The MEG II Cylindrical Drift CHamber (CDCH)

Marco Chiappini (INFN Pisa)

Mini Workshop MEG CDCH - BELLE II CDC

26/09/2024

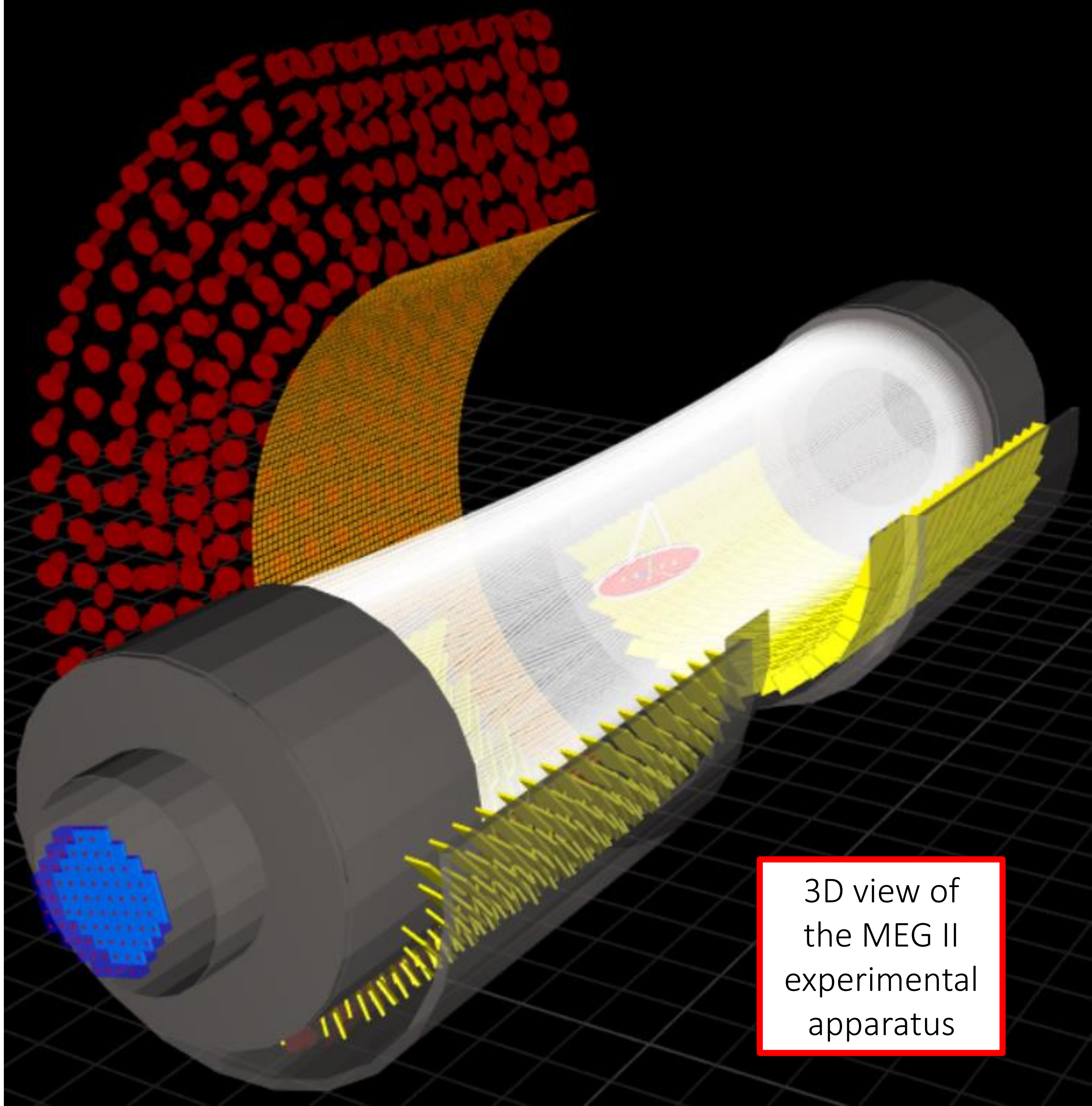
Istituto Nazionale di Fisica Nucleare

Outline

- ➢ Introduction to the MEG II experiment

- ➢ The MEG II Cylindrical Drift CHamber (CDCH)
  - Detector performance
  - New design concept and wiring
  - Assembly at INFN Pisa
  - Commissioning phase at the Paul Scherrer Institut (PSI)
  - Integration into the experimental apparatus
- ➢ Investigations on wire breakages
- ➢ Investigations on anomalous currents
- ➢ Ageing studies
- ➢ Conditioning with beam
- ➢ Physics data taking and measured performance

- ➢ Conclusions and prospects



3D view of the MEG II experimental apparatus

Introduction to the MEG II experiment

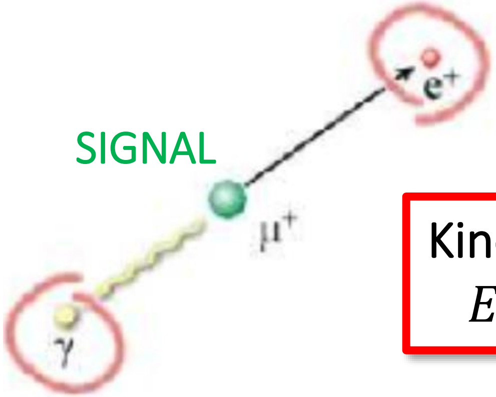
The $\mu^+ \to e^+\gamma$ decay

European Physics Journal C (2016) 76:434

- Lepton Flavour Violation (LFV) processes experimentally observed for neutral leptons
  - Neutrino oscillations $\nu_l \to \nu_{l'}$
- LFV for charged leptons (CLFV): $l \to l'$???
- If found → definitive evidence of New Physics

- In this context the MEG experiment represents the state of the art in the search for the CLFV $\mu^+ \to e^+\gamma$ decay
  - **Final results** exploiting the **full statistics** collected during the 2009-2013 data taking period at **Paul Scherrer Institut** (PSI, Switzerland)
  - $BR(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$ (90% C. L.) **world best upper limit**

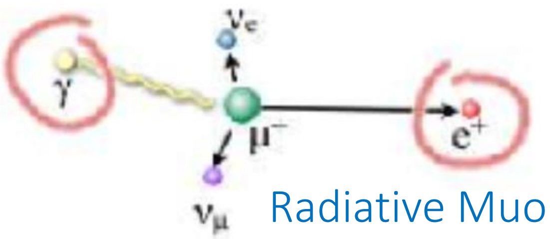
SIGNAL



Kinematic variables

$E_e, E_\gamma, t_{e\gamma}, \theta_{e\gamma}$

- 28 MeV/c μ^+ continuous beam stopped in a 174 μm-thick BC400 target (15° slant angle)
- Most intense DC muon beam in the world at PSI: $R_\mu \approx 10^8$ Hz
- μ^+ decay at rest: 2-body kinematics
- $E_\gamma = E_e = 52.8$ MeV
- $\theta_{e\gamma} = 180°$
- $t_{e\gamma} = 0$ s

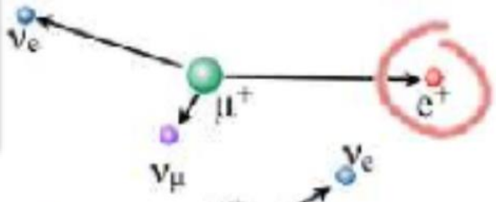


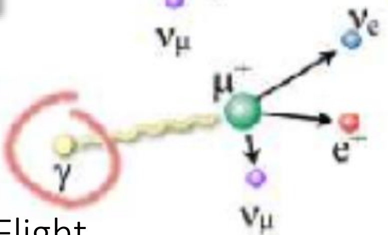
Radiative Muon Decay (RMD)

- $E_\gamma < 52.8$ MeV
- $E_e < 52.8$ MeV
- $\theta_{e\gamma} < 180°$
- $t_{e\gamma} = 0$ s

Standard μ decay
≡
Michel decay

BACKGROUNDS





From RMD, Annihilation-In-Flight or bremsstrahlung

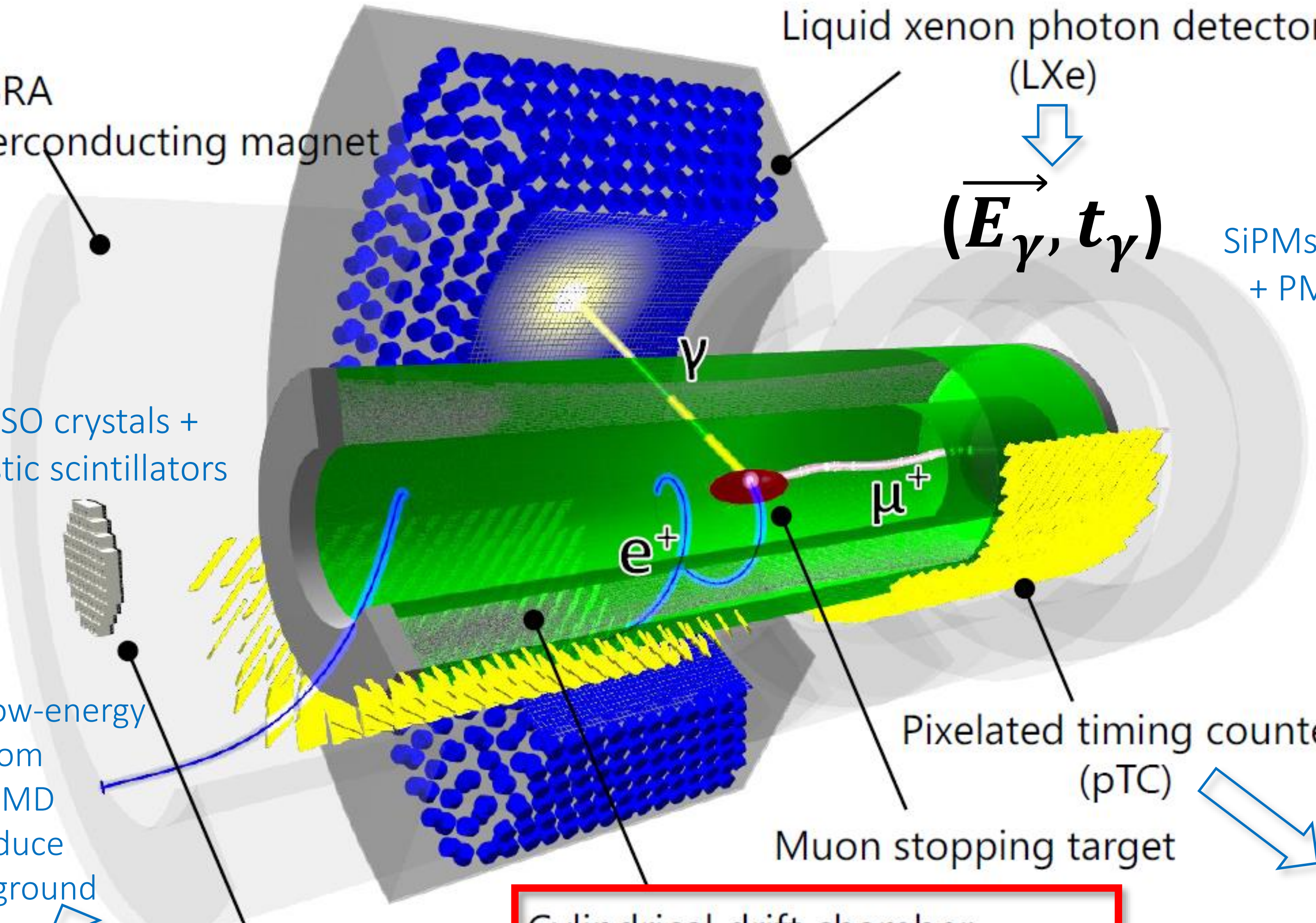
Accidental

- $E_\gamma < 52.8$ MeV
- $E_e < 52.8$ MeV
- $\theta_{e\gamma} < 180°$
- $t_{e\gamma}$ = flat

- $BKG_{ACC} \propto R_\mu \Delta E_e \Delta t_{e\gamma} \Delta E_\gamma^2 \Delta\theta_{e\gamma}^2$ ➔ DOMINANT in high-rate environments
- $BKG_{RMD} \approx 10\% \times BKG_{ACC}$

The MEG II experiment

- Full design paper
- Full commissioning paper
- Full operation paper



COBRA superconducting magnet

Liquid xenon photon detector (LXe)

$(\overrightarrow{E_\gamma}, t_\gamma)$

SiPMs on the γ entrance face + PMTs on the other faces

LYSO crystals + plastic scintillators

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

Radiative decay counter (RDC)

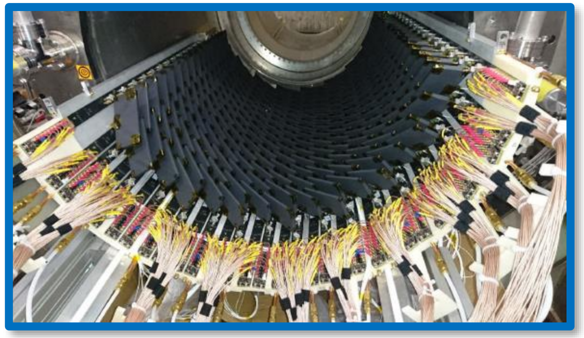
Cylindrical drift chamber (CDCH)

$\overrightarrow{E_{e^+}}$

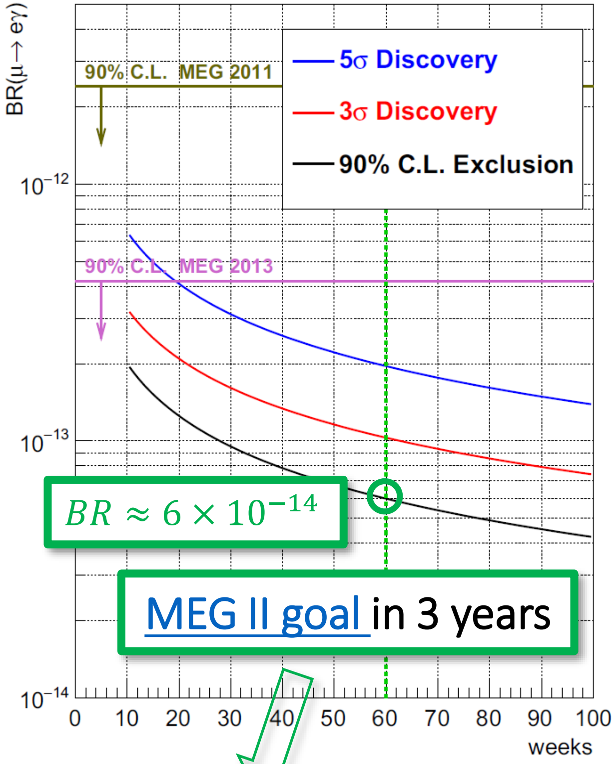
Muon stopping target

Pixelated timing counter (pTC)

t_{e^+}



Plastic scintillators tiles read out by SiPMs



$BR \approx 6 \times 10^{-14}$

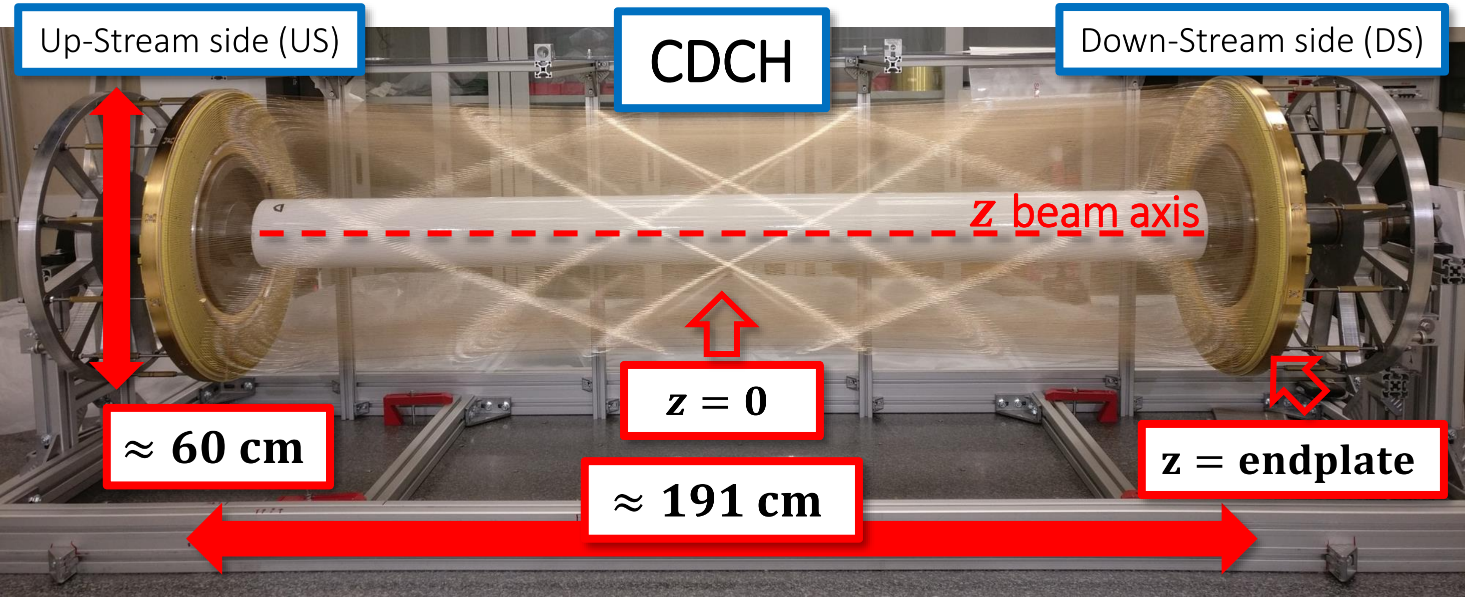
MEG II goal in 3 years

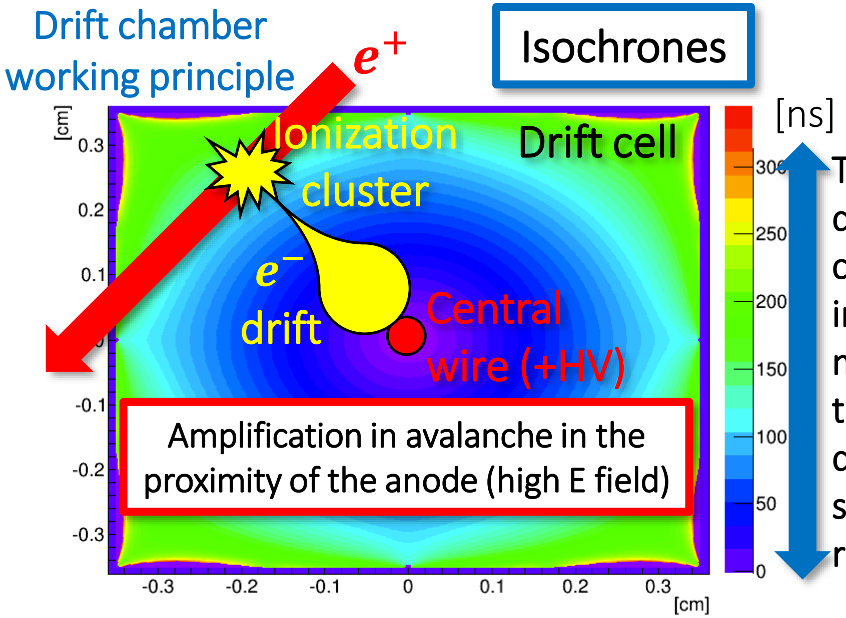
- Increasing the μ^+ stopping rate
- Improving the detectors figures of merit
  - $\times$ 2 factor than MEG

The MEG II Cylindrical Drift CHamber (CDCH)

- Design and assembly
- Commissioning

Detector performance





The measured drift time is converted into a position measurement through dedicated space-time relations

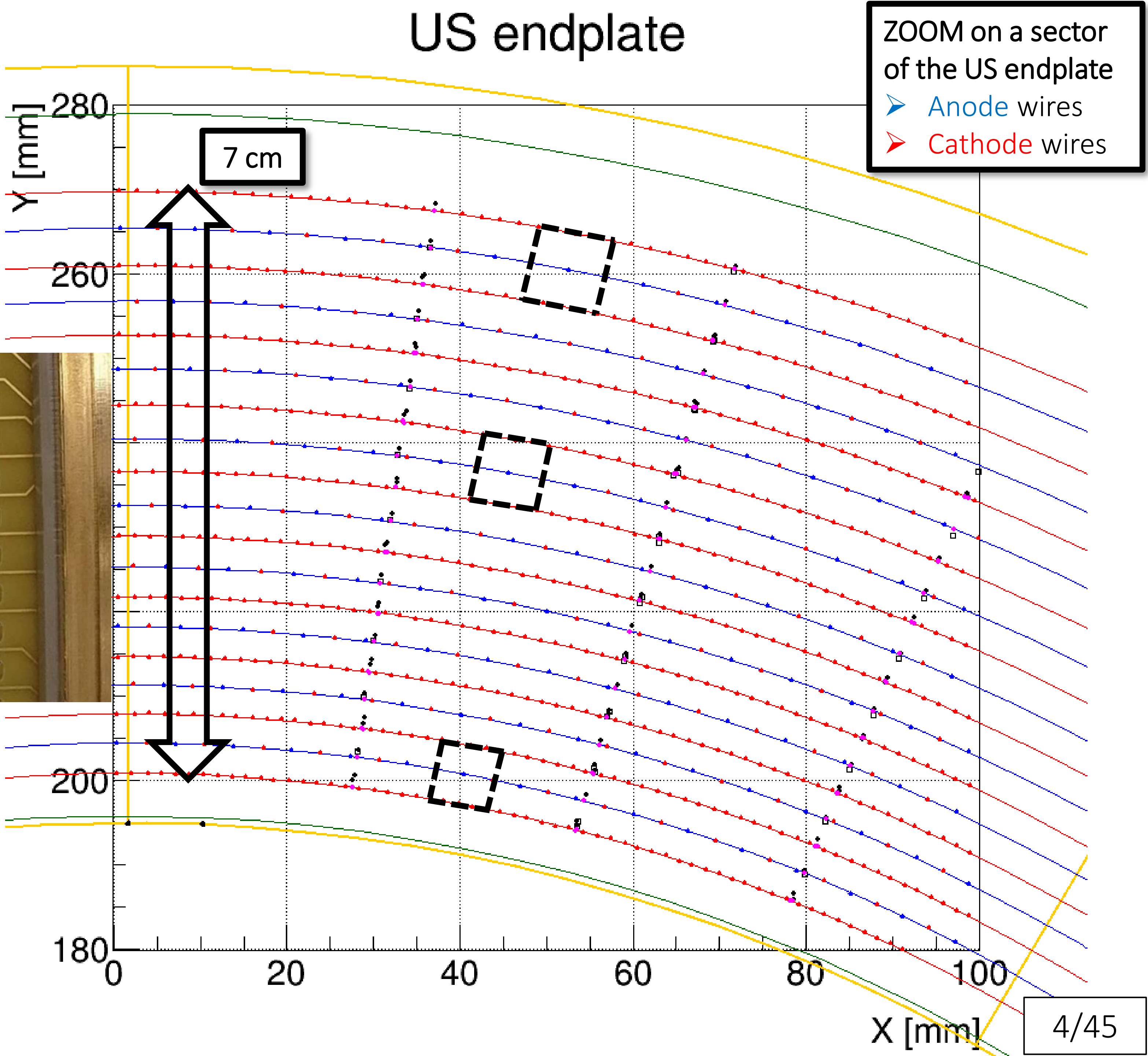
e^+ variable	MEG	MEG II
ΔE_e (keV)	380	91
$\Delta\theta_e, \Delta\varphi_e$ (mrad)	9.4, 8.7	7.2, 4.1
$\Delta Z, \Delta Y$ (at target, mm)	2.4, 1.2	2.0, 0.7
$\varepsilon_{tracking} \times \varepsilon_{TC-match}$ (%)	65 × 45	74 × 91

- Currently most updated reconstruction algorithms on real data
- Practically at the MC level

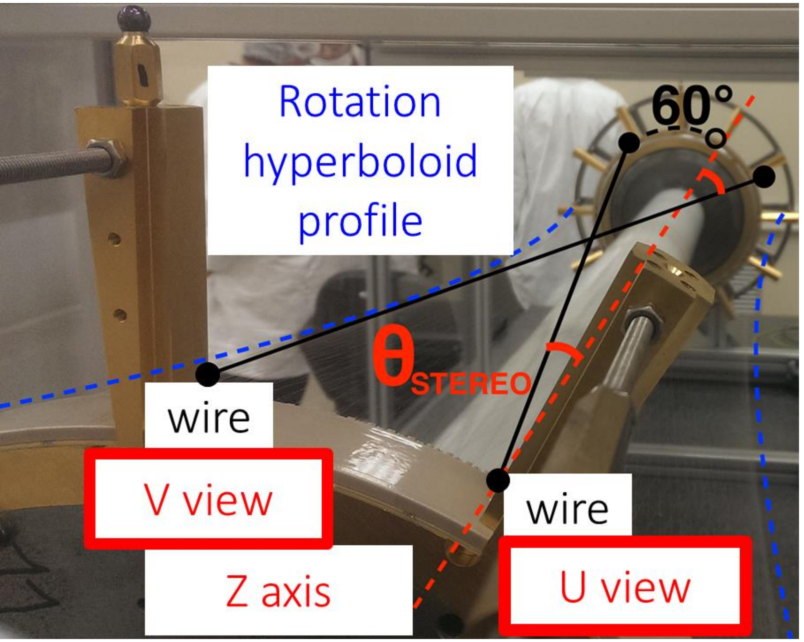
- Low-mass single volume detector with high granularity filled with He:iC_4H_{10} 90:10 gas mixture
  - + additives to improve the operational stability: 1.5% isopropyl alcohol + 0.5% Oxygen
  - 9 concentric layers of 192 drift cells defined by 11904 wires
  - Small cells few mm wide: occupancy of ≈1.5 MHz/cell (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 $2 \times 10^{-3}\ X_0$ of MEG DCH or ≈150 µm of Silicon
  - MCS minimization and γ background reduction (bremsstrahlung and Annihilation-In-Flight)
- Single-hit resolution (measured on prototypes): $\sigma_{hit} < 120\ \mu m$
- Extremely high wires density (12 wires/cm^2) → the classical technique with wires anchored to endplates with feedthroughs is hard to implement
  - CDCH is the first drift chamber ever designed and built in a modular way

Wire density

stereo wire geometry
radial perspective



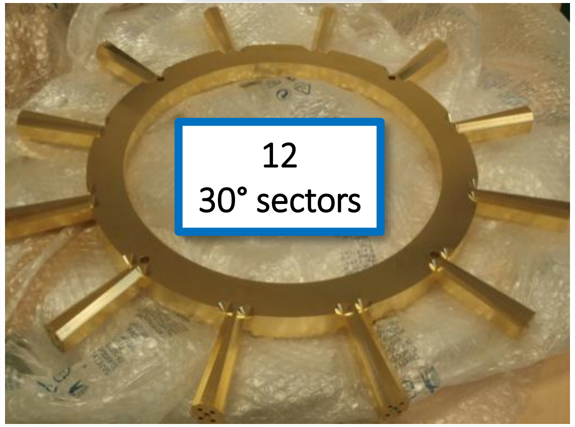
Design and wiring

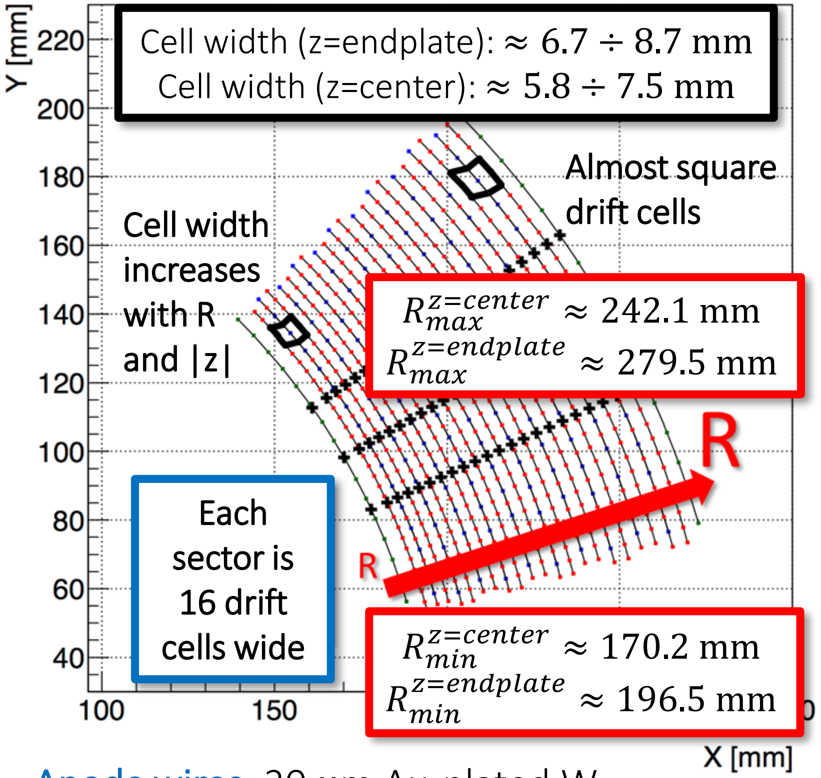


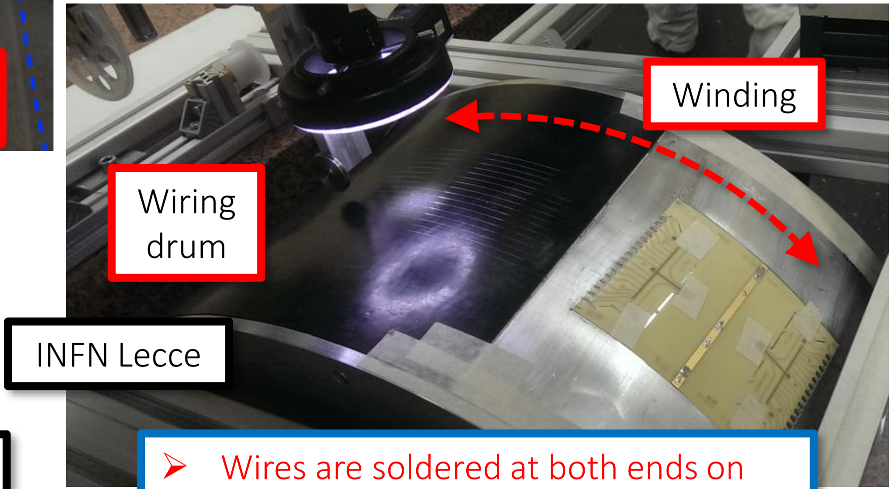
Stereo wires geometry for longitudinal hit localization

- $\theta_{stereo} \approx 6° \div 8.5°$ as R increases

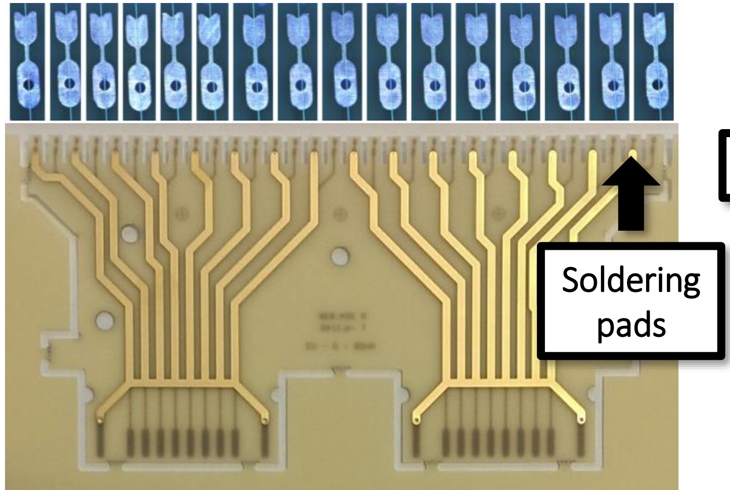
Endplate



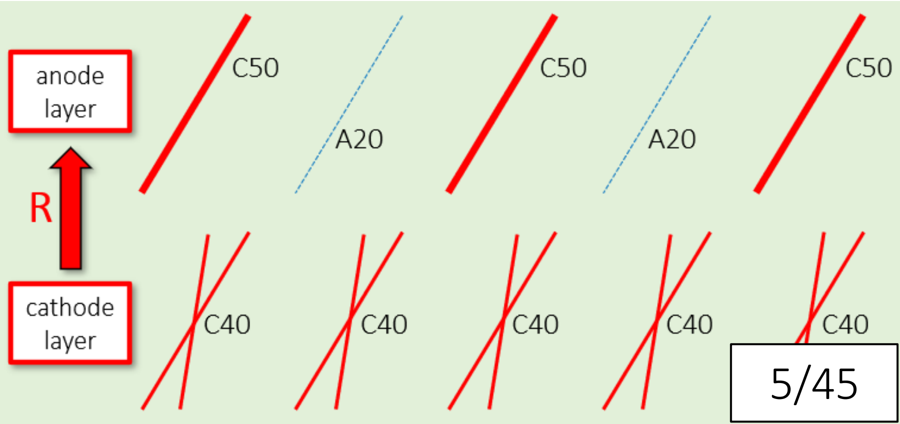




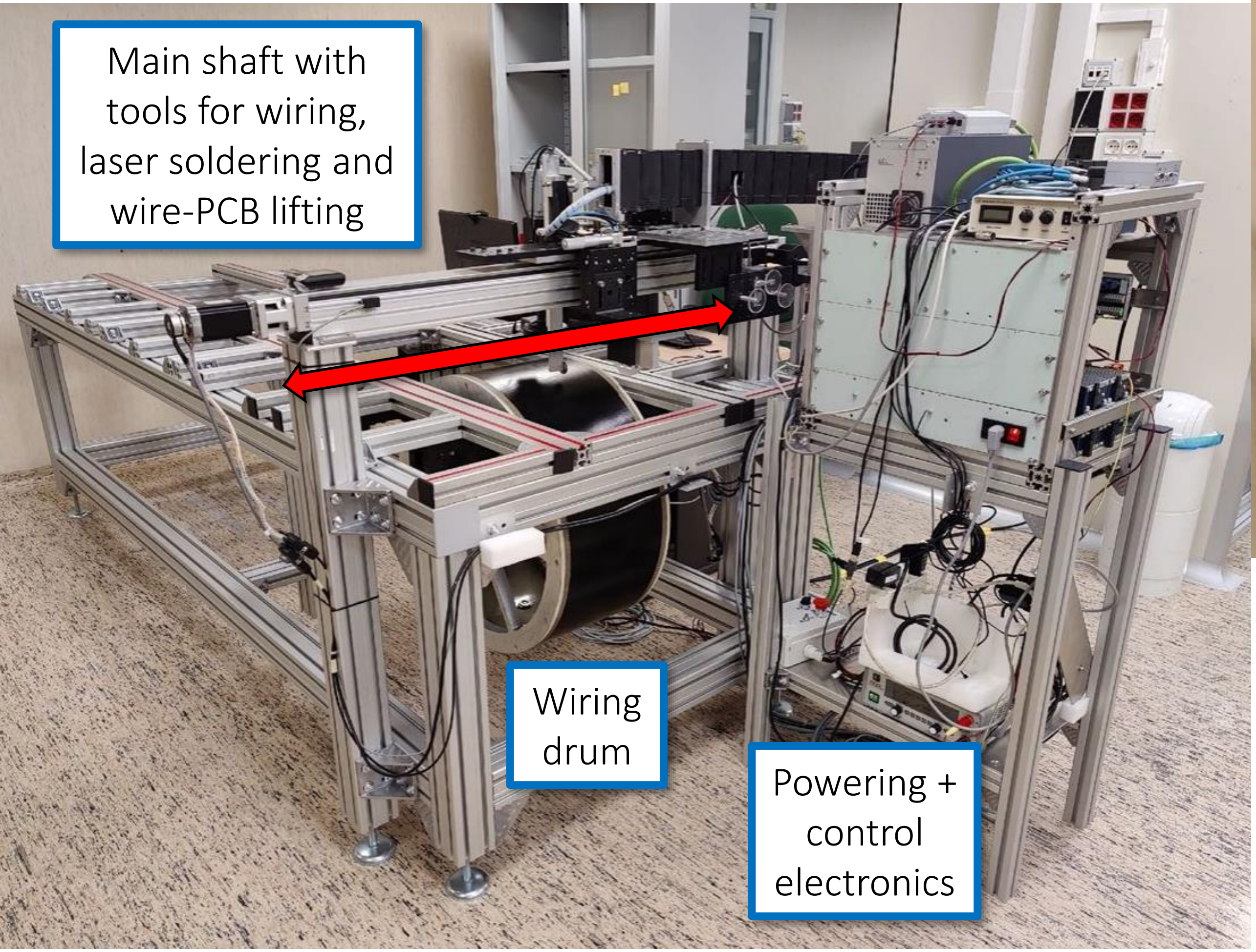
- Anode wires: 20 μm Au-plated W
- Cathode wires: 40/50 μm Ag-plated Al
  - **40 μm ground mesh between layers**
- Guard wires: 50 μm Ag-plated Al
- **Field-to-Sense wire ratio 5:1**

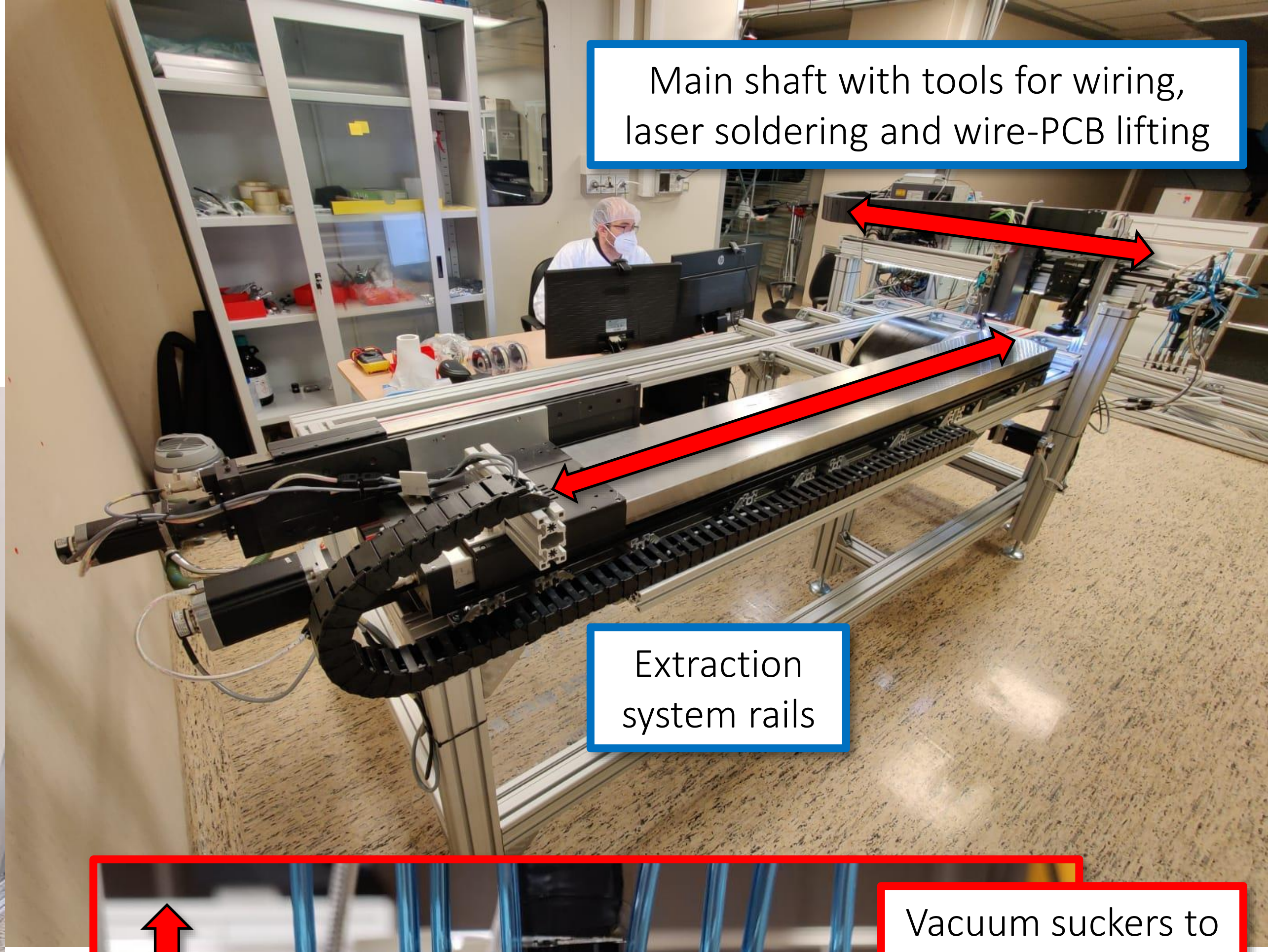


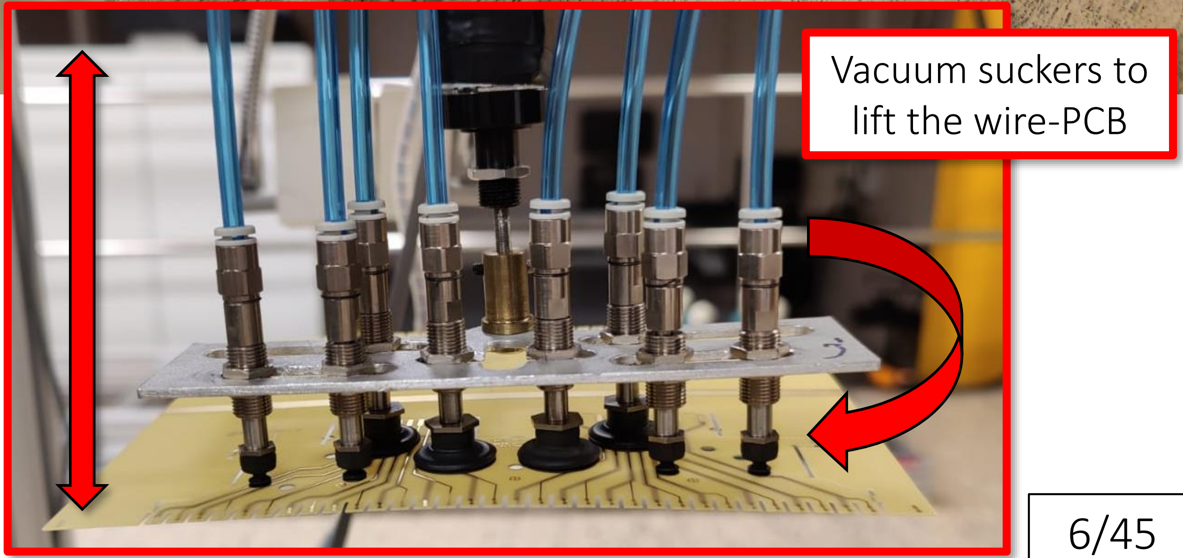
- Wires are soldered at both ends on the pads of 2 PCBs (wire-PCBs) which are then mounted on CDCH endplates
- Wiring inside a cleanroom



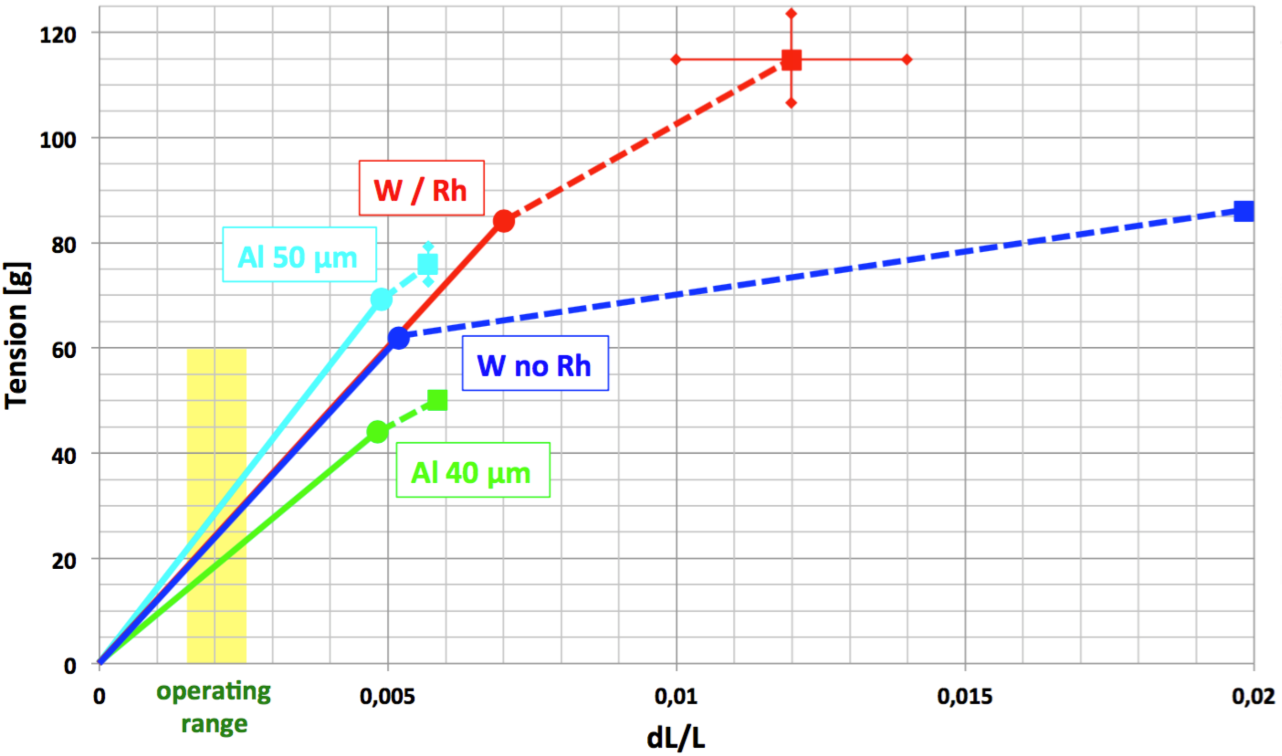
Wiring machine

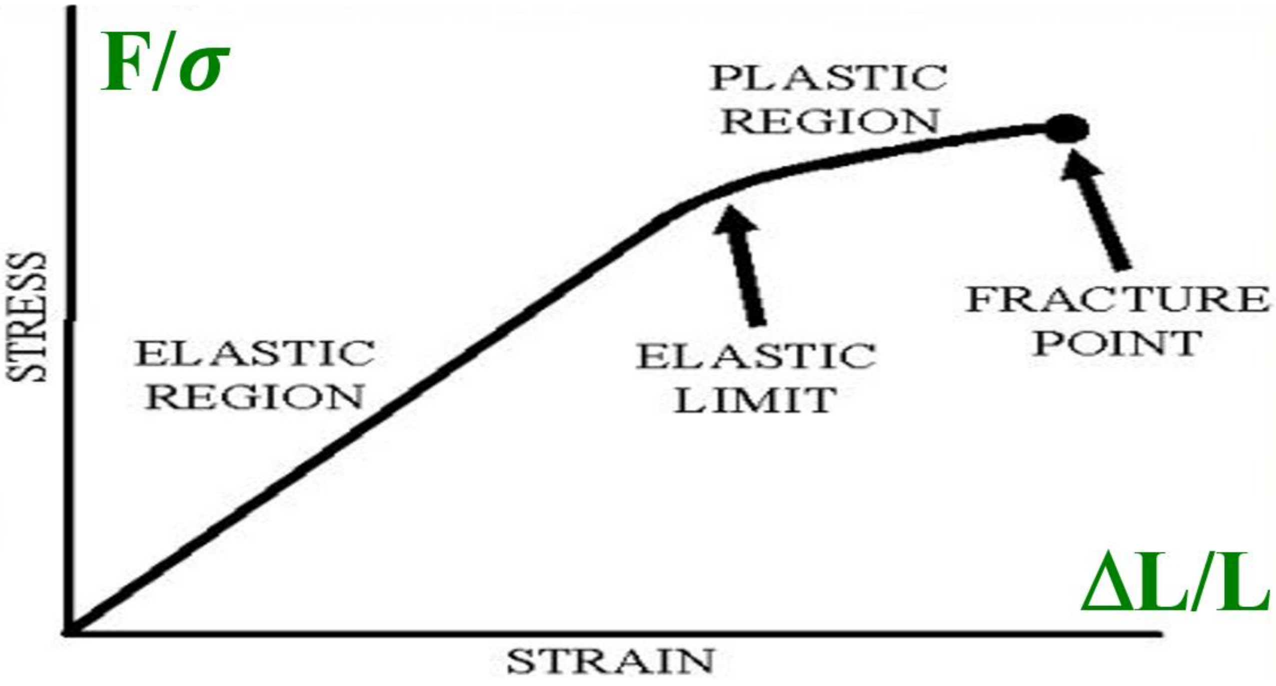






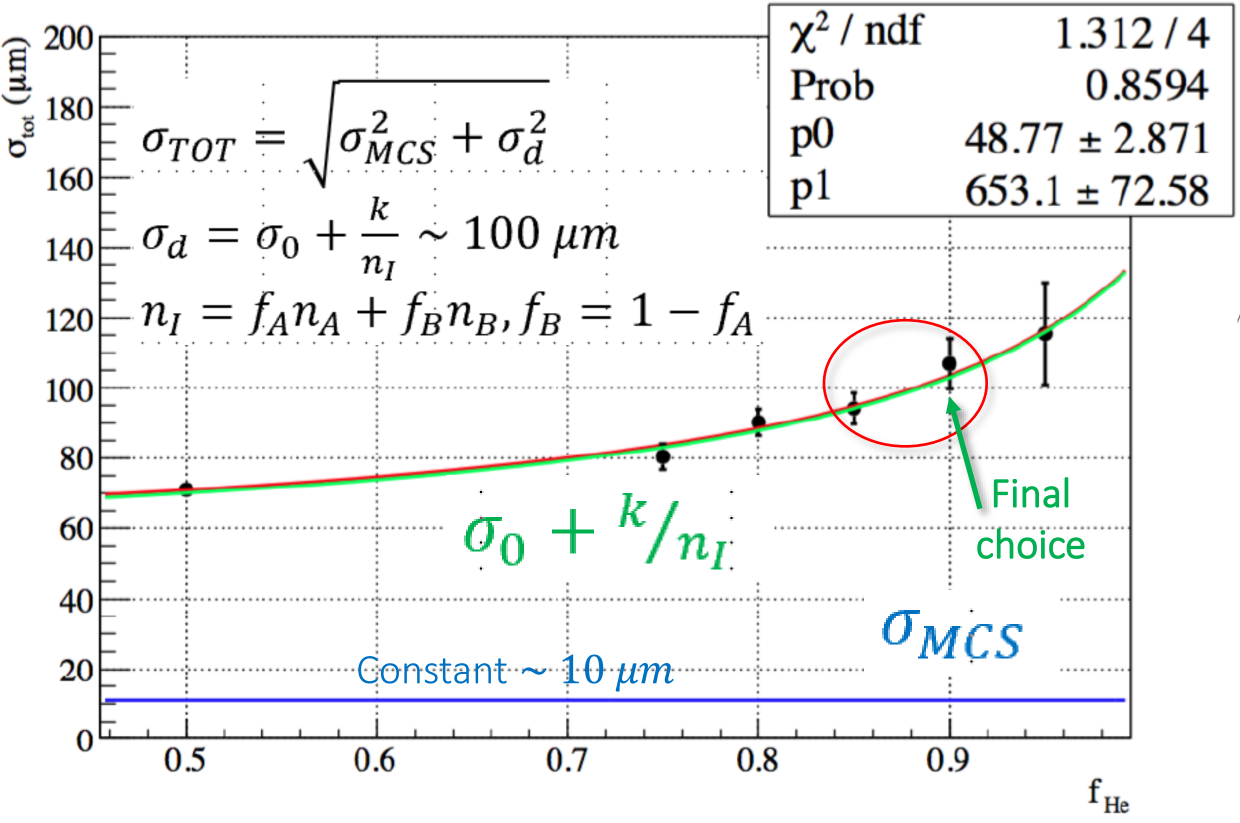
Mechanical properties of wires

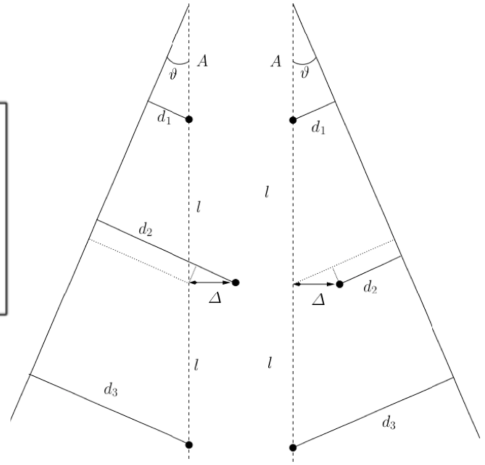




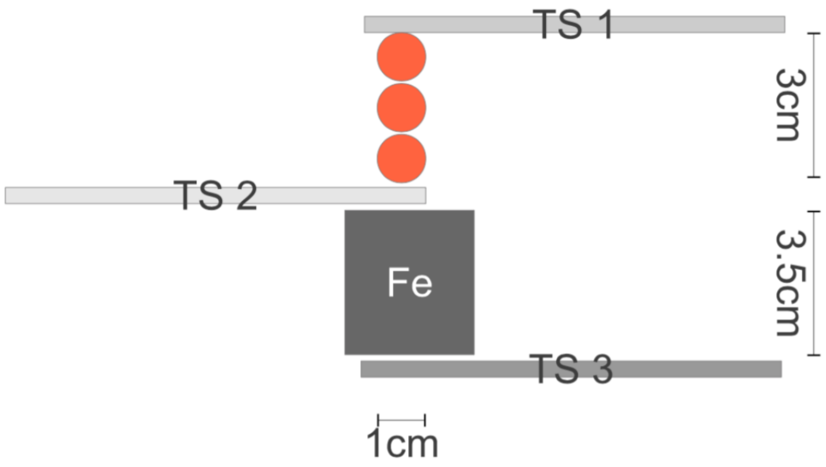
Single-hit resolution and gas choice

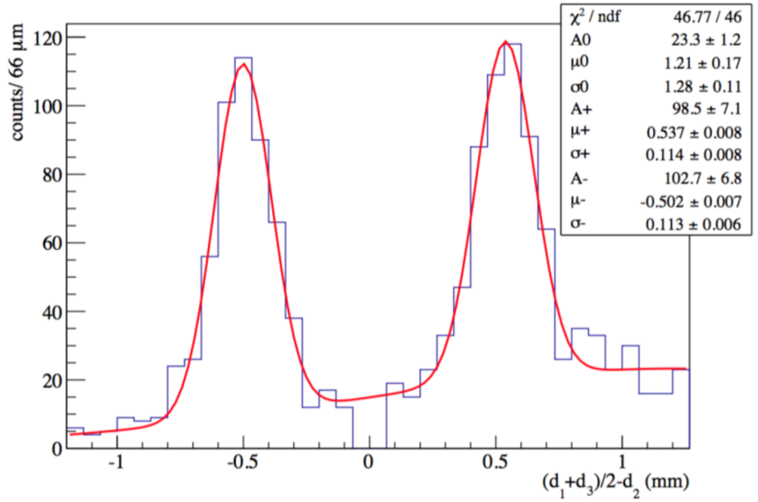
- Strictly connected to the gas mixture choice → measurement of σ_d vs f_A with **dedicated prototypes**
  - Final choice = **compromise between σ_d and material budget**
  - Base gas mixture → He:Isobutane 90:10





External Si telescope for the reference track

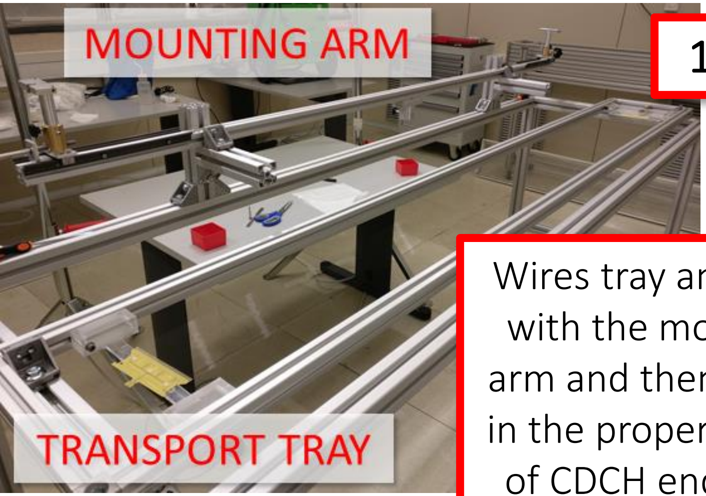




CDCH assembly

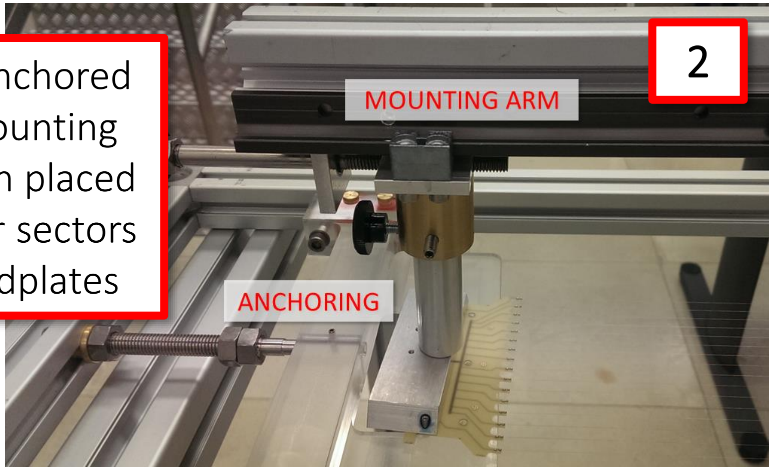
Modular assembly

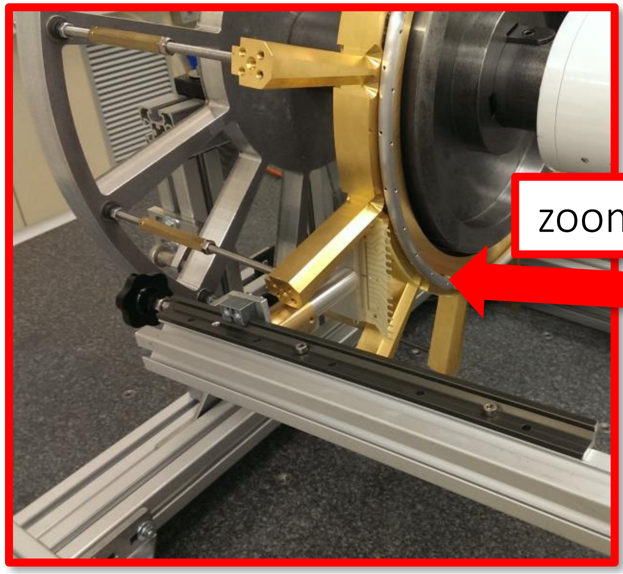
San Piero a Grado (INFN Pisa) cleanroom facility

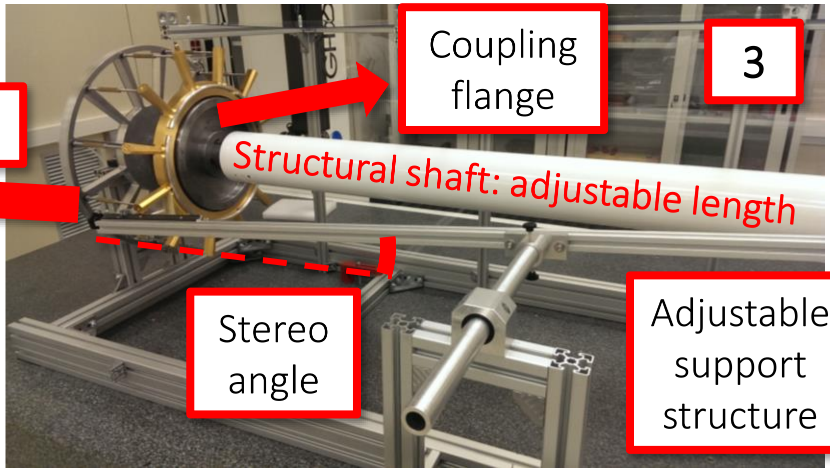


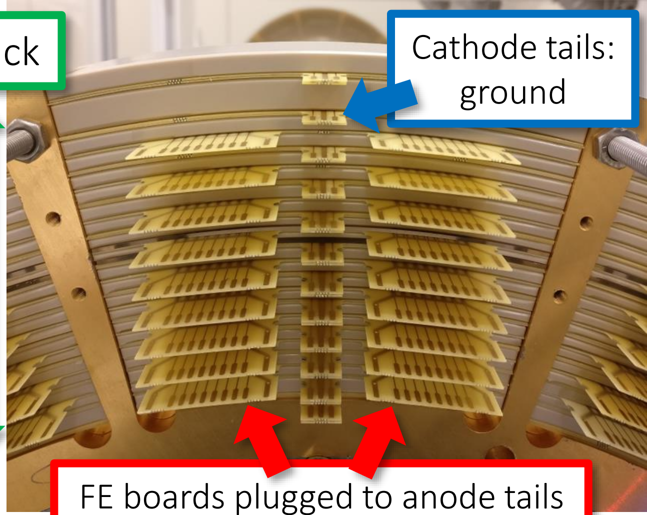
This operation is repeated for the 12 sectors in one layer and for all the wires layer

Wires tray anchored with the mounting arm and then placed in the proper sectors of CDCH endplates





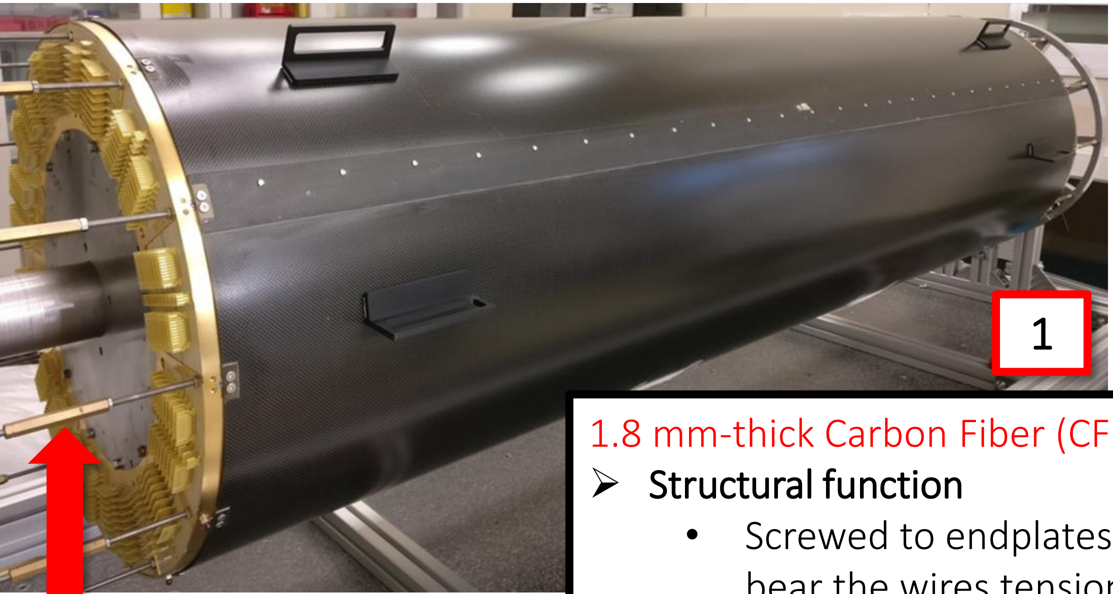


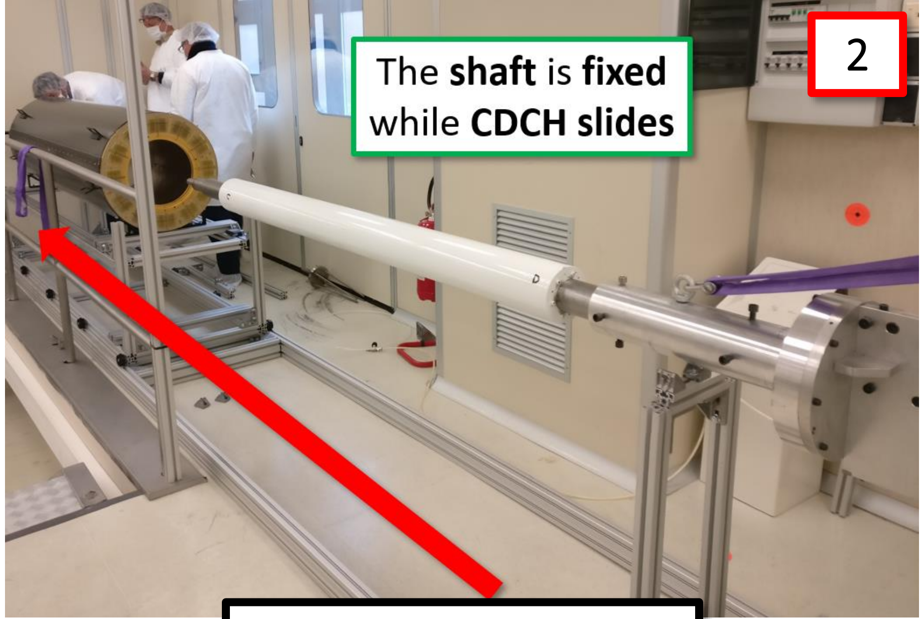


- Once each wires layer is mounted a geometry survey campaign with a Coordinate Measuring Machine (CMM) is performed to record the mounting position of each wire-PCB ($\approx 20\ \mu m$ accuracy)
- **Thickness of the PEEK spacers adjusted** to minimize the discrepancy from the nominal mounting radius

Sealing

San Piero a Grado
(INFN Pisa) facility

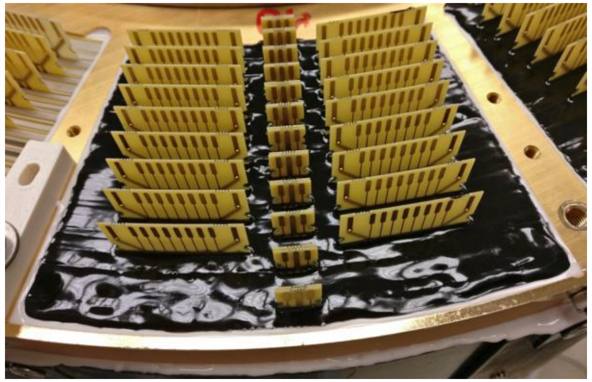




Central shaft extraction

- Fine geometry tuning by adjusting the positions of each individual spoke by acting on the 12 turnbuckles per side
- Endplate planarity and parallelism at a level better than 100 μm thanks to the CMM

1.8 mm-thick Carbon Fiber (CF) shell
- **Structural function**
  - Screwed to endplates to bear the wires tension and keep the CDCH length
- **Gas mixture tightness**
  - Sealing of CF perimeters and wire-PCBs stack with special encapsulants and adhesives (Stycast + ThreeBond)



- 20 μm-thick one-side aluminized Mylar foil at inner radius
- To separate the inner beam + target volume filled with pure He from the wires volume filled with He:IsoB 90:10 mixture

Assembly and sealing performed inside a cleanroom with a strict monitoring of temperature and relative humidity

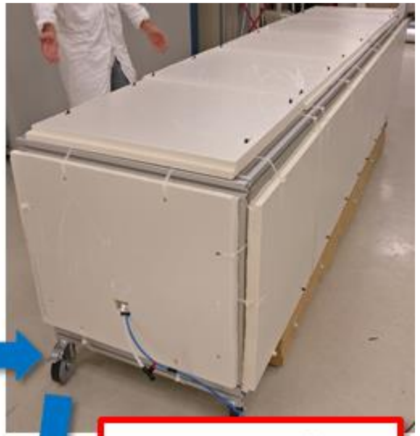
At this point CDCH was locked into a handling cage with a dumping system and transported to PSI for the commissioning activities

CDCH transport to PSI

CDCH packing

- First dumping system
  - ➢ CDCH-cage silent blocks
- First wrapping

- Second dumping system
  - ➢ Cage-floor rubber pillows
- Number of layers optimized to dump low frequency oscillations typical of a car travel



- Termal insulation panels

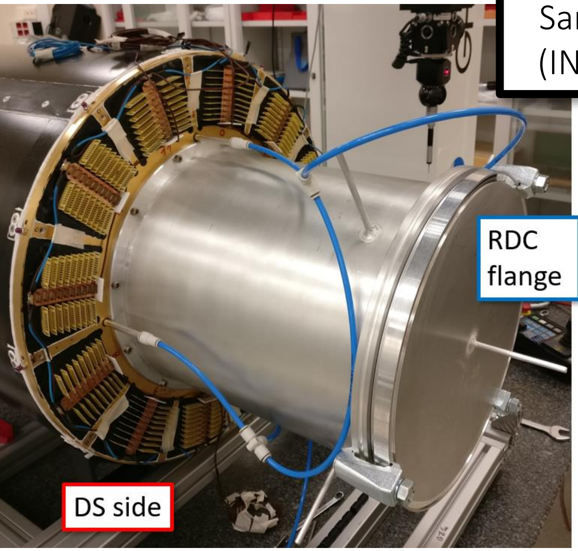
- Ready for packing

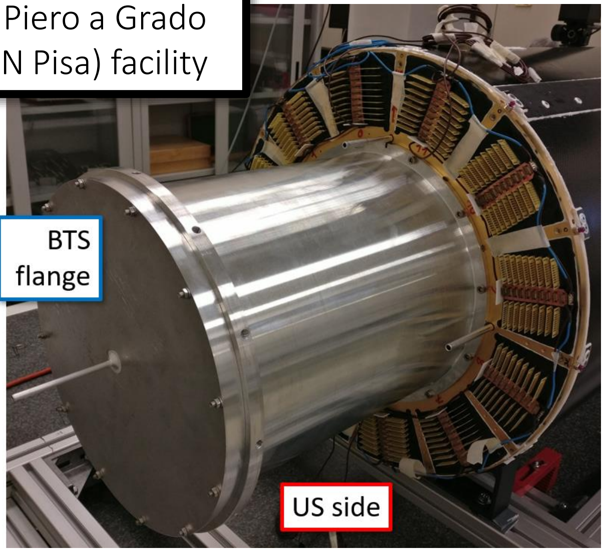
- Second wrapping

CDCH commissioning

External mechanical structures

San Piero a Grado (INFN Pisa) facility





Aluminum inner extensions to connect CDCH to the MEG II beam line

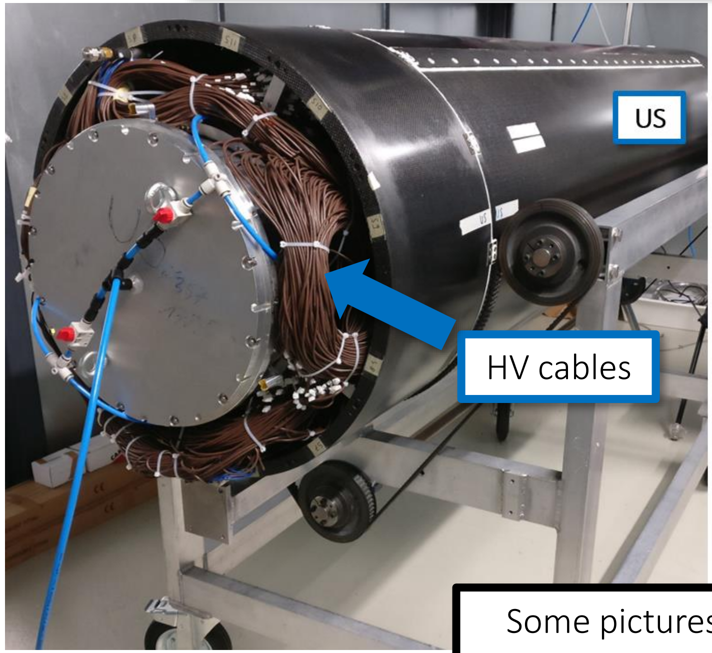
Mag (mm)
0.037
-0.010
-0.012
-0.019
-0.007
0.009
0.043
0.017
-0.020
-0.007
-0.013
-0.018

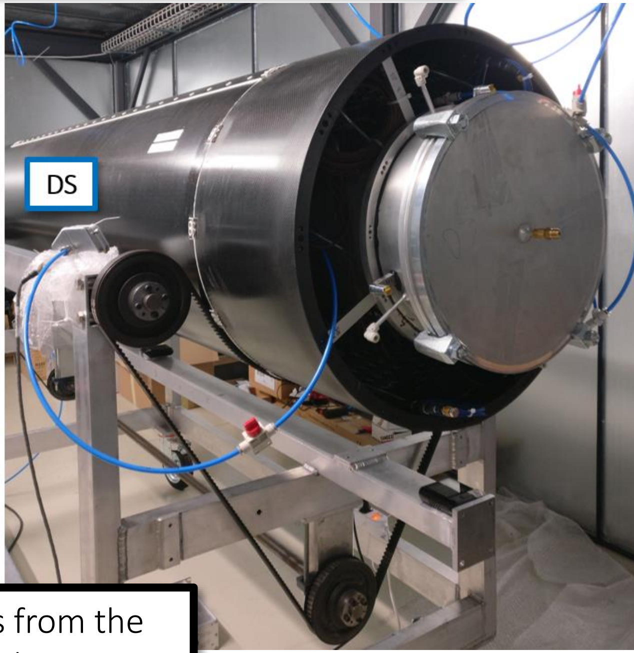
Mag (mm)
0.007
-0.000
-0.011
0.009
0.001
-0.004
-0.001
-0.003
0.005
-0.010
0.003
0.005

Endplate planarity check in the DAQ configuration

US DS

- External CF structure
  - Structural + gas tightness function
- **CDCH mechanics proved to be stable and adequate to sustain a full MEG II run and multiple handling operations during the maintenance periods**
  - **Survey measurements before/after a run show total agreement at the 10 μm level**

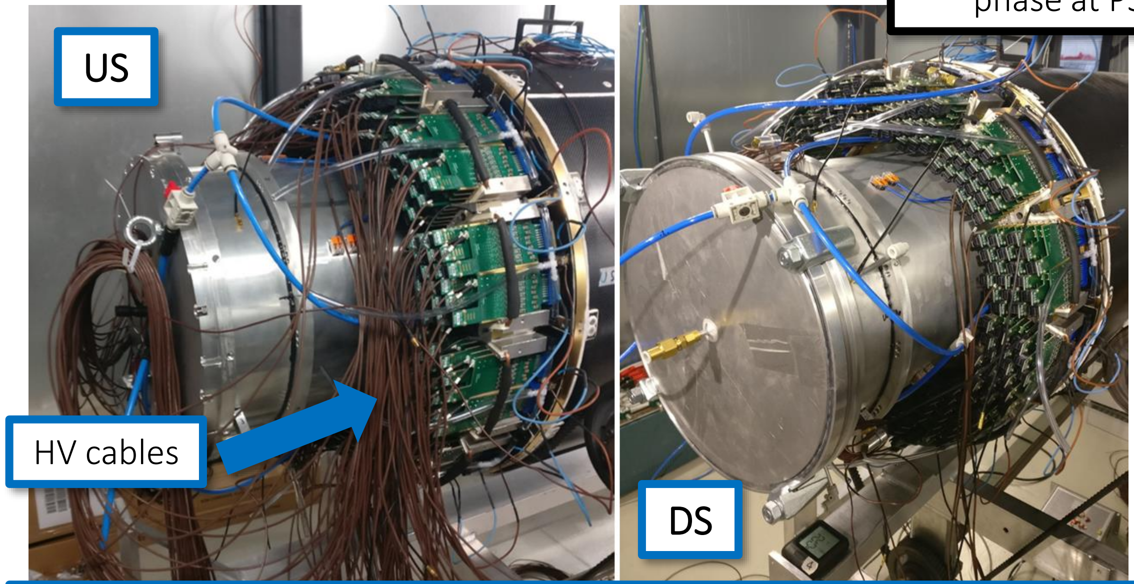


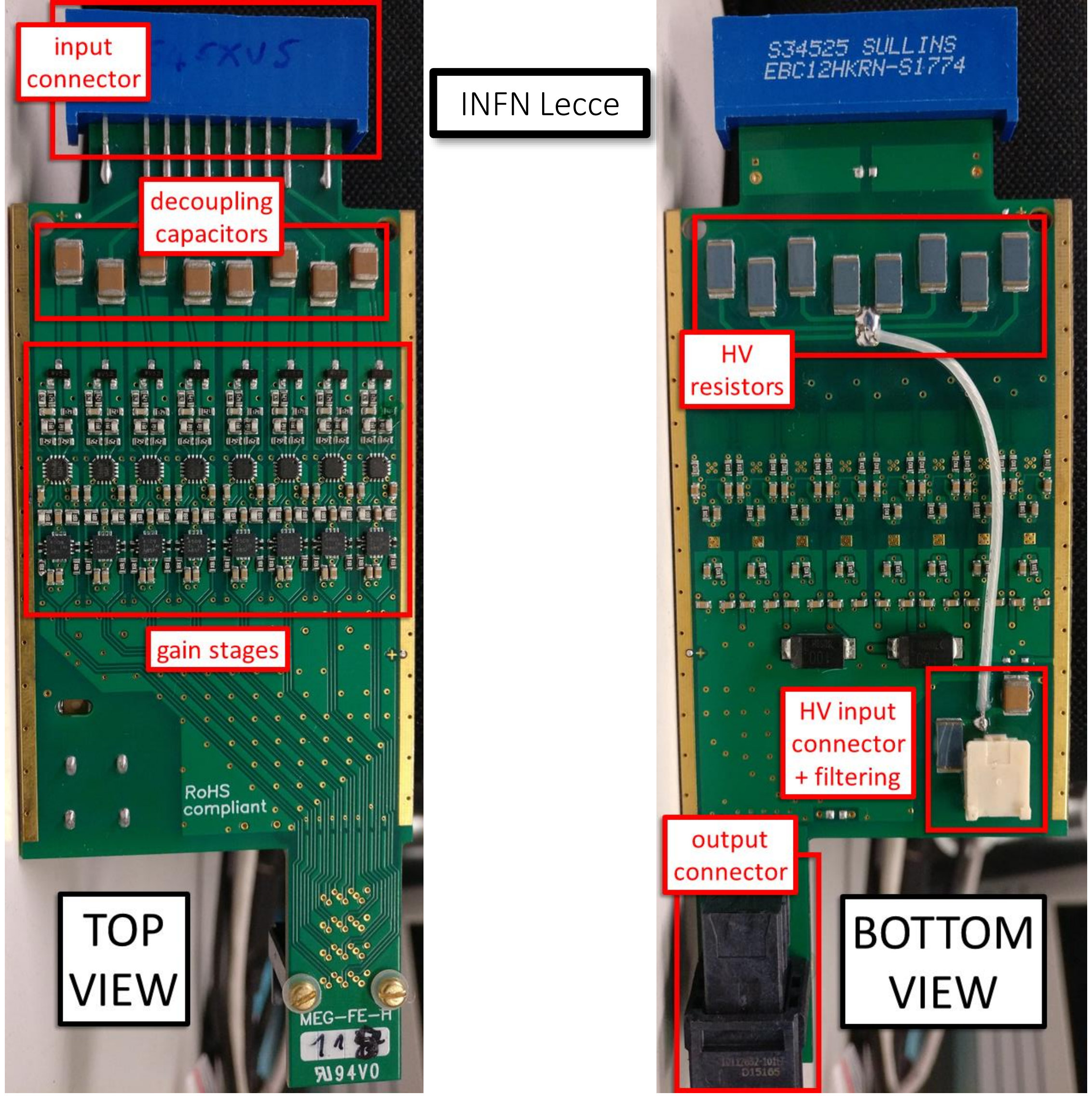


Some pictures from the commissioning phase at PSI

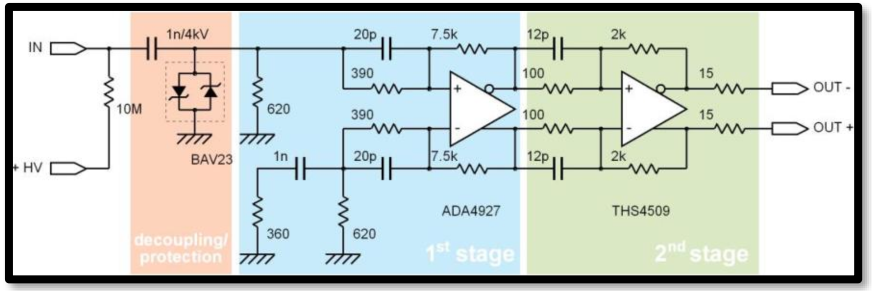
FE electronics

Some pictures from the commissioning phase at PSI

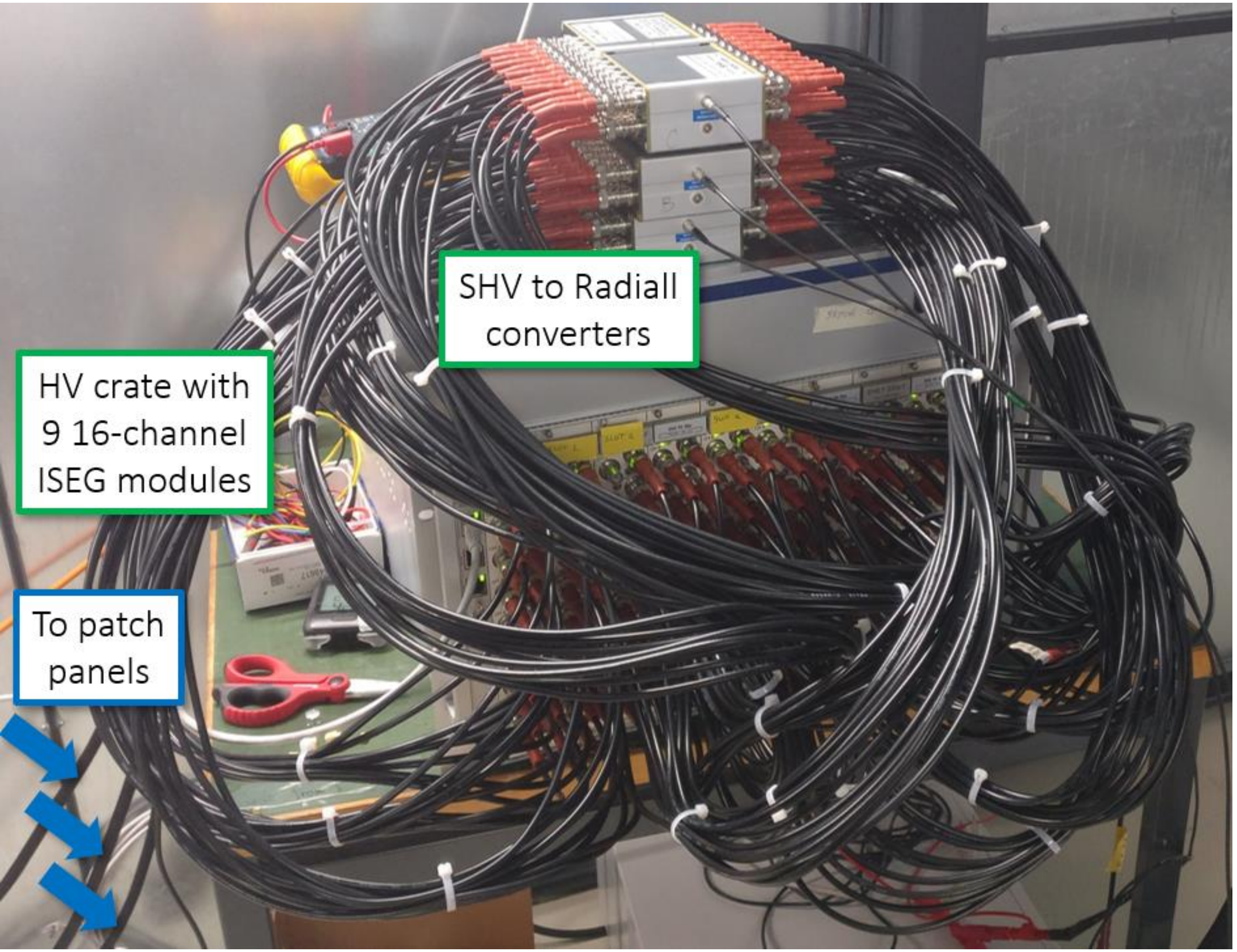




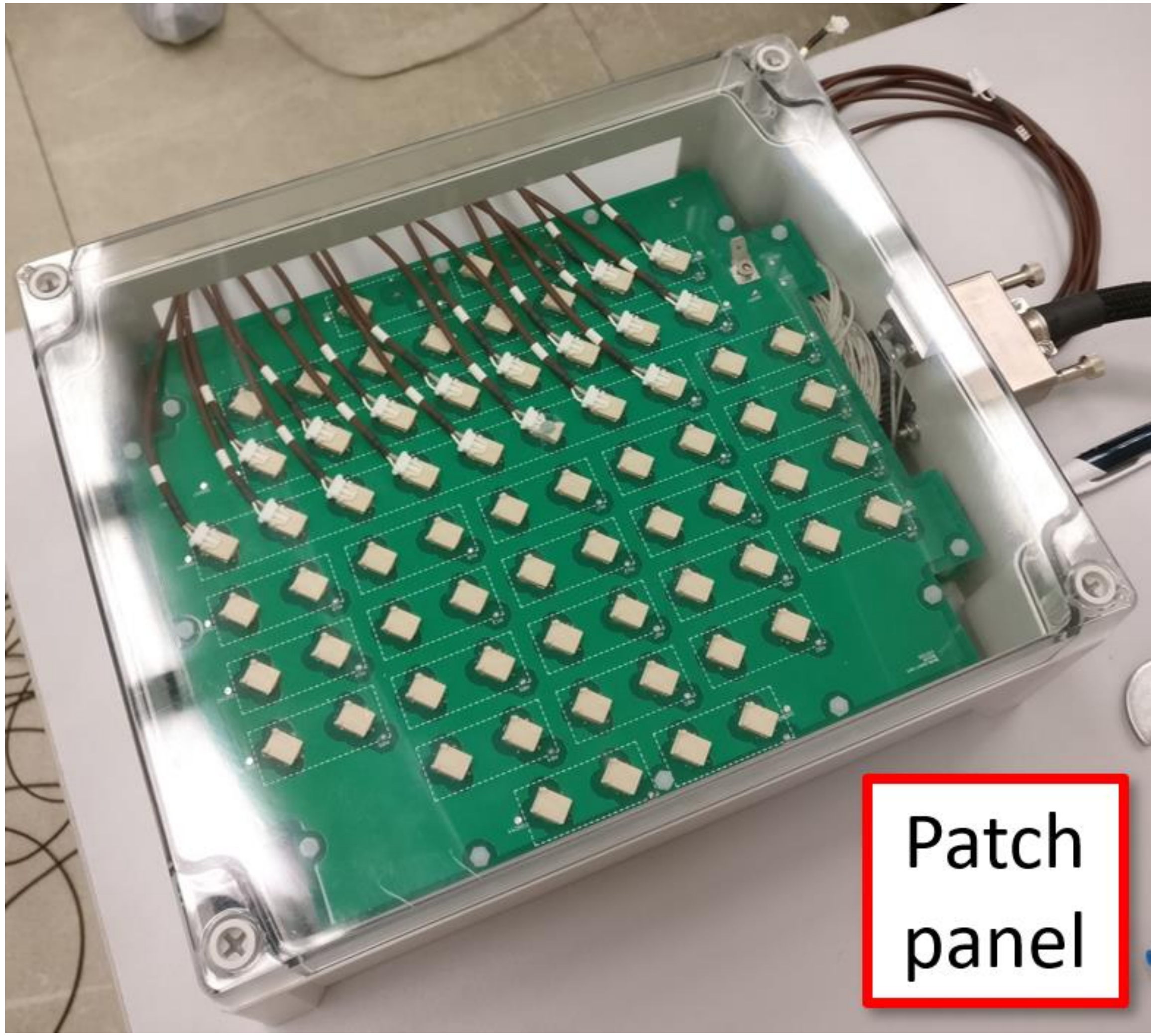
- 216 FE boards per side
  - 8 differential channels to read out signal from 8 cells
  - Double amplification stage with low noise and distortion
  - High bandwidth of nearly 400 MHz
    - To be sensitive to the single ionization cluster and improve the drift distance measurement (cluster timing technique)
- Signal read out from both CDCH sides
- HV supplied from the US side



HV distribution



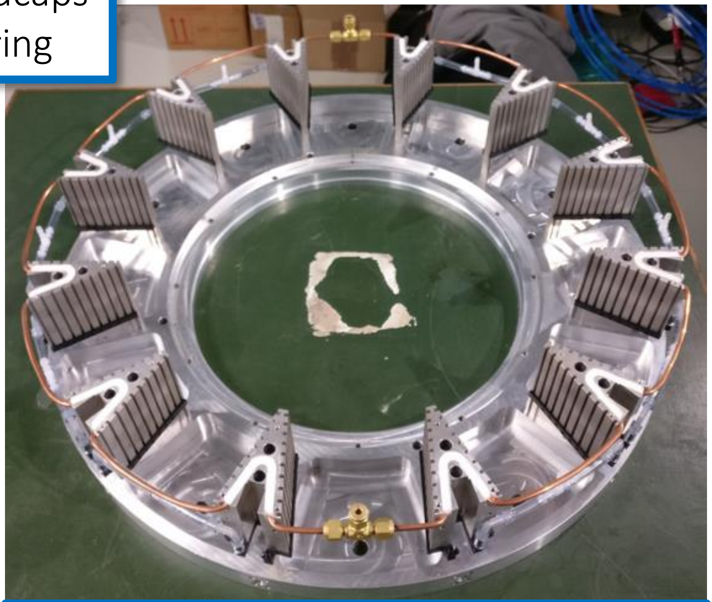
HV crate



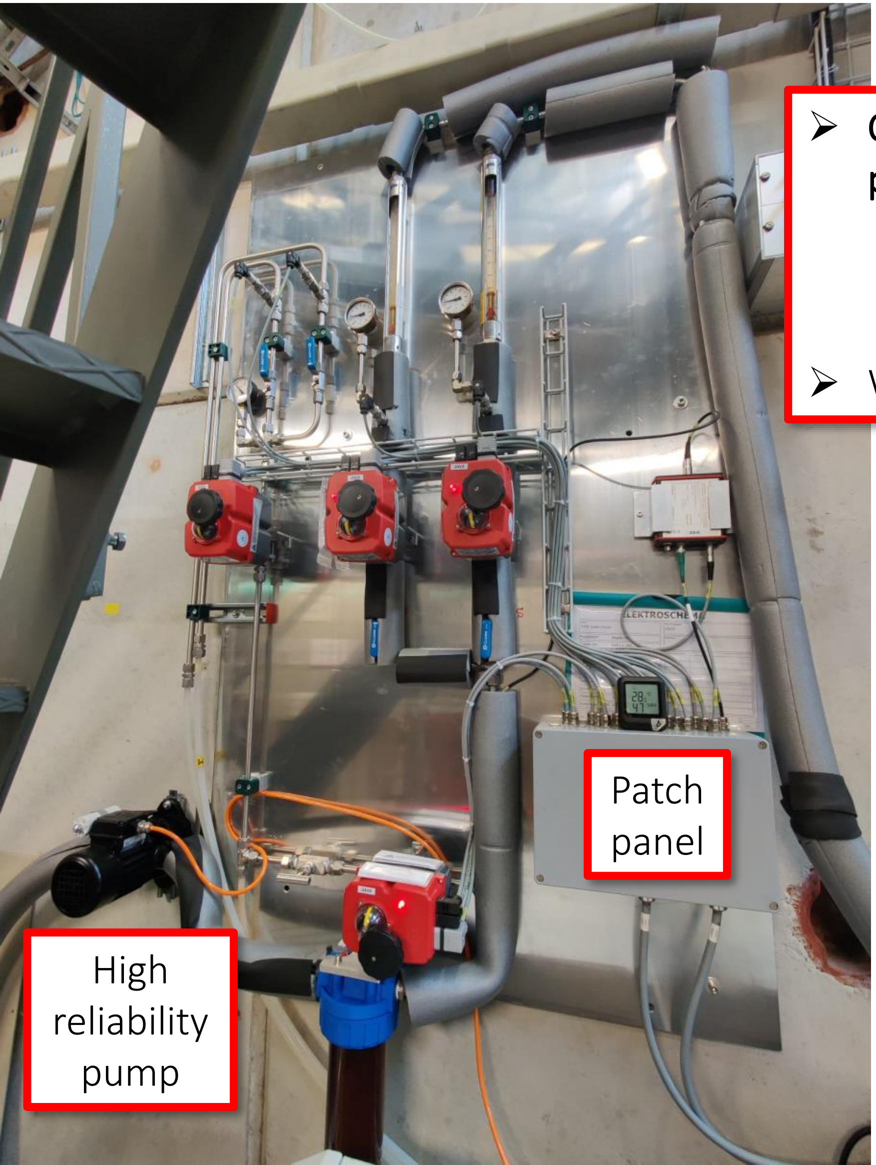
HV distribution

Cooling system

Several T and RH sensors are placed inside the endcaps for monitoring



- **Cooling system water distribution panel** with active components
  - 4 proportional valves
  - 4 pressure sensors
  - 1 flowmeter
- We kept the manual components



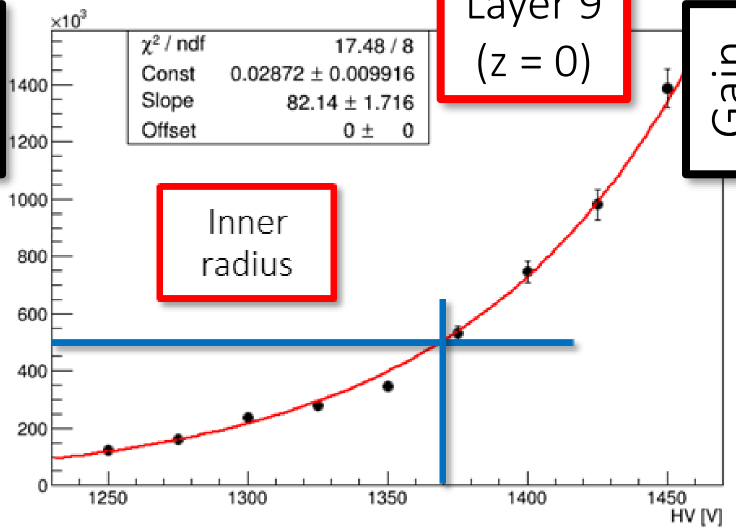
Patch panel

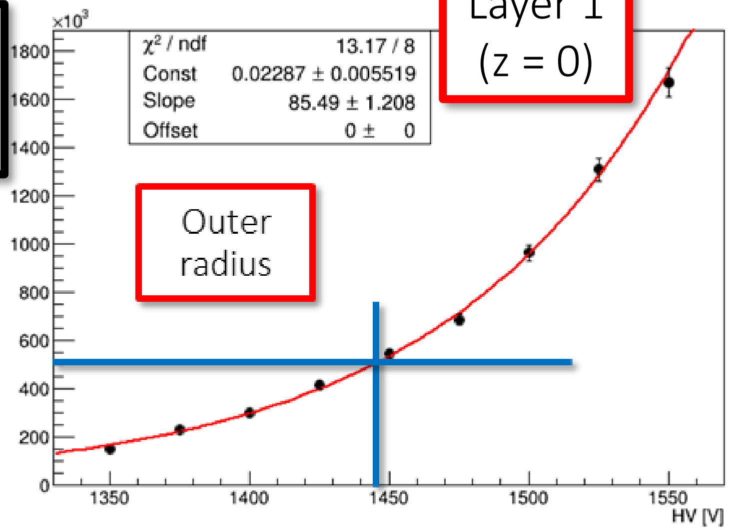
High reliability pump

Slow control (SCS 3000) crate with 3 power supply units (60 W each) and 2 input/output modules
- **Valve control via software**
- **Valves/sensors history available**

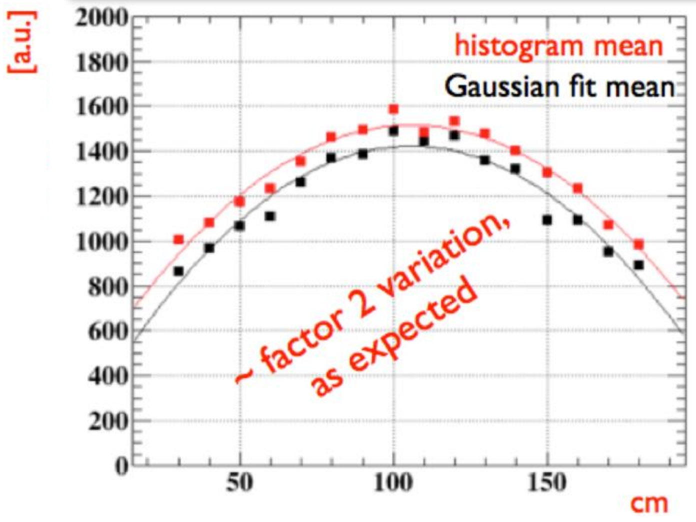
- FE electronics cooling system embedded in the board holders
  - Power consumption for each channel: 40 mA at 2.2 V
  - Heat dissipation capacity granted by a **1 kW chiller system**: 300 W/endplate
- Dry air flushing inside the endcaps to avoid water condensation on electronics and dangerous temperature gradients

