Shedding Light on X17
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Prospects for Dark Photon Searches in Mu3e

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Prospects for Dark Photon Searches in the Mu3e Experiment

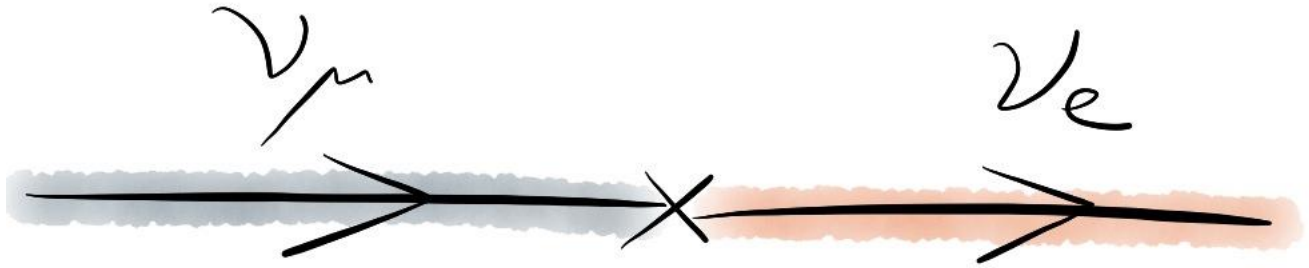
- Mu3e Experiment
  - Lepton flavour violation $\mu \rightarrow eee$
  - Detector design

- Dark photon searches
  - The easy
  - The difficult
  - The impossible

Lepton Flavour Violation

- Lepton Flavour is an accidental symmetry in the Standard Model (SM)
  - ➢Violated in many models beyond the SM (BSM)

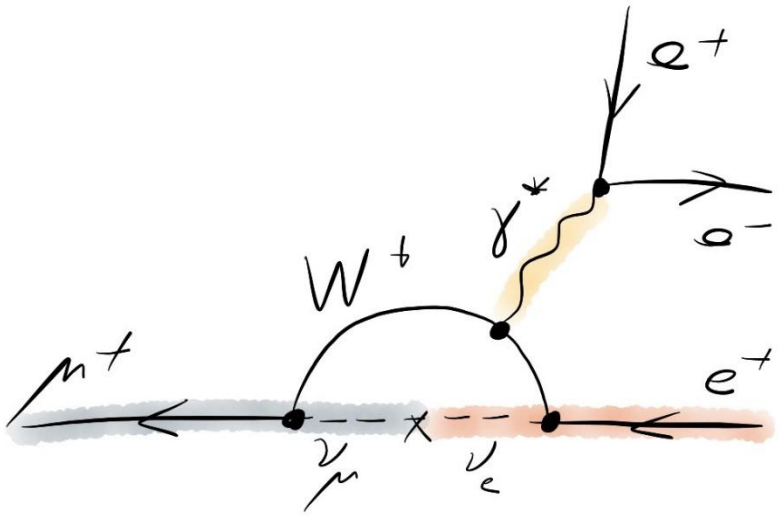
- Observation of neutrino oscillations → Lepton Flavour Violation (LFV)



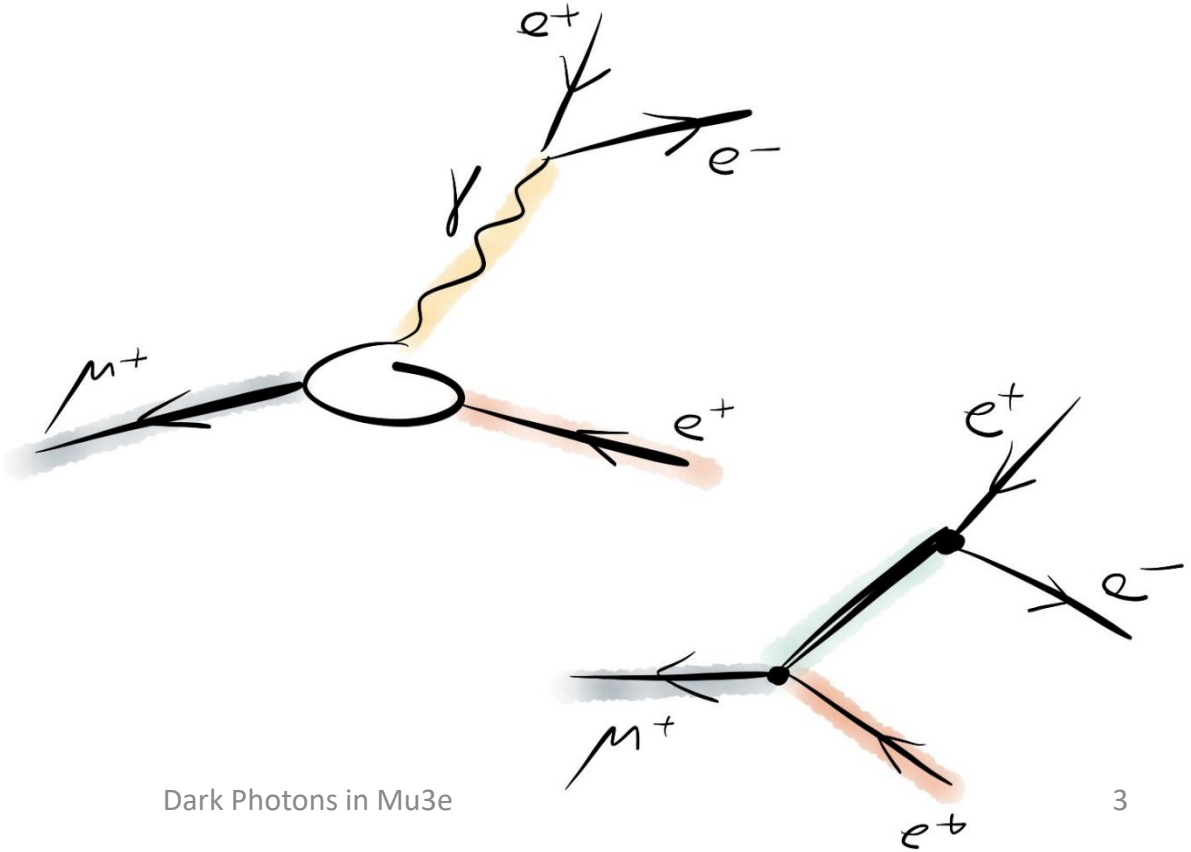
- Not (yet?) observed in charged lepton sector

Lepton Flavour Violation

- Mu3e searches for $\mu \rightarrow eee$
- Including ν mixing in the SM
  $\rightarrow \mathcal{B}(\mu \rightarrow eee) \leq 10^{-54}$

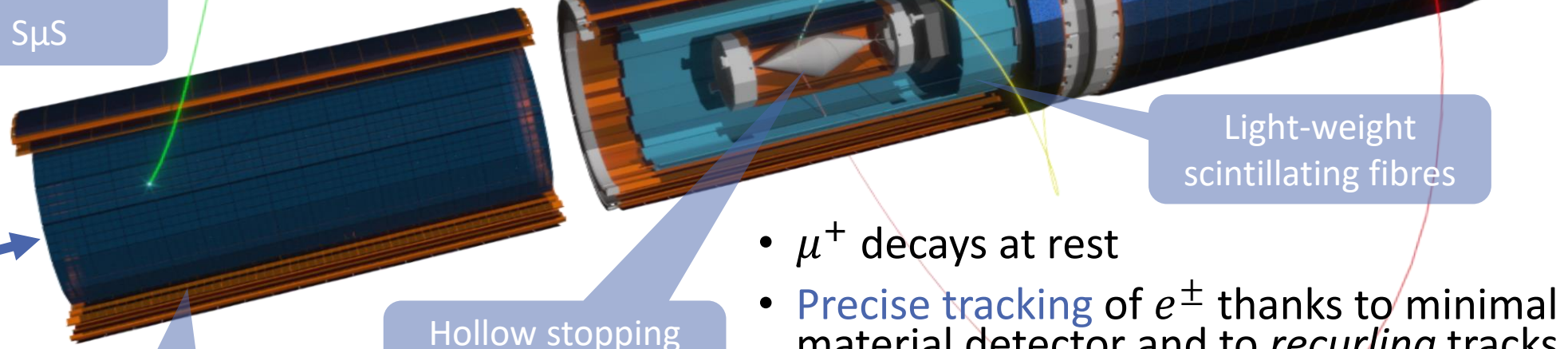


➢ Any observation is an unambiguous sign of BSM



Mu3e Experiment (Phase I)

