

Dark Photon & Displaced Vertices @ MUonE

Isaac R. Wang
Rutgers University

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

Dark Sector Mediator

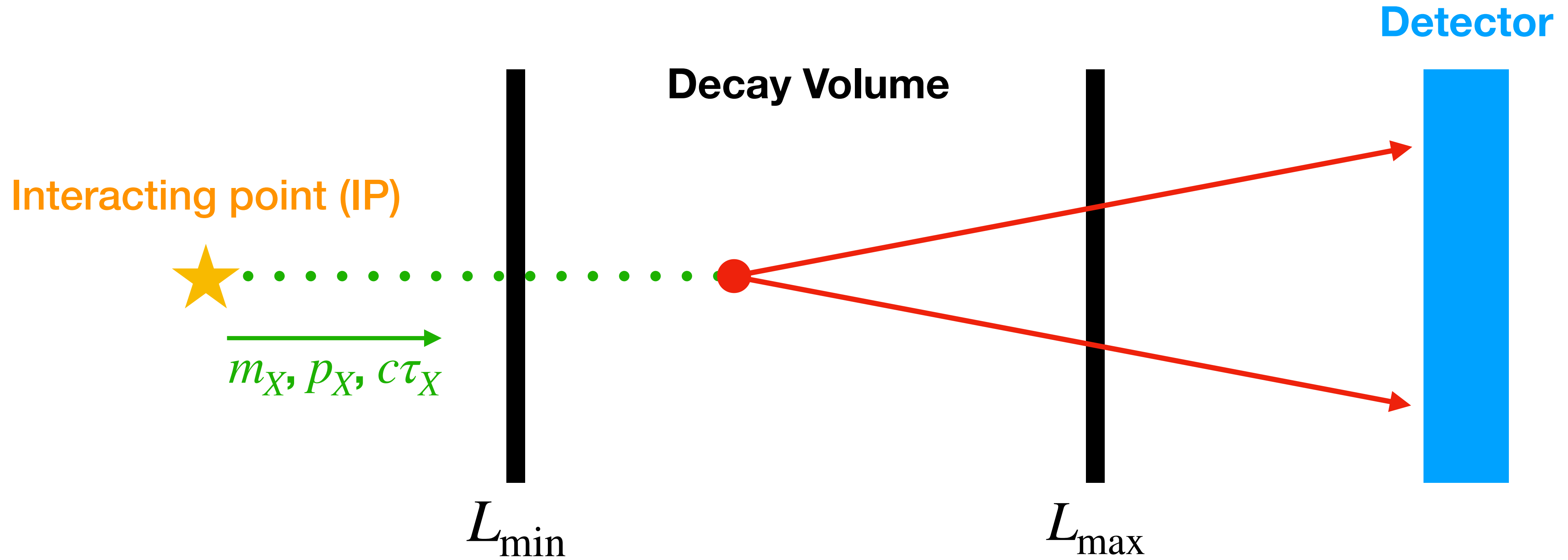


Motivation: Dark Matter, and from other puzzles

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

Light Long-lived Particles: LLP

LLP Detection

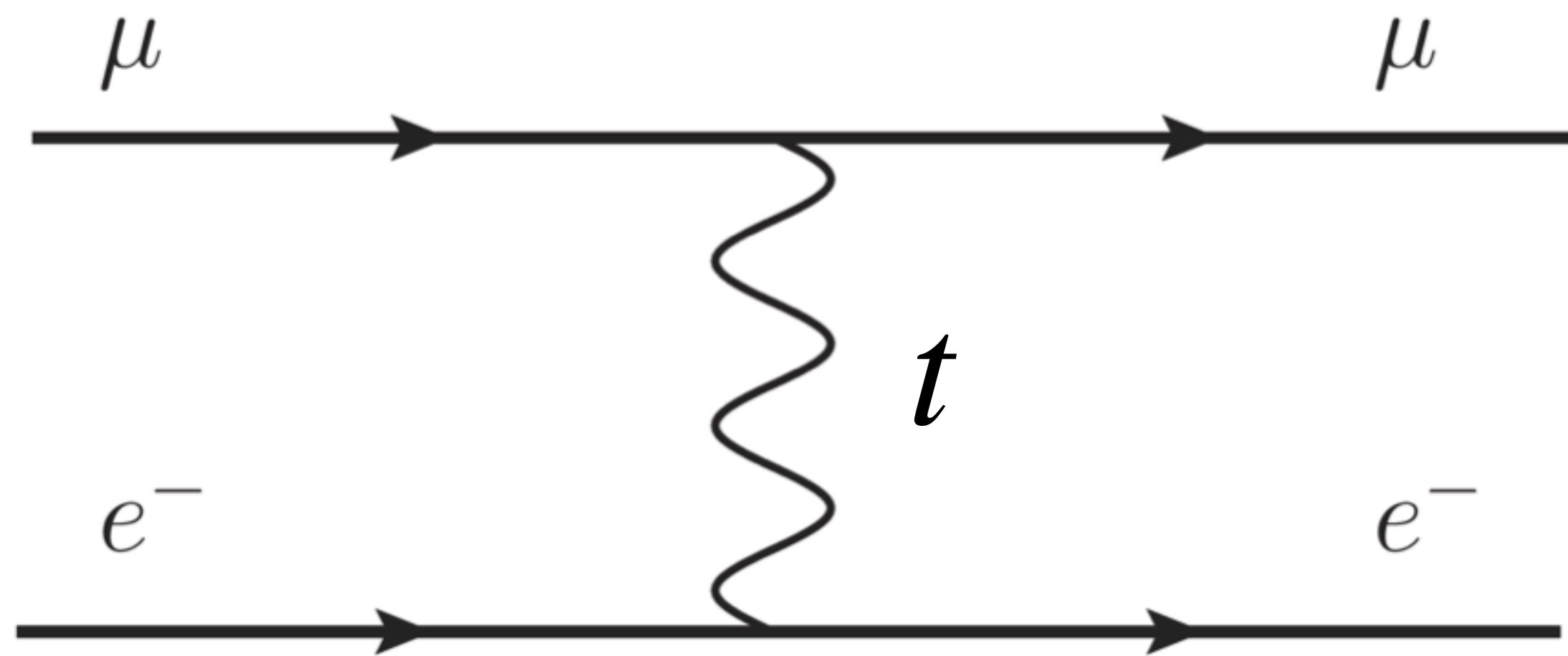


$$P_{\text{in-volume}} = e^{-L_{\min}/\bar{d}} - e^{-L_{\max}/\bar{d}}$$

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

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:

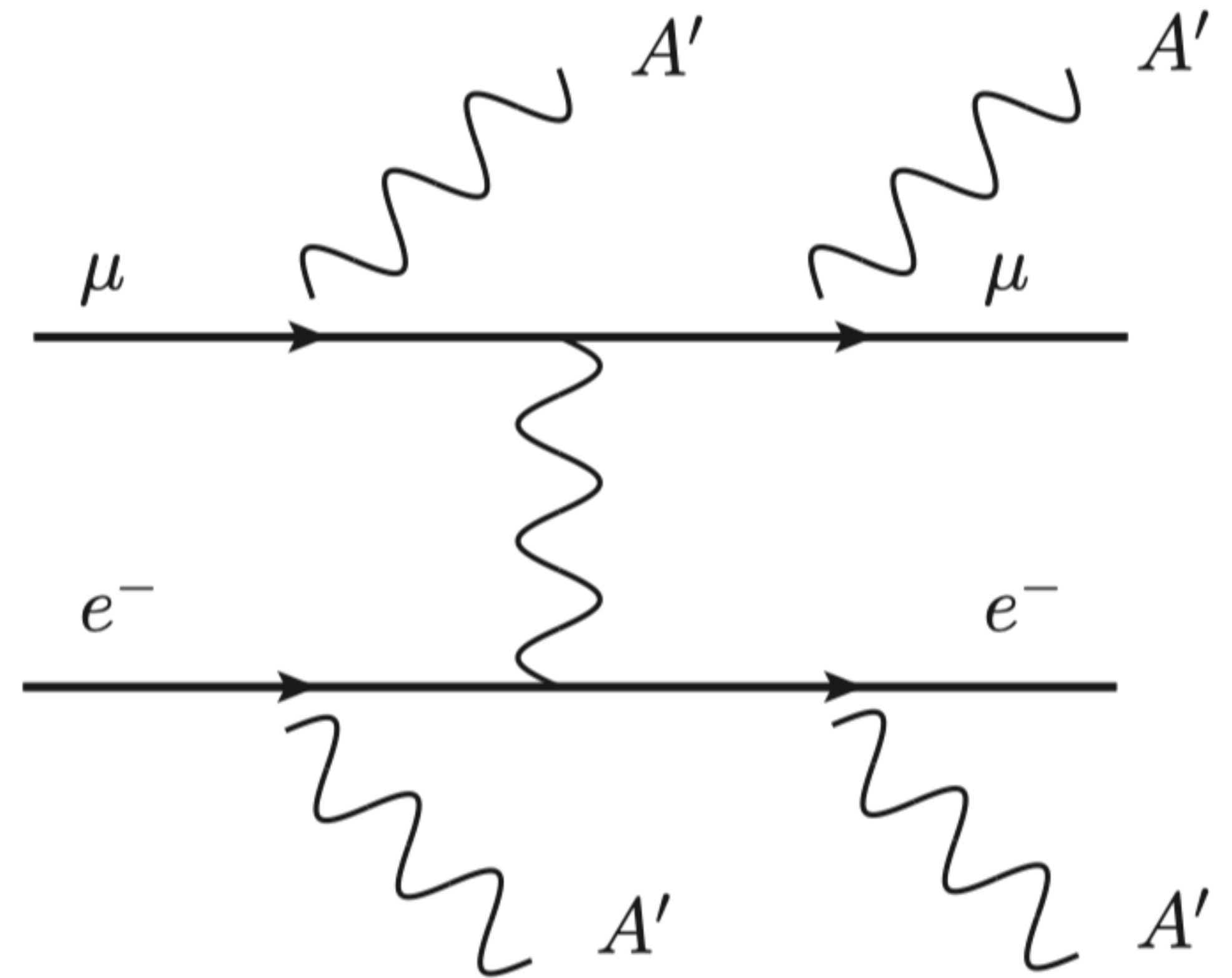
$$\mathcal{L}_{A'} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{2}m_{A'}^2 A'_\mu A'^\mu - \epsilon e A'_\mu J_{EM}^\mu$$

- Long-lived, light, weakly interacting

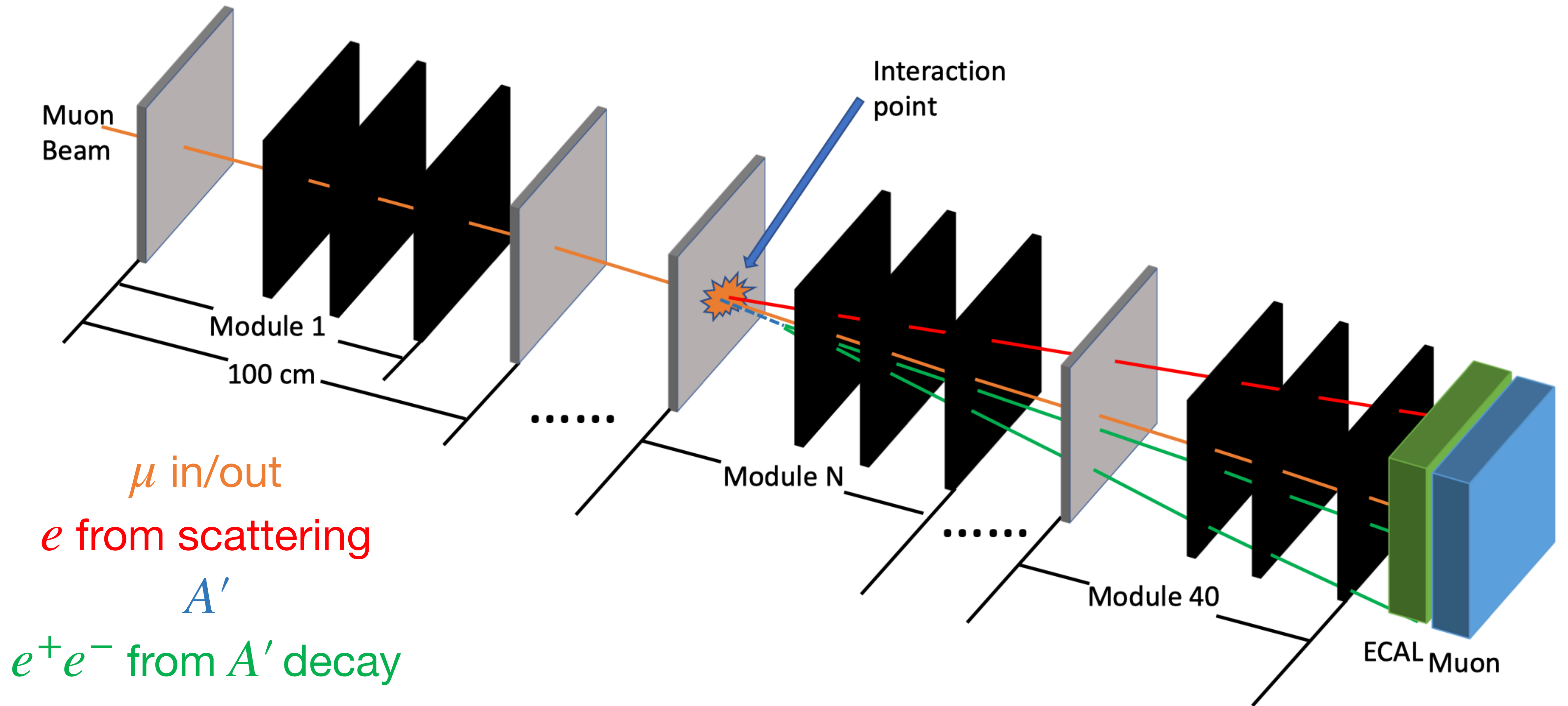
- Be produced at MUonE: $\mu e \rightarrow \mu e A'$

