The sPHENIX Experiment at RHIC

Justin Frantz

GHP 2021 APS GHP Topical Group Meeting

Ohio University

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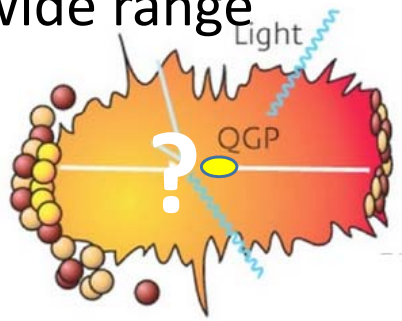
U.S. DEPARTMENT OF ENERGY

OHIO UNIVERSITY

sPHENIX Science : Quark Gluon Plasma

- The sPHENIX experiment was designed to address the latest questions in the study of the QGP
  - Completely replaces PHENIX experiment in RHIC IR Bldg 1008 with very different optimized design for specific observables – jets and HF quarkonia
  - Completely new collaboration with many new non-PHENIX members
- sPHENIX Goals (2015 LRP):

- **1)** Probe **Inner structure** of QGP with jets and other probes of wide range of Q^2 and color charge/ flavor
  - **Real, Virtual, Dressed q/g's? Scaleless strongly interacting plasma w/o quasiparticles? Entangled states?**

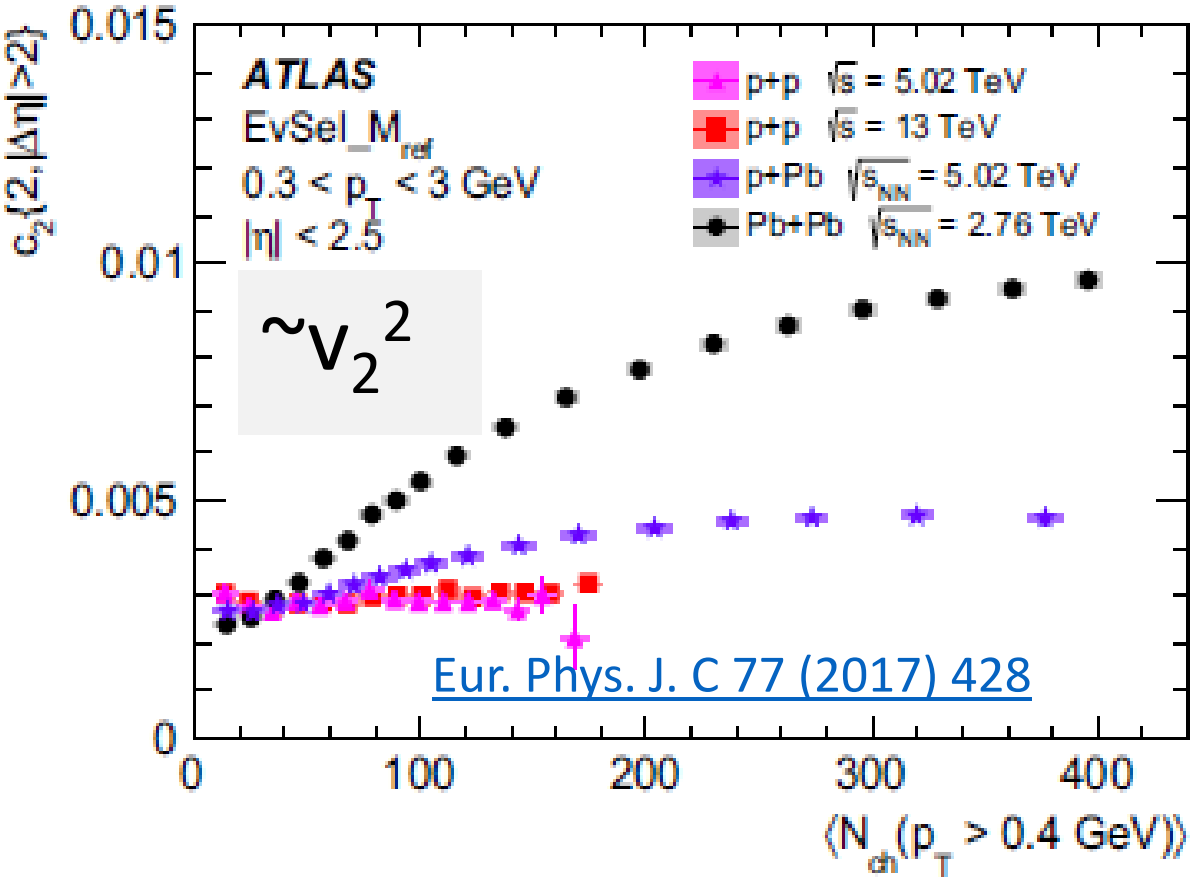


- **2)** Explore **T-dependent QGP Structure** by observing directly comparable jet modifications of longer-at-T_c QGP in **RHIC vs LHC comparison**

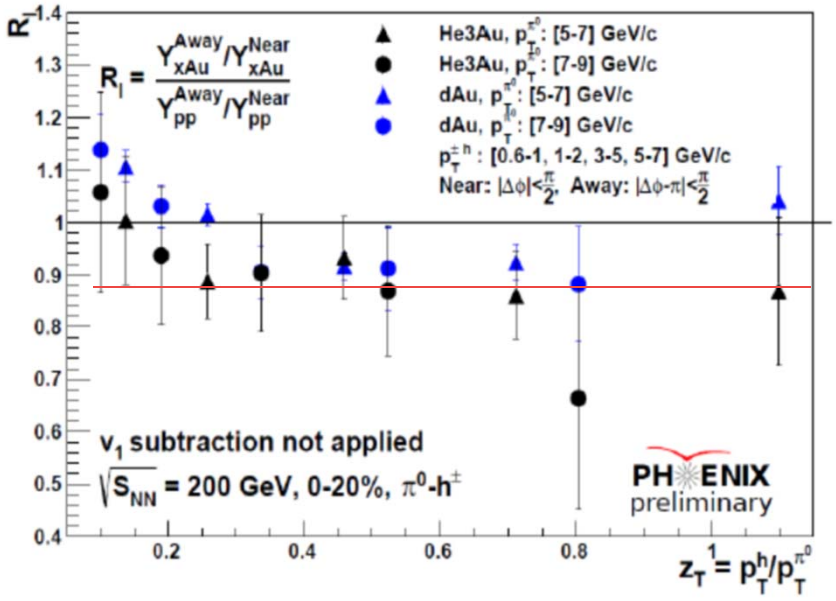
RHIC	LHC

sPHENIX Science : QGP Formation

- 3) A third question matured after the 2015 LRP process: how does the QGP emerge with collision system size p+p → A+A
- This makes smaller collision system- (e.g. p+A) running more prominent
- Carefully need to disentangle from non-QGP/non-collective traditional medium energy nuclear and hadron structure effects. **Hard probes essential!!!!**

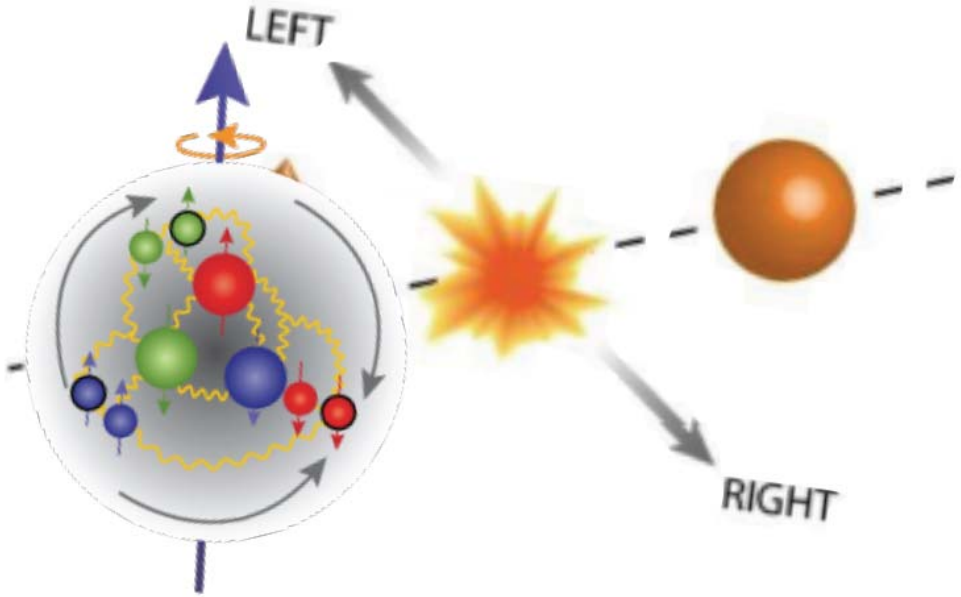


Small jet suppression in He+Au/d+Au ?



