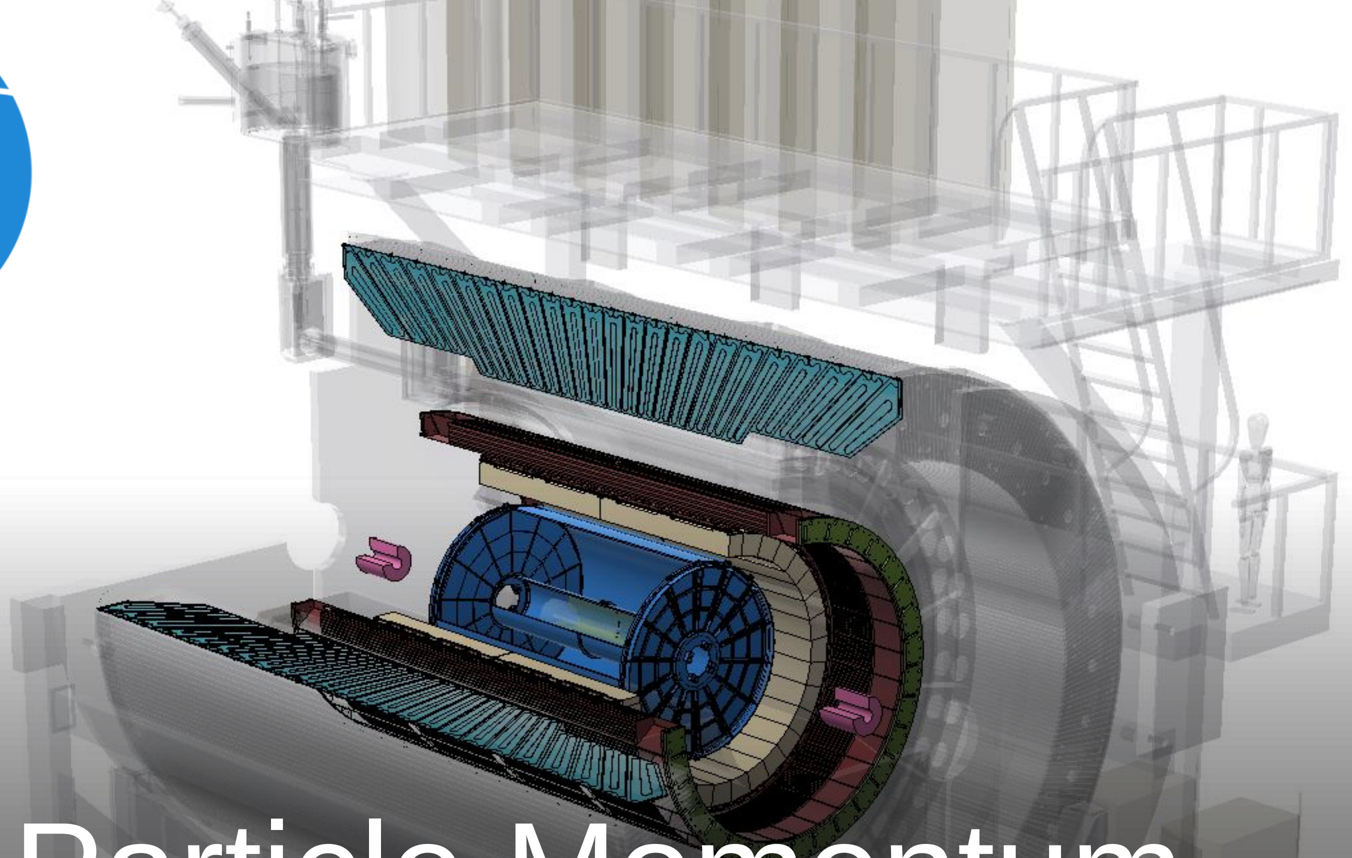


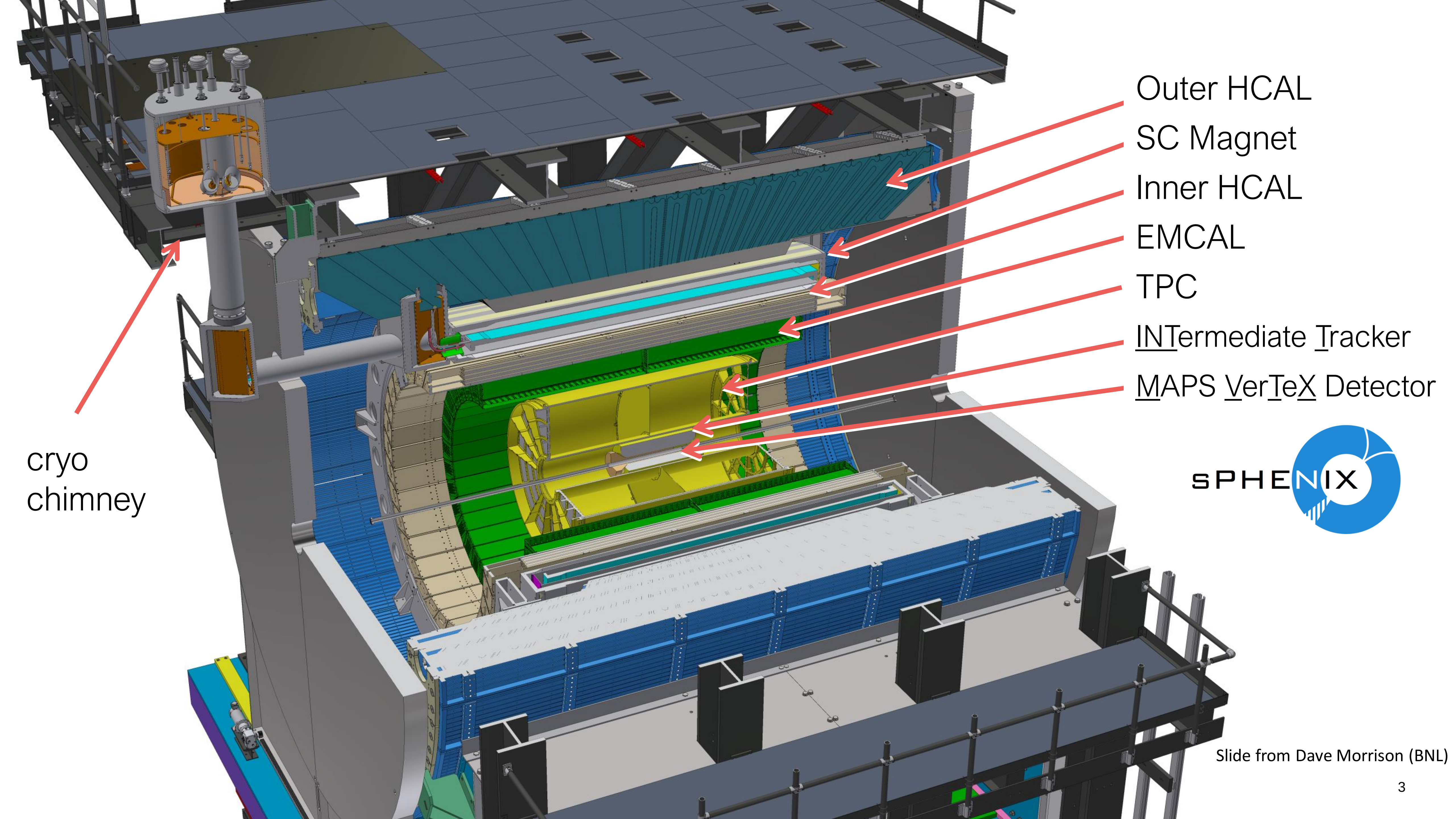
Charged Particle Momentum Resolution of the sPHENIX TPC

