FY2026 NPP LDRD Type B Pre-Proposal

Pursue Future Gaseous applications

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FY2026 NPP LDRD Type B Pre-Proposal

Proposal title: Pursue Future Gaseous applications

Primary Investigator: George Iakovidis (PO)

Other Investigators:

Indicate if this is a cross-directorate proposal: Yes ___ No_X__

If yes, identify other directorates/organizations:

Proposal Term: 2y From: October 1st, 2025 To: September 30th, 2027

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FY2026 NPP LDRD Type B Pre-Proposal

Proposal title and brief abstract: **Pursue Future Gaseous applications**
Gaseous trackers are considered in several detector proposals in future accelerators and especially in Higgs factories due to their low mass. Particle identification with Gaseous detectors has been used in the past but suffers from landau fluctuations. We propose to pursue the **cluster counting technique** which potentially provides a x2 improvement and hence better particle identification.

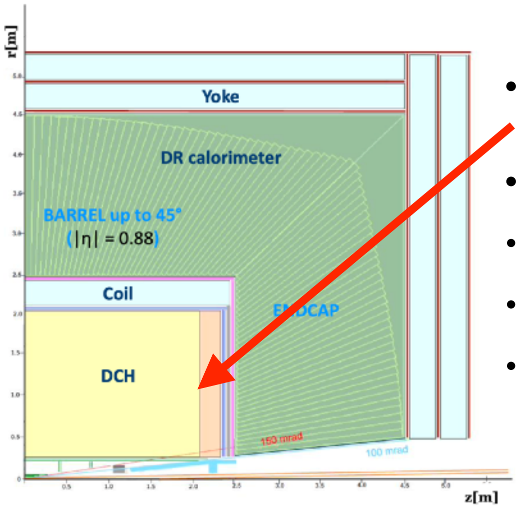
Program: HEP

Return on Investment: ~10M$ (participate in construction and operation of a gaseous tracker)

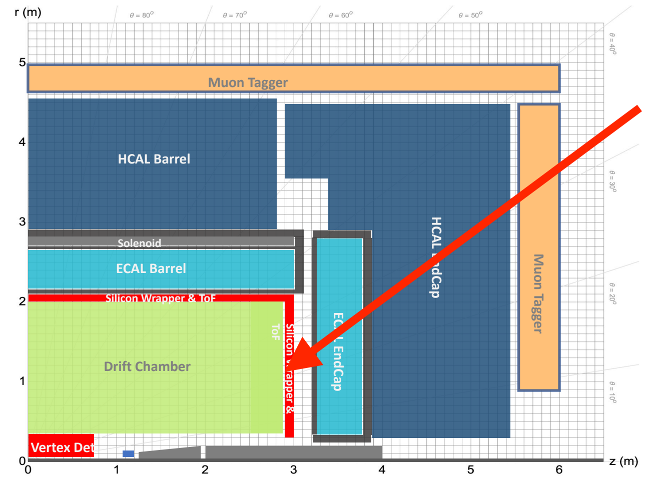
Broader impact on the activities at the laboratory: Gaseous application may be considered in other areas eg. EIC experiments, improve He based gaseous microscopic simulations, developments on electronics for waveform sampling.

Total planned funding per year in FY26 and FY27: 460k$

Future Higgs factories - FCCee

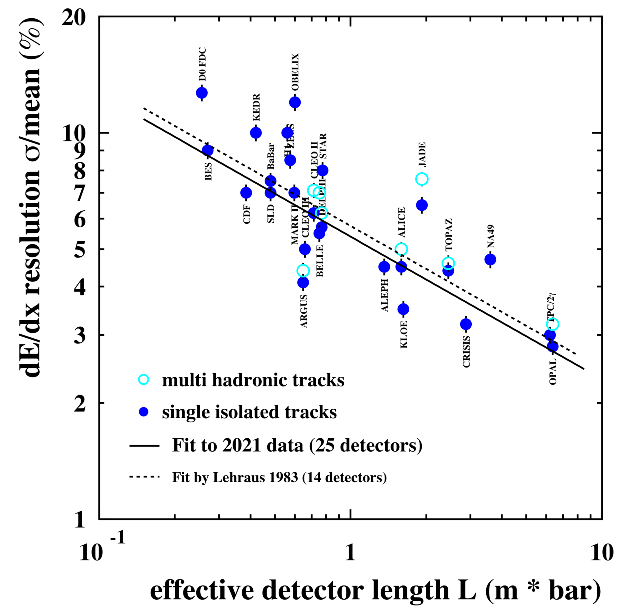


- **<u>Transparent Drift Chamber</u>**
- **4m Long**
- R = 35-200cm
- 112 layers
- (Outer Silicon wrapper for ToF)