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

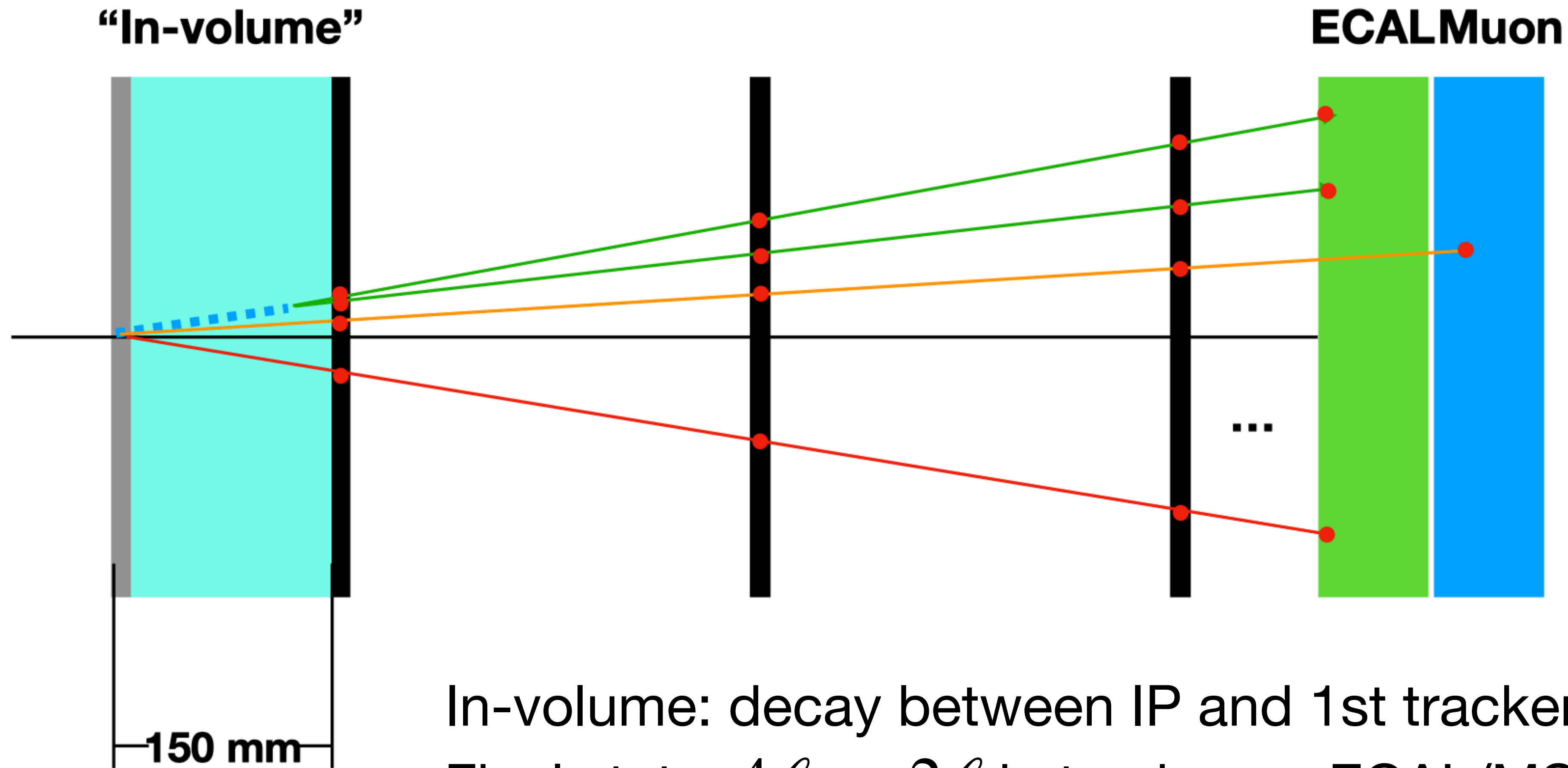
- Decay into electron-positron pair (assuming decaying into dark sector particles are kinematically forbidden)



