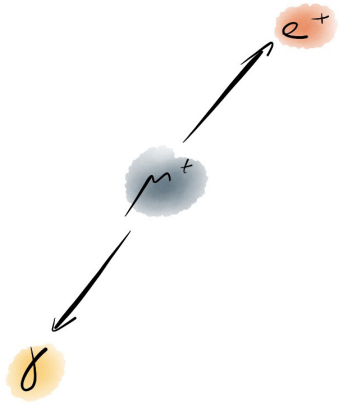
WP 4: CLFV Experiments
WP5: CLFV Data Analysis

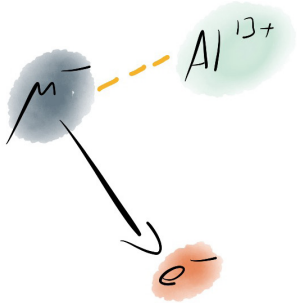
Niklaus Berger

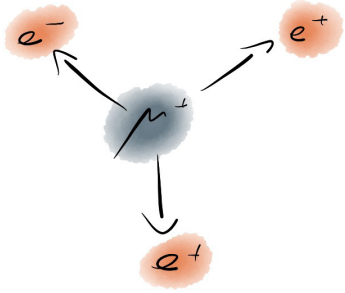
JGU Mainz

Intense Intermediate Review, December 2022

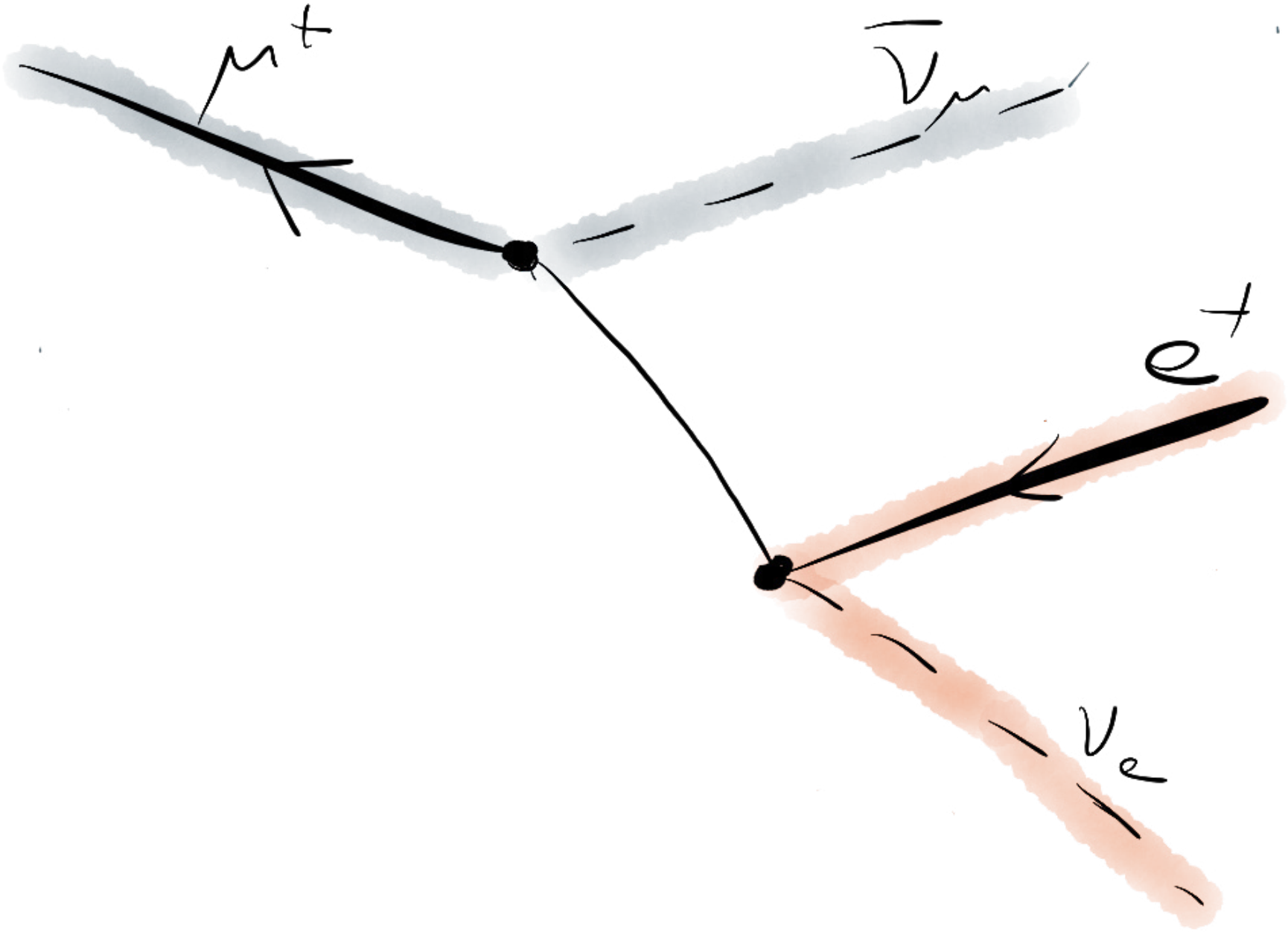
Charged Lepton Flavour Violation



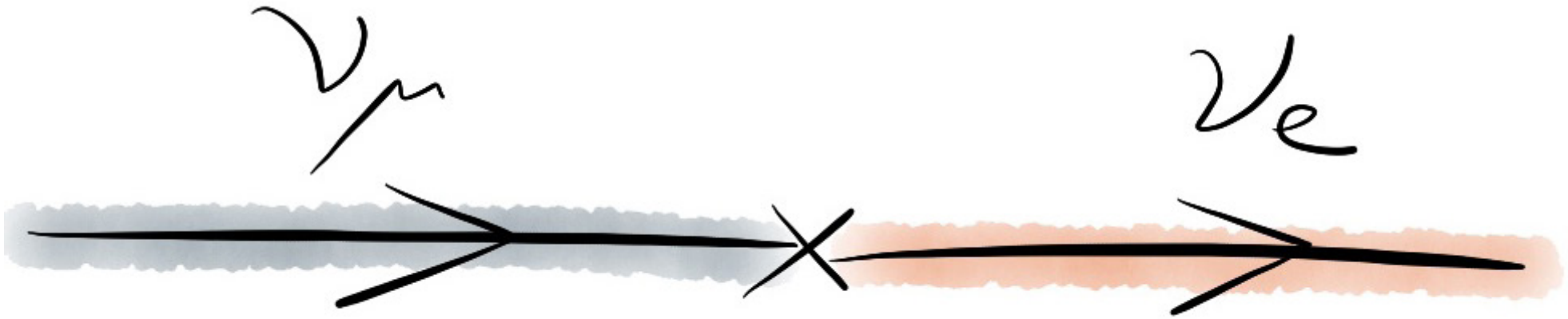




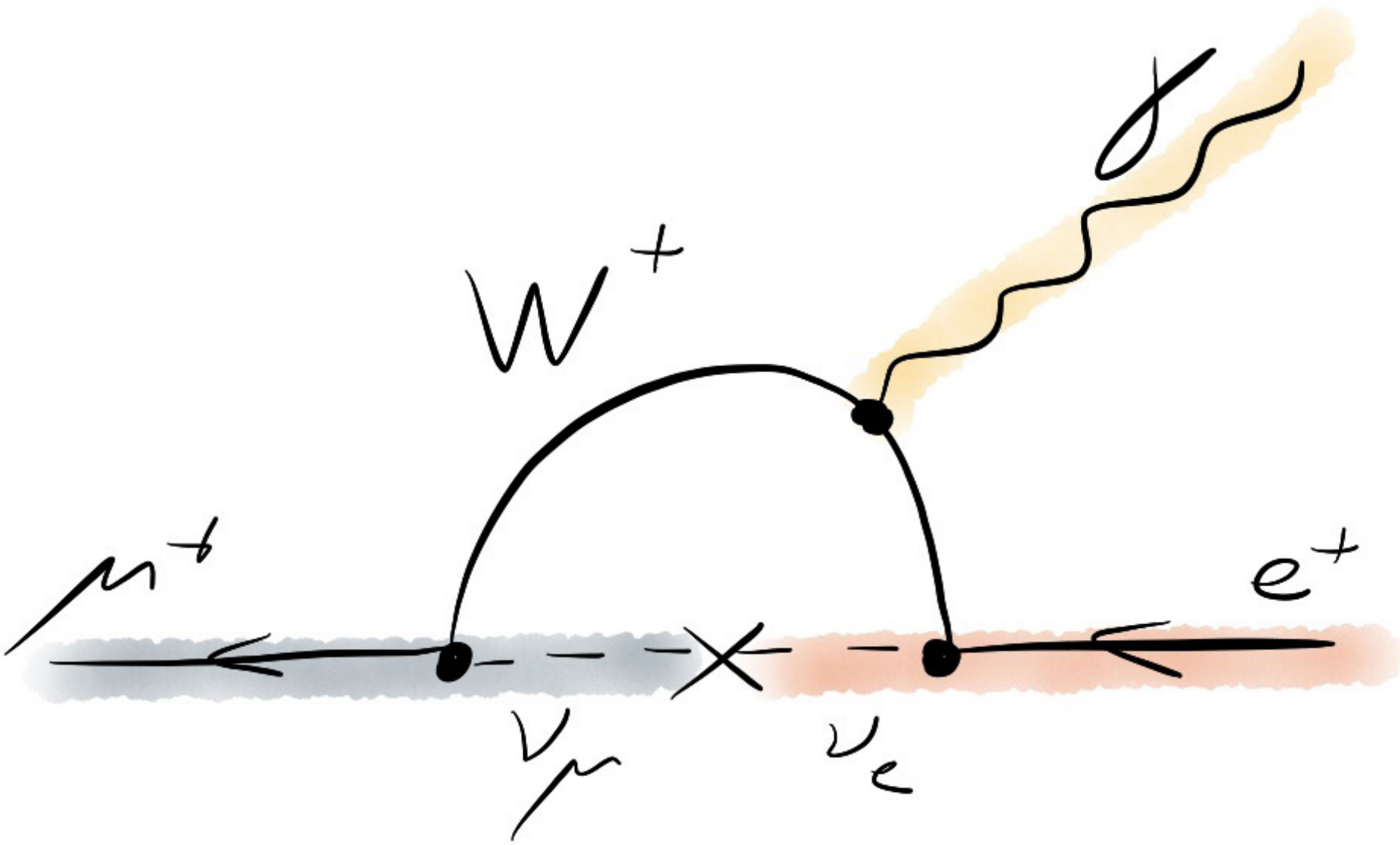
