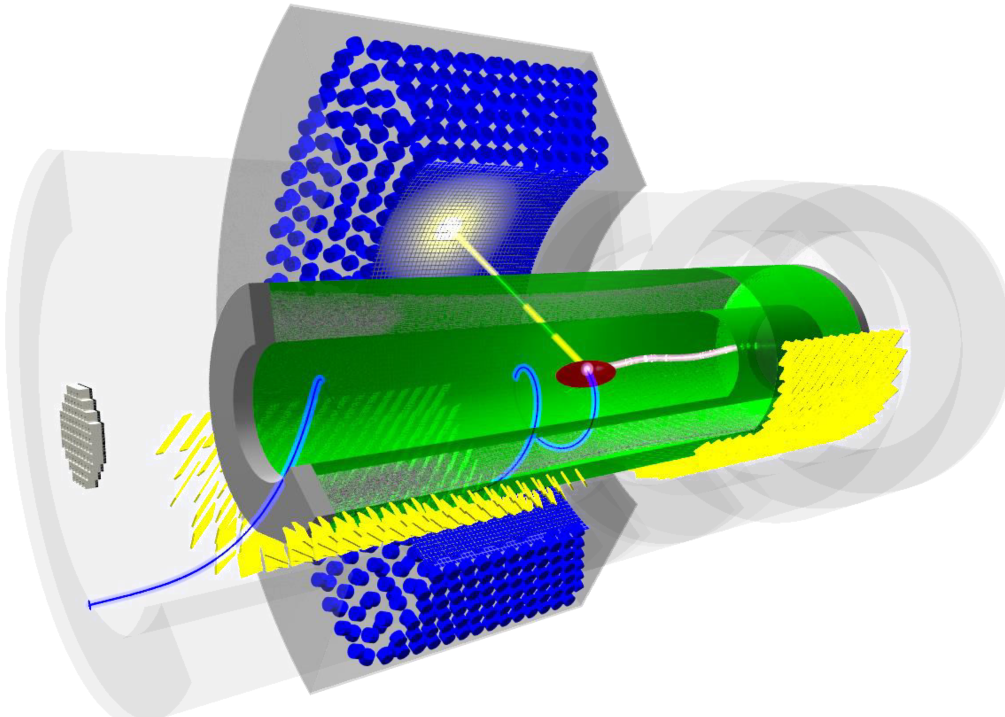
The construction technique of the high granularity and high transparency Drift Chamber of MEG II



Tassielli G.F. - *INFN* Lecce, & Mathematics and Physics Dept., *University of Salento*,
on behalf of the MEG2 Collaboration

Instrumentation for Colliding Beam Physics 2017

Outline

- MEG-I Drift Chamber
- MEG-II Drift Chamber
  - Novel approach at construction technique of high granularity and high transparency Drift Chambers
  - The wiring Robot and the stringing procedures
  - The assembly procedures
  - Front End electronics
  - Expected performance
- Summary

MEG-I Drift Chambers

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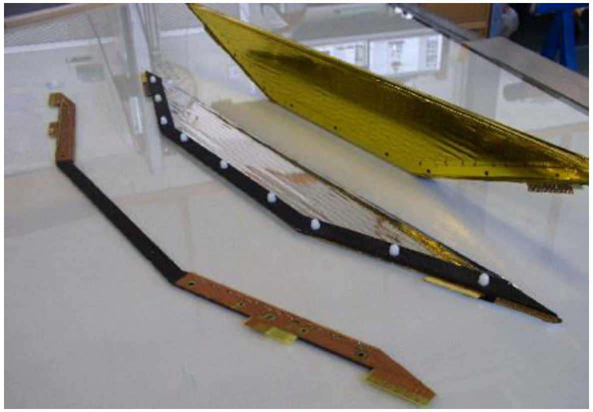
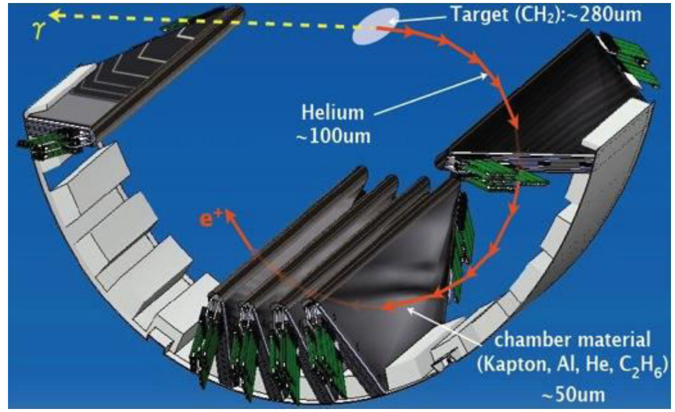
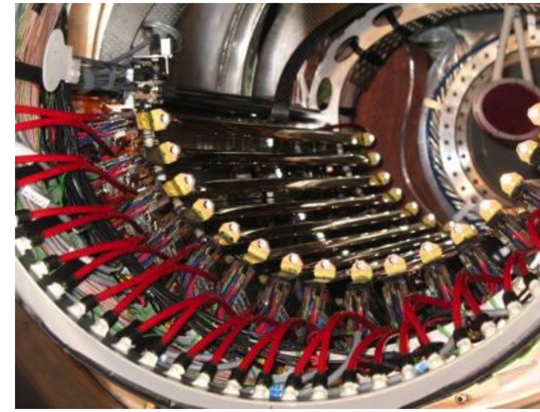


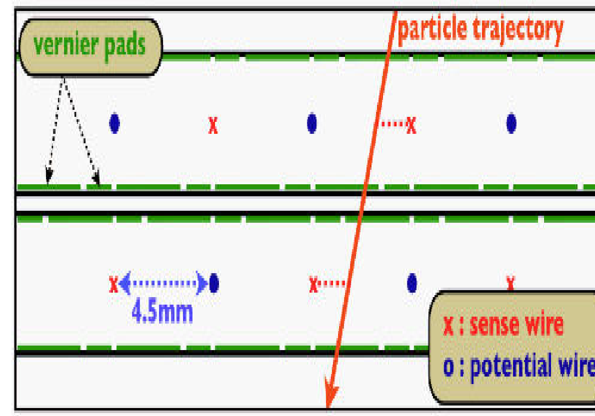


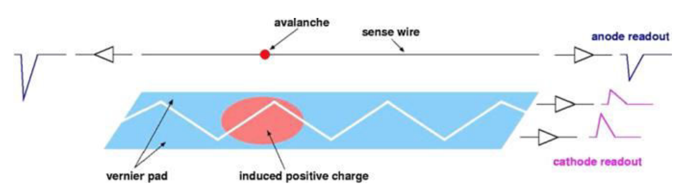


- 16 chambers
- Each chamber is composed of
  - 2 staggered arrays of drift cells
  - 1 signal wire (25 µm NiCr) and 2x2 Vernier cathode strip made 0,45 µm alluminum strip on 15 µm kapton foil
  - He:C_2H_6 (50/50)
- Single chamber ~ 2.6 10^{-4} X_0
- Full e+ turn : ~ 2.0 10^{-3} X_0

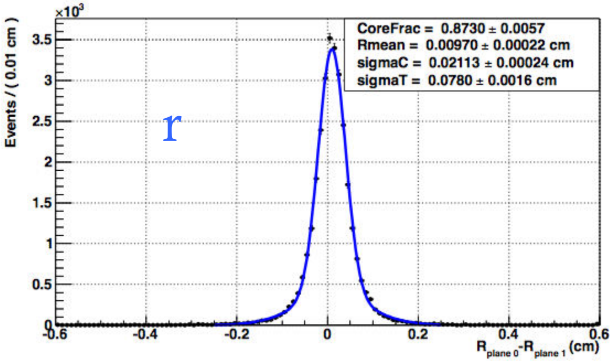
σ_{xy} ~ 210 µm (t drift)

σ_z ~ 800 µm (Vernier)



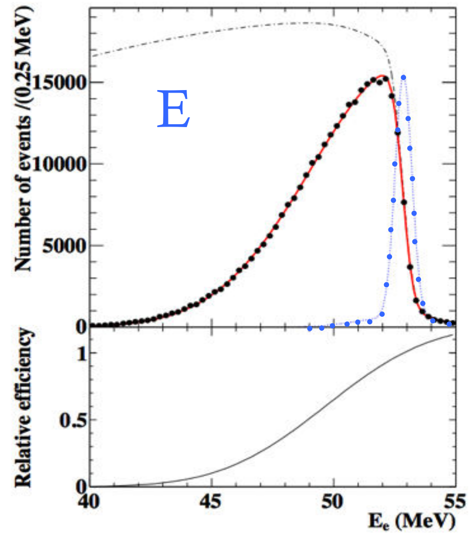


MEG-I DC: Performance



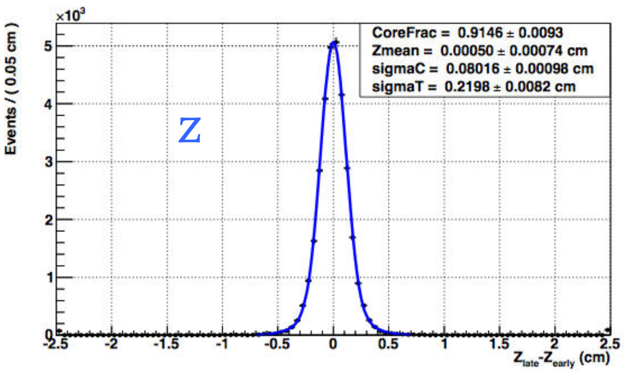
transverse coordinate resolution

$\sigma_{r,core}$ = 210 μm
$\sigma_{r,tail}$ = 780 μm
frac. = 87%
$\sigma_{r,design}$ = 200 μm



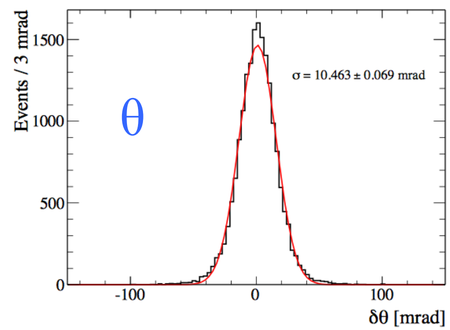
positron energy resolution

$\sigma_{E,core}$ = 330±16 keV
$\sigma_{E,tail}$ = 1.13±0.12 MeV
frac. = 82%
$\sigma_{r,design}$ = 180 keV



longitudinal coordinate resolution

$\sigma_{z,core}$ = 800 μm
$\sigma_{z,tail}$ = 2100 μm
frac. = 91%
$\sigma_{z,design}$ = 300 μm



polar angular resolution

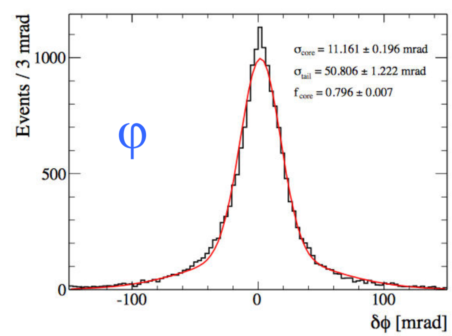
σ_θ = 9.4±0.5 mrad
$\sigma_{\theta,design}$ = 5.0 mrad

DC – TC matching efficiency

$\Sigma_{DC\text{-}TC}$ = 41%
$\Sigma_{DC\text{-}TC,design}$ = 90%

vertex resolution

$\sigma_{y,core}$ = 1.1±0.1 mm
$\sigma_{y,tail}$ = 5.3±3.0 mm
frac. = 87%
σ_z = 2.5±1.0 mm
$\sigma_{y,z,design}$= 1.0 mm



azimuth angular resolution

$\sigma_{\varphi,core}$ = 8.4±1.4 mrad
$\sigma_{\varphi,tail}$ = 38±6 mrad
frac. = 80%
$\sigma_{\varphi,design}$ = 5.0 mrad

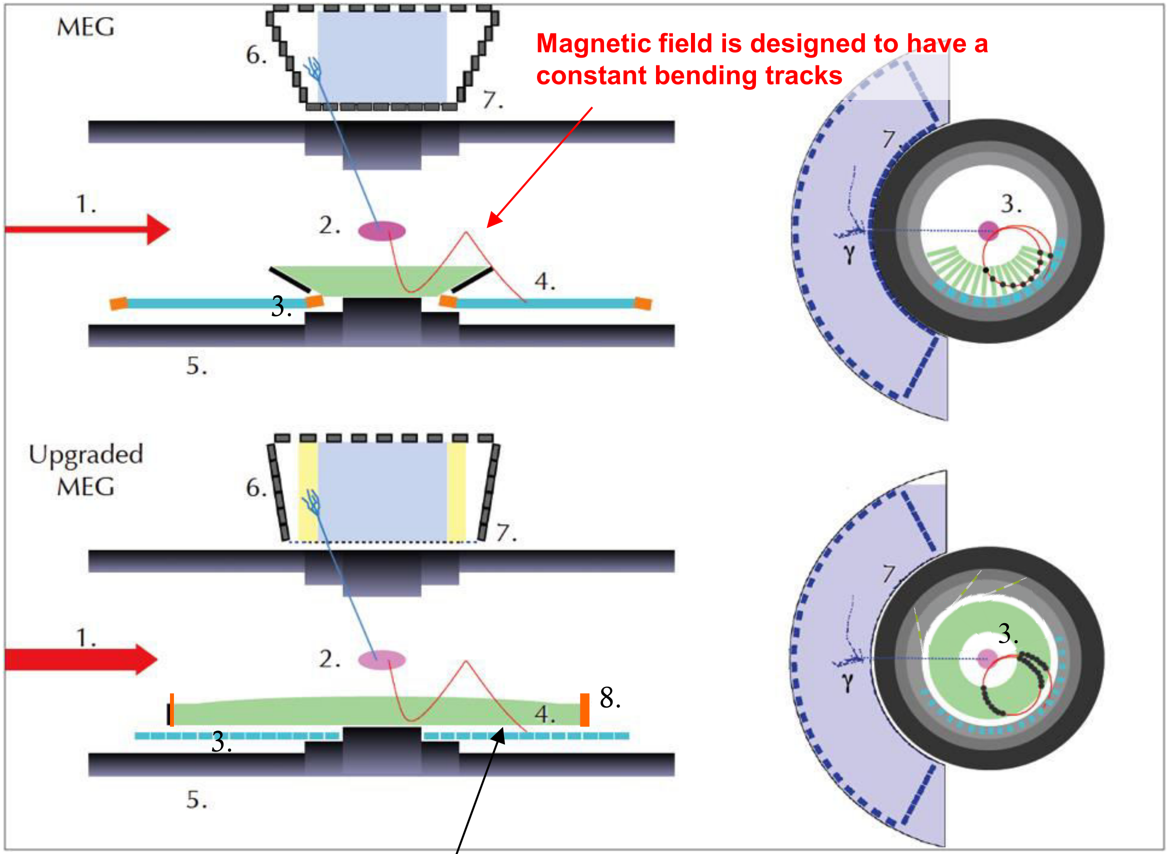
MEG-I DC: need to be upgraded

Variable	Foreseen MEG	Obtained MEG	Foreseen MEG^{UP}
$\Delta E_\gamma(\%)$	1.2	1.7	1.0
Δt_γ (ps)	43	67	–
γ position (mm)	$4(u, v)$, $6(w)$	$5(u, v)$, $6(w)$	$2.6(u)$, $2.2(v)$, $5(w)$
ΔP_e (keV)	200	306	130
e^+ angle (mrad)	$5(\varphi_e)$, $5(\vartheta_e)$	$8.7(\varphi_e)$, $9.4(\vartheta_e)$	$5.3(\varphi_e)$, $3.7(\vartheta_e)$
Δt_e (ps)	50	107	–
$\Delta t_{e\gamma}$ (ps)	65	122	84
e^+ efficiency (%)	90	40	88
γ efficiency (%)	> 40	63	69
trigger efficient(%)	$\sim$99	$\sim$99	$\sim$99

- 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
  - Unmatched coverage with Timing counter
  - Large track extrapolation to Timing counter

The MEG upgrade (MEG II)

Goal: 10x improvement in sensitivity (~5×10^{-14})

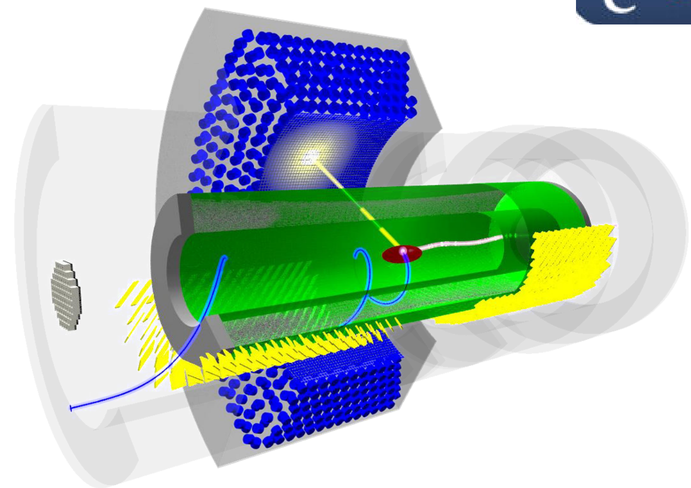


minimum materials between DC and TC;
efficiency of transfer from DC to TC improves 40% → 80%

1. Increase the number of stopped muons on target
2. Reduce the target thickness
3. Reduce the tracker radiation length and improve on granularity, resolution and efficiency
4. Improve matching DC-TC
5. Improve TC granularity
6. Extend calorimeter acceptance
7. Improve photon energy, position and timing resolution for shallow events
8. New RMD conters
9. New DAQ for higher bandwidth

MEG-II Drift Chamber

- 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 the end-plates.
- Light gas mixture **(85% He − 15% iC_4H_{10})**
- Positron efficiency > **90%** (better coupling with TC, very short extrapolation needed);
- 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 *.



