BNL Tracking workshop summary: gaseous trackers and Sci-Fi

Fabrizio Palla

INFN Pisa and CERN

FCC Week 2025

Vienna (Austria)
20 May 2025

Agenda

All Carbon fibre Drift Chamber	*Andreas Werner Jung*
Physics Large Seminar Room, Physics Building 510A	10:30 - 10:48
IDEA Drift Chamber - developments and plans	*Francesco Procacci*
Physics Large Seminar Room, Physics Building 510A	10:51 - 11:09
Plans for Straw Tracker	*Yuxiang Guo*
Physics Large Seminar Room, Physics Building 510A	11:12 - 11:30
A TPC as a central tracker in a FCCee experiment	*Peter Kluit*
Physics Large Seminar Room, Physics Building 510A	11:33 - 11:51
CDF-like tracker	*Franco Bedeschi*
Physics Large Seminar Room, Physics Building 510A	11:54 - 12:12
Guided discussion with open questions	
Physics Large Seminar Room, Physics Building 510A	12:15 - 12:30
SciFi Tracker for FCC-ee	*Radoslav Marchevski*
Physics Large Seminar Room, Physics Building 510A	15:10 - 15:30

IDEA drift chamber

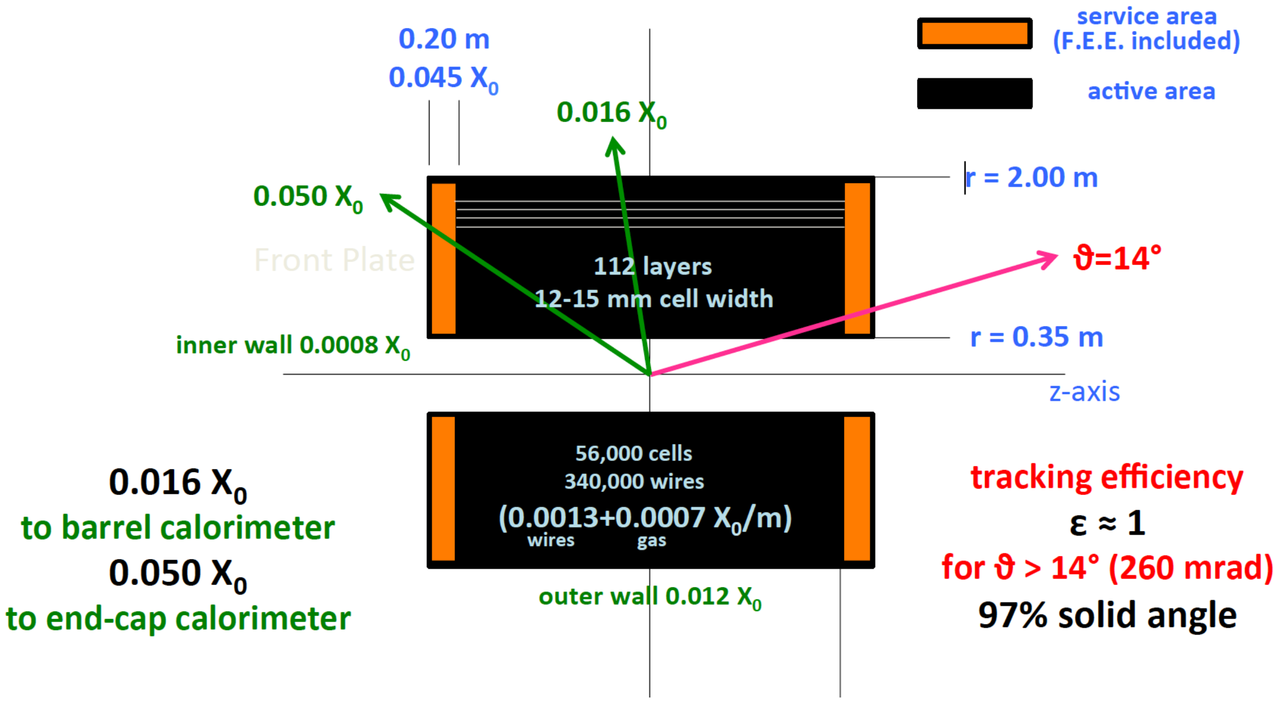
F.M. Procacci and N. De Filippis (Bari)

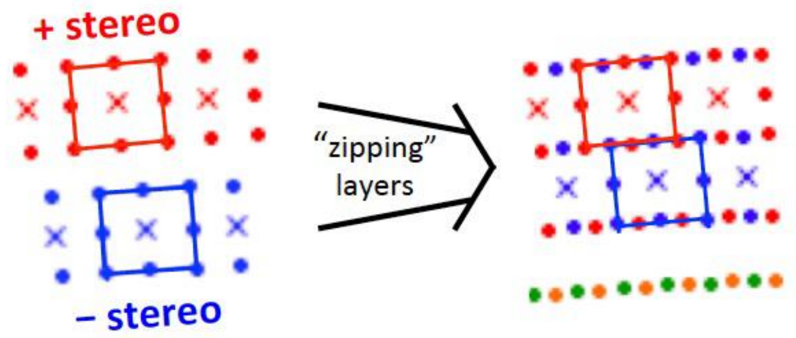
Based on MEG2 experience

Gas: He (90%) – iC_4H_{10} 10%
Dimensions: 35 <R (cm)< 200; Length= 4 m
Max drift length ~400 ns
Cell dimension: $12 \div 14.5\ mm$ wide square cells, 5:1 field to sense wire ratio
112 coaxial layers, alternating stereo angles, 24 azimuthal sectors with FE electronics

- **343968 wires** in total:
  - 56448 sense wires – 20 µm diameter W(Au)
  - 229056 field wires – 40 µm diameter Al(Ag)
  - 58464 field and guard wires – 50 µm diameter Al(Ag)

Spatial resolution: $\sigma_{xy} < 100\mu m; \sigma_z < 1mm$



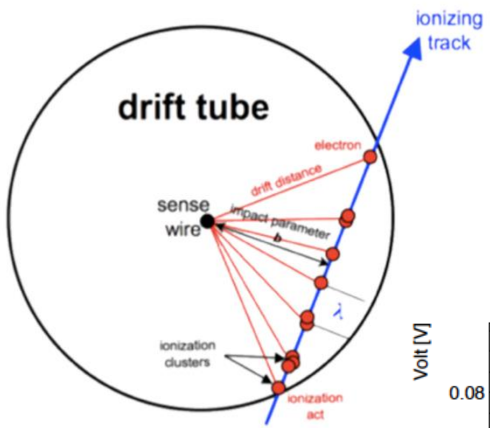


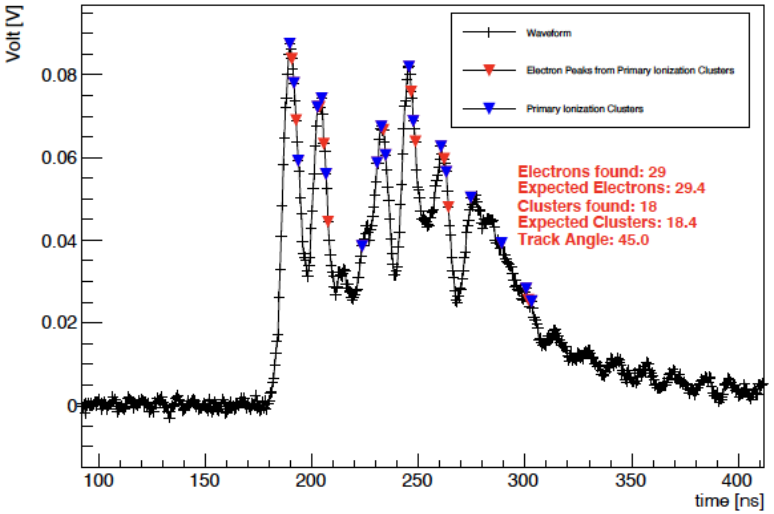
Included in DRD 1.2

Cluster counting/timing PID

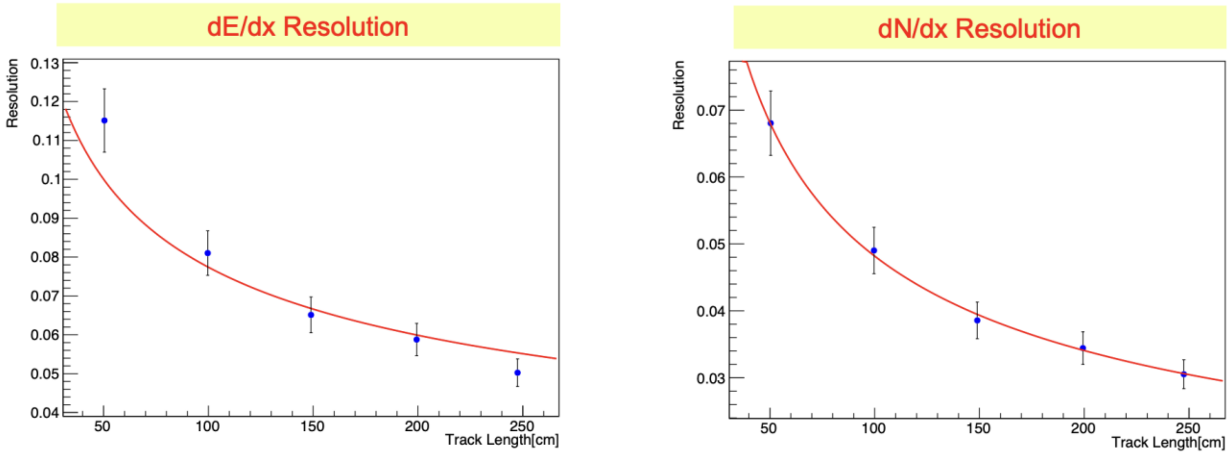
- *Signals from each ionization are spread in time to few ns, which can be identified using a fast read-out electronics*
- *Count number of ionization acts per unit length dN/dx (Poisson), with a ~2 better resolution w.r.t dE/dx (Landau)*

> - **Currently done with fast FE electronics**
>   - High sampling digitisation (2Gs/s, 12 bits and >3 kB data)
> - **Can we use analogue signals?**





