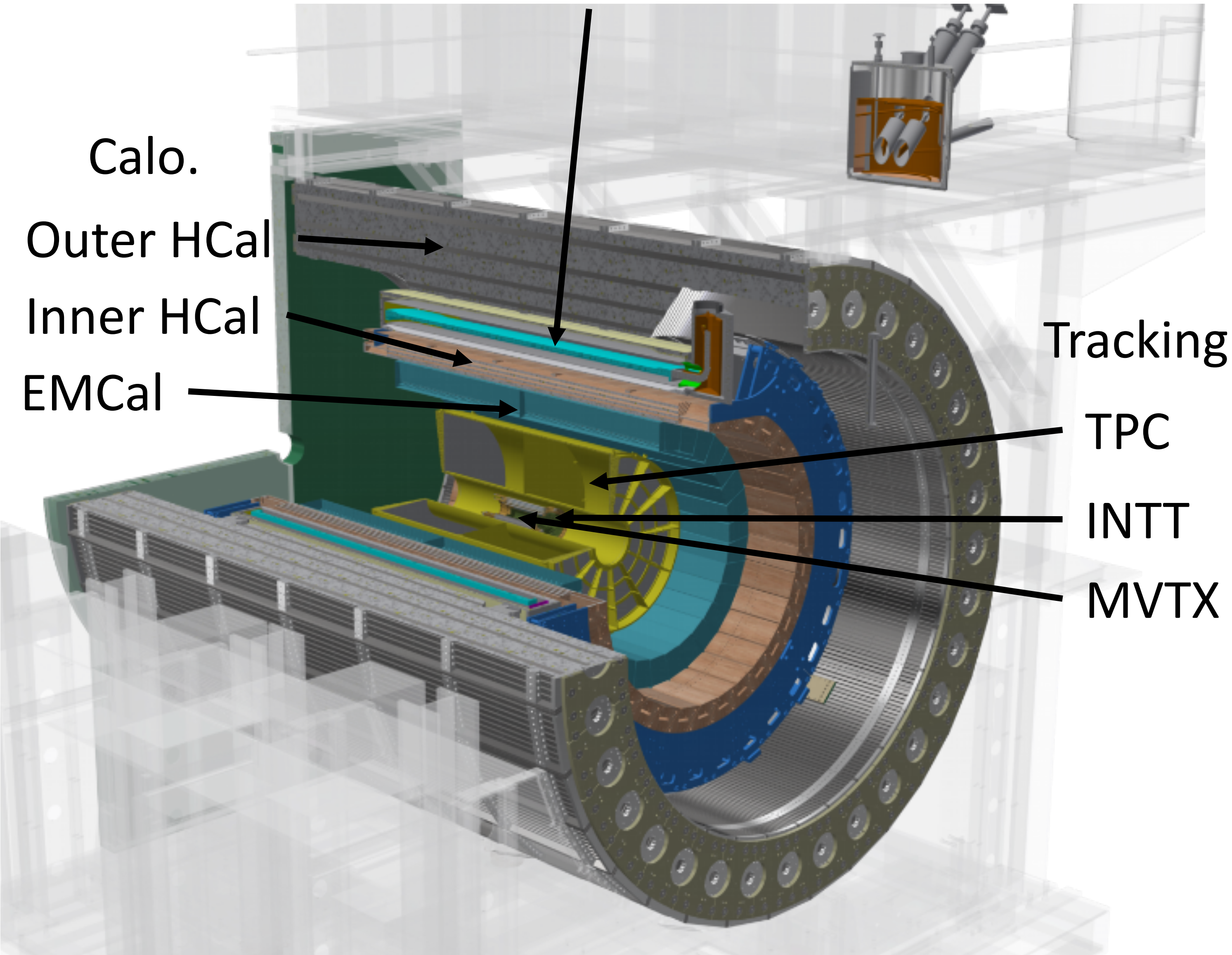


"Archival" high-luminosity Au+Au run

>140 **billion** fully min-bias Au+Au events(*) recorded to disk

(*) - $|z|$ < 10cm, 28-cryoweek scenarios

sPHENIX detector



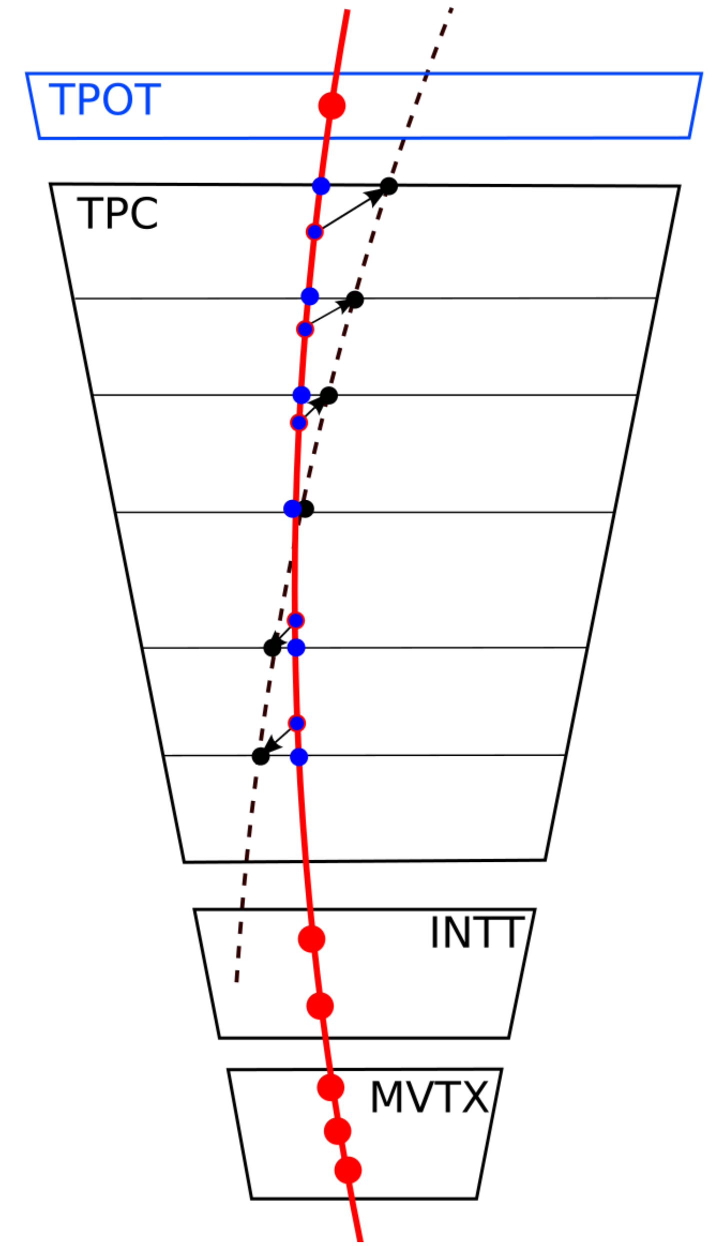
First run year	2023
$\sqrt{s_{NN}}$ [GeV]	200
Trigger Rate [kHz]	15
Magnetic Field [T]	1.4
First active point [cm]	2.5
Outer radius [cm]	270
$\|\eta\|$	$\leqslant$1.1
$\|z_{vtx}\|$ [cm]	10
N(AuAu) collisions*	1.43x10^{11}

* In 3 years of running

Key sPHENIX advantages for jet & HF probes at RHIC:

(1) large, hermetic acceptance, (2) huge data rate, (3) hadronic calorimeter, (4) precision tracking, (5) unbiased triggering in *p+p*

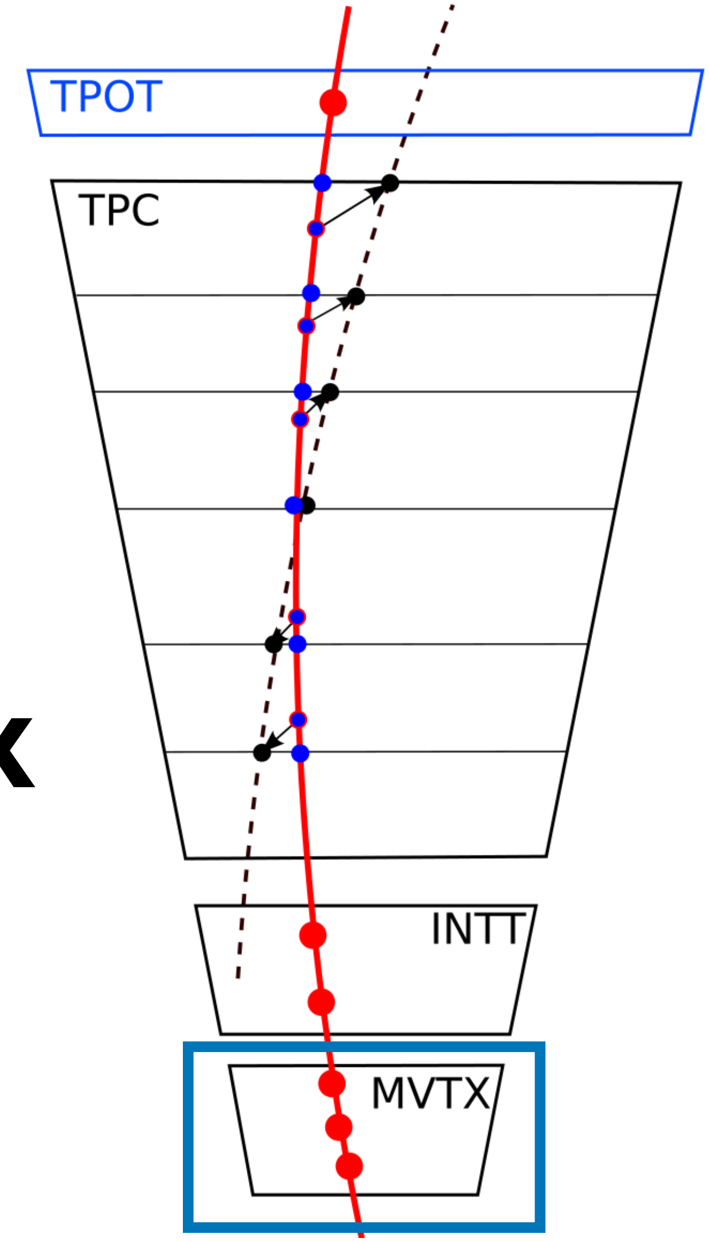
sPHENIX Tracking



sPHENIX Tracking

MAPS Vertex Detector (MVTX)