Henry Klest

Stony Brook University

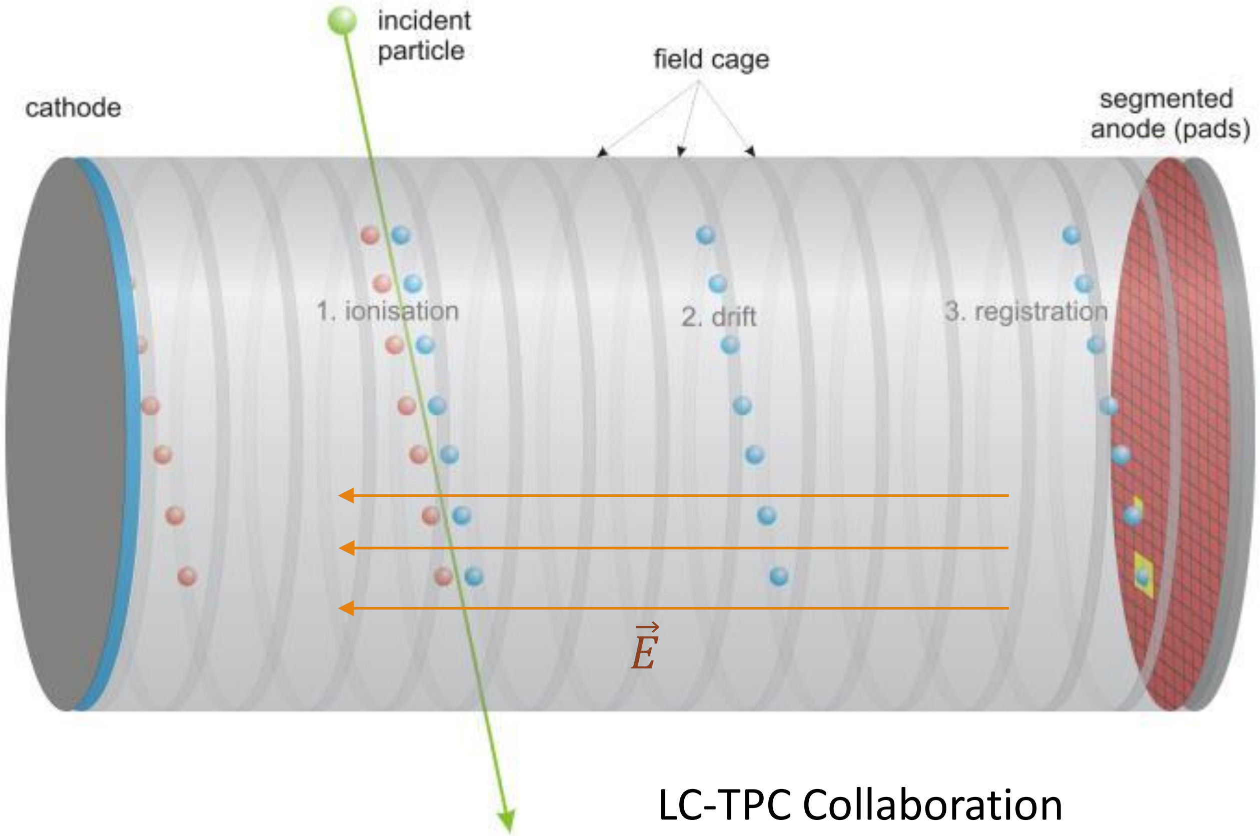
3rd JETSCAPE Workshop

Assembling Large Field Cage



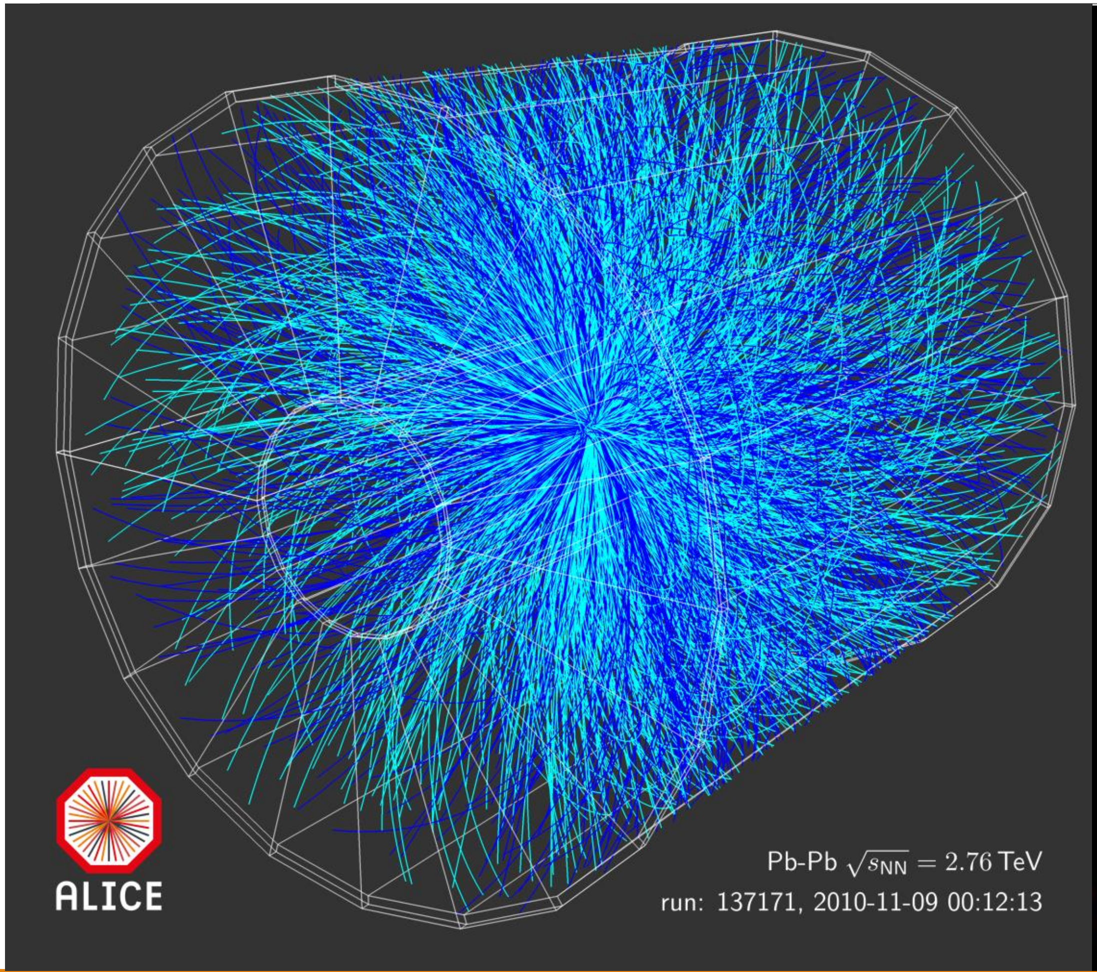
Slide from Dave Morrison (BNL)

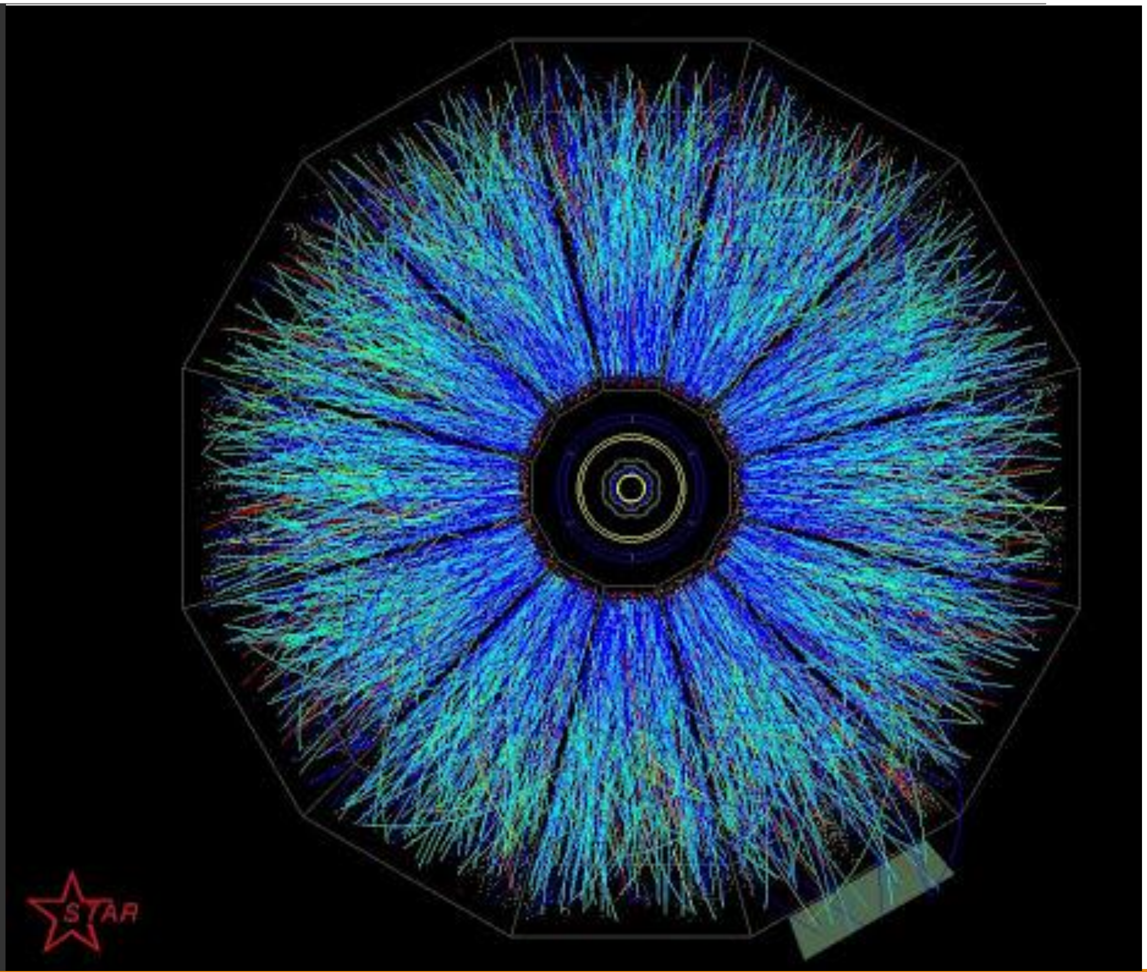
How does a Time Projection Chamber work?