Sense Wire Diameter 15 μm; Cell Size 1.0 cm
Track Angle 45; Sampling rate 2 GSa/s
Gas Mixture He:IsoB 80/20

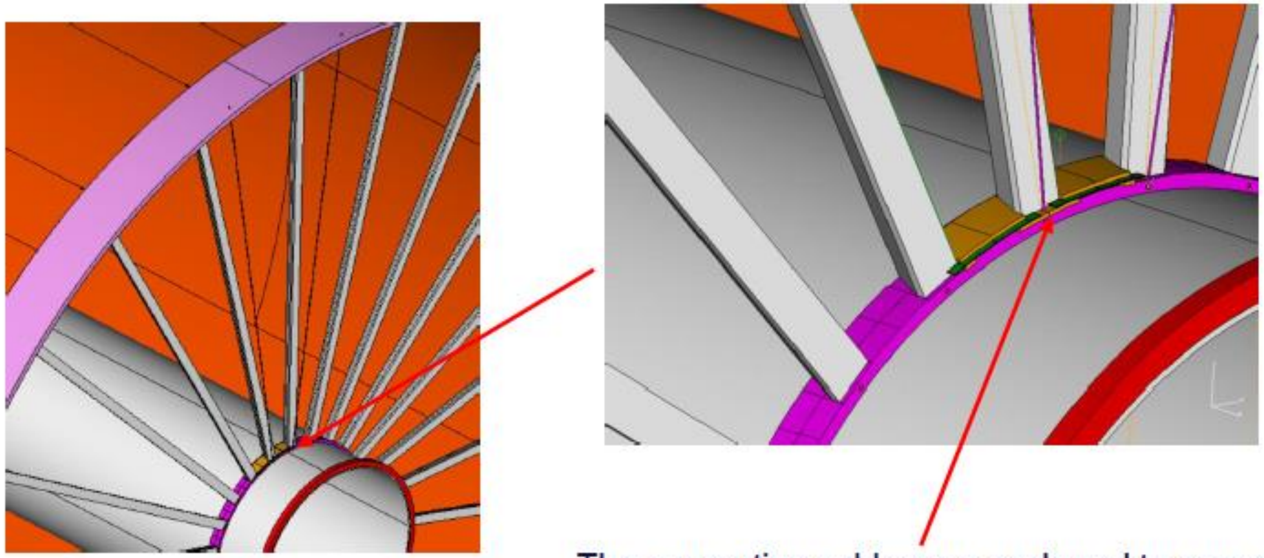


dE/dx resolution dependence on the track length $L^{-0.37}$ dN/dx resolution dependence on the track length $L^{-0.5}$

~ 2 times improvement in the resolution using dN/dx method

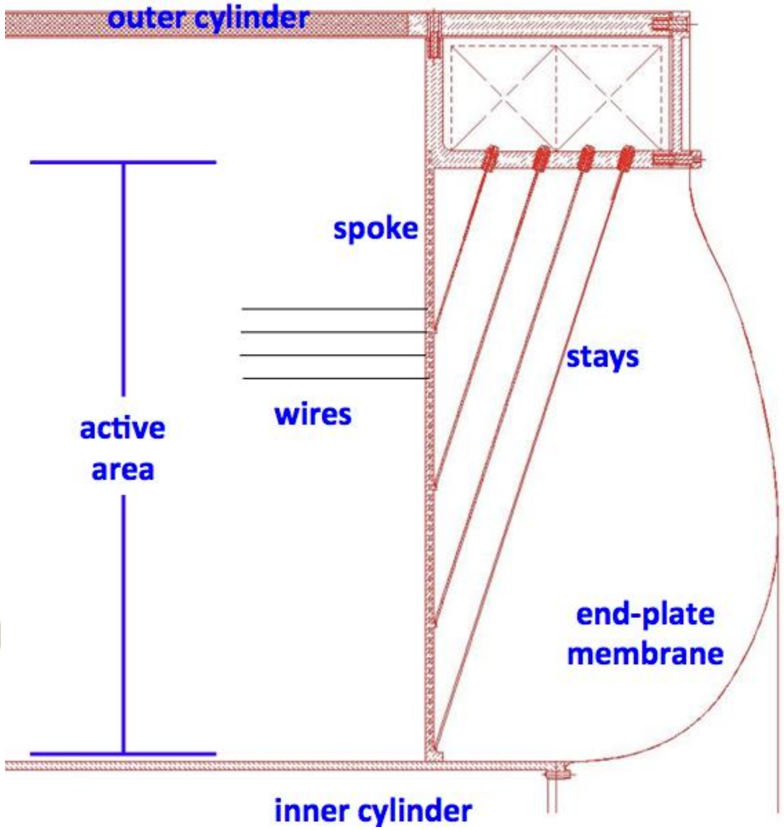
Spokes are the most innovative mechanical solution to support the wires

Mechanical design: details

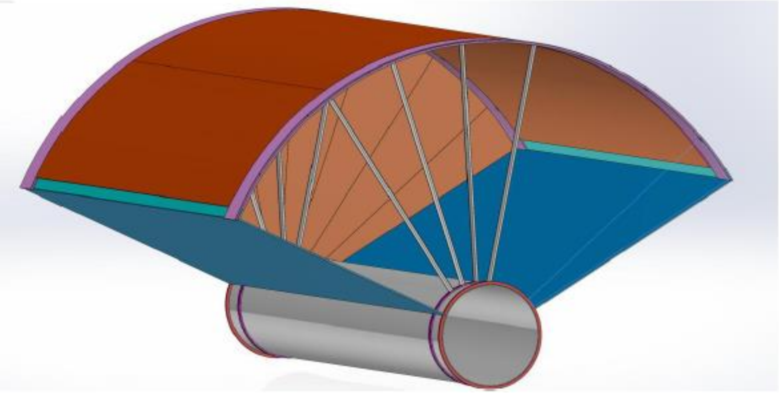


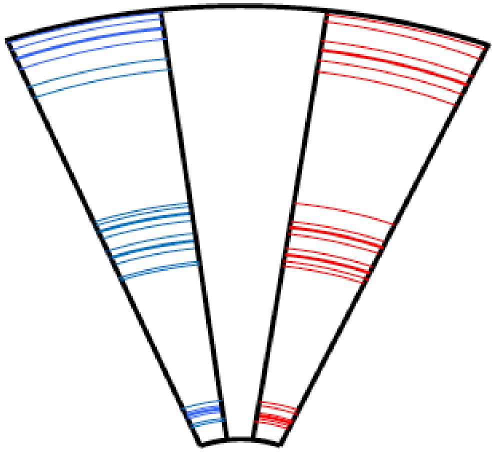
The supporting cables are anchored to some s
appropriately shaped

Carbon foam core **6x** lighter than aluminum – FOAM
ROHACELL® 35 HTC



Full length prototype

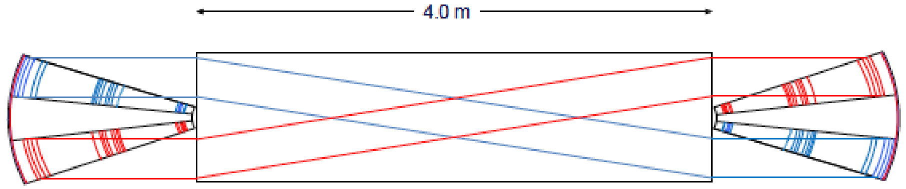




8 layers
168 sense wires
965 field wires
264 guard wires

112 readout channels

Readout channels: 8+8 + 16+16+16+16 + 16+16 = 11



INFN in collaboration with CETMA composites

Goals:

- Check the limits of wires stability at full length and stereo angles
- Test different wires material and anchoring
- Optimise wiring strategy using MEG2 DCH robot
- Validate assembly scheme
- Optimise HV and signal distribution
- Test different FE and DAQ

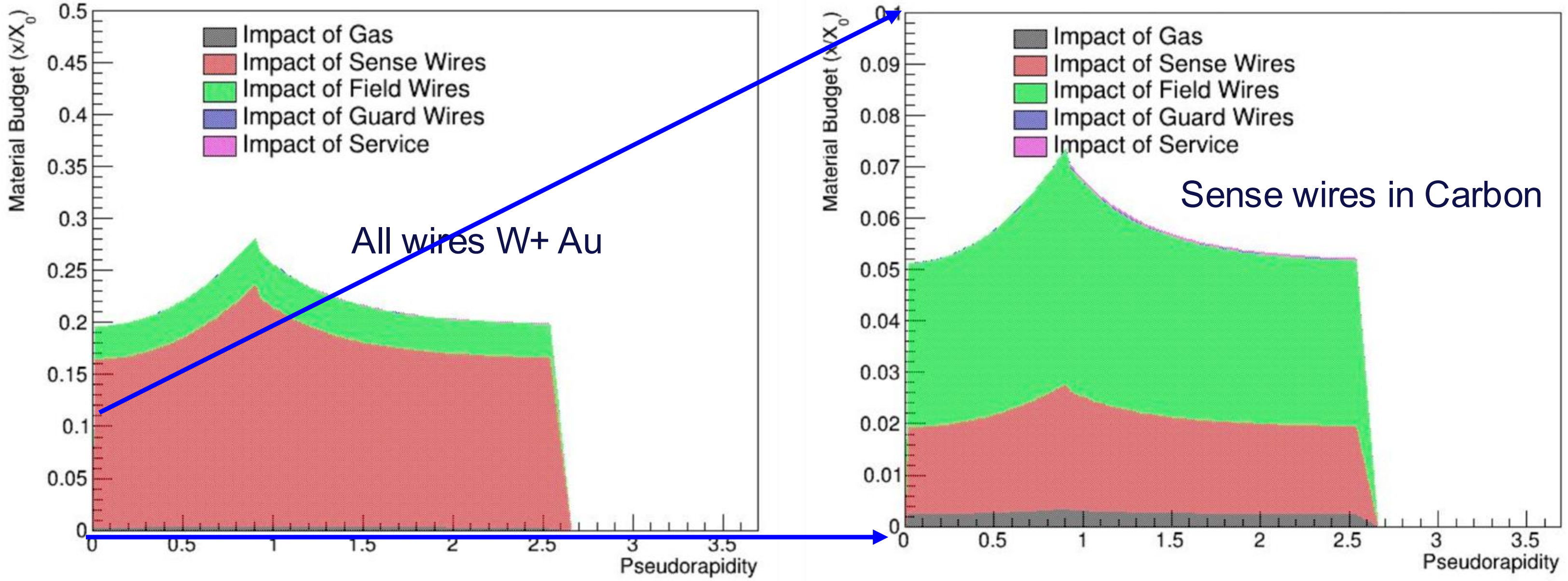
Timeline:

