Muon Colliders & Dark Sectors

Discussion Section

Cari Cesarotti & Yoni Kahn

How can we search for Dark Sectors at Muon Colliders?

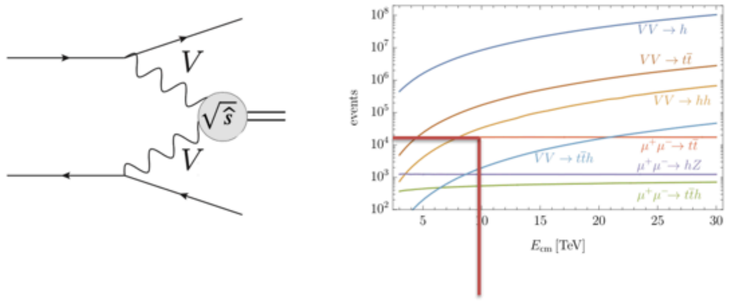
- *What can we do with higher energy? 3 TeV - 10 TeV - 100 TeV?*
- *How does the cleaner environment of the muon collider facilitate searches?*
- *What sort of beam intensity do we need to surpass other experiments?*
- *What can be done at beam dumps? At what energy? What material?*
- *Can we just use low energy things from the LINAC (400 MeV, 800 MeV, 8 GeV) or booster (8 GeV)?*

What Dark Sectors are of Interest?

- *What kind of portals are enhanced with muon colliders?*
- *What signals do we get from minimal models that can be seen at muon colliders?*
- *What models would couple more strongly to 2nd generation or EW bosons?*
- *What are the best production mechanisms for new physics?*

Slides from Talks

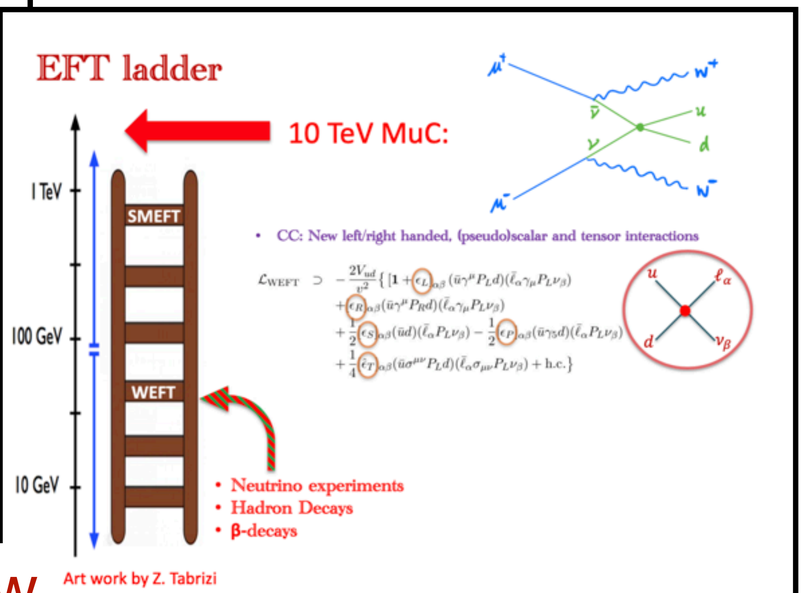
A 10 TeV muon collider would be a super-Higgs factory, producing ~ 10 million Higgs bosons with 10 /ab:



This would allow us to study the microscopic properties of the Higgs!

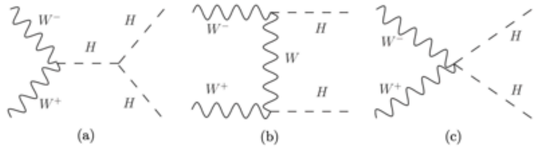
(By comparison, an "ordinary" Higgs factory produces ~ 1 million Higgses.)

