The MEG experiment

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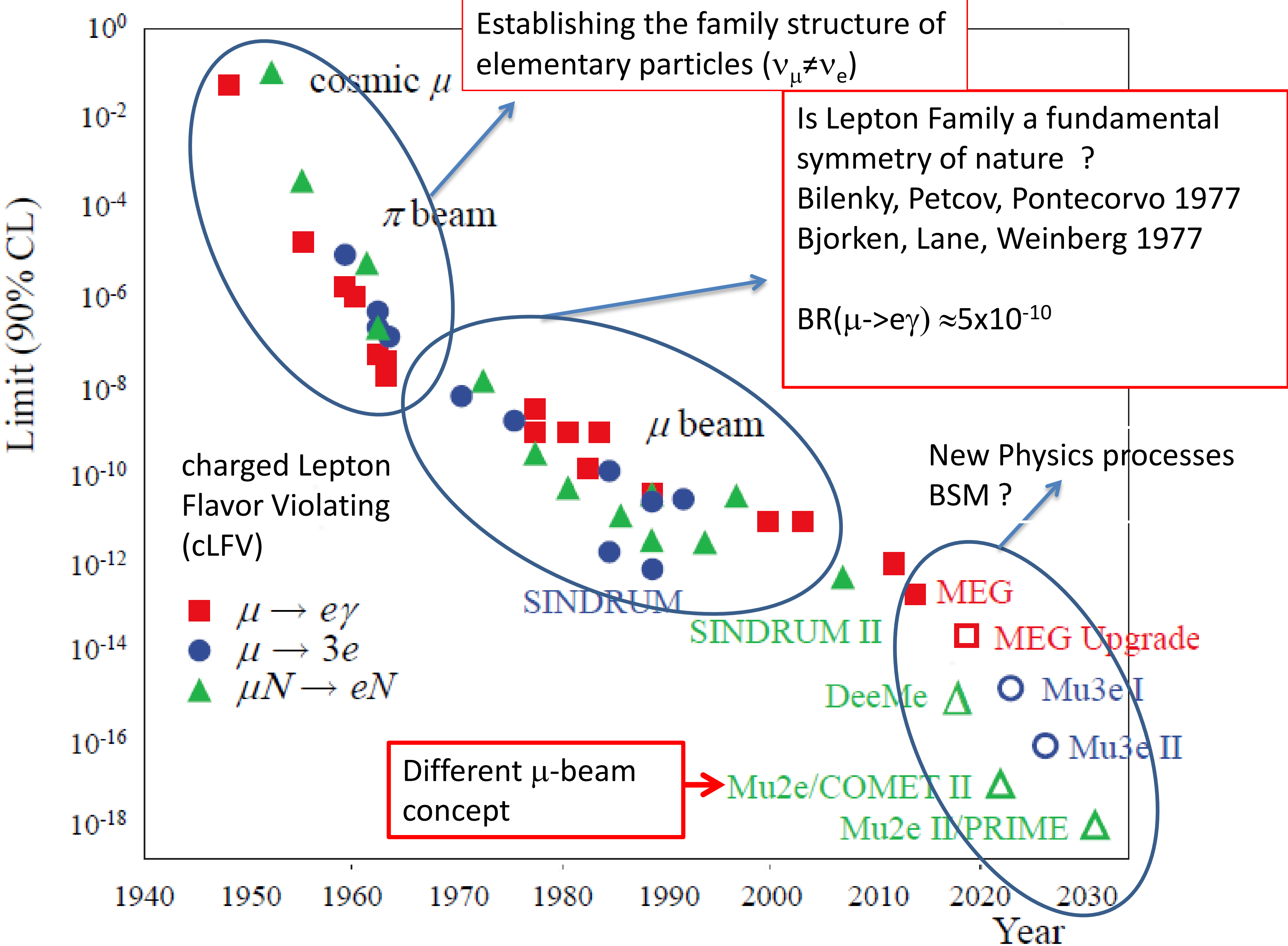
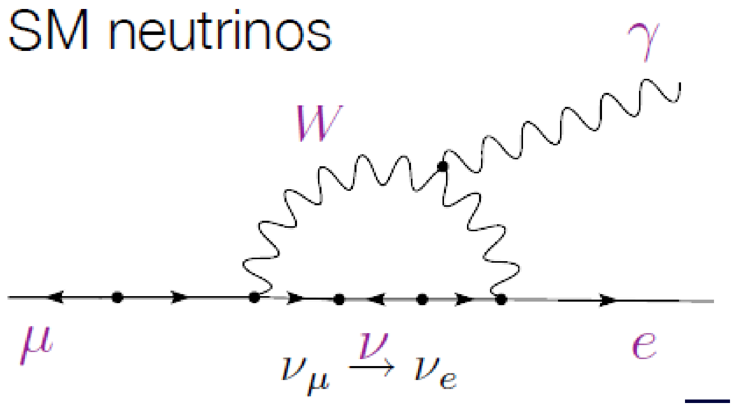
Quy Nohn August 9th 2019



Establishing the family structure of elementary particles ($\nu_\mu \neq \nu_e$)
Is Lepton Family a fundamental symmetry of nature ?
Bilenky, Petcov, Pontecorvo 1977
Bjorken, Lane, Weinberg 1977
BR(μ->eγ) ≈5x10^{-10}
cosmic μ
π beam
μ beam
charged Lepton Flavor Violating (cLFV)
$\mu \to e\gamma$
$\mu \to 3e$
$\mu N \to eN$
New Physics processes BSM ?
SINDRUM
SINDRUM II
MEG
MEG Upgrade
DeeMe
Mu3e I
Mu3e II
Different μ-beam concept
Mu2e/COMET II
Mu2e II/PRIME
Limit (90% CL)
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

Why are these processes so sensitive to BSM ?
First: cLFV in the SM are NOT observable

In pre-ν oscillations SM cLFV (charged Lepton Flavor Violating) amplitudes are 0 due to the fact that neutrino masses are 0



μ→eγ rate in the standard model after neutrino oscillations

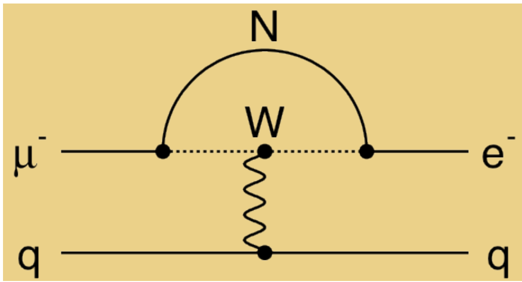
$$P_{osc} \approx \sin^2\left(\delta m_\nu^2 \frac{L}{E}\right); L \approx \frac{1}{M_W}; E \approx M_W$$

$$BR \sim \alpha P_{osc} \sim \alpha\left(\frac{\delta m_\nu^2}{M_W^2}\right)^2 \quad ; \delta m_\nu^2 \sim 10^{-5} eV^2 \Rightarrow BR \sim 10^{-55}$$

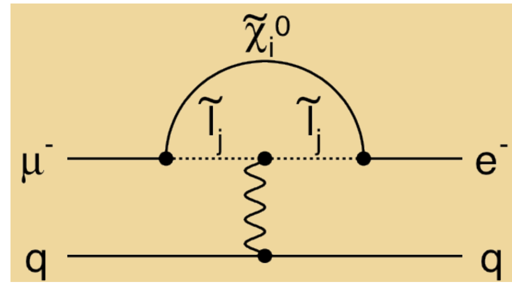
$$\frac{3\alpha}{32\pi}\left|\sum_{k=1,3}\frac{U_{\mu k}U_{ek}^* m_{\nu_k}^2}{M_W^2}\right|^2 .$$

cLFV are VERY clean channels for new physics searches

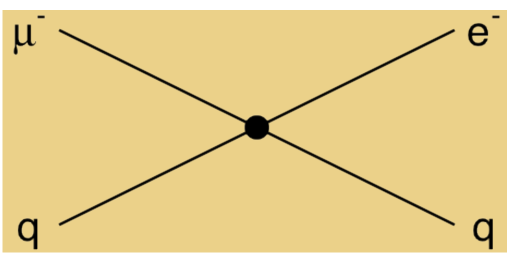
Second: as soon as one starts adding new (BSM) terms to the SM Lagrangian:



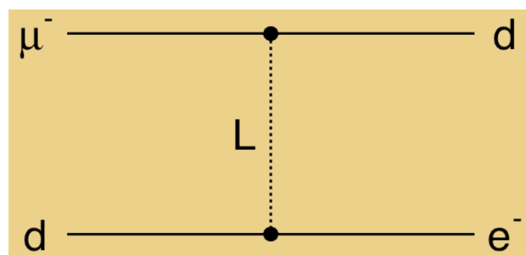
Heavy Neutrinos
(see saw)