Lepton Flavour



Lepton Flavour Violation!



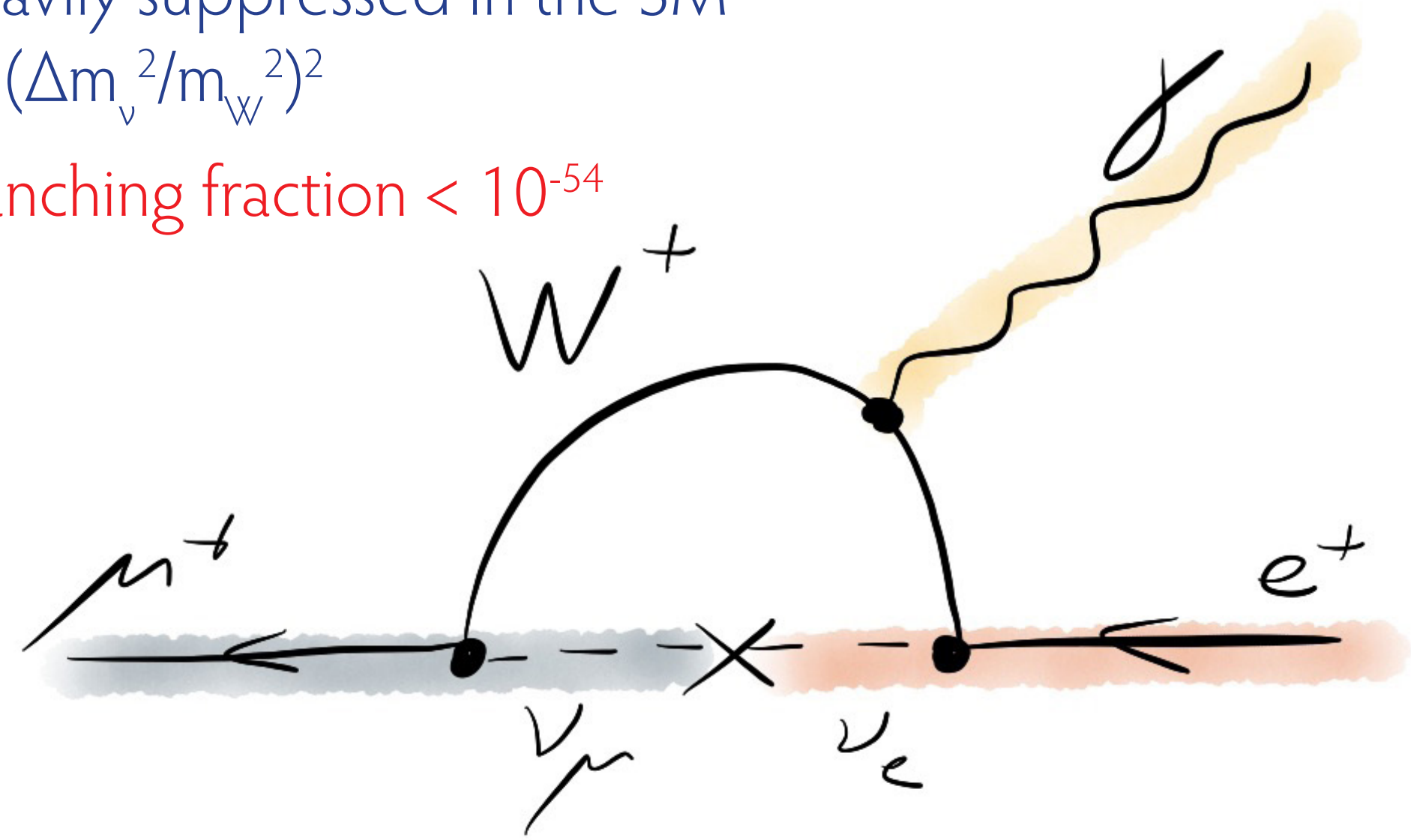
Charged Lepton Flavour Violation?



Charged Lepton Flavour Violation?

Heavily suppressed in the SM
by $(\Delta m_\nu^2/m_W^2)^2$

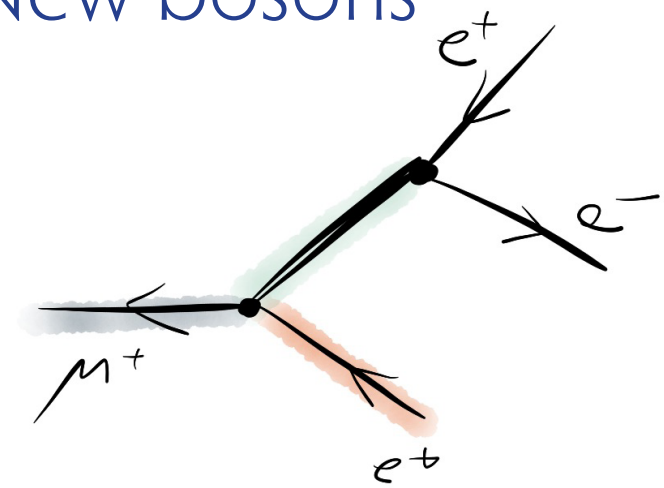
Branching fraction < 10^{-54}



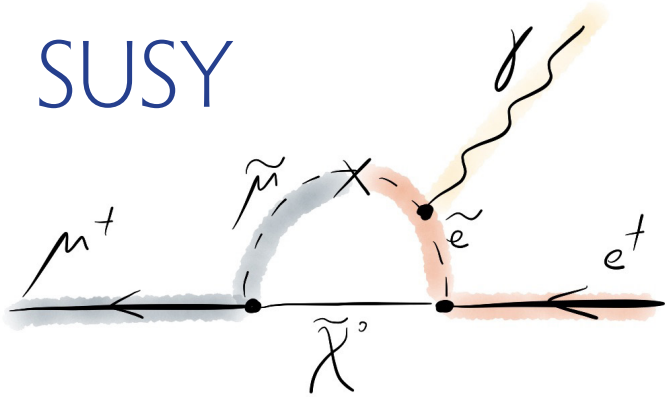
Charged Lepton Flavour Violation?