sPHENIX Science : "Cold" QCD

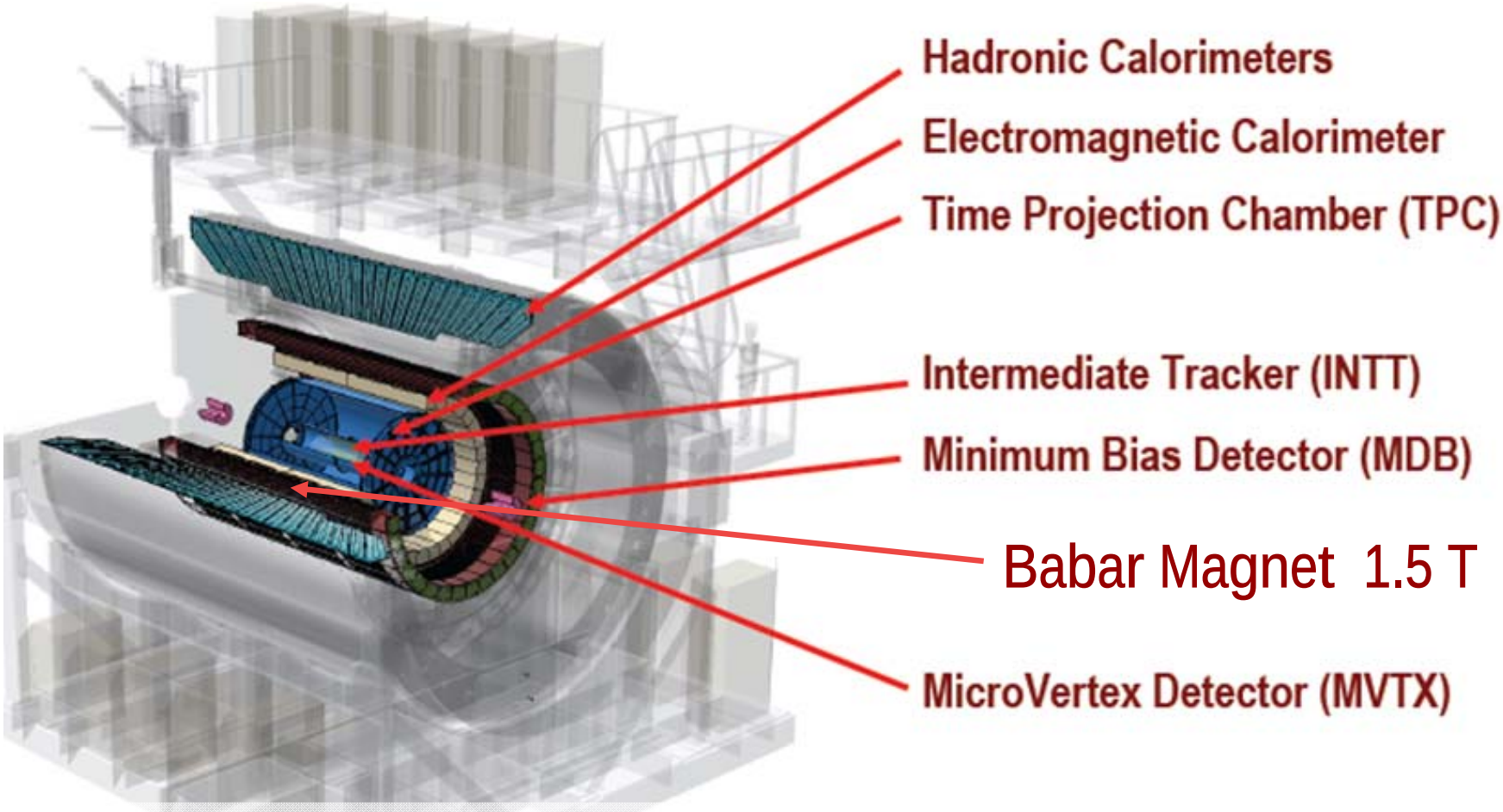
- sPHENIX will also be able to study Medium-energy QCD topics (we call them "cold" QCD)
  - p+p even p+A running will of course be polarized
  - many on sPHENIX are interested, but not a "crowded" area
- Obvious connection to EIC physics– ECCE consortium/collaboration: reuse much of sPHENIX for the EIC



Spin-orbit correlations in the transversely polarized nucleon: *single-spin asymmetries*

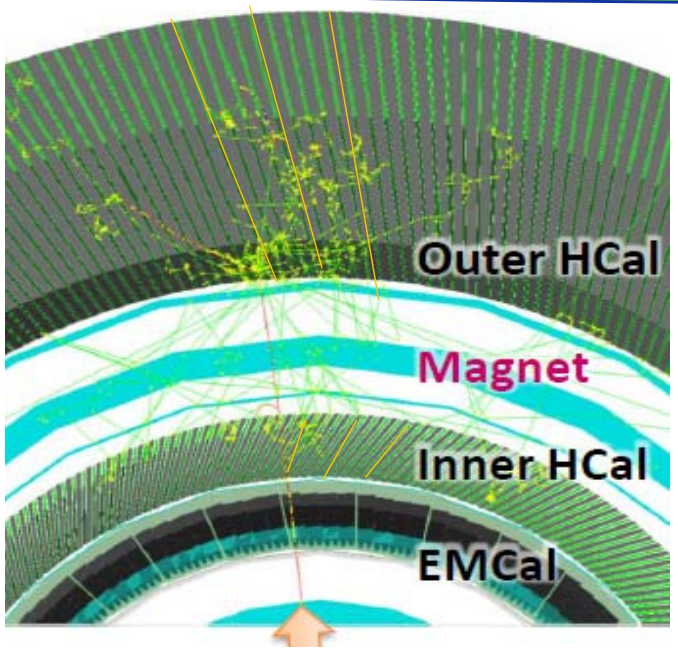
Nuclear effects and hadronization

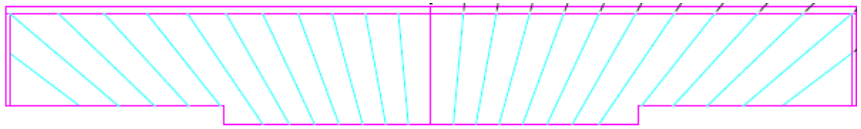
sPHENIX Detector Overview



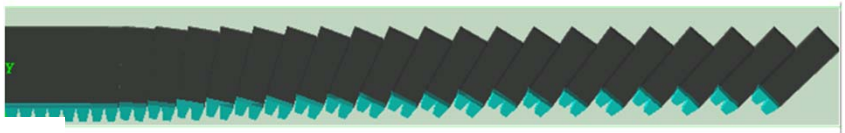
- Optimized for uniformity for jet response and compactness
- High rate DAQ (15 kHz) - Tracking streaming readout mode possible
  - Record substantial fraction of unbiased MB Au+Au luminosity – nearly all
  - Also along w/ Uniformity: Unbiased jet triggering in p+p
  - Beam crossing angle in introduced for greater focus on AuAu MB

sPHENIX Calorimeters





HCal Towers η

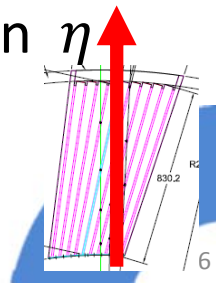


EMCal Block/Tower η

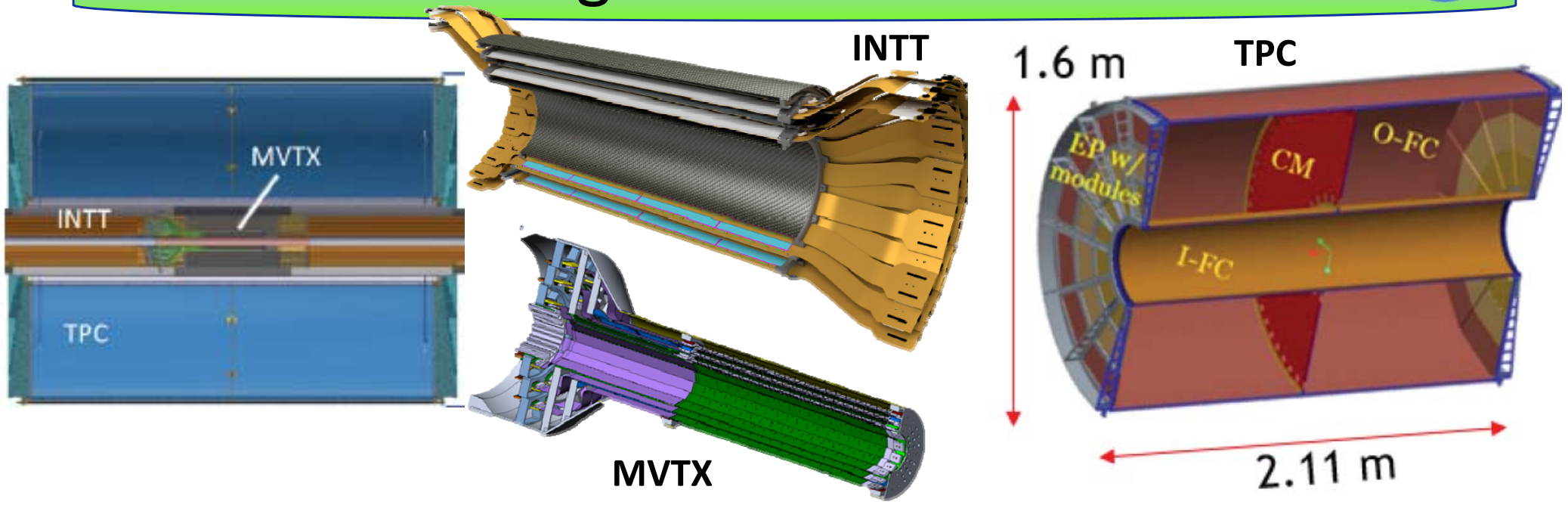
Common SiPMs

Figure 5.3: Hamamatsu S12572 MPPC (SiPM). The device is 3 × 3 mm^2 with 40,000 pixels 15μm^2.

- **Total Calorimeter System (EMC+HCal) system :** -$|\eta|$ < 1.1 , Hermetic ϕ
  -Common SiPM Light Collection Devices -5.5λ **-Novel Technology !!!**
  Demonstrated with 3 beamtests: ***IEEE Trans.Nucl.Sci.* 68 (2021) 2, 173-181**
  ***IEEE Trans.Nucl.Sci.* 65 (2018) 12, 2901-2919**
- **EMC:** -Δη × Δφ 0.025 x 0.025 W powder/Spacal Fibers -18 X_0 -1 λ
  -EMC Towers Projective ϕ & η -Inside Magnet
- **IHCAL/OHCal:** -0.1 x 0.1 Novel "Tilted Shashlik" geometry -Projective in η
  -Steel/Al scintillating tiles /embedded WLS -OHCal also flux return
  -3.8 λ / 0.25 λ (Outer/Inner) -IHCal inside Magnet

