

CPAD Workshop 2022

Stony Brook University, November 29 - December 02, 2022

Design and construction of the sPHENIX TPC

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on behalf of the sPHENIX collaboration



Stony Brook **University**

sPHENIX experiment

Collaboration of 320 members from 80 institutions in 13 countries

First data taking early 2023 3-year run plan

Superconducting Magnet (1.4 T solenoid)

formerly BaBar

Tracking system:

MAPS-based Vertex Tracker (MVTX)

Intermediate Silicon Tracker (INTT)

Time Projection Chamber (TPC)

Calorimetry:

Electromagnetic Calorimeter (EMCal)

inner Hadronic Calorimeter (iHCal)

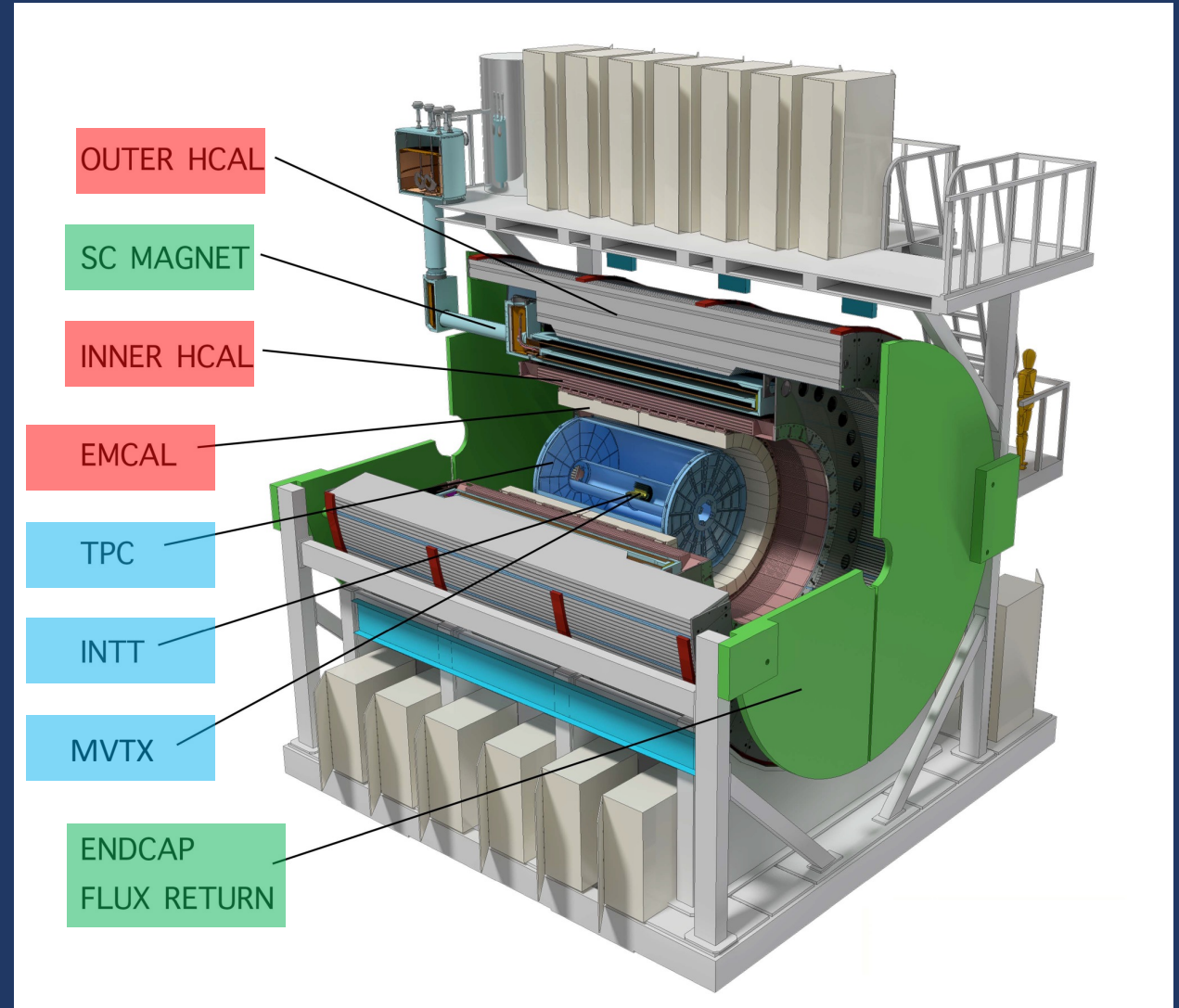
outer Hadronic Calorimeter (oHCal)

High rate:

15 kHz Trigger, >10 GB/s DAQ


Large acceptance:

full ϕ coverage; for $|z| < 10$ cm: $|\eta| \leq 1.1$




sPHENIX physics goal


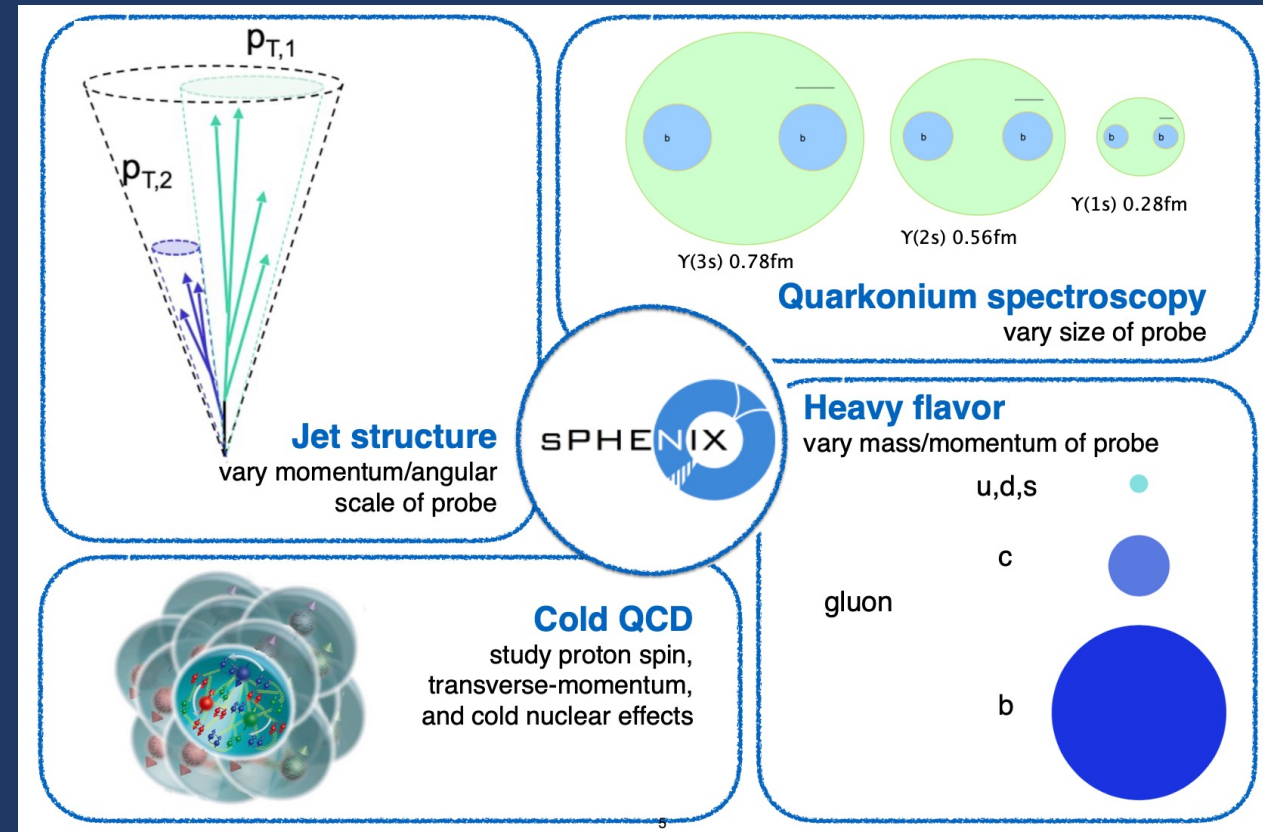
REACHING FOR THE HORIZON



The Site of the Wright Brothers' First Airplane Flight



The 2015
LONG RANGE PLAN
for NUCLEAR 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](#)

[From DVP @ DNP](#)

sPHENIX TPC

Time Projection Chamber (TPC)

Compact: $20 < r \text{ [cm]} < 78$ (active $> 30 \text{ cm}$)

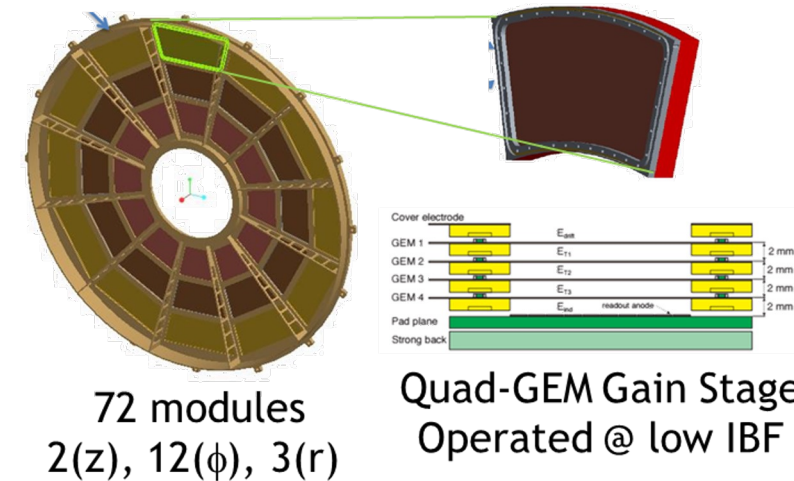
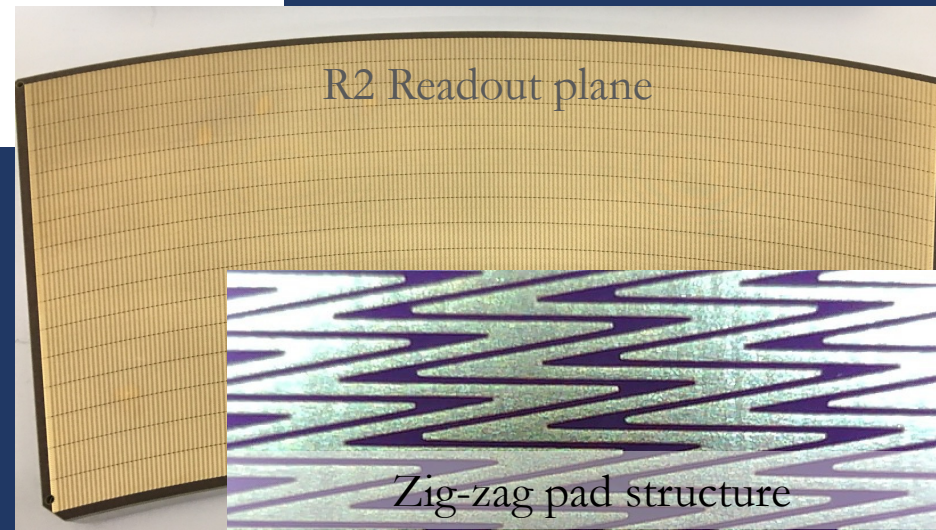
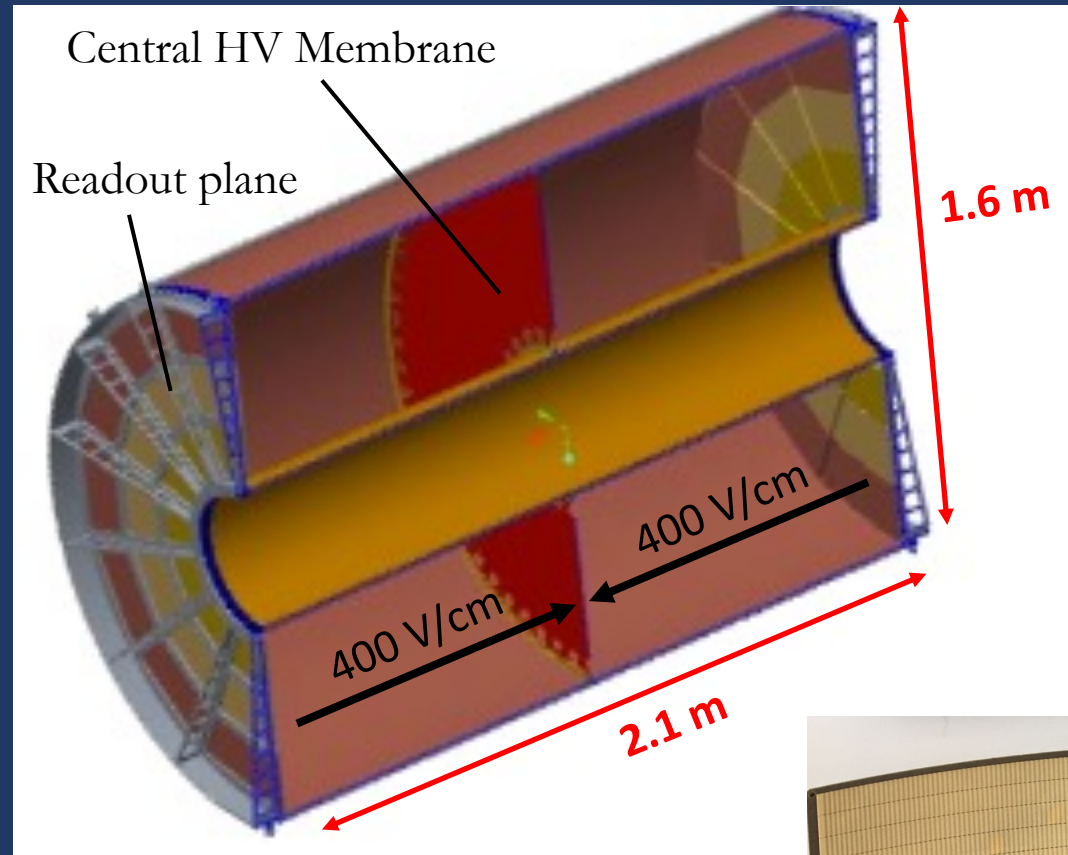
Gas: $\text{Ne}/\text{CF}_4 \Rightarrow \text{Ar}/\text{CF}_4$

