

# Dark Photon & Displaced Vertices @ MUonE

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Based on: **arXiv 2202.08843** with Dr. Iftah Galon and Prof. David Shih

# Dark Sector Mediator

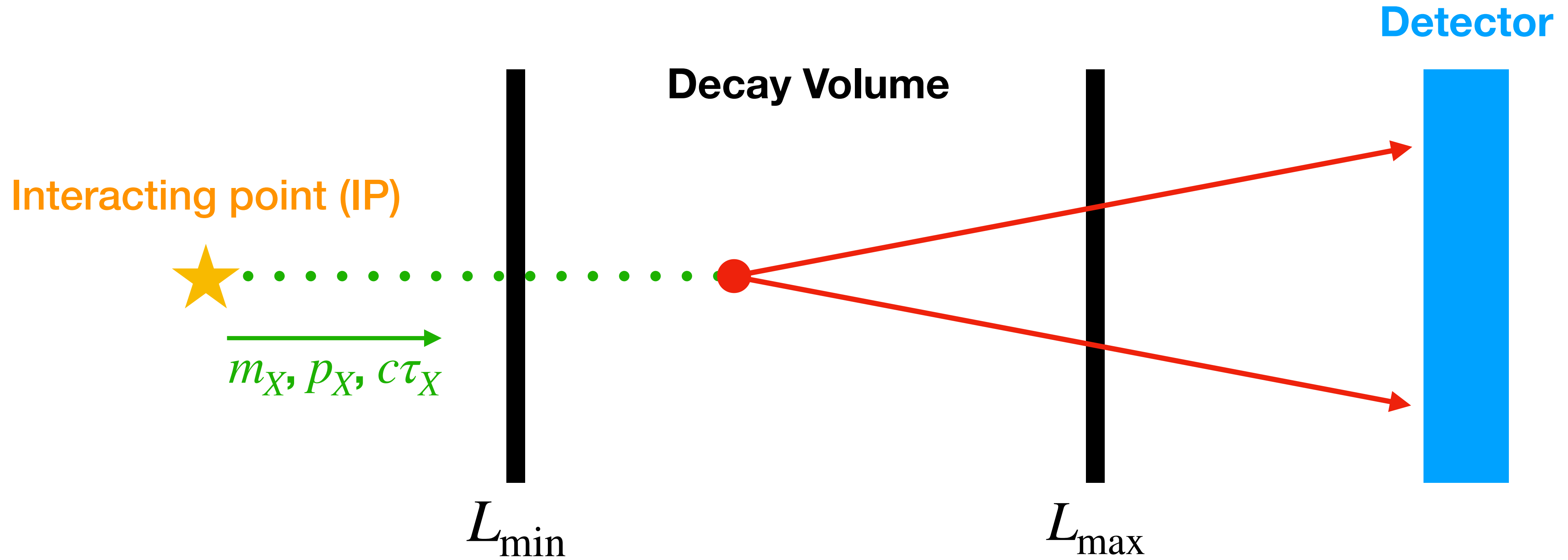


Motivation: Dark Matter, and from other puzzles

- Typically MeV to GeV range: relatively light
- Particular case: weakly-interacting, **long-lived**

**Light Long-lived Particles: LLP**

# LLP Detection

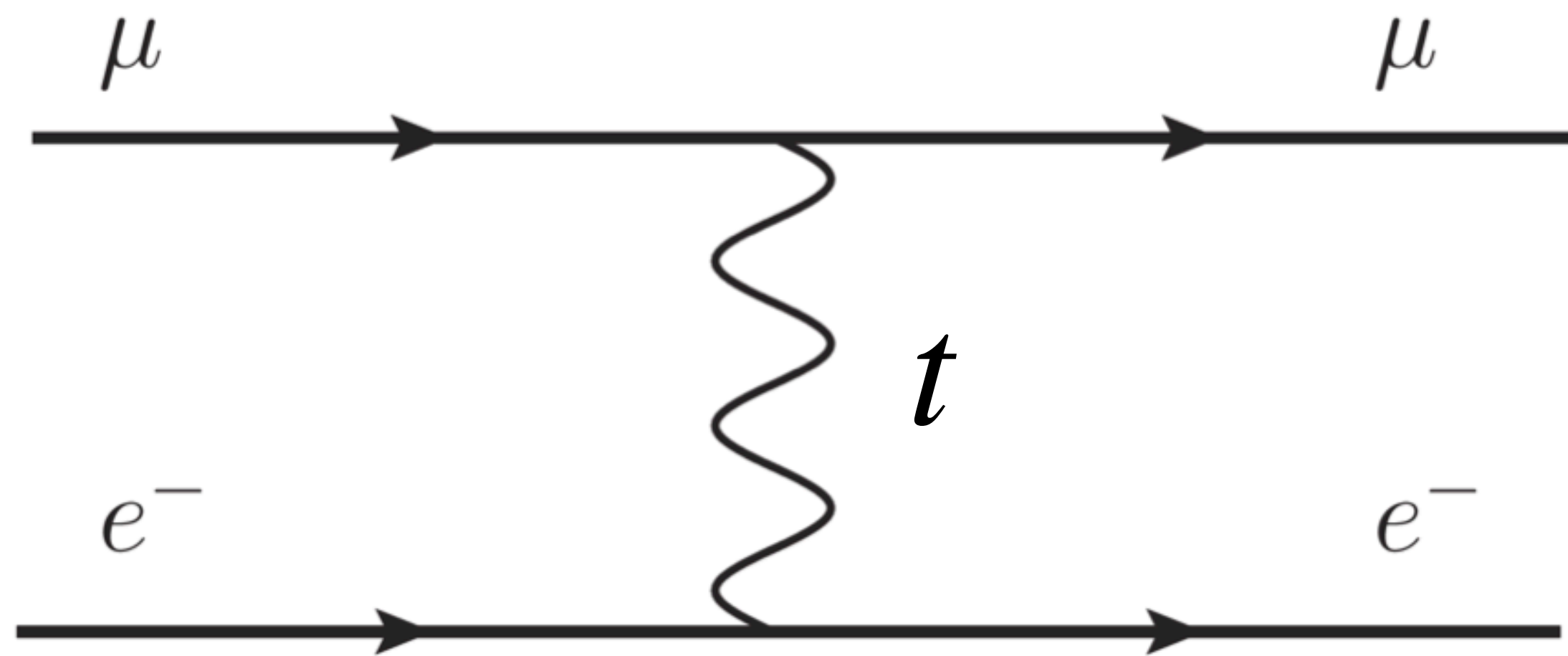


$$P_{\text{in-volume}} = e^{-L_{\min}/\bar{d}} - e^{-L_{\max}/\bar{d}}$$

$$\text{where } \bar{d} = \frac{p_X}{m_X \Gamma_X}$$

# The MUonE Experiment

Elastic  $\mu - e$  scattering



t-channel:

Measuring:  $\frac{d\sigma}{dt}$ ,

Hadronic contribution  
to running  $\alpha(t)$

High resolution for angle measurement

Great for detecting displaced vertex!