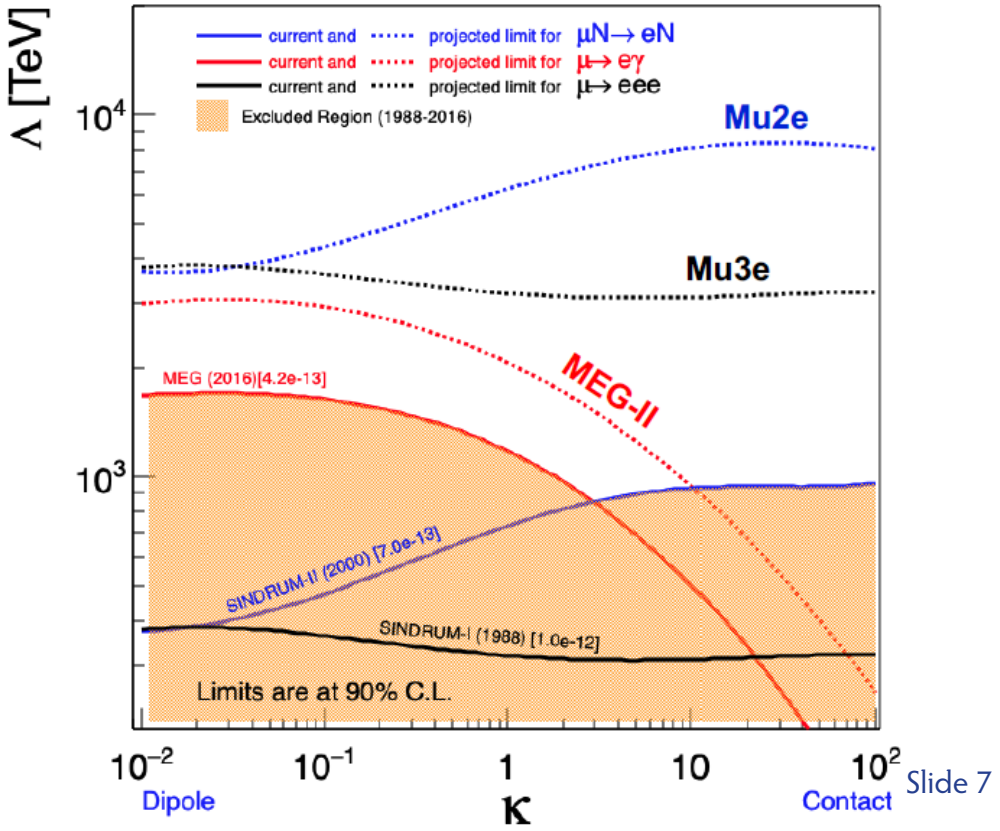
Enhanced in many models of
New Physics
Mass reach often *O*(100) - *O*(1000) TeV

New bosons



SUSY





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

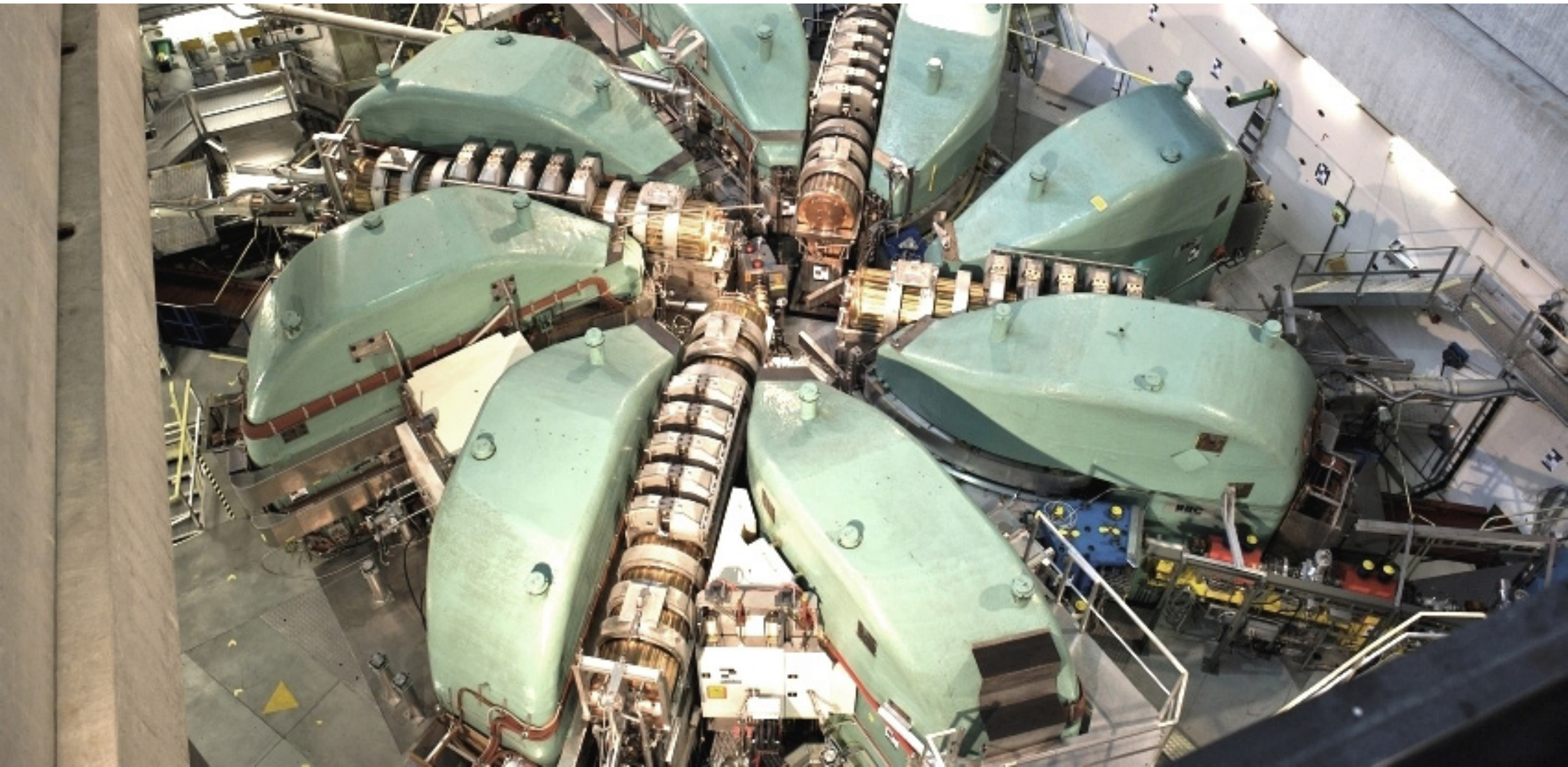
Muons from PSI

Paul Scherrer Institute in Villigen, Switzerland

World's most intensive proton beam
2.2 mA at 590 MeV: 1.3 MW of beam power

Continuous beam

10^8 μ/s available
Plan for 10^{10} μ/s (HIMB)



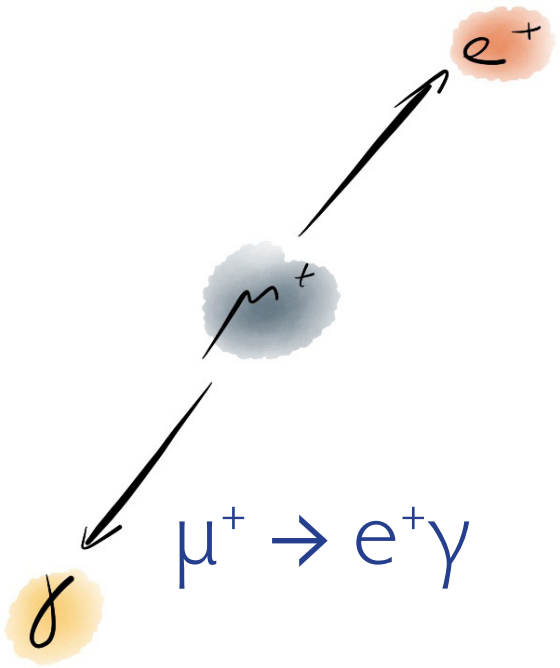
Muons from Fermilab

fnal.gov

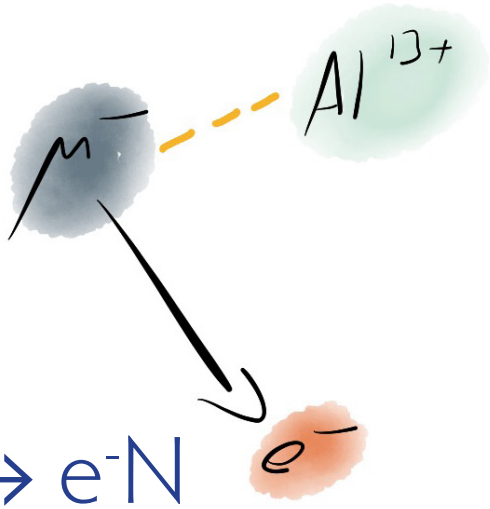
- Re-use part of the Tevatron infrastructure
- Proton pulses every 1700 ns
- $> 10^{10}$ μ/s