Nominal drift field $E = 400 \text{ V/cm}$ and magnetic field $B = 1.4 \text{ T}$ along z

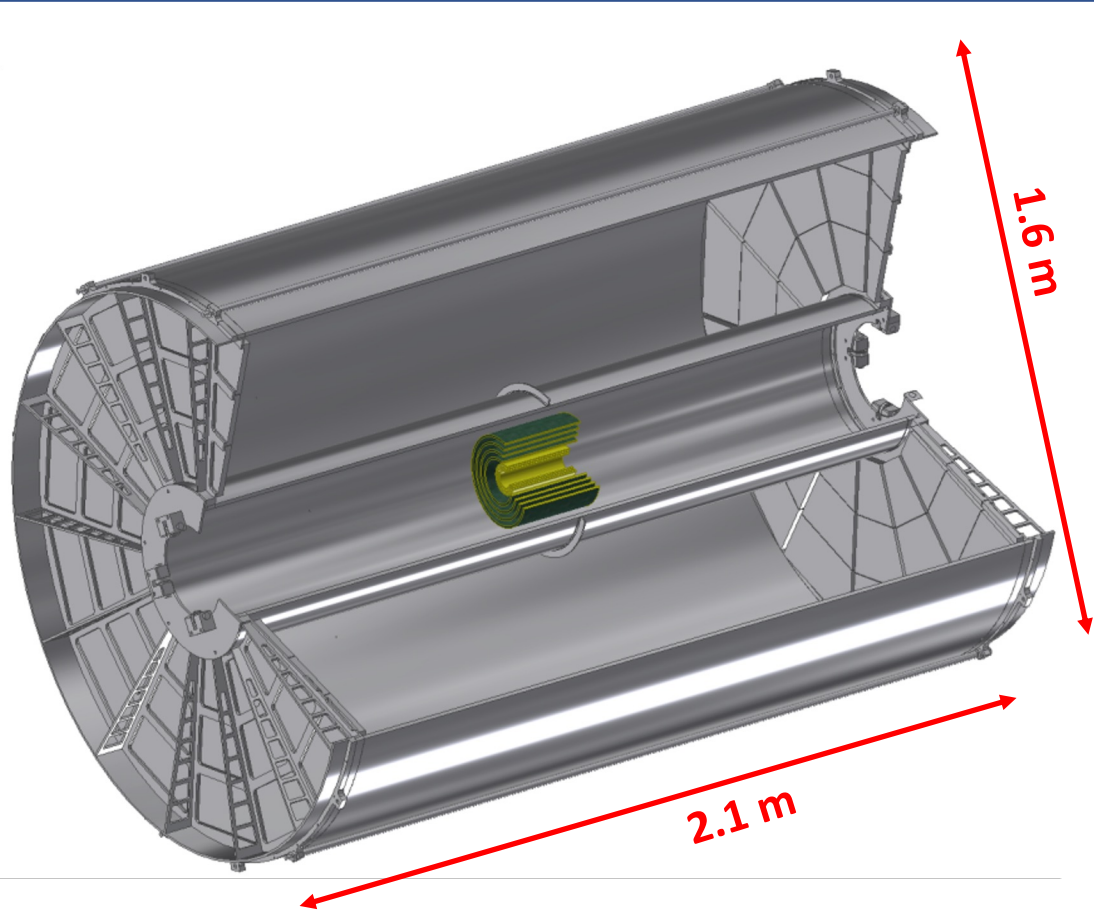
Required spatial resolution: $< 150 \mu\text{m}$

Charge collection via GEMs \rightarrow ALICE SAMPA

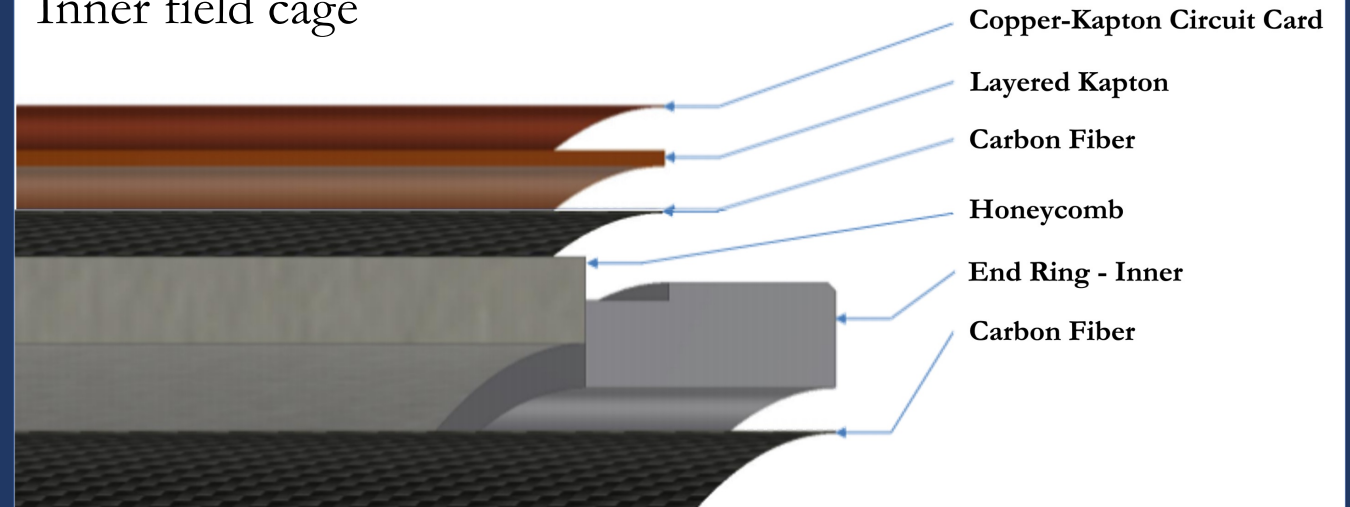
Gateless and continuous readout (GEMs for IBF suppression)



Field cage



Inner field cage

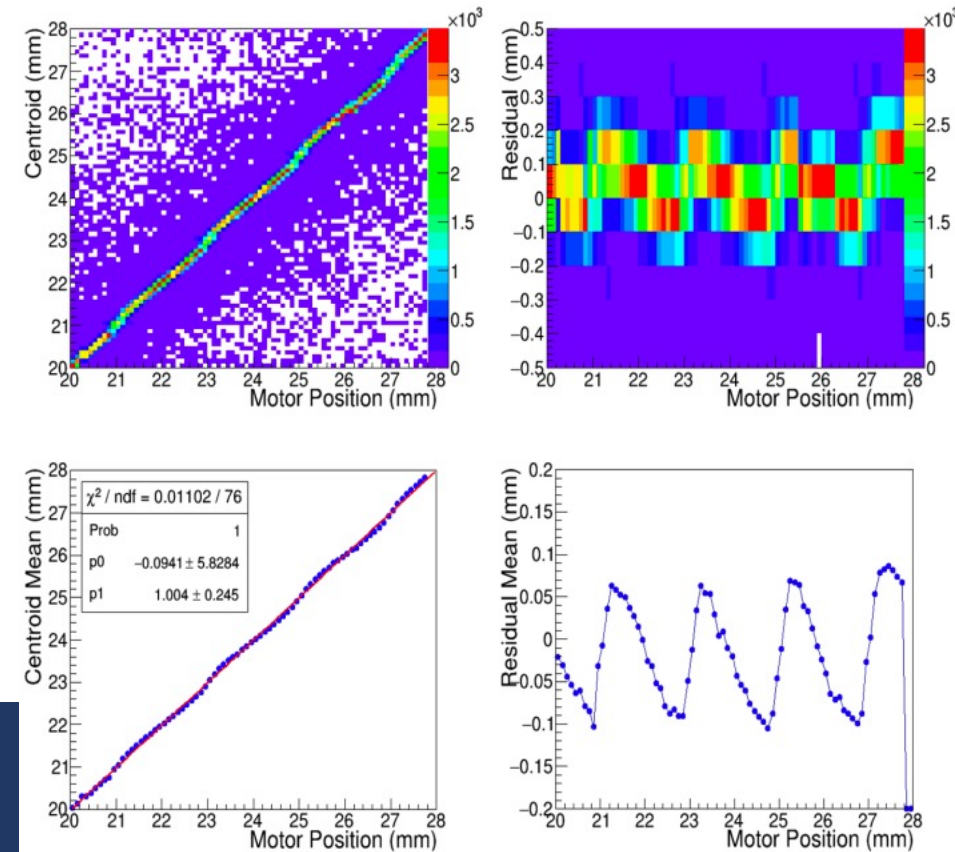
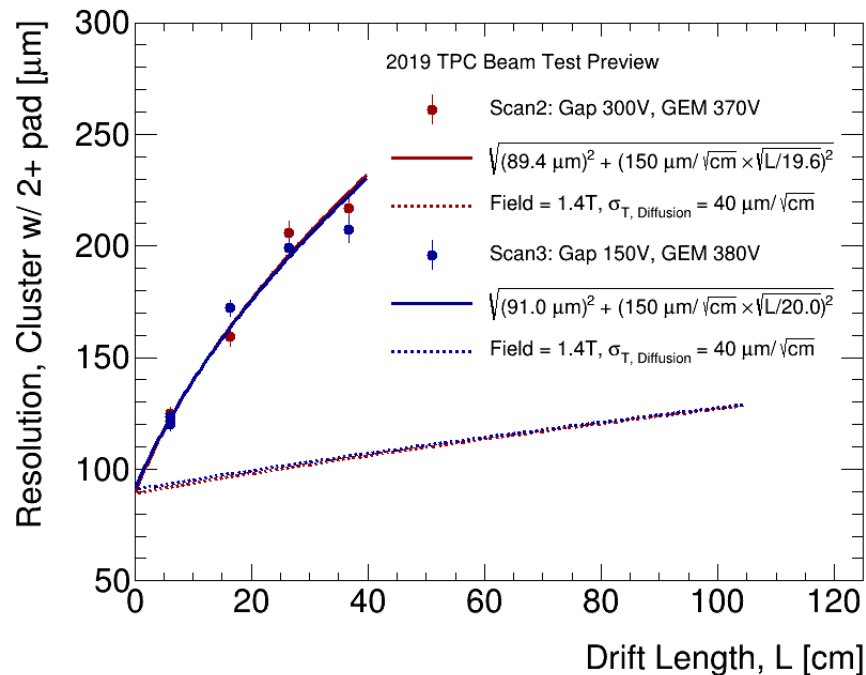
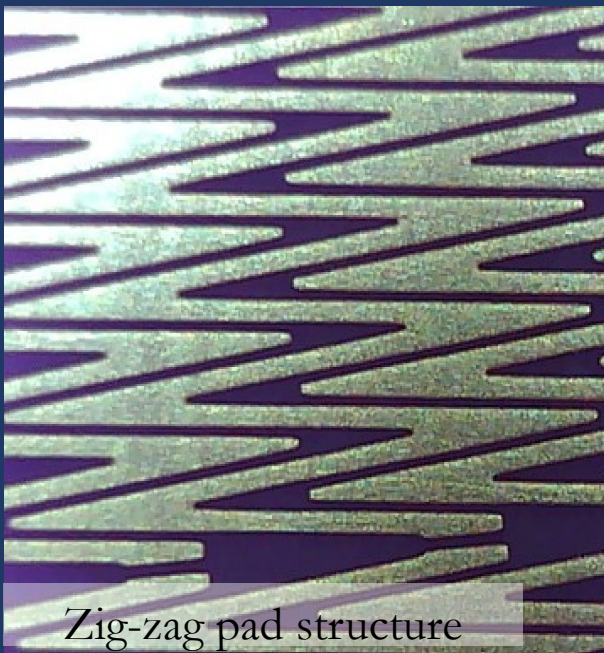