Search for $\mu \rightarrow eee$, free of background

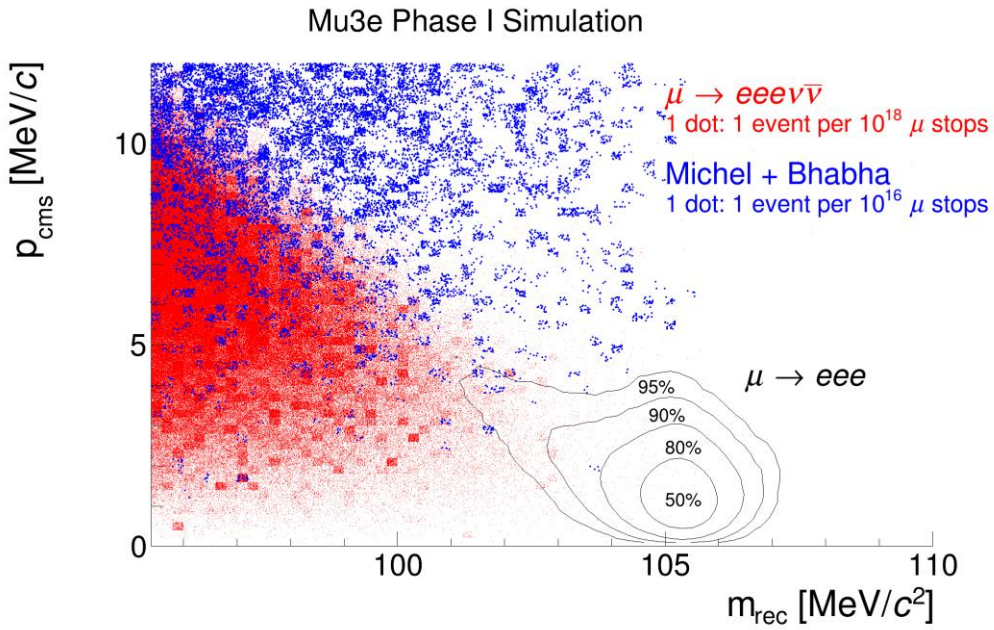


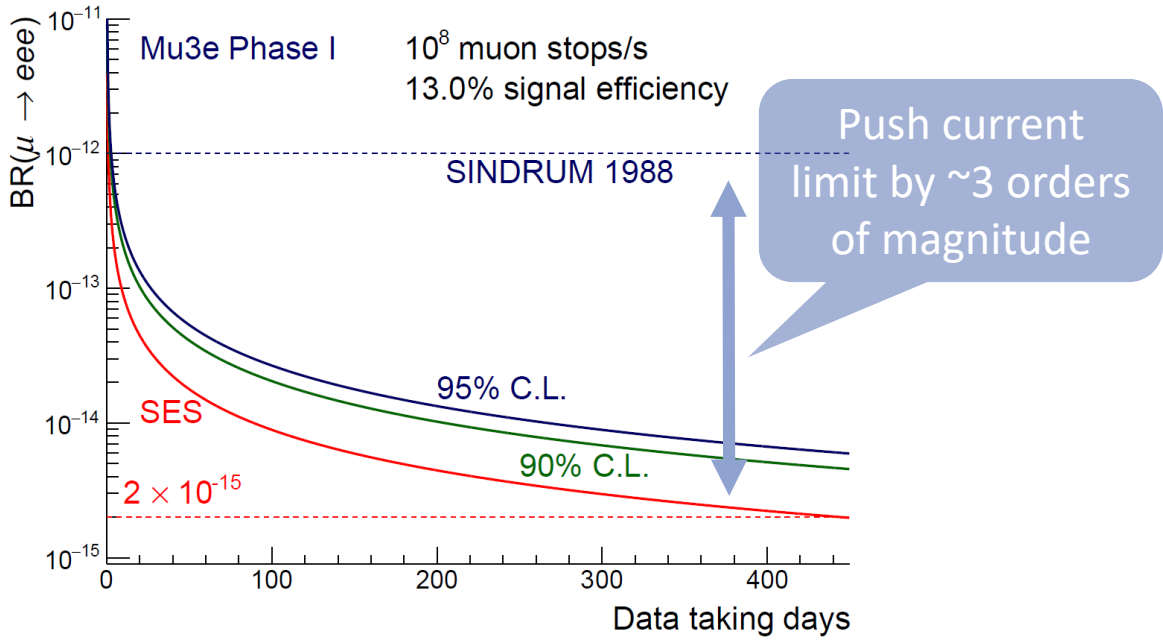
- μ^+ decays at rest
- Precise tracking of $e^\pm$ thanks to minimal material detector and to *recurling* tracks
- High geometric and momentum acceptance
- DAQ: online reconstruction of all tracks & event filtering of $\mu \rightarrow eee$ candidates
- Unprecedented dataset of $\sim 10^{15}$ μ decays

Mu3e Experiment (Phase I)

- Signal has $e^+e^-e^+$ from a common vertex with $m_{eee} = m_\mu$
- Background from $\mu \to eee\nu\nu$ and combinatorial background

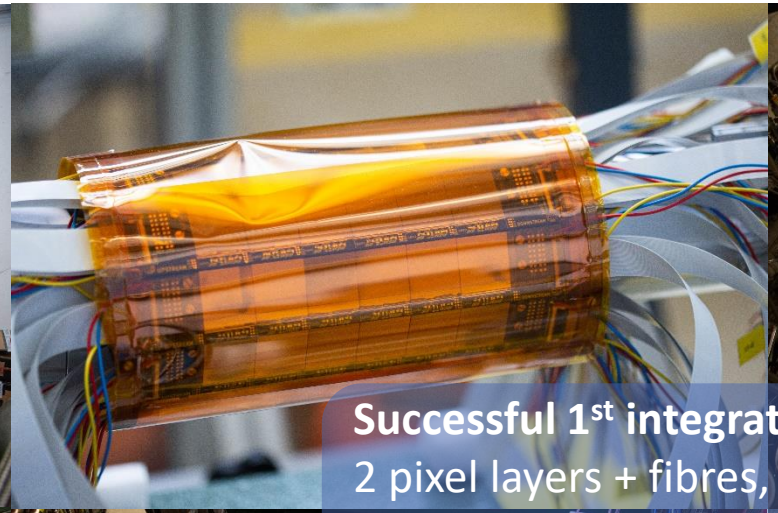
➢Probe $\mu \to eee$ with branching ratios as low as $\sim 2 \cdot 10^{-15}$

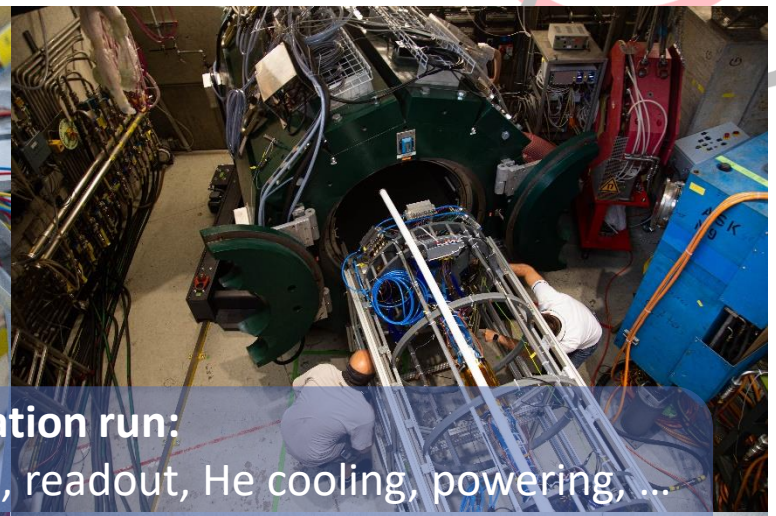




Mu3e Experiment (Phase I)

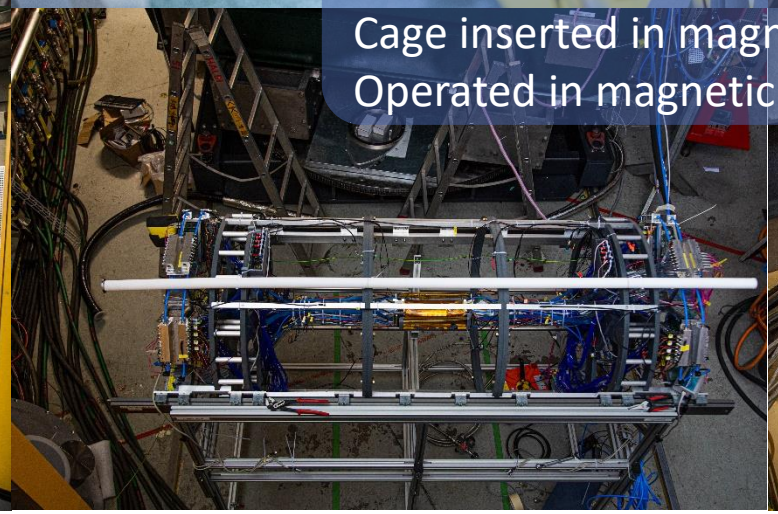
Magnet delivered and operational

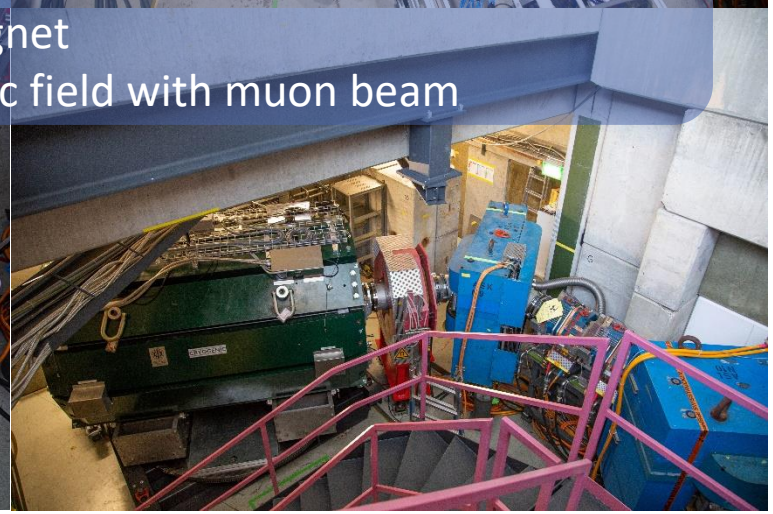




Successful 1st integration run:
2 pixel layers + fibres, readout, He cooling, powering, …
Cage inserted in magnet
Operated in magnetic field with muon beam

