A new experiment for the μ→eγ search

B. Echenard[1], D. G. Hitlin[1], F. Grancagnolo[2], G. F. Tassielli[2], S. Giovannella[3], F. Happacher[3], S. Miscetti[3], I. Sarra[3], G. Cavoto[4,5], F. Renga[4], and C. Voena[4]

1) California Institute of Technology, Pasadena, California 91125, USA

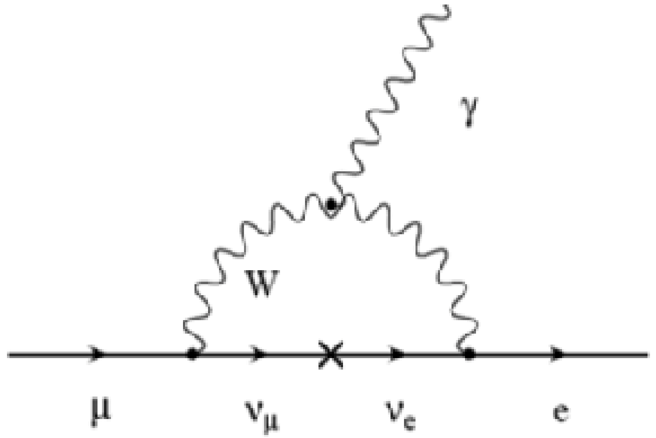
2) INFN Sezione di Lecce, Lecce I-73100, Italy

3) Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy

4) INFN Sezione di Roma1, Piazzale A. Moro, Rome I-00185, Italy

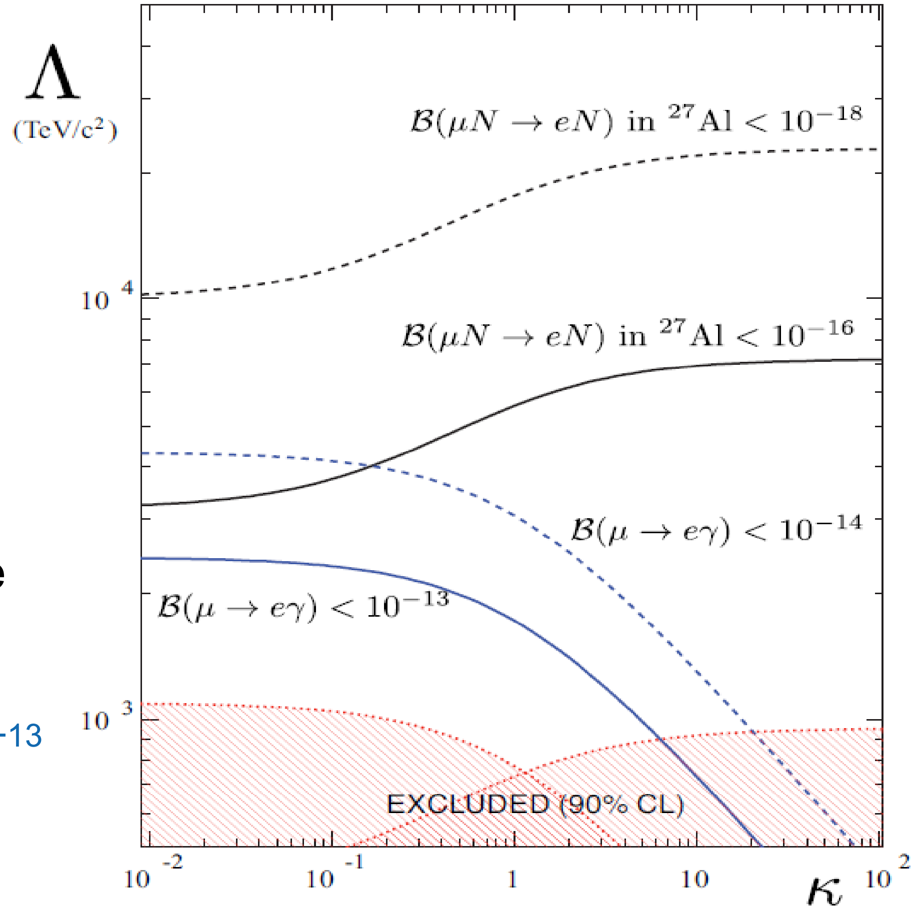
5) Dipartimento di Fisica, dell'Universitá "Sapienza", Piazzale A. Moro, Rome I-00185, Italy

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($\mu^+\to e^+\gamma$)≈$10^{-(14\text{-}15)}$)