- TPC wall thickness is dominated by an insulating kapton layer
- 45 kV at the “central membrane” & 18 layers of kapton

| Inner field cage | X_0 [cm] | cm | %X_0 |
|----------------------------|-------------|---------------|-------------|
| 1/2 Oz Copper | 1.4 | 0.0017 | 0.12 |
| kapton | 28.6 | 0.0051 | 0.02 |
| 1/2 Oz Copper | 1.4 | 0.0017 | 0.12 |
| Kapton (coverlay) | 28.6 | 0.0076 | 0.03 |
| Epoxy | 35.7 | 0.0127 | 0.04 |
| Kapton (insulating) | 28.6 | 0.2286 | 0.80 |
| Carbon Fiber | 23.4 | 0.0254 | 0.11 |
| Epoxy | 35.7 | 0.0127 | 0.04 |
| Honeycomb | 845.4 | 1.2700 | 0.15 |
| Epoxy | 35.7 | 0.0127 | 0.04 |
| Carbon Fiber | 23.4 | 0.0254 | 0.11 |
| TOTAL | | 0 | 1.56 |

Zig-zag pad structure

[Azimoun, B., et al. IEEE TNS, vol. 65, no. 7, 2018](#)



2mm pad pitch and $\sim 0.5\text{mm}$ period

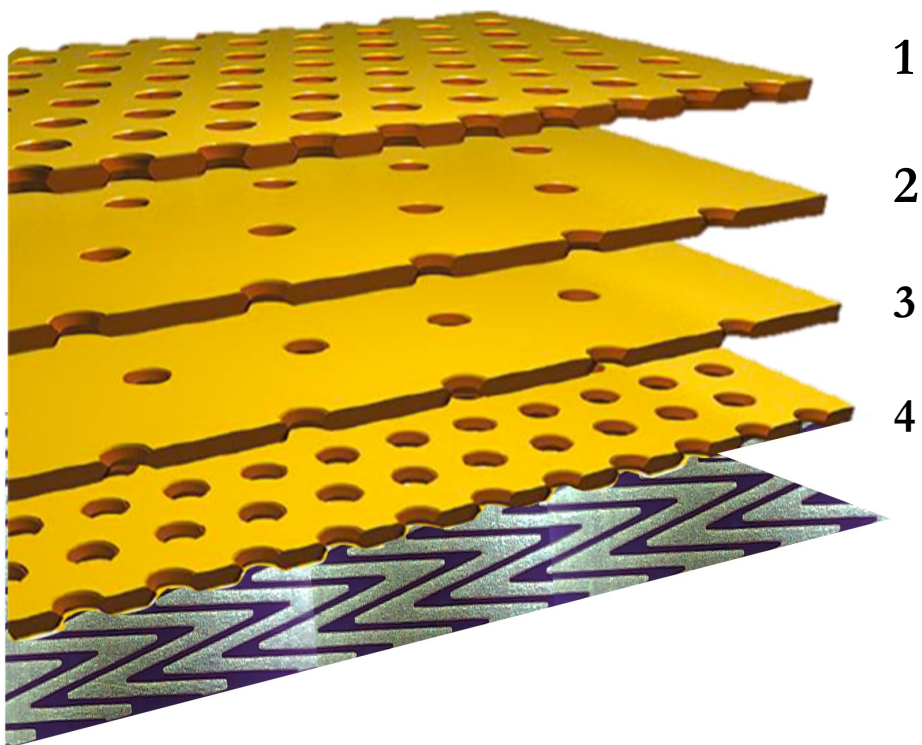
- Simulation expected the resolution of 134 μm
- On bench studies @ BNL have shown resolution of 100 μm in 750 V/cm drift field and Ar-based gas
- Test beam @ Fermi Lab Summer 2019 results provide average resolution of 90-130 μm for Ne/CF₄ 50:50

Quad-GEM

- Planned gas after 2019 test beam: Ne/CF₄ (50:50)
- GEM 3 & 4 are adjusted to achieve a total effective gain of 2000
- GEM 1 & 2 provide effective gain of 1 and used to stop IBF

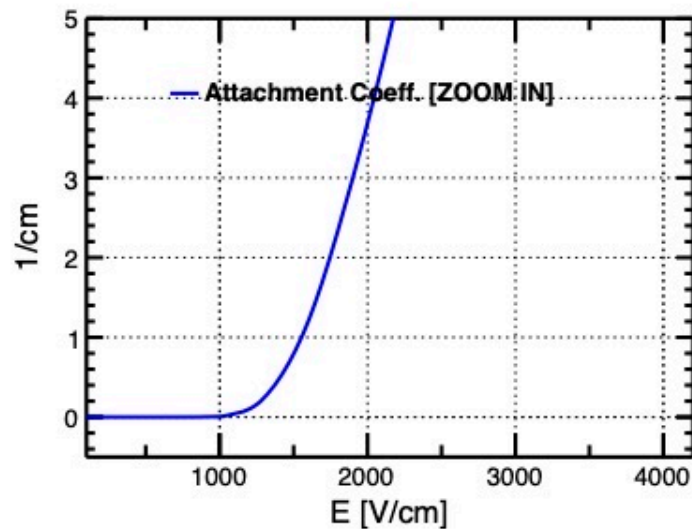
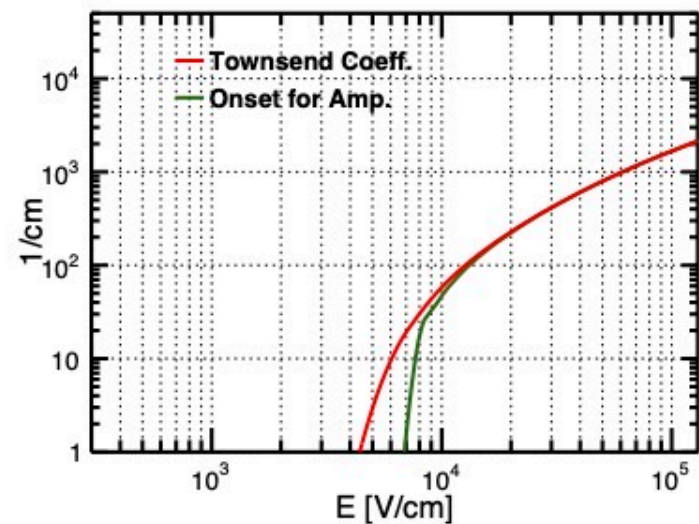
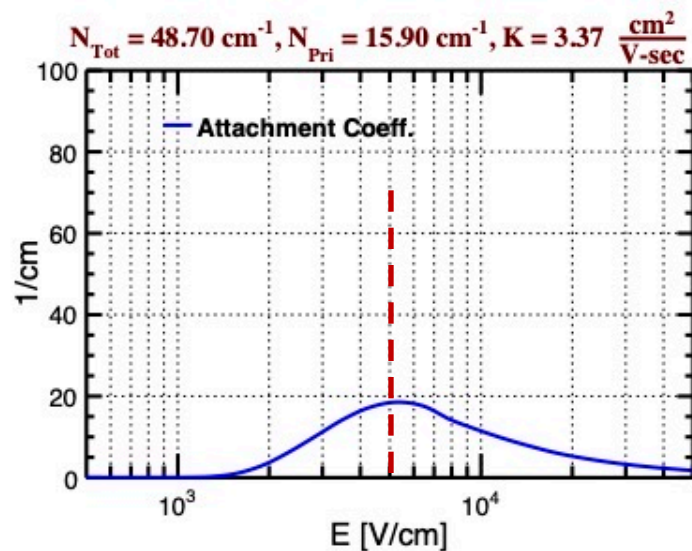
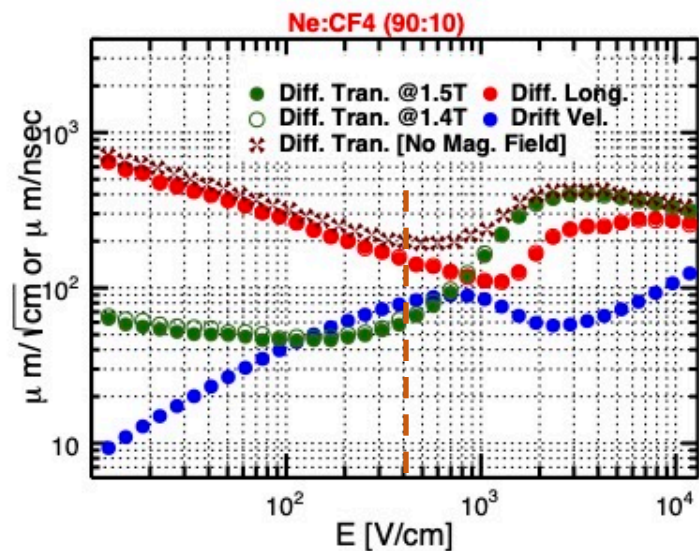


