# Test Beam Results for the sPHENIX TPC Prototype

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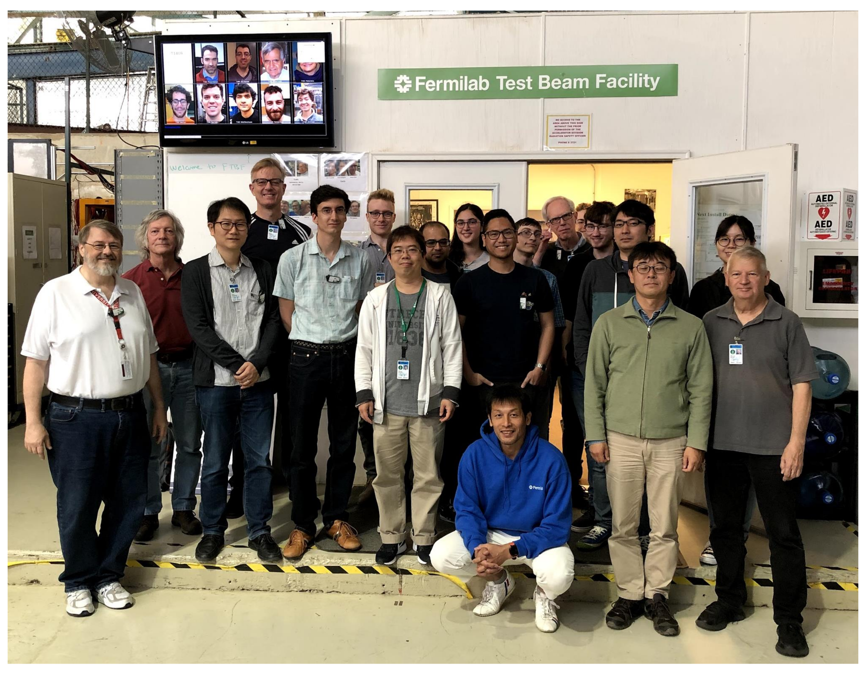
## Abstract

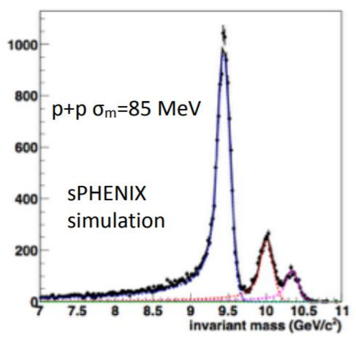
A Time Projection Chamber (TPC) will be the central tracking detector in the sPHENIX experiment. Its main task is to provide a high tracking efficiency and excellent momentum resolution for precise upsilon spectroscopy and jet measurements. The TPC will cover the full azimuth and a pseudorapidity range of up to |η| < 1.1.
A small-scale prototype TPC with a radial extension of 40 cm and a similar drift length has been manufactured which can accommodate a full-size amplification module as for the sPHENIX TPC. The prototype has been exposed to a 120 GeV proton beam at the Fermilab Test Beam Facility (FTBF). The results of the test-beam campaigns including SAMPA readout electronics will be presented.

## 2019 sPHENIX TPC Test Beam

### ⌘ Test Beam Goals

- Demonstrate stable operation of GEMs in low ion backflow mode, sPHENIX requires <1%
- Test almost final frontend electronics
- Explore Ne:CF4 50/50 mixture
- Maintain or improve spatial resolution


Several GEM voltage configurations tested for low IBF (<.5%) on tabletop at Yale were implemented successfully

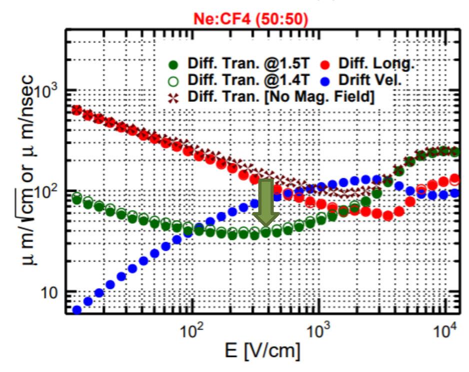
- ✓ Low Ion Backflow modes were stable
- ✓ FEE performed acceptably
- ✓ Spatial resolution improved
- ✓ dE/dx resolution measured for the first time, much better than expected, sPHENIX TPC could be used for PID

