Ultrathin Wires and Digitization Development for the IDEA Drift Chamber at FCC-ee

Speaker: Muhammad Saiel

On behalf of DCH Community

Supervisor: Nicola de Filippis

Outline

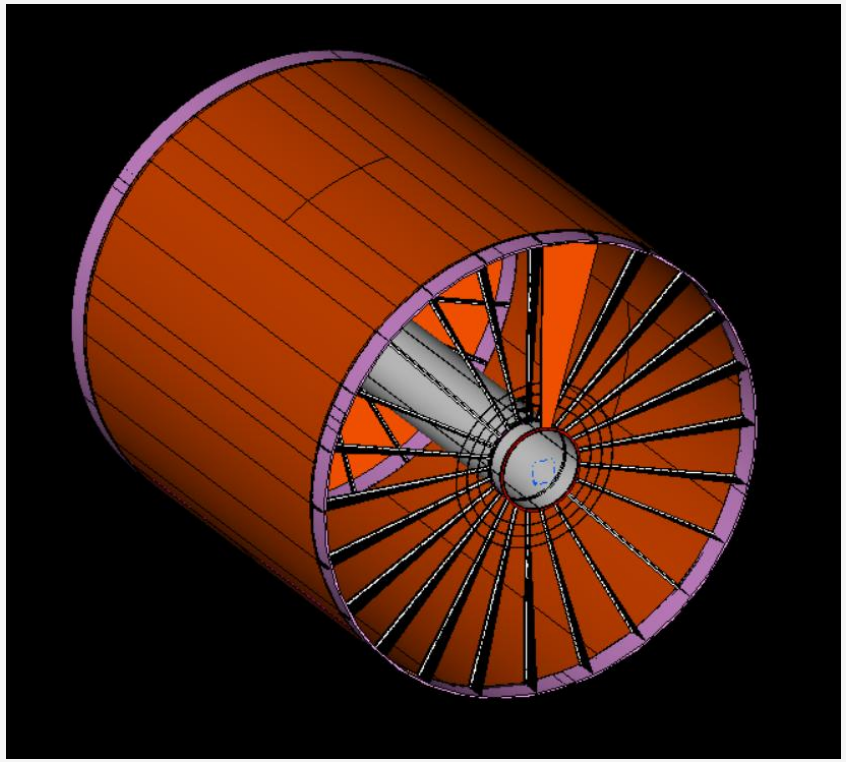
1. IDEA Drift Chamber at FCC-ee
2. Wire layout and ultra-thin wire requirements
3. Mechanical test setup and analysis method
4. Mechanical characterization of candidate wires
5. Dynamic vs static tension protocol
6. Digitization chain: from Geant4 hits to gas clusters
7. Electron drift, avalanche, and analog waveform formation
8. Electronics response, noise, and ADC digitization
9. Summary and next steps

IDEA Drift Chamber

- Low mass cylindrical with 2T solenoid field and a light gas mixture He 90% - iC_4H_{10} 10%
- Inner radius $R_{in} = 35$ cm, outer radius $R_{out} = 200$ cm
- Length $L = 400$ cm

- 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)

Ultra-thin wires reduce material budget and end-plate tension while enabling high-granularity drift-cell design.



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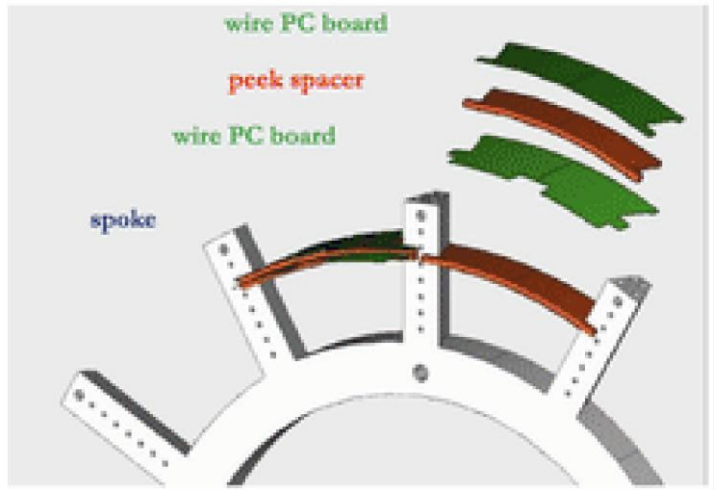
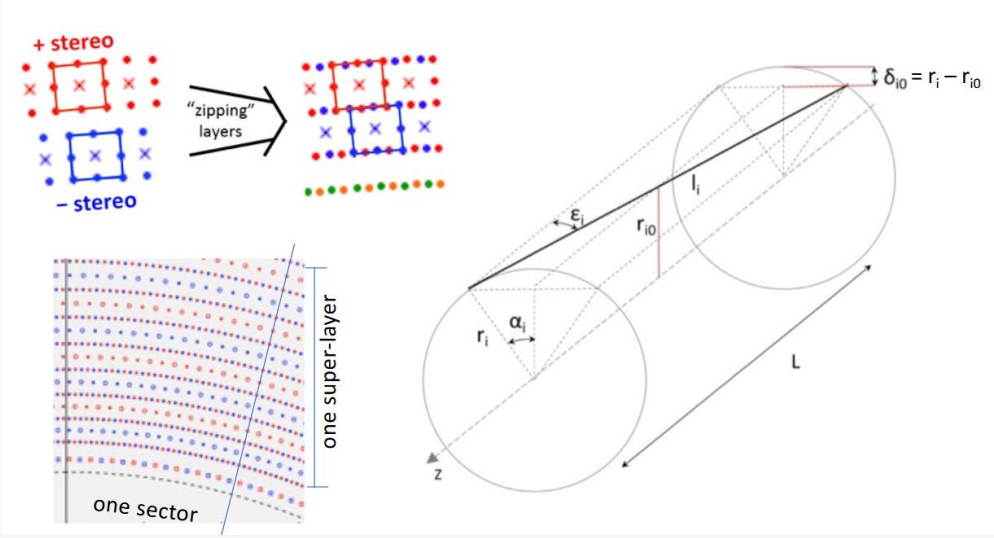
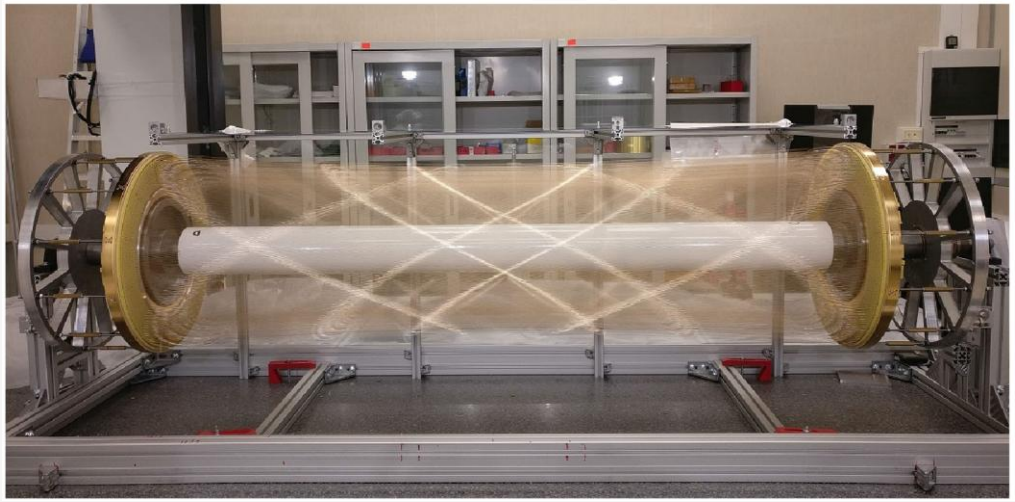
IDEA Drift Chamber: wire cage

- The **Wires** are soldered to the PCB and inserted between the spokes.
- **112 co-axial layers** (grouped in 14 superlayers of 8 layers each) **of para-axial wires**, at alternating-sign stereo angles, arranged in 24 identical azimuthal sectors.
- **Stereo configuration:** one sector is connected with the second corresponding sector in the opposite endcap (hyperbolic profile).







MEG2 experiment

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IDEA Drift Chamber: Cell

Electrostatic stability condition

$$T_c \geq \frac{C^2 V_0^2}{4\pi\epsilon w^2} L^2$$

T_c wire tension
w cell width
L wire length

C capacitance per unit length
V_0 voltage anode-cathode

For w = 1 cm, L = 4 m:

T_c > 26 g for 40 µm Al field wires (δ_{grav} = 260 μm)

T_c > 21 g for 20 µm W sense wires (δ_{grav} = 580 μm)

Elastic limit condition

$T_c < YTS \times \pi \cdot r_w^2$ *YTS = 750 Mpa* for W, *290 Mpa for Al*

T_c < 36 g for 40 µm Al field wires (δ_{grav} = 190 μm)

T_c < 24 g for 20 µm W sense wires (δ_{grav} = 510 μm)

The drift chamber length (**L = 4 m**) imposes strong constraints on the drift cell size (**w = 1 cm**)

Very little margin left ⇒ increase wires radii or cell size ⇒ use different types of wires

- Drift length ~ 1 cm, drift time ~250 ns, **σ_{xy} < 100** µm σ_z < 1 mm
- Ratio of field wires to sense wires = **5 : 1**
- 192 (at inner layer), 816 (at outer layer) **square drift cells** (16 per sector at inner layer, 68 per sector at outer layer)
- **Cell size** ranging from 11.8 mm at the innermost layer, to 14.9 mm at the outermost one

Radii (at z = 0)		
Inner Cylinder	350	mm
Guard wires layer	354	mm
First active layer	356	mm
Last (112th) active layer	1915	mm
Guard wires layer	1927	mm
Outer Cylinder	2000	mm

Radii (at end plate)		
Inner Cylinder	350	mm
Guard wires layer	366	mm
First active layer	369	mm
Last (112th) active layer	1982	mm
Guard wires layer	1995	mm
Outer Cylinder	2000	mm

Active length	2000	mm
Number of super-layers (8 layers) Number of sectors	(14x8) = 112 24	
Number of cells per layer / per sector	192÷816 / 16	
Cell size (at z=0)	11.8 ÷ 14.9	mm
2α angle	30°	
Stereo angle	43 ÷ 223	mrad
Stereo drop	12.5 ÷ 68.0	mm

sense wires	56 448
field wires	284 256
guard wires	2 016
Total wires	342 720

Wire tests with standard protocol

Tests started in a clean room at INFN Bari:

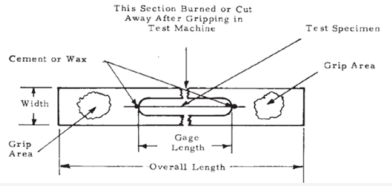
- 20 µm diameter Tungsten coated with gold
- 20 µm diameter Molybdenum coated with gold
- 33.5 µm diameter Carbon monofilament

