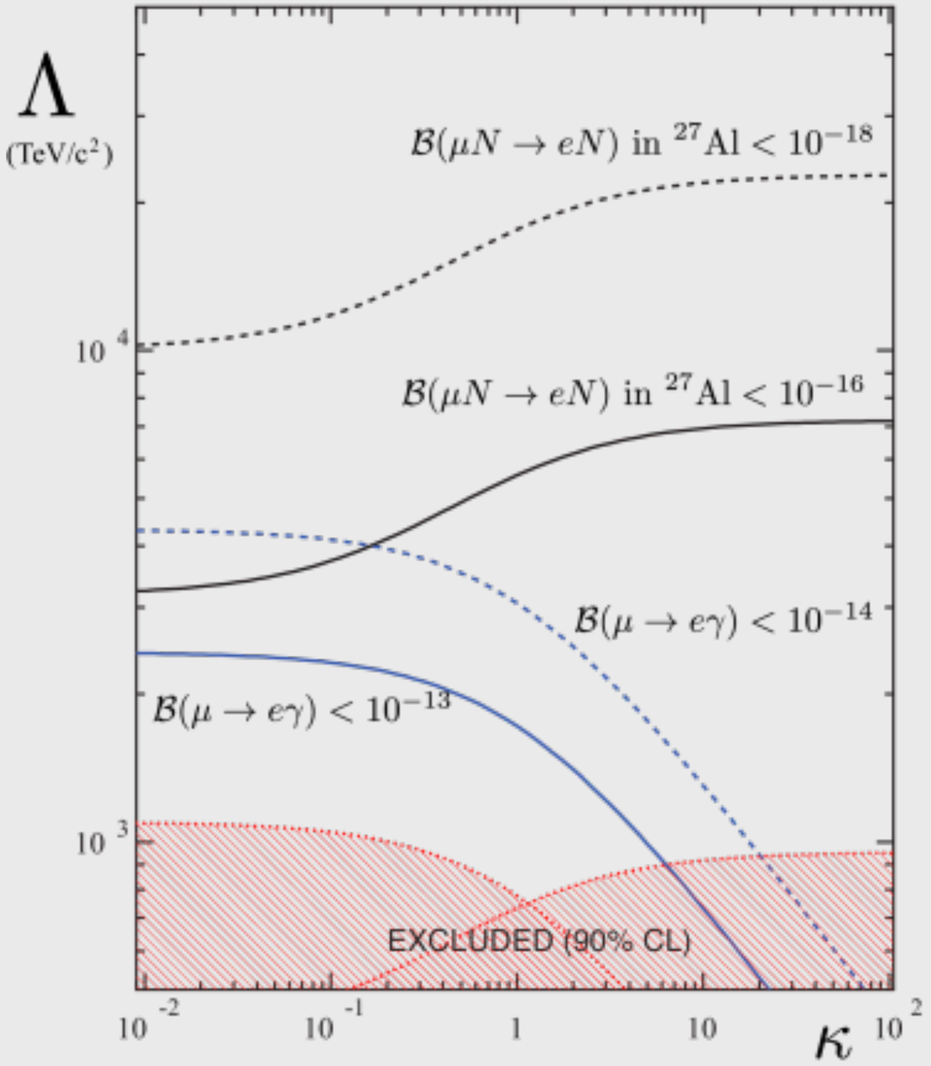
Muon & Pion Decays At Low Mass

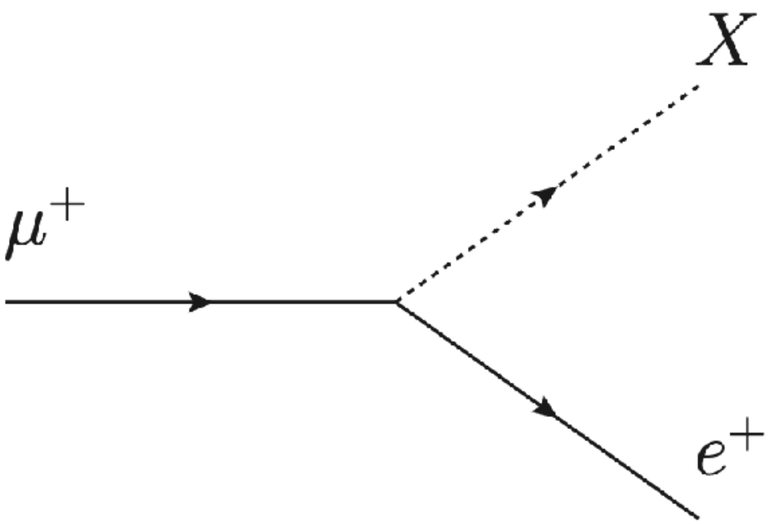
RYAN PLESTID
WALTER BURKE INSTITUTE, CALTECH

MUON COLLIDER SYNERGIES WORKSHOP | IJC ORSAY | 2023

Probing High Scales With CLFV

- We typically think of muon facilities as probes of very high scales.
- The signatures are kinematically distinctive electrons/photons.
- **Strategy:** Cut out everything else.