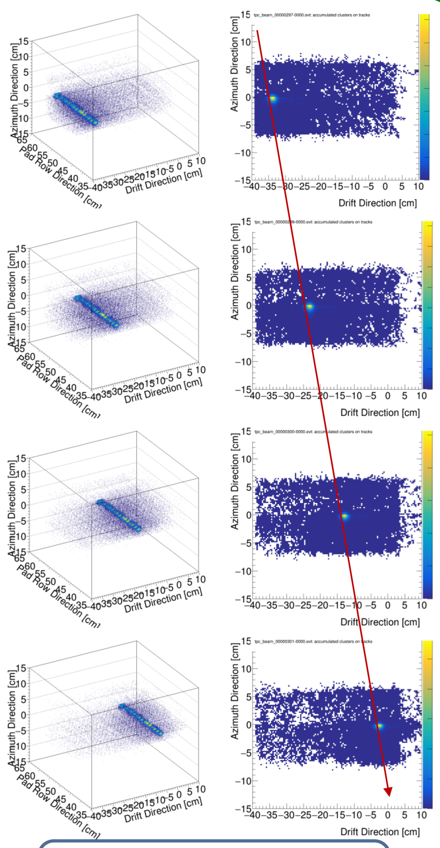
## Spatial Resolution

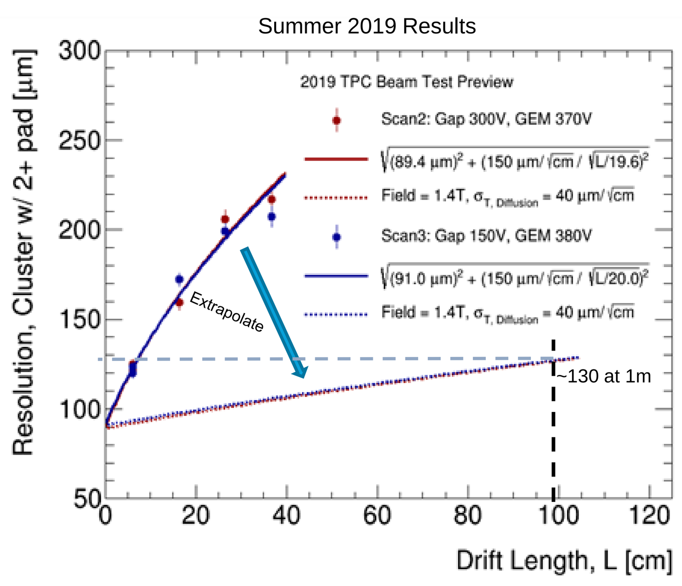
- sPHENIX physics goals require spatial resolution < 200 μm from TPC
- sPHENIX magnet will provide ~1.4T
- Measurement of resolution as a function of drift length in prototype TPC requires extrapolation to value with magnetic field
- Ne:CF4 50/50 provides a significant improvement over 90/10, likely due to reduced electron attachment