# Demonstration: Dark Photon @ MUonE

- Vanilla simplified model:

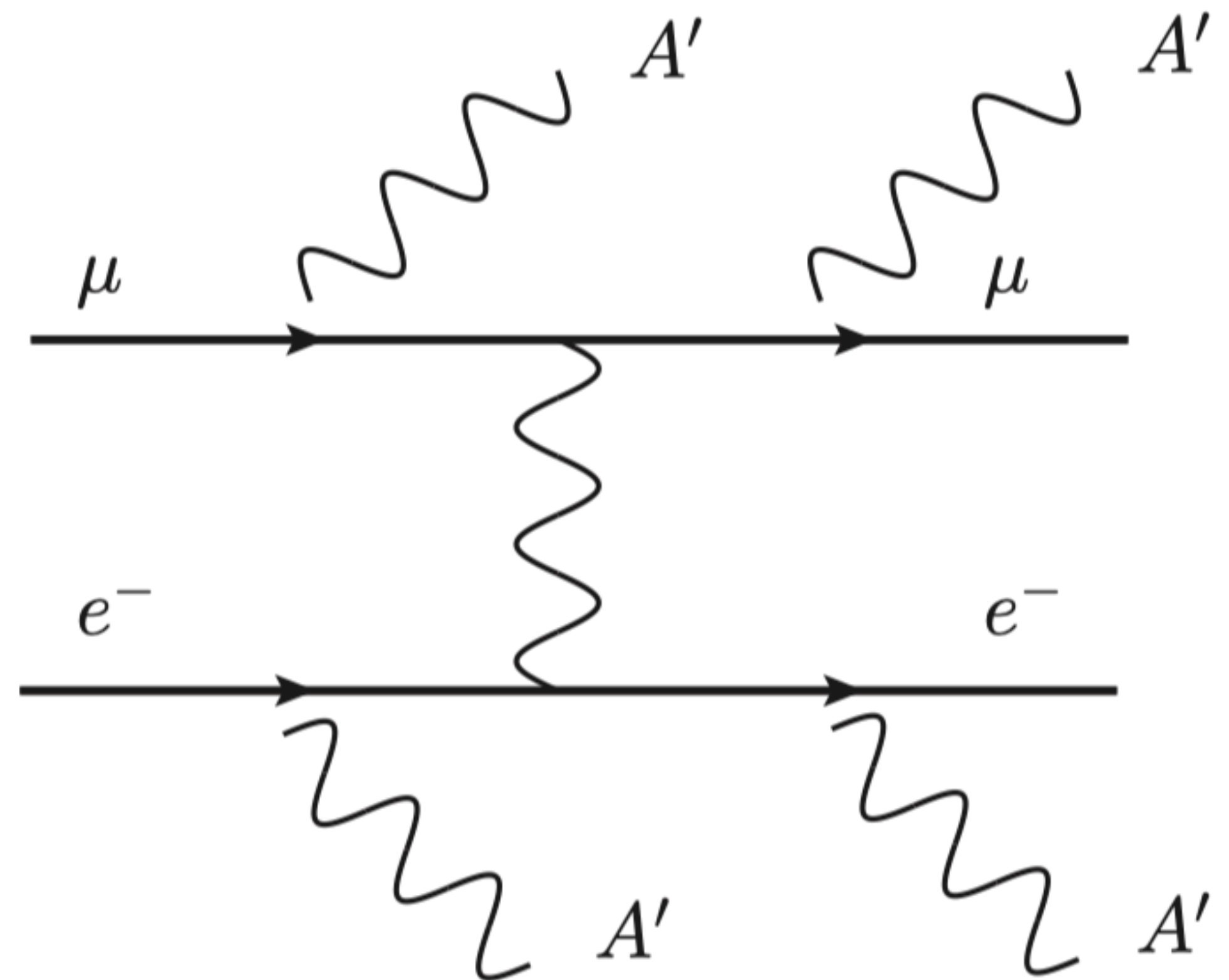
$$\mathcal{L}_{A'} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{2}m_{A'}^2 A'_\mu A'^\mu - \epsilon e A'_\mu J_{EM}^\mu$$

- Long-lived, light, weakly interacting

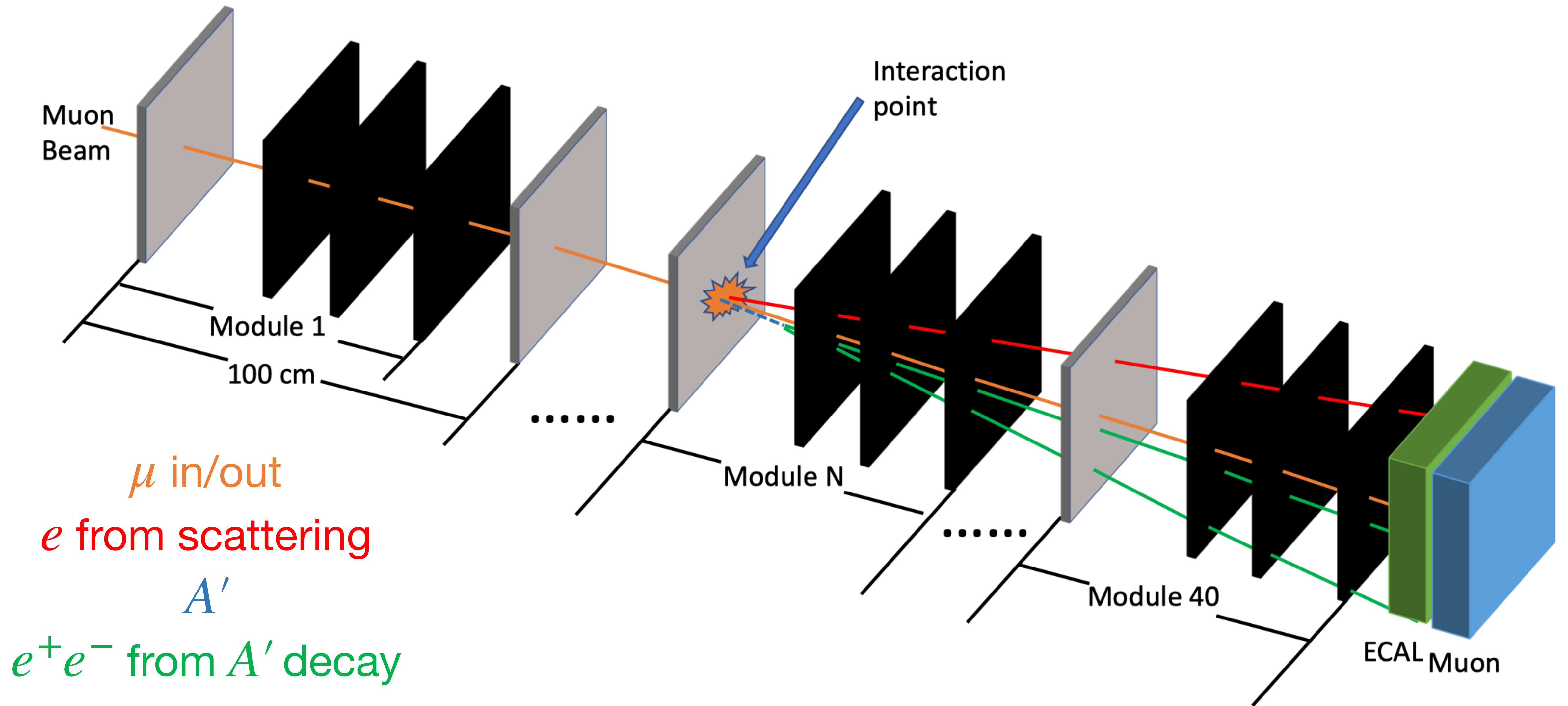
- Be produced at MUonE:  $\mu e \rightarrow \mu e A'$