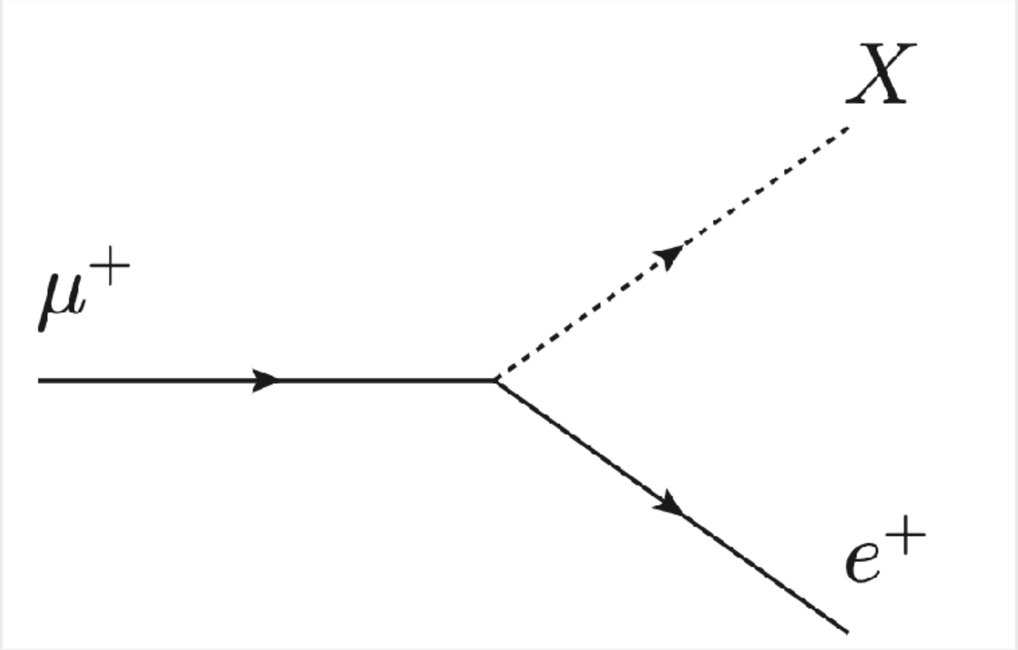


LIGHT NEW PHYSICS

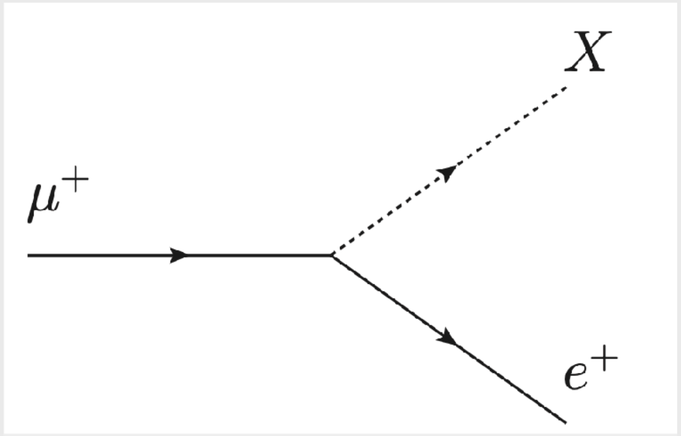
RARE BUT **KINEMATICALLY DISTINCTIVE**

Probing Low Scales With Muon Facilities