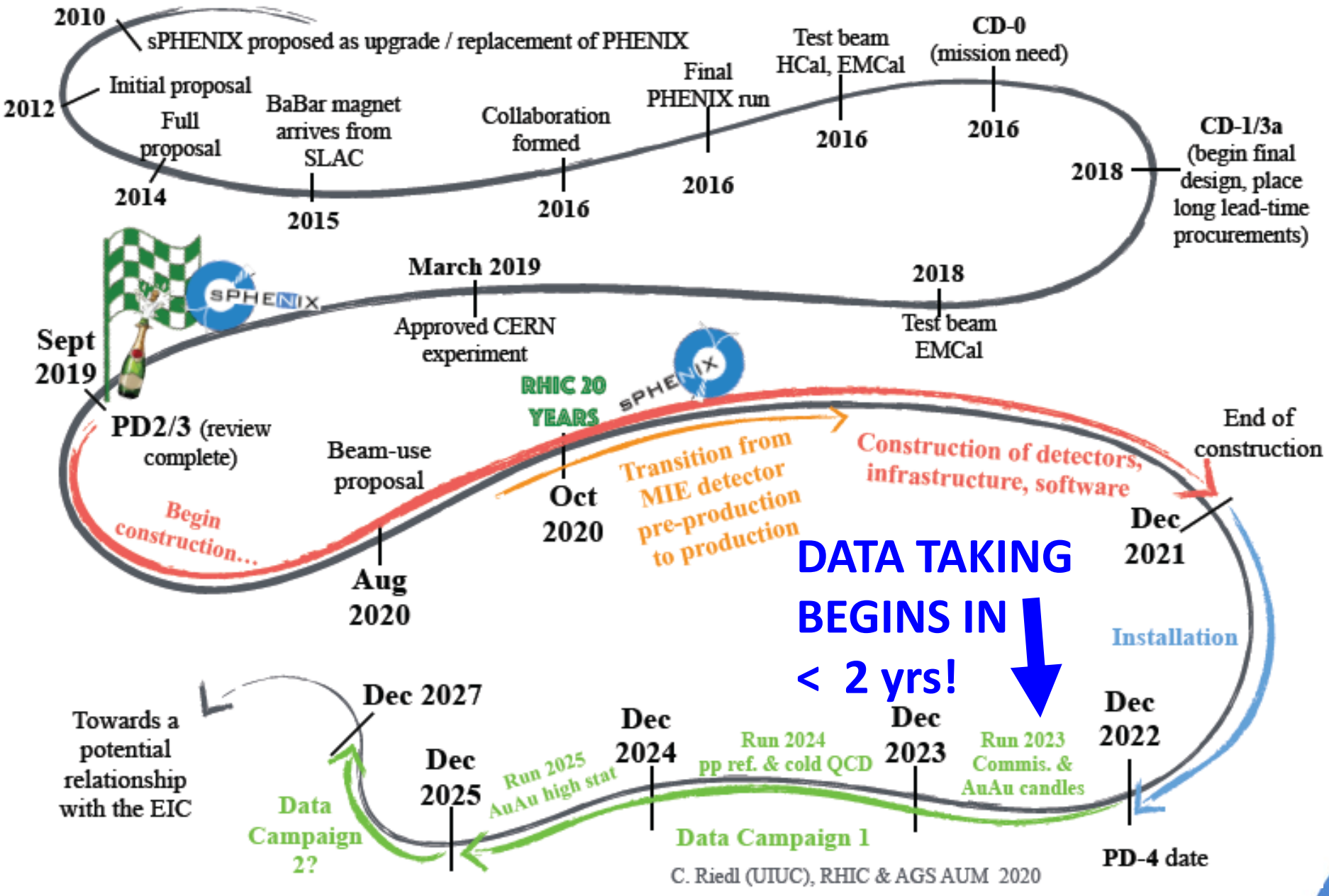


sPHENIX Tracking



- **Intermediate Silicon Tracker (INTT)** - 2 layers of strip silicon sensors
- **Time Projection Chamber (TPC)** -**Compact**: 20 < r [cm] < 78 (active (>30cm) -**Spatial resolution** < 200 μm -Charge collection via **GEMs** → ALICE SAMPA -**Gateless and continuous readout** (IBF-avoiding GEMs) - Careful study of space-charge distortion effects
- **MAPS-based Vertex Tracker (MVTX)** - 3 layers of Monolithic Active Pixel Sensors (ALICE **ALPIDE**) - **Integration time**: few μs -**XZ spatial resolution** [μm]: <6
- **STREAMING READOUT MODE→ Enhance low p_T HF physics**

sPHENIX: a short history and plan



sPHENIX Run Plan

- sPHENIX run plan already part of the RHIC PAC yearly review process
  - Initial Beam Use Proposal August 2021: sPH-TRG-2020-001
- Baseline 23-25 Running before projected EIC-build shutdown of RHIC
  - If opportunity arises, obvious benefits from running longer, we planning for till at least '27 to be ready just in case
  - Post 2025 possibilities O+O and Ar+Ar
- Latest guidance (Spring '21) from BNL only small modifications likely due to EIC developments

Year-1: commissioning, calibration, reco; Au+Au standard candles.

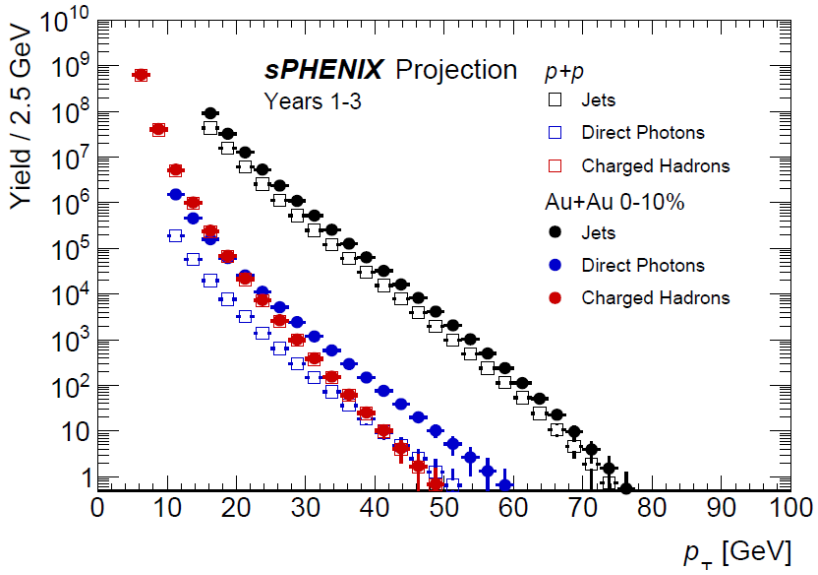
Year-2: p↑+p↑, p↑+Au: HI reference set & coldQCD

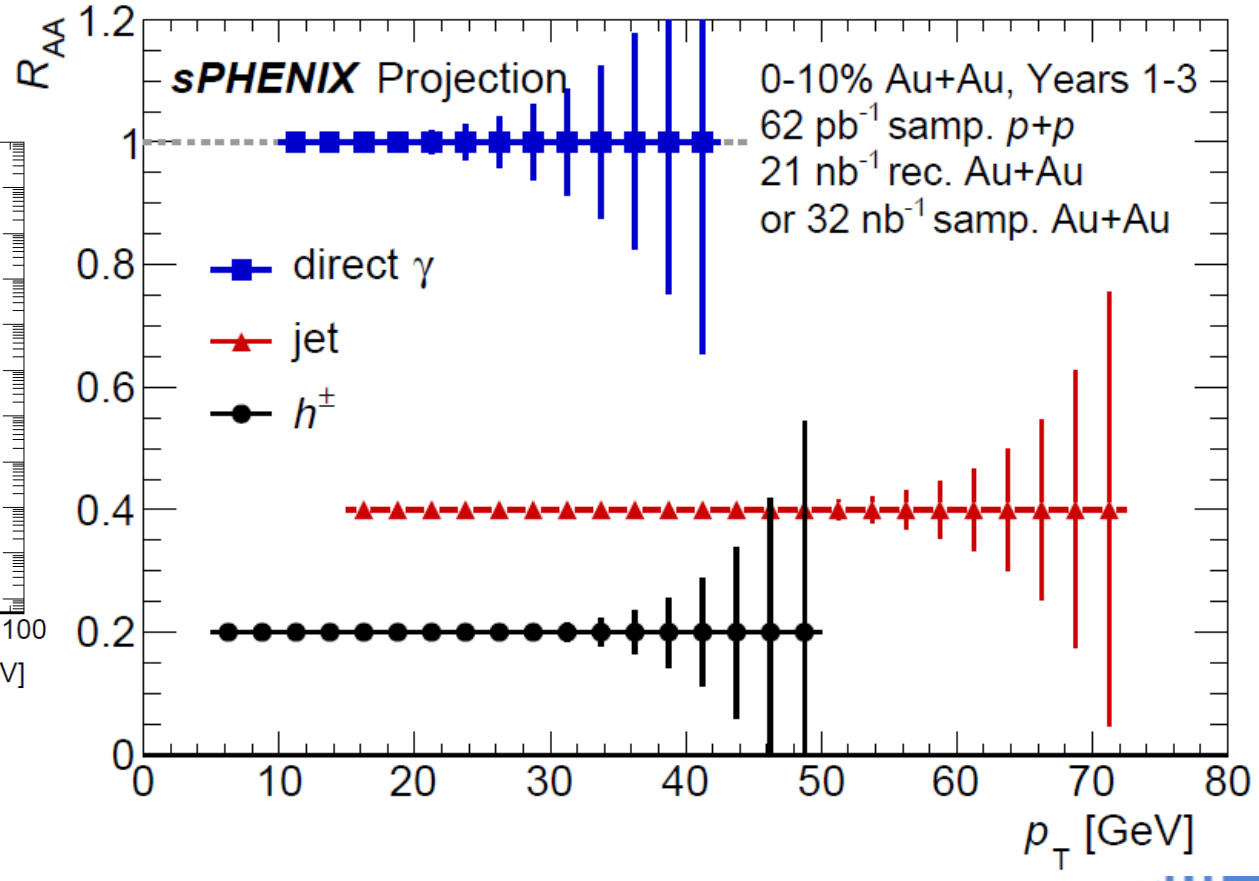
Year-3: very large Au+Au HI set

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}

sPHENIX Jets and Photons for QGP

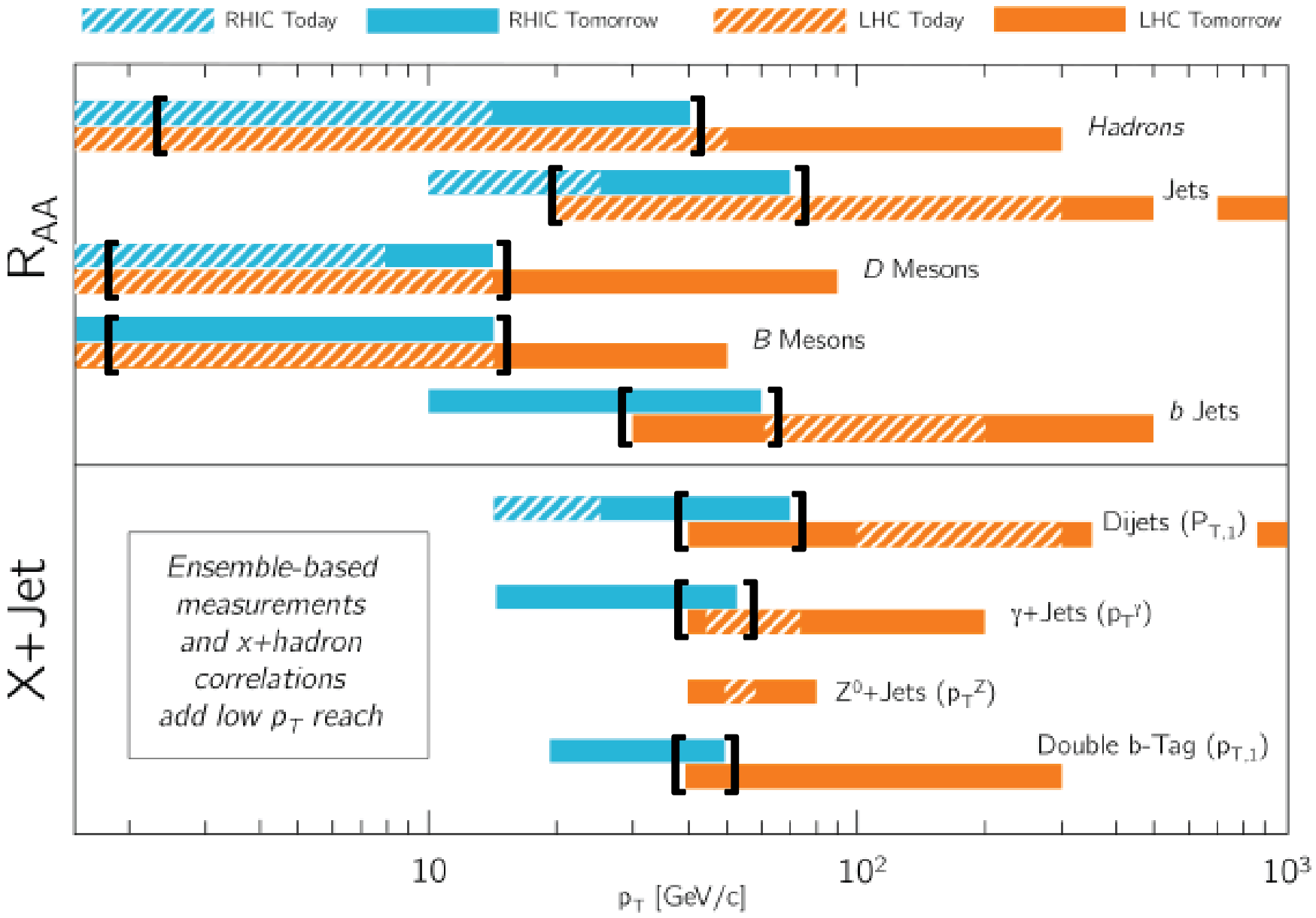
- For Au+Au Studies Statistics reach to 70 GeV in Jet Energy, 40 GeV in Photon Energy
- Showing some example jet observables on the following slides
  - **For more information please see Yeongju Go Parallel talk tomorrow**





