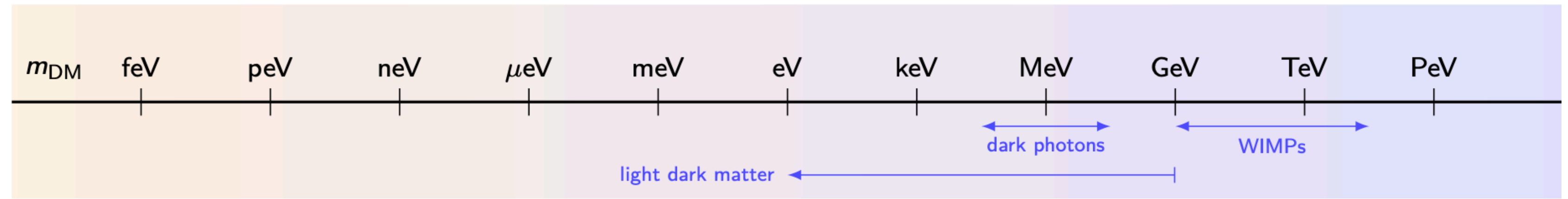




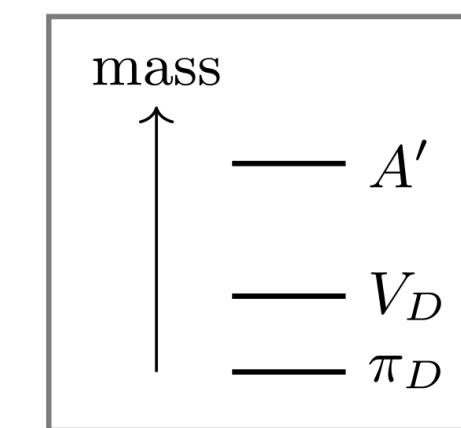
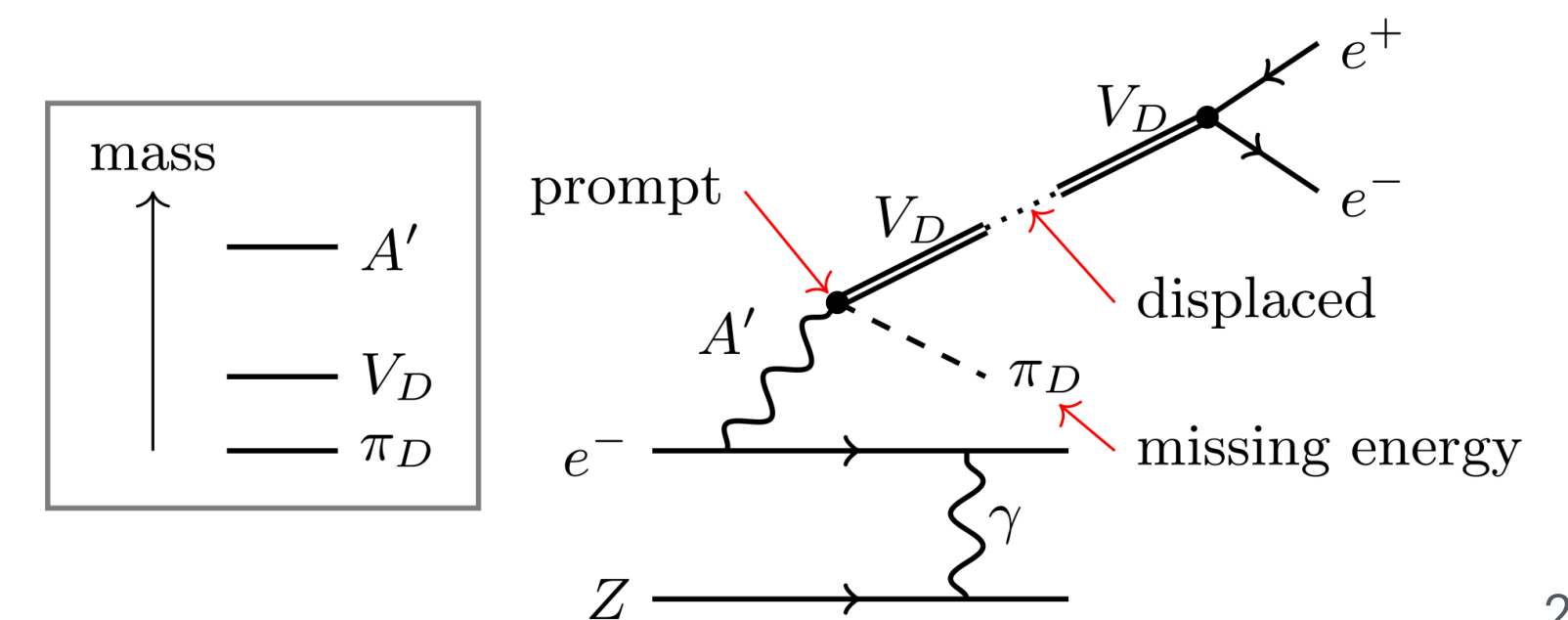
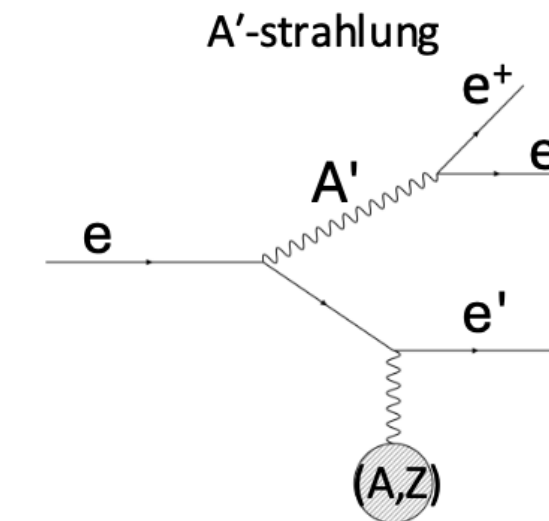
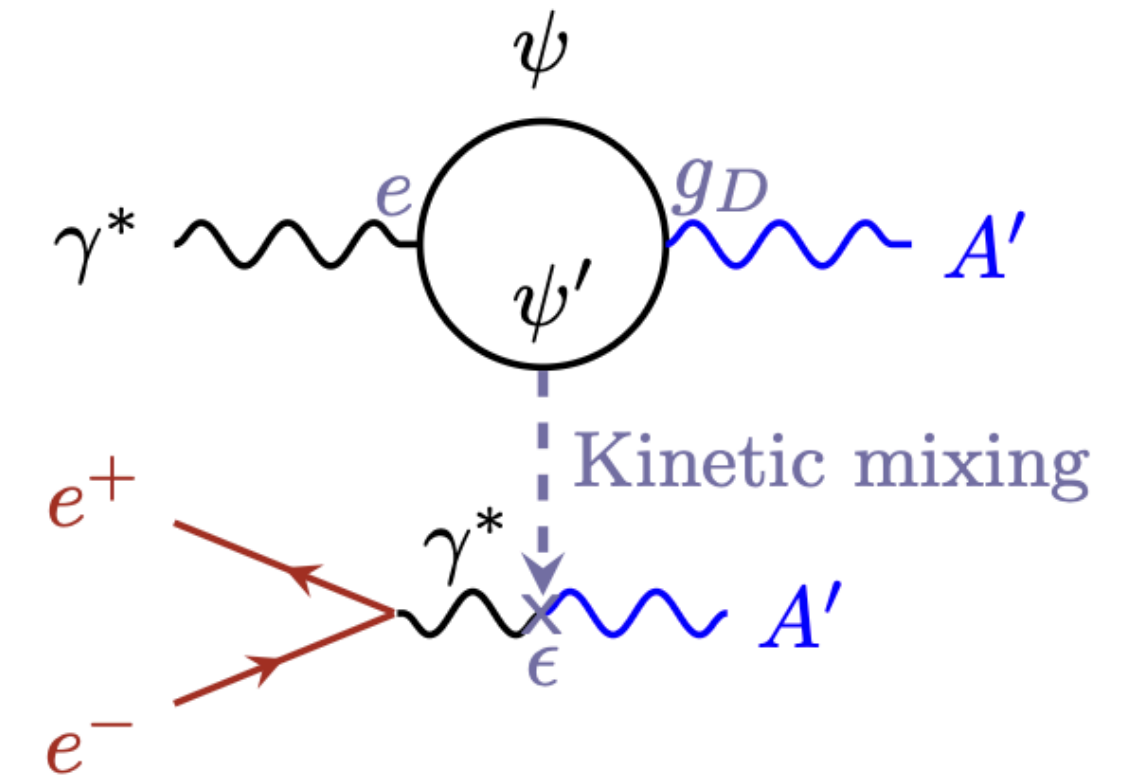
HPS Status

