Beryllium anomaly search with the MEGII experiment at PSI

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“Shedding light on the X17” workshop

Content

- cLFV with the MEGII experiment:
  The $\mu^+ \to e^+\gamma$ decay search at PSI

- Beryllium anomaly search with the MEGII apparatus: Status

Content

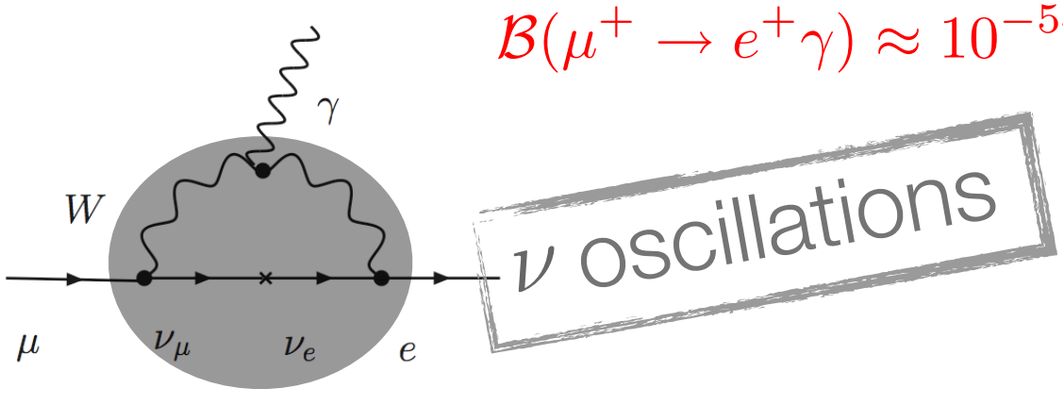
- **cLFV with the MEGII experiment: The $\mu^+ \to e^+\gamma$ decay search at PSI**

- Beryllium anomaly search with the MEGII apparatus: Status

Charged lepton flavour violation search: Motivation

SM with massive neutrinos (Dirac)

$\mathcal{B}(\mu^+ \to e^+\gamma) \approx 10^{-54}$

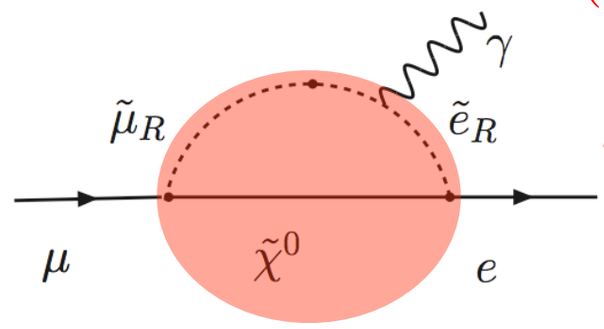


ν oscillations

too small to access experimentally

BSM

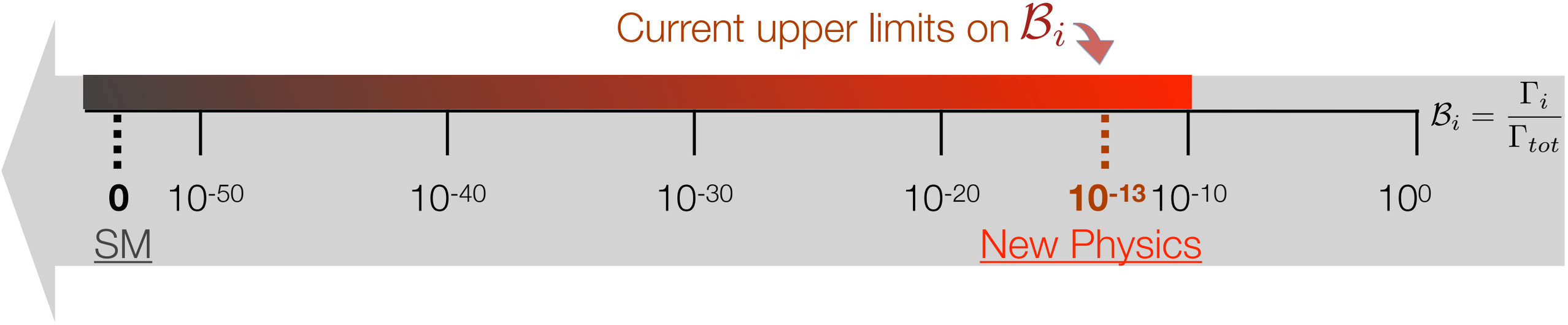
$\mathcal{B}(\mu^+ \to e^+\gamma) \gg 10^{-54}$



New particles

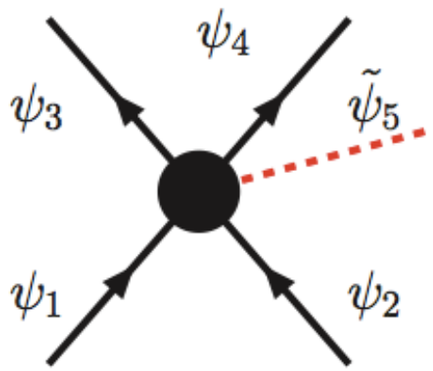
an experimental evidence:
a clear signature of New Physics NP
(SM background FREE)

Current upper limits on $\mathcal{B}_i$



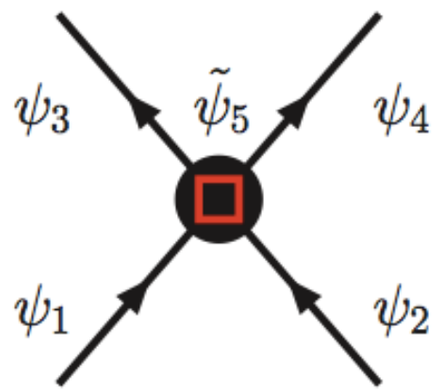
Complementary to “Energy Frontier”

Energy frontier



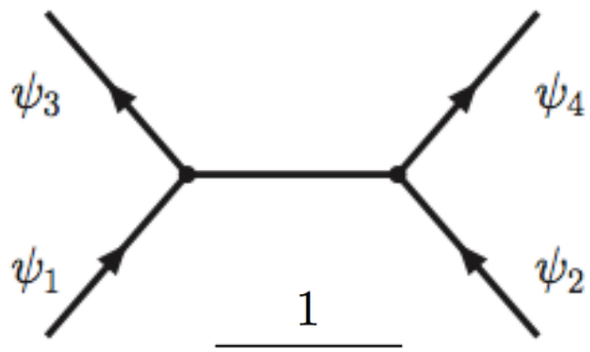
Real BSM particles

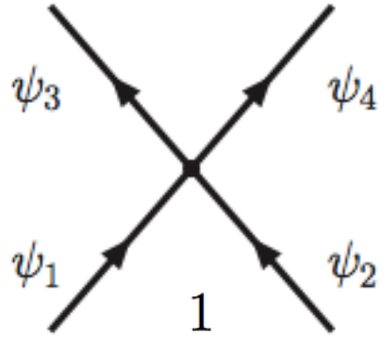
Precision and intensity frontier



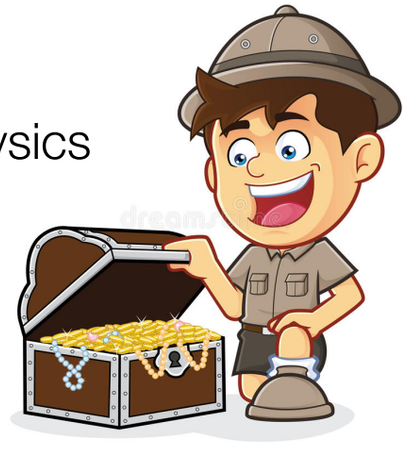
Virtual BSM particles

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{d>4} \frac{c_n^{(d)}}{\Lambda^{d-4}} \mathcal{O}^{(d)}$$





Unveil new physics



Probe energy scale otherwise unreachable

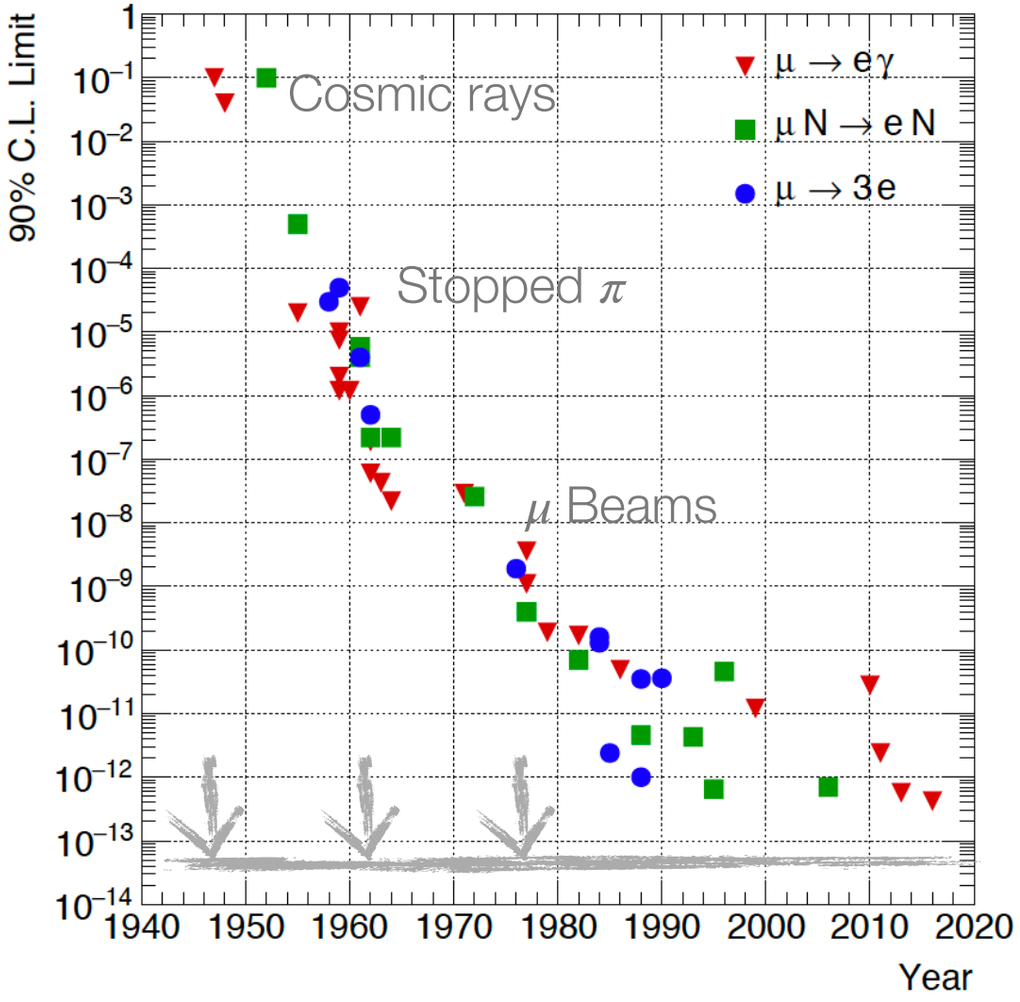
E > 1000 TeV

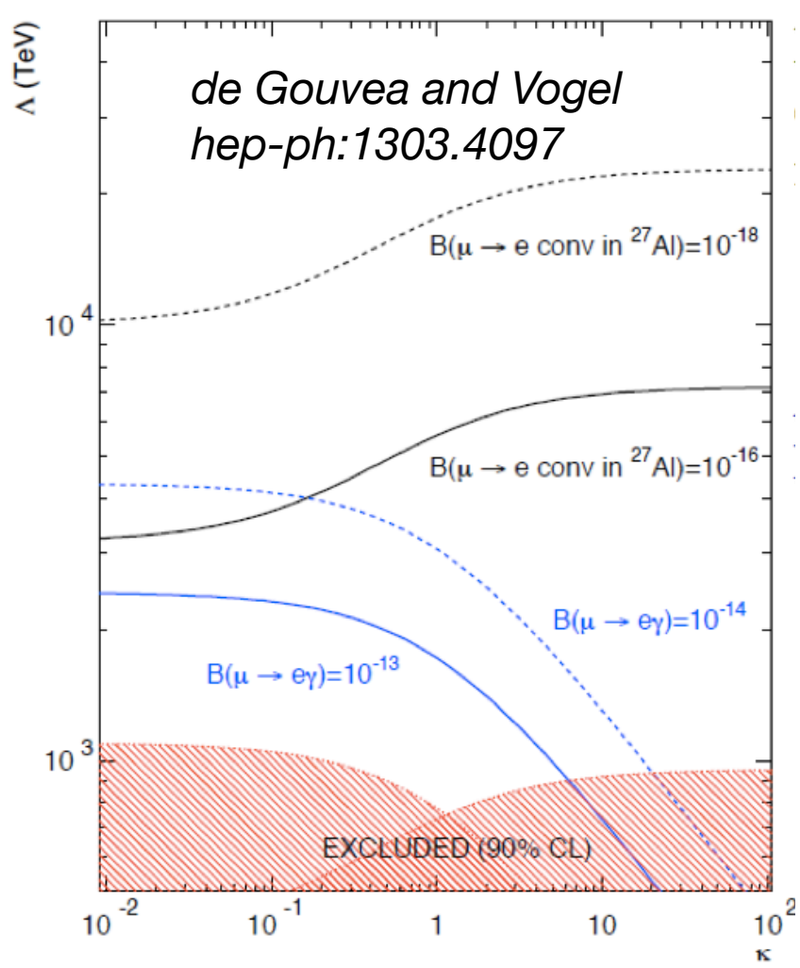
cLFV searches with muons: Status and prospects

- In the near future impressive sensitivities:

	Current upper limit	Future sensitivity
$\mu \to e\gamma$	4.2 x 10^{-13}	~ 6 x 10^{-14}
$\mu \to eee$	1.0 x 10^{-12}	~1.0 x 10^{-16}
$\mu N \to eN'$	7.0 x 10^{-13}	few x 10^{-17}

- Strong complementarities among channels: The only way to reveal the mechanism responsible for cLFV



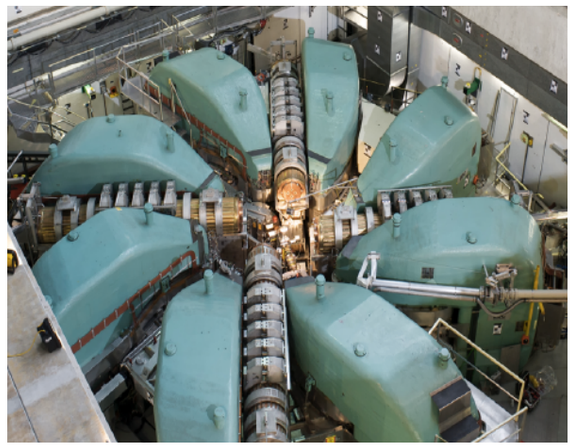


The world's most intense continuous muon beam

- τ ideal probe for NP w. r. t. μ
  - Smaller GIM suppression
  - Stronger coupling
  - Many decays
- μ most sensitive probe
  - Huge statistics

- PSI delivers the most intense continuous low momentum muon beam in the world (**Intensity Frontiers**)
- MEG/MEG II/Mu3e beam requirements:
  - Intensity O(10^8 muon/s), low momentum p = 29 MeV/c
  - Small straggling and good identification of the decay

590 MeV proton ring cyclotron
1.4 MW



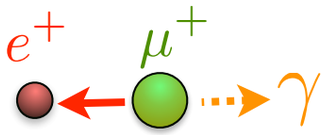
PSI landscape

A.M. Baldini et al. (MEG Collaboration),
Eur. Phys. J. C73 (2013) 2365

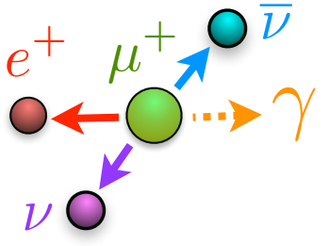
MEG: Signature and experimental setup

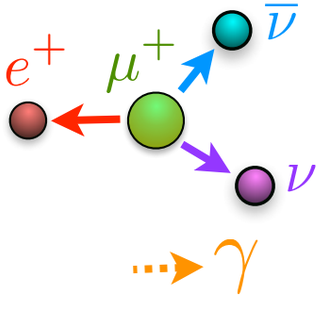
- The MEG experiment aims to search for $\mu^+ \rightarrow e^+ \gamma$ with a sensitivity of $\sim 10^{-13}$ (previous upper limit $BR(\mu^+ \rightarrow e^+ \gamma) \leq 1.2 \times 10^{-11}$ @90 C.L. by MEGA experiment)
- Five observables (E_g, E_e, t_{eg}, ϑ_{eg}, ϕ_{eg}) to characterize $\mu \rightarrow e\gamma$ events