HV working point





Expected **gain variation vs. longitudinal coordinate *z*** given the CDCH hyperbolic shape



- **Garfield simulations on single electron gain**
  - Gas mixture He:Isobutane 90:10 and P = 970 mbar (typical at PSI)
- Working point → HV for gas gain $G = 5 \times 10^5$
  - To be sensitive to the single ionization cluster

HV tuning by 10 V/layer to compensate for the variable cell dimensions with radius and z

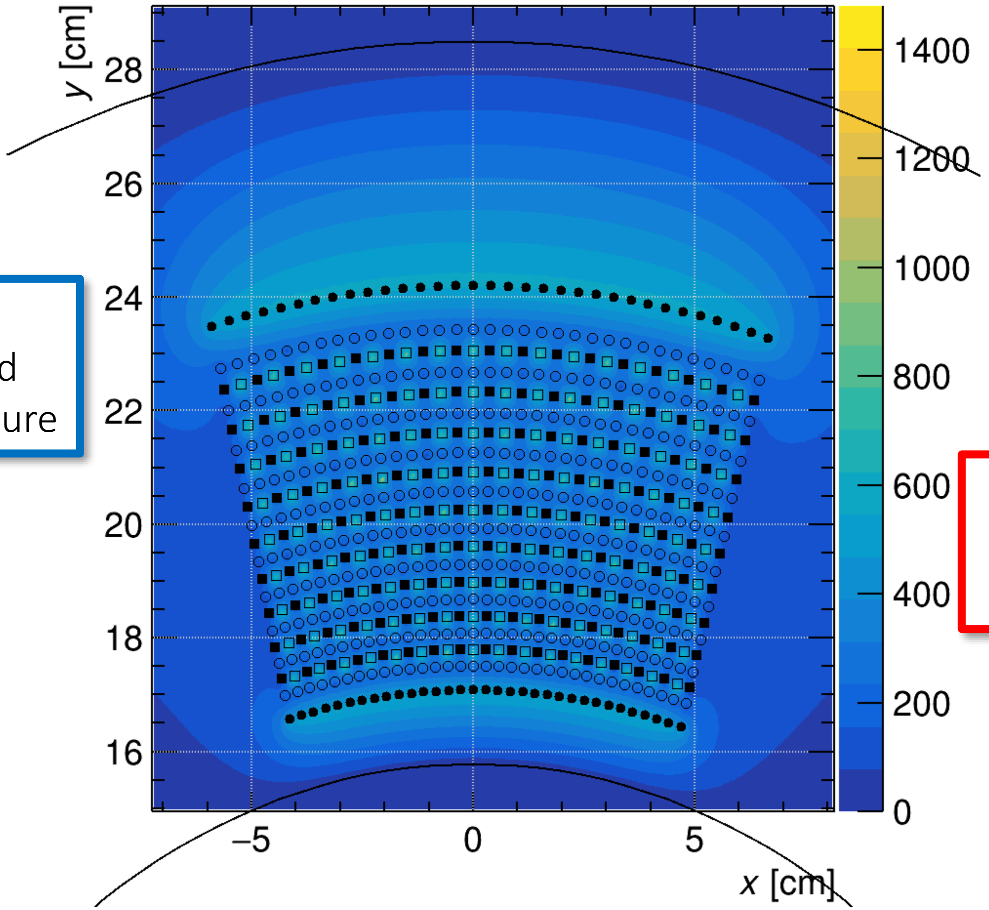
L1	L2	L3	L4	L5	L6	L7	L8	L9
1480 V	1470 V	1460 V	1450 V	1440 V	1430 V	1420 V	1410 V	1400 V

Outer layer — Inner layer

Average HV Working Point (WP) as a function of the layer

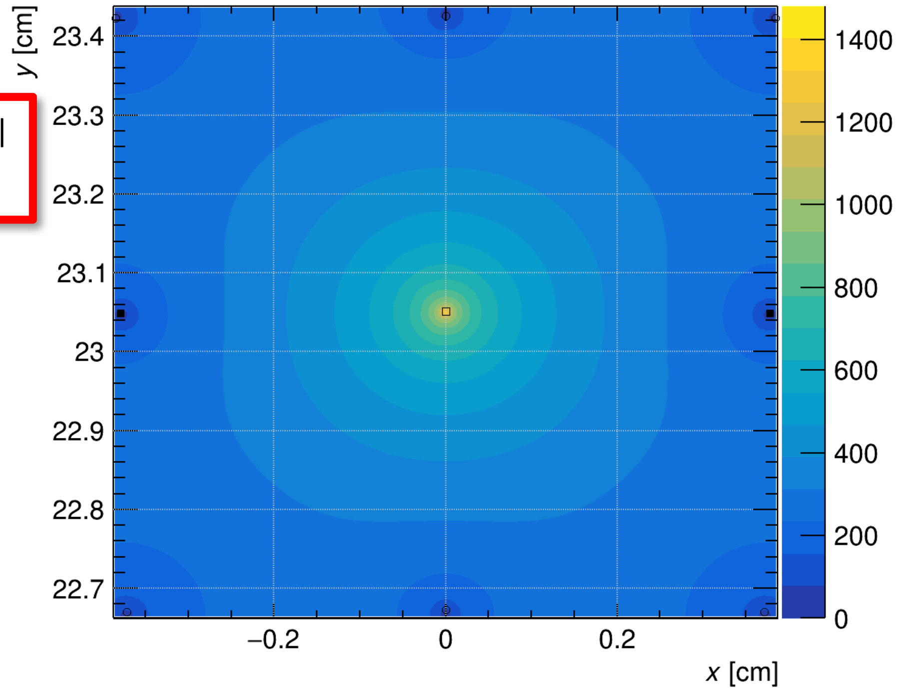
100 V safety margin above the HV WP to recover the gain drop with time

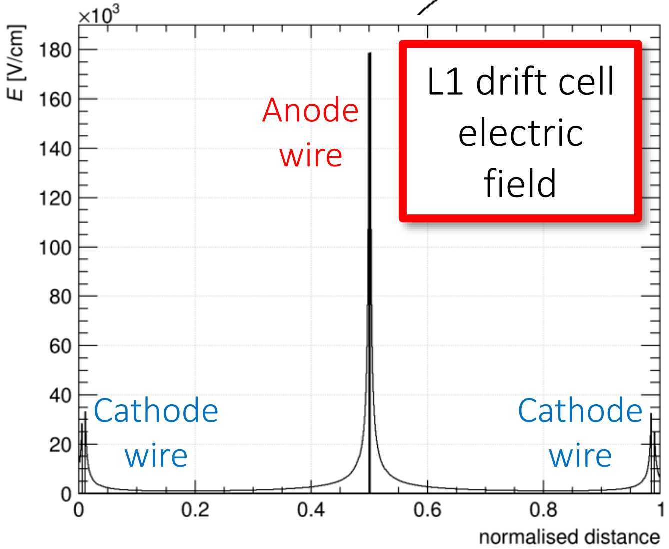
Garfield++
with HV WP and
standard gas mixture



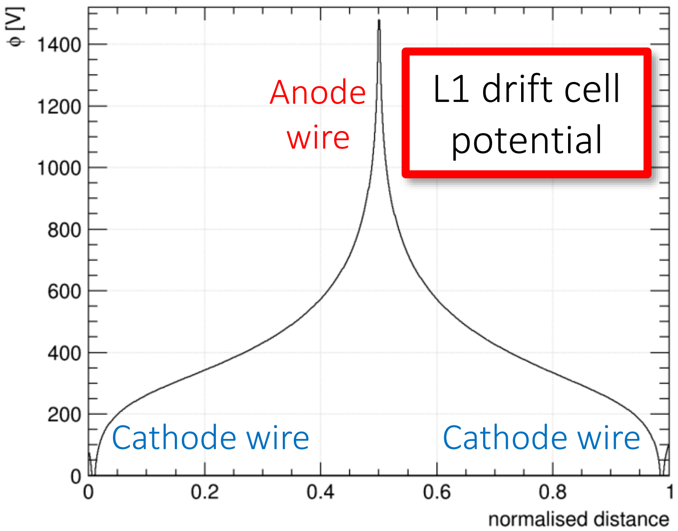
One 30° sector potential

L1 drift cell potential



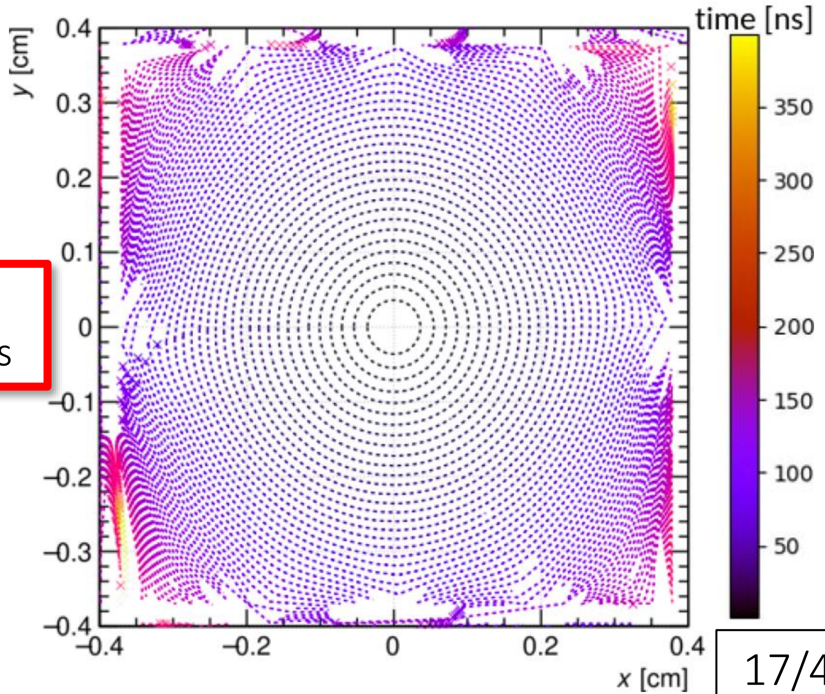


L1 drift cell electric field

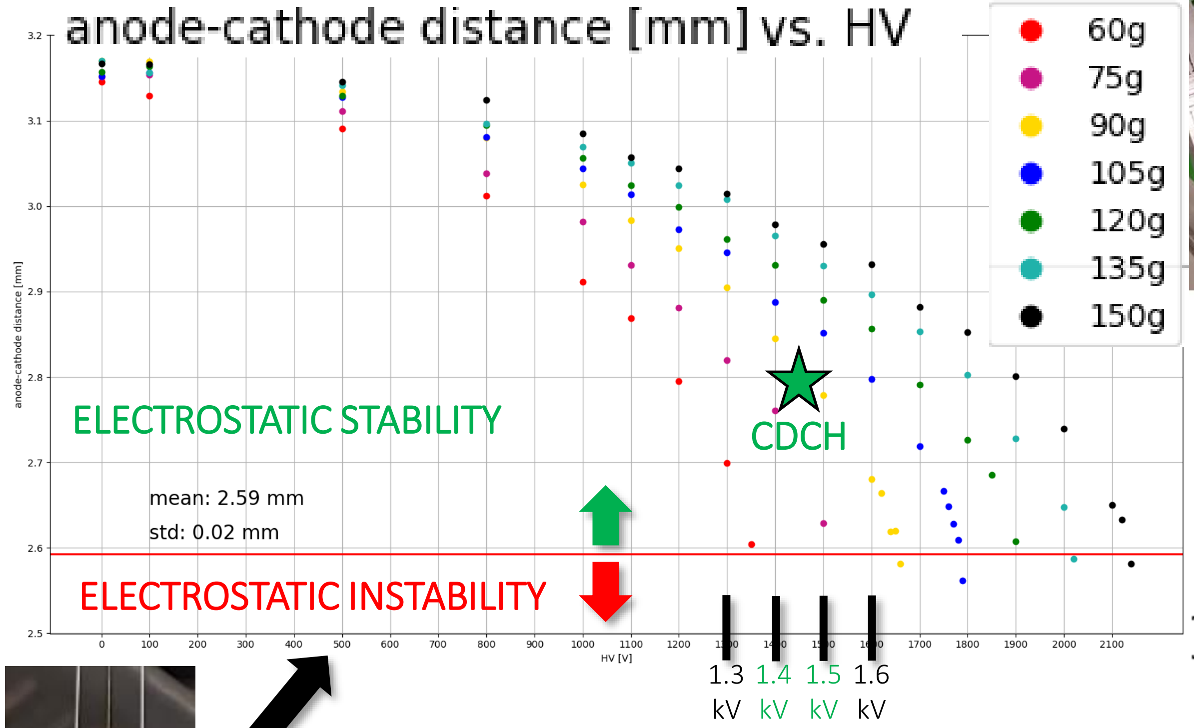


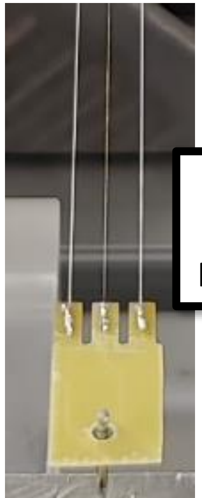
L1 drift cell potential

Example isochrones

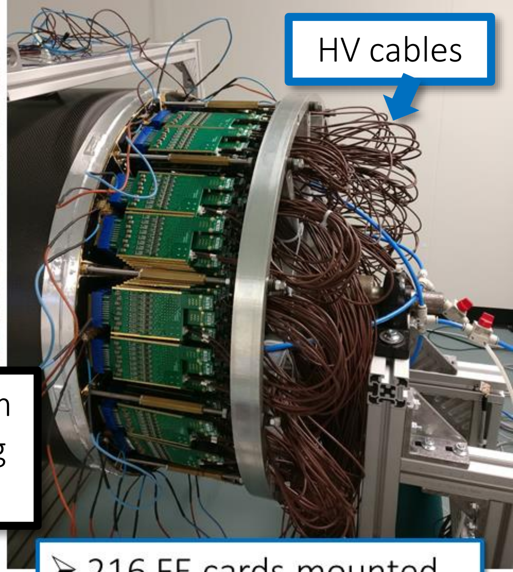


Working length





2 m-long 3-wires prototype in the MEG lab at INFN Pisa

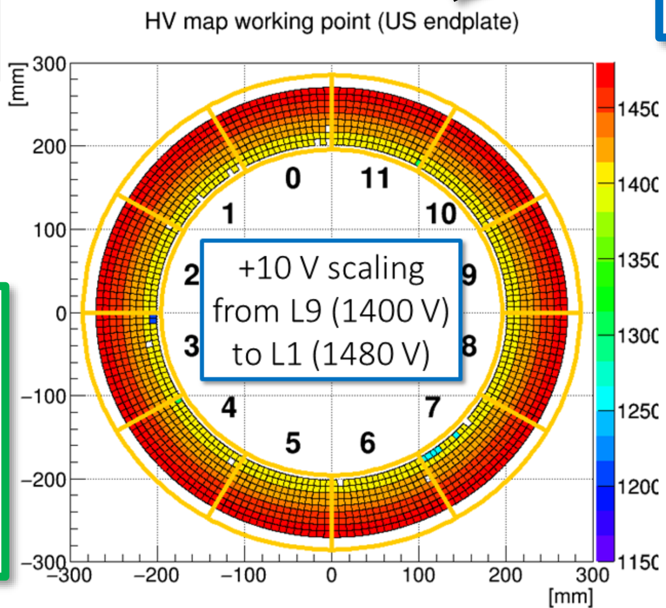


Some pictures from the commissioning phase at PSI

- CDCH temporarily sealed with CF + Al tape
- Nitrogen flux

- 216 FE cards mounted on the US side

Final CDCH length experimentally found through systematic HV tests at different lengths/wires elongations

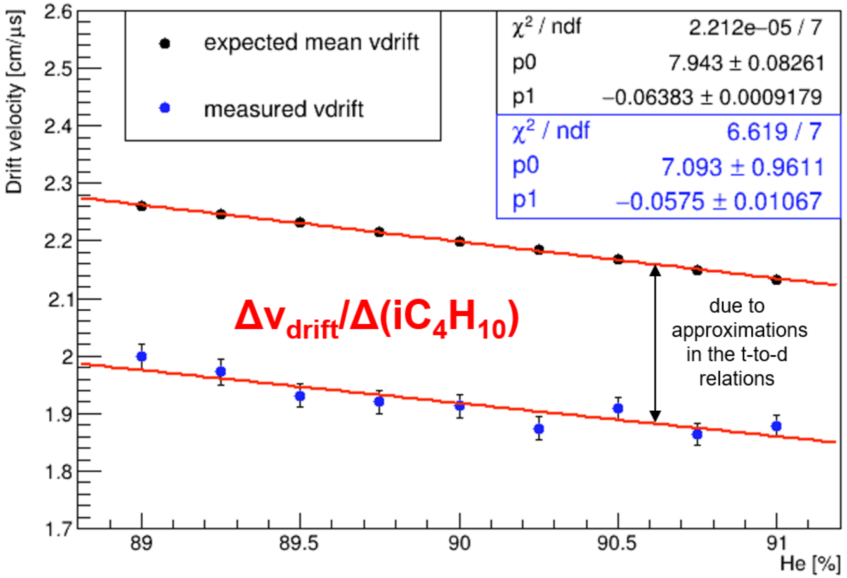


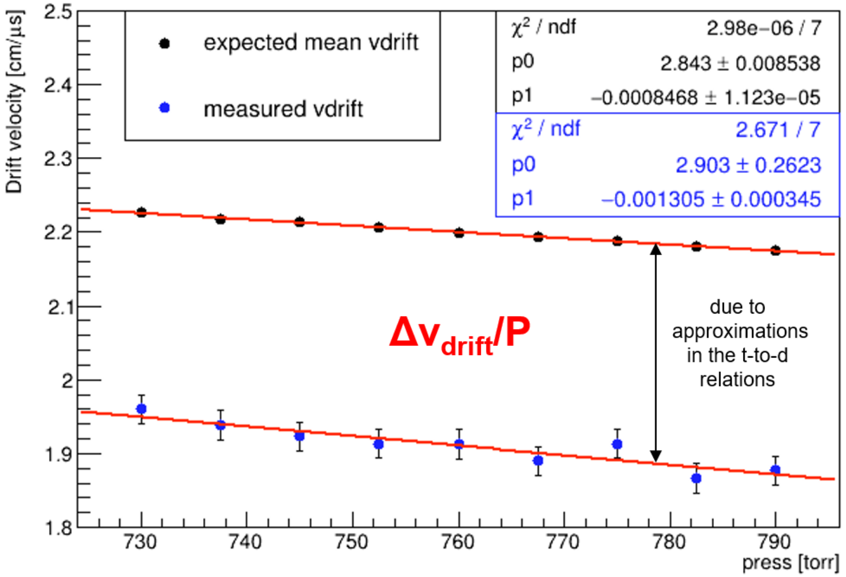
Cell inefficiency experimentally measured

- Negligible in e^+ reconstruction
  - 0.5% worsening in resolutions

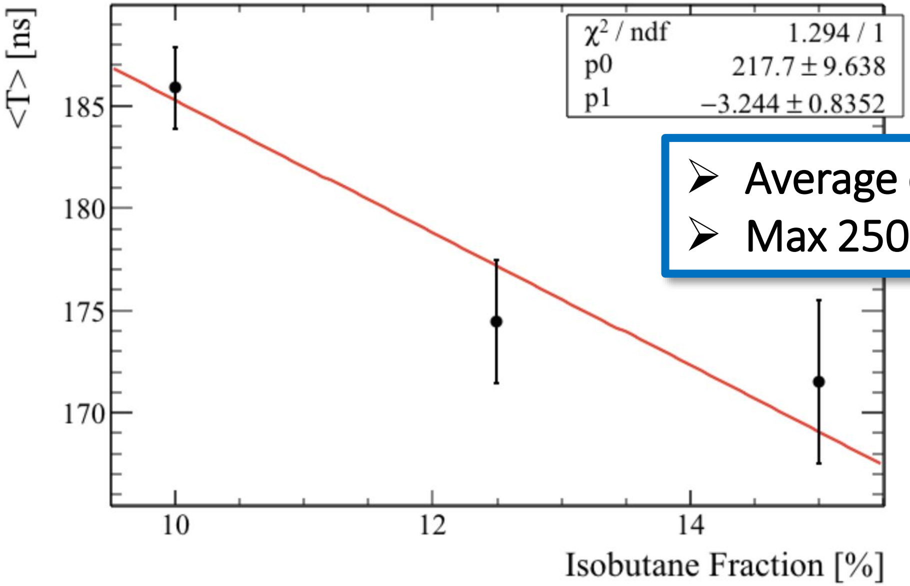
- Tests performed in 2019 and 2020 at PSI inside a cleanroom
- CDCH length adjusted through geometry survey campaigns with a laser tracker (20 μm accuracy)
- **Final length set to +5.2 mm of wires elongation**
  - **65% of the elastic limit**

Drift velocity and time

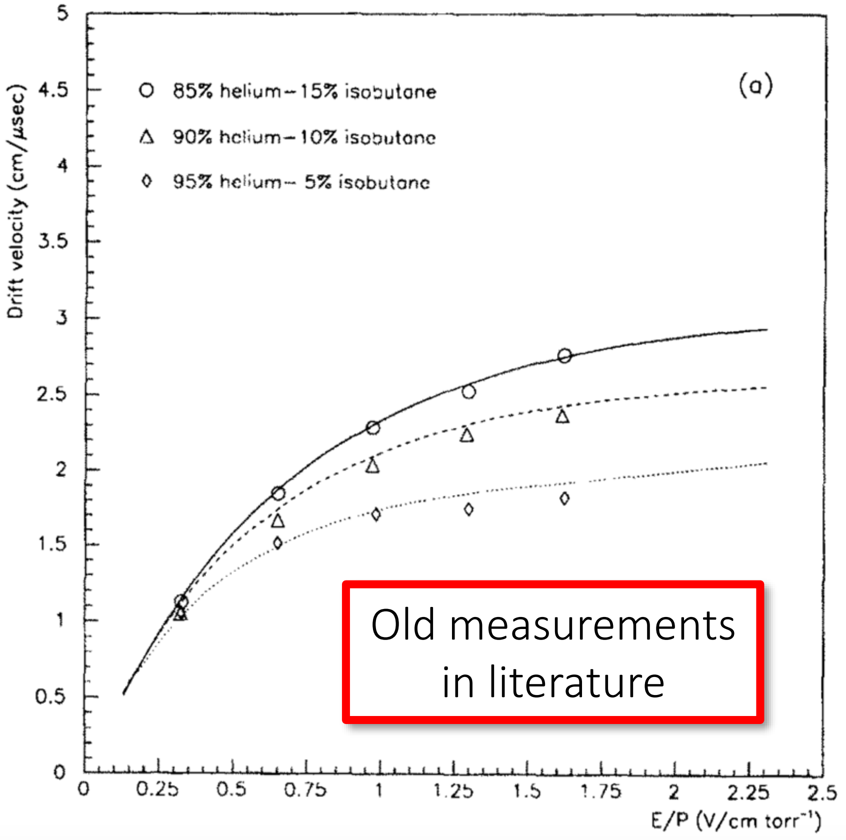




Measurements with an auxiliary **monitoring chamber**



- **Average drift time**
- **Max 250 ns** (drift cell corner)

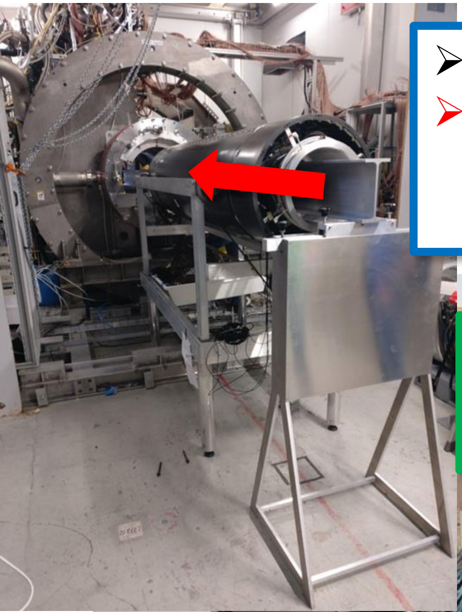


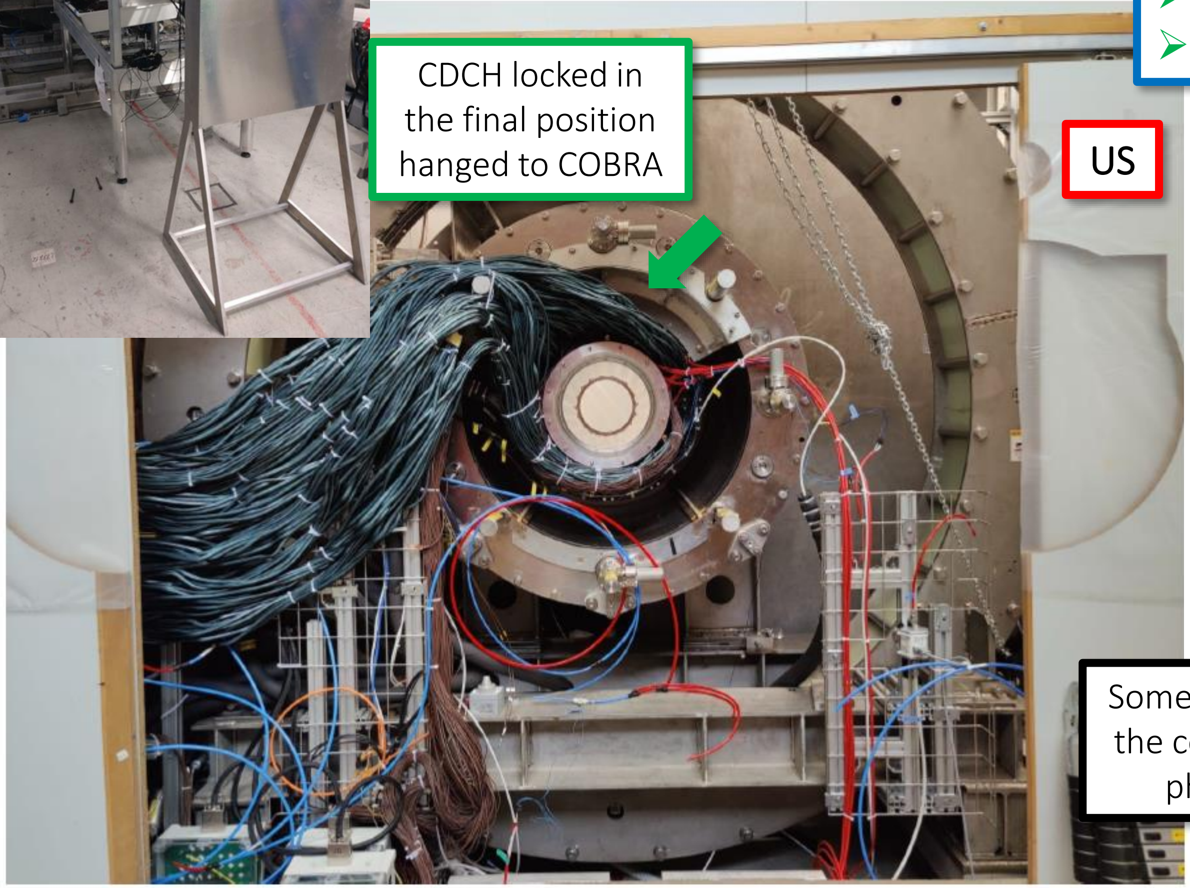
Old measurements in literature

Integration into the MEG II apparatus

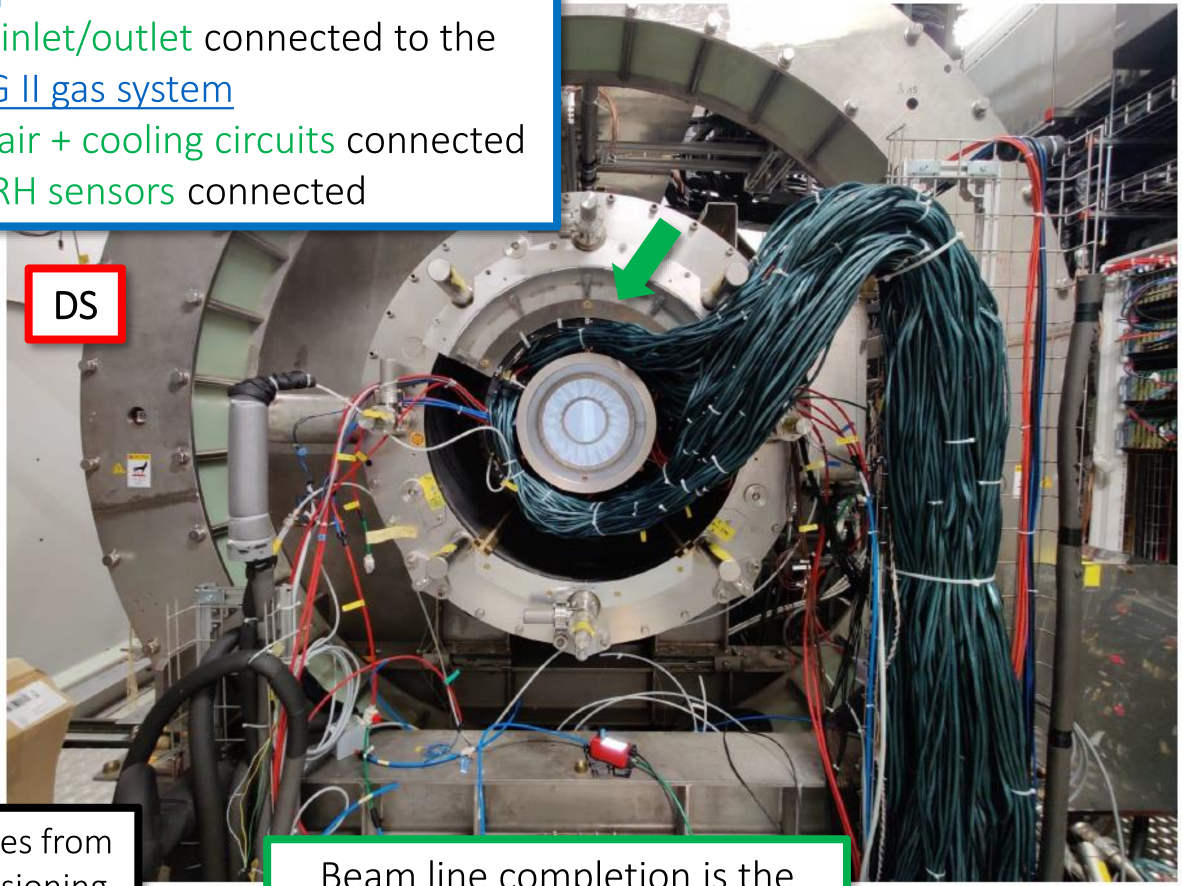
- CDCH inside the experimental area
- Insertion rail through the inner volume to slide CDCH inside the COBRA magnet

- HV + signal cabling completed for the possible 2π read out
- Gas inlet/outlet connected to the MEG II gas system
- Dry air + cooling circuits connected
- T + RH sensors connected





CDCH locked in the final position hanged to COBRA



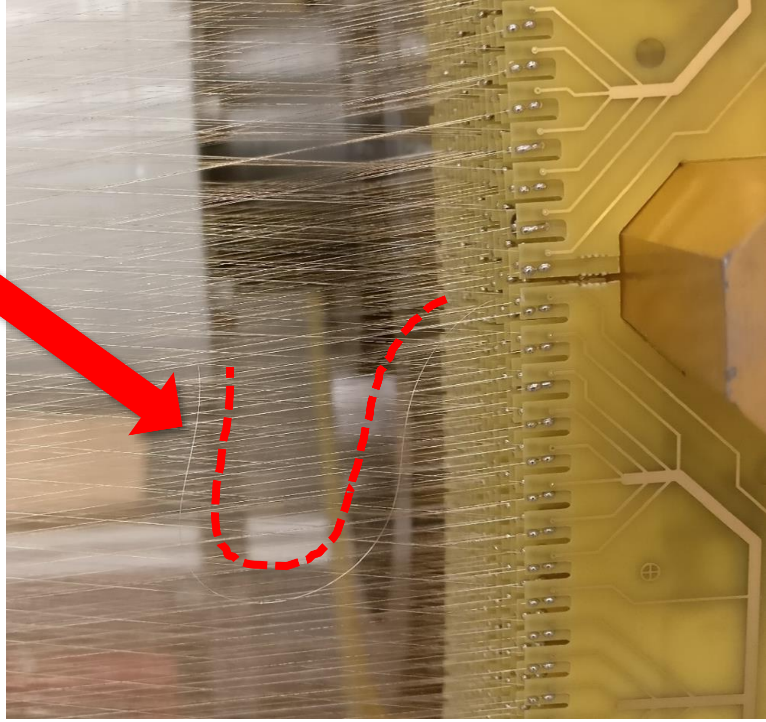
Some pictures from the commissioning phase at PSI

Beam line completion is the last operation (not shown here)

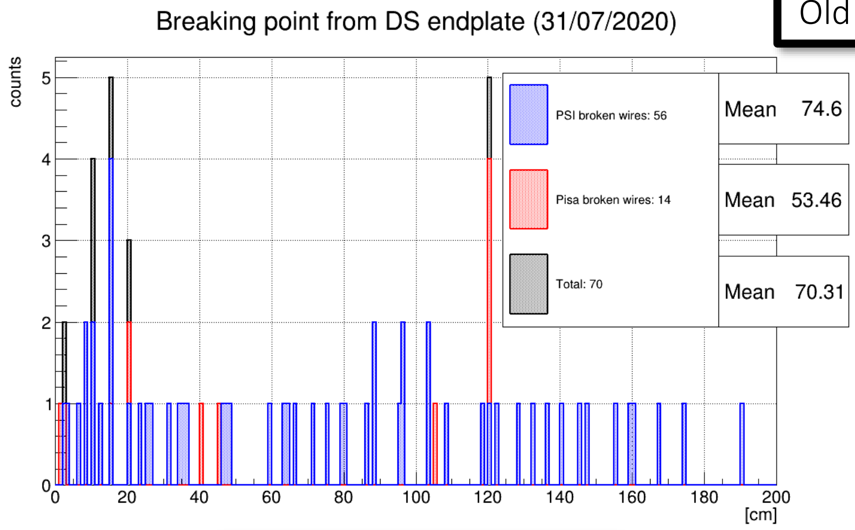
Investigations on wire breakages

Wire breakages

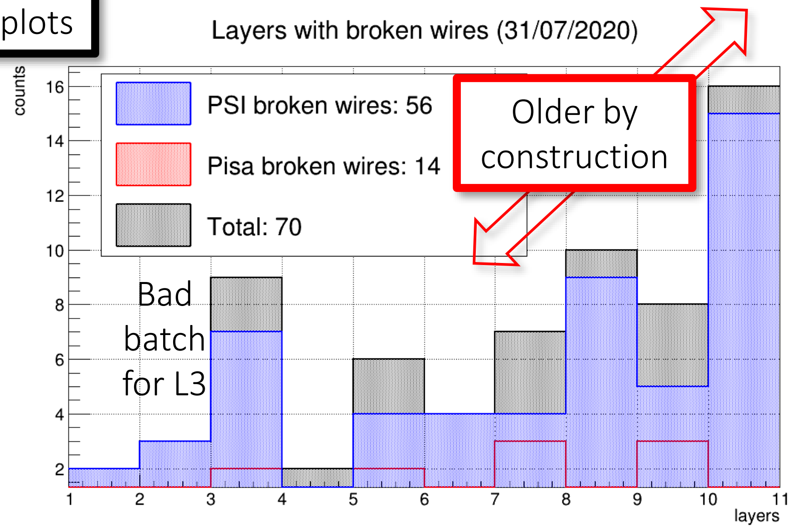
- During assembly at Pisa and the final lengthening operations at PSI we experienced the breaking of aluminum wires in the chamber
  - Mainly the 40 μm cathodes were affected
  - A few 50 μm cathodes and guards
- **107 broken wires in total during CDCH life** (14 at Pisa)
  - 97 broken 40 μm cathodes (90%)
- **Consequent delay in construction and commissioning**



Old plots

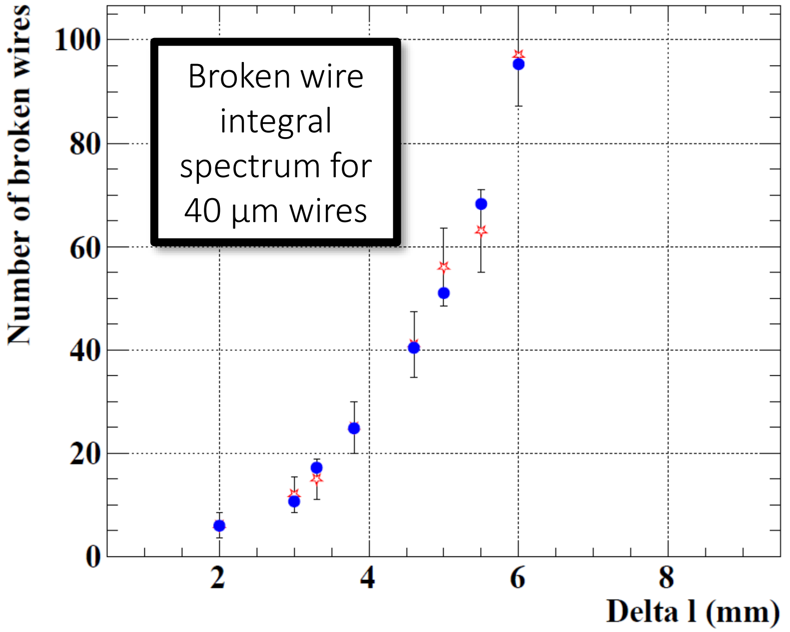


Wires length ≈ 193 cm

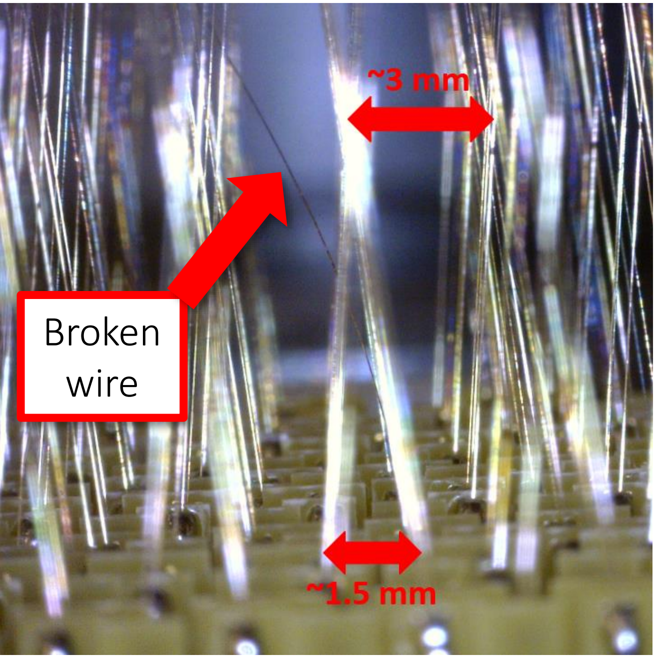


Outer layers

Inner layers



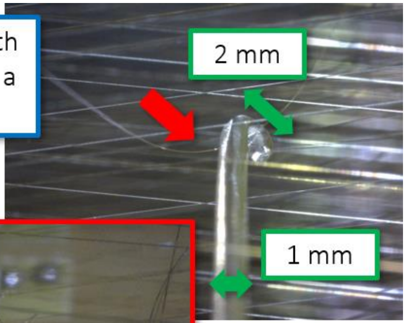
Broken wires extraction



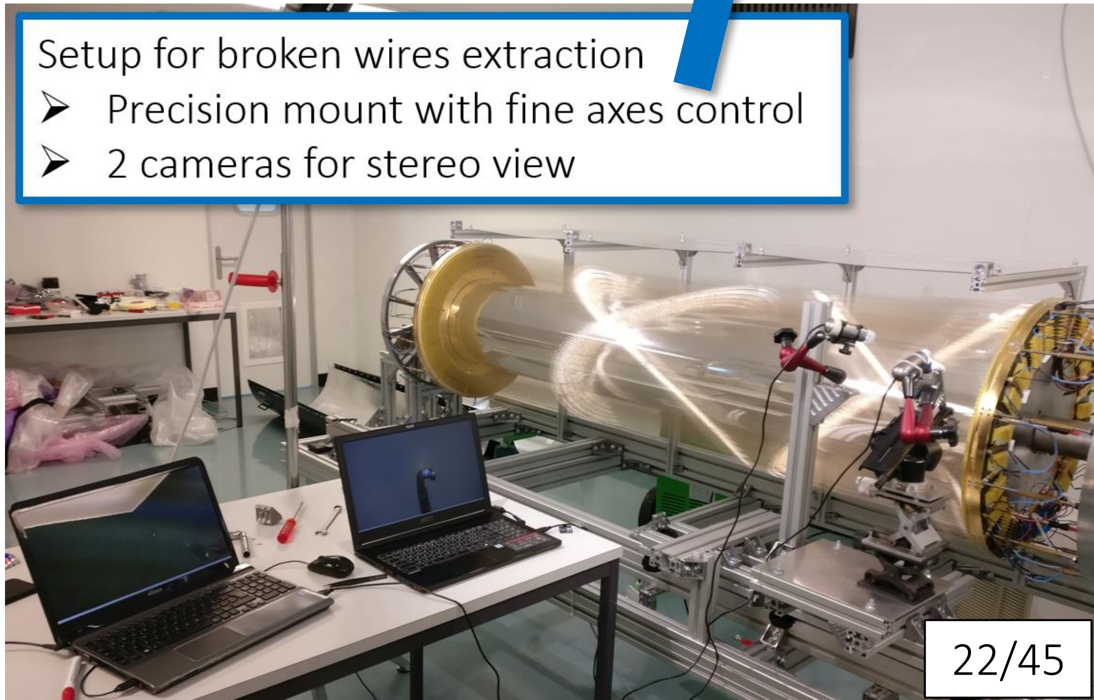
- Each broken wire piece can randomly put to ground big portion of the chamber
- They must be removed from the chamber
  - Very delicate and time-consuming operation
- We developed a safe procedure to extract the broken wires from inside CDCH
  - Exploiting the radial projective geometry given by the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

Commercial camera mount with precision movements for all axes

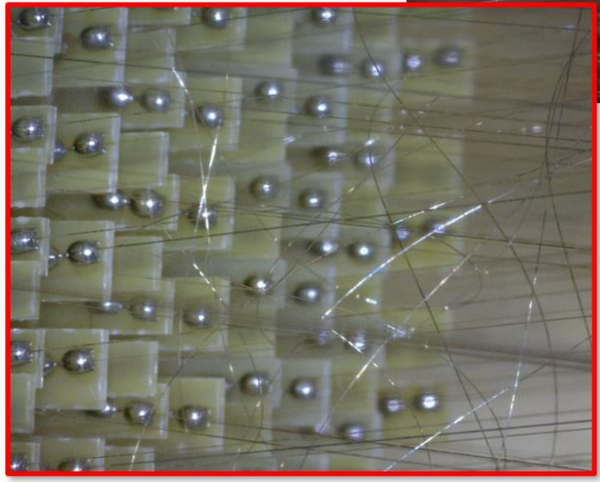
Example of extraction with a broken wire hooked by a stainless steel rod



Setup for broken wires extraction
- Precision mount with fine axes control
- 2 cameras for stereo view

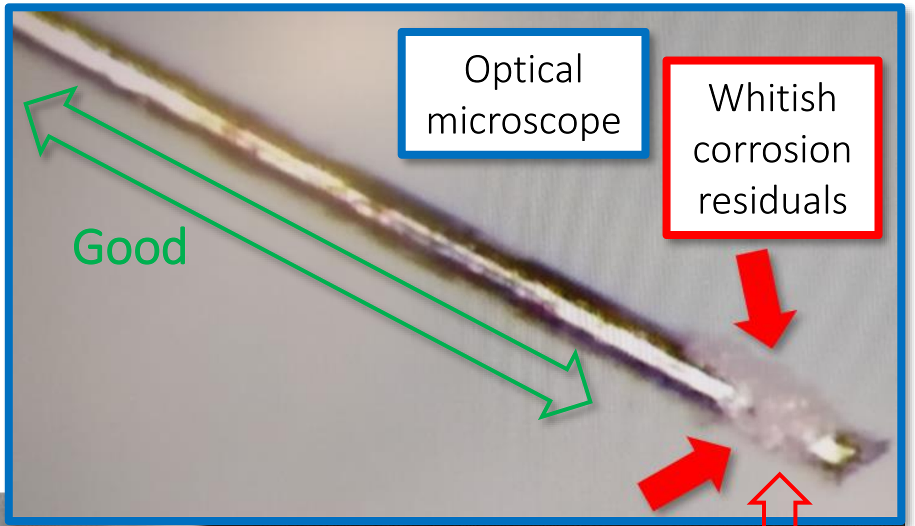


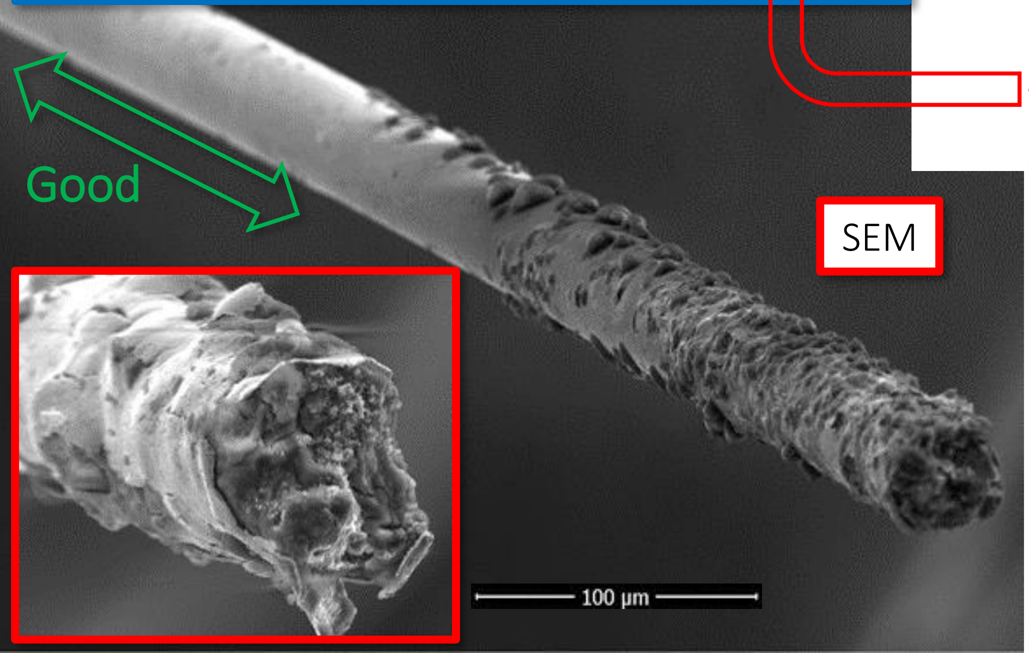
1. Enter with a small tool inside the chamber (few mm space)
2. Hook the wire piece as close as possible to the wire-PCB
3. Extract the wire segment
4. Pull it perpendicularly in the radial direction to break it at the soldering pad



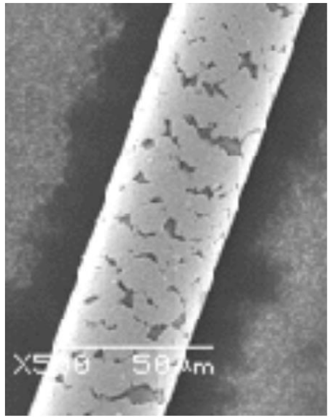
One of the worst case…

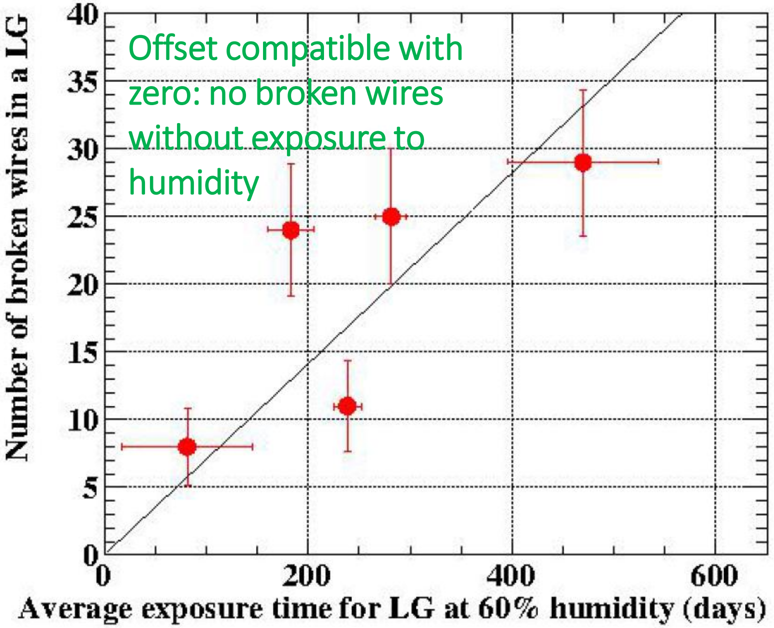
Investigations on wire breakages

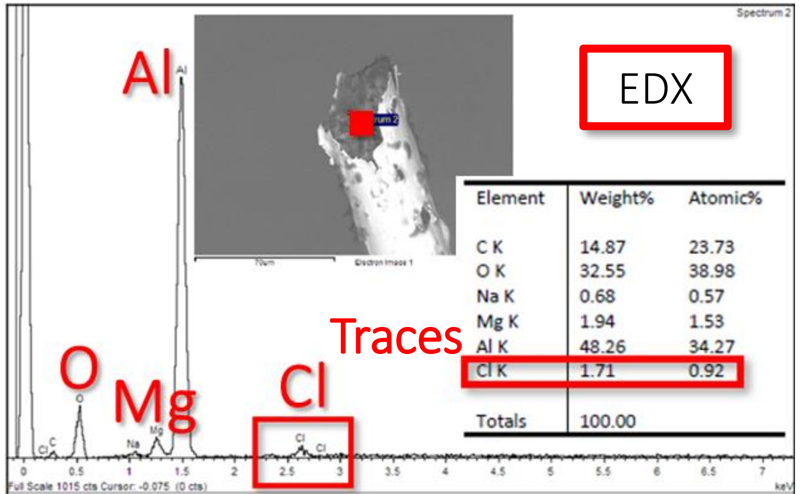




- Breakings due to corrosion of the aluminum wire core
- Two hypotheses
  1. Galvanic process between Al and Ag coating
  2. Al corrosion by Cl
- Both imply water as catalyst
  - Air moisture condensation inside cracks in the Ag coating even at low Relative Humidity (RH) levels $< 40\%$
  - Al oxide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



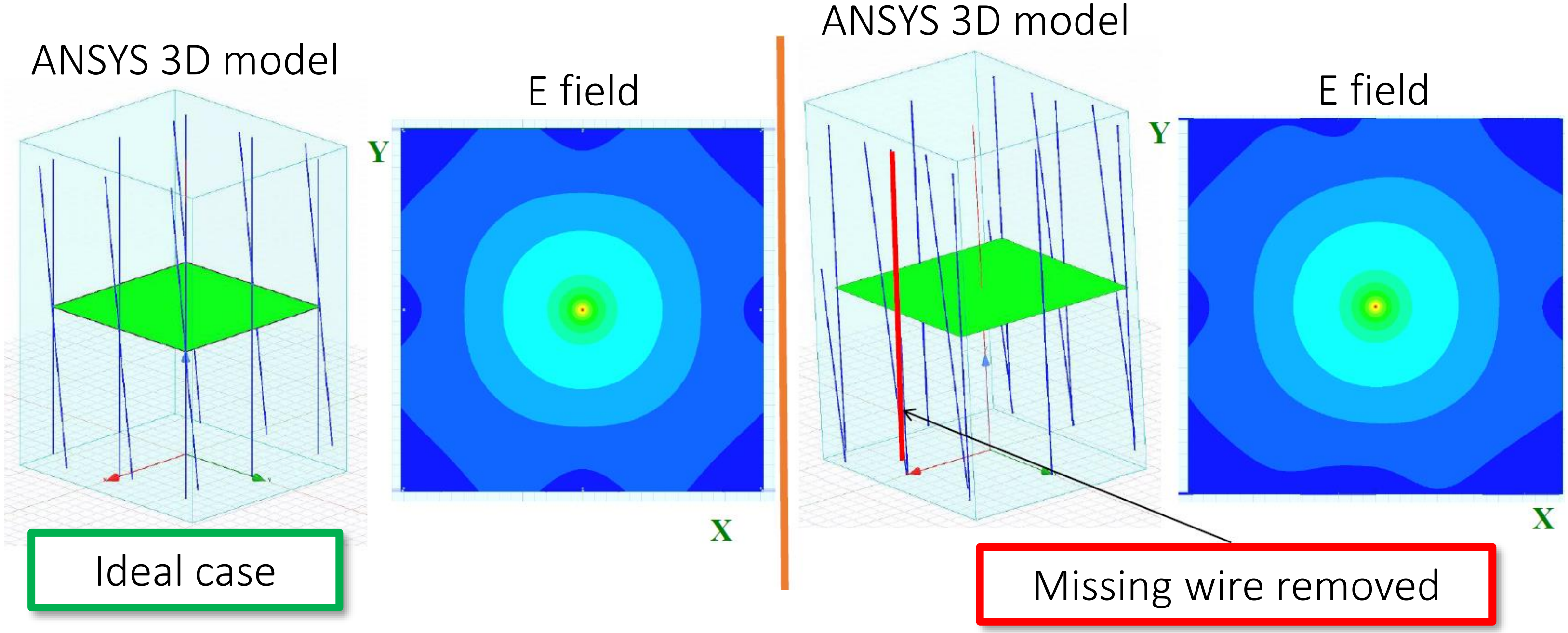




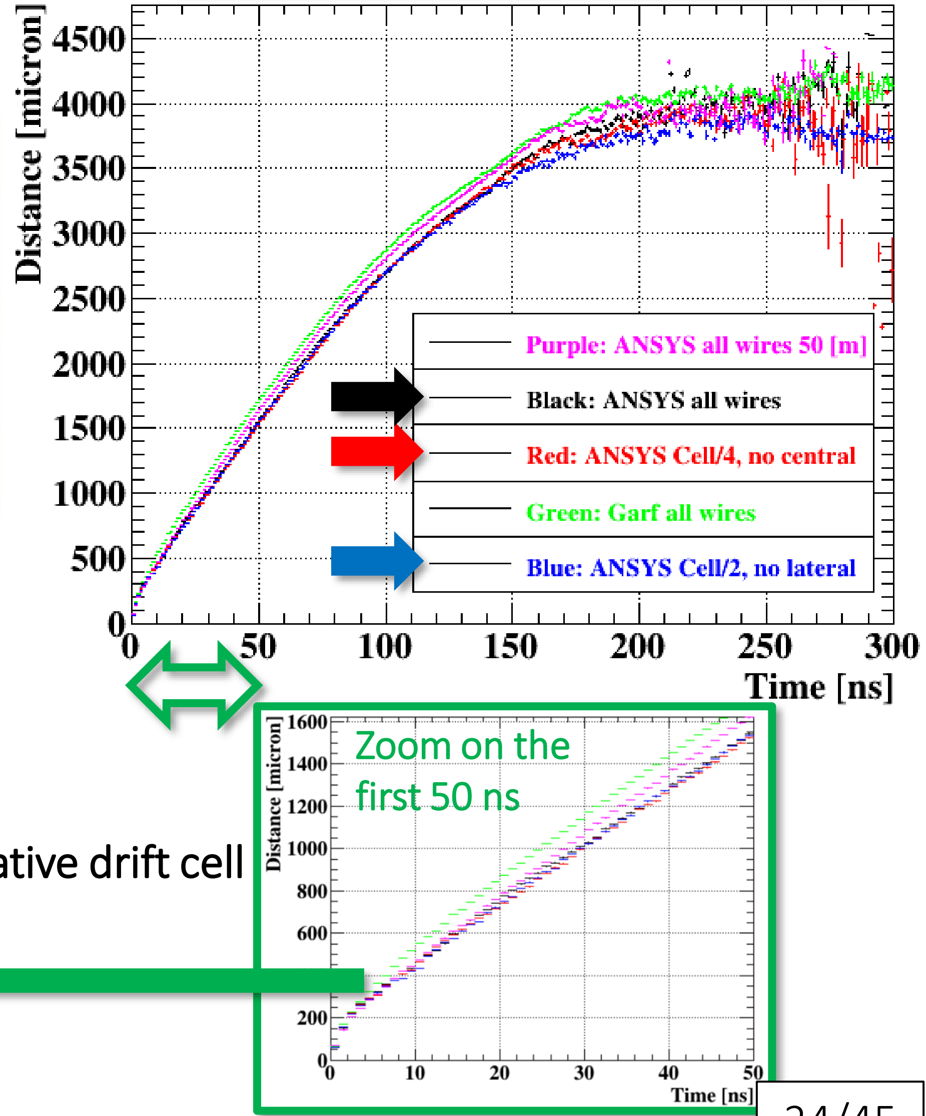
Element	Weight%	Atomic%
C K	14.87	23.73
O K	32.55	38.98
Na K	0.68	0.57
Mg K	1.94	1.53
Al K	48.26	34.27
Cl K	1.71	0.92
Totals	100.00	

- Found a good linear correlation between number of broken wires and exposure time to humidity
- The only way to **stop the corrosion** is to keep the **wires in an inert atmosphere**
- No more broken wires due to corrosion since CDCH flushed with Nitrogen or Helium once sealed

Missing wire effect



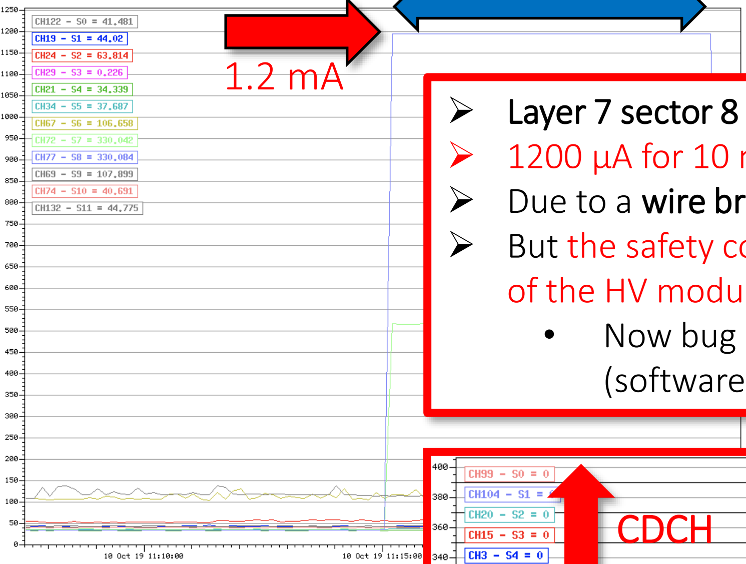
Drift distance vs. drift time relations computed with **Garfield**



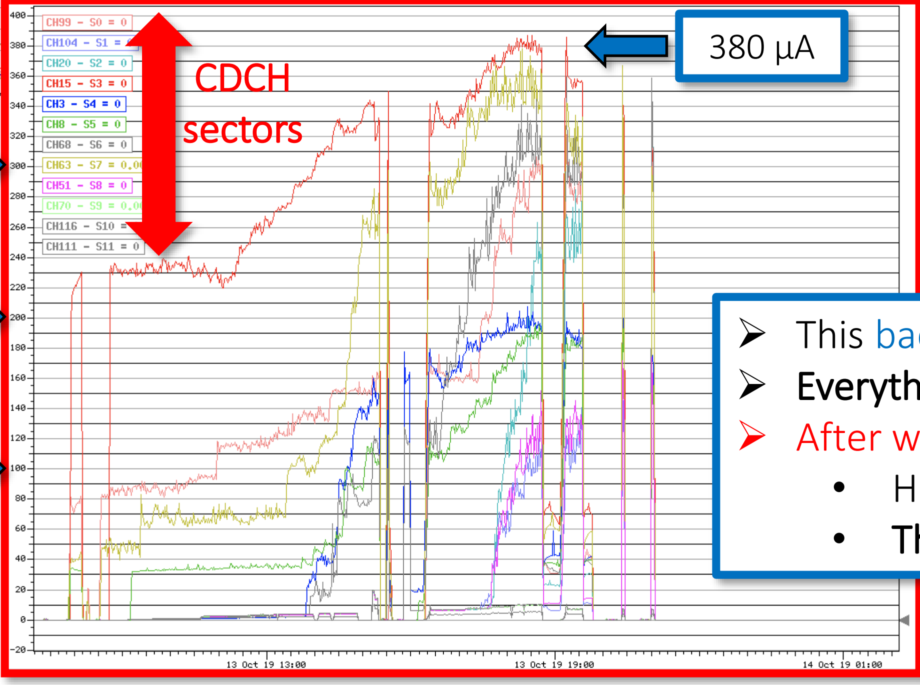
- Study the effect of a missing cathode on isochrones → e^+ reconstruction
- Used **Garfield** and **ANSYS** to **simulate the electric field in a** $\mathbf{6 \times 6\ mm^2}$ **representative drift cell**
  - Single-hit resolution $\sigma_{hit} < 120\ \mu m$
  - Difference between different curves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

Investigations on anomalous currents

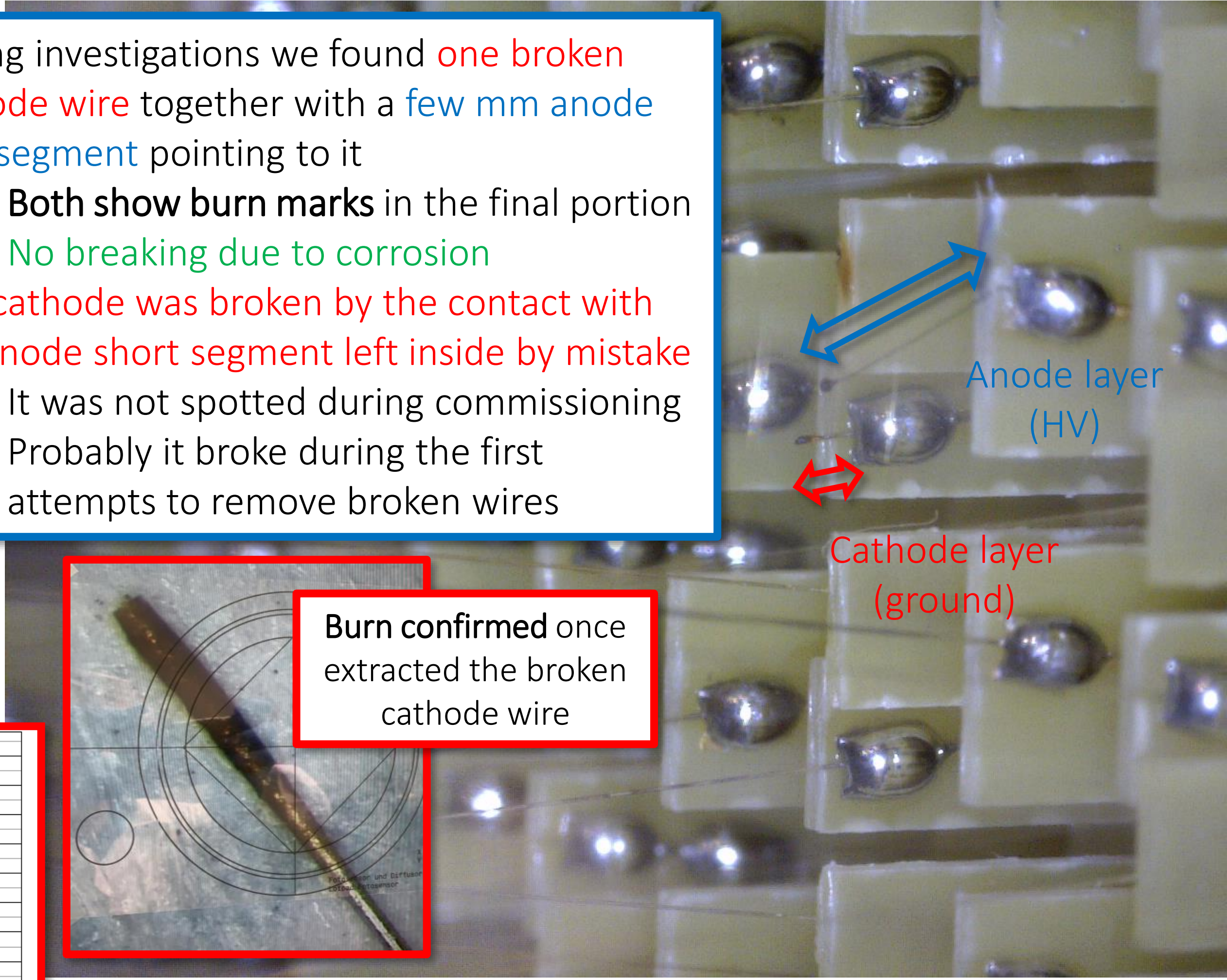
Bad event in 2019



- Layer 7 sector 8
- 1200 µA for 10 minutes
- Due to a **wire breaking**
- But the safety control (firmware) of the HV module did not work
  - Now bug solved + extra (software) safety systems



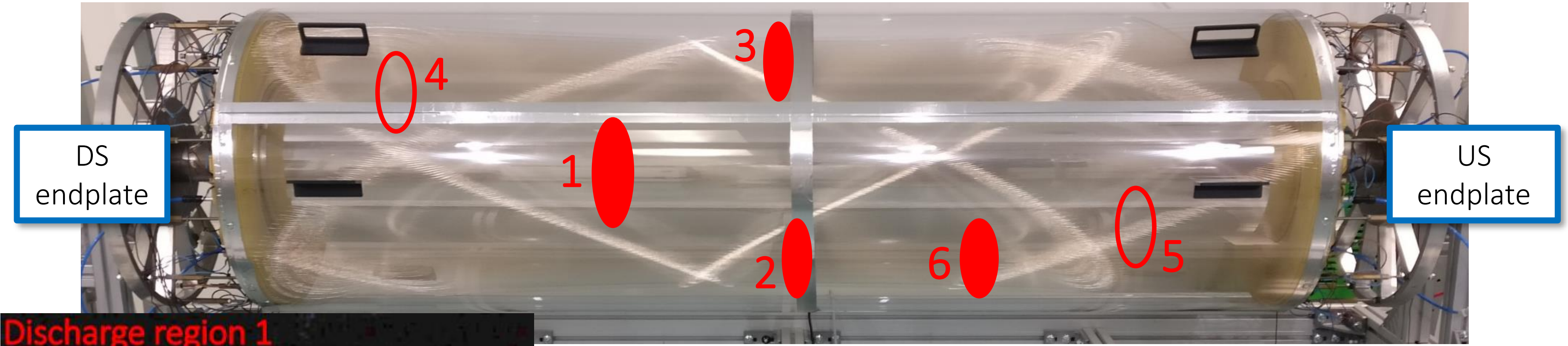
- During investigations we found one broken cathode wire together with a few mm anode wire segment pointing to it
  - **Both show burn marks** in the final portion
  - No breaking due to corrosion
- This cathode was broken by the contact with the anode short segment left inside by mistake
  - It was not spotted during commissioning
  - Probably it broke during the first attempts to remove broken wires

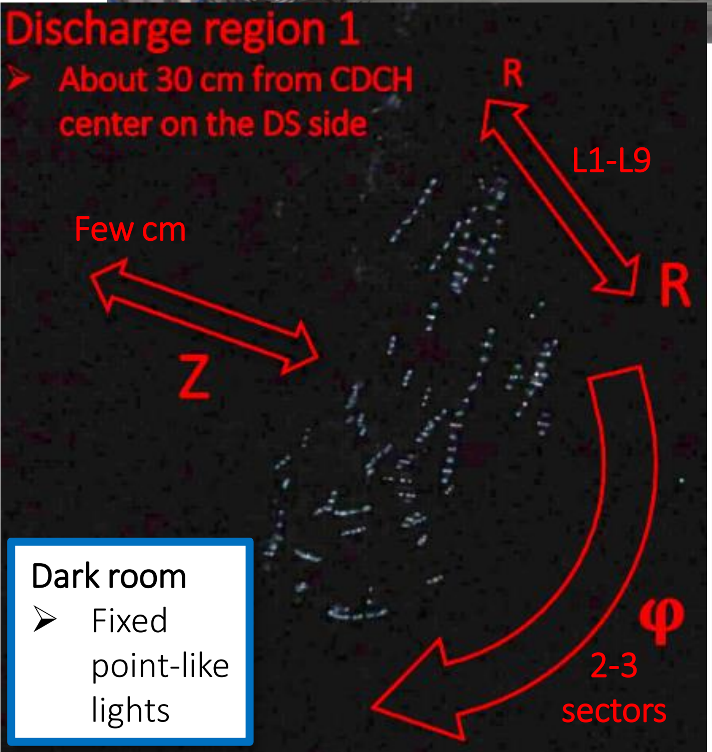


Burn confirmed once extracted the broken cathode wire

- This bad event occurred during the Michel e^+ data taking with μ^+ beam
- **Everything was good up to this moment**
- After we experienced anomalously high currents is several sectors/layers
  - Here an example for layer 2 at the HV working point + beam ON
  - **The problem has been investigated**

Investigations on high currents



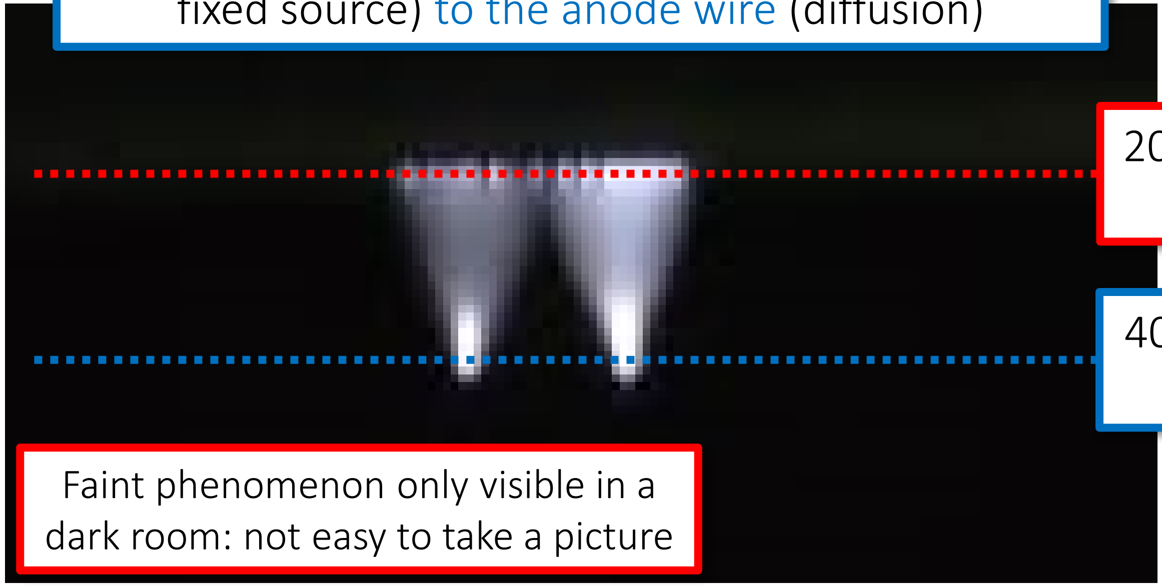


- ➢ HV tests with CDCH closed with a transparent shell and filled with the standard He:IsoB 90:10 gas mixture to spot the discharges
- ➢ We saw corona-like discharges in correspondence of 6 whitish regions
- ➢ Gas mixture optimization: different additives to the standard mixture to **test the CDCH stability** and **try to recover the normal operation**
  - Up to 5% CO_2 and 10% synthetic air (80% Nitrogen + 20% Oxygen)
  - 2000-4000 ppm of H_2O (≈10% Relative Humidity inside CDCH)
  - 1-1.5% Isopropyl alcohol
  - From 500 ppm to 2% of O_2
    - Also in combination with H_2O and Isopropyl alcohol
- ➢ Oxygen proved to be effective in reducing high currents (plasma cleaning?)
- ➢ Isopropyl alcohol crucial to keep stable the current level

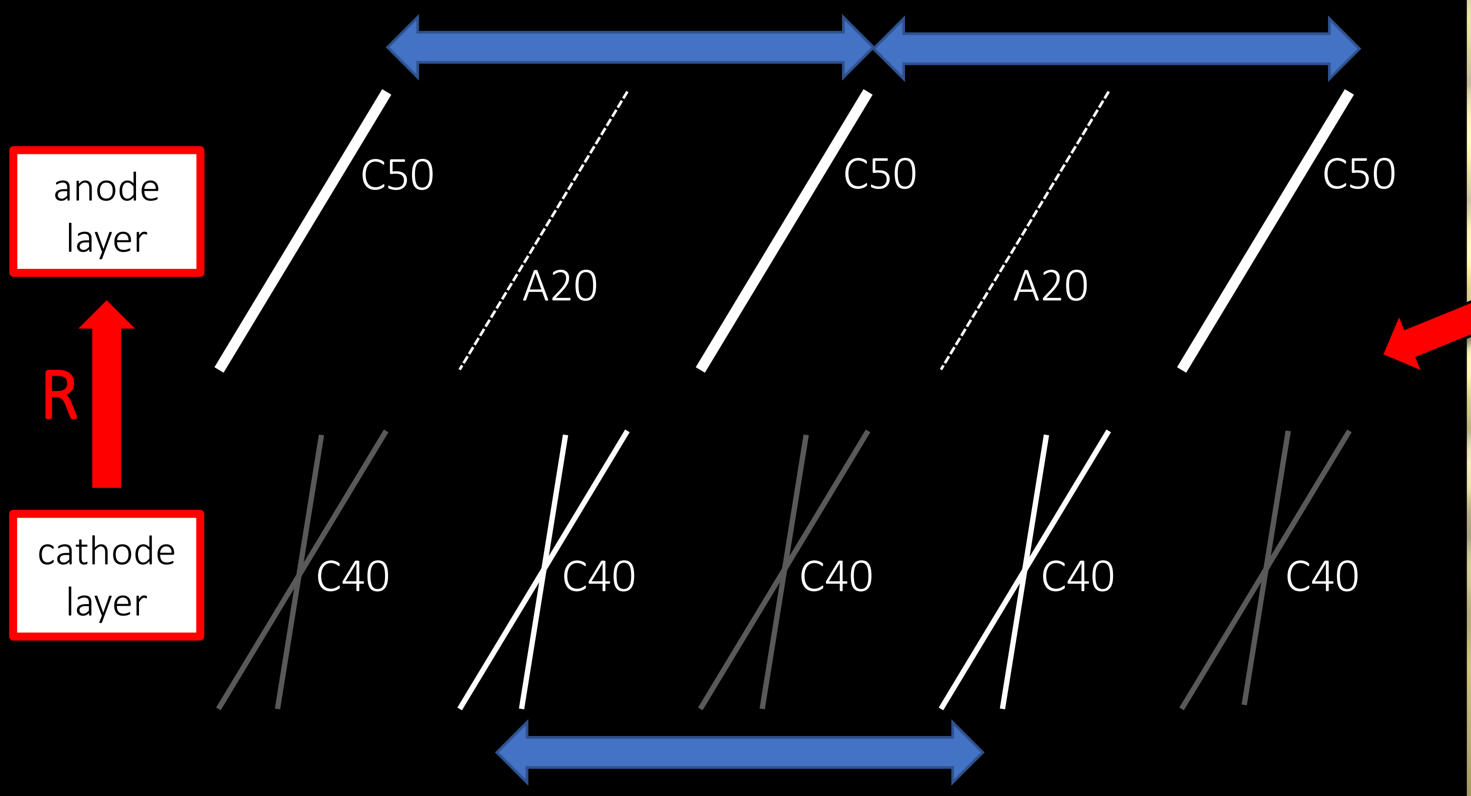
Two of the discharge regions

Corona discharges lab tests

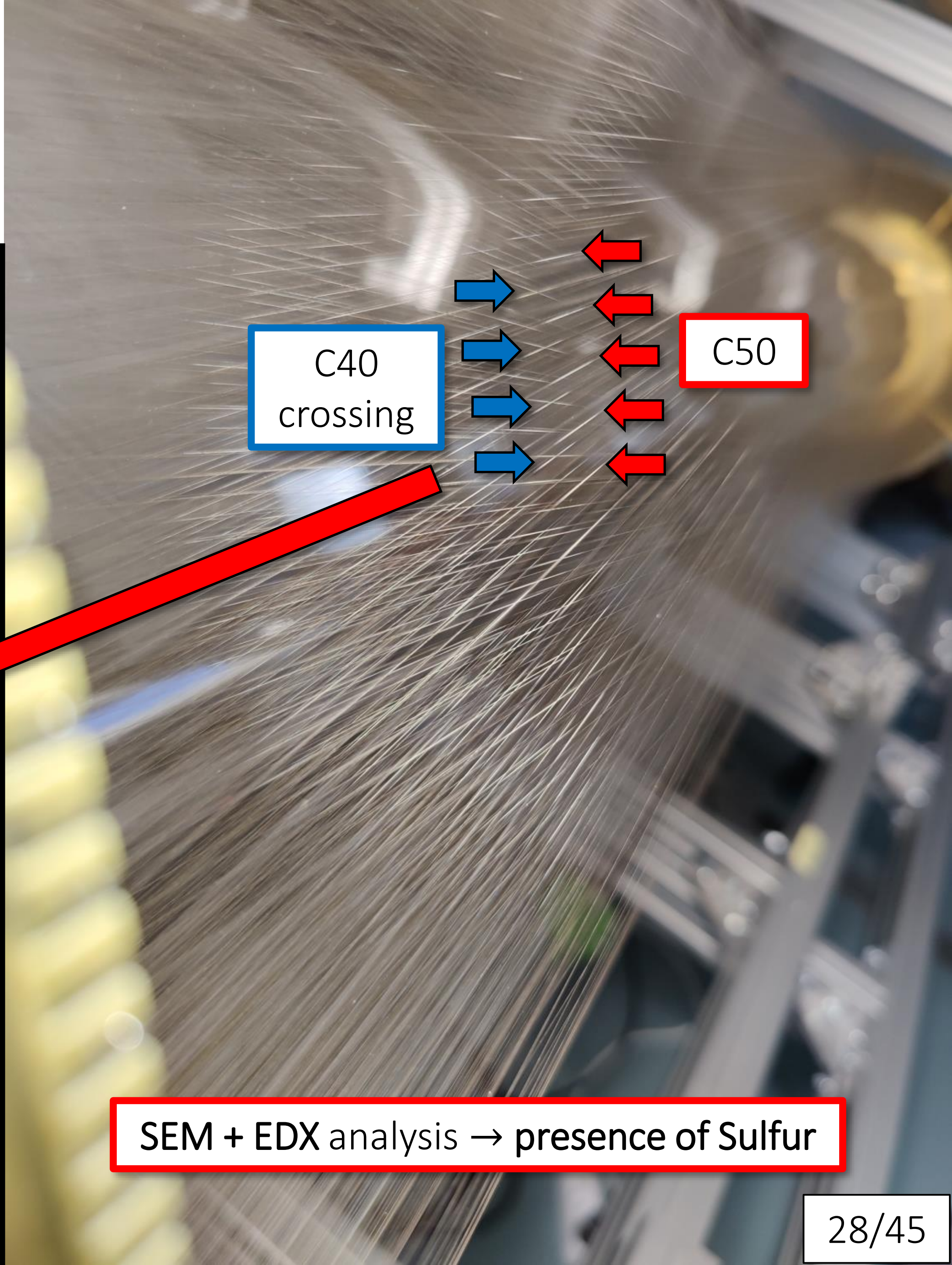
- They occurred **naturally at 2300 V (100-200 µA currents) with 40 µm cathode wire diameter and brand-new wires** (no damaged surface)
  - Known phenomenon: but why at 1400 V?
- White deposits seems to lower the corona discharge HV limit



Pattern in the white spots

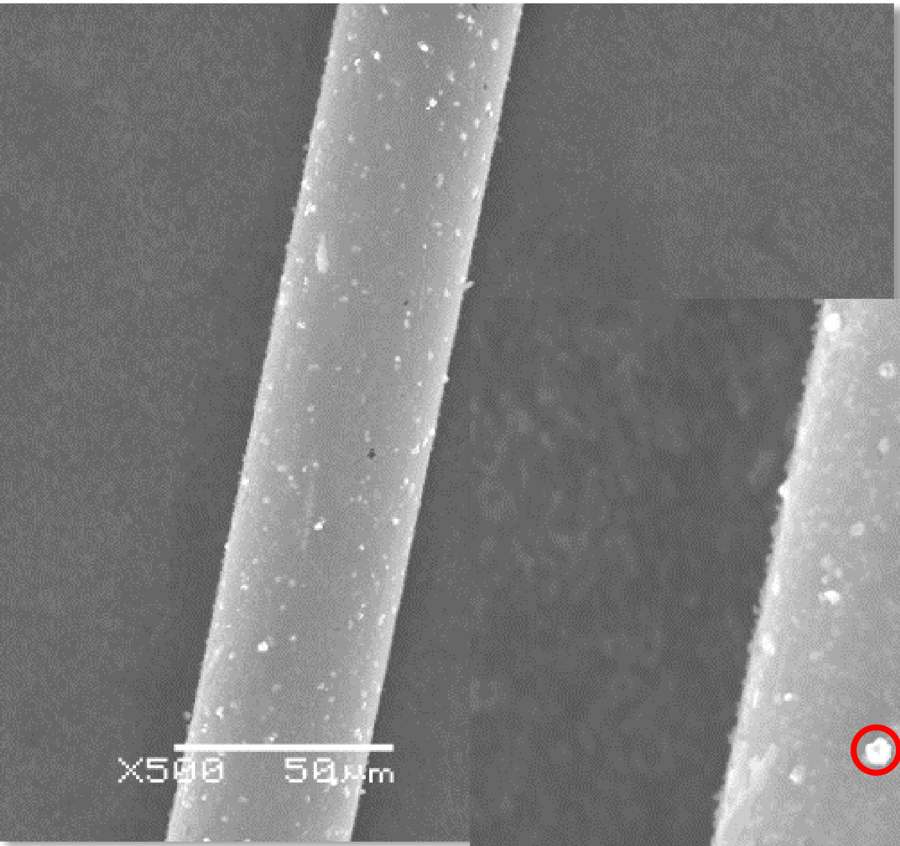


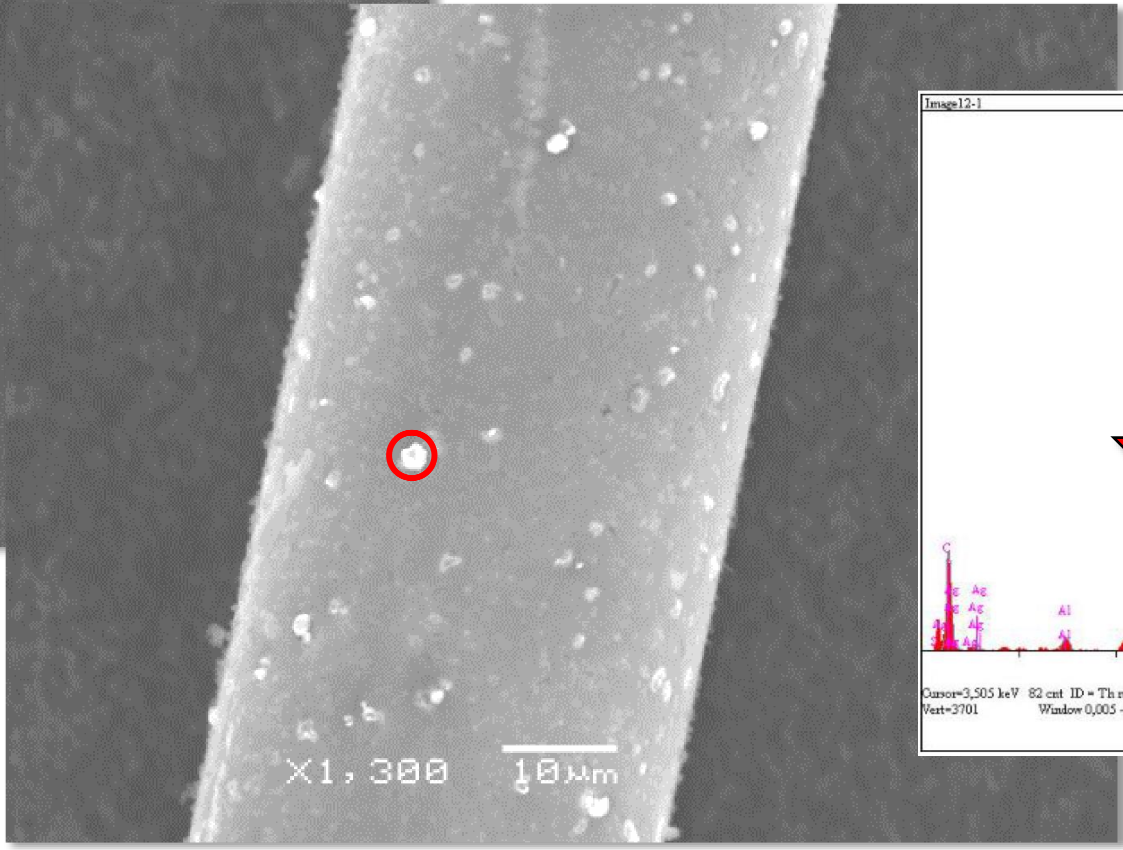
- White spot in correspondence of the 40 µm cathode wire crossing points
- The period is that of the 50 µm cathode wire

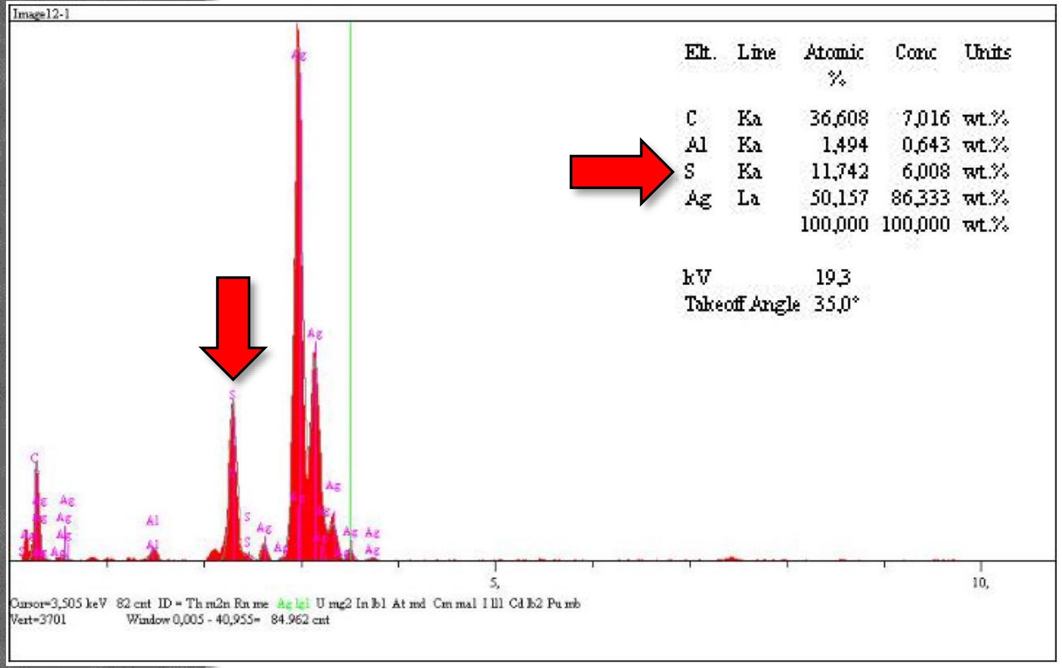


SEM + EDX analysis → **presence of Sulfur**

SEM + EDX analysis of the white deposit

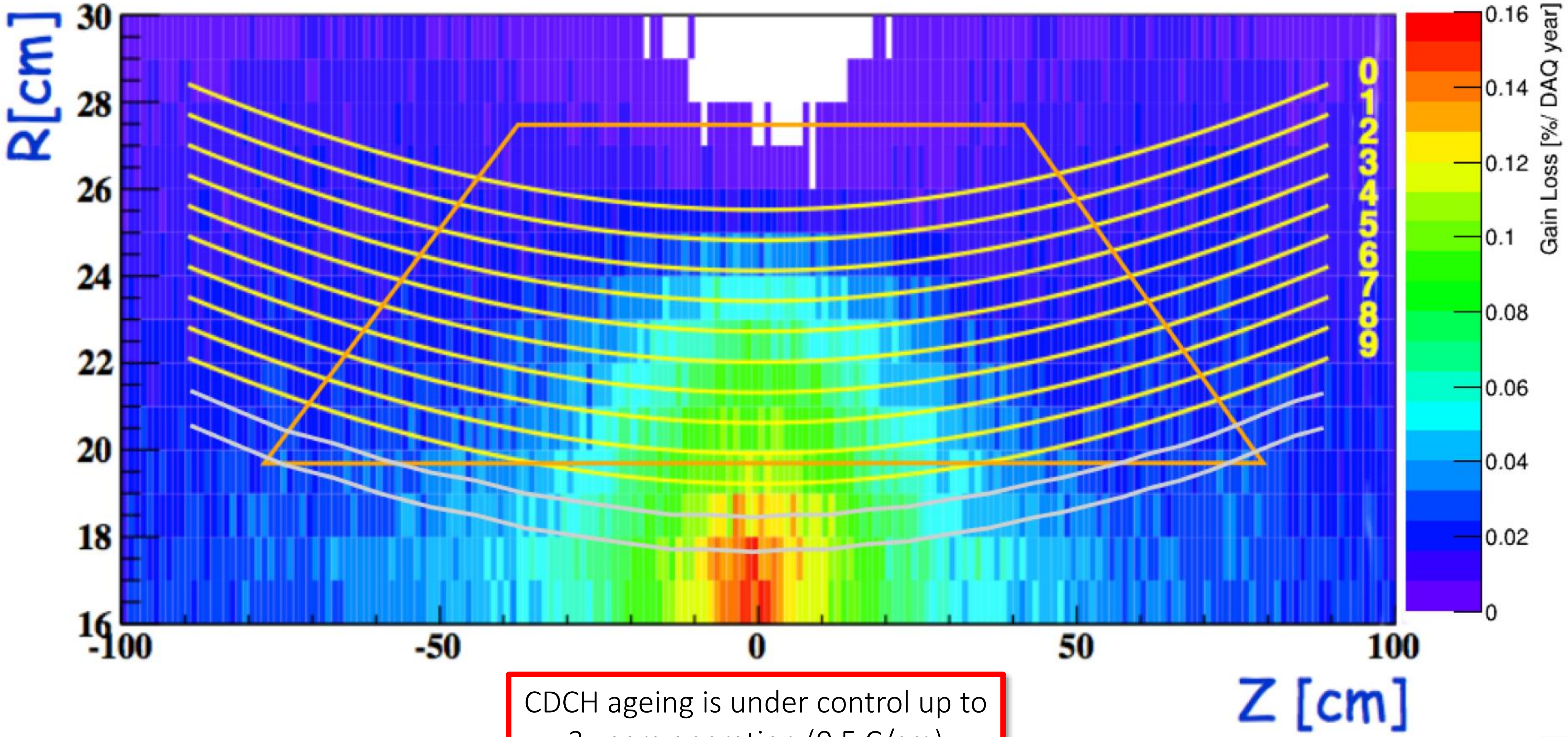






CDCH ageing studies

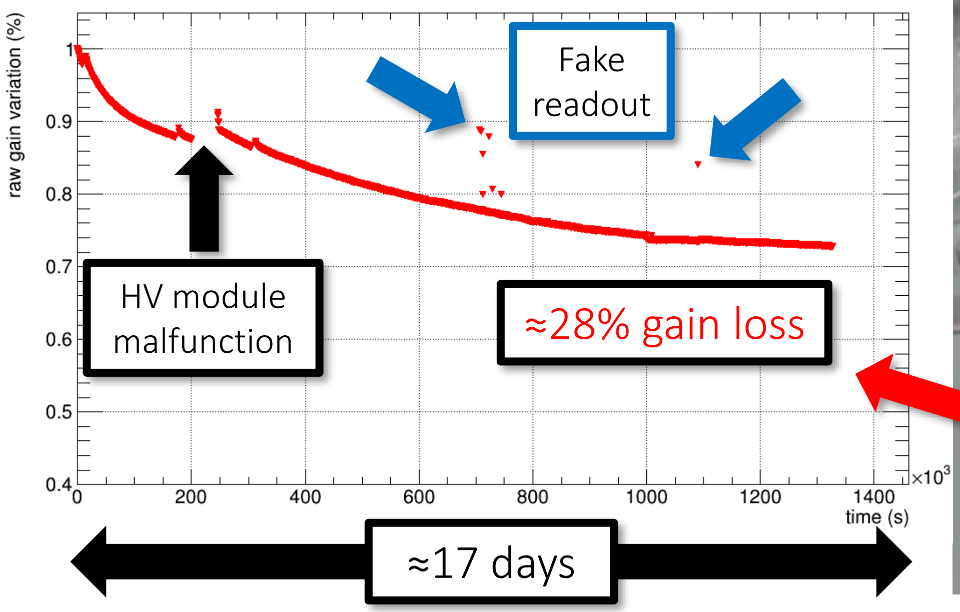
Expected gain drop per DAQ year vs. Z and R



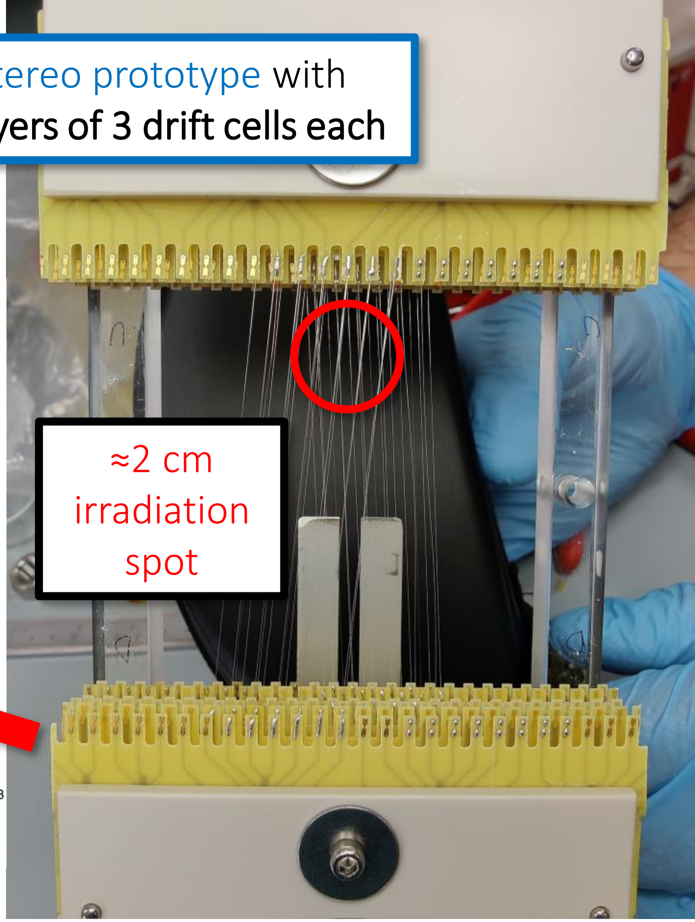
CDCH ageing is under control up to 3 years operation (0.5 C/cm)

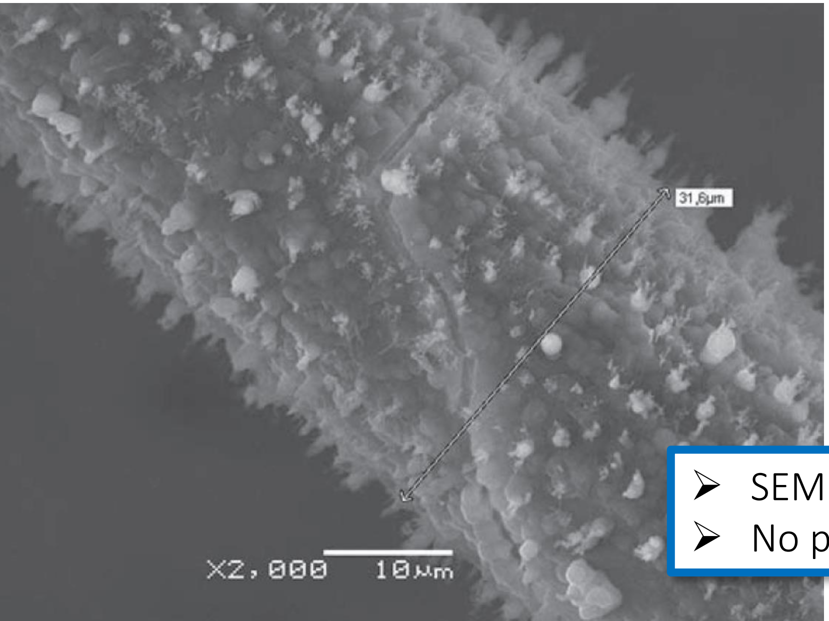
Ageing tests on prototypes

- Accelerated ageing tests on different prototypes were performed
- Prototypes with increasing complexity
  - From a 1-cell prototype to a **small 2-layer stereo prototypes** (6 cells)
  - This latter is presented here and it featured the **same geometry and materials of the CDCH endplates**

