Extending the reach of Mu3e
with displaced vertices

Michele Tammaro

@ Val di Luce, 19/12/2024

S. Knapen, T. Opferkuch, D. Redigolo, MT: 2410.13941

Istituto Nazionale di Fisica Nucleare
SEZIONE DI FIRENZE

An experiment designed to measure the anomalous magnetic moment of the muon to a very high order of accuracy has completed a preliminary trial run at the CERN proton synchrotron. The run has already confirmed the results of an experiment, known as the 'g minus 2' experiment, carried out at CERN five years ago and more detailed measurements are now under way. This article describes the experiment and its relevance to the understanding of the most mysterious of all the sub-nuclear particles — the muon.

'Who ever ordered that ?'

From CERN Courier,
1966

We can produce a lot of μ

μ is a very narrow state

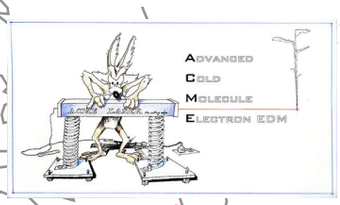
Non-universal couplings $\rightarrow$ complimentary to probes of electron coupling

Near Future

Far Future

2014 - 202X

2025



2021 - 2026

2040?

2025

2040?

2035?

2023

???

2026 - 2029

???