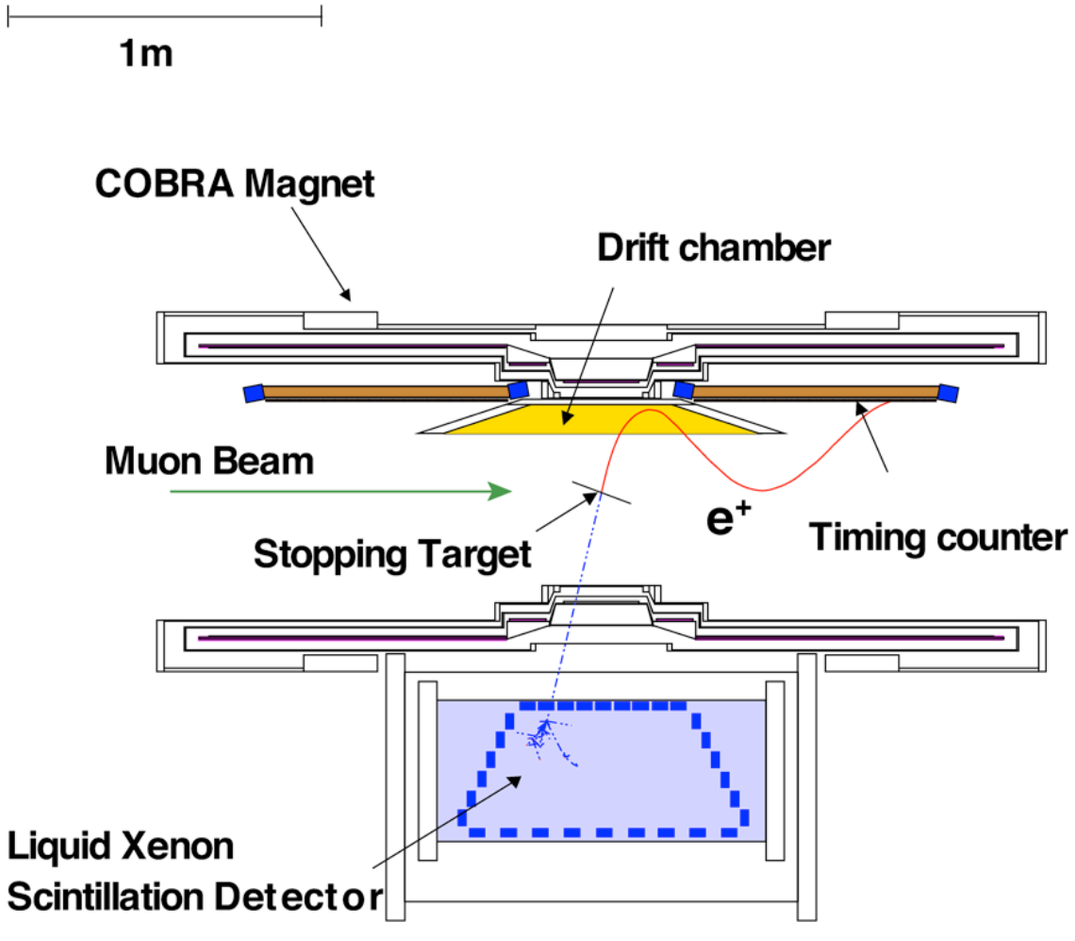
Signature

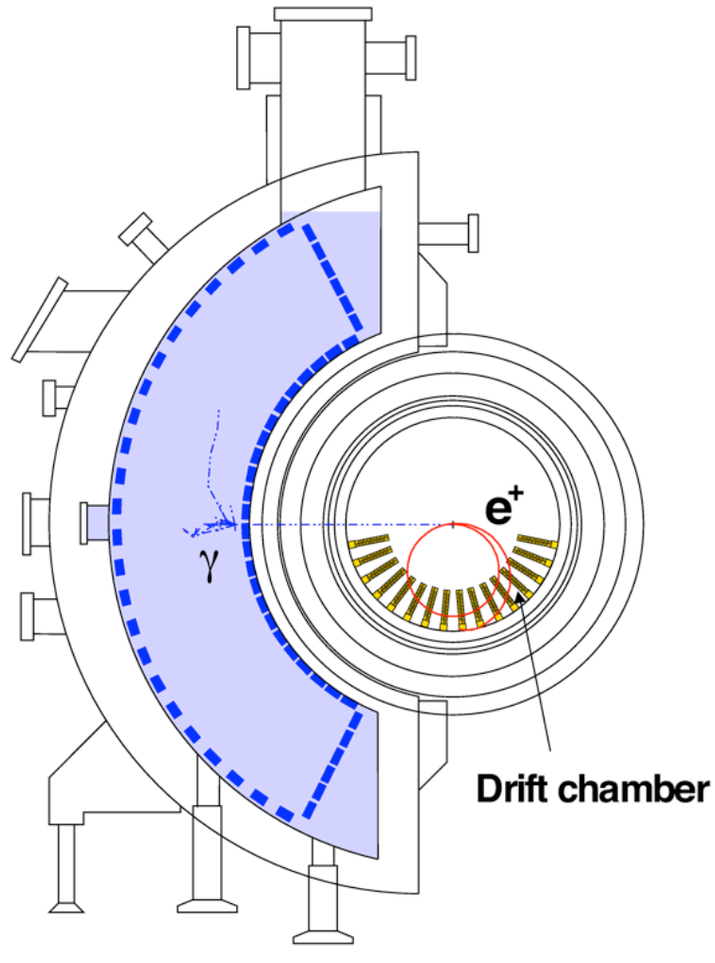


Backgrounds



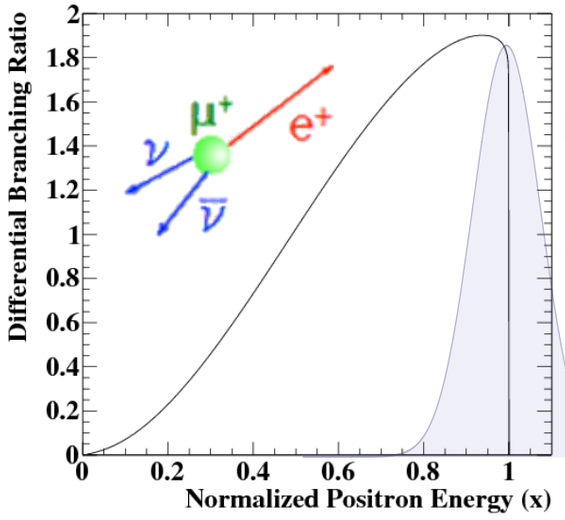


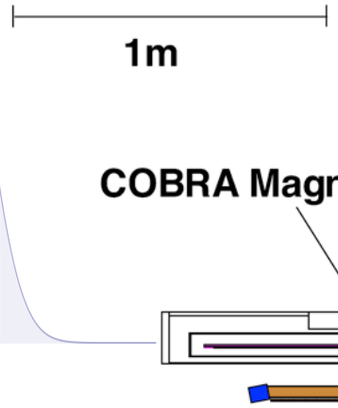


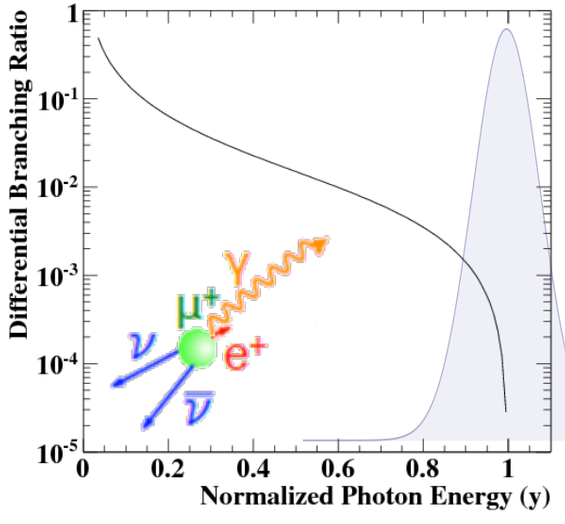


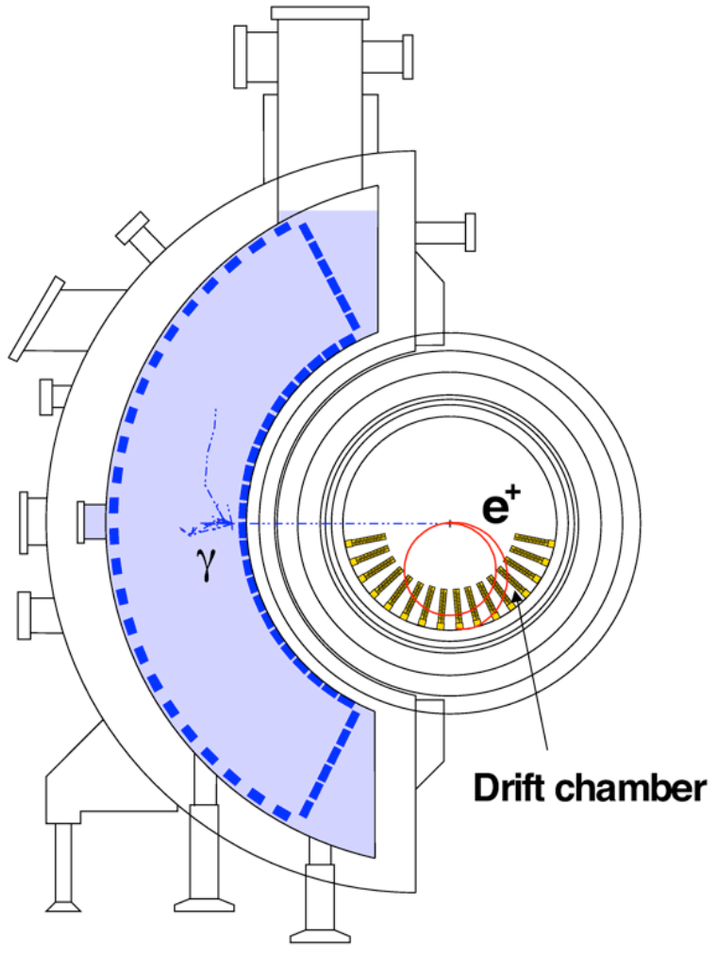
MEG: The key elements

1. The world's intense low momentum muon beam stopped in a thin and slanted target
2. The gradient field e^+-spectrometer
3. The innovative Liquid Xenon calorimeter
4. The full waveform based DAQ (digitization up to 1.6 GSample/s)
5. Complementary calibration and monitoring methods









A. M. Baldini et al. (MEG Collaboration),
Eur. Phys. J. C76 (2016) no. 8, 434

MEG: The result

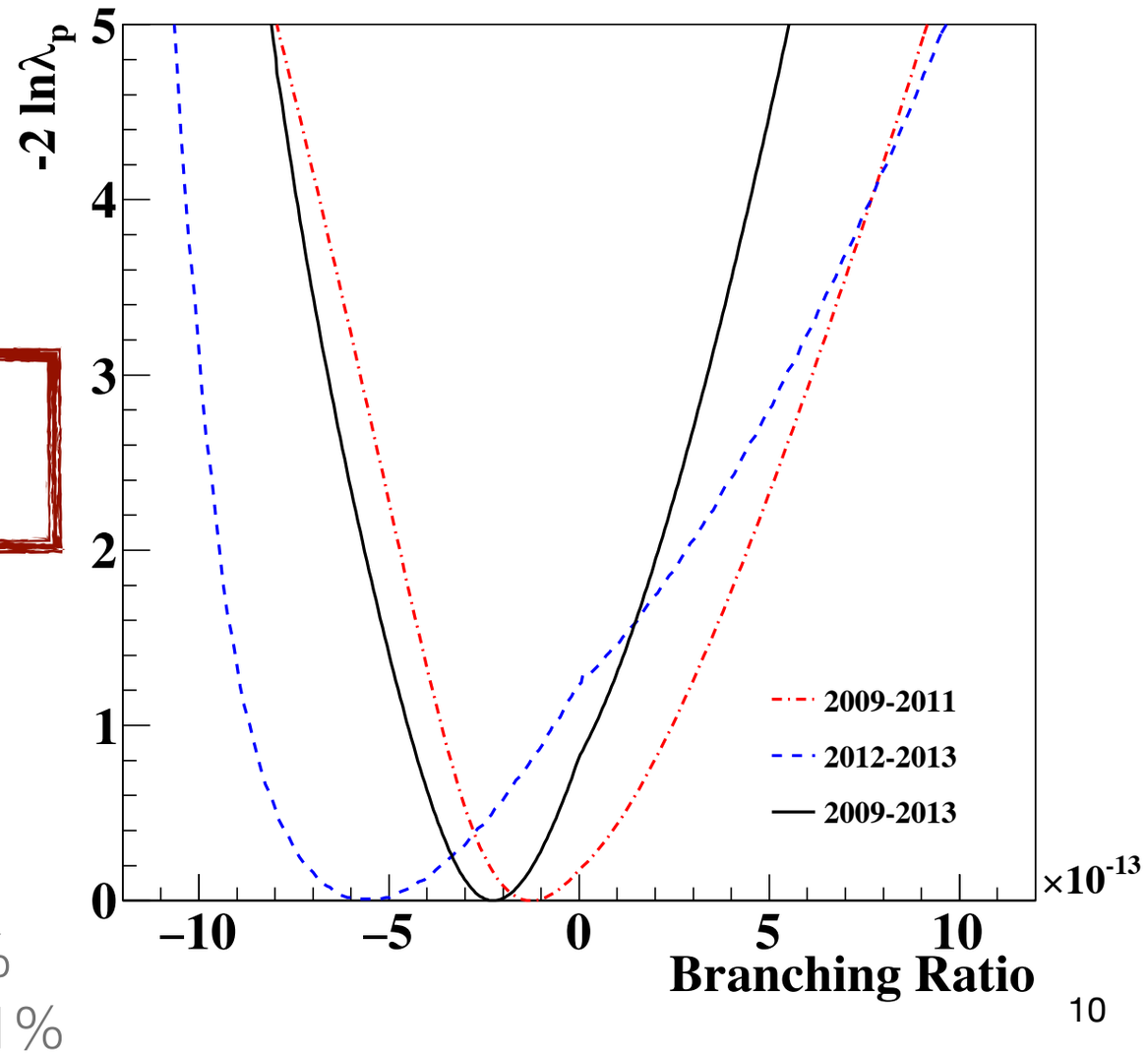
- Confidence interval calculated with Feldman & Cousin approach with profile likelihood ratio ordering
- Profile likelihood ratios as a function of the BR: all consistent with a null-signal hypothesis

Full data sample: 2009-2013
Best fitted branching ratio at 90% C.L.:

$$\mathcal{B}(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$$

From MEGA to MEG:

improvement by a factor ~ 30



Systematic uncertainties: Target “alignment”: 5%
Other sources: < 1%

How the sensitivity can be pushed down?

