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R&D Efforts Towards a Carbon-Fiber Wire Drift Chamber

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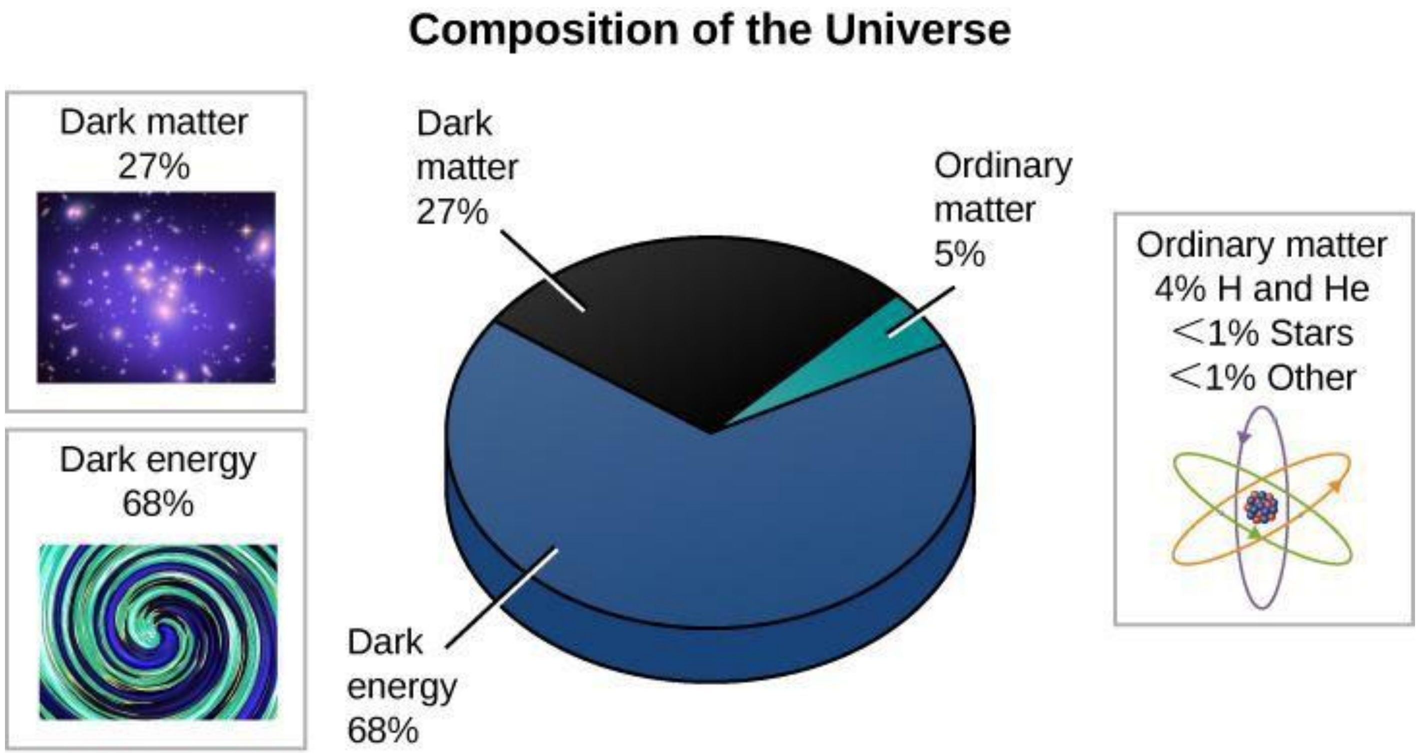
CPAD – RDC6 Gaseous Detectors Session(October 8th, 2025) – University of Pennsylvania

Why build another collider?

Many Unanswered Questions

- Dark Matter
- Antimatter Asymmetry
- CP violation
- Neutrino masses
- Is there only 1 Higgs
- Does Toponium exist
- Other new particles



Advancements in one area helps others

- Ex: Space Race

Future Colliders

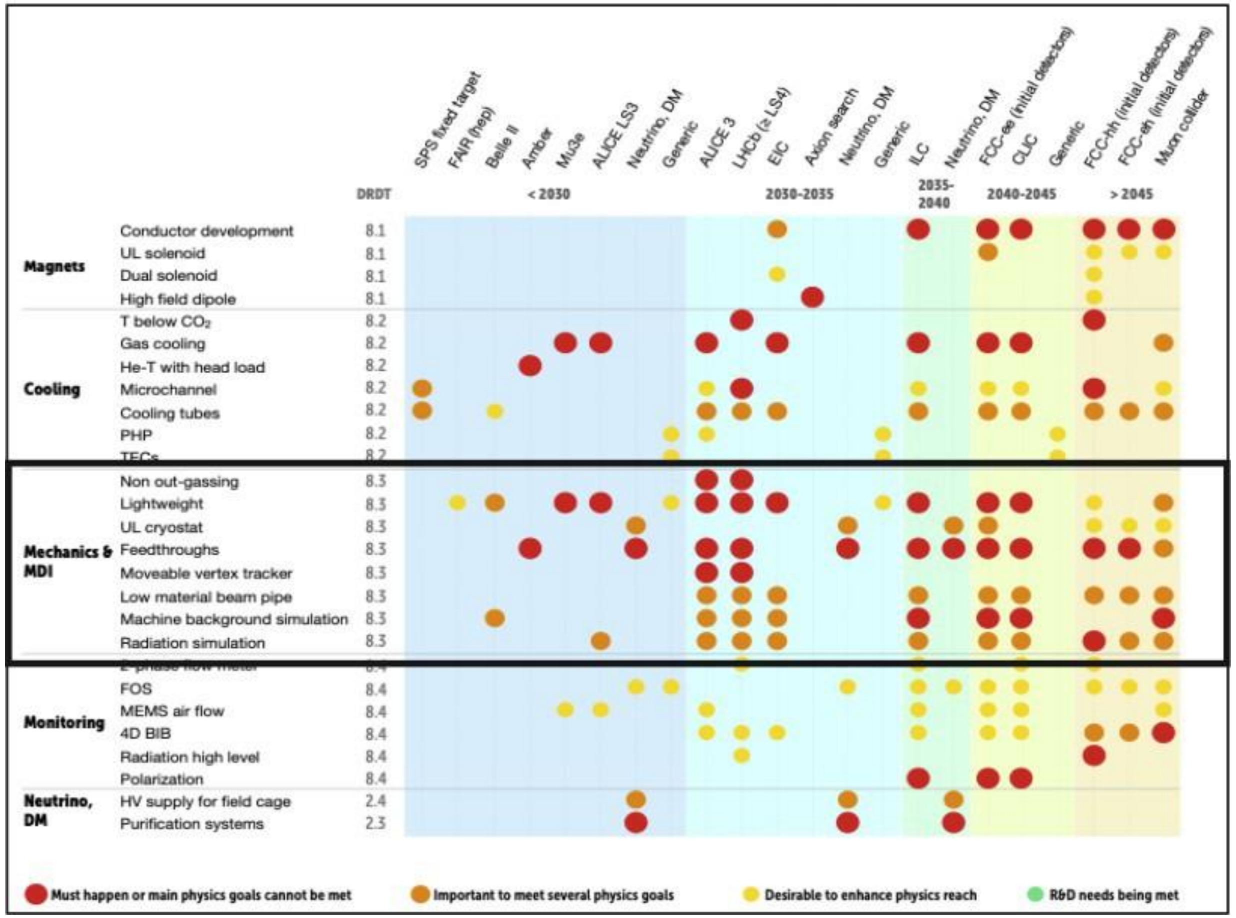
(Lepton) Colliders

- FCC-ee
- EIC
- Muon

Higher luminosity

- Require radiation resistant detectors
- More background from Bremsstrahlung

R&D for future colliders needed now!



European Committee for Future Accelerators (ECFA), 'ECFA Detector R&D Roadmap', CERN Document Server, CERN, November 2021.

