First results of the MEGII experiment at PSI

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Pisa, 20 October 2023

Outline

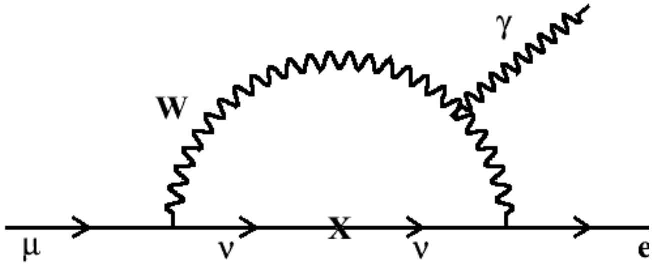
- Charged Lepton Flavour Violation with muons;
- The $\mu^+ \to e^+\gamma$ channel;
- Summary of MEG results;
- MEGII vs MEG;
- First results of MEGII;
- Other physics items;
- Conclusions and perspectives.

Charged Lepton Flavour Violation 1)

- In the **SM of electroweak interactions** leptons are grouped in doublets and there is **no space for transitions where lepton flavour is not conserved**.
- However, **lepton flavour is experimentally violated** in neutral sector (**neutrino oscillations**) ⇒ needed to **extend the standard model by including neutrino masses and coupling between flavours**.
- **CLFV** indicates **non conservation of lepton flavour** in processes involving **charged leptons**.

Charged Lepton Flavour Violation 2)

Including neutrino masses and oscillations in SM: **Experimentally not measurable !**



$$\Gamma(\mu \to e\gamma) \approx \underbrace{\frac{G_F^2 m_\mu^5}{192\pi^3}}_{\mu-\text{decay}} \underbrace{\left(\frac{\alpha}{2\pi}\right)}_{\gamma-\text{vertex}} \underbrace{\sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2}{M_W^2}\right)}_{\nu-\text{oscillation}}$$

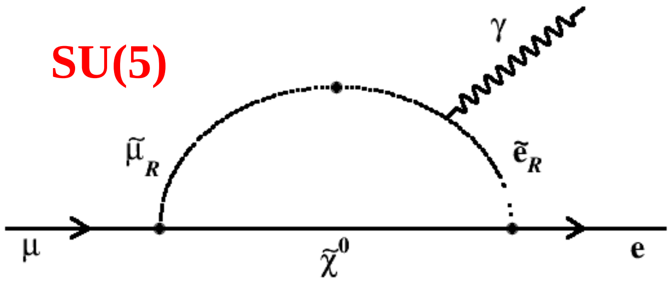
$$\approx \frac{G_F^2 m_\mu^5}{192\pi^3}\,\frac{3\alpha}{32\pi}\left(\frac{\Delta m_{23}^2 s_{13}c_{13}s_{23}}{M_W^2}\right)^2 \approx 10^{-54}$$

S.T. Petcov, Sov.J. Nucl. Phys. 25 (1977) 340
W.J. Marciano et al.. Lett. B 67 (1977) 303
B.W. Lee, et al., Phys. ReV. Lett. 38 (1977) 937
B.W. Lee et al., Phys. Rev. D 16 (1977) 1444

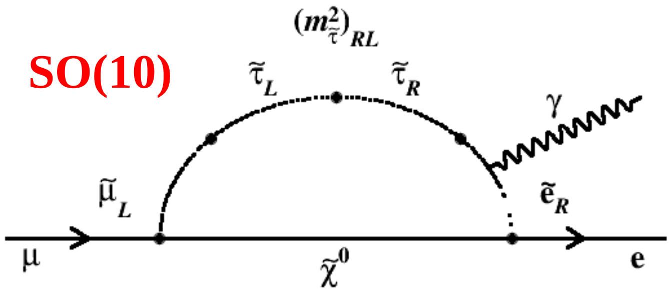
Huge rate enhancement in SM extensions (SUSY-GUT, SUGra) ⇒ **predicted rates experimentally accessible !**

(Barbieri, Masiero, Ellis, Hisano ..)

SU(5)



SO(10)



$$\approx 10^{-5}\,\frac{\Delta m^2_{\tilde e \tilde \mu}}{\bar m^2_{\tilde \ell}}\left(\frac{100\ \text{GeV}}{m_{\text{SUSY}}}\right)^4 \tan^2\beta \quad \approx 10^{-(12\div 14)}$$

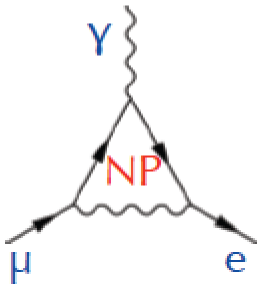
No SM background ⇒ Observation of CLFV clear evidence for physics beyond SM !!!

Charged Lepton Flavour Violation 3)

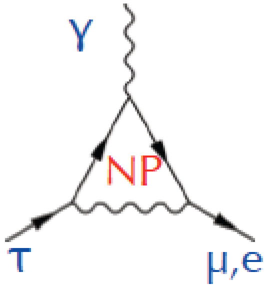
Several CLFV processes, sensitive to **New Physics** through

"new" lepton-lepton coupling $y_{ij}\bar{\ell}_i F^{\mu\nu} \ell_j \sigma_{\mu\nu}$

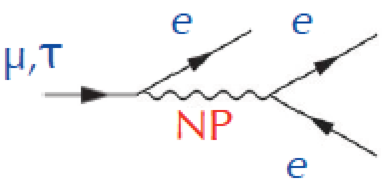
+ K, B, Z, H anomalous decays, lepton universality violation …



$\mu \to e\gamma$

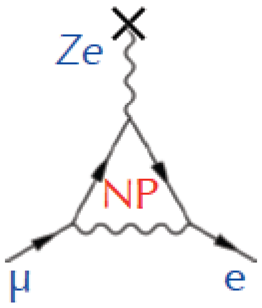


$\tau \to \mu\gamma$
$\tau \to e\gamma$



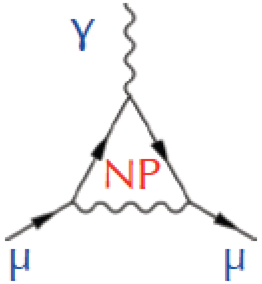
$\mu \to eee$

μ,τ anomalous decays



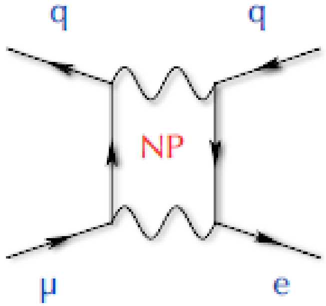
$\mu^- \mathcal{N} \to e^- \mathcal{N}$

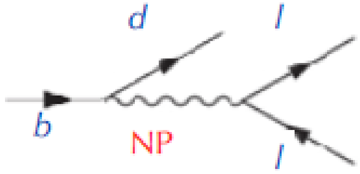
μ → e conversion



$(g-2)_\mu$

Anomalous magnetic moment





$B \to \ell\bar{\ell}'$
$B \to \ell\bar{\ell}' X_s$

Why use muons ?

Muons are **very sensitive probes** to study **Charged Lepton Flavour Violation**:

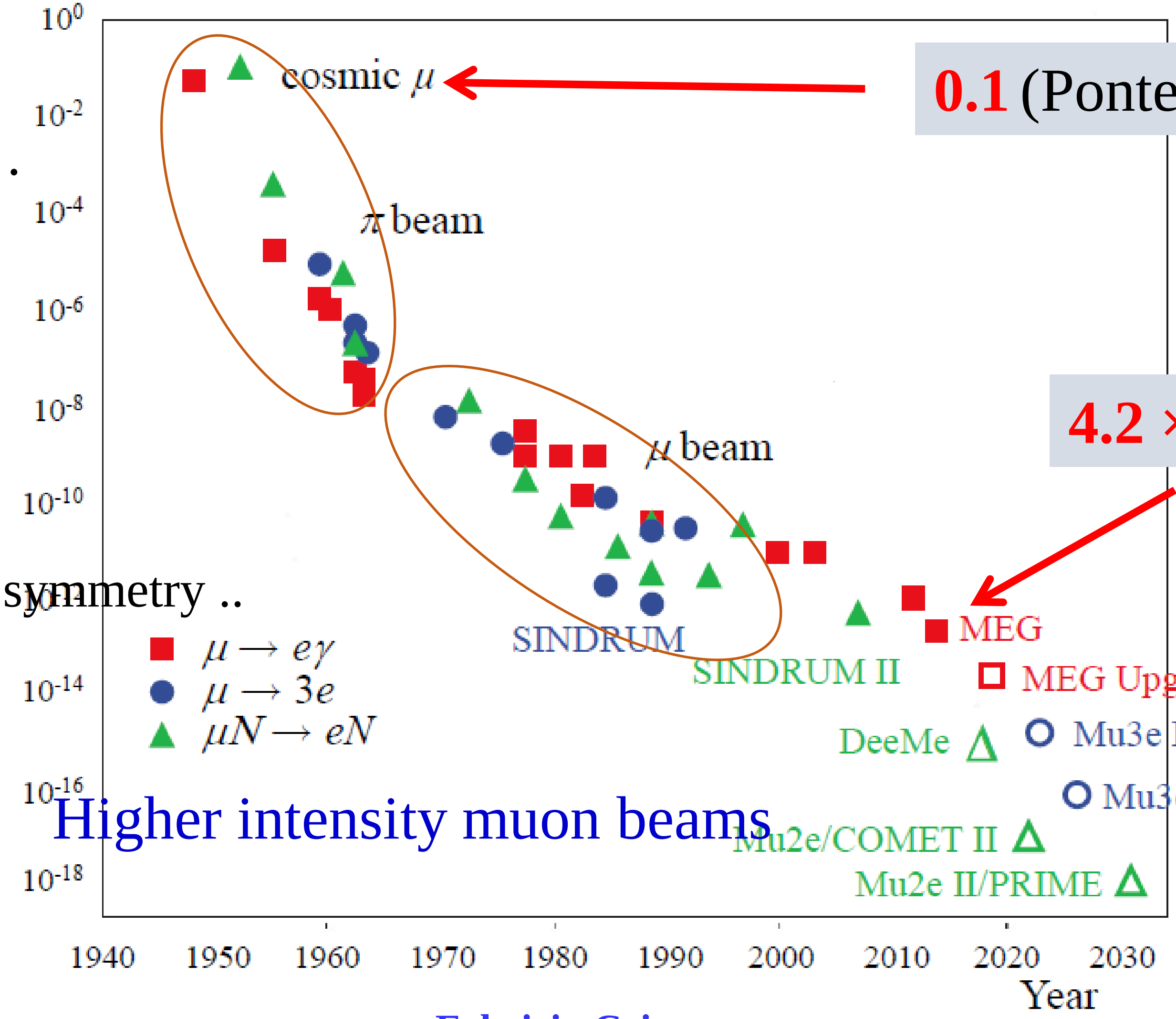
- intense muon beams can be obtained at meson factories and proton accelerators (PSI, J-PARC, Fermilab ...) ⇒ **H**igh **I**ntensity **F**rontier;
- muon lifetime is long (2.2 μs);
- final states are very simple and can be precisely measured.

A 75 year history

Family structure,
two different neutrinos …

Lepton doublets,
leptonic number symmetry ..

Filled symbols: past or present
Open symbols: future



0.1 (Pontecorvo & Hincks 1947)

4.2×10^{-13} (MEG 2016)

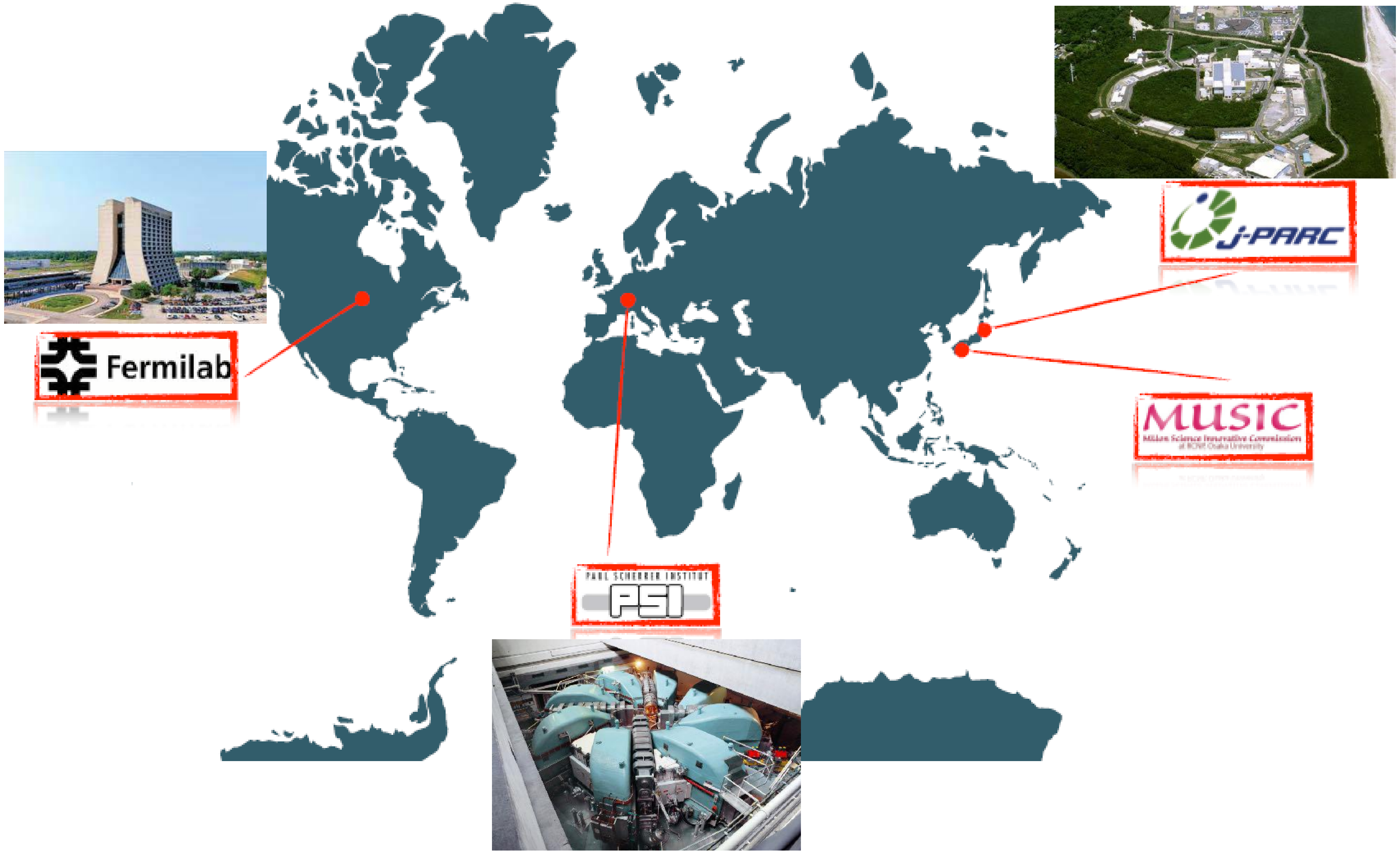
Gained **twelve orders of magnitude**

MEGII

New Physics ?

Higher intensity muon beams

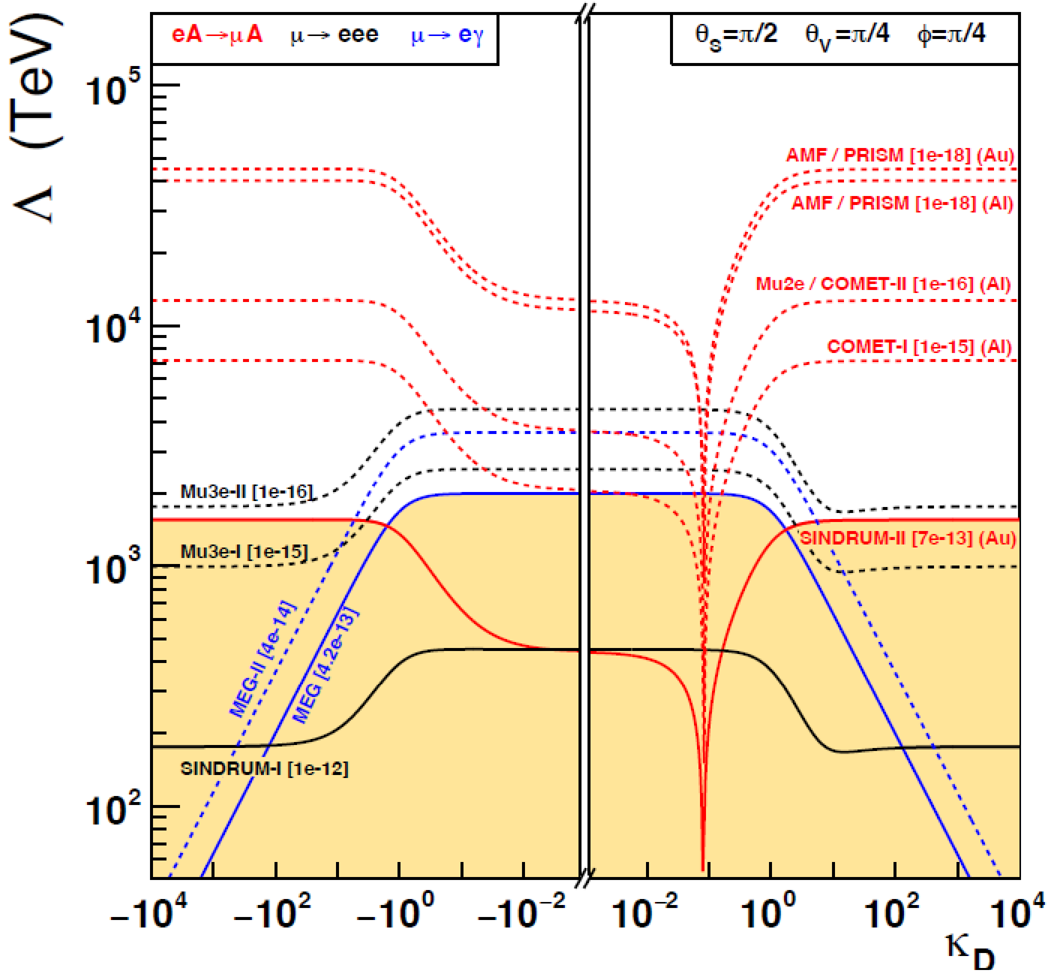
Multiple searches and complementarity 1)



The muon world:

PSI (MEGII, Mu3e)
Fermilab (Mu2e)
J-Parc (COMET/PRISM)
RCNP (MuSIC)

Multiple searches and complementarity 2)



Effective lagrangian is the
sum of a dipole term and a contact term
(4 quarks for $\mu N \rightarrow eN$, four leptons for $\mu \rightarrow 3e$)

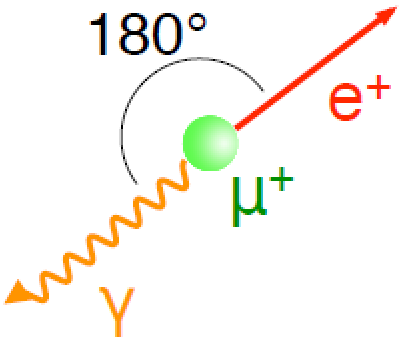
Λ = New Physics Scale
k_D = dipole vs contact relative strength

Dipole dominates for $k_D \ll 1$, contact for $k_D \gg 1$

S.Davidson and B.Echenard, Eur. Phys. J. C **82** (2022) 9, 836

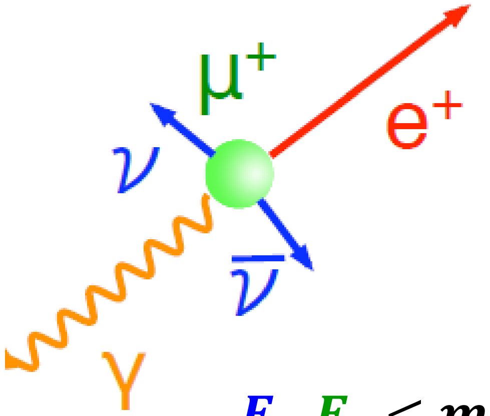
The $\mu^+ \rightarrow e^+\gamma$ decay

Signal



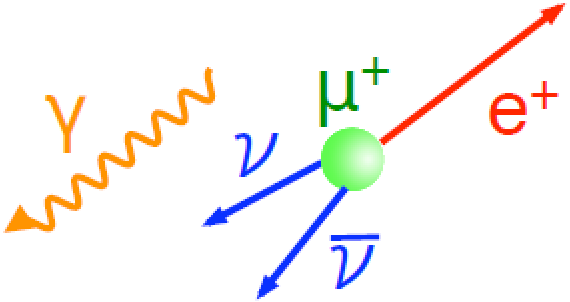
$E_e = E_\gamma = 52.8\ \mathrm{MeV} = m_\mu/2$
$T_e = T_\gamma$

Radiative muon decay (RMD)



$E_e, E_\gamma < m_\mu/2$
$T_e = T_\gamma$

Accidental Background (ACC)



e^+ from Michel (usual) μ^+ decay,
γ from RMD, e^+e^- annihilation ..
Random $\Delta T, \Delta\Theta, E_e, E_\gamma < m_\mu/2$

Signal, RMD ∝ R_μ, ACC ∝ $R_\mu^{\ 2}$ ⇒

- ➢ **ACC is dominant**;
- ➢ needed continuous beam and accurate choice of R_μ;
- ➢ needed high precision experiments.

