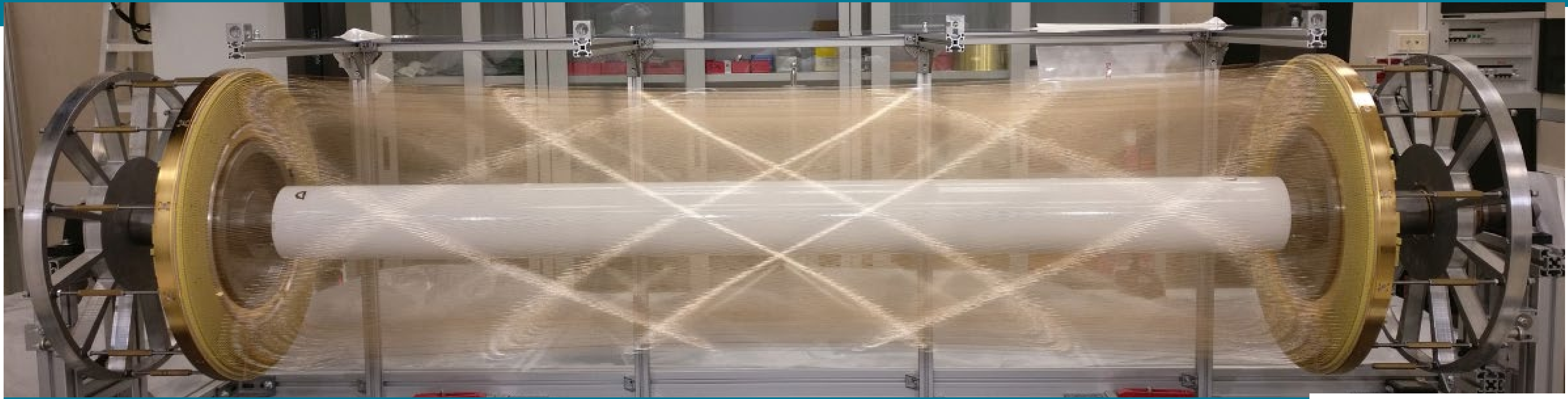


MEGII drift Chamber

Gianluigi Chiarello on behalf CDCH construction group

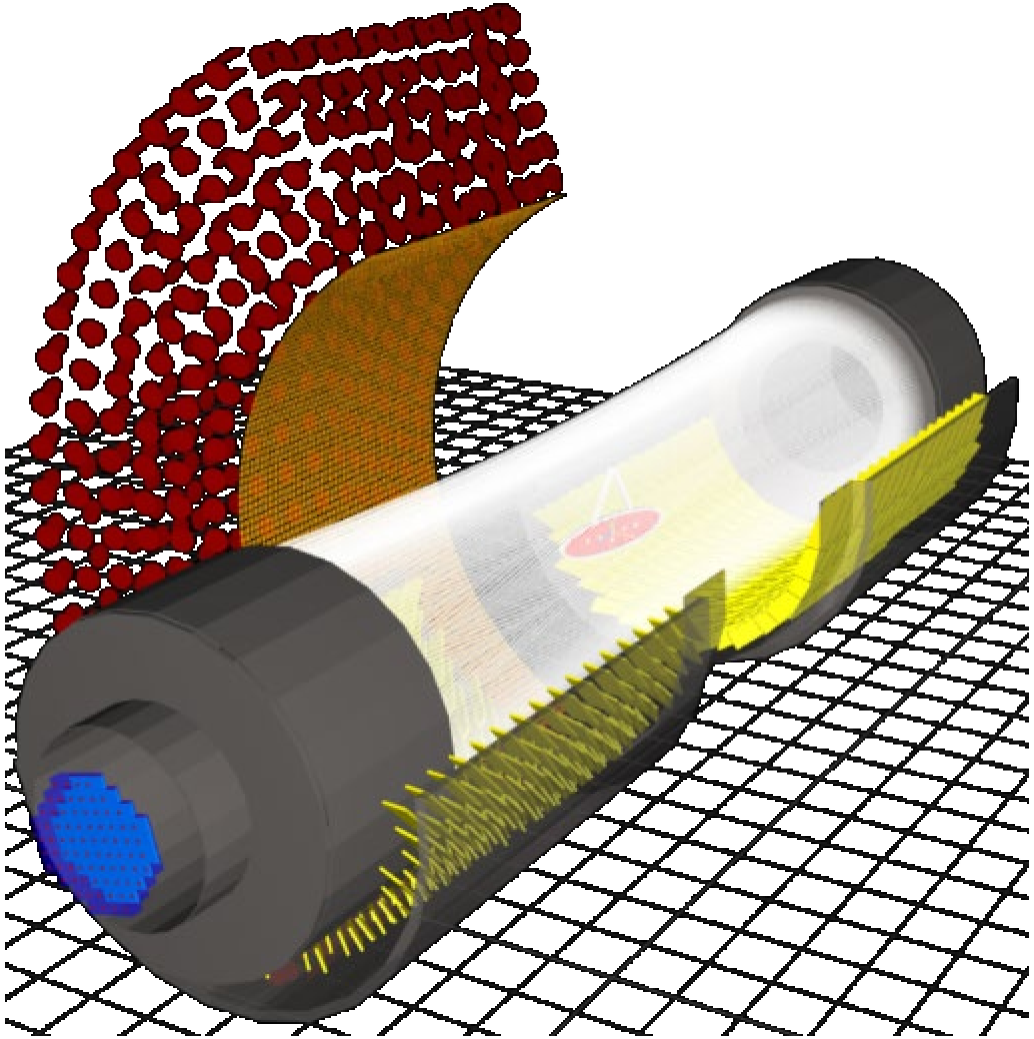
INFN Pisa

2021 International workshop CEPC

Zoom - 9 November 2021

Overview

- MEGII experiment
- MEGII Cylindrical Drift CHamber (CDCH)
  - Novel approach and construction technique
  - The wiring Robot and the wiring procedures
  - The assembly procedures
  - Front End electronics
  - Problems experienced during the construction
  - Expected performance
- Data taking runs
- Conclusions

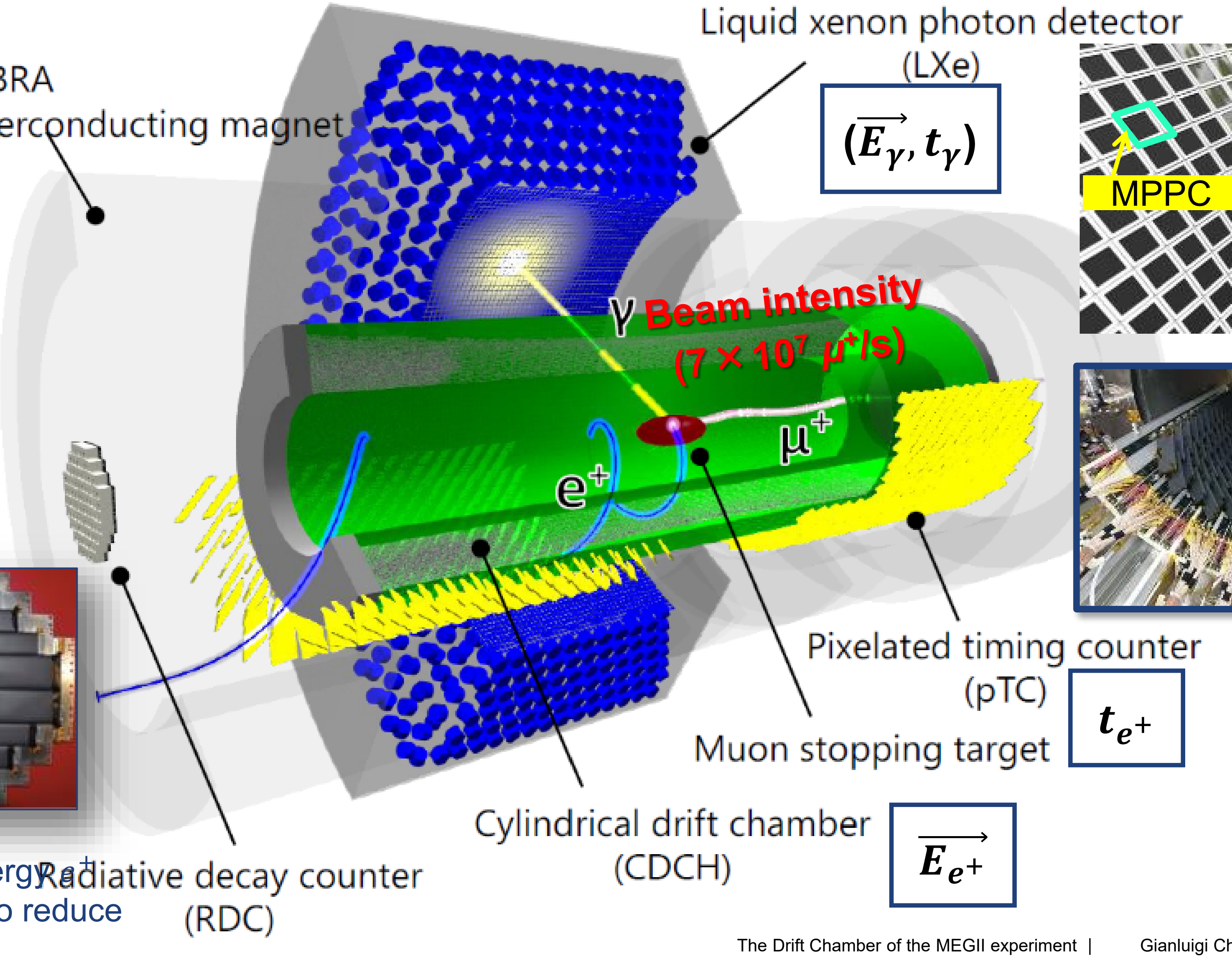


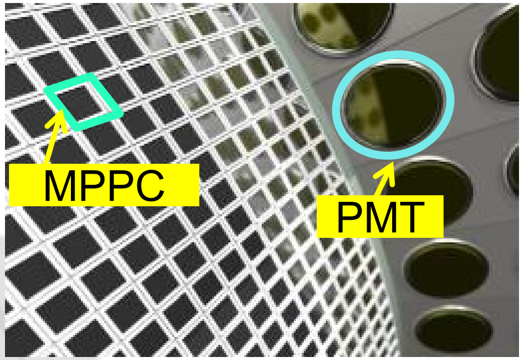
The MEGII Experiment

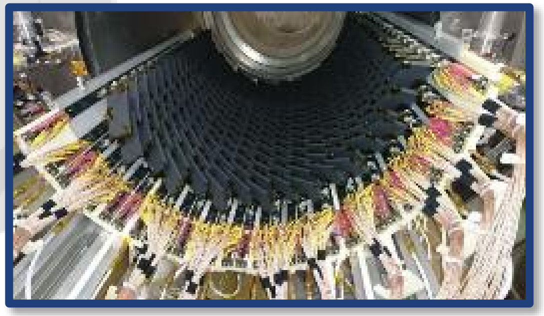
The MEGII experiment is the upgrade of MEG experiment. It represents the state of the art in the search for the CLFV $\mu^+ \rightarrow e^+\gamma$ decay.

$BR(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13}$

world best upper limit



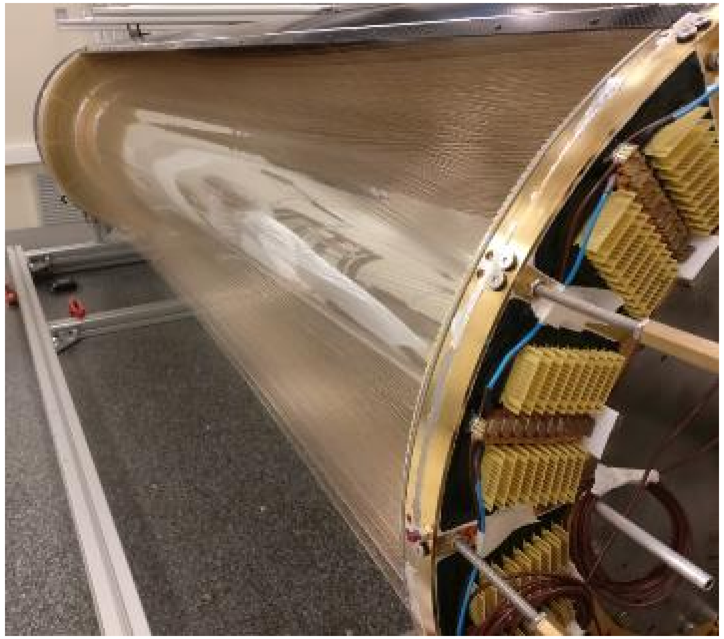




LYSO crystals + plastic scintillators

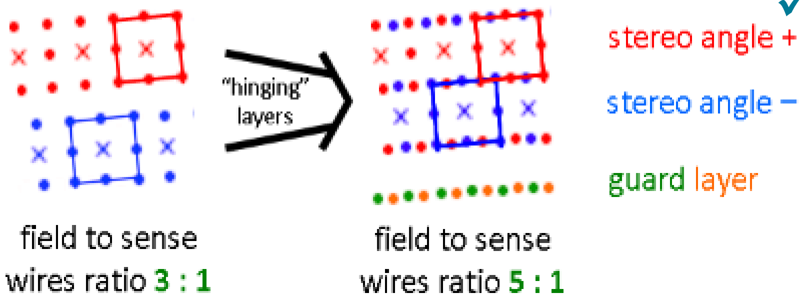
Tag low-energy e^+ from RMD to reduce background

MEGII: Drift chamber Upgrade



- ✓ **Low-mass unique volume detector with high granularity** filled with He:Isobutane 90:10 gas mixture
  - ✓ **9 concentric layers of 192 drift cells** defined by **11904 wires** (1728 sense wires and 10176 filed/guard wires)
  - ✓ **Small cells few mm wide:** occupancy of ≈1.5 MHz/cell at CDCH center near the stopping target
  - ✓ **High density of sensitive elements:** ×4 hits more than MEG drift chamber (DCH)
- ✓ **Total radiation length** $1.5 \times 10^{-3}\ X_0$: less than $1.7 \times 10^{-3}\ X_0$ of MEG DCH

e^+ variable	MEG	MEG II
ΔE_e (keV)	380	90
$\Delta\theta_e, \Delta\varphi_e$ (mrad)	9, 9	6, 5.5
Efficiency_e (%)	40	65

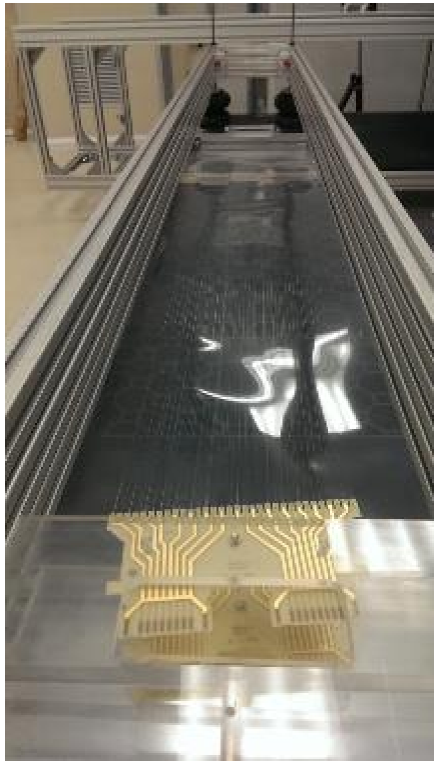


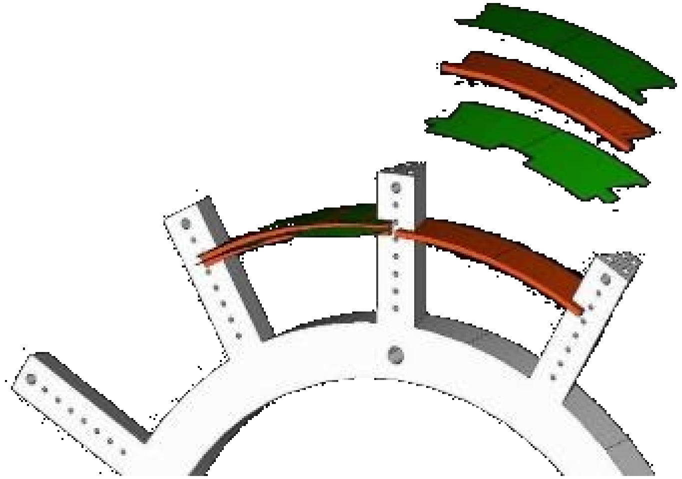
The wire net created by the combination of + and – orientation generates a more uniform equipotential planes

High wire densities, anyway, require complex and time consuming assembly procedures and need novel approaches to a feed-through-less wiring)