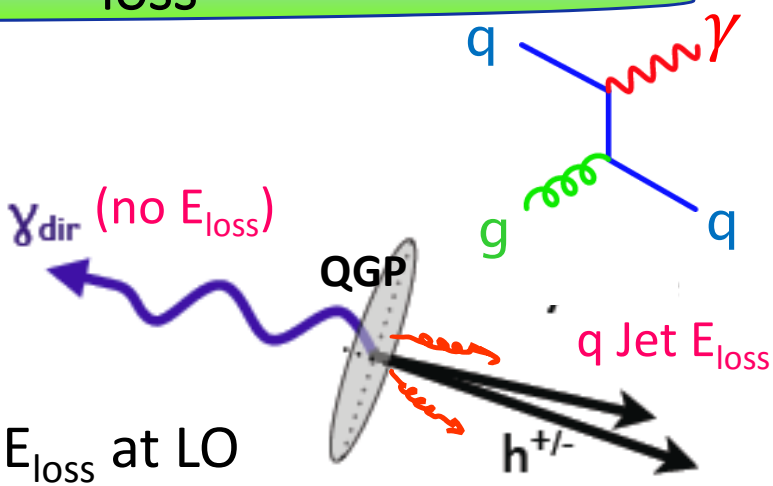
High stats needed for LRP Goal

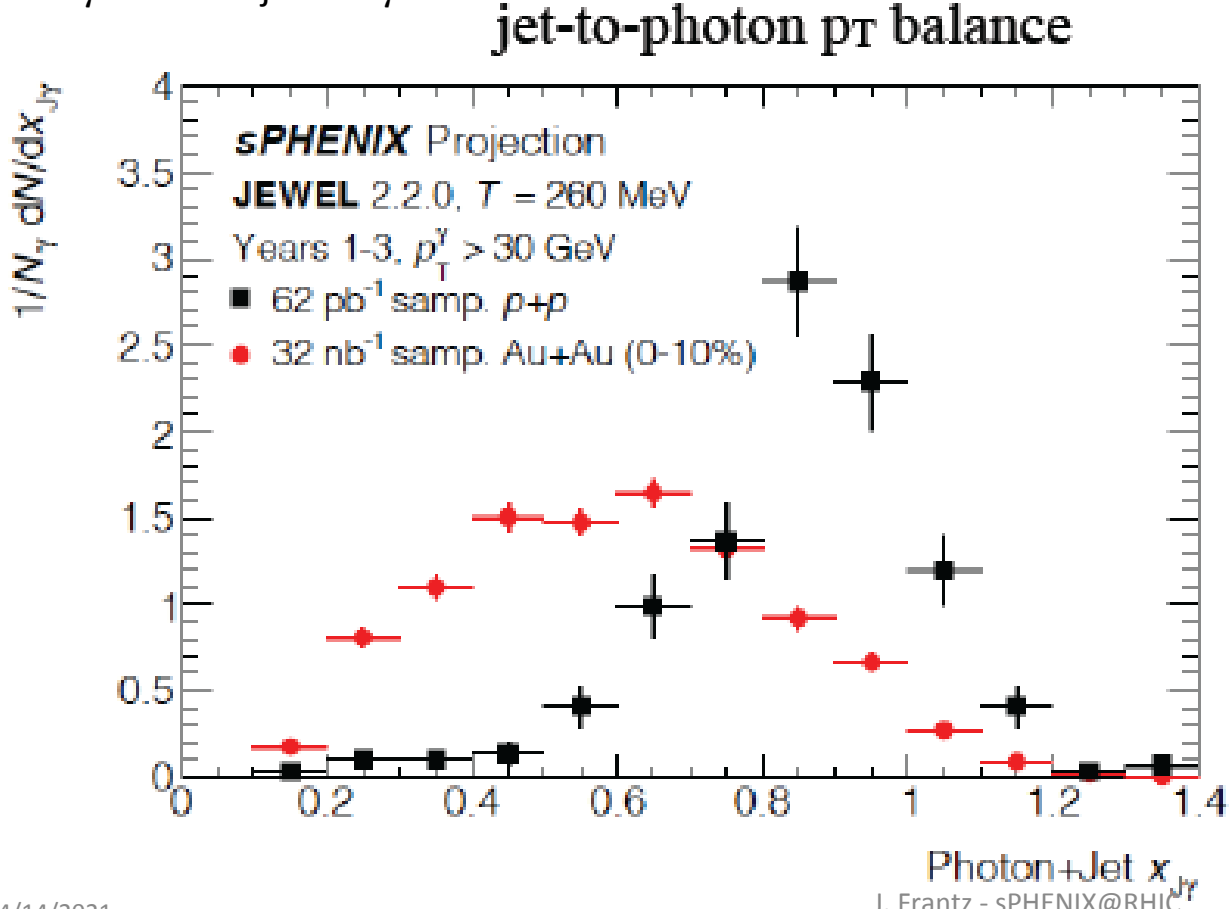
- Maximum p_T reach needed for goal 1 (Jets/Eloss)

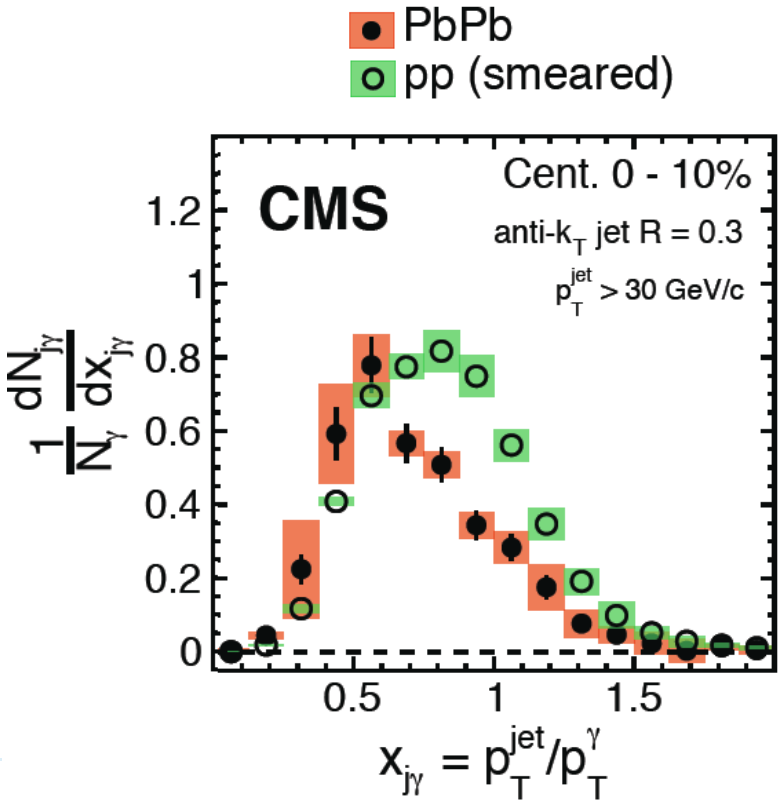


Gamma-Jet Imbalance from Jet E_{loss}

- Gamma-Jet is self calibrated golden probe of E_{loss}
  - Key in-situ jet calibration tool!
- Keeps probe color charge (q) flavor constant btw LHC/RHIC by looking at γ-Jet !
  - quark single vs gluon double color charge
- $x_{J\gamma}$ (= $p_{T\,jet}/p_{T\gamma}$) distributions : "direct" measure of E_{loss} at LO

