The MEG upgrade Drift Chamber

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on behalf of the MEG CDCH group:

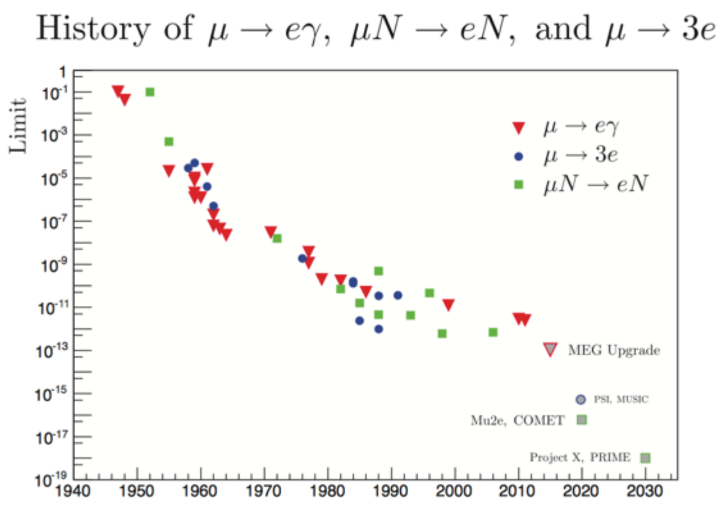
Lecce – INFN and Università del Salento, Lecce – Italy
Pisa – INFN and Università di Pisa, Pisa – Italy
PSI – "Paul Sherrer Institute", Villigen – Switzerland
Roma – INFN and Università "Sapienza", Roma – Italy

INSTR 2014 – International Conference for Colliding Beam Physics - Feb. 24/Mar. 1, BINP Novosibirsk, Russia

Outline

- Motivations for an upgrade
- Current limitations
- New drift chamber layout
- Innovative aspects of construction
- Measured and expected performance
- Plans and conclusions

Charged Lepton Flavor Violation

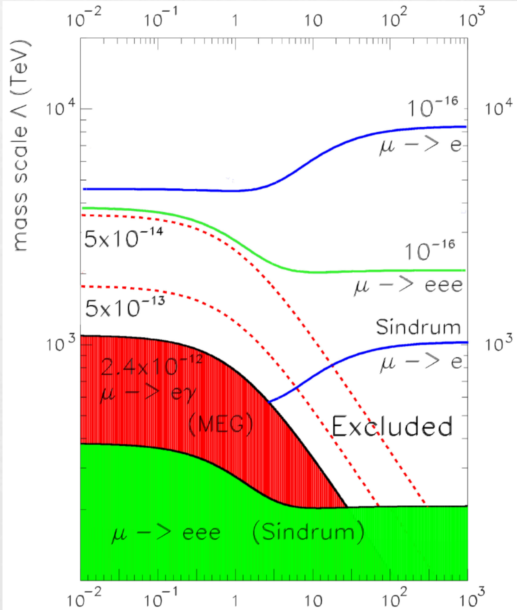


from Bernstein and Cooper, arXiv:1307.5787v3 [hep-ex] 13 Jan 2014

$$\mu \to e\gamma$$

$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M_W^2}\right|^2 \sim 10^{-54}$$

$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + \text{h.c.} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L \gamma_\mu e_L \left(\bar{e}\gamma^\mu e\right) + \text{h.c.}$$



de Gouv^ea and Vogel (2013), arXiv:1303.4097 [hep-ph]

$\mathcal{B}(\mu^+ \to e^+\gamma) < 5.7 \times 10^{-13}$ 90% CL.(Adam *et al.* [2013, 2011])

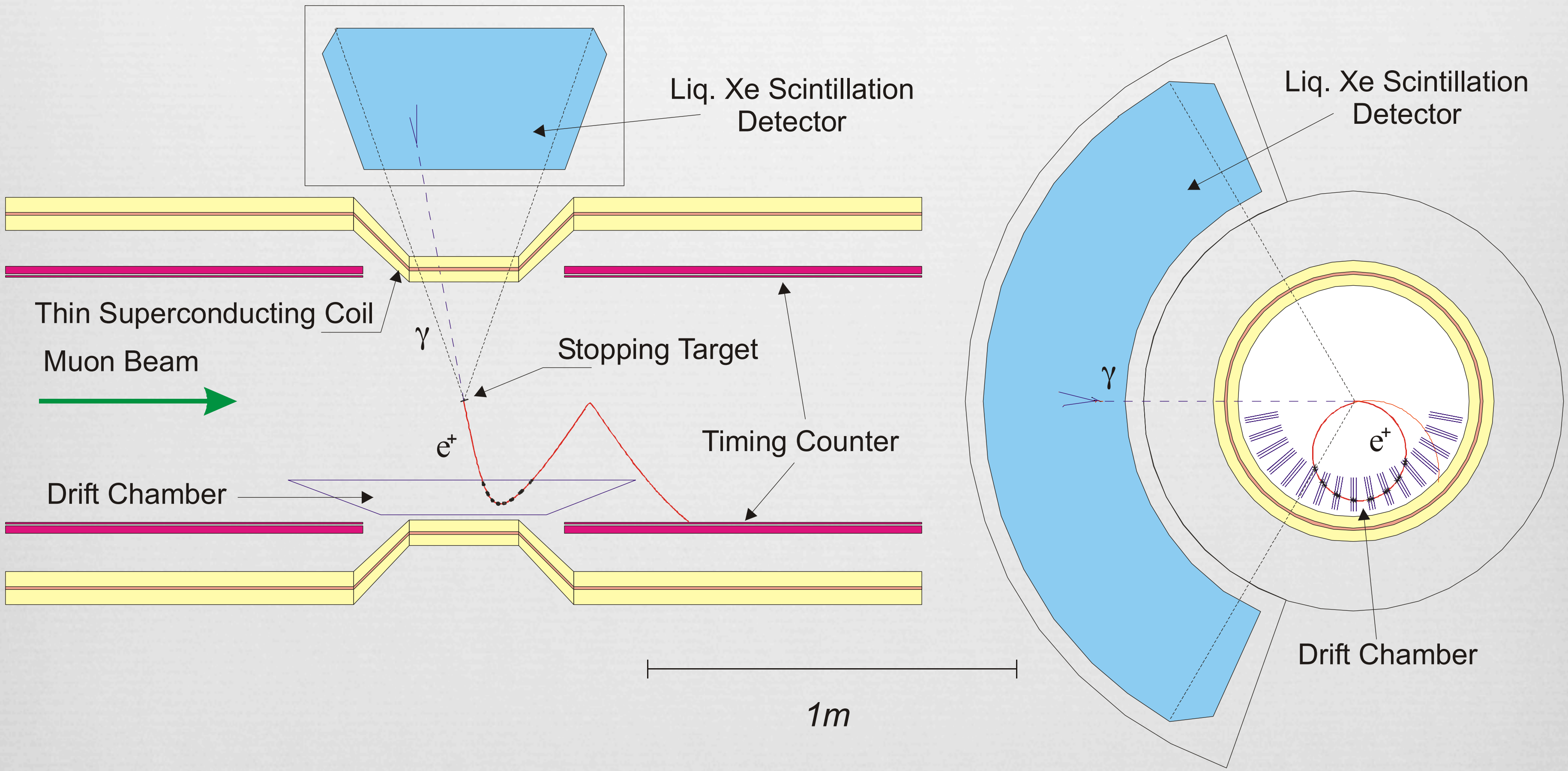
For a comprehensive and updated review on the subject, see:

1st Conference on Charged Lepton Flavor Violation - 6÷8 May 2013, Lecce (Italy)

[Nucl. Phys. B Suppl., 248-249, April 2014 – edited by F. Grancagnolo and M. Panareo]

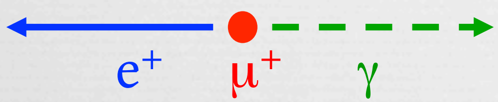
slides at https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=5488

The MEG experiment at PSI



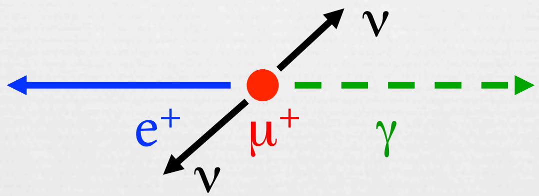
The MEG experiment at PSI

signal

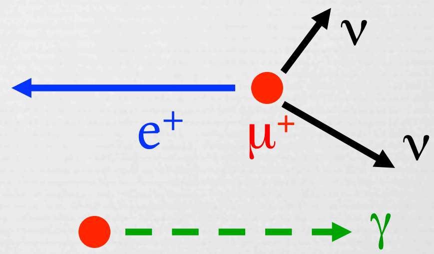


background

physics



accidental (93%)



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

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

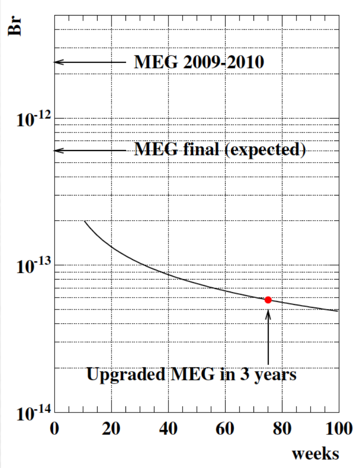
$$\mathcal{B}(\mu^+ \to e^+\gamma) < 5.7 \times 10^{-13} \text{ @ 90\% CL}$$

based on 3.6×10^{14} stopped muons on target (2009-2011 data set)
more statistics (2×) from 2012-2013 data

The MEG upgrade

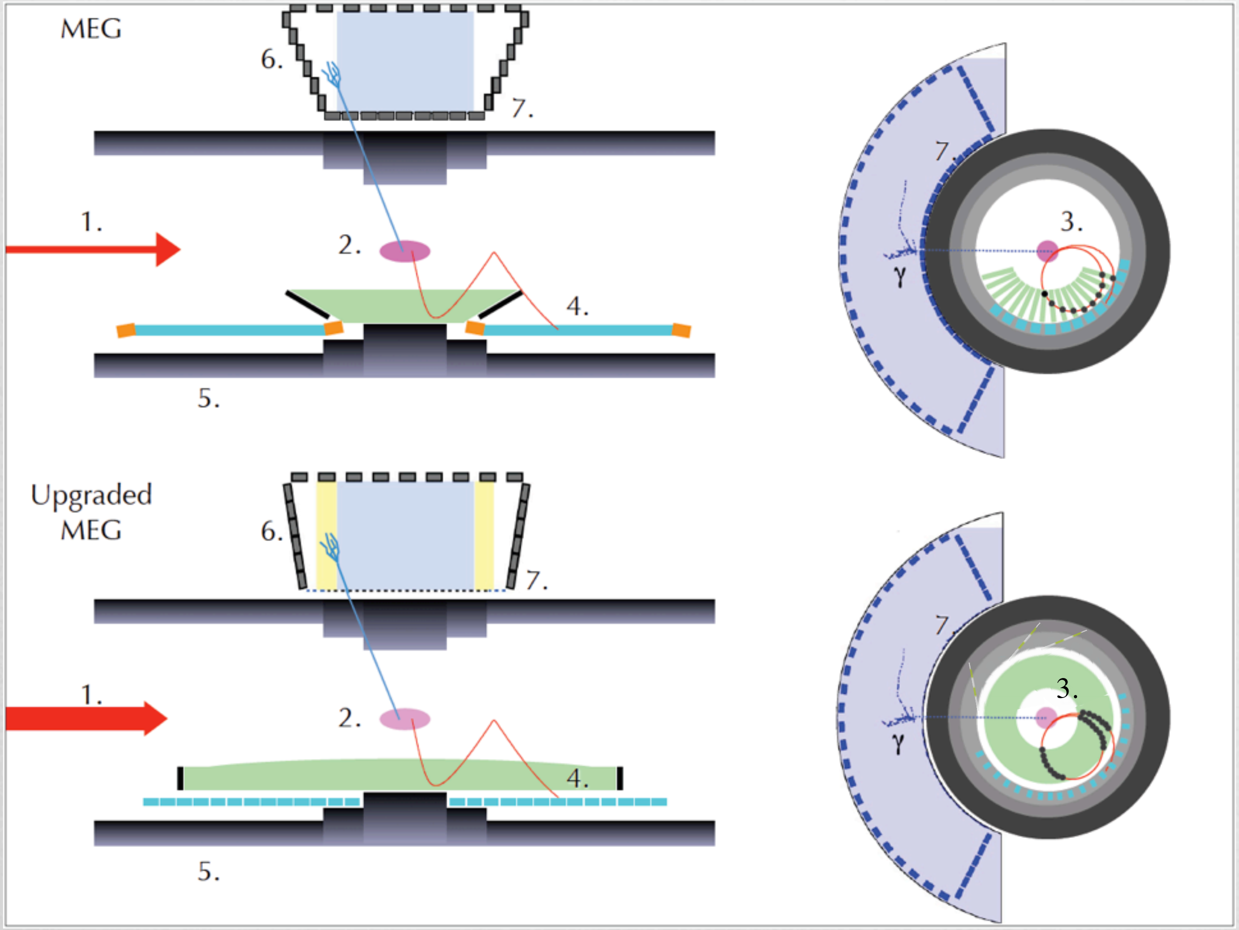
TABLE XI: Resolution (Gaussian σ) and efficiencies for MEG upgrade

PDF parameters	Present MEG	Upgrade scenario
e^+ energy (keV)	306 (core)	130
e^+ θ (mrad)	9.4	5.3
e^+ ϕ (mrad)	8.7	3.7
e^+ vertex (mm) Z/Y(core)	2.4 / 1.2	1.6 / 0.7
γ energy (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
γ position (mm) $u/v/w$	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	≈ 99	≈ 99
γ	63	69
e^+	40	88



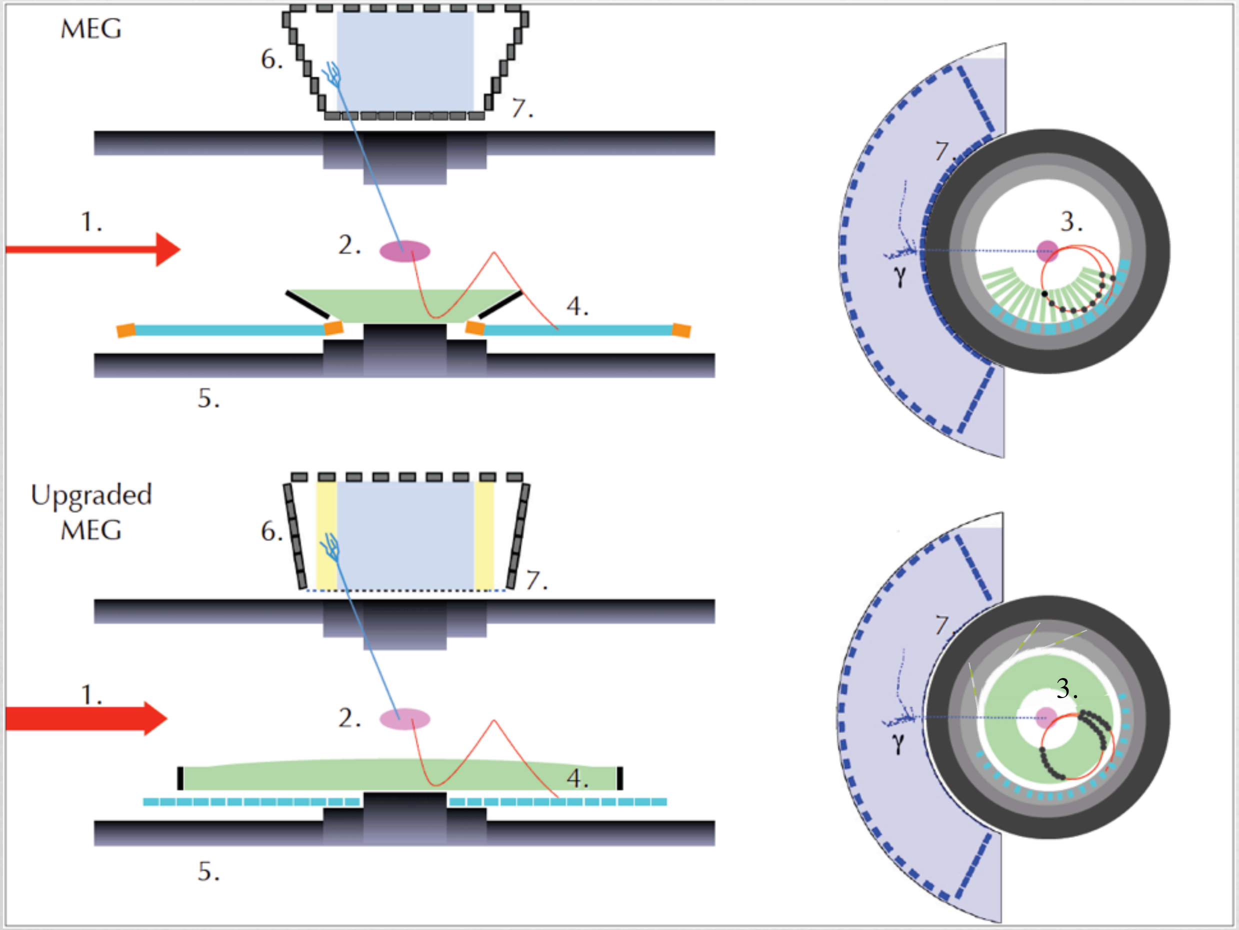
Aim at 6×10^{-14} in 3 years run

The MEG upgrade



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 timing counters granularity
6. Extend calorimeter acceptance
7. Improve photon energy, position and timing resolution for shallow events
8. New DAQ for higher bandwidth