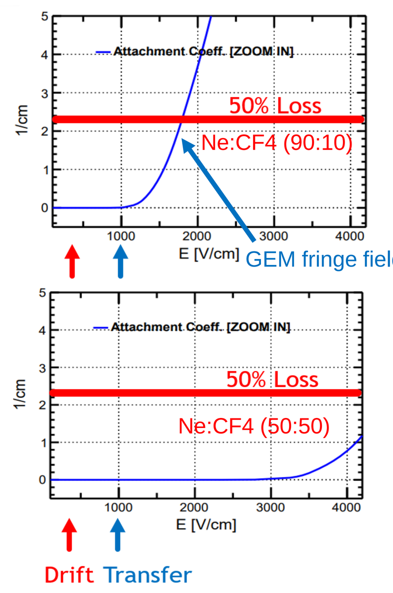
PadPlane, Drift, Space Charge

$$\sigma_{TOT}^2 = \sigma_{pad}^2 + \frac{D_T^2 L}{N_{eff}} + \sigma_{SC}^2$$



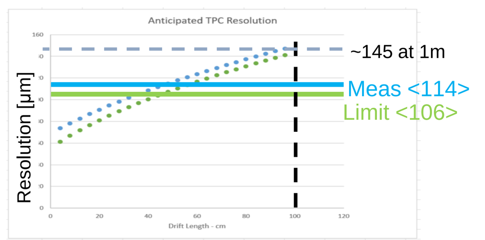





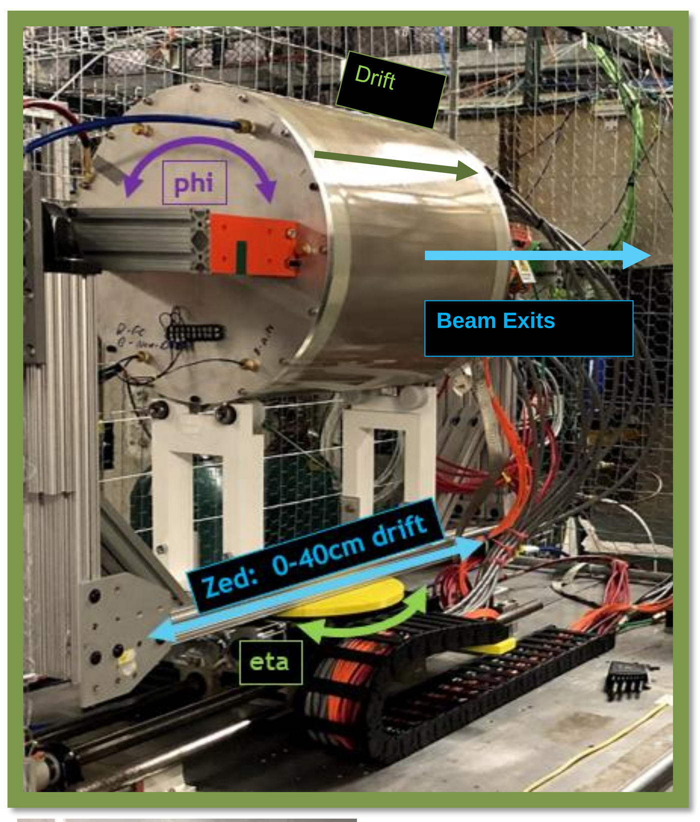

Series of events at different drift lengths used to determine spatial resolution as a function of position

Definite improvement over summer 2018 results!