Completed half-sector at LBNL



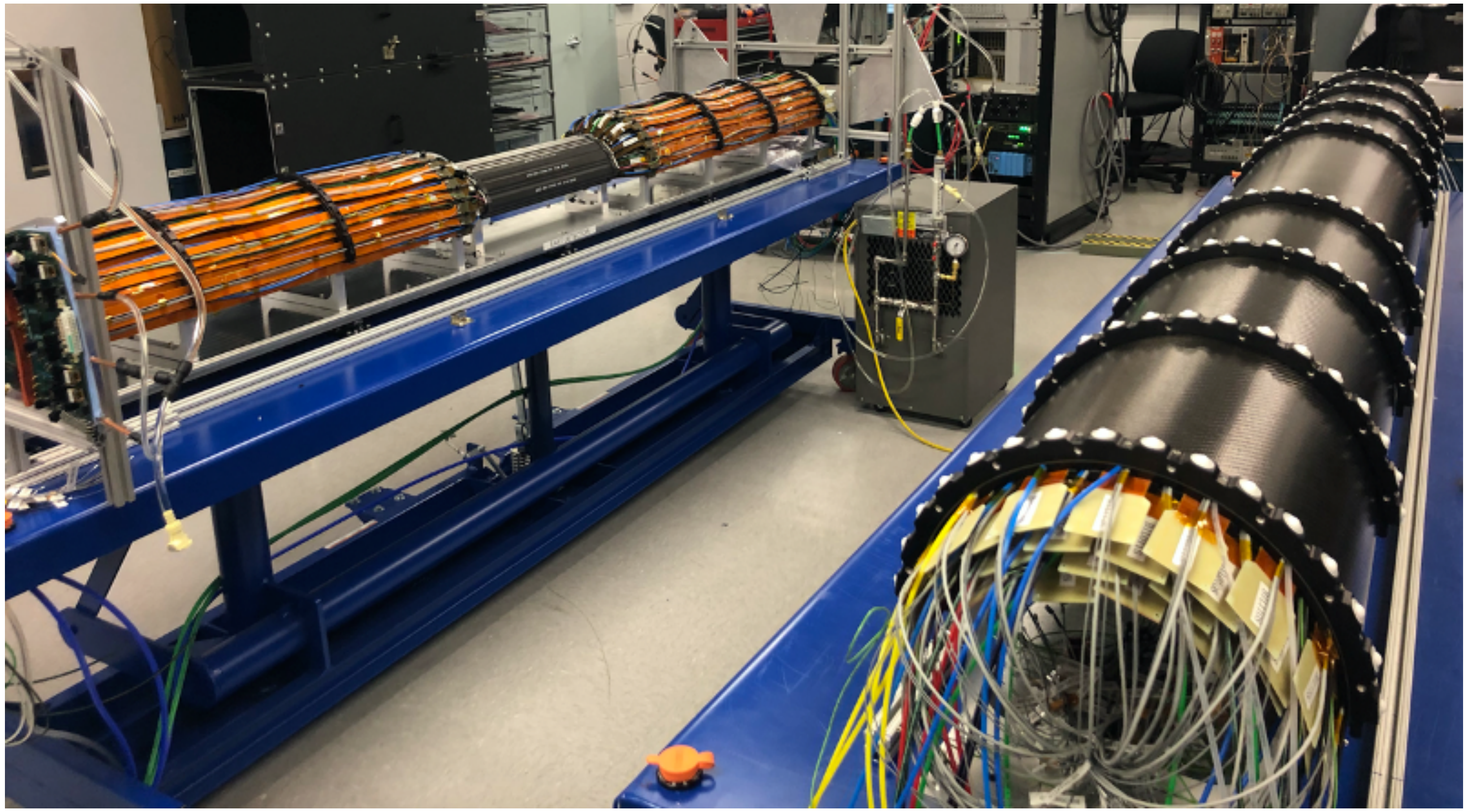
3 Layers of Monolithic Active Pixels (MAPs), small material budget

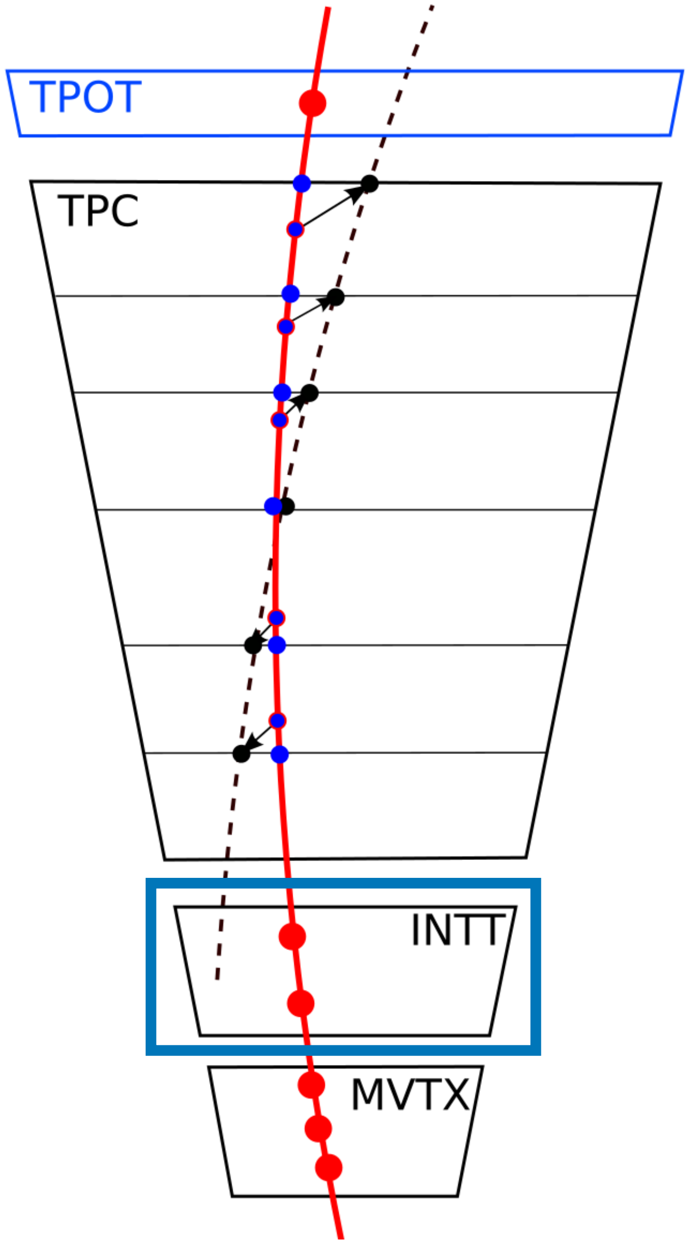
➡ Distance of Closest Approach (DCA) resolved at < 10 μm for p_T > 2 GeV

➡ Essential to heavy flavor program

sPHENIX Tracking

Half-sectors at BNL





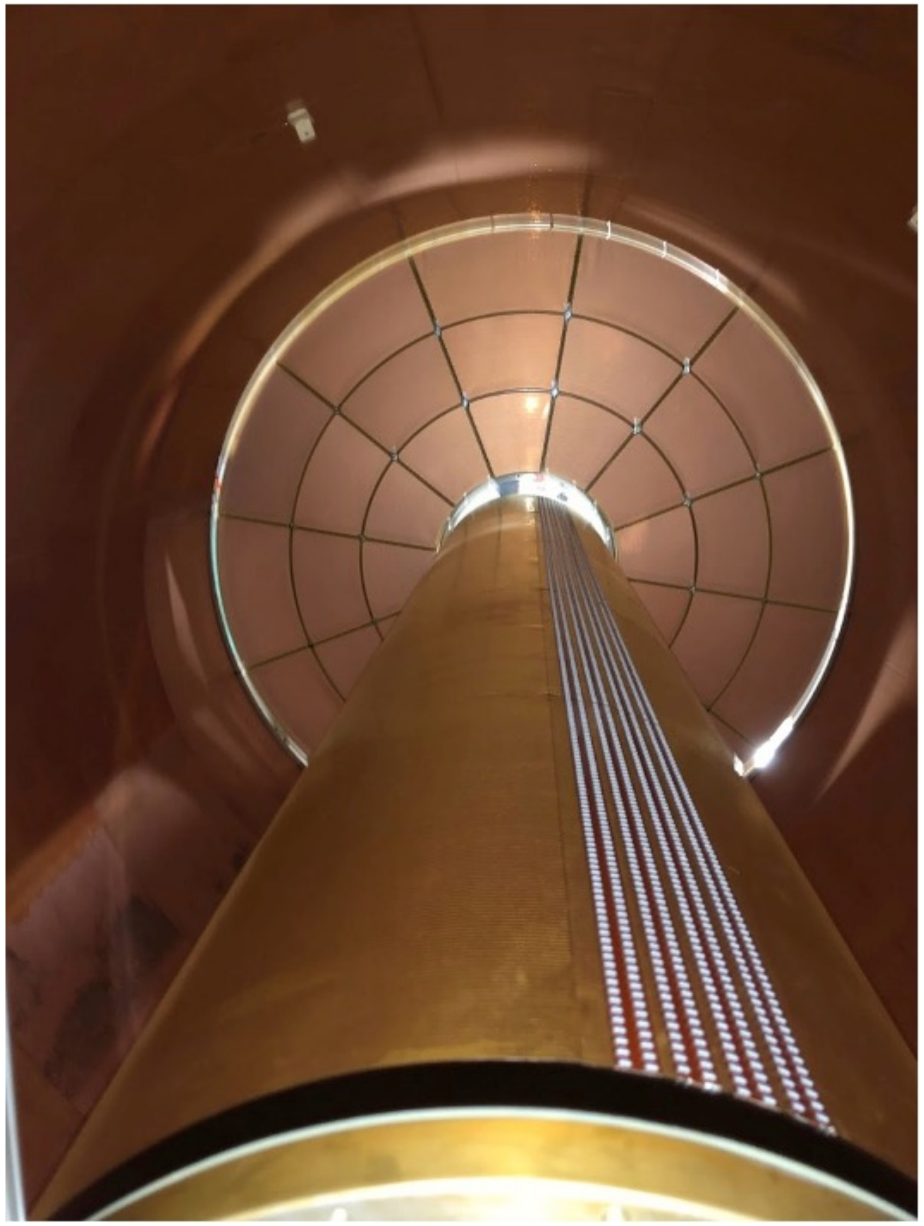
Intermediate Silicon Strip Tracker (INTT)