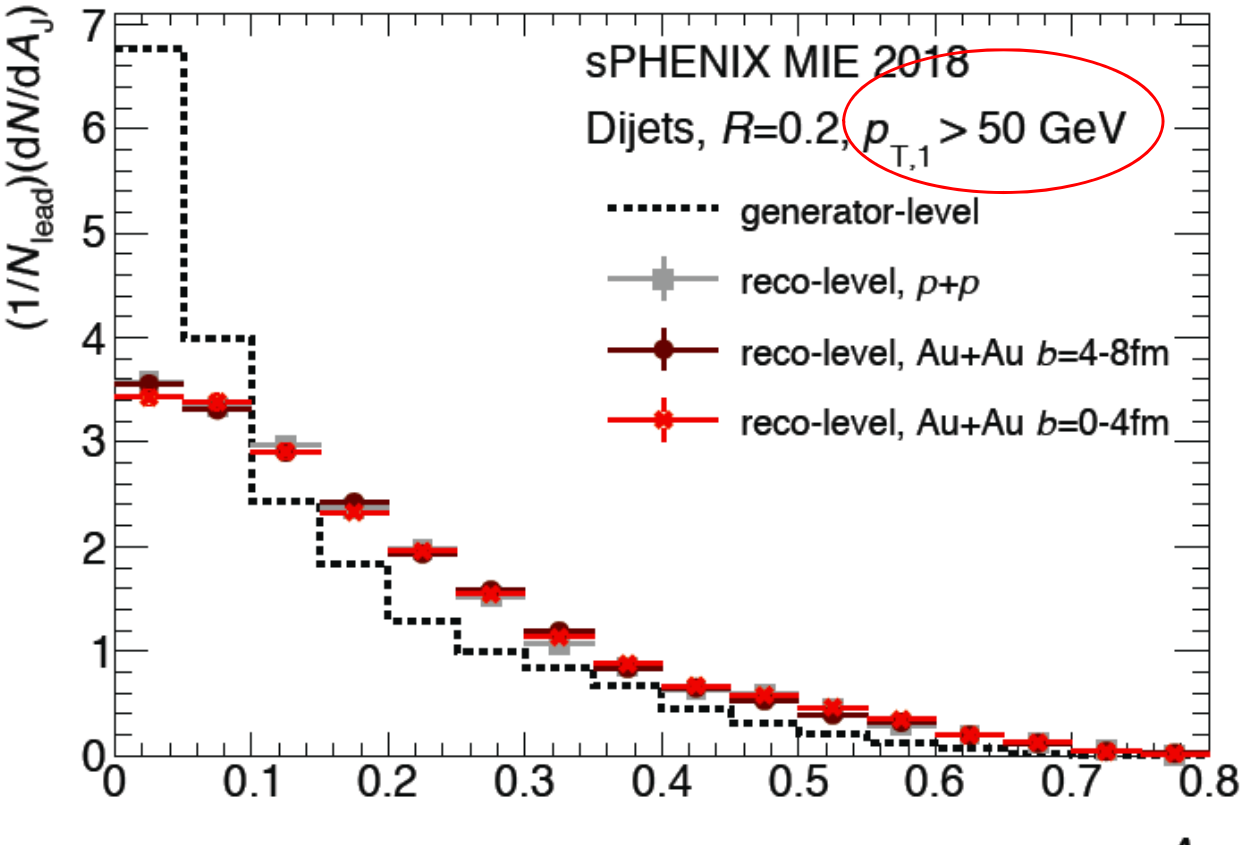






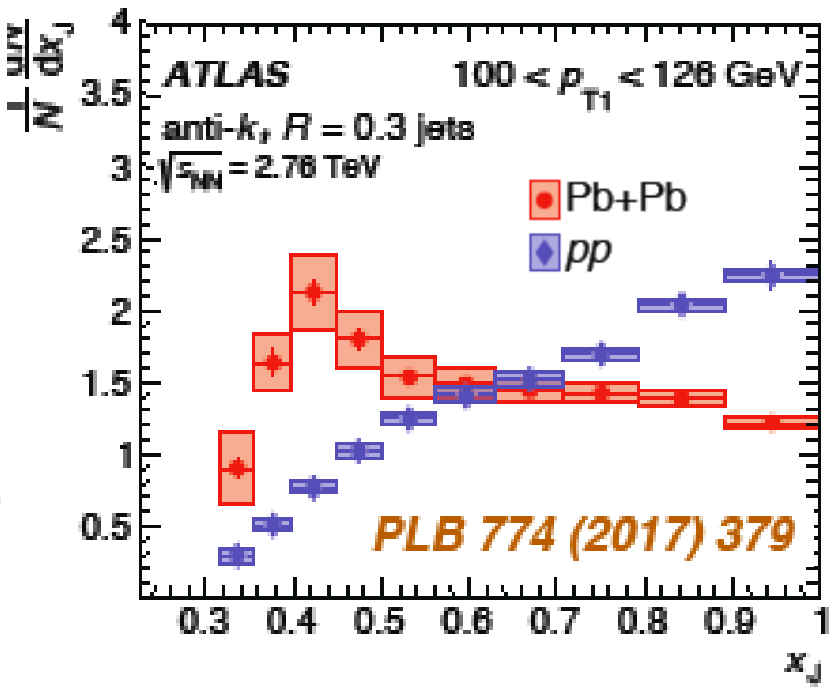
Dijet Imbalance from Jet E_{loss}

- Can also do similar measurements with di-jets with even greater statistical precision/higher E_{jet} -- good Day 1 measurement!
  - though mix of q and g needs disentangled & energies need unfolding
- Di-jet asymmetries, reco-level from our final 2018 MIE Proposal –not updated for BUP, but won't be stats-limited



$$A_J = \frac{p_{T1} - p_{T2}}{p_{T1} + p_{T2}} = \frac{1 - x_J}{1 + x_J}$$

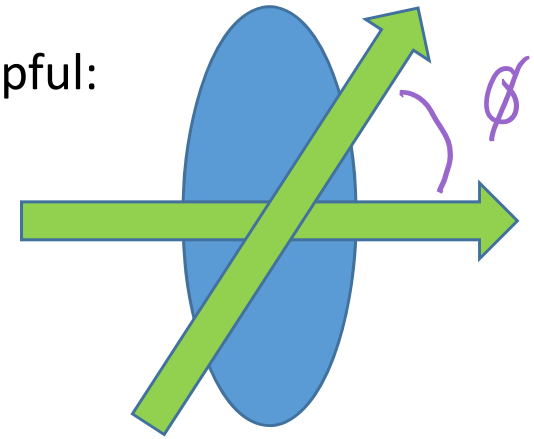
$$x_J = \frac{1 - A_J}{1 + A_J} = \frac{p_{T2}}{p_{T1}}$$

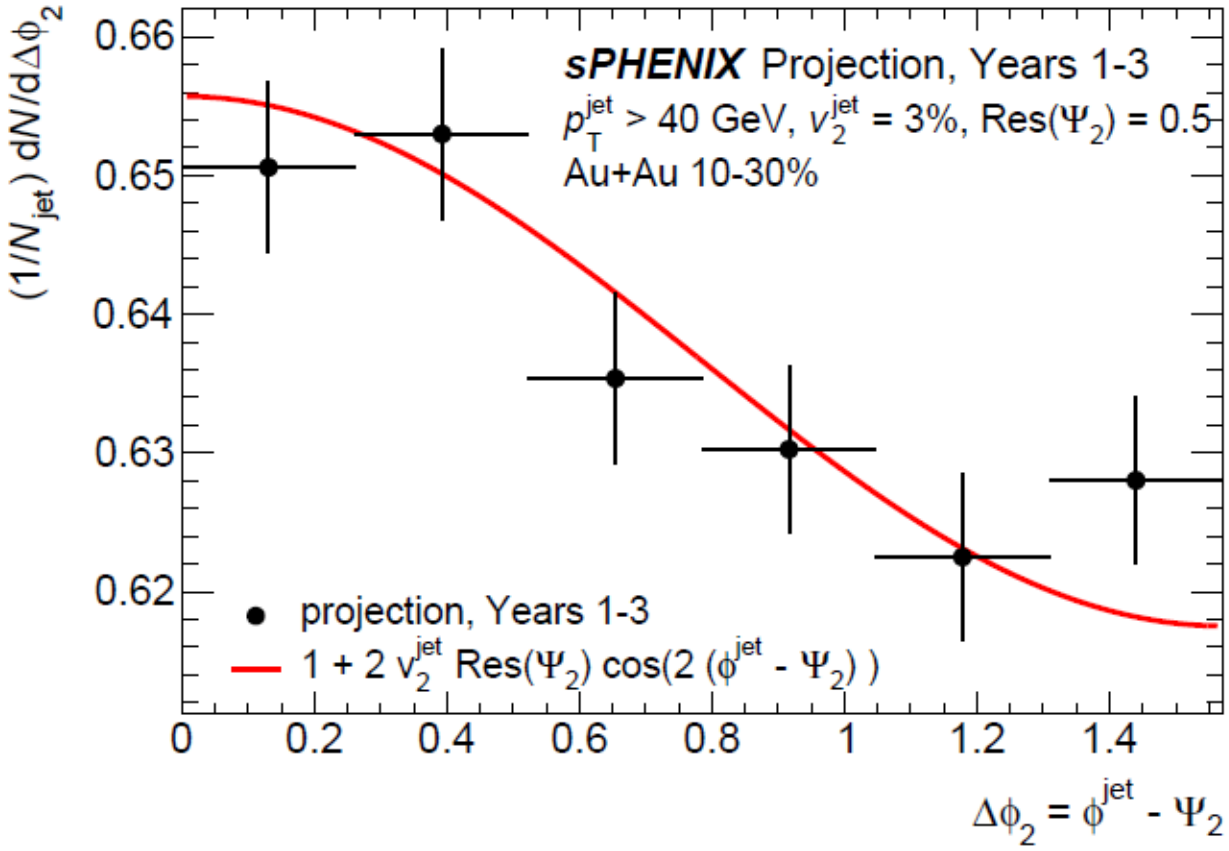


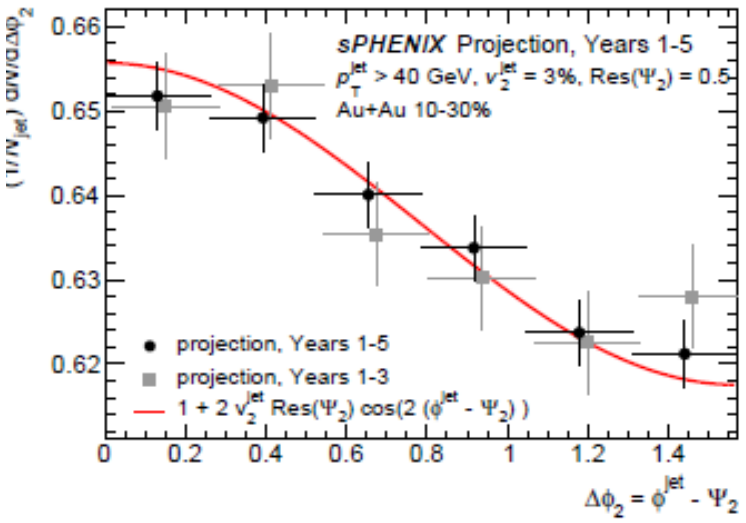
Eventually fully unfolded x_J distribution (for dominant p+p-like response)

Tomography of the QGP with Jets

- Jet anisotropy v_n at very high p_T : tomography of the overlap geometry
  - Can be especially important as system size pushed to smallest overlaps/ more peripheral collisions
  - Event plane angle resolution/wider forward acceptance very helpful: fast upgrade proposal being developed
- Statistics from post 2025 running helps here especially

