Searching for Axion-Like Particles with
the Mu3e Experiment
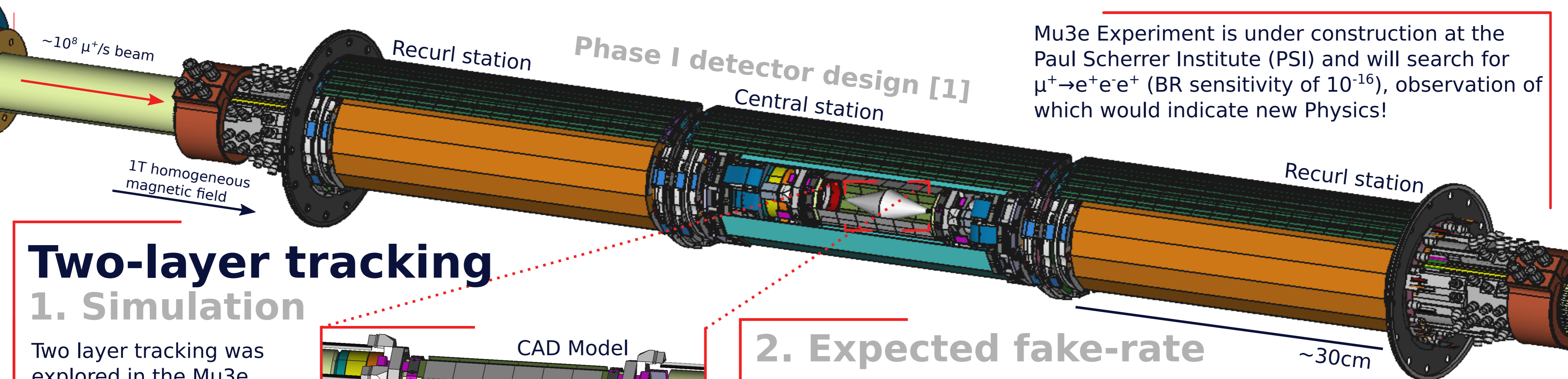
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~10^8 μ⁺/s beam

Recurl station

Phase I detector design [1]

Central station

1T homogeneous magnetic field

Mu3e Experiment is under construction at the Paul Scherrer Institute (PSI) and will search for μ⁺→e⁺e⁻e⁺ (BR sensitivity of 10^{-16}), observation of which would indicate new Physics!

Recurl station

~30cm

Two-layer tracking

1. Simulation

Two layer tracking was explored in the Mu3e integration run [2], in order to improve reconstruction.