June '26 CLAS Collaboration Meeting

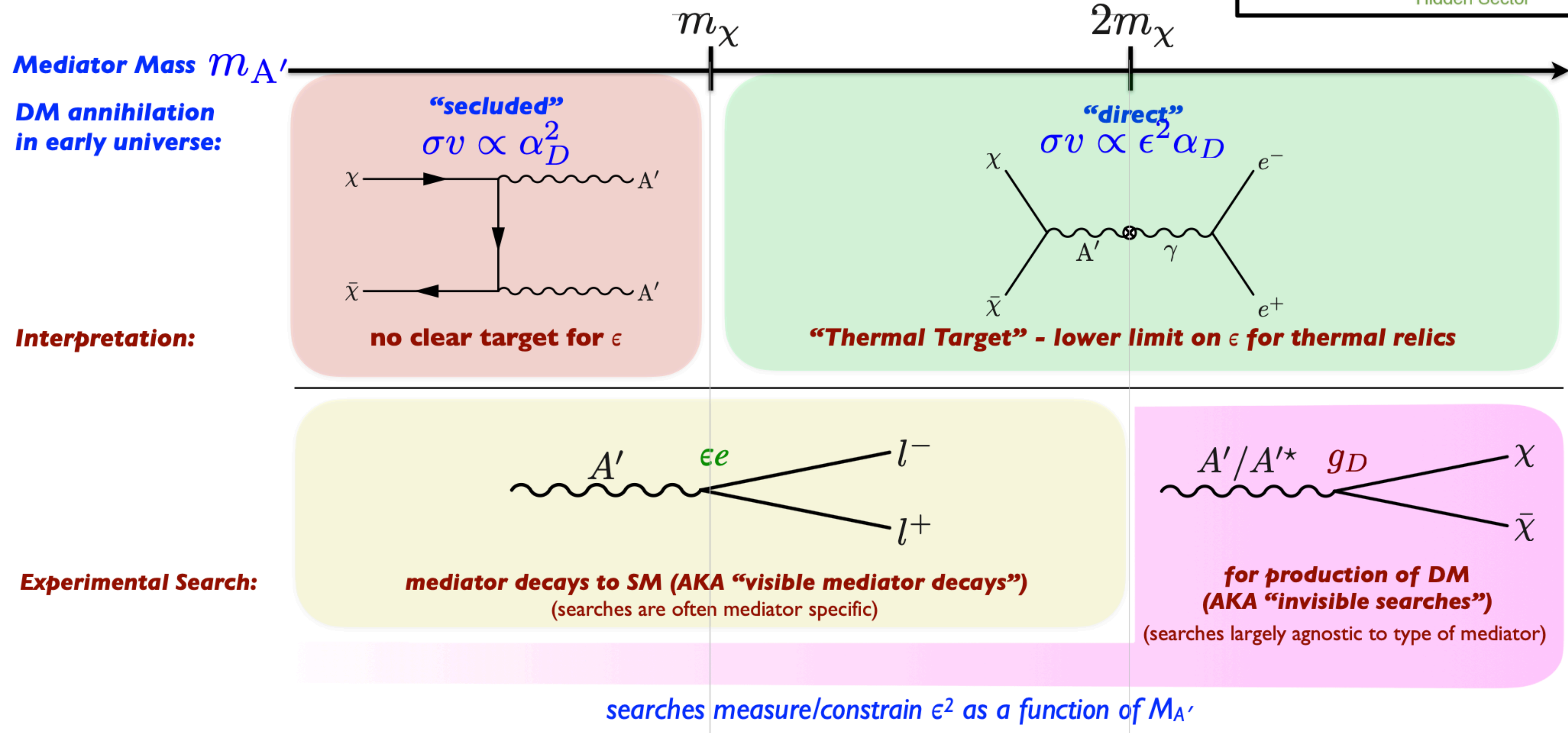
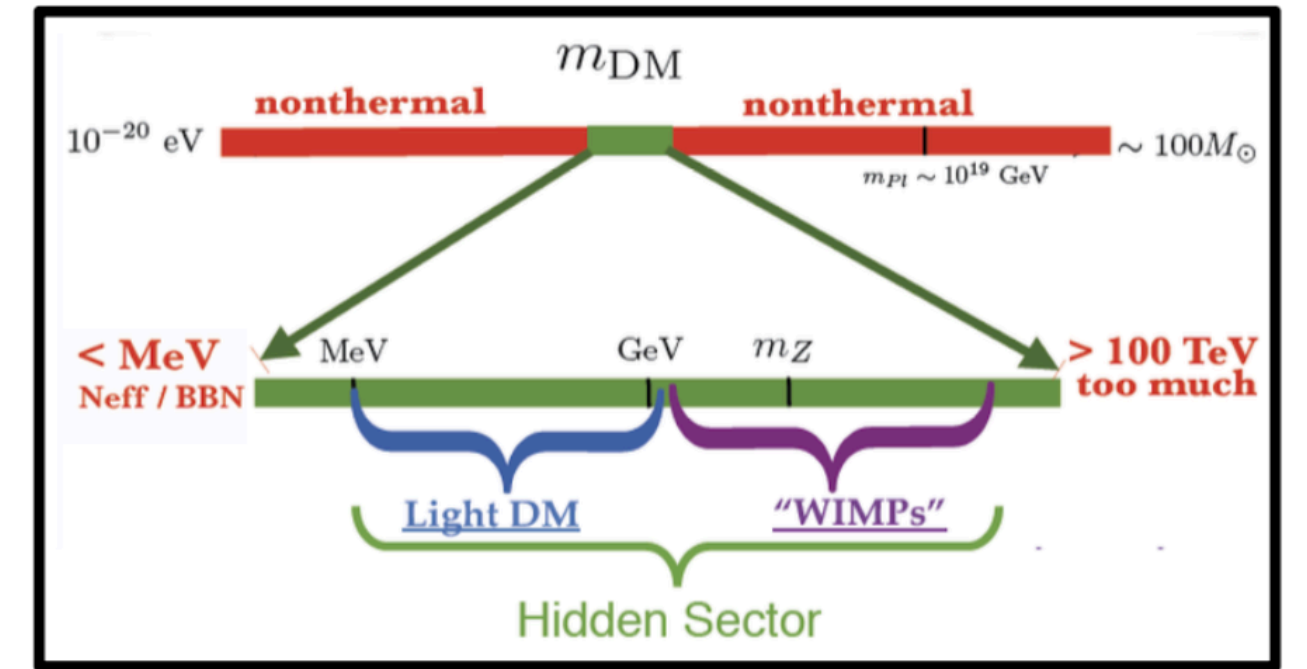
Landscape



- Standard Model extensions account for dark matter and the thermal relic abundance, by assuming new gauge symmetries and dark sectors with indirect coupling to the SM
- The simplest is a $U(1)_D$ giving rise to a massive spin-1 vector gauge boson, the "dark photon", A'
- Kinematic mixing with the SM photon enables "bremsstrahlung" A' electro-production on nuclear targets
 - Through a massive charged fermion loop, often represented by a simplified coupling strength, ϵ
- Experimental signatures of the A' decay depend on the dark sector's structure
 - Assuming it's the lightest dark state, all A' decay back to SM leptons (the proposed HPS experiment)
 - Other models include Strongly Interacting Massive Particles (SIMPs) in the dark sector
 - Y. Hochberg, et.al, Phys. Rev. Lett. 113, 171301 (2014) and Phys. Rev. Lett. 115, 021301 (2015).



A' Parameter Space



The HPS Experiment

Proposed

- Few-GeV CEBAF electron beam ("low energy") on a high-Z target, Tungsten
- Symmetric top/bottom/up/down detector, with analyzing dipole magnet and sheet-of-flame constrained by vacuum and magnet chicane
- 6-layer Silicon Vertex Tracker in uniform field, acceptance from 15 mrad, with front layer ± 0.5 mm from the beam!
- Downstream PbWO_4 Electromagnetic Calorimeter for the e^+e^- pair trigger
- Search for visible $A' \rightarrow e^+e^-$ decays in the SM background
 - Bump Hunt the invariant mass spectrum for prompt, large ϵ coupling
 - Displaced Vertex searches for small coupling

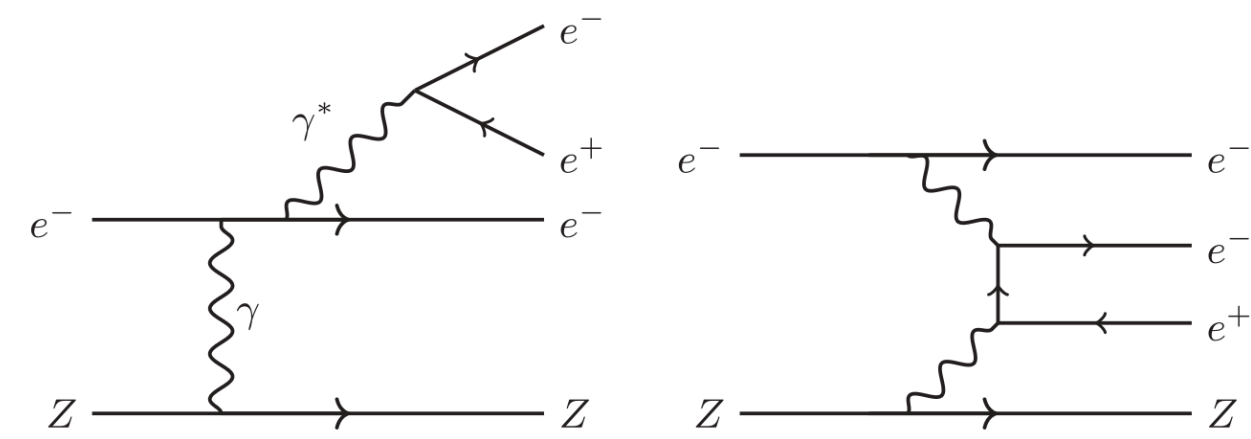
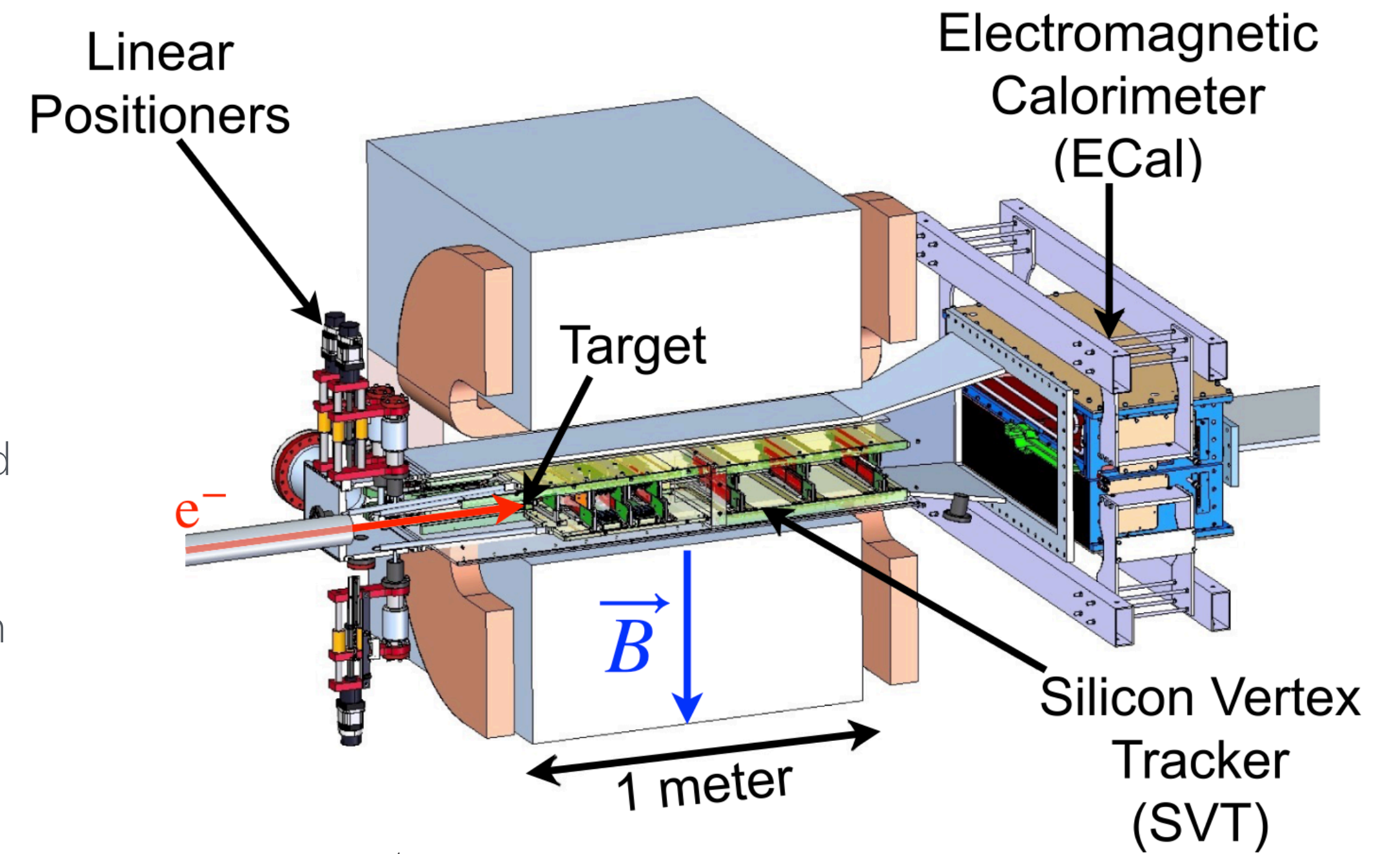
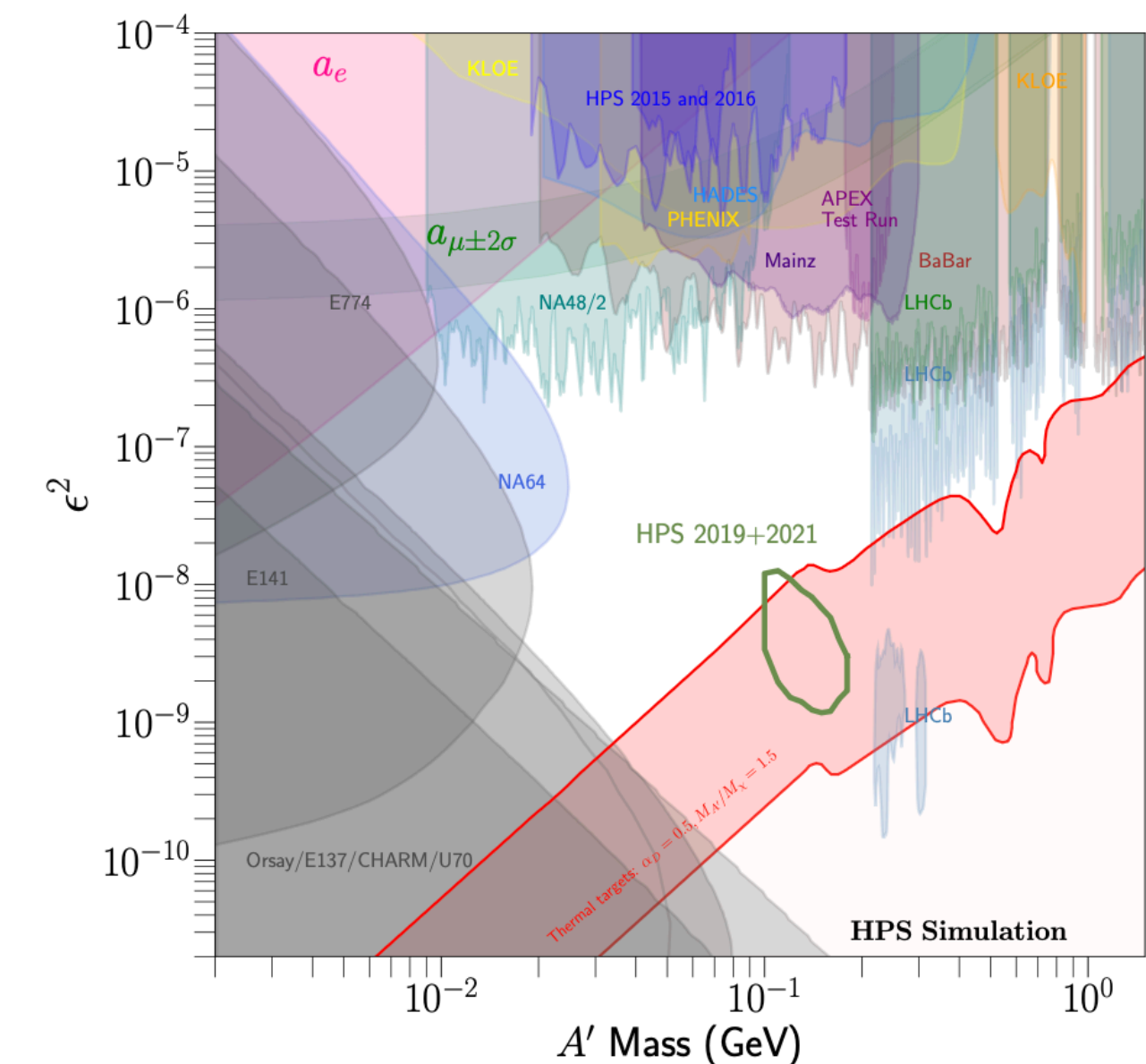