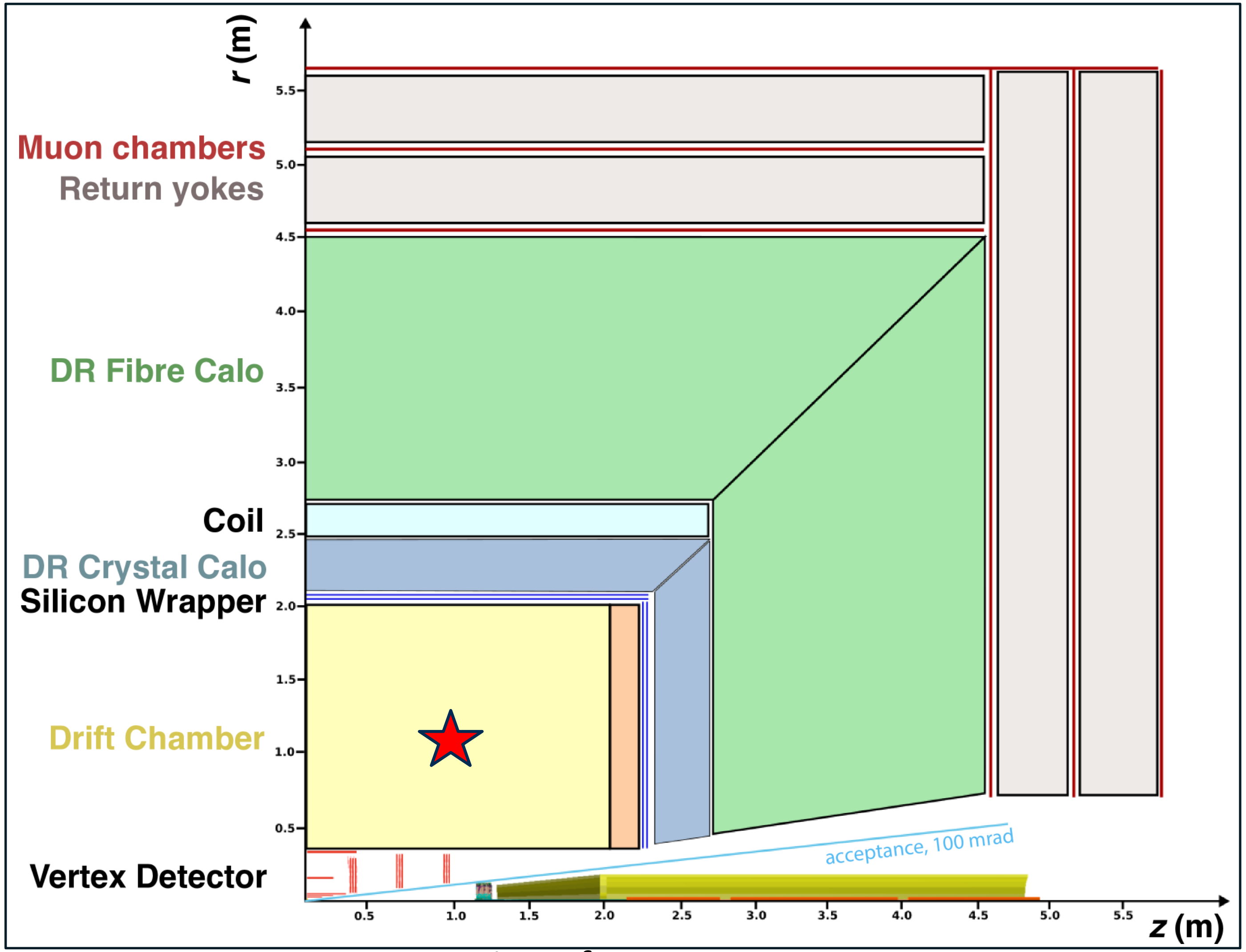
Affolder et al., 'Solid State Detectors and Tracking for Snowmass', arXiv:2209.03607, 2022.

E. Anderssen, A.W. Jung, S. Karmarkar, A.M. Koshy, et al., 'Light-weight and highly thermally conductive support structures for future tracking detectors', arXiv preprint arXiv:2203.14347 [physics.ins-det], Mar 2022.

Lepton Detectors

- FCC-ee
  - IDEA
    - W-Au Drift Chamber ★
    - Silicon wrapper
  - ALLEGRO
    - W-Au Drift Chamber
    - Silicon wrapper
- EIC
    - CF applications for Drift Chamber
- Muon
  - Potential applications for Muon Straw Chambers

IDEA Study Group, M. Abbrescia et al., 'The IDEA detector concept for FCC-ee', e-print arXiv:2502.21223 [physics.ins-det] (2025).

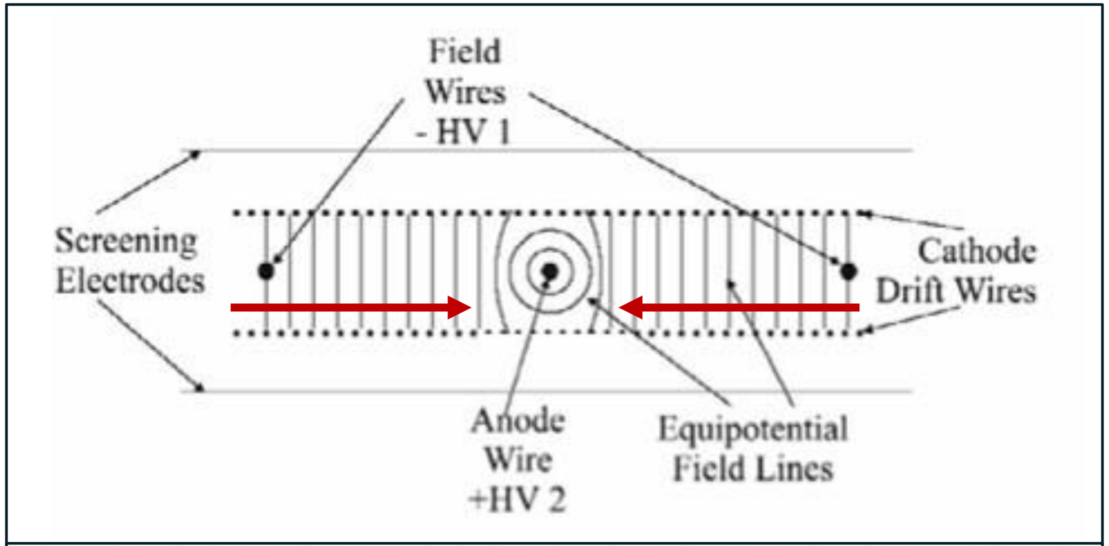


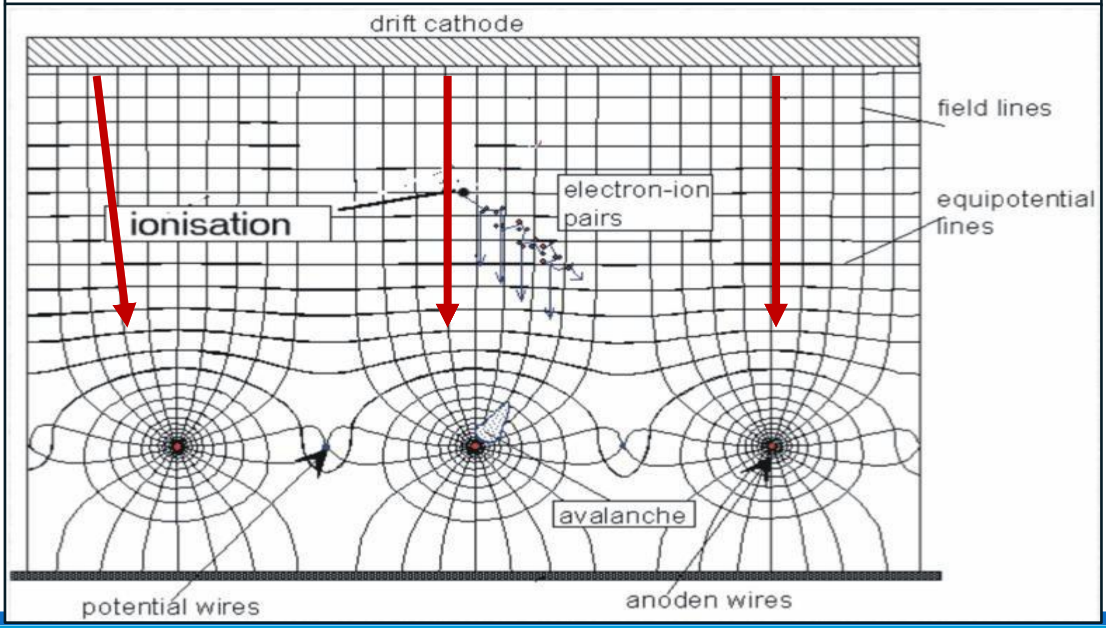
Cross Section of IDEA Detector

Wire Drift Chamber

- Charged particles ionize gas
  - Electrons then drift towards anode
  - Cathodes serve to produce equipotential field lines
- Large E Field closer to anode energizes electrons and creates avalanche to produce signal
- Drift time and velocity allows us to determine position of incoming particle