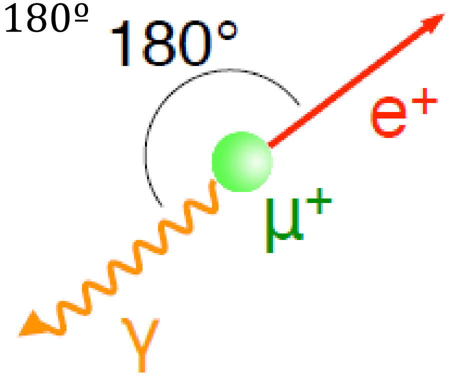
In this context the MEG experiment represents the state of the art in the search for the CLFV $\mu^+\to e^+\gamma$ decay

Final results exploiting the full statistics collected during the 2009-2013 data taking period at Paul Scherrer Institute (PSI) BR($\mu^+\to e^+\gamma$) < $4.2\cdot10^{-13}$ (90% C.L.) world best upper limit

Mu e gamma event kinematic

Signal

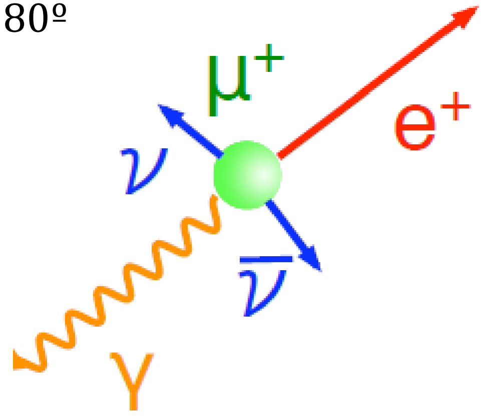
$t_e = t_\gamma$
$E_e = E_\gamma = 52.8$ MeV
$\theta_{e\gamma} = 180º$



Background

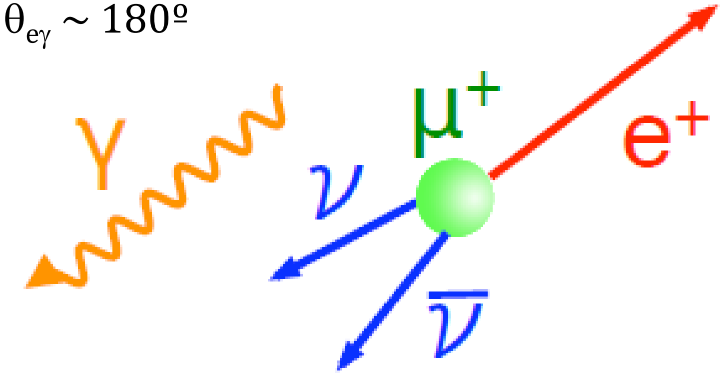
RMD

$t_e = t_\gamma$
$E_e = E_\gamma < 52.8$ 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**:

$$N_{sig} = \Gamma_\mu \cdot T \cdot \Omega \cdot BR \cdot \varepsilon_\gamma \cdot \varepsilon_{e^+} \cdot \varepsilon_s$$