The MEG upgrade



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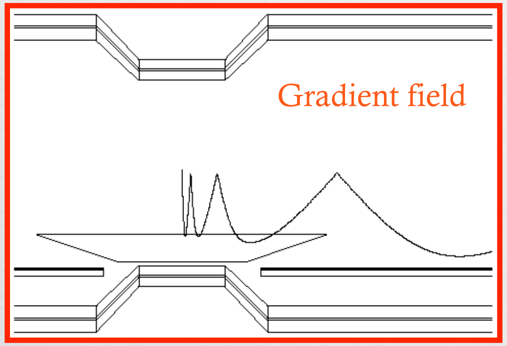
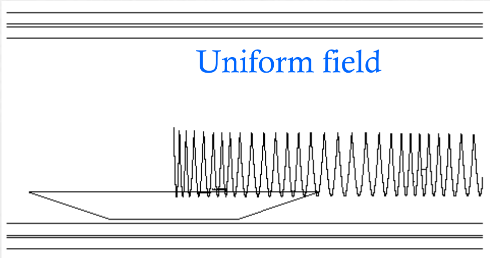
THIS TALK

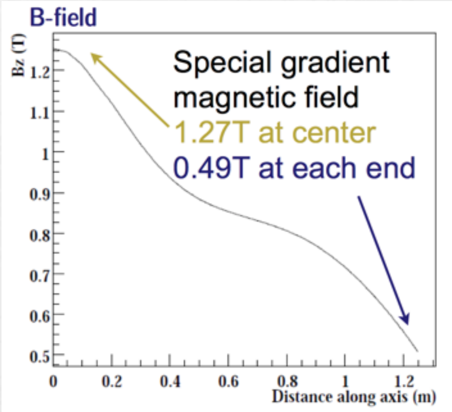
SEE IWAMOTO TALK NEXT FRIDAY

The MEG CoBRa Magnet

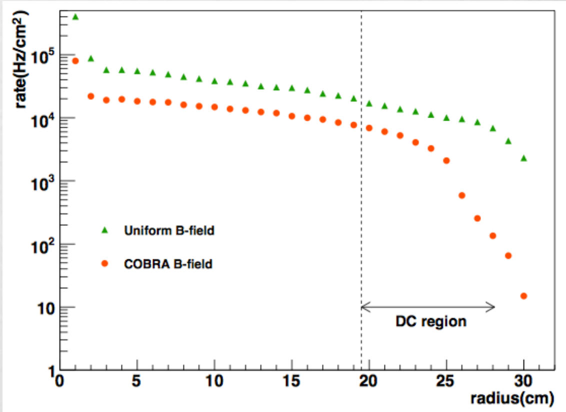
- High p_T positrons quickly swept out



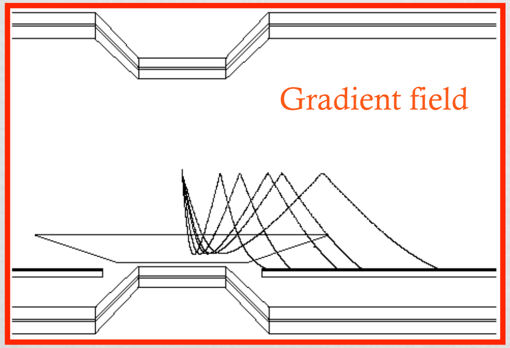


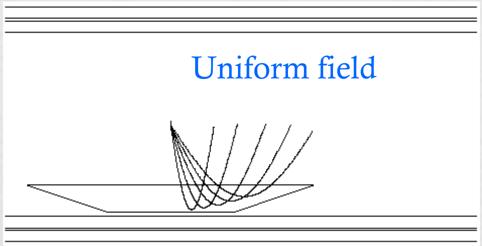


Michel hit rate versus radial distance

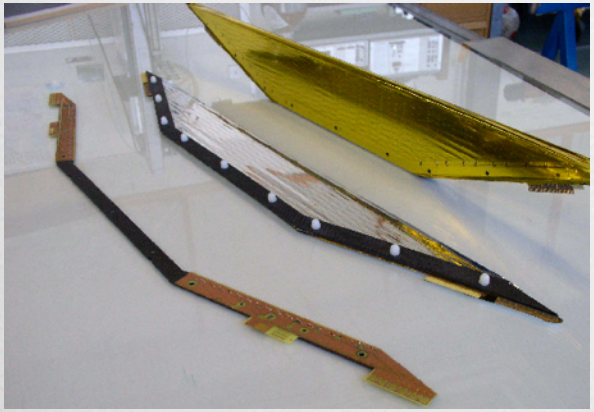


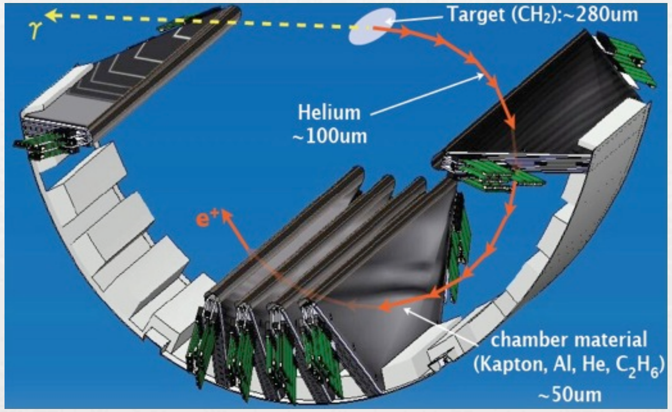
- Constant bending radius independent of emission angles

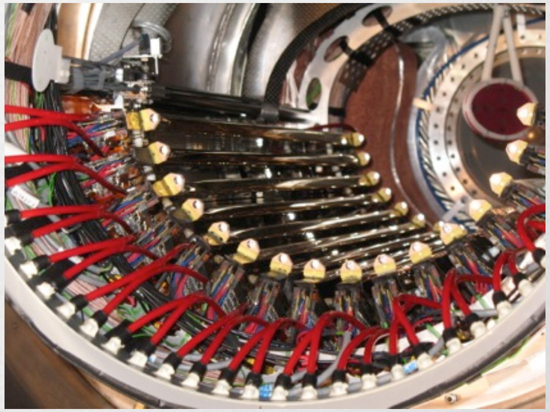




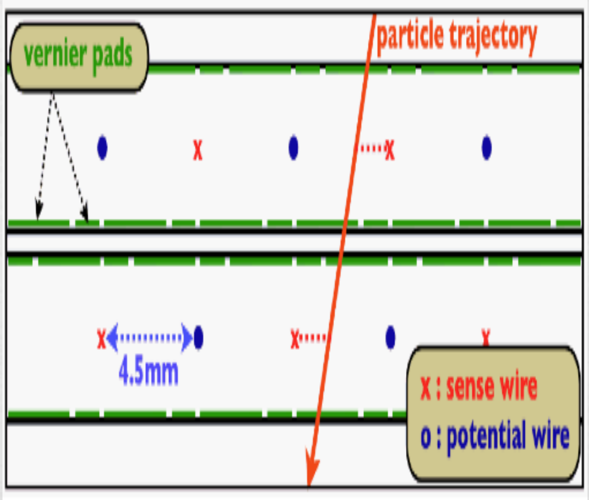
The MEG Drift Chambers



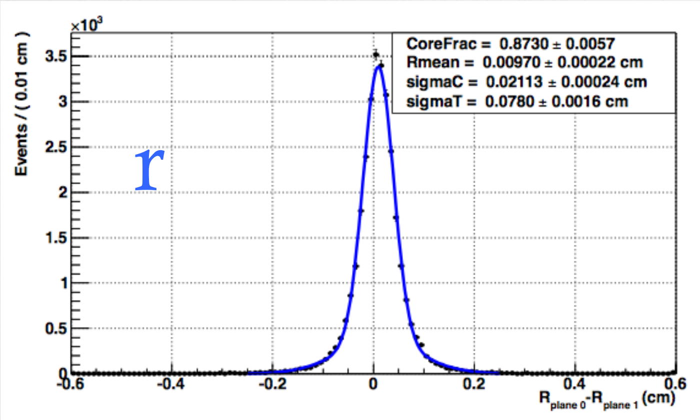




- 16 chambers
- Each chamber is composed of
  - 4 x12 μm of kapton (cathodes)
  - 50 μm BeCu cathode wires
  - 25 μm NiCr anode wires
  - 2 x 7 +3 mm He:C_2H_6 (50/50)
- Single chamber ~ 2.3 10^{-4} X_0
- Full e+ turn : ~ 1.7 10^{-3} X_0



The MEG DC Performance

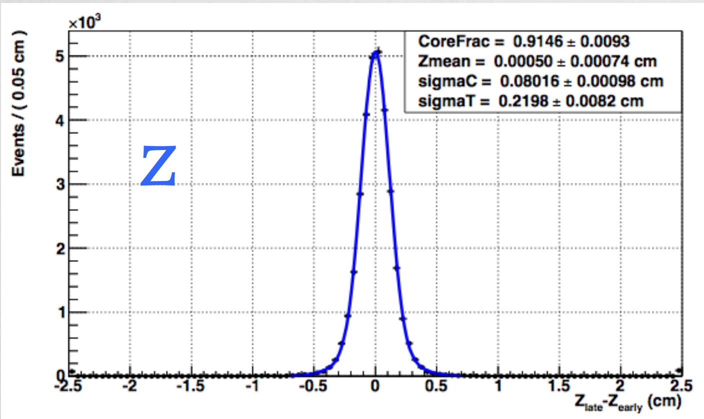


radial coordinate resolution

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

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



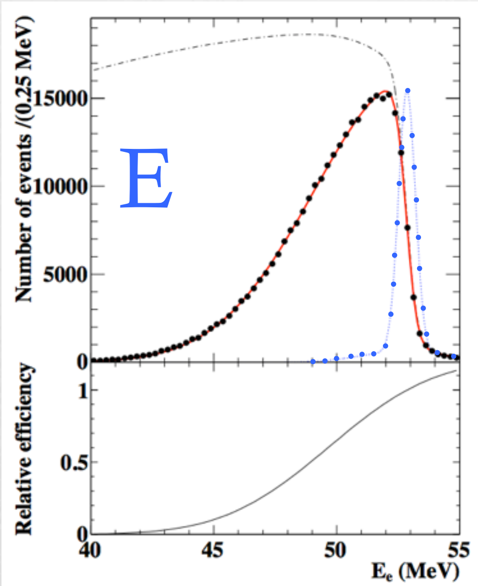
longitudinal coordinate resolution

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

DC - TC matching efficiency

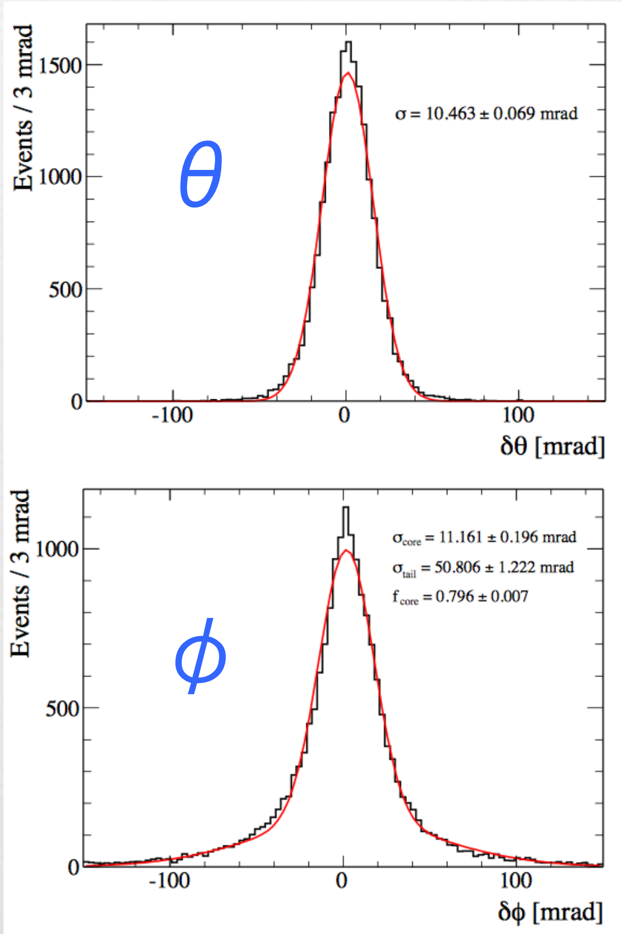
ε_{DC-TC} = 41%
$\varepsilon_{DC-TC,design}$ = 90%

The MEG DC Performance



positron energy resolution

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



polar angular resolution

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

azimuth angular resolution

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

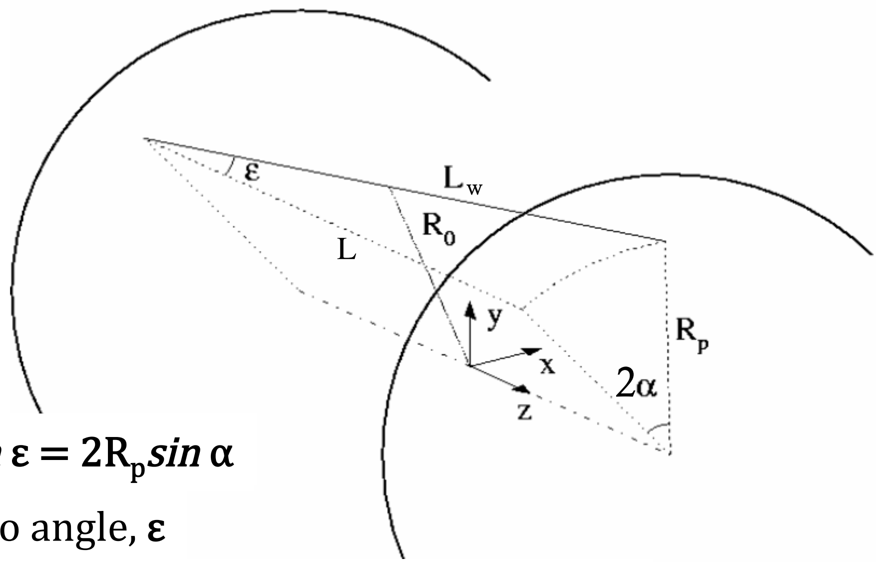
MEG upgrade DC layout

- Full stereo cylindrical d. ch. with large stereo angles **(102÷147 mrad)**
- Redundant and background insensitive **(N_{hit} ≈ 60 on signal track)**
- Small square cells **(5.8÷7.8 mm at z=0, 6.7÷9.0 at z=±L/2)**
- High ratio of field/sense **(5 : 1)** wires
- Light mechanical structure **(Al/peek end-plates, C-fiber outer cyl., Mylar inner cyl.)**
- Innovative wiring solution **(without wire feed-through)**
- Light gas mixture **(85% He – 15% iC_4H_{10})**
- Cluster Timing readout capabilities **(high bandwidth, high sampling rate)**

Active length L	1960	mm
N. of layers	10	
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

Radii	z = 0	z = ±L/2	
Guard wires layer	170.7	197.1	mm
First active layer	174.5	201.5	mm
Last (10^{th}) active layer	242.0	279.5	mm
Guard wires layer	246.0	284.0	mm