Ix-B Garcia Ferreira et al,' [The Drift Chambers Handbook](), 2005 J. Phys.: Conf. Ser. 18 346

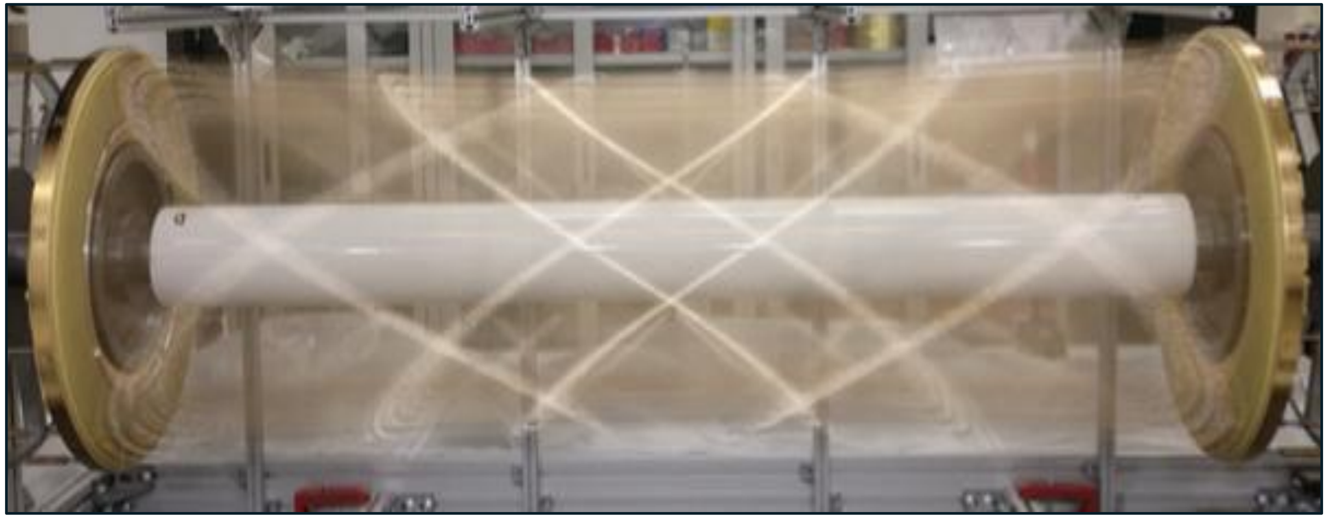




Walenta, et. al, '[Drift Chamber Experiment]()', 2nd Regional ICFA Instrumentation School – Istanbul, 2005

Why use Drift Chambers?

Eur.Phys.J.C 84 (2024)



MEG2 Drift Chamber

Pros:

- Large continuous active sensing volume
- Low material budget due to lower density
- Great particle identification via dE/dx

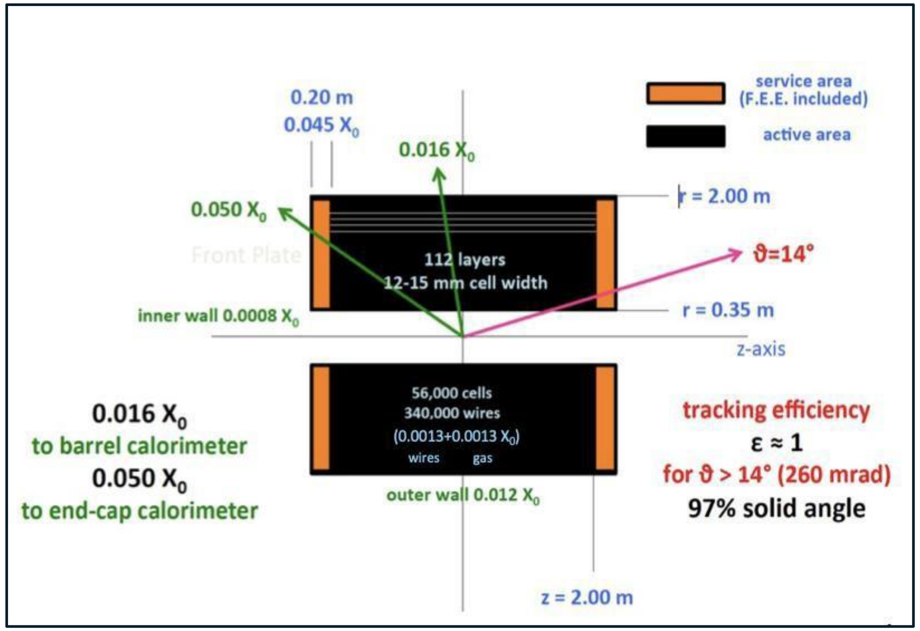
Cons:

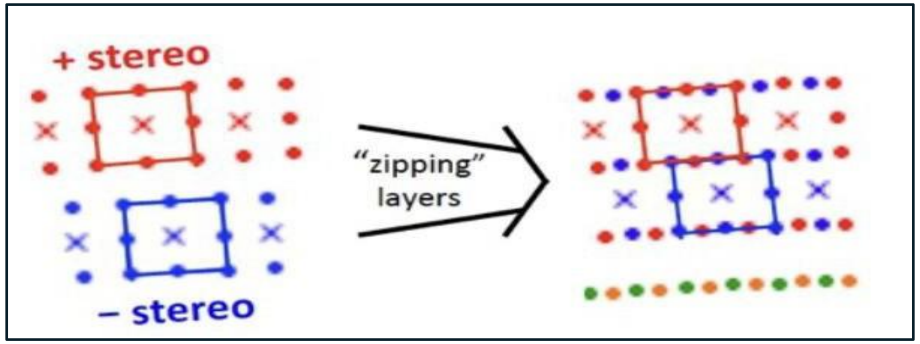
- Limited by high event rate due to drift time
- Careful calibration required
- Non-trivial mechanical upkeep
- Coarser z-resolution(silicon vertex still necessary)

IDEA Drift Chamber

IDEA Study Group, M. Abbrescia et al., 'The IDEA detector concept for FCC-ee', e-print arXiv:2502.21223 [physics.ins-det] (2025).

Gas	He 90% - iC_4H_{10} 10%
Inner Radius	R_{in} = 0.35m
Outer Radius	R_{out} = 2m
Length	L = 4m
Max Drift velocity	**≈ 2.2cm/µs**
Max Drift time	**≈ 400ns**
Average Drift time	**≈ 150ns**
Cell size	12 ÷ 14.5 mm wide square cells
Field to Sense ratio	5:1
Total wire count	**343968**
Sense wire count	**56448**
Sense wire diameter (W-Au)	**20µm**
Field wire count	229056
Field wire diameter (Al-Ag)	40µm





Francesco Grancagnolo, 'Conceptual designs and R&D challenges for drift chambers', ECFA WG3: Topical workshop on tracking and vertexing – CERN, 2023