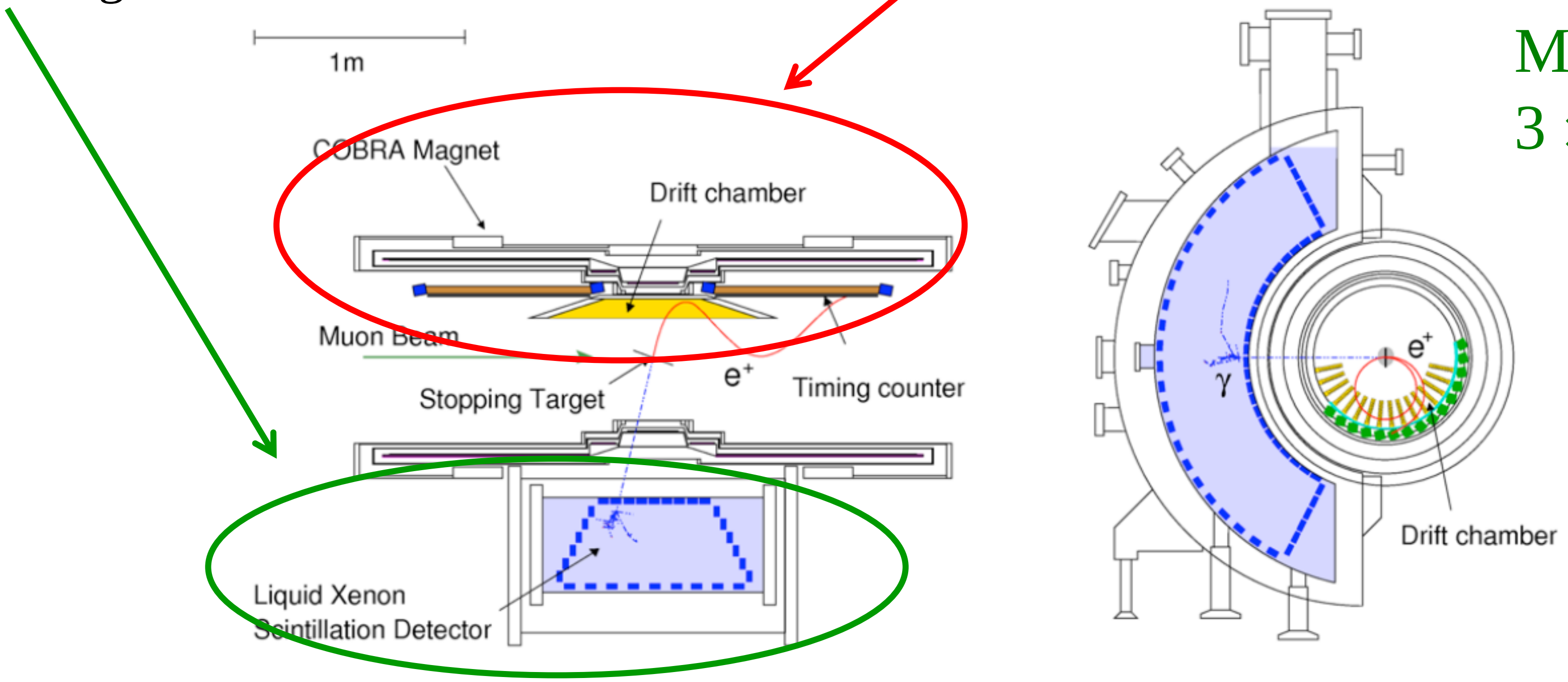
$$N_{\mathrm{bkg}} \propto R_\mu^2 \Delta T_{e\gamma} \Delta E_e \Delta E_\gamma^2 \Delta \Theta_{e\gamma}^2$$

The MEG experiment @PSI

LXe photon detector: measurement of photon energy, impact point and timing.

Positron spectrometer: measurement of positron momentum vector and timing.

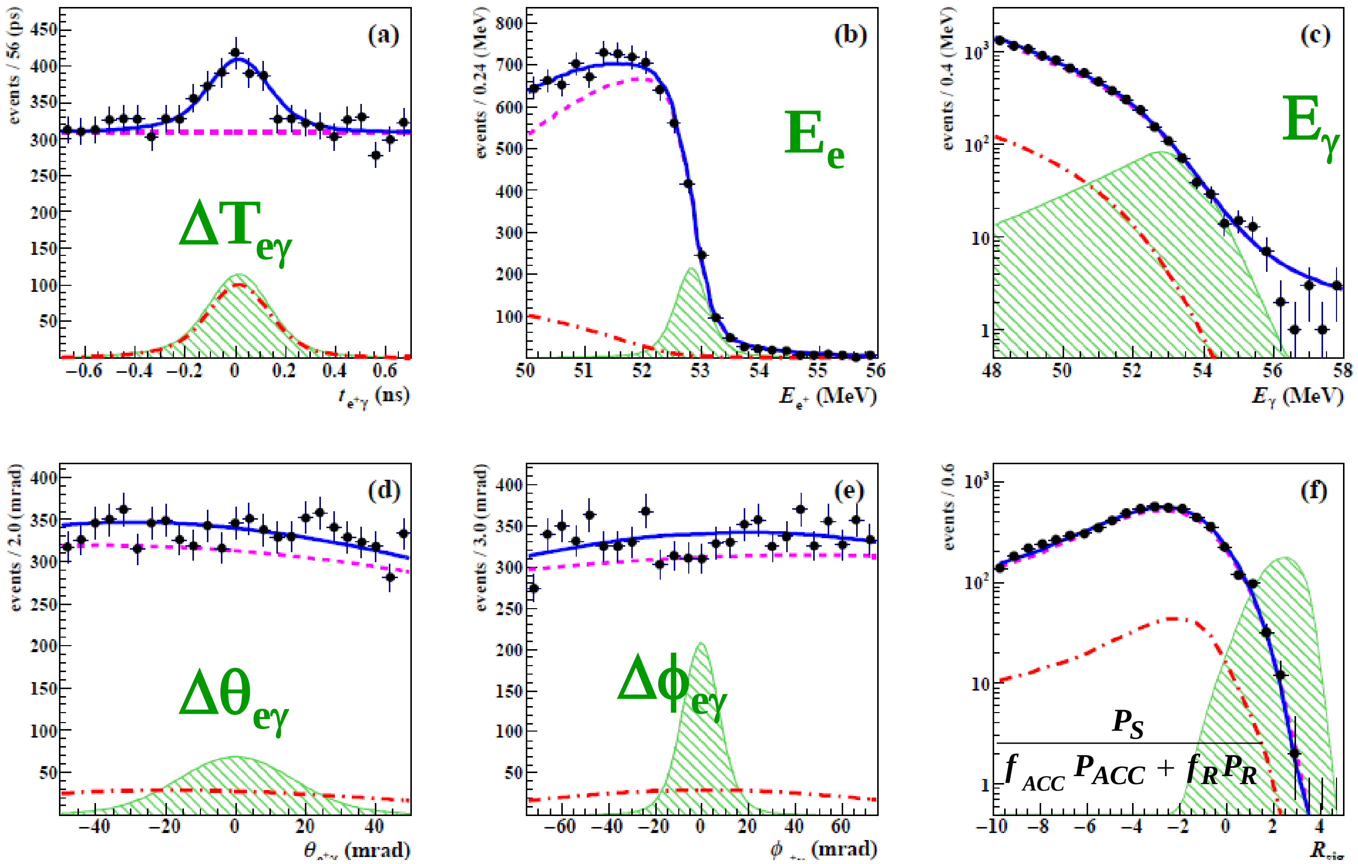
Muon beam intensity 3×10^7 stopped μ^+/s



MEG Coll., Eur. Phys. J. C **73** (2013) 2365

MEG Final result

Likelihood fit on events in **Analysis Window** within Blinding Box.
Total sample 7.5×10^{14} muons stopped on target.



MAGENTA: ACC fitted 7684 ± 103
RED: RMD fitted 663 ± 59
BLU: total
GREEN: Signal UL × 100

Best fit:
BR $(\mu^+ \to e^+\gamma) = -2.2 \times 10^{-13}$ (negative) ⇒

$$\mathbf{BR}(\mu^+ \to e^+\gamma) \leq 4.2 \times 10^{-13}$$

@ 90% CL (30 times better than previous experiments)

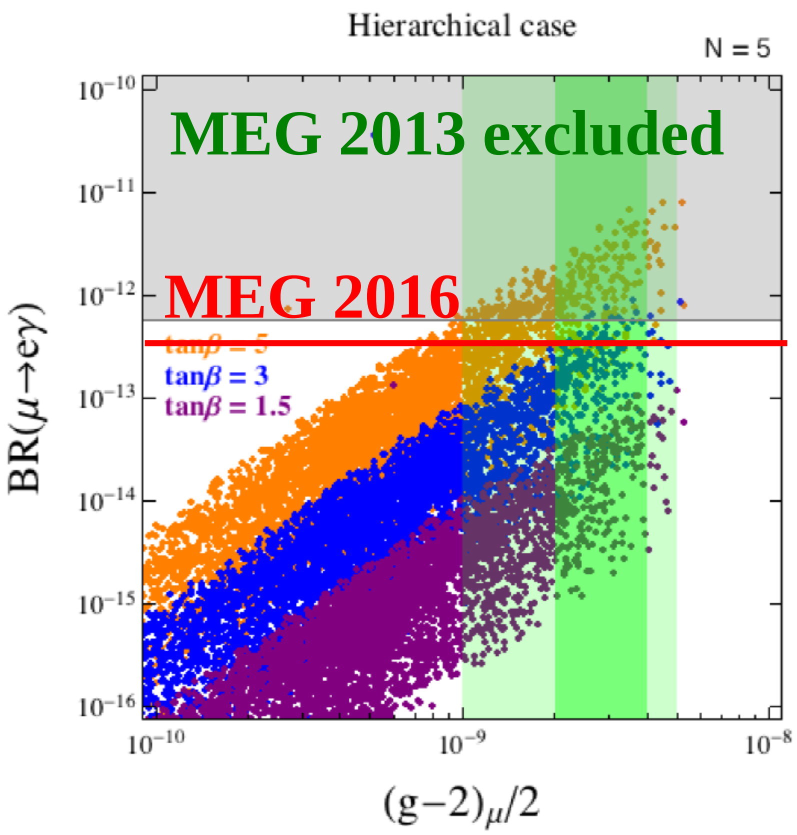
Sensitivity 5.3×10^{-13}

MEG Coll., Eur. Phys. J. C **76**(8) (2016) 434

Impact of MEG results

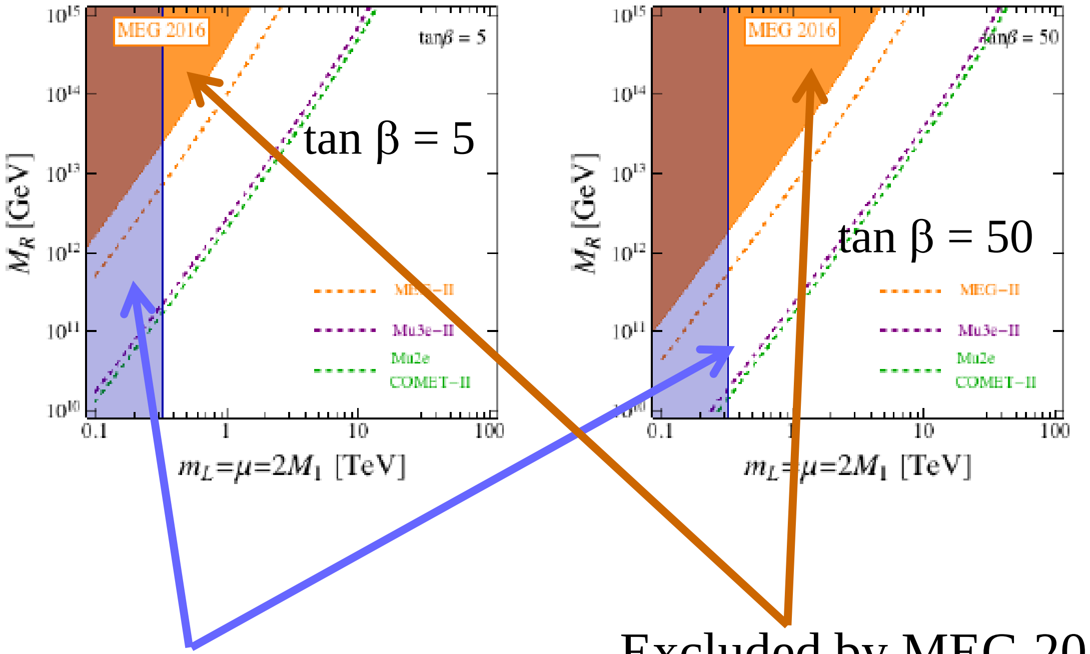
L. Calibbi et al.,
Eur. Phys. J. C **74** (2014) 1-20

μ → eγ vs (g-2)$_\mu$



L. Calibbi & G. Signorelli, Riv.
Nuovo Cim., **41** (2018) 71 and references therein

μ → eγ vs LHC

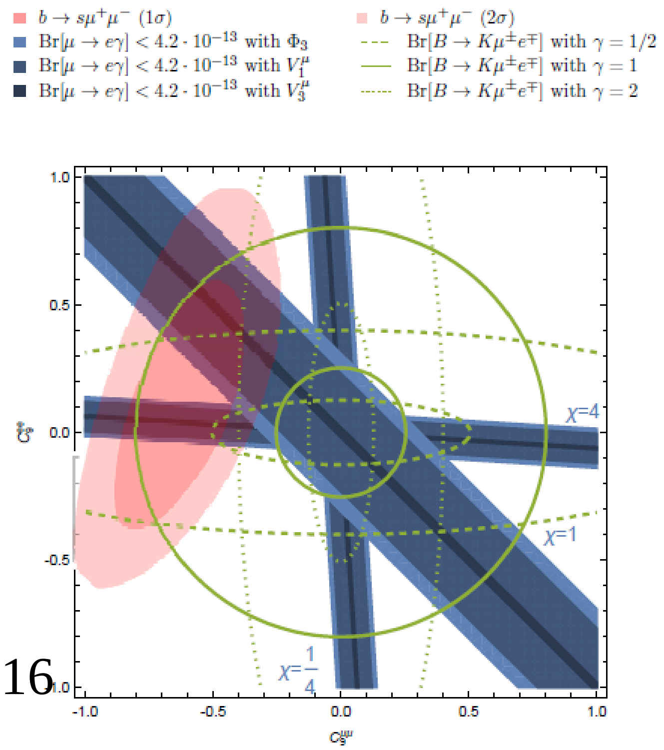


Excluded by direct
slepton searches at LHC

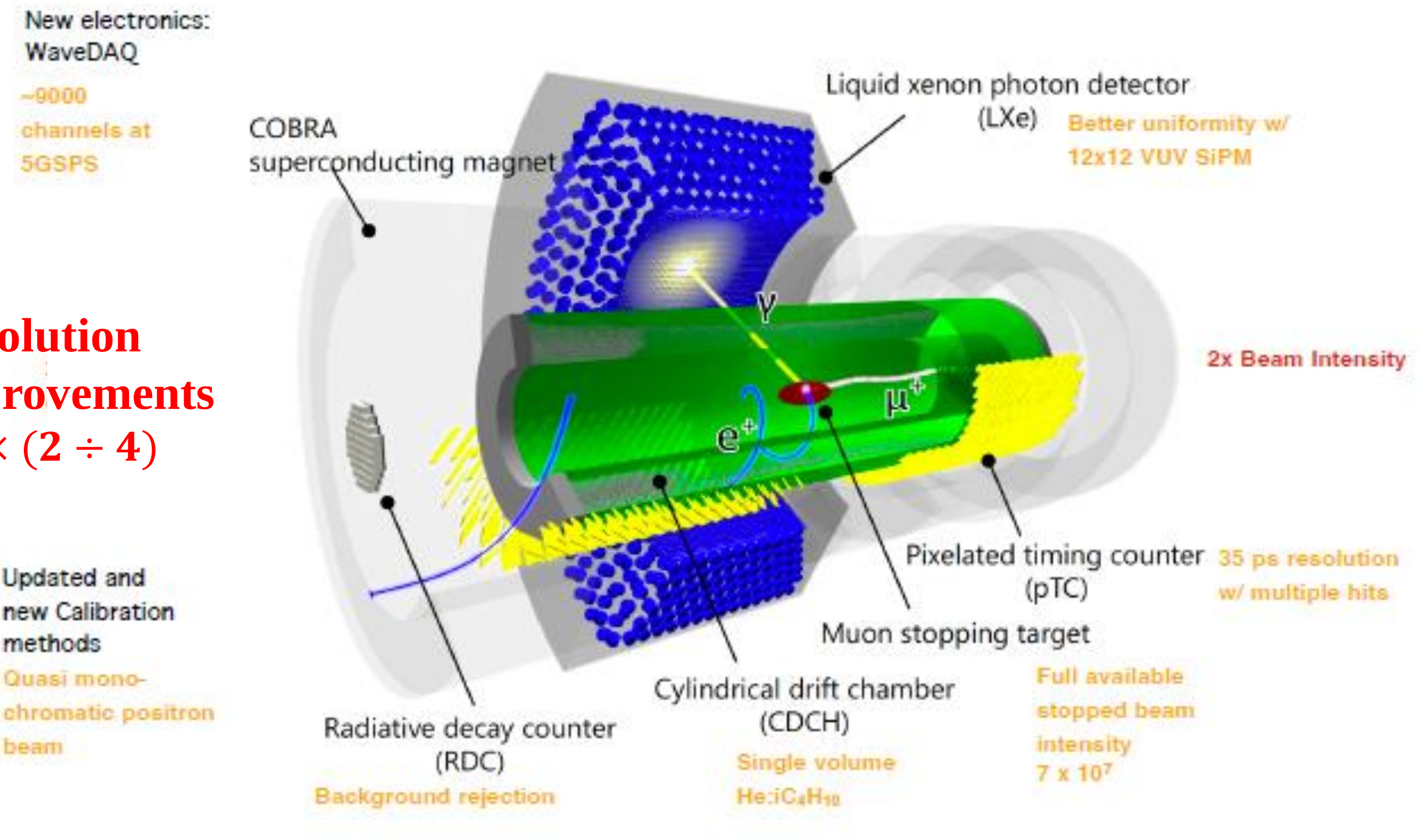
Excluded by MEG 2016

A. Crivellin et al., Phys.
Rev. D **97** (2018) 015019

μ → eγ vs B → Kμe



The MEGII experiment



Resolution improvements
$\times\,(2 \div 4)$

MEGII Collaboration, EPJC **78**(5) (2018) 380

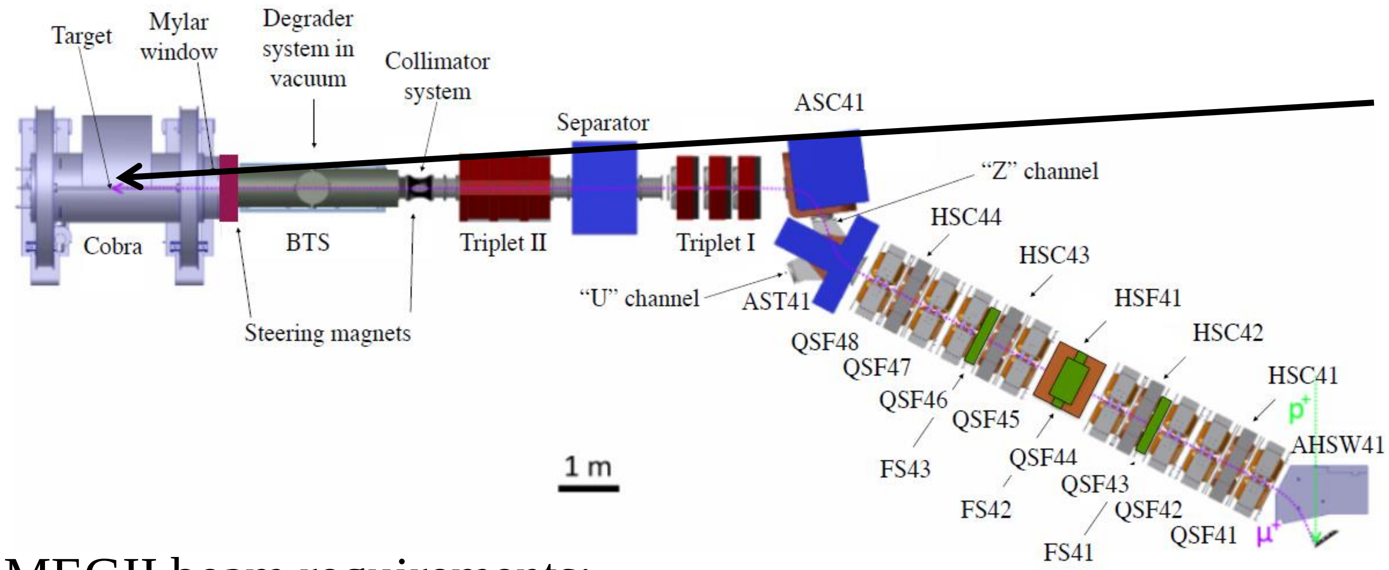
Goal:
Improve the MEG sensitivity on
$$BR(\mu^+ \rightarrow e^+\gamma)$$
by one order of magnitude:

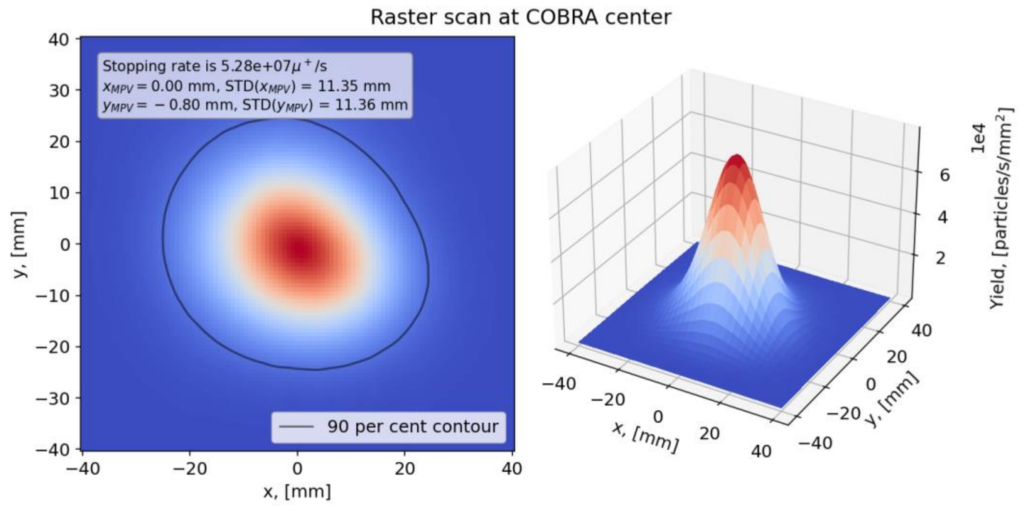
MEG	MEGII
5.3×10^{-13}	6×10^{-14}

Handles:
- higher detector resolutions;
- faster and higher bandwidth trigger & DAQ system;
- higher beam intensity.

