Extending the reach of Mu3e
with displaced vertices

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

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SEZIONE DI FIRENZE

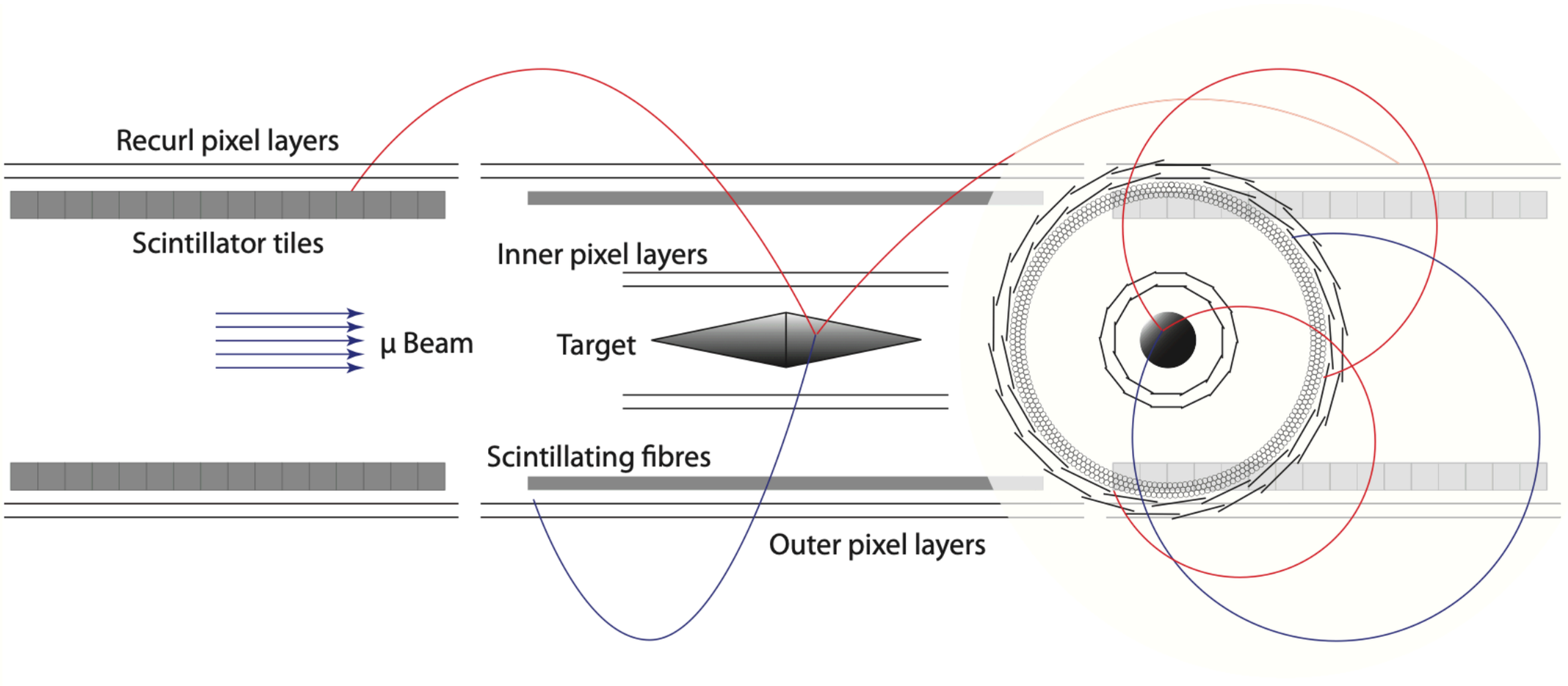
Petcov, 1976

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

Mu3e TDR: 2009.11690