CAD Model

Mylar target

Inner pixel layers ~12cm

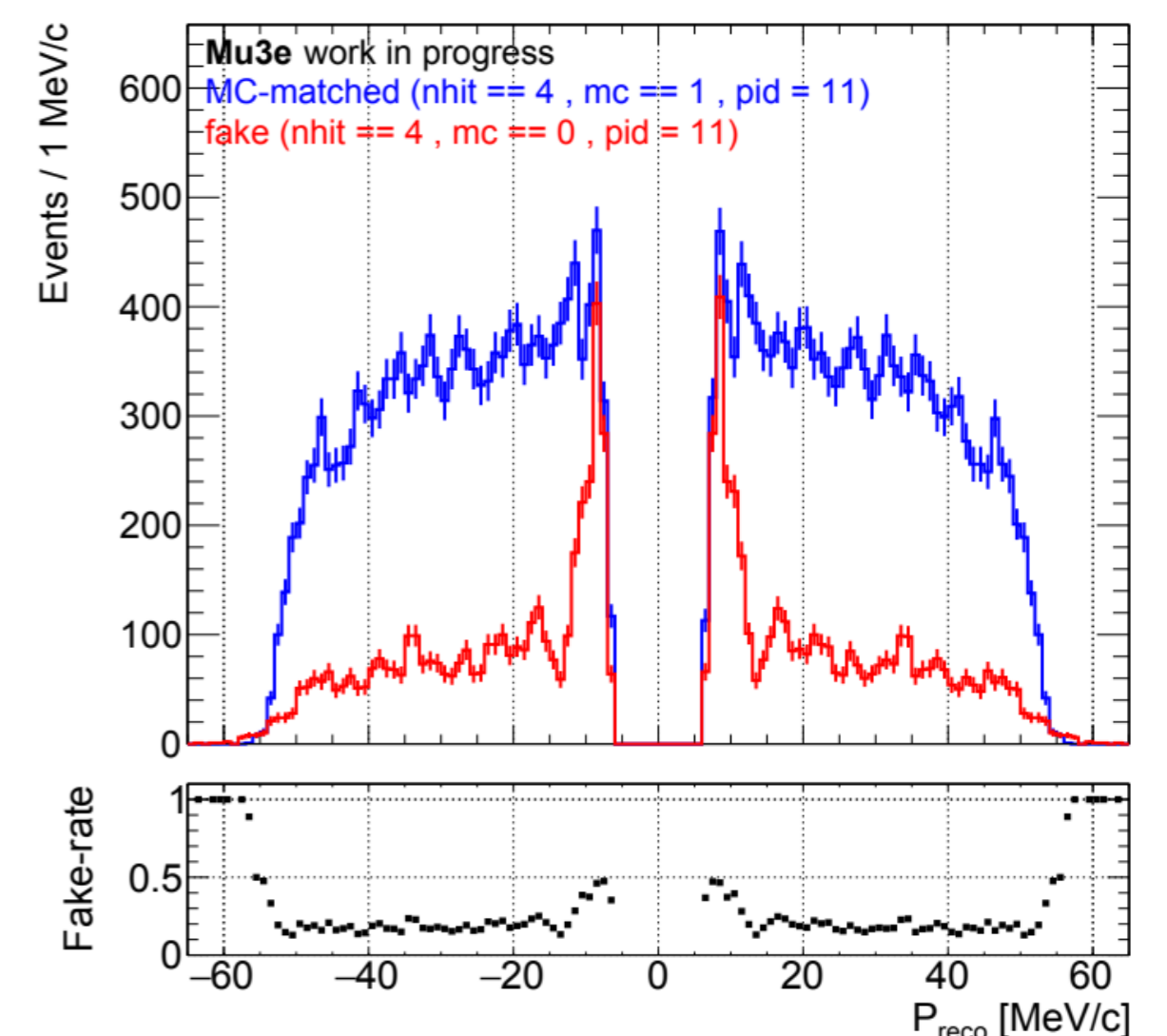Geant4 SIM - Integration run setup [2]