- Executive design finished (order placed)
- Sample components (molds and machining) ready since Fall 2024
- Wires, PCB, spacers and end-plates Fall 2025
- MEG2 robot from Pisa to Bari by Fall 2025
- Expect prototype built by early 2026

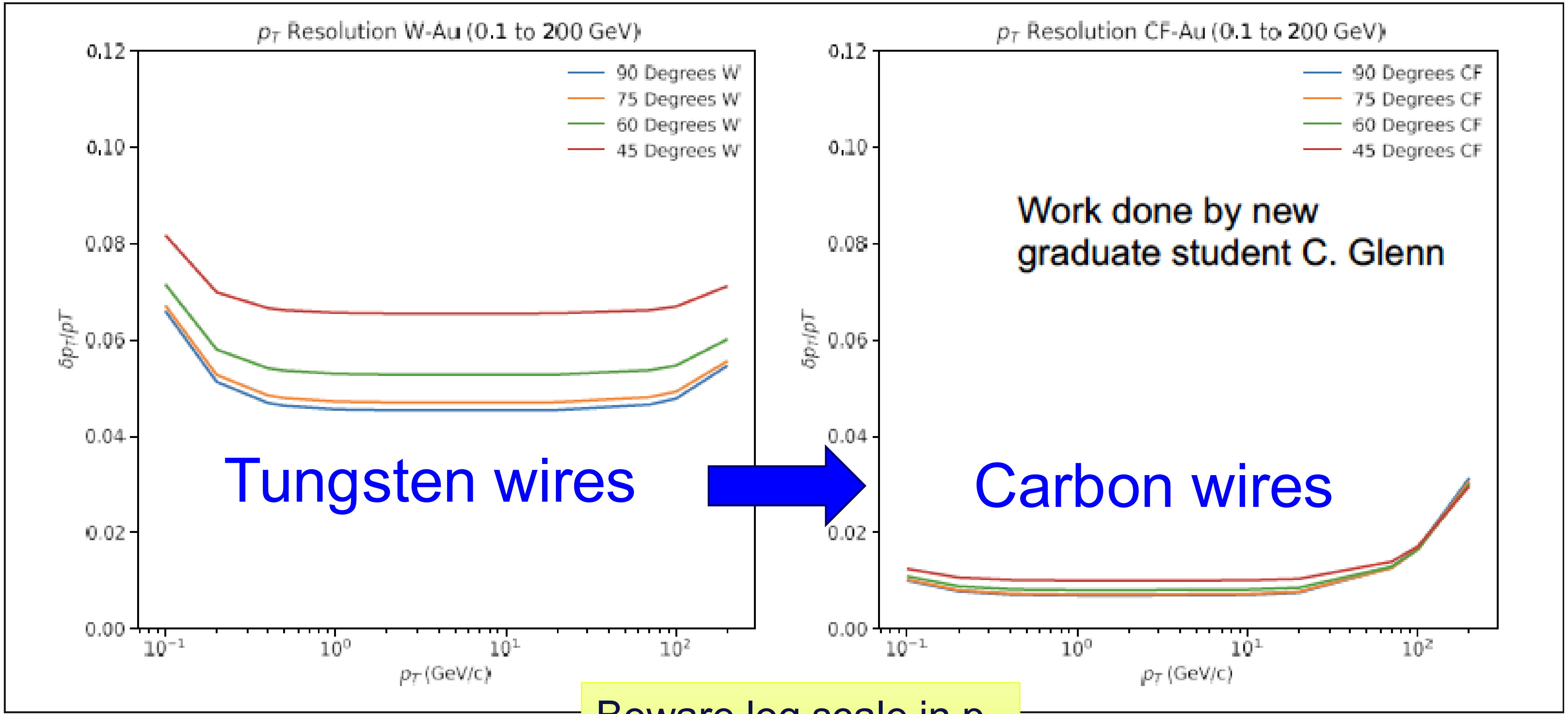
All Carbon Fibre Drift Chamber

Andy Jung (Purdue University)

- **Advantage with respect to metal wires**
- Material budget reduction
  - C+Ag/Cu is a factor ~5 smaller material compared to W+Al
- Metal coating needed
  - Purdue & Stony Brook
  - In collaboration with Oerlikon-Balzer



Resolution improvement compared to W wires



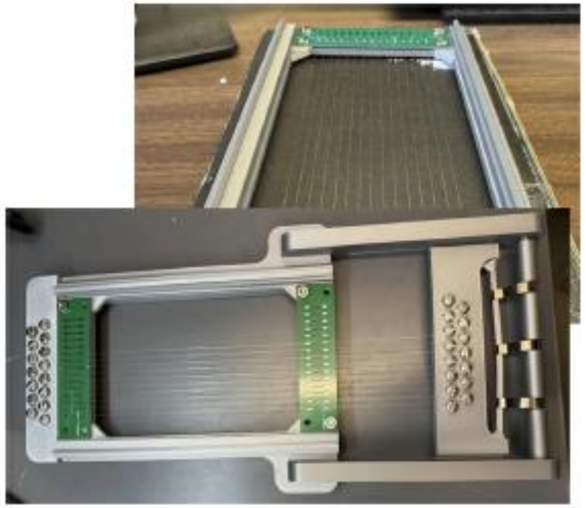
Beware log scale in p_T

Caveat: global normalization offset, consistent only between options!

Composites Manufacturing & Simulation Center

Bench-test setup @Purdue

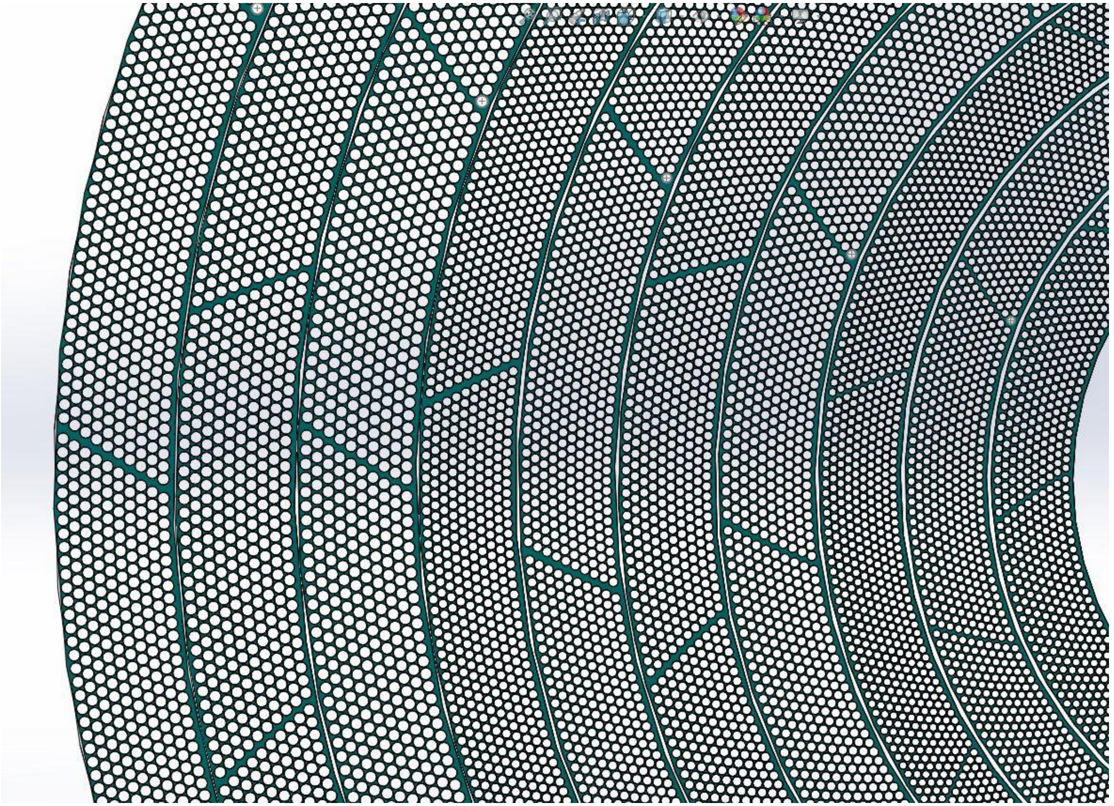
- Printed Circuit boards control the location of each wire
- Based of a ~5" existing chamber, scale to about 1' and currently assembly of two of these: one Tu and one in CF
  - High-quality Tungsten from earlier DC efforts
  - New lab being setup at Purdue for recommissioned Oerlikon-Balzer, test DC chambers, readout and so on…
- Tension is applied using constant force springs and screws on a carriage
- Next steps: Sealed source & record data & spectra
- Stay tuned…



Preexisting Wire Chamber setup

Straw tracker

Yuxiang Guo (University of Michigan)



