Lepton flavour violation in muon decays

Istituto Nazionale di Fisica Nucleare

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FPCP, Victoria Univ. 07-05-2019

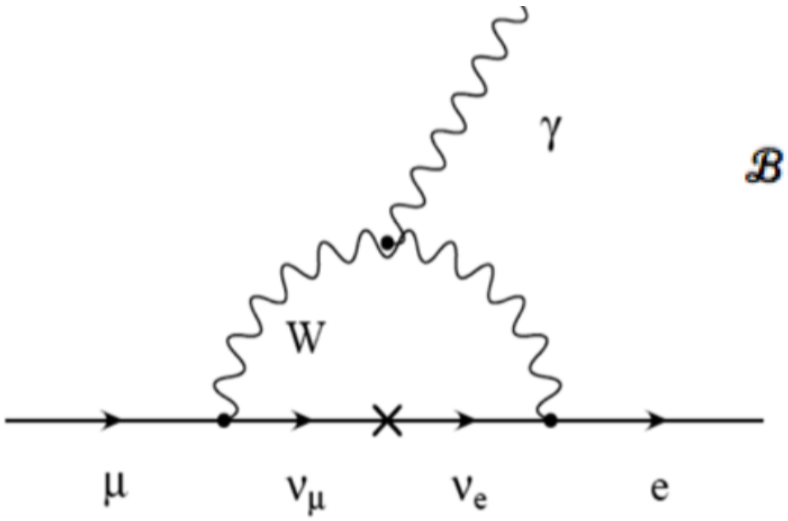
Istituto Nazionale di Fisica Nucleare

Outlook

- Quick overview of cLFV
  - *highly sensitive to physics beyond the standard model*
  - *comparison between different channels*
- Experiments
  - *MEG II @PSI*
  - *Mu2e @FNAL*
  - *COMET @JPARC*
  - *Mu3e @PSI*
- Conclusions

cLFV = physics beyond SM

- $l \rightarrow l' + X$ (X = γ, " " , ee, μμ, others…)

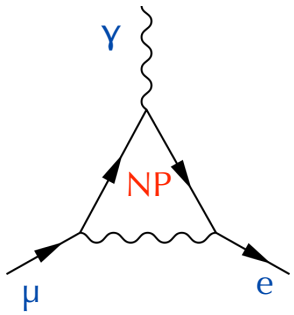


$$\mathcal{B}(\mu \rightarrow e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M^2_W}\right|^2 \simeq 10^{-54}$$

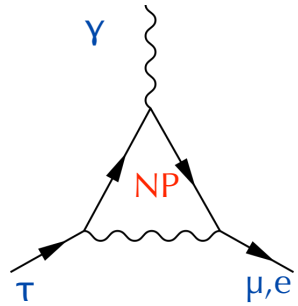
too small to be experimentally accessible → portal to New Physics extensively exploited in intensity frontier

SM background free searches!

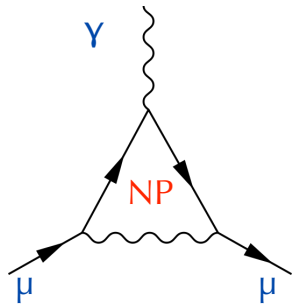
Many channels



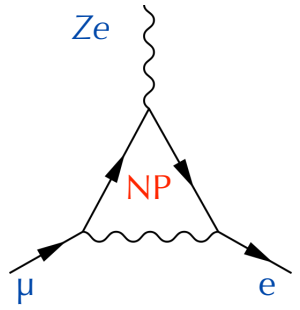
$$\mu \to e\gamma$$



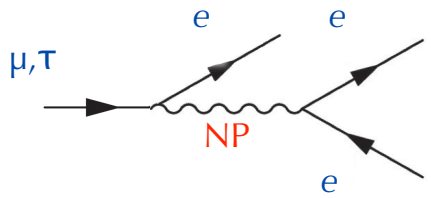
$$\tau \to \mu\gamma$$
$$\tau \to e\gamma$$



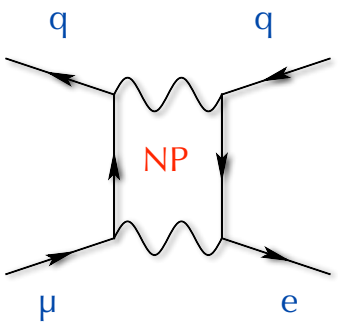
$$(g-2)_\mu$$

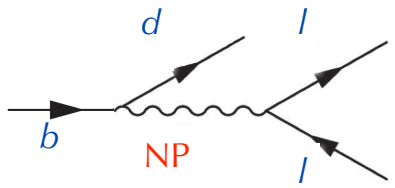


$$\mu^- \mathcal{N} \to e^- \mathcal{N}$$



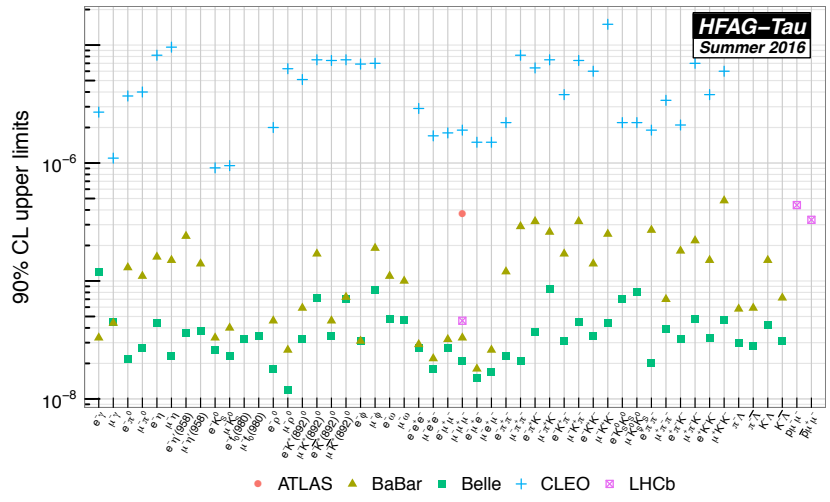
$$\mu \to eee$$





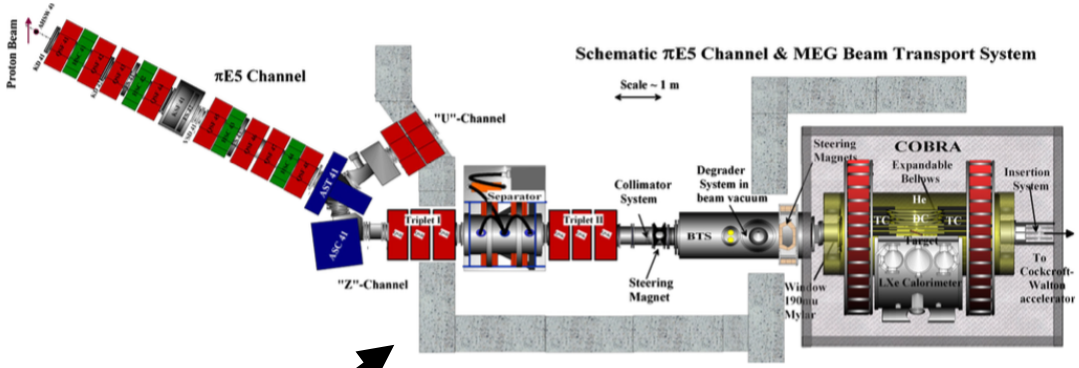
$$B \to \ell\bar{\ell}'$$
$$B \to \ell\bar{\ell}' X_s$$

- A **wide field** of research
  - ***LFV decays of leptons***
  - ***Anomalous magnetic moment for the μ***
  - ***Muon-to-electron conversion***
  - ***LFV in meson decays***

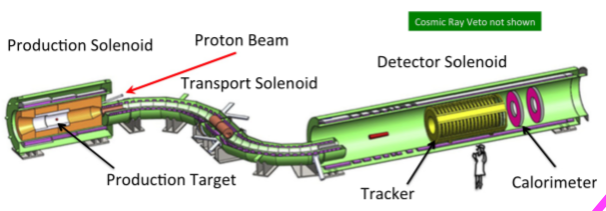


μ as a golden channel

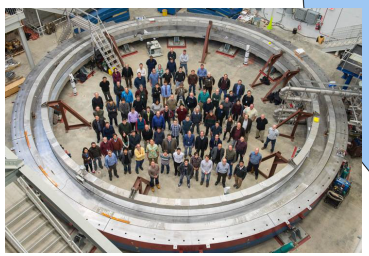
- **High intensity** and **low energy μ beams**
  - ***large statistics*** *possible*
- **long decay time**
  - *beam* ***transport*** *to a* ***target***
- **simple kinematics**
  - ***precise*** *measurements in a* ***high rate*** *background*