Proposal in 2013; works for detector upgrades started during final analysis of MEG data.

MEGII: beam line





$\sigma_x \approx \sigma_y \approx 11$ mm @$5 \times 10^7 \mu/s$

Beam profile at COBRA center (target location)

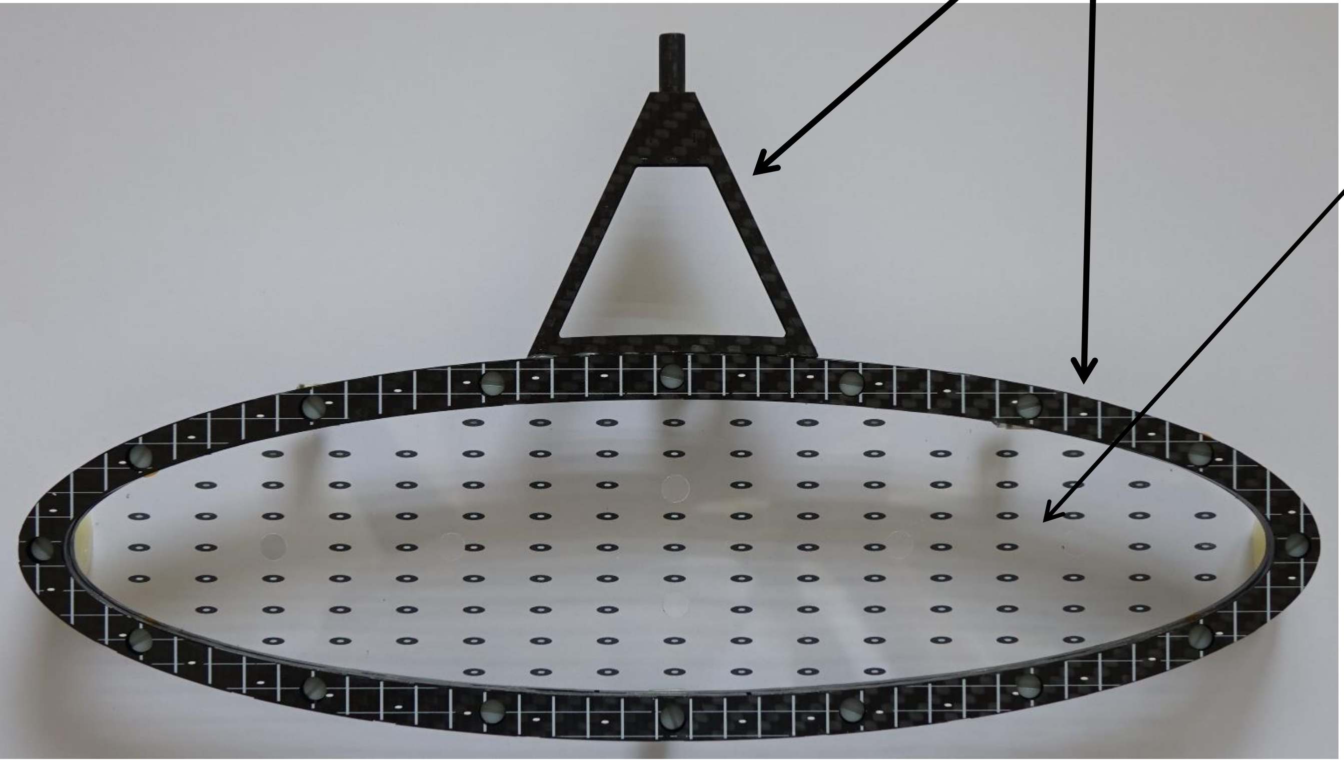
MEGII beam requirements:

- **Intensity O(10^8 stopped muons/s), low momentum $p = 28$ MeV$/c$** ("surface muons")
- **Small straggling and good identification of the decay region**

MEG II beam settings released since 2019. More then 10^8 μ/s can be transported into Cobra (**up to 2.32×10^8@2.2 mA** during the 2023 beam time at the collimator).

MEGII: target

Mechanical and suspension structure (carbon fiber frames)



Target foil:

- plastic scintillator (BC400);
- elliptical shape $(270 \times 66)\ \mathrm{mm}^2$;
- average thickness (174 ± 20) µm;
- slant angle wrt beam (75.0 ± 0.1^{o})

(optimization of target stopping power and positron path within target).

Six white holes and a pattern of dots (photographed by a camera) to continuously monitor the target shape and position.

N.B. Target deformations and position uncertainty were the main systematic effects in MEG.

MEGII: the COBRA magnet

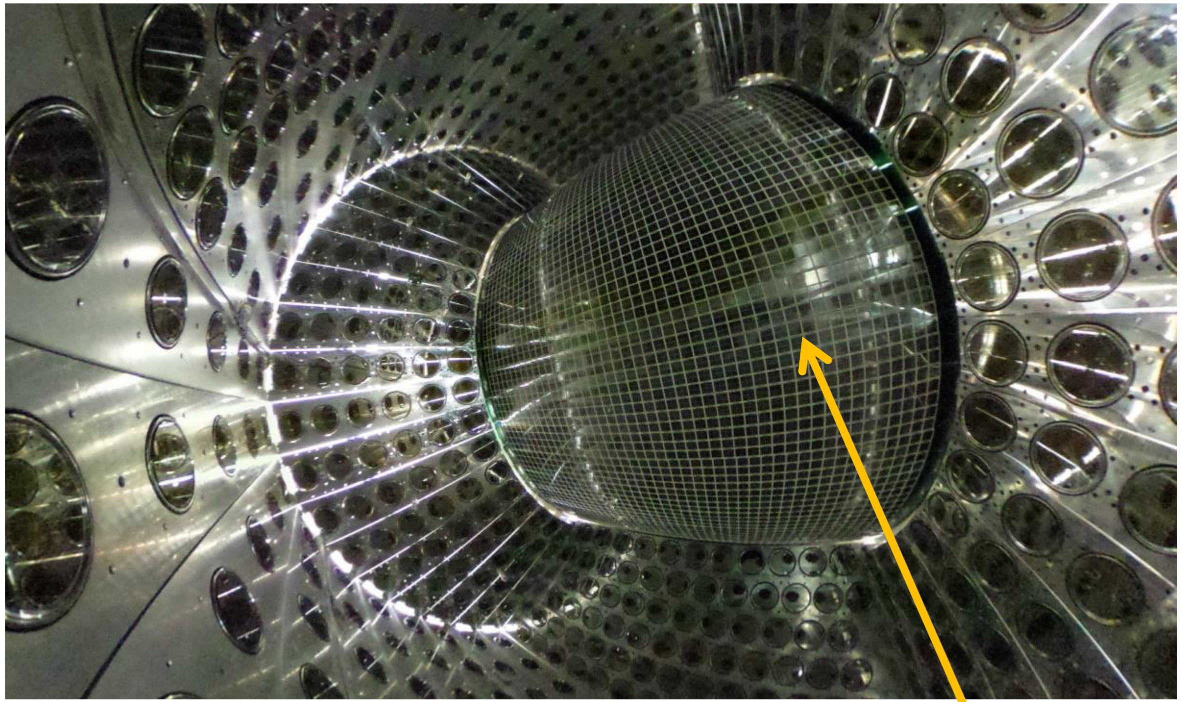
Superconducting solenoid with gradient field (**COBRA**).

Sweeps out low P_z positrons.

Bending radius nearly independent of positron emission angle wrt z axis (θ).

COnstant **B**ending **RA**dius.

MEGII: the Liquid Xenon photon detector 1)

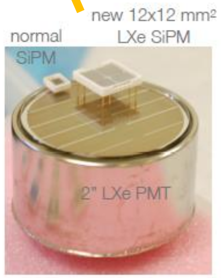


With respect to the MEG one:

- ❖ Better uniformity in front face: 216 PMTs replaced by 4092 12 × 12 mm^2 UV sensitive SiPMs;
- ❖ Enlarged acceptance and detection efficiency;
- ❖ Better pile-up rejection;
- ❖ **Increased resolution in photon interaction point, timing and energy**.

800 ℓ of LXe, UV scintillation light

Measurement of photon first interaction point coordinates, timing and energy release

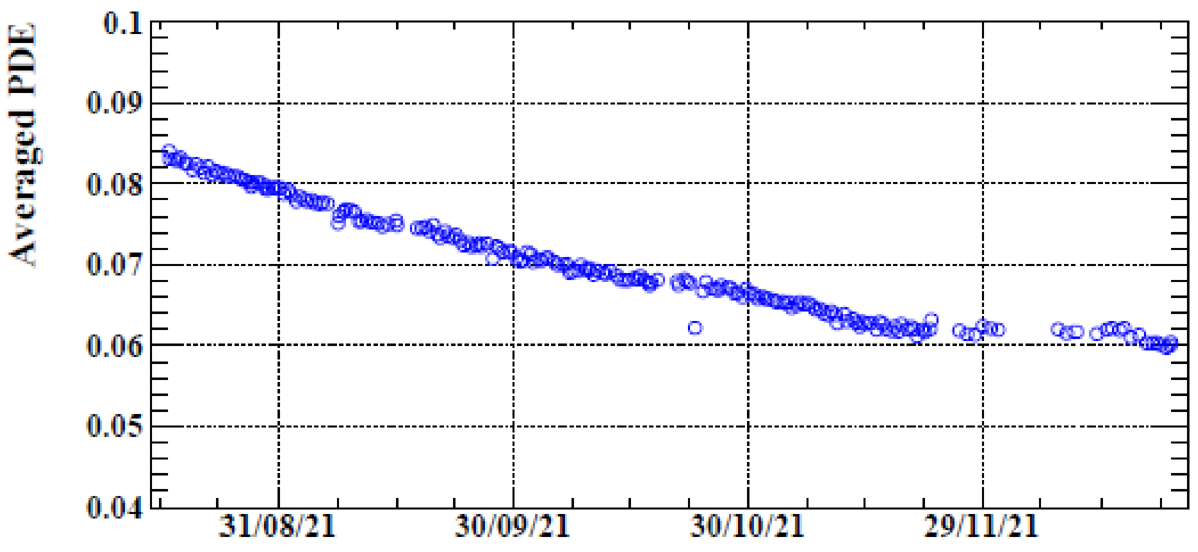


(T. Iwamoto et al., NIM A **1046** (2023) 167720)

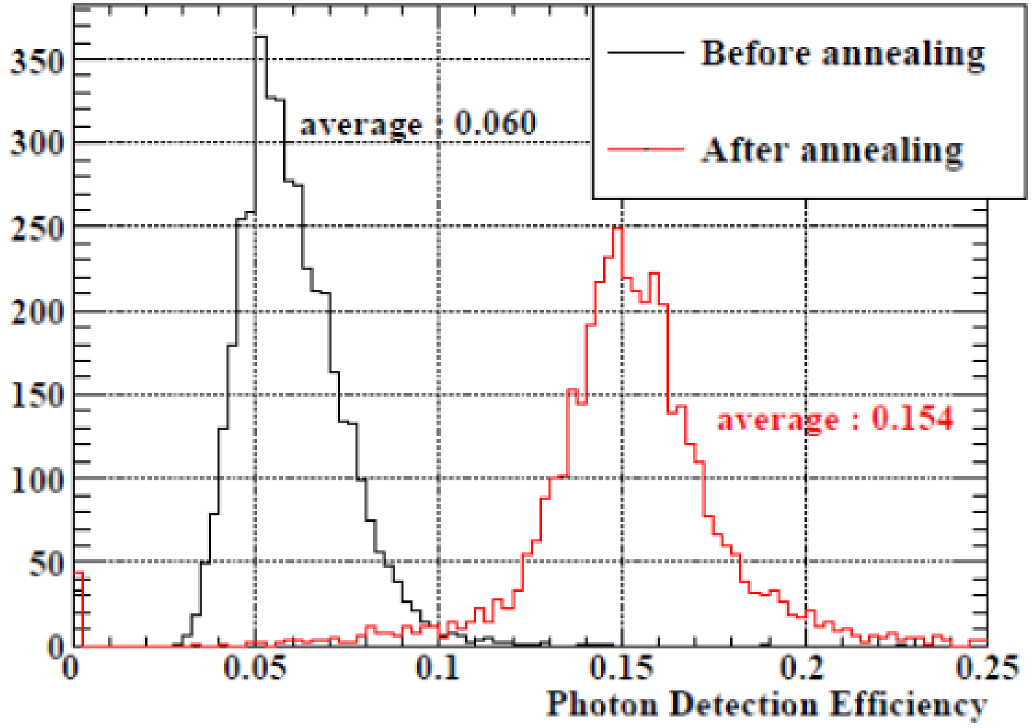
MEGII: the Liquid Xenon photon detector 2)

Long mounting and commissioning (Xenon purification, measurements of PMT/SiPM parameters …) and continuous calibrations (several calibration runs per week).

Main problem: decrease of SiPM PDE



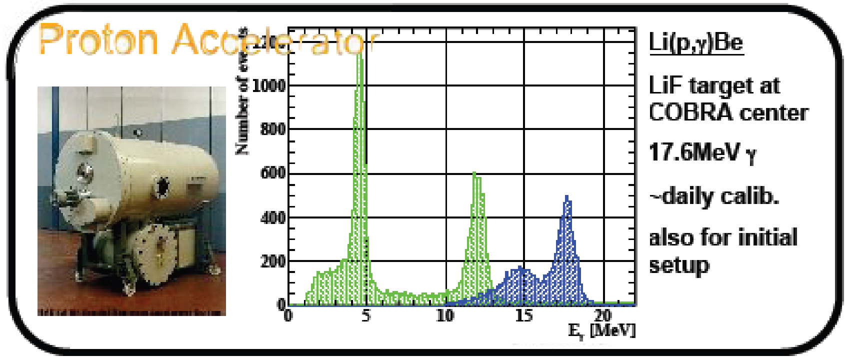
Solved by annealing (once per year)

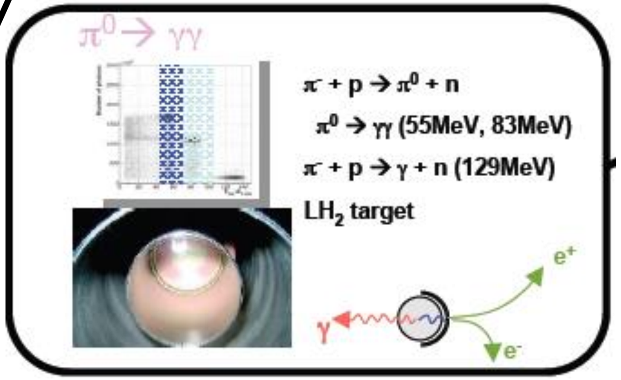


MEGII: the Liquid Xenon photon detector 3)

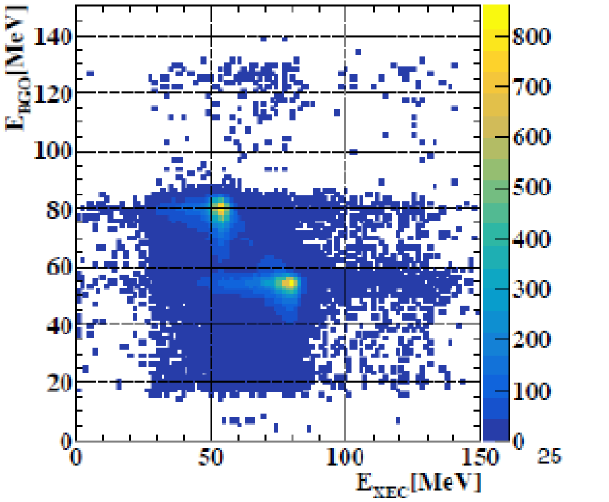
Several calibration tools:

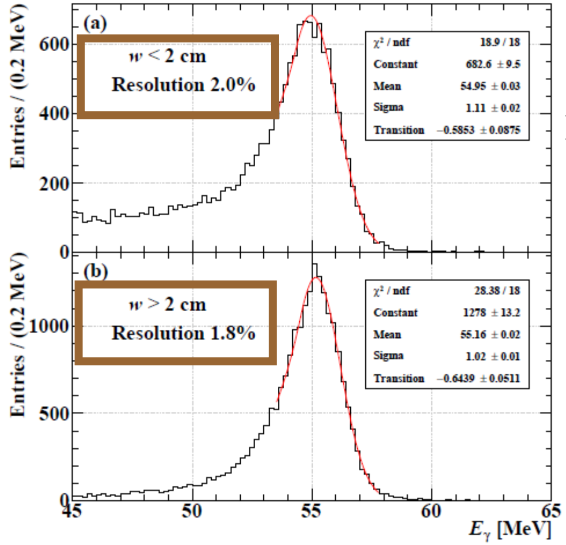
- ❑ Alpha sources on wires (SiPM/PMT PDE/QE)
- ❑ LED (SiPM/PMT Gain)
- ❑ CW proton accelerator (energy scale stability and detector response uniformity)
- ❑ Cosmic rays (energy scale stability)
- ❑ Negative pion beam and charge exchange reaction (gamma energy resolution and efficiency @ signal energy)
- ❑ Neutron generator





