sPHENIX Event Plane Detector and its flow capabilities

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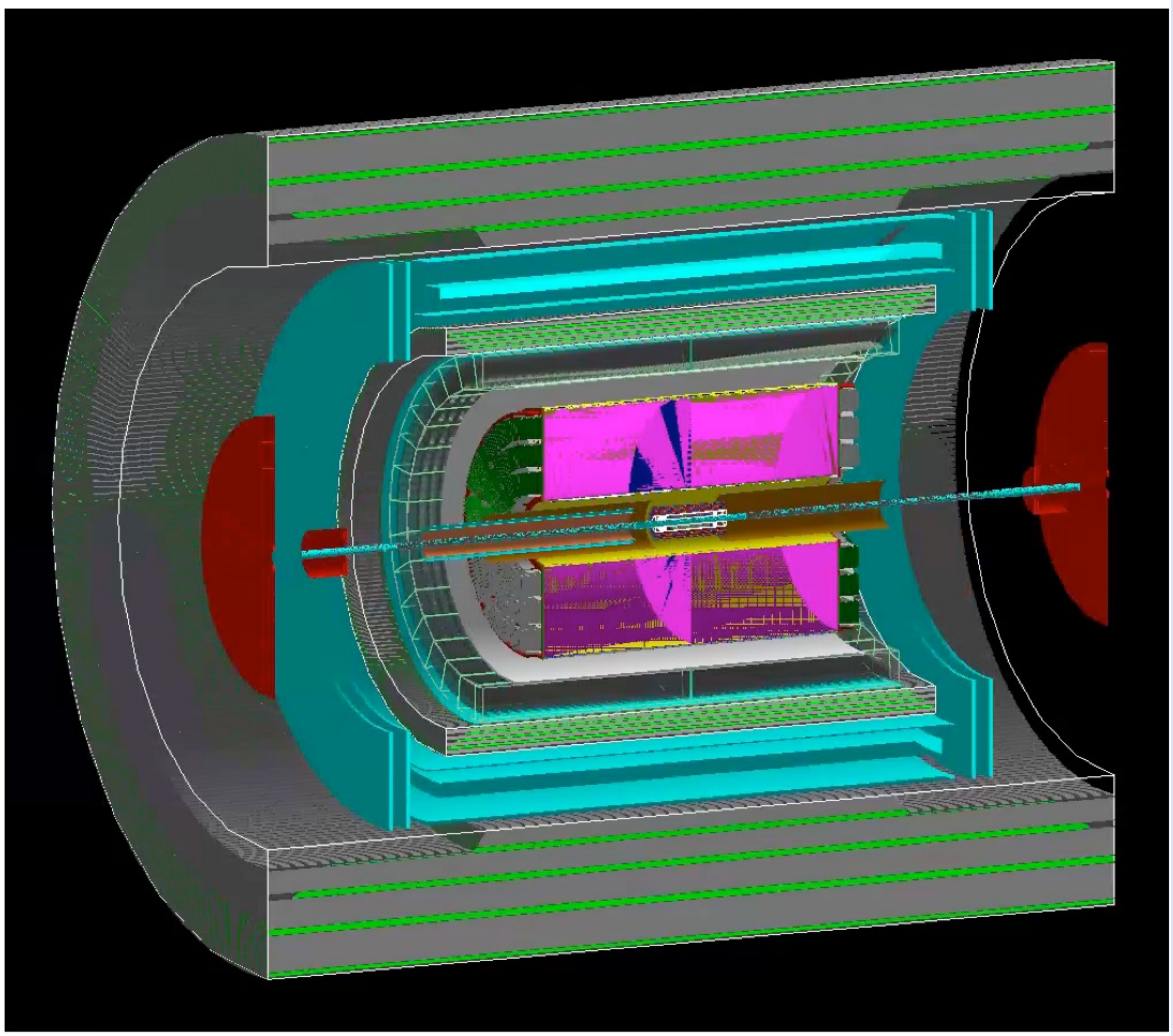
Lehigh University



sPHENIX

The Big Picture

We have gone from asking, “Does the QGP exist?” to “Precisely how does QCD lead to the emergent phenomena we observe?”

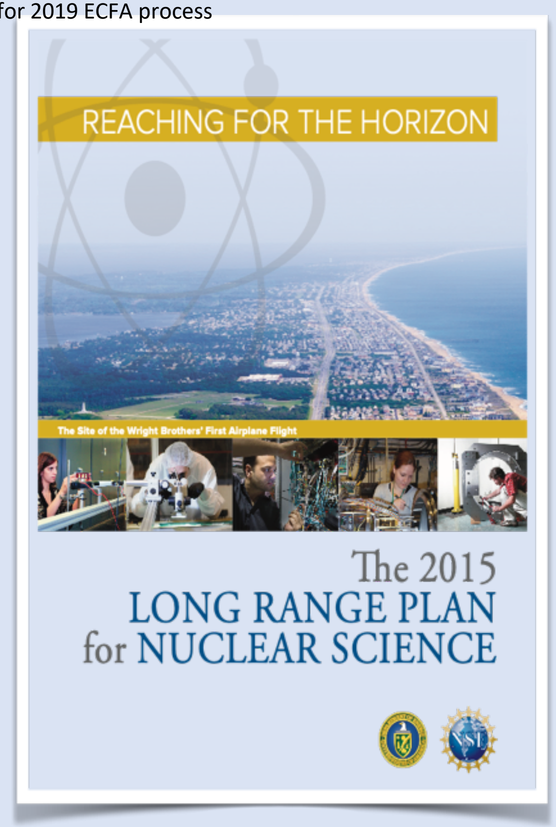
- **Qualitative** observations:
  - Jets are quenched
  - Medium is a nearly ideal fluid
  - Understanding the Event Geometry is necessary to understand the medium
- **Qualitative** observations → **quantitative** descriptions (qhat, η/S, σ, S, κ)

sPHENIX experiment will allow us to capitalize on RHIC and its major **upgrades** and answer fundamental questions about QCD

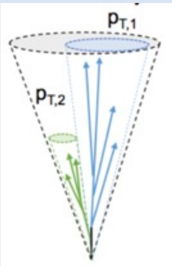
- How do quarks and gluons form a strongly coupled, nearly perfect liquid?
- What are the properties of the medium?
- What is the dependence of these properties on scale?

sPHENIX Science Mission

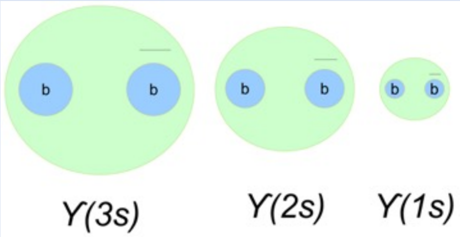
WG5 for 2019 ECFA process



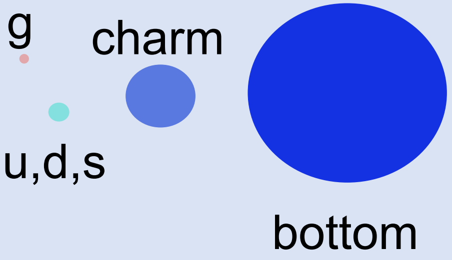
"Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of [RHIC and the LHC] is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX."



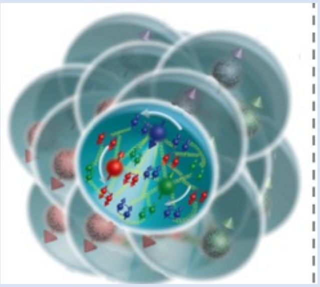
Jet structure
Vary momentum/angular scale of probe



Quarkonium spectroscopy
vary size of probe



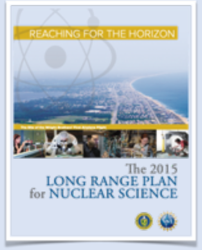
Parton energy loss
vary mass/momentum of probe



Cold QCD
vary temperature of QCD Matter

sPHENIX Timeline

2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023



sPHENIX science collaboration

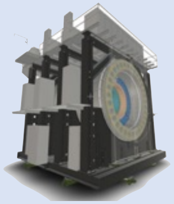
DOE CD-0 "Mission need" approval

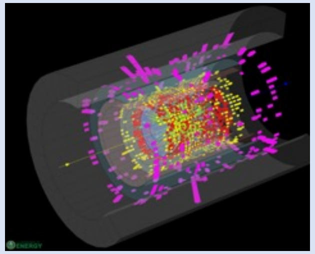
DOE CD-1/3A Cost, schedule, advance purchase approval

BNL PD-2/3 Final project design approval

We are here!!

Installation & commissioning





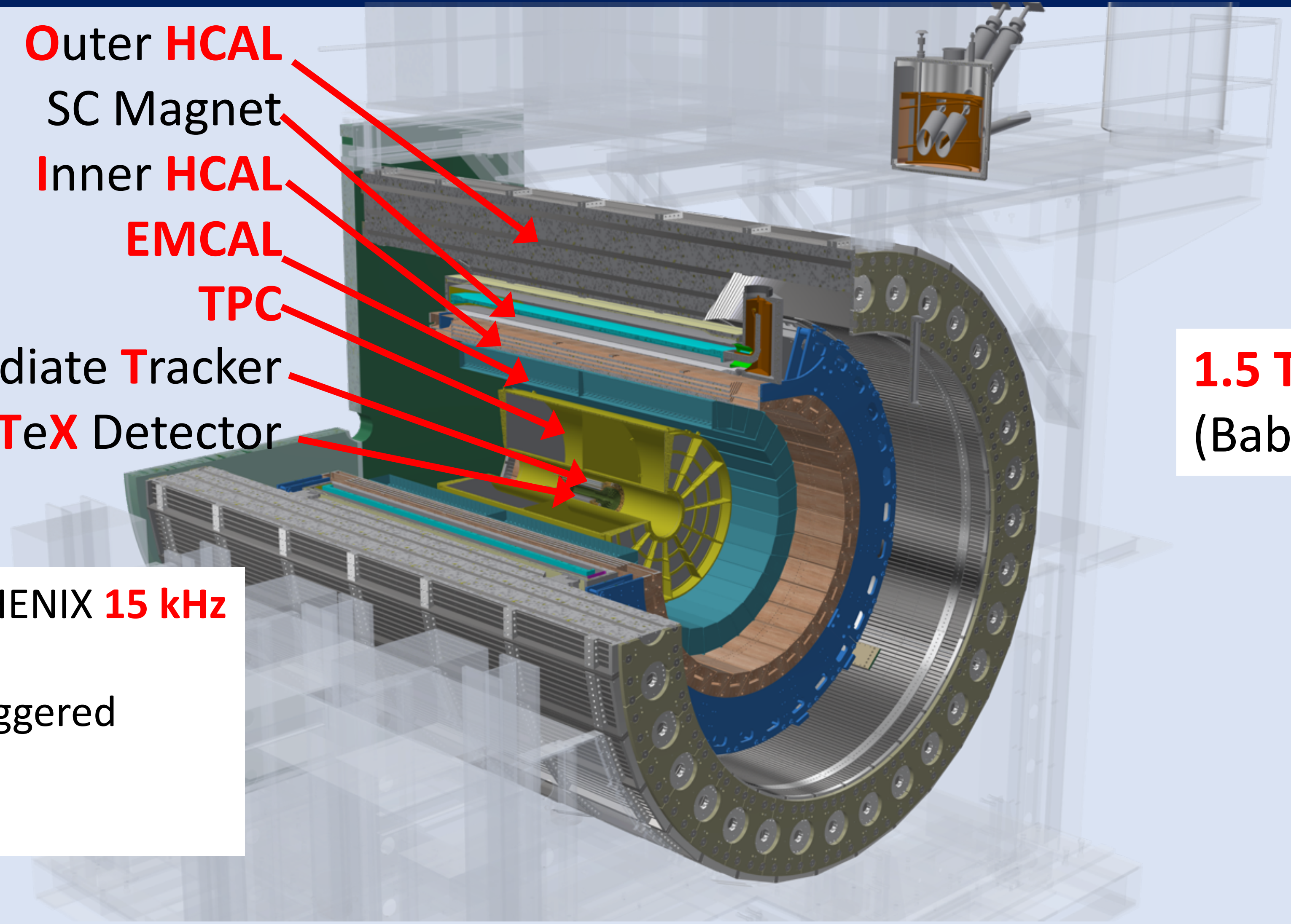
2023	2024	2025
Au+Au	p+p/p+Au	Au+Au

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}

145B (240B) MB Au+Au (5 yr plan)→
~1.5 orders of magnitude more Au+Au events than taken at RHIC to date

sPHENIX → data taking in early 2023

sPHENIX Design



1.5 Tesla B field (Babar Magnet)

All can be read out at the sPHENIX **15 kHz trigger rate**

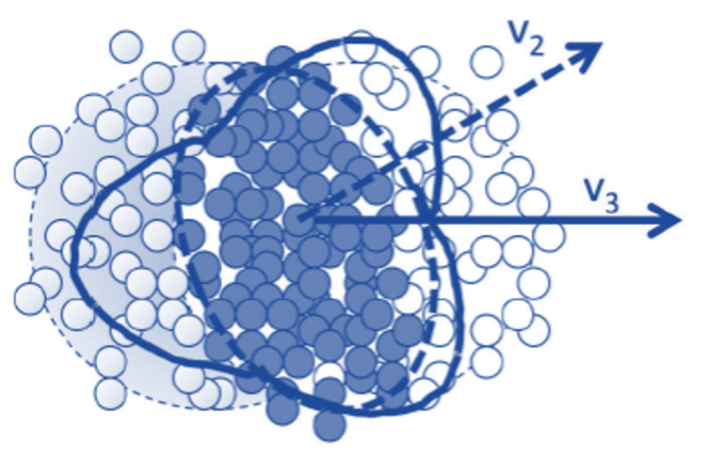
- DAQ hybrid streaming/triggered
- TPC/MVTX streaming
- Calorimeters triggered

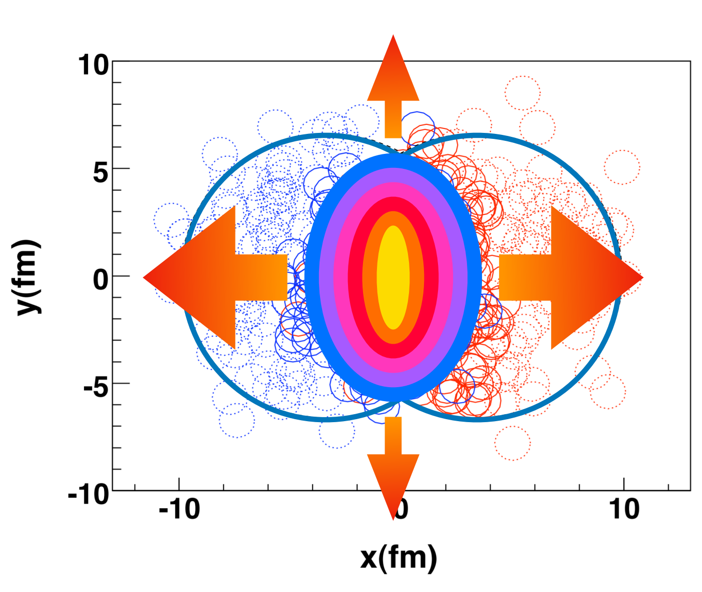
sPHENIX Construction Today

32 Outer HCal Sectors are fully installed as of Monday!!

First Two IHCal sectors on IHCal Barrel

Azimuthal Correlations





Azimuthal correlation structures arise from:

- Elliptic flow → anisotropic hydrodynamic expansion of the medium from an anisotropic initial state
- Non-flow → resonances, jets and …
- Event-by-Event Fluctuations

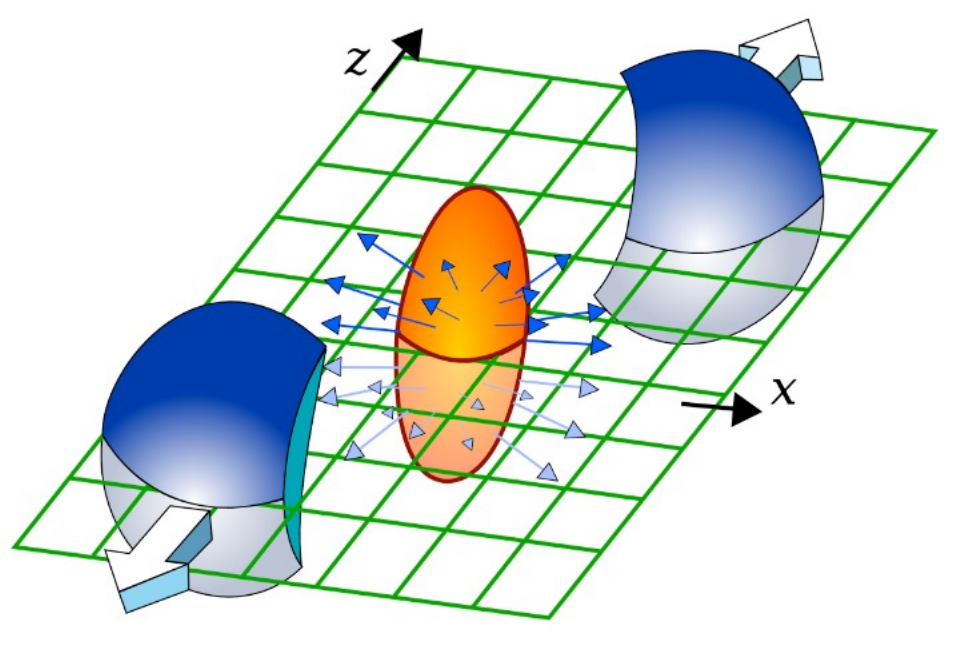
Observation of ~NCQ scaling for v_2 distributions in semi-central events was considered one of the “smoking guns” for QGP existence

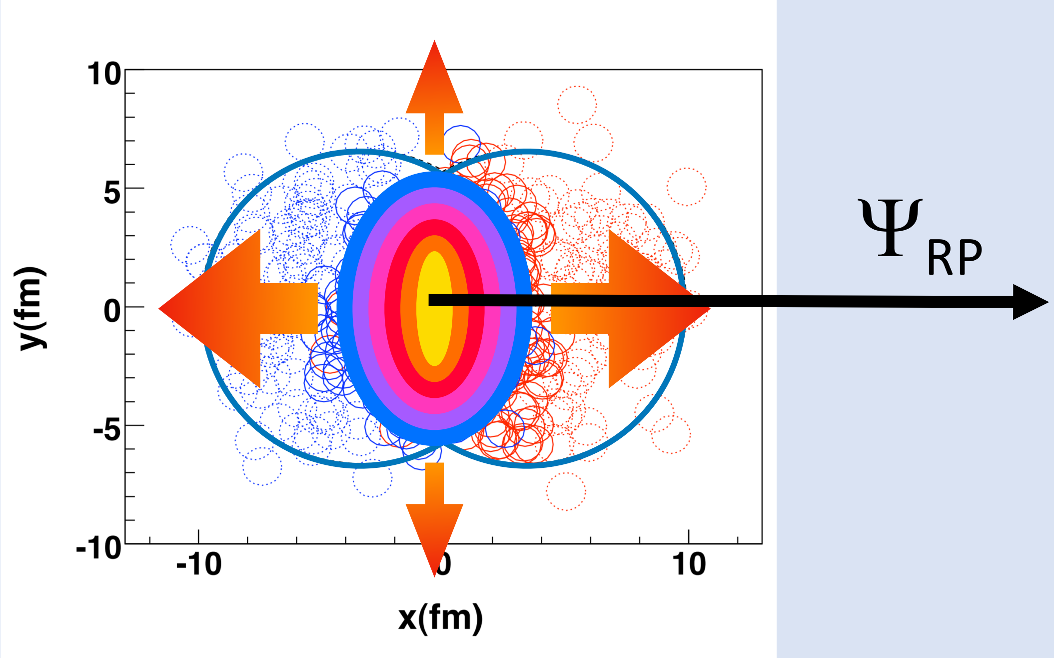
- Story is now considerably more complicated → Need to decrease statistical and systematic uncertainty!

Reminder - Measuring “Flow”

Measure symmetry plane Ψ_{RP} and correlate other measured particles

Reaction plane is not precisely the event plane





$$v_n = \langle \cos n(\phi - \Psi_{RP}) \rangle$$

$$\frac{dN}{d\varphi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos n\varphi$$

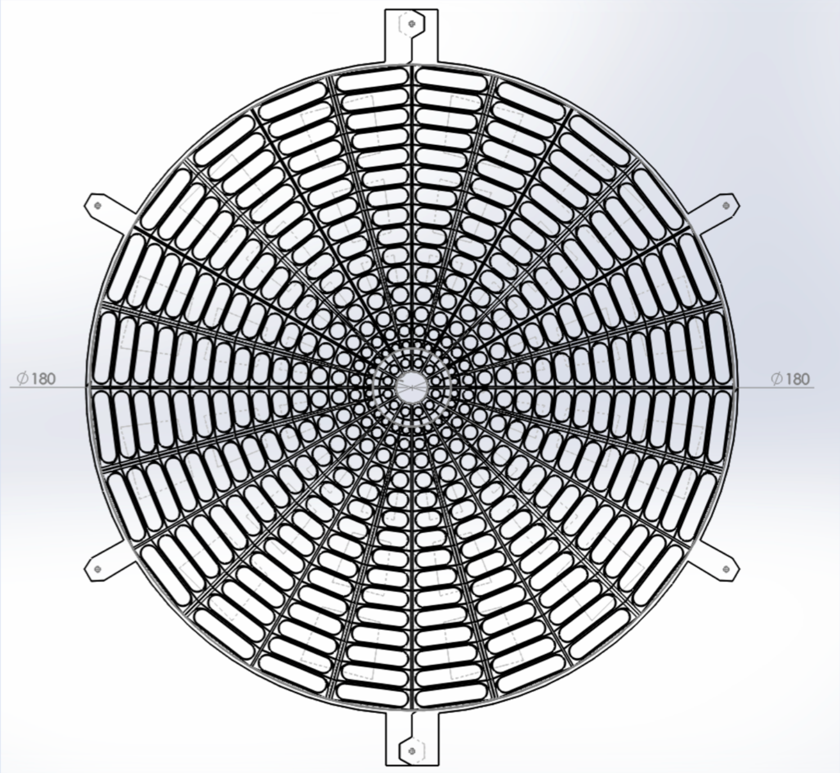
sPHENIX Event Plane Detector (sEPD)

It would be helpful for the sPHENIX science mission to be able to measure the **event plane** AND **centrality** outside of mid-rapidity.

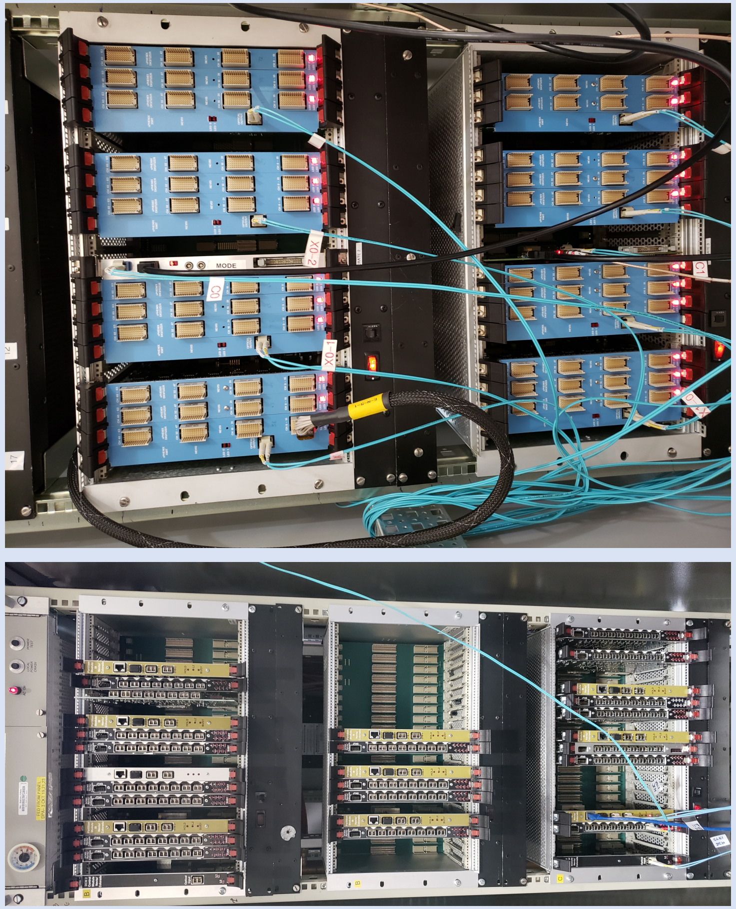
- Avoids auto-correlations with the presence of a hard process → Jets/HF
- Allows a more apples-to-apples comparison with data from LHC experiments → Complementarity
- Will also improve sPHENIX ←→STAR data comparisons

sEPD was not part of the MIE → NSF MRI to build an event plane detector similar to the STAR EPD