Today

2022 - …

International
MUON Collider
Collaboration

Petcov, 1976

$$\mathcal{B}_{\rm SM}(\mu \to eee) < 10^{-54}$$

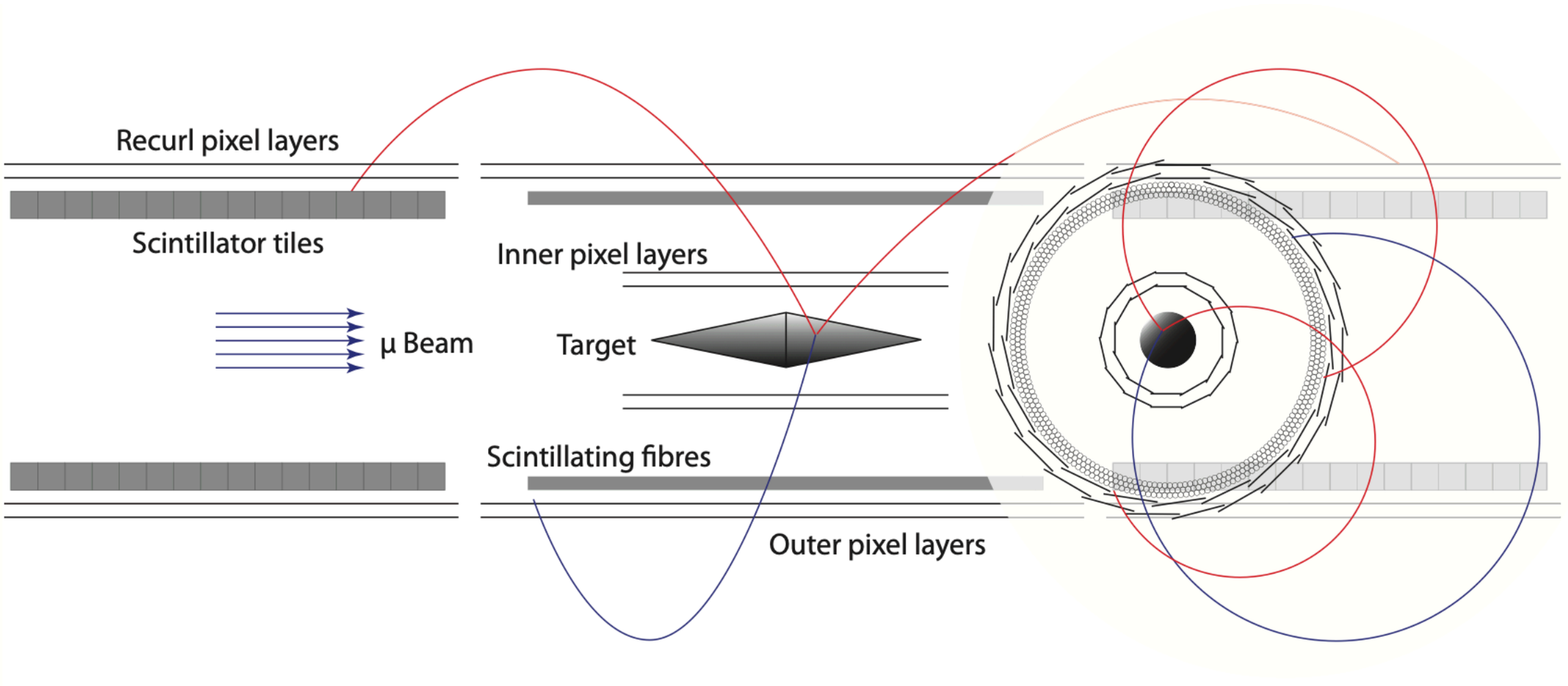
Mu3e TDR: 2009.11690

$$N_\mu = 2.5 \times 10^{15} - 5 \times 10^{16}$$

Phase-I Phase-II

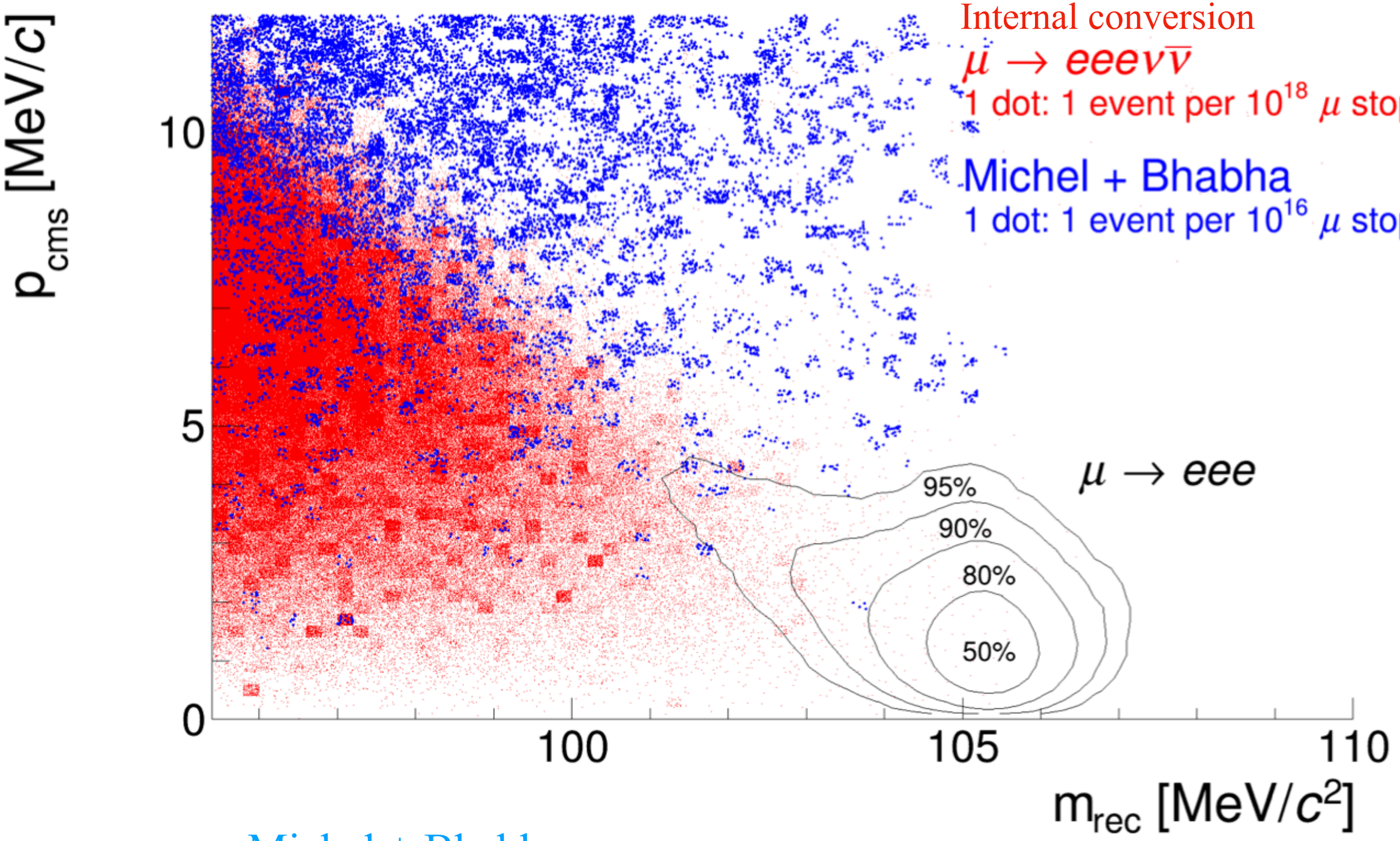
$$P_\mu \sim -1$$

D. Redigolo, MT, A. Tesi: 2408.00847



Mu3e Phase I Simulation

Perrevoort: 1812.00741