- Planned upgrades
  can give another
  2 orders of magnitude with a
  new powerful proton linac

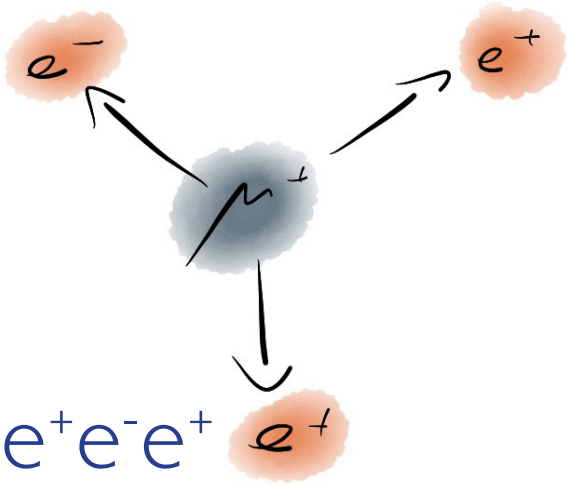
LFV Muon Decays



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

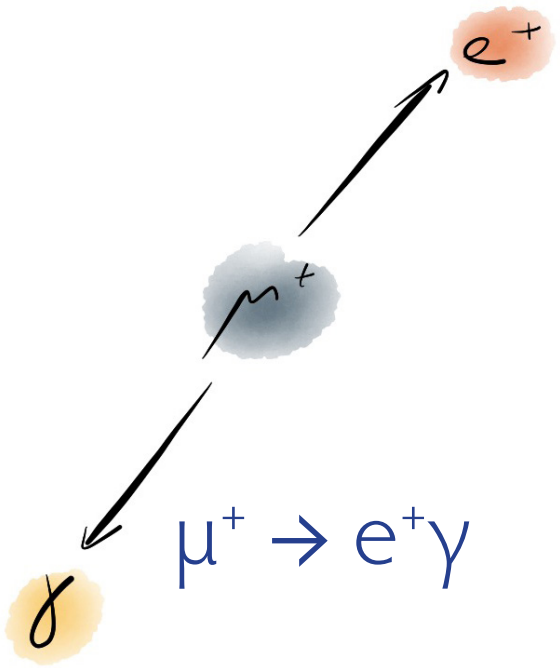


$\mu^-N \rightarrow e^-N$

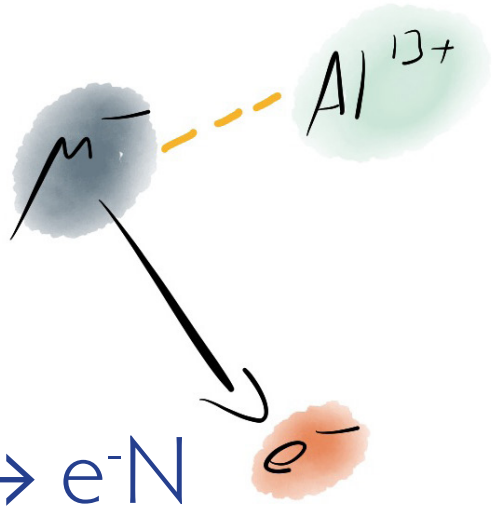


$\mu^+ \rightarrow e^+e^-e^+$

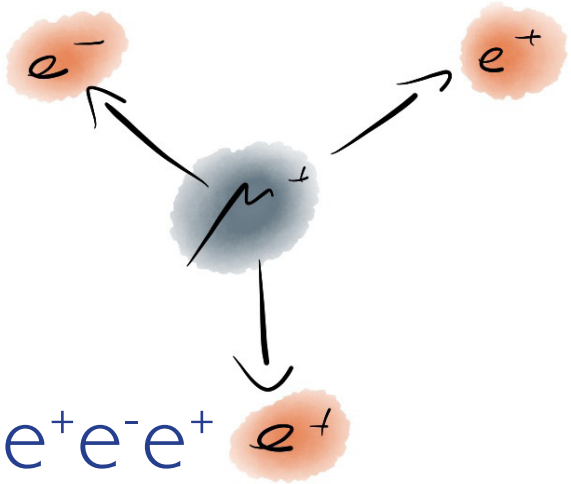
LFV Muon Decays: Experimental Situation



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



$\mu^-N \rightarrow e^-N$



$\mu^+ \rightarrow e^+e^-e^+$

MEG (PSI)

$B(\mu^+ \rightarrow e^+\gamma) < 4.2 \cdot 10^{-13}$
(2016)

SINDRUM II (PSI)

$B(\mu^- Au \rightarrow e^- Au) < 7 \cdot 10^{-13}$
(2006)

SINDRUM (PSI)

$B(\mu^+ \rightarrow e^+e^-e^+) < 1.0 \cdot 10^{-12}$
(1988)

MEG II (PSI)

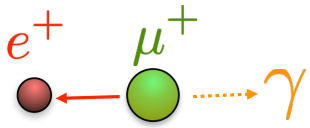
Mu2e (Fermilab)
COMET (J-PARC)

Mu3e (PSI)

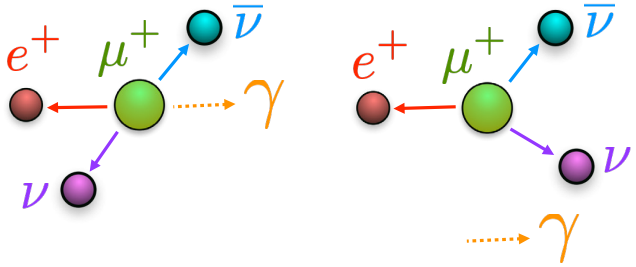
The MEG II Experiment

- Best upper limit on the BR ($\mu^+ \rightarrow e^+ \gamma$) set by the MEG experiment (**$4.2\ 10^{-13}$** @90% C.L.)
- Searching for $\mu^+ \rightarrow e^+ \gamma$ with a sensitivity of ~ **$6\ 10^{-14}$**
- Five observables **(E_g, E_e, t_{eg}, ϑ_{eg}, ϕ_{eg})** to identify $\mu^+ \rightarrow e^+ \gamma$ events