sEPD Philosophy

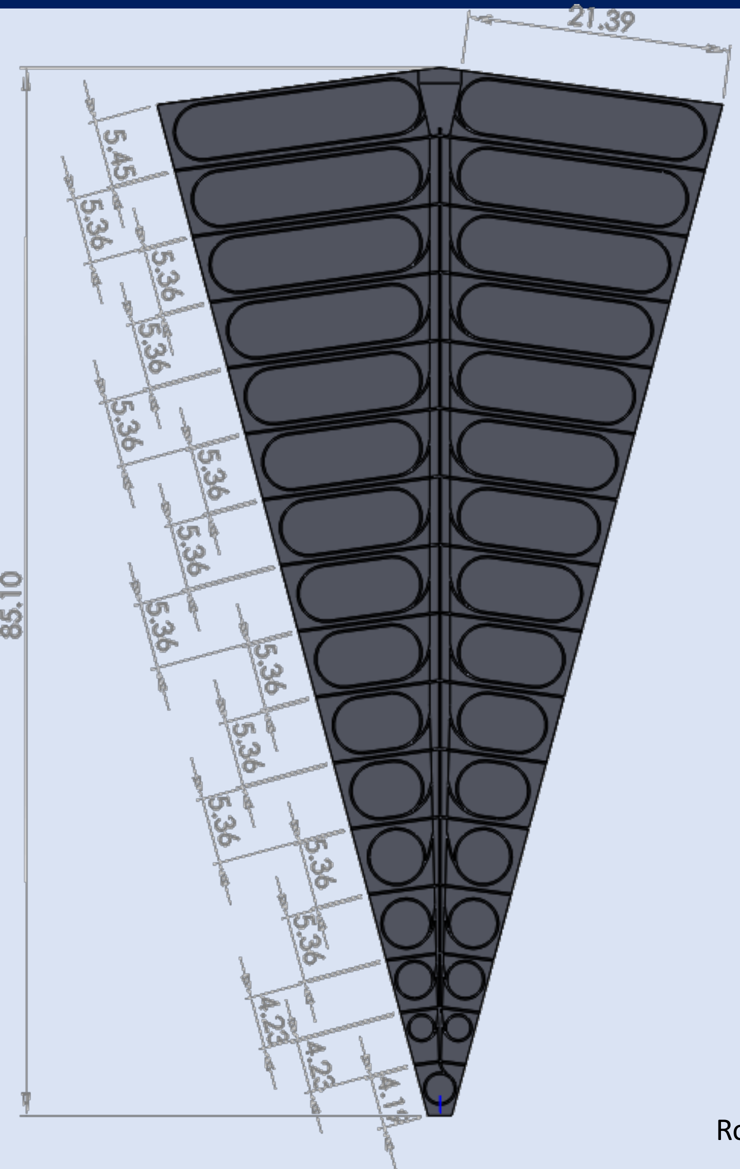


STAR scintillator design



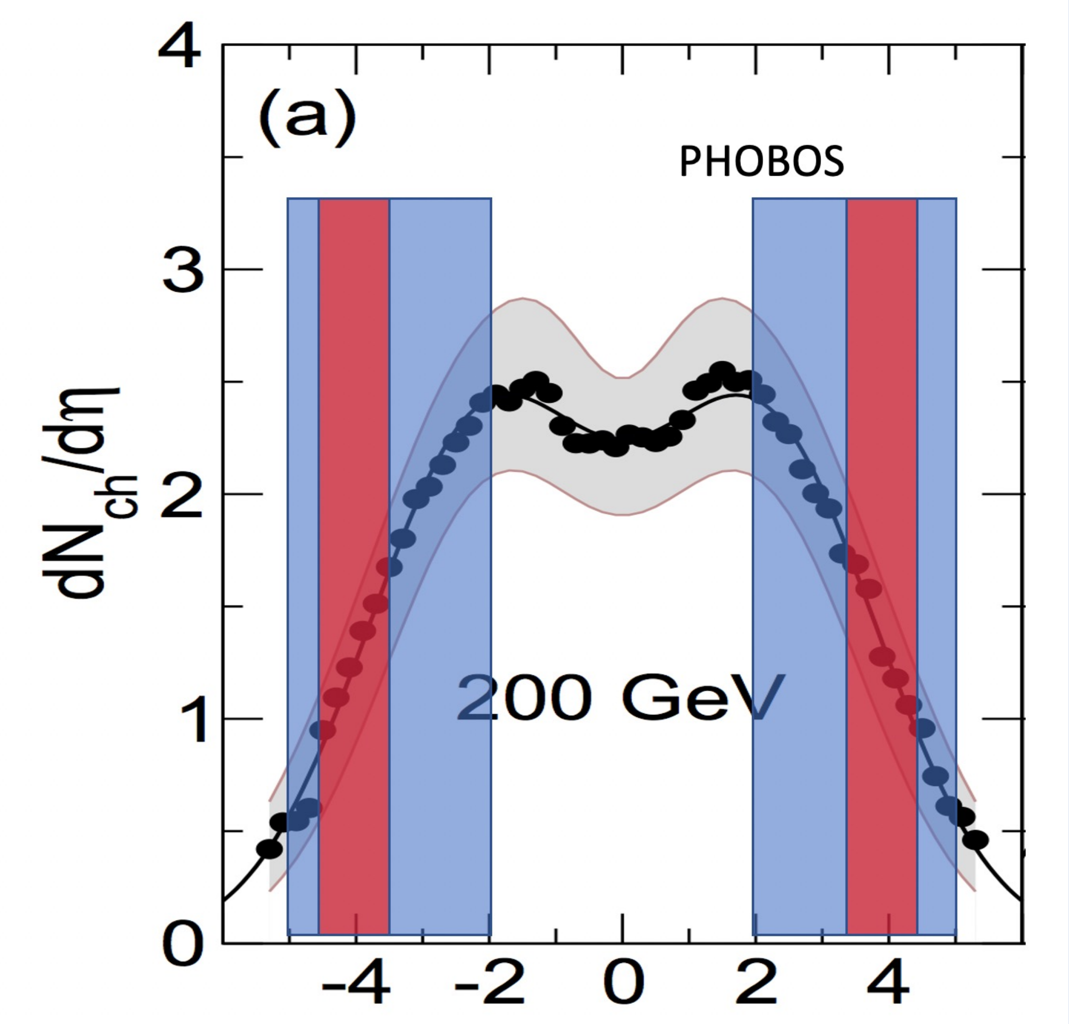
sPHENIX Electronics

Sector Design



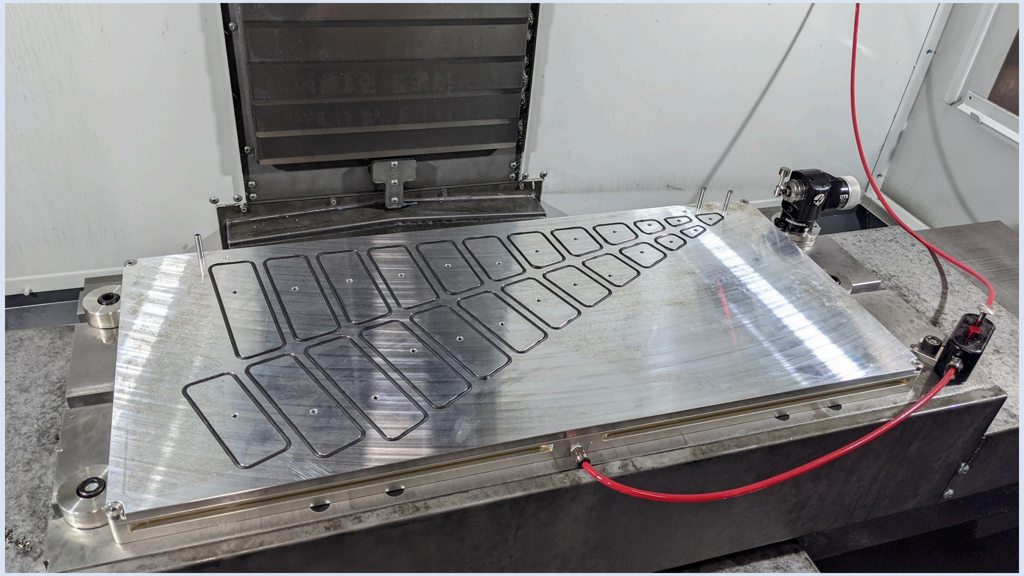
- 2 Wheels of 12 sectors with 31 optically-isolated tiles
  - **1.2-cm-thick scintillator**
- Total of 12x31x2=**744 channels**
- R_{outer} = 0.9 m, R_{inner} = 4.6 cm
- Planned location of ~z = 319 cm
  - **2.0 < |η|< 4.9**
  - STAR: 375 cm (2.1 < |η|< 5.1)
  - PHENIX BBC: (3.1 < |η|< 3.9)
  - sPHENIX MBD: 250 cm (3.51 < |η| < 4.61)
- Wavelength shifting fibers (3x loops) glued into tiles
- Machined out of a single piece of scintillator

Forward Particle Distributions



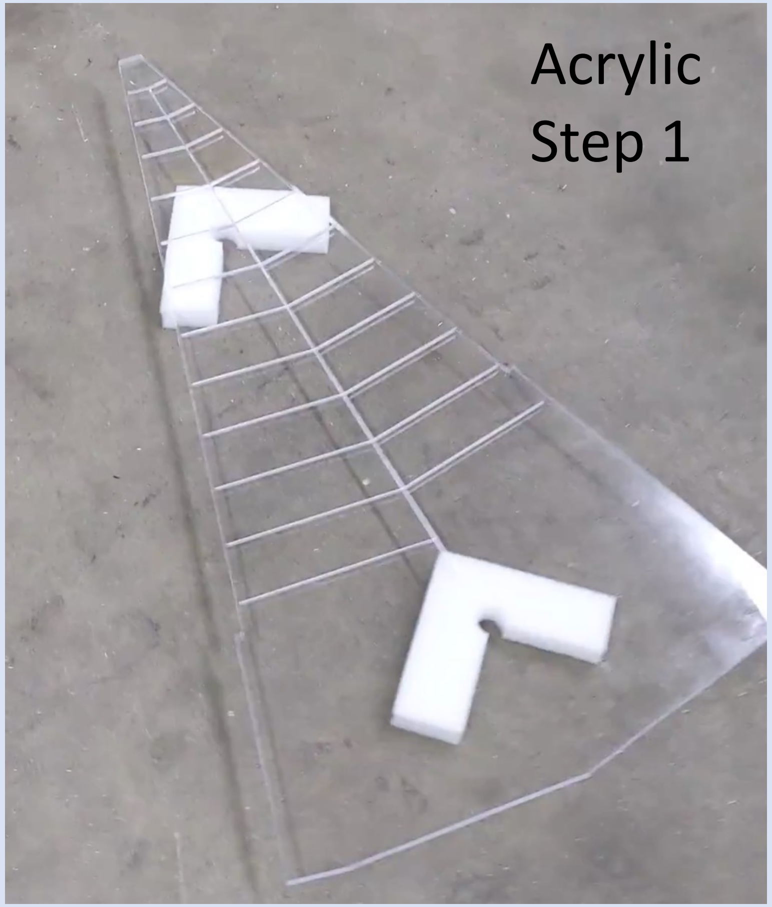
- sEPD 2.0 < |η|< 4.9
- MBD: 3.51 < |η| < 4.61
- Large acceptance with azimuthal symmetry with h gap from mid-rapidity is very useful for many analyses
  - Especially important for small systems

sEPD CNC Machining



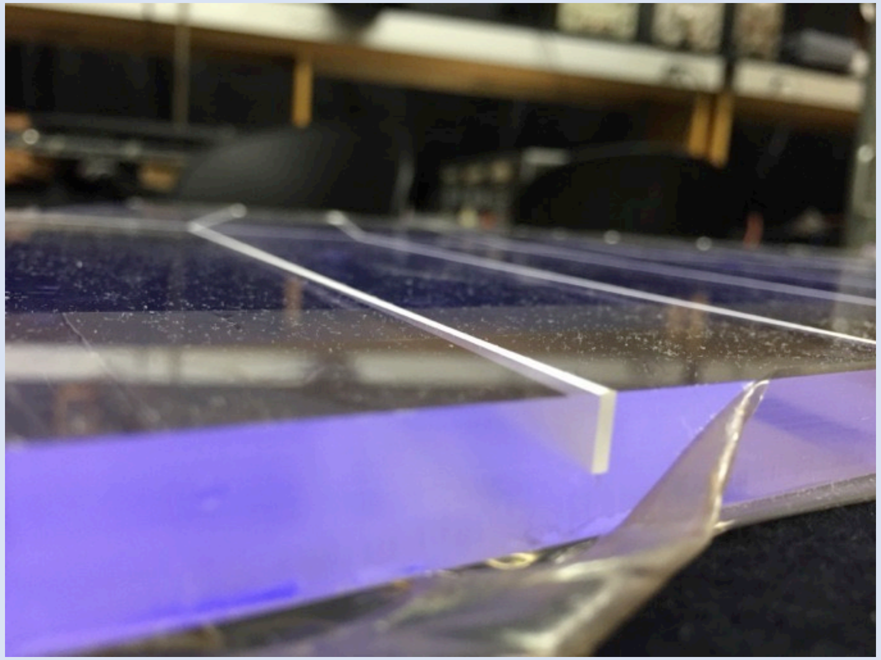
Vacuum plate to hold sector for first machining → Improvement over clamps used for STAR EPD

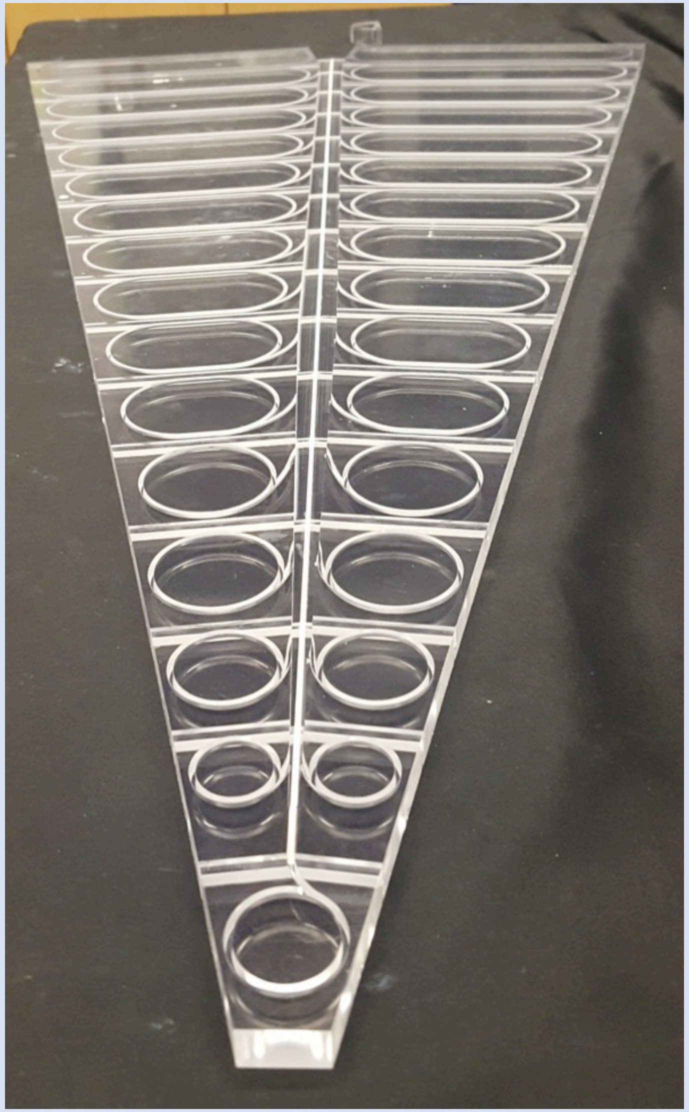
- Smaller CNC Machine → Multistep Process



A lot of coolant is required to prevent microcracking

Isolation Grooves



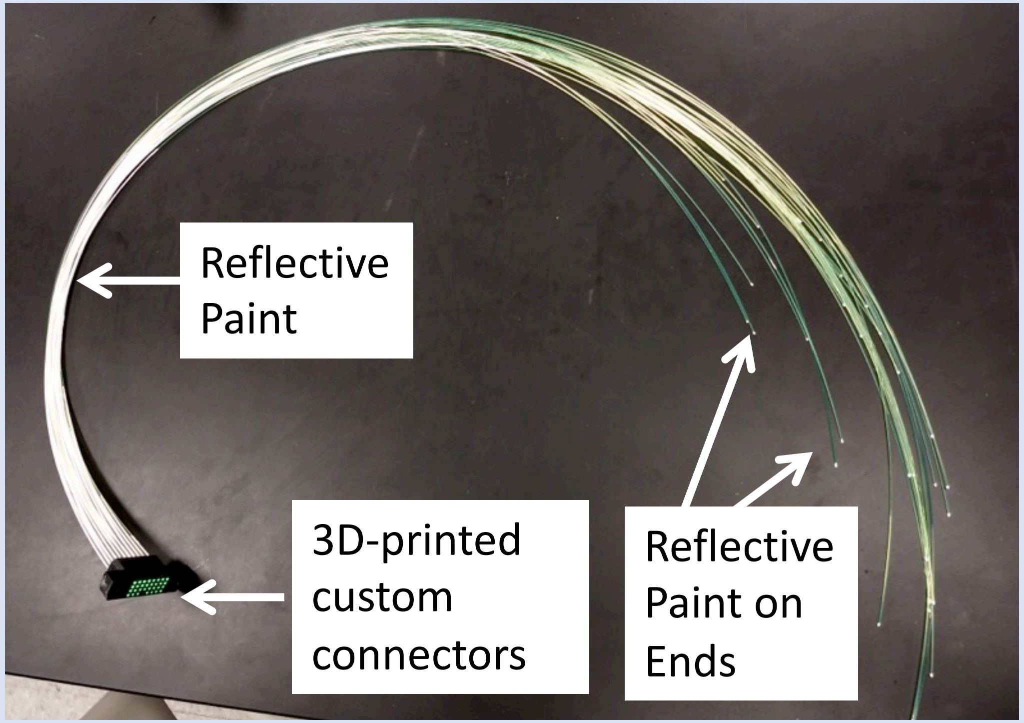


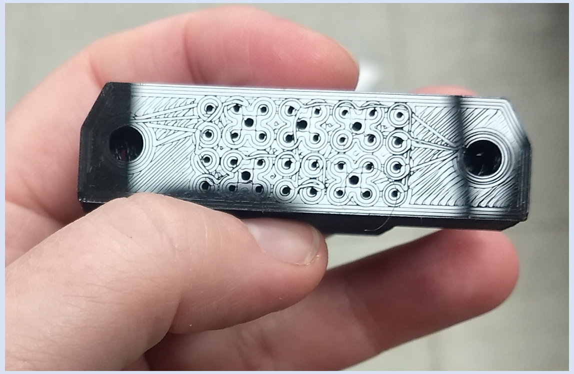
Mill “half-way” and fill groves with TiO_2 + epoxy mixture (reflective epoxy)