LC-TPC Collaboration

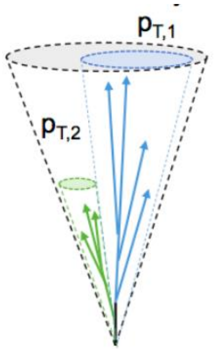
Add a magnetic field and you've got a detector

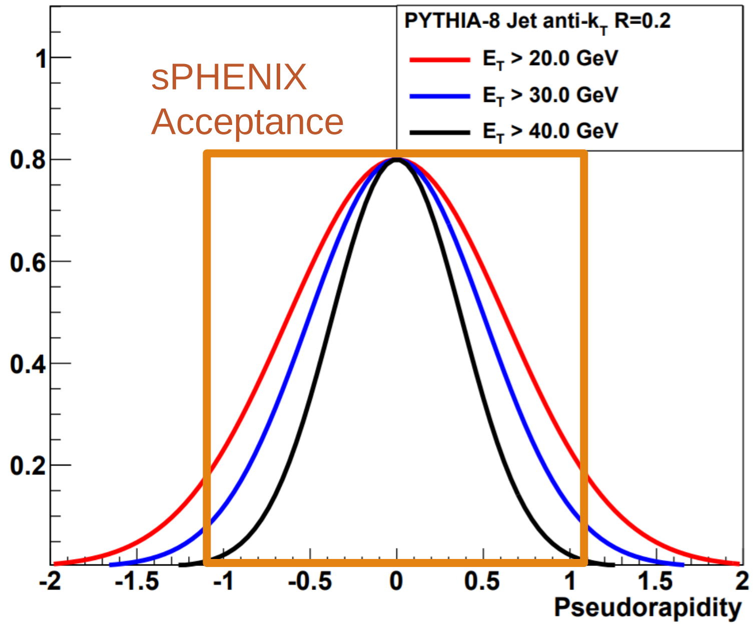


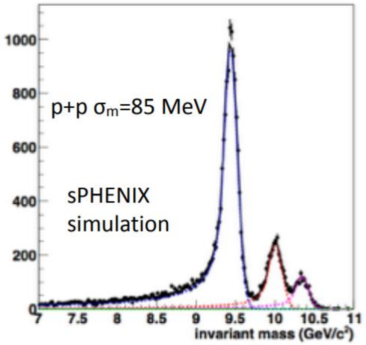


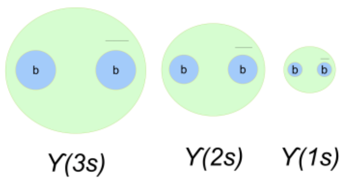
sPHENIX Physics Goals + the TPC's Role

- **Jet Structure**
  - Fragmentation functions at High and Low z
    - Low z ⟶ large acceptance, and $\frac{\sigma_p}{p} \leq 1\% * p$
    - High z ⟶ momentum resolution $\frac{\sigma_p}{p} \leq .2\% * p$ for ~40 GeV/c charged particle
- **Jet Correlations**
  - Tracking coverage of full azimuth, |η| < 1.1
  - High jet tracking efficiency
- **Parton Energy Loss**
  - Precise position and momentum measurement of tagged heavy flavor jets
- **Quarkonium Spectroscopy**
  - Upsilon, J/Psi daughter electrons measured with invariant mass resolution ~125 MeV









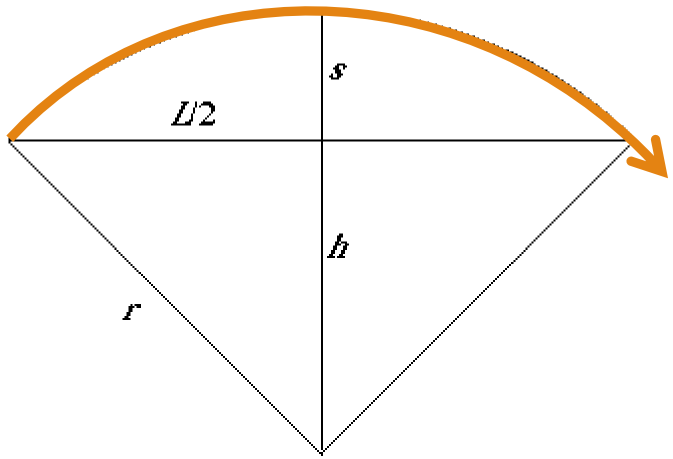
Position to momentum resolution

- In a homogenous magnetic field: $\rho = \frac{p_T}{q \cdot B}$

$$\frac{\sigma_p}{p} \propto \sigma_x * \frac{p_T}{BL^2\sqrt{N_{Pad\ Rows}}}$$

Gluckstern, 1963

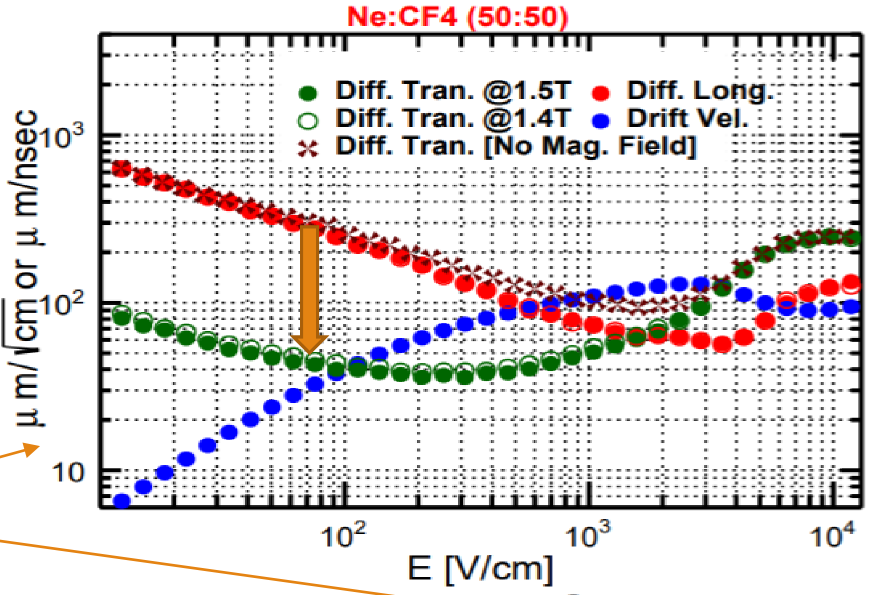
- sPHENIX TPC has 48 pad rows in r – ideally yields 48 precise measurements of position
- Due to size constraints, L and $N_{\text{pad rows}}$ are smaller than STAR, ALICE, difference compensated in B, σ_x
- sPHENIX TPC will have ~400 tracks/event in min bias compared to ~900 at ALICE



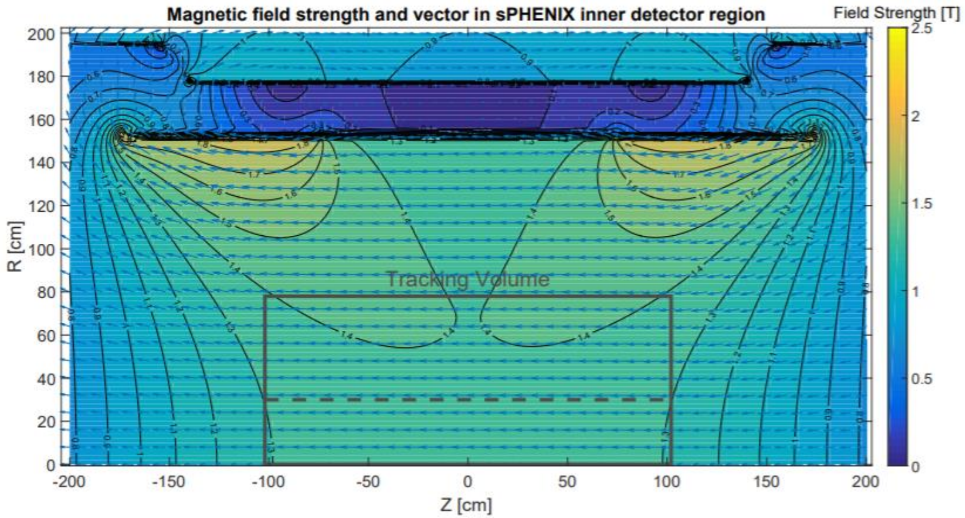
p_T error ∝ error in measurement of s (Sagitta of curve)

TPC Design Considerations

- **High Position Resolution**
  - 1.4T B-field improves high-p_T momentum resolution, significantly decreases transverse diffusion in gas, σ_x strong function of B
  - Must combat space charge distortion of tracks ⟶ gas selection, laser calibration, ion backflow suppression
- **High Statistics**
  - Maximize statistics of rare probes
  - Streaming readout and ungated gain stage ⟶ **no dead time!**
  - Rate capability increased by a factor of 10 over gated TPCs
- **Low Material Budget**
  - Minimize multiple scatterings/photon conversions
- **Size**
  - Allow room for calorimetry inside magnet
  - Takes advantage of most uniform section of magnetic field inside solenoid

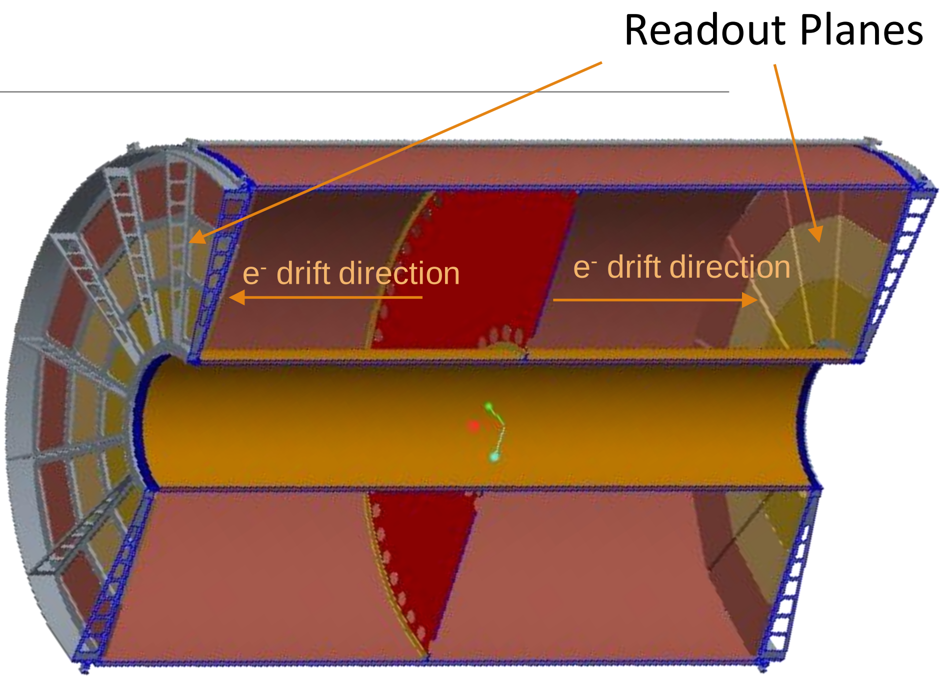


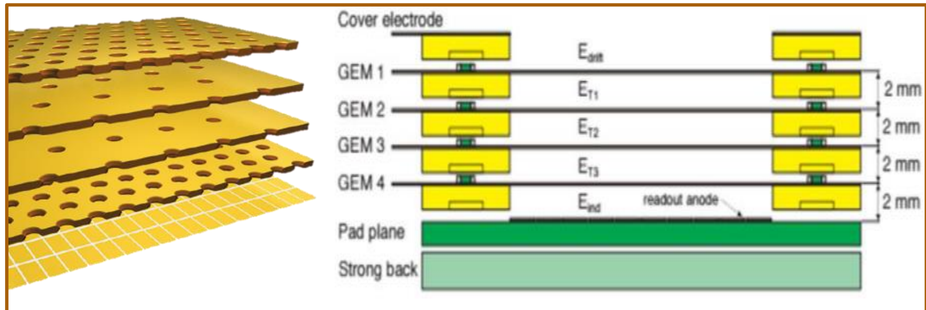
$$\sigma_x^2 = \sigma_{pad}^2 + \frac{D_T^2 L}{N_{eff}} + \sigma_{sc}^2$$



