

C³ Muon Experiments

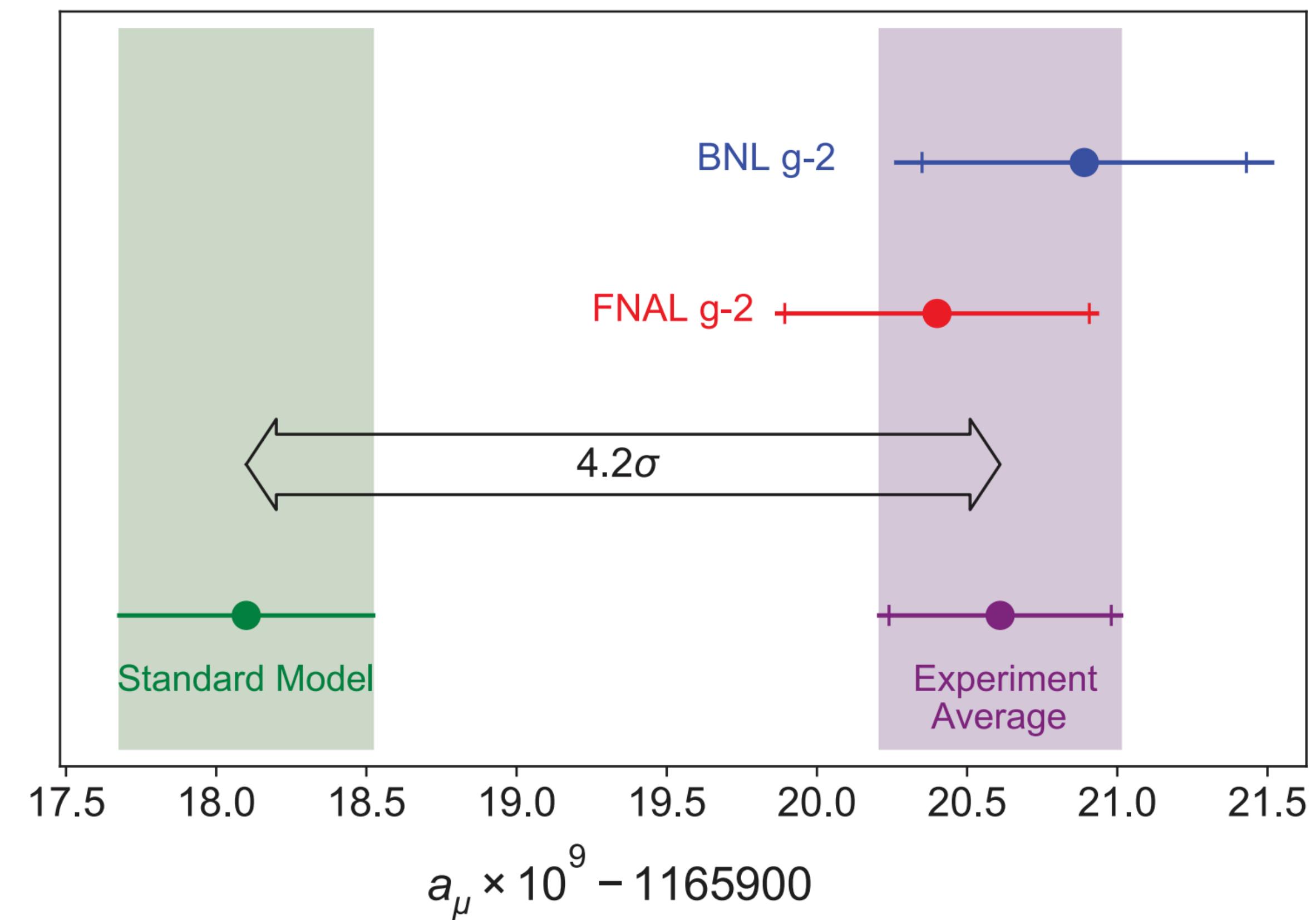
Snowmass Community Summer Study 2022

Dylan Rankin [MIT] - July 22nd, 2022

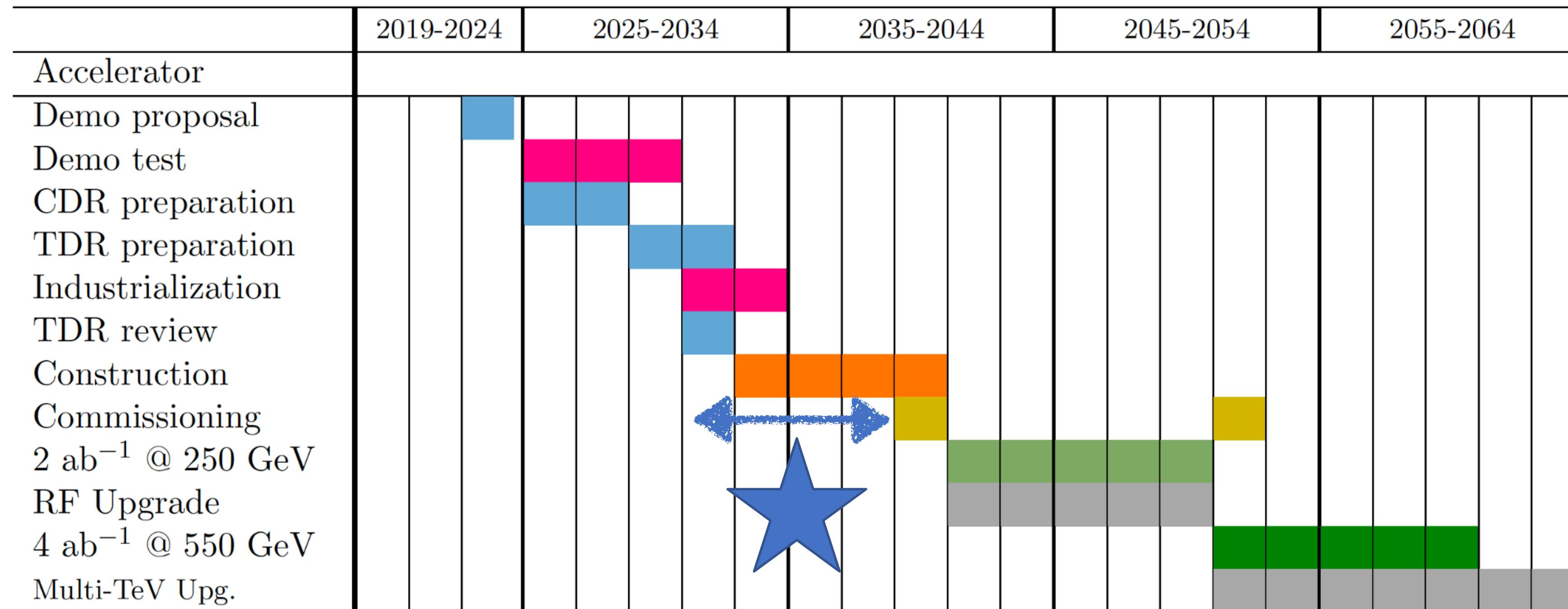
(with very helpful and necessary input from Emilio Nanni, Caterina Vernieri, Phil Harris)

Introduction

- Muons connected to many exciting recent physics results
- Having a (high energy) muon beam opens up many exciting possibilities for physics
- How do we get there? How do we test the technology?
 - What can we do along the way?