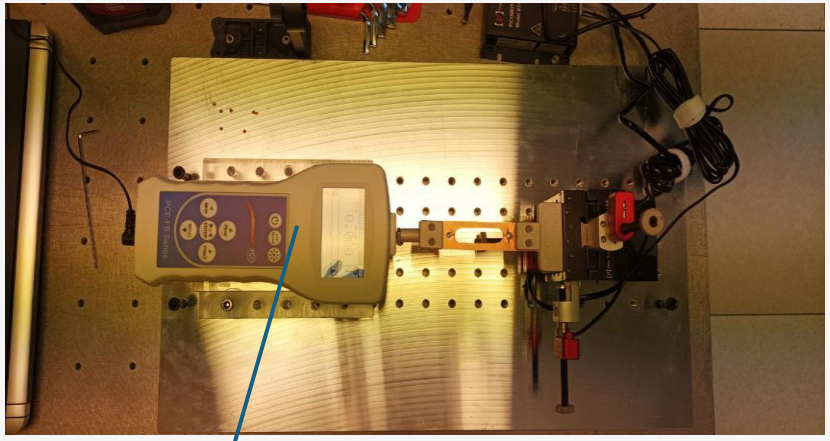
Setup:

- 3 axis picometer motor (30nm step)
- Digital dynamometer (acc. 0.001N)

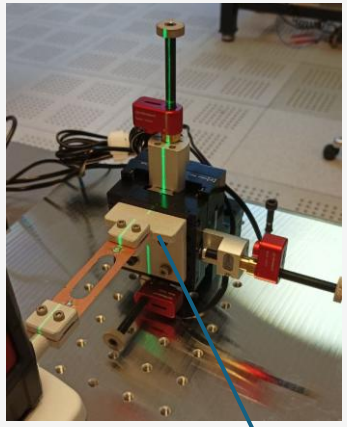
Standard ASTM D 3379 – 75

- **Scope**: Tensile Strength and Young's modulus for High-Modulus (>21 GPa) Single-Filament Materials (gage length > 2000*wire diameter)
- **Summary**: The filaments are center-line mounted on special slotted tabs. The tabs are gripped so that the test specimen is aligned axially in the jaws of a constant-speed movable-crosshead test machine. The filaments are then stressed to failure at a constant strain rate.

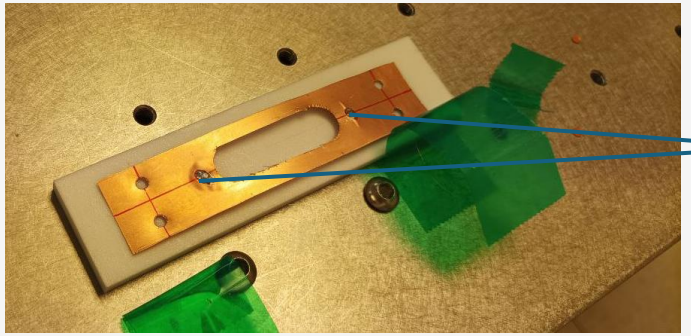




Dynamometer



Picometer



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Mechanical Property Calculations

1. Primary Experimental Variables :
   - Force from dynamometer: L (N)
   - Time t (s)
   - Crosshead speed v (µm/s)
   - Gauge length GL (mm)
   - Wire diameter d (mm)

2. Derived Parameters:

   ➢ Displacement: D = v *t (mm) ➢ Stress: L/A (GPa) ➢ Strain: D/GL

3. Key Mechanical Properties:
   ➢ Young's Modulus (Y) (GPa)
   ➢ Yield Tensile Strength (YTS) (GPa)
   ➢ Ultimate Tensile Strength (UTS) (GPa)

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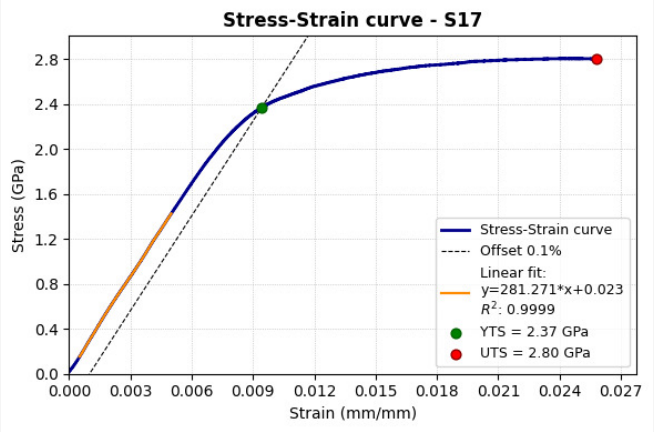
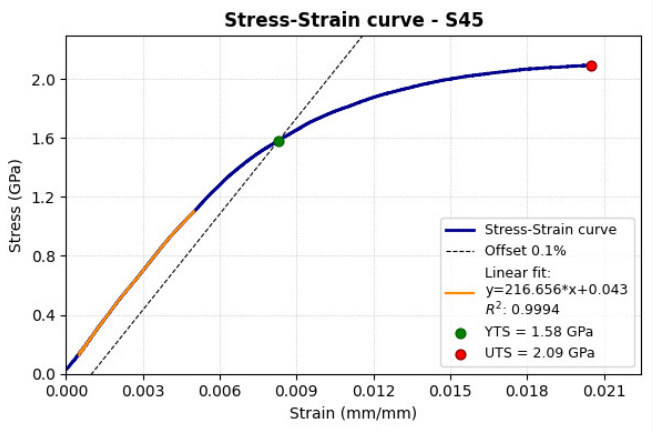
Mechanical Characterization

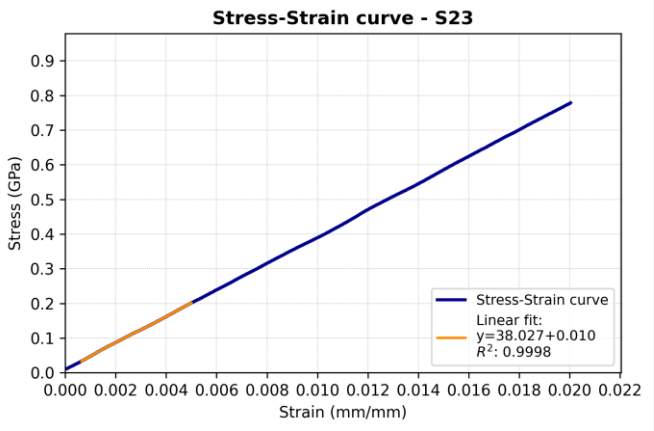
- **Gold Plated Tungsten:**
  1. Wire diameter: 20 µm
  2. Test Velocity: 20 µm/s
  3. Gauge Length: 50 mm
- **Gold Plated Molybdenum:**
  1. Wire diameter: 20 µm
  2. Test Velocity: 20 µm/s
  3. Gauge Length: 50 mm
- **Monofilament C wire:**
  1. Wire diameter: 33.5 µm
  2. Test Velocity: 20 µm/s
  3. Gauge Length: 40 mm
- **Steel Wires:**
  1. Wire diameter: 30, 50 µm
  2. Test Velocity: 60 µm/s
  3. Gauge Length: 40 mm



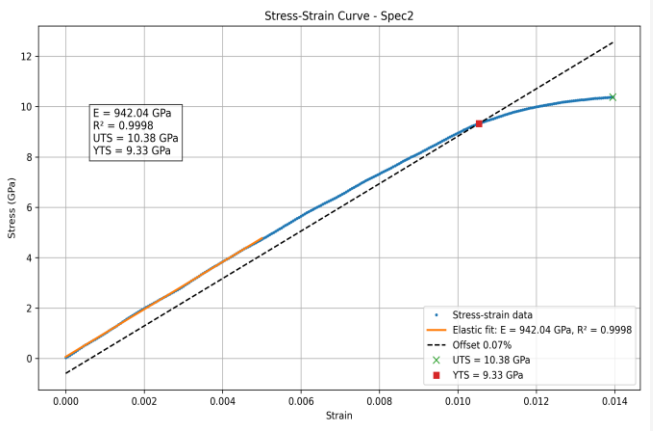
Tungsten



Molybdenum



Carbon



Steel

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Summary Table

Mechanical Properties Summary

Wire material	Statistics	UTS (GPa)	Strain at UTS (mm/mm)	Young's Modulus E (GPa)	YTS (GPa)	Elastic / YTS strain (mm/mm)	Effective test time (s)	Total elongation (mm)	Elongation (%)
Tungsten	Mean	2.80	0.0239	285.30	2.34	0.0092	63.13	1.26	2.53
	Std. Dev.	0.01	0.0008	7.49	0.03	0.0003	1.70	0.03	0.06
Molybdenum	Mean	2.11	0.0201	218.24	1.62	0.0084	51.08	1.02	2.04
	Std. Dev.	0.01	0.0003	7.91	0.03	0.0003	1.03	0.02	0.04
Carbon	Mean	0.69	0.0176	38.24	0.69	0.0176	35.12	0.70	1.75
	Std. Dev.	0.12	0.0028	0.53	0.12	0.0028	5.67	0.11	0.29
Steel	Mean	10.04	0.0139	835.42	8.54	0.0099	—	—	—
	Std. Dev.	0.46	0.0000	156.79	1.12	0.0010	—	—	—

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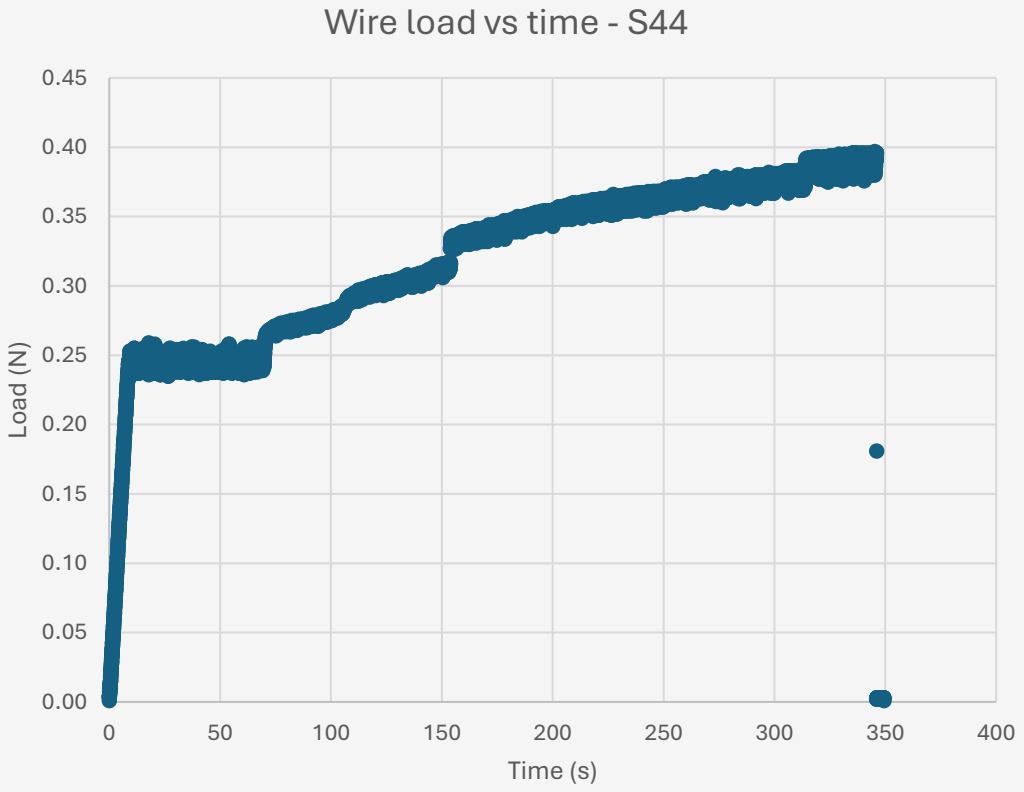
Al wire