- Decay width:  $\Gamma_{A'} = \frac{(\epsilon e)^2}{12} m_{A'} \left( 1 - 4 \frac{m_e^2}{m_{A'}^2} \right) \sqrt{1 + 2 \frac{m_e^2}{m_{A'}^2}}$

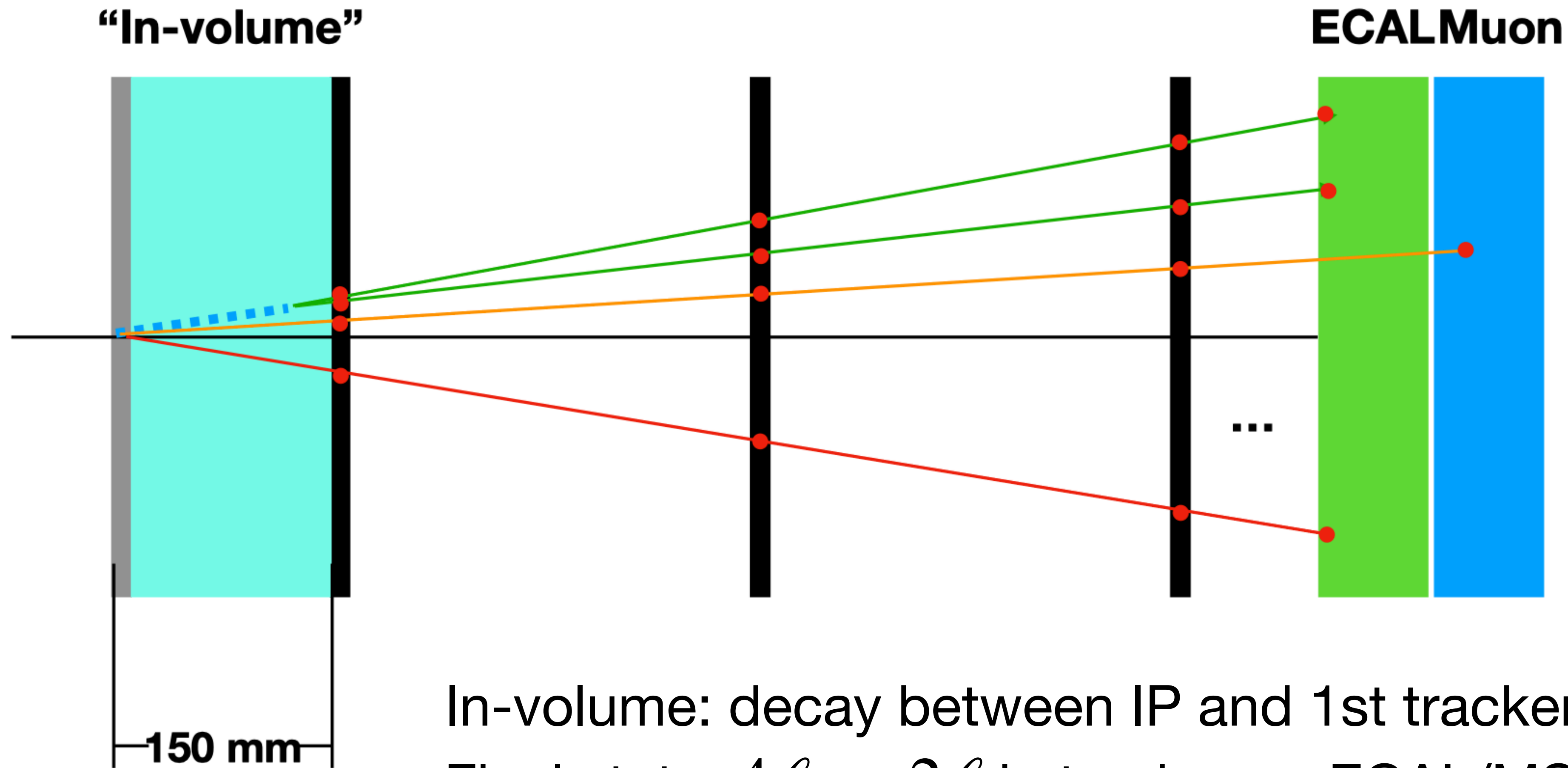
- Decay into electron-positron pair (assuming decaying into dark sector particles are kinematically forbidden)



# Dark Photons @ MUonE

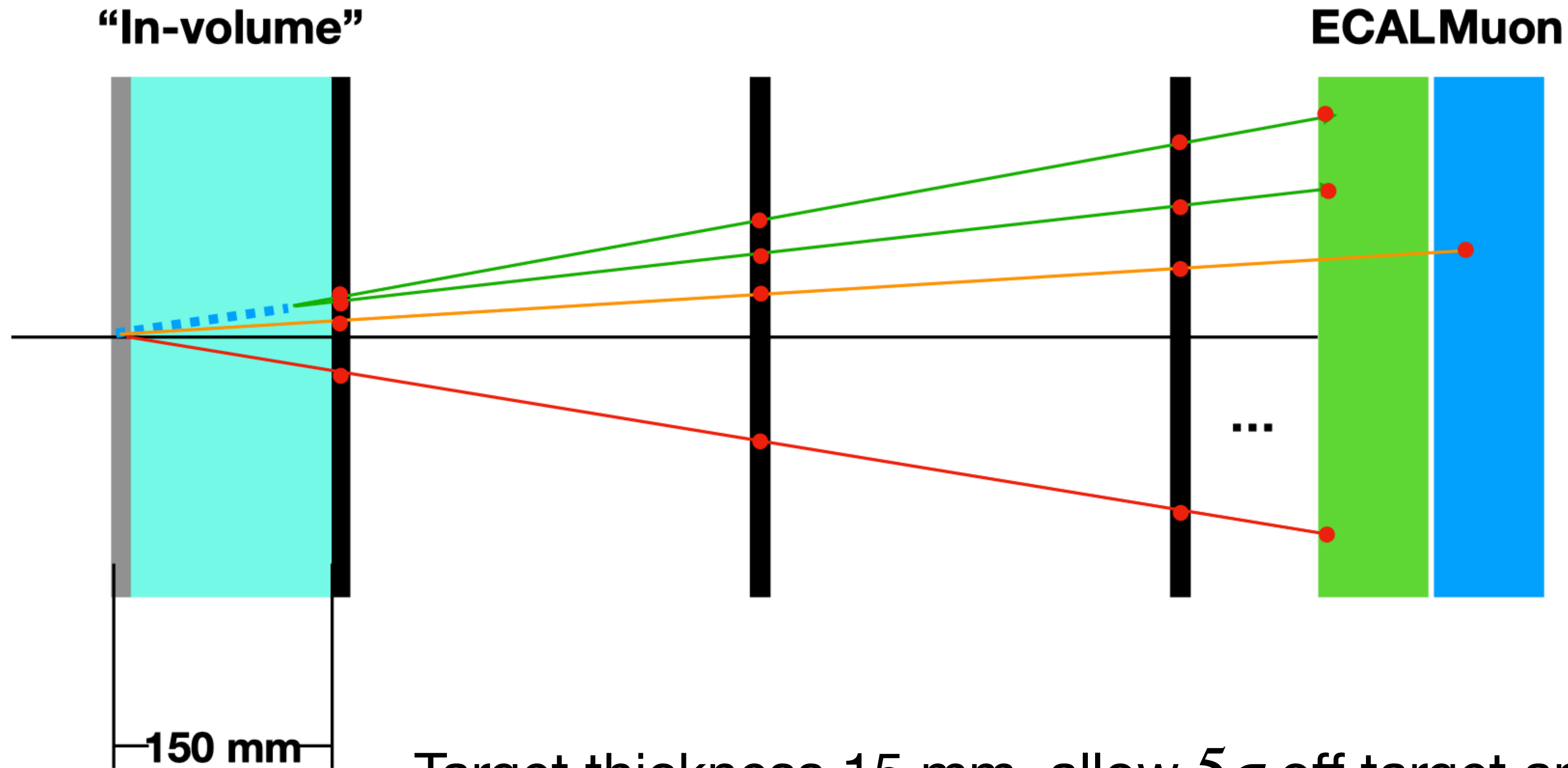


# Displaced Vertex from Dark Photon Decay



In-volume: decay between IP and 1st tracker  
Final state:  $4\ell$ , or  $2\ell$  in tracker, or ECAL/MS

# Displaced Vertex from Dark Photon Decay



Target thickness 15 mm, allow  $5\sigma$  off target and tracker.