- **<u>Transparent Drift Chamber or straw tubes</u>**
- **5m Long**
- R = 35-200cm
- Basically follows the same layout with IDEA concept
- (Outer Silicon wrapper for ToF)

- Gaseous technologies under active development for the main tracker
  - **Drift chambers** (DCH) (He + 10% iC4H10)
  - **Straw tubes** (ST)
  - Time projection chambers (TPCs) (operability is still a subject of debate)
- In addition to lowest-possible material budgets, they offer particle identification capabilities via specific energy loss
  - Performance of present generation of detectors as predicted ~40 years ago



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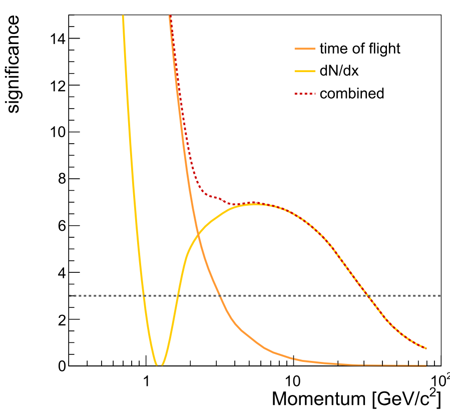
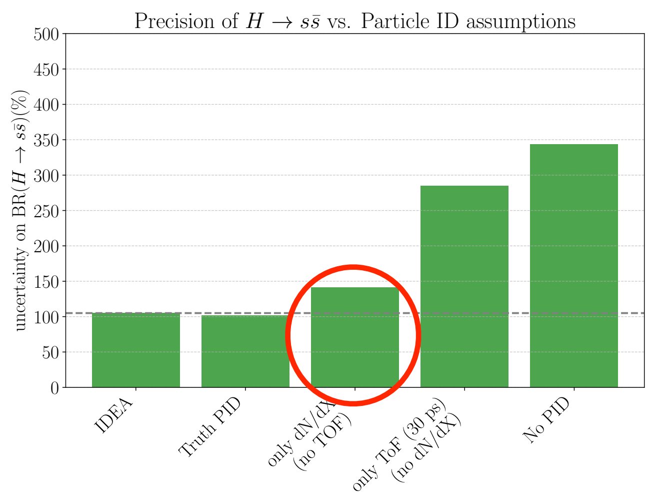
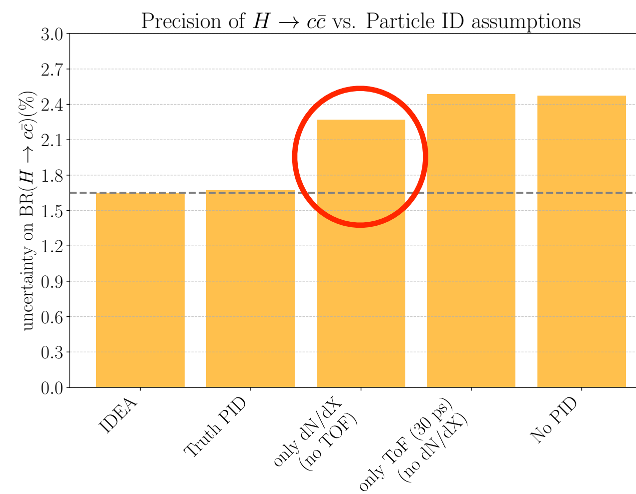
Purse $\mathrm{d}N_{\mathrm{cl}}/\mathrm{d}x$ and exploit the potential

- Future Higgs factories will offer **unprecedented precision measurements** of the Higgs boson
- We have studied in the last 2 years through the LDRDA (Capturing Leadership at the Future Higgs Factory for BNL) the Higgs **couplings** to quarks through Hadronic decays and **different detector assumptions**
- A **low mass gaseous tracker** is of significance importance to achieve the physics potential (based on **fast simulation**)
- A.H. Walenta in 1980s at BNL showed that **additional charge comes from number of primary clusters** and not from energy per cluster
  - $\mathrm{d}N_{\mathrm{cl}}/\mathrm{d}x$ (cluster counting) offers ~2x better resolution and hence better energy separation for PID → challenge for electronics

