Construction and Physics with the Event Plane Detectors

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The 39th Winter Workshop on Nuclear Dynamics

Jackson, Wyoming, Feb 11-17, 2024

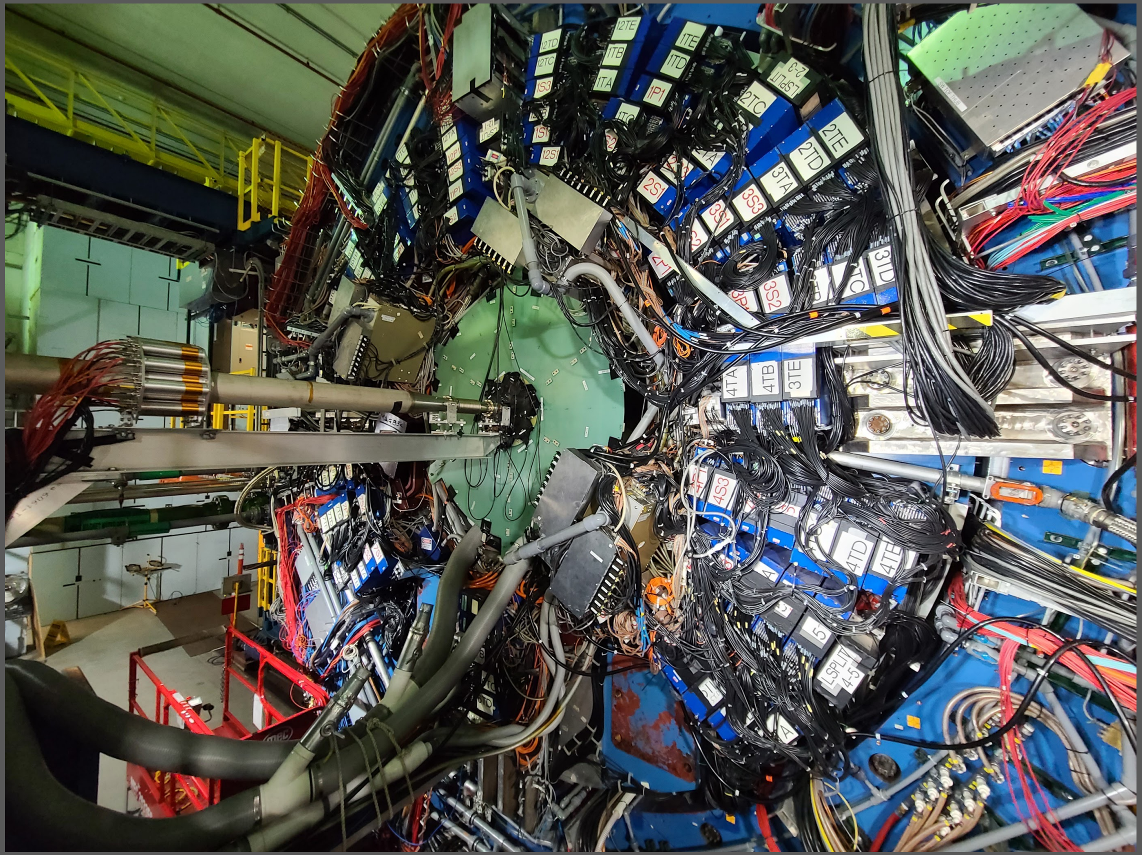
NSF

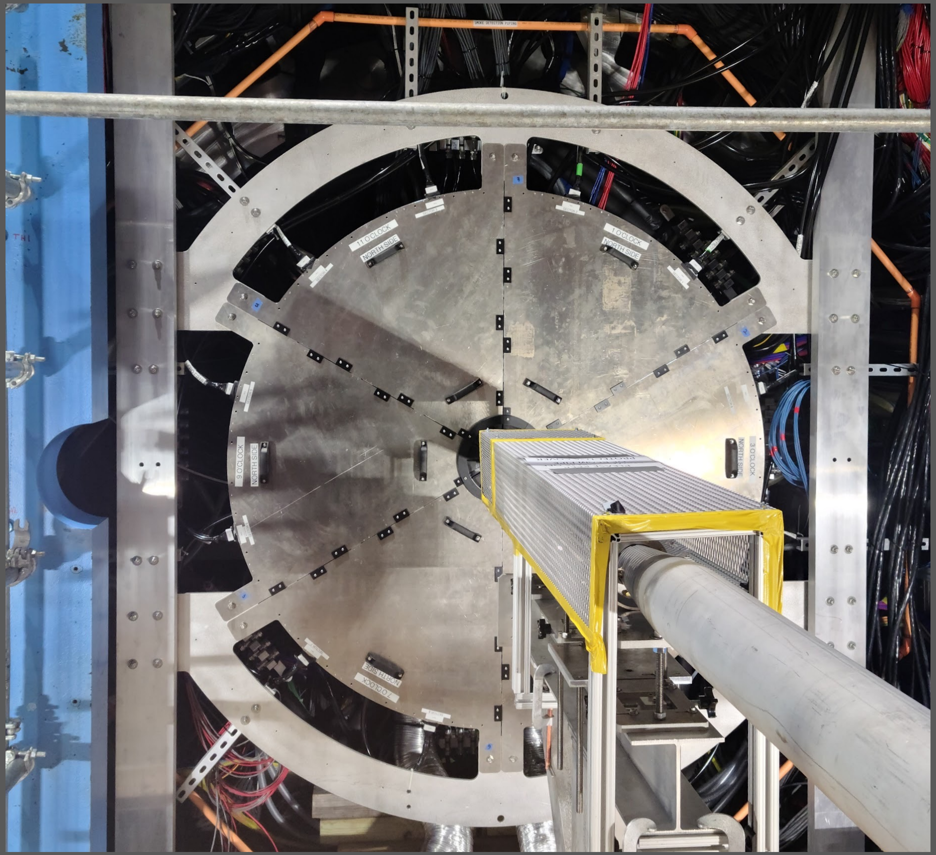
LEHIGH UNIVERSITY

Event Plane Detector

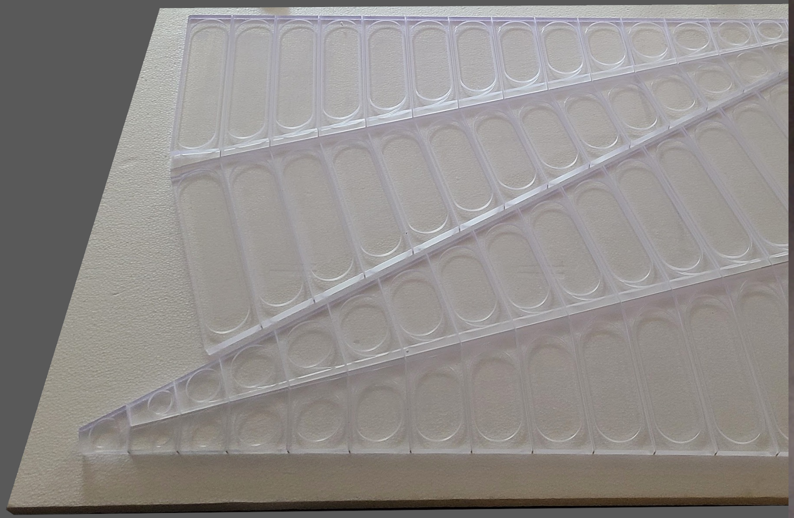
- Forward detectors at STAR and sPHENIX
- Enable comparison across RHIC detectors
  - Similar to LHC as well
- Charged particle distribution at forward rapidity
  - Ψ_n, centrality, triggering, …