- More sensitive to the signal...

high statistics

$$SES = \frac{1}{R \times T \times A_g \times \varepsilon(e^+) \times \varepsilon(\text{gamma}) \times \varepsilon(TRG) \times \varepsilon(sel)}$$

R: Beam rate; T: Acquisition time; A_g: Geometrical acceptance; $\varepsilon(e^+)$: Detector efficiency; $\varepsilon(\text{gamma})$: Detector efficiency; $\varepsilon(TRG)$: Selection efficiency; $\varepsilon(sel)$: Selection efficiency

- More effective on rejecting the background...

high resolutions

$$B_{acc} \sim R \times \Delta E_e \times (\Delta E_{gamma})^2 \times \Delta T_{egamma} \times (\Delta \Theta_{egamma})^2$$

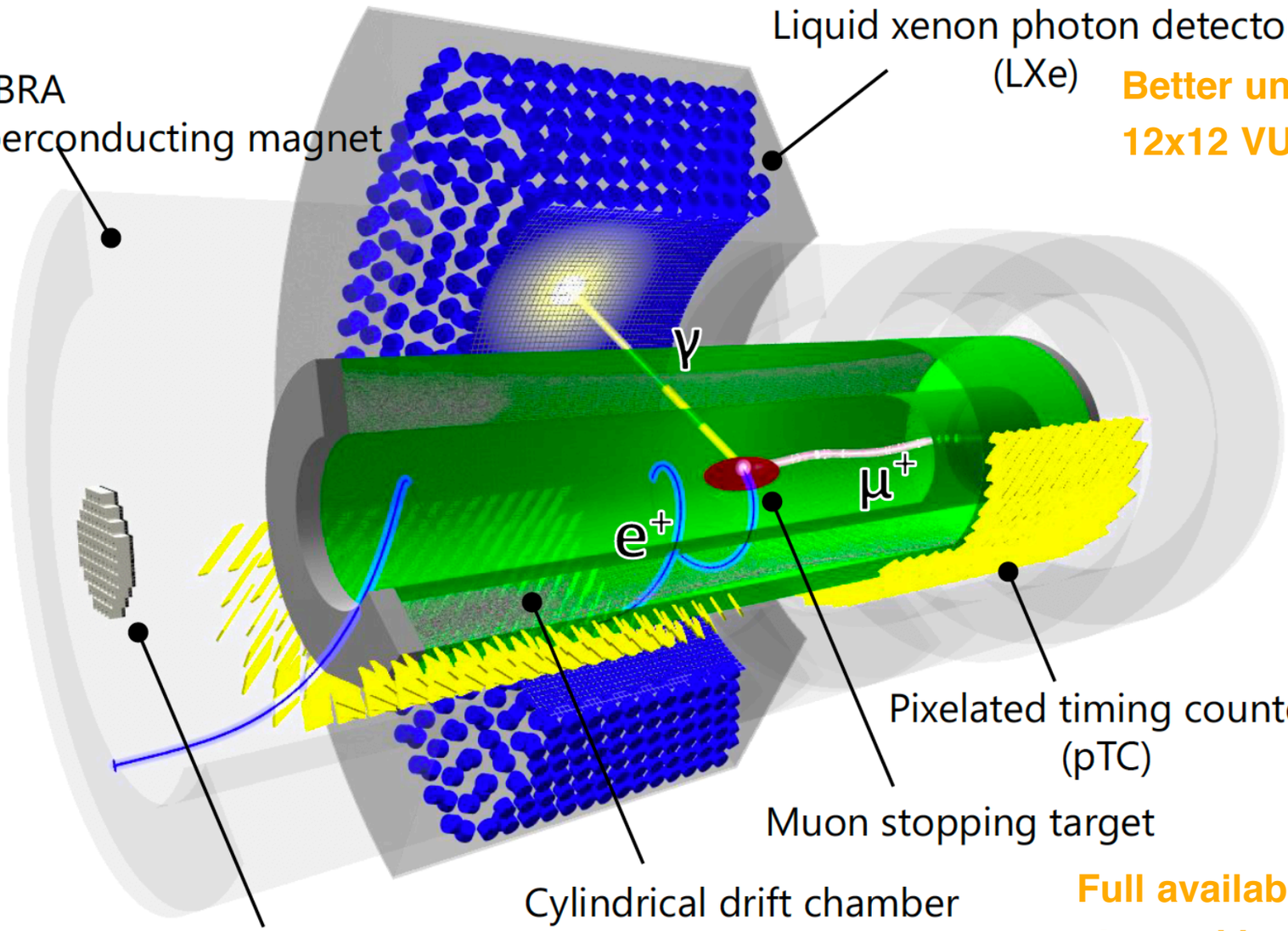
ΔE_e: Positron Energy resolution; ΔE_{gamma}: Gamma Energy resolution; ΔT_{egamma}: Relative timing resolution; $\Delta \Theta_{egamma}$: Relative angular resolution

A.M. Baldini et al. (MEGII collab.)
Eur. Phys. J. 78 (2018) 380

The MEGII experiment

New electronics:
Wavedream

~9000 channels at 5GSPS



Better uniformity w/ 12x12 VUV SiPM

x2 Resolution everywhere

x2 Beam Intensity

Updated and new Calibration methods

Quasi mono-chromatic positron beam

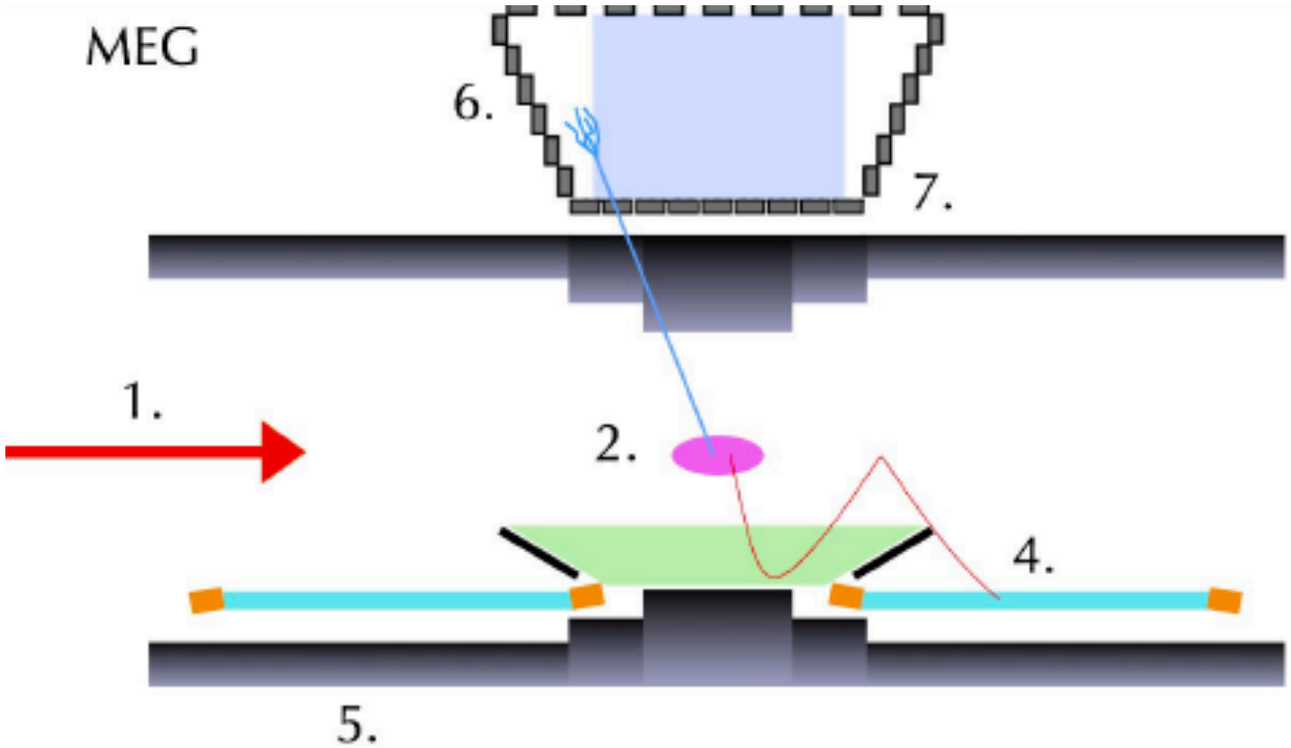
35 ps resolution w/ multiple hits

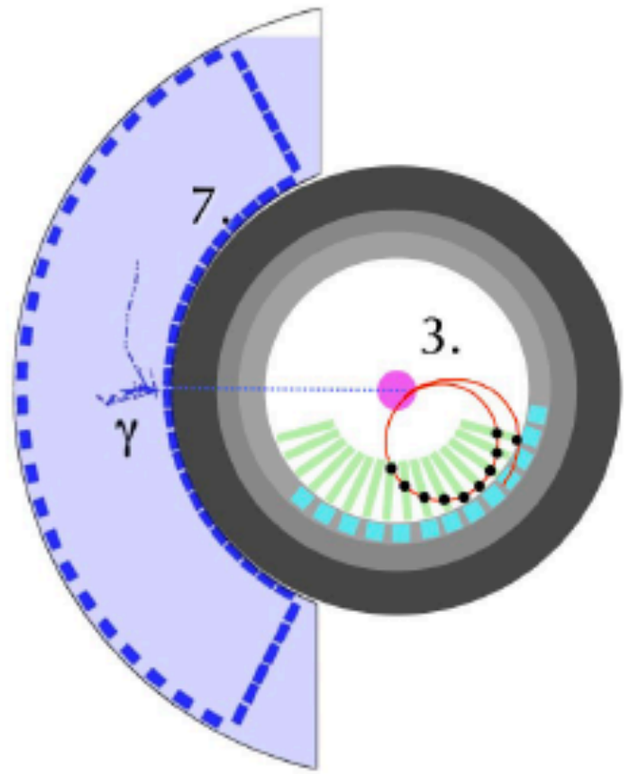
Background rejection

Single volume He:iC_4H_{10}

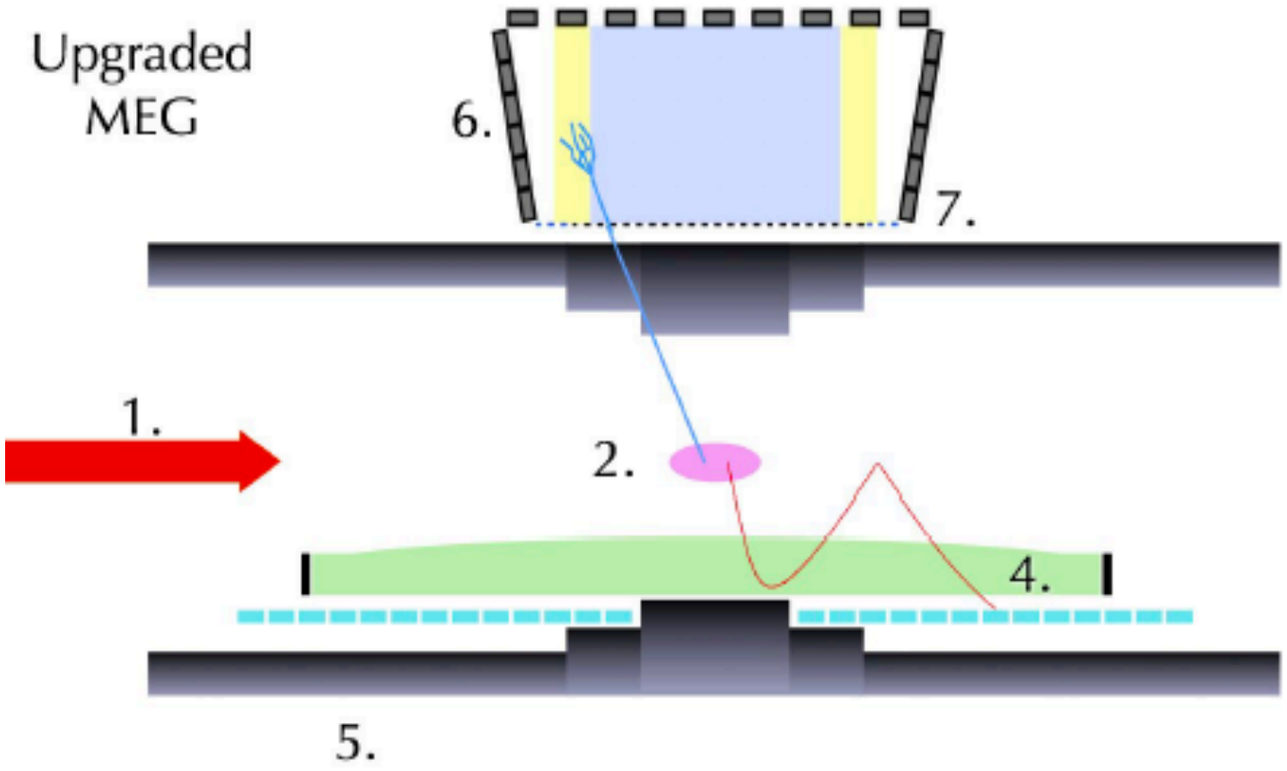
Full available stopped beam intensity 7 x 10^7

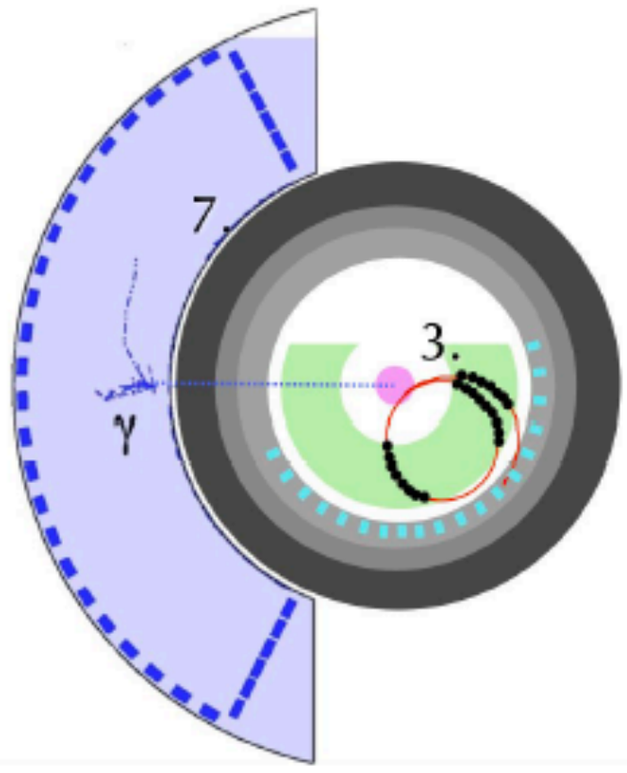
The MEG experiment vs the MEGII experiment