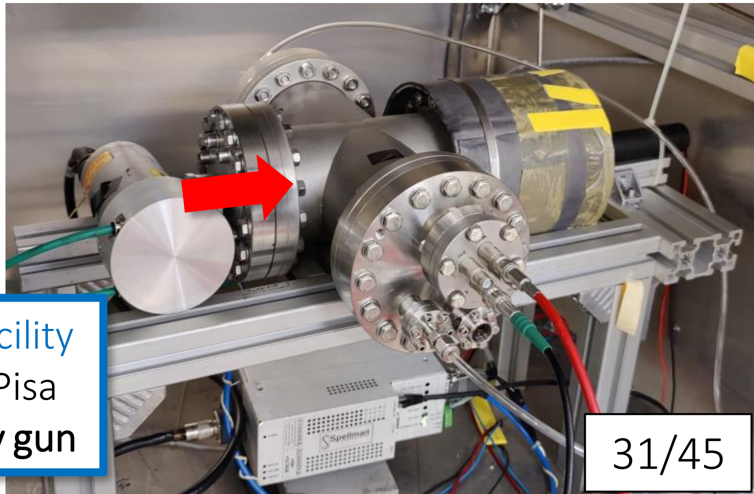


- Total **ageing acceleration factor 10 < *A* < 100**
  - Accumulated charge comparable to the total MEG II life ≈0.5 C/cm
- No issues/discharges observed





- SEM image of an aged anode wire
- No problems on cathode wires

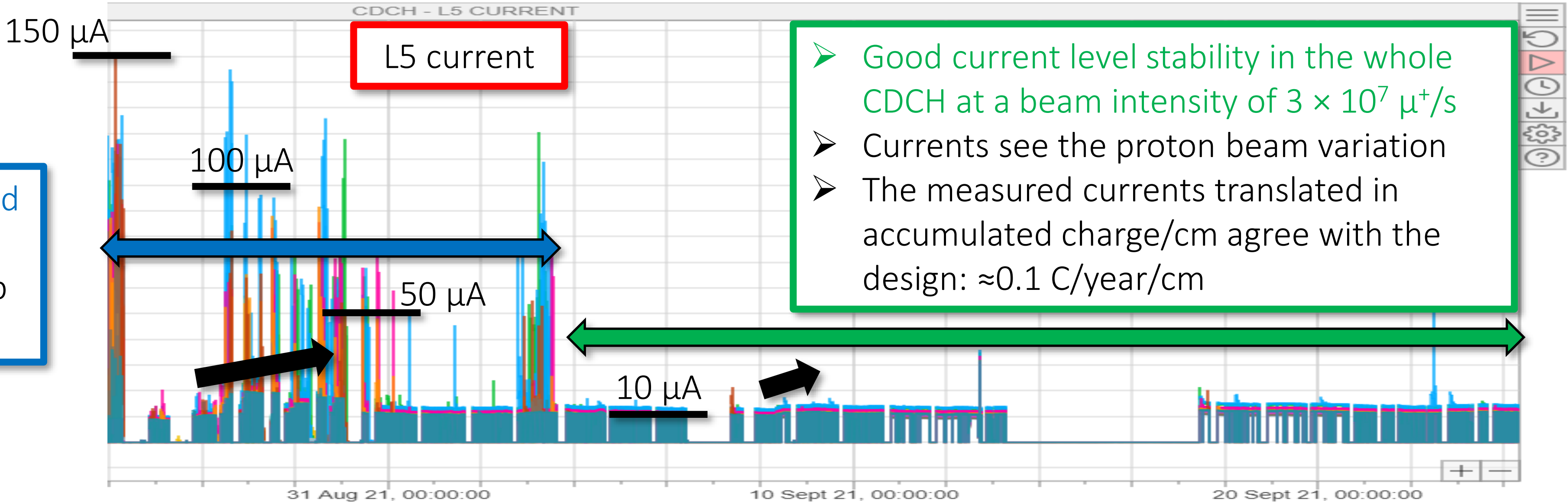


Ageing facility at INFN Pisa with **X-ray gun**

CDCH conditioning with μ^+ beam

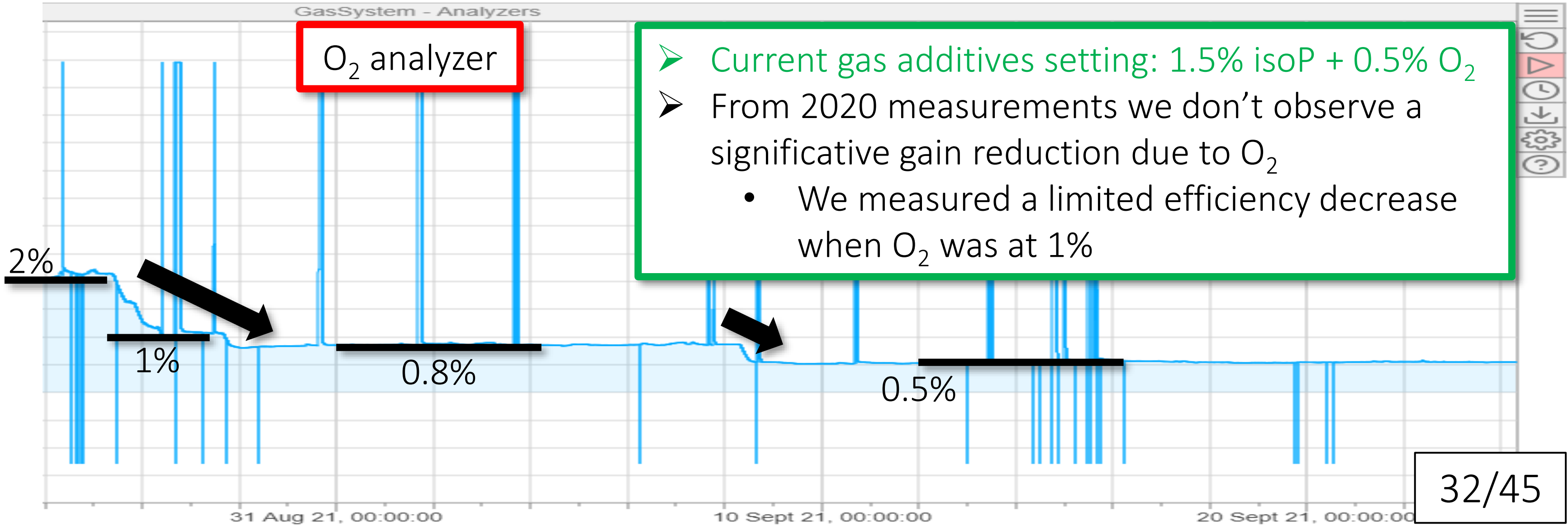
Conditioning with μ^+ beam

- Example of conditioning period with current discharges
- HV up to WP+40V to speed up the O_2 cleaning



- Good current level stability in the whole CDCH at a beam intensity of 3×10^7 μ^+/s
- Currents see the proton beam variation
- The measured currents translated in accumulated charge/cm agree with the design: ≈0.1 C/year/cm

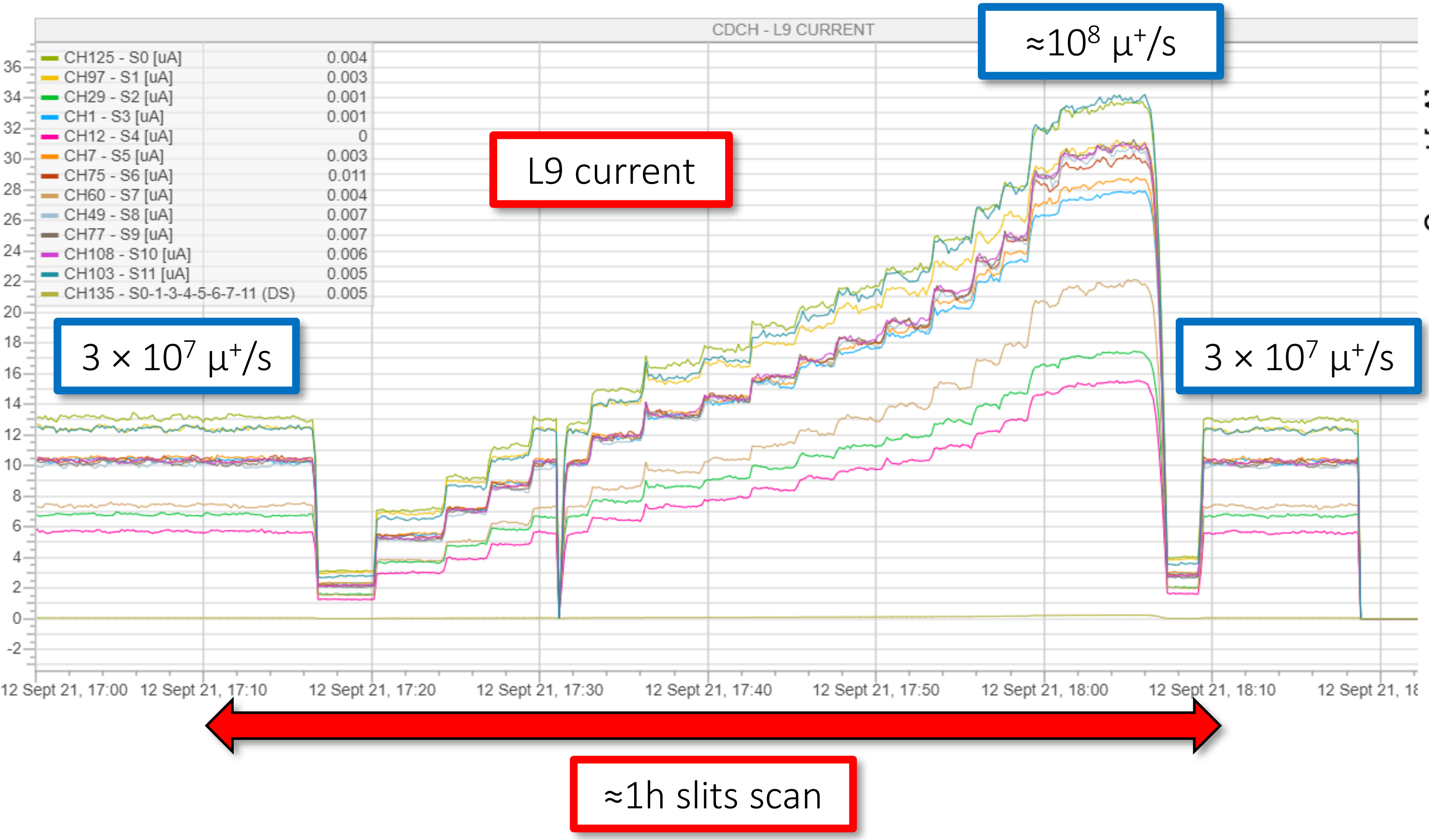
- We are very sensitive to the isopropyl alcohol concentration
- We experienced that 1-1.5% isoP concentration is crucial to keep the stability

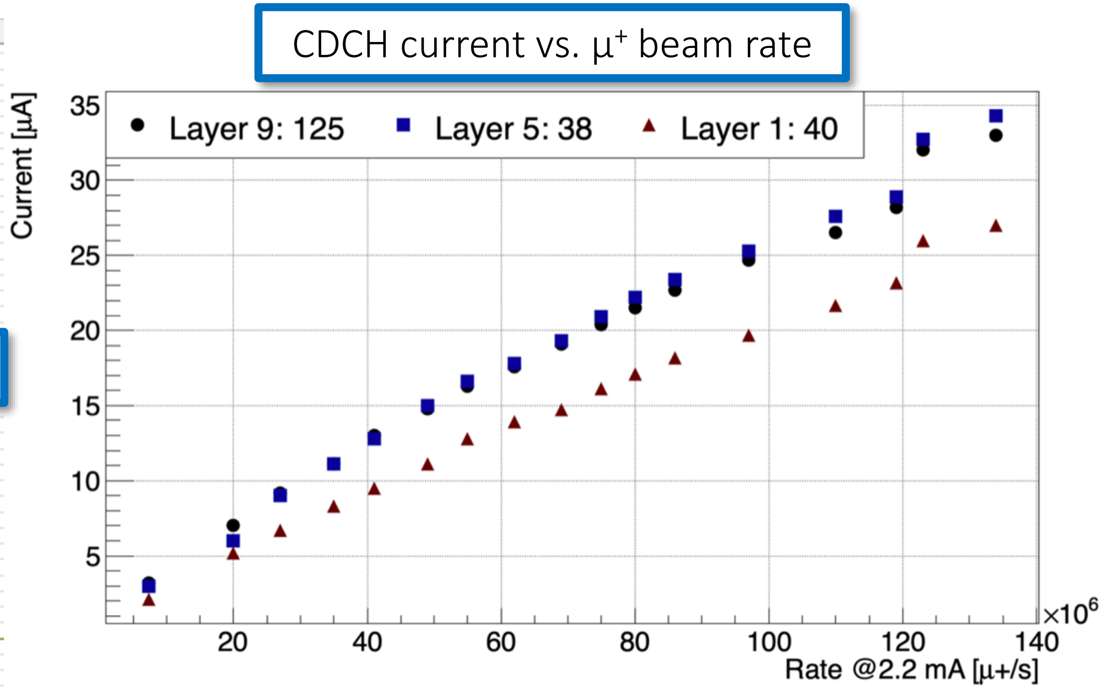


- Current gas additives setting: 1.5% isoP + 0.5% O_2
- From 2020 measurements we don't observe a significative gain reduction due to O_2
  - We measured a limited efficiency decrease when O_2 was at 1%

CDCH currents vs. μ⁺ beam intensity

- CDCH currents followed reasonably well the beam intensity up to intensities never reached before
- Good proportionality with the μ⁺ rate

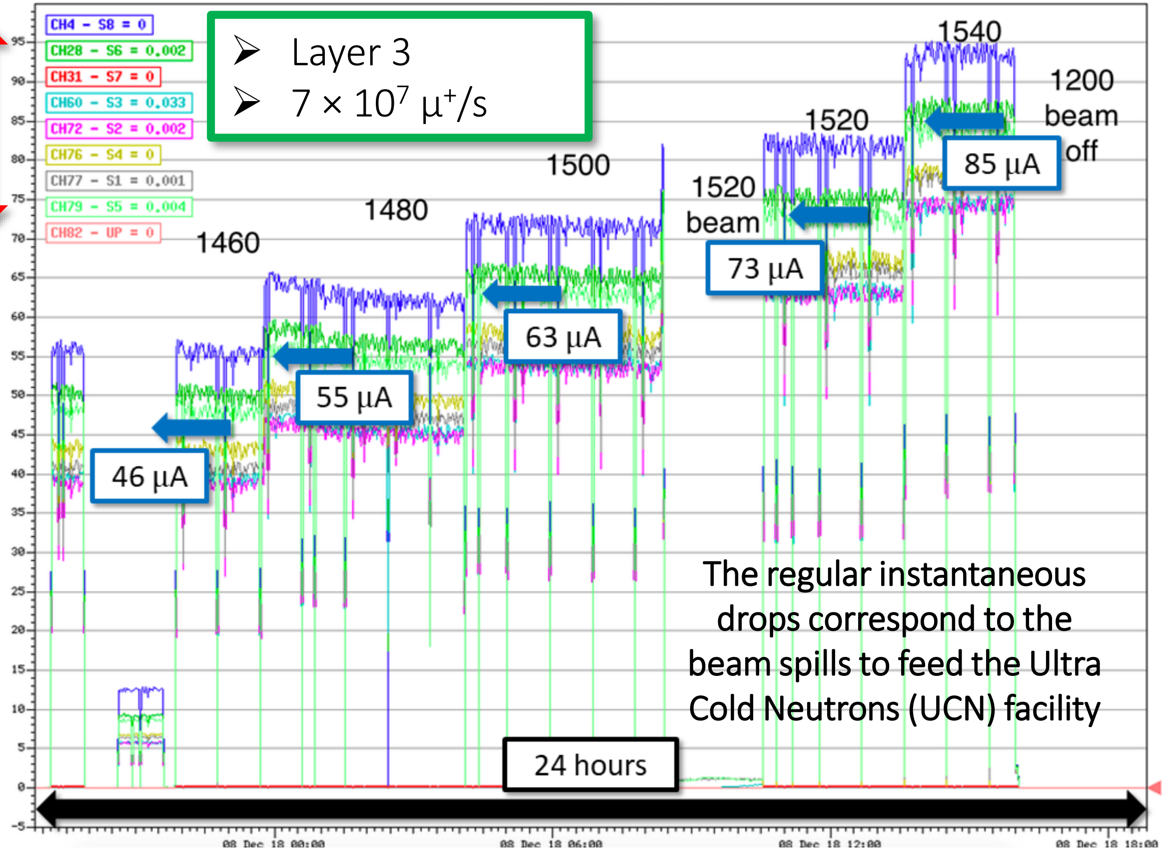


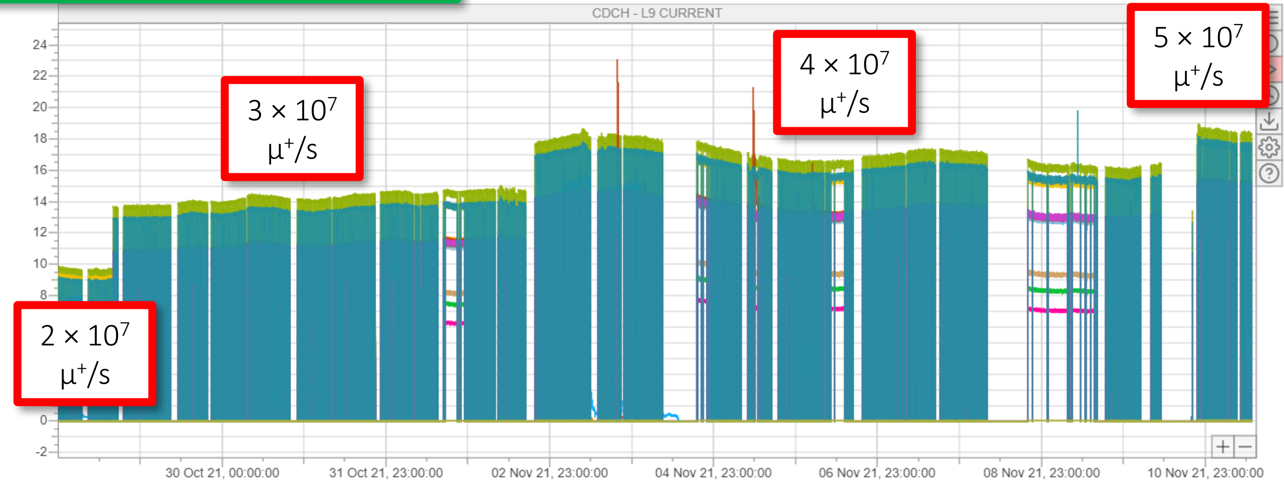


Example of gain curves with CDCH stable

Different colors correspond to different CDCH sectors

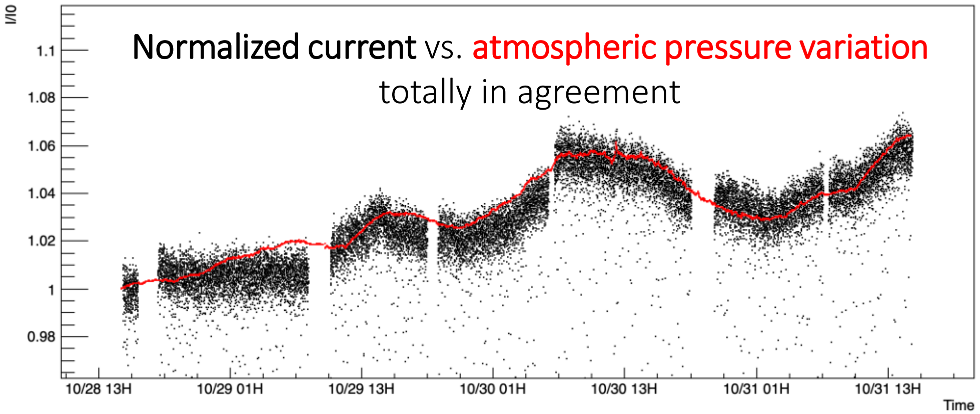
CDCH current level vs. (HV or μ^+ beam intensity)





- Currents correctly follow the beam intensity
- Gas gain is also sensitive to the variations of the atmospheric pressure

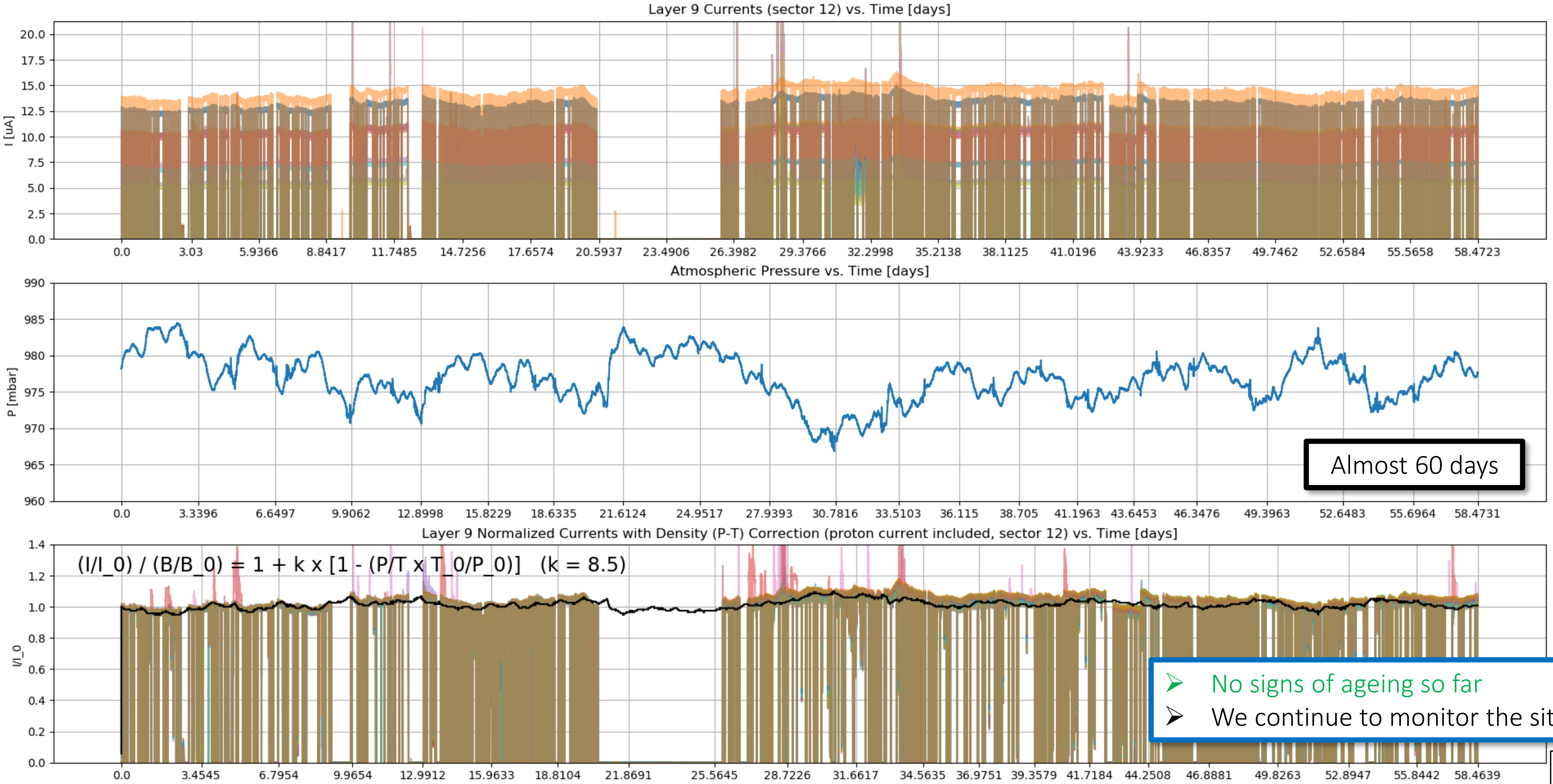
$$\frac{\Delta G}{G} = -k\frac{\Delta P}{P}$$



$$\frac{I}{I_0} = 1 - 5\frac{\Delta P}{P}$$

$$k = 5$$

L9 normalized current vs. gas density (P, T)

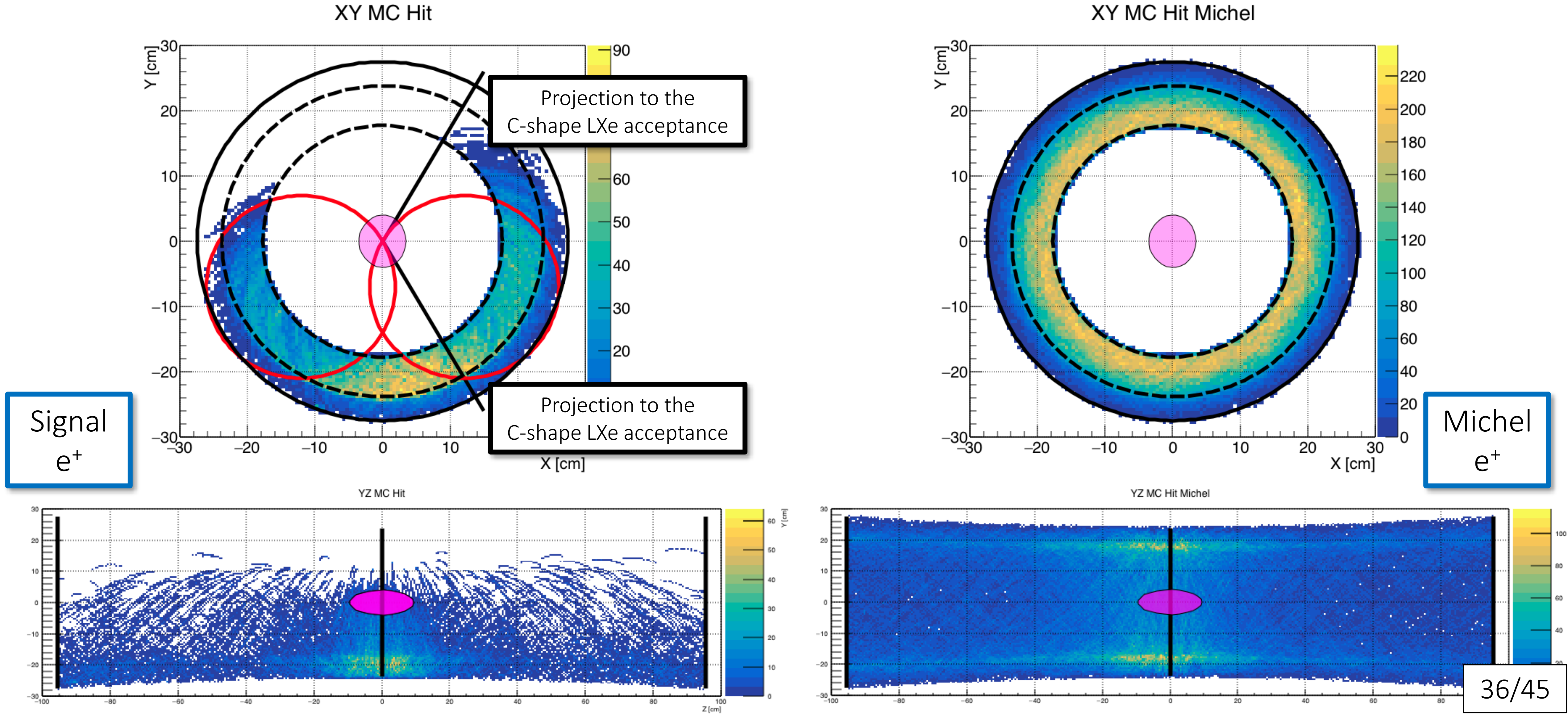


Almost 60 days

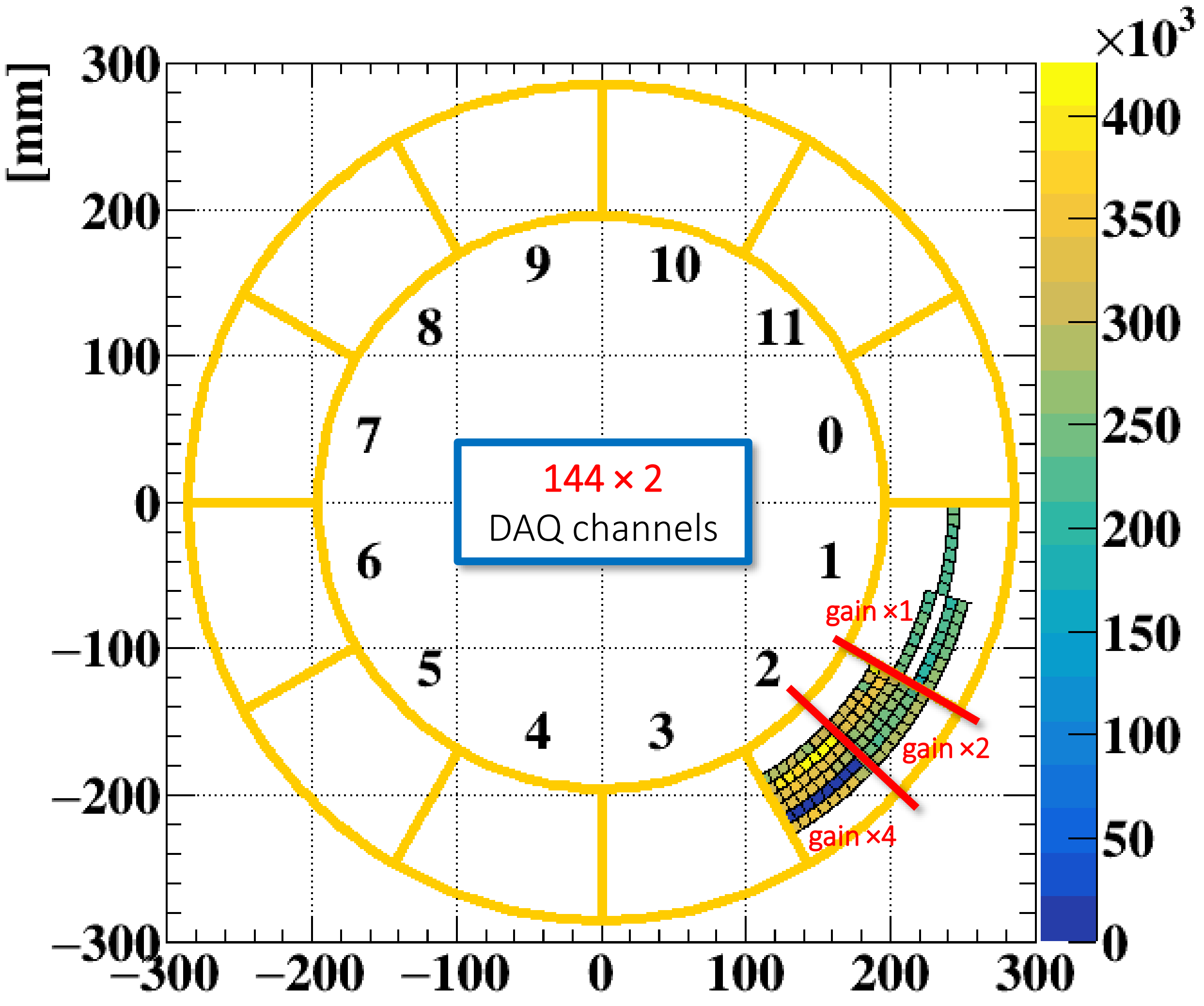
- No signs of ageing so far
- We continue to monitor the situation

Physics data taking (planned 2021-2026)

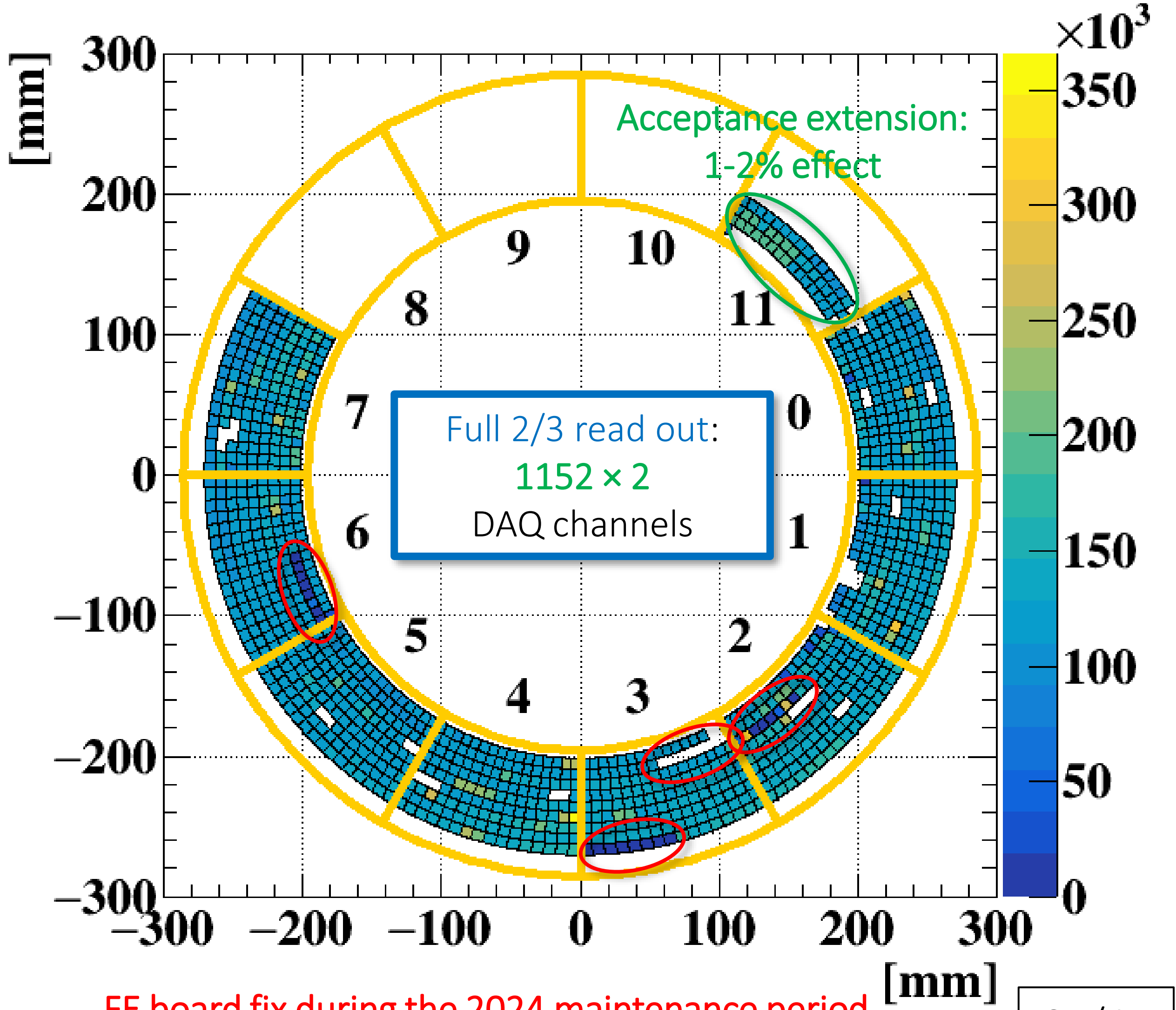
Example of CDCH occupancy from MC



2020 vs. 2023 readout

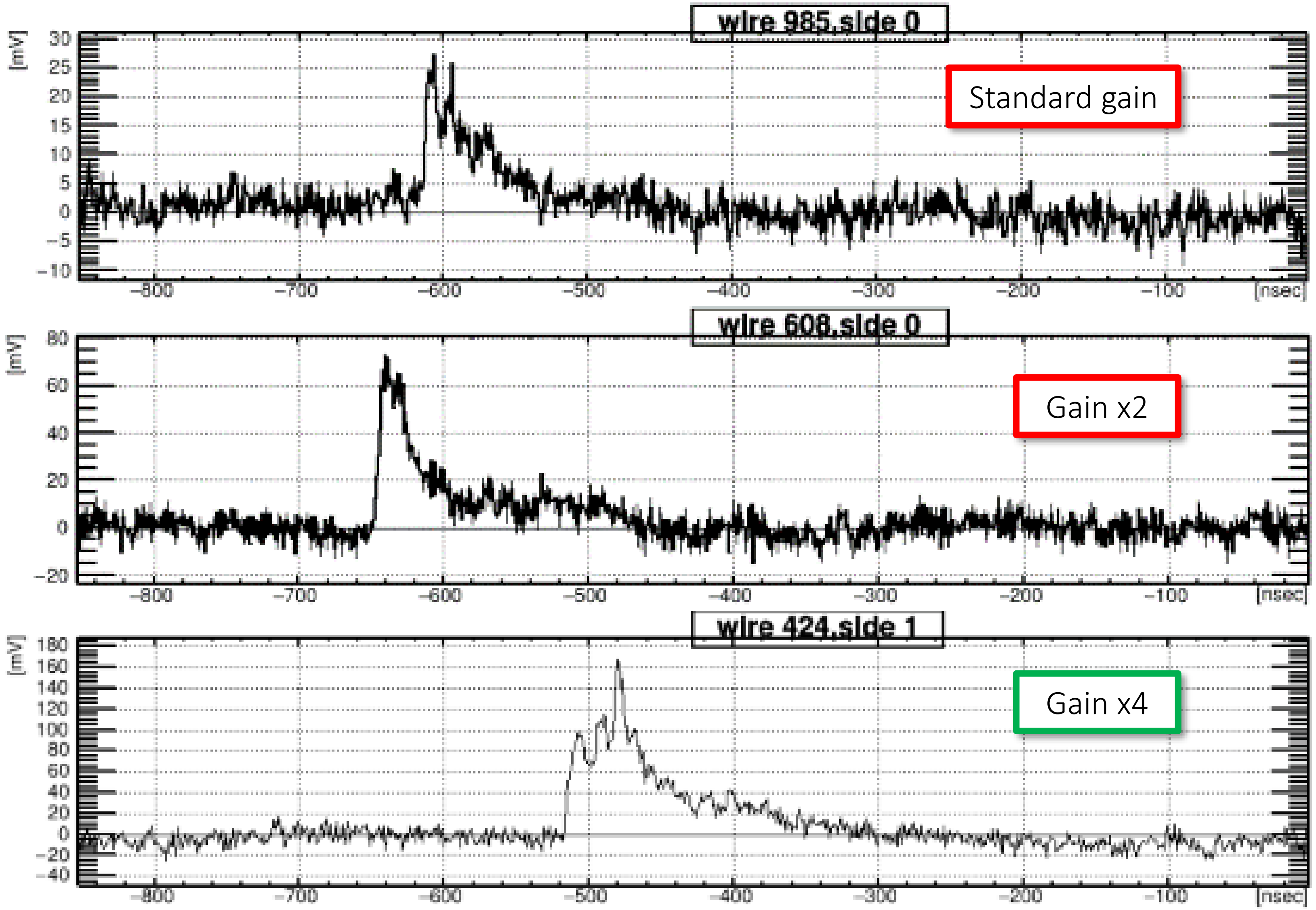


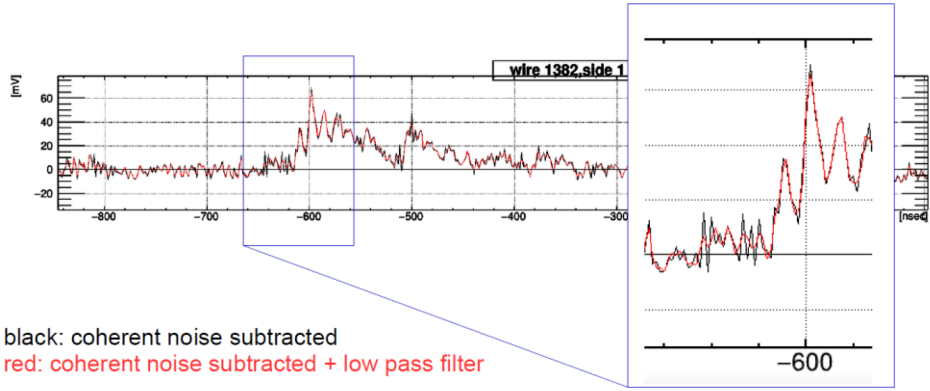
3 FE gain configurations tested:
gain x4 chosen → best SNR



FE board fix during the 2024 maintenance period

Example of signal Waveforms



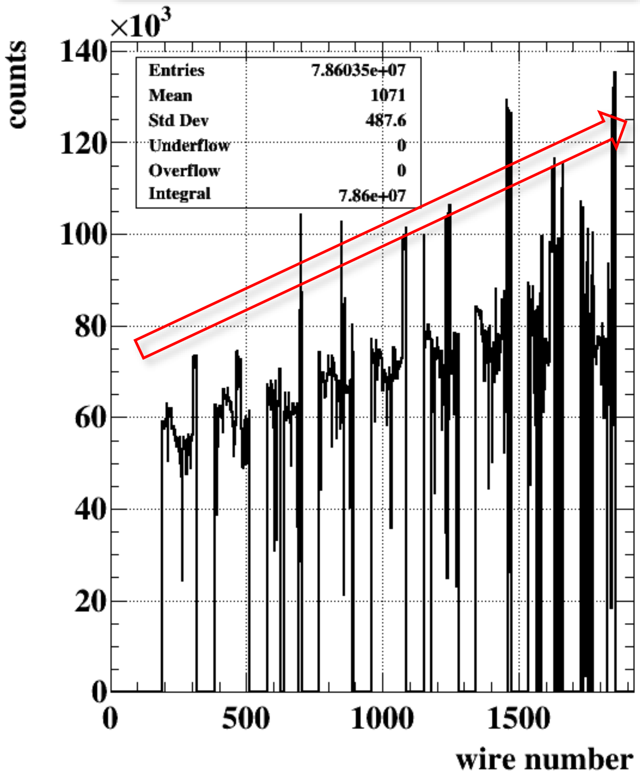


- In MEG all the signal WF is recorded
- Then a fine analysis is made offline to get the hit information
  - Timing, signal amplitude, signal integral, position
- Coherent noise subtraction + 225 MHz digital low-pass filter are applied

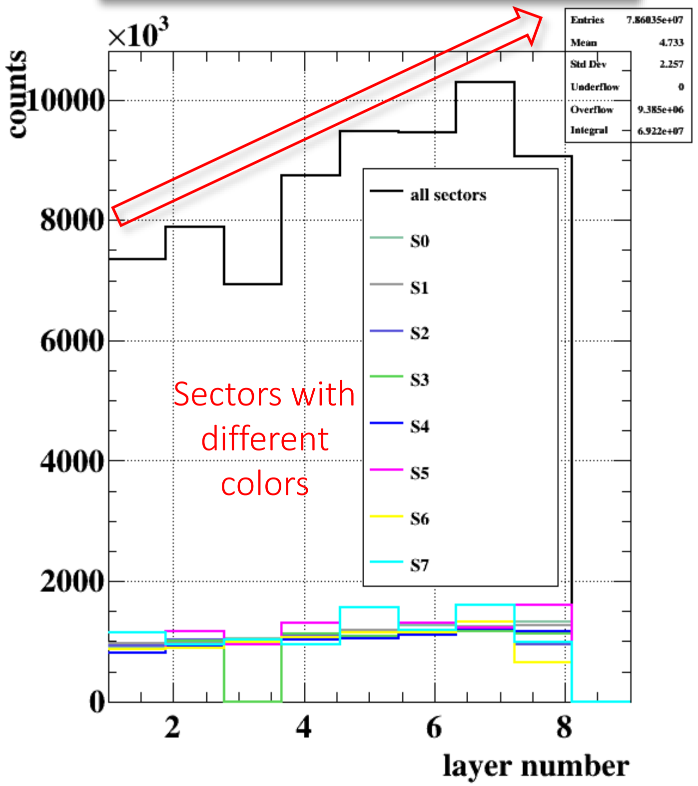
- 3 FE gain configurations tested
- Gain x4 chosen → best SNR

Some diagnostic plots from Michel e^+ data

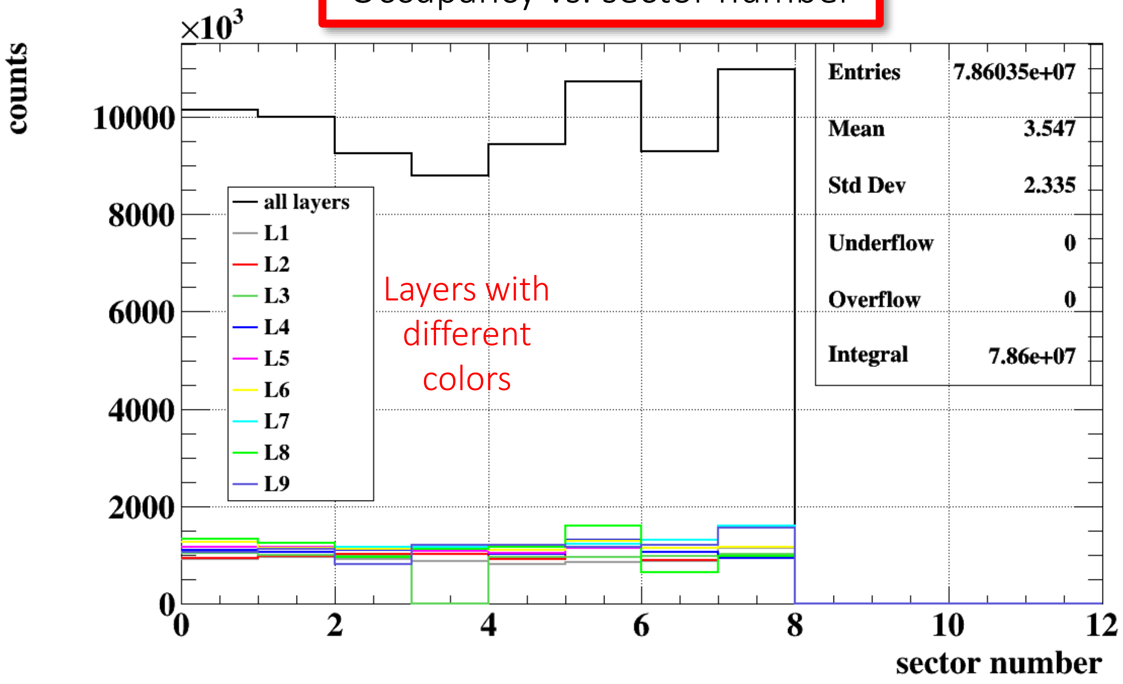
Occupancy vs. wire number



Occupancy vs. layer number



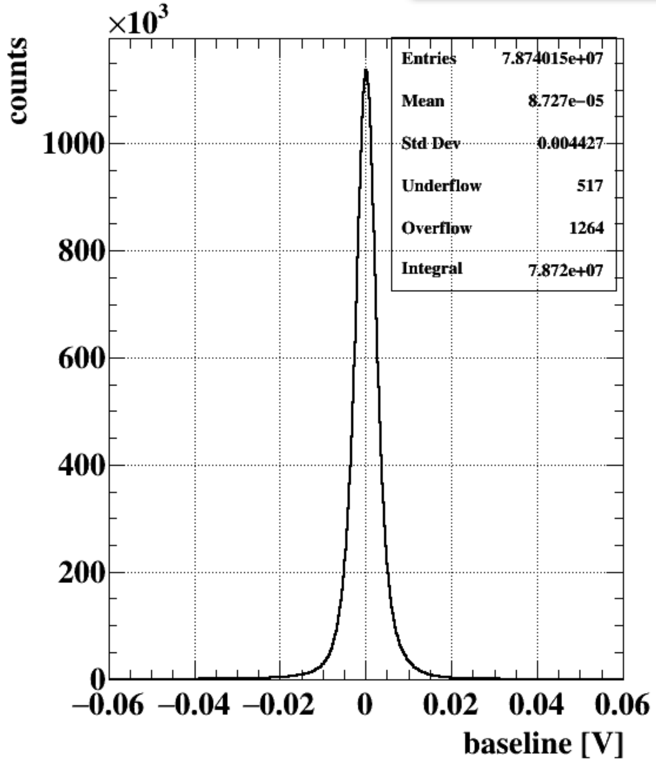
Occupancy vs. sector number

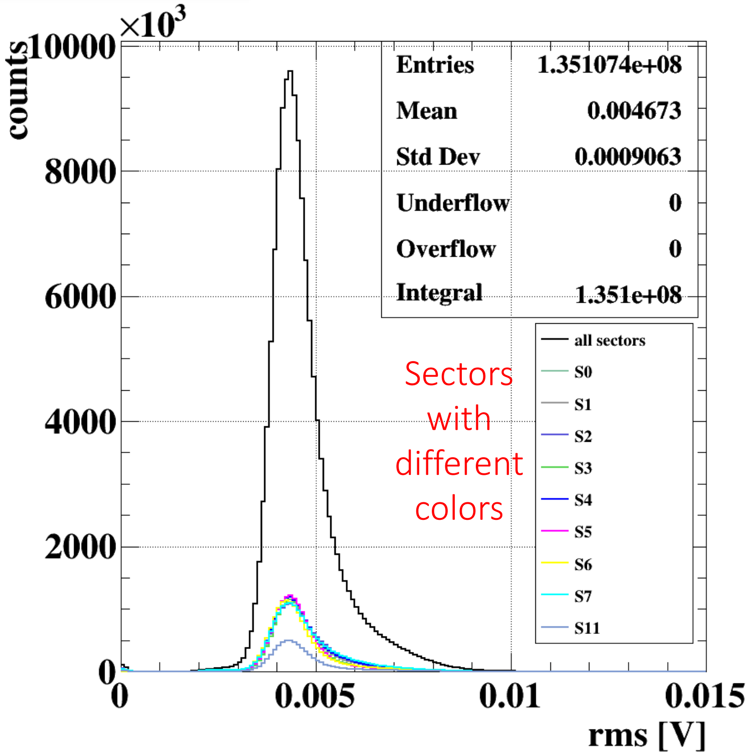


Scaling by radius as expected with Michel e^+ events

Some diagnostic plots from Michel e^+ data

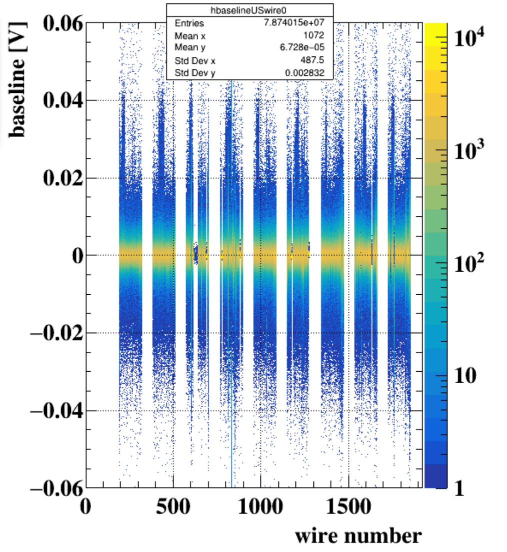
Baseline and RMS levels

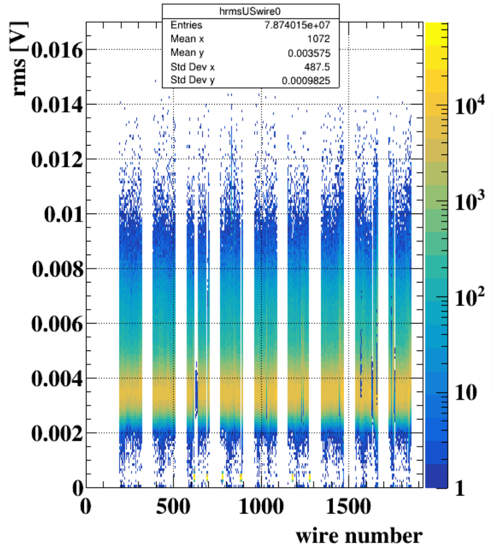




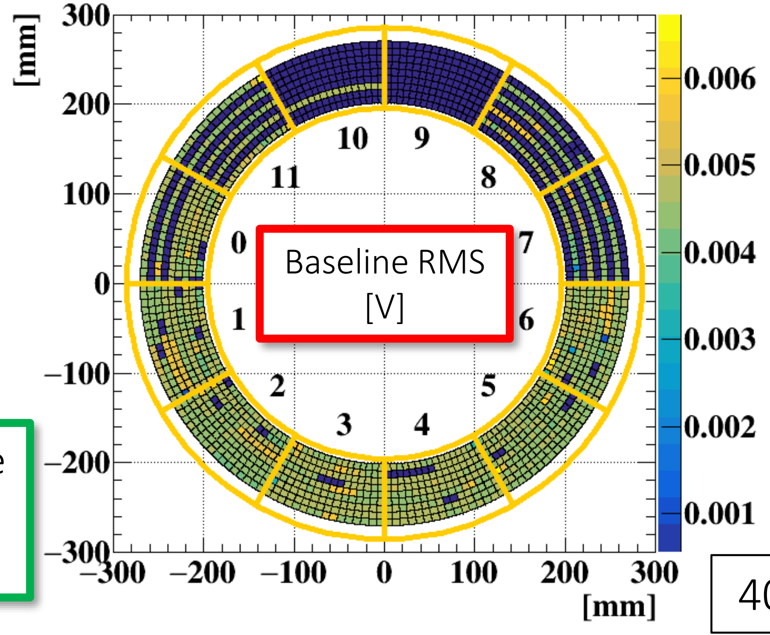
Sectors with different colors

Baseline US wire by wire





RMS US wire by wire



Baseline RMS [V]

Noise situation is under control

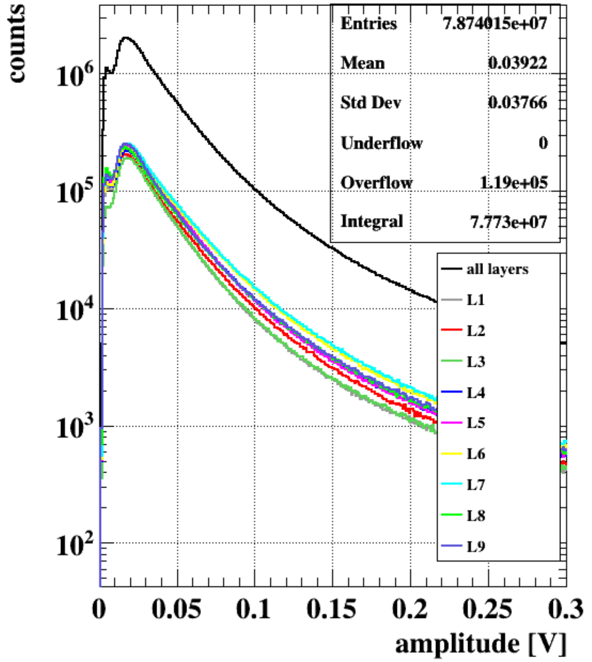
Good noise level at <4.5 mV>

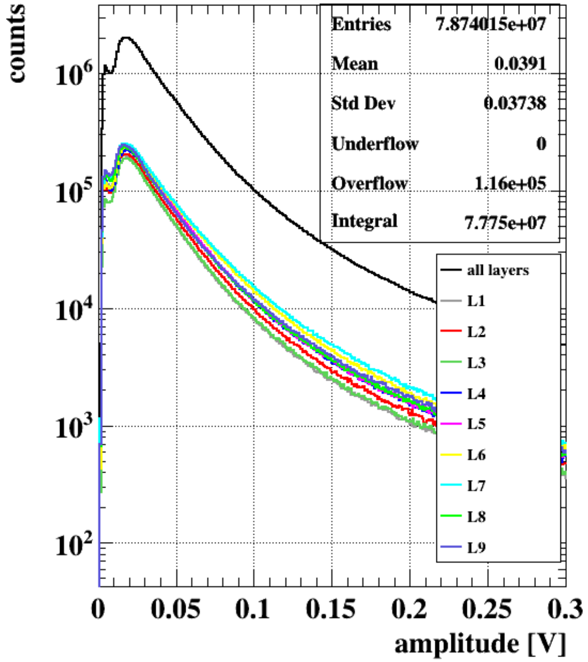
Some diagnostic plots from Michel e^+ data

US signal amplitude

Layers with different colors

DS signal amplitude

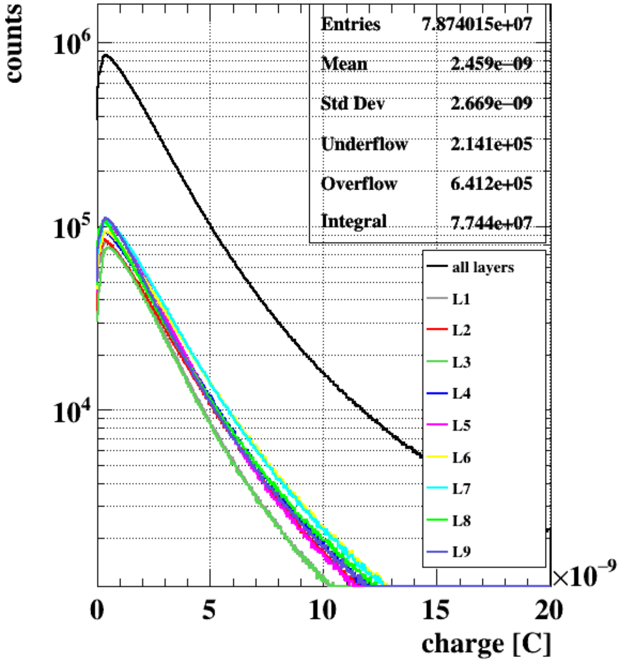


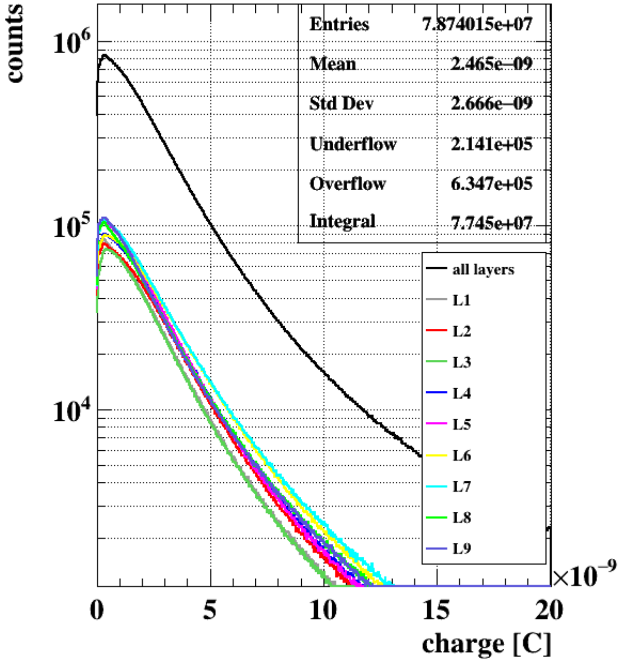


US signal charge

Layers with different colors

DS signal charge

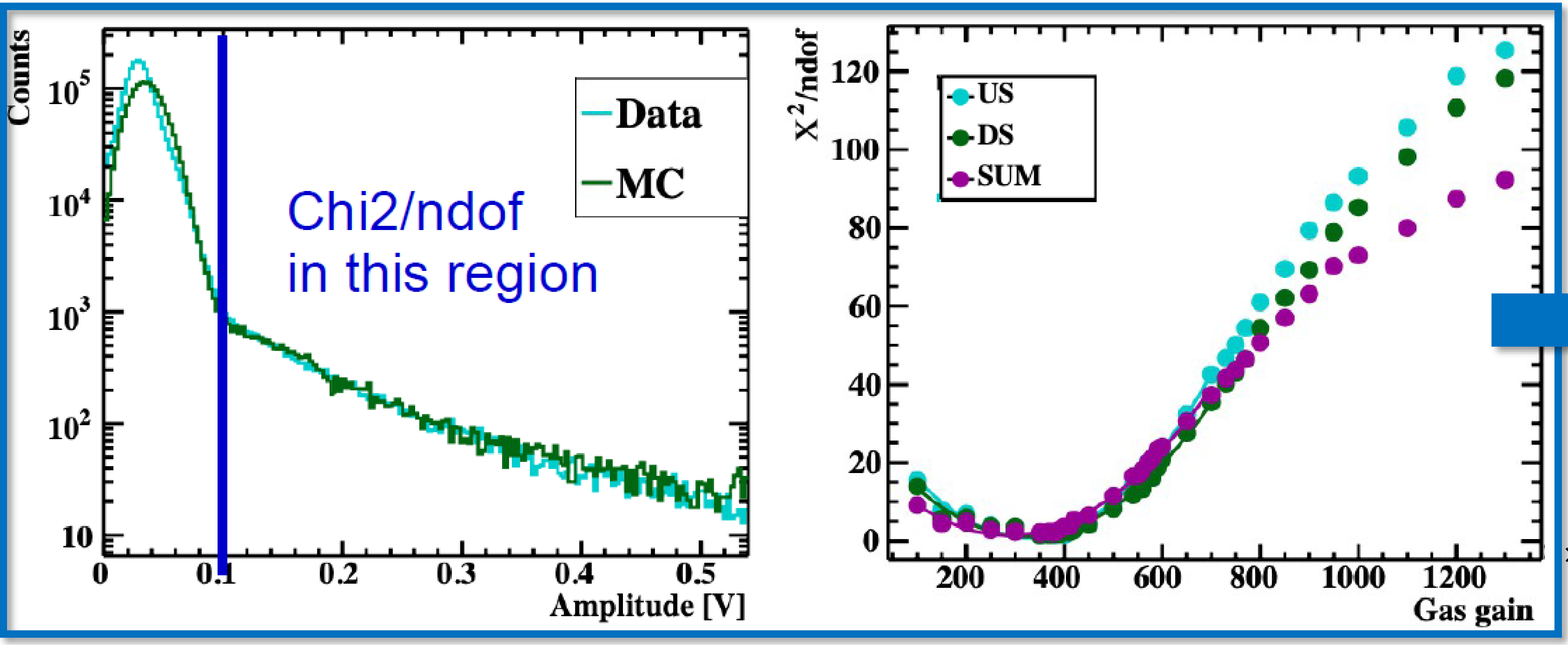


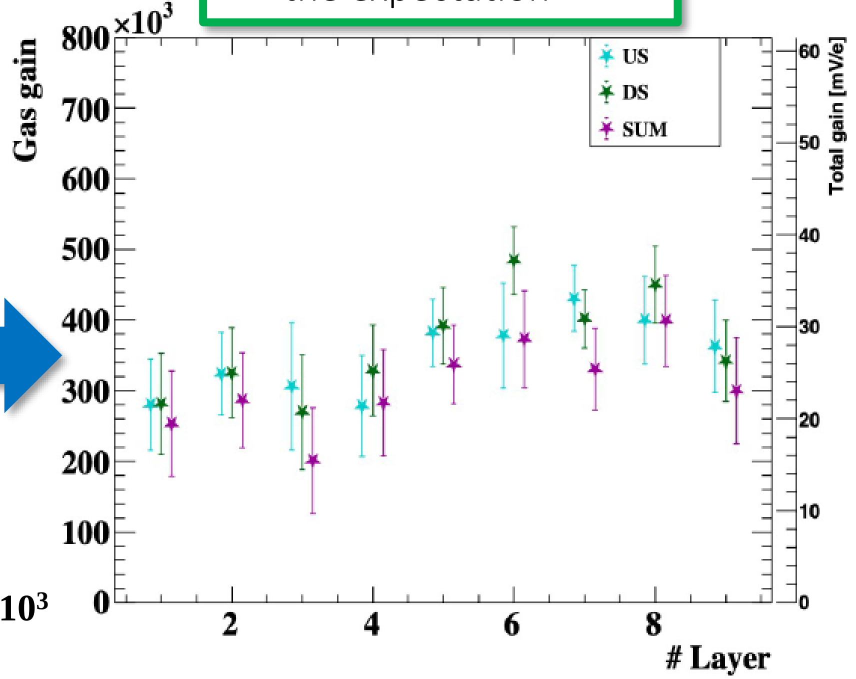


- Good uniformity of the **signal amplitude** between layers
- 10 V scaling of the HV works well

Gas gain measurement

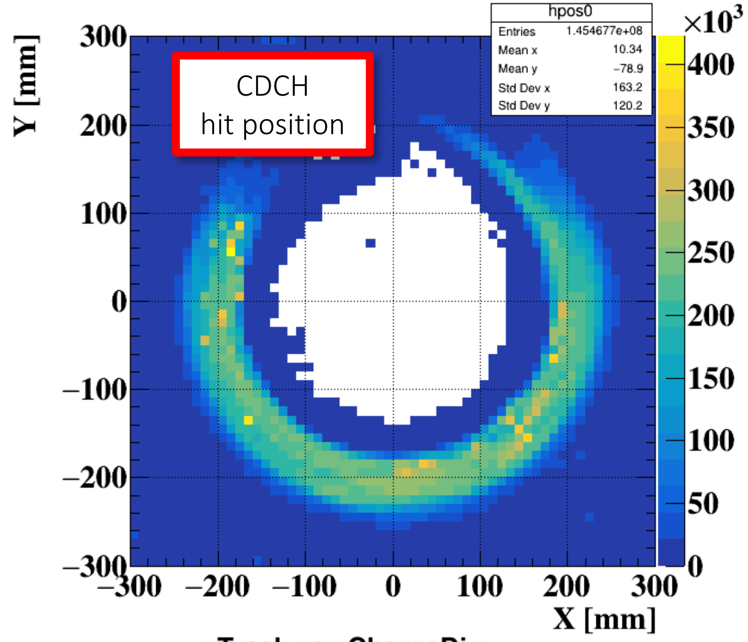
- 2021 measurement
- Gas gain = (2÷4) × 10^5 in agreement with the expectation

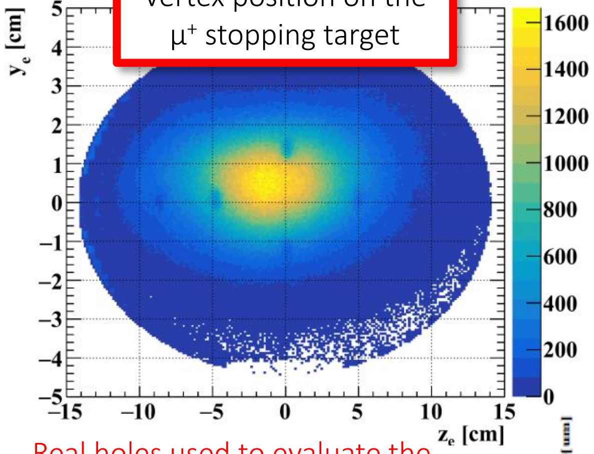




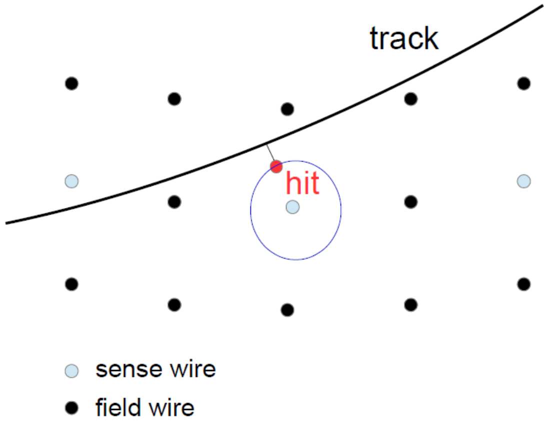
- **Signal amplitude distribution** from Cosmic Ray events: clean environment
- The only parameter to be tuned in MC to reproduce data is the Total gain = Gas gain × FE gain
- FE gain measured to be 0.120 mV/fC
  - FE response to real single-electron drift chamber signals produced by laser ionization on a prototype
- Gas gain = Total gain / FE gain

Hit reconstruction and resolution

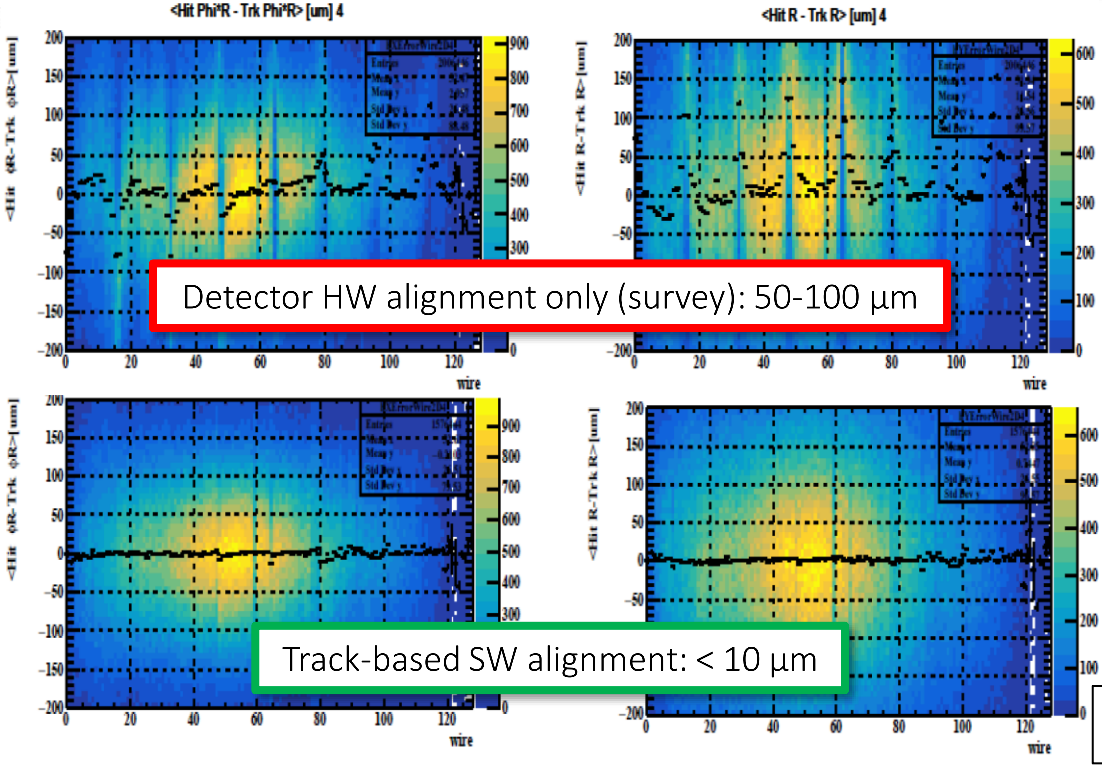




Real holes used to evaluate the vertex reconstruction accuracy

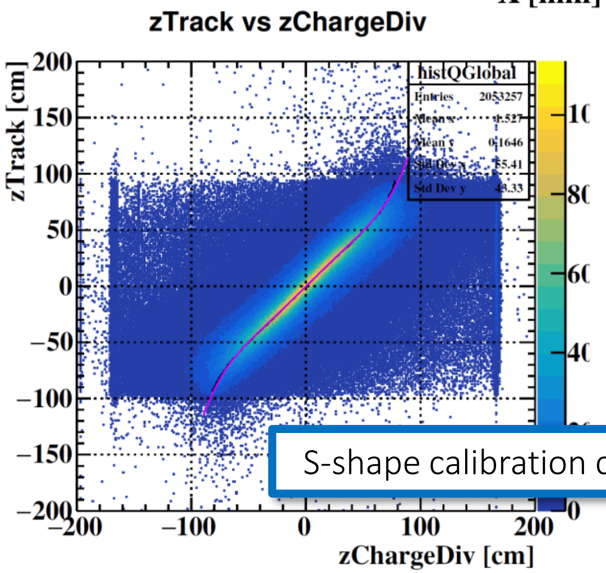


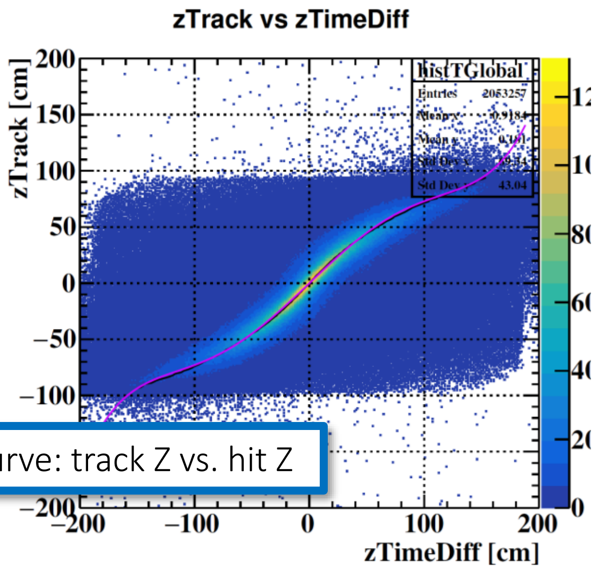
Hit-track residual give a measurement of how misalignments, single-hit resolution and other systematics (B field) combine to determine the reconstruction performance



Detector HW alignment only (survey): 50-100 μm

Track-based SW alignment: < 10 μm



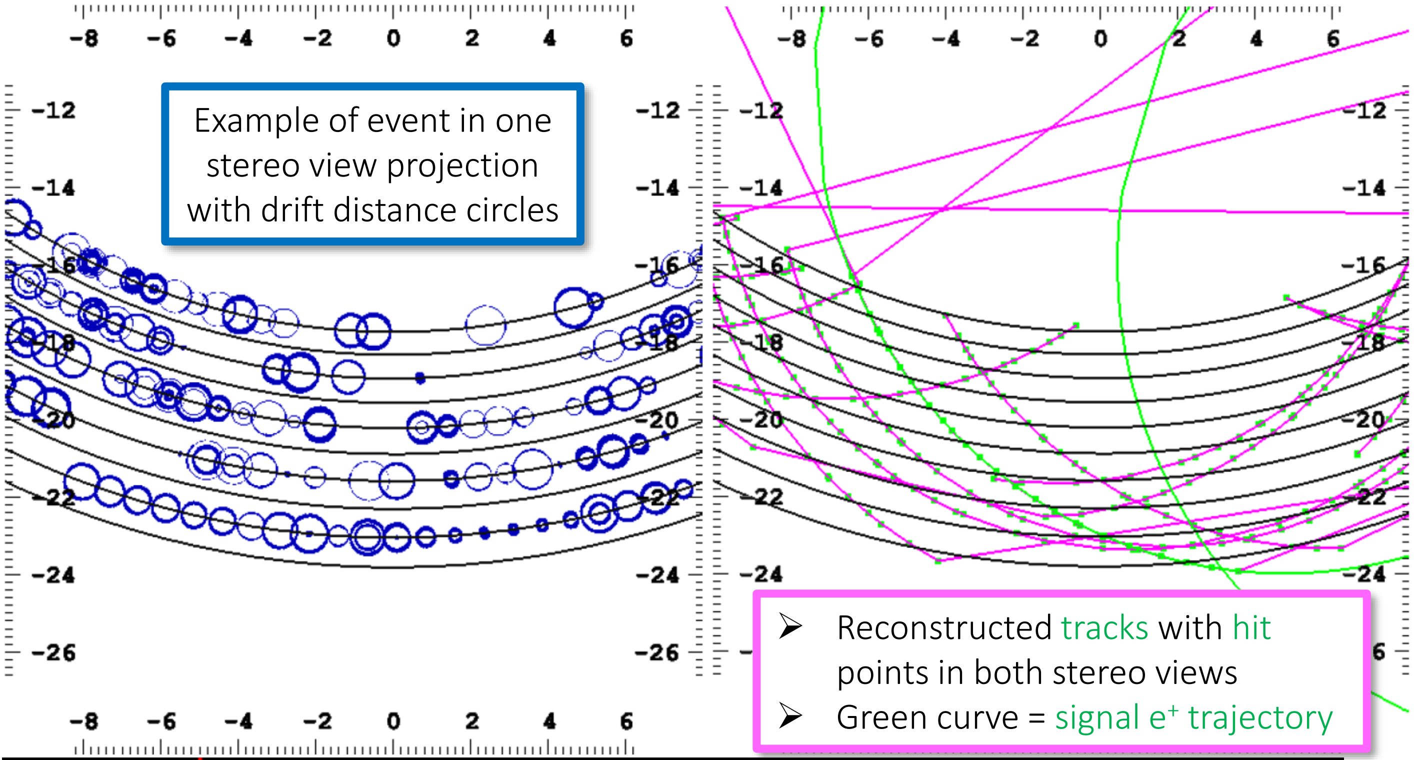


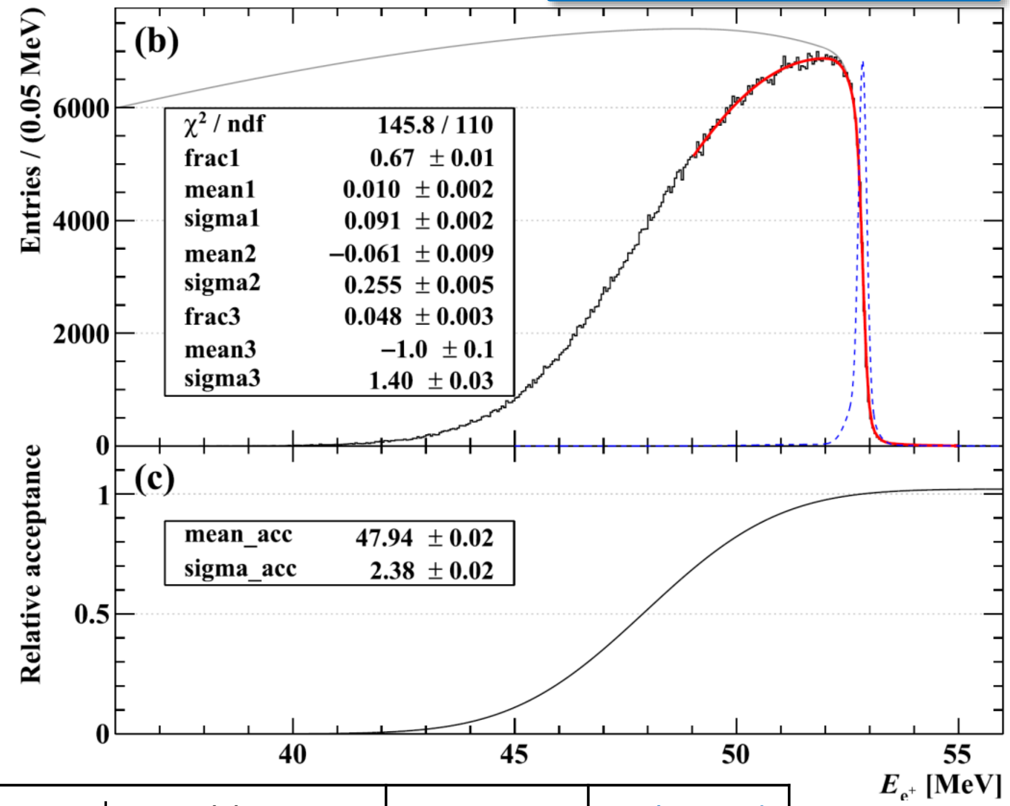
S-shape calibration curve: track Z vs. hit Z

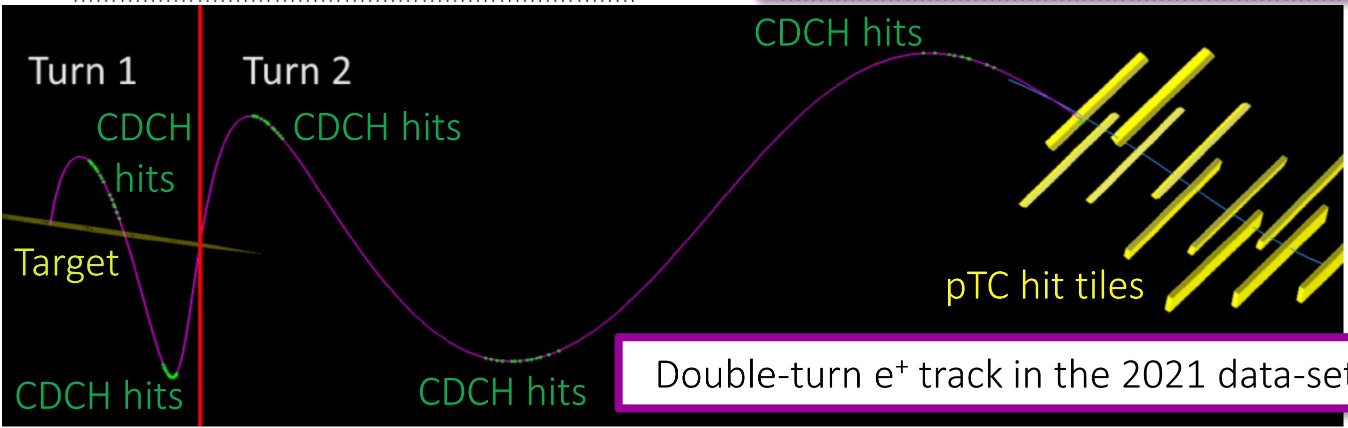
$3 \times 10^7\ \mu^+/s$

Tracking and Momentum resolution

$PDF(p) = [PDF_{THEORY}(p) \times Acceptance(p)] \otimes Resolution_{TRIPLE\text{-}GAUSSIAN}(\Delta p)$



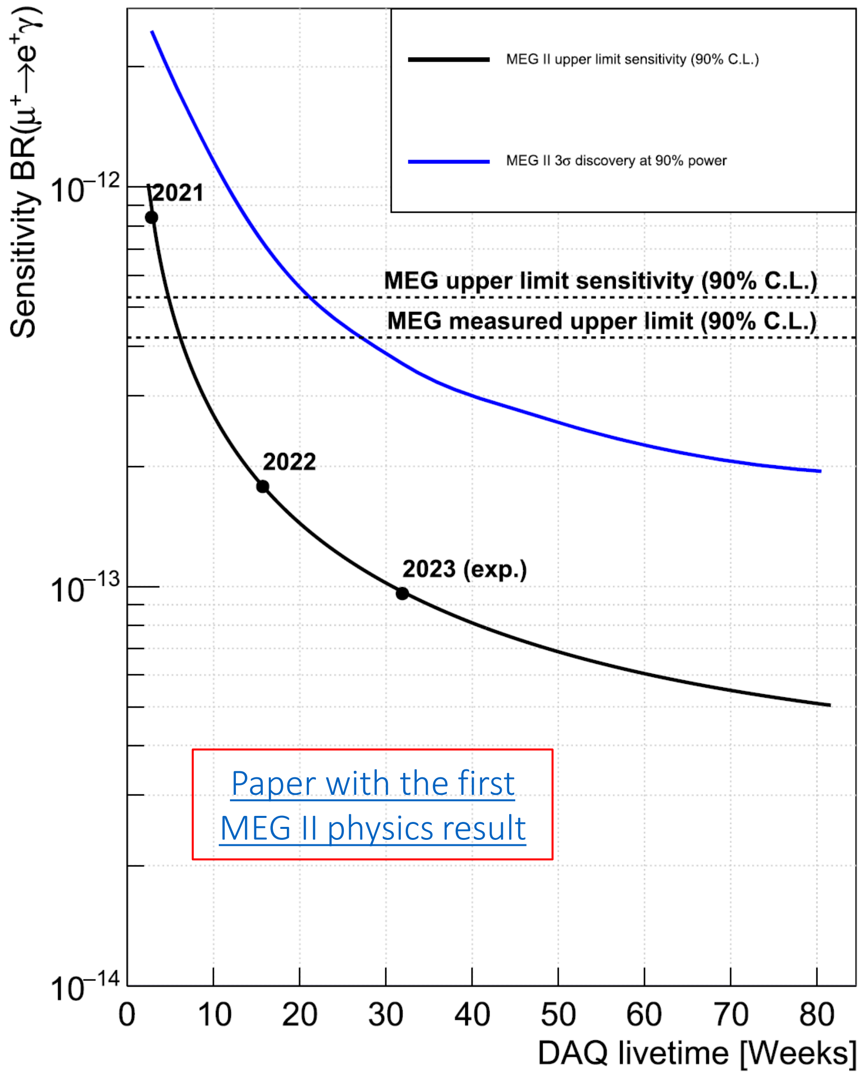




Double-turn e+ track in the 2021 data-set

e^+ variable	Foreseen	Achieved
ΔE_e (keV)	100	91
$\Delta\theta_e, \Delta\varphi_e$ (mrad)	6.7, 3.7	7.2, 4.1
$\Delta Z, \Delta Y$ (at target, mm)	1.6, 0.7	2.0, 0.7
ε_e (%)	65	67

Conclusions and prospects



- The new drift chamber CDCH of the MEG II experiment has been presented
  - **Full azimuthal coverage** around the stopping target
  - **Extremely low material budget**: minimization of MCS and γ background
  - **High granularity**: 1728 drift cells few mm wide in ΔR ≈ 8 cm active region
    - Improve angular and momentum resolutions of the e^+ kinematic variables
  - Stereo design concept, modular construction, light and reliable mechanics
- Despite the **COVID-19 situation** we were able to perform the 2020 and 2021 commissioning of all the MEG II subdetectors and the experiment started the physics data taking in 2021
  - Some **results from 2021-2023 data** have been presented (full data taking 2021-2026)
  - Data analysis and continuous developments ongoing
- Problems along the path
  - Corrosion and breakage of 107 aluminum wires in presence of 40-65% humidity level
    - Especially 40 μm wires (90%) proved to be prone to corrosion
    - Problem fully cured by keeping CDCH in dry atmosphere
  - Anomalously high currents experienced
    - Probably triggered by a bad event during the 2019 engineering run
    - CDCH operation recovered by using additives (**0.5% O_2 + 1.5% Isopropyl alcohol**) to the standard He:iC_4H_{10} 90:10 gas mixture

- **Beyond $\mu^+ \to e^+\gamma$: the X(17) boson search**
  - Atomki collaboration (2016): excess in the angular distribution of the Internal Pair Creation (IPC) in the ^{7}Li(p, e^+e^-)^{8}Be nuclear reaction
  - Possible interpretation with a new physics boson mediator with mass expected around 17 MeV: p N → N'* → N' (X →) e^+e^-
  - MEG II has all the ingredients (CW accelerator + Spectrometer) to repeat the measurement → **data unblinding soon**

THANKS
FOR YOUR ATTENTION

BACK-UP SLIDES

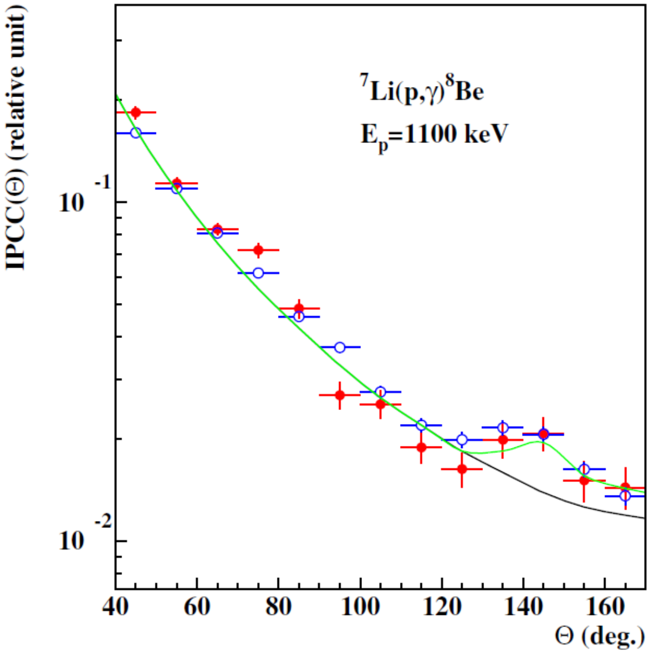
Beyond $\mu^+ \to e^+\gamma$: the X(17) boson search

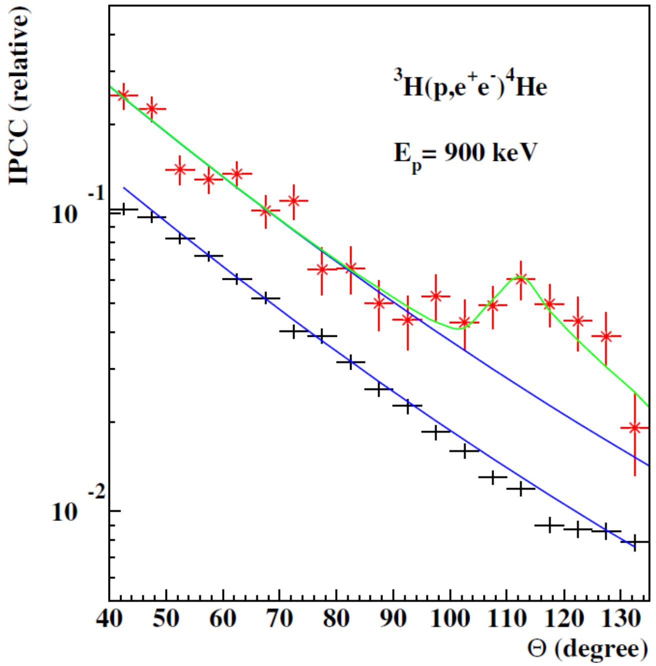
- In 2016 the Atomki collaboration measured an excess in the angular distribution of the Internal Pair Creation (IPC) in the $^7Li(p, e^+e^-)^8Be$ nuclear reaction
- This anomaly was confirmed by further measurements
  - $^3H(p, e^+e^-)^4He$ reaction
- Possible interpretation
  - Production of a new physics boson mediator of a fifth fundamental force that describes the interaction between dark and ordinary matter

    p N → N'* → N' (X →) e^+e^-

  - Its mass is expected to be 17 MeV → X(17)
- An independent experiment could confirm or not this results
  - Artifact of the detector geometry???