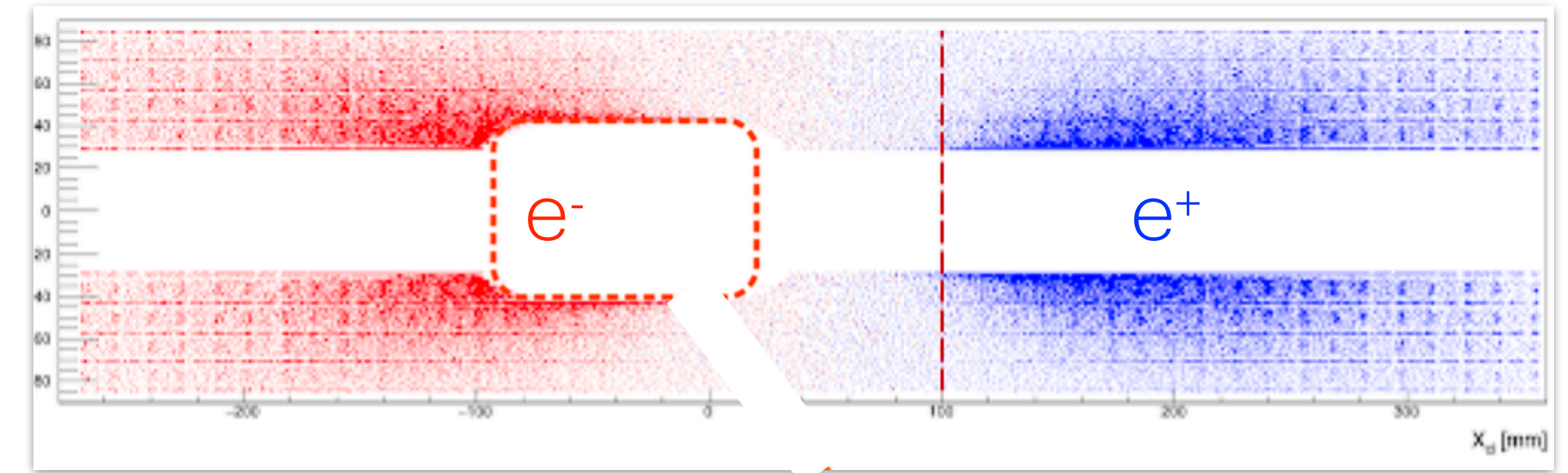
FIG. 3. Radiative (left) and Bethe-Heitler tridents (right) have the same final state particles as the e^+e^- production from a dark vector decay shown in Fig. 1.



The HPS Experiment

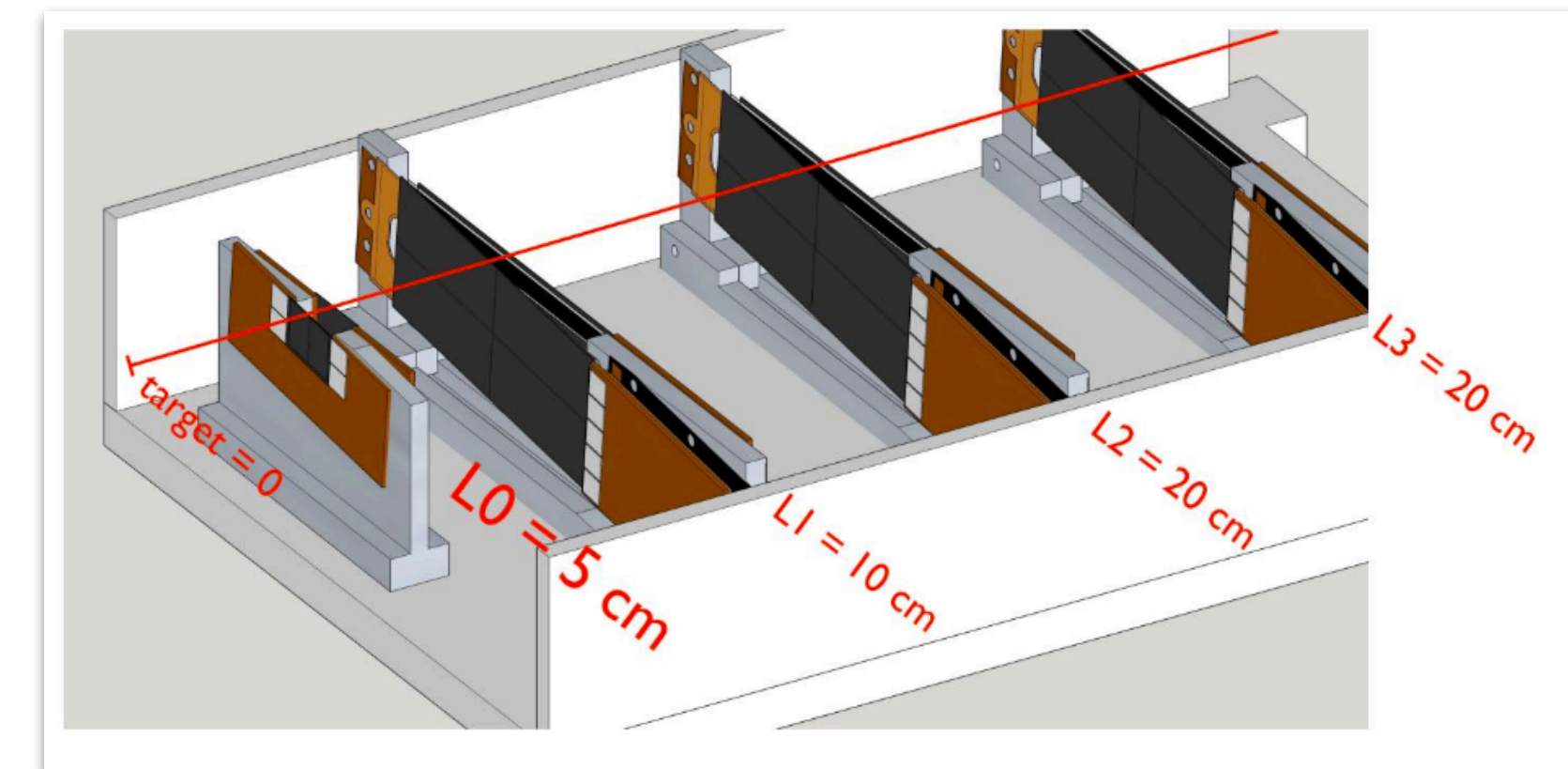
Status

- PAC Days: 180 approved, ~half remain
 - 2015 Engineering Run (1.1 GeV, 2 days)
 - 2016 Engineering Run (2.3 GeV, 5 days)
 - Training ground for understanding background, detector performance, analysis techniques
 - 2019 Physics Run (4.6 GeV, 130 pb⁻¹)
 - 2021 Physics Run (3.8 GeV, 170 pb⁻¹)
- HPS's proposed A' searches were published from the short engineering run
- The 10x larger 2021 data set is coming soon with combined analysis
- Meanwhile, HPS can also do A' SIMP searches too ...
 - No bump hunting due to missing (SIMP) energy, only detached vertexing



Detector Upgrades for 2019+

- Additional L0 tracking layer nearest the target
- Single-arm "positron" trigger with new hodoscope



Event Selection

- HPS's low-coupling, visible $A' \rightarrow l^+l^-$ searches and SIMP searches are very similar
- All the same background sources, using everything we learned from previous analyses
- Except ... SIMPs push the missing energy to lower e^+e^- energy-sum, while for visible A' we select high $P(e^+e^-)$ for signal purity
- Data analyzed in separate L1L1, L1L2, L2L2 topologies, denoting the first hit layer in each track