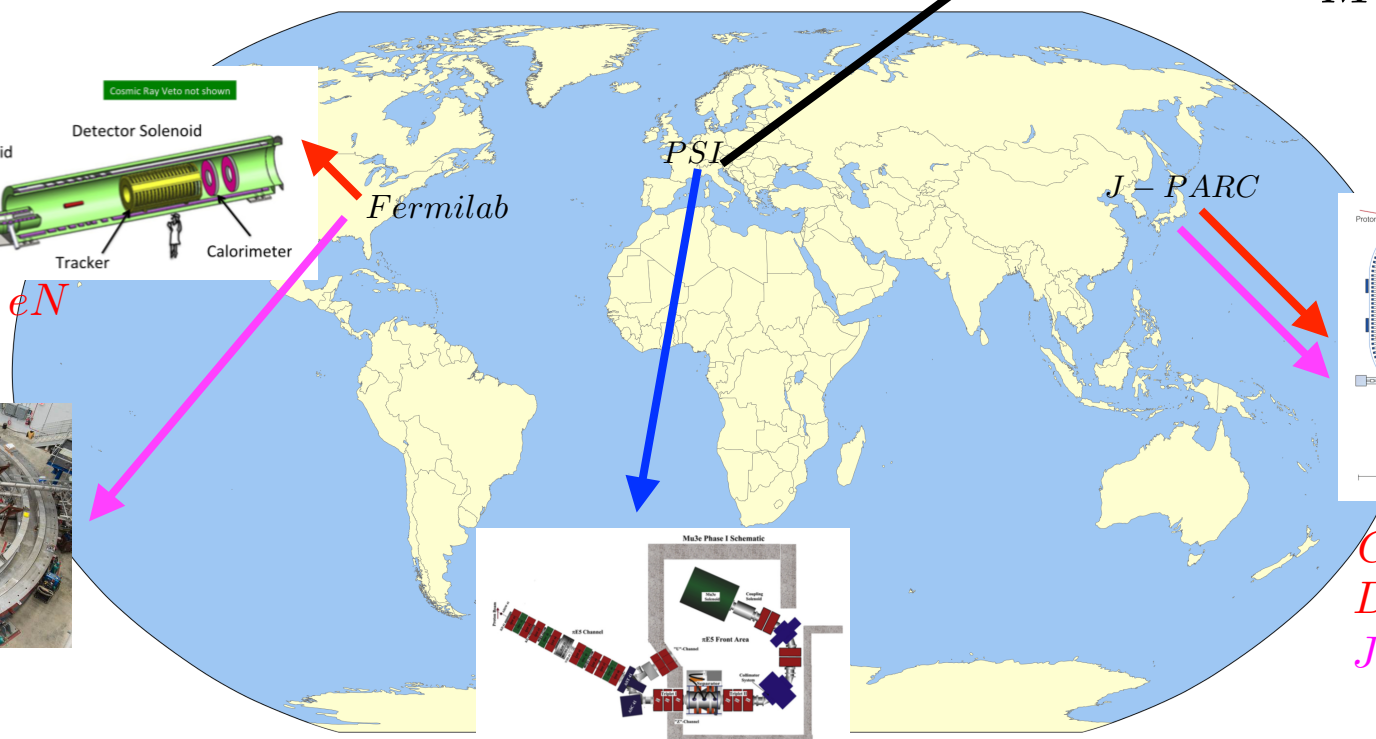
$MEG : \mu \to e\gamma$



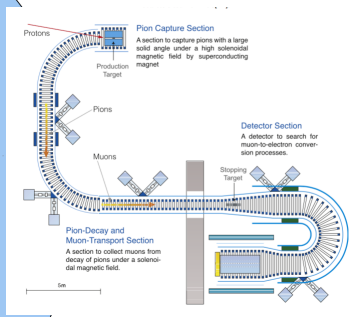
$Mu2e : \mu N \to eN$



$Muon \quad g-2$



$Mu3e : \mu \to eee$



$COMET : \mu N \to eN$
$DeeMe : \mu N \to eN$
$J-PARC \quad g-2$

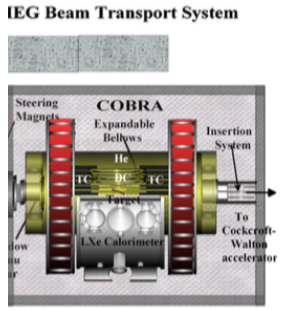
μ as a golden channel

- High intens
  - *large s*
- long decay
  - *beam t*
- simple kine
  - *precise*

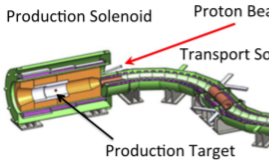
Table 8
"DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

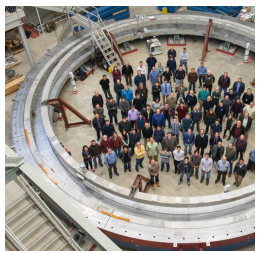
Altmannhofer et al, Nuclear physics B, 2010