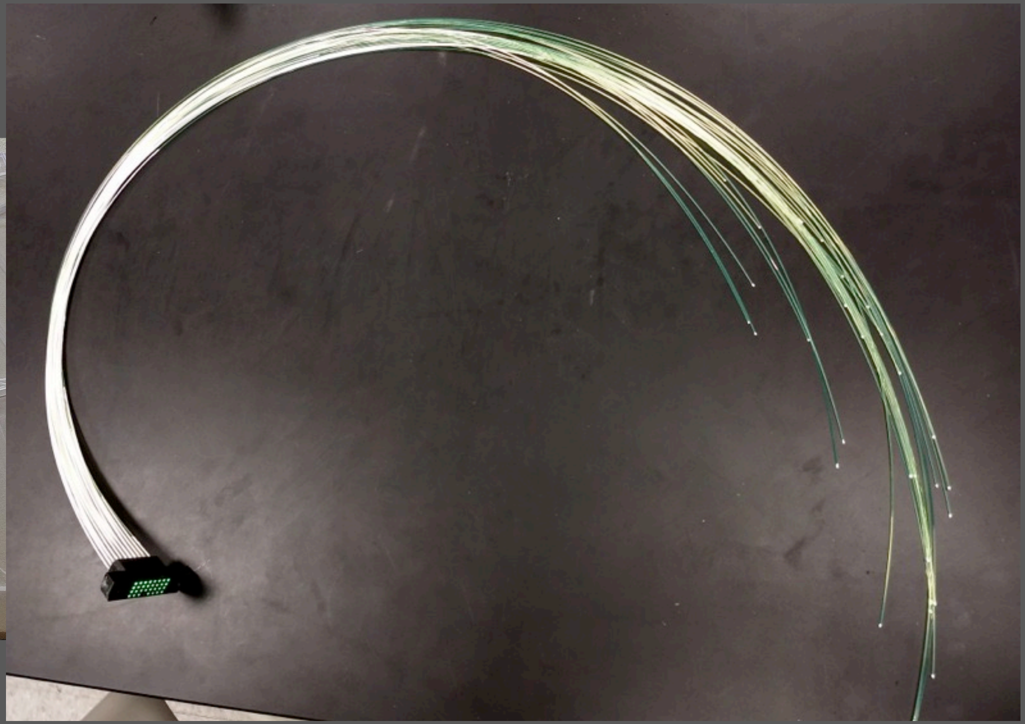
STAR and sPHENIX

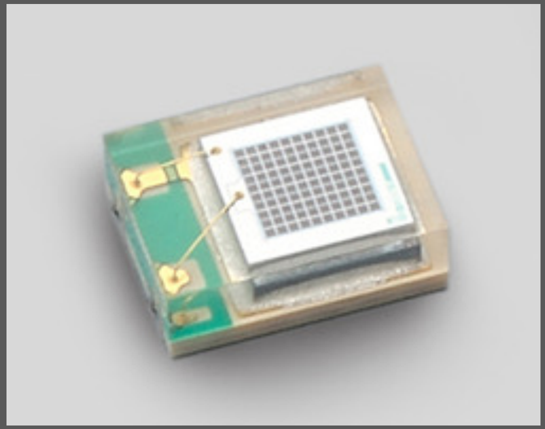




Principles of operation





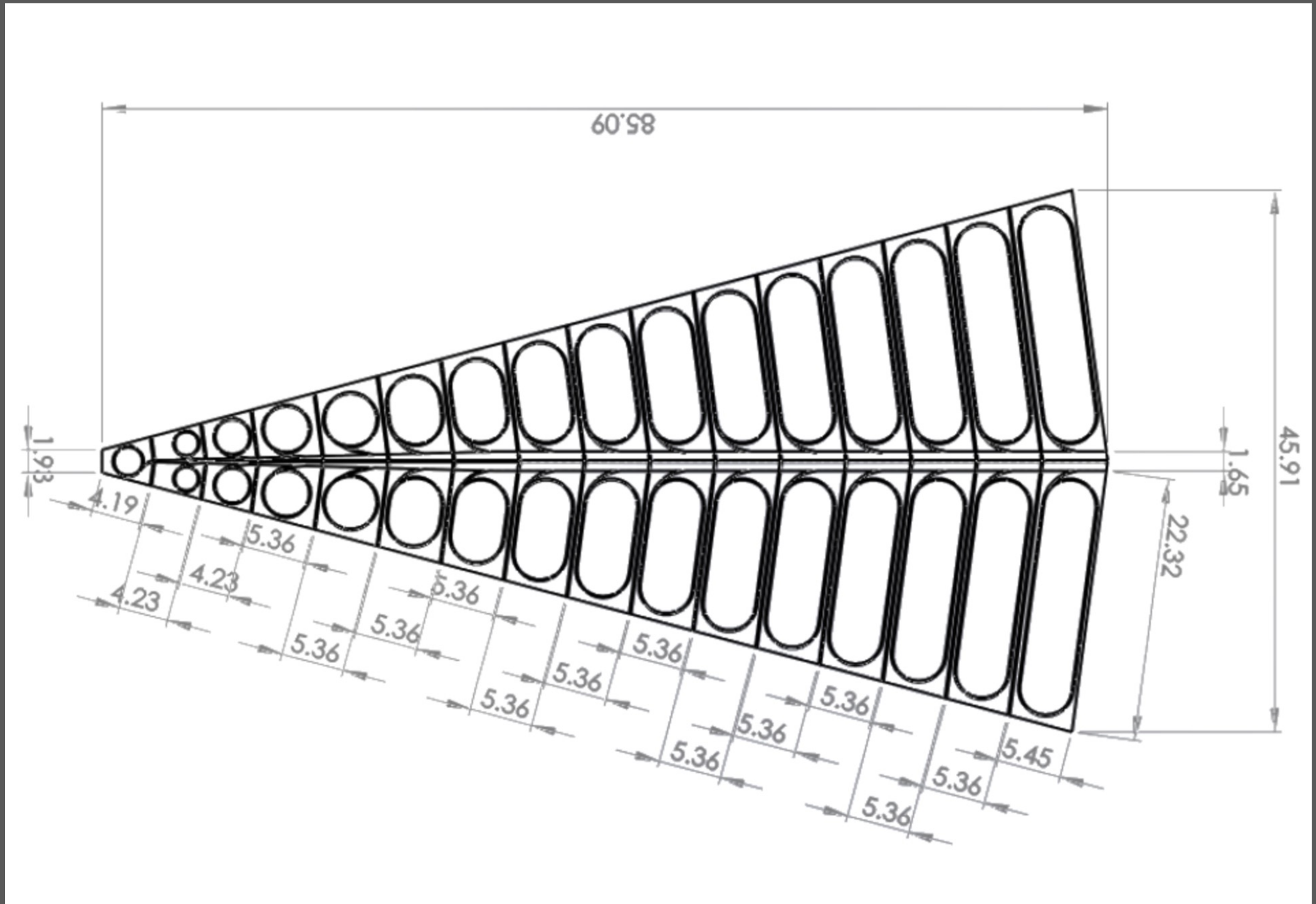


Scintillating plastic

Wavelength shifting fiber

SiPM readout

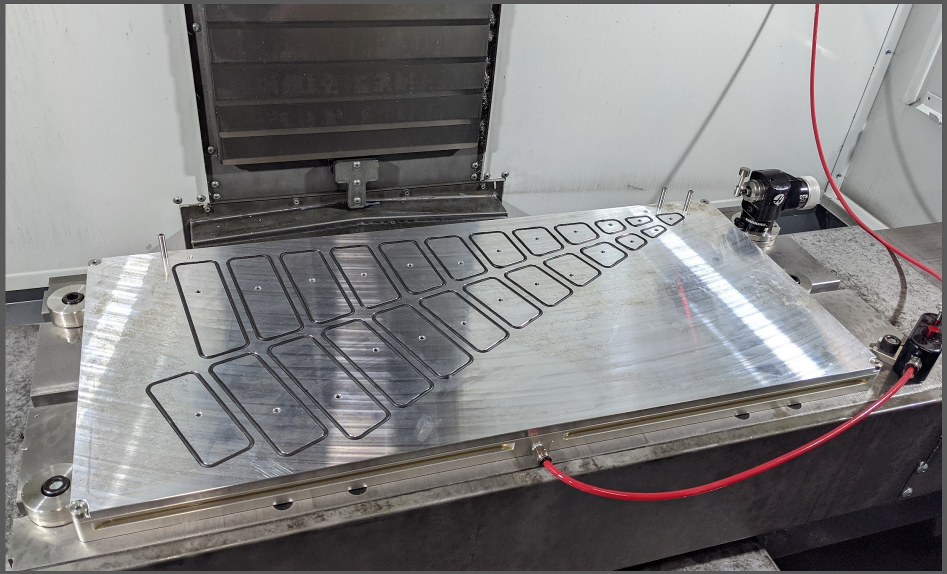
Scintillator



- 372 optically isolated tiles per side
  - 31 tiles per sector, from single sheet of scintillator
- 2π coverage
  - STAR: $2.1 < |\eta| < 5.1$
  - sPHENIX: $2 < |\eta| < 4.9$
- Eljen EJ-200 scintillator
  - 1.2 cm thickness
  - Emission peak at 425 nm

Scintillator Preparation

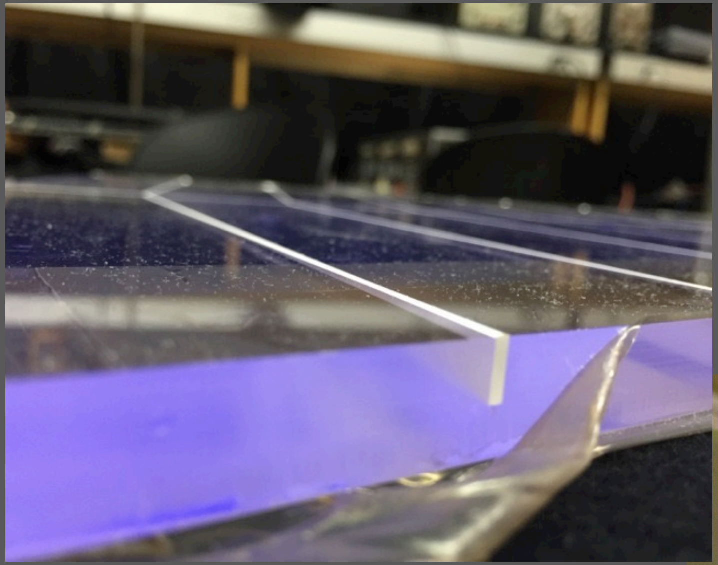
- Scintillator received as rectangular sheets
  - Two sectors per sheet



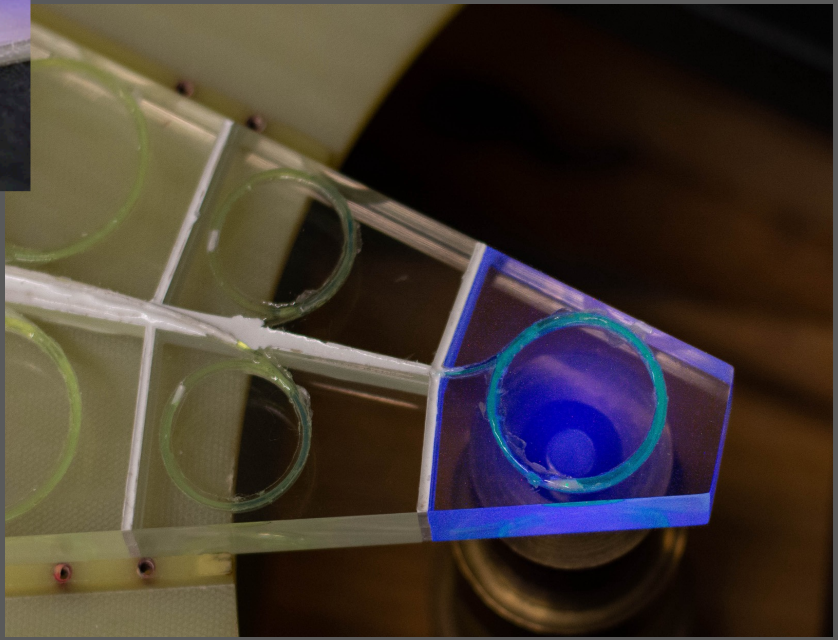
- **STAR**
  - Milled with low feed rate and depth of cut
  - Clamped traditionally

- **sPHENIX**
  - Milled with high feed rate and low depth of cut
  - Enabled by strong flood coolant
  - Held with vacuum bed to apply uniform pressure

Optical Isolation



Milled to half depth



Superimposed long exposure demonstrating isolation

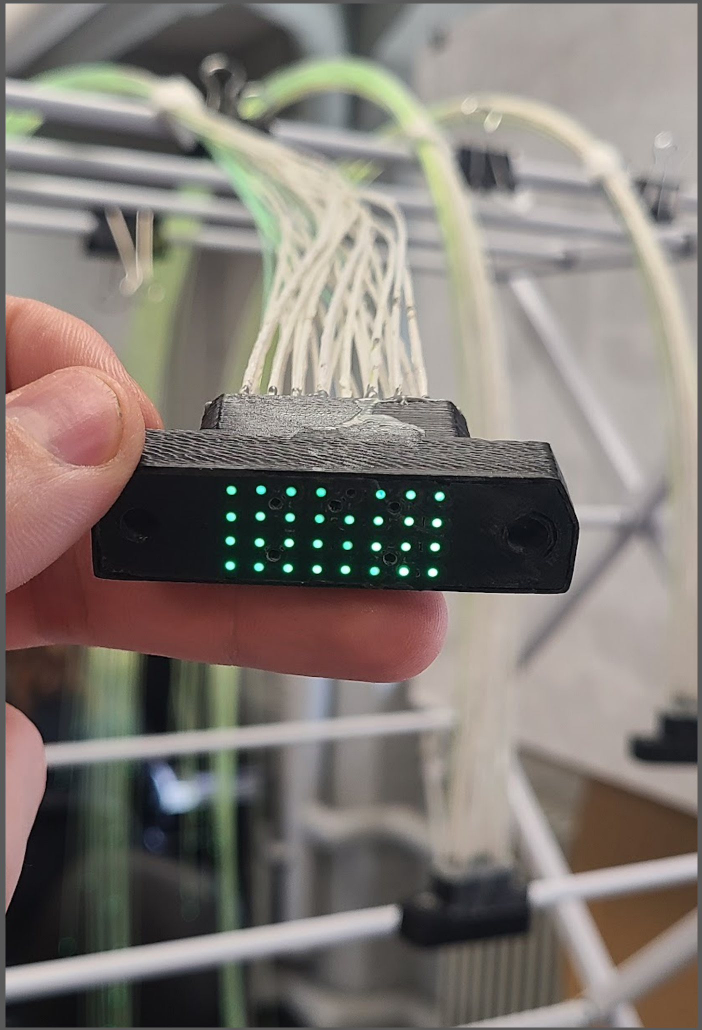
- ❖ Each tile is optically isolated

1. Mill to half depth
2. Fill with reflective epoxy
3. Flip and mill to epoxy depth

Reflective epoxy

- Titanium doped epoxy
  - Provides structure for sector
  - Isolates tiles
  - Reflects photons back in towards WLS fibers
- Manufactured in large batch, flash frozen until needed
- Scintillator surface protected with Teflon tape