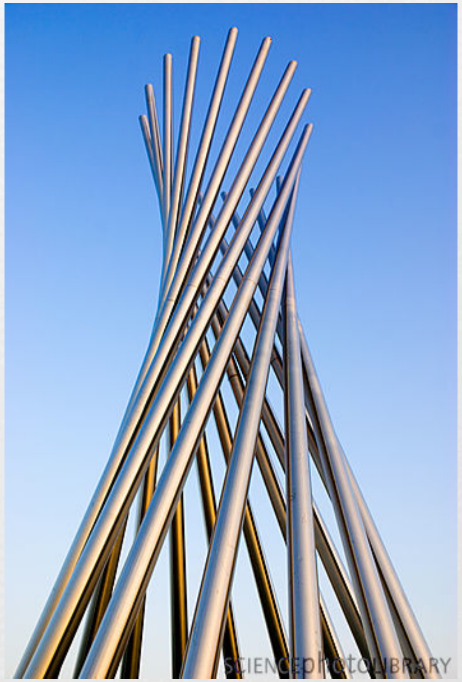
MEG upgrade DC: stereo



$L \tan\varepsilon = 2R_p \sin\alpha$

stereo angle, ε

stereo drop, $\delta_p = R_p - R_0 = R_p(1 - \cos\alpha)$

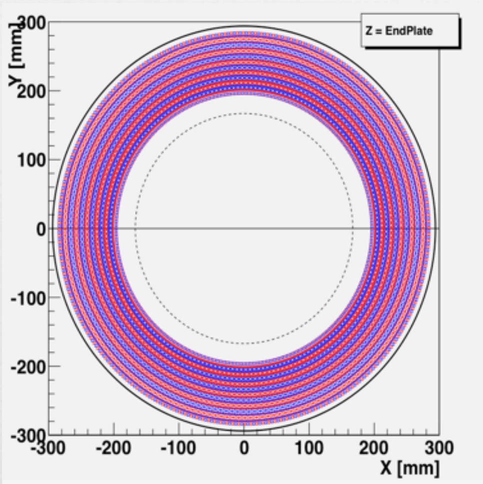


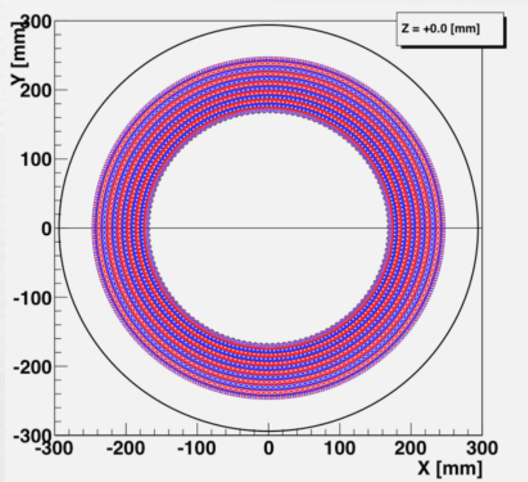
OPTIONAL CHIOCES (for fixed L):

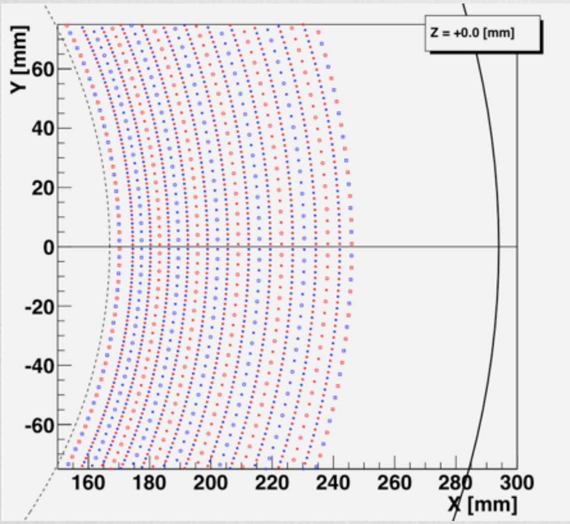
- constant δ : KLOE choice
- constant ε : simpler radial construction, simpler track finding, two real independent x-y views
- constant α : simpler azimuthal construction, preserves projectivity, fewer space-time relations

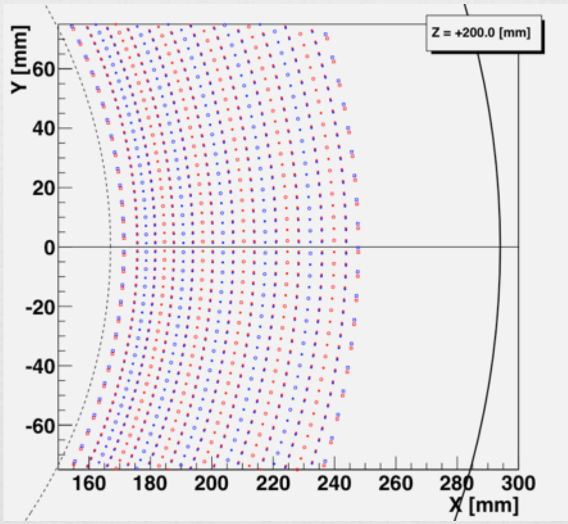
beware of the drift cell **aspect ratio** **h(z)/w(z)**

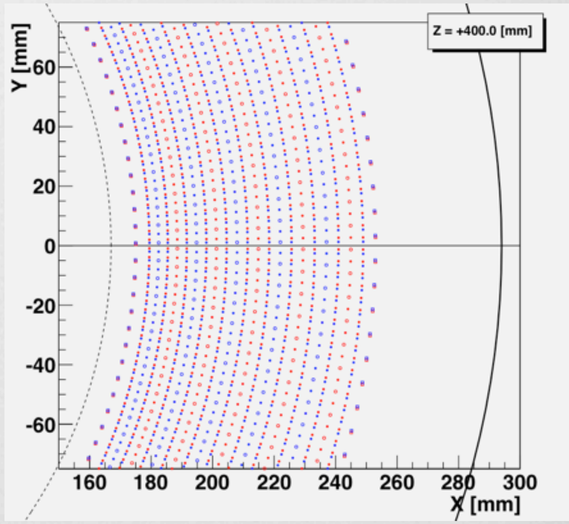
MEG upgrade DC: layers







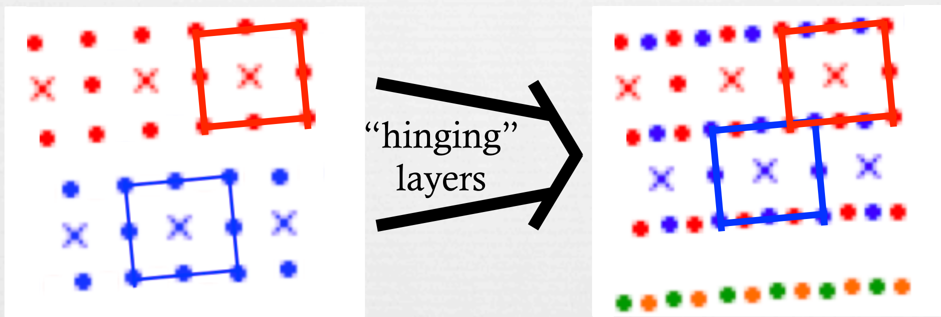




MEG upgrade DC: layers

stereo angle +

stereo angle –



stereo angle +

stereo angle –

guard layer

field to sense wires ratio **3 : 1**

field to sense wires ratio **5 : 1**

sense wires:	20 μm diameter W(Au)	=>	1920	wires
field and guard wires:	40 μm diameter Al(Ag)	=>	8448	wires
potential wires:	50 μm diameter Al(Ag)	=>	1920	wires

12,288 wires in total

MEG upgrade DC: wiring

- A larger 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.
- **Large field to sense wires ratios** and **small cells**, on the other end, imply high wire densities and, because of the reduced wire spacing, prevent the use of feed-through.
- Large number of wires, anyway, require complicated and time consuming **assembly procedures** and, therefore, they need a **novel approach** to the problem