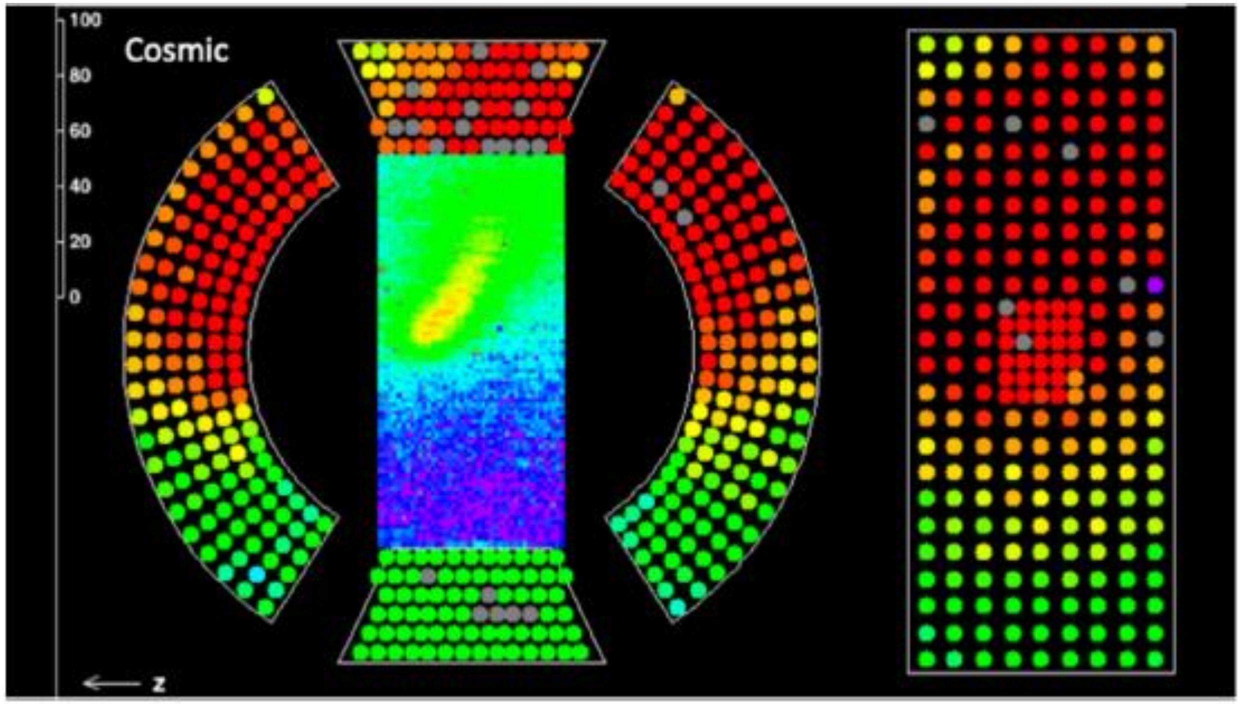
Data from the **first** Physics Run2021

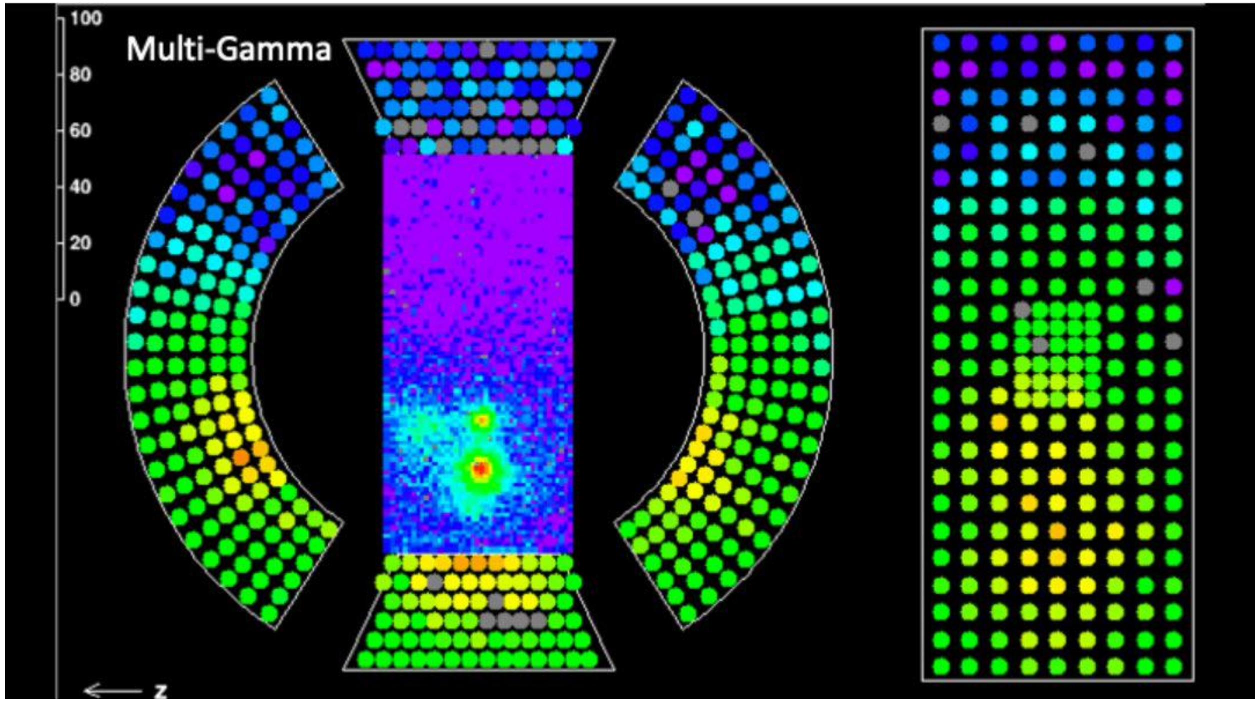




Energy resolution at 54.9 MeV

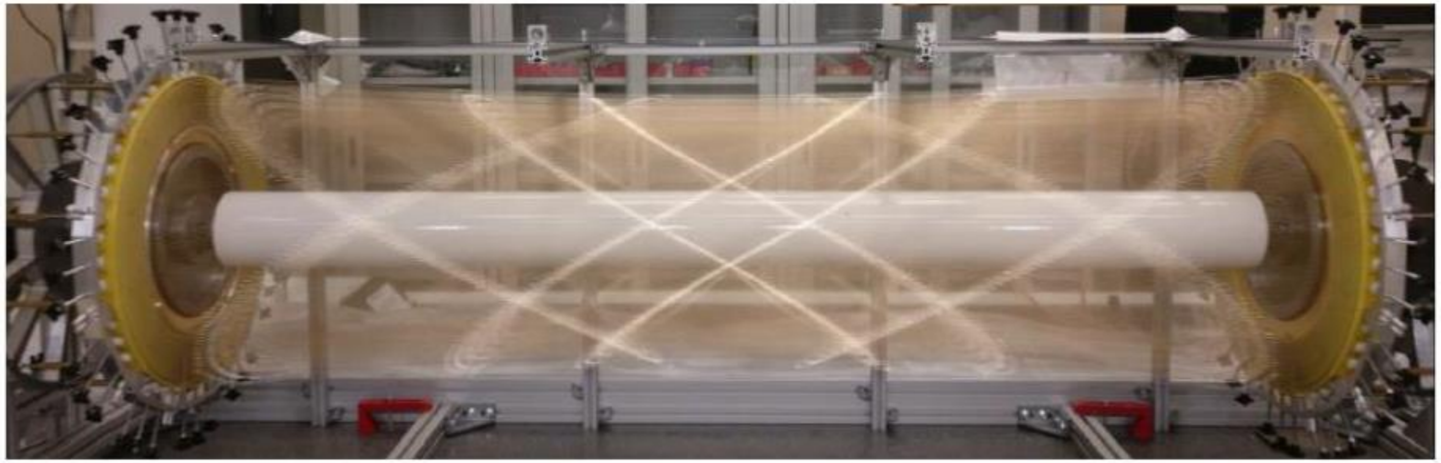
MEGII: the Liquid Xenon photon detector 4)





Left: a cosmic ray event; Right: a multi-gamma event (three separated clusters on inner face)

MEGII: the Cylindrical Drift CHamber 1)



Big technological challenge; designed, mounted and commissioned by INFN people (Pisa, Lecce, Roma).

In operation in good conditions since late 2020.

A backup chamber with only 50 μm bare Al cathode wires will be ready in 2024.

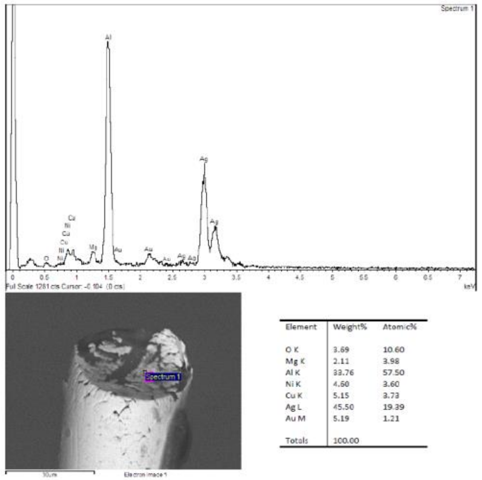
- Single volume, stereo U-V views chamber, 7-8° stereo angle, based on KLOE experience;
- Almost squared cells (~7 × 7 mm^2), He-Isobutane 90:10 mixture + additives (oxygen and isopropyl alcohol);
- 1728 anode wires (ϕ = 20 μm Au+W wires), >10000 cathode and guard wires (ϕ = 40 − 50 μm Ag-plated Al wires);
- Mounting delayed by fragility problems of 40 μm cathodes; **ready in 2018**;
- Much closer to Timing Counter ⇒ **improved tracking & matching efficiency**;
- ~40 ÷ 60 fitted hits for 52.8 MeV e^+ (3 × MEG);
- Single hit resolution ~120 μm.

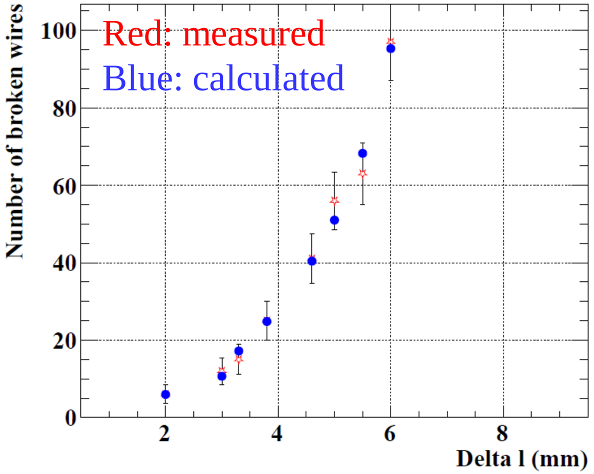
(A. Baldini et al. arXiv 2310.12865)

MEGII: the Cylindrical Drift CHamber 2)

Some years of mounting, preparation and commissioning work

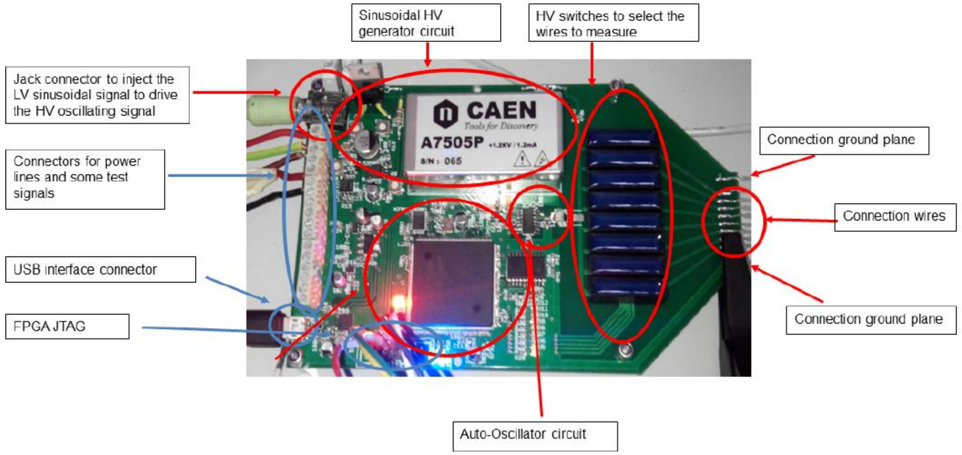
Analysis of broken wires (A. Baldini et al. JINST **16** (2021) T12003)

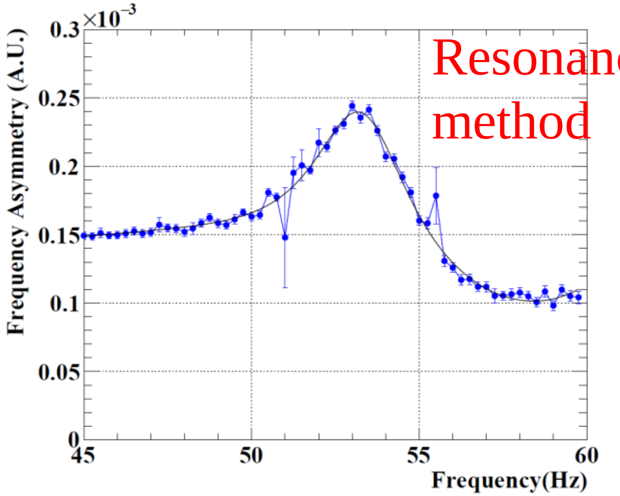




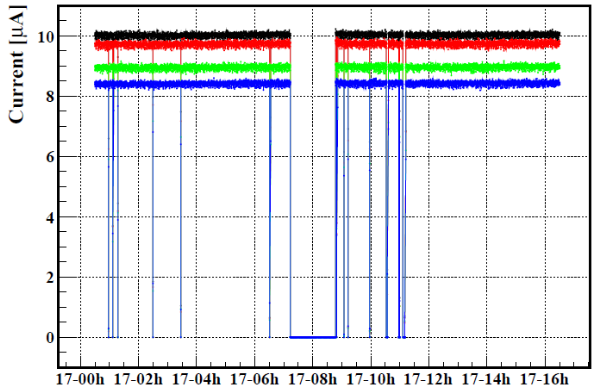
Measurement of wire tension

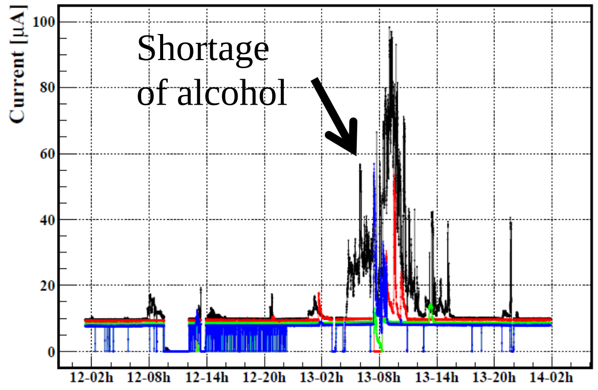
(A. Baldini et al. NIM A **1045** (2023) 167534





Definition of working point and gas mixture



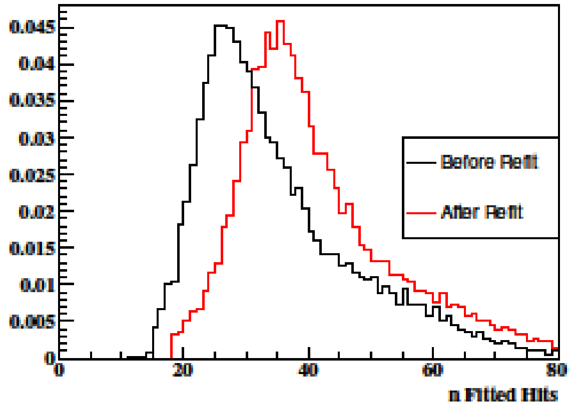


Current spikes solved by addition of oxygen and isopropyl alcohol

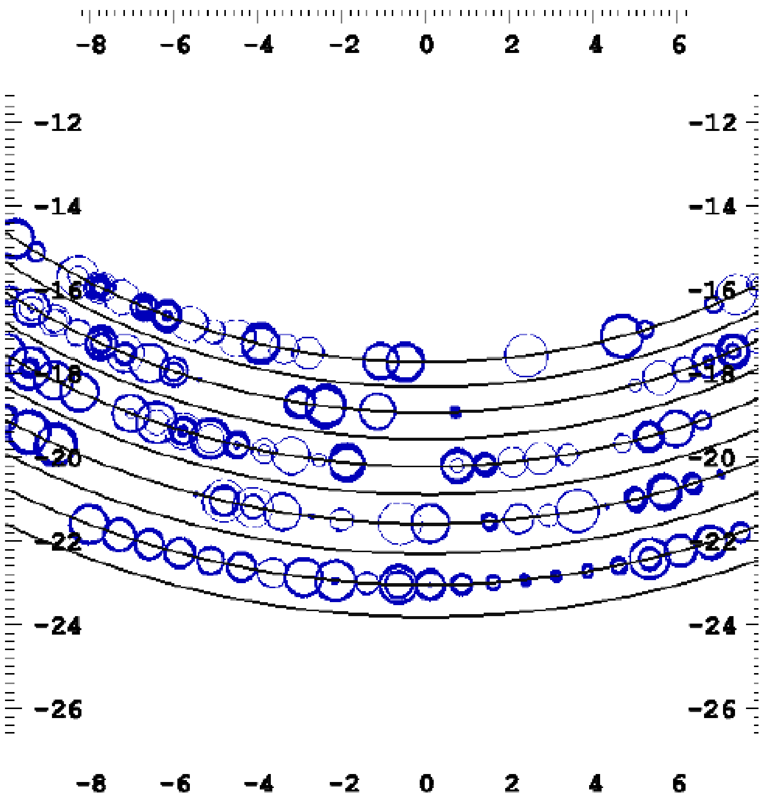
MEGII: the Cylindrical Drift CHamber 3)

Reconstruction steps

- Waveform decoding → signal timing, charge → hit reconstruction
- Track finding (Kalman filter based pattern recognition)
- Track fitting (Kalman filter fit)
- Forward (Timing counter) and backward (target) track propagation
- Recovery of missing hits and new fit («Refit»)



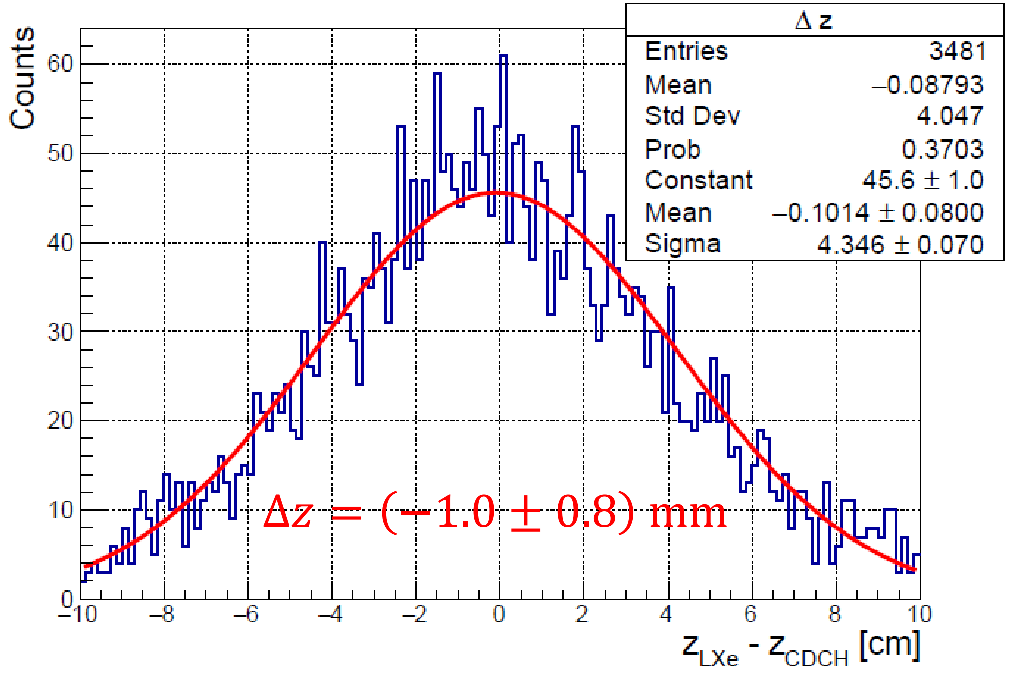
«Alice/Belle II – like» occupancy

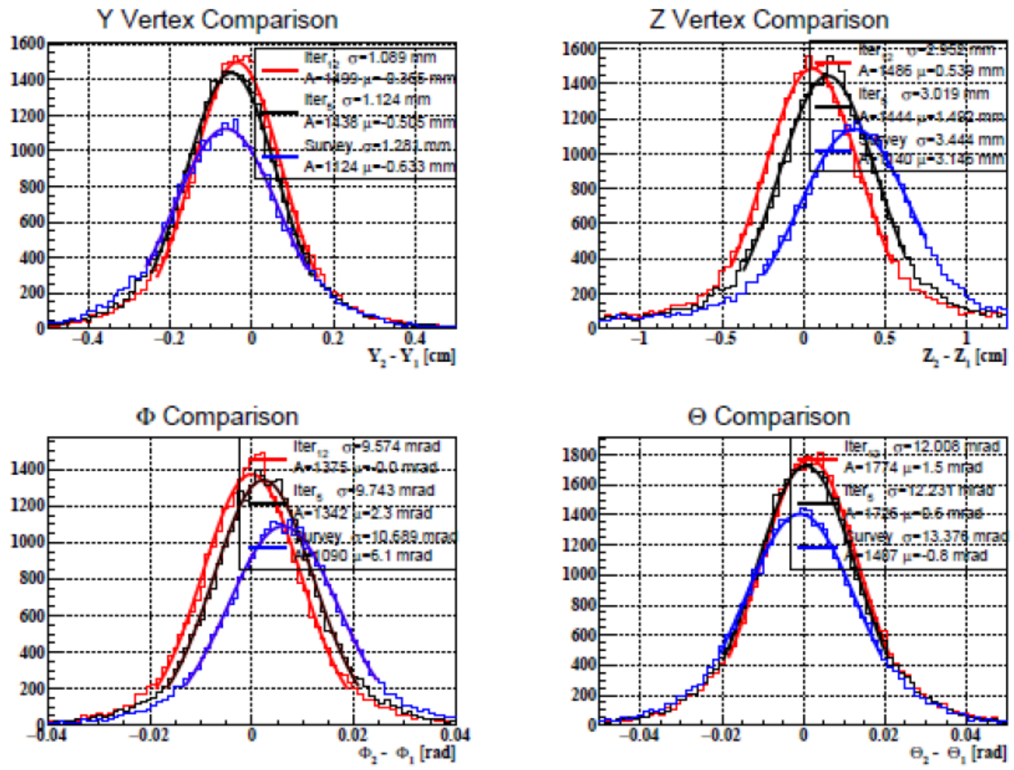


MEGII: the Cylindrical Drift CHamber 4)