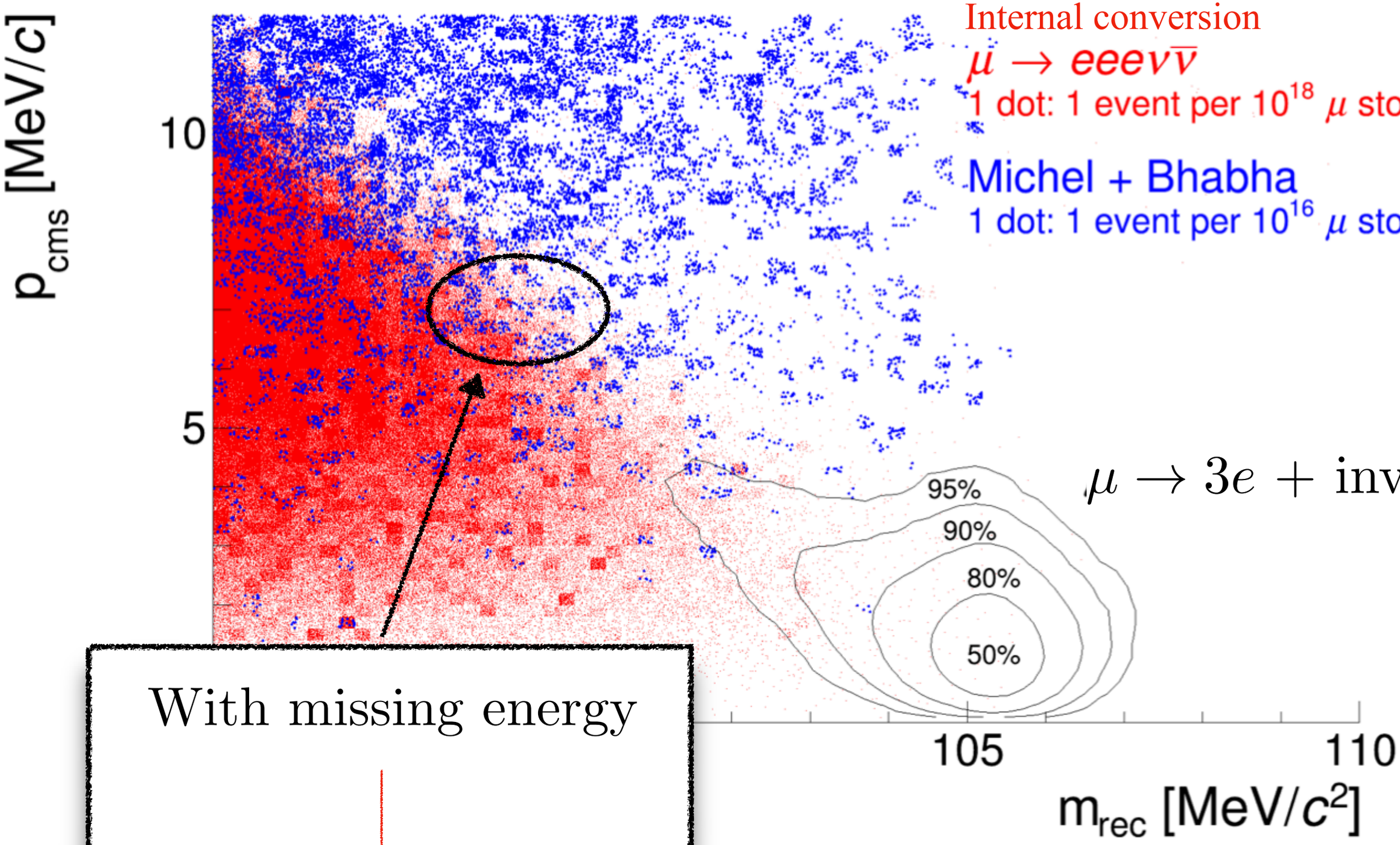
Michel + Bhabha

$$\mu^+ \to e^+\nu\bar{\nu}$$

$$e^+e^- \to e^+e^-$$

Mu3e Phase I Simulation

Perrevoort: 1812.00741

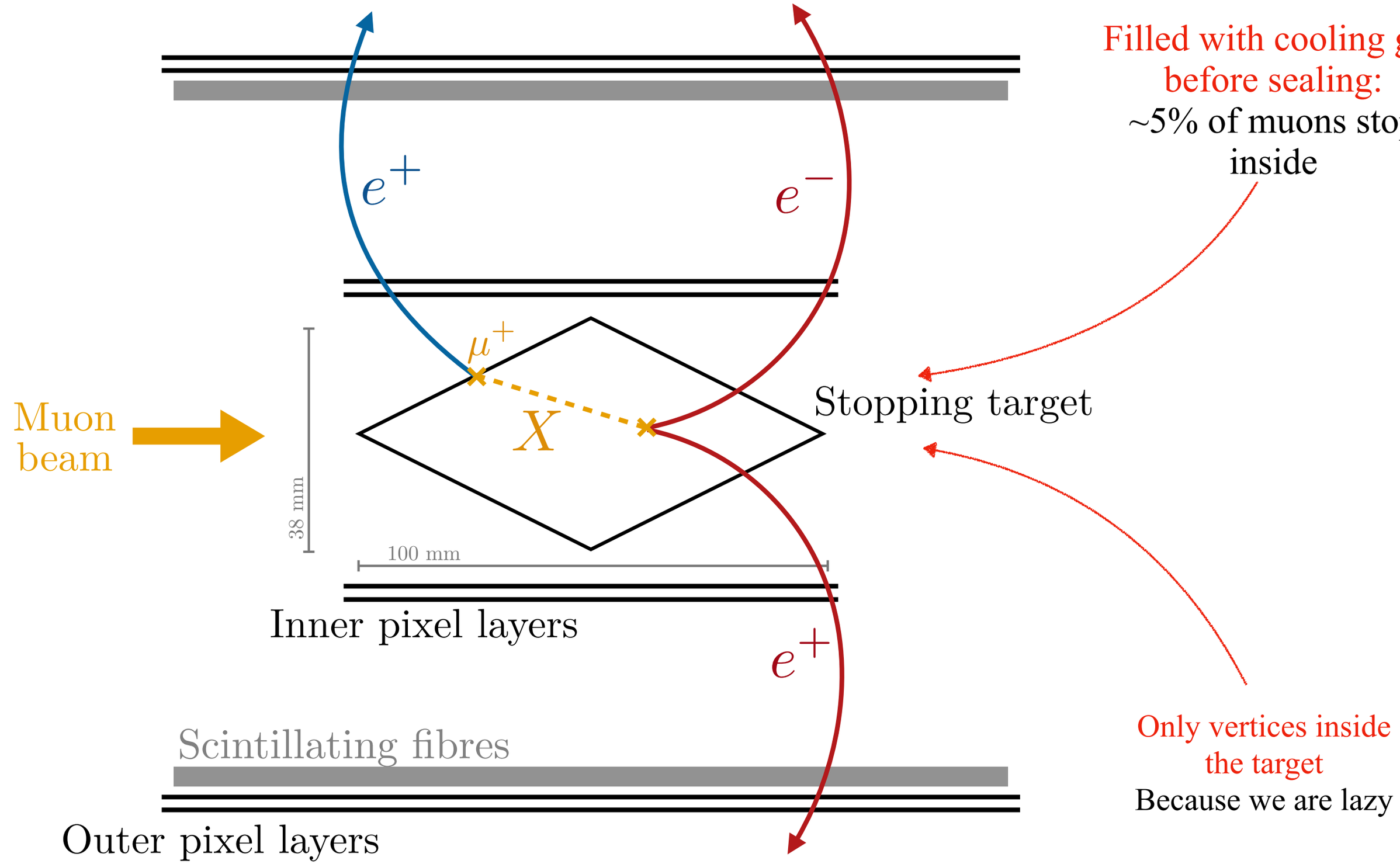


With missing energy

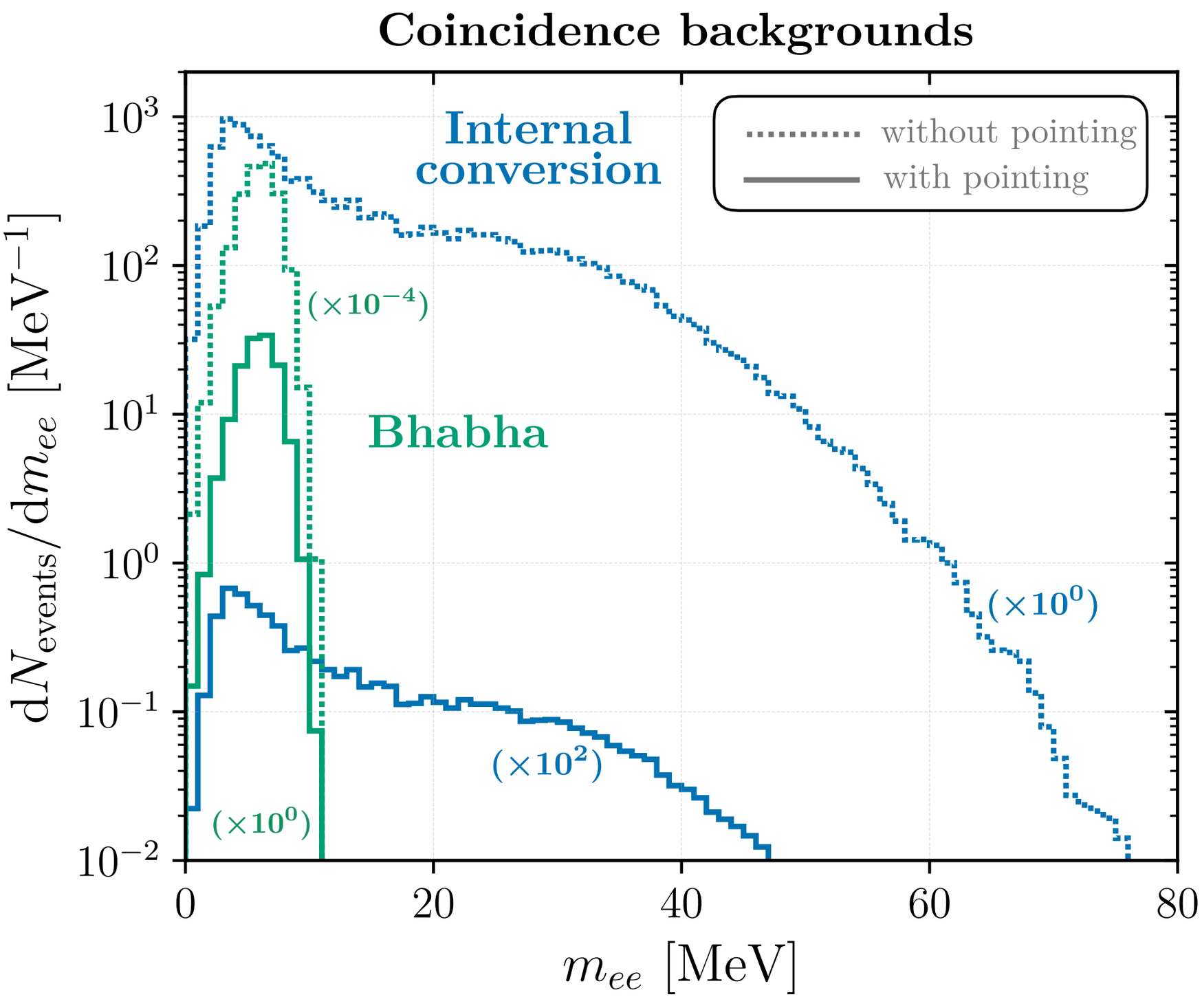
↓

Reduce bkg with displaced vertices

Displaced vertices



Backgrounds



No “neutrinos”

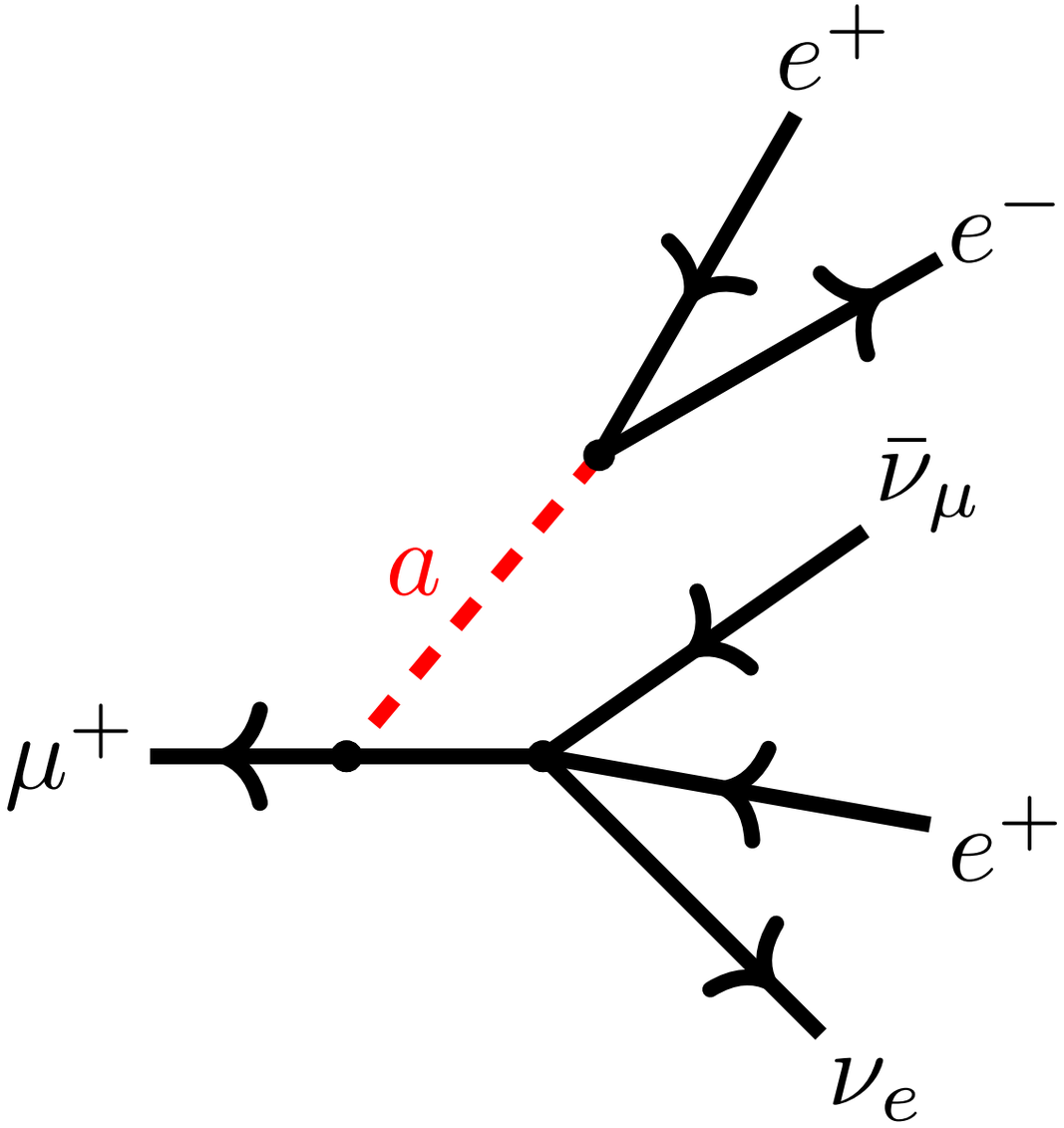
$$p^{\mu}_{\not{E}} = 0$$

Whit “neutrinos”