1. Wire diameter: 40 µm
2. Test Velocity: 20 µm/s
3. Gauge Length: 50 mm

Problem: The wire is Slipping at the glued point. For this we need to use a strong gule



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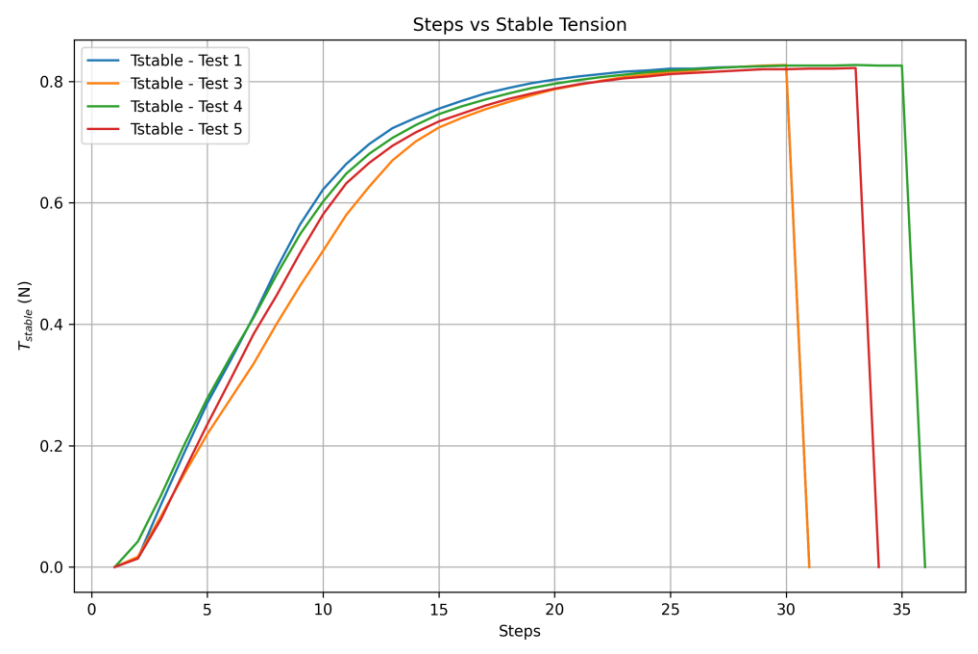
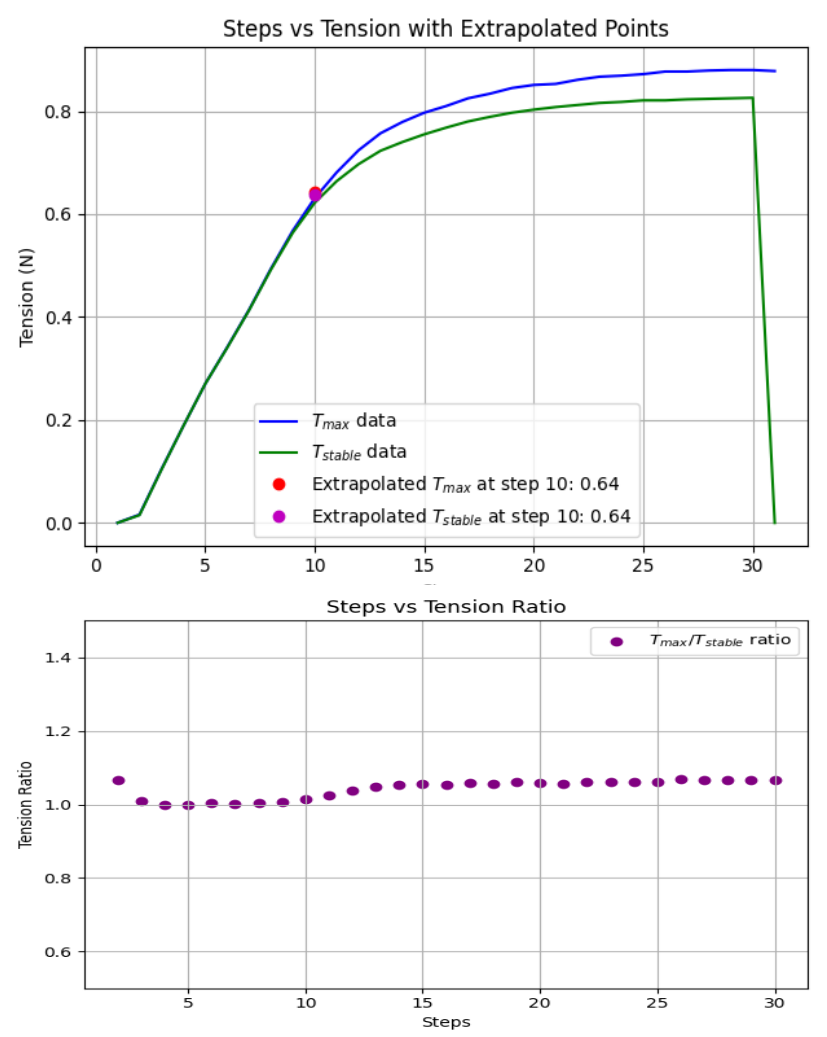
Static Tension: W+Au

- The Pico motor is moving in steps
- Along the motion, the tension increases
- Wait until the tension stabilize.
- The step size should be kept small

1. Wire diameter: 20 µm
2. Step size: 50 µm
3. Gauge Length: 50 mm





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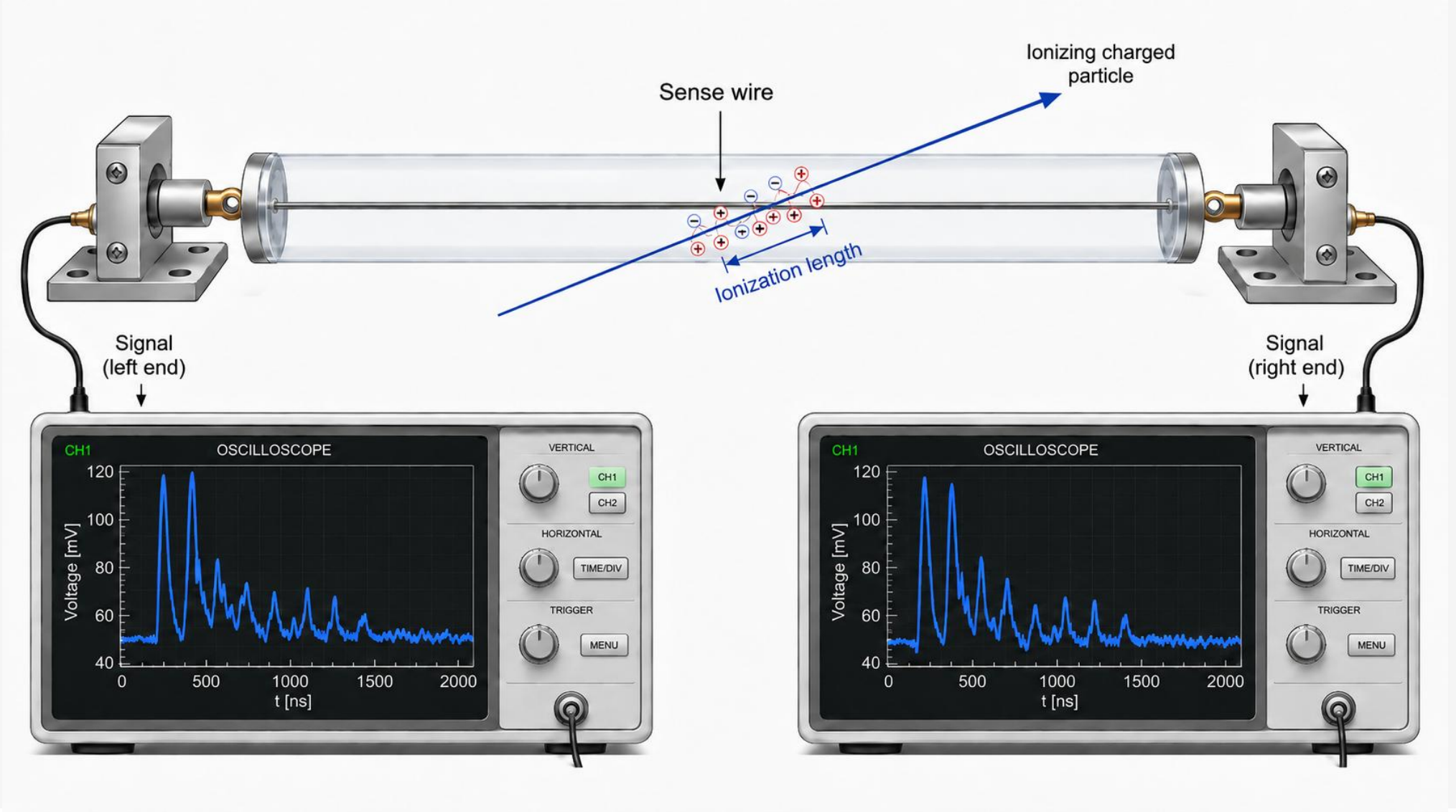
Digitization in the IDEA Drift Chamber

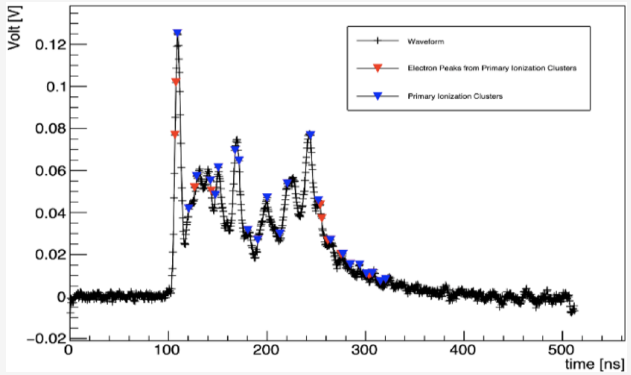


Strategy of hit digitization for the IDEA DCH

- Result of a hit cell digitization at the lowest level, L_0, must be a **waveform**

  Parameters of the waveform are:

  - time bin size
  - amplitude bit size



- At a higher level, L_1, results of hit digitization are:
  - list of electron peak positions and relative amplitudes (i.e., ionization electrons after peak finding – red markers in the picture) or
  - list of ionization cluster positions and relative amplitudes (after electrons clusterization algorithm – blue markers in the picture)
- At an even higher level, L_2, results of hit digitization are:
  - impact parameter d_{DCA}
  - number of clusters n_{cl}