Wiring procedure

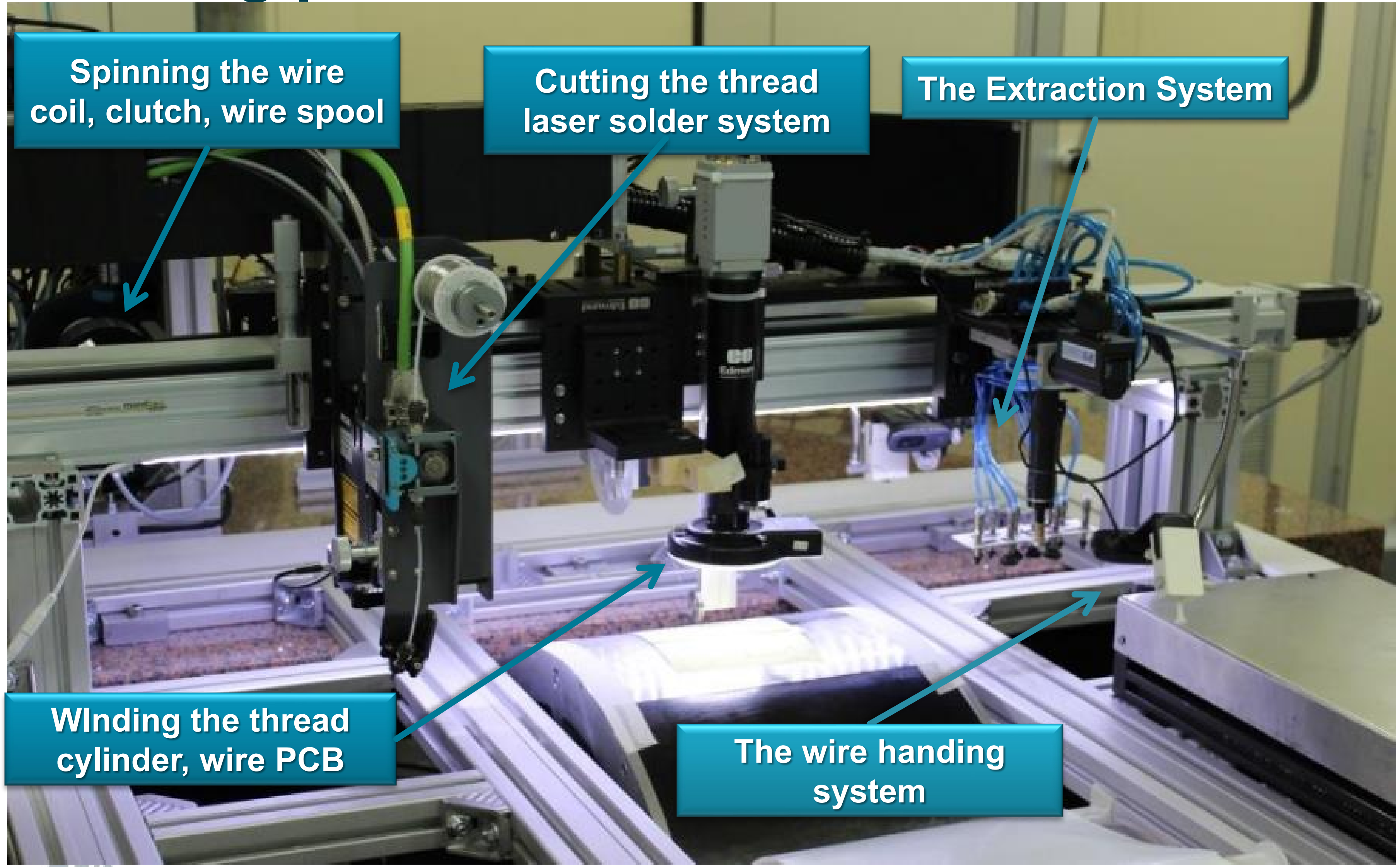
The basic element is multiwire layer made of 32 parallel wires;





- end-plates numerically machined from solid Aluminum (mechanical support only);
- Field, Sense and Guard wires placed azimuthally by Wiring Robot with better than one wire diameter accuracy;
- wire PC board layers (green) radially spaced by numerically machined peek spacers (red) (accuracy < 20 μm);
- wire tension defined by homogeneous winding and wire elongation (ΔL = 100μm corresponds to ≈ 0.5 g);
- Drift Chamber assembly done on a 3D digital measuring table;
- build up of layers continuously checked and corrected during assembly
- End-plate gas sealing will be done with glue.

Wiring procedure



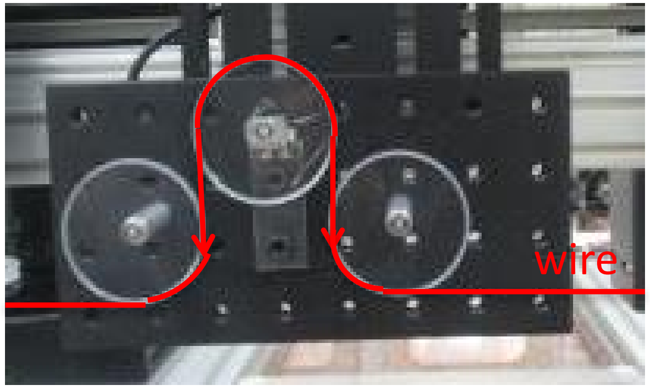
The tasks of the wiring robot are:

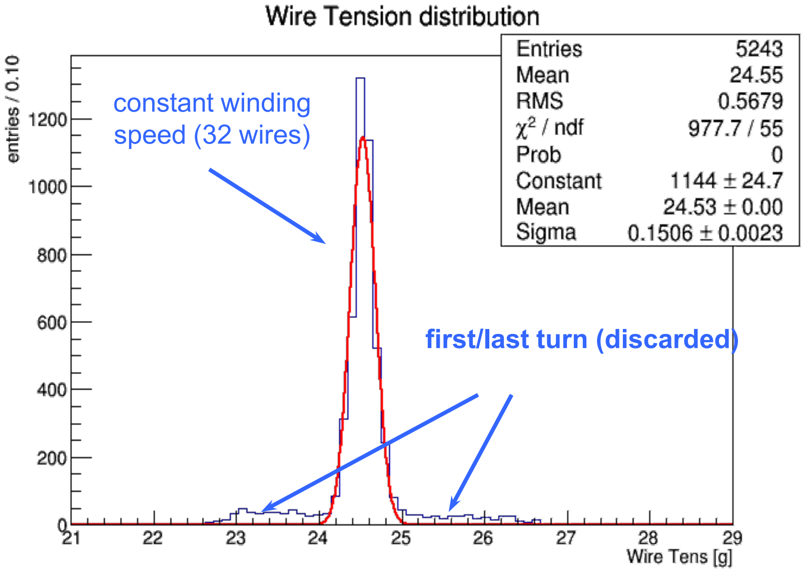
- the wiring of a multiwire layer made of 32 parallel wires;
- settable wire tension (±0.05g);
- 20μm of accuracy on wire position.

Wiring procedure

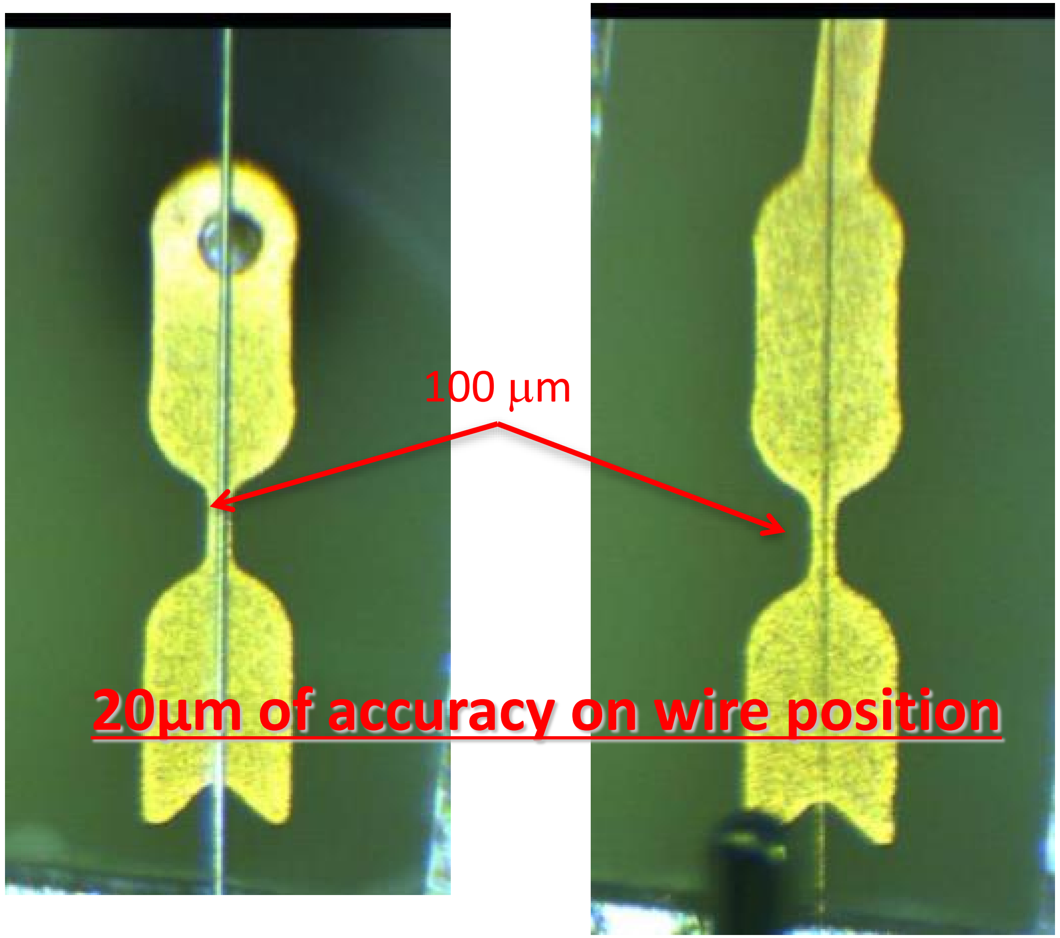
The wire mechanical tension is corrected by the real-time feedback system.