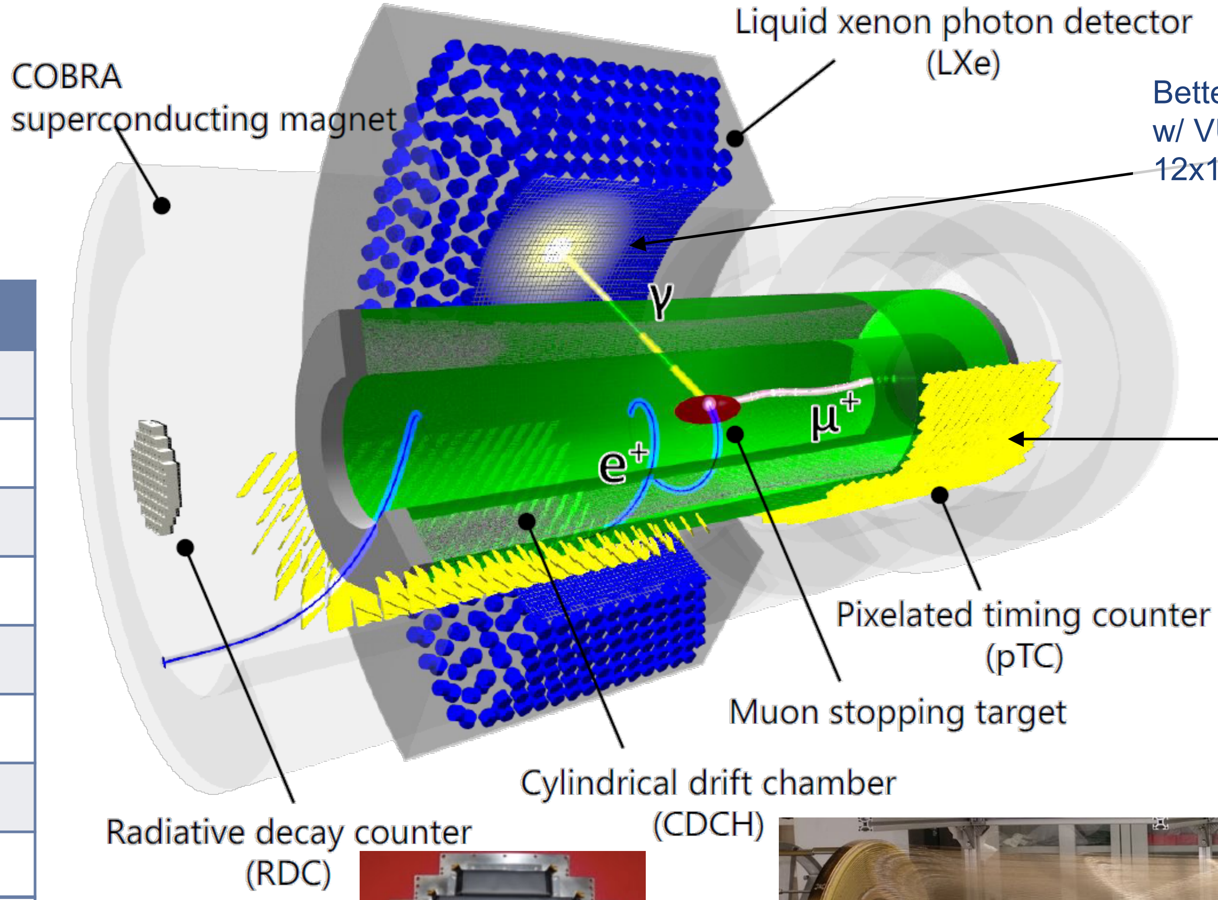
$$N_{acc} \propto \Gamma_\mu^2 \cdot \Delta E_\gamma^2 \cdot \Delta p_{e^+} \cdot \Delta\Theta_{e^+\gamma}^2 \cdot \Delta t_{e^+\gamma} \cdot T$$

$$N_{RMB} \sim 0.1 \cdot N_{acc}$$

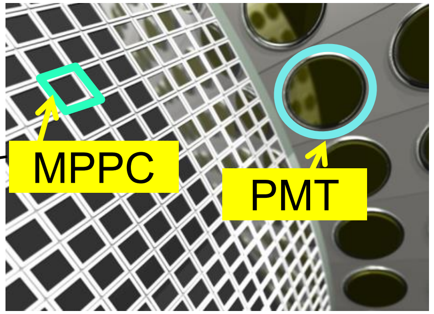
The state of the art: MEG II Experiment

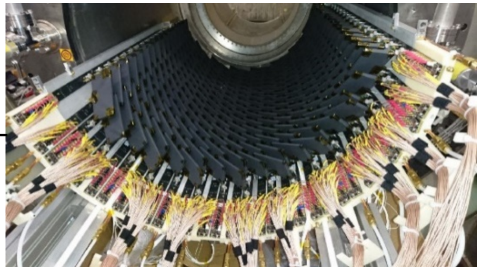
Target Sensitivity: $6 \cdot 10^{-14}$
in 3 years of running

	expected
Δp_{e+} (keV)	110
$\Delta\theta_{e+}$ / $\Delta\varphi_{e+}$ (mrad)	5.3 / 3.7
ΔZ_{e+}/ΔY_{e+} (mm) *core*	1.6 / 0.7
ΔE_γ (MeV)	~1.1/1.0
Δu_γ, Δv_γ, Δw_γ (mm)	2.6 / 2.2 / 5
$\Delta t_{e+\gamma}$ (ps)	84
Ω (%)	11
ε_γ	69
ε_{e+} (trac.×matc.)	70



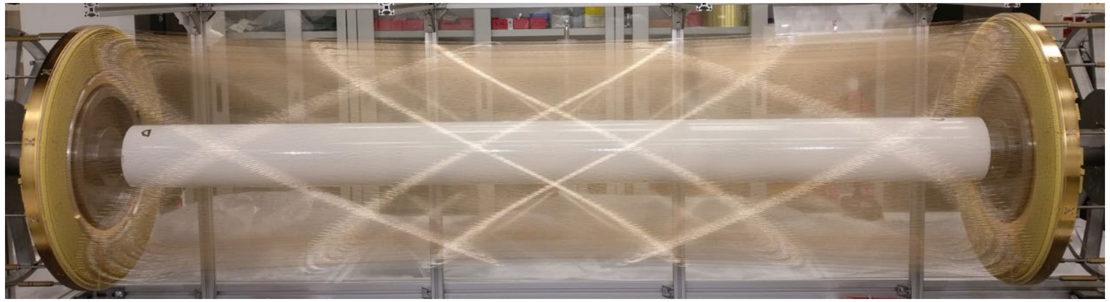
Better uniformity w/ VUV-sensitive $12 \times 12 mm^2$ SiPM