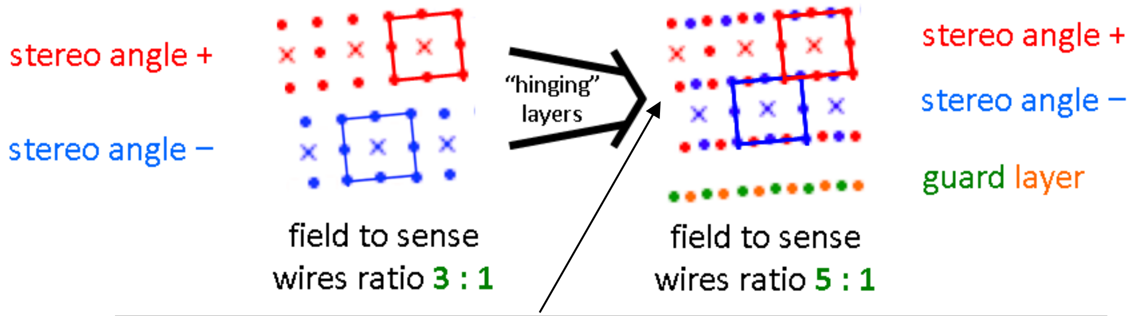
Item	Description	Thickness $10^{-3}\ X_0$	
MEG target	(140 μm plastic)	0.28	0.28
Sense wires	(20 μm W)	0.41	0.78
Field wires	(40 and 50 μm Al)	0.33	
guard wires	(40 μm Al)	0.04	
inner cylinder	(20 μm Kapton)	0.21	0.21
Inner gas	(pure He)	0.06	0.59
Tracker gas	(He/iBut. 85/15)	0.53	
Total	1 full turn w/o target	1.58	

** For details see G.Chiarello's poster:*
"Application of the Cluster Counting and Timing techniques to improve the performance of the high transparency Drift Chambers for modern High Energy Physics experiments."

MEG-II Drift Chamber

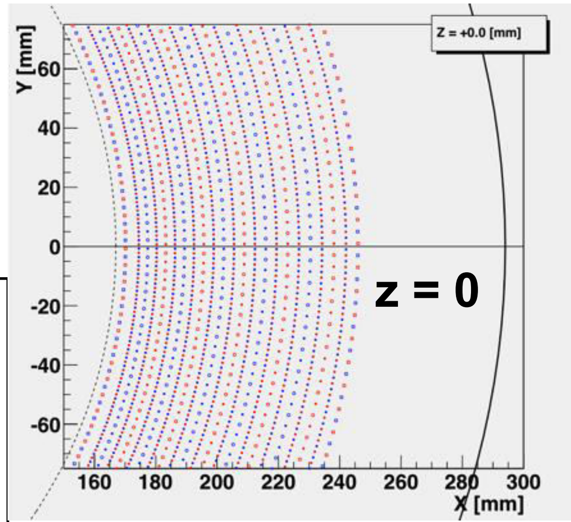
Chamber characteristics:

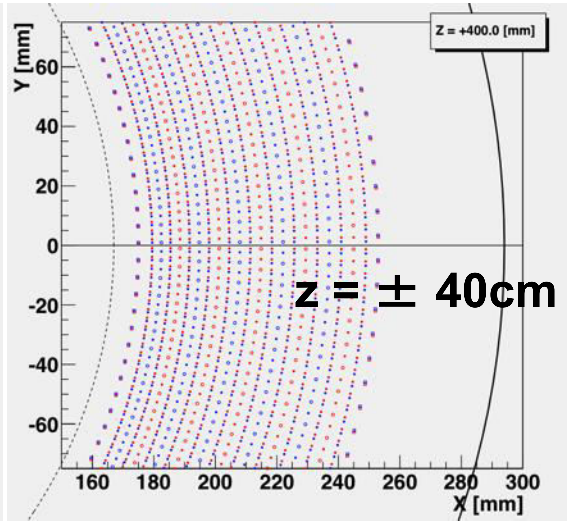
- r_{in}~ 16cm r_{out}~ 30cm
- L ~ 2m
- 10 layers
- 12 cylindrical sectors
- 16 cells per sector
- full stereo with large stereo angles **(102÷147 mrad)**
- small square cells **(5.8÷7.8 mm at z=0, 6.7÷9.0 at z=±L/2)** (see pictures:)



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

1920 sense wires: *W(Au) 20 μm*
7680 field wires: *Al(Ag) 40 μm*
2688 guard wires: *Al(Ag) 50 μm*
12288 wires in total
(~ 12 wires/cm²)

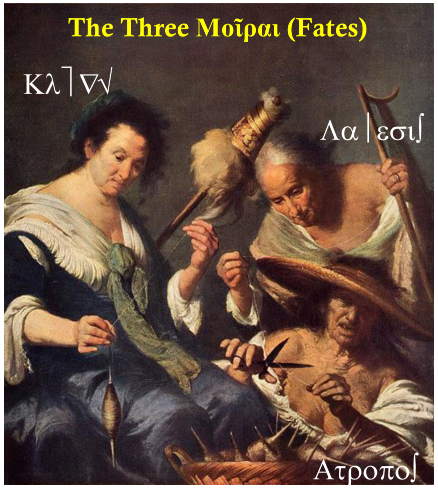




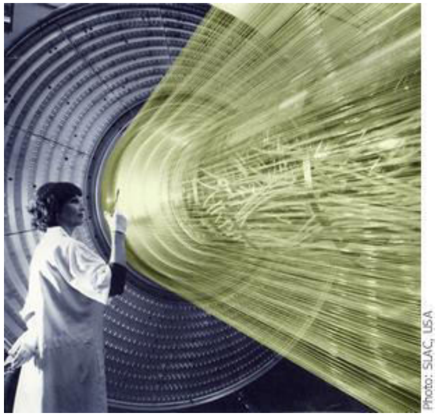
High wire densities prevent the use of feed-through, needing novel approaches to the wiring procedures

DC stringing: the old way

The Old Way

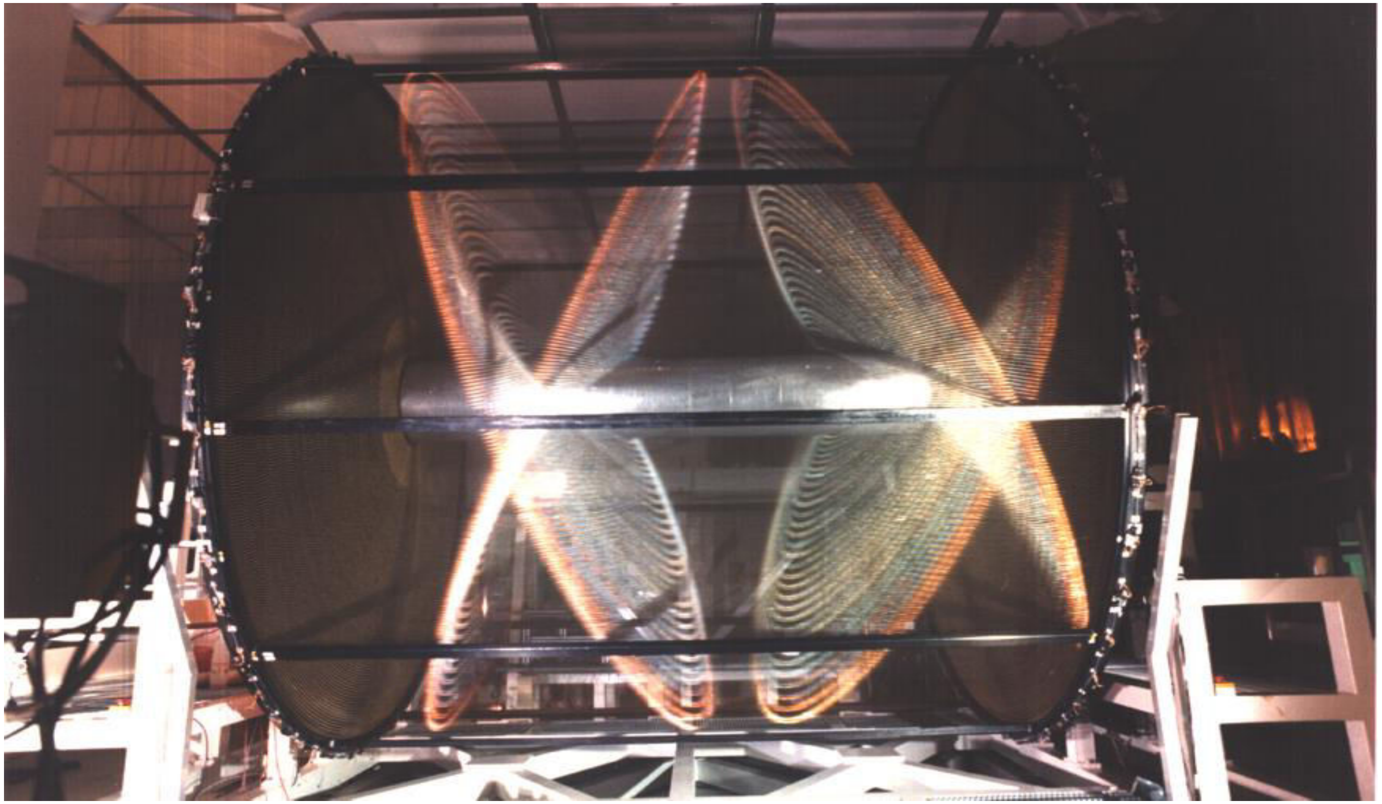


Bernardo Strozzi – Le tre Parche – Venezia, circa 1620



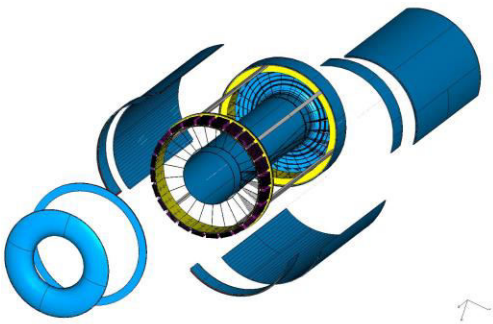
The KLOE Drift Chamber

45 m^3 > 52,000 wires He/iC_4H_{10}



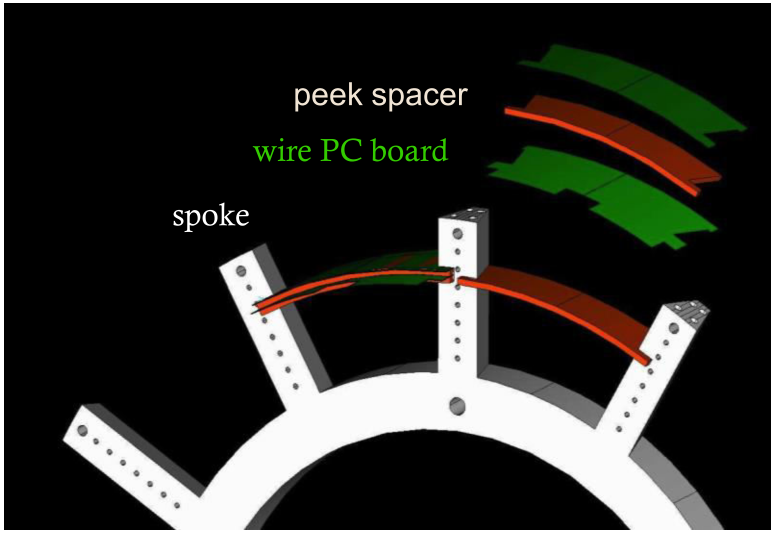
MEG-II DC: the novel way

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



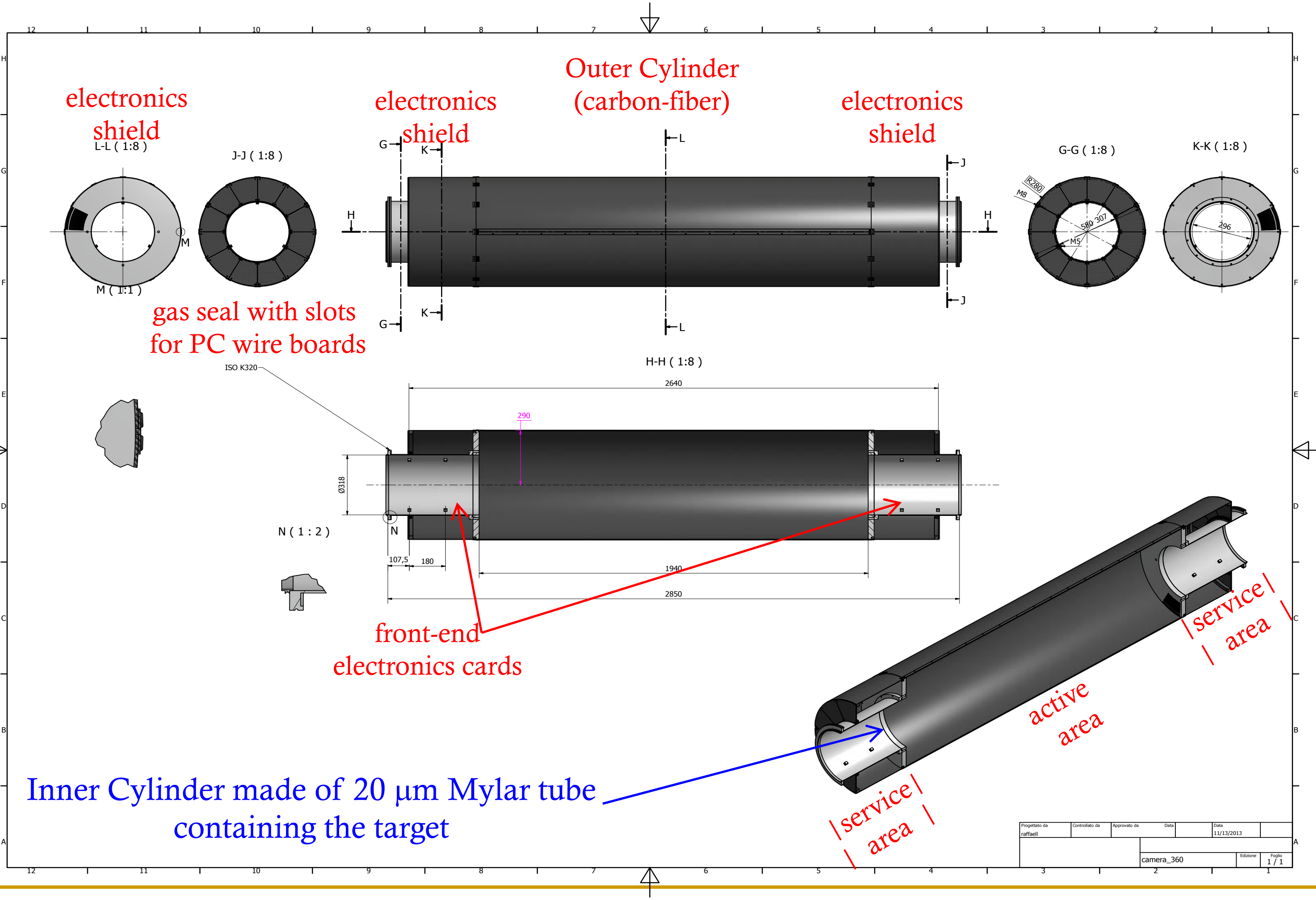
The solution found for MEG II:

- 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.



MEG-II DC: the novel way

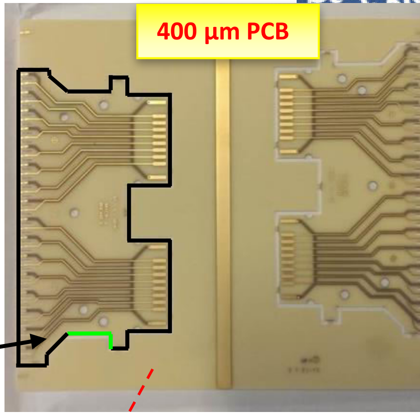
The carbon fiber outer cylinder is the only mechanical structure supporting the wire tension



MEG-II DC: stringing (*the Wiring Robot*)

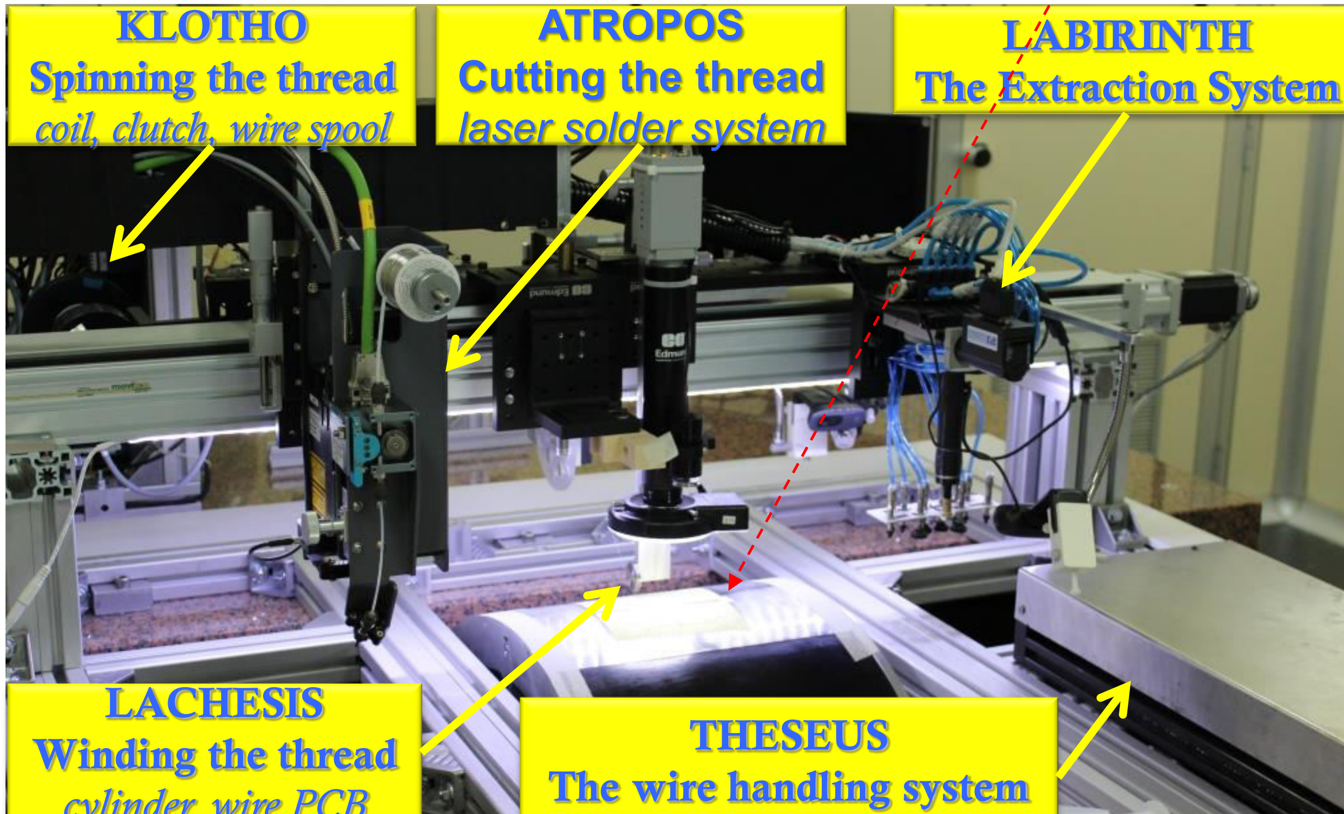
The tasks of the wiring robot are:

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

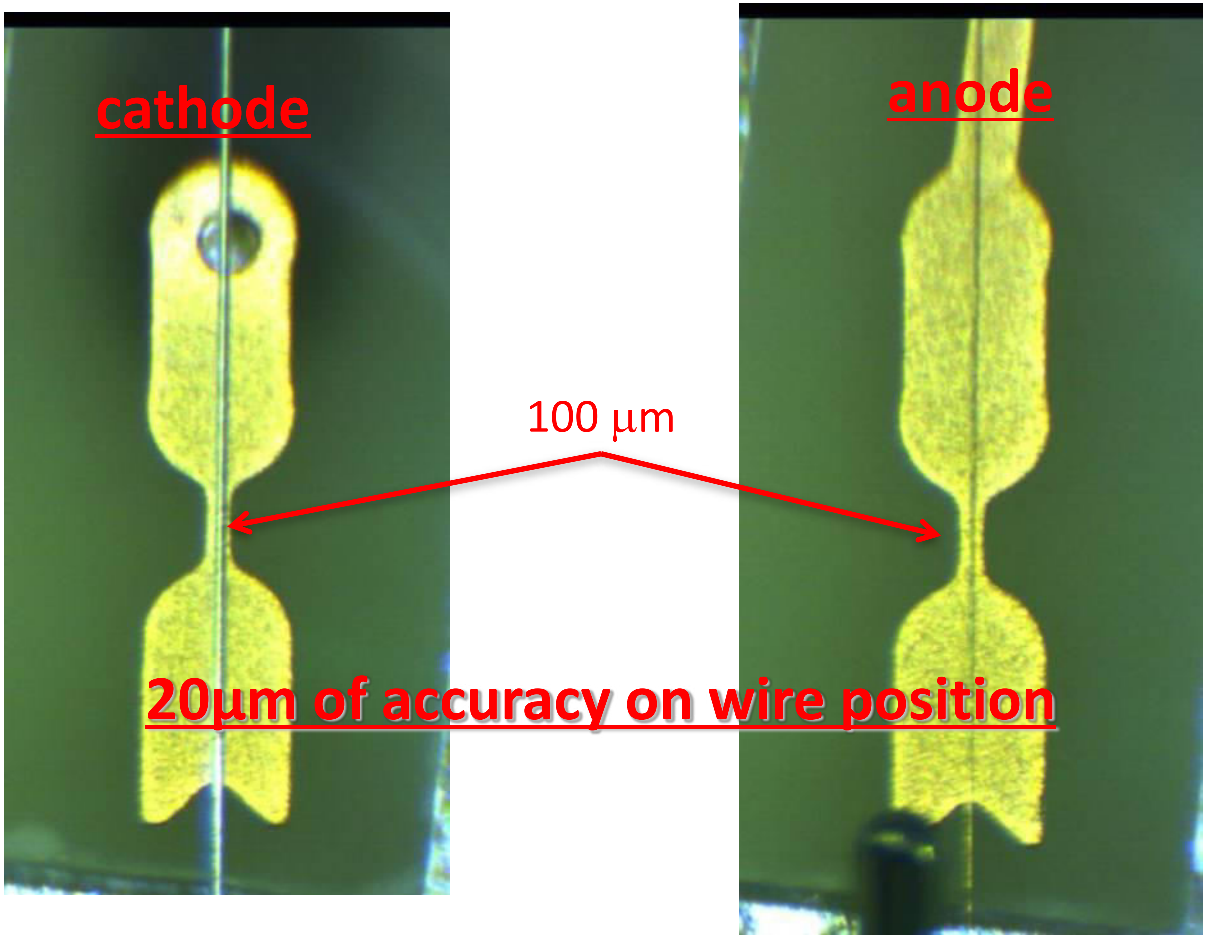


Its main parts are:

- a winding drum;
- an electromagnetic brake;
- a system of pulleys;
- a strain gauge;
- an high resolution camera;
- 5 linear synchronized axes;
- a CompactRIO controller;
- a contactless soldering system;
- a PCB extraction system.

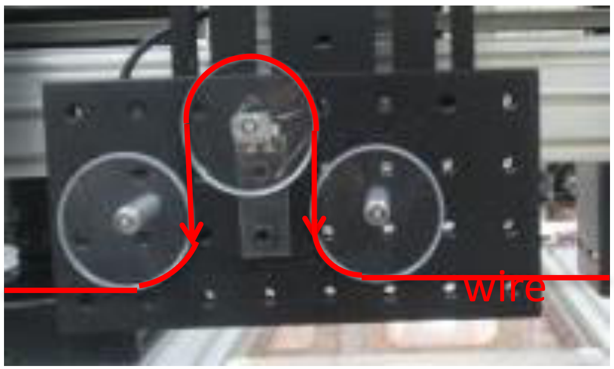


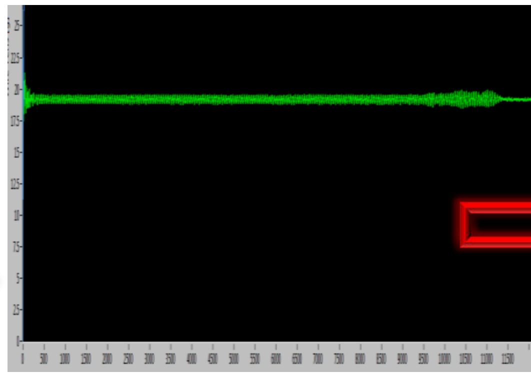
WIRING SYSTEM (***Klotho and Lachesis***): wire position

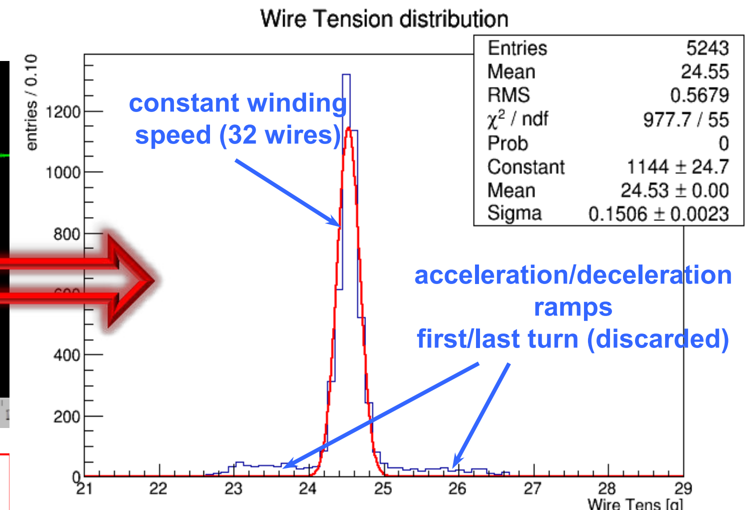


WIRING SYSTEM (*Klotho and Lachesis*): wire tension

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.

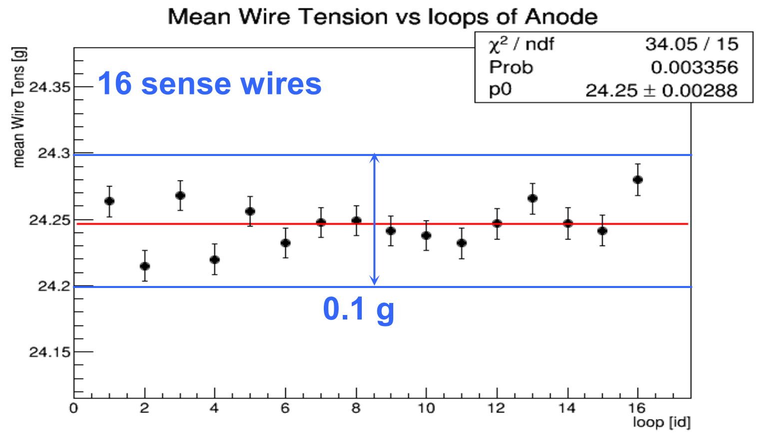


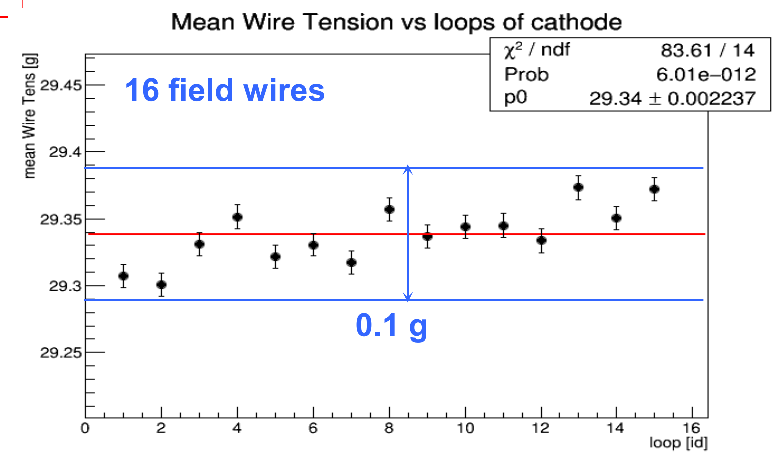




mean wire tension is stable at the level of 0.05 g

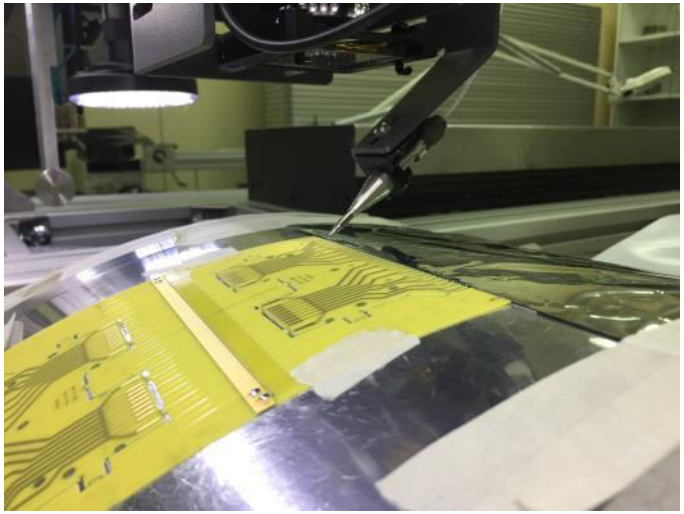
For single wire (turn):

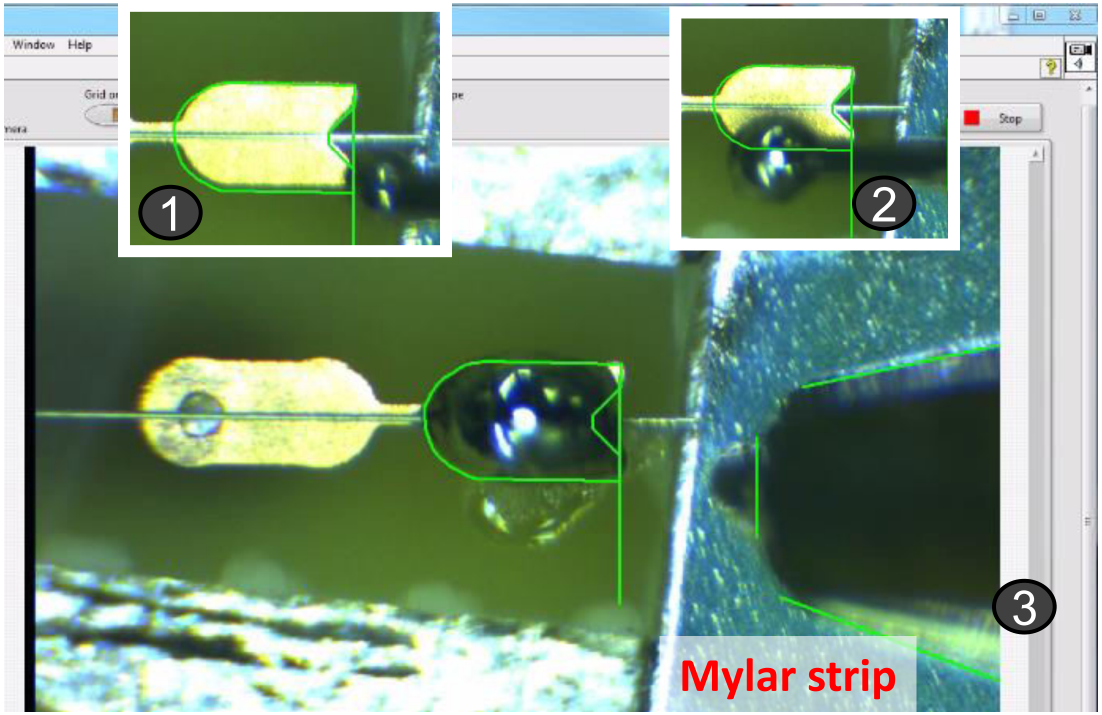




SOLDERING SYSTEM (*Atropos*)

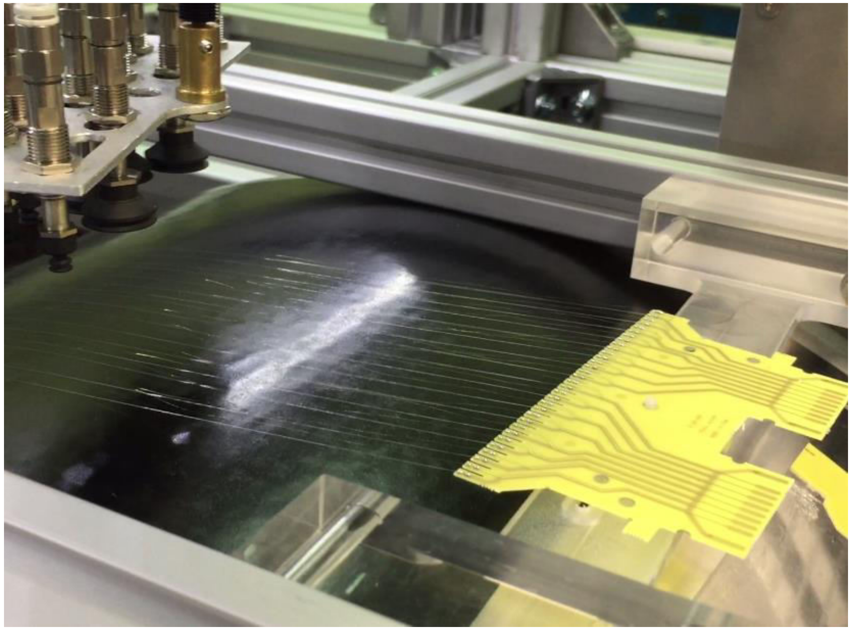
- The soldering phase is accomplished by an LASCON 501 IR laser soldering System using a low temperature (180 ° C) melting tin.
- The laser system is controlled by the NI CompactRIO and is synchronized with the positioning system.
- The wires, during the soldering phase, are protected with a Mylar foil to avoid flux splashing.

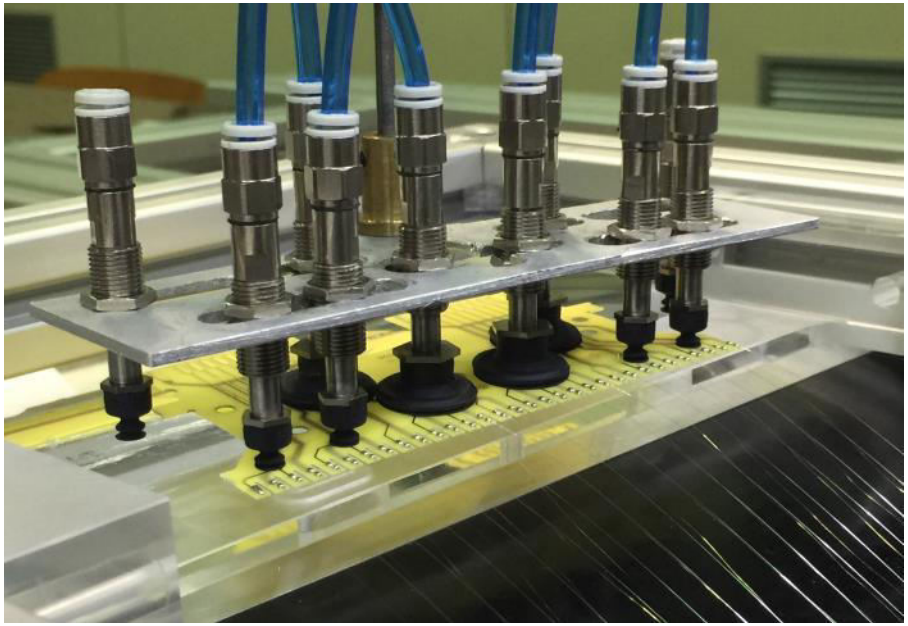




EXTRACTION SYSTEM (*Labirinth and Theseus*)

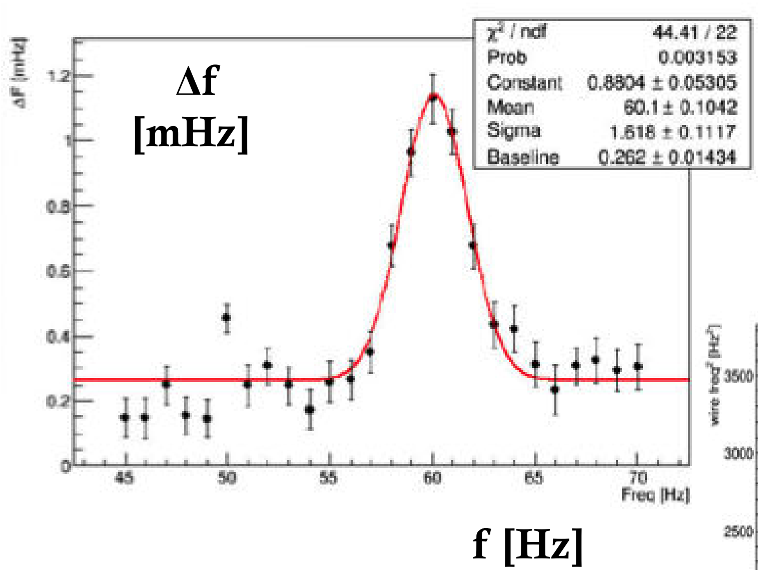
- The wound layer of soldered wires must be unrolled from the winding drum and de-tensioned for storage and transport to the assembly station at INFN Pisa.
- The wire PCBs are lifted off from the cylinder with a linear actuator connected to a set of vacuum operated suction cups.

