

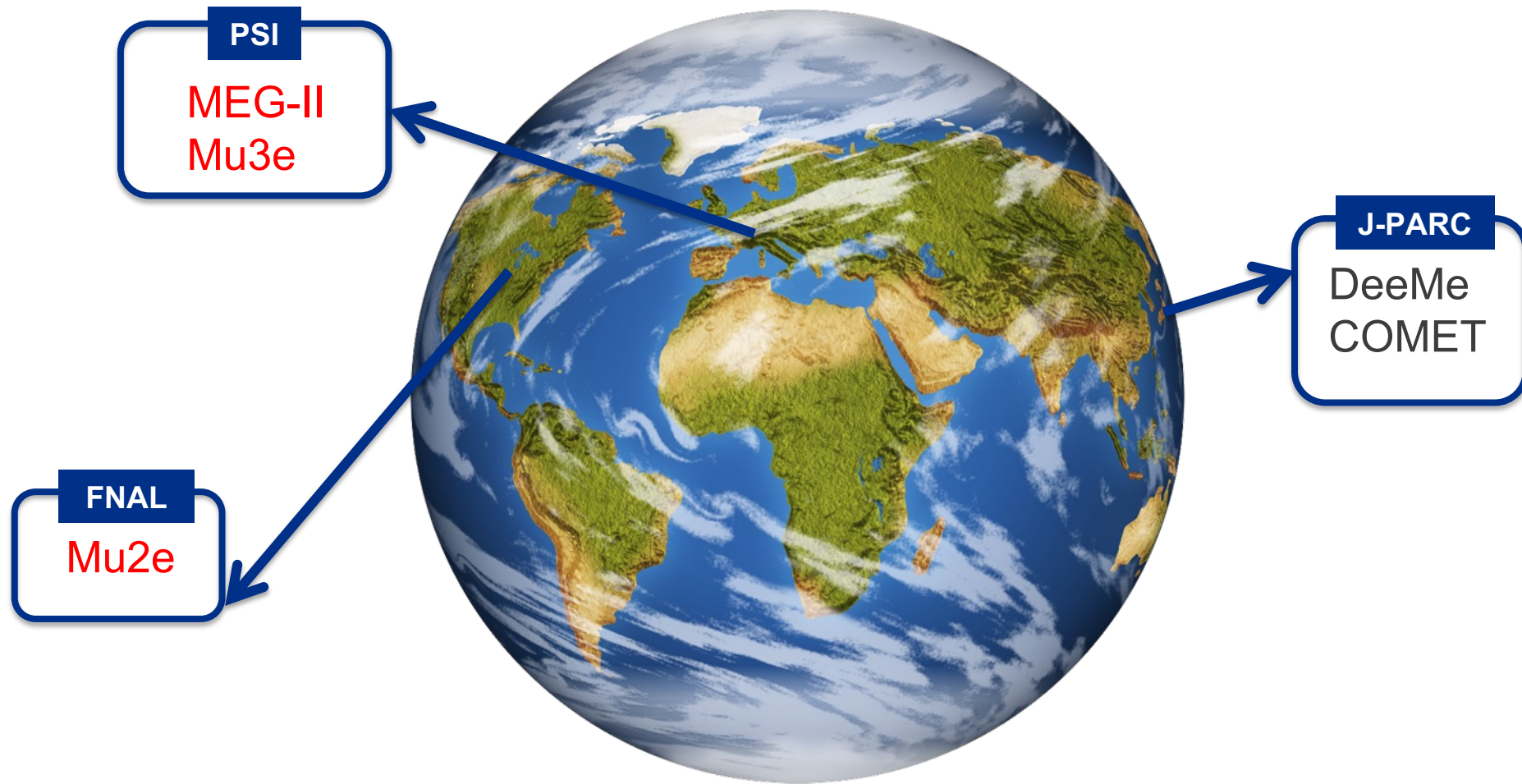
INTENSE WP4

Charged Lepton Flavour Violation Experiments

Mark Lancaster



CLFV is a worldwide endeavour



INTENSE is supporting research at PSI and Fermilab : particularly the secondments to Fermilab for Mu2e

Two Types of Measurement Using Muon Beams

Looking for deviation from precise SM prediction e.g. (g-2), Lepton Universality

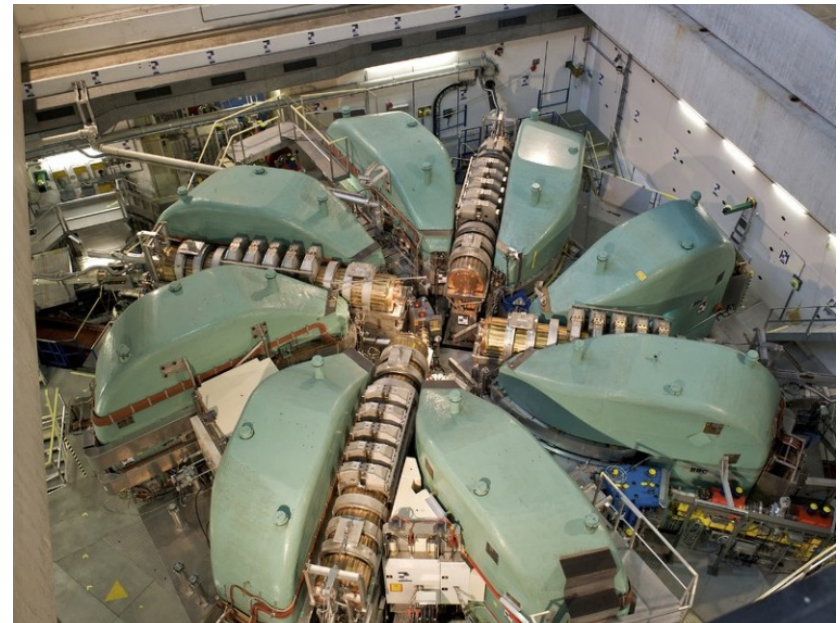
Looking for a signal that is essentially zero in the SM

e.g. muon electric dipole moment (EDM) or charged lepton flavour violation (CLFV)

FNAL $\sim 10^{10}$ μ /sec [Pulsed]