Cut description	Requirement
Trigger	Pair1
Track time relative to trigger	$ t_{\text{trk}} \leq 6 \text{ ns}$
Cluster time difference	$\Delta(t_{\text{clu},e^-}, t_{\text{clu},e^+}) \leq 1.45 \text{ ns}$
Track-cluster time difference	$\Delta(t_{\text{trk}}, t_{\text{clu}}) \leq 4.0 \text{ ns}$
Track quality	$\chi_{\text{trk}}^2/\text{n.d.f.} \leq 20.0$
Beam electron cut	$p_{e^-} \leq 1.75 \text{ GeV}$
Minimum hits on track	$N_{\text{hits}} \geq 7$
Unconstrained vertex quality	$\chi_{\text{vtx}}^2 \leq 20.0$
e^+e^- momentum sum	$p_{\text{sum}} \leq 2.4 \text{ GeV}$

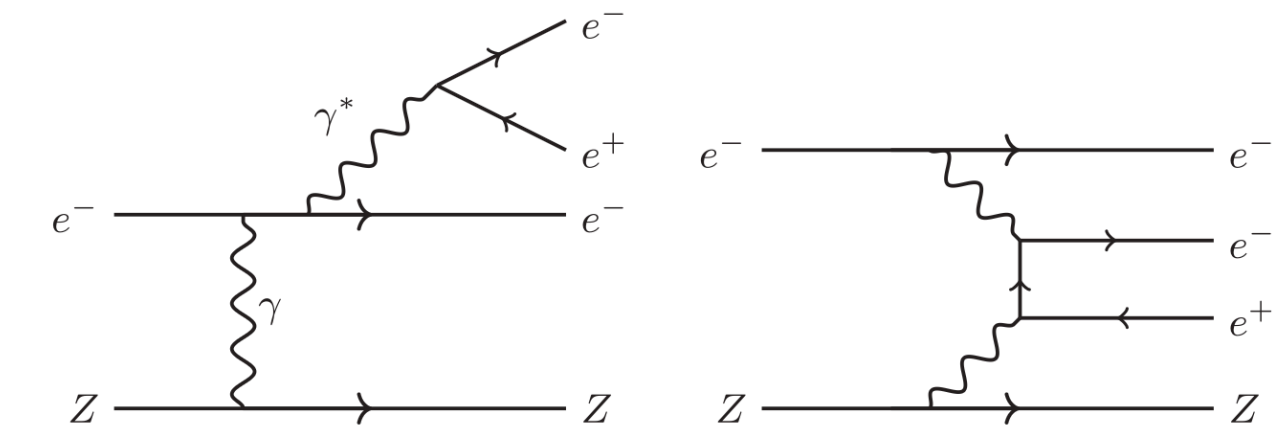
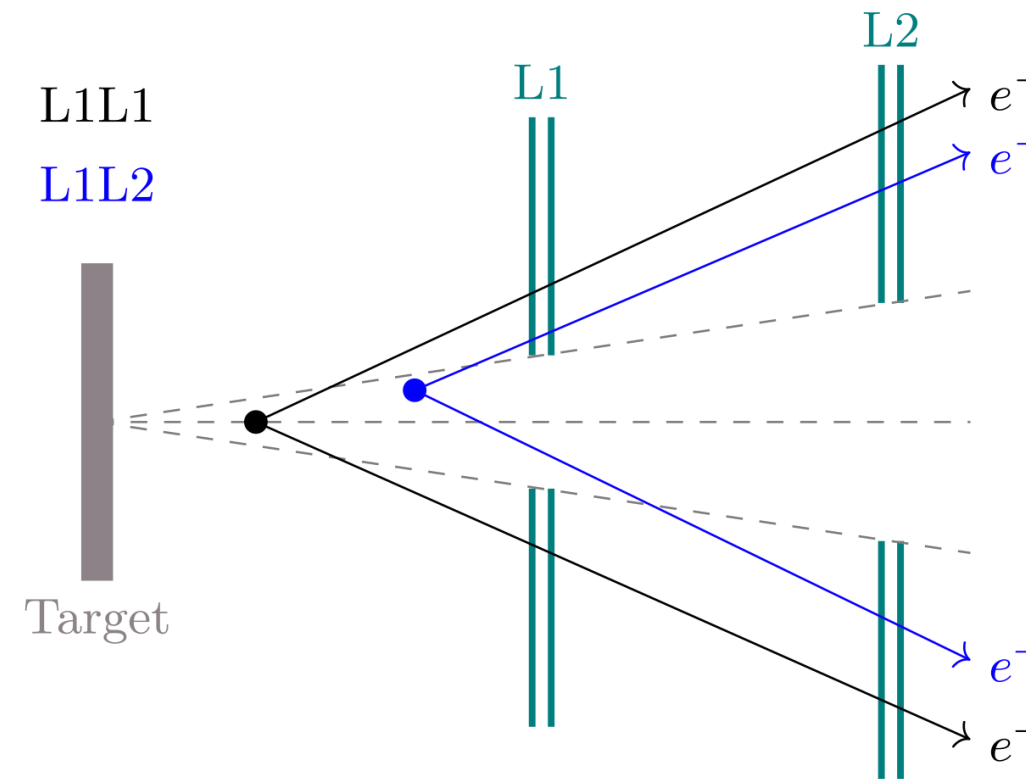
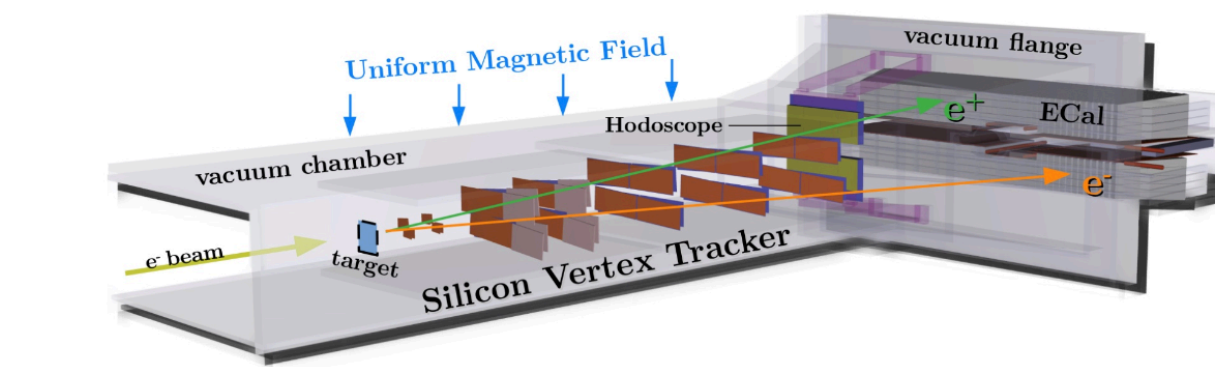
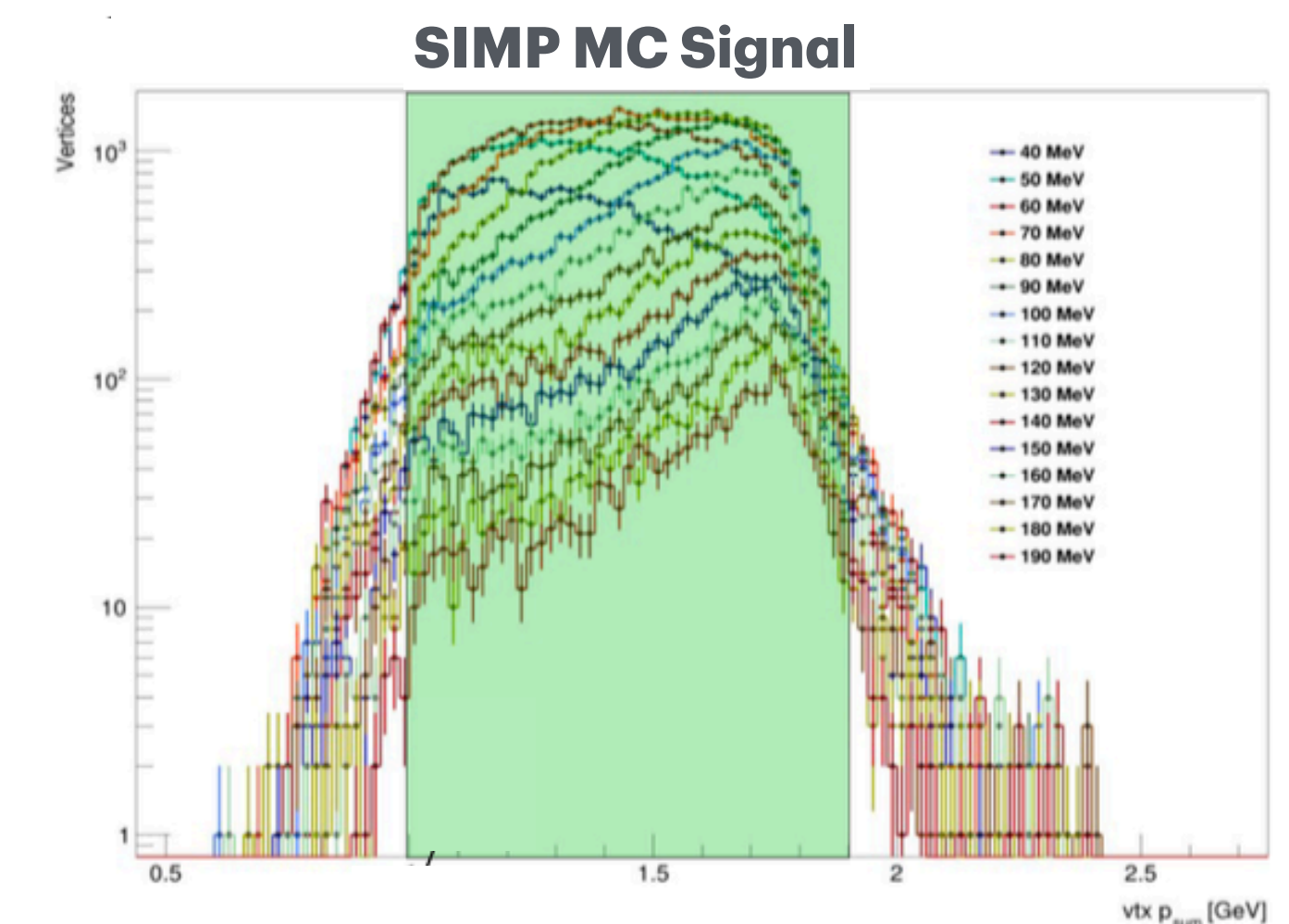
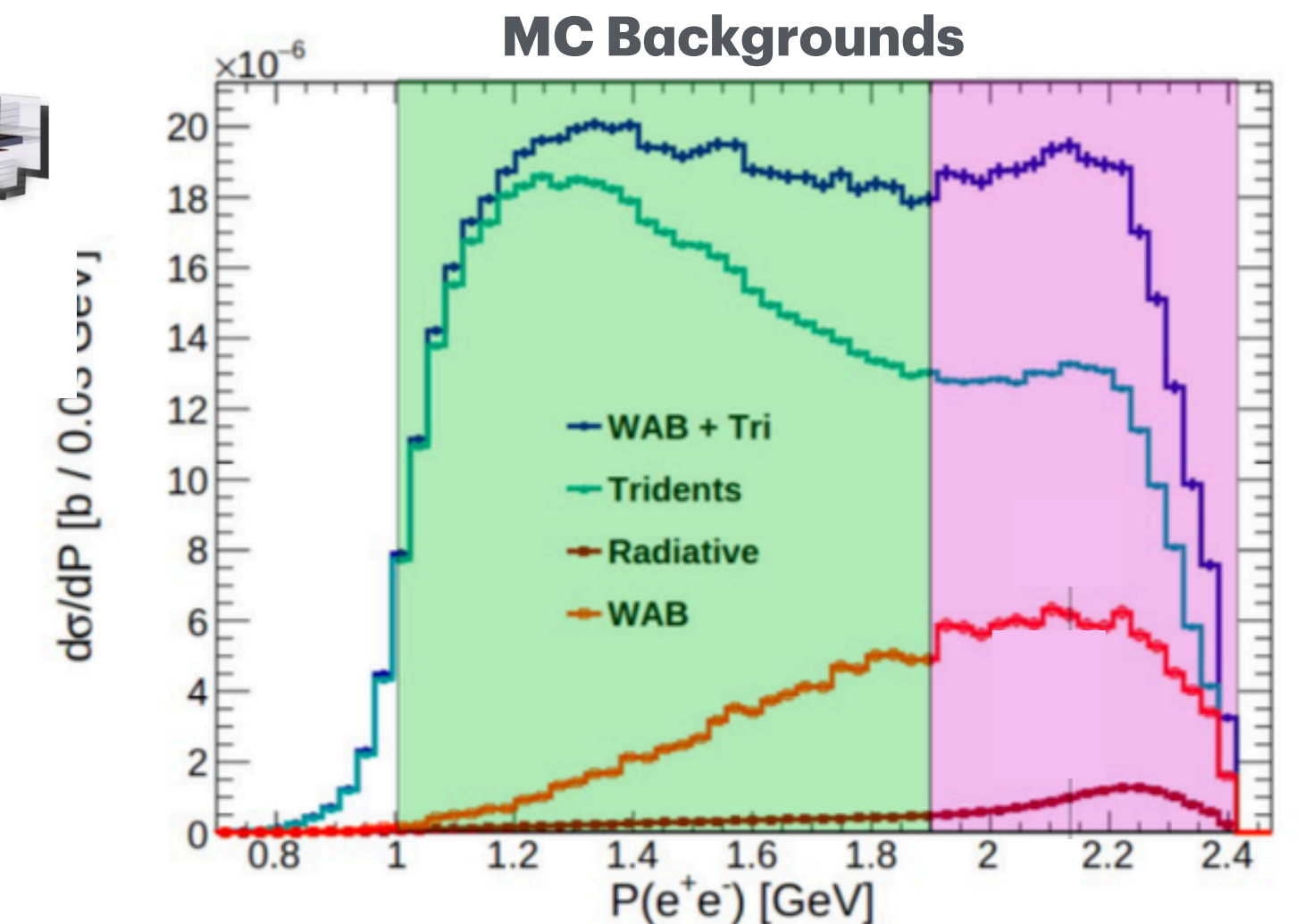
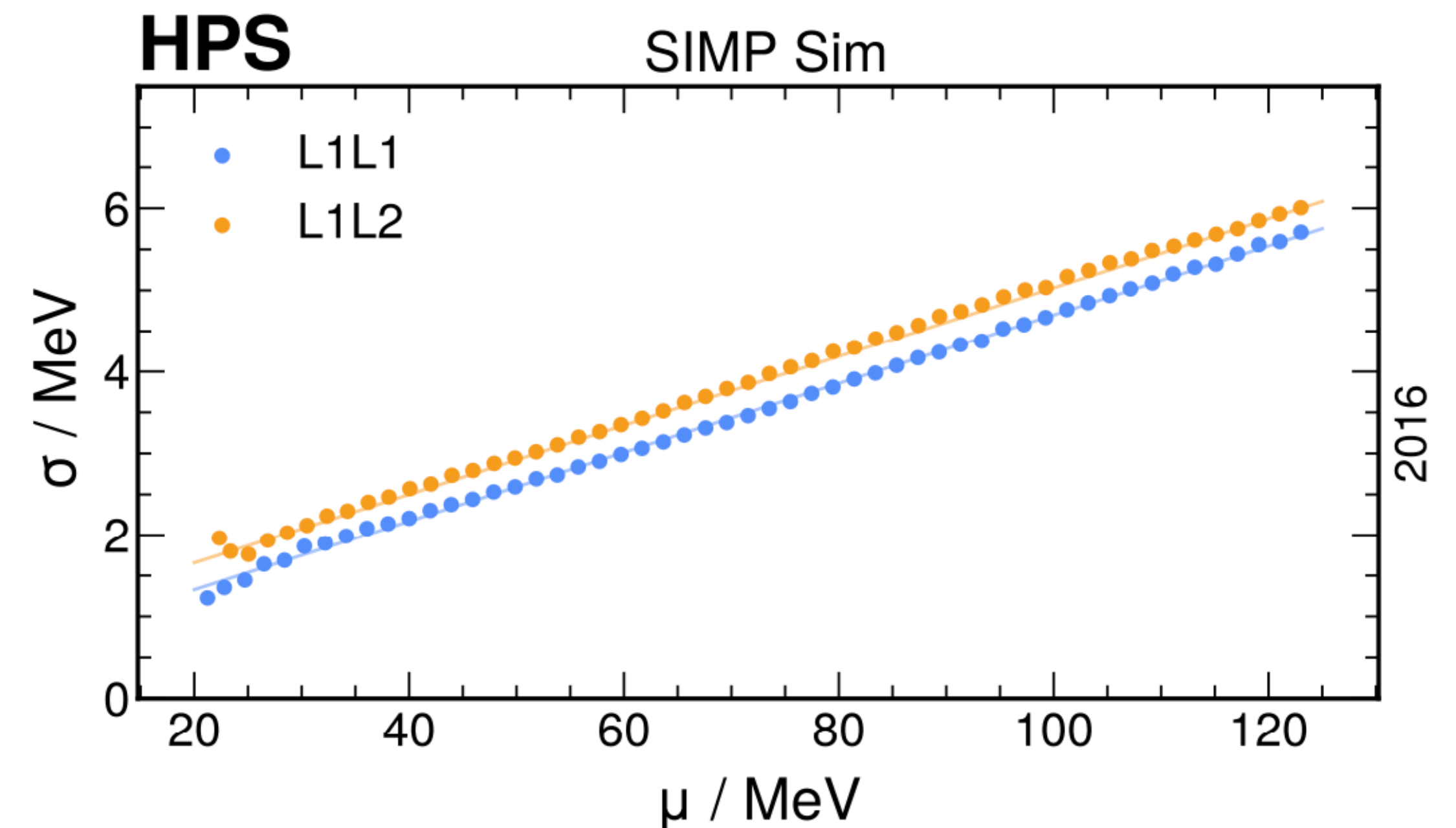
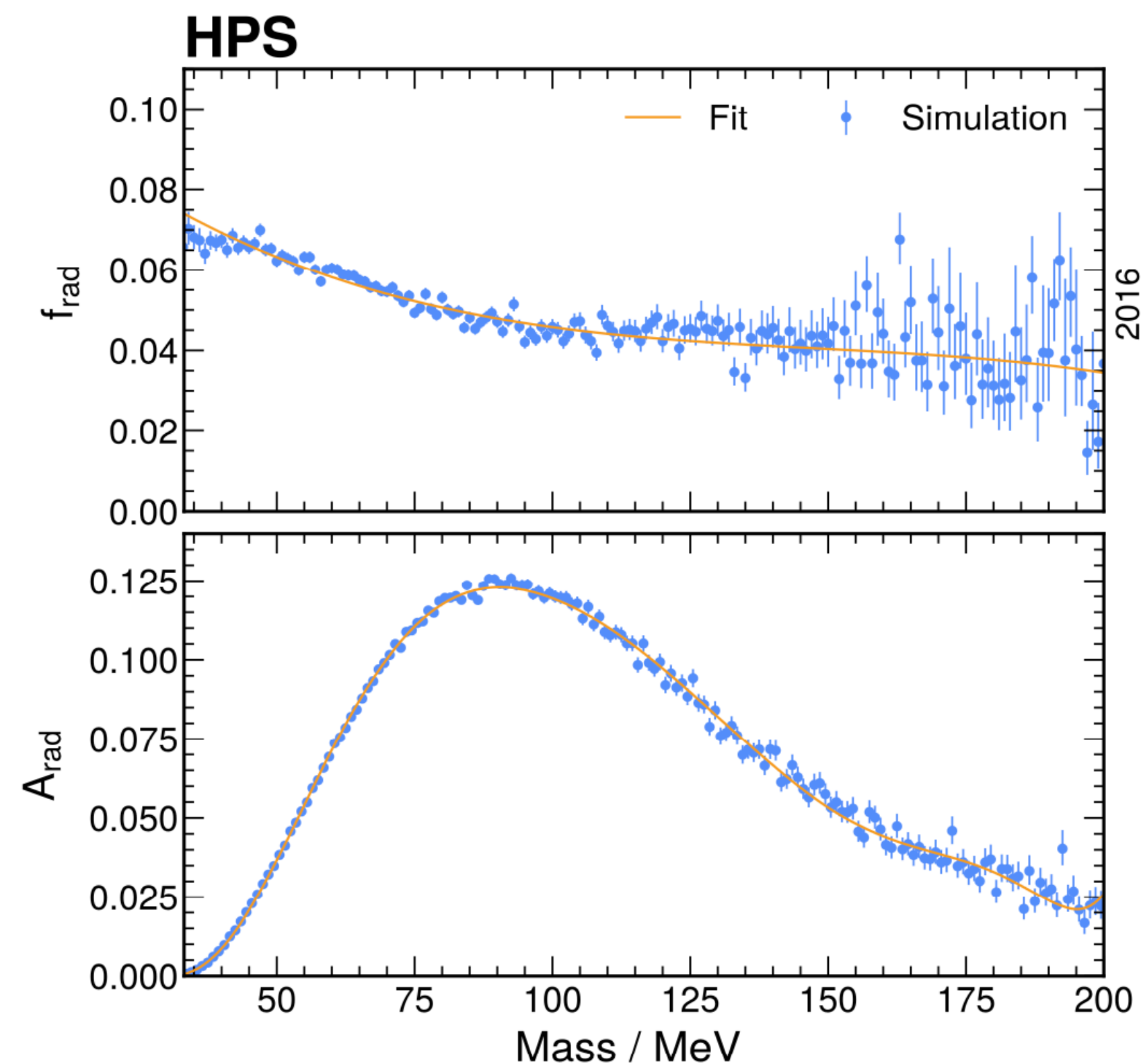