Decay volume:  $L_{\min} = 20$  mm,  $L_{\max} = 145$  mm

# Backgrounds

- SM processes with an inherently displaced vertex.

e.g. Kaons from coherent and deep inelastic  $\mu - Nuc$  scattering.

Typically soft, or contains hadronic process.

Need to fake electrons. Likely to be reduced.

- SM process with prompt decay but mis-reconstructed as displaced vertex.

e.g.  $\mu e \rightarrow \mu e \gamma^* (\gamma^* \rightarrow ee)$ , reduced by “decay in-volume” requirement + id

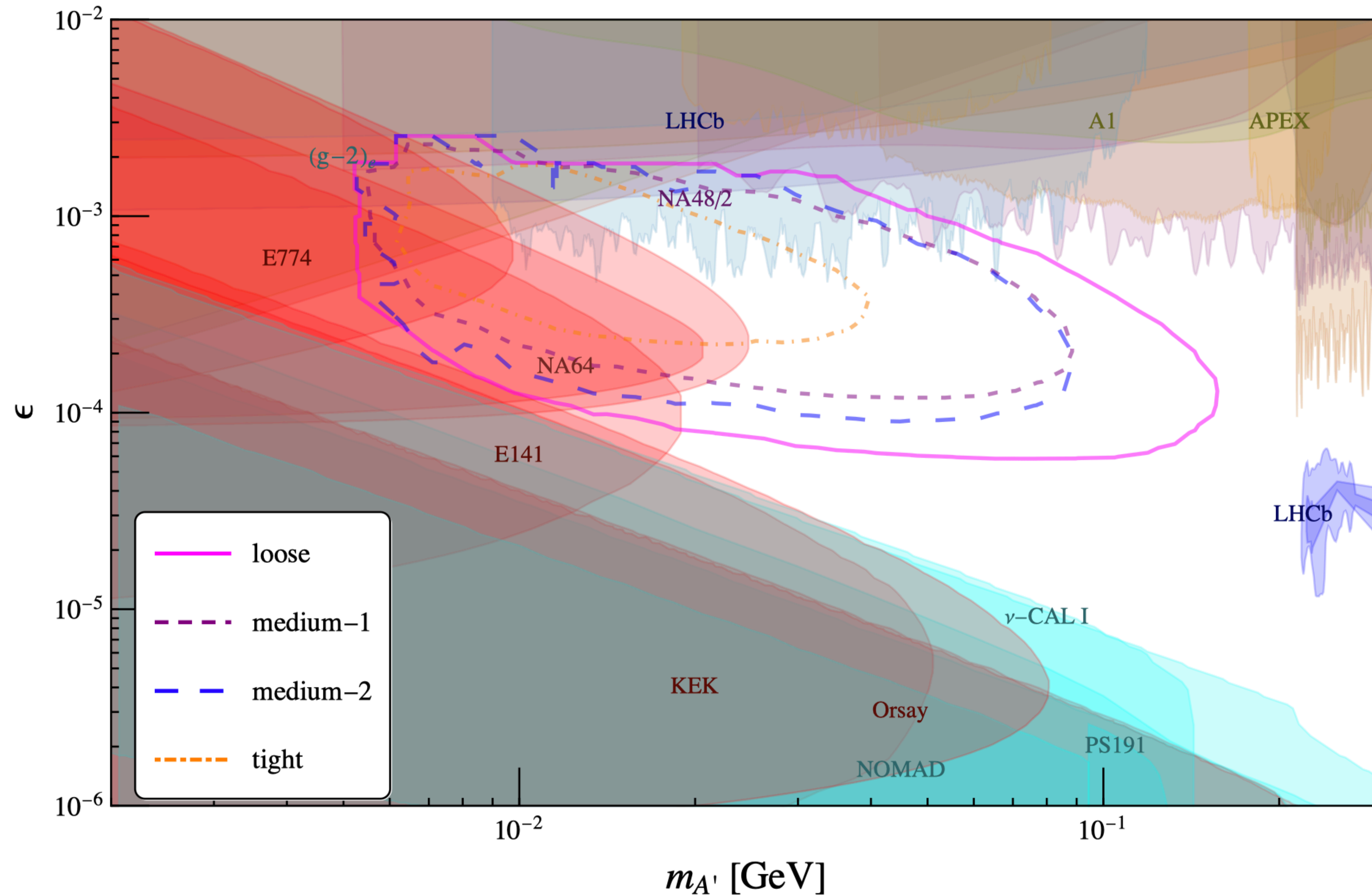
# Search Strategies

- “loose”: require a displaced vertex ( $e^+e^-$ ) through 3 trackers
- “medium 1”: require particle id for this pair, need entering ECAL
- “medium 2”: detect all 4 leptons in trackers
- “tight”: 4 leptons to enter ECAL

Comments:

- $E_\ell > 5$  GeV for leptons that required to be detected
- $\theta_{ee} > 1$  mrad for resolution
- For ECAL/MS requirement, use only last 5 modules
- Enforce angular acceptance of detectors

# Results: 90% CL for 0 Backgrounds



# Conclusions

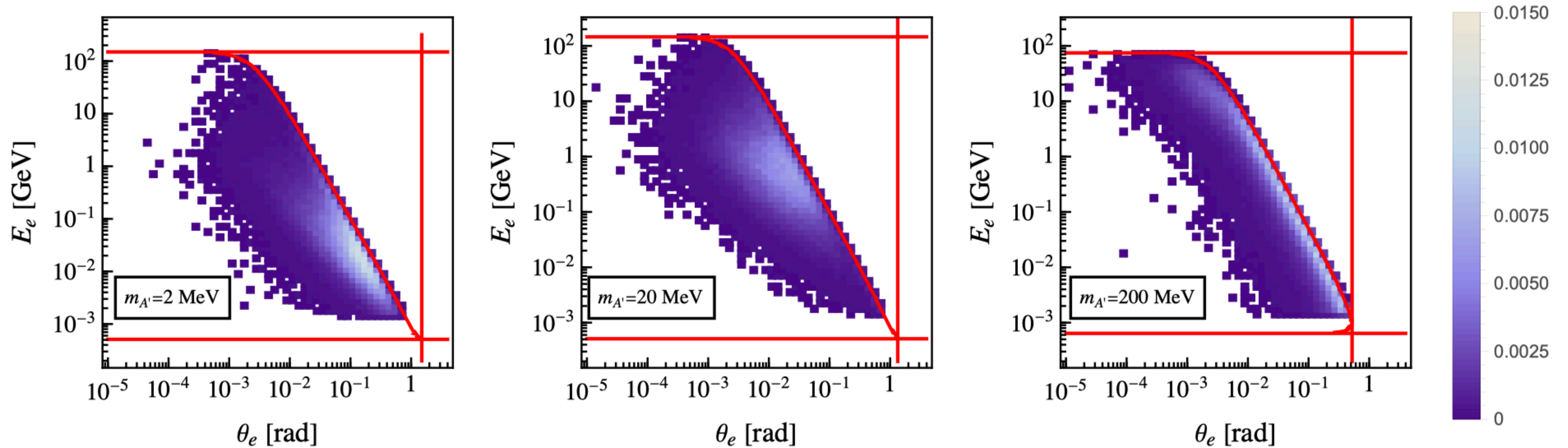
- MUonE is an experiment aiming at measuring the HVP contribution to elastic  $e\mu$  scattering. Its high resolution makes it a good experiment for detecting BSM physics.
- We proposed a search strategy for detecting displaced vertex  $A' \rightarrow e^+e^-$ . Further detailed background estimation is required.