$$p^{2}_{\not{E}} > 0$$

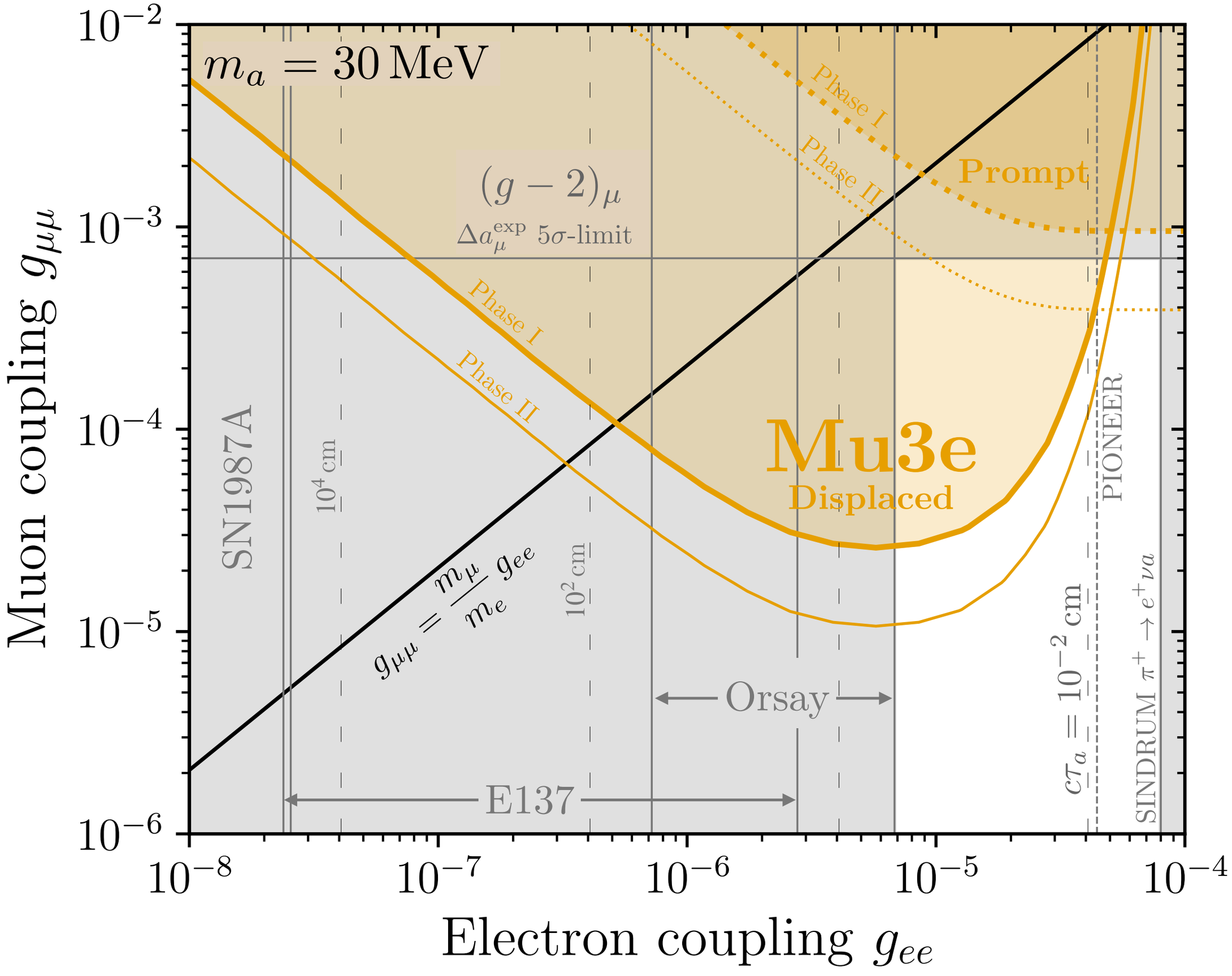
LFC ALP

$$\mathcal{L}_a = g_{\mu\mu} a \bar{\mu} \gamma_5 \mu + g_{ee} a \bar{e} \gamma_5 e$$



Pointing

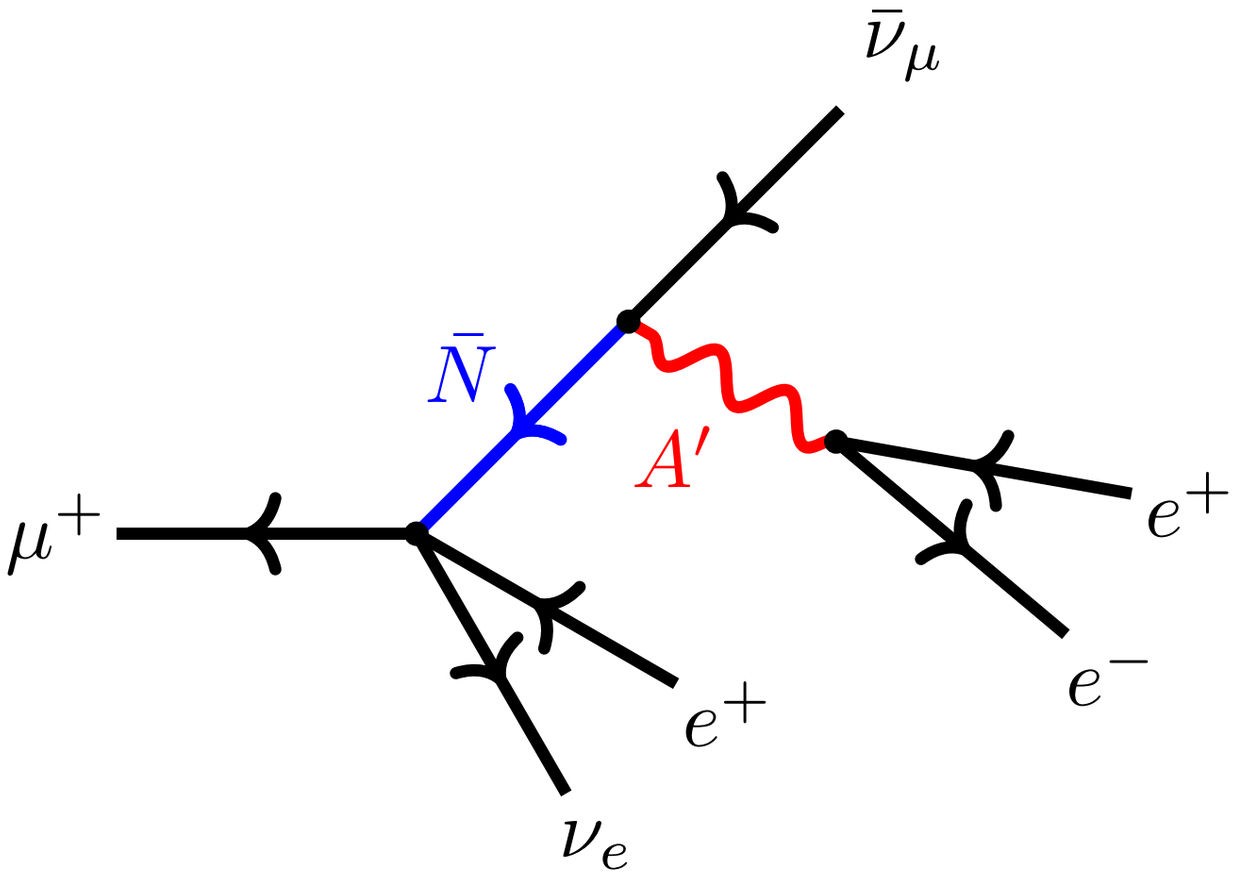
Mass reconstruction


$m_a = 30\,\mathrm{MeV}$
$(g-2)_\mu$
$\Delta a_\mu^{\mathrm{exp}}$ 5σ-limit
Phase I
Phase II
Prompt
Phase I
Phase II
Mu3e
Displaced
SN1987A
$10^4\,\mathrm{cm}$
$10^2\,\mathrm{cm}$
$g_{\mu\mu} = \frac{m_\mu}{m_e} g_{ee}$
Orsay
E137
PIONEER
$c\tau_a = 10^{-2}\,\mathrm{cm}$
SINDRUM $\pi^+ \to e^+ \nu a$
Muon coupling $g_{\mu\mu}$
Electron coupling g_{ee}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}