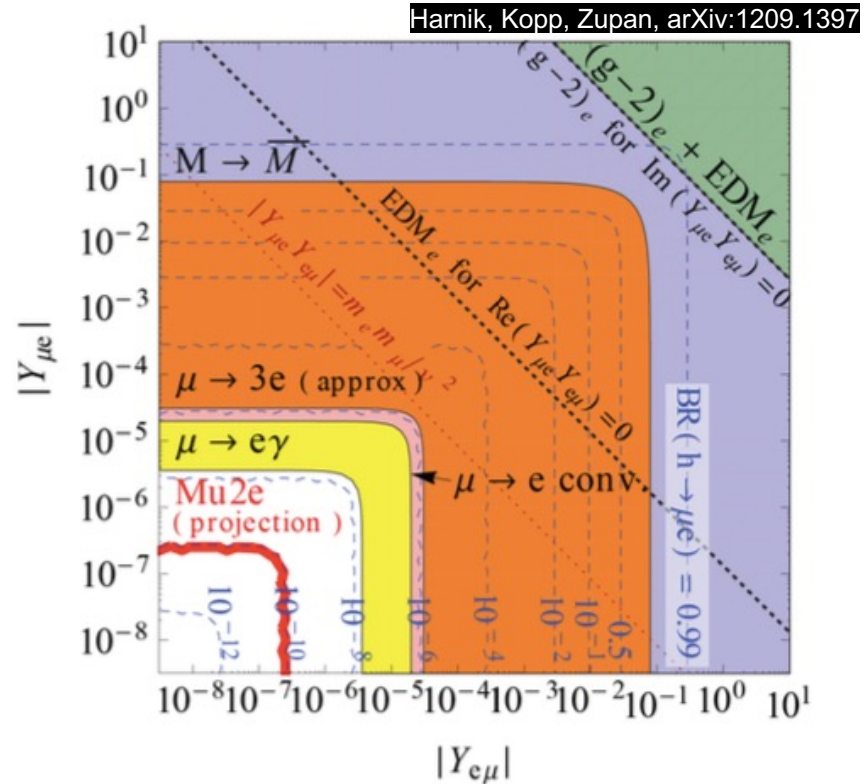
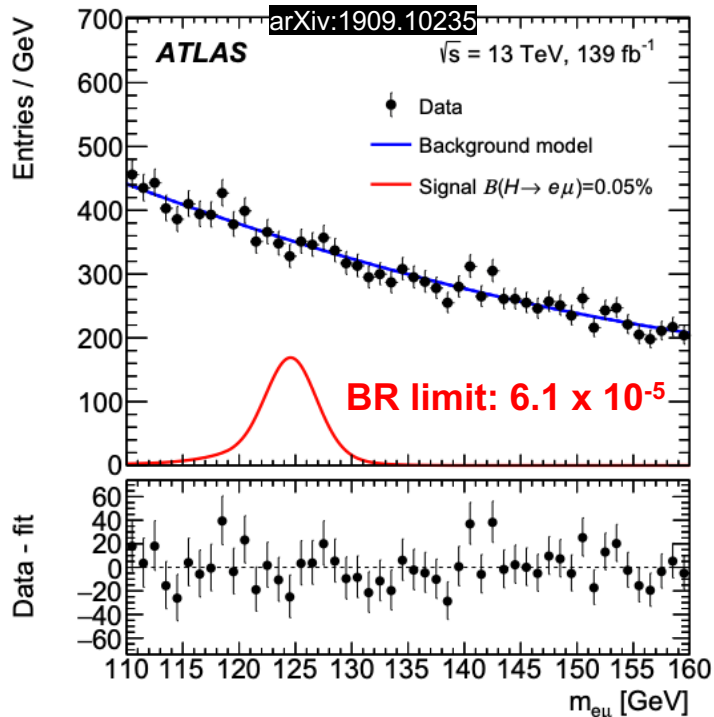


PSI: $\sim 10^8$ μ /sec [DC]



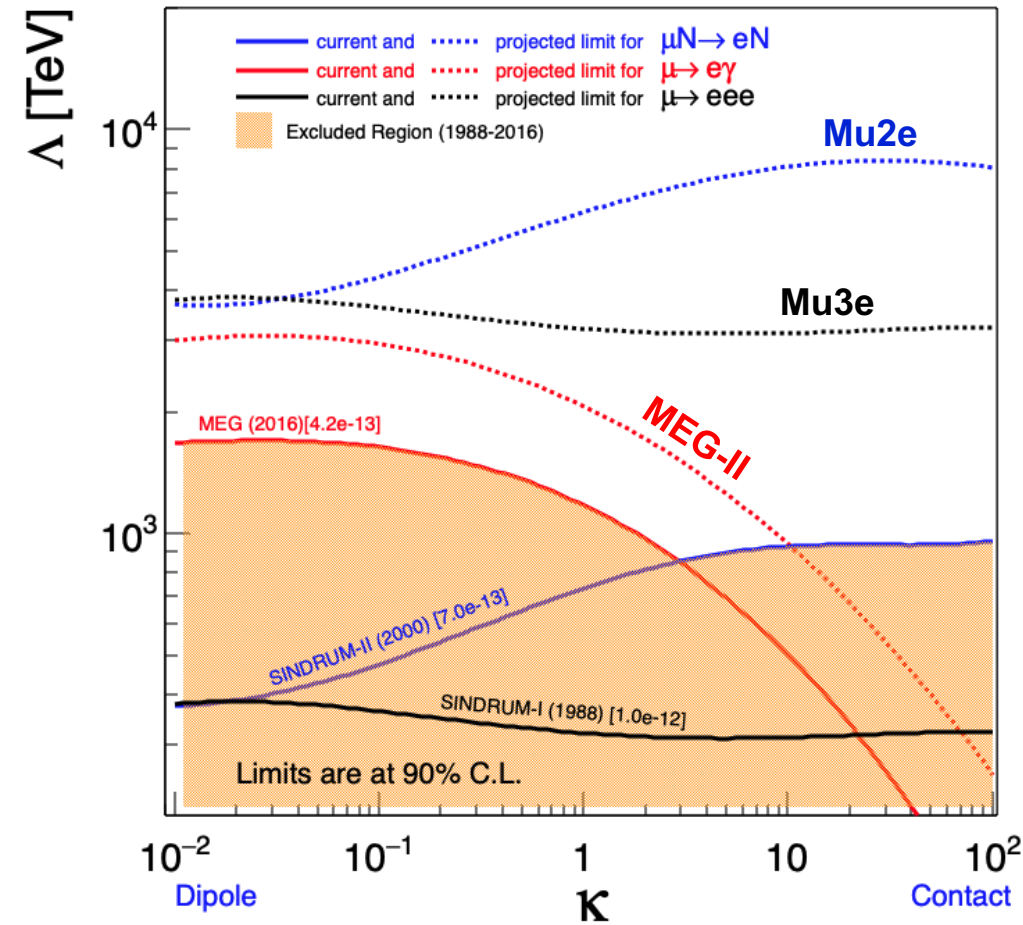
Why Muons ?

