The Cylindrical Drift Chamber of the MEG II Experiment

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Frontier Detectors for Frontier Physics

15th Pisa meeting on advanced detectors

La Biodola • Isola d'Elba • Italy

22 - 28 May, 2022

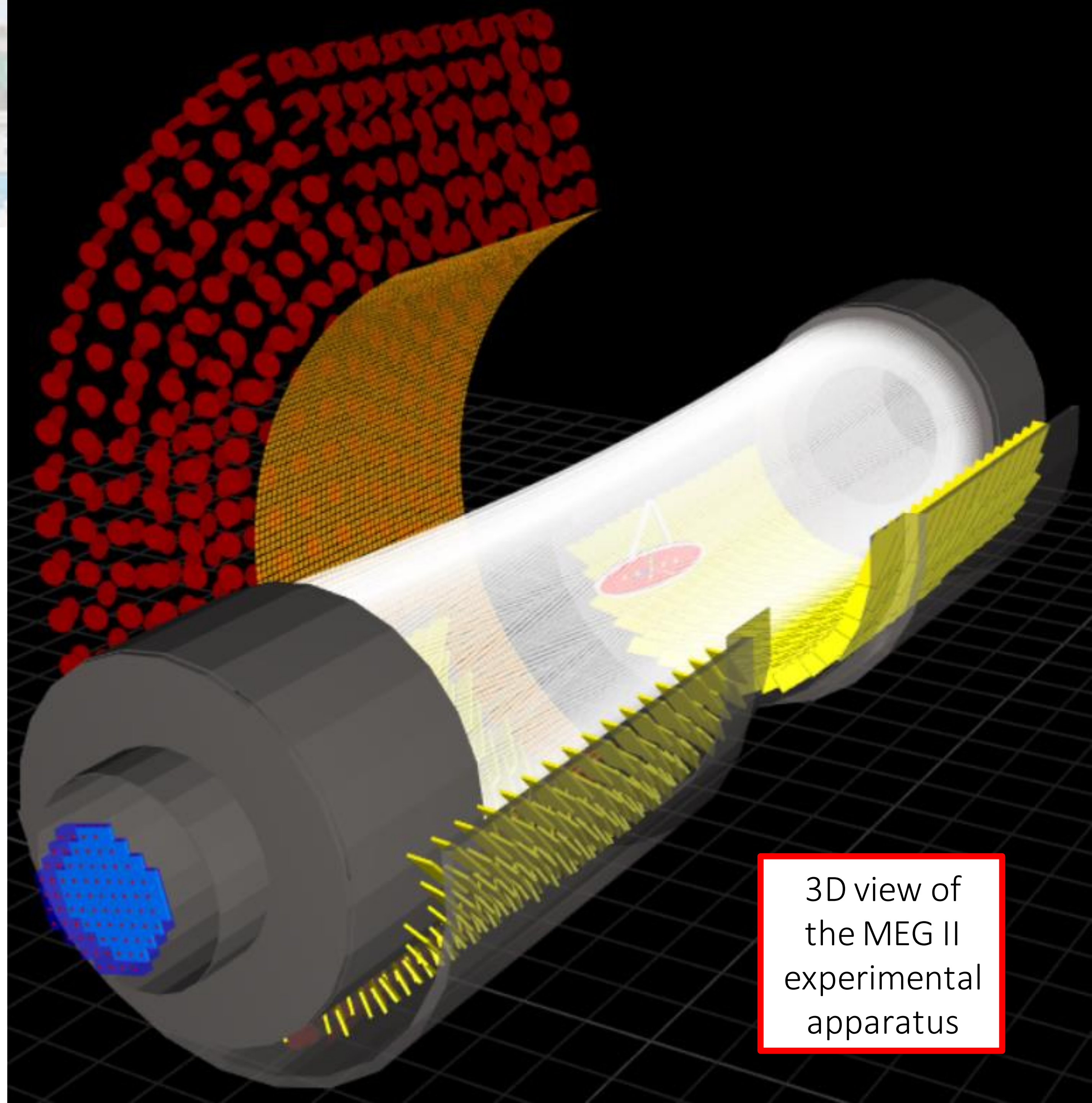
Link to the contribution on Indico

Istituto Nazionale di Fisica Nucleare

MEG II

Outline

- Introduction to the MEG II experiment
- Construction and Commissioning of the MEG II Cylindrical Drift CHamber (CDCH)
  - Performance and new design concept
  - Mechanics and electronics
  - Final working point
  - Integration into the experimental apparatus
  - Problems along the path and how to solve them
- Preliminary performance with the first physics data
- Conclusions and prospects



3D view of the MEG II experimental apparatus

Introduction to the MEG II experiment

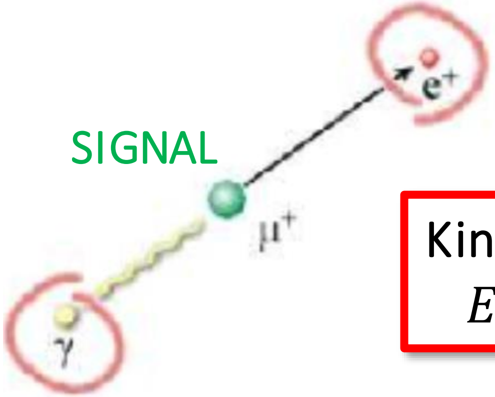
The $\mu^+ \to e^+\gamma$ decay

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

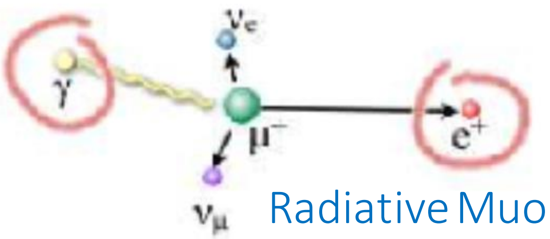
- In this context the MEG experiment represents the state of the art in the search for the CLFV $\mu^+ \to e^+\gamma$ decay
  - **Final results** exploiting the **full statistics** collected during the 2009-2013 data taking period at **Paul Scherrer Institut** (PSI, Switzerland)
  - $BR(\mu^+ \to e^+\gamma)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

SIGNAL



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

- $28\ \mathrm{MeV/c}\ \mu^+$ continuous beam stopped in a $130\ \mu\mathrm{m}$-thick polyvinyl toluene target ($15°$ slant angle)
- Most intense DC muon beam in the world at PSI: $R_\mu \approx 10^8\ \mathrm{Hz}$
- μ^+ decay at rest: 2-body kinematics
- $E_\gamma = E_e = 52.8\ \mathrm{MeV}$
- $\theta_{e\gamma} = 180°$
- $t_{e\gamma} = 0\ \mathrm{s}$



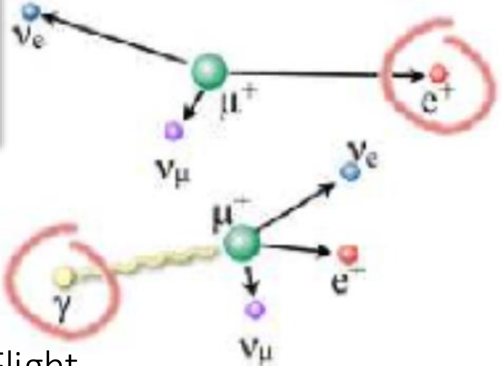
Radiative Muon Decay (RMD)

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

Standard μ decay
≡
Michel decay

BACKGROUNDS

From RMD, Annihilation-In-Flight or bremsstrahlung

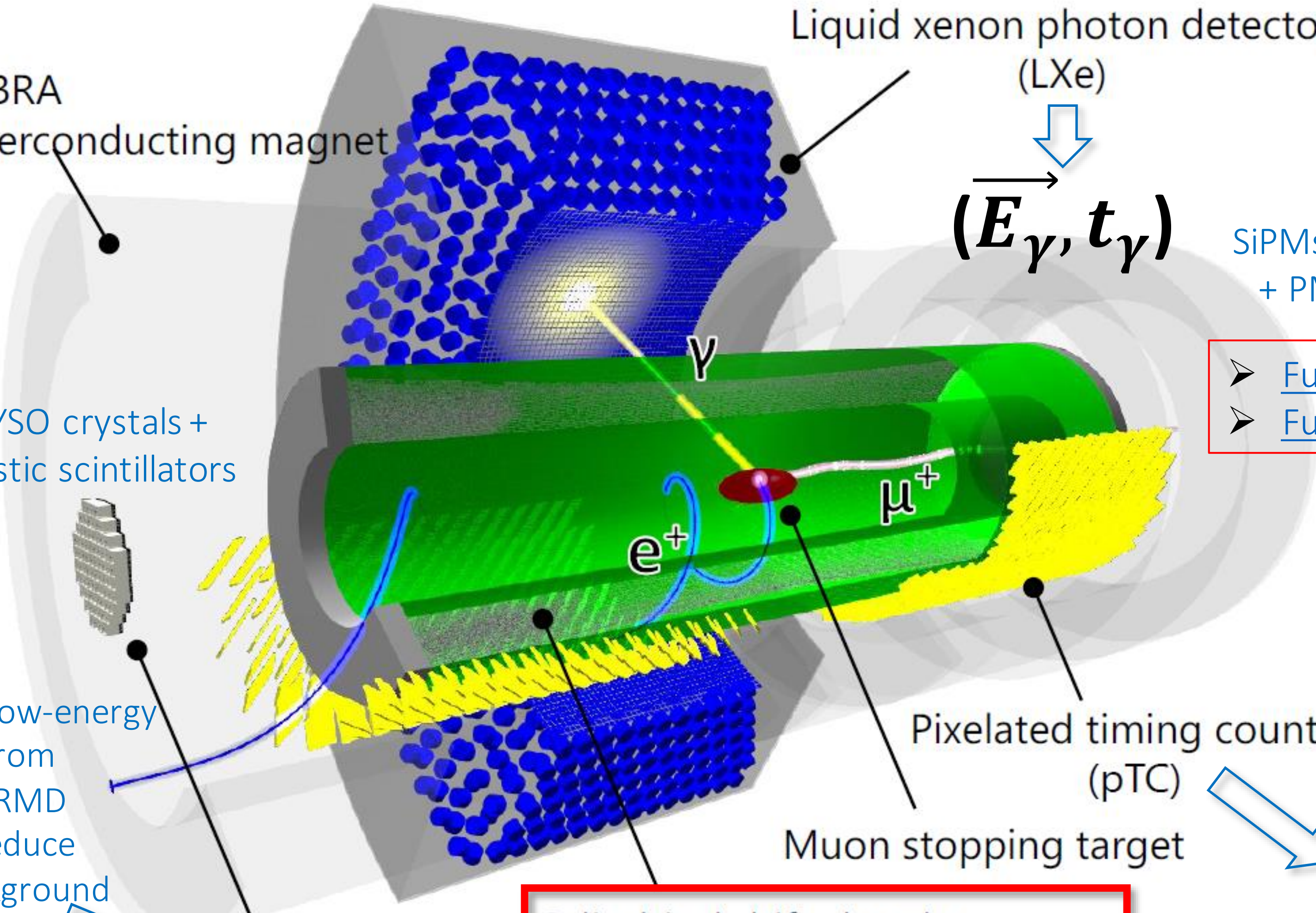


Accidental

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

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

The MEG II experiment



COBRA superconducting magnet

Liquid xenon photon detector (LXe)

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

LYSO crystals + plastic scintillators

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

Radiative decay counter (RDC)

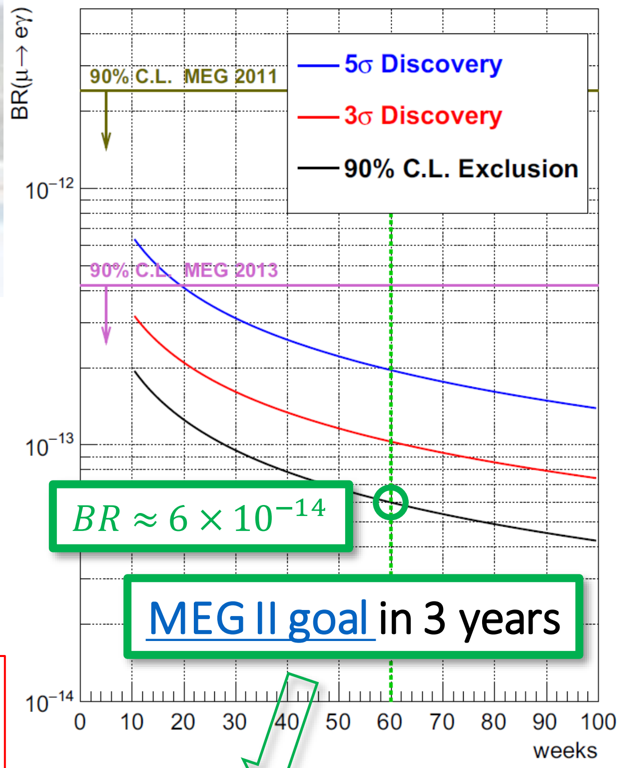
Cylindrical drift chamber (CDCH) $\overrightarrow{E_{e^+}}$

Muon stopping target

Pixelated timing counter (pTC) t_{e^+}

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

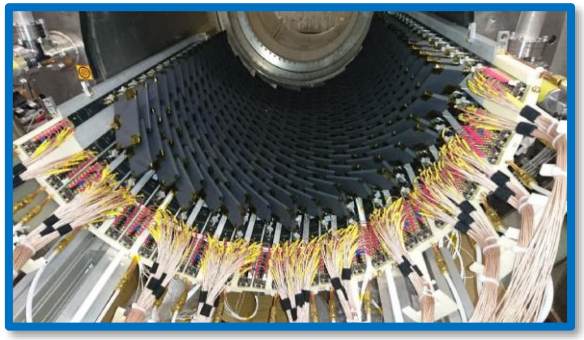
- Full design paper
- Full commissioning paper