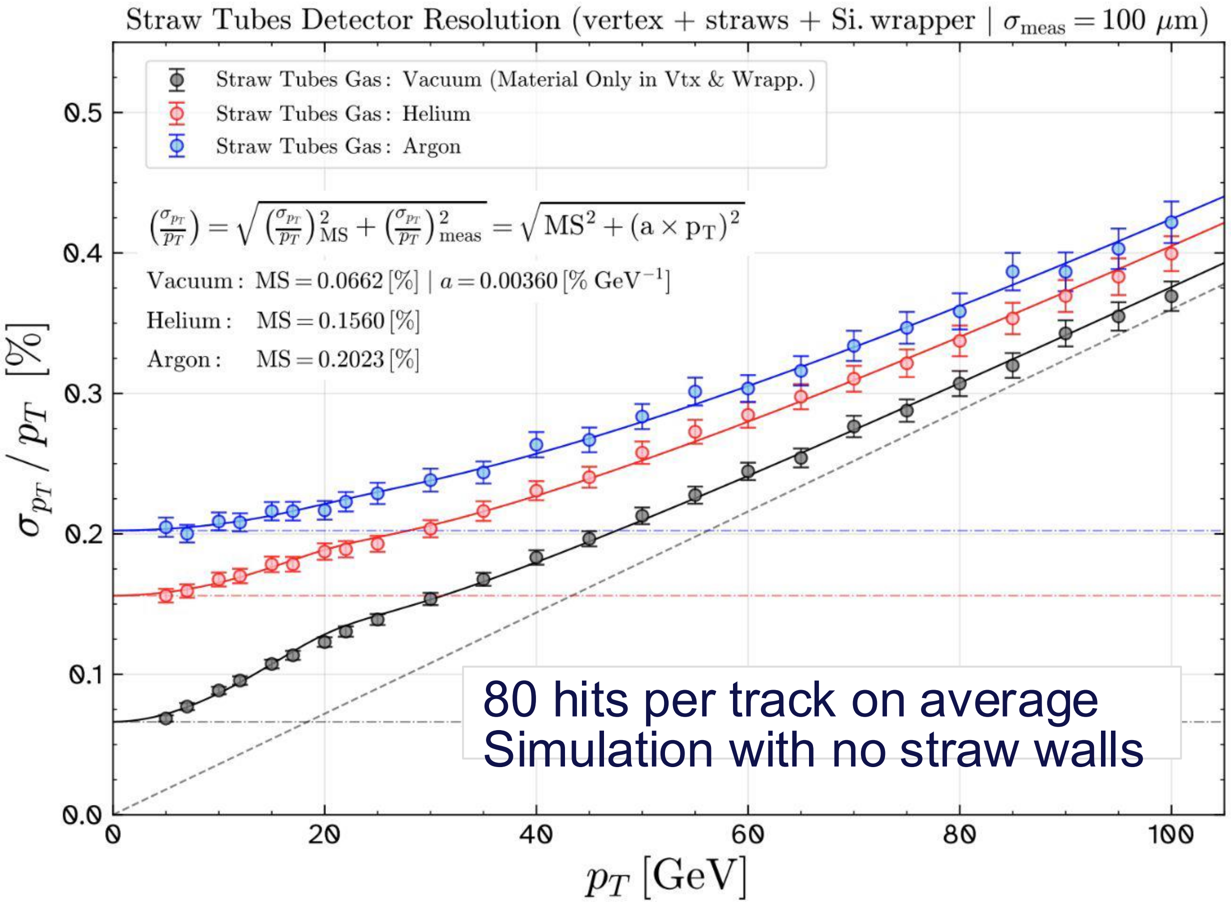
Benefits

- Low material budget
- Straws with different radii at different regions
- Radial symmetric electric field
- Simpler endplate wrt Drift chambers/TPC
- Low wire density

Difficulties

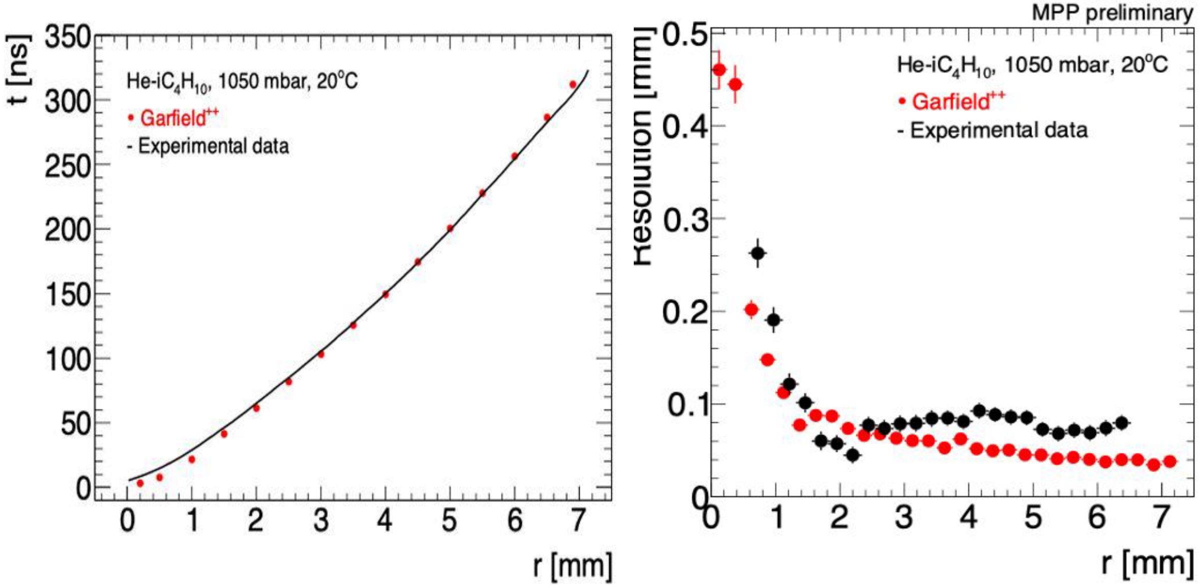
- PID with dN/dx is challenging
- Long thin straw production and assembly

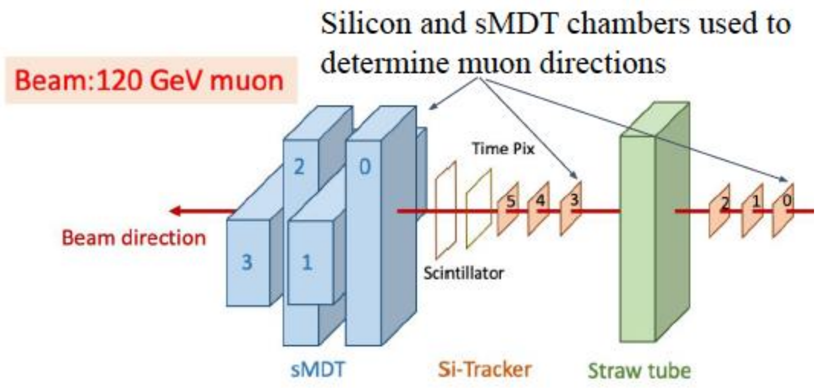
Resolution



Slightly larger multiple scattering term wrt IDEA drift chamber
Similar slope

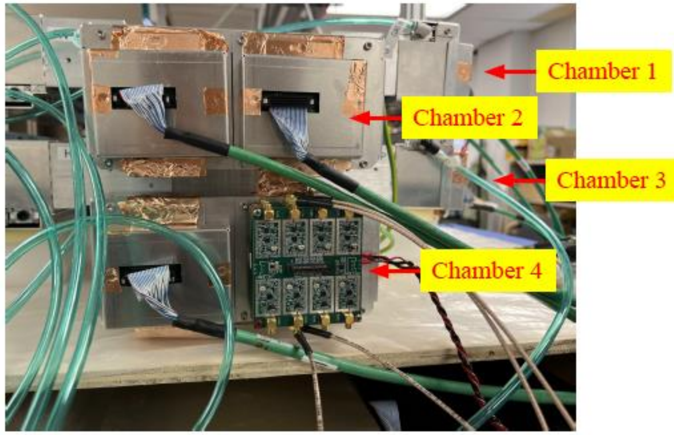
Garfield++ simulation matches well with data



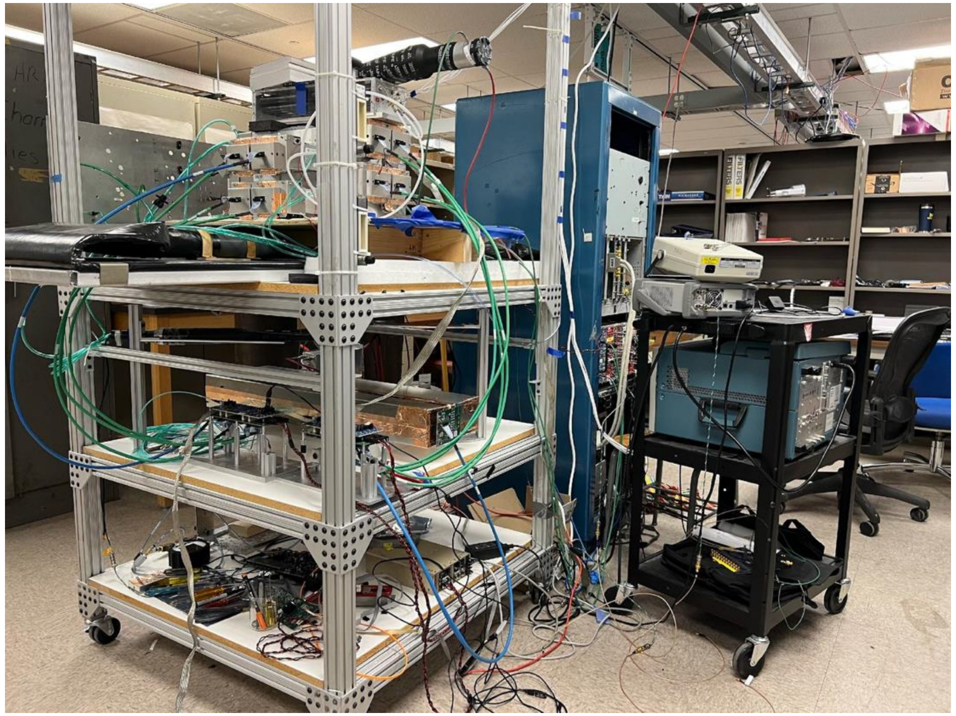


Ar (70) CO2 (30) gas mixture
Single hit resolution **100 µm,**
Second coordinate **~5 mm** for 2 degrees stereo angle
Efficiency >98%