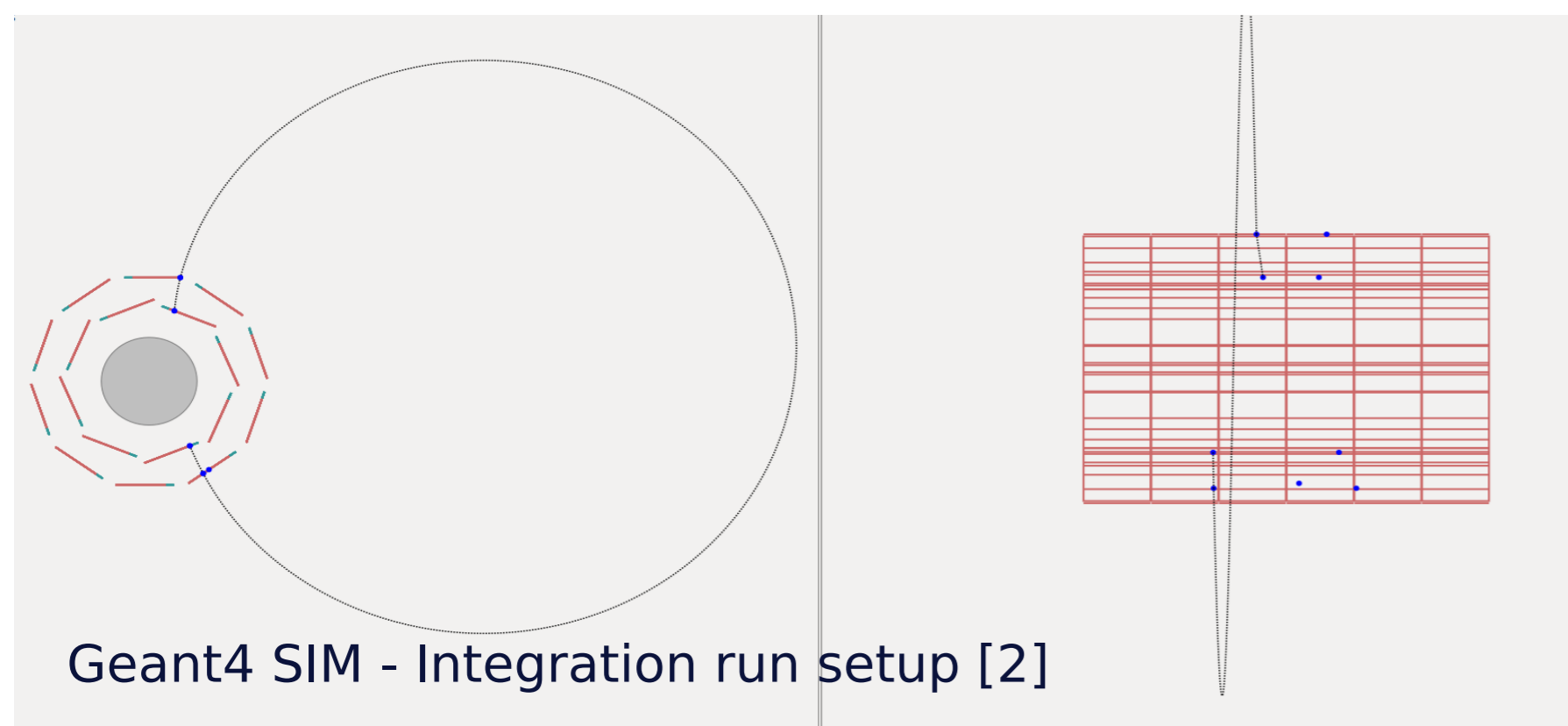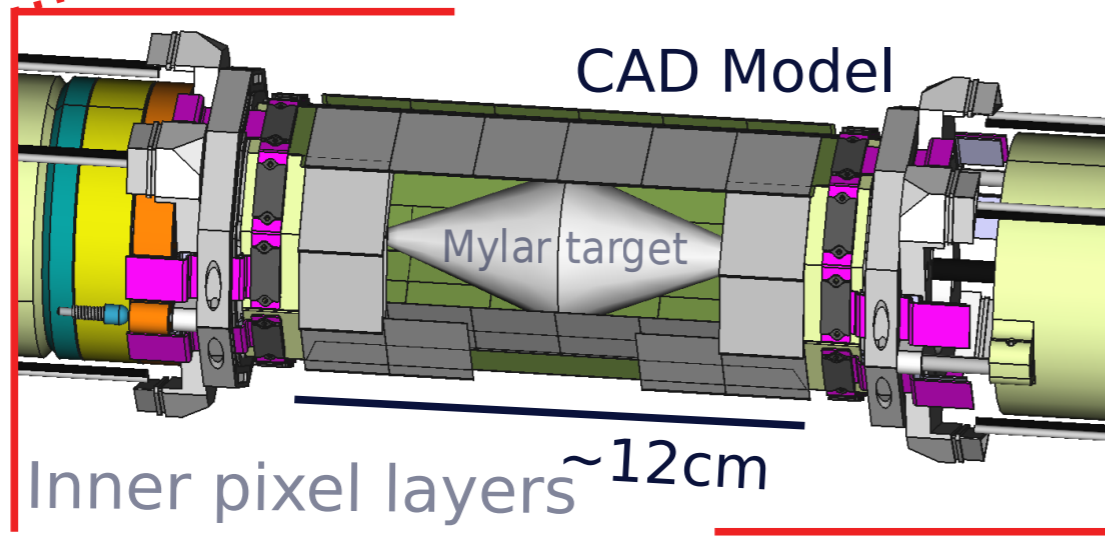
2. Expected fake-rate

