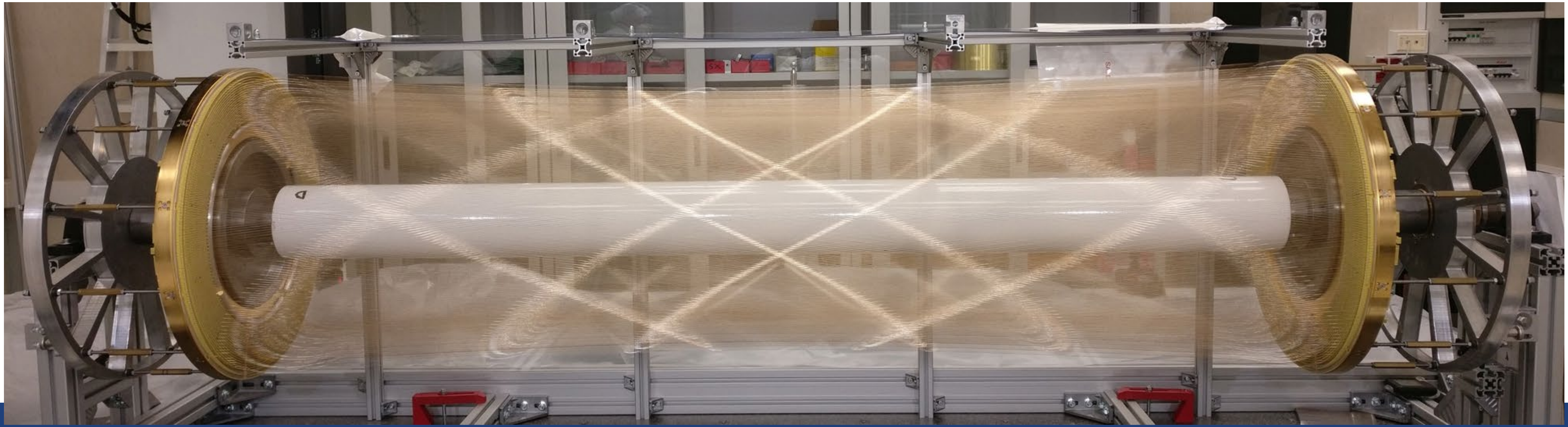


The Drift Chamber of the MEGII experiment

Giovanni Francesco Tassielli,

Gianluigi Chiarello and Marco Chiappini

on behalf of MEG-II CDCH groups - INFN Lecce, Roma and Pisa

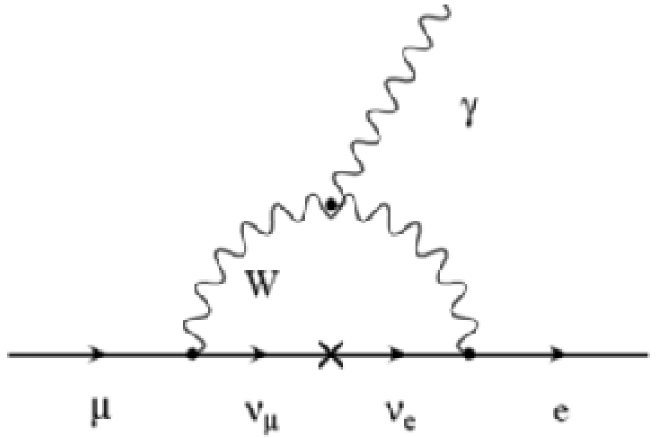
28 February 2020 INSTR 2020 - Novosibrisk

INSTR'20

Overview

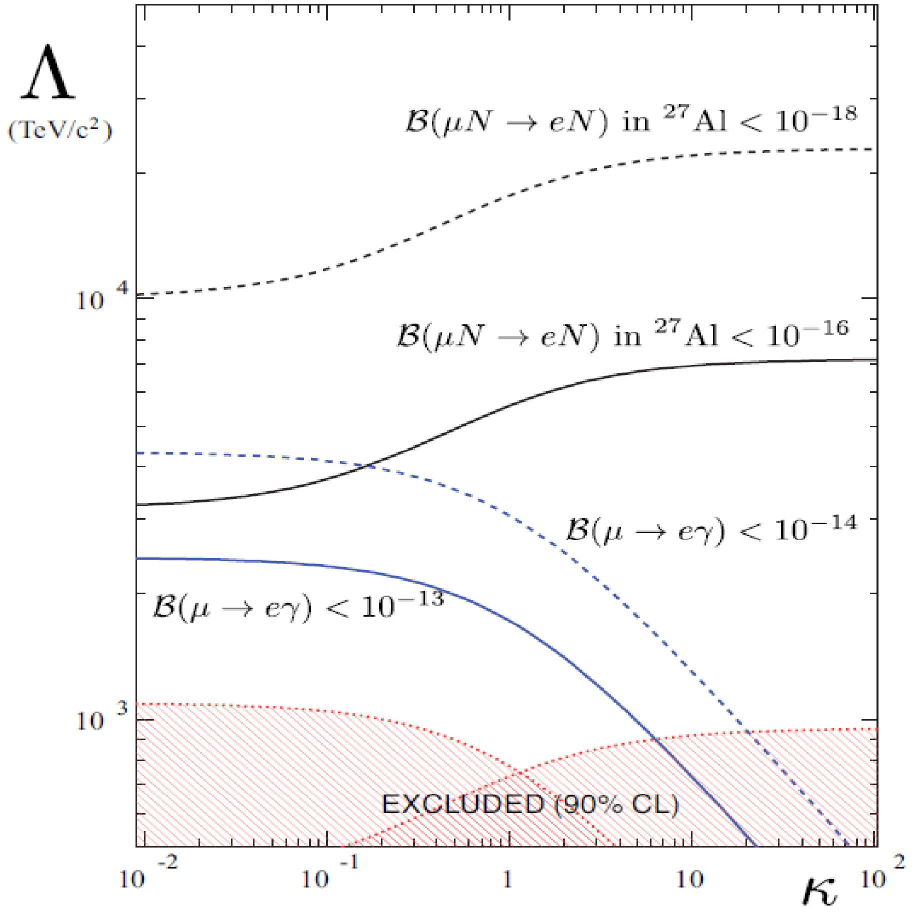
- Mu E Gamma search and MEG-II
- MEG II Cylindrical Drift CHamber (CDCH)
  - Novel approach for construction technique of high granularity and high transparency Drift Chambers
  - The wiring Robot and the wiring procedures
  - The assembly procedure
  - Front End electronics
  - Problems experienced during the construction
  - Expected performance
- Data taking runs
- Conclusions

Mu e gamma search



$$\mathcal{L}_{cLFV} = \frac{m_\mu}{(k+1)\Lambda^2}\mathcal{L}_{loop} + \frac{k}{(k+1)\Lambda^2}\mathcal{L}_{contact} + h.c.$$

Mass scale inaccessible to direct search



SM extension + ν oscillations

- **but not experimentally observable**: m_ν small → **BR<10^{-50}**

Beyond SM theories (SUSY-GUT) predict cLFV interactions rare but enhancement up to an observable level (BR($\mu^+ \to e^+\gamma$)≈10$^{-(14\text{-}15)}$)

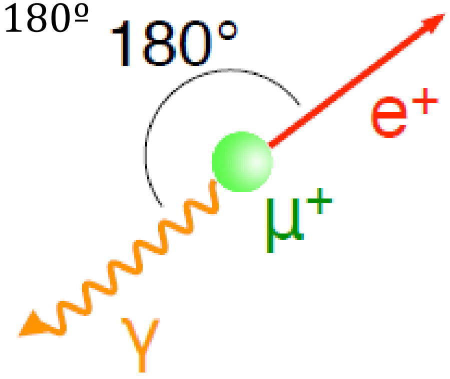
In this context the MEG experiment represents the state of the art in the search for the CLFV $\mu^+ \to e^+\gamma$ decay

Final results exploiting the full statistics collected during the 2009-2013 data taking period at Paul Scherrer Institute (PSI) BR($\mu^+ \to e^+\gamma$) < 4.2·10^{-13} (90% C.L.) world best upper limit

MEG event kinematic

Signal

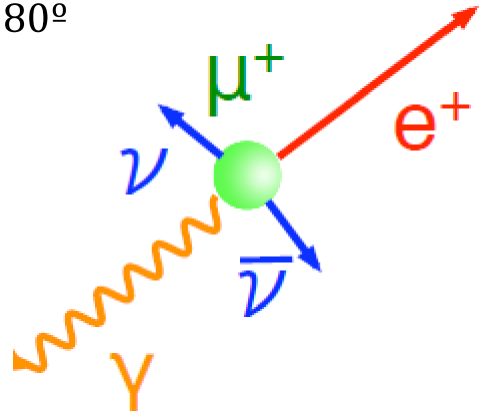
$t_e = t_\gamma$
$E_e = E_\gamma = 52.8$ MeV
$\theta_{e\gamma} = 180º$



Background

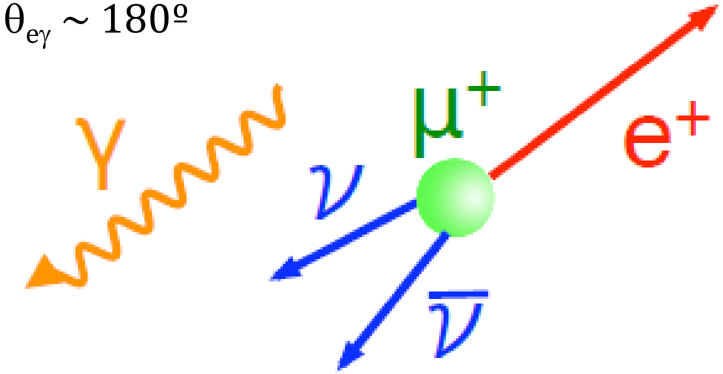
RMD

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



Accidental

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



- $\mu \to e\gamma$ signature
- radiative decay $\mu \to e\nu\nu\gamma$: two neutrinos have low energy and γ and *e* emitted back-to-back with high energy
- "accidental": *e* and γ from different sources but with compatible kinematics to the $\mu \to e\gamma$ (e.g. e^+ from Michel decay, γ from RMD, e^+e^- annihilation…)

Accidental background is **dominant** and determined by **beam rate** and **resolutions**:

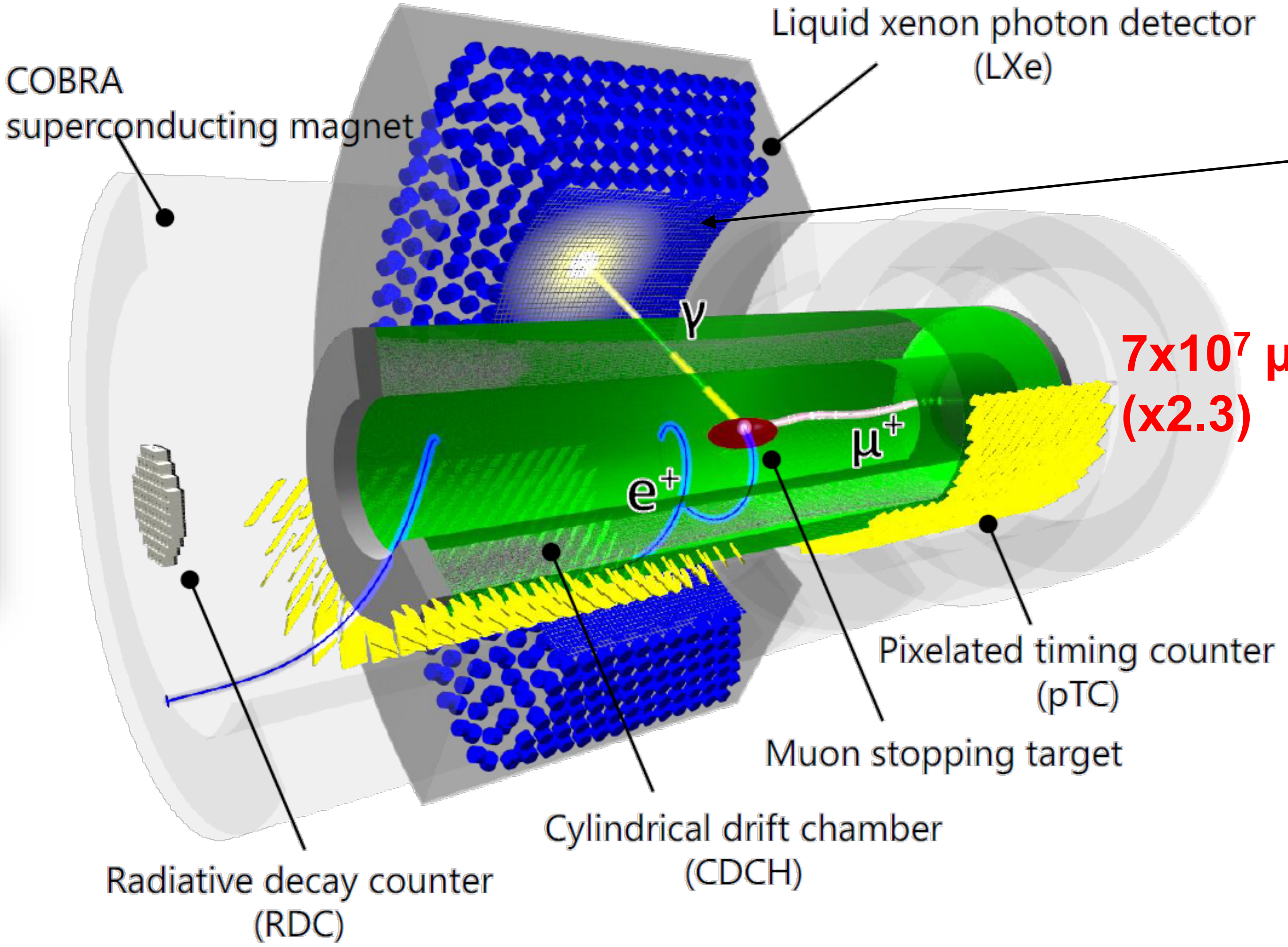
$$B_{acc} \propto R_\mu^2 \, \Delta E_e \, \Delta E_\gamma^2 \, \Delta\theta_{e\gamma}^2 \, \Delta t_{e\gamma}$$

$$B_{RMD} \approx 0.1 \cdot B_{acc}$$

The MEG II Experiment

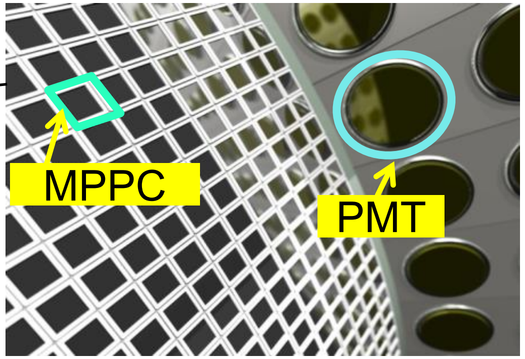
Target Sensitivity: $6 \cdot 10^{-14}$ in 3 years of running