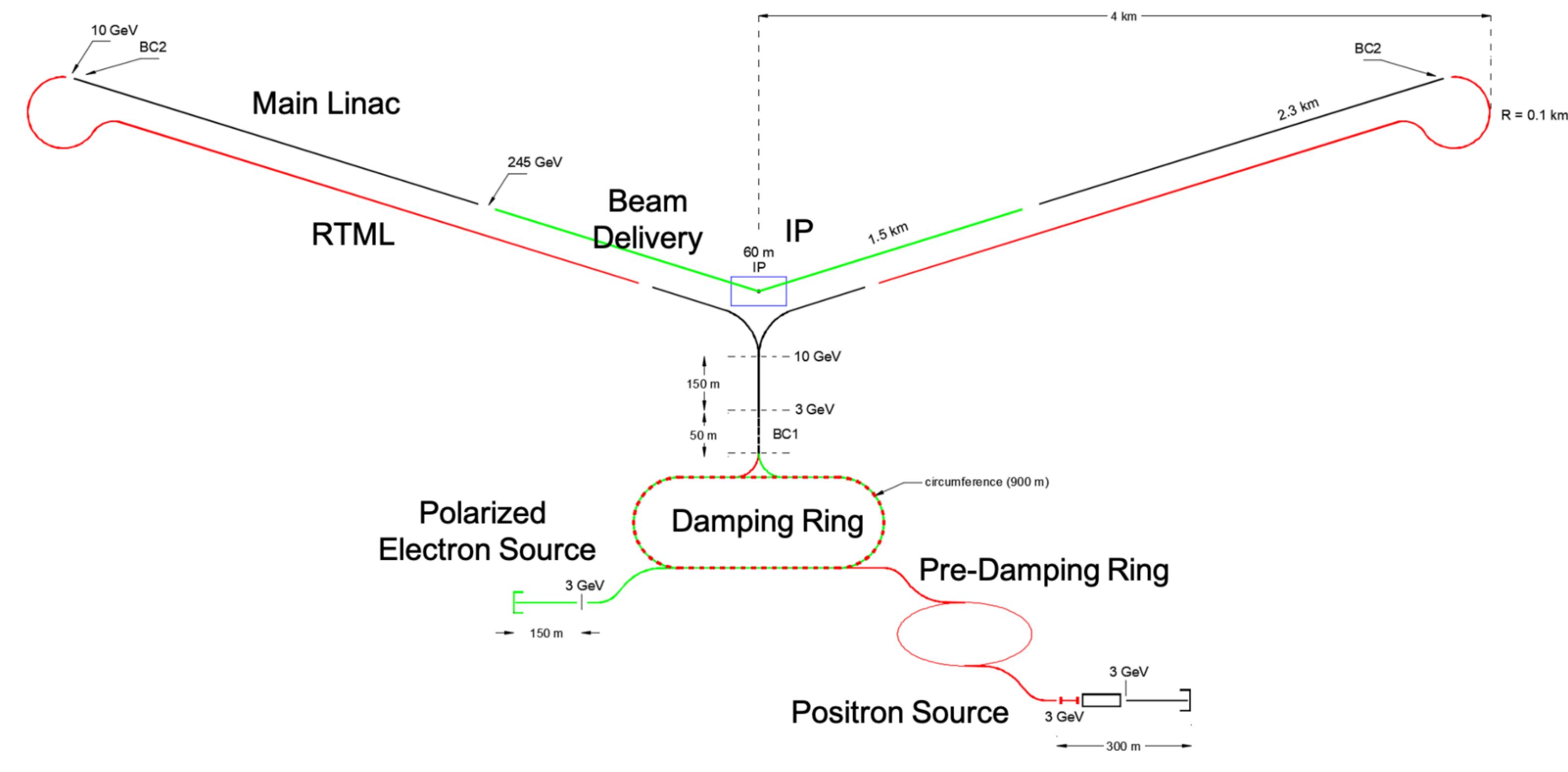
Physics During C³ Construction



- Between end of demonstration plan and first Higgs there is a **10-12 year gap**
- **Could we use this time for string tests to build confidence in the technology, train project workforce, deliver physics, particularly related to muons?**