Ian Low

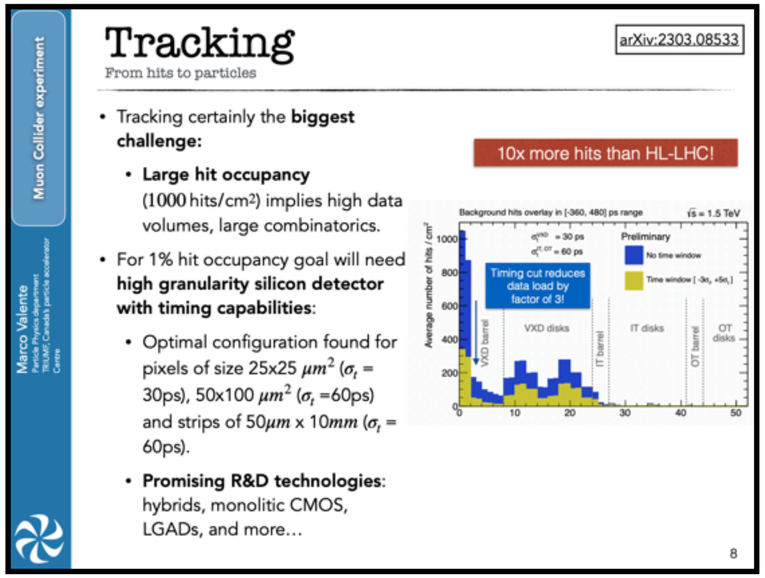


Art work by Z. Tabrizi

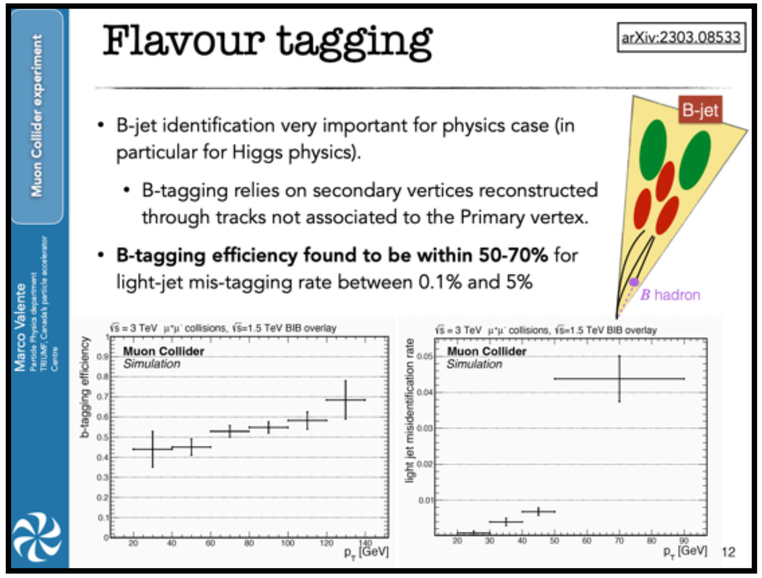
- At a lepton collider, both the trilinear and quartic couplings can be probed in double Higgs production through VBF:



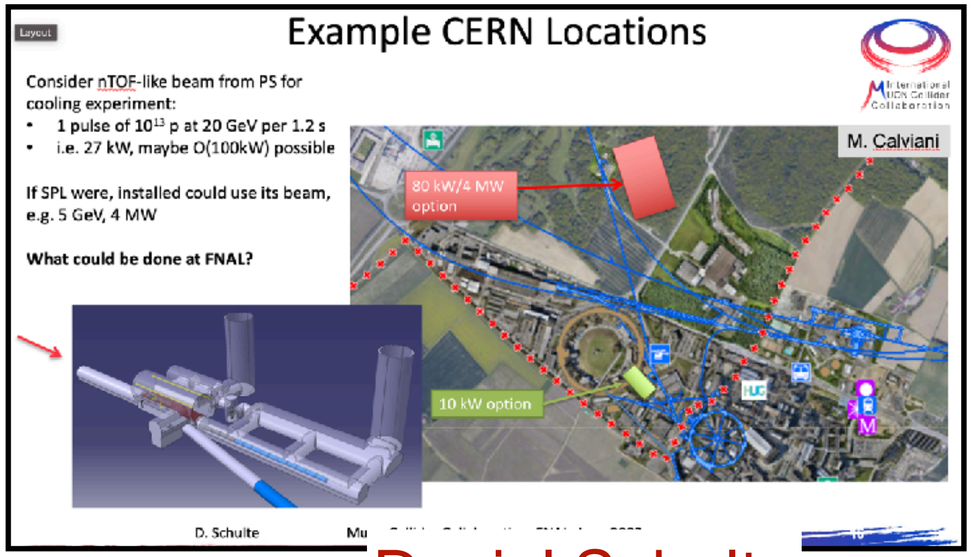
Notice the process is sensitive to **both** HHH and WWHH couplings!