- MEG II has all the ingredients to repeat the Atomki measurement
  - CW proton accelerator (used for LXe detector calibrations)
  - CDCH for e^+e^- measurement
  - pTC as trigger
  - B field → e^+e^- invariant mass with CDCH + COBRA magnet

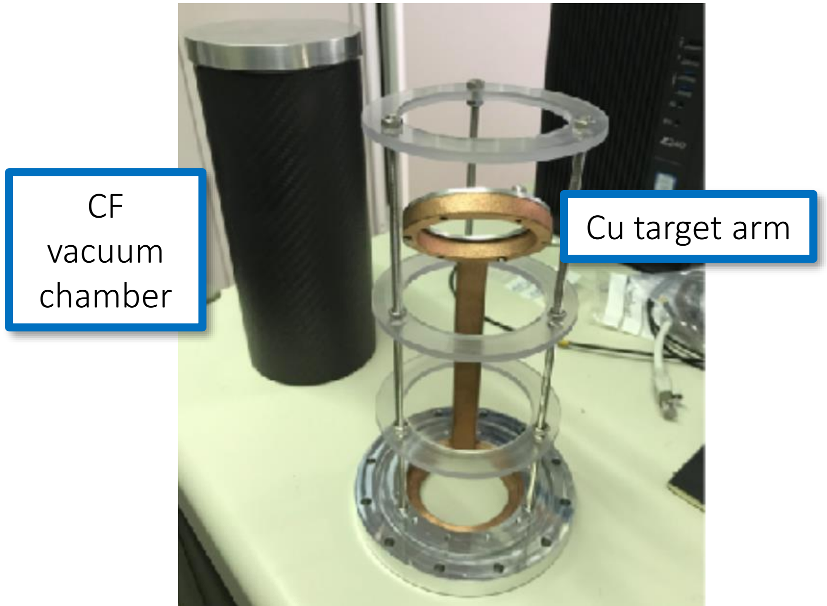




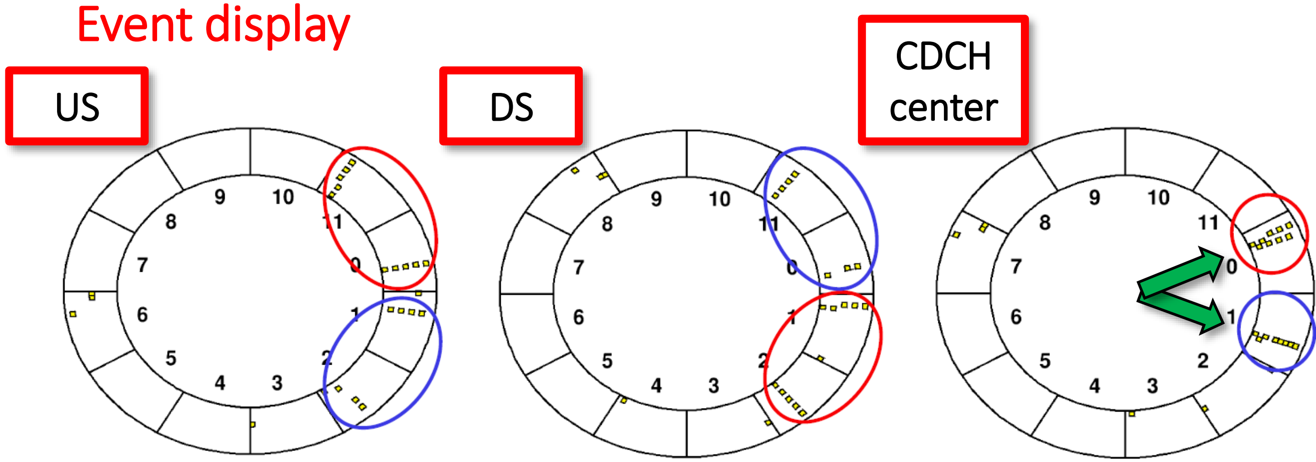
First test with CDCH and B field OFF

- CW Li(p,γ)Be reaction with e^+e^- pairs from γ conversion (likely in the CW beamline)
- **First test with an existing aluminum vacuum chamber**

- For the final measurement to minimize the MCS and achieve a better resolution the CW target region was re-design
  - The new setup consists of a 10 μm thick Li_2O layer on a 25 μm thick Cu substrate
  - Connection to the CW beamline by means of a Cu arm
  - Both structures are placed in a CF vacuum chamber

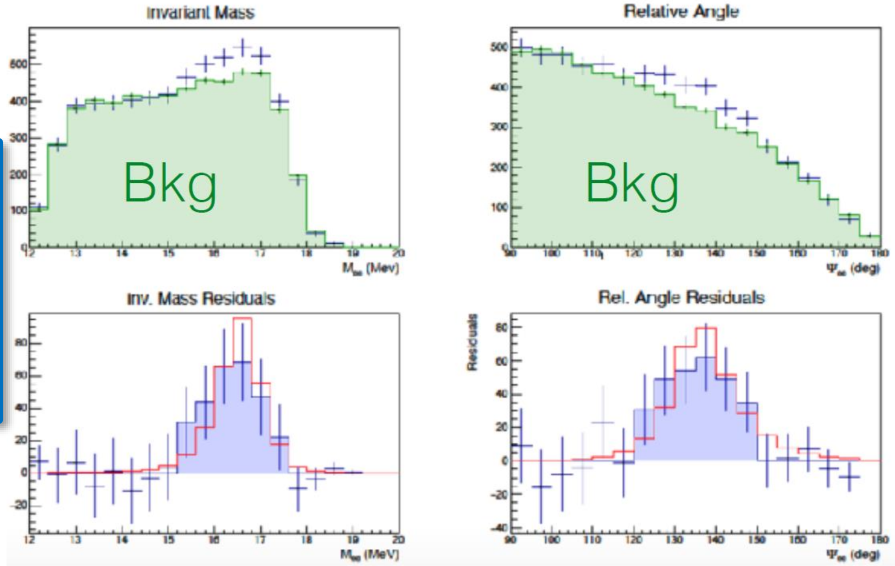


Event display



- Events are near Z=0
- 2 particles leave 2 tracks at CDCH center and 4 at Z=endplates due to the stereo angle

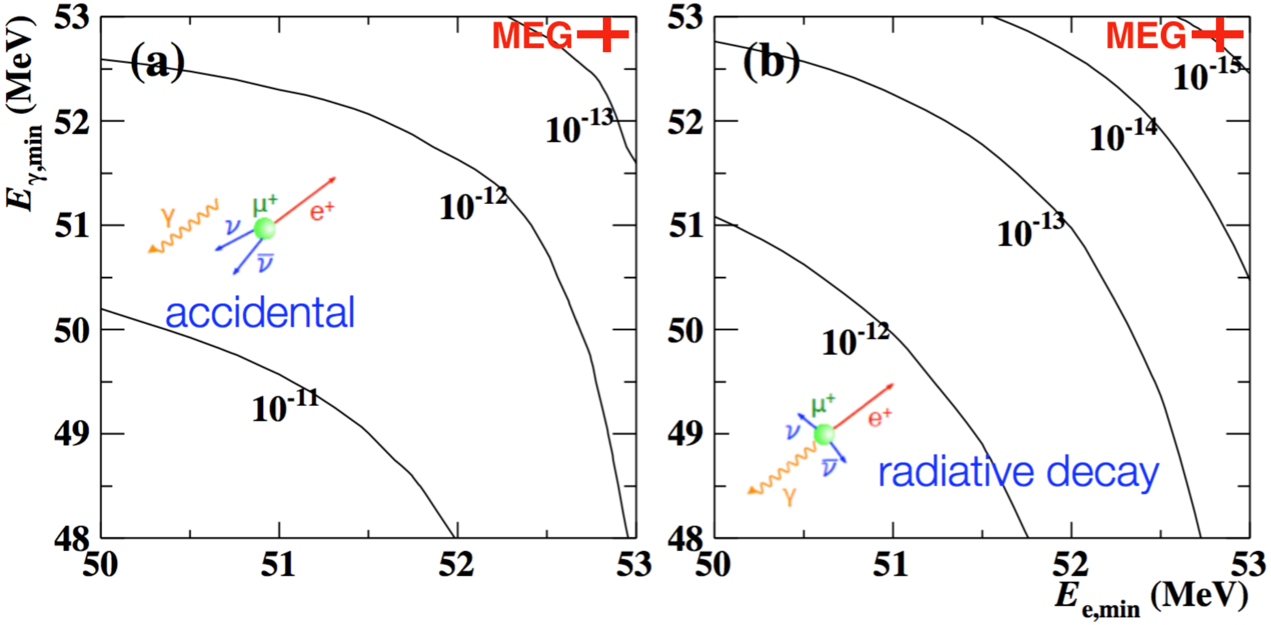
MC studies shows that a 5σ significance can be achieved in order few weeks

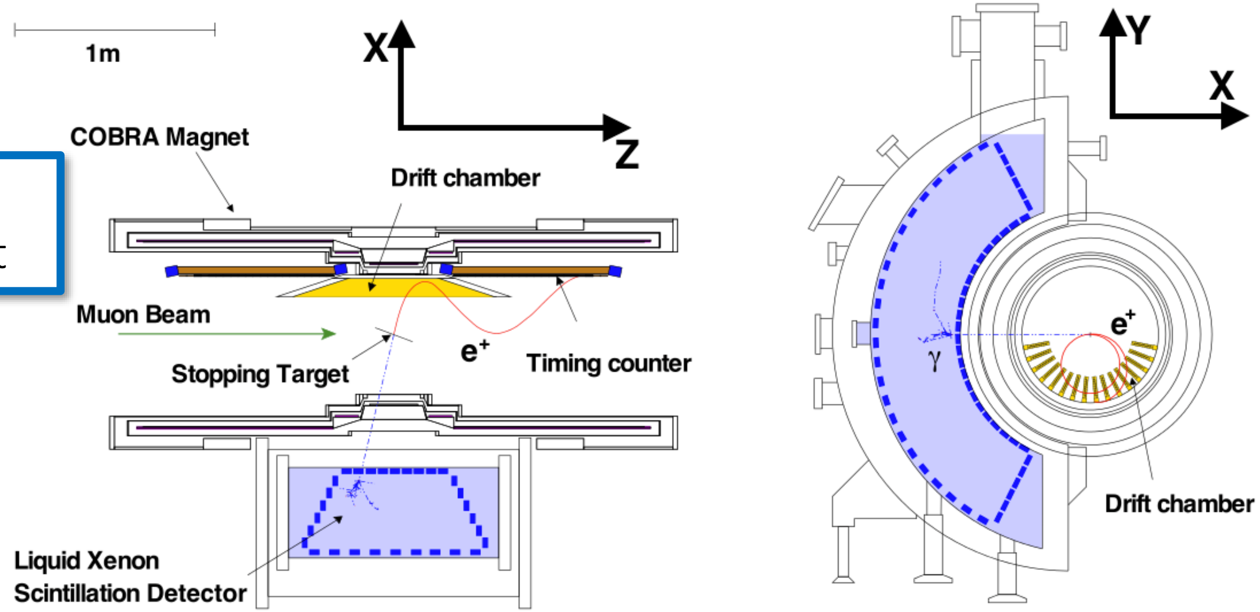


MEG

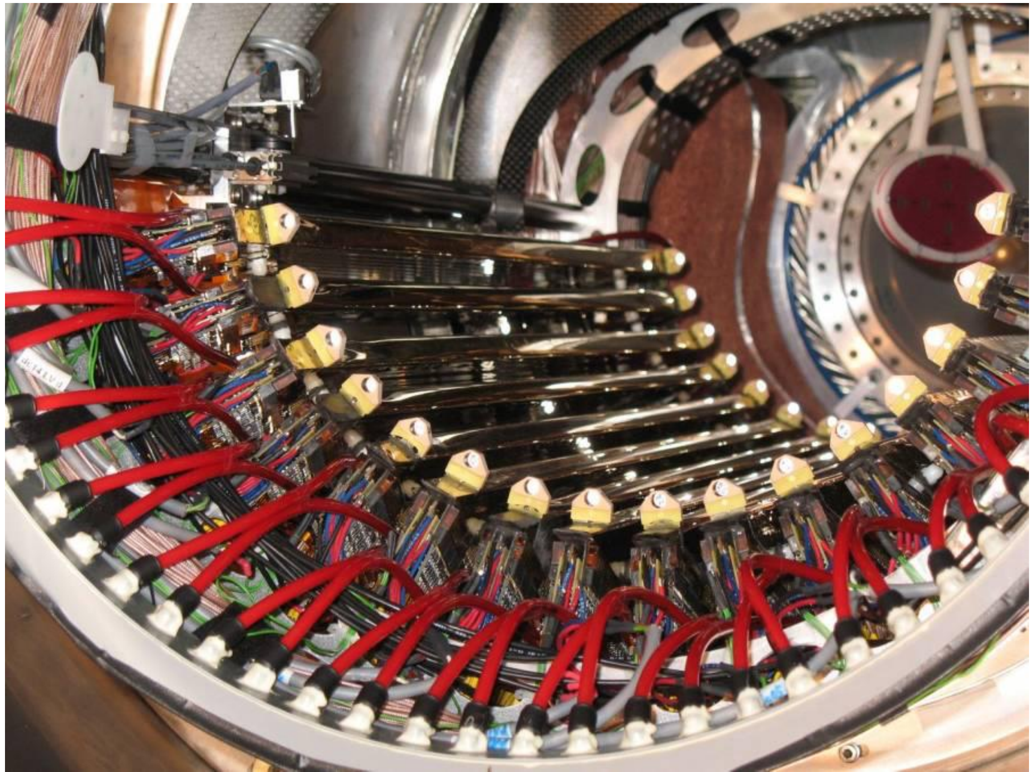
The MEG experiment

Backgrounds





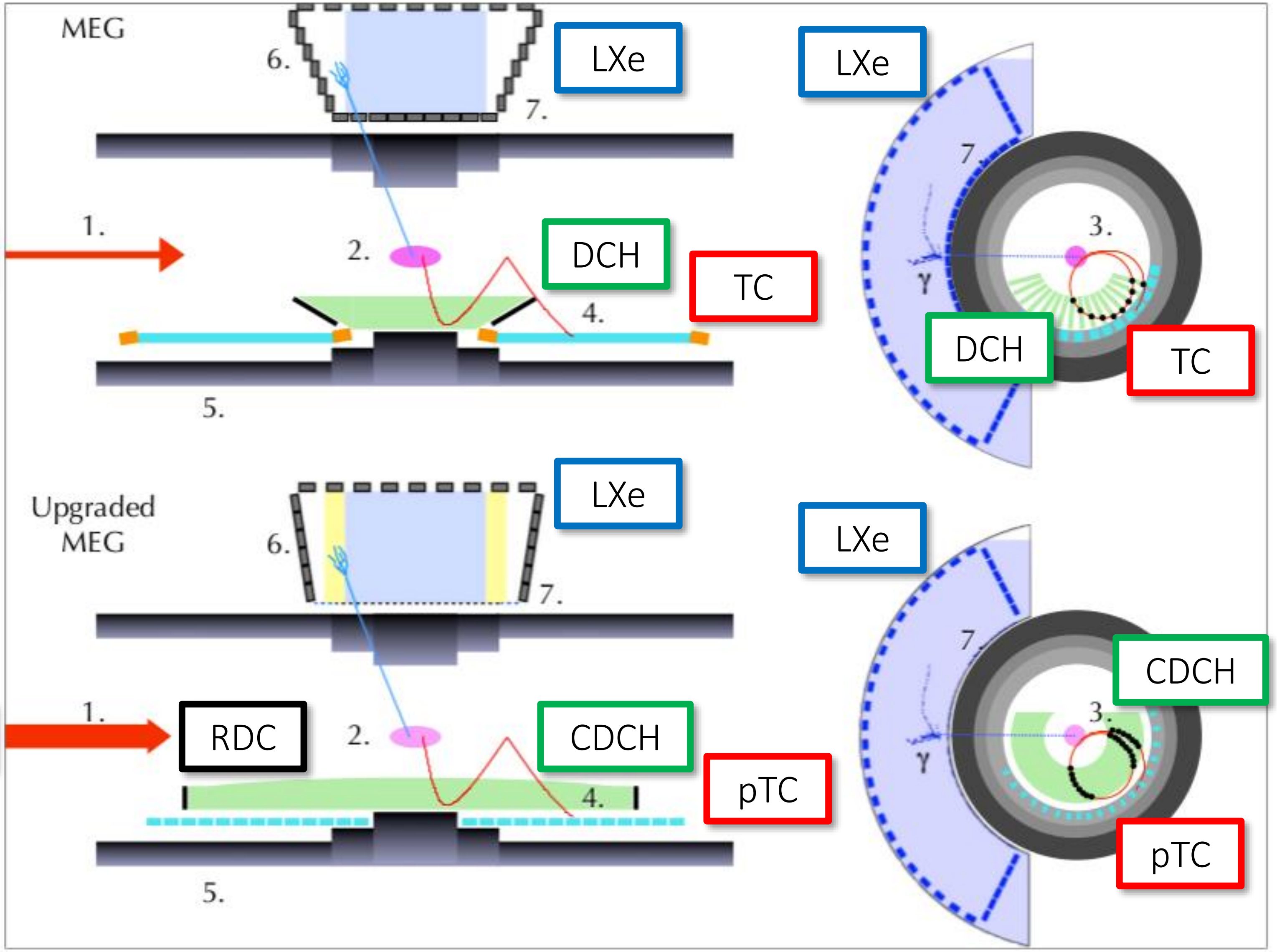
DCH



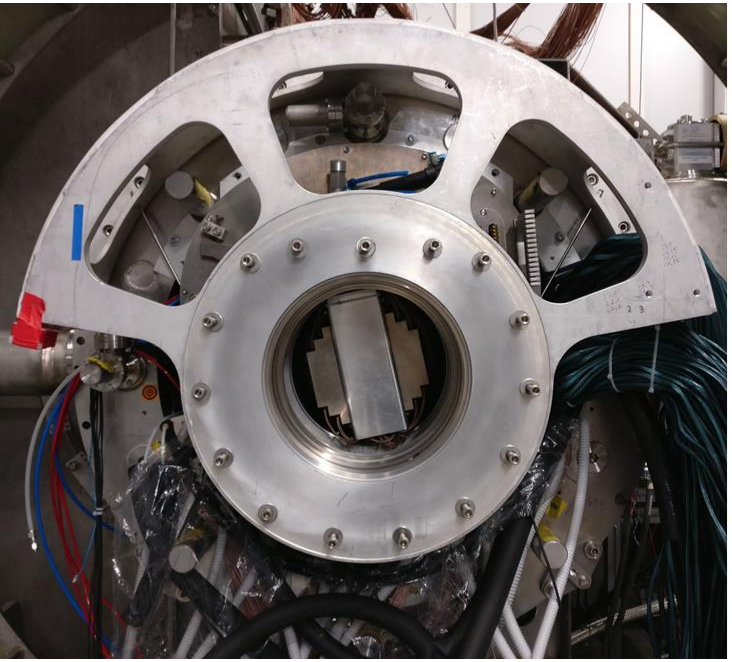
MEG vs. MEG II

$3 \times 10^7\ \mu^+/s$

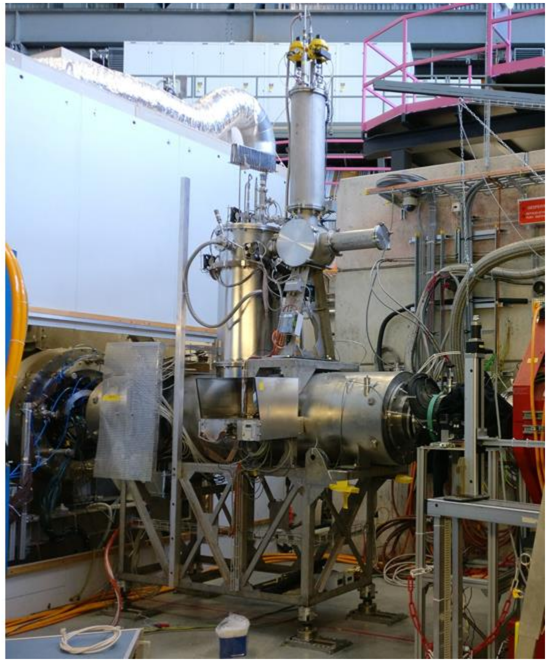
$7 \times 10^7\ \mu^+/s$



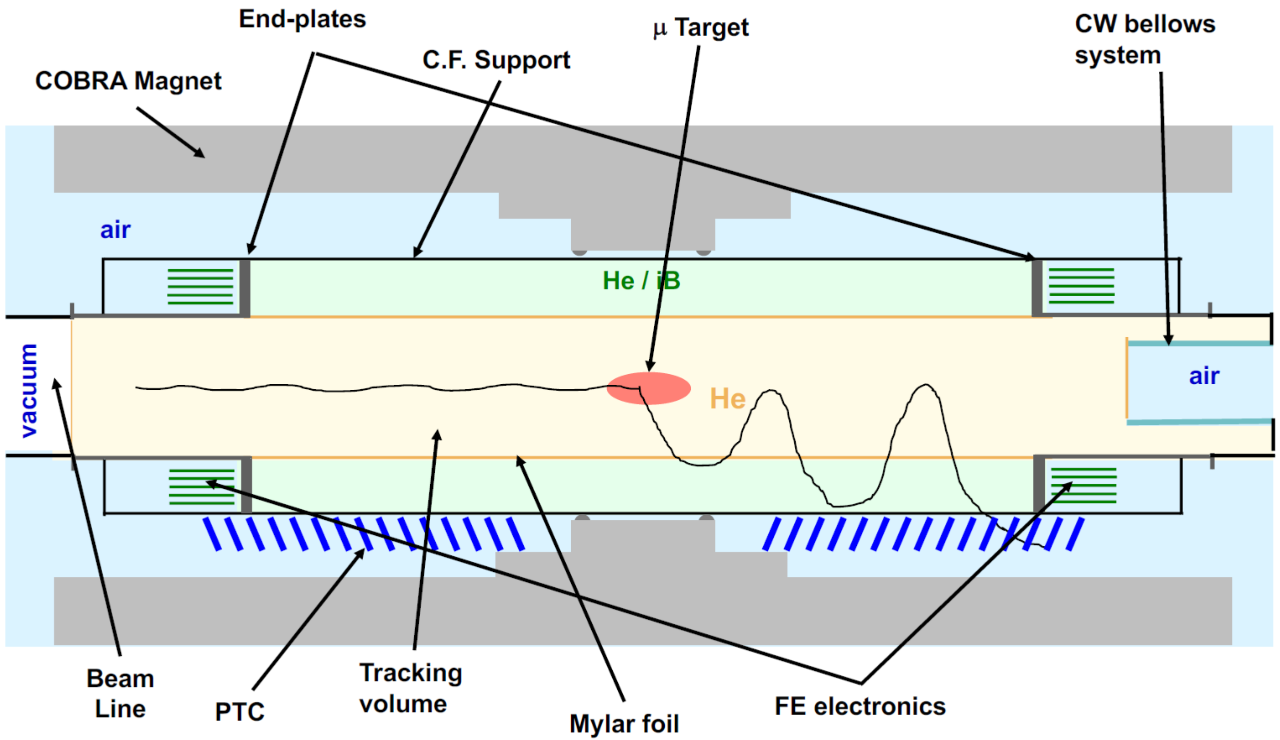
MEG II beam line



RDC



BTS



MEG upgrade motivations

- 2009-2011 data analysis: $BR(\mu^+ \to e^+\gamma) < 5.7 \times 10^{-13}$ (90% C. L.) Phys. Rev. Lett. 110, 201801 (2013)
  - 36% improvement with the final MEG result
  - Statistics increased by more than a factor 2: $N_\mu^{2009-2011} \approx 3.5 \times 10^{14} \rightarrow N_\mu^{2009-2013} \approx 7.5 \times 10^{14}$
- The MEG sensitivity does not increase linearly with the amount of data taking anymore
  - **Limited by the resolutions on the measurement of the kinematic variables** of the two decay products
- Upgrade (MEG II) of the experimental apparatus designed and presently in the commissioning phase at PSI

Variable	Design (MEG)	Obtained (MEG)	Current (MEG II)
ΔE_e (keV)	200	380	100
$\Delta\theta_e, \Delta\varphi_e$ (mrad)	5, 5	9, 9	6.7, 6.7
Efficiency_e (%)	90	30	65
ΔE_γ (%)	1.2	1.7	1.7
$\Delta\text{Position}_\gamma$ (mm)	4	5	2.4
$\Delta t_{e\gamma}$ (ps)	65	120	70
Efficiency_γ (%)	> 40	60	70

Positron variables

- Obtained with high statistics full Monte Carlo simulations of the MEG II experimental apparatus
- Using the currently updated reconstruction algorithms
  - Still margin for improvements

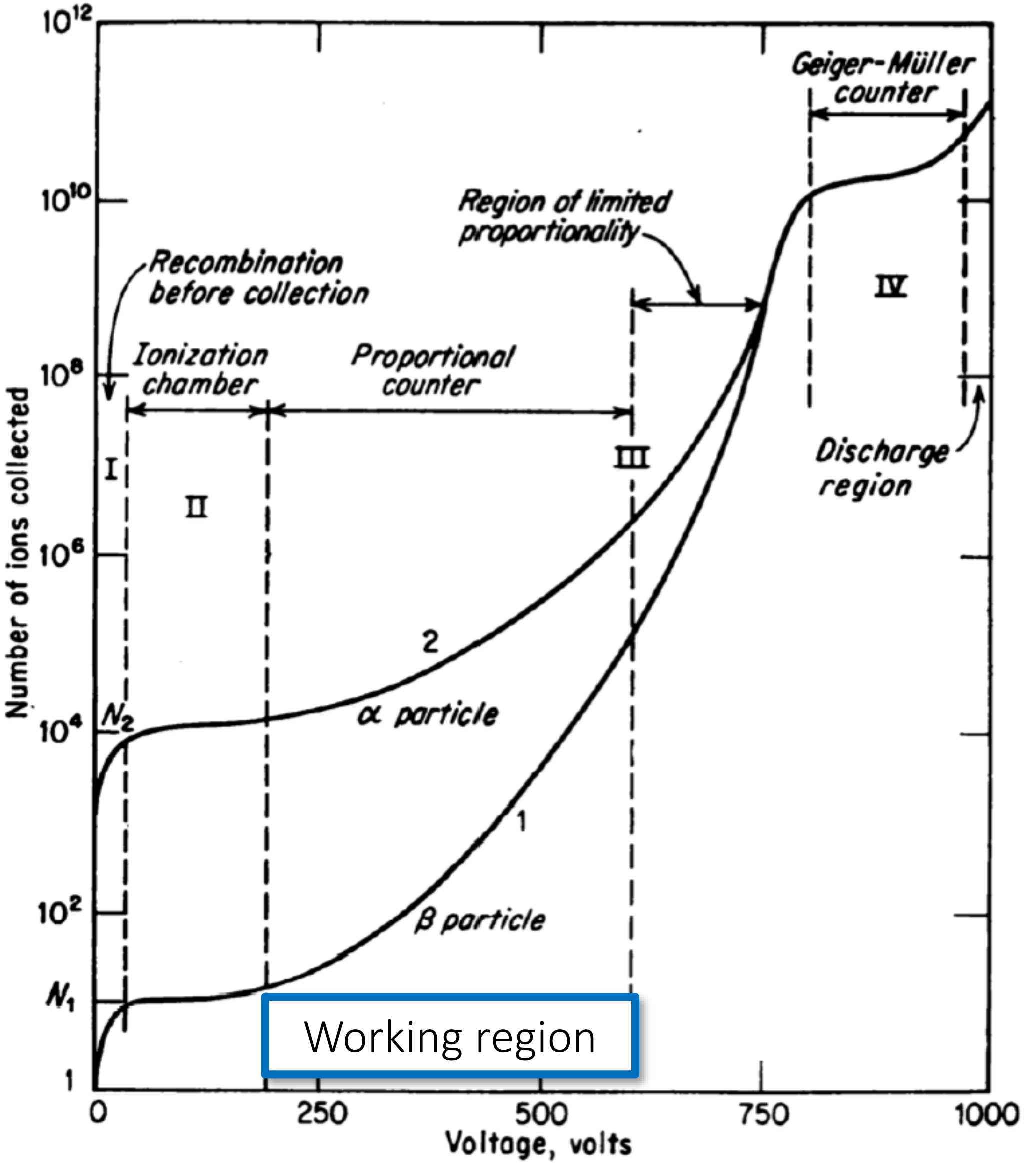
Cell inefficiency studies

- To understand the effect of such cell inefficiency in L9 and L8 we performed **simulation studies with 100k signal + Michel** events and the **currently updated reconstruction algorithms**
  - By killing the inefficient cells found with the last HV test
  - Inefficient = safety HV point not reached
  - Effects are negligible

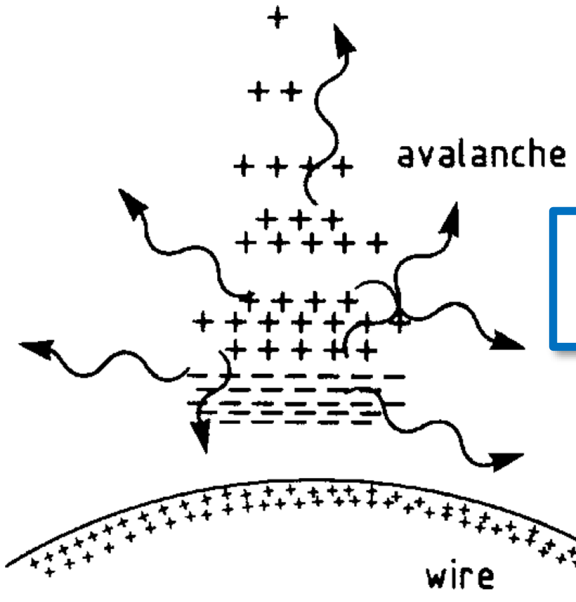
EFFICIENCY	ε_{CDCH} (%) ± 0.2% (single hits)	ε_{e+} (%) ± 0.2%
standard	75.8	63.4
usable wires	74.6	62.6

RESOLUTIONS	**σθ/RMSθ (mrad) ±0.03**	**σφ /RMSφ (mrad) ±0.03**	**σp/RMSp (keV) ±0.4**	**σz/RMSz (mm) ±0.006**	**σy/RMSy (mm) ±0.006**
standard	6.217/6.876	5.766 /6.514	87.5/103.6	1.379/1.590	0.728/0.828
usable wires	6.221/6.879 +0.04%	5.822/6.585 +1%	88.0/103.9 +0.3%	1.384/1.601 +0.7%	0.736/0.837 +1%

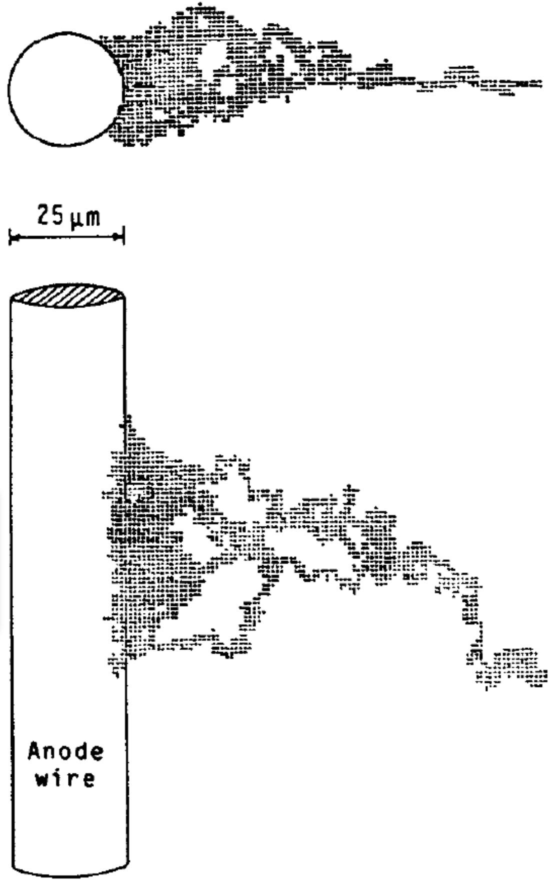
Drift chambers working

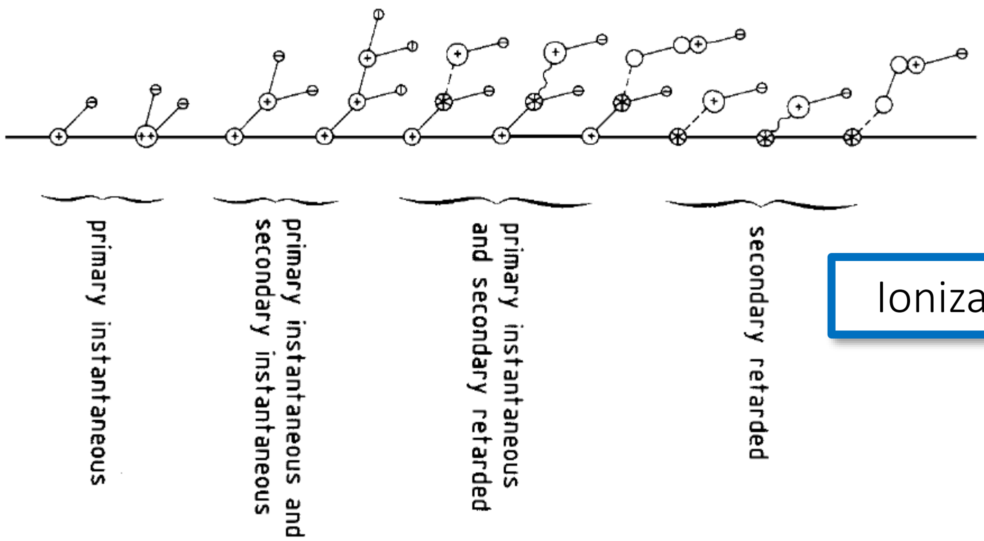


Working region



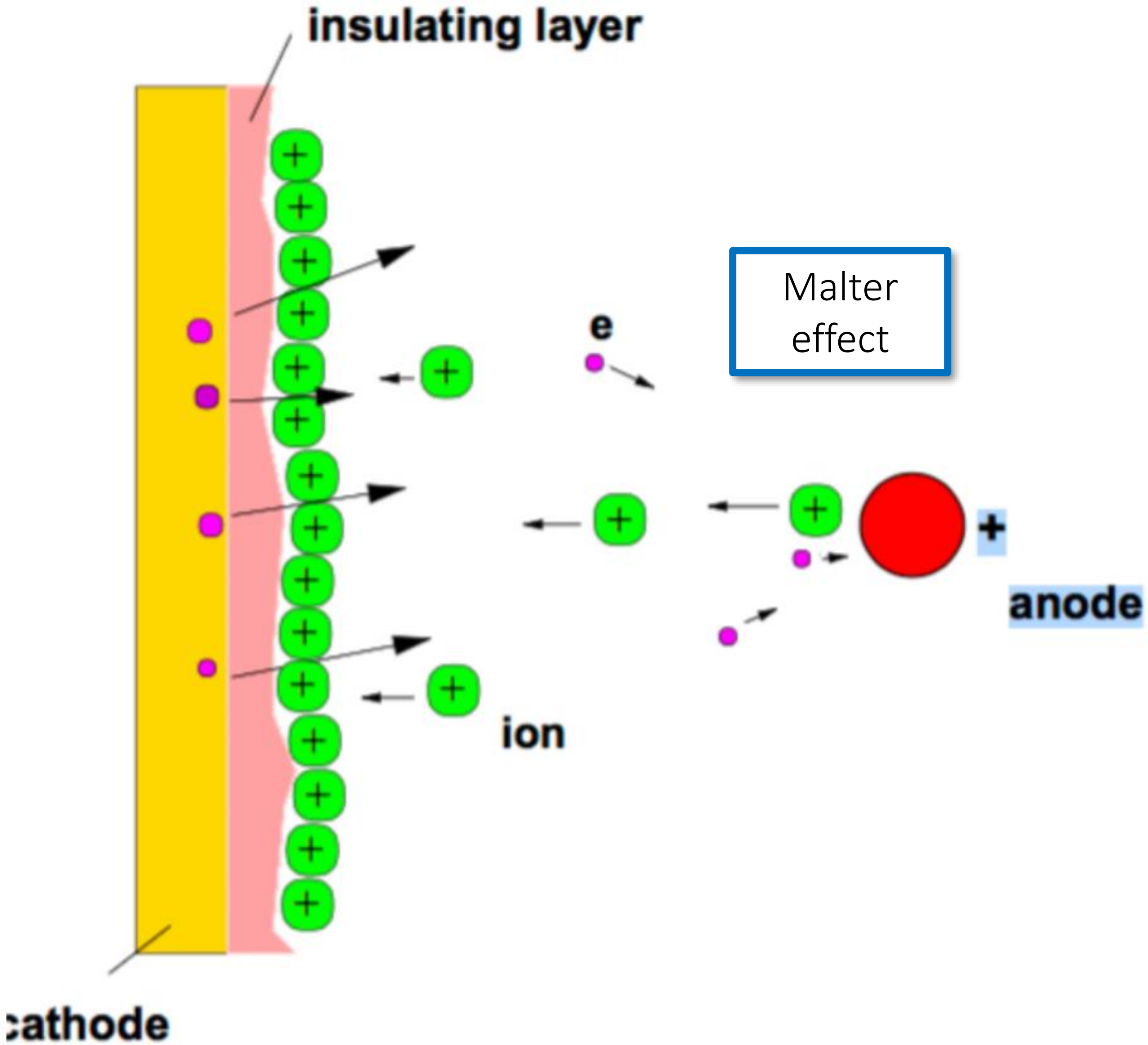
Avalanche development



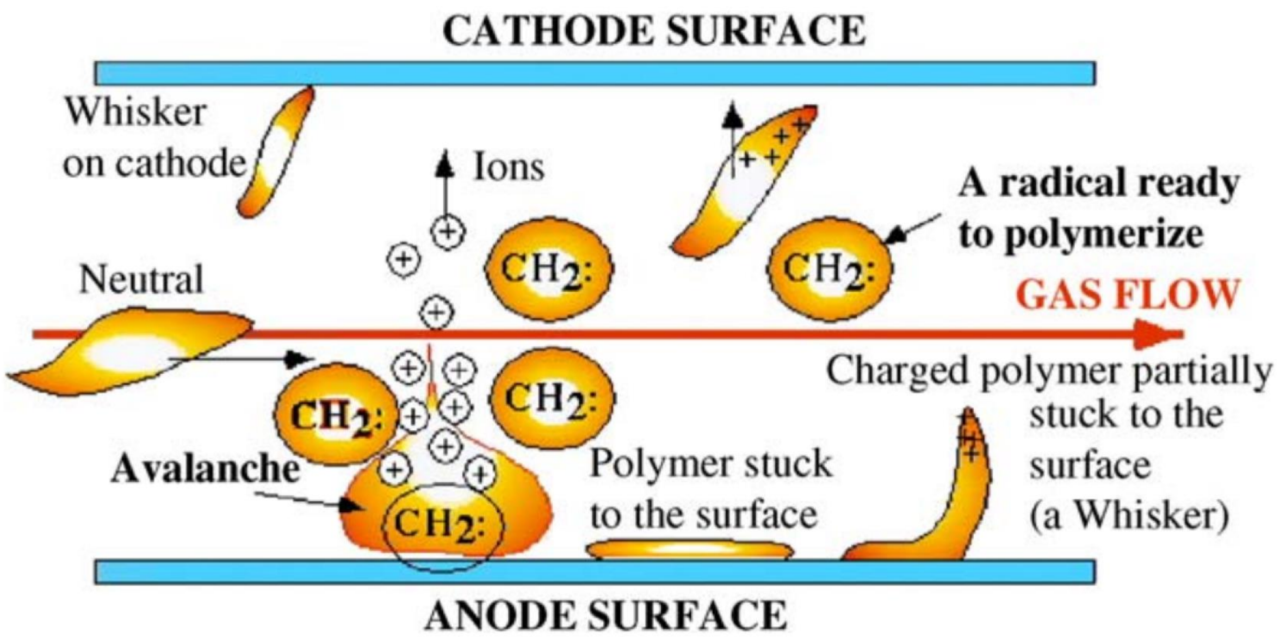


Ionization

Malter effect and free radicals

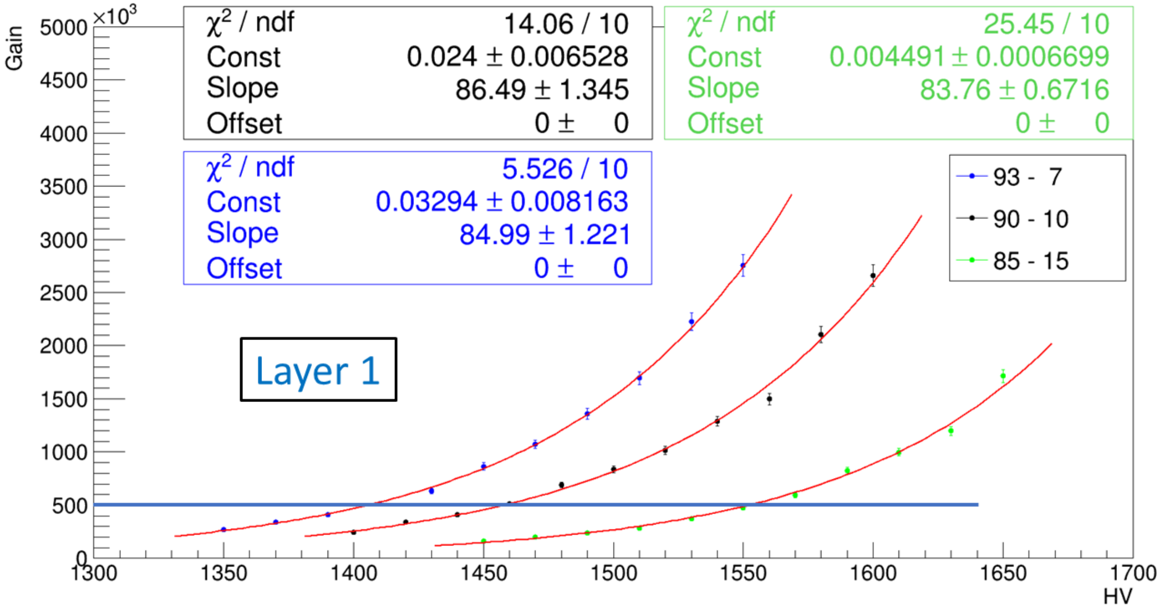


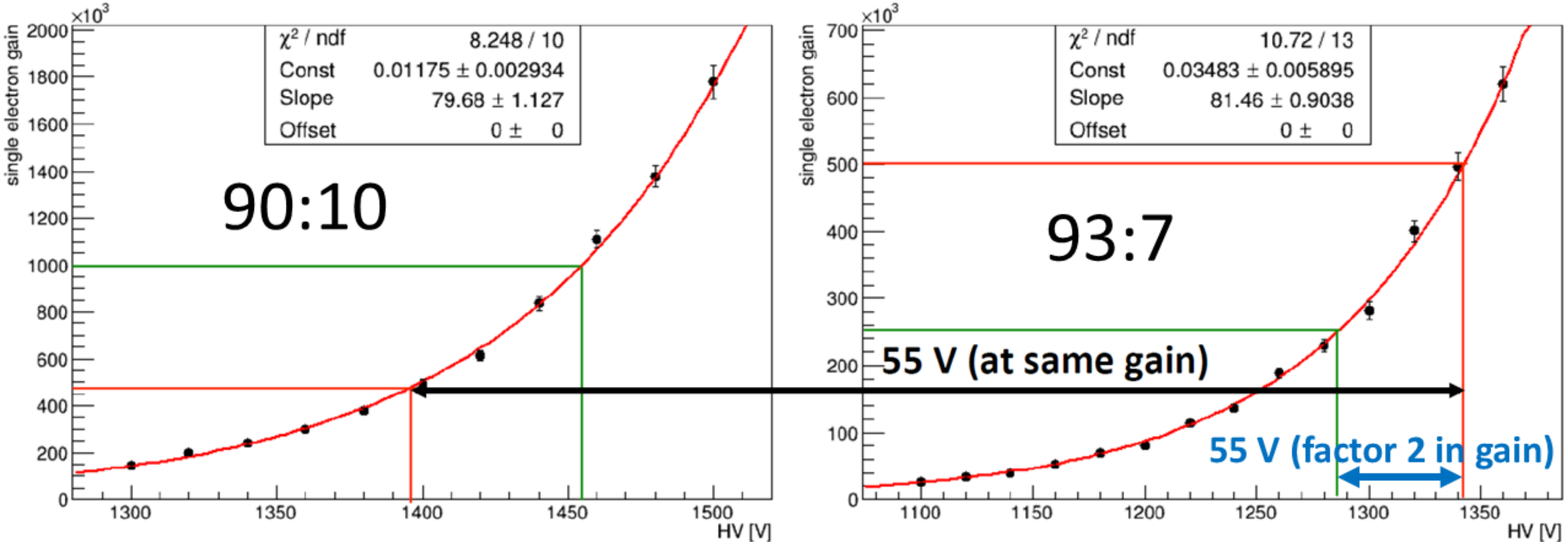
Malter effect



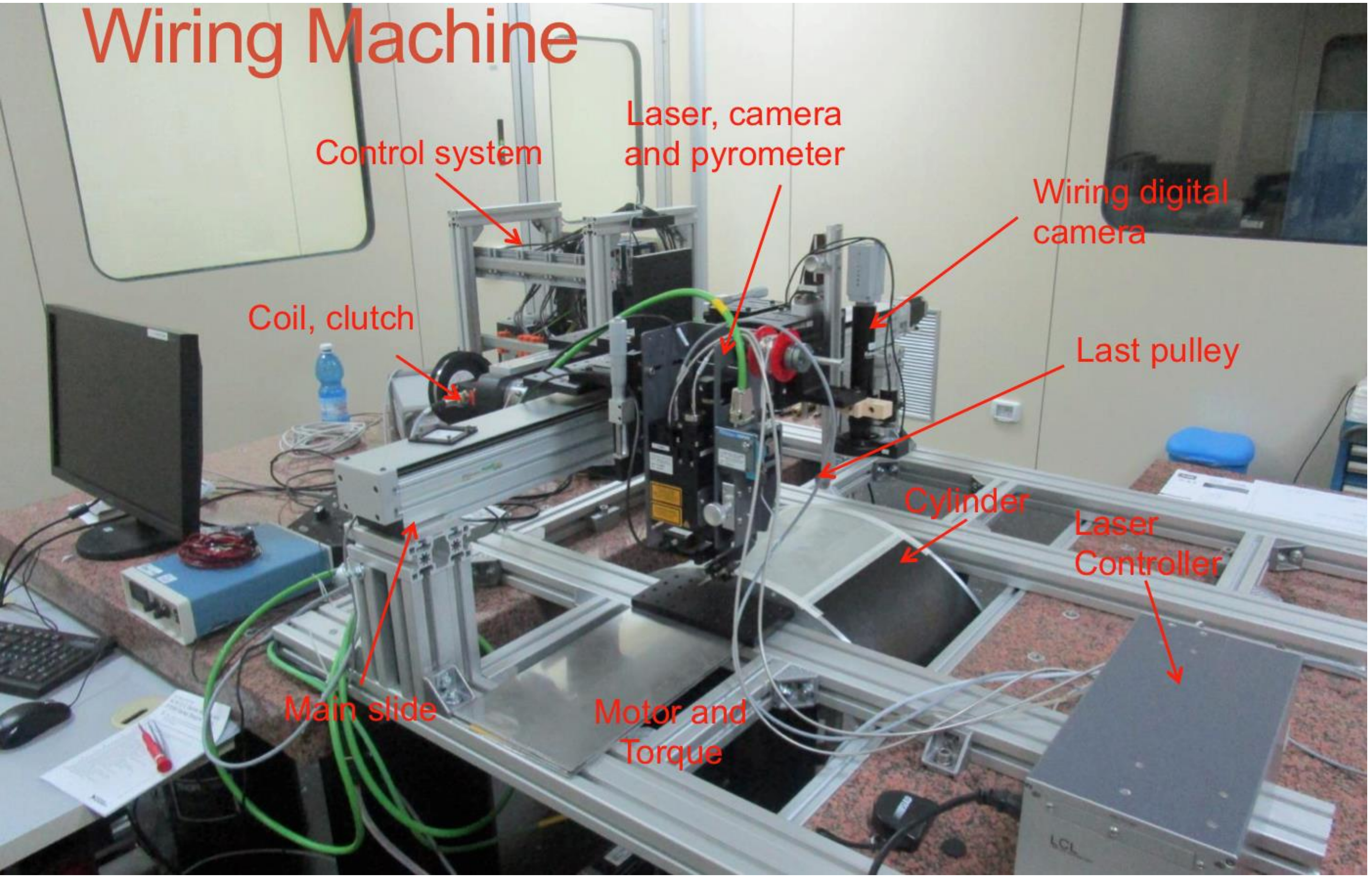
Free radicals formation

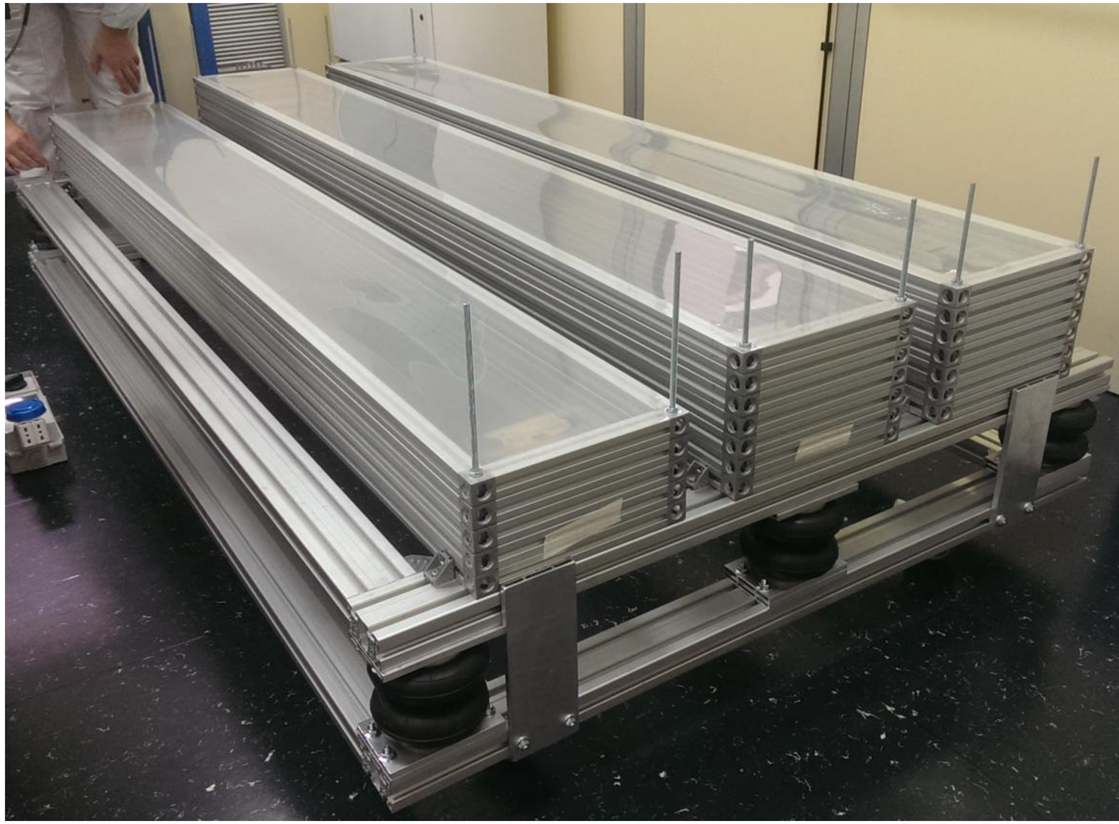
Simulated gain curves





Wiring machine

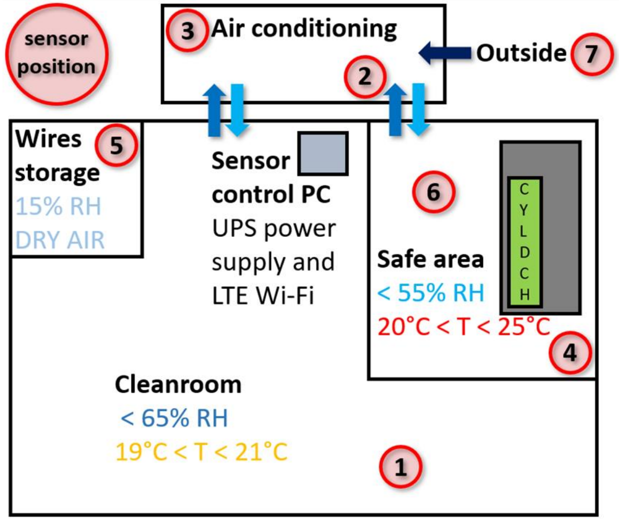


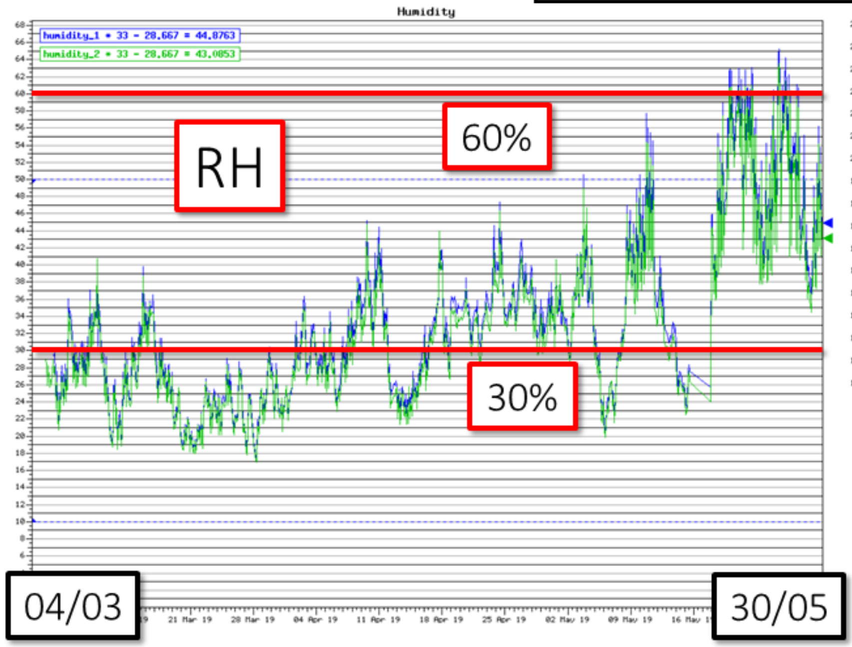


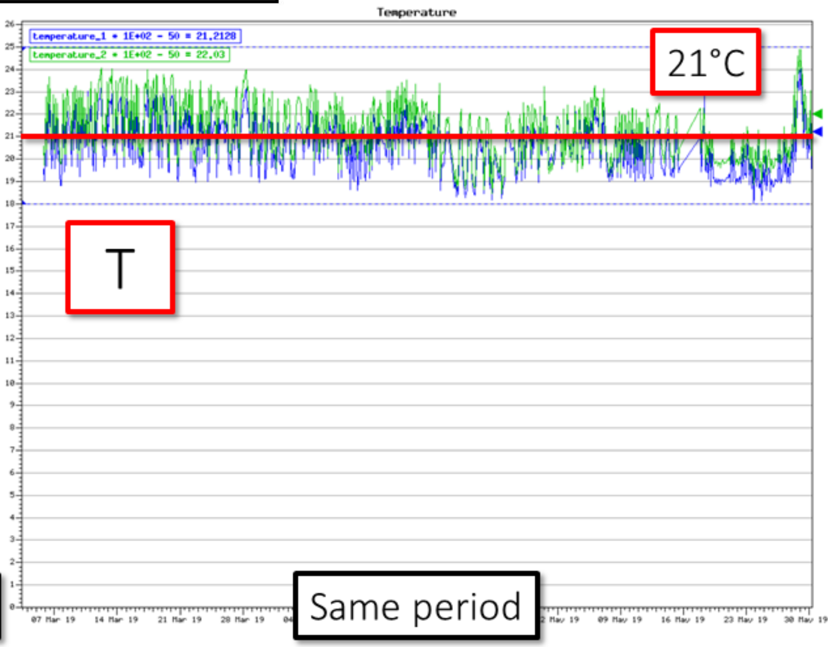
Transport trays +
dumping structure

Environmental condition monitoring

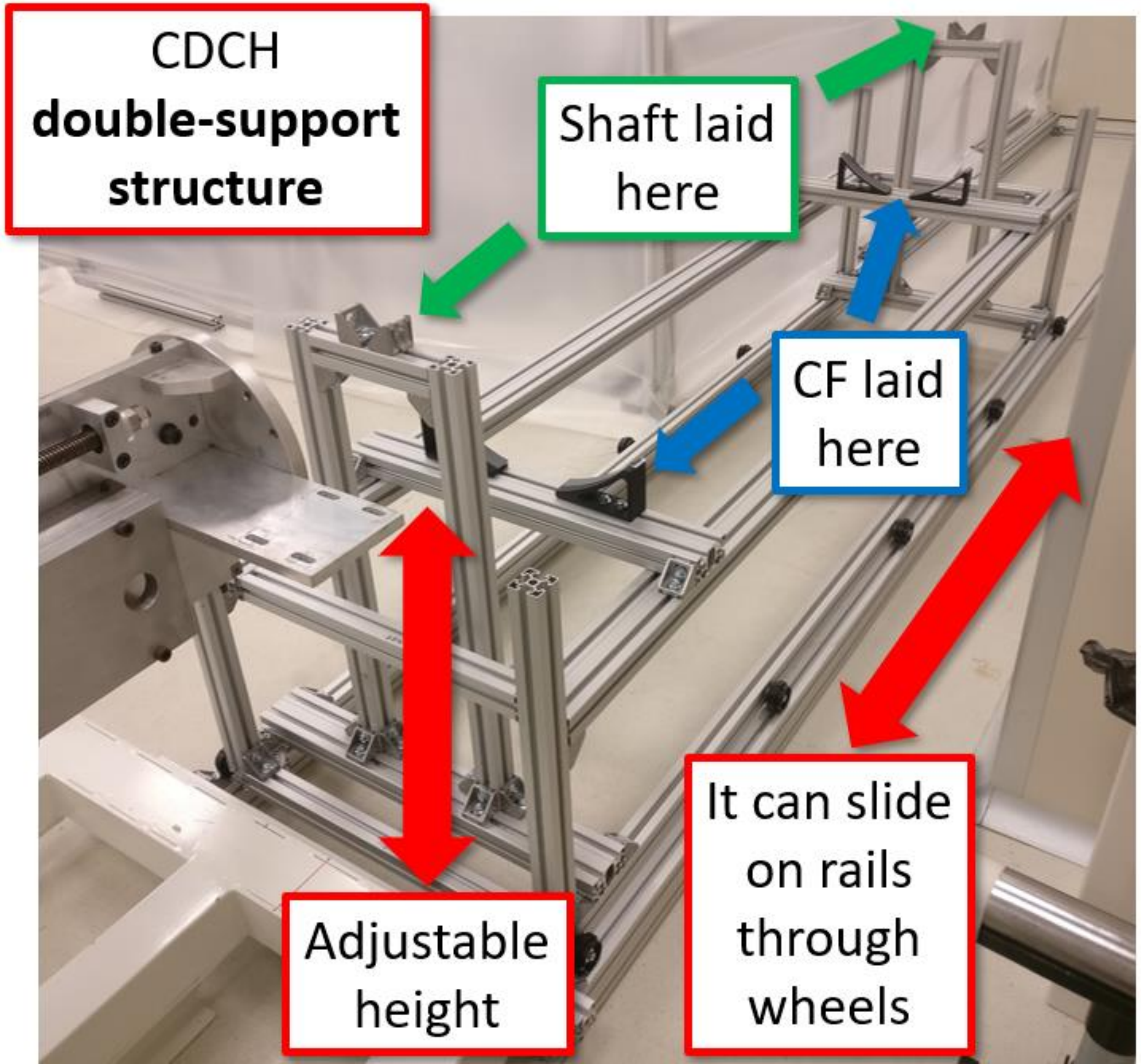
CDCH assembly inside

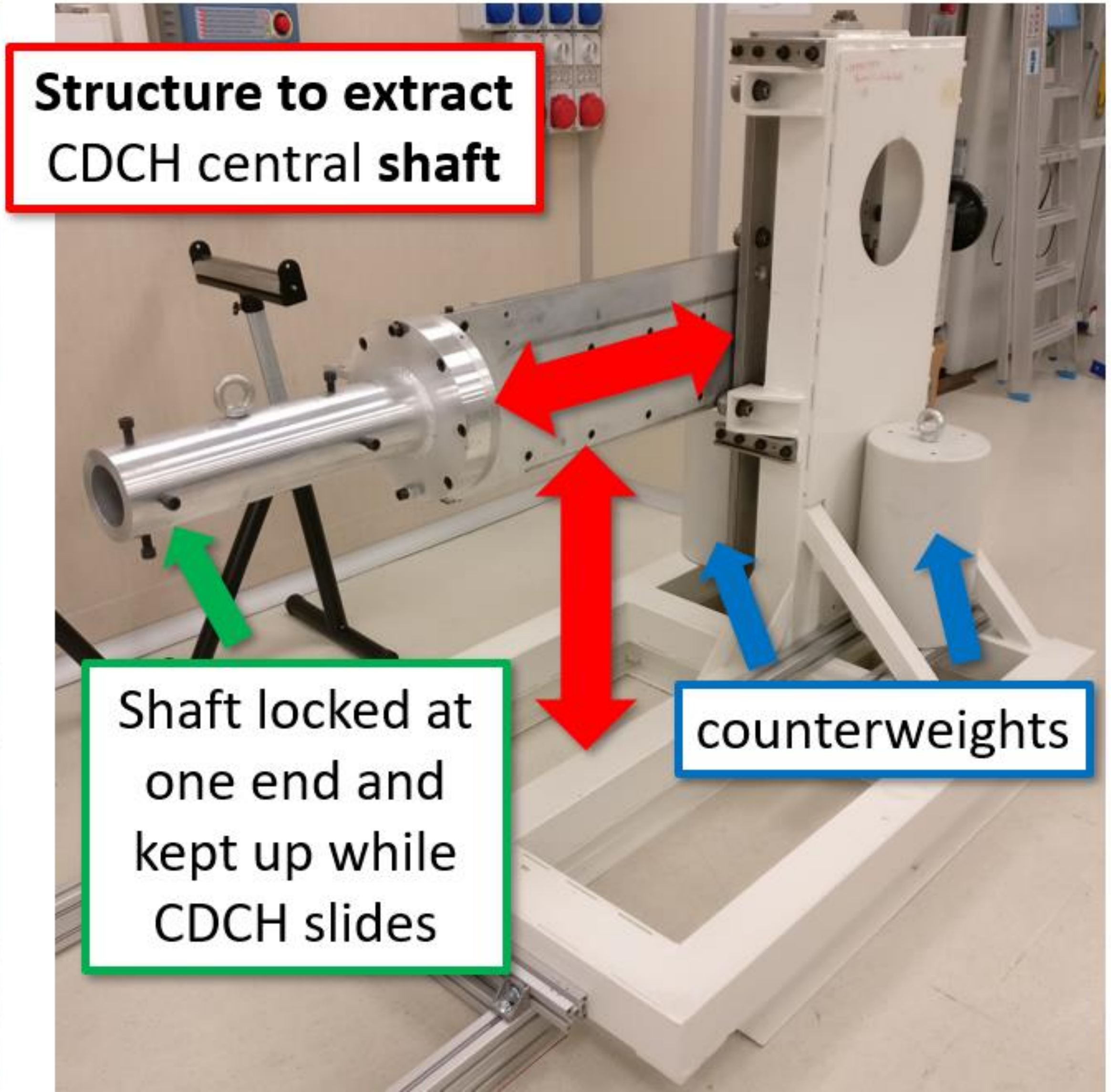




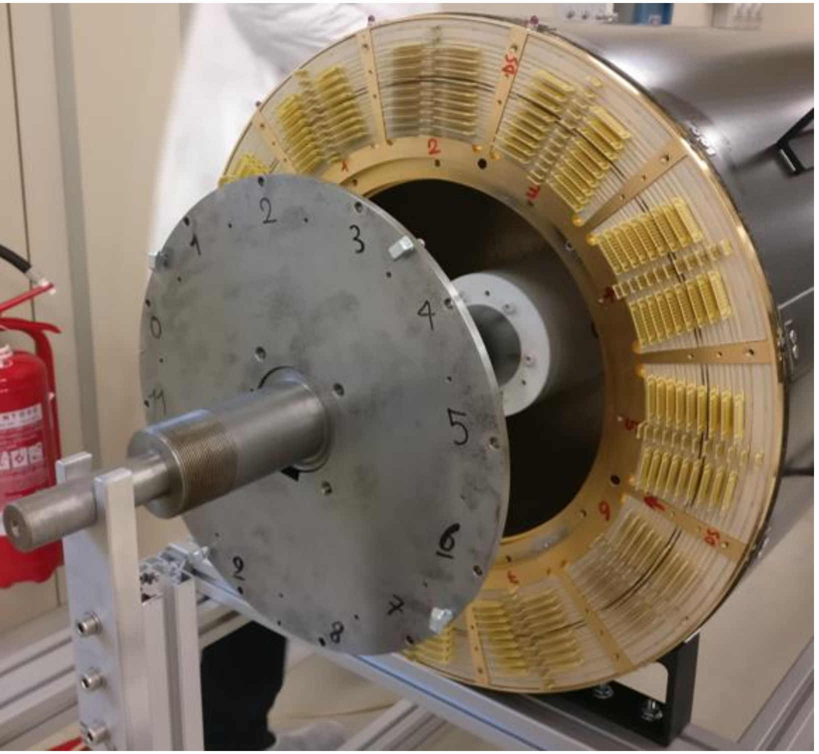


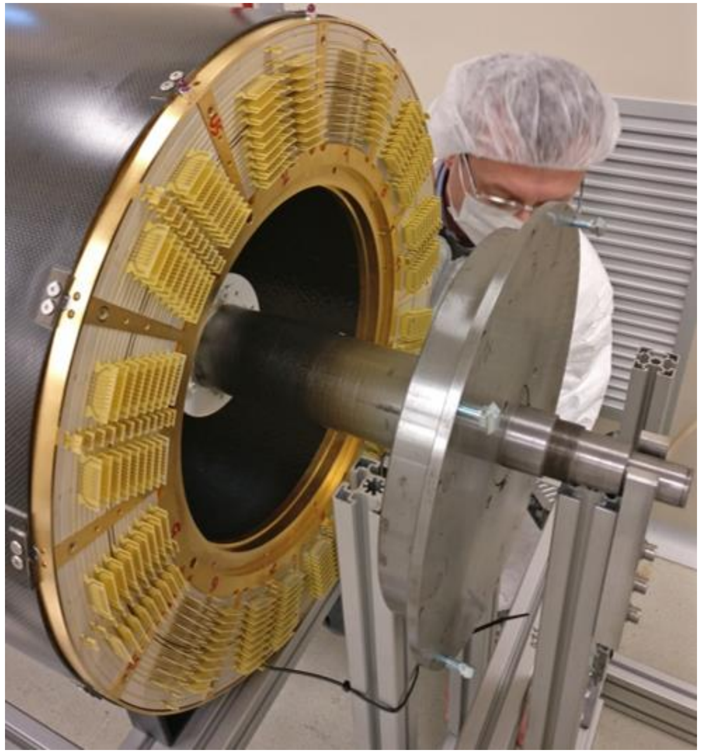
Auxiliary tools





CF + shaft



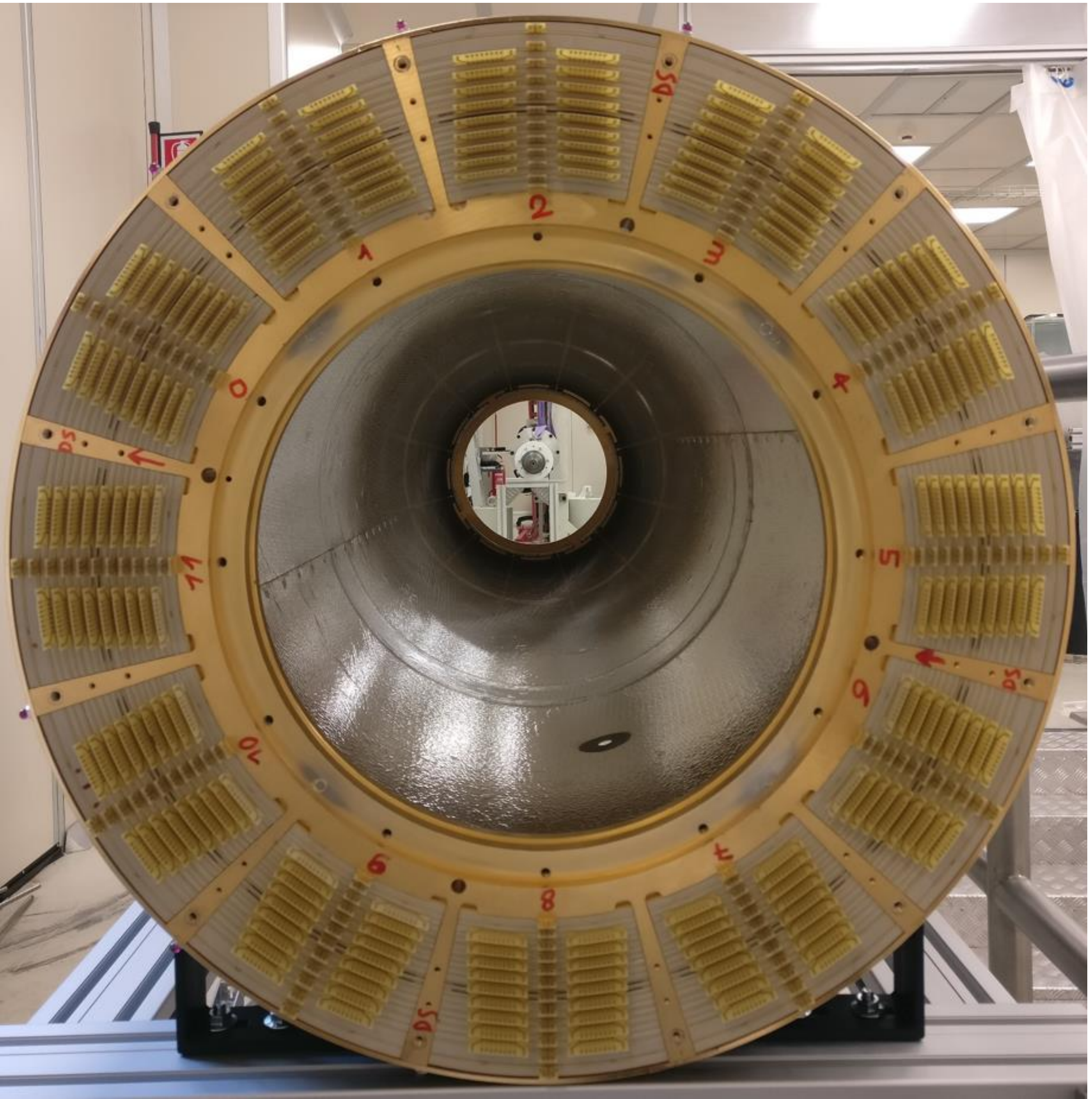


CDCH-shaft decoupling

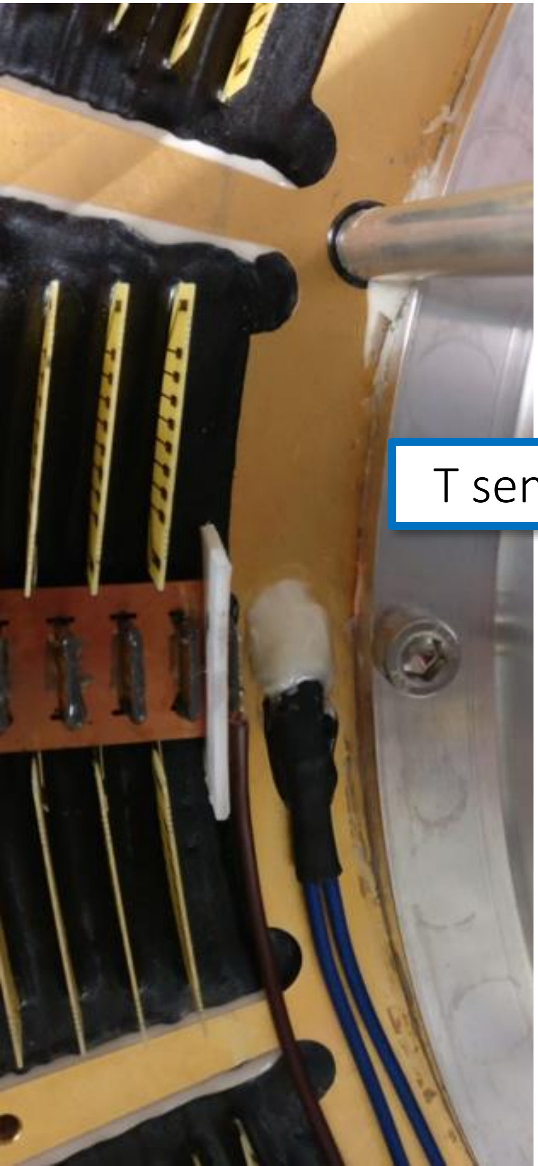
CF half-cylinders

Al foil in the inner faces

Wireless chamber

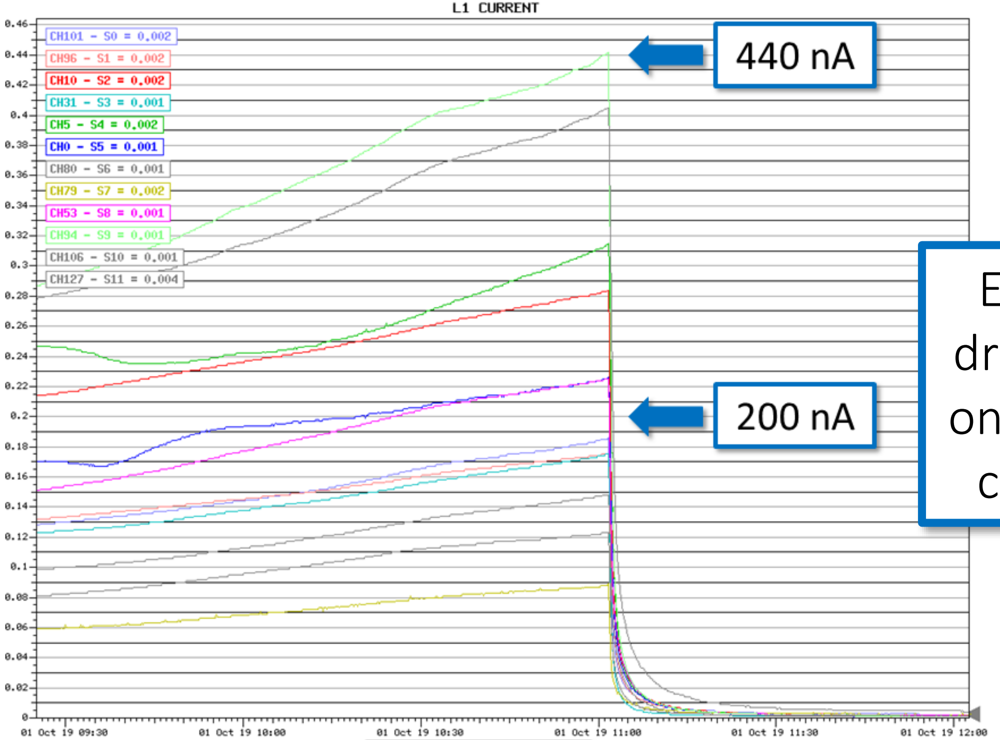


T and RH sensors



T sensors

ThreeBond glue to seal the modified caps

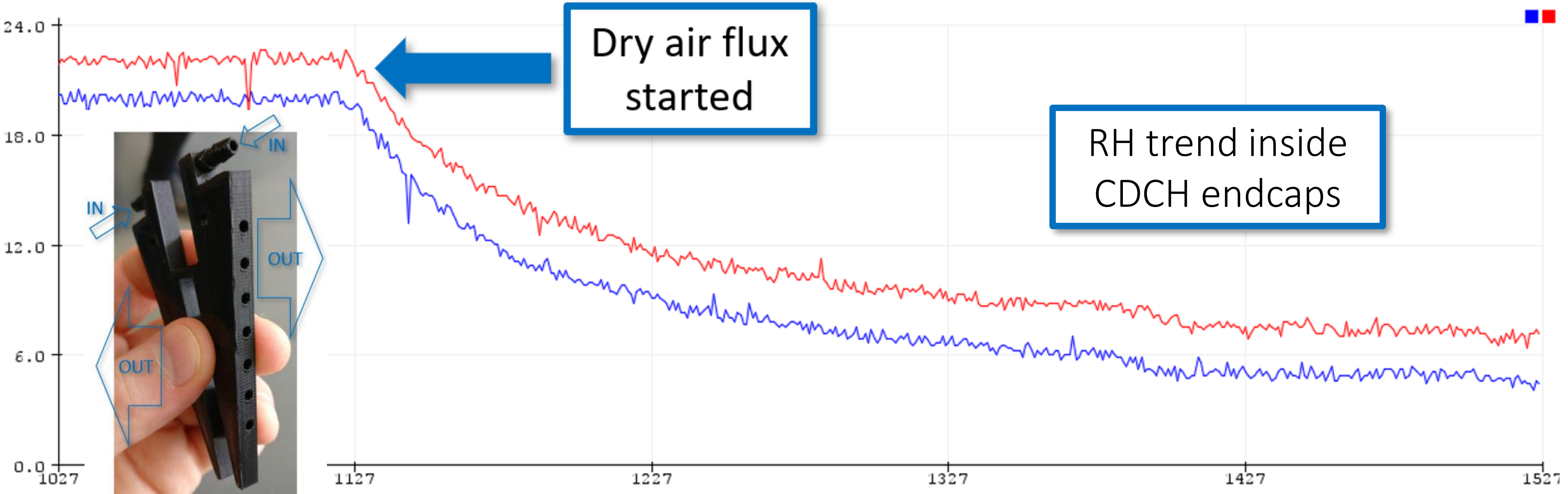


440 nA

200 nA

Effect of dry air flux on residual currents

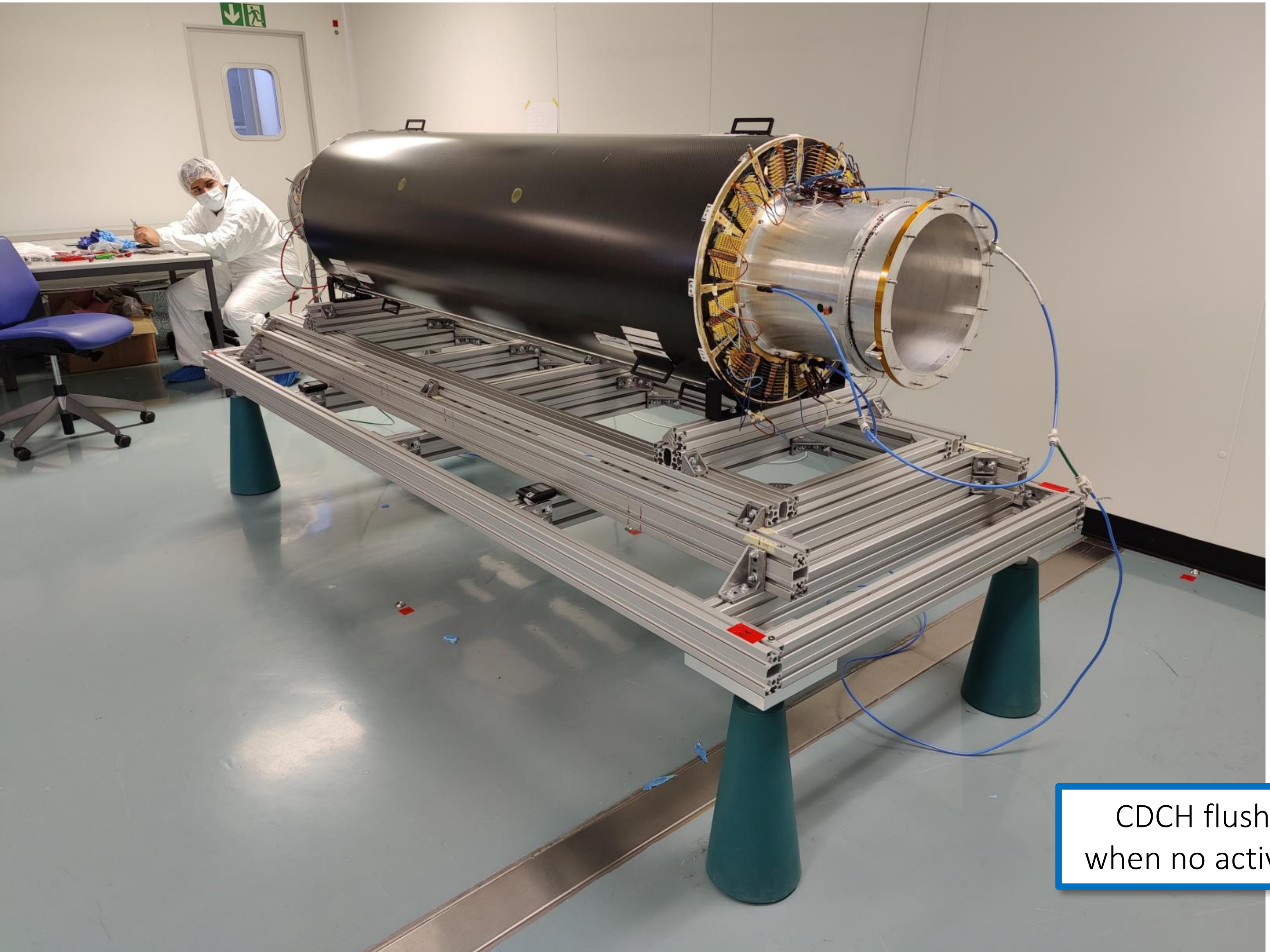
20 minutes



Dry air flux started

RH trend inside CDCH endcaps

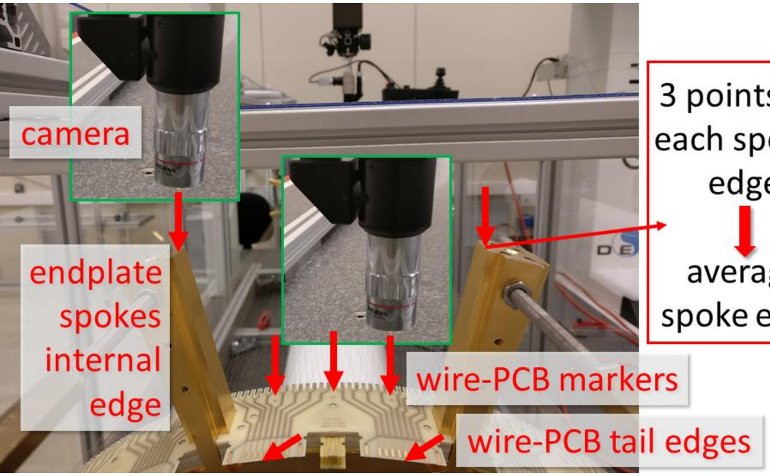
Last activities in the cleanroom

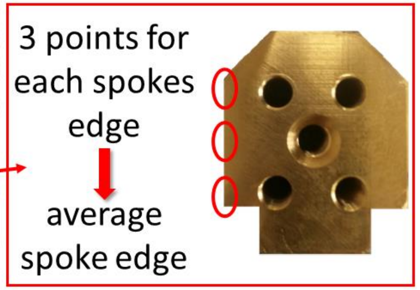


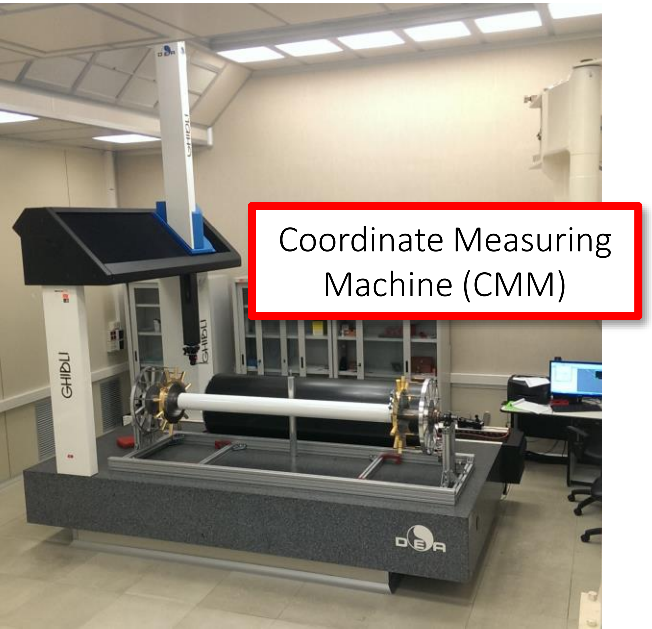
- **Structural shaft** extraction
- **Inner extensions** mounting
- **ThreeBond** sealing

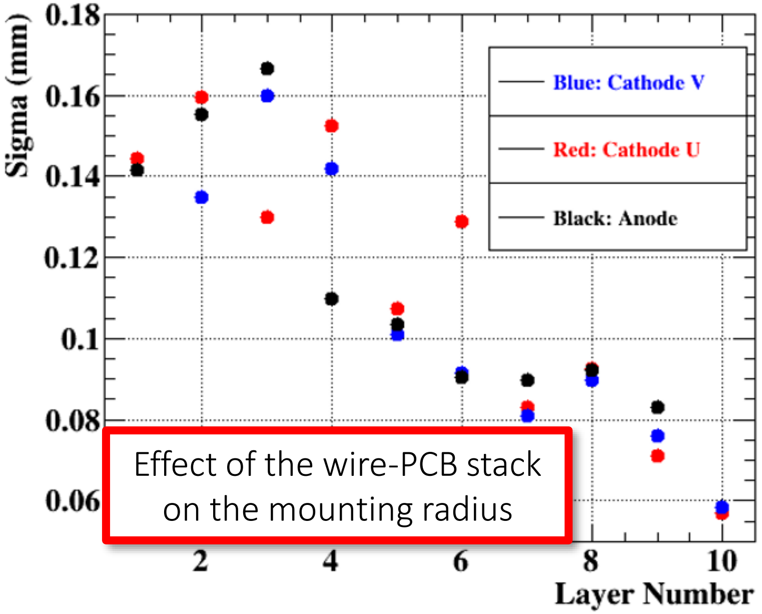
CDCH flushed with **synthetic air** when no activities in the cleanroom

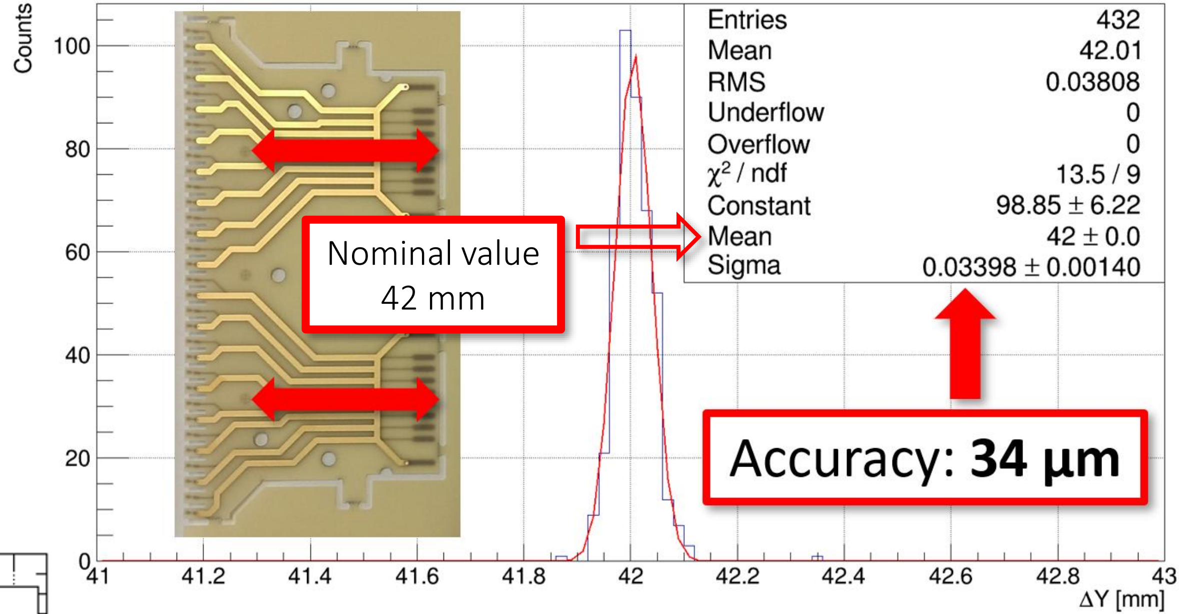
Local reference frame on each sector





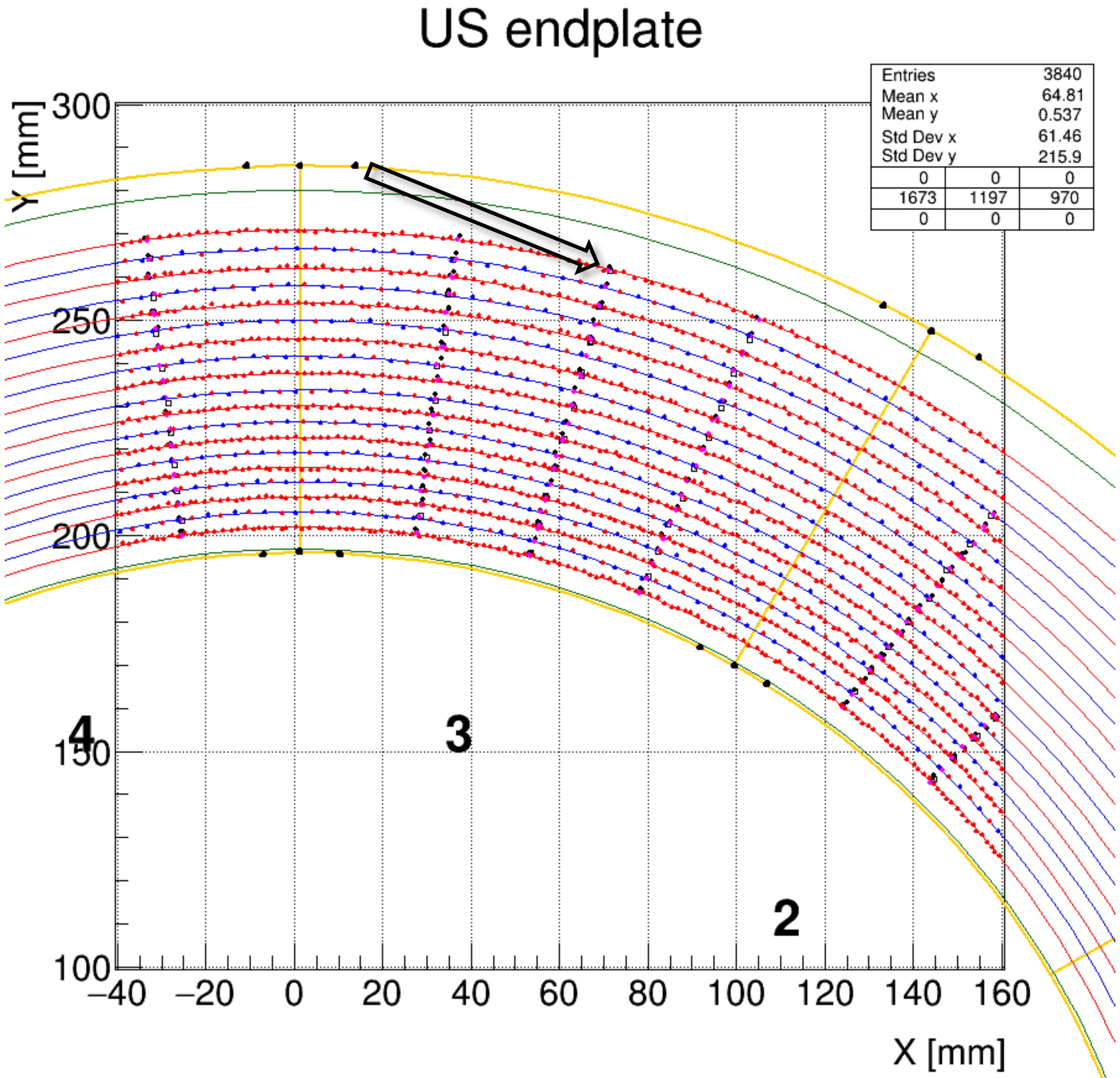






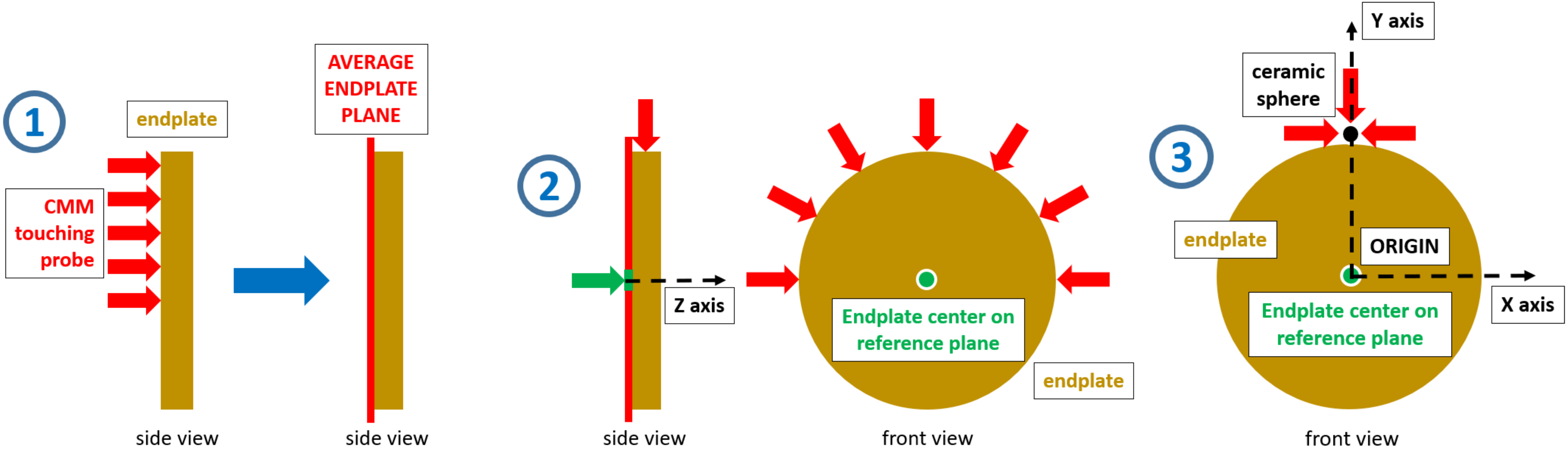
Accuracy of the optical measurements performed during the CDCH assembly phase

Local → global reference frame



- The local reference frame on each sector is then transferred to the global CDCH reference frame considering the nominal values of the endplate mechanical features
  - In particular exploiting the measured edges of each spokes…
    ↓
  - …we place the central reference marker of each wire-PCBs in the endplate reference frame…
    ↓
  - …then we place the soldering pads in the endplate reference frame based on the CAD files of each wire-PCBs
- **The US and DS endplates are treated independently**
  - Once computed the suspension points of all the wires we create the wire vector by connecting the corresponding end points

CDCH reference frame

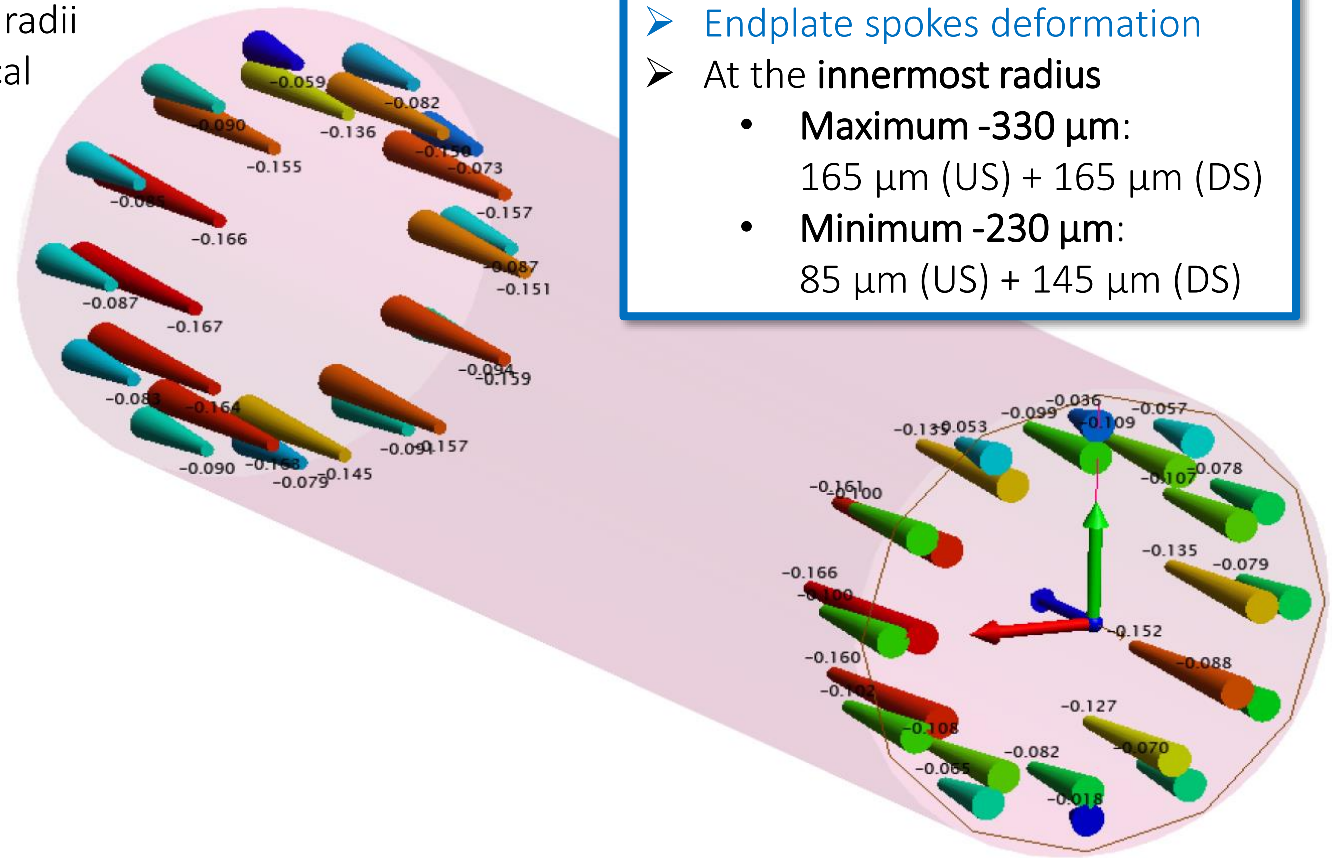


Geometry survey measurement

- ➢ Alignment of the endplates at a very good level < 65 μm

- ➢ Endplates are kept at the correct distance with the external CF support structure
  - We have a Z deformation toward CDCH center going to inner radii
  - Smaller cells going to inner radii → electrostatic stability critical

- ➢ The final working length has been experimentally set



- ➢ Endplate spokes deformation
- ➢ At the **innermost radius**
  - **Maximum -330 μm**: 165 μm (US) + 165 μm (DS)
  - **Minimum -230 μm**: 85 μm (US) + 145 μm (DS)

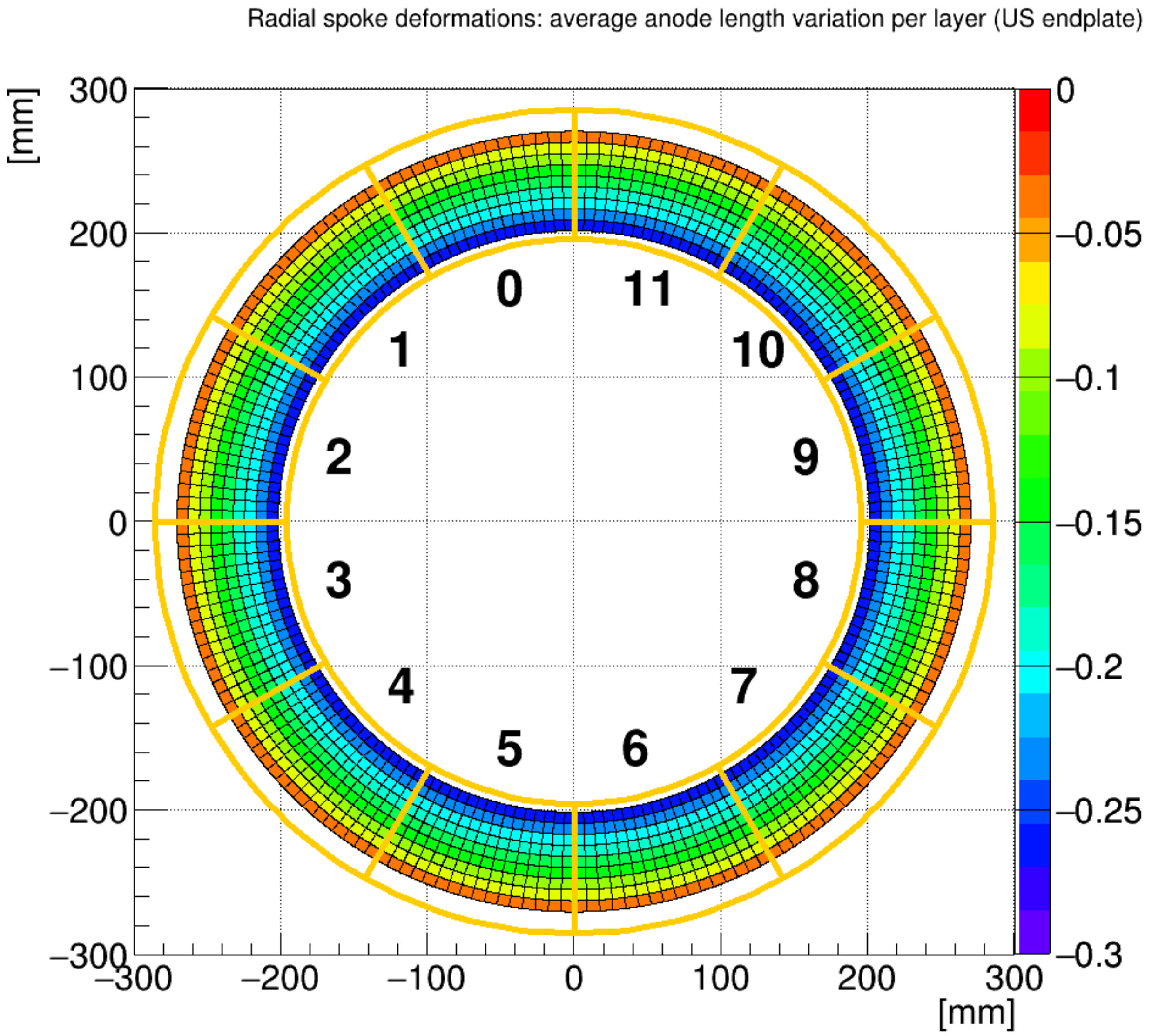
Mag (mm)
0.037
-0.010
-0.012
-0.019
-0.007
0.009
0.043
0.017
-0.020
-0.007
-0.013
-0.018

Endplate planarity

US DS

Mag (mm)
0.007
-0.000
-0.011
0.009
0.001
-0.004
-0.001
-0.003
0.005
-0.010
0.003
0.005

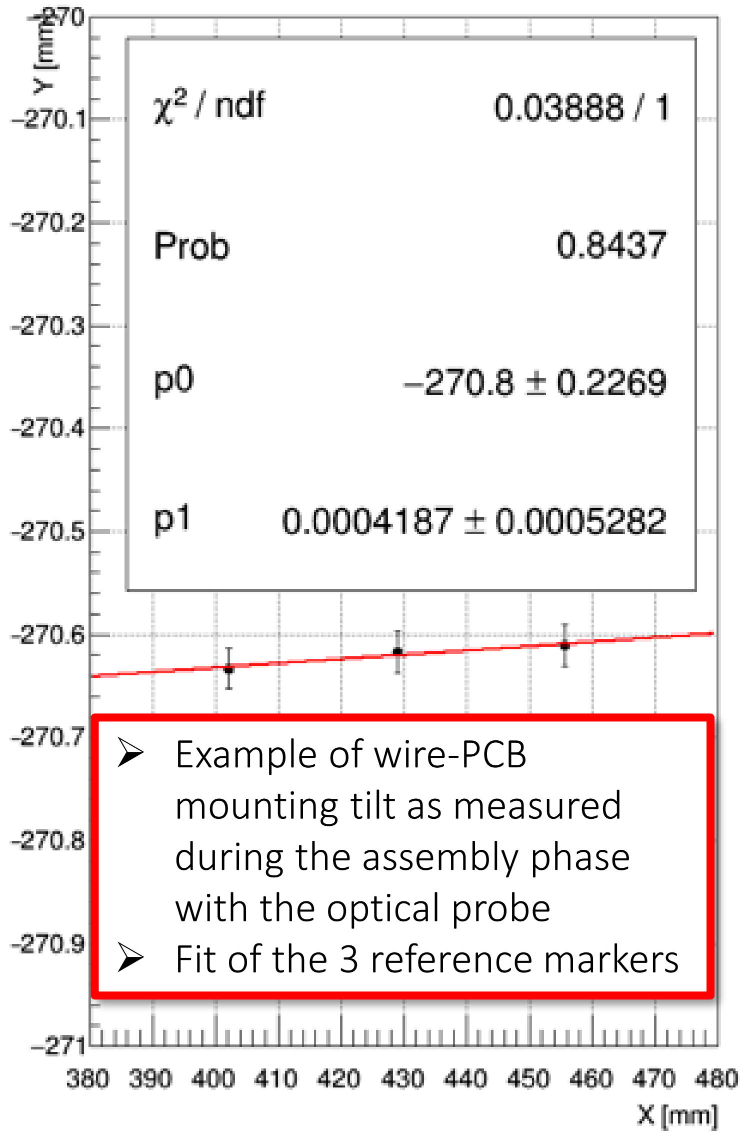
Radial deformation of the endplate spokes