4 Layer (2-hit) Silicon Strip Detector

➡ Timing resolution ~100ns

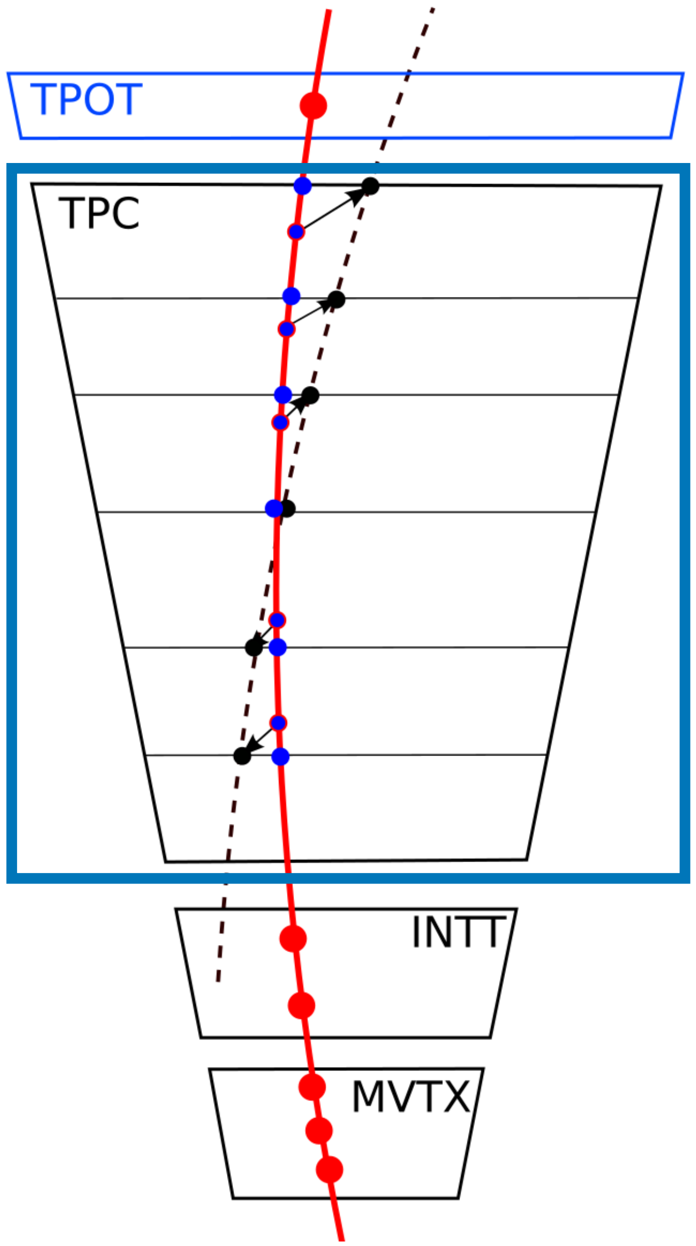
➡ Resolves single RHIC bunch crossing & connects closer/further trackers

sPHENIX Tracking



TPC under assembly at Stony Brook

Time Projection Chamber (TPC)

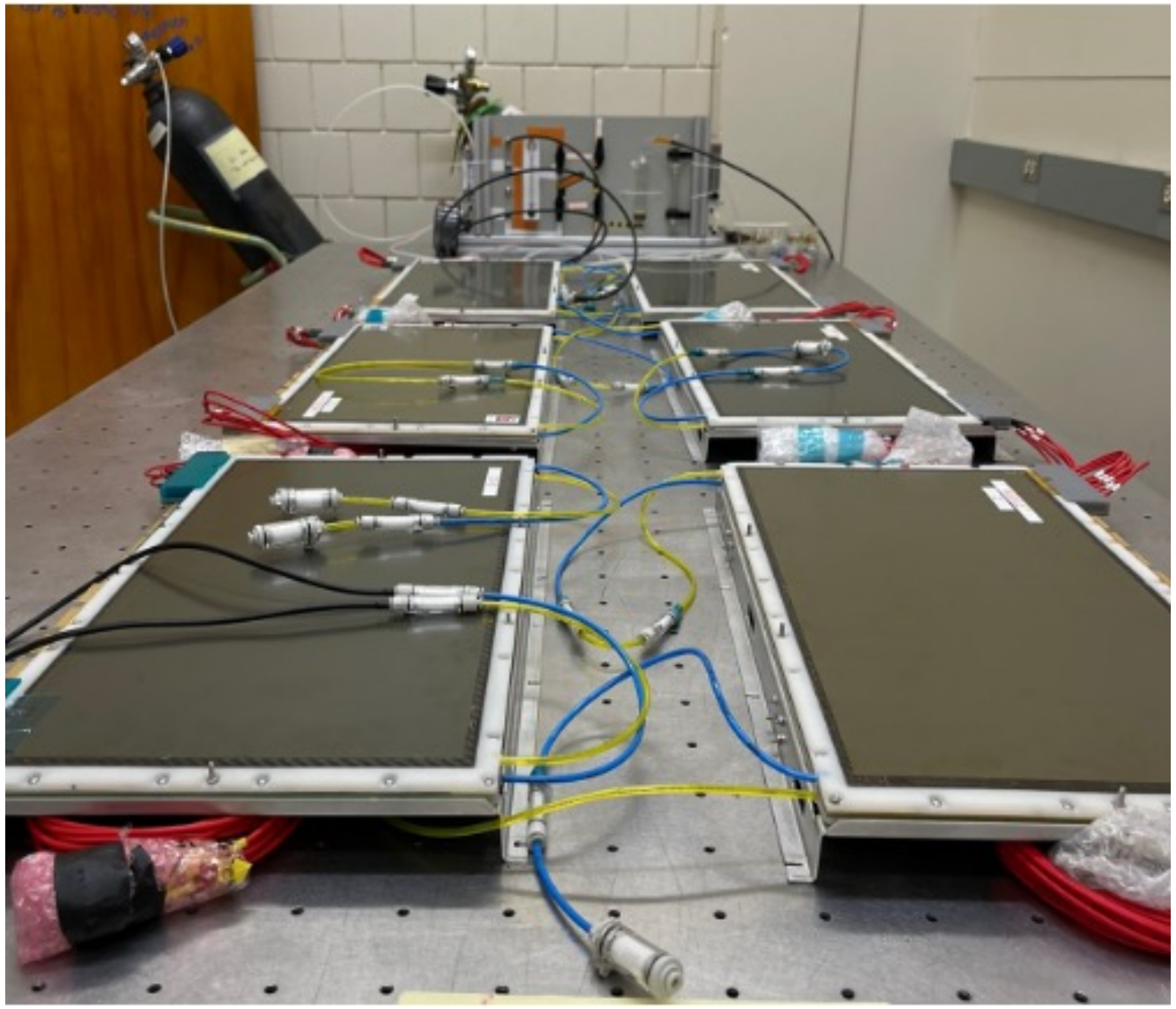


Compact design, active region 30 < r < 78 cm

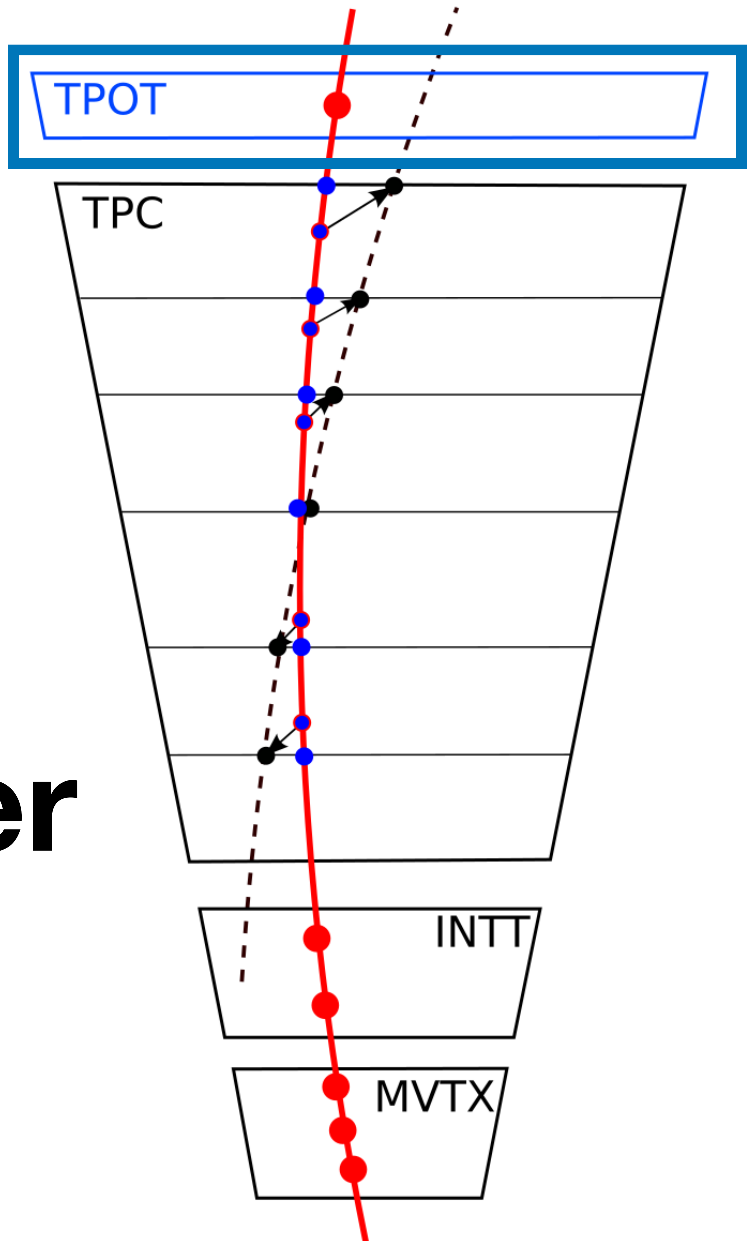
➡ Gateless, employs GEMs to minimize ion backflow, continuous streaming readout