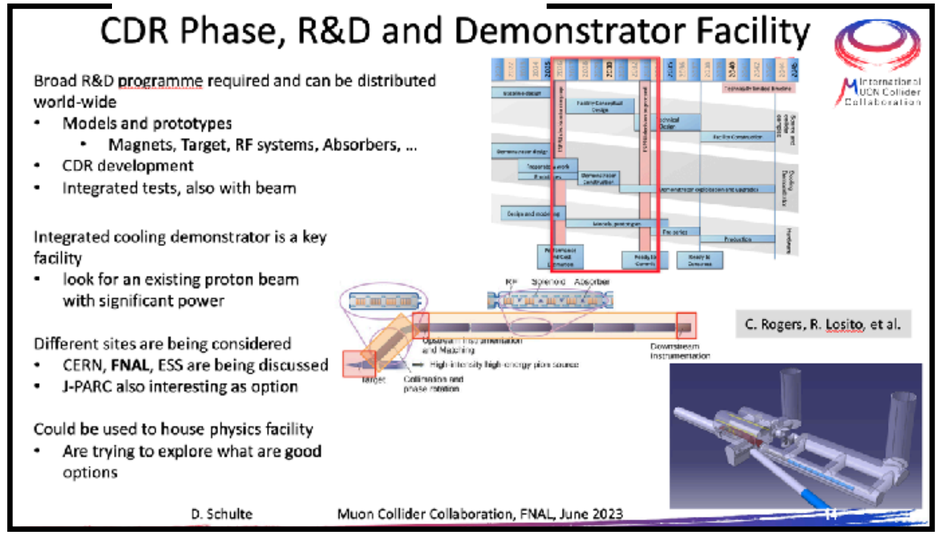
Marco Valente

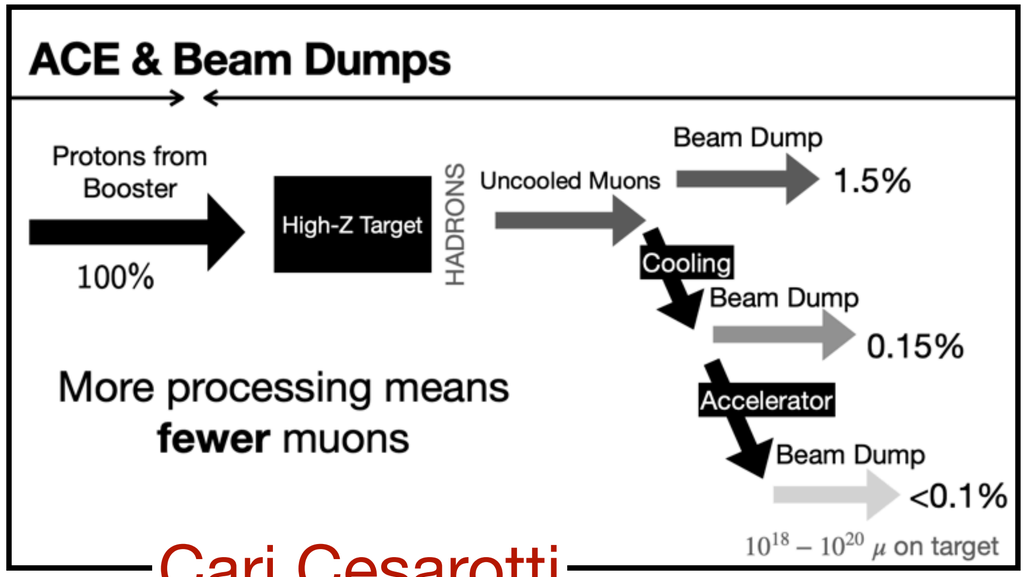


Slides from Talks

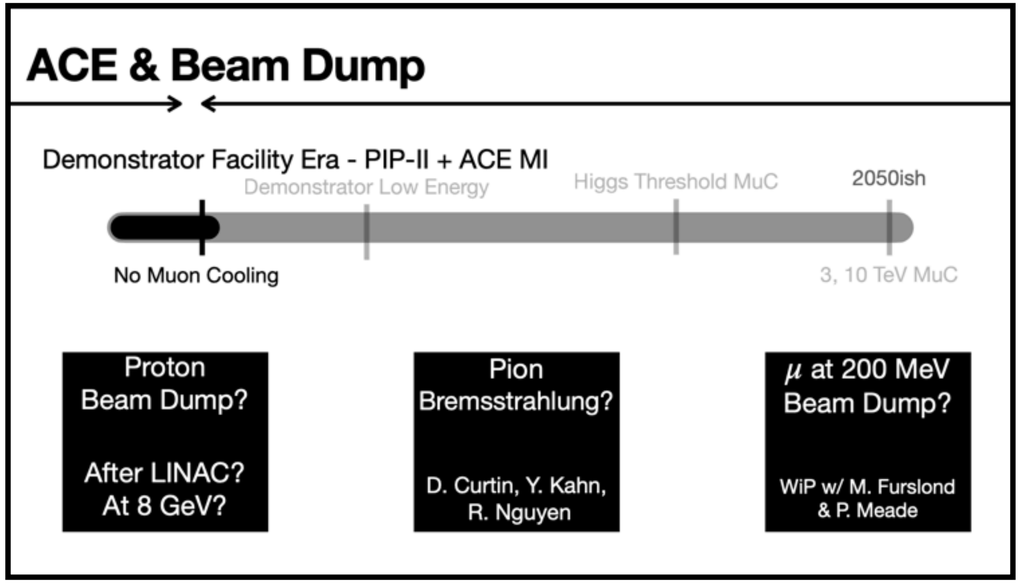


Daniel Schulte





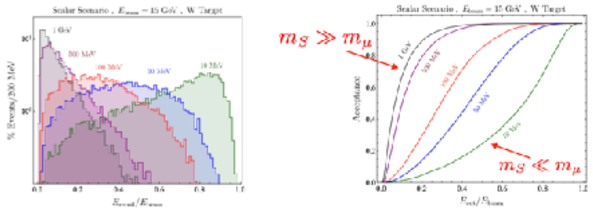
Cari Cesarotti



Slides from Talks

Choose a slide to add to this presentation.

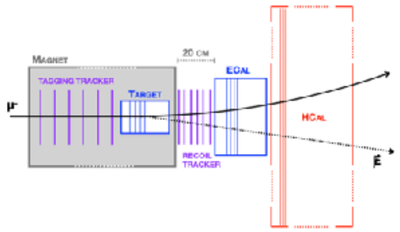
Setup



outgoing energy distribution — acceptance

Unlike electron beam, invisible particle doesn't take all the beam energy:
low-mass invisibles are QED-like (and hard to distinguish from background)