mean wire tension is stable at the level of 0.05 g



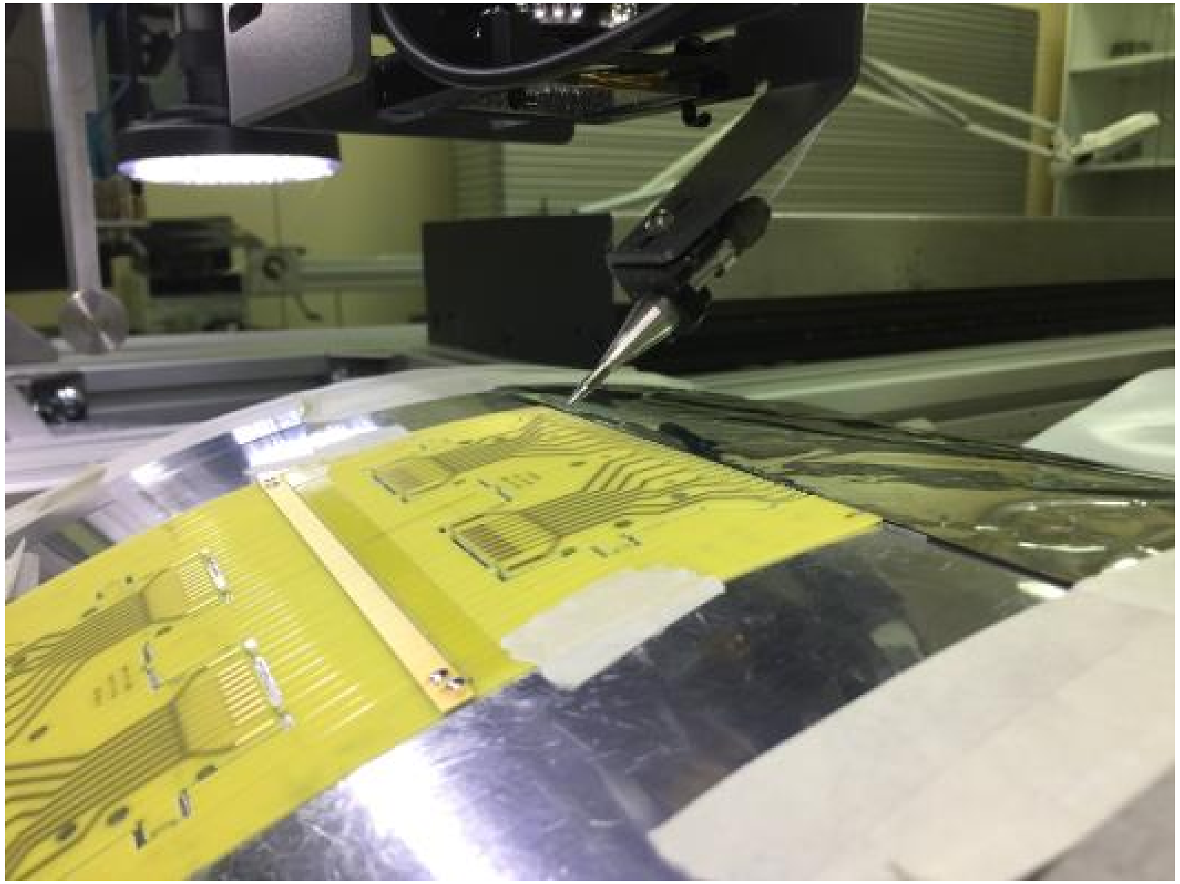


Wire position

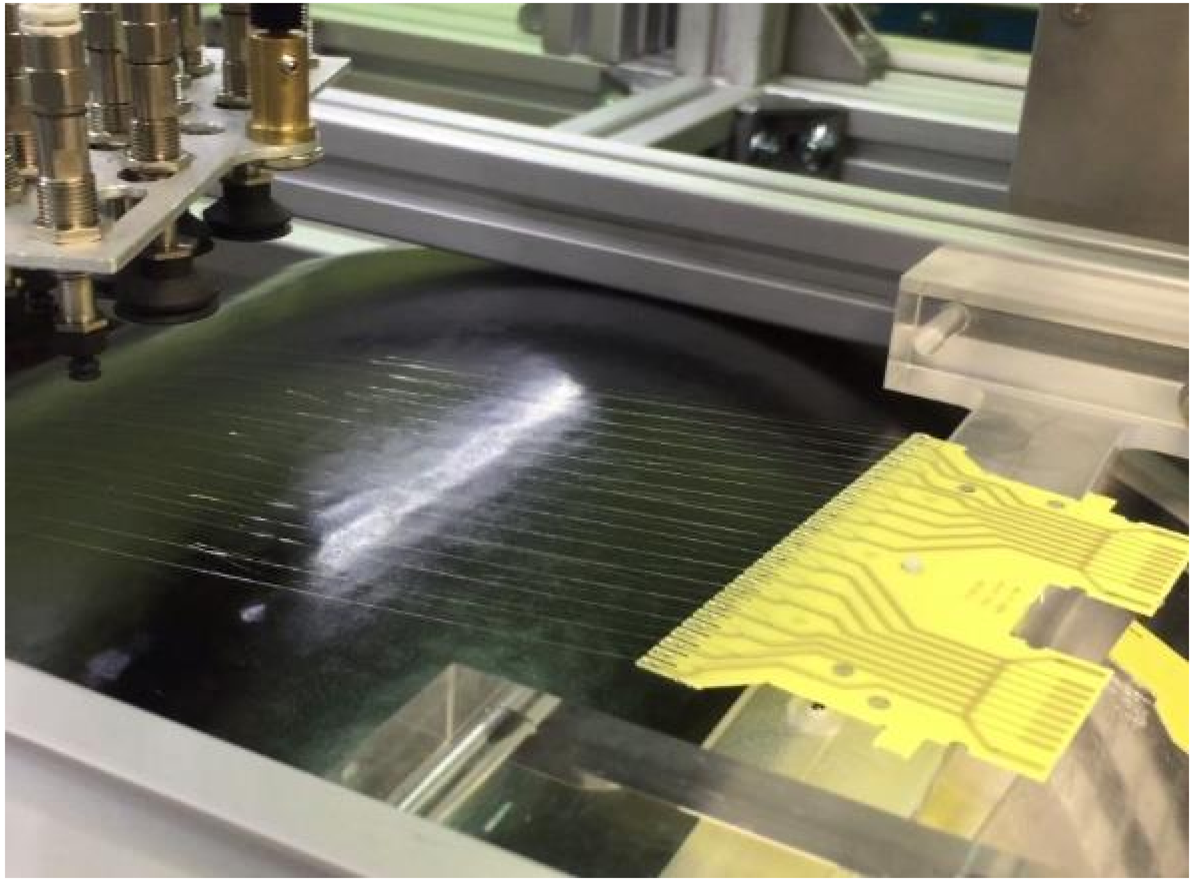


Wiring procedure

- Soldering



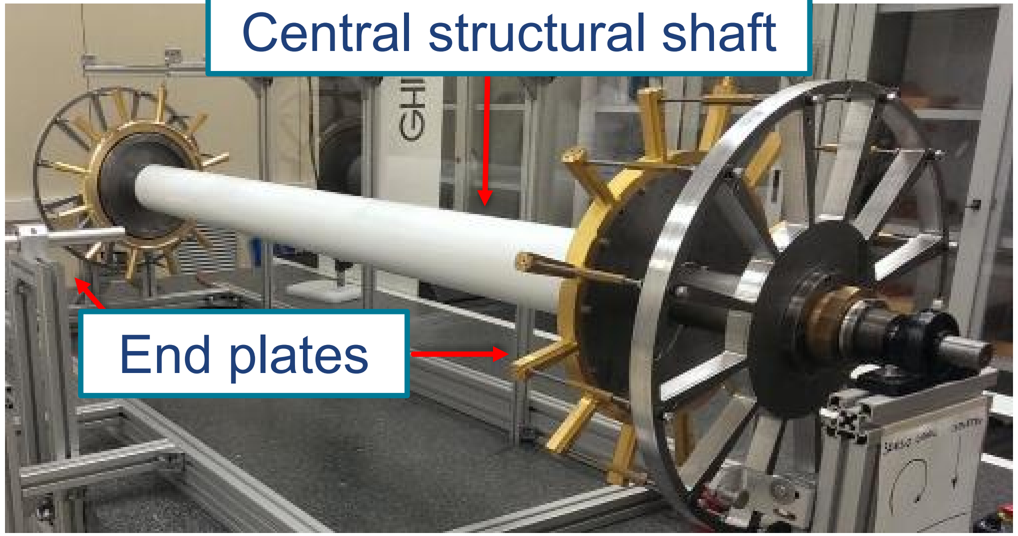
- Extraction



Assembled

Central structural shaft

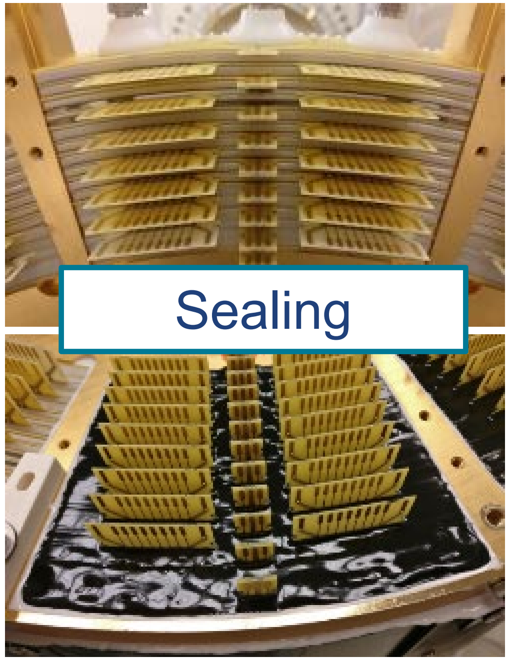
End plates



Assembled chamber

Inner foil

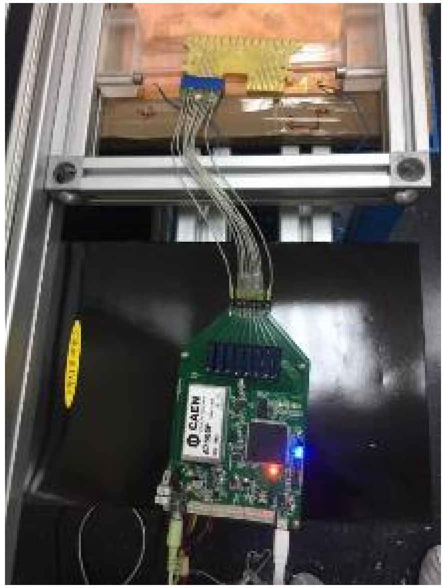
Sealing

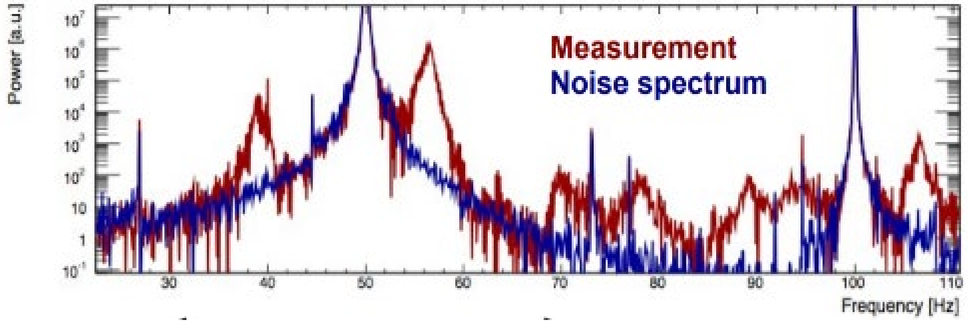


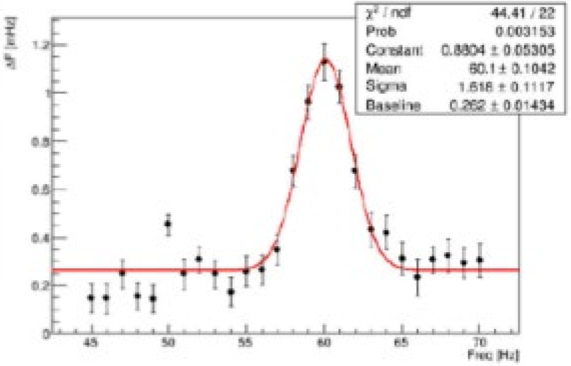
Carbon fibre

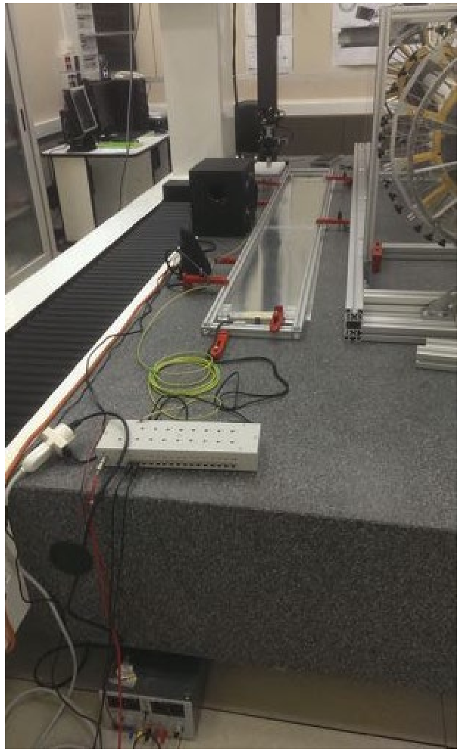
Wiring procedure

- Check mechanical tension:
  - The tension of the drift chamber wires is measured with two different methods:
    - an **acoustic method** in which mechanical oscillations are induced by acoustic bursts on wires at high voltage,
    - an **electrical method** with oscillations induced by an applied sinusoidal high voltage.

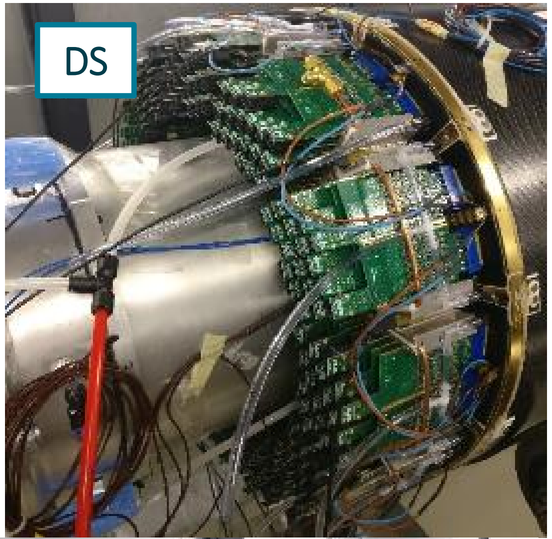


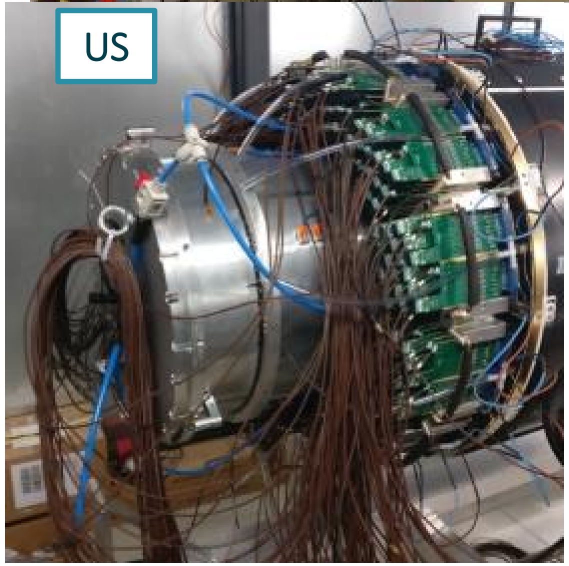


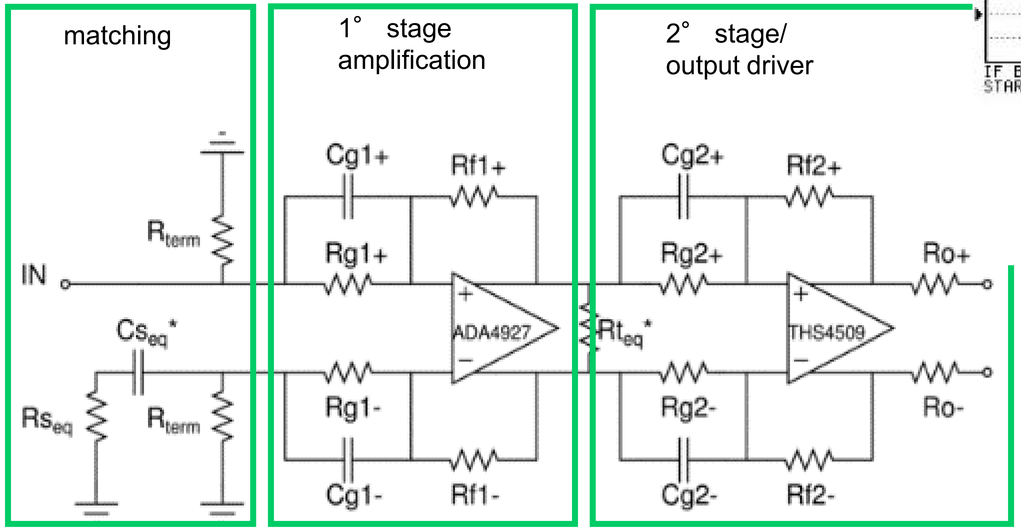


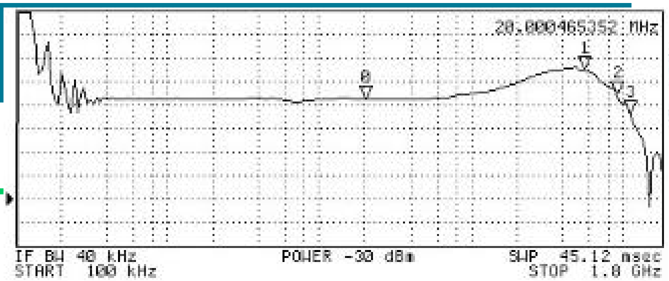


FE electronics

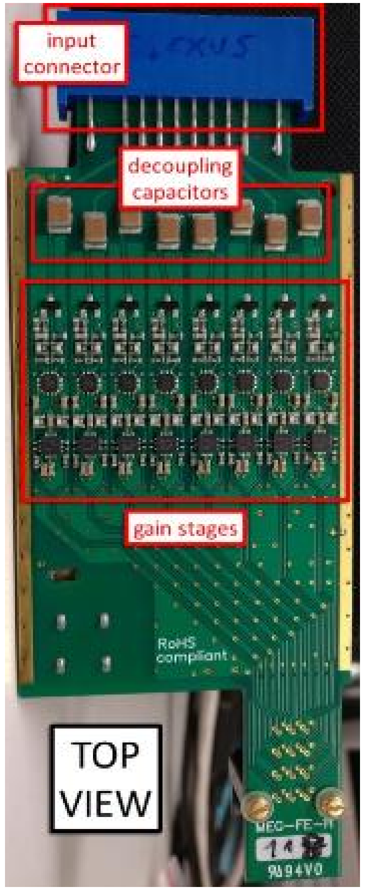








N	SWP PARAM	VAL
0	20.000465352 MHz	21.236 dB
1	554.109452707 MHz	27.458 dB
2	899.74895028 MHz	22.206 dB
3	1.099455926016 GHz	18.203 dB

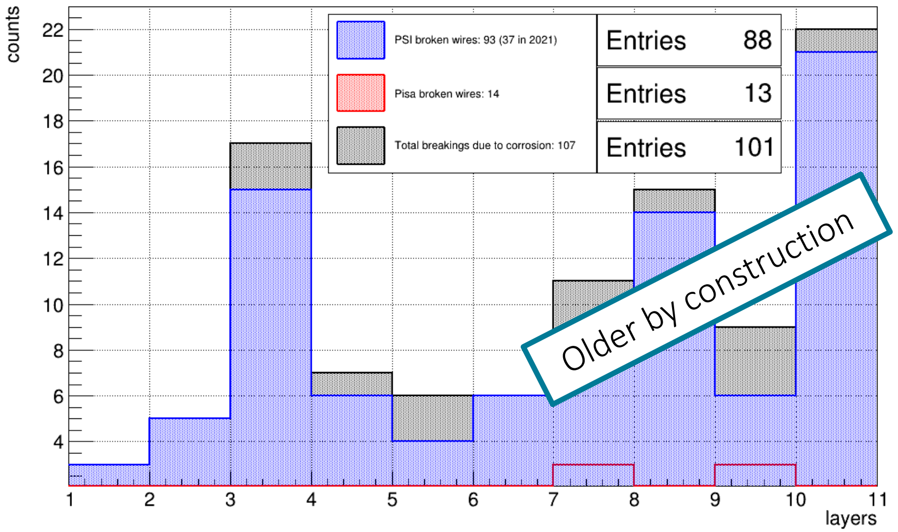


- 216 FE boards per side
  - Double amplification stage with low noise and distortion
  - High bandwidth of nearly 700 MHz
    - To use the cluster timing technique
- This year, we have reworked all the boards to increase the gain

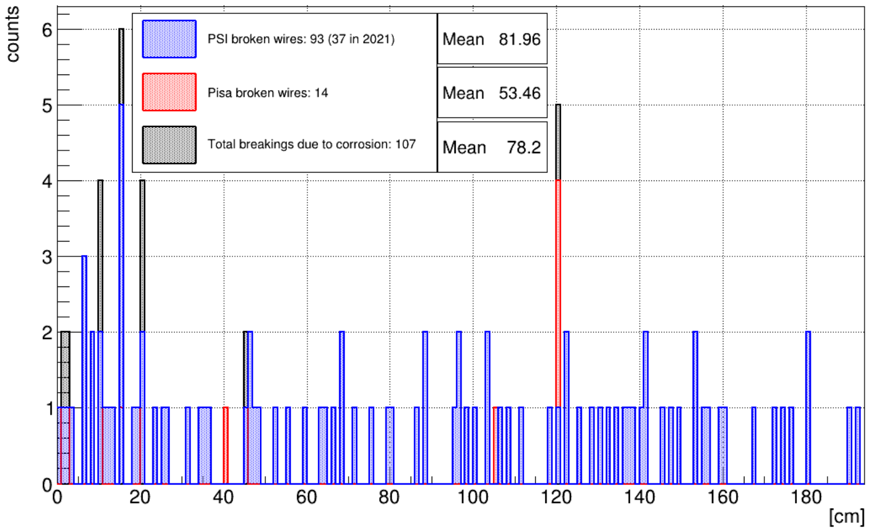
Wire breakages

- During assembly at Pisa and the final lengthening operations at PSI we experienced the breakages of some Al wires in the chamber
  - Mainly the 40 μm cathodes were affected
  - A few 50 μm cathodes and guards
- **101 broken wires in total (about 50% for over stretching)**
- Missing wire effect negligible

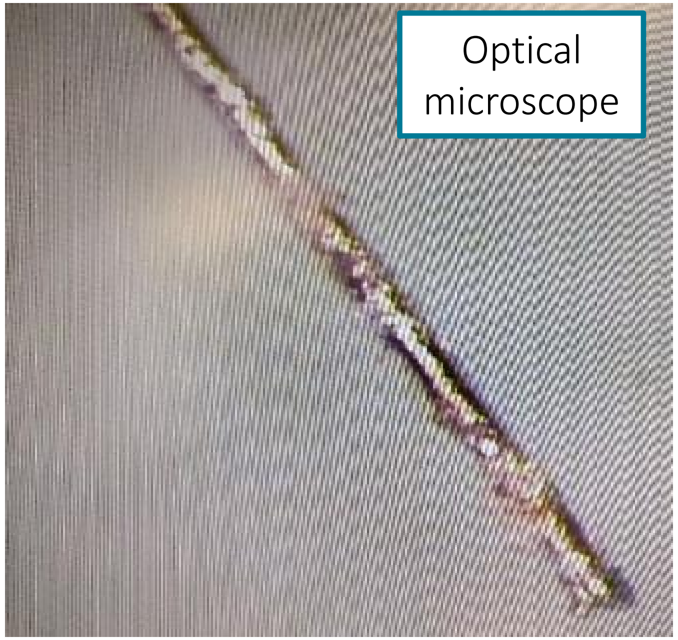
Layers with broken wires (17/03/2021)

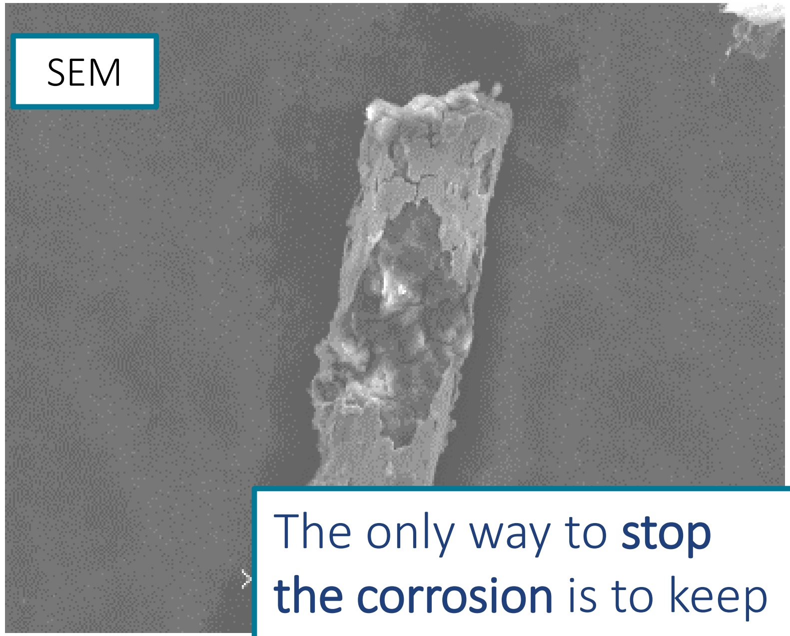


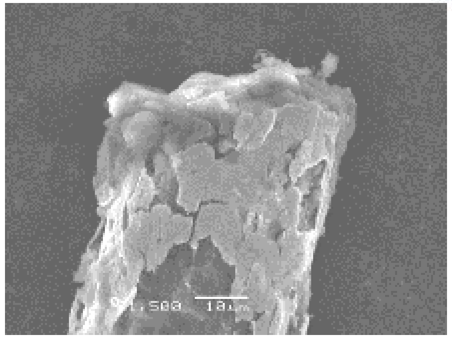
Breaking point from DS endplate (17/03/2021)