FIG. 3. Radiative (left) and Bethe-Heitler tridents (right) have the same final state particles as the e^+e^- production from a dark vector decay shown in Fig. 1.



Radiative Fraction and Mass Resolution

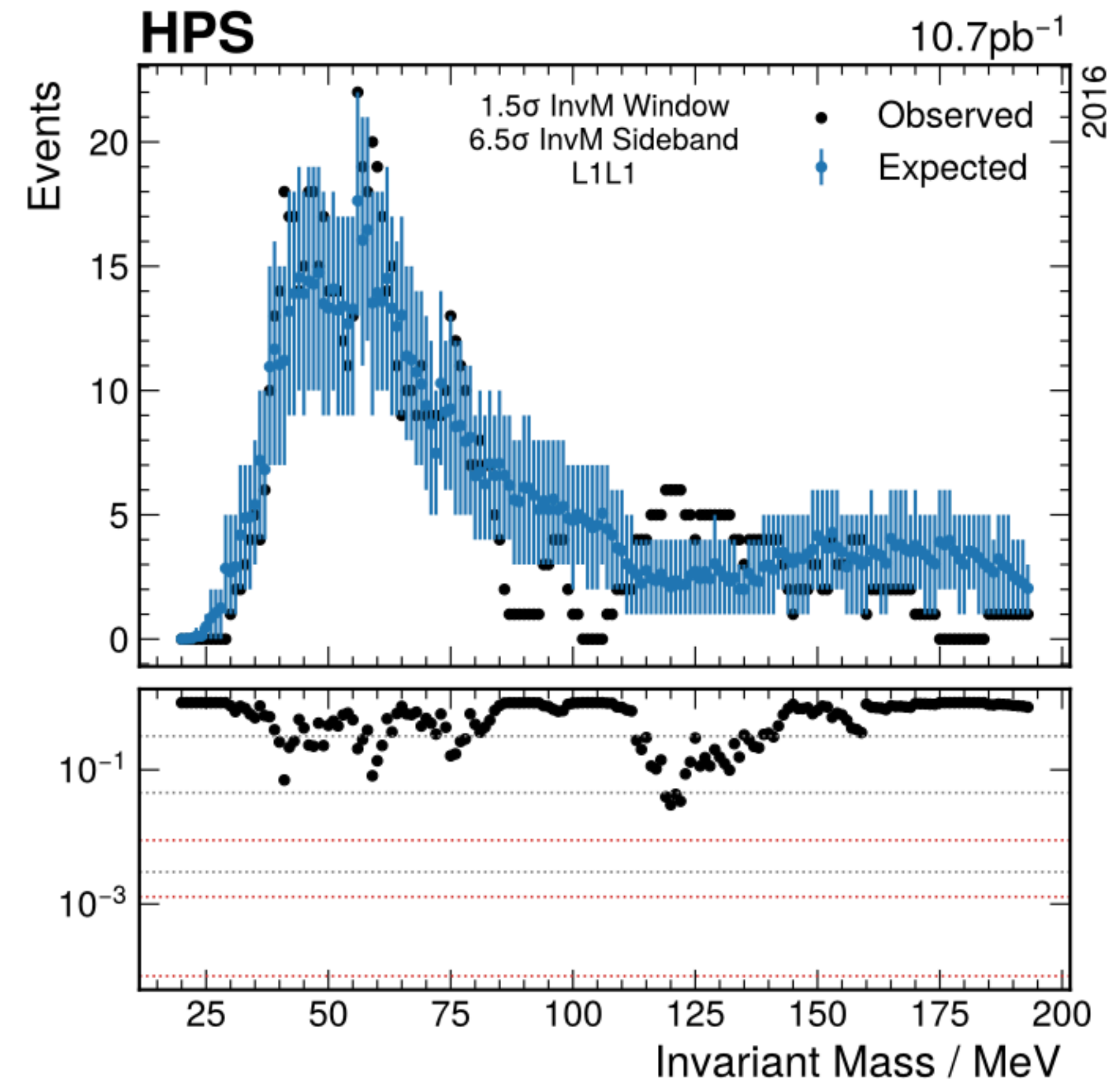
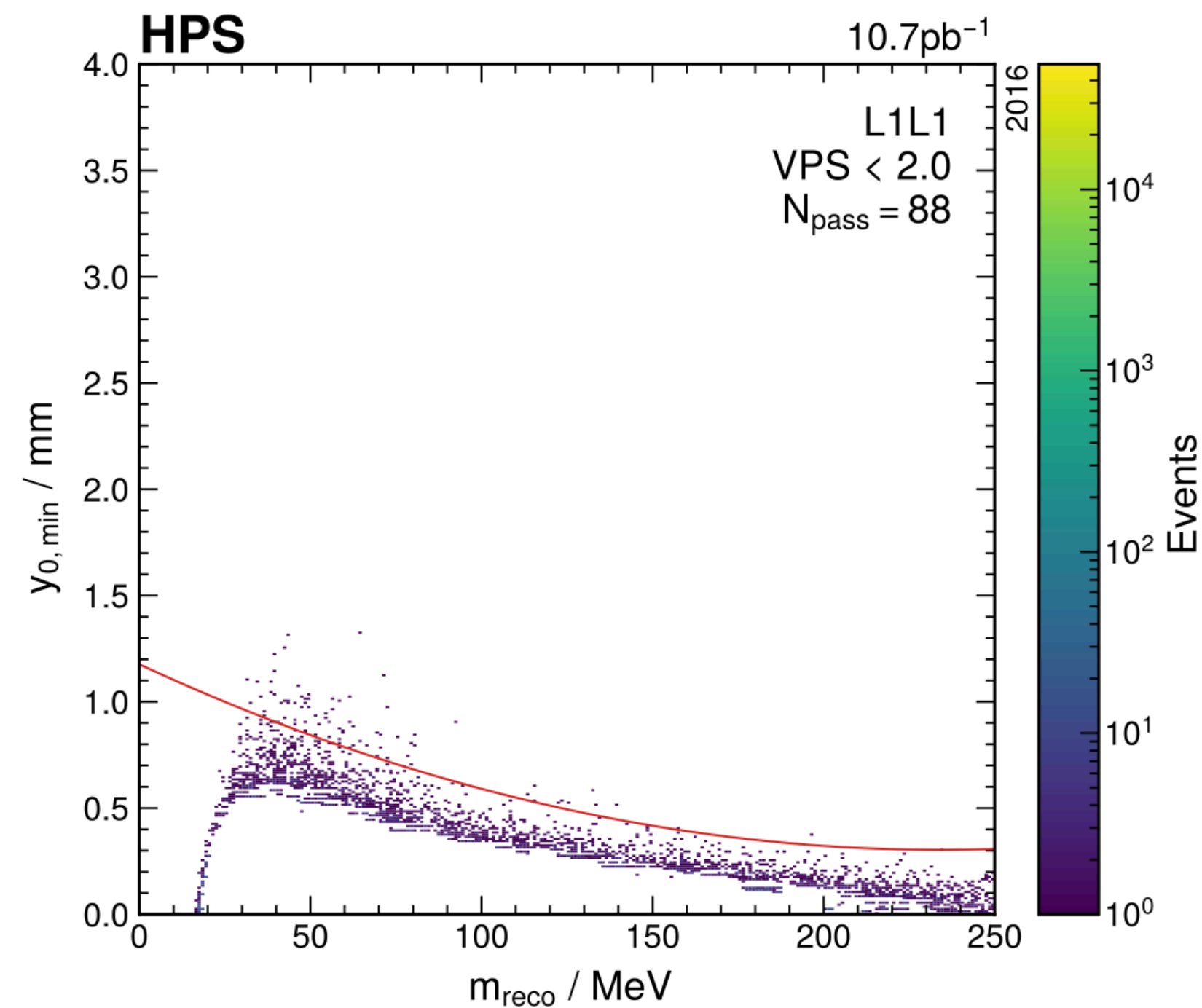
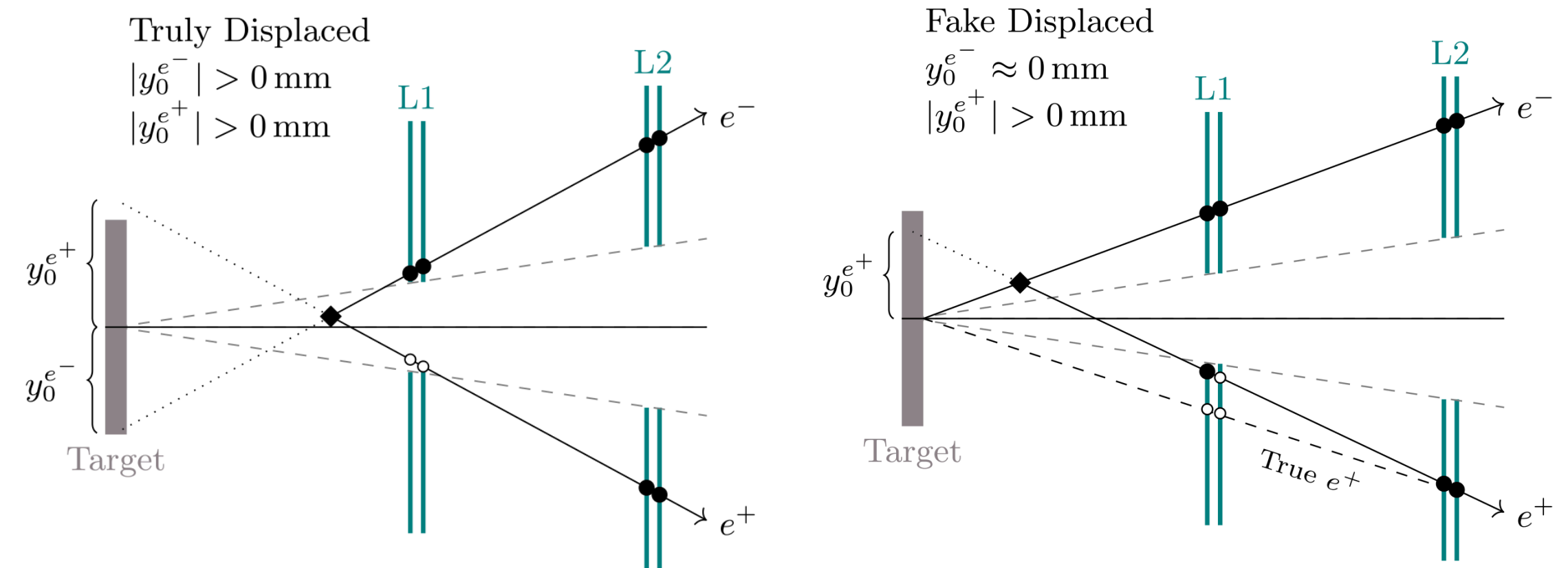
- With the irreducible Bethe-Heitler background, radiative fraction is always a key A' ingredient, and larger for a SIMP analysis
- And mass resolution, which we model with simulation and benchmark with Moller scattering