π, K separation of IDEA DCH along with a TOF measurement at 2m







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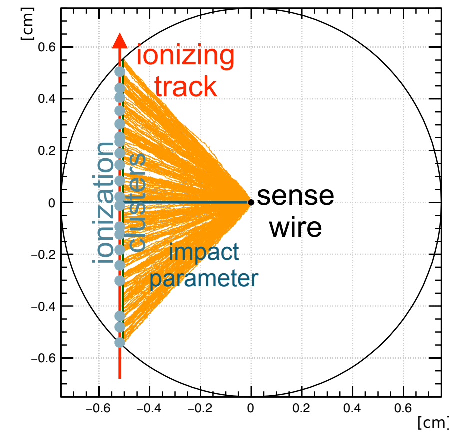
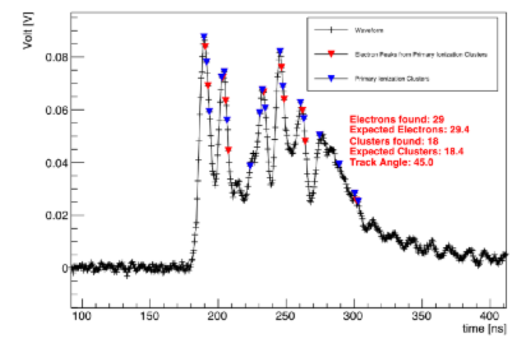
Importance of Particle ID through dN/dx

This LDRD-B Proposal

- We propose for this LDRDB to support the main PI (HFCC L3 coordinator for gaseous trackers) + ~50% of a research associate (talent already in LDRDA up to Sept. 25)
- **Develop a microscopic simulation** studying the interaction of charged particles in He-based gases (greener solutions ?), ionization, drift, avalanche, signal formation - **relevant for any gaseous application (Milestone 1 - FY26)**
- Full simulation implementation in FCCee framework to validate the feasibility of the cluster counting technique:
    - Purse the performance by participating in Test-beams (small procurements) with international partners (within DRD1 at CERN) already established **(Milestone 2 - FY26)**
        - **Beam availability** limited next years
    - Analyze test beam data and compare to simulation **(Milestone 3 - FY27)**
    - Develop AI algorithms for the reconstruction **(Milestone 4 - FY27)**
- Define the requirements of the electronics and the mode to be used in order to provide information sufficient for cluster counting - Input to instrumentation colleagues **(Milestone 5 - FY27)**
- Explore potential participation in the construction of a gaseous tracker, study wires (small **procurement**), detector layout
- Publish work in journal and in conferences





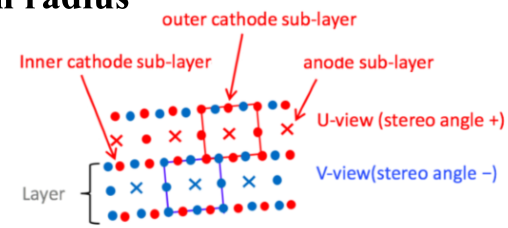
Summary Slide

- Future Higgs Factories will offer the potential for unprecedented precision measurements of the Higgs boson
- At BNL (first in US) we have already studied through fast simulation, the Higgs couplings to quarks through hadronic decays - major impact of the LDRDA
- A low mass gaseous tracker will provide excellent PID capabilities if the cluster counting can be applied
  - This proposal will exploit the cluster counting potential based on reliable microscopic simulation (similar techniques already validated through previous experience in ATLAS, CSC, NSW) - impact on any gaseous application
  - Maintain and buildup the gaseous detectors expertise at BNL
  - Define the electronics requirements, can be developed for all gaseous trackers
- Set BNL among the leading institutes for gaseous tracking developments and explore the possibility to construct and operate such a system (identified as potential major US contribution in USHFCC tracker coordination)
  - Collaboration are under formation for different experiments, we need to be in those!