Full stereo, with high granularity and high transparency ($\sim 1.6 \cdot 10^{-3}$ X_0) Drift Chamber (improve tracking performance and minimizing the background sources)

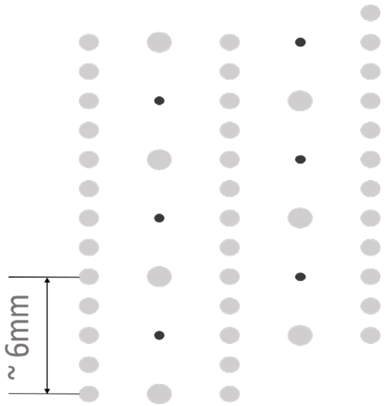
LYSO crystals + plastic scintillators (Further reduction of radiative BG)



Strategy to improve the sensitivity by at least one order of magnitude

Theoretical speculations, driven by the formulas:

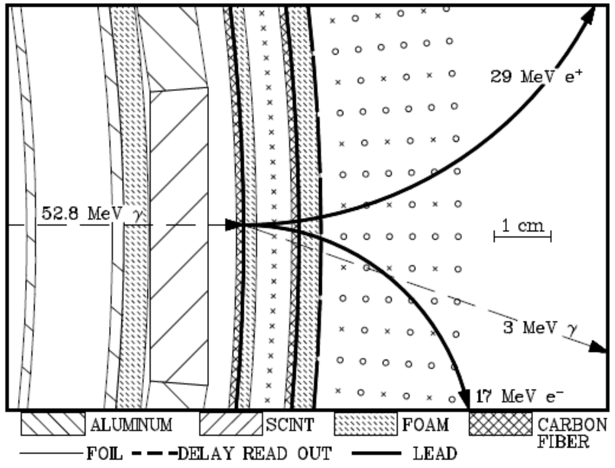
- The beam rate ($\boldsymbol{\Gamma}_{\mu}$) has to be increased but the detector resolutions limits the available max usable beam rate in order to keep a reasonable signal to background ratio;
- $\boldsymbol{N_{acc}}$ depends on the $\boldsymbol{\Delta E_{\gamma}^{2}} \cdot \boldsymbol{\Delta \Theta_{e^{+}\gamma}^{2}}$ $\Rightarrow$ improvements on the photon detection have more relevant effects on the sensitivity limitations
- The expected MEG II positron momentum resolution should be adequate, but the rate capability of its innermost layers needs to be improved at level ~MHz/cm^2 for $\boldsymbol{\Gamma}_{\mu}$ up to 10^{10} μ/s. Fluxes ≳200 kHz/cm^2 could be sustained by a drift chamber, similar to the MEG II one, but with shorter cells arranged orthogonally to the beam;
- A light Si based or MPGD detector could be used in the hottest part close to the target but the MS effects has to be evaluated carefully.



How to improve the photon detection and resolutions

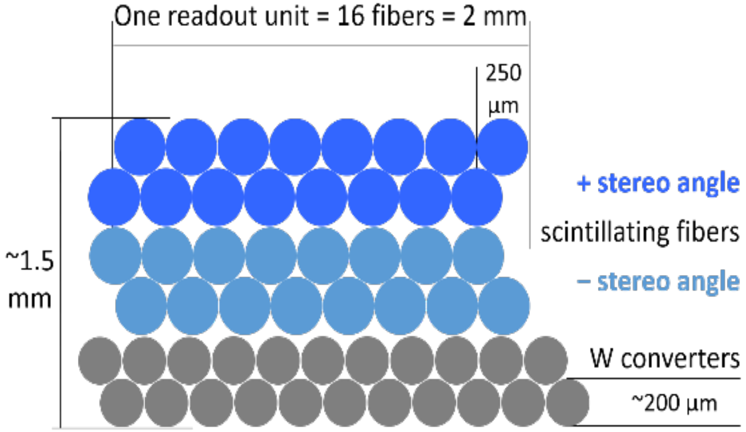
An alternative way to identify and measure the 52.8 MeV photon with improved energy and angular resolutions relies on a precise reconstruction of the electron and positron tracks from its conversion.