Signal Extraction

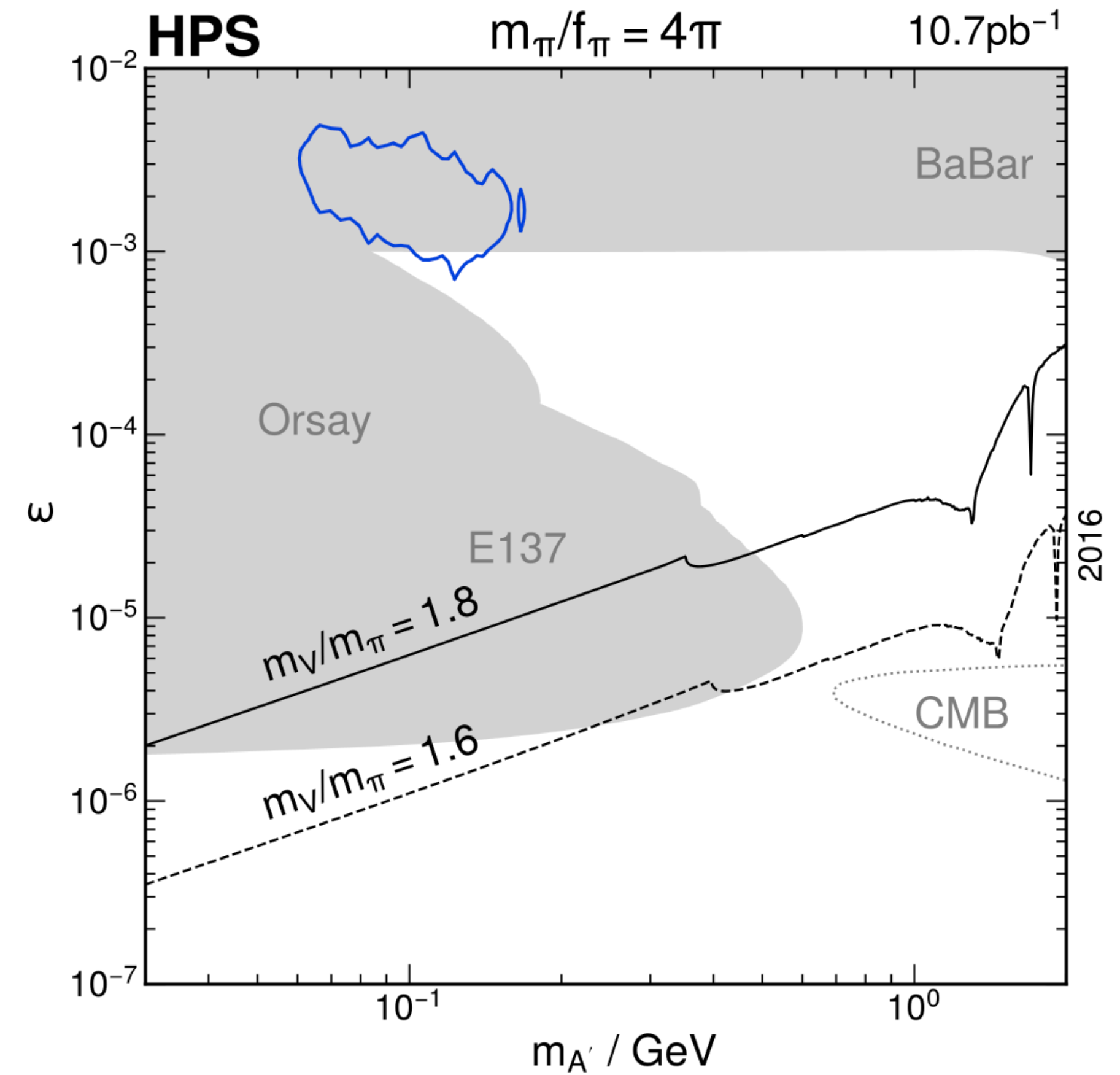
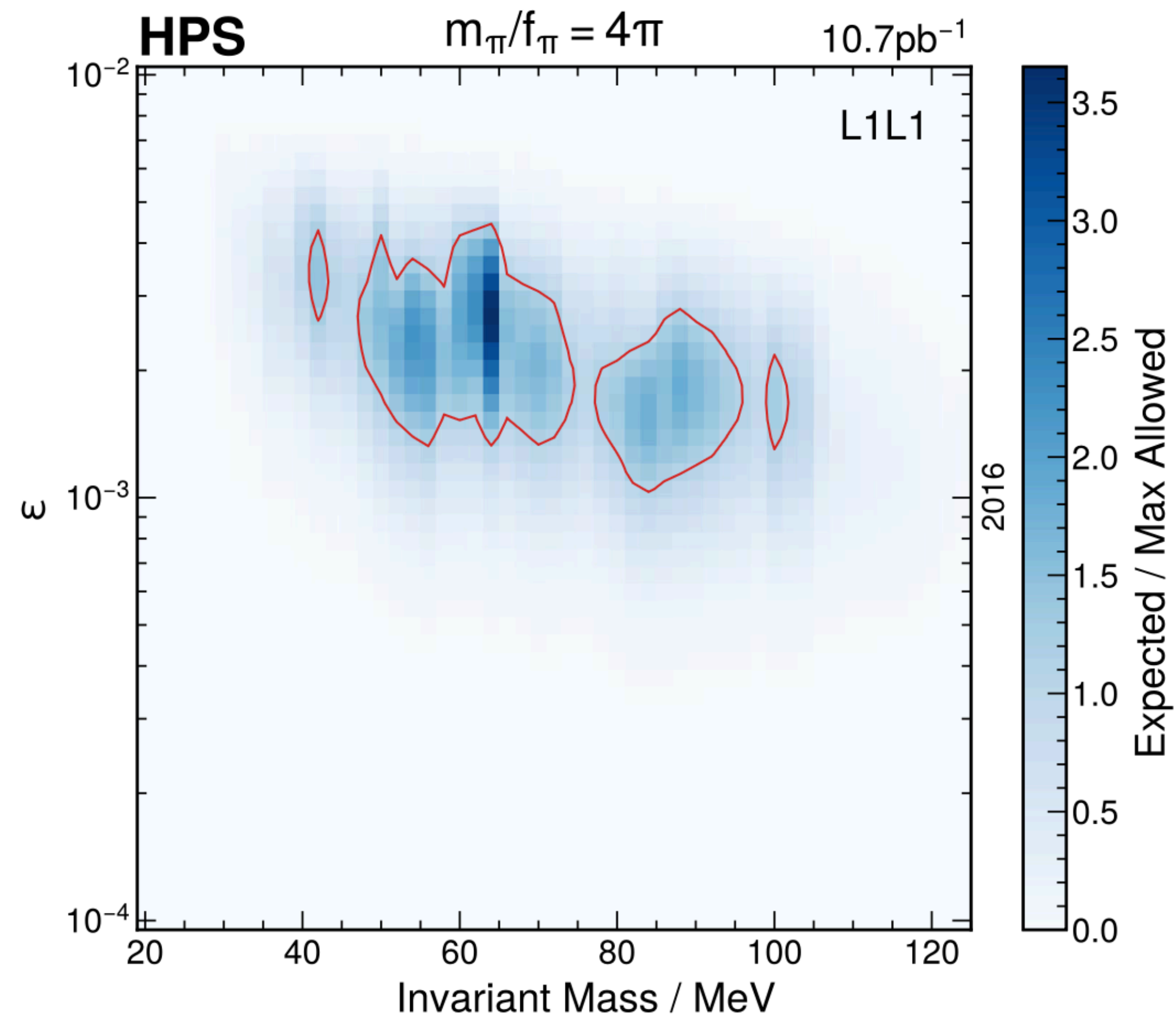
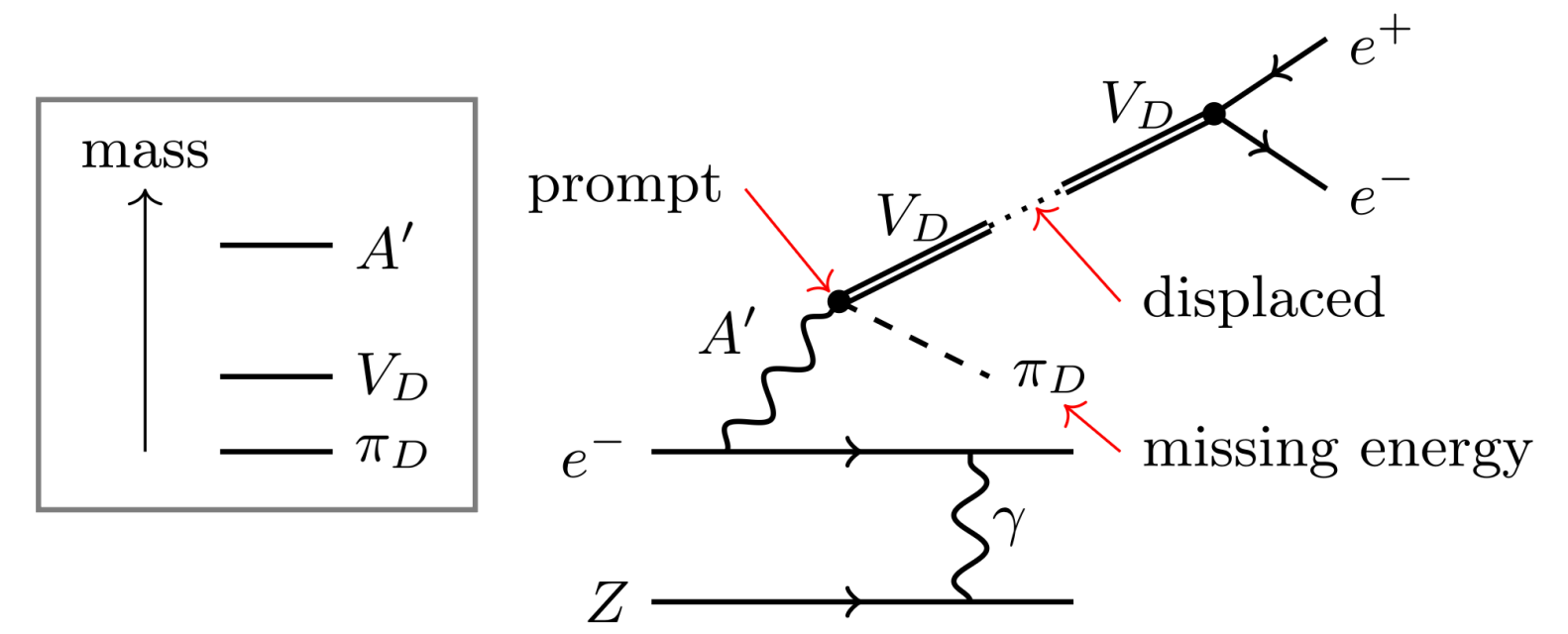
SIMPS - Displaced Vertex

- Proxy variable, $y_{0,\min}$, for quantifying vertex detachment and separating fake displaced backgrounds
- And then counting displaced event excess in each mass window, utilizing a sideband analysis, and an optimal interval method for the confidence level