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

MEG II goal in 3 years

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

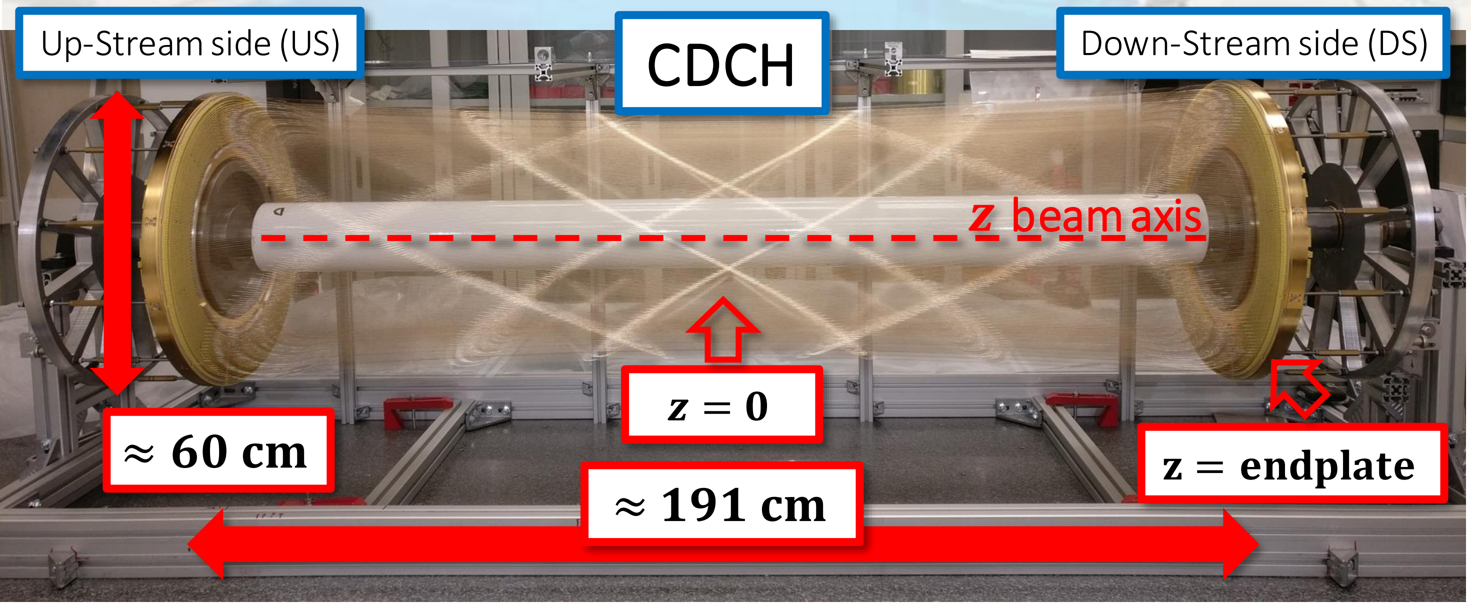


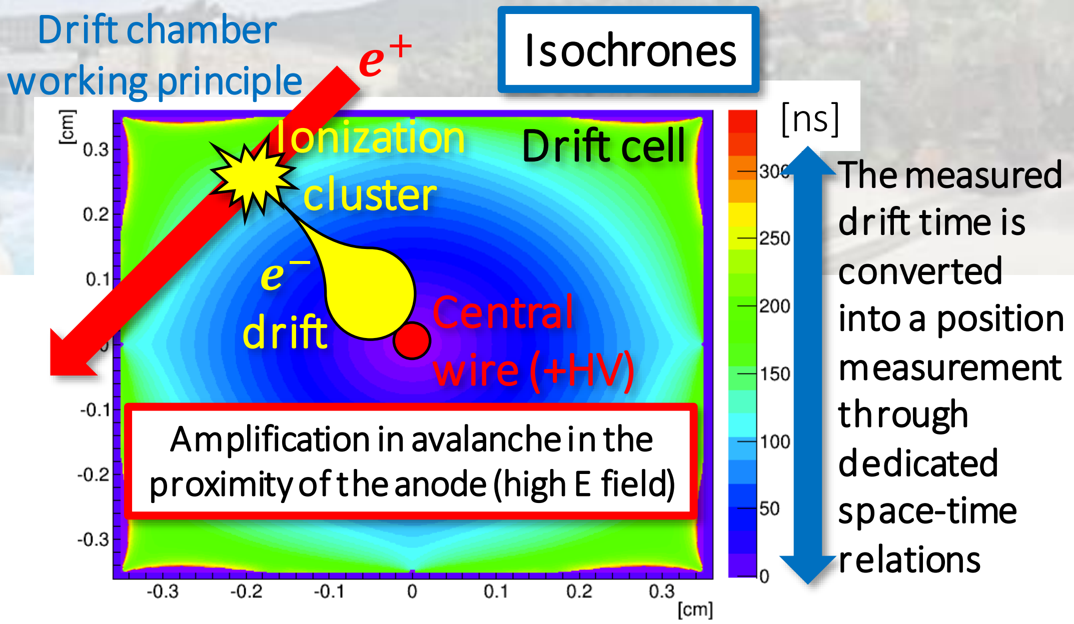
Plastic scintillators tiles read out by SiPMs

The MEG II Cylindrical Drift CHamber (CDCH)

- Design and assembly
- Commissioning

Detector performance



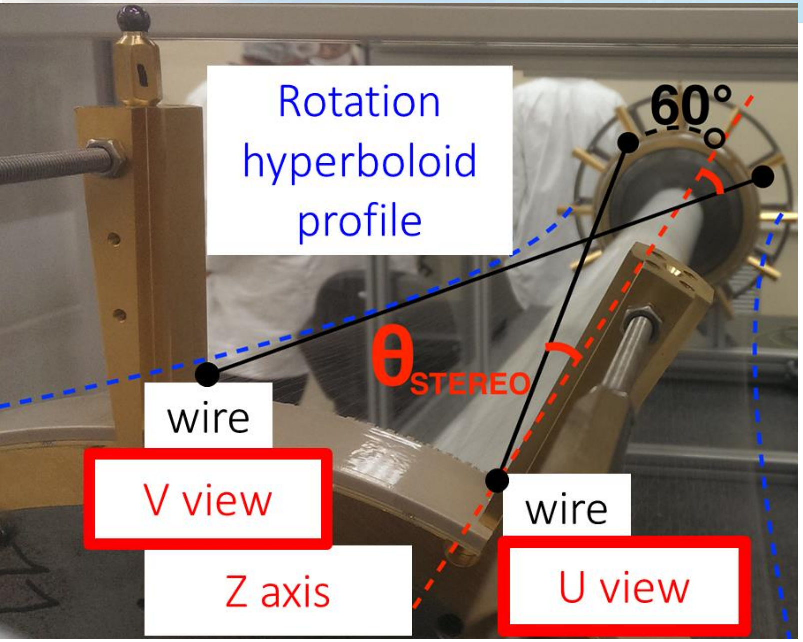


e^+ variable	MEG	MEG II
ΔE_e (keV)	380	100
$\Delta\theta_e$, $\Delta\varphi_e$ (mrad)	9.4, 8.7	7.2, 5.0
ΔZ, ΔY (at target, mm)	2.4, 1.2	1.8, 0.8
$\varepsilon_{tracking} \times \varepsilon_{match}$ (%)	65 × 45	69 × 89

- Currently most updated reconstruction algorithms with full MC simulations
- Still margin of improvements

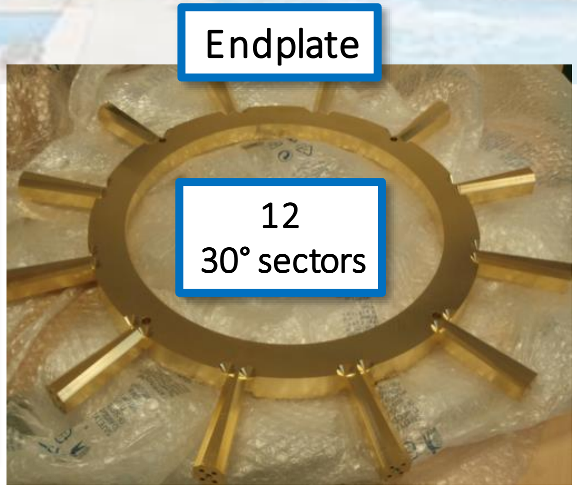
- Low-mass single volume detector with high granularity filled with He:iC_4H_{10} 90:10 gas mixture
  - + additives to improve the operational stability: 1.5% isopropyl alcohol + 0.5% Oxygen
  - 9 concentric layers of 192 drift cells defined by 11904 wires
  - Small cells few mm wide: occupancy of ≈1.5 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

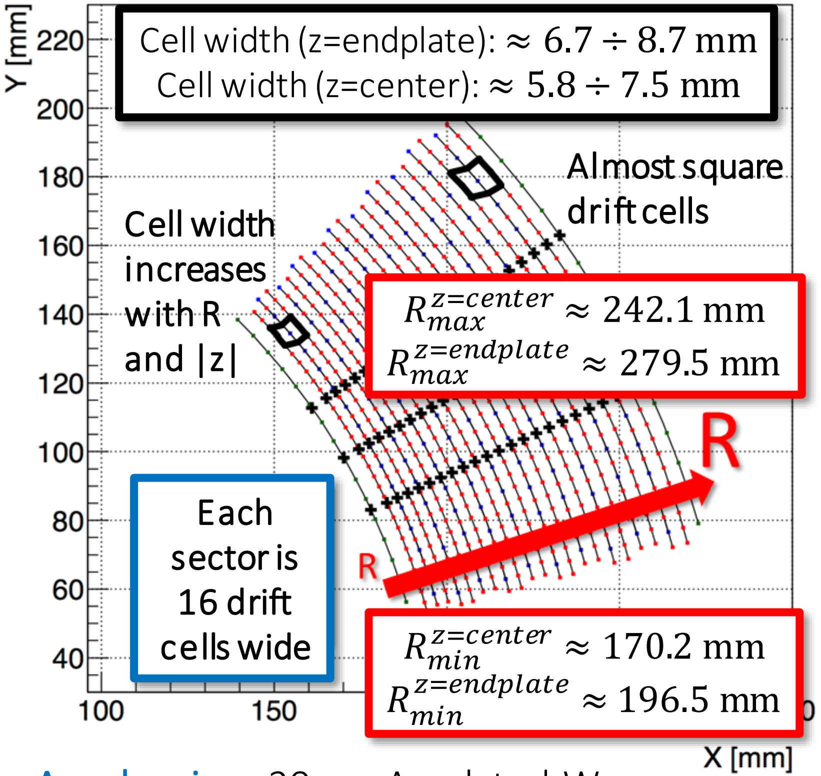
Design and wiring

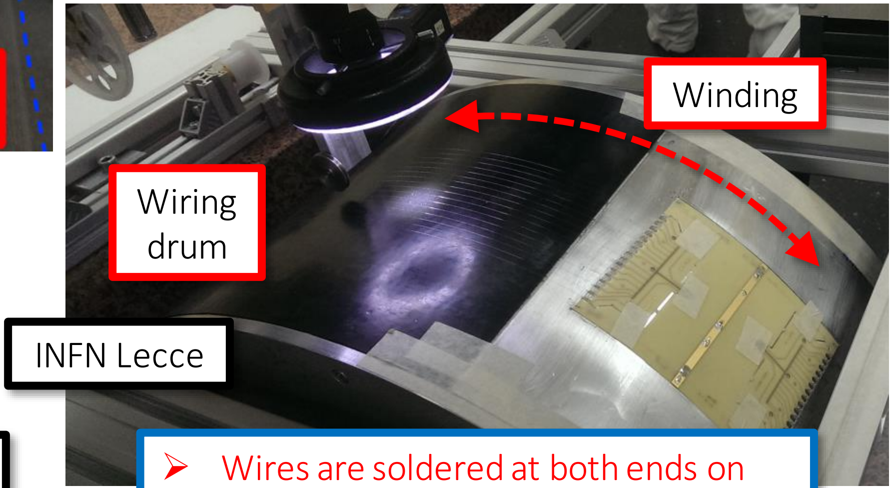


Stereo wires geometry for longitudinal hit localization

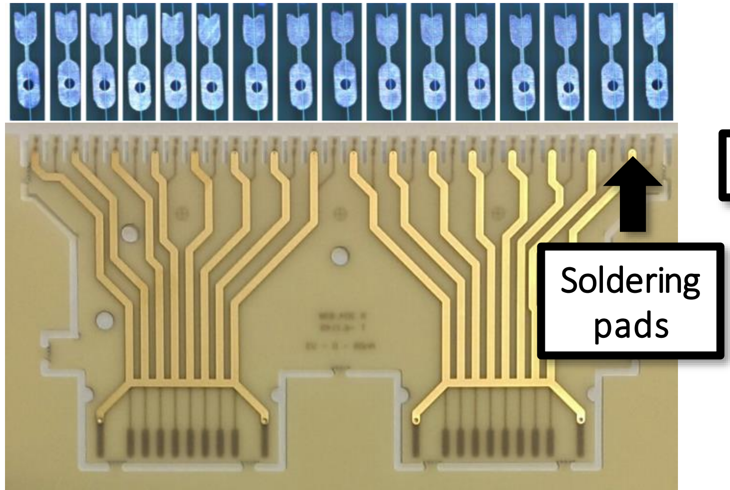
- $\theta_{stereo} \approx 6° \div 8.5°$ as R increases