- **Optical isolation!**

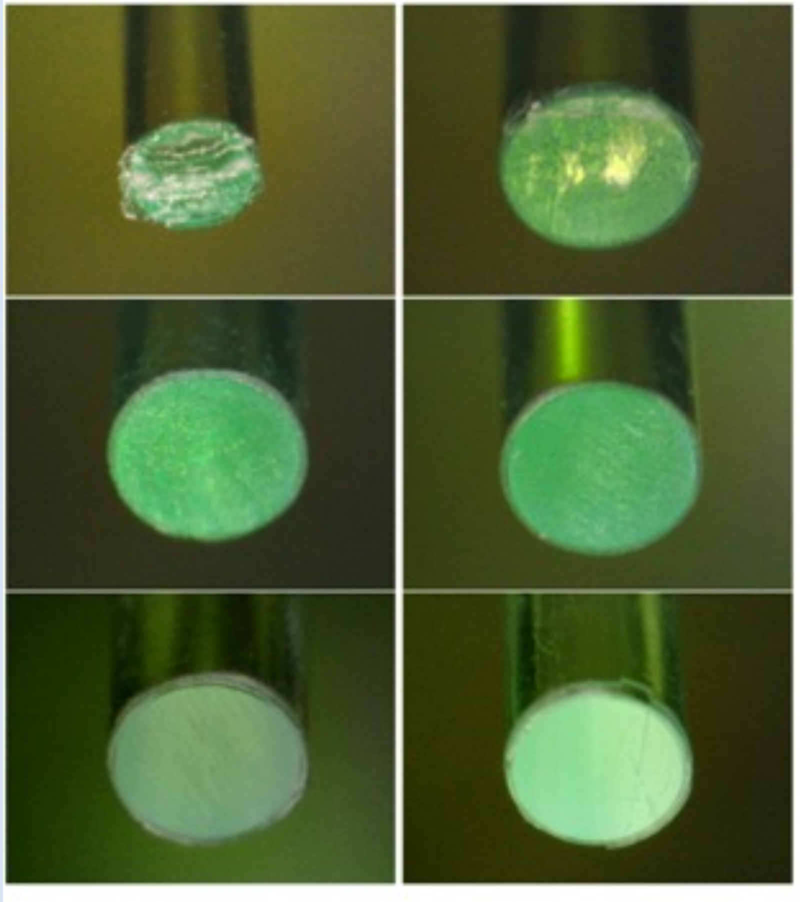
Flip over and finish milling the groves + Fiber channels

WLS Fiber Preperation





Connectors polished prior to gluing, inserts for panel screws

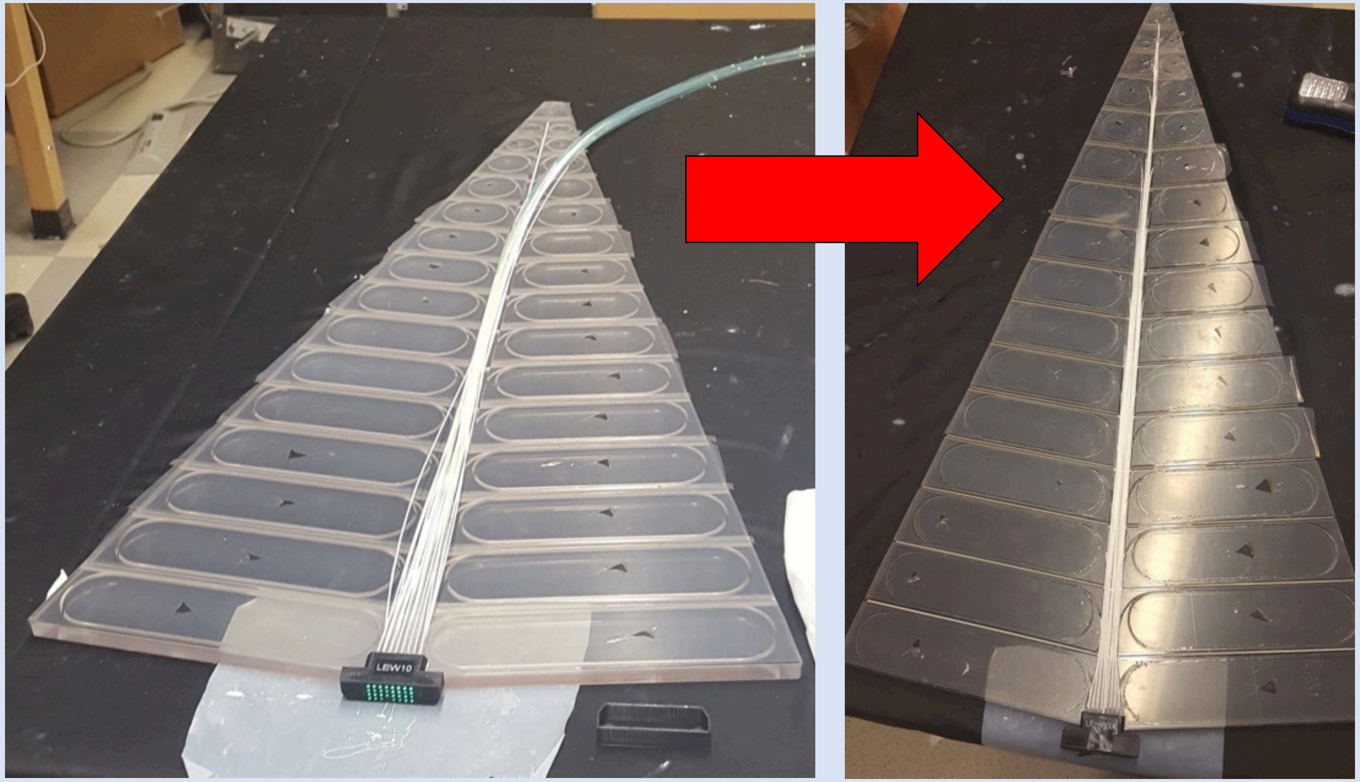


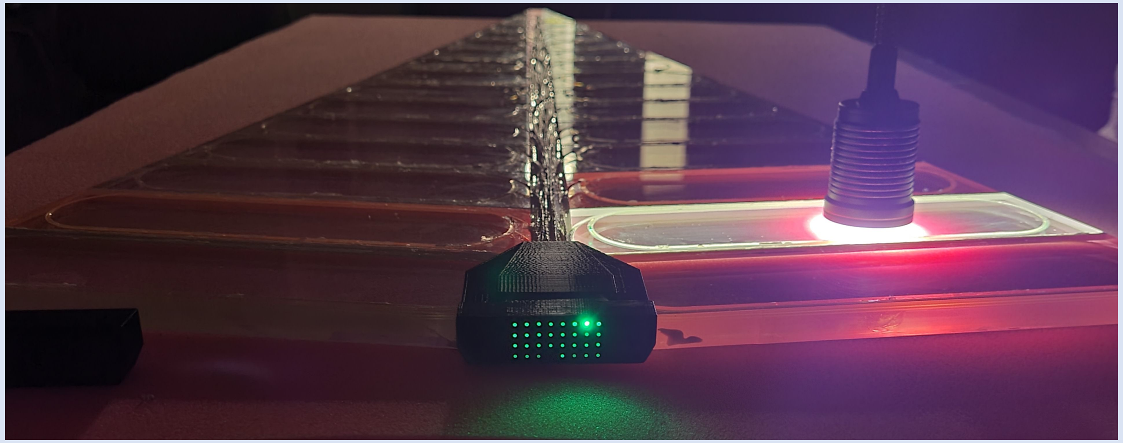
Reflective paint for “Central Channel”

- **Decreases cross-talk**

Fiber ends painted→ Increases light yield by ~30-50%

sEPD Sector Construction





Optical Isolation is important! Sectors will be checked after construction

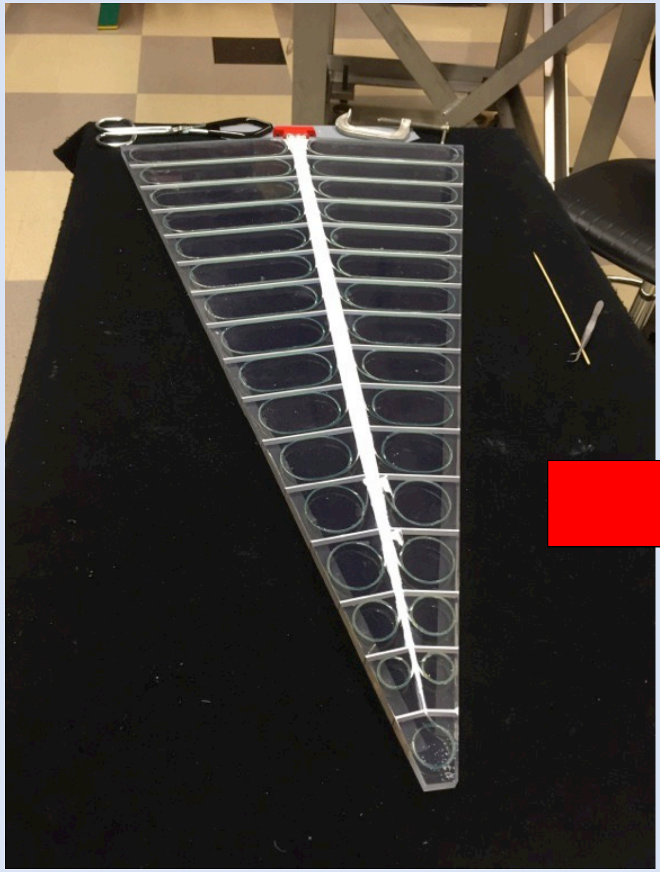
- Connector glued into place (reflective epoxy), then fibers (optical epoxy)
- Central channel and front grooves filled with reflective epoxy
- Tape removed and scintillator polished

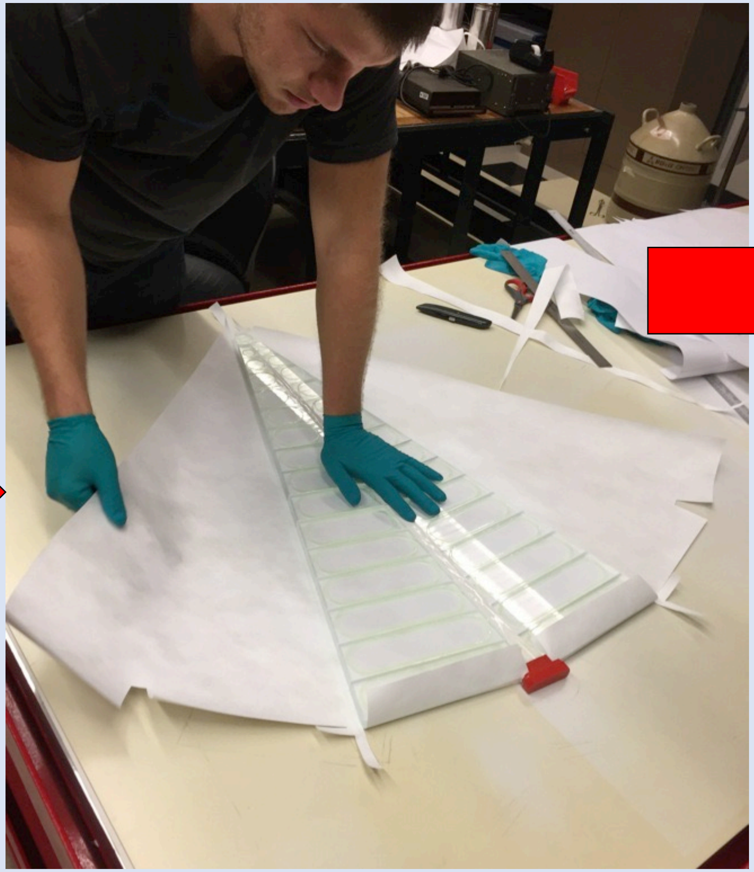
sEPD Sector Construction

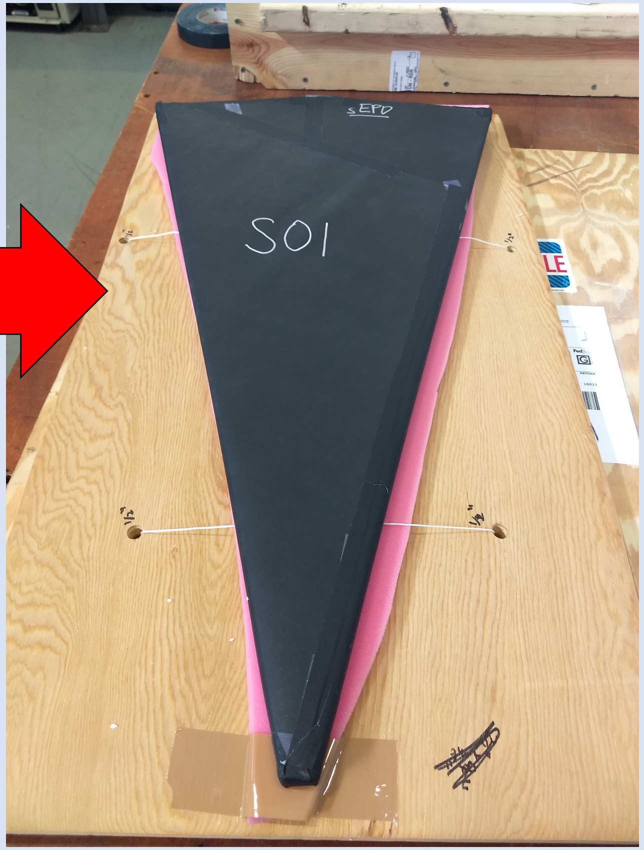
- Connector glued into place (reflective epoxy), then fibers (optical epoxy)
- Central channel and front grooves filled with reflective epoxy
- Tape removed and scintillator polished