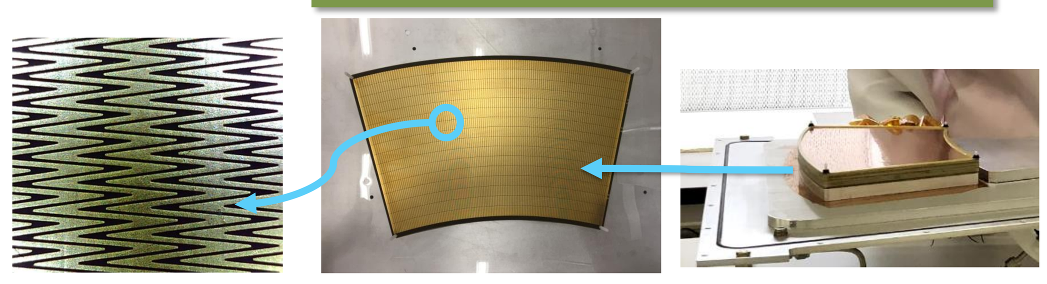


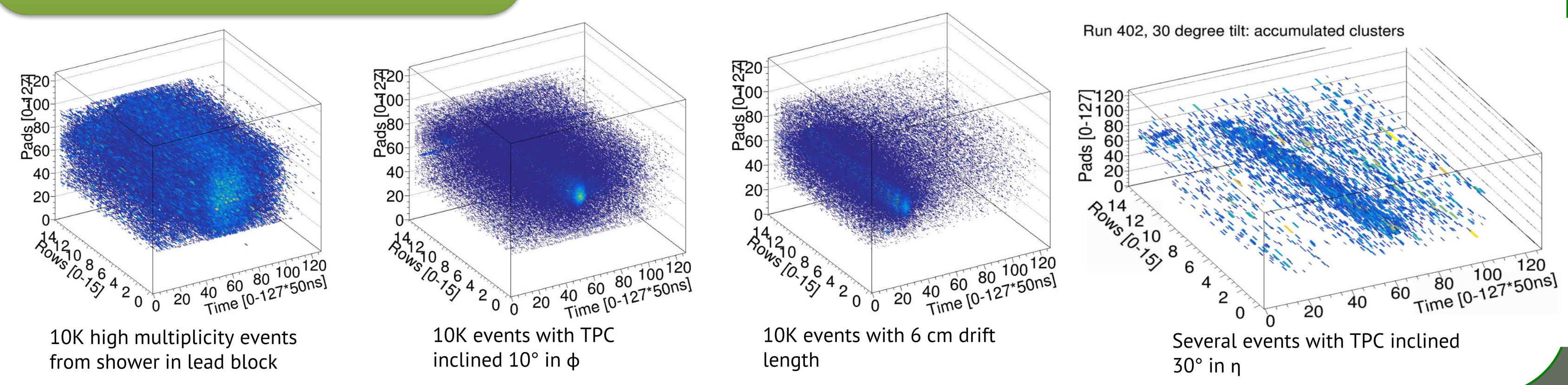

## sPHENIX Prototype TPC

- 40 cm long, one-sided TPC
- Exposed to 120 GeV protons at Fermilab Test Beam Facility
- 400 V/cm drift field
- Ne:CF4 50/50 gas mixture
- Single module, 1/36 of an endcap
- Quad-GEM with zig-zag pads
- Moving stage allows for movement simulating tracks inclined in z,η,ϕ
- No magnetic field, realistic momentum resolution requires extrapolation
- Free parameters: GEM voltages, cathode voltage, gas mixture, TPC position, beam species