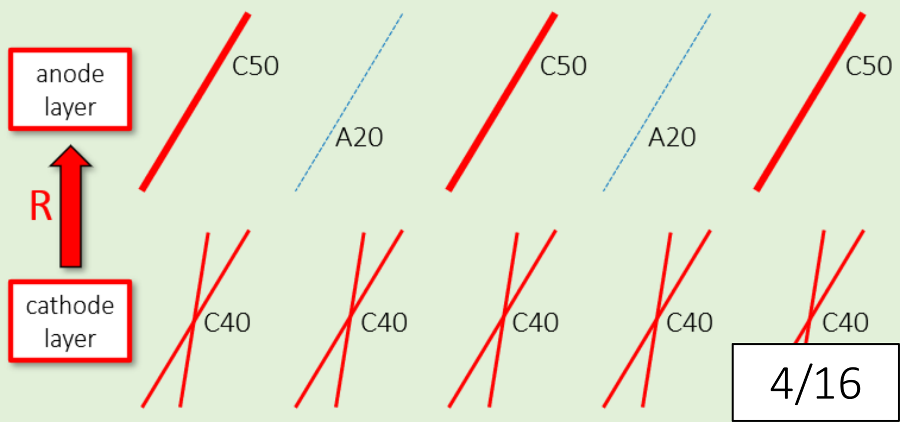




- Wires are soldered at both ends on the pads of 2 PCBs (wire-PCBs) which are then mounted on CDCH endplates
- Wiring inside a cleanroom

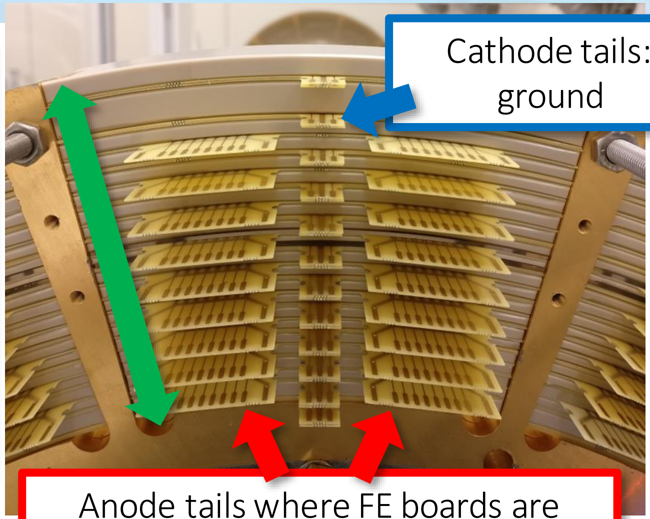


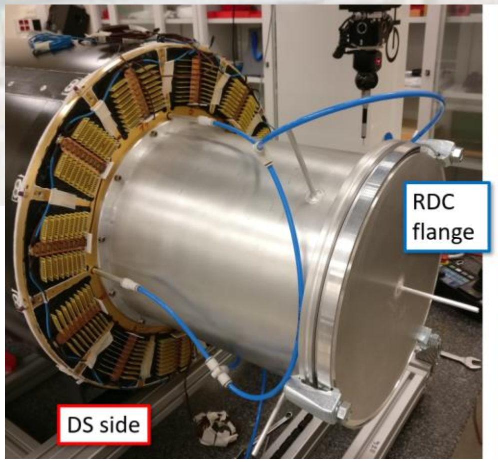
- **Anode wires**: 20 μm Au-plated W
- **Cathode wires**: 40/50 μm Ag-plated Al
  - **40 μm ground mesh between layers**
- **Guard wires**: 50 μm Ag-plated Al
- **Field-to-Sense wire ratio 5:1**

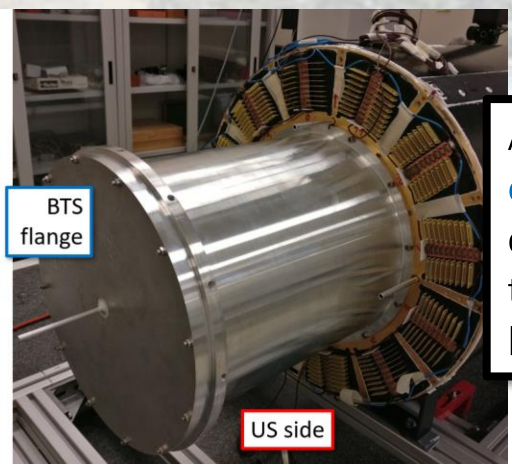


Mechanical structure

- Modular assembly inside a cleanroom
- Final stack of wire-PCBs in one sector
- PEEK spacers adjustment after CMM geometry measurements

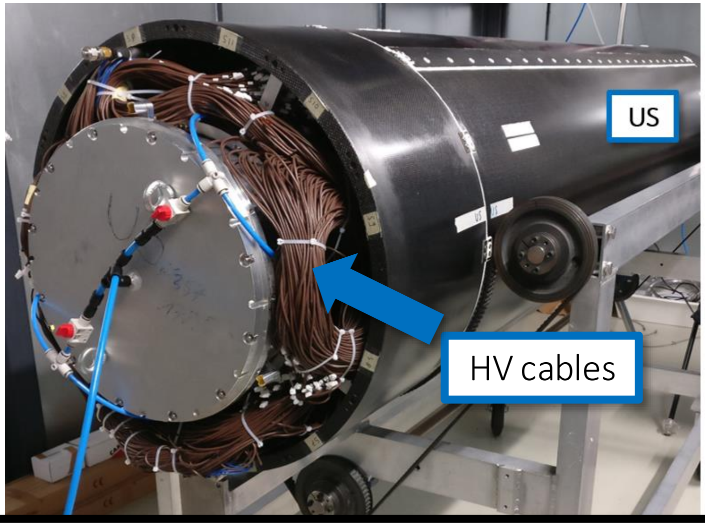


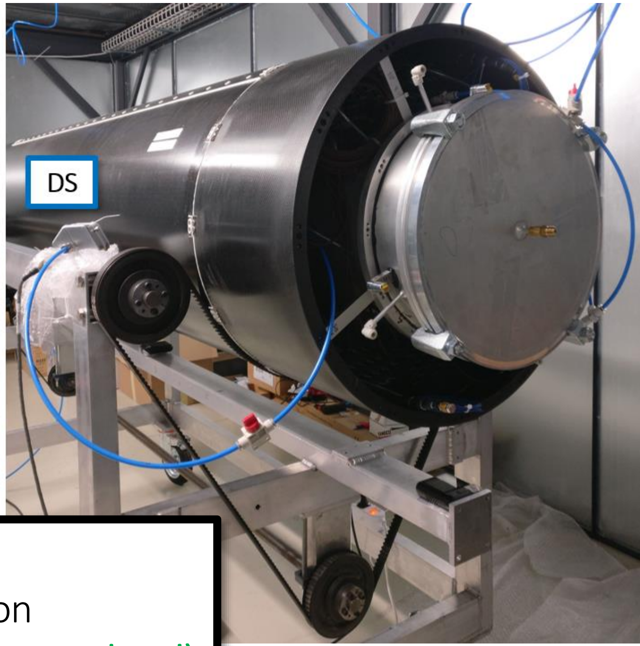




Aluminum inner extensions to connect CDCH to the MEG II beam line

- 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

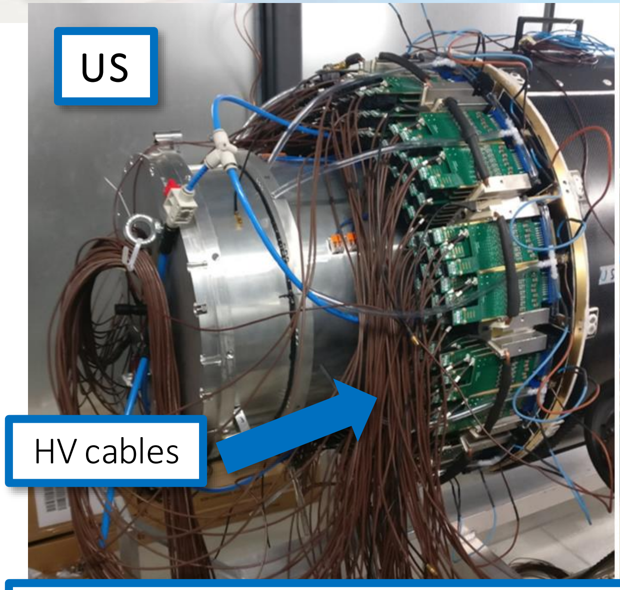


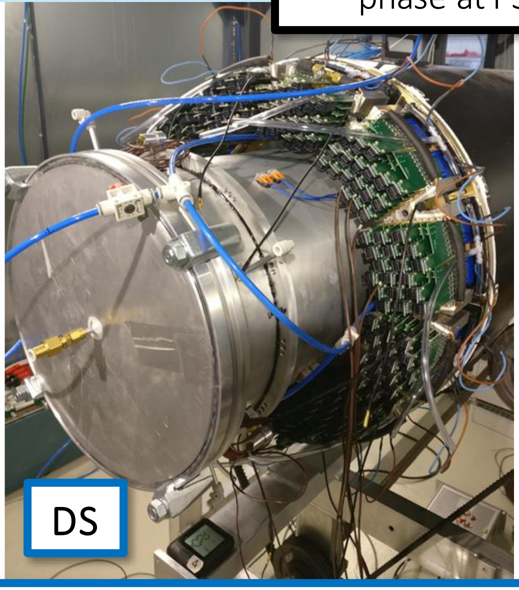


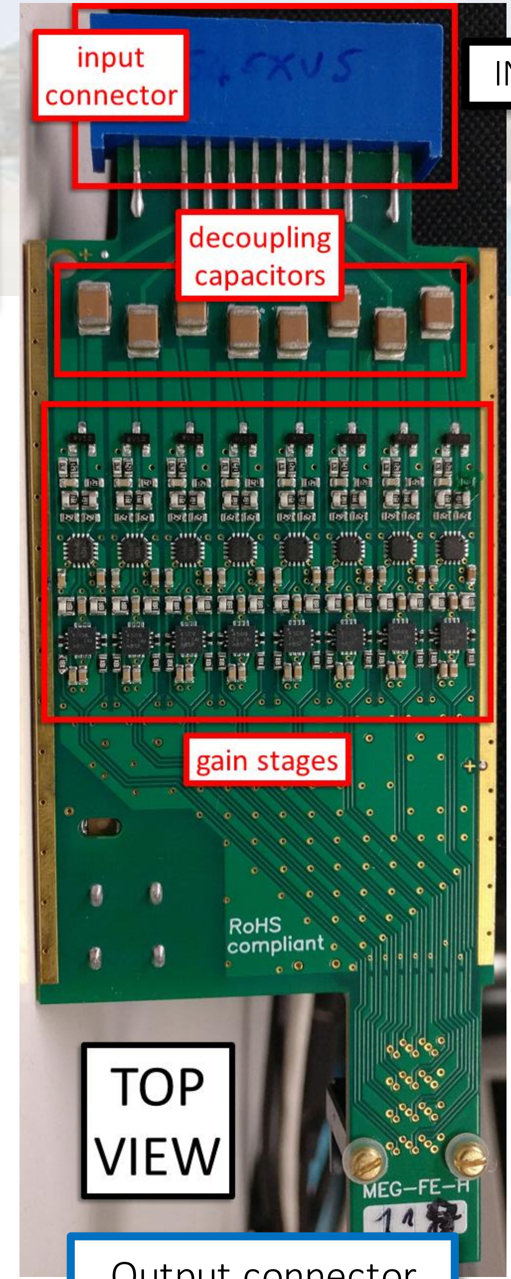
- External CF structure
  - Structural + gas tightness function
- CDCH mechanics proved to be stable (at μm level) and adequate to sustain a full MEG II run

FE electronics

Some pictures from the commissioning phase at PSI

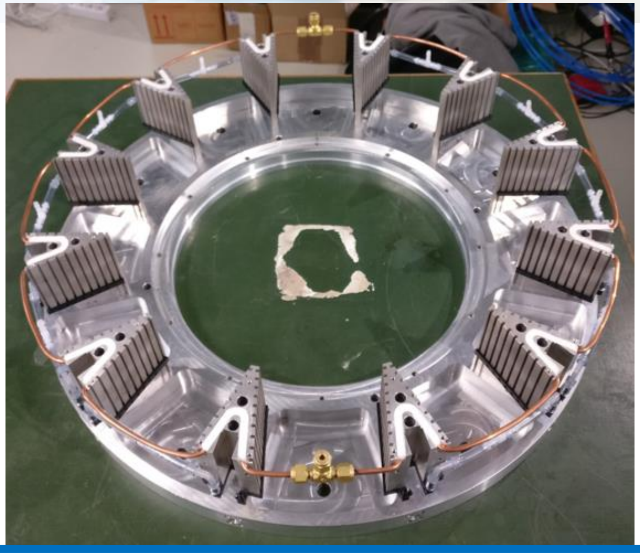






Output connector and HV stage on the bottom side

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



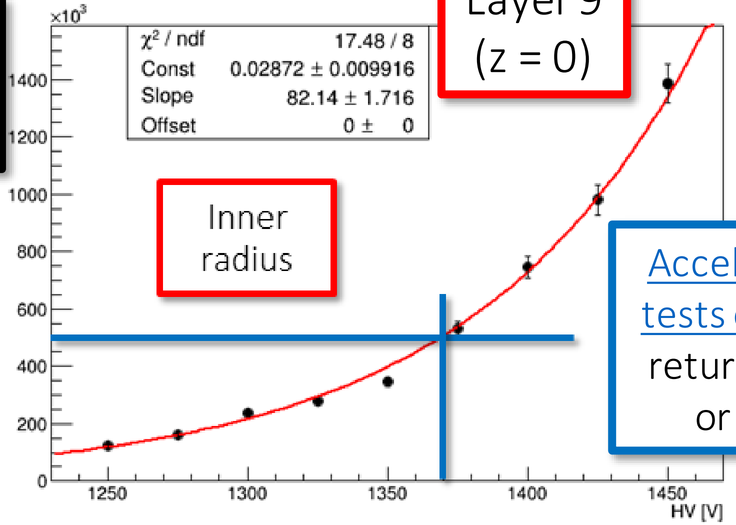
- 216 FE boards per side
  - 8 differential channels to read out signal from 8 cells
  - Double amplification stage with low noise and distortion
  - High bandwidth of nearly 400 MHz
    - To be sensitive to the single ionization cluster and improve the drift distance measurement (cluster timing technique)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