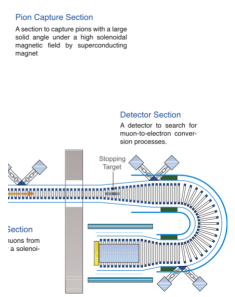
$: \mu \to e\gamma$



$Mu2e : \mu N -$

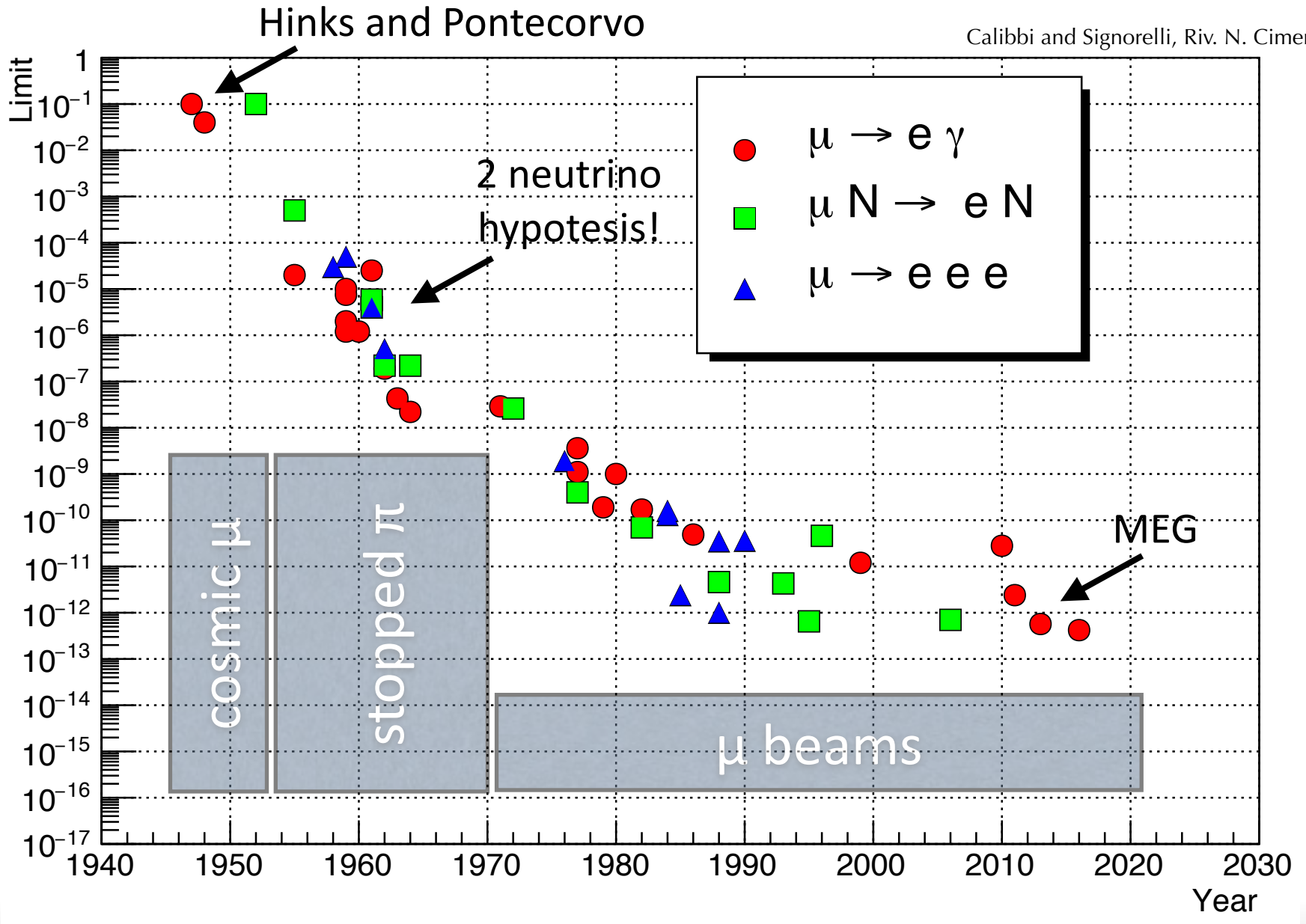


$Muon \quad g -$

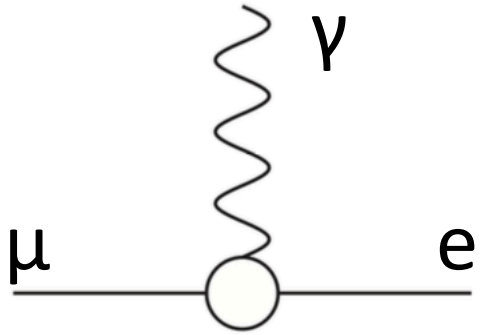


$lET : \mu N \to eN$
$Ie : \mu N \to eN$
$PARC \quad g-2$

70 years of searches

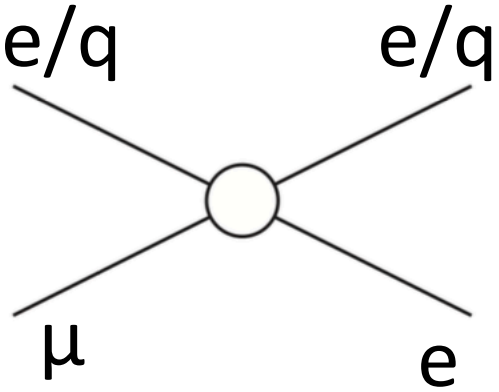


New physics* couplings



dipole transition

μ→eγ favoured



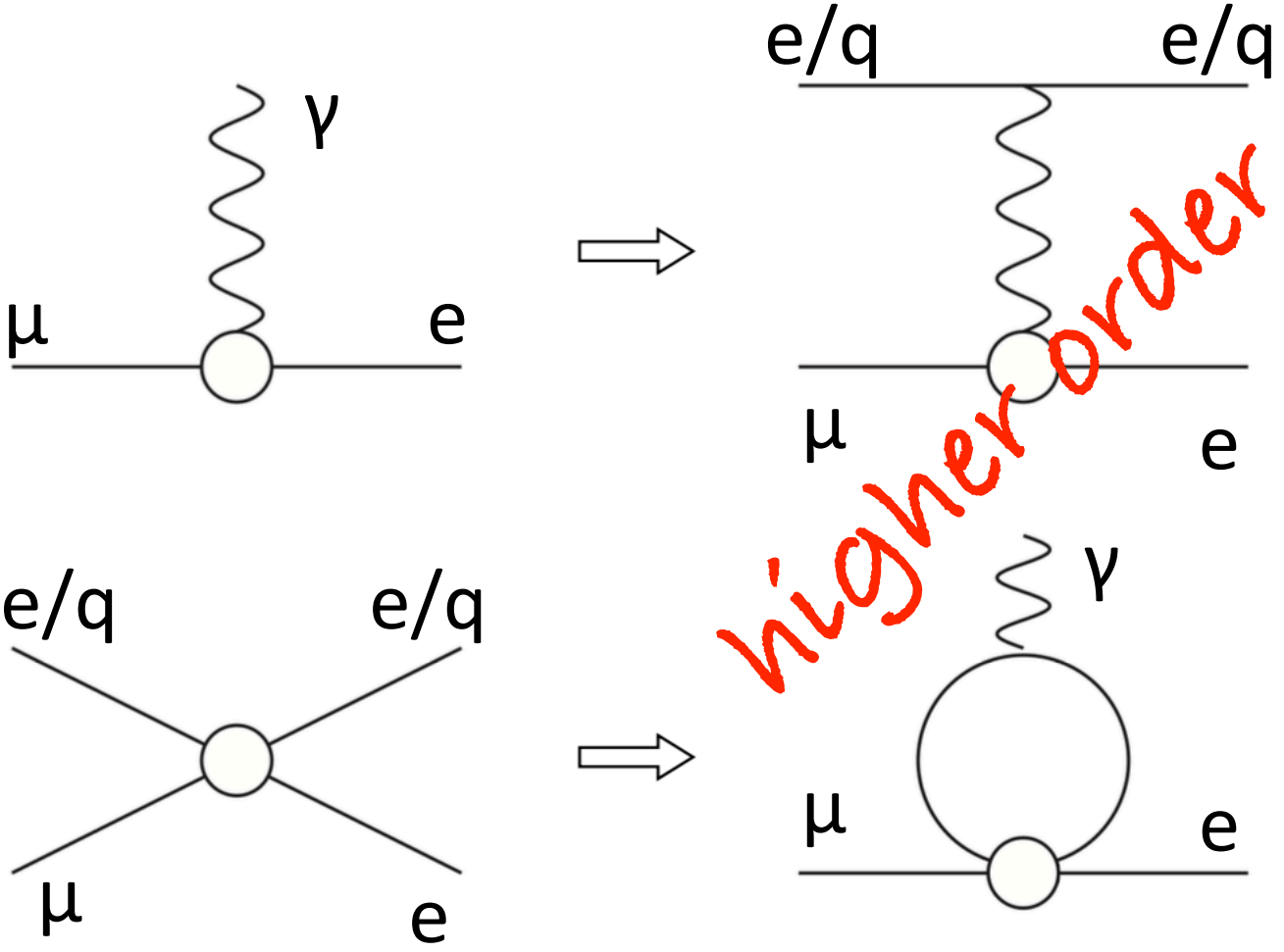
four particle interaction

μN→eN, μ→eee favoured

*Model independent approach

Calibbi and Signorelli, Riv. N. Cimento, 2017

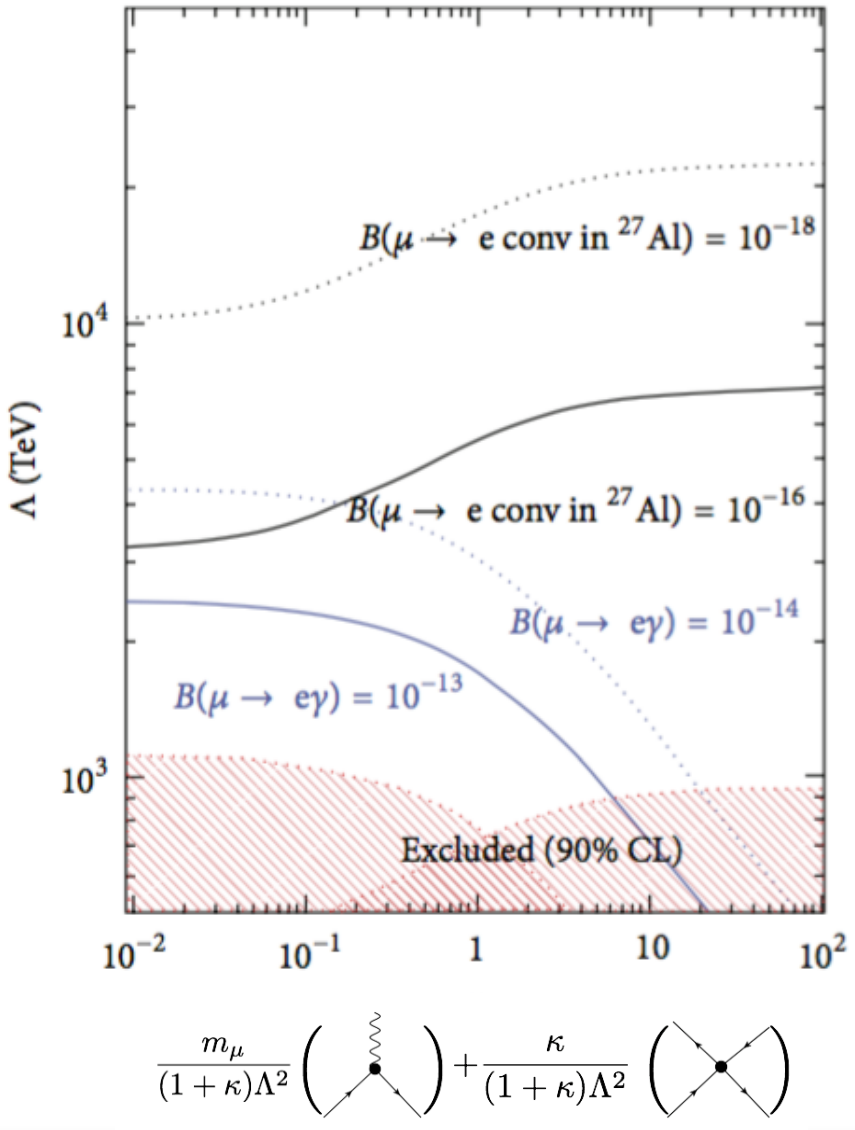
New physics* couplings



*Model independent approach

Calibbi and Signorelli, Riv. N. Cimento, 2017

Effective parametrisation

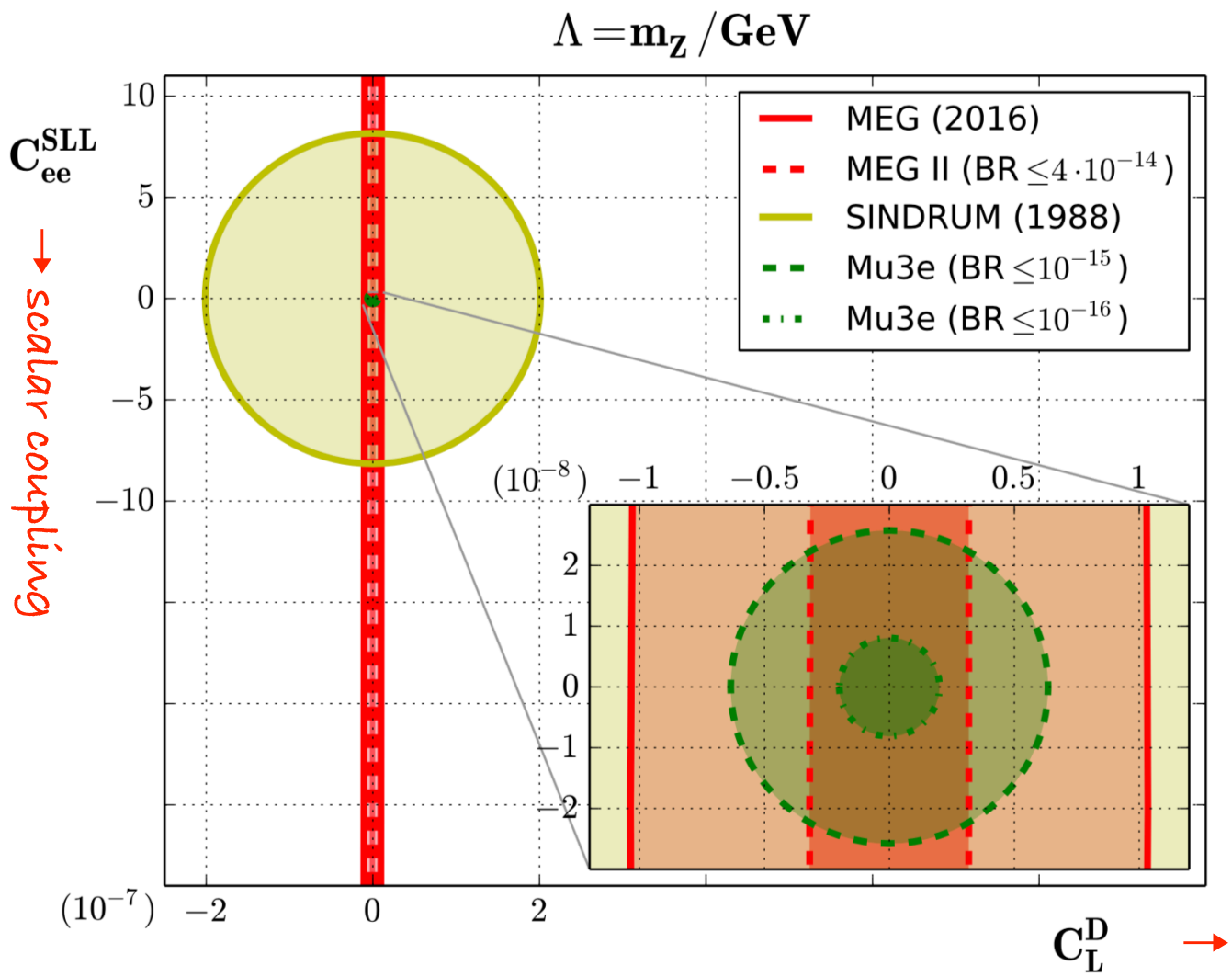


de Gouvea and Vogel, Prog. Part. Nucl. Phys. 2013

- **effective Lagrangian**
  - *function of the **NP scale Λ** and **NP nature** through **κ***
    - **dipole transition**
      - *BR(μ -> eγ)/BR(μN->eN)≈10^{-2}*
    - **four fermion** interaction
      - *μN->eN favoured*