Can be produced in large numbers and live long enough

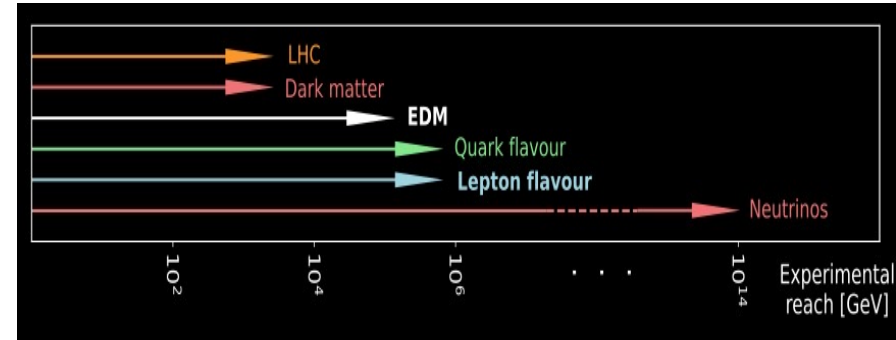


Mu2e has sensitivity to $\text{BR}(h \rightarrow \mu e)$ of 10^{-10}

Access to high mass scales

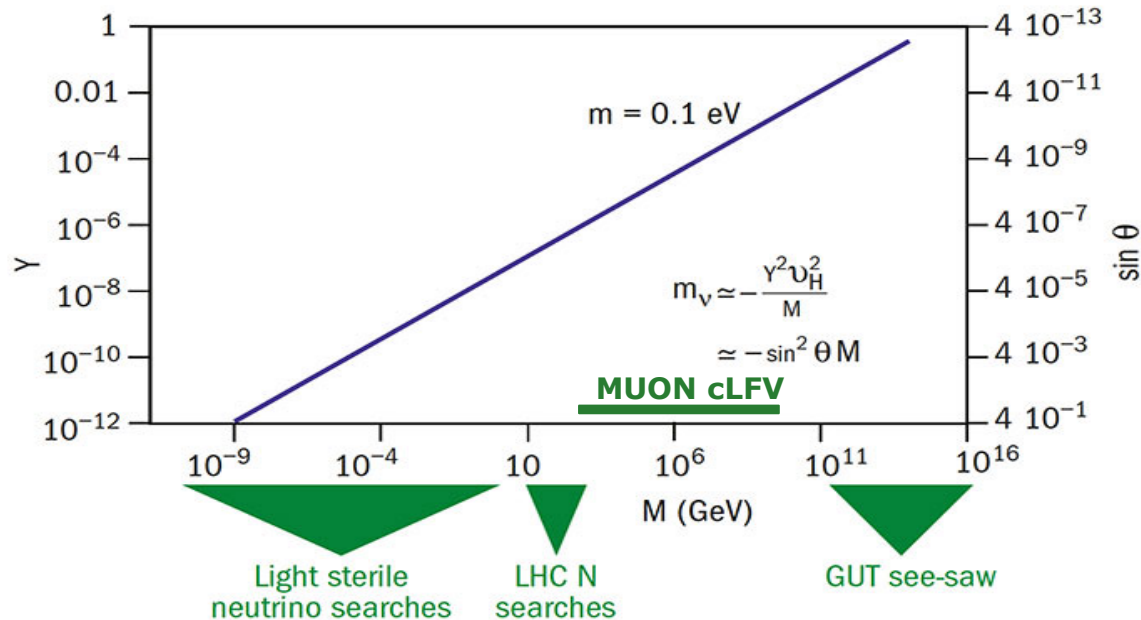
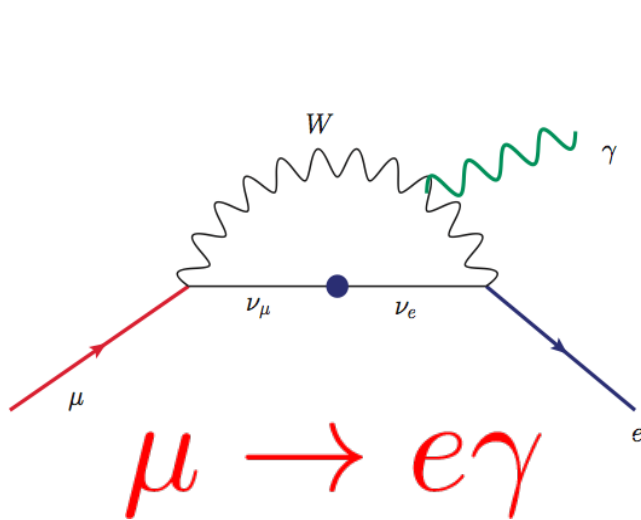


Updated from A. de Gouvea, P. Vogel, arXiv:1303.4097



Charged Lepton Flavour Violation (cLFV)

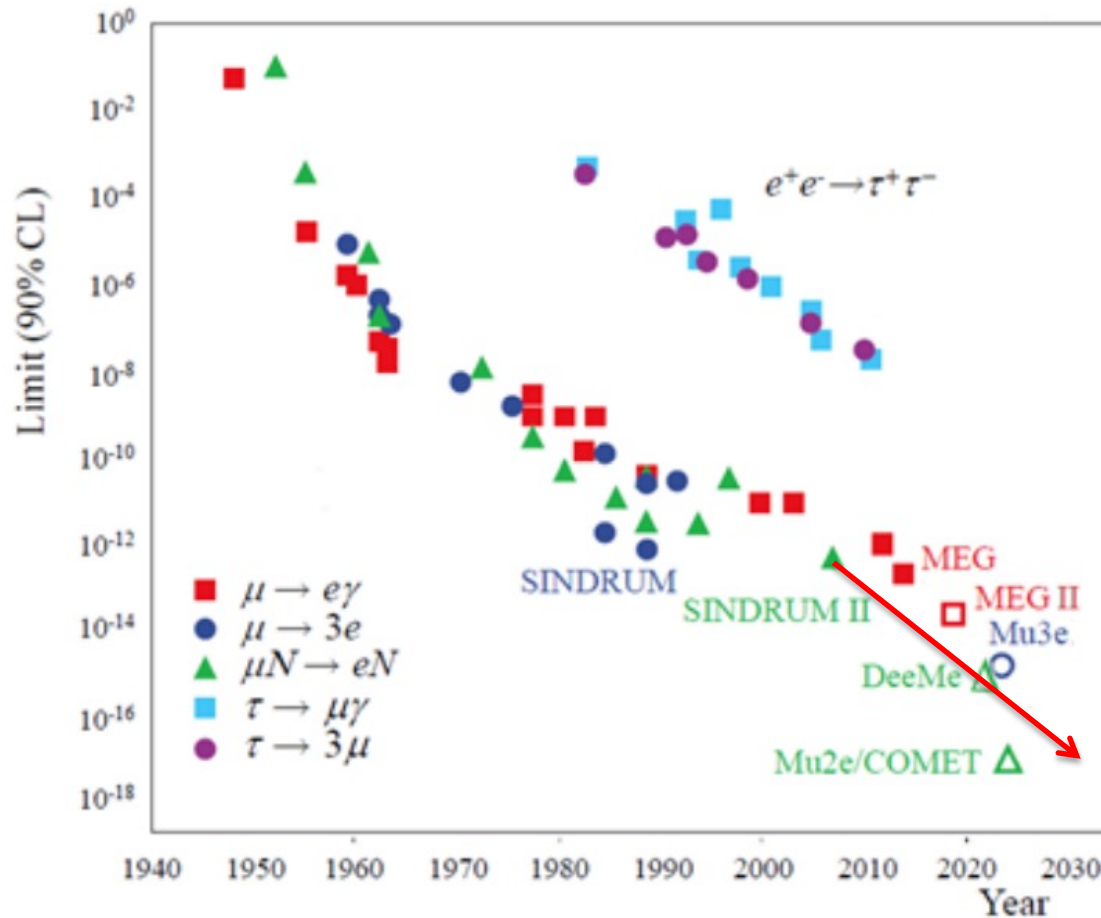
In SM: neutrino oscillations (masses) are intimately connected with charged lepton flavour violation



and also in BSM: $\nu_{RH} \rightarrow l^- H^+$

And thus to **extensions to the Higgs sector.**

Charged Lepton Flavour Violation (cLFV)