- 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

Working point

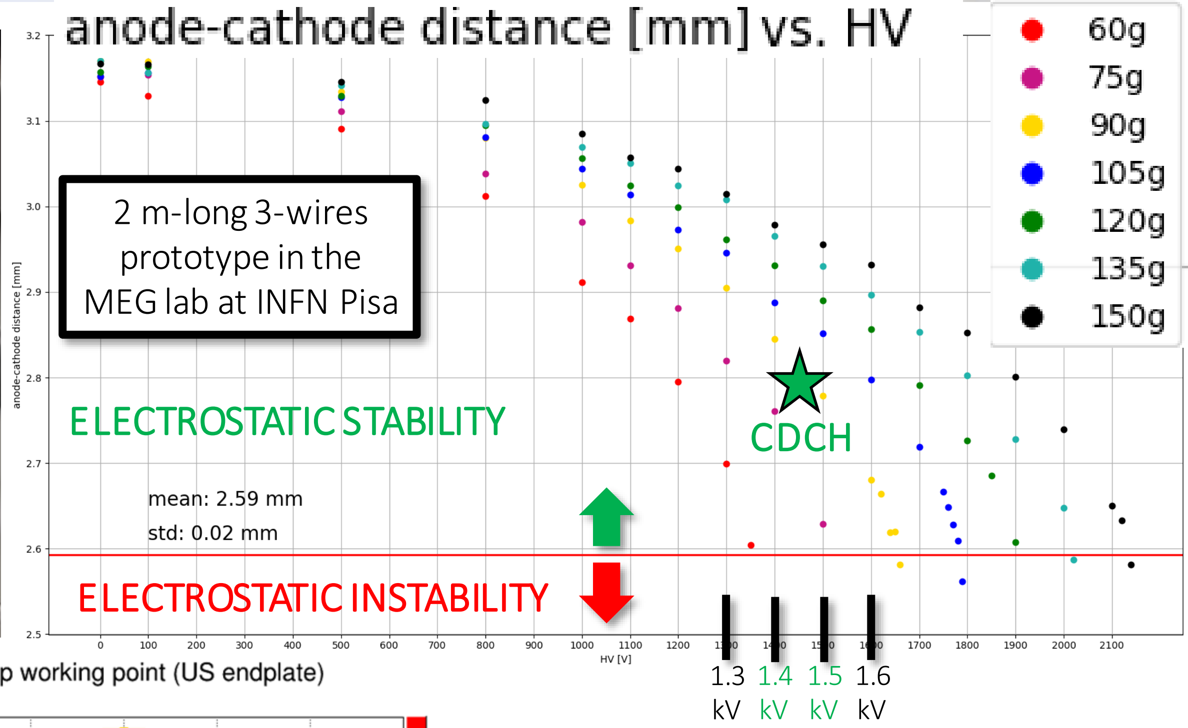
Gain

Layer 9 (z = 0)

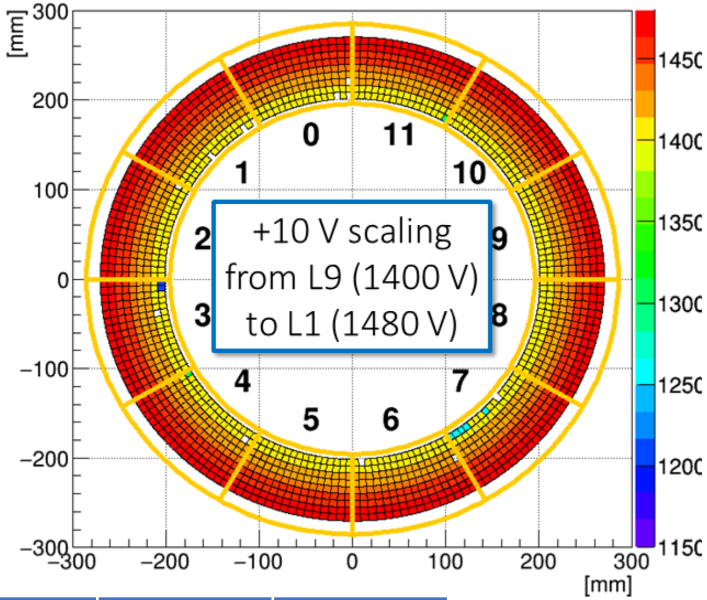


[Accelerated ageing tests on prototypes]() returned no issues or discharges

- 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 map working point (US endplate)



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

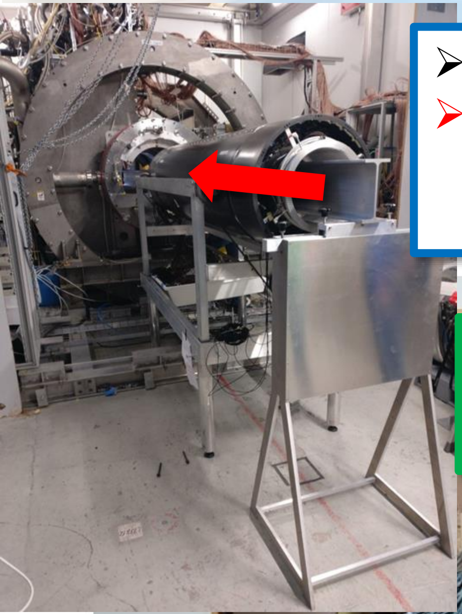
- Tests performed in 2019 and 2020 at PSI inside a cleanroom
- CDCH length adjusted through geometry survey campaigns with a laser tracker (20 μm accuracy)
- Final length set to +5.2 mm of wires elongation
  - 65% of the elastic limit

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

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

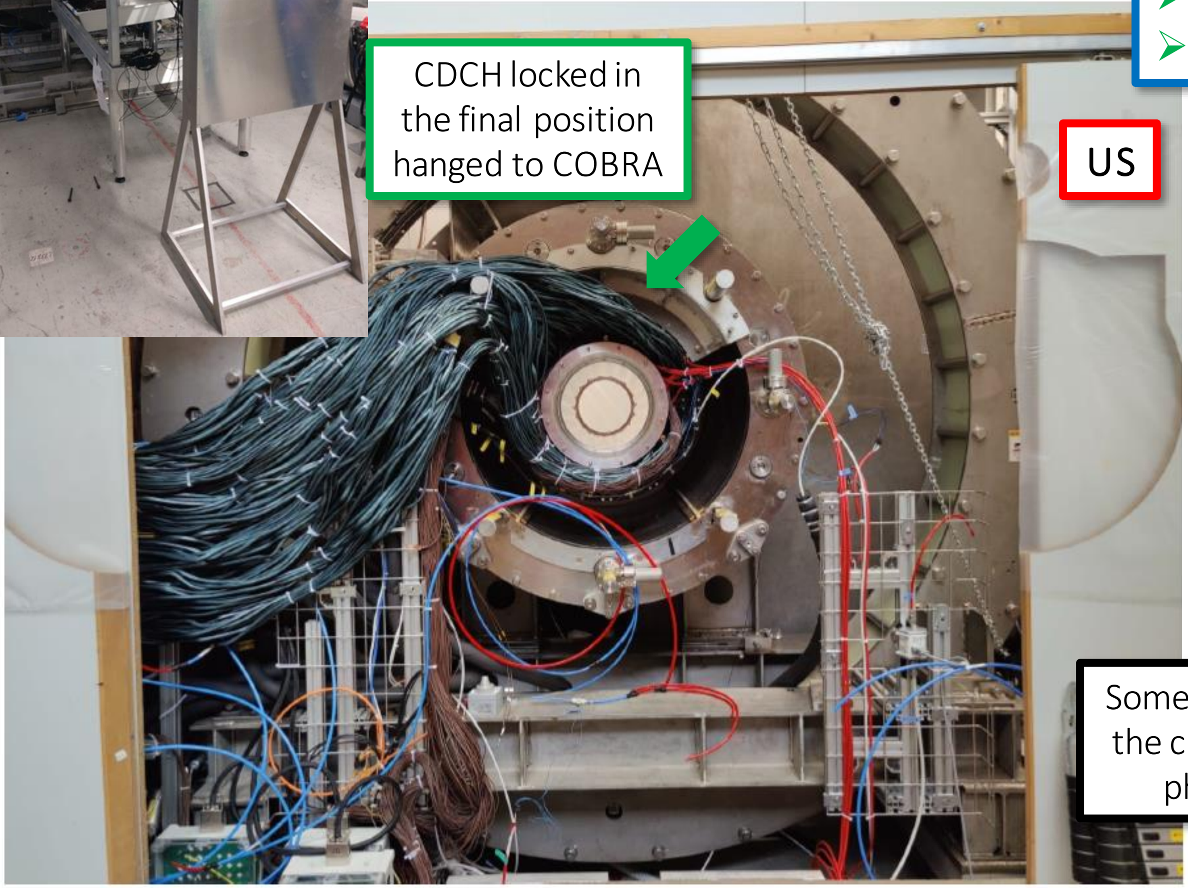
L1	L2	L3	L4	L5	L6	L7	L8	L9
1480 V	1470 V	1460 V	1450 V	1440 V	1430 V	1420 V	1410 V	1400 V

Integration into the MEG II apparatus



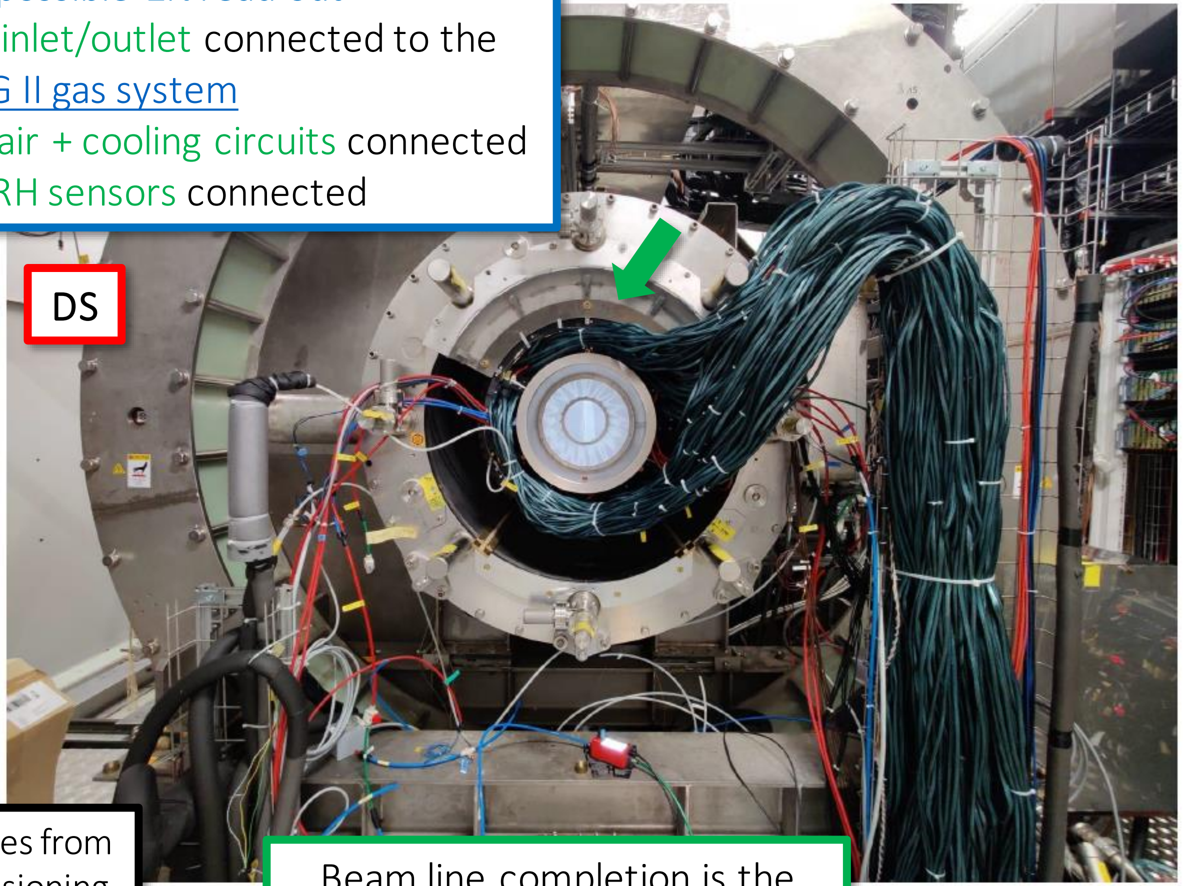
- CDCH inside the experimental area
- Insertion rail through the inner volume to slide CDCH inside the COBRA magnet