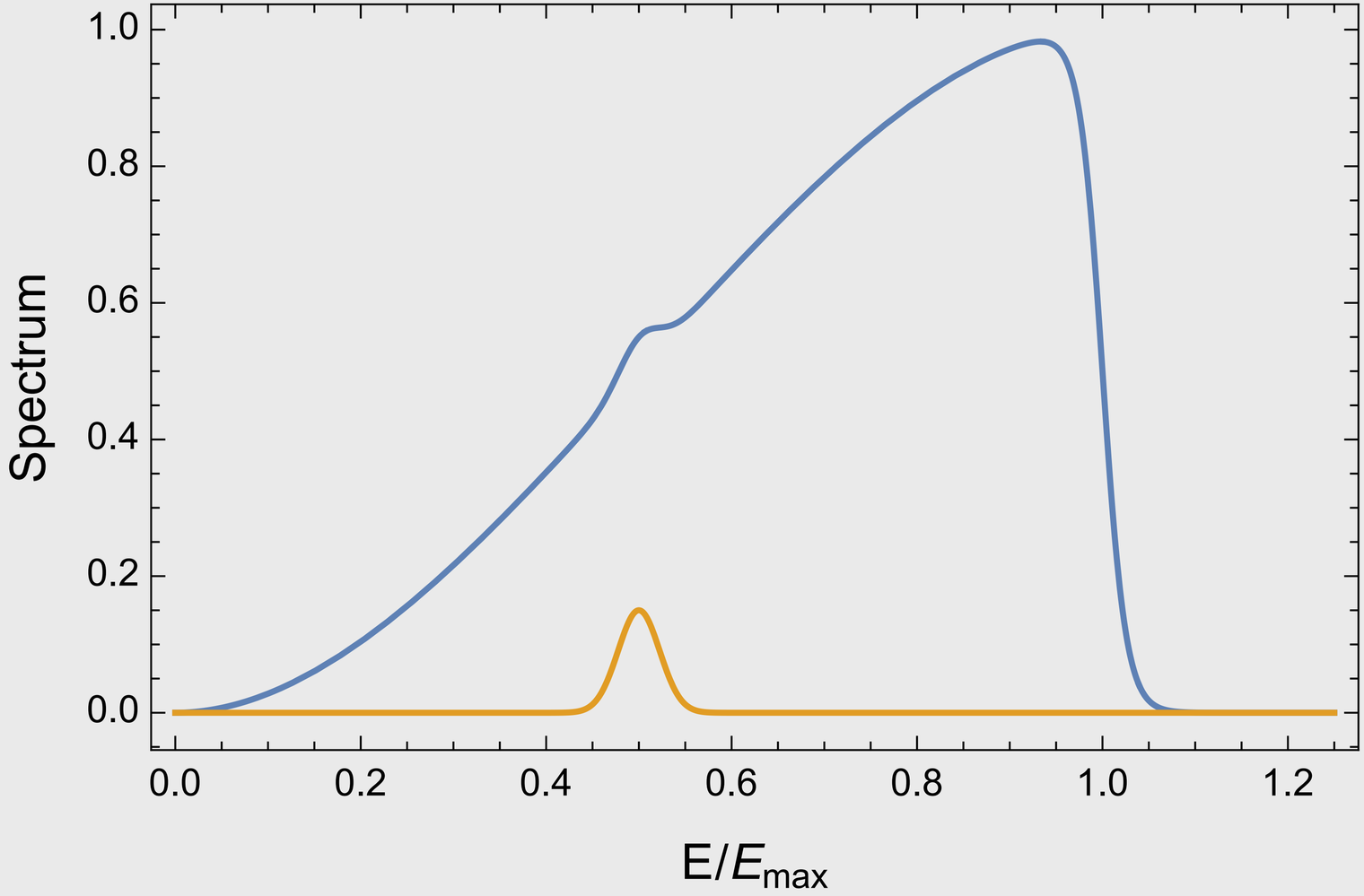
- High statistics: Attack weak coupling limit.
- Kinematically distinctive signatures.
- Generally outside the "central mission" of the facility.