Signature

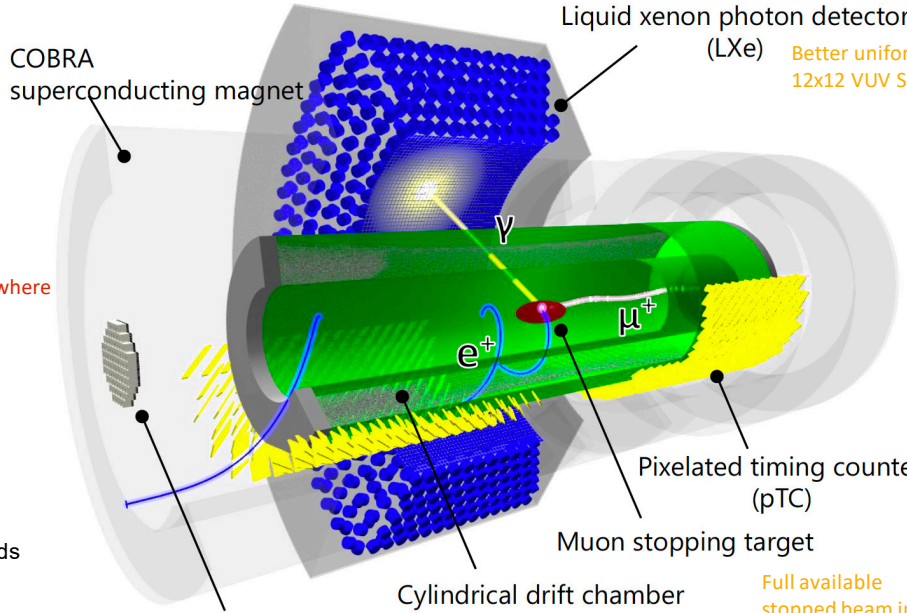


Backgrounds



New electronics:
Wavedream

~9000 channels
at 5GSPS



x2 Resolution everywhere

x2 Beam Intensity

Updated and
new Calibration methods

Quasi mono-chromatic
positron beam

Full available
stopped beam intensity
7×10^7

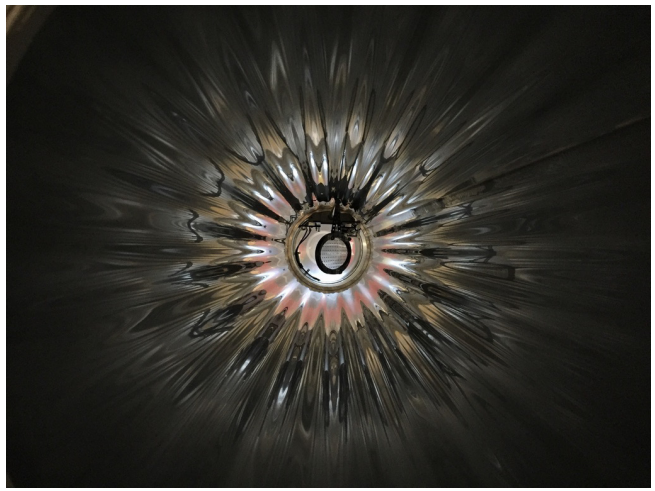
MEG II Status

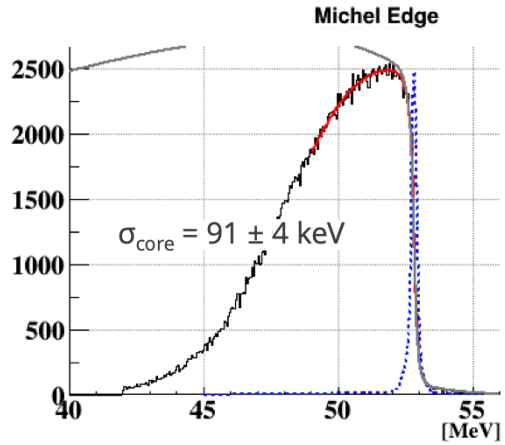
Key points:

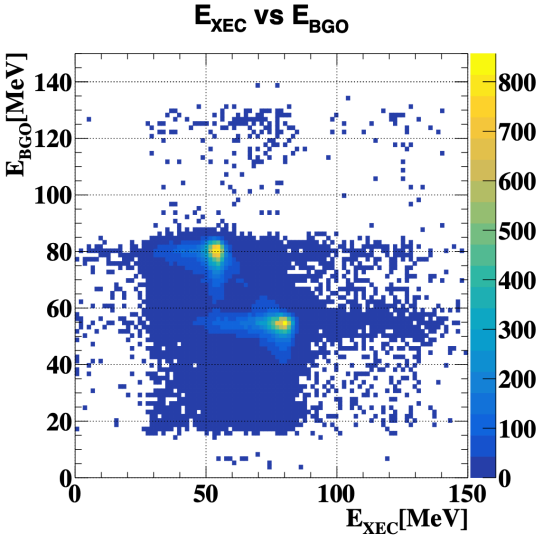
- **Run2021 very successful**
- Electronics fully installed and tested with all sub-detectors and calibration tools
- All calibration and physics trigger configurations released
- Assessed performances of each sub-detectors in the final MEG II conditions
- Collected data at different beam intensities
- Dedicated RMD at reduced beam intensity as proof-of-principle of the experiment quality
- **Physics run started at the end of September 2021**
- …with the COVID19 outbreak ongoing

Outlook:

- **MEGII beam time 2022 started on June 7th**
- The run with muons has been completed on Nov 17th
- MEG sensitivity expected to be **surpassed by the Run 2022 and actually fully addressed it**
- **MEG 2022 the MOST efficient physics run compared to all the others (including MEG) physics run!!!**
- **Calibration of the detectors with pion beam currently ongoing**

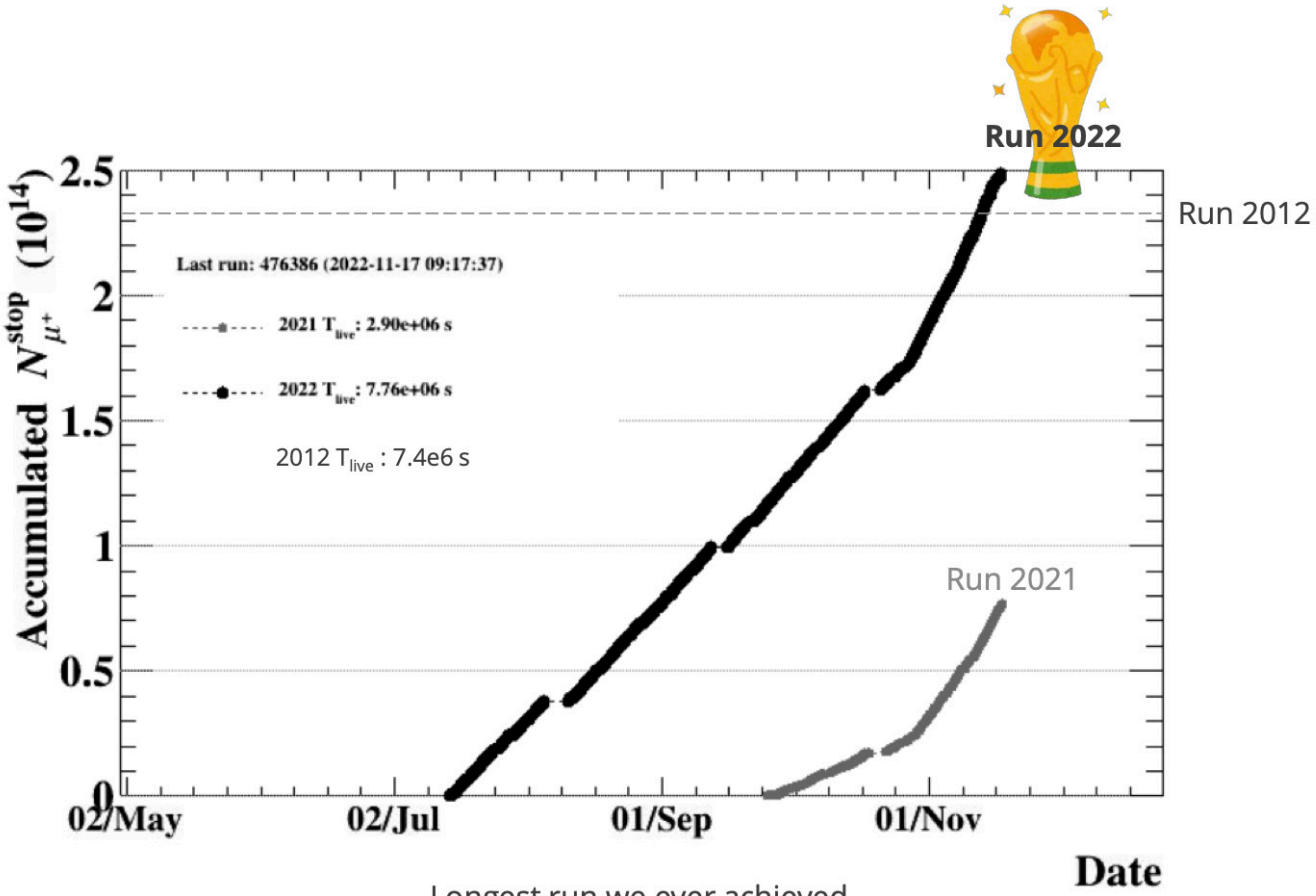






MEG II Physics Run

- A large amount of data already collected
- Intense work on the analysis to be ready with all the algorithms for the mu to e gamma search



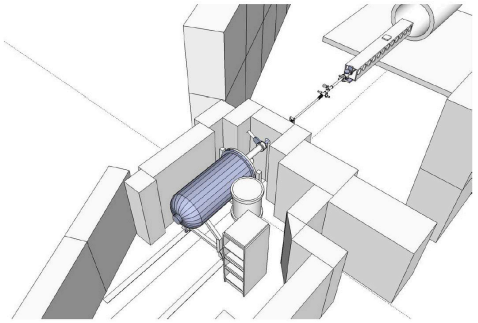
Longest run we ever achieved,
×3 statistics of 2021

The X17 Search at MEG II

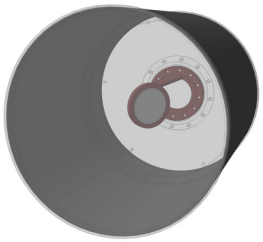
Status:

- Several intermediate tests have been performed during 2021 mainly focused on the beam, target and magnetic field configuration
- A first data sample has been collected to study the detector performances, the backgrounds, the TDAQ and the analysis code with real data
- Current effort on data analysis:
  - Reconstruction code
  - Efficiency evaluation
  - Background study: focused on External Pair Conversion (depends on the material of the experimental setup) and Internal Pair Conversion (IPC)