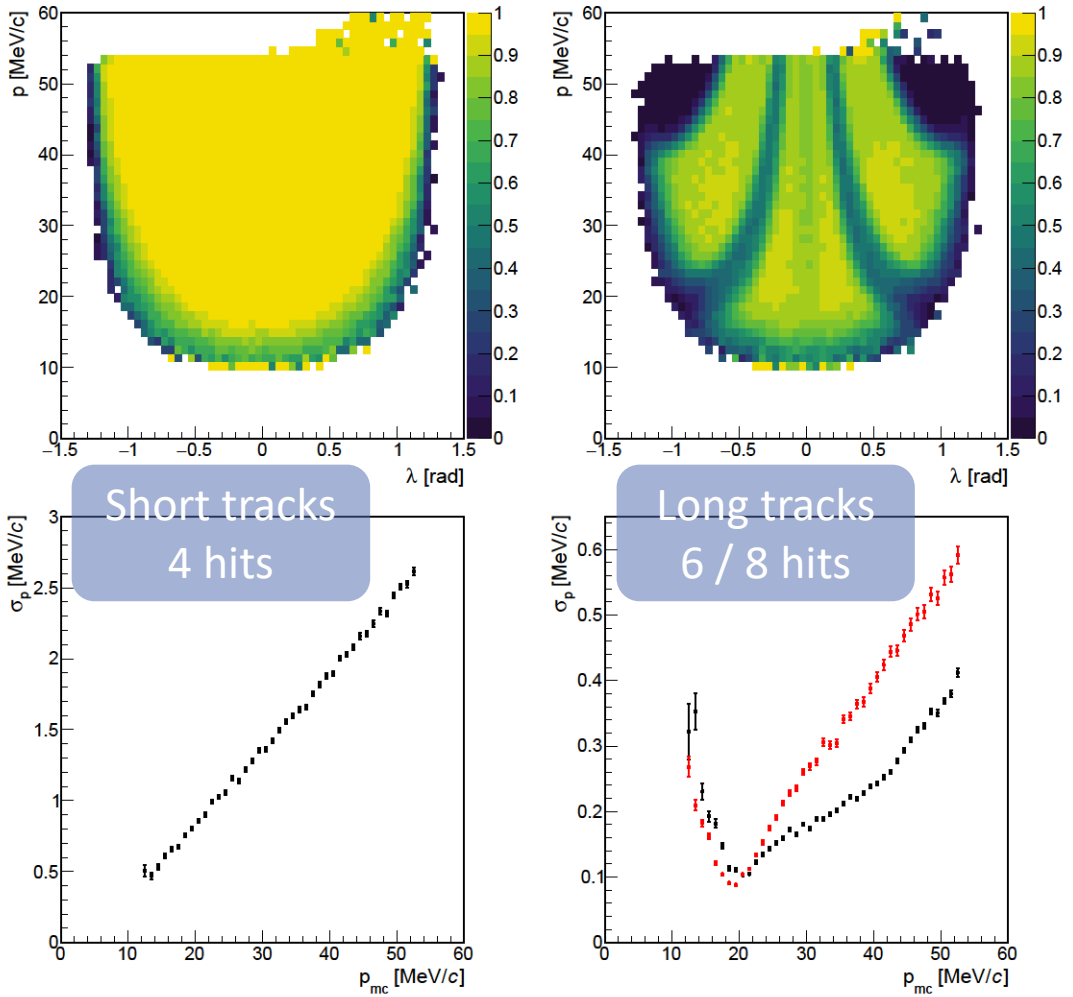
Compact **M**uon **B**eamline





Dark Photon Searches in Mu3e

- Measure $e^{\pm}$ trajectories with high precision
  - Minimum p_T of 10 MeV
  - High angular coverage
  - Excellent momentum resolution
  - Precise timing
- DAQ: $e^+e^-e^+$ events are recorded
  - Simplified track reconstruction and vertex finding performed online
  - No cut on missing momentum
- $\mathcal{O}(10^{15})$ μ decays in phase I

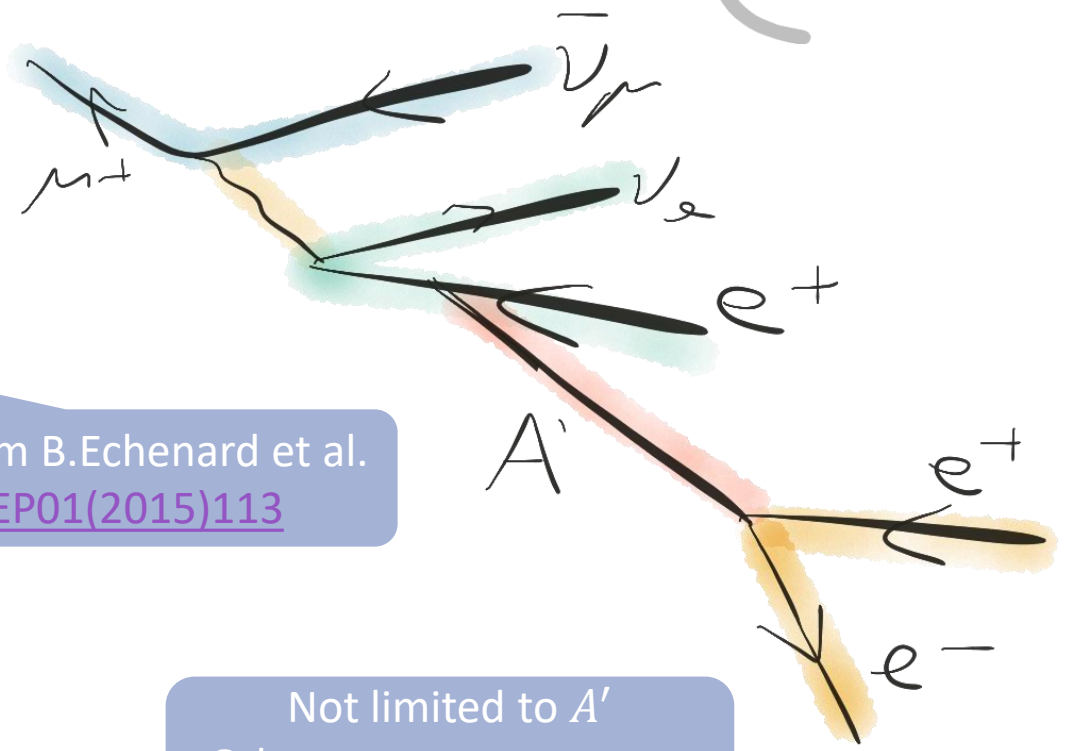


Dark Photon Searches in Mu3e

- Dark photon A'
  - Vector portal to dark sector
  - Interaction with SM particles via kinetic mixing with the photon
    $\mathcal{L}_{A'} = -\frac{\varepsilon}{2}F'_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m_{A'}A'_{\mu}A'^{\mu}$
  - Test A' with $m_{A'} < m_{\mu}$ in Mu3e

➢Search for e^+e^- resonance

- Search strategy depends on A' lifetime
  $c\tau = 0.8\text{mm}\left(\frac{10^{-4}}{\varepsilon}\right)^2 \frac{10\text{MeV}}{m_{A'}}$



$\mathcal{L}_{A'}$ from B.Echenard et al. JHEP01(2015)113

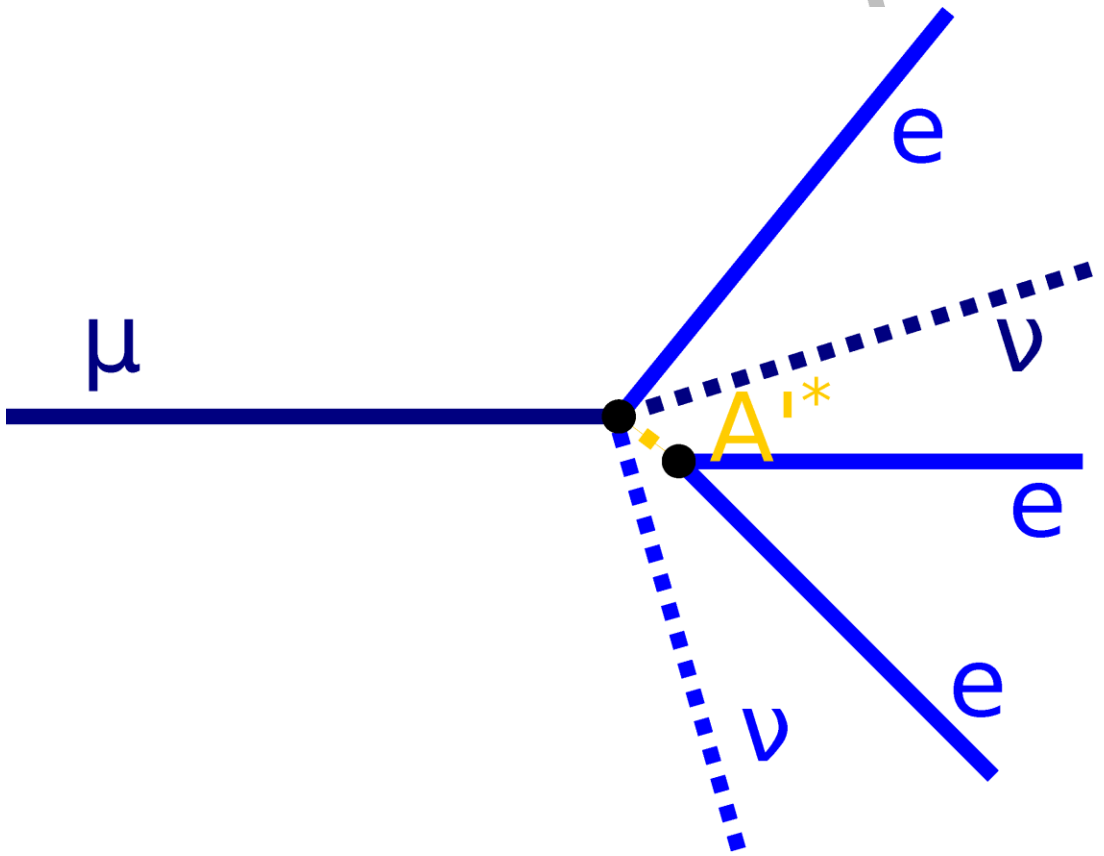
Not limited to A'
Other ee resonances can be investigated as well