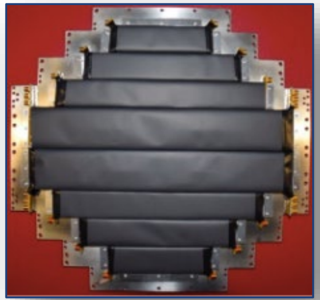
x2 resolution everywhere



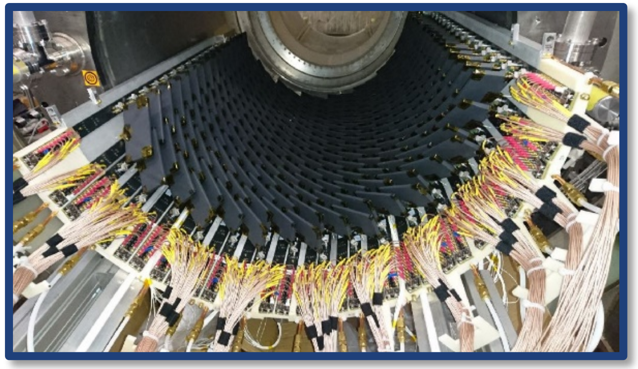
7×10^{7} μ/s (x2.3)

Better uniformity w/ VUV-sensitive $12 \times 12 mm^2$ SiPM





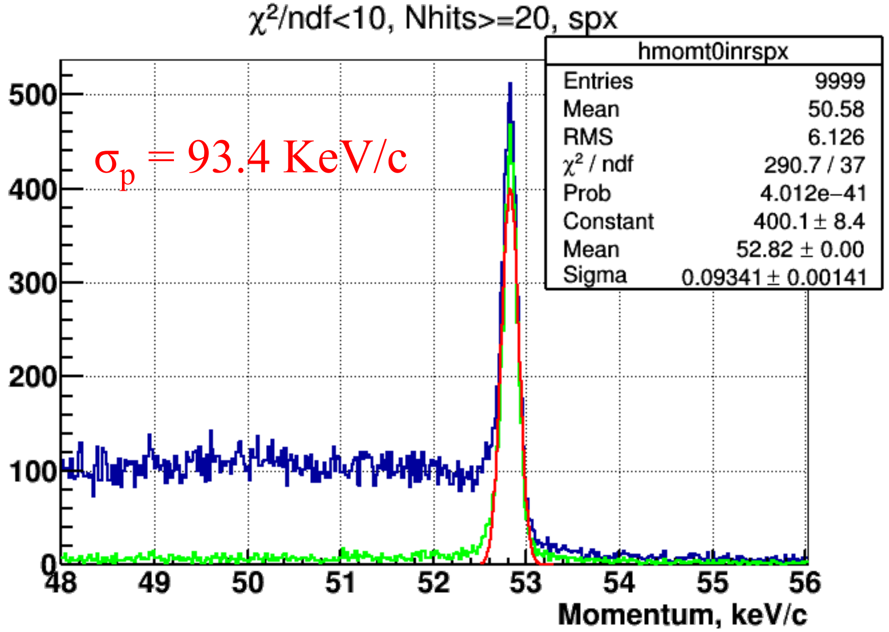
LYSO crystals + plastic scintillators (Further reduction of radiative BG)



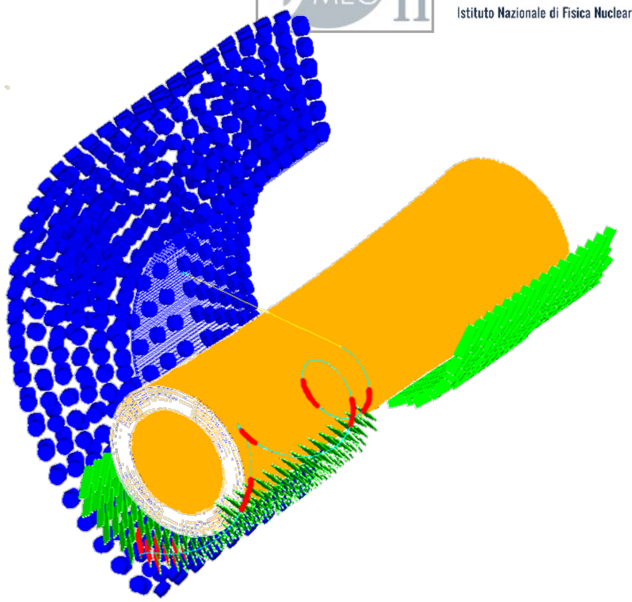
The MEG II Experiment

- 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
- MEG I DC did not perform as expected.
- Main problems were:
  - Few hits on the positron track (8-16)
  - Active volume of the detector only partly instrumented
  - Large track extrapolation to Timing counter

Variable	Design (MEG)	Obtained (MEG)	Foreseen (MEG II)
ΔE_e (keV)	200	380	~100
$\Delta\theta_e, \Delta\varphi_e$ (mrad)	5, 5	9, 9	6, 5.5
$\mathrm{Efficiency}_e$ (%)	90	40	>65
ΔE_γ (keV)	1.2	1.7	1.0
$\Delta\mathrm{Position}_\gamma$ (mm)	4	5	< 3
$\Delta t_{e\gamma}$ (ps)	65	120	85
$\mathrm{Efficiency}_\gamma$ (%)	> 40	60	70



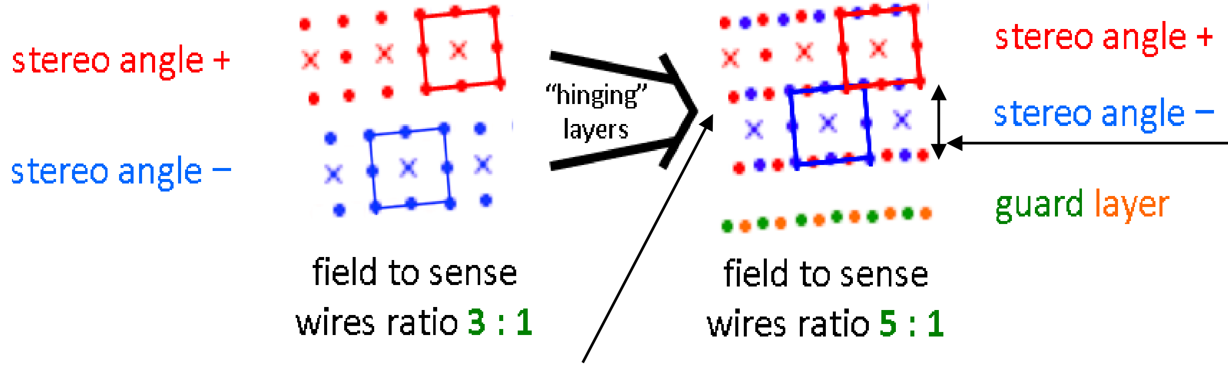
MEG II Drift chamber: design



- Single volume, small cells, full stereo cylindrical drift chamber;
- A large field to sense wires ratio (5 : 1) allows for thinner field wires, thus reducing the **wire contribution to multiple scattering** and the **total wire tension** on the end-plates.
- Light gas mixture **(90% He – 10% iC_4H_{10})**
- Positron efficiency > 65% (better coupling with TC, very short extrapolation needed);
- High rate capability (at the centre 30kHz/cm^2), drift cell size of **~6mm** required
- Single hit resolution **(~110 μm)** and gas aging effects verified on prototypes and test stations (at 7×10^7 μ/s and 10^5 gain, **Δg/ΔV ~ 4%/V** over 3 years equivalent).
- Cluster Timing readout capabilities **(high bandwidth, high sampling rate) to** further reduce spatial resolution

Item	Description	Thickness 10^{-3} X_0	
MEG target	(140 μm plastic)	0.28	0.28
Sense wires	(20 μm W)	0.41	0.78
Field wires	(40 and 50 μm Al)	0.33	
guard wires	(40 μm Al)	0.04	
inner cylinder	(20 μm Kapton)	0.21	0.21
Inner gas	(pure He)	0.06	0.59
Tracker gas	(He/iBut. 90/10)	0.53	
Total	1 full turn w/o target	**1.58**	

MEG II Drift chamber: design



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

Full stereo cylindrical DC with large stereo angles (102÷147 mrad)
Small square cells
(5.8÷7.8 mm at z=0, 6.7÷9.0 at z=±L/2)
(~ **12 wires/cm²**)

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

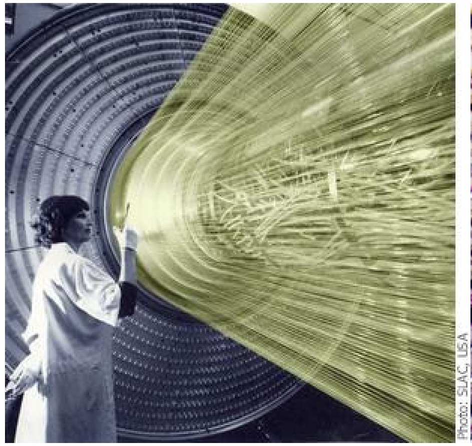
sense wires: 20 μm diameter W(Au) => 1728 wires
field wires: 40 μm diameter Al(Ag) => 7680 wires
f. and g. wires: 50 μm diameter Al(Ag) => 2496 wires
11904 wires in total

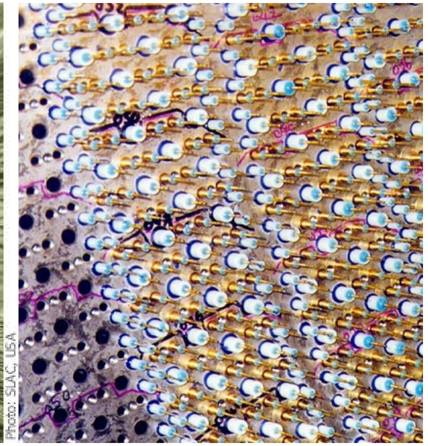
High wire densities, anyway, require complex and time consuming assembly procedures and need novel approaches to a feed-through-less wiring

MEG II Drift chamber: The novel approch

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

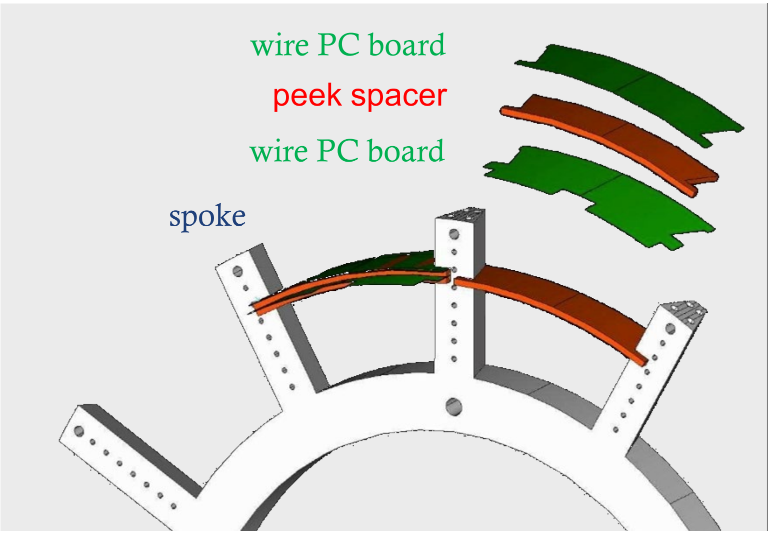
($\sim$ **12 wires/cm^2**) can't be built with feedthrough