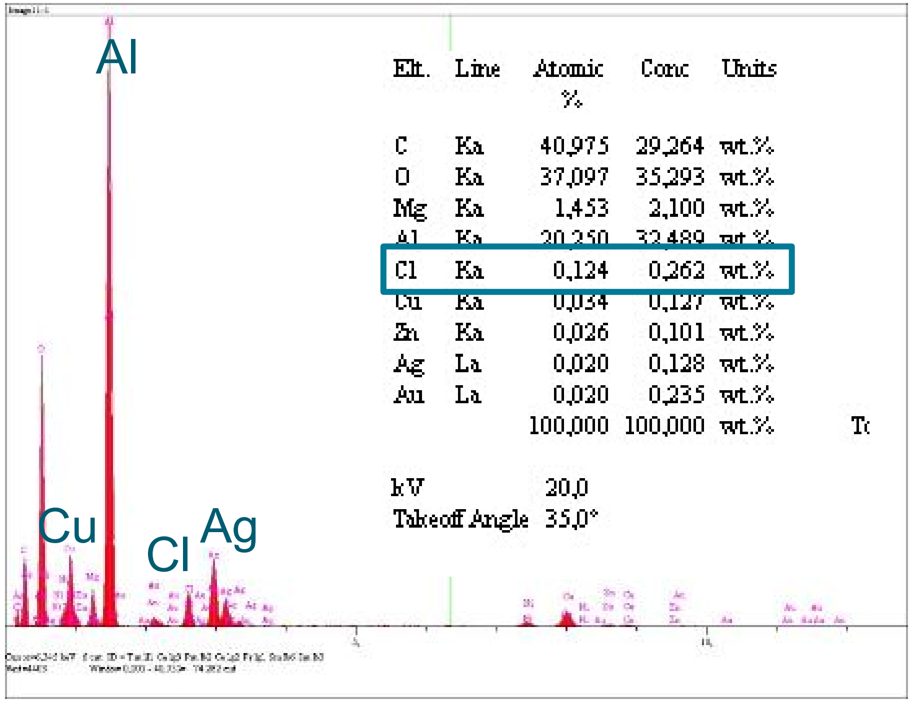


Wire breakages









Elt.	Line	Atomic %	Conc	Units
C	Ka	40,975	29,264	wt.%
O	Ka	37,097	35,293	wt.%
Mg	Ka	1,453	2,100	wt.%
Al	Ka	20,250	32,489	wt.%
Cl	Ka	0,124	0,262	wt.%
Cu	Ka	0,034	0,127	wt.%
Zn	Ka	0,026	0,101	wt.%
Ag	La	0,020	0,128	wt.%
Au	La	0,020	0,235	wt.%
		100,000	100,000	wt.%

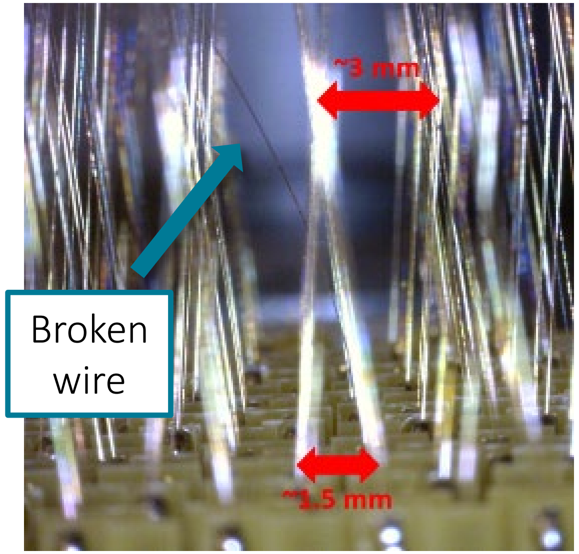
The only way to **stop the corrosion** is to keep the **wires in an inert atmosphere**

- Breakages due to corrosion of the Al wire core
- Two hypotheses
  - Galvanic process between Al and Ag coating
  - Al corrosion by Cl
- Both imply water as catalyst
  - Air moisture condensation inside cracks in the Ag coating even at low Relative Humidity (RH) levels $< 40\%$
  - Al oxide or hydroxide deposits

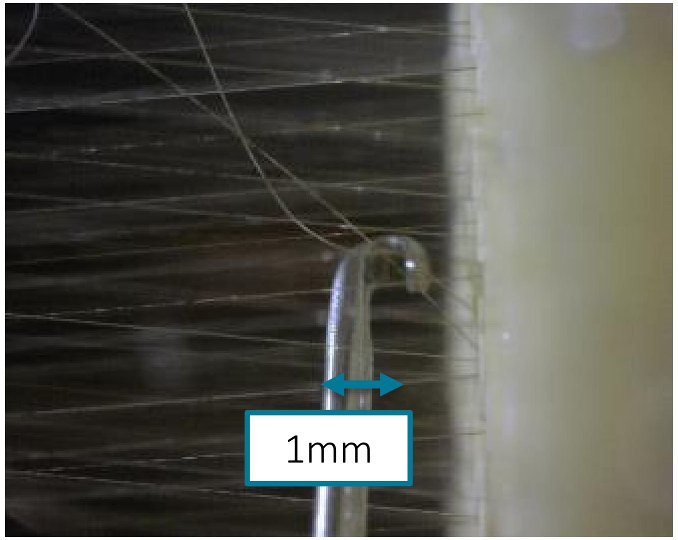
$$Al + 3Cl^- \longleftrightarrow AlCl_3 + 3e^-$$

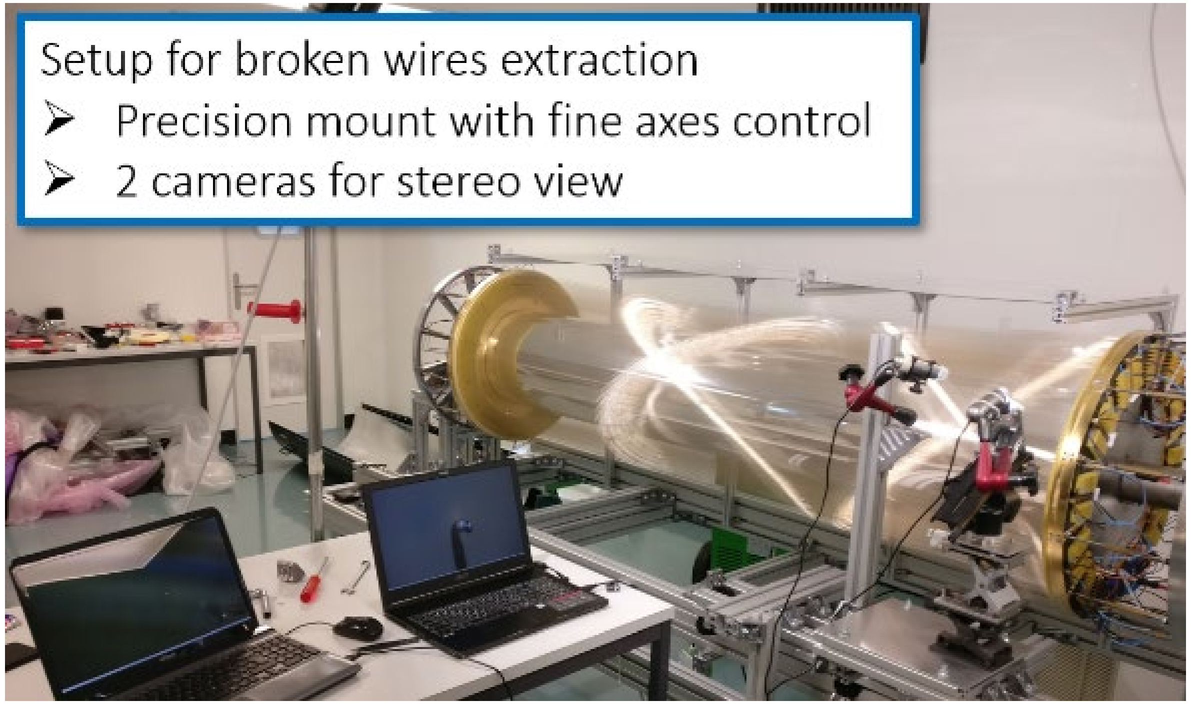
$$AlCl_3 + 3H_2O \longleftrightarrow Al(OH)_3 + 3H^+ + 3Cl^-$$

Wire extraction



- Each broken wire piece can randomly put to ground big portion of the chamber
- They must be removed from the chamber
  - Very delicate and time-consuming operation
- We developed a safe procedure to extract the broken wires from inside CDCH
  - Exploiting the radial projective geometry given by the stereo wire configuration

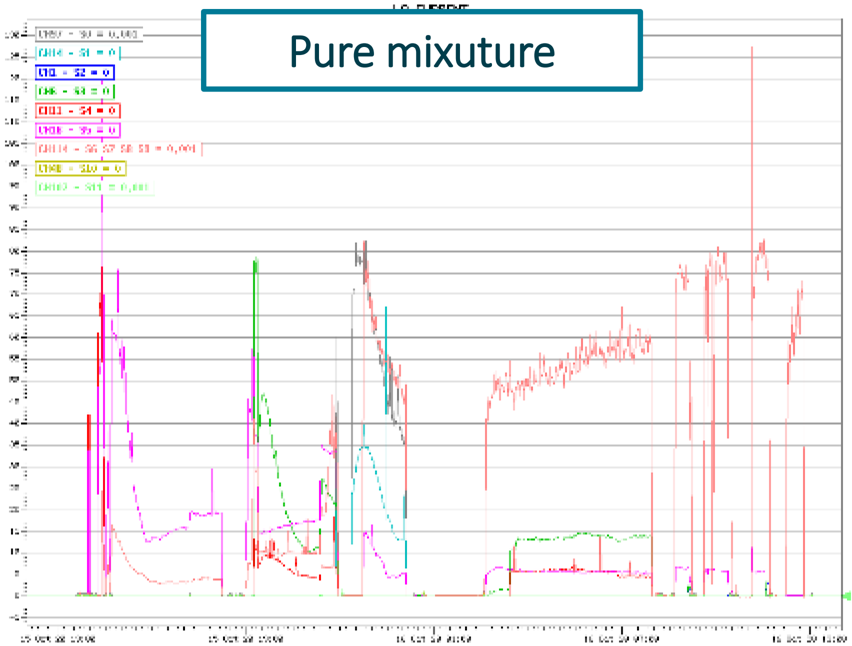




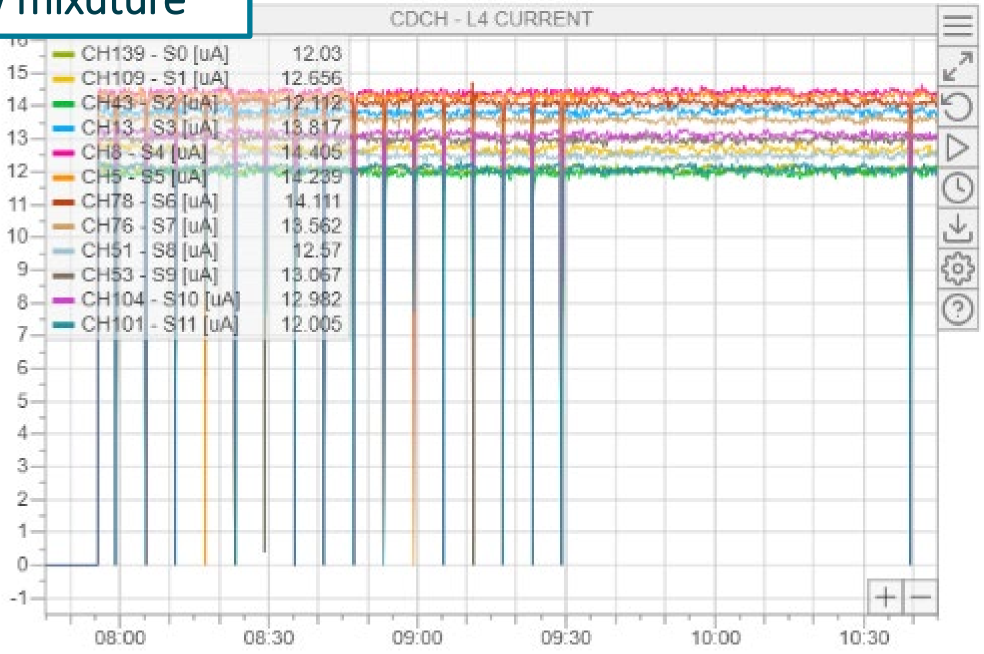
High current

- High anomalous currents observed in several sector/layers during the run with pure gas mixuture
  - This currents are observed only with the beam
- After testing some gas mixtures with additives (water, isopropyl alcohol, CO2, O). We have verified that the mixture that allows us to run without high currents is that with **1.2% isopropyl alcohol and 0.5% oxygen**

Pure mixuture

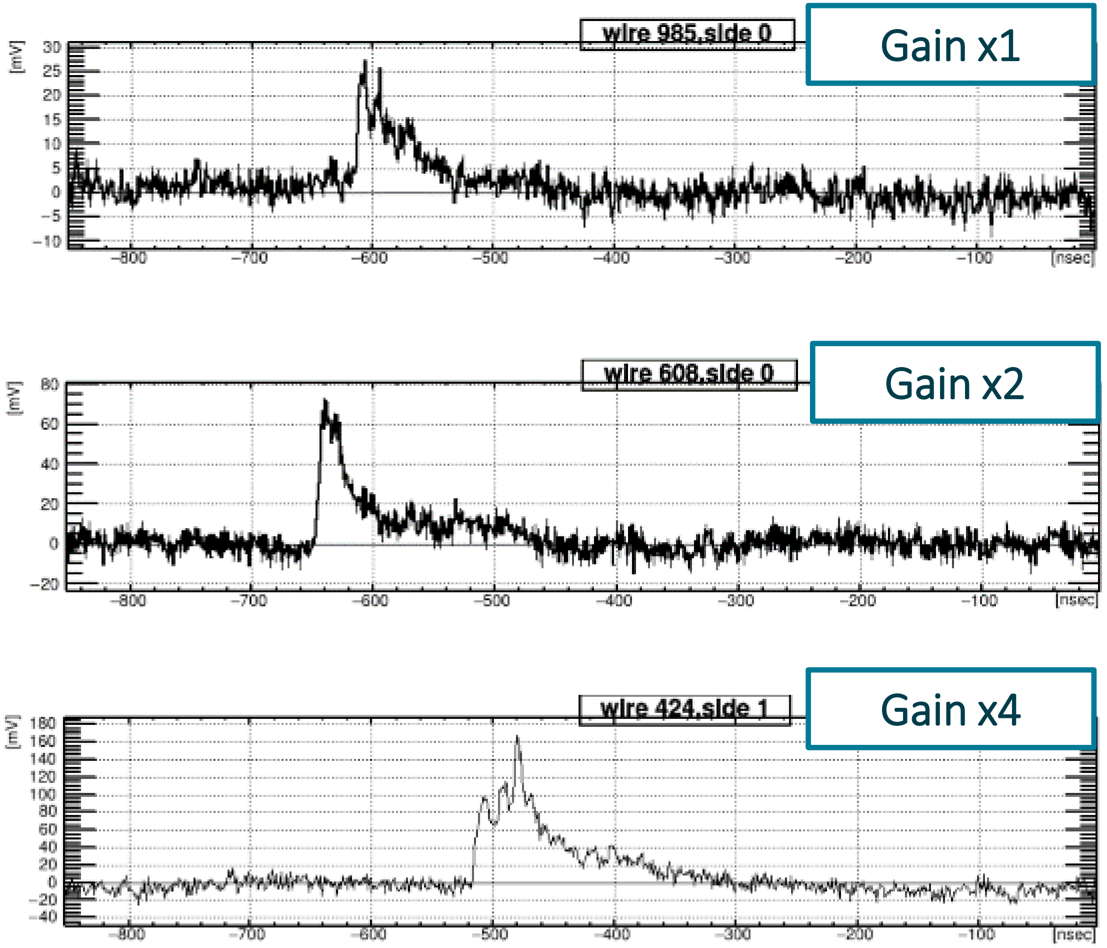


New mixuture



Data taking 2020

- Only 144 cells with readout (8%)
- During the 2020 run, we tested different gas mixtures to "cure" the high currents. In particular:
  - Cosmic ray:
    - with and without the addition of pure O_2 (1% and 2%) or Synthetic Air + water or isopropyl alcohol
  - Muon beam data:
    - Collected with the addition of pure O_2 (0.5%, 1% and 2%) or Synthetic Air + water or isopropyl alcohol
    - 3 different muon intensity levels (up to the nominal MEG II intensity)