Easy: $\mu \to e\nu\nu A'$ with prompt $A' \to ee$

- $e^+e^-e^+$ from a common vertex on/close to target

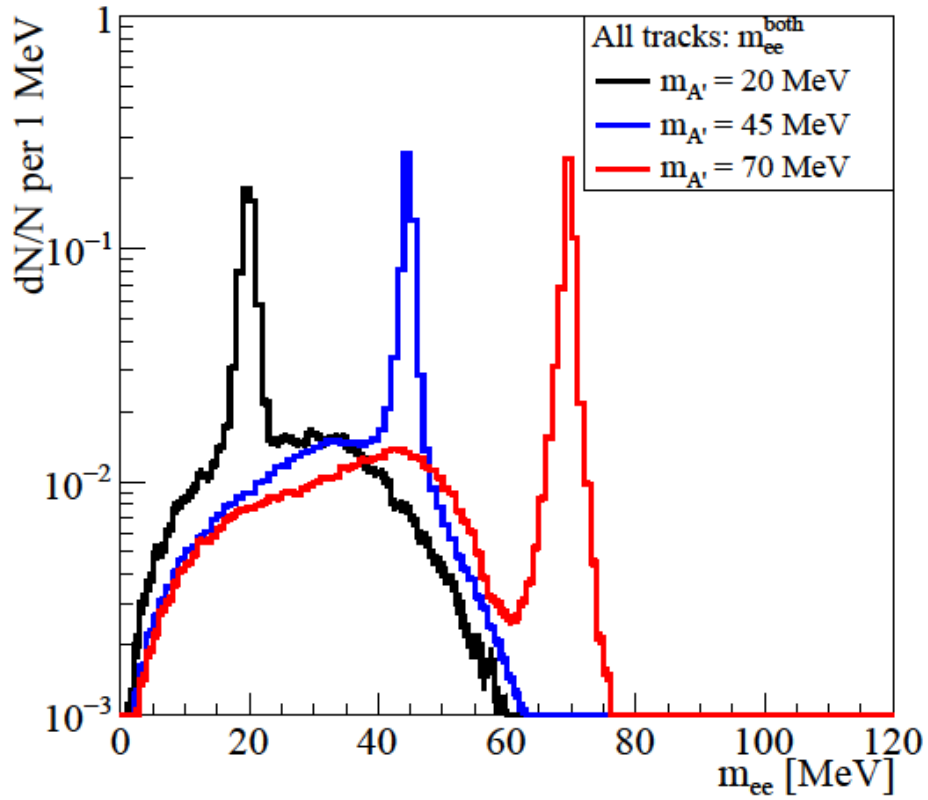
➢Same dataset as for $\mu \to eee$ search

- Search for resonance in m_{ee} in e^+e^- pairs
- Background
  - Rare muon decay $\mu \to eee\nu\nu$
  - Combinations of Bhabha scattering events with Michel decays

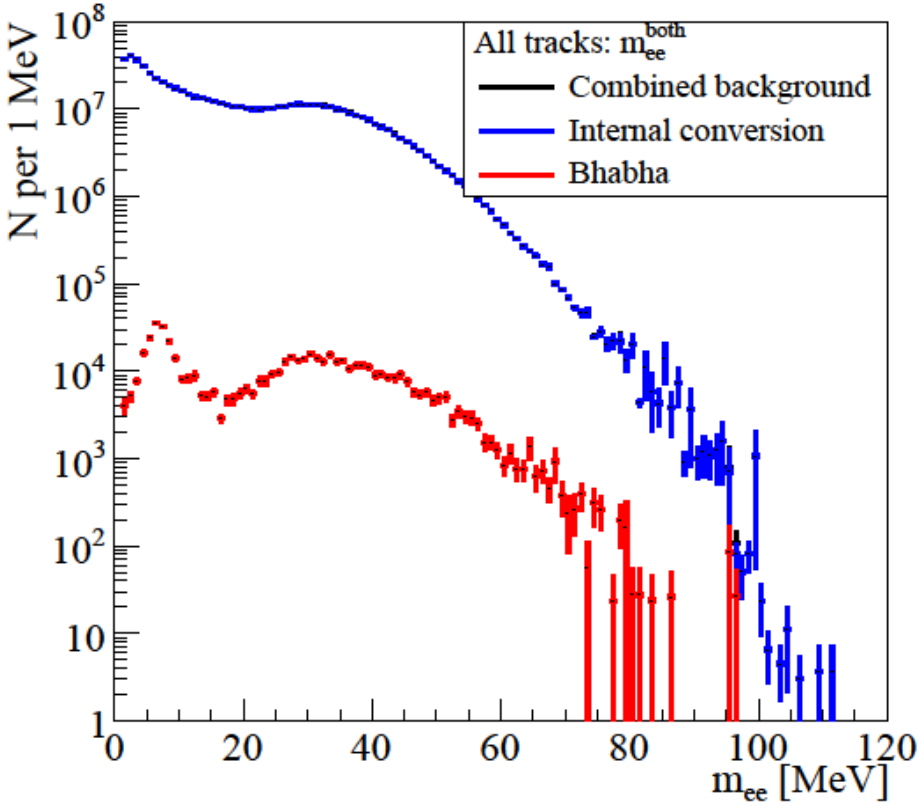


Easy: $\mu \to e\nu\nu A'$ with prompt $A' \to ee$

Signal



Background



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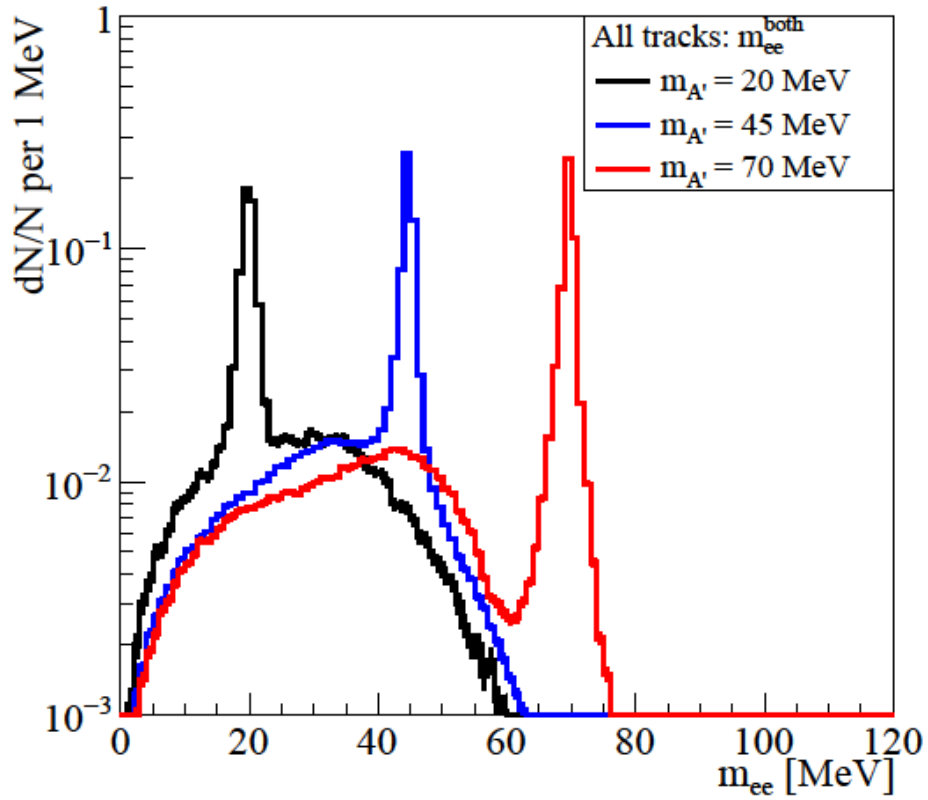