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

Phase-I Phase-II

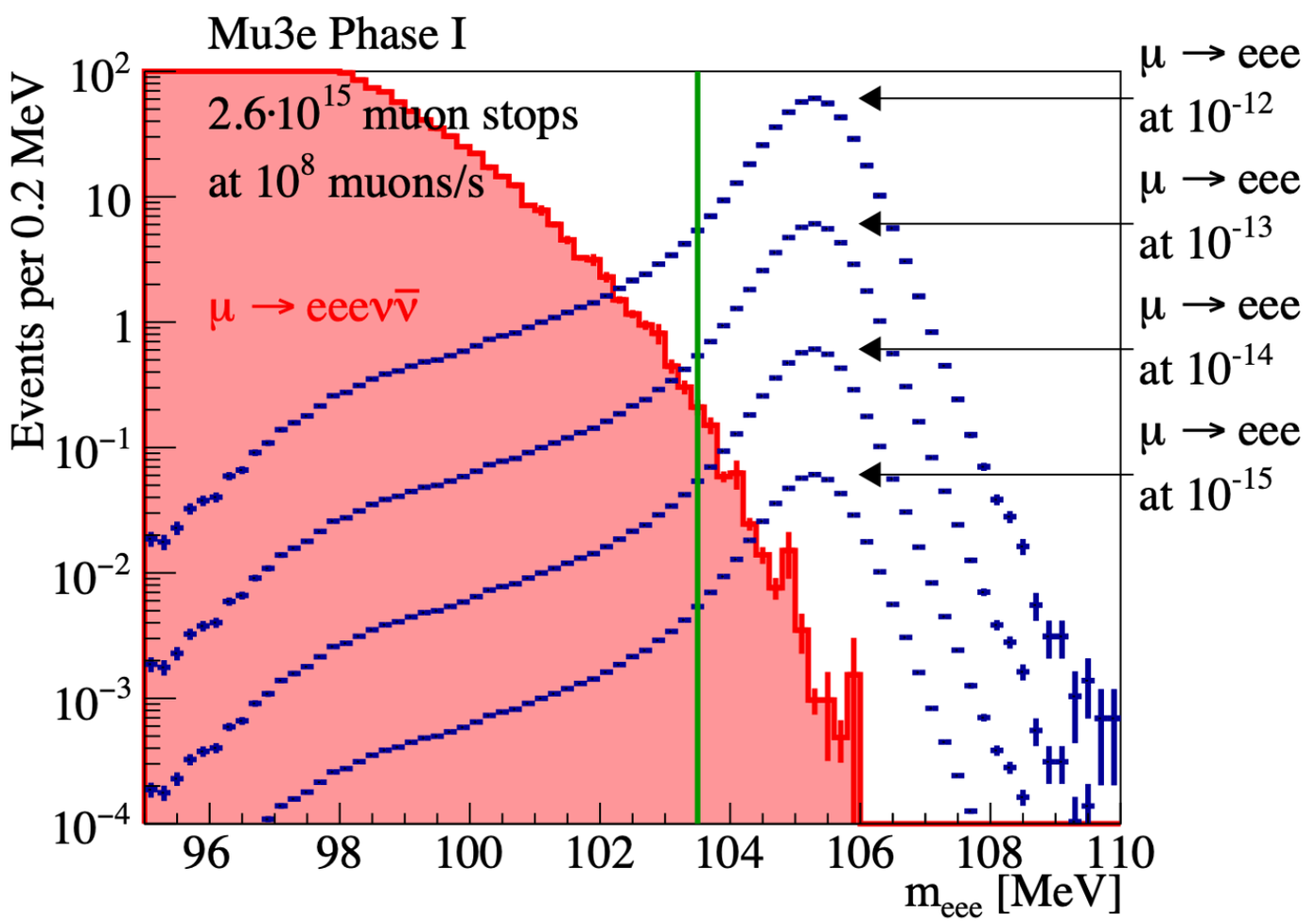


Michel

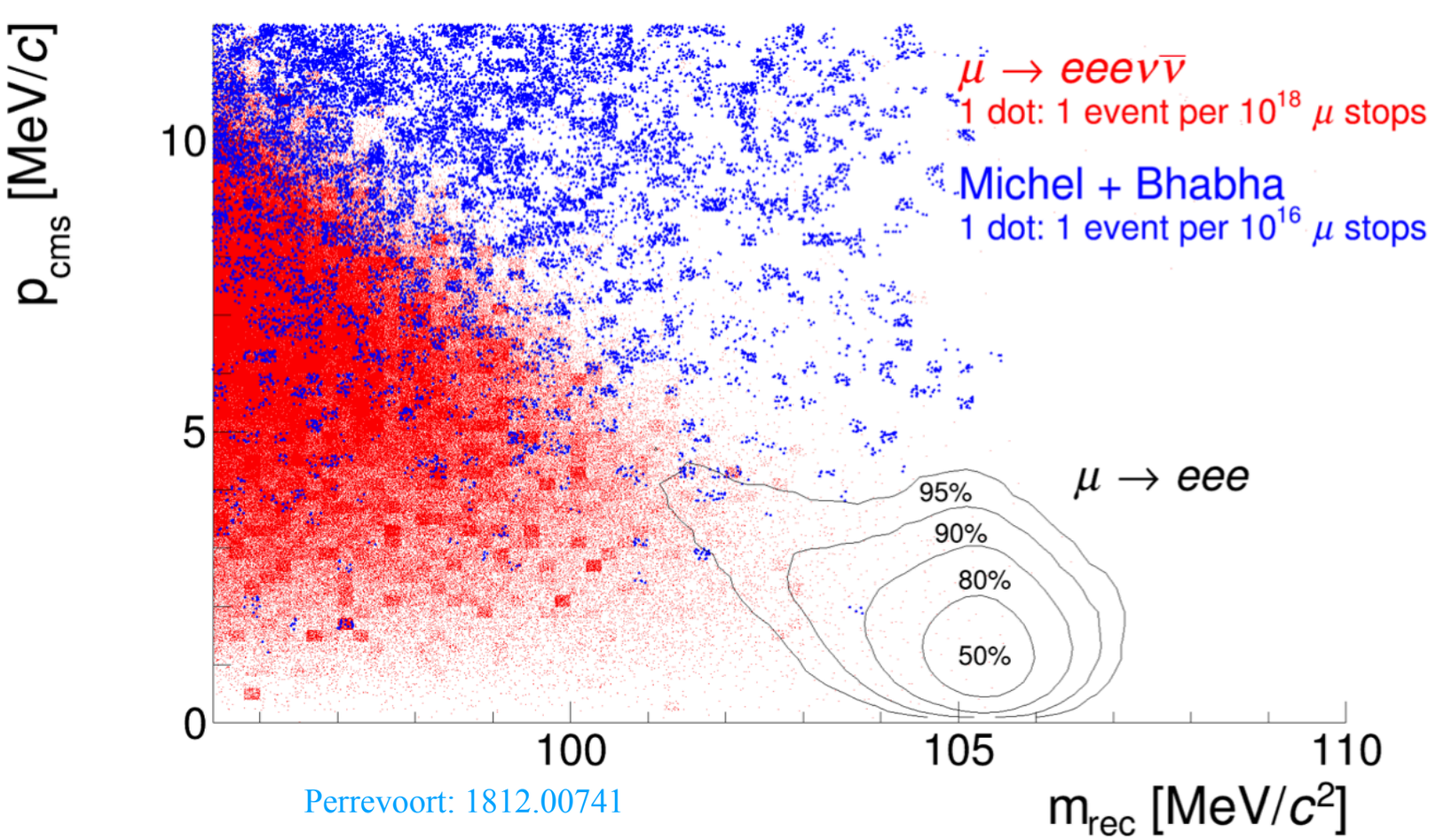
$$\mu^+ \to e^+ \nu \bar{\nu}$$

Internal conversion

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



Mu3e Phase I Simulation



Perrevoort: 1812.00741

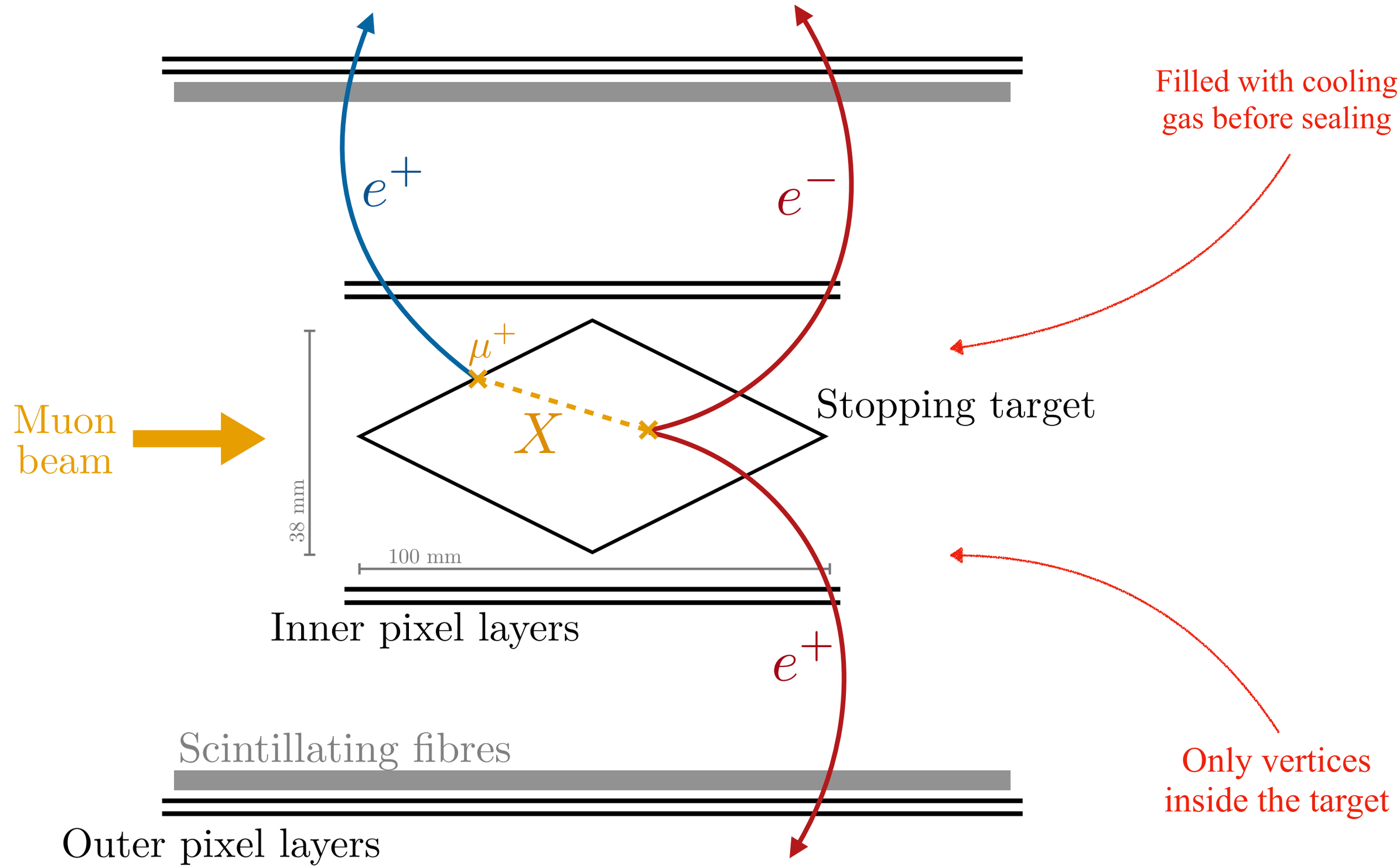
