A straw tracker for FCC-ee

Yuxiang Guo

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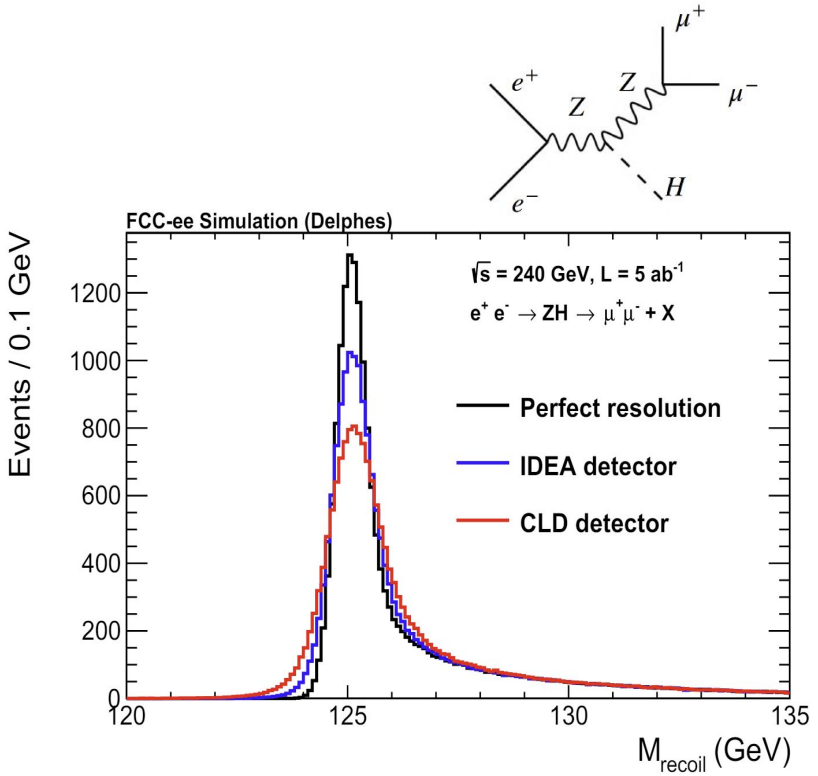
Momentum resolution requirement for the tracker

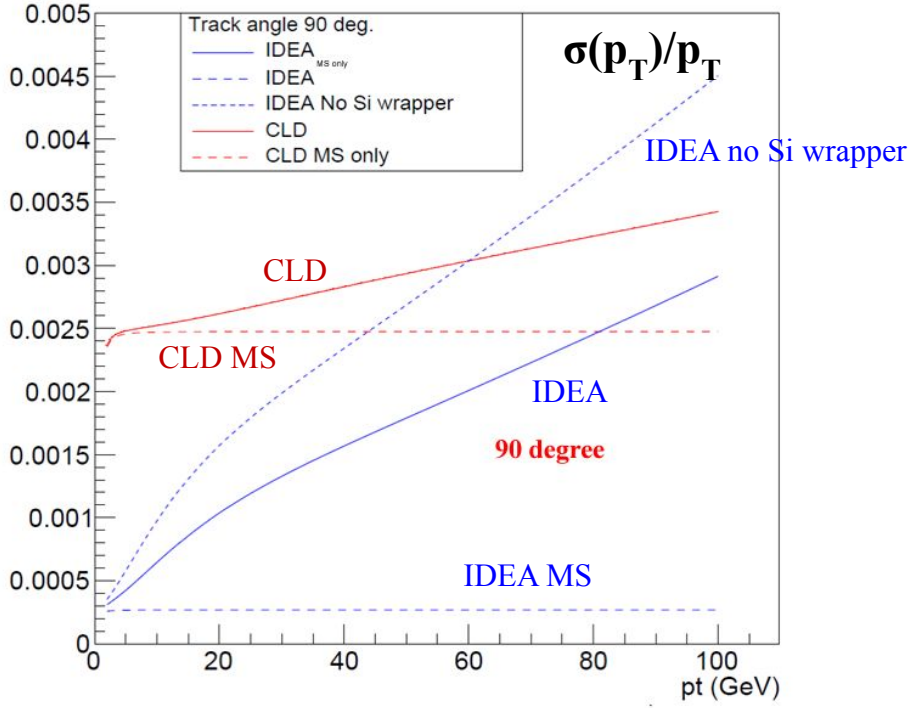
- Important to reconstruct the recoil mass distribution for the Higgs mass and ZH cross section measurements

$$M^2_{recoil} = (\sqrt{s} - E_{l\bar{l}})^2 - p^2_{l\bar{l}} = s - 2E_{l\bar{l}}\sqrt{s} + m^2_{l\bar{l}}$$

- Sensitivity dominated by the Z➡μμ channel
- Require the track momentum resolution should not be worse than the beam energy spread (~0.16% at 240 GeV)
  - $\sigma(p_T)/p_T$ ~ 0.2% at 45 GeV
  - a factor of 5~10 better than the current ATLAS and CMS inner tracker momentum resolution
- Current proposals for FCC-ee experiment inner tracker:
  - CLD: full silicon pixel+strip
  - IDEA/ALLEGRO: silicon pixel + Drift Chamber + Outer silicon wrapper