- 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

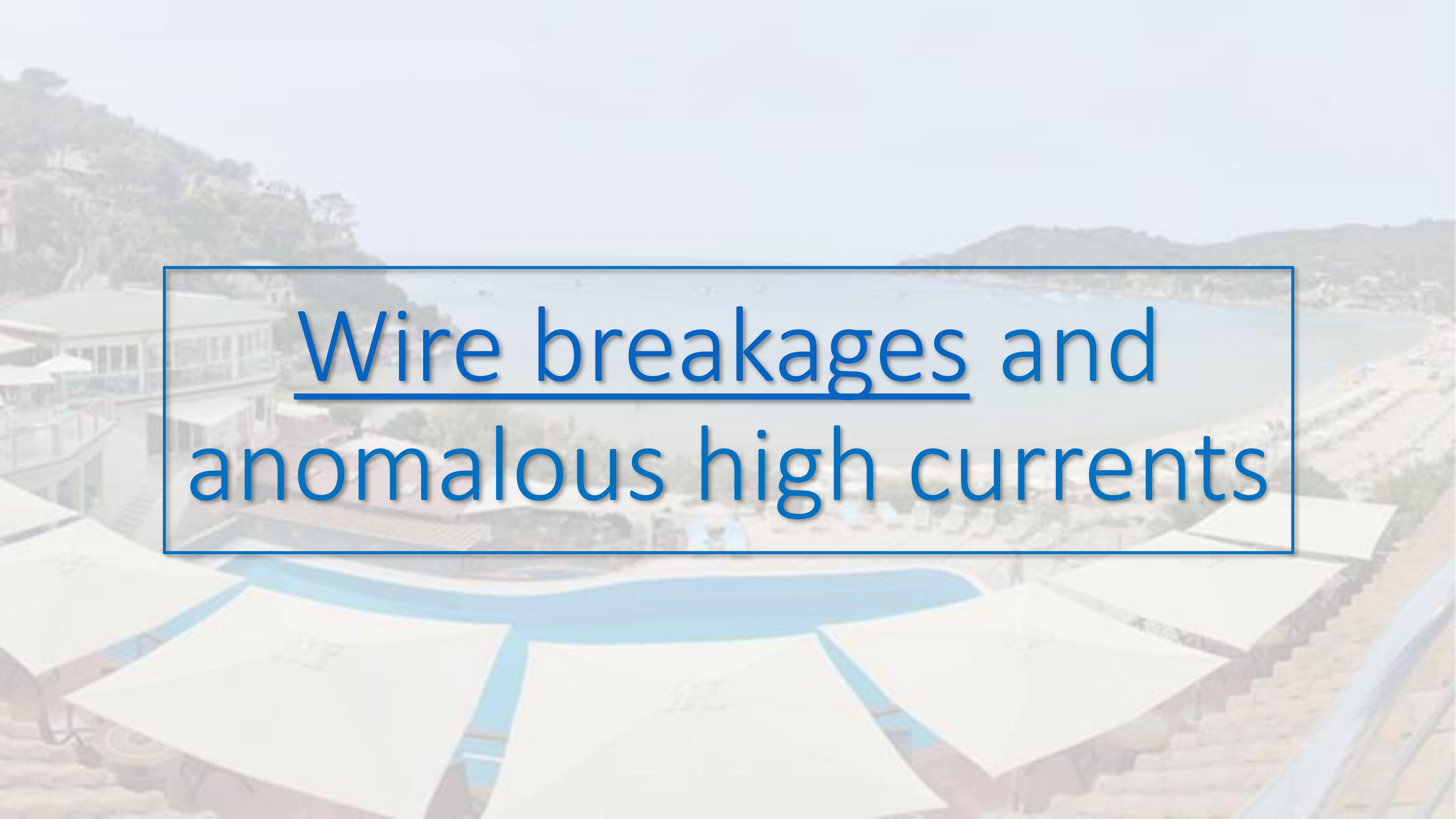
US



DS

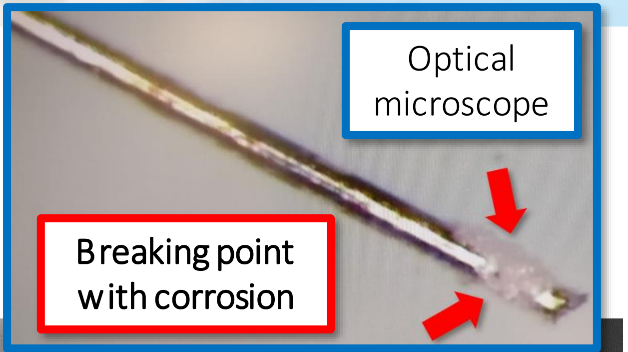
Some pictures from the commissioning phase at PSI

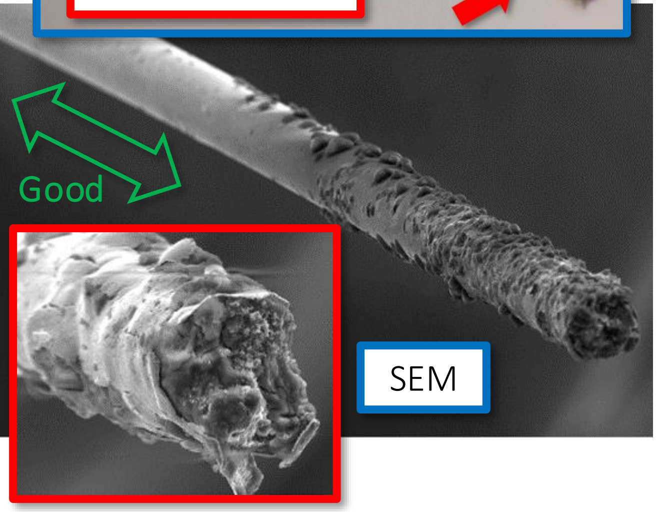
Beam line completion is the last operation (not shown here)

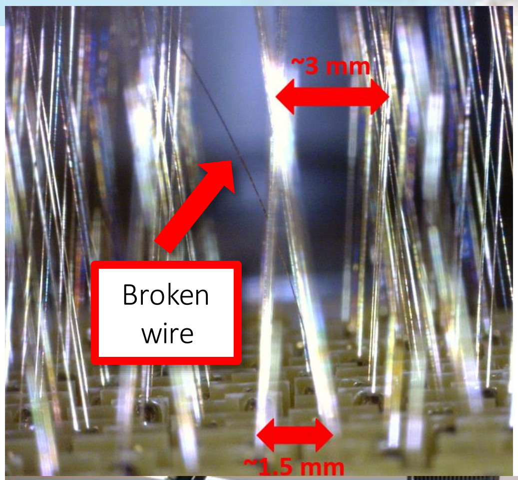


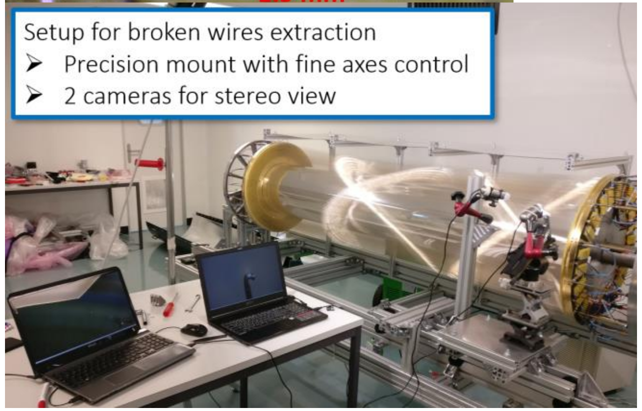
Wire breakages and anomalous high currents

Problems along the path

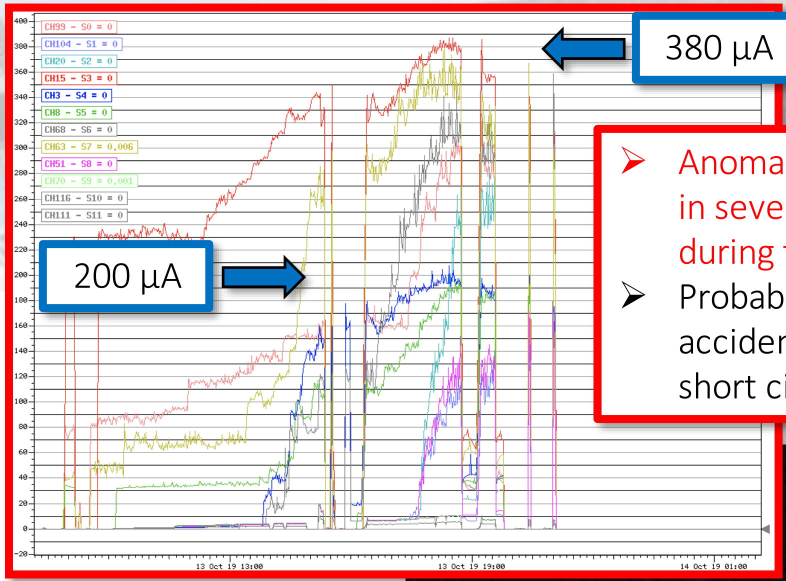




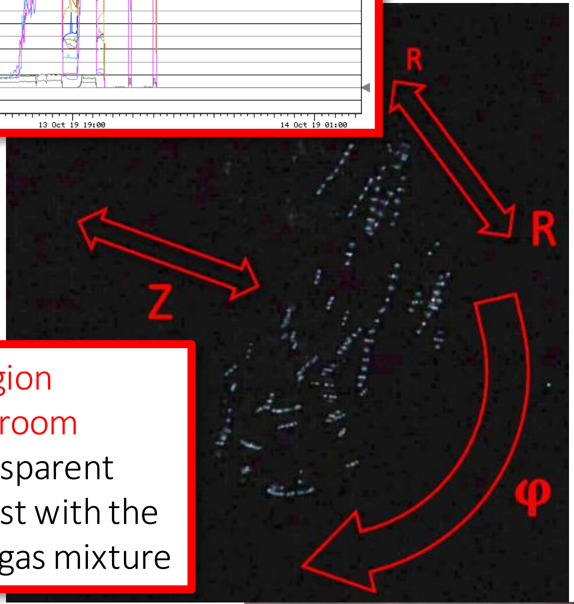




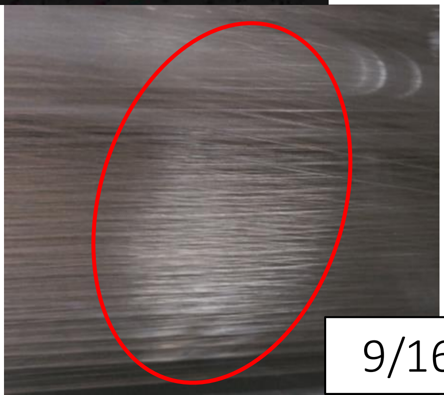
- ➢ Breaking of 107 Al wires (90% 40 µm wire) in presence of humidity
- ➢ All broken wires successfully removed and eliminated other possible damaged wires by extra stretching CDCH (then again CDCH at the working length)
- ➢ No more broken wires due to corrosion since CDCH kept in inert atmosphere (flushed with Nitrogen or Helium once sealed)



- ➢ Anomalously high currents in several sectors/layers during the data taking
- ➢ Probably triggered by an accidental anode-cathode short circuit



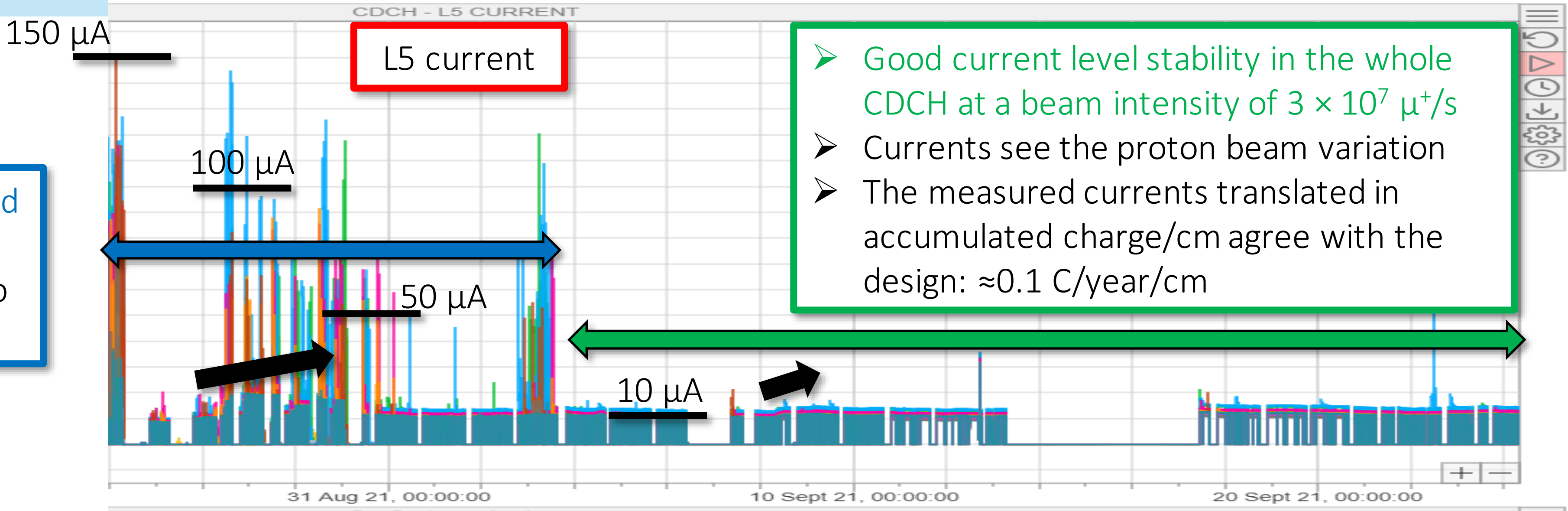
- ➢ One of the discharge region photographed in a dark room
- ➢ CDCH closed with a transparent plexiglas shell and HV test with the standard He:IsoB 90:10 gas mixture