Challenges of improving Wire Drift Chambers

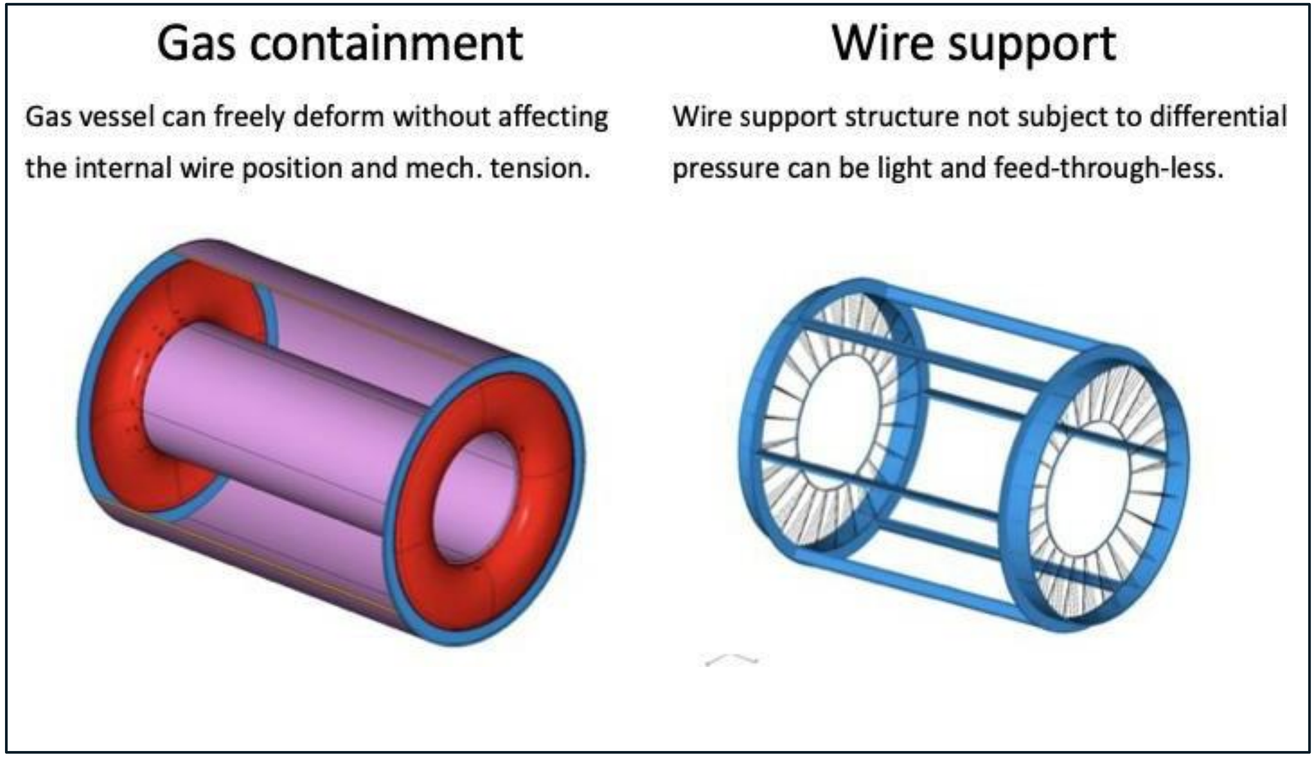
Mechanics

- Material choice for wires
  - Previously used W-Au Sense Wires
- Number of wires
  - MEG2 has 11904 total
  - IDEA has 343968 total
- Wire Cage
- Gas Envelope

Simulations:

- dN/dx #of ionizations per unit length
- dE/dx ionization energy loss per unit length

Francesco Grancagnolo, 'Conceptual designs and R&D challenges for drift chambers', ECFA WG3: Topical workshop on tracking and vertexing – CERN, 2023



Why Carbon-Fiber Sense Wires over Tungsten?

PROS

Due to low number of protons Z=6 (W, Z=74)

- Higher X_0 = lower material budget x/X_0
- Reduces background from multiple scattering

Higher radiation resistance

- Lattice structure coupled with less protons

Less stressful on support structures

- Less sag due to Gravity

CONS

More difficult to achieve preferred surface smoothness and roundness

- Affects coating uniformity
- Surface imperfections can cause field hot-spots

Why not just Carbon-Fiber Sense Wires?

Imperfections from manufacturing

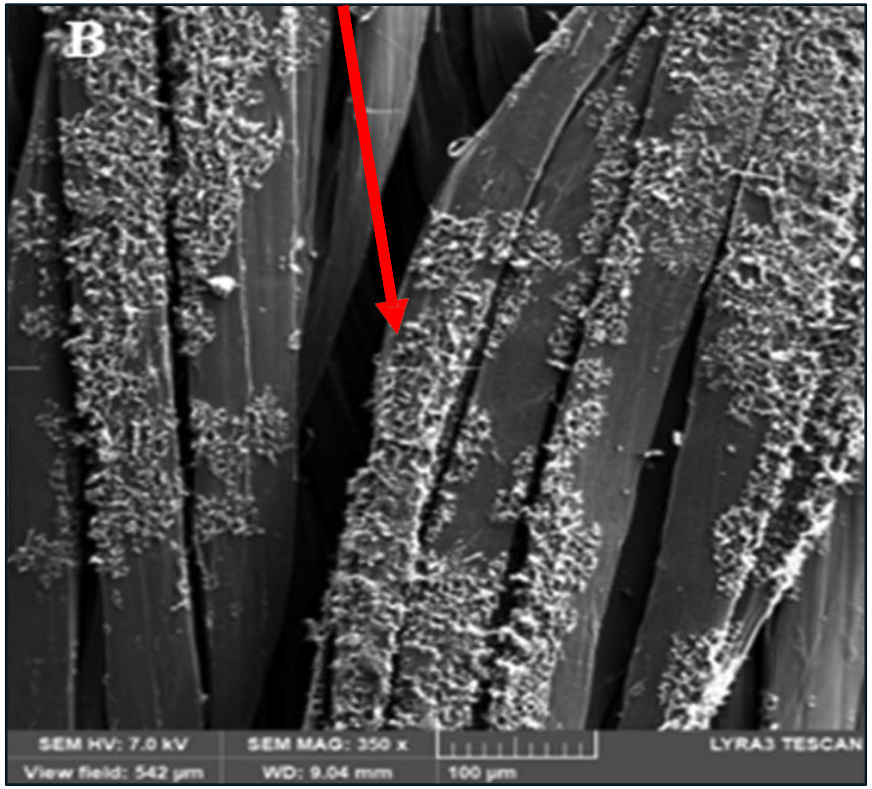
- Build up localized charge from inconsistent conductivity
- Unstable electric field
- Sparking and outgassing at high voltage

Comparative conductance of Carbon-Fiber

- Relatively poor compared to metals
- Different types, orientations and surface treatments can improve this

Coat the wires

- Gold or Silver?
- Silver susceptible to tarnishing over time
- Gold has exceptional corrosion resistance while still providing excellent conductivity
- Could require an additional adhesion layer