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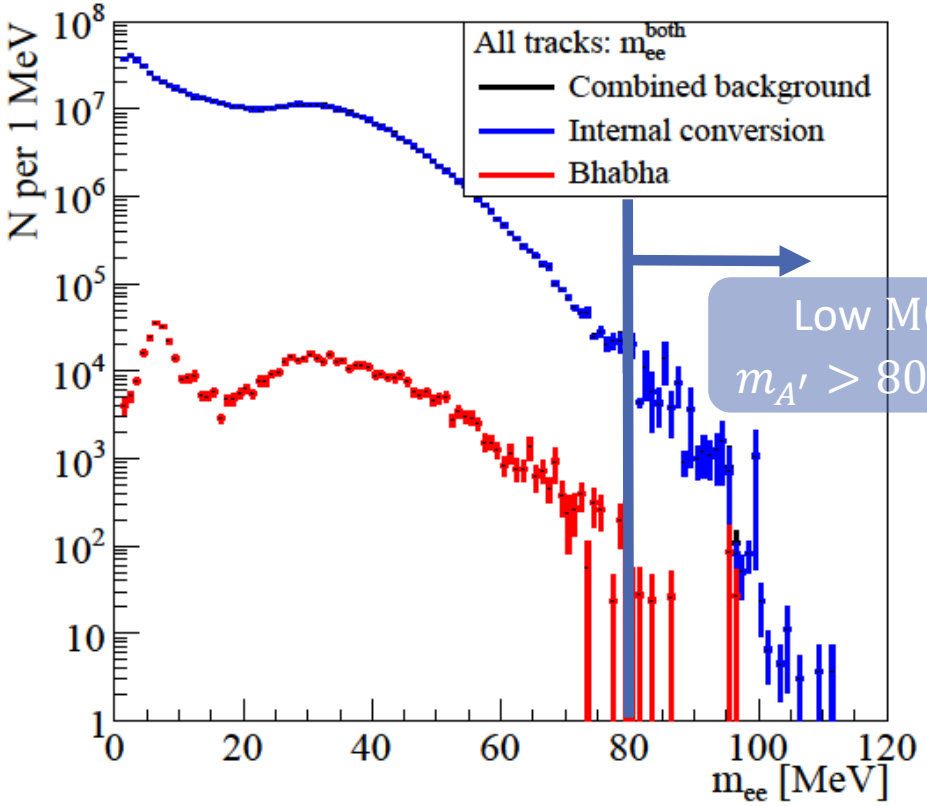
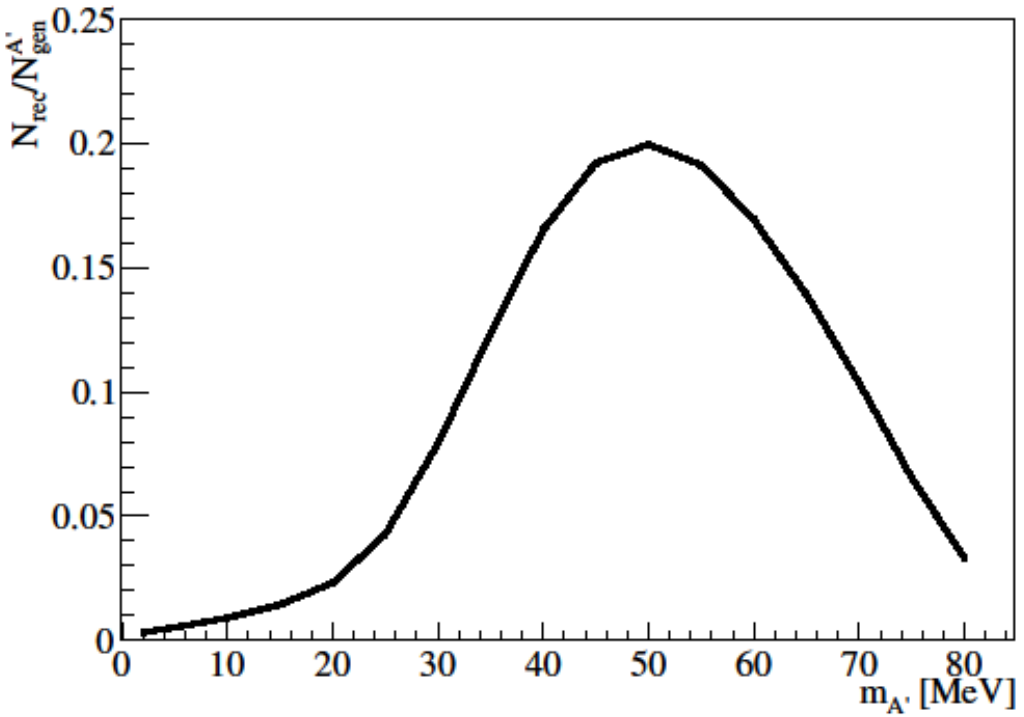


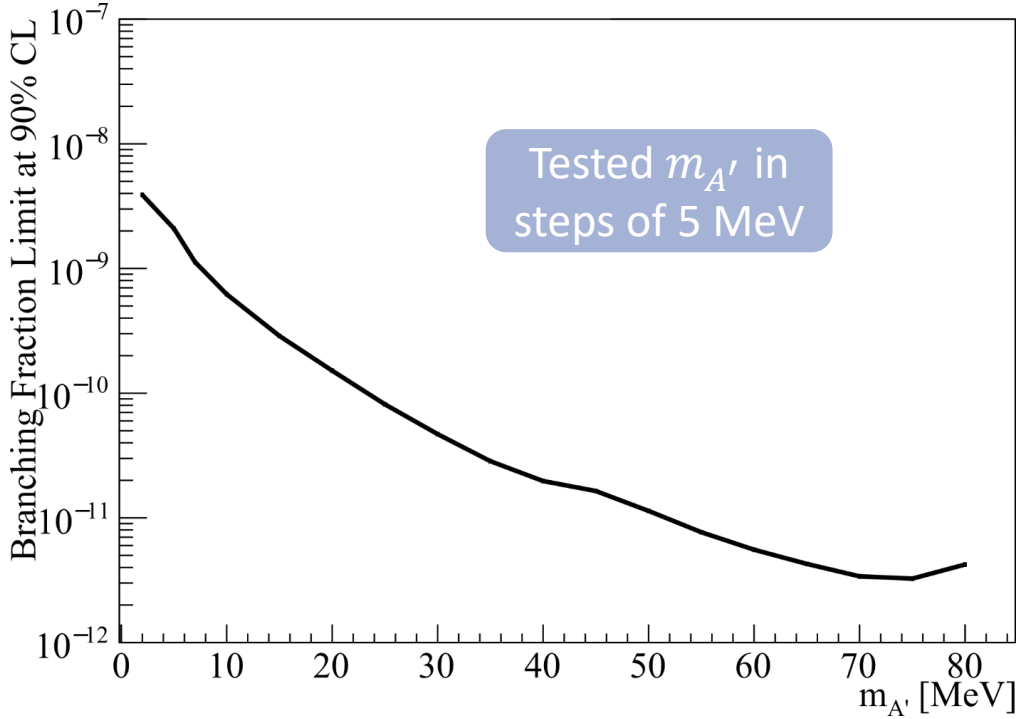
Low MC_{bkg} stats:
$m_{A'} > 80$MeV omitted

Easy: $\mu \to e\nu\nu A'$ with prompt $A' \to ee$

Signal reconstruction efficiency



Prospected $\mathcal{B}$ sensitivity in Phase I



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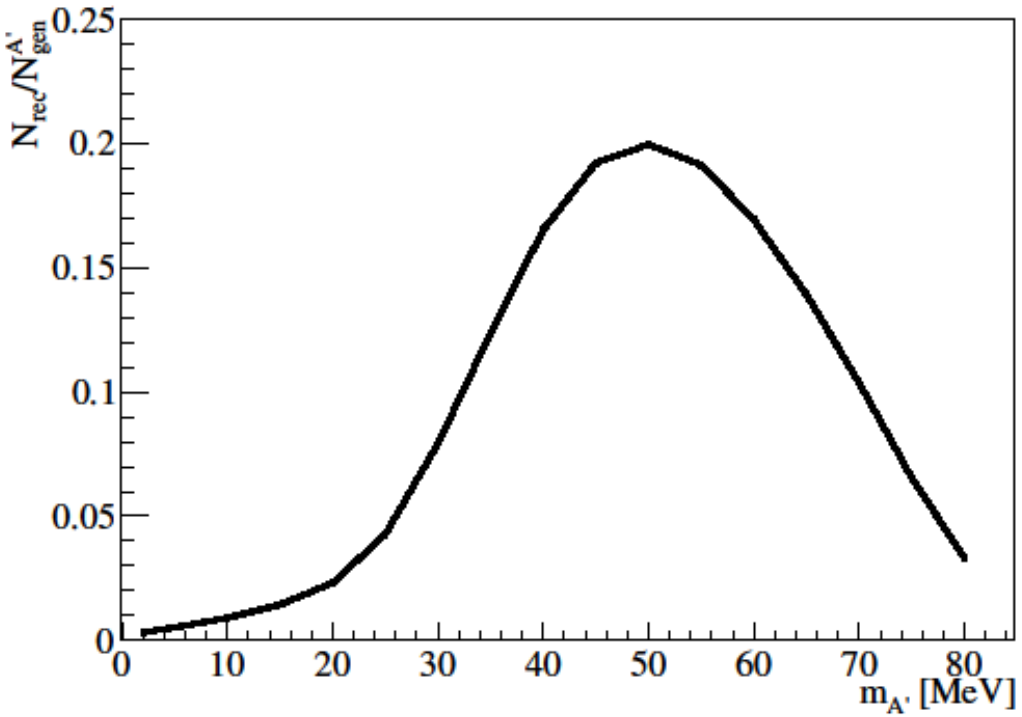