MEG upgrade DC: wiring

The Old Way

Bernardo Strozzi – Le tre Parche – Venezia, circa 1620

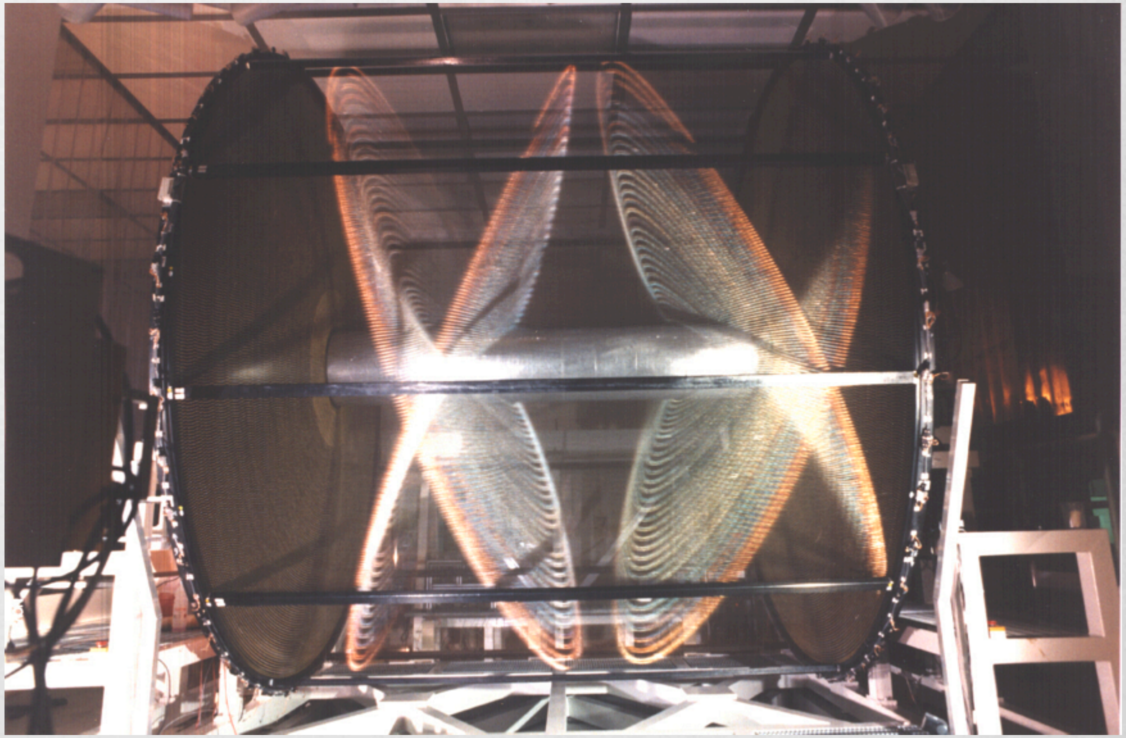
MEG upgrade DC: wiring

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}

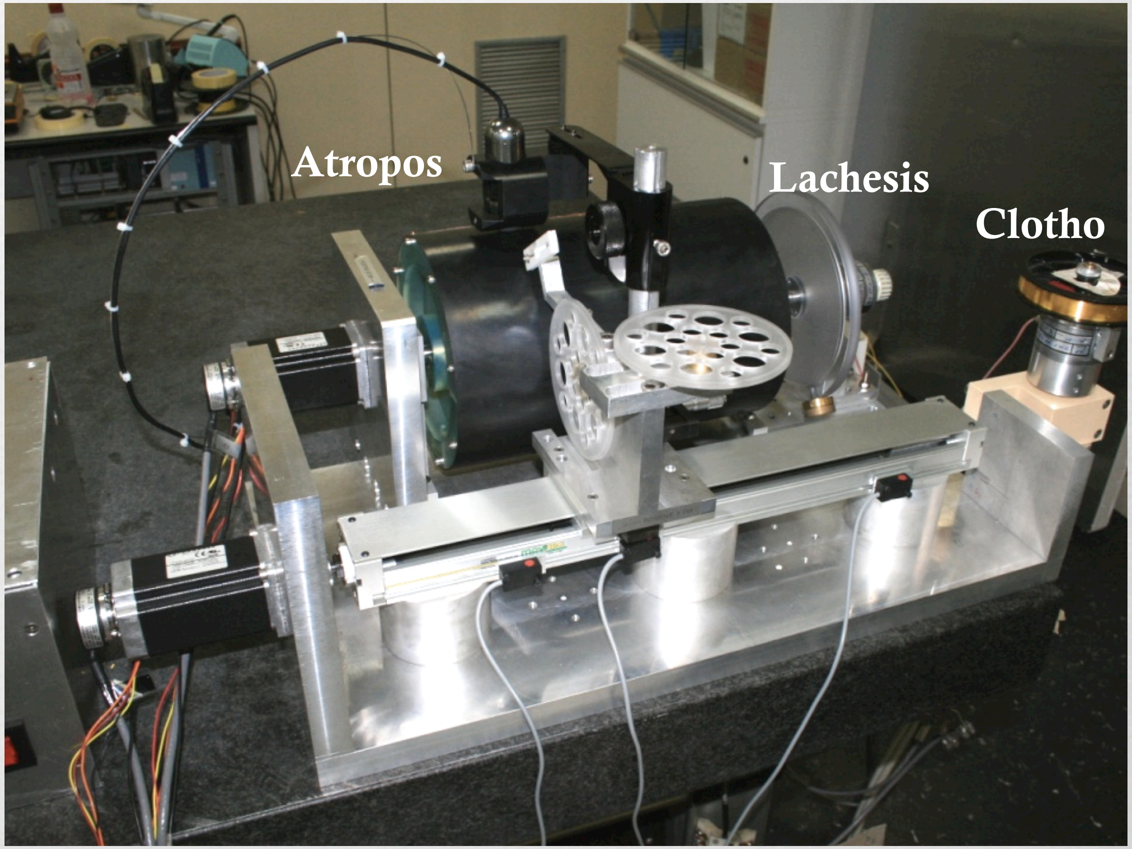


MEG upgrade DC: wiring

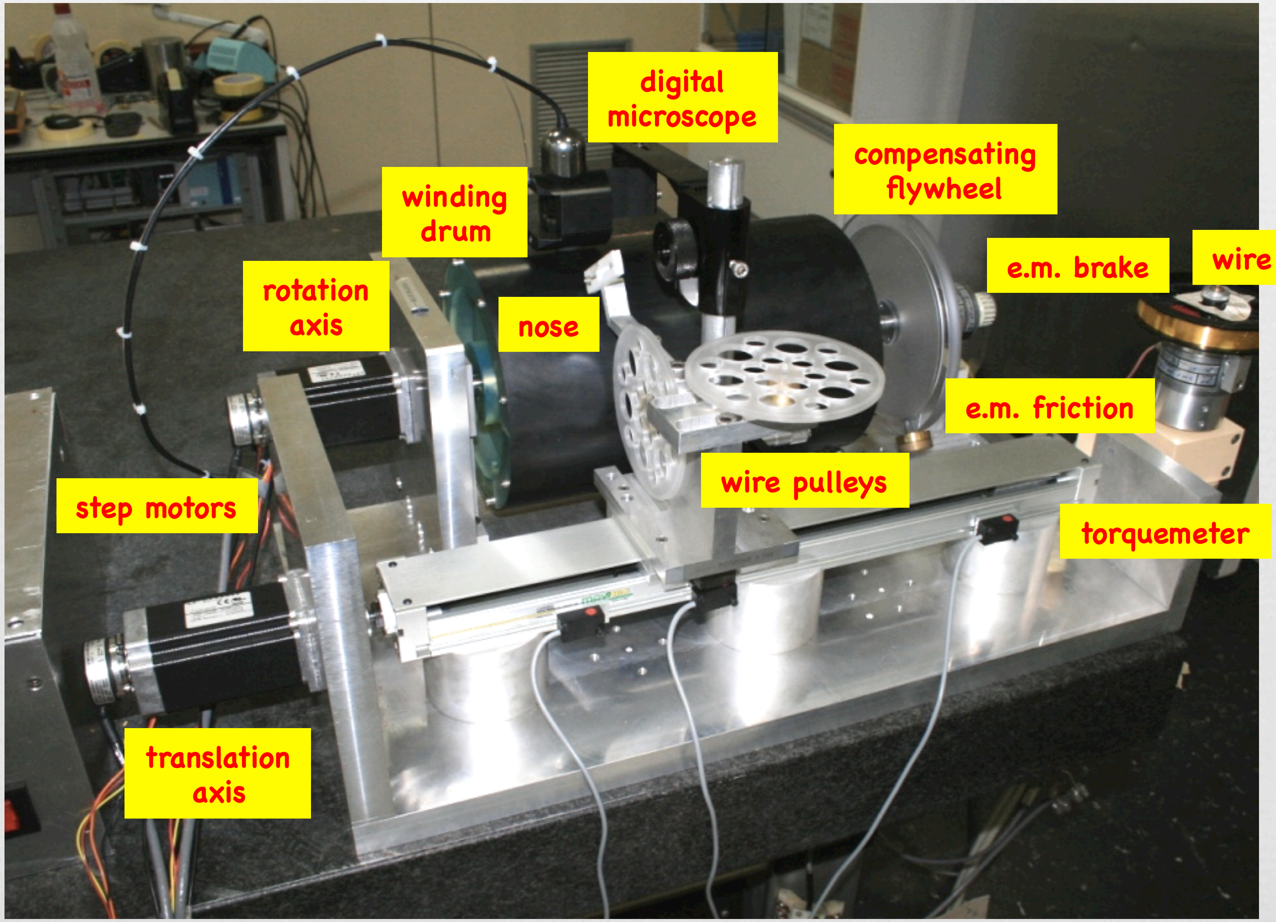
The Old Way

Bernardo Strozzi – Le tre Parche – Venezia, circa 1620

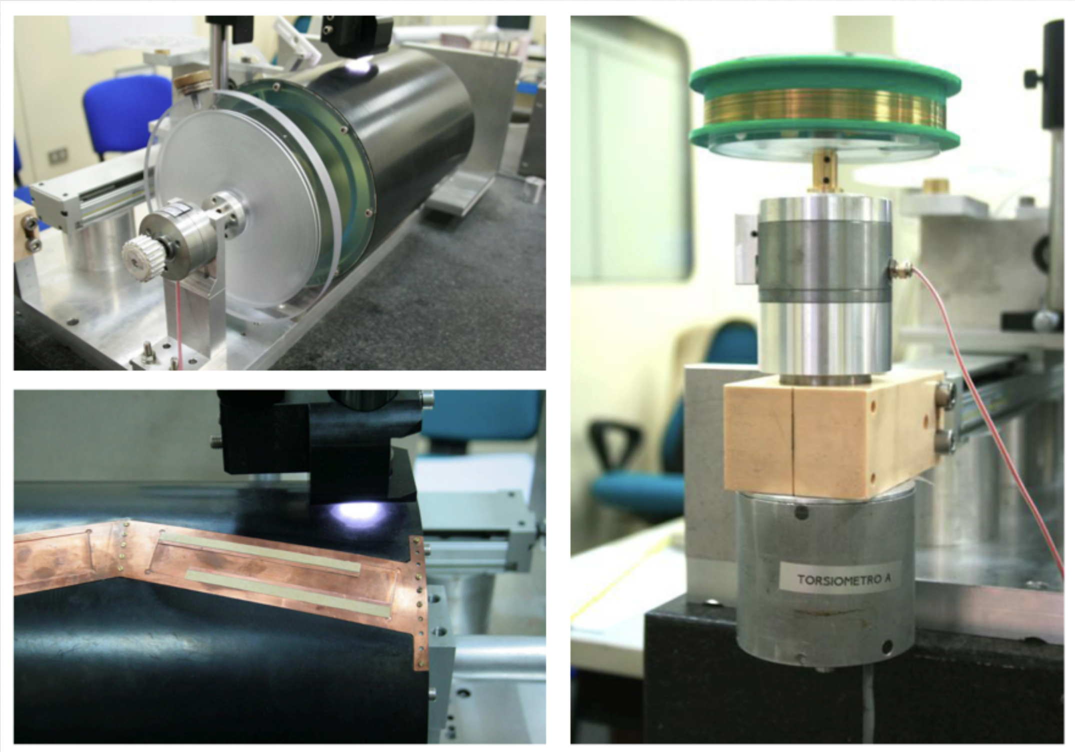
A novel approach: the Wiring Robot



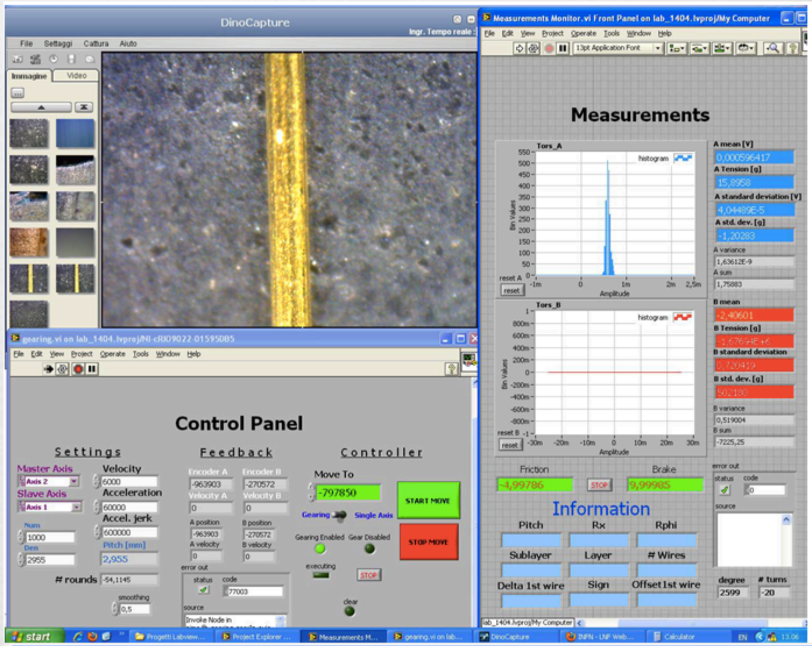
The wiring ROBOT



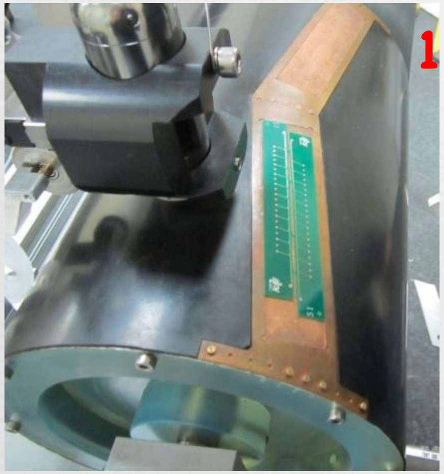
The wiring ROBOT

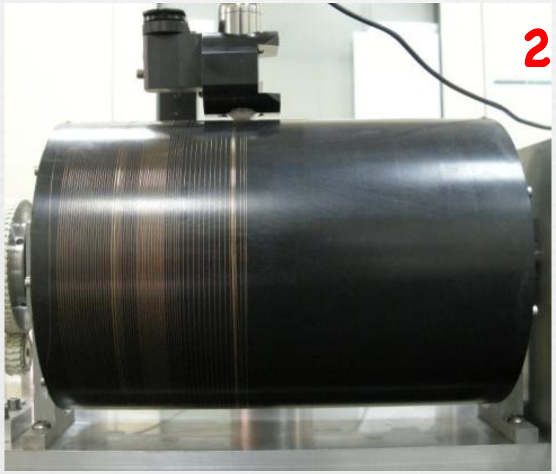


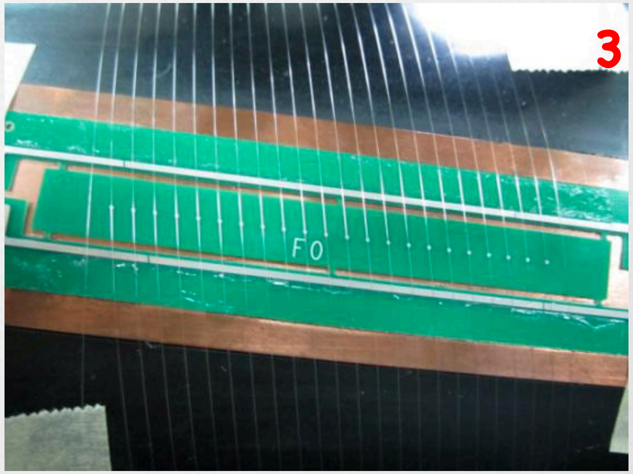
The monitor

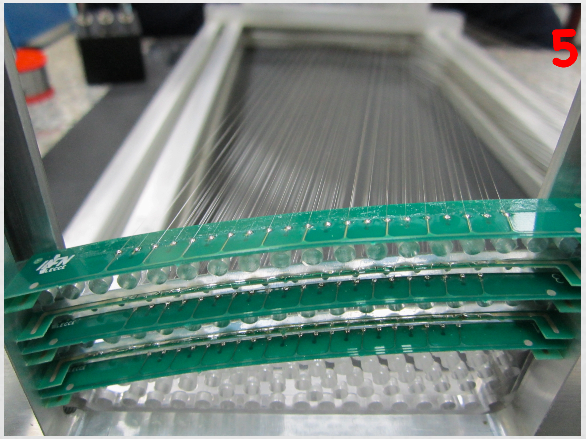


The wiring procedure



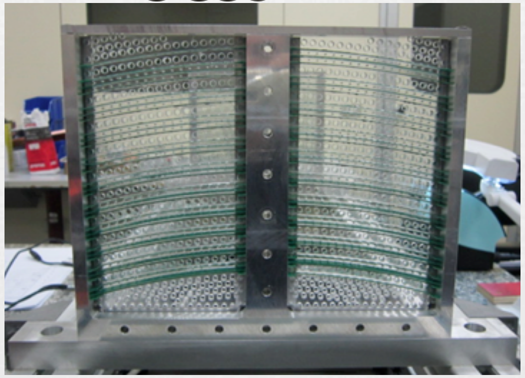


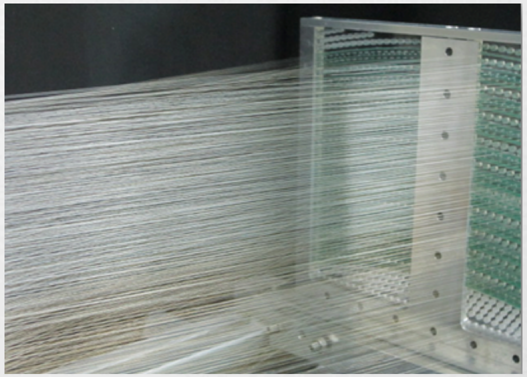


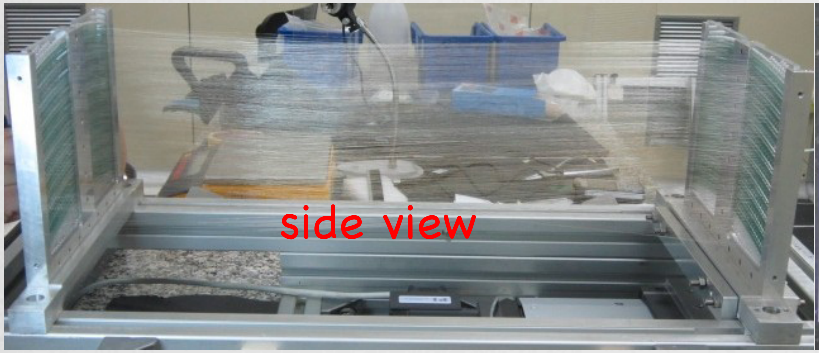


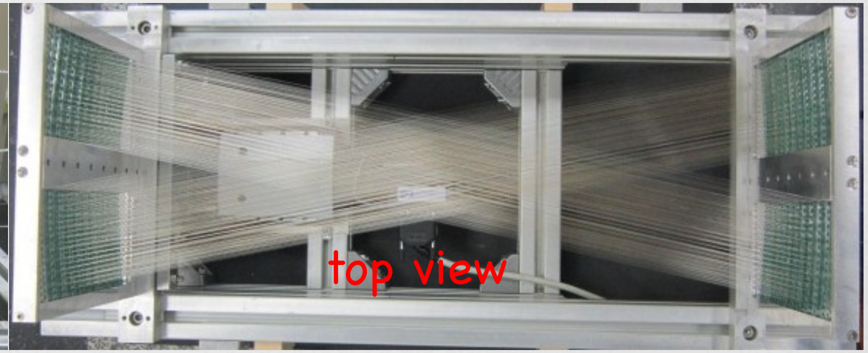
1. Align the wire boards on the winding drum at the required stereo angle
2. Start automatic winding with the required pitch
3. Solder the wires on the pads
4. Cut the wires and unroll the wire layer
5. Place the new layer straight up (upside down) onto the spacer

The Mu2e Prototype





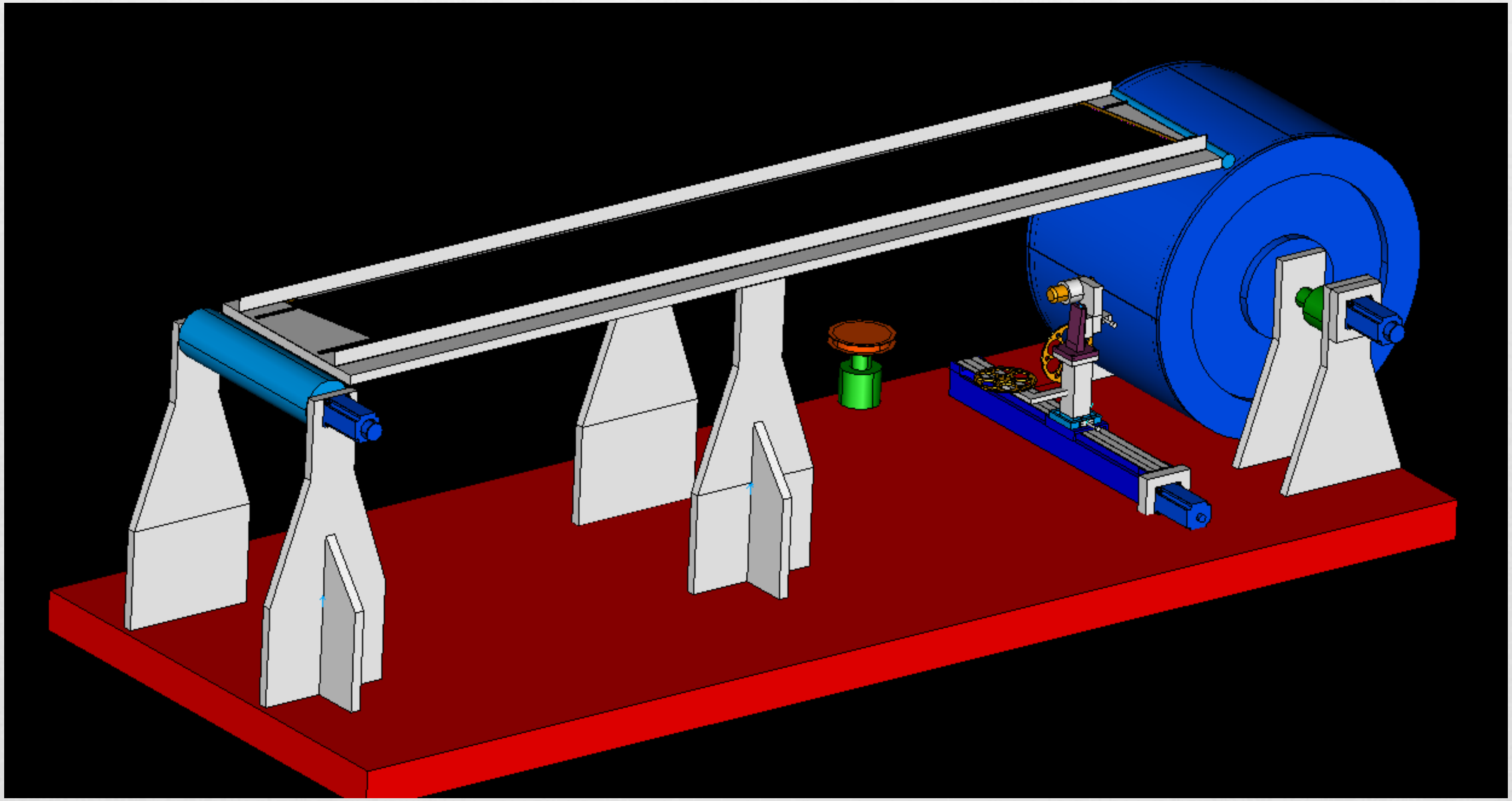




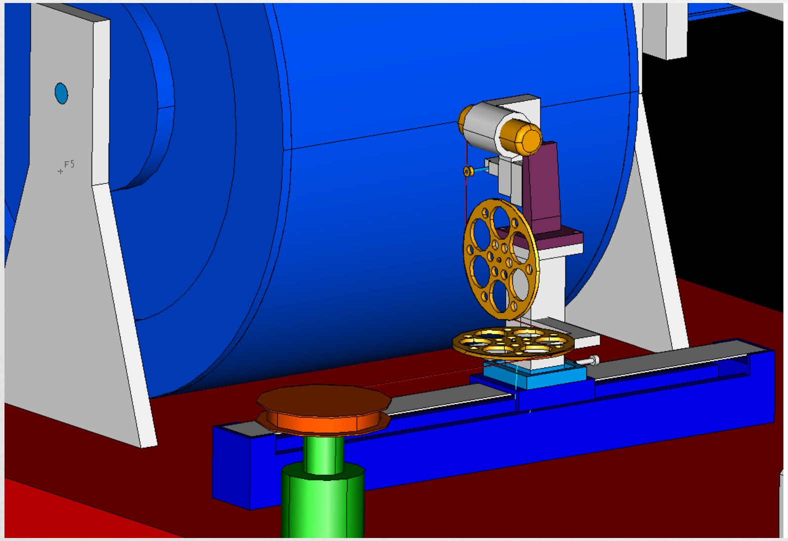
1302 wires
1102 field 40 μm Al(Ag)
200 sense 20 μm Mo(Ag) or W(Au)
cell size 6 mm ÷ 8 mm
stereo angle ± 200 mrad - length ≈ 60 cm

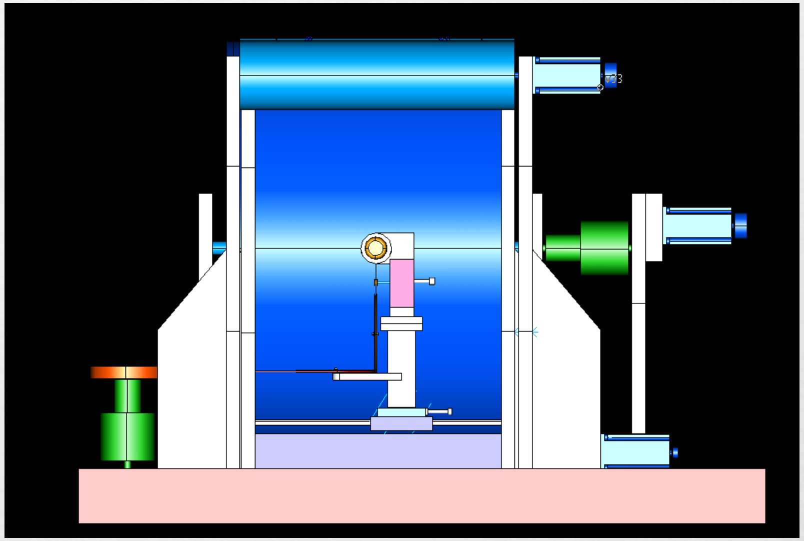
A similar prototype (200 cm long) is under construction for the drift chamber of the upgrade of MEG experiment at PSI