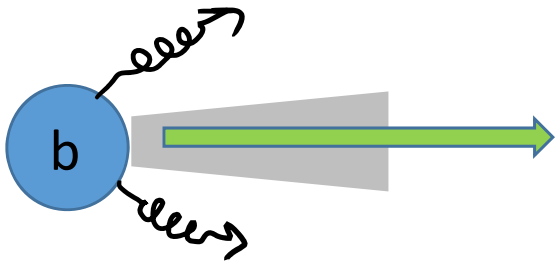


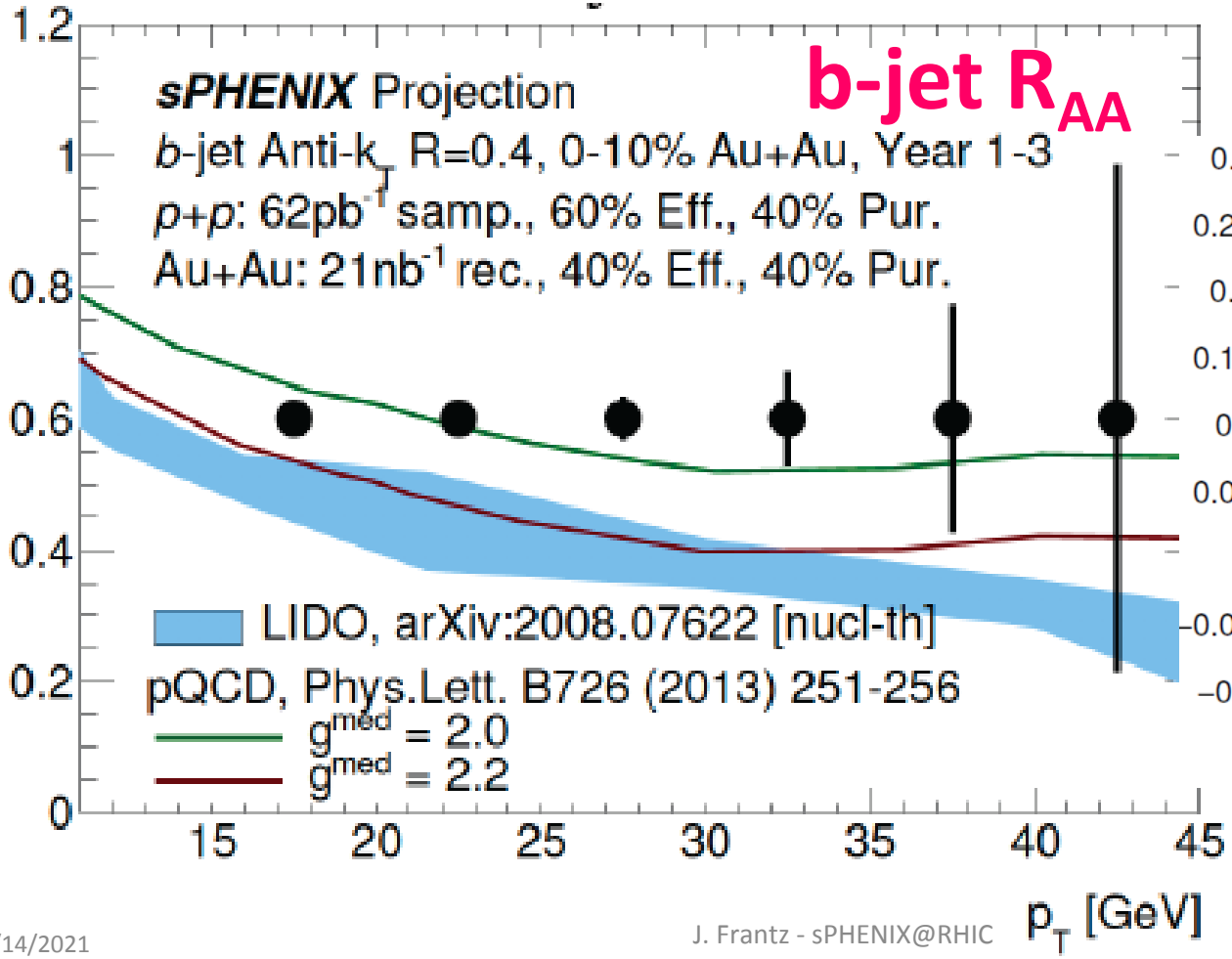


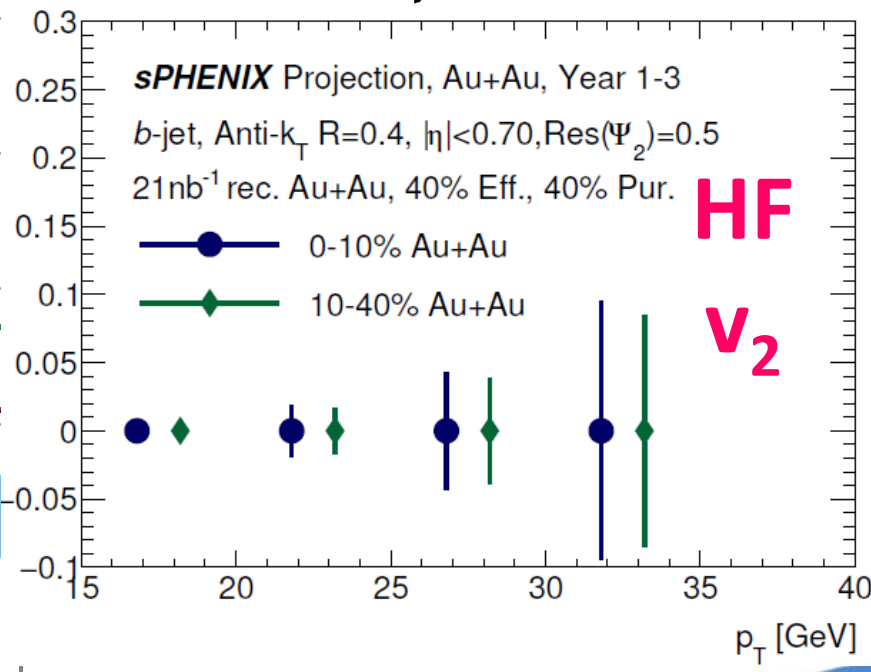


HF E_{loss} : b-Jets

- Heavy Flavor important complement to light parton jet observables
  - Slower HF quarks less radiative Eloss
- sPHENIX b-Jet tagging capabilities determined: strong measurements of both R_{AA} and v_2 (also for HF mesons!) comprehensively
- **See talk in this session by Hugo Pereira da Costa !**





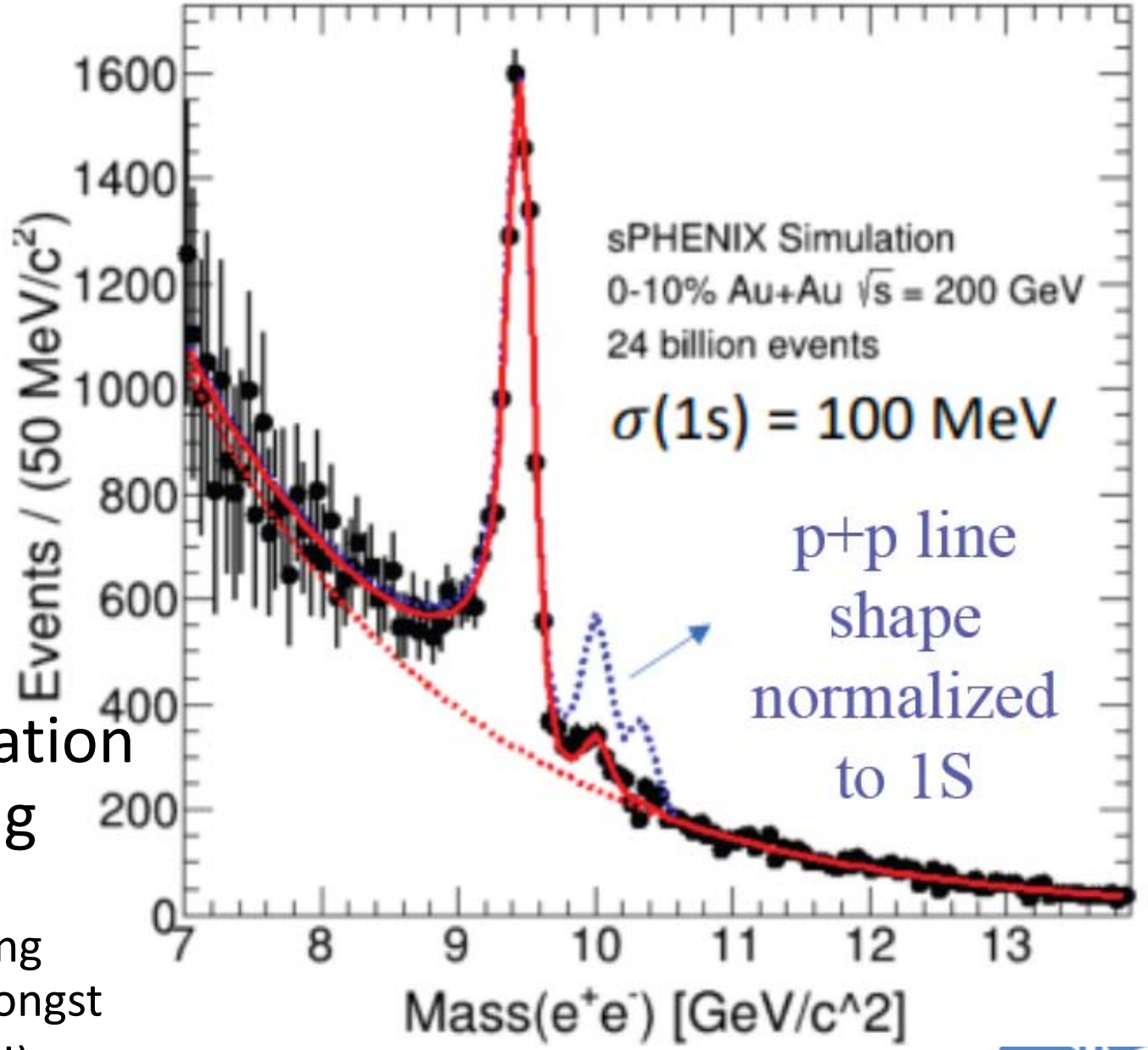


sPHENIX Tracking/Onia/Upsilon program

- Thermometer of the QGP:

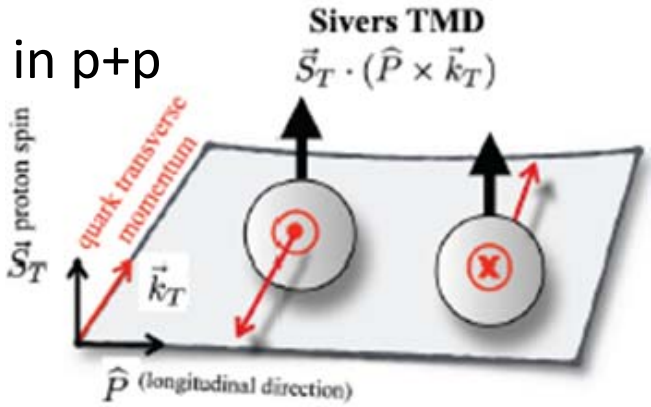
  HF Quarkonia melting

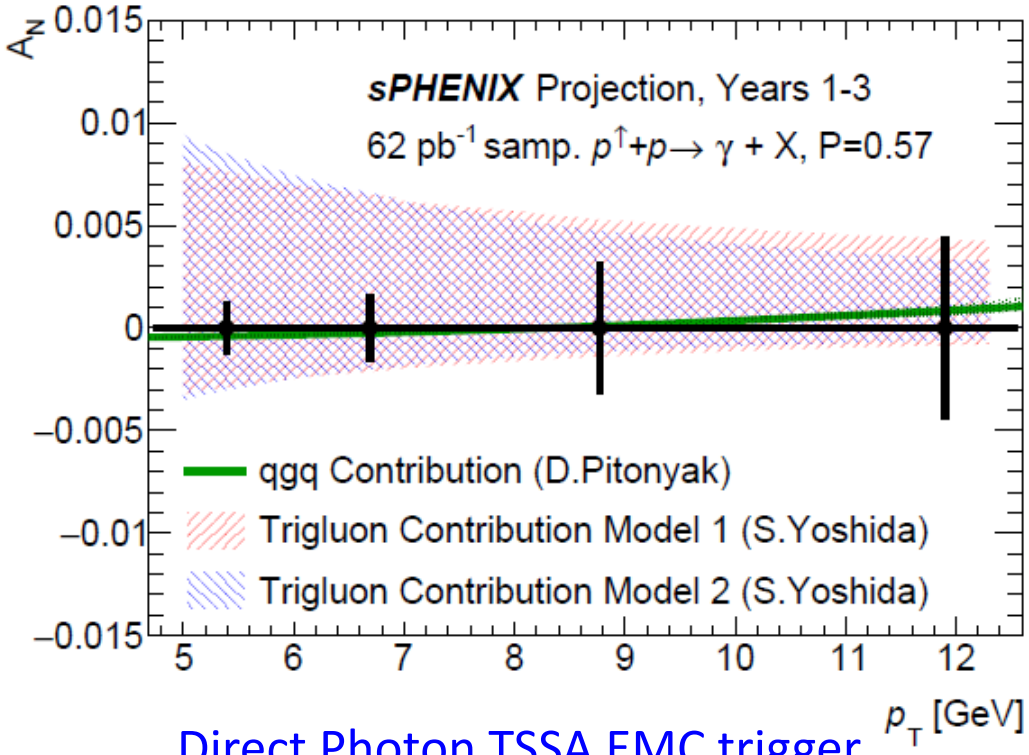
- First time at RHIC Clear separation of Υ states : excellent precise mass reso in central AuAu
- Precision 1S vs 2S
- Past ~yr: implementation of latest ACTS tracking
  - Orders of magnitude improvements in processing time over past ~year (amongst many other achievements!)



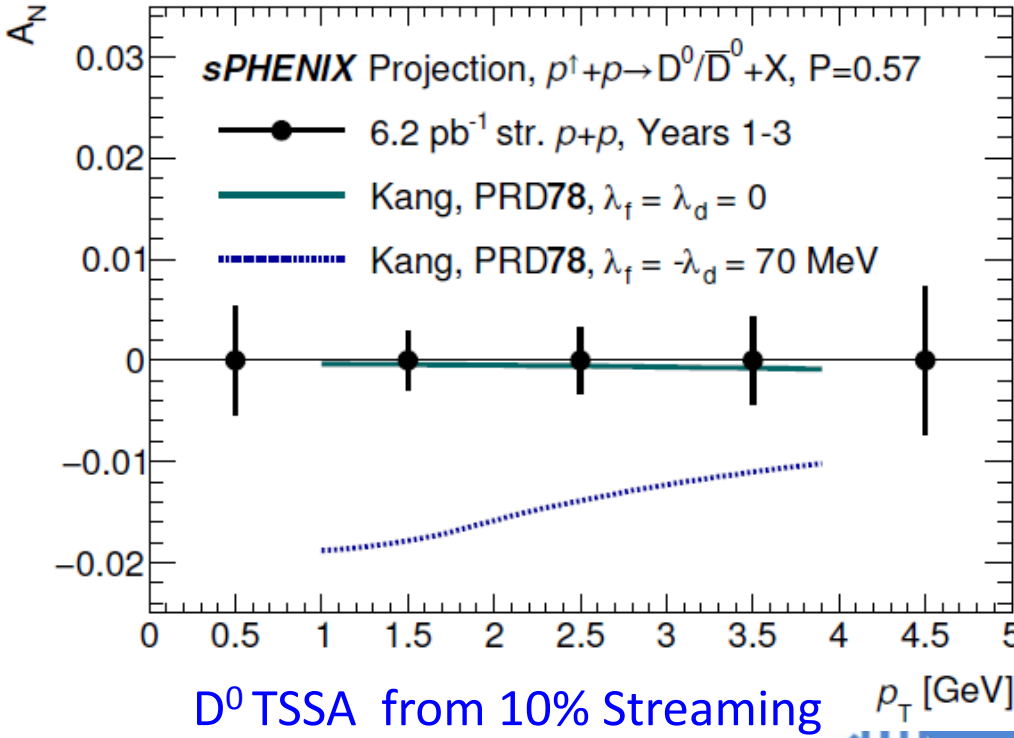
sPHENIX "Cold" QCD: Spin Physics

- Photon and HF TSSA sensitive to Gluon Sivers TMD
  - D^0 TSSA also nicely improved from streaming readout in p+p
- Other Sivers, Collins, TMD Effects from jets, hadron tagging/hadron fragmentation
- Intrinsic k_T : di-jet correlation





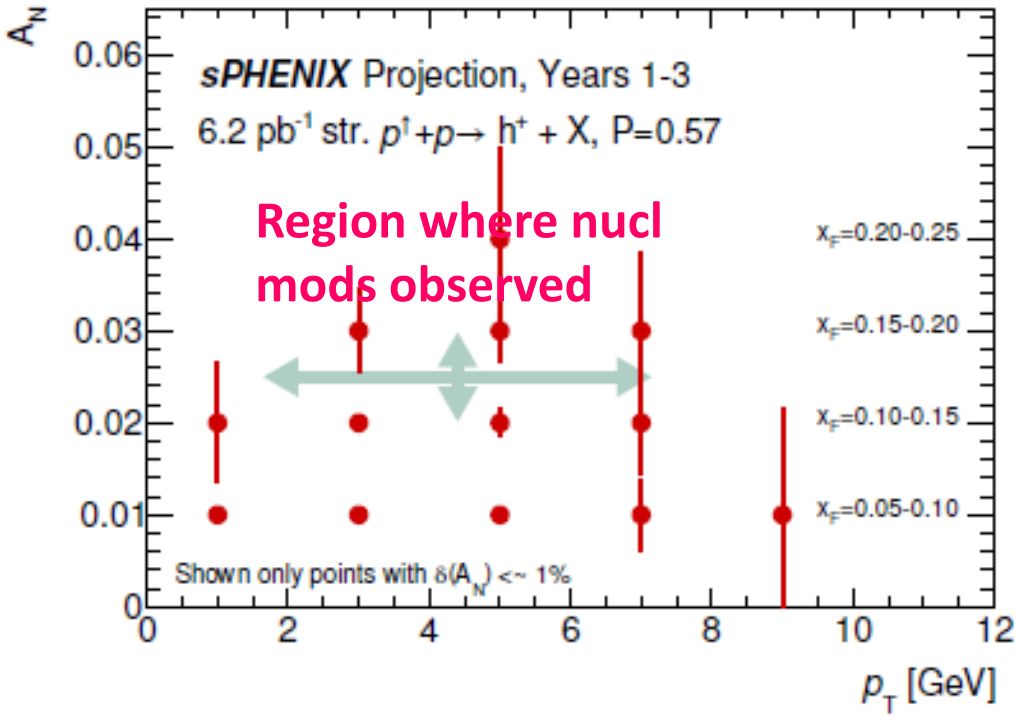
Direct Photon TSSA EMC trigger

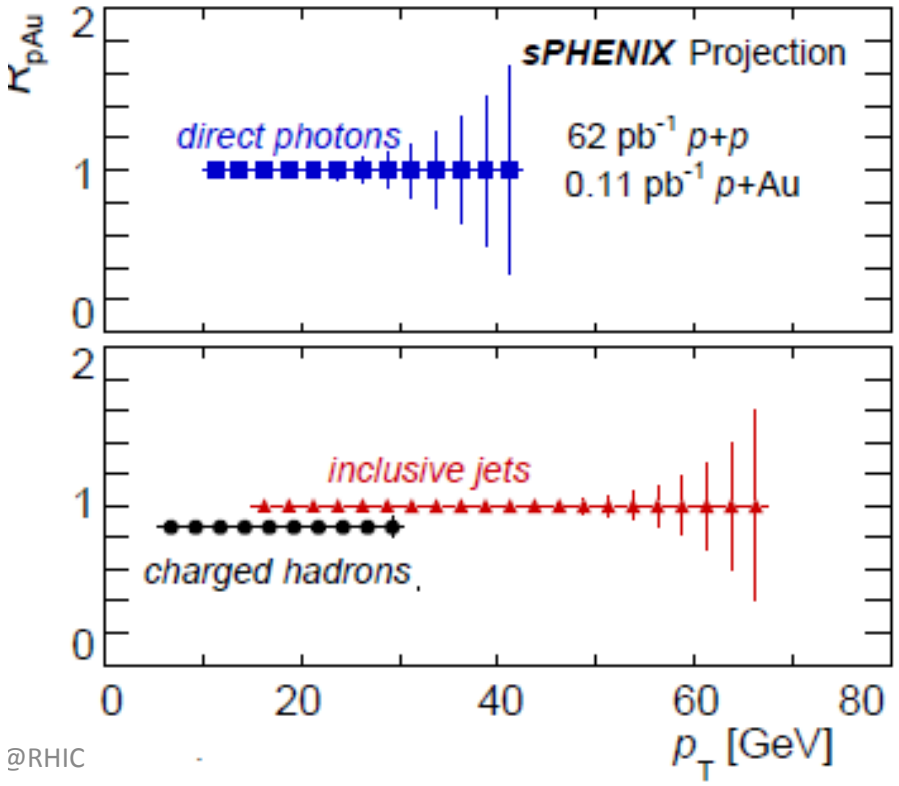


D^0 TSSA from 10% Streaming Readout

sPHENIX Cold QCD $p^{\uparrow}$ (!) +A Physics

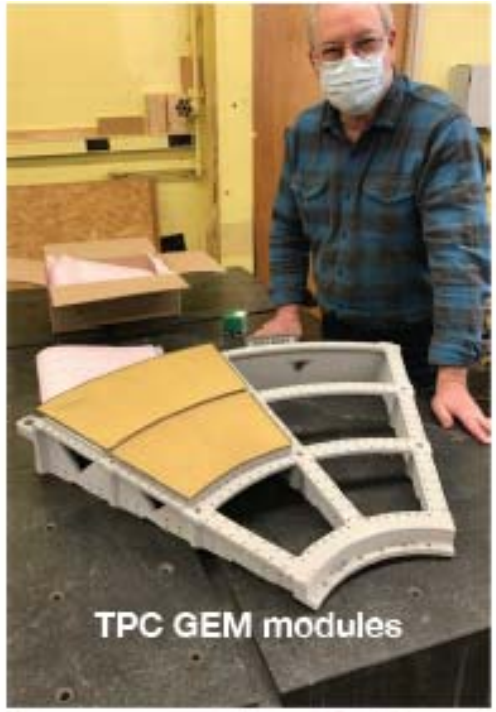
- TSSA also possible in $p^{\uparrow}$ + A!!! **Spin Effects in Nuclei!!!** ($p^{\uparrow}p$ h^{+} TSSA in plot below)
  - Rich physics $p^{\uparrow}$ A (see below) e.g. Color Glass Condensate connection to Odderon - though ~no forward detection in sPHENIX (parasitic EIC R&D?)
  - High stats Measurements of nuclear modification factor *R*pA: direct γ, inclusive jets, charged hadrons
- Disentangling nucleon / nucleus intrinsic k_T
- Many others: Hadronization studies and nuclear modification of hadronization: multidimensional (z, j_T, r) fragmentation measurements & fragmentation jT: dijet and photon-jet measurements Heavy quarkonium production mechanism: ϒ and J/ψ polarization measurements