- This approach was used by the MEGA experiment using a lead foil of 0.045 X_0 equivalent thickness preceded by a scintillator layer for timing and followed by 4 layers of drift cells to measure the emerging charged tracks. (ΔE_γ ~1.7 MeV, $\Delta\theta_\gamma$ ~ 180 mrad, $\Delta t_{e+\gamma}$ ~ 1.6 ns);



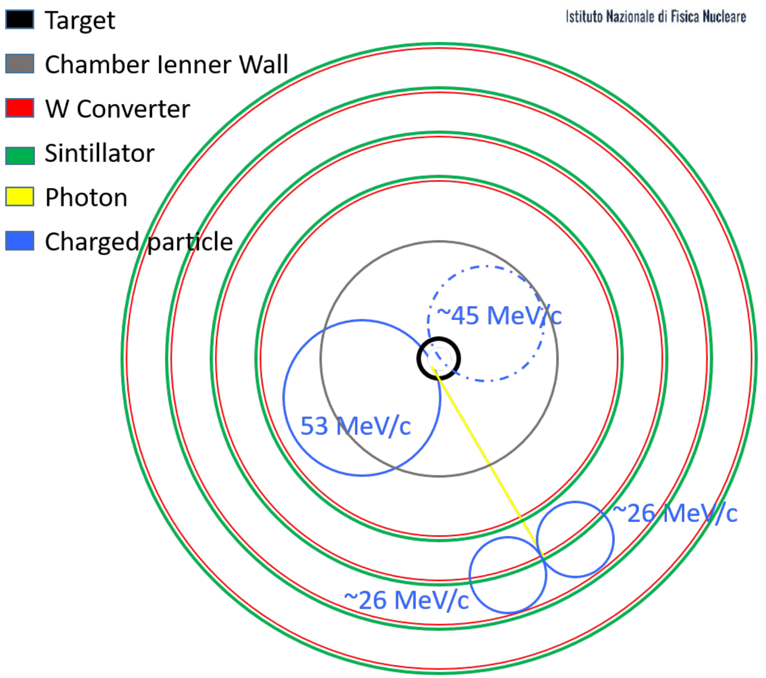
- by using tungsten (W) wires to create a thin, ~0.1 X/X_0, conversion layer followed by a layer of scintillating fibres, it should be possible to reach (ΔE_γ ~0.3 keV, $\Delta\theta_\gamma$ ~ 8 mrad, $\Delta t_{e+\gamma}$ ~ 50 ps);

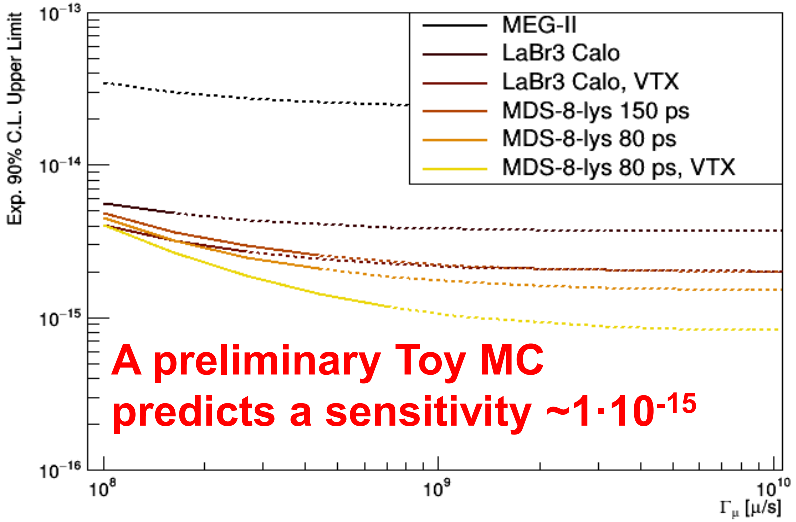
- a possible construction strategy could be to insert the radiator shells in the drift chamber volume, without creating dead regions, by placing bundles of W wires at the same stereo angle as the drift chamber layers.