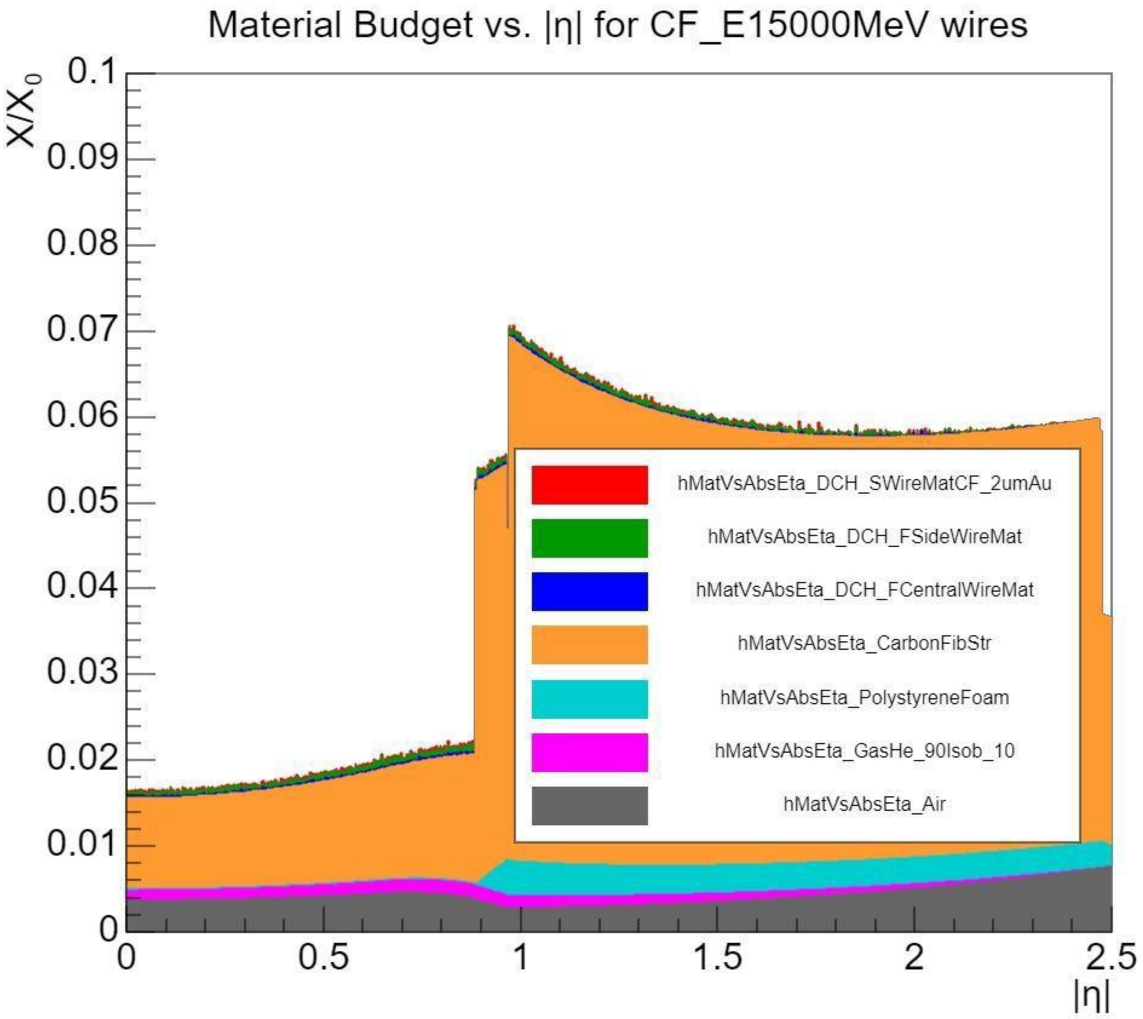


Dexmat CF Pictures

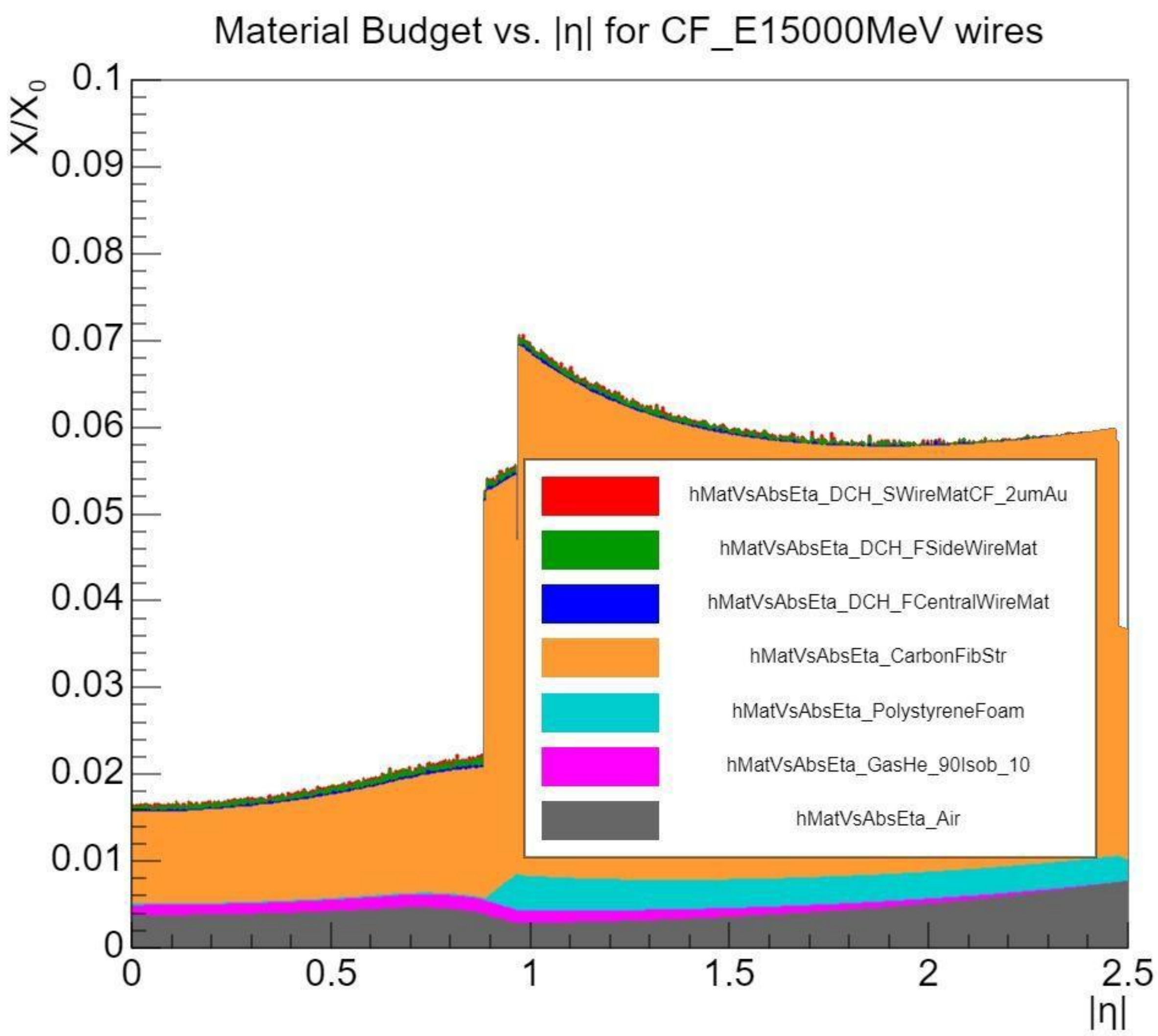
Material Budget Simulation IDEA(v3) DCH(v2)

DD4hep simulation:

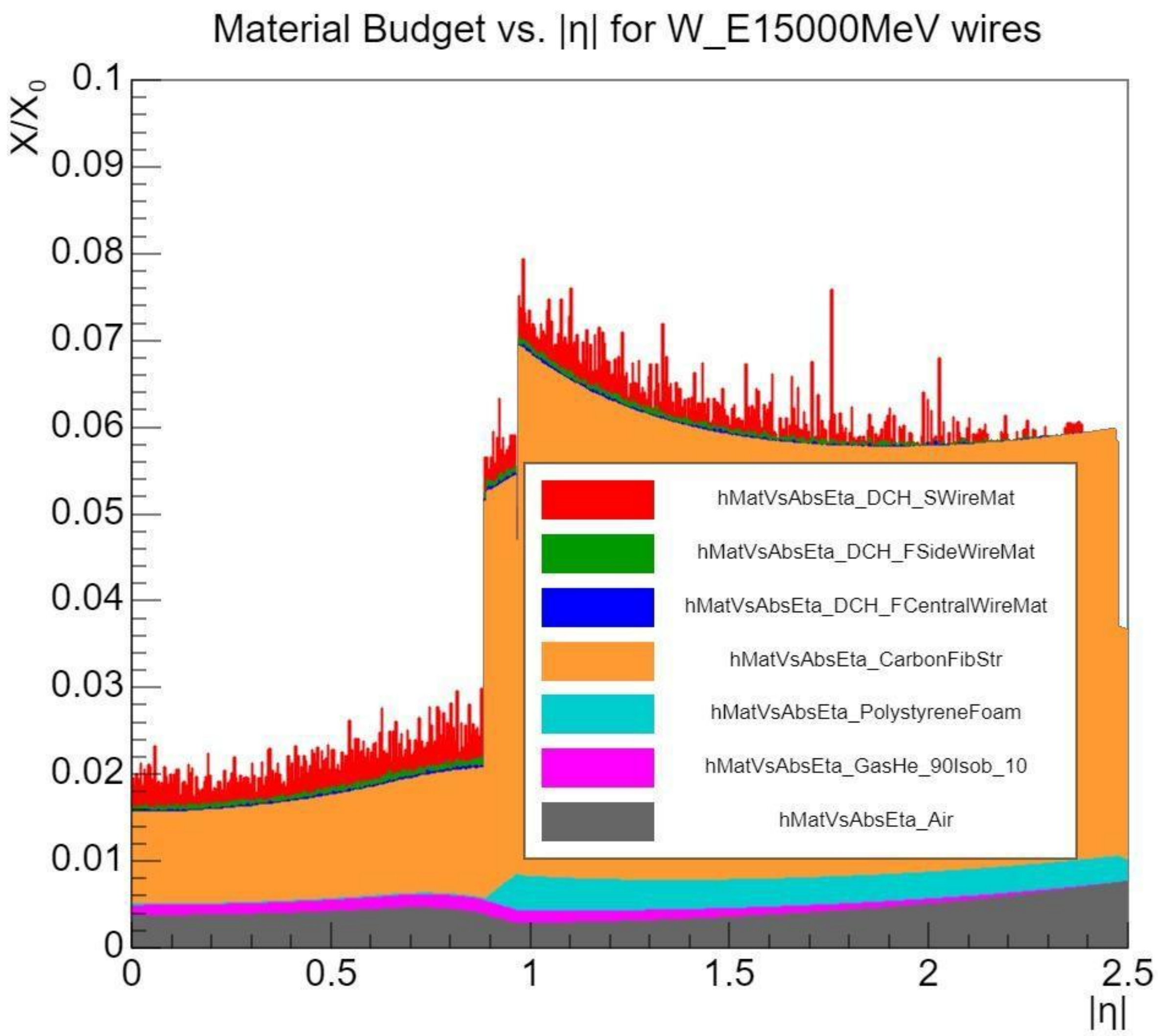
- Used K4geo IDEA_o1_v03.xml
- Remove all trackers and components apart from Drift Chamber
- Add new sense wire material for Carbon Fiber runs
- Keep same wire measurements(20µm core diameter + 0.3µm Au coating) for Tungsten and change to 25µm core diameter + 2µm Au coating when running Carbon Fiber
- Used 15GeV "Geantinos"
- Averaged over 32 different phi angles per eta bin