Momentum resolution

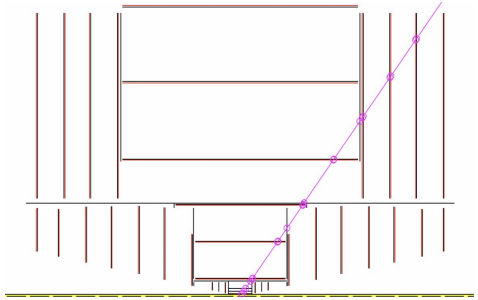


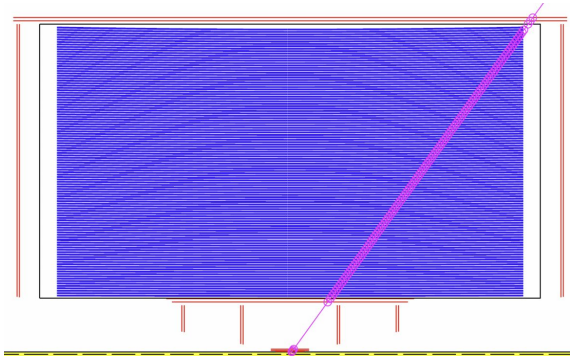
Transparent tracker is the key for the momentum resolution

But material budget is not the only parameter that determines the inner tracker's momentum resolution

Straw tracker

- We propose to have a straw tracker (combined with pixel and silicon wrapper) for an FCC-ee inner tracker:
  - Reasonable single hit resolution: 100~120 μm, similar or better momentum resolution than the pixel detector due to more hits detected (N) and a longer lever arm (L)
  - Low material and less multiple scattering with straws
  - Pattern recognition
  - Particle identification (π-K, K-p identifications)
  - Long-lived particle searches
  - Capable of triggering





$$\frac{\sigma_{p_T}}{p_T}|_{meas} \simeq \sqrt{\frac{720}{N+4}} \frac{\sigma_x \, p_T}{0.3BL^2}$$

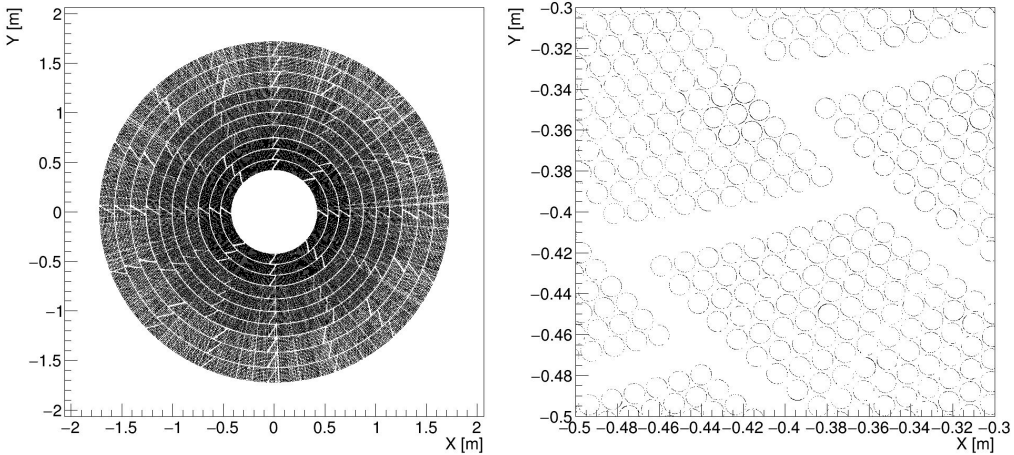
p_T-resolution due to hit position resolution

Pixel: σ_x=3-5 μm
N=6
L~0.3 m

Gaseous: σ_x=100-150 μm
N~100
L~1.5 m

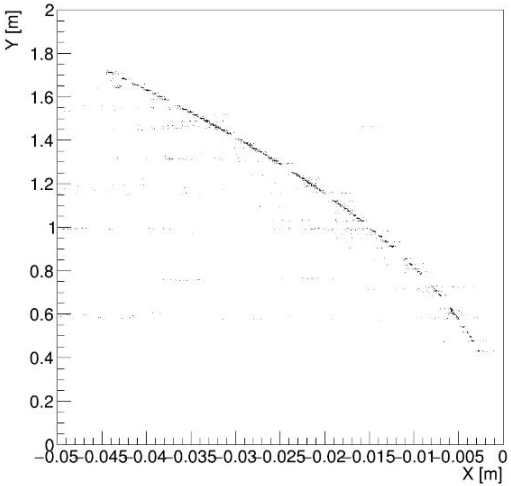
Material budget for a straw tracker

- For straws with a Mylar wall thickness of 12 um, 100 layers means ~3 mm Mylar films ~1.2% X_0
- 0.05 μm Aluminum coating on the inner wall
- Sense wire: radius of 10 um Tungsten
- Endplate supporting structure could be similar to DCH
- We have implemented a GEANT simulation of a 100-layer straw tracker in GEANT
- Put in place of IDEA drift chamber between vertex detector and silicon wrapper