➡ Provides lever arm for momentum resolution

sPHENIX Tracking



TPOT panels at Stony Brook



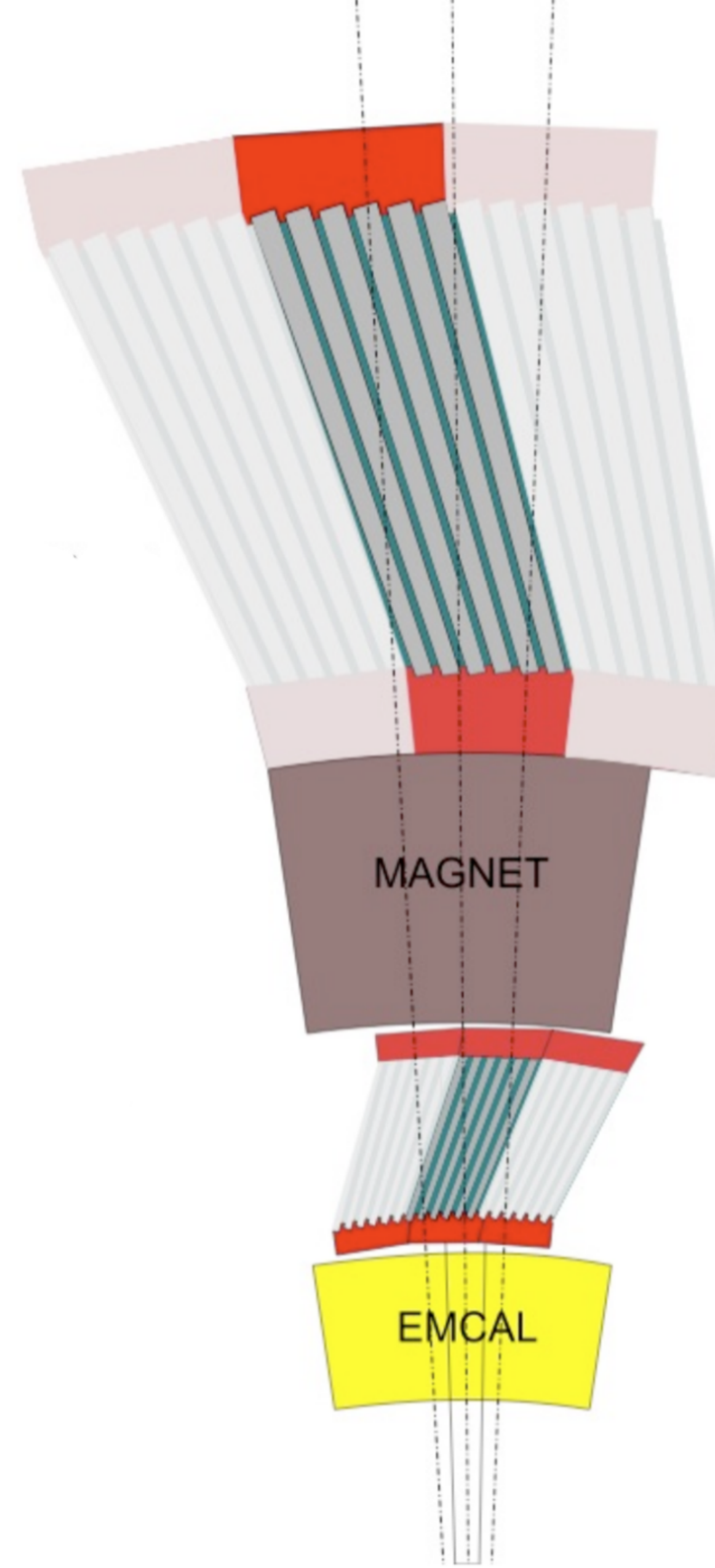
TPC Outer Tracker (TPOT)

Micromegas-based detector with 8 sectors

➡ Situated between TPC and EMCal

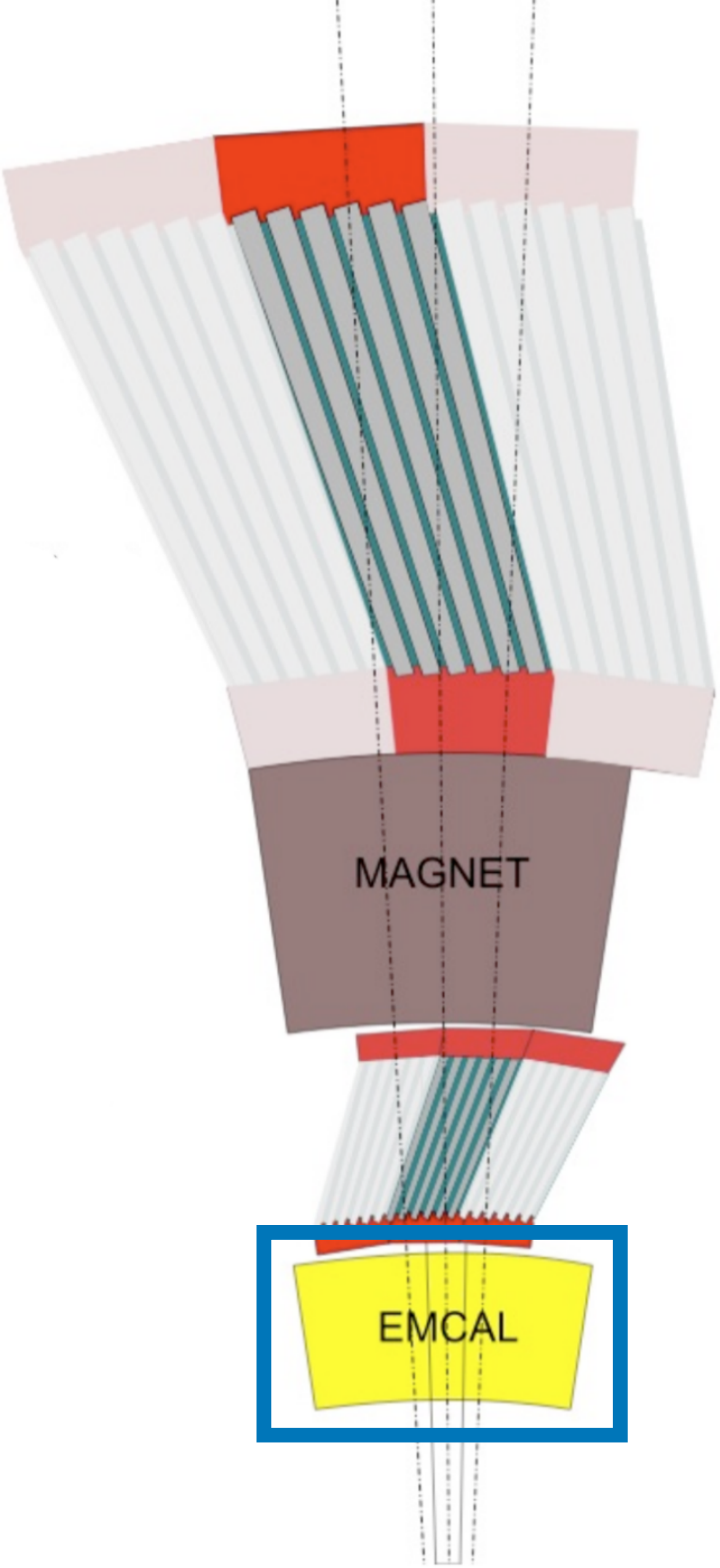
➡ Correct for beam-induced space charge distortions of the TPC

sPHENIX Calorimetry



sPHENIX Calorimetry

10/32 sectors installed



Electromagnetic Calorimeter (EMCal)

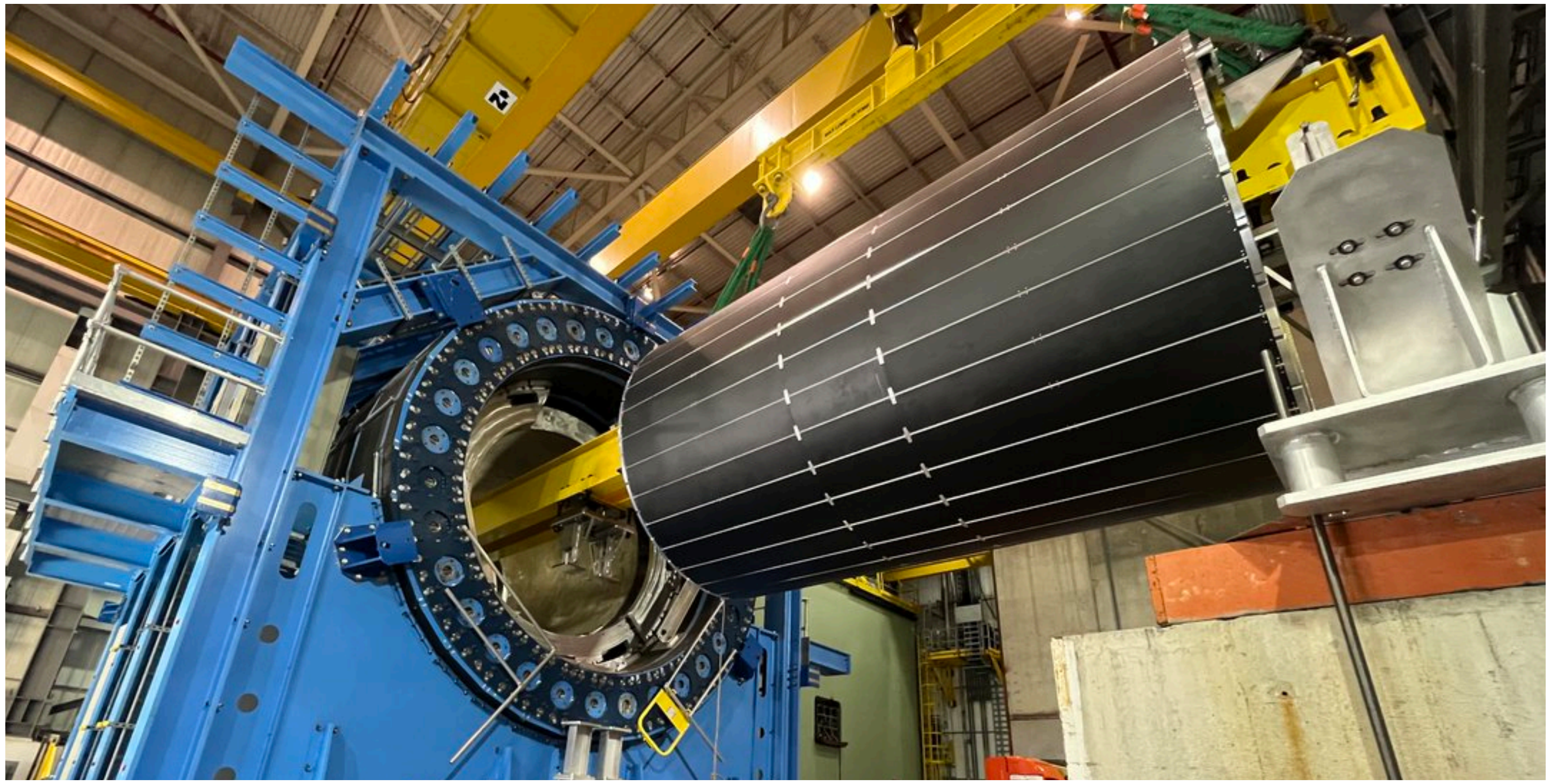
Tungsten & scintillating fiber, 2-D projective design