sPHENIX TPC Design

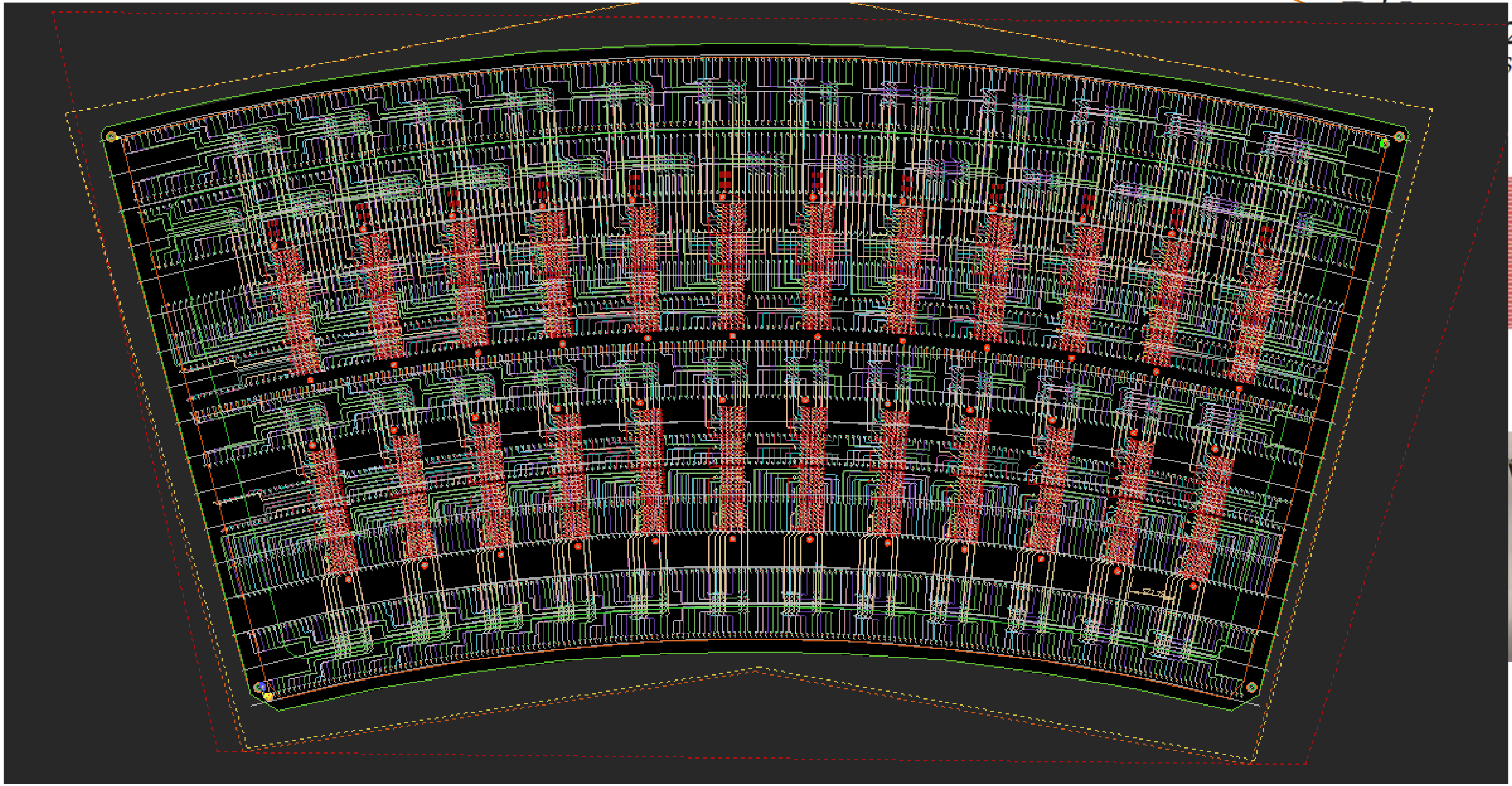
- 20 cm < r < 78 cm, |η| <1.1 (2.11 meters long)
  - Outer radius smaller than ALICE inner radius!
- 1-meter drift length in Ne:CF4 50-50 mixture
- Metallized central "membrane" held at 40 kV, drift field of 400 V/cm
- Utilizes 4 stacked gas electron multipliers (GEMs) to produce signal from single ionized electrons, same as ALICE upgrade

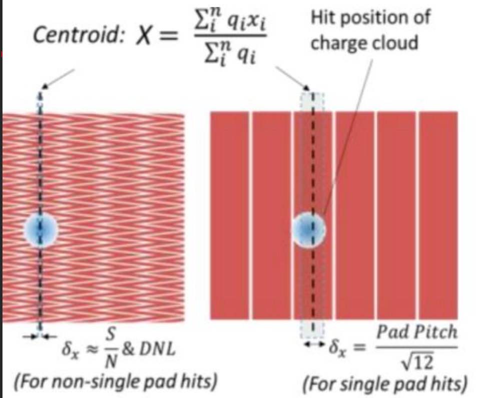


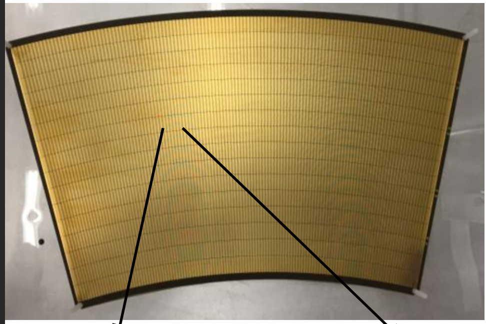


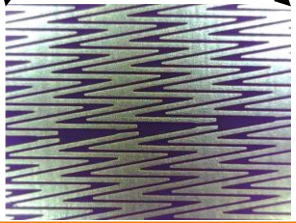
ALICE TPC Collaboration

Transverse diffusion coefficient

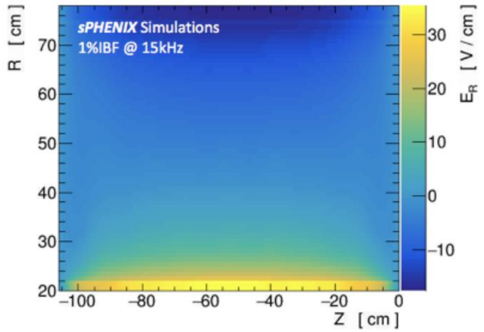




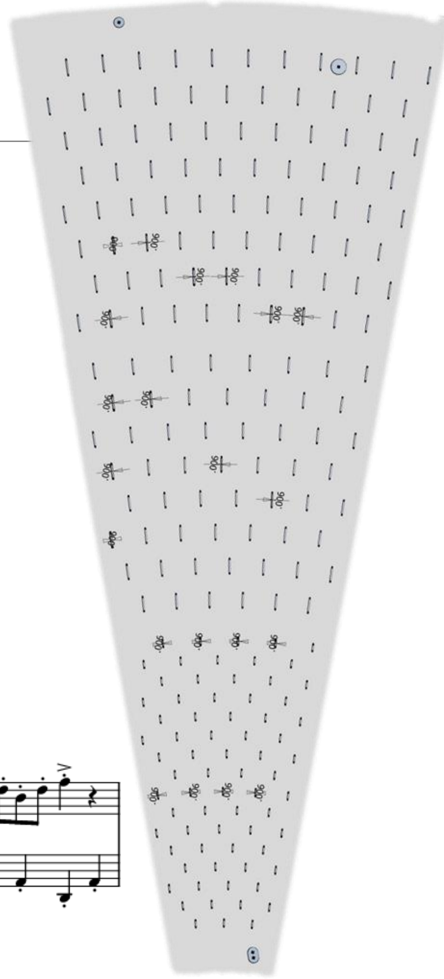




Space Charge Correction

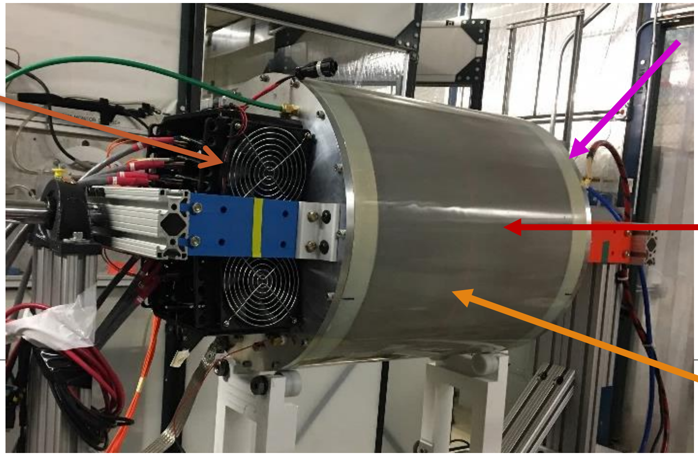


- Want to measure space charge distortions to apply correction
  - Transient distortions from varying track density on top of static distortions
- Solid gold-coated central membrane, with aluminum stripes
- Diffuse laser inside TPC shining on Al produces electrons via photoelectric effect
  - No e^- from gold
  - Know where the e^- originated
  - Know where it ended up from normal readout
  - Can build a (time-dependent!) map of distortions