- Average effect of the US + DS radial deformation of the spokes on the anode wires length

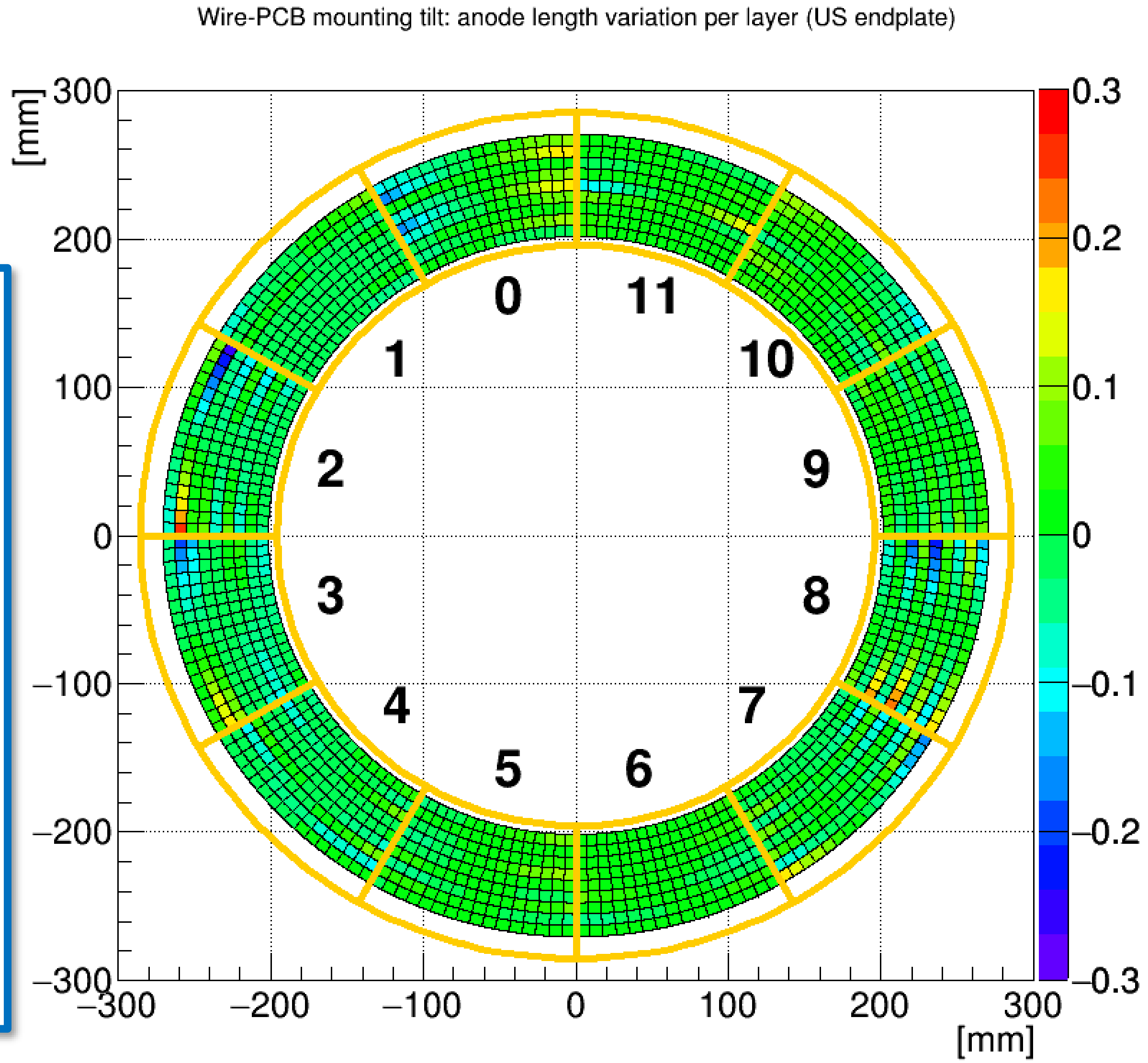
- The radial deformation of the endplate spokes enters as a Z correction of the wire suspension point
  - **Each US and DS sector is treated independently**
  - Then the single corrections are combined → effect on the wires length

Wire-PCB mounting tilt

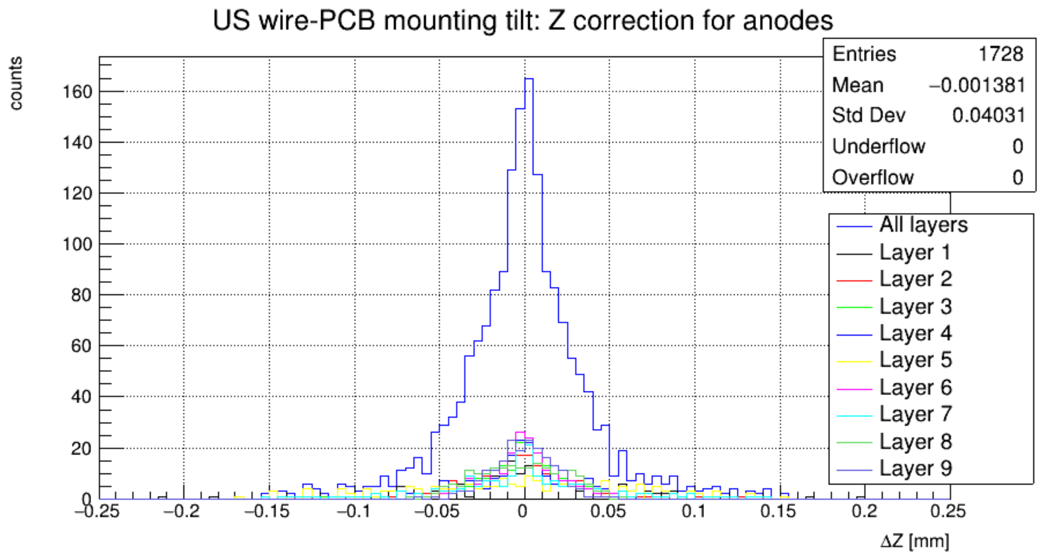


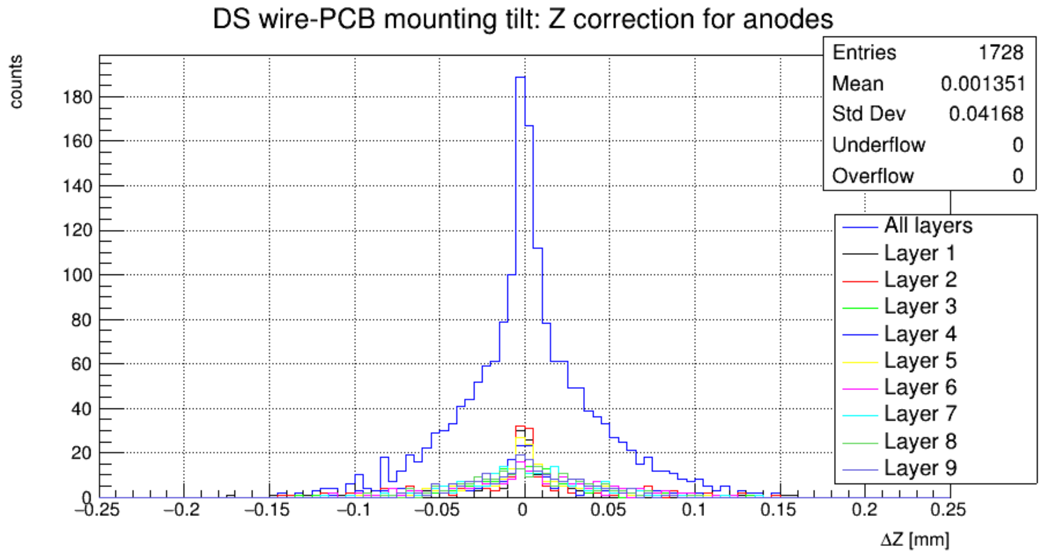
- Example of wire-PCB mounting tilt as measured during the assembly phase with the optical probe
- Fit of the 3 reference markers

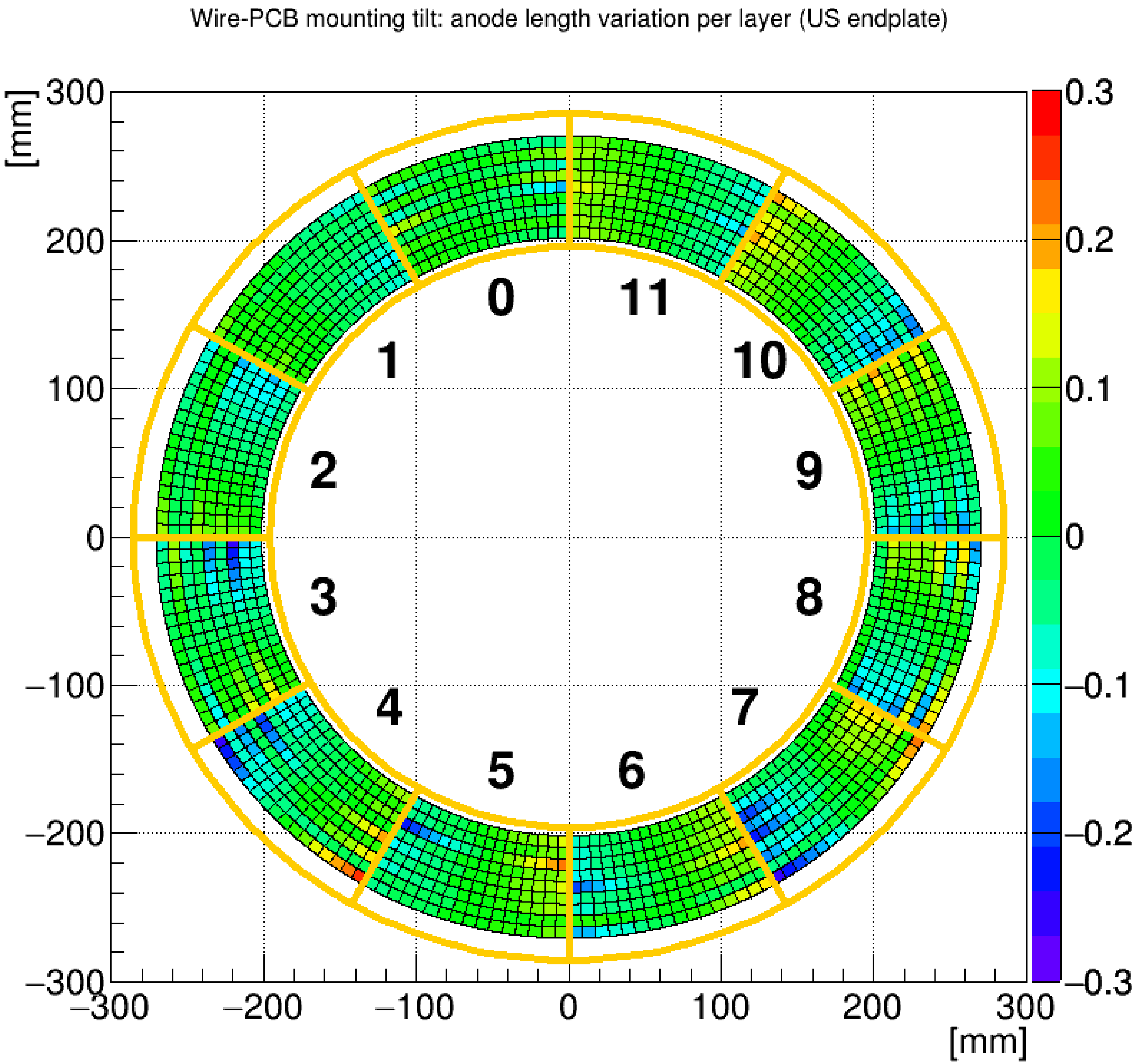
- Effect of the US + DS wire-PCB mounting tilt on the anode wires length
- The wire-PCB mounting tilt enters as a Z correction of the wire suspension point
  - **The correction is computed for all the US and DS soldering pads independently**
  - Then the single corrections are combined → effect on the wires length



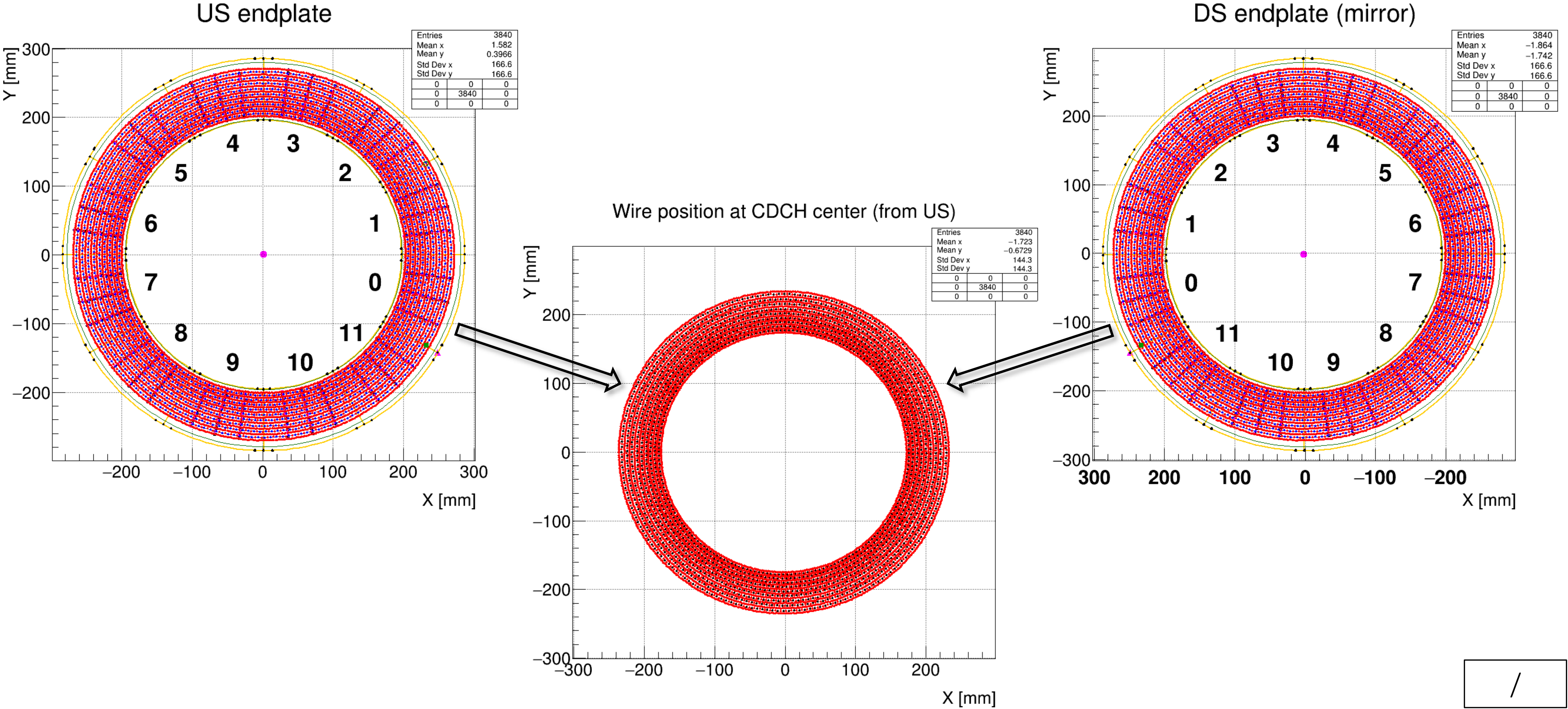
/


US wire-PCB mounting tilt: Z correction for anodes
counts
Entries 1728
Mean −0.001381
Std Dev 0.04031
Underflow 0
Overflow 0
All layers
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
ΔZ [mm]

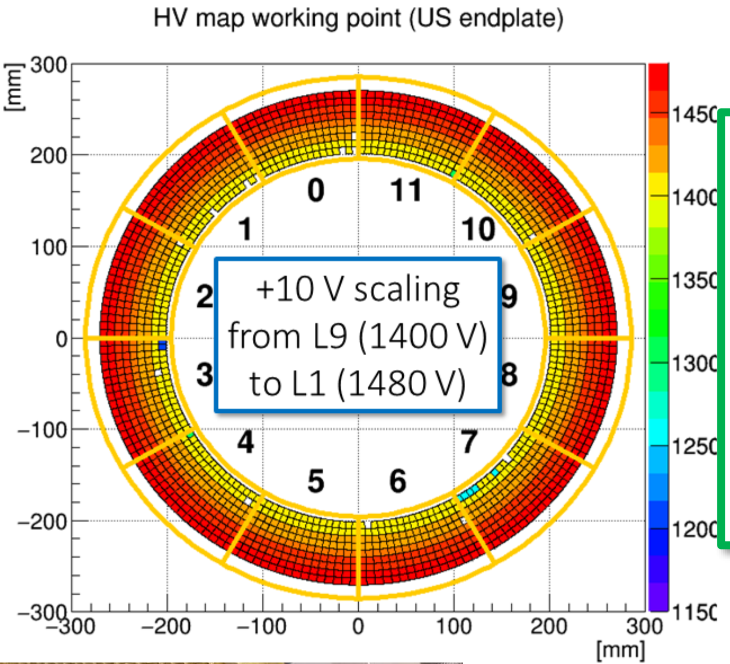

DS wire-PCB mounting tilt: Z correction for anodes
counts
Entries 1728
Mean 0.001351
Std Dev 0.04168
Underflow 0
Overflow 0
All layers
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
ΔZ [mm]


Wire-PCB mounting tilt: anode length variation per layer (US endplate)
[mm]
[mm]
0
1
2
3
4
5
6
7
8
9
10
11

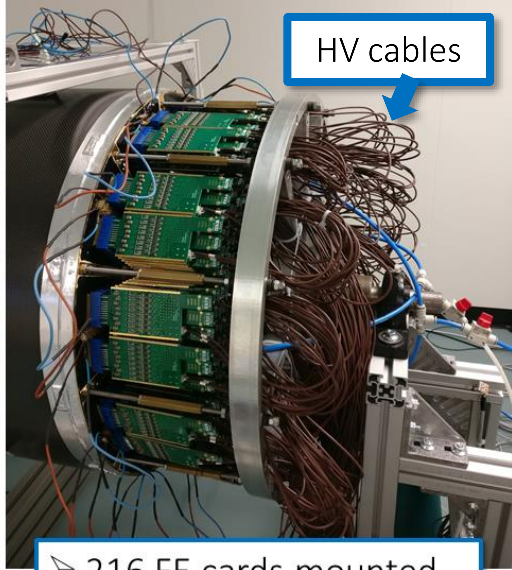
Wire positions



Working length



Some pictures from the commissioning phase at PSI



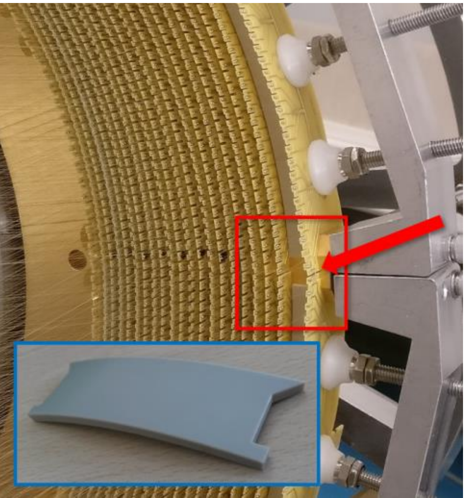
- CDCH temporarily sealed with CF + Al tape
- Nitrogen flux

- 216 FE cards mounted on the US side

Cell inefficiency experimentally measured
- Negligible in e^+ reconstruction
  - 0.5% worsening in resolutions
- Tests with high statistics full MC

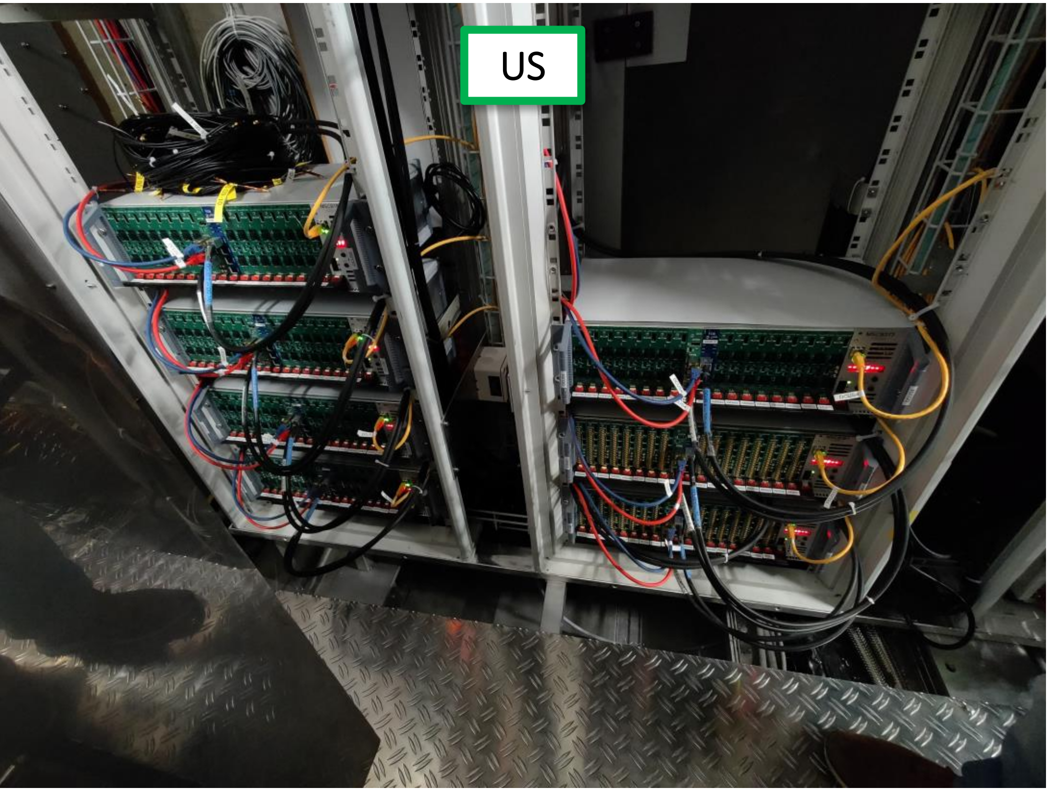
Final CDCH length experimentally found through systematic HV tests at different lengths/wires elongations

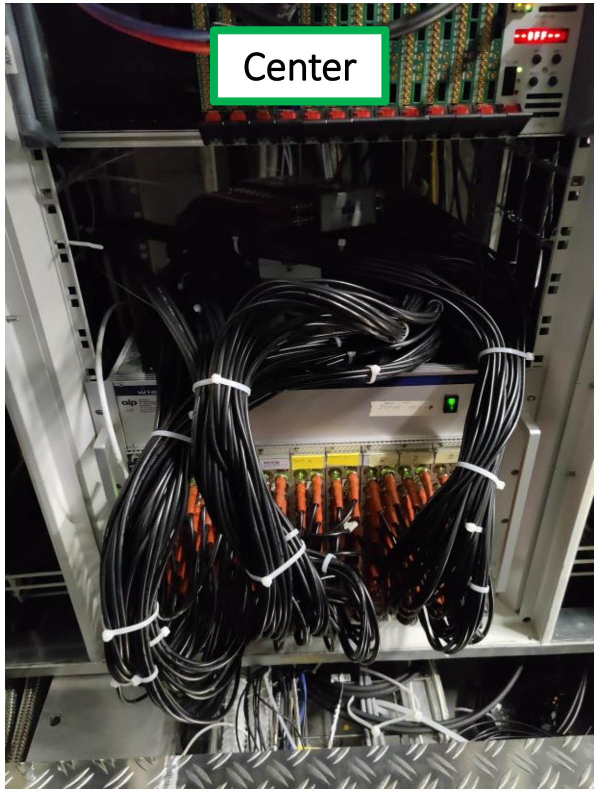
- Tests performed in 2019 and 2020 at PSI inside a cleanroom
- CDCH length adjusted through geometry survey campaigns with a laser tracker (20 μm accuracy)
- **Final length set to +5.2 mm of wires elongation**
  - **65% of the elastic limit**

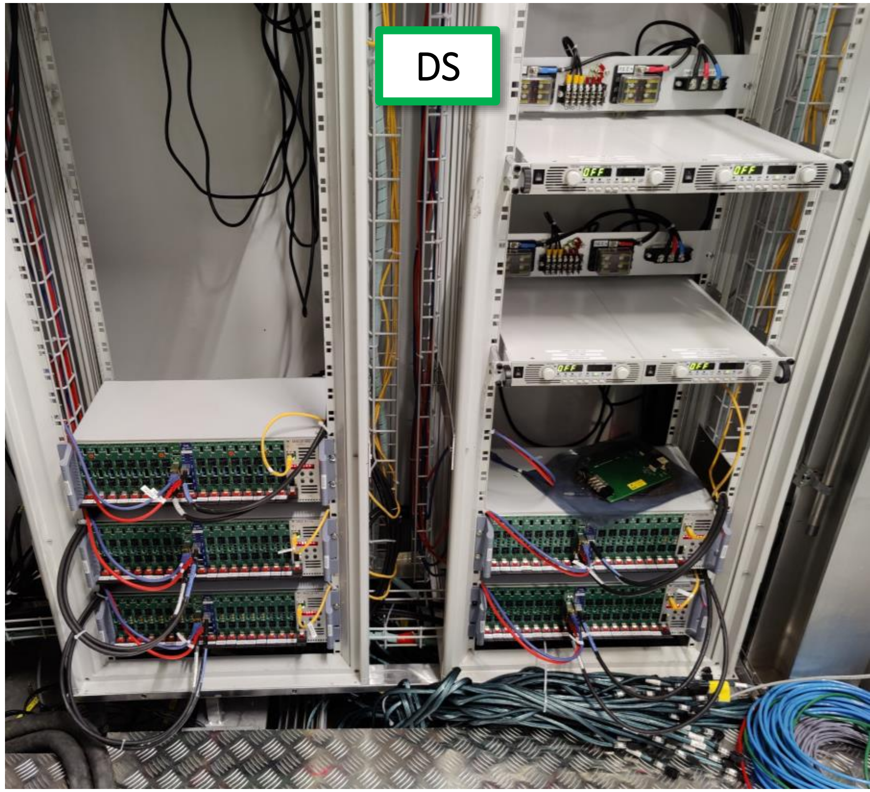


- **Some drift cells at the border between 2 adjacent sectors presented electrostatic instability**
- Due to wire-PCB geometry
- Once the PEEK spacers are mounted the correct circular shape is expected to be recovered
- But sometimes deformations O(a few hundred μm) remain causing electrostatic instabilities
- **HV kept at lower values for the involved cells**

Status of the electronics racks

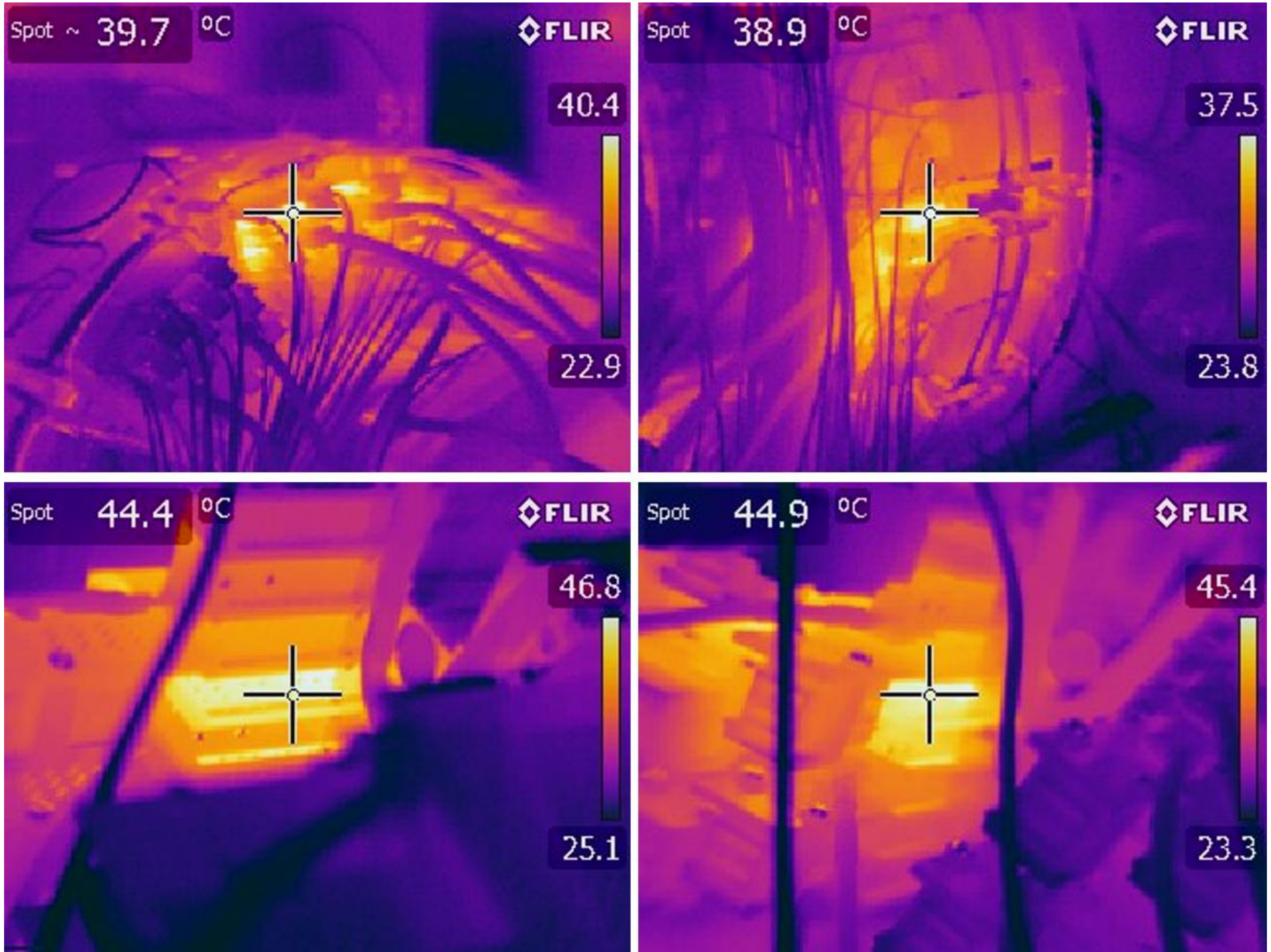




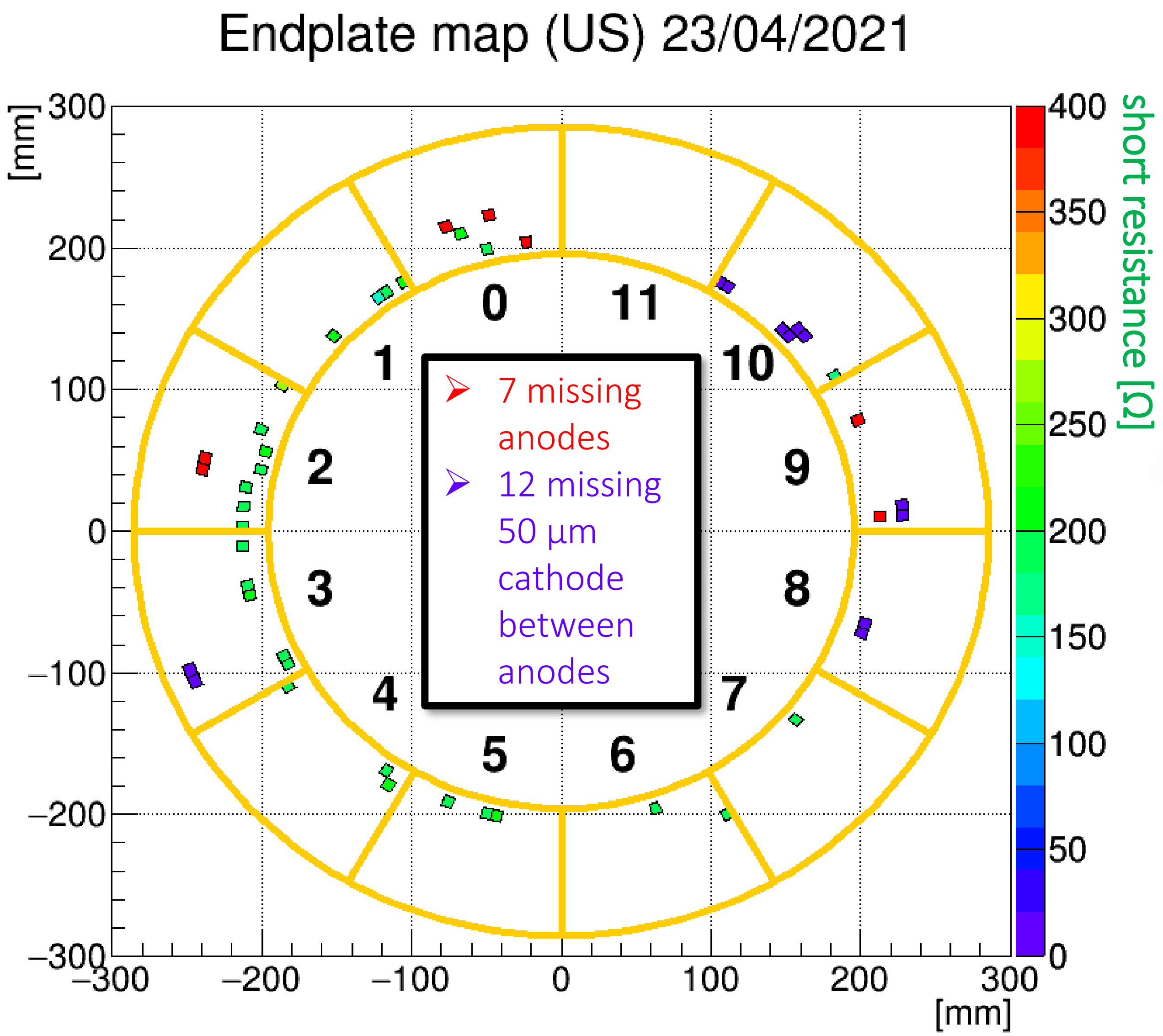


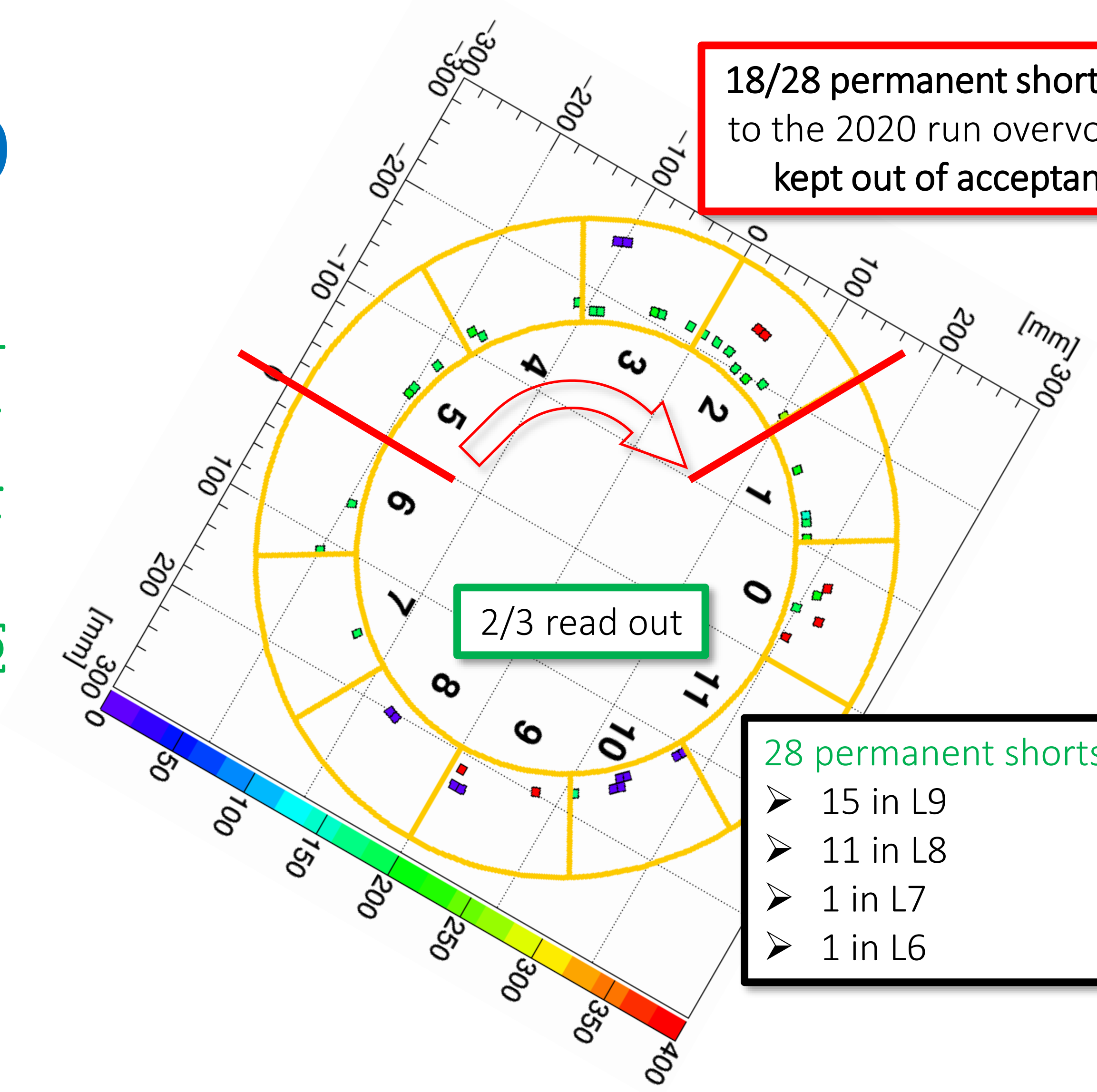
- **5 WDB crates per side** (12+1 WDBs with T input per side to monitor the temperature of the FE holders)
- **LV modules installed and successfully tested**
- **HV crate installed in the final position and successfully tested**

Thermal camera photos with FE ON



Current endplate map



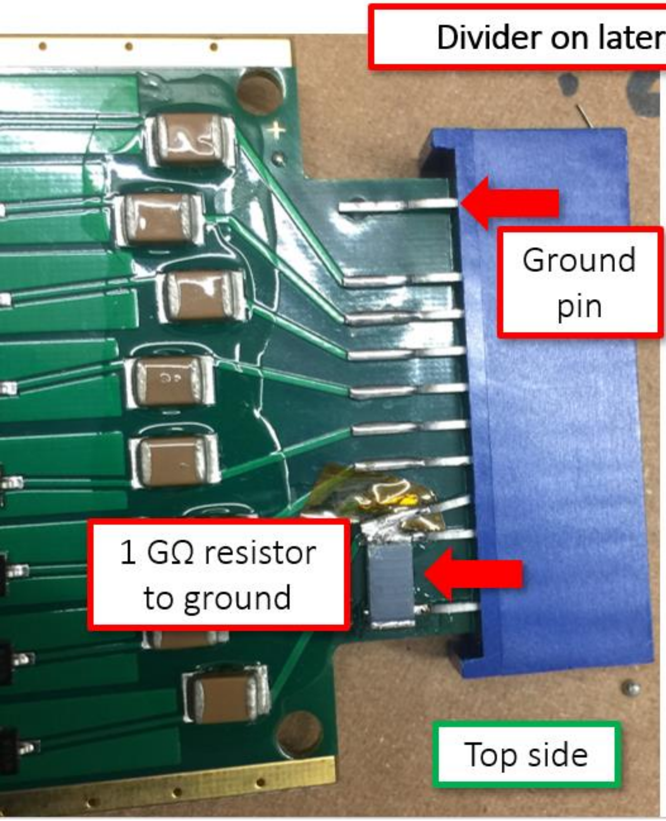


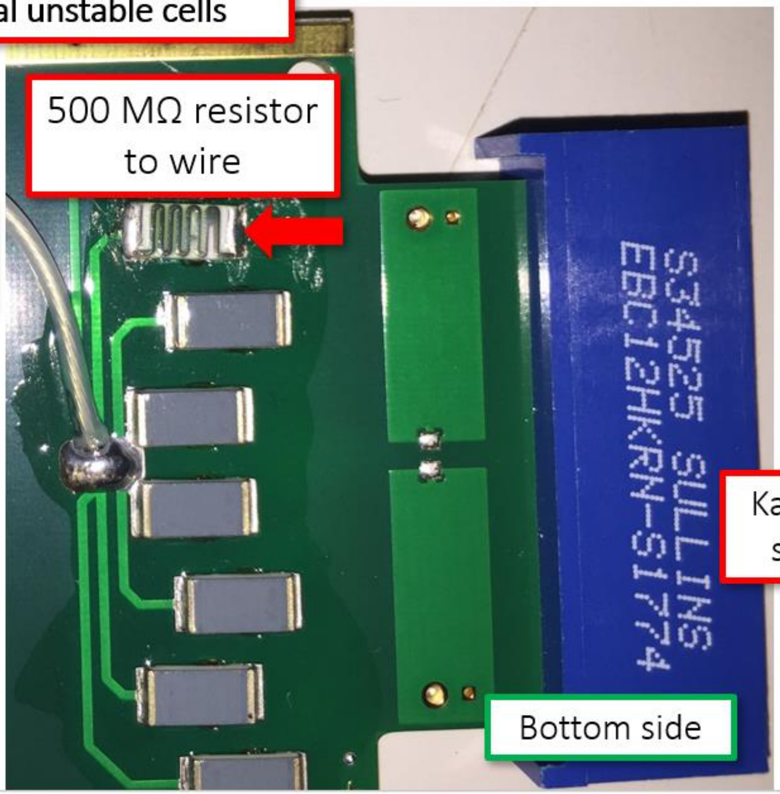
18/28 permanent shorts due to the 2020 run overvoltage **kept out of acceptance**

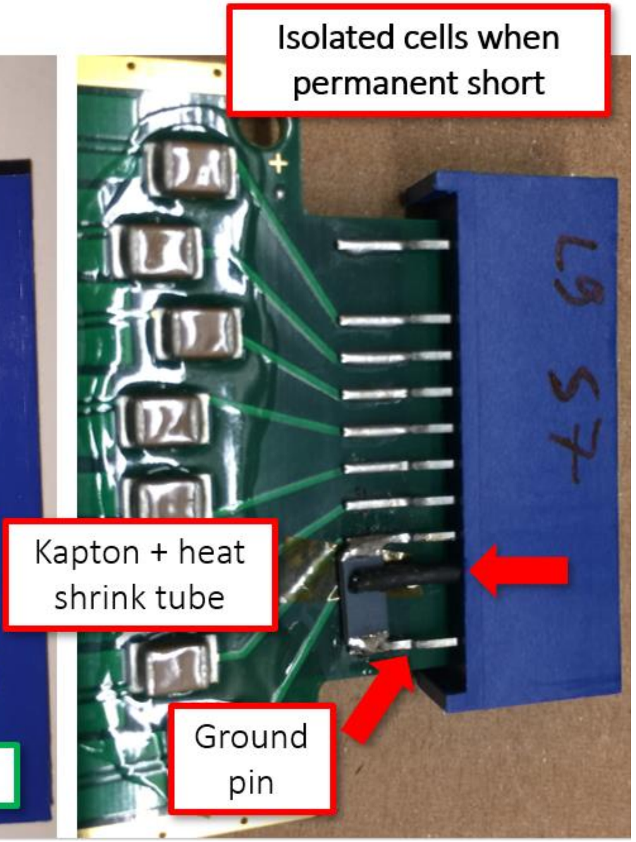
28 permanent shorts
- 15 in L9
- 11 in L8
- 1 in L7
- 1 in L6

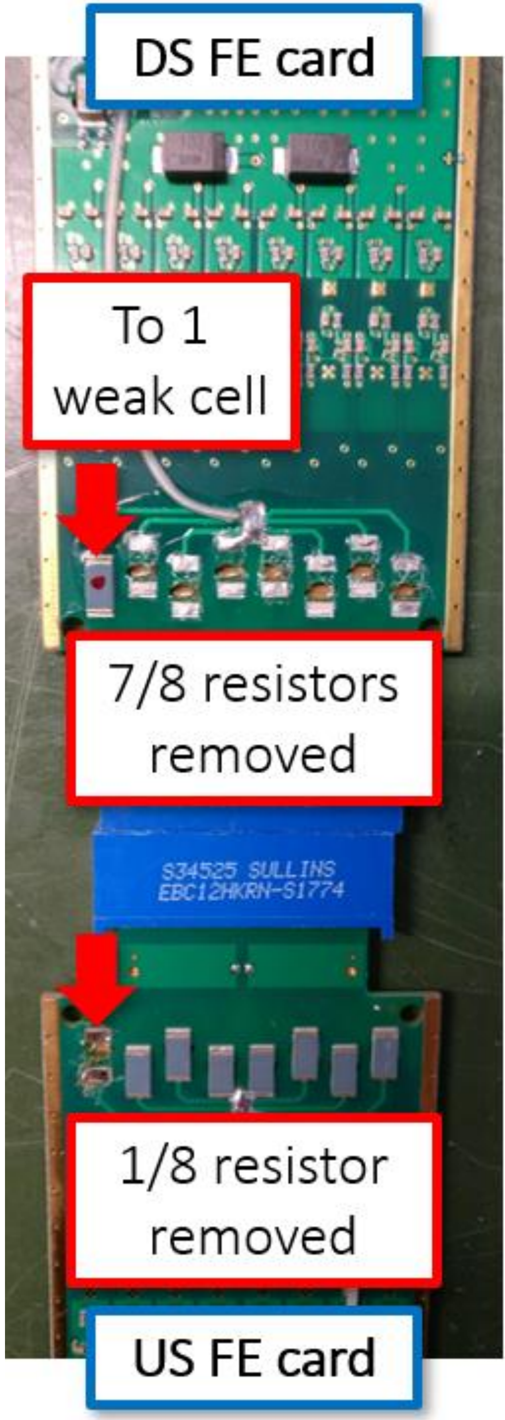
Final CDCH orientation to optimize the number of good cells in the acceptance region
- From US: counterclockwise rotation of 8 30°-sector steps

FE boards re-working





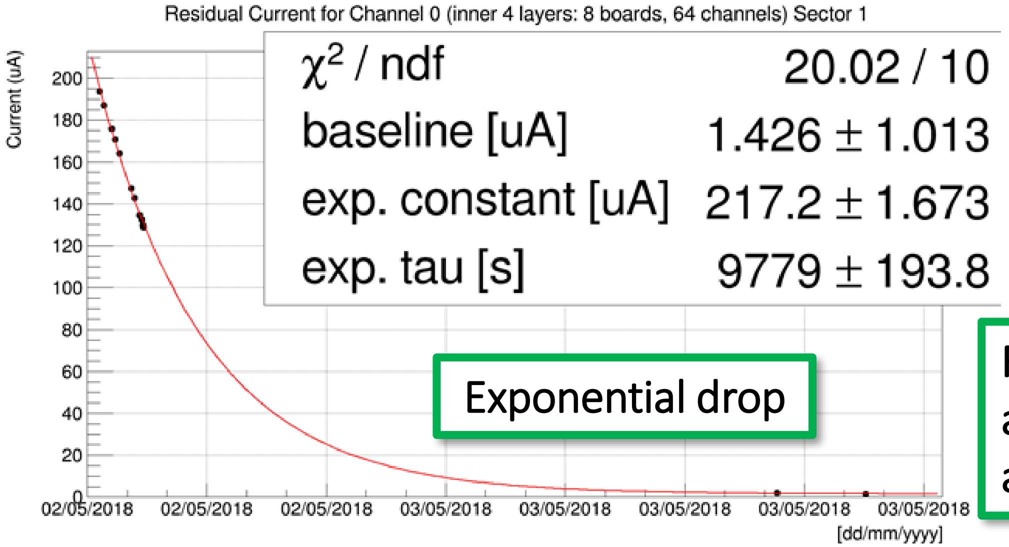




HV conditioning and gas monitoring

Example of HV conditioning at the first power up (here at 700 V)

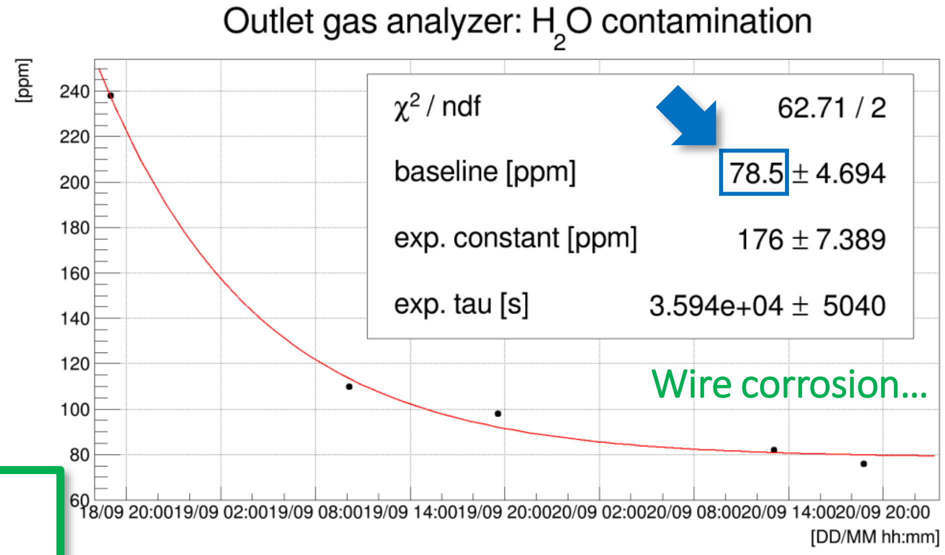
- Residual currents drawn by the HV channels to correctly polarize the dielectric materials of the endplates



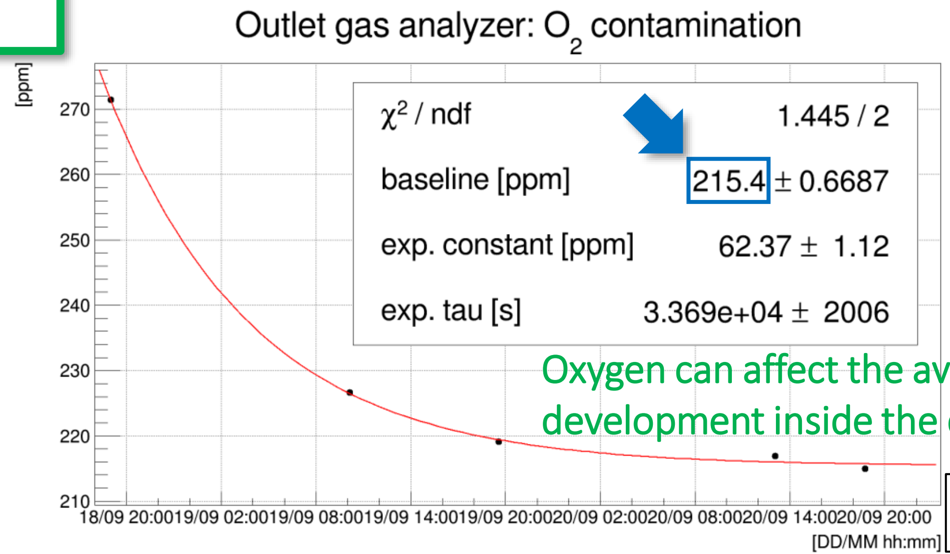
Exponential drop

Residual current of about 10 nA/cell after about 3 hours

$\tau \approx 9$ hours after starting the gas flux

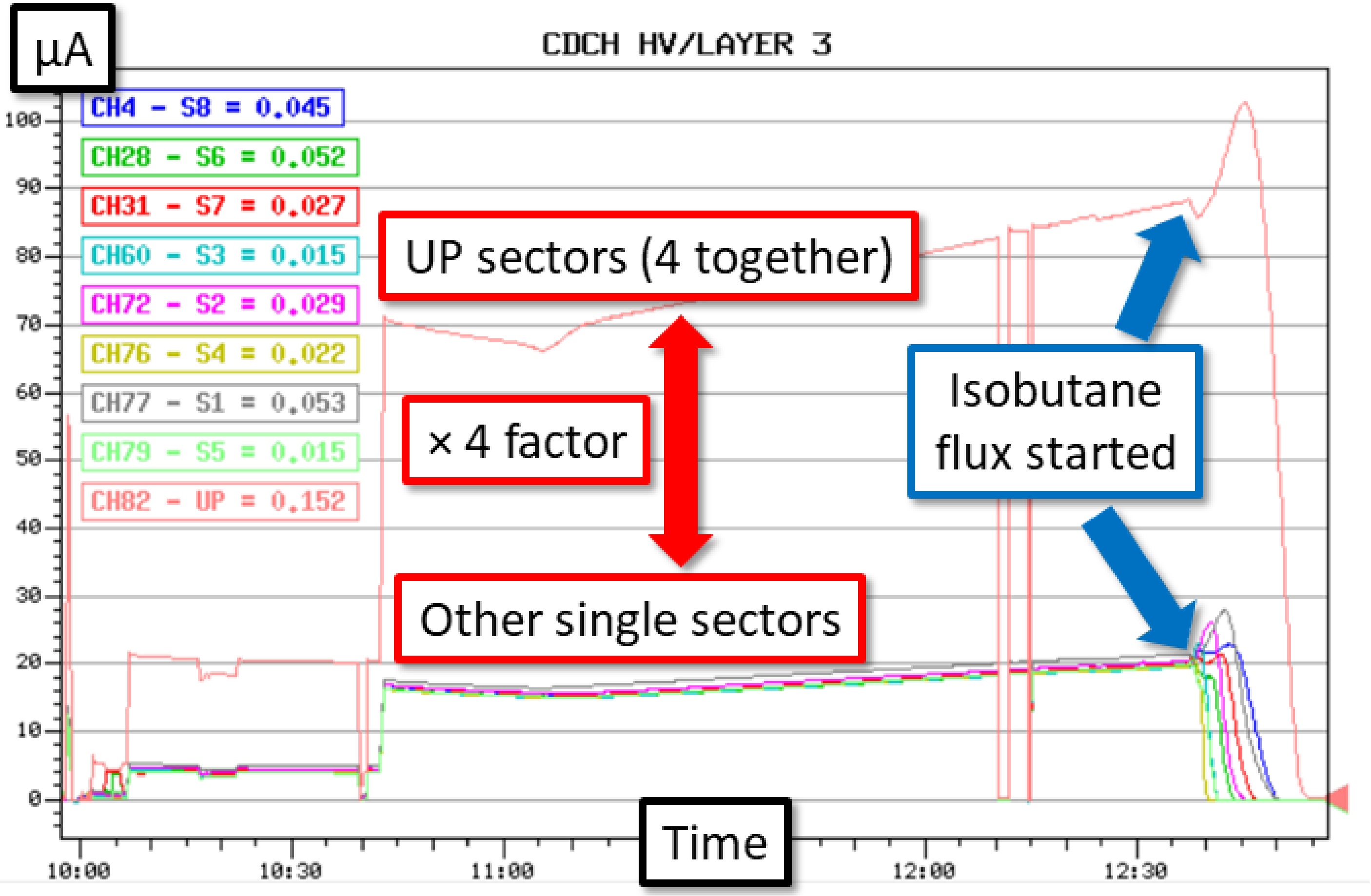


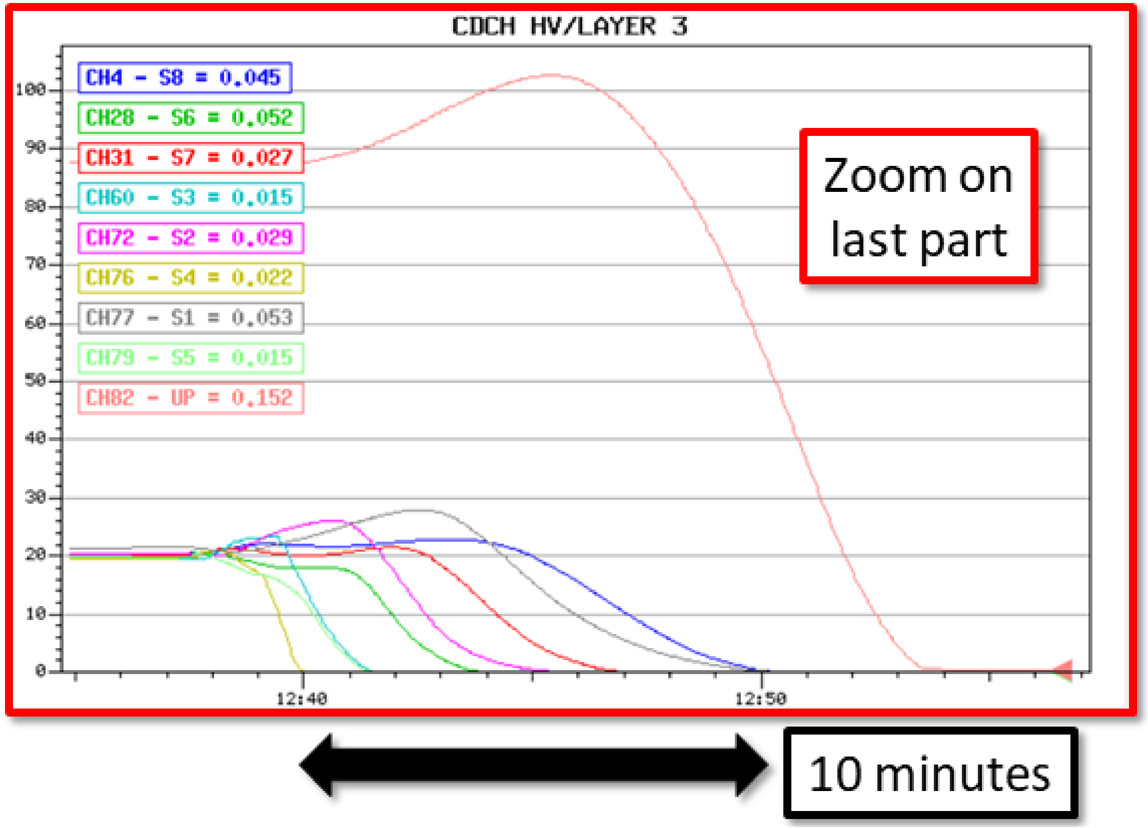
Wire corrosion…



Oxygen can affect the avalanche development inside the drift cell

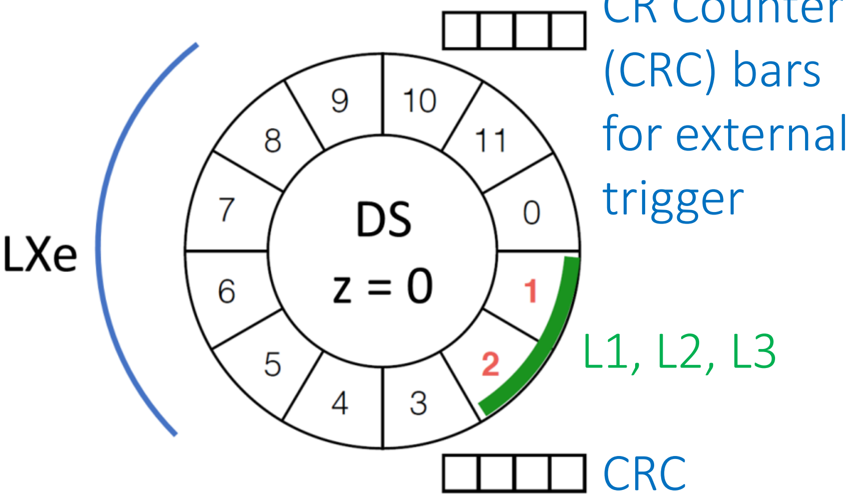
Isobutane addition above 500 V

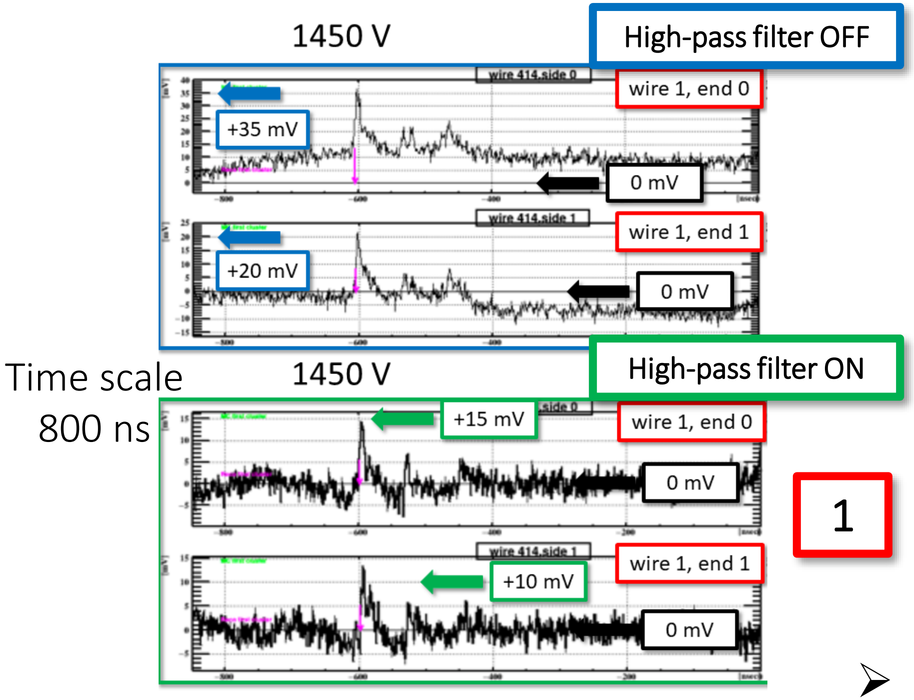


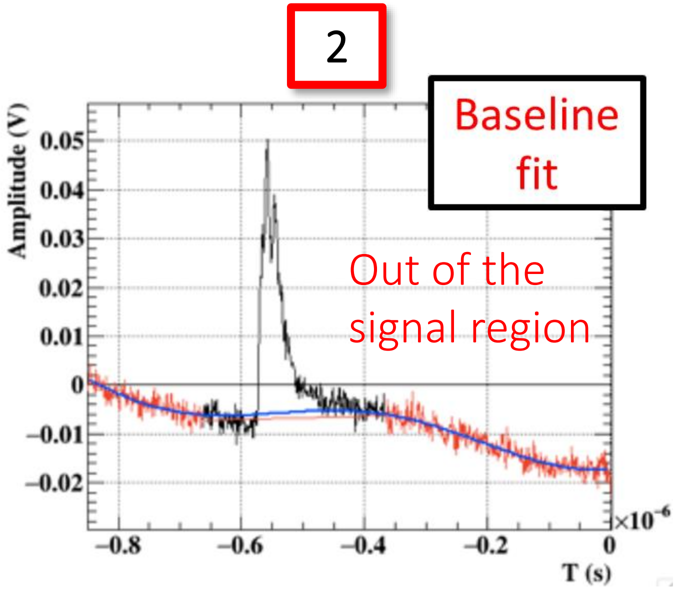


CRC bars

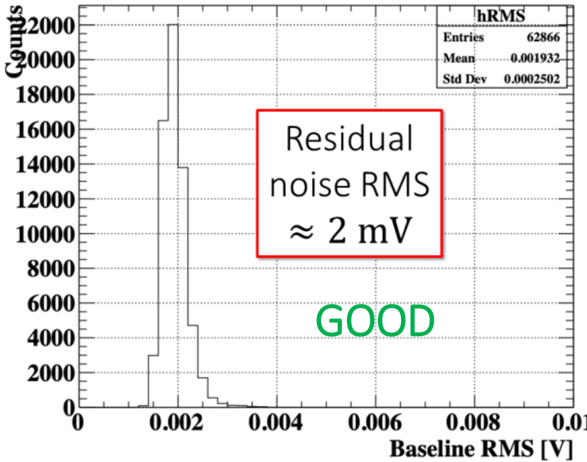
Read out configuration and noise







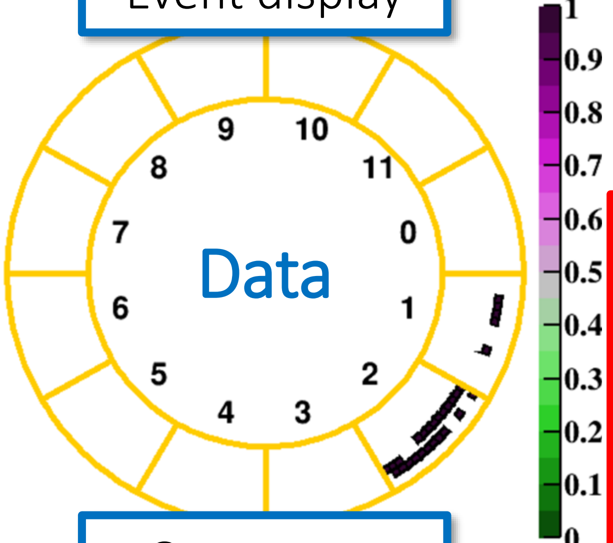
- Only 192 DAQ channels available for 2018 and 2019 runs
- **HV scan** performed with
  - **Cosmic Rays** (CR) for gain calibration purposes in a clean environment
  - **Michel e^+ with μ^+ beam at different intensities** (pTC trigger)



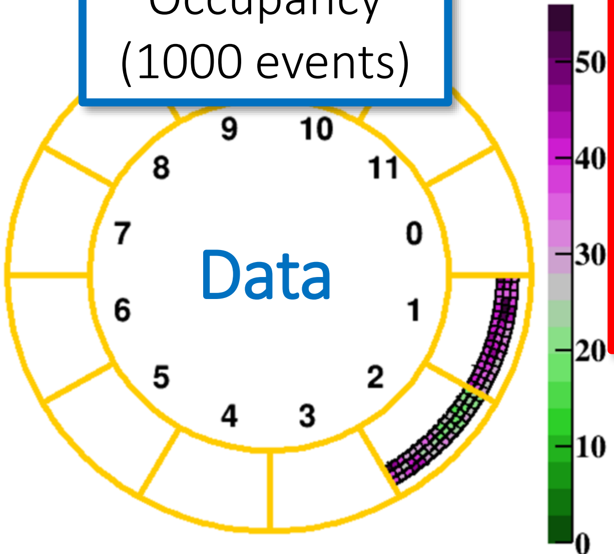
- Typical signal waveforms (WF)
- **Low frequency (~MHz) noise**
- **Origin found**
- No baseline oscillation with the final version of the DAQ boards
- Temporary solution
  1. High-pass filter
  2. Baseline subtraction

CR (3 layers)

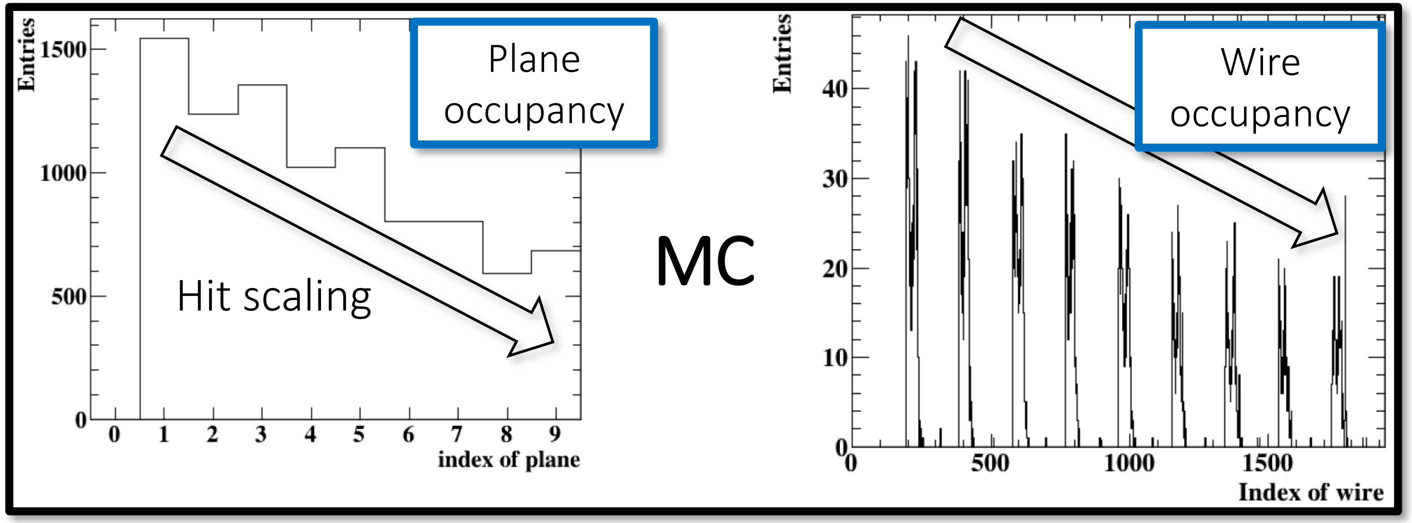
Event display

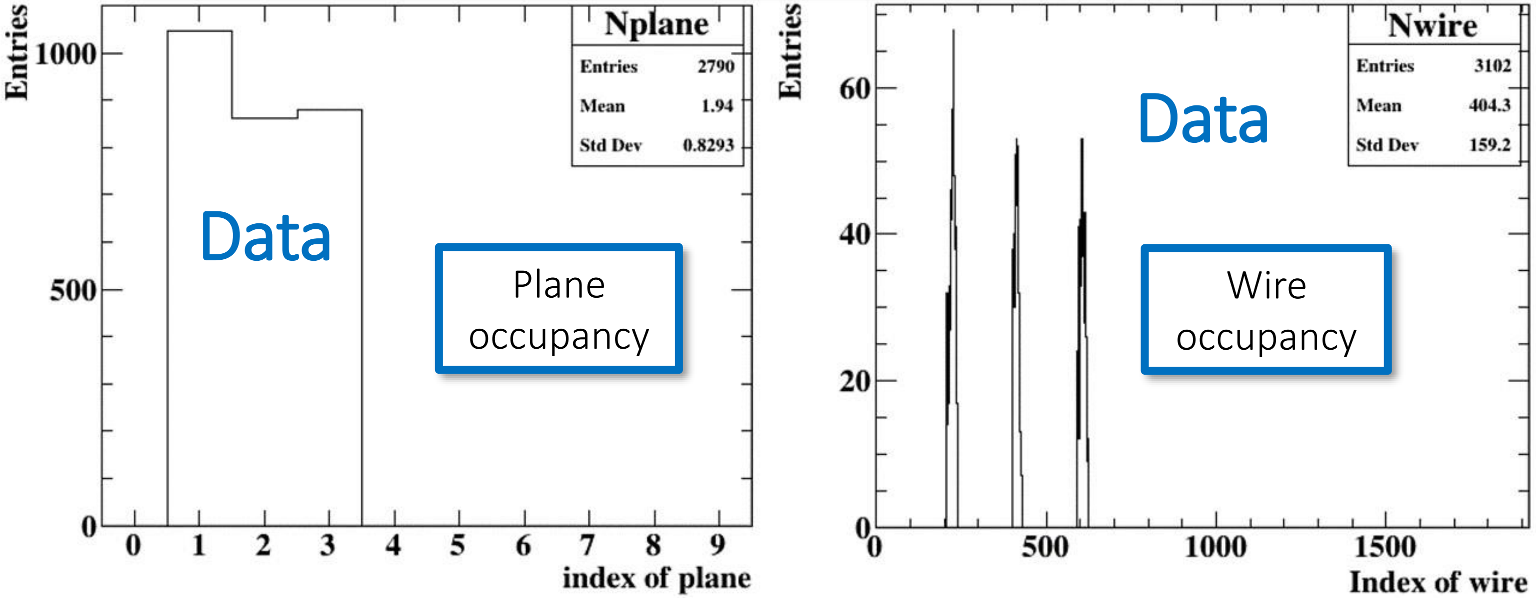


Occupancy (1000 events)



- L1, L2, L3 at 1500 V
- **One drift cell has a hit if the WF exceeds a predefined threshold**
- Typically × 5 the RMS of the noise baseline



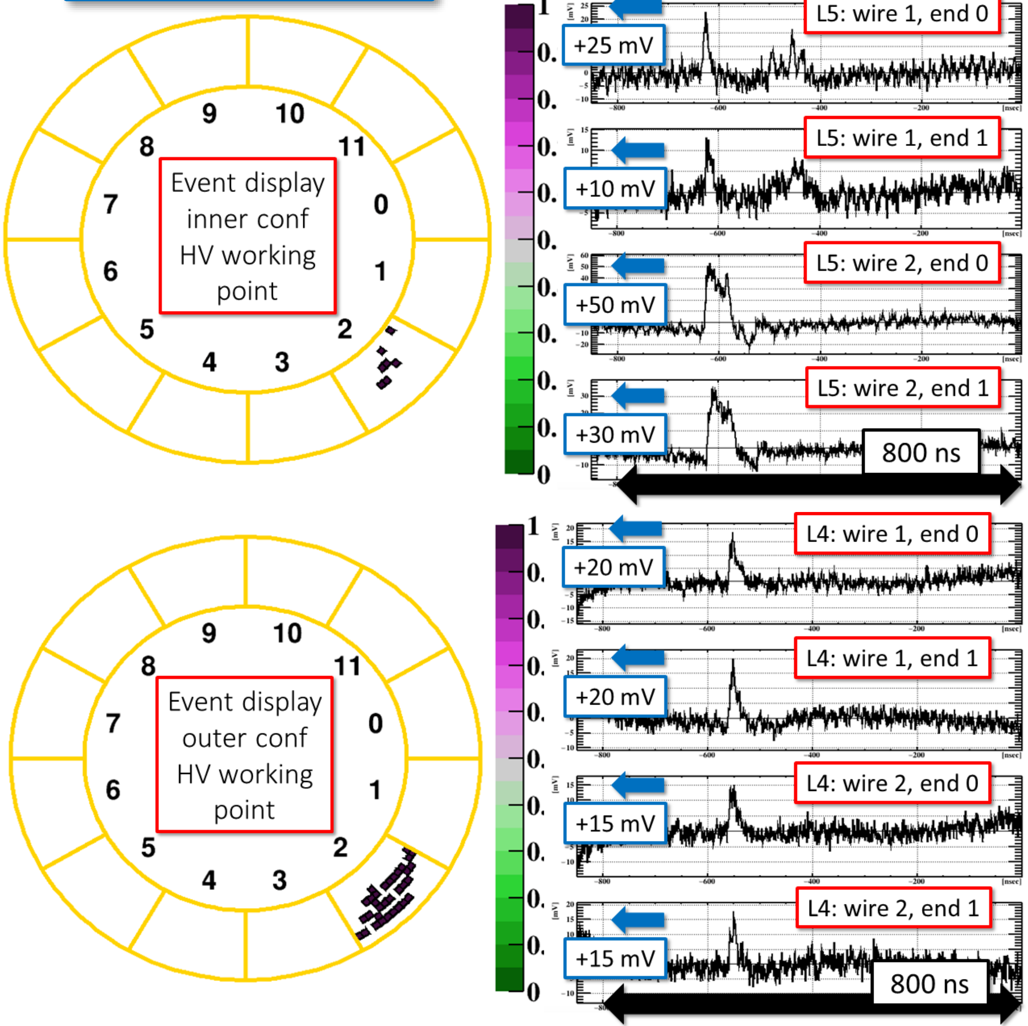


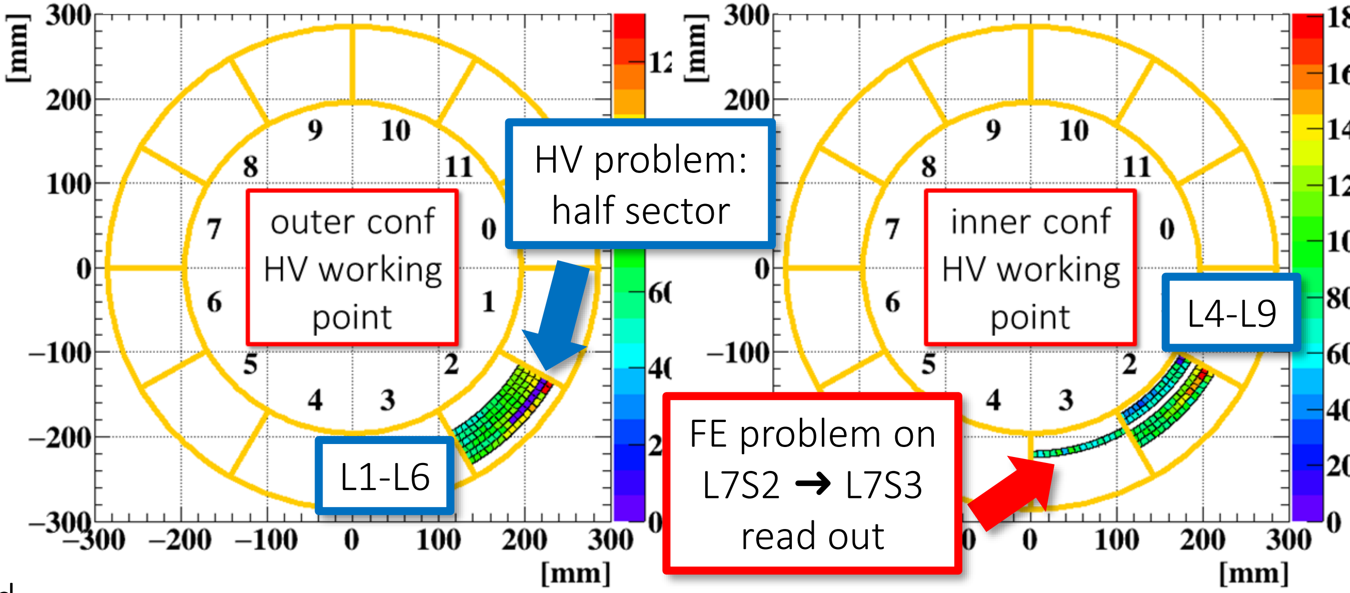
- Example of online event display for a single CR event and occupancy plots
- Agreement with Monte Carlo (MC) simulation

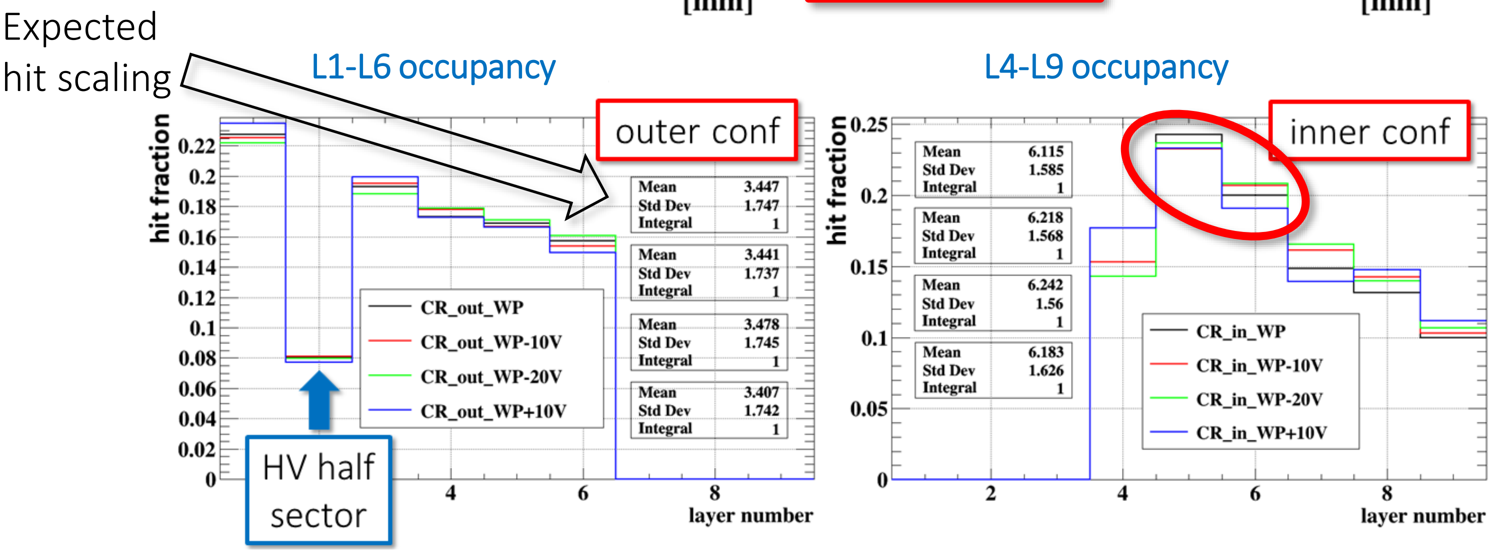
CR (6 layers)

HV configurations
1. Working Point
2. WP - 10 V
3. WP - 20 V
4. WP + 10 V

Event display

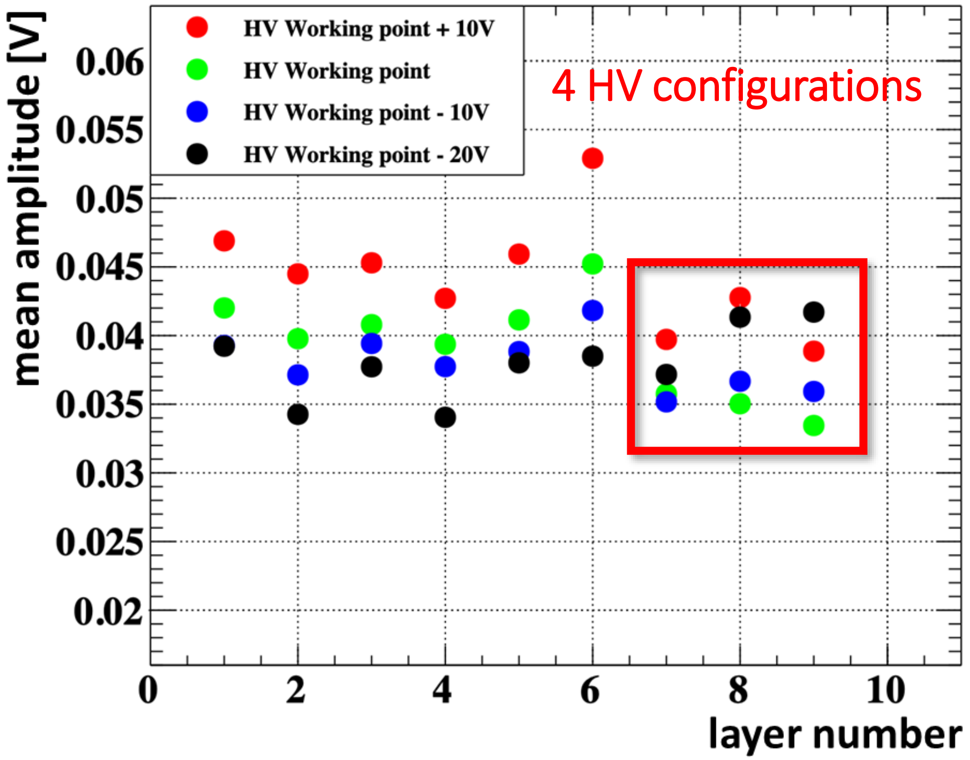


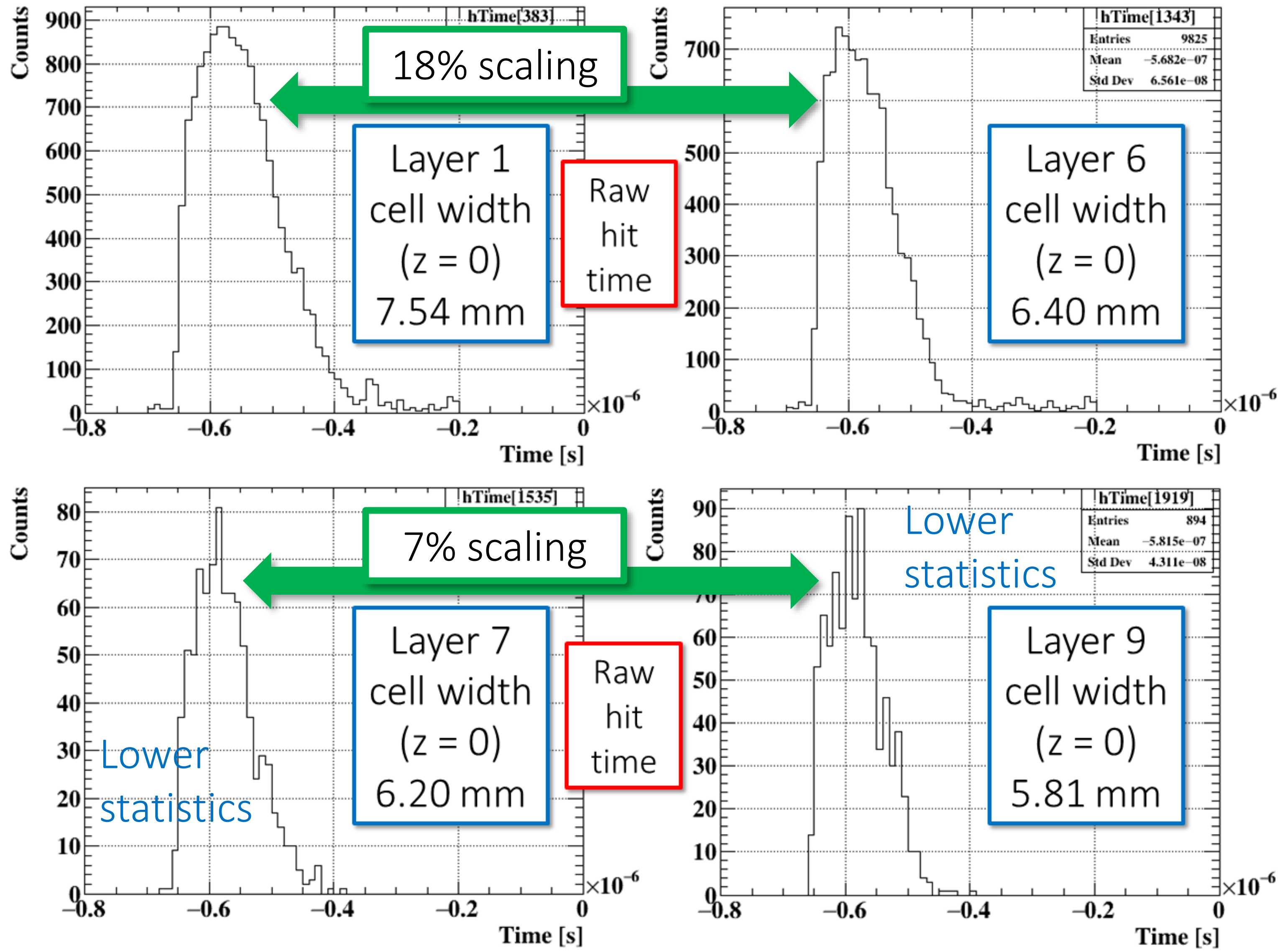




- Outer configuration: expected hit scaling from outer to inner layers
- Inner configuration: L5 and L6 result more efficient than L4
  - HV tuning needed to compensate for inefficiencies

CR (9 layers)

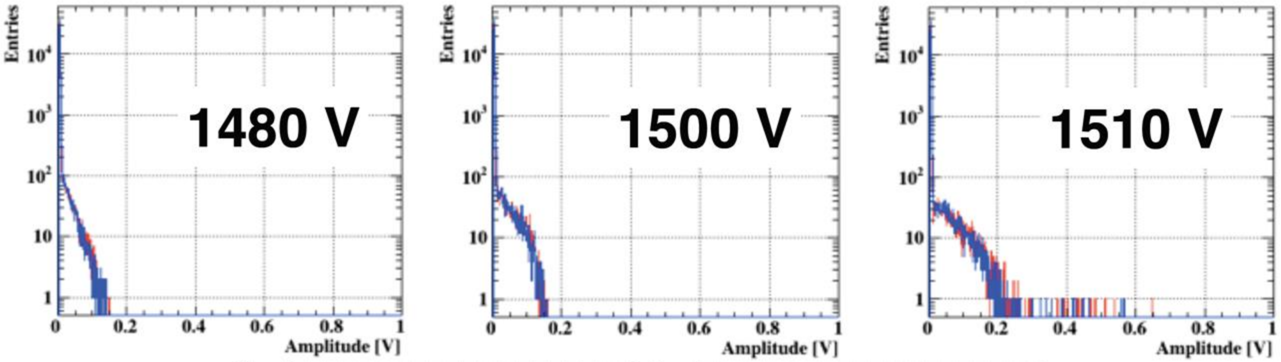




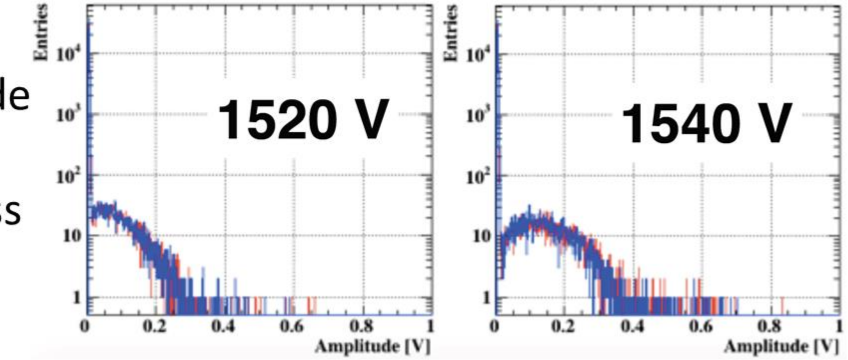
- First comparison among signals belonging to every layer
- **HV tuning** needed **to equalize the gain**
  - Especially for the 3 inner layers where the WP seems worse than other HV configurations

The width of the time distributions is directly correlated with the cell dimensions

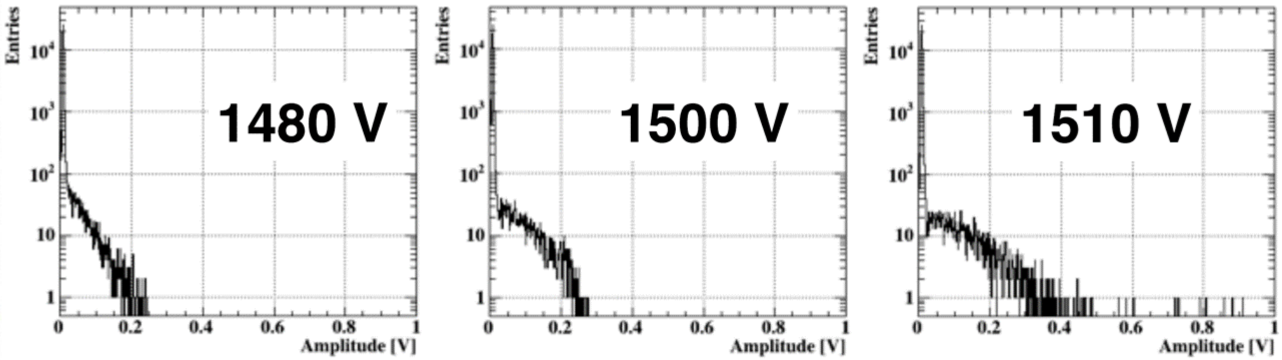
Amplitude distributions vs. HV



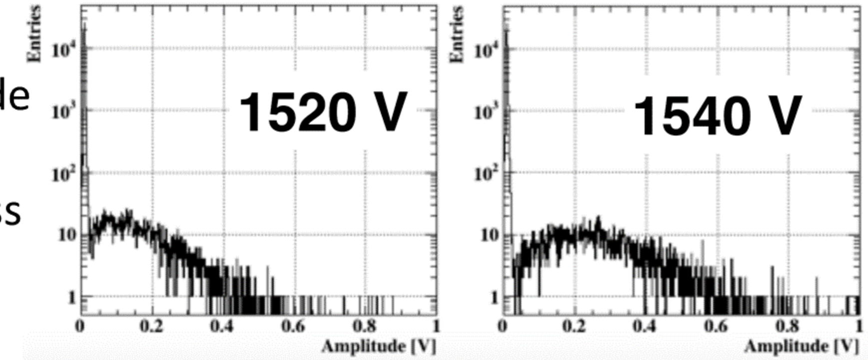
Amplitude with high-pass filter



US
DS



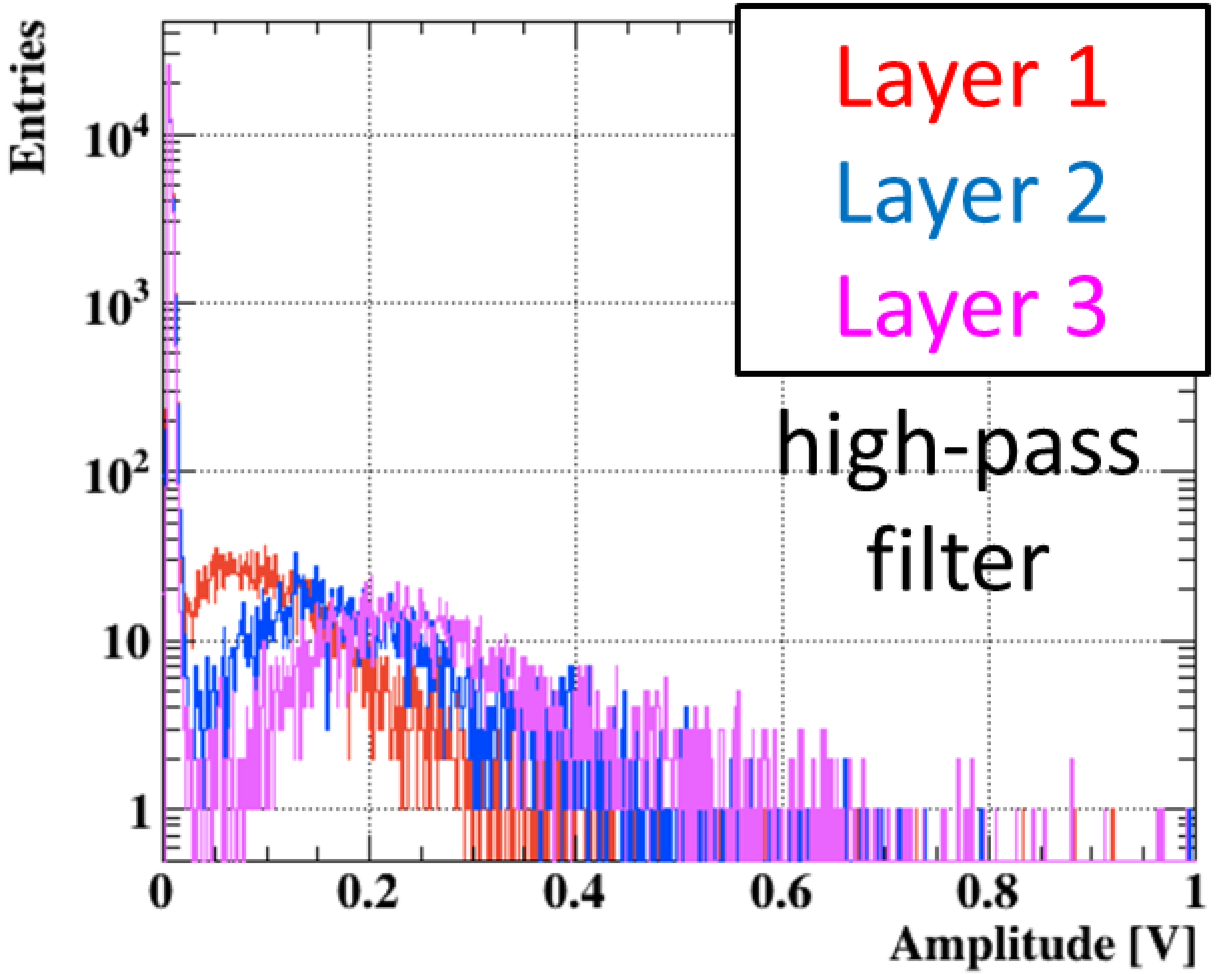
Amplitude with high-pass filter

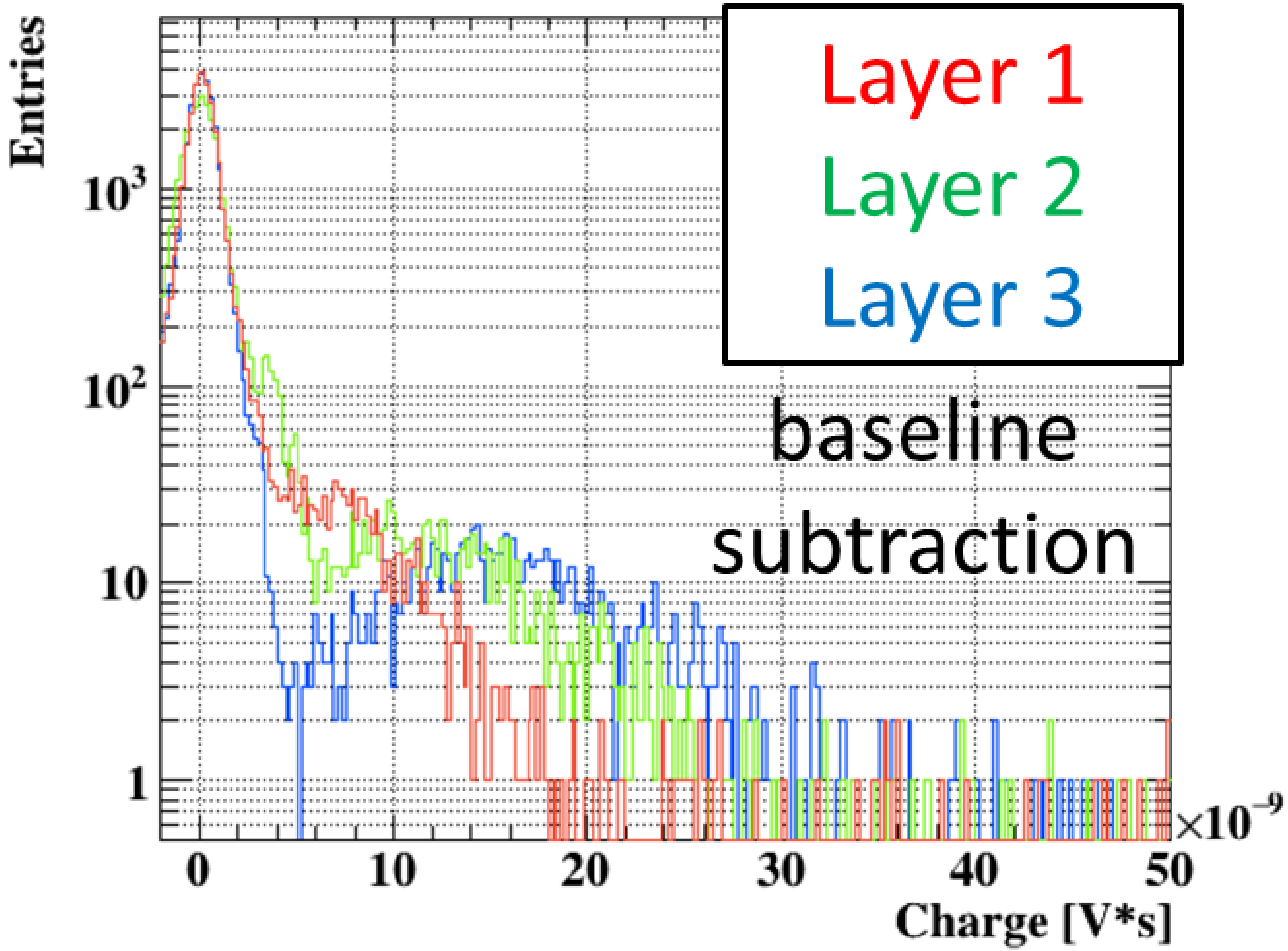


US
+
DS

Amplitude and charge vs. layers

US + DS 1540 V

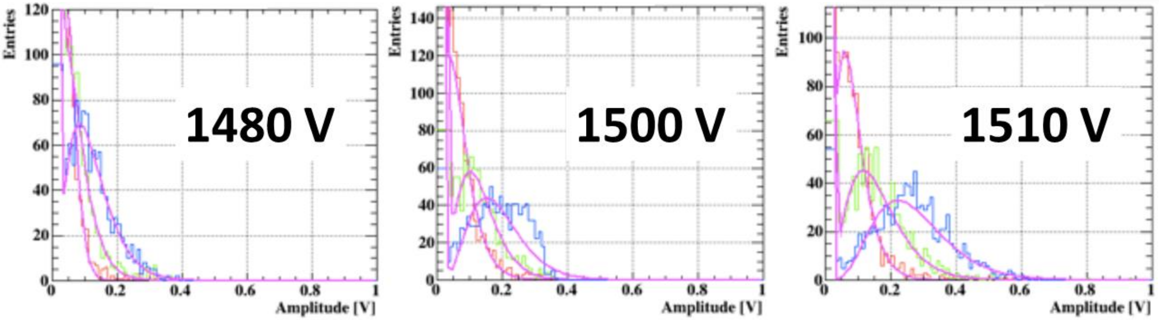




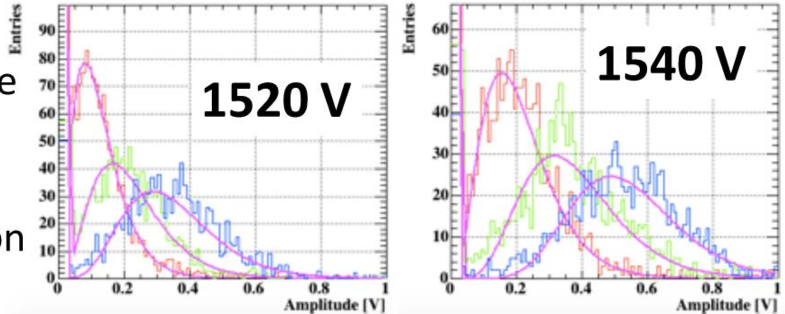
HV scan with CR

- Distributions of the signal amplitude and charge (signal integral) as a function of the HV applied
- Fit with a gaussian pedestal + Pólya distribution for signal (typical shape from the avalanche statistics)
  - The mean amplitude and thus the separation from pedestal increase as the HV is set to higher values
    - Same for the mean charge
  - The mean amplitude (at fixed HV) is higher for L3 than L1 given the higher gain for inner layers (smaller cells)
- **These plots will be used to extract the first gain estimate**