Dark Photons @ MUonE

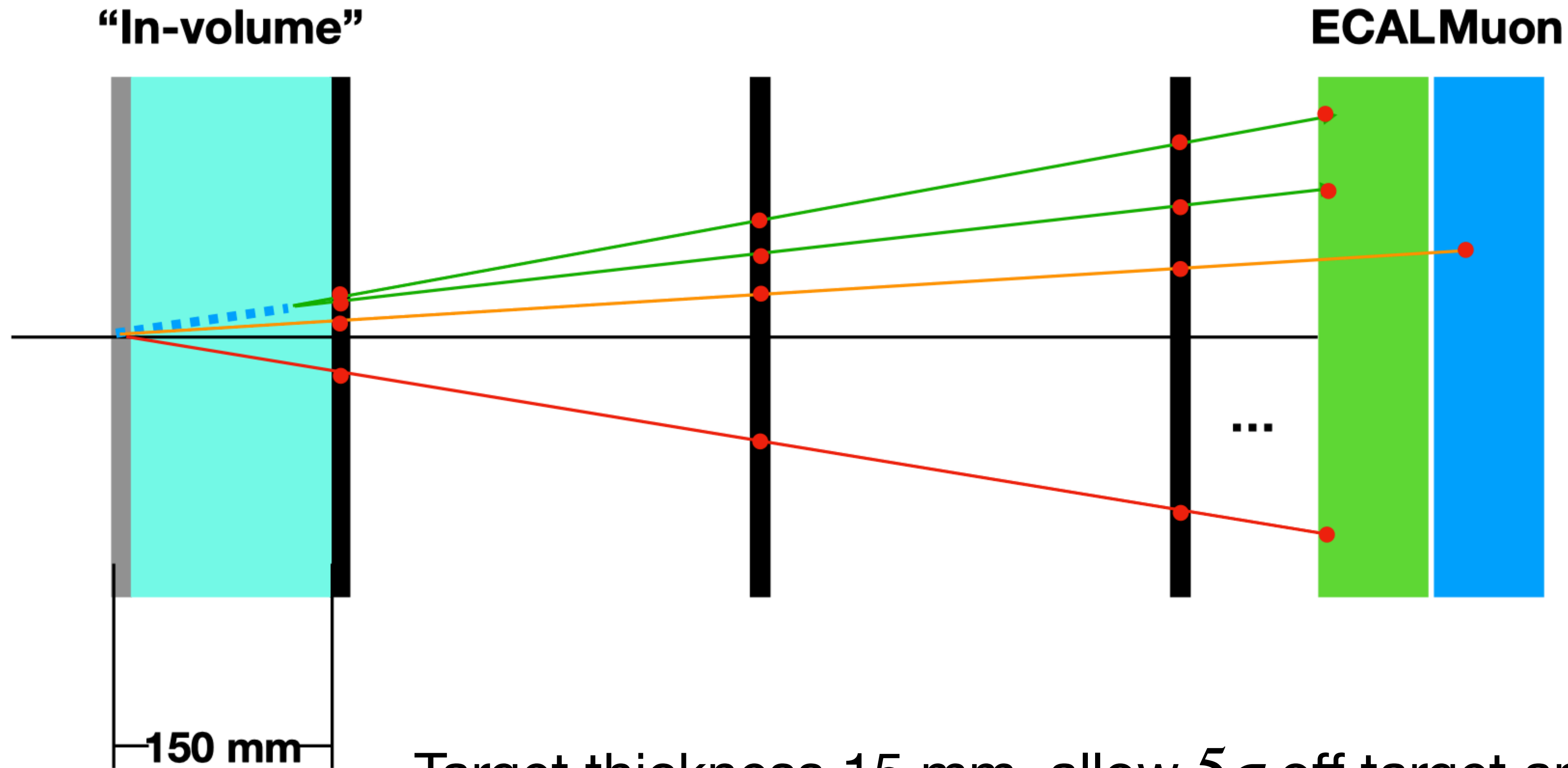


Displaced Vertex from Dark Photon Decay



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

Displaced Vertex from Dark Photon Decay



Target thickness 15 mm, allow 5σ 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