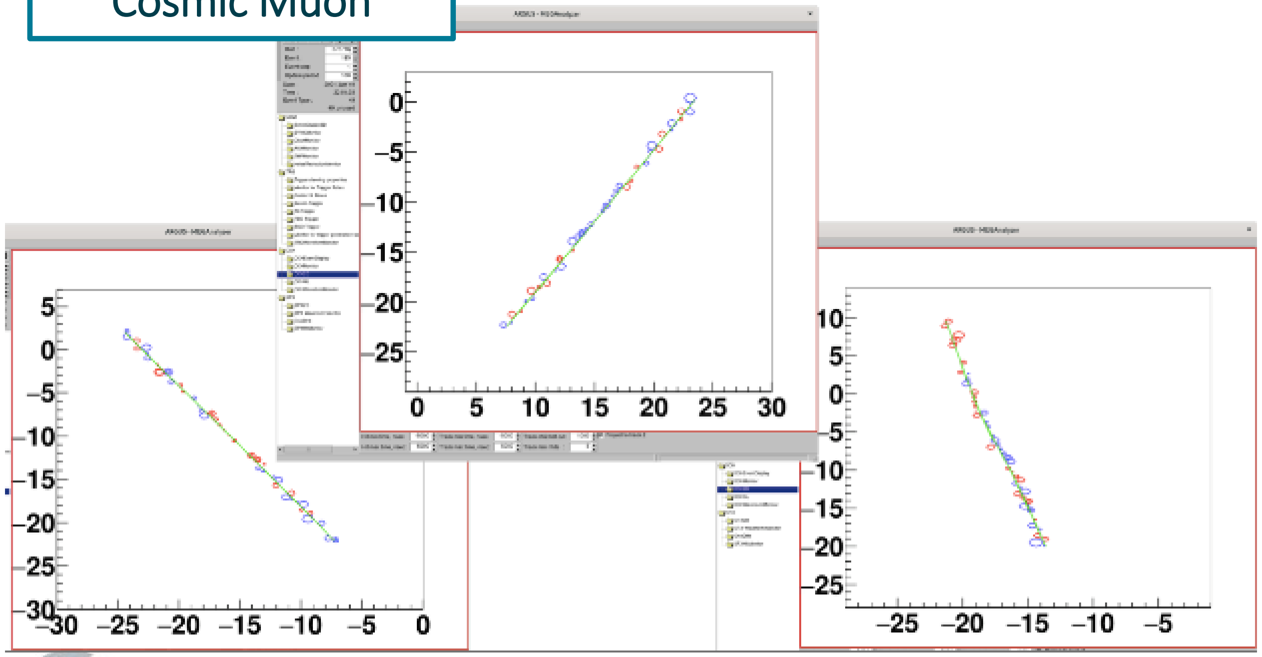


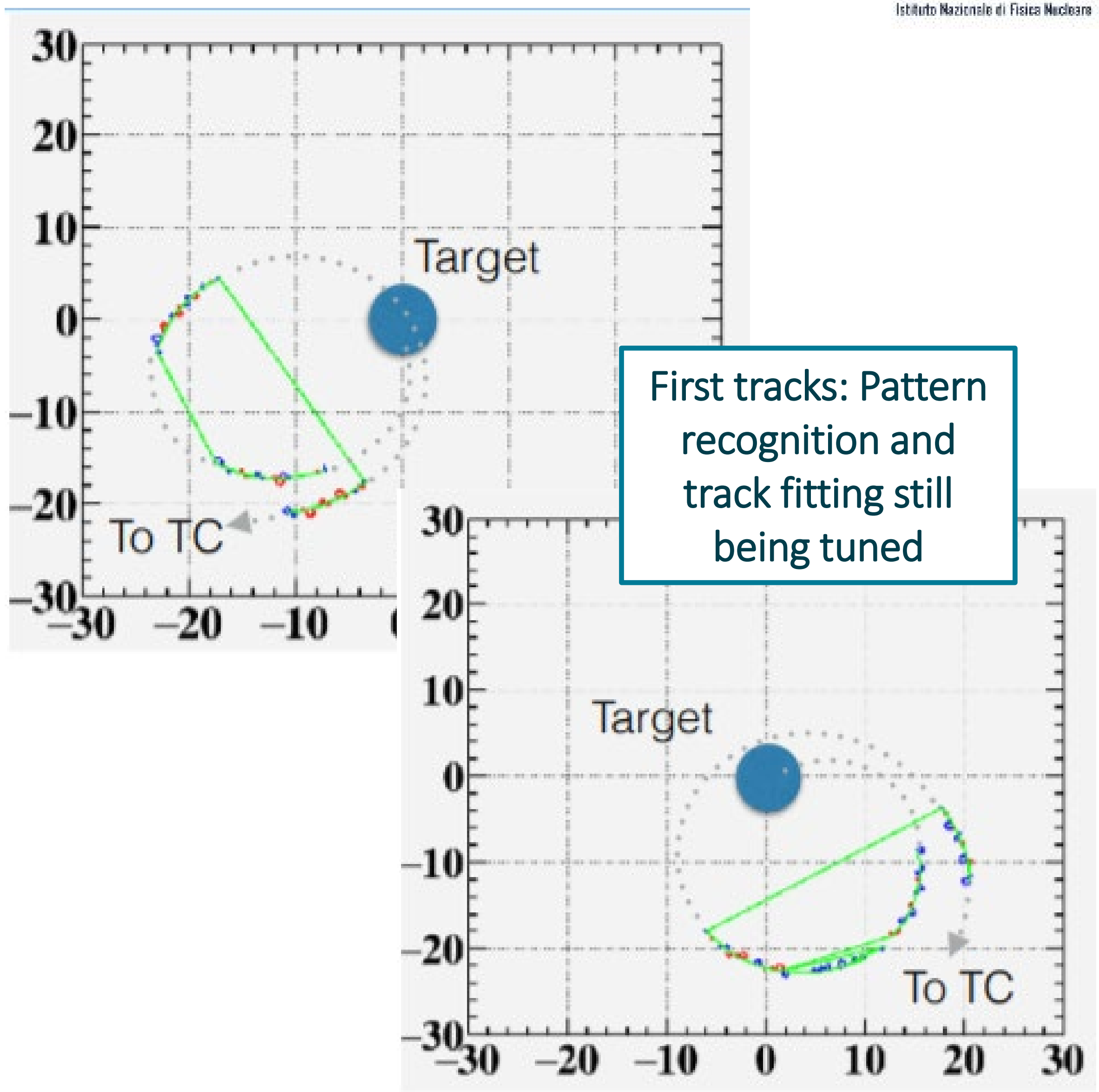
Full Analysis ongoing

Data taking 2021

- All cells with readout
- Gain FE modif with gain x4
- Stable gas mixture (1.2% isopropyl alcohol
- + 0.5% oxygen)

Cosmic Muon





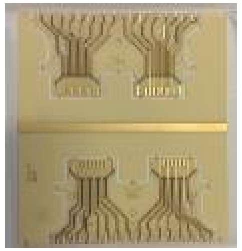
First tracks: Pattern recognition and track fitting still being tuned

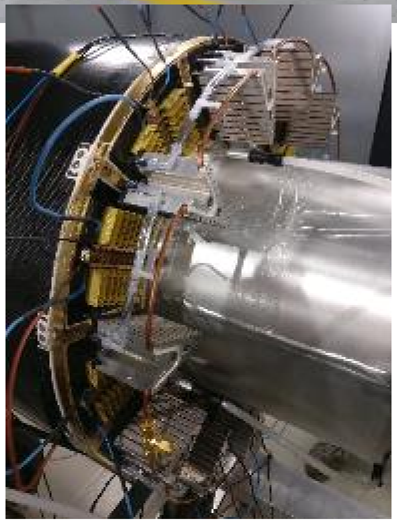
Conclusion and prospect

- The drift chamber CDCH of the MEGII experiment has some novelties in the construction of drift chambers:
  - **Full azimuthal coverage** around the stopping target
  - **Extremely low material budget**: low MCS and background
  - **High granularity**: 1728 drift cells few mm wide in $\Delta R \approx 8$ cm active region
  - Stereo design concept, modular construction, light and reliable mechanics,
- Problems along the path
  - **Corrosion and breakage of Al(Ag) field wires** in presence of 40-65% humidity level
    - Problem: most of the breaks occurred on the 40um wires
    - Problem fully cured by keeping CDCH in dry atmosphere: **no breakages for 2 years**
  - **Anomalous high currents still under investigations**
    - Probably triggered by a **burnt wire last year**
    - Attempts to recover the CDCH operation are ongoing by using **different additives to the standard He:IsoB 90:10 gas mixture**

Construction CDCH2: Mechanics

- Given the history of CDCH we think it a good chamber for a physics run in 2021. We can use it to consolidate our understanding of all detector parameters.
- In these years of engineering runs and commissioning we have understood that:
  - The CDCH geometry is adequate for the integration in the detector and for the MEGII resolutions and pileup rejection
  - The problem encountered is the type of chemical processing that is carried out on the wire in the production phase
- The mechanical design (endplates, carbon fibre structure, wirePCB, spacer .....) are already defined and ready to be produced.
- FE electronics, cooling system, gas system will be reused in the chamber and integrated to the new specifications



Construction CDCH2: Production Site

- The construction phase of the CDCH was done in two locations:
- The CDCH2 will be built entirely in Pisa.
- New wire to overcome the fragility of the 40um wire. All CDCH will use 50um aluminum wires – no ultrafinished

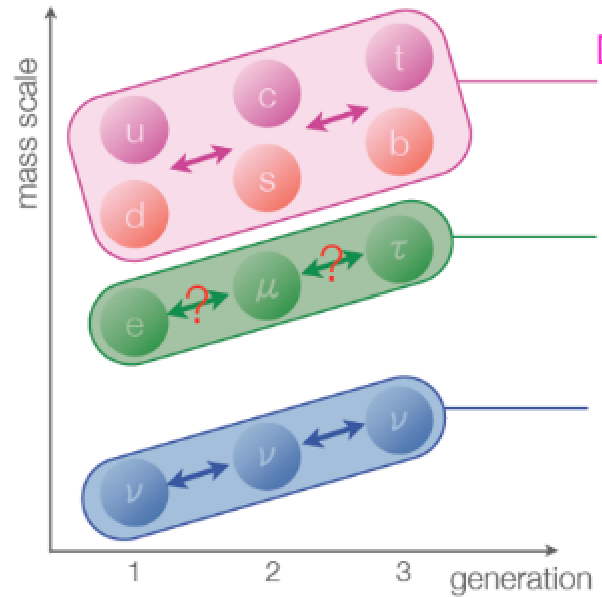
Conclusion

- The CDCH was successfully built and integrated into the experiment;

- The innovative challenge for its construction was complex:
  - New construction method: no feedthrough
  - Full stereo
  - Wire size too small
  - Electronics for cluster counting
- We learned to overcome these challenges during the construction of the first CDCH
- We have started the construction phase of the new CDCH

BACKUP

Overview

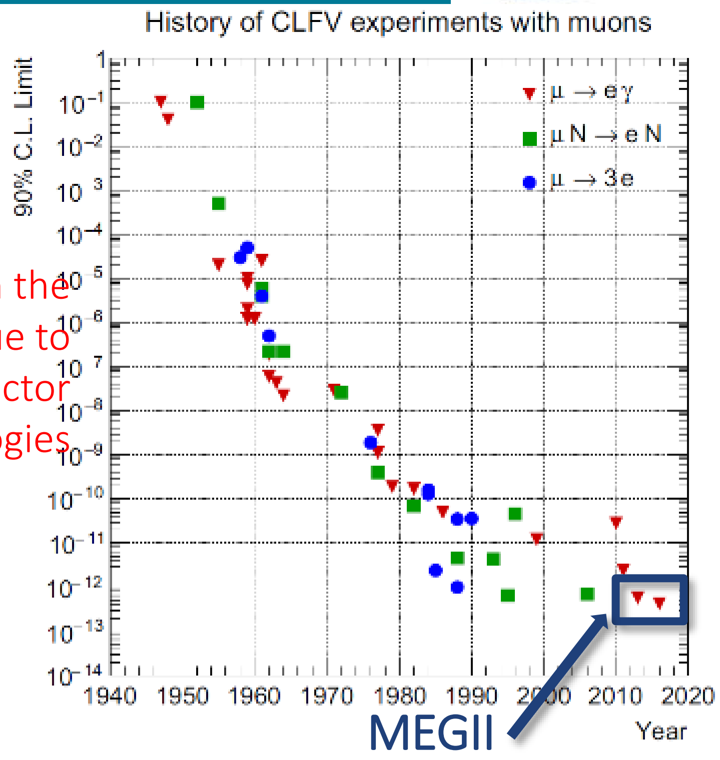


☑ Quarks
- Quark mixing observed by various accelerator experiments
- Standard Model: *CKM mixing matrix*

☐ Charged lepton flavor violation
- Not observed

☑ Neutrinos
- Neutrino oscillations observed by various neutrino experiments
- Standard Model: *PMNS mixing matrix*

3 orders of magnitude in the last 35 years mainly due to improvements in detector and beam technologies

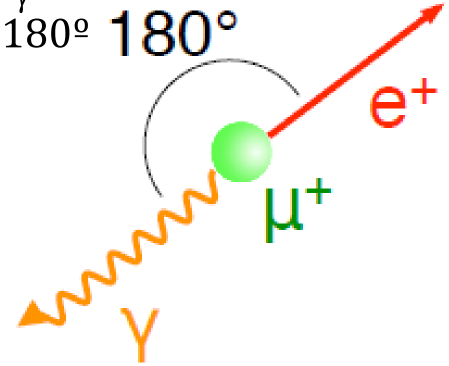


- SM extension + ν oscillations
  - **But not experimentally observable**: m_ν small ➜ $\mathrm{BR} < 10^{-50}$
- Beyond SM theories (SUSY-GUT) predict **additional particles and interactions**
  - CLFV rare but enhancement up to an observable level $\left(\mathrm{BR} \approx 10^{-(14\div15)}\right)$
- In this context the MEG experiment represents the state of the art in the search for the CLFV $\mu^+ \rightarrow e^+\gamma$ decay
  - **Final results** exploiting the **full statistics** collected during the 2009-2013 data taking period at **Paul Scherrer Institut** (PSI)
  - $BR(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13}$ $(90\%\ \mathrm{C.L.})$ **world best upper limit**

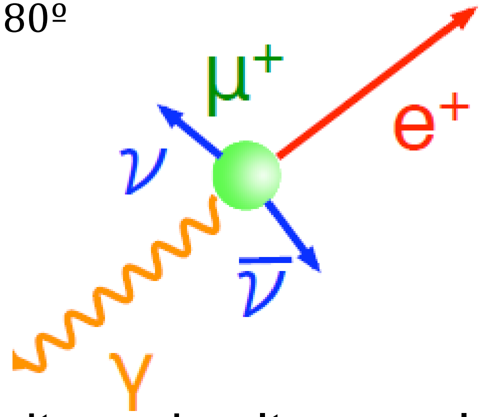
MEG event kinematic

Signal

$t_e = t_\gamma$
$E_e = E_\gamma = 52.8$ MeV
$\theta_{e\gamma} = 180º$

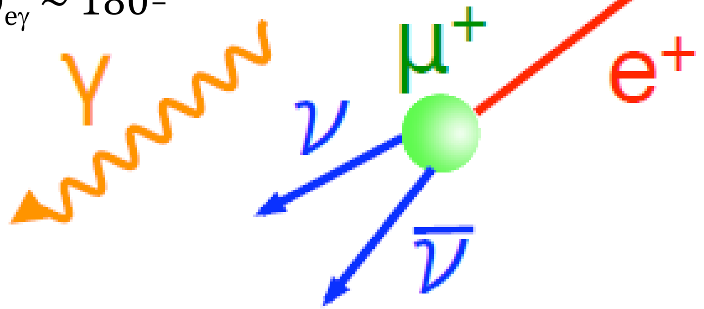


$t_e = t_\gamma$
$E_e = E_\gamma < 52.8$ MeV ($\pm\delta E$)
$\theta_{e\gamma} < 180º$



Accidental

$t_e = t_\gamma \pm \delta$
$E_e \sim E_\gamma \sim 52.8$MeV ($\pm\delta E$)
$\theta_{e\gamma} \sim 180º$



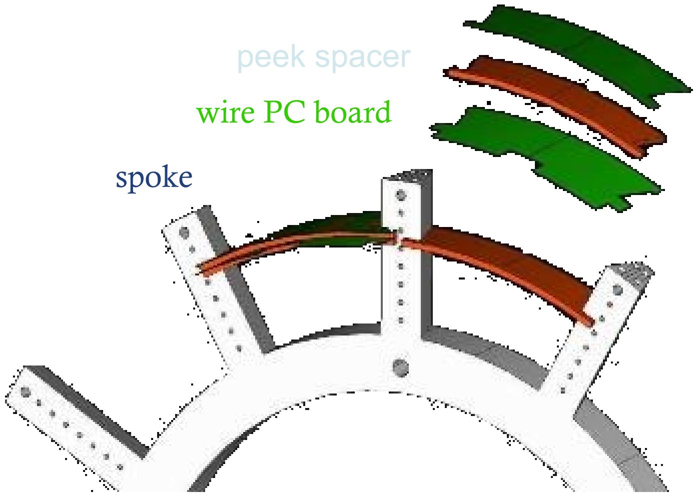
- **$\mu\to e\gamma$ signature**: photon and positron simultaneously emitted back-to-back and with equal energies in the Center-Of-Mass system.
- radiative decay $\mu\to e\nu\nu\gamma$: two neutrinos have low energy and γ and *e* emitted back-to-back with high energy (rare)
- "accidental": *e* and γ from different sources but with compatible kinematics to the $\mu\to e\gamma$ (e.g. e^+ from Michel decay, γ from RMD, e^+e^- annihilation…)
- To distinguish the signal from the background it is necessary to have a high resolution detector and an efficient algorithm

MEGII Drift chamber: The novel approch

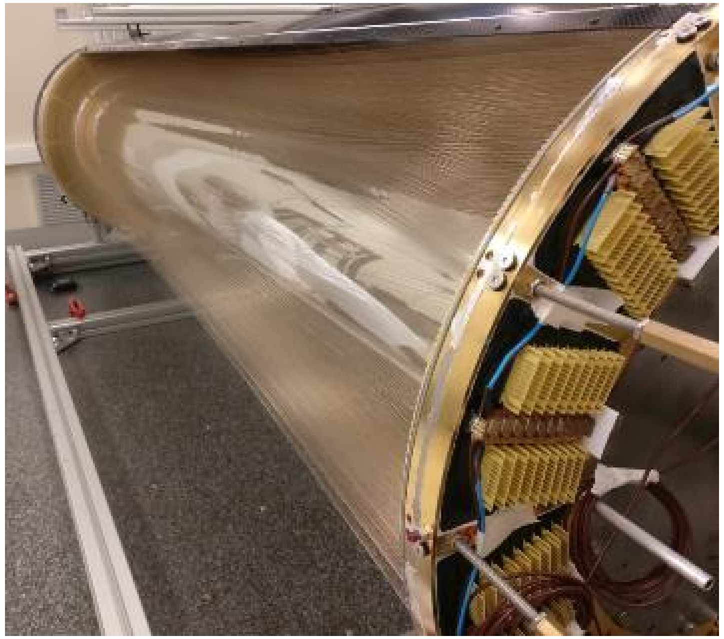
- Separate the end-plate function: mechanical support for the wires and gas sealer;
- Find a feed-trough-less wiring procedure.