Sector Wrapping

sPHENIX

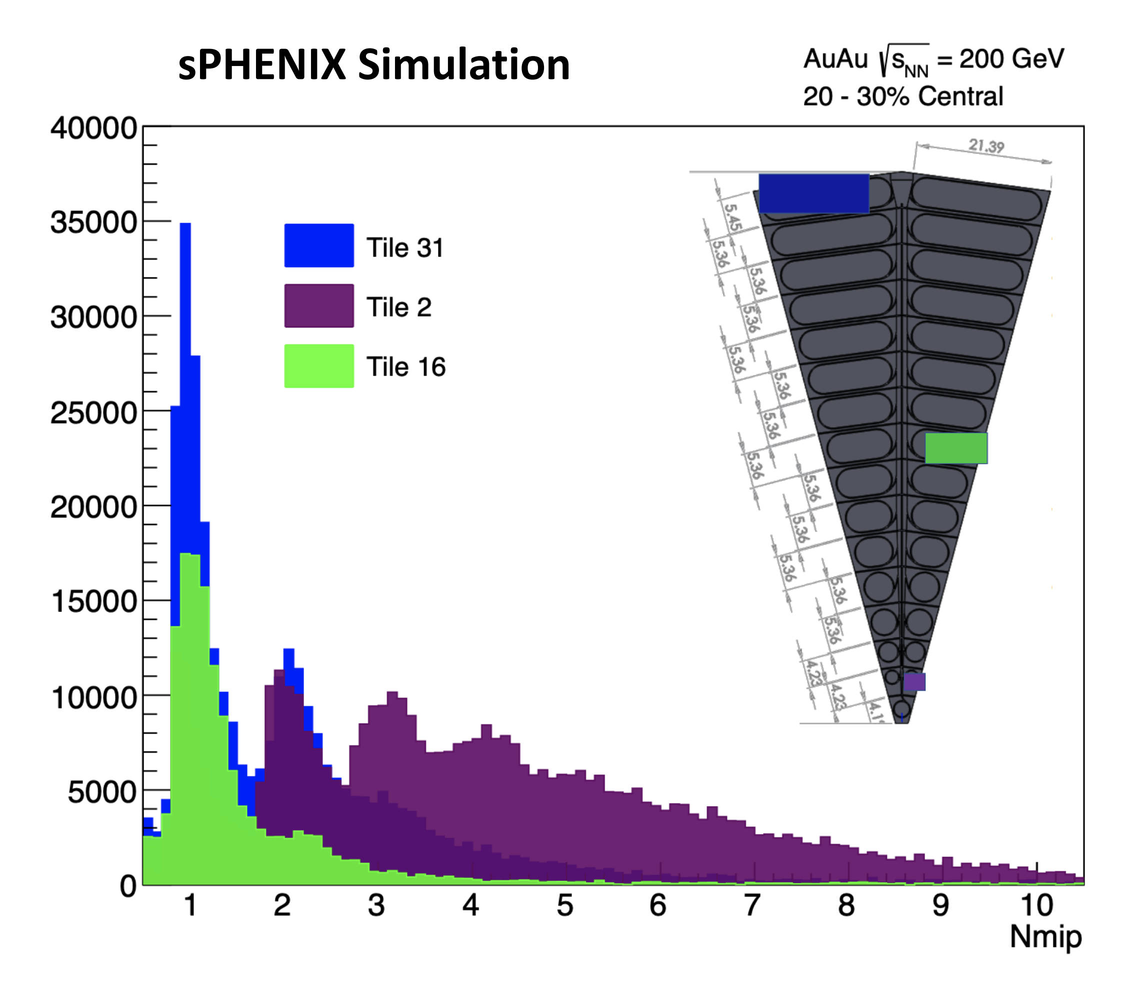






One layer of Tyvek (for reflectivity) & 2 layers of thick black paper (for light tightness)

Simulation Scintillator Performance



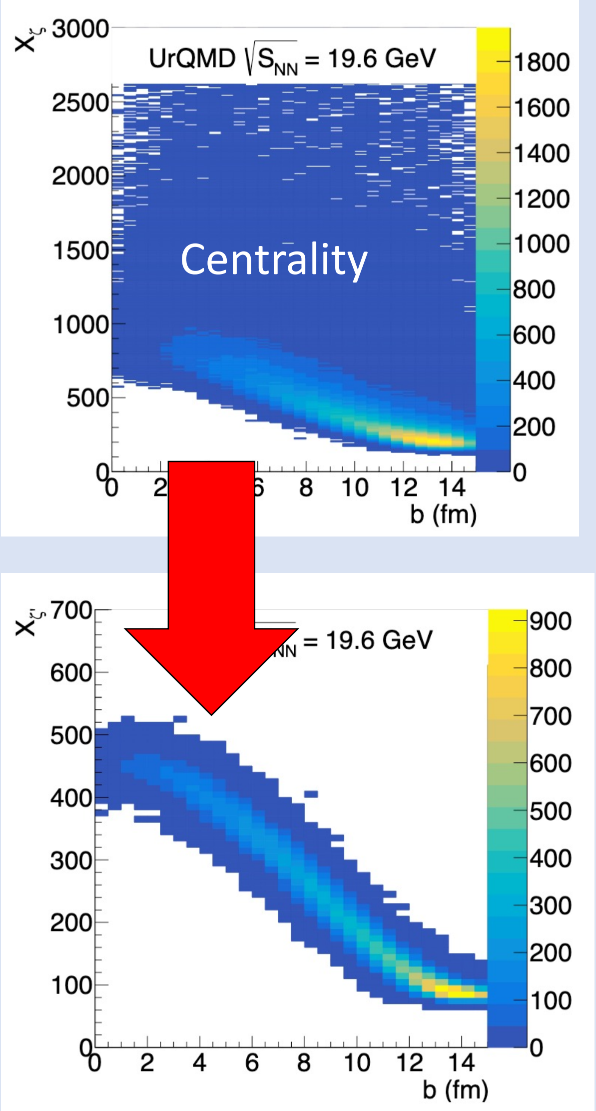
Large tail in the Landau distribution will diminish the signal → Truncation routine

$$Nmip = \frac{dE}{dE_{MPV}}$$

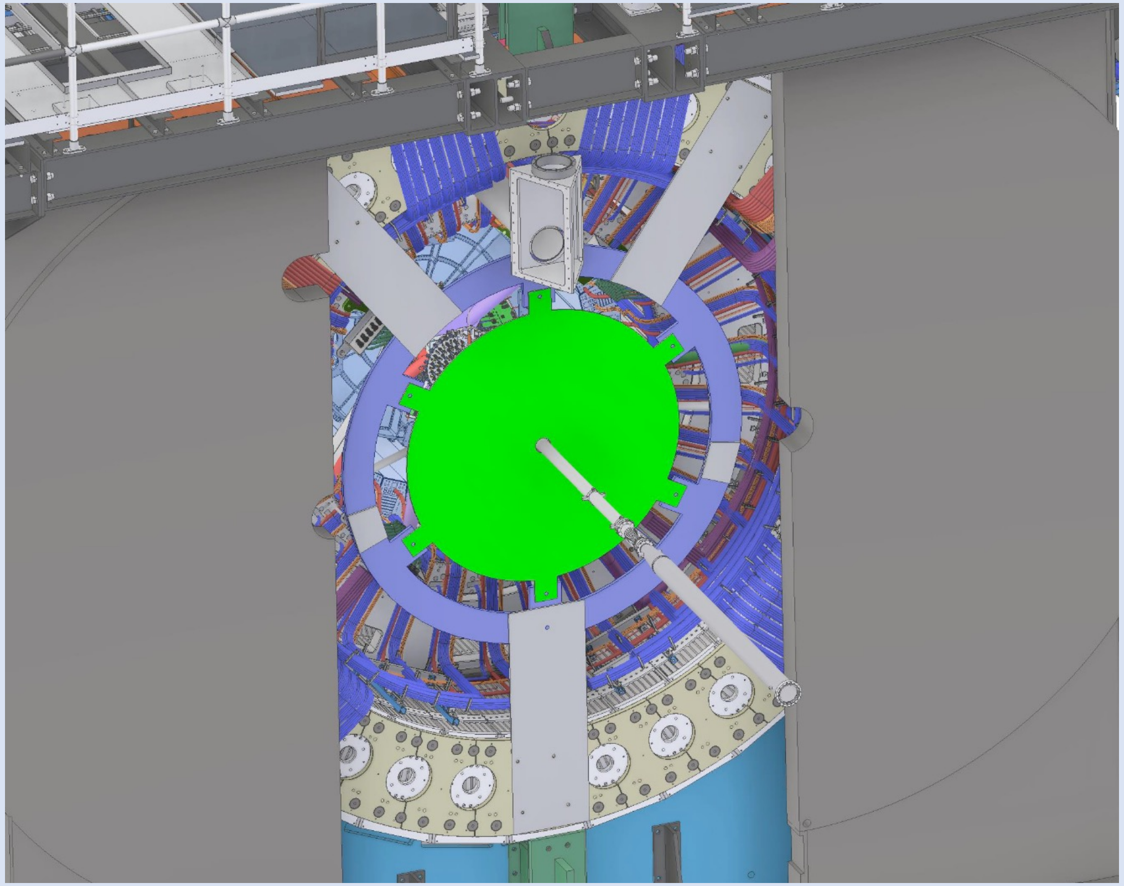
Optimized input signal :

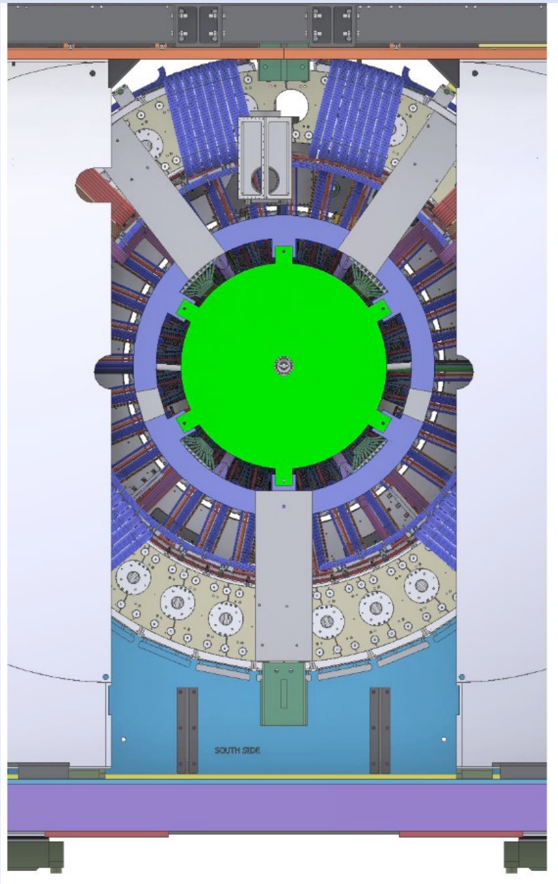
$$Nmip^{Truncate} \equiv \begin{cases} Nmip, & Nmip < Mx \\ Mx, & otherwise \end{cases}$$

M_x determined by most probable value of # of Hits



Mechanical Frame

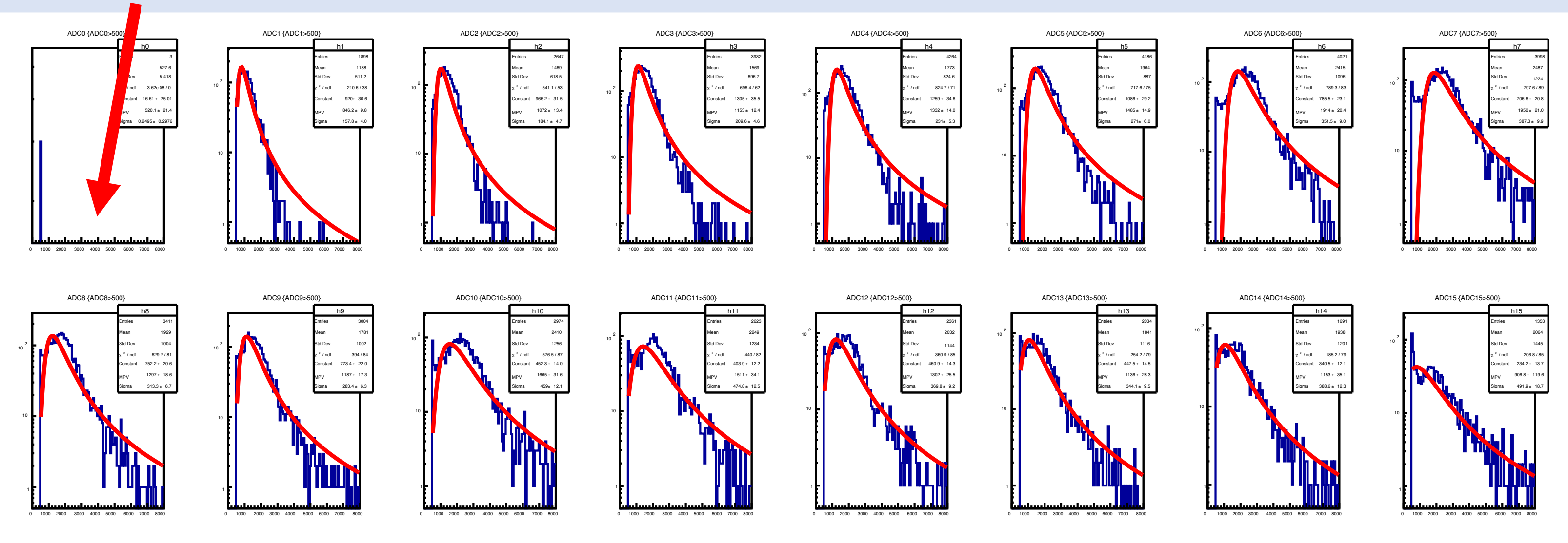


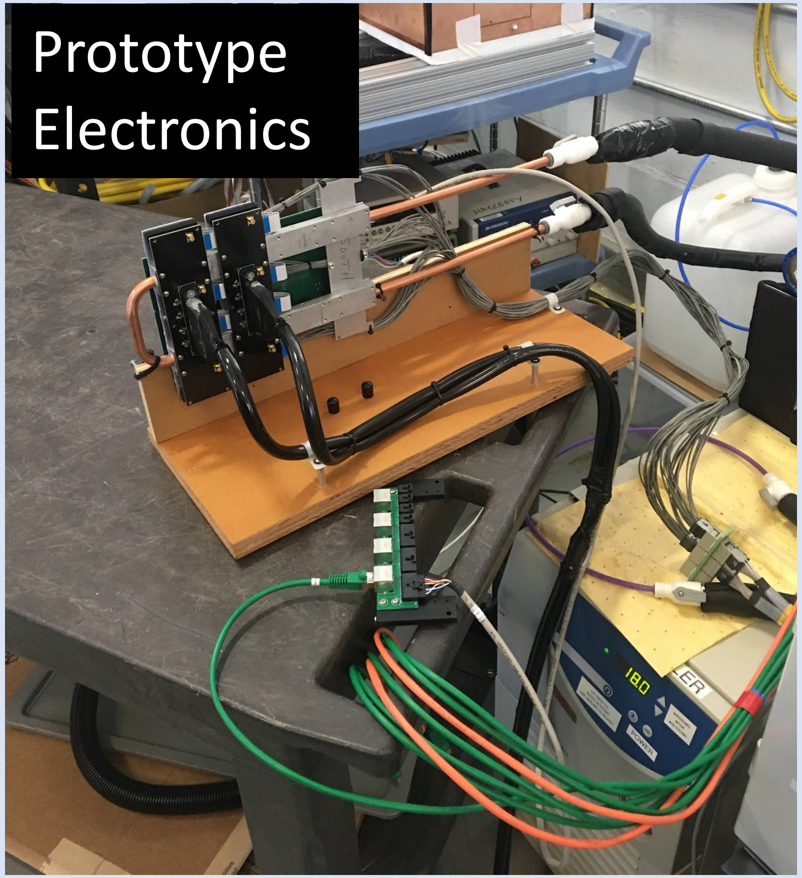


Strongback mounts to a frame just inside of the sPHENIX Solenoidal magnet → 4” of clearance with the magnet doors → Last on, first off during installation