Signals Below The Michel Edge

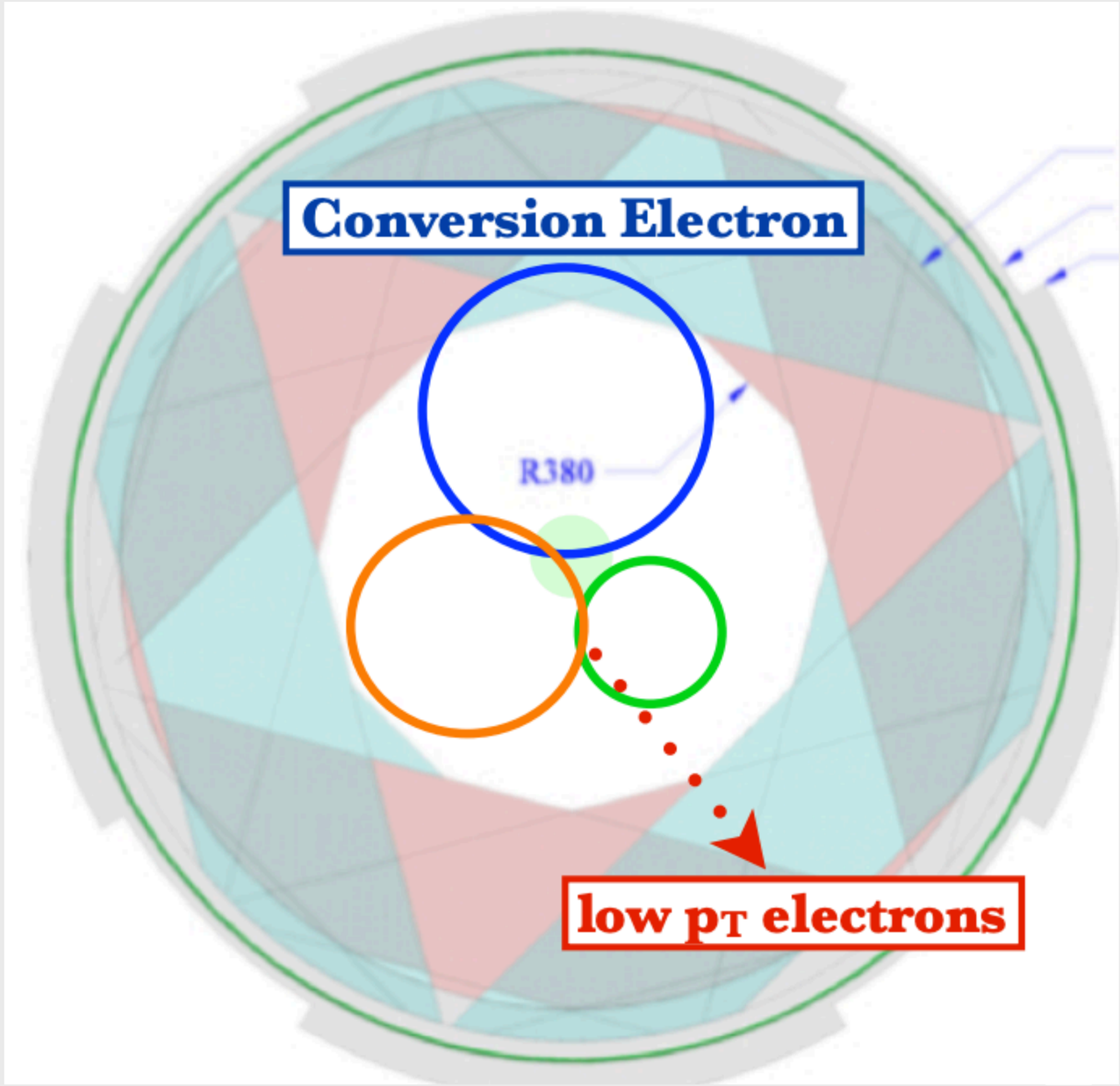


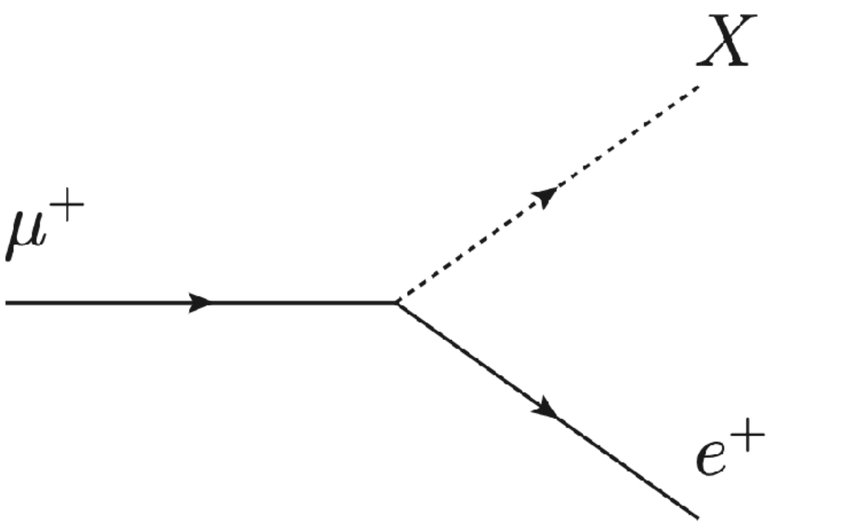
- Search for a mono-energetic positron.
- Look for a bump on the Michel spectrum.