- ➢ Corona-like discharges in correspondence of 6 whitish regions
- ➢ Problem cured with additives in the gas mixture
- ➢ Oxygen proved to be effective in reducing high currents (plasma cleaning?)
- ➢ Isopropyl alcohol crucial to keep stable the current level

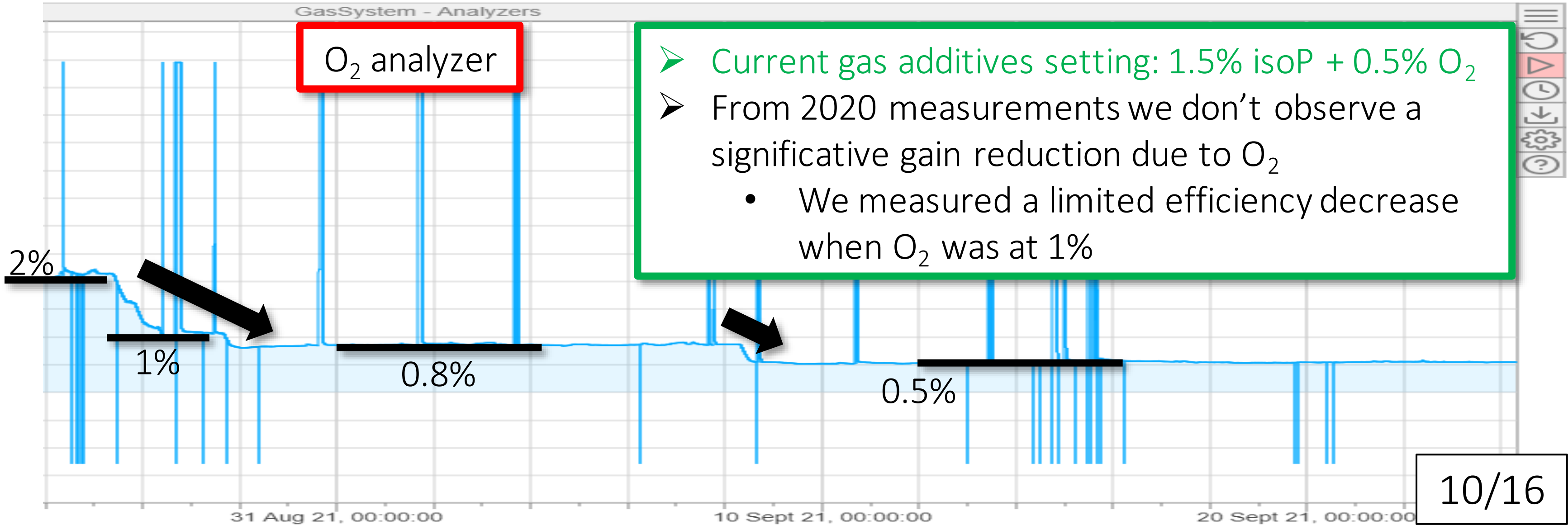
Conditioning with μ^+ beam

- 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 $3 \times 10^7\ \mu^+/s$
- Currents see the proton beam variation
- The measured currents translated in accumulated charge/cm agree with the design: ≈0.1 C/year/cm

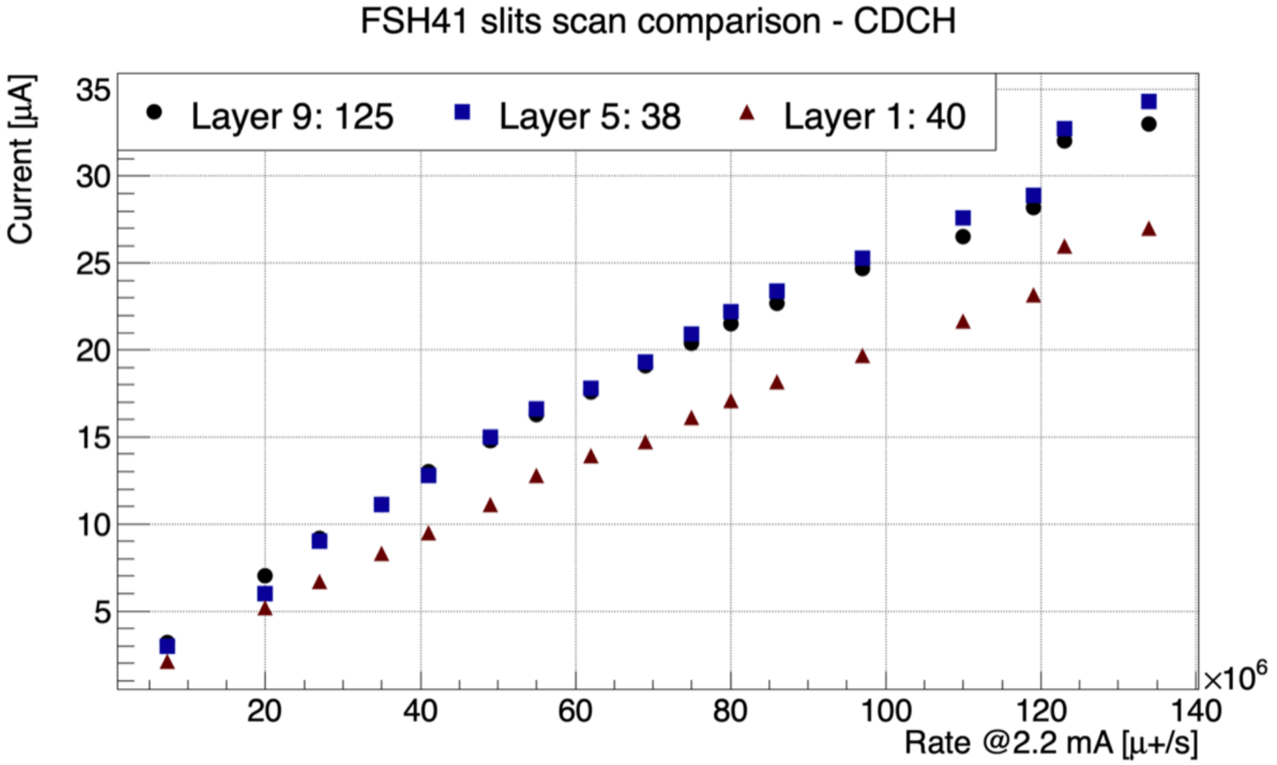
- We are very sensitive to the isopropyl alcohol concentration
- We experienced that 1-1.5% isoP concentration is crucial to keep the stability

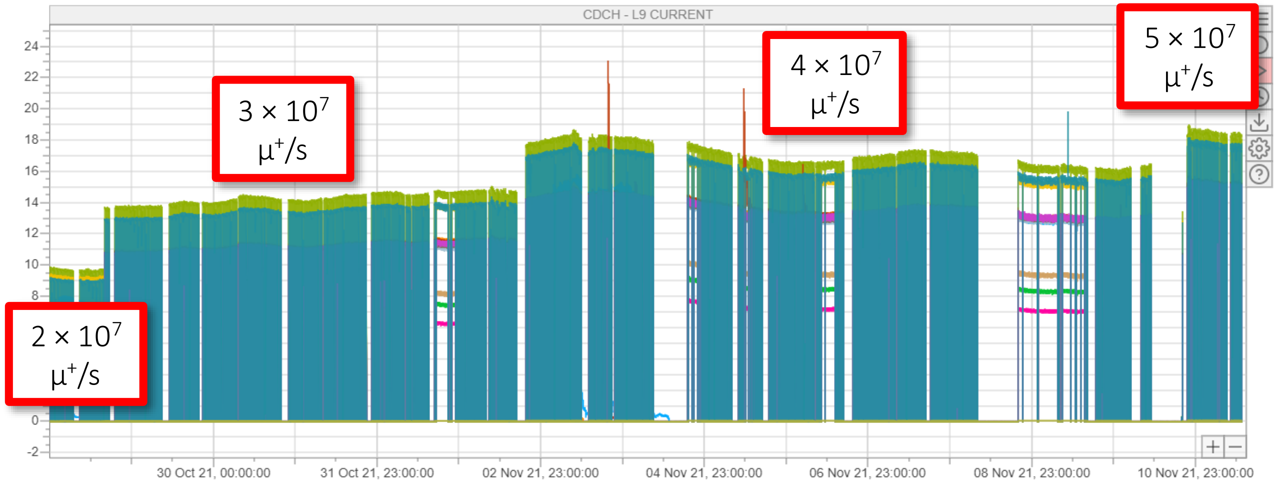


- Current gas additives setting: 1.5% isoP + 0.5% O_2
- From 2020 measurements we don't observe a significative gain reduction due to O_2
  - We measured a limited efficiency decrease when O_2 was at 1%

CDCH currents vs. μ^+ beam intensity

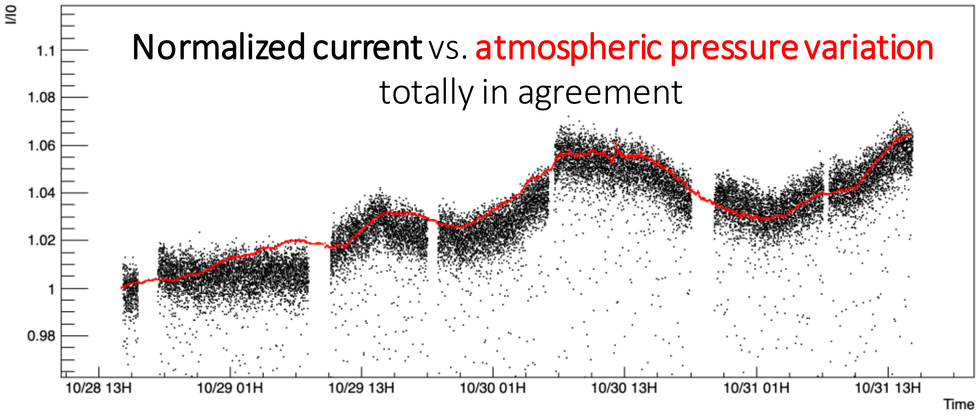
- CDCH currents followed reasonably well the beam intensity up to intensities never reached before
- The proportionality to the μ^+ rate is good