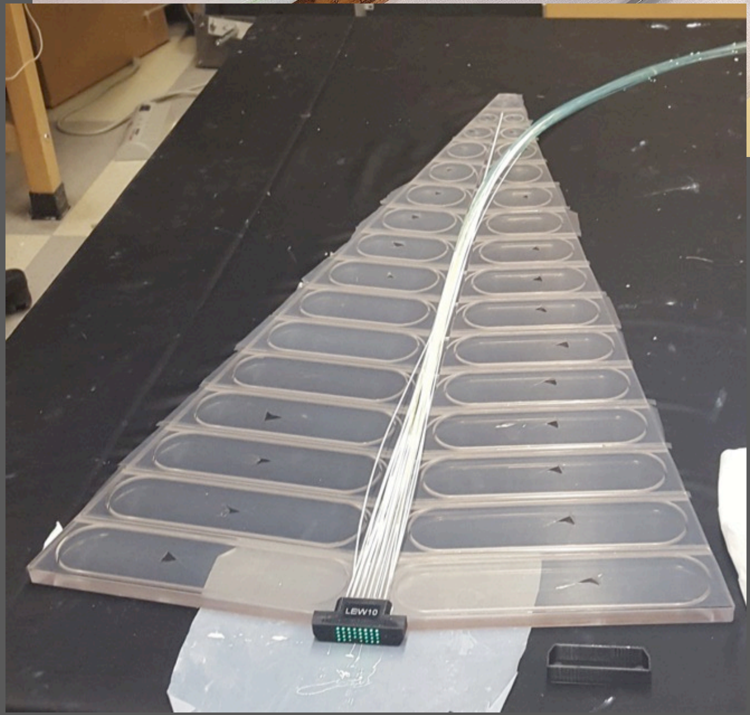
Wavelength Shifting Fiber



- Kuraray Y-11(200) wavelength shifting fiber
- Blue to green shifter
  - Captures scintillation light
  - Shifts to total internal reflection
- Long attenuation length and high light yield

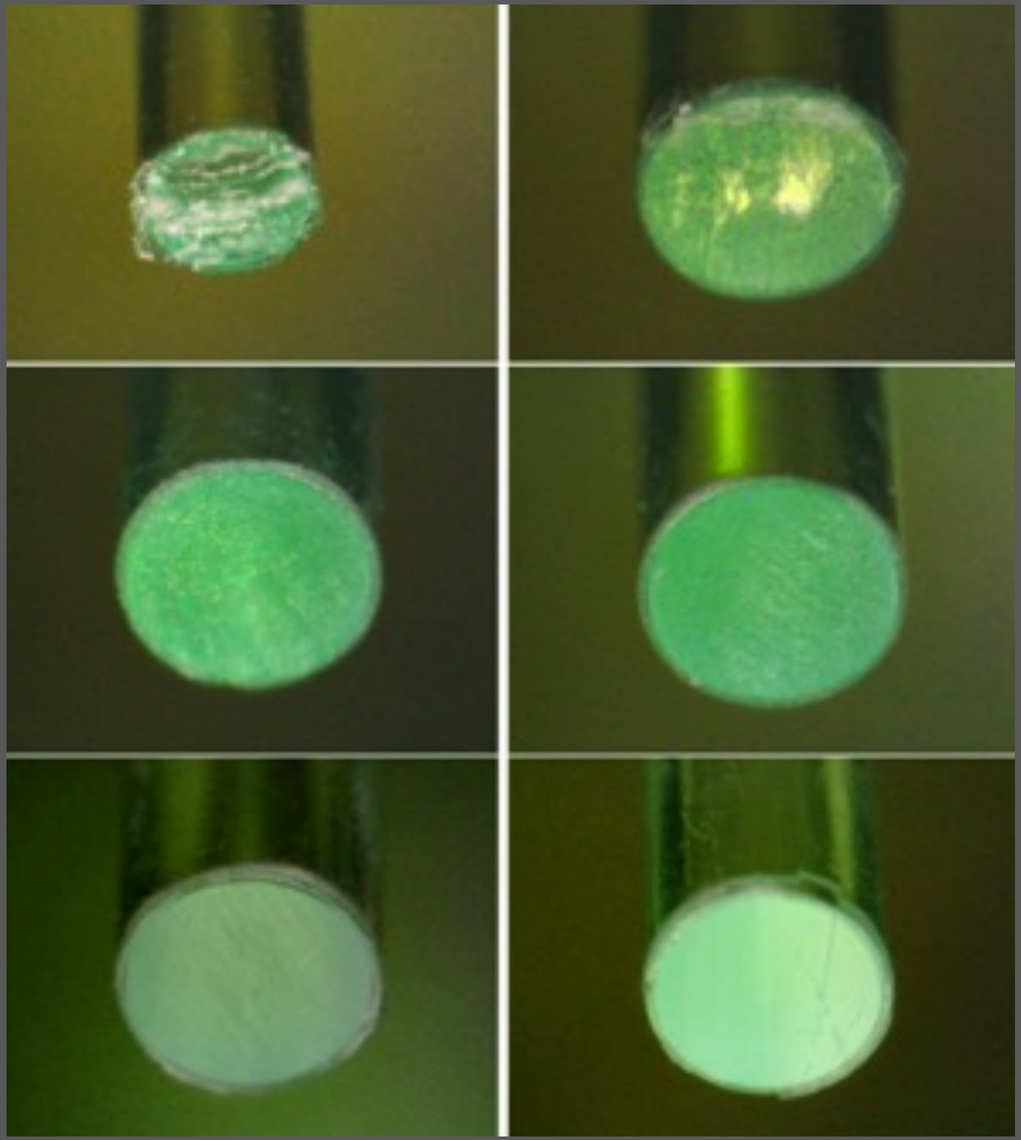
Preparing wavelength shifting fiber

- ❖ Fibers painted with reflective paint to avoid crosstalk and maximize signal
- ❖ WLS fibers arranged into bundles of 31
- ❖ 3D printed connector
  - o PLA
  - o Survived 6 years of running at STAR



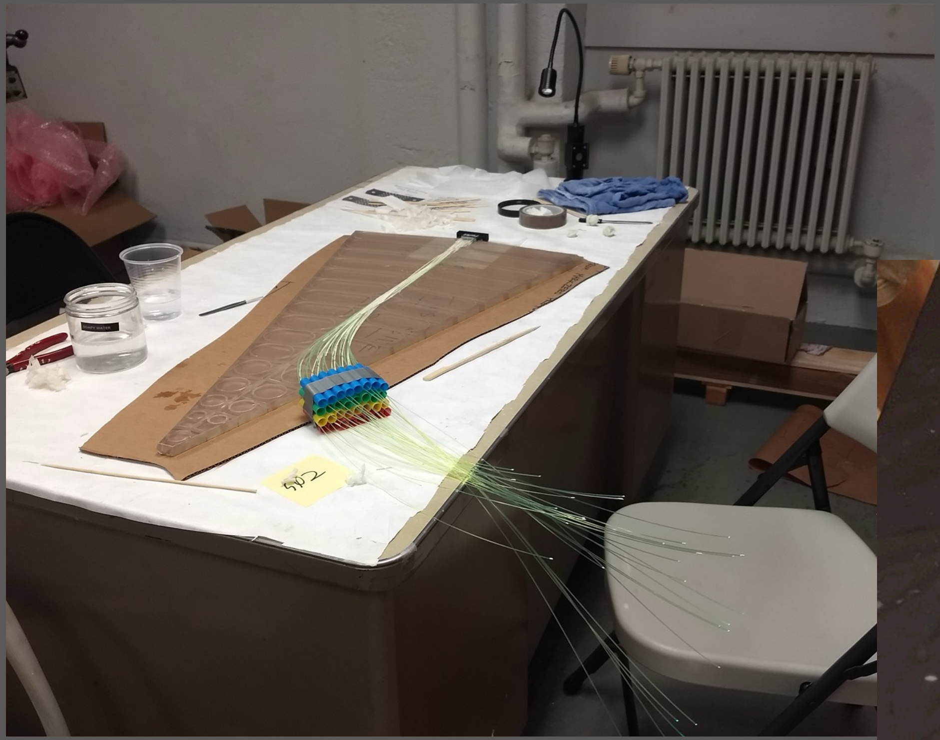
Fiber bundle polishing

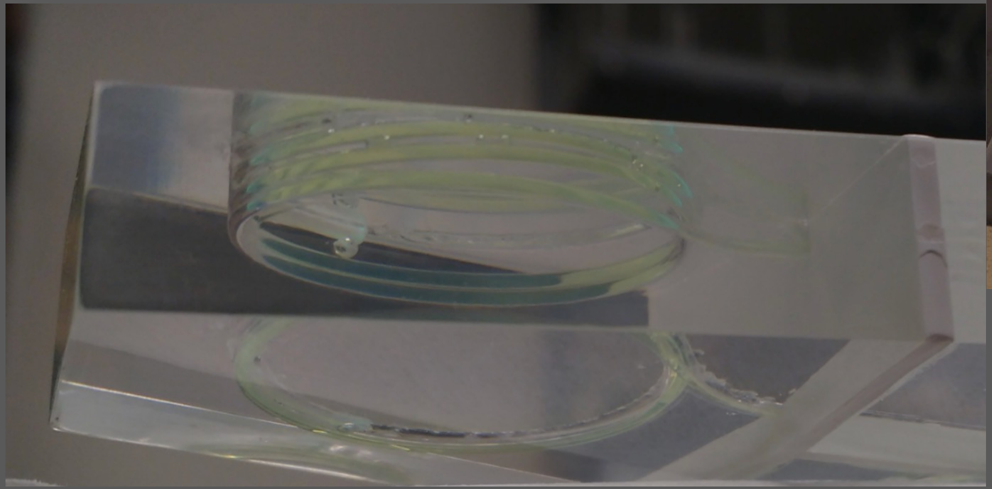
- ❖ Polished to 5 μm lapping paper
- ❖ Each fiber inspected under microscope for surface defects



