Status of the MEGII experiment at PSI

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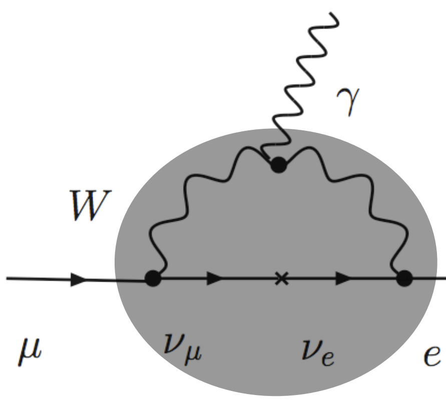
Content

- Charged Lepton flavour violation search (cLFV): Motivations
- The most intense continuous muon beams in the world at the Paul Scherrer Institute (PSI)
- cLFV with the MEGII:
  The $\mu^+ \to e^+\gamma$ decay search at PSI

Charged lepton flavour violation search: Motivation

SM with massive neutrinos (Dirac)

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

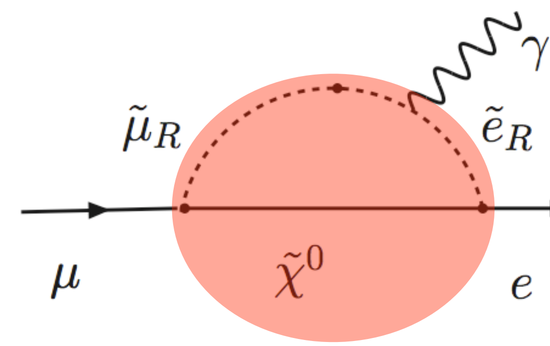


ν oscillations

too small to access experimentally

BSM

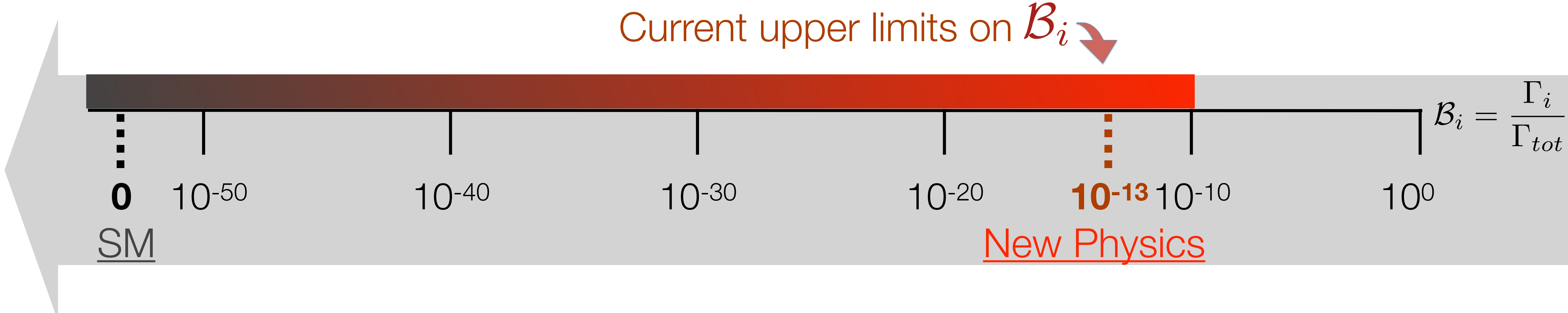
$\mathcal{B}(\mu^+ \to e^+\gamma) \gg 10^{-54}$



New particles

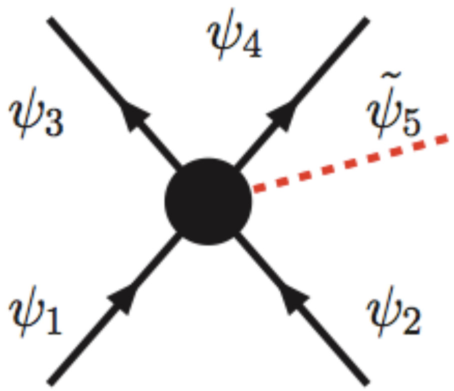
an experimental evidence:
a clear signature of New Physics NP
(SM background FREE)

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



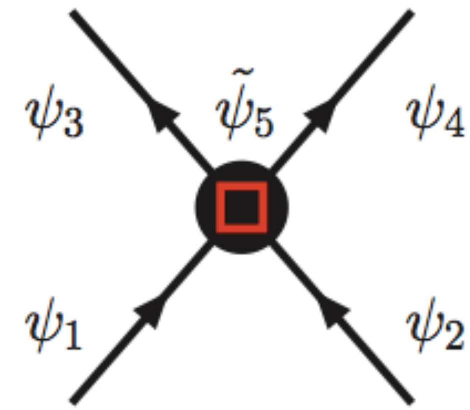
Complementary to "Energy Frontier"

Energy frontier



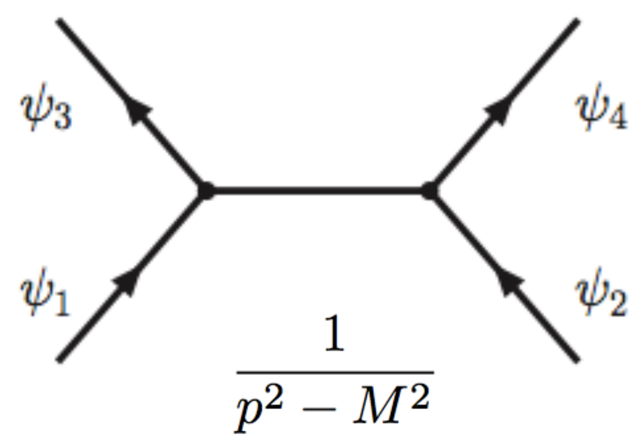
Real BSM particles

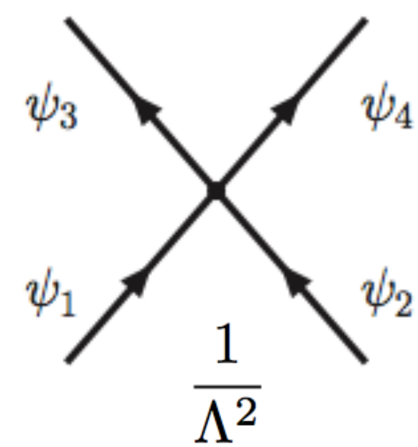
Precision and intensity frontier



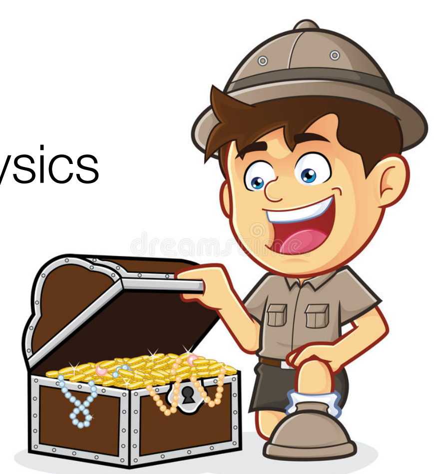
Virtual BSM particles

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





Unveil new physics



Probe energy scale otherwise unreachable

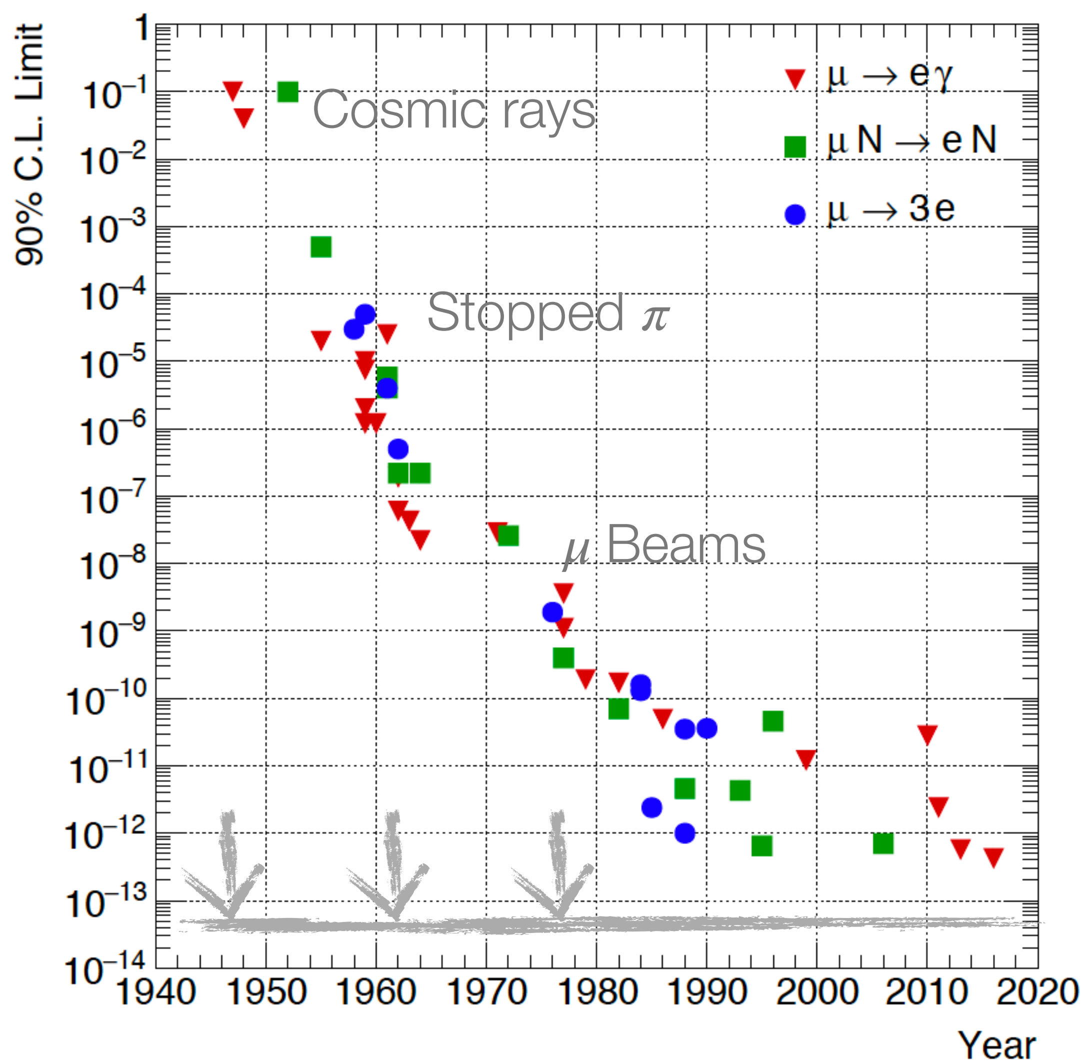
E > 1000 TeV

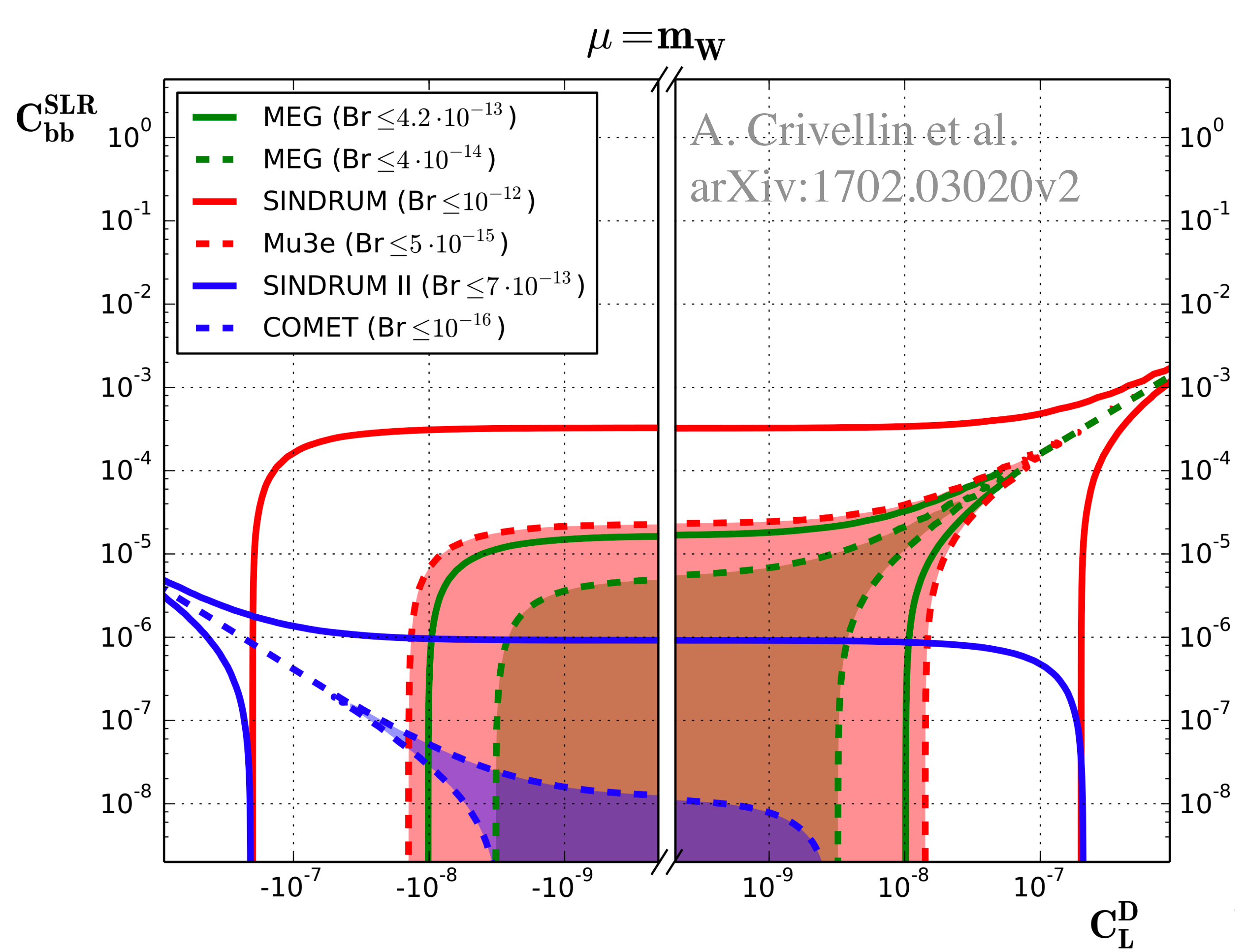
cLFV searches with muons: Status and prospects

- In the near future impressive sensitivities:

	Current upper limit	Future sensitivity
$\mu \to e\gamma$	4.2 x 10^{-13}	~ 4 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}	< 10^{-16}