W-Au & CF-Au Material Budgets



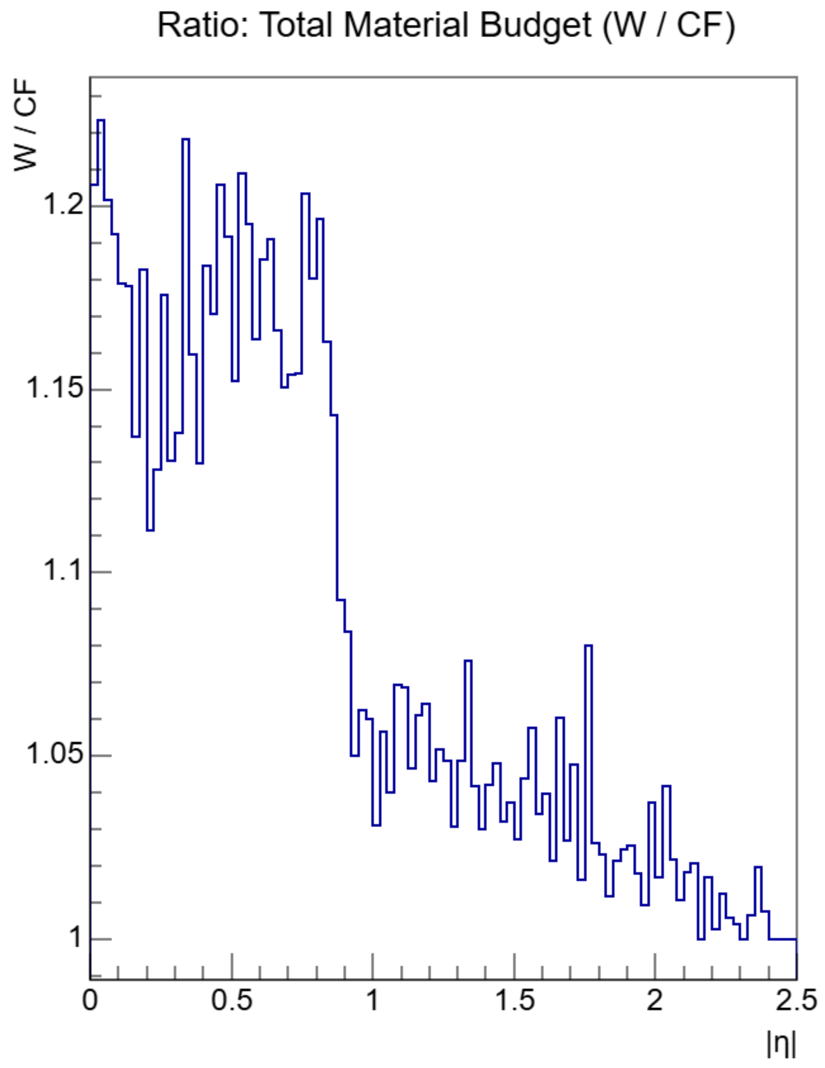
25µmCF + 2µmAu Material Budget vs. |η| for IDEA DCH_v2



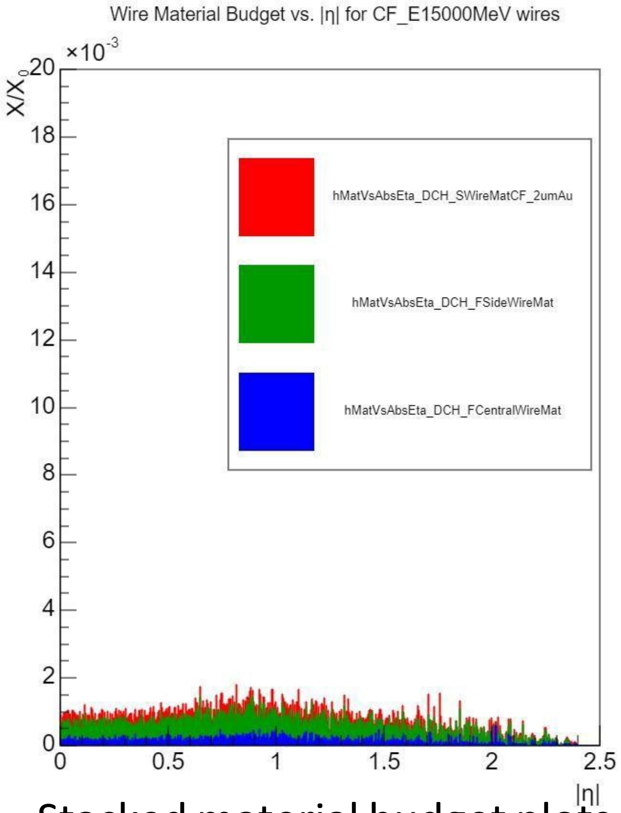
20µmW+0.3µmAu Material Budget vs. |η| for IDEA DCH_v2

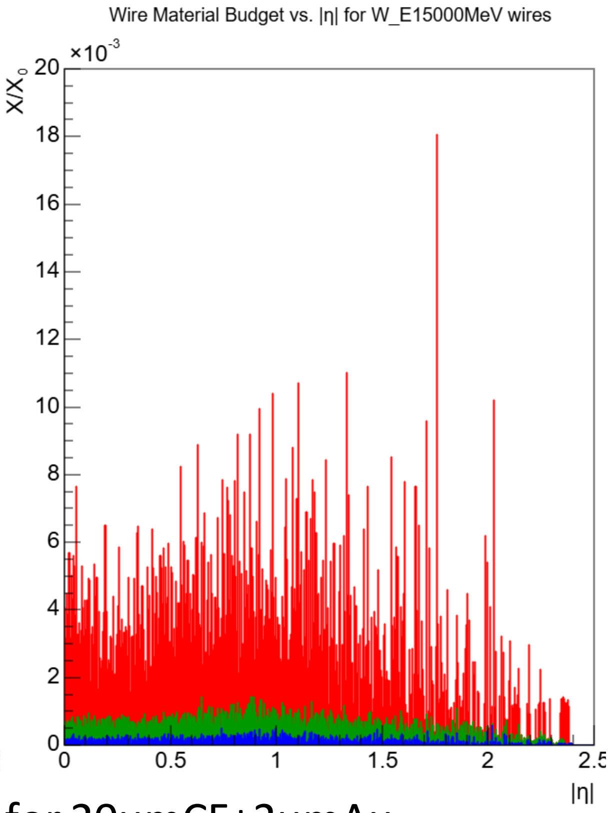
Ratio of Tungsten over Carbon Fiber for Total DCH Material Budgets

- 15-20% reduction in **total** drift chamber material budget before service area dominates.
  - Service area currently filled with Carbon Fiber to achieve 5% X/X0 as an estimate
  - Very different result compared to our previously estimated with back of the envelope calculations
  - Our previous calculations had no service area included and used a 0.5µm Au coating instead of current 2µm Au coating on Carbon Fiber used for this