Bonding wavelength shifting fiber

- Connector glued into sector with reflective epoxy
- Each fiber looped three times around its tile
- Glued with Eljen optical epoxy





Finishing Touches

Sector wrapping

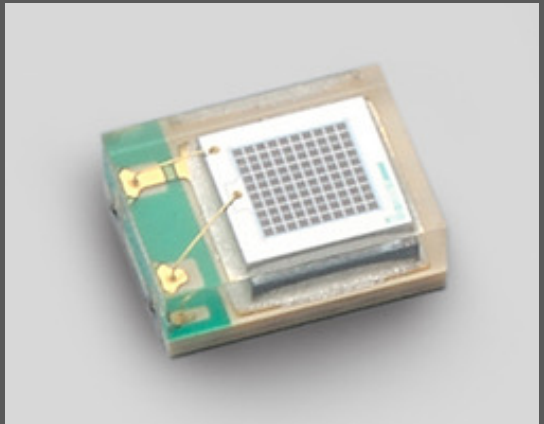
- ❖ Wrapped in Tyvek to maximize reflectivity
- ❖ Wrapped in black felt paper to ensure light tightness
- ❖ Light tightness checked at start of each run

Clear fiber bundles

- ❖ SiPMs located off detector to minimize radiation damage
- ❖ Clear fiber carries signal from detector to SiPM
  - o STAR: 5 meters
  - o sPHENIX: 6.5 meters
- ❖ 3D printed coupling

SiPM

- Hamamatsu S13360-1325PE
- 1.3 x 1.3 mm photosensitive area
  - Matched to 1.15 mm diameter clear fiber
- 25 um pixel pitch, 2668 pixels
- Lower fill factor -> Higher dynamic range
- Peak sensitivity at 450 nm



Readout Electroncs

STAR

- ❖ Charge integrating ADC
- ❖ Inner rings include timing data for triggering
- ❖ Minimum bias trigger runs 18-21

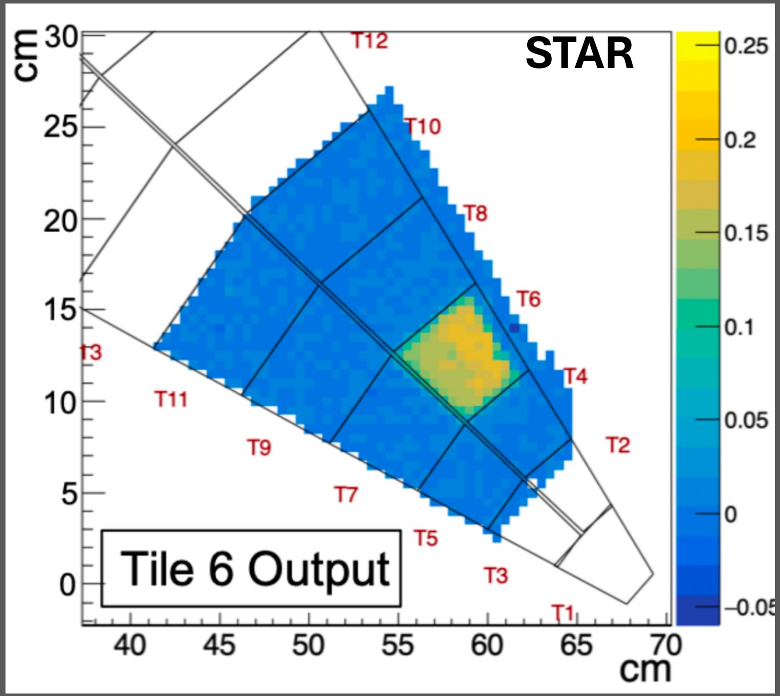
sPHENIX

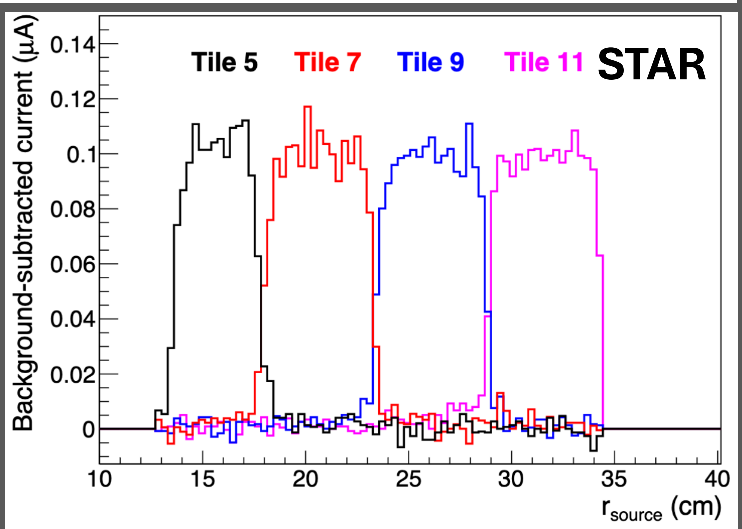
- ❖ Borrowed design from sPHENIX calorimetry
- ❖ Up to 31 14 bit samples per trigger
  - o Lowered to 12 in regular running
- ❖ Signal extracted with template fit

Bench Testing

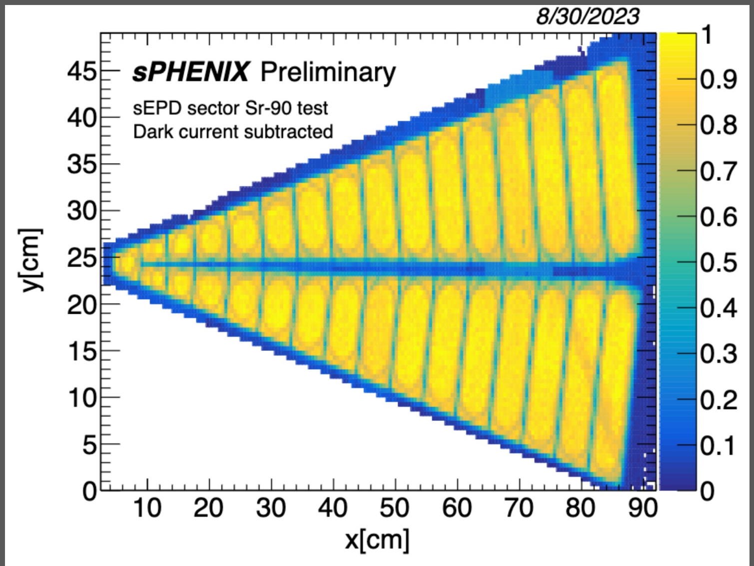
- ❖ Tile uniformity and crosstalk checked on xy table
- ❖ Efficiency checked with cosmics
- ❖ Sector performance graded and ranked

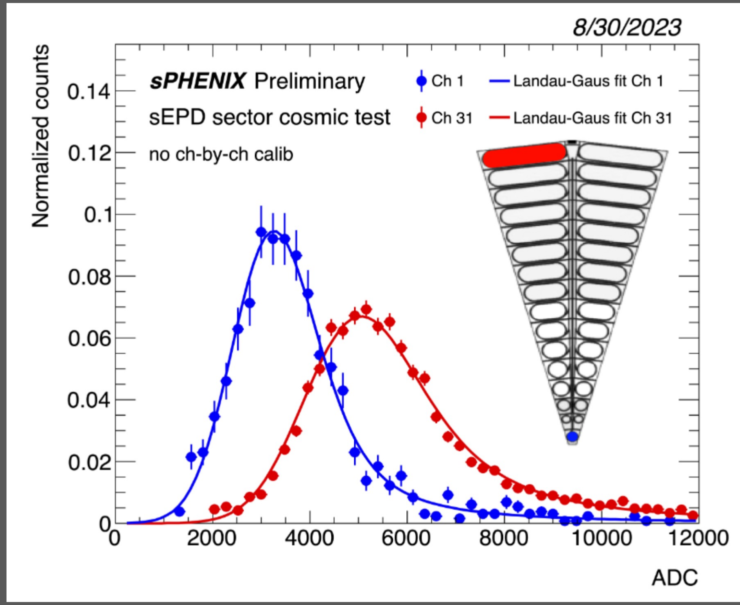
J. Adams et. al.
Nucl.Instrum.Meth.A 968 (2020) 163970