Cosmic Check Sector S01

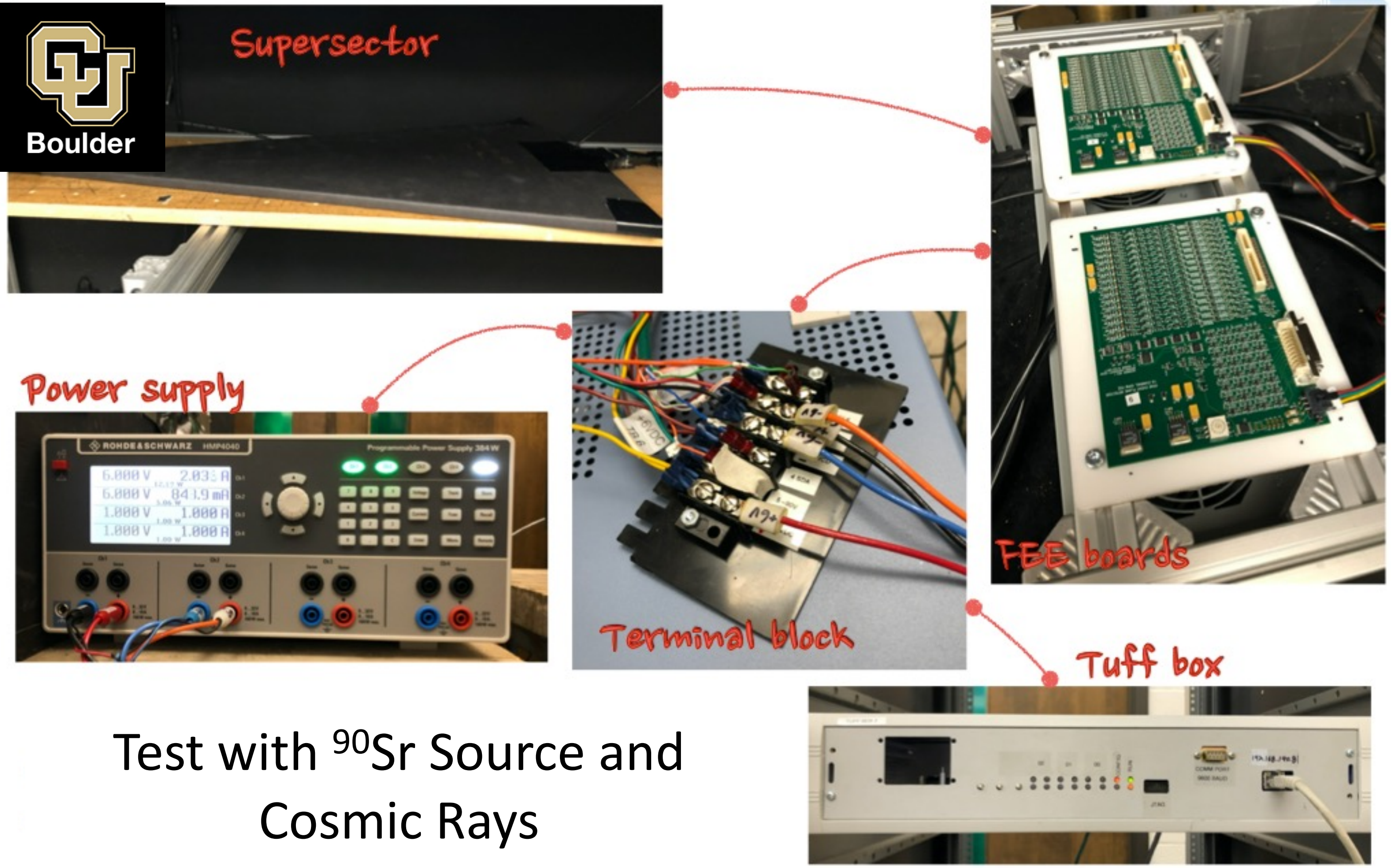
Blank Channel



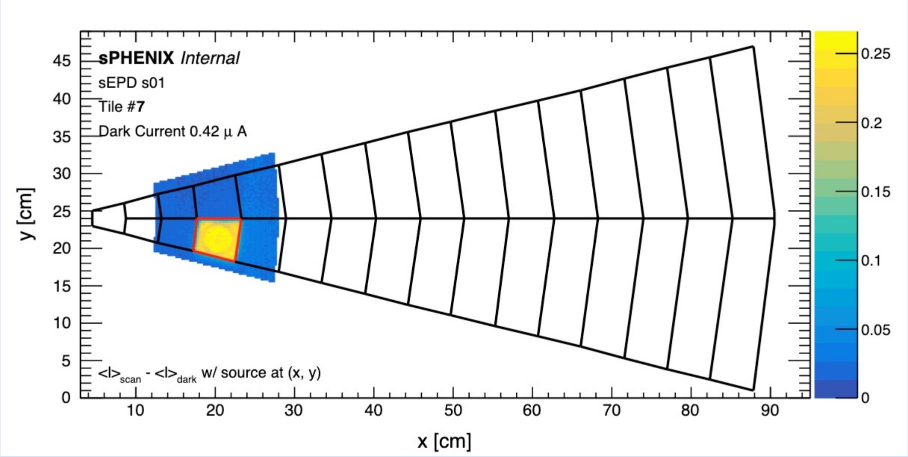


Cosmic check of first sector validates SiPM choice + sPHENIX Electronics Selection (Also validates sector construction process)

Uniformity Testing of Sectors

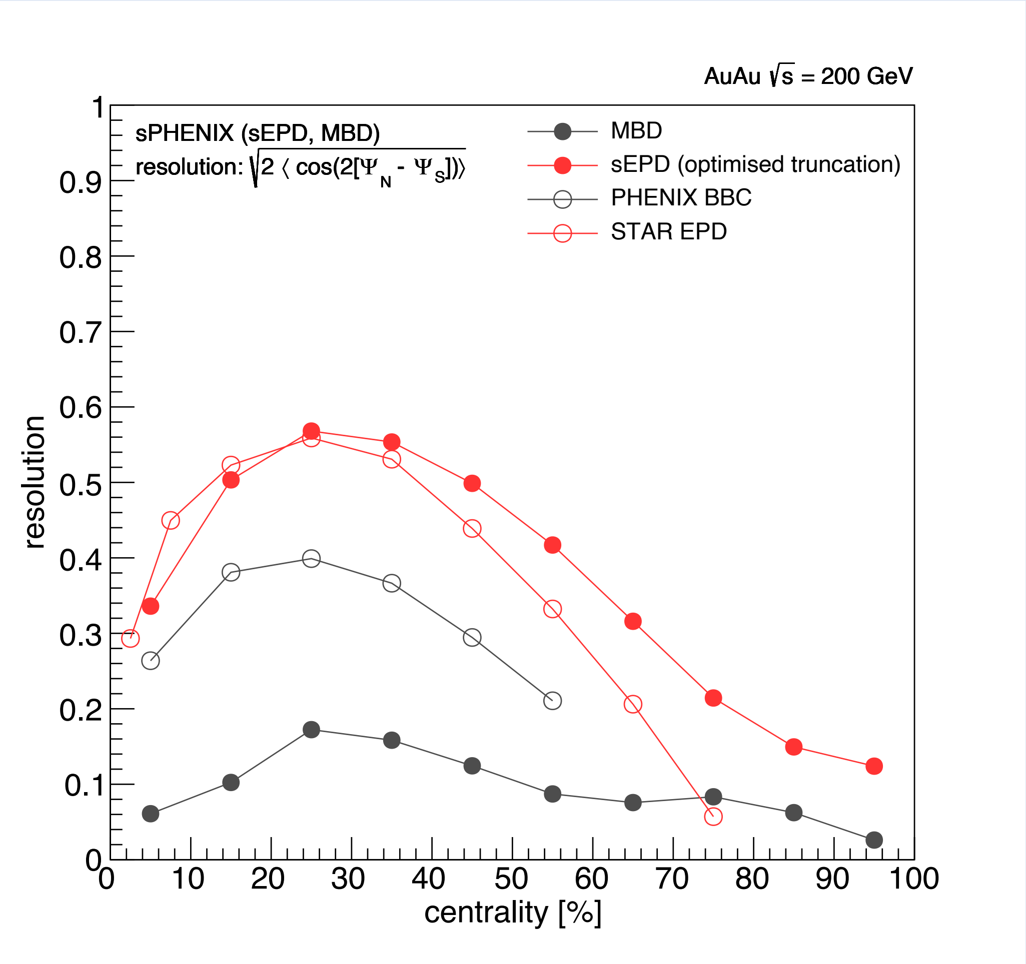


Test with ^{90}Sr Source and Cosmic Rays



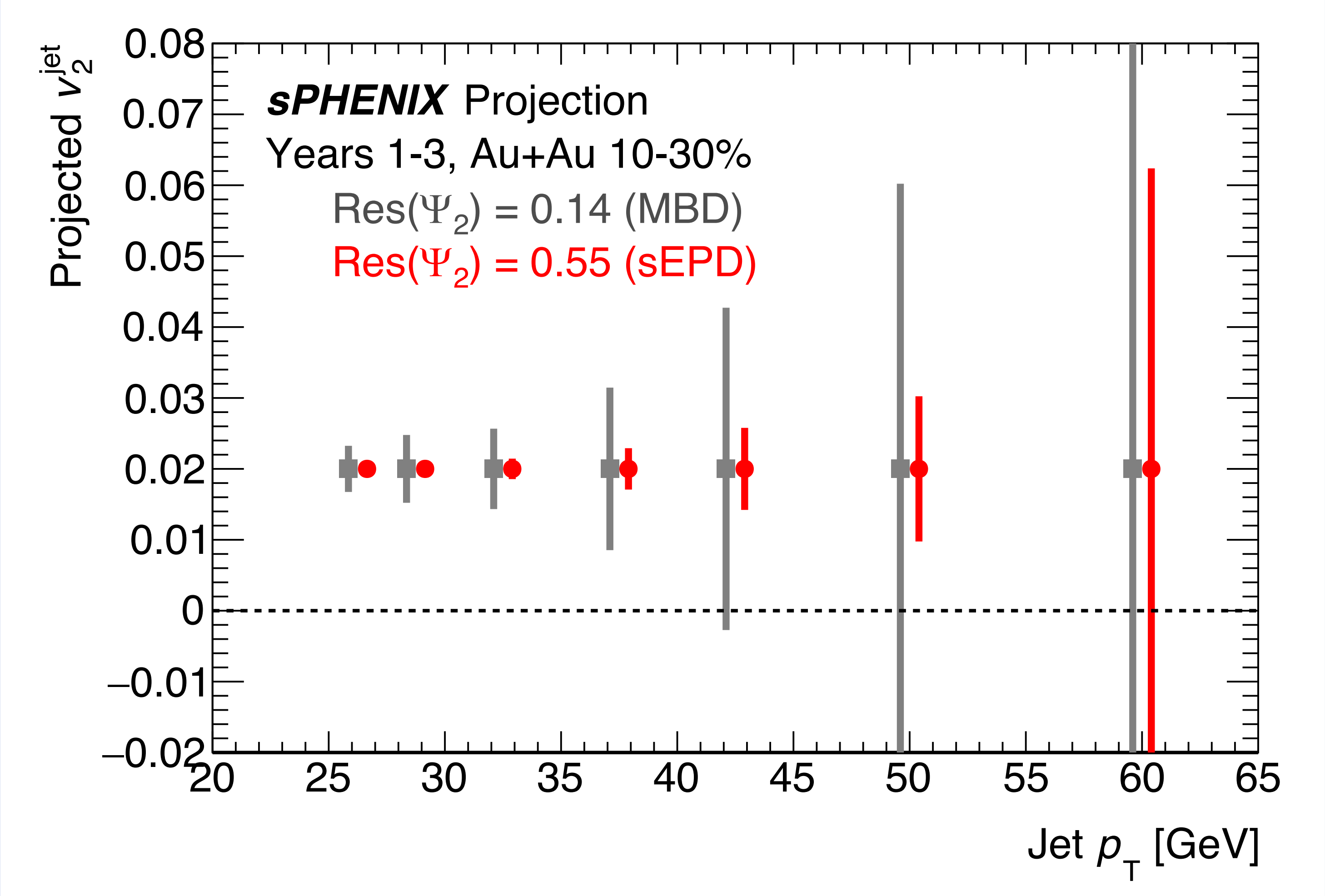
- Uniformity of response for each tile is checked via 90Sr Source
- Efficiency will be determined via Cosmic Rays
- Select best sectors for detector

sEPD Event Plane Resolution



- Second order EP resolution calculated via subevent method (Ψ_N vs Ψ_S)
- Better resolution than MBD due to larger acceptance
- Weighting can be done ring-by-ring to improve resolution
  - Truncation values can also be tuned
  - Waiting for start of data taking to validate