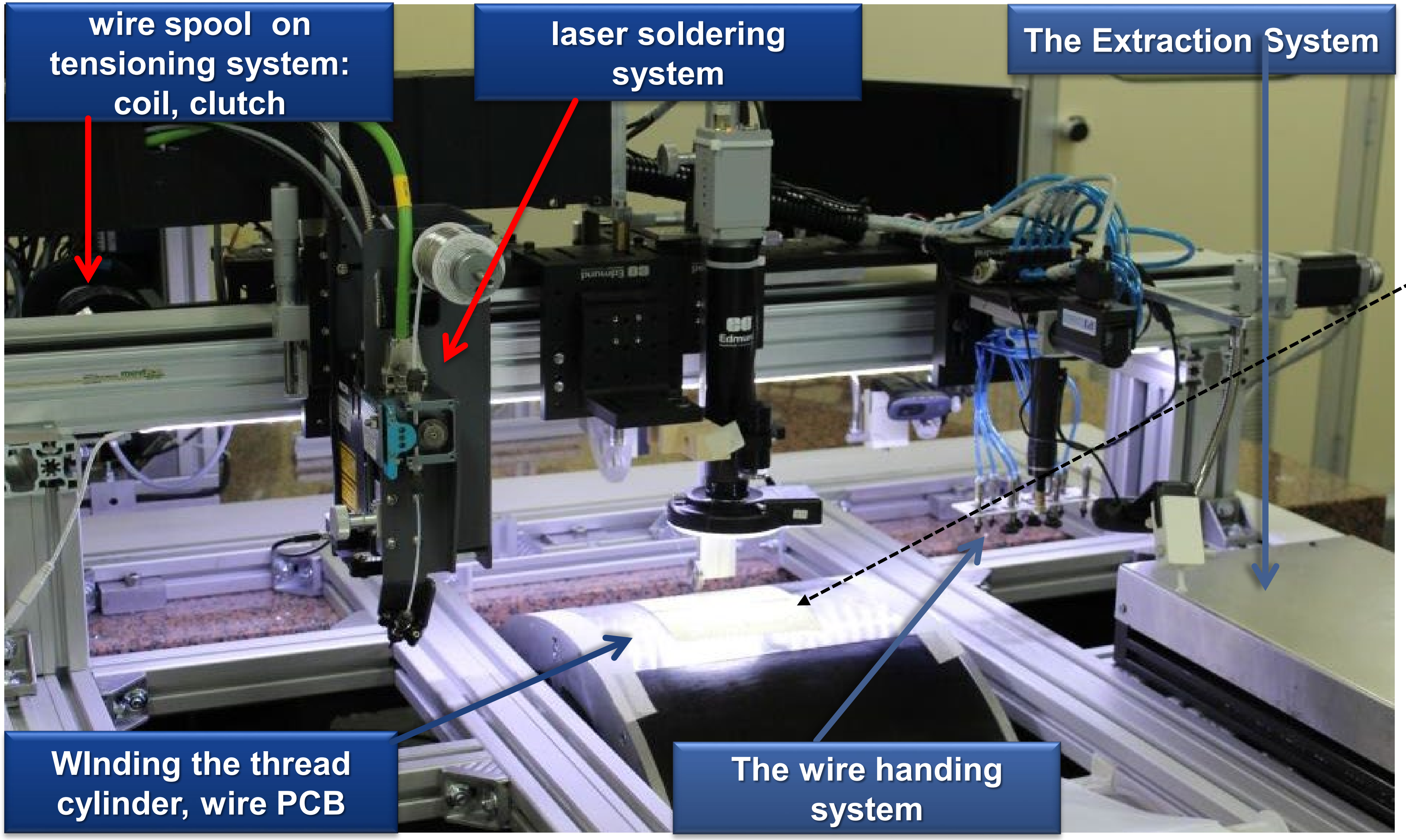
The solution found for MEG II:

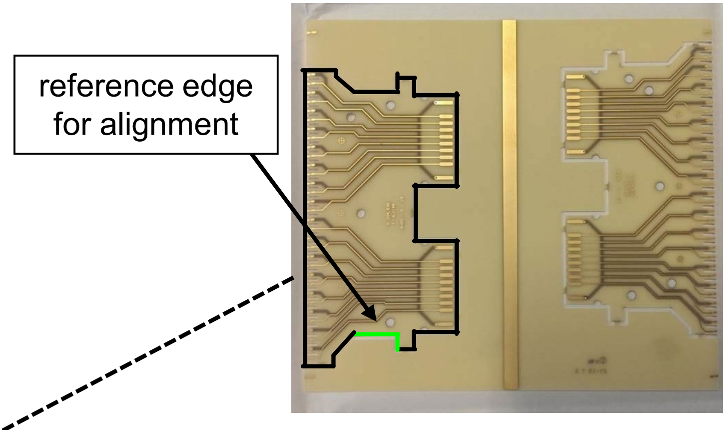
- end-plates numerically machined from solid Aluminum (mechanical support only);
- Field, Sense and Guard wires placed azimuthally by Wiring Robot with better than one wire diameter accuracy;
- wire PC board layers (green) radially spaced by numerically machined peek spacers (red) (accuracy < 20 μm);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



see poster 91: NEW CONCEPTS FOR LIGHT MECHANICAL STRUCTURES OF CYLINDRICAL DRIFT CHAMBERS

MEG II Drift chamber: Wiring procedure





The main tasks of the wiring robot are:

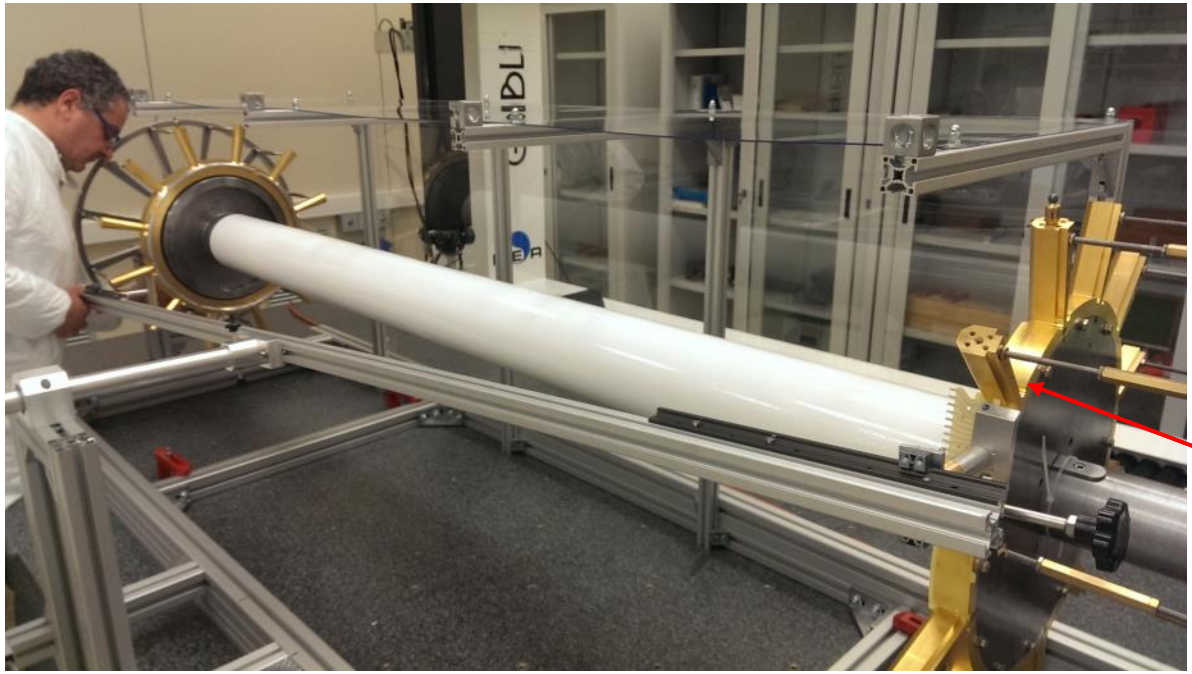
- the wiring of a multiwire layer made of 32 parallel wires;
- settable wire tension ($\pm$0.05g);
- 20μm of accuracy on wire position;
- anchor the wires using a contact-less technique

see poster 11: An automatic system for the construction of Drift Chambers for modern High Energy Physics experiments

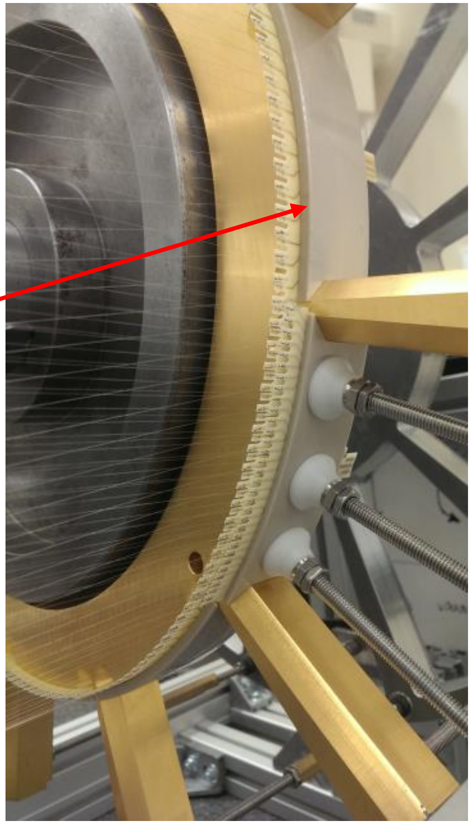
MEG II Drift chamber: Assembling

Procedure:

- The mounting arm (with the multi-wire layer) is then placed next to the end plates for the engagement procedure
- The mounting arm is fixed to a support structure to prevent damaging the wires
- This structure transfers the multi-layer wire on the end plates between two spokes
- Spacers, to separate the successive layer, are pressed and glued in position



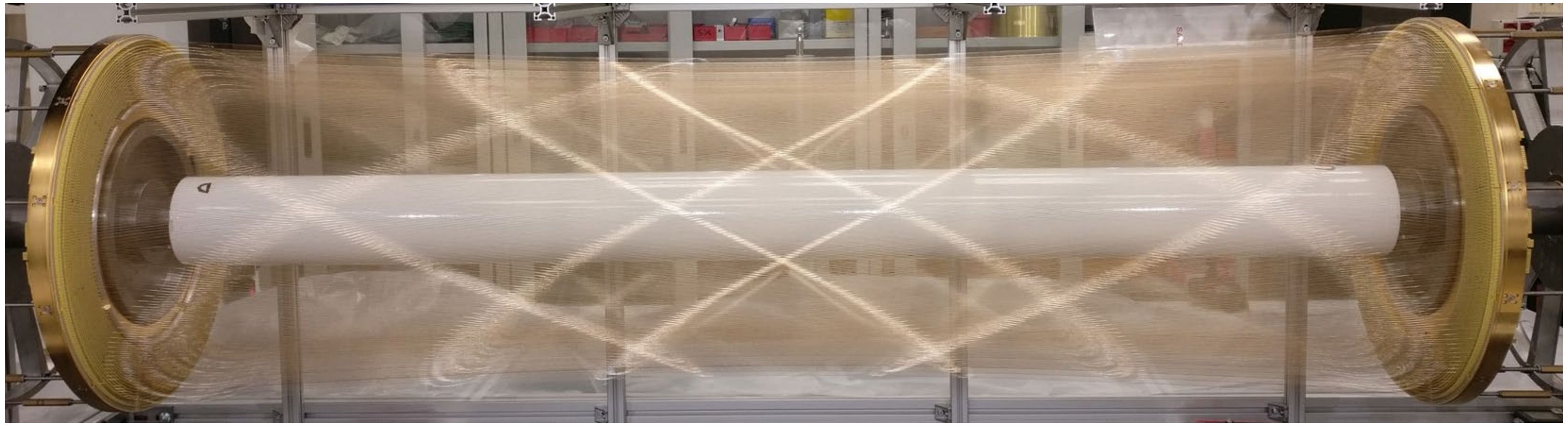
Spoke used as reference for the alignment of the pcb

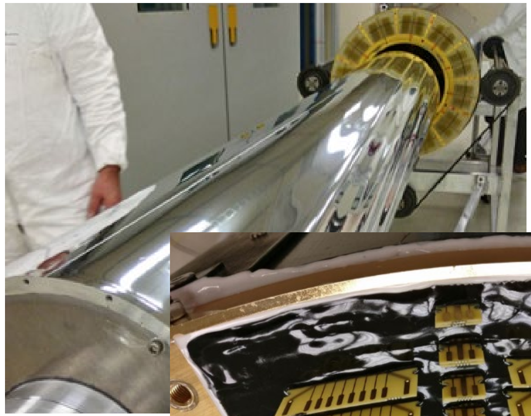


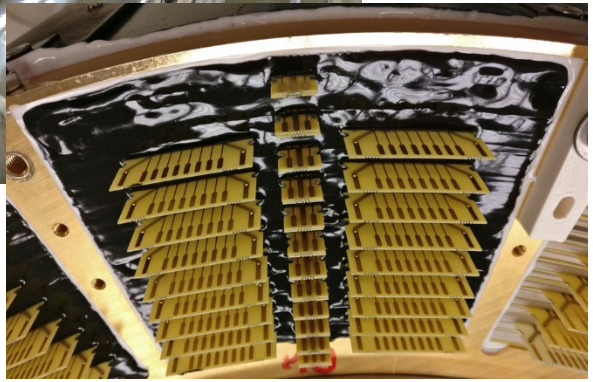
MEG II Drift chamber: Assembed

Procedure:

- After assembling all the layers, the DC is closed with 2 mm-thick carbon fiber shell for structural function and gas tightness.
- DC was rotated 90 degrees to seal the end plate (wire-pcb and spacer);
- The inner mylar aluminized foil (20 μm) was mounted
- Fine geometry tuning by adjusting the positions of each individual spoke by acting on the 12 turnbuckles per side
- Endplates planarity and parallelism at a level better than 100 μm thanks to the CMM