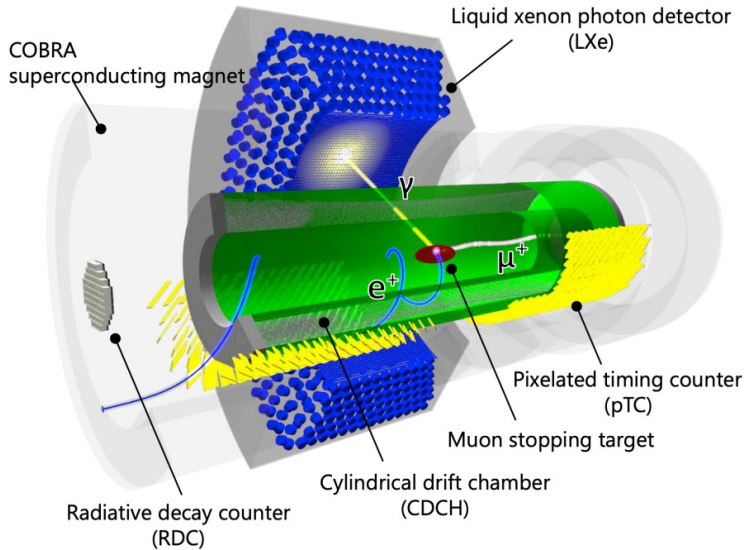
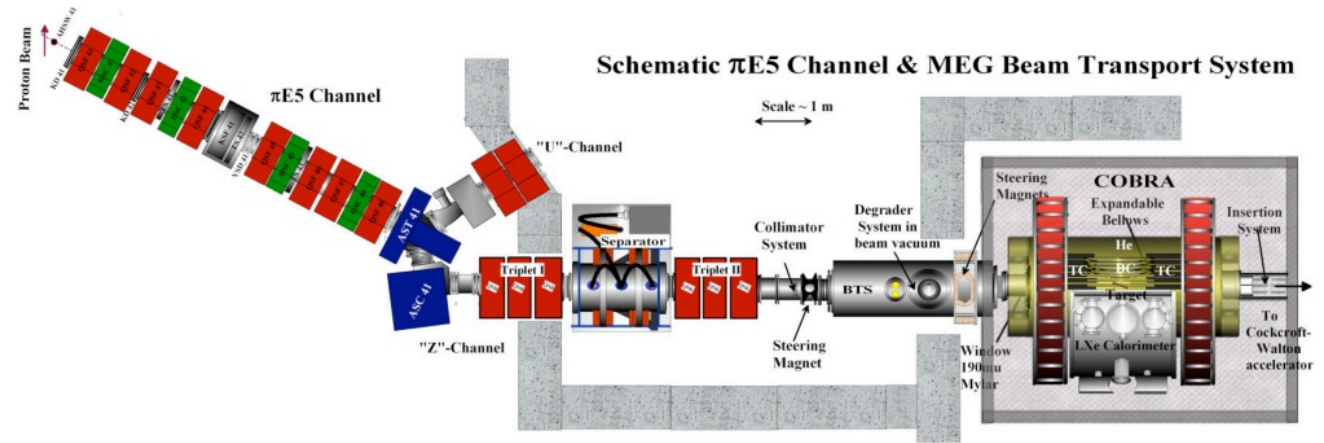
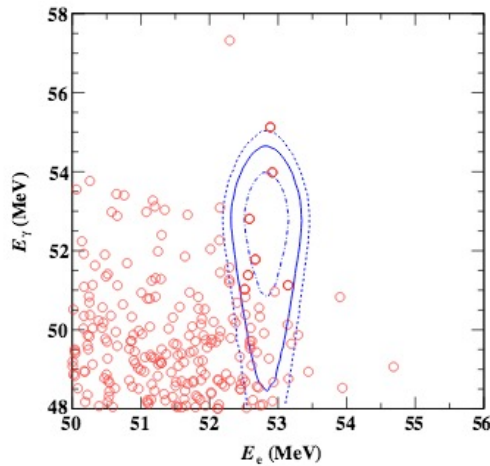


Ratio of the 3 different CLFV processes is model dependent and depend on model parameters.

*$O(10^4)$
improvement
driven by new
technology*

Being probed by **MEG** ($\mu^+ \rightarrow e^+ \gamma$), **Mu3e** ($\mu^+ \rightarrow e^+ e^- e^+$), **DeeMe/COMET/Mu2e** ($\mu^- N \rightarrow e^- N'$)

MEG-II at PSI

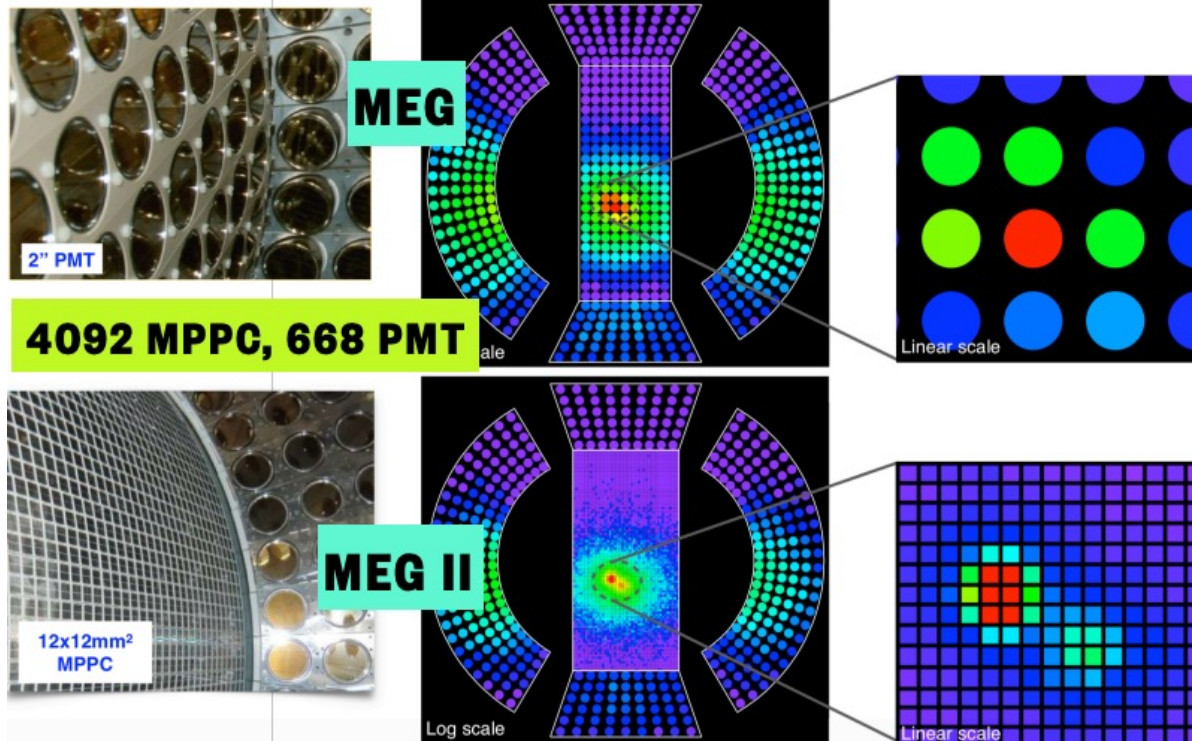


MEG-I (2016) : $BR(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}$ (90%CL)