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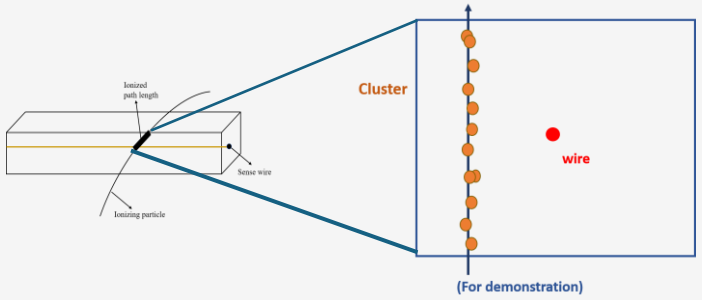
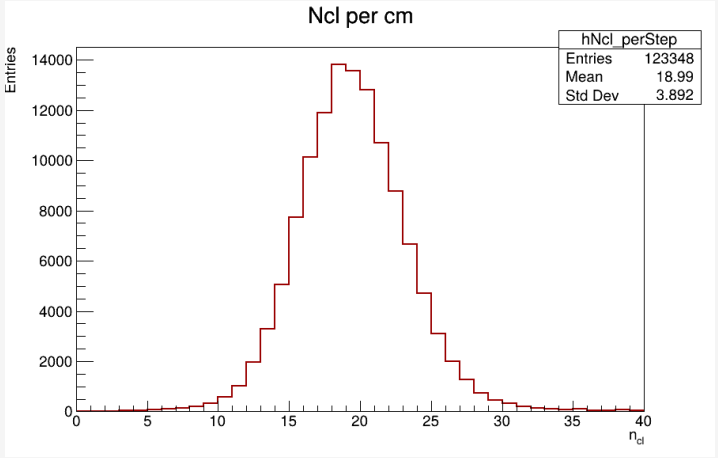
Sequence of steps for the simulation

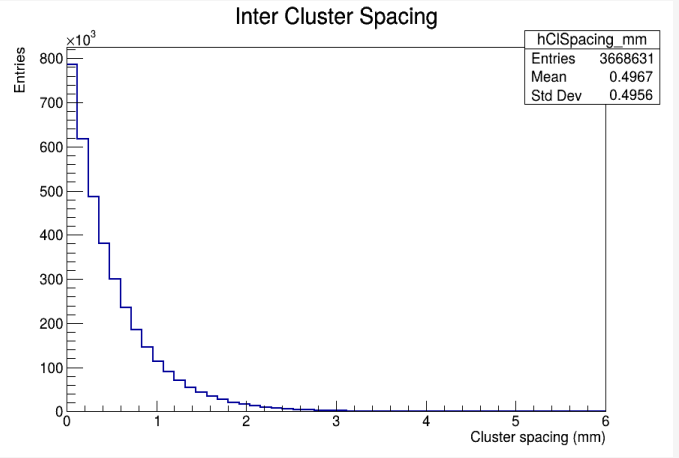
Intersect the physical particle trajectory with the space volume defined by the fired cell (input to digitization).

1. Define the ionization length L (Geant4 weighted step length) of the particle track within the cell volume.

2. Extract a number of ionization acts n_{cl} according to a Poisson distribution with peak value $(dN_{cl}/dx) \times L$, and distribute them along L using exponential spacings with a mean free path $1/(dN_{cl}/dx)$.
   dN_{cl}/dx is a tabulated function only of the particle $\beta\gamma$
   I. This function can be provided by the test beam Experimental result.
   II. At the moment we are relying on the Bethe-Bloch parameterization.







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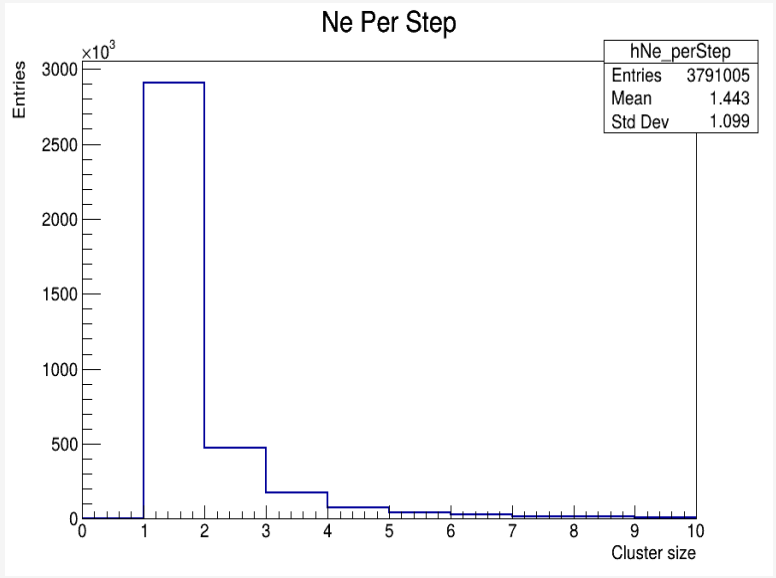
Sequence of steps for the simulation

3. For each of the n_{cl} extract, for the given gas mixture (He 90% – isobutane 10%), a number of electrons n_e according to the **experimental distributions** given in the Experimental determination of ionization cluster size distributions in counting gases Ref [1].

k	CH_4	Ar	He	CO_2
1	78.6	65.6	76.60	72.50
2	12.0	15.0	12.50	14.00
3	3.4	6.4	4.60	4.20
4	1.6	3.5	2.0	2.20
5	0.95	2.25	1.2	1.40
6	0.60	1.55	0.75	1.00
7	0.44	1.05	0.50	0.75
8	0.34	0.81	0.36	0.55
9	0.27	0.61	0.25	0.46
10	0.21	0.49	0.19	0.38
11	0.17	0.39	0.14	0.34
12	0.13	0.30	0.10	0.28
13	0.10	0.25	0.08	0.24
14	0.08	0.20	0.06	0.20
15	0.06	0.16	0.048	0.16
16	(0.050)	0.12	(0.043)	0.12
17	(0.042)	0.095	(0.038)	0.09
18	(0.037)	0.075	(0.034)	(0.064)
19	(0.033)	(0.063)	(0.030)	(0.048)
≥20	$(11.9/k^2)$	$(21.6/k^2)$	$(10.9/k^2)$	$(14.9/k^2)$

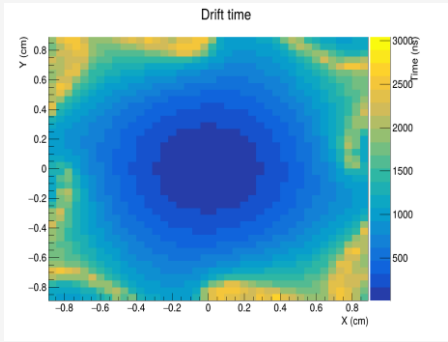


4. Transport each of the n_e electrons to the sense wire.

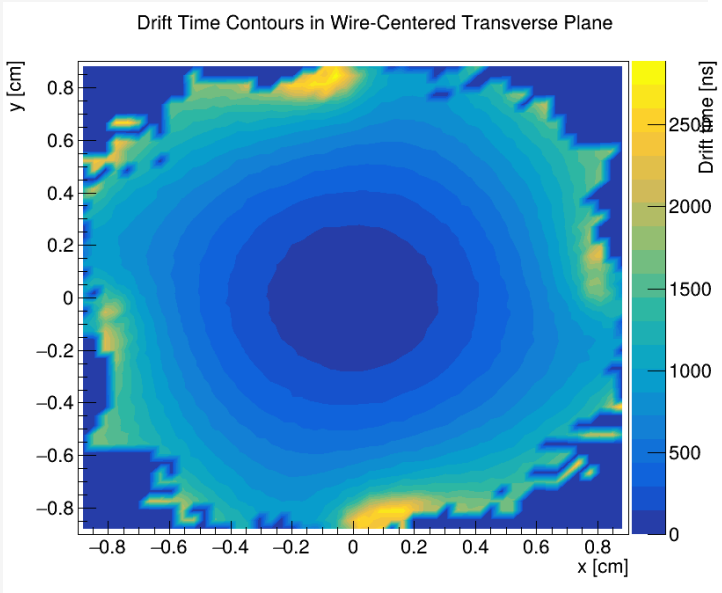
   Use tabulated distance-to-time distributions.

   I. Smear the drift time with properly calculated diffusion, according to experimental measurements.

   II. Alternatively, obtain the transport and diffusion from Garfield.



Mean drift time distribution in cell size 1.8 * 1.8 cm Ref. [7]



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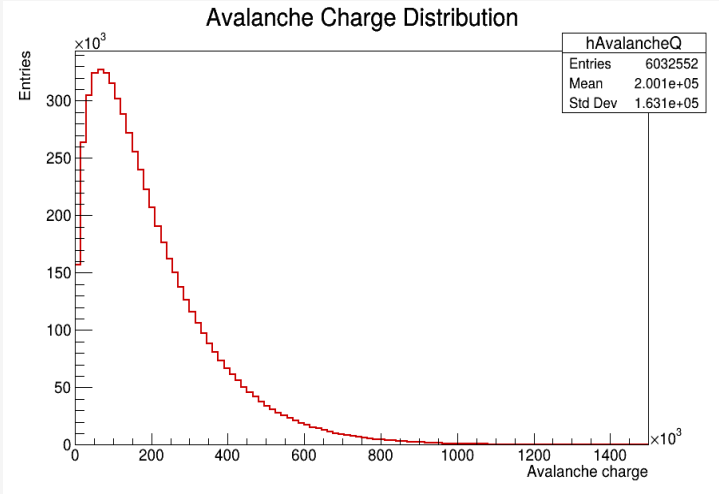
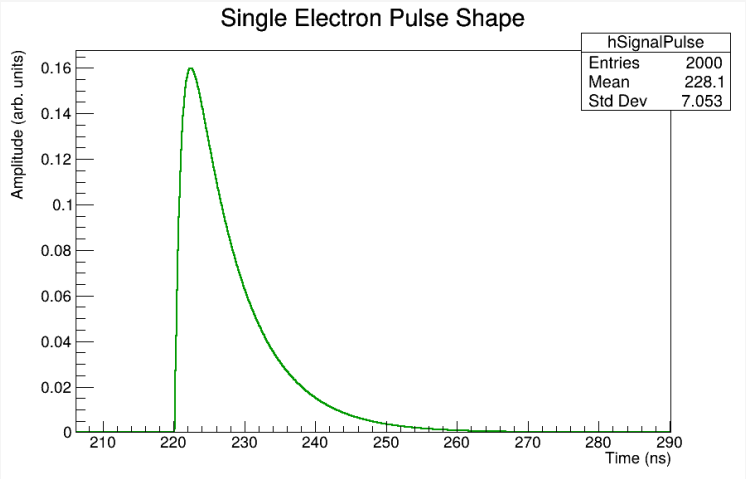
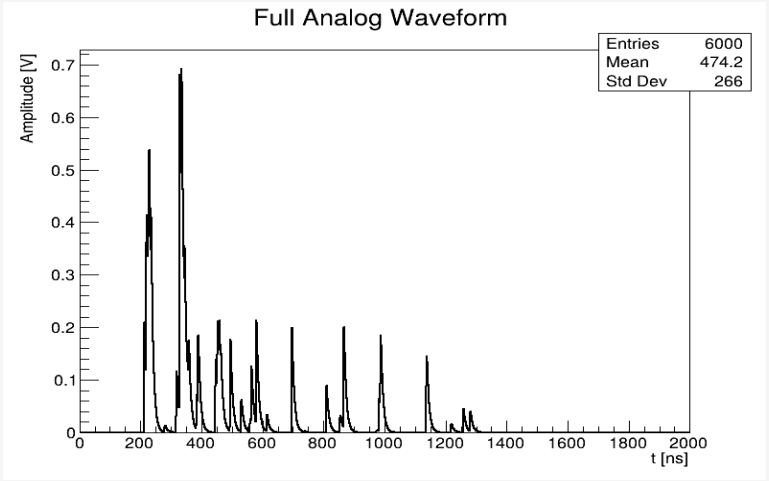
Sequence of steps for the simulation