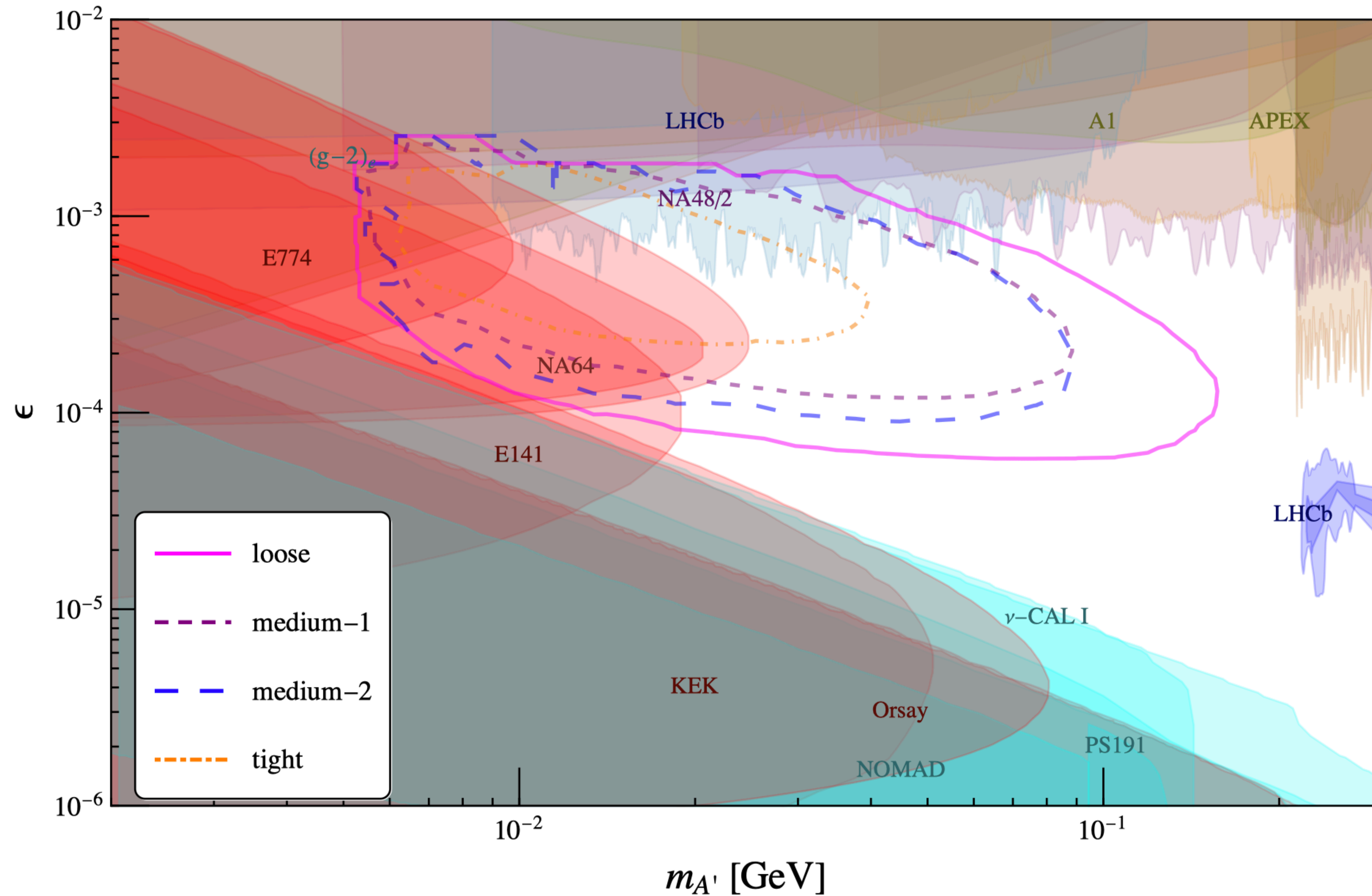
Search Strategies

- “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

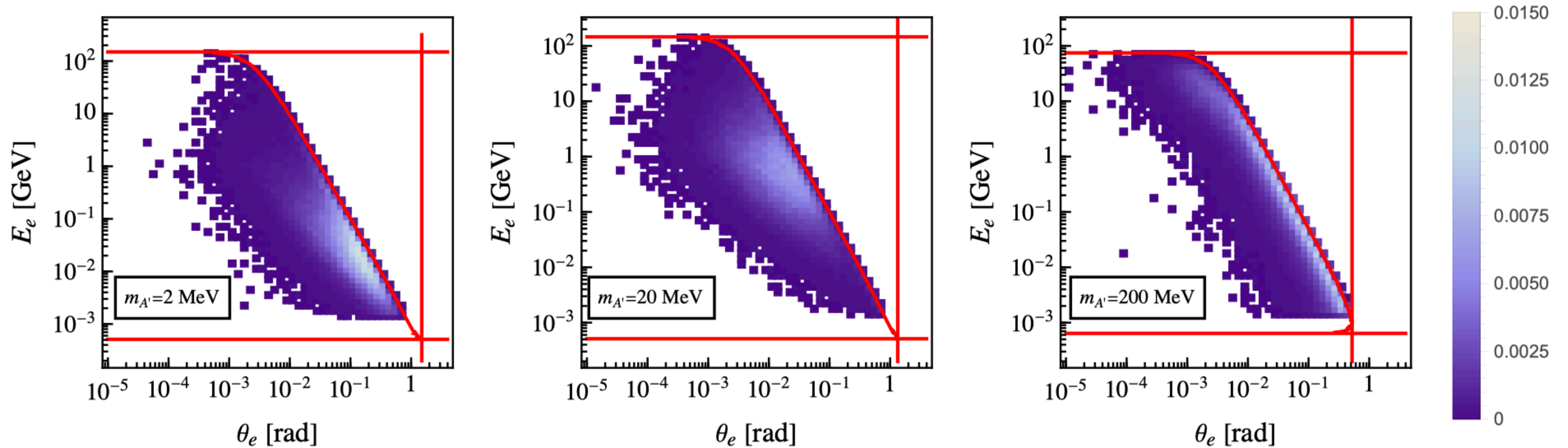
- MUonE is an experiment aiming at measuring the HVP contribution to elastic $e\mu$ scattering. Its high resolution makes it a good experiment for detecting BSM physics.
- We proposed a search strategy for detecting displaced vertex $A' \rightarrow e^+e^-$. Further detailed background estimation is required.

Backup

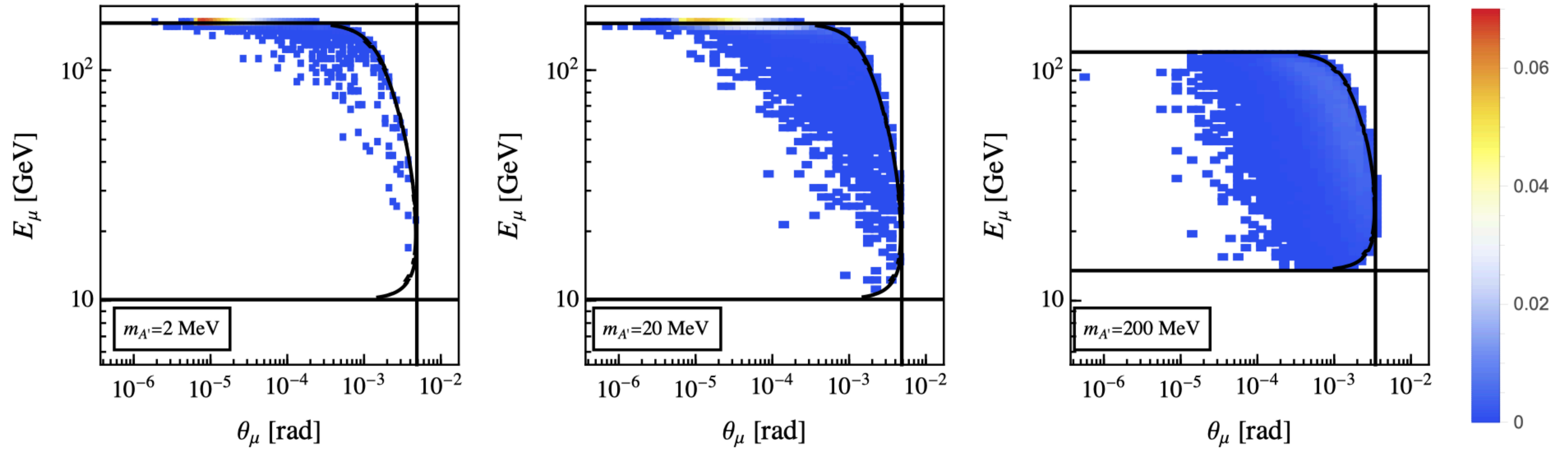
Implementation

- 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.