Hits for 5000 muons with p_T=20 GeV

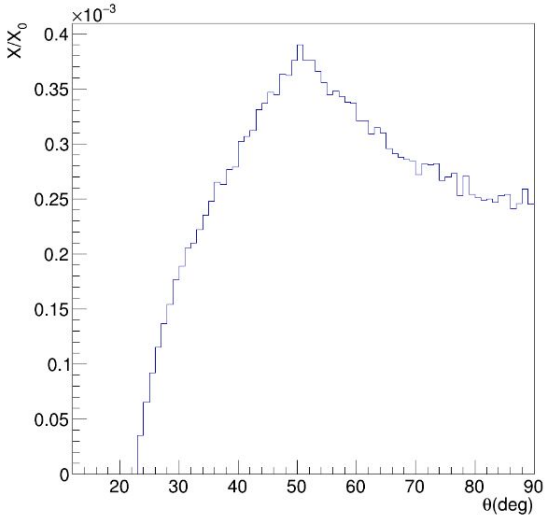
1000 muon with p_T=20 GeV



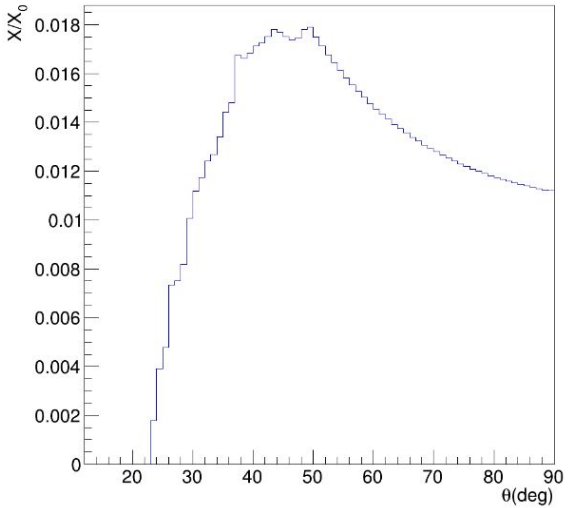
Hits inside tubes

Material budget from the GEANT simulation

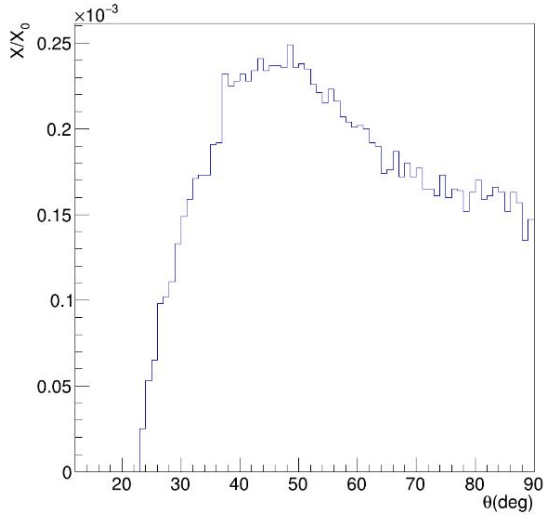
- Material budget breakdown for individual components
- Negligible contribution from Helium and Aluminum coating. Mostly from Mylar wall



He



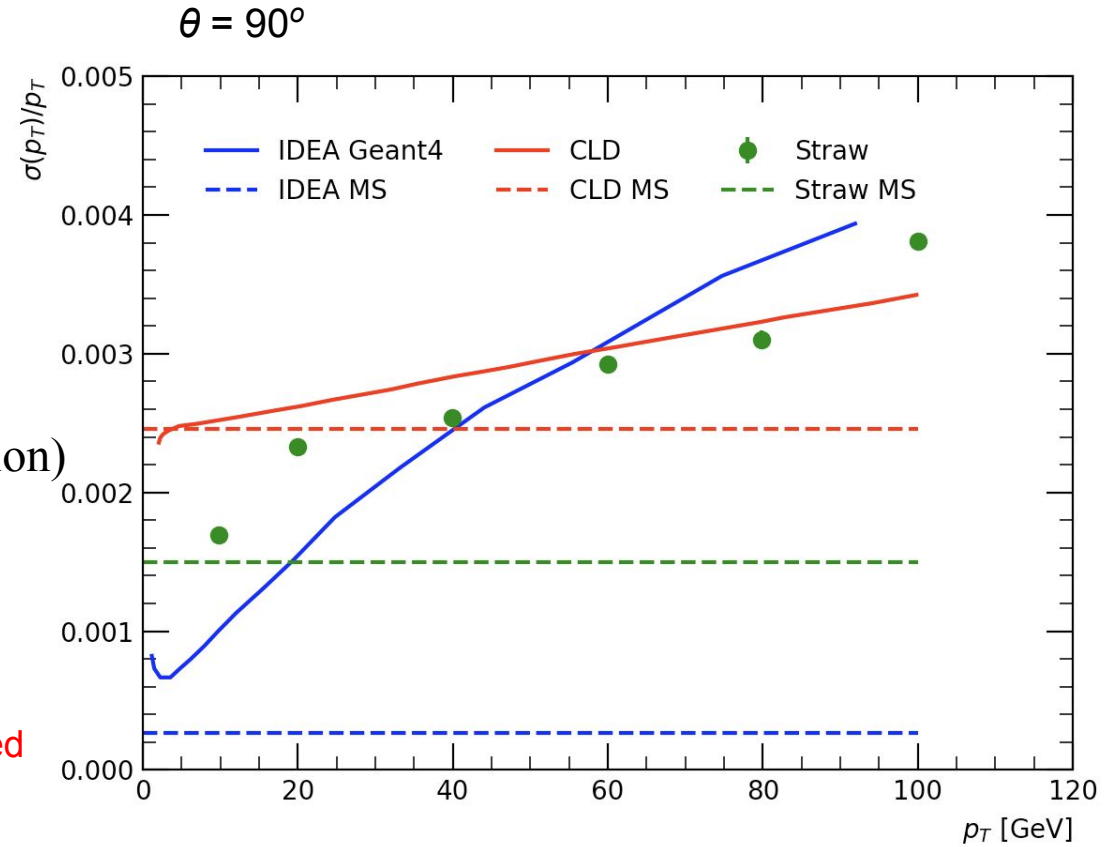
Mylar wall (12 μm)