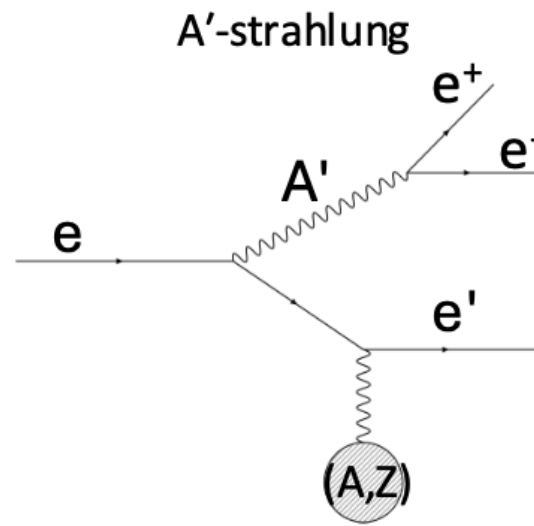
SIMPs

Exclusion Result - 2016 Run

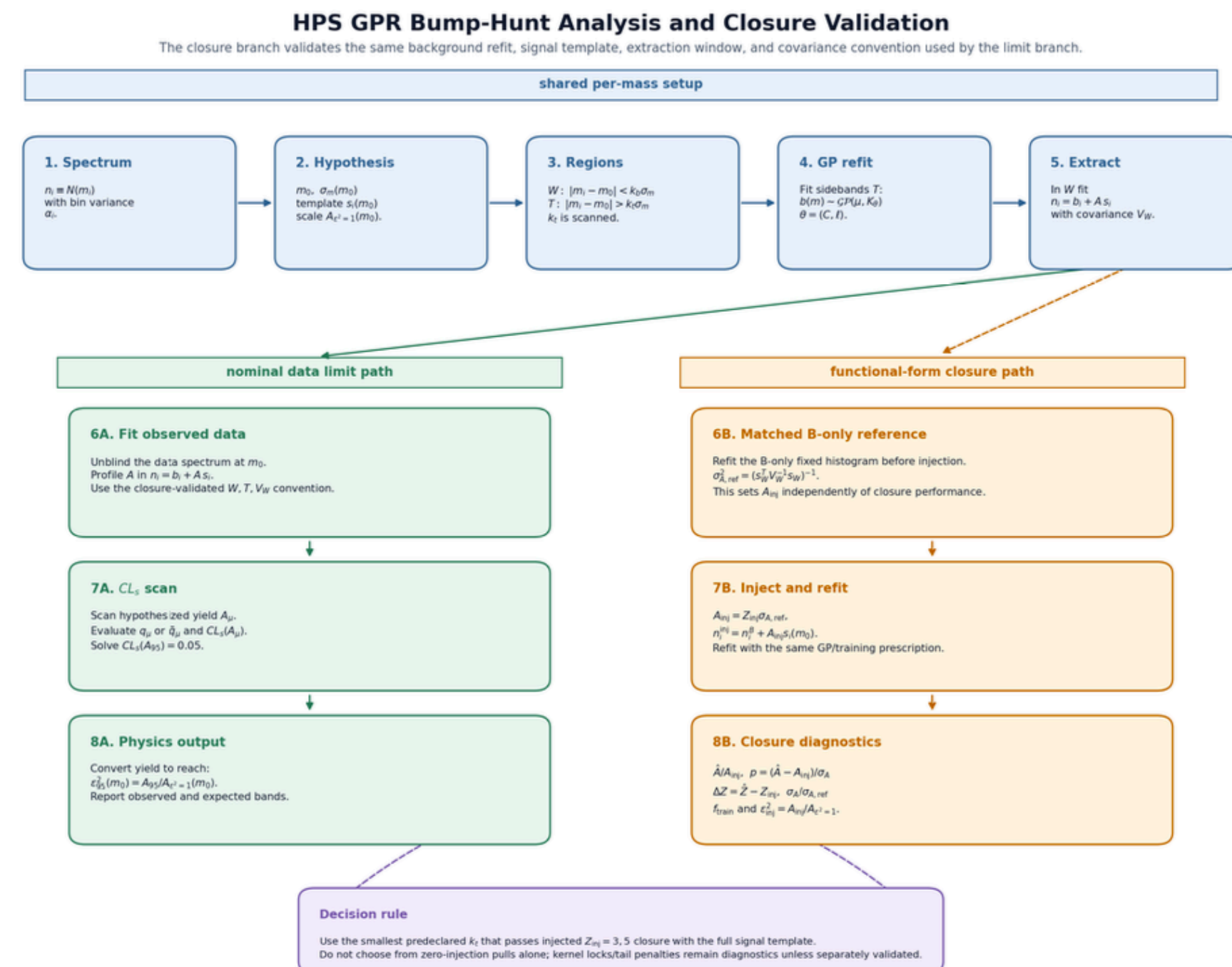
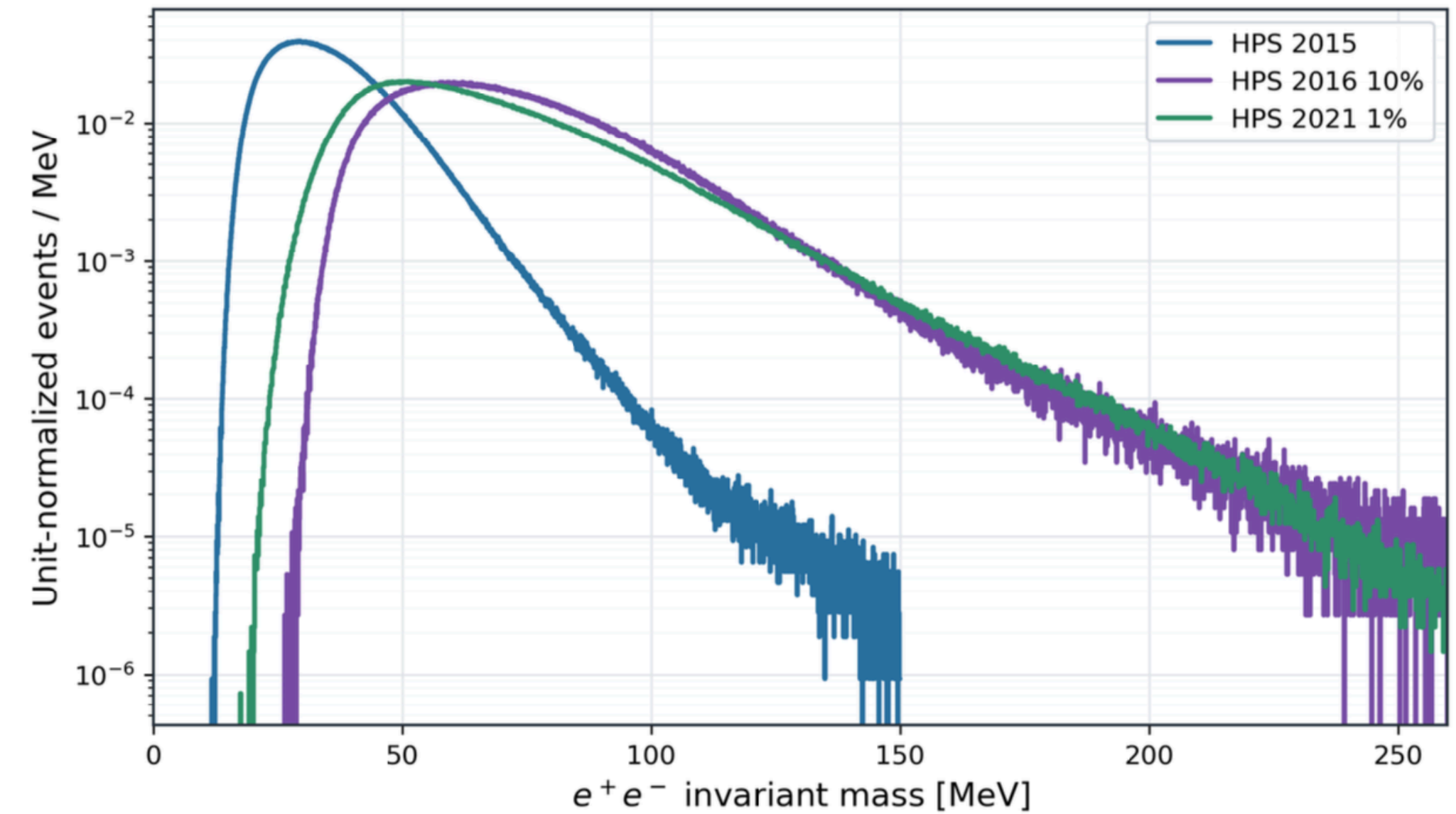


Visible A'

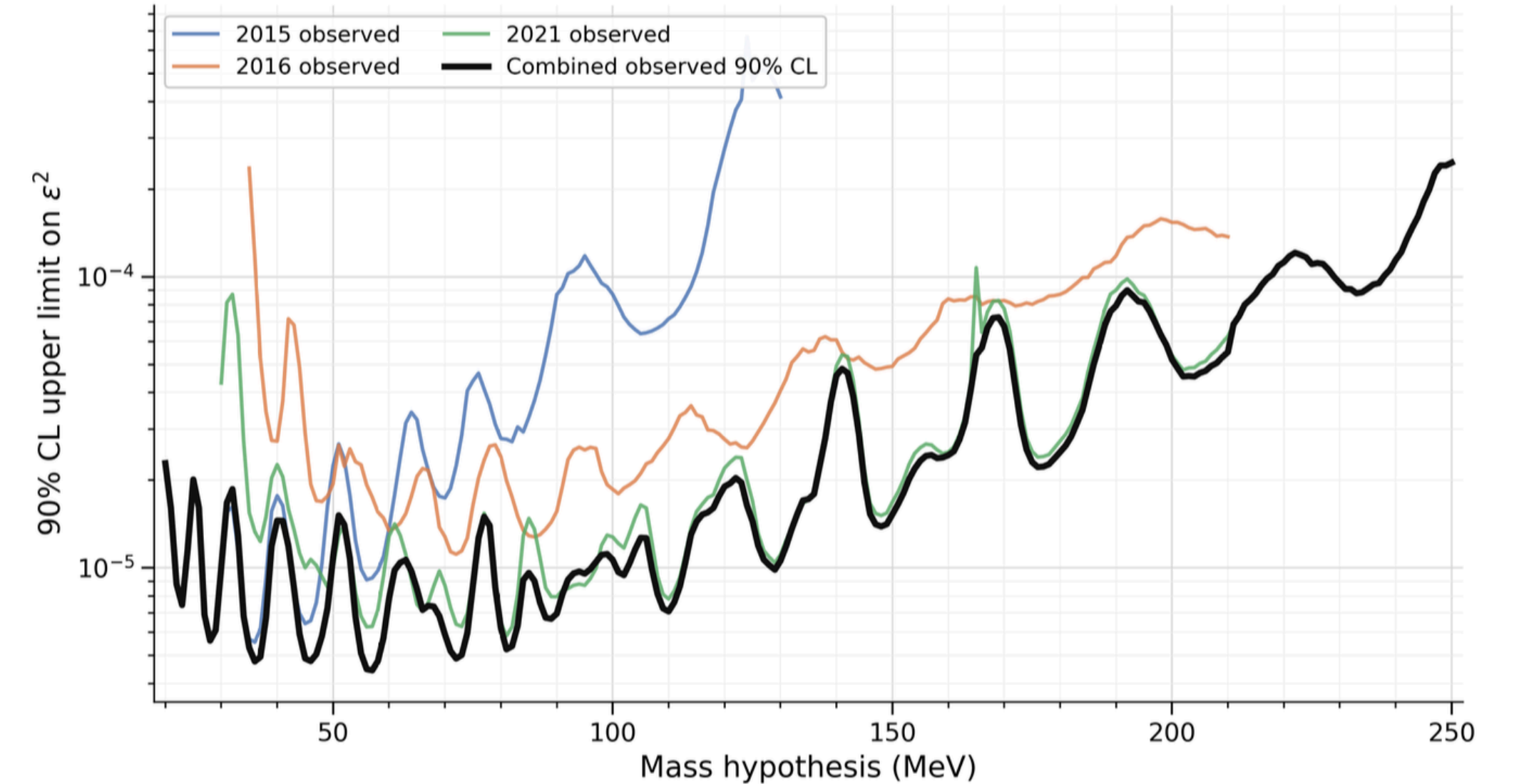
2021 Bump Hunt



- Gaussian Process Regression technique adopted for bump hunts, with Gaussian-profiled background nuisances, more robust and minimizing systematics
- Review of blinded analysis is finishing, unblinding is next, preparation for publication



90% CL observed limits: individual datasets and simultaneous combination



Summary



- HPS's first SIMPs search was published early this year, with our 2016 engineering run data set, extending beyond HPS's proposed measurements.
- HPS's visible A' searches with 2021 data, in a combined analysis, is coming soon.

PHYSICAL REVIEW D **113**, 032019 (2026)

First displaced vertex search for electroproduced dark-sector strongly interacting massive particles by the HPS experiment

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Systematic	Value
Radiative fraction	7%
Preselection cuts	Neglected
Final selection cuts	Neglected
Radiative acceptance	
From preselection	Neglected
From target uncertainty	~5%
Signal yield	
From target uncertainty	2%
From mass resolution	0.5%
Beamspot	Neglected
p_{sum} shape	~3%
Total	~10%