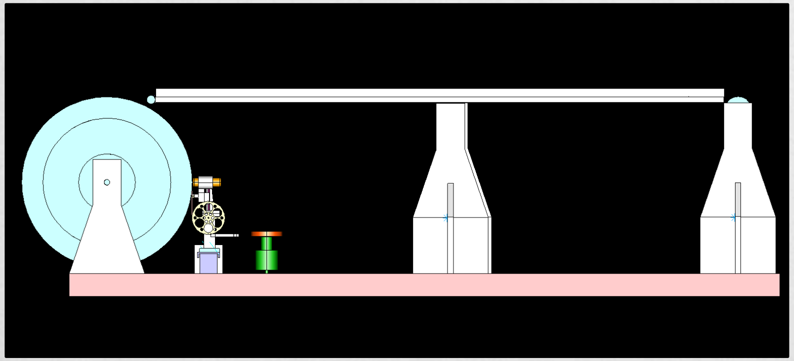
The MEG upgrade ROBOT

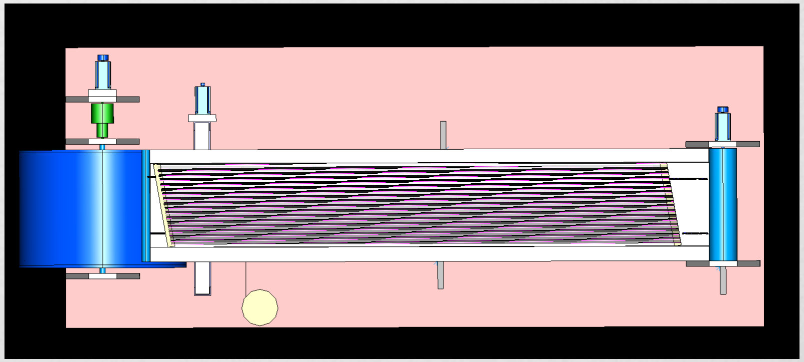


The MEG upgrade ROBOT

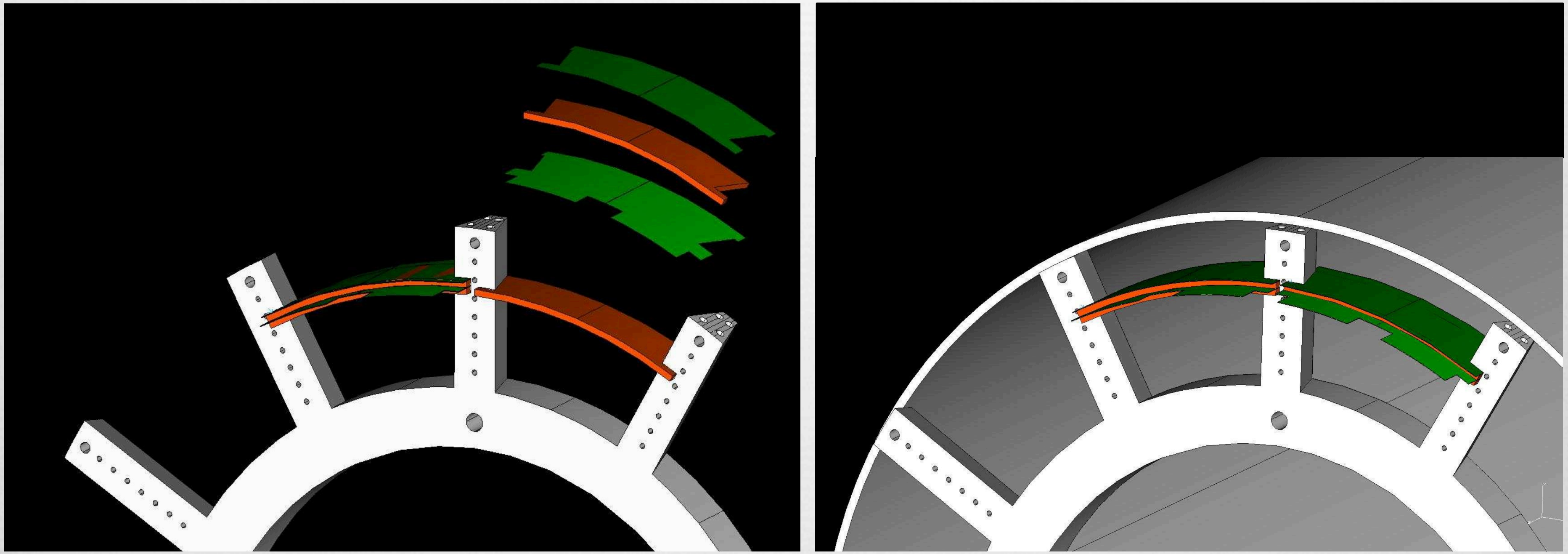






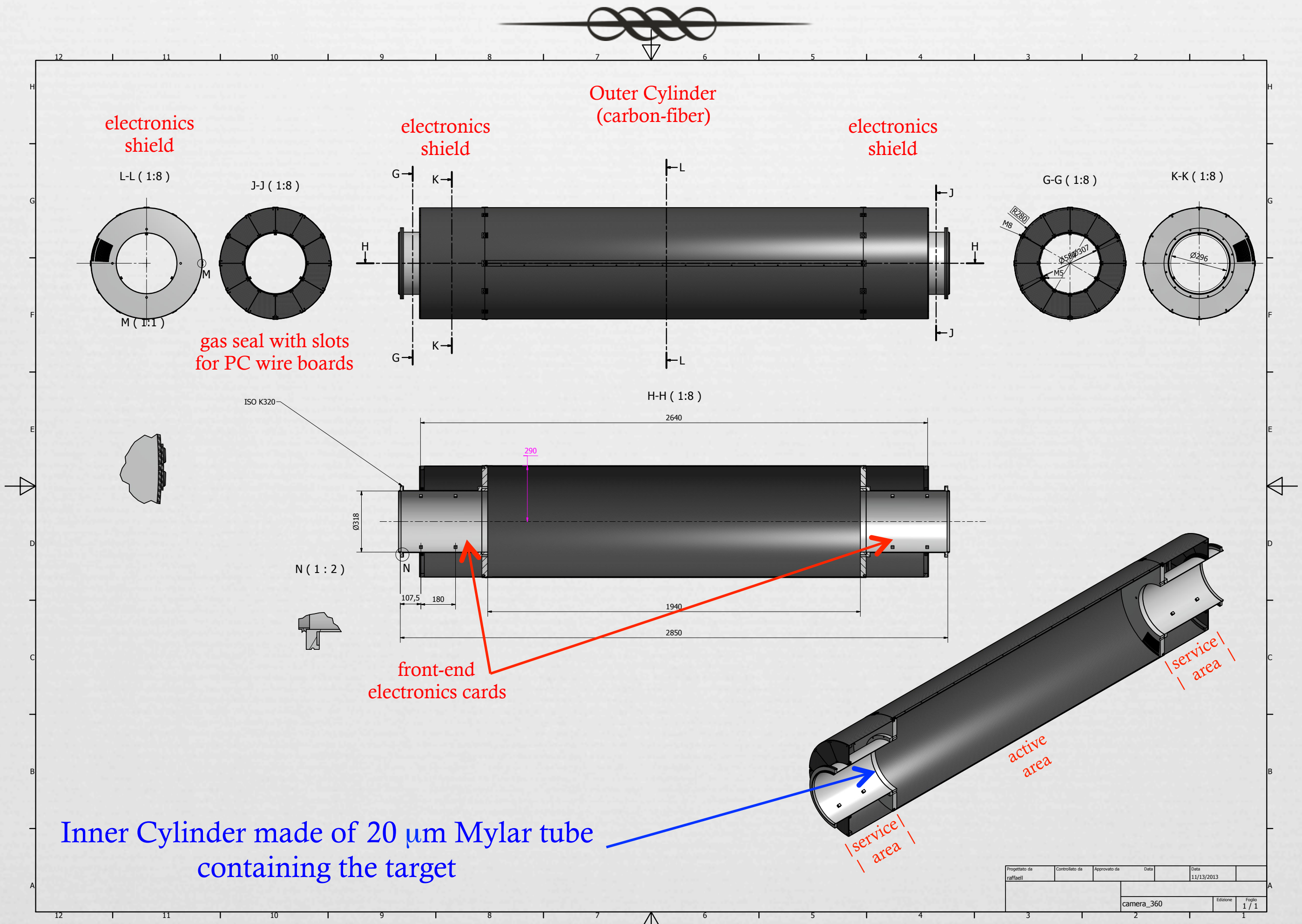


MEG upgrade DC: EndPlates

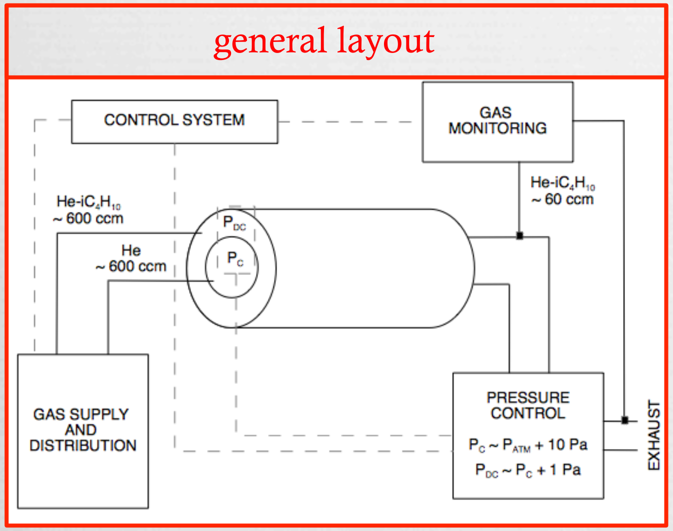


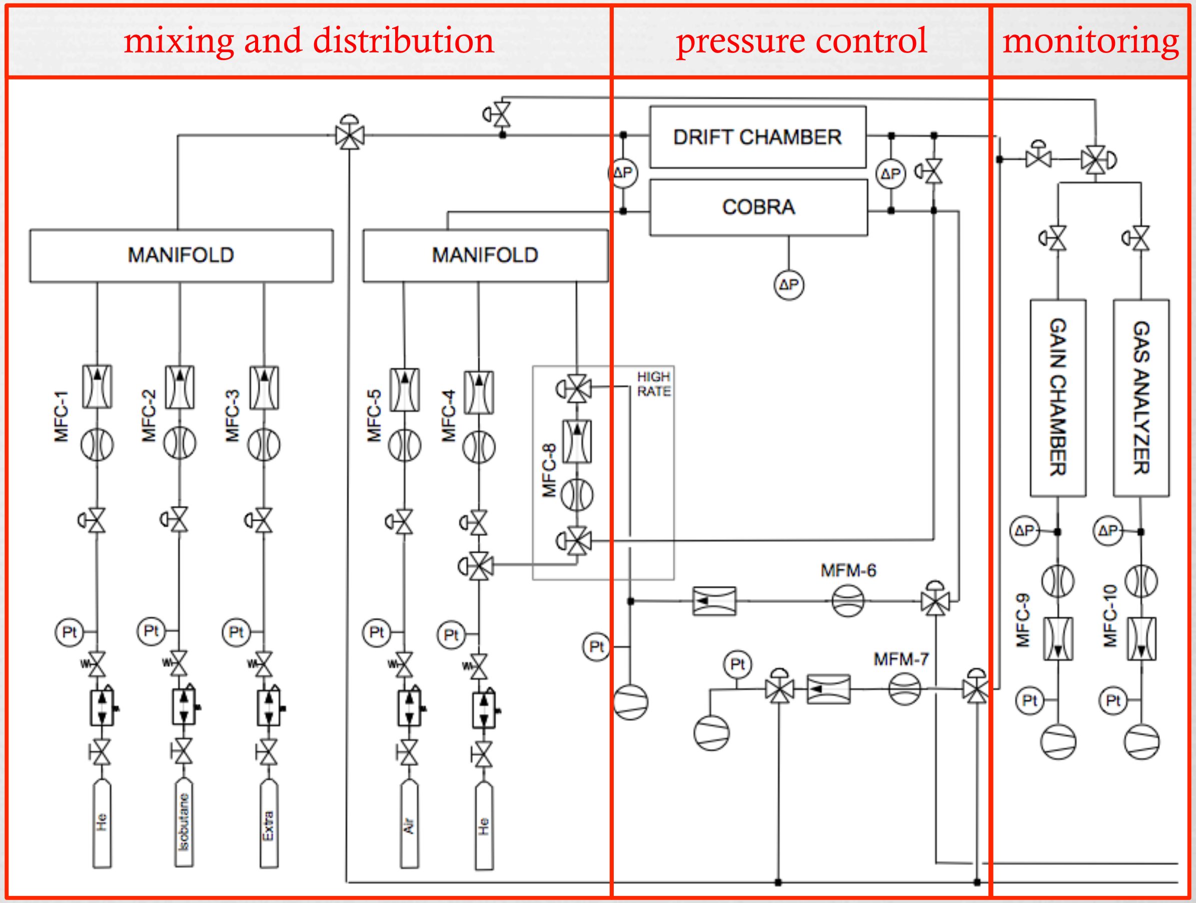
- End-plates numerically machined from solid Aluminum
- Field, Sense and Guard wires placed azimuthally by Wiring Robot with better than one wire diameter accuracy
- Wire PC board layers (green) radially spaced by numerically machined peek spacers (red) (accuracy < 20 μm)
- Wire tension defined by homogeneous winding and wire elongation ($\Delta L = 100$ μm 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

MEG upgrade DC: Assembly



MEG upgrade DC: Gas distr.





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

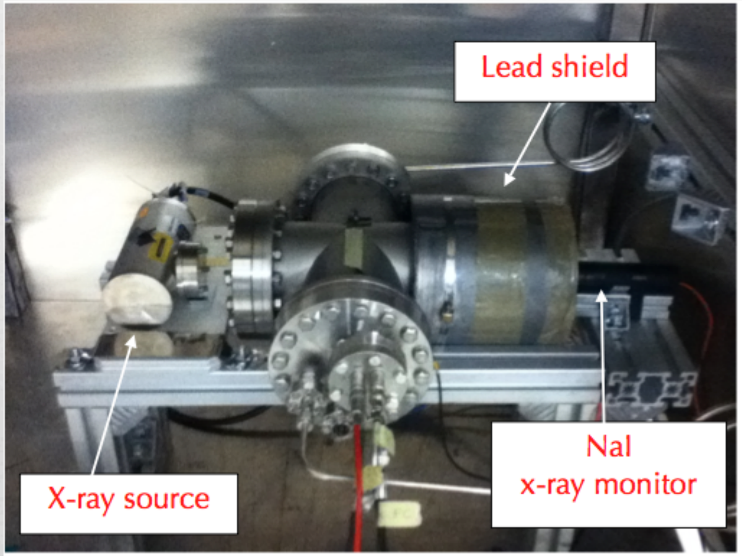
MEG upgrade DC: HV distr.