Al coating (50 nm)

Understanding the momentum resolution

- Compare straw tube to other detector concepts
- Assumptions:
  - Straw tube: 120 microns
  - Pixel: 5 microns
  - Silicon wrapper: 15 microns
- Straw MS is from analytical calculation (included in simulation)
- Straw tube geometry is not yet optimized

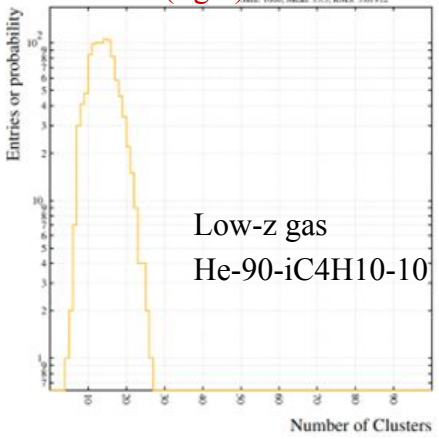


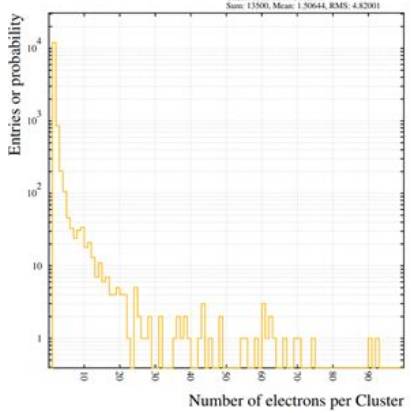
These resolutions are likely calculated based on different assumptions and should be viewed with a grain of salt

Gas simulation with Garfield

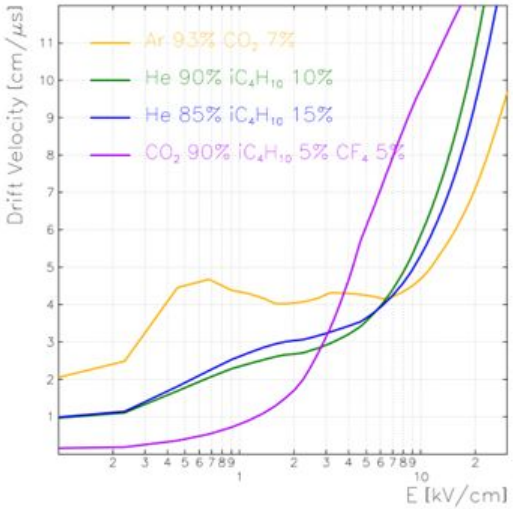
- Ongoing Garfield simulation:
  - Ionization statistics in several gas mixtures
  - Electron and ion transportation properties
  - Signal induction and timing structure
- Provide essential inputs for the gas optimization and dE/dx(dN/dx) measurement for PID

Simulated primary ionization cluster number (left) and size (right) for 4 GeV muon in a 10 mm-diameter straw