Signal Is Invisible

- Tracker is designed to let Michel positrons pass through middle.
- Whole idea seems doomed from the outset.





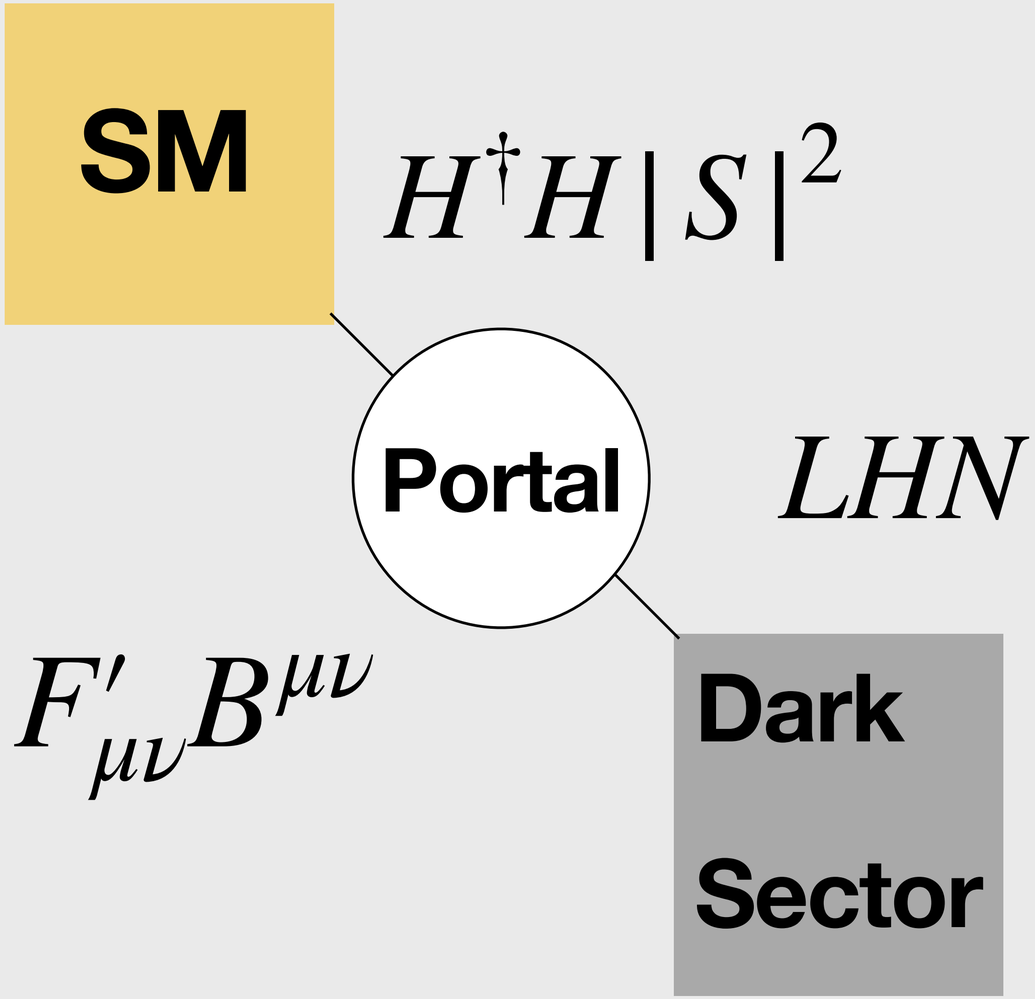
LIGHT NEW PHYSICS

RARE BUT **KINEMATICALLY DISTINCTIVE**

Motivation

- Dark matter strongly hints at the existence of dark sectors.
- A simple, model agnostic program exists.
- Focus on portals i.e. couplings that could talk to the SM.