Bhabha

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

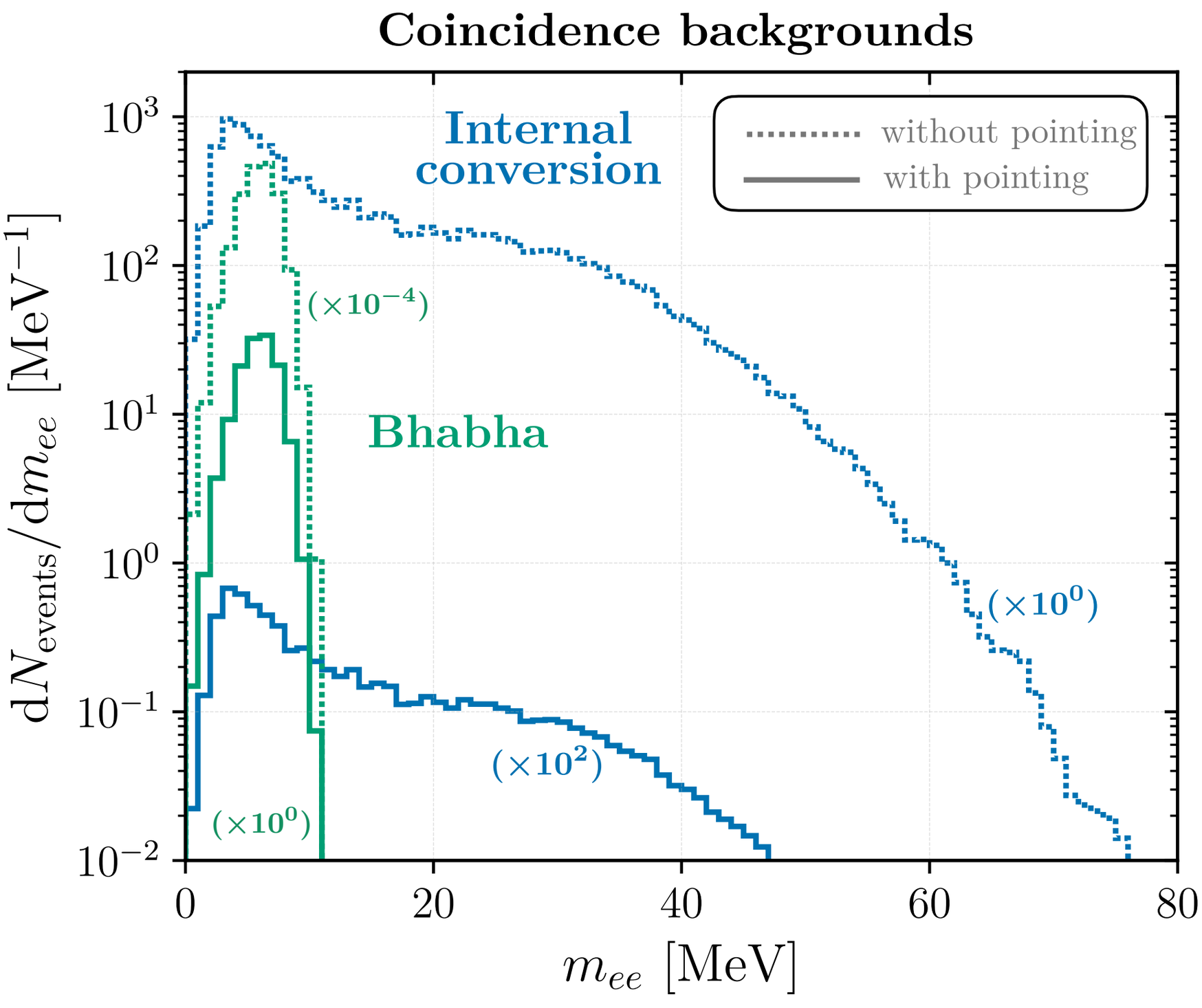
+ coincidence

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

Displaced vertices



Backgrounds



No “neutrinos”

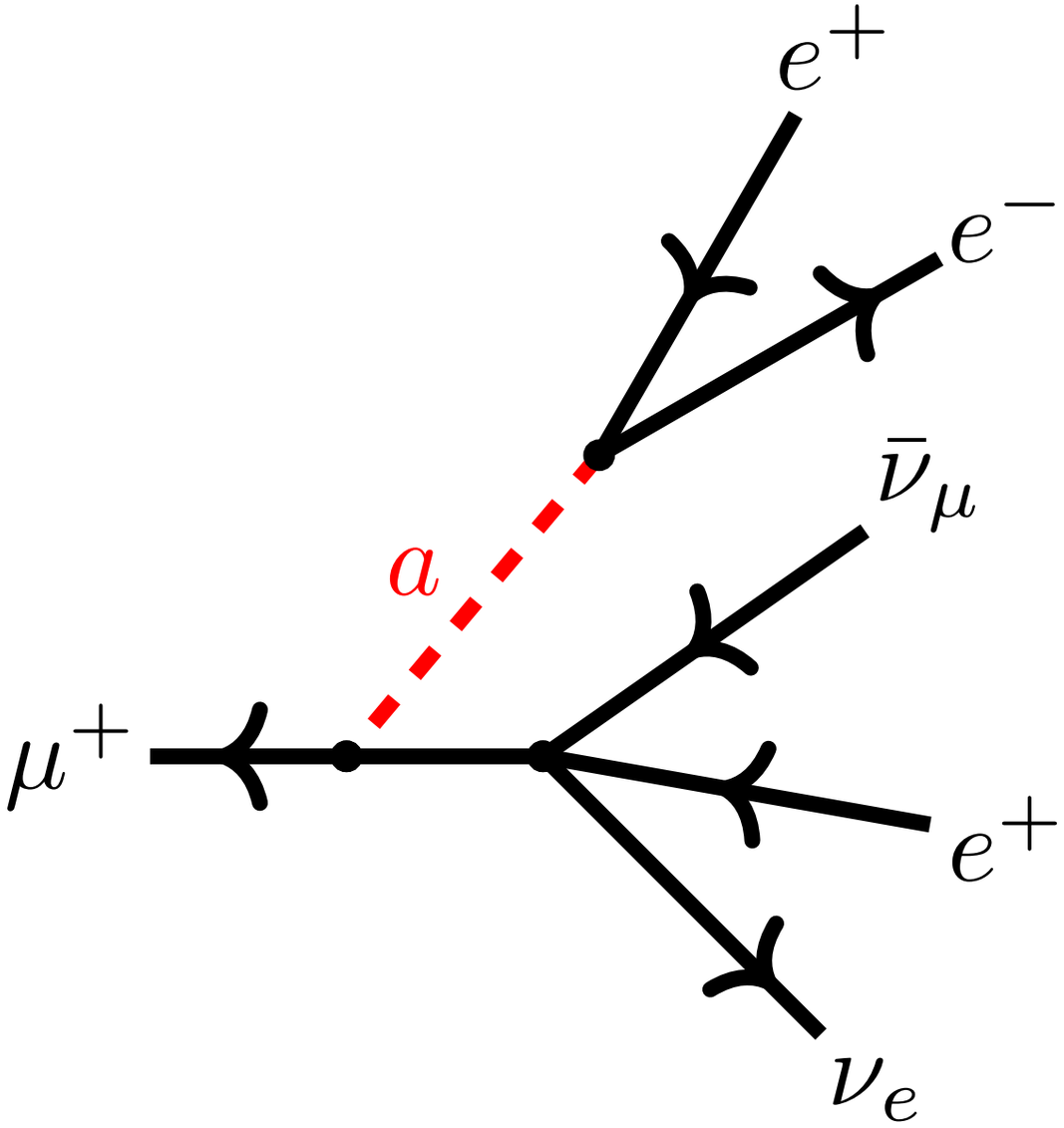
$$p^{\mu}_{\not{E}} = 0$$

Whit “neutrinos”