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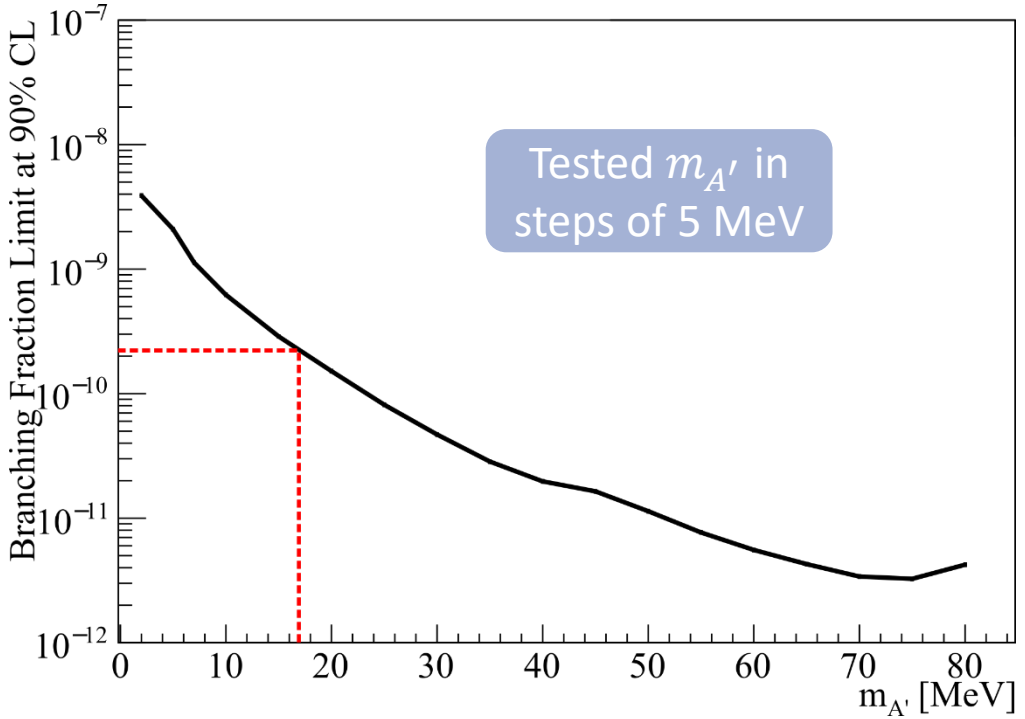

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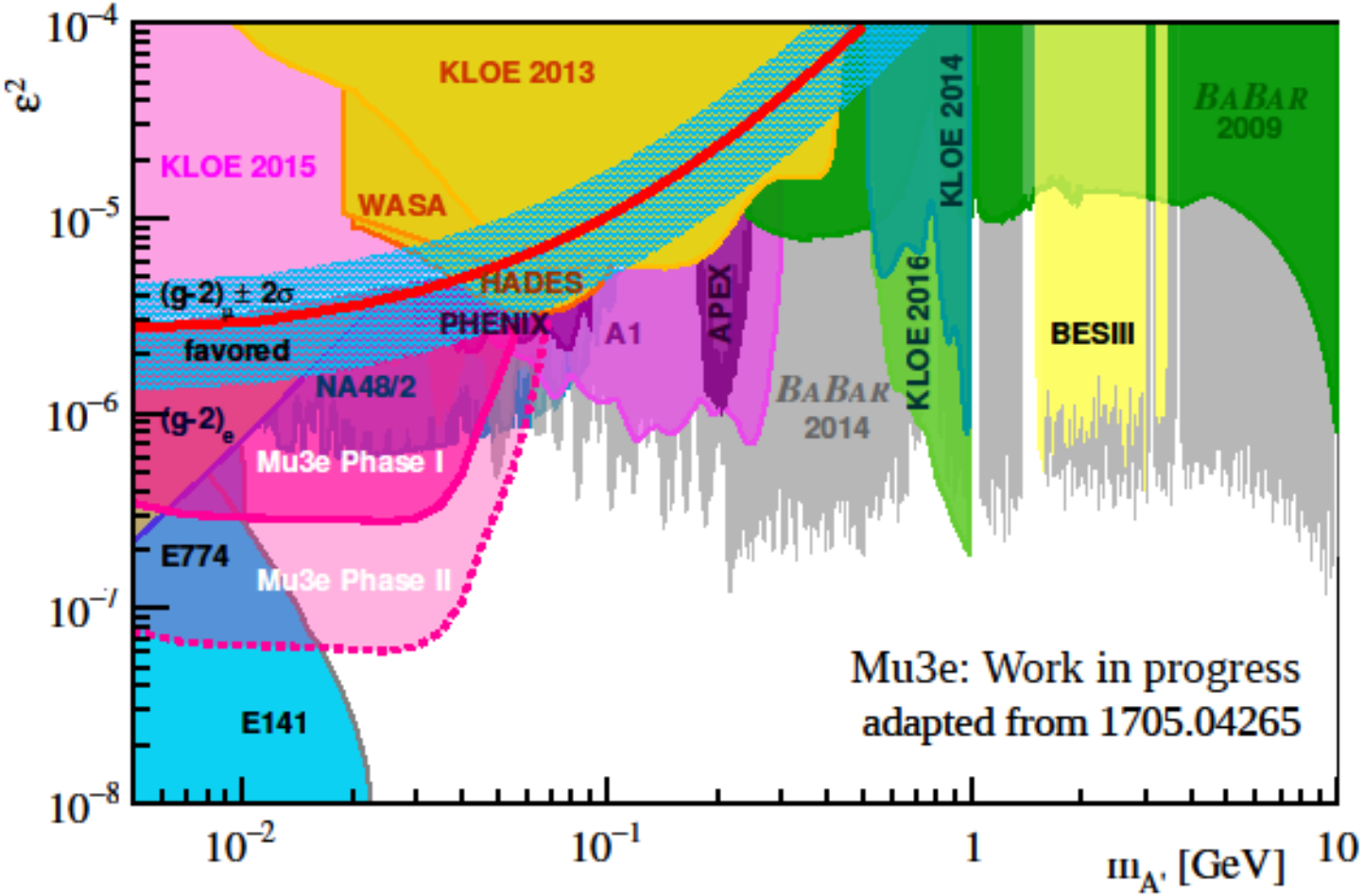


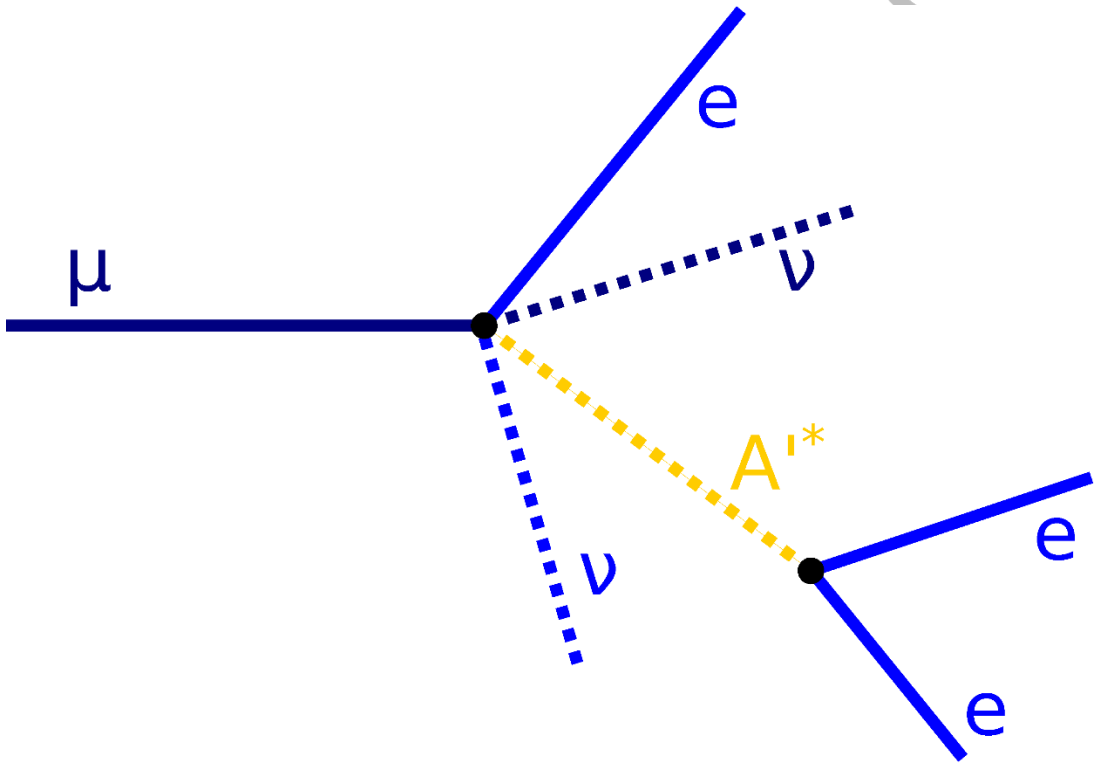
Reach in A' parameter space (assuming $\mathcal{B}(A' \to ee) = 1$)