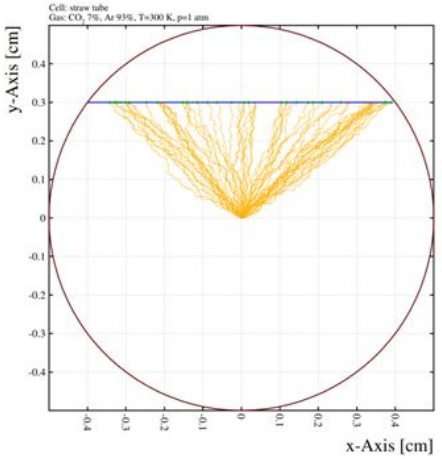




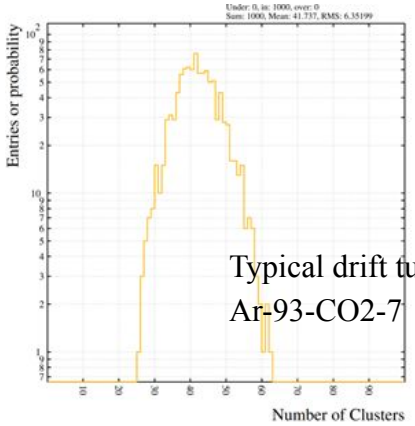
Low-z gas
He-90-iC4H10-10

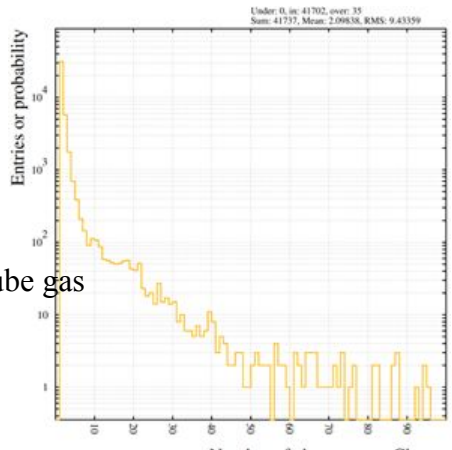


Electron drift velocity vs. e-field



Simulated ionizations created by a muon track and primary electron drift towards wire

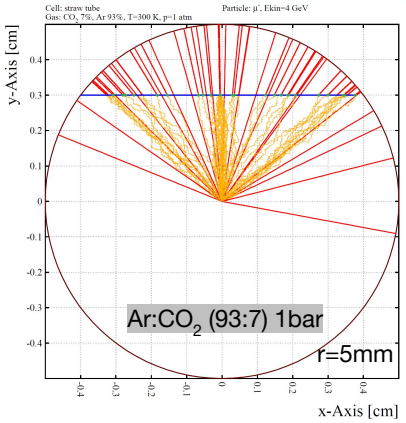


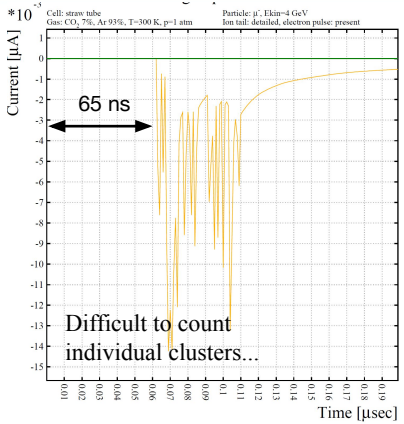


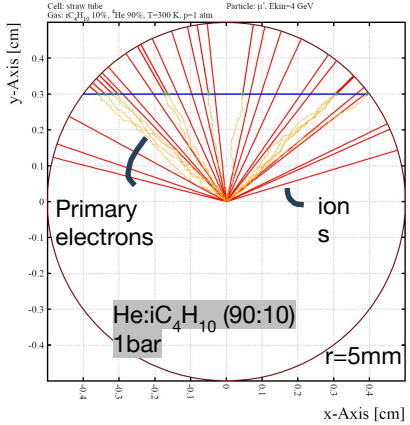
Typical drift tube gas
Ar-93-CO2-7

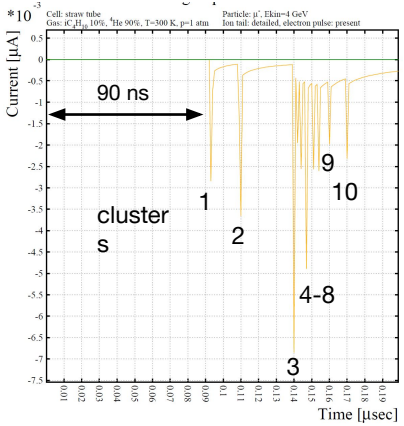
Simulation of signals in different gas mixtures

- dN/dx expected to improve dE/dx PID based on traditional charge measurements
- Ar-based gas: high ionization density (~40/cm) and moderate electron drift velocity 50 mm/ns (@E~2kV/cm). Mean cluster arrival time separation: ~5ns
- He-based gas: lower ionization density (~20/cm) and 30 mm/ns (@E~2kV/cm). Mean cluster arrival time separation: ~15ns