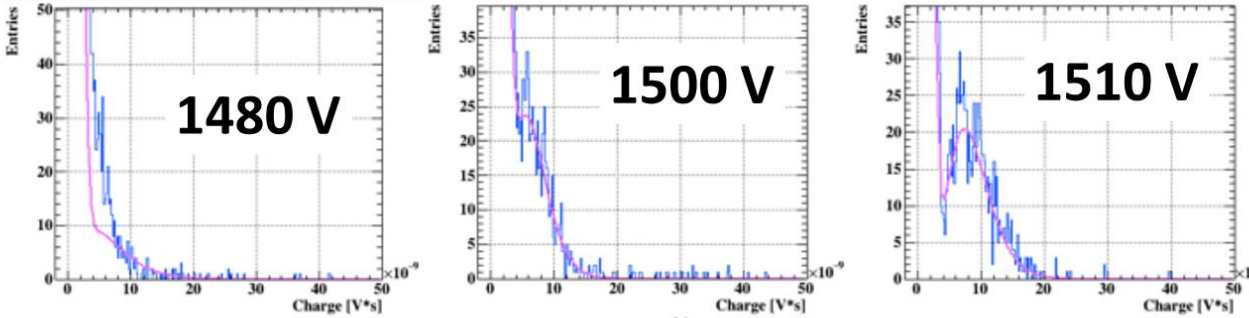
Same HV values applied to L1, L2, L3



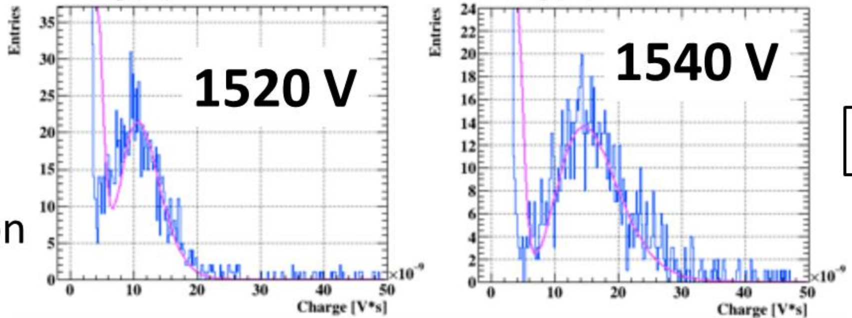
Amplitude with baseline subtraction



Layer 1
Layer 2
Layer 3



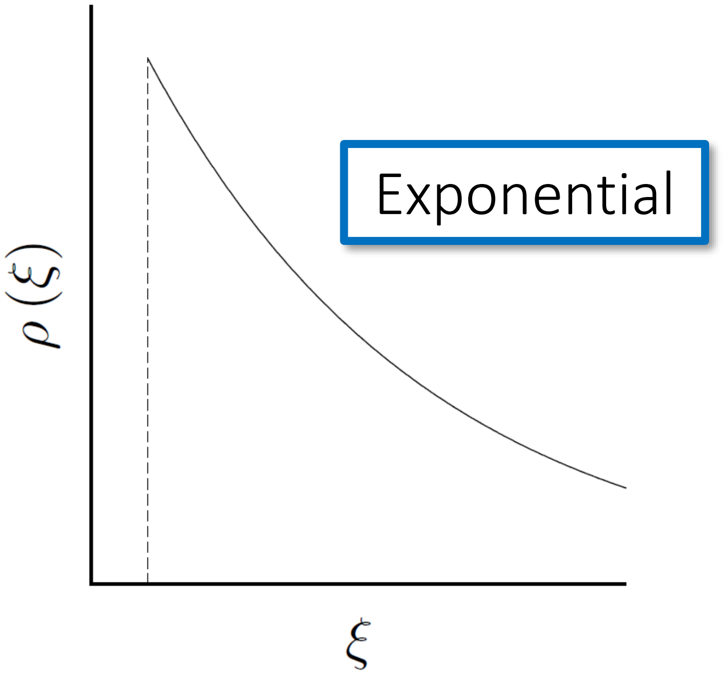
Charge with baseline subtraction

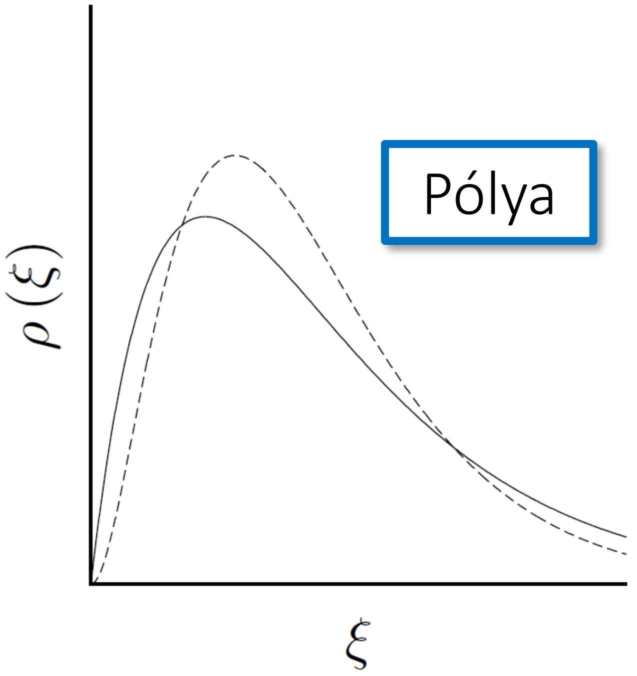


Layer 3

Pólya distribution

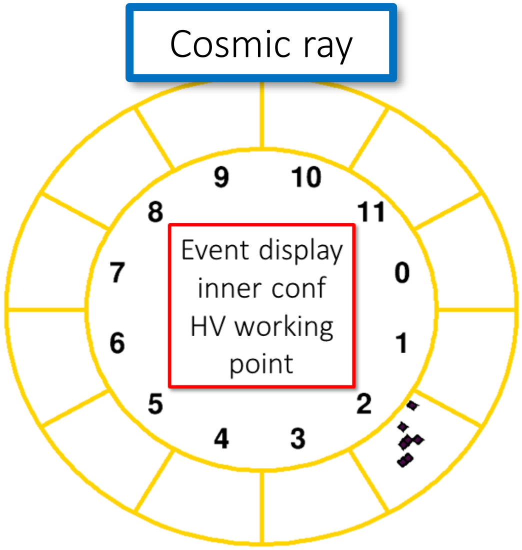
$$\overline{n}P_n = \frac{(1+\theta)^{(1+\theta)}}{\Gamma(1+\theta)} \left(\frac{n}{\overline{n}}\right)^{\theta} e^{-(1+\theta)n/\overline{n}}$$

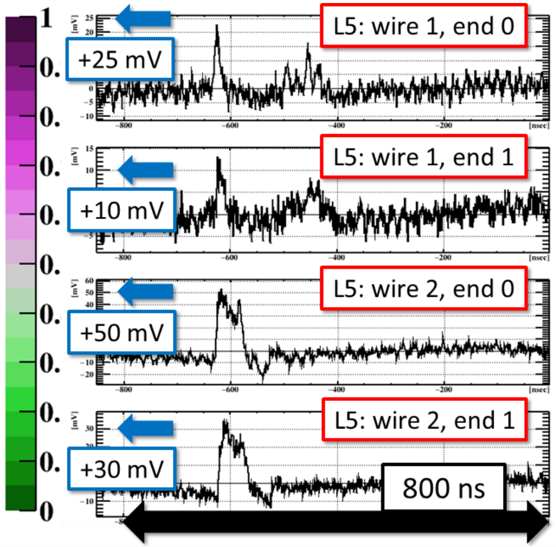




- The Pólya distribution is a model for the shape of avalanche size at high gain
- θ is the so-called Pólya parameter
  - It changes the shape of the curve

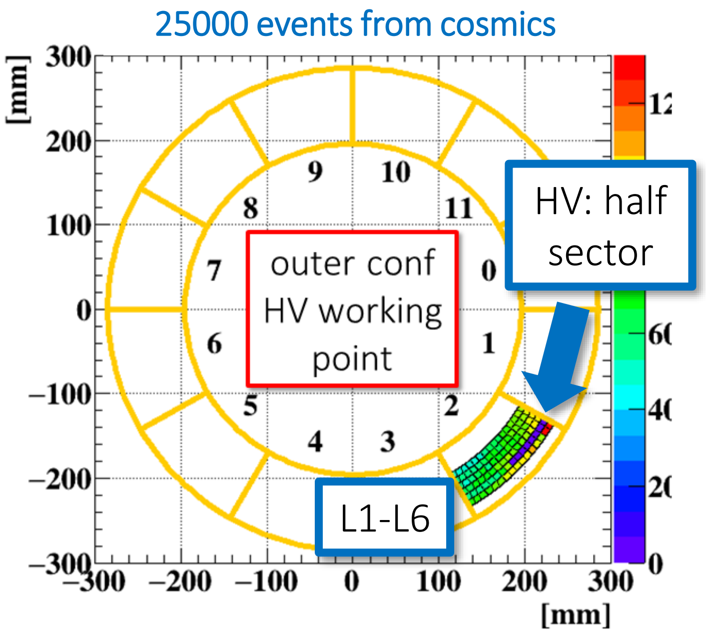
First collected data

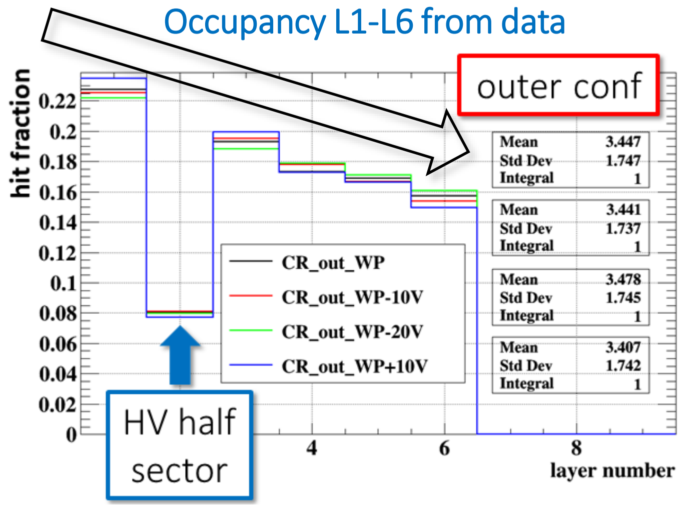


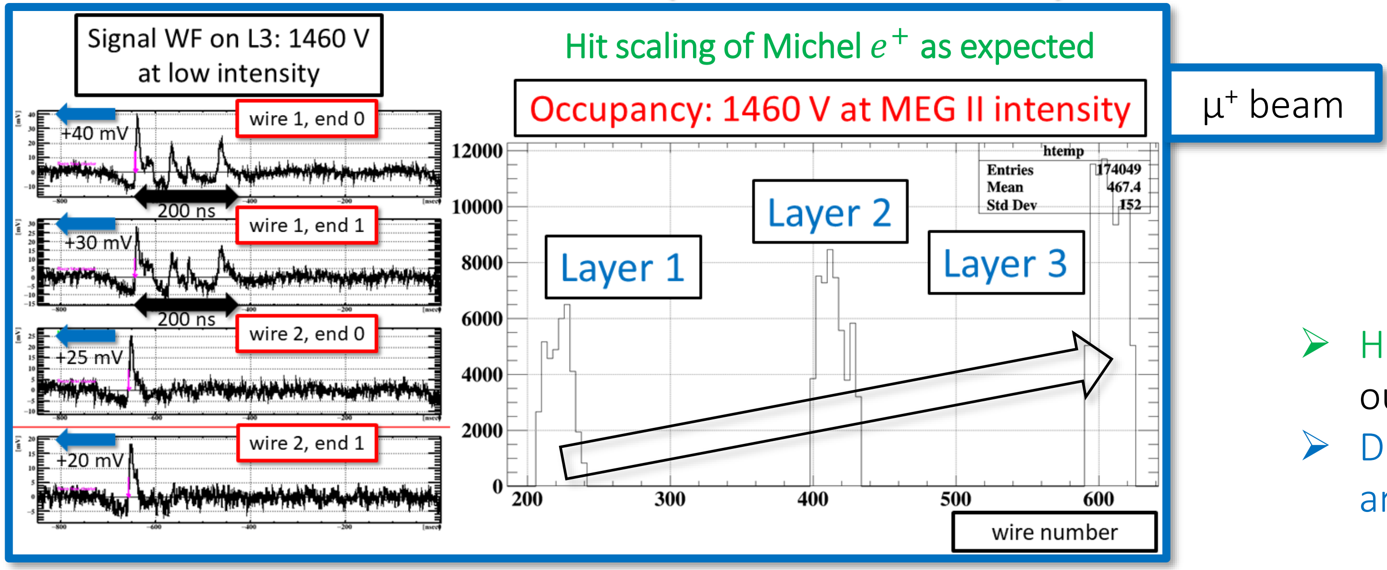


Only a limited number of DAQ channels is available

- 192 in 2018 and 2019
  - 6 layers in one sector
  - Inner configuration (L4-L9)
  - Outer configuration (L1-L6)
- 256 in 2020
  - Data taking ongoing
- Expected full read out in 2021





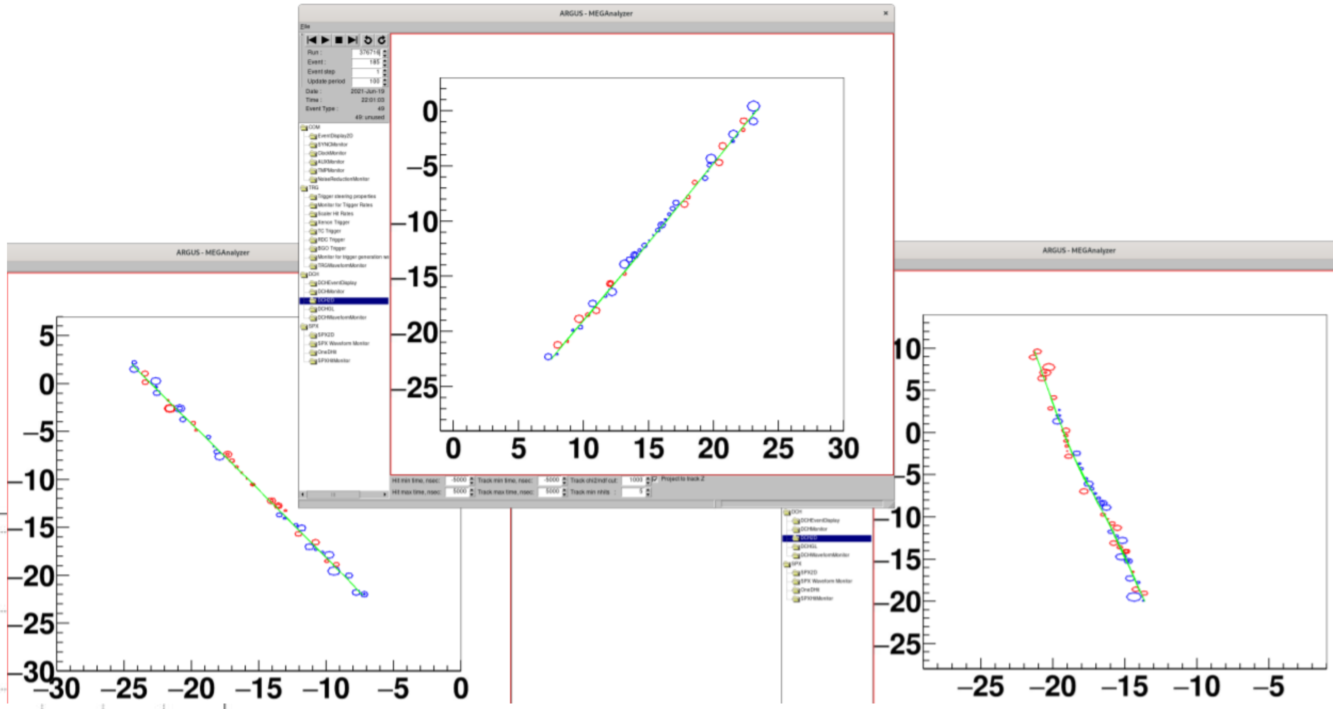


- Hit scaling as expected from the outer layer (L1) to the inner layer (L9)
- Different HV configurations tested around the working point

Data collection without μ^+ beam and B field

- Cosmic muons
  - CRC trigger
  - CDCH self-trigger (2&2 or 2|2 multiplicity)
    - Thanks to the trigger group
- Plots by Fedor

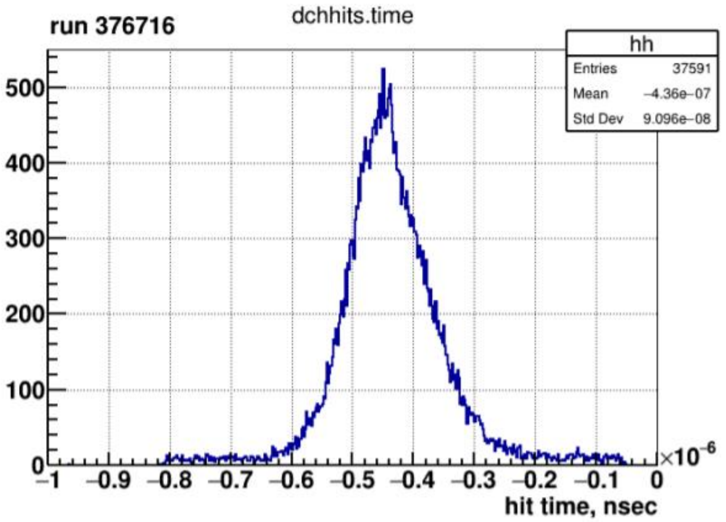
Self triggered events



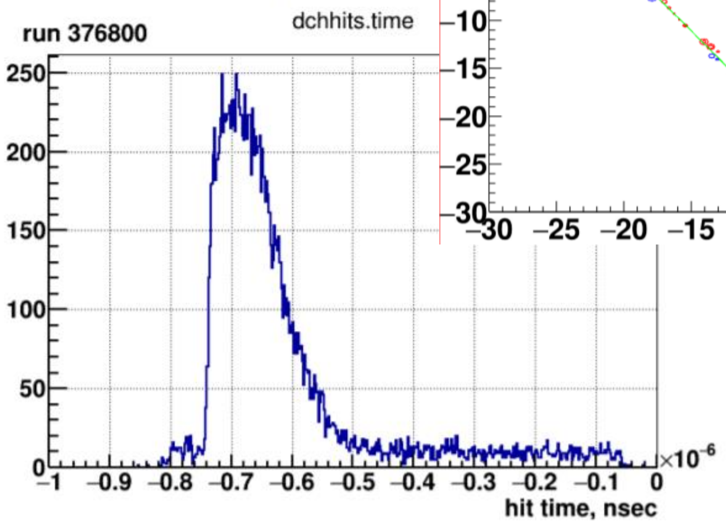
Self TRG:1k events/3-4 minutes

CRC :1k events/23 minutes

Self triggered CDCH



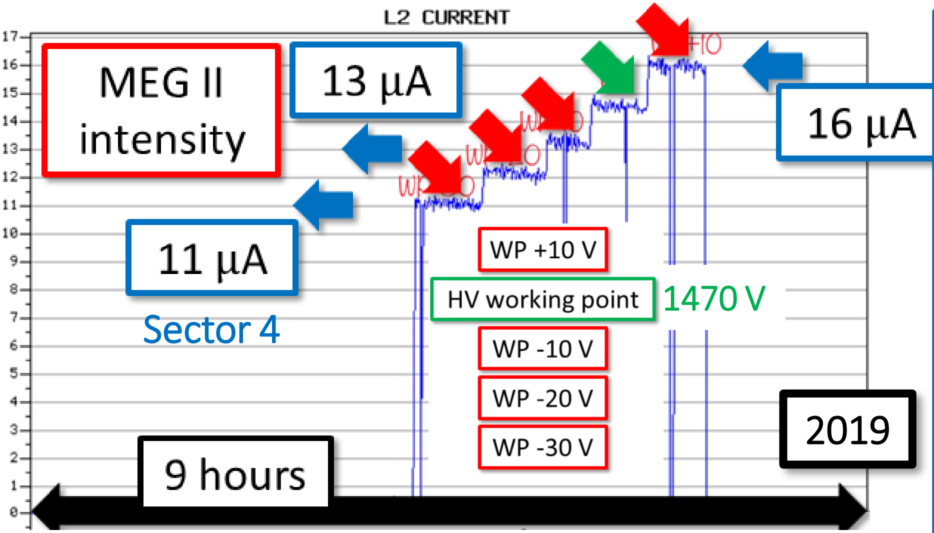
CRC runs

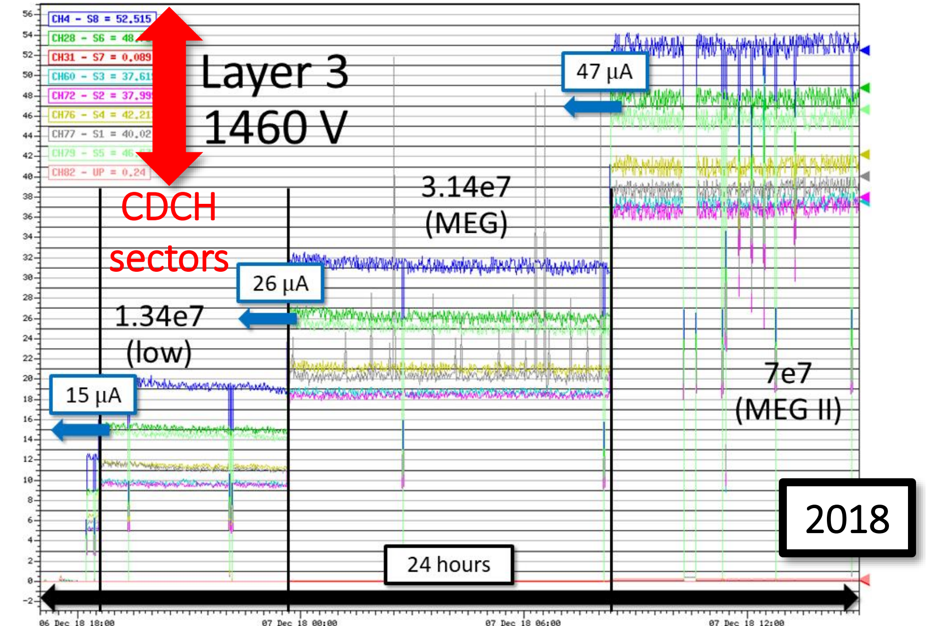


Self triggered runs: T0 can be roughly estimated as minimal hit time in event

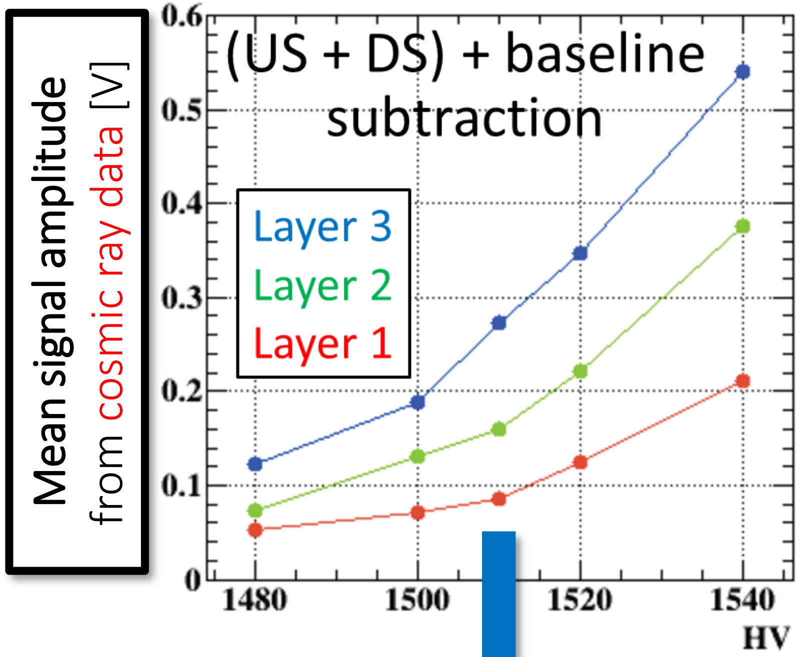
CRC runs: T0 can be taken very precisely from CRC counters

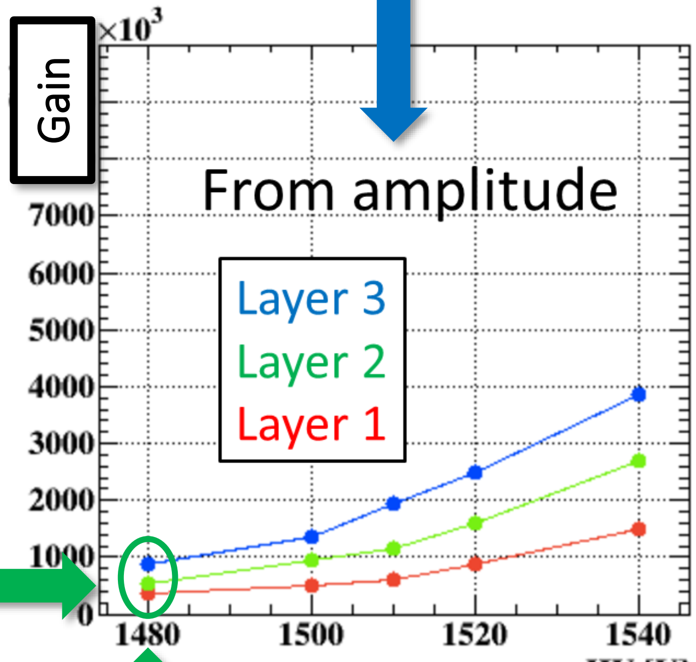
First gain studies





- Example of gain curves for L2 and L3
  - Currents drawn by the HV channels with **μ^+ beam at different intensities**
- ~ exponential behaviour in the current value with the HV increase as expected from simulations





The mean amplitude from cosmic ray data are converted into the effective gas gain G

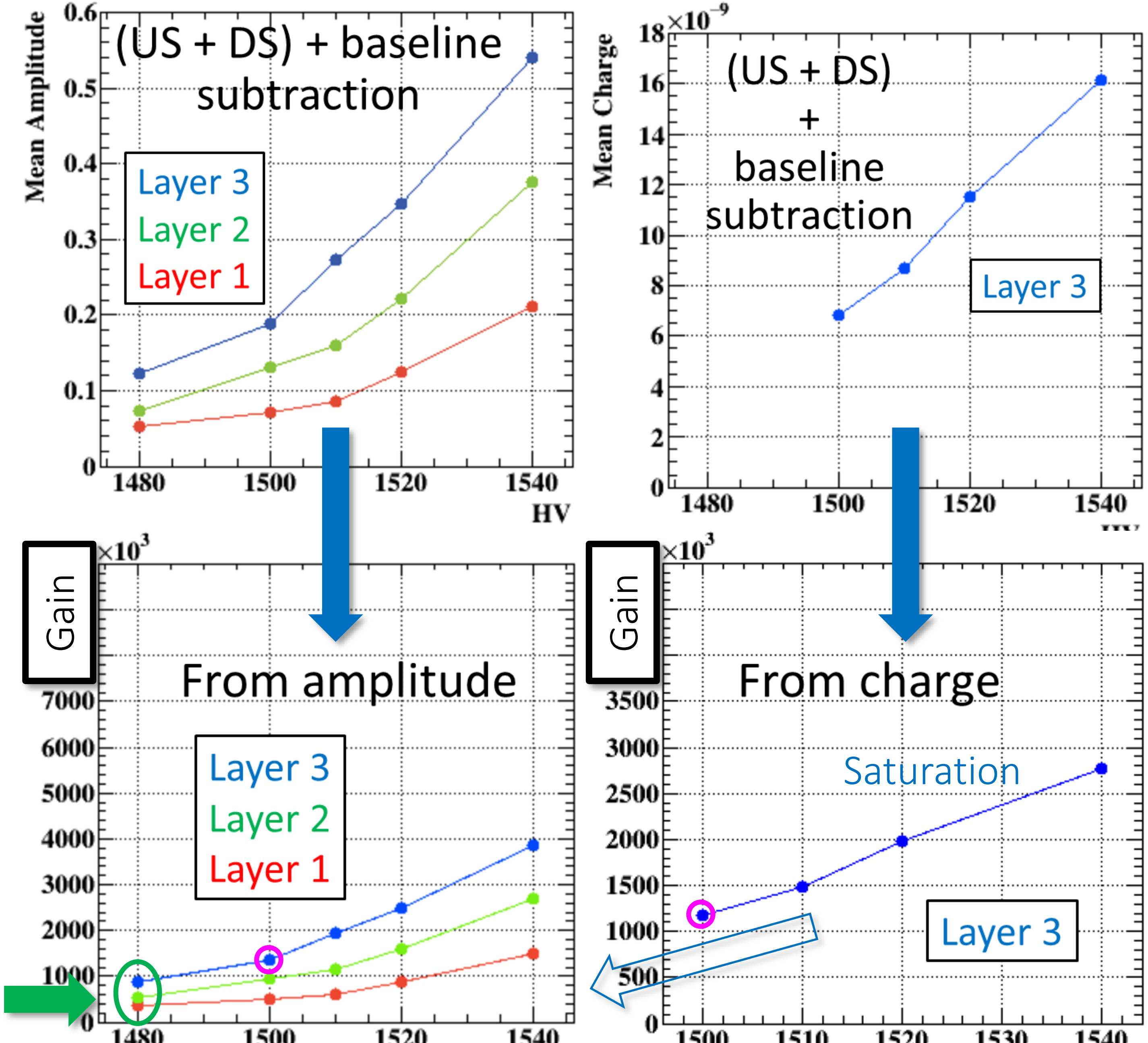
- By means of simulations of the ionization clusters and the response of the FE amplification stage
- **Calibrated gain curves in agreement with simulations**

$G \approx 5 \times 10^5$ at Working Point

Gain studies

The mean amplitude and charge from cosmic ray data are converted into the effective gas gain G

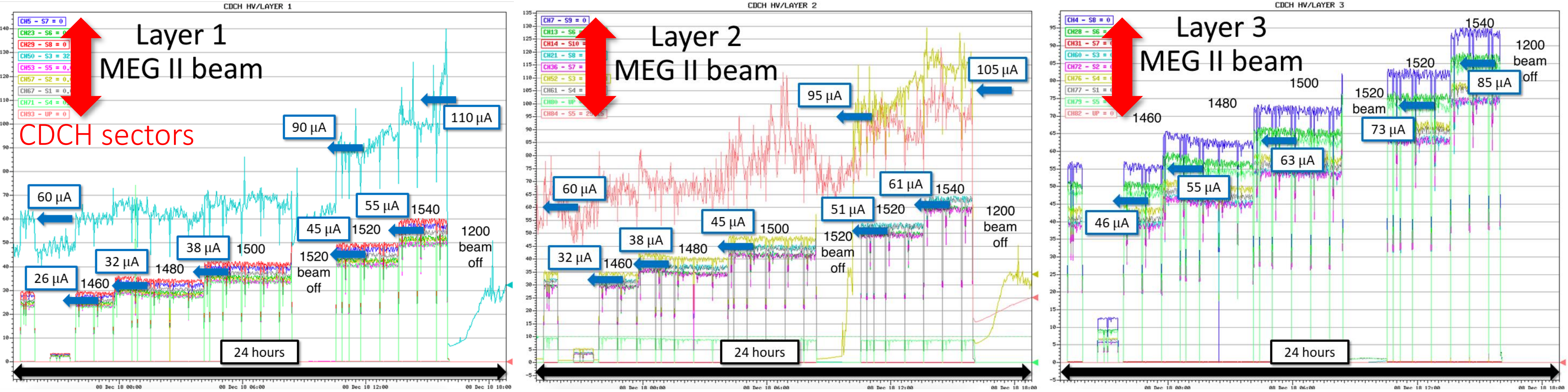
- By means of simulations of the ionization clusters and the response of the FE amplification stage
- **Calibrated gain curves in agreement with simulations**



$G \approx 5 \times 10^5$ at Working Point

Extrapolation to WP in agreement with simulations

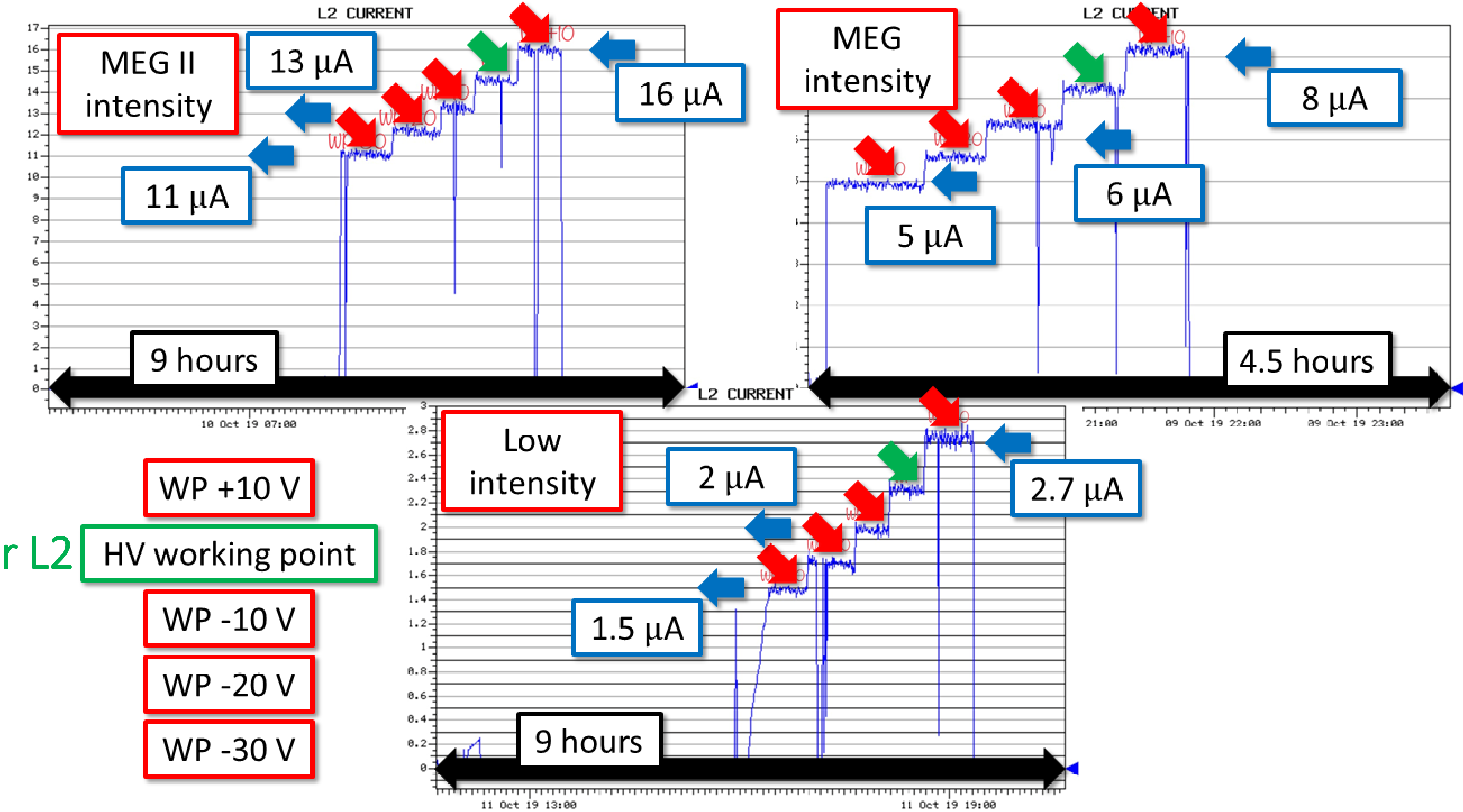
HV scan with μ^+ beam



- Gain curves as a function of the HV applied to L1, L2, L3
- ~ exponential behaviour with the HV increase as expected from simulations
- The regular instantaneous drops correspond to the beam spills to feed the Ultra Cold Neutrons (UCN) facility
- **Same anomalous high current values** in L1S3 and L2S5
  - L2S3 started later
- **More investigations needed**

HV scan with μ^+ beam

- Example gain curves for L2
- ~ exponential behaviour with the HV increase as expected



WP +10 V

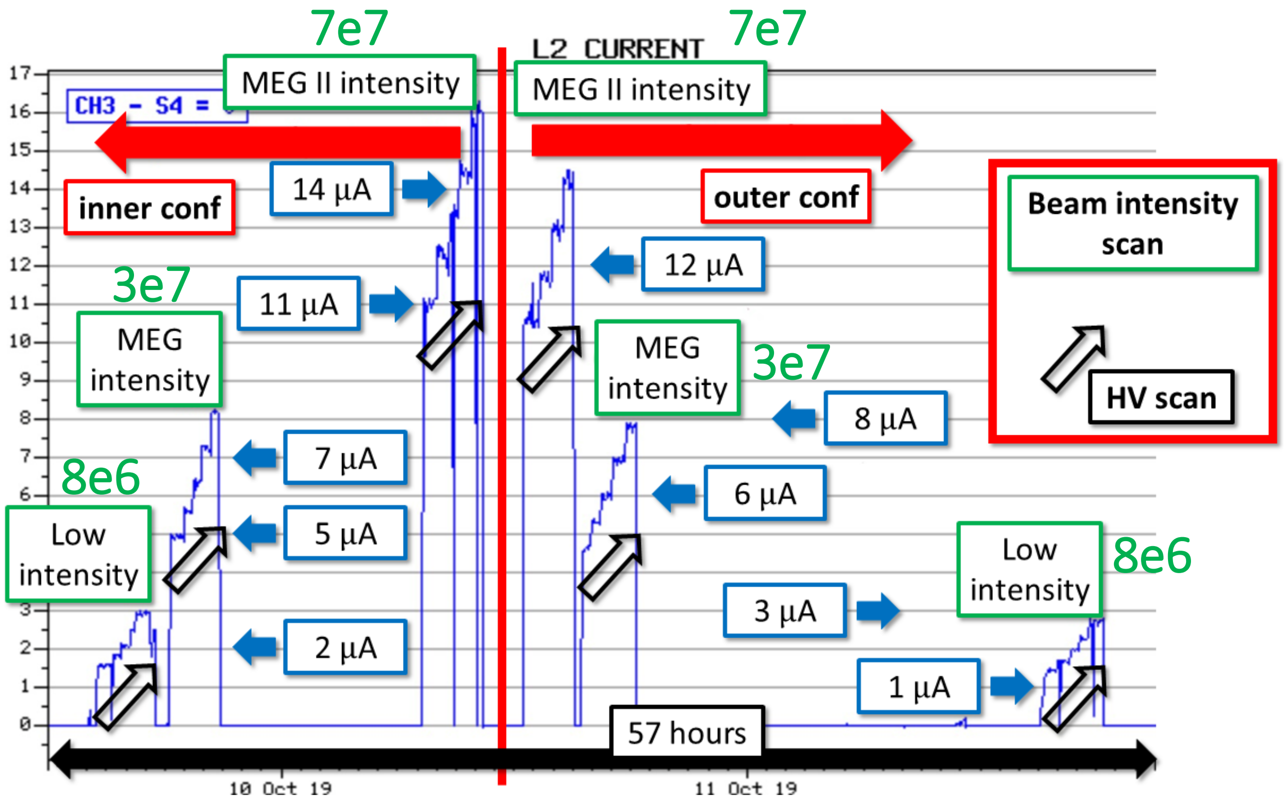
1470 V for L2 — HV working point

WP -10 V

WP -20 V

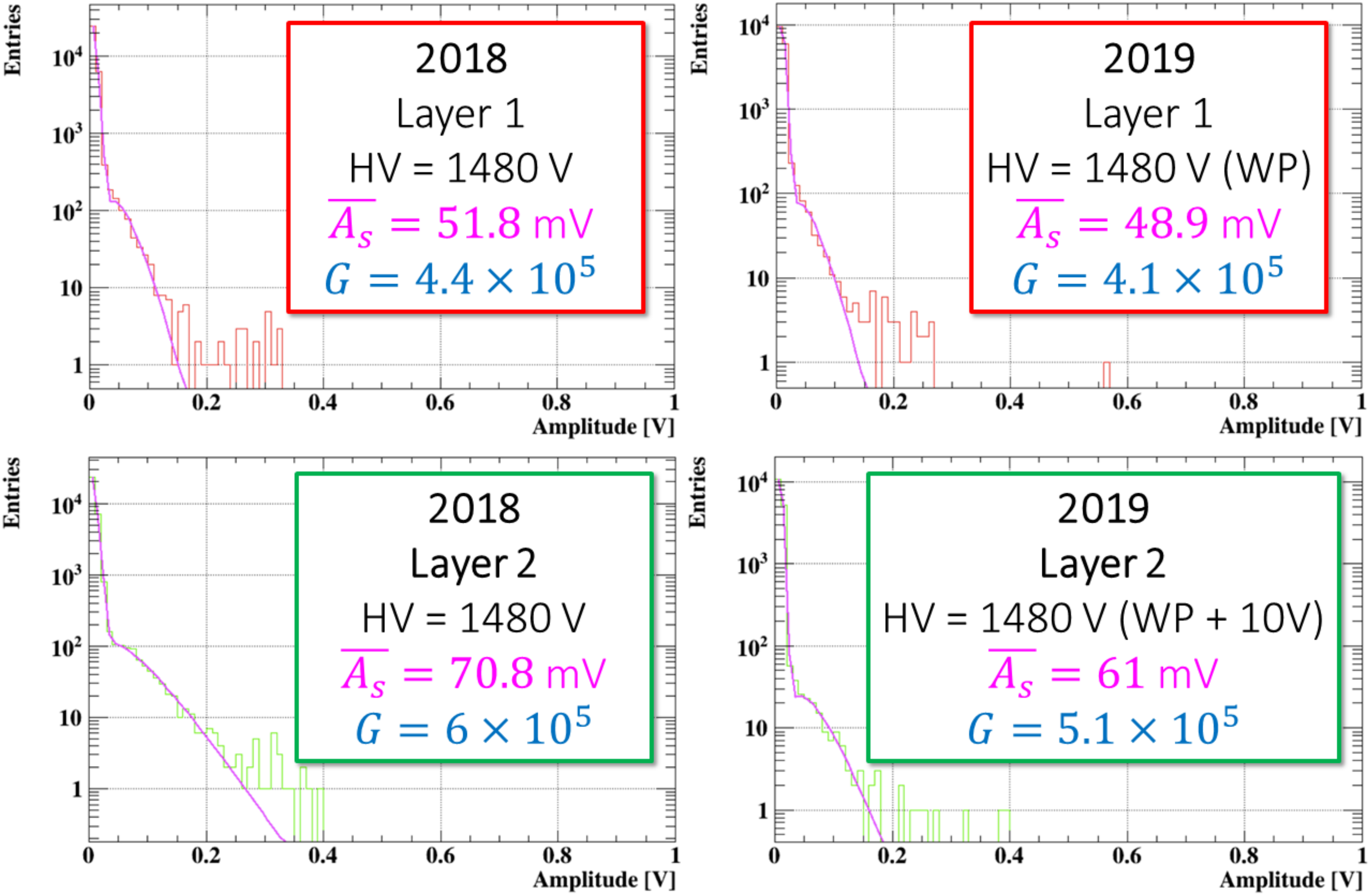
WP -30 V

μ^+ beam



- μ^+ beam intensity scan
  - Example gain curves for L2
- Linear proportionality as a function of the beam flux

2018-2019 gain comparison

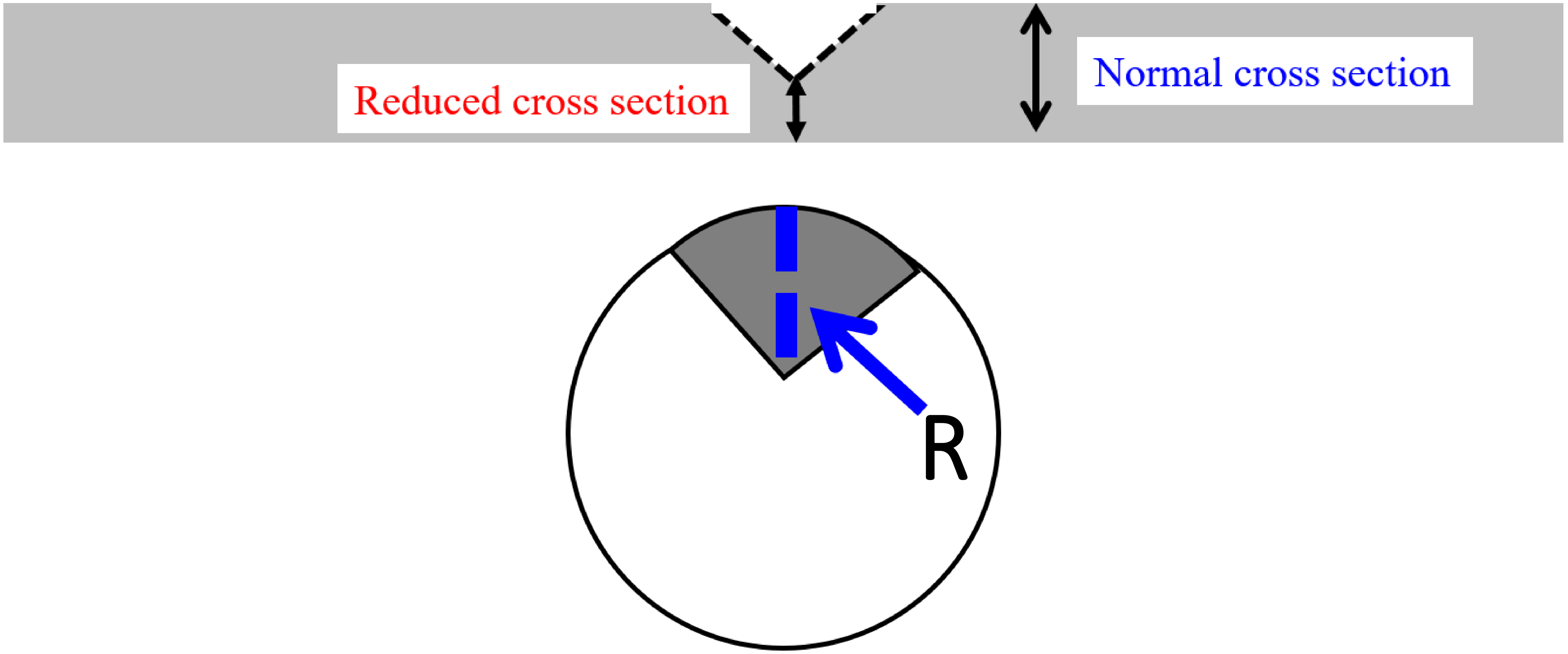


Preliminary

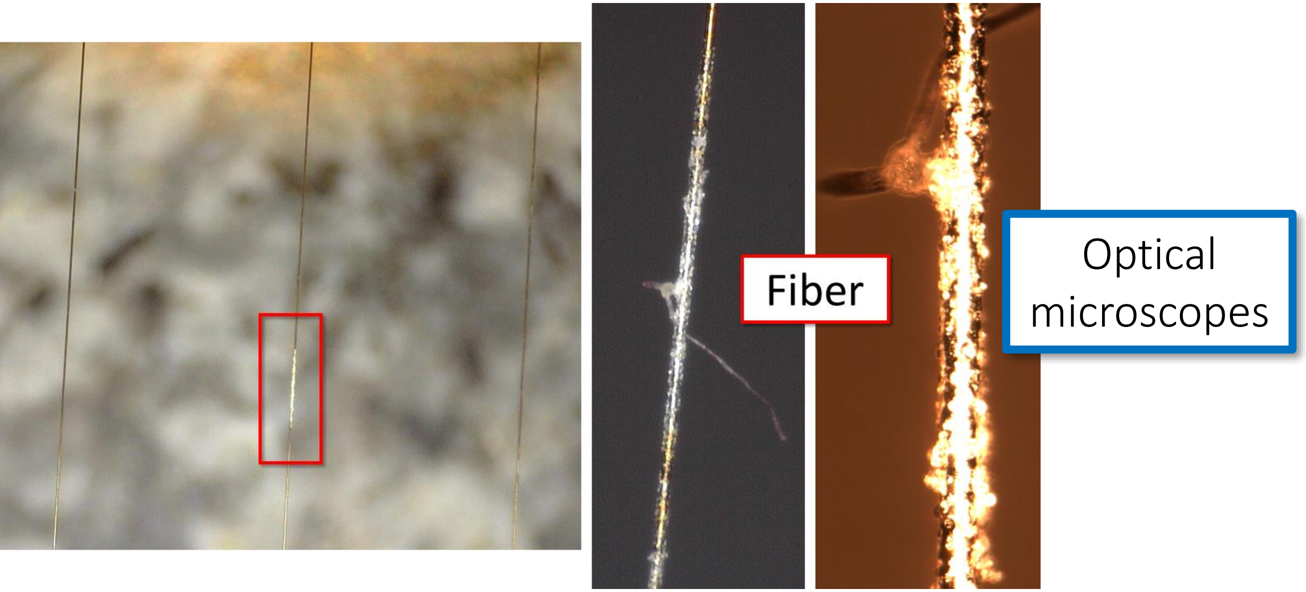
HV tuning by 10 V/layer fundamental to obtain the gain equalization among different layers

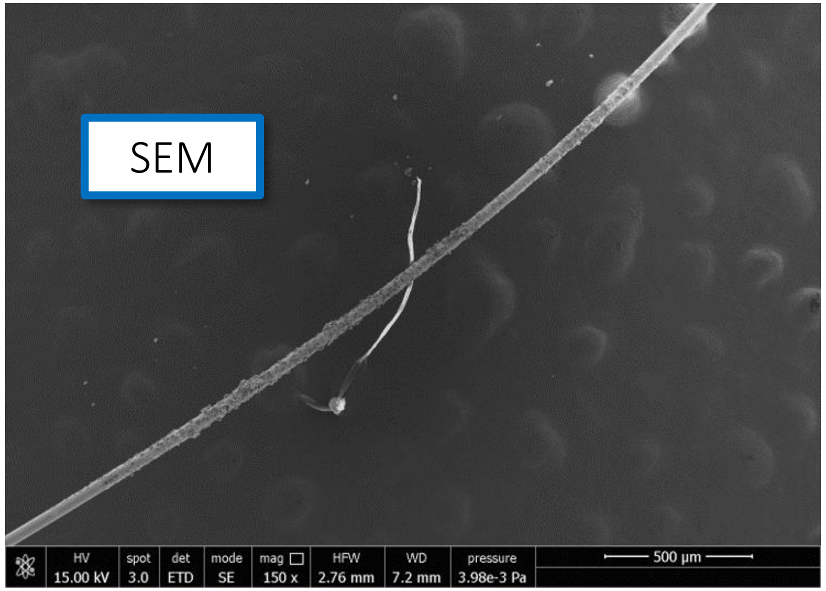
- Due to the variable cell dimensions as a function of the radius

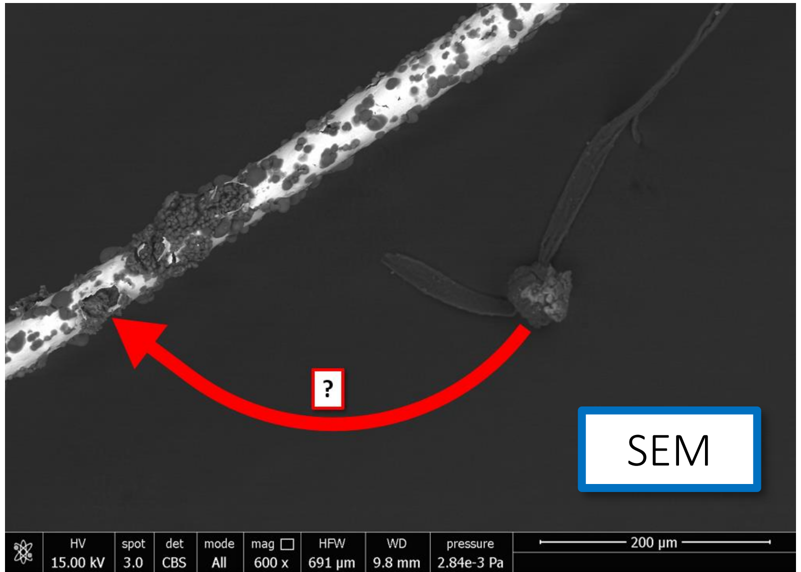
Wire core thinning due to corrosion

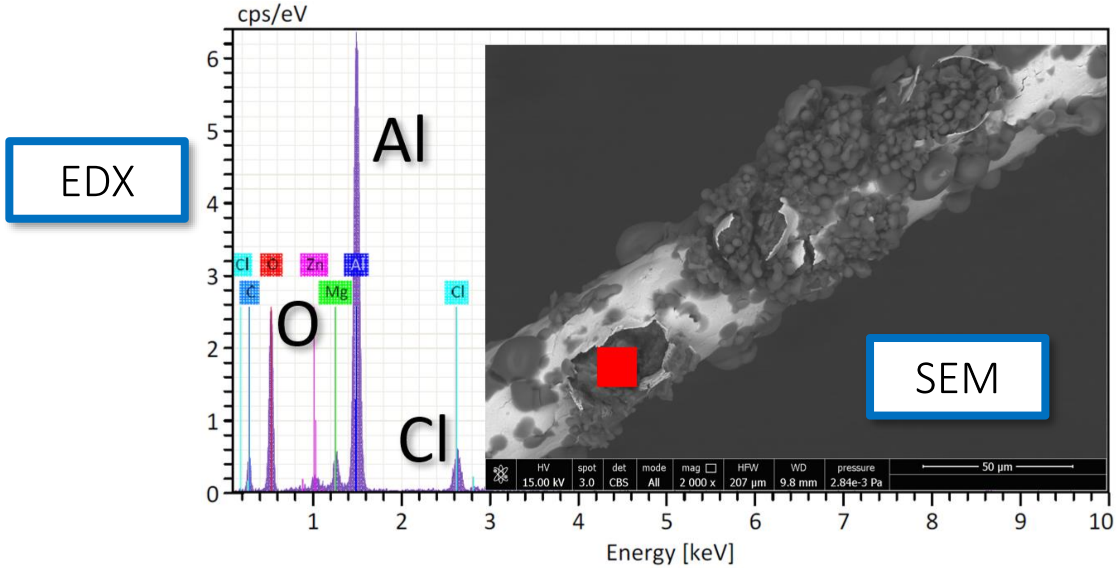


White spot on a wire due to a fiber

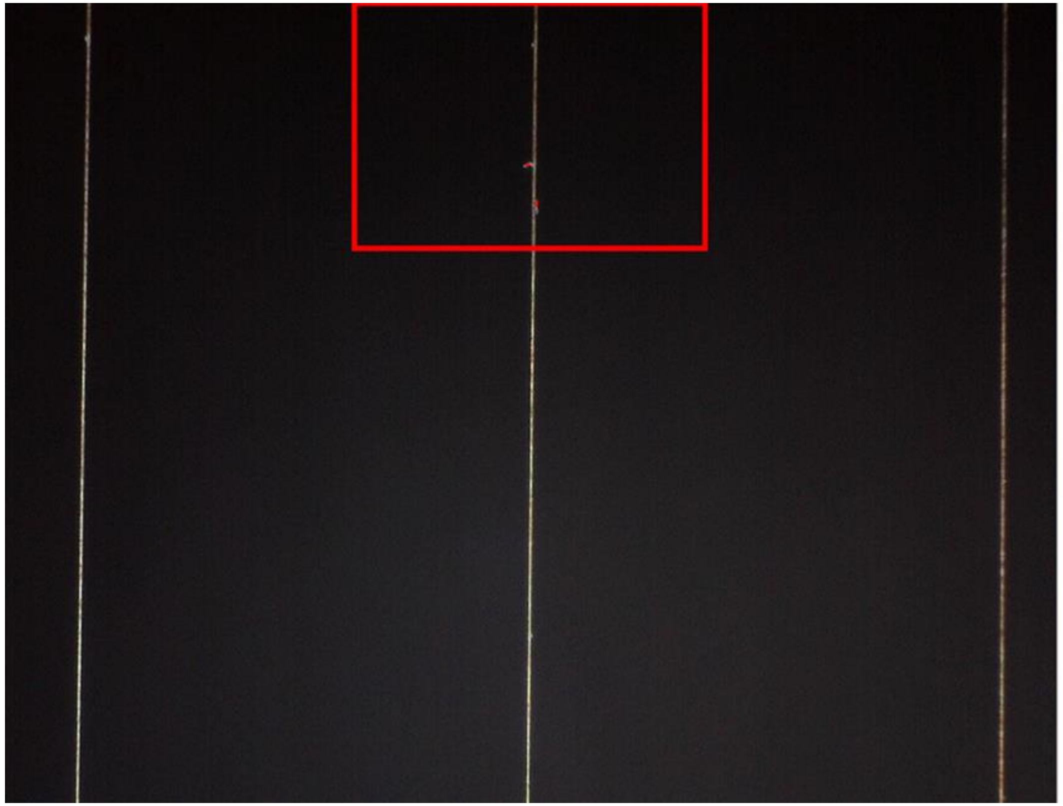






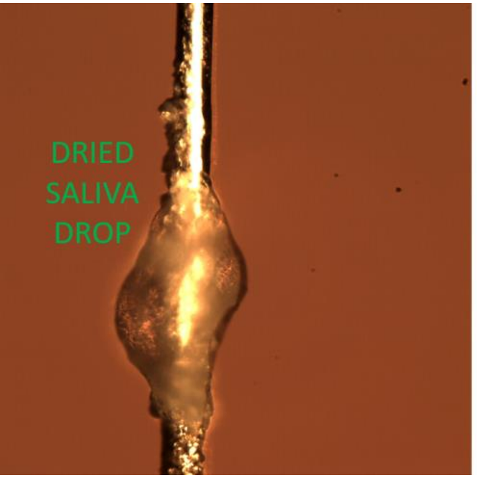


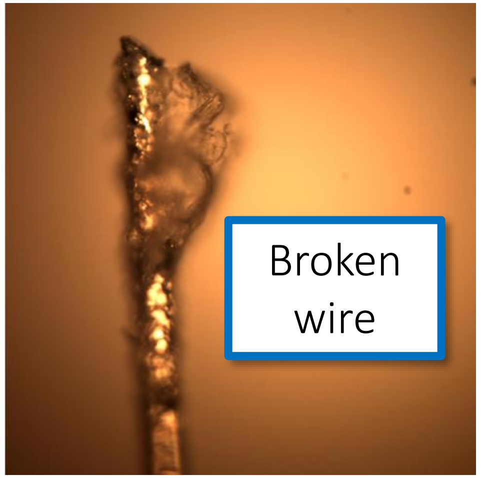
Automatic detection of wires defects

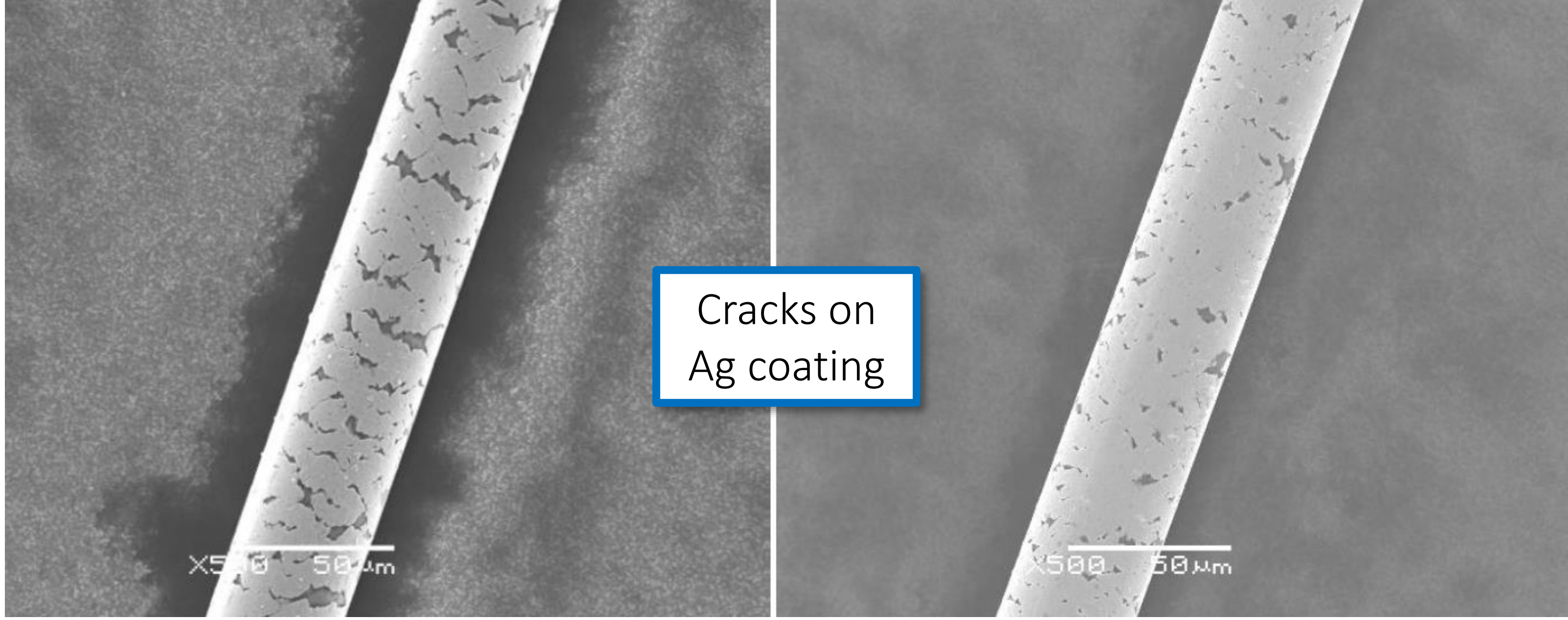


Pattern recognition exploiting the MathWorks Image Processing Toolbox (MATLAB)

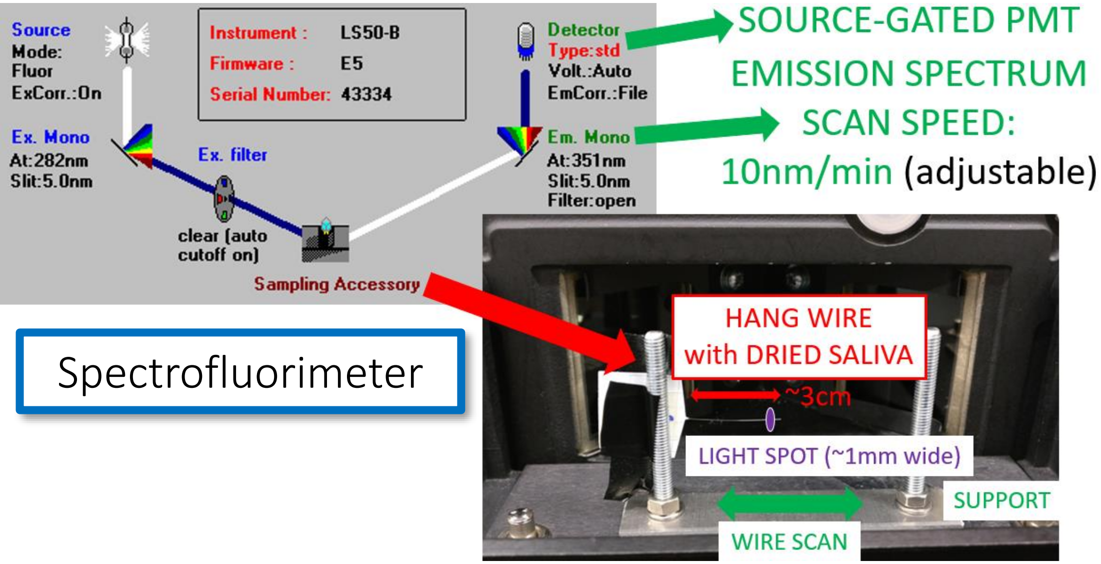
Saliva on wires





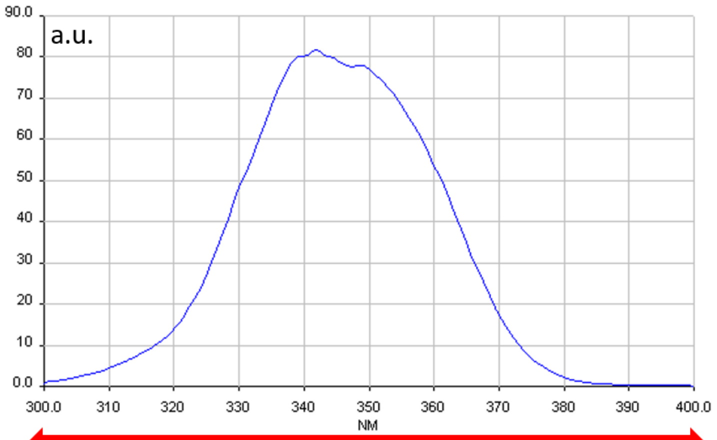


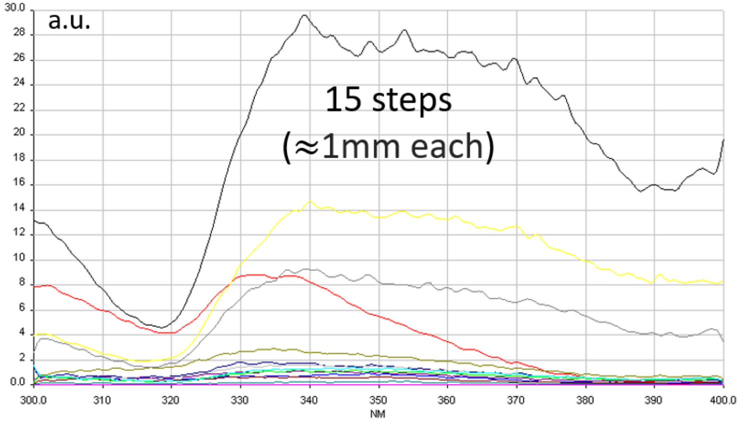
Cracks on Ag coating



Spectrofluorimeter

Fluorescence spectrum of ≈ 3 mm saliva deposit on wire





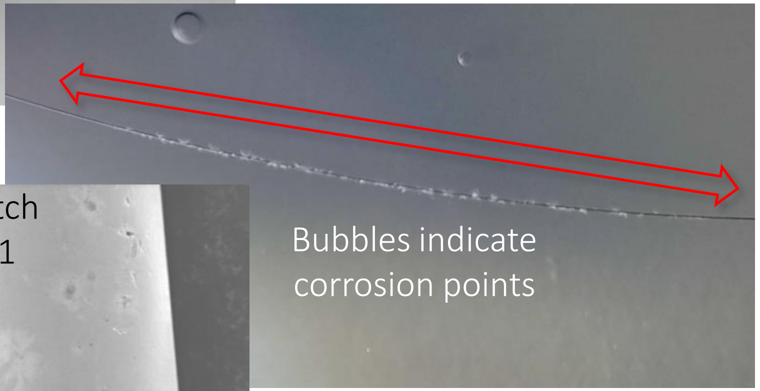
EMISSION SPECTRUM SCAN RANGE: 300÷400nm (adjustable)

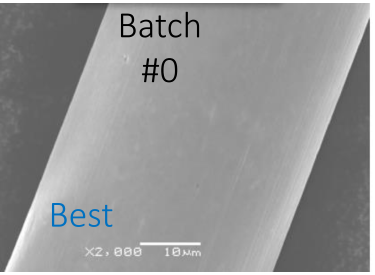
Al(Ag) wires: CDCH vs. CDCH2

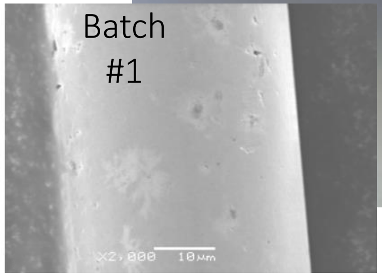
CDCH: 40 µm (75.5%) + 50 µm (24.5%) Al(Ag) wires

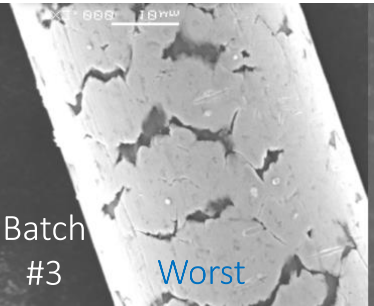
50 µm wire samples (1 meter each) immersed in distilled water

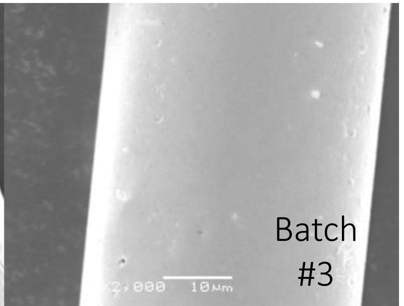
- Continuous corrosion points
- Breakings with no stress
- 40 µm wire samples completely destroyed







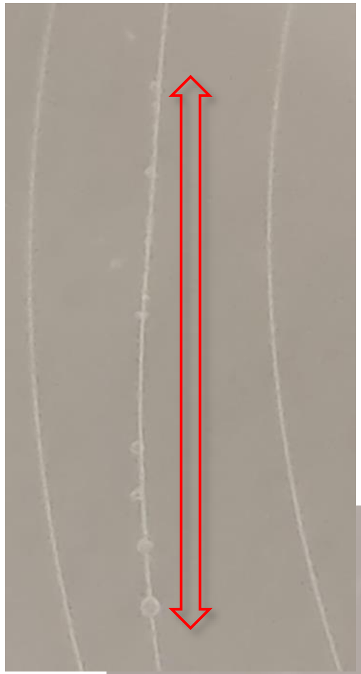


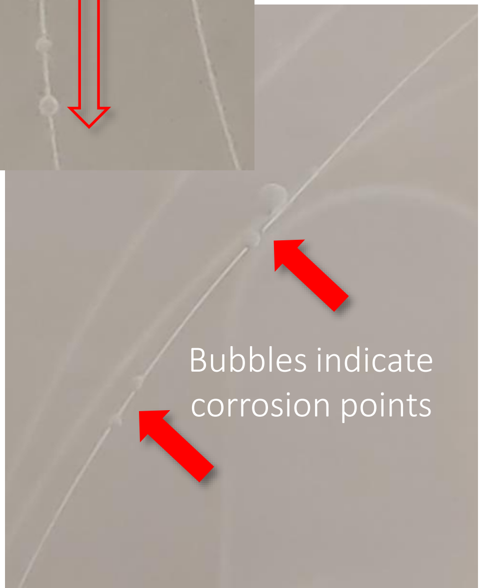


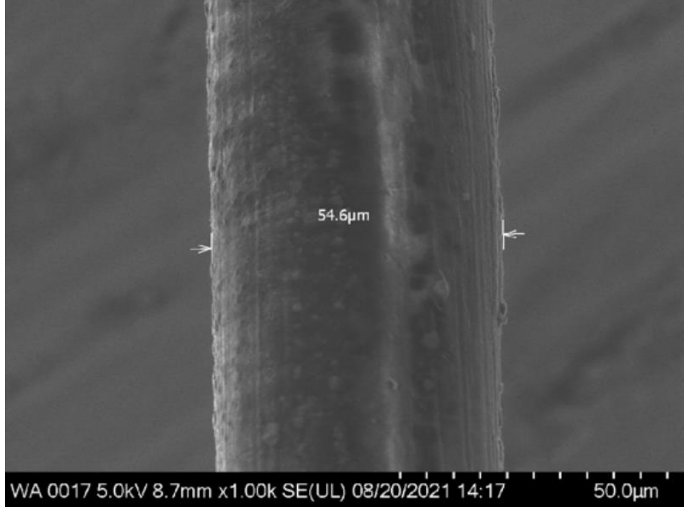
Production batch-dependent wire surface quality

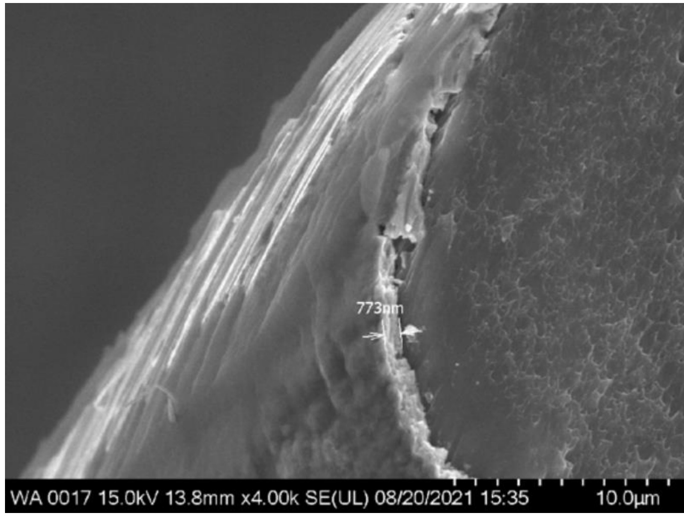
- Final drawing process (polish) on plated wires
- Cracks on the surface
- Weak points prone to corrosion

CDCH2: 50 µm (100%) Al(Ag) wires









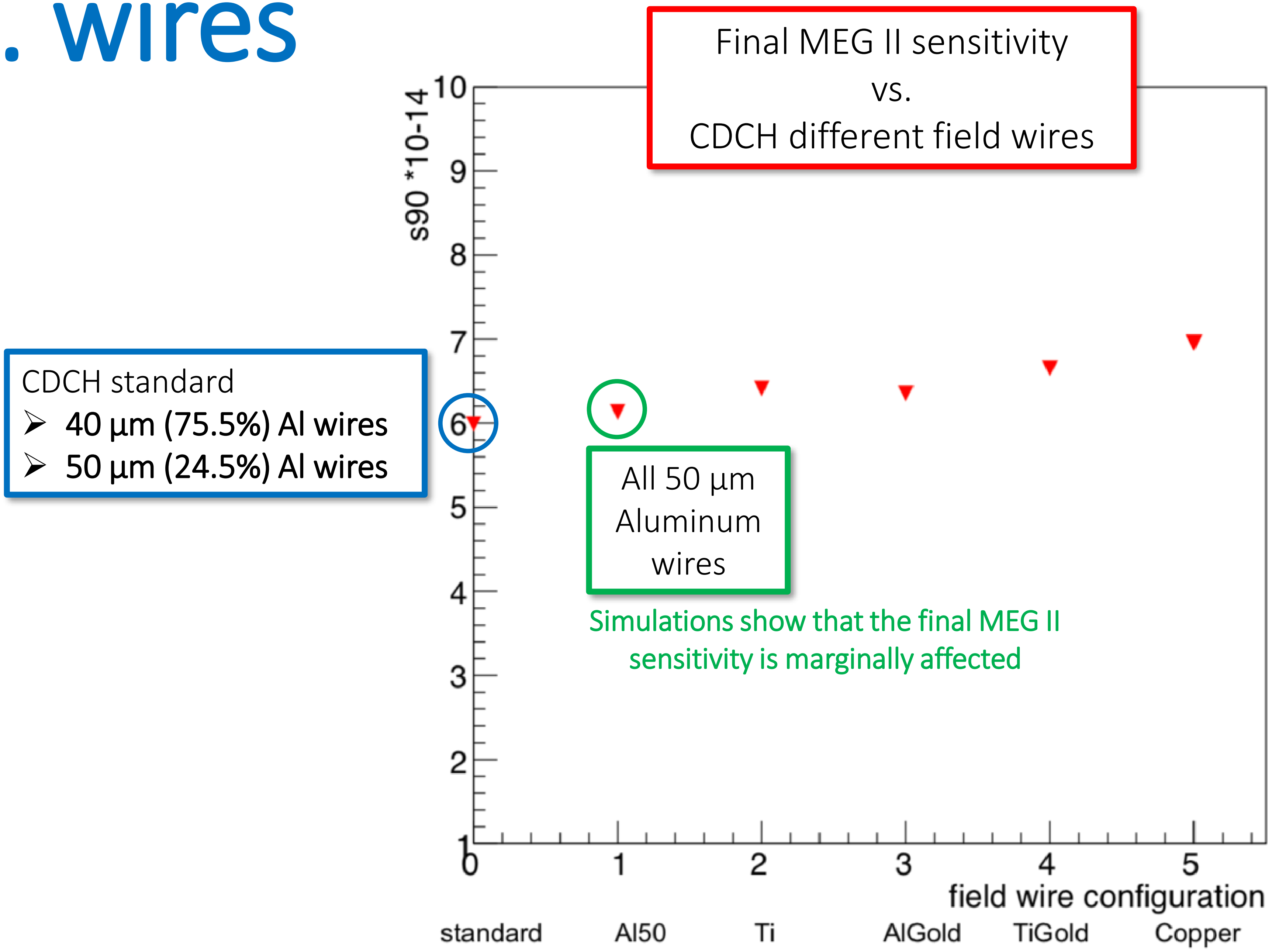
Uniform and thicker Silver coating

- No final drawing process
- No cracks on the surface

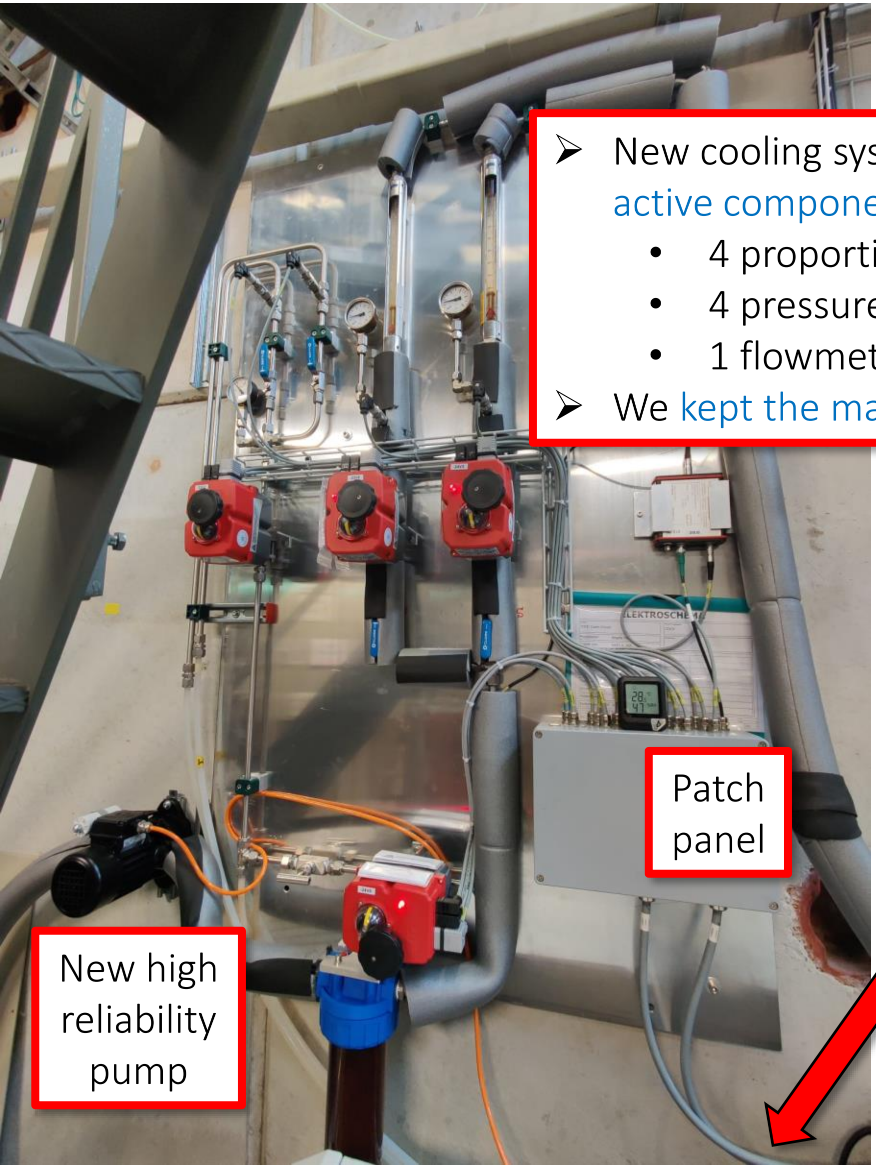
50 µm wire samples (1 meter each) immersed in distilled water

- Just a few isolated corrosion points
- A factor of 3 better than the best CDCH production batch

Sensitivity vs. wires



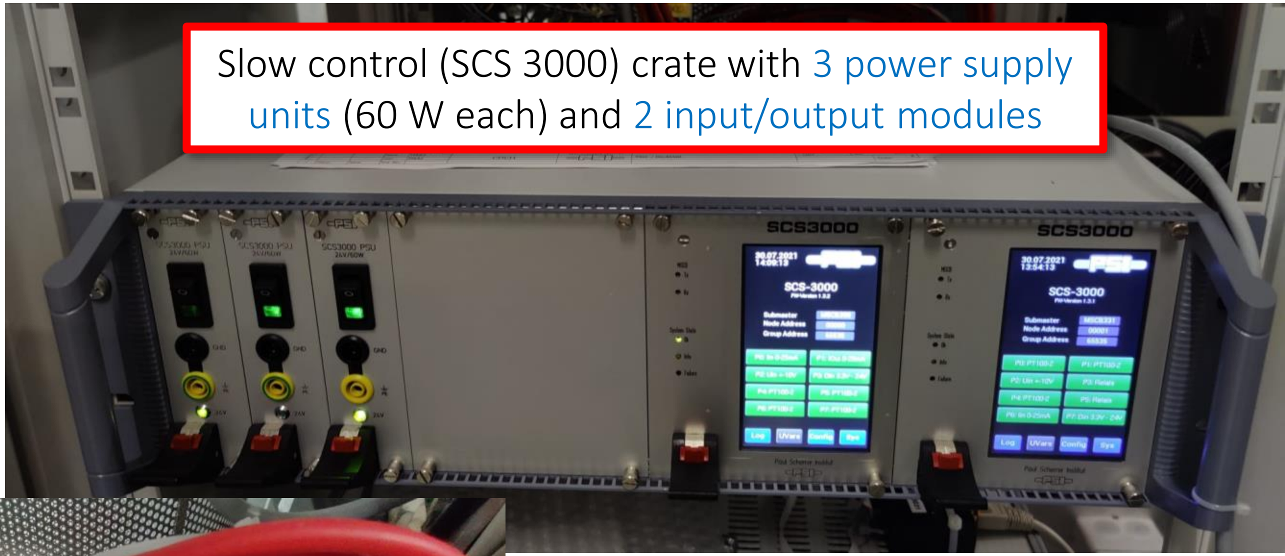
New cooling system



- New cooling system panel with active components
  - 4 proportional valves
  - 4 pressure sensors
  - 1 flowmeter
- We kept the manual components

Patch panel

New high reliability pump

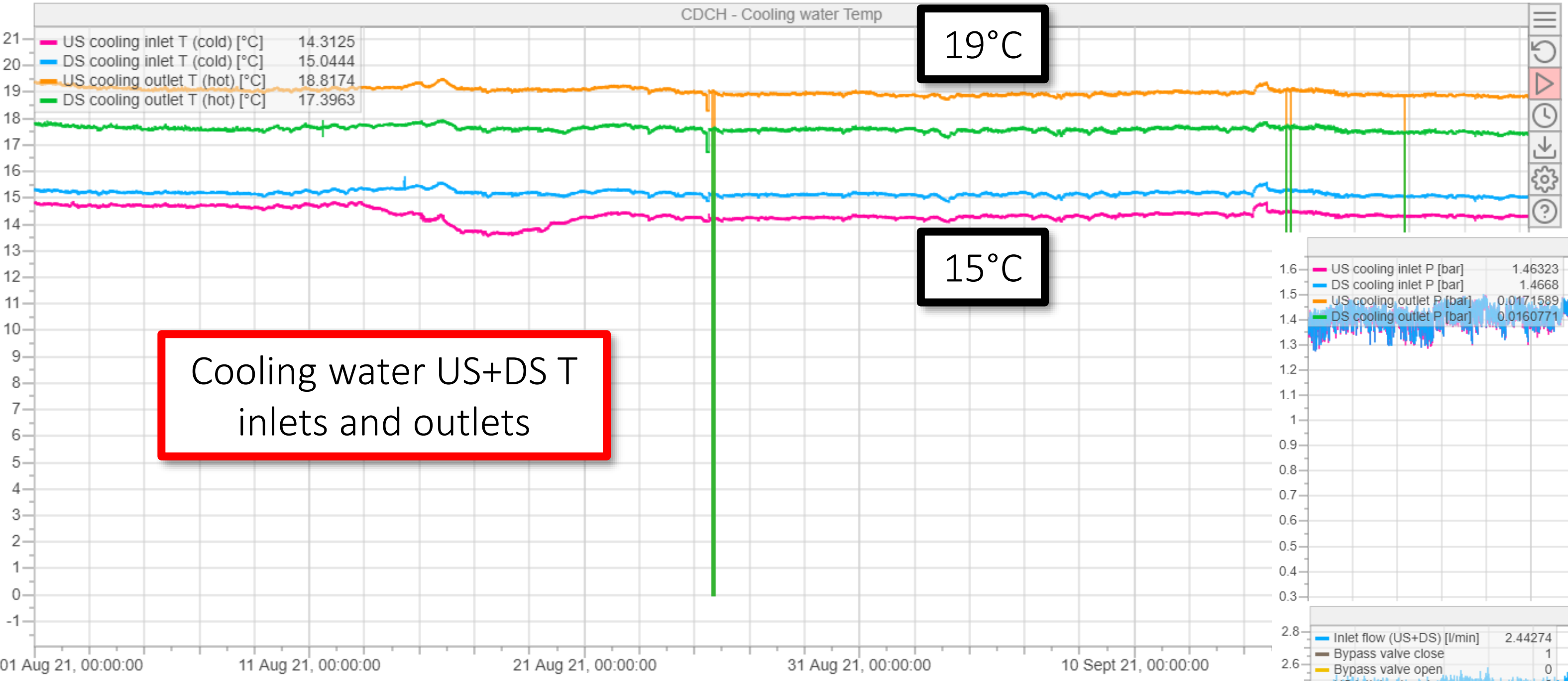


Slow control (SCS 3000) crate with 3 power supply units (60 W each) and 2 input/output modules

Terminal block

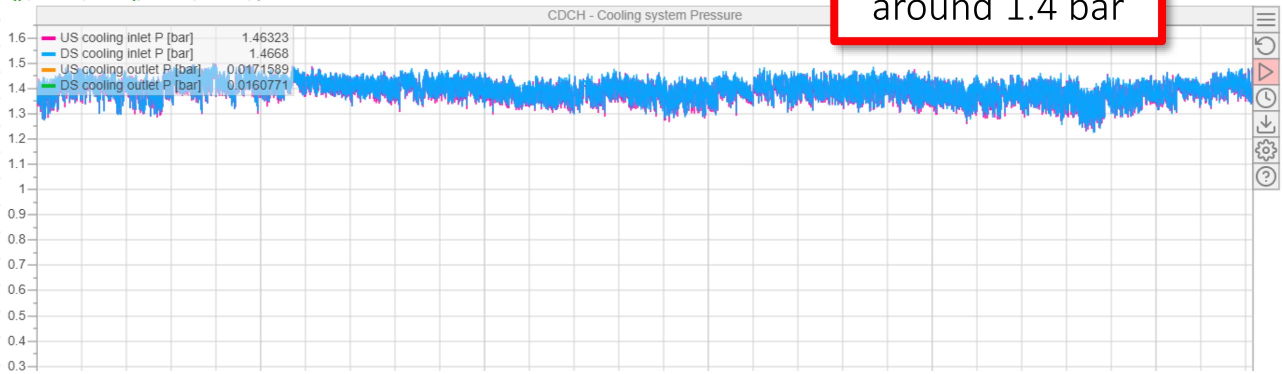
- New cooling system in operation since the end of May 2021
  - Full connections completed
  - Cooling system devices (input/output) + CDCH sensors (input)
- Valve control via software
- History OK

Cooling system stability 01/08-24/09



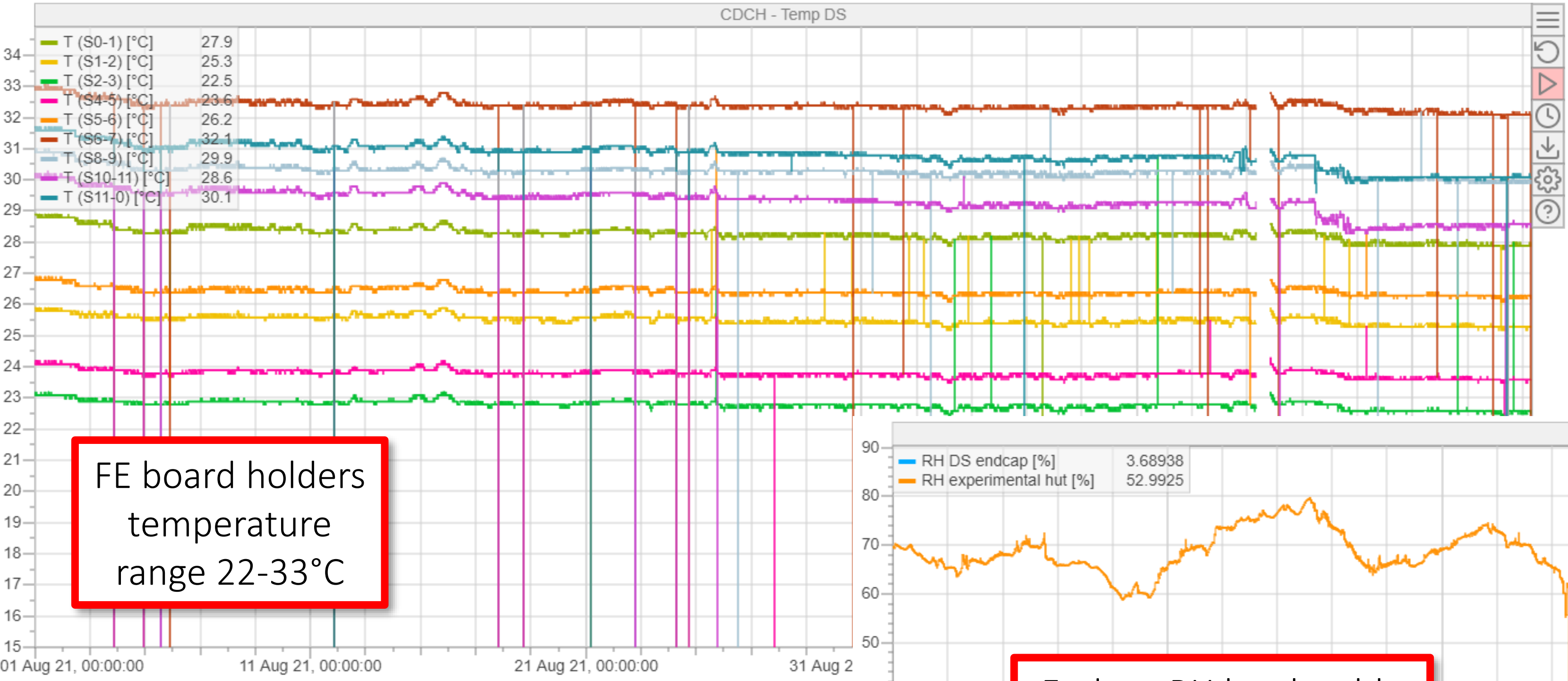
Cooling water US+DS T inlets and outlets