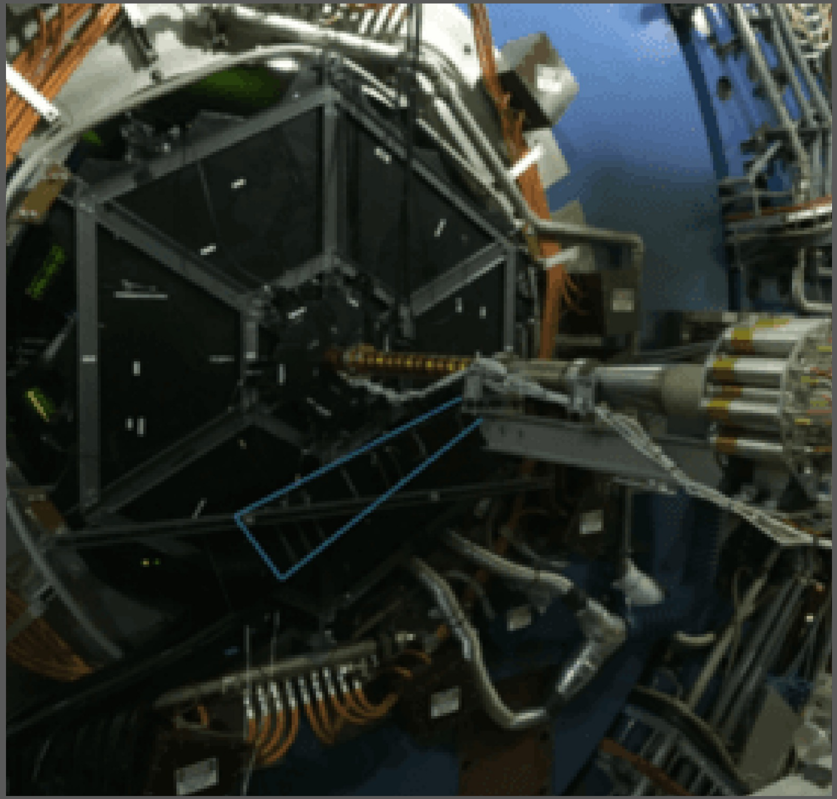


J. Park, QM 23





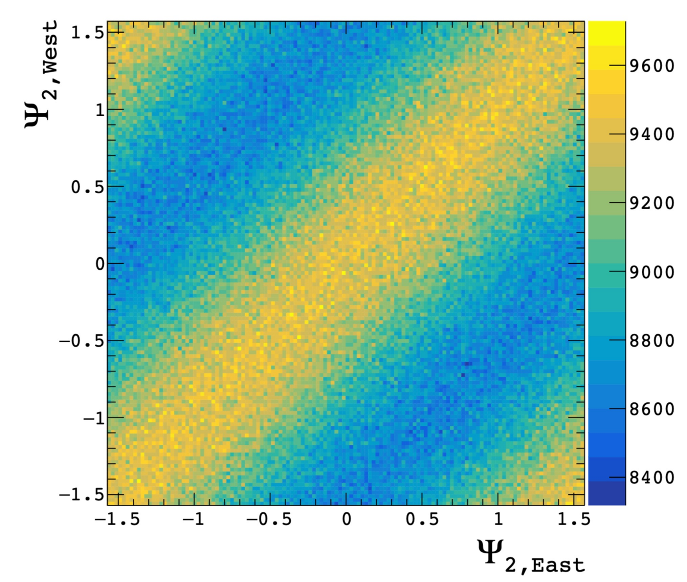
“Beam” tests at STAR



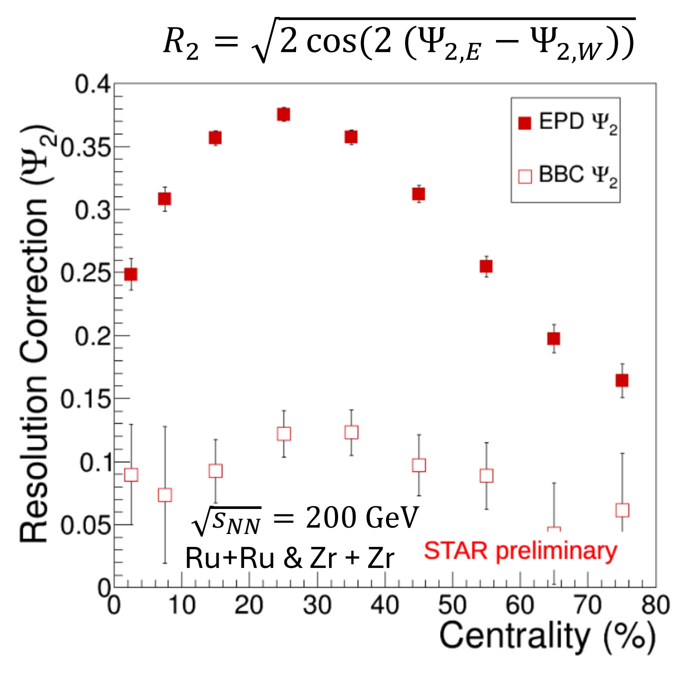
- Tests done at STAR in runs 15 through 17
- Allowed designs to be validated in the final environment
- Not repeated for sPHENIX – we knew how the design performs!
  - Saved significant time and cost

Event Plane Determination

- Measure Ψ_n independently of hard processes at mid-rapidity
  - ~1 unit of psuedorapidity separation
- Suppress jets, resonances from biasing Ψ_n
- 1.5~2.5 improvement over STAR Beam-Beam counter
- 2x resolution -> 4x statistics

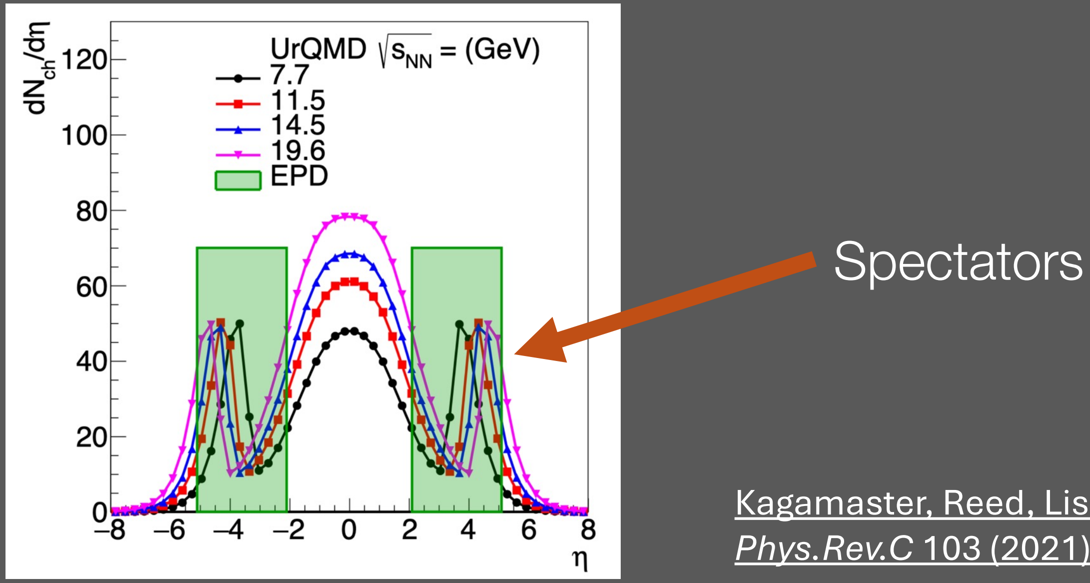


I. Upsal, QM 18

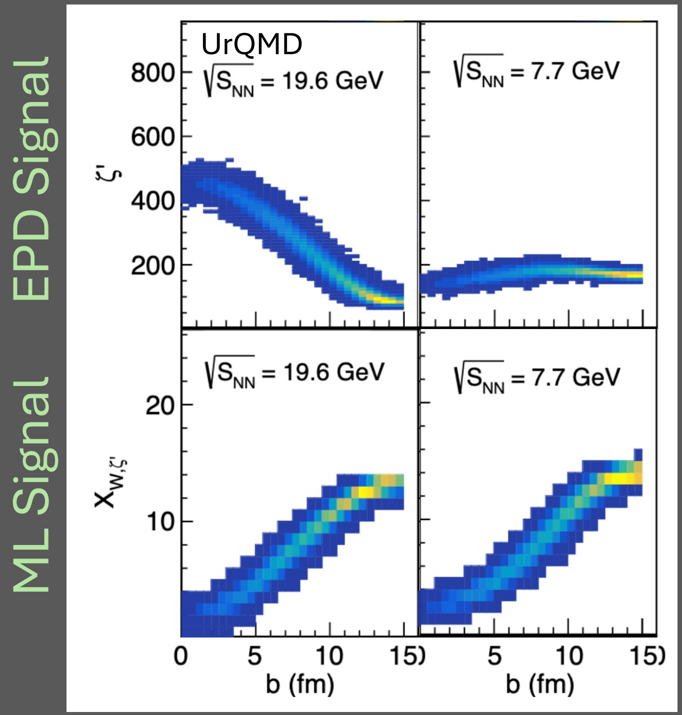


Centrality determination

- ❖ Good choice for measuring centrality
- ❖ At lower energies, need to deal with spectator contamination
- ❖ ML algorithm reweights rings to account for spectators



Kagamaster, Reed, Lisa, *Phys.Rev.C* 103 (2021) 4, 044902



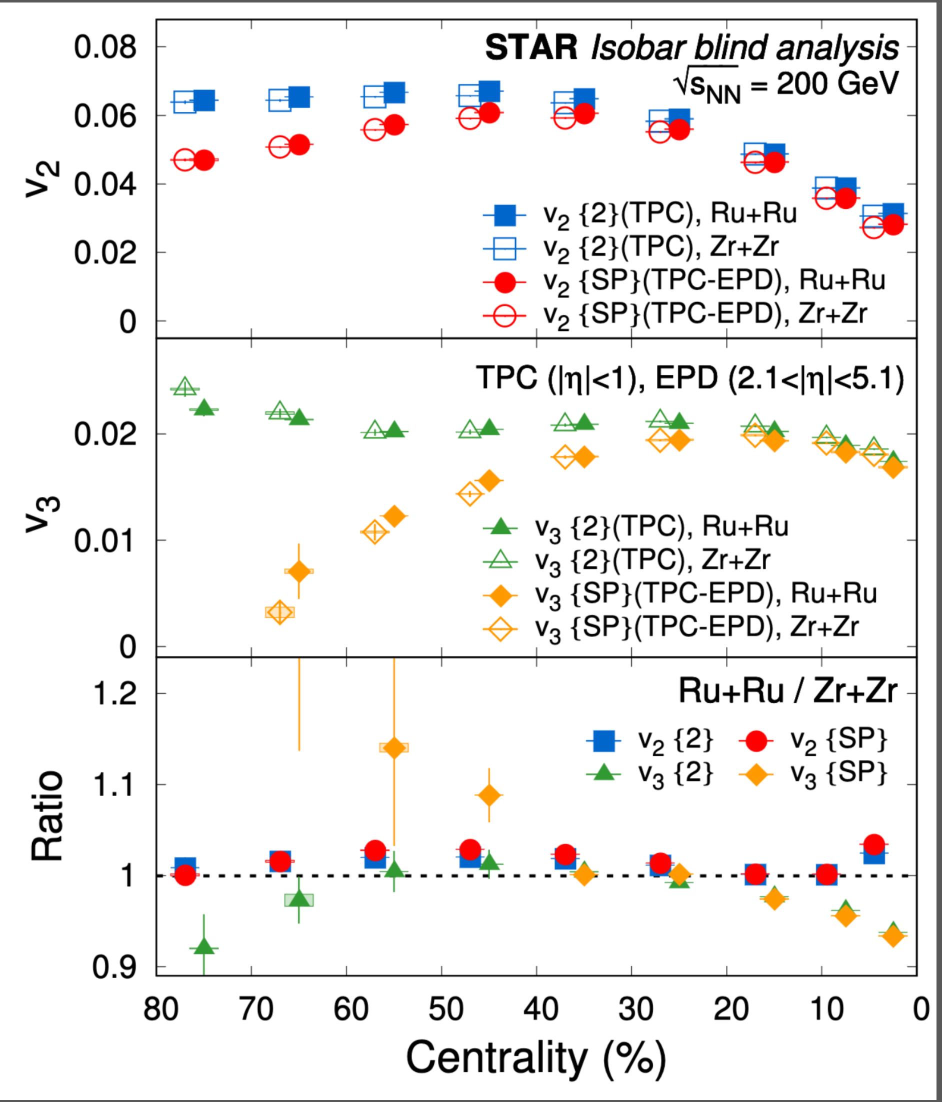
CME Background

- Many chiral magnetic effect observables have a v_2 background
  - Most significant to $\Delta\gamma_{112}$
- EPD offers independent measure of elliptic flow from TPC
  - Useful for controlling systematics

$$v_n\{\mathrm{SP}\}(\mathrm{TPC}-\mathrm{EPD}) = < \cos(n\phi - n\Psi_n^{\mathrm{EPD}}) >$$

$$= \frac{< Q_{n,TPC}Q^*_{N,EPDE} + Q_{n,TPC}Q^*_{n,EPDW} >}{2\sqrt{< Q_{n,EPDE}Q^*_{n,EPDW} >}}$$