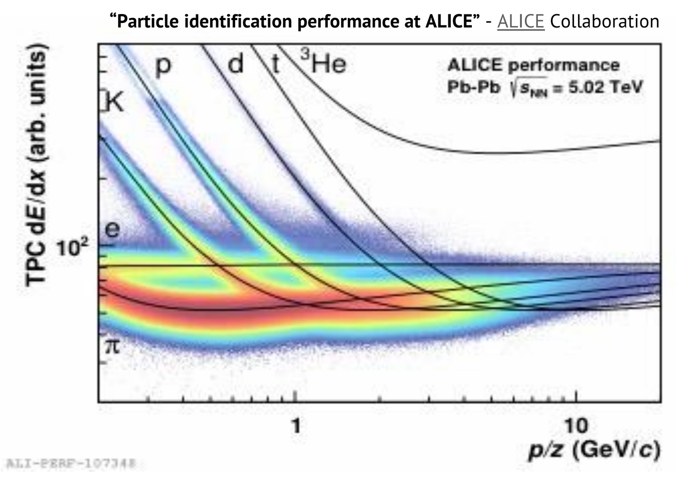

**Identical setup to Summer 2018 test beam allows for performance comparison of gas mixtures and voltages**



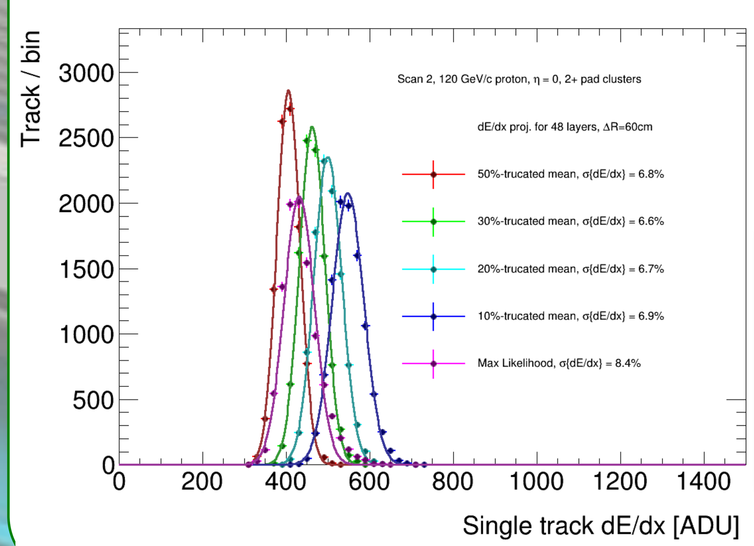



## dE/dx Resolution

- Measuring the energy loss for different particle species enables particle identification in a TPC, critical measurement for EIC
- sPHENIX TPC is compact, covers 20 < r < 78 cm
- dE/dx measurements generally use long baseline: STAR radial drift volume 150 cm, ALICE 162 cm
- Due to large ratio of primary ionization to total ionization, $CF_4$ enables high dE/dx resolution in a smaller TPC




| TPC | Pad rows | Gas | Radial Drift Vol. [cm] | dE/dx [keV/cm] | Primary Ionization [/cm] | Total Ionization [/cm] | Total Ionization/Initial Ionization | Integrated Primary Ionization | dE/dx resolution eta=0 | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| STAR w/ iTPC | 72 | P10 - 10% methane, 90% argon | 150 | 2.344 | 23.2 | 89.9 | 3.9 | 3,480 | 6.5% | RHIC S&T review 2019, Caines; iTPC proposal |
| ALICE 2010 | 160 | (Ne/CO2 90/10)/N2 5% (N2 not in calculation) | 161.8 | 1.705 | 14.35 | 47.8 | 3.3 | 2,322 | 5% (cosmic) | doi:10.1016/j.nima.2010.04.042 |
| sPHENIX2019 w/ EIC R1 | 48 | Ne/CF4 50/50 | 60 | 4.28 | 31.5 | 71.5 | 2.3 | 1,890 | This study | sPHENIX TDR; arXiv:1402.1209 [nucl-ex] |