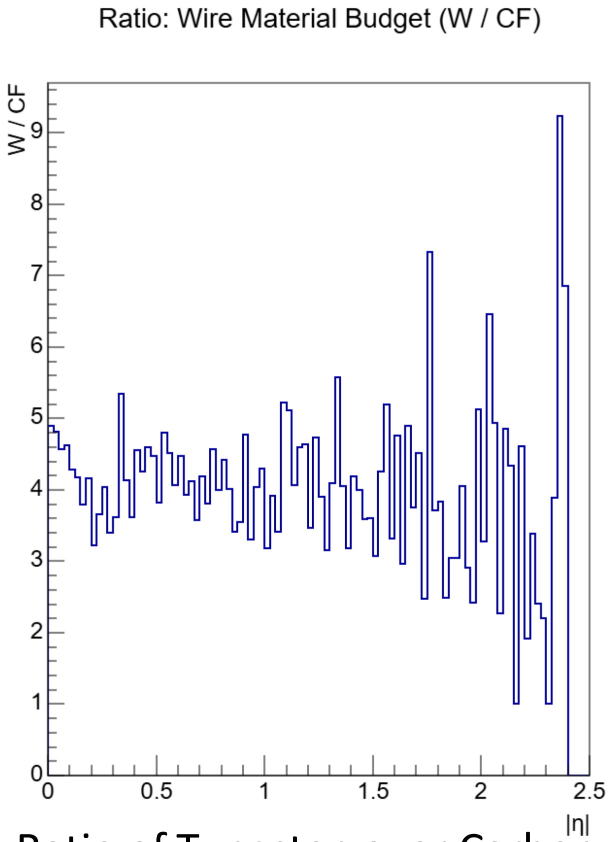
Wire Only Material Budget Comparison For IDEA(v03) DCH(V_2)



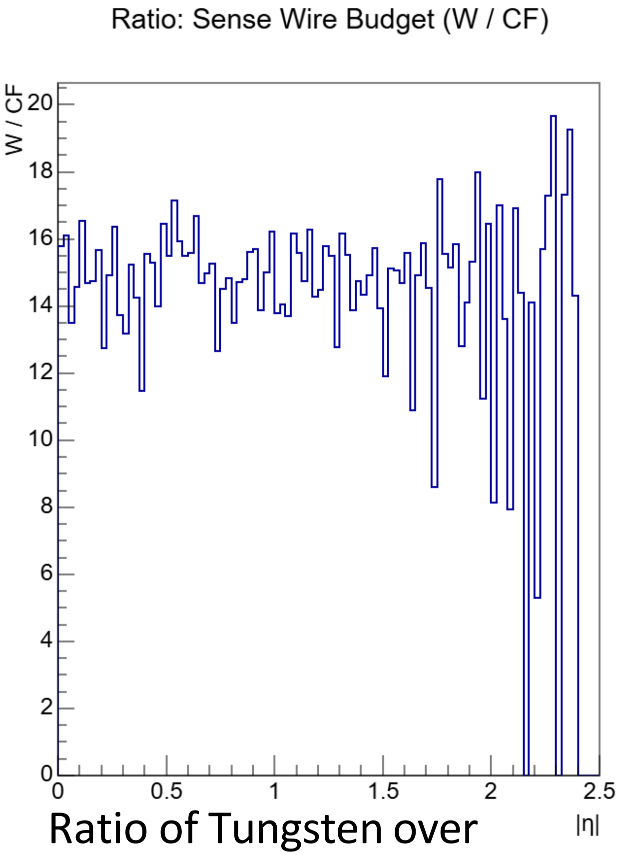


Stacked material budget plots for 20µmCF+2µmAu sense(left) and 20µmTungsten+0.3µmAu sense(right) with the two field wire types added.

Red = Sense Green = FieldSide Blue = FieldCentral



Ratio of Tungsten over Carbon Fiber material budgets for sense +field wires



Ratio of Tungsten over Carbon Fiber material budgets for sense wires only

Summary/Next Steps

Carbon-Fiber is a great option for:

- Reducing total DCH material budget

IDEA DCH Track Fitting required for detailed p_T resolution studies

- Recent k4RecTracker github pull request updates show great promise

Finish Assembly of drift wire chambers

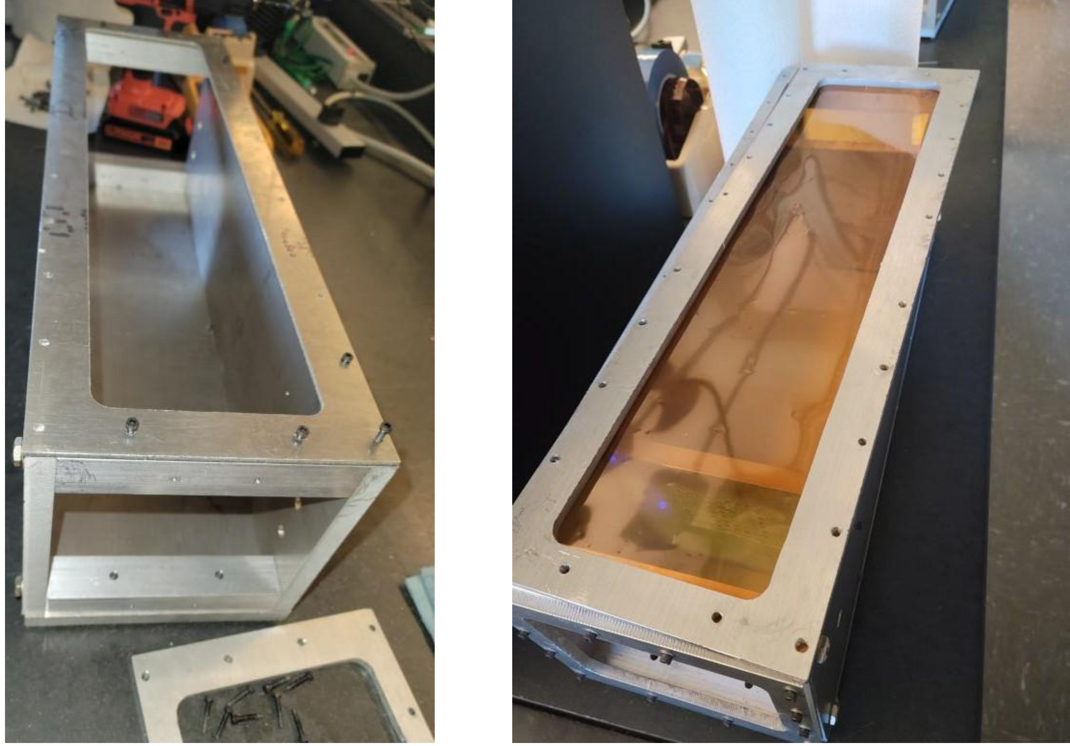
- 1 W-Au chamber, 1 CF-Au chamber
- Design Tensioning Methods
- Test with source
- Timescale of a few months

Build DAQ System

- Charge-sensitive amplifier, FPGA, Digitizer

Analysis of W-Au vs CF-Au

- Take data



Two New Wire Chambers Being Built

Preexisting Wire Chamber setup

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Thank you for listening! Questions?

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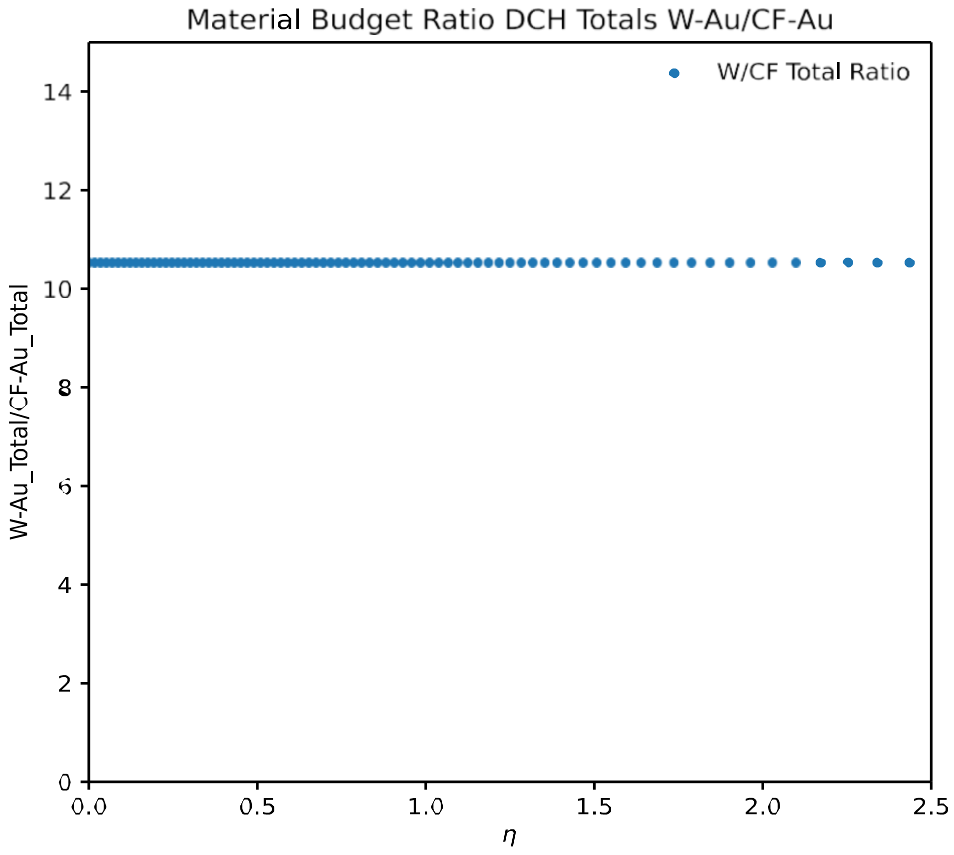
Backup Slides

How thick is this coating?