Phase I: $2.6 \cdot 10^{15}$ μ decays

Phase II: $5.5 \cdot 10^{16}$ μ decays, detector improvements not considered

Difficult: $\mu \rightarrow e\nu\nu A'$ with displaced $A' \rightarrow ee$

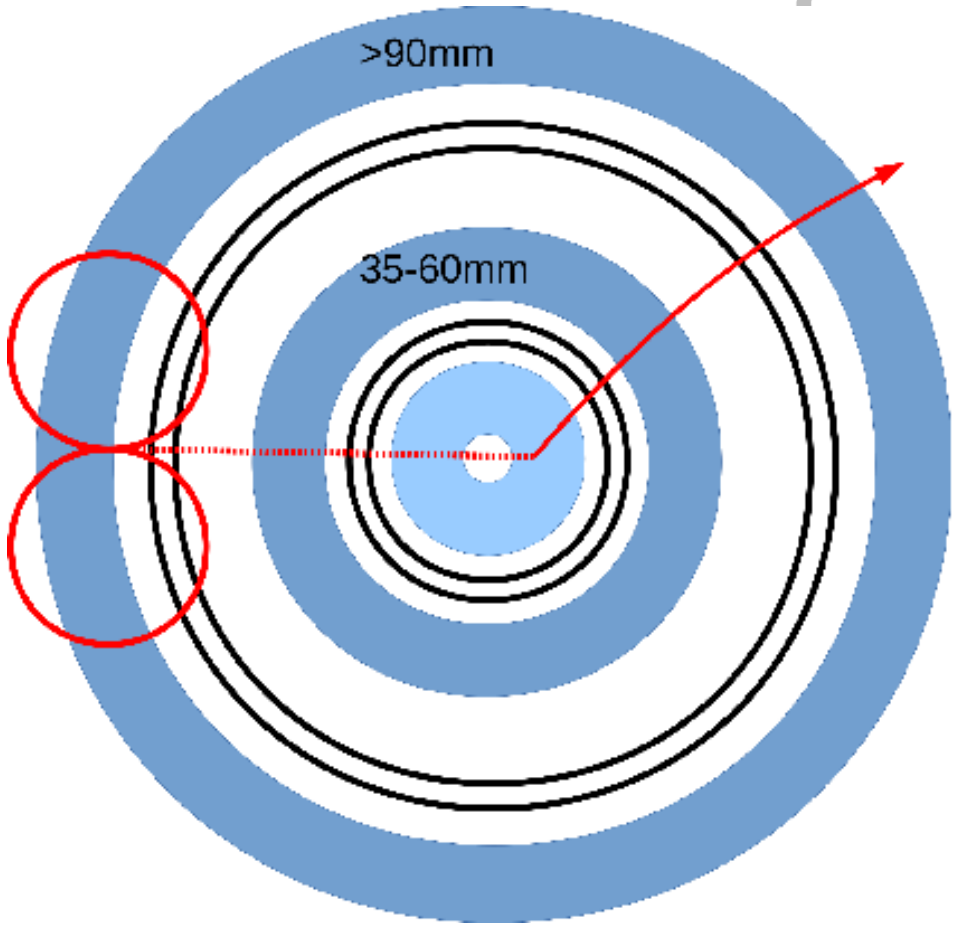
- e^+e^- pair from a displaced vertex
- Background from Bhabha scattering and photon conversion
- Difficulties:
  - Current online event filtering selects only 3 e events
  - ➢ No online track reconstruction for tracks originating from outside target region
  - ➢ No online displaced vertex reconstruction
  - Recording single-e events not feasible
  - First studies on offline track and vertex reconstruction



Difficult: $\mu \rightarrow e\nu\nu A'$ with displaced $A' \rightarrow ee$

- Fiducial volume:
  - Volume around target covered by prompt analysis
  - Leave out areas close to pixel layers and fibres due to background
  - Decay $e^{\pm}$ have to pass at least 2 pixel layers
- Decay lengths of several cm can be studied → small ε

$$c\tau = 0.8\text{mm}\left(\frac{10^{-4}}{\varepsilon}\right)^2 \frac{10\text{MeV}}{m_{A'}}$$



Impossible: $\mu \to e\nu\nu A'$ with invisible A'

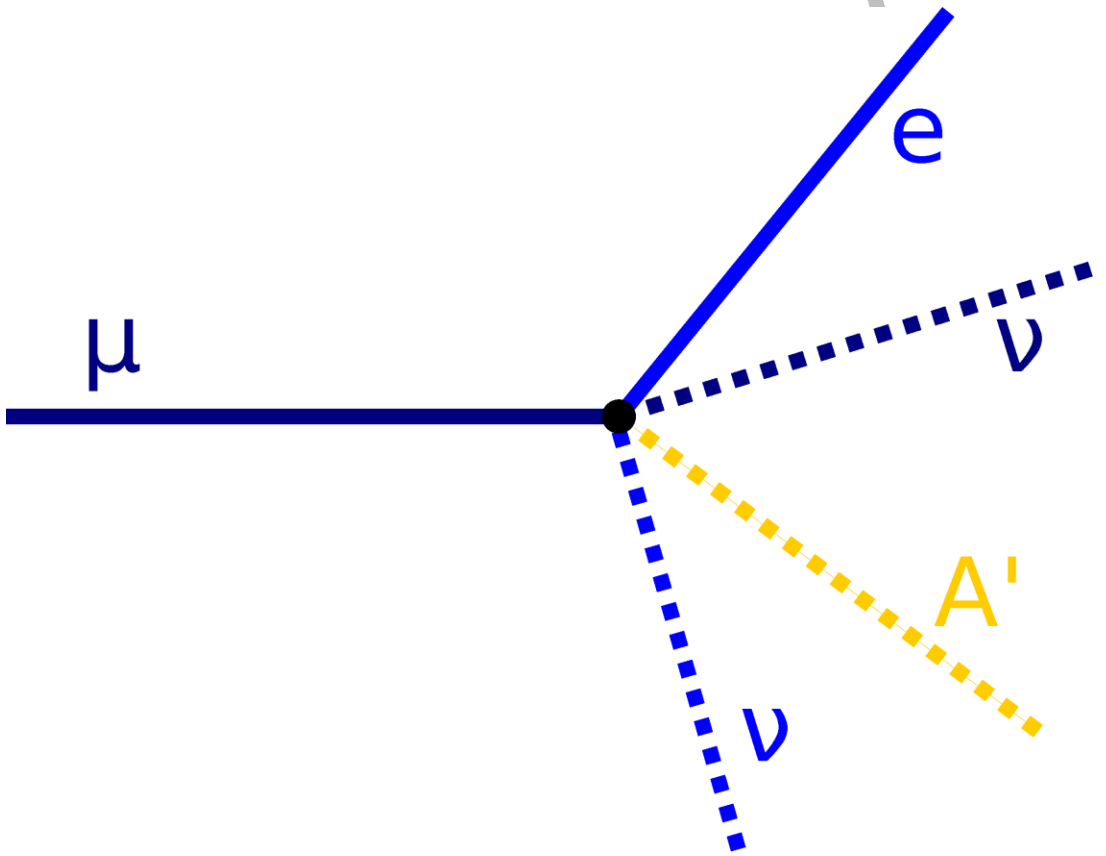
- Invisible A': stable, long-lived or decaying to invisible

- Only one electron to be detected

➢Similar to dominant Michel decay $\mu \to e\nu\nu$

➢Deviation in the p_e spectrum?