Alignment 1):

- ✓ Wire-wire relative alignment
  - ❑ Optical survey (preliminary, hundreds of micron accuracy);
  - ❑ Track-based iterative algorithm (check with double turn method).
- ✓ CDCH – LXe alignment (cosmic ray tracks)





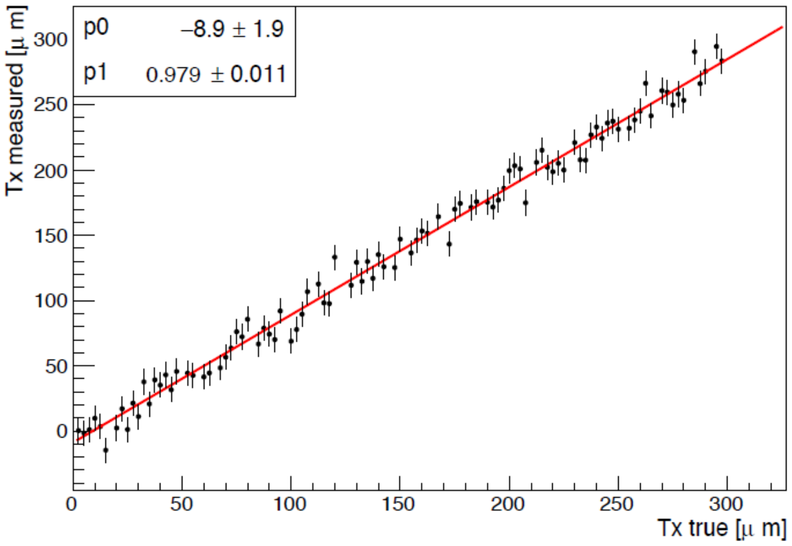
Blue: survey
Black: 5 alignment iterations
Red: 12 alignment iterations

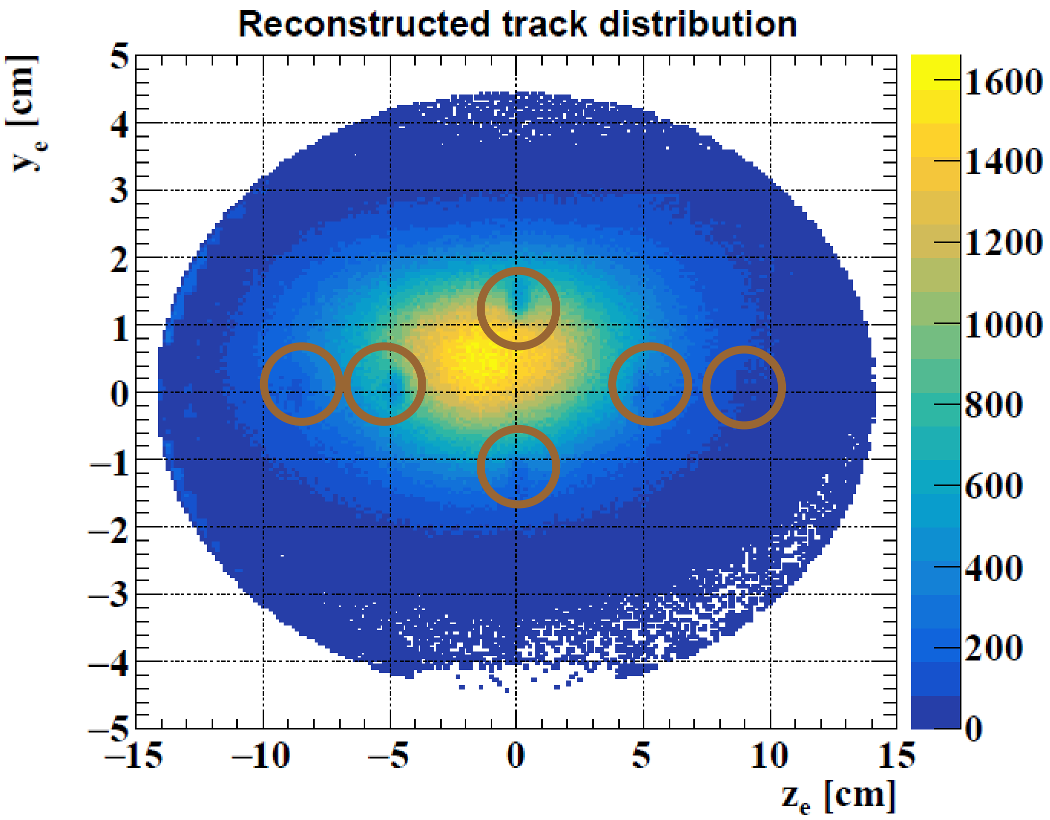
MEGII: the Cylindrical Drift CHamber 5)

Alignment 2):
CDCH – target alignment

Relative displacement between target and CDCH measured by using off-line reconstruction and on-line camera measurements (target hole method)

Calibration of photographic camera on a optical table





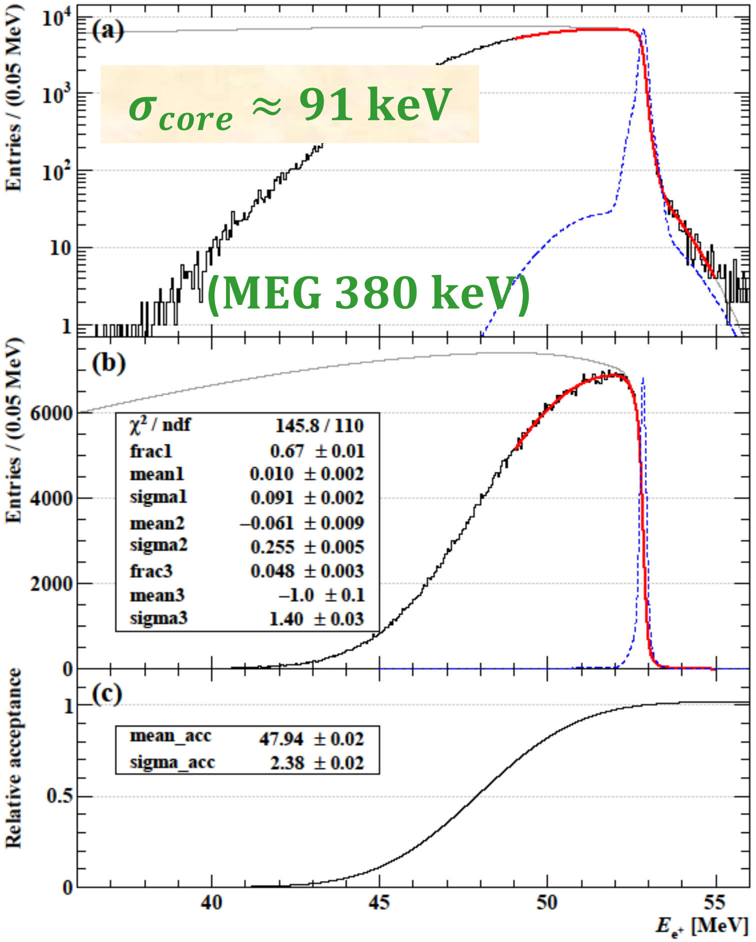
Reconstruction of positron production point on the target in (y_e, z_e) plane.

Holes

MEGII: the Cylindrical Drift CHamber 6)

Performances

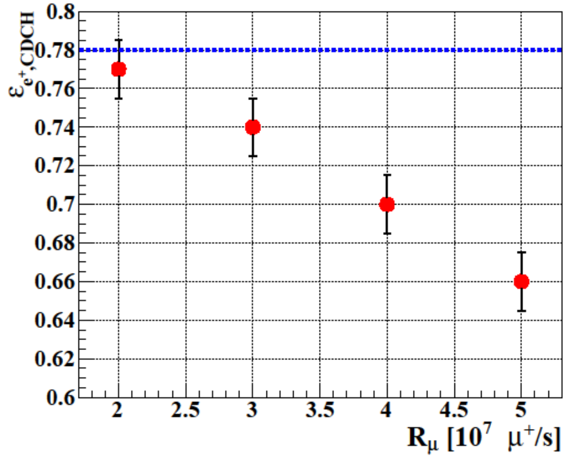
Momentum resolution



$\sigma_{core} \approx 91$ keV

(MEG 380 keV)

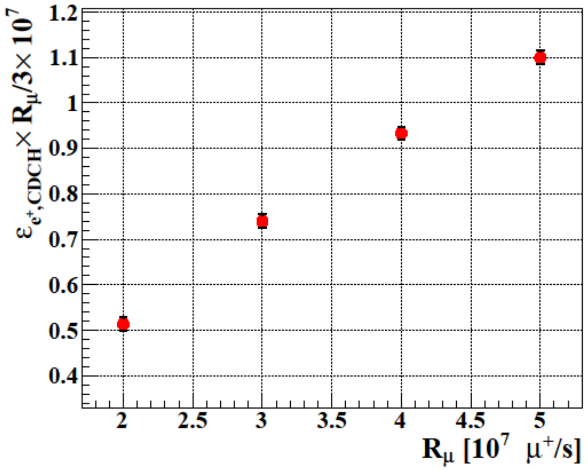
CDCH efficiency



At $R = 3 \times 10^7\ \mu/s$:

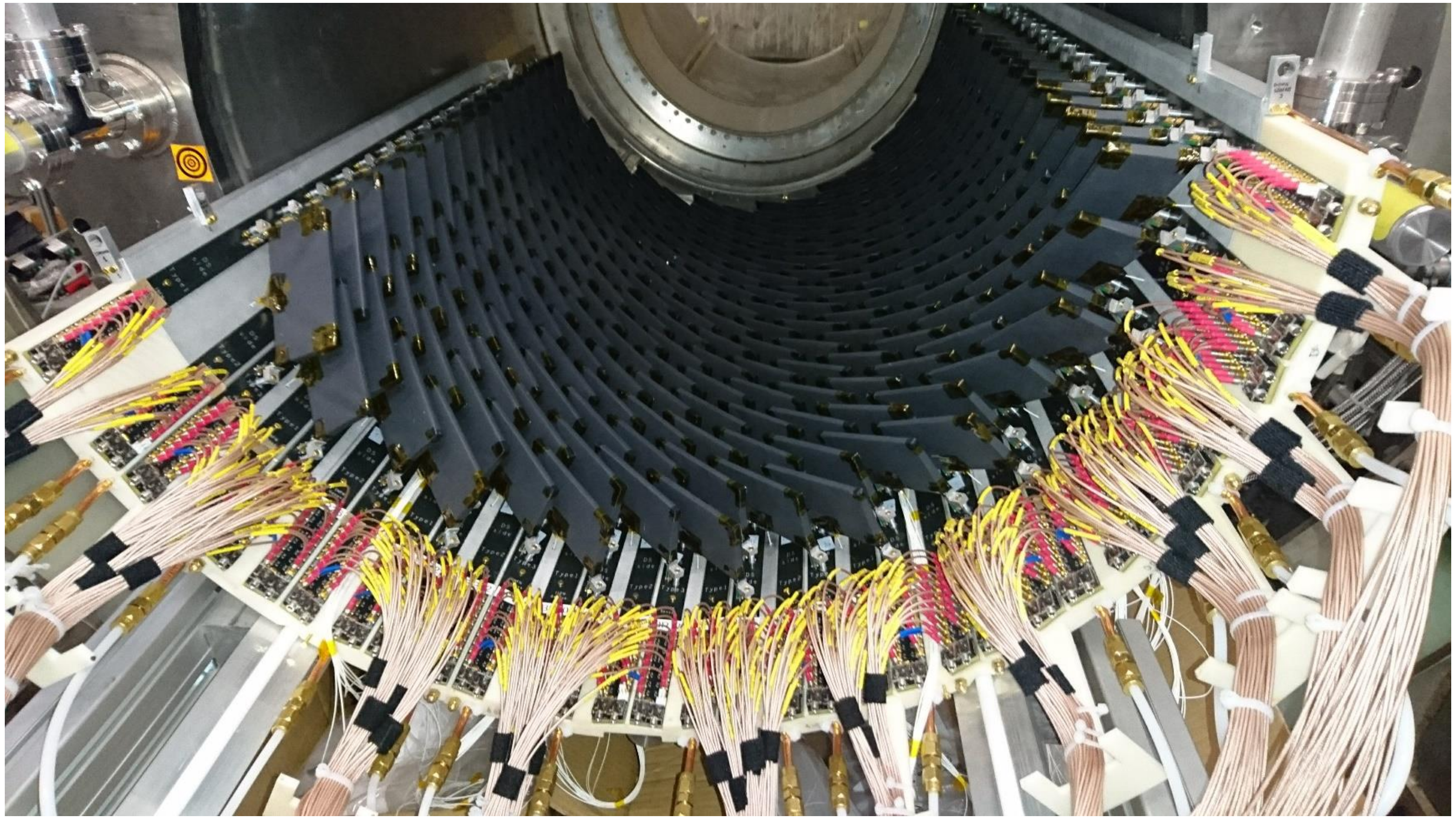
$\varepsilon = 74\ \%$

(MEG 40 %)



Higher beam intensities are advantageous

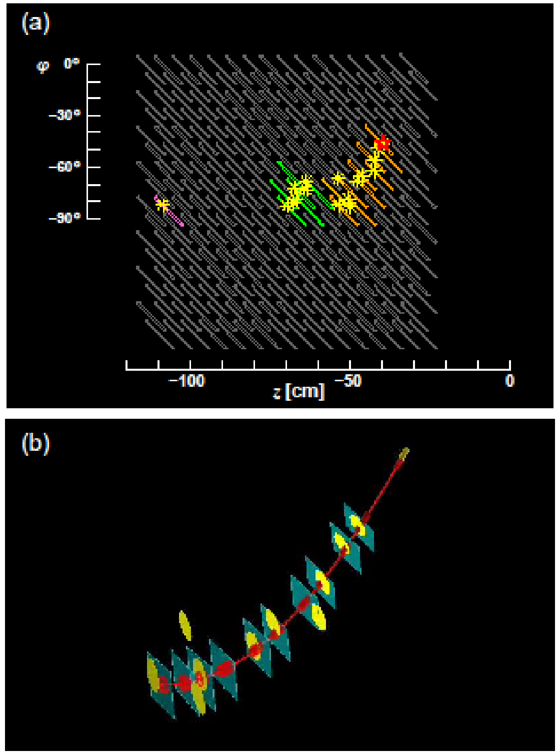
MEGII: the pixelized scintillation Timing Counter 1)



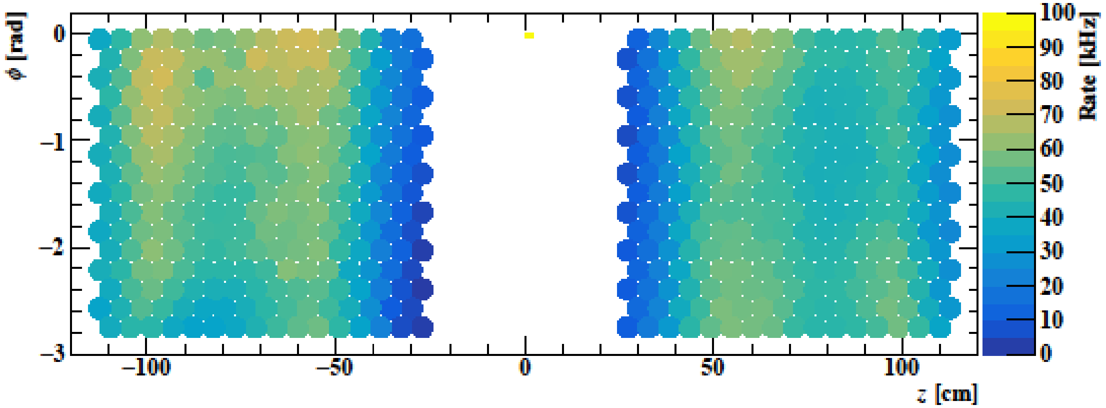
- Two sectors made of 256 scintillating BC422 tiles read by Advansid SiPMs;
- Time obtained by averaging the tiles hit by a positron; 8 tiles on average for signal positrons;
- A laser system is used for calibrations and monitoring;
- In stable operations since 2017; some SiPM replaced for maintenance in several years.

(P. Cattaneo et al., NIM A **1046** (2023) 167751)

MEGII: the pixelized scintillation Timing Counter 2)



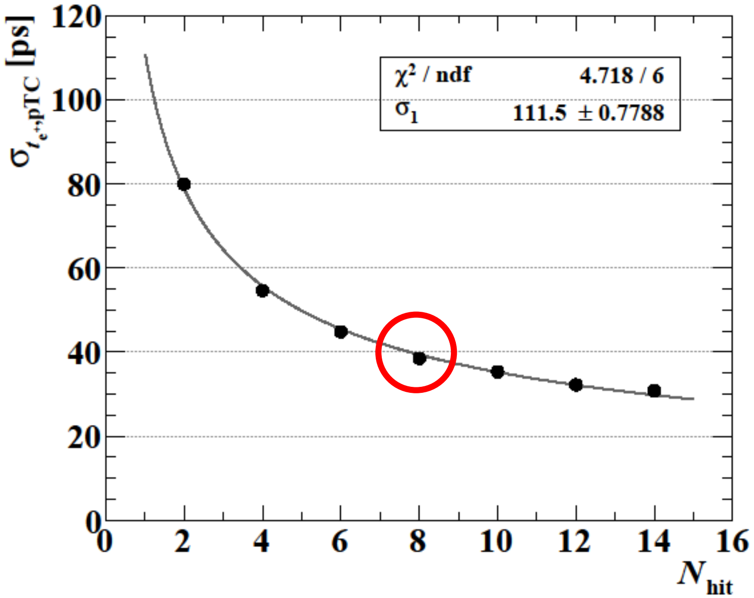
A Michel positron track in pTC system



Hit distribution in pTC detector (used for diagnostic). Excess for $z < 0$ due to muon beam polarization; measured on MEG data:

$$P_\mu = -0.86 \pm 0.02\ (stat)^{+0.05}_{-0.06}\ (syst)$$

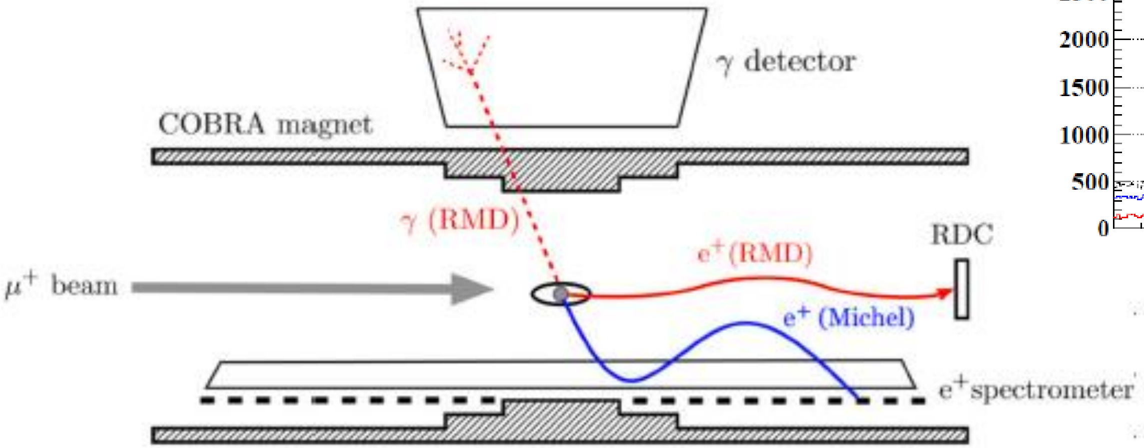
(A.M. Baldini et al. EPJC **76** (2016) 223)

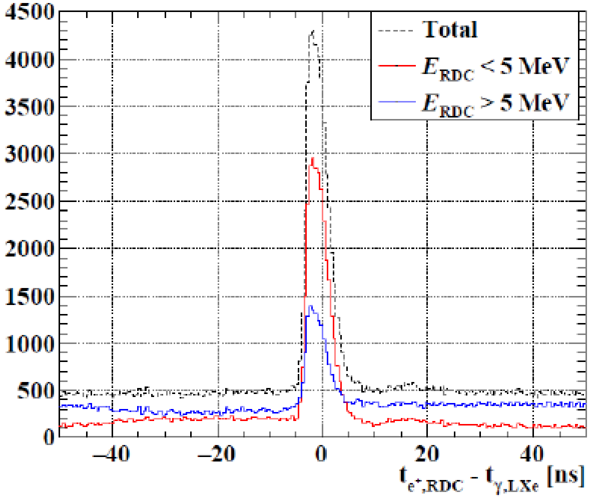


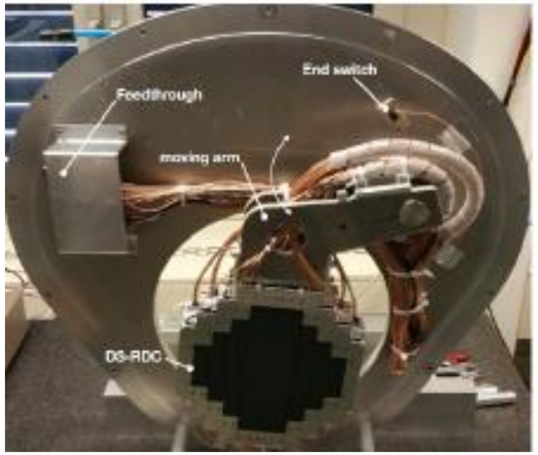
Positron timing resolution
$\sigma_t \approx 35$ ps
for 8 hits (MEG 70 ps)

MEGII: Radiative Decay Counter

Auxiliary detector to tag photons from RMD decay associated to low energy positrons

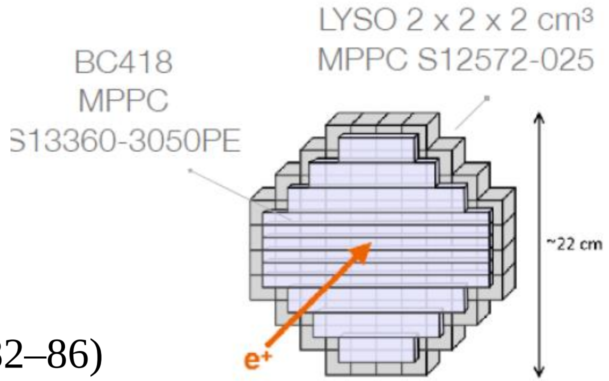






Lyso plastic scintillator array read by SiPM.