M³ schematic



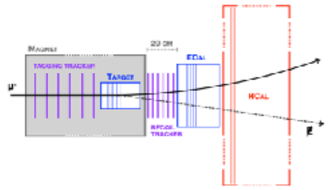
Similar in spirit to LDMX (electron beam missing momentum)

Main differences from LDMX:
- **thicker (50 X0) active target** (muon is a MIP)
- outgoing muon momentum measured **exclusively by recoil tracker**
  ıd HCal for veto only)

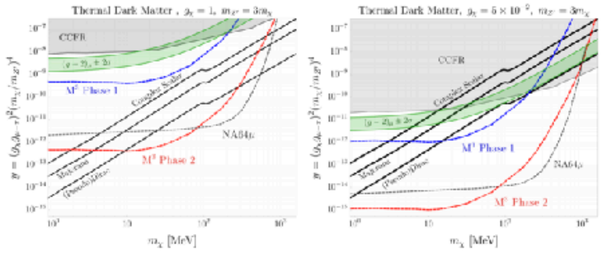
Yoni Kahn

Beam requirements

- Lots of muons on target (MoT), i.e. high rep rate
- Identify and track each one so that we know they lost a significant amount of momentum ($p_{\rm out} \lesssim 0.5\, p_{\rm in}$)
- Pion contamination = bad (esp. pions decaying in target). Estimate 10^{-6} will suffice for g-2 search
- $p_{\rm in}$ > ~several GeV - 10s of GeV:
  - lower boundary: need significant amount of lost momentum above detector thresholds to detect bkg processes
  - upper boundary: high momentum beam requires more B field lever arm, makes for a big and expensive detector with poor coverage



Reach



Phase 1 (10^{10} MOT): **complete coverage of g-2 region** for any invisibly-decaying particle lighter than the muon

Phase 2 (10^{13} MOT): can probe large parts of **well-motivated DM parameter space**

SM as an Effective Field Theory in the presence of FIPs

Typical BSM model-independent approach is to include all possible BSM operators + light new states explicitly.

$L_{SM+BSM} = - m_H^2 (H^+_{SM} H_{SM}) +$ all dim 4 terms $(A_{SM}, \psi_{SM}, H_{SM}) +$

(W.coeff. $/\Lambda^2$) × Dim 6 etc $(A_{SM}, \psi_{SM}, H_{SM}) + \ldots$

all lowest dimension portals $(A_{SM}, \psi_{SM}, H, A_{DS}, \psi_{DS}, H_{DS}) \times$ portal couplings

+ dark sector interactions $(A_{DS}, \psi_{DS}, H_{DS})$

SM = Standard Model

DS – Dark Sector

6

Maxim Pospelov

Minimal portal interactions

Let us *classify* possible connections between Dark sector and SM

$H^+H\,(\lambda S^2 + A S)$ Higgs-singlet scalar interactions (scalar portal)

$B_{\mu\nu} V_{\mu\nu}$ "Kinetic mixing" with additional U(1)' group

(becomes a specific example of $J_\mu^i A_\mu$ extension)

$LH\,N$ neutrino Yukawa coupling, N – RH neutrino

$J_\mu^i A_\mu$ requires gauge invariance and anomaly cancellation

It is very likely that the observed neutrino masses indicate that Nature may have used the LHN portal…