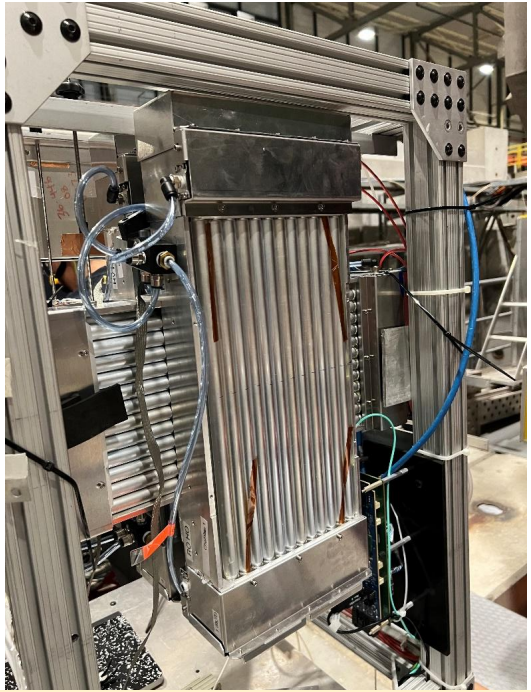




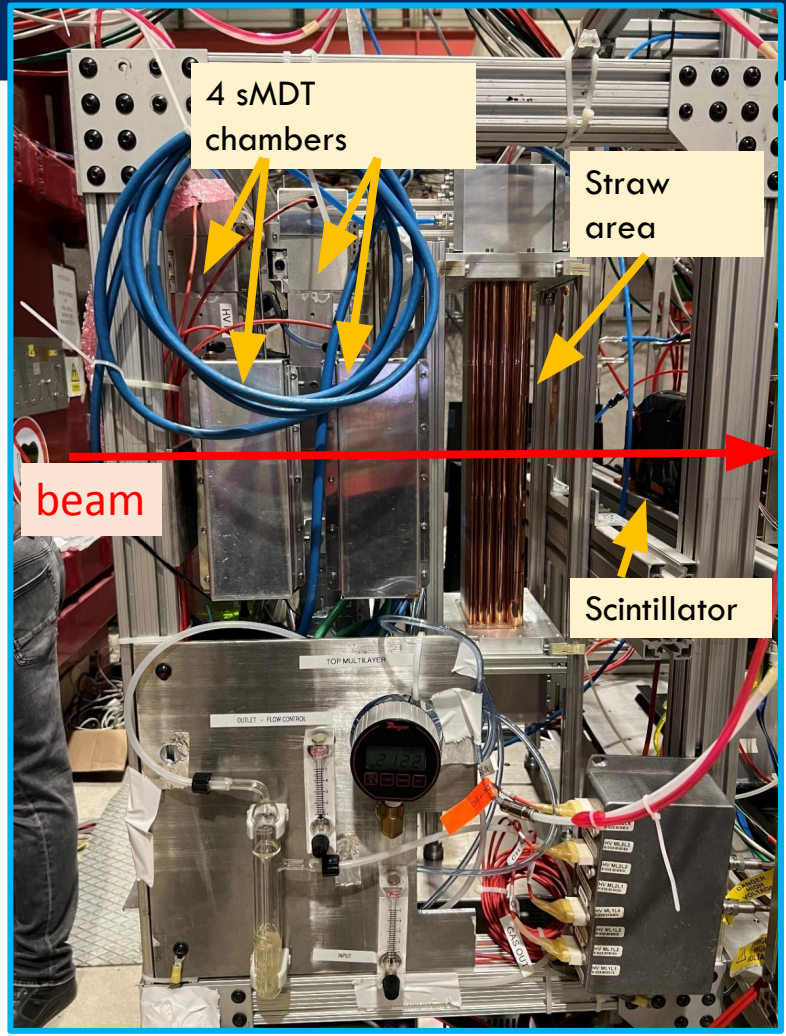
5mm radius tube with 1 bar and 1kV simulated here

Test beam at CERN H4 & T9

- Straw diameters: 5, 10, 20 mm;
- To evaluate operation working points (high voltage, thresholds, gas)

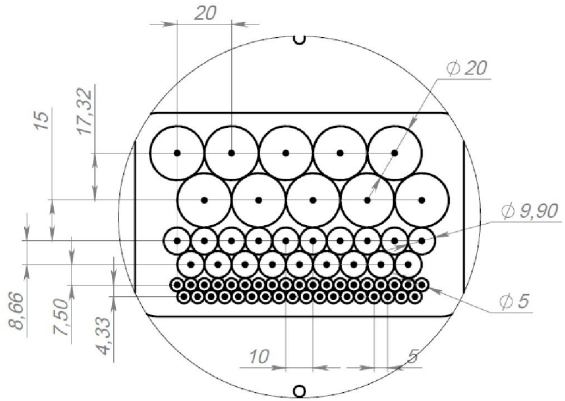


The UM sMDT telescope 8-layers in x and y directions

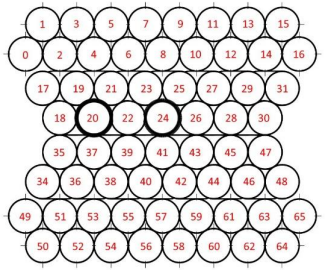


Straw tube prototypes tested

- Tube-wall 36 μm coated with 20 nm gold and 70 nm copper
- Central wire diameter 30 μm (similar as used in NA62 experiment)
- 2 prototypes (from different production) of straw chambers used