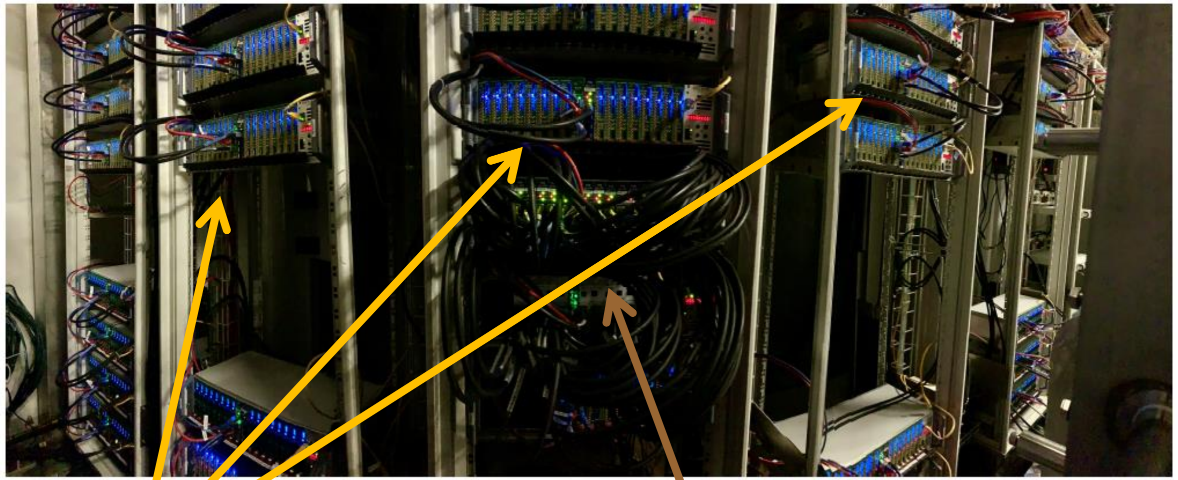
Operating since 2016.



(R. Iwai et al., Proc. Phys. **212** (2017) 82–86)

NEW detector, not in MEG

MEGII: Trigger and DAQ system



DAQ Boards («WaveDREAM»)

Trigger boards

(L. Galli et al., NIM A **936** (2019) 399–400)
(M. Francesconi et al., NIM A **1045** (2023) 167542)

Full waveform recording at 1.4 GSPS with a custom made system.

Custom made integrated trigger to perform a fast and efficient event selection:

- no CDCH information (drift time ~ 300 ns)
- LXe detector total charge → $\boldsymbol{E_\gamma > 40}$ **MeV**
- pTC + LXe timing → $|\Delta t(e^+, \gamma)| < 12.5$ **ns**
- pTC + LXe fast topological information → **almost back-to-back condition**.

DAQ fully installed in 2021 (9000 channels); **trigger rate $(10 \div 30)$ Hz** depending on muon beam intensity.

MEGII vs MEG detector performances

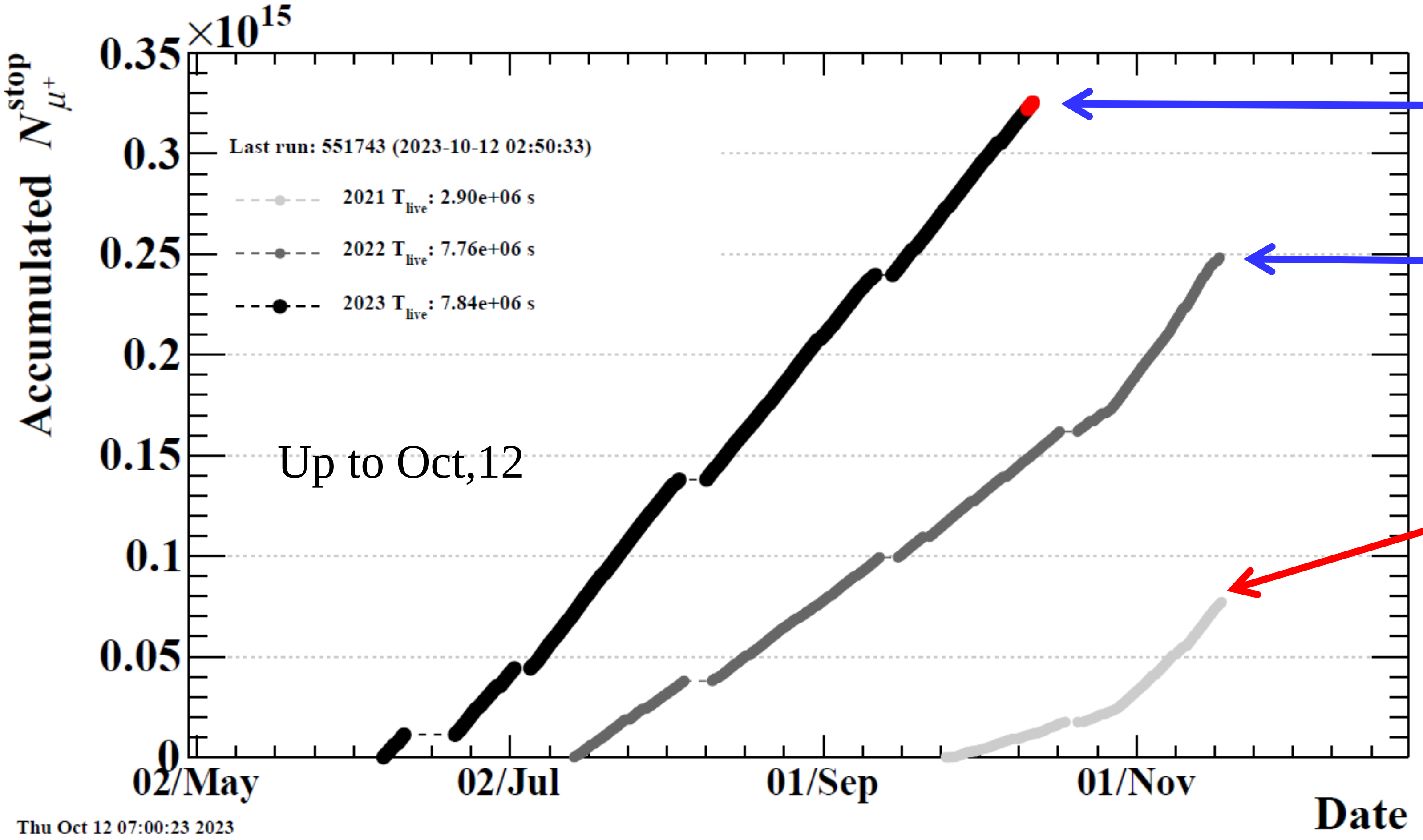
2021 run → Achieved

Resolutions	Foreseen	Achieved	MEG	Ratio
E_{e^+} (keV)	100	89	380	X 4
ϕ_{e^+}, θ_{e^+} (mrad)	3.7/6.7	4.1/7.4	8.7/9.4	X 2 / X 1.5
y_{e^+}, z_{e^+} (mm)	0.7/1.6	0.7/2.0	1.2/2.4	X 2 / X 1.25
E_γ(%) (w<2 cm)/(w>2 cm)	1.7/1.7	2.0/1.8	2.4/1.7	X 1.2/ X 1.0
$u_\gamma, v_\gamma, w_\gamma$, (mm)	2.4/2.4/5.0	2.5/2.5/5.0	5/5/6	X 2/ X 2/ X 1.25
$t_{e^+\gamma}$ (ps)	70	78	122	X 1.6
Efficiency (%)				
ε_γ	69	62	63	X 1
ε_{e^+}	65	67	30	X 2.2
ε_{TRG}	≈99	80	99	X 0.8

- **Better S/N**
- **Much smaller analysis windows**
- **Reduced computing time**

Fictitious, trigger efficiency for MEG in first data taking year was 69%. Effect of unstable operations in 2021 (different beam intensities, unstable photon detector energy thresholds …). **Foreseen efficiency reachable in stable data taking conditions**.

MEGII Data Taking History



Present year

Last year: calibration, reprocessing stage

2021: this presentation; 8.5×10^{13} stopped muons on target (10.1 including prescaling)

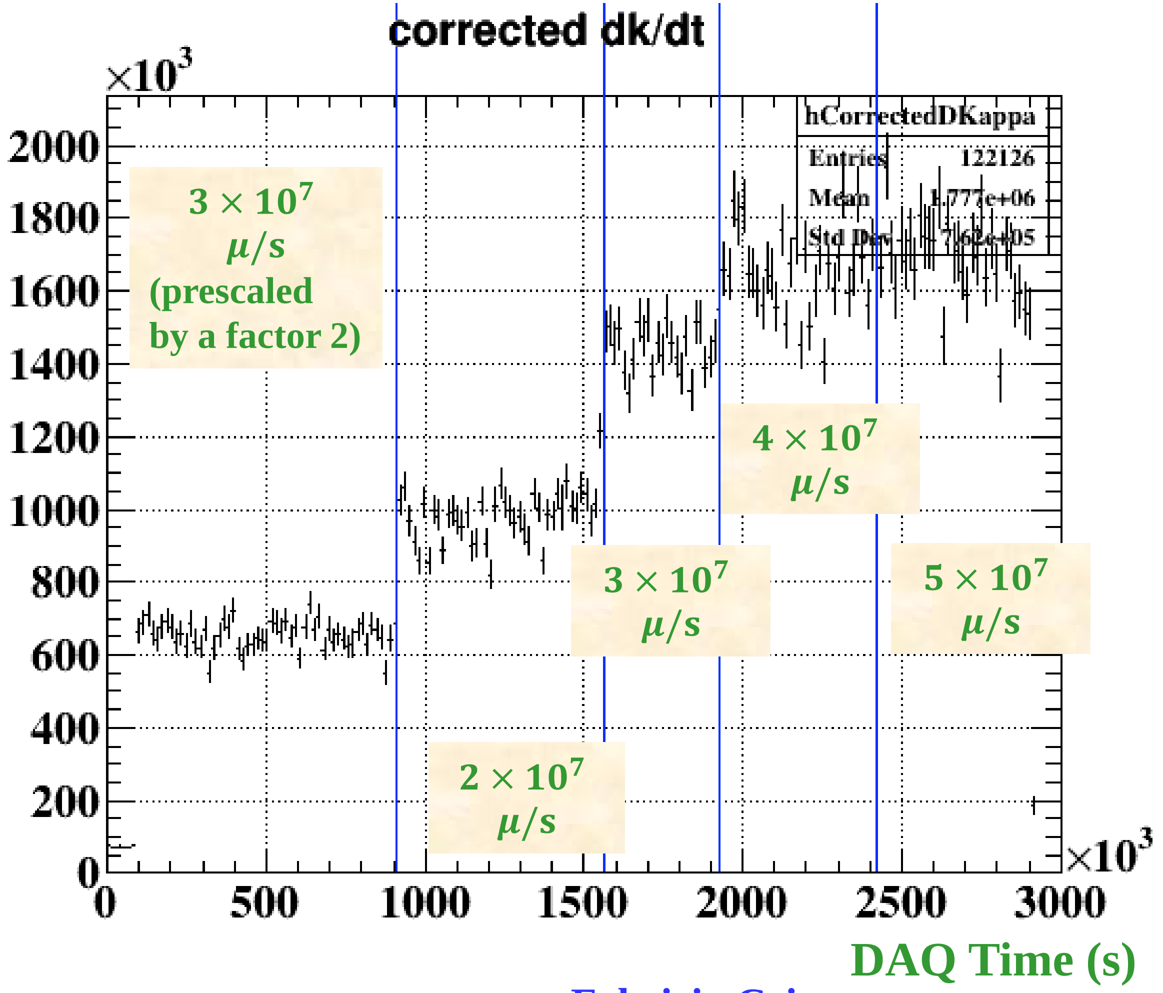
Total MEG sample already reached

Data taking during 2021 and normalization

Normalization factor k as a function of time during 2021 data taking.

Five different periods correspond to different beam intensities.

k includes DAQ efficiency, tracking efficiency, reconstruction efficiency …



k measured using a pre-scaled trigger based on pTC only and/or RMD events; combined value

$$k = (2.64 \pm 0.12) \times 10^{12}$$

Meaning of k:

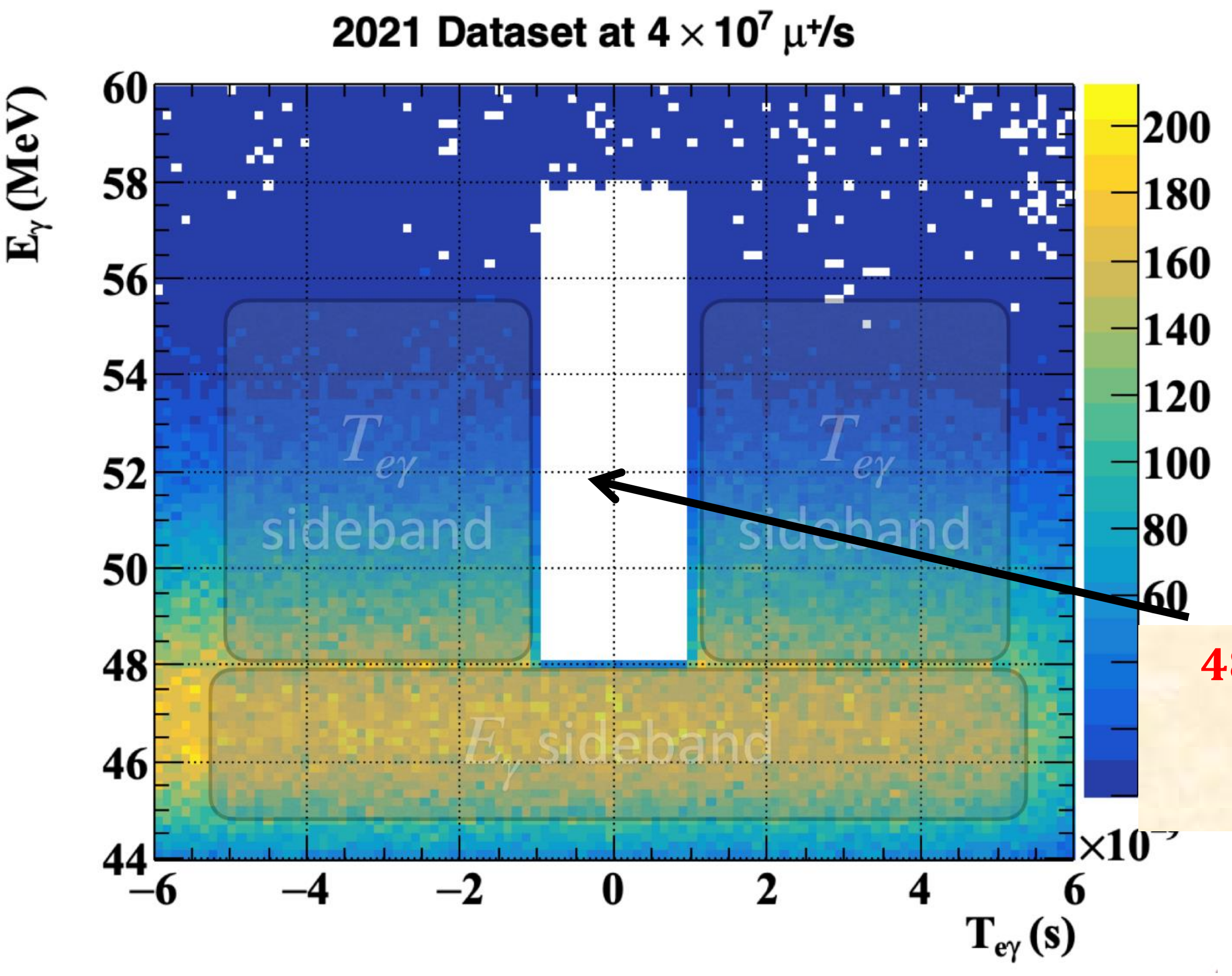
$$BR(\mu^+ \to e^+\gamma) = \frac{N_{signal}}{k}$$

«Equivalent number» of detected μ's

MEGII analysis strategy

Combination of «blind» and «likelihood» analysis (usual strategy for experiments searching for rare signals).

Events in the «Blinding box» (the white region) are hidden, while events in the Sidebands, calibrations and simulations are used to determine the «Probability Distribution Functions» (PDFs) for Signal, RMD and Accidental background.



$48\ \text{MeV} < E_\gamma < 58\ \text{MeV}$
&&
$|\Delta T_{e\gamma}| < 1\ \text{ns}$

MEGII Likelihood function

Sideband constraints

$$\mathcal{L}\left(N_{\rm sig}, N_{\rm RMD}, N_{\rm ACC}, \boldsymbol{t}\right) = \frac{e^{-N}}{N_{\rm obs}!} C(N_{\rm RMD}, N_{\rm ACC}, \boldsymbol{t}) \times \prod_{i=1}^{N_{\rm obs}} \left(N_{\rm sig} S(\boldsymbol{x}_i, \boldsymbol{t}) + N_{\rm RMD} R(\boldsymbol{x}_i) + N_{\rm ACC} A(\boldsymbol{x}_i)\right)$$

$$\boldsymbol{x}_i = \{E_{\mathrm{e}^+}, E_\gamma, \Delta T_{\mathrm{e}\gamma}, \Delta\varphi_{\mathrm{e}\gamma}, \Delta\theta_{\mathrm{e}\gamma}\}$$

Maximum likelihood fit extracts:

- N_{Sig}, N_{RMD}, N_{ACC} = number of Signal, RMD and Accidental events
- $\boldsymbol{t}$ = vector of «nuisance» parameters (calibration uncertainties, systematic effects …)

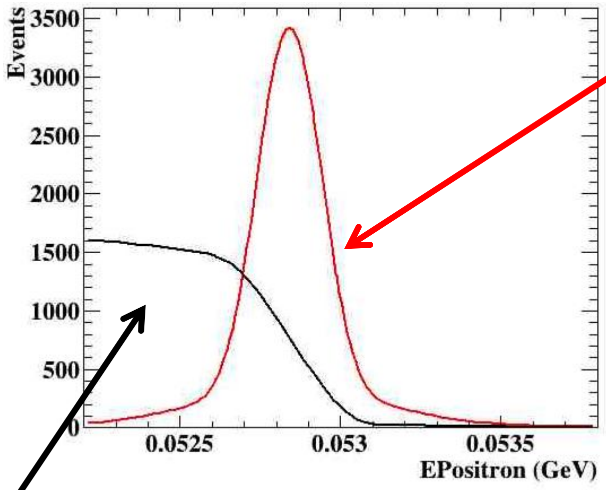
Two independent analyses based on different PDF types:

- **Per-event PDF**;
  PDF parameters changed event by event to take into account detector response, disuniformities …;
  Higher sensitivity (30% better), but more complicated;
- **Constant PDF**;
  same PDF used for all events, but a different set for each data taking period and separated sets for deeper or shallower events in the photon detector;
  Lower sensitivity, but much simpler.

Collaboration agreement: assume the **per-event PDF analysis as the official one**, but the **two analyses must give consistent results** within 5% tolerance.