A possible new experiment

- A central low mass tracker system (a drift chamber and, eventually, a vertex detector) surrounds the stopping target.
- The inner and outer radii of the tracker are chosen to cut off all the positron tracks with momenta <45 MeV/c, and fully contain those with momenta of 52.8 MeV/c.
- The tracker is surrounded by a sequence of co-axial cylindrical photon spectrometers (as described before).
- A sufficient number of alternating sign stereo layers (about 12-16) of 1cm square drift cells can be located between two radiator shells in order to efficiently and precisely reconstruct the looping electron-positron pairs.
- A geometrical acceptance of Ω ~ 90% is feasible with a ε_γ > 50%
- The accidental background could be relatively reduced due to:
  - measurements of the photon vertex and direction;
  - reduction of the photon overlap contribution





Root to contributed paper

Current status:

- A preliminary geant4 simulation for the tracking photon spectrometer is ready
- A preliminary tool to evaluate the expected sensitivity is ready

Plans:

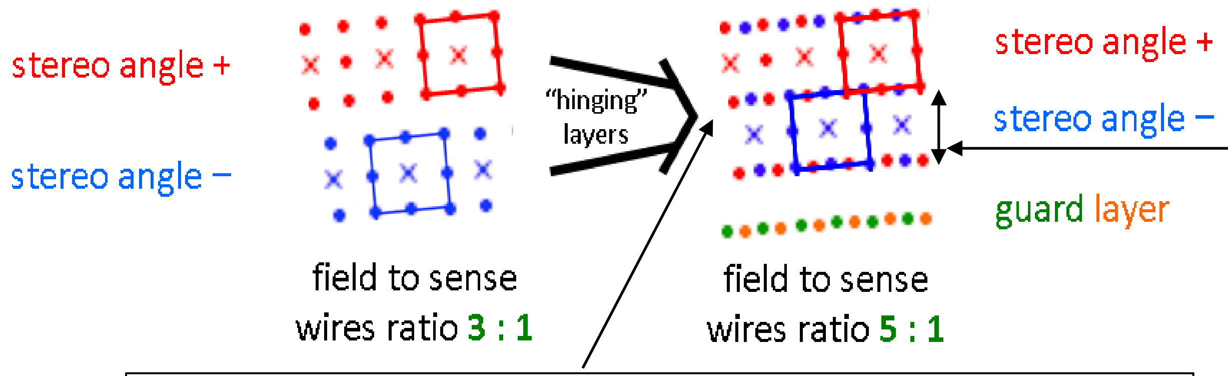
- Implement a constrained reconstruction of the e^+-e^- pairs and study the expected resolutions on photon (Dic. 20)
- Implement a full detector (simplified/fast) simulation (Jan. 21)
- Study and compare the possible beam configurations usable (Feb. 21)
- Produce the needed statistics (Mar. 21)
- Improve the tools to evaluate the expected sensitivity (Apr. 21)
- Submit the contribution paper (Jul. 21)

Summary

- Preliminary studies show that an experiment for the $\mu^+ \rightarrow e^+\gamma$ with a sensitivity of ~10^{-15} can be envisioned;
- The main construction peculiarities don't seem to be a showstopper;
- Significant work is needed and is ongoing to have the right tools to prove it;
- By exploiting the potential of the PIP II at Fermilab, as well as increasing the accidental background rejection and optimizing the photon reconstruction strategy, branching ratios down to $O(10^{-16})$ could be reach;
- More collaborators are welcome to join it;
- We hope that the SnowMass process will see the important physics case for building an experiment for the mu e gamma search at 10^{-16} level and promote the R&D to develop the needed technologies.

backup

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**

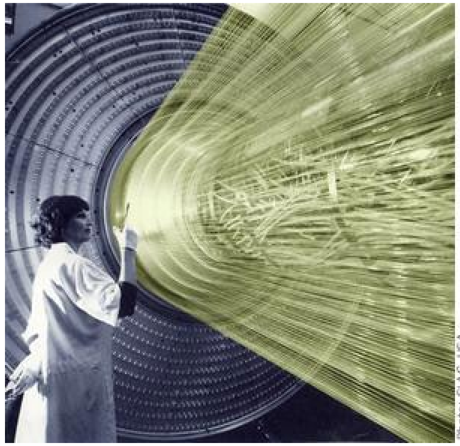
sense wires: 20 μm diameter W(Au) => 1728 wires
field wires: 40 μm diameter Al(Ag) => 7680 wires
f. and g. wires: 50 μm diameter Al(Ag) => 2496 wires
11904 wires in total

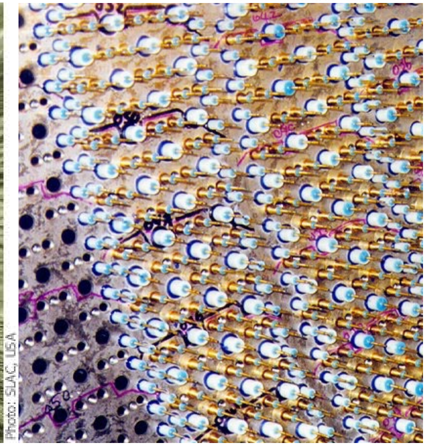
High wire densities, anyway, require complex and time consuming assembly procedures and need novel approaches to a feed-through-less wiring

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.