The solution found for MEGII:

- end-plates numerically machined from solid Aluminum (mechanical support only);
- Field, Sense and Guard wires placed azimuthally by Wiring Robot with better than one wire diameter accuracy;
- wire PC board layers (green) radially spaced by numerically machined peek spacers (red) (accuracy < 20 μm);
- wire tension defined by homogeneous winding and wire elongation (ΔL = 100μm corresponds to ≈ 0.5 g);
- Drift Chamber assembly done on a 3D digital measuring table;
- build up of layers continuously checked and corrected during assembly
- End-plate gas sealing will be done with glue.



MEGII: Drift chamber Upgrade

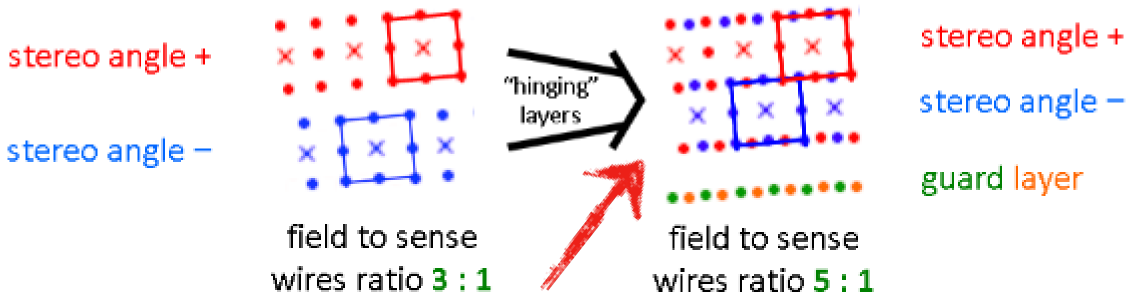


- ✓ **9 concentric layers of 192 drift cells** defined by **11904 wires**
- ✓ **Small cells few mm wide:** occupancy of ≈1.5 MHz/cell at CDCH center near the stopping target
- ✓ **High density of sensitive elements:** ×4 hits more than MEG drift chamber (DCH)
- ✓ **Total radiation length** $1.5 \times 10^{-3}\ X_0$: less than $1.7 \times 10^{-3}\ X_0$ of MEG DCH
  - MCS minimization and γ background reduction (bremsstrahlung and Annihilation-In-Flight)

e^+ variable	MEG	MEG II
ΔE_e (keV)	380	90
$\Delta\theta_e, \Delta\varphi_e$ (mrad)	9, 9	6, 5.5
$\mathrm{Efficiency}_e$ (%)	40	65

Active length L	1932	mm
N. of layers	9	
N. of stereo sectors	12	
N. of cells per layer	192	
N. of cells per sector	16	
Cell size (at z=0)	5.8 ÷ 7.8	mm
Twist angle	±60°	
Stereo angle	102 ÷ 147	mrad
Stereo drop	35.7 ÷ 51.4	mm

Upgrade



The wire net created by the combination of + and – orientation generates a more uniform equipotential planes

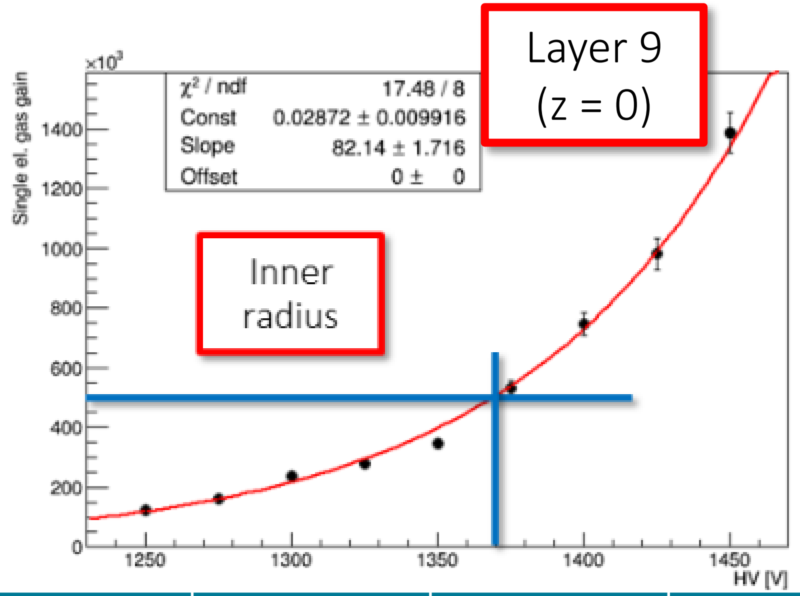
sense wires: 20 μm diameter W(Au) => 1728 wires
Field/guard wires: 40/50 μm diameter Al(Ag)=> 10176 wires

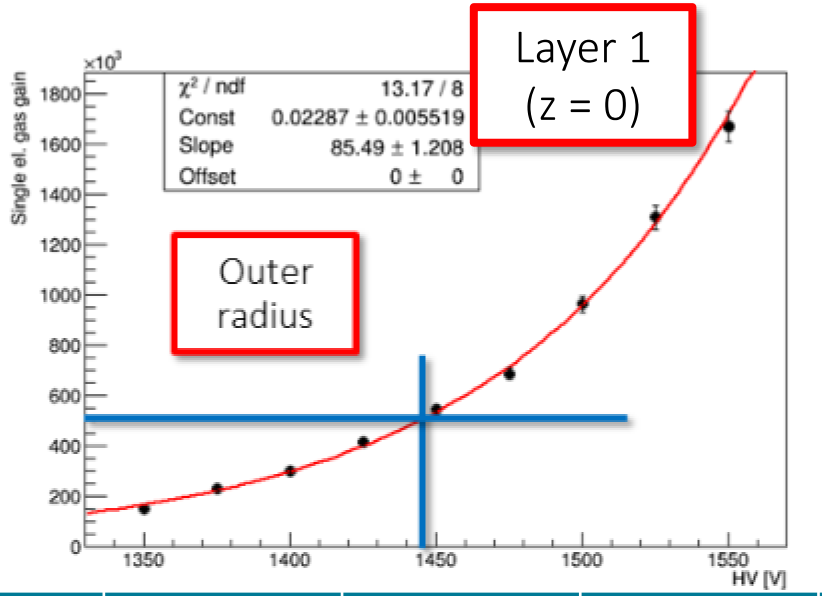
High wire densities, anyway, require complex and time consuming assembly procedures and need novel approaches to a feed-through-less wiring

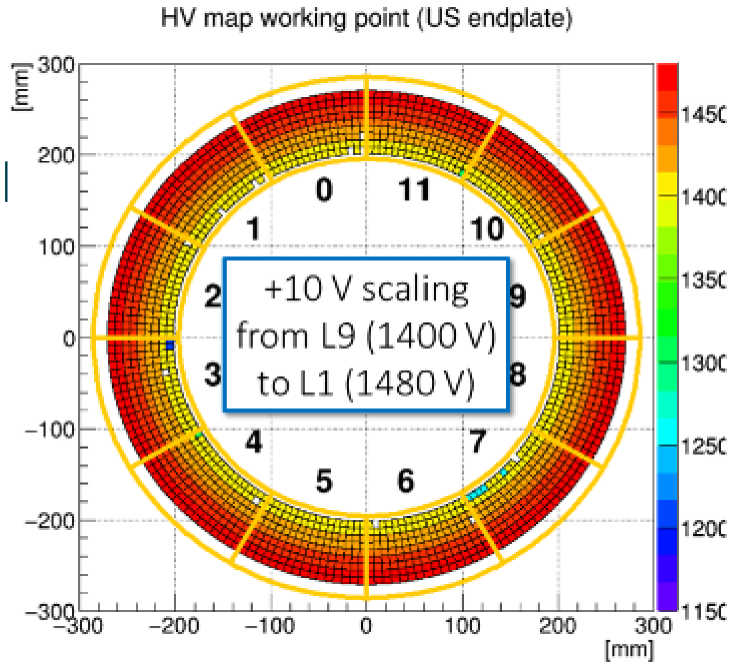
- Requirements:
  - **Light Material**
  - **High Rate\High Resolution**
- Single volume, **small cells**, **full stereo** cylindrical drift chamber;
- A large field to sense wires ratio allows for thinner field wires, thus reducing the **wire contribution to multiple scattering** and the **total wire tension** on the the end-plates;
- Light gas mixture **(90% He – 10% iC_4H_{10})**

HV working point

- Garfield simulations on single electron gain
- Gas mixture He:Isobutane 90:10 and P = 970 mbar (typical at PSI)
- Working point ➞ HV for gain $G = 5 \times 10^5$



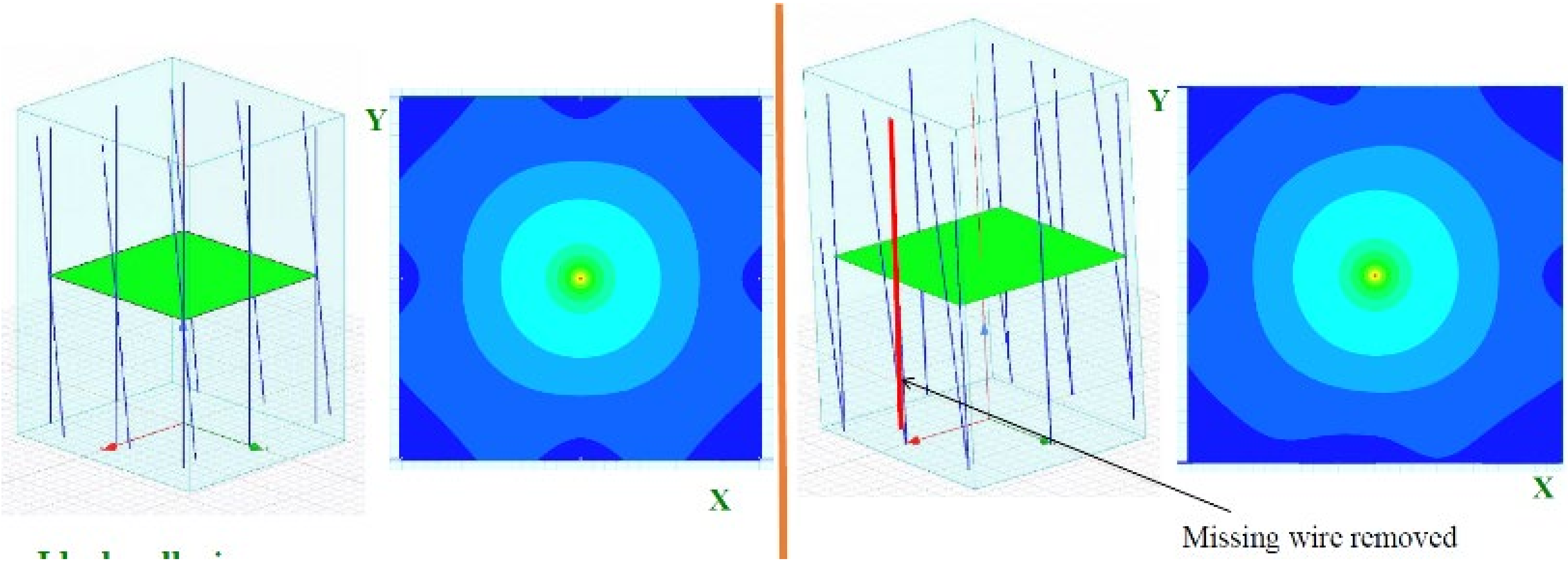




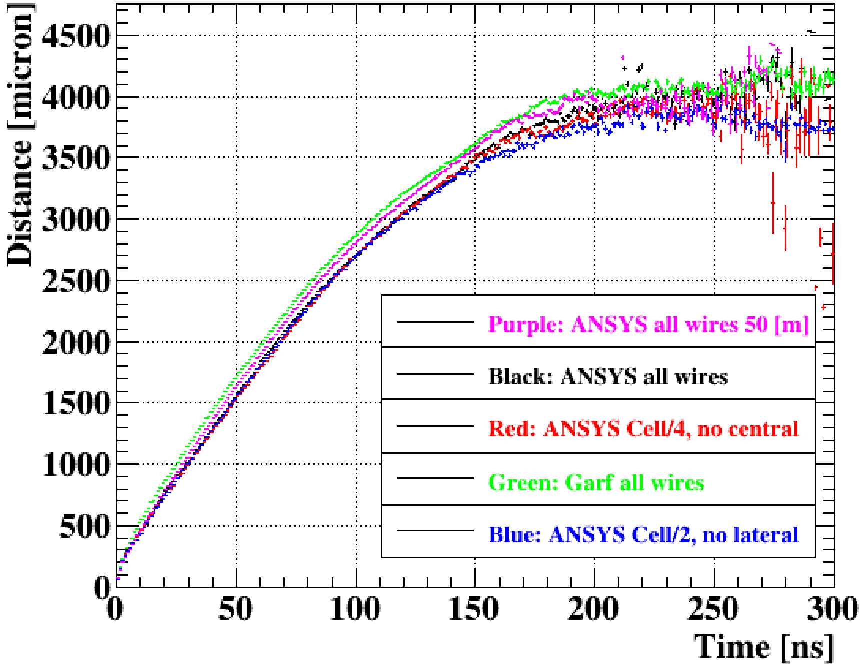
Cell inefficiency of 1.3% negligible in e^+ reconstruction

L1	L2	L3	L4	L5	L6	L7	L8	L9
1480 V	1470 V	1460 V	1450 V	1440 V	1430 V	1420 V	1410 V	1400 V

MEGII Drift chamber: Missing wires effect



Drift distance vs. drift time relations computed with **Garfield**

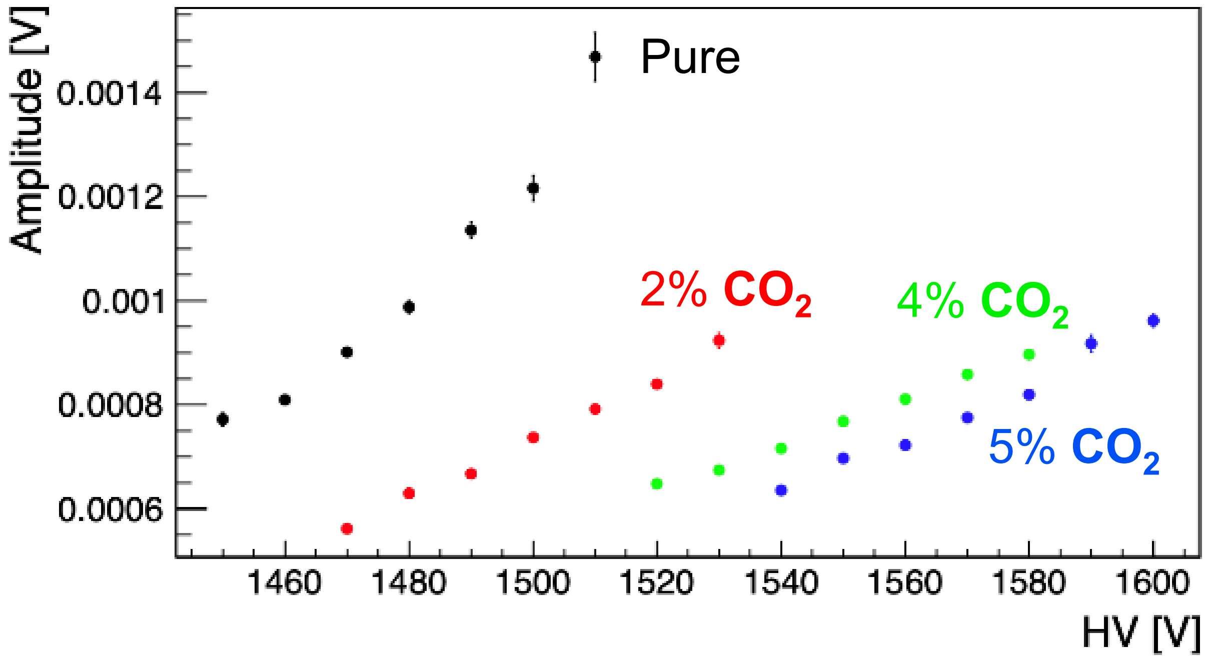


- Study the effect of a missing cathode on isochrones ➜ e^+ reconstruction
- Used **Garfield** and **ANSYS** to **simulate the electric field in a 6×6 mm^2 representative drift cell**
  - Single-hit resolution $\sigma_{hit} < 120$ μm
  - Difference between different curves ➜ ≈ 10 μm
- **Missing wire effect negligible**

Study Gain Gas

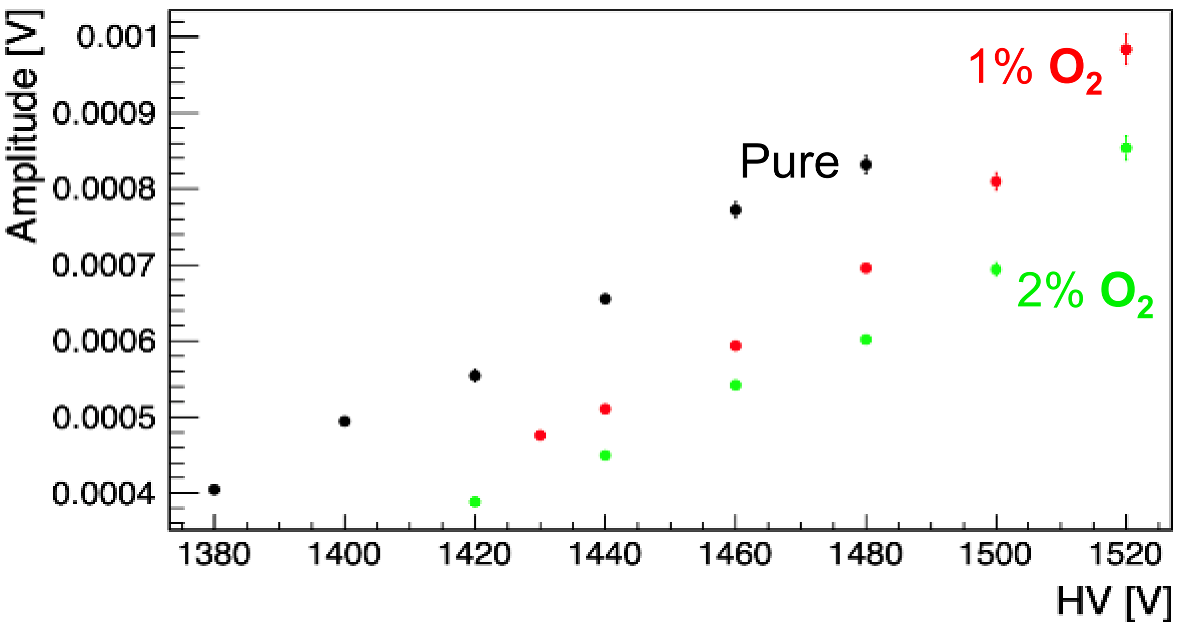
Gain with **He+ iC_4H_{10} +x CO_2:**

- the same gain reached with the pure gas-mixture, the HV has to be increased by 50V with 2% of CO_2, 100V with 4% of CO_2 and 120V with 5% of CO_2.