5. For each of the n_e electrons sample an avalanche charge q from the Polya distribution.
   I. Gas gain, G = 2 * 10^5 . Ref [2]
   II. Polya shape parameter $\theta = 0.5$. Ref [3]



6. For each electron, an individual pulse is generated at its arrival time.
   The pulse shape is defined by rise time τ_r and fall time τ_f





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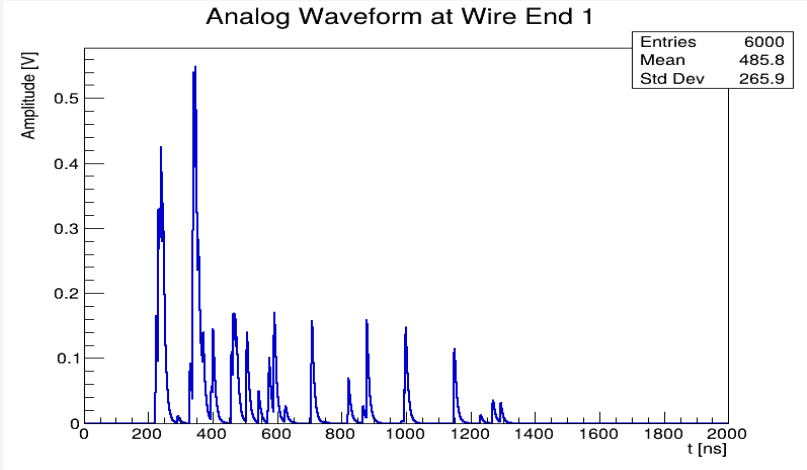
Sequence of steps for the simulation

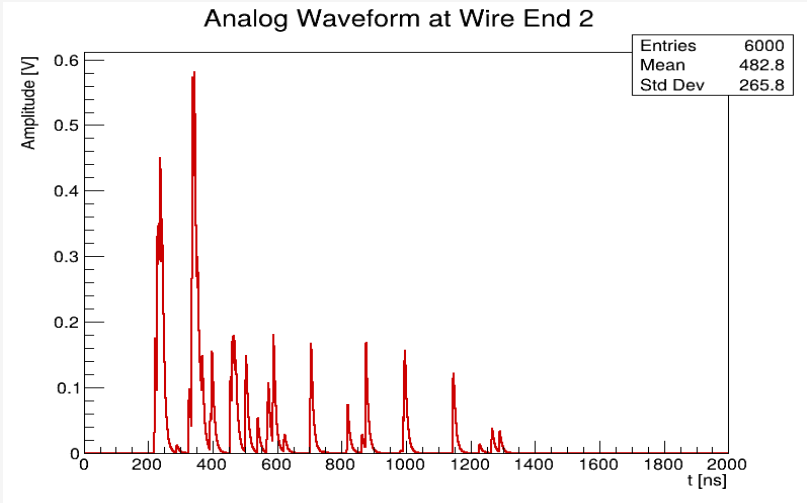
7. Build the Analog waveform by summing up the individual contributions of all single electrons

8. Propagate the Analog Waveform at both ends of the wire by taking into account:
   proper transit time (as a first attempt, ~ 5ns/m).
   signal attenuation along the sense wire, according to experimental measurements.
   Att(d) = exp(−d/λ), 1.0 Ref. [3]

① $d_R = \frac{\frac{L}{2} - hit\ Pos}{\cos(Wirestereo)}$

② $d_L = \frac{\frac{L}{2} + hit\ Pos}{\cos(Wirestereo)}$





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Sequence of steps for the simulation

9. **Applying the pre amplifier transfer functions:**

Impedance mismatch scaling:

Compute the reflection coefficient Γ and rescale the amplitude with 1- Γ

Parameters: Matching Resistance, Tube Impedance

Electronics transfer function

Build impulse-response by Shape:
rise * fall time followed by a normalization factor

Parameters: τ_r = 3.0 ns, τ_{f1} = 9.0 ns, τ_{f2} = 25 ns Ref. [2]

Discrete Convolution: $y[i] = \Delta t \sum_j x[i-j]\ k[j]$ Ref. [6]

10. **Adding proper noise :**

Use experimental frequency-domain noise template:

- frequency bins, magnitude, normalization.

Match to waveform sampling.

Assign random phase $\phi \in [0, 2\pi]$

Apply inverse FFT to obtain time-domain noise.

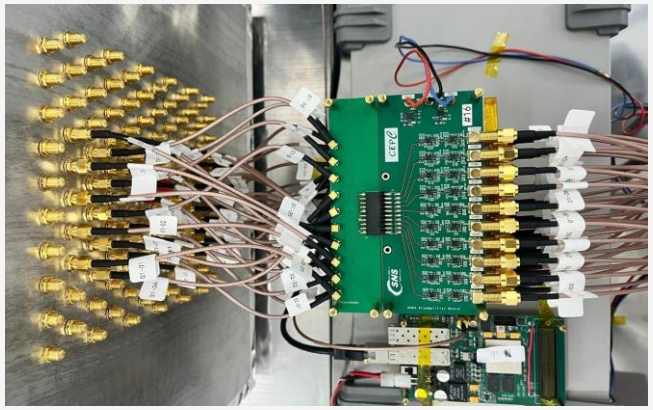
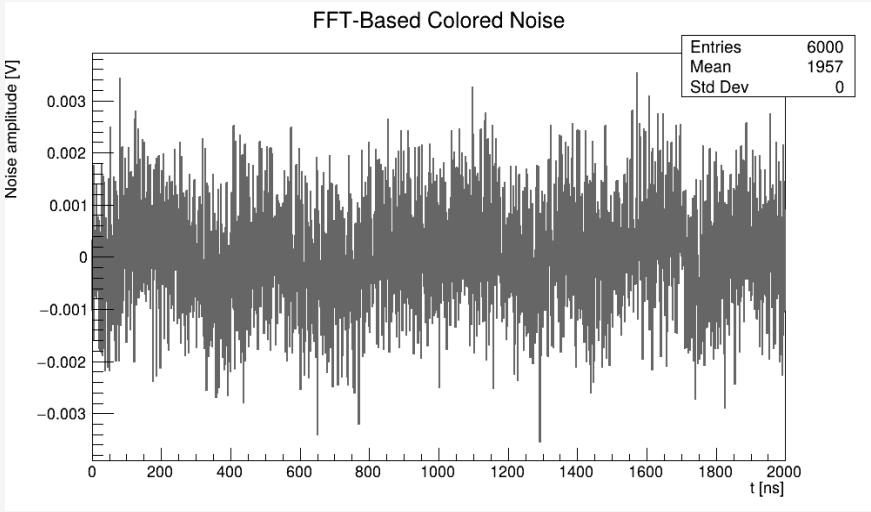


Fig: Pre Amplifier of the DCH Porotype in IHEP



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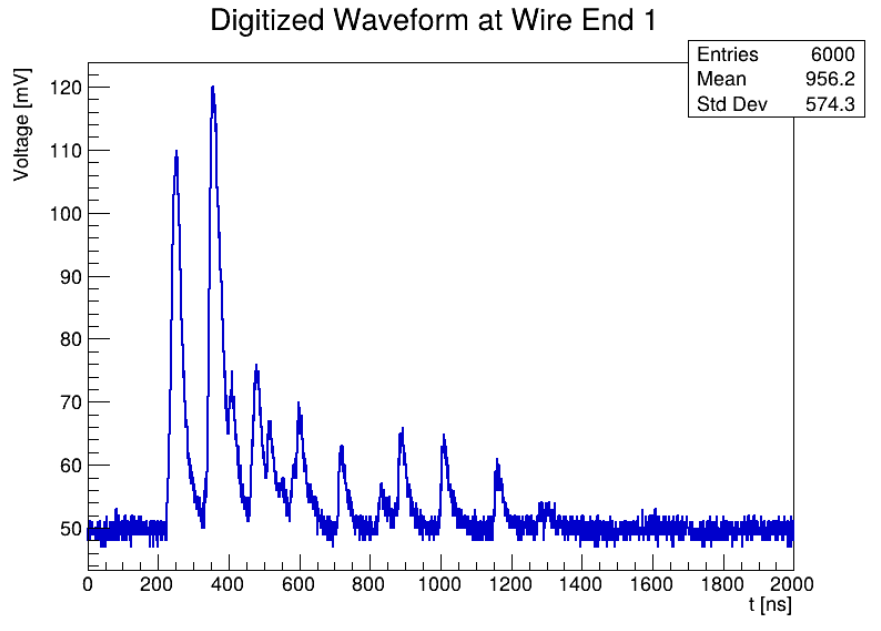
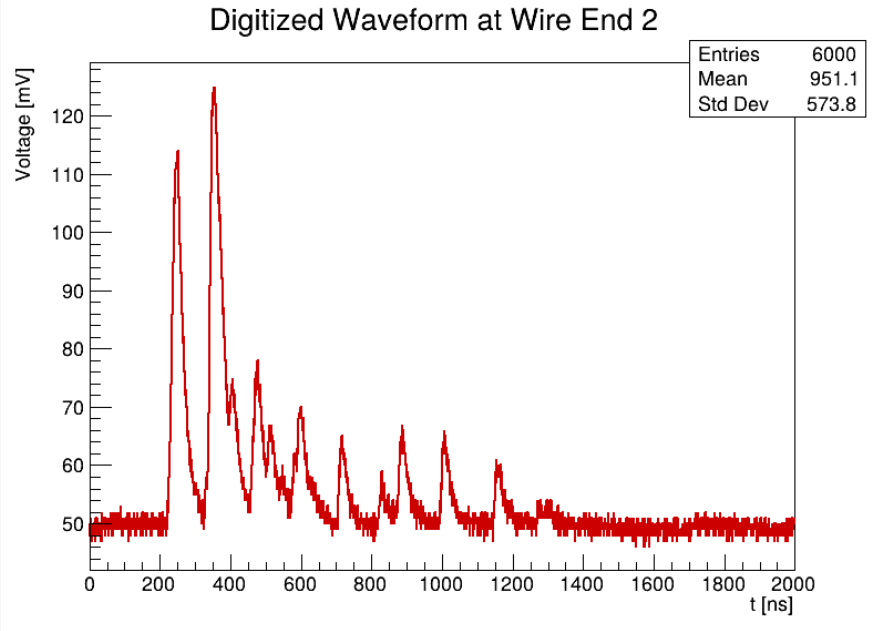
Digitized waveform

Time bin size: 0.5 ns (2 GSa/s), Amplitude bit size: 12 bits





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Conclusion

Ultrathin wires:

- **Gold-plated Tungsten (20 µm)**
  - **UTS 2.79–2.81 Gpa, Young's Modulus ≈ 276 - 296 Gpa (Ref 8: 407 GPa),** Very stable elastic behavior
- **Gold-plated Molybdenum (20 µm)**
  - **UTS 2.09–2.12 Gpa, Young's Modulus ≈ 205 - 225 Gpa (Ref 8: 320 GPa),** Slightly lower stiffness compared to W
- **Carbon Monofilament (33.5 µm)**
  - **UTS 0.53–0.83 Gpa, Young's Modulus ≈ 37 - 39 Gpa,** Transition from **dynamic to static stepwise tensioning** improves measurement stability and reproducibility.