- From **current** and **future experiments 10³ TeV** new physics scale **sensitivity**

	current limit	future limit
μ->eγ	4.2x10^{-13}	6x10^{-14}
μN->eN	10^{-12} - 10^{-13}	3x10^{-17}
μ->eee	10^{-12}	10^{-15} - 10^{-16}

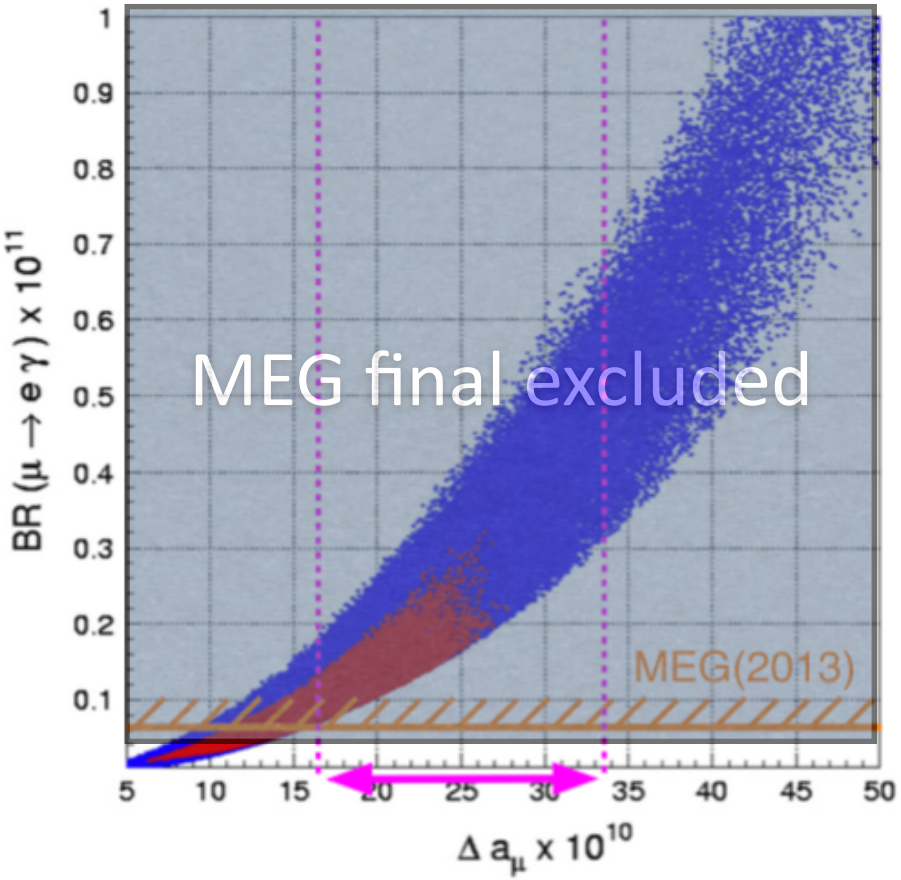
Complementarity μ→eγ ⇔ eee



Crivellin, Davidson et al, arXiv:1611.03409, 2016

Comparison* with g-2 experiment

- **3.4 σ discrepancy** w.r.t. Standard Model prediction
  - *possible **hint** of **new physics***
  - *this **would enhance** to **μ->eγ** for example in a **supersymmetric** model*
    - **cLFV coupling** $|\delta_{LL}^{12}|^2 \approx 10^{-4}$ **almost excluded**
- resolution **improvements** by a **factor 4** from future experiments at **Fermilab** and **J-PARC**
  - *together with **new generation** cLFV **experiments** will be **sensitive** to* $|\delta_{LL}^{12}|^2 \approx 10^{-5}$

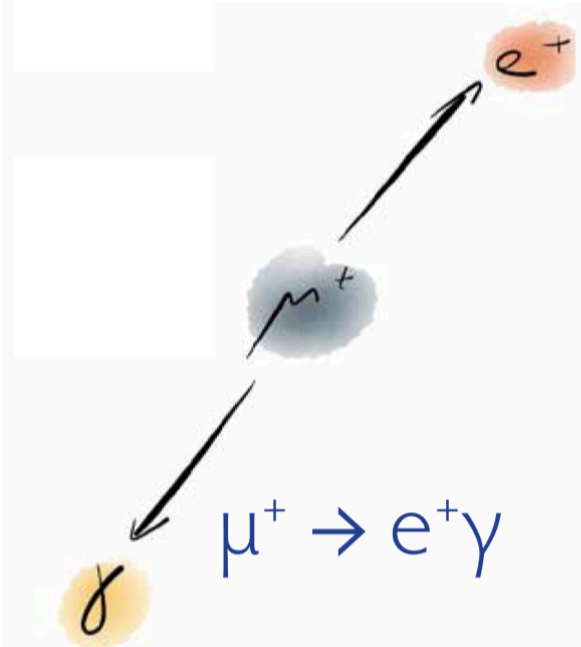


$$\mathcal{B}(\mu \to e\gamma) \approx 10^{-4} \left(\frac{\Delta a_\mu}{200 \times 10^{-11}} \right)^2 |\delta_{LL}^{12}|^2$$