Dim>4

$J_\mu^A\, \partial_\mu a / f$ axionic portal

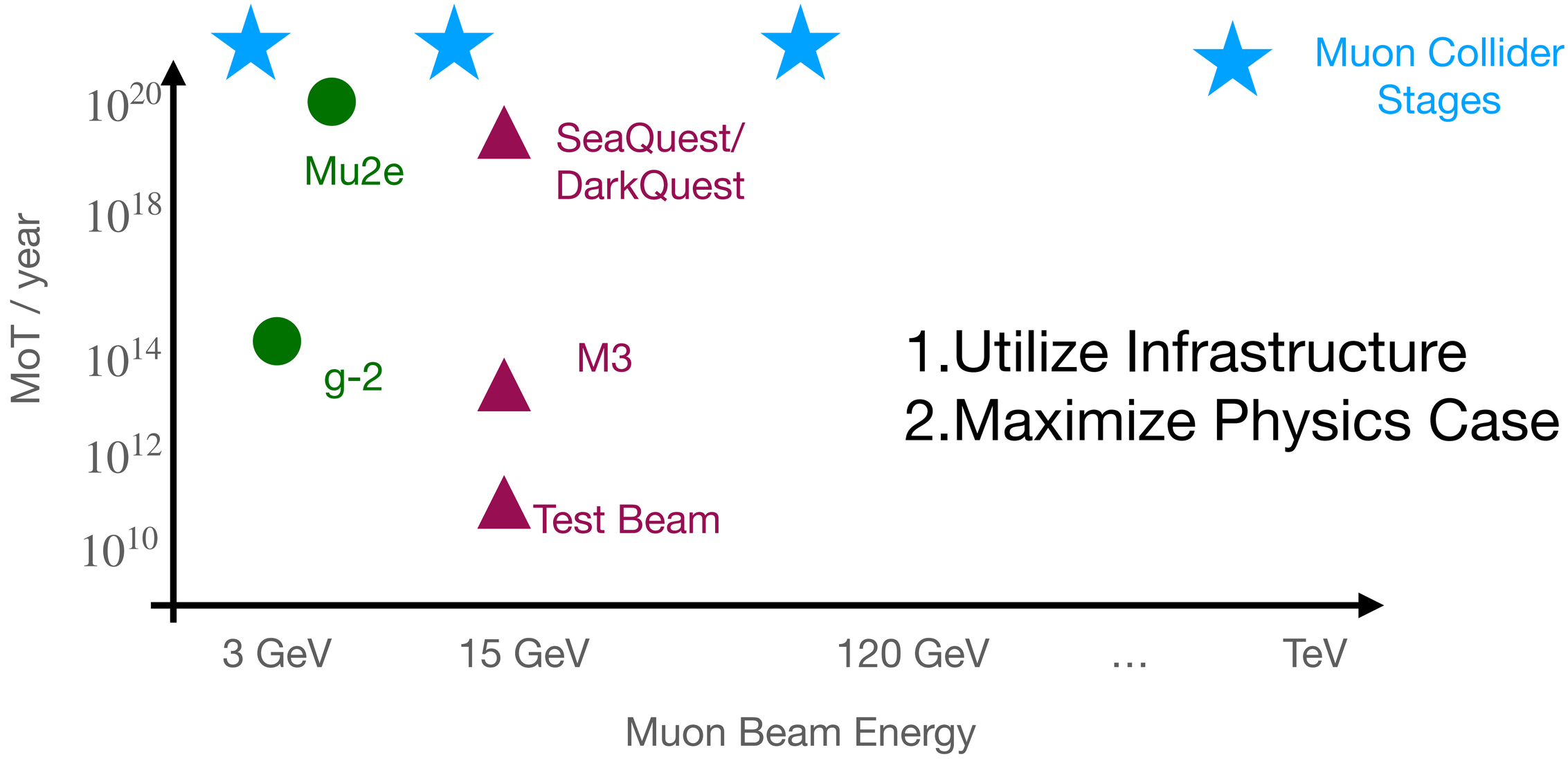
$$\mathcal{L}_{\rm mediation} = \sum_{k,l,n}^{k+l=n+4} \frac{\mathcal{O}^{(k)}_{\rm med}\mathcal{O}^{(l)}_{\rm SM}}{\Lambda^n},$$

……

Owing to small couplings, such particles represent "dark sector"

7

Dark Sectors & Muon Colliders



1.Utilize Infrastructure
2.Maximize Physics Case

Dark Sectors & Muon Colliders

Things to Do:

1. Z’ at muon Colliders: inclusive and semi-inclusive searches
2. Second generation right-handed neutrino production
3. Mu2e beams, beam dump infrastructure already in place!