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

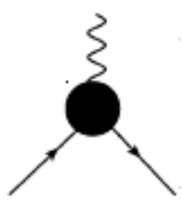
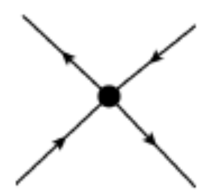




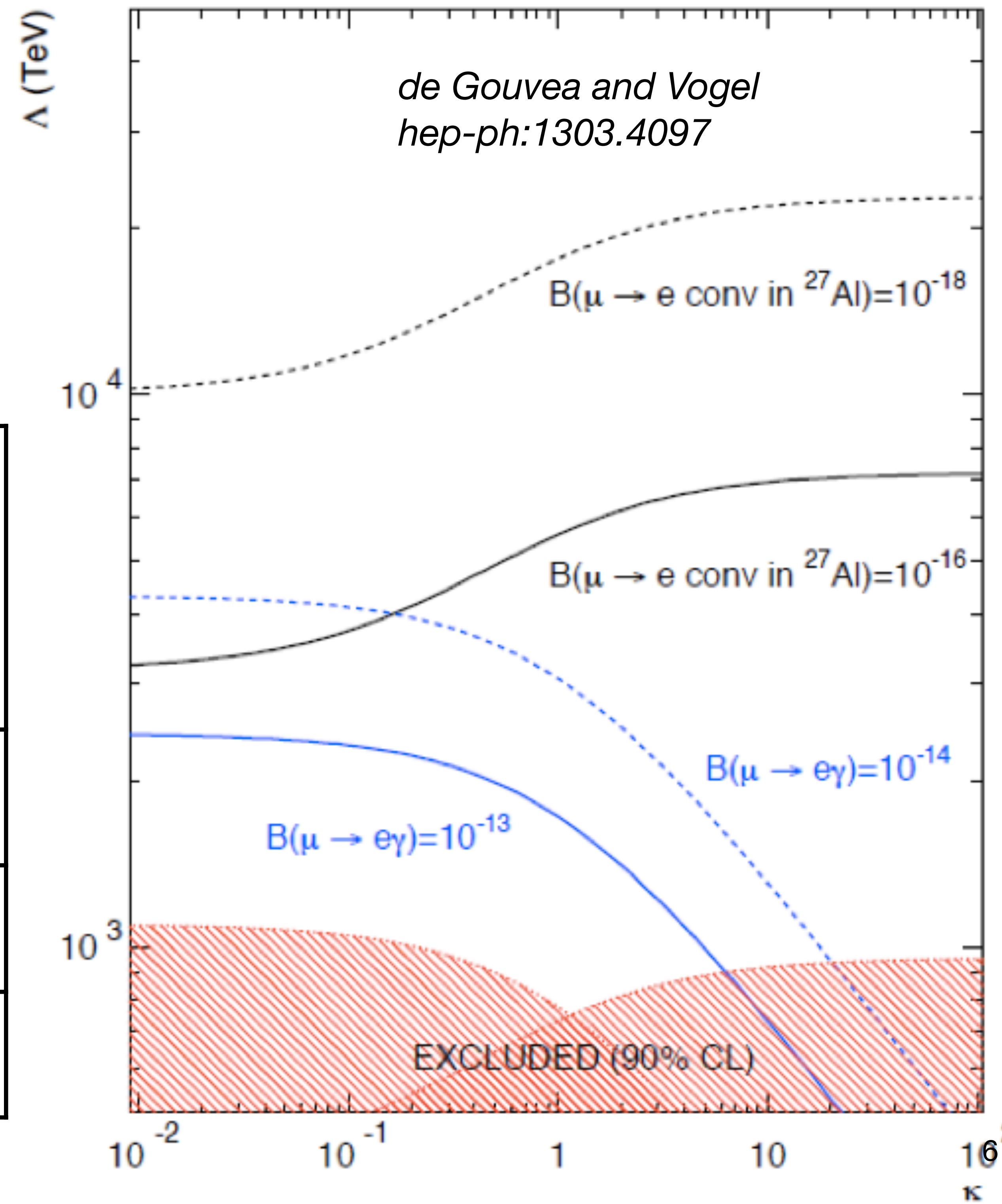
cLFV: "Effective" lagrangian with the k-parameter

- Due to the **extremely-low** accessible **branching ratios**, muon cLFV can strongly **constrain** new physics models and scales

Model independent lagrangian

$\frac{m_\mu}{(\kappa+1)\Lambda^2} \times$  $+ \frac{\kappa}{(\kappa+1)\Lambda^2} \times$ 

dipole term	contact term
$\mu \to e\gamma$	
$\mu \to eee$	
$\mu N \to eN$	



cLFV searches with muons: Status and prospects

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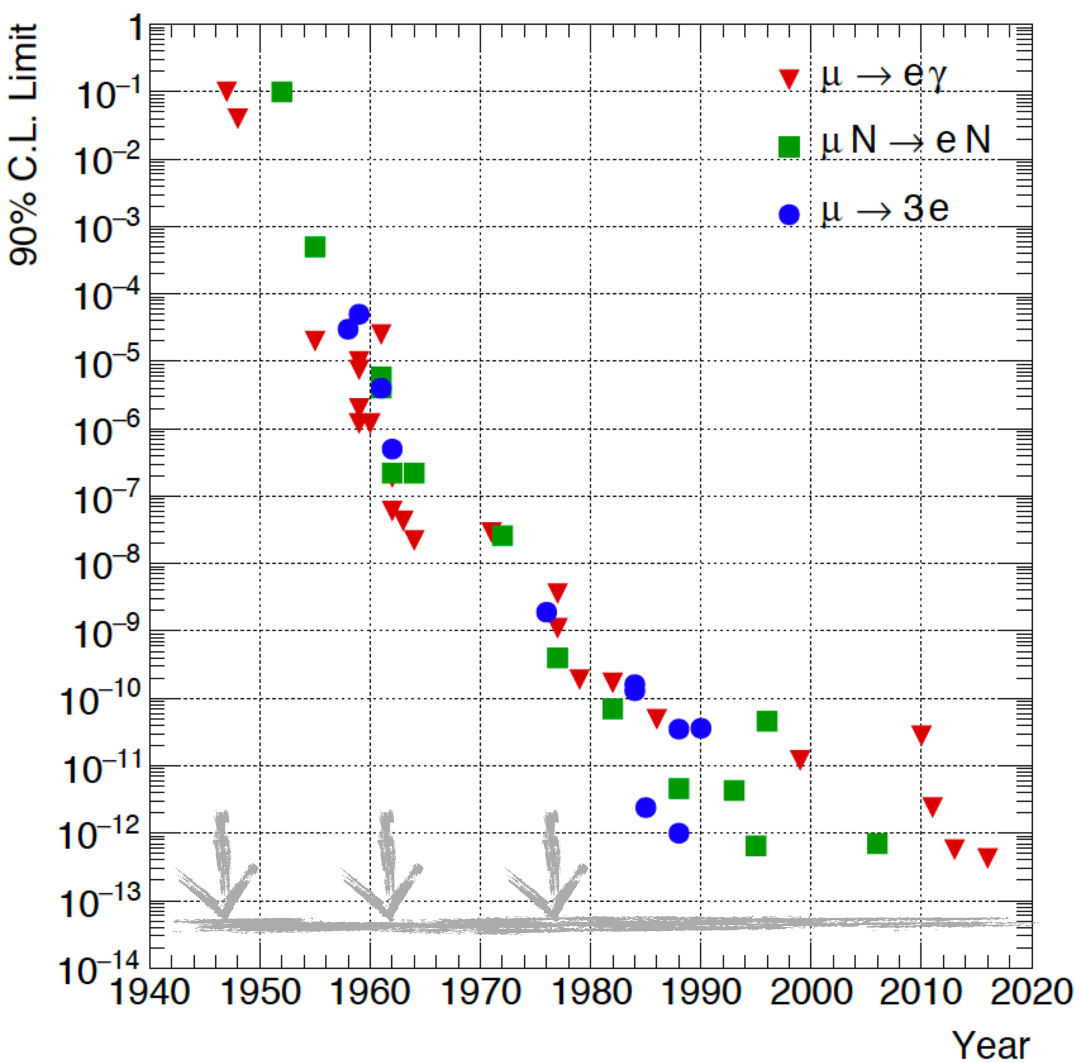
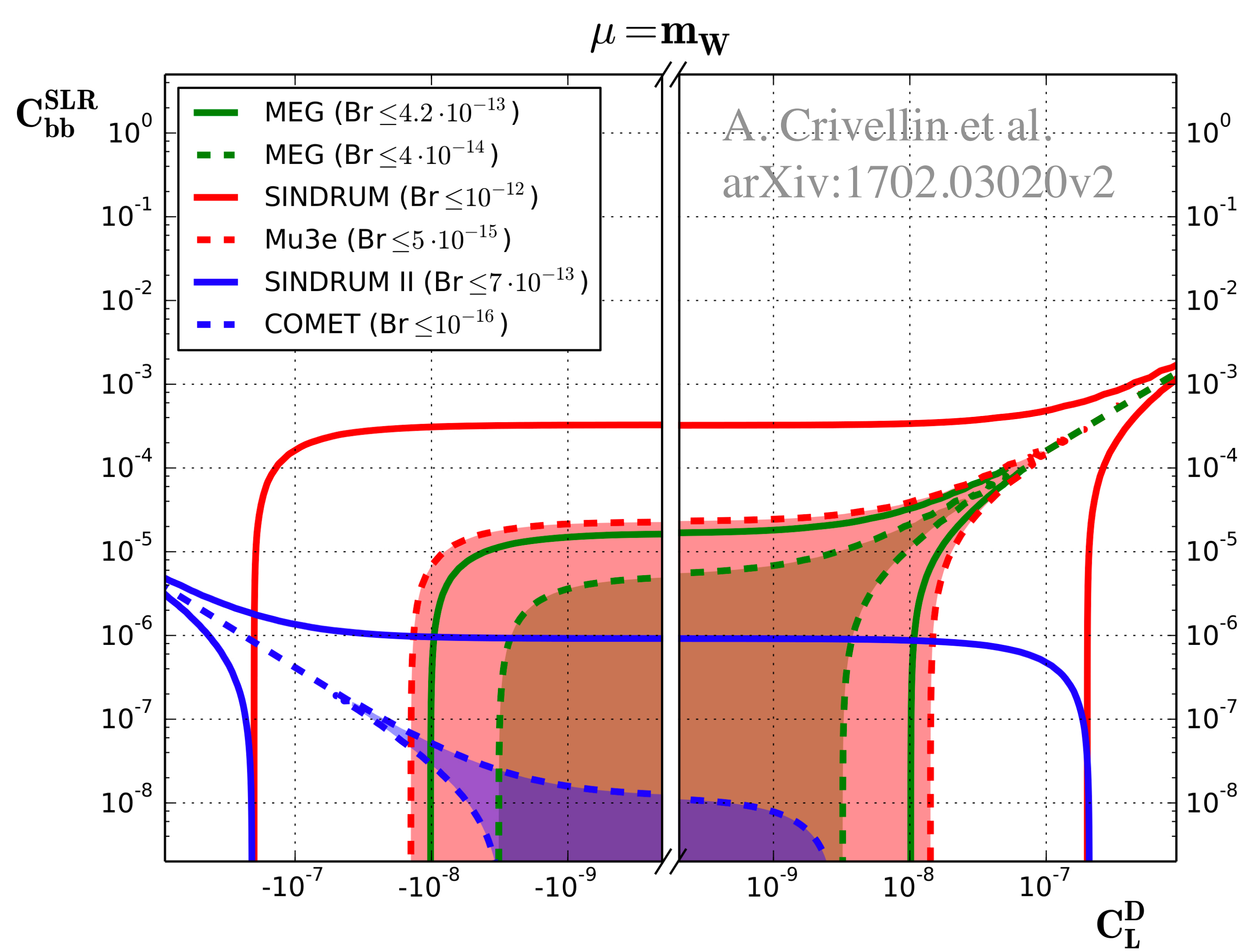
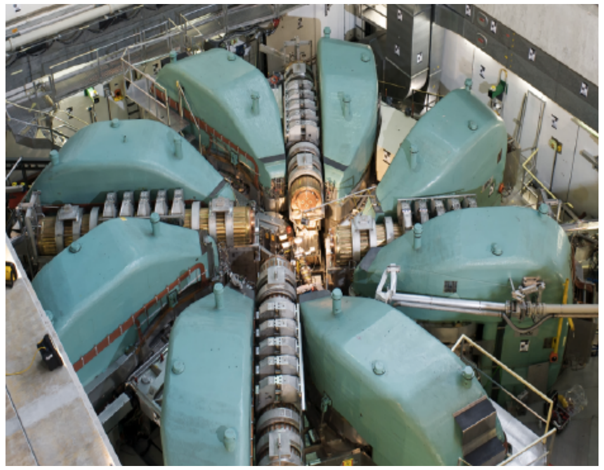