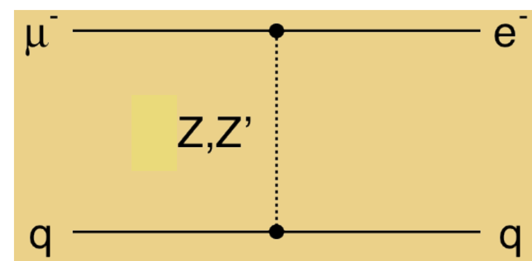
Supersymmetry



Compositeness



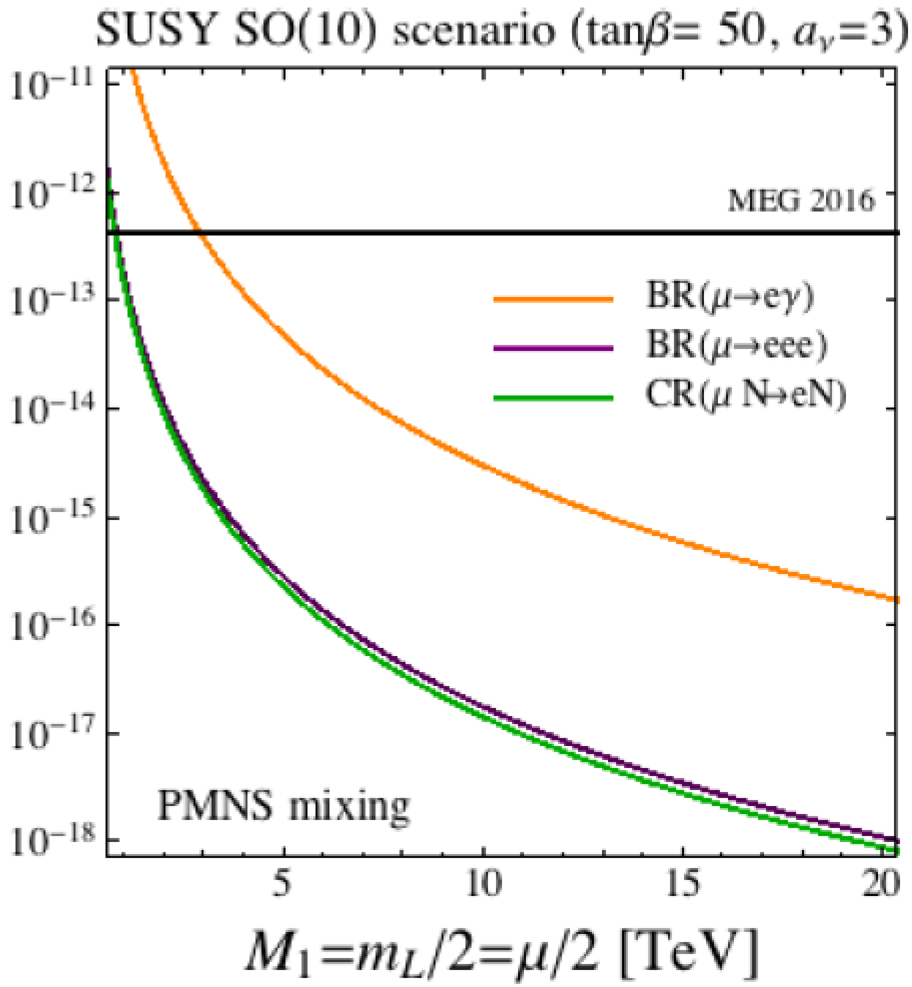
Leptoquarks



New Heavy Bosons / Anomalous Couplings

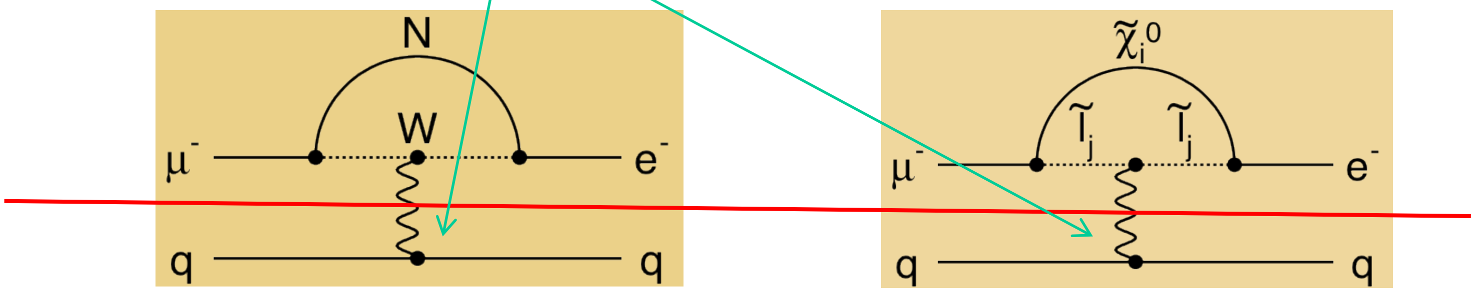
Charged Lepton flavor violating amplitudes arise at measurable levels in the same way in which V_{PMNS} and V_{CKM} arise (Yukawa mass terms diagonalization)

An example…



SUSY seesaw SO(10) with PMNS slepton mixing; Calibbi, Signorelli 2017 and references therein.

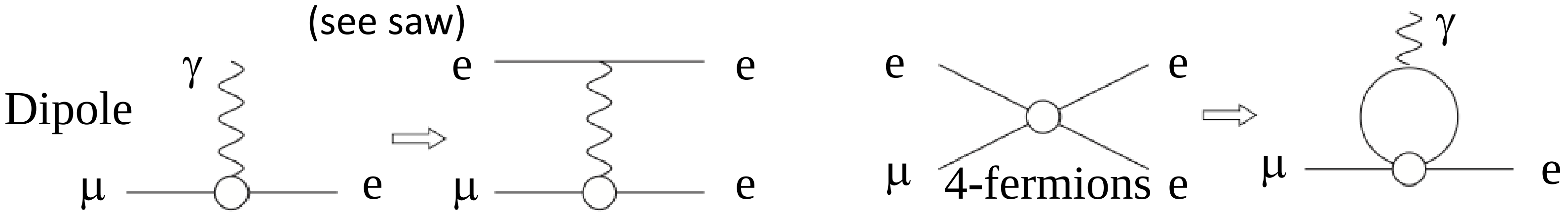
In case model prefer dipole operator (Supersymmetry) μ–>eγ is enhanced by roughly a factor 1/α wrt μ->e conversion or μ->3e

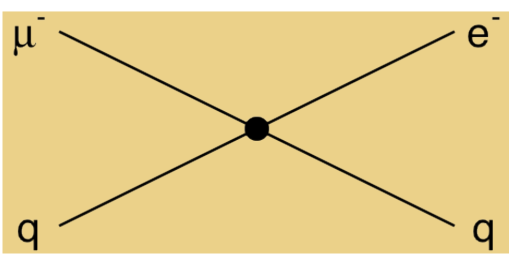


(e) Heavy Neutrinos (see saw) (e)

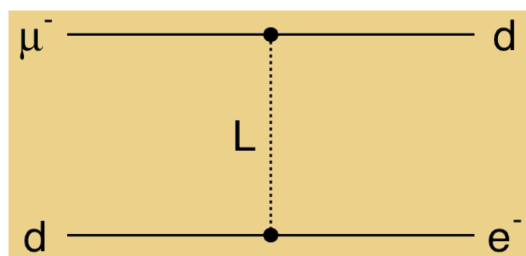
(e) Supersymmetry (e)

μ→eγ

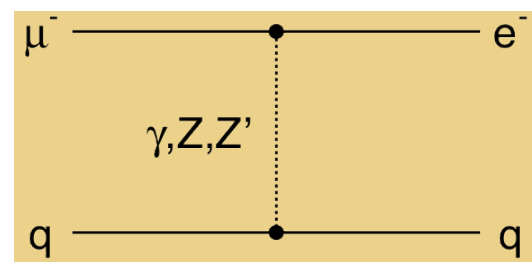




Compositeness



Leptoquarks

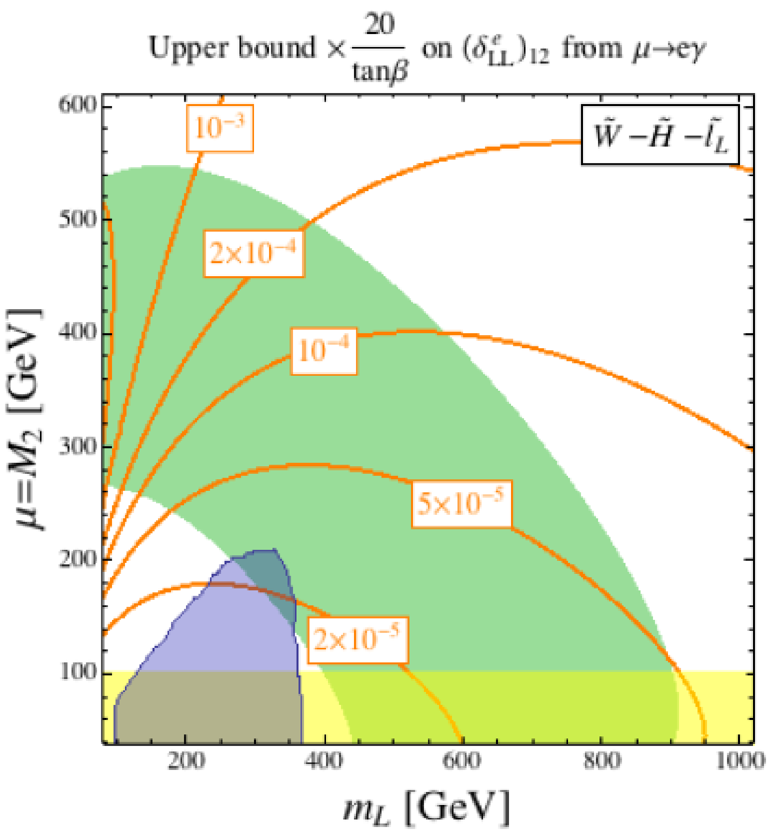


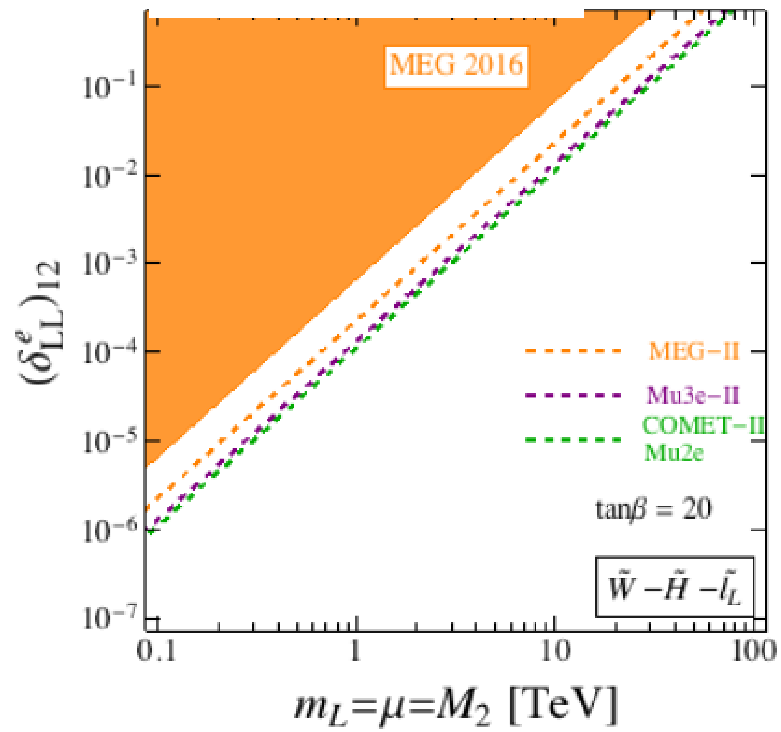
New Heavy Bosons / Anomalous Couplings

In other cases μ->e conversion or μ->3e dominate ➔ Complementarity + possibility of distinguishing among different models

Comparison with SUSY searches at LHC: a particular case

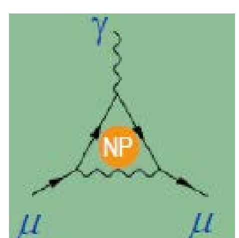
$$(\delta_{LL})_{ij} = \frac{(\Delta_{LL})_{ij}}{\sqrt{(\tilde{m}^2_L)_{ii}(\tilde{m}^2_L)_{jj}}} \approx C \quad A_{CLFV} \propto \frac{\delta}{M^2}$$