Simulated normal muon beam incident on simulation of integration run set up.

Two-layer tracking algorithms were used to test and compare tracks constructed from random hit combinations versus monte-carlo truth tracks.
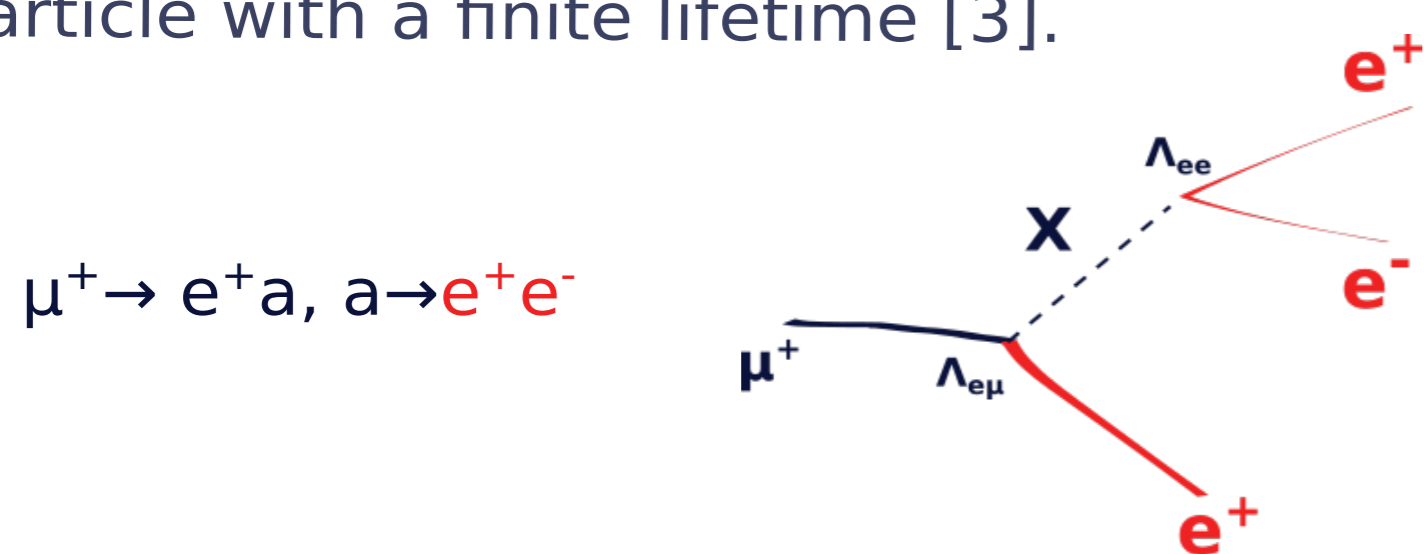
Fake-rate defined as fake tracks resulting from these random combinations, over the total number of reconstructed tracks.

Mu3e work in progress
MC-matched (nhit == 4 , mc == 1 , pid = 11)
fake (nhit == 4 , mc == 0 , pid = 11)
Events / 1 MeV/c
Fake-rate
P_{reco} [MeV/c]

The search for Axion-Like Particles

1. Signal topology

Searching for an Axion-Like Particle with a finite lifetime [3].