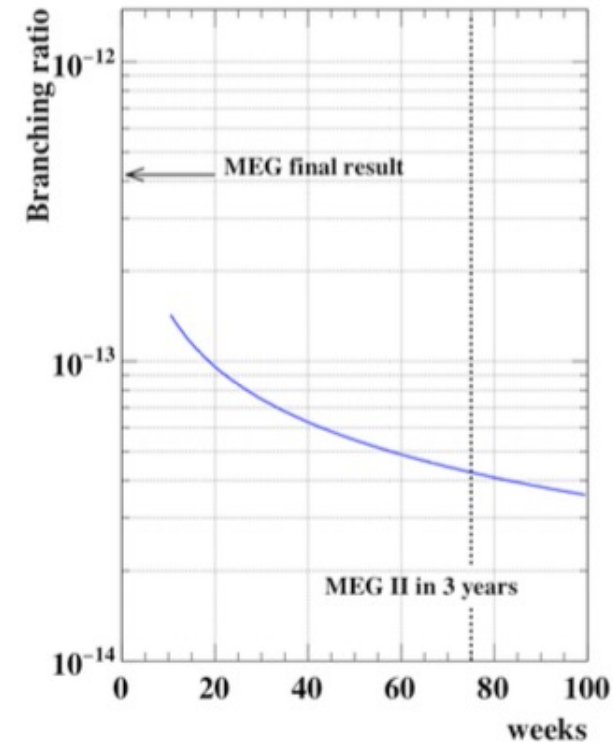
MEG-II to reach 6×10^{-14}

$$N_{BG} = \left(\frac{R_{\mu}}{D} \right)^2 \Delta t_{e\gamma} \Delta E_e (\Delta E_{\gamma})^2 (\Delta \Theta_{e\gamma})^2$$

MEG-II at PSI

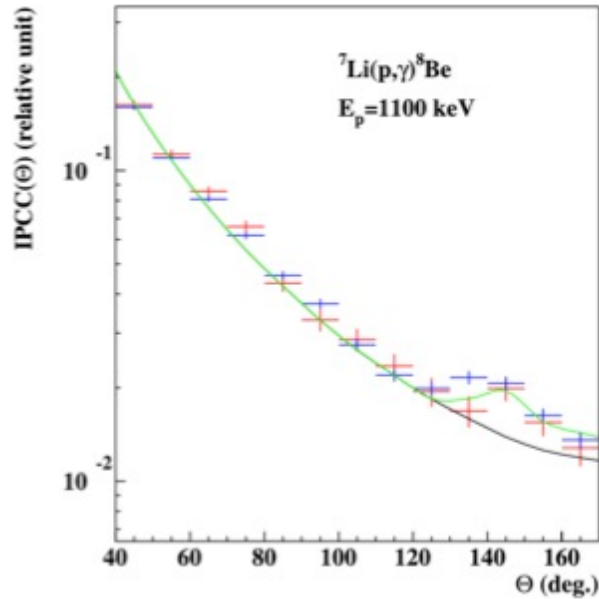


| | MEG-I | MEG-II |
|-----------------------|---------|---------|
| $\sigma(E_e)$ | 380 keV | 100 keV |
| $\sigma(t_{e\gamma})$ | 120 ps | 70 ps |
| $\sigma(\phi_e)$ | 11 mrad | 4 mrad |
| $\sigma(E_\gamma)$ | 1.6% | 1 % |
| $\sigma(\theta_e)$ | 9 mrad | 7 mrad |



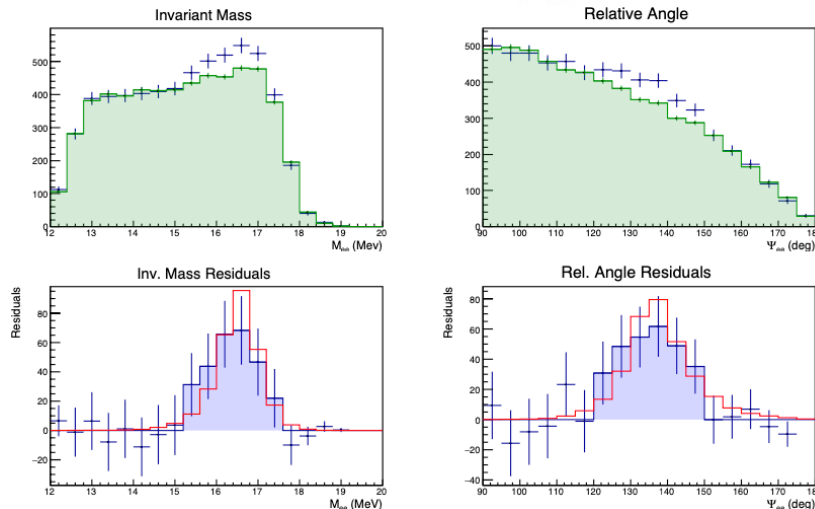
Improved detector **resolution** and **granularity**
 Higher **beam intensity** achievable: $7 \times 10^7 \mu/s$
 New positron tracker
 New detector for RMD
 New TDAQ system
 Improved photon detector

MEG-II : X(17)



J. Phys. Conf. Ser. **2018**, 1056, 012028 (${}^8\text{Be}^*$)
J. Phys. Conf. Ser. **2020**, 1643, 012001 (${}^4\text{He}^*$)

Possible interpretation : 17 MeV boson ($\text{BR} \sim 6 \times 10^{-6}$)



Li_2O layer on Cu substrate in PSI proton beam
MEG-II has improved resolution compared to Atomki

Data to be taken in 2022 prior to CLFV running.

MEG-II GEANT4: mass resolution: 0.5 MeV

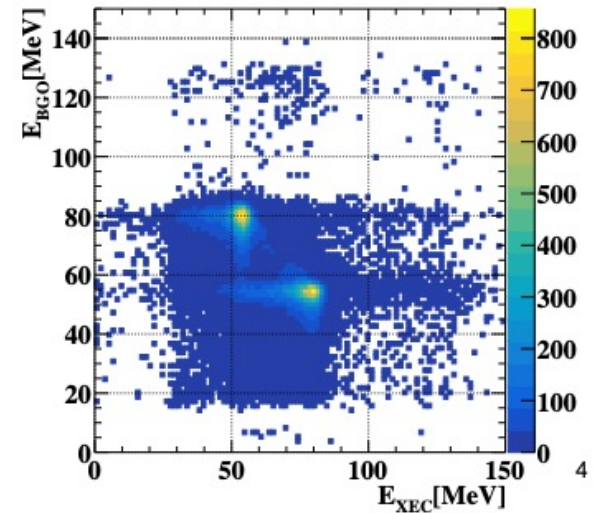
MEG-II

2020 / 2021 – commissioning
Sep – Dec 21 : data for X(17)