The world's most intense continuous muon beam

- 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



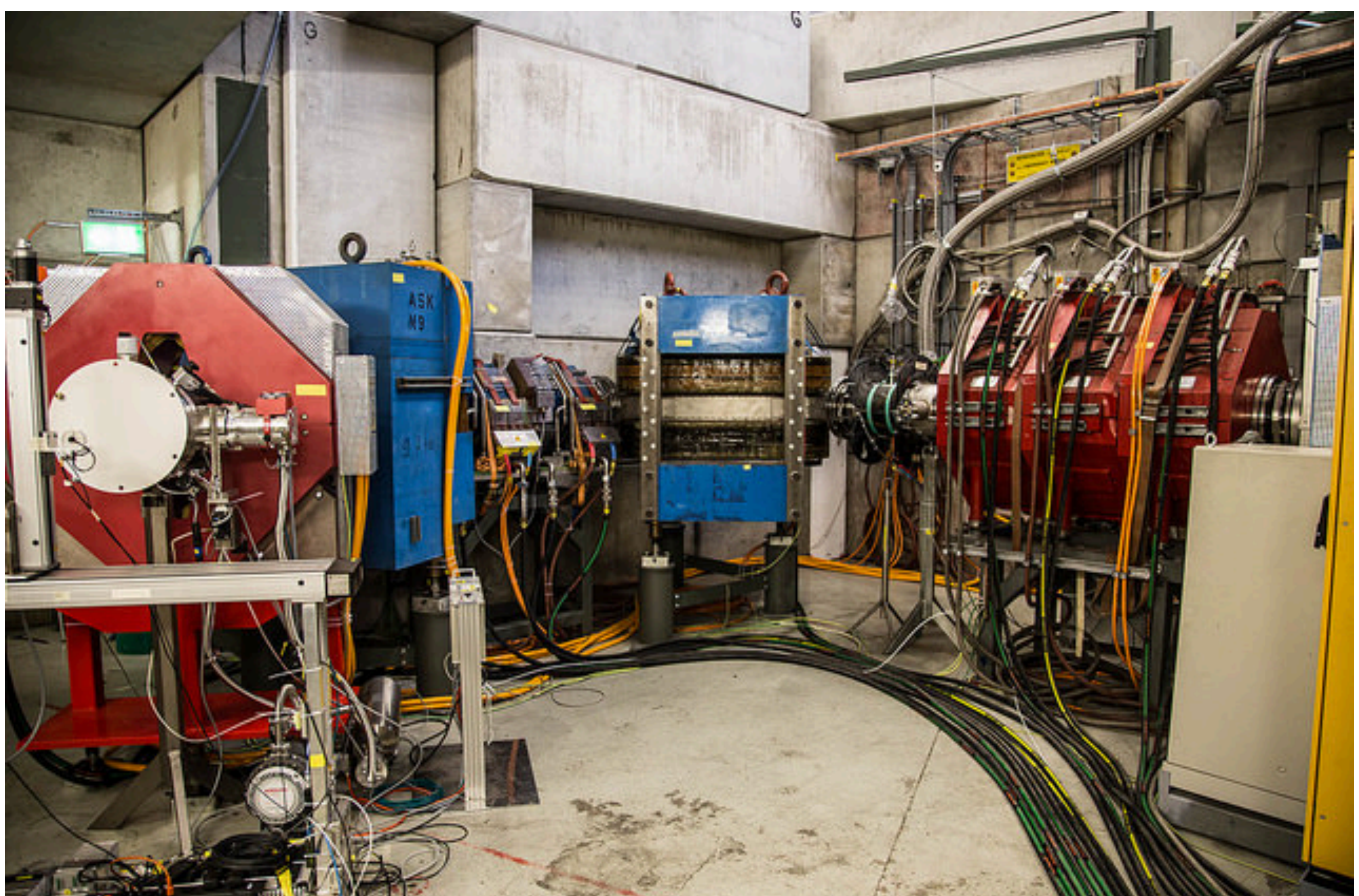
590 MeV proton
ring cyclotron
1.4 MW

PSI landscape

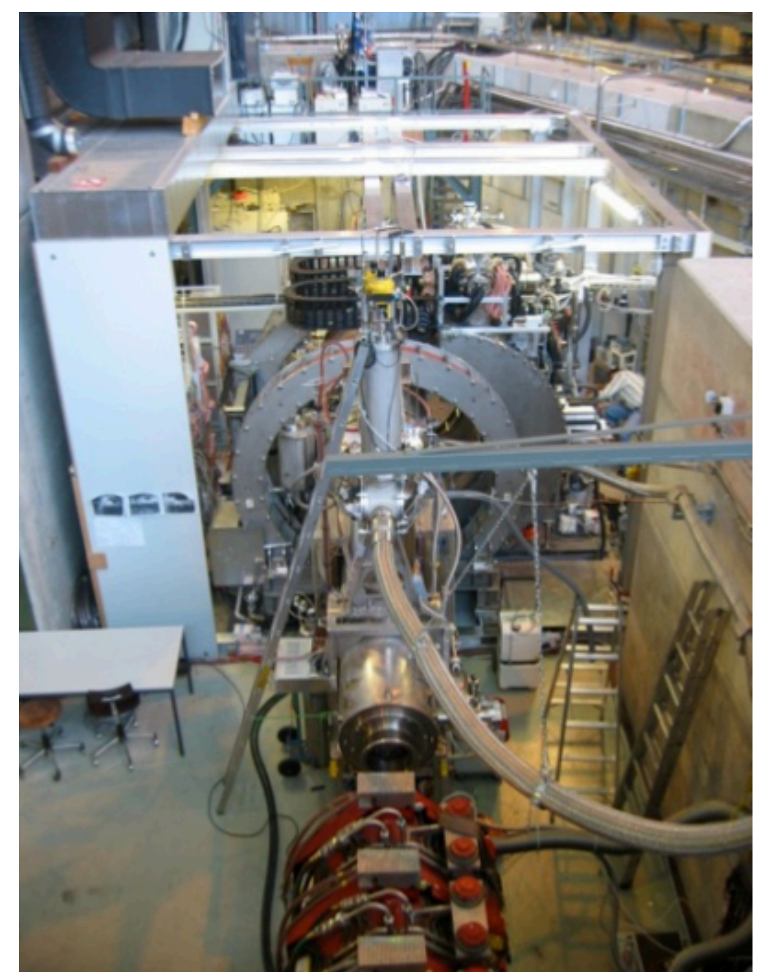
The MEGII (and Mu3e) beam lines

- MEGII and Mu3e (phase I) similar beam requirements:
    - **Intensity O(10^8 muon/s), low momentum p = 28 MeV/c**
    - **Small straggling and good identification of the decay region**
- A dedicated compact muon beam line (CMBL) will serve Mu3e
- Proof-of-Principle: Delivered 8 x 10^7 muon/s during 2016 test beam

The Mu3e CMBL



The MEGII BL

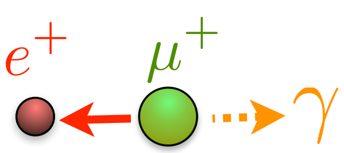


A.M. Baldini et al. (MEG Collaboration), Eur. Phys. J. C73 (2013) 2365

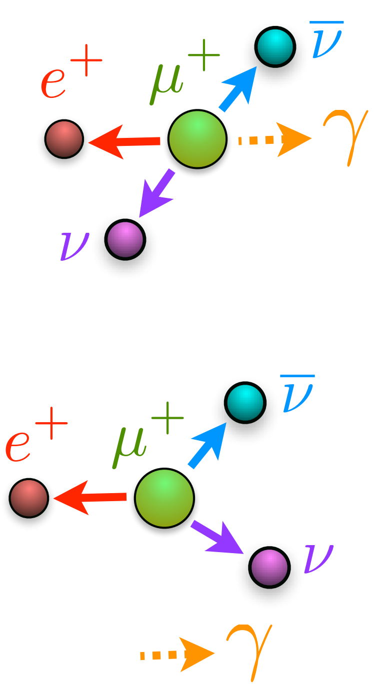
MEG: Signature and experimental setup

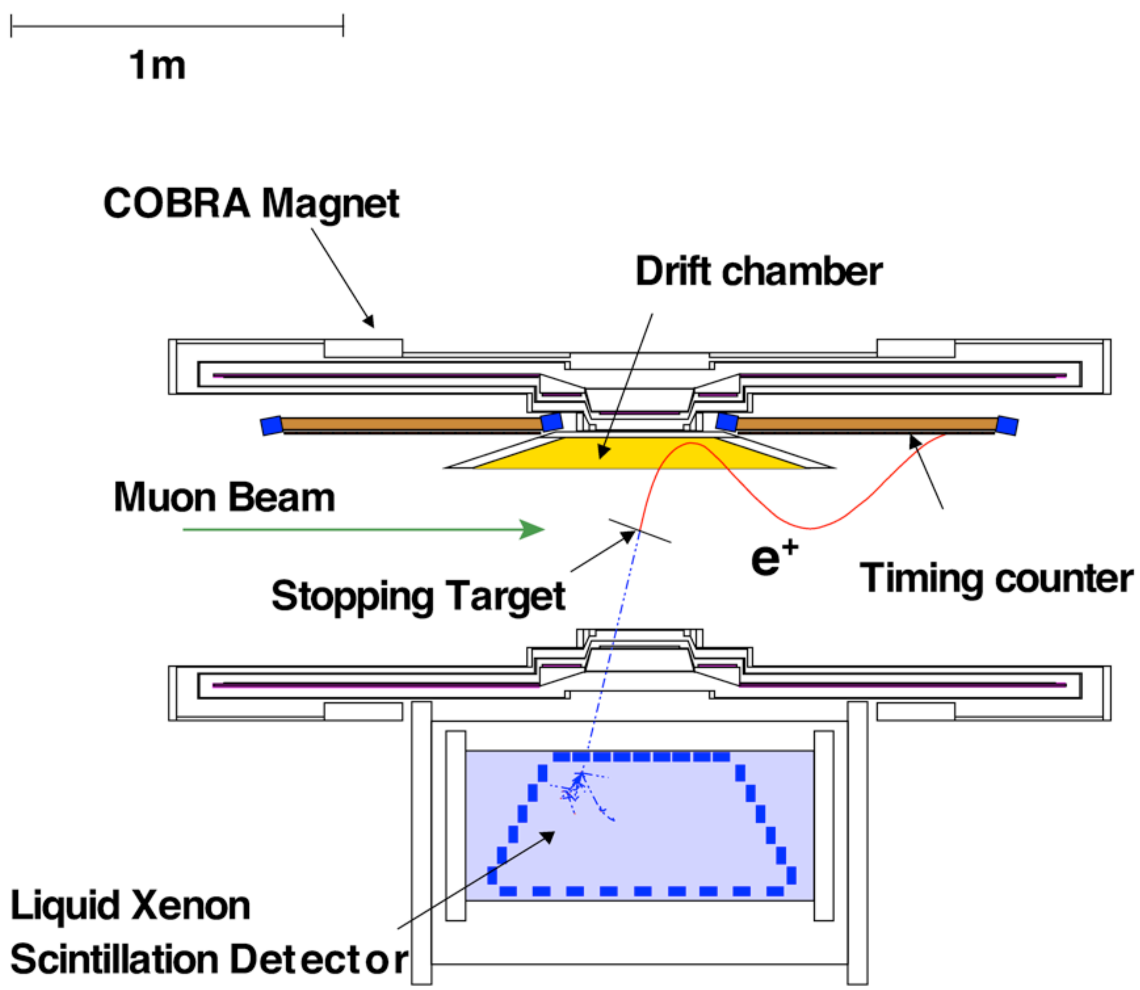
- The MEG experiment aims to search for $\mu^+ \to e^+ \gamma$ with a sensitivity of ~10^{-13} (previous upper limit BR($\mu^+ \to e^+ \gamma$) ≤ 1.2×10^{-11} @90 C.L. by MEGA experiment)
- Five observables (E_g, E_e, t_{eg}, ϑ_{eg}, ϕ_{eg}) to characterize $\mu \to e\gamma$ events

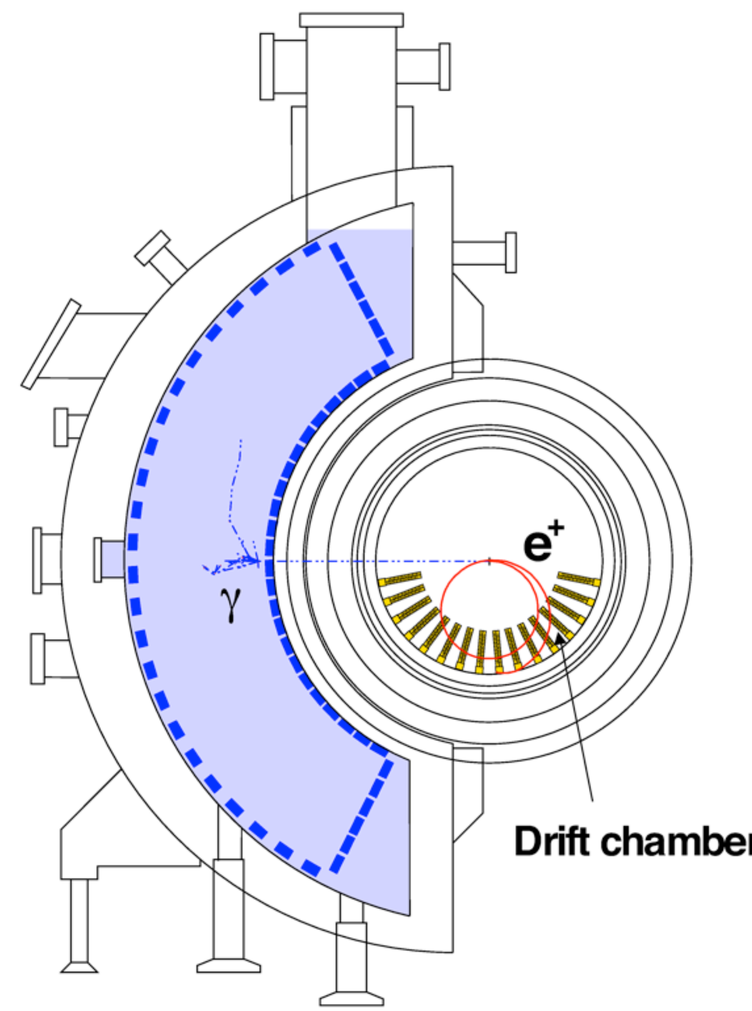
Signature



Backgrounds







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

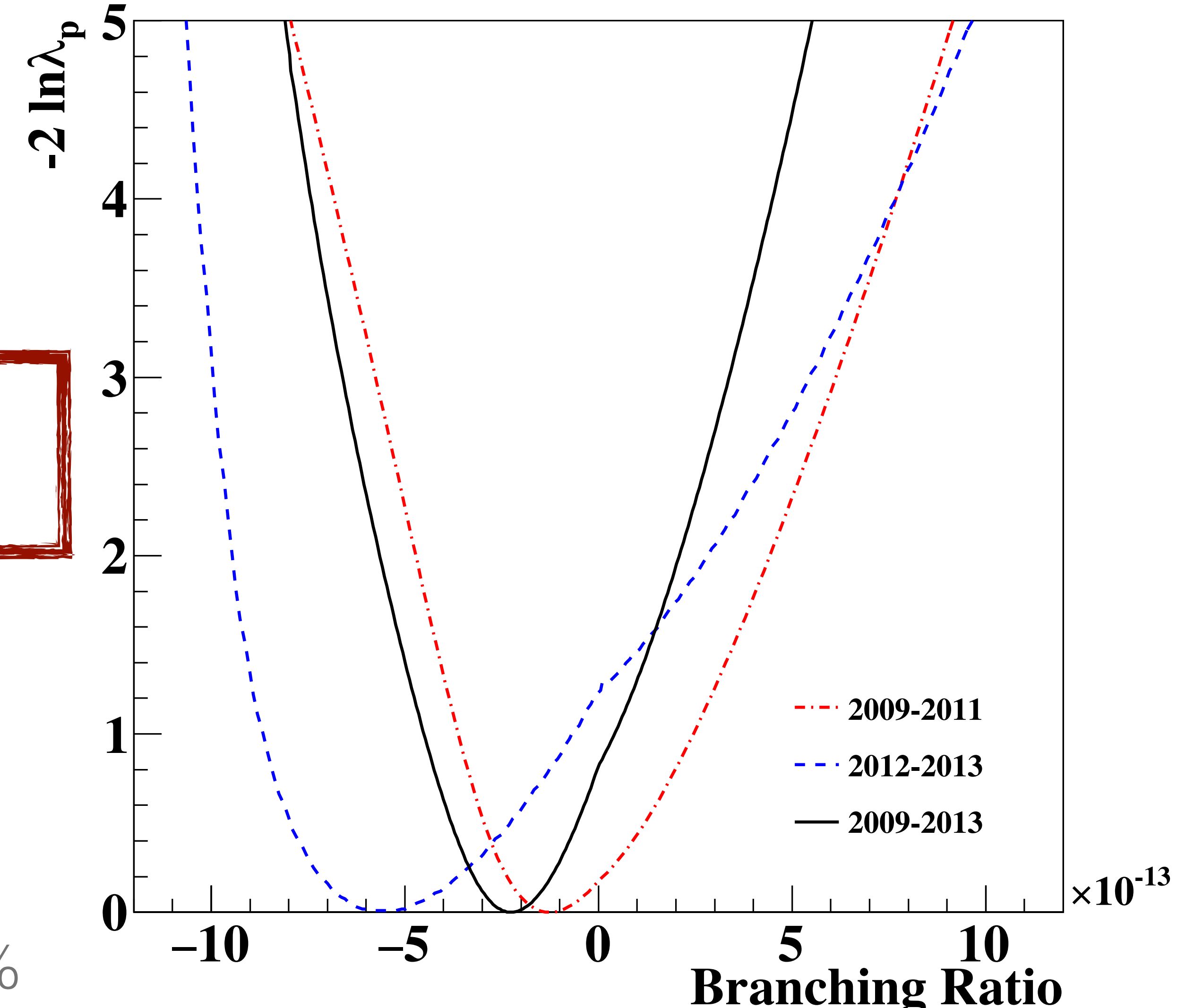
MEG: The result

- 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.:

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

From MEGA to MEG:
improvement by a factor ~ 30



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

How the sensitivity can be pushed down?

high statistics

- More sensitive to the signal...