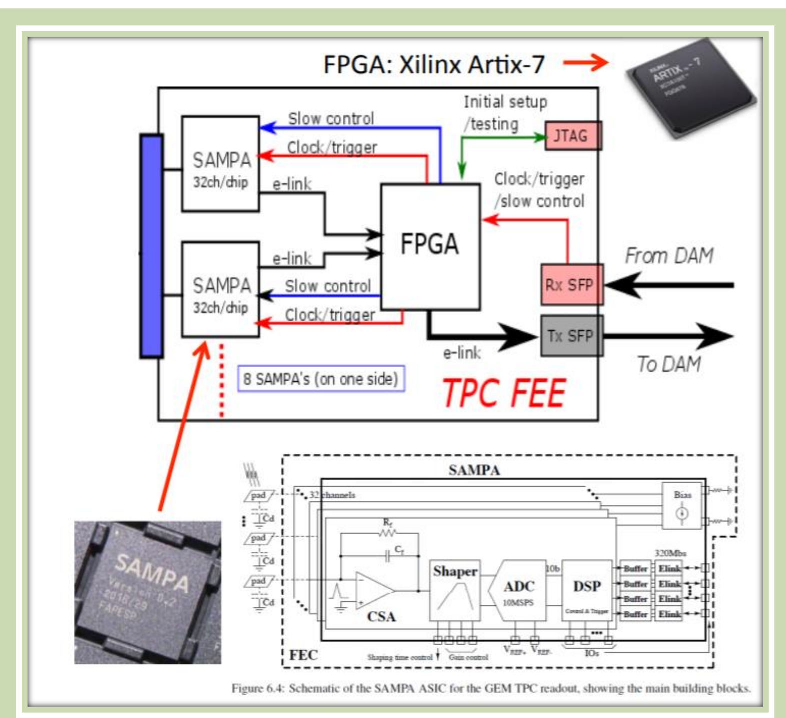

- sPHENIX needs to run in low IBF configuration due to high rate and occupation, makes dE/dx more difficult, but for EIC IBF is not as large of a concern
- Projection of test beam data to full TPC provides a possible dE/dx resolution of σ = 6.6%
- sPHENIX TPC is a capable day-one detector for EIC!

## Readout Electronics

- Continuous readout via 8 SAMPA per front-end card
- 8 FEE cards for prototype TPC
- 256 Channel SAMPA Optical readout

3D printed cradle contains 8 cards, 2048 total channels

Fiber Optic Transmission Lines

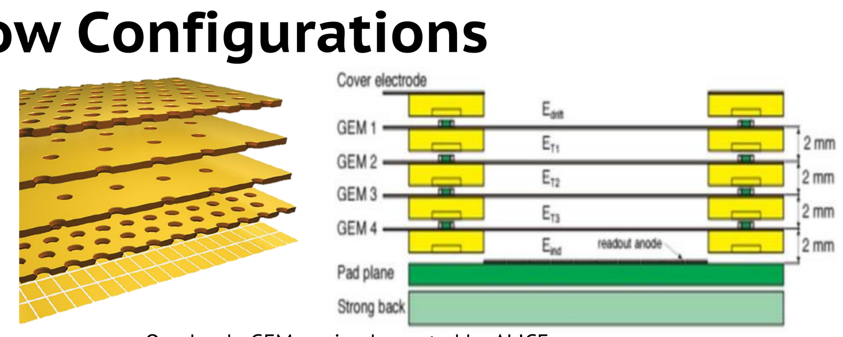



Structure of TPC Front-end electronics

- Prototype employs almost-final FEE
- 80 ns peaking time required for sPHENIX
- SAMPA v5 coming soon!
- Streaming readout performed well, aside from some event chopping issues

## Low Ion Backflow Configurations

- Space charge from ions in the avalanche can significantly distort the electric field lines
- MPGDs such as GEMs and Micromegas can reduce the amount of ion backflow below 1%
- The IBF of several configurations of voltages on individual GEM layers was tested at Yale
- These configurations were then implemented in the prototype TPC
- Voltages on GEM tops and bottoms could be tuned remotely during a run
- All low IBF configurations were stable with no sparking
- Passive gating grid has potential to further reduce IBF (See Poster by P. Garg)




Quadruple GEMs as implemented by ALICE
(R. Majka, "The ALICE TPC Upgrade Project", Quark Matter 2017, Feb. 8 2017)

| | | | | |
|---|---|---|---|---|
| IBF % No Passive Gating Grid | 0.44% | .39% | .33% | .31% |
| IBF % With Grid | .22% | .2% | .17% | .16% |
| GEM1 Top | 4208V | 4658V | 5124V | 5118V |
| GEM1 Bot | 3951V | 4401V | 4851V | 4861V |
| GEM2 Top | 3051V | 3351V | 3651V | 3661V |
| GEM2 Bot | 2721V | 3021V | 3321V | 3342V |
| GEM3 Top | 1821V | 1971V | 2121V | 2142V |
| GEM3 Bot | 1409V | 1559V | 1709V | 1709V |
| GEM4 Top | 1379V | 1529V | 1679V | 1679V |
| GEM4 Bot | 900V | 1050V | 1200V | 1200V |

GEM Voltage Configurations With IBF Properties Tested at Yale

Stony Brook University