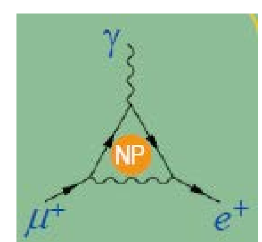


focus only on the particles relevant for CLFV observables (limits from LHC on coloured sparticles much stronger)

g-2



μ->e γ

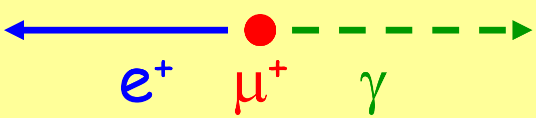


Calibbi, Signorelli, NC 2017

The distinction of Signal from background

signal

$\mu \to e\,\gamma$



$\theta_{e\gamma} = 180°$

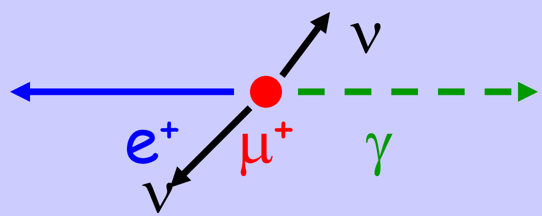
$E_e = E_\gamma = 52.8\ \text{MeV}$

$T_e = T_\gamma$

background

physical

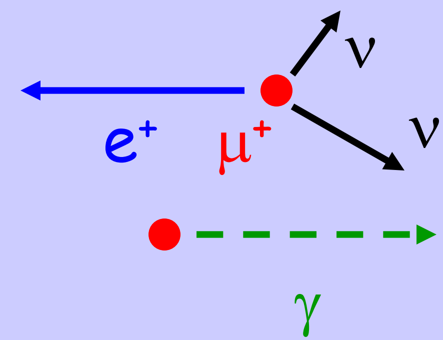
$\mu \to e\,\gamma\,\nu\,\nu$



accidental

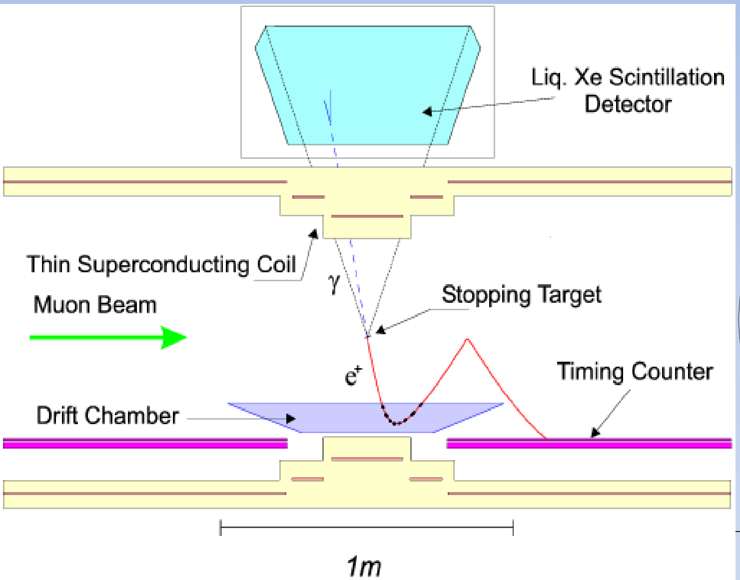
$\mu \to e\,\nu\,\nu$

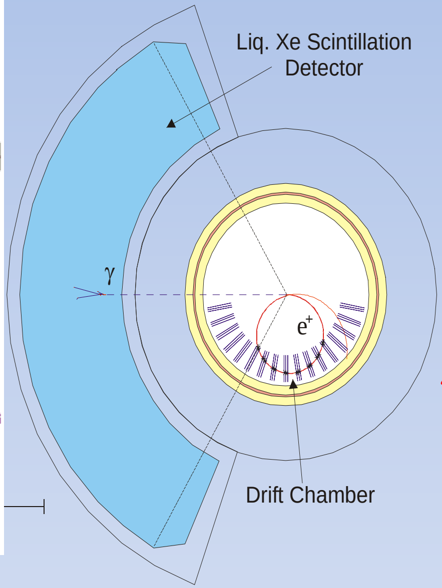
$$\begin{cases} \mu \to e\,\gamma\,\nu\,\nu \\ ee \to \gamma\,\gamma \\ eZ \to eZ\,\gamma \end{cases}$$



4 variables measured: measure them in the best possible way in order to separate signal from background

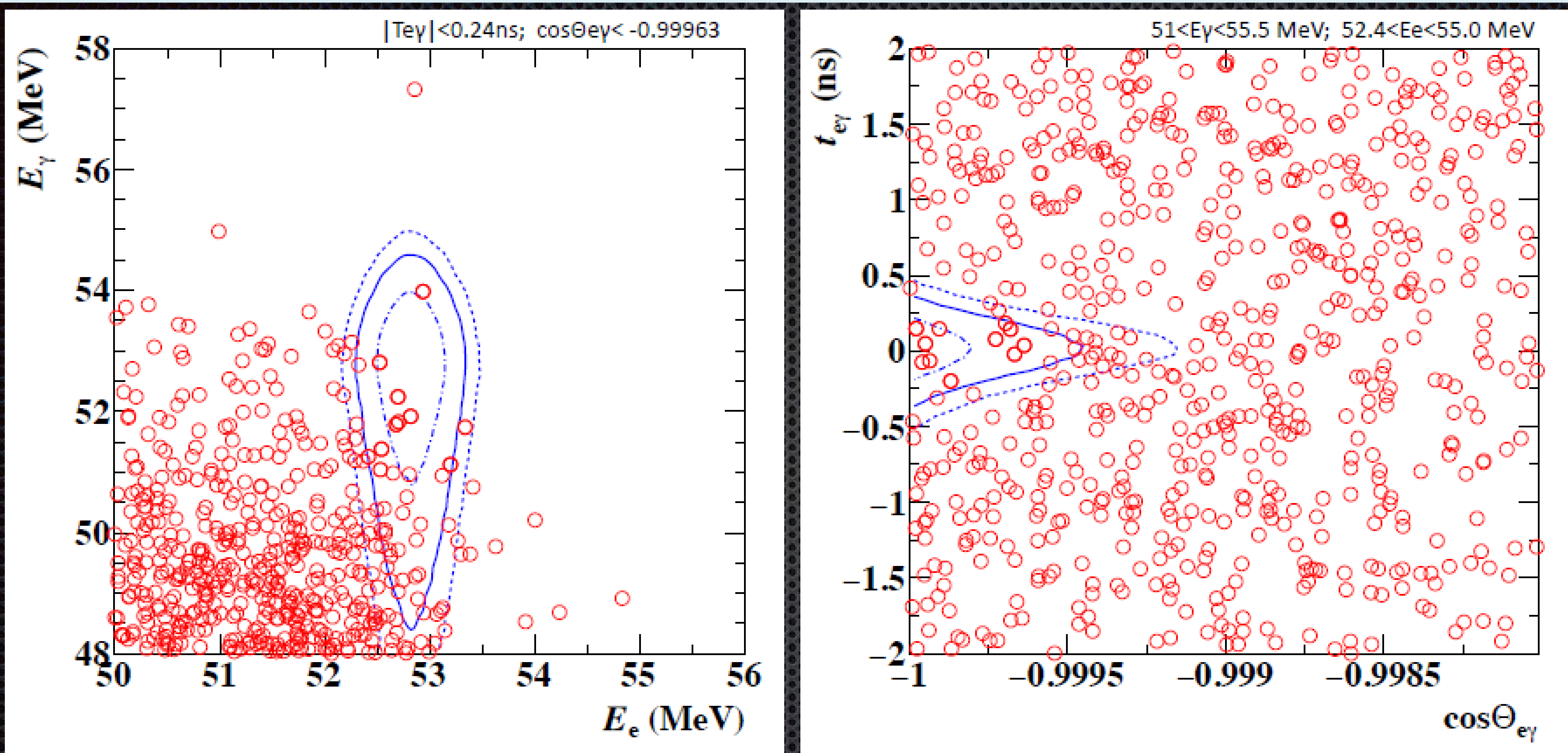
The MEG experiment…





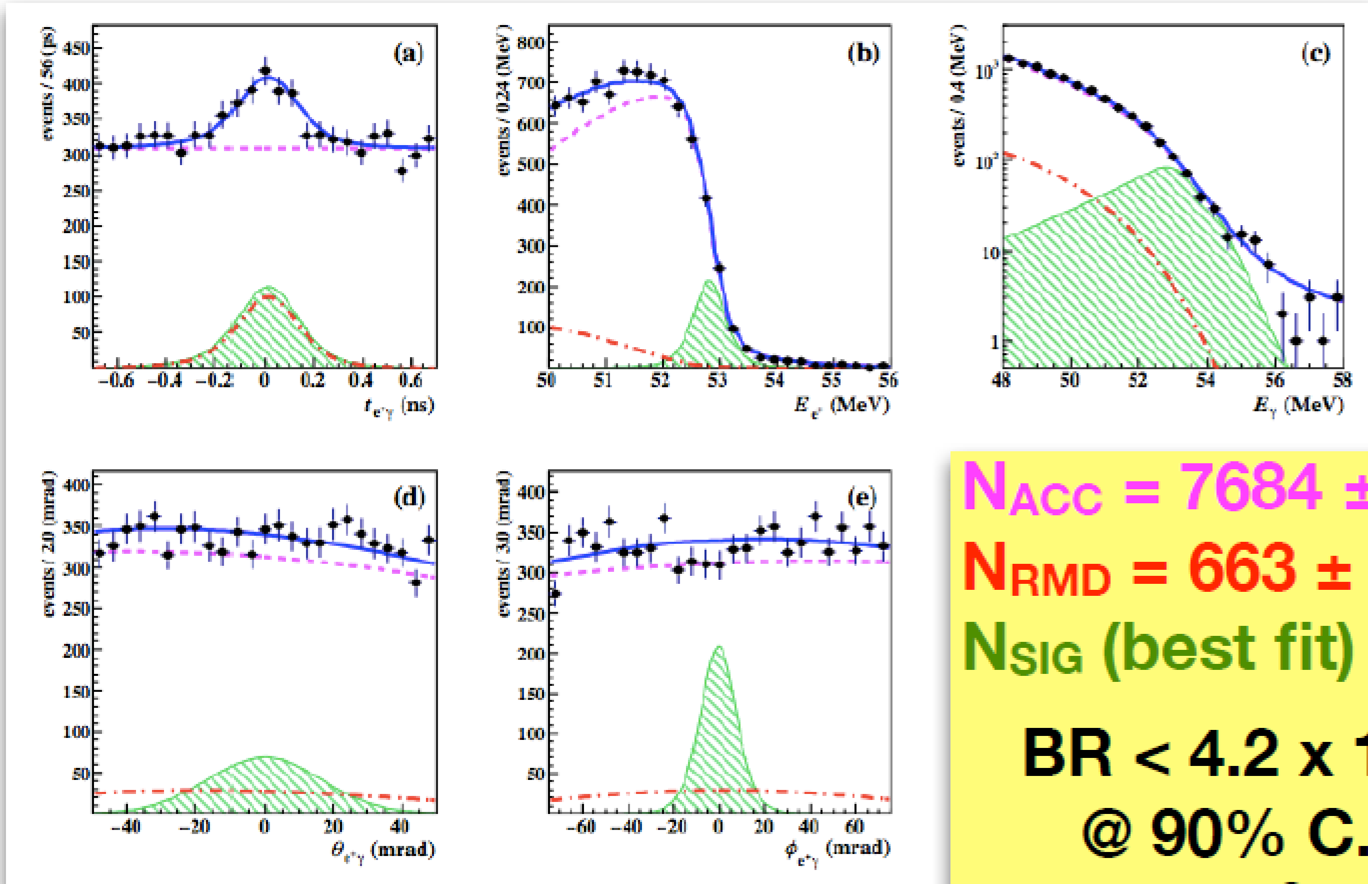
1. Stopped beam of 3 10^7 μ /sec in a 150 μm target
2. Solenoid spectrometer & drift chambers for e^+ momentum
3. Scintillation counters for e^+ timing
4. Liquid Xenon calorimeter for γ detection (scintillation)

The interesting 4D region split in 2 bidimensional plots



signal contours of 1, 1.64, 2σ are shown

A more quantitative comparison…



N_{ACC} = 7684 ± 103

N_{RMD} = 663 ± 59

N_{SIG} (best fit) = -2.2

BR < 4.2 x 10^{-13}

@ 90% C.L.