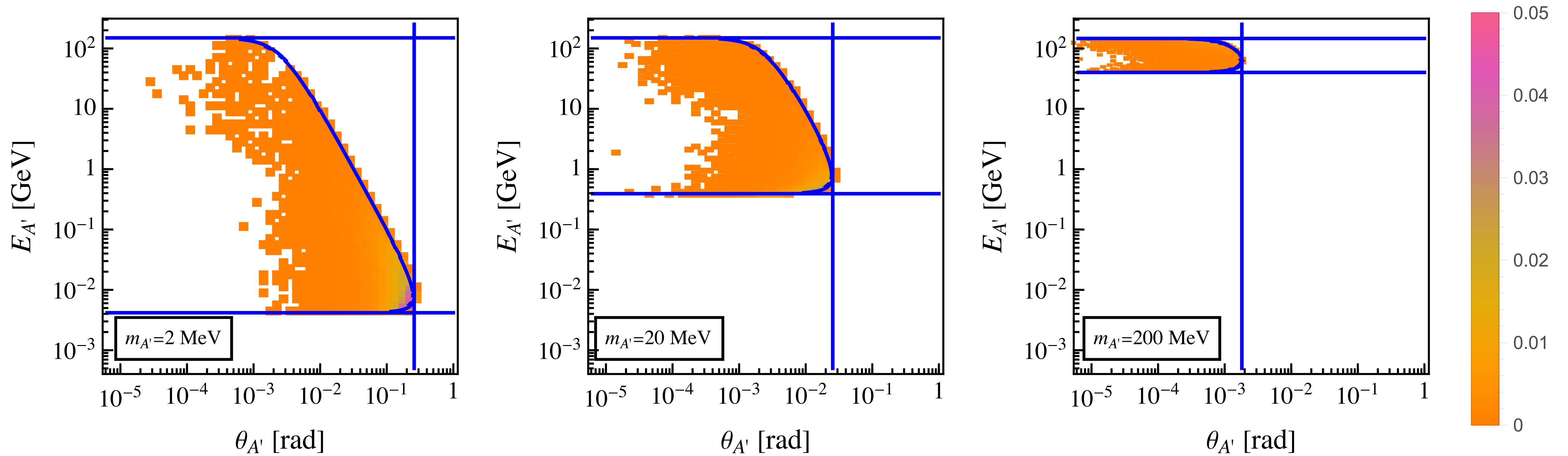
Phase space distribution



Phase space distribution

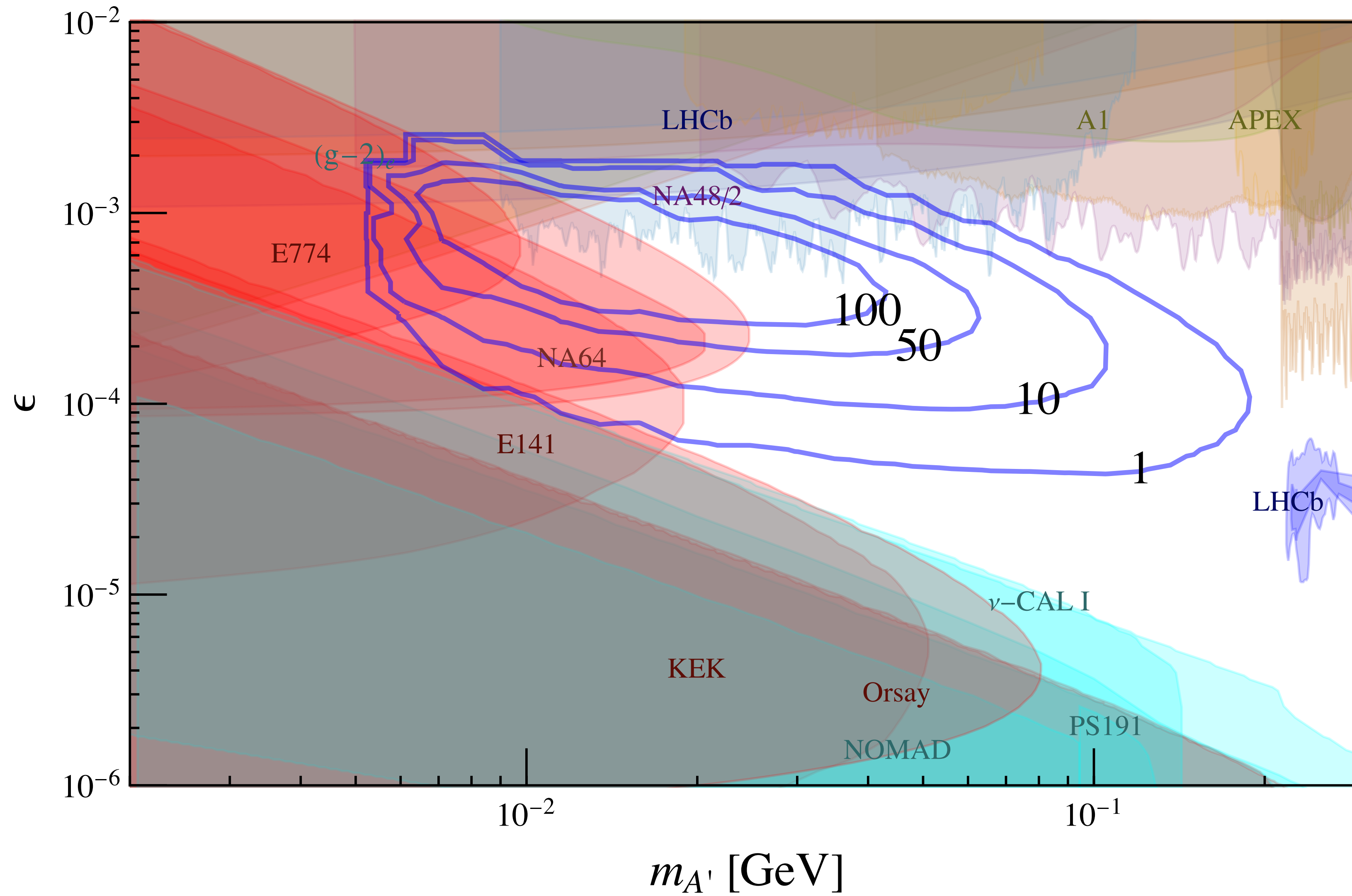


Phase space distribution



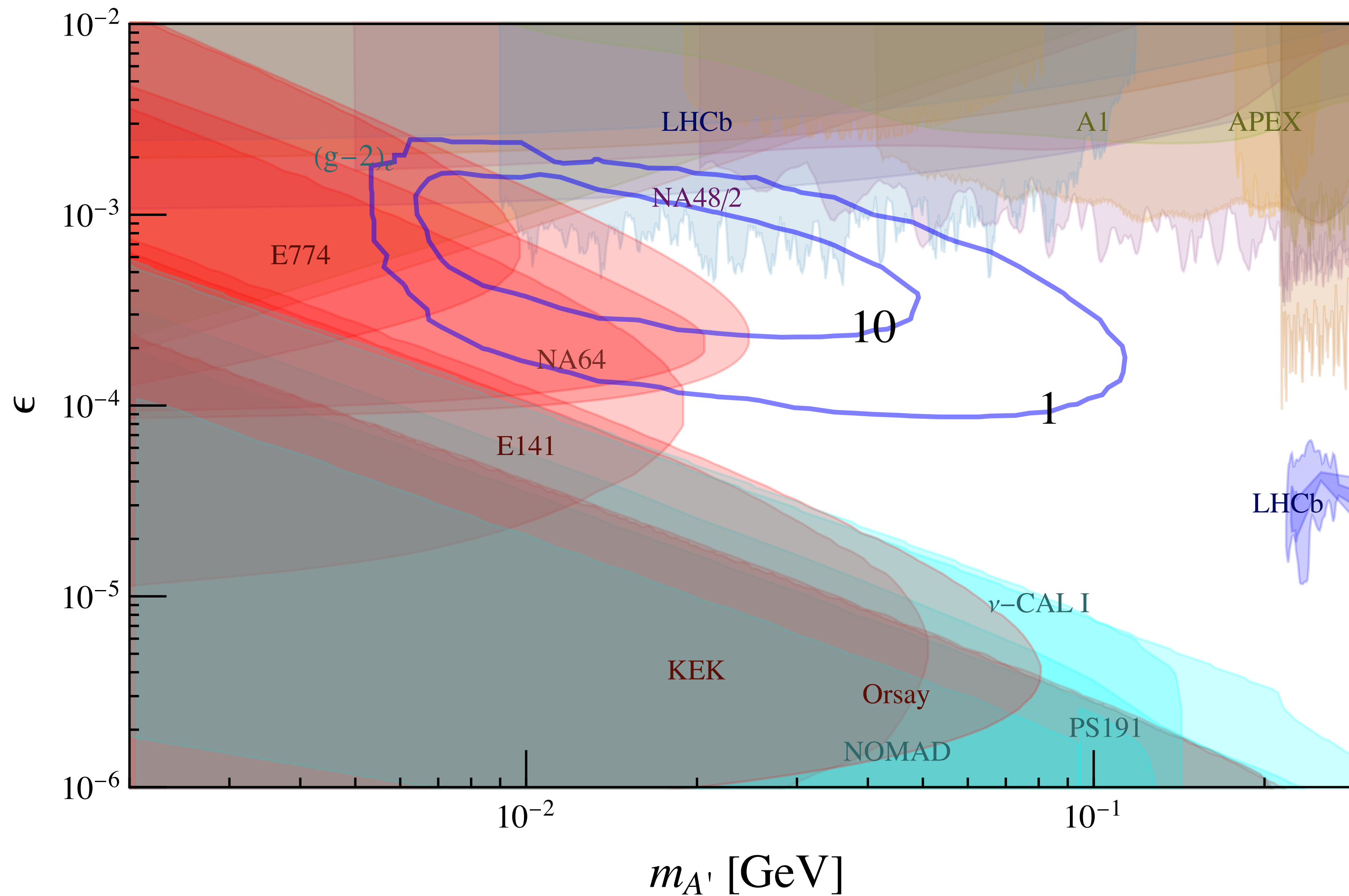