HNL + Dark Photon

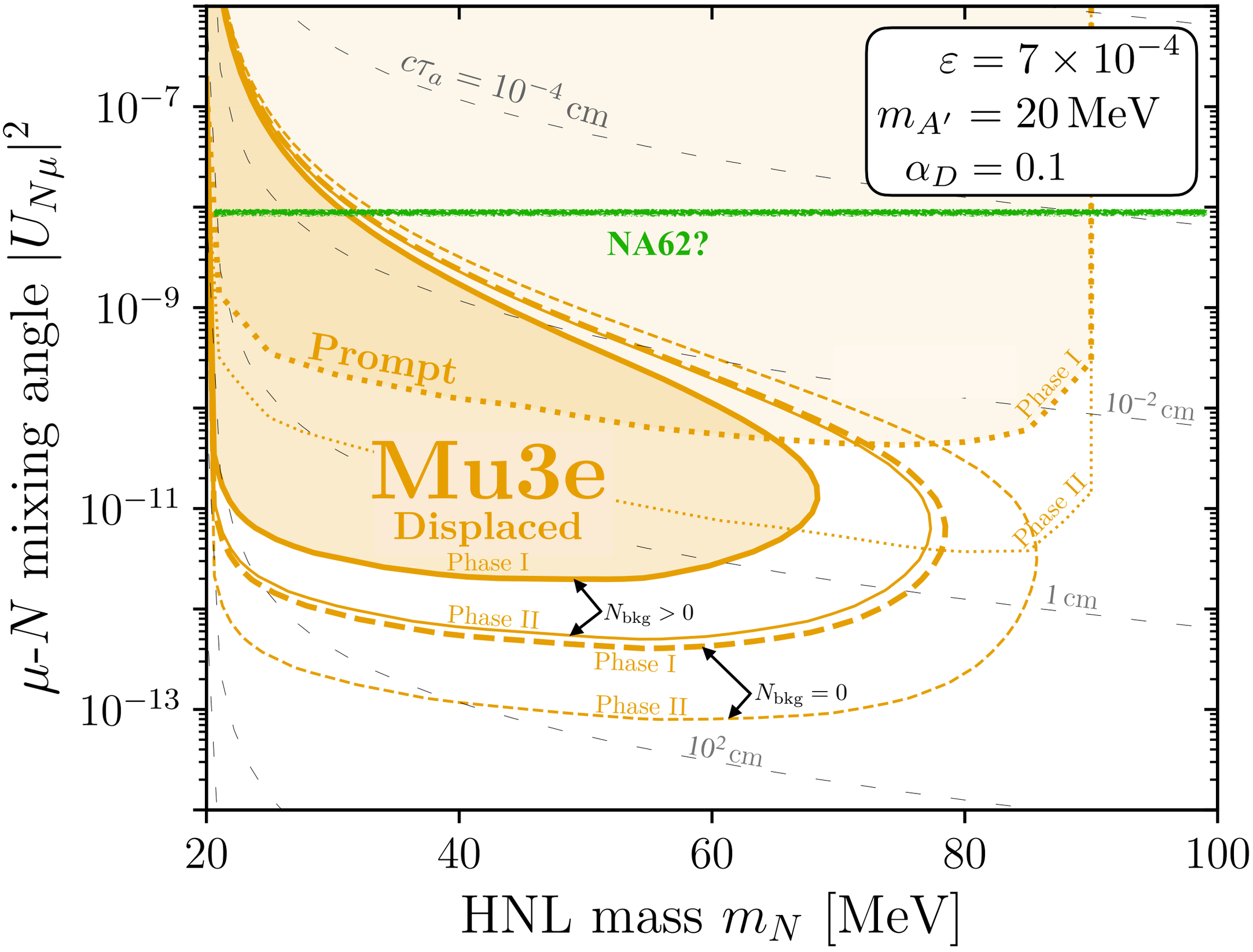
Ballett, Hostert, Pascoli: 1903.07589

$$2m_e < m_{A'} < m_N < m_\mu$$



Pointing

Mass reconstruction


$\varepsilon = 7 \times 10^{-4}$
$m_{A'} = 20\,\mathrm{MeV}$
$\alpha_D = 0.1$
$c\tau_a = 10^{-4}\,\mathrm{cm}$
NA62?
Prompt
Mu3e
Displaced
Phase I
Phase II
$N_{\mathrm{bkg}} > 0$
Phase I
Phase II
$N_{\mathrm{bkg}} = 0$
Phase I
Phase II
$10^{-2}\,\mathrm{cm}$
$1\,\mathrm{cm}$
$10^{2}\,\mathrm{cm}$
10^{-7}
10^{-9}
10^{-11}
10^{-13}
μ-N mixing angle $|U_{N\mu}|^2$
20
40
60
80
100
HNL mass m_N [MeV]

Summary

- Mu3e can search for displaced vertices

- We suggest using reco mass and pointing to cut bkg

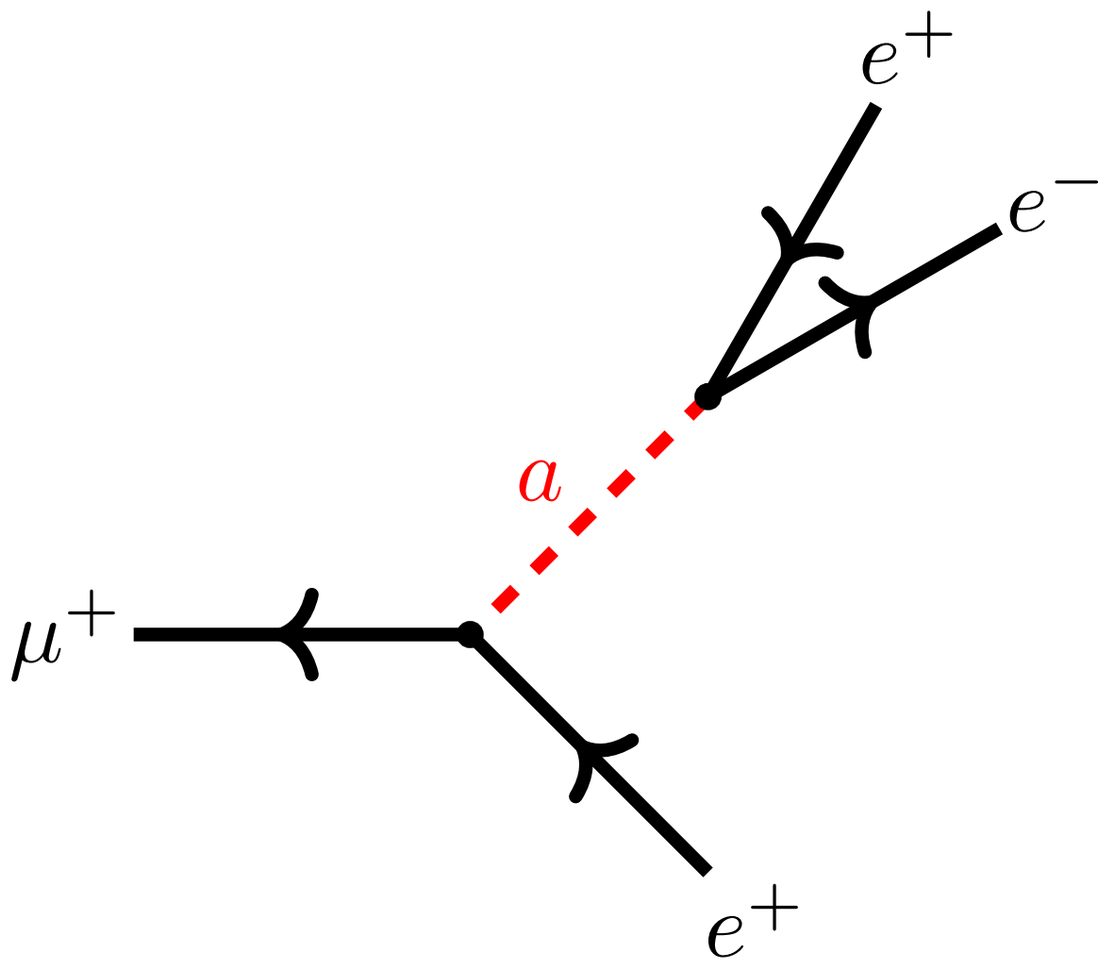
- Reach greatly improves in models with invisible states