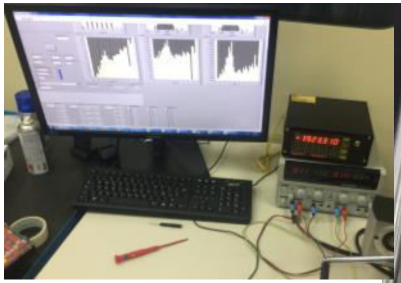


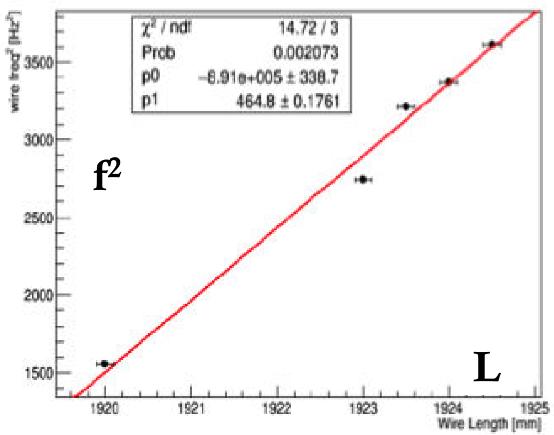


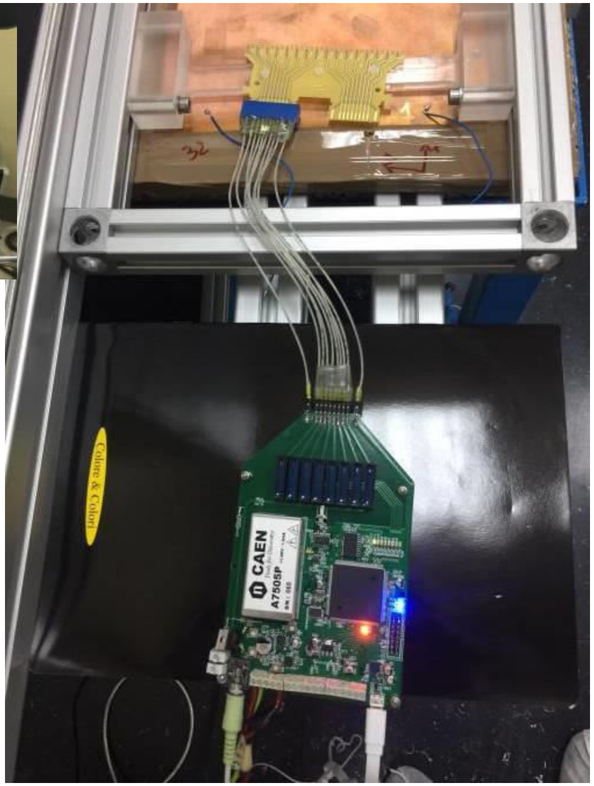
CHECK MECHANICAL TENSION WIRE

- The system measures the resonant frequency of the wire oscillations induced by a sinusoidal HV signal.
- The system cycles on each wire by multiplexing the HV signal.
- Each cycle of 16 wires takes about 10 min.



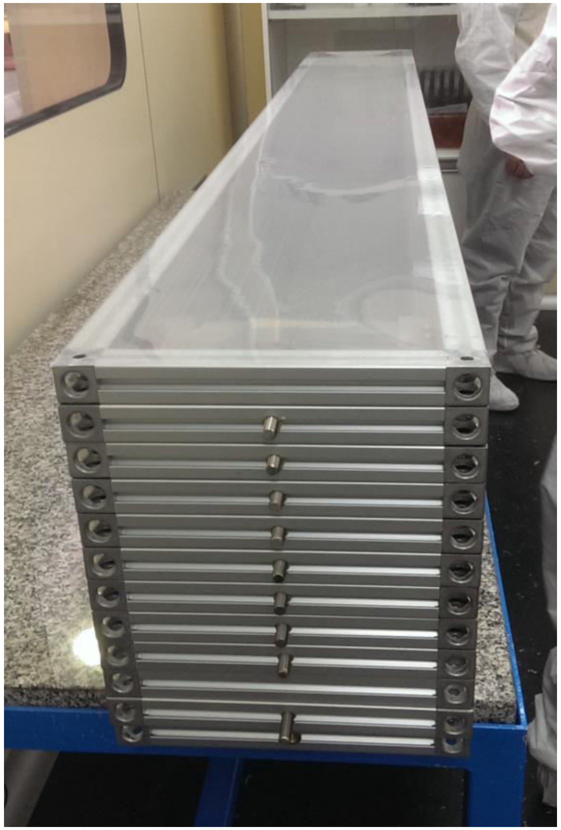


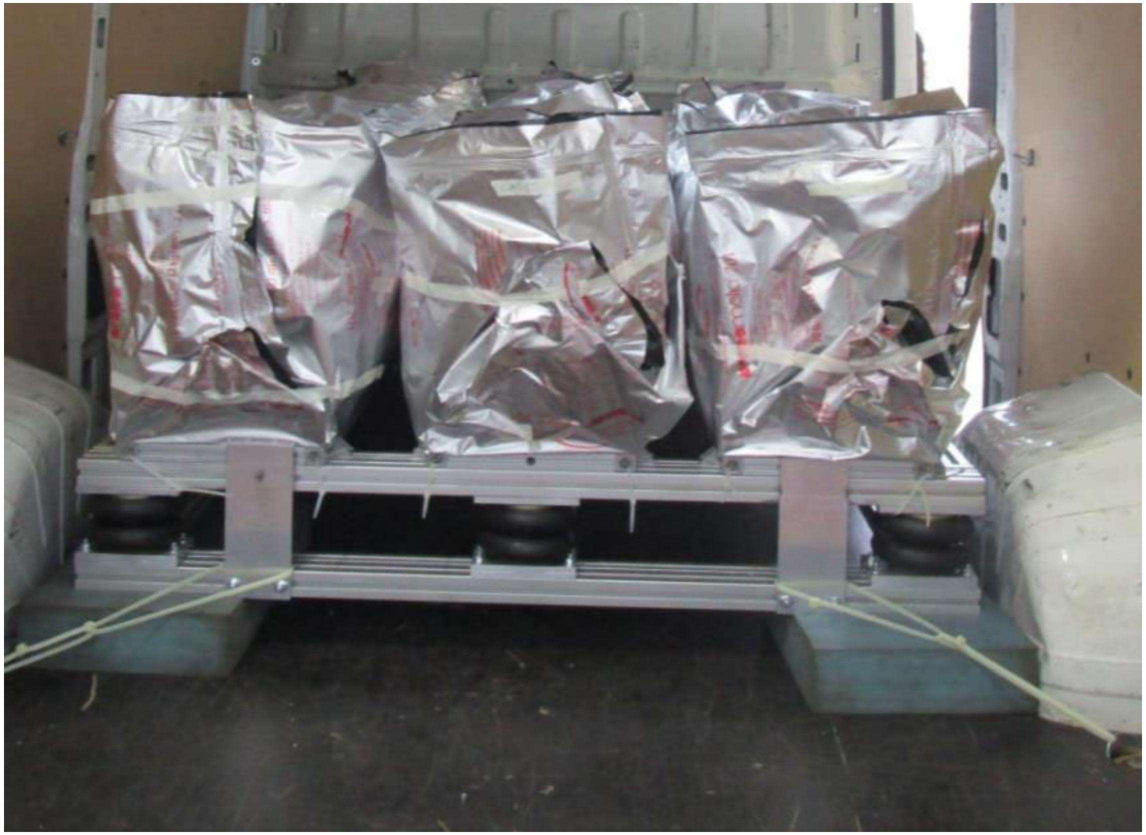




TRASPORT FORM LECCE TO PISA

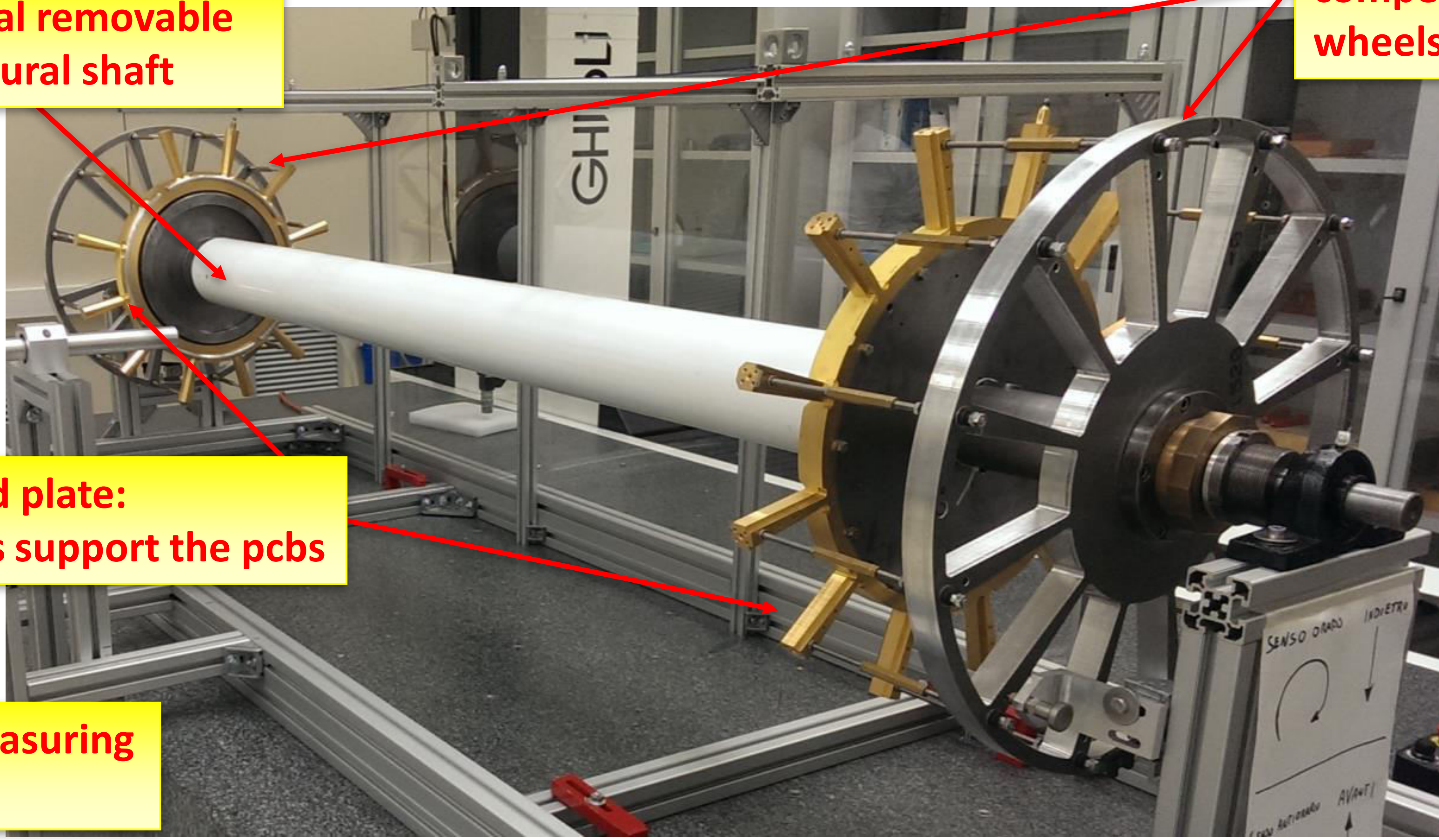
- During transport, 3 sets of 13 frames each are wrapped in a welded sealing bag, to avoid contamination, and flushed with dry gas, to avoid water vapor condensation





MEG-II DC: assembly-I

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



Central removable structural shaft

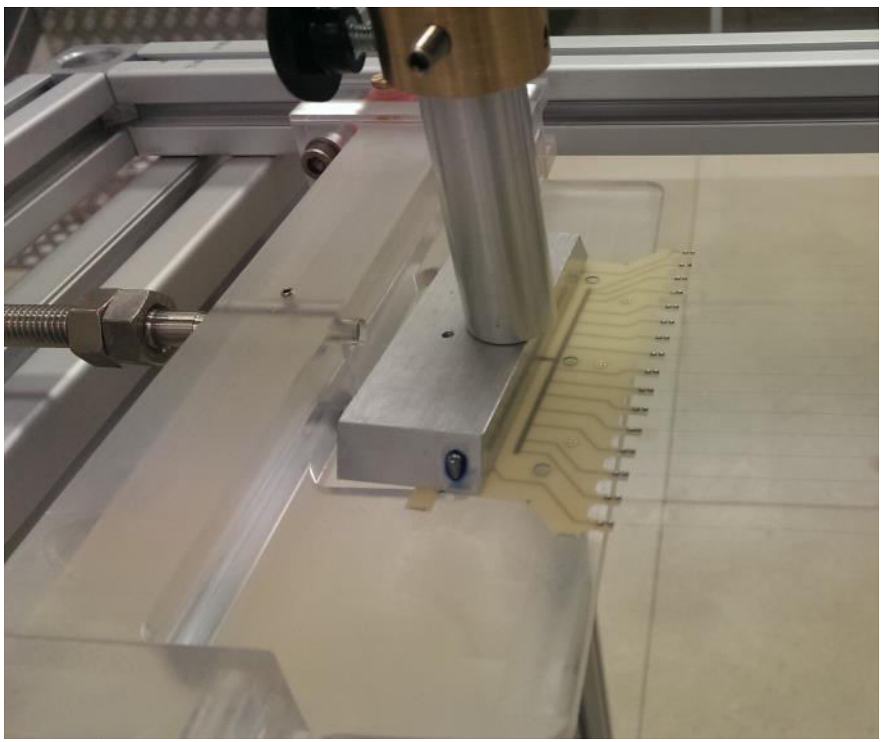
wire tension compensating wheels

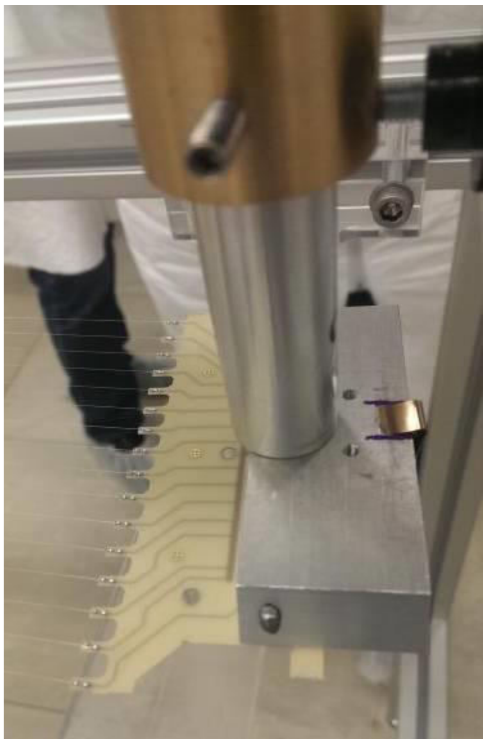
DC End plate: spokes support the pcbs

3D measuring table

MEG-II DC: assembly-II

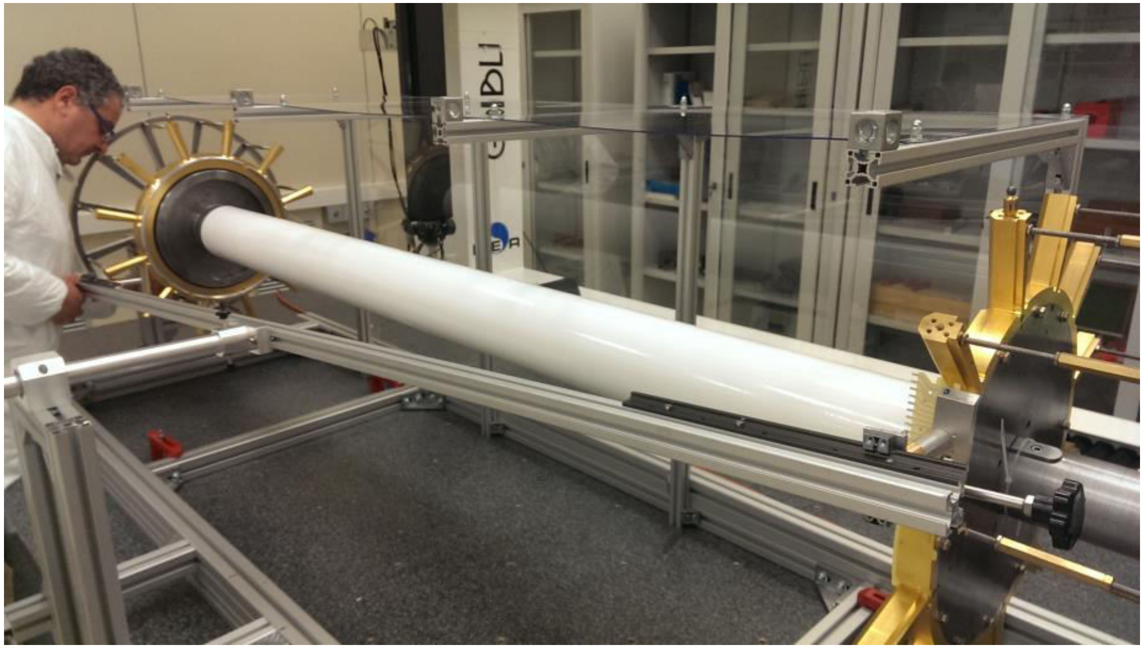
- The mounting procedure is performed with an adjustable arm and a flipping arm (used only for flipped layers);
- The wire-PCBs, fixed on the transport frame, are anchored to the mounting arm with a clip and released from the frame.