N_{events} Contours

Selection: loose



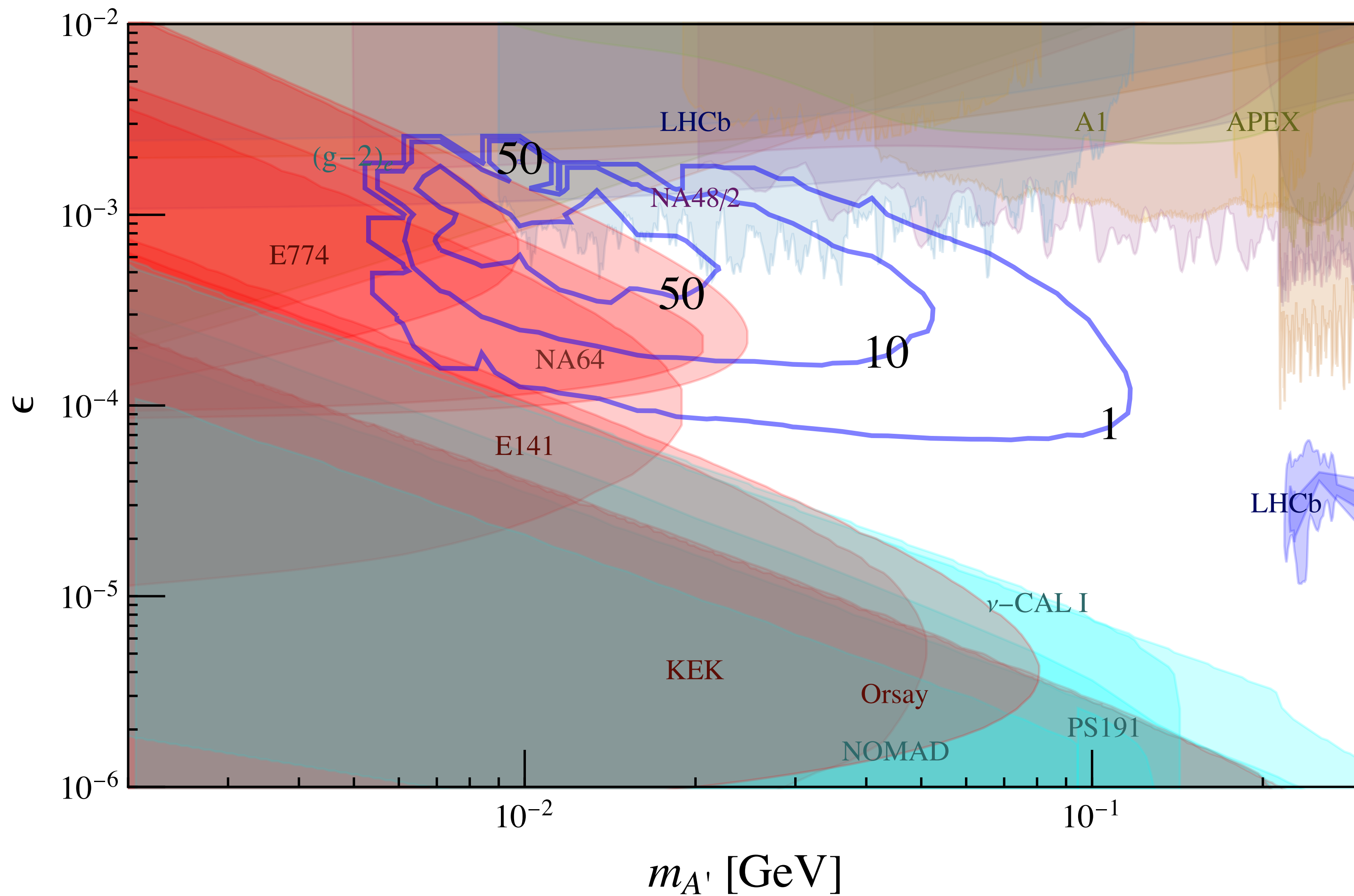
N_{events} Contours

Selection: Medium-1



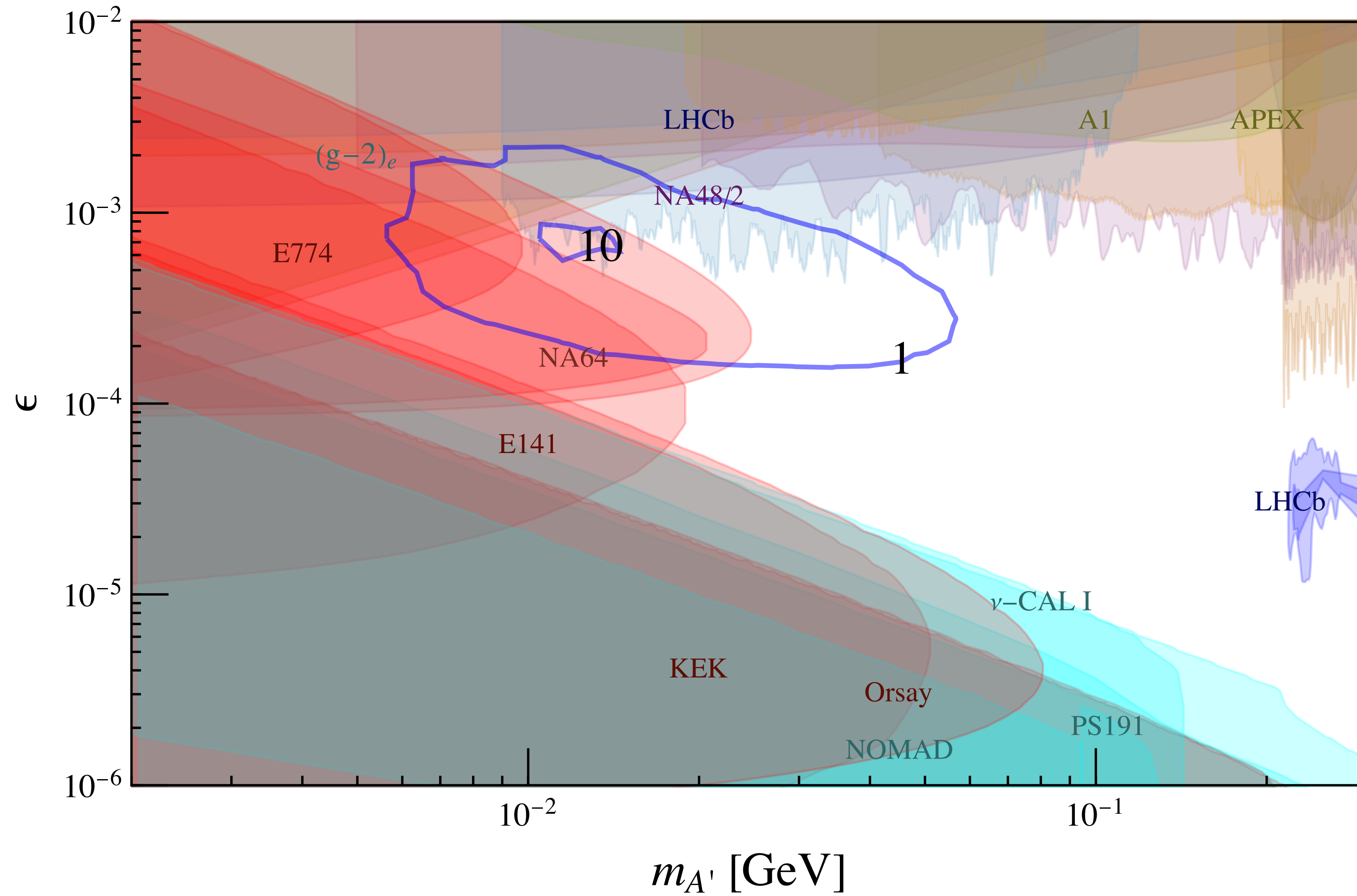