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

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

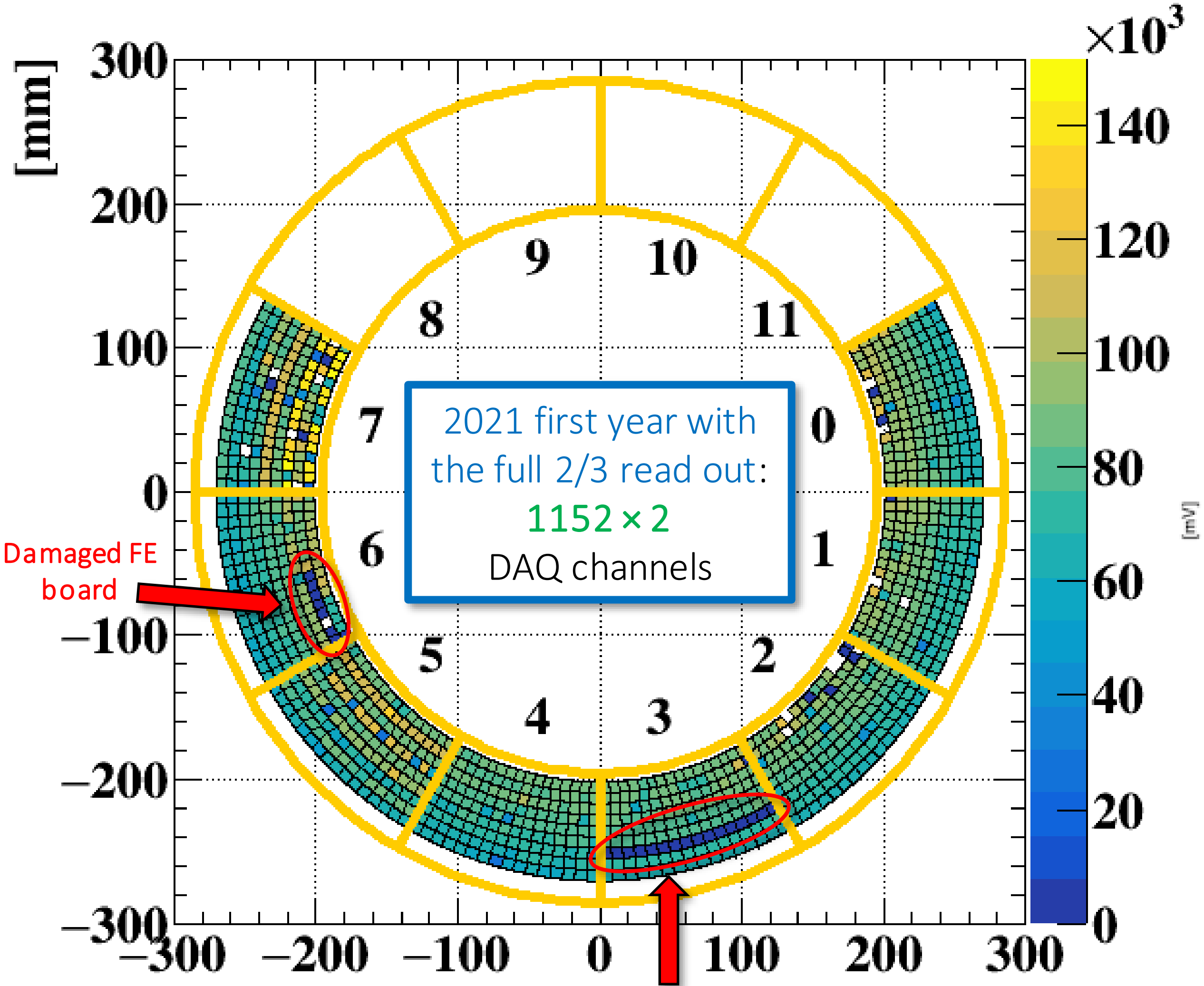


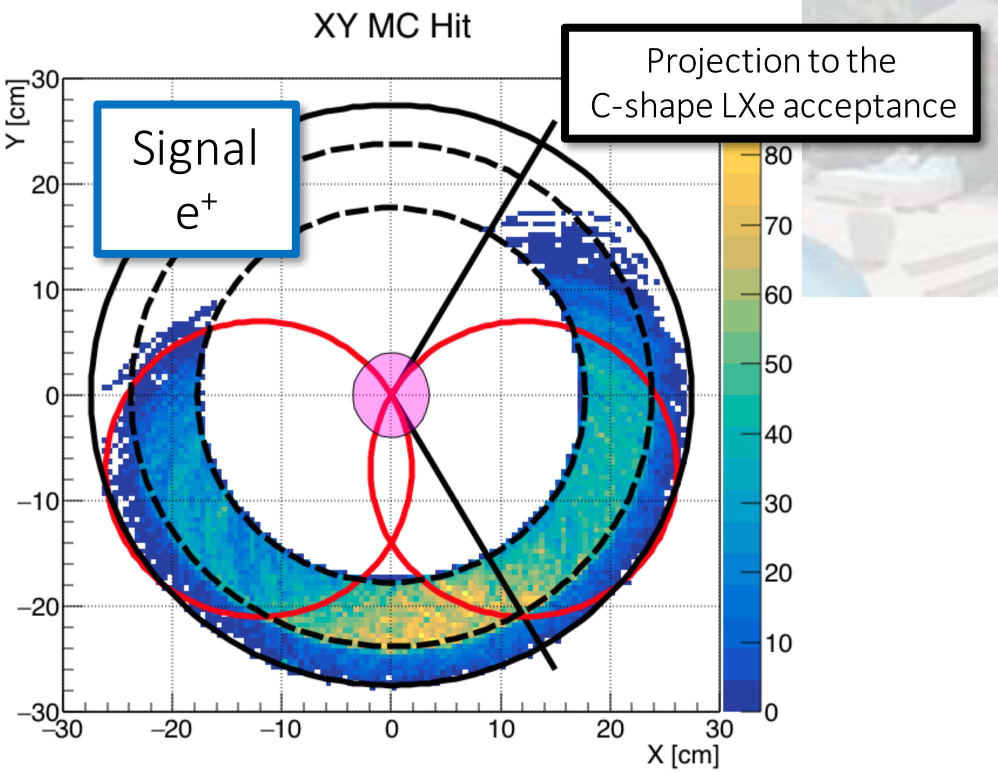
$$\frac{I}{I_0} = 1 - k\frac{\Delta P}{P}$$

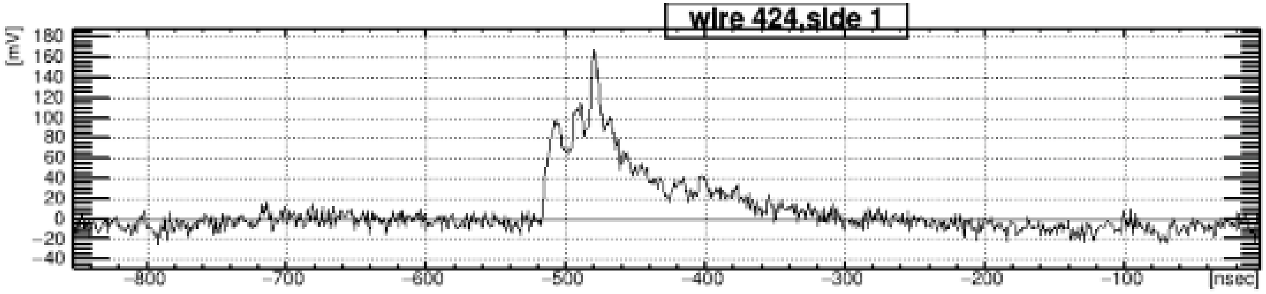
$$k = 5$$

Start of the physics data taking

Full 2/3 readout



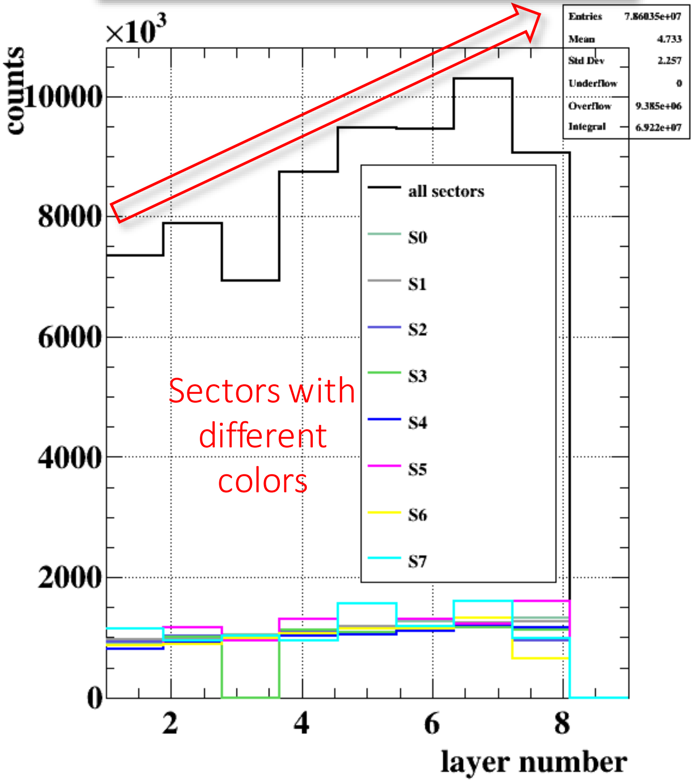




- ➢ In MEG all the signal WF is recorded
- ➢ Then a fine analysis is made offline to get the hit information
  - Timing, signal amplitude, signal integral, position
- ➢ **Coherent noise subtraction + 225 MHz digital low-pass filter** are applied

Occupancy, signal amplitude and gas gain

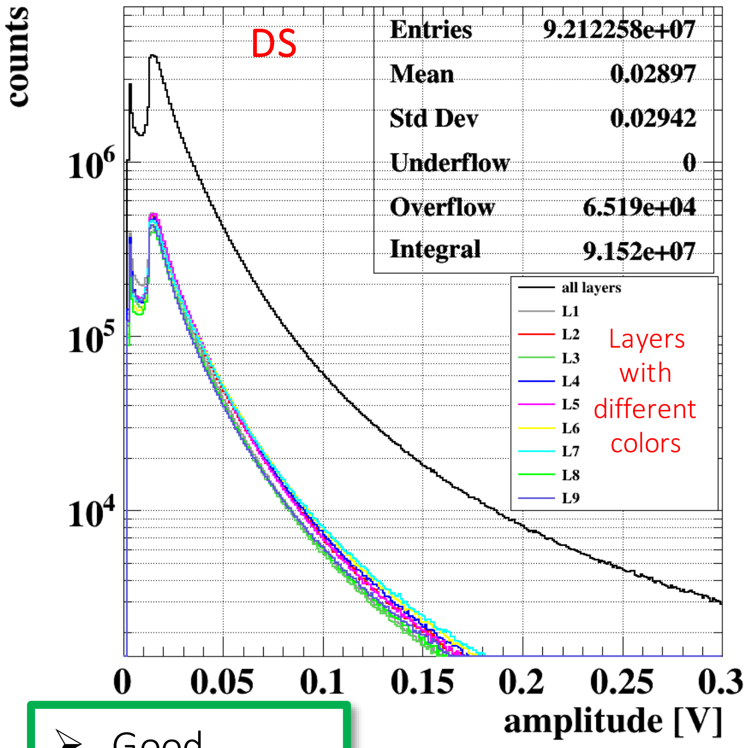
Occupancy vs. layer number



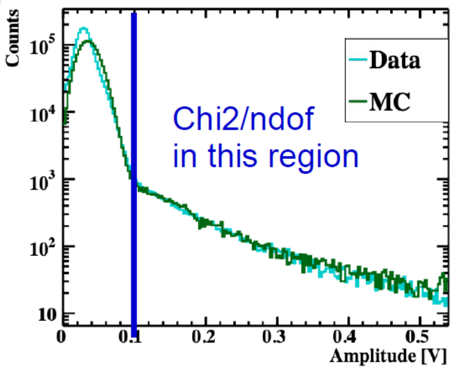
Outer layer

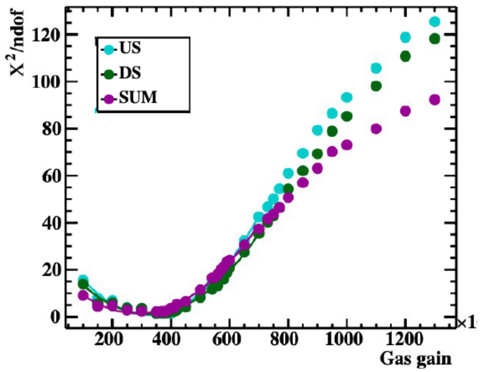
Inner layer

Scaling by radius as expected with Michel e^+ events

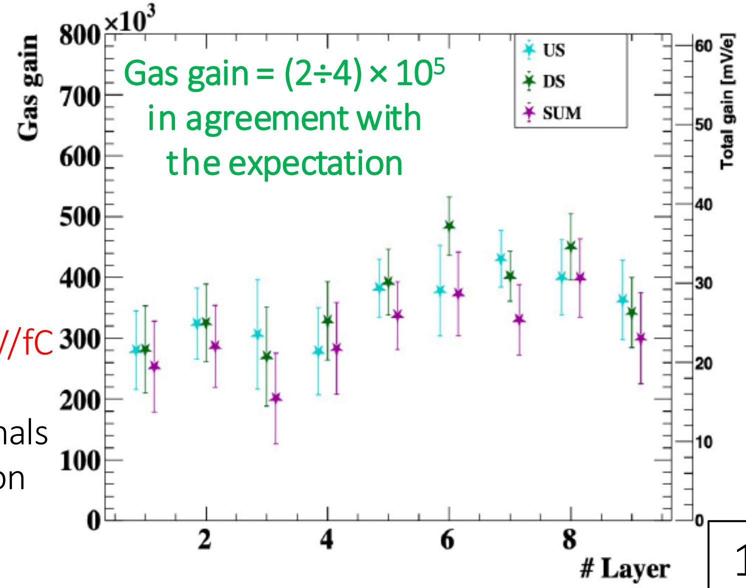


- Good uniformity between layers
- 10 V scaling of the HV works well



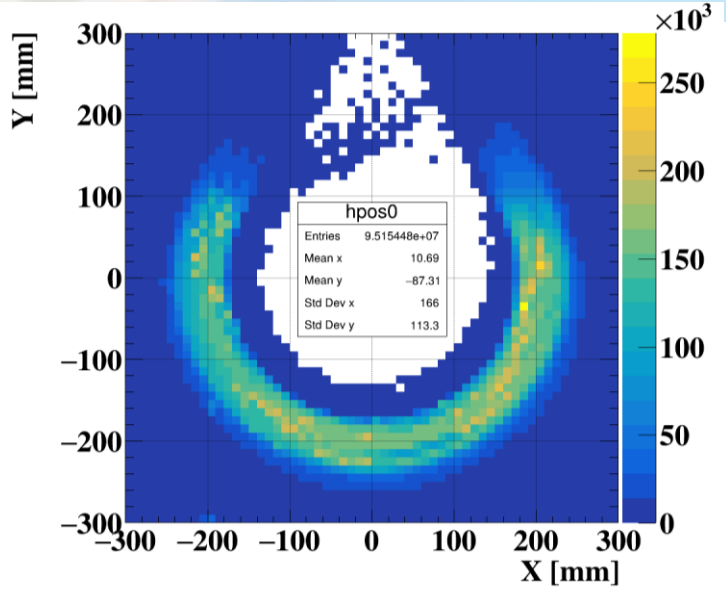


- **Signal amplitude distribution** from Cosmic Ray events: clean environment
- The only parameter to be tuned in MC to reproduce data is the Total gain = Gas gain × FE gain