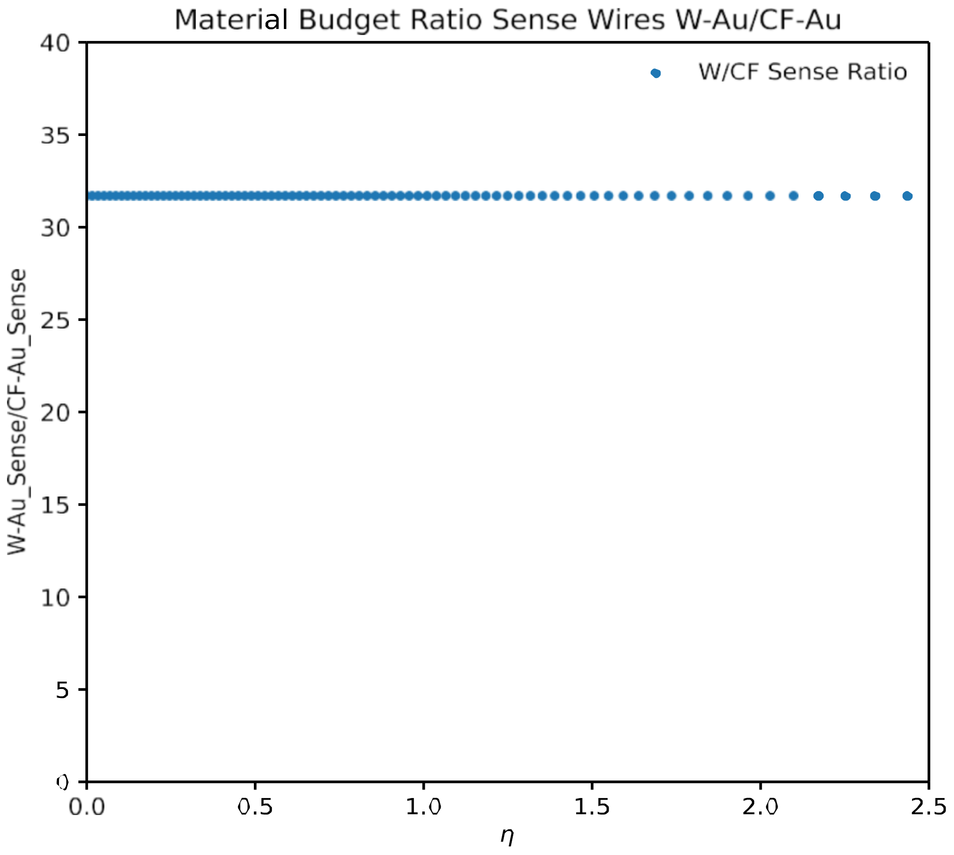
Previously estimated 0.5µm thick Au coating

- Less conductivity compared to 20µm diameter Tungsten + 0.3µm Au coating
- Calculated ~2.0µm thickness required assuming the carbon fiber's contribution to conductivity is negligible

Ratio of Material Budgets W-Au/CF-Au



Total Material Budget Ratio W-Au/CF-Au



Sense Wires Material Budget Ratio W-Au/CF-Au

Past Drift Chamber Implementations

Trackers at e^+e^- Colliders

past

SPEAR	MARK2	Drift Chamber
	MARK3	Drift Chamber
DORIS	PLUTO	MWPC
	ARGUS	Drift Chamber
CESR	CLEO1,2,3	Drift Chamber
VEPP2/4M	CMD-2	Drift Chamber
	KEDR	Drift Chamber
	NSD	Drift Chamber
PETRA	CELLO	MWPC + Drift Ch.
	JADE	Drift Chamber
	PLUTO	MWPC
	MARK-J	TEC + Drift Ch.
	TASSO	MWPC + Drift Ch.
TRISTAN	AMY	Drift Chamber
	VENUS	Drift Chamber
	TOPAZ	TPC

PEP	MARK2	Drift Chamber
	PEP-4	TPC
	MAC	Drift Chamber
	HRS	Drift Chamber
	DELCO	MWPC
BEPC	BES1,2	Drift Chamber
LEP	ALEPH	TPC
	DELPHI	TPC
	L3	Si + TEC
	OPAL	Drift Chamber
SLC	MARK2	Drift Chamber
	SLD	Drift Chamber
DAPHNE	KLOE	Drift Chamber
PEP2	BaBar	Drift Chamber
KEKB	Belle	Drift Chamber

present

VEPP2000	CMD-3	Drift Chamber
	KEDR	Drift Chamber
BEPC2	BES3	Drift Chamber
S.KEKB	Belle2	Drift Chamber

future

ILC	ILD	TPC	
	SiD	Si	
CLIC	CLIC	Si	
FCC-ee	CLD	Si	
	IDEA	Drift Chamber	
CEPC	Baseline	TPC	Si
	4th	Si + Drift Chamber	
	IDEA	Drift Chamber	
SCTF	BINP	Drift Chamber	
STCF	HIEPA	Drift Chamber	

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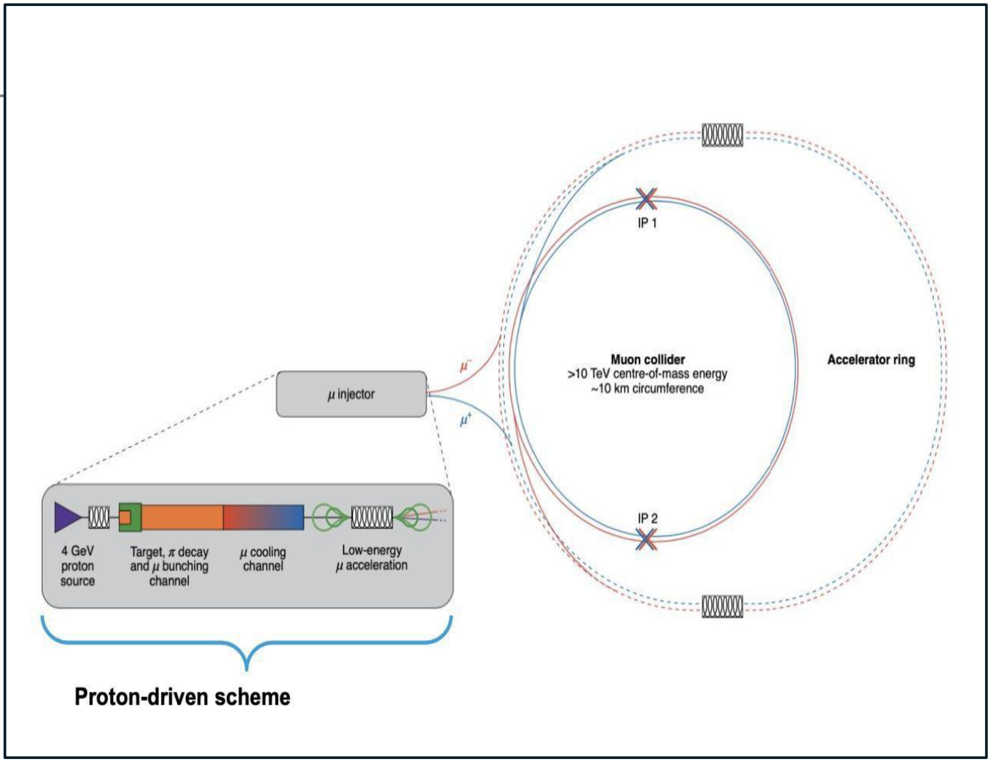
Muon Collider

Technical Challenges

- Muon limited lifetime: 2.2μs at rest
- Acceleration and cooling
- Neutrino flux from decay of muons in collider ring
- Beam induced background

Challenges require more R&D



https://arxiv.org/pdf/2303.08533