N_{events} Contours

Selection: Medium-2

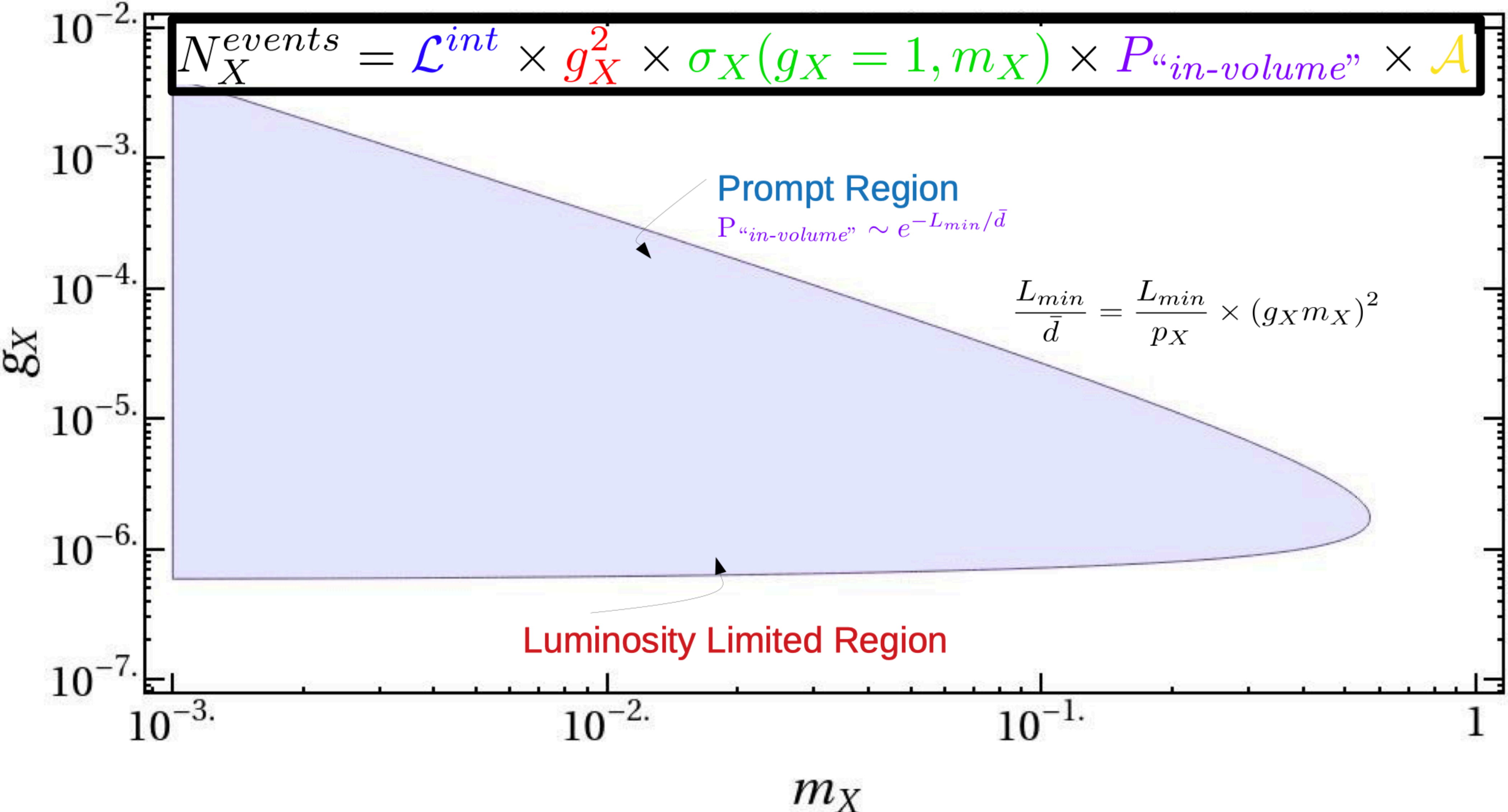


N_{events} Contours

Selection: Tight



Shape of Exclusion



Dark Photon Production Cross-Section