$$E_{\text{drift}} = 400 \text{ V/cm}$$



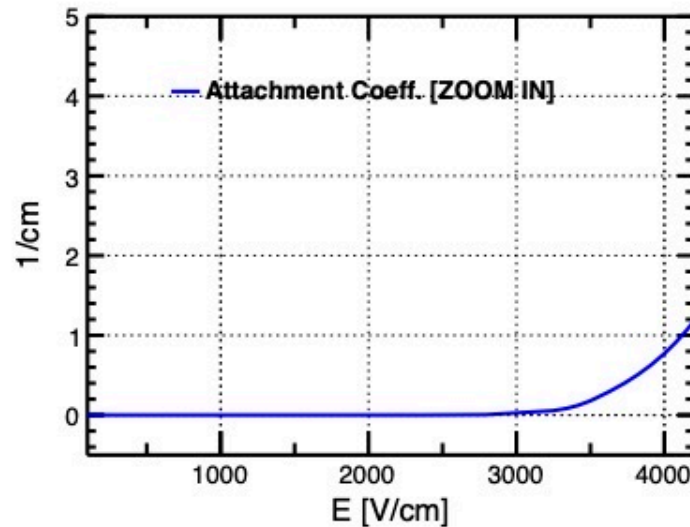
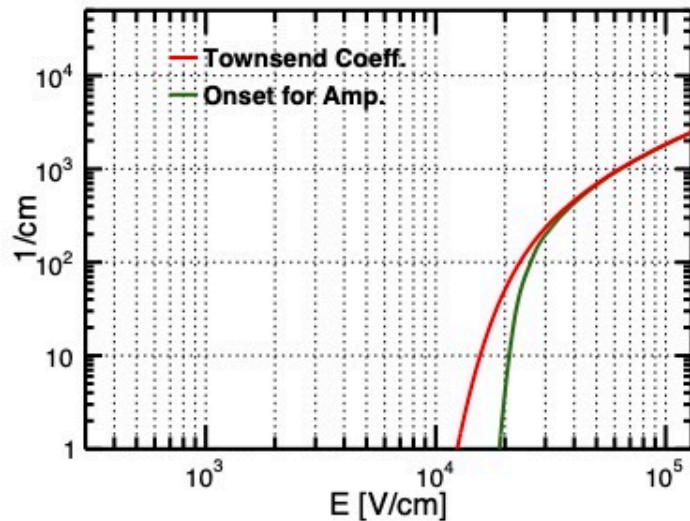
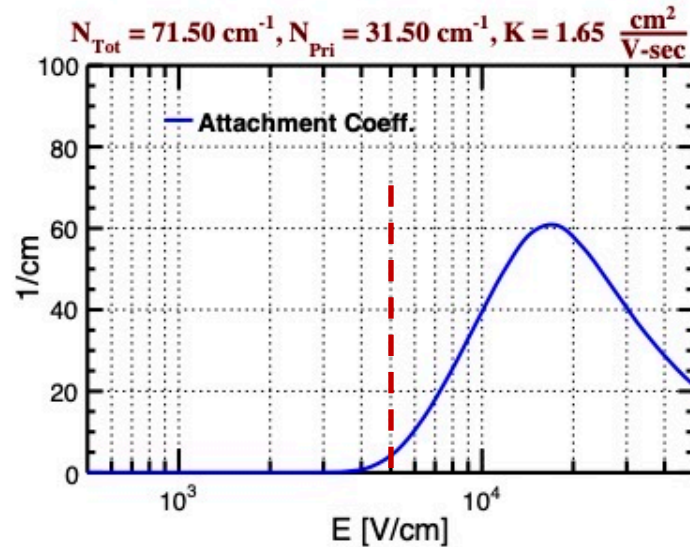
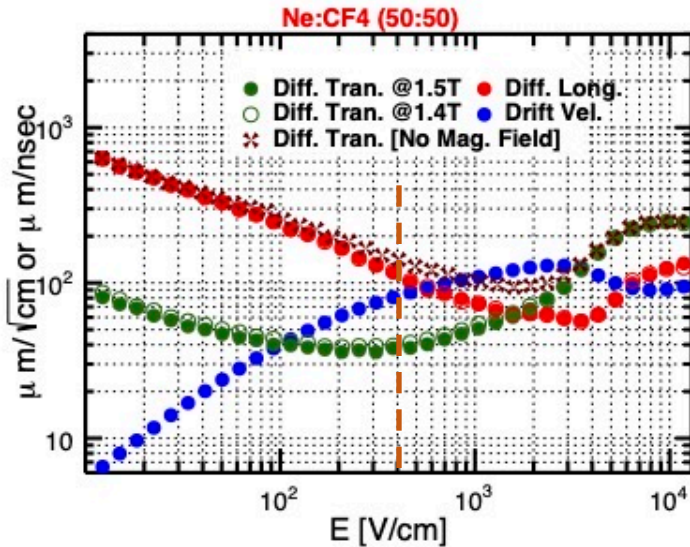
| GEM foil | U [V] | ΔV [V] | E_{drift} [V/cm] |
|----------|-------|----------------|---------------------------|
| G4 b | 600 | - | - |
| G4 t | 1098 | 498 | - |
| G3 b | 1128 | 30 | 95 |
| G3 t | 1578 | 450 | - |
| G2 b | 2778 | 1200 | 3750 |
| G2 t | 3110 | 332 | - |
| G1 b | 4310 | 1200 | 3750 |
| G1 t | 4578 | 267 | - |

TPC gas



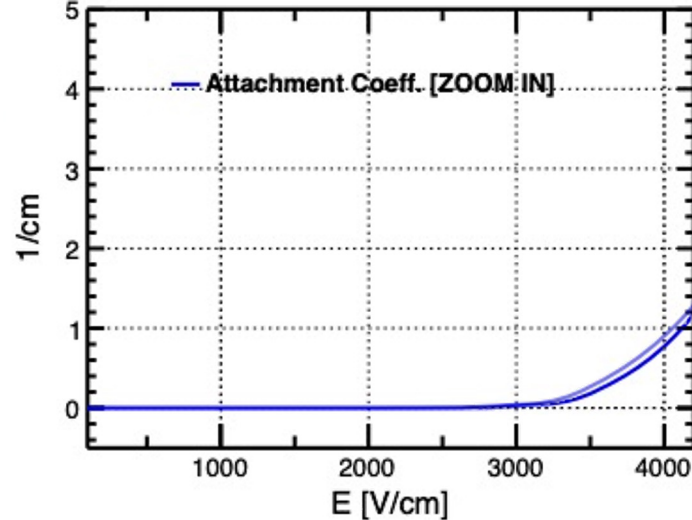
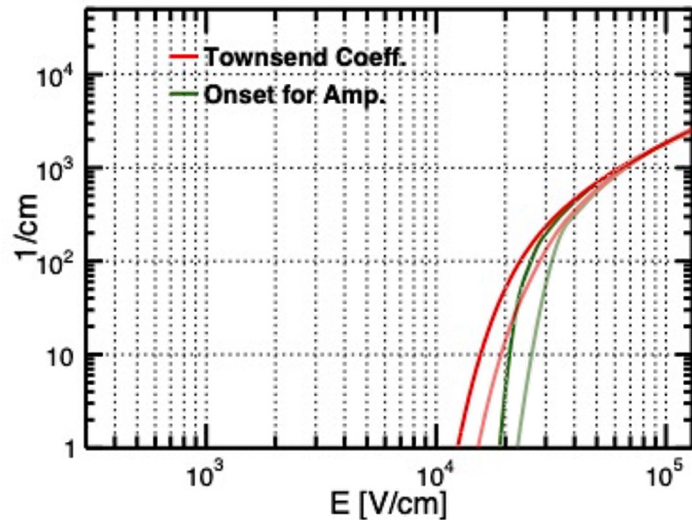
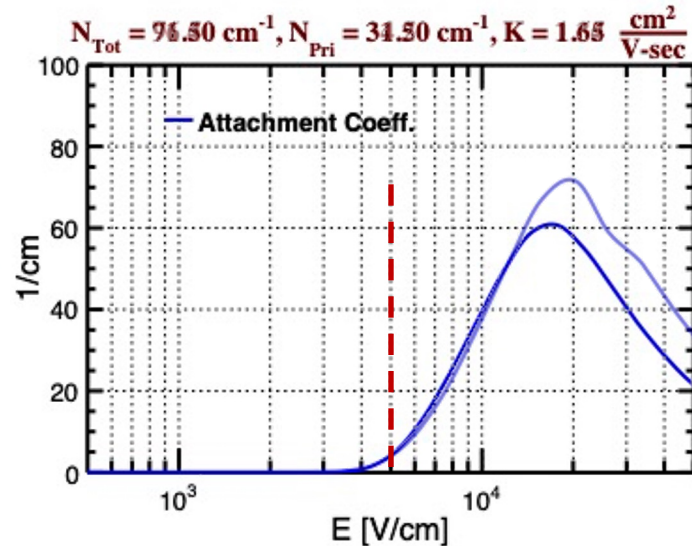
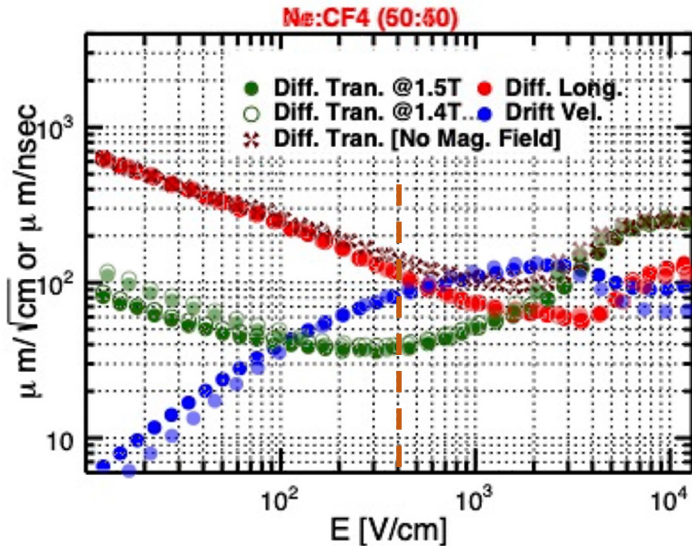
- Initially planned gas Ne:CF₄ 90:10
- Rejected due to the high attachment

TPC gas



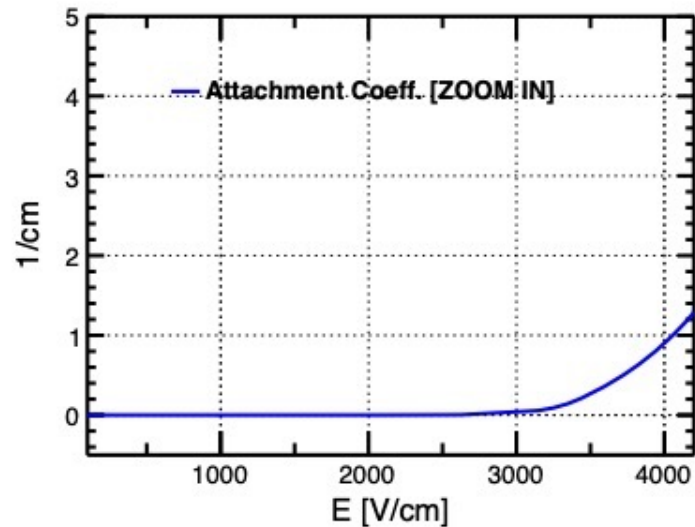
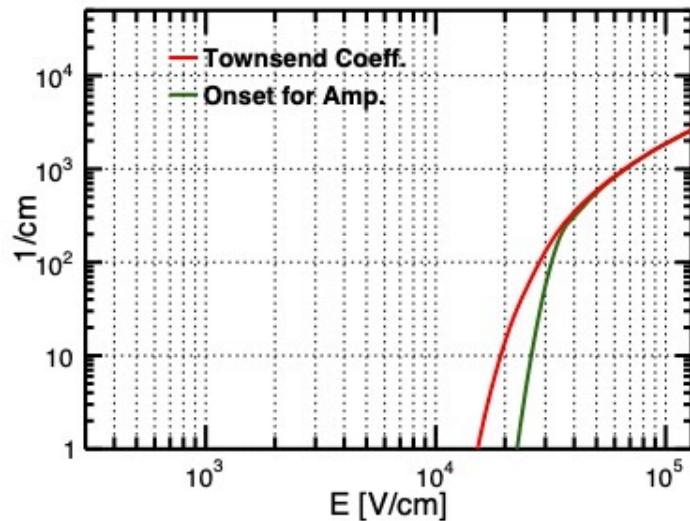
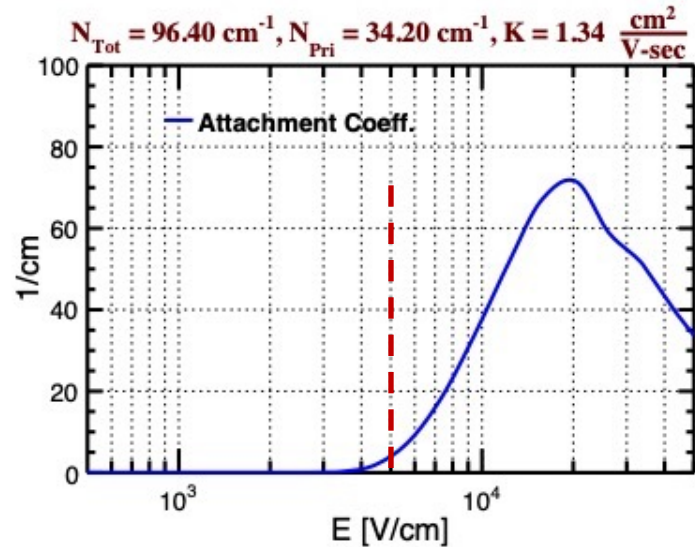
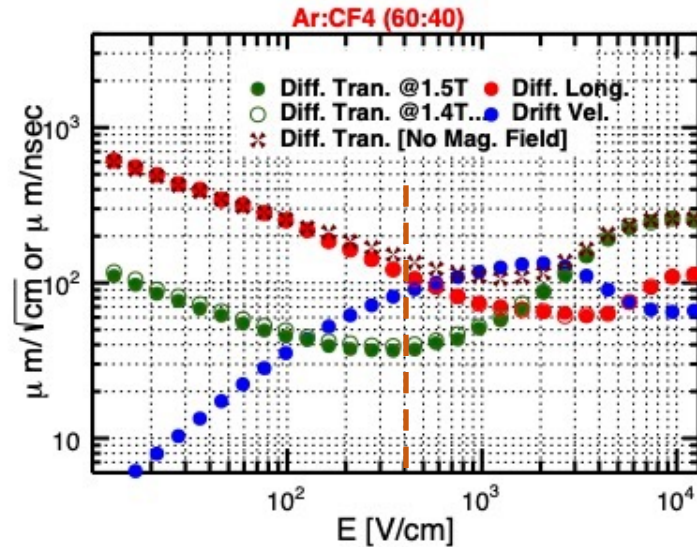
- Initially planned gas Ne:CF₄ 90:10
- Rejected due to the high attachment
- Switched to Ne:CF₄ 50:50
- Successful tests during test beam 2019
- Beginning 2022: main Ne supplier Ukraine is out of business due to the Russian aggression
- Need a new gas