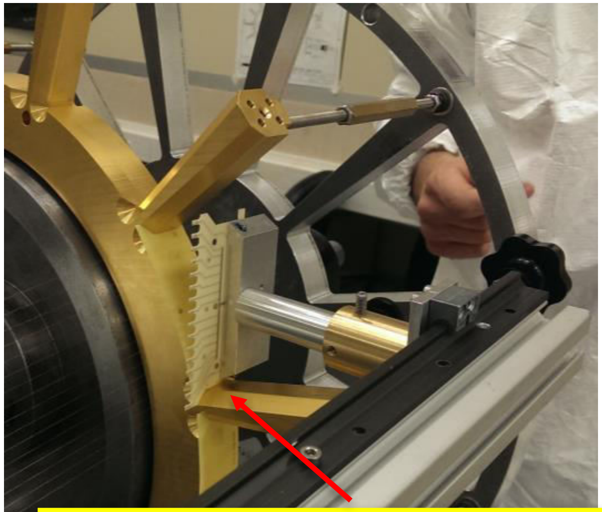


MEG-II DC: assembly-III

- 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.

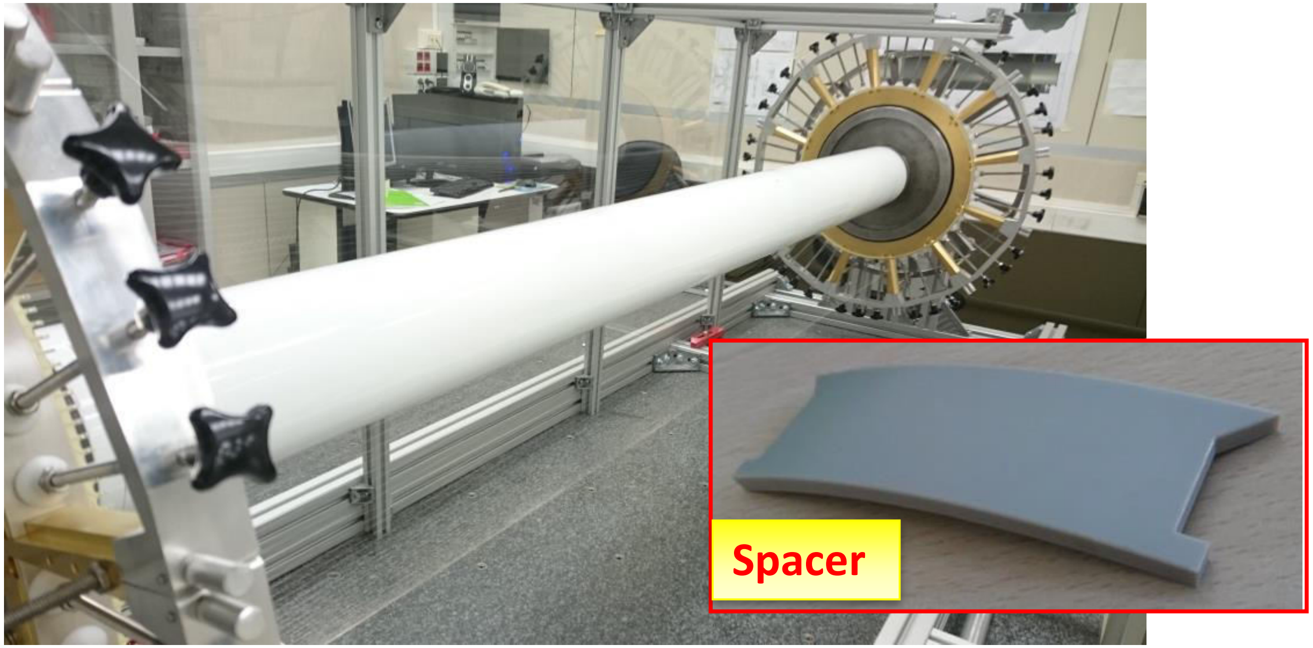


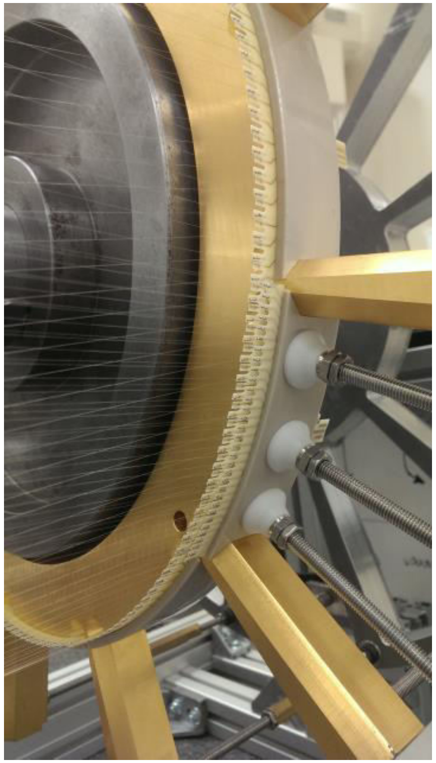


Spoke used as reference for the alignment of the pcb

MEG-II DC: assembly-IV

- This procedure is repeated for each of the 12 sectors.
- After completing the installation of one layer, a survey is performed on the radial layer position.
- Half cell spacers are pressed and glued in position with a calibrated pressure-sensitive film.
- The procedure is repeated for all layers.

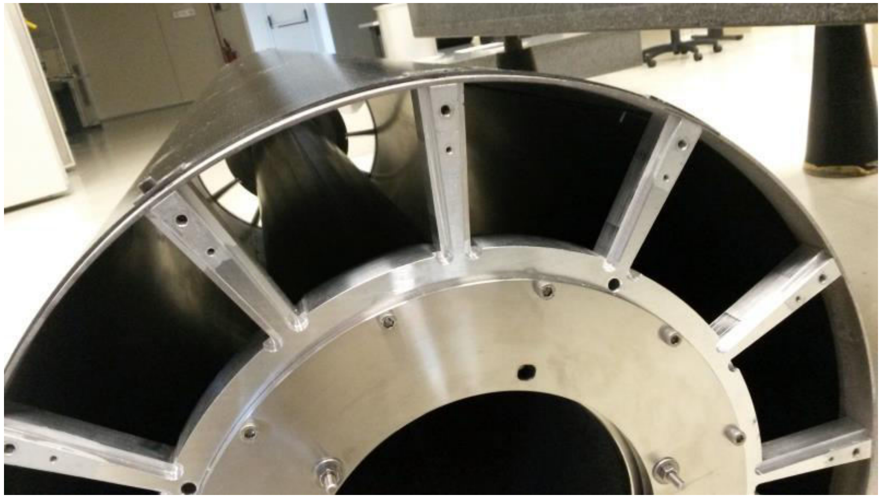




MEG-II DC: assembly-V

- After assembling all layers, the DC is closed with the carbon fiber outer panels.
- The DC will be put vertically to seal the end plate (wire-pcb and spacer).
- After sealing, the mechanical supports and the extender structure for the front-end electronics will be mounted.
- The inner mylar cylinder will be mounted after shipping the DC to PSI.

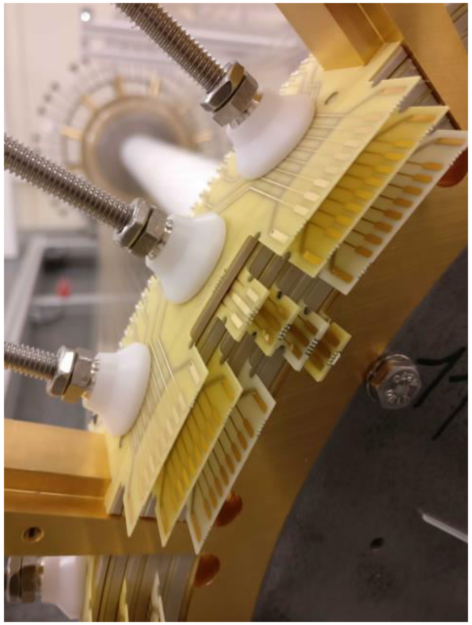
All mounting procedure, together with the DC insertion in the COBRA magnet has been successfully tested with a Mock-up chamber mechanically identical

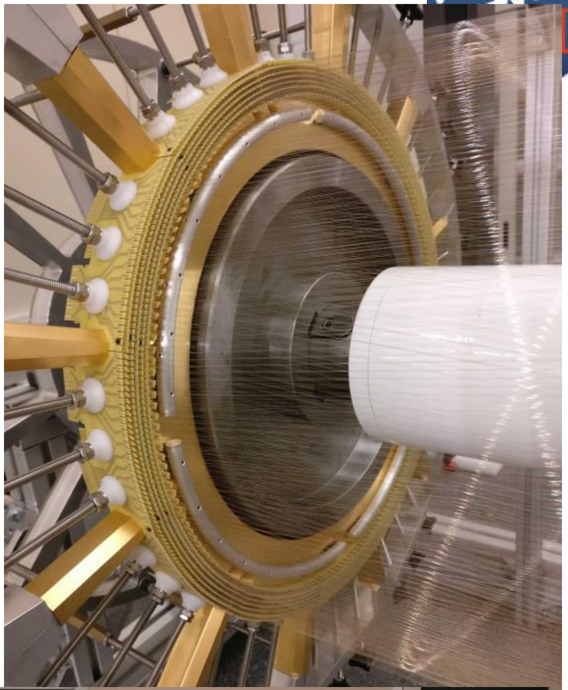


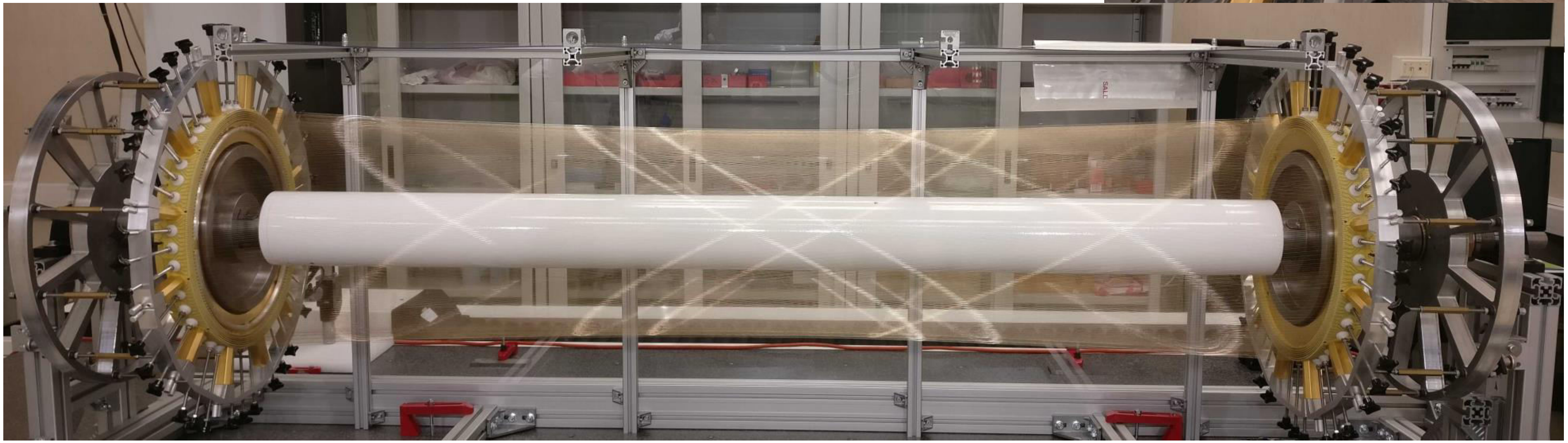
MEG-II DC: Status

At today:

- The first 4 layers have been wired. In the last weeks a wiring rate better than expected has been reached;
- The first 3 layers have been mounted, the assembly procedure has been reliably tested.

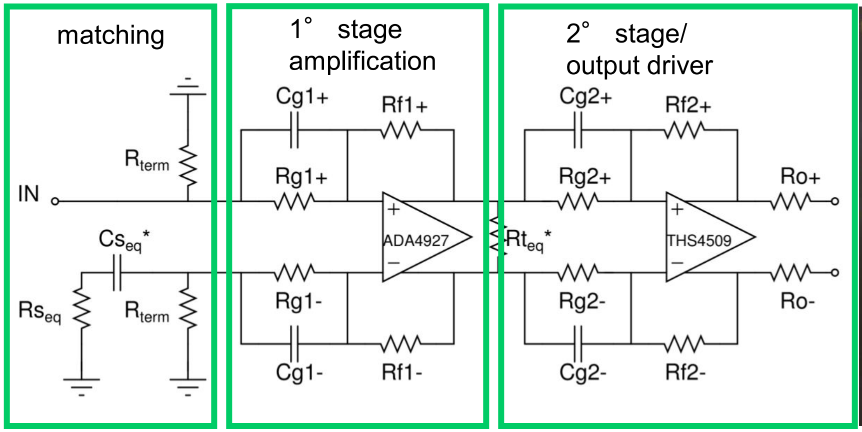


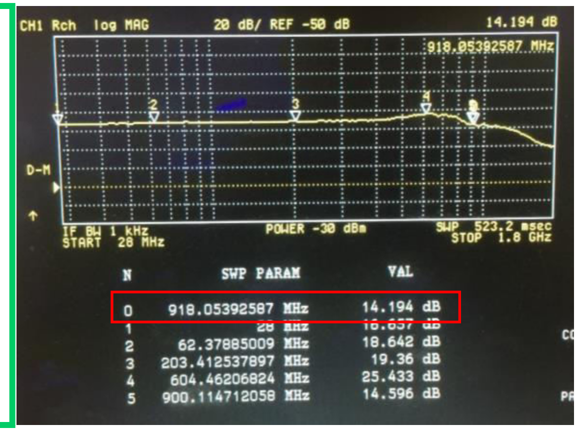




MEG-II DC: Front End electronics

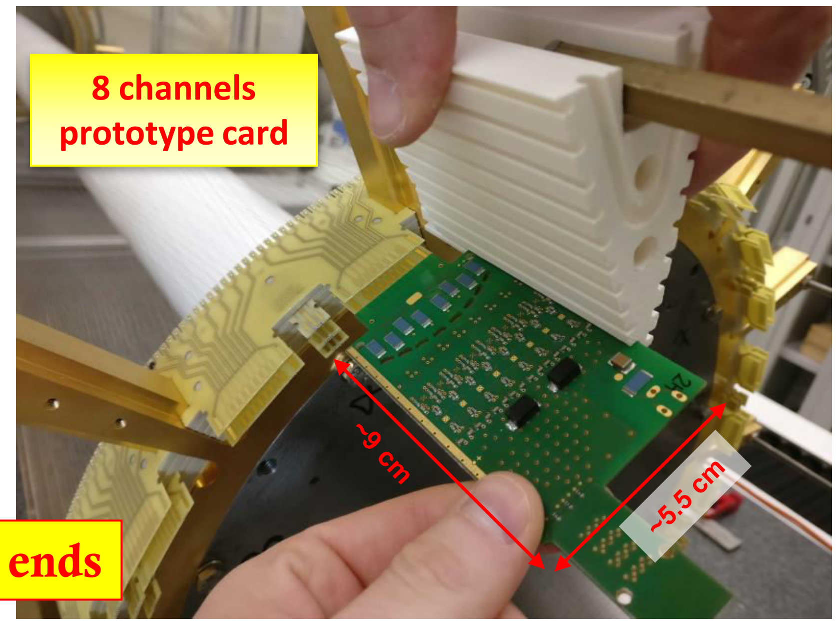
Requirements:
- High bandwidth >700 MHz
- Good gain: ~10
- High density < 7mm channel width
- Fully differential





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

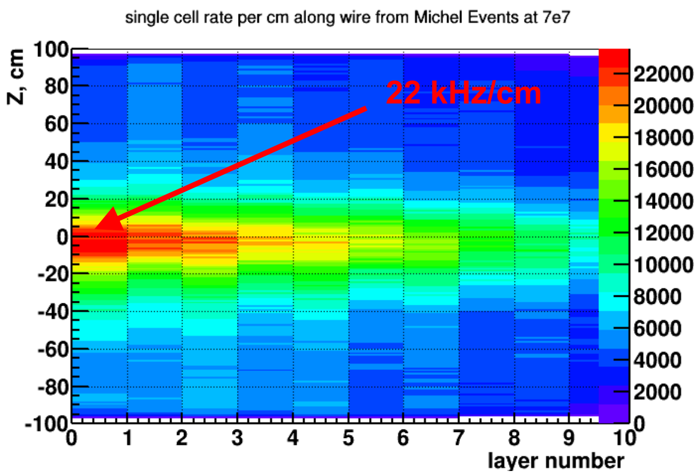
Layout:
- 2 stage amplifiers based on commercial devices:
  - ADA4927 (AD) Ultralow distortion current feedback
  - THS4509 (TI) Wideband low noise fully differential amplifier
- Pre-emphasis implemented on both stages in order to balance the attenuation of output cable
- High overall (*after 5m of cable*) bandwidth (FE input to DRS WaveDream input): ~1GHz
- Low power: 50mW @ ±2.5V