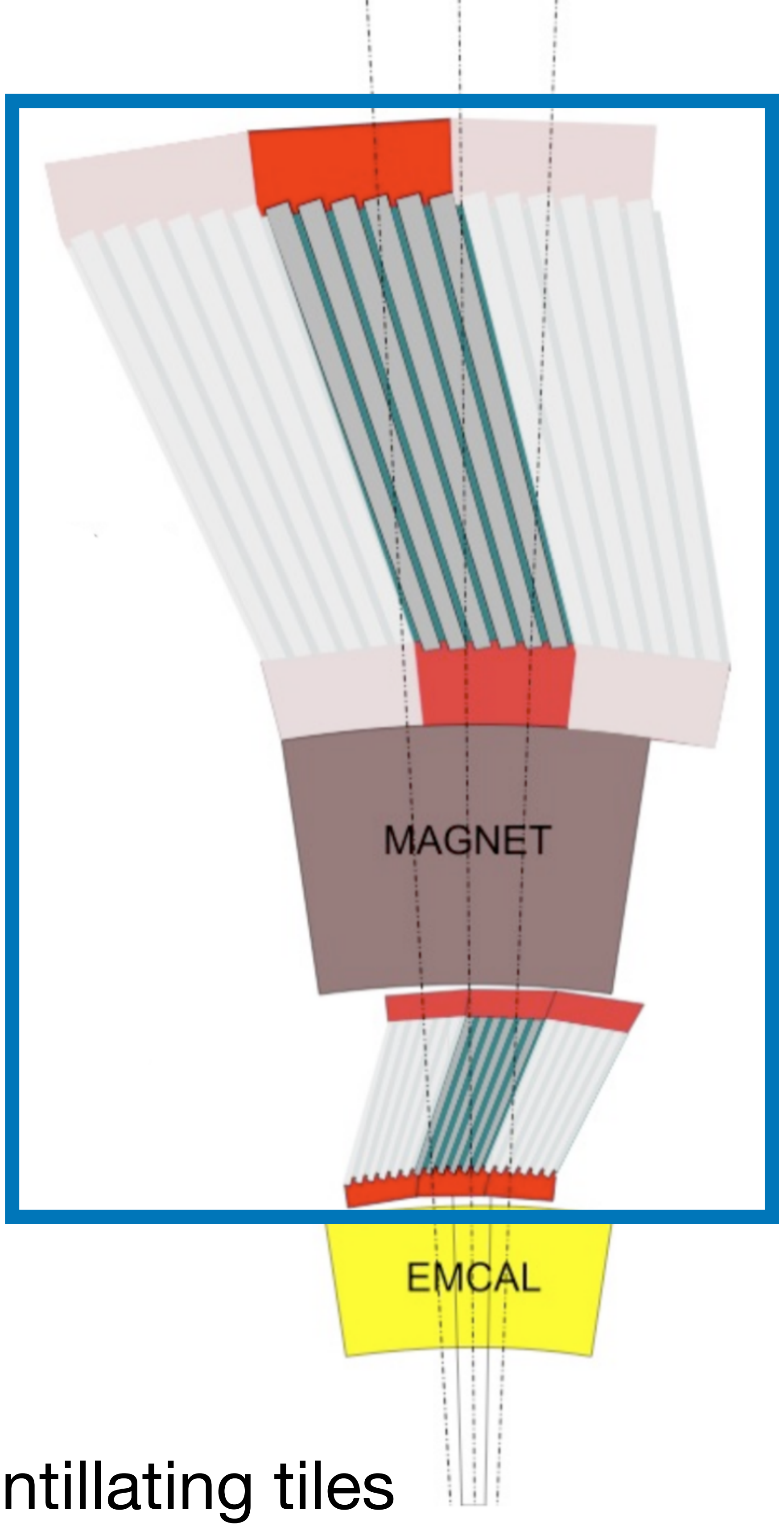
➡ 0.025x0.025 towers, ~20 X_0, $|\eta| < 1.1$, 2π azimuthal acceptance

➡ 16%/√E resolution for photons (ɣ, jets), electrons (ϒ spectroscopy)

sPHENIX Calorimetry

IHCal installation into OHCal+magnet





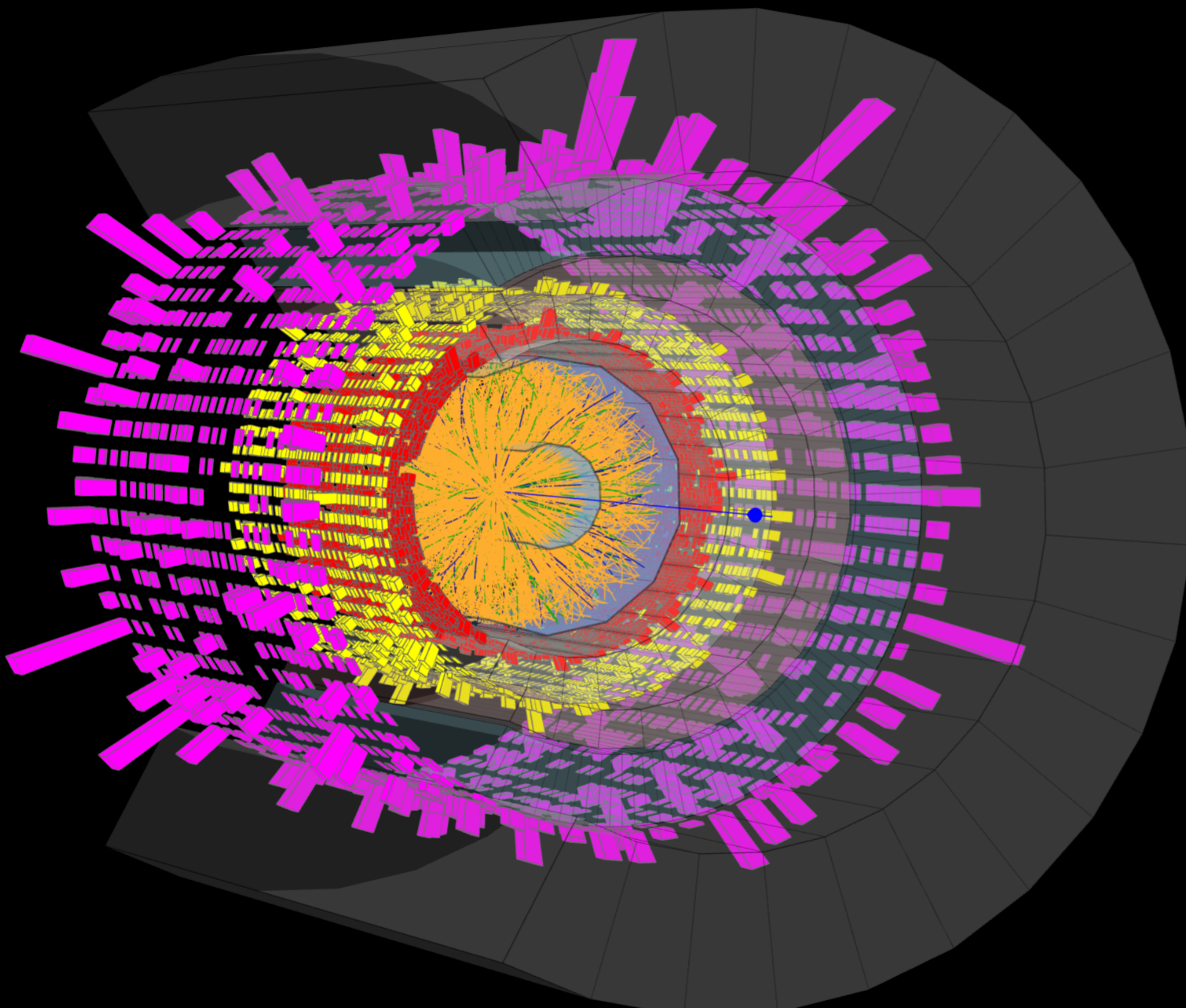
Inner & Outer Hadronic Calorimeter (HCal)

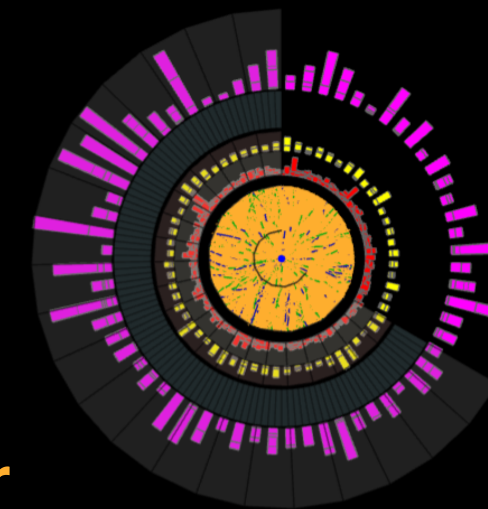
Aluminum (IHCal) or Steel (OHCal) interleaved w/ scintillating tiles

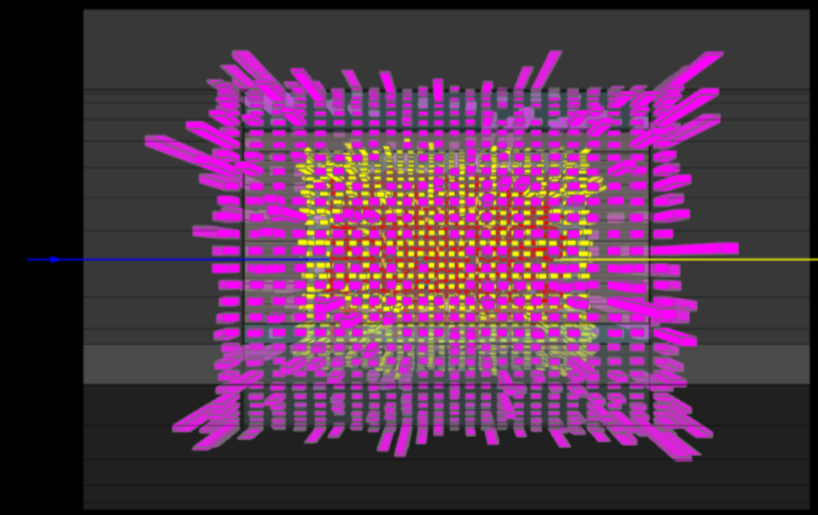
➡ ~5 λ_0 total, IHCal catches start of hadronic showers before magnet

➡ 0.1x0.1 segmentation & excellent energy resolution for jet measurements

GEANT4 simulation of Au+Au event in sPHENIX







➡ **Jet, HF, Quarkonia measurements happening in a large, fluctuating background with huge dynamic variations event by event!**

sPHENIX Collaboration

More than **360** members from **82** institutions in **14** countries as of 2022

- ➡ steady growth since collaboration formation with 40 institutions
- ➡ world-class expertise in physics, silicon, TPCs, calorimeter, electronics, computing, …