MEGII PDFs

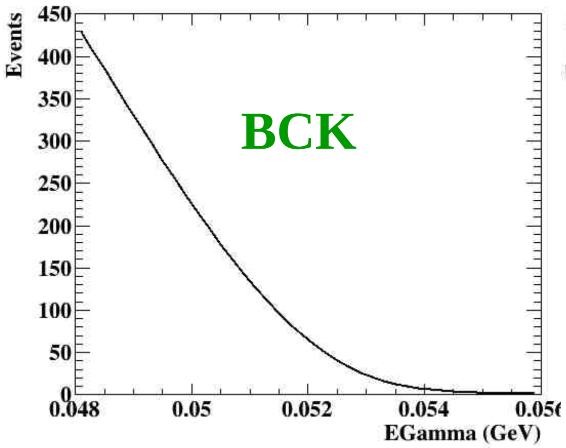
Positron energy



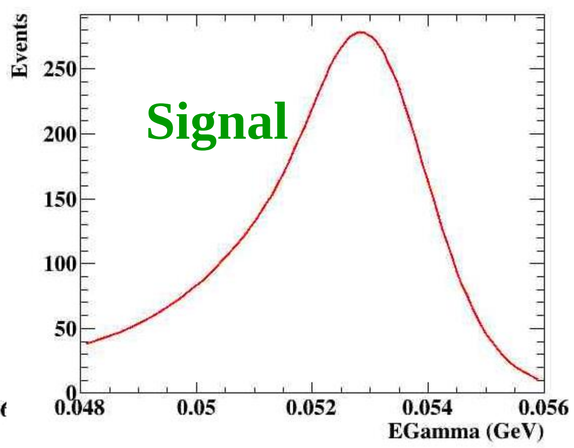
Signal;
fit of Michel spectrum
@ 52.8 MeV

BCK; fit from sidebands

Photon energy

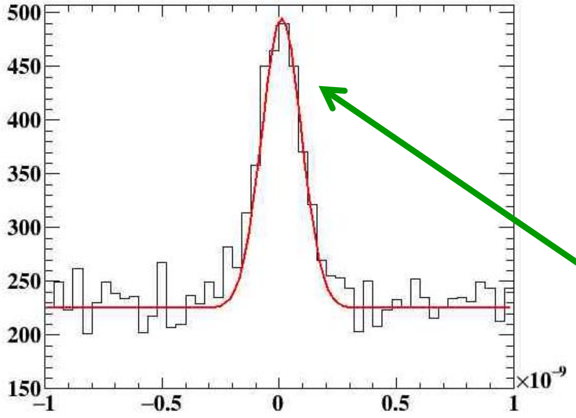


fit from sidebands



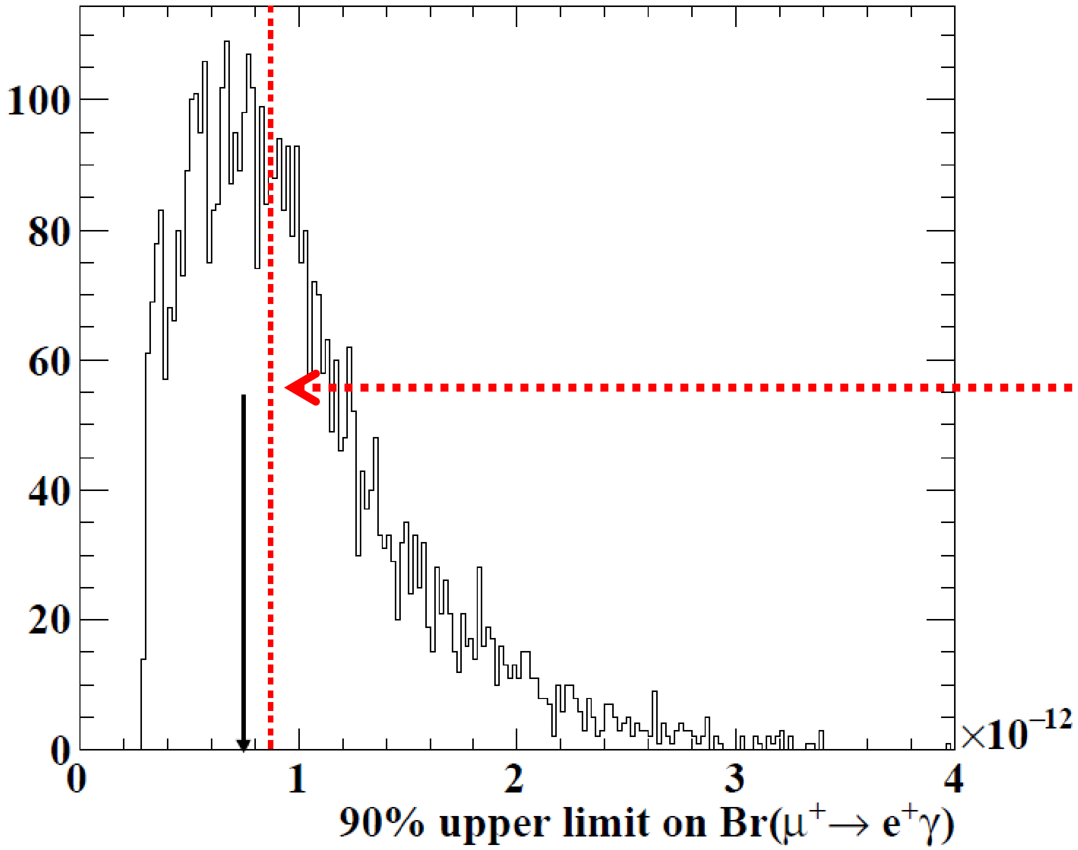
fit of 54.9 MeV peak
from CEX reaction +
MC corrections

Positron-photon
relative time $\Delta T_{e\gamma}$



RMD peak

MEGII sensitivity for 2021



Distribution of 90% C.L. upper limit obtained on a sample of 10^3 toy MC with no signal events.

The **sensitivity S_{90}**, according to Feldman-Cousins prescription is **the median (50% probability)** of this distribution:

$$S_{90} = 8.8 \times 10^{-13}$$

Sistematic effects (target position, photon energy resolution …) account for (3 ÷ 5) % of sensitivity.

And the black arrow ?

One moment, please ….

MEGII Maximum Likelihood fit 1): per-event PDF

66 events in the Analysis Window

GREEN: ACC
RED: RMD
BLU: total
CYAN: Signal UL × 4

Best fit:

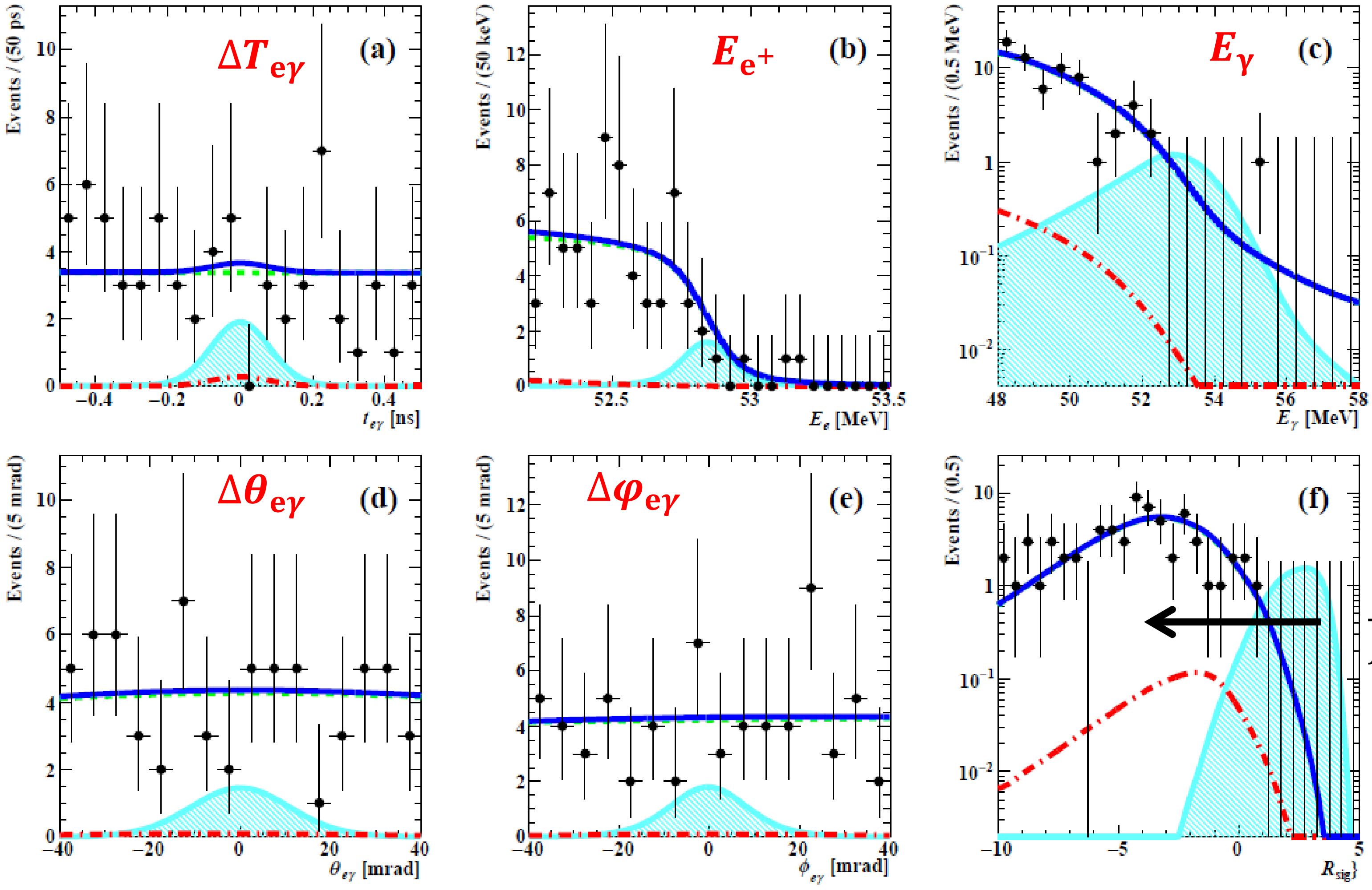
$BR\ (\mu^+ \to e^+\gamma) = -1.1 \times 10^{-16}$

$\Rightarrow$

UL

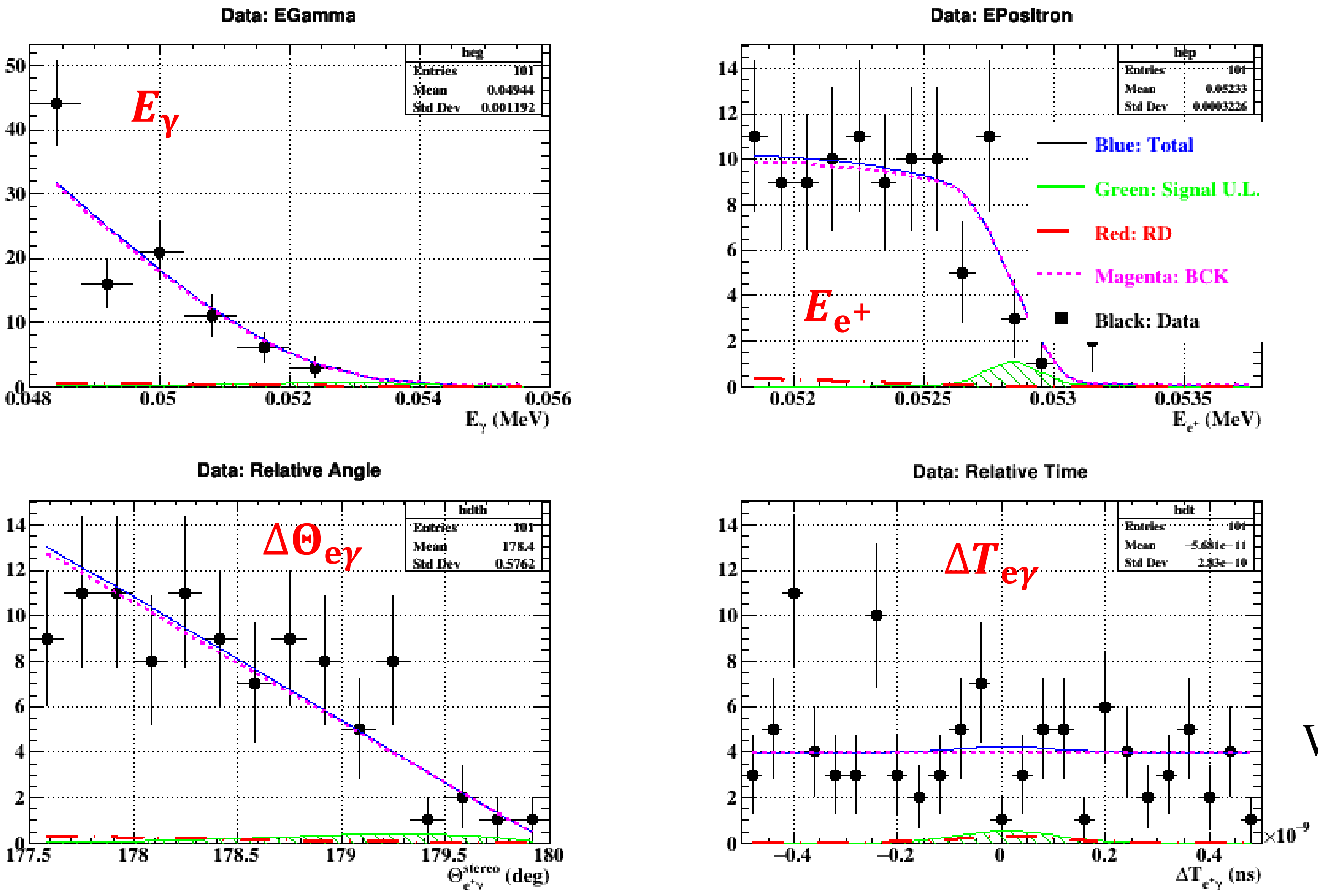
$BR\ (\mu^+ \to e^+\gamma) \leq 7.5 \times 10^{-13}$
@90% CL

Fit (66 ± 8) BCK and (0.0 ± 3.9) RMD events;
expected (68.0 ± 3.5) and (1.2 ± 0.2).



$$\frac{p_S}{f_R p_R + f_A p_A}$$

MEG Maximum Likelihood fit 2): constant PDF



99 events in Analysis Window

Best fit:

$$BR\ (\mu^+ \to e^+\gamma) = -3.1 \times 10^{-13}$$

$$\Rightarrow$$

UL

$$BR\ (\mu^+ \to e^+\gamma) \leq 1.3 \times 10^{-12}$$

@90% CL

25% compatibility with per-event PDF

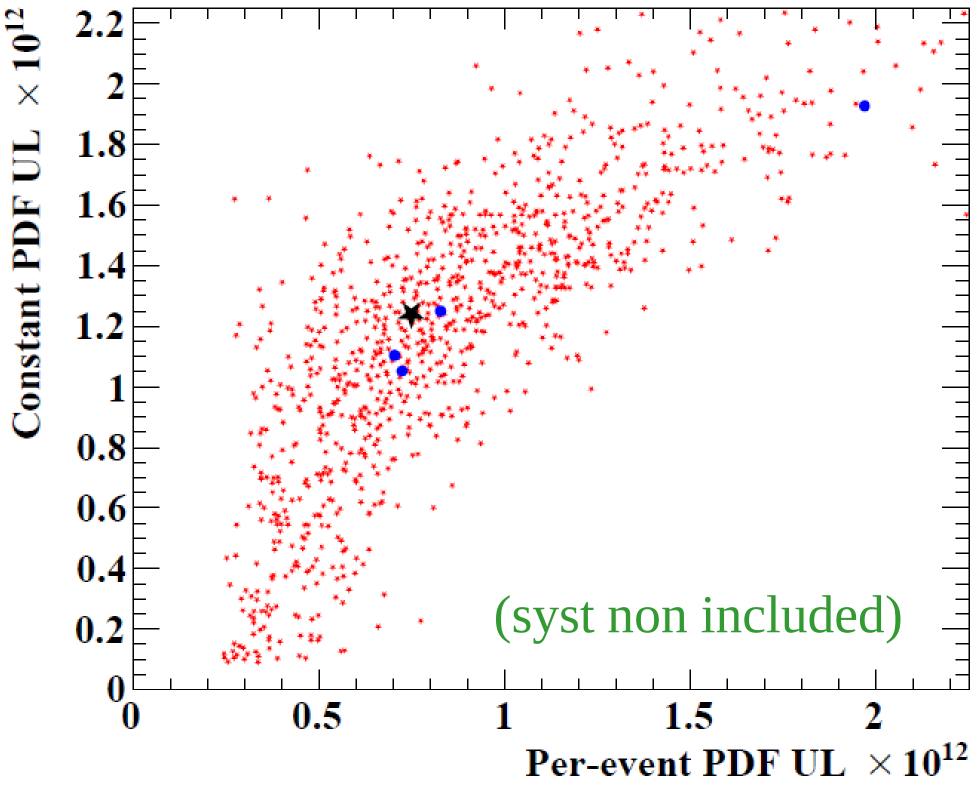
Wider Analysis Window for positron ($E > 51.8$ MeV)

Analysis comparison

Highest rank events

Run	Event	ΔT_{eg} (ns)	E_e (GeV)	E_γ (GeV)	$\Delta\varphi_{eg}$ (rad)	$\Delta\theta_{eg}$ (rad)	Rank Per-event	Rank Constant
401563	1286	-0.108186	0.052974	0.051952	-0.002235	-0.027659	1	1
402458	22	0.136768	0.052695	0.049514	0.003376	0.001311	2	3
403059	2406	-0.286985	0.052738	0.052013	-0.001397	-0.013269	3	2
405442	9	-0.039713	0.052772	0.049721	0.009852	-0.030290	4	4
401603	2718	-0.099251	0.052766	0.049186	-0.022790	0.023956	5	6

$$R = \frac{p_S}{f_R p_R + f_A p_A}$$

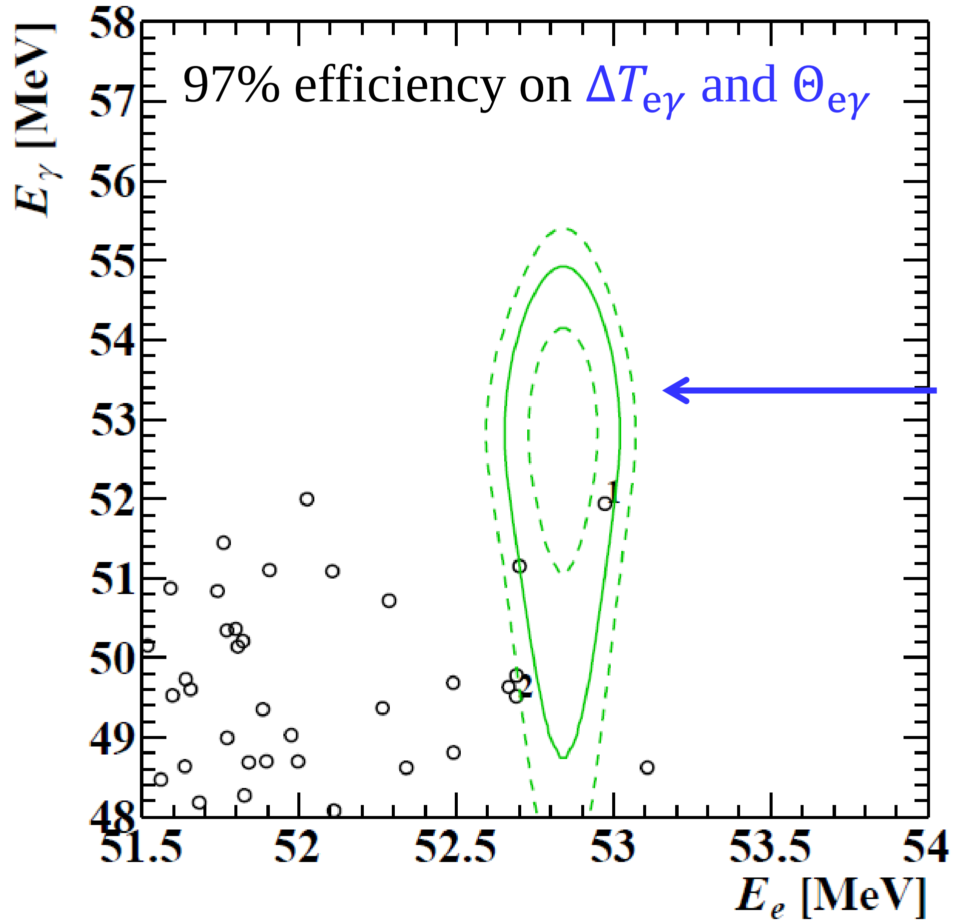


Black Star: signal box

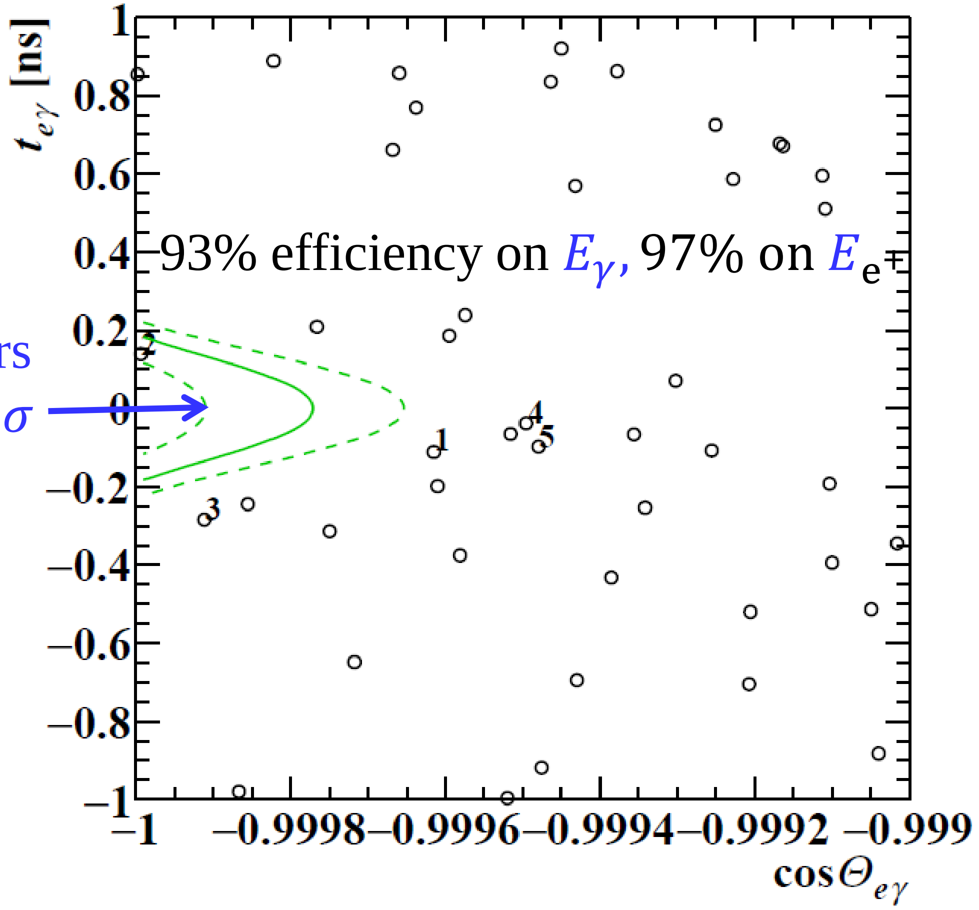
Blue dots: control sidebands

Red Points: 10^3 common toy MCs, no signal

Event distribution



PDF Contours
1σ, 1.64σ, 2σ



MEGII vs MEG

MEG
~15 months of physics data taking
Often in stable conditions

Total $N_\mu = 7.5 \times 10^{14}$

MEGII (2021)
6 weeks of physics data taking

Variable conditions
(beam intensity, photon energy thresholds …)