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

Beam rate
Acquisition time
Geometrical acceptance
Detector efficiency
Selection efficiency

high resolutions

- More effective on rejecting the background...

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

Positron Energy resolution
Gamma Energy resolution
Relative timing resolution
Relative angular resolution

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

The MEGII experiment

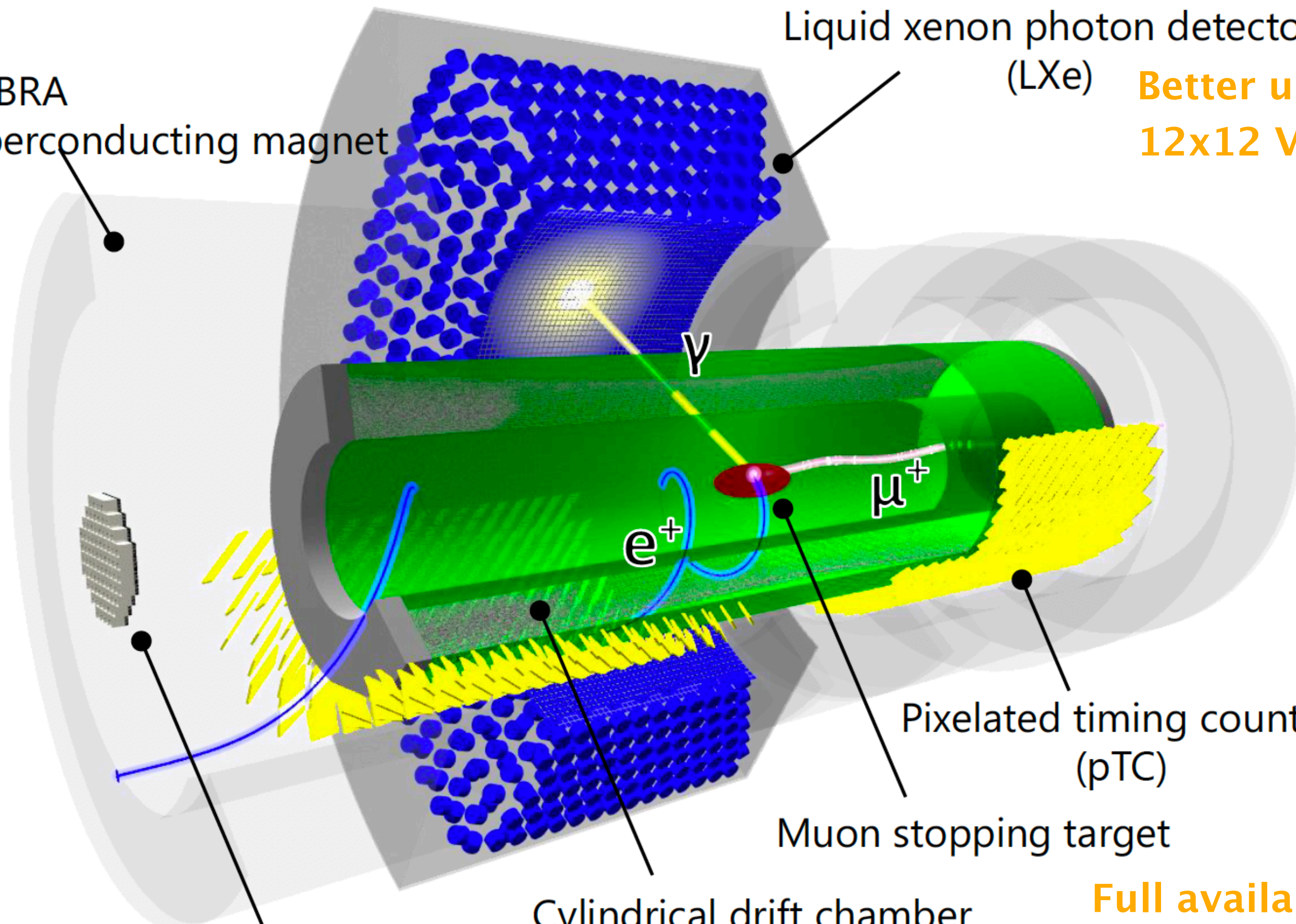
New electronics:
Wavedream

~9000 channels at 5GSPS

x2 Resolution everywhere

Updated and new Calibration methods

Quasi mono-chromatic positron beam



Better uniformity w/ 12x12 VUV SiPM

x2 Beam Intensity

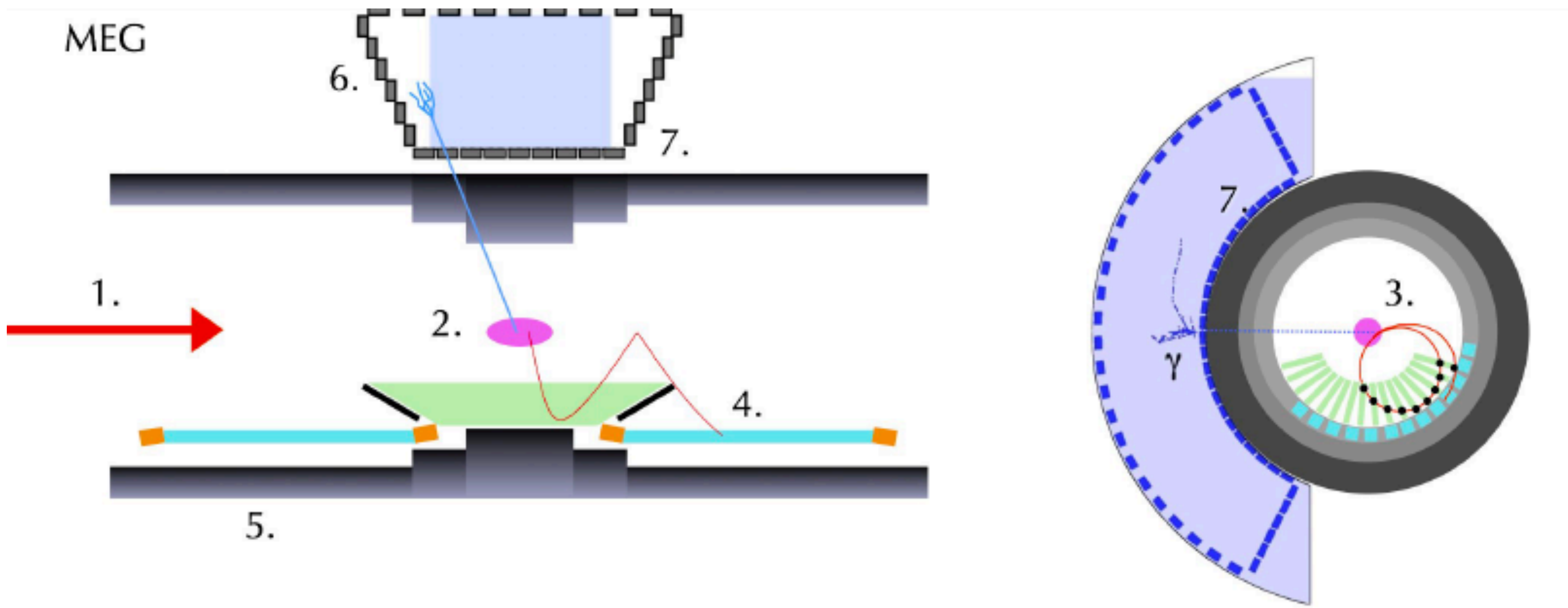
35 ps resolution w/ multiple hits

Background rejection

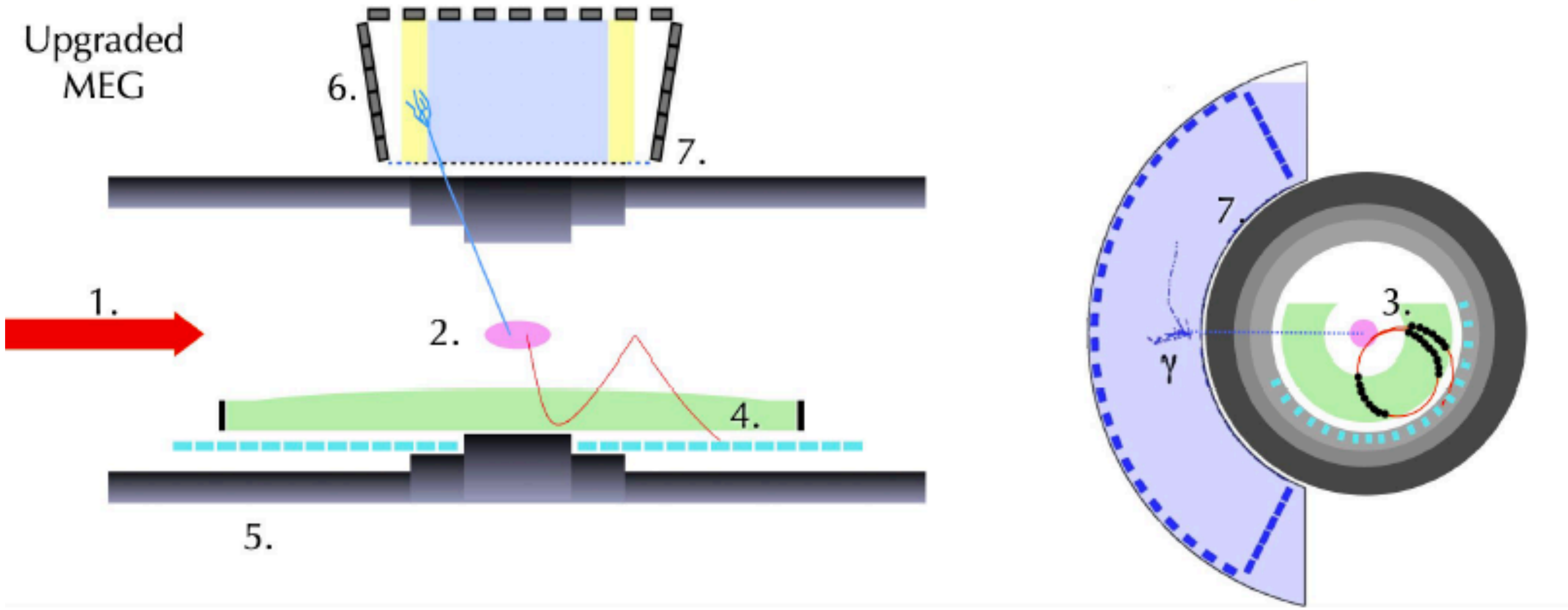
Single volume $He:iC_4H_{10}$

Full available stopped beam intensity
7×10^7

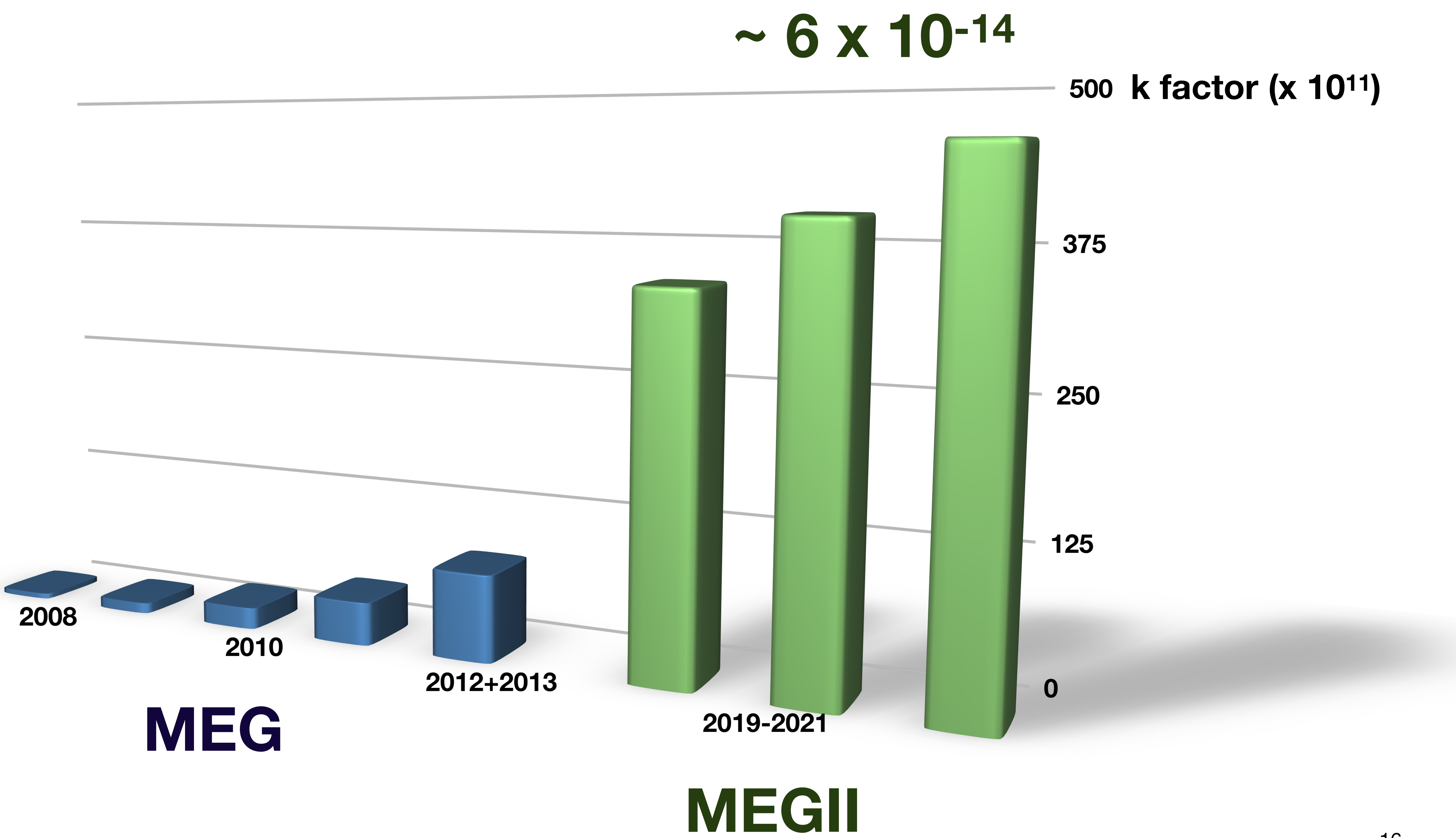
The MEG experiment vs the MEGII experiment