2016 **2017** **2018** **2019**

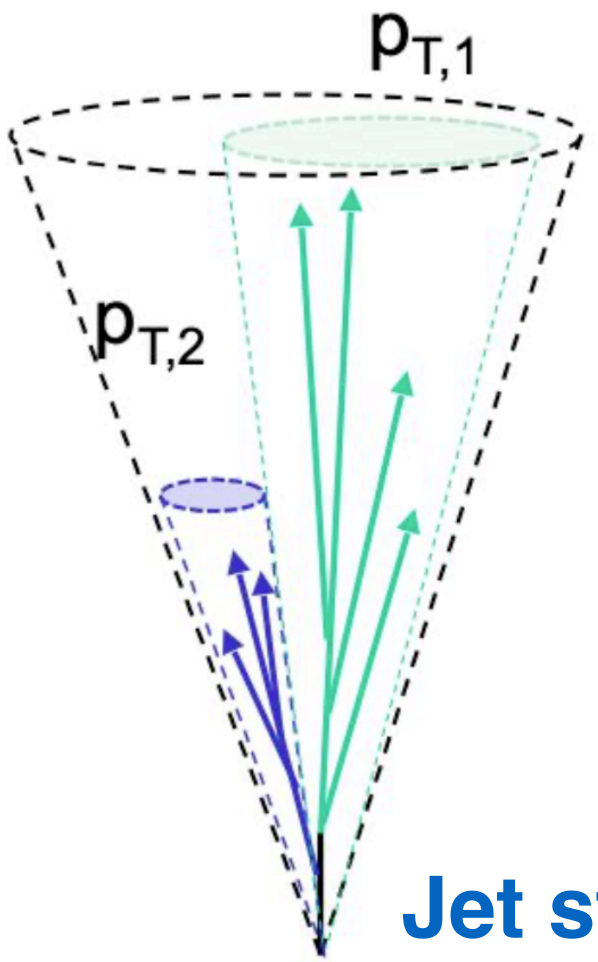
U. Sao Paolo

NCU, Taiwan

Florida AMU

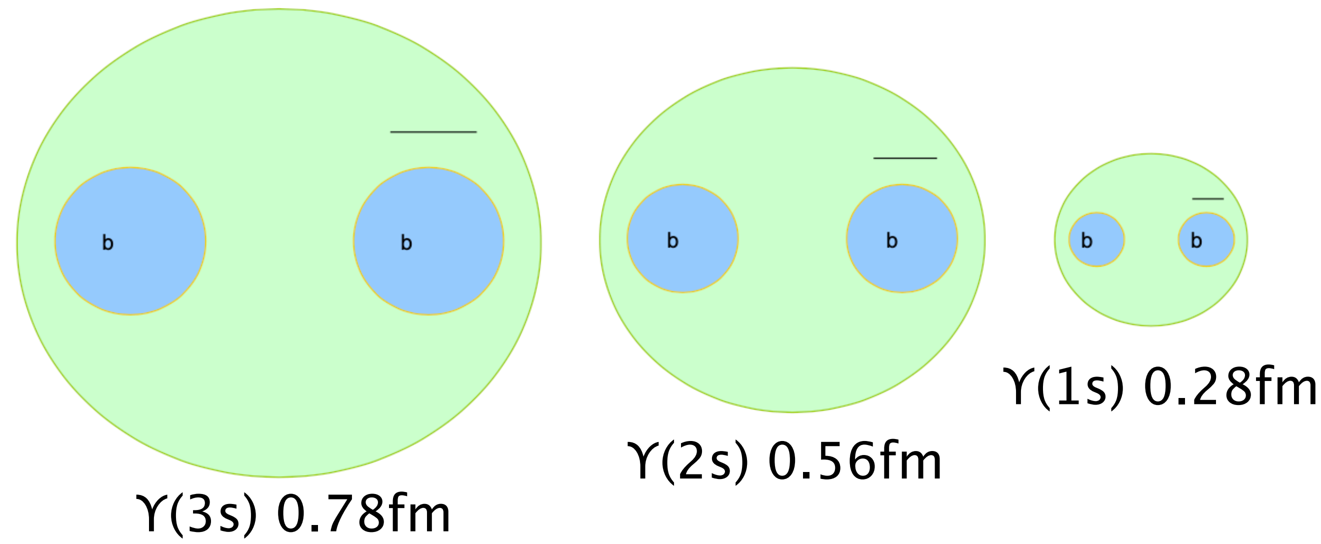
Institutions joining after CD-0

2020 **2021**



Jet structure

vary momentum/angular scale of probe

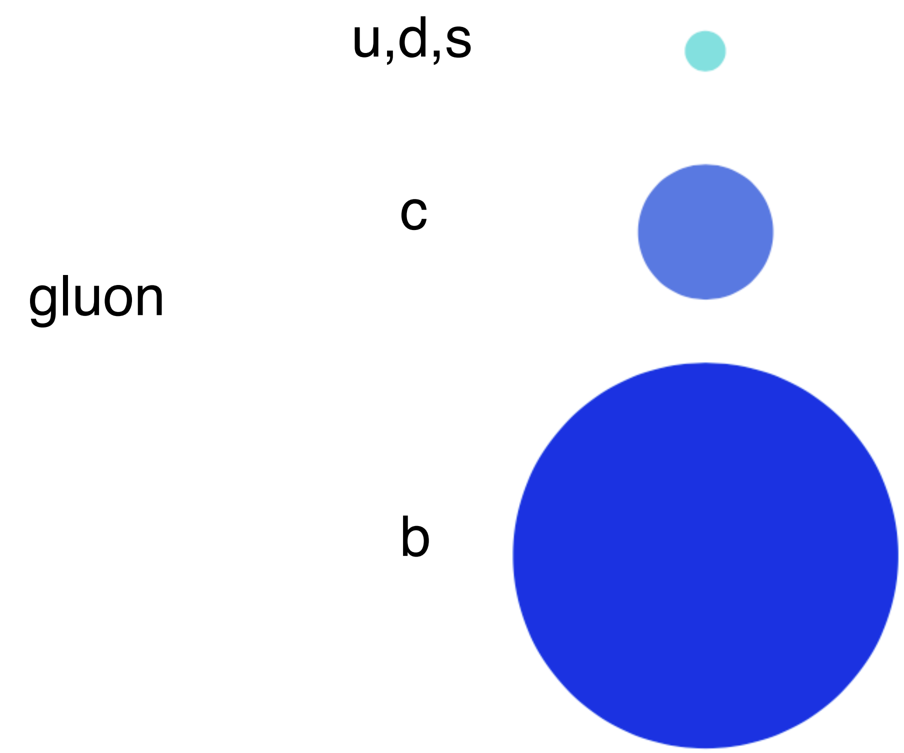


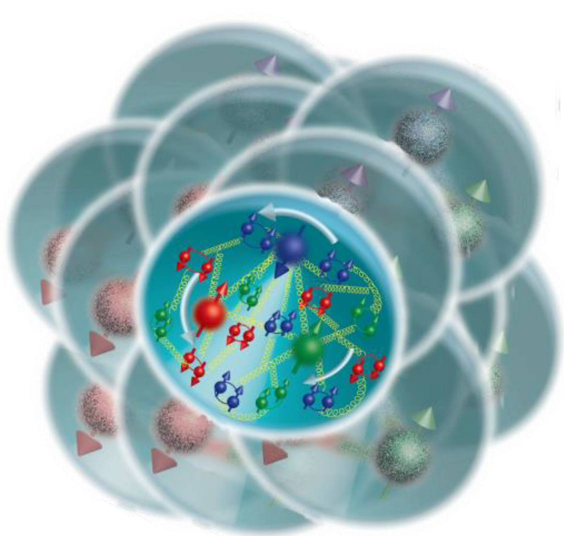
Quarkonium spectroscopy

vary size of probe

Parton energy loss

vary mass/momentum of probe

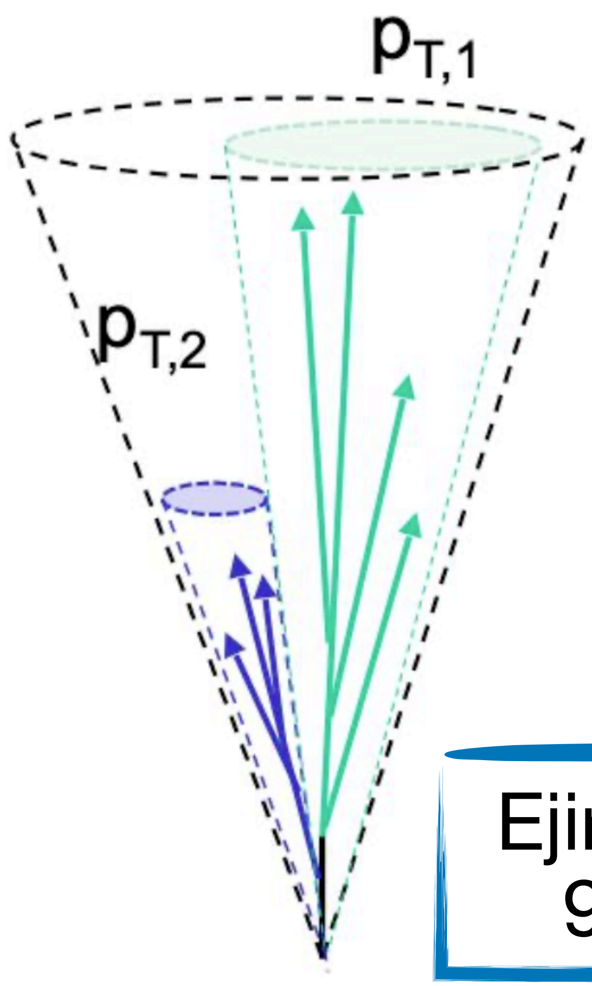




Cold QCD

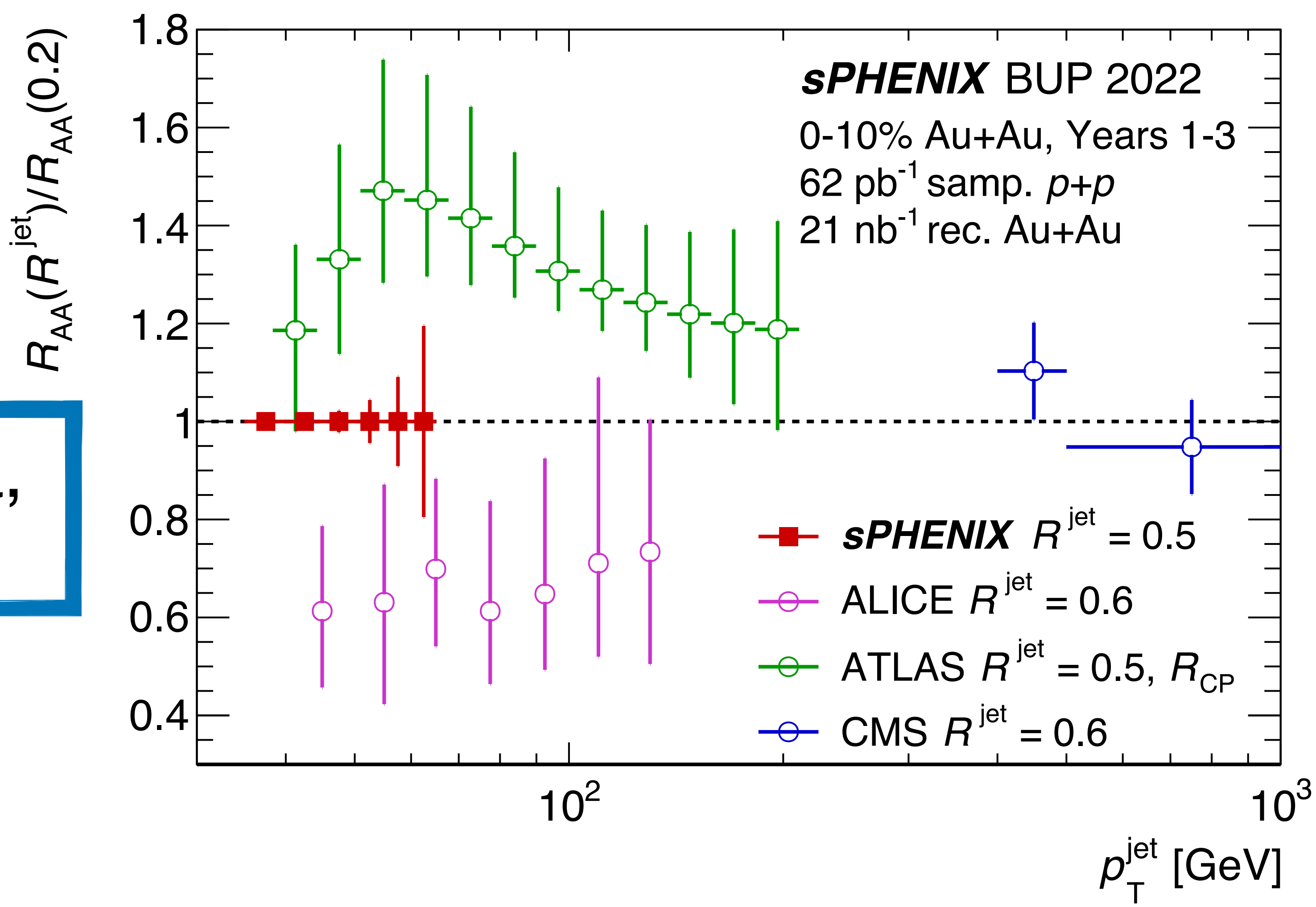
study proton spin, transverse-momentum, and cold nuclear effects

Jet probes of the QGP



Ejiro Umaka,
9/7, 1pm

Jet structure