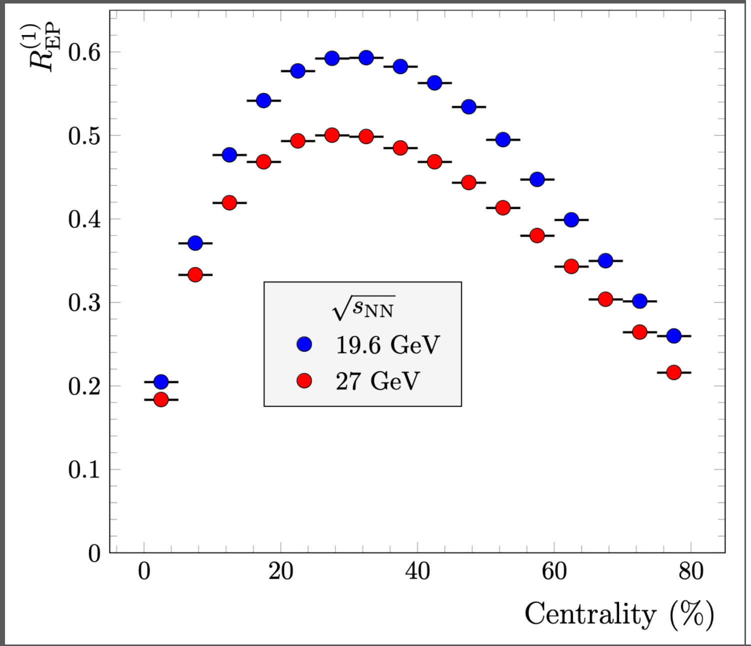
STAR Collaboration, *Phys.Rev.C* 105 (2022) 1, 014901

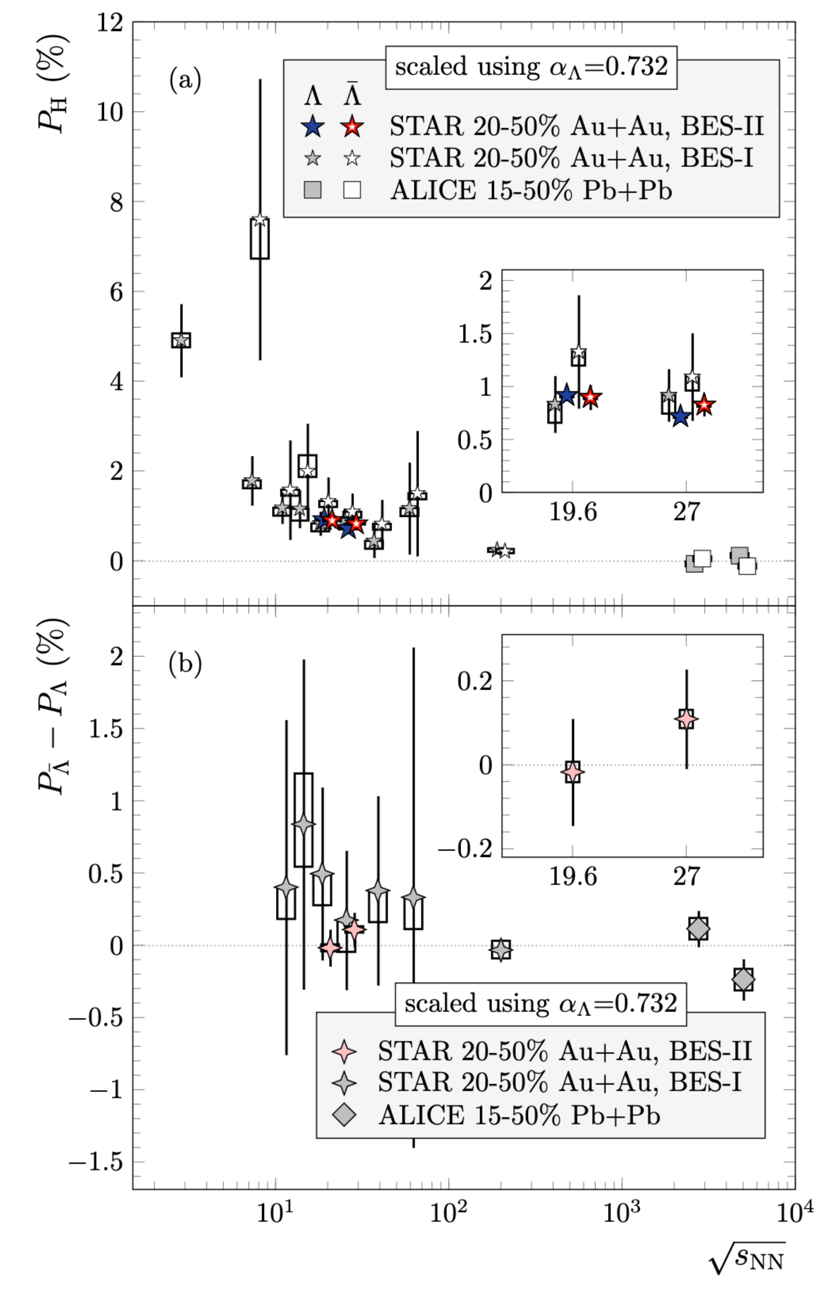


Λ Polarization

- ❖ Orbital angular momentum aligned with event plane
- ❖ Improved Ψ_1 resolution -> reduction in uncertainties
- ❖ Increased BES-II data and EPD upgrade show no splitting

STAR Collaboration, *Phys.Rev.C* 108 (2023)