TPC gas



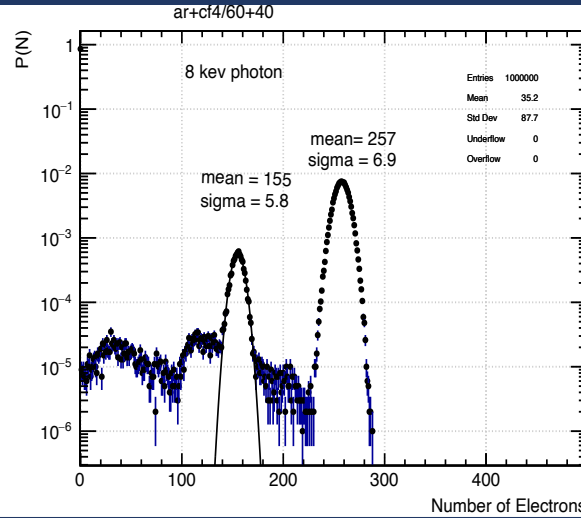
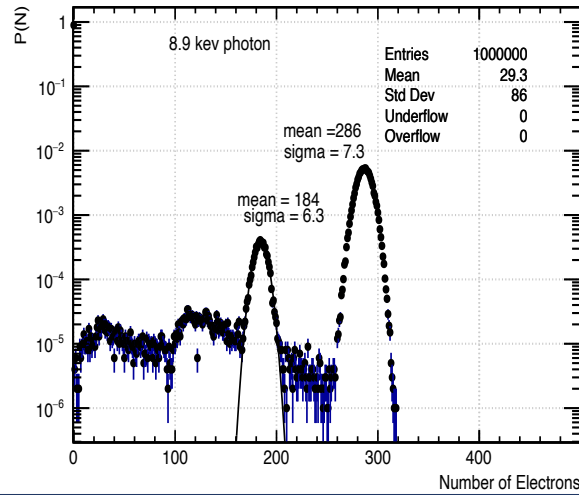
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- Rejected due to the high attachment
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- Need a new gas
- Ar:CF₄ 60:40 is a great candidate for replacement

TPC gas

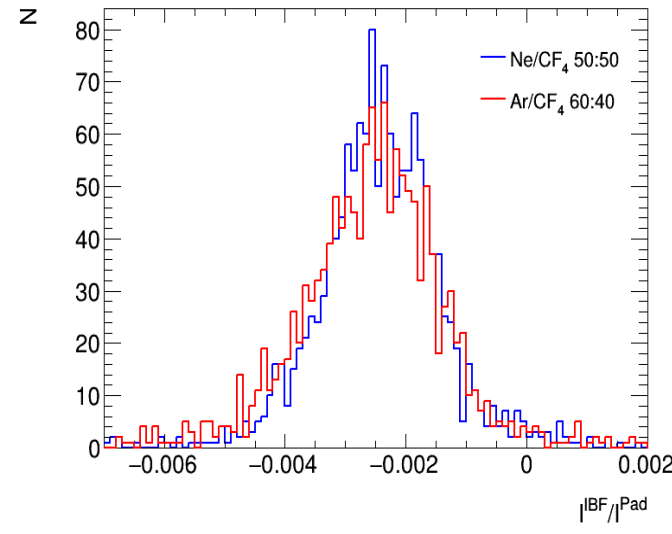
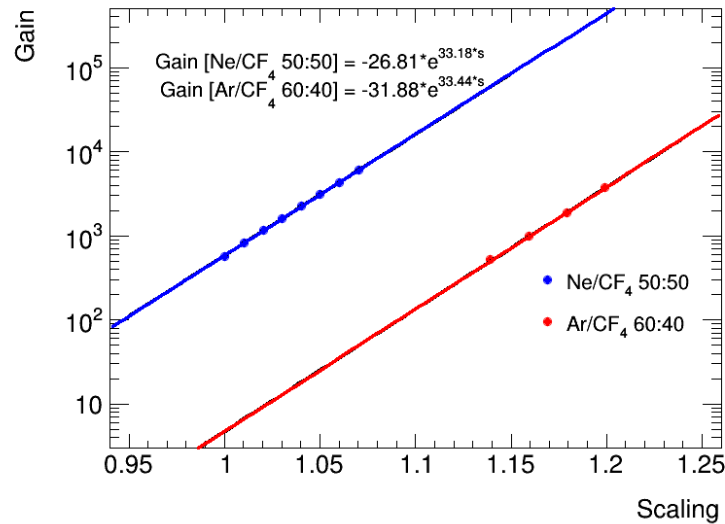


- Initially planned gas Ne:CF₄ 90:10
- Rejected due to the high attachment
- Switched to Ne:CF₄ 50:50
- Successful tests during test beam 2019
- Beginning 2022: main Ne supplier Ukraine is out of business due to the Russian aggression
- Need a new gas as the price got 7 times higher
- Ar:CF₄ 60:40 is a great candidate for replacement
- Became our main gas ~2 months ago

TPC gas: IBF test

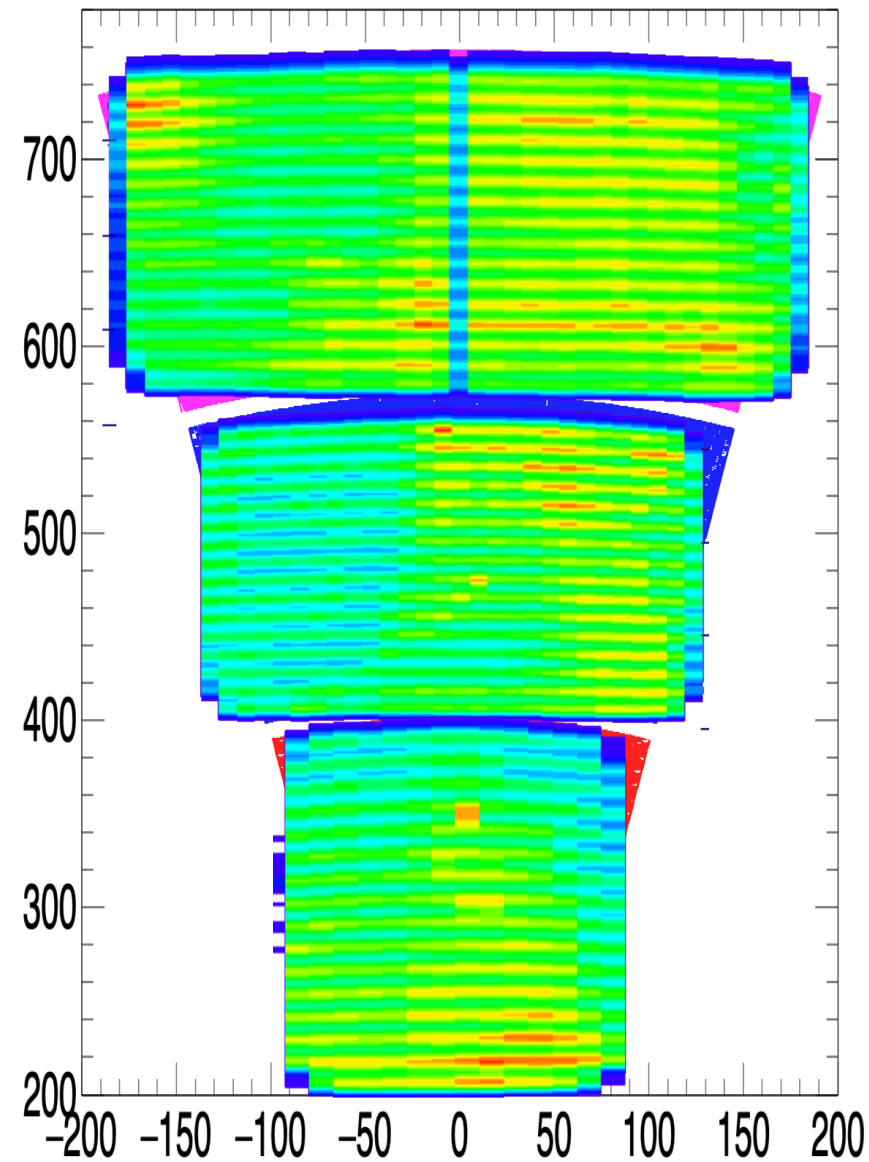
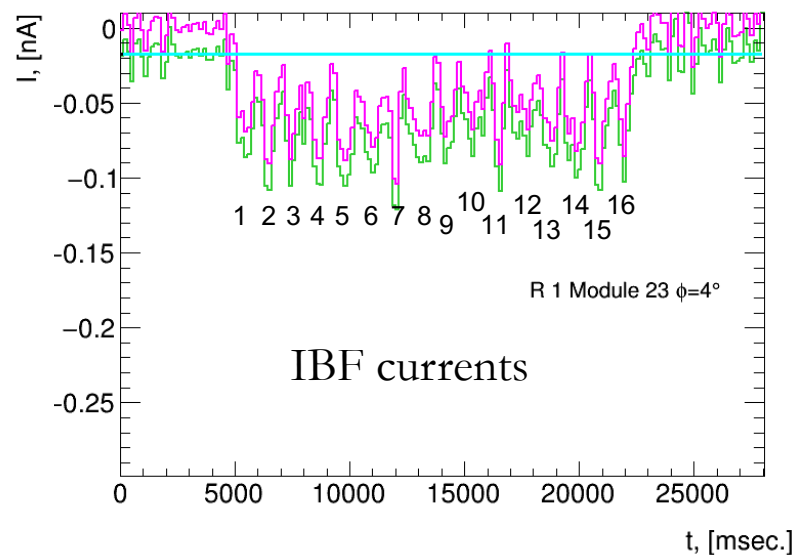
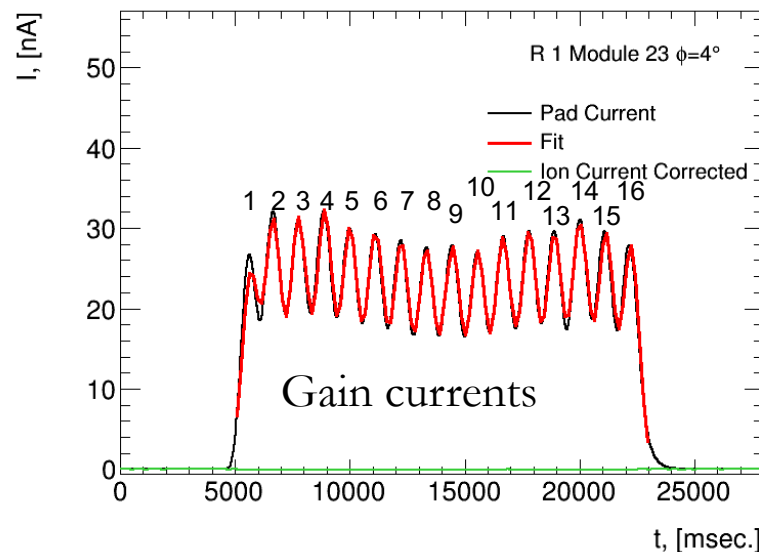
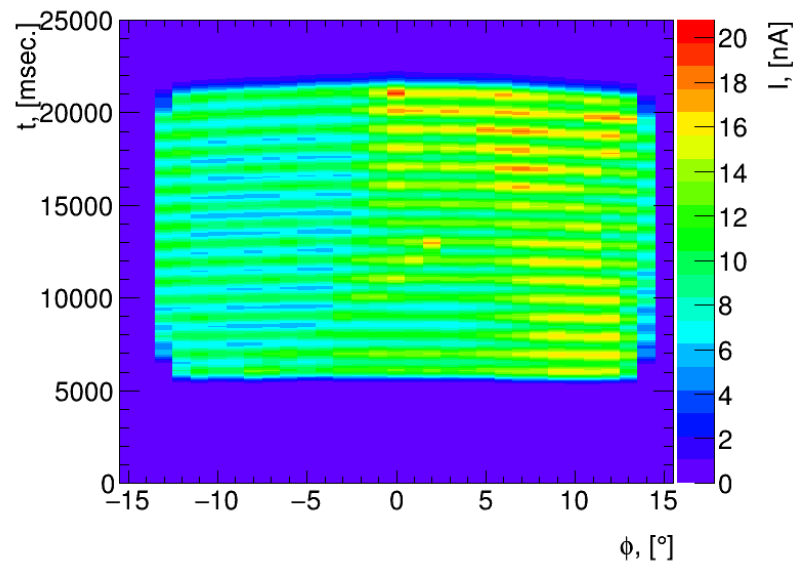