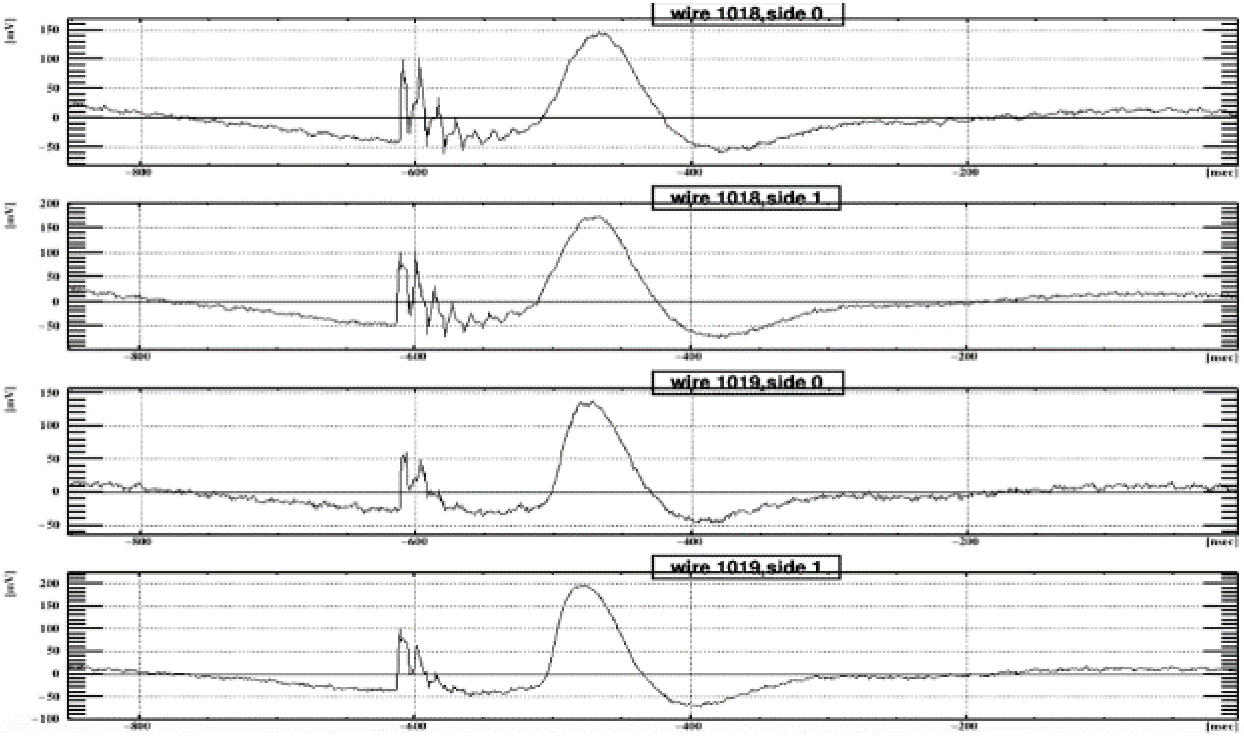


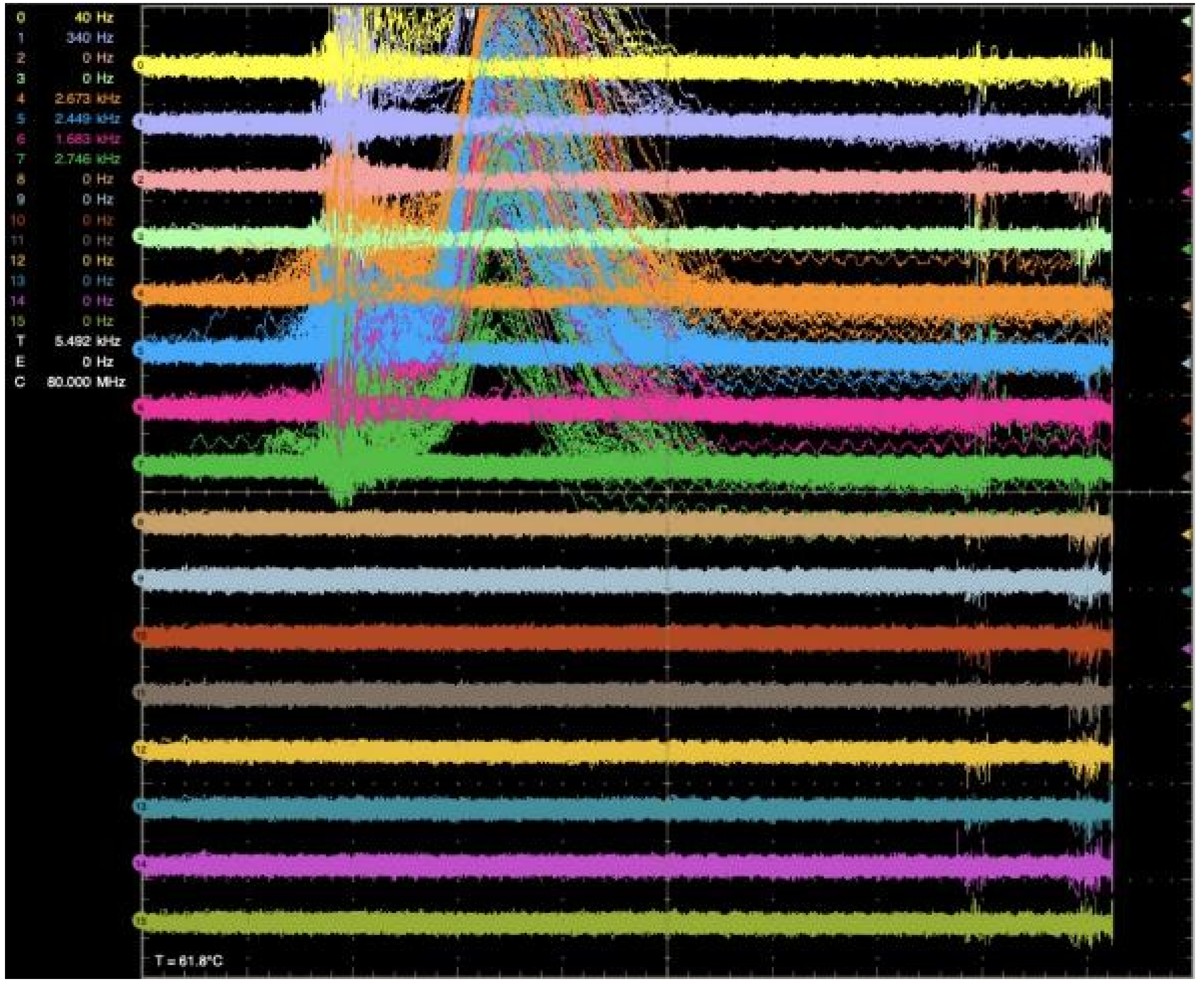
Gain with **He+ iC_4H_{10} + O_2:**

- the same gain reached with the pure gas-mixture, the HV has to be increased by 20V with 1% of O_2, 40V with 2% of O_2.



MEGII Drift chamber: High current





- WFs from CDCH online monitoring and WDB software
- Big signals (around 200 mV) after initial smaller pulses (around 100 mV)

Construction CDCH2: Wire choice

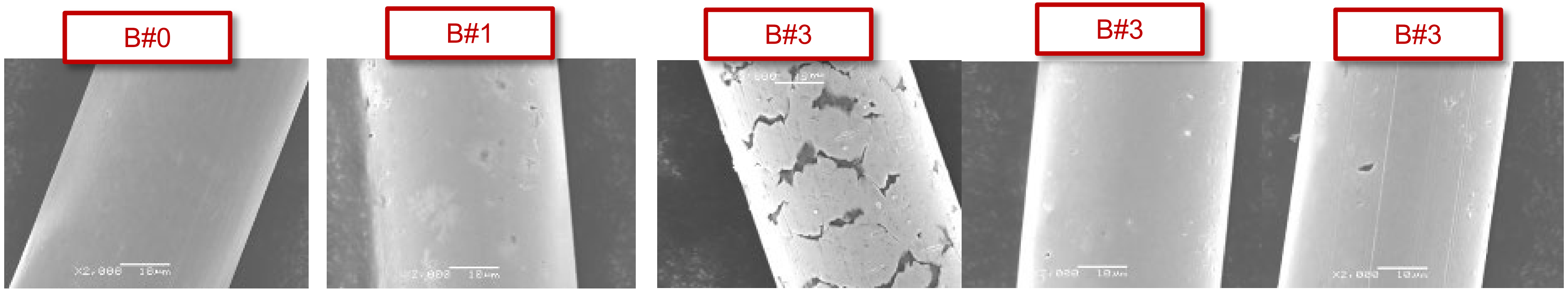
Non coated Al5056 μm

Several soldering materials and methods tested

1. ~~Alu1 by Stannol~~
   - ~~Worse than Al-S~~
2. ~~C-solder by Cametics~~
   - ~~Wire slipping by pulling at a few grams in ≈10% of cases~~
3. ~~Al-P by Elsold-Tamura~~
   - ~~Too corrosive~~
4. Al-S by Elsold-Tamura
   - **Wire slipping, needed both gluing and soldering.**
5. ~~Ultrasonic soldering by MBR electronics~~
   - ~~**Wire slipping or breaking**~~
6. Alu-Sol type D by Loctite-Henkel
   - **Wire breaking even after cleaning with alcohol**
   - *Type DH is considered the best solution for Aluminum but unfortunately it is no longer in production*

Construction CDCH2: Wire choice - Al/Ag quality

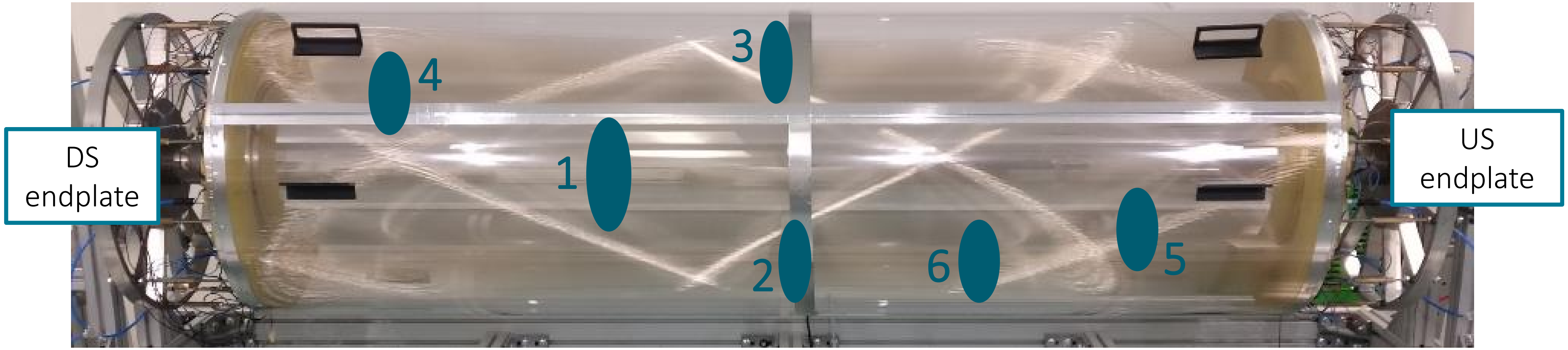
- Humid/wet environment quickly breaks the Al/Ag wires
  - True for all wires including the 80 um Al/Ag wires used in KLOE
  - Al alloy 5056 survives in water , and also salted water
  - Indirect sign of Al + an other metal composition with cracks
- the batches produced by CFW have different qualities (numbers of cracks)
  - The cracks are due to the ultrafineshed process

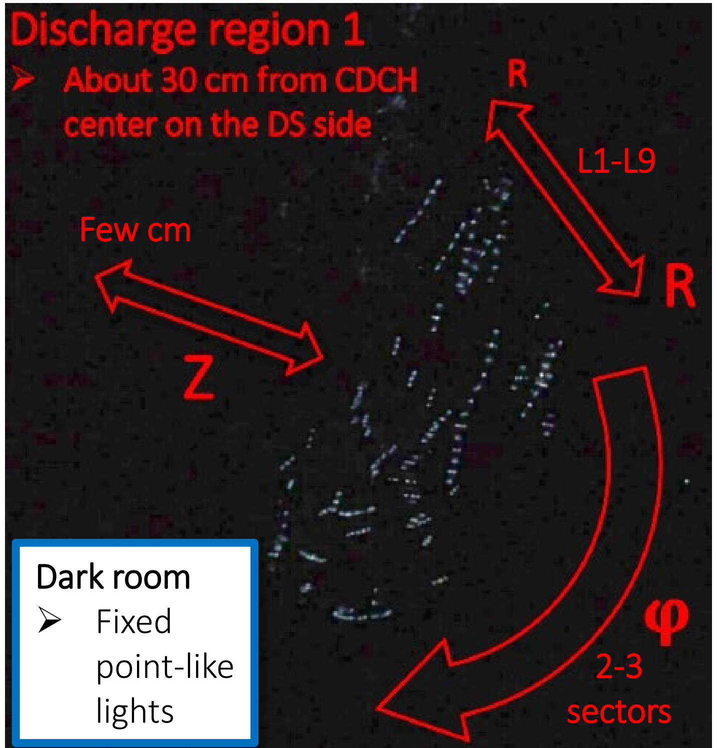


Construction CDCH2: Wire choice - Corrosion test

- To test the quality of the wire, we immerse a meter of wire in water and check the type of breakage and "the number of bubbles“
- We have verified the corrosion of the ultrafinsh and no ultrafinsh Ag /Al wire
- The non ultrafinish is more resistant to corrosion in water

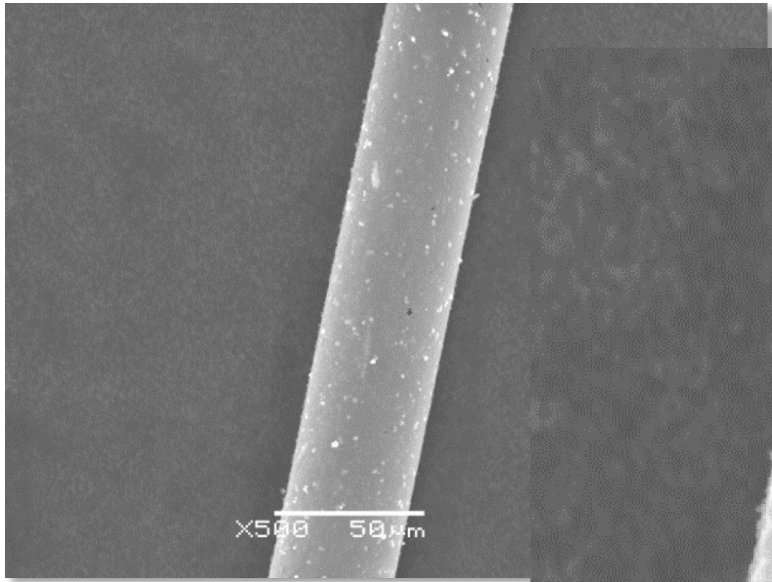
MEGII Drift chamber: High current investigation