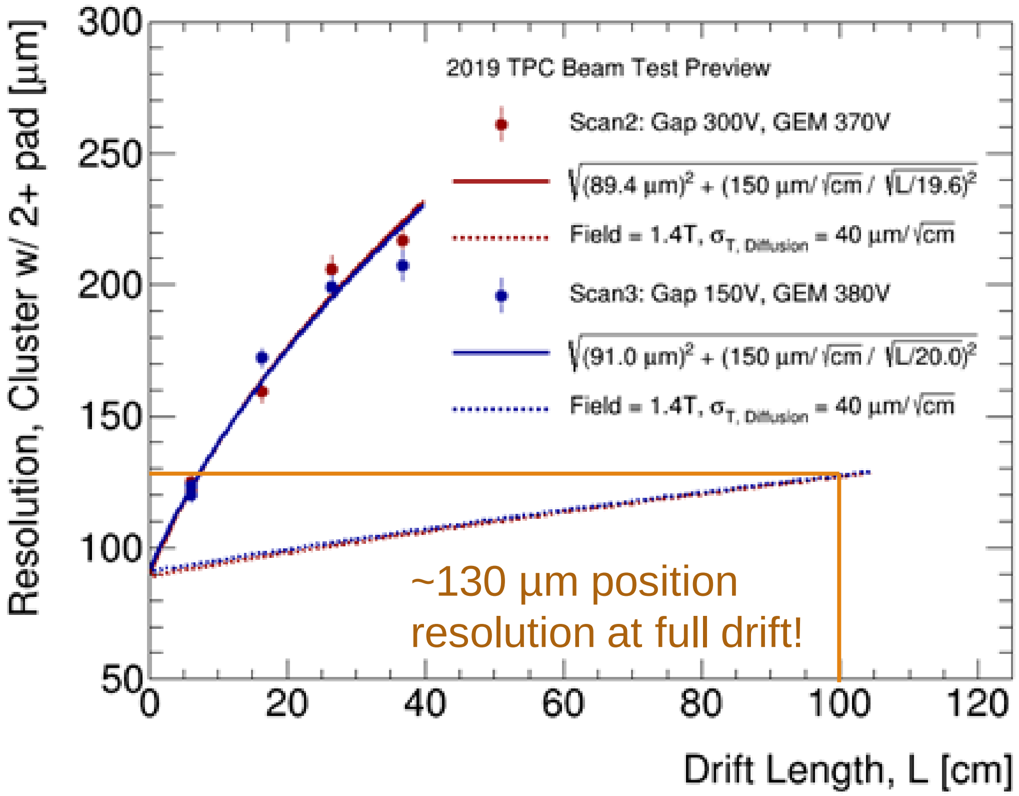


Uniquely identifiable pattern of modified stripes – “In the Hall of the Mountain King” by Edvard Grieg

Test Beam Results



- Prototype TPC introduced to 120 GeV/c proton beam at FNAL
- 40-cm one sided TPC with one full readout module (4 GEMs + pad plane + real front-end electronics)
- 3-D position controlled to mimic tracks at different angles, drift lengths
- Caveats: no space charge, no multiple scattering

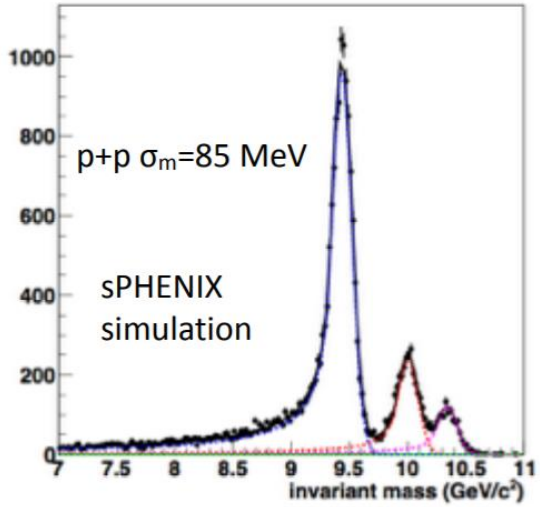


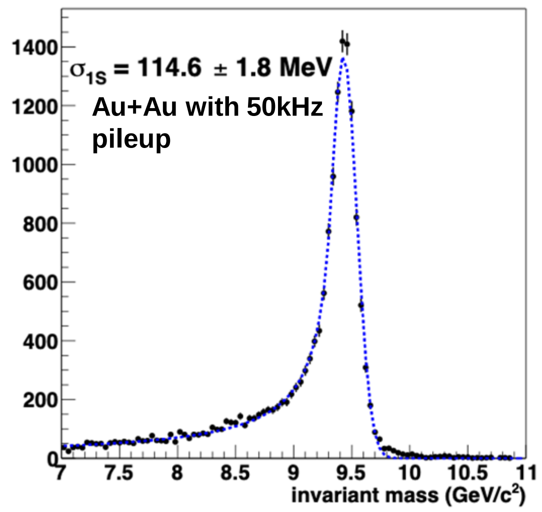
Decreased L improves σ_x

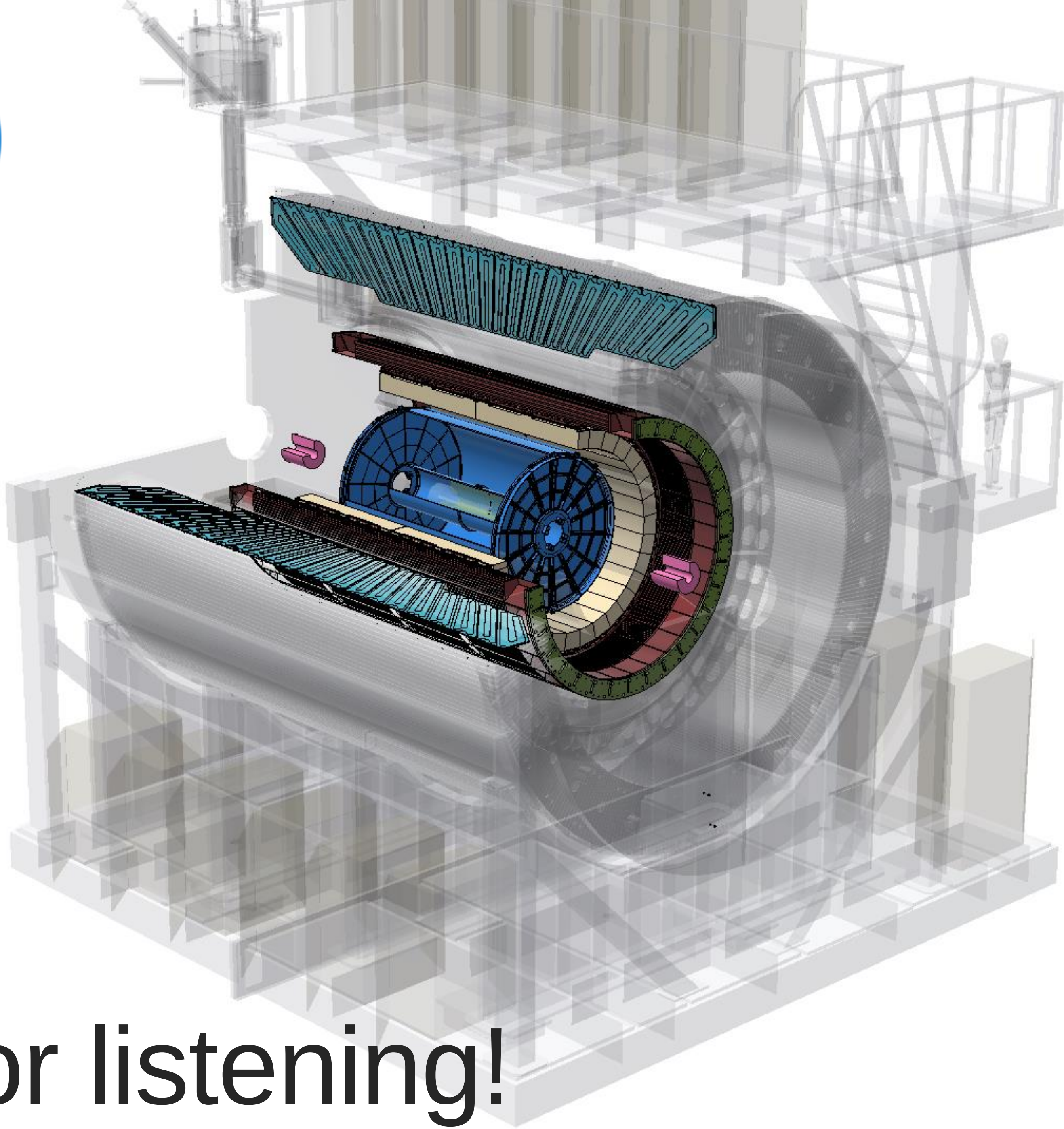
$$\sigma_x^2 = \sigma_{pad}^2 + \frac{D_T^2 L}{N_{eff}} + \sigma_{sc}^2$$

Test Beam Results (Cont.)