G. Isidori et al., PRD, 2007

*Model dependent

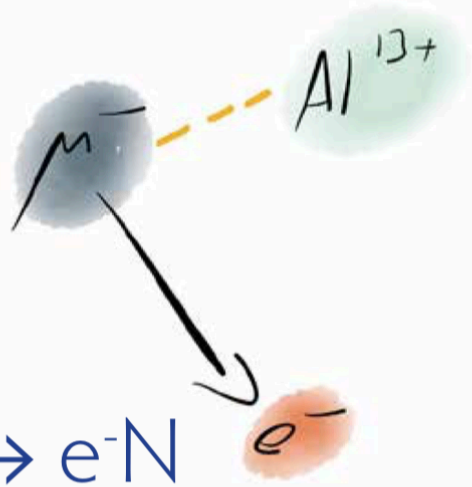
Muon cLFV: kinematics



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

Kinematics

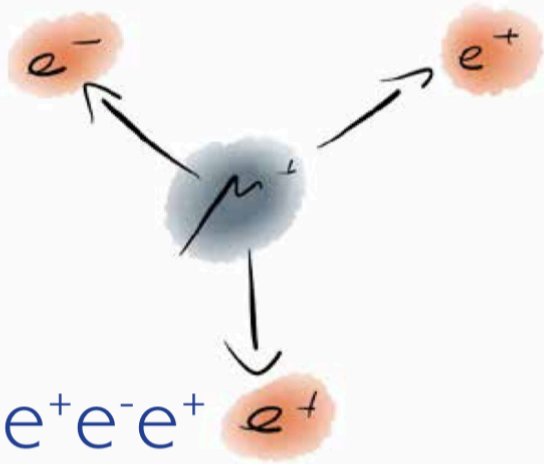
- 2-body decay
- Monoenergetic e^+, γ
- Back-to-back



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

Kinematics

- Quasi 2-body decay
- Monoenergetic e^-
- Single particle detected

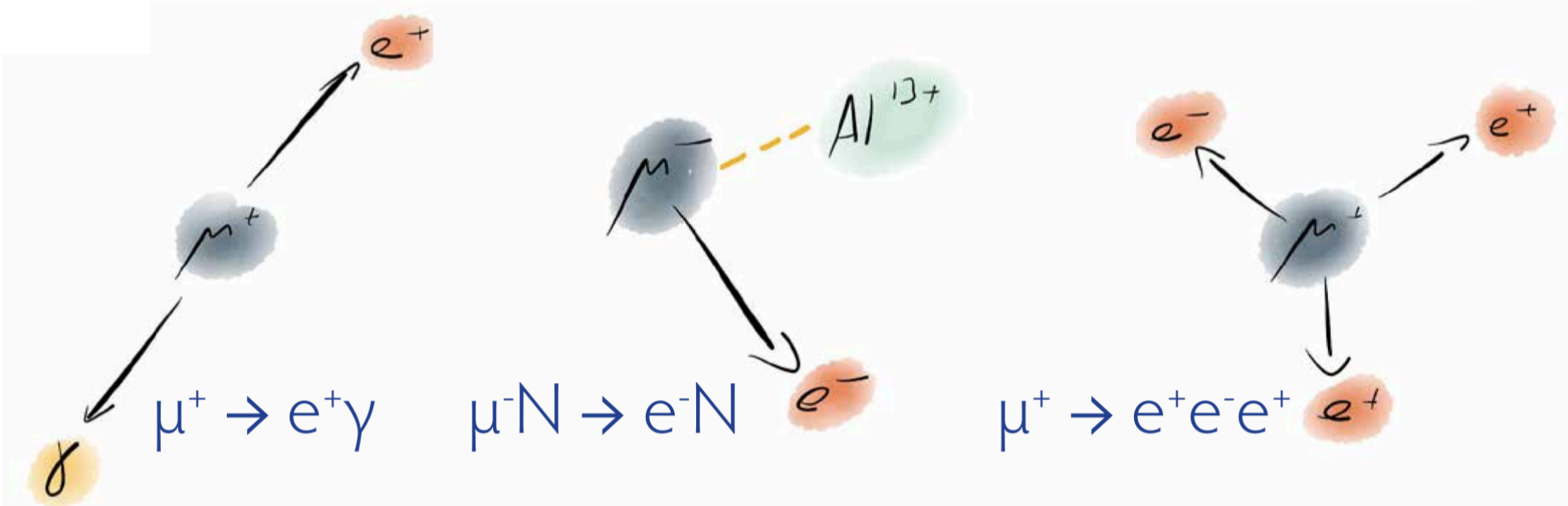


$\mu^+ \rightarrow e^+e^-e^+$

Kinematics

- 3-body decay
- Invariant mass constraint
- $\Sigma\, p_i = 0$

Muon cLFV: background



Kinematics
- 2-body decay
- Monoenergetic e^+, γ
- Back-to-back

Background
- Accidental background

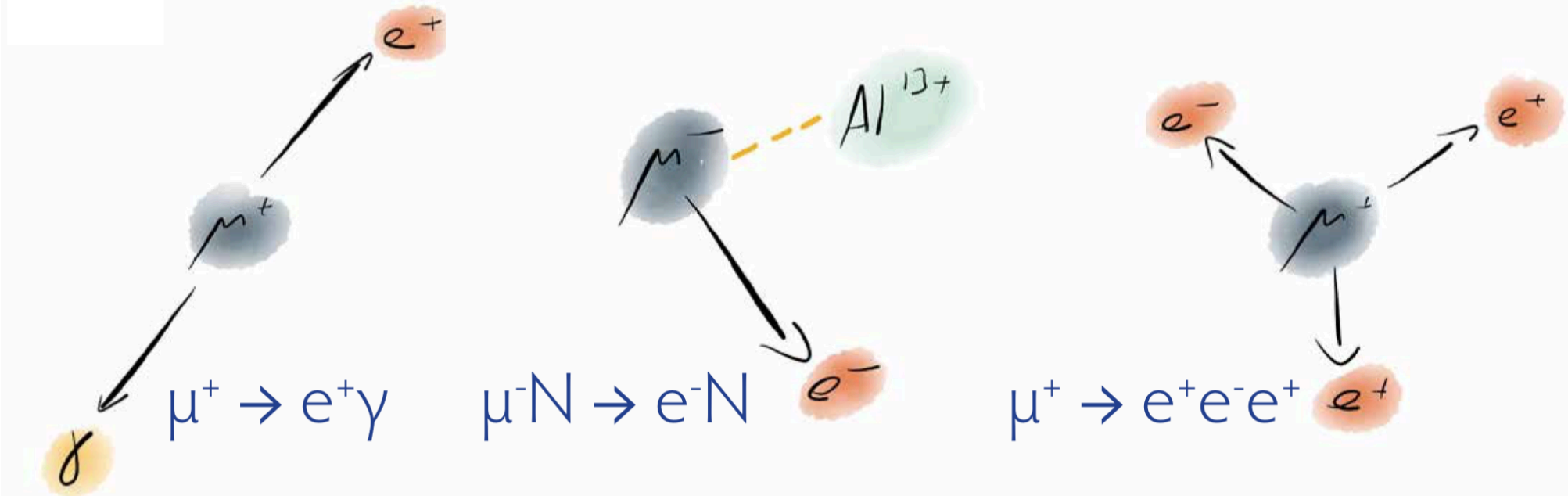
Kinematics
- Quasi 2-body decay
- Monoenergetic e^-
- Single particle detected