Eur. Phys. J. C76 (2016)

Magnified signal (BR = 4 x 10^{-11})

The relative angle is split into zenith and azimuth

The MEG Collaboration

University of Tokyo
KEK

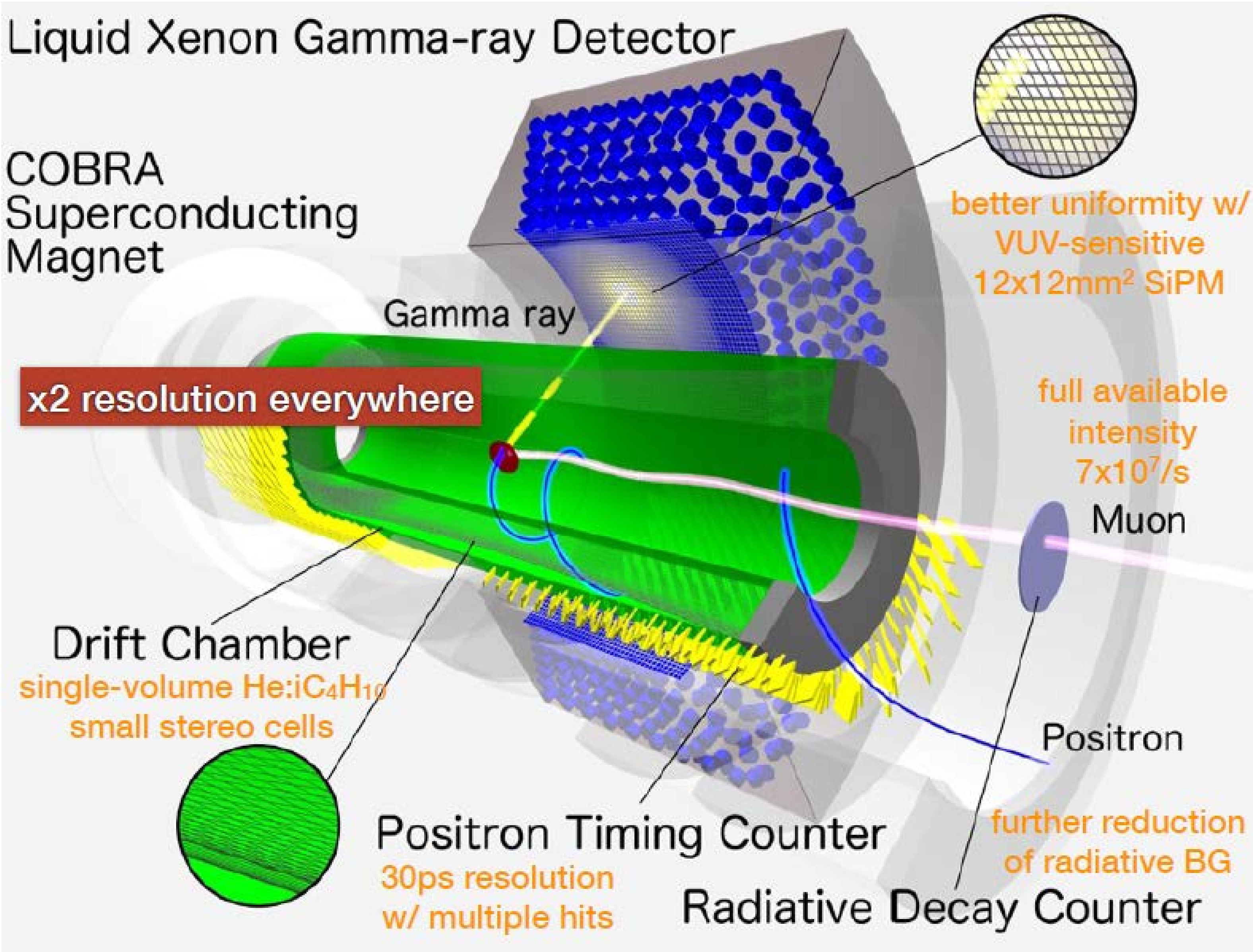
INFN & University of Genova
INFN & University of Lecce
INFN & University of Pavia
INFN & University of Pisa
INFN & University of Roma 1

Paul Scherrer Institut

JINR Dubna
BINP Novosibirsk

University of California Irvine

The MEG II detector



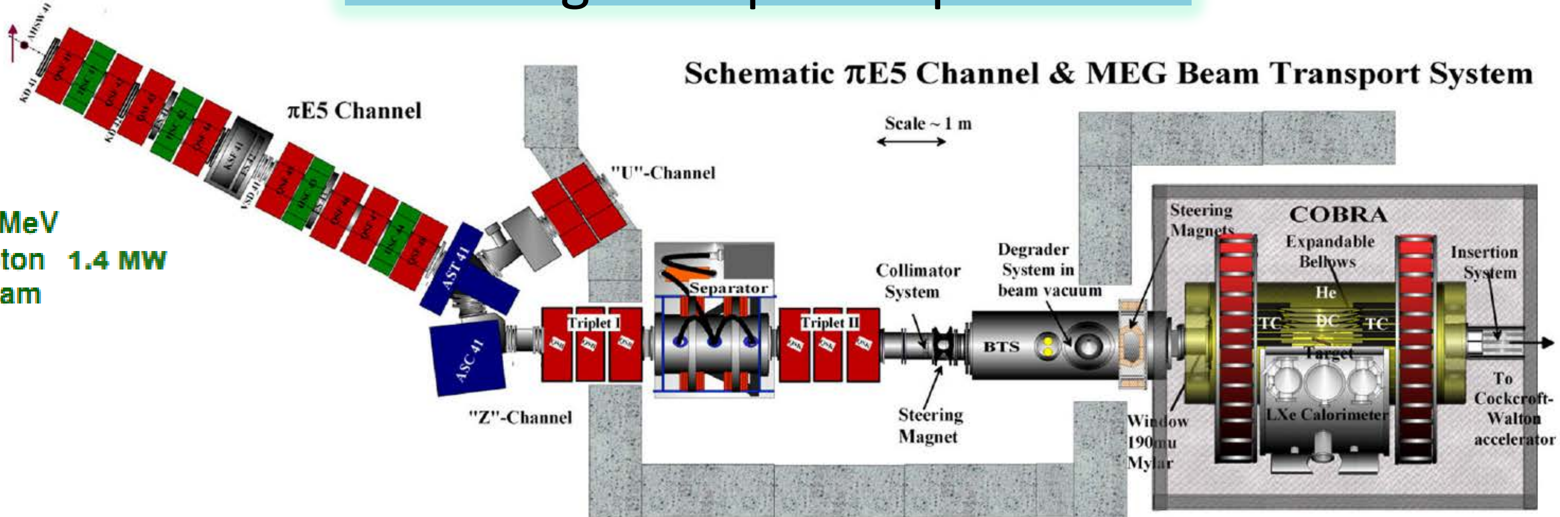
The PSI surface muon beam: learning from past experience

$P_{\mu} \sim 29 MeV / c$

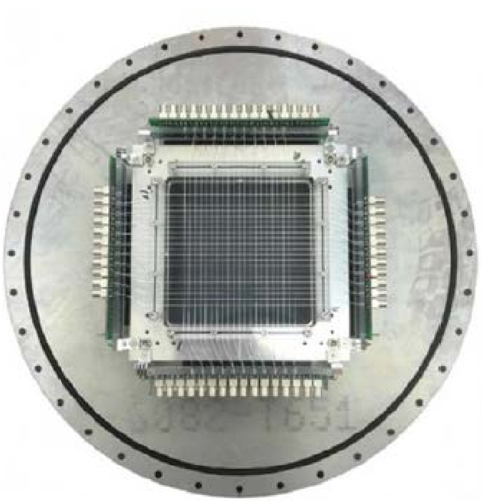
$\pi \rightarrow \mu\nu$

at rest

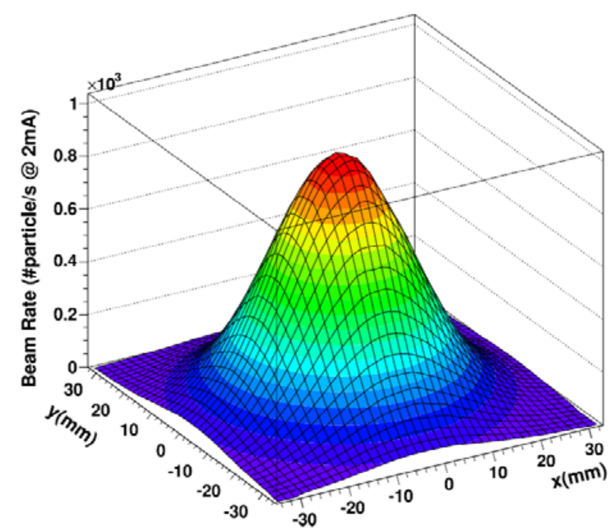
590 MeV proton 1.4 MW beam



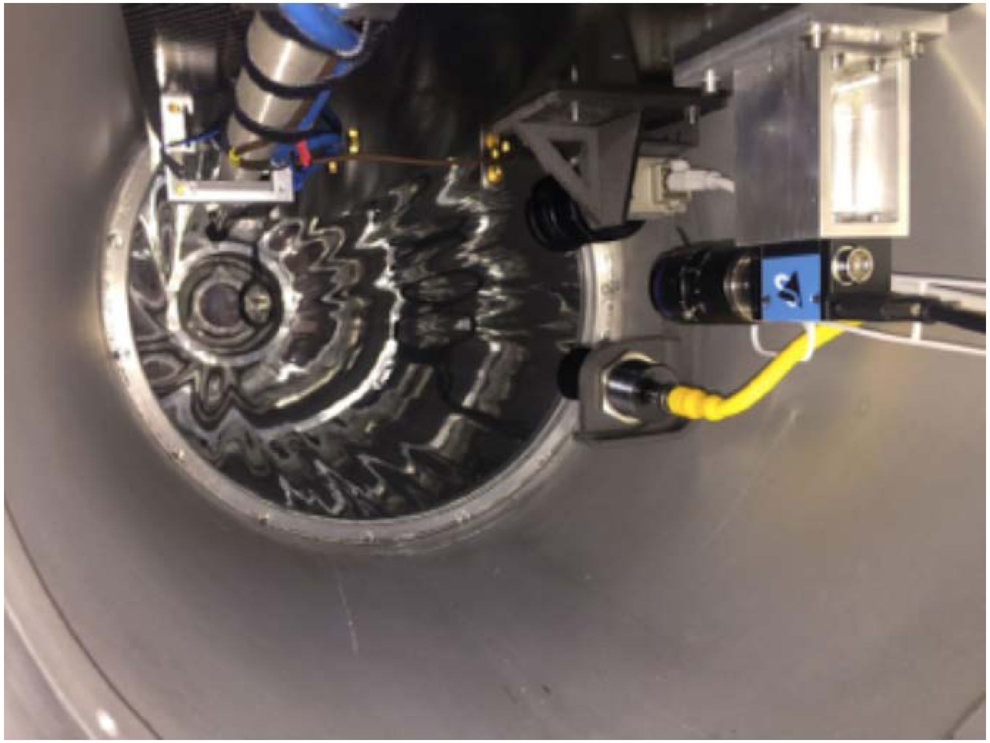
- 10^8 μ/s from the decay at rest of π^+ on the target surface (the μ range is approx. .1 gr/cm^3): almost completely polarized