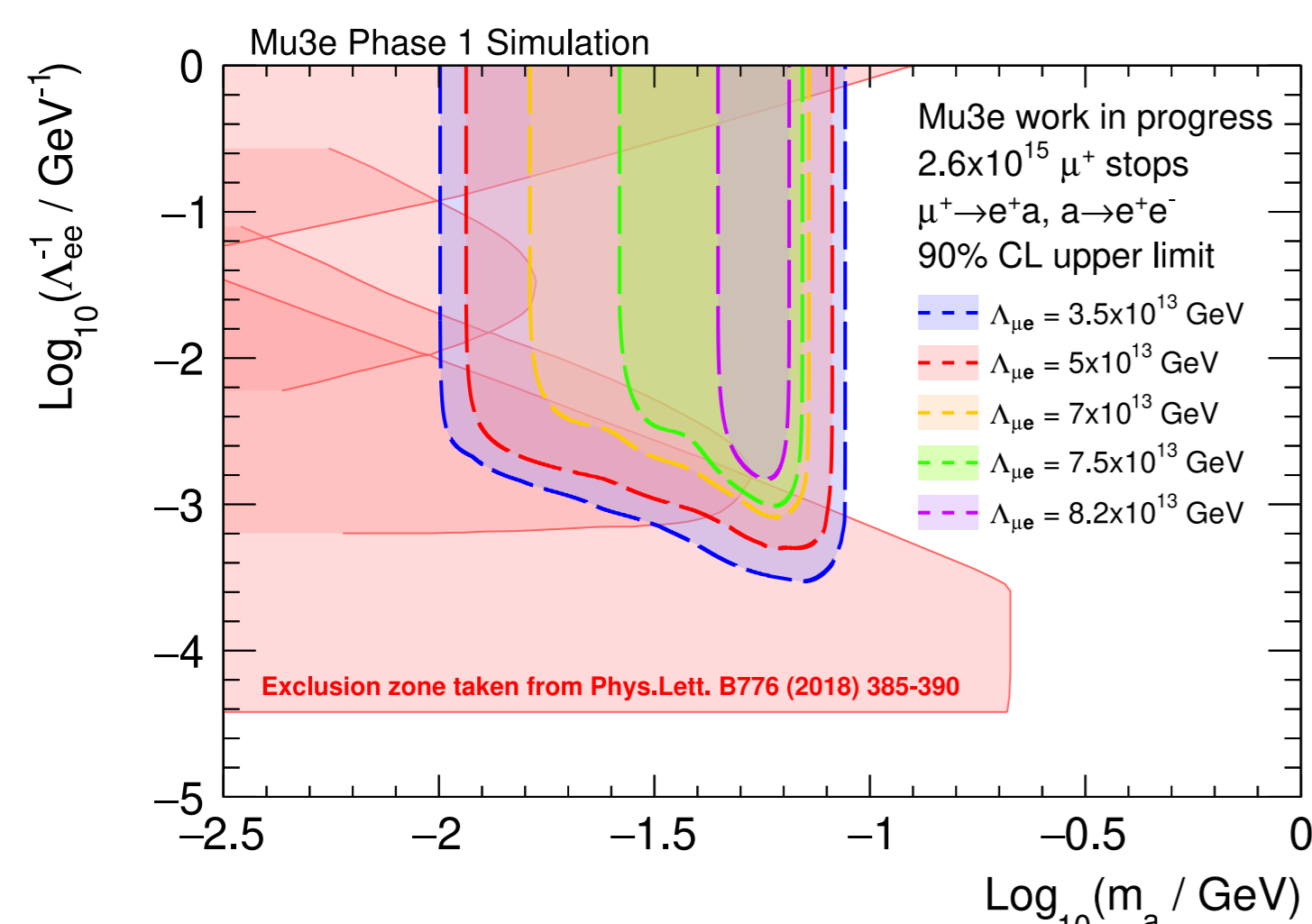$$\mu^+ \to e^+ a, \; a \to e^+ e^-$$

Λ_ee
e⁺
e⁻
X
μ⁺
Λ_eμ
e⁺

3. Final result

Mu3e Phase 1 Simulation
Mu3e work in progress
2.6x10^{15} μ⁺ stops
μ⁺→e⁺a, a→e⁺e⁻
90% CL upper limit
$\Lambda_{\mu e}$ = 3.5x10^{13} GeV
$\Lambda_{\mu e}$ = 5x10^{13} GeV
$\Lambda_{\mu e}$ = 7x10^{13} GeV
$\Lambda_{\mu e}$ = 7.5x10^{13} GeV
$\Lambda_{\mu e}$ = 8.2x10^{13} GeV
Exclusion zone taken from Phys.Lett. B776 (2018) 385-390
$Log_{10}(\Lambda_{ee}^{-1} / GeV^{-1})$
$Log_{10}(m_a / GeV)$

Expected Mu3e sensitivity to appear in [4].