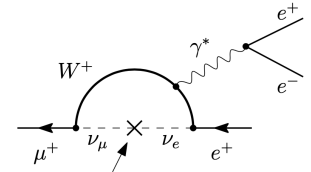
Jun-7 22 : began 1st CLFV physics run

Expect to surpass MEG-I sensitivity
with this year's data

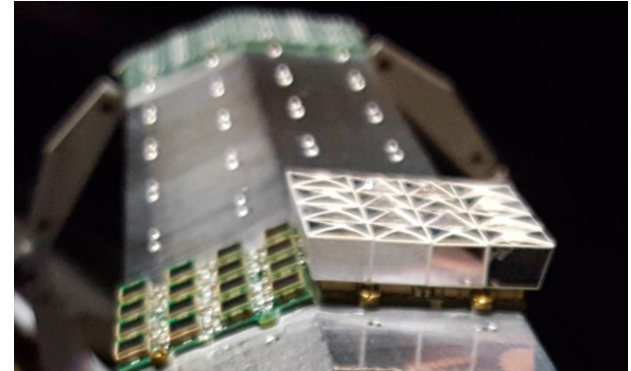
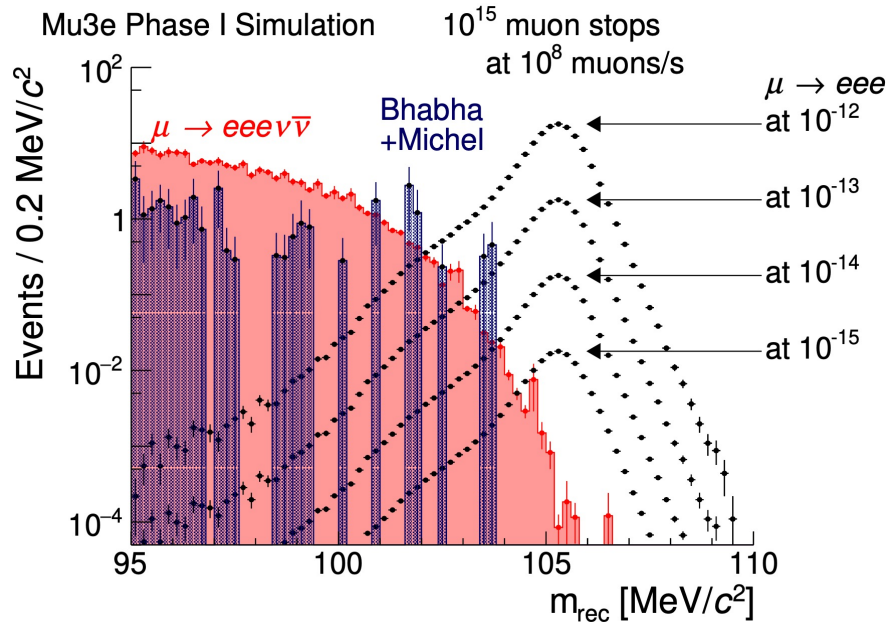
Data from the **first** Physics Run2021



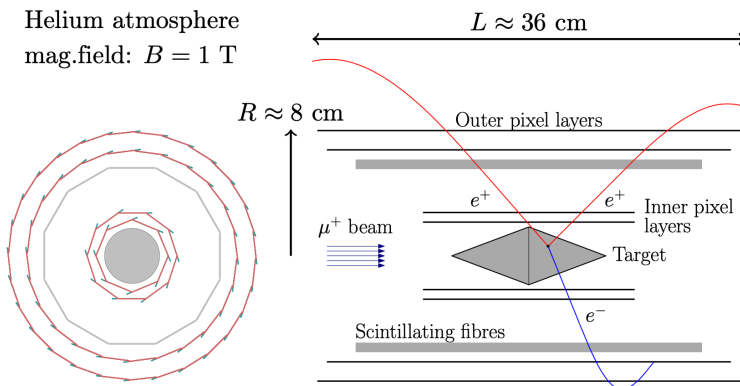
Mu3e at PSI



10^3 improvement in limit - Phase-I & further factor of ~ 10 with HIMB 10^{10} mu/sec upgrade



Helium atmosphere
mag.field: $B = 1 \text{ T}$



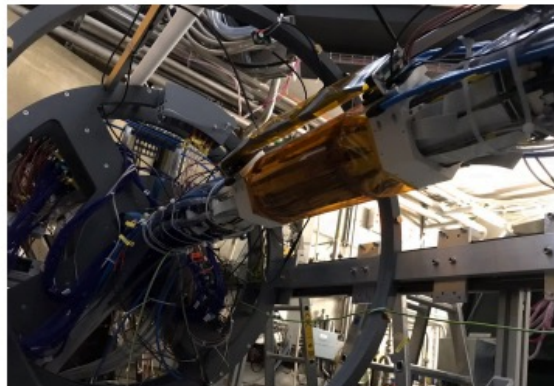
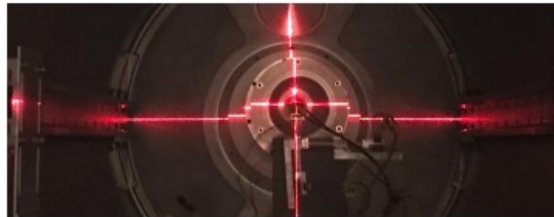
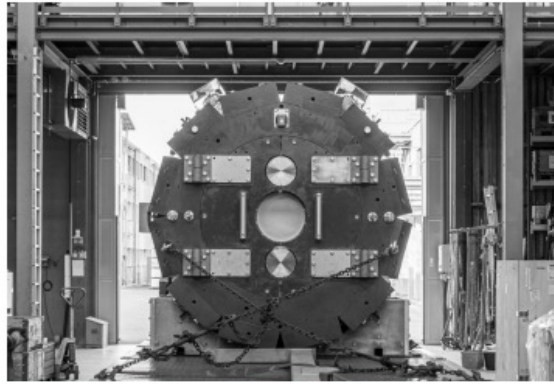
Mu3e at PSI

First integration Run 2021

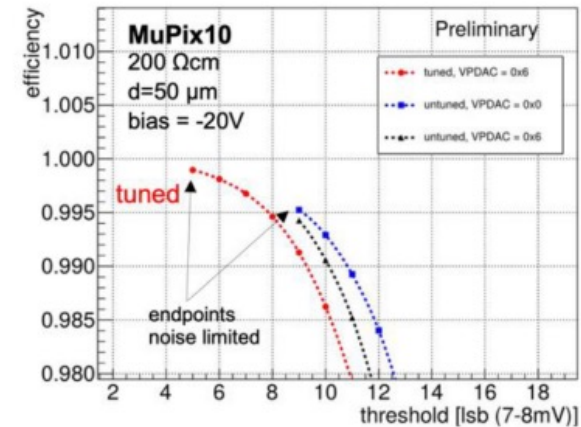
Full beam line commissioning 2022
- required muon rate ($2.5 \times 10^8/\text{s}$) achieved

Tracker production will conclude in 2023
ready for integration run

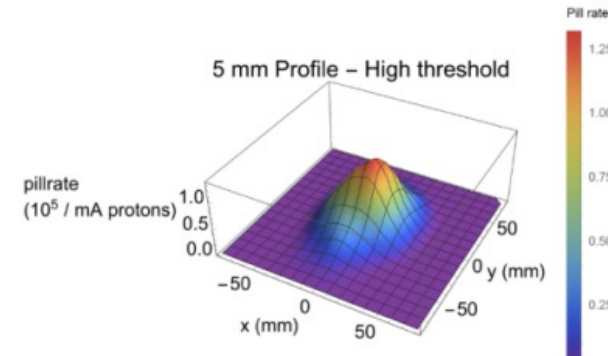
2024 – engineering run
2025 - 1st physics CLFV run