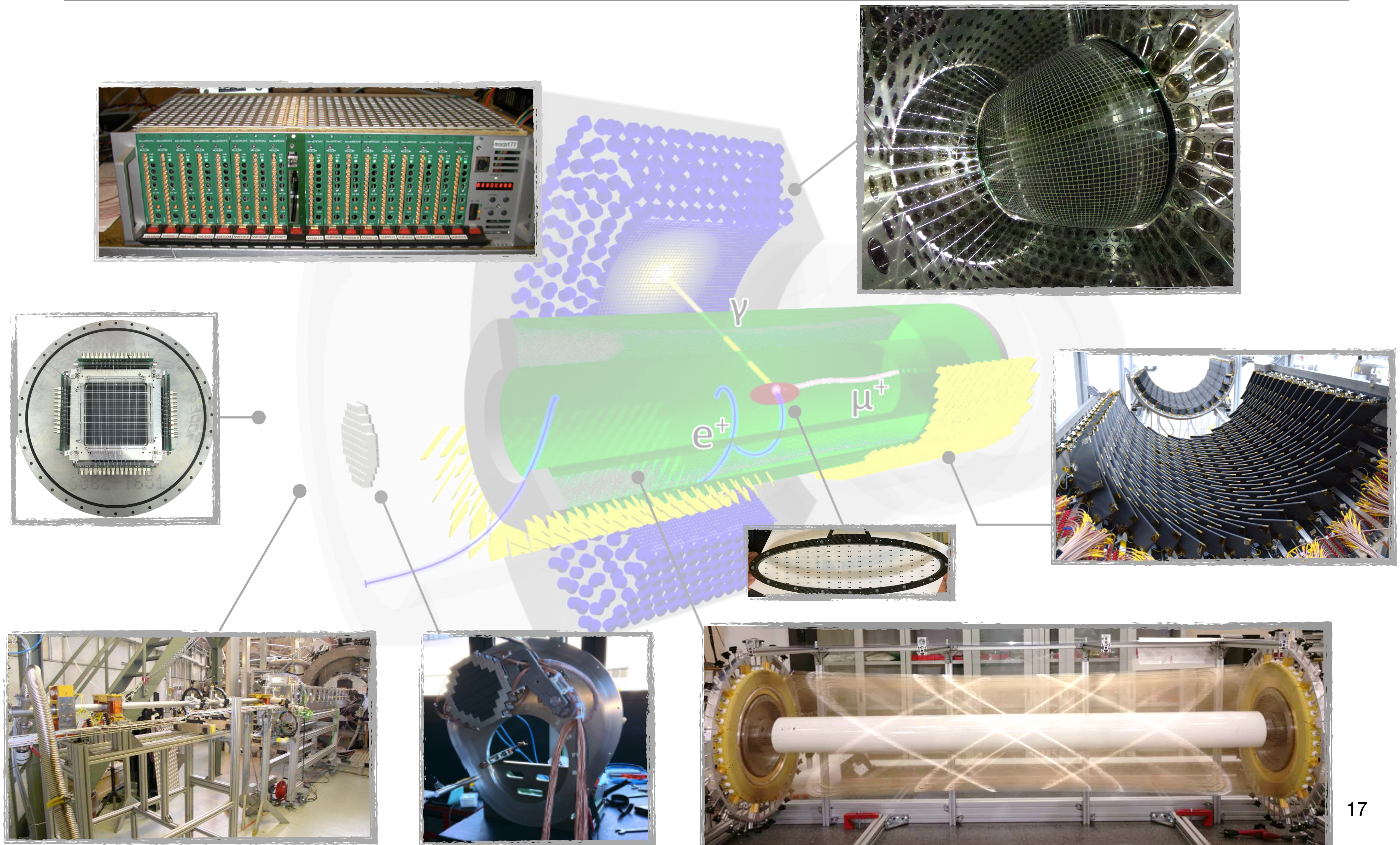
The MEG experiment vs the MEGII experiment



Where we will be

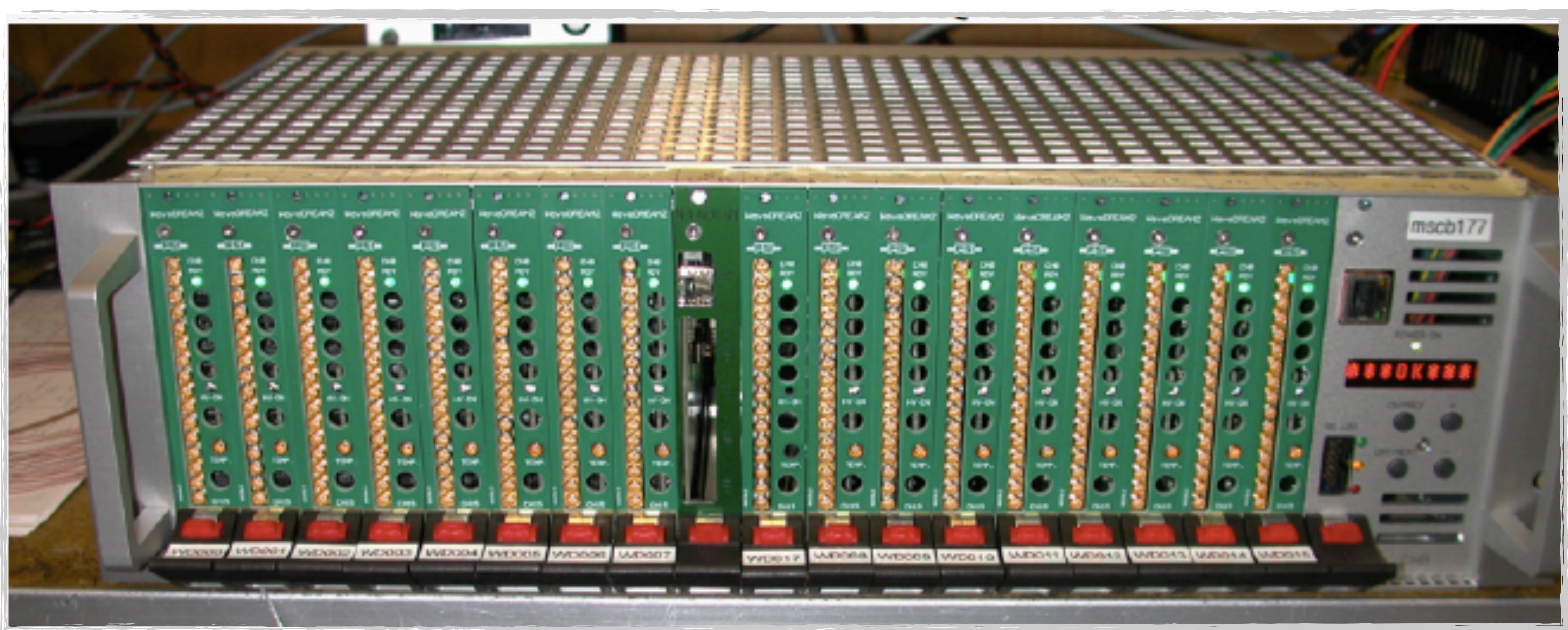


Where we are



MEGII: The new electronic - DAQ and Trigger

- DAQ and Trigger
  - ~9000 channels (5 GSPS)
  - Bias voltage, preamplifiers and shaping included for SiPMs
- 256 channels (1 crate) abundant tested during the 2016 pre-engineering run; >1000 channels available for the 2017 pre-engineering run; optimised version for 2018 engineering run.
- Trigger electronics and several trigger algorithms included and successfully delivered for the test beams/engineering runs