2 systems for almost “continuous” beam monitoring: scintillating fibers and scintillating target



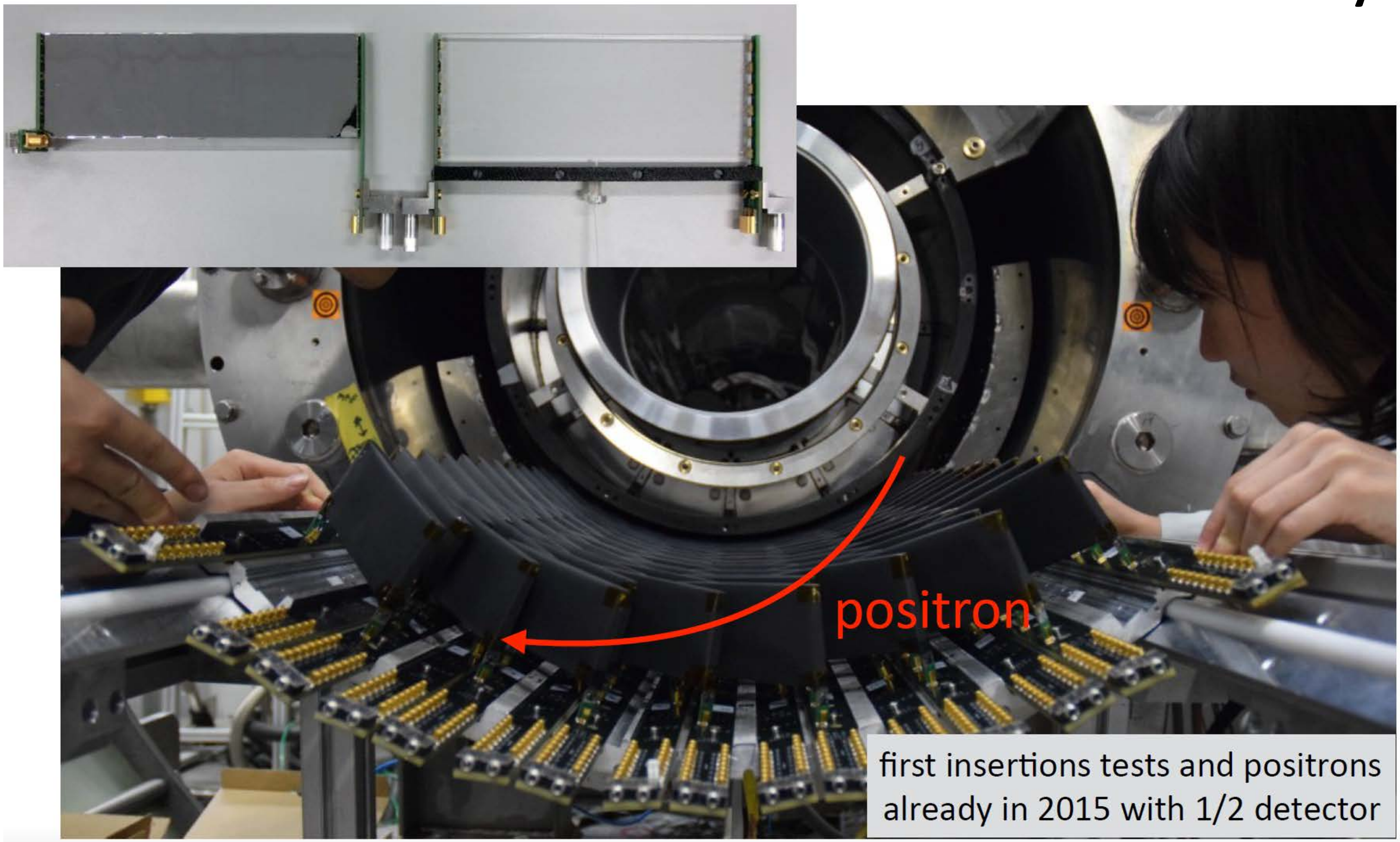
New target



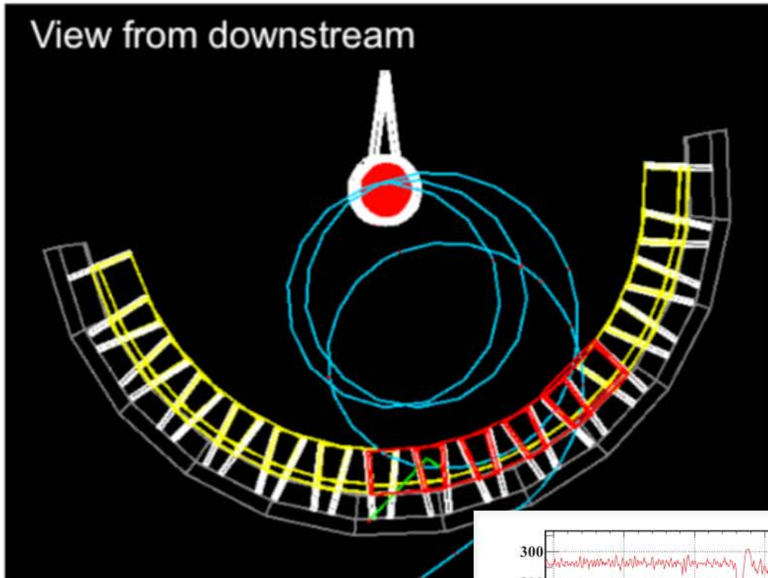
Measuring possible deformations with a camera

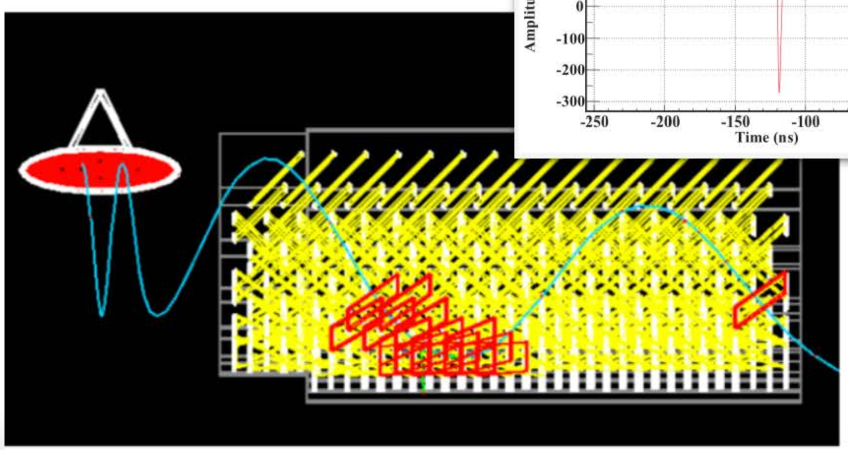
New Pixelated Timing Counter

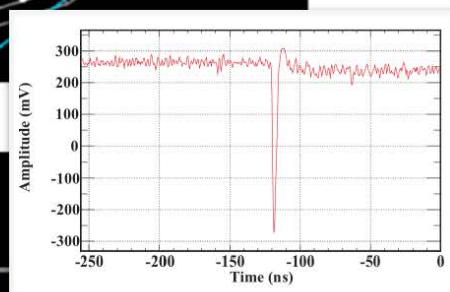
2017 : ready

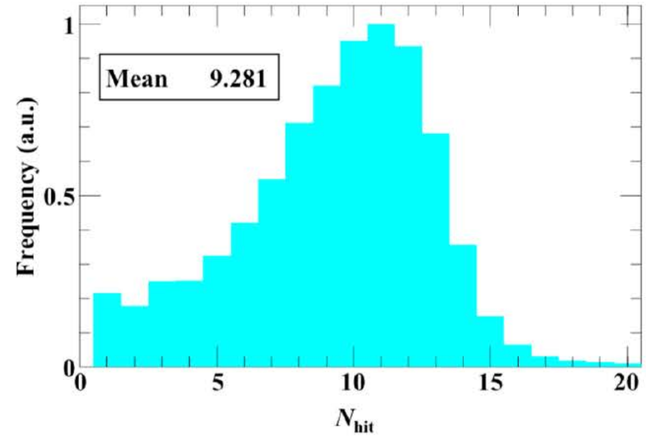


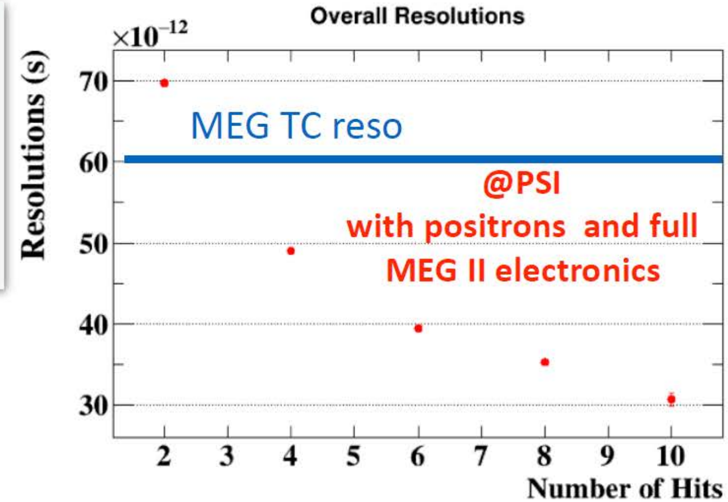
Timing Counter (2)