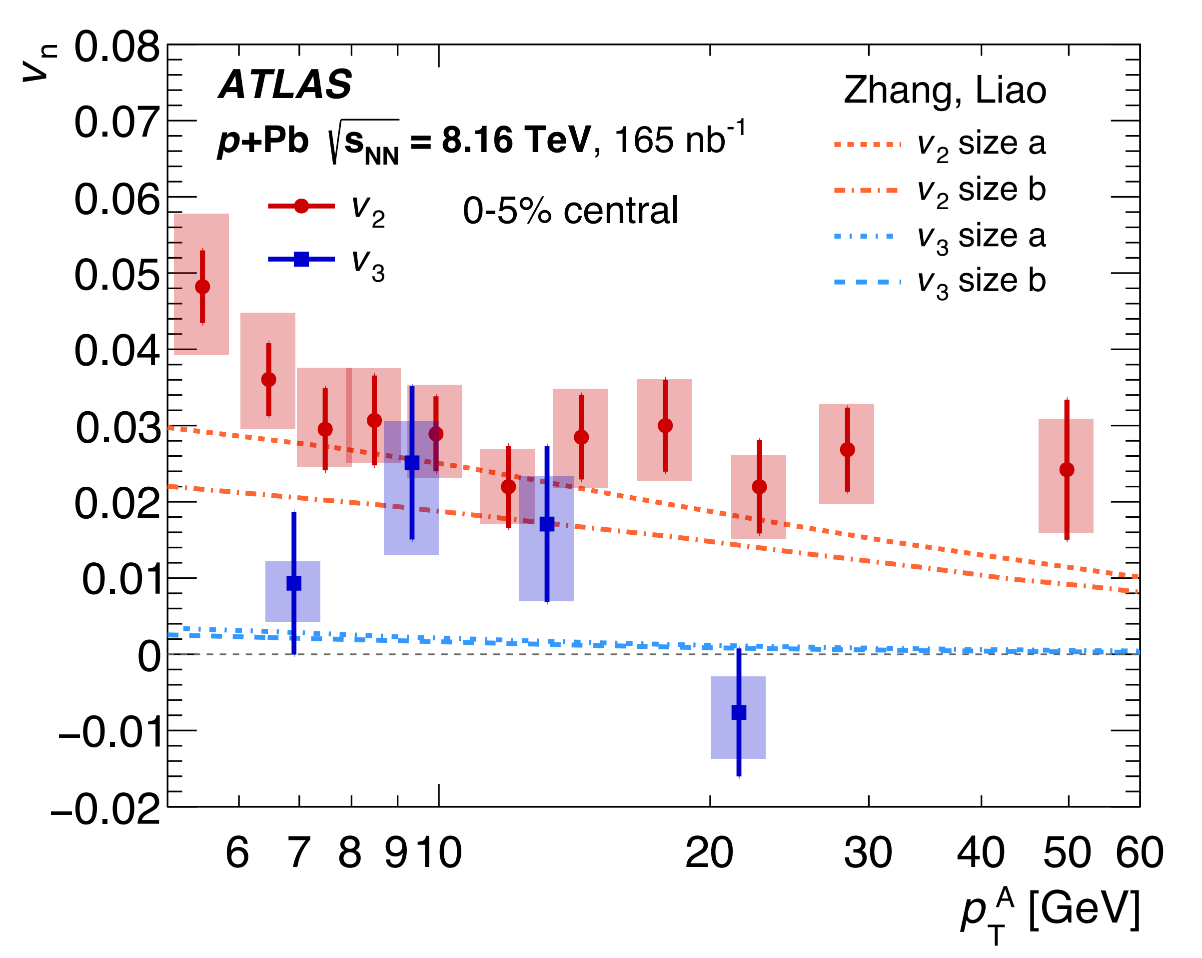
Azimuthal Distributions of Jets



Allows measurements of the modification of the jet yield with respect to the reaction plan (jet v_2)

- Path-length dependent Energy Loss
- Complementary to measurements which have a different sensitivity to: path-length dependence, event-by-event energy loss fluctuations
  - Example - di-jet asymmetries
- Jet v_2 allows one to better disentangle multiple effects

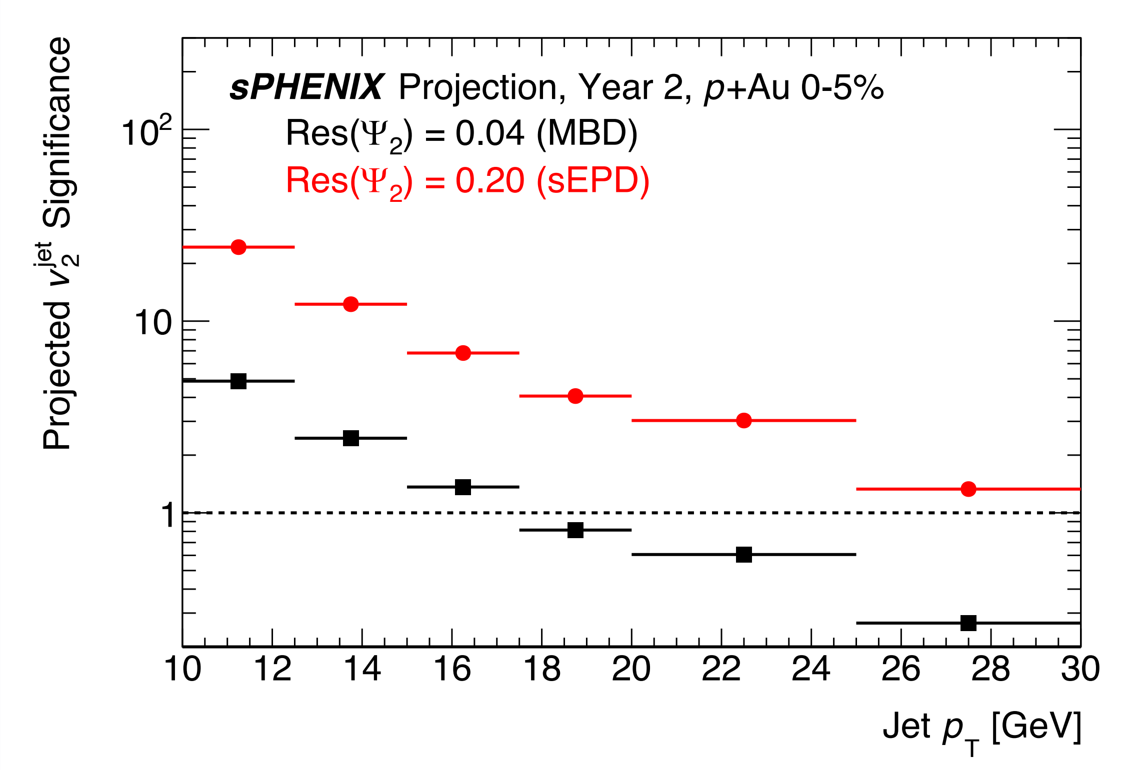
Jets in Small Systems

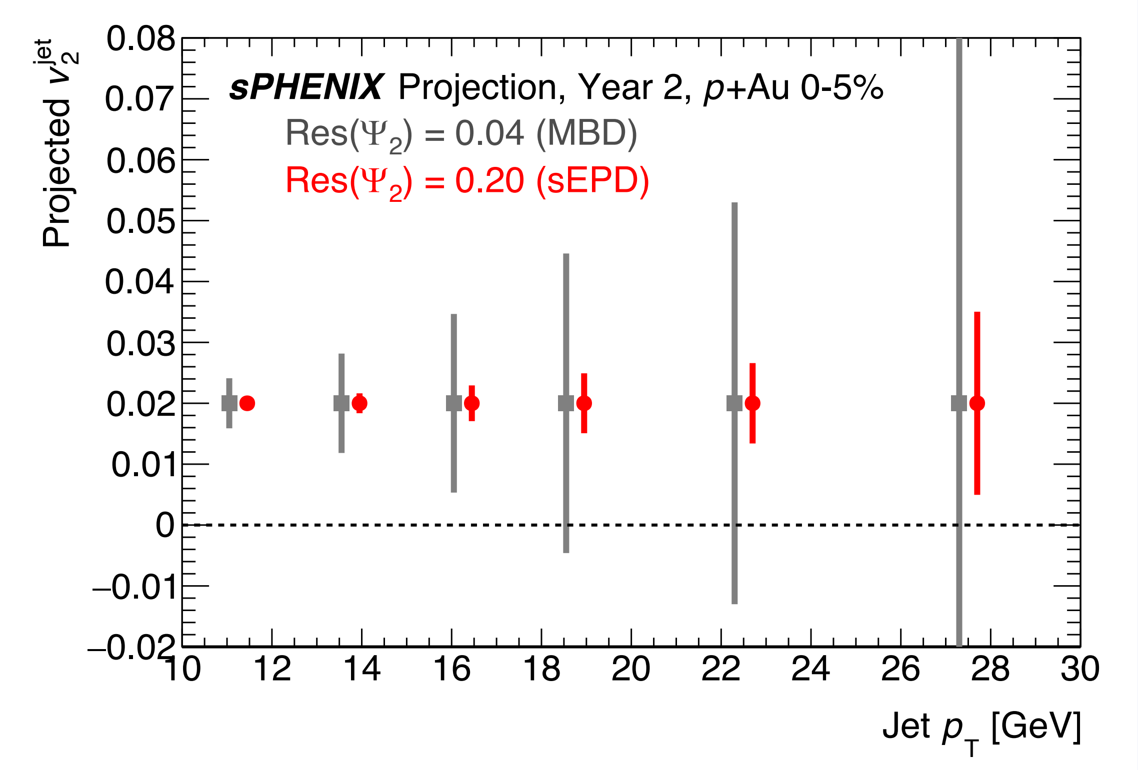


v_2 for high p_T particles (i.e. jets) is not zero in pA!

- Standard paradigm of AA collisions → v_2 aresults from a path-length dependent E_{loss}
  - Observation of jet quenching in pA collisions
  - No other indications (example R_{pA} ~ 1)
- Major challenge in the understanding of small systems
- Is our understanding of AA collisions correct?

Jets in Small Systems with sPHENIX

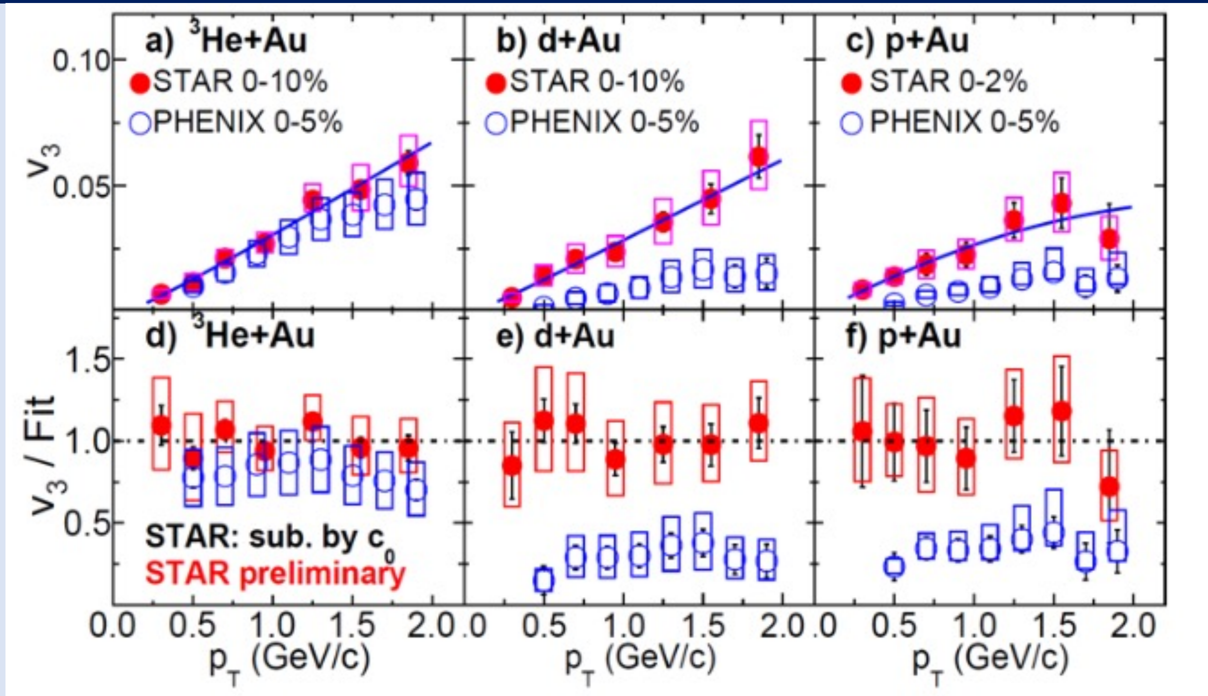




Allows a more precise + differential measurement of the jet v_2 in pAu

- Complement other measurements of jet production and modification
- Allows for a more complete picture of hard processes in small systems

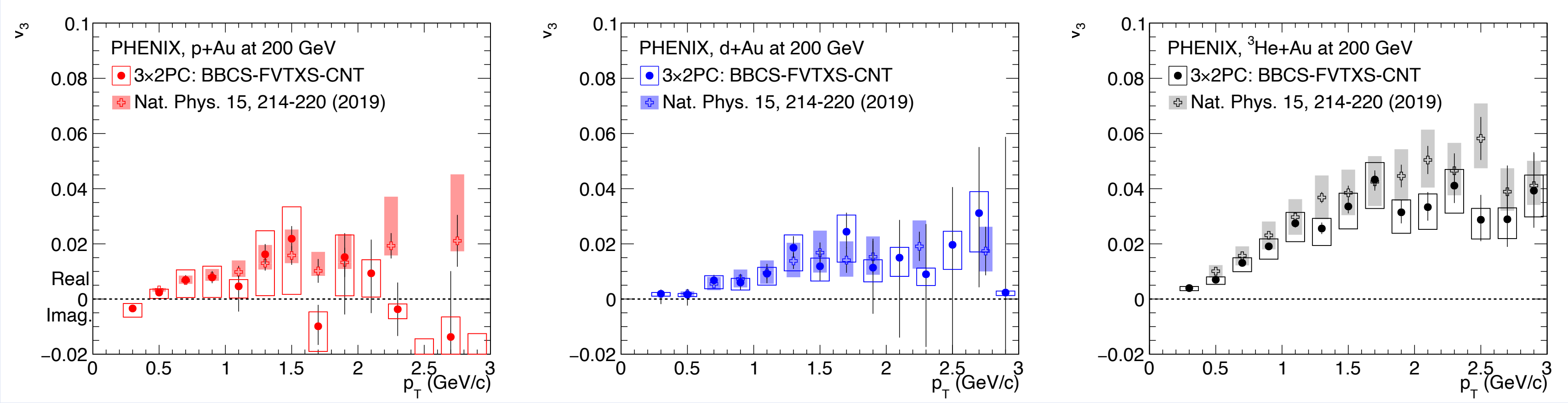
Small System Discrepancy



QM2019: STAR preliminary results in conflict with PHENIX published results in v_3 in p+Au and d+Au

- PHENIX has completed new analysis confirming the results with different sensitivity to various experimental effects
- STAR/PHENIX have very different detector acceptances → discrepancy may reveal interesting physics
  - η dependent effects!