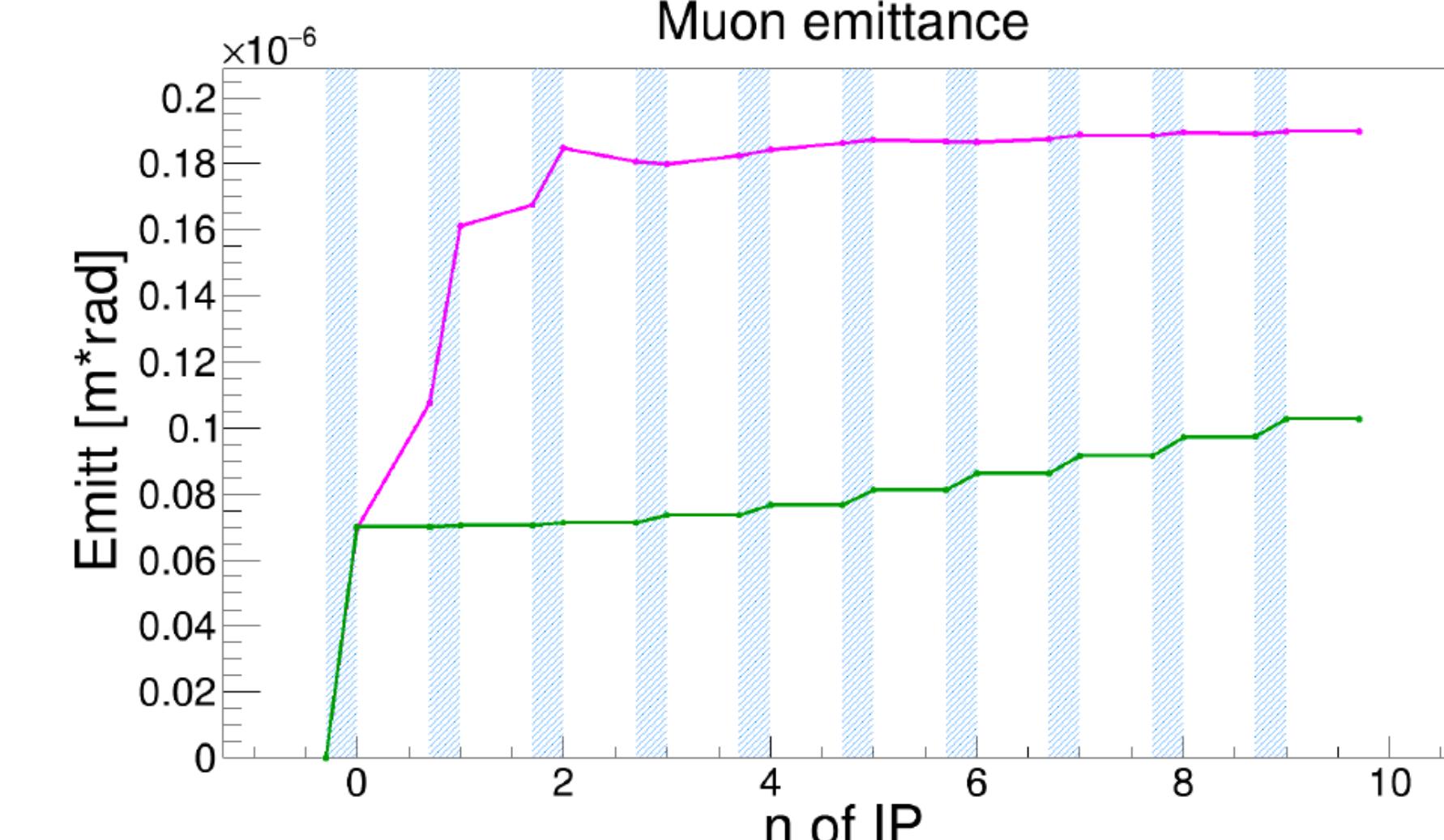
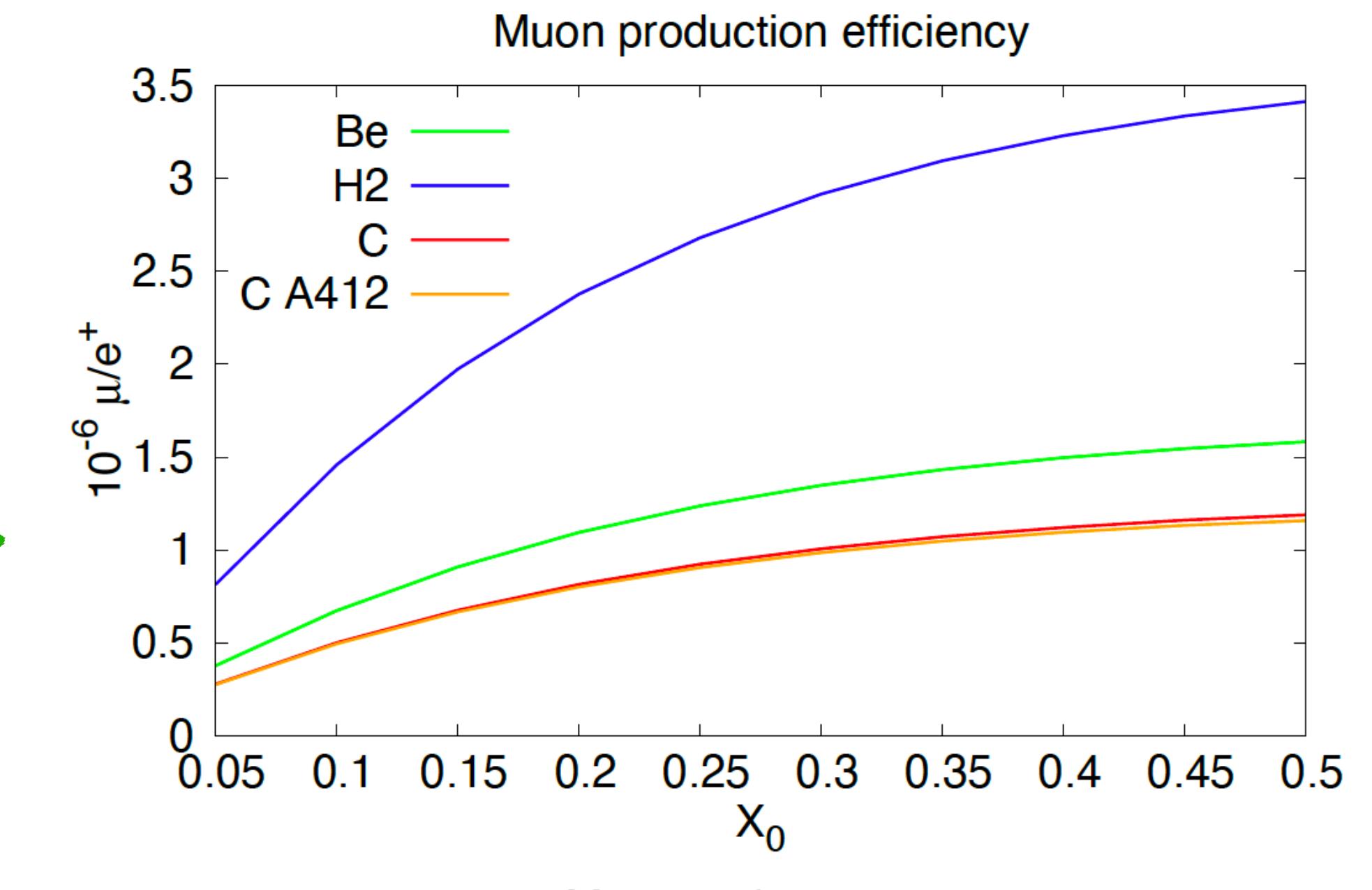
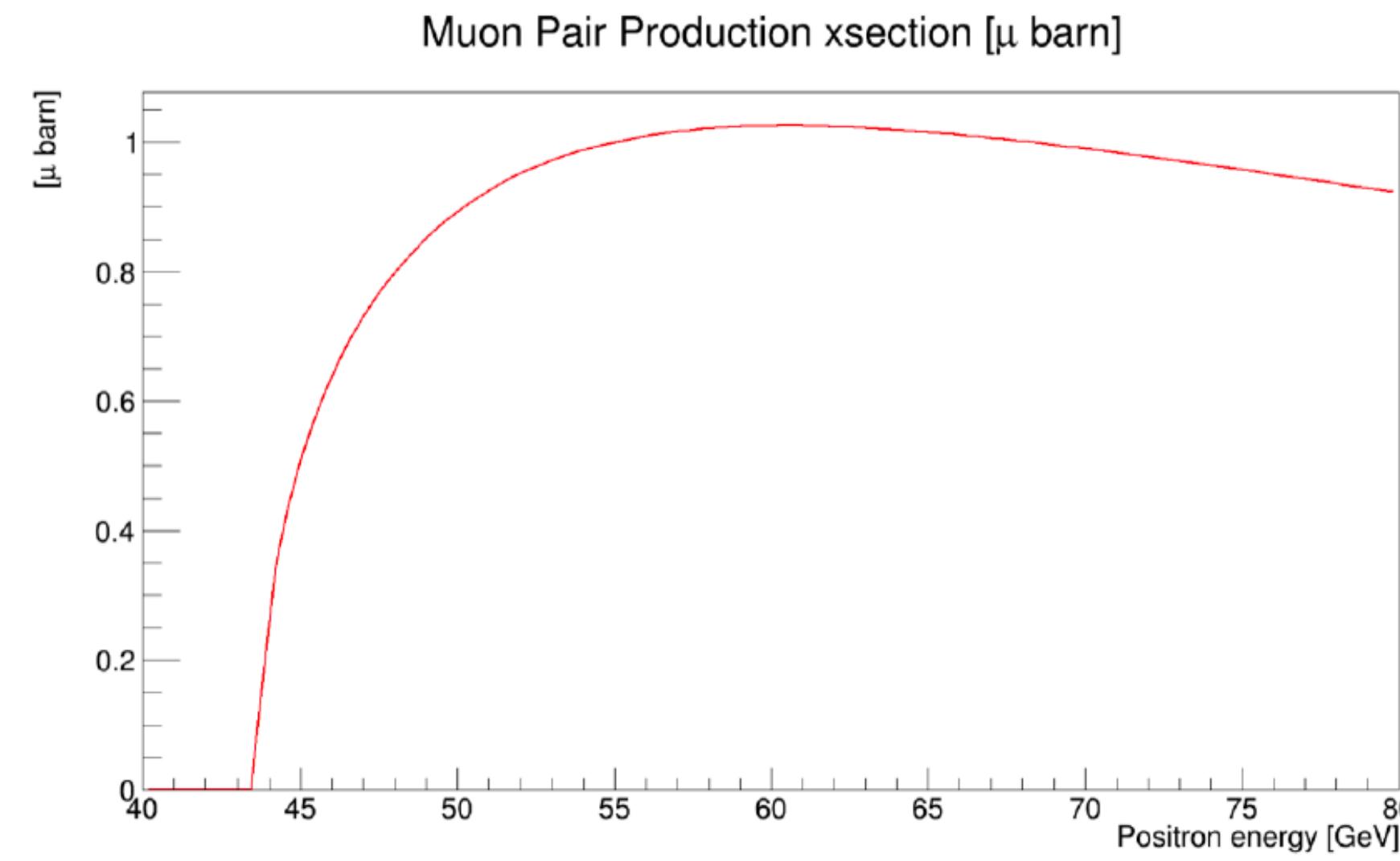
Physics During C³ Construction

- Necessary elements:
 - Positron Source – Few GeV electron linac, positron target, positron capture
 - Damping ring?
 - Main linac to 45 GeV – ~550-700 m (low to high current), 1 cryo plant



Muon Production with Positrons at 45 GeV

- Low EMittance Muon Accelerator (LEMMA) Concept (avoid muon cooling)
- Positron (45 GeV) on fixed low Z target
 - $e^+e^- \rightarrow \mu^+\mu^-$, muons at 22.5 GeV
- High conversion efficiency and low emittance



Muon Production* with Positrons at 45 GeV for C³

C3 String Test Low Muon Current

Parameter	Value
Number of RF Pulses Per Year (180 days)	1.87×10^9
RF Pulse Length	700 ns
# of Muons per RF Cycle	1
Muon Δt (smallest)	175 ps
Muons / Year (Max)	7.46×10^{12}