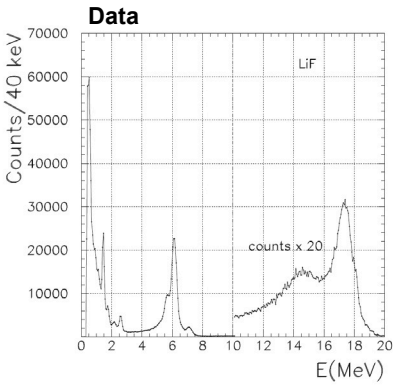
The MEG II CW accelerator and its beamline



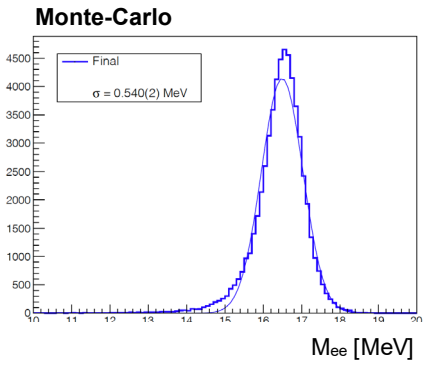
The new X17-Boson target region



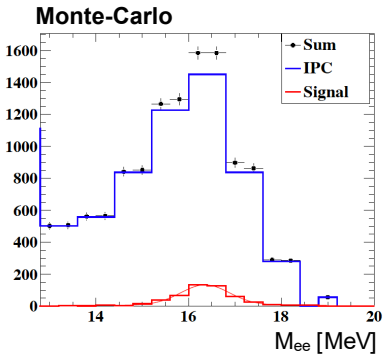
In blue the 17.6 MeV gamma line used for calibrating the XEC detector



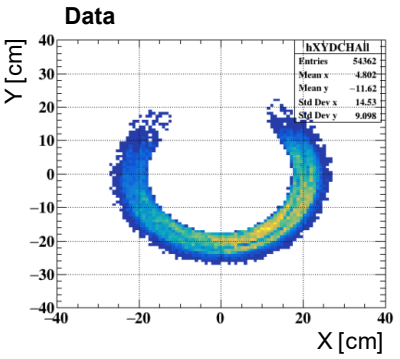
The expected reconstructed invariant mass of the e+/e- pair with the MEGII apparatus



The invariant mass distribution for the e+/e- pair produced either from the hypothetical X17 or the IPC (Internal Pair Conversion). The sum of the two is also given



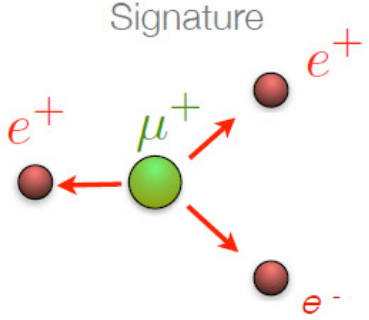
An example of hit distribution (real data) in the CDCH during the first data collection performed in February 2022



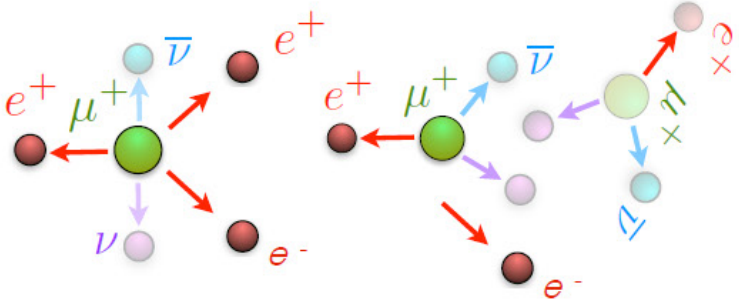
The Mu3e Experiment

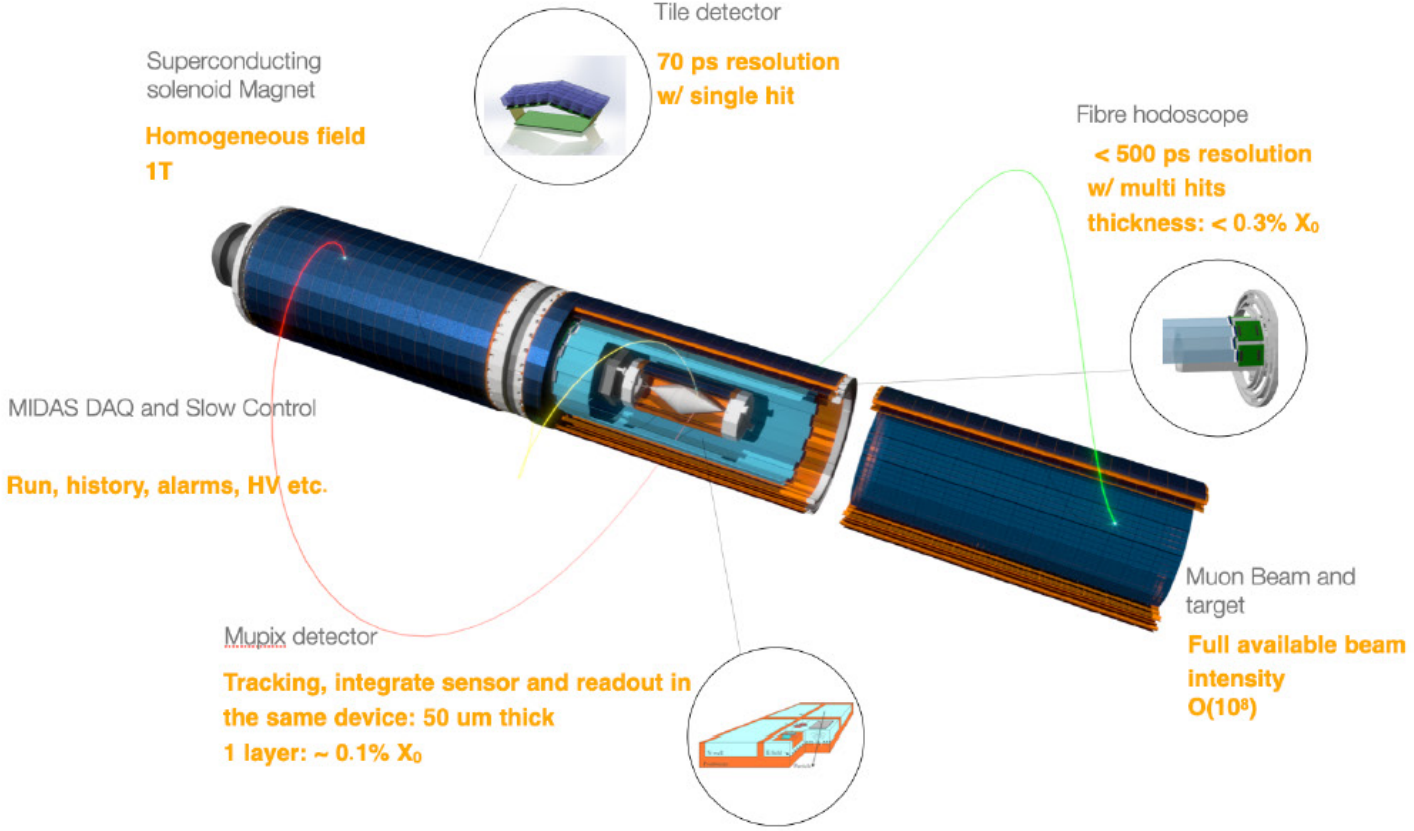
- The Mu3e experiment aims to search for $\mu^+ \rightarrow e^+ e^+ e^-$ with a sensitivity of $\sim 10^{-15}$ (Phase I) up to down $\sim 10^{-16}$ (Phase II). Previous upper limit BR($\mu^+ \rightarrow e^+ e^+ e^-$) $\leq 1 \times 10^{-12}$ @90 C.L. by SINDRUM experiment)
- Observables (E_e, t_e, vertex) to characterize $\mu \rightarrow$ eee events