- Tracks with shorter drift will naturally have higher position resolution due to decreased diffusion in gas
- Integrated over N_{ch} and η, average e^- drift length is 75 cm, position resolution is 115 μm, Upsilon invariant mass resolution of ***TPC alone*** is ~100 MeV
- Preliminary result corresponds to a momentum resolution of $\frac{\sigma_p}{p} \approx .2\% * p$
- **TPC meets sPHENIX physics needs!**

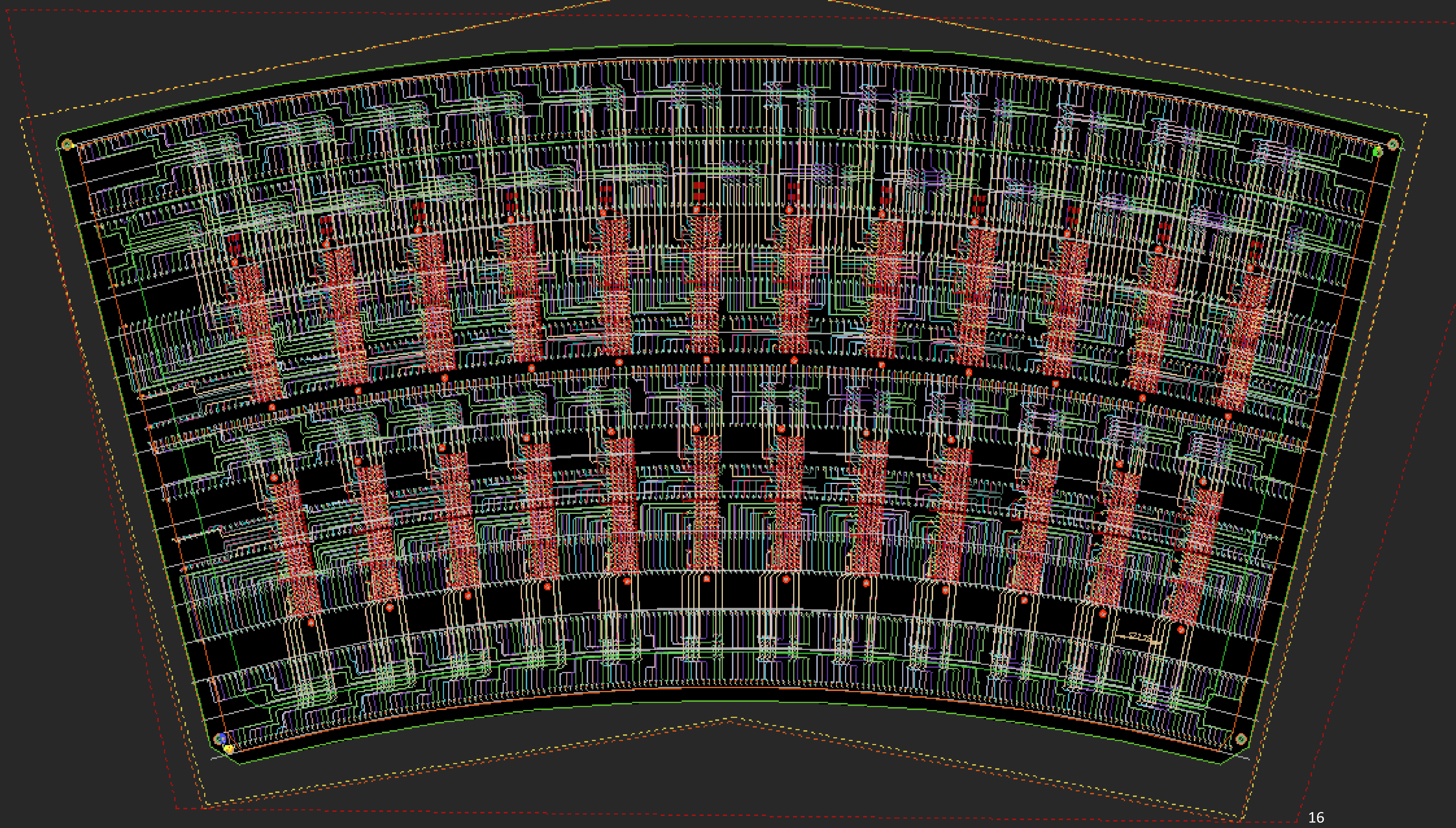






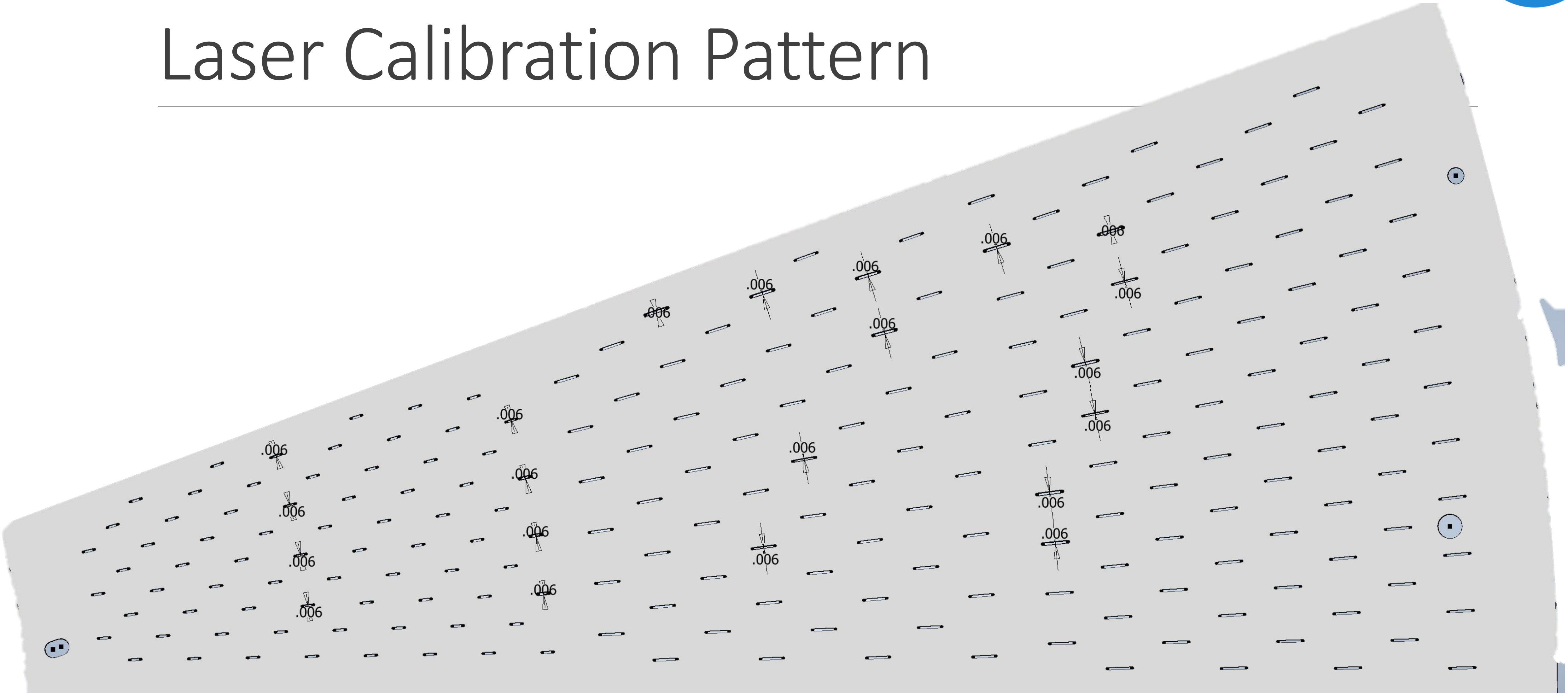
Thanks for listening!