Digitization:

- Ionization is modeled through **cluster generation and electron multiplication**, using **βγ-dependent dNcl/dx.**
- Electron drift times are computed using **tabulated X–T relations (2D LUT)** with **diffusion smearing,** where Each **drifting electron** is assigned an **avalanche charge (gain)**.
- Individual electron pulses are shaped using **measured rise/fall times**, summed to form the **analog waveform**, propagated along the wire, and processed through **electronics response and FFT-based noise injection**.

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To Do List

➢Wire characterization

- Finalize the static stepwise tension protocol and quantify its reproducibility.
- Improve bonding for thin Al wires and repeat tensile tests after stabilization.
- Complete comparison of candidate wires using Young's modulus, YTS, UTS, solderability, and mechanical stability.

➢Digitization development

- Validate the L0 digitized waveform against test-beam.
- Develop L1 reconstruction: electron peak finding and ionization-cluster reconstruction. (Bari DCH Analysis Group, Asif Ali)
- Extend to L2 reconstruction: extract d_{DCA} ,estimate its uncertainty, and evaluate $dN_{\mathrm{cl}}/dx$for PID.

Thank you for your attention!

References

[1] Fischle, Hansjörg, Joachim Heintze, and Bernhard Schmidt. "Experimental determination of ionization cluster size distributions in counting gases." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 301.2 (1991): 202-214.

[2] Elmetenawee, W., et al. "Enhancing particle identification in helium-based drift chambers using cluster counting: insights from beam test studies." *Journal of Instrumentation* 20.11 (2025): P11019.

[3] Blum, Walter, Werner Riegler, and Luigi Rolandi. *Particle detection with drift chambers*. Springer Science & Business Media, 2008.

[4] Knoll, Glenn F. *Radiation detection and measurement*. John Wiley & Sons, 2010.

[5] IDEA Study Group. "The IDEA detector concept for FCC-ee." *arXiv preprint arXiv:2502.21223* (2025).

[6] Oppenheim, Alan V. "Discrete-time signal processing: Alan V. Oppenheim." *(No Title)*.

[7] Zhao, Guang, et al. "Peak finding algorithm for cluster counting with domain adaptation." *Computer Physics Communications* 300 (2024): 109208.

[8] Callister Jr, W. D., & Rethwisch, D. G. (2020). *Materials science and engineering: an introduction*. John wiley & sons.

Back Up Slides

Test n. 01 – W+Au coating (Spool n. 174586)

- Wire diameter: 20µm

  Color legend: Green (good), orange (to discuss)

Samples	Wiring date	Test date	Comments	Gauge length (mm)	Motor velocity (step/sec	Velocity (um/sec)
05	20/03/2025	31/03/2025	Broken at the soldering point	60	2000	60
04	20/03/2025	31/03/2025	Broken in the middle, pre load	60	2000	60
03	20/03/2025	31/03/2025	Broken at 20mm from one soldering point	60	2000	60
02	20/03/2025	01/04/2025	Broken at 5mm from one soldering point	60	2000	60
01	20/03/2025	01/04/2025	Broken at 20mm from one soldering point	60	2000	60
11	02/04/2025	02/04/2025	Broken at 10mm from one soldering point	50	2000	60
33	29/04/2025	30/04/2025	Broken at 10mm from one soldering point	50	2000	60
34	29/04/2025	30/04/2025	Broken at 20mm from one soldering point	50	2000	60
35	29/04/2025	30/04/2025	Broken at 5mm from one soldering point	50	2000	60
36	29/04/2025	30/04/2025	Broken at 20mm from one soldering point	50	2000	60
12	02/04/2025	08/04/2025	Broken at 10mm from one soldering point	50	1000	30
13	02/04/2025	08/04/2025	Broken at the soldering point	50	1000	30
15	08/04/2025	09/04/2025	Broken at the soldering point	50	1000	30
16	08/04/2025	09/04/2025	Broken at the soldering point	50	1000	30
37	29/04/2025	30/04/2025	Broken at 20mm from one soldering point	50	1000	30
17	08/04/2025	09/04/2025	Broken at 20mm from one soldering point	50	667	20
18	08/04/2025	09/04/2025	Broken at 20mm from one soldering point	50	667	20
19	09/04/2025	09/04/2025	Broken at 15mm from one soldering point	50	667	20
20	09/04/2025	09/04/2025	Broken at 5mm from one soldering point	50	667	20
38	29/04/2025	30/04/2025	Broken at 15mm from one soldering point	50	667	20
65	01/10/2025	01/10/2025	Broken at 20mm from one soldering point	50	1333	40
66	01/10/2025	01/10/2025	Broken at the soldering point	50	1333	40
67	01/10/2025	01/10/2025	Broken at the soldering point	50	1333	40
68	01/10/2025	01/10/2025	Broken at 5mm from one soldering point. The wire was stressed and relaxed before the test	50	1333	40
69	01/10/2025	01/10/2025	Broken at the soldering point	50	1333	40
70	01/10/2025	02/10/2025	Broken at 20mm from one soldering point	50	1667	50
71	01/10/2025	02/10/2025	Broken at 20mm from one soldering point	50	1667	50
73	01/10/2025	02/10/2025	Broken at 10mm from one soldering point	50	1667	50
74	01/10/2025	02/10/2025	Broken at the soldering point	50	1667	50
75	01/10/2025	02/10/2025	Broken at 10mm from one soldering point	50	1667	50
76	01/10/2025	02/10/2025	Broken at 12mm from one soldering point. Overcome 6400 events	50	333	10
78	01/10/2025	02/10/2025	Broken at the soldering point	50	333	10
79	01/10/2025	02/10/2025	Broken at 25mm from one soldering point	50	333	10
80	01/10/2025	02/10/2025	Broken at 25mm from one soldering point	50	333	10
81	01/10/2025	02/10/2025	Broken at 25mm from one soldering point	50	333	10

Results Spool n. 01

Specimen number	Tensile Strength - UTS (GPa)	Young module (Gpa)	R^2	Effective test time (s)	Total wire elongation (mm)	Elongation (%)	Fracture strain - ε_f (%)	Elongation at break (%)	Elastic limit strain - ε_y(%)	Yield Tensile Strength - YTS (GPa)	Velocity (um/s)
1	2.811	220.833	0.9986	34.15	2.049	3.415	0.034	3.415	0.006	1.237	60
2	2.820	212.381	0.9979	35.23	2.114	3.523	0.035	3.523	0.006	1.325	60
3	2.814	214.348	0.9995	38.90	2.334	3.890	0.039	3.890	0.006	1.249	60
4	2.718	207.523	0.9997	40.00	2.400	4.000	0.040	4.000	0.006	1.307	60
5	2.833	221.242	0.9990	34.88	2.093	3.488	0.035	3.488	0.006	1.267	60
Av. Set	2.799	215.265	0.9989	36.63	2.198	3.663	0.037	3.663	0.006	1.277	
St.Dev.	0.046	5.827	0.0007	2.63	0.158	0.263	0.003	0.263	0.000	0.038	
11	2.843	226.744	0.9993	33.70	2.022	4.044	0.040	4.044	0.006	1.345	60
33	2.827	228.538	0.9992	29.30	1.758	3.516	0.035	3.516	0.006	1.329	60
34	2.839	265.360	0.9987	26.48	1.589	3.177	0.032	3.177	0.006	1.567	60
35	2.820	262.116	0.9996	25.13	1.508	3.015	0.030	3.015	0.006	1.550	60
36	2.820	207.422	0.9994	29.13	1.748	3.495	0.035	3.495	0.006	1.230	60
Av. Set	2.830	238.036	0.9992	28.75	1.725	3.449	0.034	3.449	0.006	1.404	
St.Dev.	0.011	24.907	0.0003	3.29	0.197	0.395	0.004	0.395	0.000	0.148	
12	2.817	297.947	0.9998	45.58	1.367	2.735	0.027	2.735	0.004	1.324	30
13	2.811	296.225	0.9995	40.53	1.216	2.432	0.024	2.432	0.004	1.312	30
15	2.820	283.525	0.9998	47.95	1.439	2.877	0.029	2.877	0.004	1.242	30
16	2.814	303.444	0.9997	43.55	1.307	2.613	0.026	2.613	0.004	1.320	30
37	2.843	308.218	0.9998	41.90	1.257	2.514	0.027	2.735	0.004	1.605	30
Av. Set	2.821	297.872	0.9997	43.90	1.317	2.634	0.027	2.678	0.004	1.361	
St.Dev.	0.013	9.309	0.0001	2.95	0.088	0.177	0.002	0.167	0.000	0.140	
17	2.807	281.131	0.9998	64.75	1.295	2.590	0.026	2.590	0.006	1.672	20
18	2.811	283.814	0.9997	62.95	1.259	2.518	0.025	2.517	0.006	1.725	20
19	2.792	274.393	0.9997	64.15	1.283	2.566	0.026	2.566	0.006	1.642	20
20	2.792	282.702	0.9996	64.75	1.295	2.590	0.026	2.590	0.006	1.661	20
38	2.792	291.537	0.9997	60.63	1.213	2.425	0.024	2.425	0.006	1.719	20
Av. Set	2.799	282.716	0.9997	63.45	1.269	2.538	0.025	2.538	0.006	1.684	
St.Dev.	0.010	6.140	0.0001	1.74	0.035	0.070	0.001	0.070	0.000	0.037	
65	2.843	308.044	0.9993	28.78	1.151	2.302	0.023	2.302	0.006	1.852	40
66	2.817	307.938	0.9999	24.45	0.978	1.956	0.020	1.956	0.006	1.823	40
67	2.820	287.497	0.9994	26.75	1.070	2.140	0.021	2.140	0.006	1.654	40
68	2.862	321.157	0.9996	23.18	0.927	1.854	0.019	1.854	0.006	1.881	40
69	2.792	285.160	0.9996	25.00	1.000	2.000	0.020	2.000	0.006	1.709	40
Av. Set	2.827	301.959	1.000	25.630	1.025	2.050	0.021	2.050	0.006	1.784	
St.Dev.	0.024	13.658	0.000	1.947	0.078	0.156	0.002	0.156	0.000	0.088	
70	2.836	299.004	0.9983	25.45	1.273	2.545	0.025	2.545	0.007	2.213	50
71	2.846	282.889	0.9989	24.13	1.206	2.413	0.024	2.413	0.007	2.110	50
73	2.846	294.255	0.9992	25.95	1.298	2.595	0.026	2.595	0.007	2.179	50
74	2.839	291.494	0.9969	25.53	1.276	2.553	0.026	2.553	0.007	2.176	50
75	2.852	289.763	0.9987	25.90	1.295	2.590	0.026	2.590	0.007	2.182	50
Av. Set	2.844	291.481	0.998	25.390	1.270	2.539	0.025	2.539	0.007	2.172	
St.Dev.	0.006	5.312	0.001	0.663	0.033	0.066	0.001	0.066	0.000	0.034	
76	2.779	278.525	0.9998	133.63	1.336	2.673	0.027	2.673	0.006	1.788	10
78	2.795	276.937	0.9994	124.80	1.248	2.496	0.025	2.496	0.007	1.926	10
79	2.782	305.380	0.9993	124.50	1.245	2.490	0.025	2.490	0.007	2.087	10
80	2.782	275.344	0.9984	136.90	1.369	2.738	0.027	2.738	0.007	1.954	10
81	2.788	287.613	0.9978	126.80	1.268	2.536	0.025	2.536	0.007	2.042	10
Av. Set	2.785	284.760	0.999	129.325	1.293	2.587	0.026	2.587	0.007	1.960	
St.Dev.	0.006	11.154	0.001	5.020	0.050	0.100	0.001	0.100	0.000	0.103	