**Backup**

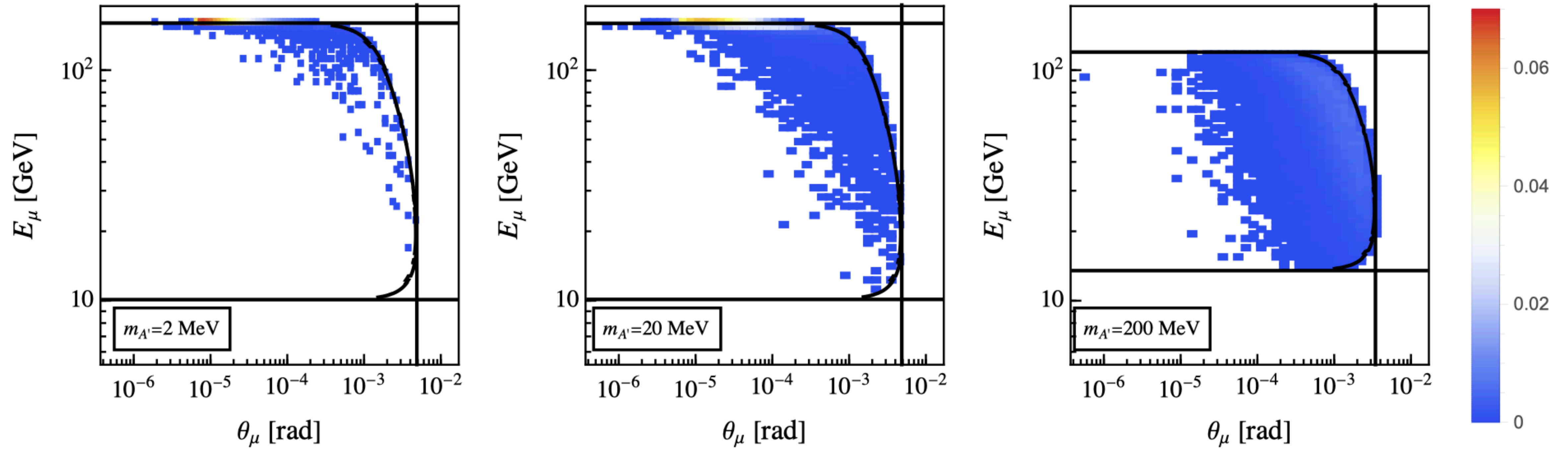
# Implementation

- Create UFO file and generate 100K  $\mu e \rightarrow \mu e A'$  events in MadGraph5 for different dark photon masses.
- Coupling  $\epsilon e = 1$  are kept during simulation. Cross-sections and decay width are computed and rescaled according to  $(\epsilon e)^2$ .
- Simulate dark photon decay by hand event-by-event, including decay length, and 4-momentum of decay products.
- Apply cuts by hand
- Event number is computed by the rescaled cross-section described above.