2. Simulation study

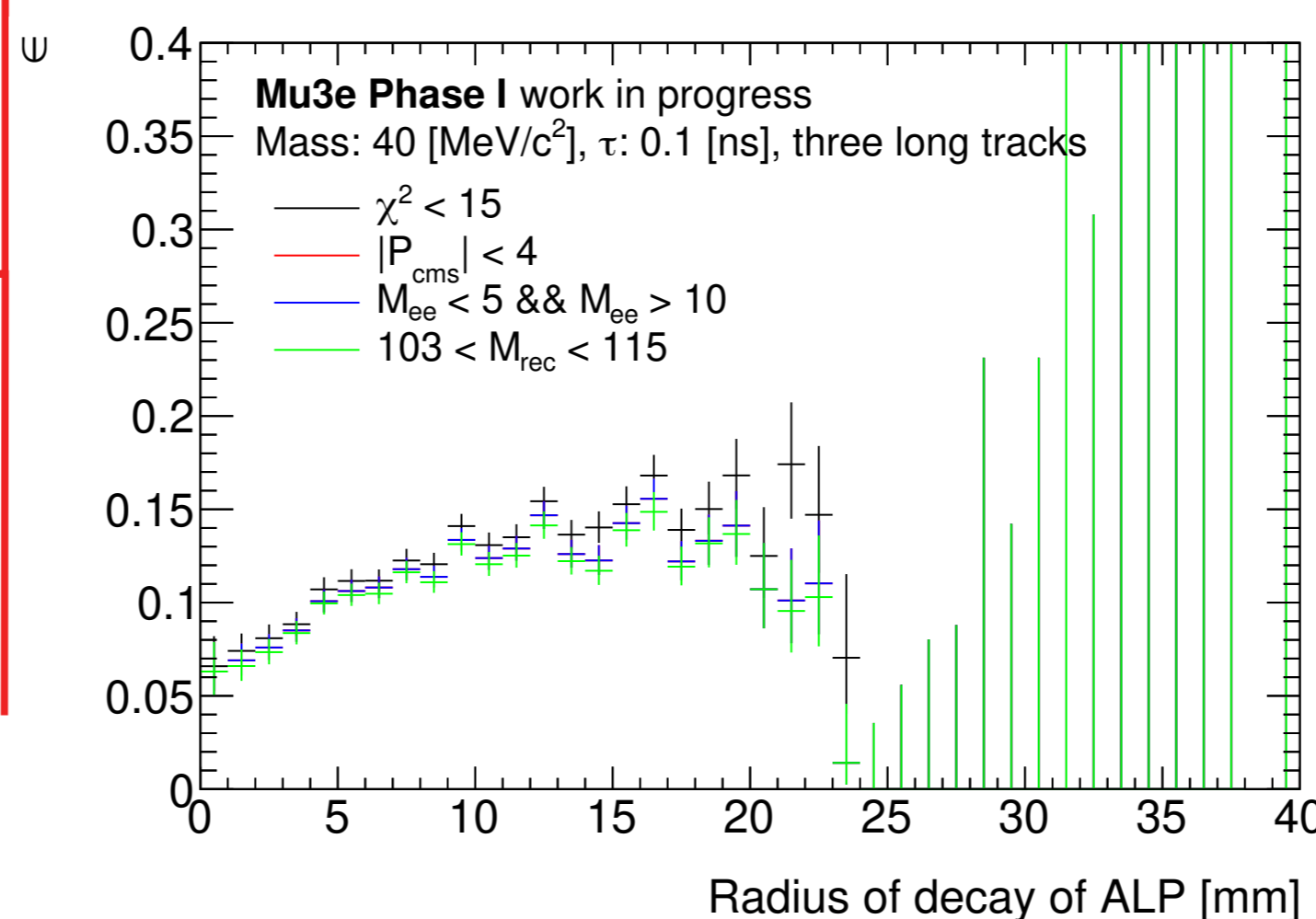Analysis follows the same signal selection used in the μ⁺→e⁺e⁻e⁺ analysis as in [1], and assumes zero background.