Signature



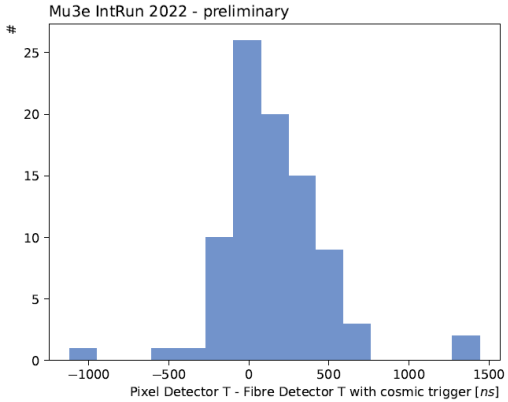
Backgrounds

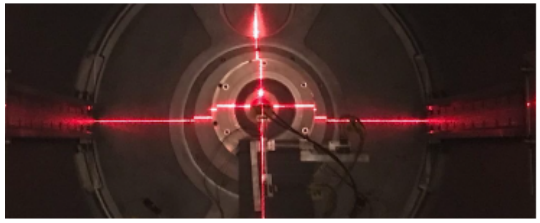


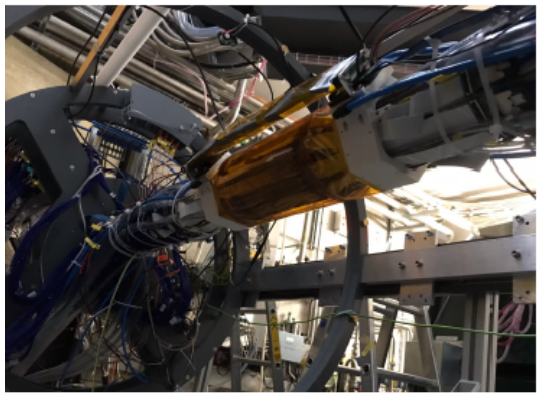


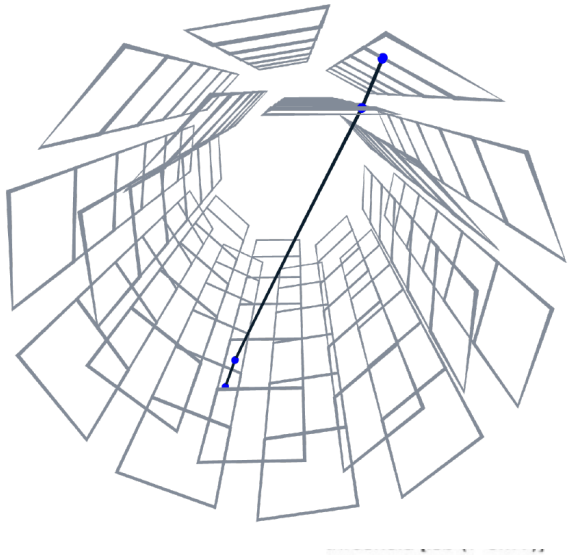
Mu3e Status

- Integration run 2021, cosmic run 2022: Inner pixel layers, scintillating fibres, DAQ, services all run together
- Full beam-line commissioning 2022: Design values for muon rates achieved
- Pixel sensor mass production ongoing
- Full detector construction 2023
- Engineering run 2024
- First physics run 2025