vary momentum/angular scale of probe

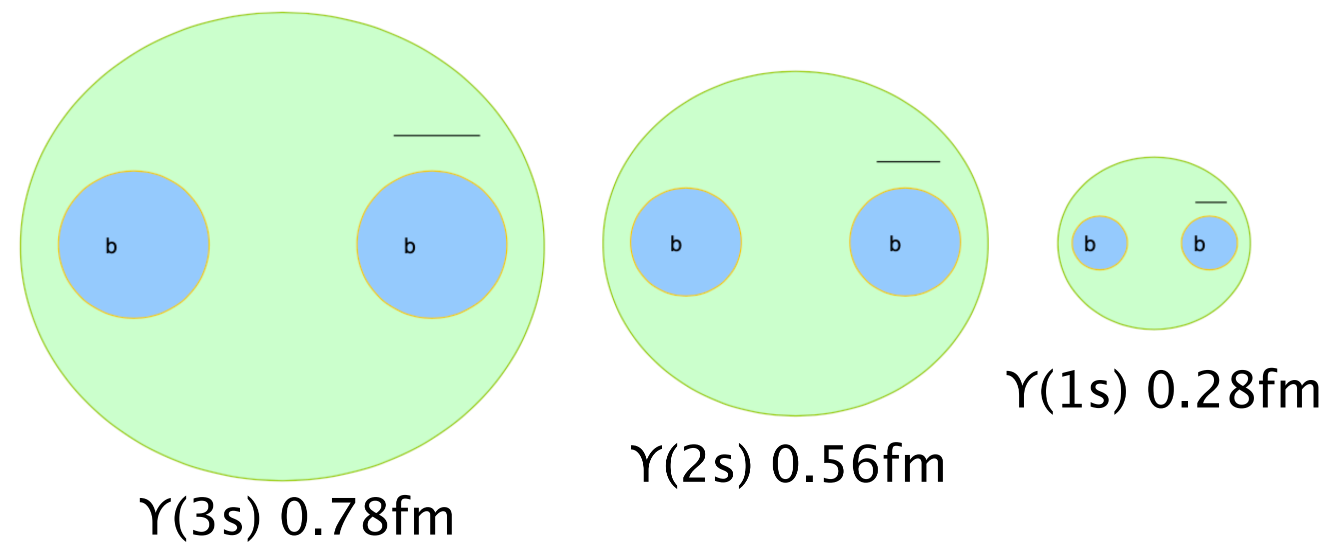


sPHENIX is a dedicated jet detector for detailed studies of the parton shower - QGP interaction

➡ Capabilities enable a rich physics program with many channels!

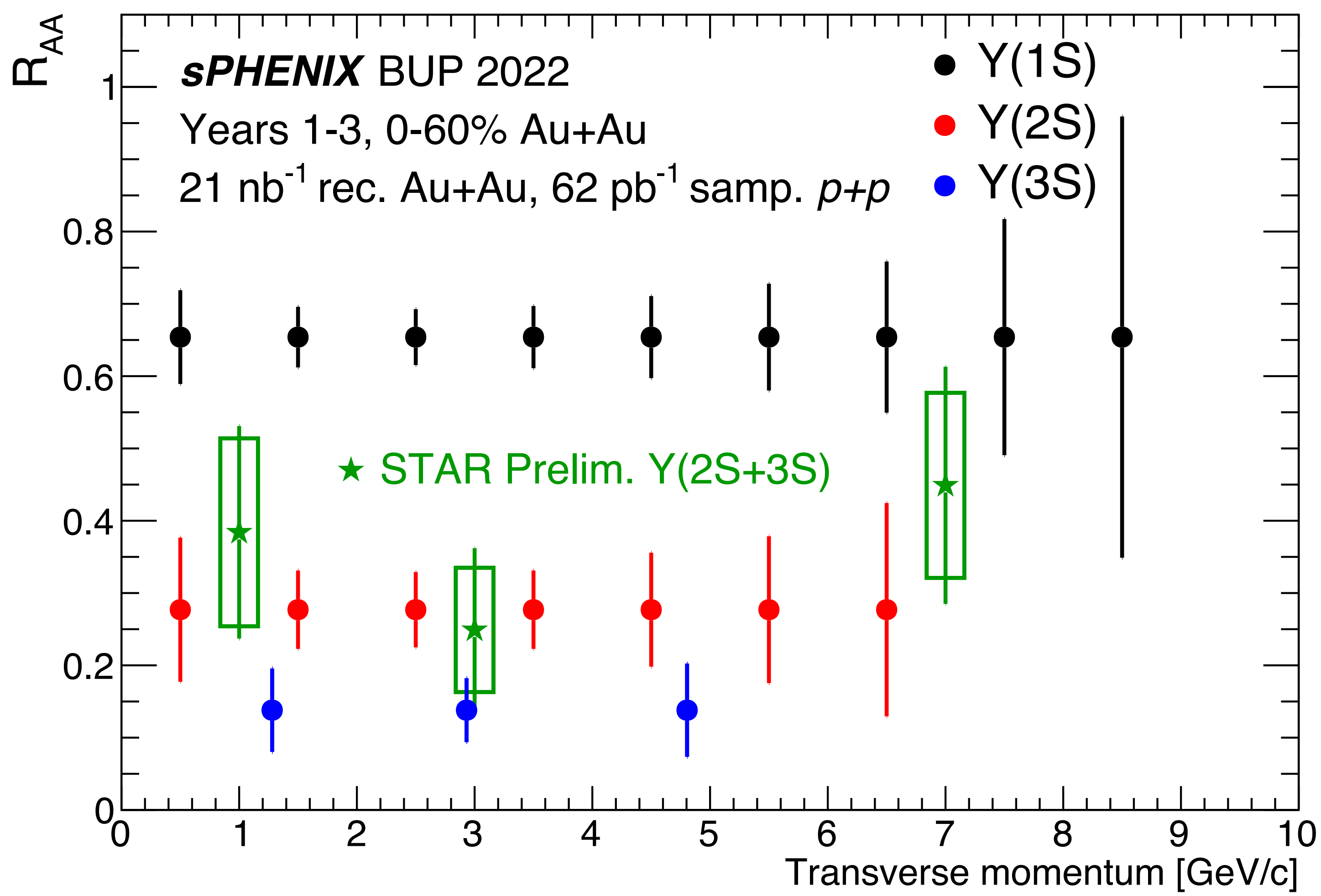
➡ One example above: jet suppression at large cone size *R*

Upsilon spectroscopy



Quarkonium spectroscopy

vary size of probe



Sequential Upsilon dissociation: systematic probe of QGP temperature profile

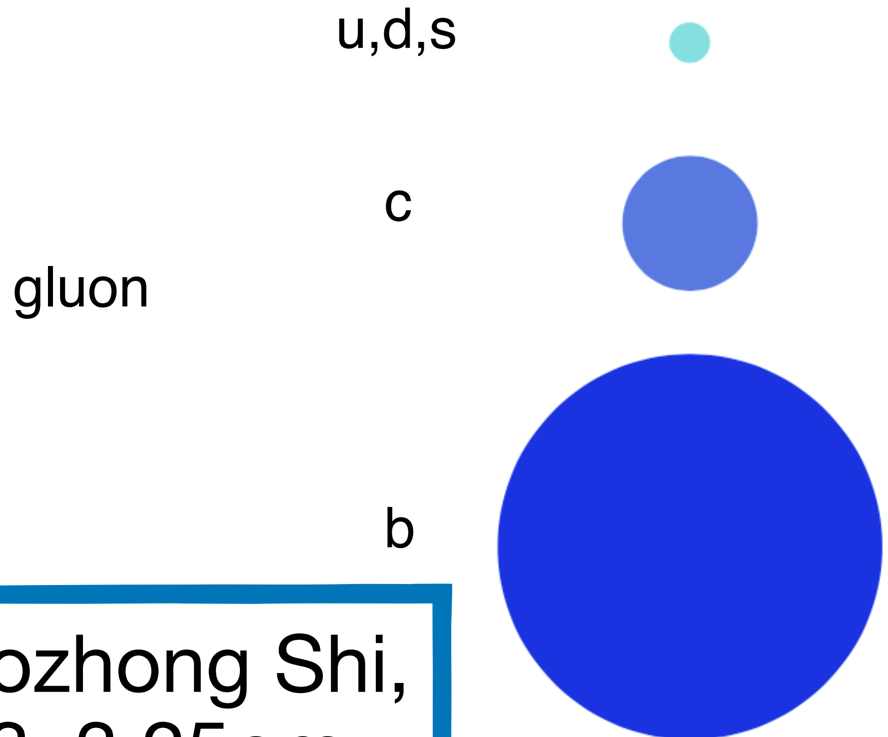
➡ Precise tracking system designed to separate 1S, 2S, and 3S states

➡ Unique opportunity to observe ϒ(3S) at RHIC!