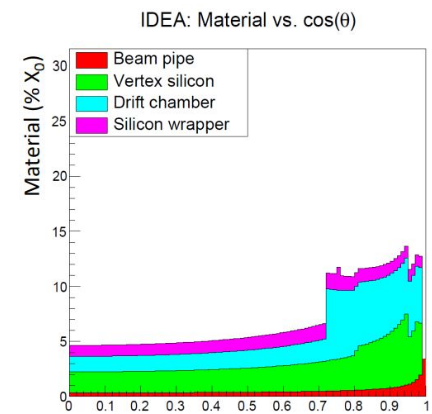
backup

IDEA Drift Chamber

- Dimensions: **4 m long** (active volume), **35cm to 2m radius**
- **Low material budget**
  - Barrel: ~ 1.6% X_0
  - Forward directions: ~ 5% X_0
- Stereo layout
  - **112 layers** ranging from 50 to 250 mrad
- Operating gas mixture: **He + 10% iC_4H_{10}**
  - Average drift velocity of ~ 2 cm/µs ⟶ drift time t_D < 400 ns
  - Number of cluster (per m.i.p.) ~ 12.5 cm^{-1} avg. with ~ 1.6 electrons/cluster)
- Sense (anode): 20µm W(Au) → 56448 total
- Field (cathode): 40µm Al(Ag) → 285504 total
- Guard (cathode): 50µm Al(Ag) → 2016 total
- Active volume: 56448 almost squared drift cells (12 ÷ 14.5 mm), with a 5 : 1 field-to-sense wire ratio for simpler time-to-distance relations
- Overall **expected resolution**: σ_{xy} ~ 100 µm and σ_z ~ 1 mm

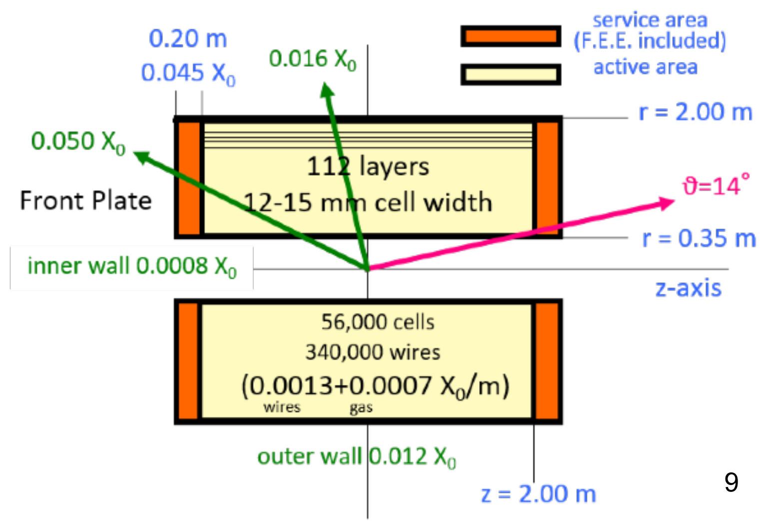


5 : 1 field-to-sense wire ratio



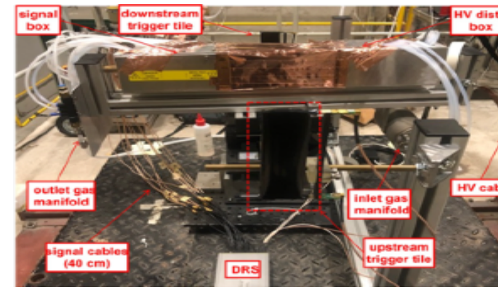
tracking efficiency ε ≈ 1
for ϑ > 14° (260 mrad)
97% solid angle

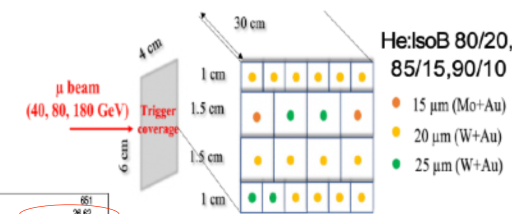
$0.016\ X_0$ to barrel calorimeter
$0.050\ X_0$ to end-cap calorimeter