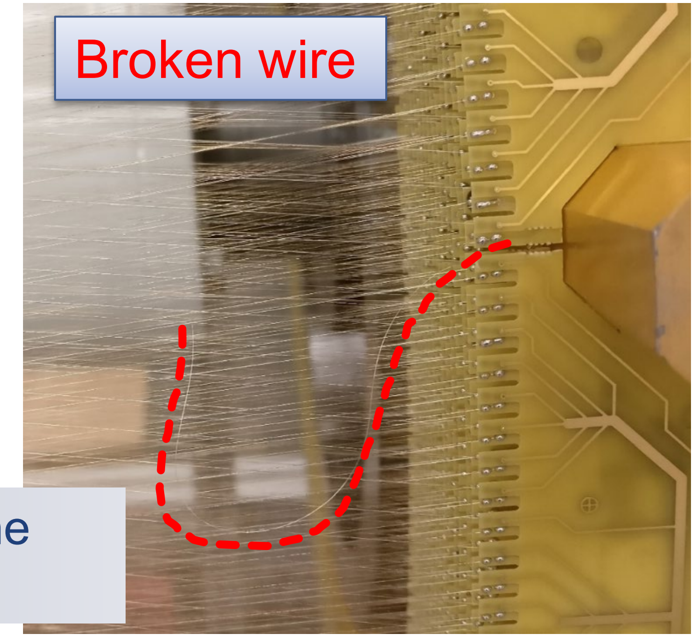


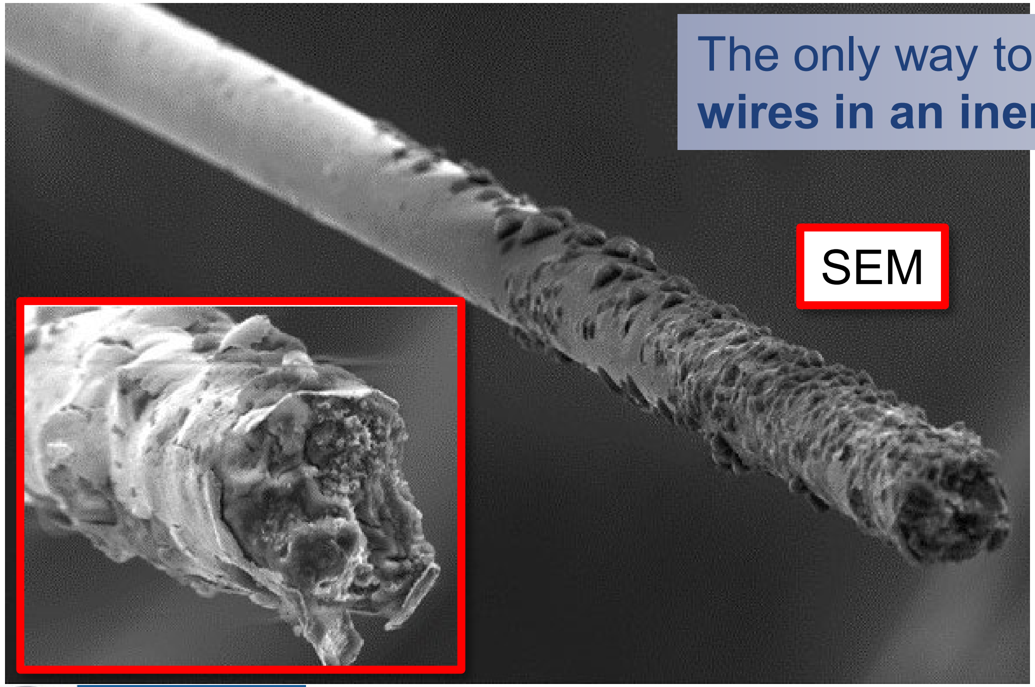




MEG II Drift chamber: Wire breakages

- During assembly at Pisa and the final lengthening operations at PSI we experienced the breakages of some Al wires in the chamber
  - Mainly the 40 μm cathodes were affected
  - A few 50 μm cathodes and guards
- **65 broken wires in total during CDCH life**
- **Consequent delay in construction and commissioning**

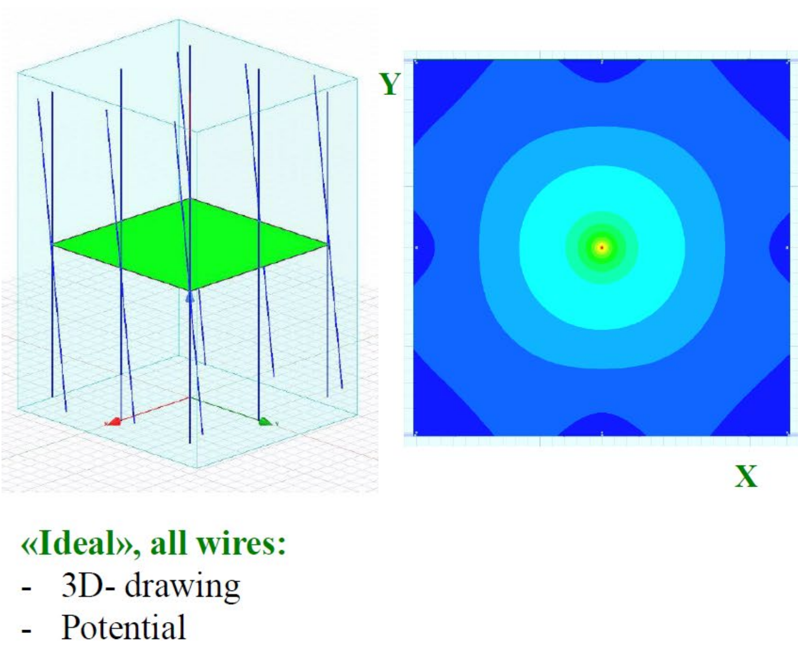


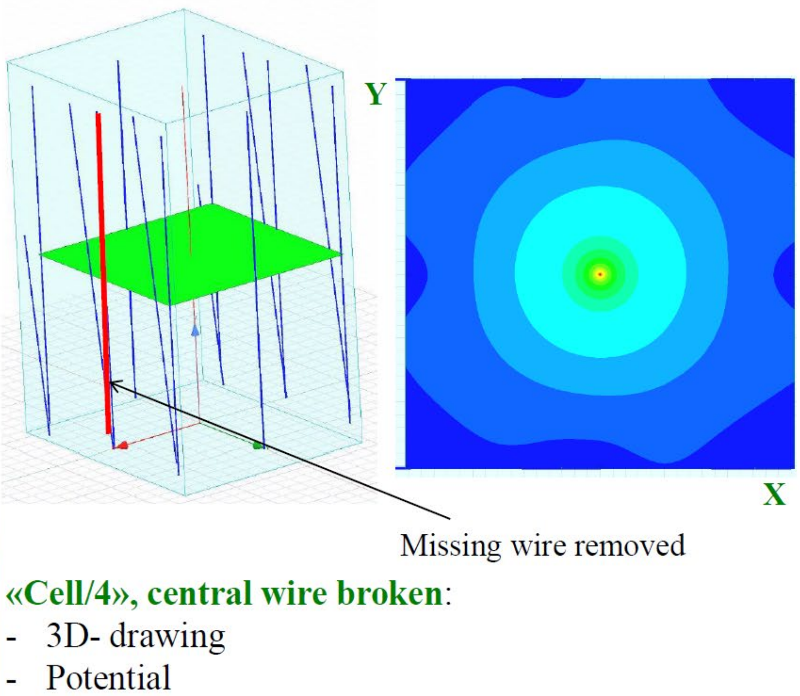


The only way to **stop the corrosion** is to keep the **wires in an inert atmosphere**

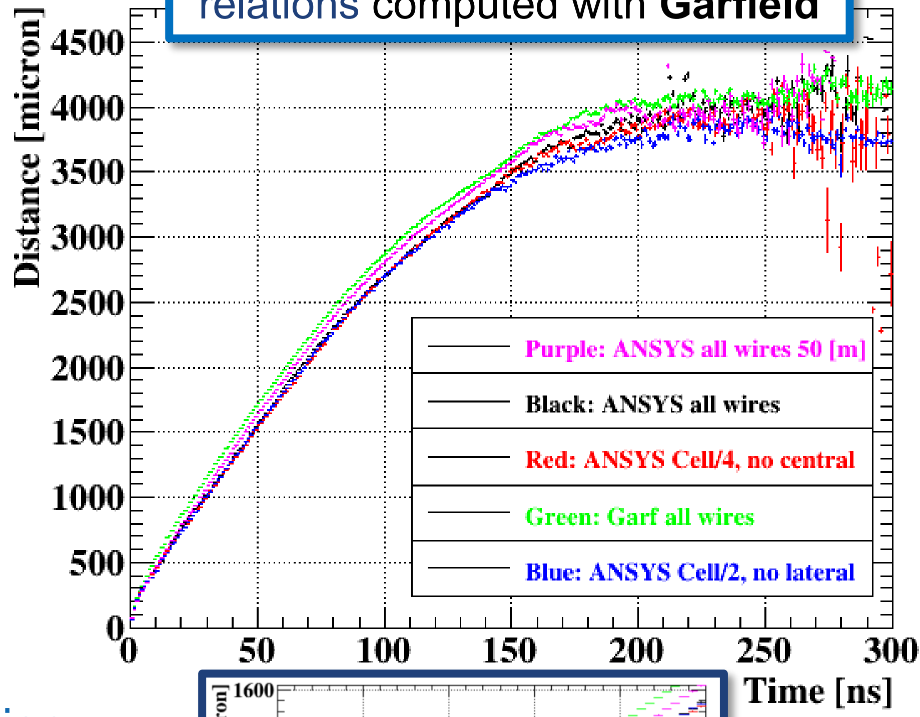
- Breakages due to corrosion of the Al wire core
- **Two hypotheses**
  - Galvanic process between Al and Ag coating
  - Al corrosion by Cl
- Both imply water as catalyst
  - **Air moisture condensation inside cracks in the Ag coating even at low Relative Humidity (RH) levels <40%**
  - Al oxide or hydroxide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

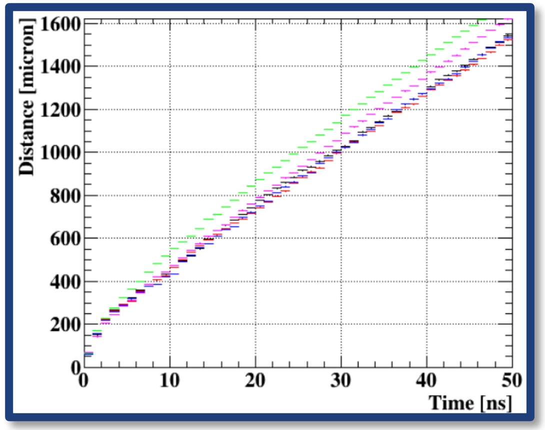
MEG II Drift chamber: Missing wires effect





Drift distance vs. drift time relations computed with Garfield





- Study the effect of a missing cathode on isochrones → e^+ reconstruction
- Used **Garfield** and **ANSYS** to simulate the electric field in a 6x6 mm^2 representative drift cell
  - Single-hit resolution σhit < 120 μm
  - Difference between different curves → ≈ 10 μm
- **Missing wire effect negligible (<10%)**

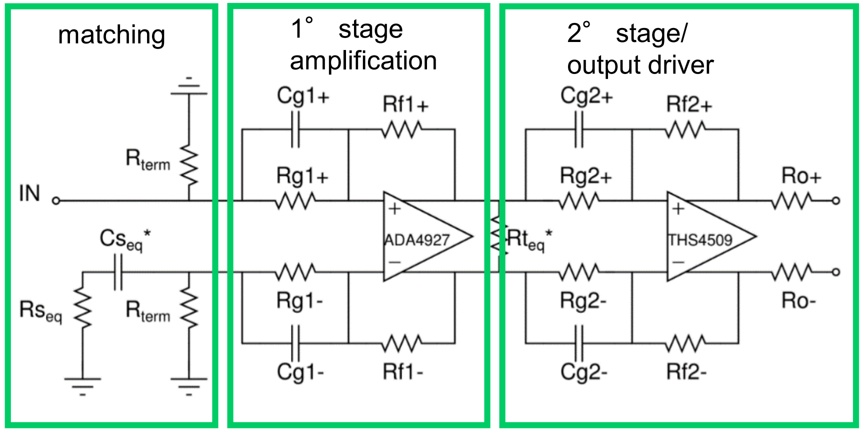
MEG II Drift chamber: Electronics

Requirements:

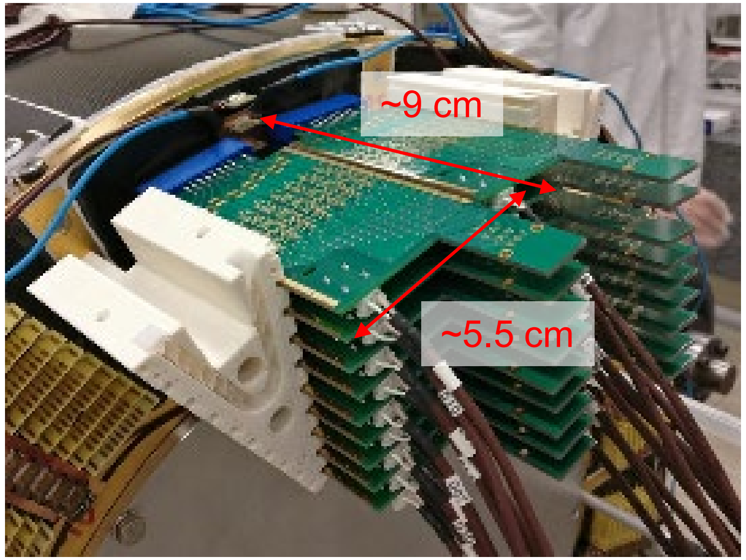
- High bandwidth >700 MHz
- Good gain: ~10
- High density < 7mm channel width
- Fully differential
- Low power consumption (50mW)

analog gain and Bandwidth after 5m cable: 19db and ~ 900MHz

see poster 87: The Front End Electronics for the Drift Chamber readout in MEG experiment upgrade



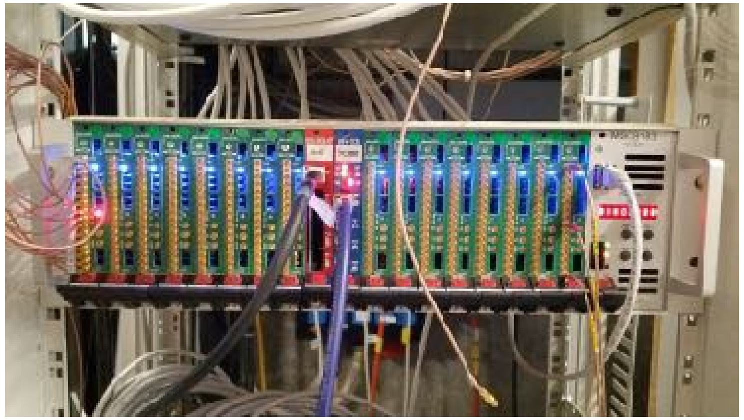
8 channels per card



DAQ based on Waveform digitizer (DRS4), called WaveDREAM, developed by PSI:

- 1.2 - 2 GS/s
- 1024 bins

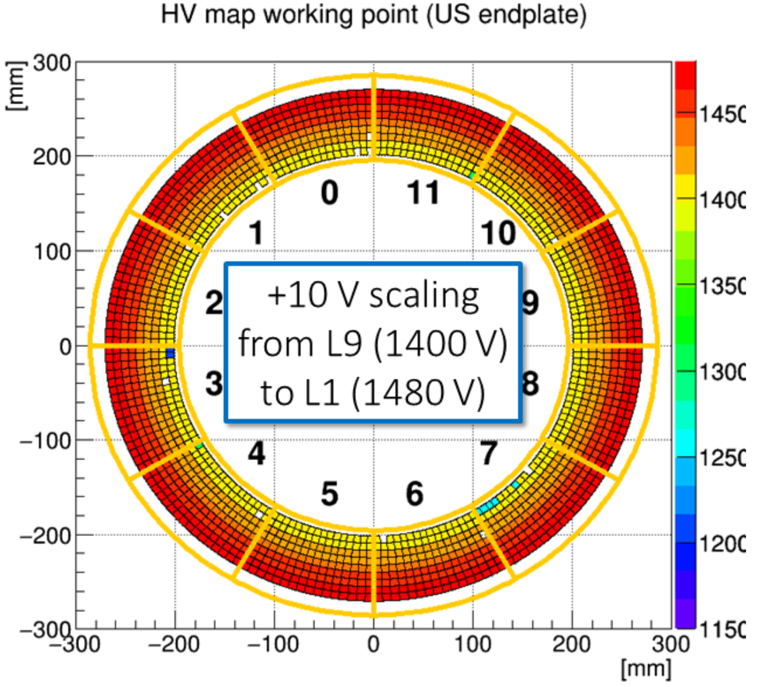
(not available with full differential input for the commissioning, we had to convert back the signal to single-end)



MEG II Drift chamber: HV working point

- Garfield simulations on single electron gain
- Gas mixture He:Isobutane 90:10 and P = 970 mbar (typical at PSI)
- Working point → HV for gain $G = 5\cdot10^5$ (1400-1480V)

see poster 10: Commissioning of the MEG II tracker system

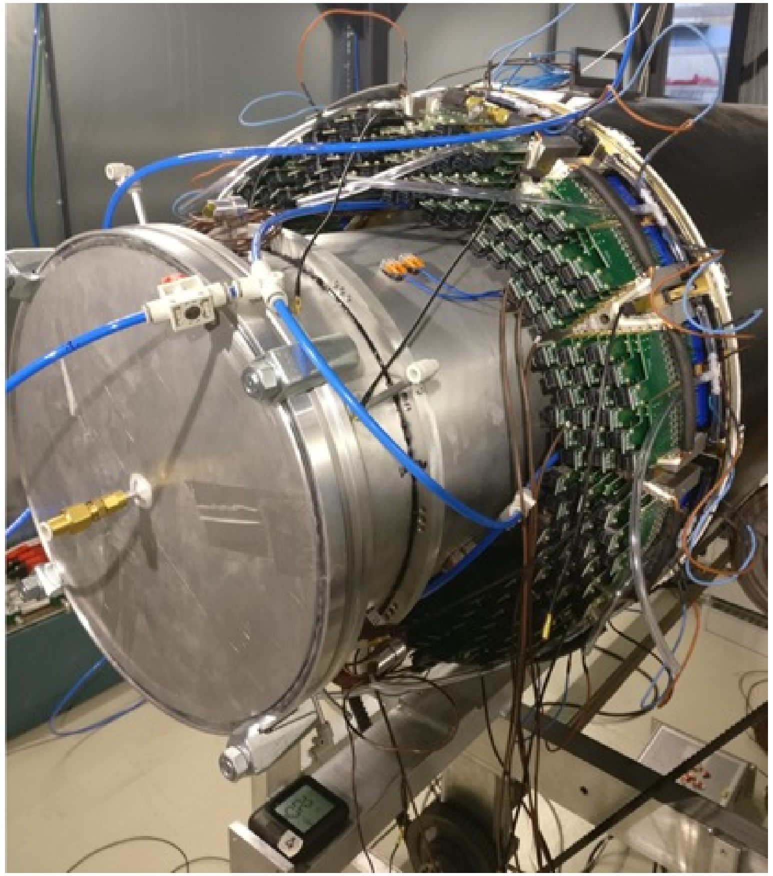


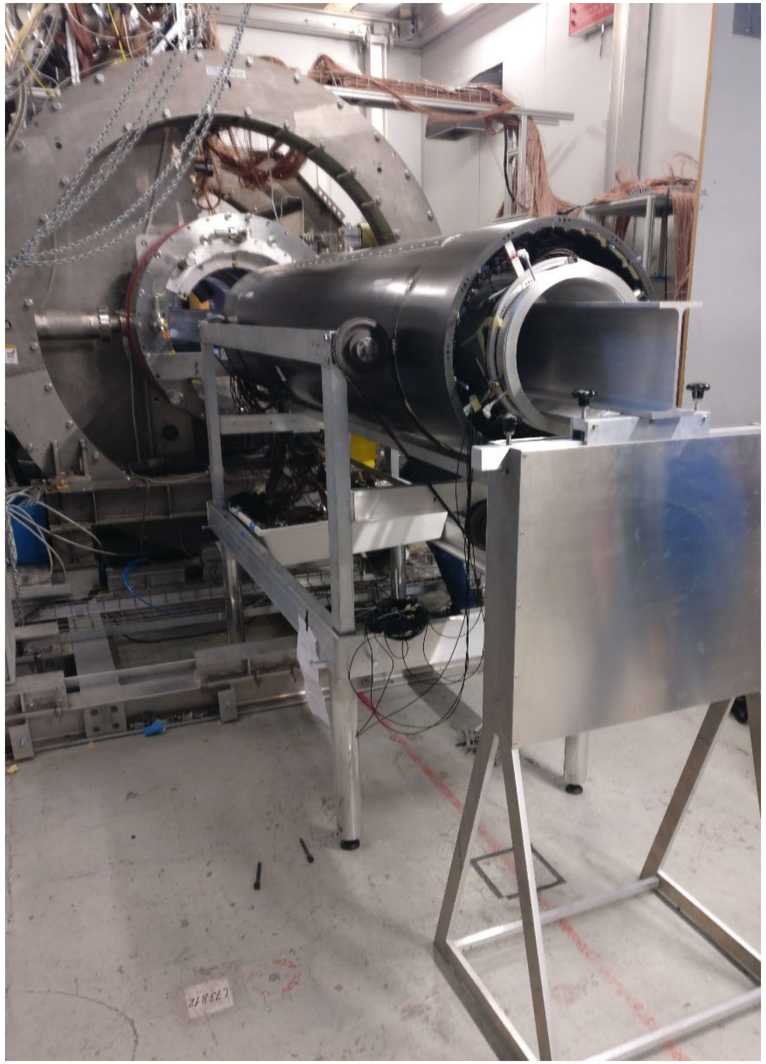
We tested electrostatic stability up to working point + 100V
(green = goal reached)

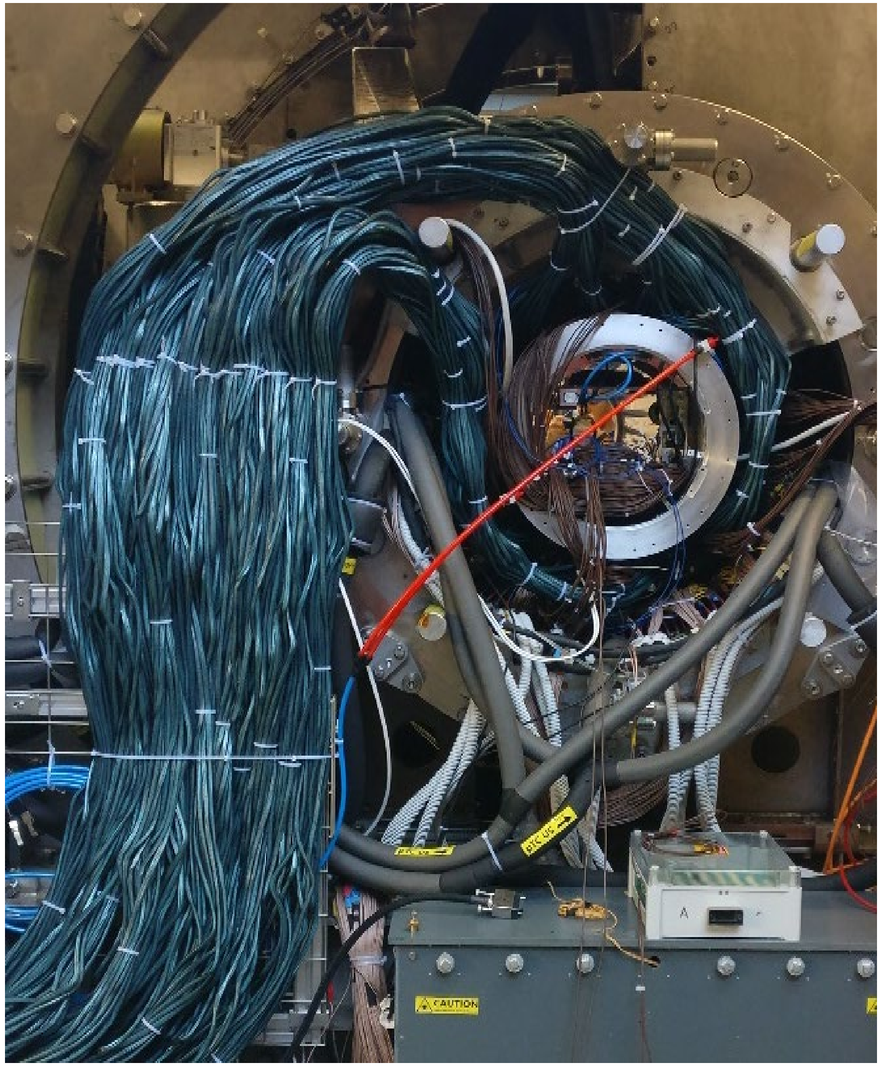
Layer	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
9 (1500 V)	1500	1500	1500	1500	1500	1430	1500	1500	1500	1500	1500	1500
8 (1510 V)	1510	1510	1510	1500	1510	1510	1510	1510	1510	1510	1510	1510
7 (1520 V)	1520	1520	1520	1520	1520	1520	1520	1520	1520	1520	1520	1520
6 (1530 V)	1530	1530	1530	1530	1530	1530	1530	1530	1530	1530	1530	1530
5 (1540 V)	1540	1540	1540	1540	1540	1540	1540	1540	1540	1540	1540	1540
4 (1550 V)	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
3 (1560 V)	1560	1560	1560	1560	1560	1560	1560	1560	1560	1560	1560	1560
2 (1570 V)	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570
1 (1580 V)	1580	1580	1580	1580	1580	1580	1580	1580	1580	1580	1580	1580