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

MEG upgrade DC: Aging



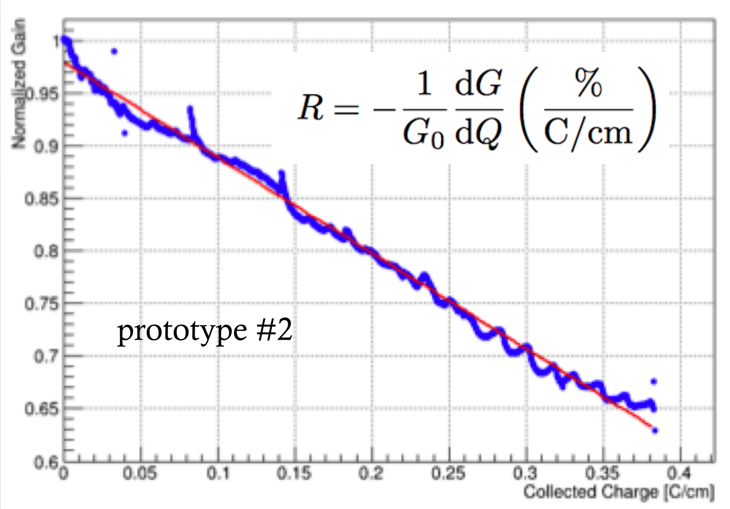
@ 7×10⁷ μ/s and 10⁵ gas gain

expect ≈ 6 nA/cm in the hottest point

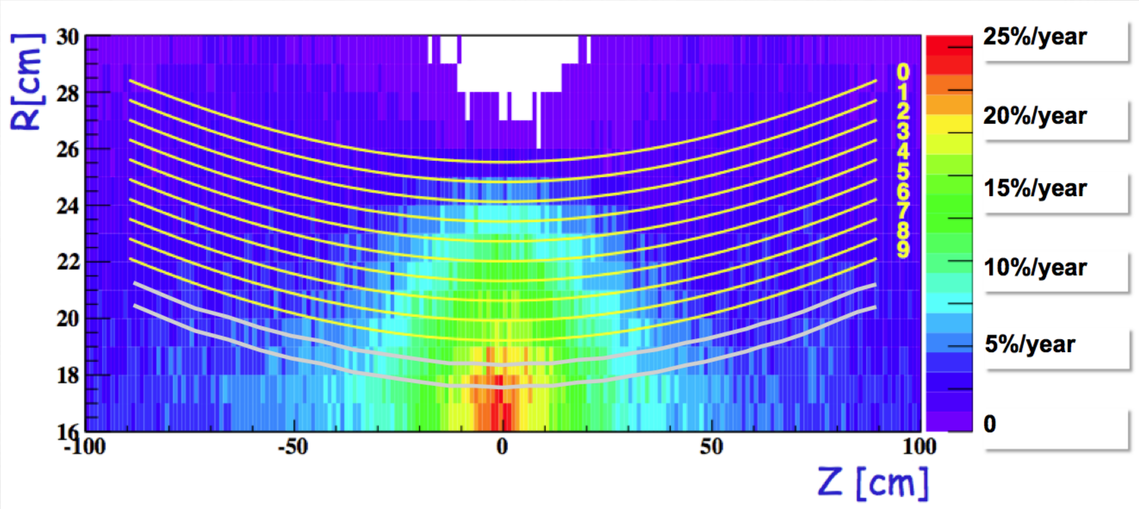
≈ 0.32 C/cm

integrated over 3 years data taking

(however, @ G = 10⁵, dG/dV ≈ 3-4%/Volt)



gain drop



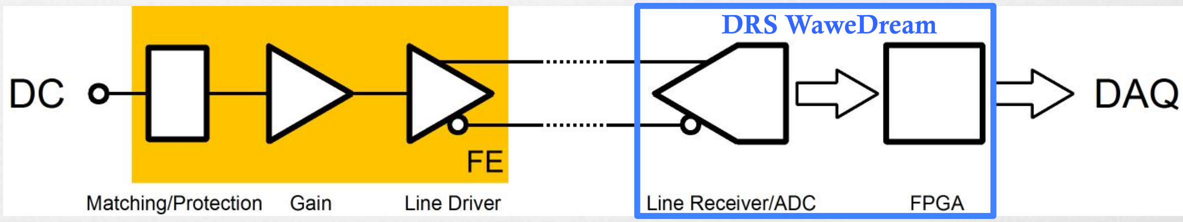
MEG upgrade DC: F. E. Elec.

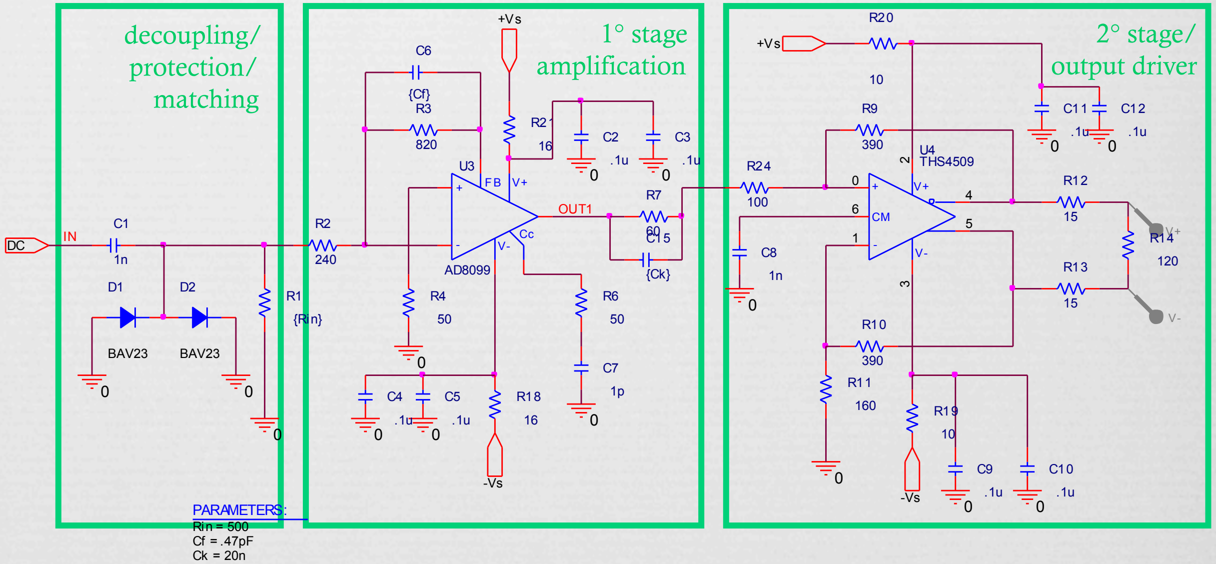
Requirements

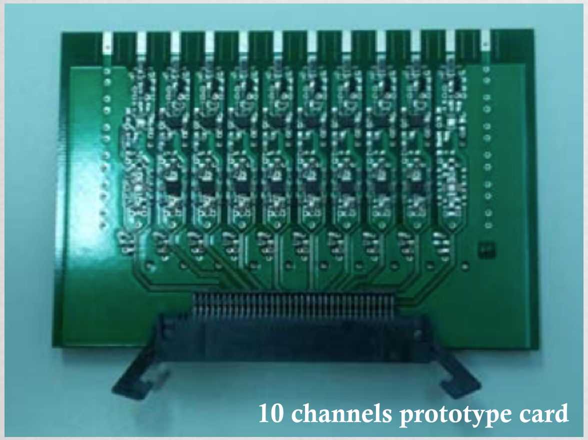
- High bandwidth >700 MHz
- Good gain: ~10
- High density < 7mm width
- Fully differential

Layout

- Double stage
- AD8099 and THS4509
- Direct connection to digitizer

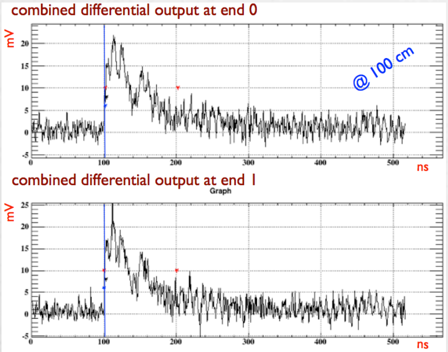





10 channels prototype card

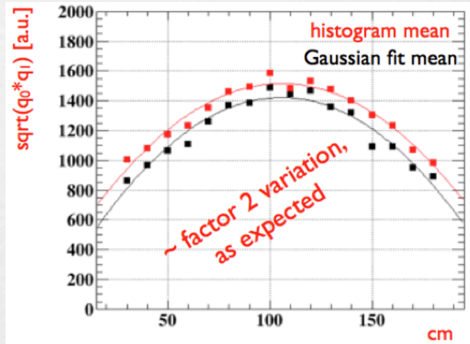
1280 out of 1920 channels (2/3) readout on both ends

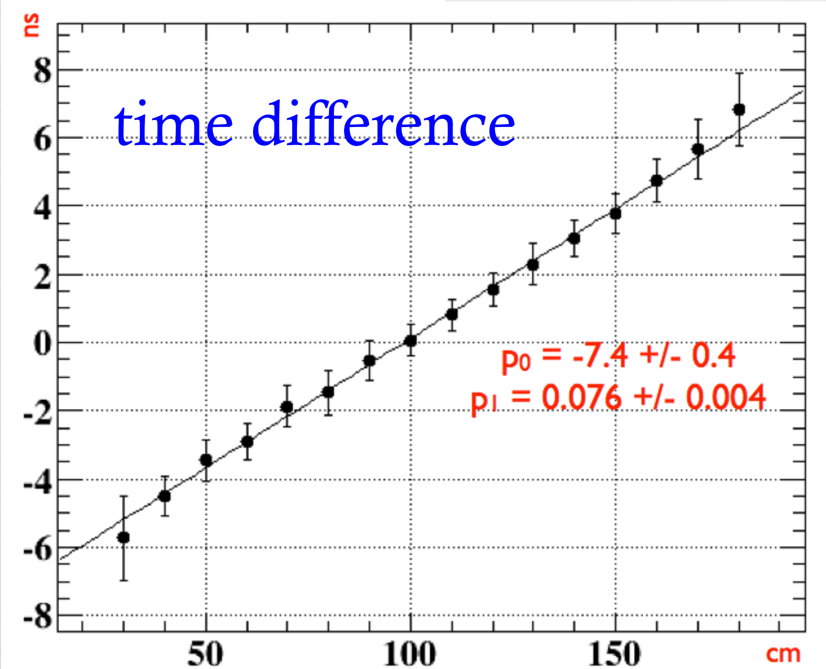
MEG upgrade DC: Longitudinal resolution

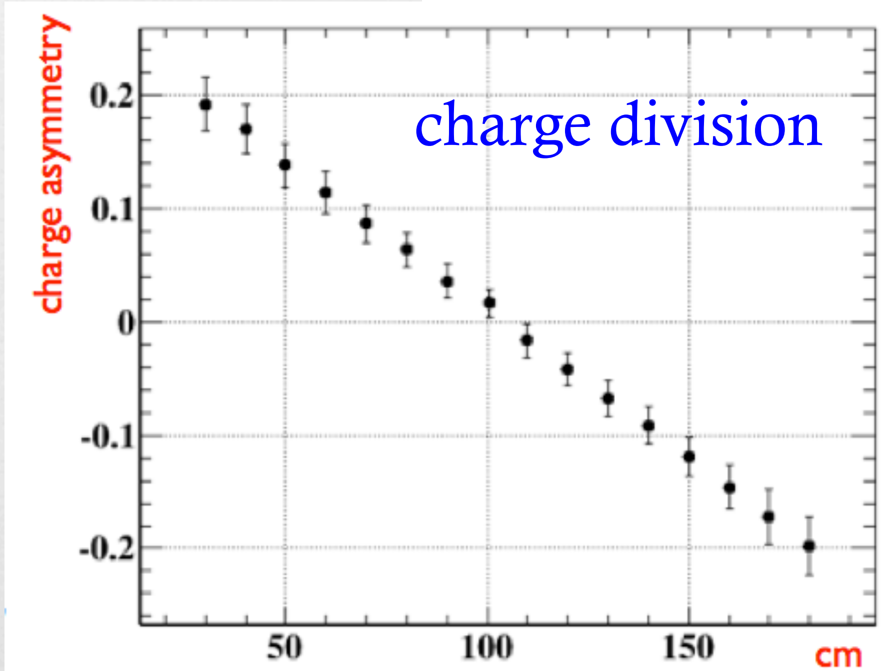


v_s = 13.2 cm/ns
$\sigma_{\Delta t} \approx$ 0.5 ns
$\sigma_z \approx$ 10 cm

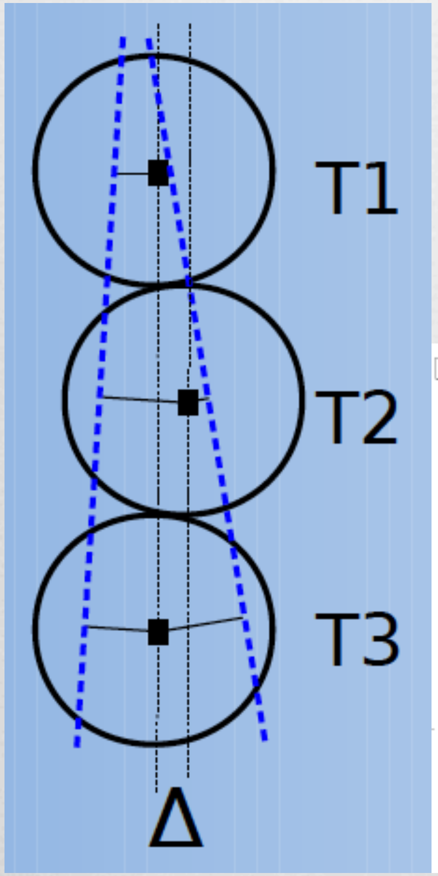
R_w = 150 Ω/m
20 μm W wire
$\sigma_z \approx$ 10 cm







MEG upgrade DC: Spatial resolution I

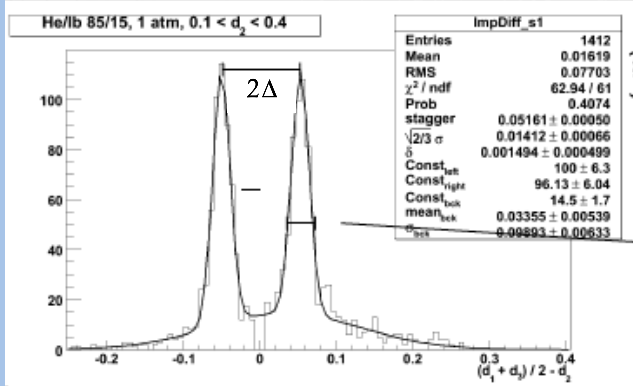


Staggered 3-tubes method with cosmic rays

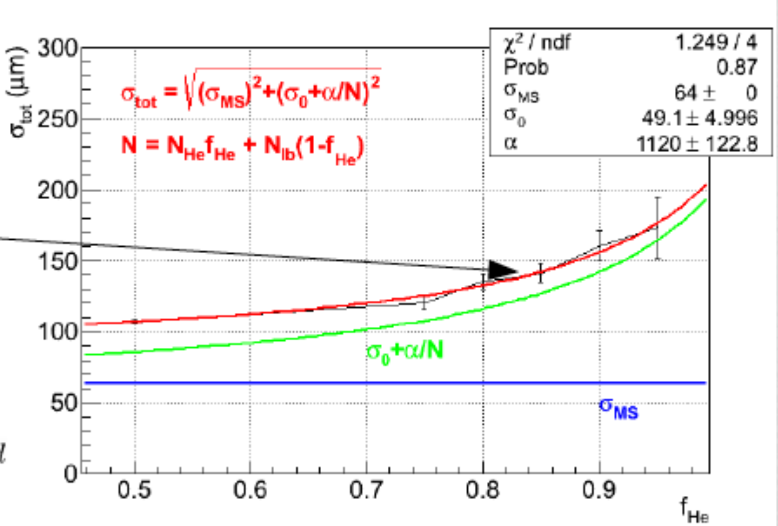
85% He – 15% iC_4H_{10} : $\sigma_{drift} \approx 130\ \mu m$

averaged over all impact parameters and angles

(leading edge discrimination, no cluster timing)

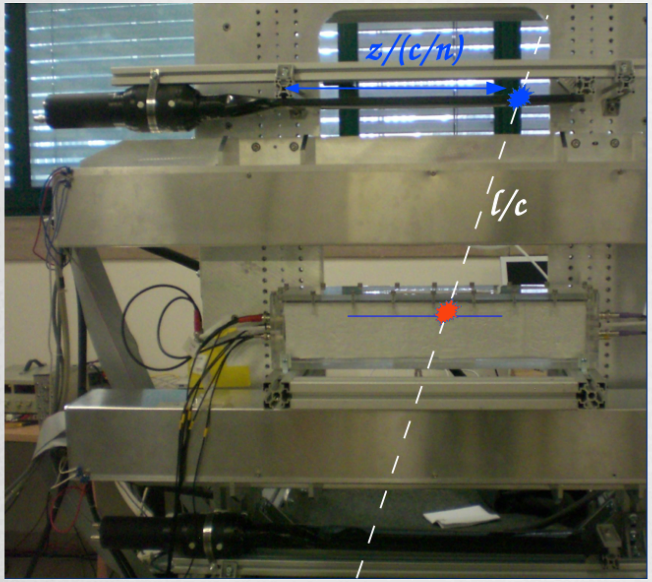


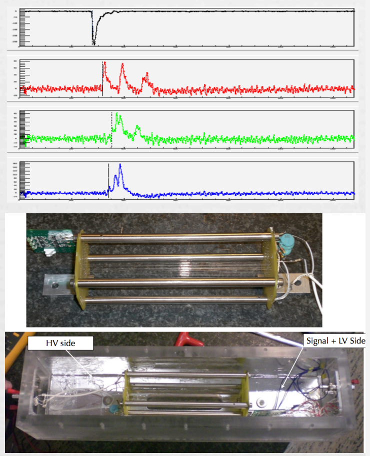
$$D = \frac{d_1 + d_3}{2} - d_2 \qquad \sigma_D = \sqrt{\frac{3}{2}}\sigma_d$$