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

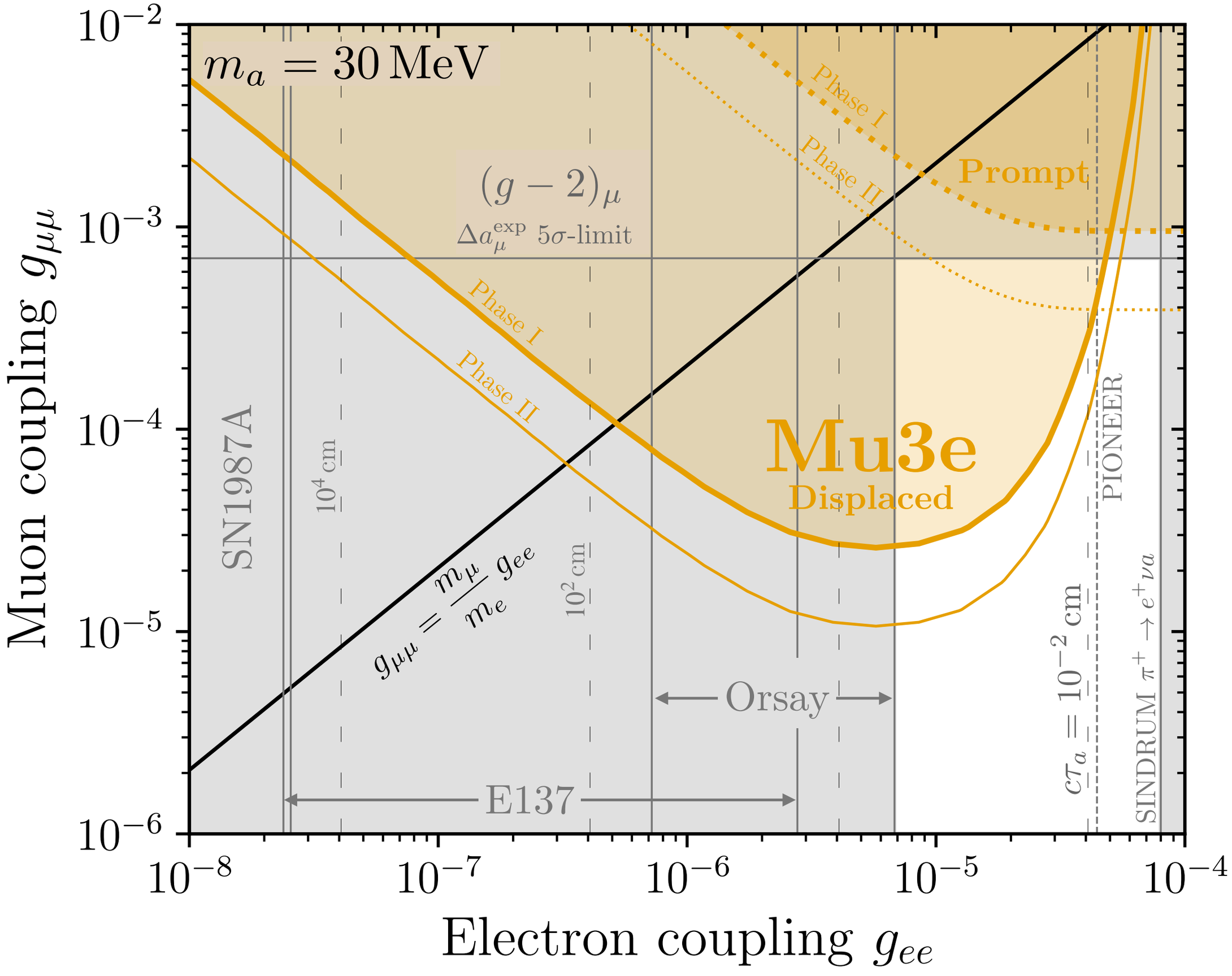
LFC ALP

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



Pointing

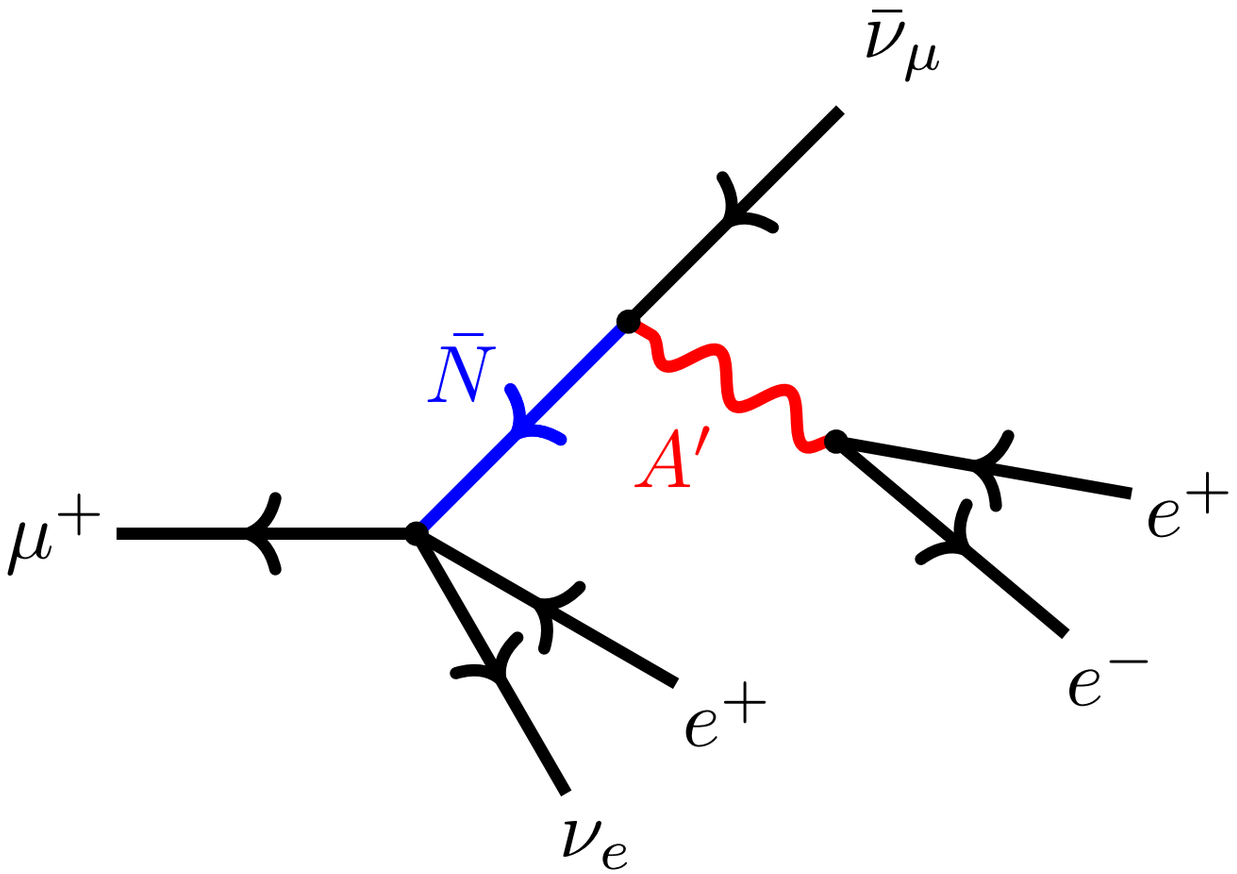
Mass reconstruction


$m_a = 30\,\mathrm{MeV}$
$(g-2)_\mu$
$\Delta a_\mu^{\mathrm{exp}}$ 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