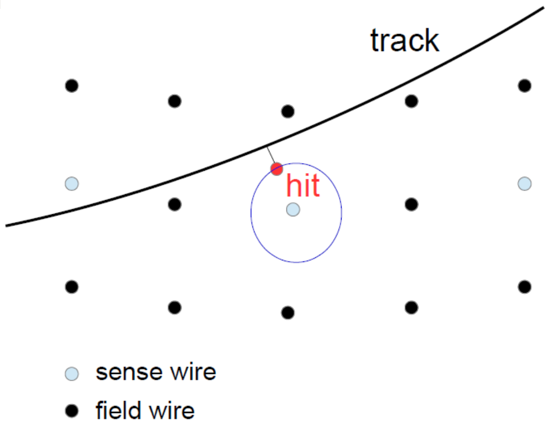


- FE gain measured to be 0.120 mV/fC
  - FE response to real single-electron drift chamber signals produced by laser ionization on a prototype
- Gas gain = Total gain / FE gain

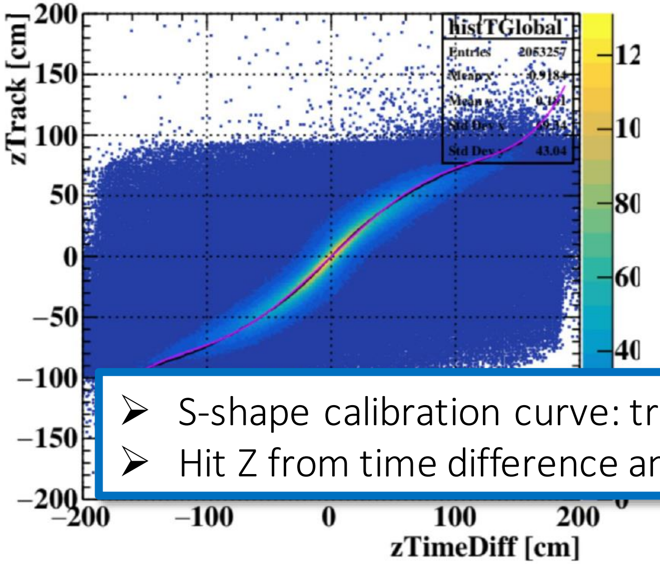
Reconstructed hit position and resolution

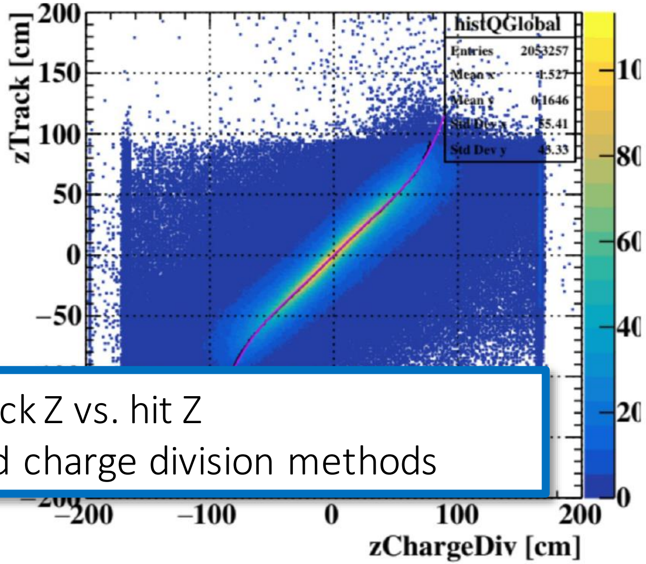


Preliminary: data analysis and continuous developments ongoing

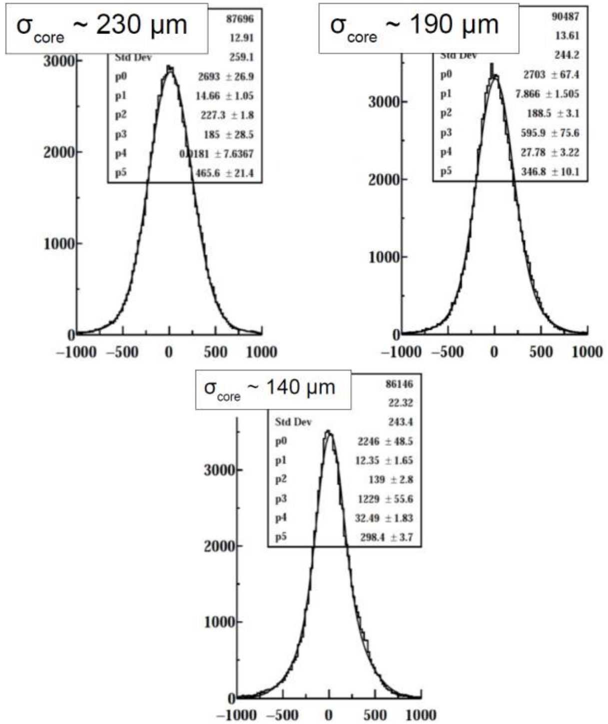


Hit-track residual gives a measurement of how misalignments, single-hit resolution and other systematics (B field) combine to determine the reconstruction performance





- S-shape calibration curve: track Z vs. hit Z
- Hit Z from time difference and charge division methods



Detector HW alignment only

- Wire positions only based on geometry survey

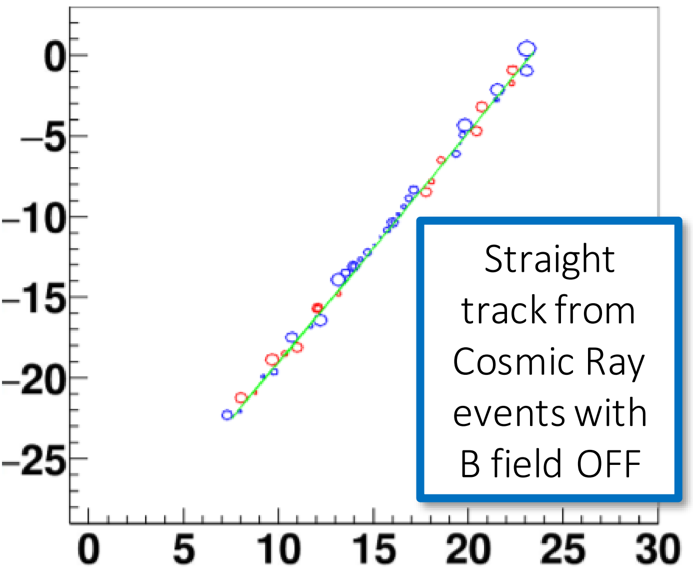
First version of SW alignment

- Wire sag to be implemented
- New TXY tables recently introduced → calibration

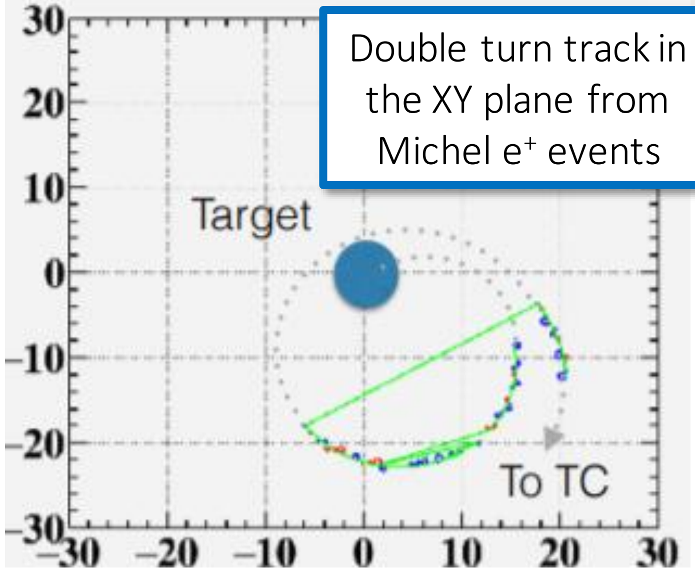
After correcting the drift time of CDCH hits using the correct propagation time from the hit to pTC

- Track-based SW alignment under development

Tracking and Momentum resolution



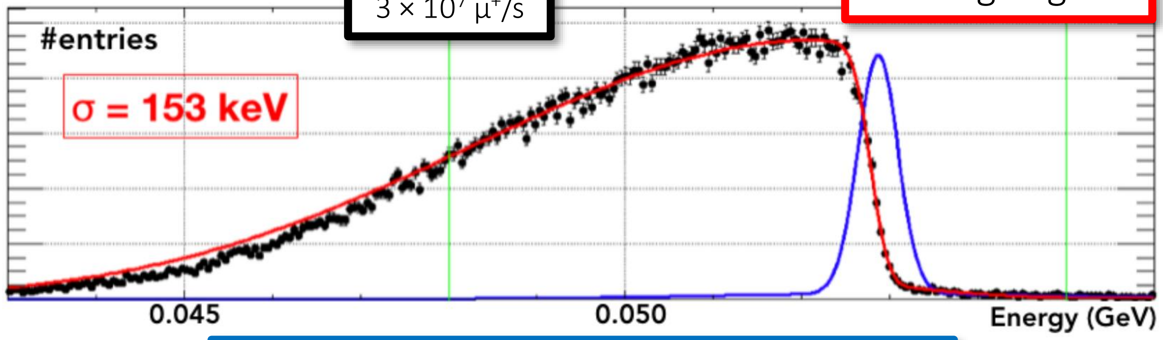
Straight track from Cosmic Ray events with B field OFF



Double turn track in the XY plane from Michel e⁺ events

Preliminary: data analysis and continuous developments ongoing

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

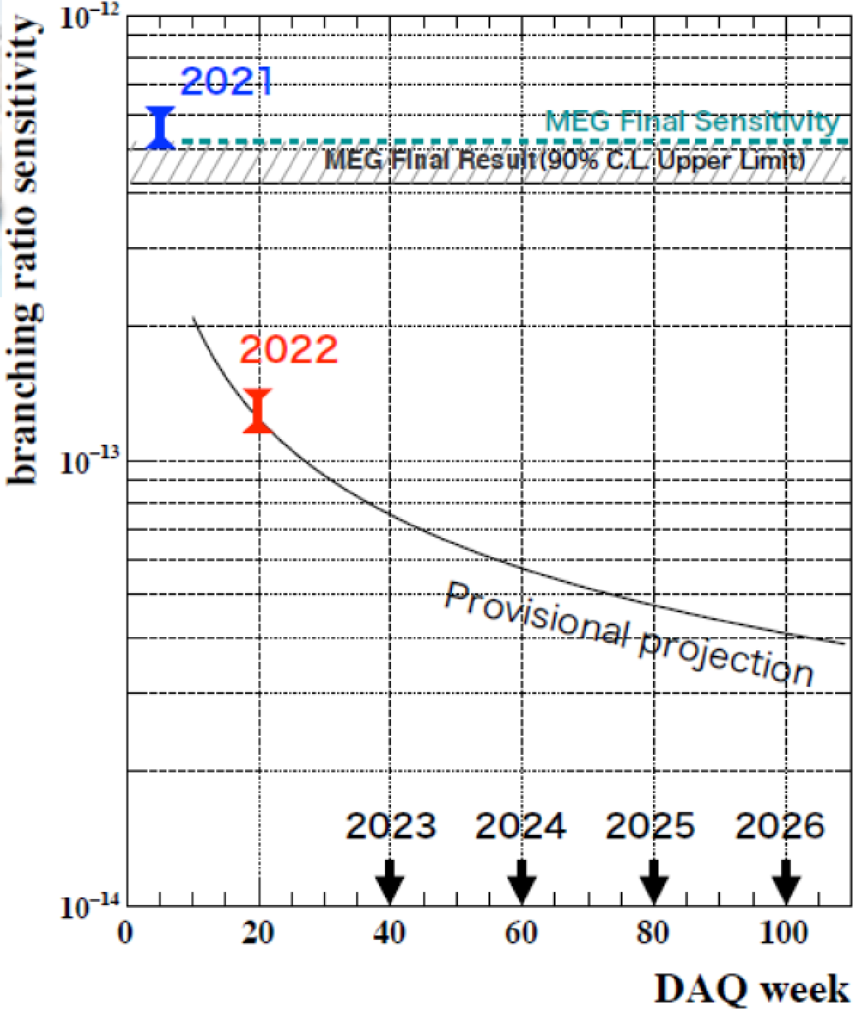


$$PDF(p) = [PDF_{THEORY}(p) \times Acceptance(p)] \otimes Resolution_{DOUBLE\text{-}GAUSSIAN}(\Delta p)$$

Full track trajectory from a Michel e⁺ event

e^+ variable	DATA PRELIMINARY
ΔE_e (keV)	≈150
$\Delta\theta_e, \Delta\varphi_e$ (mrad)	7.8, 6.2
$\Delta Z, \Delta Y$ (mm)	2.4, 0.9
$\varepsilon_{tracking}$ (%)	≈65

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 recently started the physics data taking
  - Some **preliminary results from 2021 data** have been presented
  - Data analysis and continuous developments ongoing
- Problems along the path
  - Corrosion and breakage of 107 aluminum wires in presence of humidity
    - 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 an accidental anode-cathode short circuit 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 $^7Li(p, e^+e^-)^8Be$ 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 → **first data analysis is ongoing**

Gas Detectors - Poster Session (May 27)

- Analysis and study of the problems on the wires used in the MEG CDCH and the construction of the new drift chamber
  - Gianluigi Chiarello (INFN Pisa)

- A new calibration tool for the MEGII spectrometer
  - Hicham Benmansour (INFN Pisa/PSI)

- A monitoring chamber for high precision measurements of the drift velocity in gas detectors
  - Federica Cuna (INFN Lecce)

THANKS
FOR YOUR ATTENTION