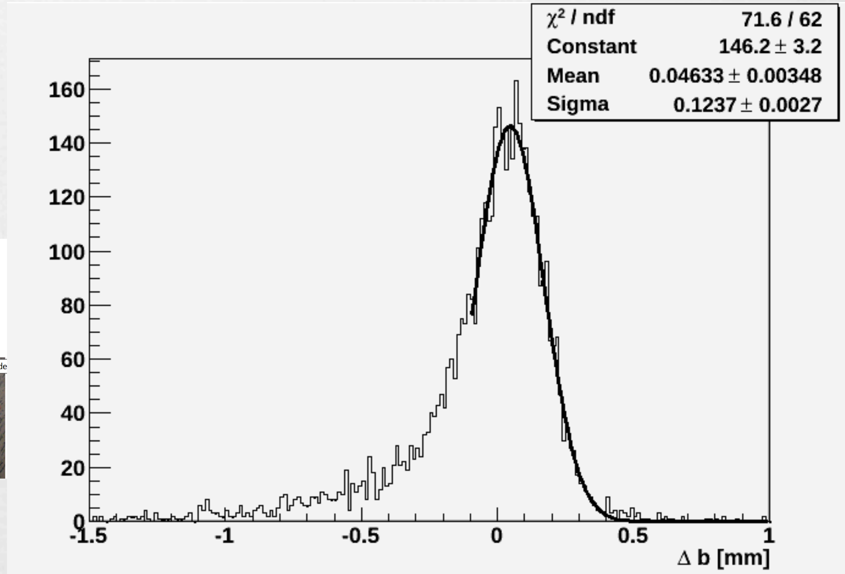
MEG upgrade DC: Spatial resolution II

Staggered 3-cells method under Si telescope



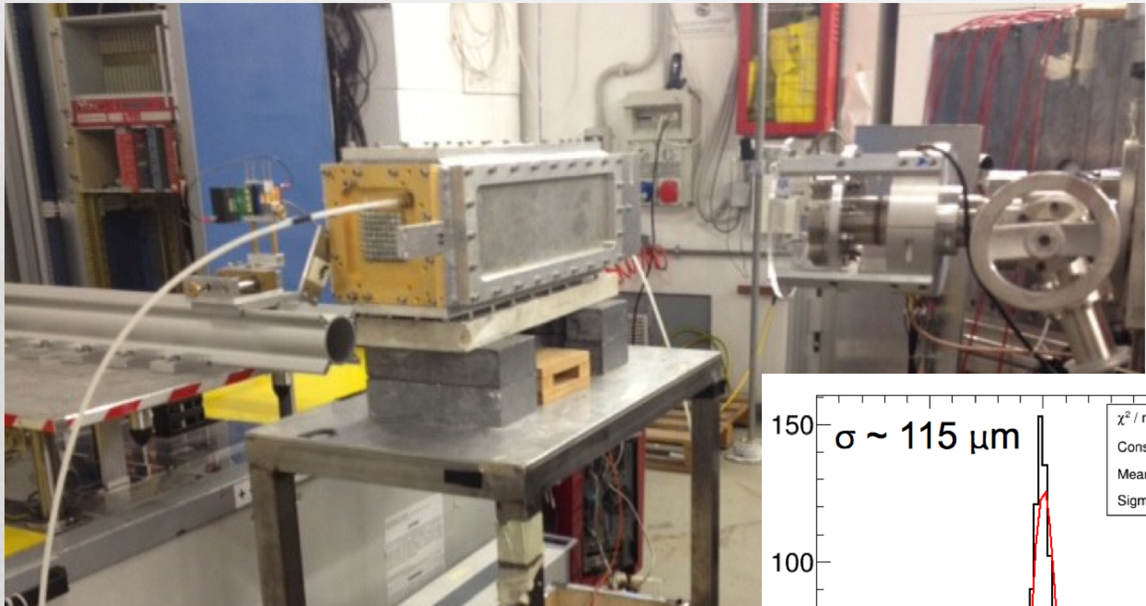


85% He – 15% iC_4H_{10}



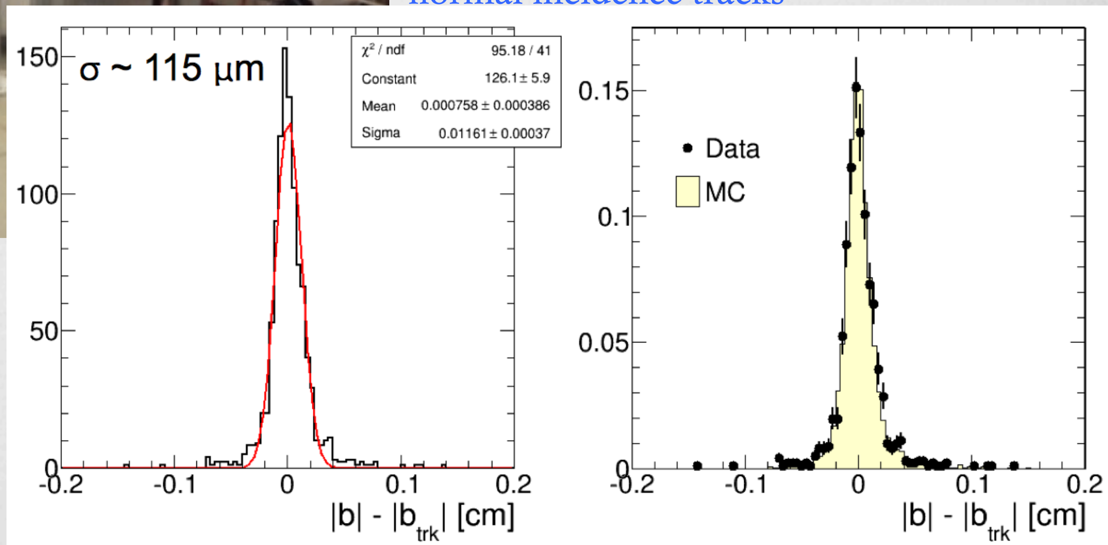
Average hit resolution σ_{drift} = 108 ± 5 μm

MEG upgrade DC: Spatial resolution III



Beam test at BTF – LNF

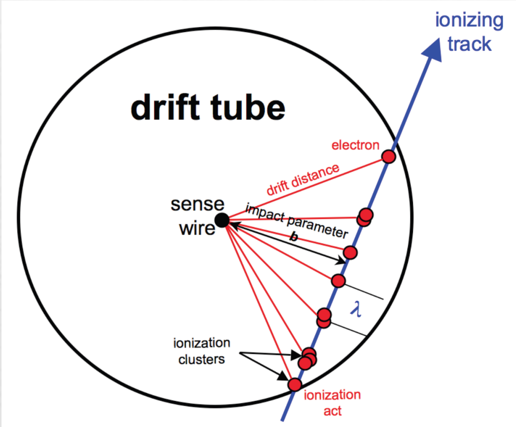
normal incidence tracks



Average hit resolution

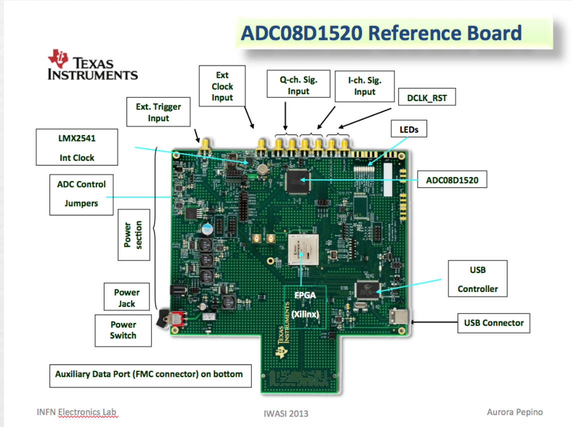
σ_{drift} = 116 ± 4 μm

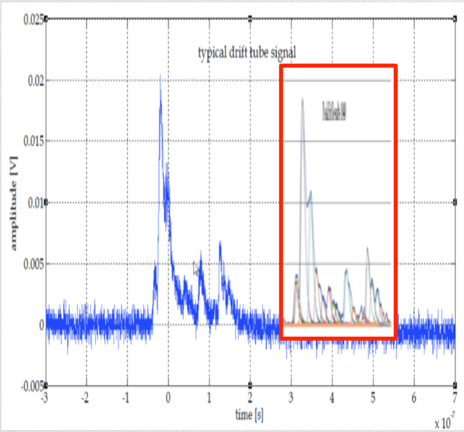
MEG upgrade DC: Cluster Timing

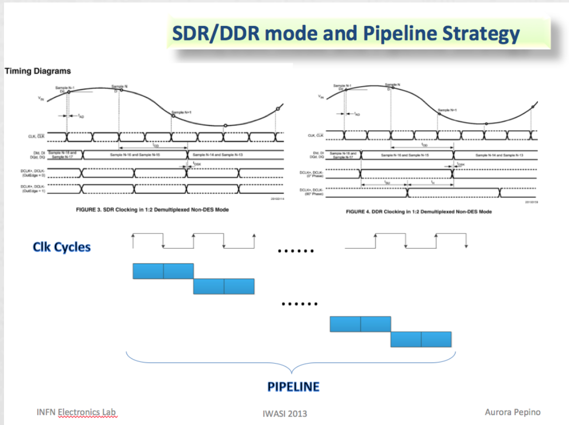


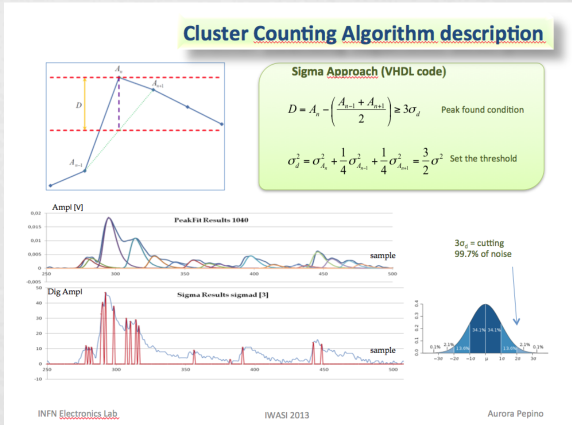
Recording the digitized information of all active sense wires in a drift chamber with full details (2 Gsa/s) may be a cumbersome task.

We have developed a fast, simple and effective algorithm, implemented with a pipeline strategy on an FPGA, to isolate, in real time, the peak structures in the digitized signal and to be able to transfer only the time and amplitude of the peak sequence.





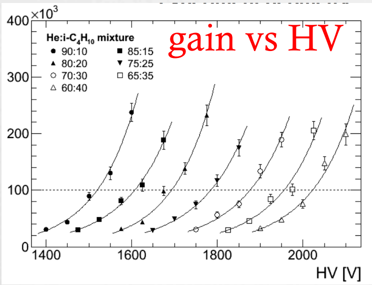


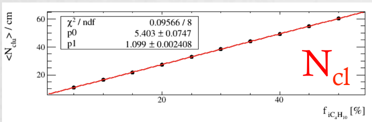


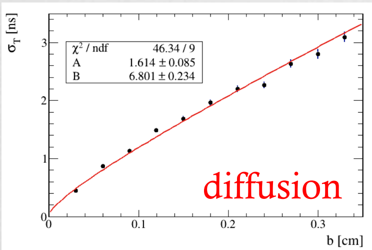
A. Pepino, INFN Lecce - IWASI 2013 - 5th IEEE International Workshop on Advances in Sensors and Interfaces. 13-14 June 2013 - Bari, Italy