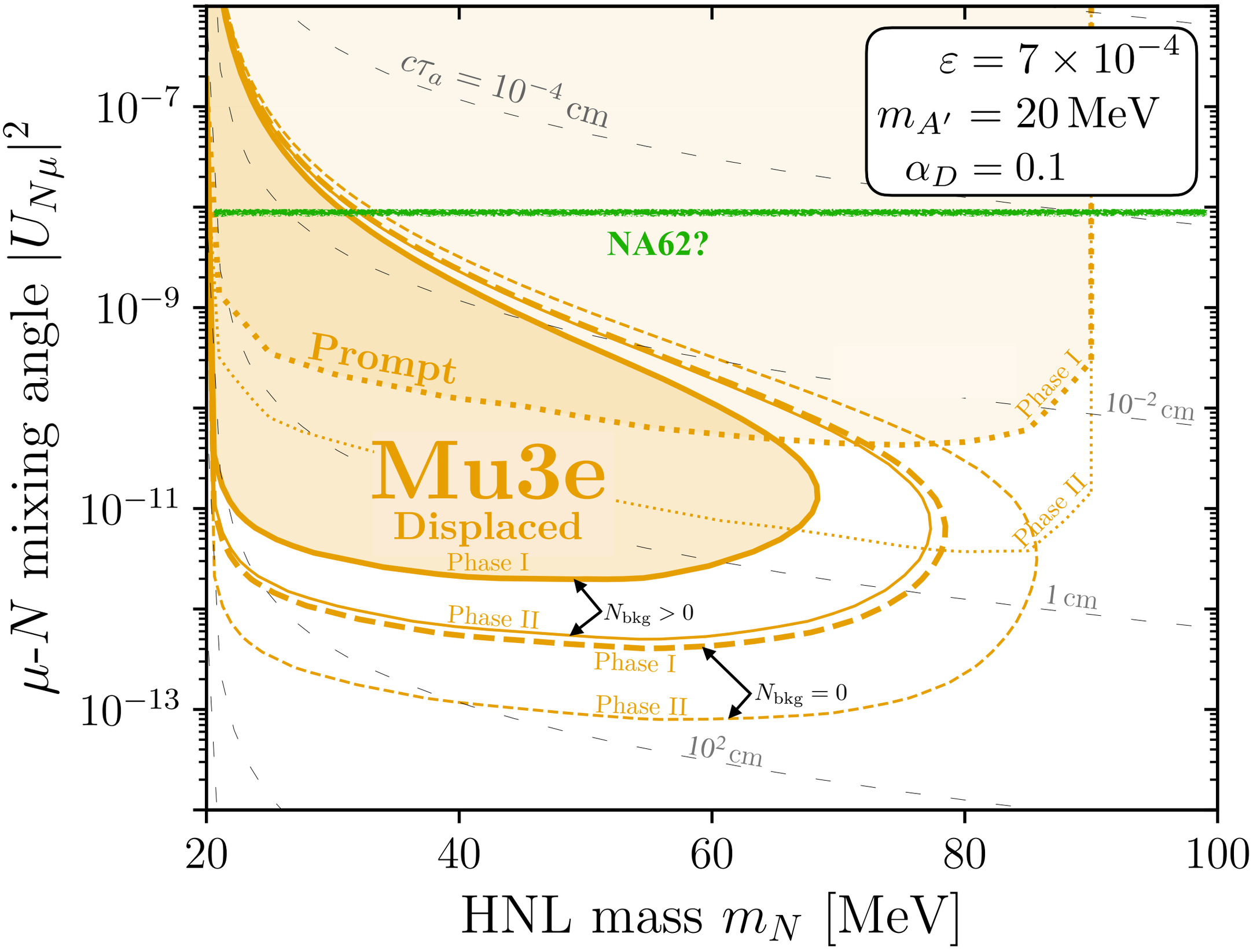
Ballett, Hostert, Pascoli: 1903.07589

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



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

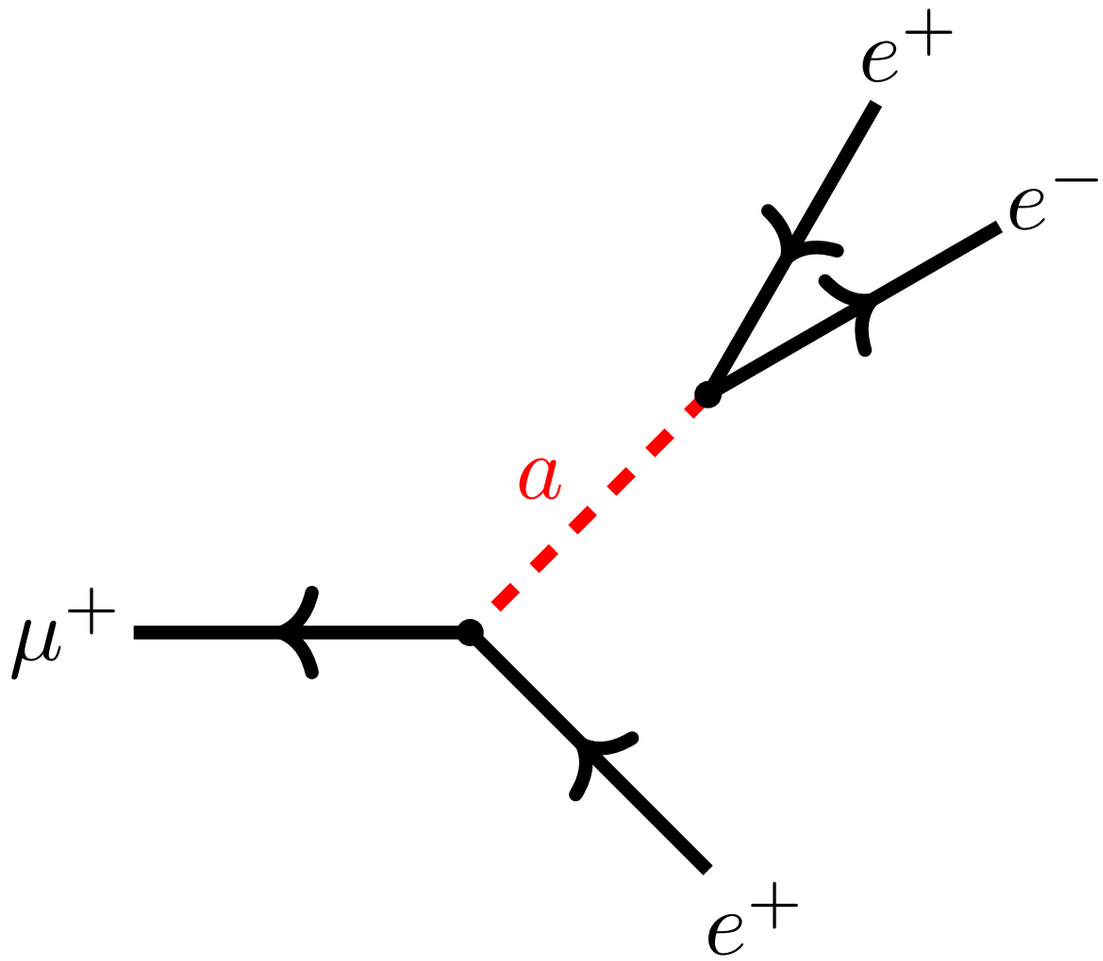
- We suggest using reco mass and pointing to cut bkg