*LEMMA Target Single Pass

Includes 10^{-6} efficiency for e⁺ conversion

C3 String Test High Muon Current

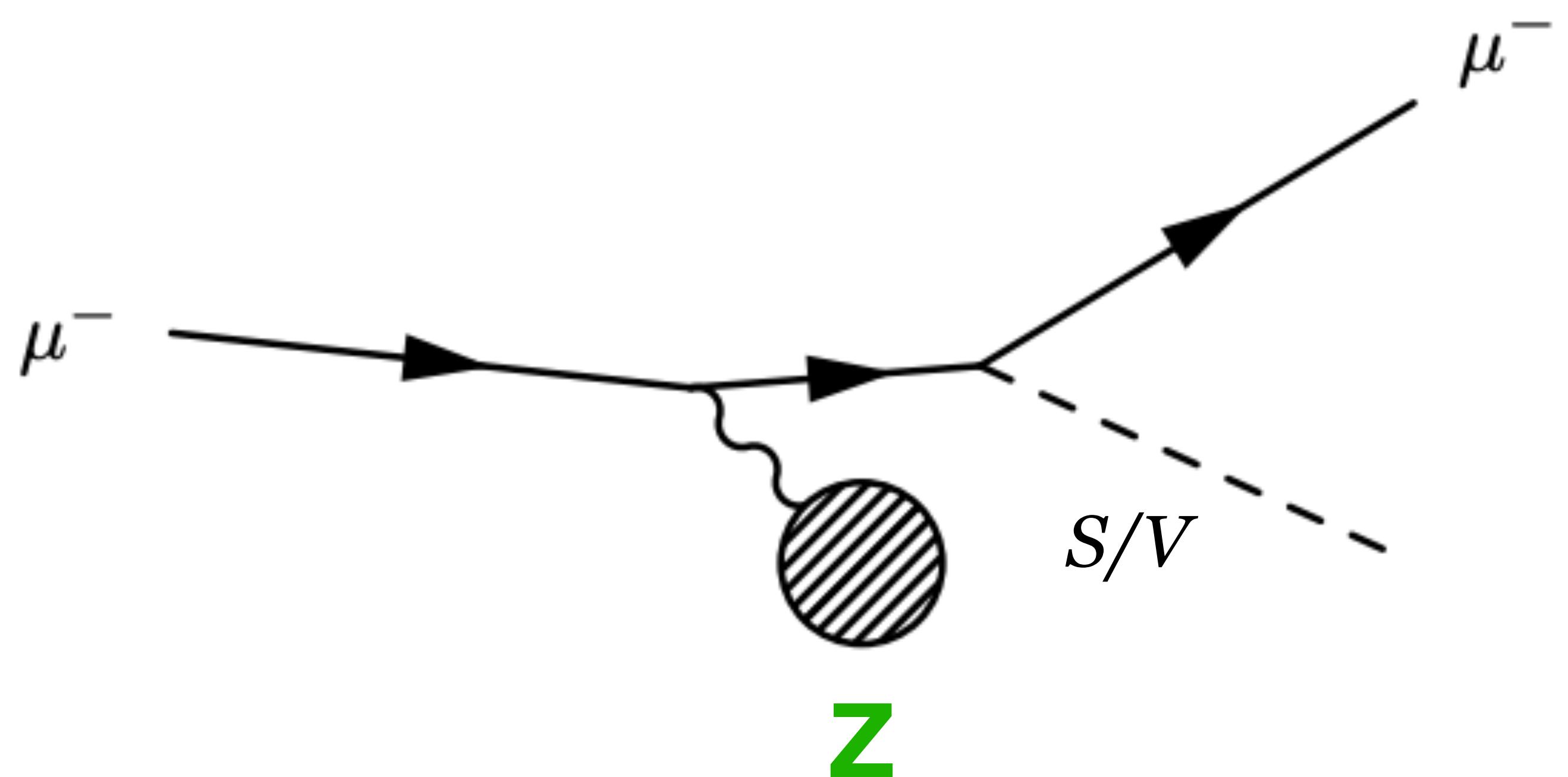
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Number of RF Pulses Per Year (180 days)	1.87×10^9
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# of Bunches per RF Pulse	133
# of Muons per Bunch	6×10^3
# of Muons per RF Pulse	8×10^5
Muon Δt (smallest)	5.26 ns
Muons / Year (Max)	1.5×10^{15}

Muon Beam Physics

- What physics can be done with this muon beam?
- Muon beam dump
 - Minimal additional infrastructure if (sufficiently intense) muon beam is produced
- Higher energies could allow more tests of muon acceleration