Background
- Decay in orbit
- Antiprotons, pions

Kinematics
- 3-body decay
- Invariant mass constraint
- $\Sigma p_i = 0$

Background
- Radiative decay
- Accidental background

Muon cLFV: beam line



Kinematics
- 2-body decay
- Monoenerge
- Back-to-b

Backgro
- A al background

Continuous Beam

Kinematics
- Quasi 2-body d
- Monoenerge
- Single p etected

Backgro
- D orbit
- An protons, pions

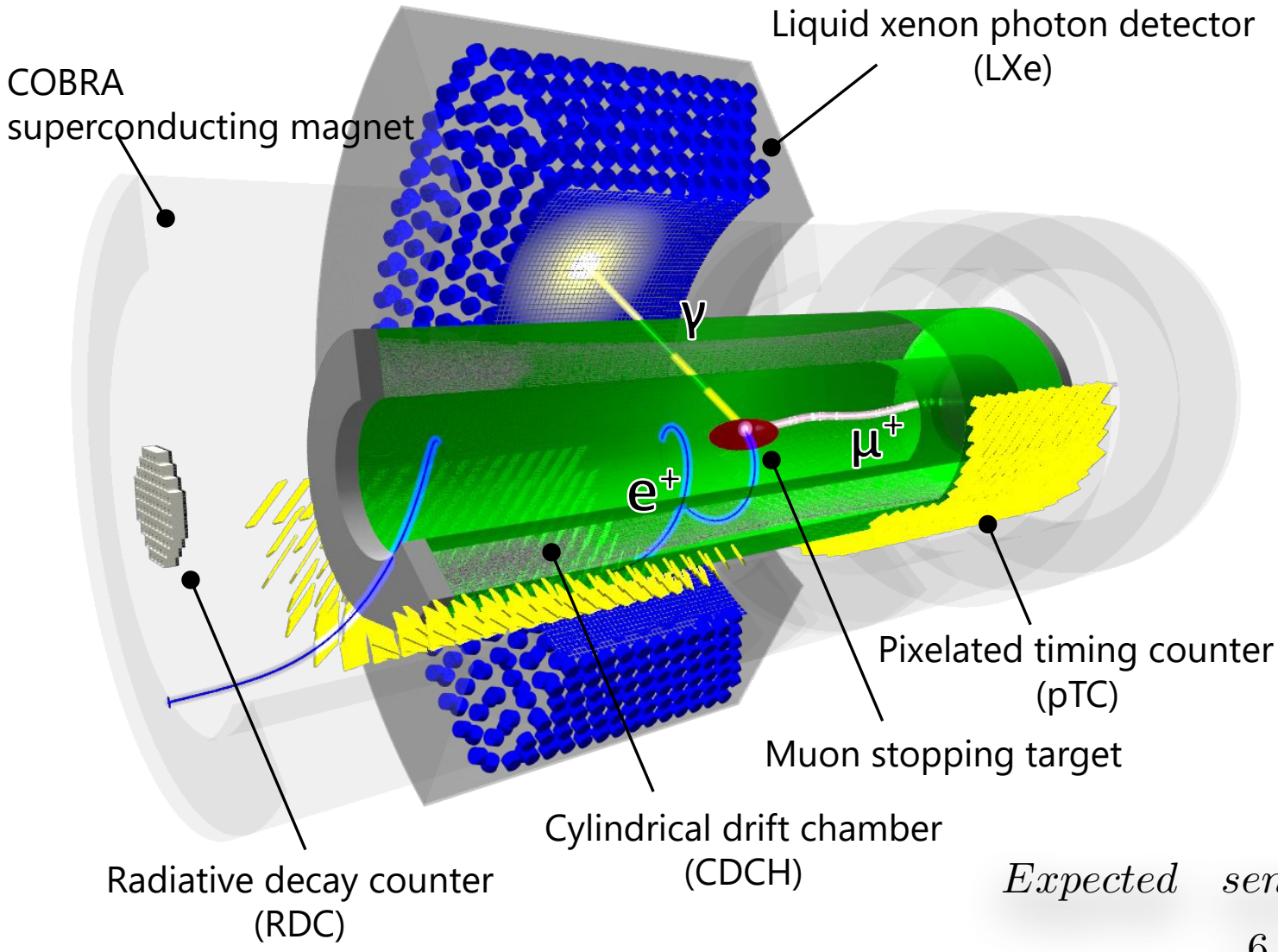
Pulsed Beam

Kinematics
- 3-body decay
- Invariant mas aint
- $\Sigma p_i = 0$

Backgro
- R decay
- Ac dental background

Continuous Beam

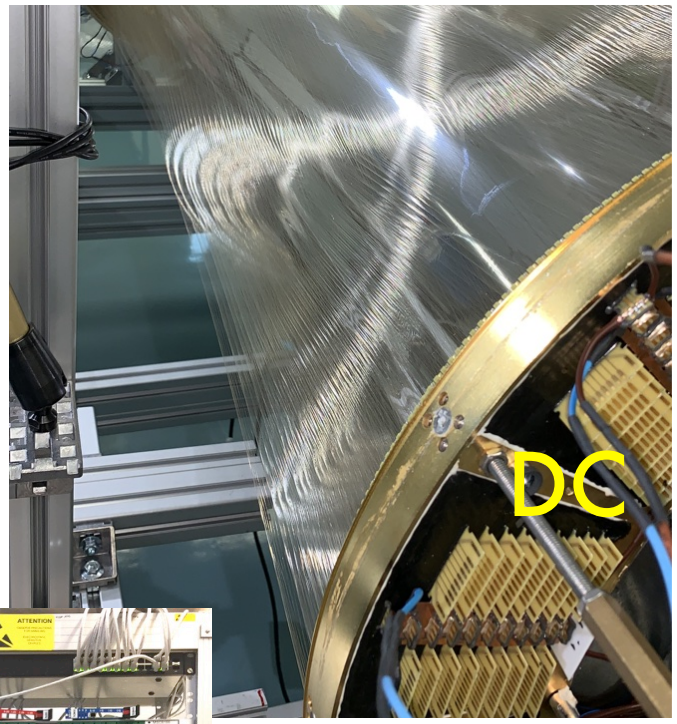
MEG II@PSI

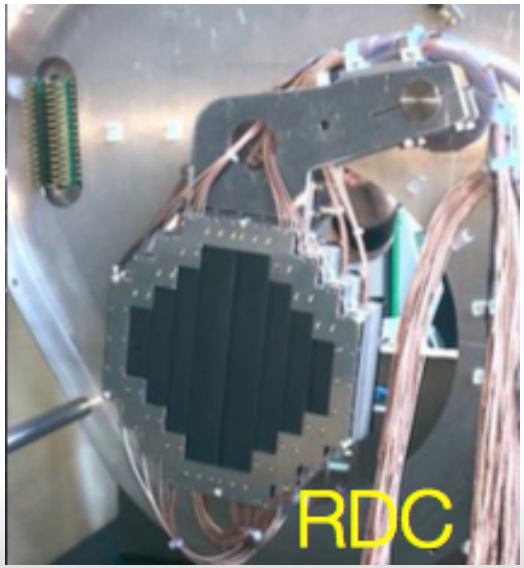


$$Expected \quad sensitivity$$

$$6 \times 10^{-14}$$

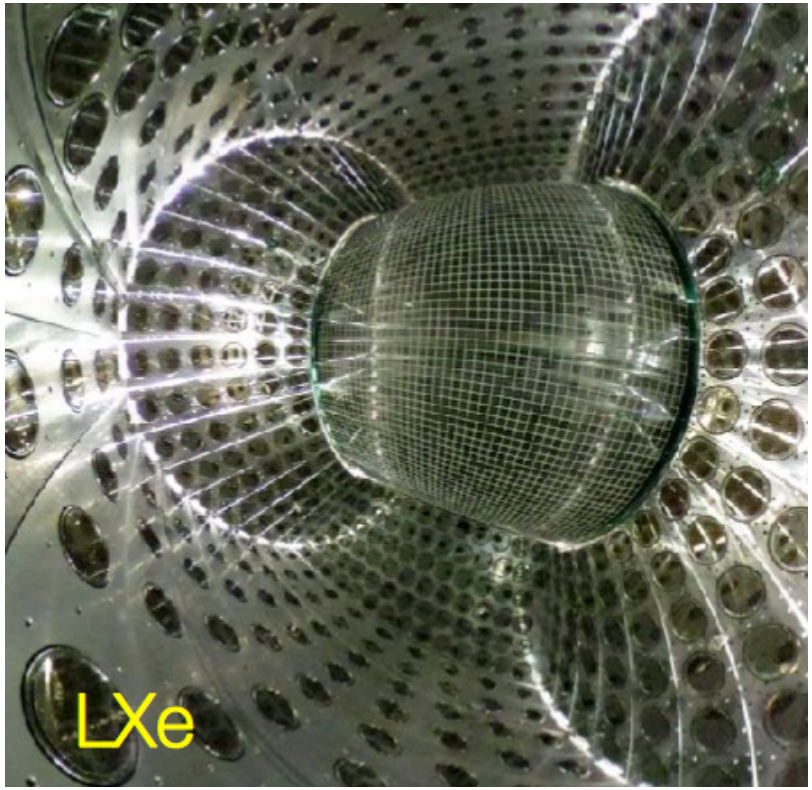