Gold Plated Tungsten Wire

- Wire diameter: 20 µm,
- conductive and easy to solder

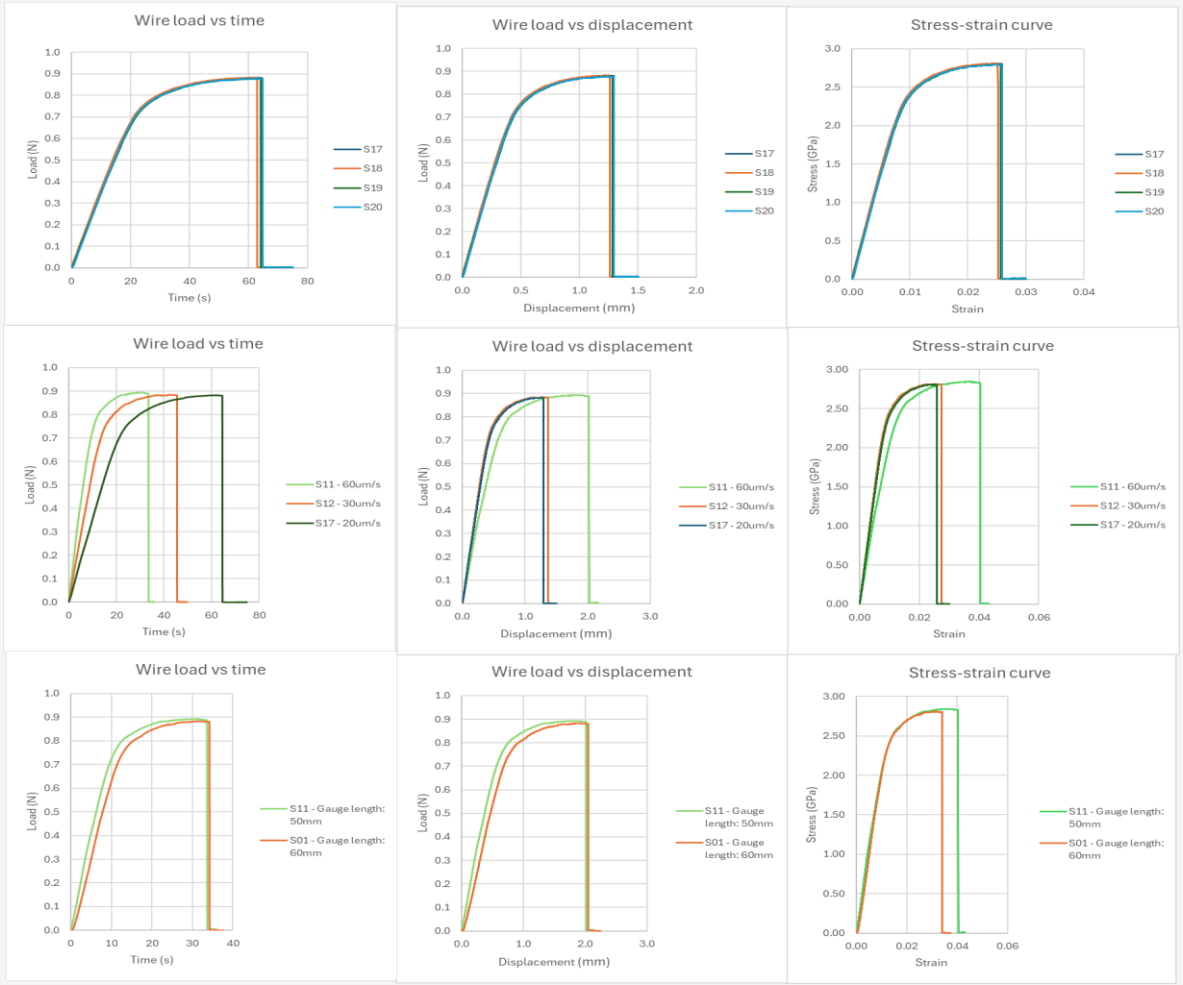
Specimen number	Tensile Strength - UTS (GPa)	Young module (Gpa)	R^2	Effective test time (s)	Total wire elongation (mm)	Elongation (%)
1	2.811	186.561	0.9990	34.15	2.049	4.098
2	2.820	172.631	0.9980	35.23	2.114	4.227
3	2.814	178.624	0.9995	38.90	2.334	4.668
4	2.718	172.790	0.9998	40.00	2.400	4.800
5	2.833	185.590	0.9993	34.88	2.093	4.185
Av. Set	2.799	179.239	0.9991	36.63	2.198	4.396
11	2.843	211.047	0.9972	33.70	2.022	4.044
33	2.827	220.920	0.9991	29.30	1.758	3.516
34	2.839	246.097	0.9962	26.48	1.589	3.177
35	2.820	246.673	0.9974	25.13	1.508	3.015
36	2.820	209.416	0.9998	29.13	1.748	3.495
Av. Set	2.830	226.831	0.9980	28.75	1.725	3.449
12	2.817	295.044	0.9998	45.58	1.367	2.735
13	2.811	289.015	0.9992	40.53	1.216	2.432
15	2.820	278.925	0.9997	47.95	1.439	2.877
16	2.814	303.444	0.9997	43.55	1.307	2.613
37	2.843	308.218	0.9998	41.90	1.257	2.514
Av. Set	2.821	294.929	0.9996	43.90	1.317	2.634
17	2.807	281.131	0.9998	64.75	1.295	2.590
18	2.811	283.814	0.9997	62.95	1.259	2.518
19	2.792	274.393	0.9997	64.15	1.283	2.566
20	2.792	282.702	0.9996	64.75	1.295	2.590
38	2.792	291.537	0.9997	60.63	1.213	2.425
Av. Set	2.799	282.715	0.9997	63.45	1.269	2.538

v=60 µm/s
l=60mm

v=60 µm/s
l=50mm

v=30 µm/s
l=50mm

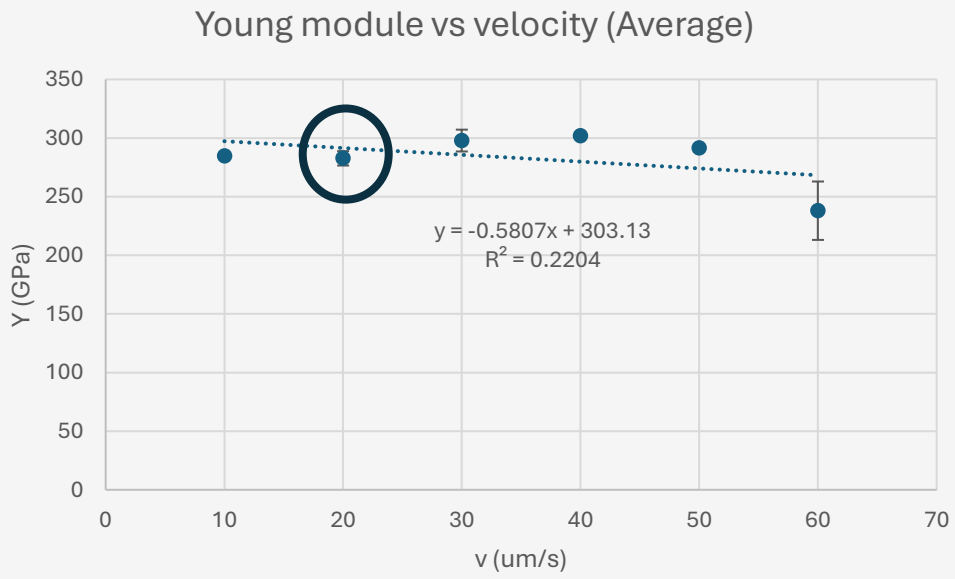
v=20 µm/s
l=50mm

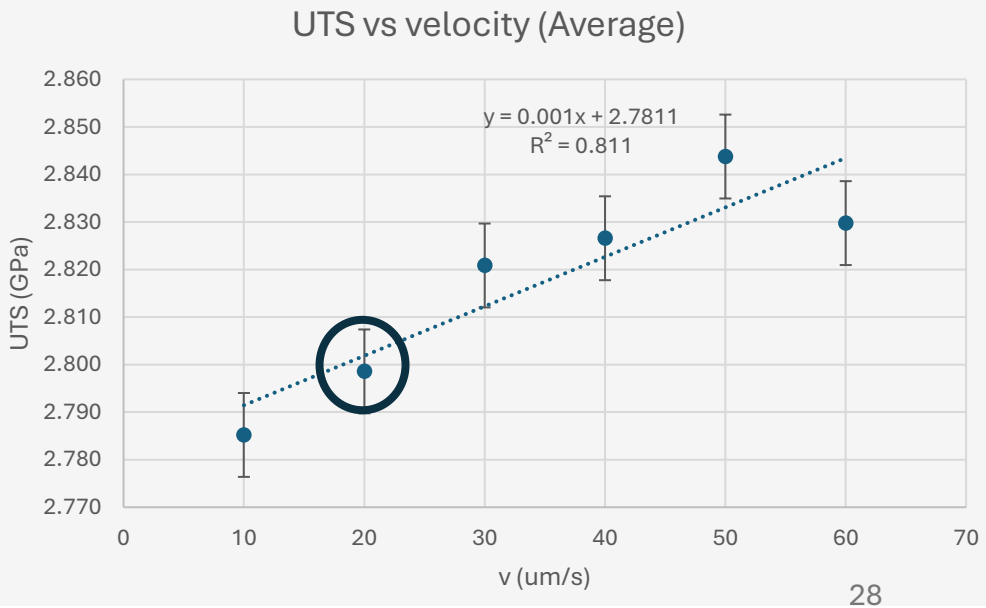


Gold Plated Tungsten Wire

Dependence on test velocity

- Slight dependence of the Young module from the velocity of the picometer
- Slight increase of the Tensile Strenght with the velocity of the picometer