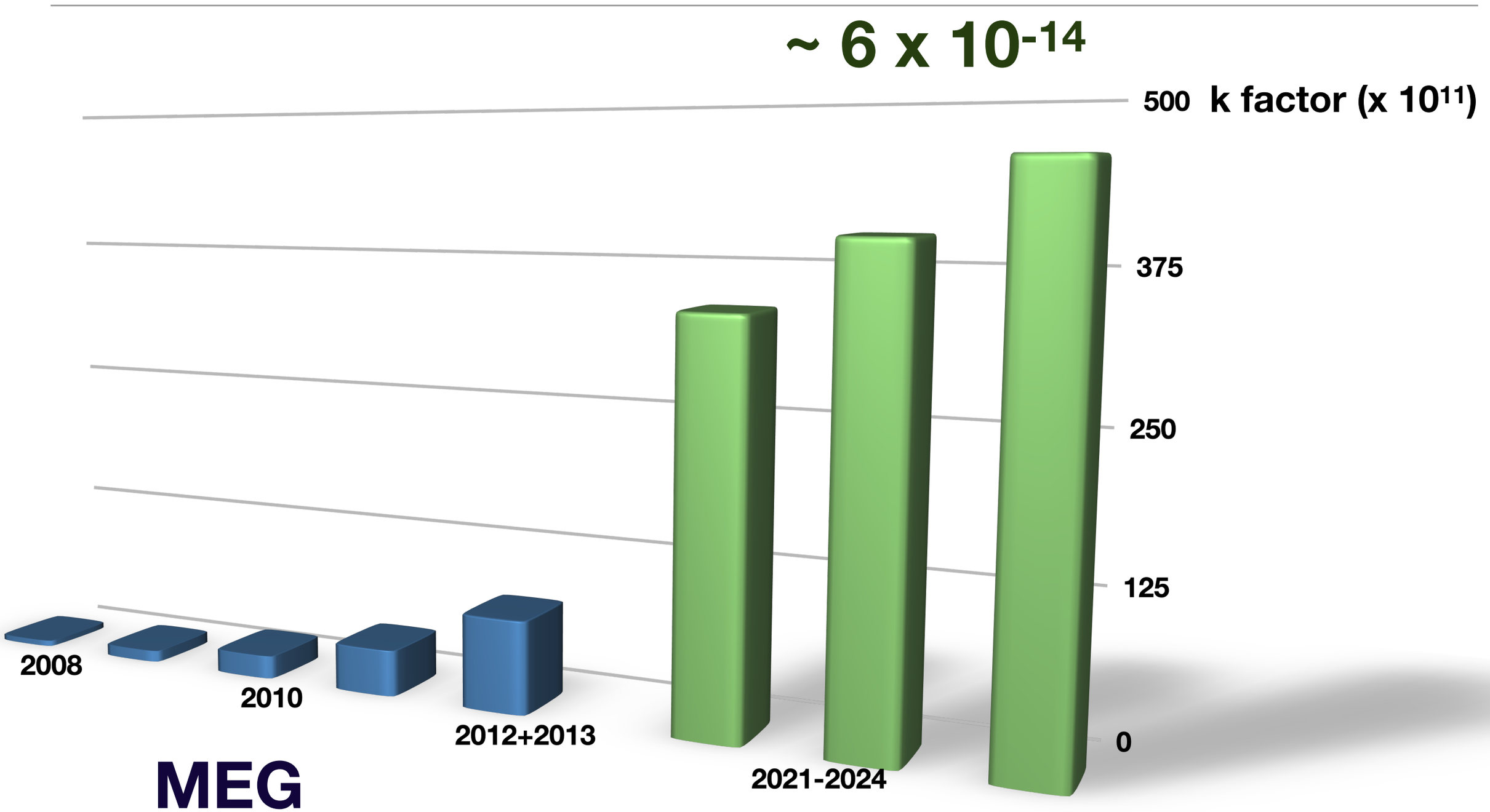


The MEG experiment vs the MEGII experiment

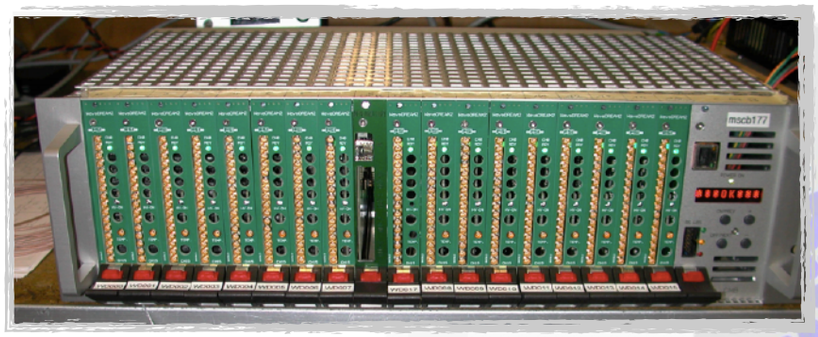


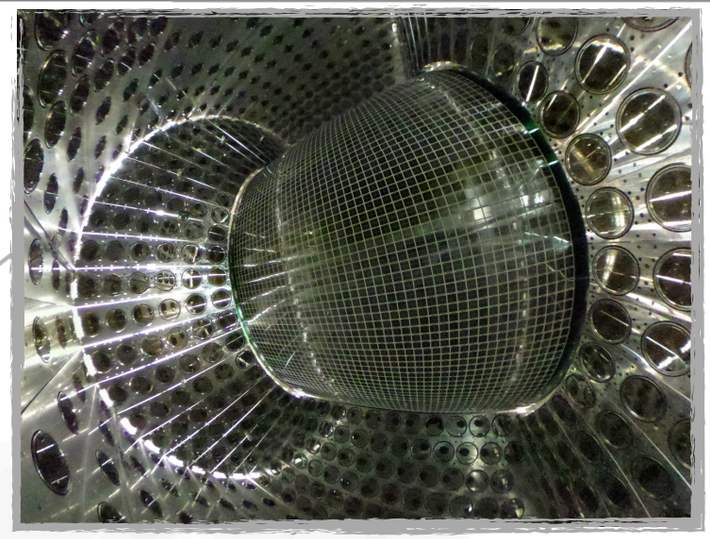


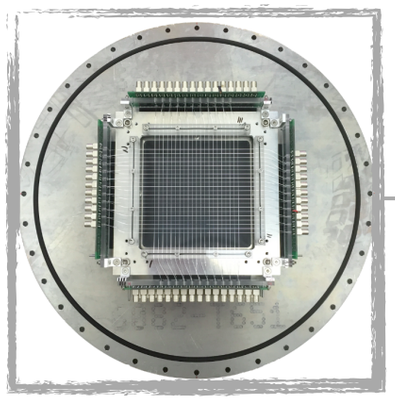
Where we will be

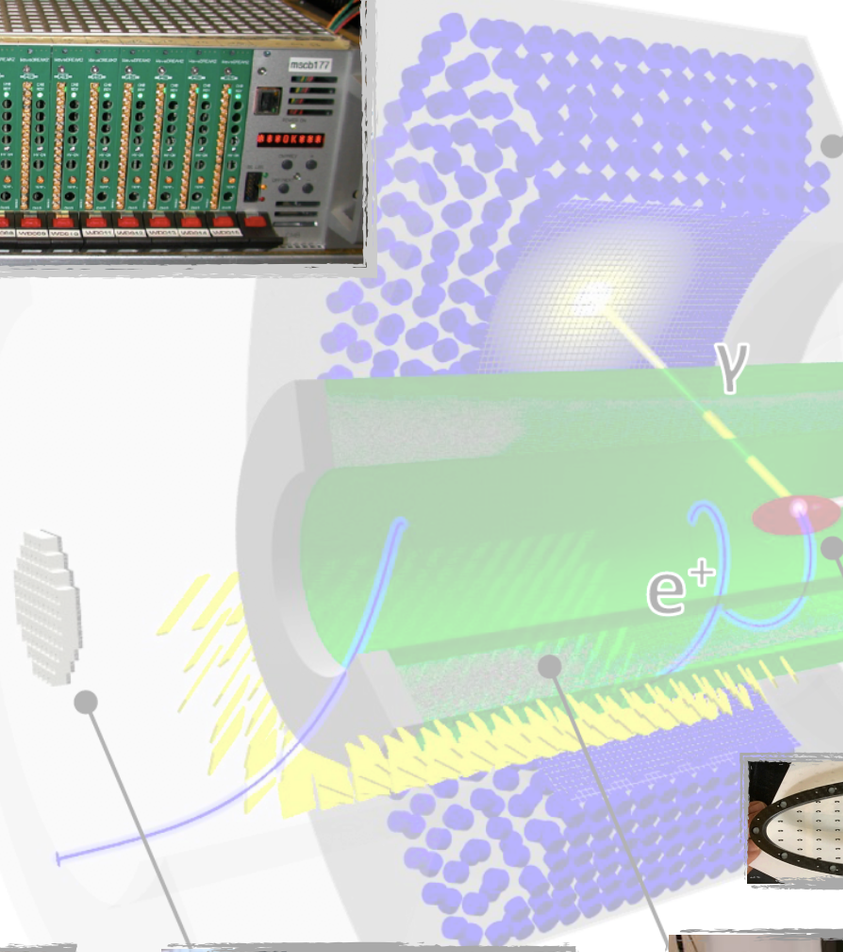


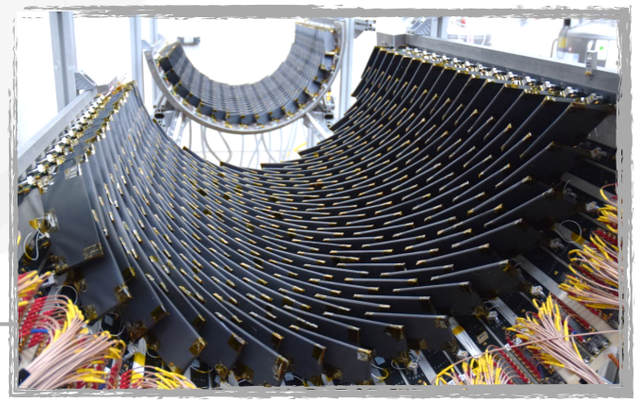
Where we are: eng run/physics run 2021

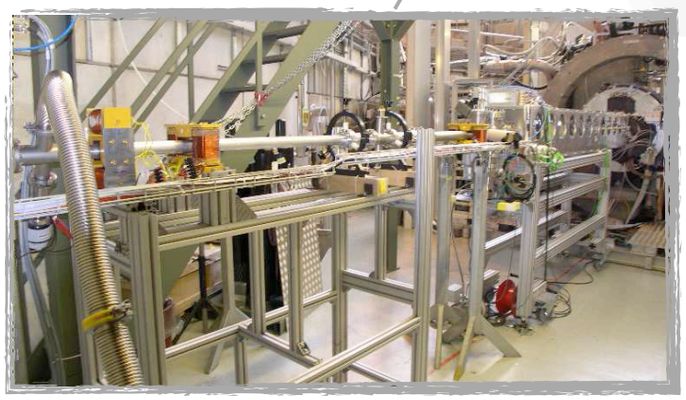


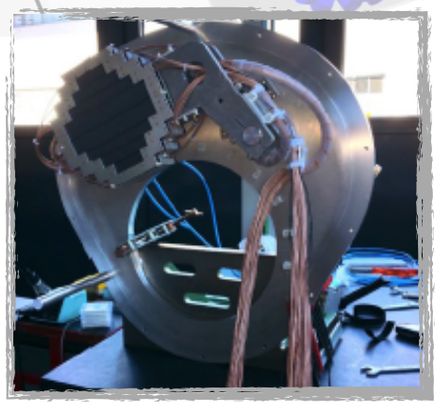


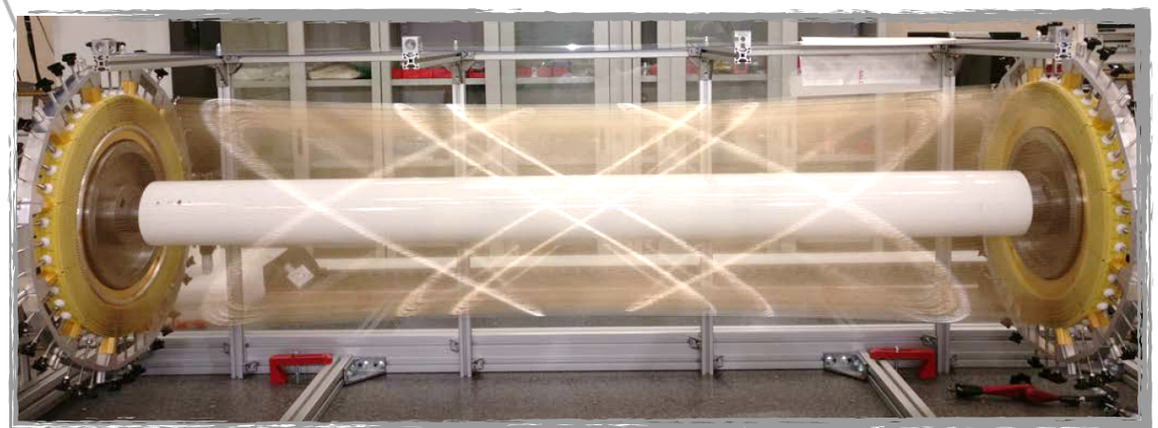










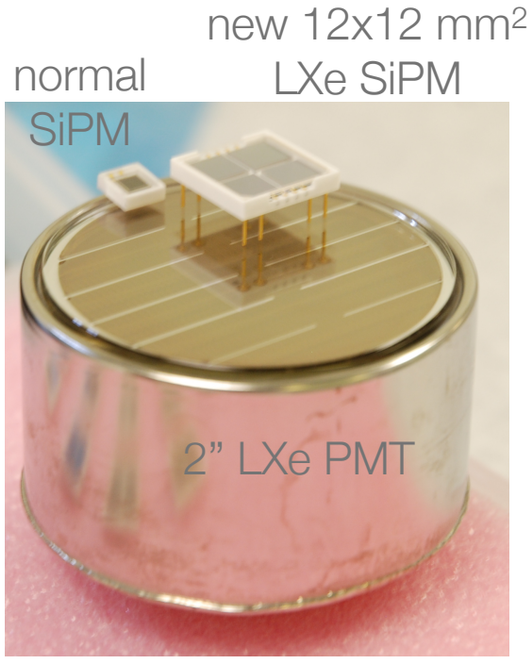


MEGII: The new electronic - DAQ and Trigger

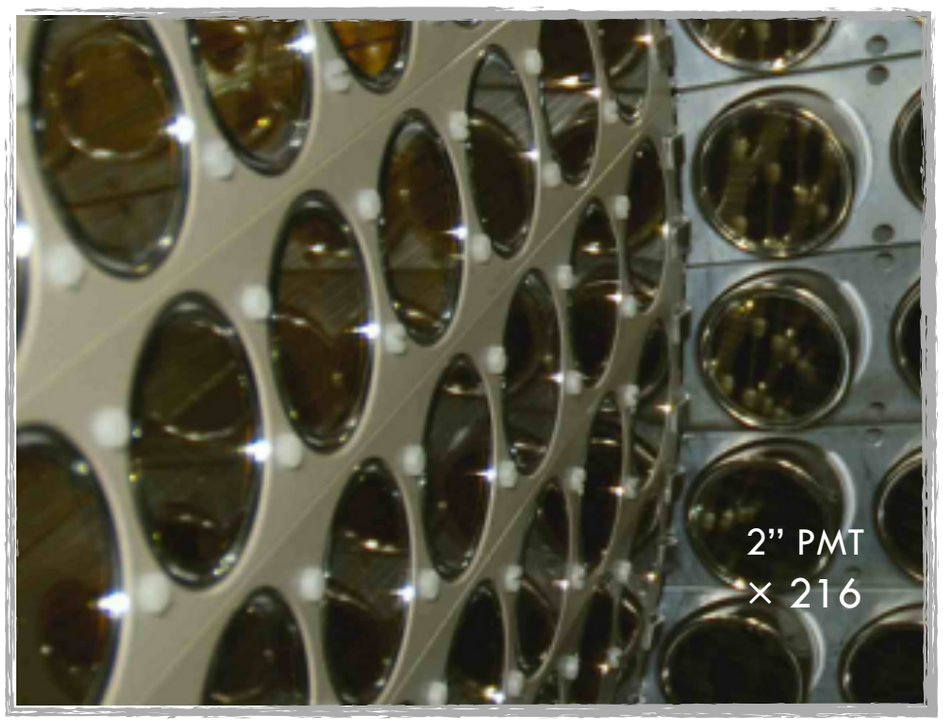
- Full electronics (DAQ and Trigger) installed
  - ~9000 channels (up to 5 GSPS)
  - Bias voltage, preamplifiers and shaping included for SiPMs
- Trigger electronics and several trigger algorithms included and successfully delivered for the test beams/engineering run

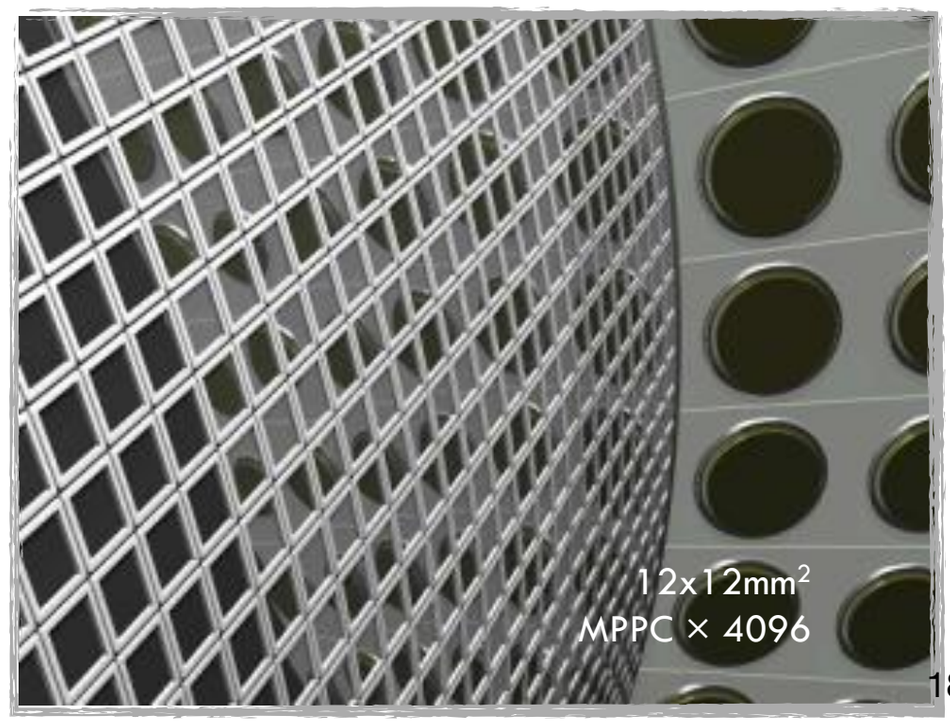
MEGII: The upgraded LXe calorimeter

- Increased uniformity/resolutions
- Increased pile-up rejection capability
- Increased acceptance and detection efficiency
- Assembly: Completed
- Detector filled with LXe
- Purification: Ongoing
- Monitoring and calibrations: Ongoing