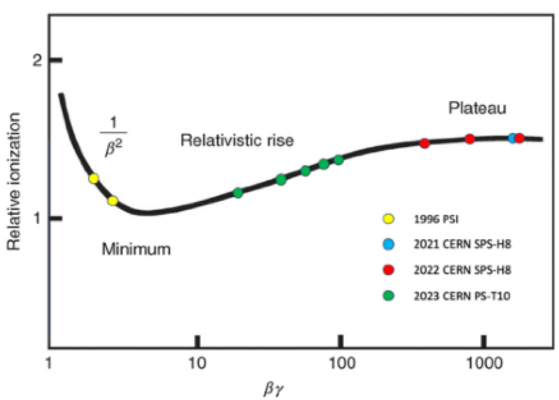


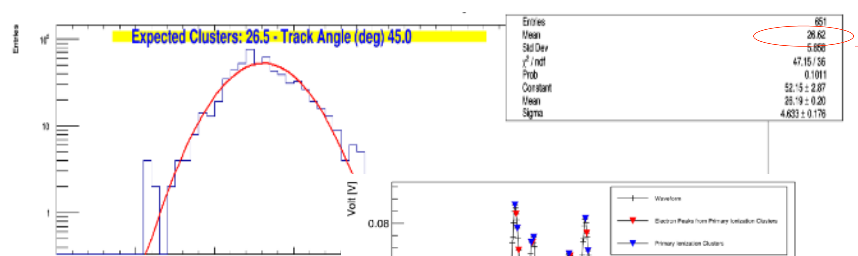
Reconstruction techniques, test-beam results

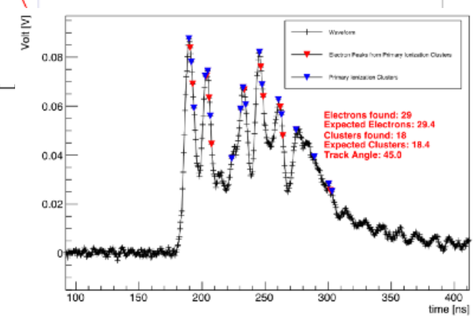
- Several **test beams** to experimentally assess and optimize the performance of the cluster counting/timing techniques covering big range of $\beta\gamma$ range
- **Several algorithms under testing**
  - Derivative Algorithm (DERIV)
  - Running Template Algorithm (RTA)
  - Long short-term memory (LSTM) (Recurrent Neural Network - RNN) for peak finding & Dynamic Graph Convolutional neural networks (DGCNN) to identify electrons in the same primary cluster

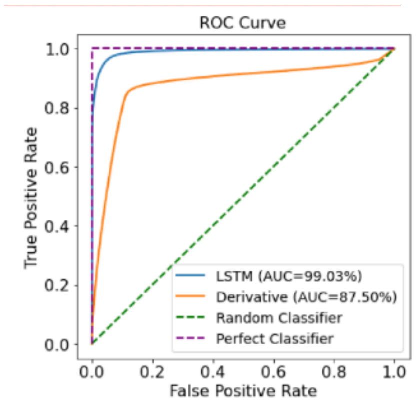












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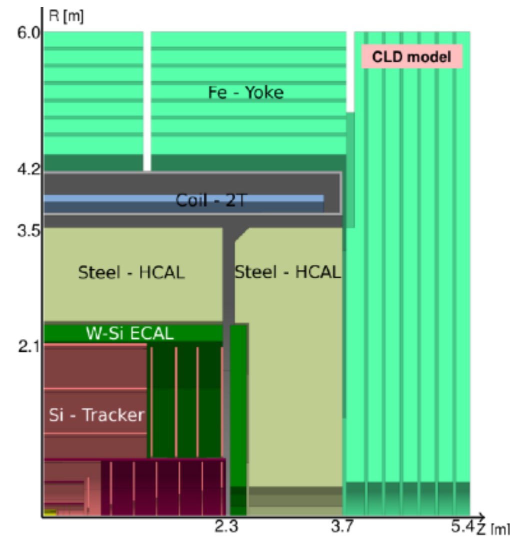
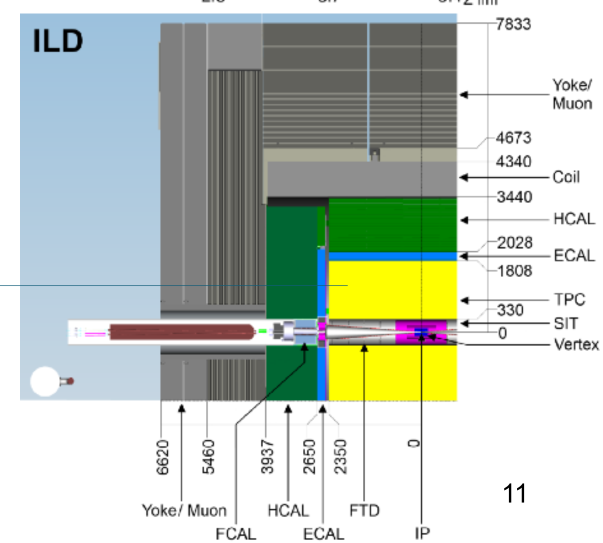
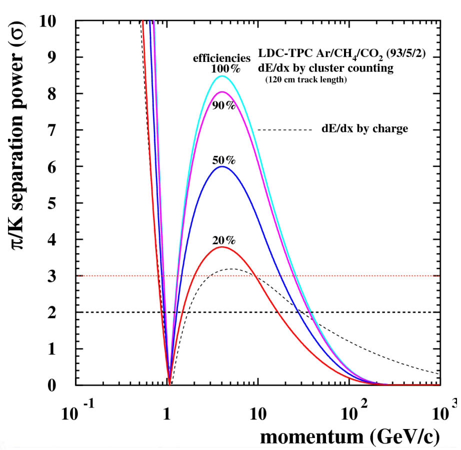
TPC as a main tracker at CLD