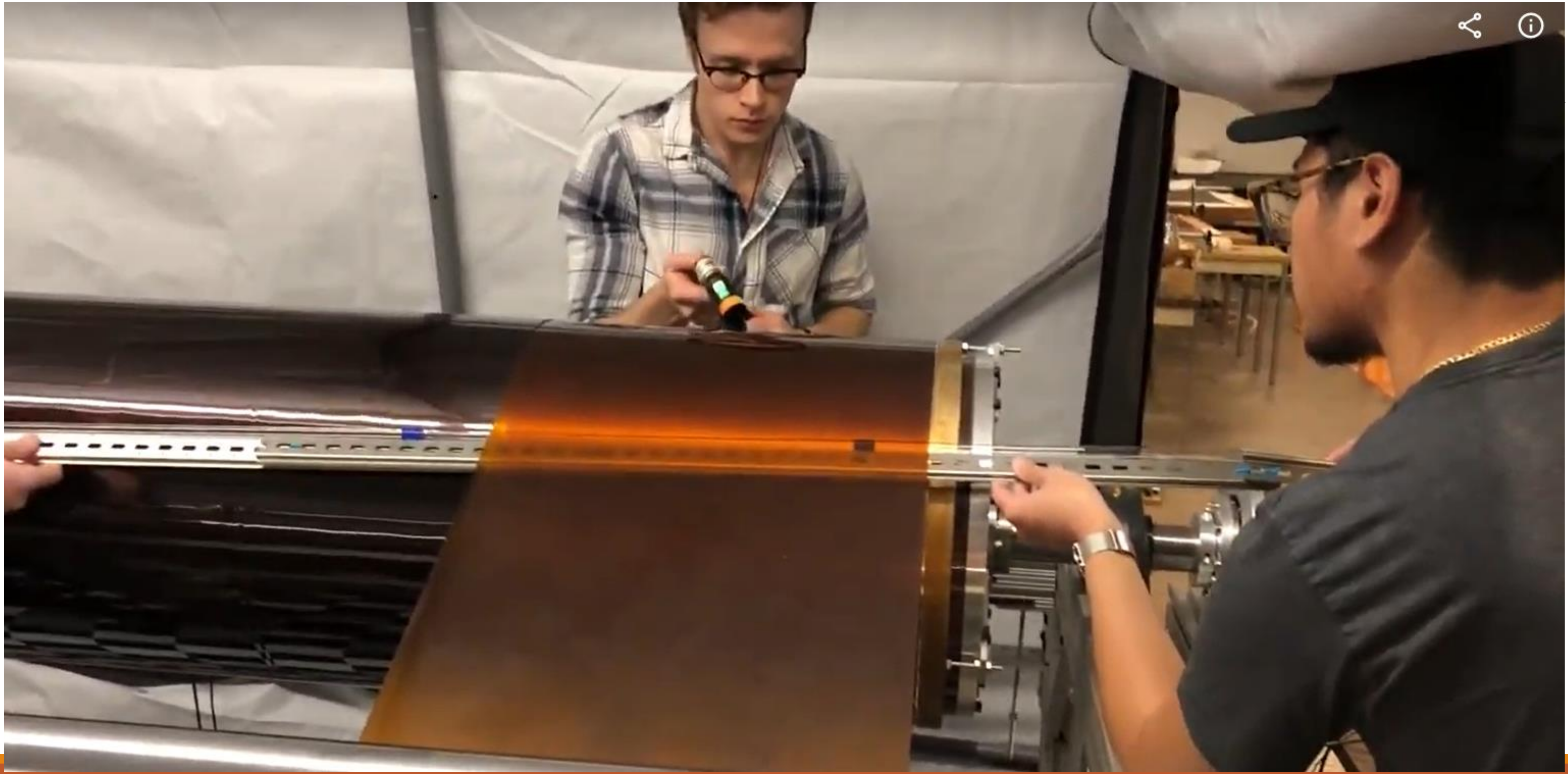
Backup

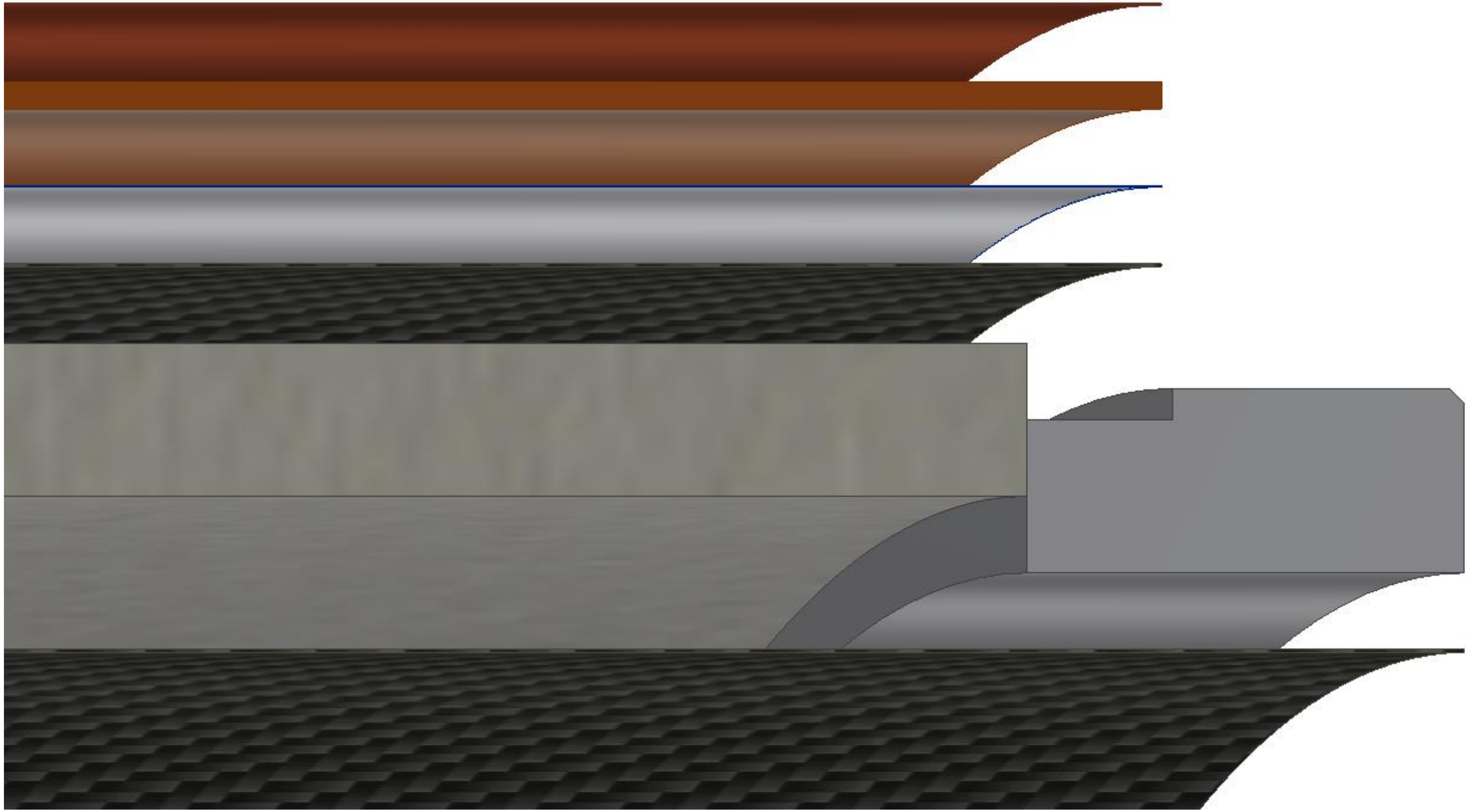


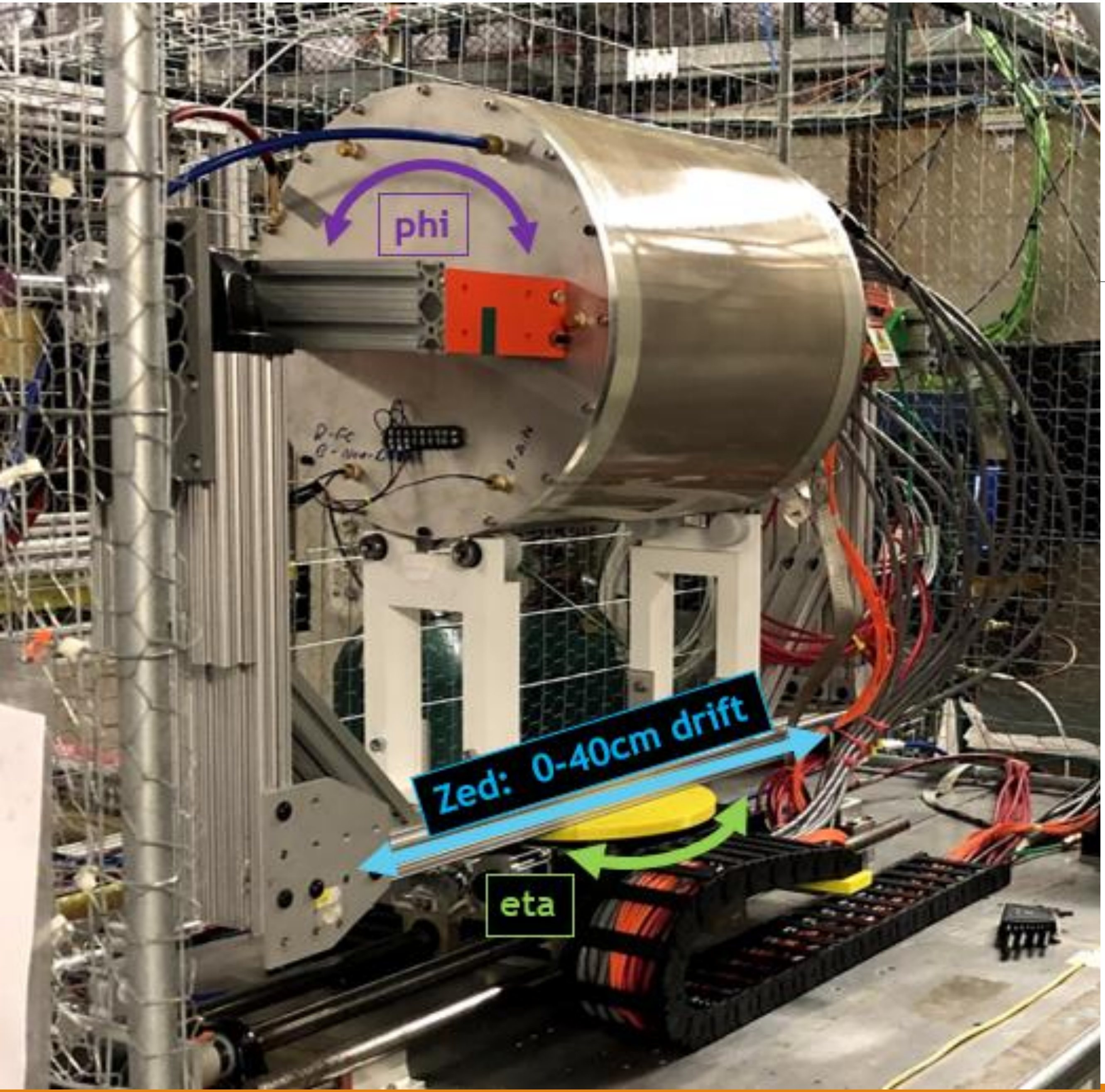
Parameters	sPHENIX (Au+Au 200 GeV)	ALICE (Pb+Pb 5.5 TeV)
dN/dy (Minbias) η coverage of TPC # of tracks in TPC	180 2.2 ($\vert\eta\vert < 1.1$) 396	500 1.8 ($\vert\eta\vert < 0.9$) 900
Effective # of tracks in TPC (accounted for r-dep. η coverage change)	560	1690
Effective factor for track # increase for accounting albedo background	2	2
# of measurements in r # of samples in ϕ # of samples in timing # of bits of each sample	40 3 5 10	159 2 10 10
Data volume increase factor by SAMPA header	1.4	1.4
Data volume/event (bits) Data volume/event (bytes)	9.41×10^6 1.18×10^6	1.50×10^8 1.88×10^7
Collision rate [kHz]	100	50
Total data rate (bits/sec) Total data rate (bytes/sec)	9.41×10^{11} 1.18×10^{11}	7.52×10^{12} 9.41×10^{11}