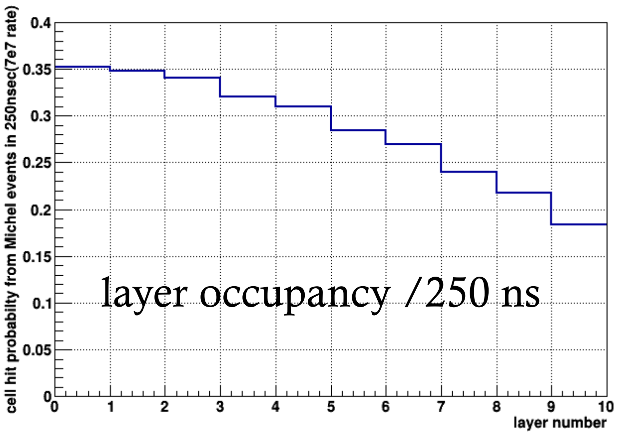


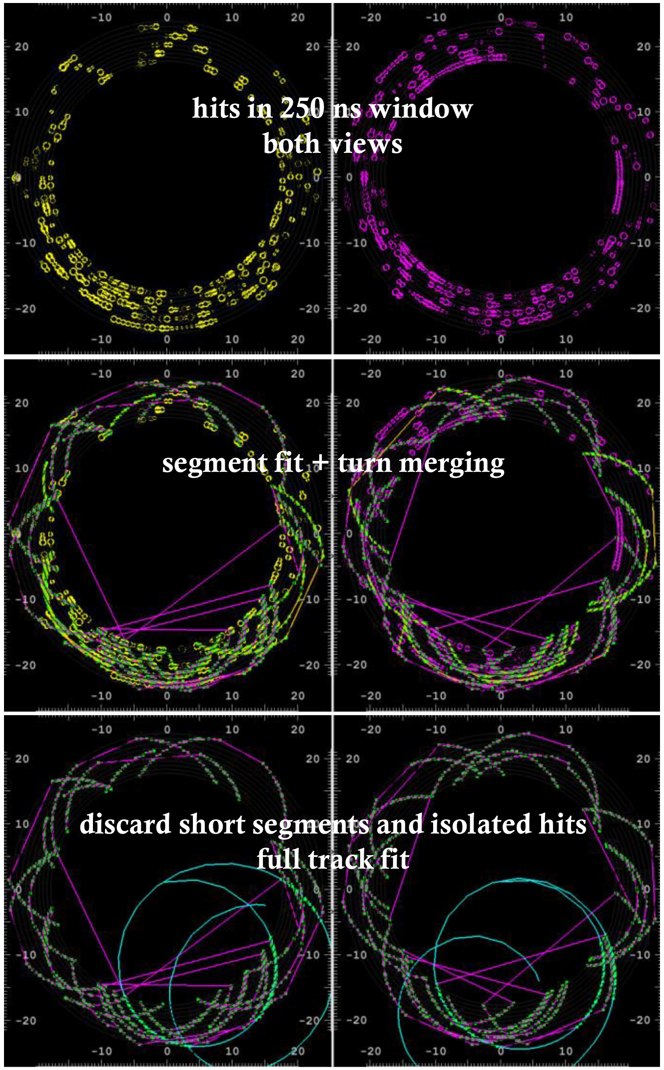
1280 out of 1920 channels (2/3) readout on both ends

MEG-II DC: expected performance

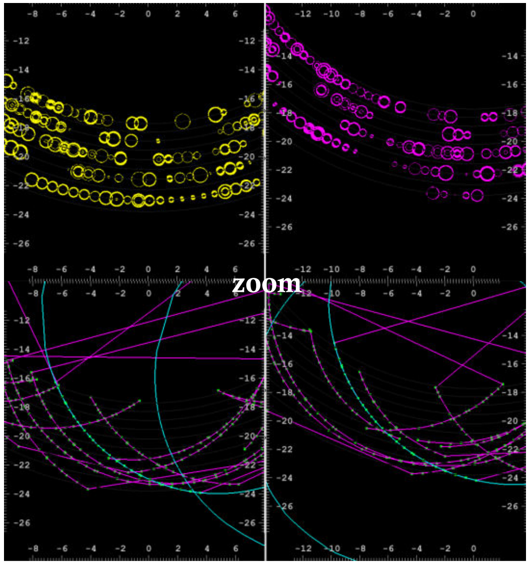
thanks to F. Ignatov







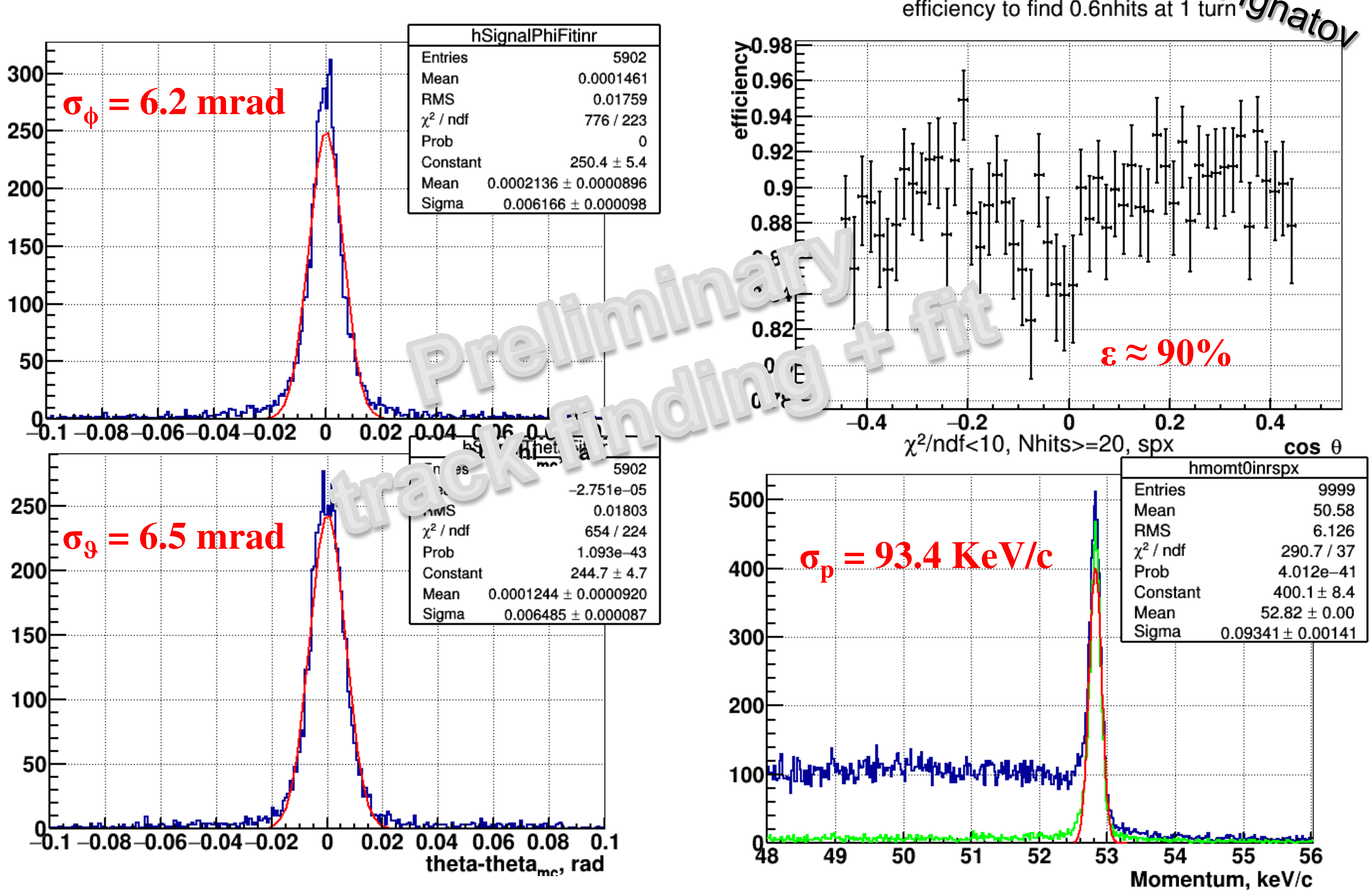
3D track finding and fit



signal track

MEG-II DC: expected performance

thanks to F. Ignatov



MEG-II DC: summary

	MEG	MEG2
single hit contribution to m.s.	2.6×10^{-4} X_0	4.6×10^{-5} X_0
transverse position resolution	210 μm	110 μm
e^+ momentum resolution	330 KeV/c	*94 KeV/c*
e^+ (angle	9.4 mrad	*6.2 mrad*
e^+) angle	8.4 mrad	*6.5 mrad*
e^+ y vertex	1.6 mm	0.9 mm
e^+ z vertex	2.5 mm	1.1 mm
DC−TC matching efficiency	41%	89%

remember!

$$N_{\mathrm{sig}} = R_\mu \times T \times \Omega \times \mathcal{B} \times \epsilon_\gamma \times \epsilon_{\mathrm{e}} \times \epsilon_{\mathrm{s}}$$

$$N_{\mathrm{acc}} \propto R_\mu^2 \times \Delta E_\gamma{}^2 \times \Delta P_{\mathrm{e}} \times \Delta\Theta_{\mathrm{e}\gamma}^2 \times \Delta t_{\mathrm{e}\gamma} \times T$$

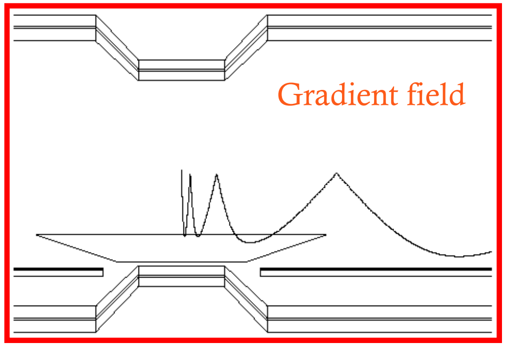
Summary

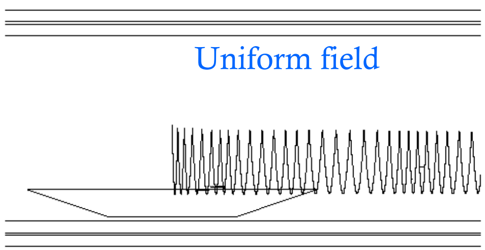
- Strong motivations for an upgraded MEG experiment aiming at setting an upper limit $B(\mu^+ \rightarrow e^+ + \gamma) < 5 \times 10^{-14}$.
- The upgrade of the positron tracker consists in a a full stereo and high transparency Drift Chamber.
- The high density of wires constituting the DC has required a novel approach to the wiring procedure.
- Reached chamber accuracy:
  - stereo angle < 35 μrad
  - wire position on PCB pad < 25 μm
  - cell width (wire pitch) < 1 μm
  - cell height (spacer) < 50 μm
  - wire tension < 0.1 g
  - PCB offset vs spoke < 50 μm
  - chamber length < 200 μm
- Its expected performance is in line with the requirements.
- The DC will start commissioning at PSI in fall 2017.