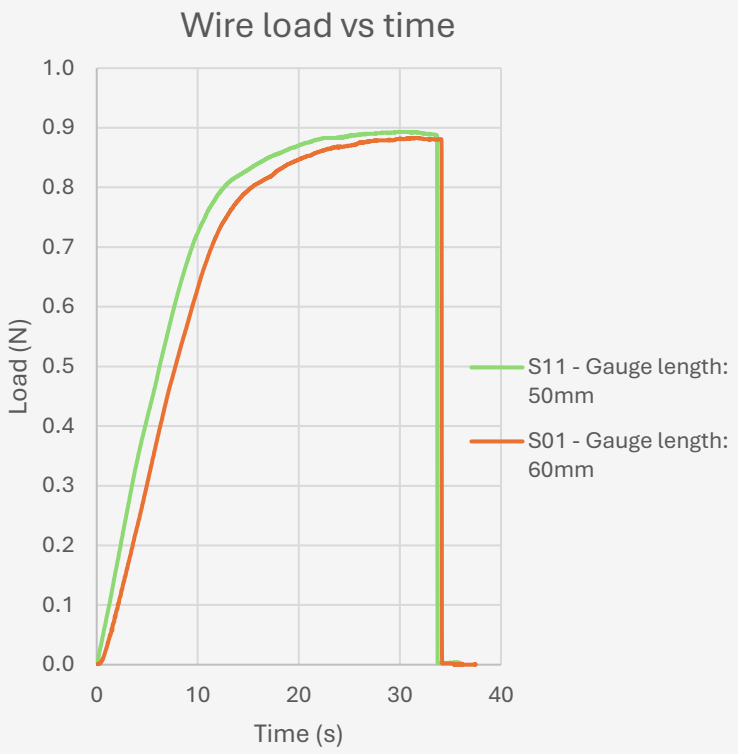


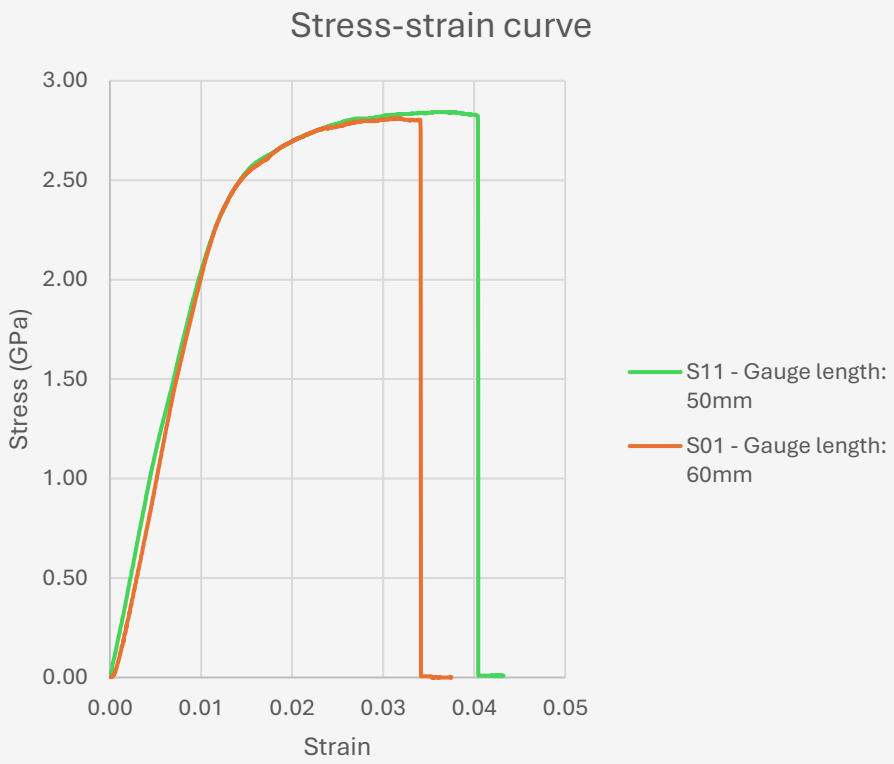
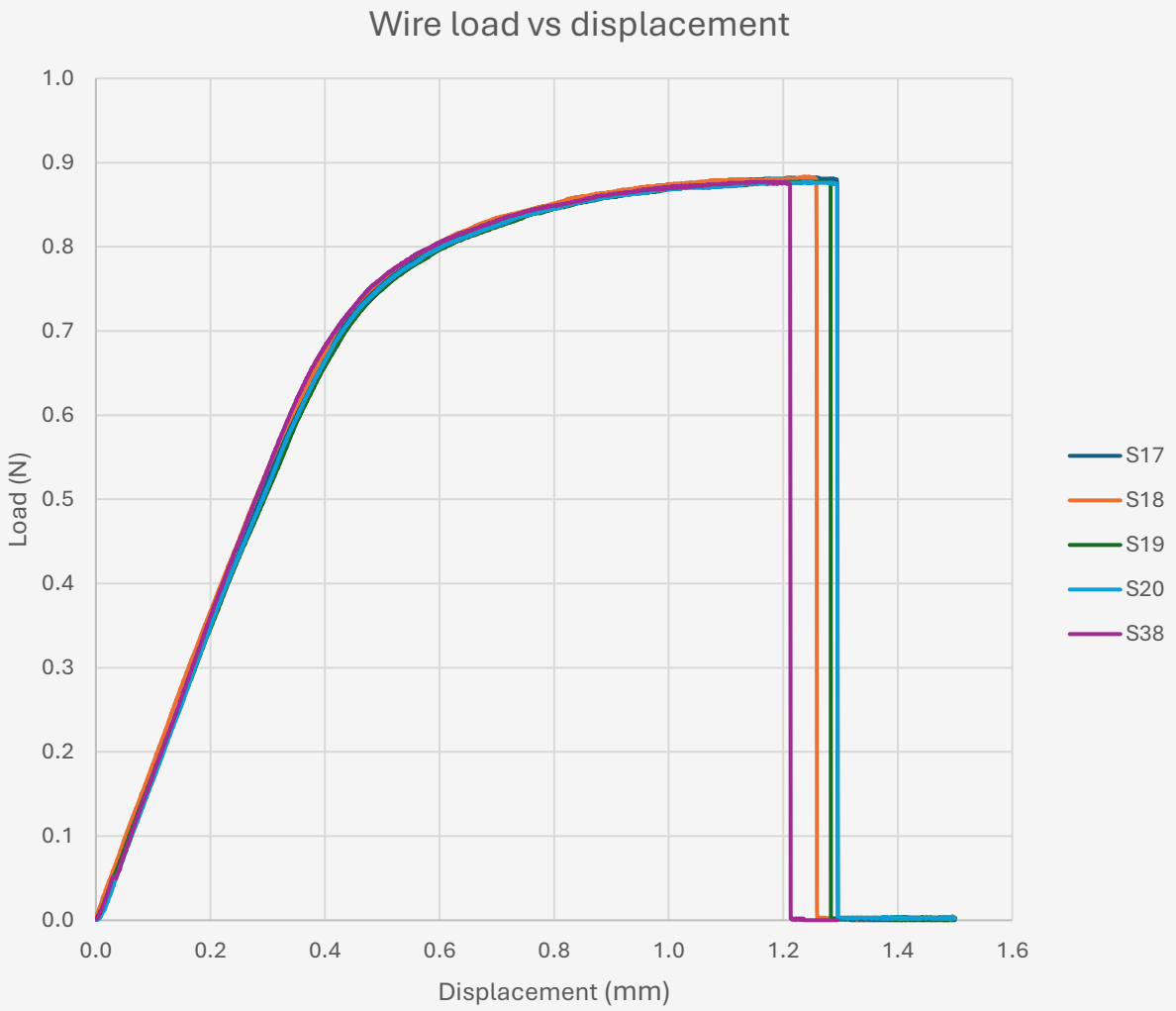
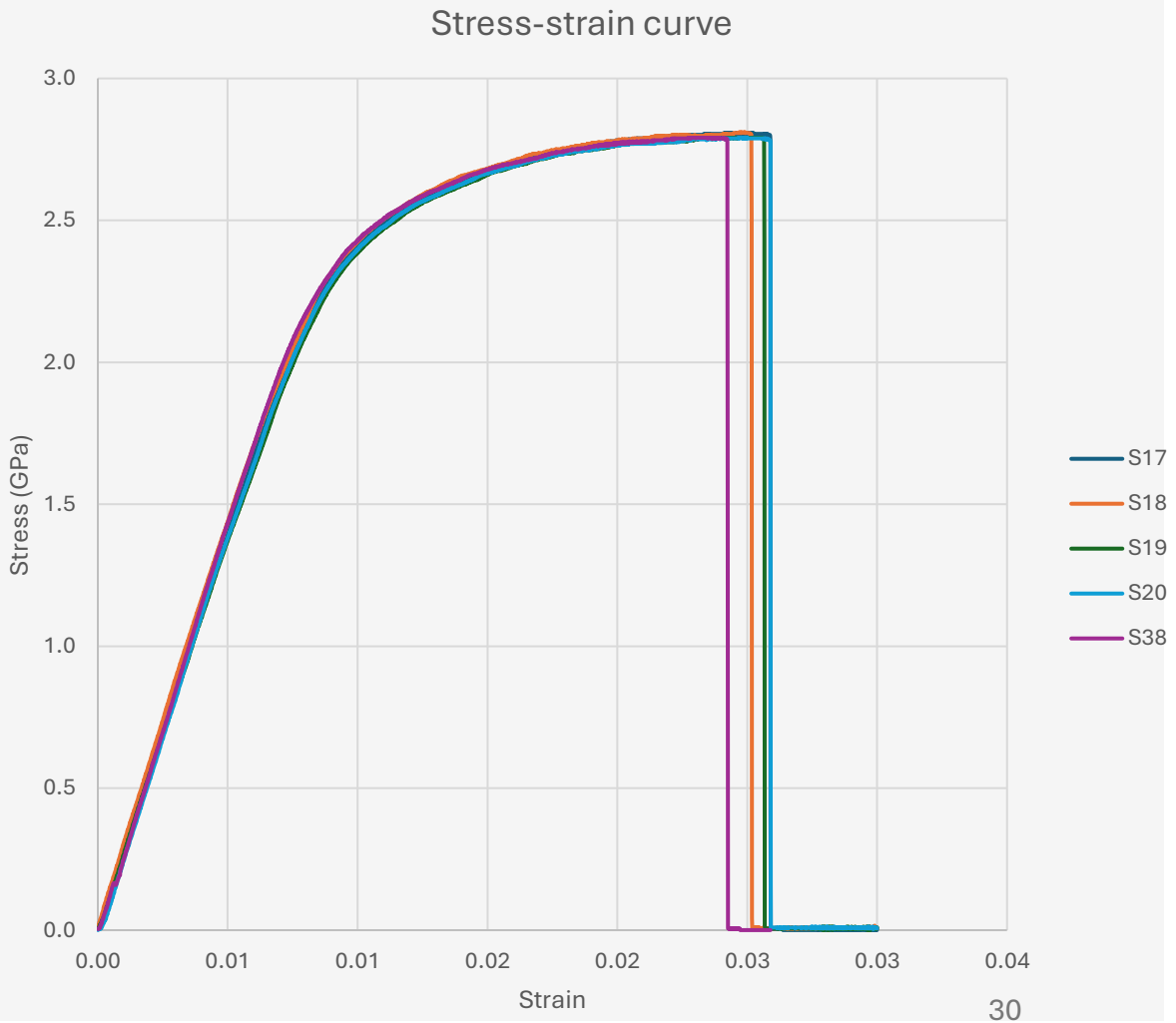


Gold Plated Tungsten Wire

Dependence on Gauge Length

No effective change in the elastic region of the wire while changing the gauge length.





Plot overlapping with velocity 20um/s