- Reach greatly improves in models with invisible states

Backup slides

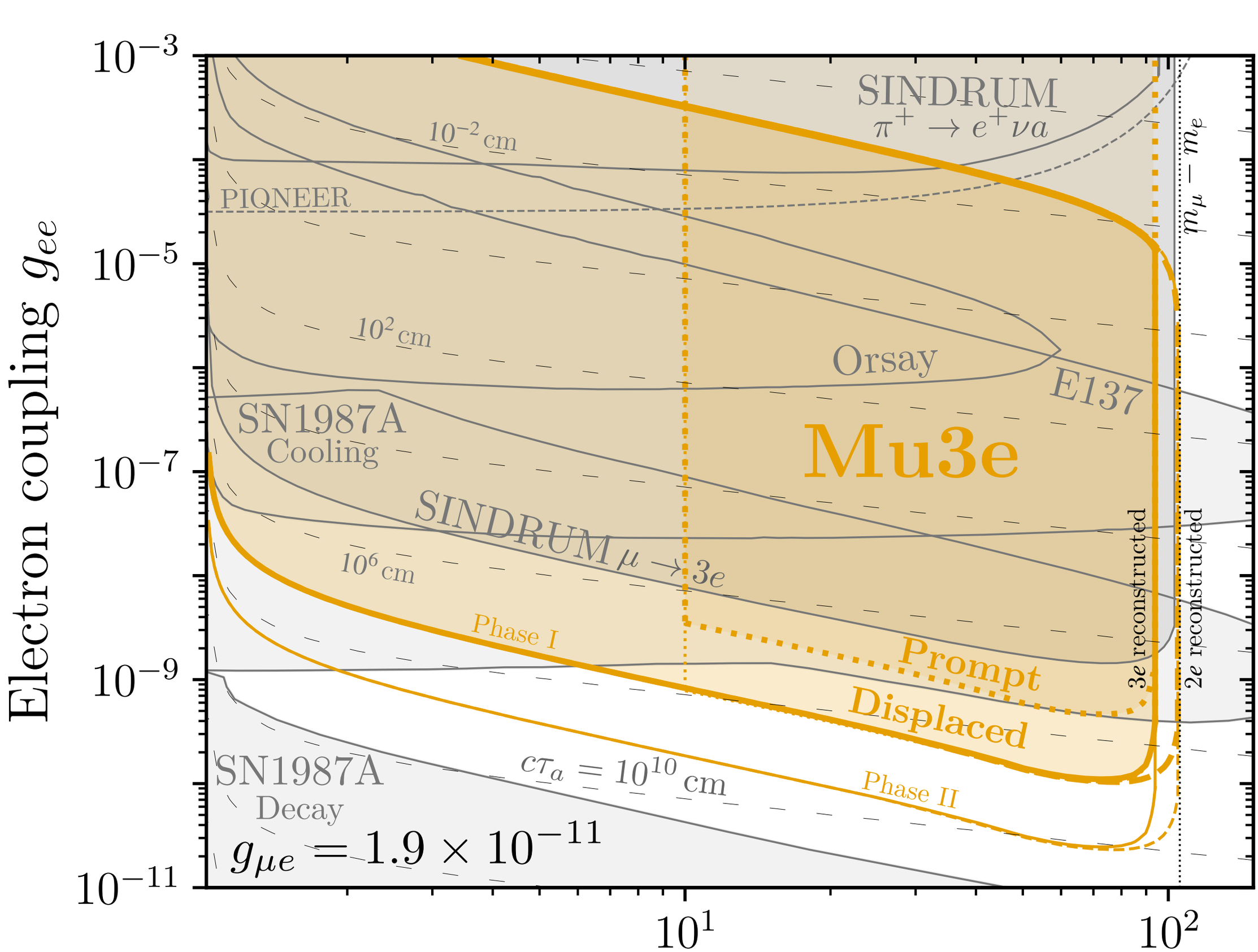
LFV ALP

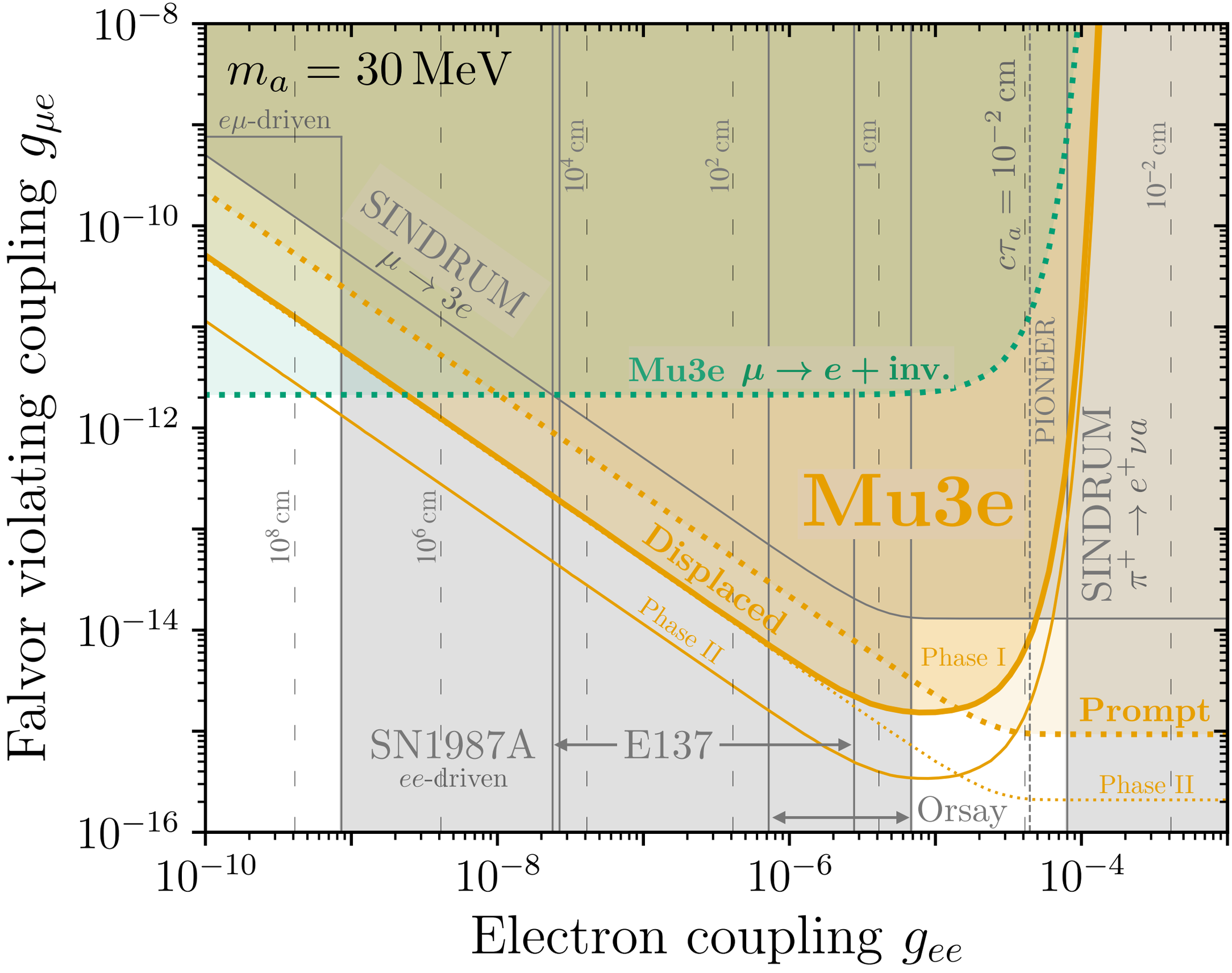
$$\mathcal{L}_a = g_{ee} a \bar{e} \gamma_5 e + g_{\mu e} a \bar{\mu} \gamma_5 e$$