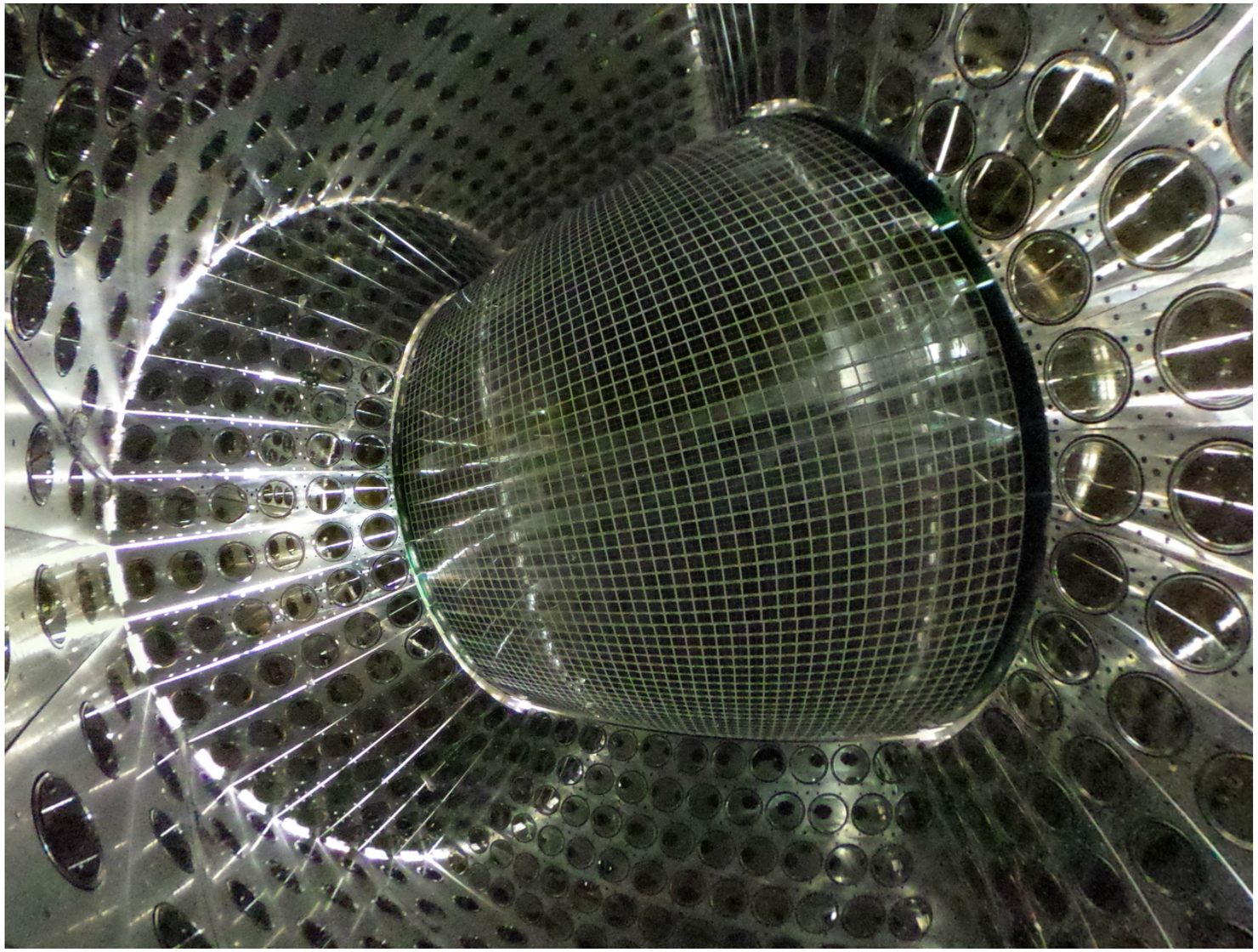
	MEG	MEGII
u [mm]	5	2.4
v [mm]	5	2.2
w [mm]	6	3.1
E [w<2cm]	2.4%	1.1%
E [w>2cm]	1.7%	1.0%
t [ps]	67	60



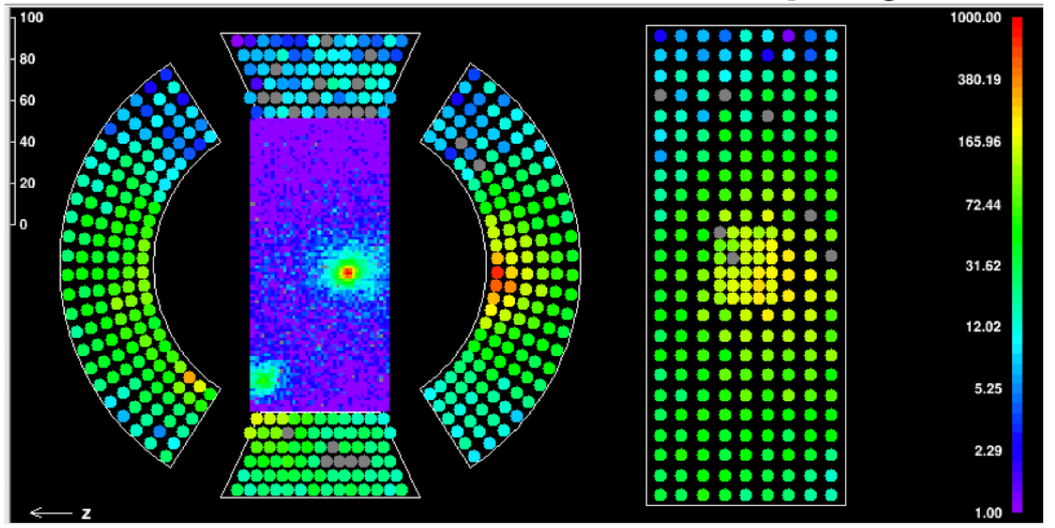


MEGII: The upgraded LXe calorimeter

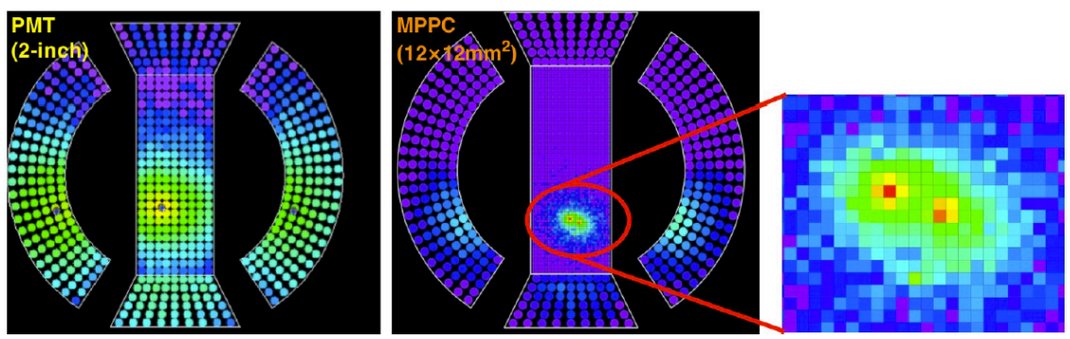
Detector commissioning: Ongoing



Data with muon beam (2021)



MC simulation

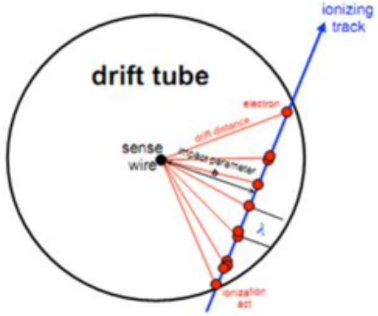


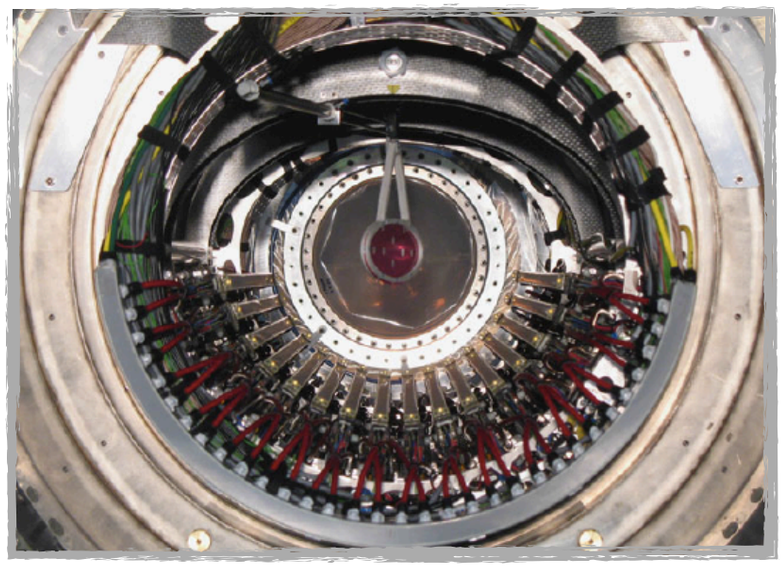
MEGII: The new single volume chamber

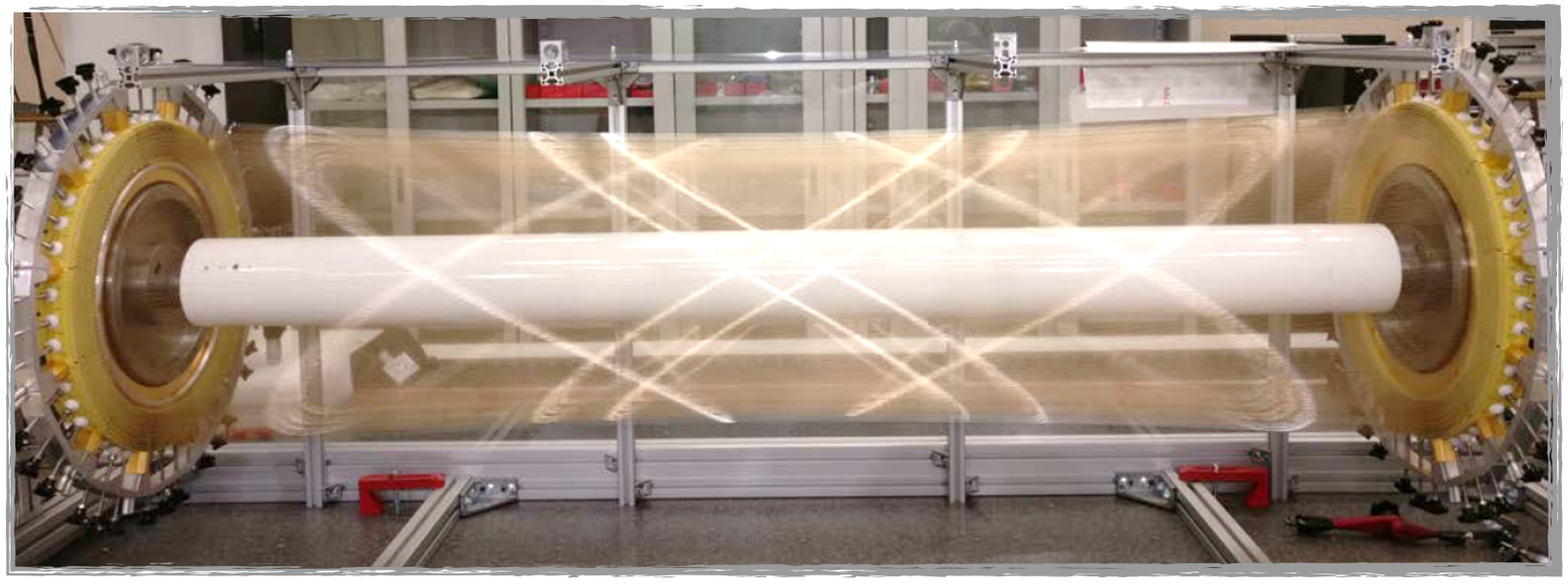
- Improved hit resolution: σ_r ~< 120 um (210 um)
- High granularity/Increased number of hits per track/ cluster timing technique
- Less material (helium: isobutane = 90:10, 1.6x10^{-3} X_0)
- High transparency towards the TC
- Status: Detector commissioning with muon beam ongoing

	MEG	MEGII
p [keV]	306	130
θ [mrad]	9.4	6.3
ϕ [mrad]	8.7	5.0
ϵ [%]*	40	70

(*) It includes also the matching with the Timing Counter



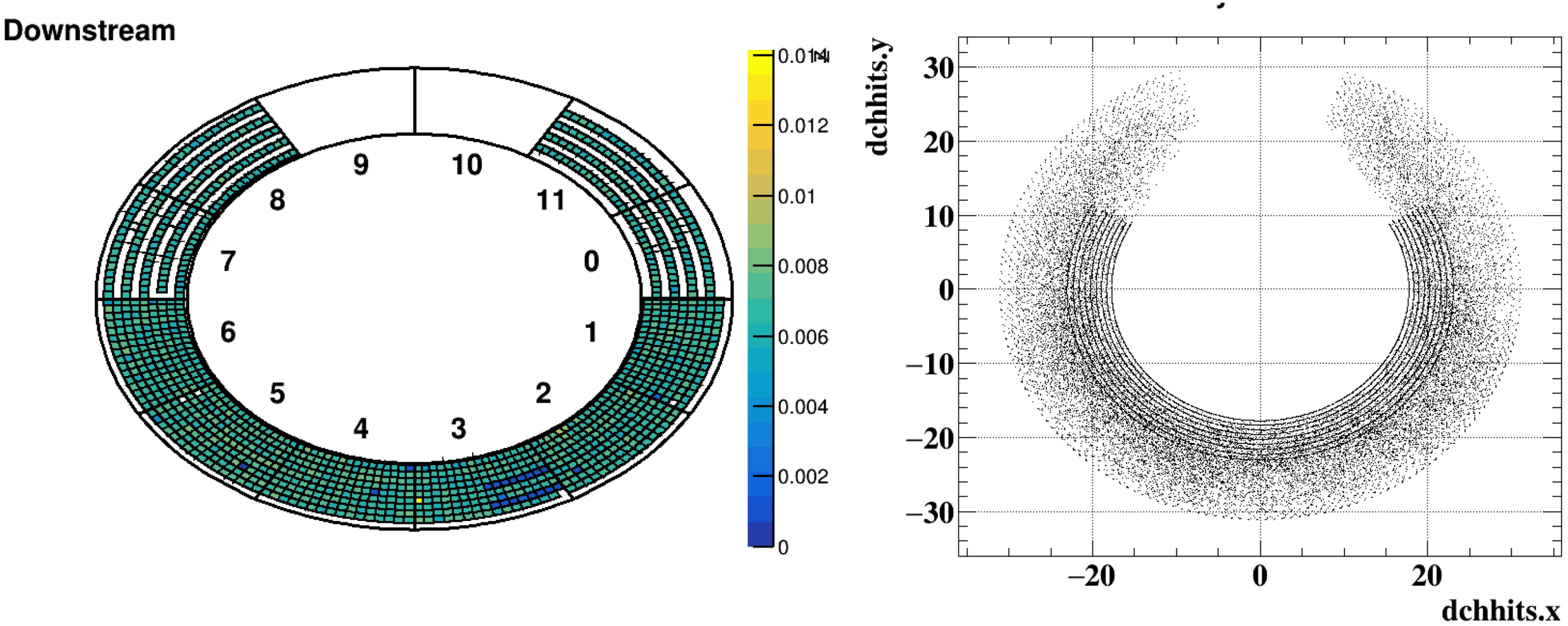




MEGII: The new single volume chamber

Detector commissioning: Ongoing

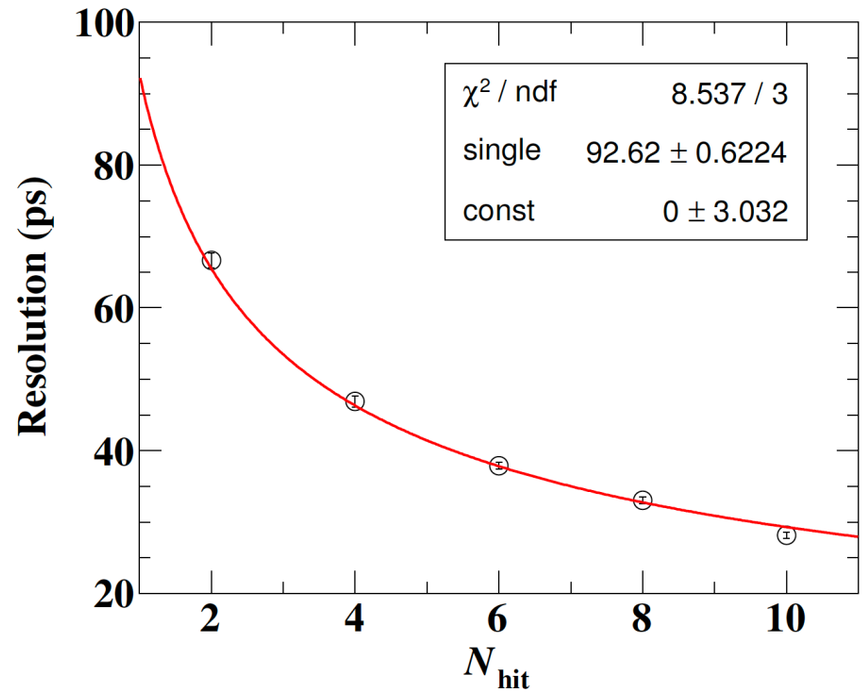
Data with calibration and muon beam (2021)