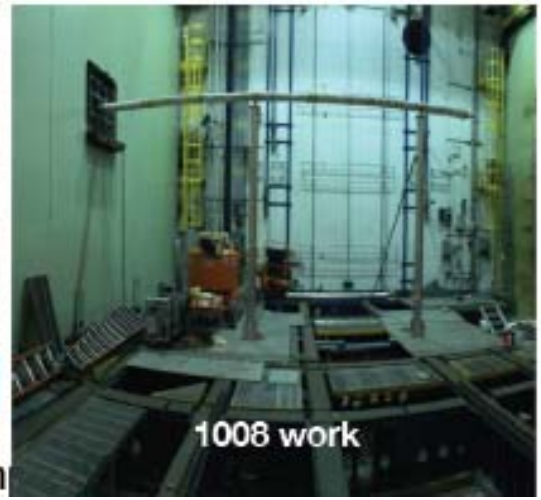




Construction

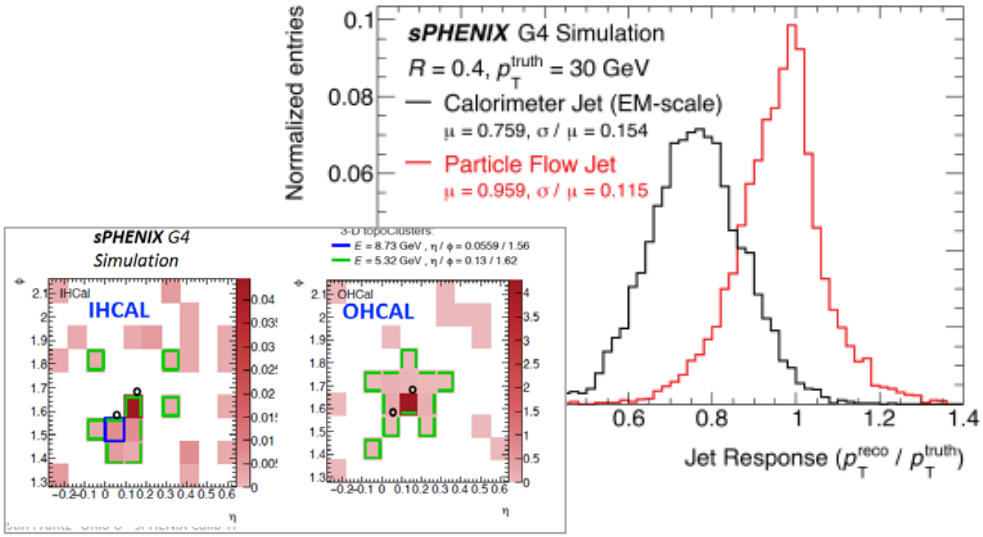
- Construction over ~half complete! 60.3% for majority MIE portion



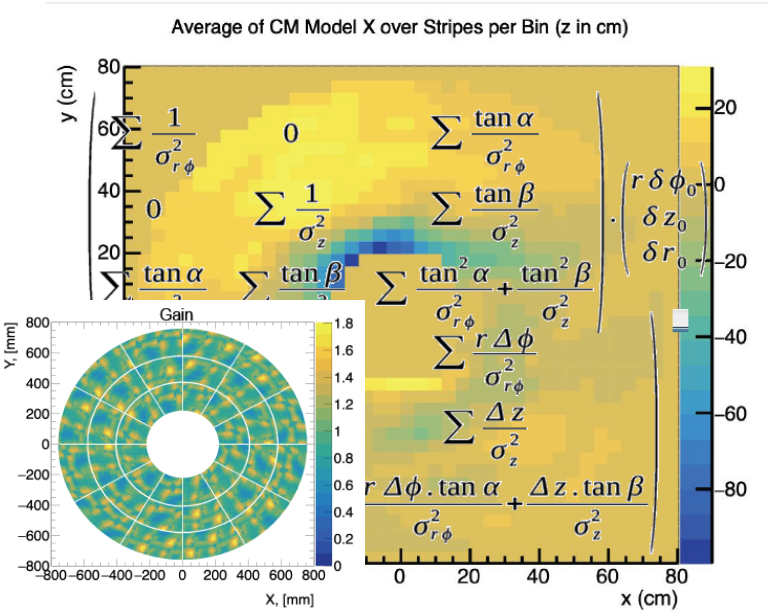


Computing and Software

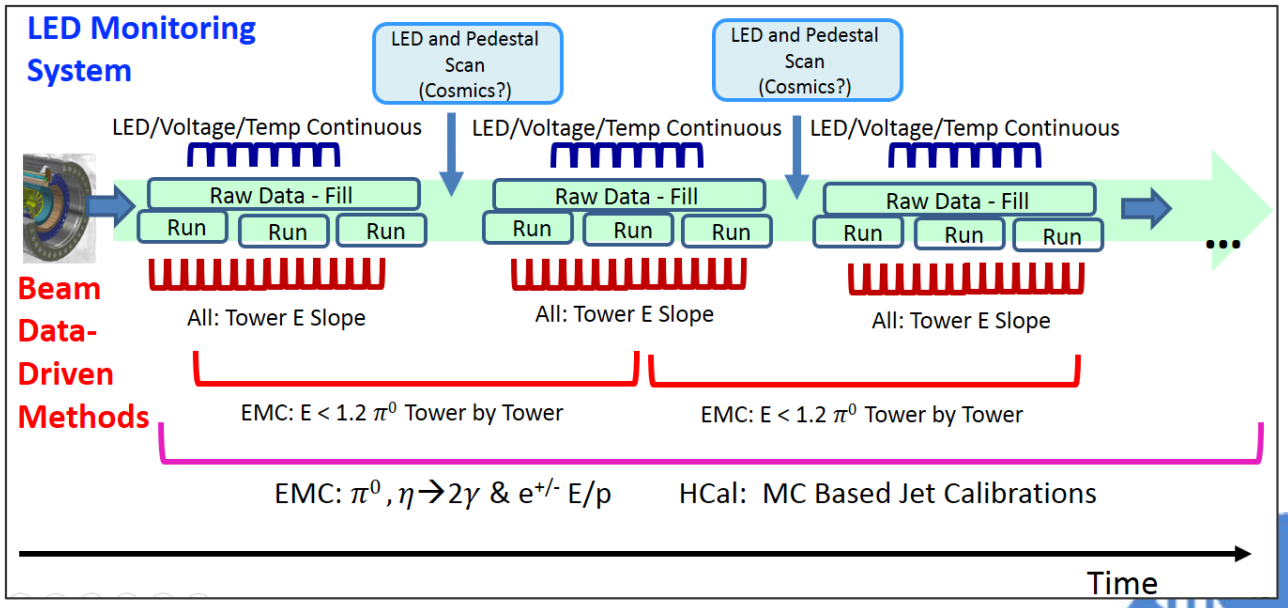
- Much other technically challenging and fun work ramping up in preparation for first data in ~1.5 years
  - A great time to join sPHENIX!



3D All-Calo Clustering/Jet Particle Flow



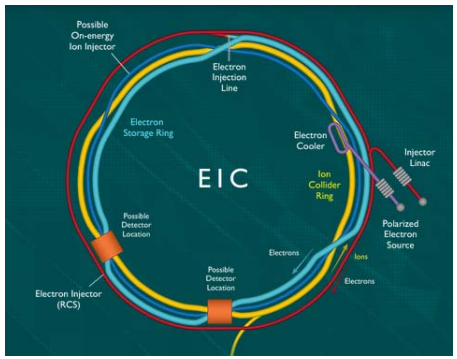
ACTS Tracking/ TPC Distortion Corrections



Calo Calibration Strategy/Infrastructure

sPHENIX@RHIC → ECCE@EIC

- Consideration of **potential reuse of parts of the sPHENIX detector** and **its infrastructure for possible EIC detector has been rapidly developing**
  - As recently as Sept'20, RHIC PAC PAC encourages the sPHENIX Collaboration to "**continue the exploration of the connection to the future EIC.**"
- Consortium Fall'20 incl. non-sPHENIX members from the Jlab/ep physics community
  - Editorial Board: Or Hen (MIT), Tanja Horn (CUA), John Lajoie (ISU)
- The EIC Collider dEtector (**ECCE**) consortium comprises 36 institutions assembled around the idea of building on the foundation of existing infrastructure available at RHIC IP8 and experimental equipment available there and elsewhere at JLab and RHIC.
  - **Nov '20: Expression of Interest** from the **EIC Project** →
    Planned submission of detector proposal Dec '21
- https://www.ecce-eic.org/
- Collaboration is meeting regularly now , WG/Conveners leading effort, 1st Software meeting recently



Conclusions

- **sPHENIX is new collaboration and detector in the RHIC IR 1008 based around a 1.5 T magnet, compact and uniform design, good acceptance for hardest parton scatterings, successfully employing several novel design features**

- sPHENIX is poised to make strong advances on the study of the QGP and other high energy nuclear physics in the last years of RHIC
  - Robust to EIC developments for three year run plan 2023-2025
  - Making full preparations for opportunistic running past 2025 if possible within EIC schedule

- sPHENIX construction and collaboration Development **on schedule !!!**
  - Pandemic delays have been mitigated: **due to extraordinary effort of many collaborators!!!**

- sPHENIX Magnet, Detectors, Expertise, Technical Breadth, and Infrastructure offer strong and cost-effective foundation for a 2nd EIC detector :
  - ECCE@ EIC Consortium/Collaboration https://www.ecce-eic.org/