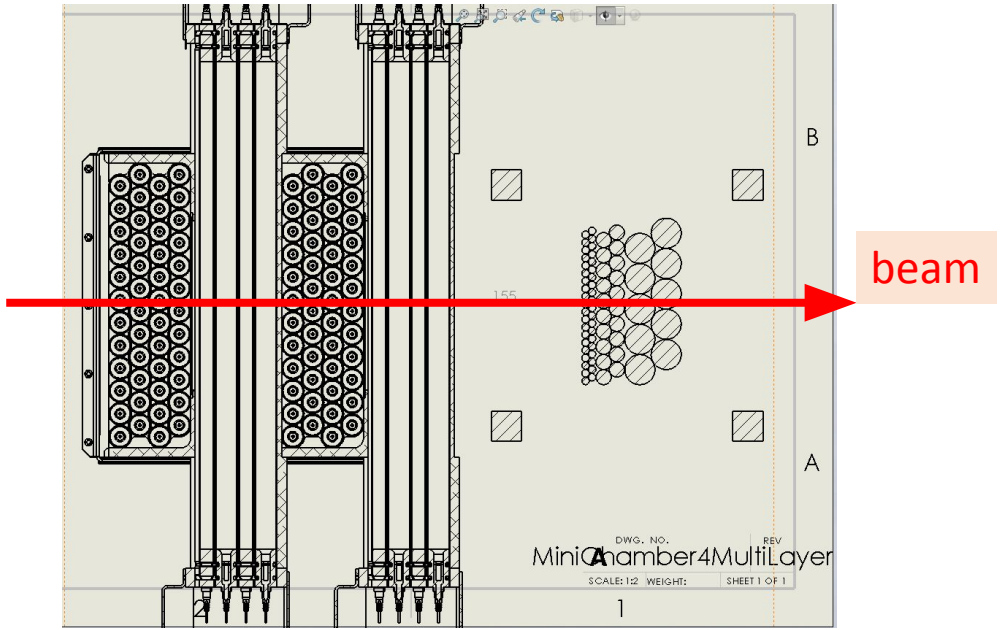


Prototype 1: 5 mm, 10 mm, and 20 mm tubes area



Prototype 2: 10 mm tube area only. Two planes of X, two planes of U (2°), two planes of V (−2°) and two planes of X.

sMDT as tracker beam test (at CERN H4)



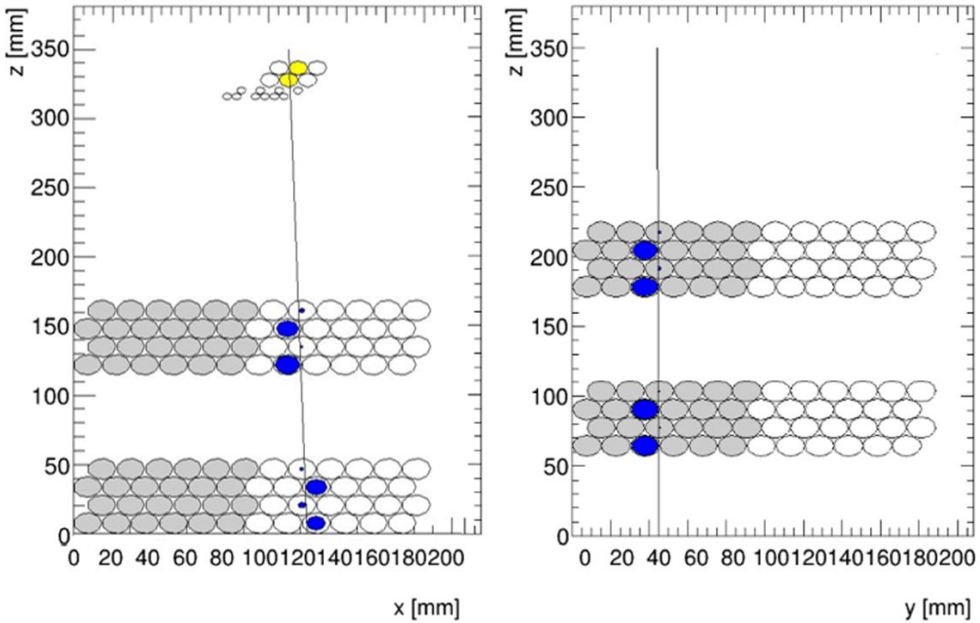
- sMDT chambers in perpendicular position for a 3-d track reconstruction
- Using scintillator triggers