Current R&D

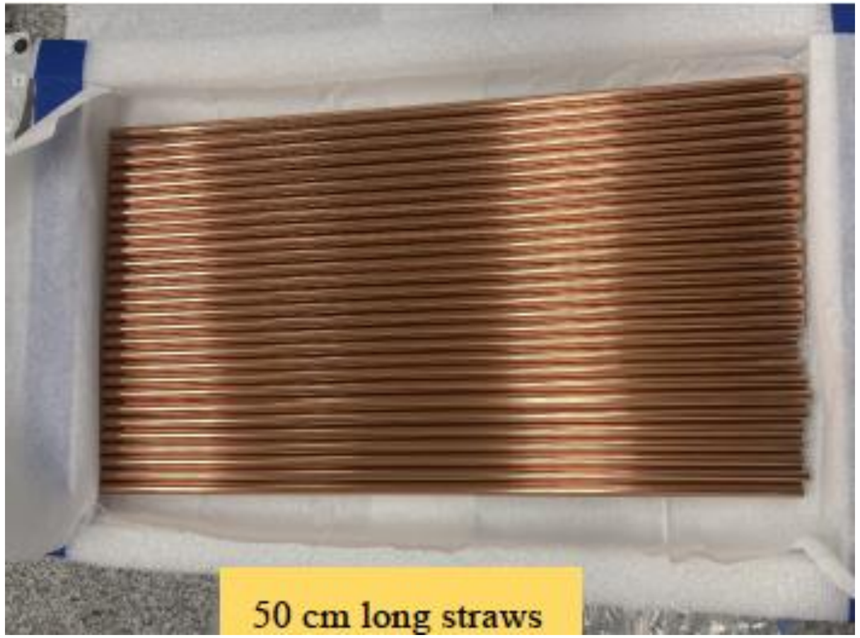


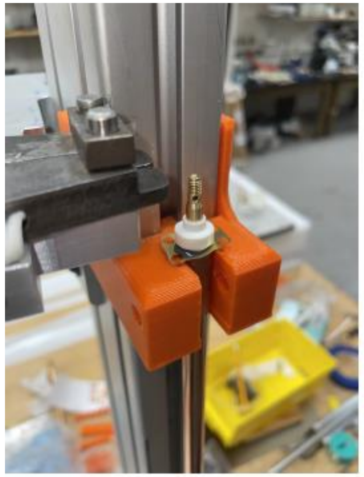
- **Gas mixture studies**
  - Optimisation of hit resolution and dN/dx
- **New amplification board for dN/dx**
  - For beam test and cosmic rack
    - *-3 dB Bandwidth: 1.5-872 MHz*
    - *Charge Gain: 20.58 mV/fC*
- ***Cosmic rack in U. of Michigan***
  - *Four sMTD chambers*
    - *Four layers of 1.5 cm diameter and 50 μm wire*
      - *100 μm resolution*

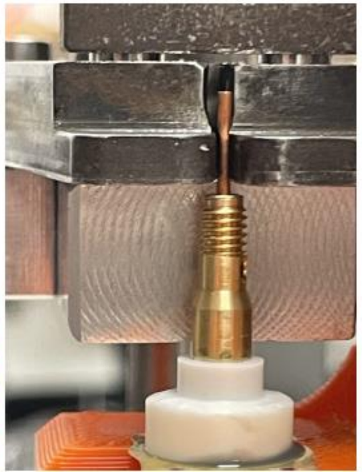


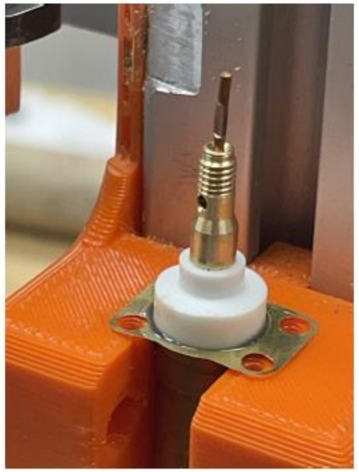
Prototype

- **Building a 50 cm long chamber with 25 straws**
  - 4 planes of 6 straws
  - Uses modified ATLAS sMTD setup
  - Define wiring procedure
  - Design gas distribution system
  - Evaluate single tube performance
    - Gas leak, dark current, signal size, noise rate
- **Plan a test beam at CERN in Aug/Nov 2025**







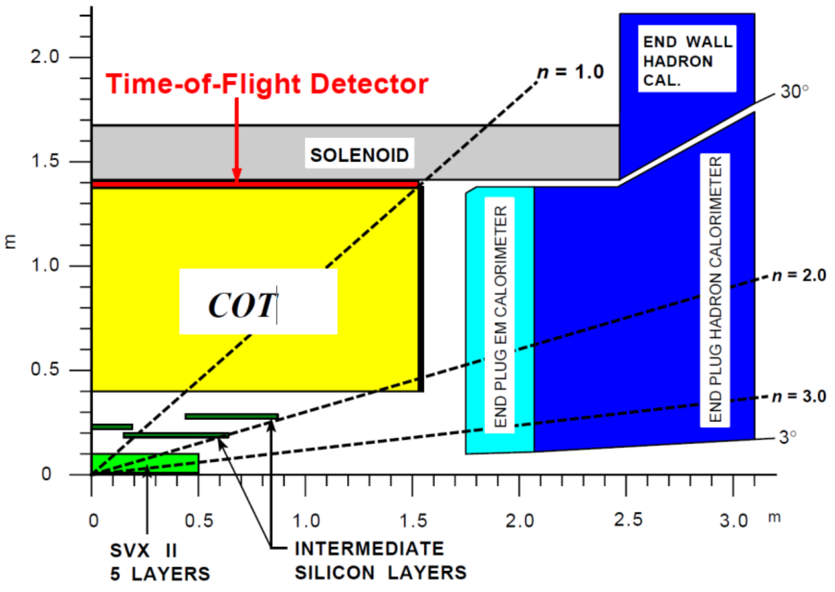


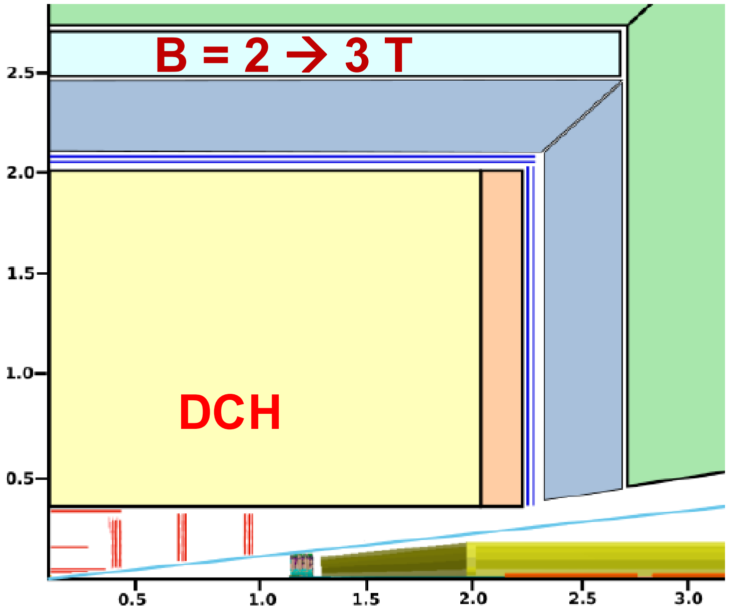
A CDF-like drift chamber for FCC-ee

Franco Bedeschi (Pisa)

- **Main differences**
  - Not many, but substantial in size, gas mixture and material budget
  - Cell electric field shape is different
    - CDF is a "jet" chamber, while IDEA is a "drift" chamber
- **How does the same concept would adapt to FCC-ee?**

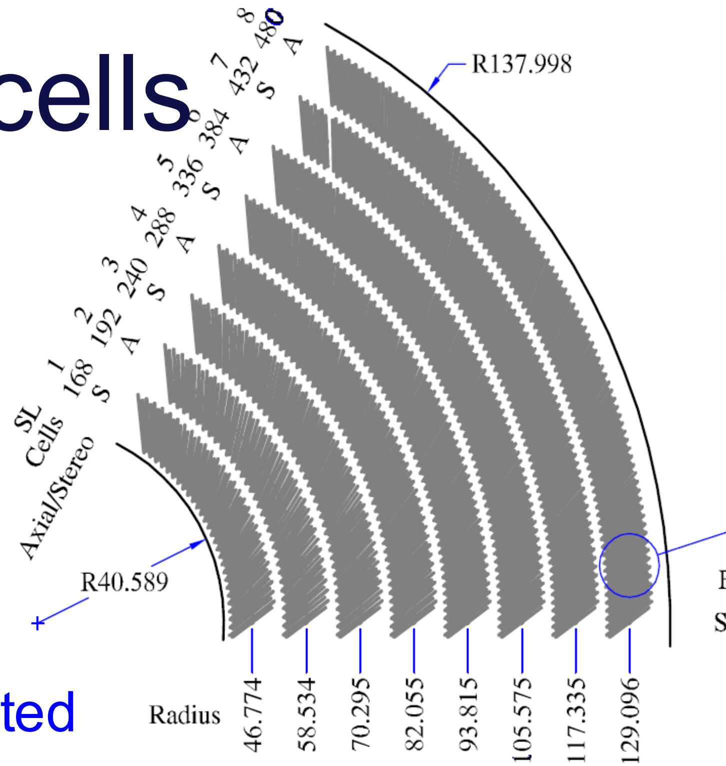
Parameter	CDF	IDEA
Length (m)	3.10	4
R_{in} (cm)	43.4	36
R_{out} (cm)	132	200
No. cells	30,240	56,488
Gas mixture	Ar(50): C_sH_6 (50)	He(90): C_4H_{10} (10)
Stereo	50%	Full stereo
X0 (%) active	1.7	0.3
B field (Tesla)	1.41	2