"dead" channels of 1.3% negligible in e+ reconstruction

MEG II Drift chamber: In the experiment





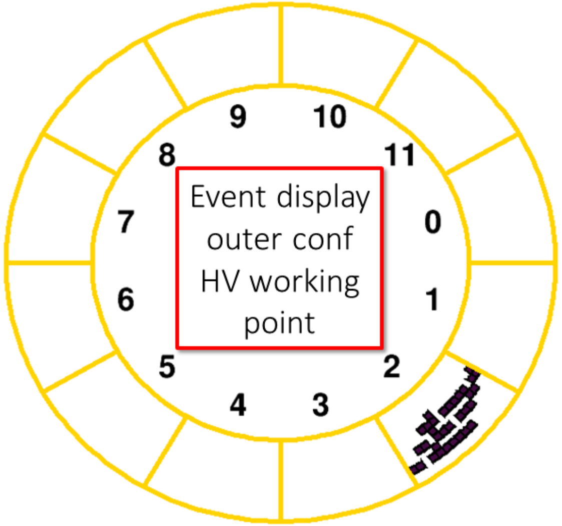


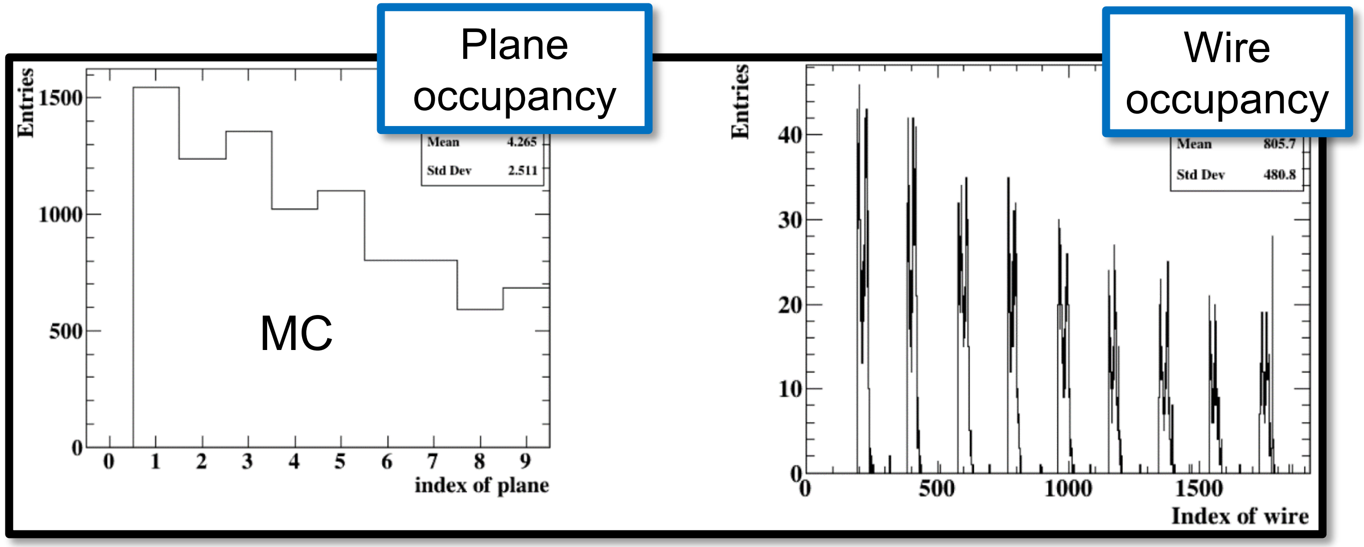
MEG II Drift chamber: data taking

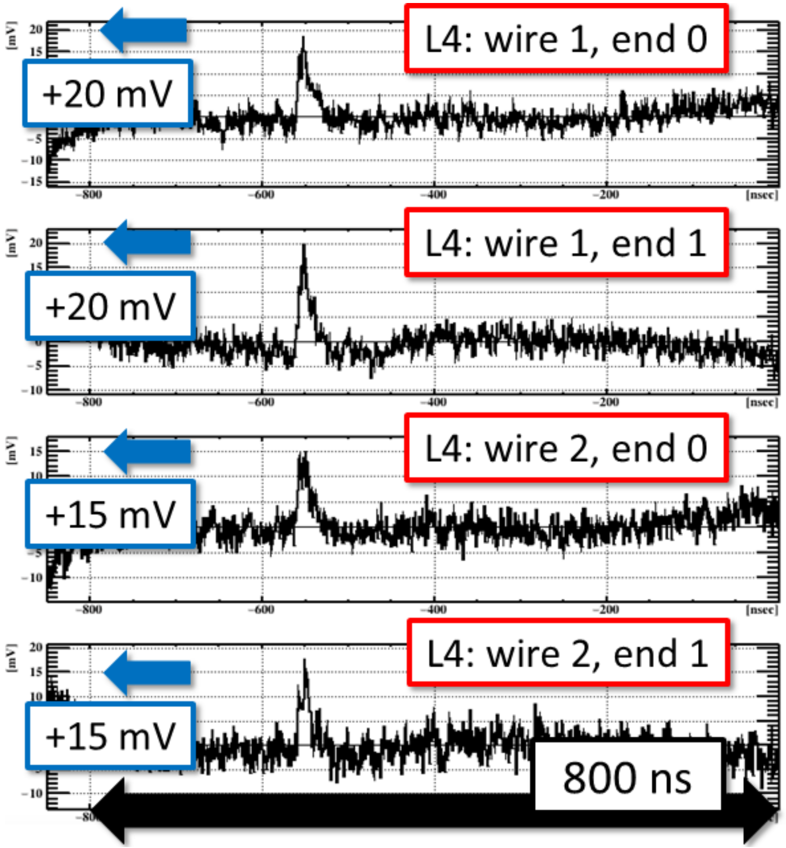
Only 192 DAQ channels available for 2018 and 2019 runs

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)

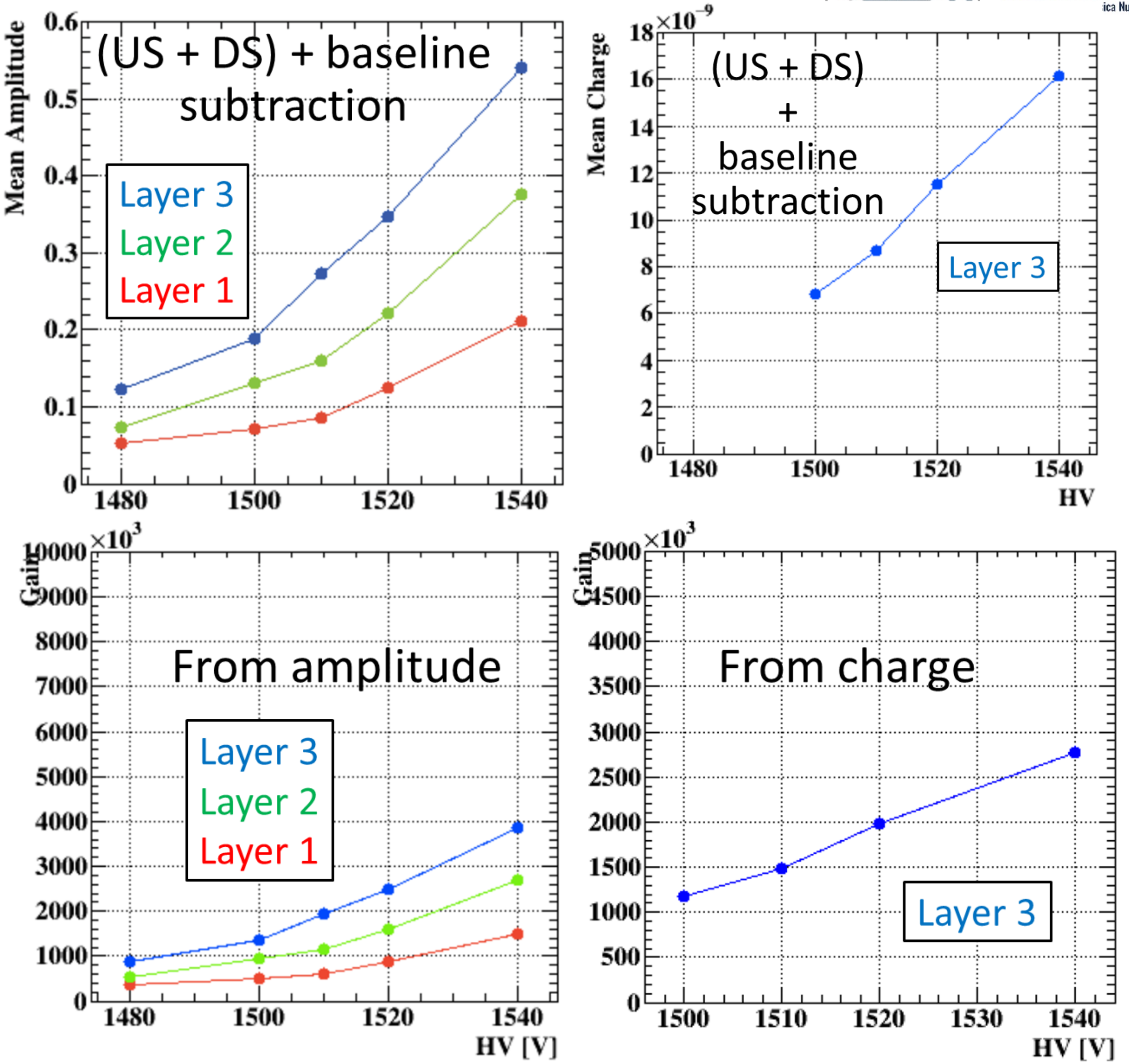






MEG II Drift chamber: data taking

- 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



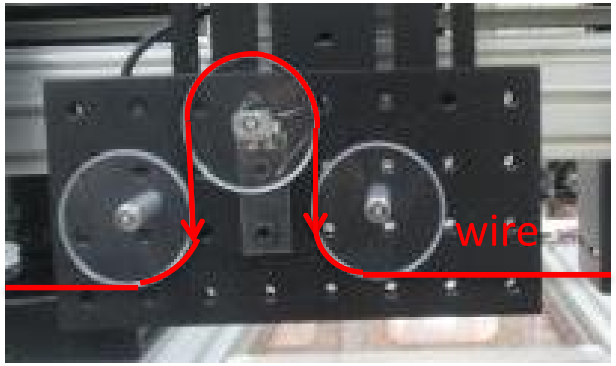
CONCLUSION

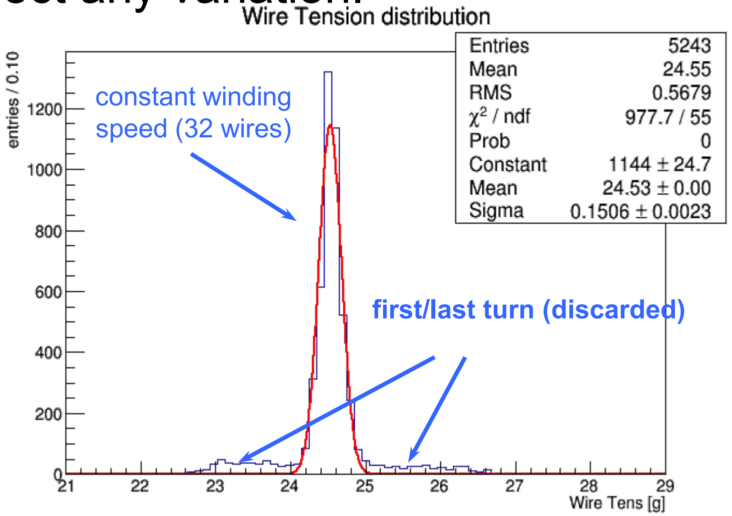
- The upgrade of the positron tracker of the MEG II experiment consists in a full stereo, with high granularity and high transparency (~$1.6 \cdot 10^{-3}$ X_0) Drift Chamber
- It is a crucial detector to improve the angular and momentum resolutions of the e^+ kinematic variables, thus minimizing the background sources
- The novel design concept and the modular construction have been described
- CDCH mechanics proved to be stable and adequate to sustain a MEG II run
- We experienced some ~60 (over ~12000) broken wires, all of them due to a corrosion issue, no additional breaks after the closing of the chamber in the right atmosphere
- During the commissioning activities at PSI the working configuration was reached and CDCH was fully integrated into the MEG II experimental apparatus for the data taking
- The commissioning is still on going to fix the unexpected problems about the stability of the chamber
- We expect to reinstall the chamber during the 2020 for a final commissioning and starting the data tacking

backup

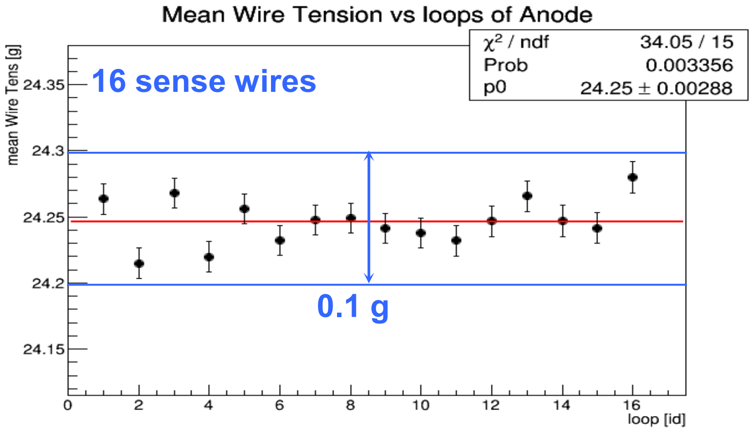
MEG II Drift chamber: Wiring procedure

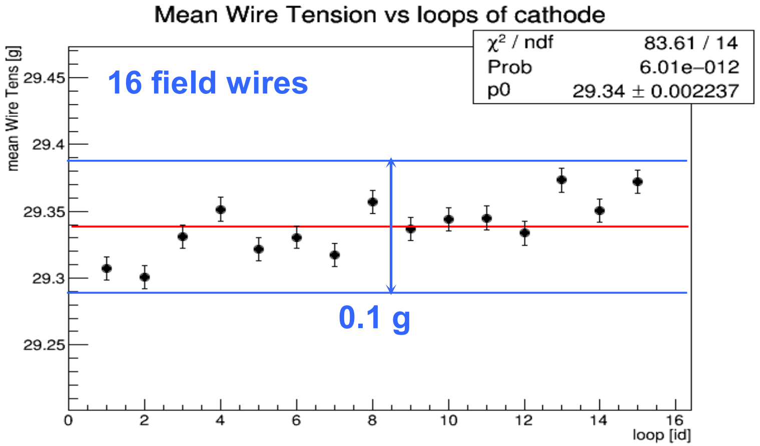
The wire mechanical tension is delivered by an electromagnetic clutch and its on-line monitored by a high precision strain gauge, a real-time feedback system correct any variation.





wire tension mean value is stable at the level of 0.05 g



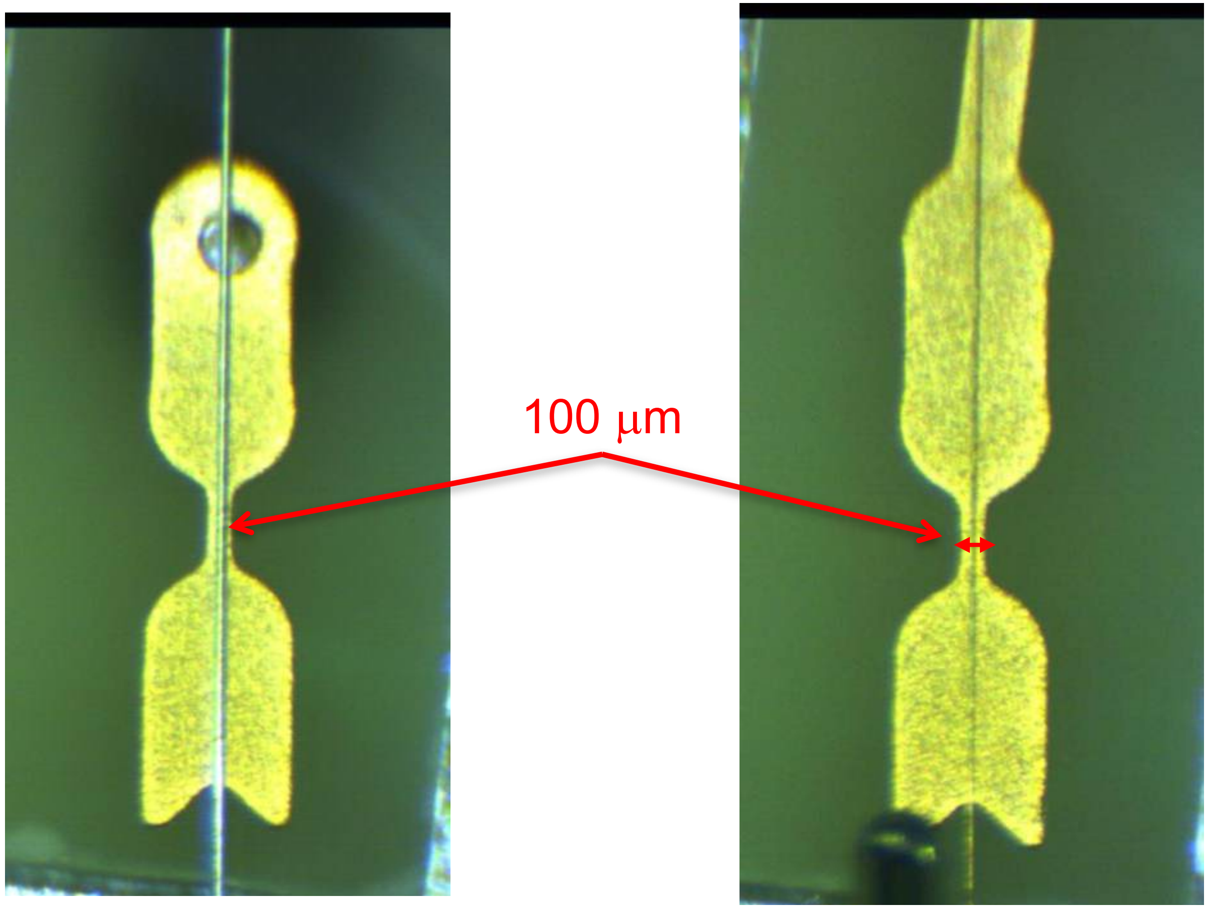


MEG II Drift chamber: Wiring procedure

All wires position is optically monitored, a precision on the relative position is ~20 μm