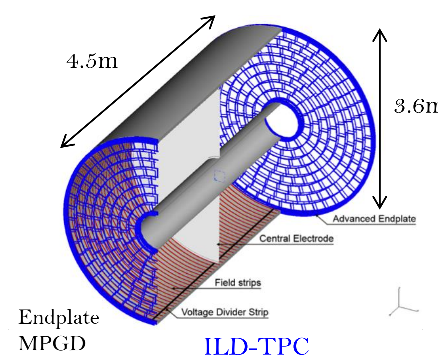
- During the 7th FCC Physics Workshop in Annecy, the [ILD/CLD concept studies with a TPC] were presented
- Proposal of a TPC based the developments for ILD using MPGDs like Triple/Double GEMs, Resistive Micromegas or GridPix (a must have for dN_{cl}/dx to work)
- 5% X_0 in barrel 25% X_0 in endcap
- **Differences between ILC and FCC-ee operations:**
  - ILC consisting of 1312 bunches (0.73 ms total) in a bunch train spaced every ~0.5μs and a 199 ms with no activity
  - FCC-ee up to 170 times more luminosity at Z-pole with bunch spacing of 20-25ns

➡ Imposes big challenges for a TPC operation









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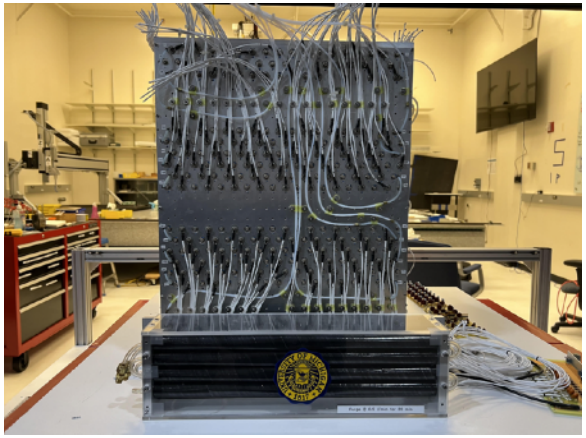
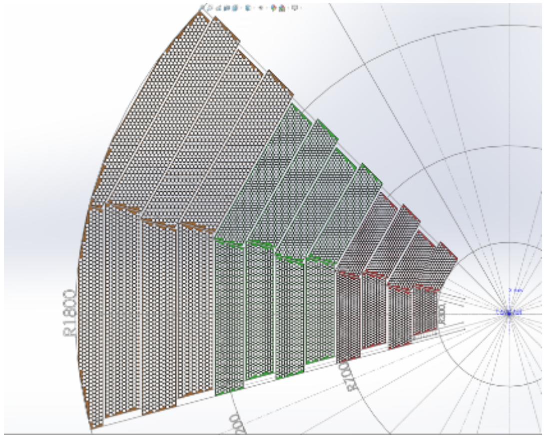
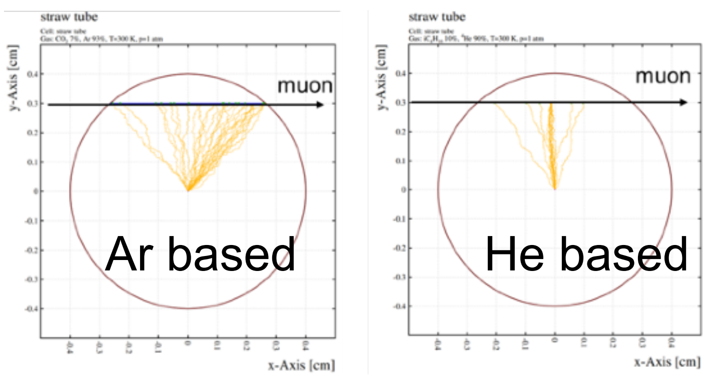
Straw tubes