Construction status

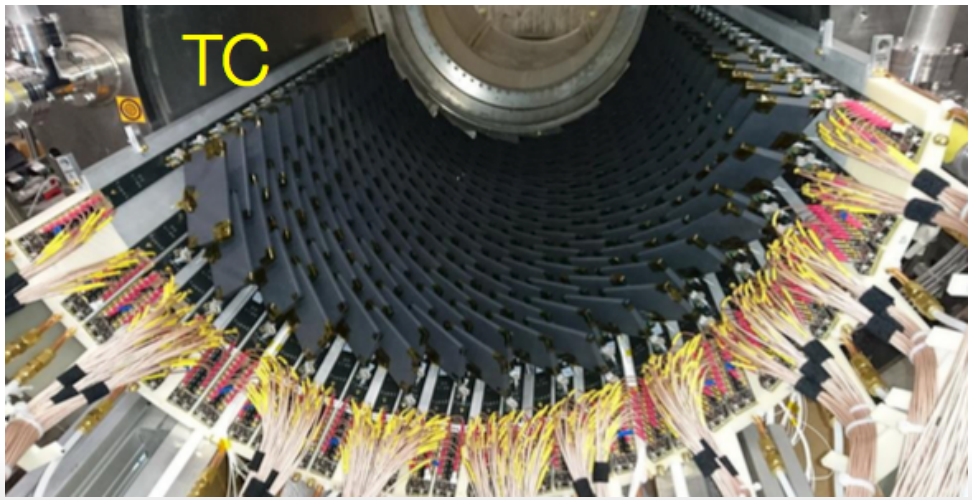




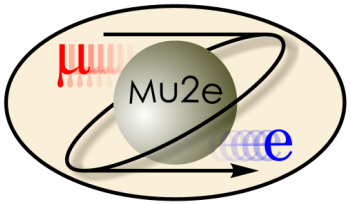
R&D
Commissioning
DAQ
MEG II

2012
2017
2022





Mu2e @FNAL



INFN
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R&D
Commissioning
DAQ

2017

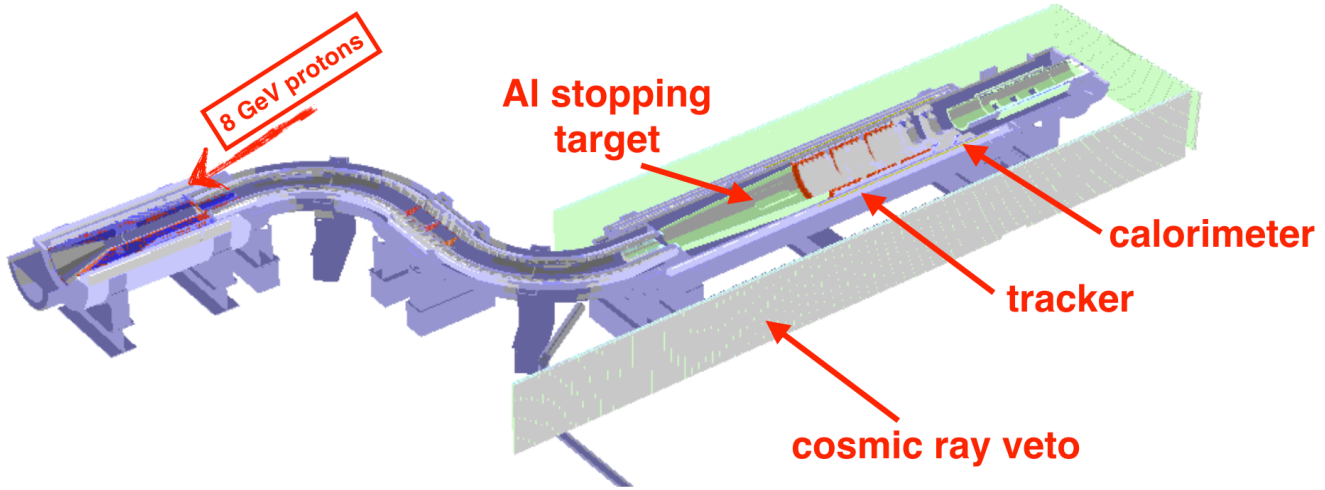
2020

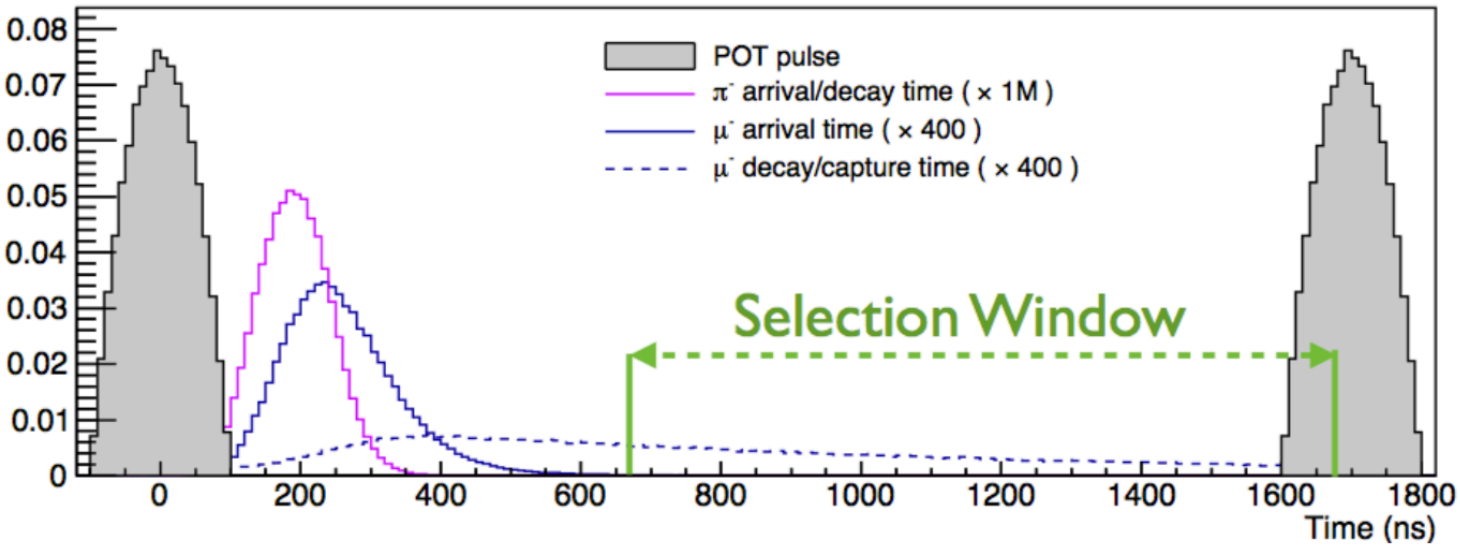
2023

Mu2e

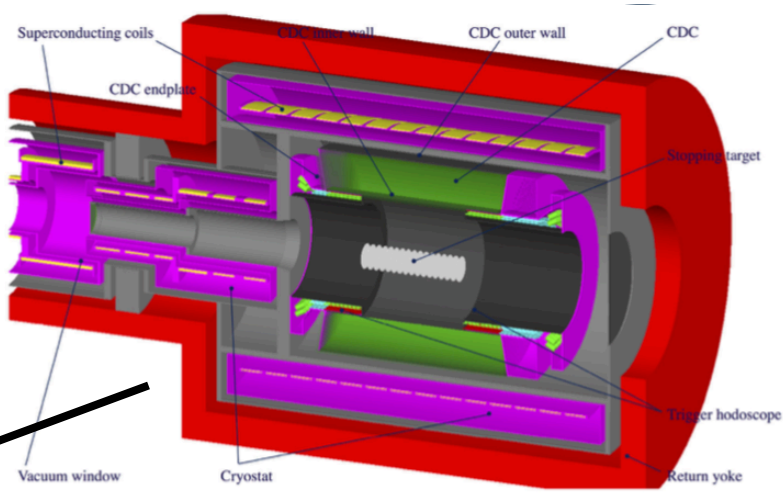
$Expected \quad sensitivity$

$\approx 3 \times 10^{-17}$





COMET @J-PARC



R&D

2016

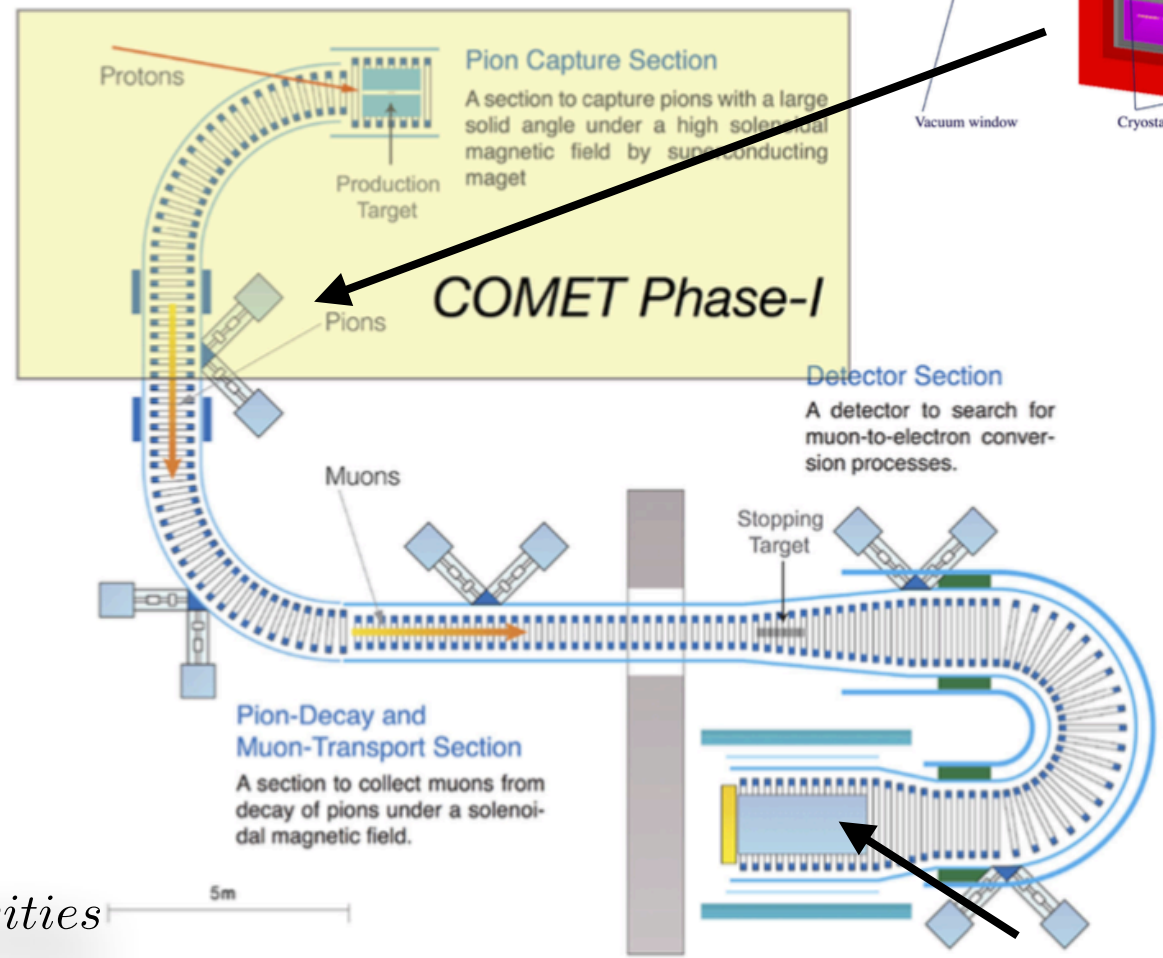
Phase-I

2019

Phase-II

2022

COMET



Straw tube tracker

$$Expected \quad sensitivities$$

$$Phase-I \quad 7 \times 10^{-15}$$

$$Phase-II \quad 3 \times 10^{-17}$$

Mu3e @PSI

Istituto Nazionale di Fisica Nucleare

R&D

Commissioning