Portals



Motivation

- Q: How many ways can light new physics couple to the SM?
- A: Not many once you restrict to low-dim operators!

$$\mathcal{O}^{[4]}_{\text{singlet}} = \phi^2 |H|^2 \quad \text{or} \quad LHN \quad \text{or} \quad B^{\mu\nu} B'_{\mu\nu}$$

Scalars **HNLs** **Z-Prime**

$$\mathcal{O}^{[5]}_{\text{singlet}} = \frac{1}{\Lambda} (\partial_\mu a)\, J^\mu + \dots$$

ALPs

Light New Physics

- Data demands that new physics be heavy, or weakly coupled

- What could we see in a ~100 MeV experiment?

Z-Prime

$$\mathscr{L} \subset g' \bar{\mu} \Gamma_\mu e \, Z'^\mu$$

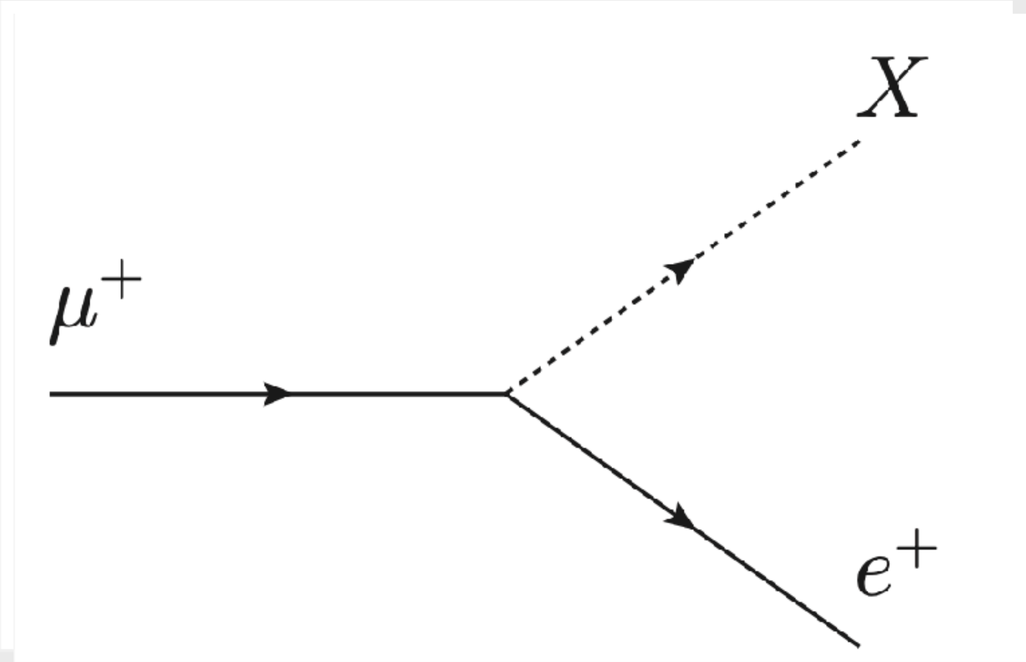
$$\mathscr{L} \subset \frac{1}{\Lambda} \bar{\mu} \Gamma_\mu e \, \partial^\mu a$$