Track Reconstruction with sMDT data

Straws

sMDT 2

sMDT 0



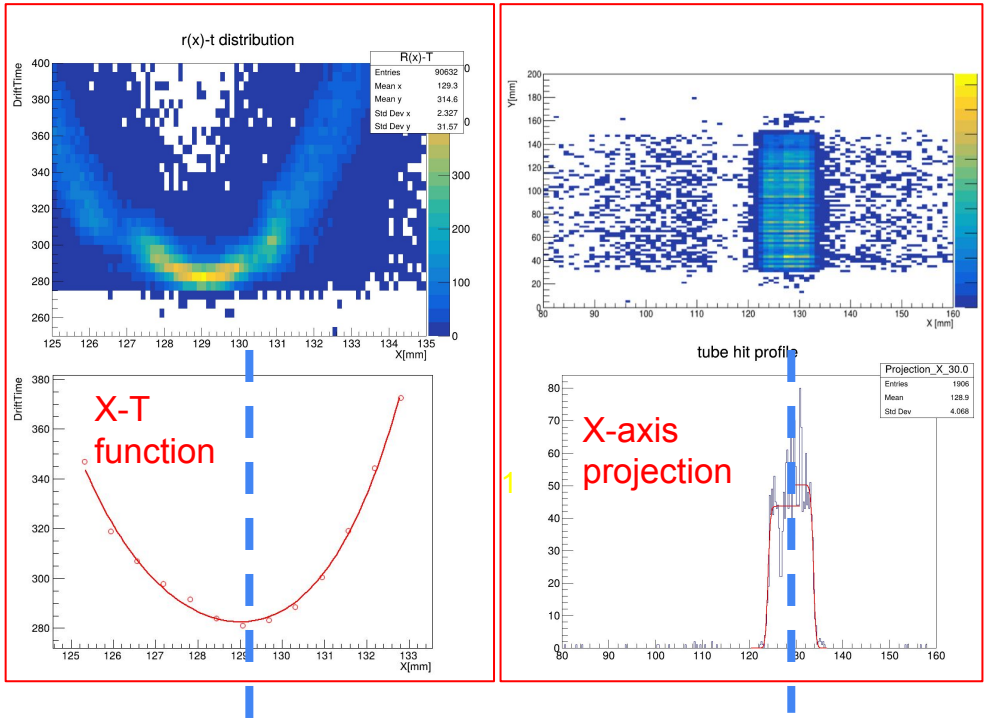
sMDT 3

sMDT 1

- threshold: -28 mV (~3.1 fC), 70% Ar, 30% CO2 at 1 bar
- HV = 1750 V (1450 V) for 10mm (5 mm) tubes
- Blue circle: sMDT chamber hits used for muon reconstruction (σ=100 μm per wire)
- Yellow circle: Straw hits

The Measured Space-Time (RT) Function (10 mm straw)

- The **position (x)** of beam hit tube determined by the sMDT telescope tracking
- Straw **drift time (y) is** readout using the sMDT front-end electronics
- Wire position can be found from the RT function curve (at the lowest point in drift time)
- The asymmetric RT of the 10 mm straw tube indicates the wire position is off the tube center
- This results indicates that we need to learn how to make precision straw tube (chamber) for high precision tracking. (as a reference, the sMDT wire position precision is about 10 microns)

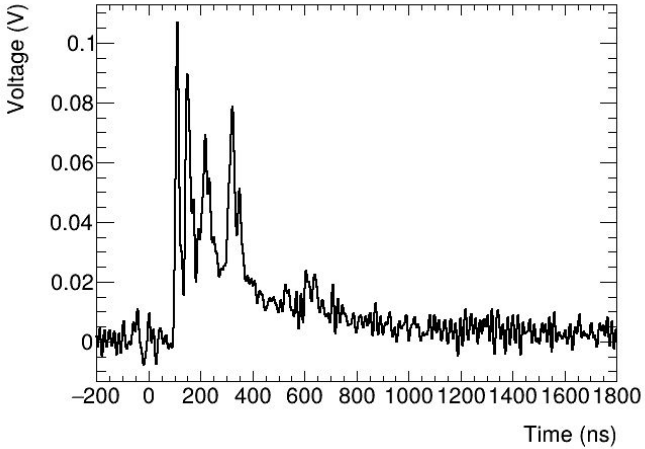


Difference between straw center with wire: Δx~340 μm

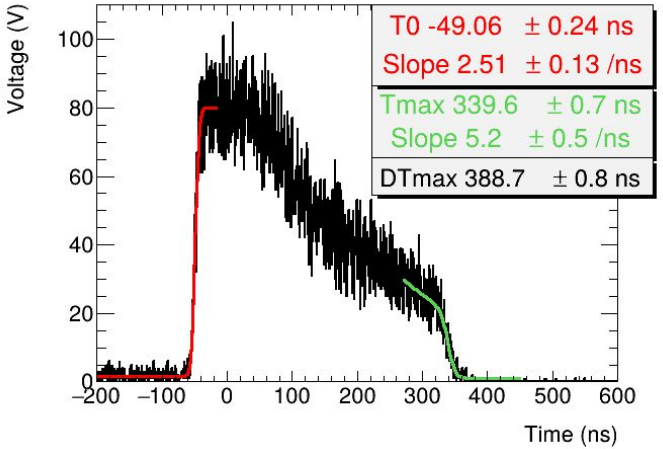
Prototype 2 has a better wire offset ~60 μm

Straw waveform digitization (cosmic ray)

- Straw signal amplified by NIM amplifiers
- Digitized by an oscilloscope
- Individual clusters could be seen from the raw signal
- Cluster counting algorithm to be developed



Raw signal from the straw tube



First leading edge time spectrum

Summary

- A straw tracker could be a good option for FCC-ee experiments
  - Reasonable material budget (~1.15% X_0 for ~100 layers with wall-thickness of 12 μm)
  - straws with 12-19 μm-thick wall (ultrasonic welding) and 3.5 (×2) μm-thick wall (winding) are available
  - will have another 10+ years for industry to improve the yield for straws with wall thinner than 15 μm and develop even thinner straws
  - could use >4 m straws to extend the tracker volume
- Mature technology, robust and can achieve high performance for tracking and particle identification
- DRD1 WP3 Project A “Straw and Drift tube development for future collider experiments”, Oliver Kortner (MPI) and Junjie Zhu (Michigan) are coordinators
- Participating institutions include MPI, Michigan, UMass-Amherst, Tufts, Harvard, MSU, UCI, Duke and UT Austin
- Close collaboration with people working on the DCH, straw production companies, and other experiments using straws
- Synergies with almost all drift chamber studies: gas, front-end electronics, dE/dx(dN/dx) etc