Successfully reconstructing the vertex due to favourable kinematics; up until 23.3 mm (radius of layer 1) reasonable efficiency is expected.
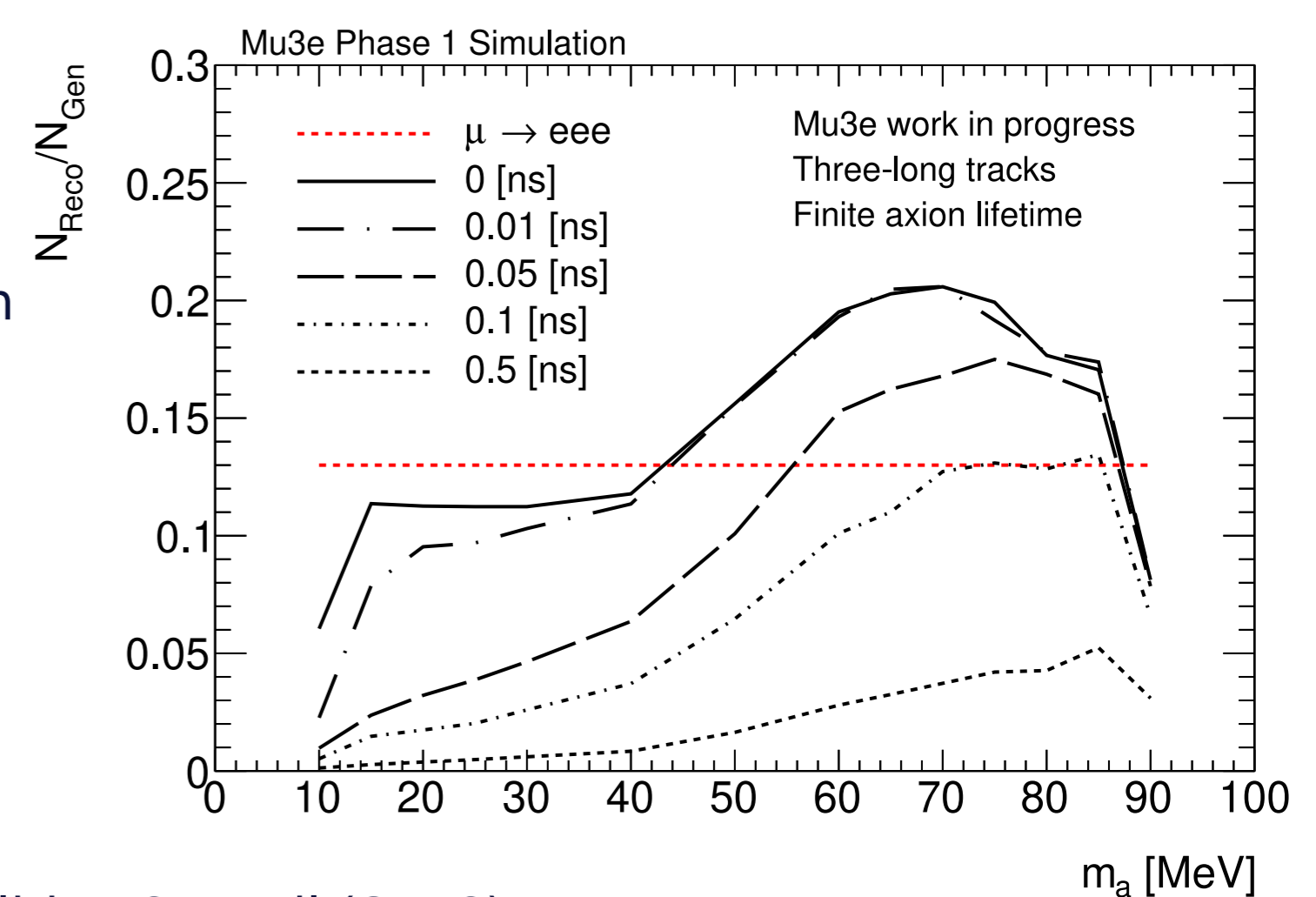
Mu3e Phase 1 Simulation
Mu3e work in progress
m_a = 40 MeV, τ = 0.01 ns
m_a = 40 MeV, τ = 0.1 ns
m_a = 40 MeV, τ = 1 ns
Events
|vtx_{reco} - vtx_{true}| [mm]

Mu3e Phase I work in progress
Mass: 40 [MeV/c²], τ: 0.1 [ns], three long tracks
χ^2 < 15
|P_{cms}| < 4
M_{ee} < 5 && M_{ee} > 10
103 < M_{rec} < 115
Radius of decay of ALP [mm]

Layer 3
Layer 2
Layer 1
Target
MuPix chips
mm

Reconstruction efficiency remains high for a range of lifetimes. Efficiencies interpolated to obtain branching ratio upper limits.

Mu3e Phase 1 Simulation
N_{Reco}/N_{Gen}
μ → eee
Mu3e work in progress
Three-long tracks
Finite axion lifetime
0 [ns]
0.01 [ns]
0.05 [ns]
0.1 [ns]
0.5 [ns]
m_a [MeV]

References:
[1] Nucl.Instrum.Meth.A 1014 (2021) 165679 (Mu3e TDR)
[2] e-Print: 2203.07855 [physics.ins-det] (Integration run paper)
[3] Phys.Lett. B776 (2018) 385-390
[4] Snowmass 2022, To-Be submitted