- Cu provides 8 keV and 8.9 keV lines at 15 kV
- Drift fields define GEM stack transparency to ions
- Thus, only ΔV on GEMs is scaled
- 0.3 % IBF is measured for both gas mixtures



| GEM foil | U [V] | ΔV [V] | E^{drift} [V/cm] |
|----------|-------|----------------|---------------------------|
| G4 b | 600 | - | - |
| G4 t | 1168 | 568 | - |
| G3 b | 1198 | 30 | 95 |
| G3 t | 1711 | 513 | - |
| G2 b | 2911 | 1200 | 3750 |
| G2 t | 3289 | 378 | - |
| G1 b | 4489 | 1200 | 3750 |
| G1 t | 4793 | 305 | - |

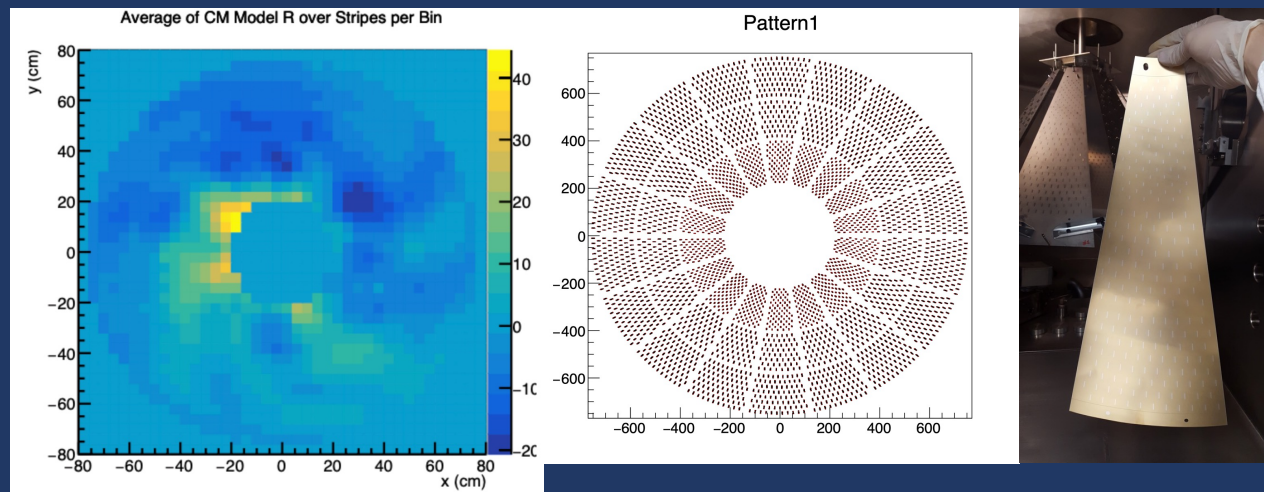
Gain & IBF measurements



- All modules are scanned for Gain & IBF characterization
- IBF is correlated with gain
- Gain is uniform
- 0.3 % IBF is measured for all modules
- The scans are used for IBF values estimation for the digital currents

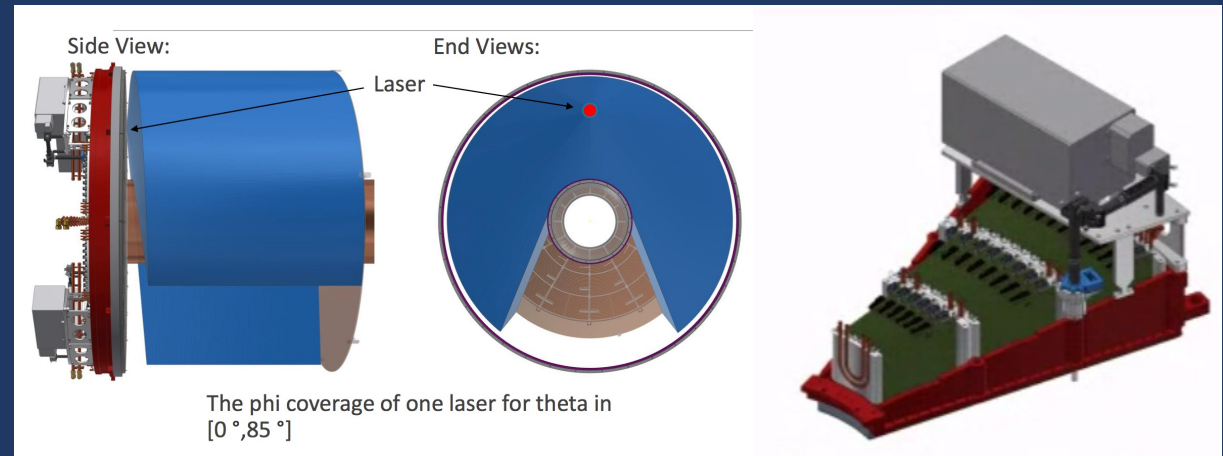
Distortion Monitors

Diffuse Laser

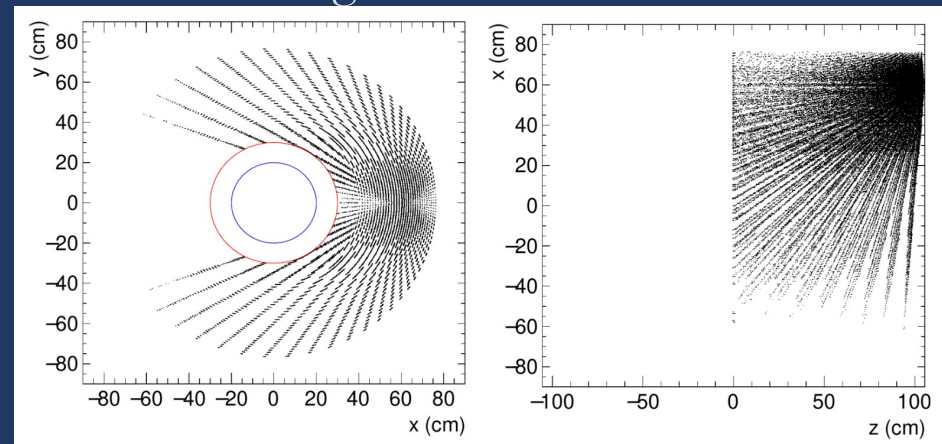


- Al stripes on Central Membrane
- kHz diffuse UV laser releases e^-
- Reconstructed stripes measure distortion at CM
- fast, interleaved with data \Rightarrow monitors fluctuations

Direct Laser



- 4 steerable lasers on each side of TPC
- Almost all points can be reached by 2+ lasers
- Creates straight-line tracks at \sim Hz



- Reconstructed laser track measures distortion in volume
- Slow, not used during run \Rightarrow monitors static distortion