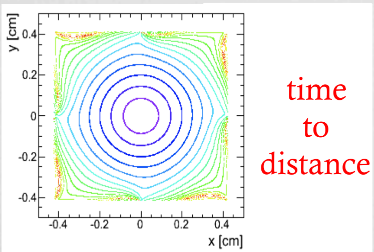
MEG upgrade DC: Simulated performance

Garfield++ Heed++ MagBoltz

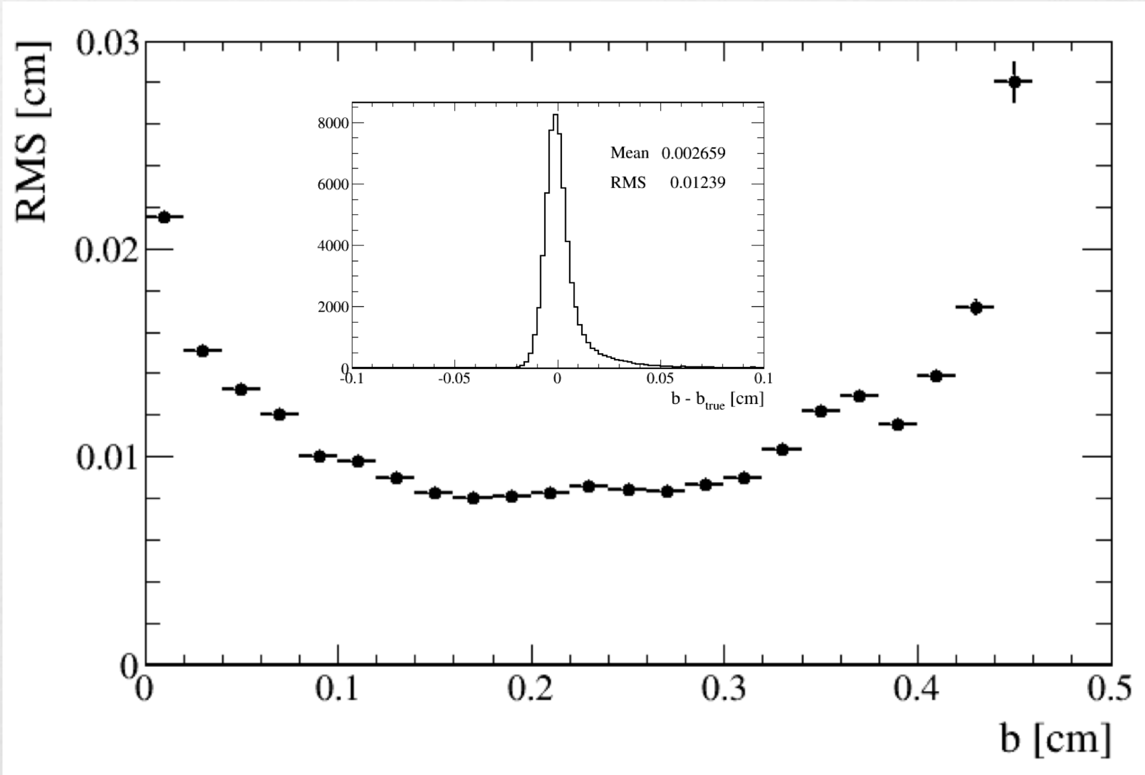




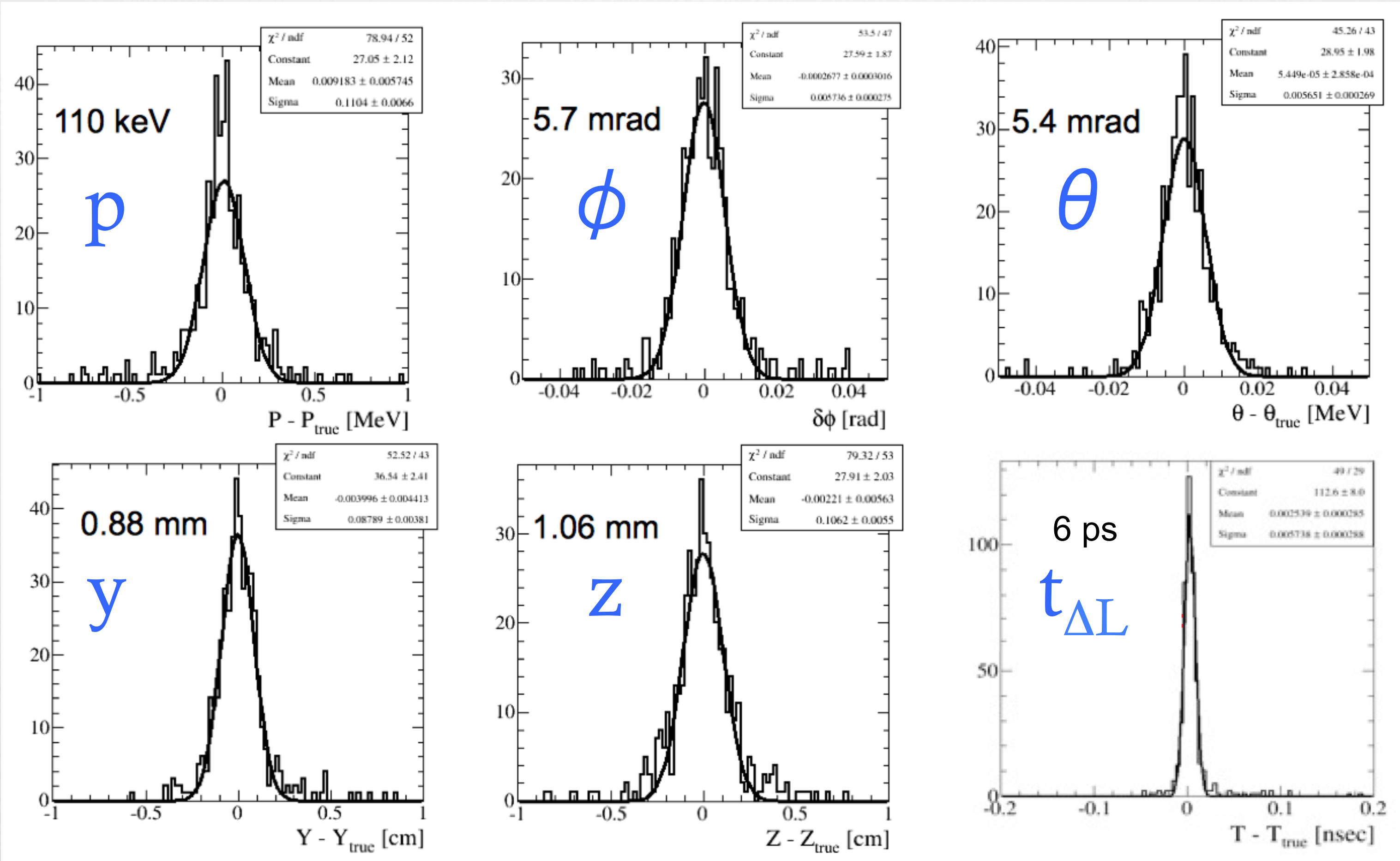




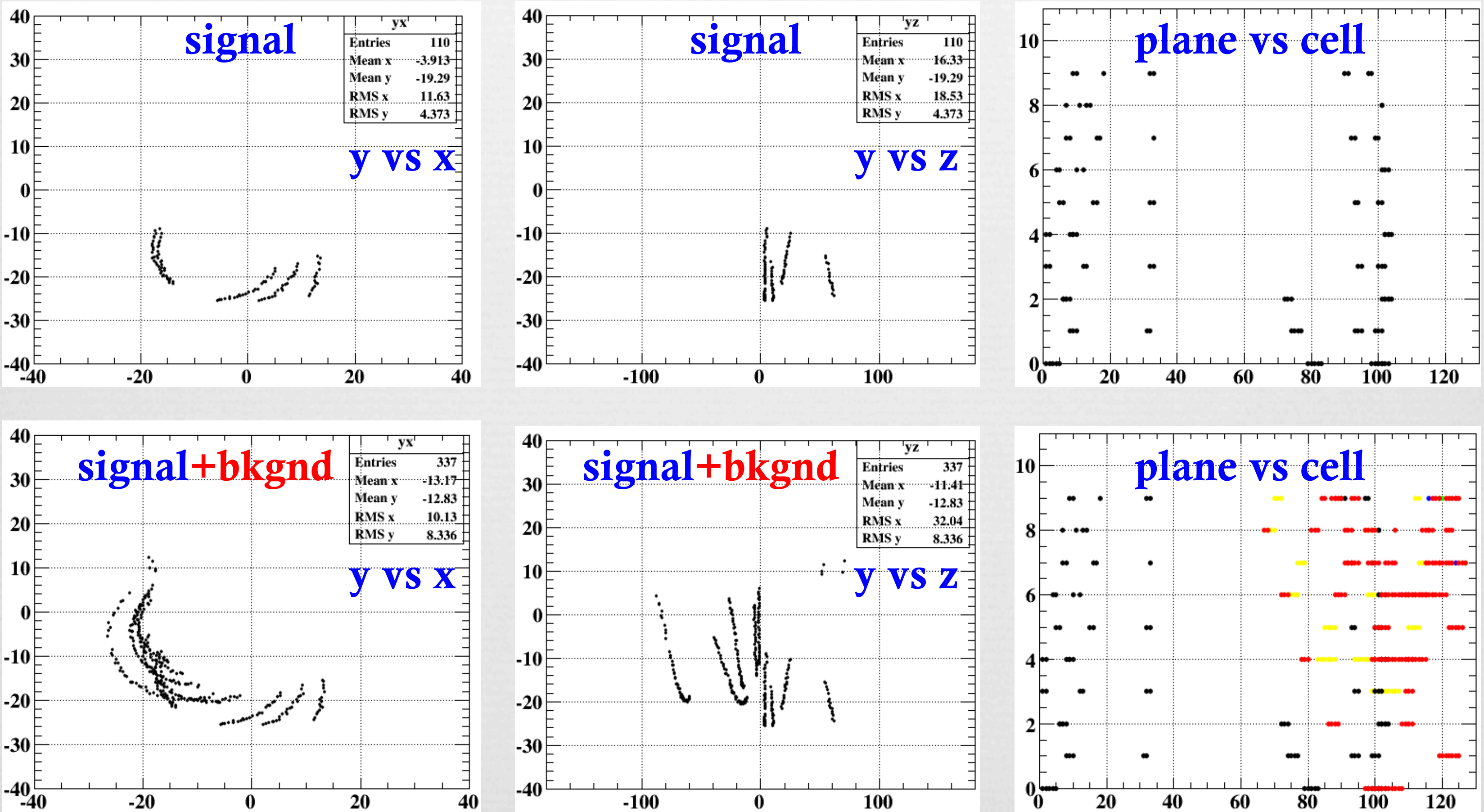
Average hit resolution σ_{drift} = 124μm



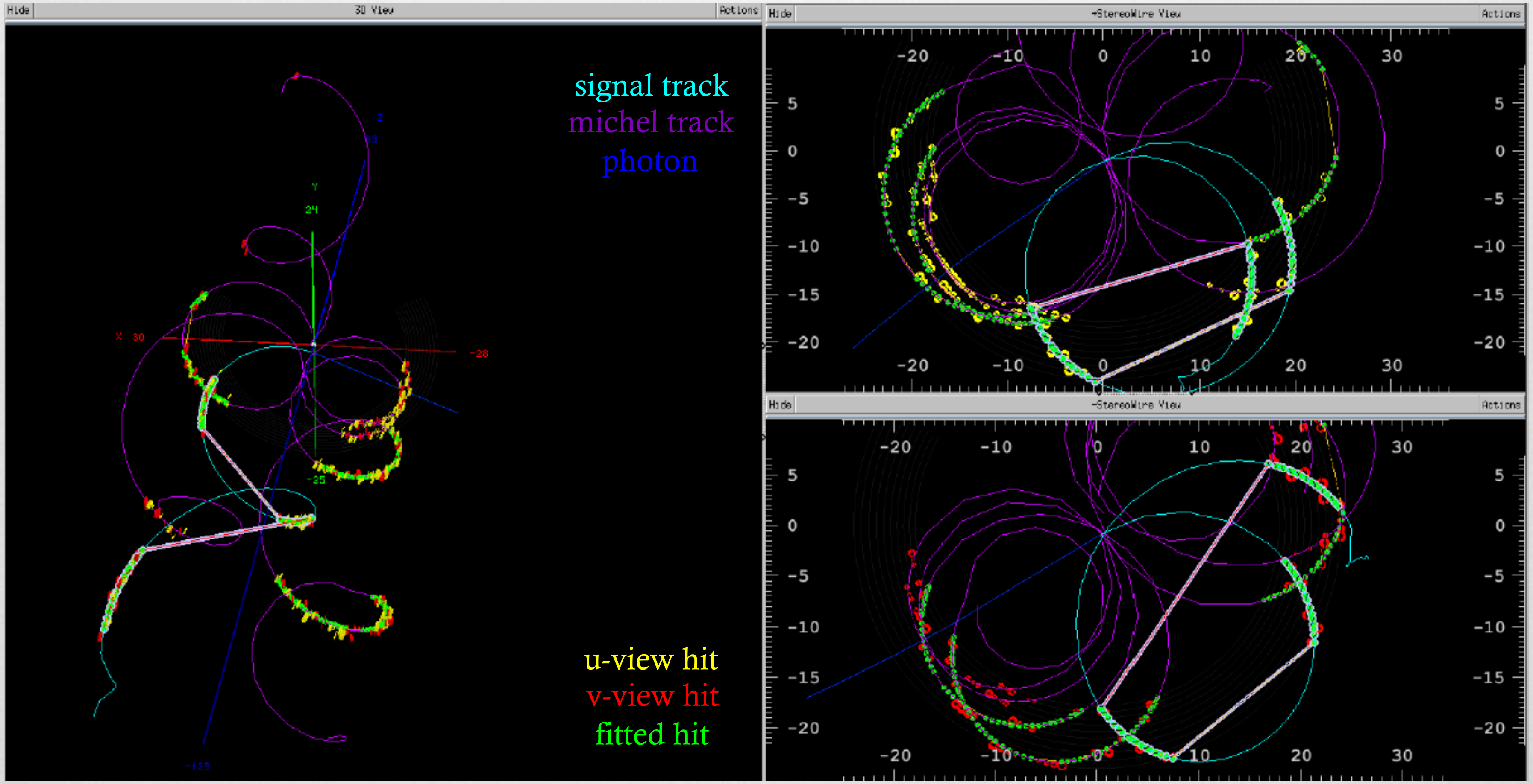
MEG upgrade DC: Simulated performance



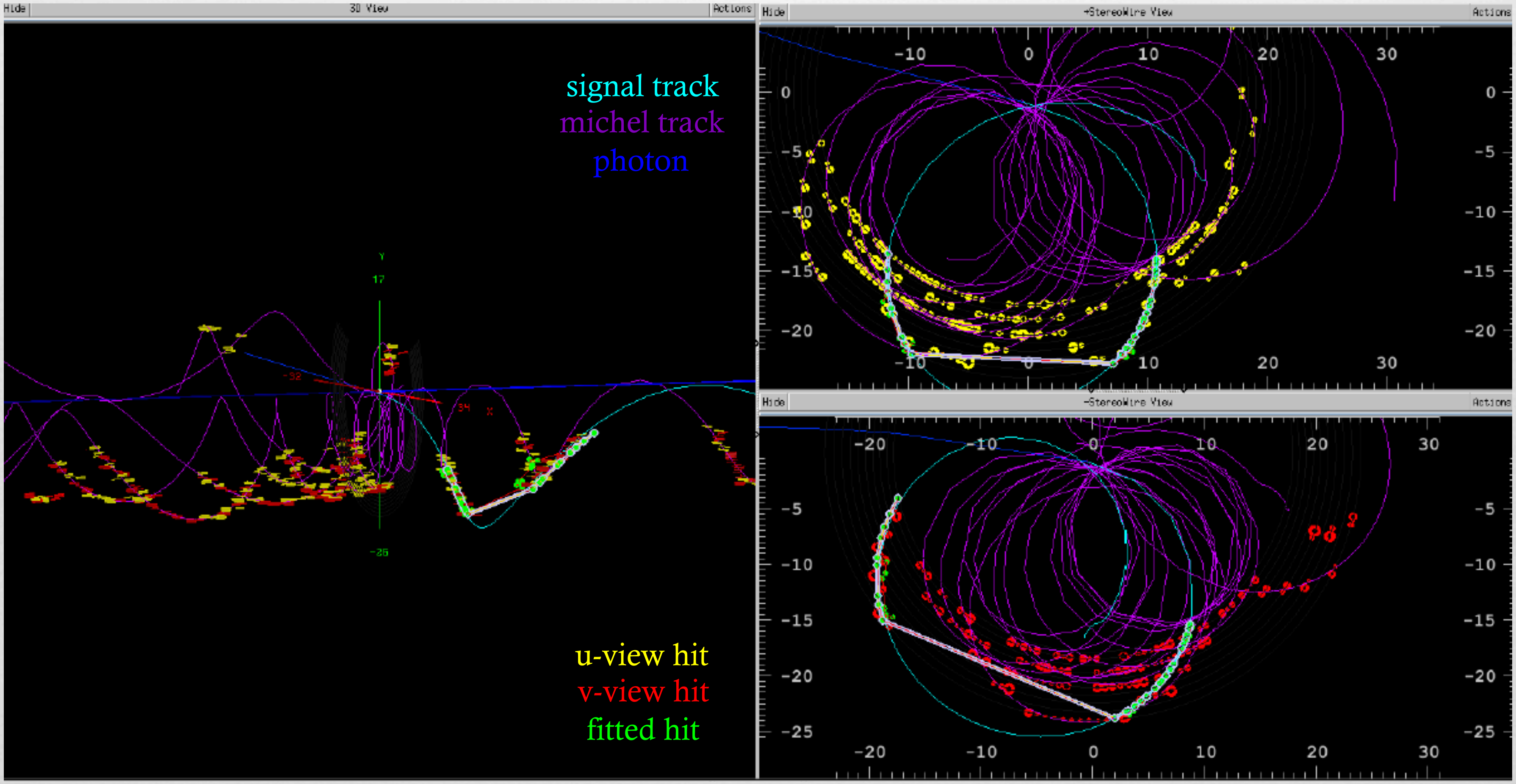
MEG upgrade DC: Track Finding



MEG upgrade DC: 3D Track Finding



MEG upgrade DC: 3D Track Finding



MEG upgrade DC

	Present MEG	MEG upgrade
single hit contribution to m.s.	2.3×10^{-4} X_0	4.6×10^{-5} X_0
transverse position resolution	210 μm	120 μm
e^+ momentum resolution	330 KeV/c	115 KeV/c
e^+ θ angle	9.4 mrad	5.4 mrad
e^+ ϕ angle	8.4 mrad	5.7 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%

MEG upgrade DC

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single hit contribution to m.s.	2.3×10^{-4} X_0	4.6×10^{-5} X_0
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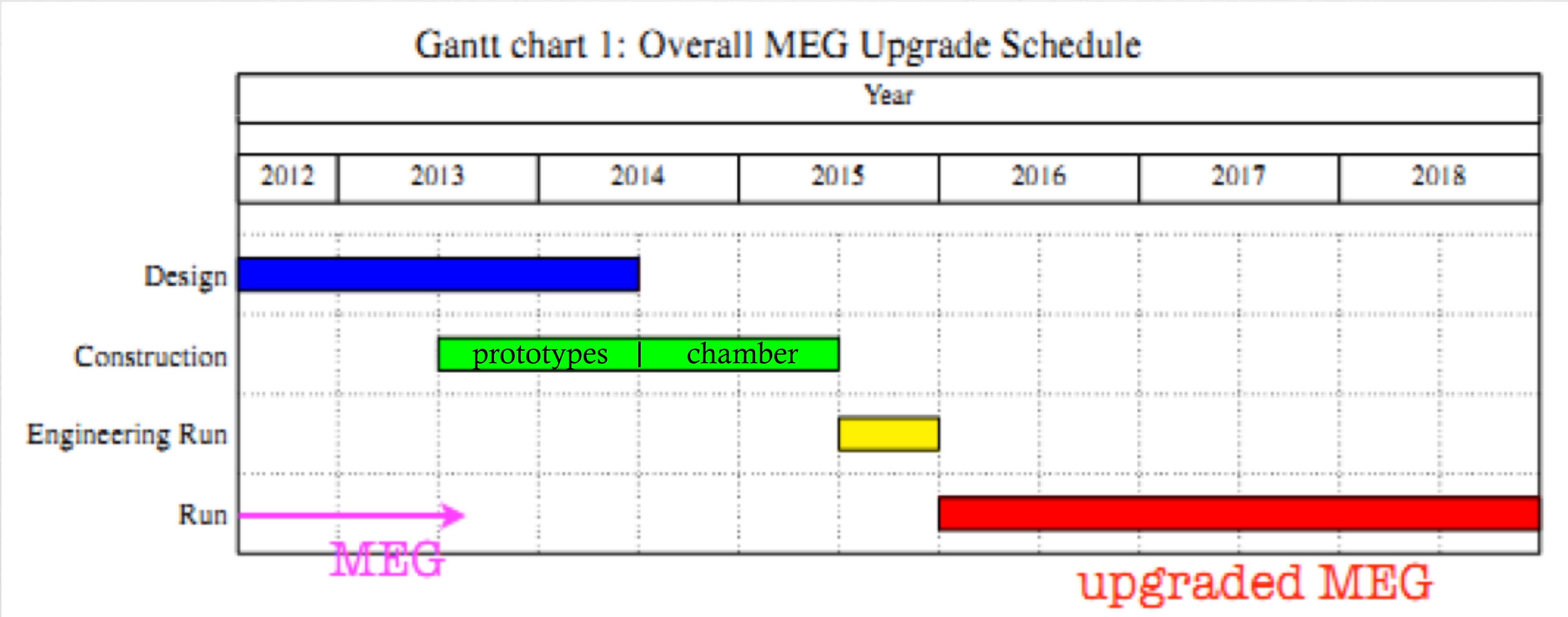
e^+ y vertex	1.6 mm	0.9 mm
e^+ z vertex	2.5 mm	1.1 mm
DC–TC matching efficiency	41%	89%

remember!

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

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

MEG upgrade DC: schedule



Conclusions

- Strong motivations for an upgraded MEG experiment aiming at setting an upper limit $\mathcal{B}(\mu^+ \longrightarrow e^+ + \gamma) < 6 \times 10^{-14}$.
- The design and the performance of the new tracking system, among the other subsystems, are crucial to reaching this goal.
- A high wire density – light gas mixture – feed-through-less – all stereo – drift chamber has been proposed and funded and is actually being built.
- Several different prototypes, together with detailed montecarlo simulations, have demonstrated the required basic performance.