Test beam **2021**



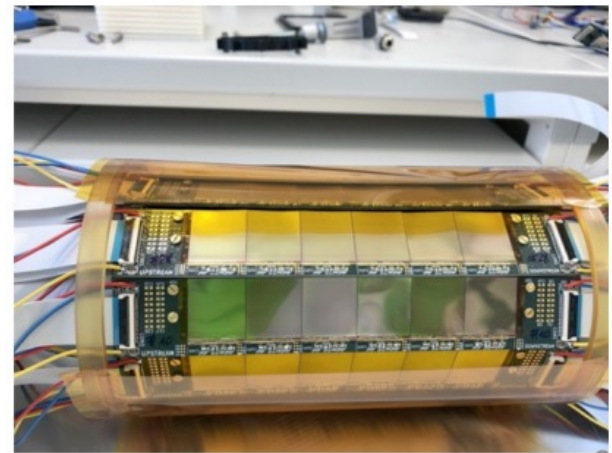
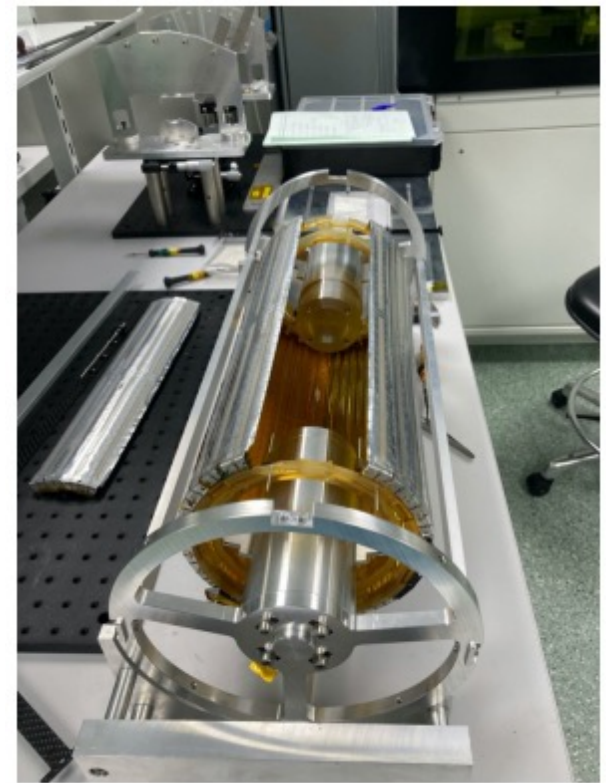
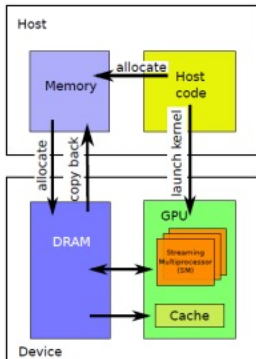
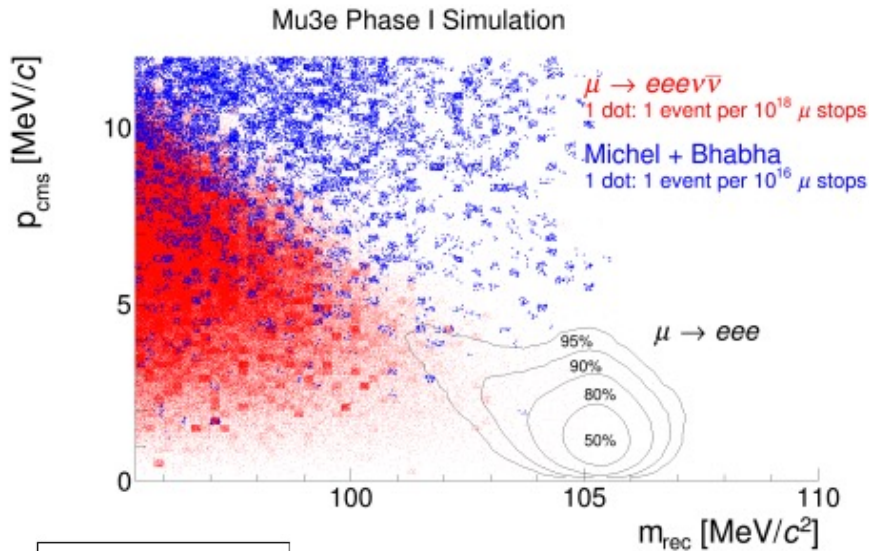
Beam commissioning **2022**



2.49×10^8 mu/s @ 2.4 mA

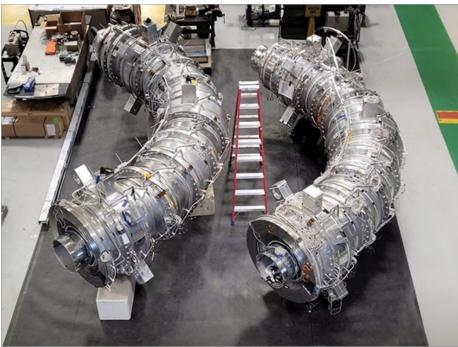
Mu3e at PSI

Significant progress on simulation
and developing the online analysis tools (GPUs)