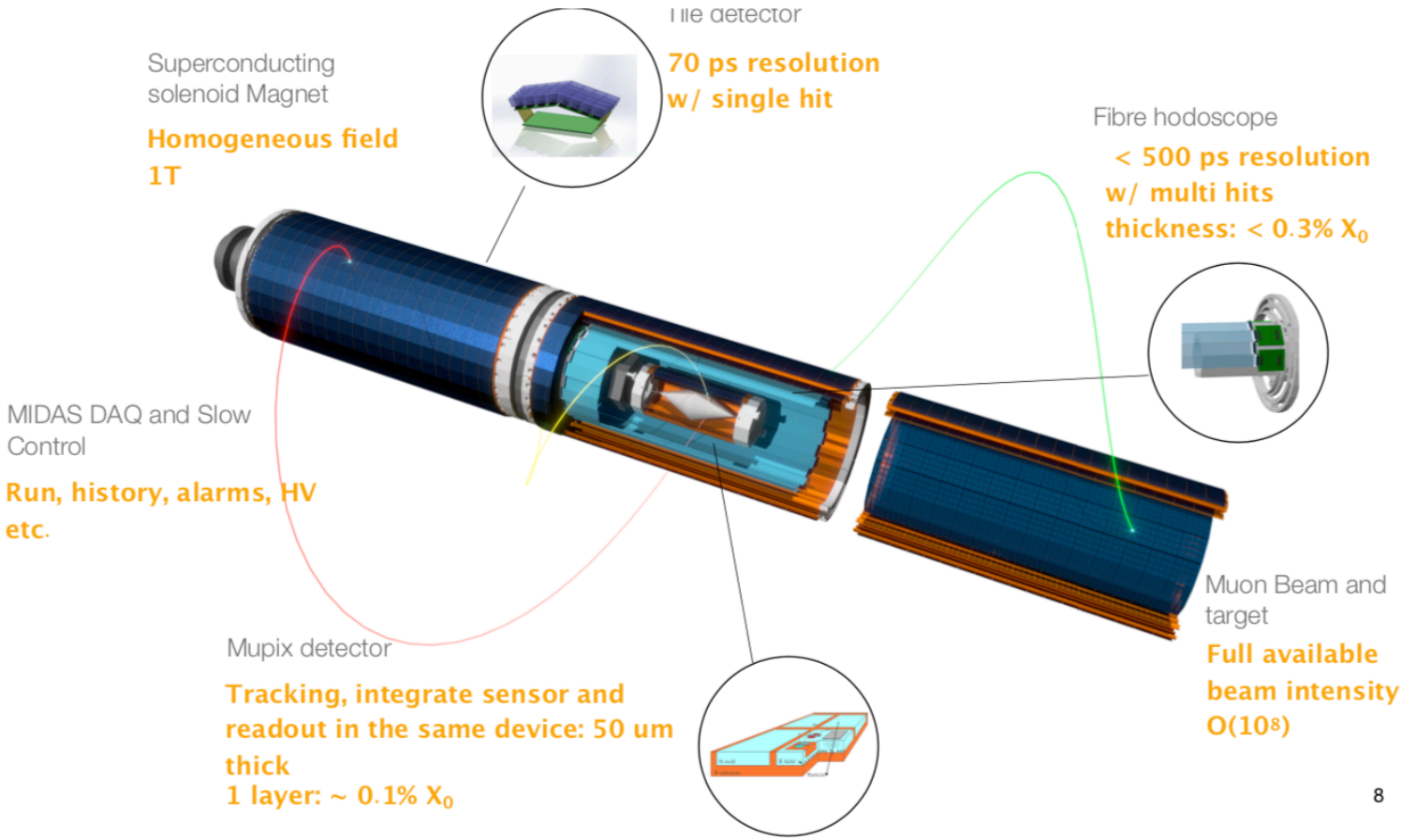
DAQ

2014

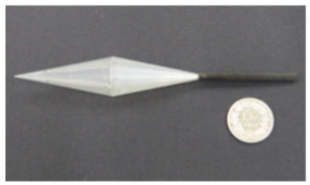
2020

2024

Mu3e



Target prototype



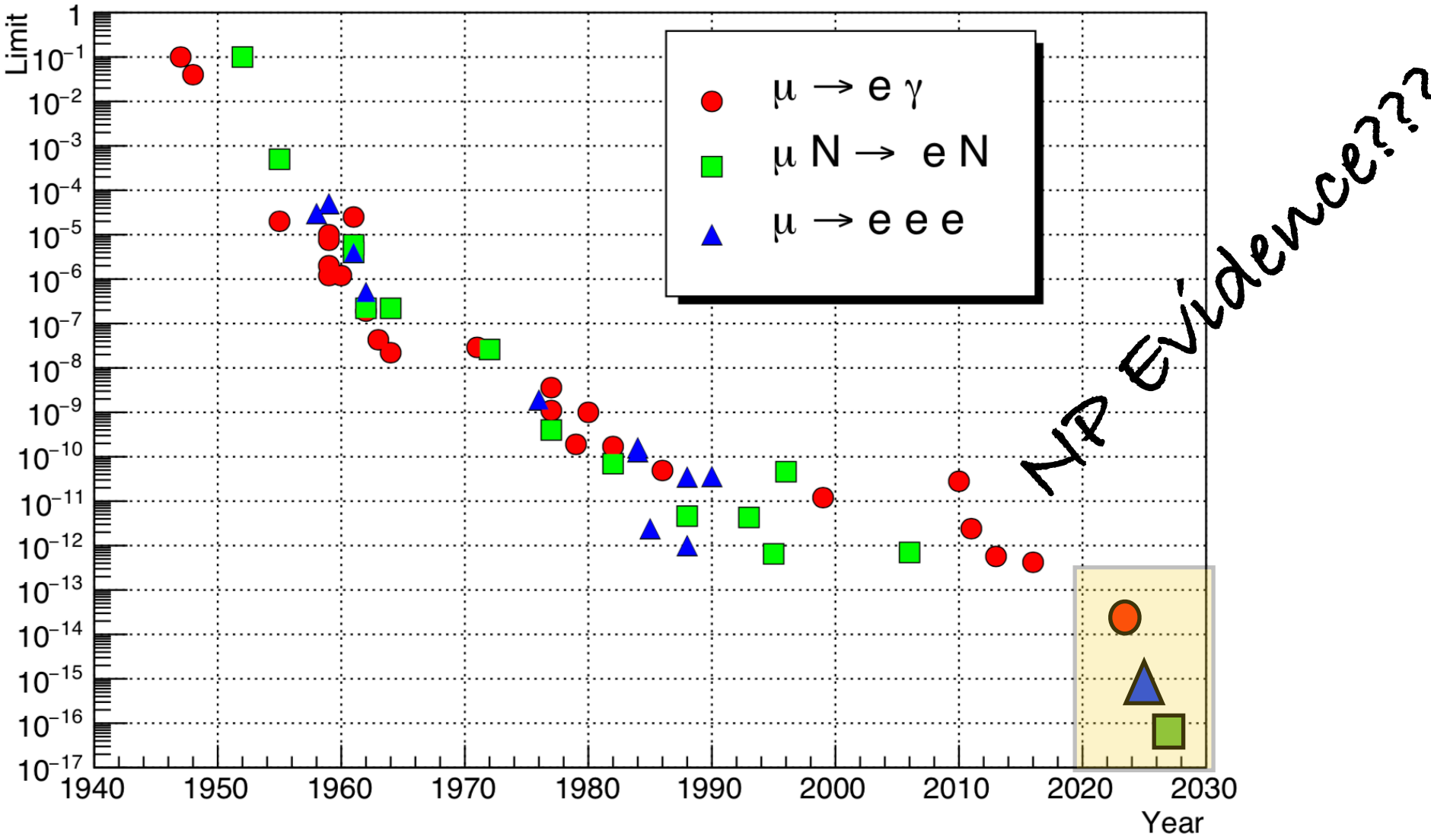
$$Expected \quad sensitivities$$

$$Phase - I \quad \approx 10^{-15}$$

$$Phaze - II \quad \approx 10^{-16}$$

$$\Delta t_{eee} = 0 \qquad \Sigma \overline{p}_e = 0 \qquad \Sigma E_e = m_\mu$$

cLFV in 10 years



Conclusions

- cLFV with muons features a unique opportunity to discover physics beyond the standard model
  - *muon sector is the most promising from:*
    - μ→eγ, μN→eN and μ→eee
      - *complementary searches: sensitive to different new physics dynamics*
- A full complementary experimental search ongoing
  - *R&D in very advanced phase*
  - *results in five years from now*