- Multilepton signatures at K and B factories?

Backup slides

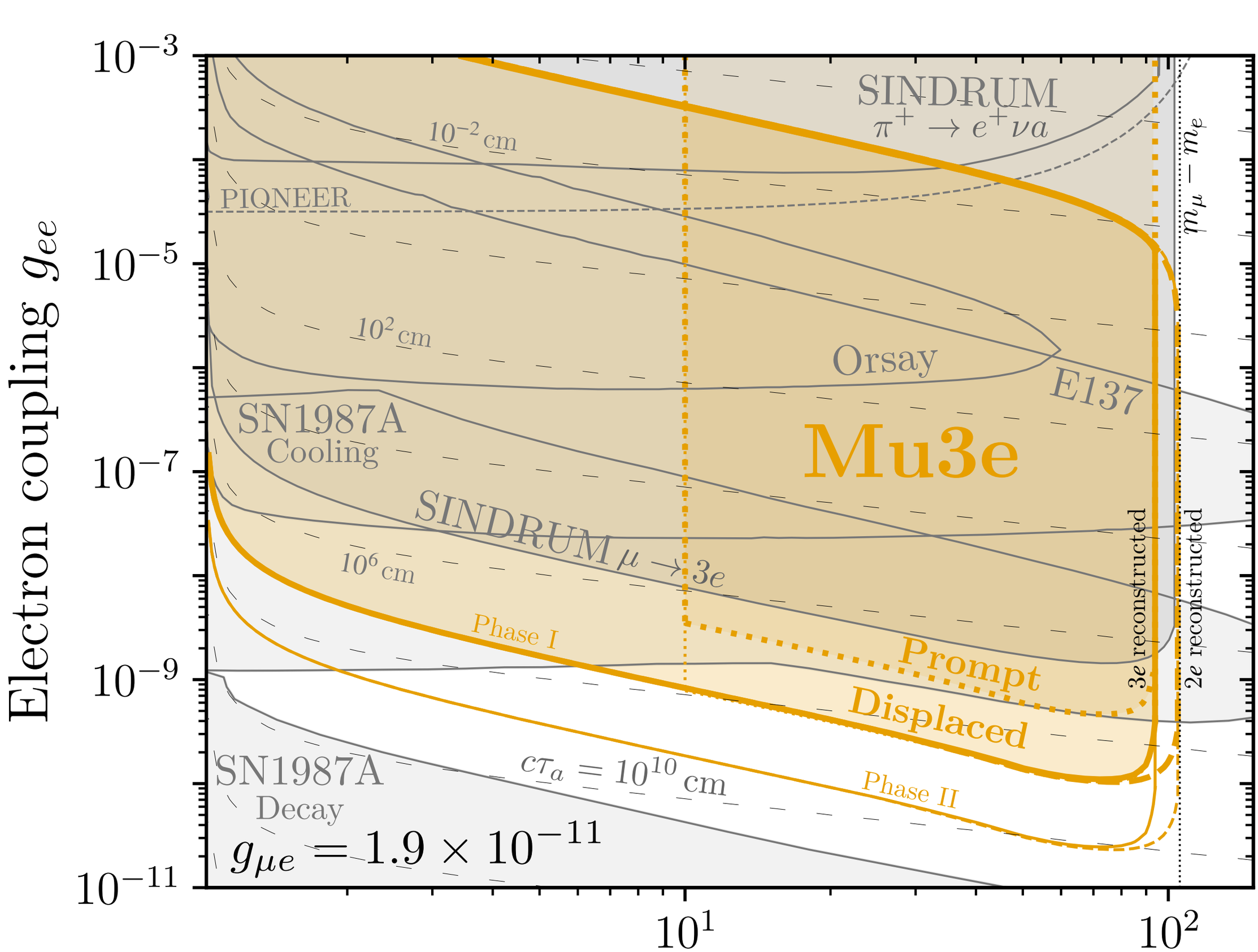
LFV ALP

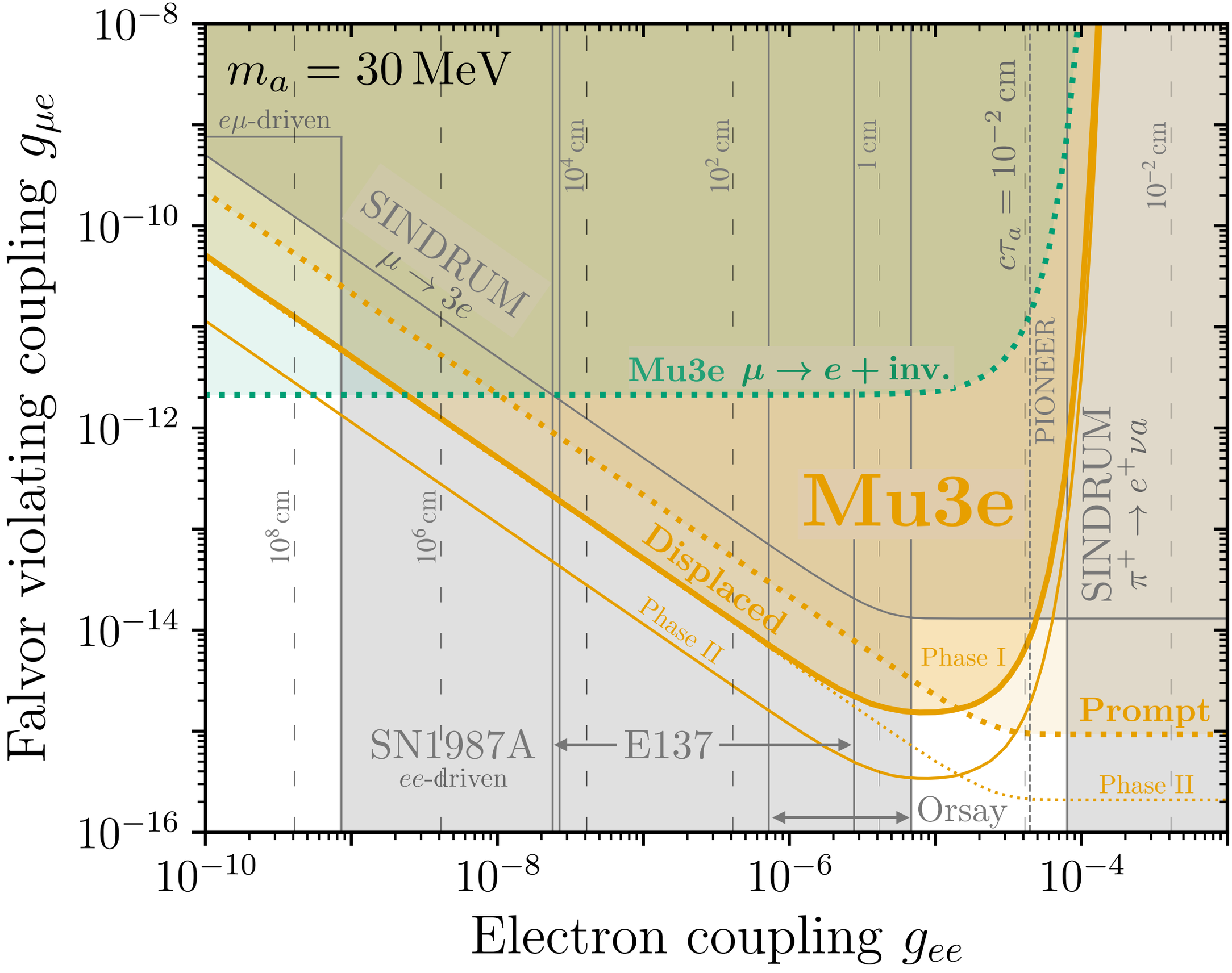
$$\mathcal{L}_a = g_{ee} a \bar{e} \gamma_5 e + g_{\mu e} a \bar{\mu} \gamma_5 e$$