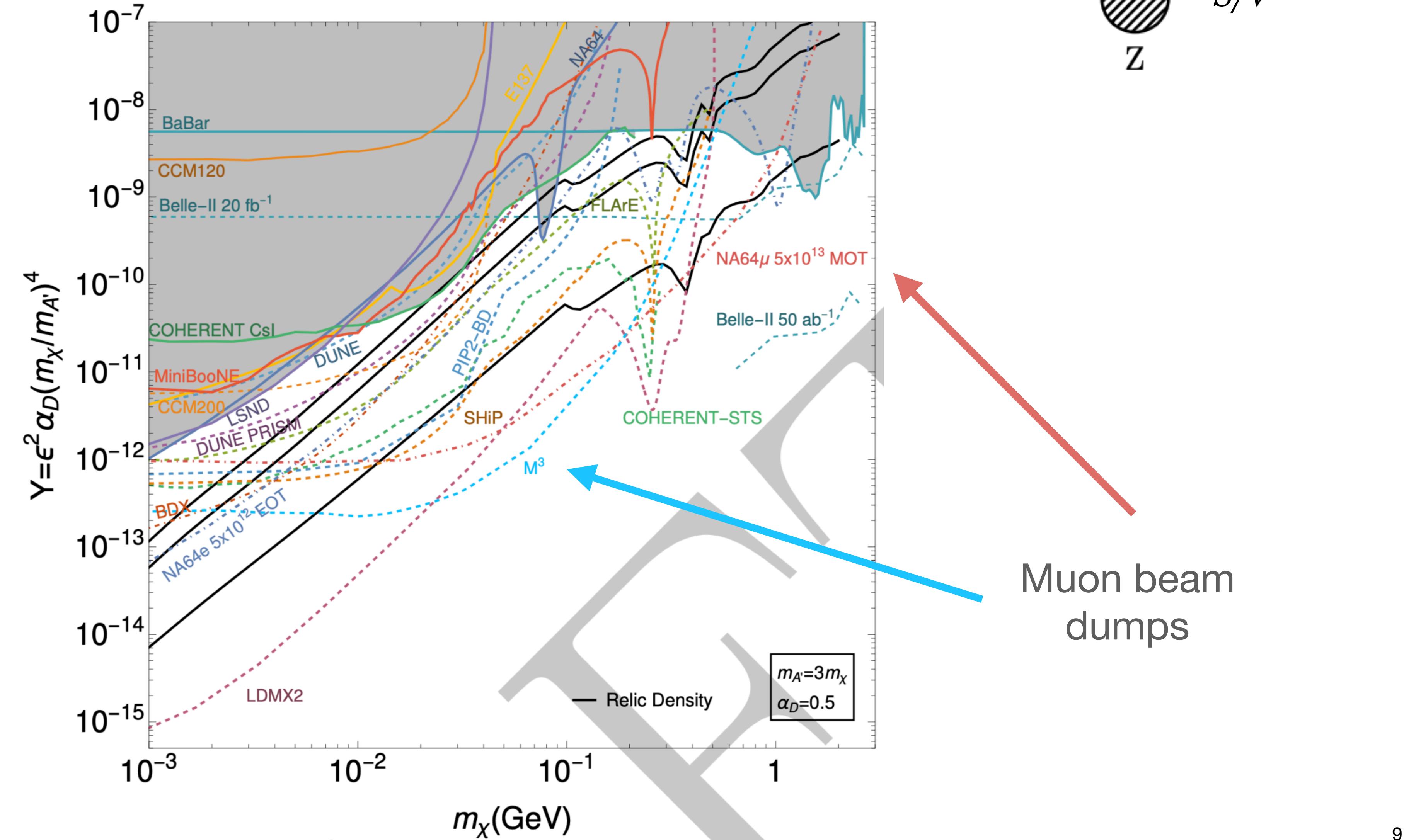
Muon Beam Dump

- Muon beam incident on **target (Z)**



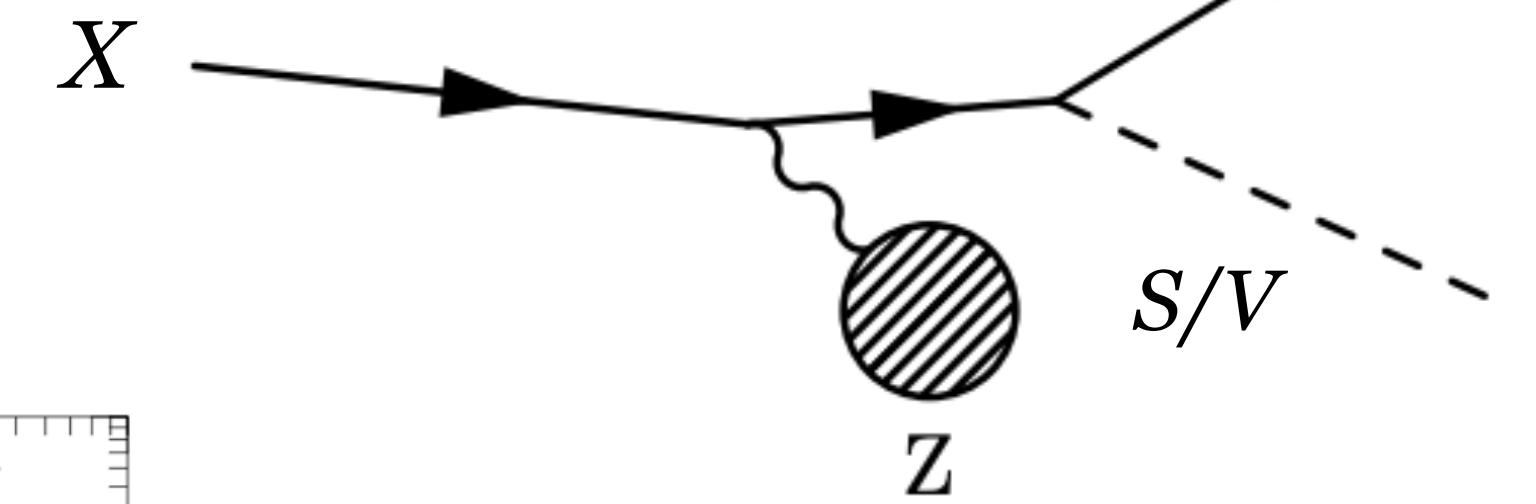
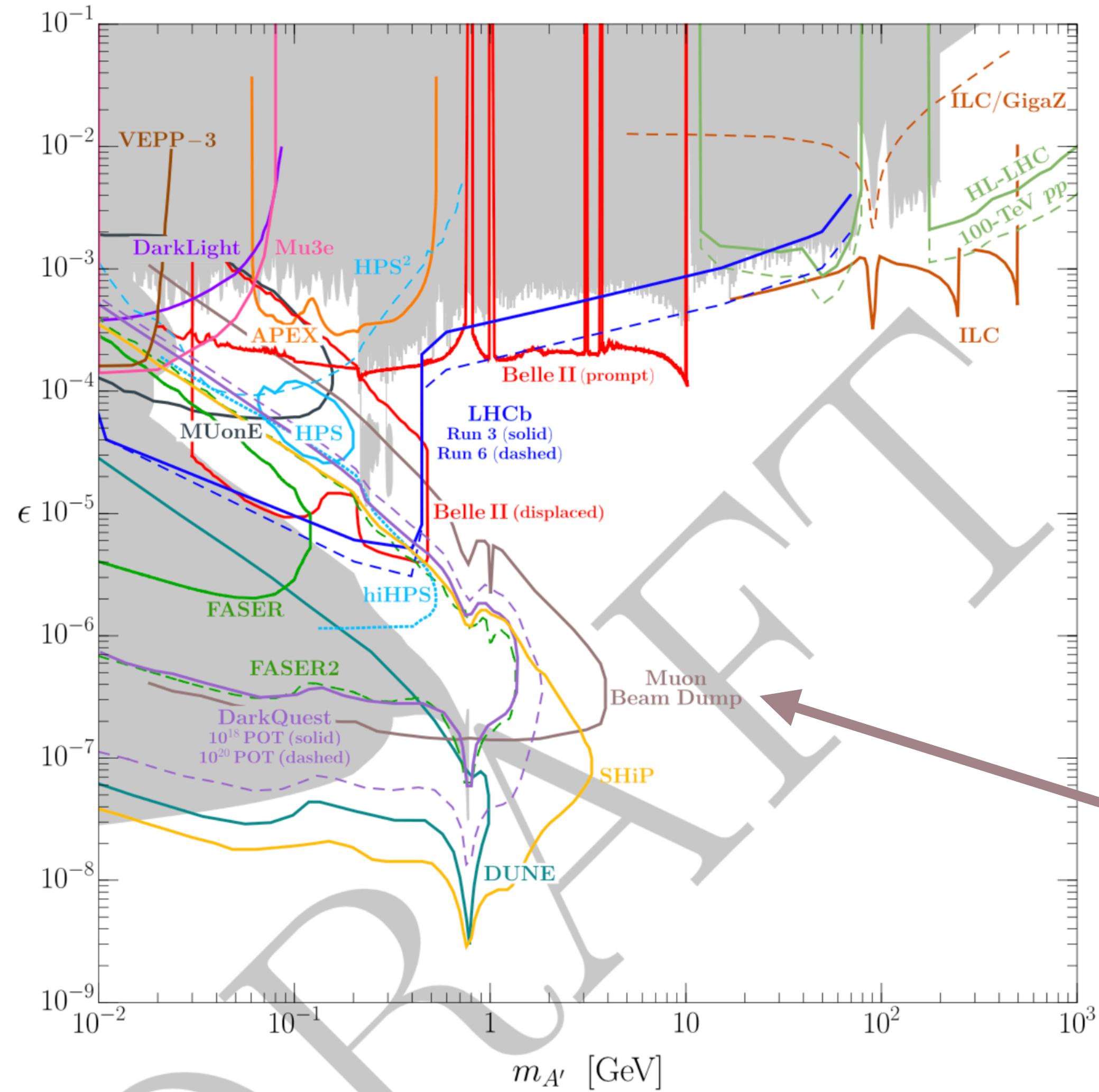
Why a Beam Dump?

- Dark matter



Why a Beam Dump?