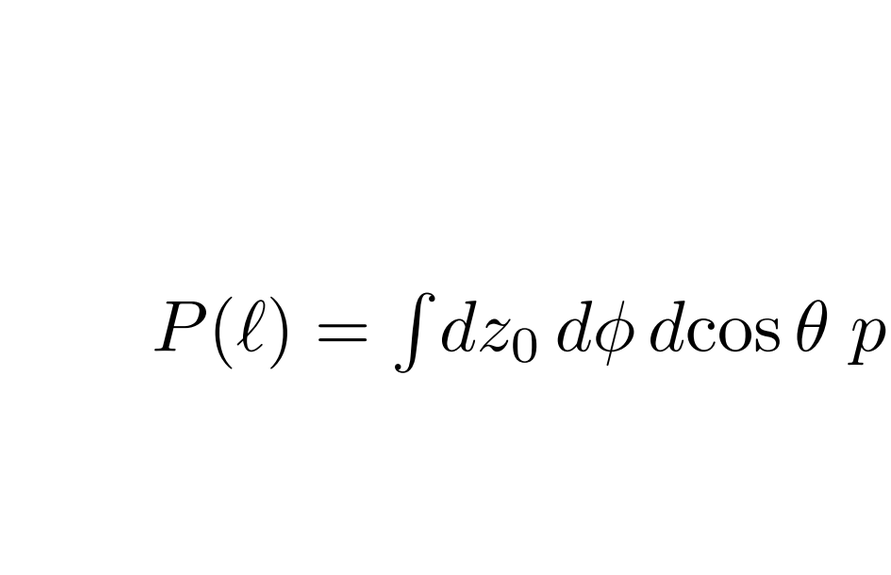
✓ Pointing

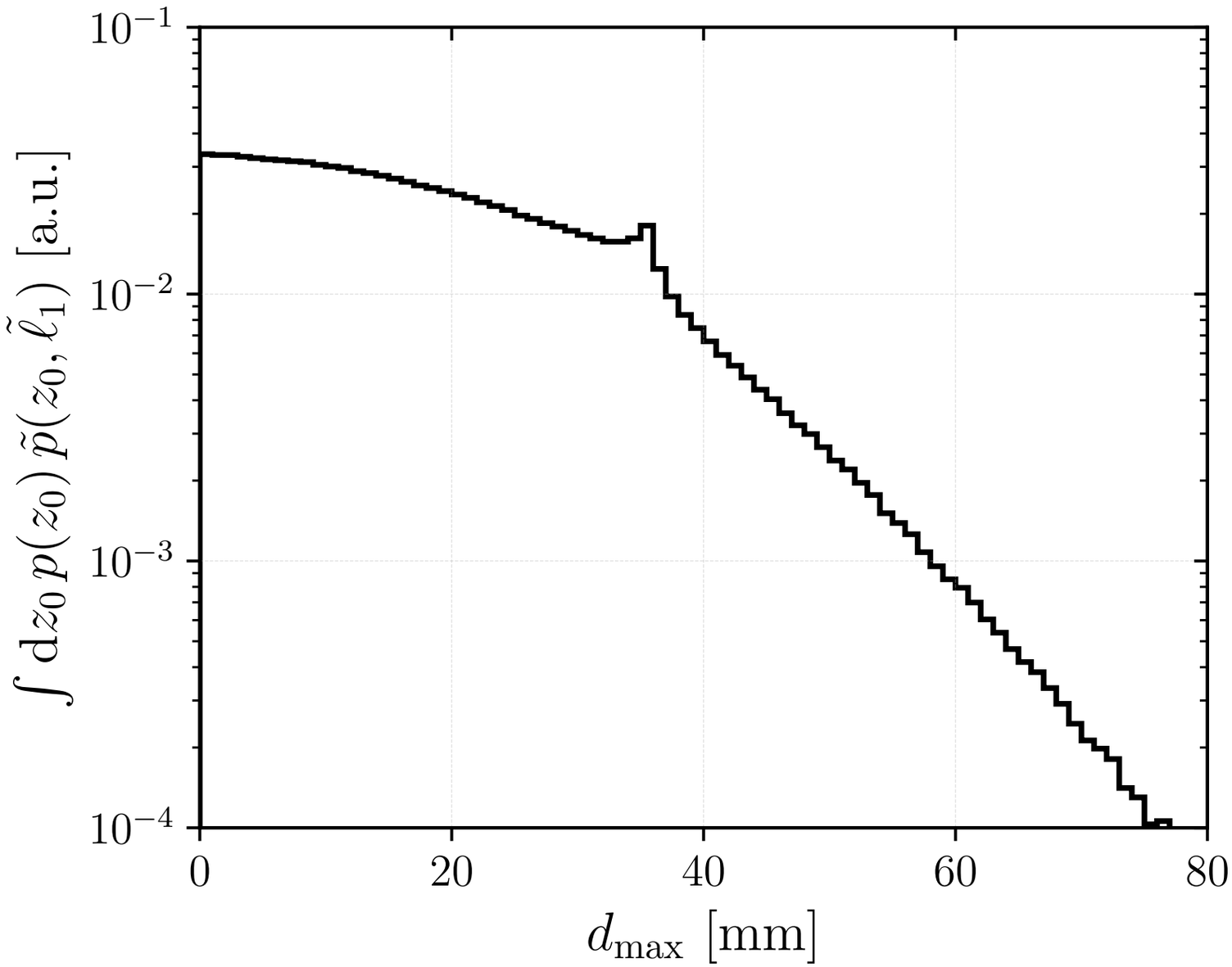
✓ Mass reconstruction


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

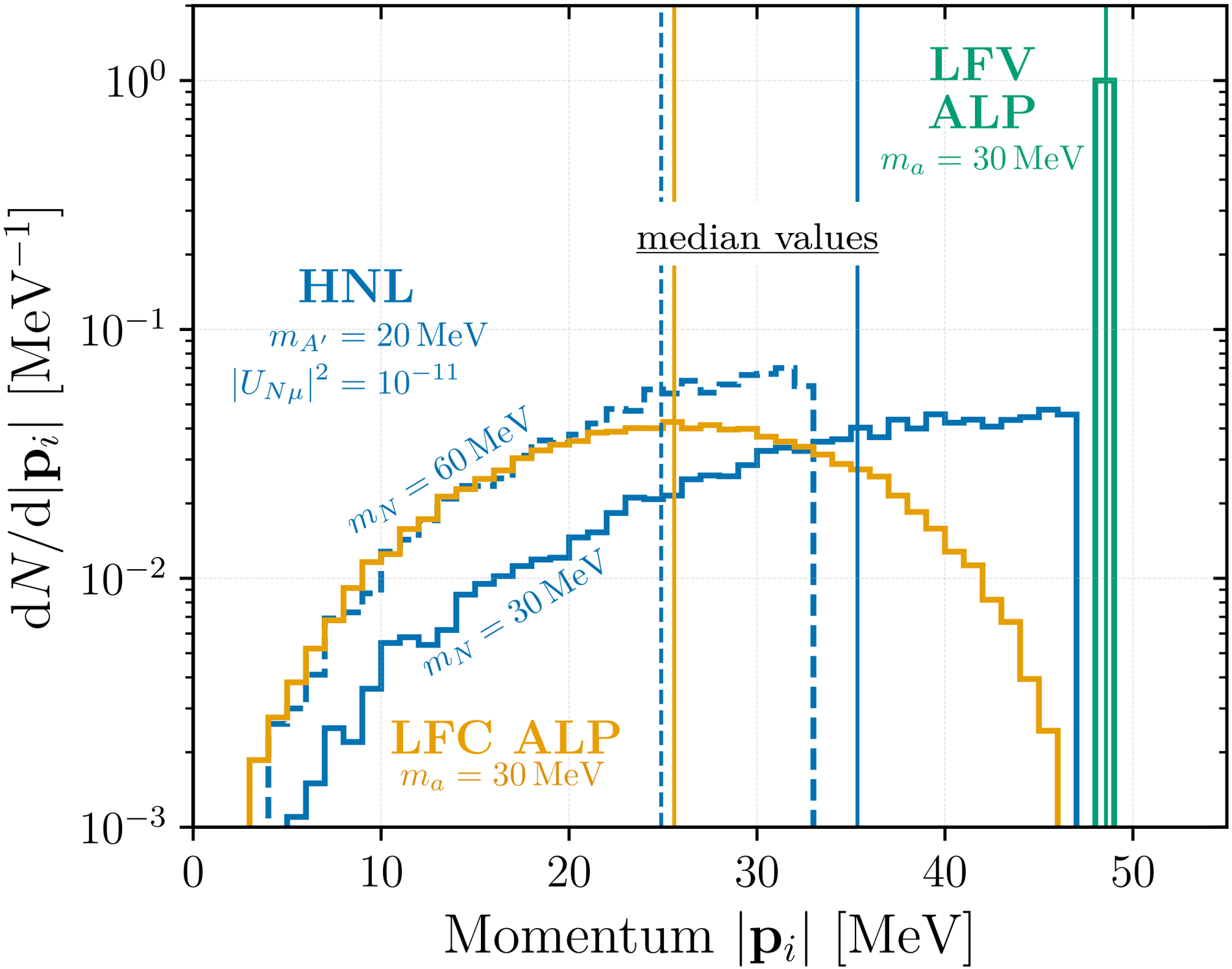

$m_a = 30\,\mathrm{MeV}$
$e\mu$-driven
SINDRUM
$\mu \to 3e$
$10^4\,\mathrm{cm}$
$10^2\,\mathrm{cm}$
$1\,\mathrm{cm}$
$c\tau_a = 10^{-2}\,\mathrm{cm}$