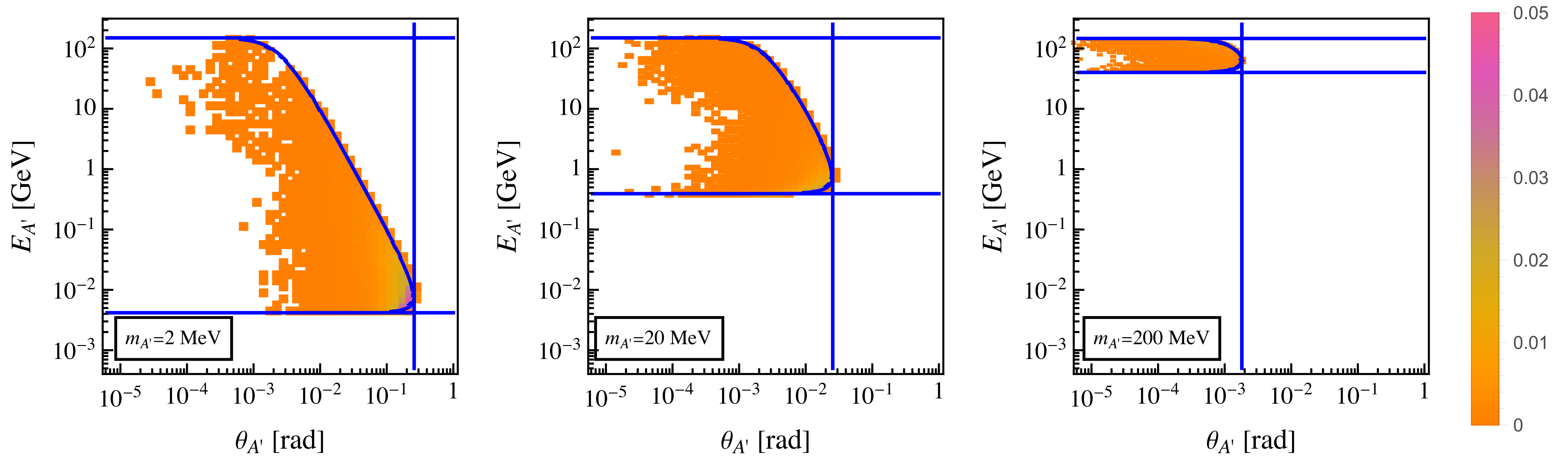
# Phase space distribution



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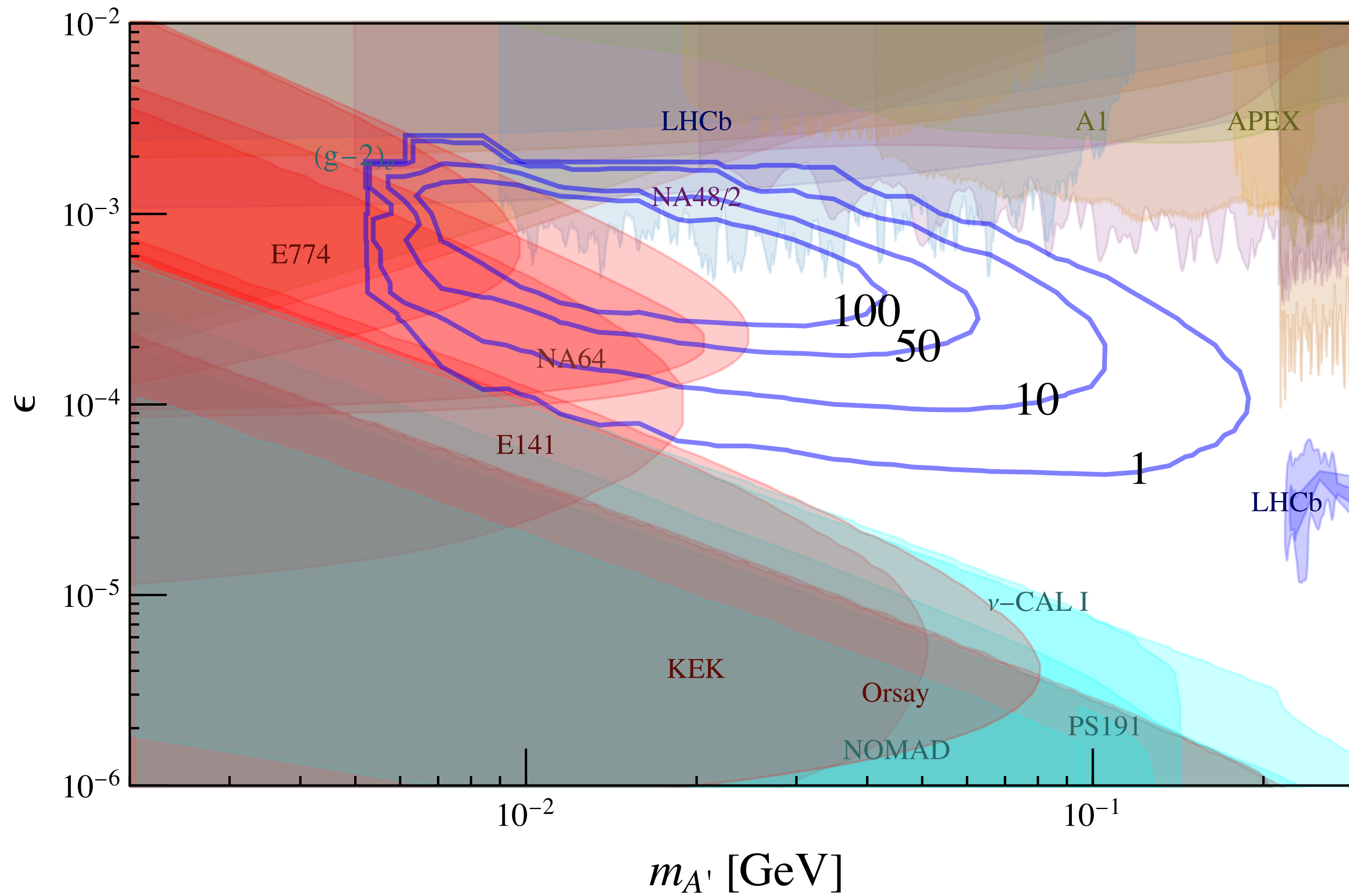