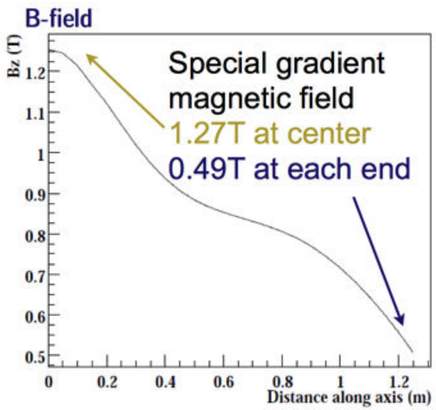
Backup

The MEG CoBRa Magnet

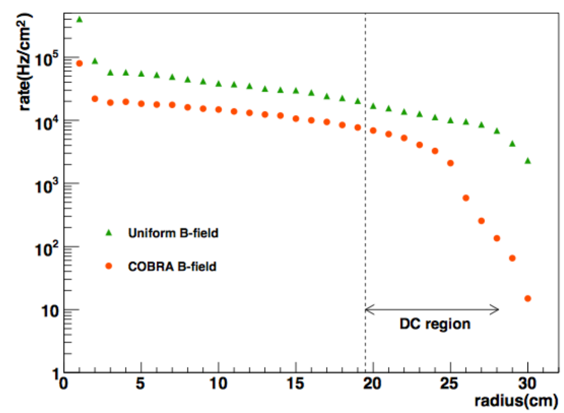
- High p_T positrons quickly swept out



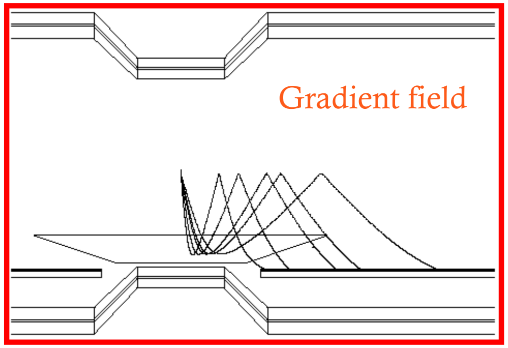


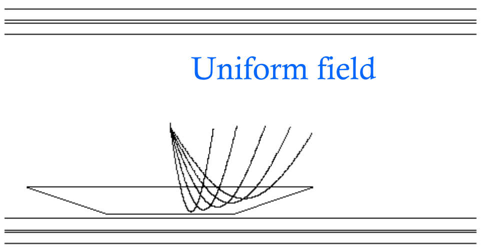


Michel hit rate versus radial distance

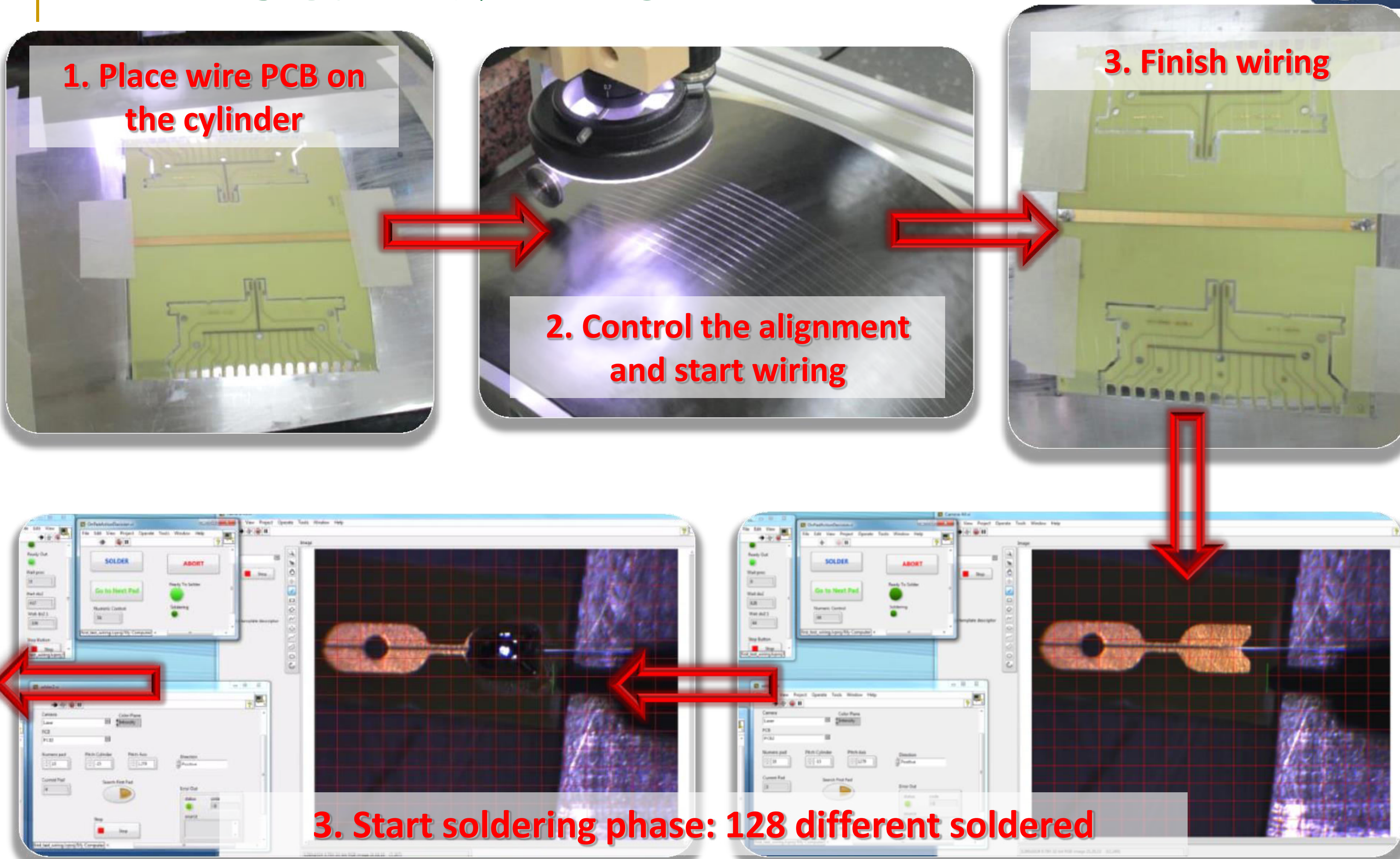


- Constant bending radius independent of emission angles

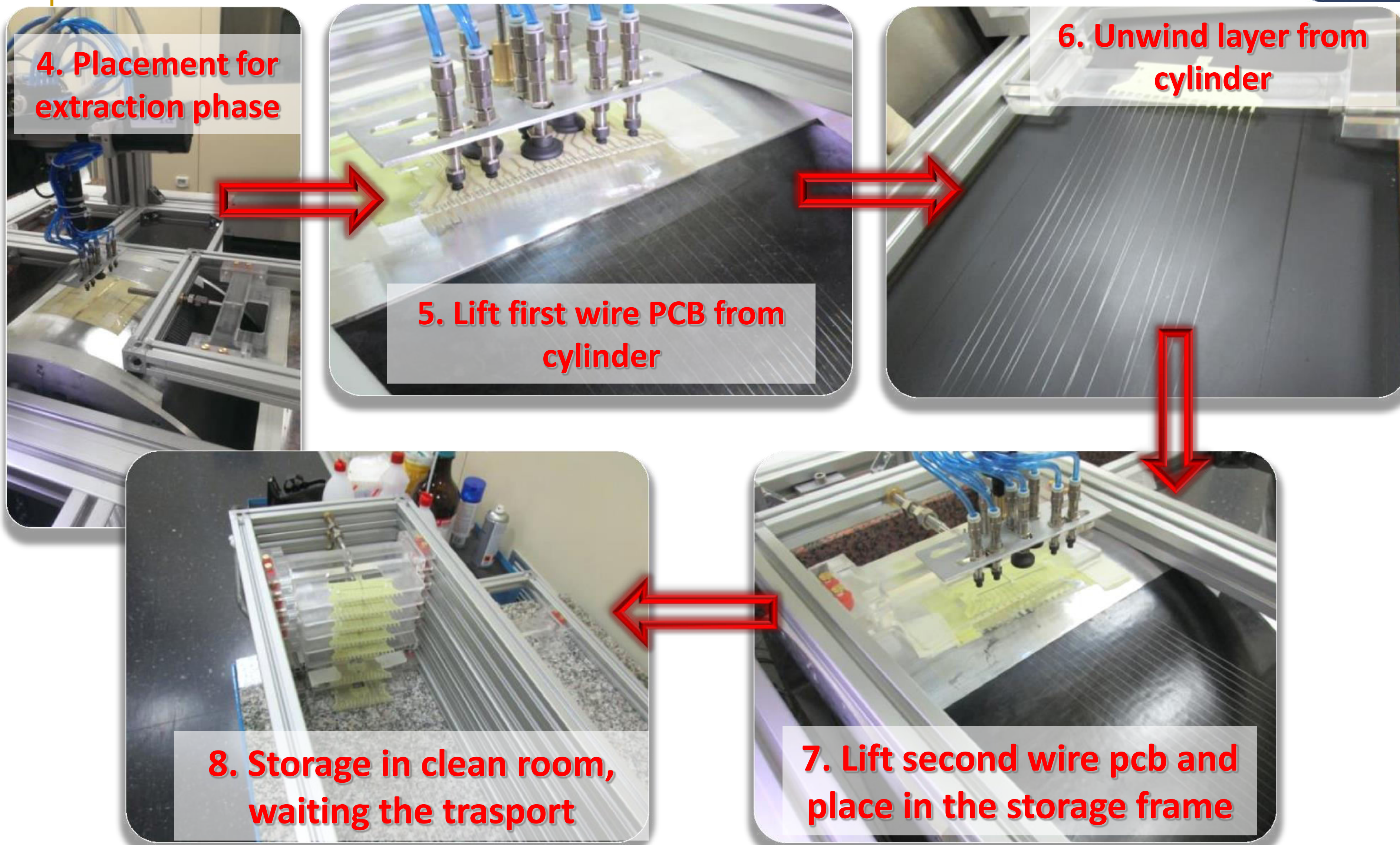




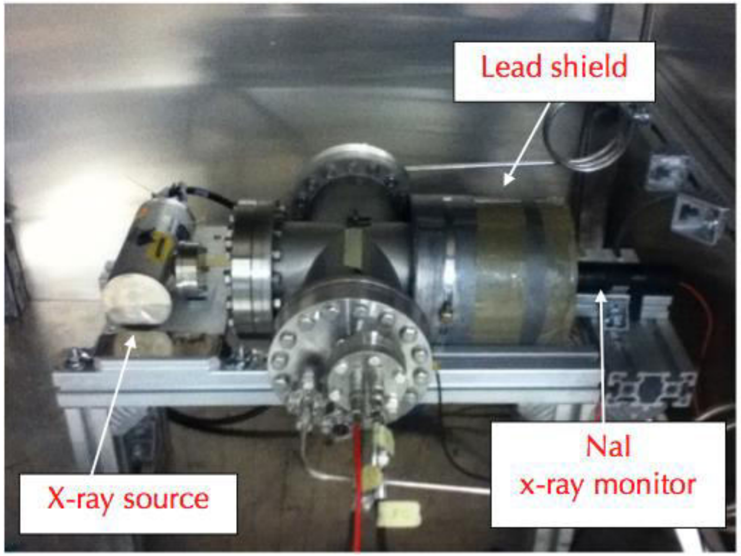
PRODUCTION PHASE



PRODUCTION PHASE



MEG-II DC: aging



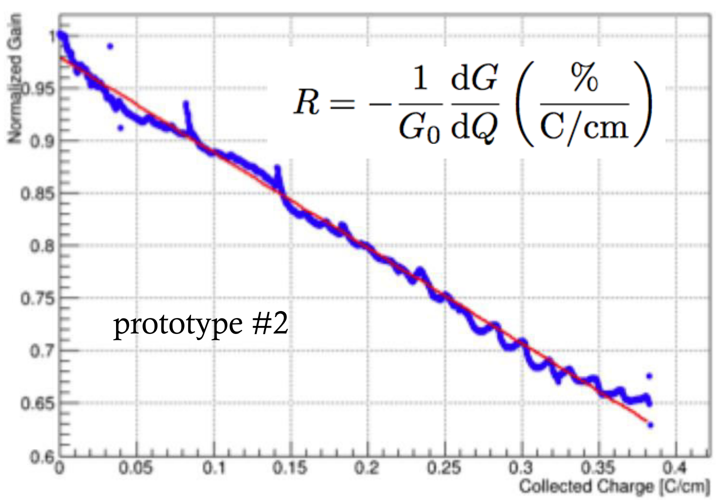
@ 7×10^{7} ∫/s and 10^{5} gas gain

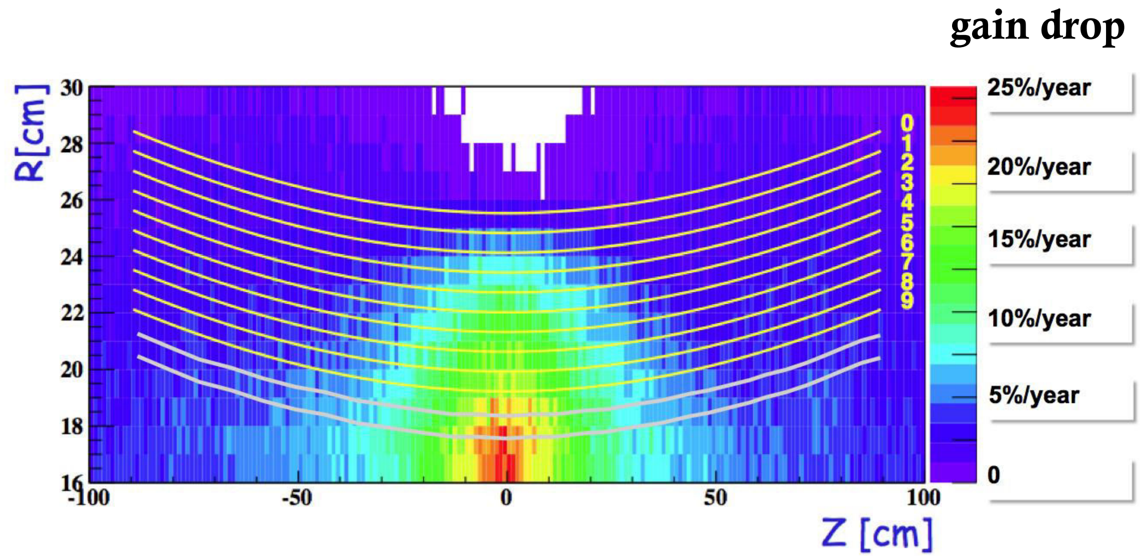
expect ≈ 6 nA/cm in the hottest point

≈ 0.32 C/cm

integrated over 3 years data taking

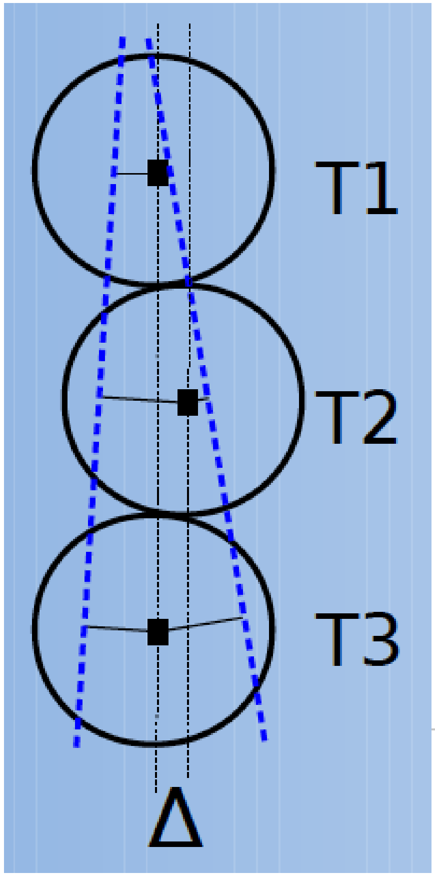
(however, @ G = 10^{5}, dG/dV ≈ 3-4%/Volt)





MEG-II DC: single hit resolution

Spatial resolution I

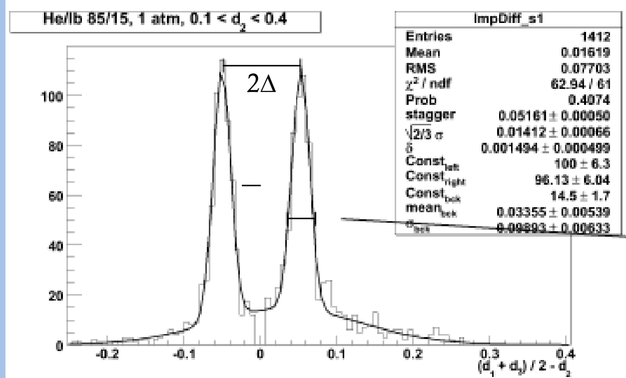


Staggered 3-tubes method with cosmic rays

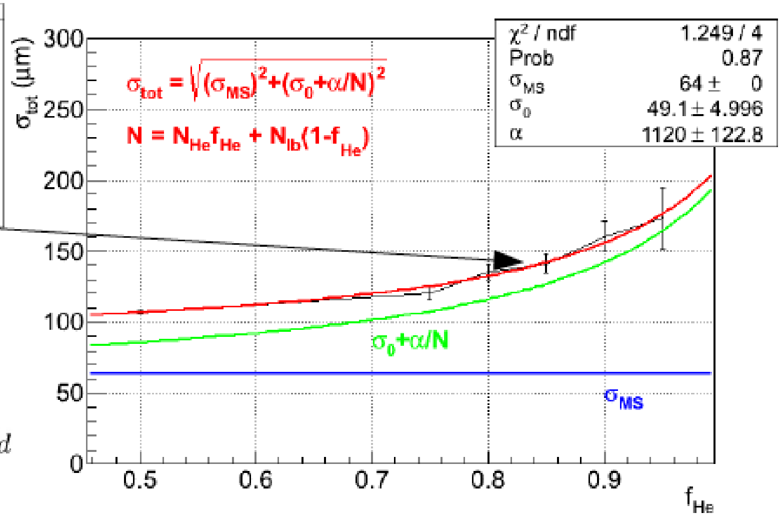
85% He – 15% iC_4H_{10} : $\sigma_{drift} \approx 130\ \mu m$

averaged over all impact parameters and angles

(leading edge discrimination, no cluster timing)



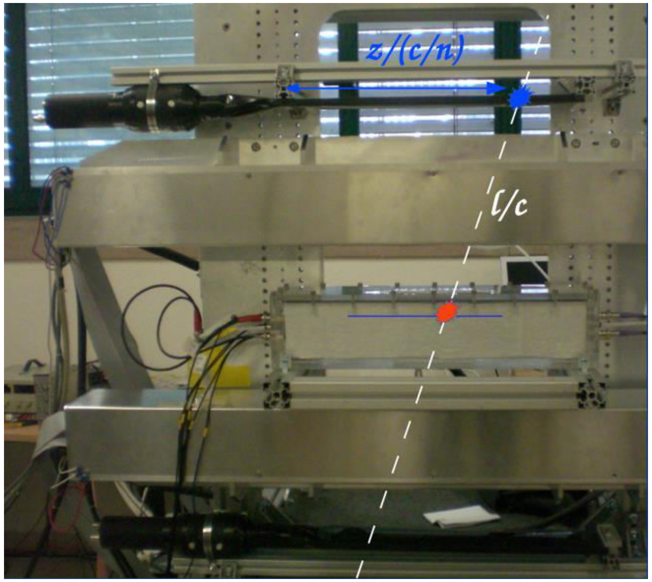
$$D = \frac{d_1 + d_3}{2} - d_2 \qquad \sigma_D = \sqrt{\frac{3}{2}}\sigma_d$$