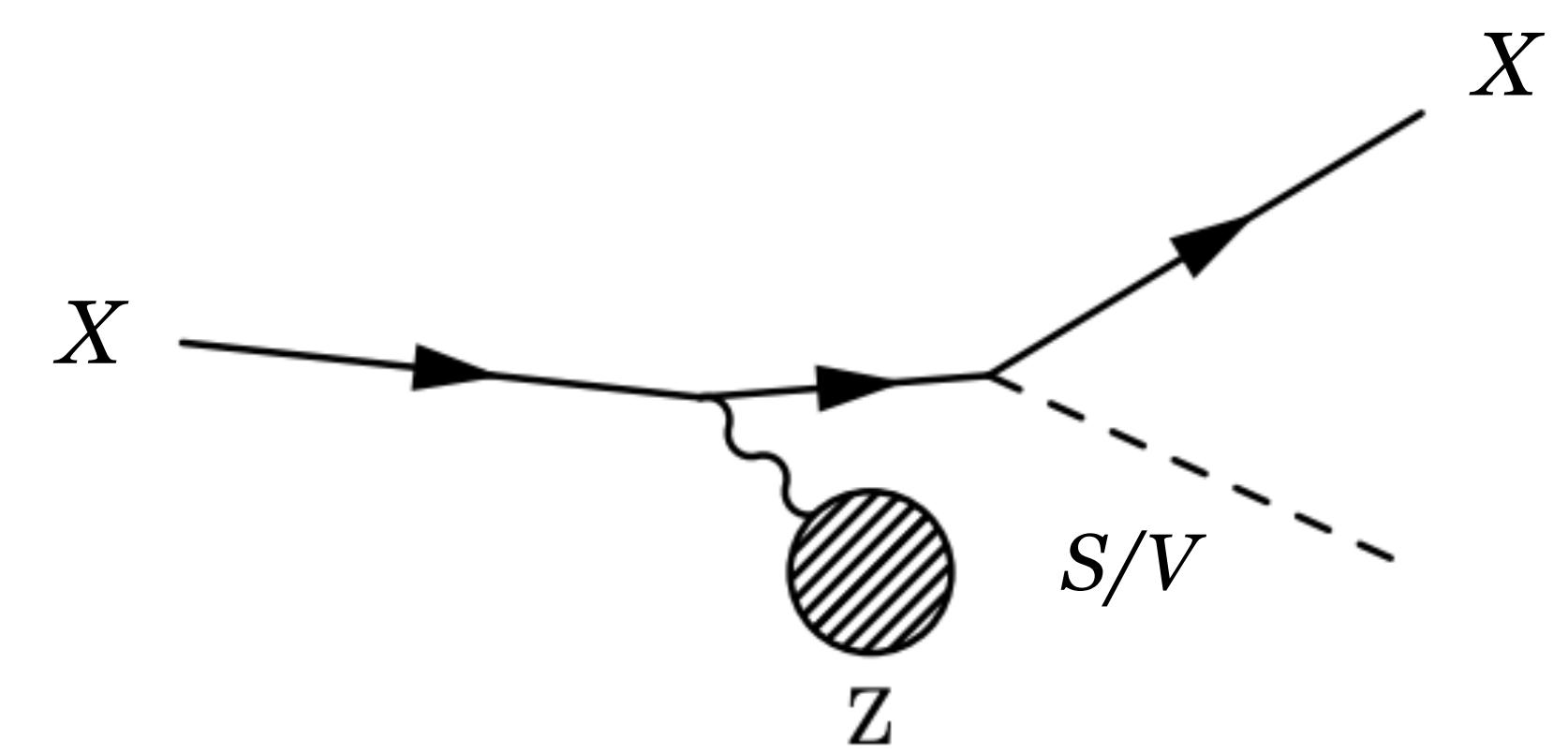
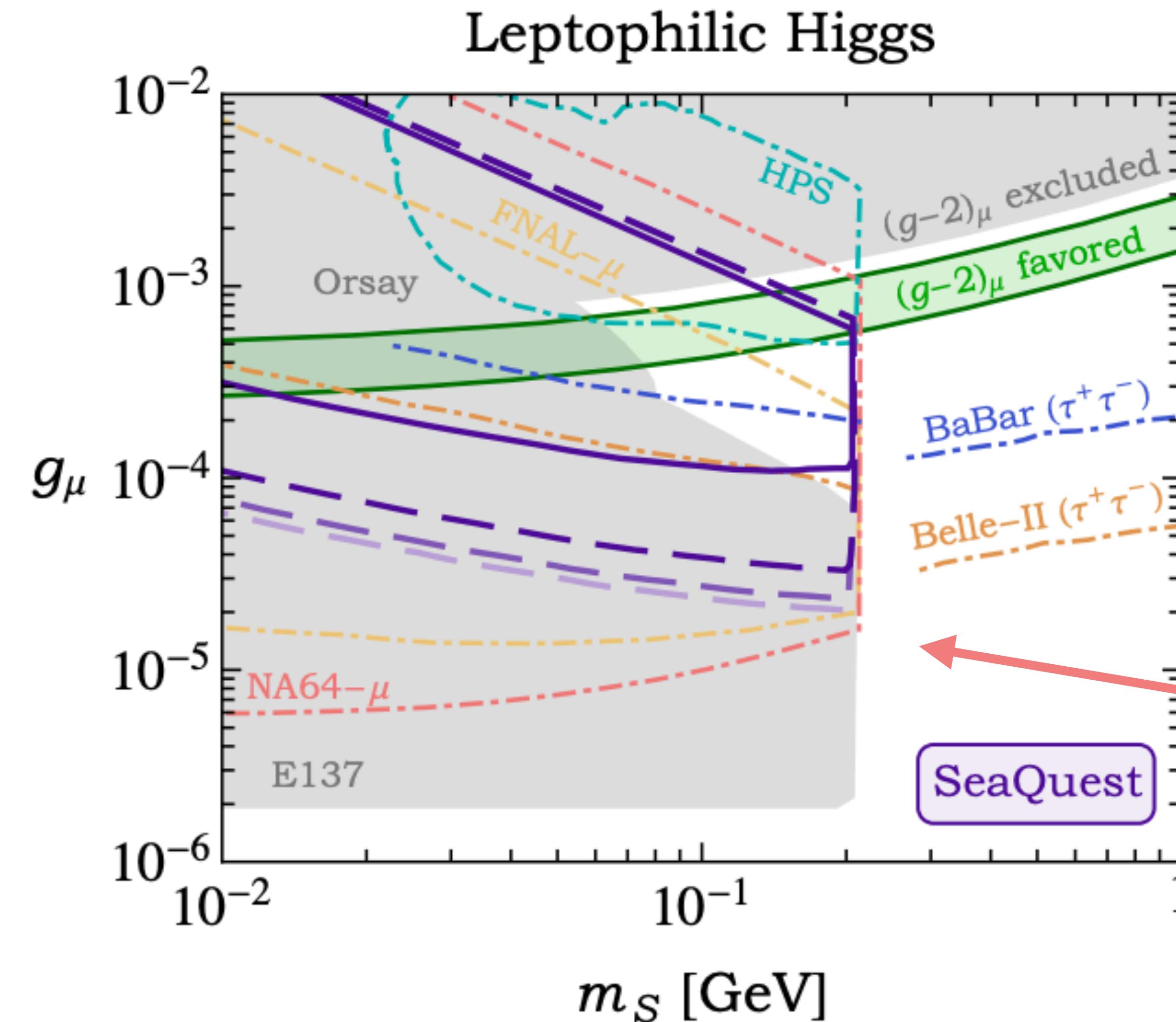
- Dark photon