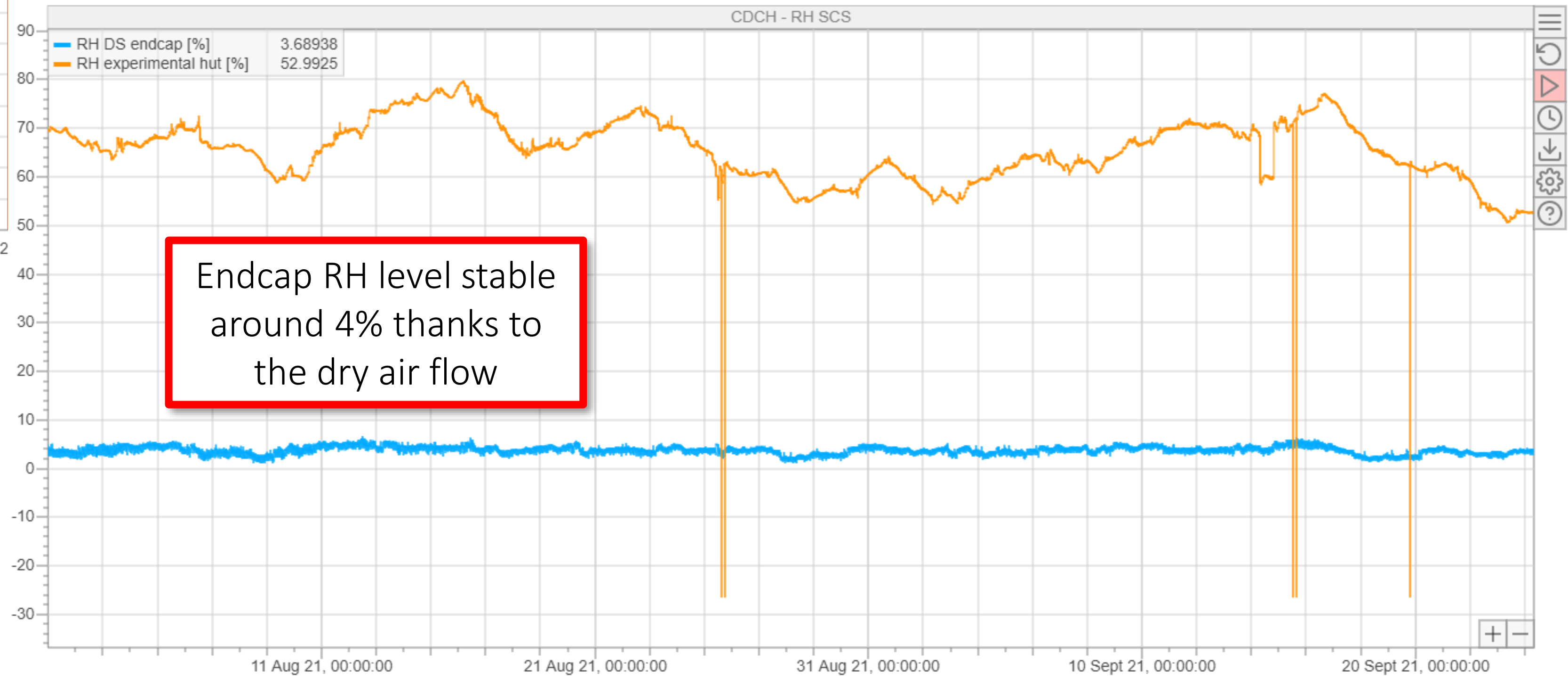
Cooling circuit pressure stable around 1.4 bar



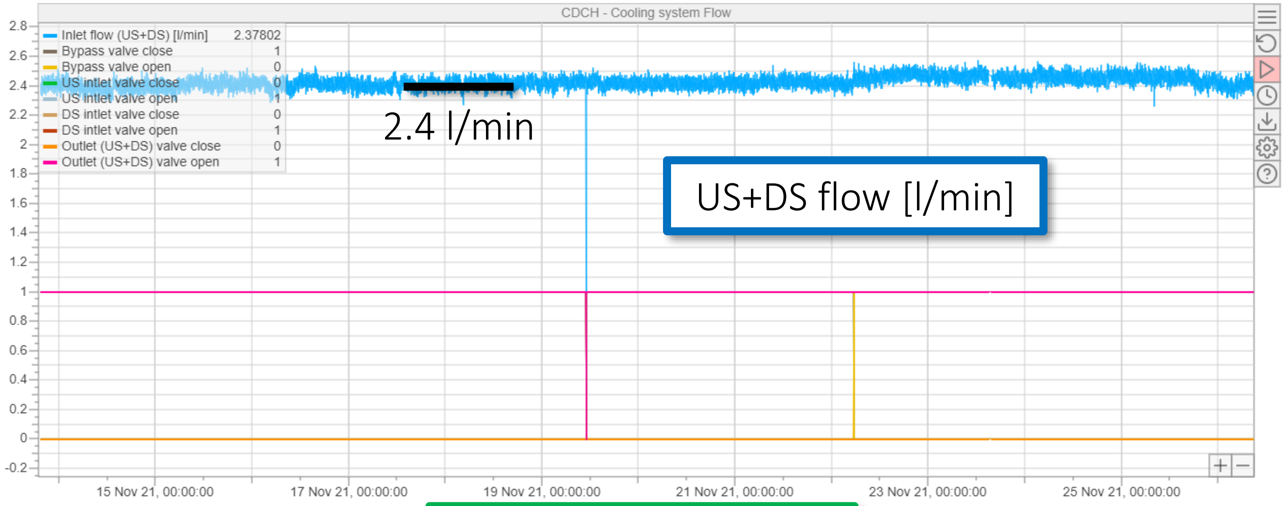
Cooling water US+DS flow stable around 2.4 l/min

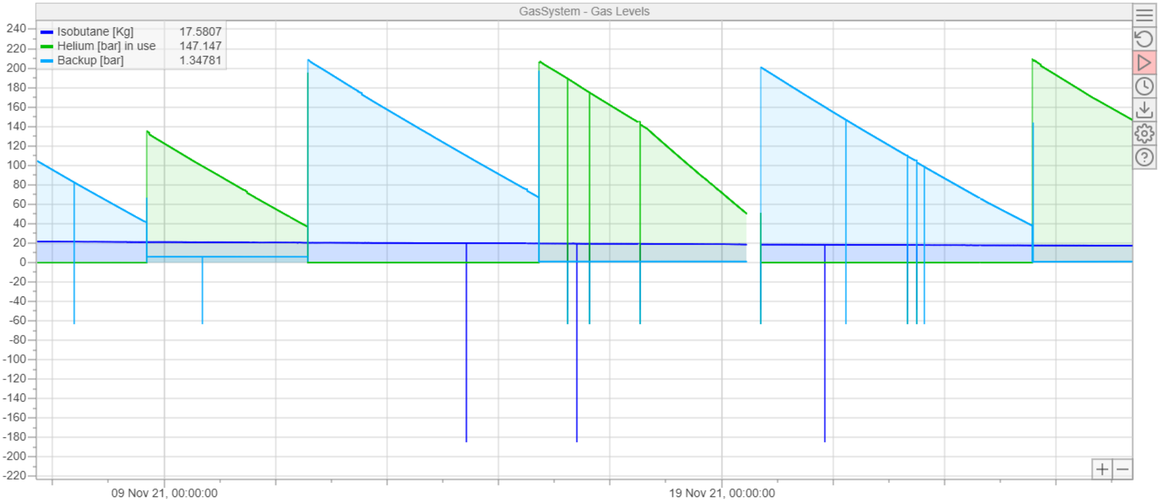
Endcap T-RH stability 01/08-24/09





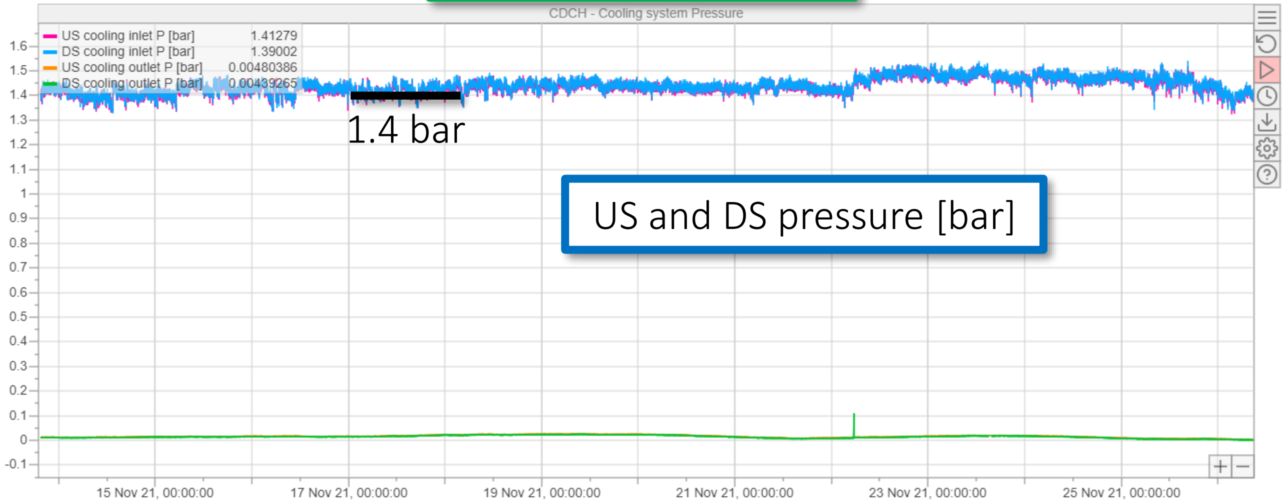
Gas and Cooling systems stability



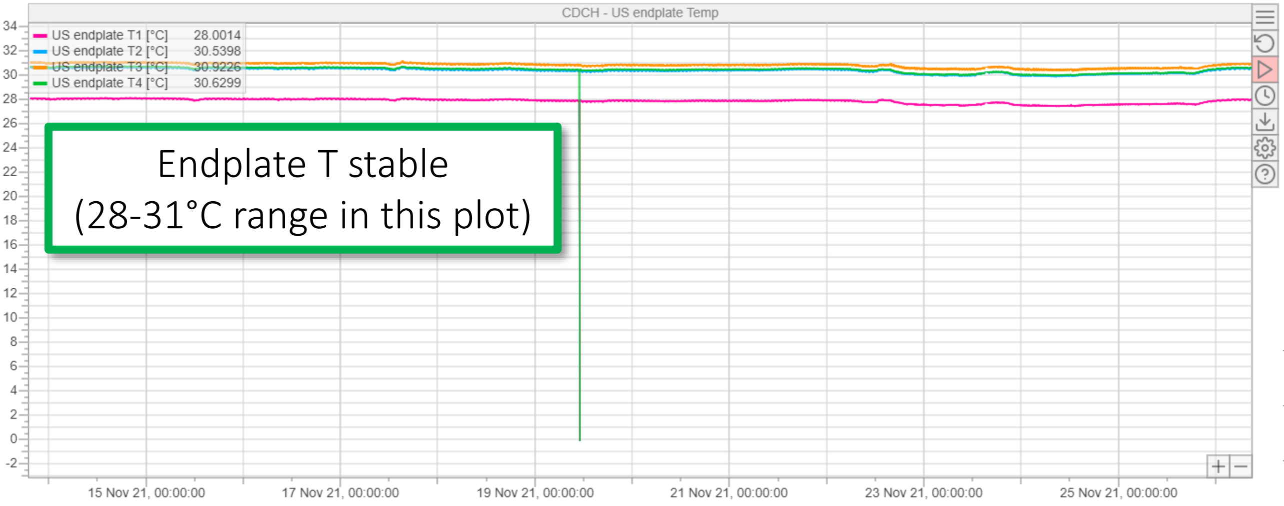


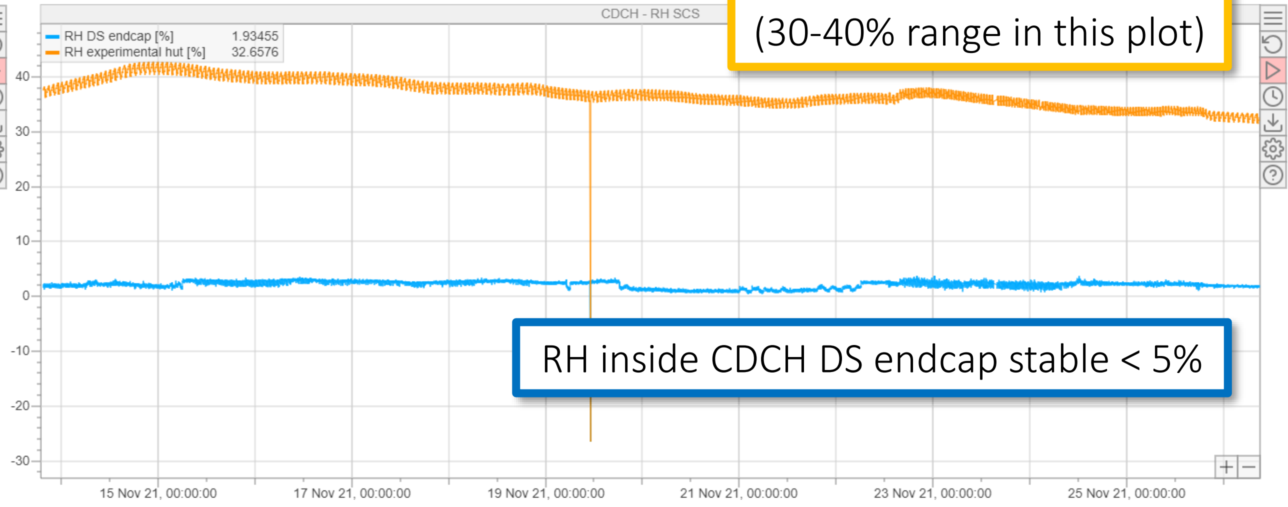
- ➢ Gas system stable
- ➢ He bottle exchanges continue
    - Thanks to the people involved

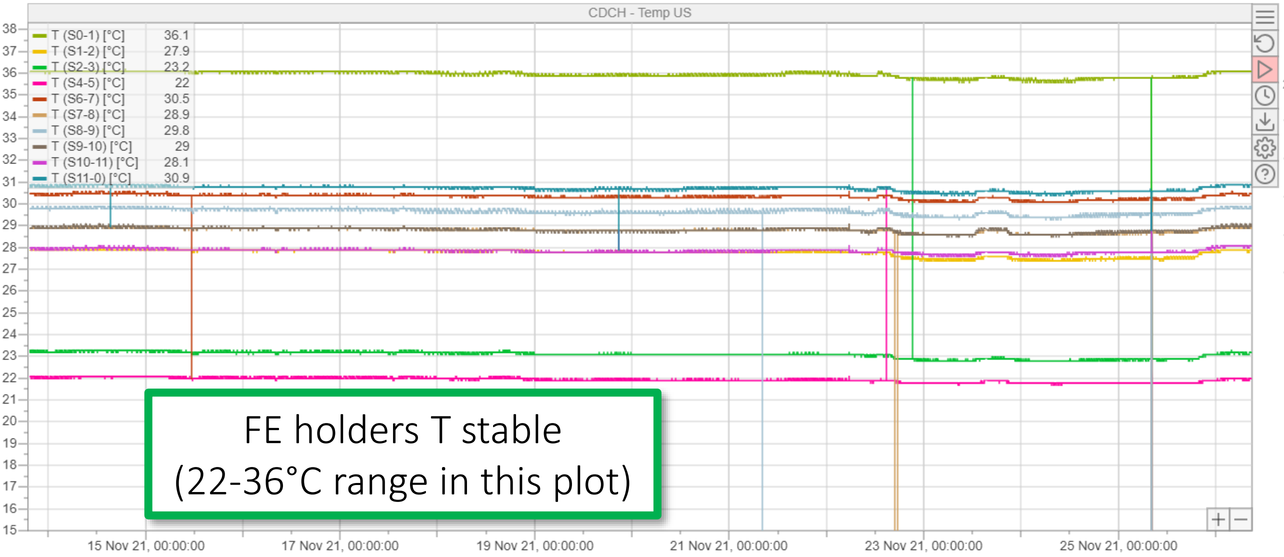
Cooling system stable

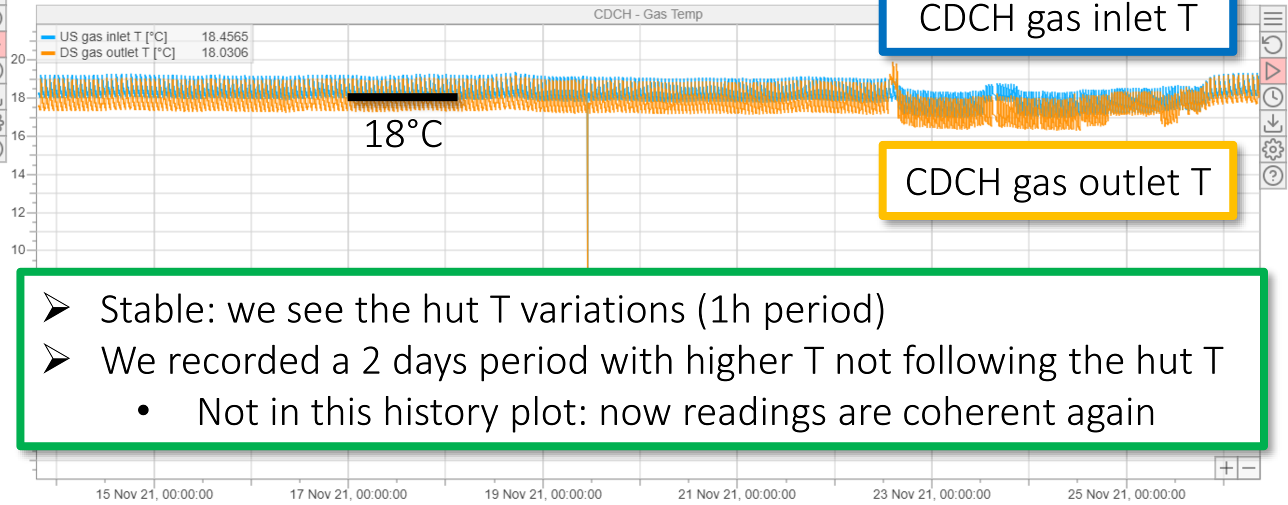


T and RH stability



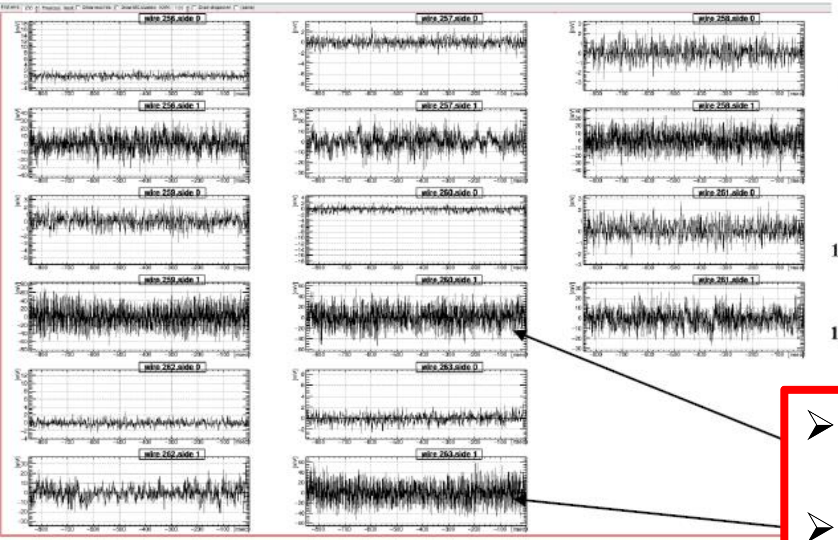


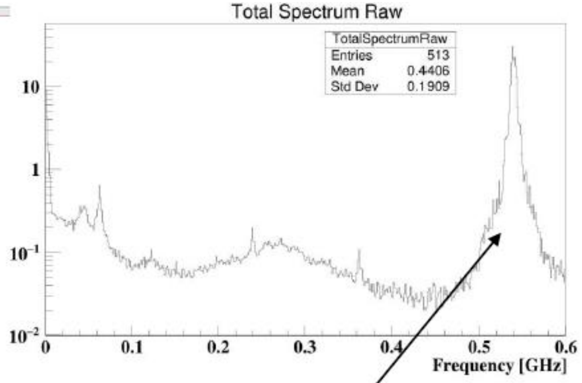




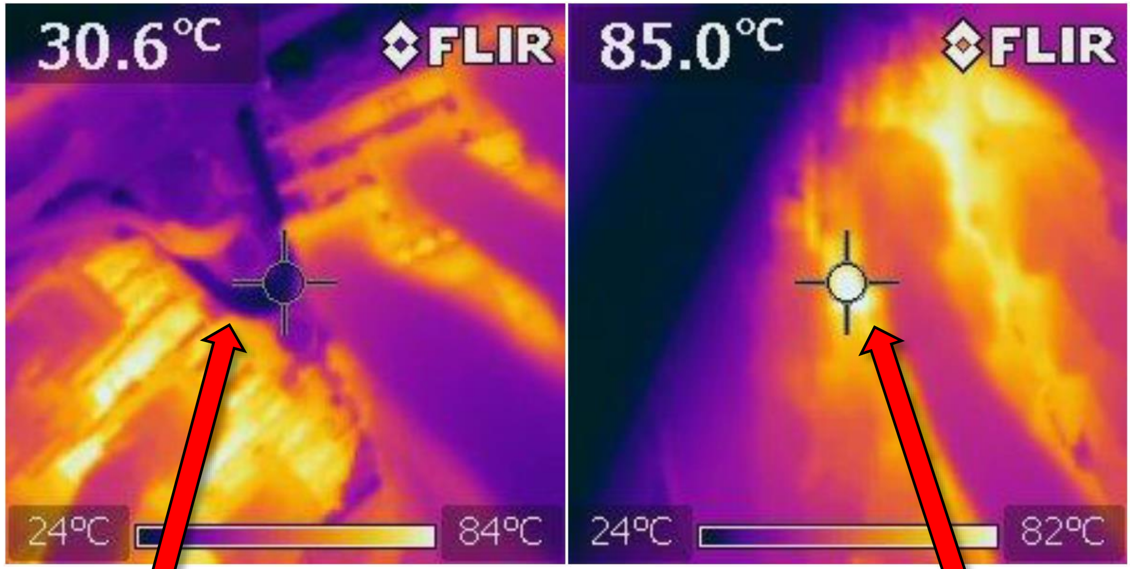
- Stable: we see the hut T variations (1h period)
- We recorded a 2 days period with higher T not following the hut T
  - Not in this history plot: now readings are coherent again

First LV power ON of the whole CDCH





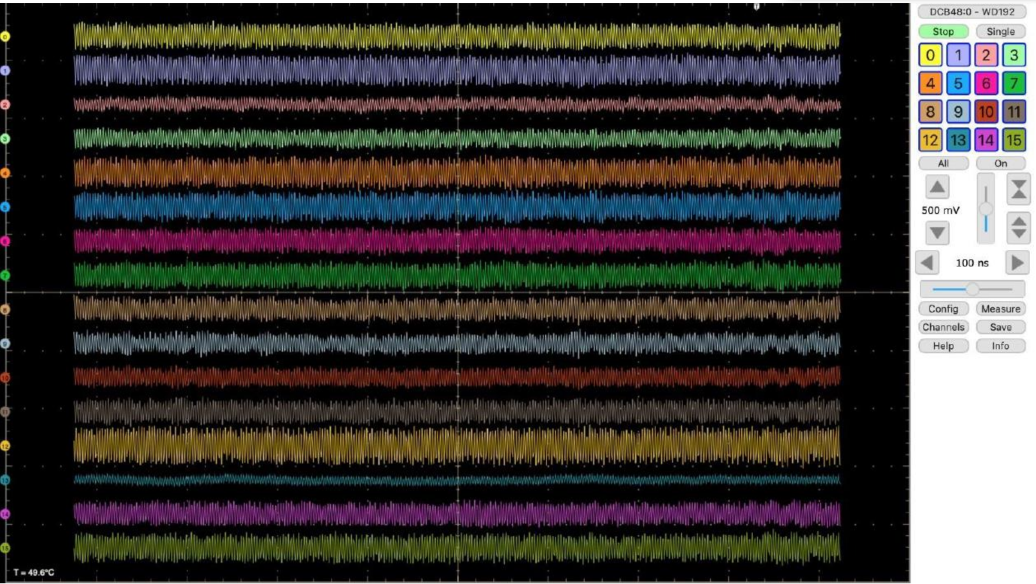
- High frequency burst noise from pedestal runs
- WDS view below



Cooling pipe embedded in the FE holder

Thermographic pictures from inside the endcap

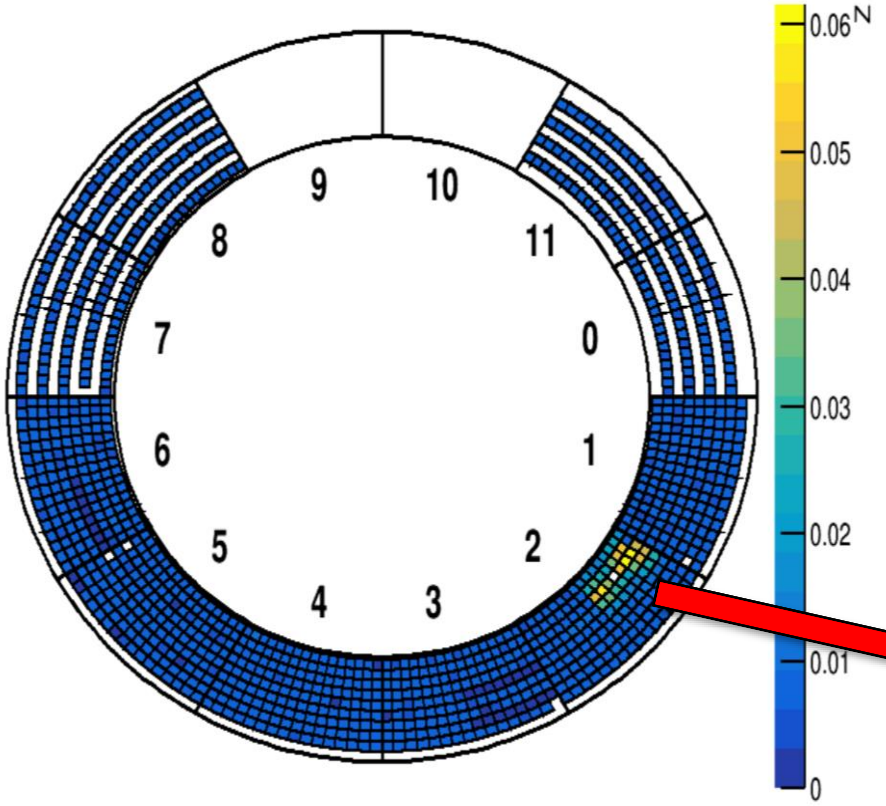
FE board region



- HF noise observed in several channels
- The onset occurs a few minutes after the LV power ON before reaching the equilibrium temperature
- Generated by a few FE boards and picked up everywhere

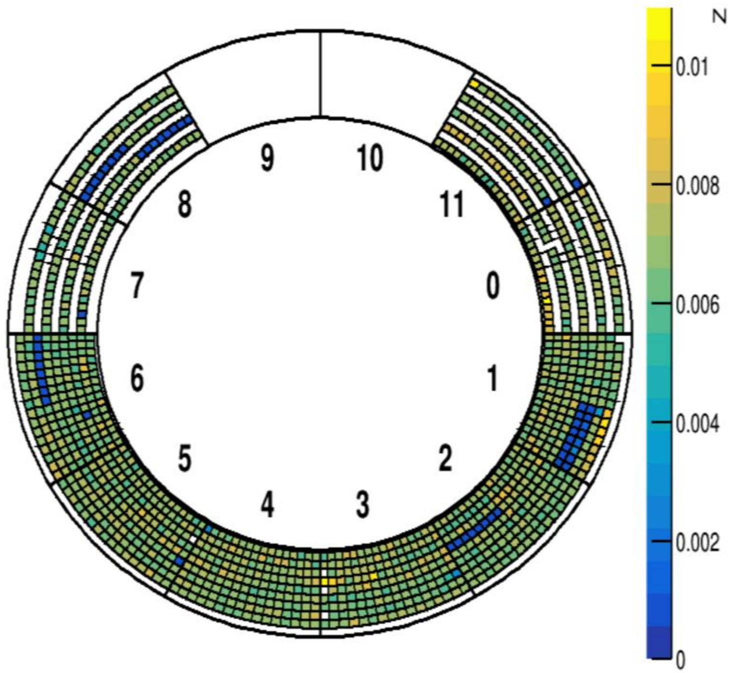
Search for the noisy boards

Downstream

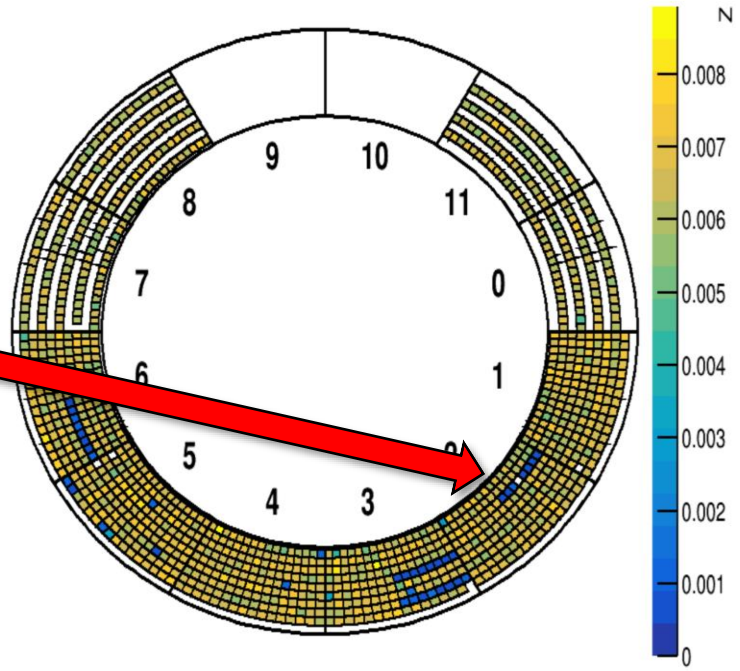


- US and DS views of the FE boards disconnected on a single side
  - 6 US
  - 4 DS
- Sometimes only one wire is masked out in the analyzer

Upstream



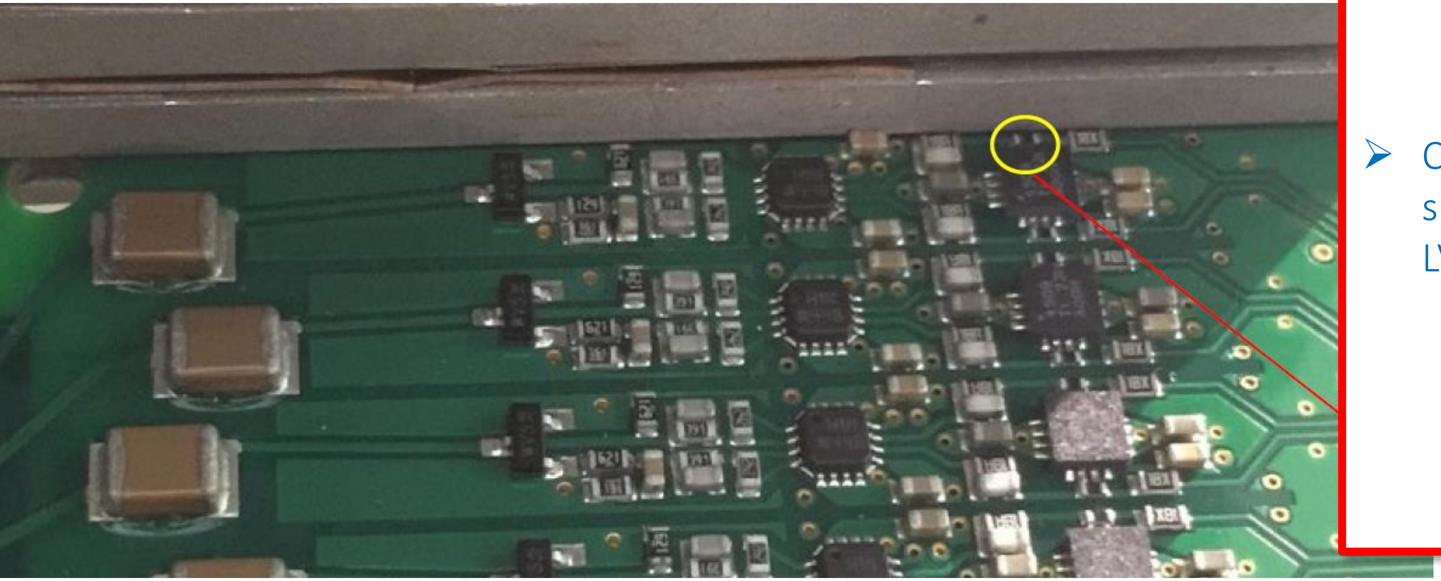
Downstream

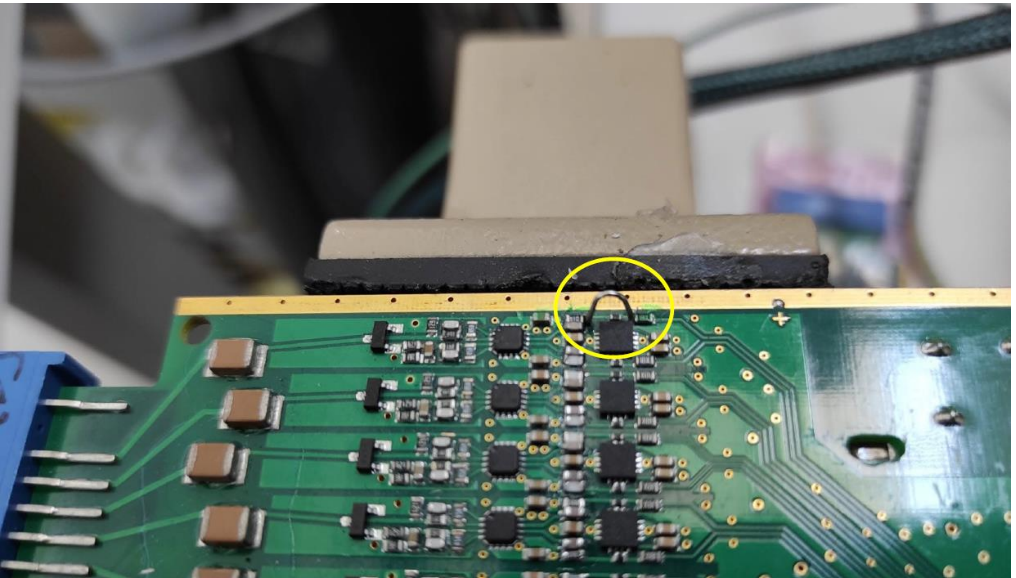


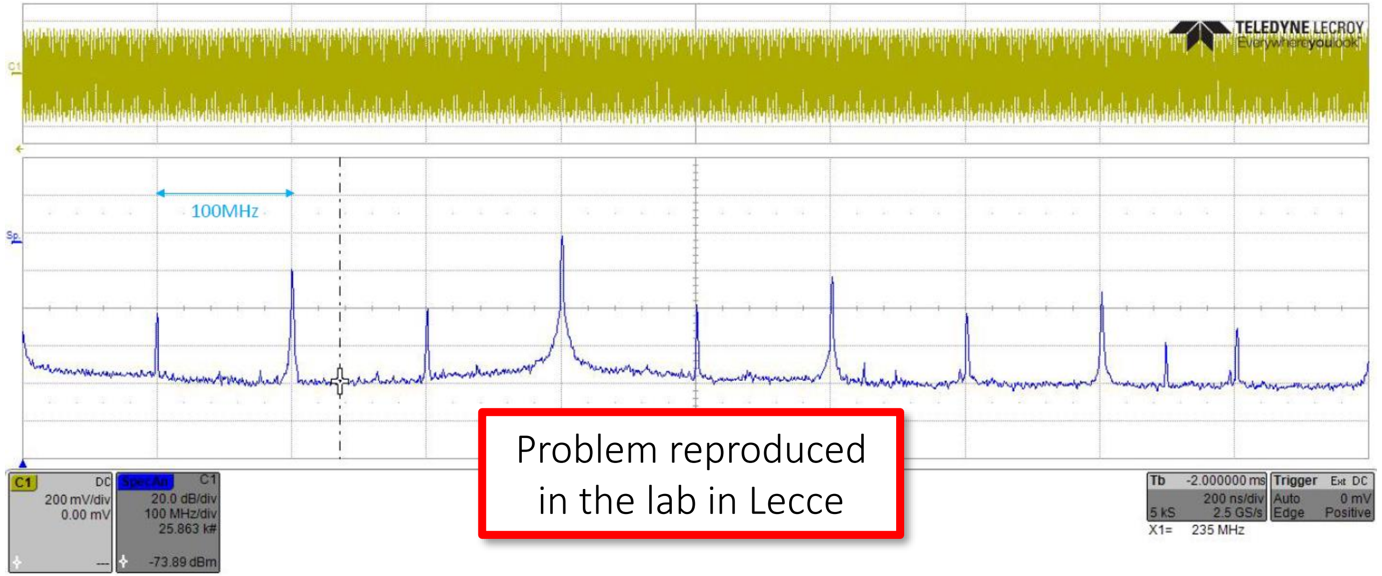
Example of noisy FE board search
- You can see a hotspot in the RMS 2D plot in the CDCH analyzer
- If you disconnect the signal cable of the involved board from the WDB a good noise level is recovered

HF noise investigation

- ➢ One of the feedback resistor of the second amplification stage can touch the FE holder
  - If this component is shorted the amplifier feedback is unbalanced and the amplifier start to oscillate
  - The oscillation propagates to all the channels of the involved board
- ➢ Clearance left during the FE board mounting but during the signal cabling and likely with the higher temperatures at the LV power ON the board can slightly move
  - Signal cabling with CDCH already inside COBRA
  - Insulation (insulating varnish) and clearance of lateral components is not enough
  - This will be solved in CDCH2 with a re-design of the FE holders



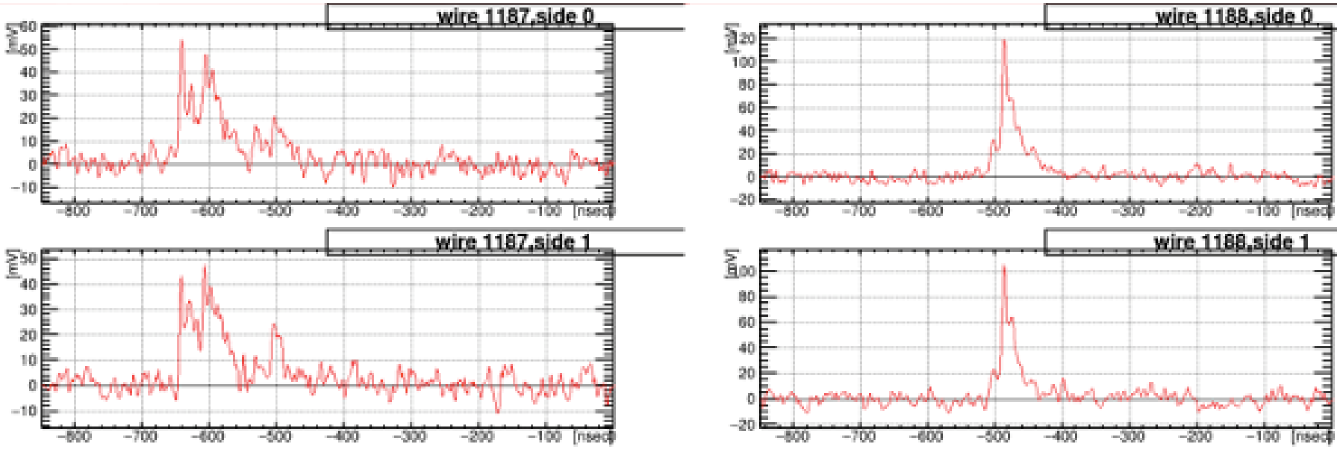




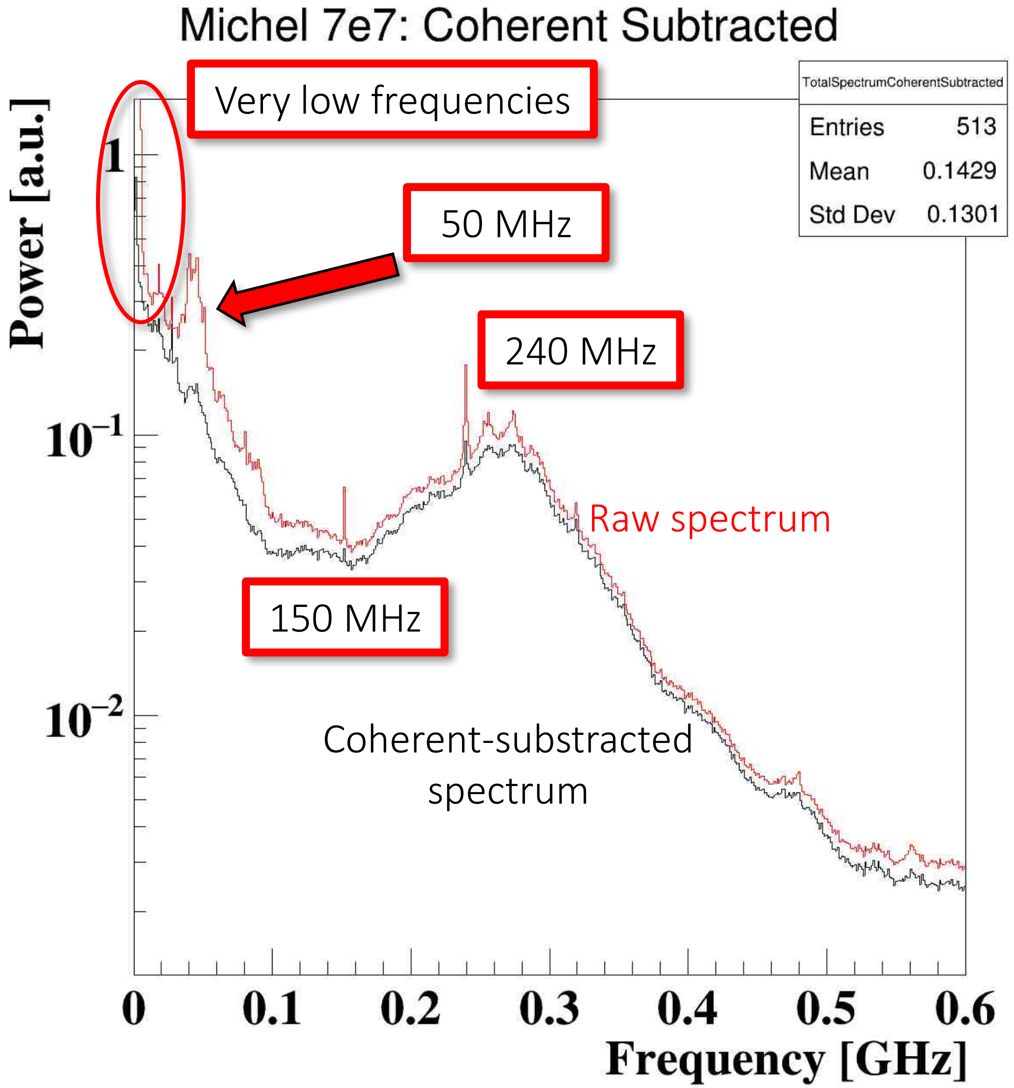
Problem reproduced in the lab in Lecce

Signal check + noise spectrum from data

Coherent Subtracted + DFT HFC + MA



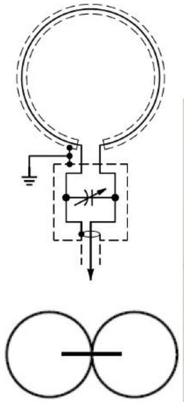
- Channels have normally voltage RMS 6-9 mV
- Coherent noise contribution clearly visible
  - Largest contributions at very low frequencies and around 50 MHz
- Investigations on the origin of the coherent component performed

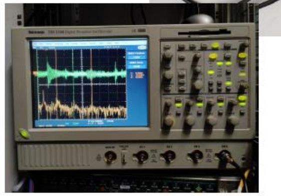


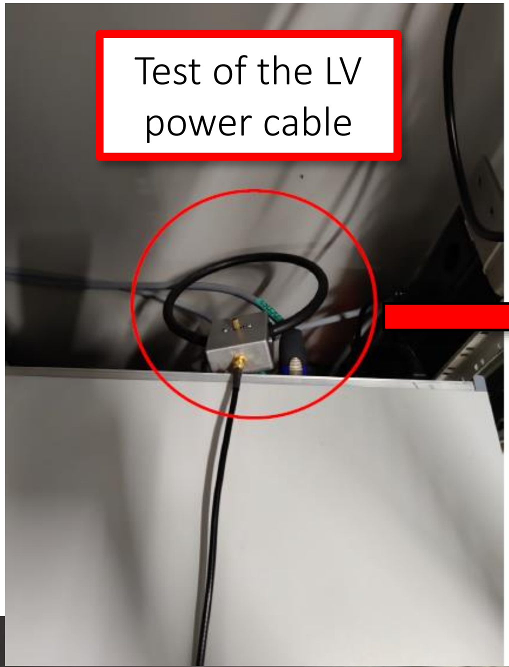
First noise investigation inside the area

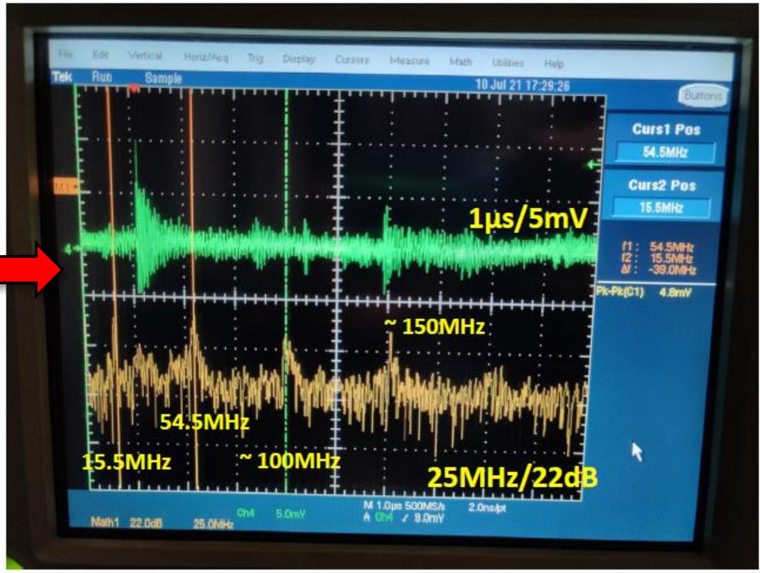
The probe

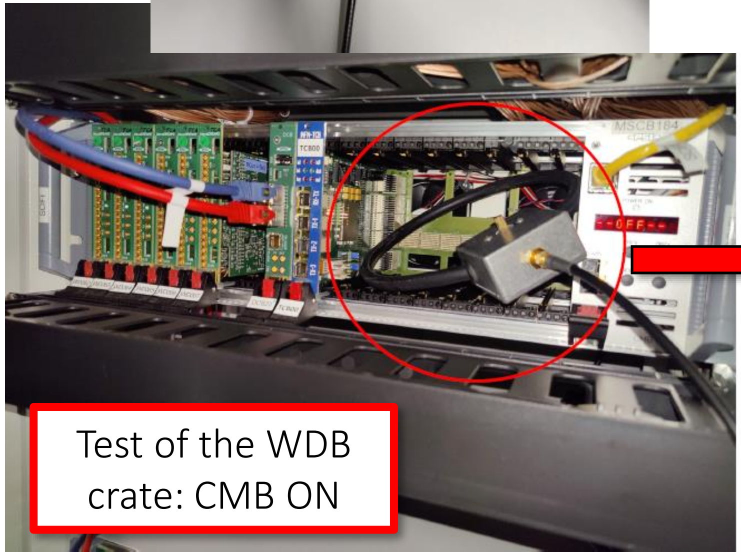
- To probe the e.m. field a loop antenna has been used. The antenna can be tuned by using a shielded capacitor. Diameter of the loop is about 17cm
- The pattern of the loop is balanced to indicate the direction toward the e.m. source
- The antenna is connected to an oscilloscope (Tek TDS5104 1GHz/5GSPS) though an RG58 cable
- All the measurement has been done with the WD crates off

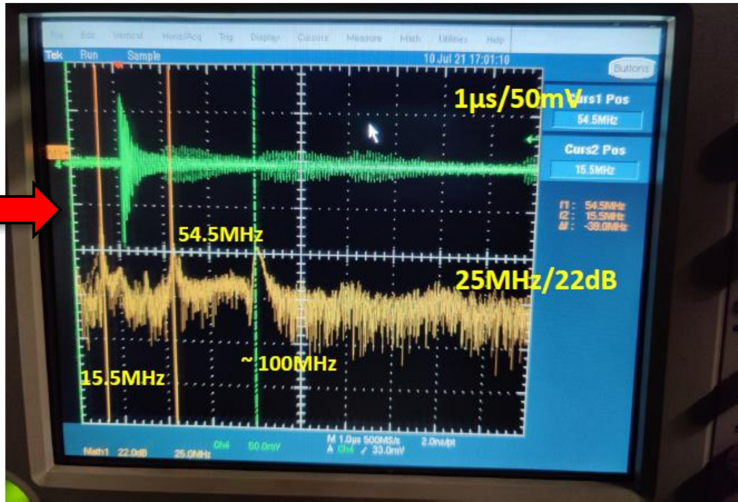








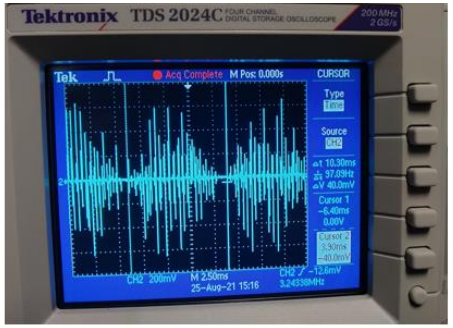




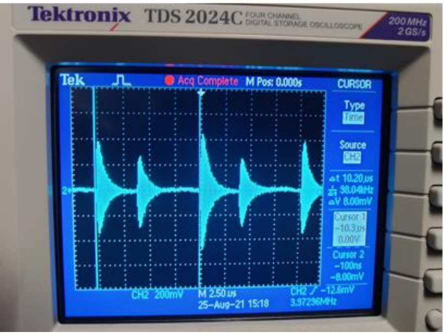
- ➢ CMB with old DC-DC converter
- ➢ The ≈15 MHz noise comes from the CDCH LV power supply modules
- ➢ One possible source of the ≈50 MHz noise could be the accelerator
  - Comparison between pedestal data with the accelerator ON and OFF could help to understand

More noise investigation inside the area

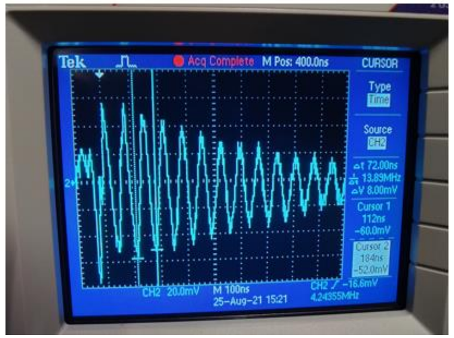
We used the noise probe by Marco P. and Alessandro C. to check the noise source at the LV module.



Time scale = 2.5 ms
Voltage scale = 200 mV
f = 100 Hz



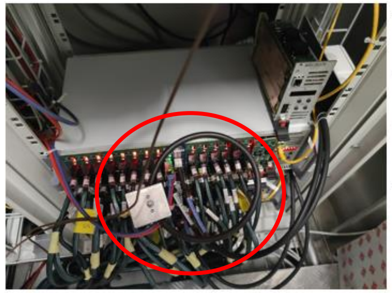
Time scale = 2.5 μs
Voltage scale = 200 mV
f = 100 kHz



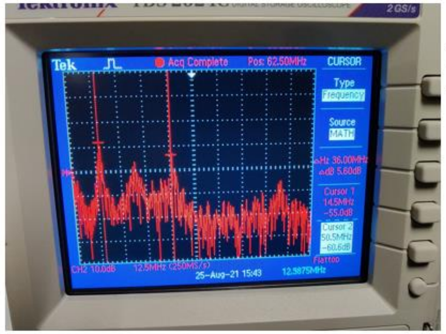
Time scale = 100 ns
Voltage scale = 20 mV
f = 14 MHz

- ➢ Test of the LV power supply module
- ➢ Found noise contributions at different time and amplitude scales

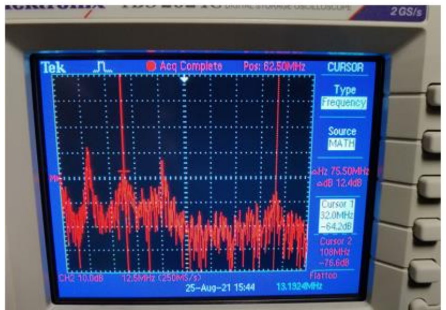
- ➢ Test of the WDB crate
- ➢ CMB with new DC-DC converter
- ➢ Noise contributions found with the previous test confirmed
- ➢ The ferrite beads clamped on the LV power cable have no effect
- ➢ Effect only clamping the ferrites on a signal cable
  - Signal? 432 signal cables…



We checked the noise source at the WD crate level.
The test was performed using the new CMB board with the low noise DC-DC converter.



Frequency scale = 12.5 MHz
Amplitude scale = 10 dB
f1 = 14.5 MHz
f2 = 50.5 MHz



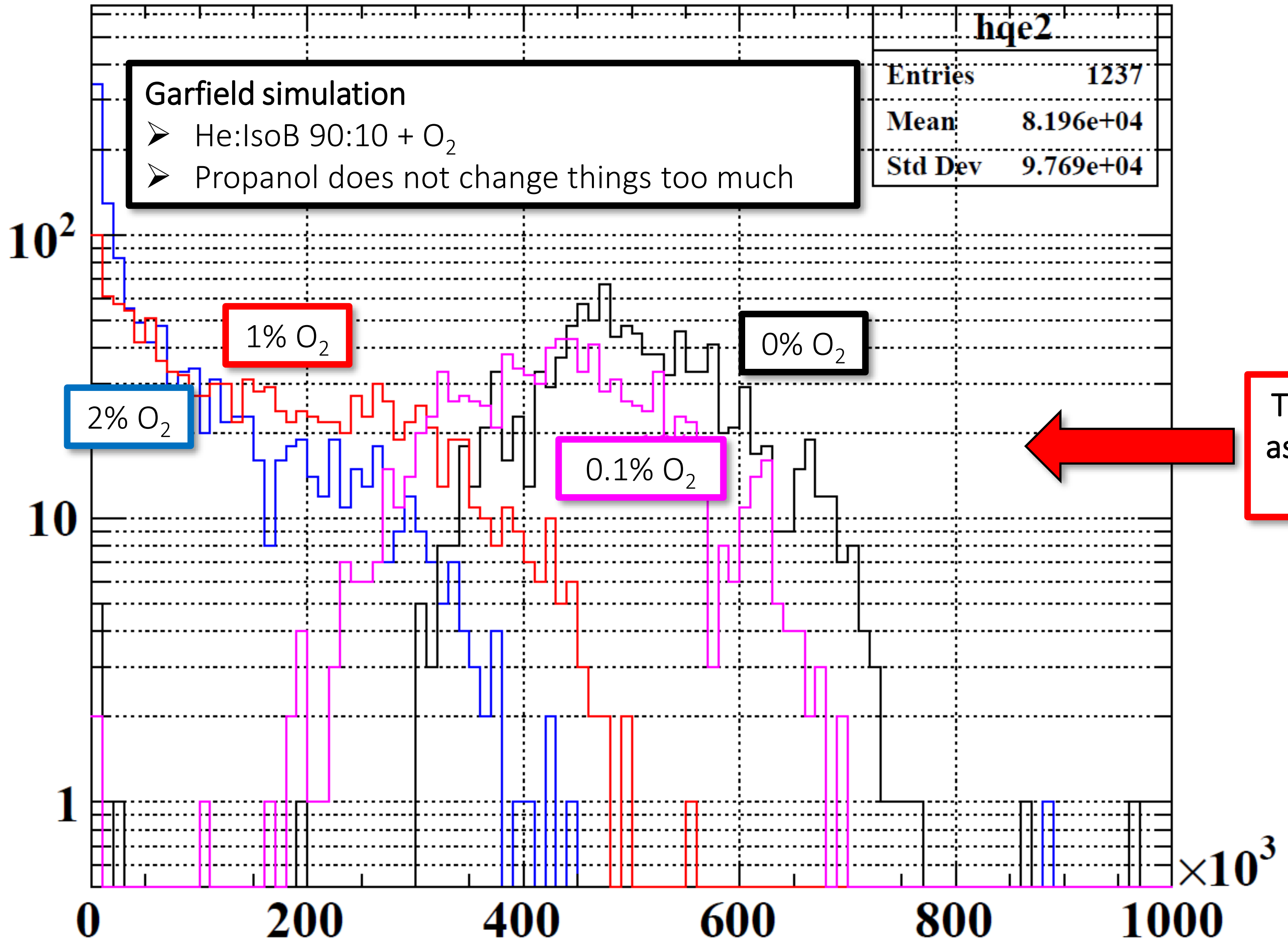
Frequency scale = 12.5 MHz
Amplitude scale = 10 dB
f1 = 32 MHz
f2 =108 MHz

Test 0

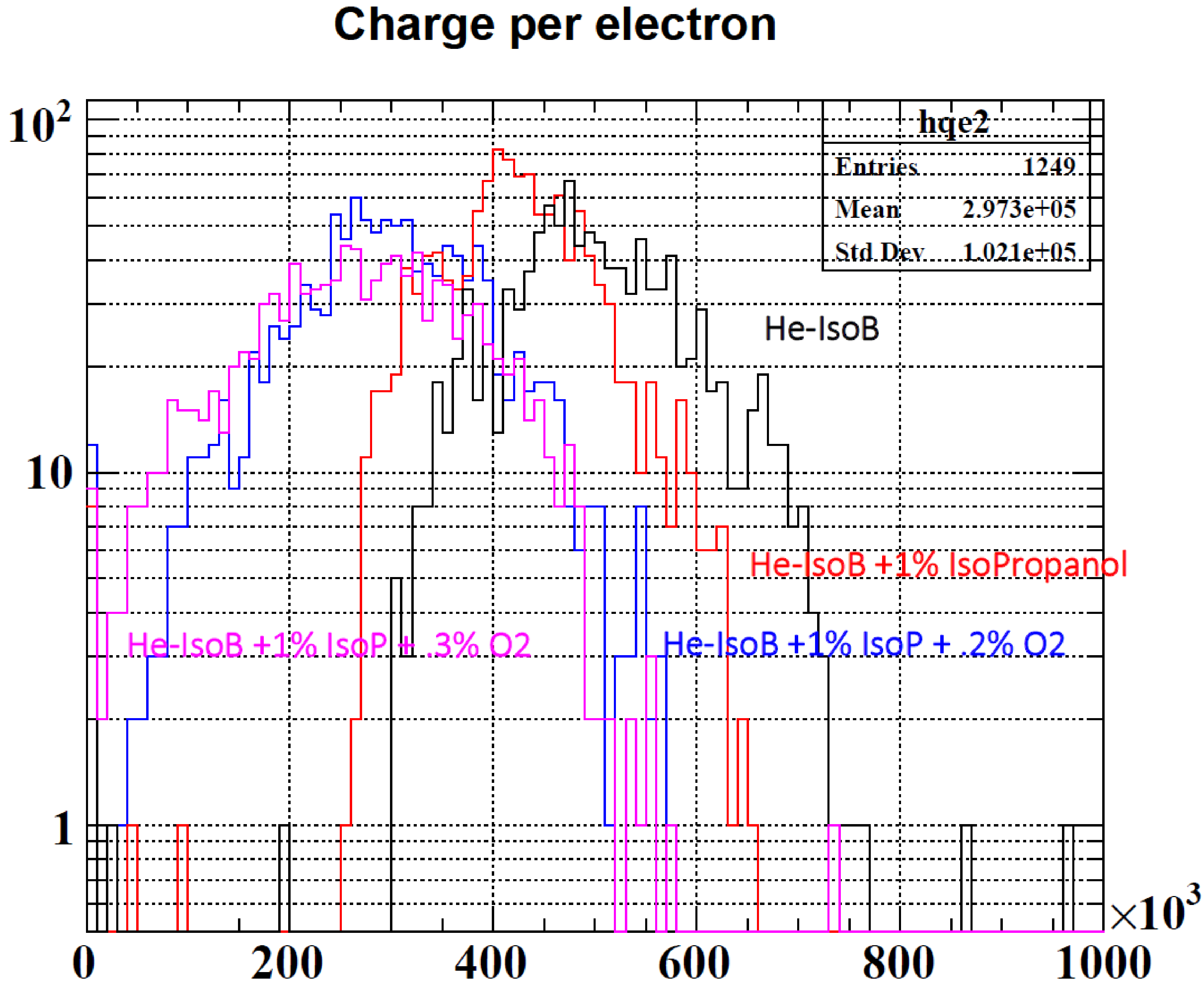
- Ferrite components on LV cable
- Noise probe on WD crate

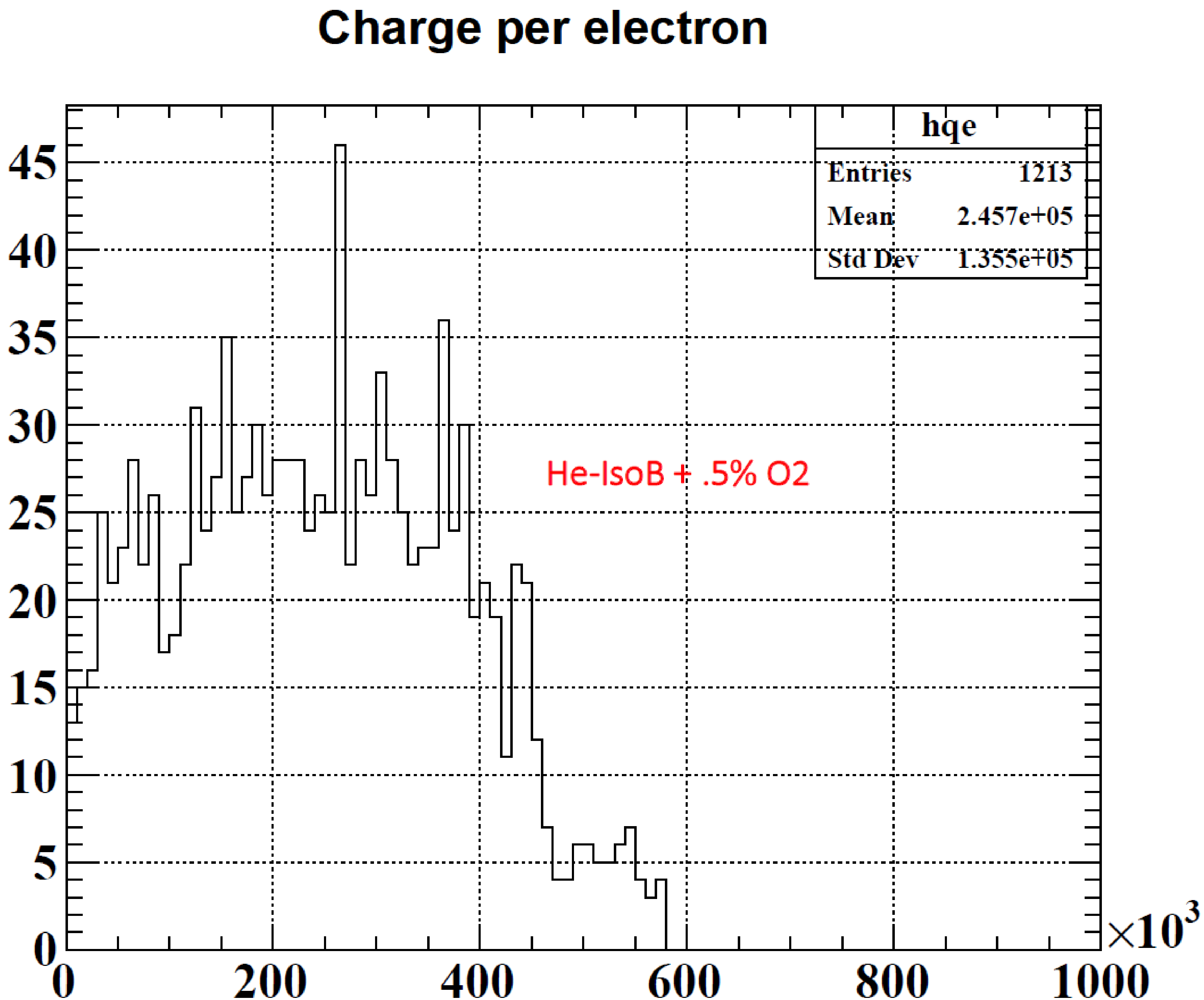
No effect.

Charge per electron vs. O_2 content



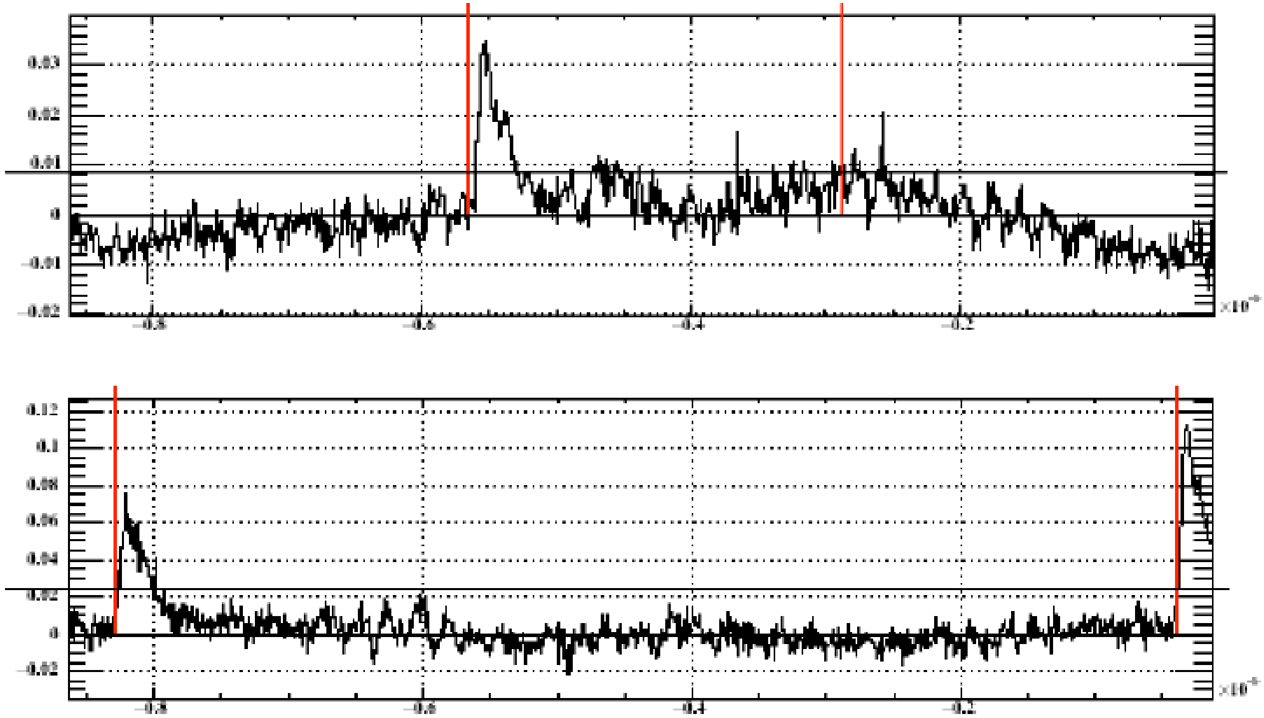
The reason to diminish as much as possible the Oxygen content


Charge per electron
hqe2
Entries 1249
Mean 2.973e+05
Std Dev 1.021e+05
He-IsoB
He-IsoB +1% IsoPropanol
He-IsoB +1% IsoP + .3% O2
He-IsoB +1% IsoP + .2% O2
10^2
10
1
0
200
400
600
800
1000
$\times10^3$


Charge per electron
hqe
Entries 1213
Mean 2.457e+05
Std Dev 1.355e+05
He-IsoB + .5% O2
0
5
10
15
20
25
30
35
40
45
0
200
400
600
800
1000
×10^3

Impact of O_2 from 2020 data

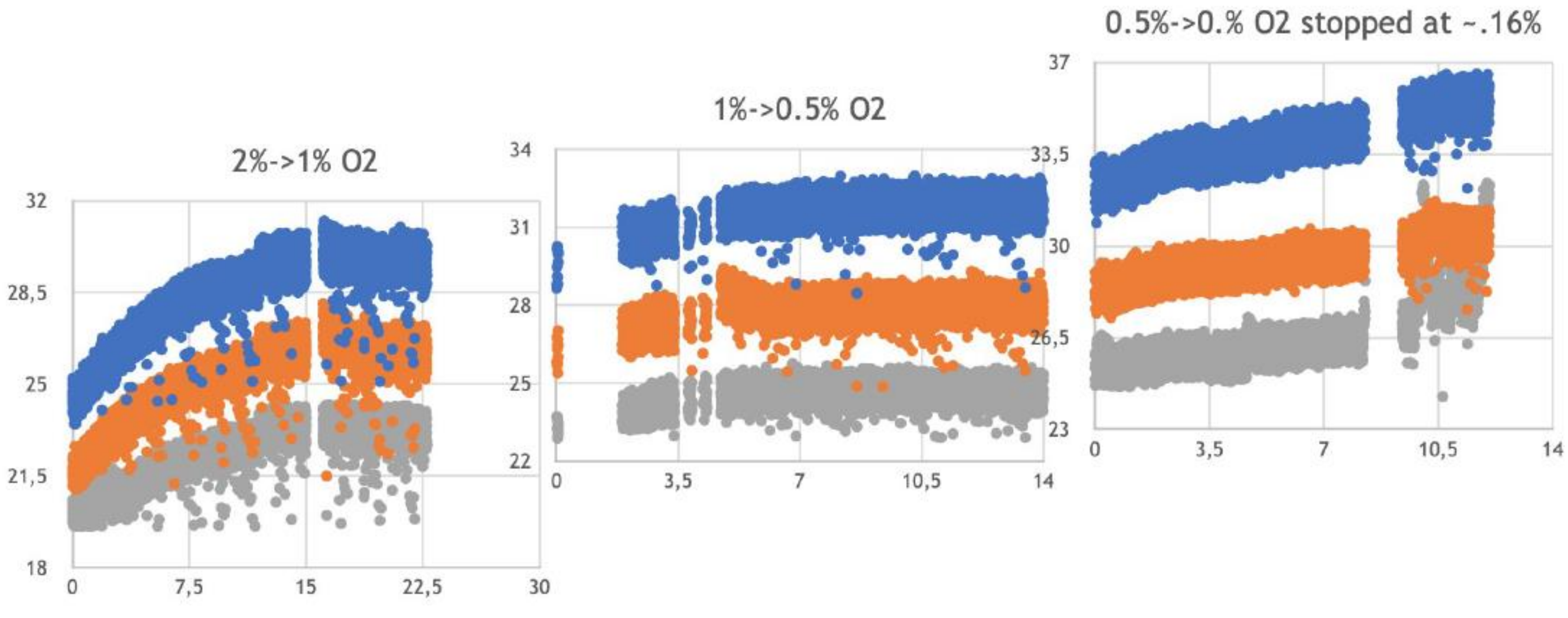
Muon beam data, 2% O_2 + 1% isopropyl alcohol



- We do not observe evident pathologies looking at the raw waveforms with the addition of O_2

Impact of O_2 from 2020 data

- Effect (similar in magnitude) observed on currents drawn by the HV power supplies (16 wires per channel)



Expected Current ~ 5 x 10^5 x 16ch x 1.3 Mhz/ch x 15e ~ 25 μA

Gas gain

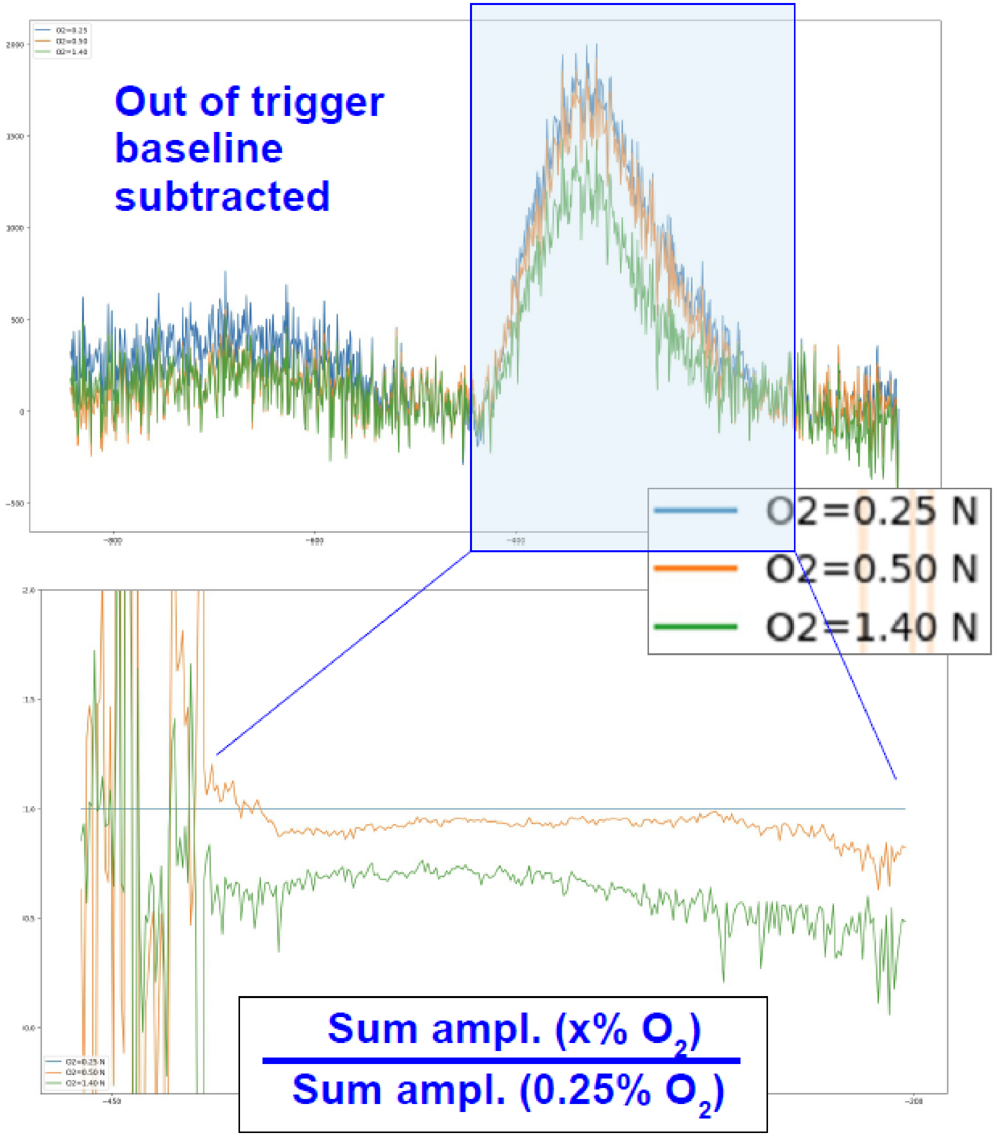
Hit rate

#electrons per hit

Impact of O_2 from 2020 data

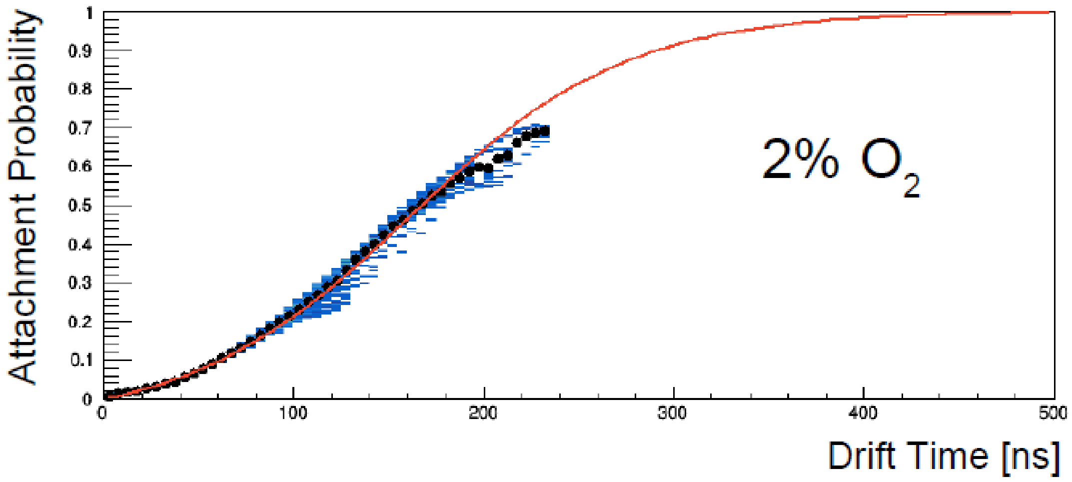
Muon beam data
(1% isopropyl alcohol)

- Summing up many waveforms, with the addition of O_2 we observe a decrease of the size of hits
  - 20-30% loss with 1-2% O_2
- The decrease is larger at larger hit times, as expected from attachment



Impact of O_2 from 2020 data

- We modeled the attachment in the MC according to the expectations from GARFIELD as a function of the drift time



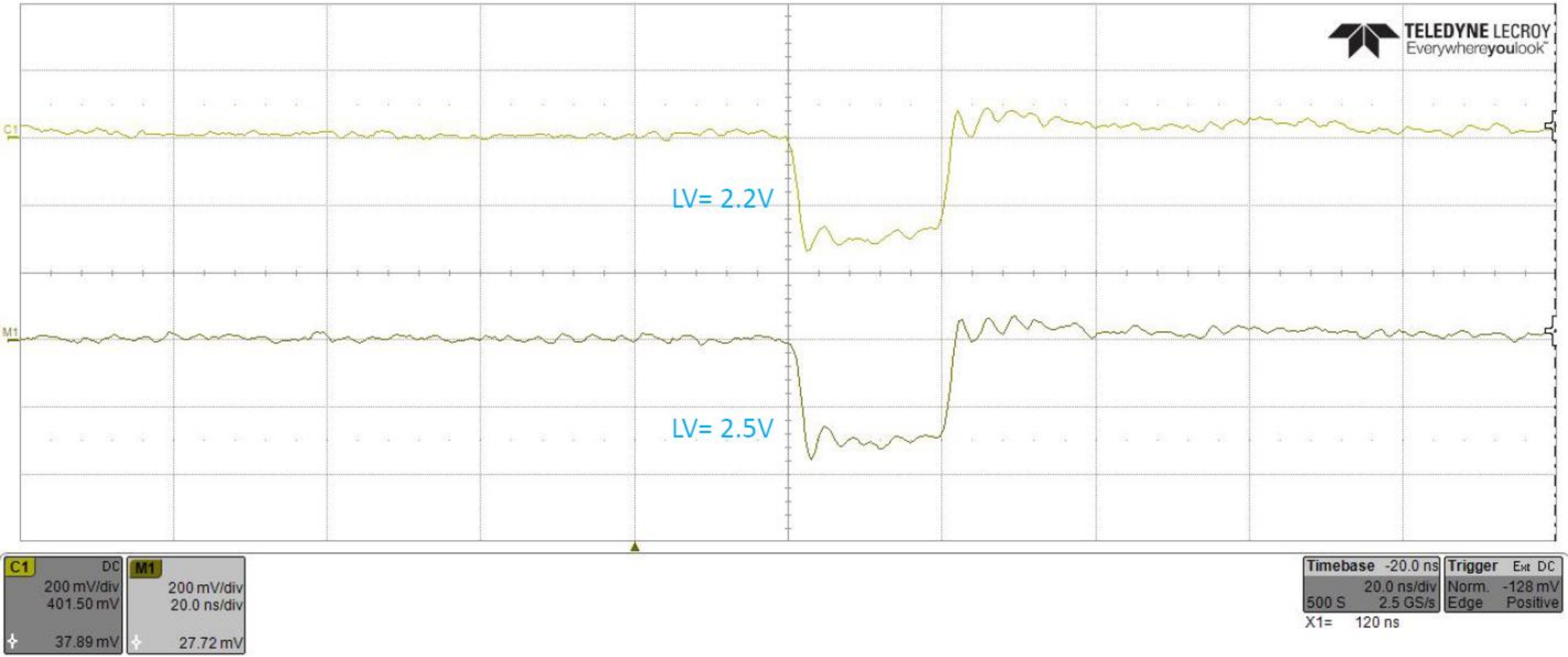
GARFIELD with 1/6 suppression of attachment

O_2 conc. [%]	Positron Efficiency [%] ± 1.0%	Momentum Resolution [keV] ± 3 keV	Angular Resolution [mrad] ± 0.15 mrad
0	64.6	96	6.7/6.7
0.5	62.5	95	6.7/6.2
1	62.7	94	6.5/6.4
2	58.2	97	6.6/6.3

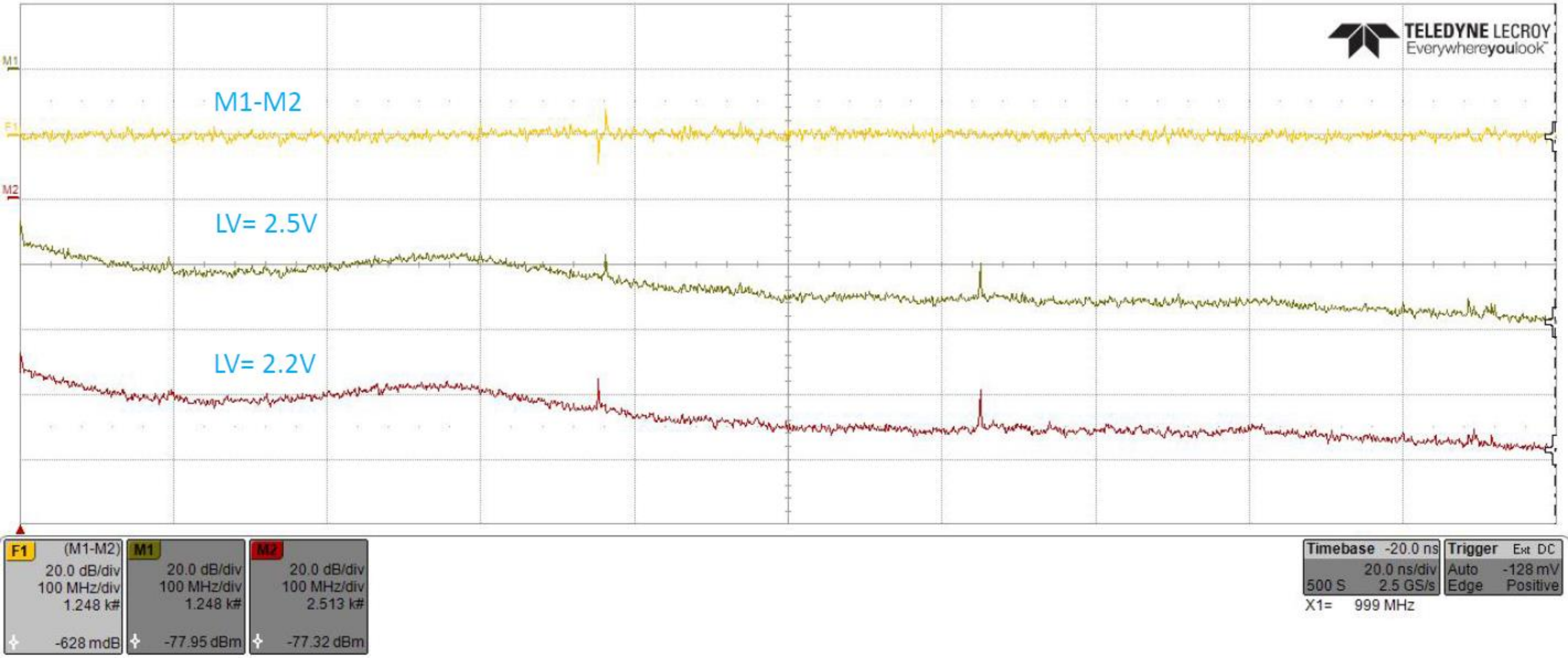
Impact of O_2 from 2020 data

- We have some preliminary indication that the effect of O_2 is overestimated by GARFIELD
- Our measurements on data suggest ~ 20-30% signal size loss with 1-2% O_2, with some trends vs. time indicating that it *partially* comes from the attachment
- In cosmic ray tracks, 7-9% of hit loss, caused by the attachment of the first cluster
- If we assume that there is a factor 6 overestimate of the attachment in GARFIELD, we mainly expect a small loss of positron reconstruction efficiency with 0.5 and 1% O_2 and a more substantial one with 2% O_2
  - N.B. MEG II sensitivity is at most linear in efficiency x DAQ time (*zero background regime*)

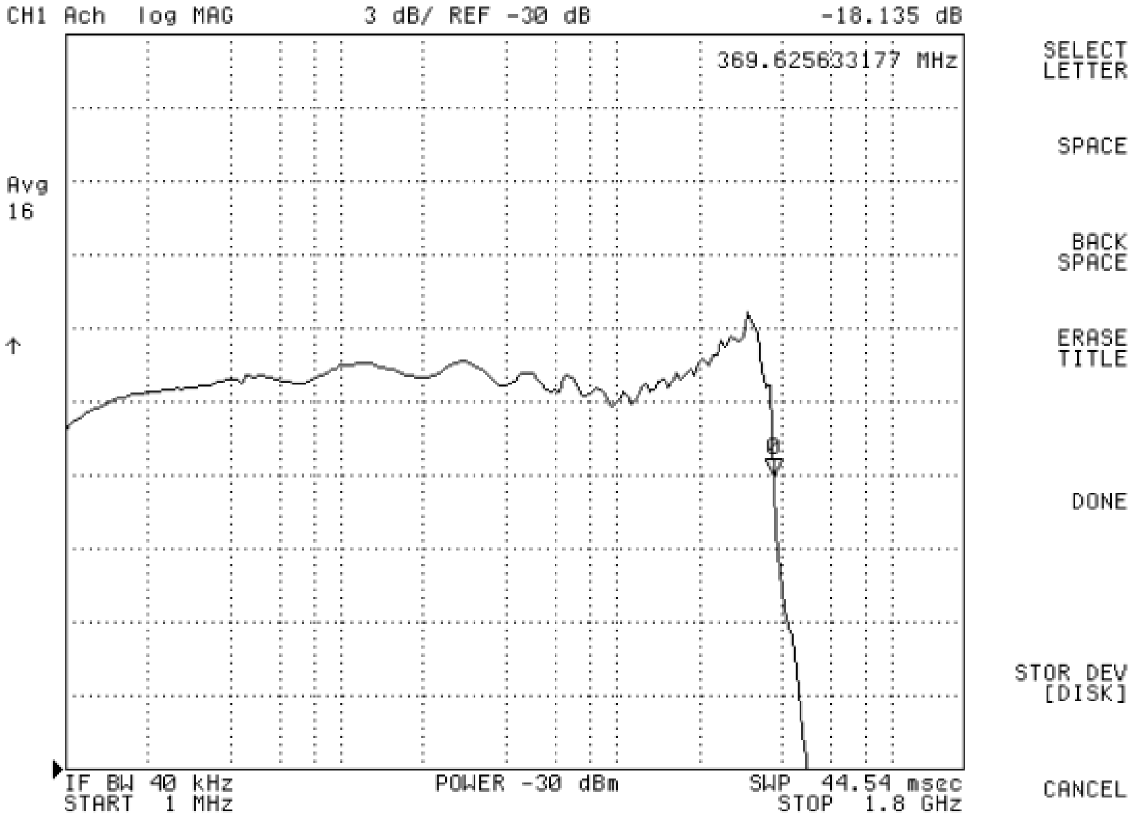
Pulse response vs. LV applied (bench test)



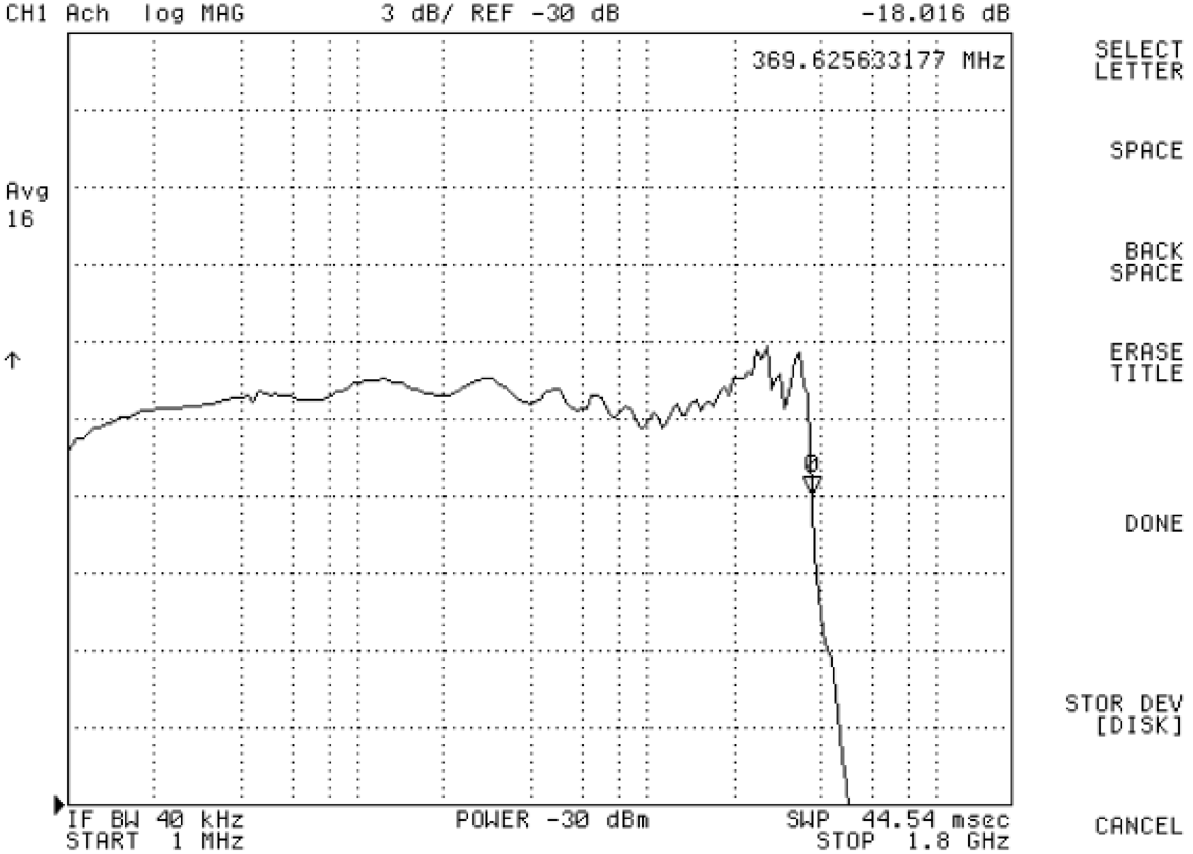
Noise spectrum vs. LV applied (bench test)



Bandwidth vs. LV applied (bench test)

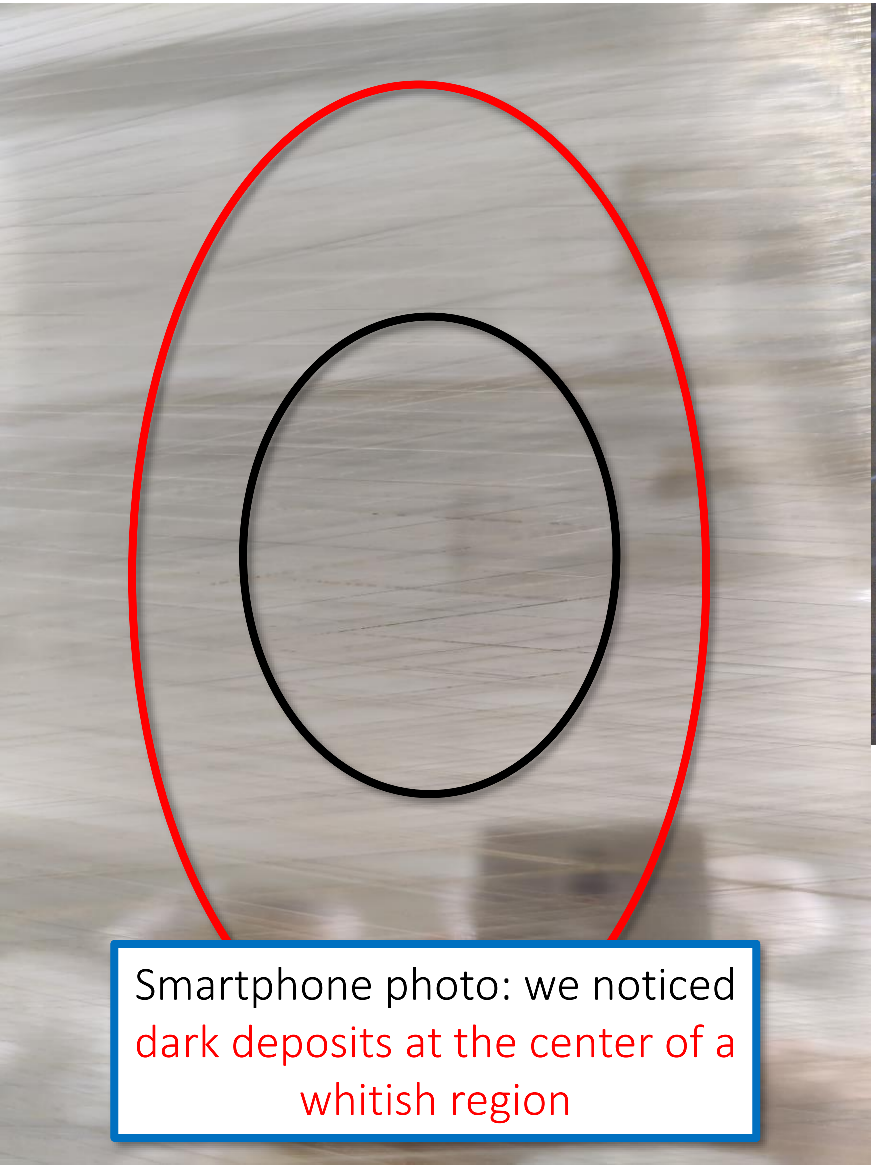


LV=2.5V

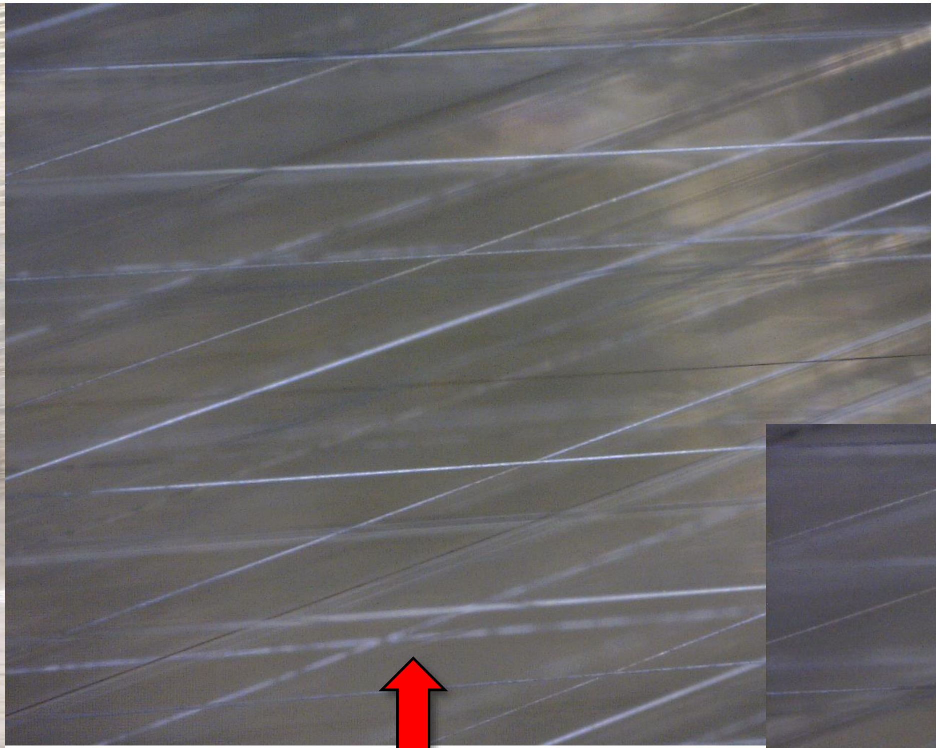


LV= 2.2V

Looking closely at the whitish regions



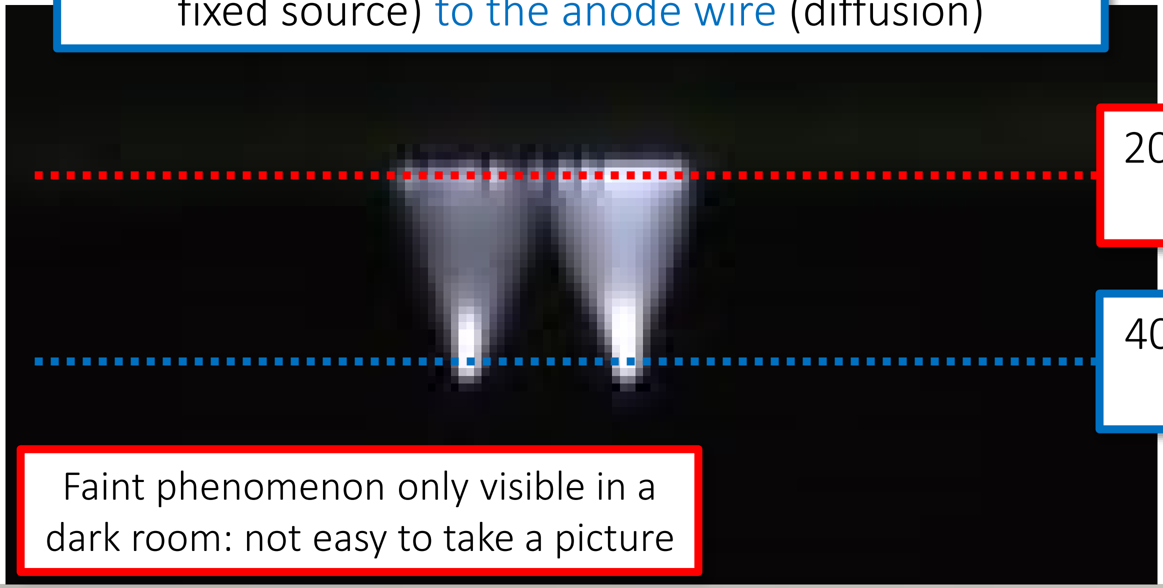
Smartphone photo: we noticed dark deposits at the center of a whitish region