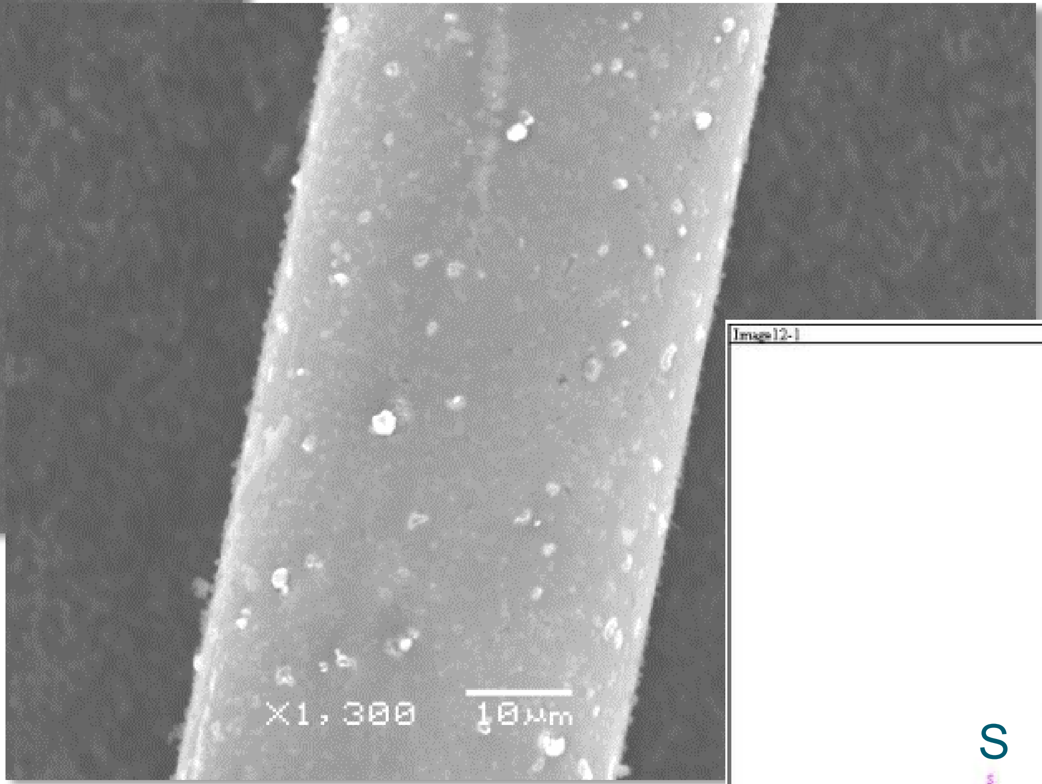


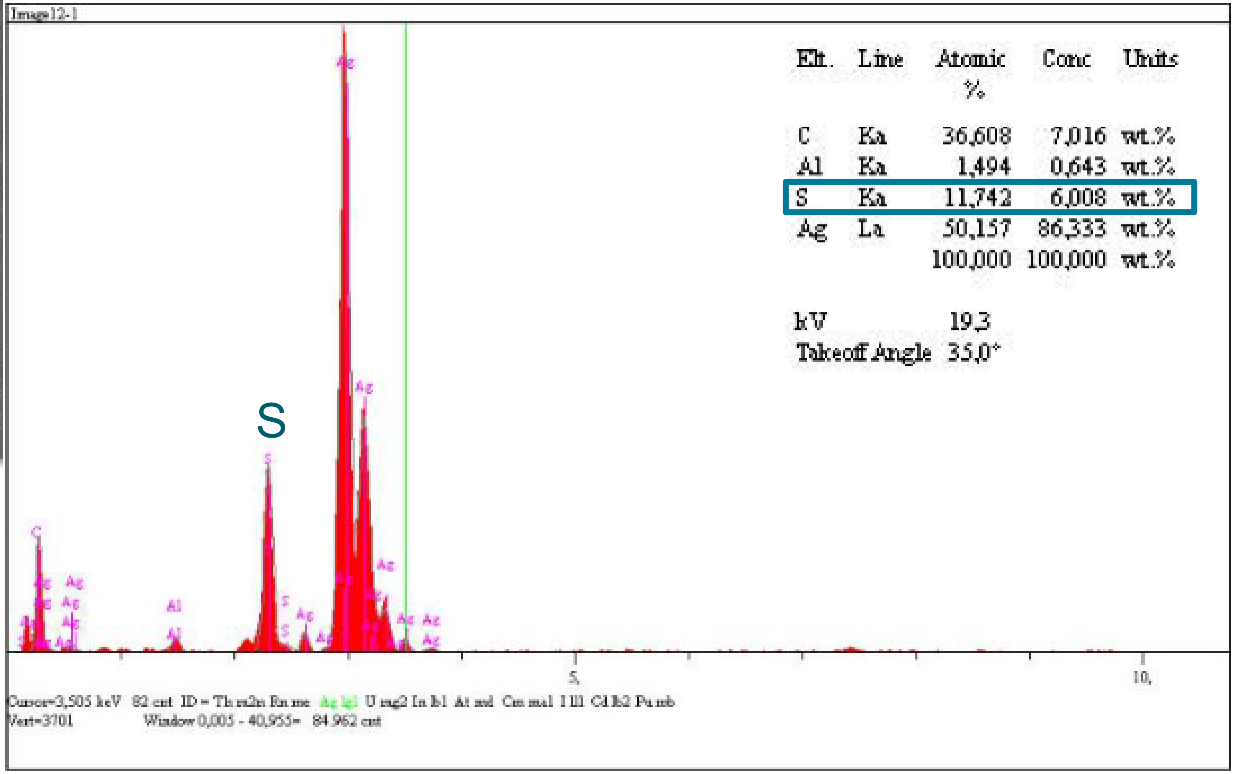


- We saw corona-like discharges in correspondence of 6 whitish regions
- We are trying different additives to the standard gas mixture to **test the CDCH stability** and **try to recover the normal operation**
  - 5% CO_2
  - 2000-4000 ppm of H_2O
  - From 500-600 ppm to 1% of O_2 (also in combination with H_2O)
- Oxygen seems to be effective in reducing high currents => **Reduces gas gain and there is a risk of accelerating aging**

MEGII Drift chamber: High current investigation

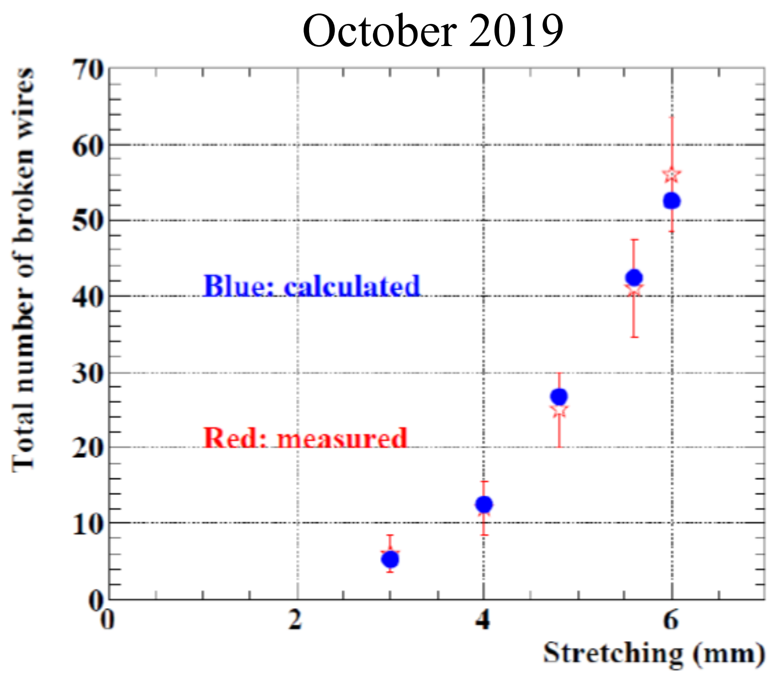


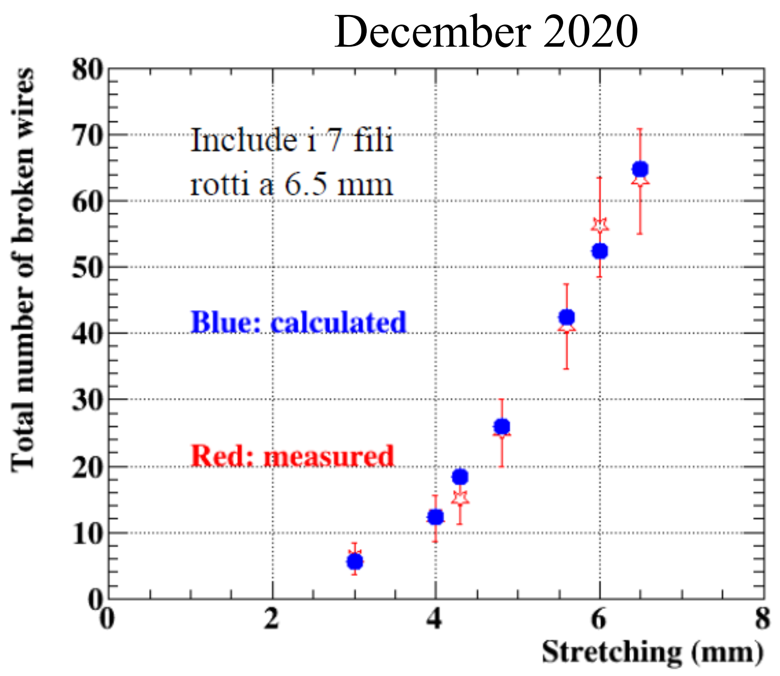




Construction CDCH2: Wire choice - Corrosion test

- From these tests we have defined a model of wire breakage under corrosion. Parameters time of exposure to humid atmosphere, stretching of the wire, corrosion rate.
- The model is in good agreement with the breaking rate of the wires at different lengths

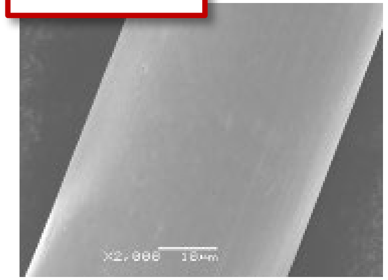




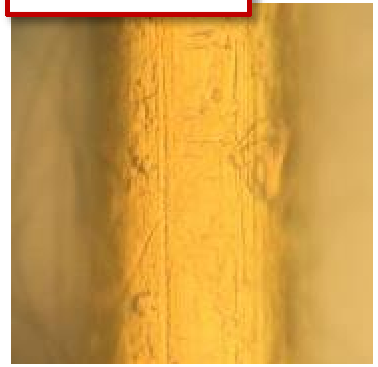
Construction CDCH2: Wire choice

- The problem with the CDCH is the wire used for the cathodes.
- In CDCH2, only 50 μm cathodes will be used because the probability of corrosion is lower
- In these months we have explored the use of other materials:
  - Al 5056 non coated - 50 μm
    - Insensitive to humidity
    - Soldering possible but very difficult
    - Gluing possible but need development
  - Al 5056/Ag no ultrafinish - 50 μm
    - Wire used for CDCH but without chemical treatment which damages the wire surface
  - Ti 50 μm
    - Same as Aluminum but even more difficult to solder - discarded
  - Cu 50 μm
    - Worst in resolution - discarded
  - We considered other materials but nor CFW or other companies were able to produce or quote 50 μm wires.

Ultrafinish

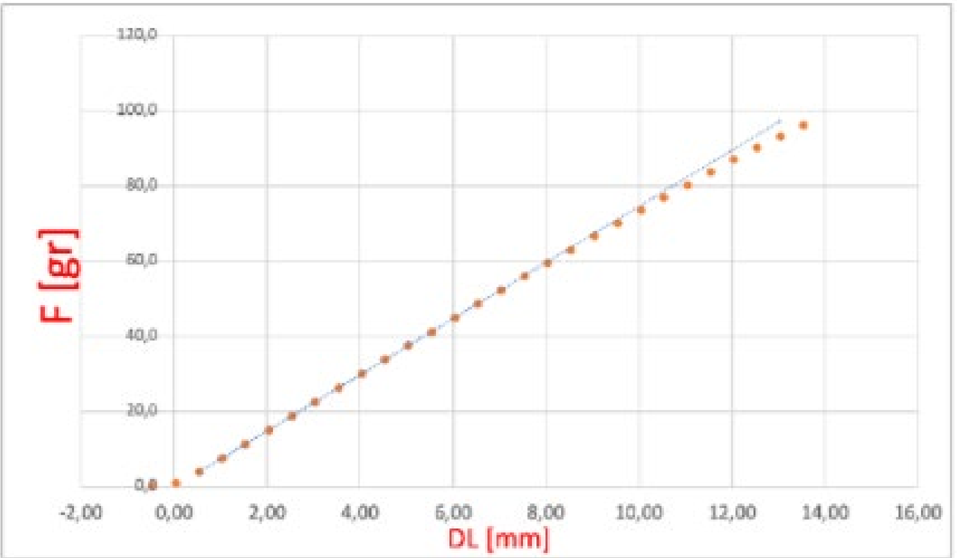


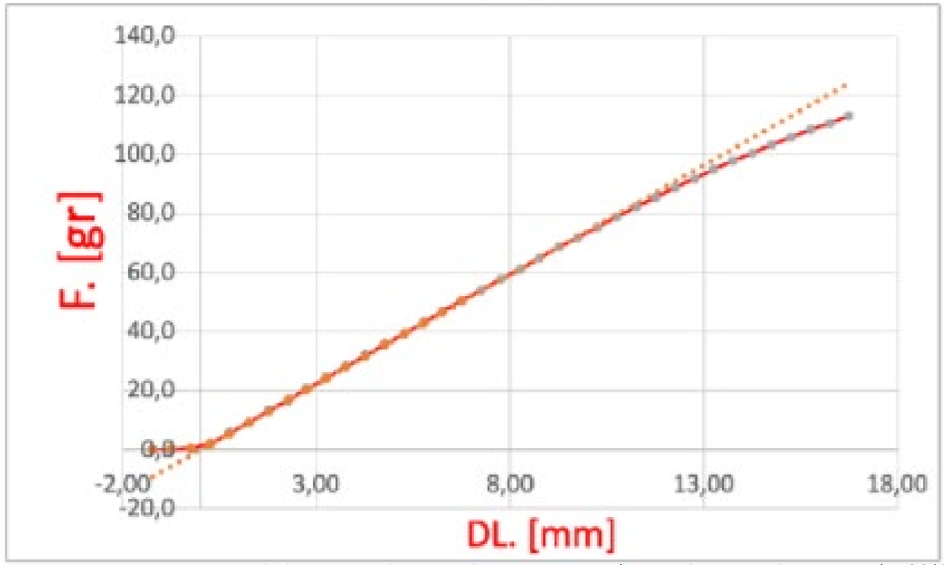
NoUltrafinish



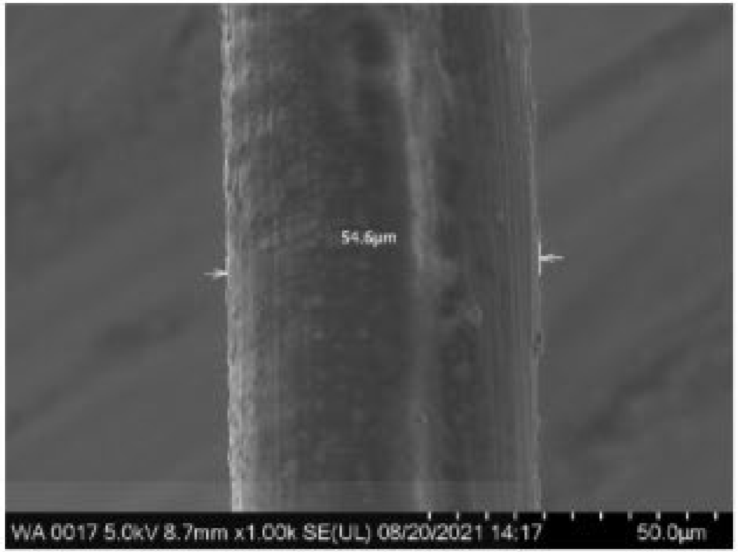
Construction CDCH2: Wires stress curves

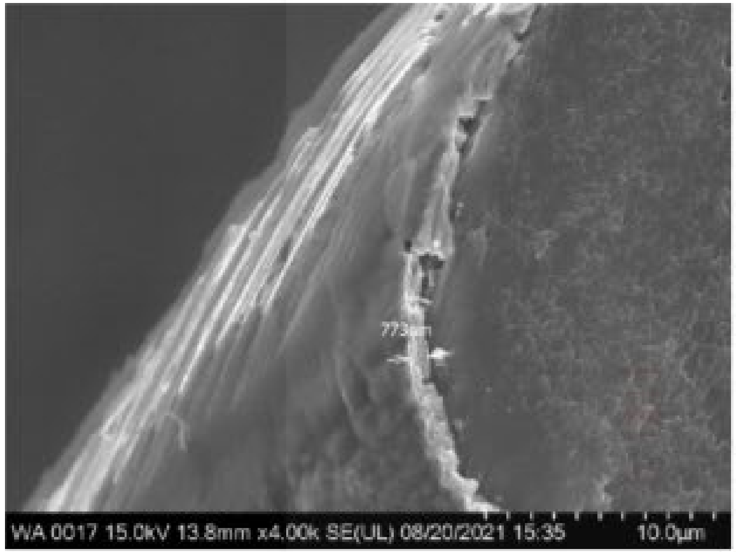
- linear regime up to 10 mm (0.5%)
- short plastic regime, before breaking
- UTS near to datasheet ~80000 PSI
- Modulus of elasticity as expected at ~76 GPa

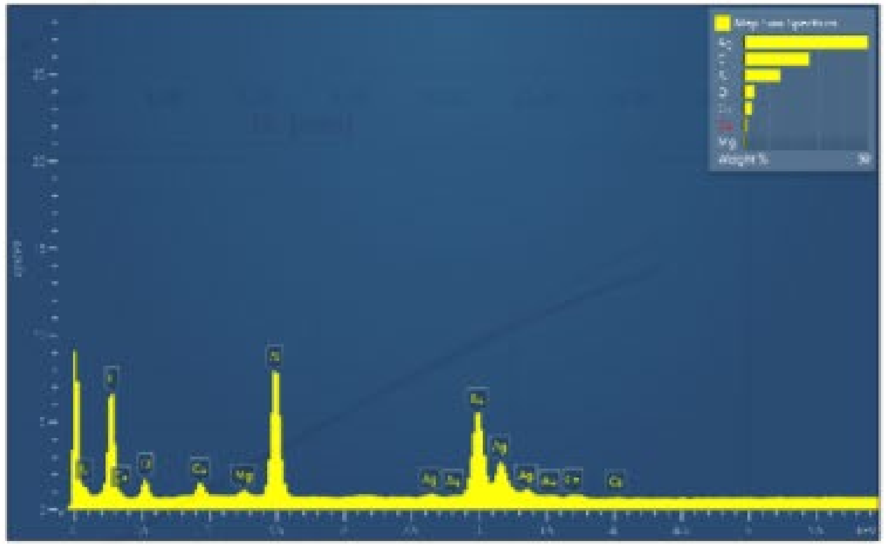




Construction CDCH2: SEM Analysis







- The wire was analyzed by SEM:
  - diameter within tolerance
  - Ag coating thickness in tolerance
  - From the EDX analysis the materials present are those of the manufacture (there are no traces of strange elements)