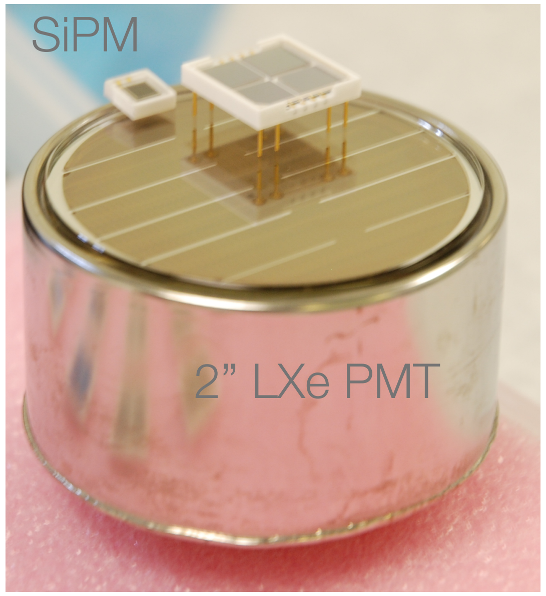
MEGII: The upgraded LXe calorimeter

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

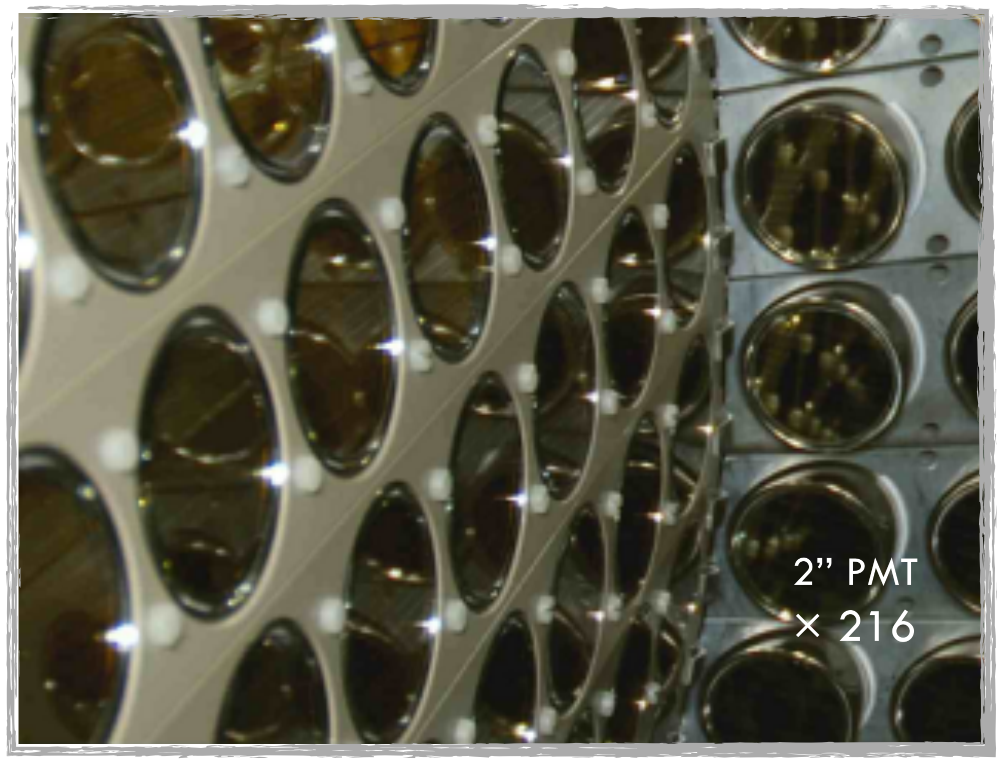
New

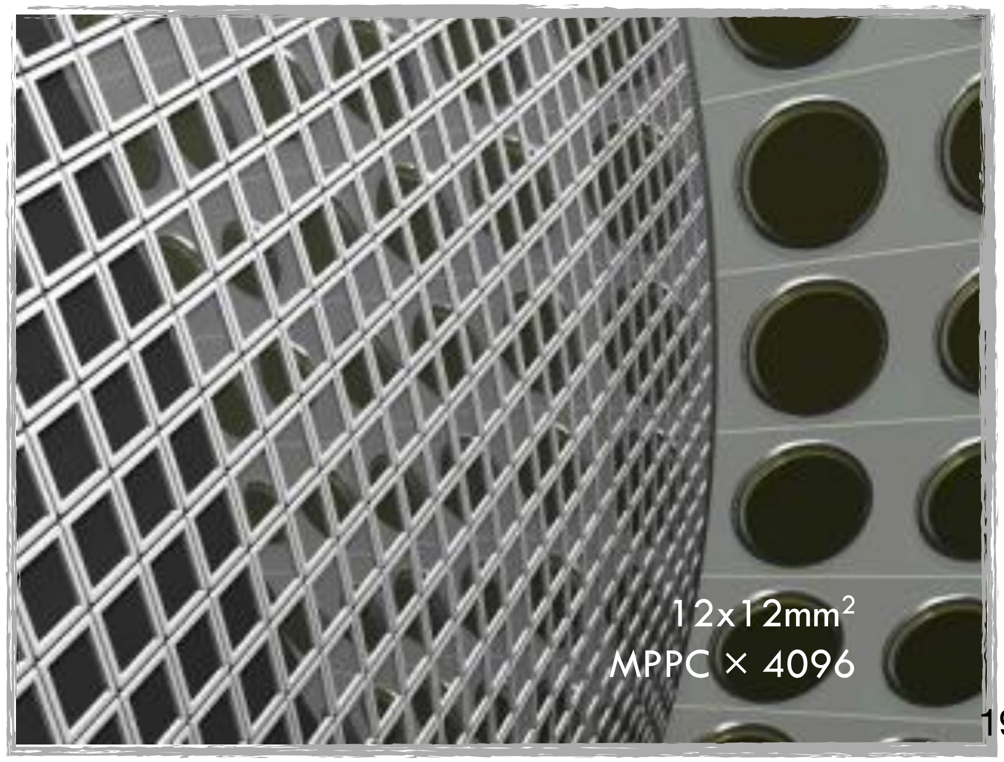
normal SiPM

new 12x12 mm²
LXe SiPM



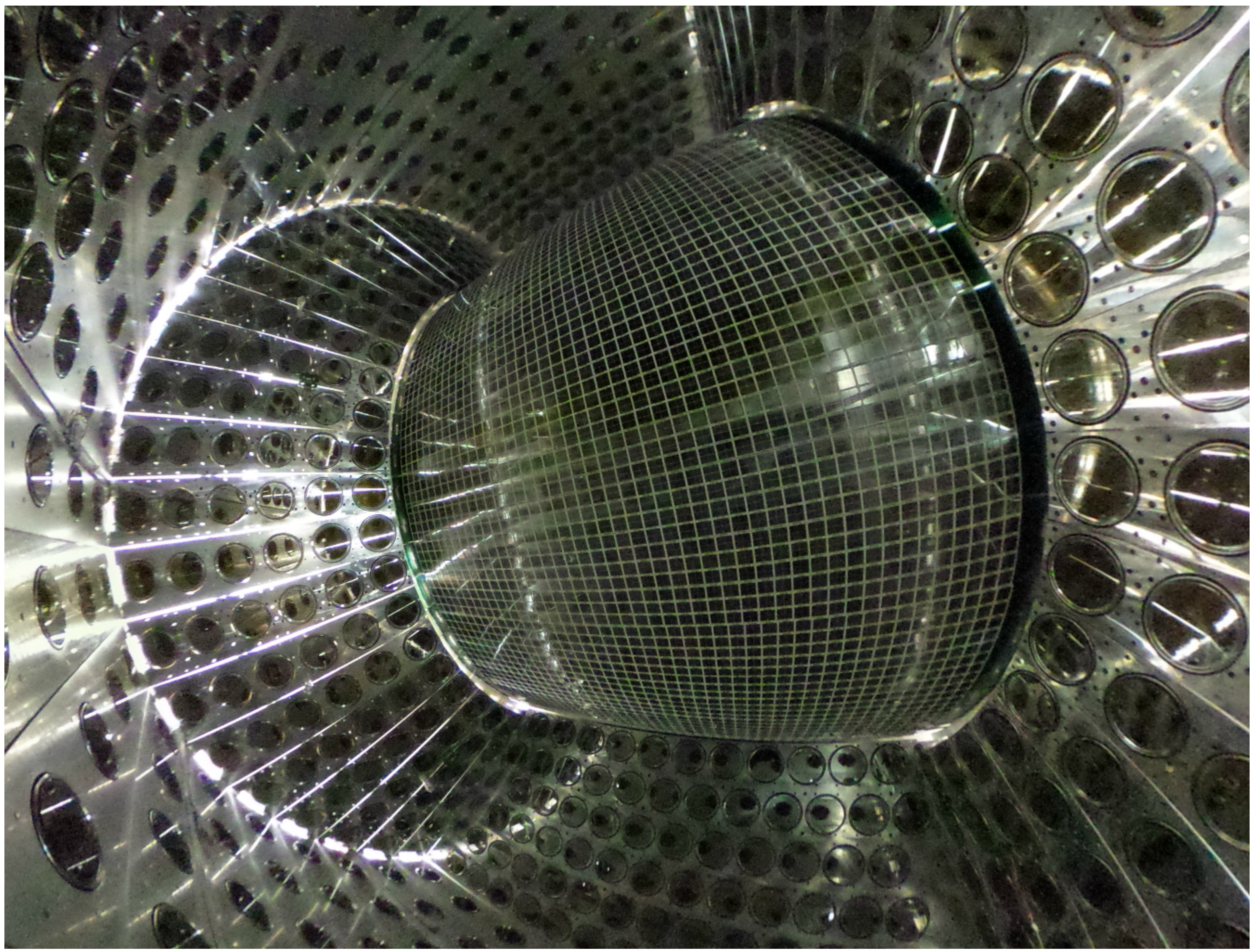
	MEG	MEGII
u [mm]	5	2.4
v [mm]	5	2.2
w [mm]	6	3.1
E [w<2cm]	2.4%	1.1%
E [w>2cm]	1.7%	1.0%
t [ps]	67	60



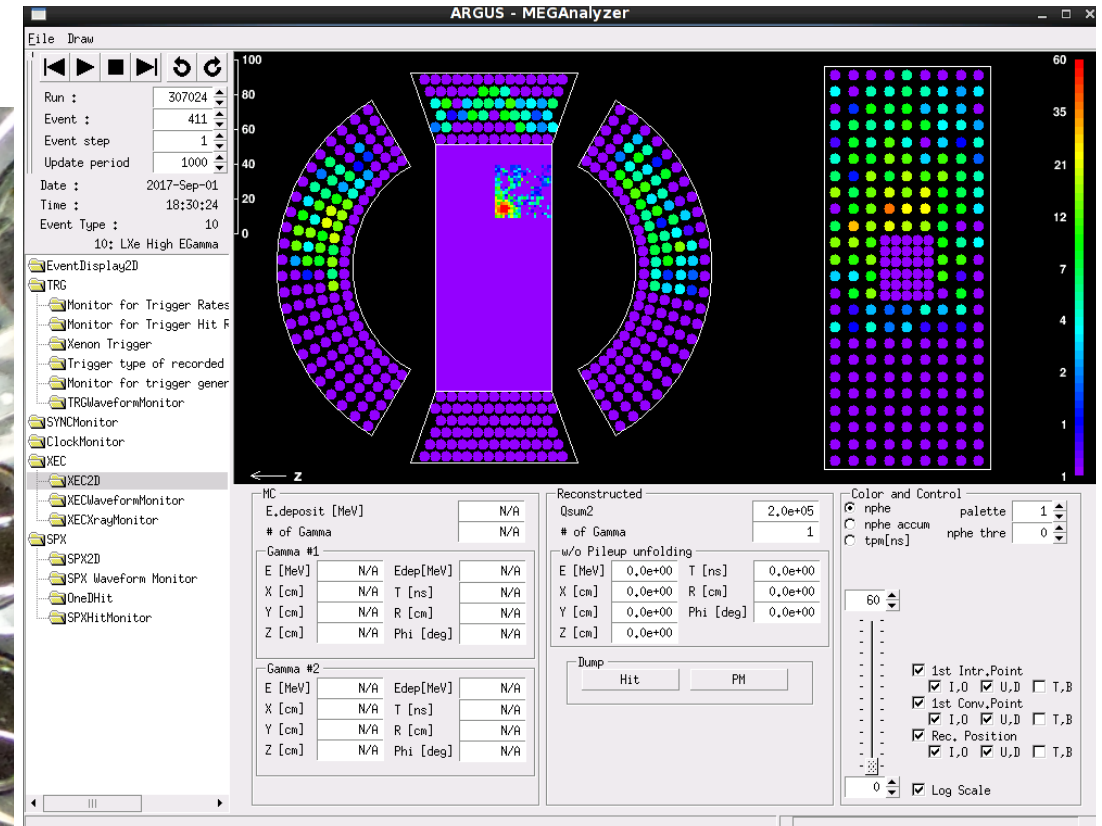


MEGII: The upgraded LXe calorimeter

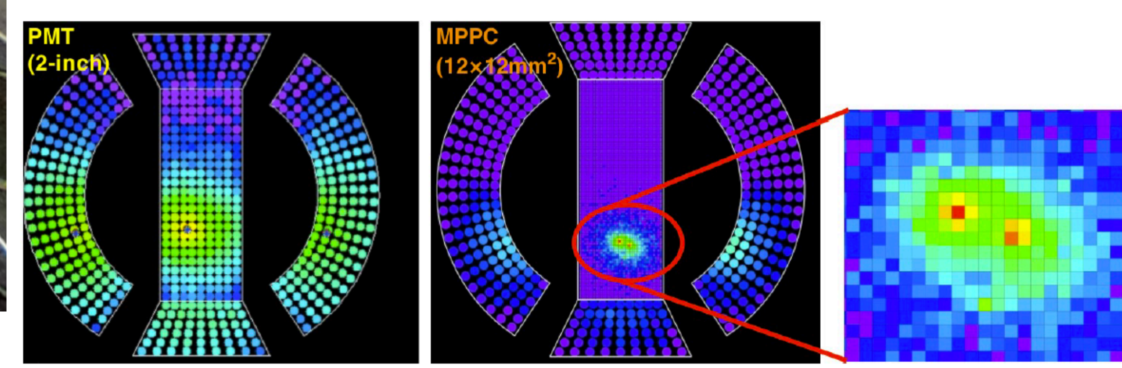
Detector commissioning started ! **New**



Data



MC simulation

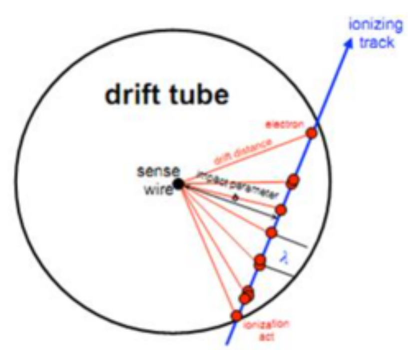


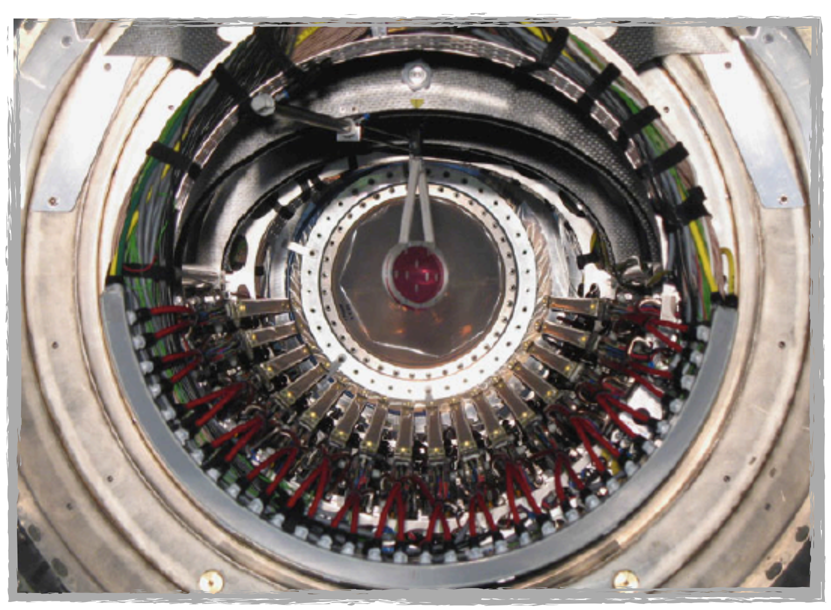
MEGII: The new single volume chamber

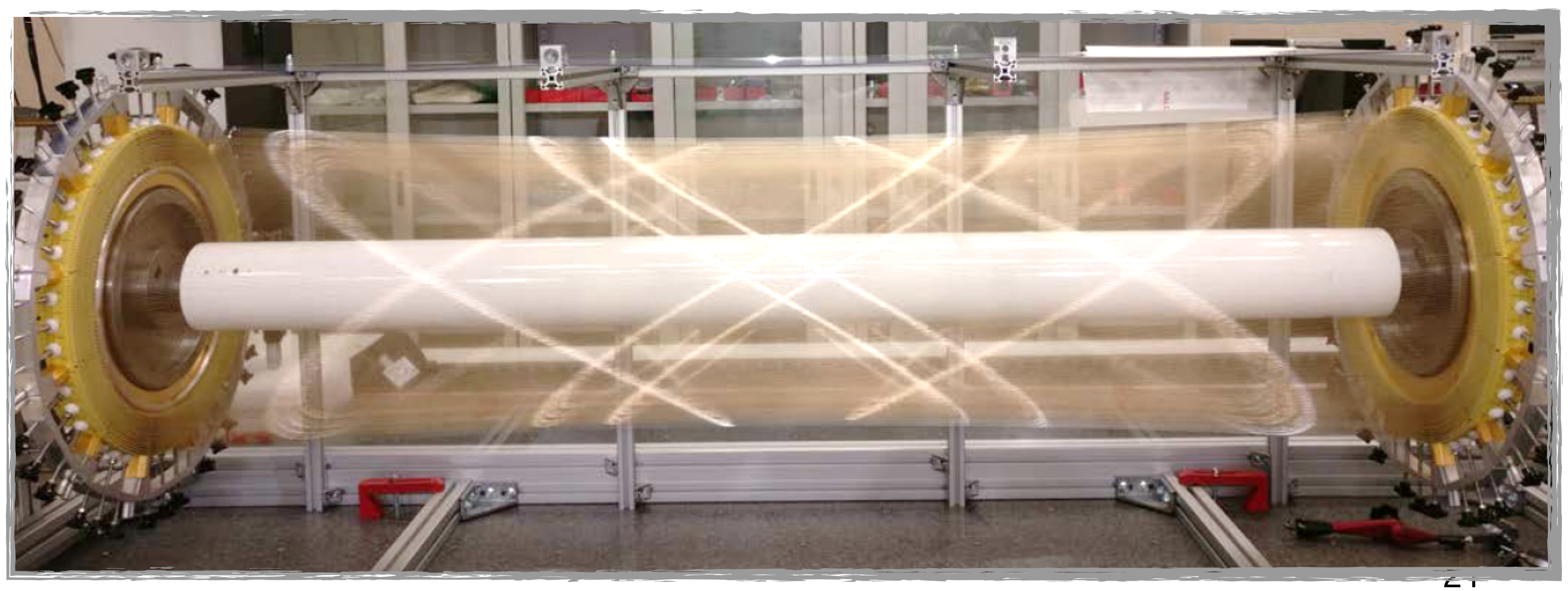
- Improved hit resolution: σ_r ~< 120 um (210 um)
- High granularity/Increased number of hits per track/ cluster timing technique
- Less material (helium: isobutane = 90:10, $1.6\times10^{-3}\,X_0$)
- High transparency towards the TC
- Status: Construction COMPLETED. Detector at PSI