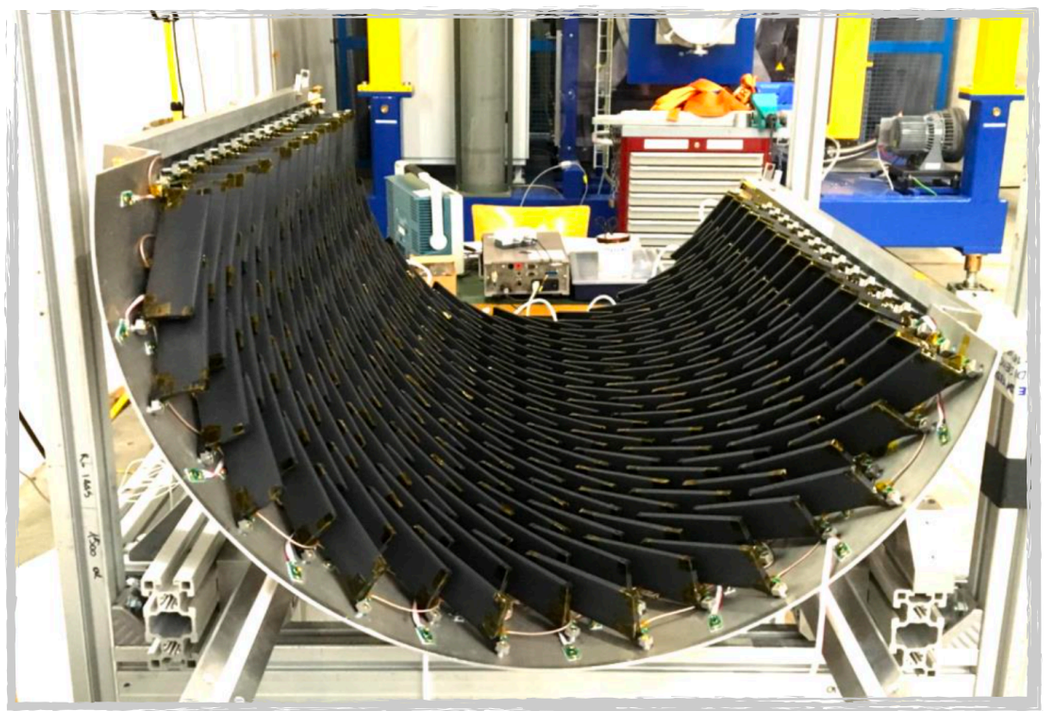


MEGII: the pixelized Timing Counter

- Higher granularity: 2 x 256 of BC422 scintillator plates (120 x 40 (or 50) x 5 mm^3) readout by AdvanSiD SiPM ASD-NUM3S-P-50-High-Gain
- Improved timing resolution: from 70 ps to 35 ps (multi-hits)
- Less multiple scattering and pile-up
- Expected detector performances confirmed with data (exposure to the muon beam) during pre-eng. 2016 and 2017

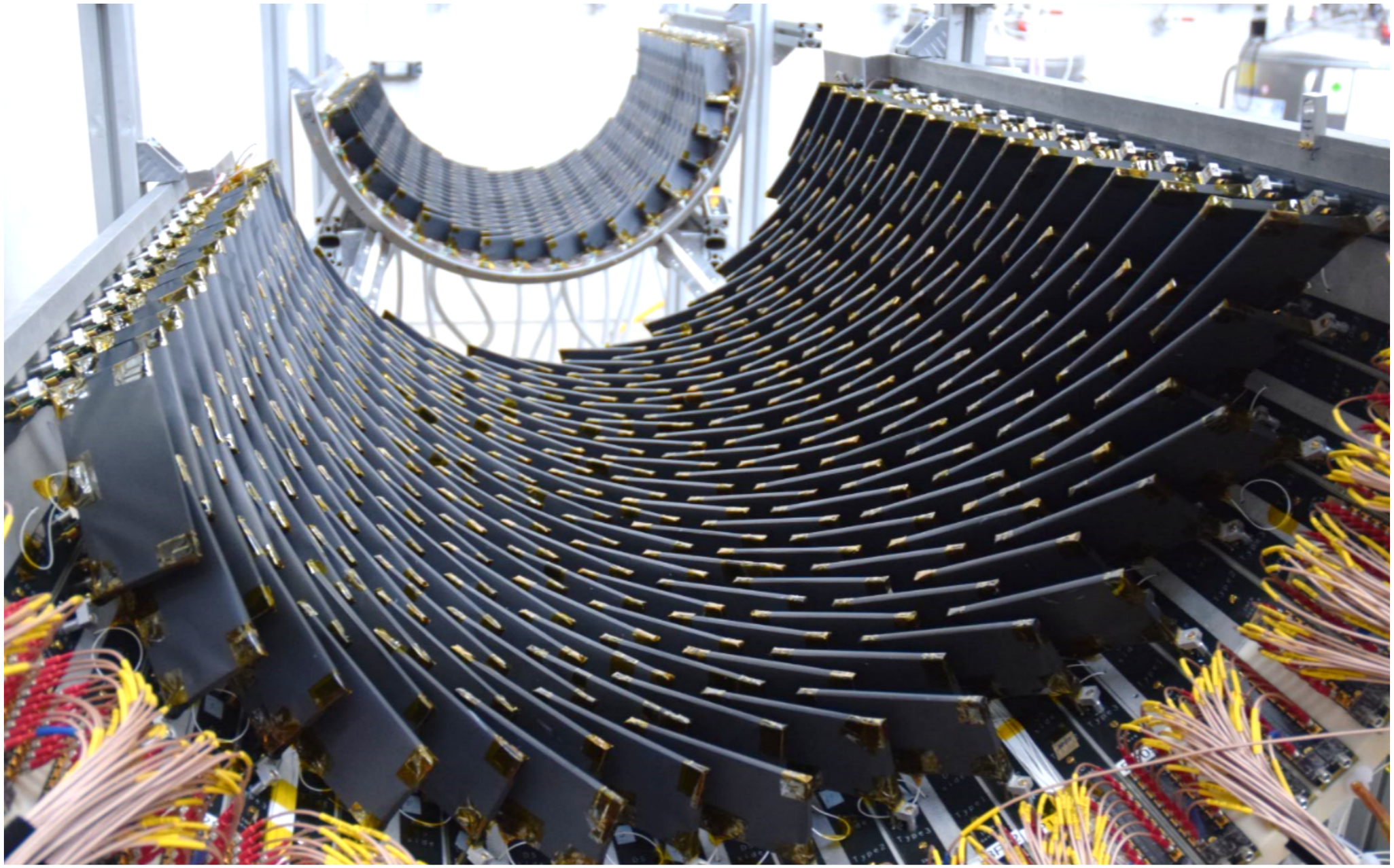
Pilot run 2016





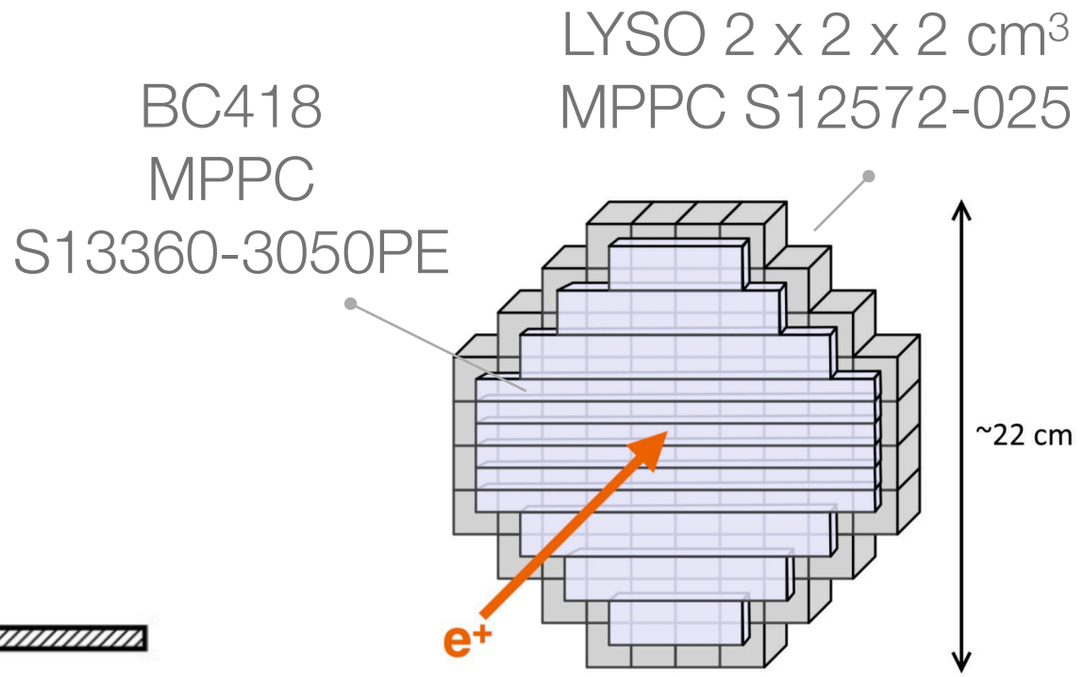
MEGII: the pixelized Timing Counter

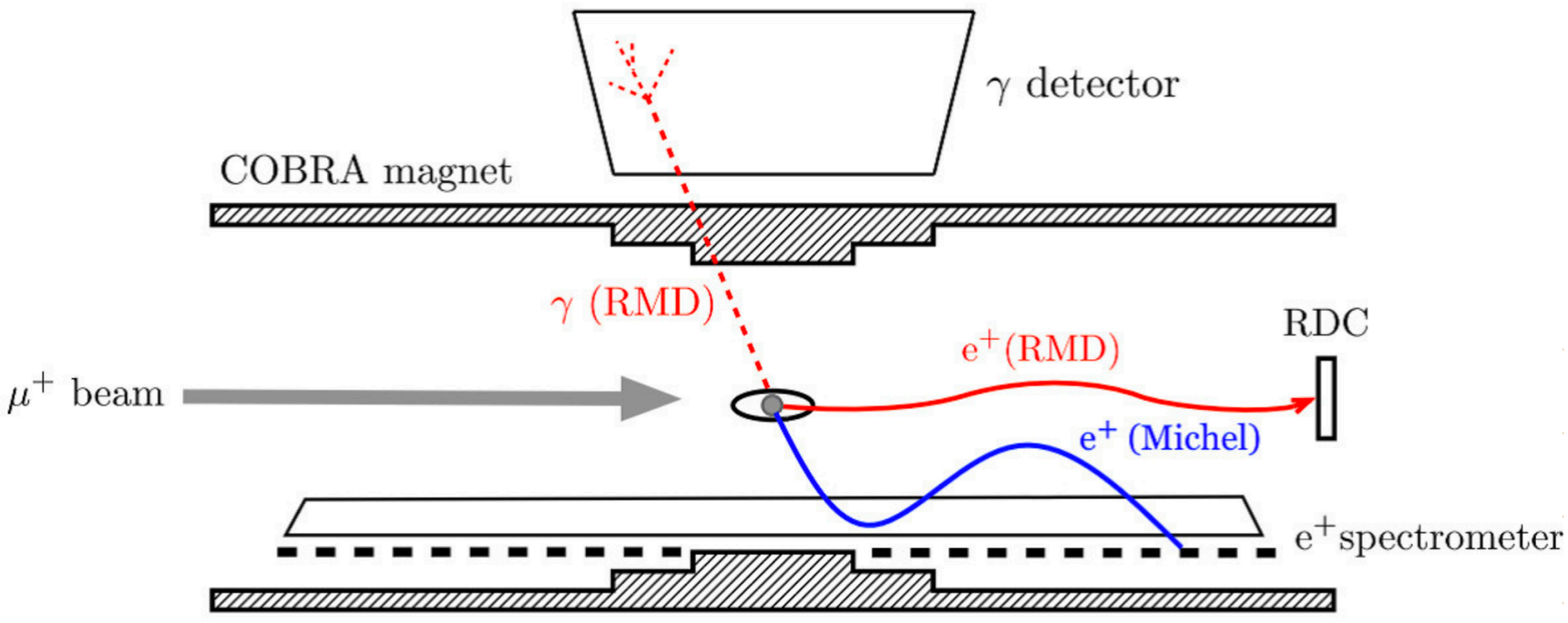
Full commissioned: Ready for MEGII

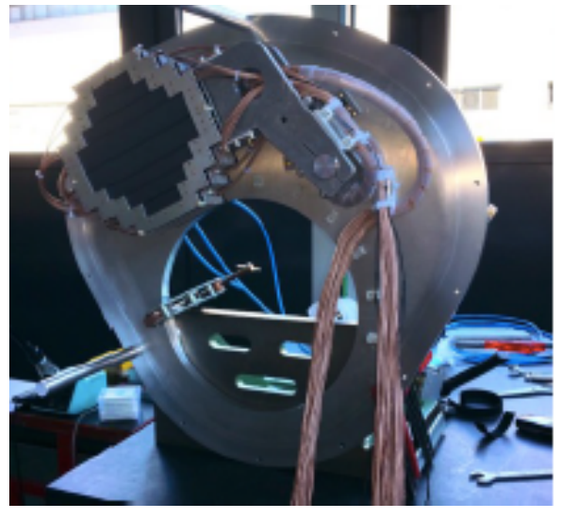


MEGII: The Radiative Decay Counter

- Added a new auxiliary detector for background rejection purpose. Impact into the experiment: Improved sensitivity by 20%
- Commissioning during the 2016 pre-engineering run
- Status: Ready for MEGII



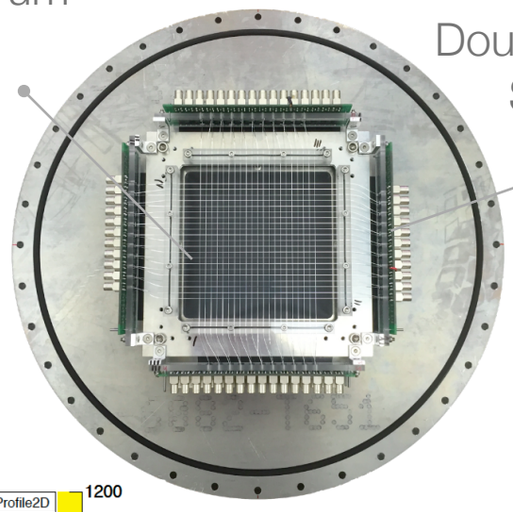




MEGII: new calibration methods and upgrades

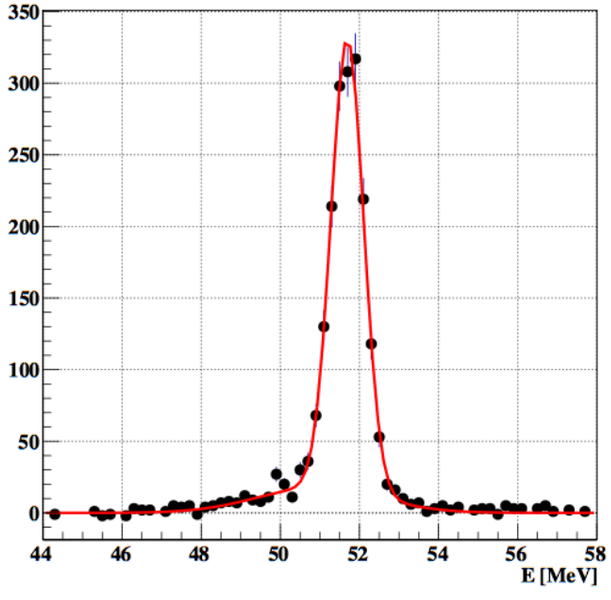
- CEX reaction: $p(\pi^-, \pi^0)n$, $\pi^0 \to \gamma\gamma$
- 1MV Cockcroft-Walton accelerator
- Pulsed D-D Neutron generator
- NEW: Mott scattered positron beam to fully exploit the new spectrometer
- NEW: SciFi beam monitoring. Not invasive, ID particle identification, vacuum compatible, working in magnetic field, online beam monitor (beam rate and profile)
- NEW: Luminophore (CsI(Tl) on Lavsan/Mylar equivalent) to measure the beam properties at the Cobra center
- NEW: LXe X-ray survey
- NEW: Laser system for the pTC

MC BCF12 250 x 250 um^2 scintillating fibers



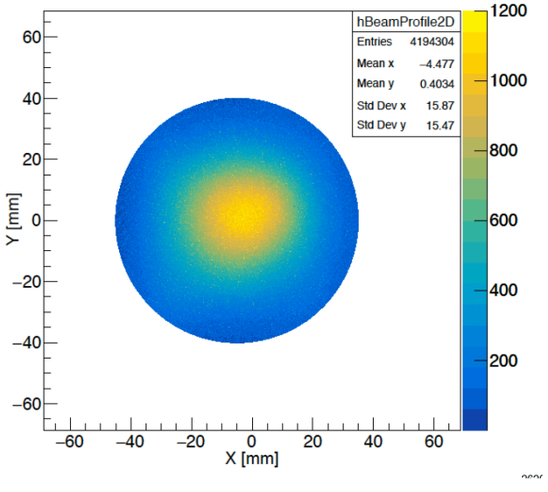
Double readout: MPPC S13360-3050C

Monochromatic e-line

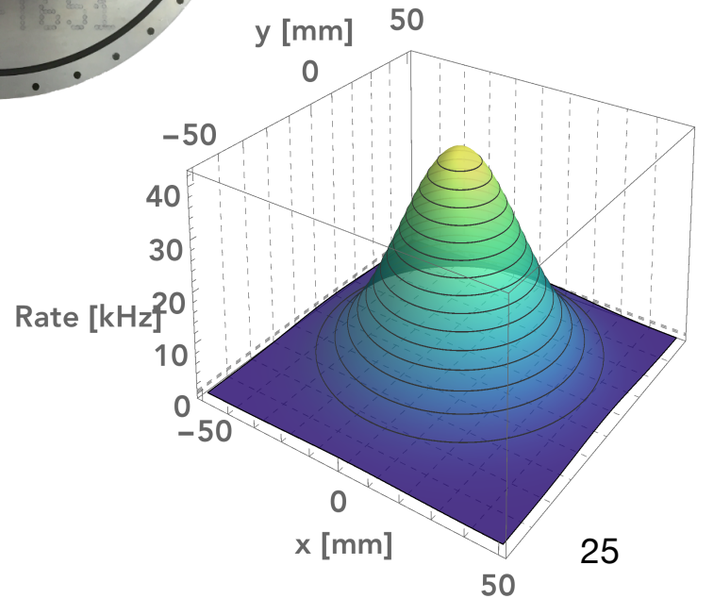


pTC's laser

Luminophore



SciFi



Content

- cLFV with the MEGII experiment:
  The $\mu^+ \to e^+\gamma$ decay search at PSI