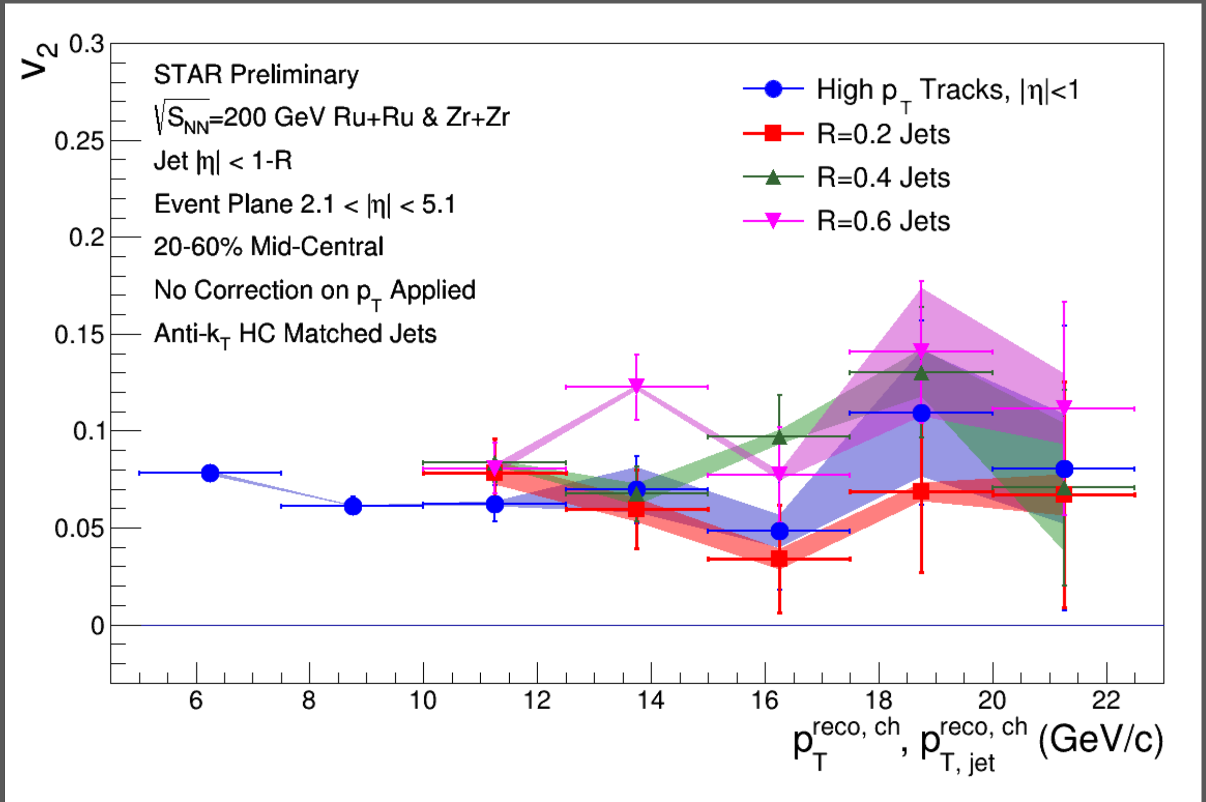




Jet v_2

T. Protzman, Hard Probes 2023

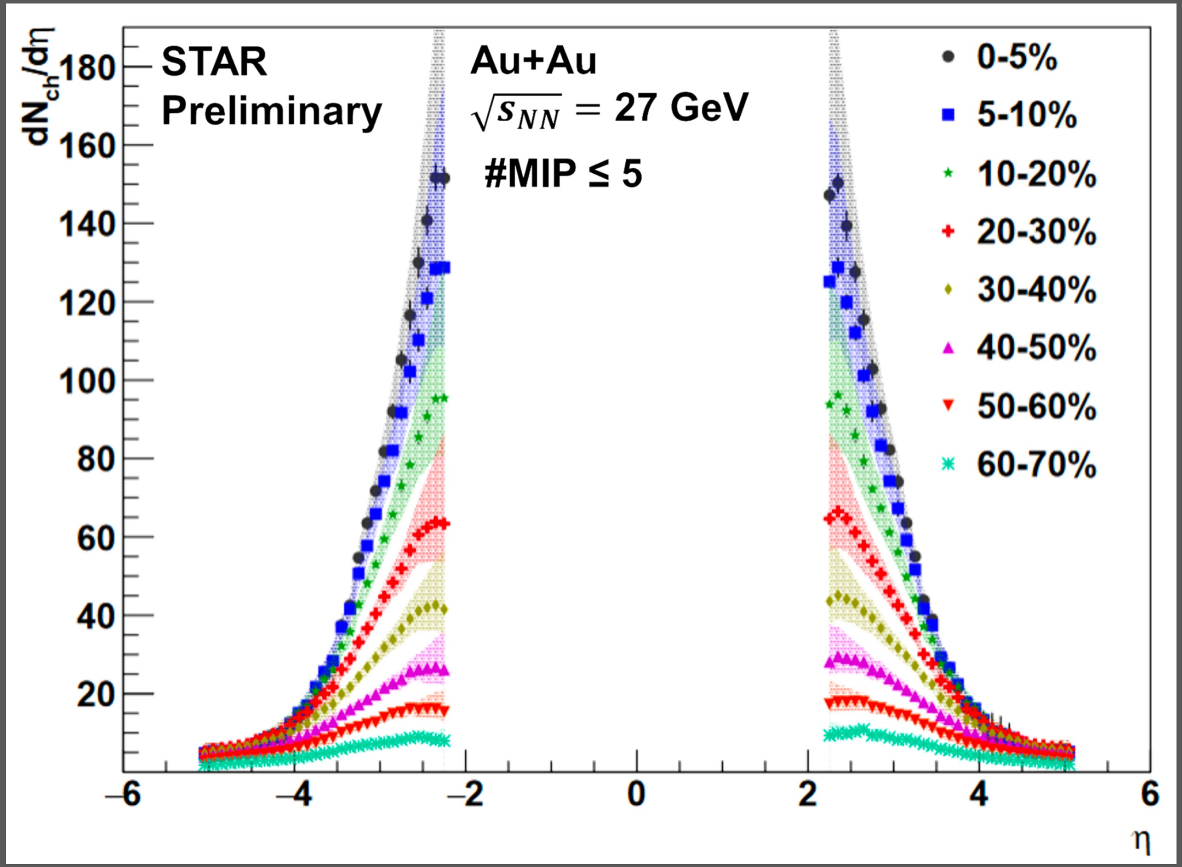
- Forward detector removes autocorrelation between jet finding and event plane measurement
- Hint of positive jet v_2 observed in mid-central Ru+Ru and Zr+Zr collisions
- May be interpreted as path-length dependent quenching



$dN/d\eta$

M Molnár, *Universe* 9 (2023) 7, 335

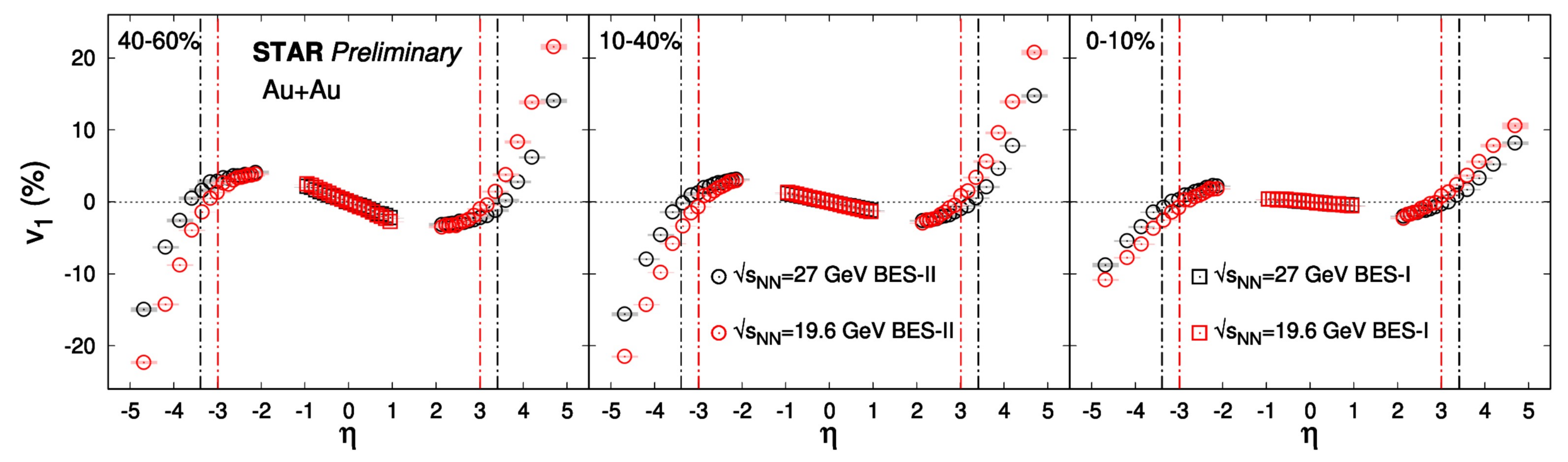
- EPD used to measure particles of interest
- Radial segmentation allows η dependent measurements
- Unfolded for secondary scatterings and neutral decays



v_1

- ❖ Allows measurement of v_1 over 10 units of pseudorapidity
- ❖ Sensitive to shear viscosity, baryon stopping, EoS, …
- ❖ Change in sign around beam rapidity observed

X. Liu, QM 23



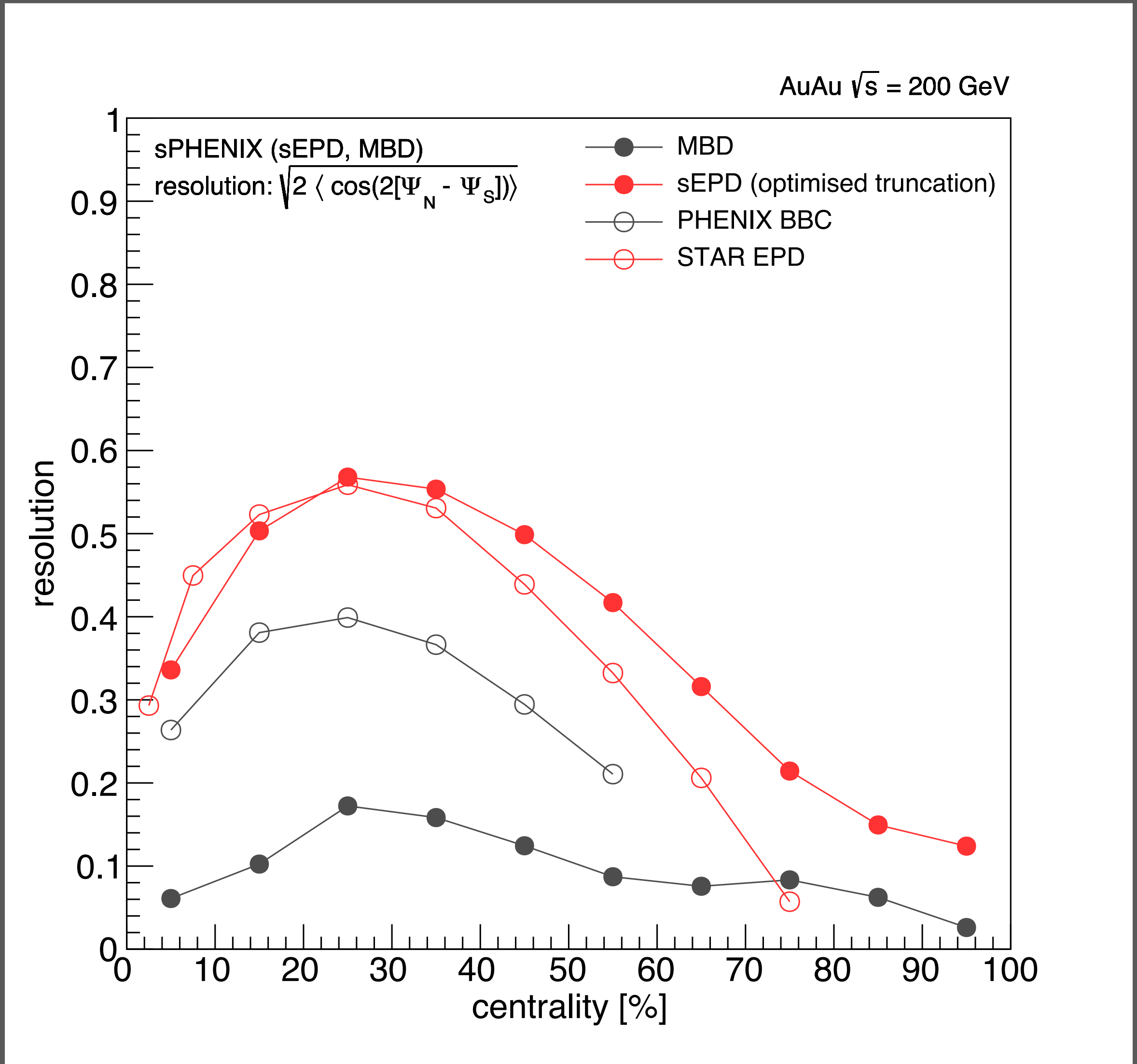
Prospects at sPHENIX

Installation

- Installation at sPHENIX delayed to maintain access to tracking detectors
- First two sectors instrumented mid-run
- Remaining installation was scheduled two days after the early end of the RHIC run

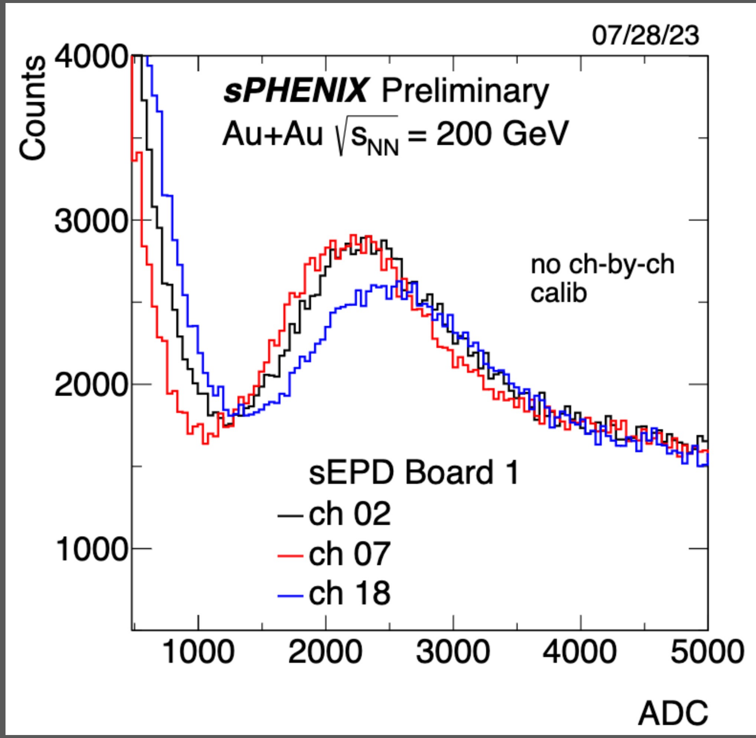
Resolution

- ❖ NSF MRI upgrade to sPHENIX detector
- ❖ Factor of ~3 improvement over base detector, relying on Minimum Bias Detector for centrality
  - o Larger acceptances, finer segmentation