	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





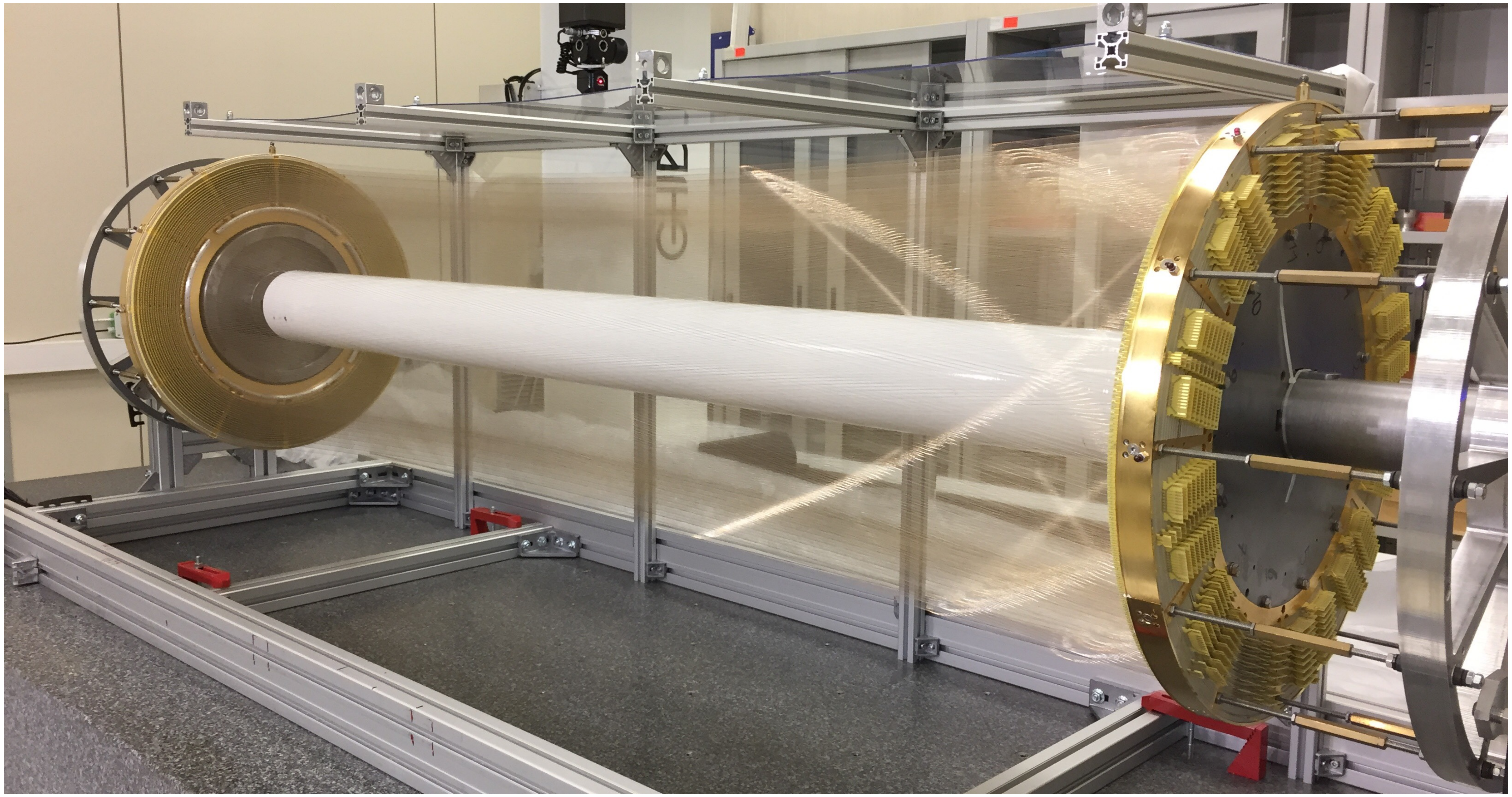


MEGII: The new single volume chamber

DCH Mock-up used during pre-eng 2017

MEGII: The new single volume chamber

The Real DCH: Assembling completed !



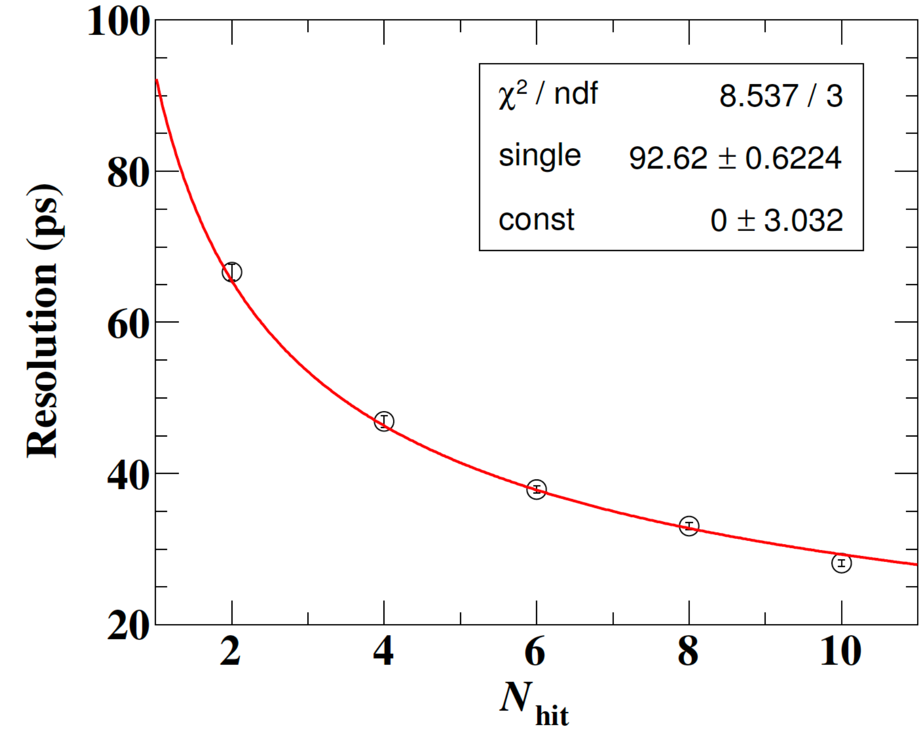
MEGII: The new single volume chamber

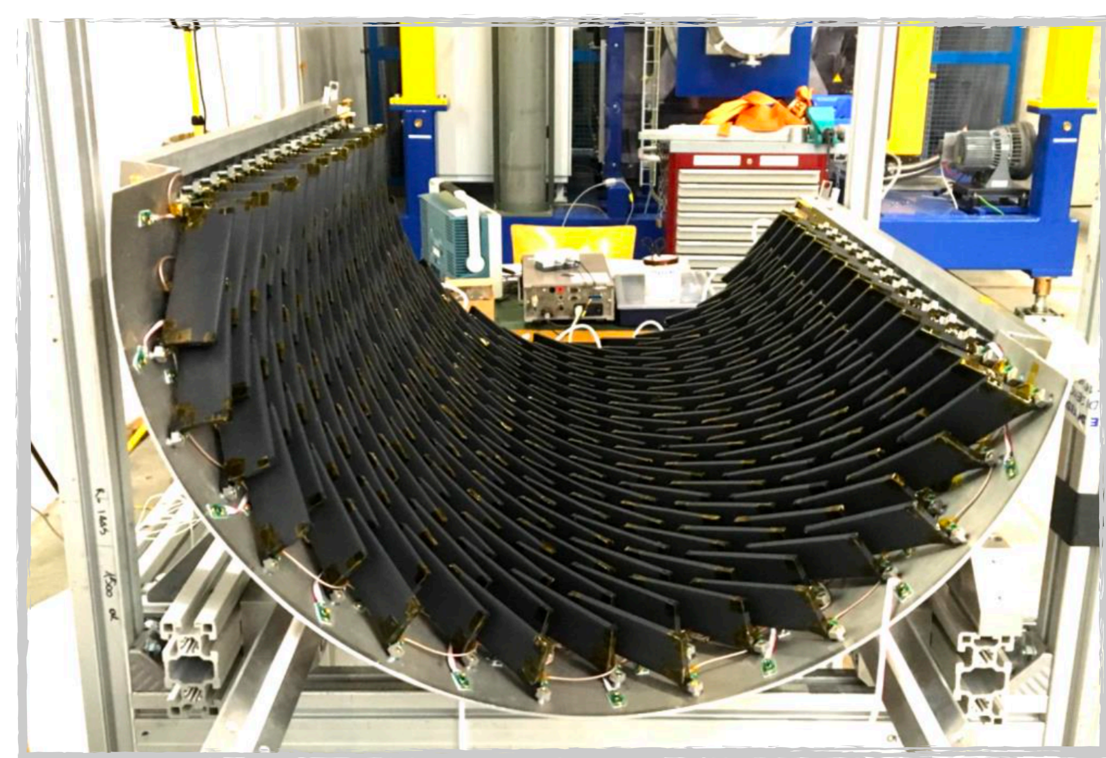
The Real DCH: Assembling completed and at PSI!

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
- Assembly: Completed
- Expected detector performances confirmed with data during pre-eng. 2016 and 2017

Pilot run 2016

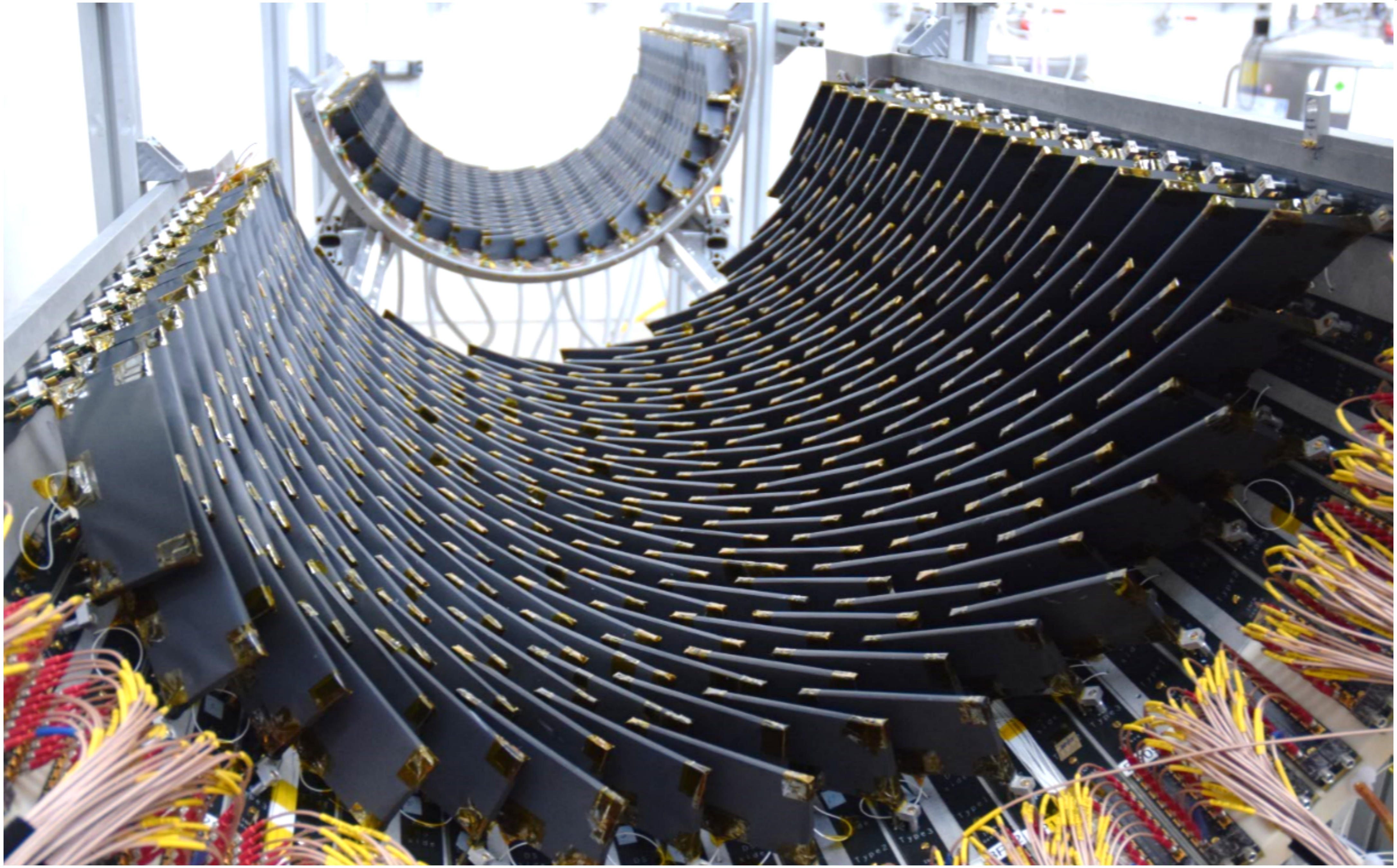




MEGII: the pixelized Timing Counter

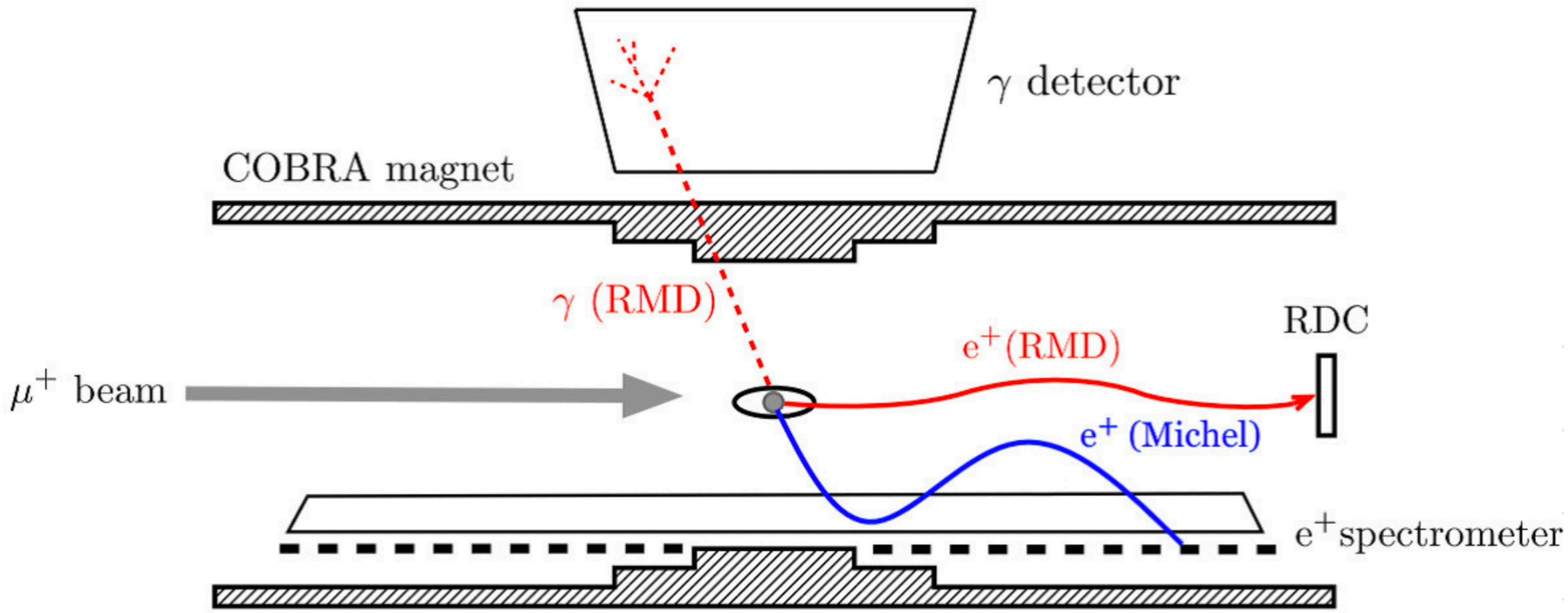
Full commissioned: Ready for MEGII!