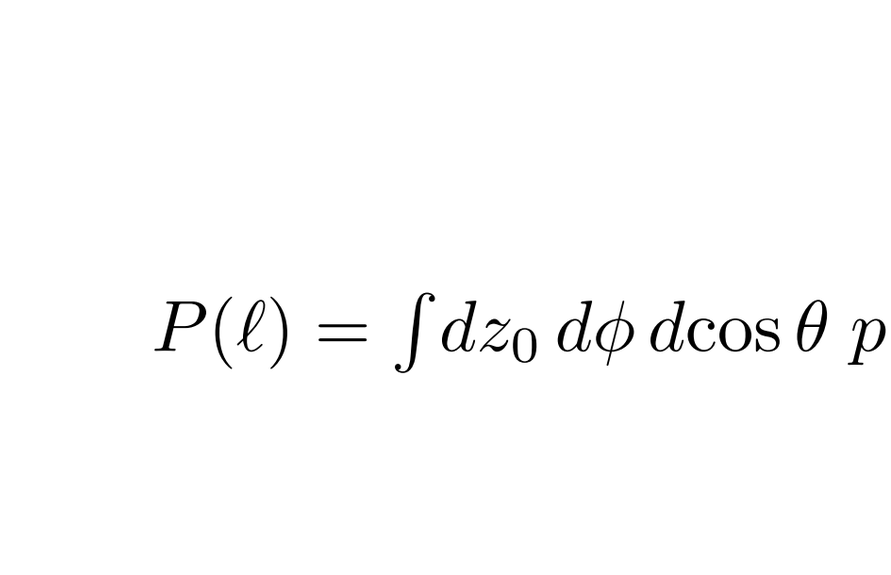
✓ Pointing

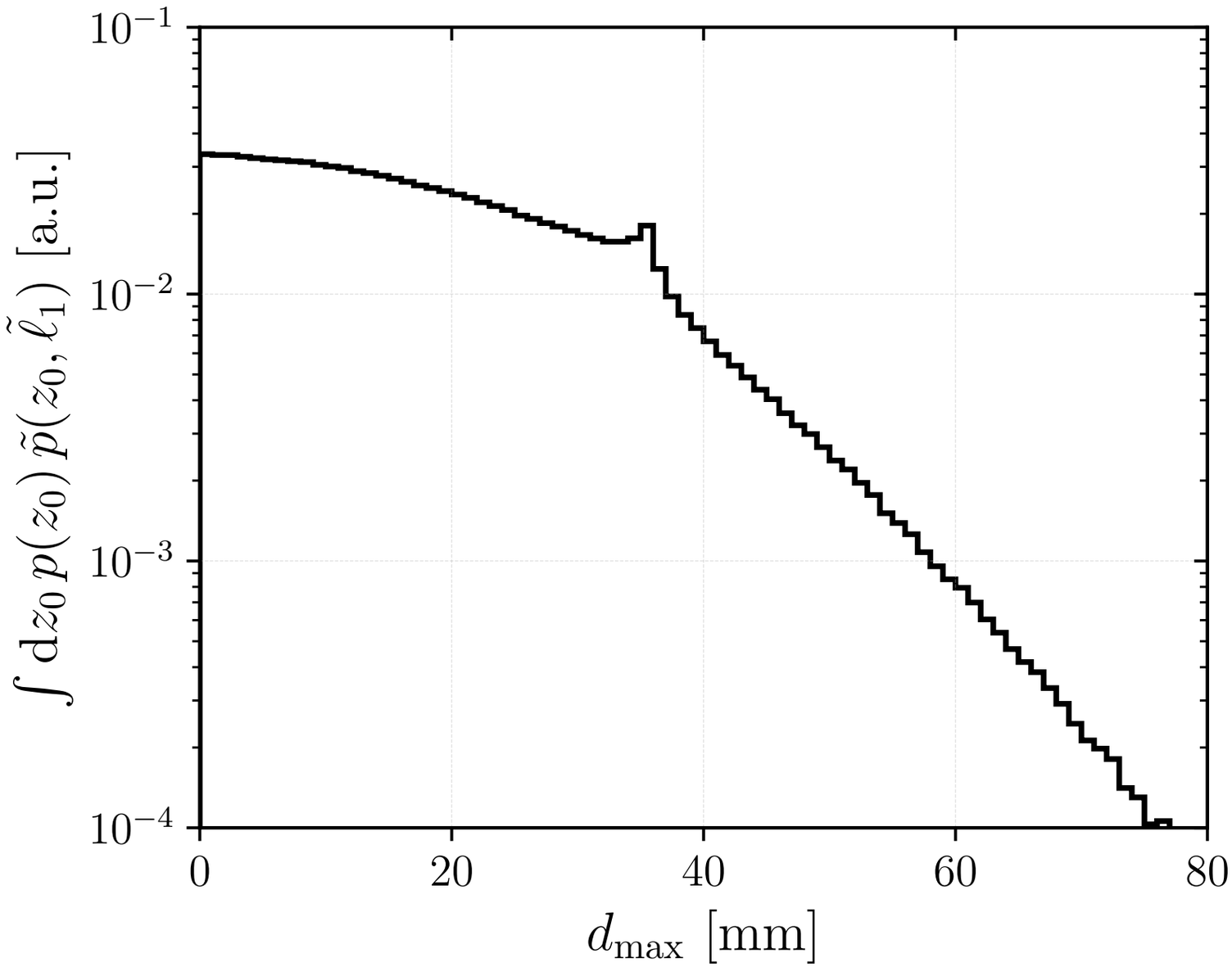
✓ Mass reconstruction


SINDRUM
$\pi^+ \to e^+ \nu a$
10^{-2} cm
PIONEER
10^2 cm
Orsay
E137
SN1987A
Cooling
Mu3e
SINDRUM $\mu \to 3e$
10^6 cm
Phase I
Prompt
Displaced
$m_\mu - m_e$
3e reconstructed
2e reconstructed
SN1987A
Decay
$c\tau_a = 10^{10}$ cm
Phase II
$g_{\mu e} = 1.9 \times 10^{-11}$
Electron coupling g_{ee}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
10^1
10^2
ALP mass m_a [MeV]