- **Beryllium anomaly search with the MEGII apparatus: Status**

MEGII spectrometer + The CW accelerator

- Beryllium anomaly search with the MEGII apparatus: aiming at performing the measurement with a **different** apparatus and **improved** detector performances

- The key ingredients:

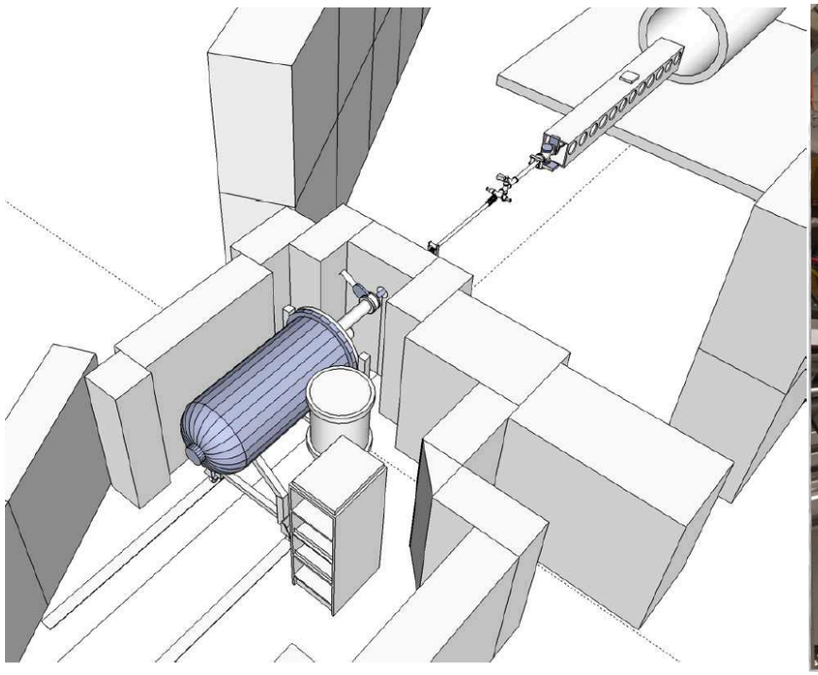
  - The CW accelerator able to deliver protons up to 1.1 MeV energy (maximal current = 100 uA)

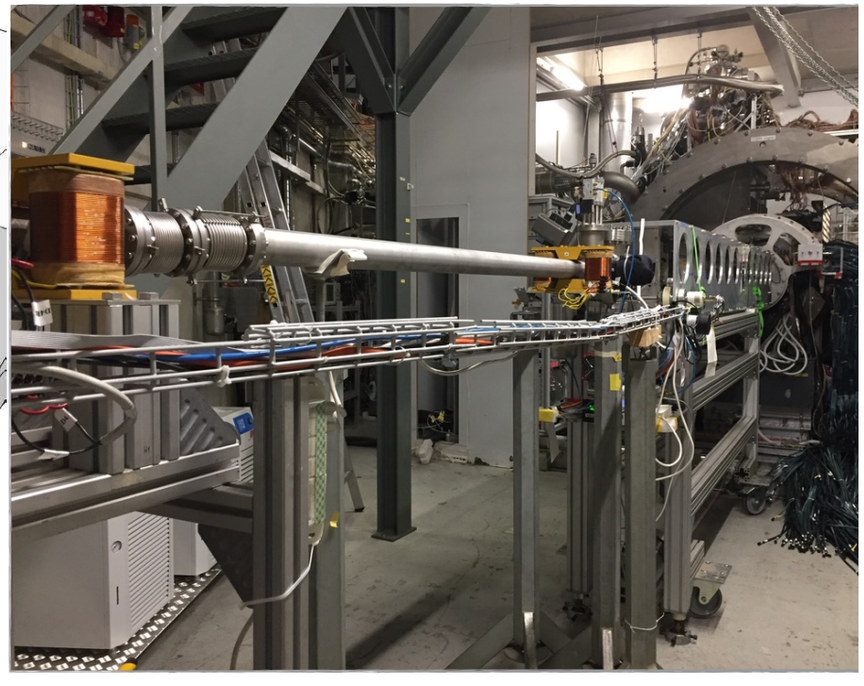
  - MEGII spectrometer with reduced magnetic field to detect the e+ e- pair (B field reduced by ~0.17 to cover the proper energy range of the e+ e- pair)

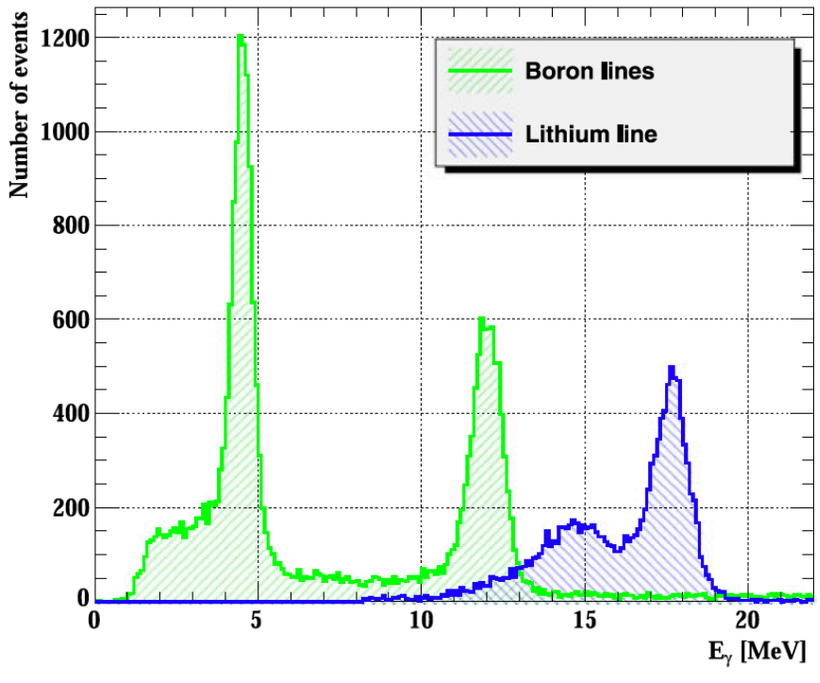
  - A new target/CW end line optimised for the Beryllium anomaly search

The MEGII CW accelerator

- The CW accelerator is abundantly used in the MEGII experiment to calibrate and monitor the MEGII sub-detectors (LXe calorimeter/TC and recently CDCH) using the Li resonance at 440 keV and the B reaction at 1 MeV
- The CW beam line reaches the center of the MEGII apparatus from DS (opposite to US direction from where the muons come)
- Settings for the Beryllium anomaly search: Protons with Ep = 1.1 MeV and Ip = 1 uA





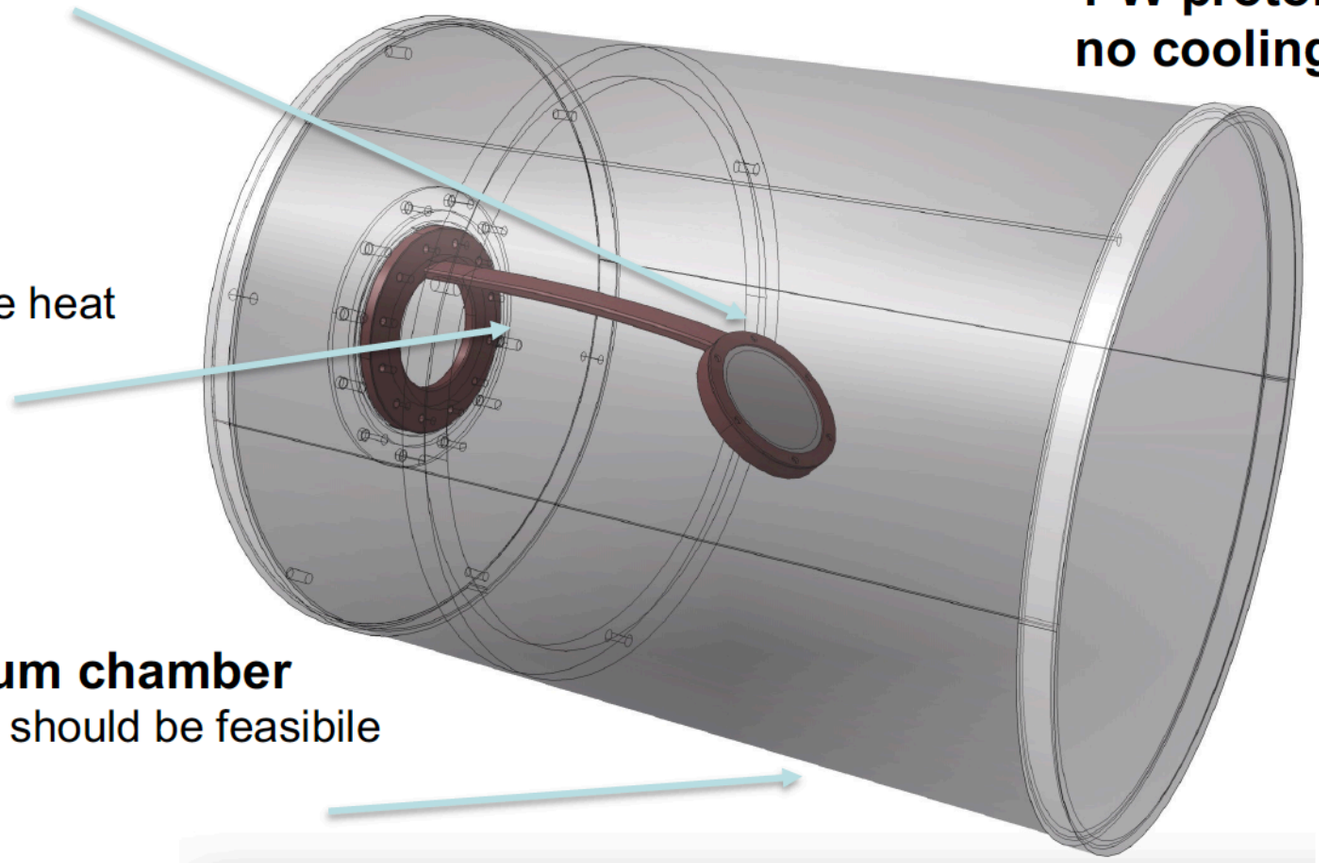


The new target region

- The new target region has been optimised based on the GEANT4 simulation and ASYS simulations

10 μm Li_2O target sputtered on a 25 μm Cu substrate
- slant angle: 45° around x axis
- Li_2O/Cu interface requires particular care

target arm
COBRA center
material: Cu to dissipate heat

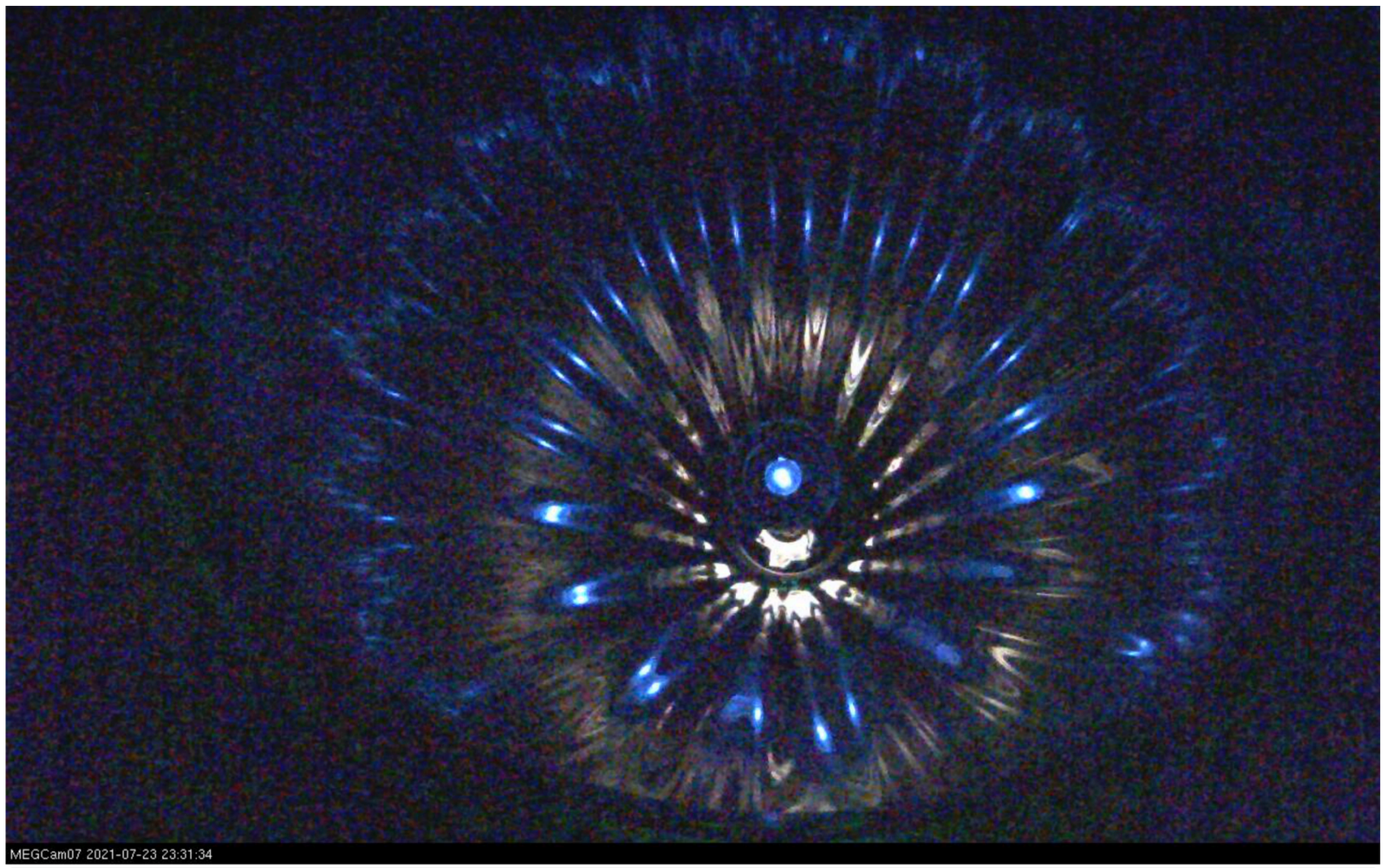


Steel beam pipe
Al adapter
1 W proton beam
no cooling

Carbon fiber vacuum chamber
- thickness 400 micron should be feasibile
- diameter = 260mm
- length = 250mm
- type of fiber: epoxy fiber

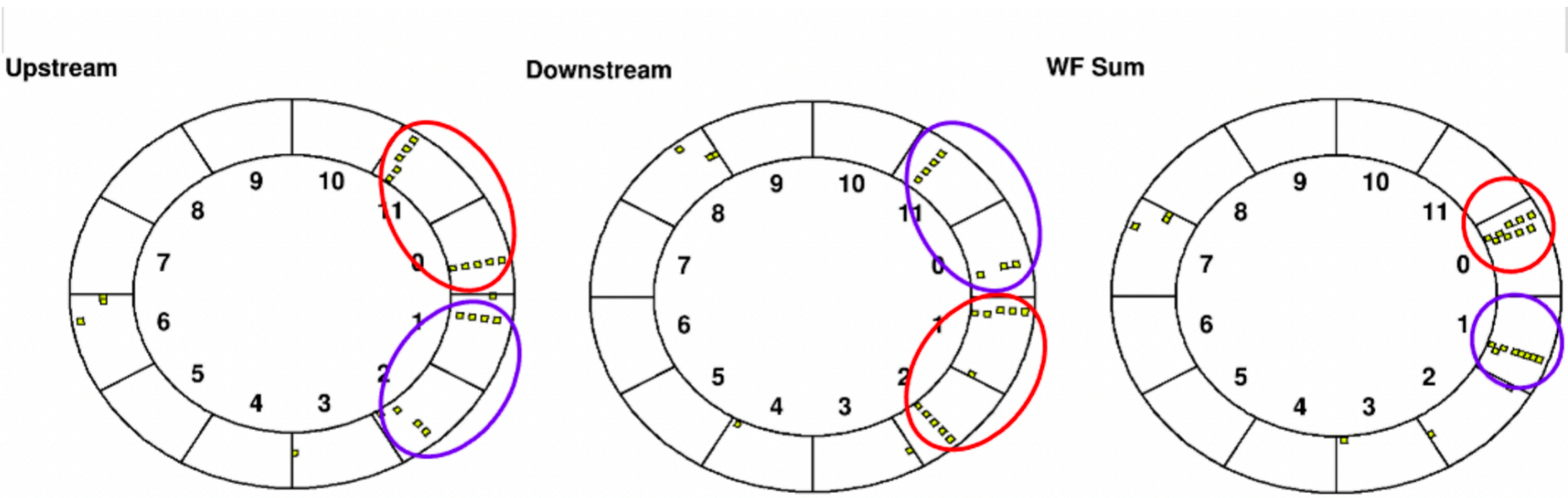
Proton beam tuning at reduced magnetic field