- Single-e events not selected in online filter farm



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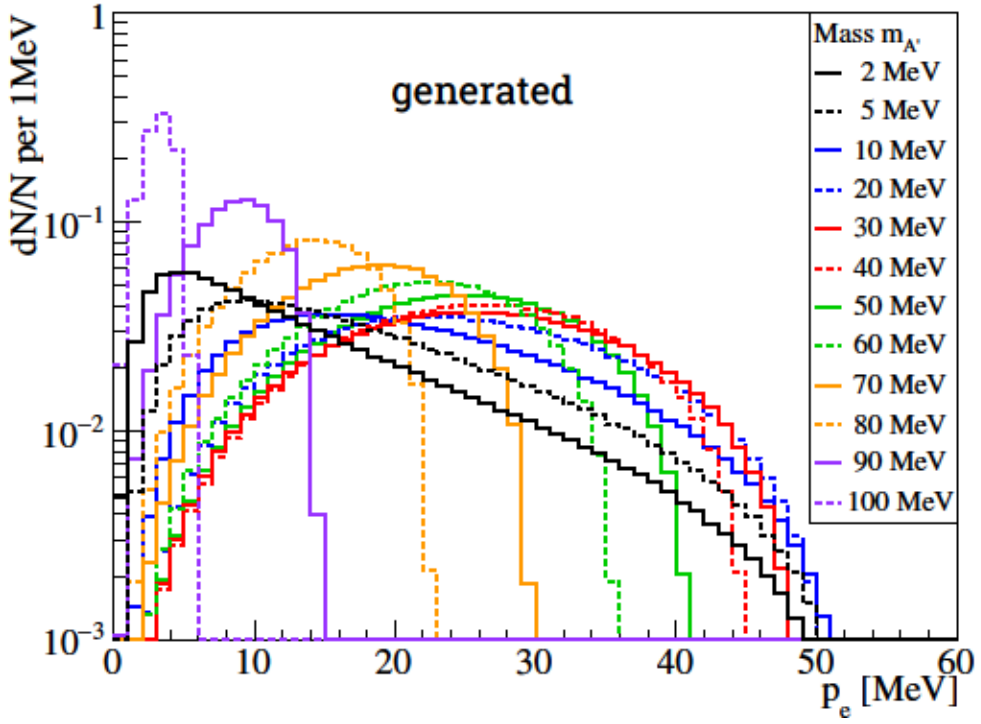
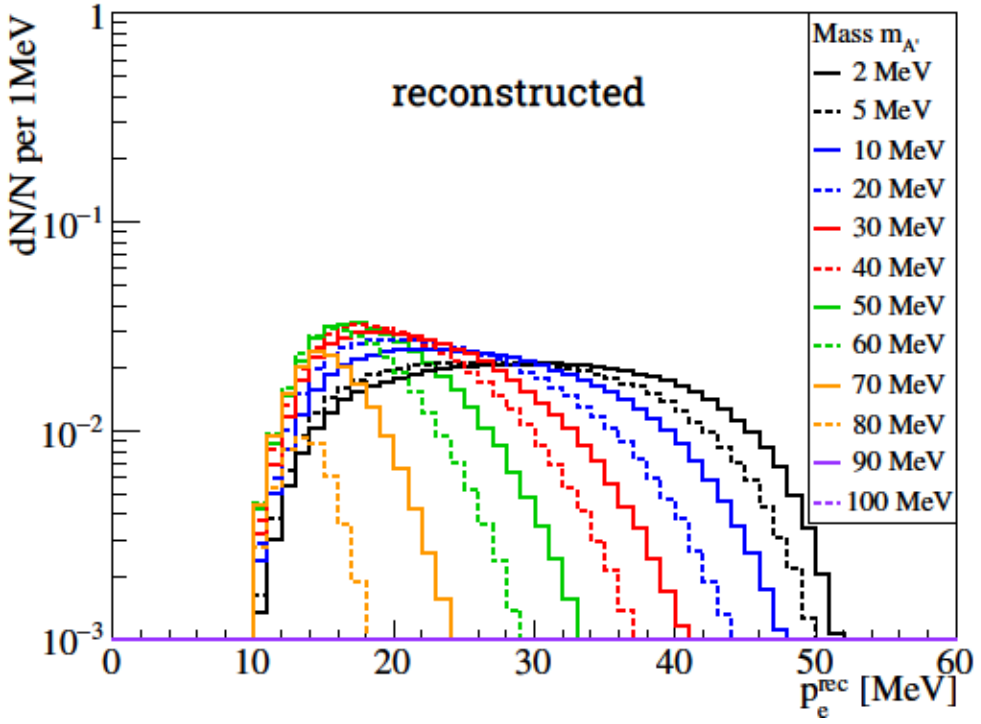
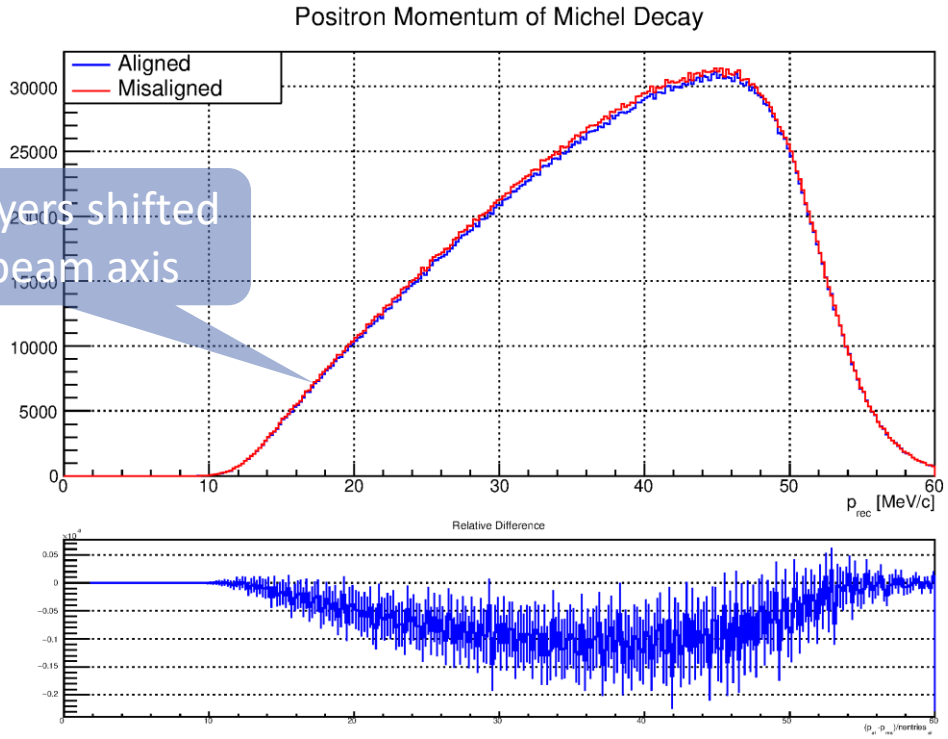
Deviation in the p_e spectrum?



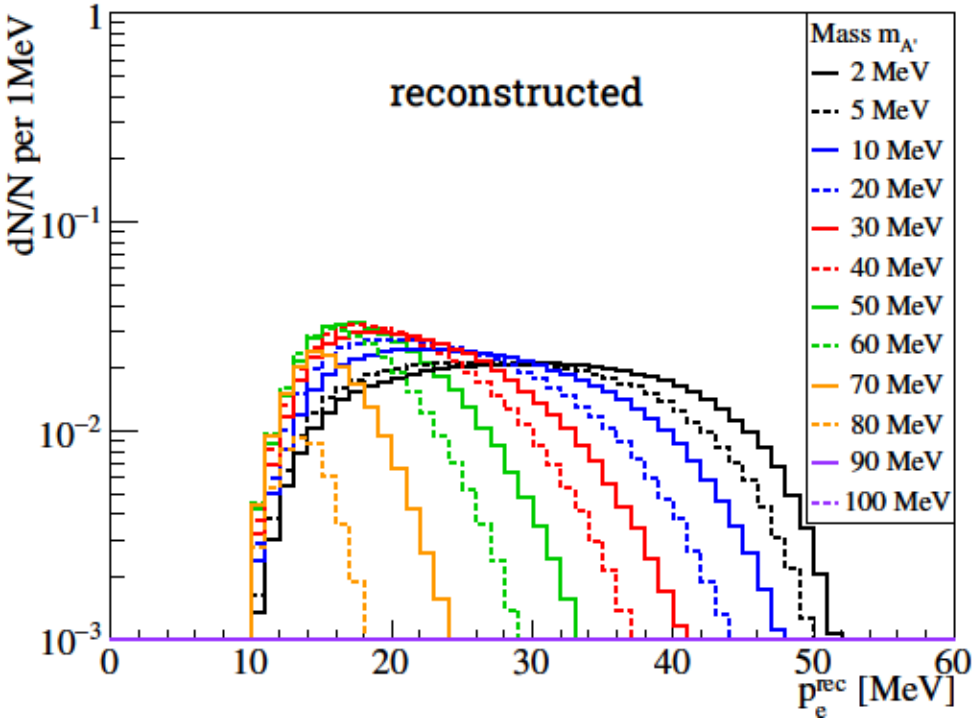


Impossible: $\mu \to e\nu\nu A'$ with invisible A'

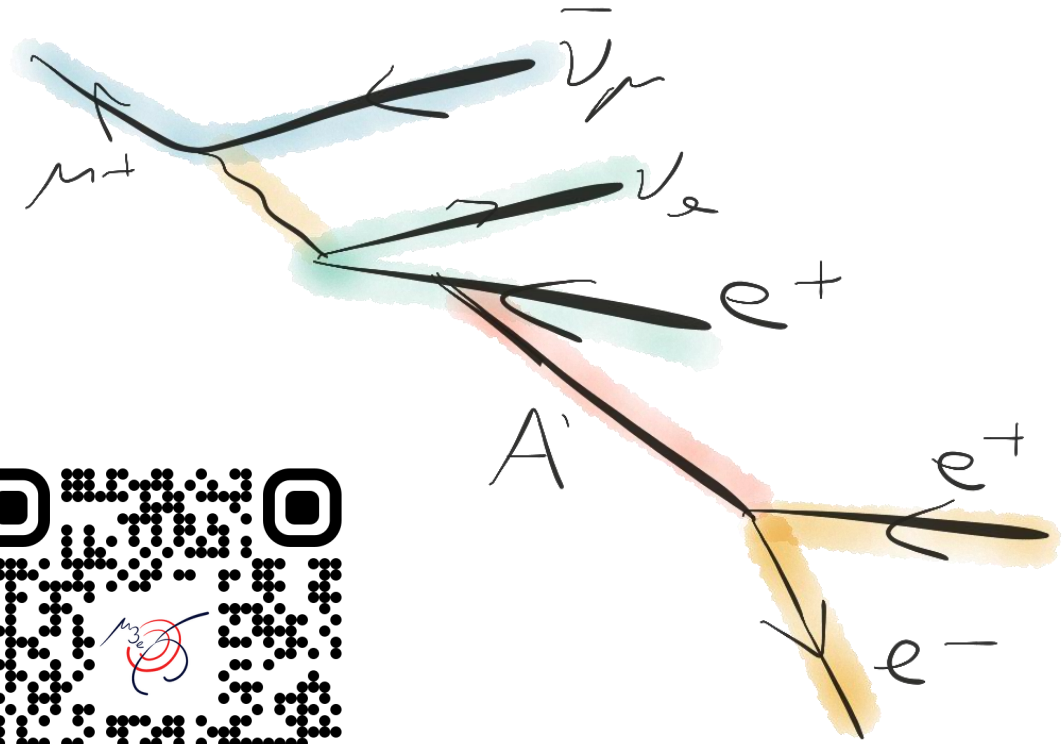
Deviation in the p_e spectrum? → Looks like mis-alignment



Vertex layers shifted along beam axis



Prospects for Dark Photon Searches in the Mu3e experiment



https://www.psi.ch/en/mu3e

- Mu3e will record an unprecedented dataset of $\mathcal{O}(10^{15})$ μ decays in phase I
- Precise $e^{\pm}$ tracking and high acceptance

- Prospects for A' searches
  - Dark photons with $m_{A'} \leq 100\text{MeV}$ in $\mu \to evvA'(\to ee)$
  - Promptly decaying A' in nominal $\mu \to eee$ data
  - Displaced $A' \to ee$ vertices only possible with significant changes to DAQ and reconstruction
  - Invisible A' most likely not accessible