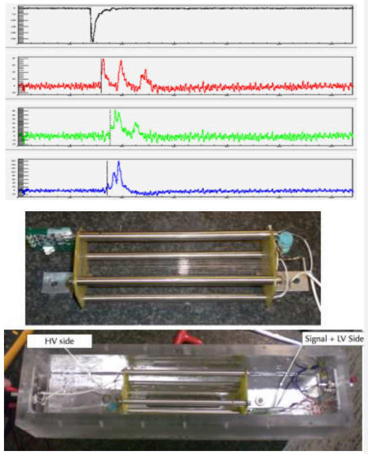


MEG-II DC: single hit resolution

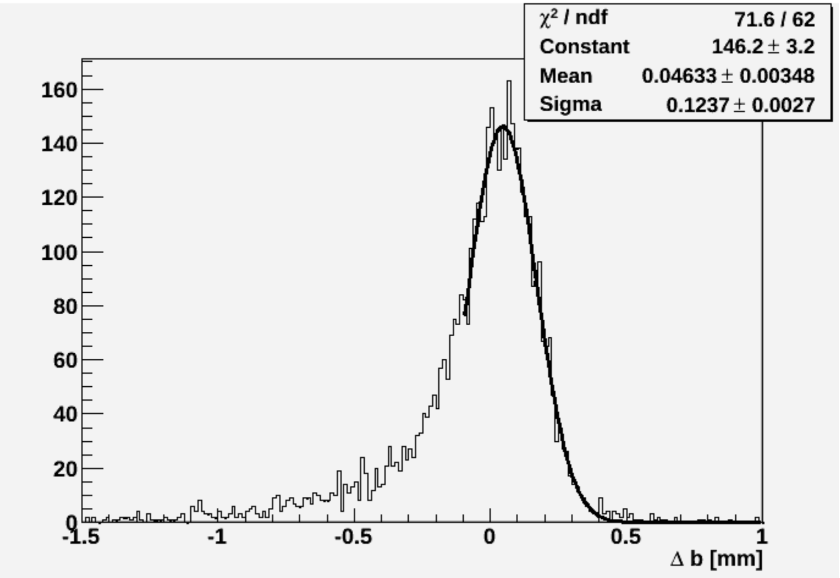
Spatial resolution II

Staggered 3-cells method under Si telescope





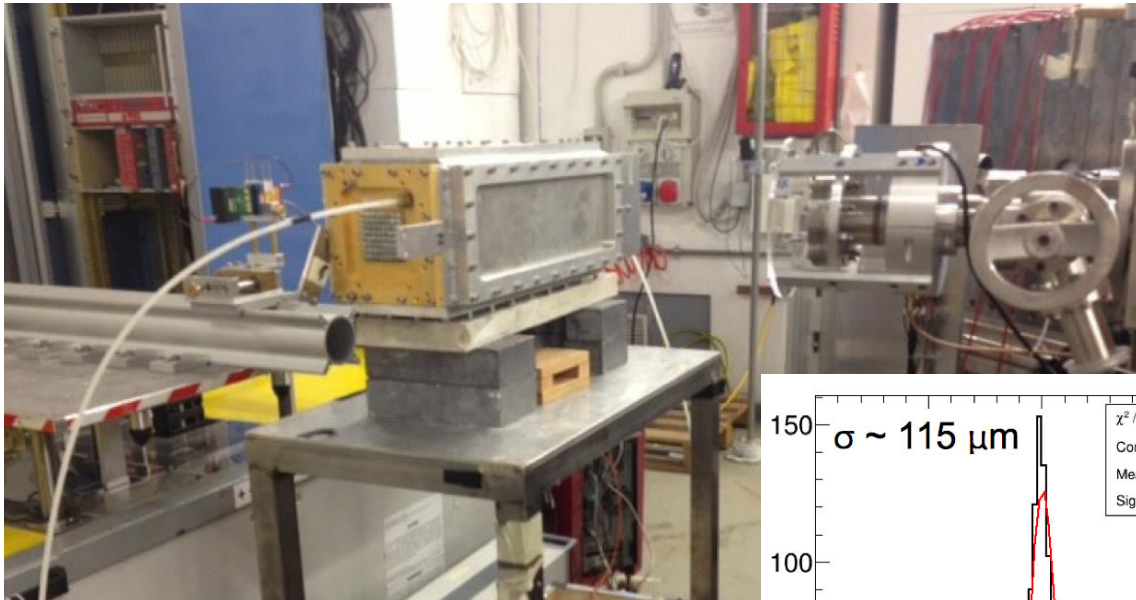
85% He – 15% iC_4H_{10}



Average hit resolution $\sigma_{drift} = 108 \pm 5\ \mu m$

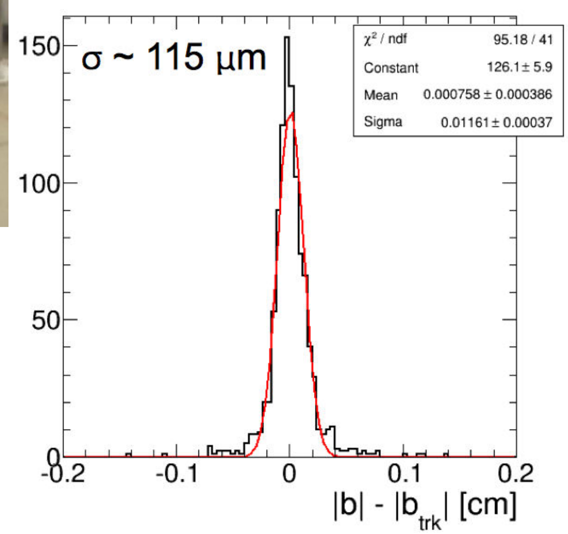
MEG-II DC: single hit resolution

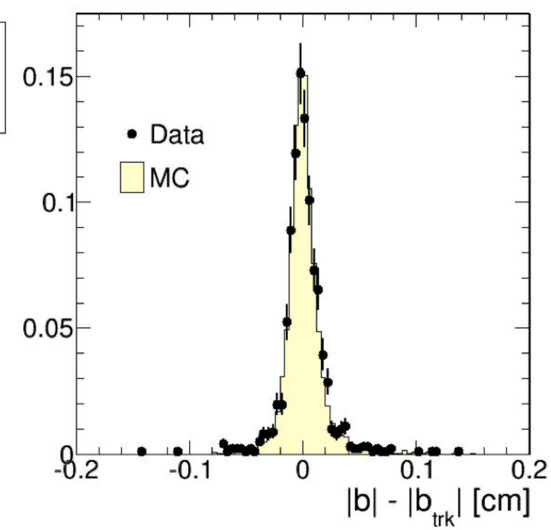
Spatial resolution III



Beam test at BTF – LNF

normal incidence tracks



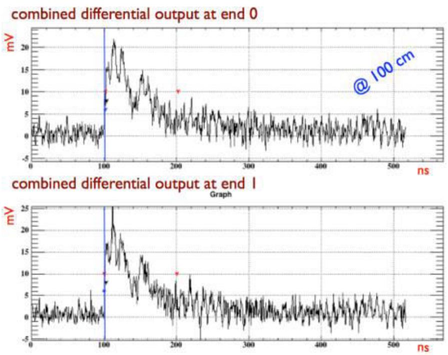


Average hit resolution

$\sigma_{drift} = 116 \pm 4\ \mu m$

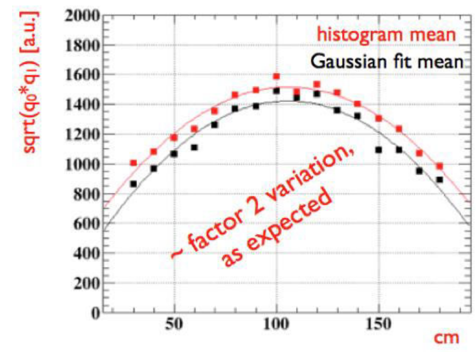
MEG-II DC: single hit resolution

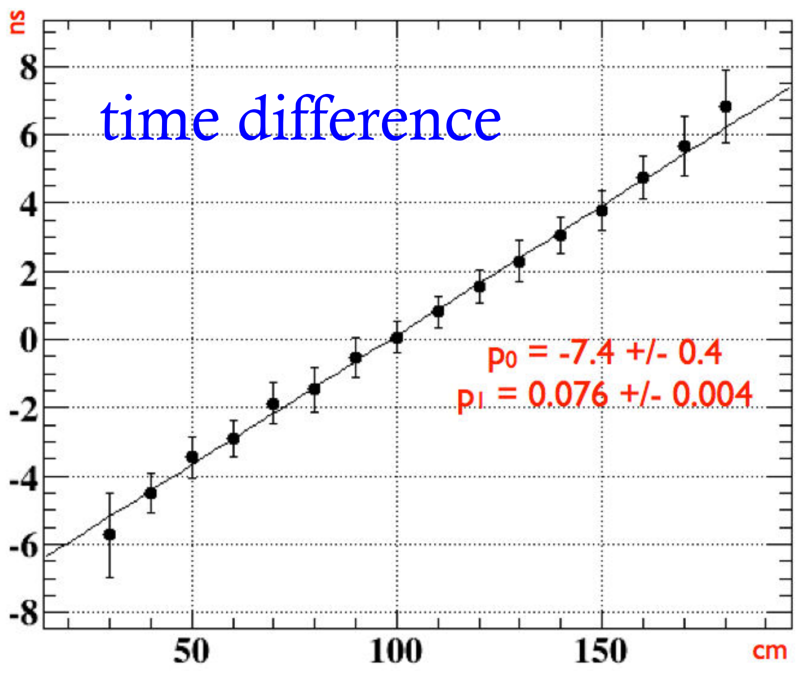
Longitudinal resolution

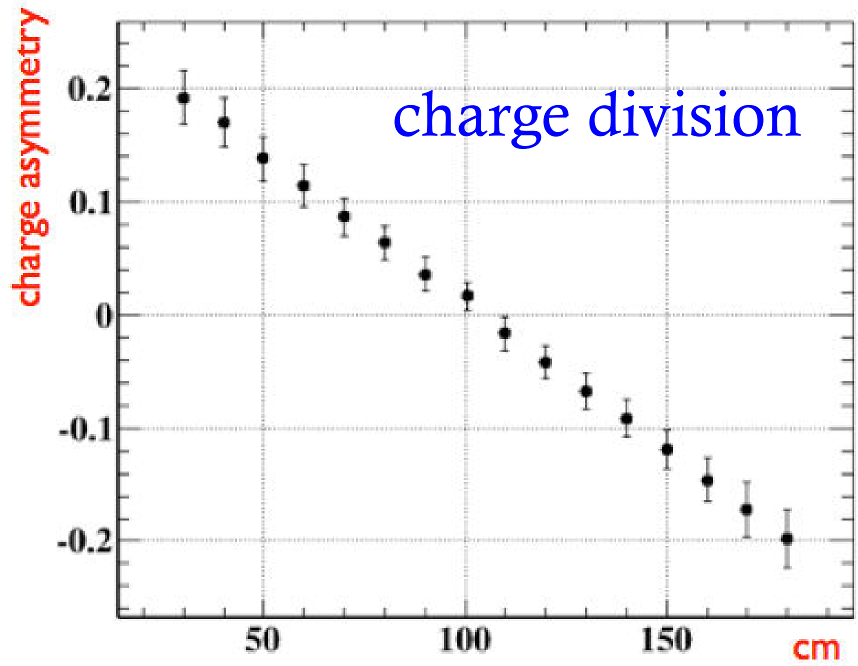


v_s = 13.2 cm/ns
$\sigma_{\Delta t} \approx 0.5$ ns
$\sigma_z \approx 10$ cm

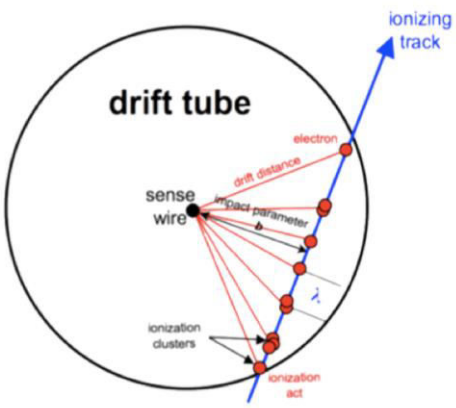
R_w = 150 Ω/m
20 μm W wire
$\sigma_z \approx 10$ cm



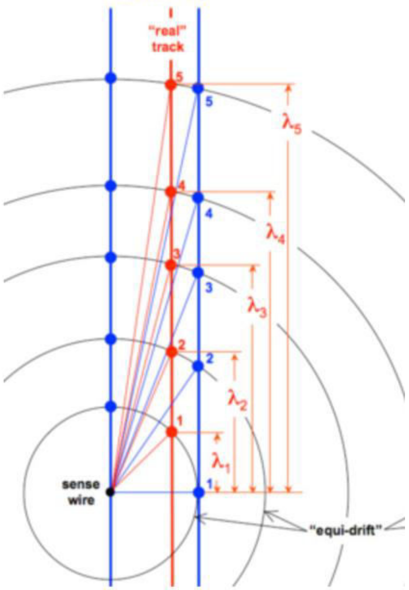




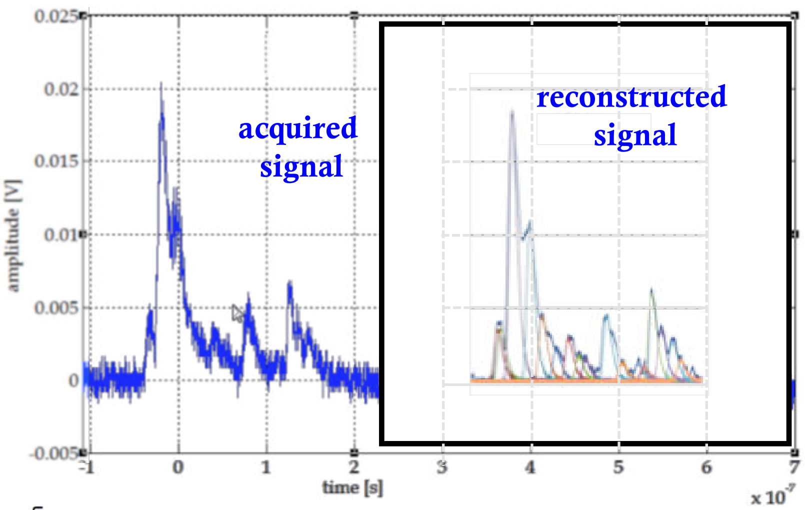
Cluster Timing

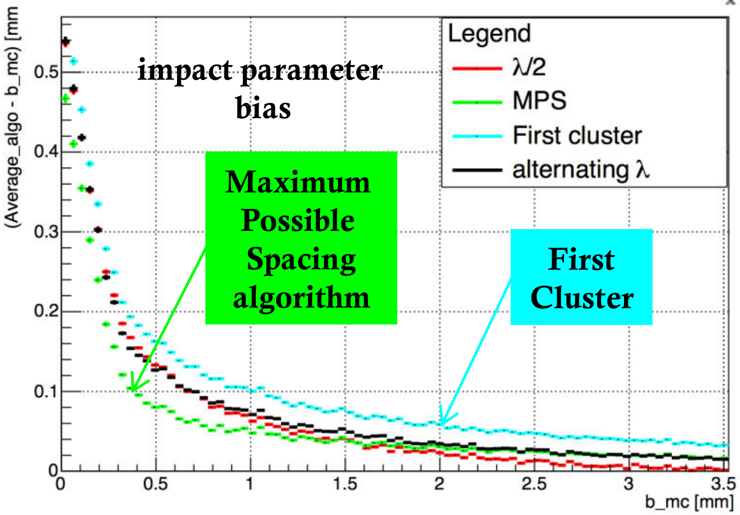


From the **ordered sequence of the electrons arrival times**, considering the average time separation between clusters and their time spread due to diffusion, **reconstruct the most probable sequence of clusters drif**$\{t_i^d\} \quad i=1, N_d$



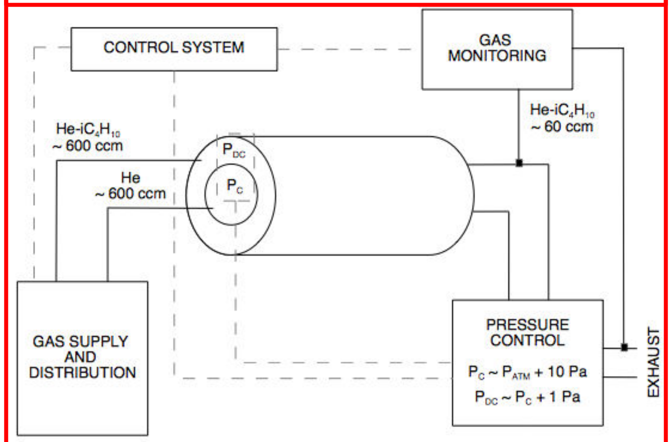
For any given first cluster (**FC**) drift time, the **cluster timing technique** exploits the drift time distribution of all successive clusters to $\{t_i^d\}$ determine the most probable impact parameter, thus reducing the **bias** and the average **drift distance resolution** with respect to what is obtained from with the FC only.



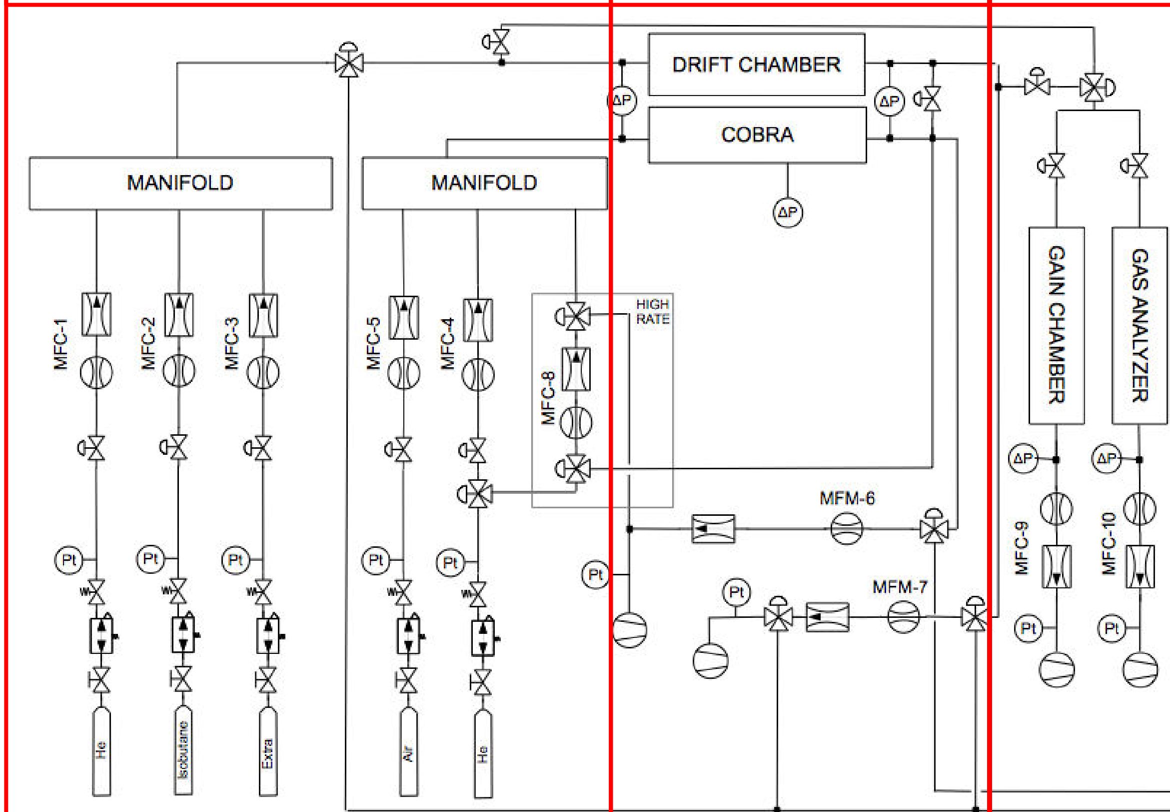


MEG-II DC: gas system

general layout



mixing and distribution | pressure control | monitoring



basic gas mixture:
85% He – 15% iC_4H_{10}
(+ H_2O vapor?)
DC volume ≈ 350 liters
1 volume exchange / 10 h

MEG-II DC: HV distribution

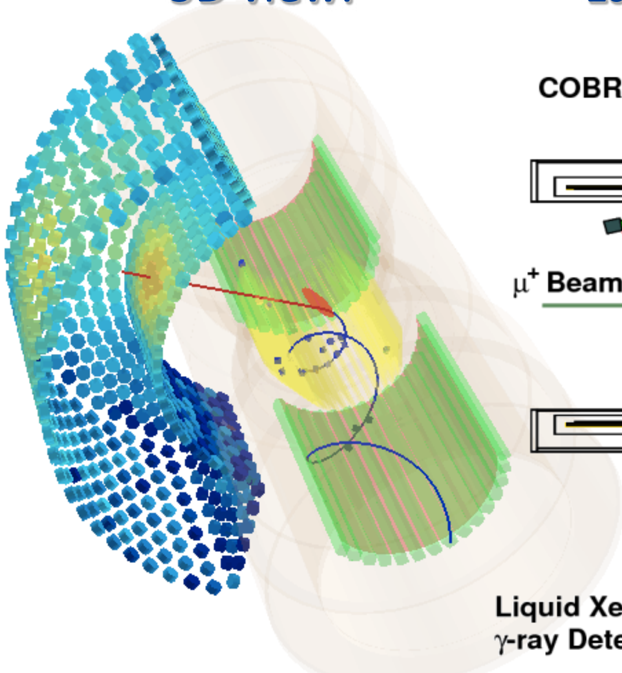
6 boards ISEG

EHS F230p 305F SHV 16ch 3kV, 3mA
in a 10 slot crate

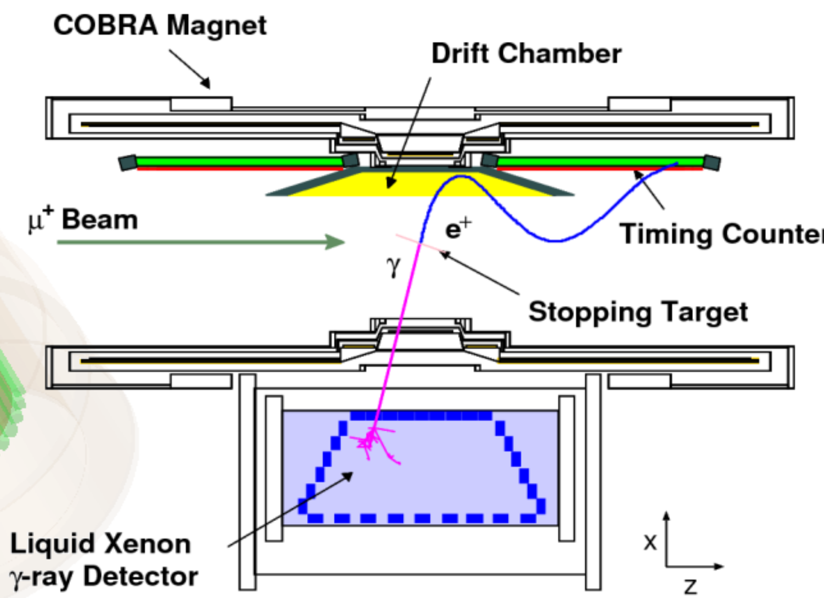
1 HV channel (≈ 1450 V) / 16 cells / sector / layer × 8 sectors × 10 layers = **80 channels**
instrumented active region (2/3 of chamber)
1 HV channel / 64 cells / 4 sectors / layer × 4 sectors × 10 layers = **10 channels**
not instrumented region (1/3 of chamber) only for field distribution
2 HV channels /2 double guard layers × 2 layers = **2 channels**
+ 4 spares = total 96 channels

The MEG-I Detector

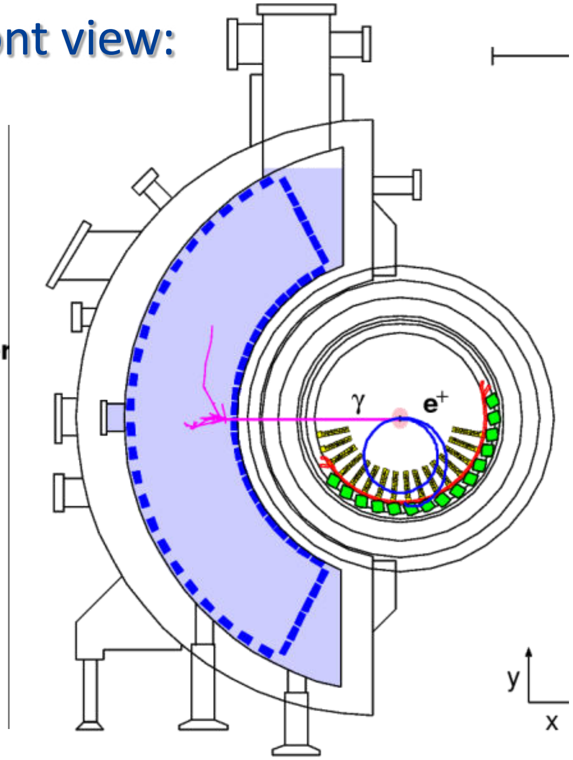
3D view:



Lateral view:



Front view:



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- Dedicated detector with non-symmetric coverage ($\Omega_{MEG}/4\pi = 11\%$):

1. Photon detector with excellent spatial, time & energy resolutions
2. Positron spectrometer with excellent energy & timing capabilities
3. Stable and well monitored & calibrated detector (multitude of calibration & monitoring tools)
4. High performance DAQ system (multi-GHz waveform digitization of nearly all 3k channels)