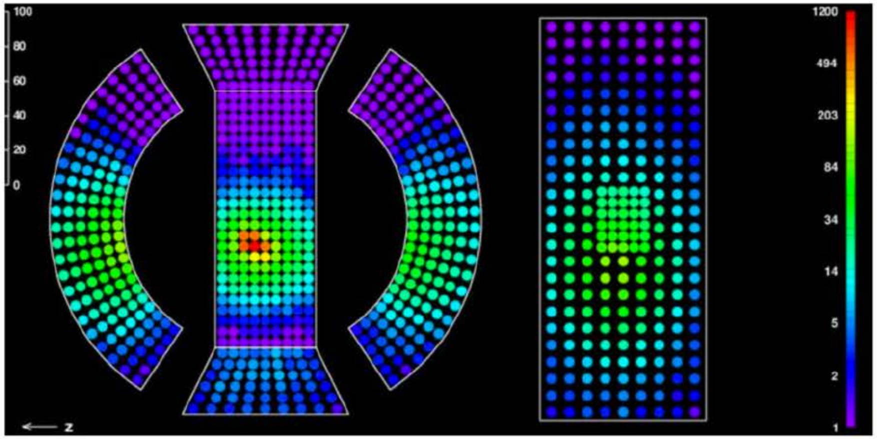


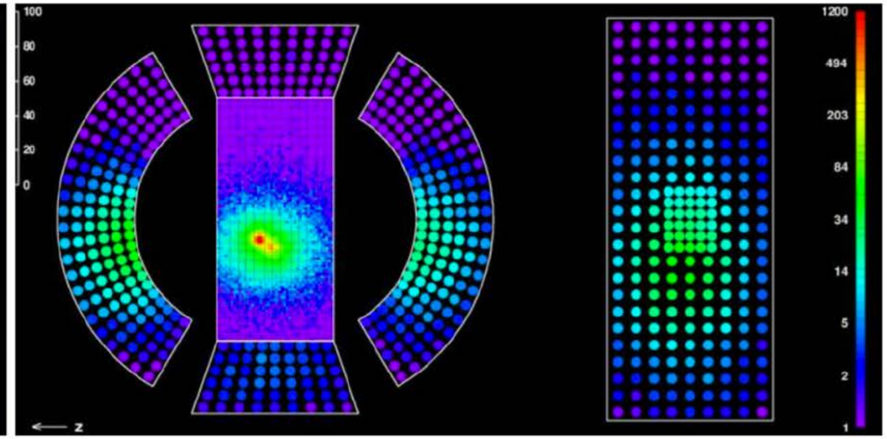




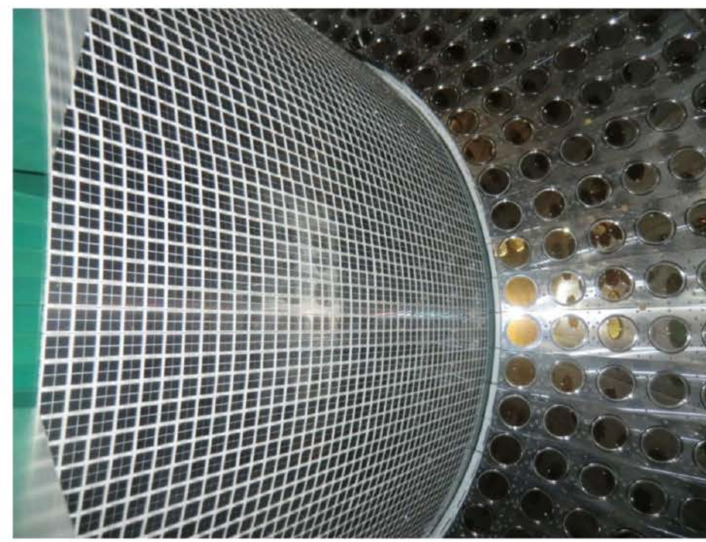
Liquid Xenon detector

2017: ready

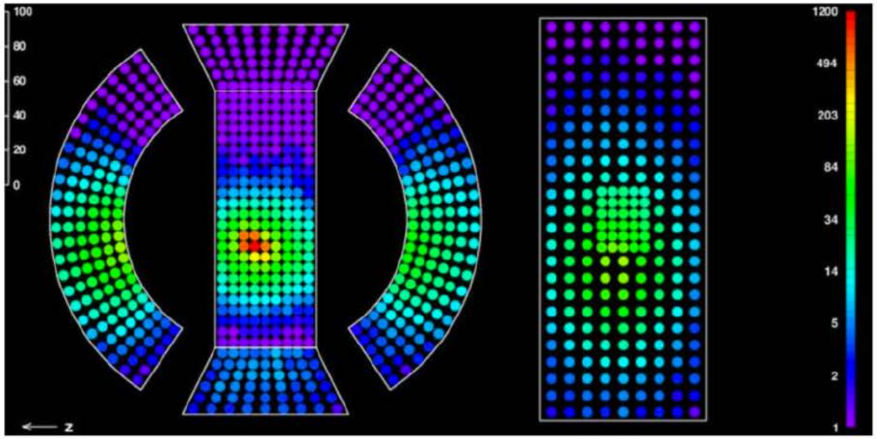


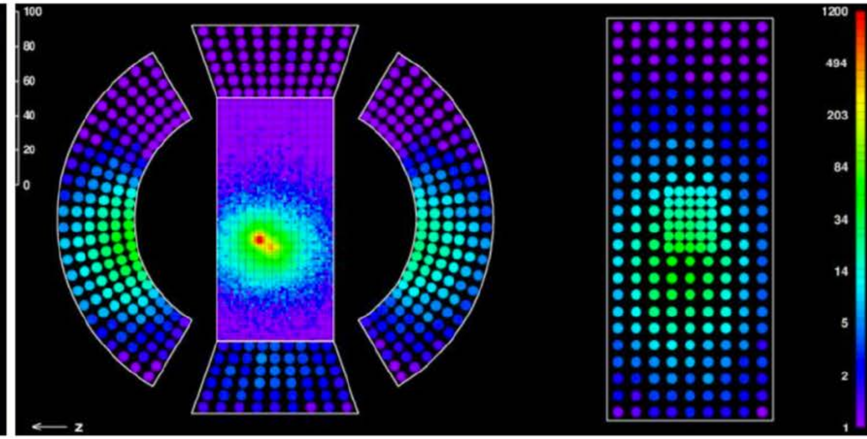


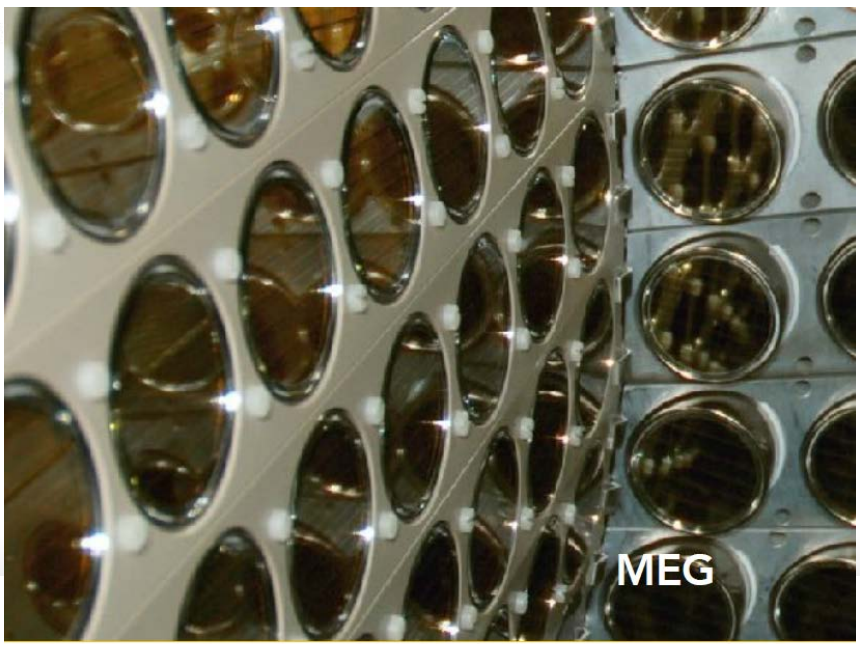
- Same detector as MEG
- homogenous
  - *LXe as scintillator*
    - bright: 40 photons/keV
    - fast: 4/22/40 ns
  - *VUV MPPC replacing PMTs in the inners face*
    - 4192 channels instead of 216!!
    - uniform response in particular for shallow events

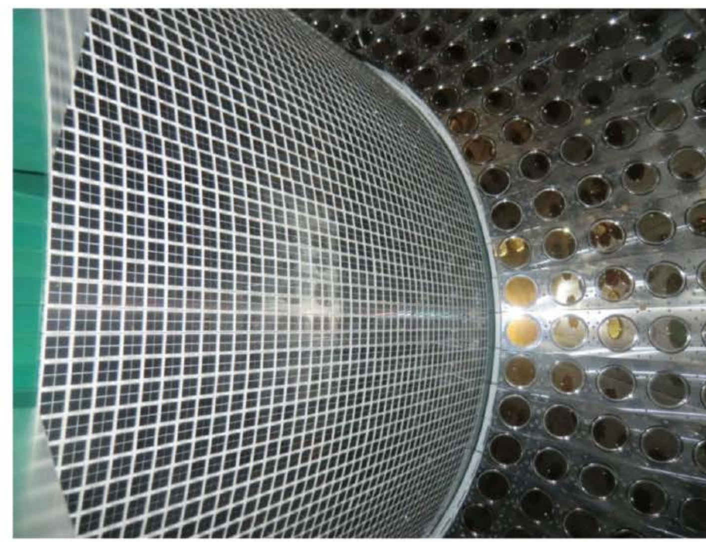


Liquid Xenon detector (2)