Performance

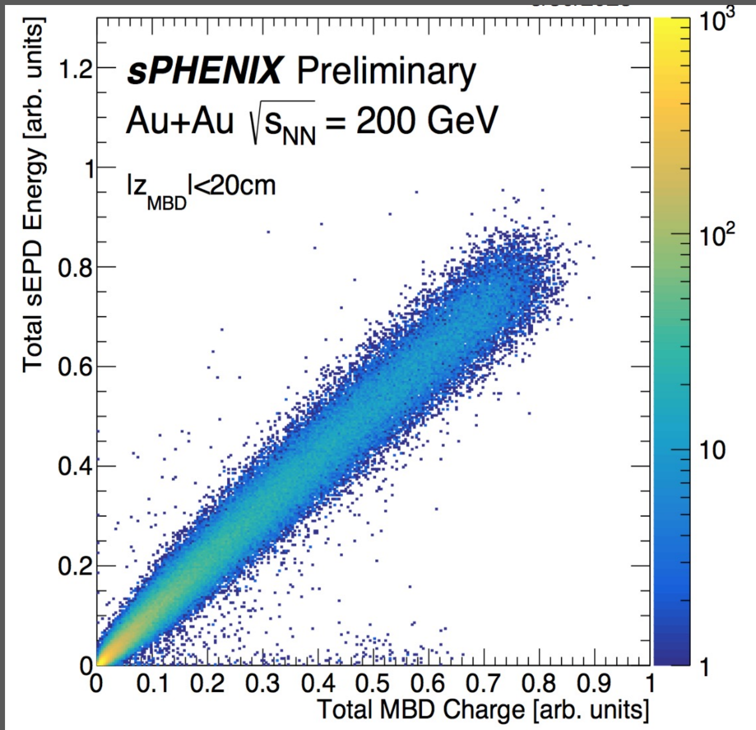
- ❖ MIP peak observed in all instrumented channels



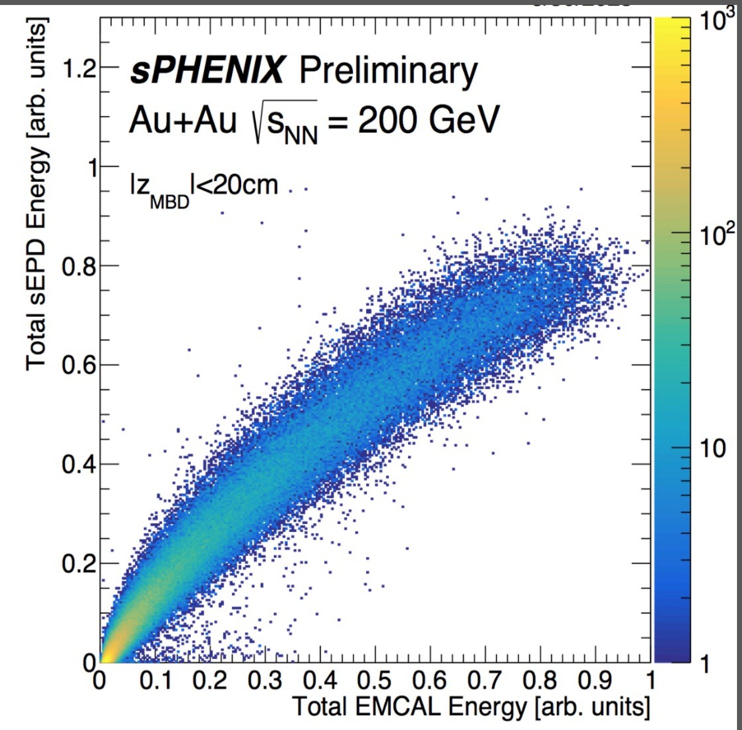
- ❖ Strong correlation observed between sEPD and MBD, EMCal

J. Park, QM 23

sEPD



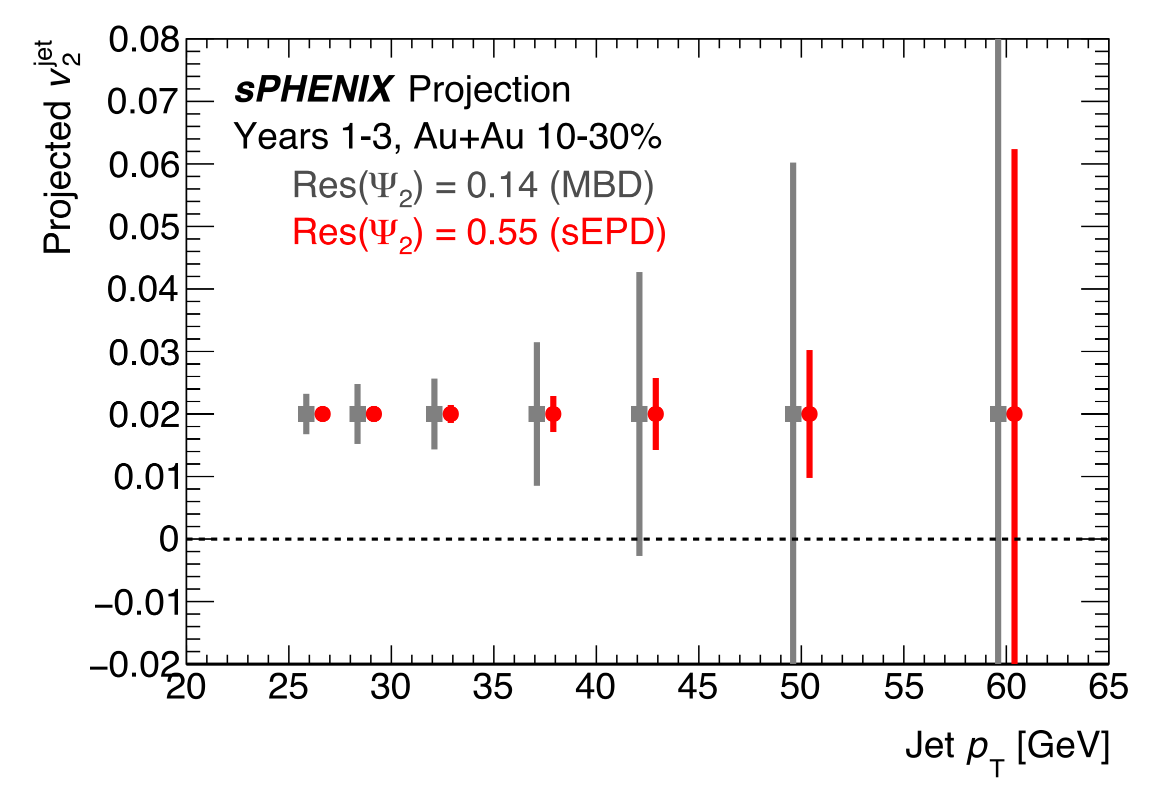
MBD



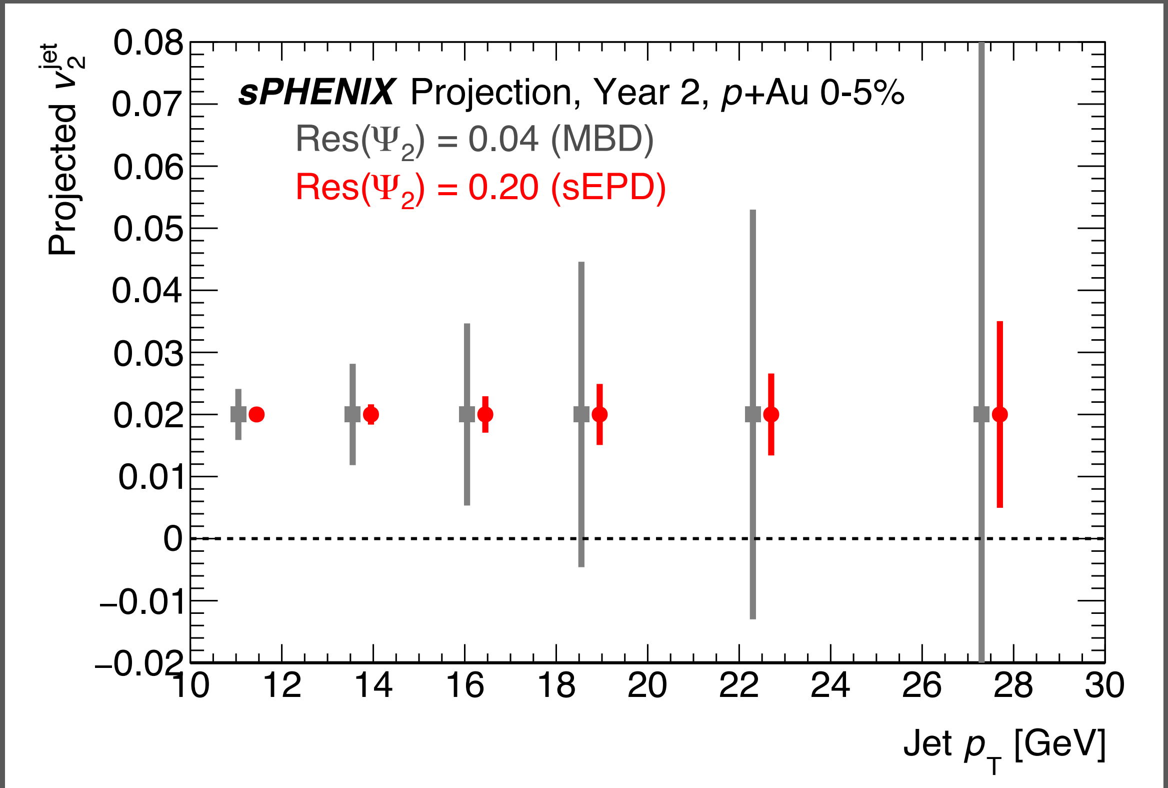
EMCal

Projections - AA

- Will be able to significantly reduce uncertainties in jet v_2 measurement
- First jet measurements at RHIC to include hadronic component
- Better control over path-length dependent energy loss



Projections - pA



- ❖ sEPD enables precise and differential measurement of jet v_2 in pA
- ❖ Probe jet modification in small systems

Collaborating Institutions and Funding

STAR: NSF Grants 1614835 and 1614474, Ministry of Science and Technology (MoST) of China under grant No. 2016YFE0104800

sPHENIX: NSF MRI 2117773

STAR

The Ohio State University
Berkeley Lab
Indiana University
University of Science and Technology of China (1958)
National Cheng Kung University (1931)
Brookhaven National Laboratory
Lehigh University
Fudan University (1905)

sPHENIX

Lehigh University
Iowa State
University of Colorado Boulder
UNCG
Brookhaven National Laboratory
Muhlenberg College

Conclusions

- ❖ Event Plane Detectors provide charged particle distributions at forward rapidities
- ❖ Significant improvement to event plane resolution
  - o 2x improvement ≈ 4x statistics
- ❖ Wide range of uses have been explored
  - o Flow, CME, polarization, jets, triggering
- ❖ Complimentary detectors at STAR and sPHENIX