- Recent proposal to explore the **possibility of a straw tube tracker**
- Variable diameter (inner to outer) ⟶ optimise occupancy
- Similar characteristics to drift tubes but lower material budget
  - Assuming **Aluminized Mylar** (15μm mylar, 0.05μm aluminum) and 25μm **tungsten** wires ⟶ ~1.2% X_0
    - **Not including** mechanical supports on the estimation
    - **Challenging** for long straws of 4m (construction and transmission wise)
      - Termination to improve signal ? Noise ?
  - Operating gas? Ar based ⟶ 0.15% X_0 not ideal for cluster counting compared to He based ⟶ 0.035% X_0 , signal small though due to density, optimization is needed!
- Group is looking to build a small prototype with 20-50 straws and perform various studies



A straw tracker at the UM ATLAS muon detector construction lab

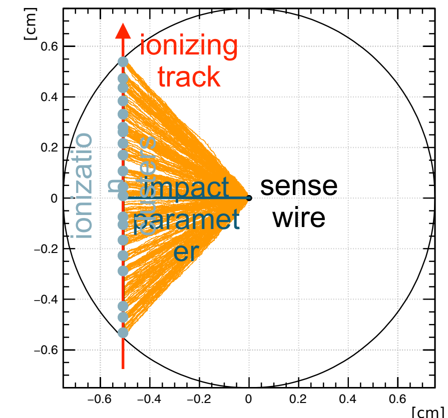


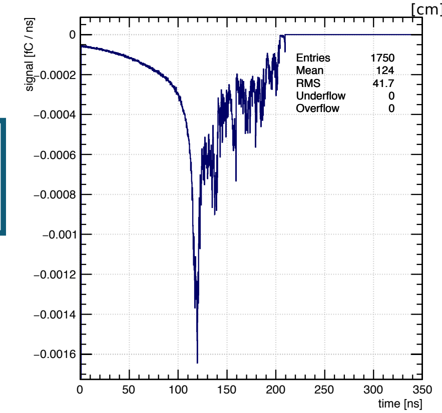


The dN_{cl}/dx technique

- Based on A.H. **Walenta** research in 1980s who showed that **additional charge** comes from **number of primary clusters** and not from energy per cluster
- Technique is to **define ionization clusters** from the signal formation **distribution** within the track footprint
    - Ordered in time electrons (average time separation within clusters)
    - Electrons per cluster (primary & secondary ionizations)
    - Number of clusters per track
- Further improvement by adding the Cluster timing (spatial resolution, timestamp etc)

Drift tube simulation
Garfield





dE/dx	dN_{cl}/dx
$\frac{\sigma_{dE/dx}}{(dE/dx)} = 0.41 \cdot n^{-0.43}(L_{track}[m] \cdot P[atm])^{-32}$	$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = (\delta_{cl} \cdot L_{track})^{-1/2} = N_{cl}^{-1/2}$

trunc. mean (80%), n=112, 2m at 1atm (Walenta param.)

IDEA DCH $\delta_{cl} = 12.5/\mathrm{cm}$ for He+10%iC_4H_{10} and 2m (Poisson distr.)

$\sigma \approx 4.3\,\%$

$\sigma \approx 2.0\,\%$

- G. Cataldi et al, NIM A 386 (1997) 458-469
- P. Rehak and A.H. Walenta, IEEE Trans. Nucl. Sci. vol. 27, no. 1, pp. 54-58, Feb. 1980
- F. Grancagnolo, AIDAinnova 3rd Annual meeting, 2024

Challenge for electronics - GHz bandwidth !