$10^{-2}\,\mathrm{cm}$
PIONER
SINDRUM
$\pi^+ \to e^+ \nu a$
Mu3e $\mu \to e +$ inv.
Mu3e
Displaced
Phase II
Phase I
Prompt
Phase II
$10^8\,\mathrm{cm}$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

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

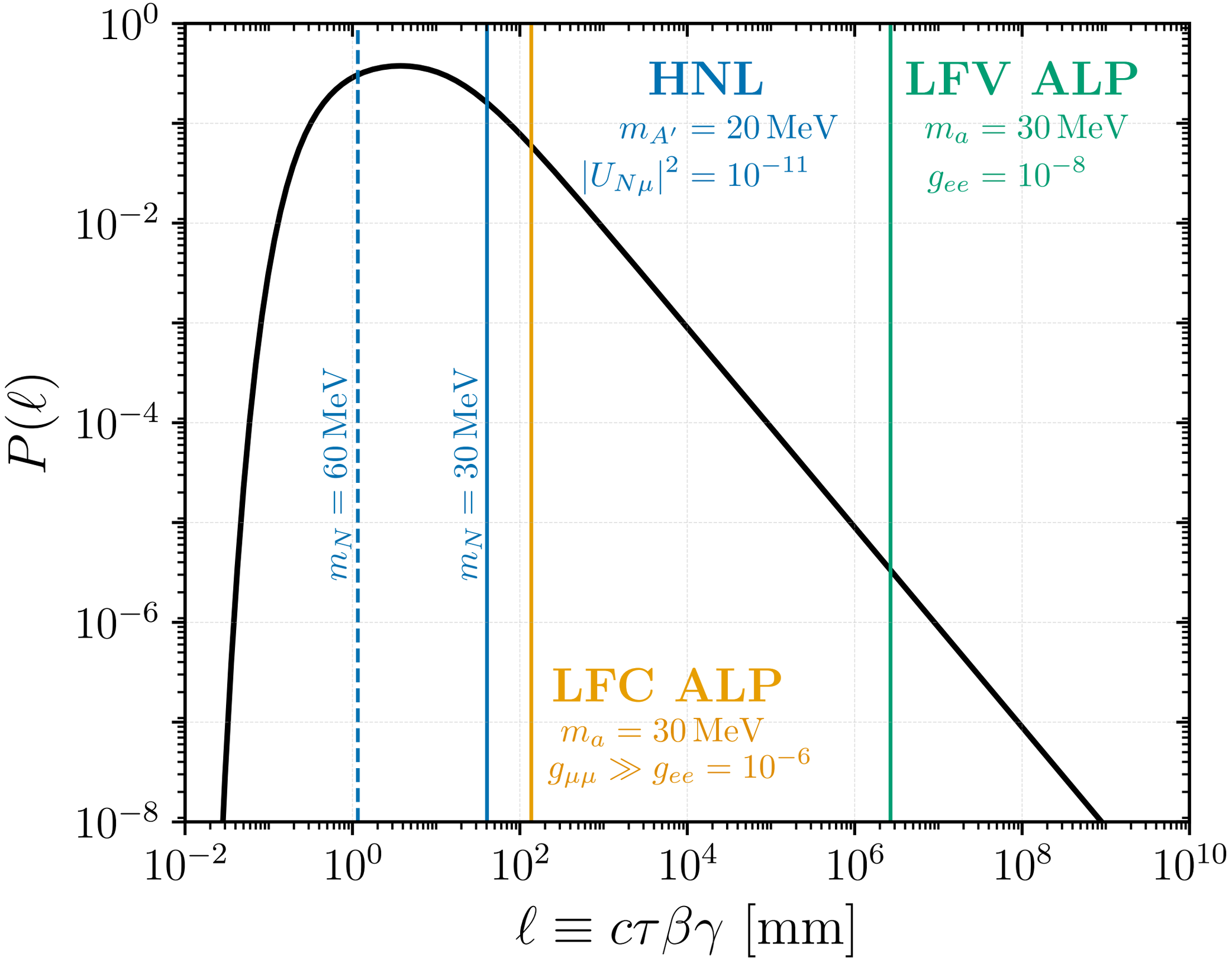




Momentum distributions



Momentum distributions



Efficiencies