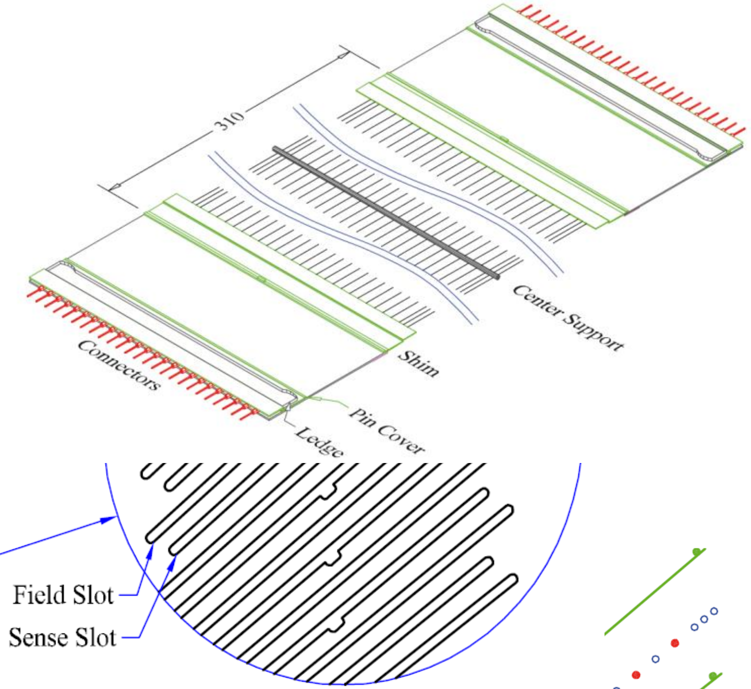


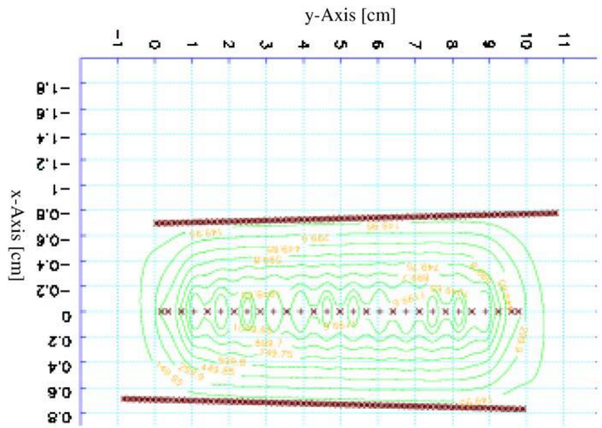


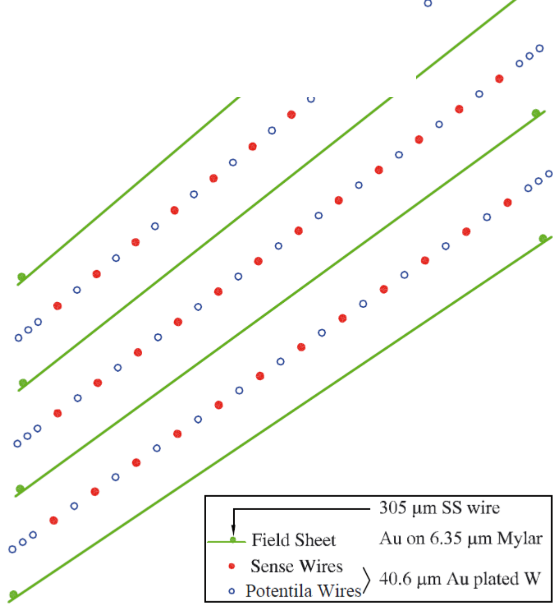
Segmentation and cells

- **CDF**
  - 96 layers in 8 superlayers
- **IDEA**
  - 112 layers
- **CDF Cell structure**
  - Sense + potential wires
  - Field sheet of 6.5 μm Mylar gold plated
    - Reinforced at the centre
    - Allows to electrically separate one layer from the next
    - Easier to remove broken wires
  - Uniform electric field configuration
    - Allows two track separation









How to reduce material budget

- **Use Carbon field wires**
  - 0.24% X_0
    - Or remove stainless steel wire to allow field sheet
- **Sense wires**
  - Reduce wire diameter to 25 µm & Al potential wires to reach 0.14% X_0
- **Use lighter gas mixture**
  - He(90) : Isobutane(10) → 0.24% X_0

Component	Cell density (g/cm)	X_0 (g/cm^2)	$\langle L \rangle / X_0$ (%)
Field sheet			*0.628*
Mylar (1.39 g/cm^3)	0.00874	39.95	0.100
Gold (19.32 g/cm^3)	0.00134	6.44	0.095
SS wire	0.0111	13.84	0.365
Center support	0.0022	27	0.037
Epoxy	0.0027	40	0.031
Wire plane			*0.524*
Tungsten (19.30 g/cm^3)	0.00703	6.76	0.474
Gold (5%)	0.000352	6.44	0.025
Center support	0.00107	~19.4	0.025
	Length (cm)	X_0 (cm)	$\langle L \rangle / X_0$ (%)
Gas			*0.557*
Argon (50%)	92.49	10,983	0.421
Ethane (50%)	92.49	34,035	0.136
Total			**1.709**

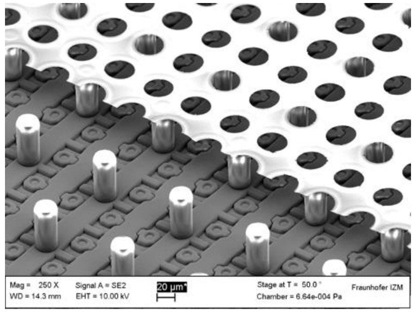
Potential to go a total of ~0.66% X_0 after scaling for the size

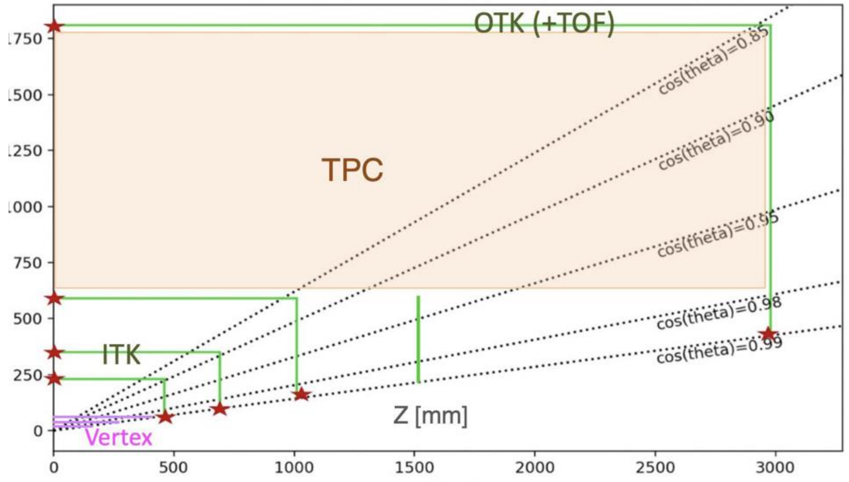
A (Pixel) TPC as a central tracker in a FCCee experiment

Peter Kluit (Nikhef)

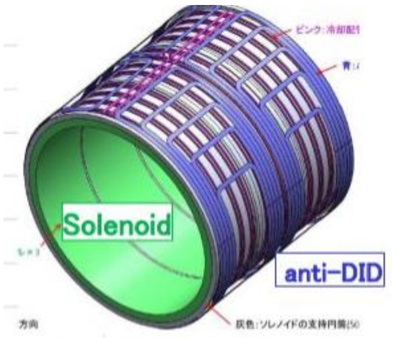
TPC (at larger inner radii) has been selected for CepC baseline detector

- **A TPC can be used at WW, ZH and t-tbar energies**
- More challenging to be used at the Z
- **Use GridPix technology**
- Superior 2-hit resolution and low gain x IBF
  - R&D ongoing to cope with Tera-Z running
- **Good spatial resolution**
  - $\sigma_{r-\phi} = 60(\text{near}) - 100(\text{far})\mu m$
  - $\sigma_{r-z} = 0.4(\text{near}) - 1.4(\text{far})mm$

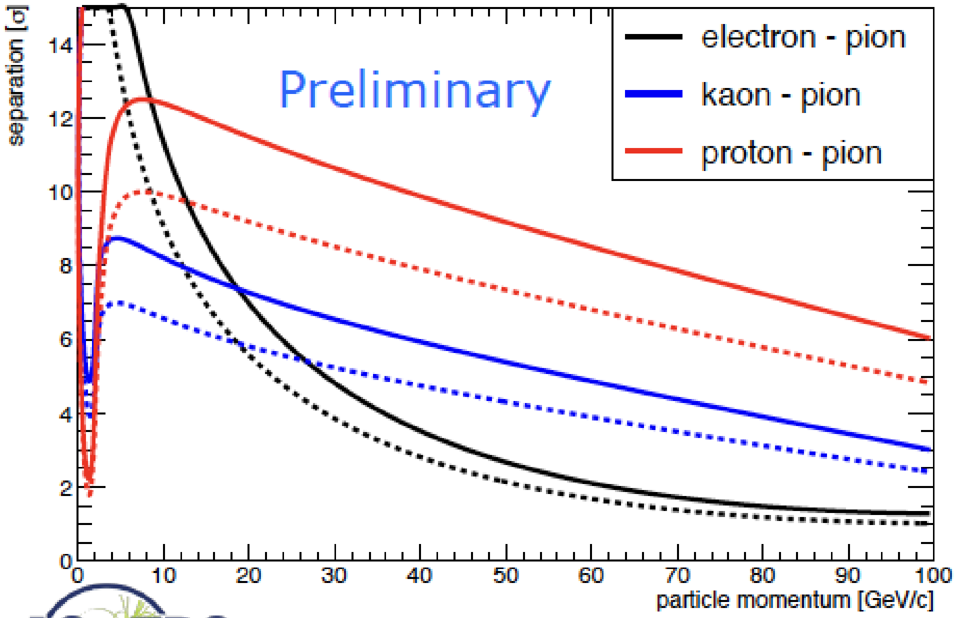




It will need modifications to the detector magnetic configuration adding a dipole field (anti-DID)



Particle ID



Two methods

- Truncated dE/dx
- Cluster counting (template fit)