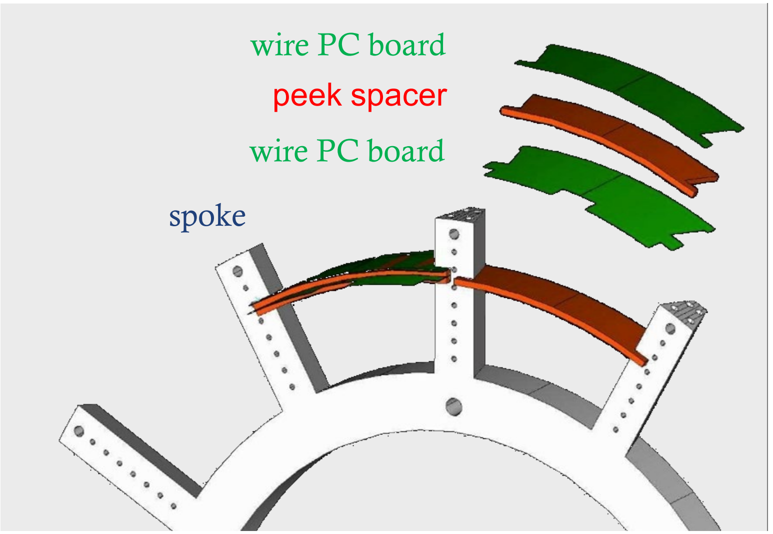
(~ 12 wires/cm²) can't be built with feedthrough





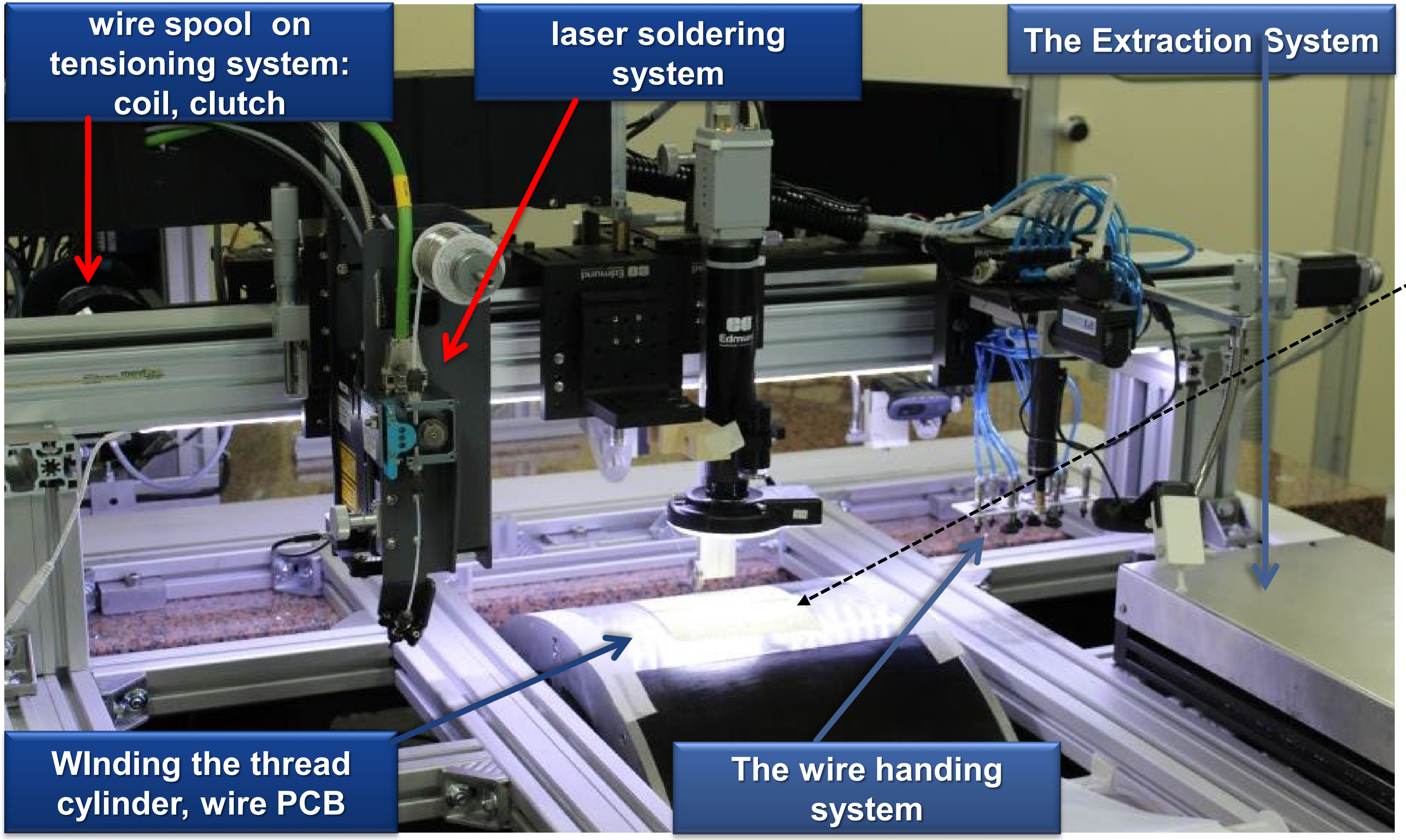
The solution found for MEG II:

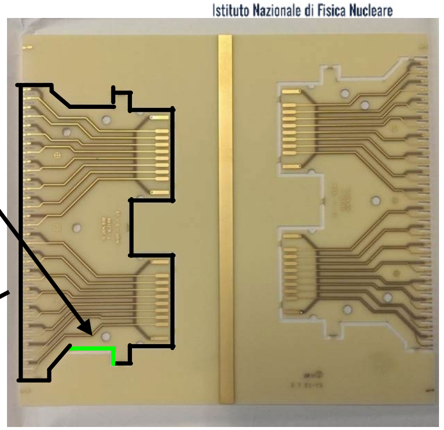
- end-plates numerically machined from solid Aluminum (mechanical support only);
- Field, Sense and Guard wires placed azimuthally by Wiring Robot with better than one wire diameter accuracy;
- wire PC board layers (green) radially spaced by numerically machined peek spacers (red) (accuracy < 20 μm);
- 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:

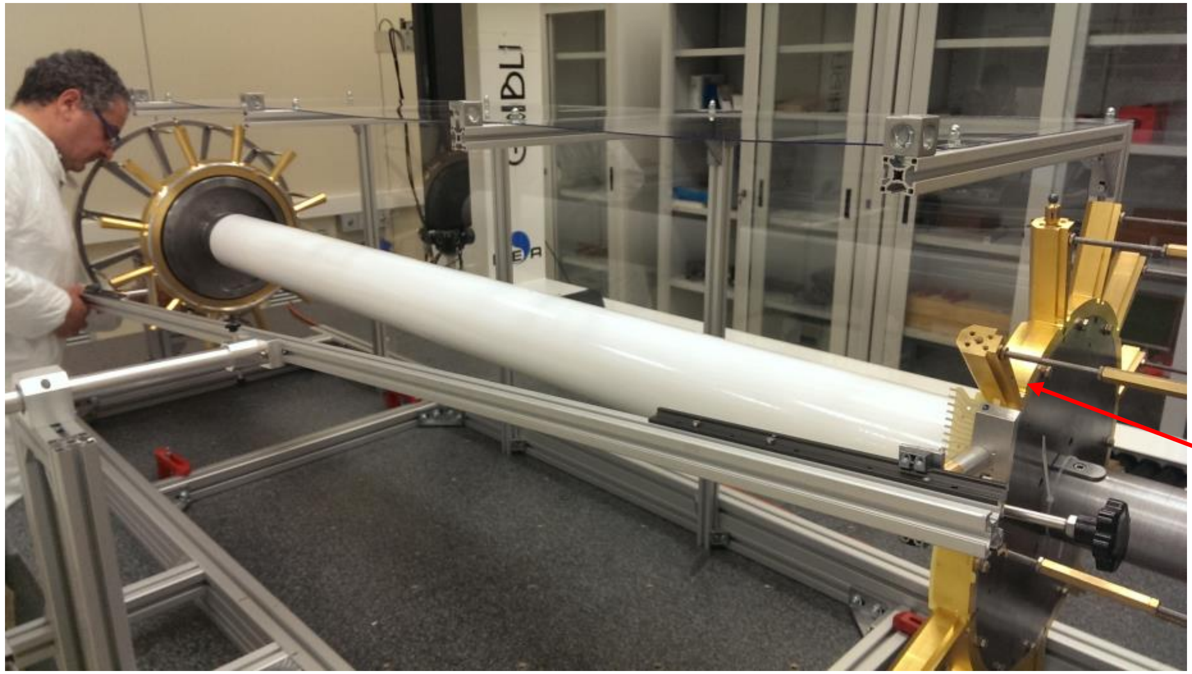
- the wiring of a multiwire layer made of 32 parallel wires;
- settable wire tension (±0.05g);
- 20μm of accuracy on wire position;
- anchor the wires using a contact-less technique

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