Distortion Monitors: Digital Currents

Charge measured on the pads (r, φ, t) as a proxy of the space-charge density

Continuous data stream, stored in the calibration data base

Integration over fixed time intervals of ~ 1 ms

Grouping and robust averaging over several pads and pad rows

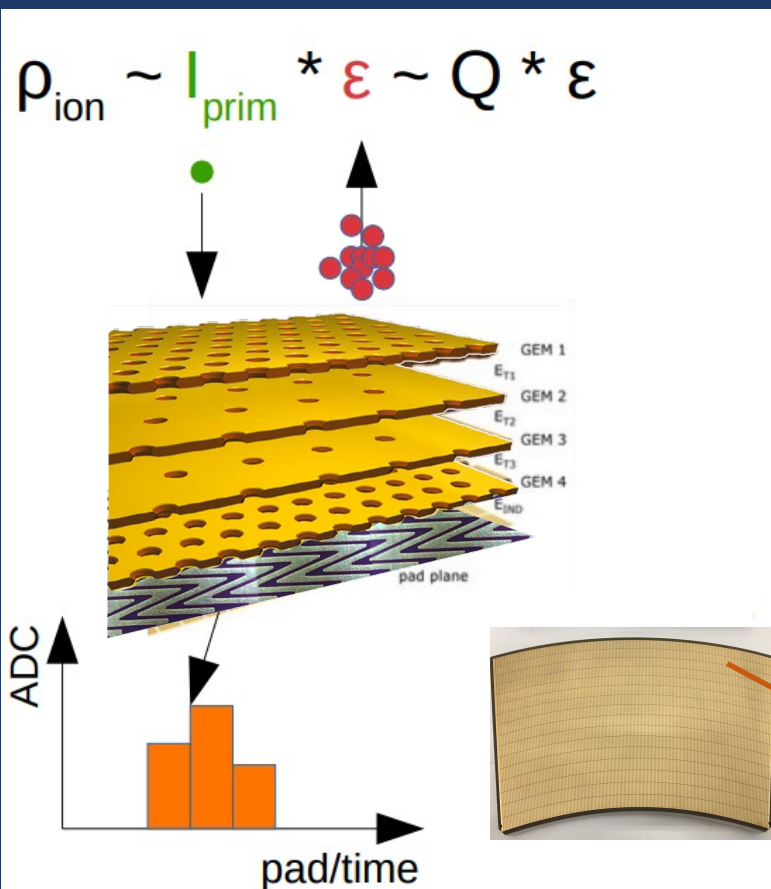
Required precision

Data size

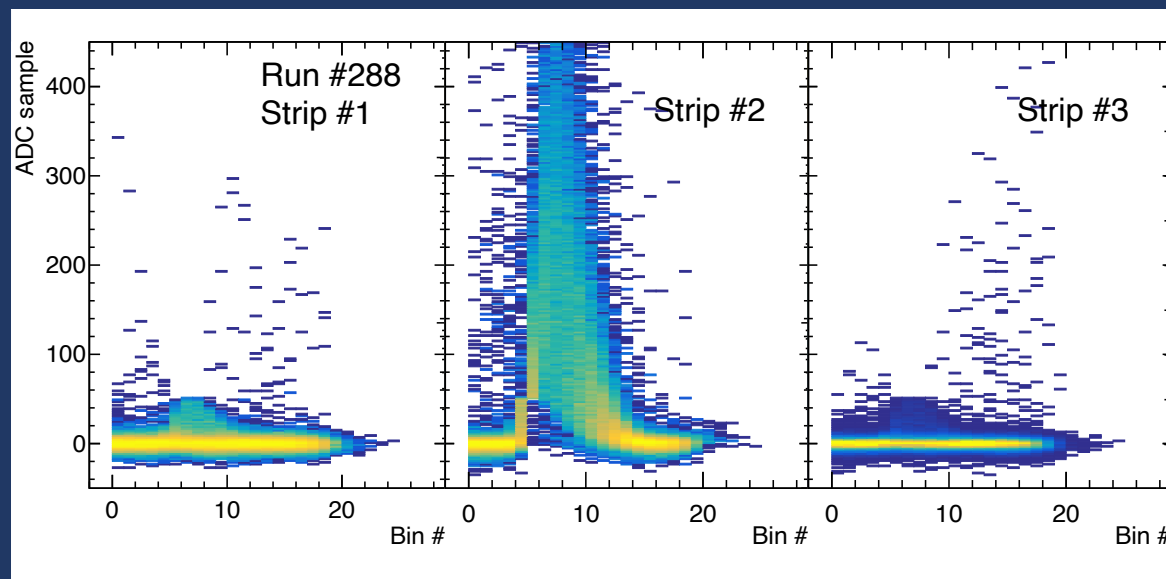
Relation to the space-charge density

Local ϵ

Drift-field distortions for ions

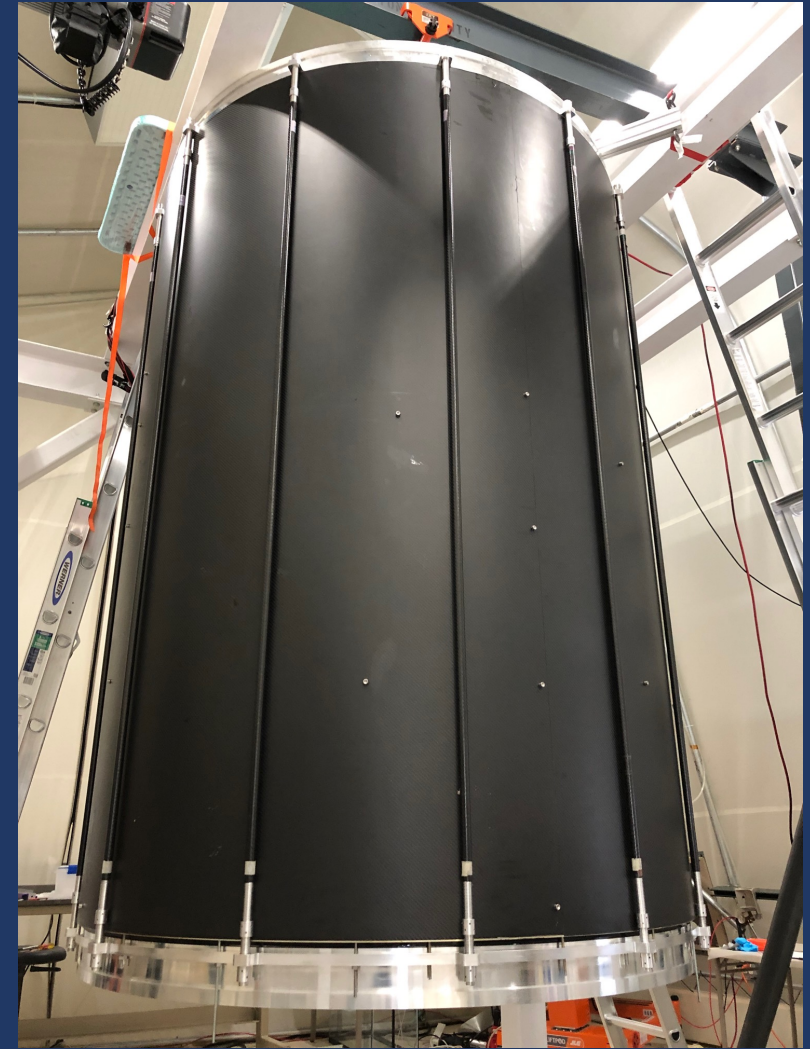
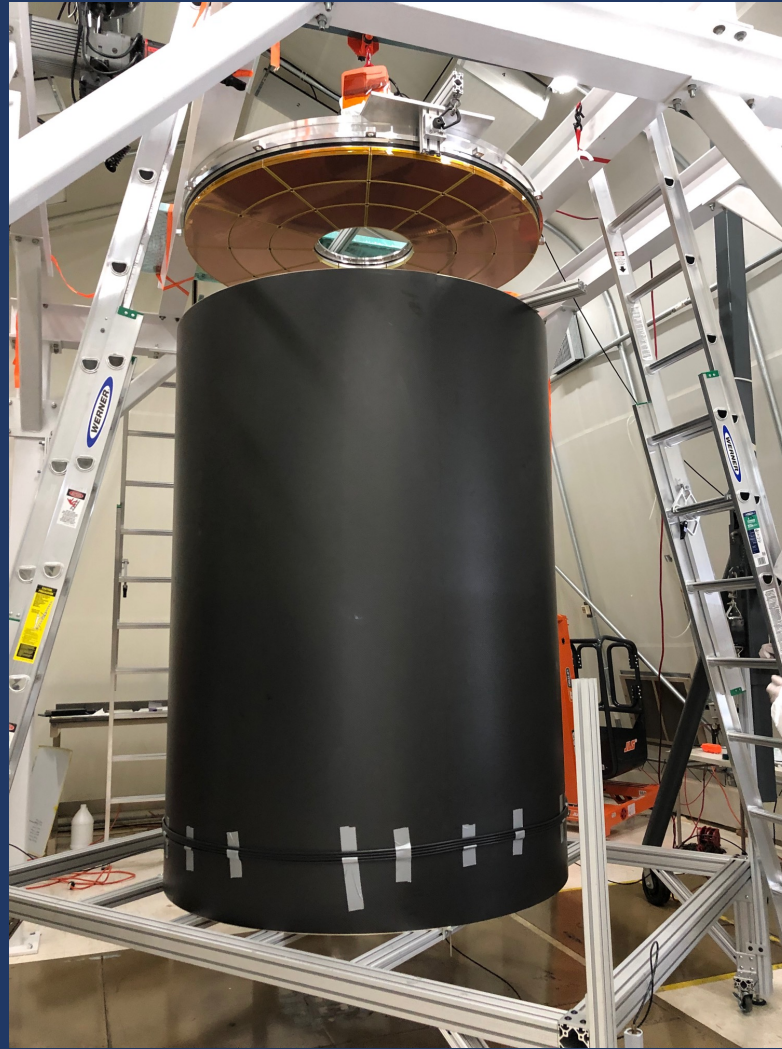
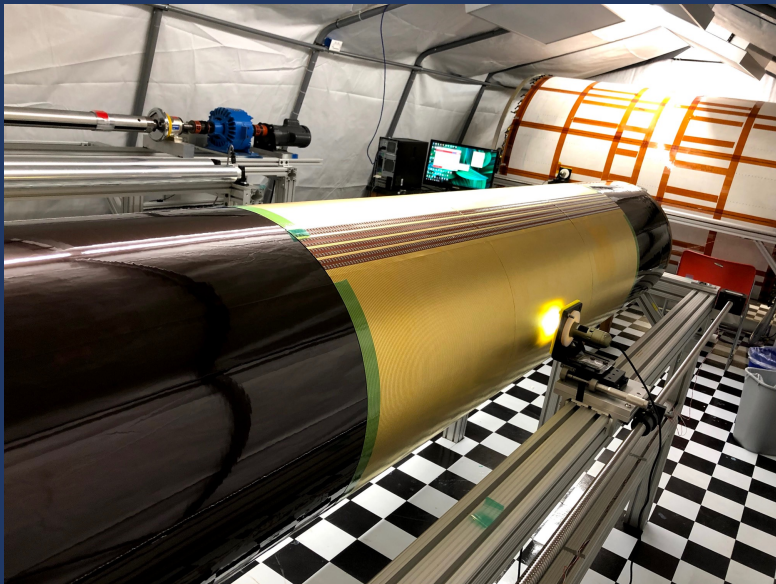


$$IDC = Q \sim I_{\text{prim}} * \text{gain}$$

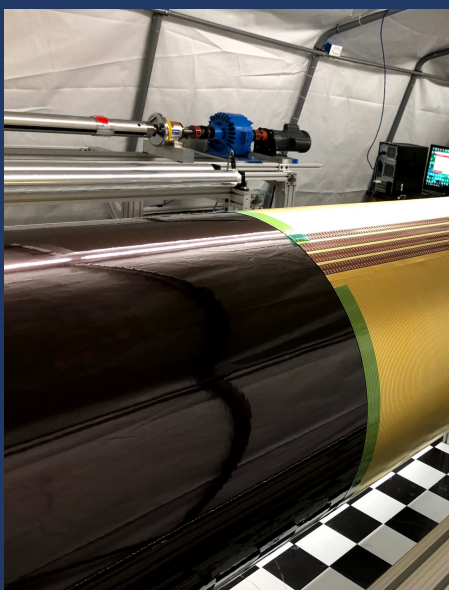
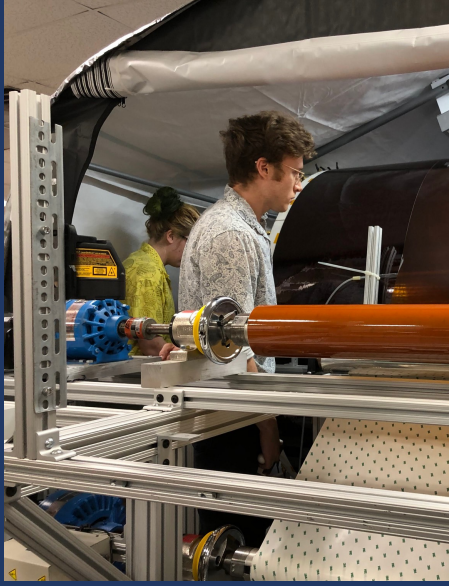


ADC signals from
3 neighboring zig-
zag pads (stripes)
from beam-test
2019

TPC assembly



TPC assembly

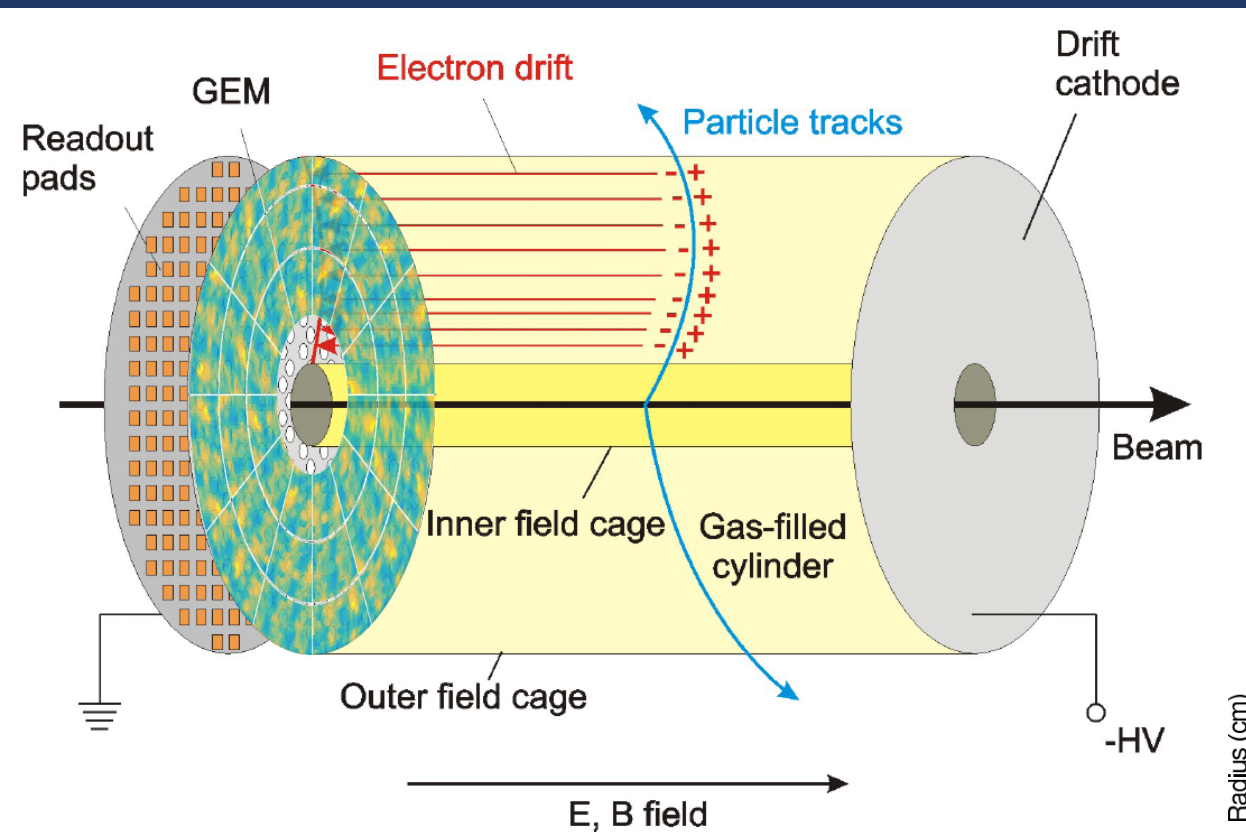


Summary

- Cylindrical TPC adopting new technologies is built @ SBU for the sPHENIX tracking
- The TPC will provide 70 to 150 μm depending on the drift length
- Calibration systems are designed to address static and “event by event” distortions
- It is instrumented and awaiting its turn to be installed @ BNL