Measured resolutions in test beam and 1 T field

- 3.6 % dE/dx
- 2.9 % template fit

- Allows to discriminate K from π up to 45 GeV with more than 5 σ

Pixel TPC at a circular collider

- A Tera Z FCCee physics program* could be carried out, but
  - It needs a lot of power to process the large amounts of background hits in the tracking detectors
  - It needs more study to reduce the beam background by an improved MDI
  - Fitting techniques should be studied to correct for the TPC distortions
  - The current TPX3 read out should be optimized to cope with the high readout rate and minimise the power consumption

* The physics case seems IMO rather weak to go beyond 10 Giga Zs

A pixel TPC is a challenging option for the Z

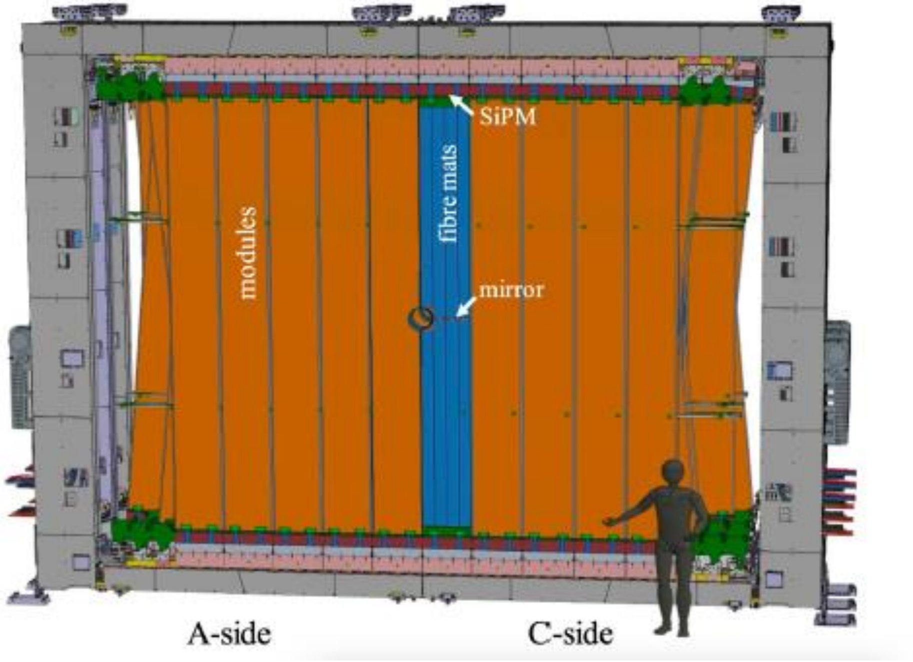
Conclusions: Pixel TPC at a circular collider

- The performance of a pixel TPC based on GridPixes has been studied based on prototypes and test beam measurements. It provides
  - high precision continuous tracking with a low material budget
  - very powerful particle identification
- At the FCCee a pixel TPC as a central tracker – sliced between silicon detectors as in the ILD concept detector - is well suited to carry out the WW, ZH and tt physics program.
- A 10 Giga-Z FCCee physics program looks realistic with the proposed pixel TPC and the current FCCee MDI design.
- After years of R&D, a pixel TPC has become a realistic viable option for experiments
- R&D on a Pixel TPC with GridPix devices with reduced ion back flow based on the TPX3 or TPX4 ASICs are part of the DRD1 program

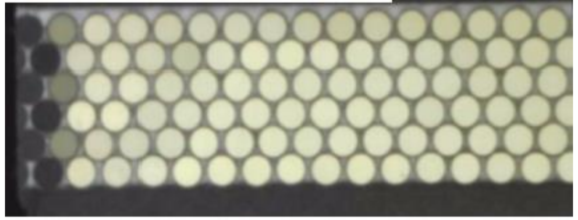
Scintillating Fibre Tracker for FCC-ee

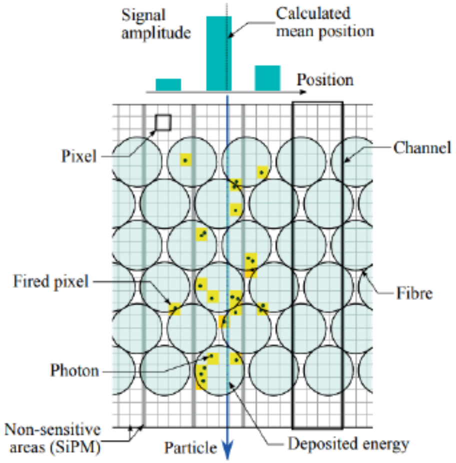
G. Haefeli, L. Shchutska, R. Marchevski (EPFL)

- **From LHCb Sci-Fi Tracker**
  - 2 meters long fibres with mirrors at the end
    - ~300 ph/MIP, 3.5 m attenuation length
  - Fibres readout by custom SiPM (Hamamatsu)
    - Photon Detection Efficiency ~45%
    - Cryo-cooled (L N_2) to limit dark current



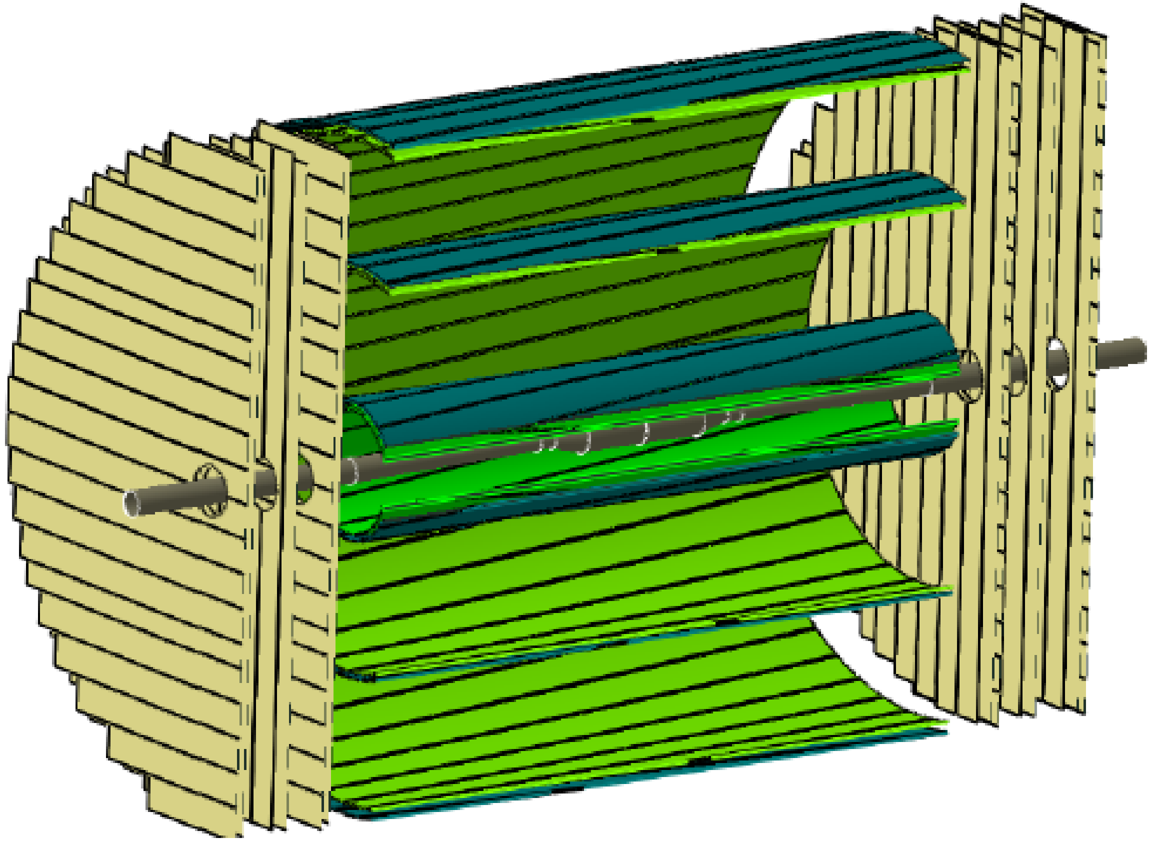
Fibre mat cross section after cut



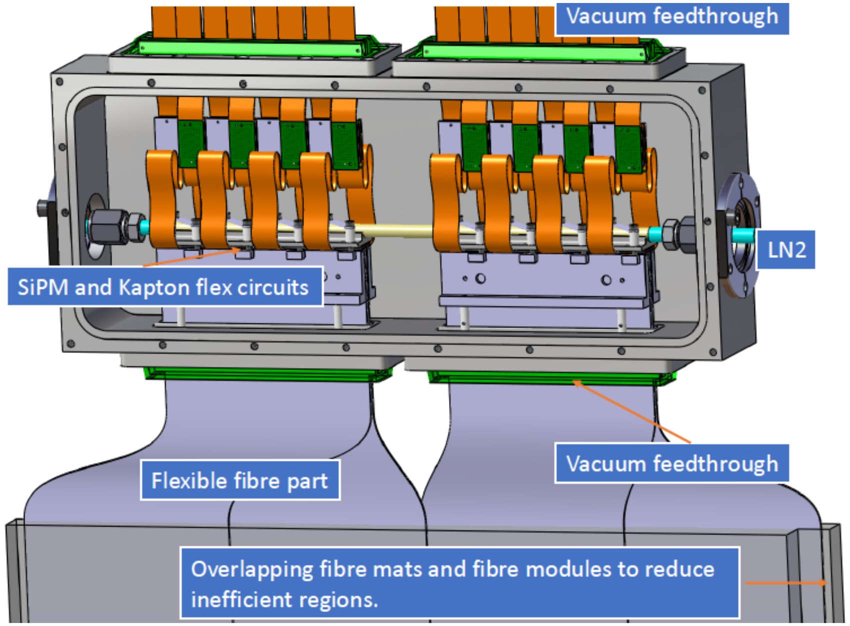


Geometry for FCC-ee

- **Barrel**
  - 4 meters long fibres with double sided readout
    - SiPM at the end
    - $r - \phi$ resolution 70-100 µm
  - Time resolution 0.2 (short) to 1 ns (far) could give some handle on z position
- **Endcap**
  - XY layers