Muon beam
dump

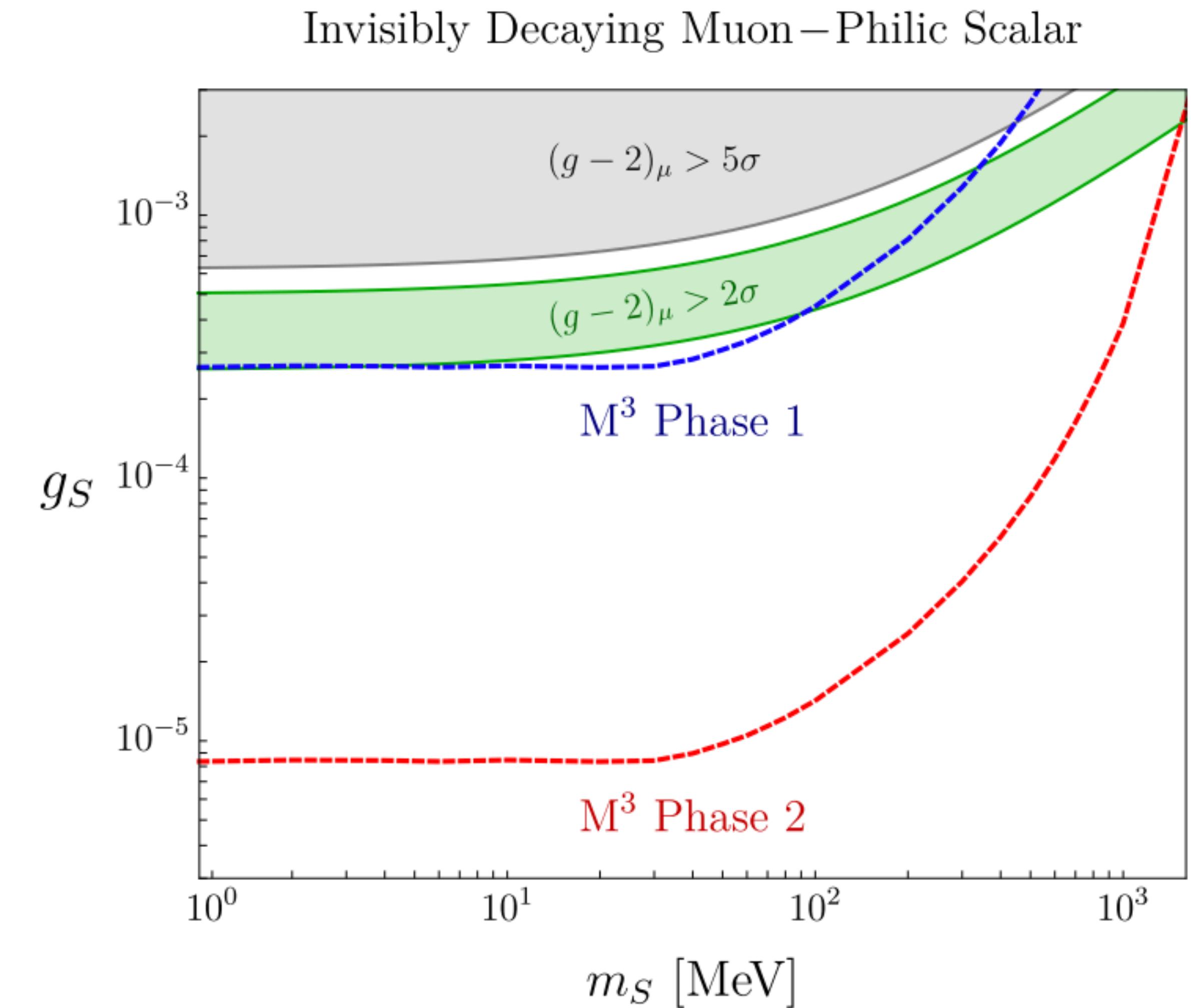
Why a Beam Dump?

- Weakly coupled scalars
 - eg. $U(1)_{L_\mu - L_\tau}$



Muon Missing Momentum (M^3)

- 15 GeV muon beam
- **Phase 1:** 10^{10} muons on target (MOT), probe large part of $(g-2)_\mu$ region
- **Phase 2:** 10^{13} MOT, thermal muon-philic DM search



M³ (Phase 1)

- Proposal suggests to use Fermilab Main Injector beamline to provides proton beam of 120 GeV → 10^5 muons per spill at 10-30 GeV
- The time between spills is approximately one minute
- Over one week of continuous running, this sums to approximately 10^9 MOT
 - **2.5×10^{10} MOT / yr**

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M³ (Phase 2 +)

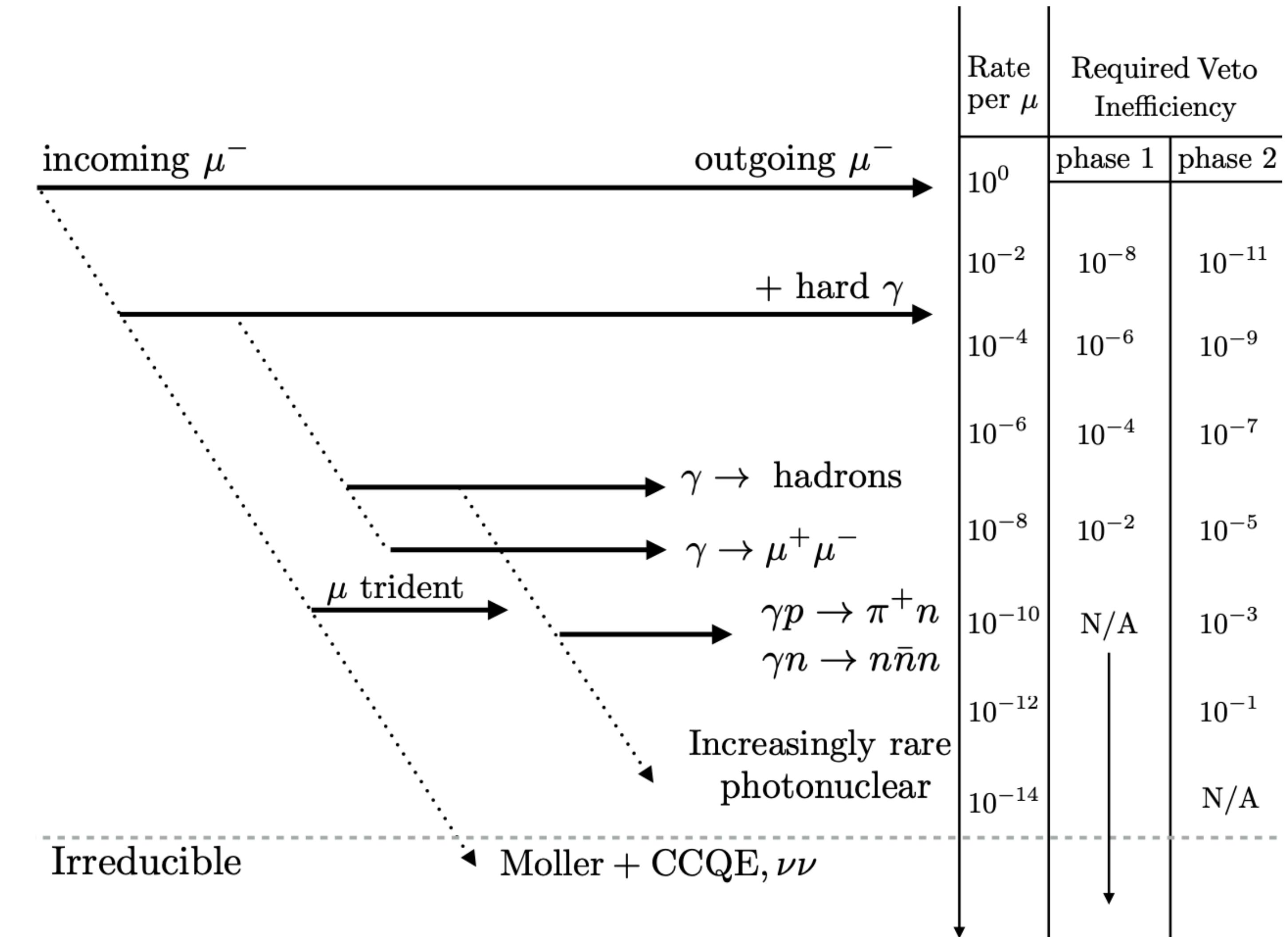
- Phase 2 requires upgrades to accelerator (beamline), detector (trigger)
 - 10^7 muons per spill
- **2.5×10^{12} MOT / yr**