New



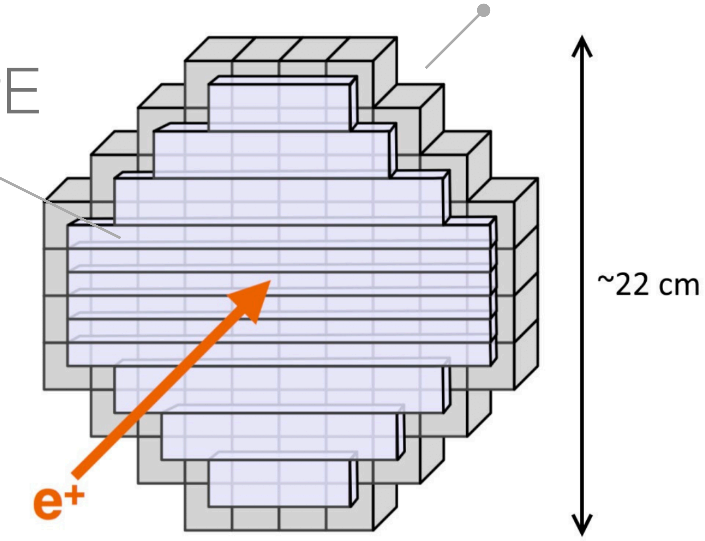
MEGII: The Radiative Decay Counter

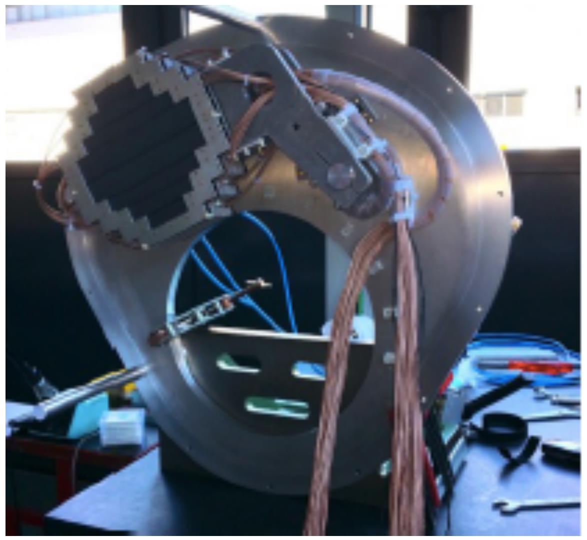
- Added a new auxiliary detector for background rejection purpose. Impact into the experiment: Improved sensitivity by 20%
- Commissioning during the 2016 pre-engineering run
- Status: Ready for MEGII !



BC418
MPPC
S13360-3050PE

LYSO 2 x 2 x 2 cm^3
MPPC S12572-025



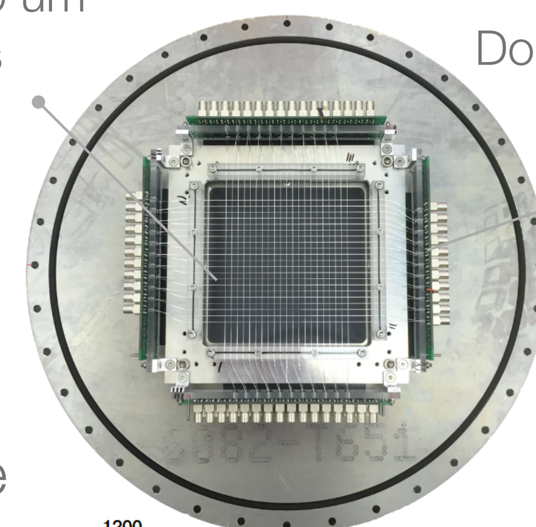


MEGII: new calibration methods and upgrades

- CEX reaction: $p(\pi^-,\pi^0)n$, $\pi^0 \rightarrow \gamma\gamma$
- 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

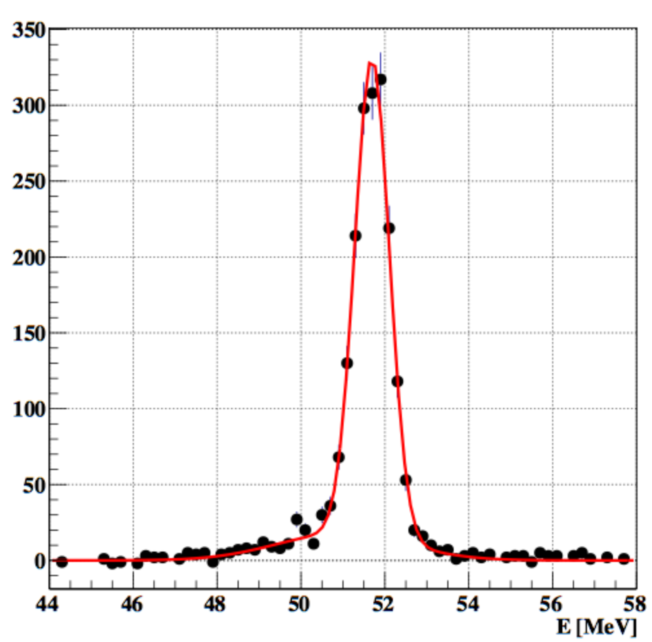
MC BCF12 250 x 250 um^2 scintillating fibers

Double readout: MPPC S13360-3050C



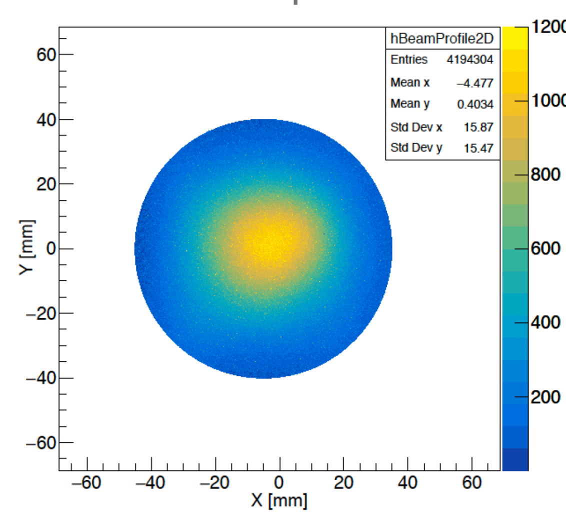
SciFi

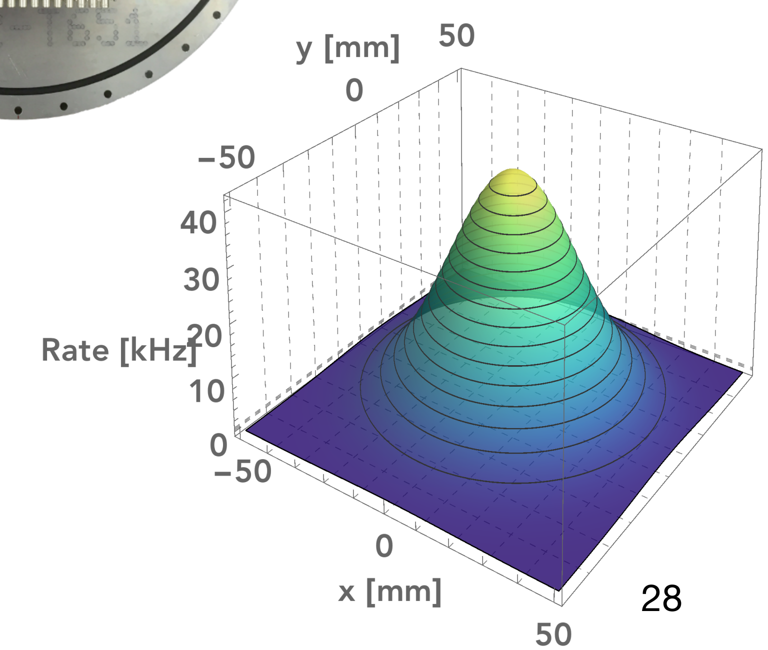
Monochromatic e-line



pTC's laser

Luminophore





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 expect to start next year the full engineering run followed by a physics run aiming at a sensitivity **down to 6×10^{-14}**

- **cLFV remains one of the most exiting place where to search for new physics**

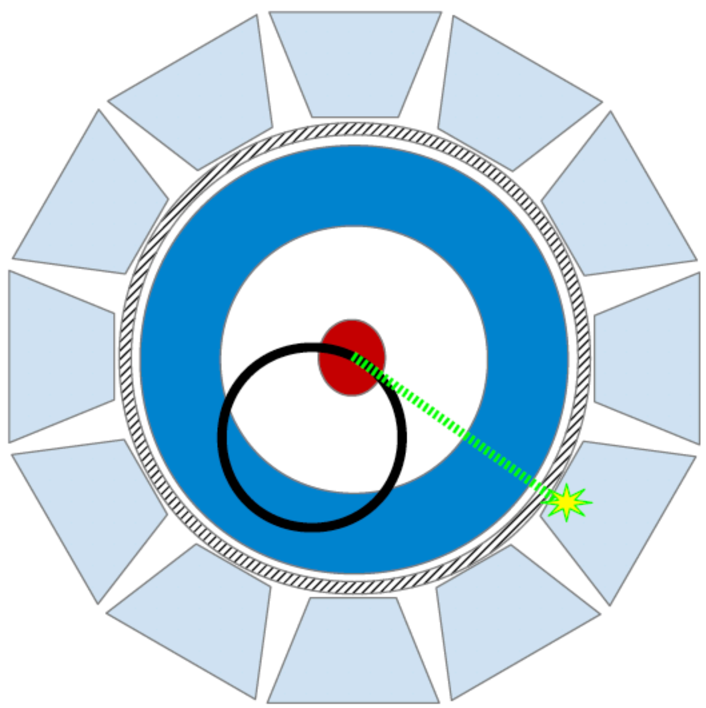
Thanks for your attention

G. Cavoto, A. Papa, F. Renga, E. Ripiccini, C. Voena, Eur. Phys. J. C**78** (2018) 37

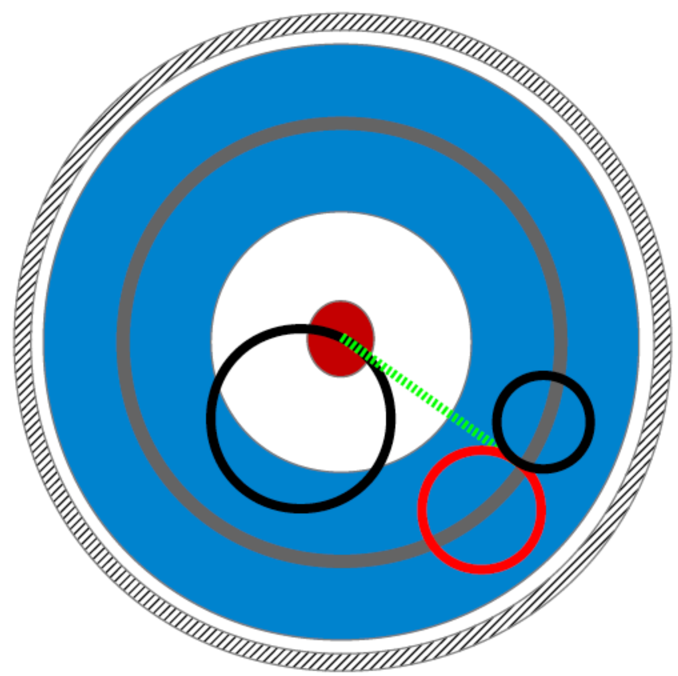
Future prospects: Where the limits are

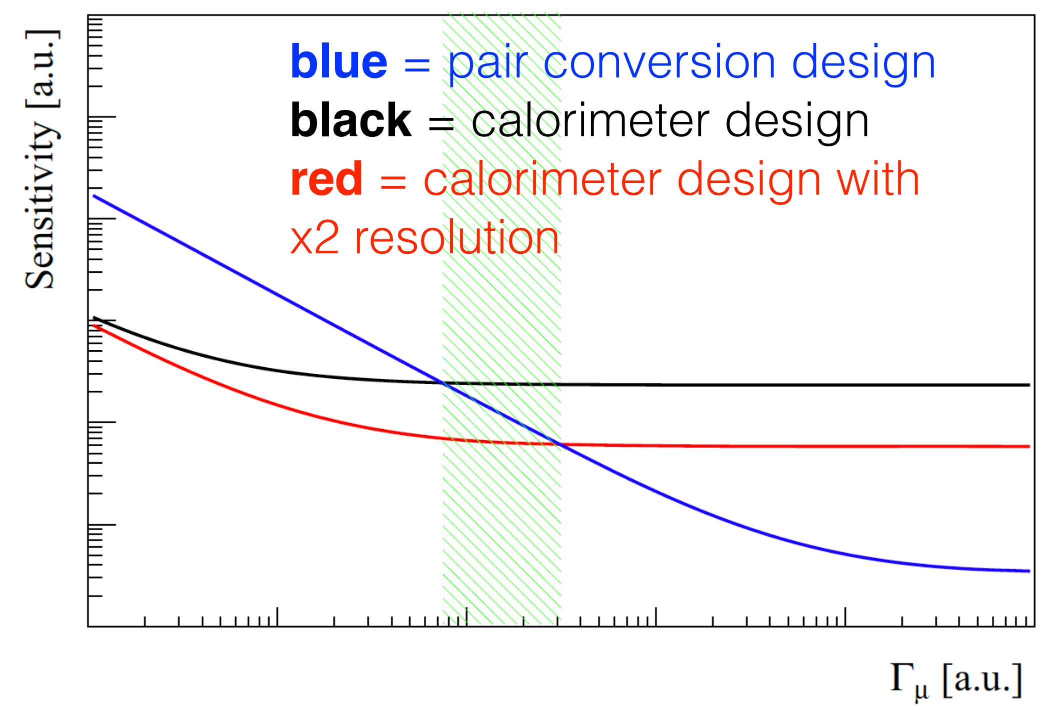
- **$\mu^+ \to e^+ \gamma$** at the highest muon beam intensities: Calorimetry vs gamma conversion + tracking

Calorimetry



Conversion + tracking





- High detection efficiency (calorimetry) vs better energy resolution (conversion+tracking)
- For a given detector the optimum R is that corresponding to negligible (no more than few) background events over the running time
- At very high rate the low efficiency of the conversion can be compensated keeping the background under control thanks to the better resolutions

Future prospects: Where the limits are

Observable	One photon conversion layer	Photon calorimeter
$T_{e\gamma}$ (ps)	60	50
E_e (keV)	100	100
E_γ (keV)	320	850
Efficiency (%)	1.2	42