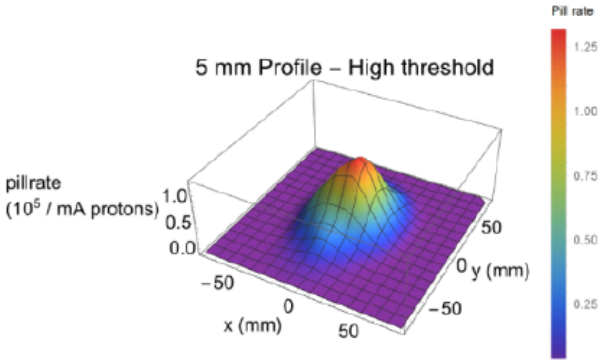








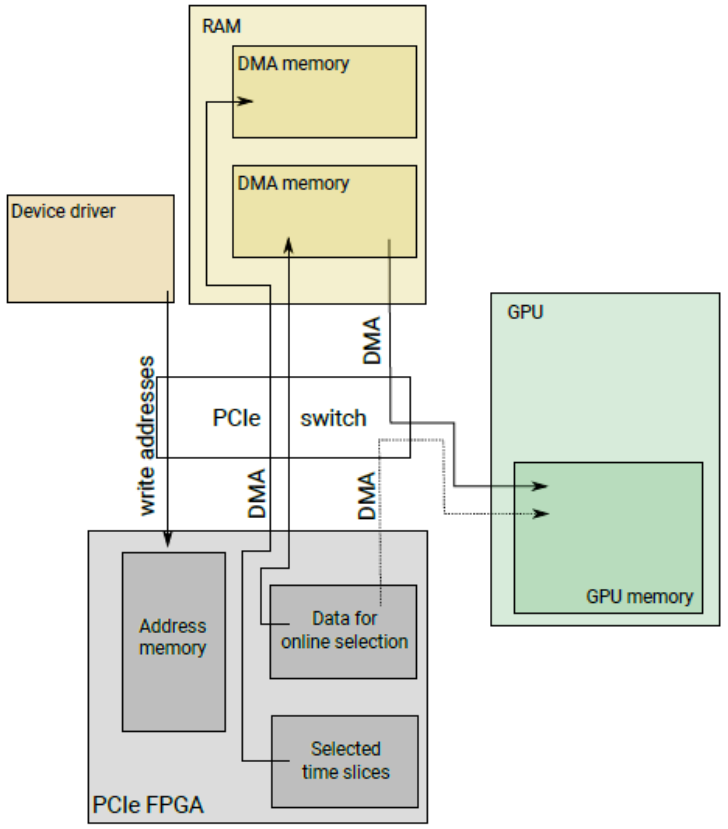
Beam commissioning **2022**



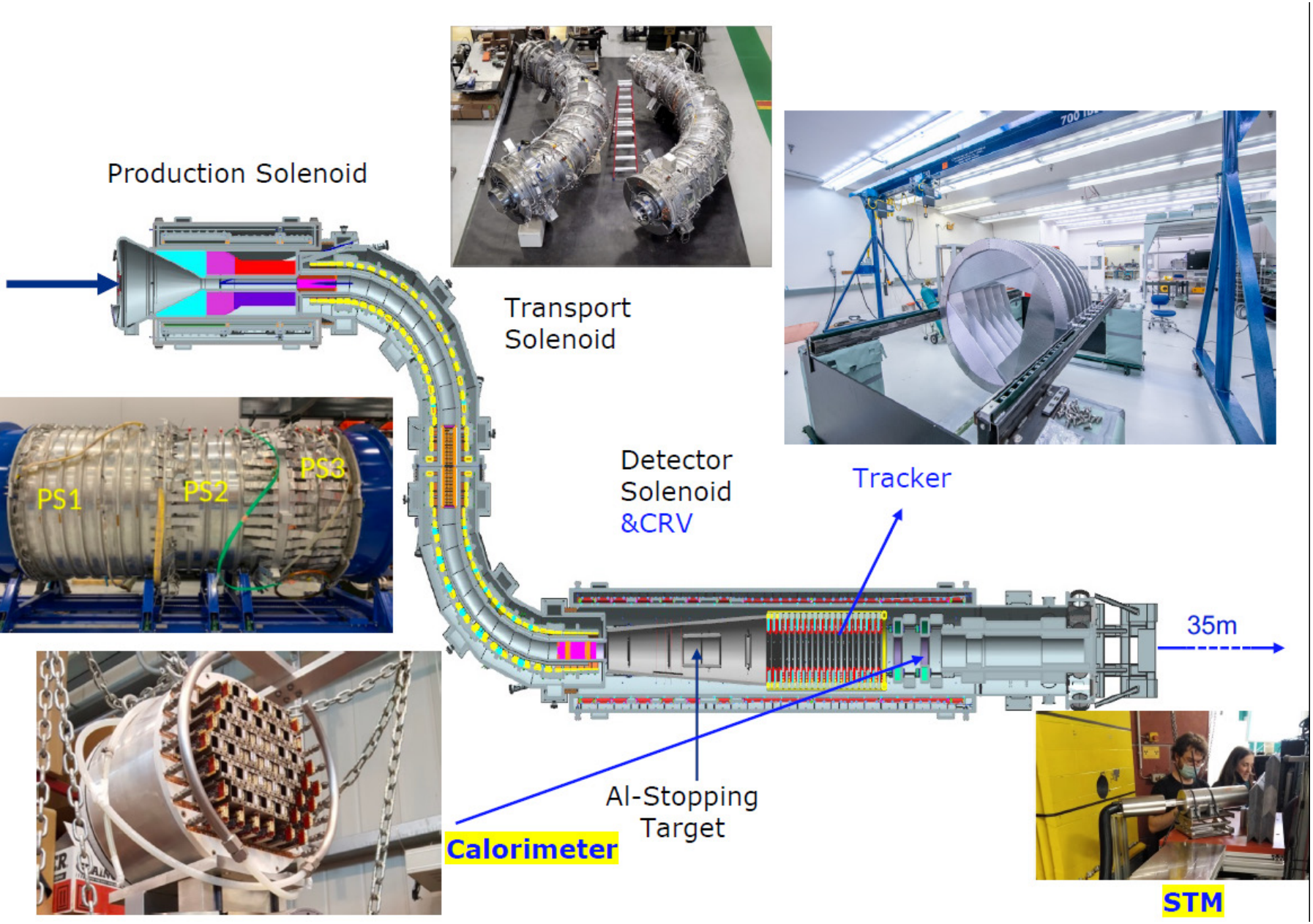
2.49e10[8] mu/s @2.4 mA

Mu3e Online Analysis

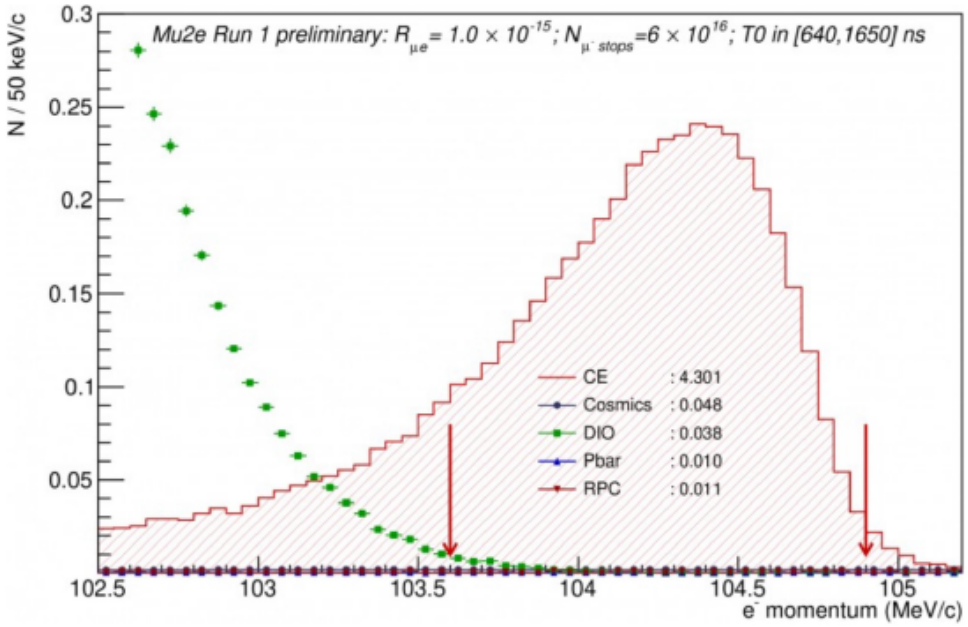
- Mu3e needs to do full track and vertex reconstruction online: Use GPUs
- Just received hardware prototypes - integration of algorithms with data flow firmware ongoing
- Online analysis needs excellent knowledge of detector alignment and calibration: Work on a camera system to supplement track-based alignment



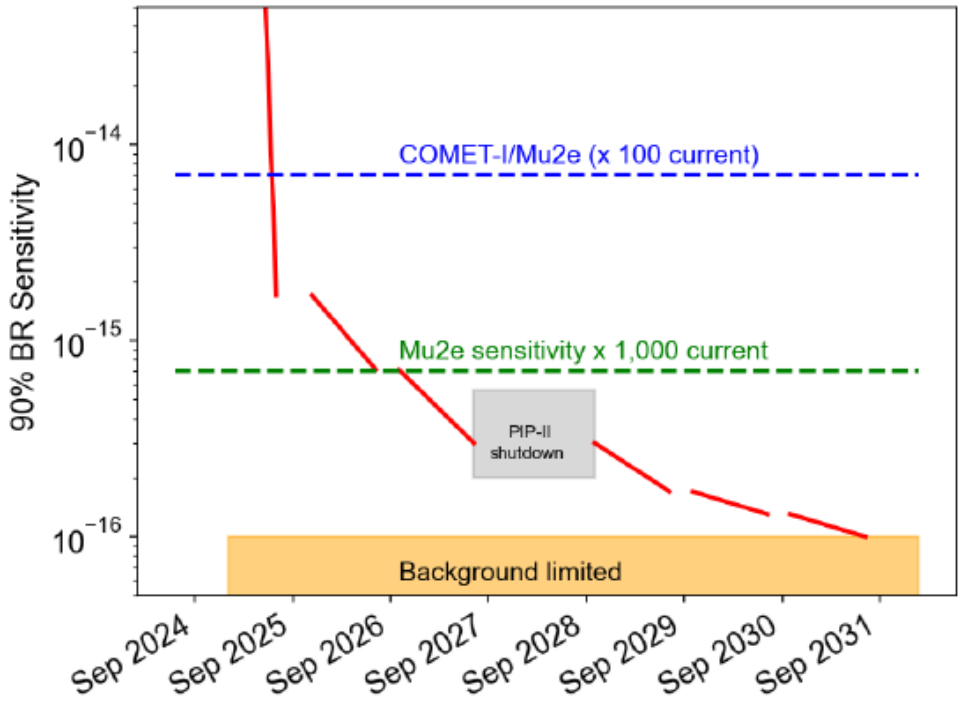
The Mu2e Experiment



Mu2e Plans



Beam commissioning 2023
Detector commissioning 2024
Physics running 2025

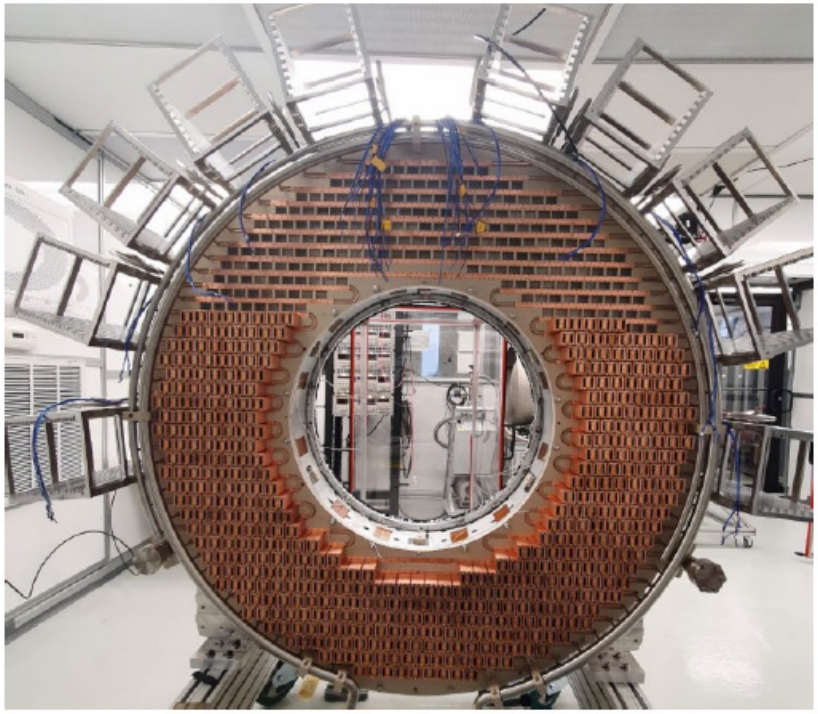


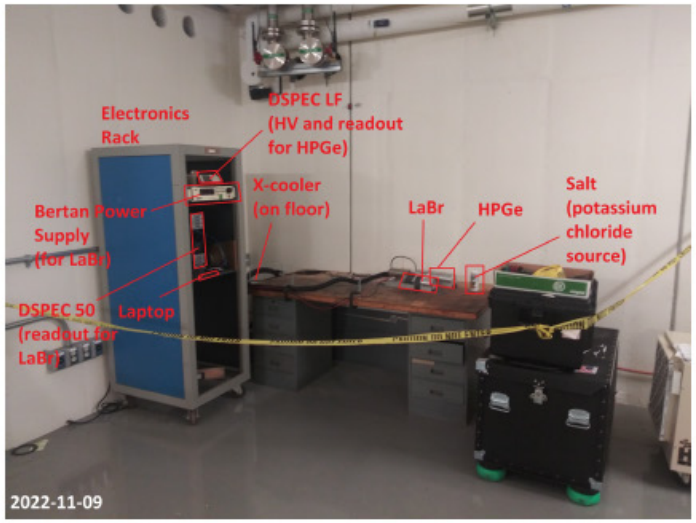
Mu2e activities at Fermilab

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.





Conclusion

Great time to do CLFV physics

- MEG II just collected the largest data set - calibration and analysis ongoing
- Mu2e and Mu3e both very active building detectors, commissioning beam lines, integrating systems and preparing data taking
- The INTENSE early stage researchers and their secondments have been and are key to this - thanks for the great support