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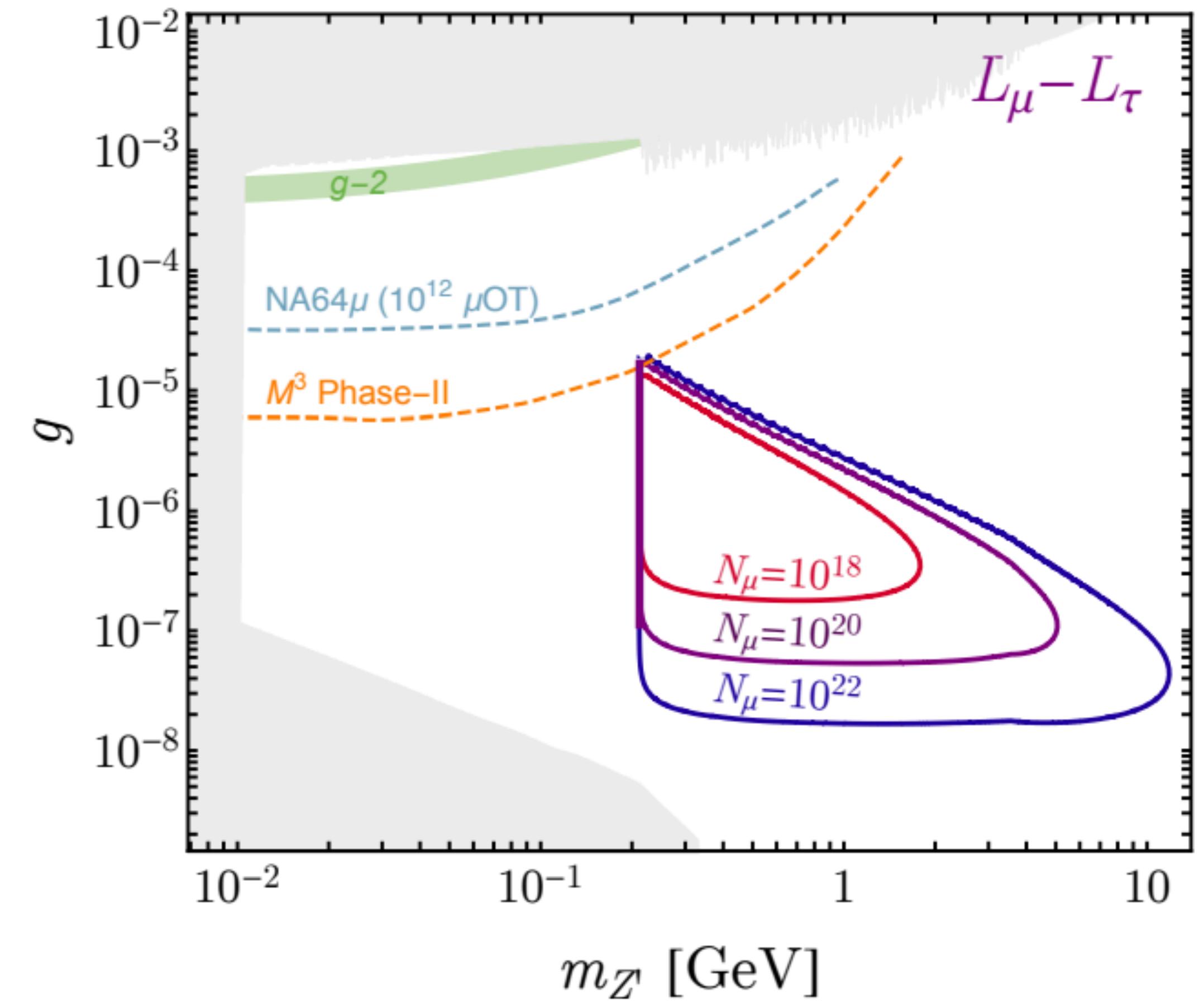
M³ (Phase 2 +)

- 10^{15} MOT from C³ gets to irreducible background floor for M³
- Nice place to be
 - Increase in MOT would not improve limits significantly



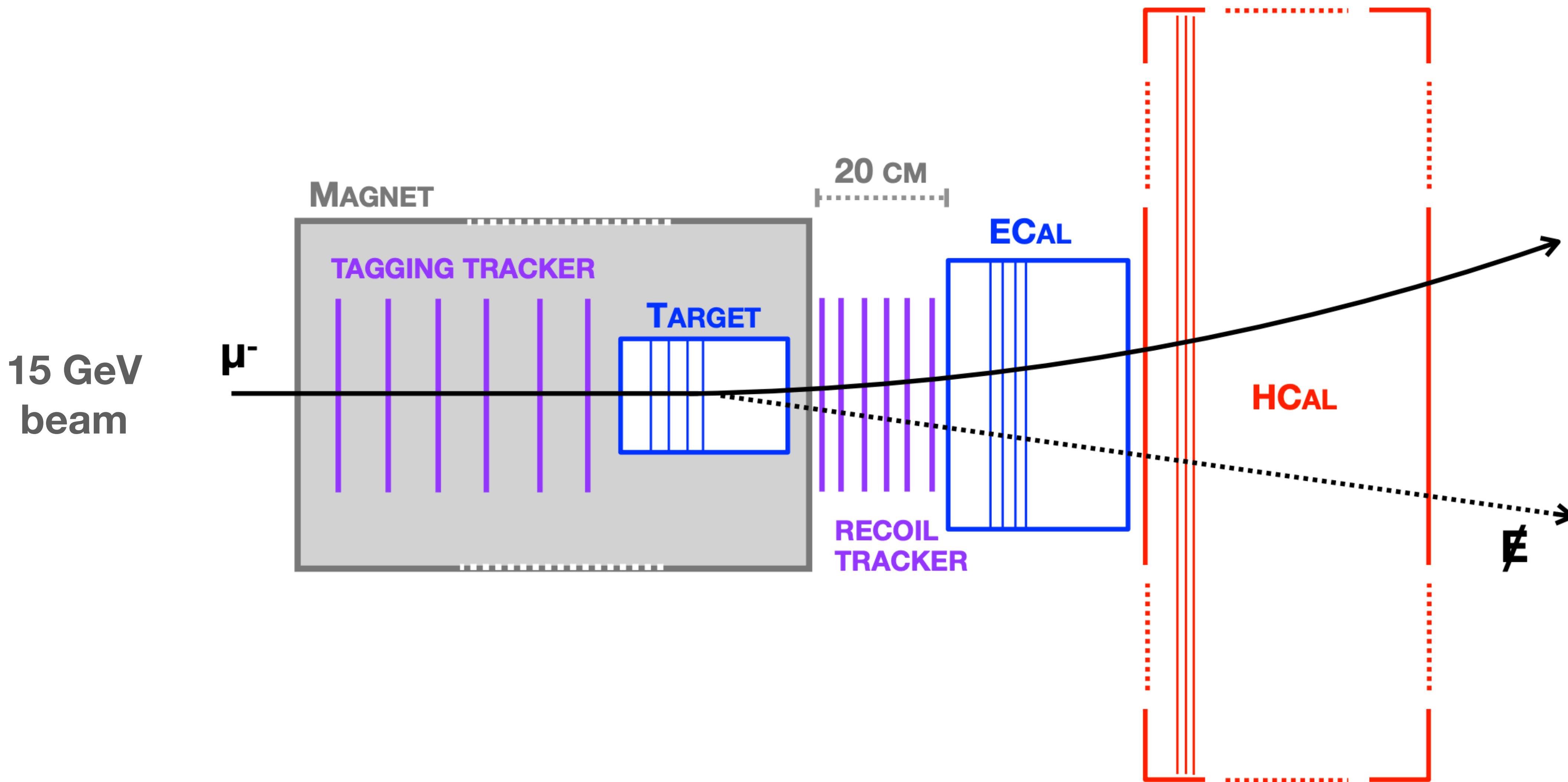
High-Energy Muon Beam Dump

- Envisioned for 3 TeV muon collider (1.5 TeV μ)
- $10^{18} - 10^{22}$ MOT
- What is gained from increasing muon energy?
- From physics perspective, adjust the probed parameter space
 - e.g. for DM, increased $E_\mu \rightarrow$ increased m_{med}
 - 500 GeV beam \rightarrow 20 GeV m_{med}
 - 50 GeV beam \rightarrow 5 GeV m_{med}



BACKUP

Muon Missing Momentum (M^3)



High-Energy Muon Beam Dump