STAR
QM2019



PHENIX,
PhysRevC.105.024901

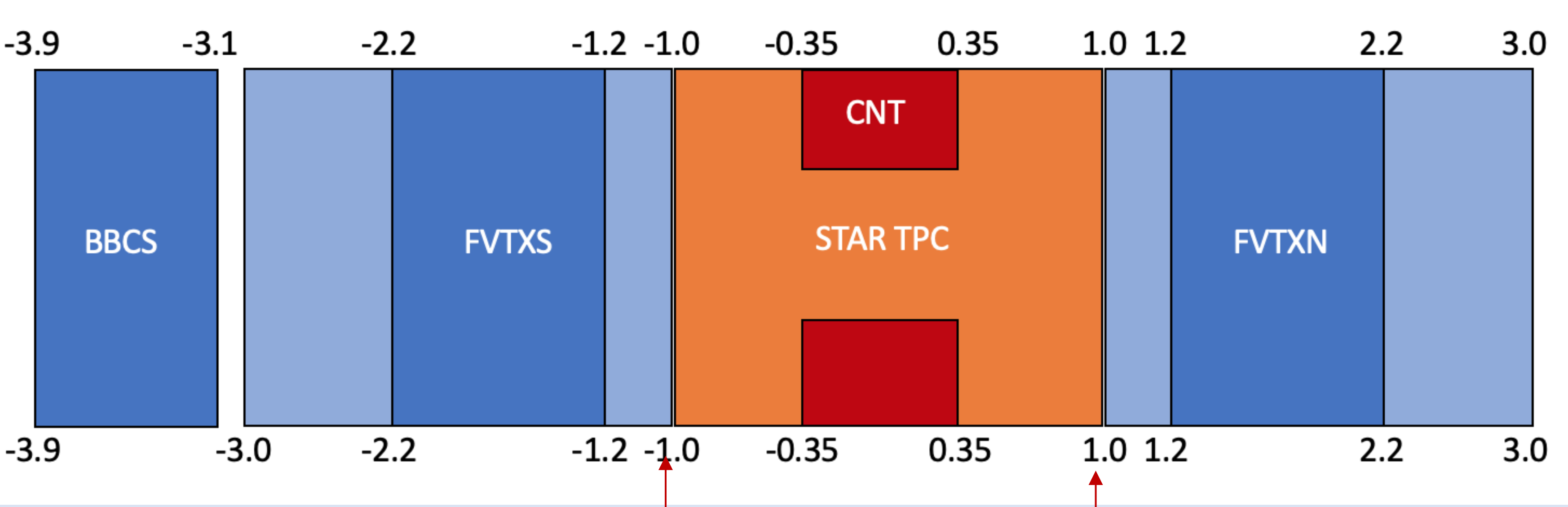
Small System Discrepancy

← Au

Pseudorapidity

PHENIX

p/d/He →



STAR 2015

Figure from R. Belmont, IS2021

"We furthermore recommend that more data will be taken in the future, with the upgraded STAR and the new sPHENIX detectors which significantly extend the rapidity coverage." → Report from Task Force on Small Systems Flow (J.Dunlop)

Now:

STAR EPD (2.1-5.1)

STAR iTPC(-1.5-1.5)

STAR EPD

2024:

sPHENIX EPD (2-5)

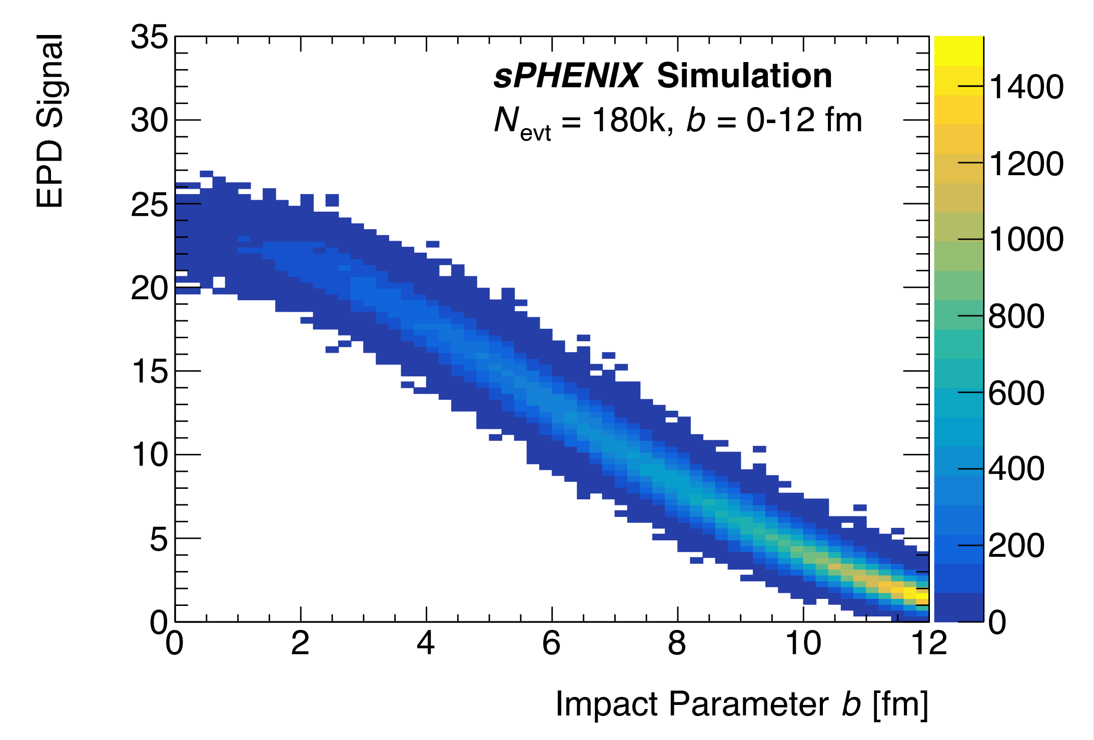
sPHENIX (-1.1-1.1)

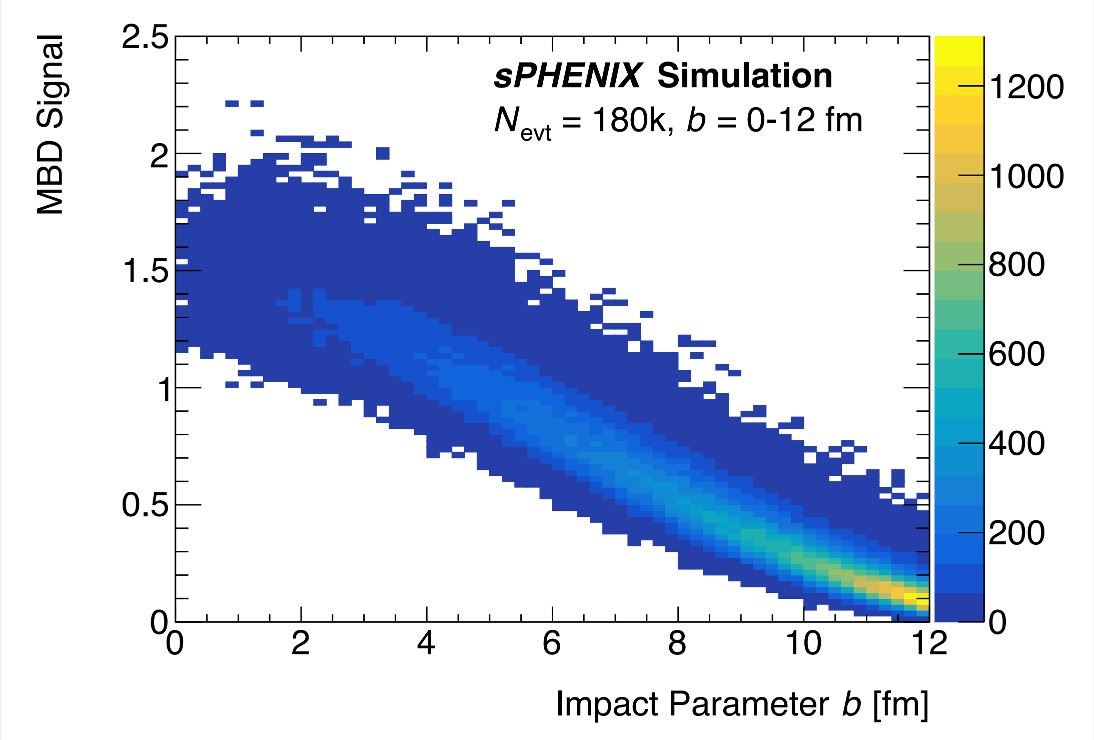
sPHENIX EPD (2-5)

sEPD Advantages

- The sEPD will expand the acceptance of sPHENIX, and we can see that there is a lot of interesting physics with pseudorapidity dependence
- Small system "discrepancy" between STAR and PHENIX shows that we have a lot to learn!
- In addition to jet v_2 and v_3 we will be able to measure heavy flavor azimuthal distributions
- Centrality can be quantified in this forward region
- Much, much more

Centrality Performance





- The event plane detector is also a good centrality detector!
- It is important to have centrality/event activity defined outside of mid-rapidity
  - Especially necessary for jet measurements in lower multiplicity events

Conclusions

- Improved capabilities from accelerator upgrades + sPHENIX will result in an exciting Era of HI collisions at RHIC
  - **Improved tracking, calorimetry** (including hadronic)
  - Increased **kinematic reach** + improved statistics
- sPHENIX will probe the QGP structure at a variety of scales
  - On track for data taking in **2023!**
  - Complementary to HI LHC measurements in 2020s
  - Allow new observables to be measured at RHIC → rich QGP and QCD physics (b-jets, b-dijet, D-D correlations + others)
  - Motivated by HEP experience
- The sPHENIX EPD will play a large role in many future measurements

The jet physics program with sPHENIX
V.Bailey Tuesday

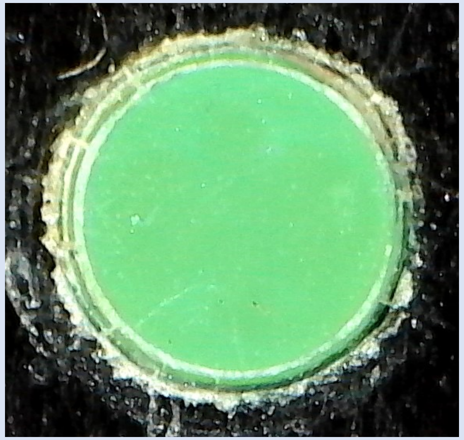
Heavy Flavor and Quarkonia Physics at sPHENIX
T.Marshall Friday

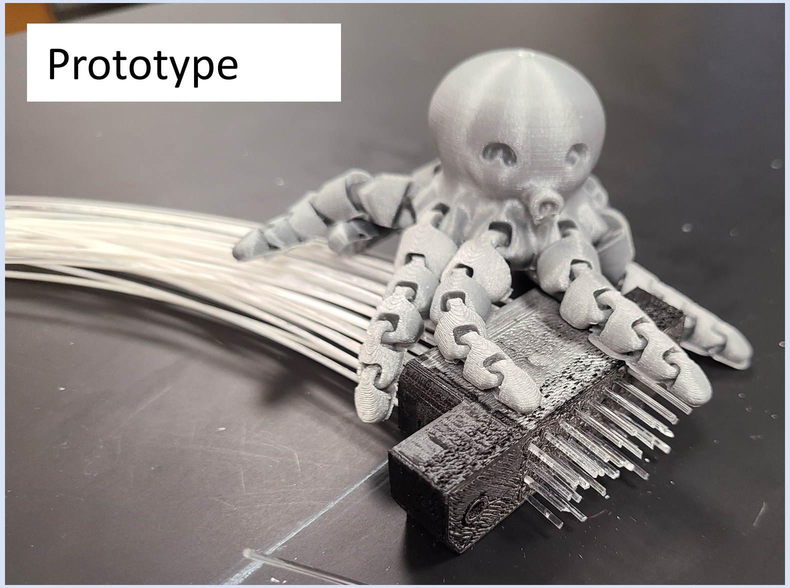
Back Up

Connector Construction

Sanded with 320 grit

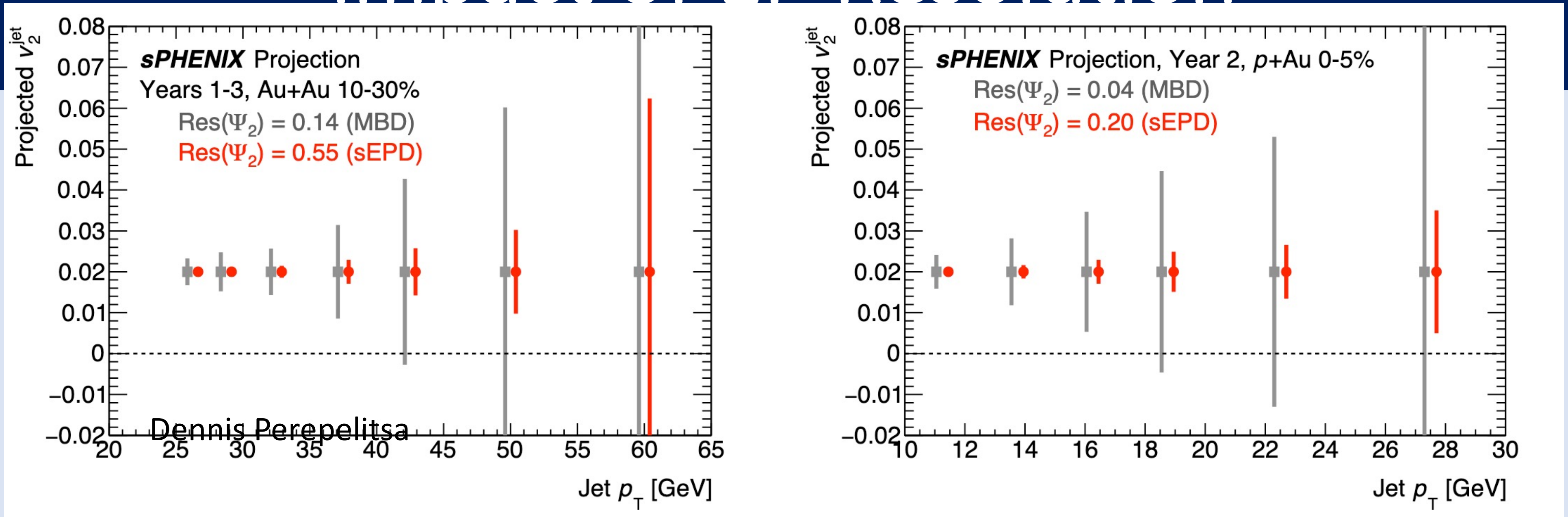
Polished w/1um diamond polishing sheets





- After painting, fibers are glued into prepared connectors
- Hand polished → ~8 hours per connector

Impact of EP Resolution



- The event plane detector improves EP resolution in AA **+ pA**
- From PAC Meeting: [Dunlop PAC Talk] (slide 9):

"We furthermore recommend that more data will be taken in the future, with the upgraded STAR and the new sPHENIX detectors which significantly extend the rapidity coverage."

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Conclusions in a Nutshell

- In summary, there is no sign that any of the two analyses is technically wrong. We believe that all the observed differences could be ascribed to the different treatment of nonflow effects and of the flow (and non-flow) rapidity dependence.

- In conclusion, this controversy brings up useful physics questions. Resolving them will require more data, taken with upgraded STAR and the sPHENIX detectors, and probably improved methods of analysis.