20μm of accuracy on wire position

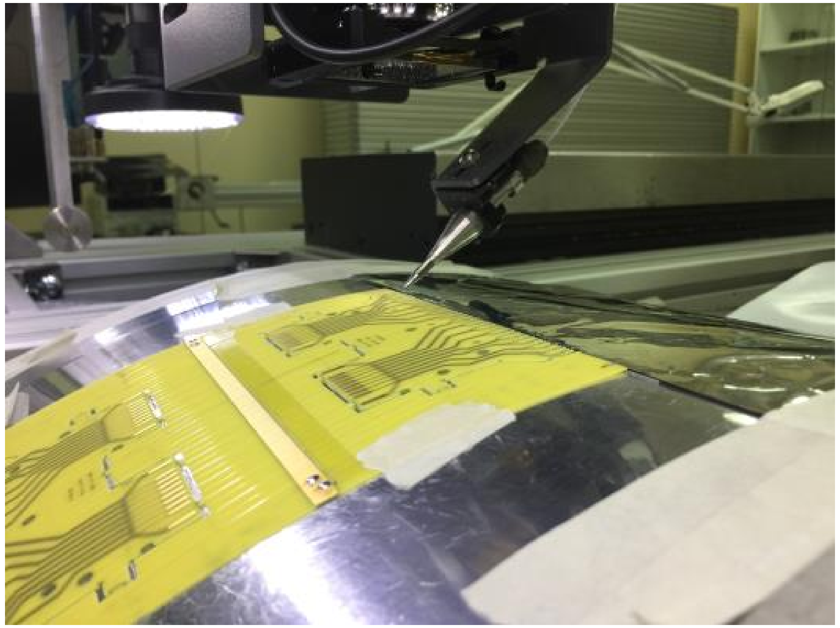
cathode **anode**

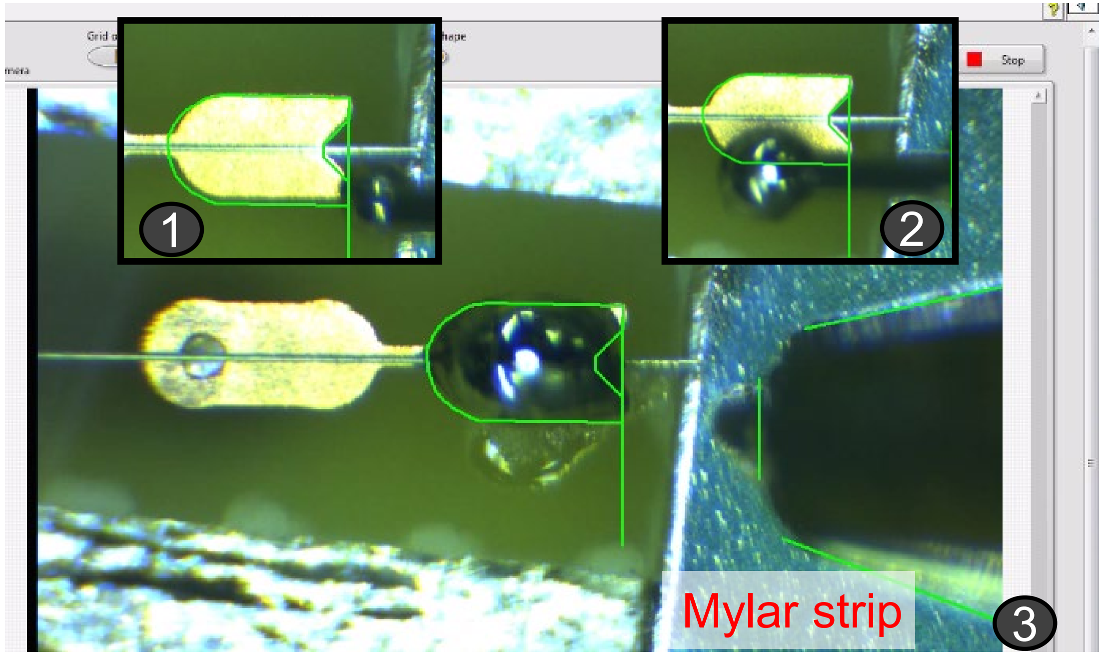


MEG II Drift chamber: Wiring procedure

Soldering:

- The soldering phase is accomplished by an LASCON 501 IR laser soldering System.
- The laser system is controlled by the NI Compact RIO and is synchronized with the positioning system.
- The wires, during the soldering phase, are covered by a Mylar foil

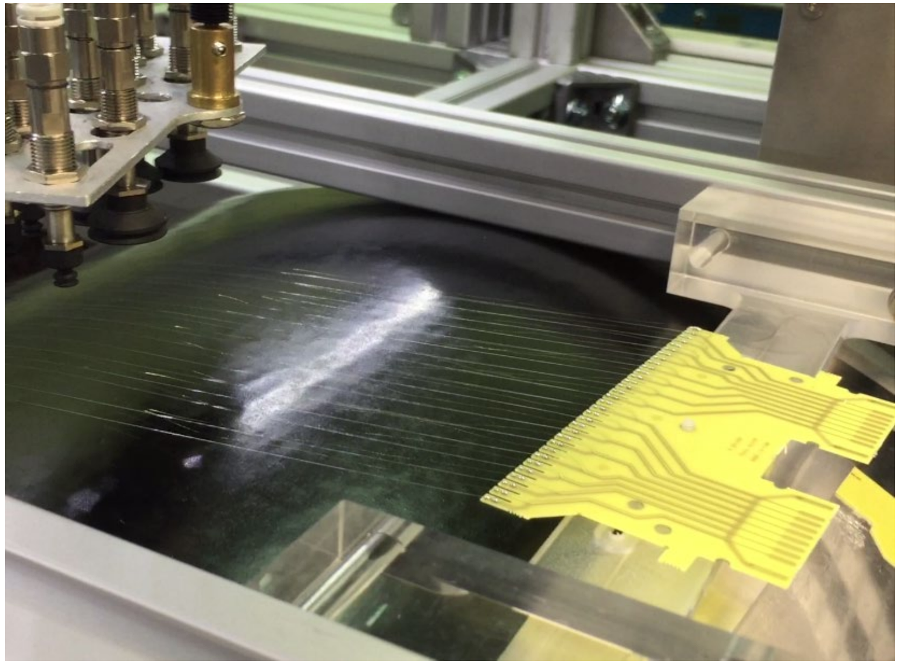


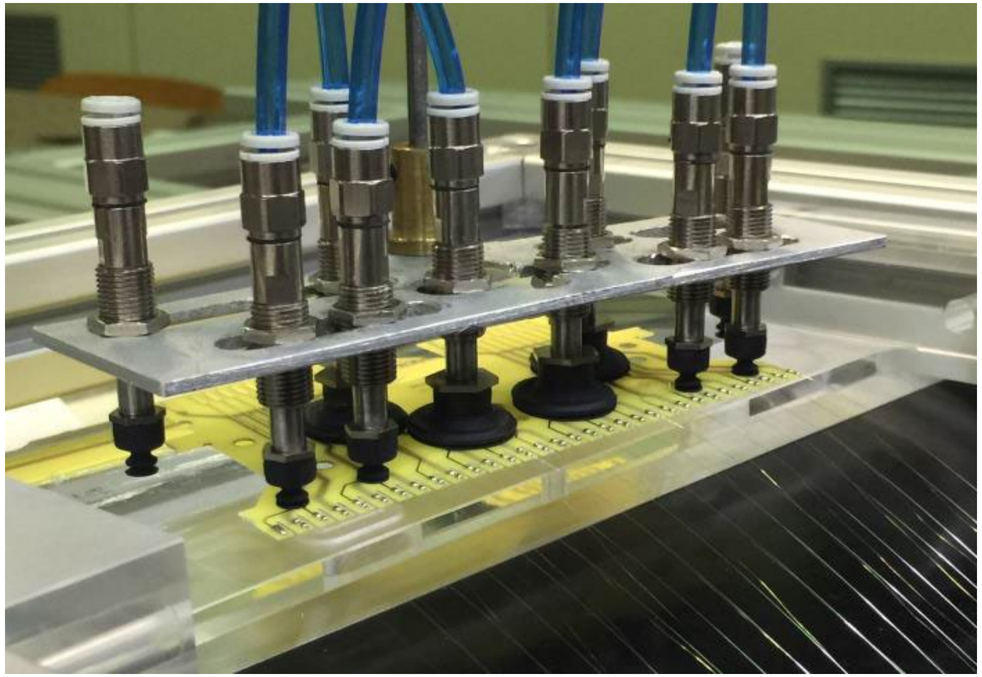


MEG II Drift chamber: Wiring procedure

Extraction:

- The wound layer of soldered wires must be unrolled from the winding drum and de-tensioned for storage and transport to the assembly station.
- The wire PCBs are lifted off from the cylinder with a linear actuator connected to a set of vacuum operated suction cups.

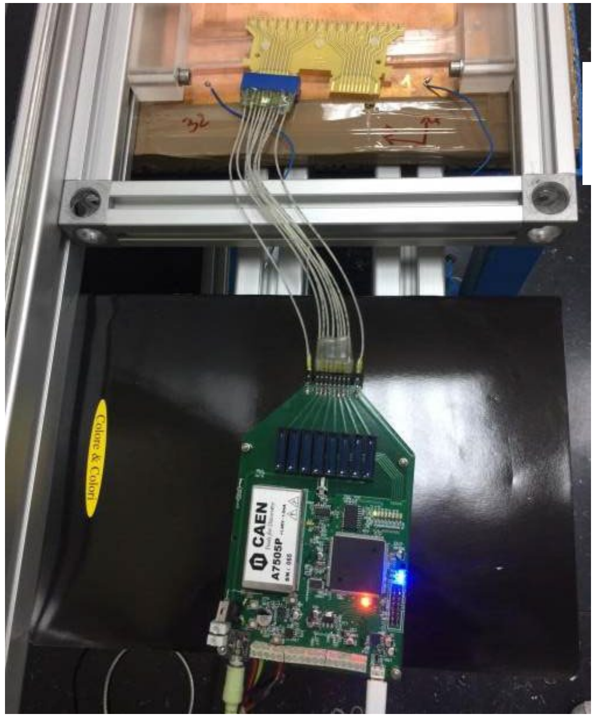


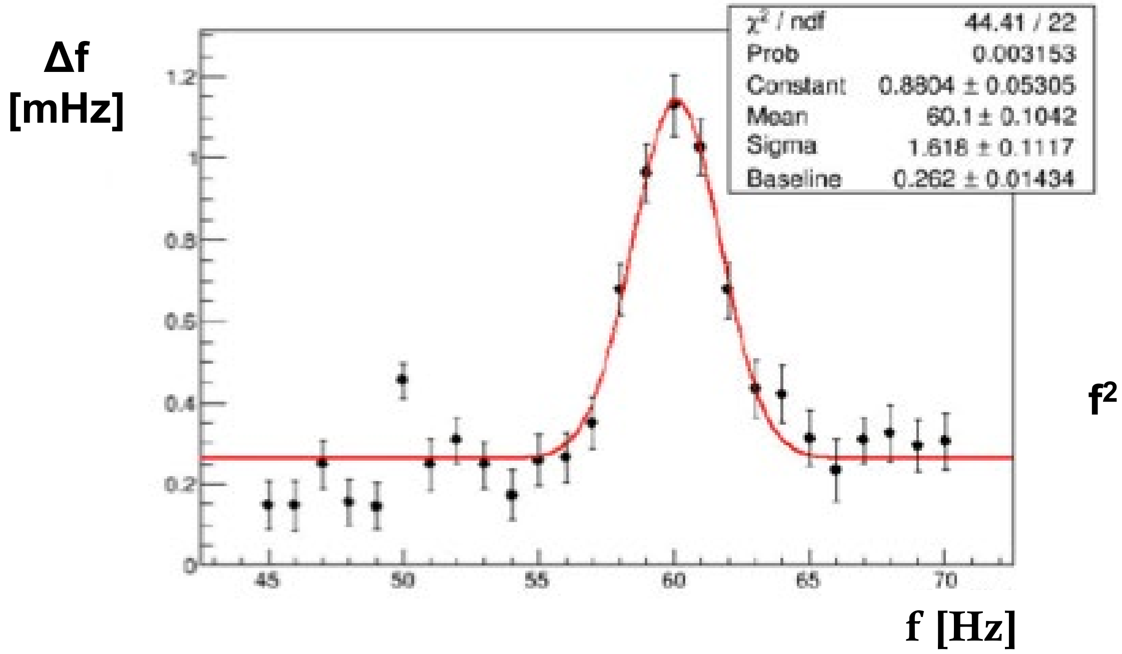


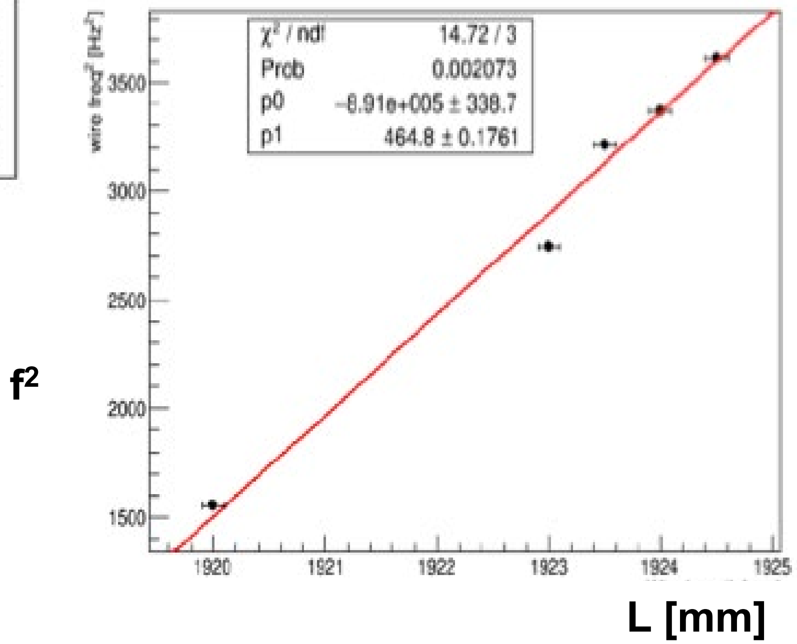
MEG II Drift chamber: Wiring procedure

Check mechanical tension:

- The system induces oscillation in a wire by means of a pulsed HV signal and measures the frequency of the first harmonic resonance of wire by measuring the variation of its capacitance
- The system shows the ability to resolve each frequencies of two field wires in a system made by two field wires and one sense wire placed in the middle



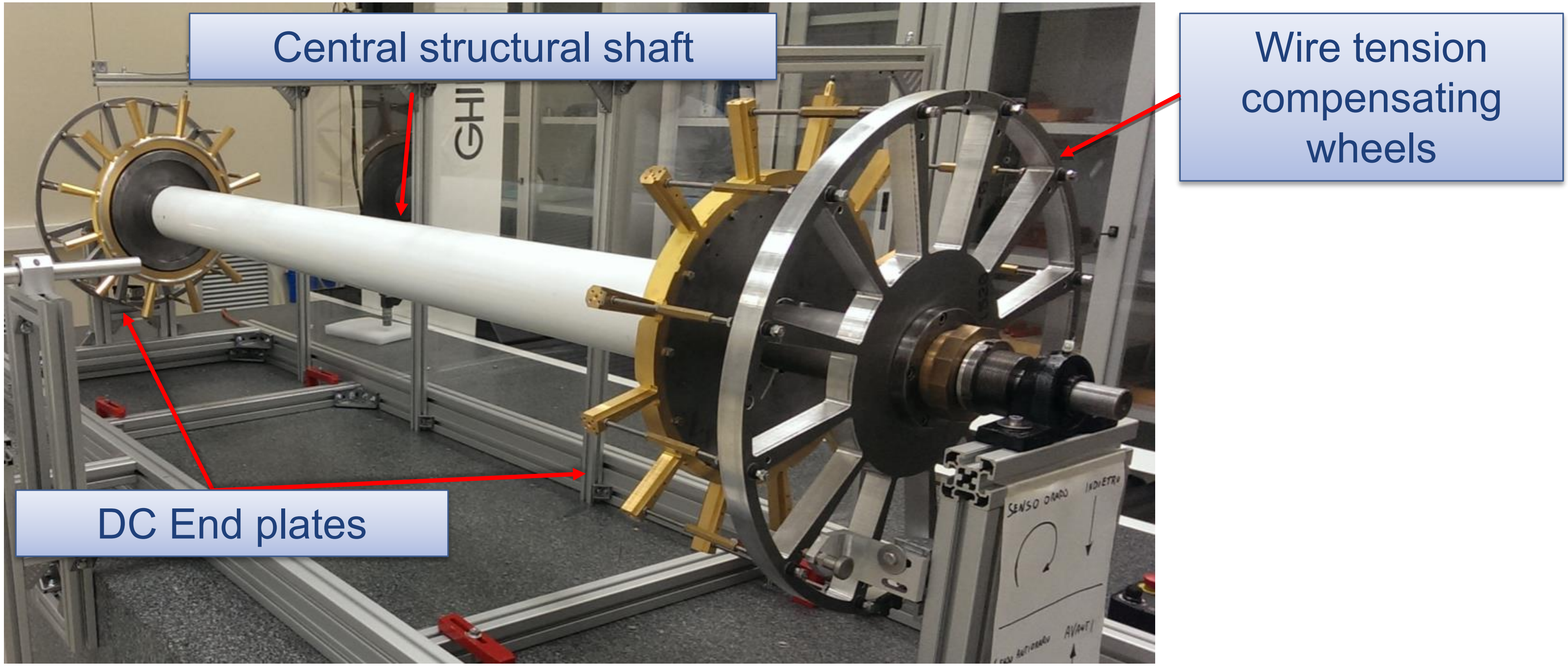




MEG II Drift chamber: Assembling

Structure:

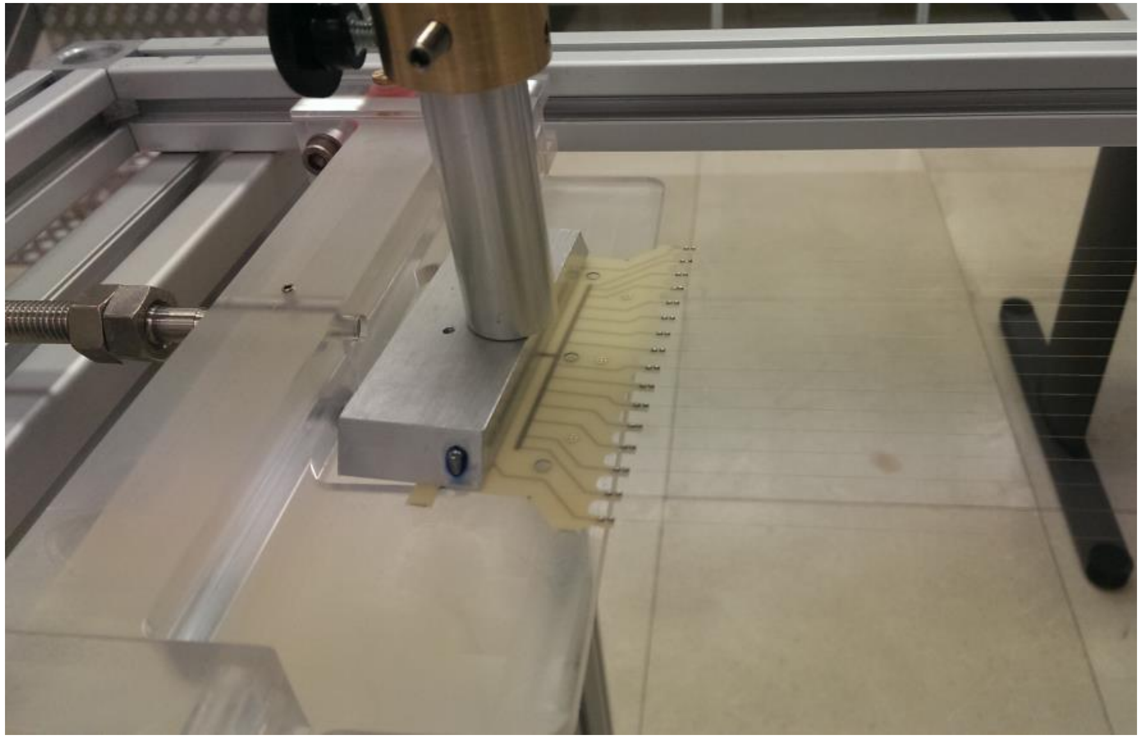
- During the assembly phase, the endplates are placed at a shorter distance than nominal to avoid stressing the wires

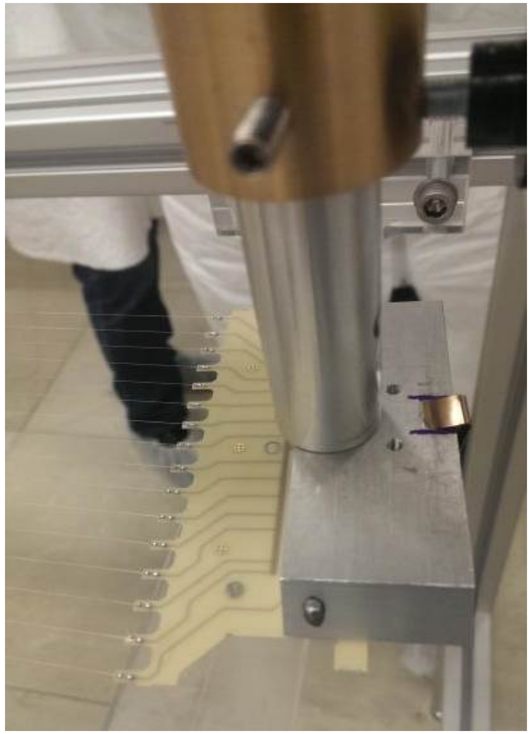


MEG II Drift chamber: Assembling

Procedure:

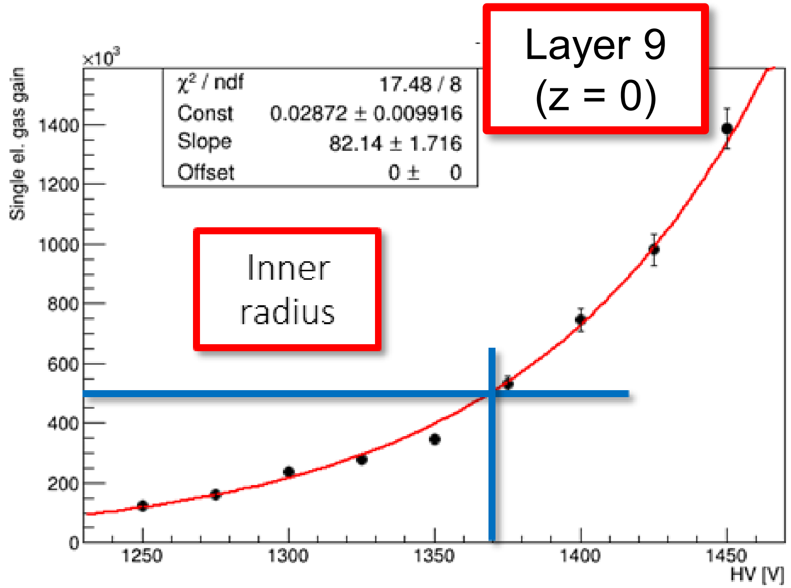
- The mounting procedure is performed with an adjustable arm and a flipping arm which is used to flip layers;
- The wire-PCBs, fixed on the transport frame, are anchored to the mounting arm with a clip and released from the frame.

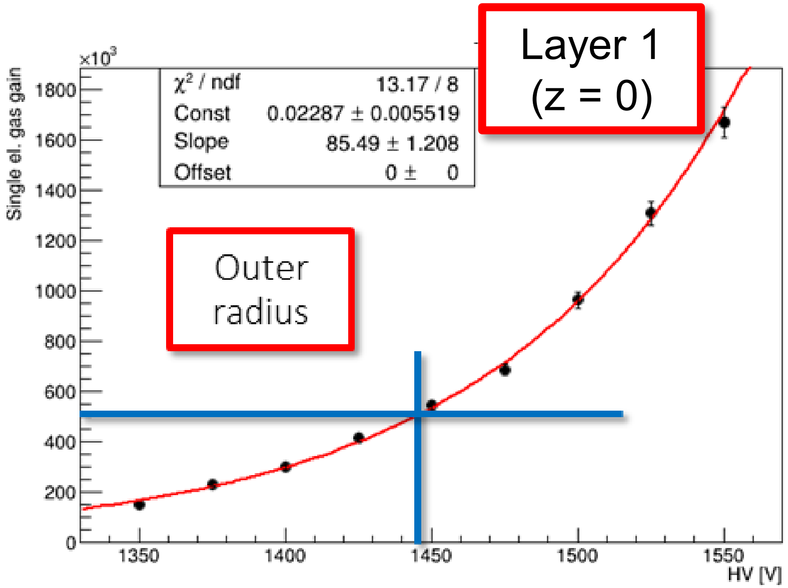


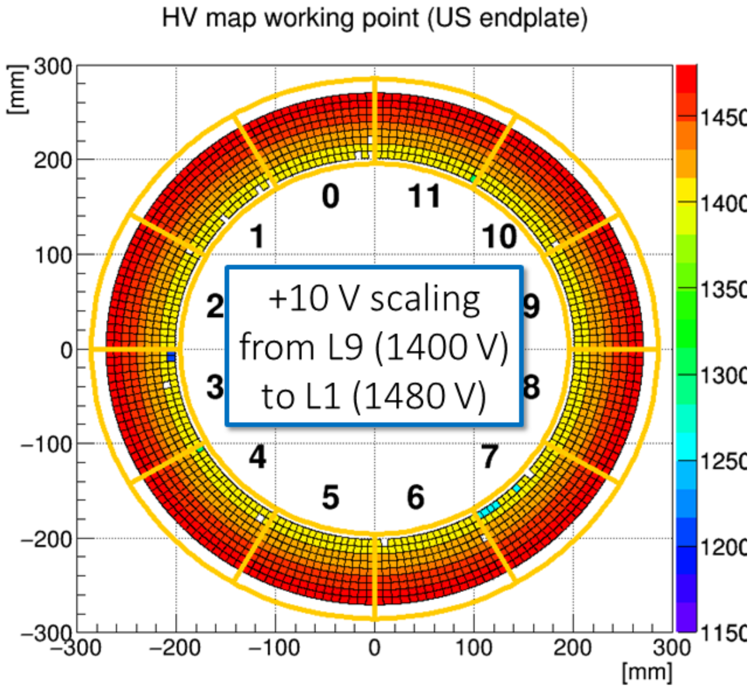


MEG II Drift chamber: HV working point

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







"dead" channels of 1.3%
negligible in e+ reconstruction

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