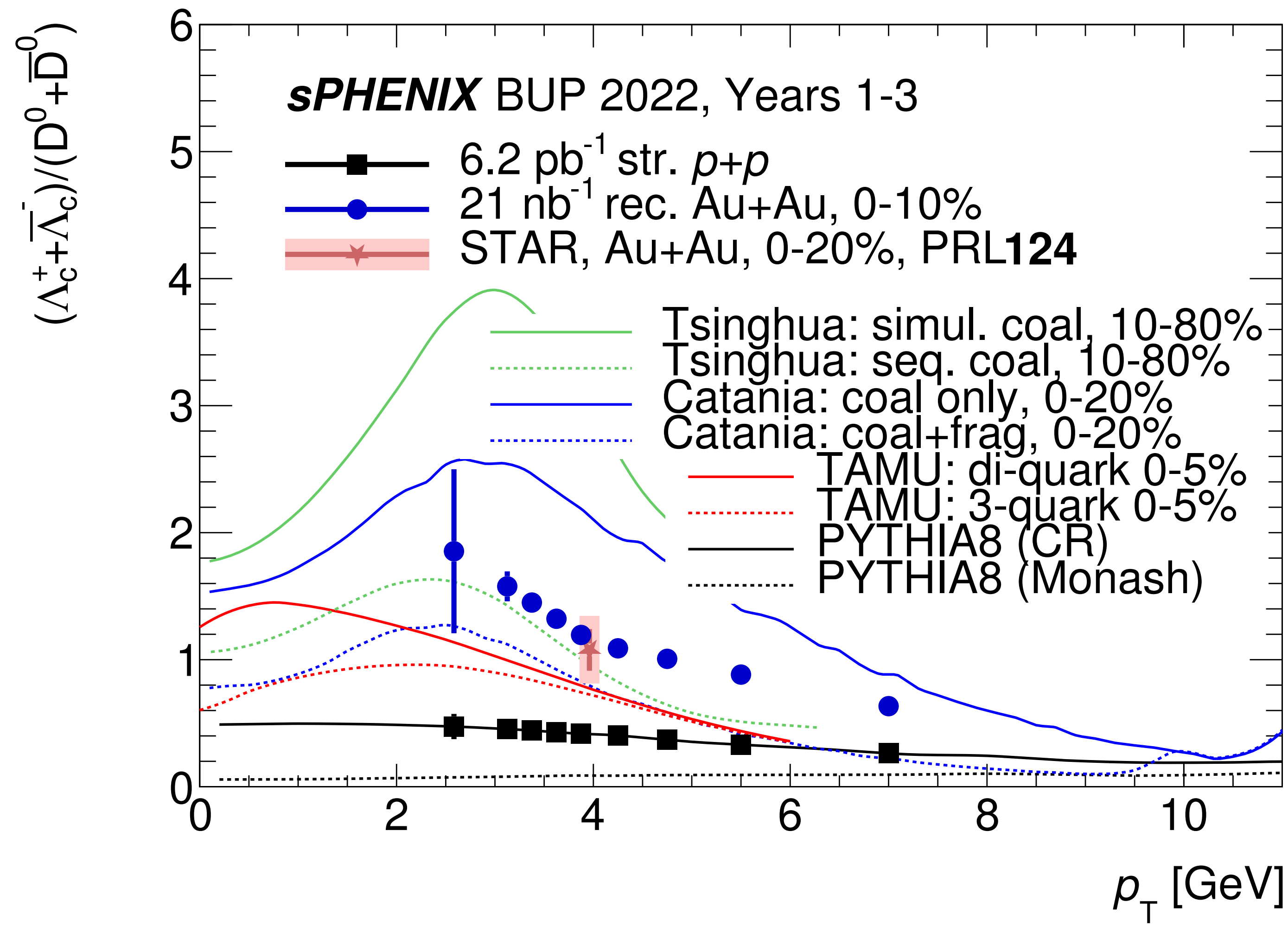
Heavy flavor physics

Parton energy loss

vary mass/momentum of probe



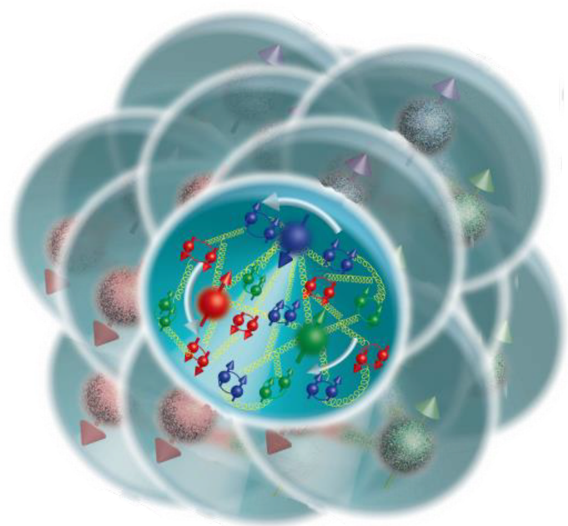
Zhaozhong Shi, 9/8, 3:25pm



Heavy flavor hadron & jet program enabled by vertex detector & streaming readout

➡ In-medium modification of *D*/*B* hadrons, and HF-tagged jets

➡ One example above: explore hadronization in nuclear medium



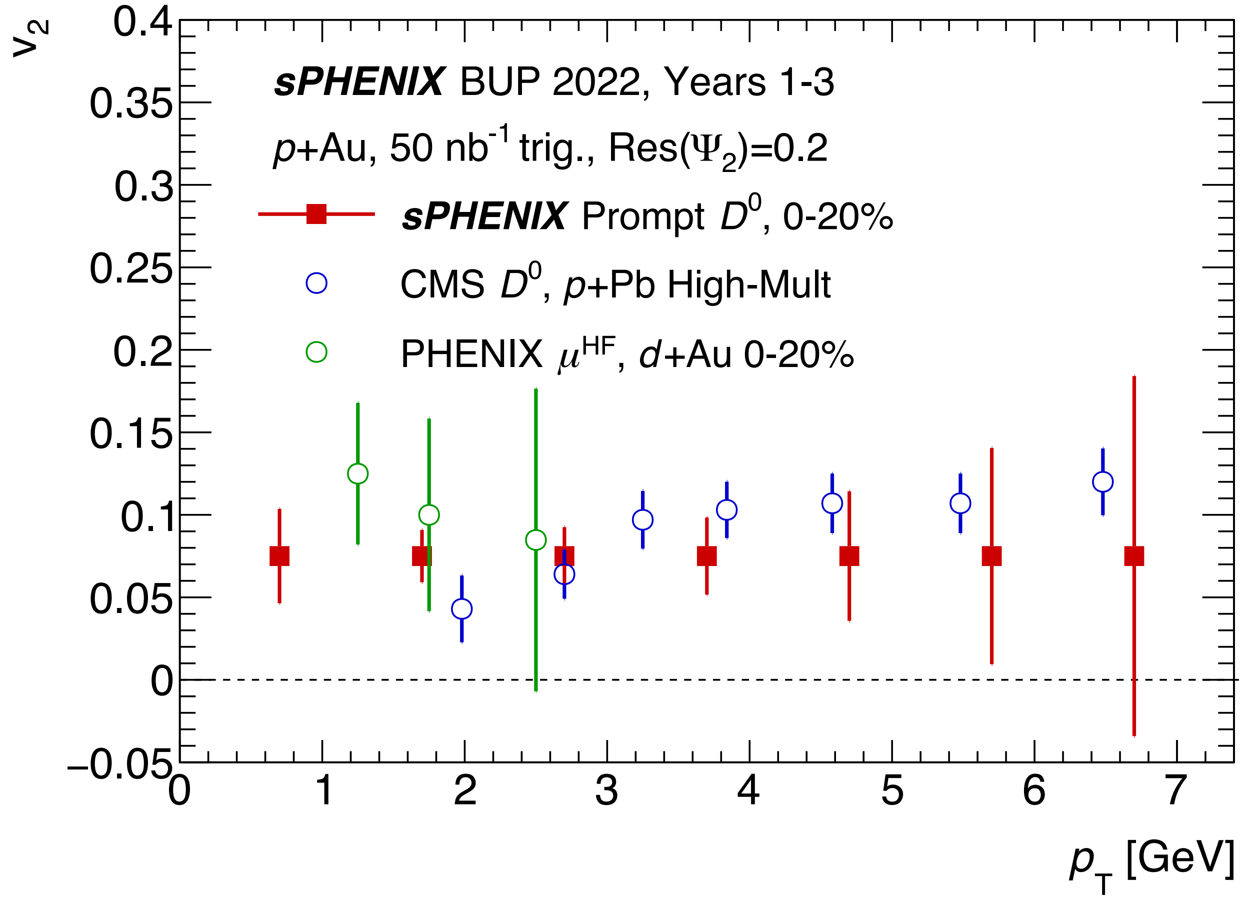
Cold QCD

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

p+A physics program

Collective behavior in small systems - a revolutionary discovery in heavy ion physics

➡ sPHENIX will have new tools to investigate these phenomena - e.g. heavy flavor “flow” at RHIC energies



Also a dedicated “Cold QCD” physics program taking advantage of transversely polarized *p* beams

➡ measurements looking towards Electron-Ion Collider at BNL!

Conclusion

- sPHENIX is a dedicated jet & heavy flavor physics detector for QGP microscopy, with new, purpose-built capabilities never deployed at RHIC

  ➡ Complementary to LHC Run 3 program, while also breaking new ground in regions unique to sPHENIX

  ➡ Major priority for U.S. Nuclear Physics community - finish the scientific mission of RHIC!

- Looking forward to commissioning & first data-taking next year in 2023!

sPHENIX