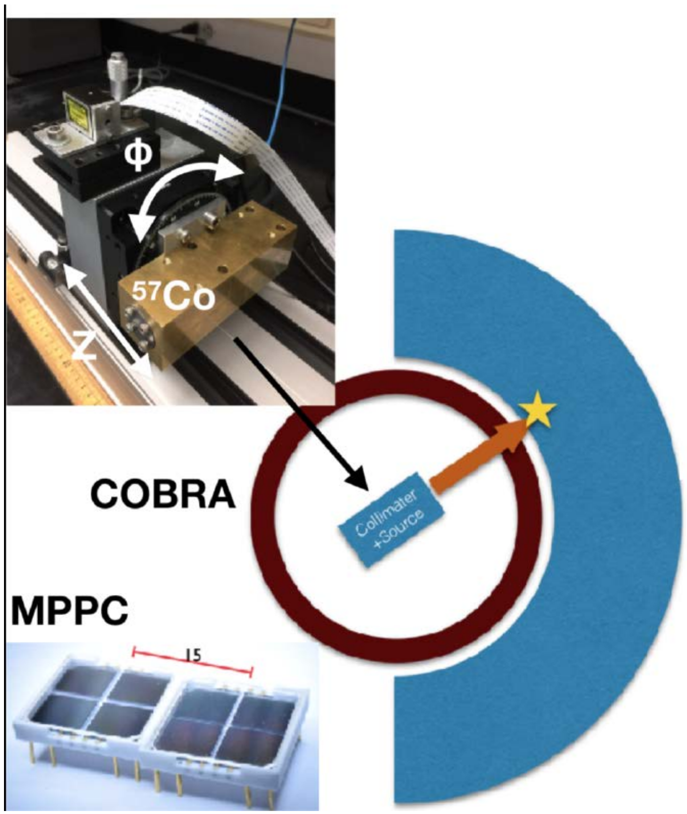


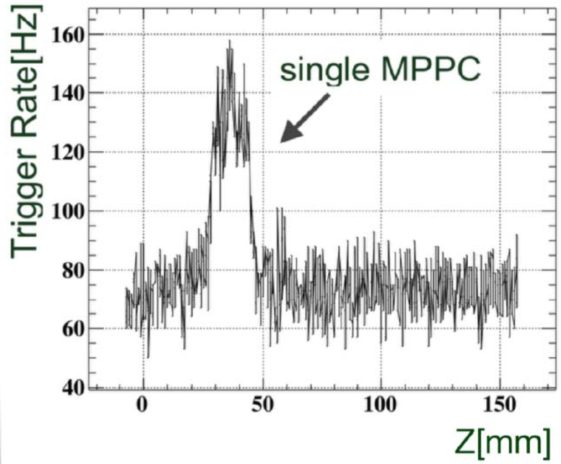


Better position resolution➔ angular resolution

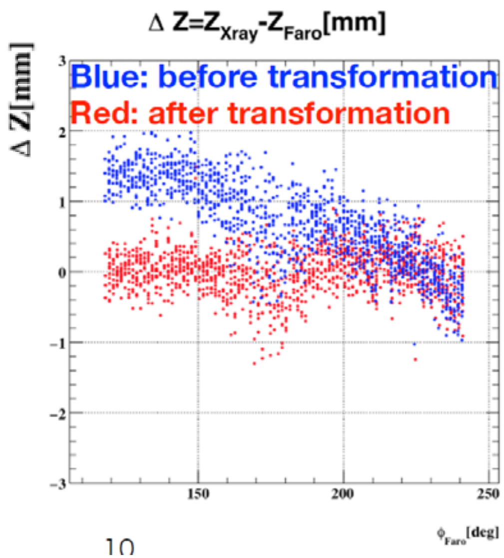
Better uniformity➔ energy resolution

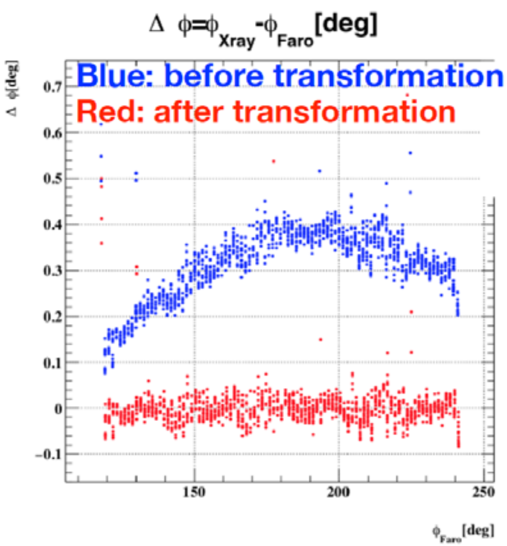
Liquid Xenon detector (3) : MMPC (SiPM) positions measurement





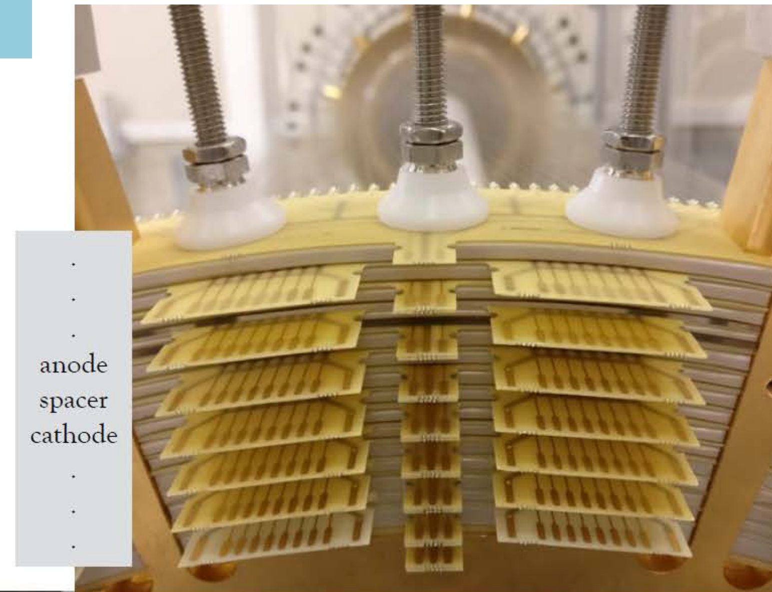
- Scaling factor is consistent with thermal coefficient of stainless steel (cryostat material ~0.0016), and no position dependent deviation observed.

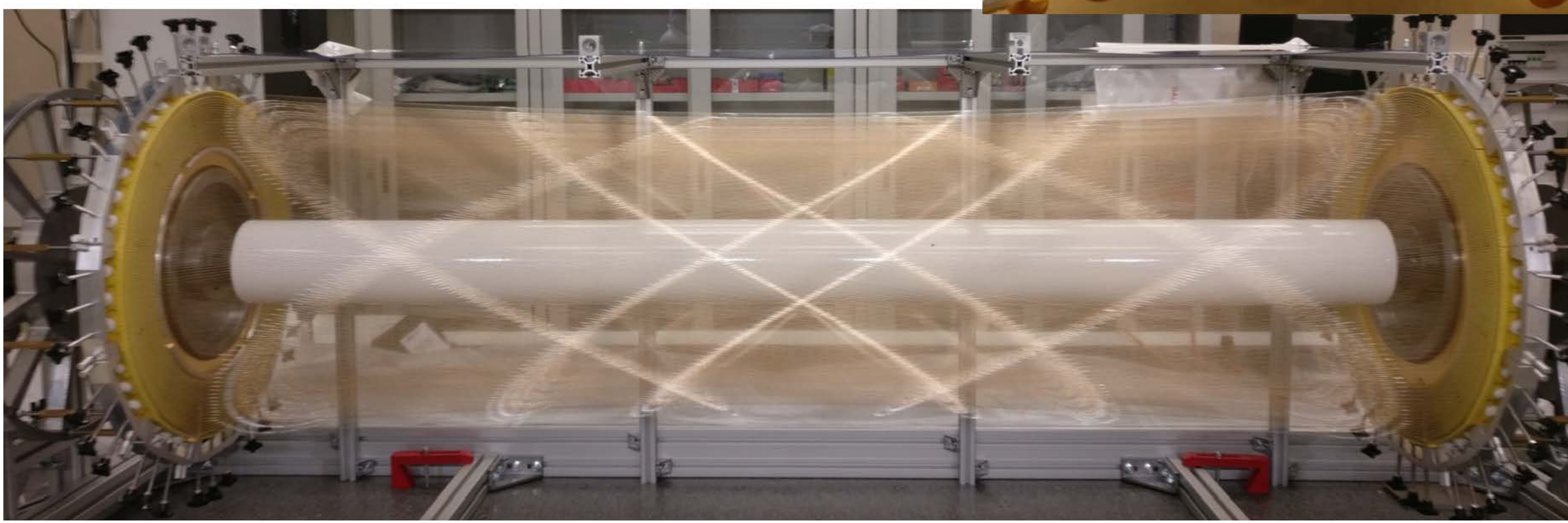




New Cylindrical Drift Chamber

- Stereo u-v wires, based on the Kloe experience
- **single** volume DC
- **He-Isobuthane** (85-15) **low mass** gas mixture
  - ***2 x 10^{-3} radiation length*** *per* ***track*** (20% less than MEG)
- **1728 anode** wires + **~10000 cathodes**
  - ***anode**: **20μm** W/Au, **cathode**: **40/50 μm** Al/Ag*
  - ***7 degree stereo** angle*

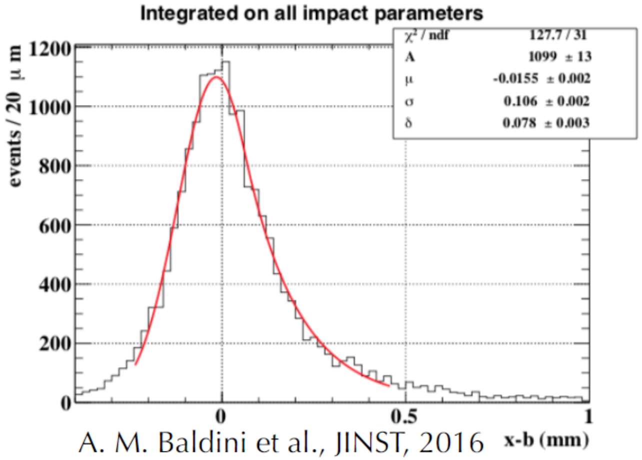




Ready in **2018** due to a problem of 40 μm cathodes fragility

New Cylindrical Drift Chamber (2)

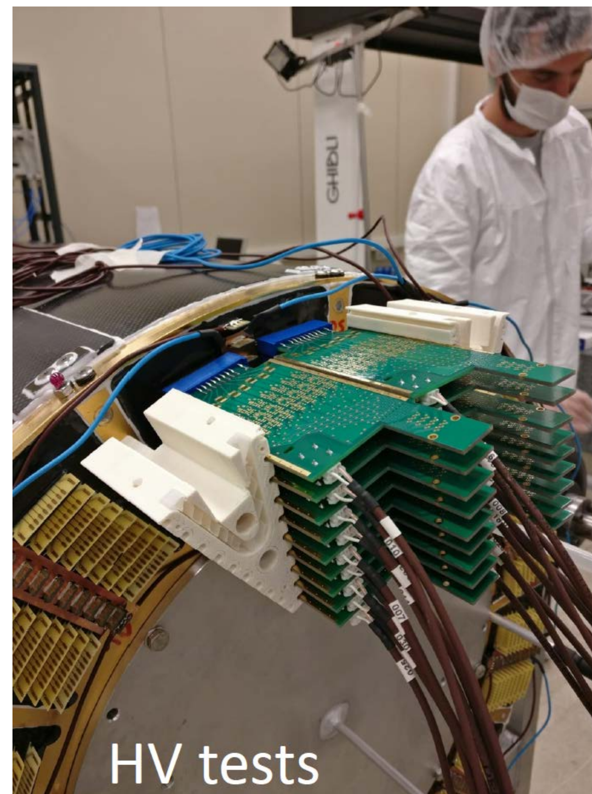
Single hit resolution
measured in dedicated facility