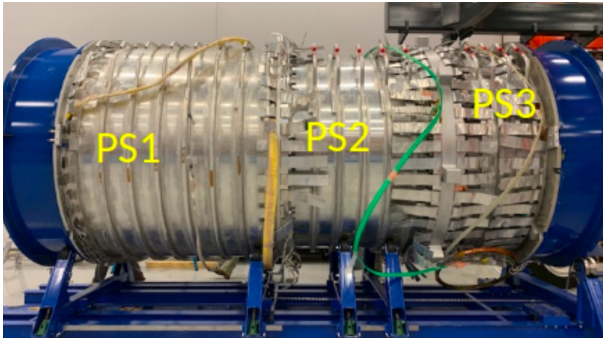


Mu2e @ FNAL

Production Solenoid



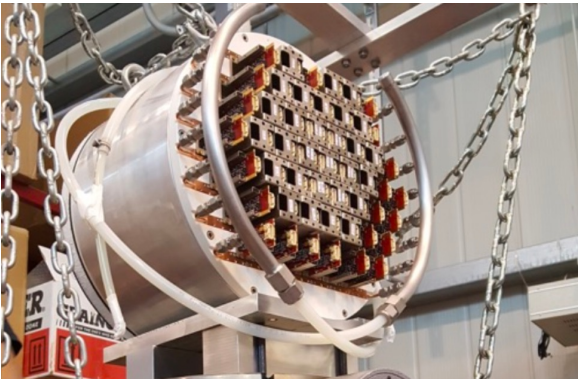
Transport Solenoid



Detector Solenoid & CRV

Tracker

35m



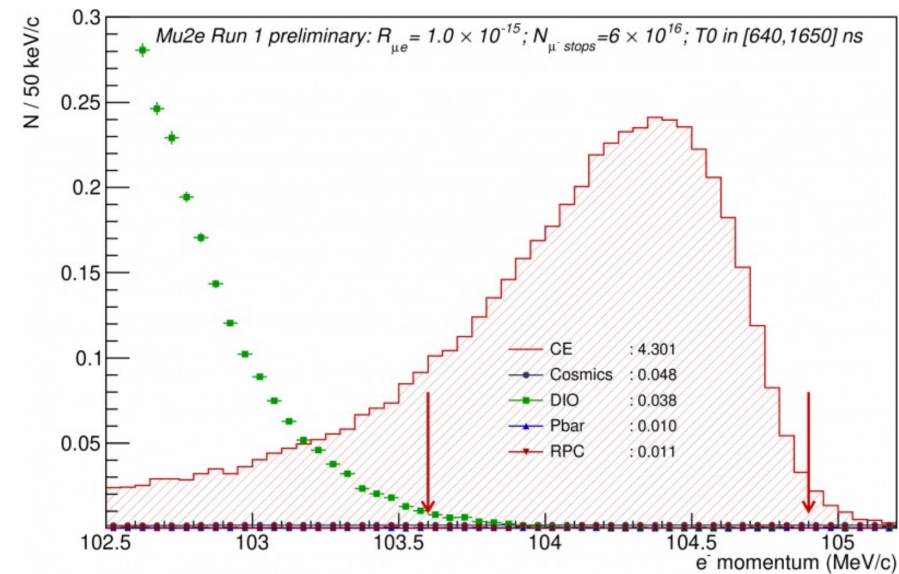
Al-Stopping Target

Calorimeter

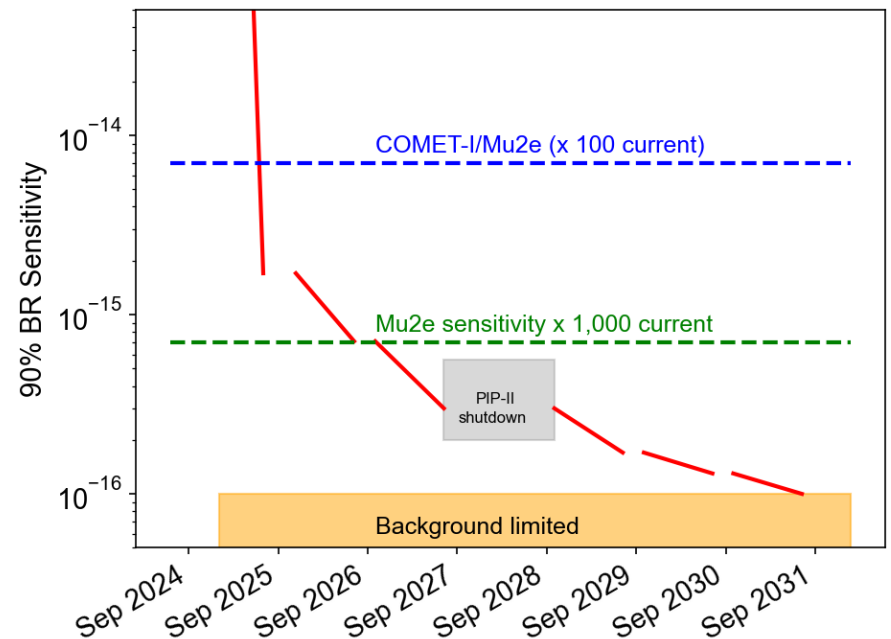


STM

Mu2e



Beam commissioning 2023
 Detector commissioning 2024
 Physics running 2025

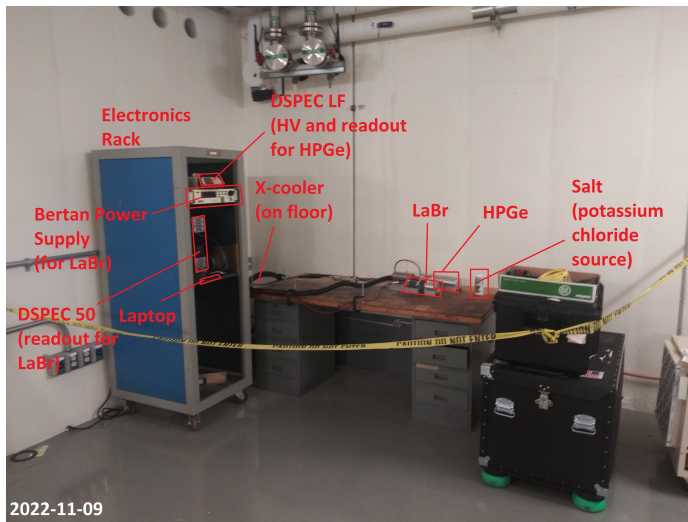
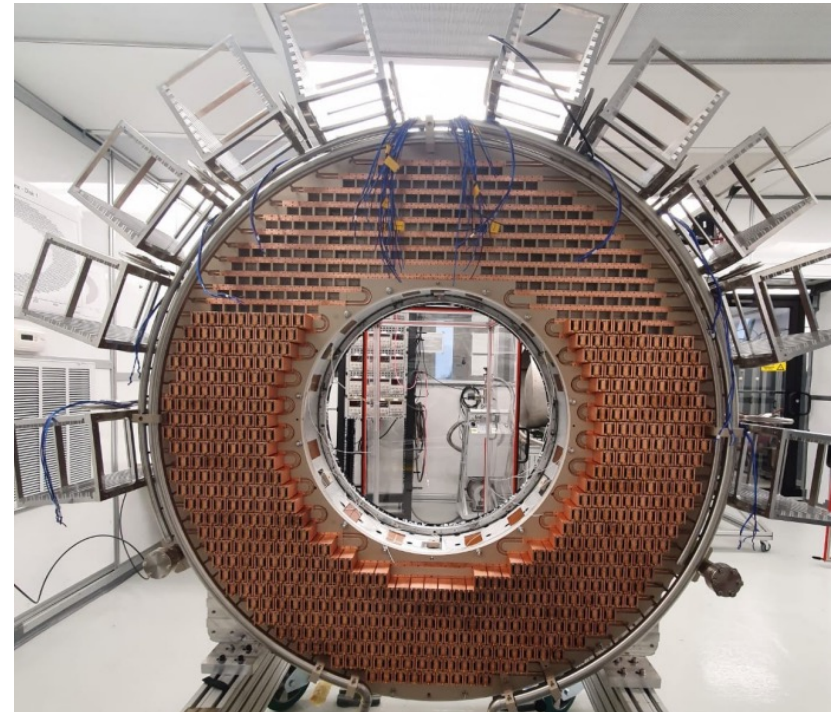
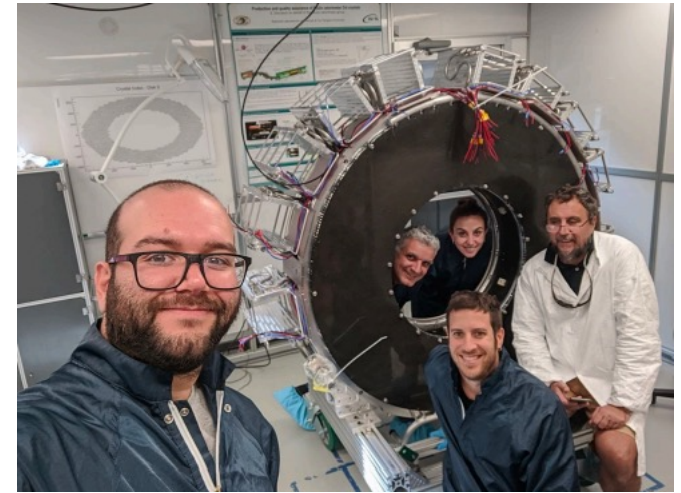


Mu2e : FNAL activities

Calorimeter (INFN) construction is taking place in SiDet cleanroom

1st disk construction well advanced
2nd disk will start 2023

STM (UK) integration starting in Mu2e-hall
with aim to do end-end DAQ/Art test in summer 2023.



Conclusions

Great time for muon CLFV physics.

Leadership in 3 of the 4 key experiments: MEG-II, Mu3e and Mu2e

MEG-II has begun physics running and Mu3e/Mu2e will begin in next 2-3 years

Support from EU-INTENSE has been vital in allowing us to integrate and commission our detectors : thank-you.