# Phase space distribution



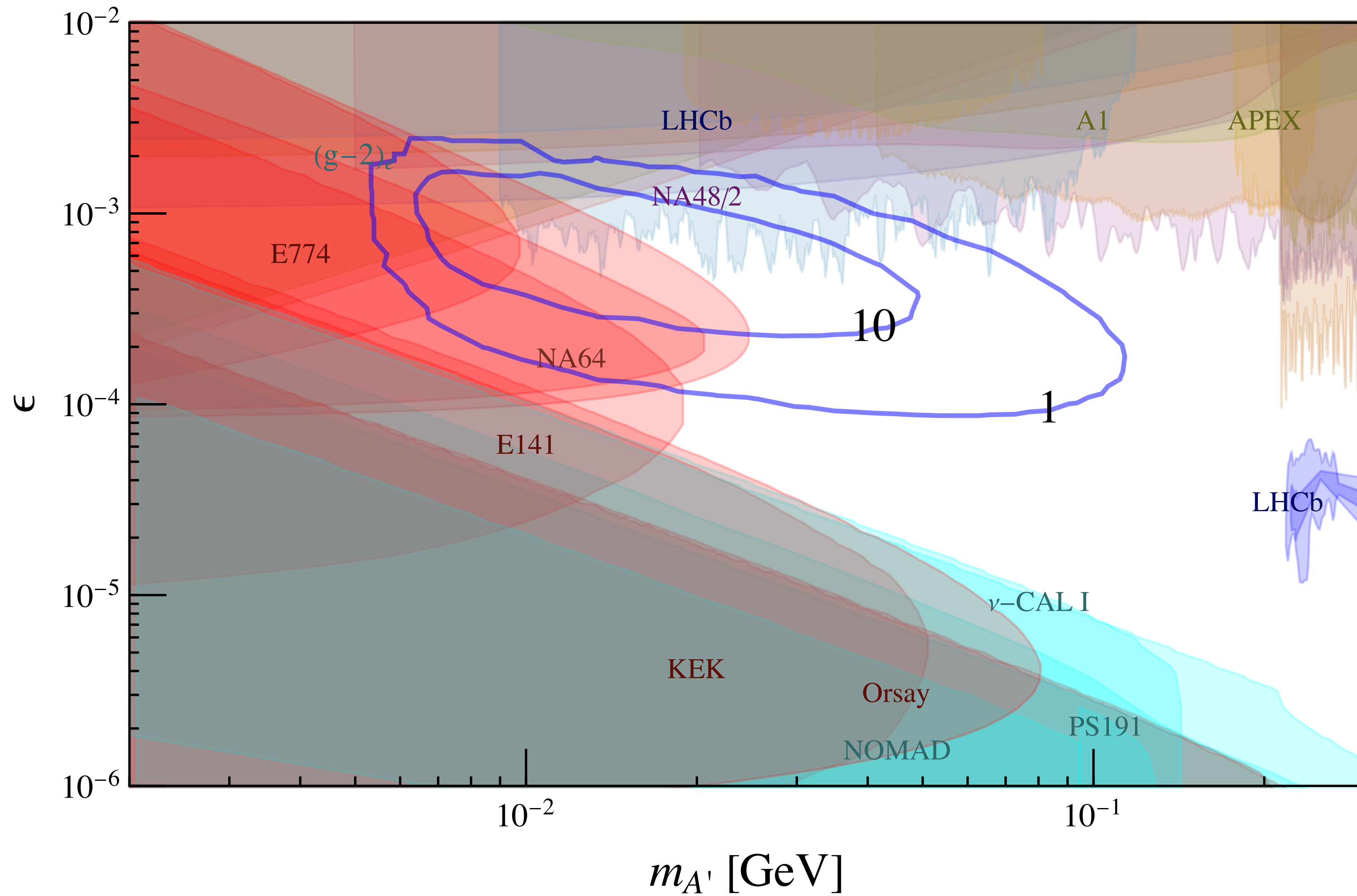
# $N_{events}$ Contours

Selection: loose



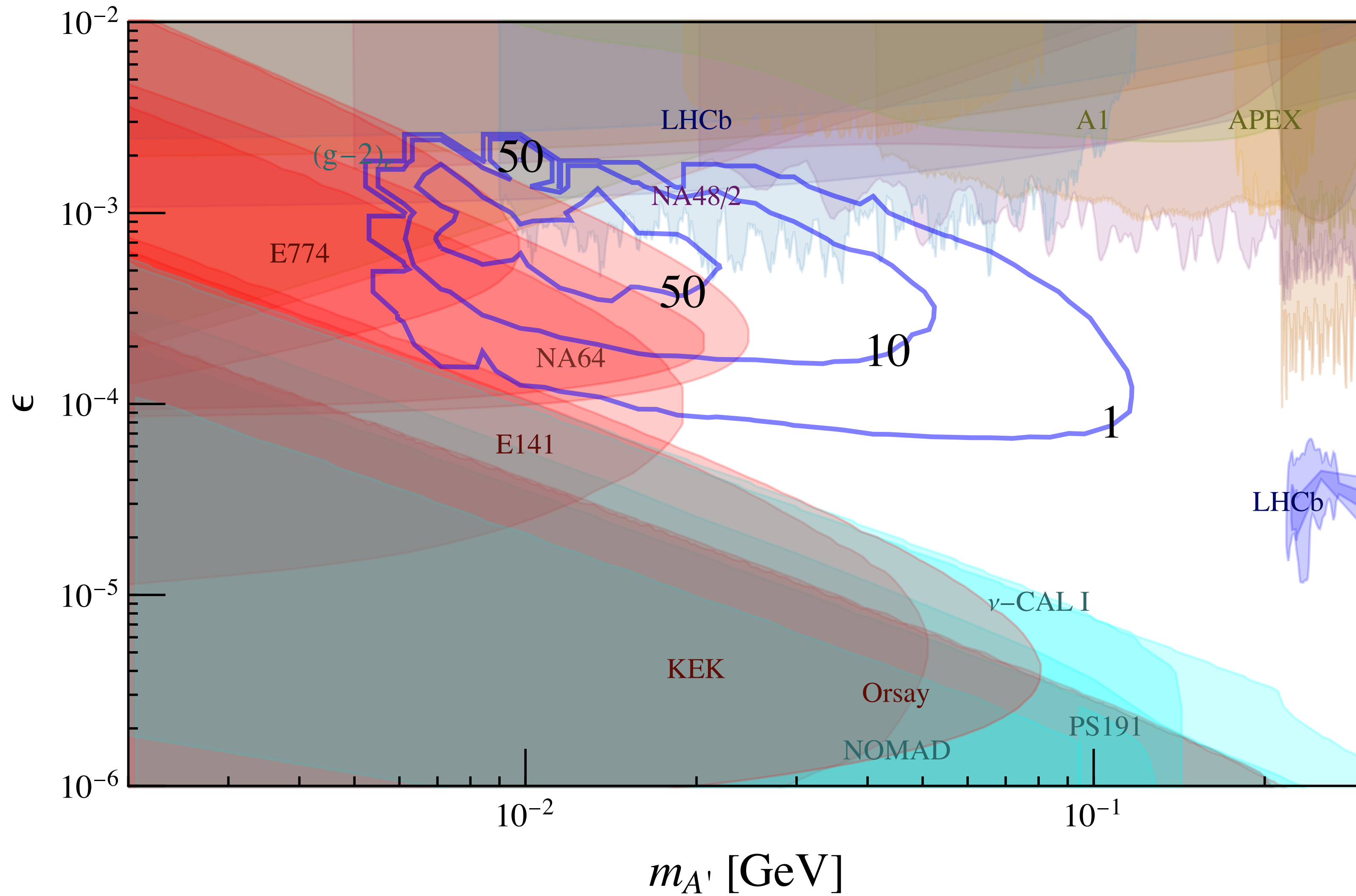
# $N_{events}$ Contours

Selection: Medium-1



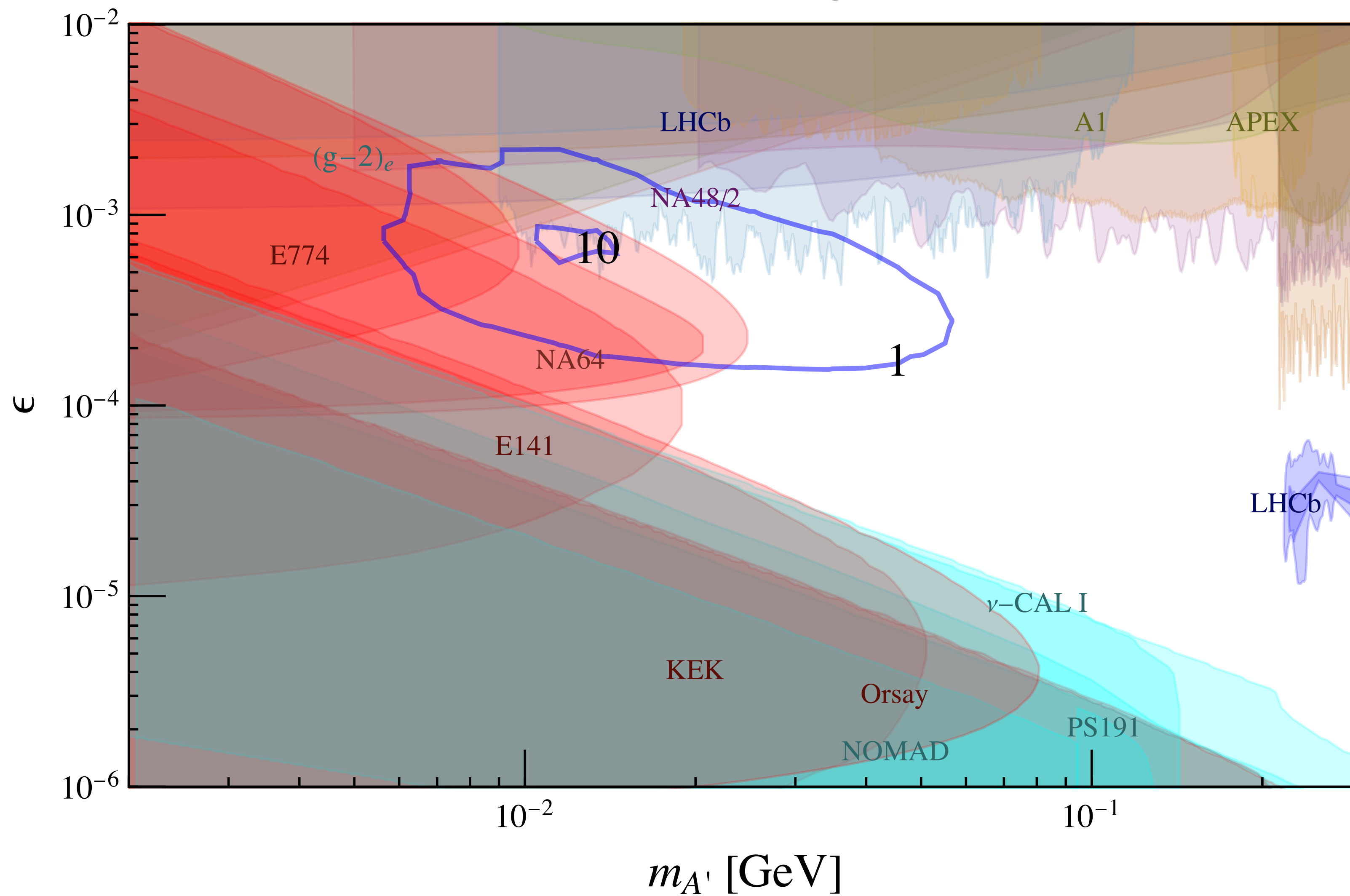