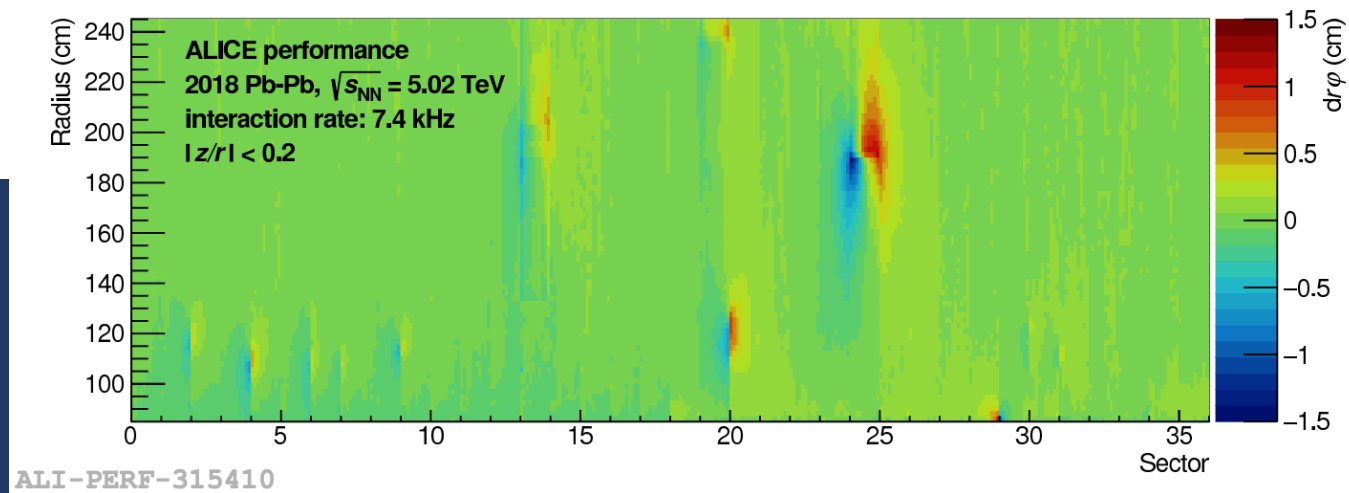
Backup

Space charge effects

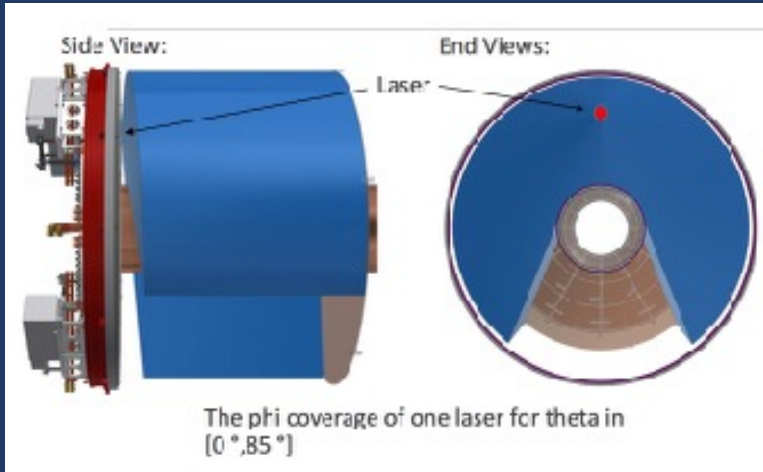


- Space charge (SC) is formed in the TPC
- Electric fields are distorted due to SC
- Tracking performance is affected
- 95 % of SC is Ion Backflow (IBF)
- Minimization of IBF is our goal

ALICE Pb-Pb φ distortion measurements



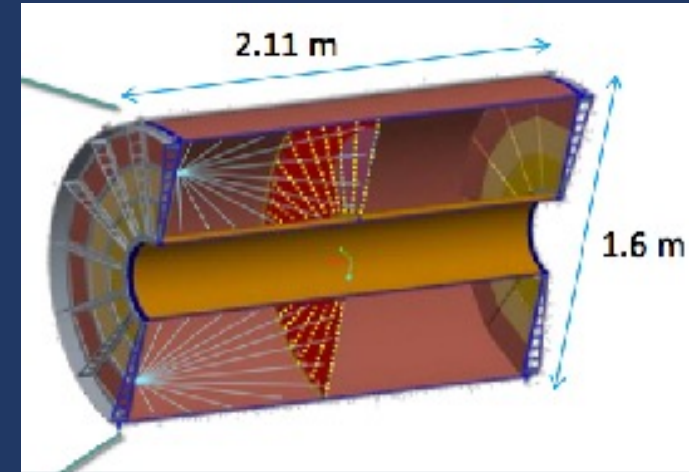
Monitoring Distortions Directly



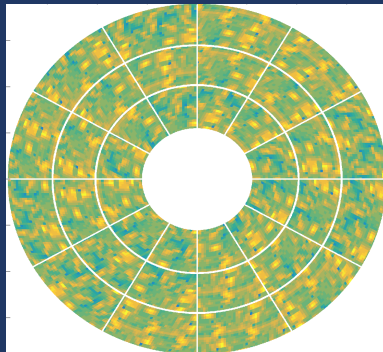
Static Distortions mapped (full 3D) by **line laser**. B field also mapped directly.



Average distortions monitored (full 3D) by **tracking with TPOT** after statics removed.



Distortion fluctuations monitored (2D) by **CM pattern/diffuse laser** after averages removed.



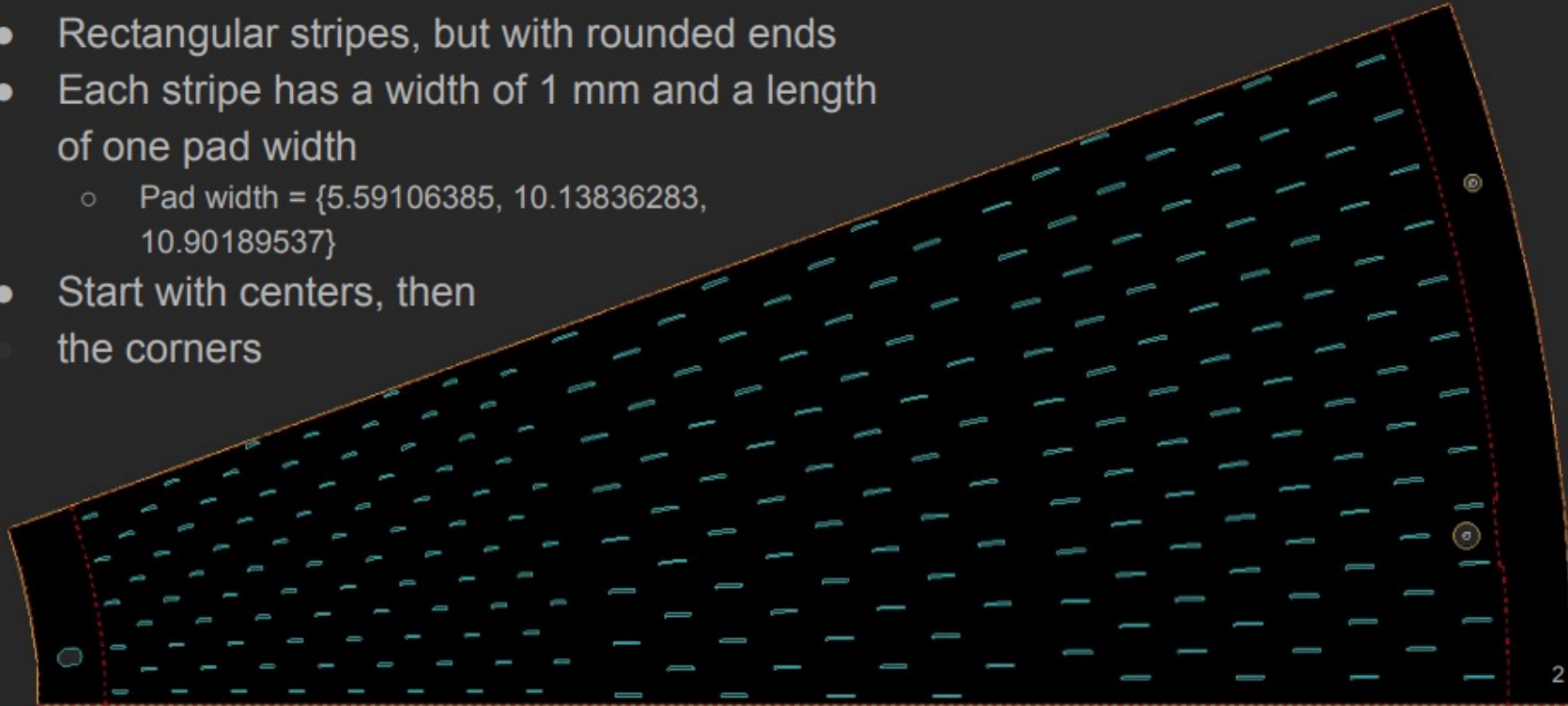
Digital current provides orthogonal, but indirect, measure of SC distortion

Central Membrane



The Stripe Pattern

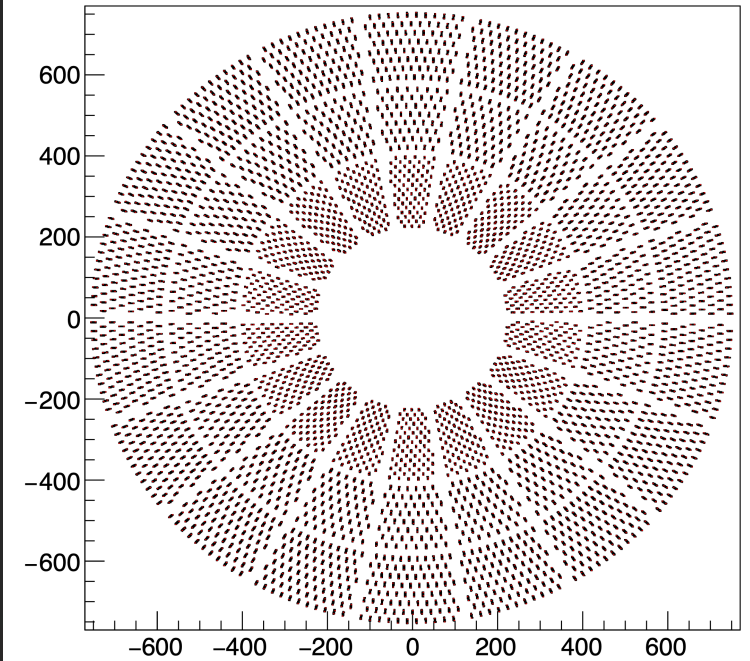
- Rectangular stripes, but with rounded ends
- Each stripe has a width of 1 mm and a length of one pad width
 - Pad width = {5.59106385, 10.13836283, 10.90189537}
- Start with centers, then the corners



“Hall of the Mountain King” by E. Grieg



Pattern1



Position of the stripes is predefined

Al pads on CM release charge when strobed with diffuse laser (15kHz) → calibration for SC distortions

Gain & IBF measurements



- All modules are scanned for Gain & IBF characterization
- IBF is correlated with gain
- The scans are used for IBF values estimation for the digital currents