Directions for R&D

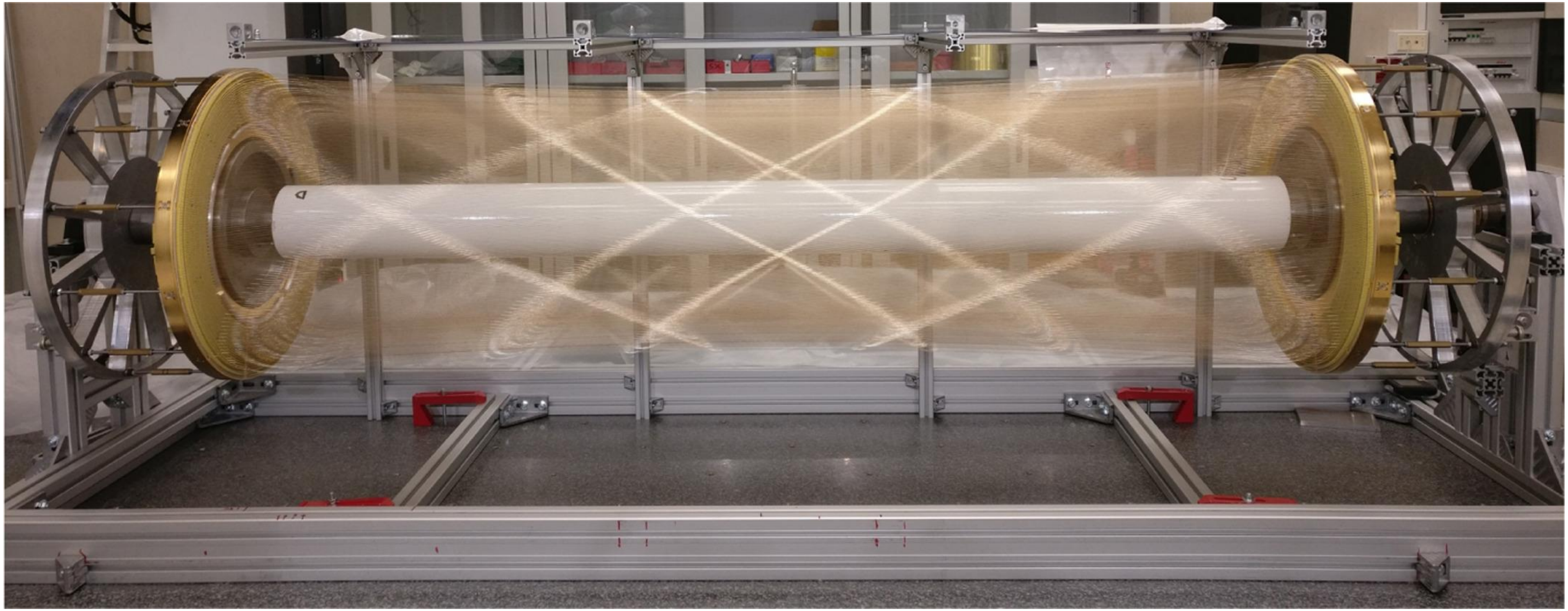


- **Adapt SciFi technology to 4π detector**
- **Minimisation of the material budget**
  - Mat thickness
  - Total number of layers
  - Improve light collection and reduce SiPM noise
- **Move to digital SiPM readout**
  - Avoid dead regions between channels
  - Could improve online signal processing
  - Less material in acceptance

Conclusions

- **Several options have been discussed for the gaseous detectors for the FCC-ee which also provide PID**
- Drift chamber
  - Full scale (4 m) prototyping on going
  - Carbon fiber wires R&D
  - Alternative electric field configuration proposed (jet chamber/CDF inspired) improving double track resolution
- Straw tubes based tracker
  - Small scale prototype on going
    - Needs to scale up
- TPC
  - Good solution for non Tera-Z run with pixelated readout, with distortions
- **Sci-Fi based tracker**
- Needs to optimise resolution and efficiency versus number of layers (and material budget)
- Very limited PID capability

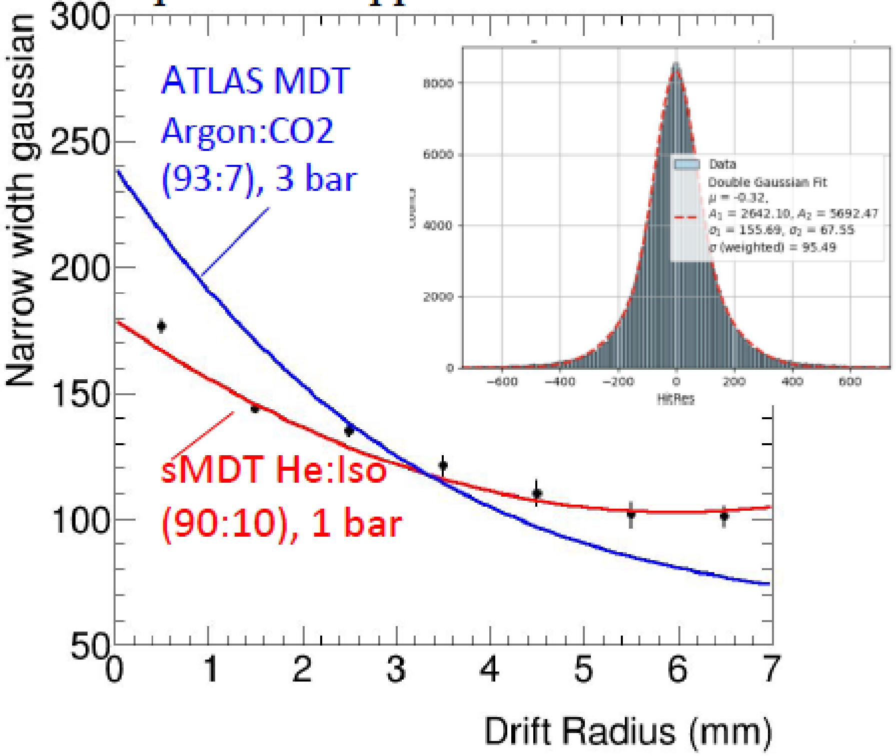
Backup



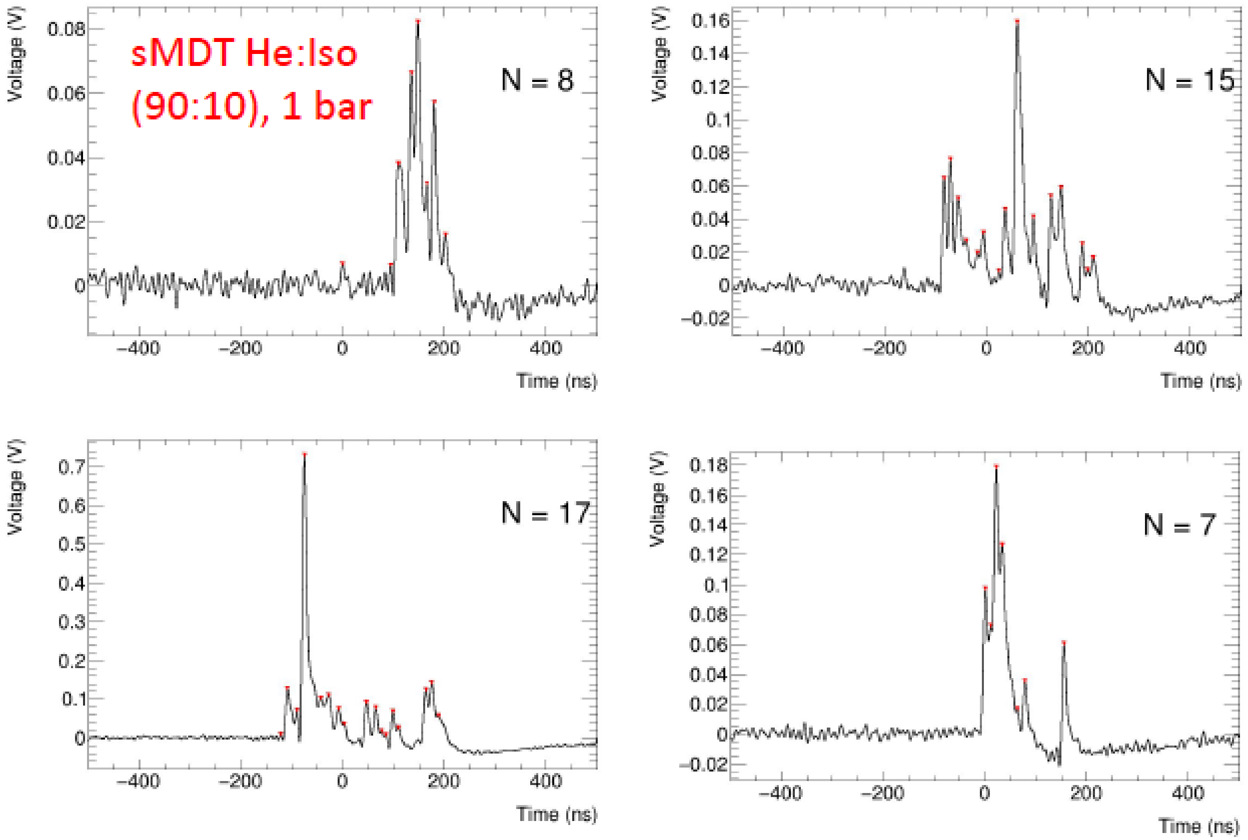
MEG2 drift chamber

Cosmic Ray Test Results with He-based gas

- Study He-based gas detector tracking resolution with sMDT tracker (σ~125 μm)
- Use the new amplifier to record raw cosmic ray waveforms from the sMDT tracker. These waveforms will be used to develop dN/dX algorithms for PID.
- Low pass filter applied for waveform to reduce noise and derivative method used for cluster finding (tentative).



Helium:Isobutane (90:10) gas mixture resolution vs drift radius. Single tube resolution = 125 μm



TPC distortions