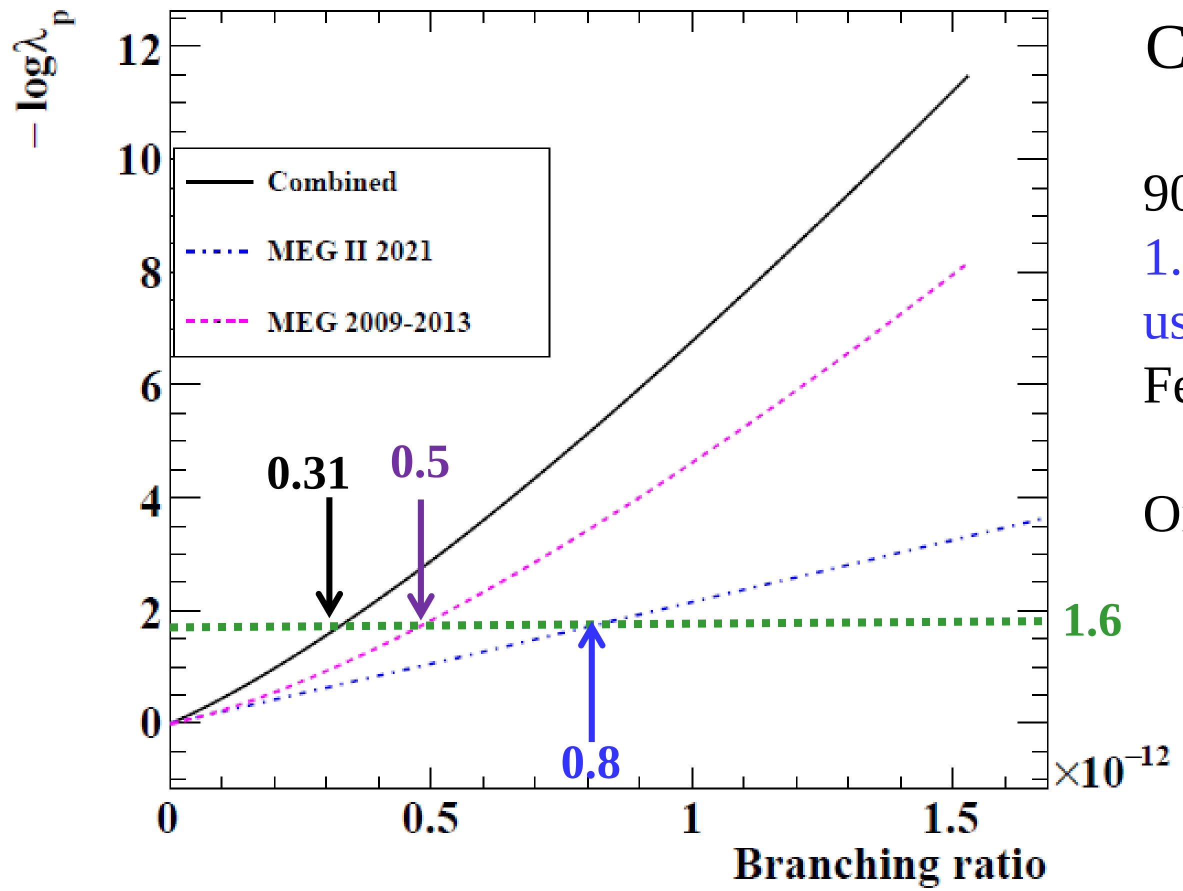
Total $N_\mu = 8.5 \times 10^{13}$ $9 \times$

Nevertheless …

MEG
$k = 1.7 \times 10^{13}$
$BR\ UL = 4.2 \times 10^{-13}$

MEGII (2021)
$k = 2.64 \times 10^{12}$ $6.5 \times$ Higher efficiency & beam intensity
$BR\ UL = 7.5 \times 10^{-13}$ $1.8 \times$ Better resolutions

MEG-MEGII combined result



Combination based on profile-log-likelihood method

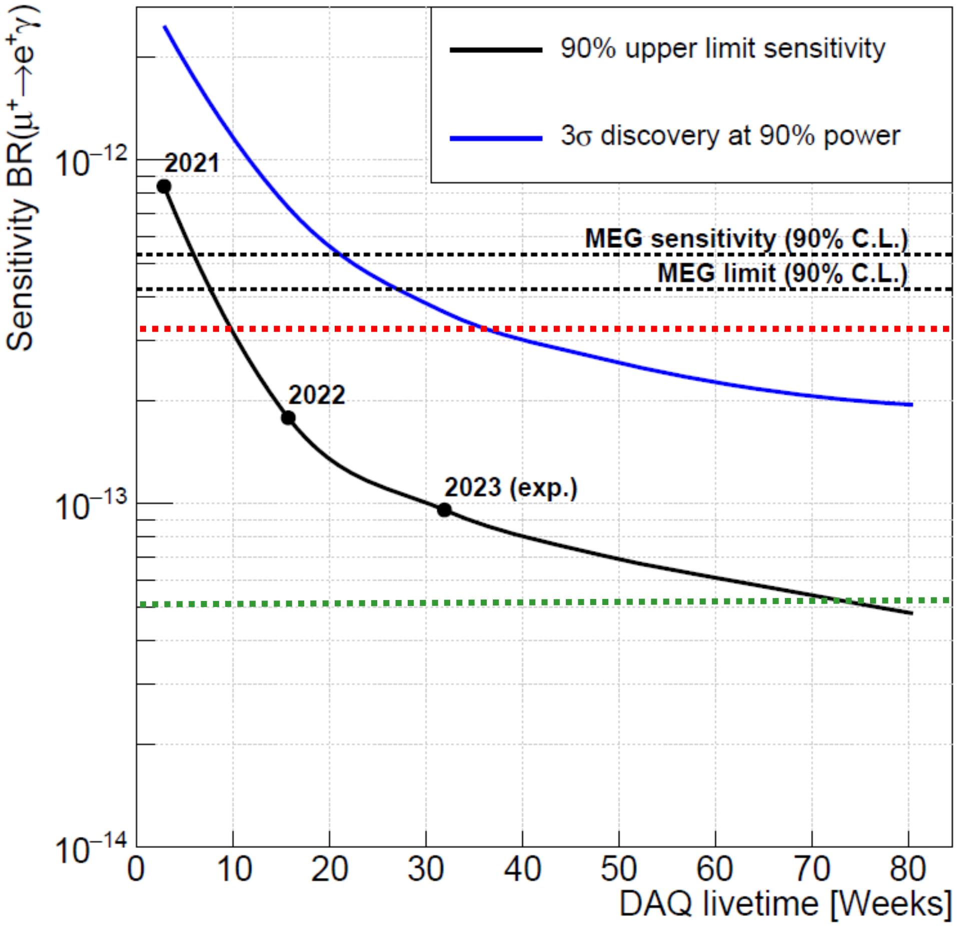
90% C.L corresponds to 1.35 in vertical scale, but we use 1.6 (more conservative) since profile-log-likelihood method usually underestimates the UL by $(10-15)$ % wrt Feldman-Cousins prescription.

On combined curve:

$$BR(\mu^+ \to e^+\gamma) \leq 3.1 \times 10^{-13}$$

Future MEGII Sensitivity

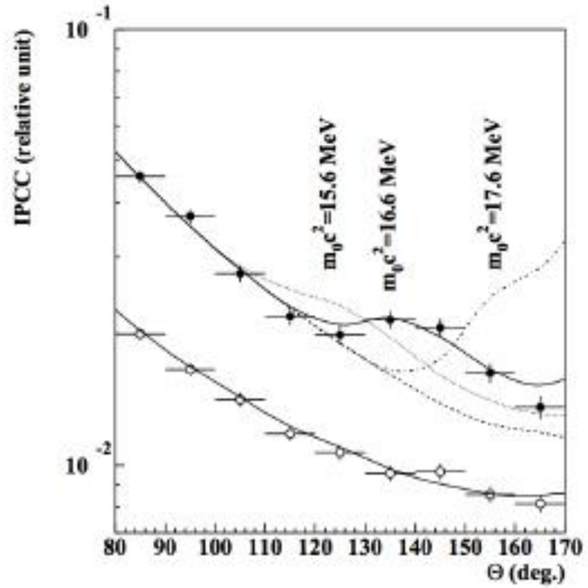
An order of magnitude improvement in sensitivity wrt MEG is expected in about 80 weeks of DAQ livetime.



MEG+MEGII combined limit (90% C.L.)

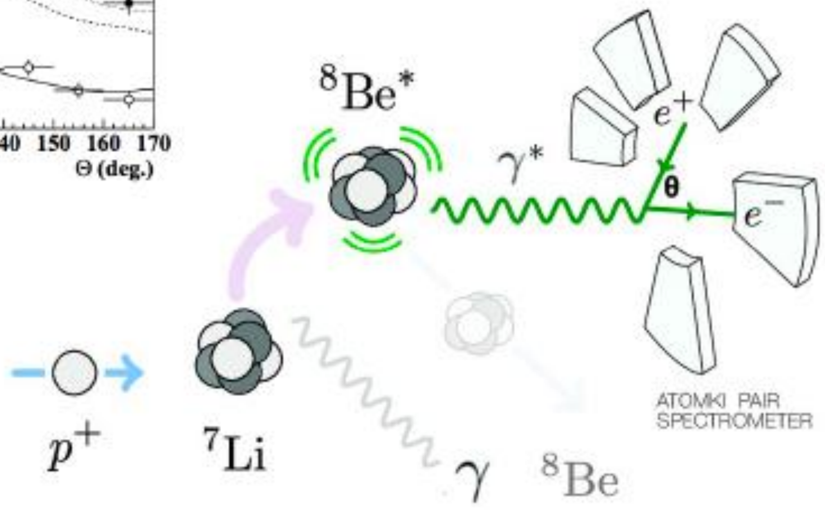
5×10^{-4} sensitivity

Other «exotic» searches: X17 1)



A. J. Krasznahorkay et al.,
Phys. Rev. Lett. **116** (2016) 042501
A. J. Krasznahorkay et al.,
Phys. Rev. C **104** (2021) 044003
J.L. Feng et al.,
Phys. Rev. D **95** (2017) 035017

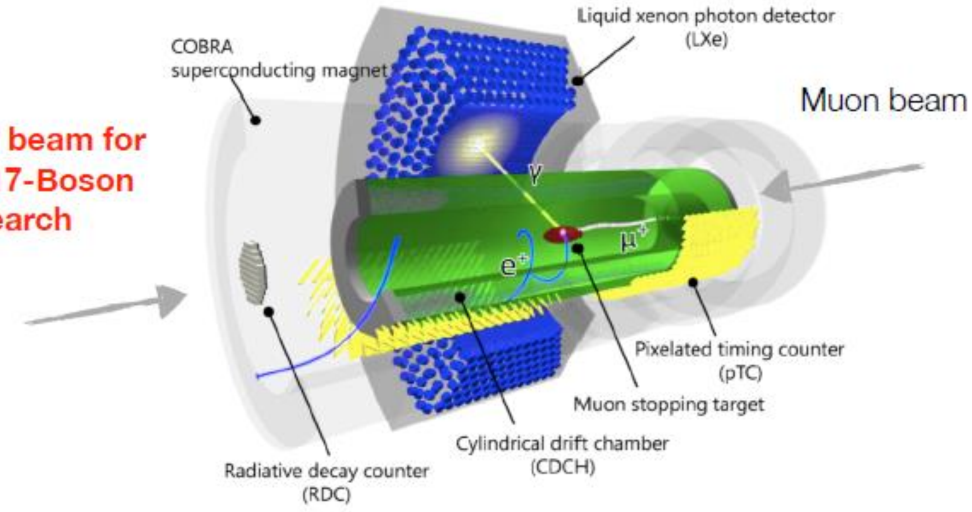
In 2016 the ATOMKI experiment reported an excess in the angular distribution of e^+e^- pairs in an inelastic interaction of protons on a Li target. This excess can be interpreted as due to the production of a 17 MeV boson «X17», mediator of an hypotethical fifth force.



In MEGII **we can search for X17** by using:

- ❖ CDCH + pTC spectrometer;
- ❖ Dedicated X17 target;
- ❖ Reduced magnetic field;
- ❖ CW accelerator proton beam;
- ❖ XEC detector;
- ❖ Dedicated trigger scheme;
- ❖ CDCH reconstruction code extended to search for two opposite charge particles.

Other «exotic» searches: X17 2)



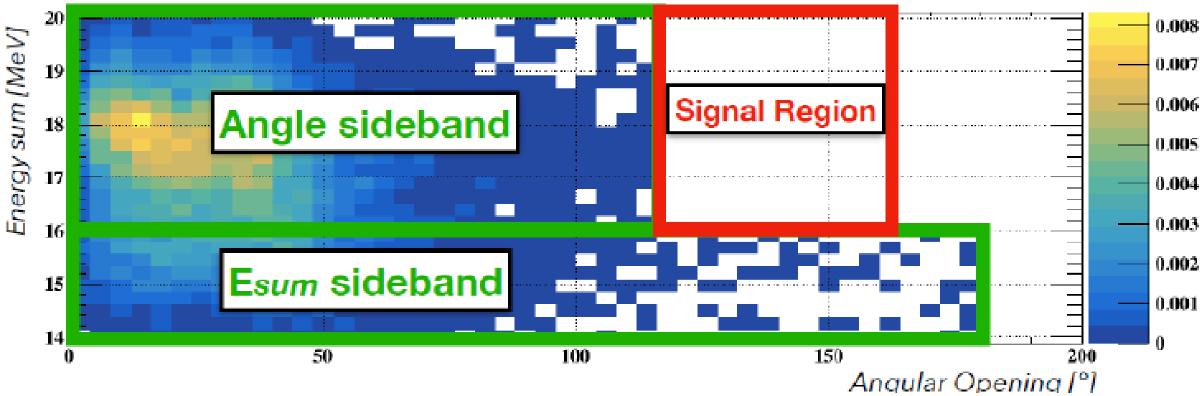
Preliminary studies in 2021/2022: beam, target, magnetic field, DAQ, analysis codes, background/signal simulation …

Main backgrounds: e^+e^- pairs produced by γ conversions on material (**EPC**, **E** = **E**xternal) or inner bremsstrahlung (**IPC**, **I** = **I**nternal).

First dedicated data taking in 2023.

Analysis ongoing, **blind + likelihood strategy**

- **Higher invariant mass resolution**
- **Full solid angle production**



$(E_{e^-} + E_{e^+})$
vs
$\Delta\Theta_{e^+e^-}$

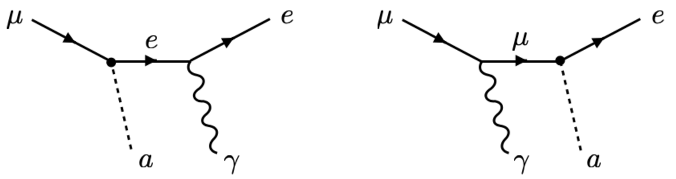
blinding plane

Other «exotic» searches: Axion Like Particles

The Axion Like Particles (**ALP**) are pseudoscalar bosons, not present in SM and with feeble coupling with SM particles ⇒ **ALP detection would be signature for New Physics**.

ALP can be searched in MEGII looking at CLFV decay:

$\boldsymbol{\mu^+ \to e^+ a \gamma}$



Three body decay, with $e^+ + \gamma$ pair not back-to-back

⇓

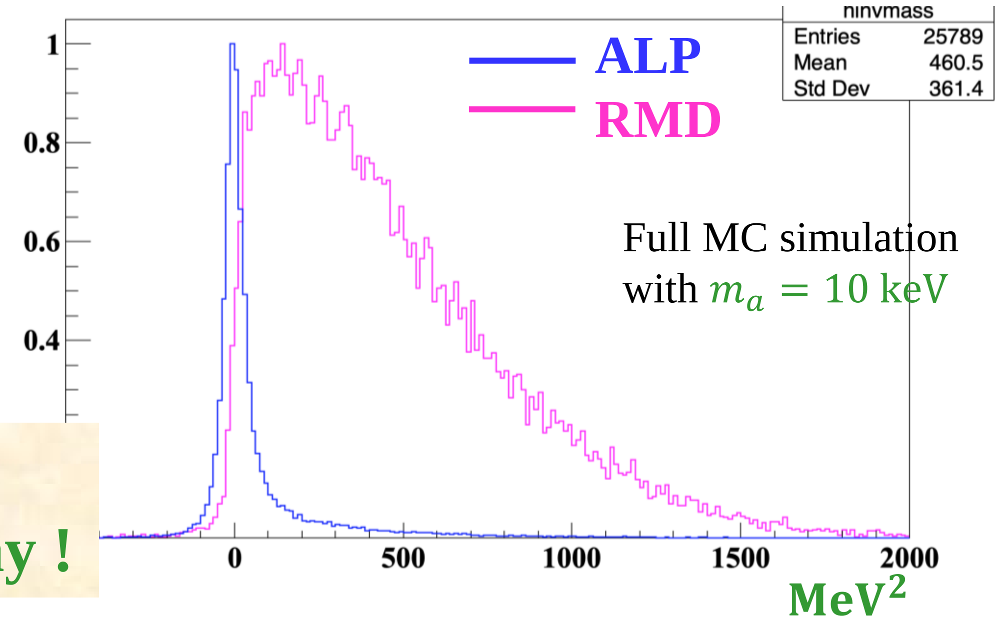
Different DAQ and analysis strategy wrt $\mu^+ \to e^+\gamma$:

- Lower energy cut (→ 10 MeV);
- Release back-to-back topological cut;
- Reduce beam intensity ($\to 1 \times 10^6\ \mu/s$)

Main background: RMD events.

Search for **a peak in invariant mass distribution**:

$$m_a^2 \approx m_\mu^2 - 2m_\mu(E_\gamma + E_{e^+}) + 4E_\gamma E_{e^+} \sin^2\left[\frac{\Theta_{e\gamma}}{2}\right]$$



See E. Grandoni's thesis next Monday !

Conclusions

- The MEG experiment established in 2016 **the best world upper limit** on $\boldsymbol{BR(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13}}$ (90% C.L.), with sensitivity = 5.3×10^{-13}.
- The MEGII detector has efficiencies and resolutions $(2 \div 4) \times$ better than the MEG ones and can be operated at beam intensities up to $5 \times 10^{7}\ \mu/\mathrm{s}$.
- MEGII is taking data since 2021 and the amount of data collected until now is larger than the full MEG sample.
- The analysis of physics runs in 2021 showed no evidence of $\mu^+ \rightarrow e^+\gamma$ decay and **an upper limit of $\boldsymbol{7.5 \times 10^{-13}}$** was set. Combining this result with the MEG upper bound with the profile-log-likelihood method gives **a combined UL of $\boldsymbol{3.1 \times 10^{-13}}$ (90% C.L.).**
- MEGII data taking is foreseen until 2026 (with possible "interference" with another experiment); **the expected final sensitivity of the experiment is $\boldsymbol{(5 \div 6) \times 10^{-14}}$**.

Thanks for your attention