Axions

HNLs

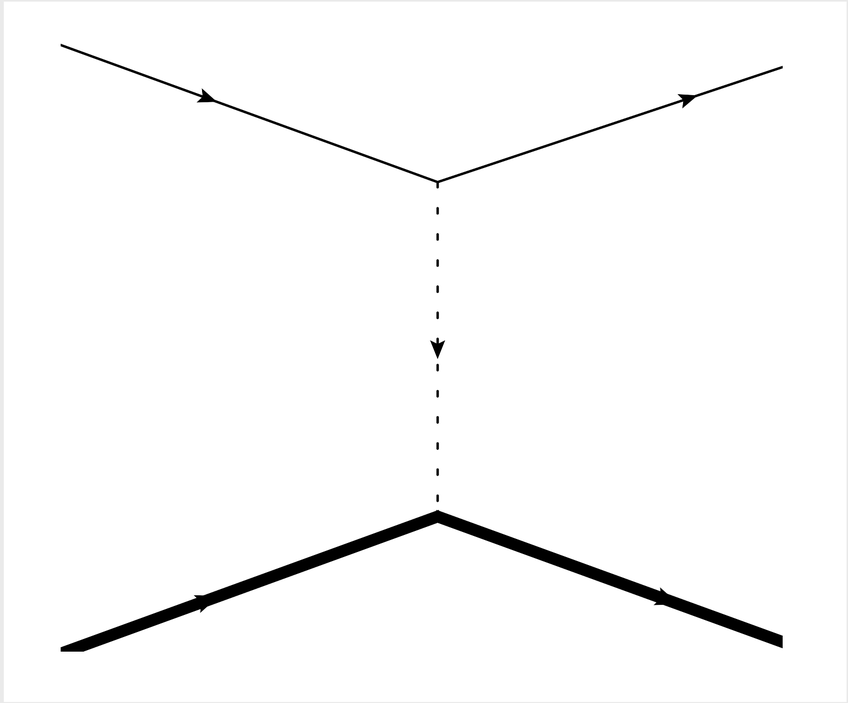
$$\mathscr{L} \subset U_{eN} \left[f_\pi G_F \left(\partial_\mu \pi \right) \bar{N} \gamma^\mu P_L e \right]$$

On-Shell Vs Off-Shell Processes



$$\Gamma \sim O(g^2)$$

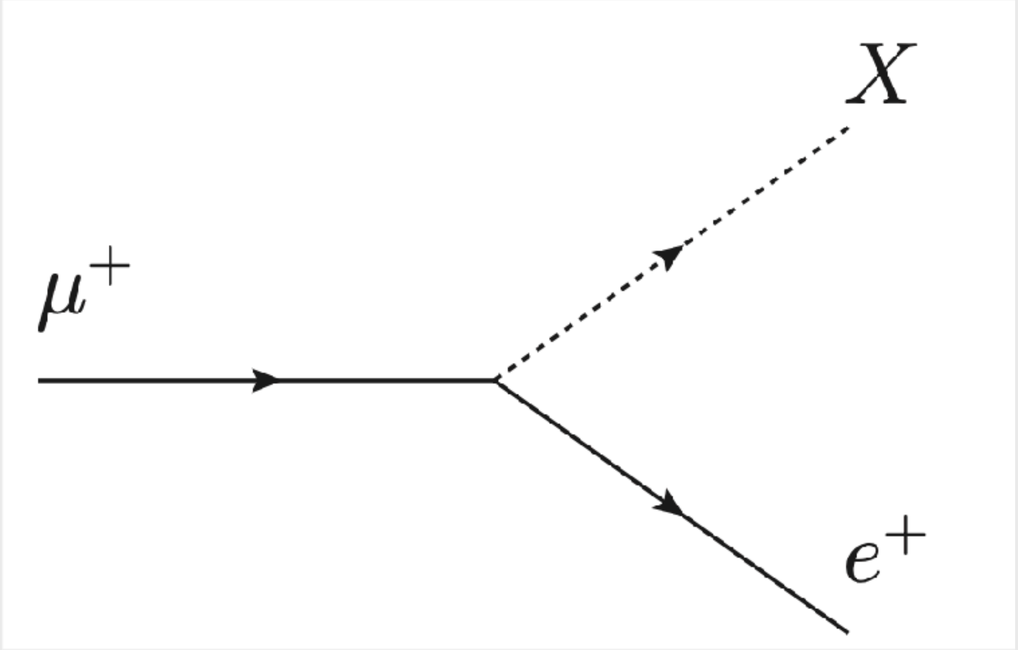
THIS WINS



$$\Gamma \sim O(g^4)$$

Probing Low Scales With Muon Facilities

- High statistics: Attack weak coupling limit.
- Kinematically distinctive signatures.
- Generally outside the "central mission" of the facility.