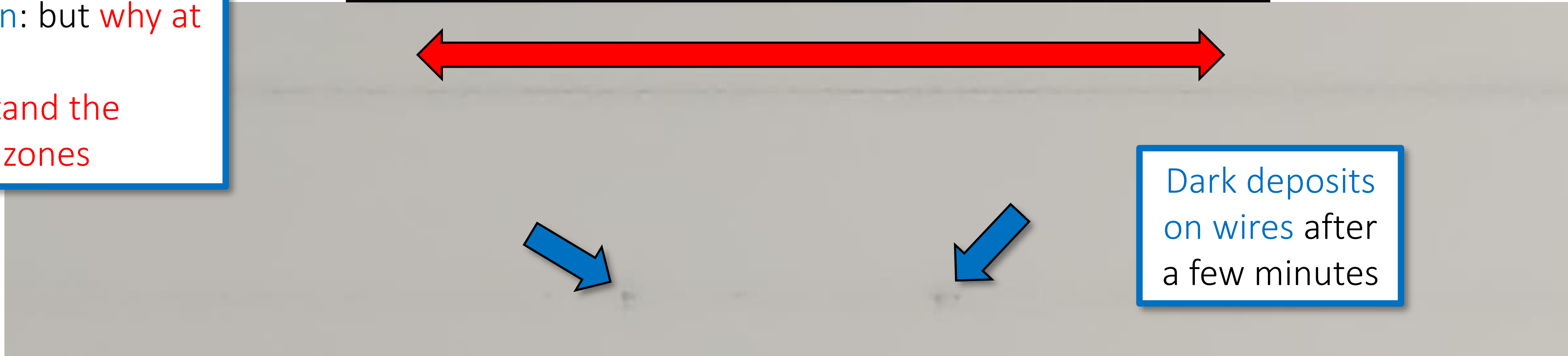


Microscope photos confirmed the white wire portions (different surface than the rest of the chamber) and dark deposits at the center

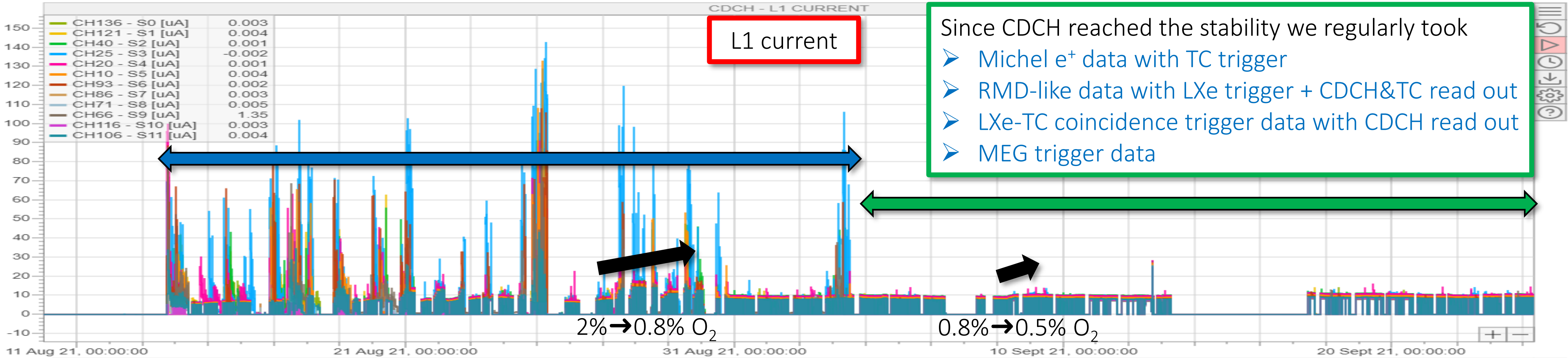
Corona discharges at Pisa

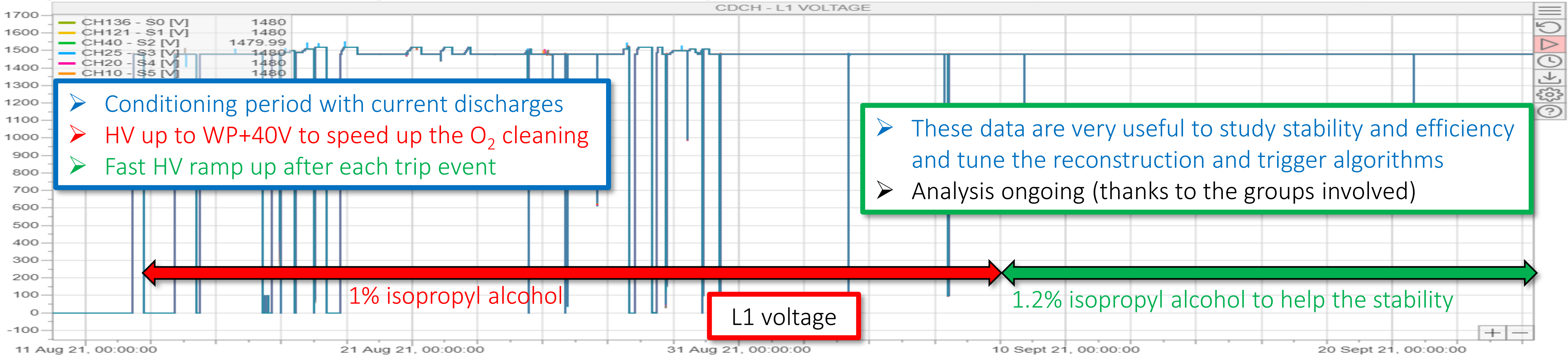
- Do white zones (deposit?) lower the corona discharge HV limit?
- Corona discharges might cause dark deposits on wires as observed in Pisa with a more powerful power supply
- They occurred **naturally at 2300 V (100-200 μA currents) with 40 μm cathode wire diameter and brand-new wires** (no damaged surface)
  - Known phenomenon: but why at 1400 V?
  - We need to understand the nature of the white zones



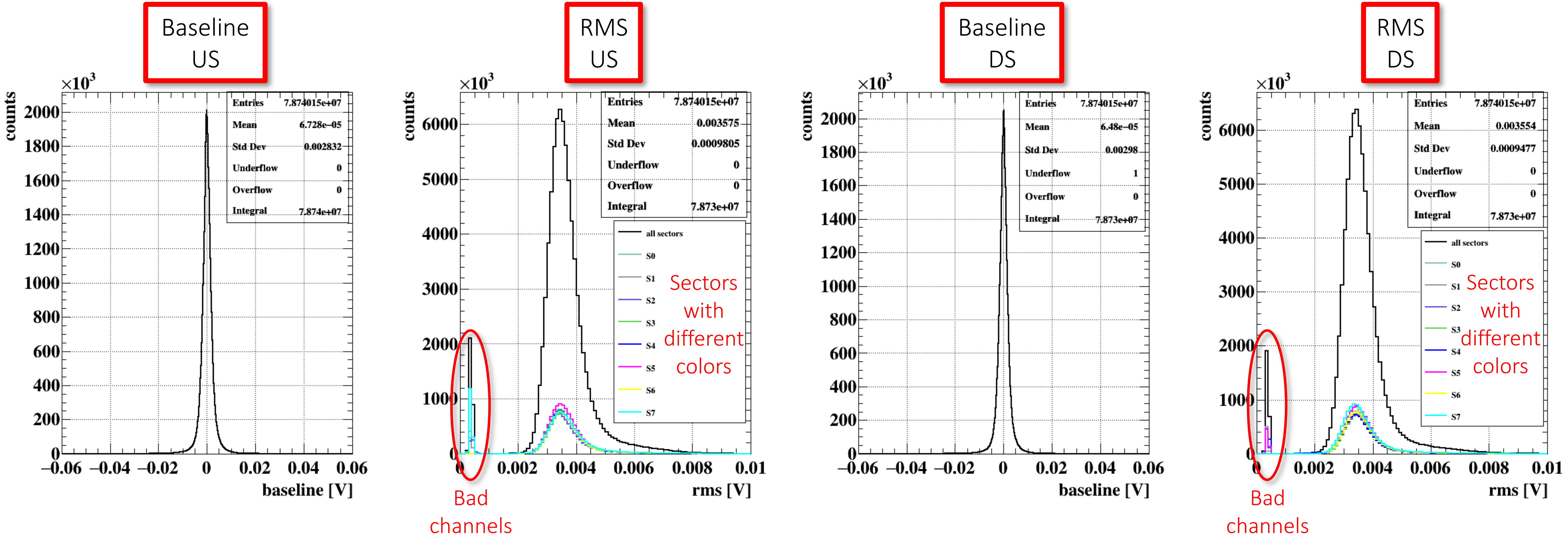


CDCH conditioning with beam 10/08-24/09





Some diagnostic plots from Michel e^+ data



Some diagnostic plots from Michel e^+ data

Baseline US wire by wire

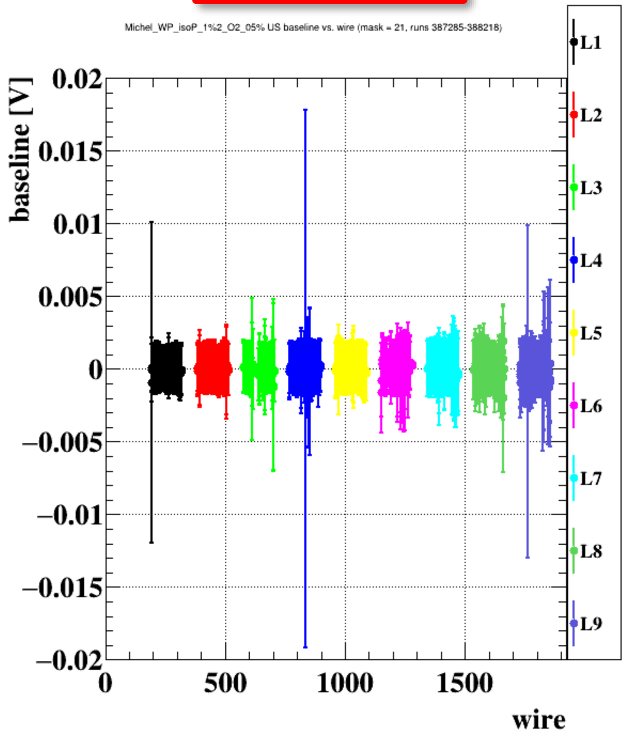
Layers with different colors

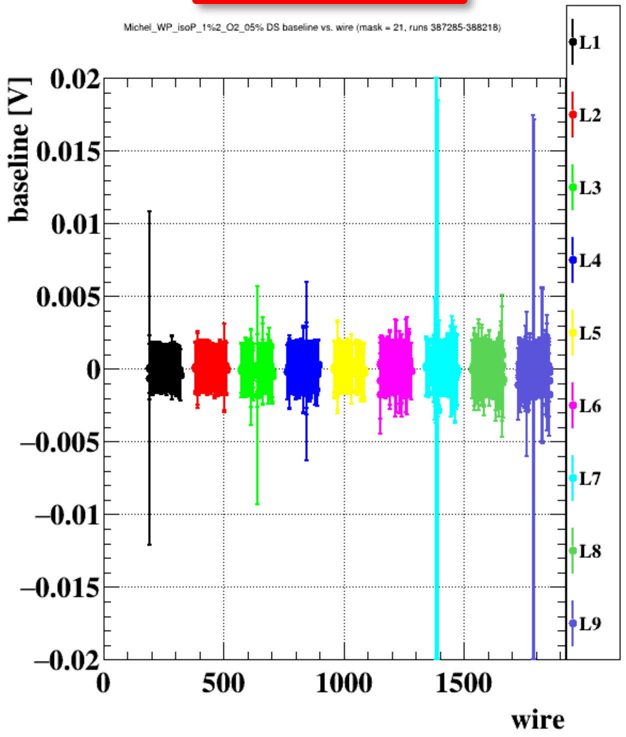
Baseline DS wire by wire

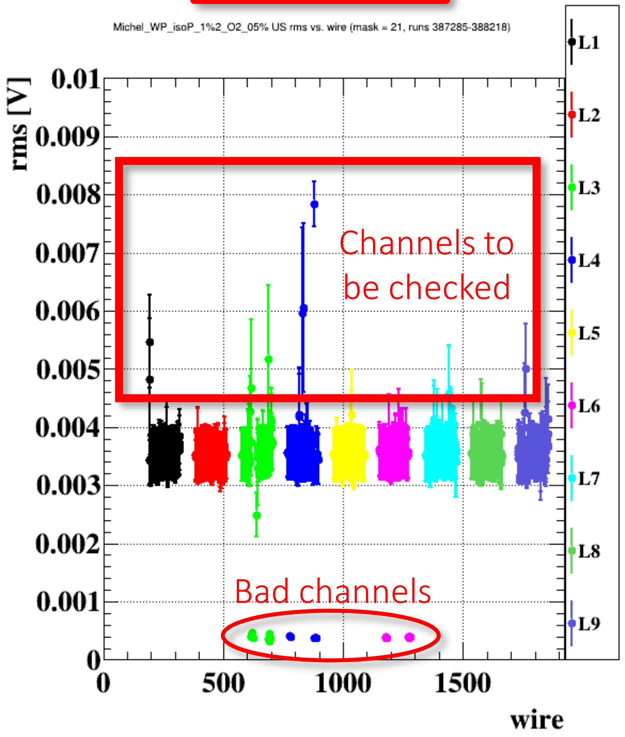
RMS US wire by wire

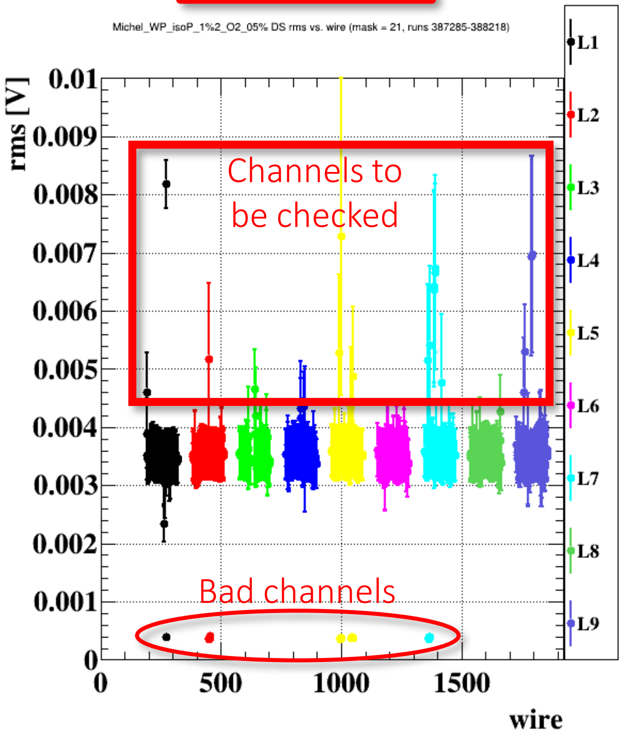
Layers with different colors

RMS US wire by wire



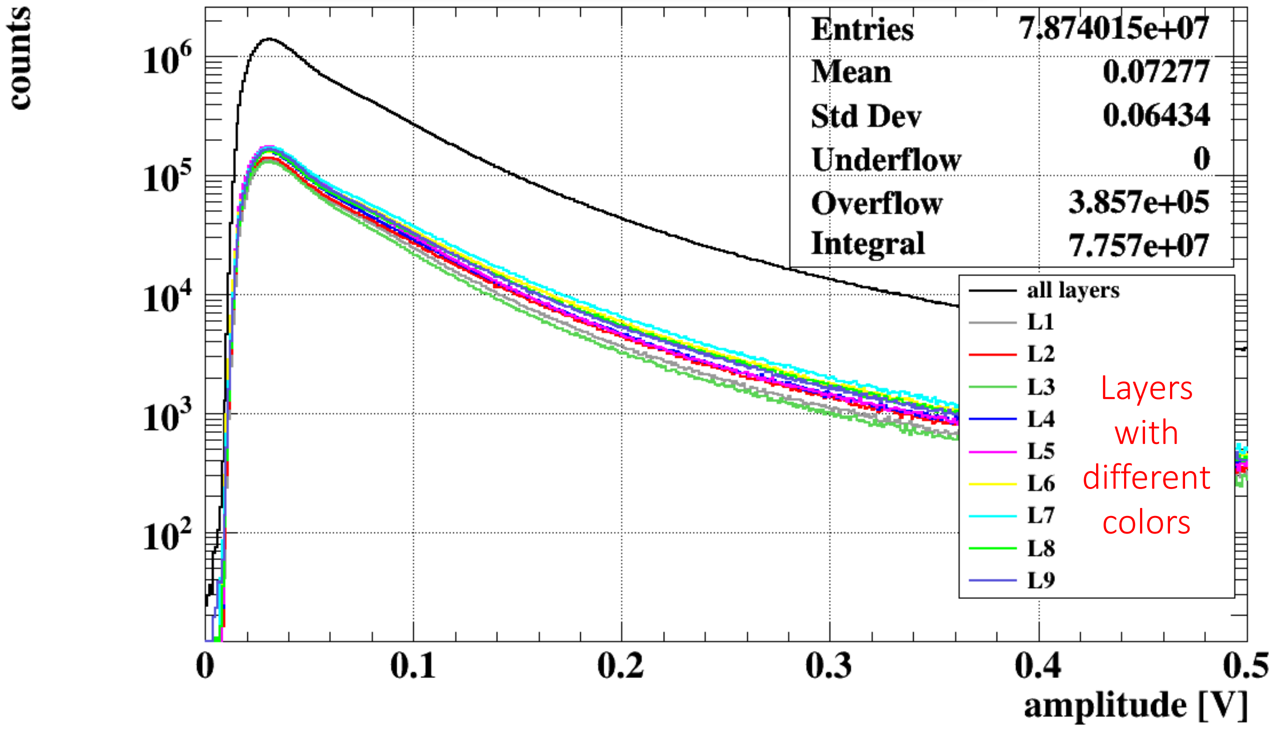




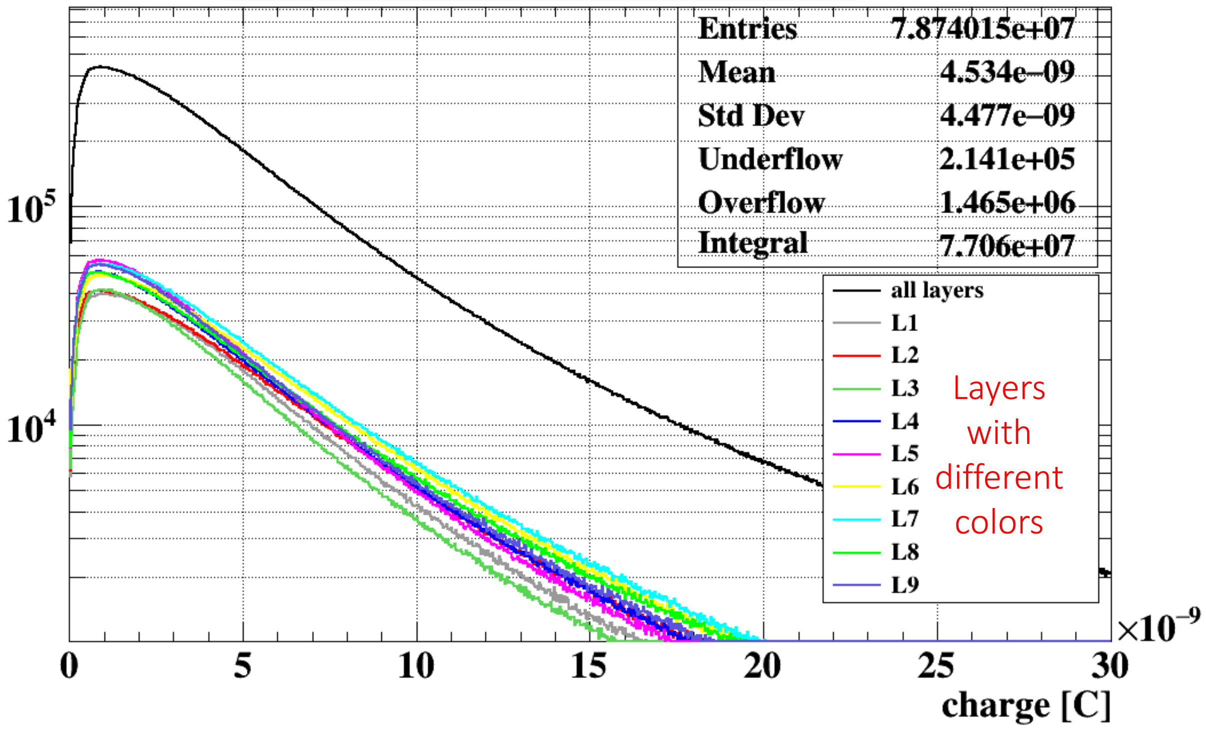


Some diagnostic plots from Michel e^+ data

US + DS signal amplitude distribution



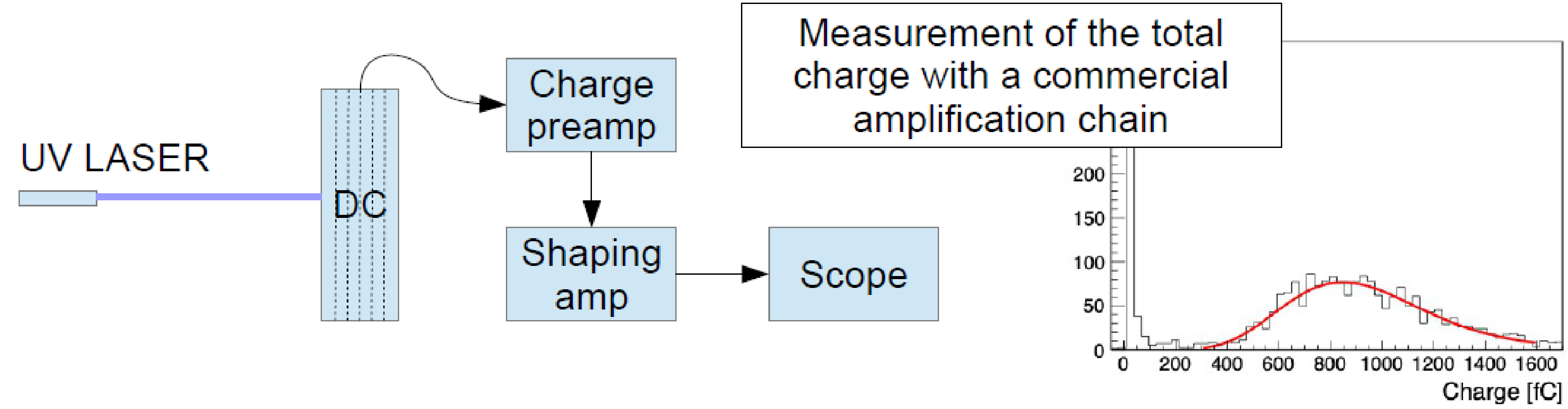
US + DS signal charge distribution

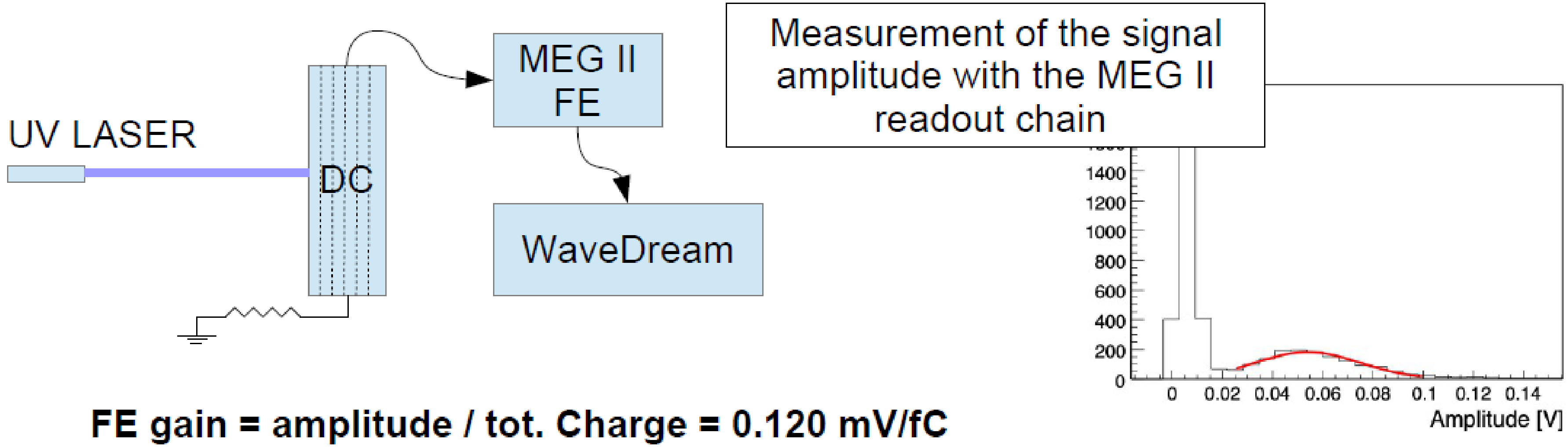


Good uniformity by layer thanks to the 10 V scaling of the HV

FE gain measurement

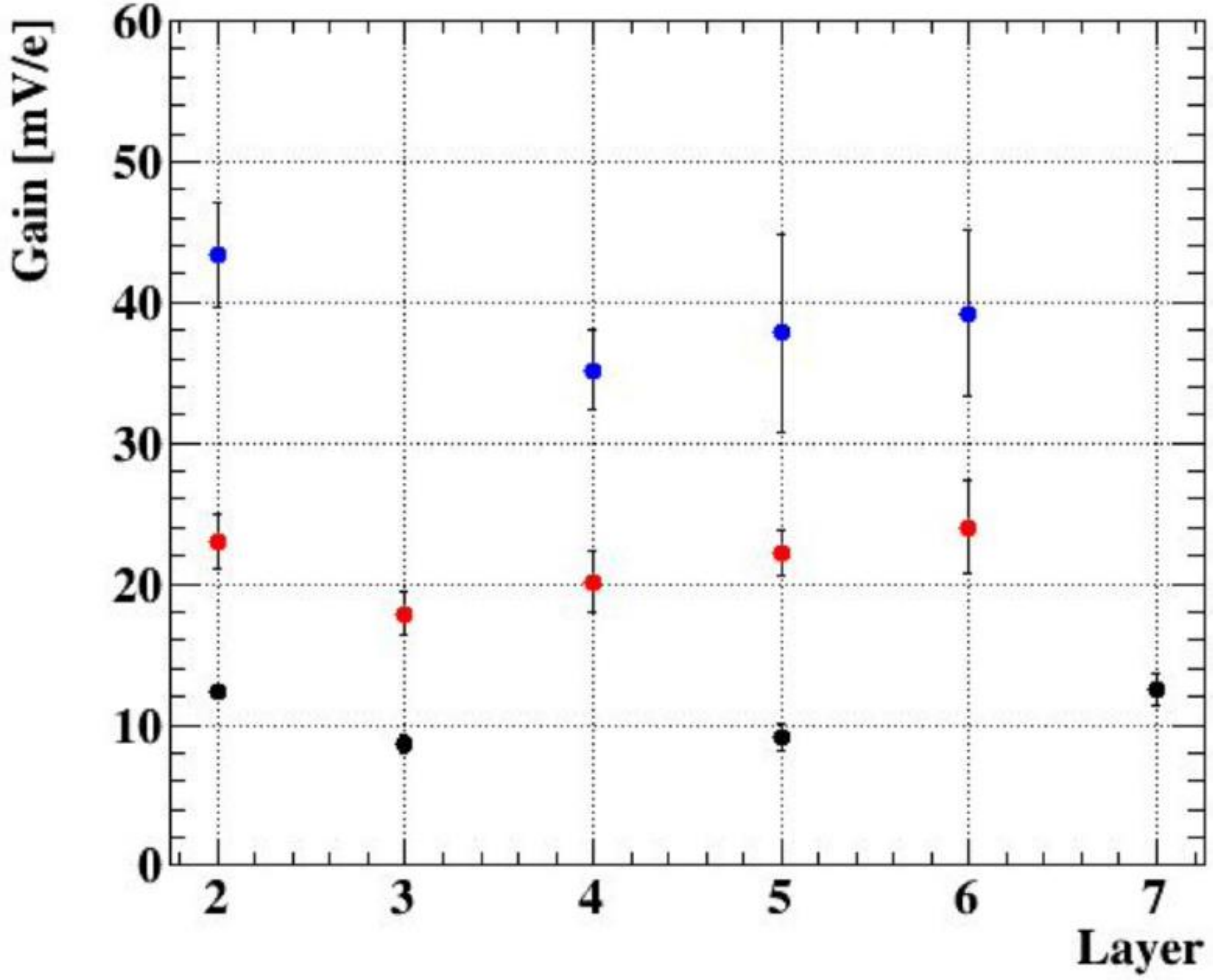
- Measurement of the FE response to real single-electron drift chamber signals produced by laser ionization on a prototype





FE gain = amplitude / tot. Charge = 0.120 mV/fC

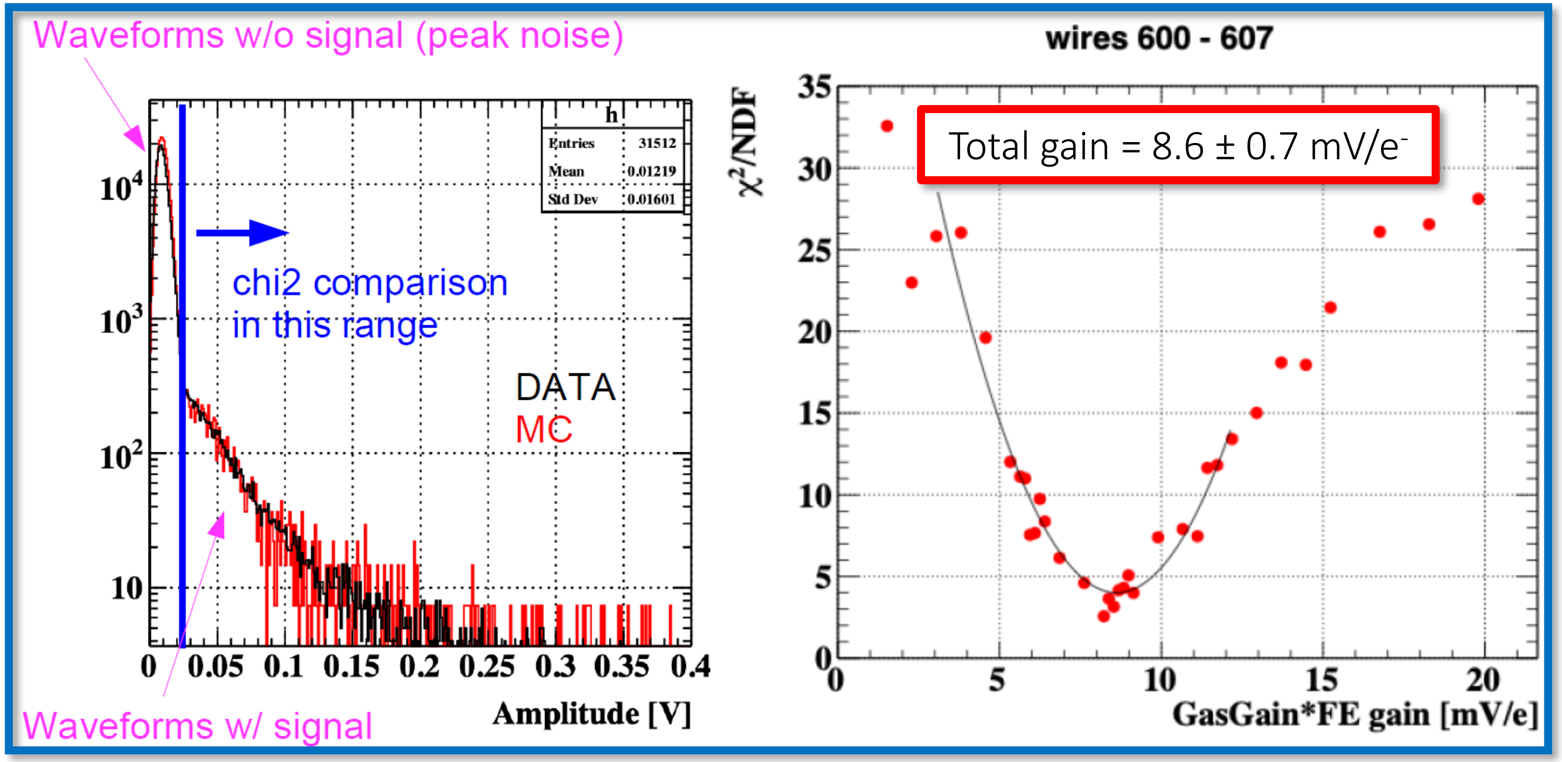
Total gain with different FE

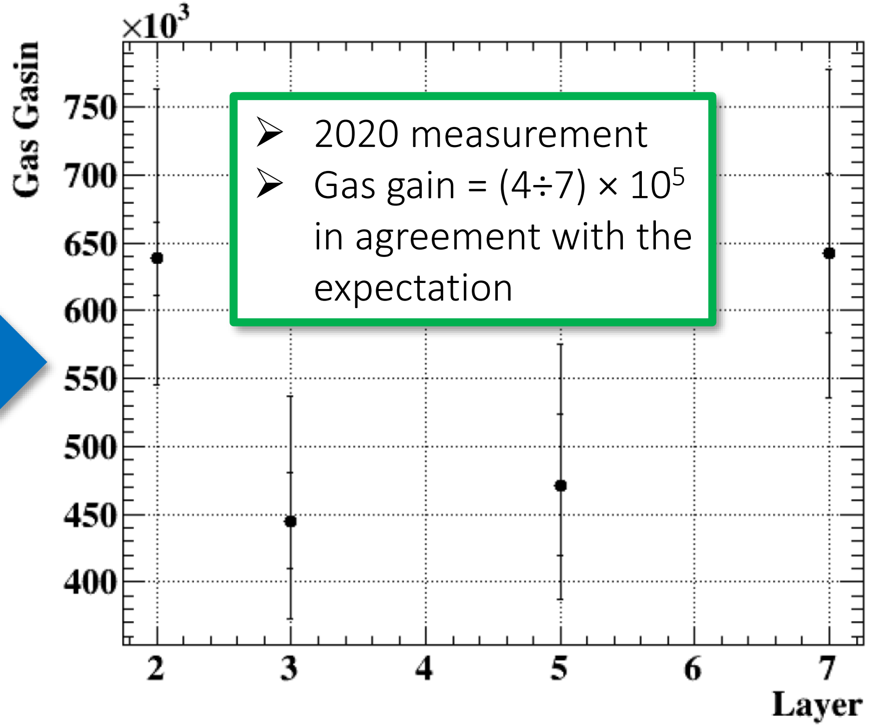


Cosmic rays
(2500 ppm H_20)

STANDARD FE
GAIN x2
GAIN x4

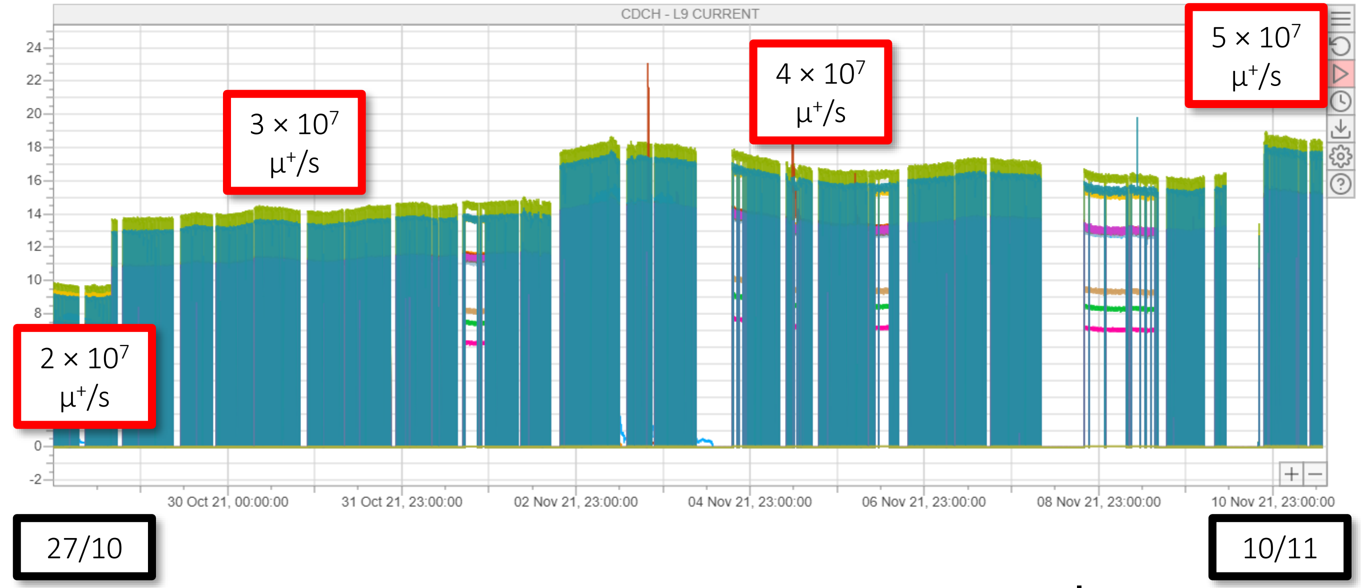
Gain measurement



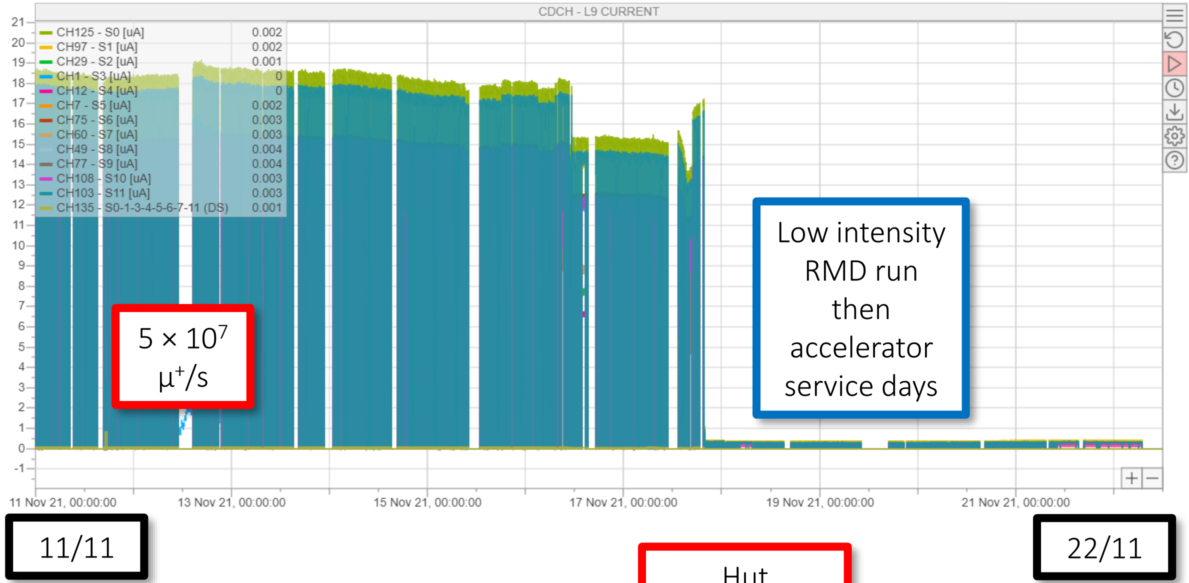


- **Signal amplitude distribution** from Cosmic Ray events: clean environment
- The only parameter to be tuned in MC to reproduce data is the Total gain = Gas gain × FE gain
- FE gain measured to be 0.120 mV/fC
  - FE response to real single-electron drift chamber signals produced by laser ionization on a prototype
- Gas gain = Total gain / FE gain

CDCH currents stability



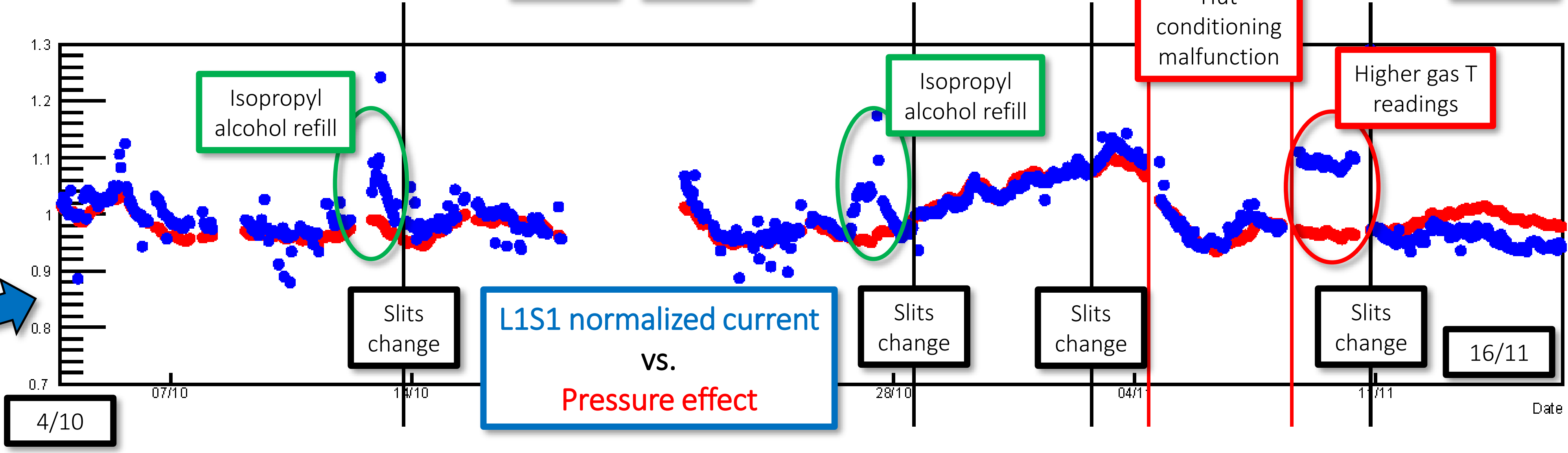
Currents correctly follow the beam intensity



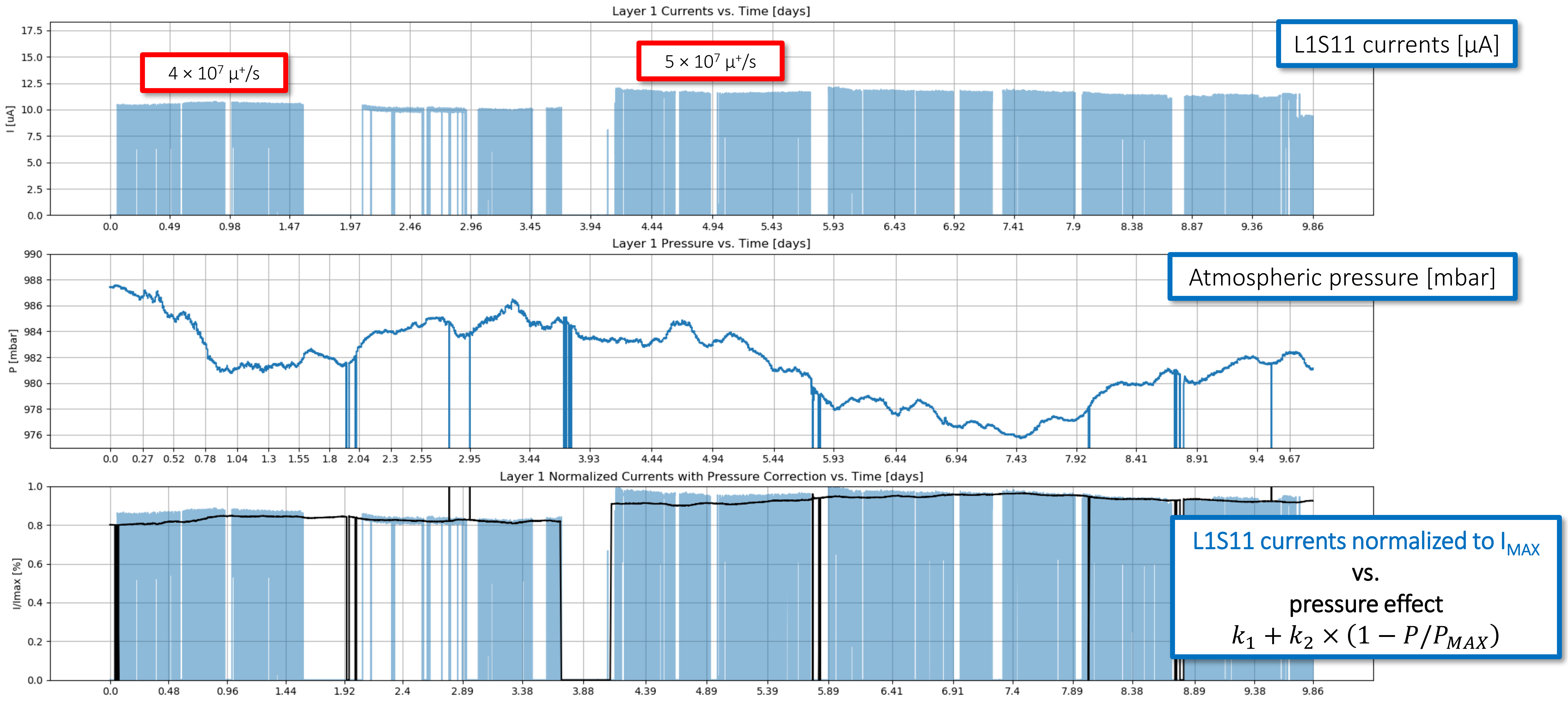
- With CDCH stable we see the gas gain variations with the atmospheric pressure (gas density)

$$\frac{\Delta G}{G} = -k\frac{\Delta P}{P}$$

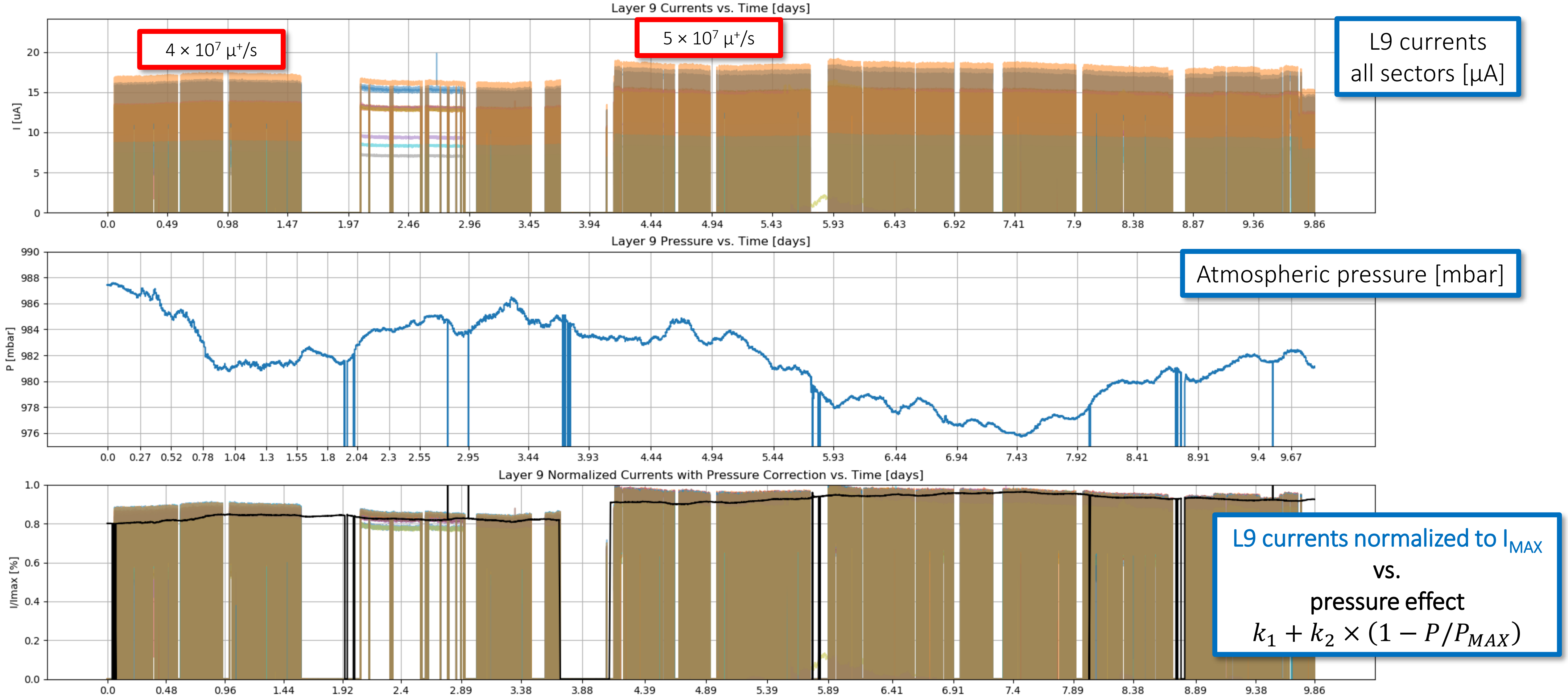
- L1S1 currents (normalized to the initial values) corrected by T, proton current and slits changes



Currents (4-14/11) vs. atmospheric pressure

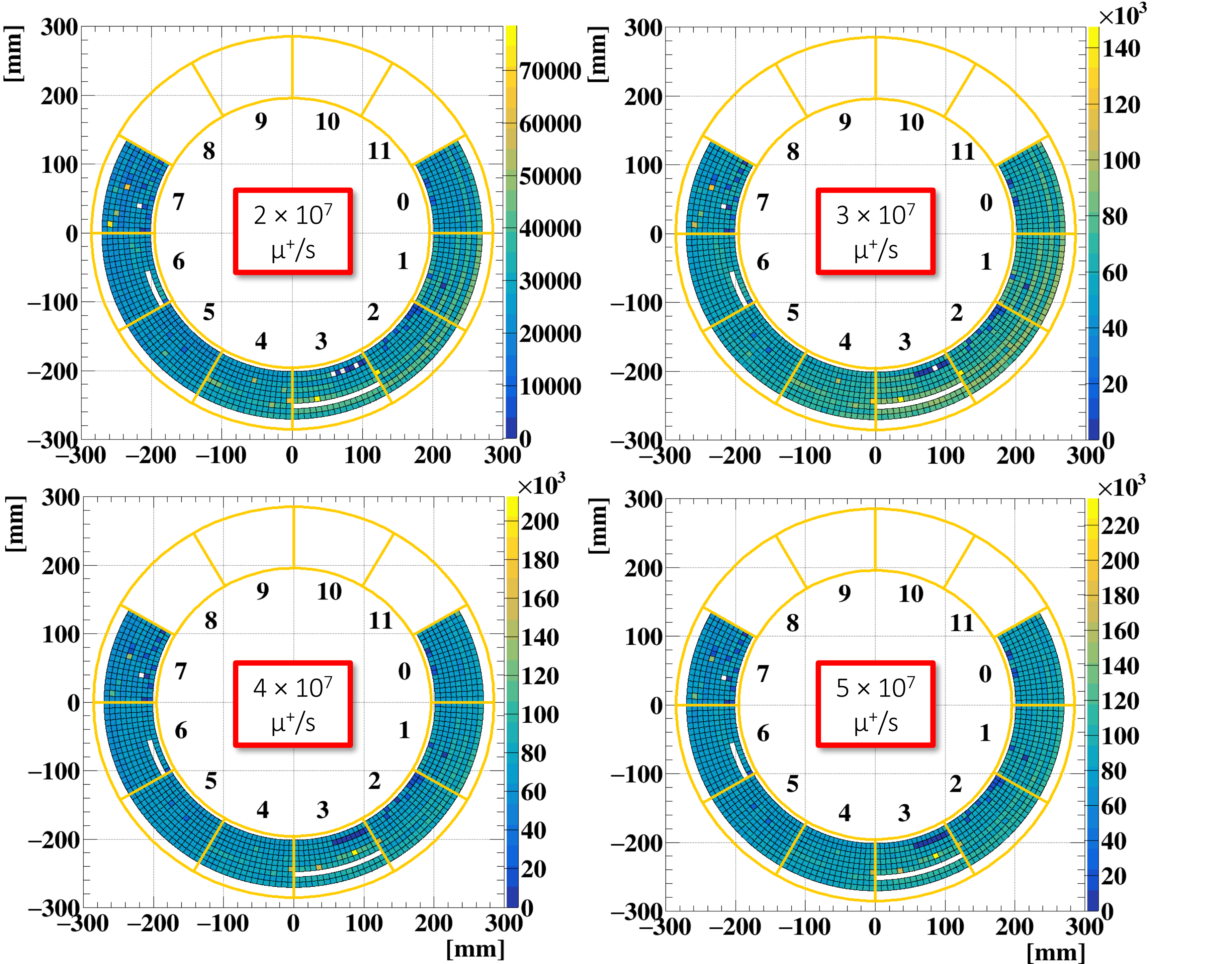


Currents (4-14/11) vs. atmospheric pressure

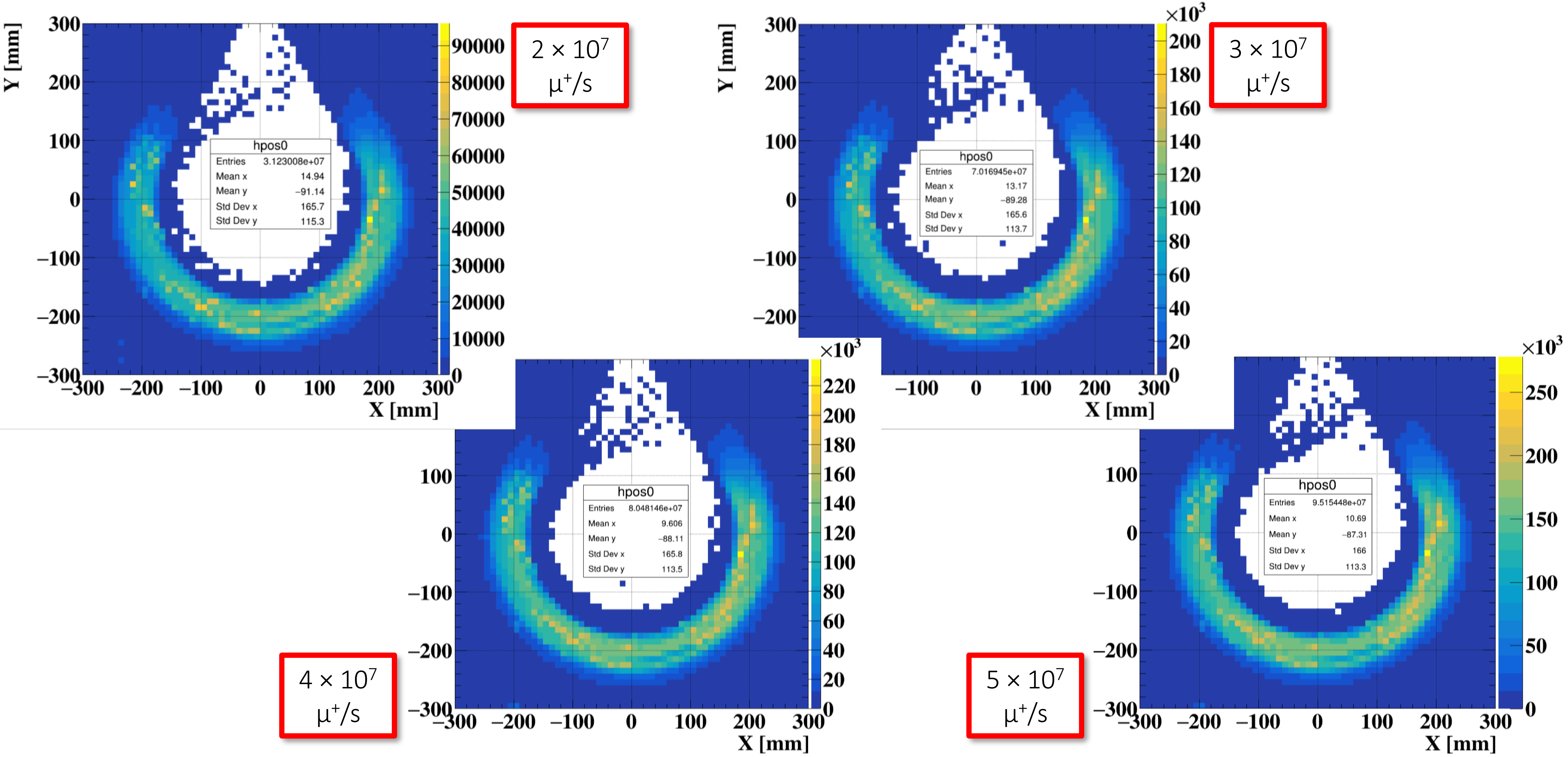


Occupancy

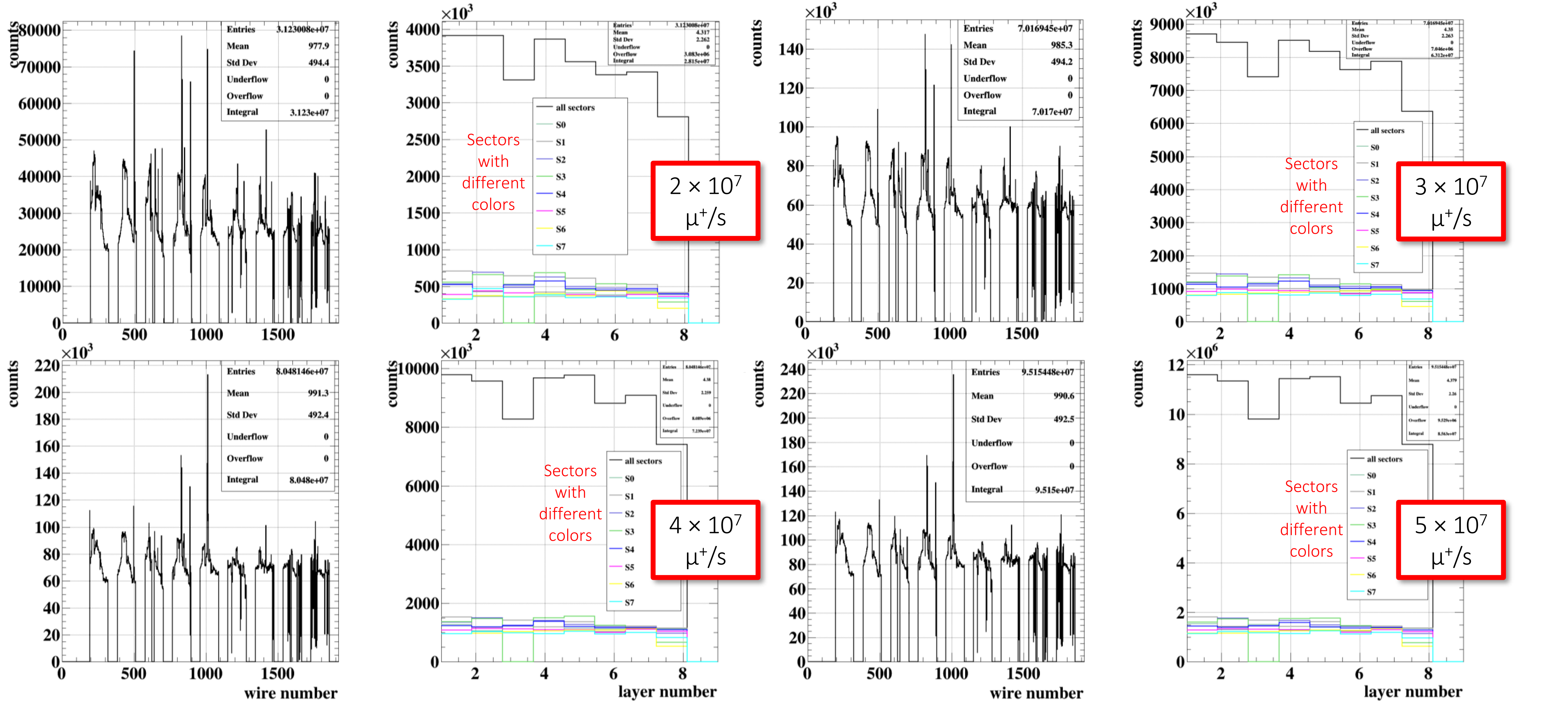
- MEG trigger (mask 0)
- 79 runs for each beam intensity
  - 2e7
  - 3e7
  - 4e7
  - 5e7
- No issues or worsening found



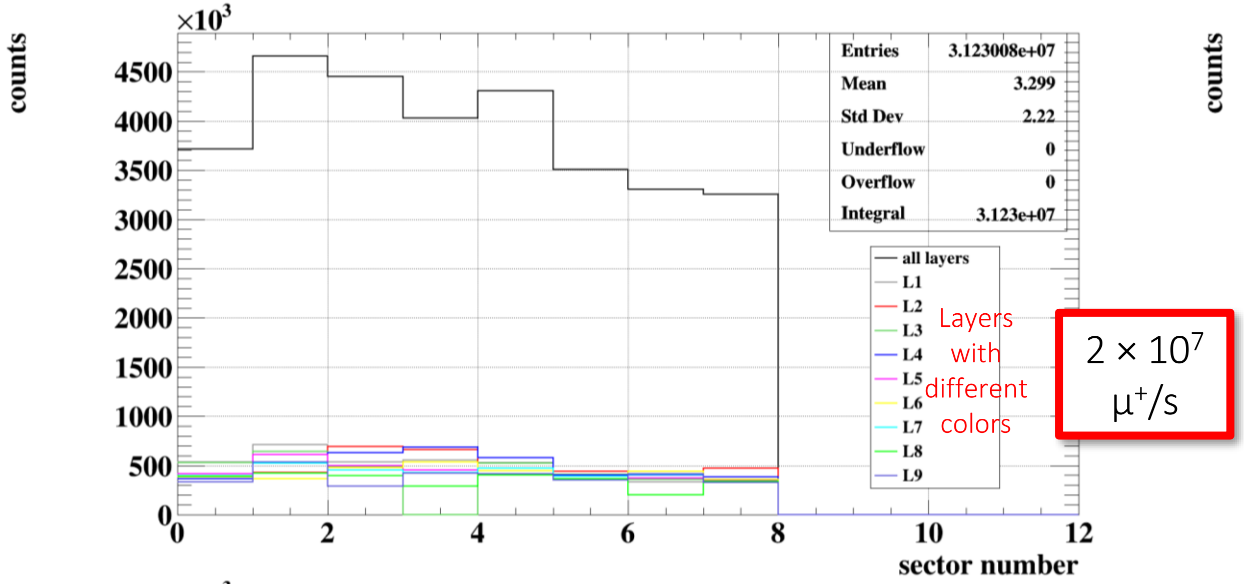
Reconstructed hit XY position

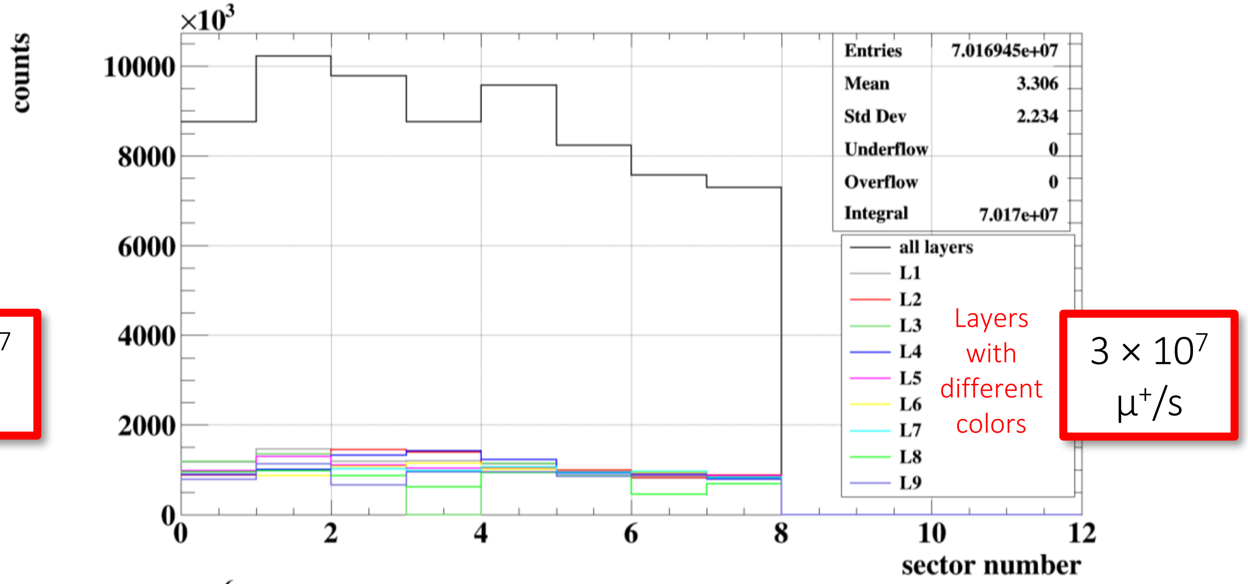


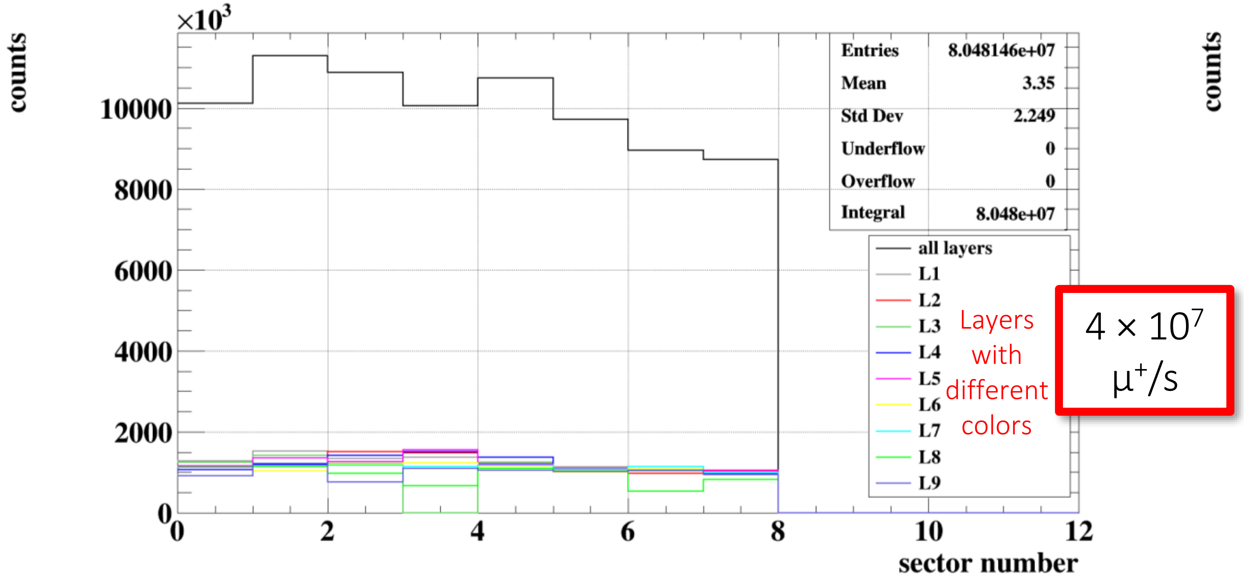
Occupancy by wire and layer

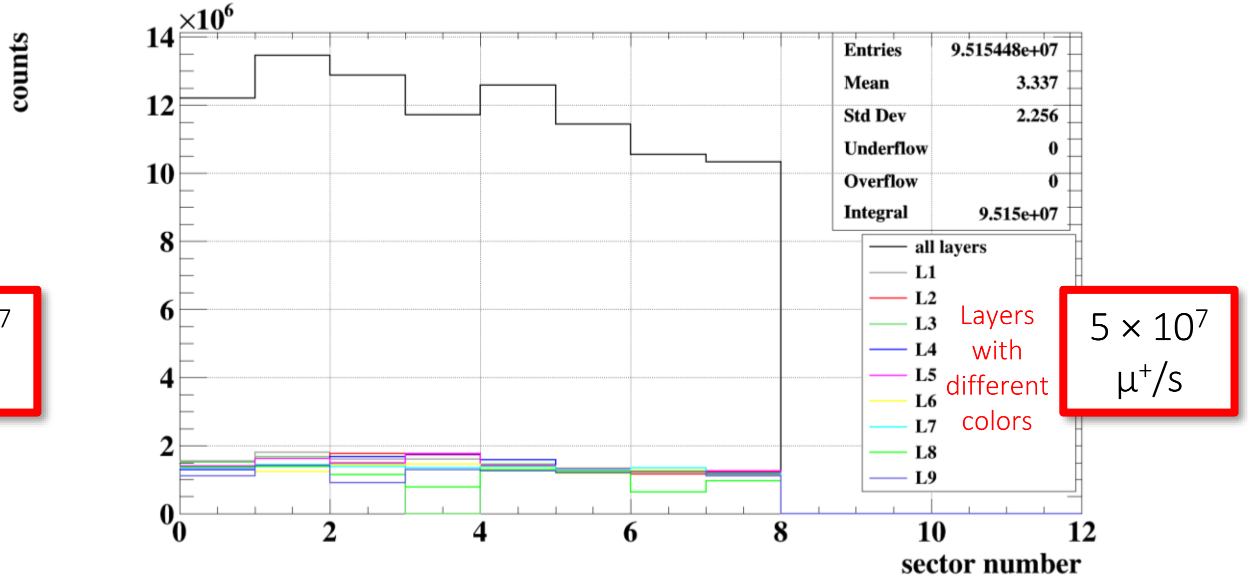


Occupancy by sector



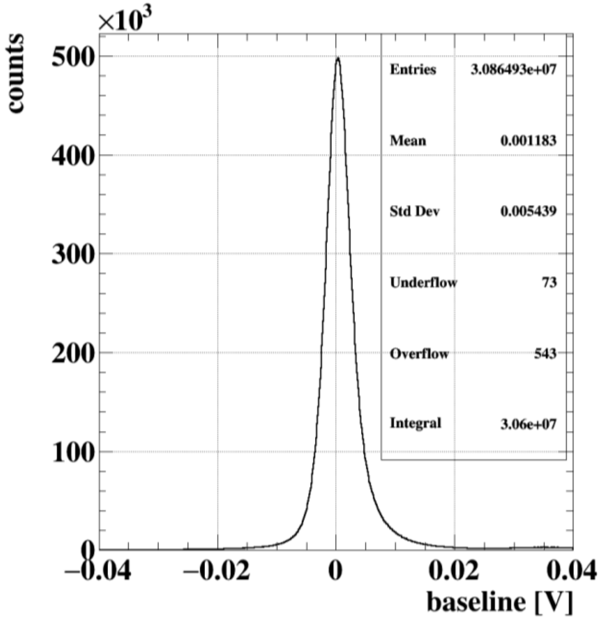




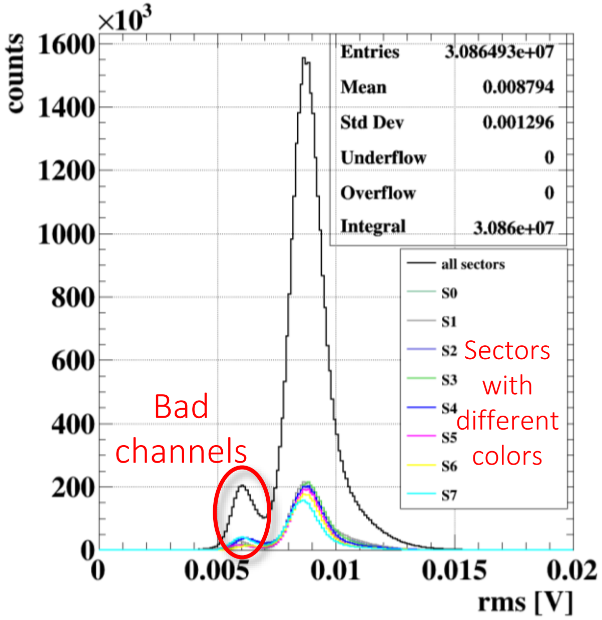


US + DS baseline and RMS

- Mean: 1.2 mV
- RMS: 5.4 mV

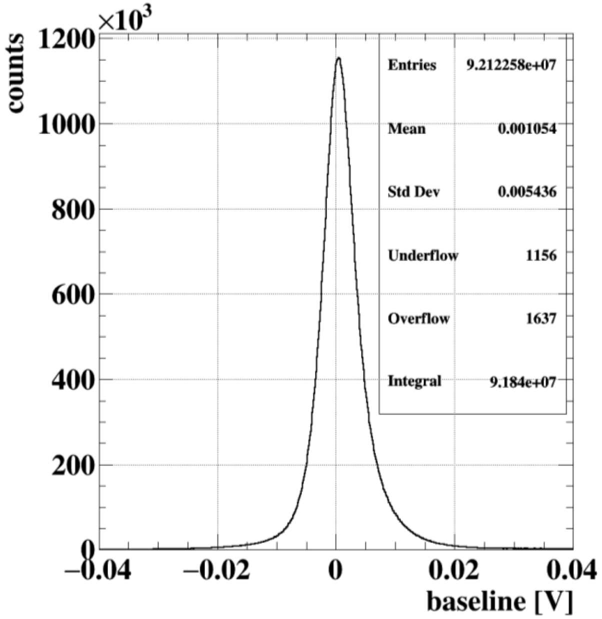


- Mean: 8.8 mV
- RMS: 1.3 mV

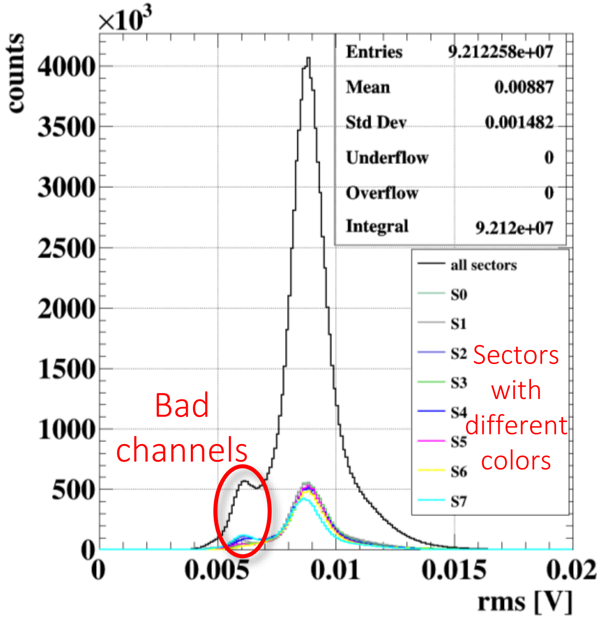


2×10^7 μ^+/s

- Mean: 1.1 mV
- RMS: 5.4 mV

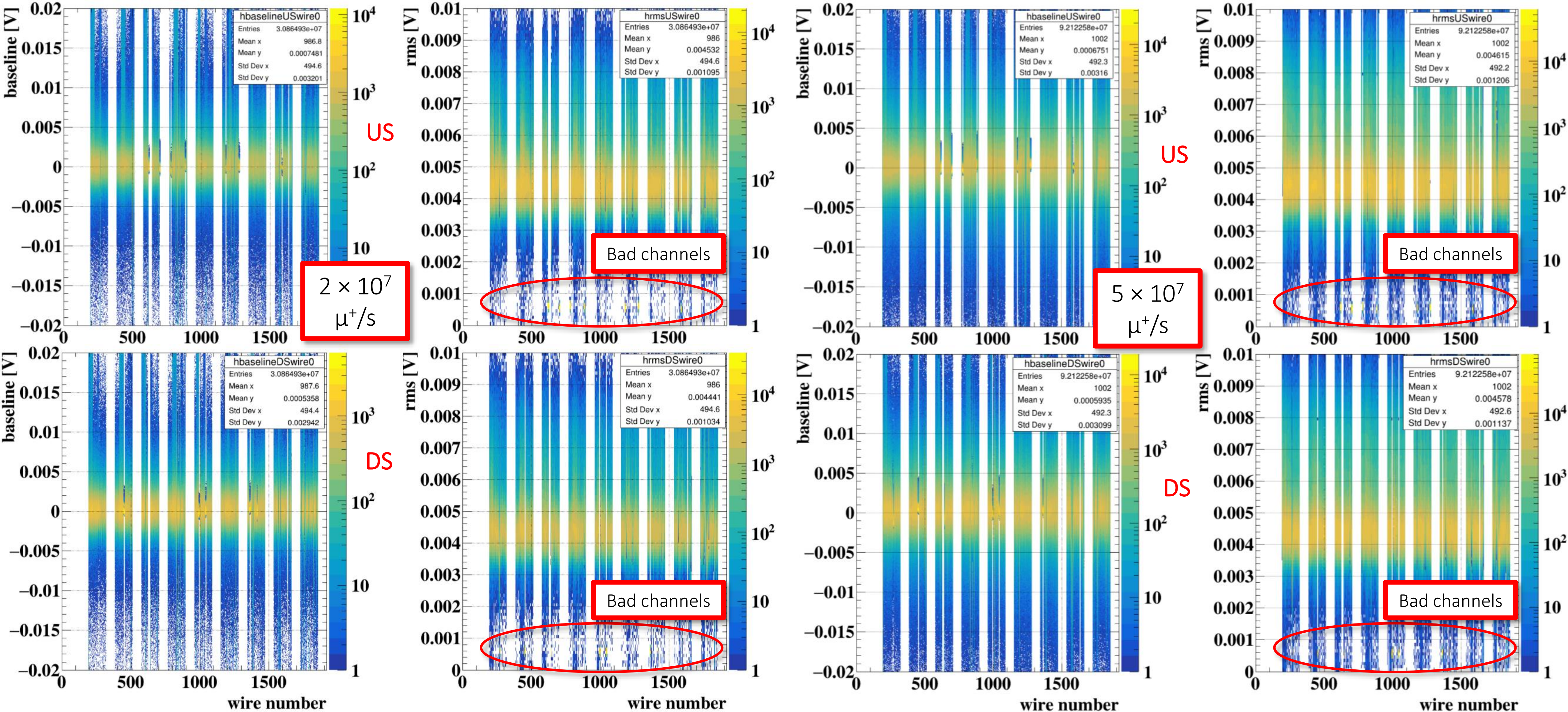


- Mean: 8.9 mV
- RMS: 1.5 mV

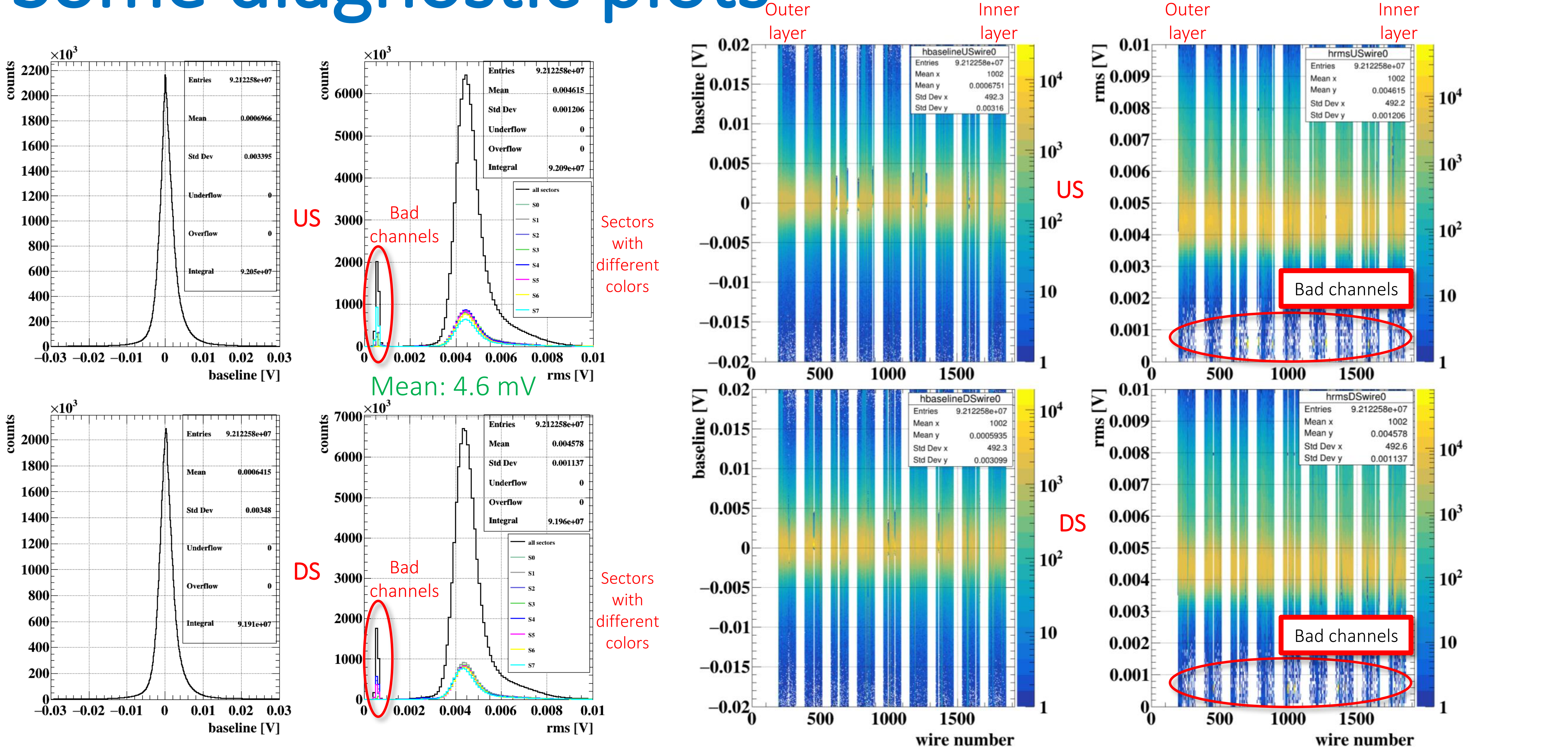


5×10^7 μ^+/s

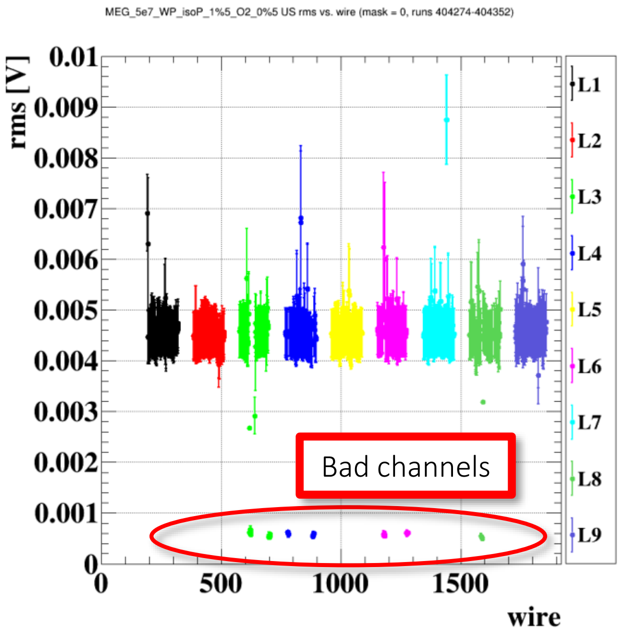
Baseline and RMS by wire

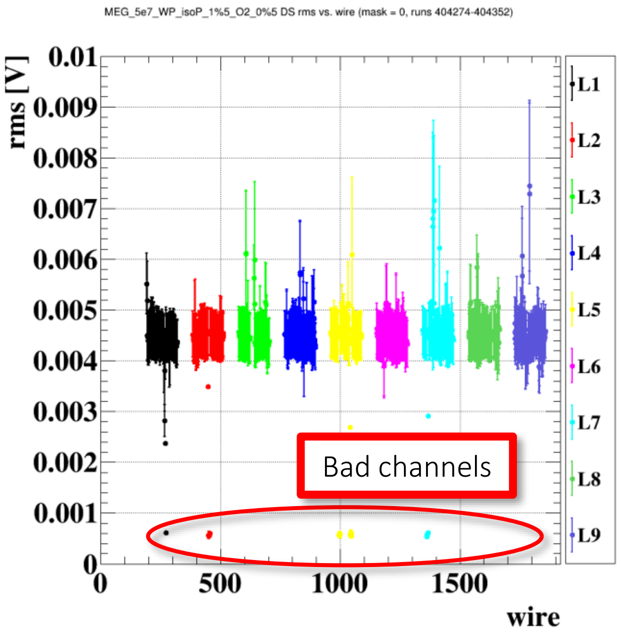


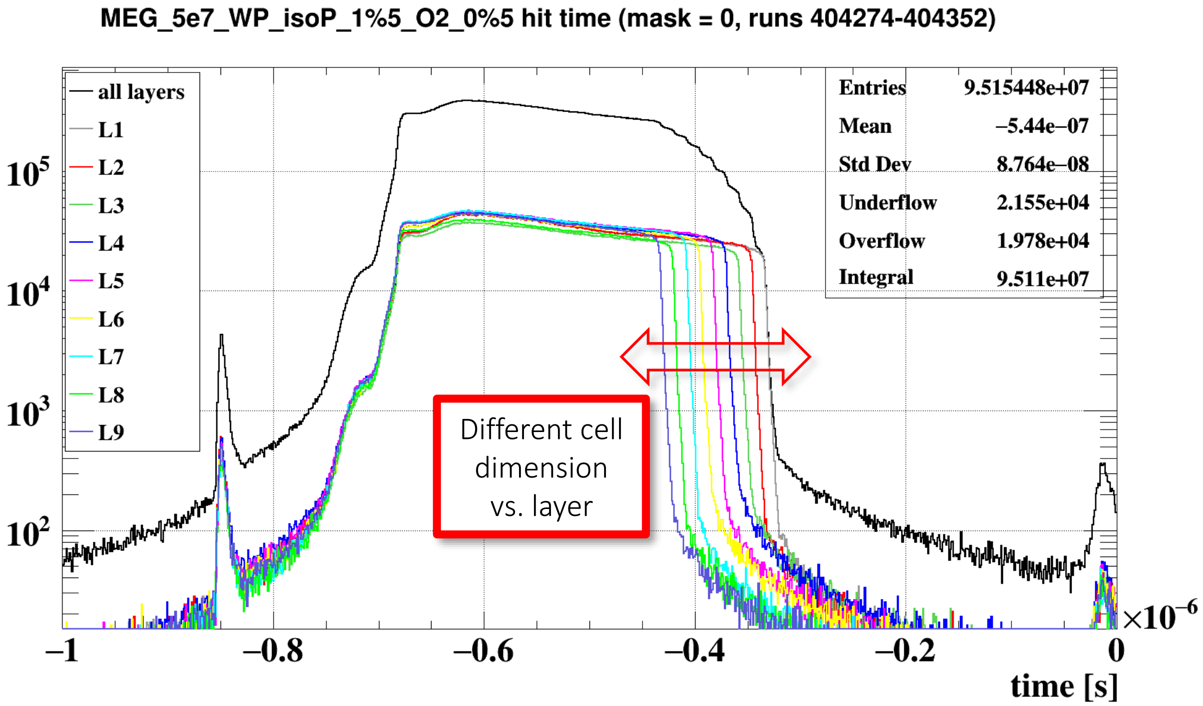
Some diagnostic plots

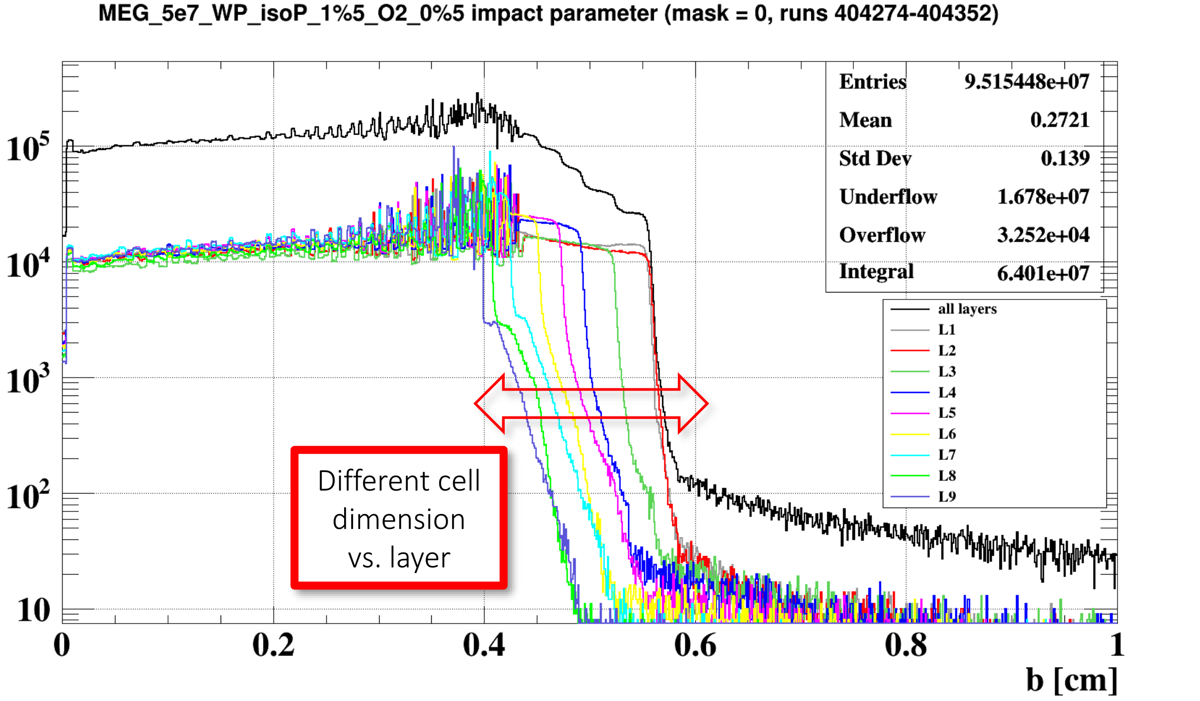


$5 \times 10^7\ \mu^+/s$

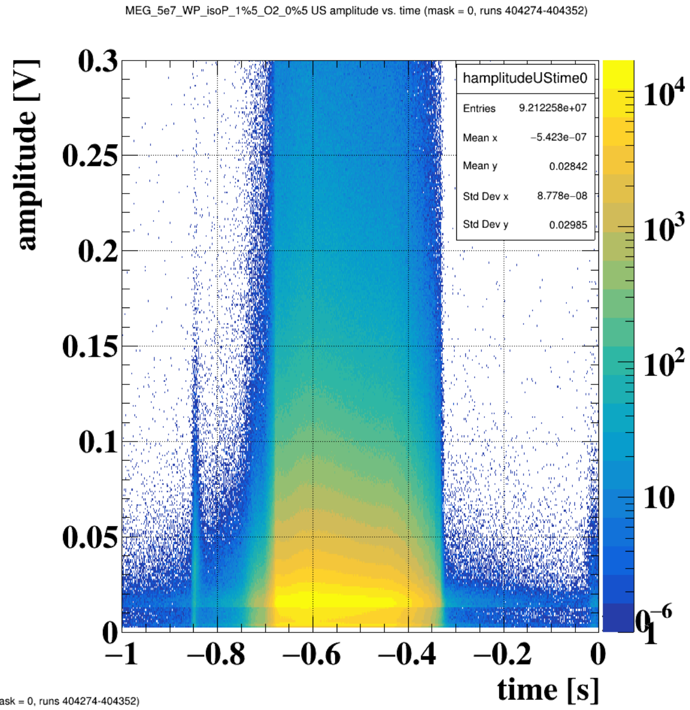


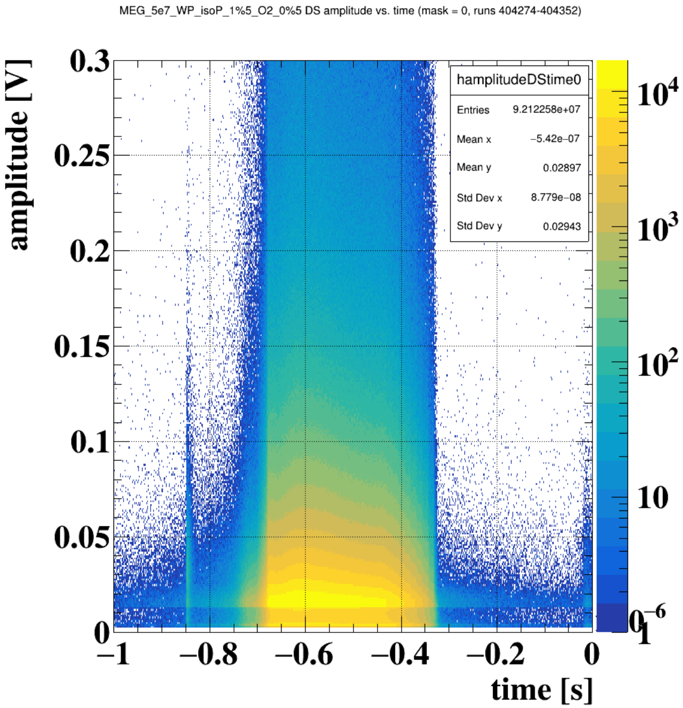


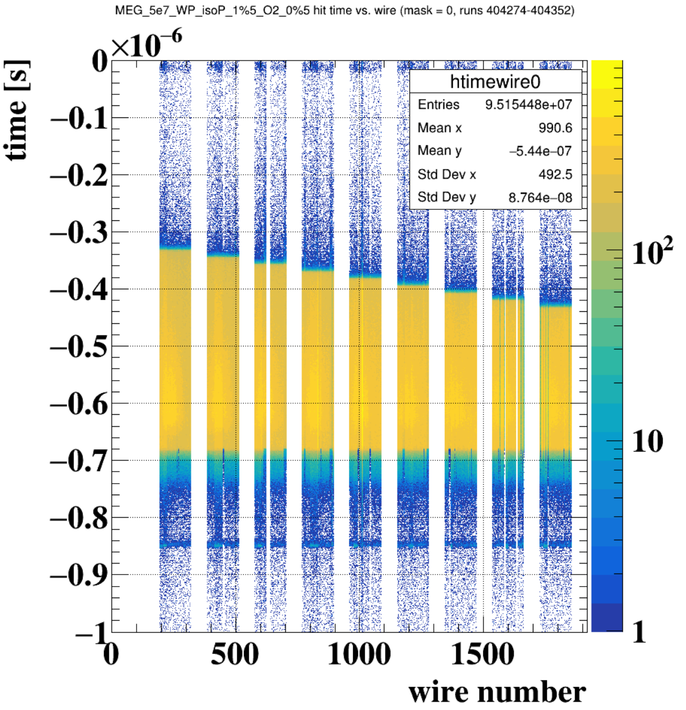


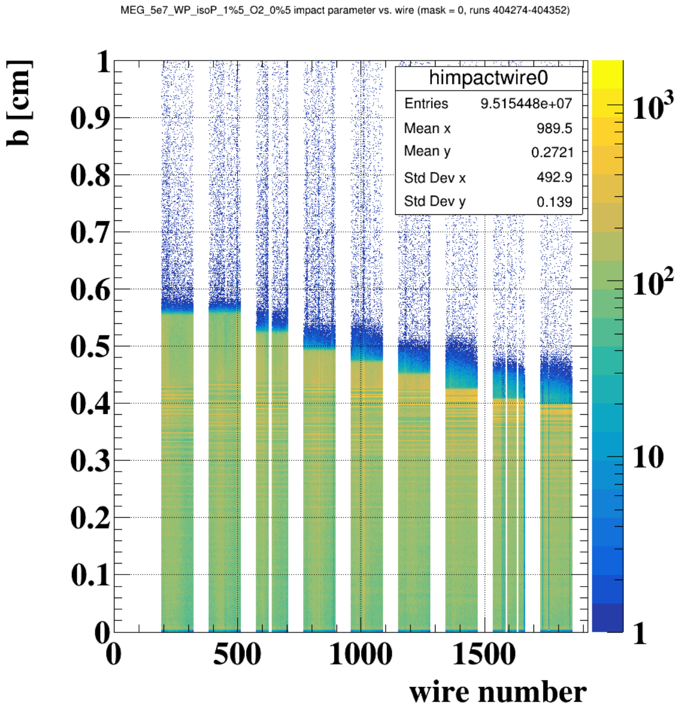


$5 \times 10^7\ \mu^+/s$









Preliminary hit resolution