- To perform the Beryllium anomaly measurement the default magnetic field (1.25 T at Cobra Center) must be reduced by a factor ~0.17
- A field map at reduced magnetic field and the proton beam tuning in this conditions have been performed



External gamma conversion events from Li in the CDCH detector

- To perform the Beryllium anomaly measurement the default magnetic field (1.25 T at Cobra Center) must be reduced by a factor ~0.17
- A very first look at external conversion of gammas from Li events with the magnetic field on/off (below with magnetic field off) has been done and will be fully exploit during the next HIPA service shut down (Sept & Oct)

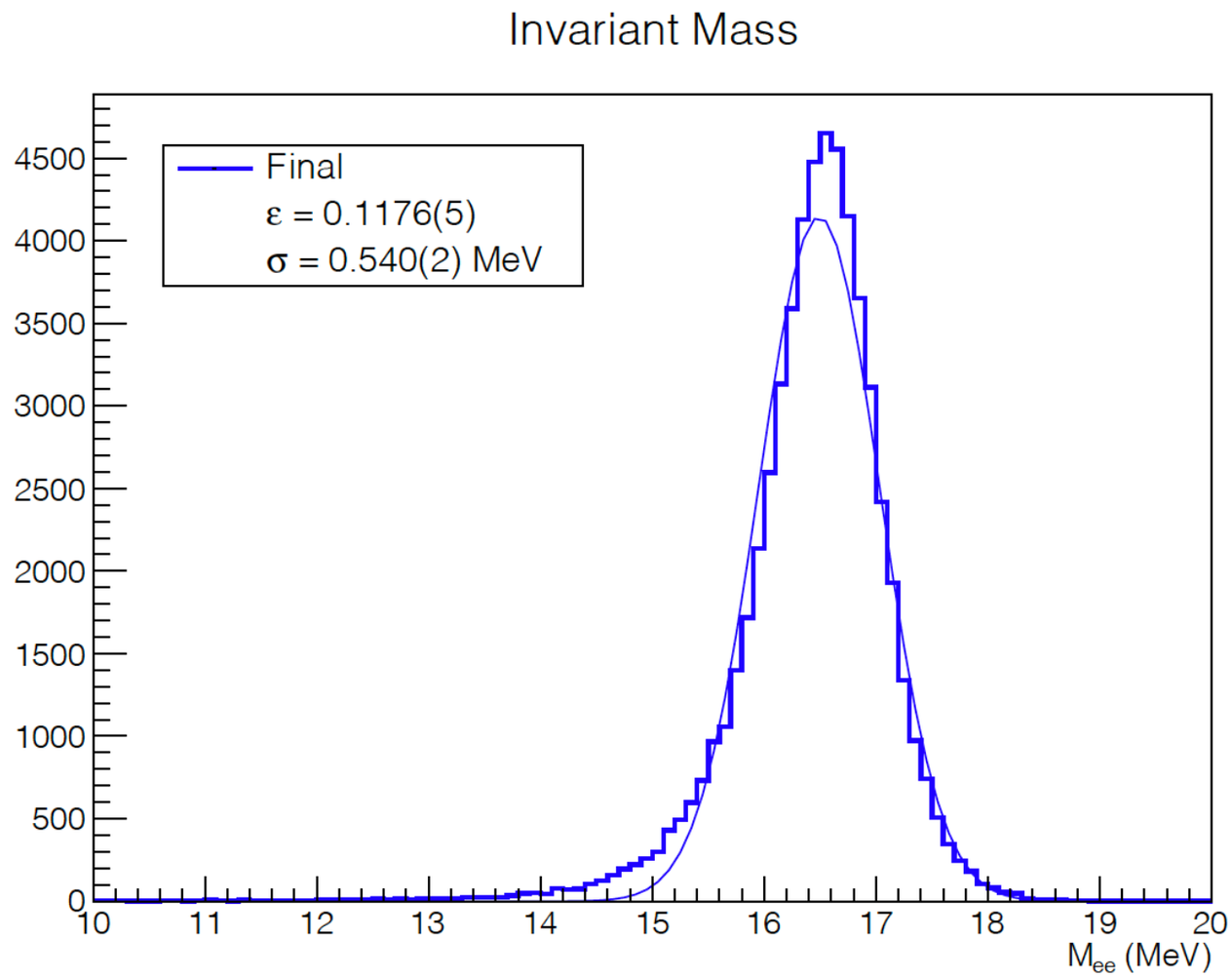


- Event near z=0

2 particles leaves 2 tracks in the center and 4 at the endplates due to stereo angle

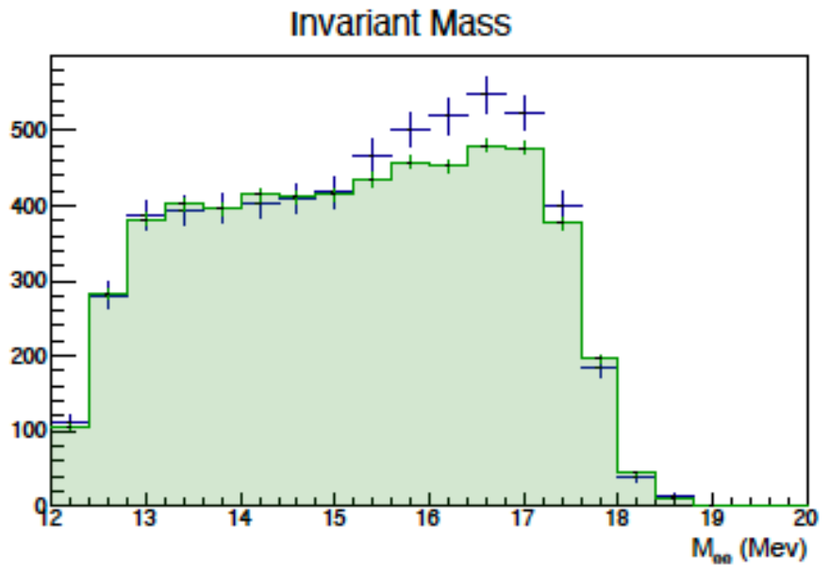
Beryllium anomaly search: Signal and Backgrounds

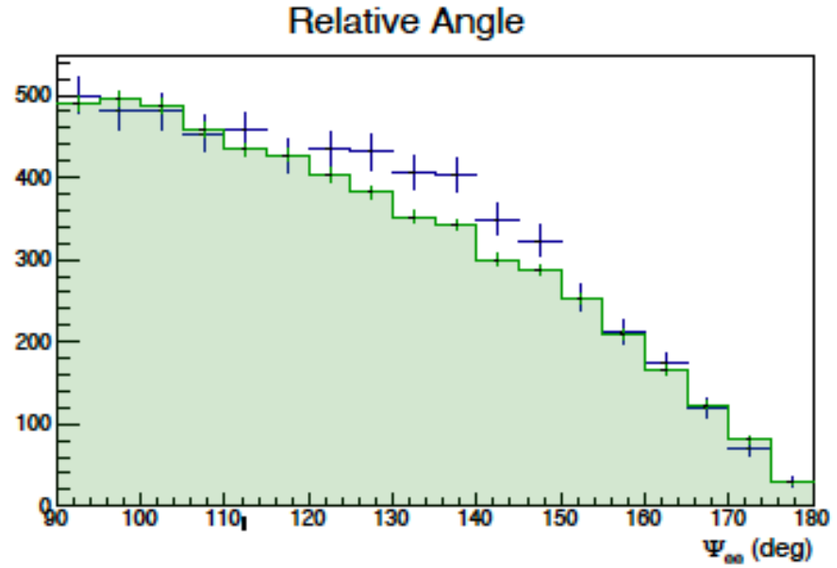
- MC simulation based on GEANT4
- Signal (assumed rate from ATOKMI measurement)
- Backgrounds: EPC (depends on the material of the experimental setup) and IPC
- IPC: Resonant from 18.1 MeV gamma conversion (M1 transition) and non resonant (multi polarities)
  - Implemented the Zhang-Miller model
- **Signal rate: ~ 7 10^{-2} /s**
- **Background (IPC) rate ~ 40 /s**



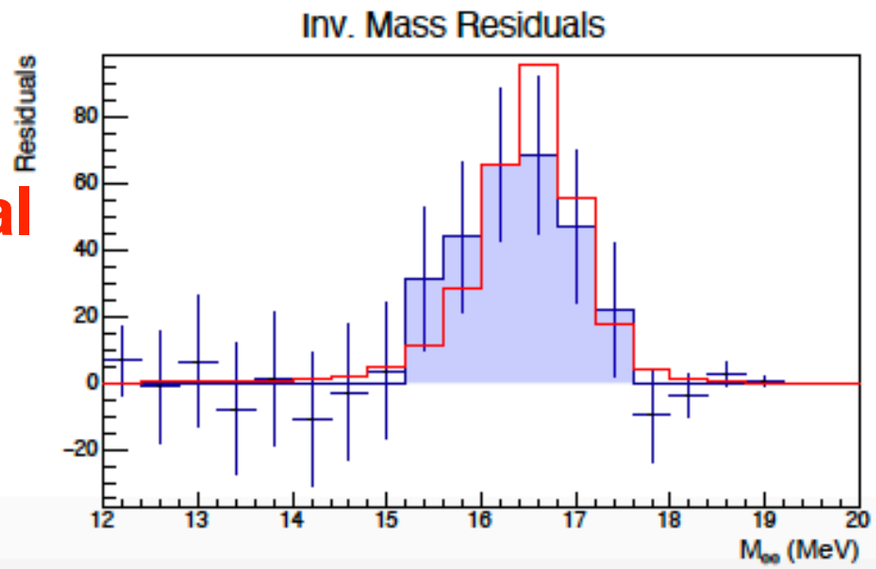
Beryllium anomaly search: Observables

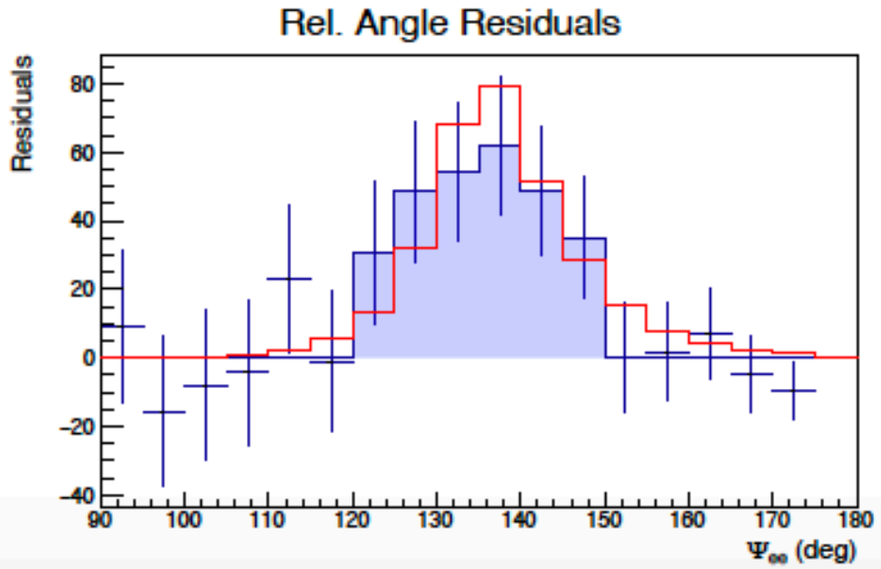
Signal+Bkg
IPC





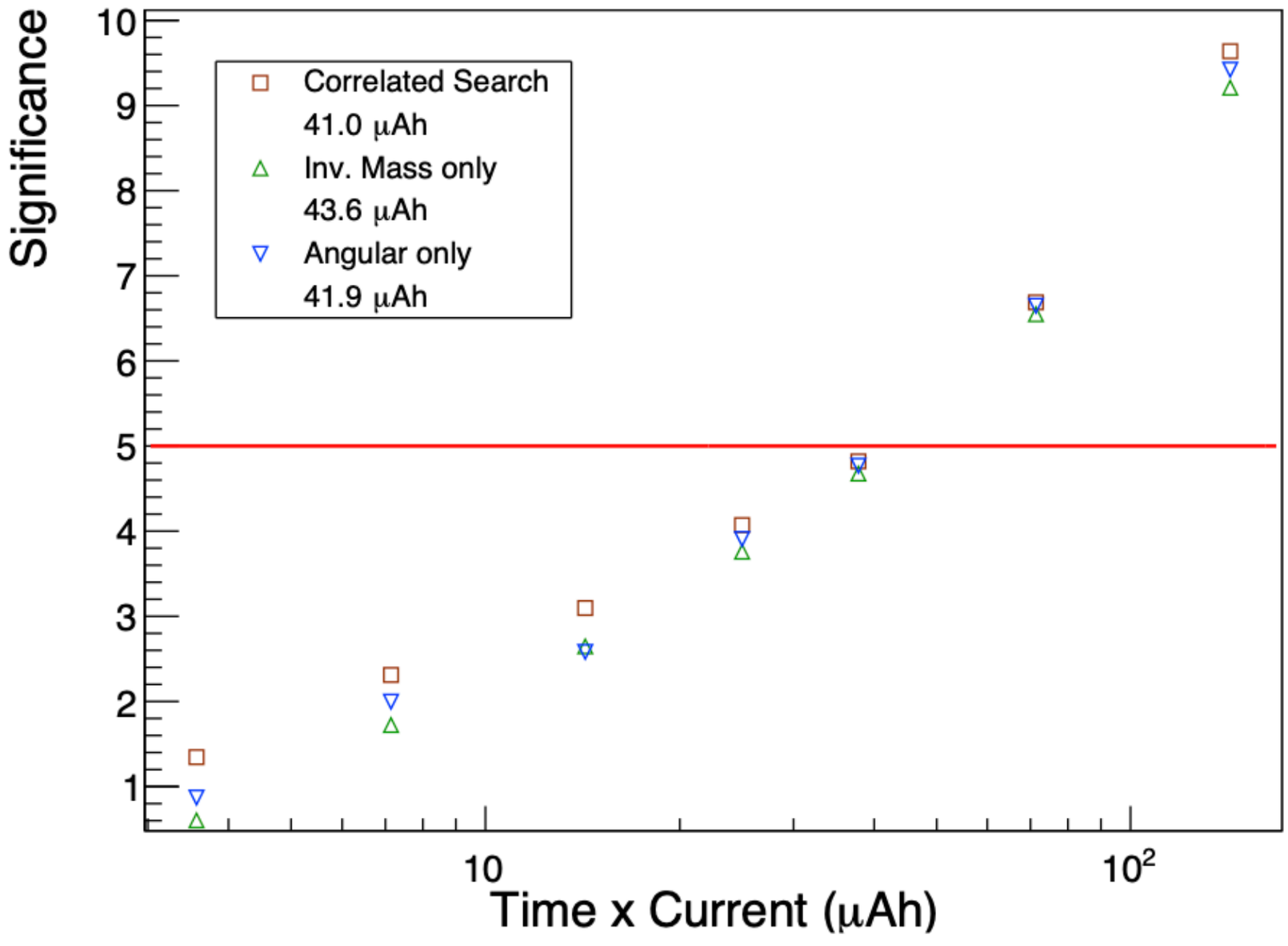
Residuals
Simulated signal





Significance

- 5σ significance after ~50 h DAQ at 1uA



Executive plan for the Beryllium anomaly search

- **Goal**: Measurement during the HIPA main **shutdown 2022**
- Preparation for the final measurements integrated in the MEGII 2021 schedule without interference with the main MEGII program:
    - Build all new parts for the setup
    - Execute and complete all hardware and mechanical tests
    - Implement and test the TDAQ
    - Collect and analyse curved tracks at reduced magnetic field during the HIPA accelerator service periods

Outlooks

- The MEG experiment has set a new upper limit for the branching ratio of **$B(\mu^+ \to e^+ \gamma) < 4.2 \times 10^{-13}$** at 90% C.L. (a factor 30 improvement with respect to the previous MEGA experiment and also the strongest bound on any forbidden decay particle)

- An upgrade of the apparatus is ongoing: MEGII is going to start the full engineering run followed by a physics run aiming at a sensitivity **down to 6×10^{-14}**

- The MEGII apparatus can explore also the **Be anomaly**. A **dedicated measurement** is scheduled during the HIPA shut down **2022**

Thanks for your attention