# $N_{events}$ Contours

Selection: Medium-2

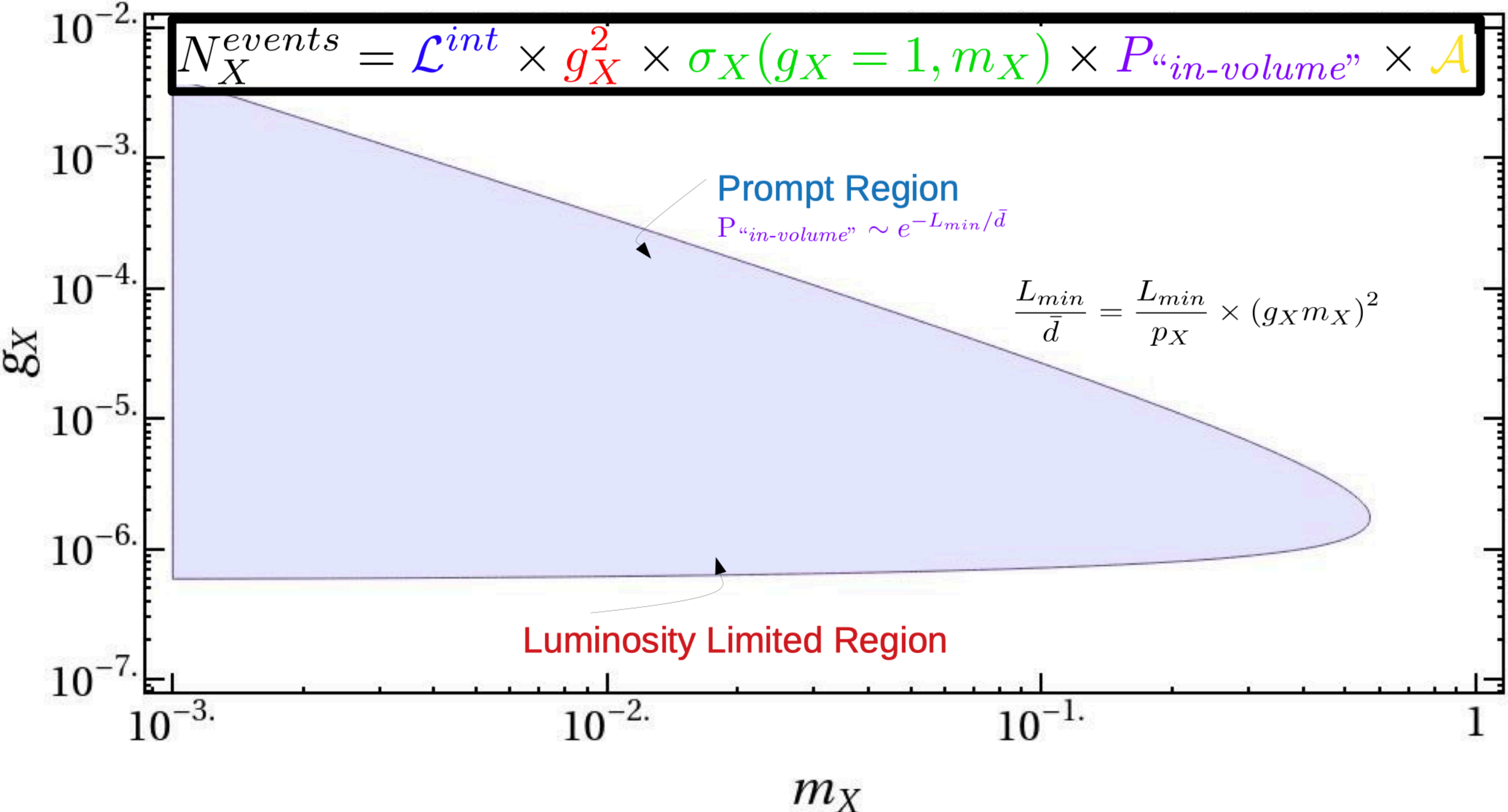


# $N_{events}$ Contours

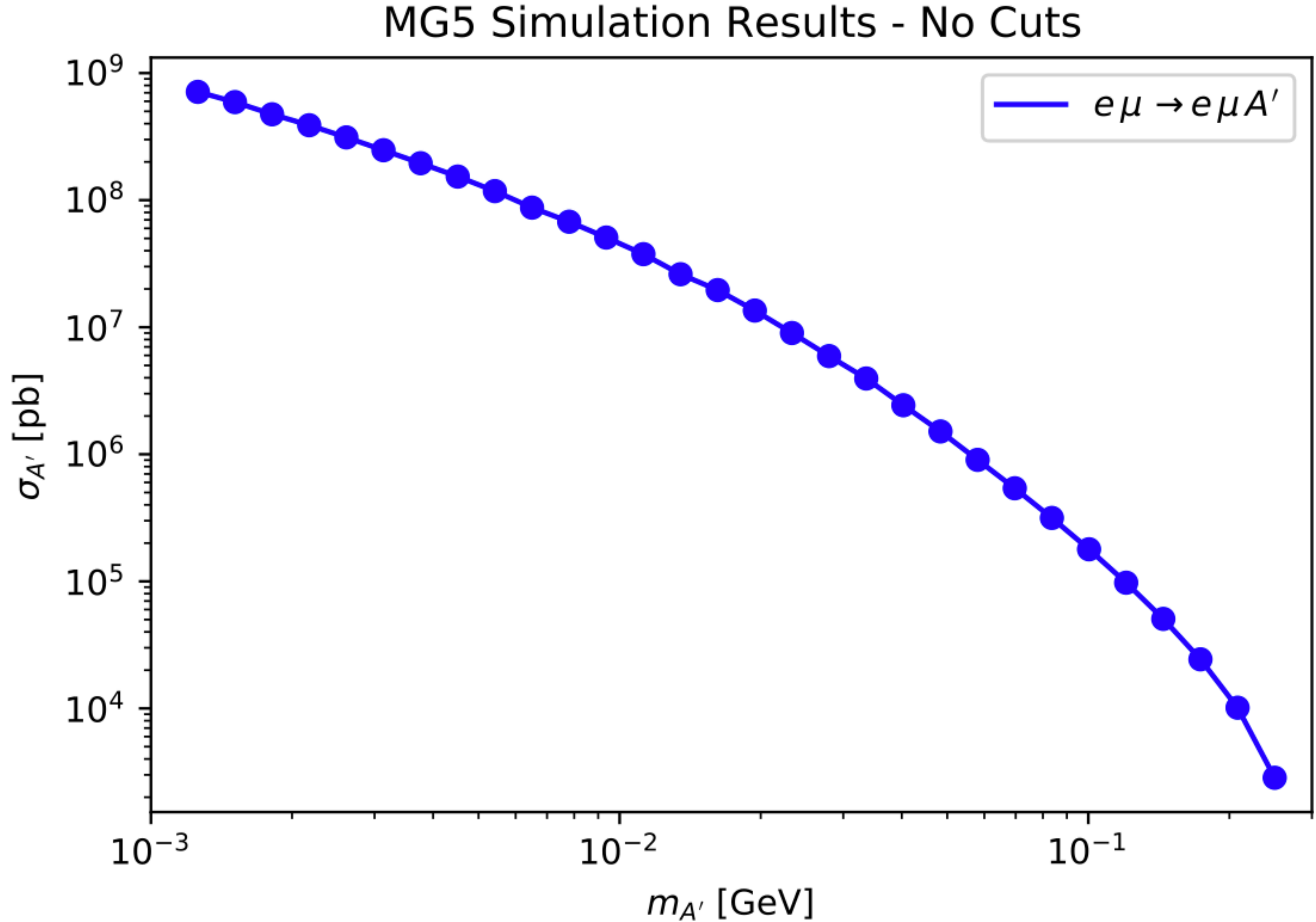
Selection: Tight



# Shape of Exclusion



# Dark Photon Production Cross-Section



# 10 sigma tail