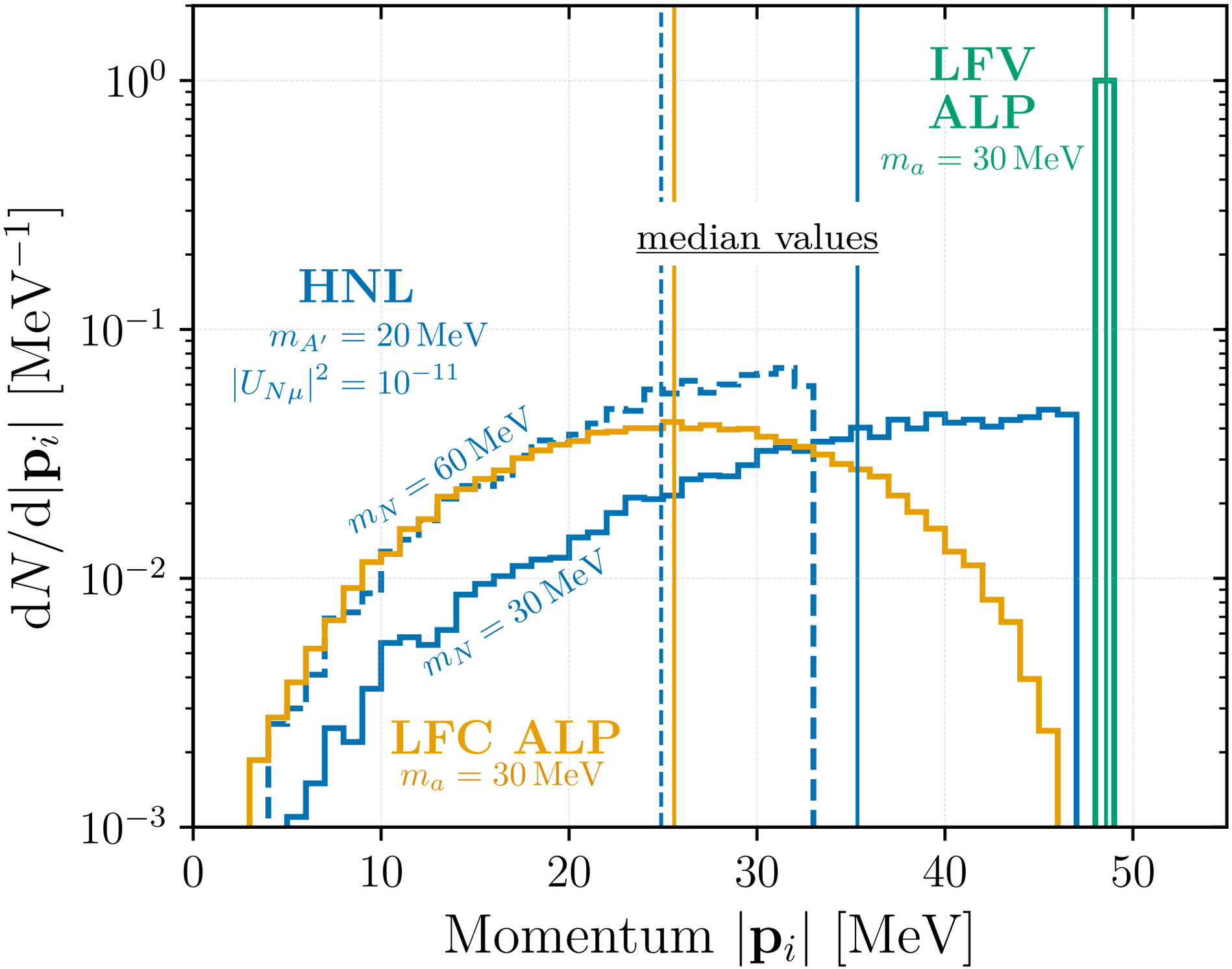

$m_a = 30\,\mathrm{MeV}$
$e\mu$-driven
SINDRUM
$\mu \to 3e$
$10^4\,\mathrm{cm}$
$10^2\,\mathrm{cm}$
$1\,\mathrm{cm}$
$c\tau_a = 10^{-2}\,\mathrm{cm}$
$10^{-2}\,\mathrm{cm}$
Mu3e $\mu \to e +$ inv.
PIONER
SINDRUM
$\pi^+ \to e^+ \nu a$
Mu3e
Displaced
Phase II
Phase I
Prompt
Phase II
$10^8\,\mathrm{cm}$
$10^6\,\mathrm{cm}$
SN1987A
ee-driven
E137
Orsay
Falvor violating coupling $g_{\mu e}$
Electron coupling g_{ee}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

$$P(\ell) = \int dz_0\, d\phi\, d\cos\theta\; p(z_0) \times A(z_0, \phi, \cos\theta) \times \left[e^{-\ell_0/\ell} - e^{-\ell_1(z_0,\phi,\cos\theta)/\ell}\right]$$

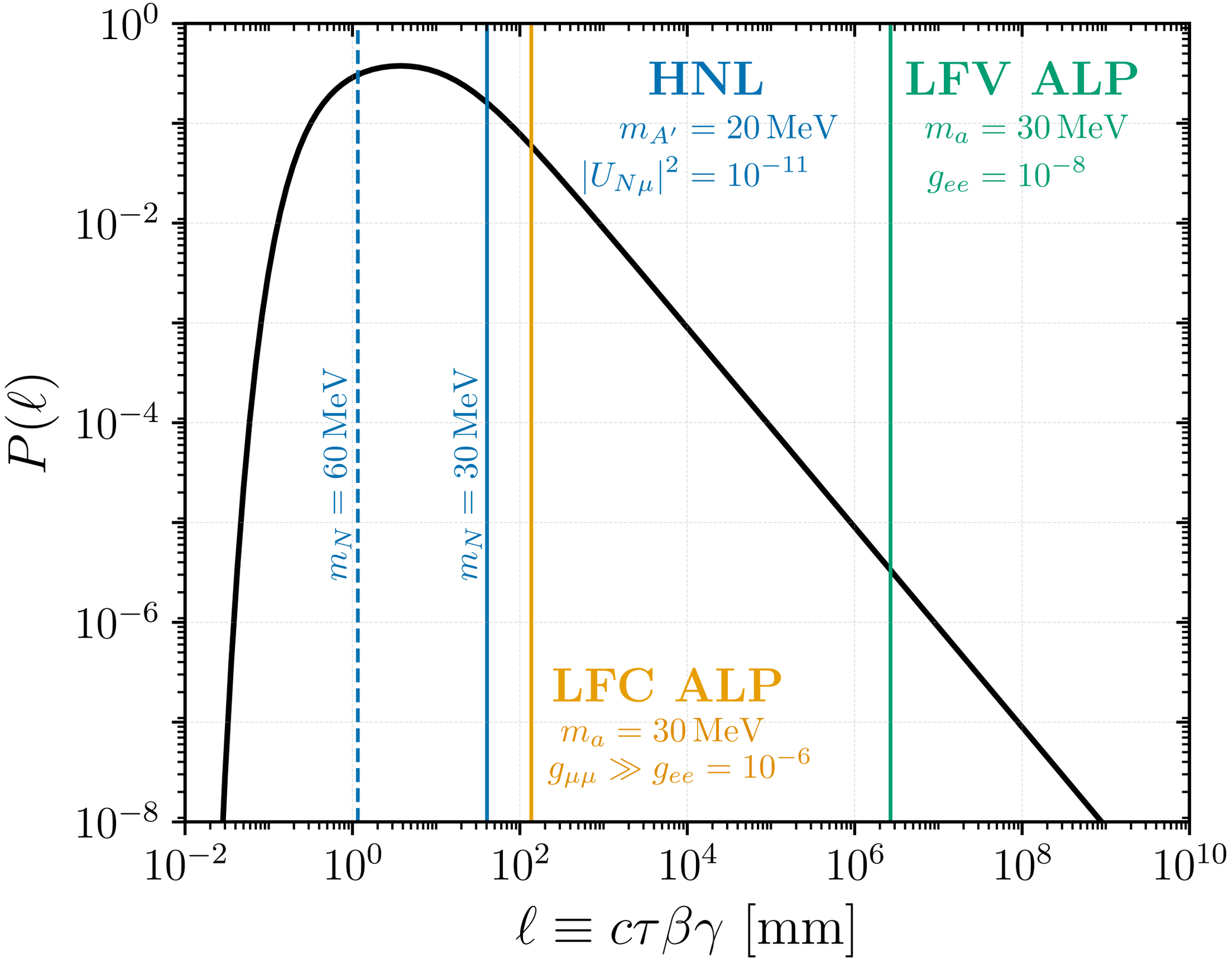




Momentum distributions



Momentum distributions



Efficiencies