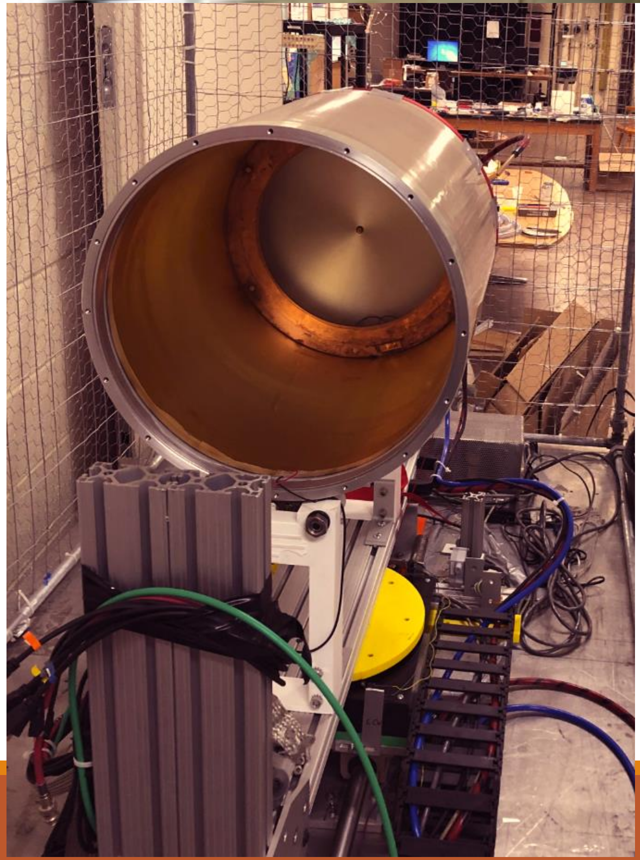
Laser Calibration Pattern

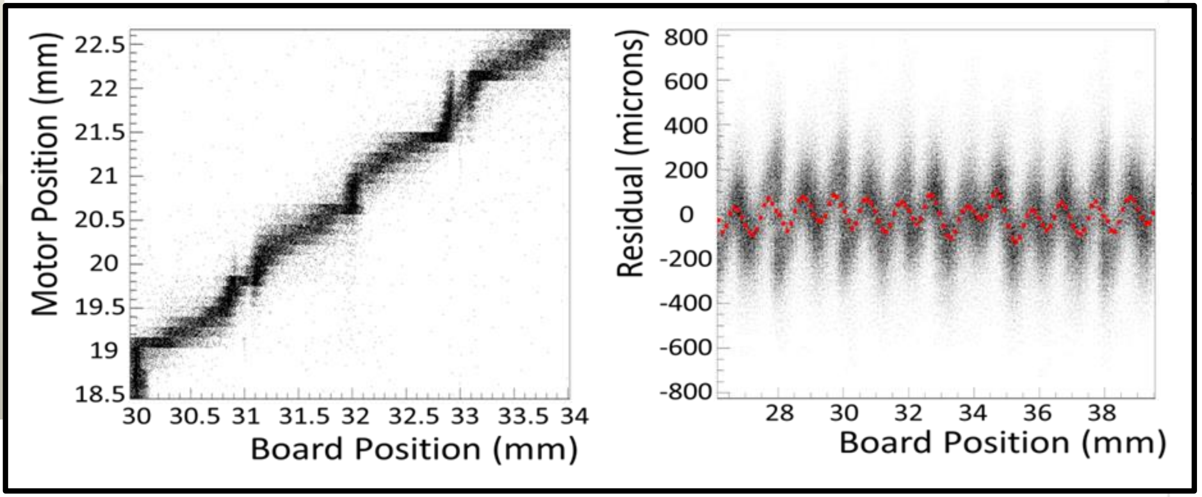




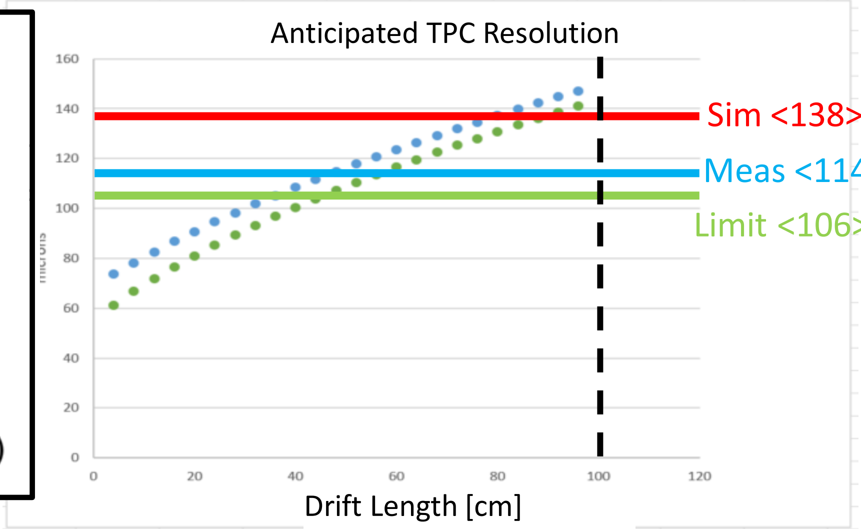



phi
Zed: 0-40cm drift
eta





Motor Position (mm)
22.5
22
21.5
21
20.5
20
19.5
19
18.5
30 30.5 31 31.5 32 32.5 33 33.5 34
Board Position (mm)
Residual (microns)
800
600
400
200
0
-200
-400
-600
-800
28 30 32 34 36 38
Board Position (mm)



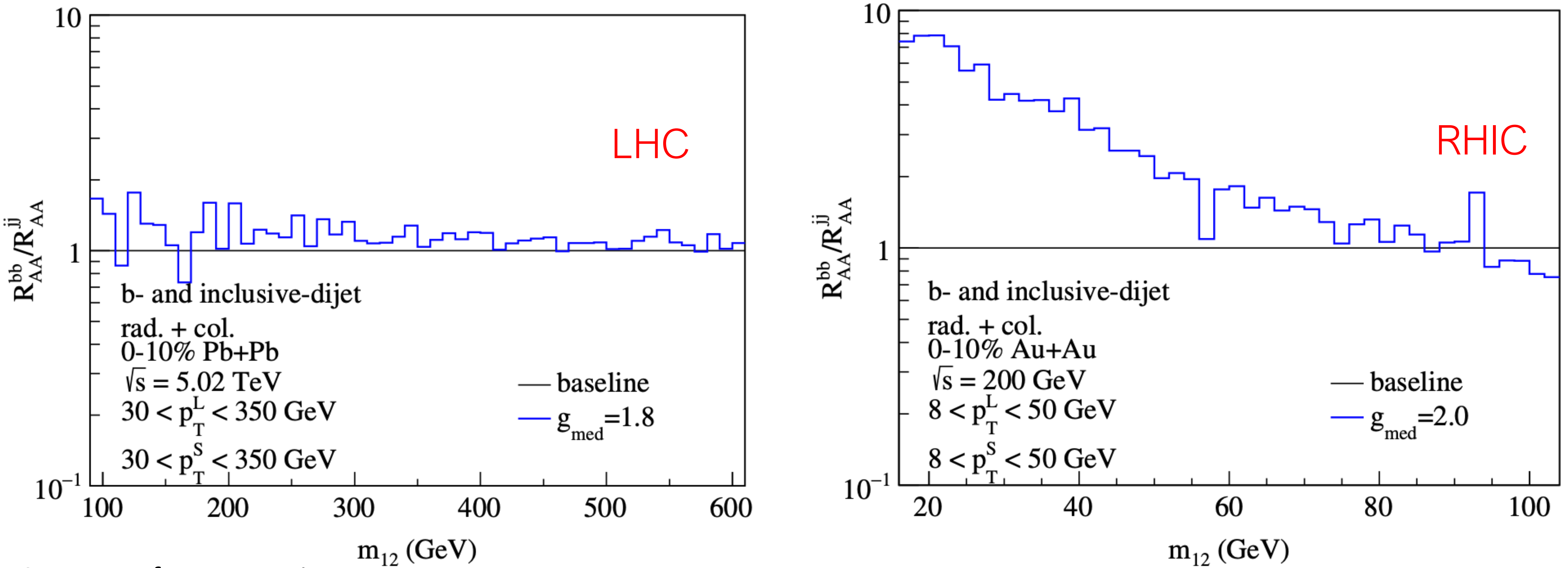
Anticipated TPC Resolution
160
140
120
100
80
60
40
20
0
0 20 40 60 80 100 120
Drift Length [cm]
Sim <138>
Meas <114
Limit <106>

	Ne:CF4 - 90:10	Ne:CF4 - 50:50	Comment
$v_{drift}\left(\frac{\mu m}{ns}\right)$	78	80	Improvement
$D_{Transverse}\left(\frac{\mu m}{\sqrt{cm}}\right)$	65	40	Improvement
$D_{Longitudinal}\left(\frac{\mu m}{\sqrt{cm}}\right)$	160	110	Improvement
$N_{primary}\left(\frac{e}{cm}\right)$	16	31.5	Improvement
$N_{total}\left(\frac{e}{cm}\right)$	48.7	71.5	Improvement
Space Charge (arb)	1.00	1.42	Max 3mm → 4.25mm Likely Tolerable

Sensitivity of novel heavy flavor jet observables

Z-B Kang, J Reiten, I Vitev, B Yoon, "Light and heavy flavor dijet production and dijet mass modification in heavy ion collisions", Phys. Rev. D99 034006 (2019)

strong coupling to the medium near T_c ⇔ pronounced b-dijet effect at RHIC



Courtesy of Dave Morrison