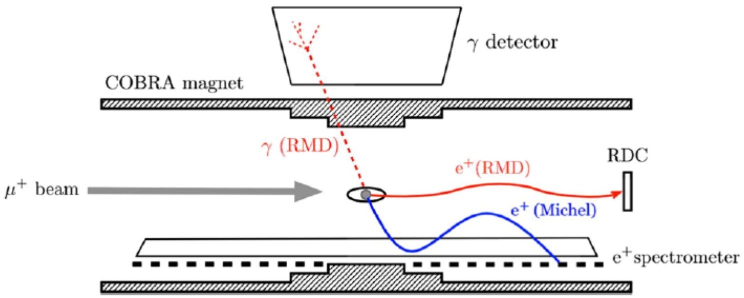
A. M. Baldini et al., JINST, 2016
L. Galli et al., TNS, 2015

4 times the number of hits in MEG DC ➔ improved momentum resolution

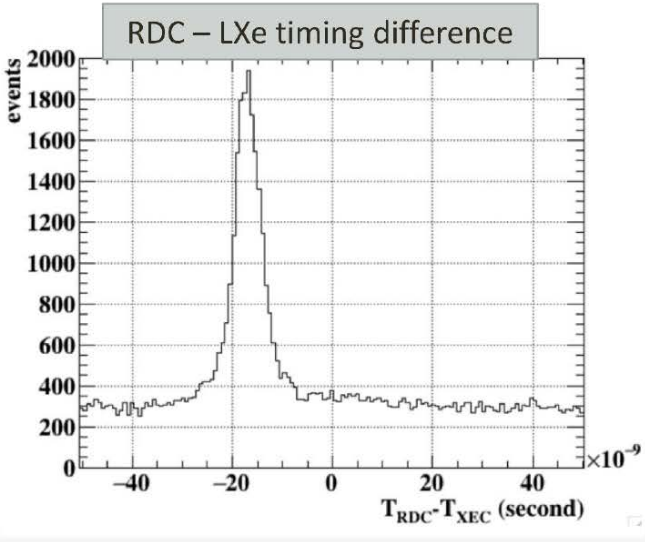
Tracks are followed down to the TC➔ higher matching efficiency

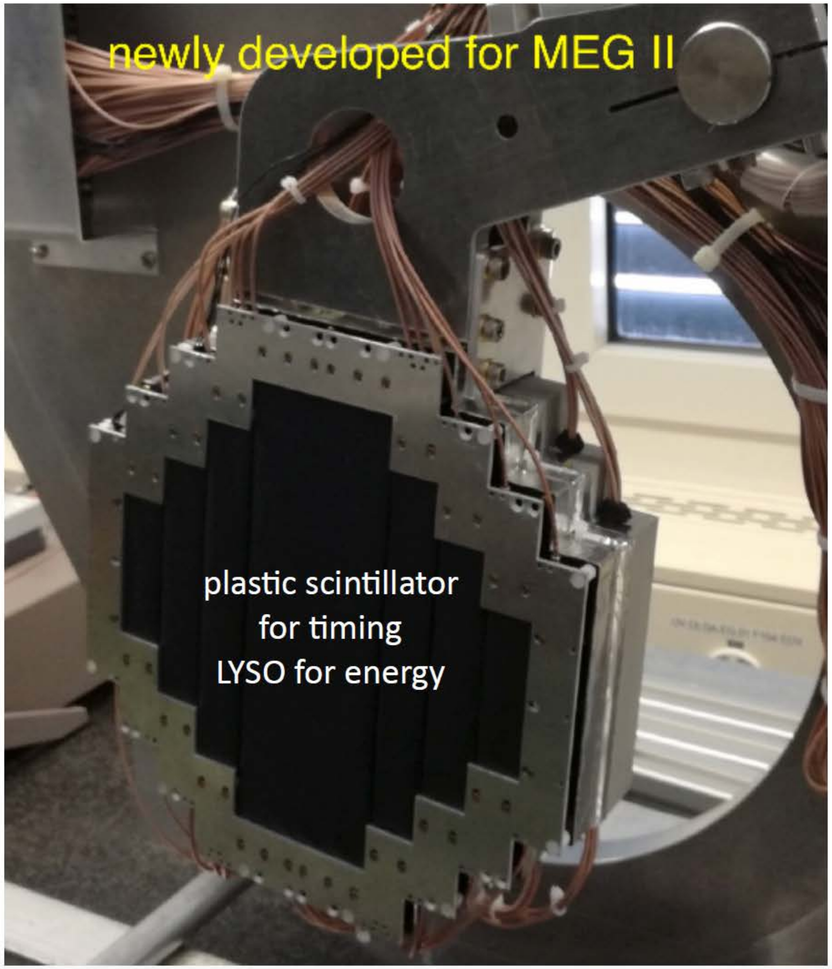


New detector: Radiative Decay Counter



- Tags BG gamma rays from radiative decays by measuring low energy positrons
- Improves sensitivity by 15%





Completely New Trigger and DAQ electronics

- Fully custom
- Trigger and DAQ integrated
  - *wfm digitiser @2GSPS with DRS chip*
    - SiPM power supply and amplification included
  - *Complex FPGA based trigger with latency <450ps*

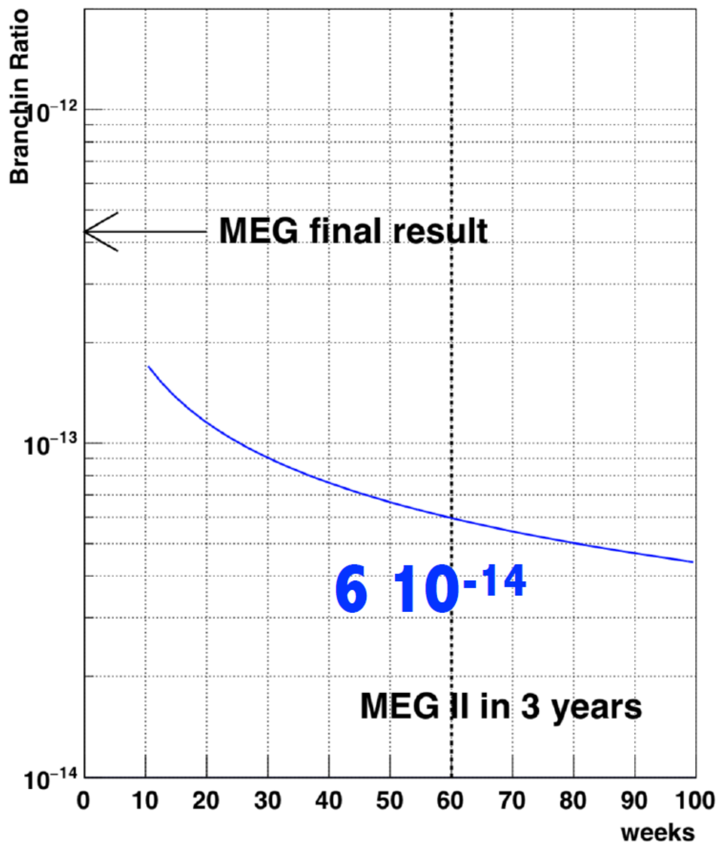
System demonstrator successfully tested in 2017 with LXe, TC and RDC

≈20% of the 8000 needed channels available ; complete production by spring 2020

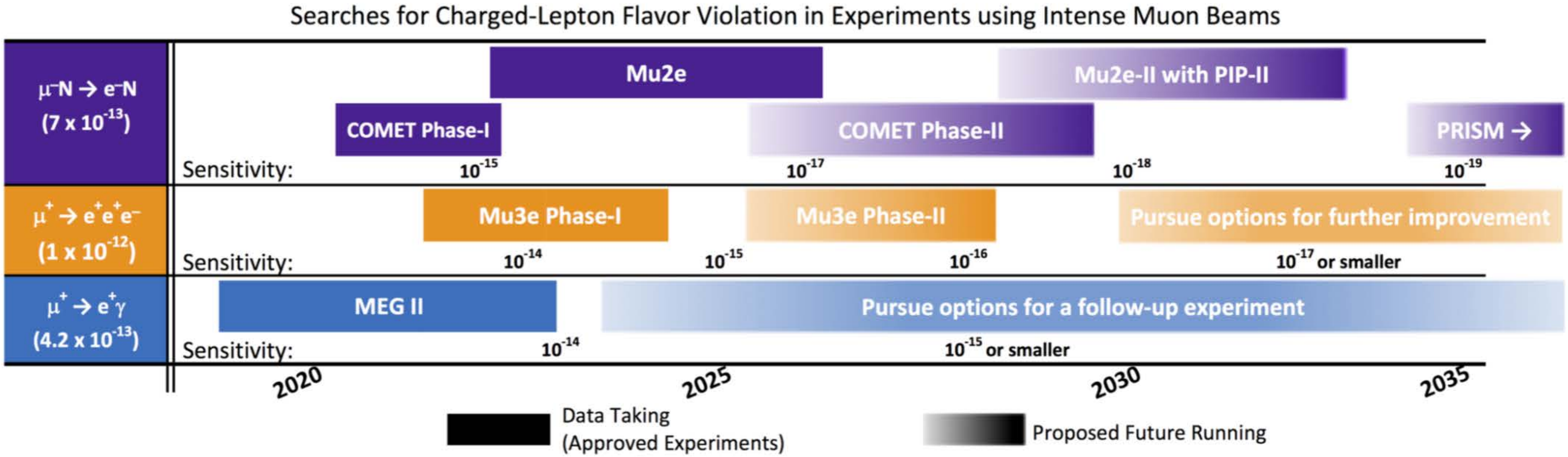
Final sensitivity of $6x10^{-14}$

PDF parameters	MEG	MEG II
E_{e^+} (keV)	380	130
θ_{e^+} (mrad)	9.4	5.3
ϕ_{e^+} (mrad)	8.7	3.7
z_{e^+}/y_{e^+} (mm) core	2.4/1.2	1.6/0.7
E_γ(%) (w>2 cm)/(w<2 cm)	2.4/1.7	1.1/1.0
$u_\gamma, v_\gamma, w_\gamma$ (mm)	5/5/6	2.6/2.2/5
$t_{e^+\gamma}$ (ps)	122	84
Efficiency (%)		
Trigger	≈ 99	≈ 99
Photon	63	69
e^+(tracking × matching)	30	70

$$\boxed{B_{acc} \propto R_\mu \Delta E_e \Delta E_\gamma^2 \Delta\Theta_{e\gamma}^2 \Delta t_{e\gamma}}$$



Schedule of the muon LFV experiments



Input to Eur. Particle Physics Strategy
"Charged Lepton Flavour Violation using Intense Muon Beams at Future Facilities"

Summary

$\mu \rightarrow e\,\gamma$ (CLFV) is an excellent probe for search of physics Beyond the Standard Model

Complementary search (high intensity or precision frontier) of BSM wrt to the high energy frontier (LHC)

MEG II , largely improved with respect to MEG, should soon start data taking

Delay in the schedule due mostly to DAQ eletronics complexity: 2018/2019 test of detectors with subset of DAQ electronic channels

Three years of data taking to reach a final sensitivity of 6×10^{-14}

Thank you for your attention