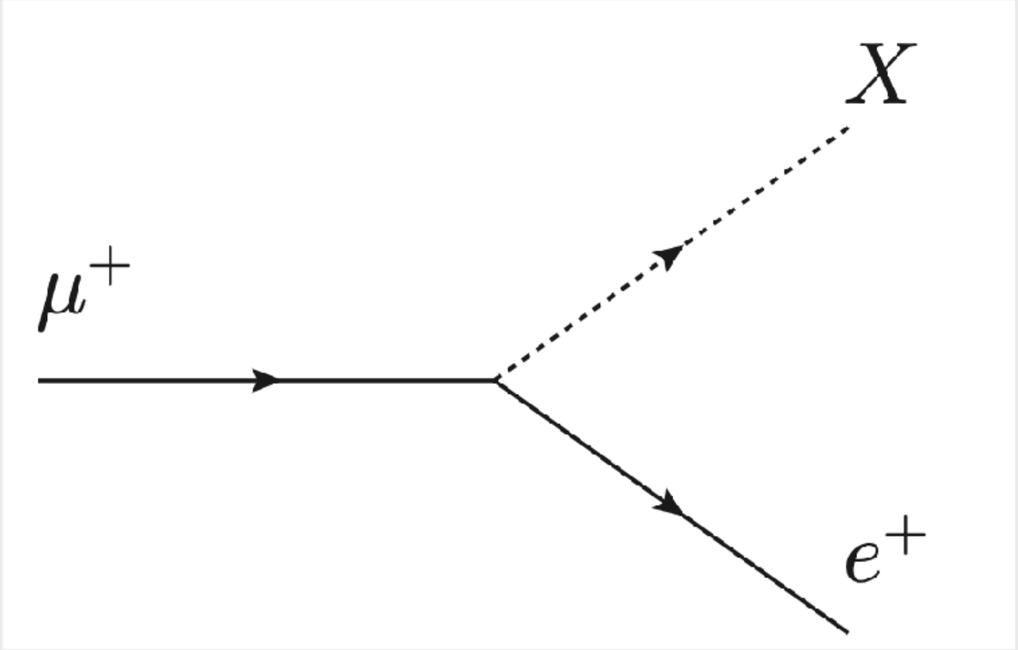
Probing Low Scales With Muon Facilities

Main Idea

- Light new physics is well motivated. Portals are constrained by gauge group of SM.
- On-shell decays have much better reach than off-shell mediated processes
- This is the opposite of high-scale scenarios.

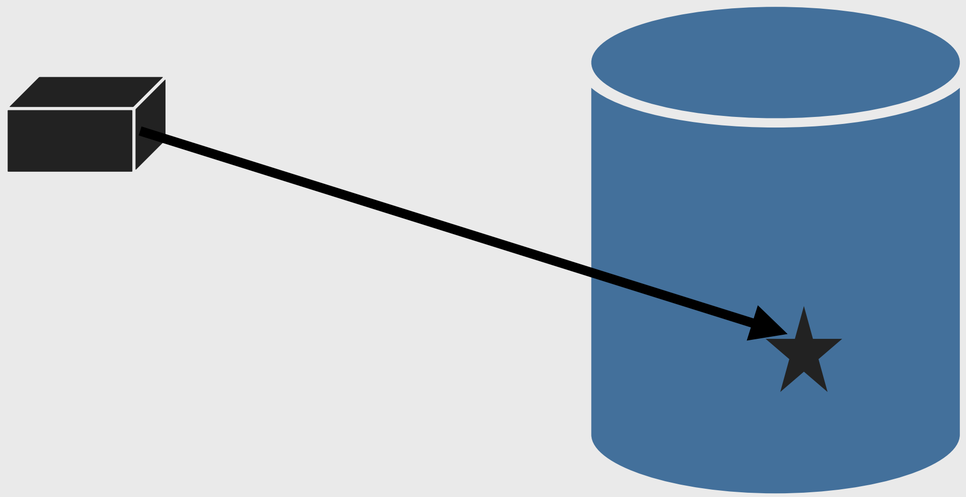
Invisible/Indirect Searches

- Tag on positron and do a bump hunt.
- Independent of decay length of X.



Visible Decay Searches

- Search for produced light particle downstream in a separate (dedicated) detector.
- Depends on decay length.



Different Searches

Strengths/Weaknesses

- Direct searches need a high quality spectrometer (good energy resolution).
- Decay searches are good, but difficult to compete with π decay at rest experiments $\sim 10^{23}$ pions.

$$10^{13}\ \mu/\mathrm{s} \times 3 \cdot 10^{7}\mathrm{s/yr} \sim 3 \times 10^{20}\ \mu/\mathrm{yr}$$

Direct Searches

$\pi^+ \to e^+ X$

- Need $\sim 10^{12}$ π^+ for world leading constraints.

$\mu^+ \to e^+ X$

- Need $\sim 10^{14}$ μ^+ for world leading constraints.