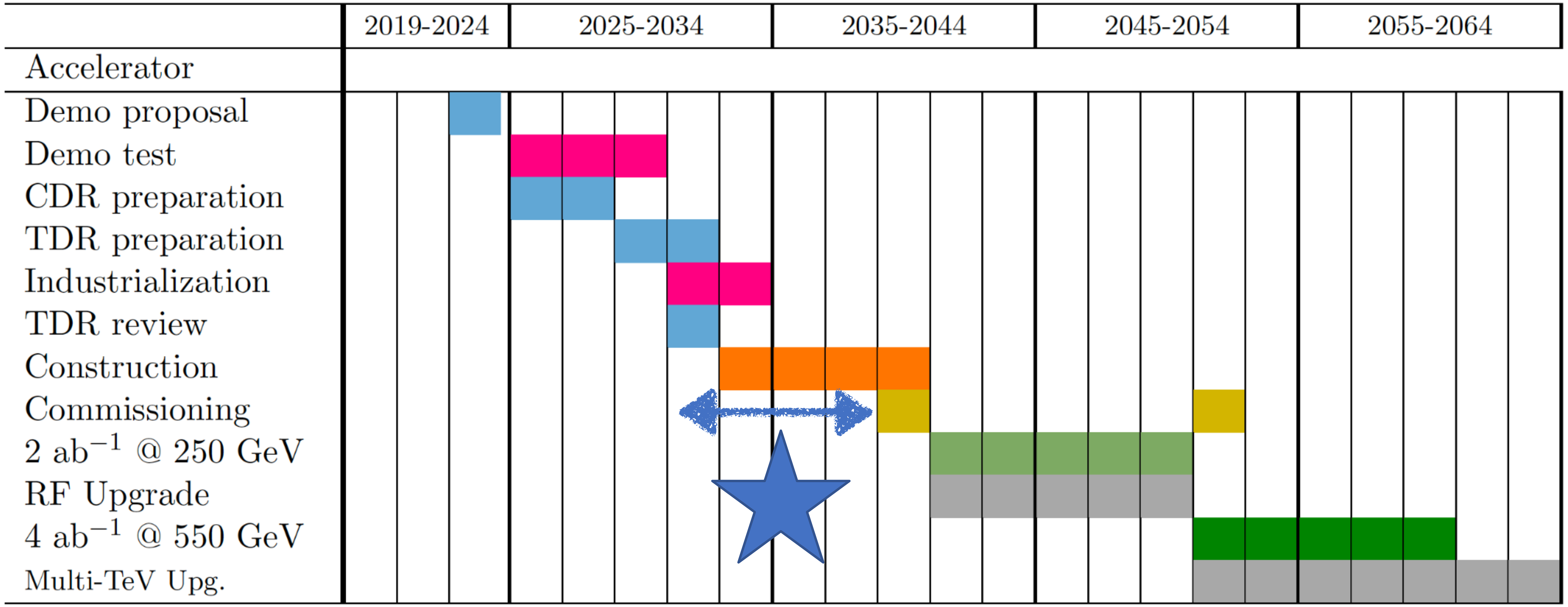
Beam Dump Experiments

C³ Workshop - 13-14 October 2022

Dylan Rankin [MIT] - October 14th, 2022

with help from
Emilio Nanni, Caterina Vernieri [SLAC]
Phil Harris [MIT]
Marco Zanetti [CERN]
Gordon Krnjaic, Duncan Rocha [UChicago]

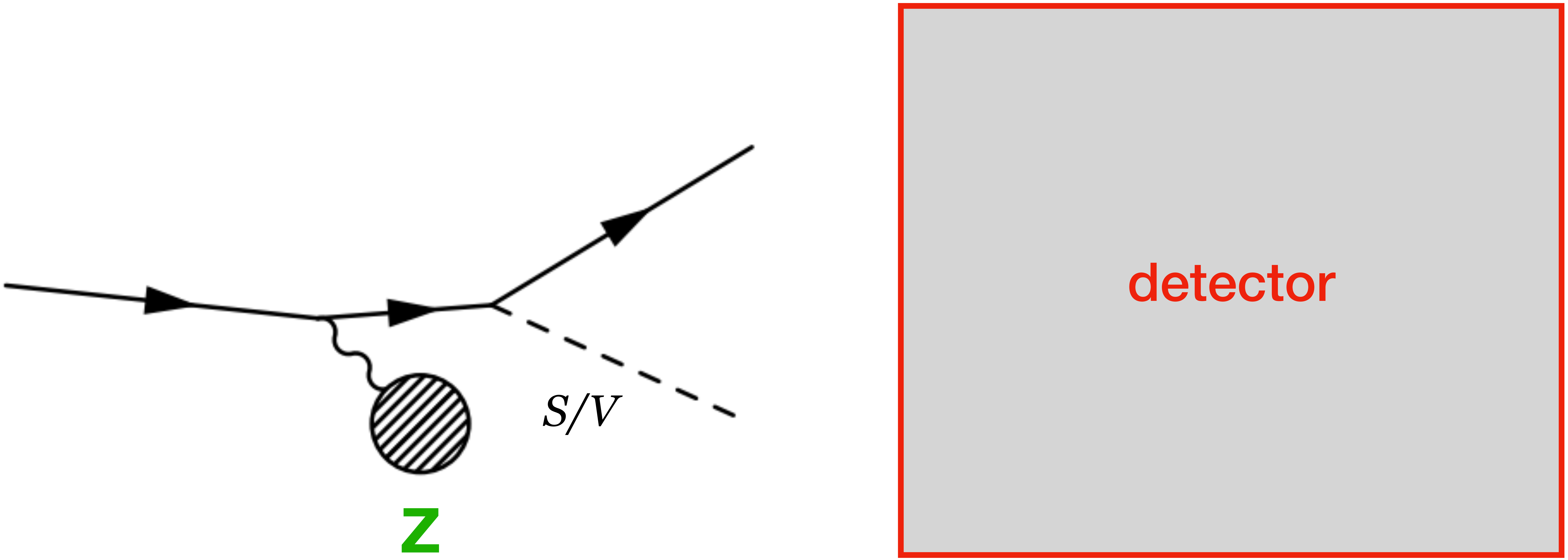
Physics During C^3 Construction



- 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?**

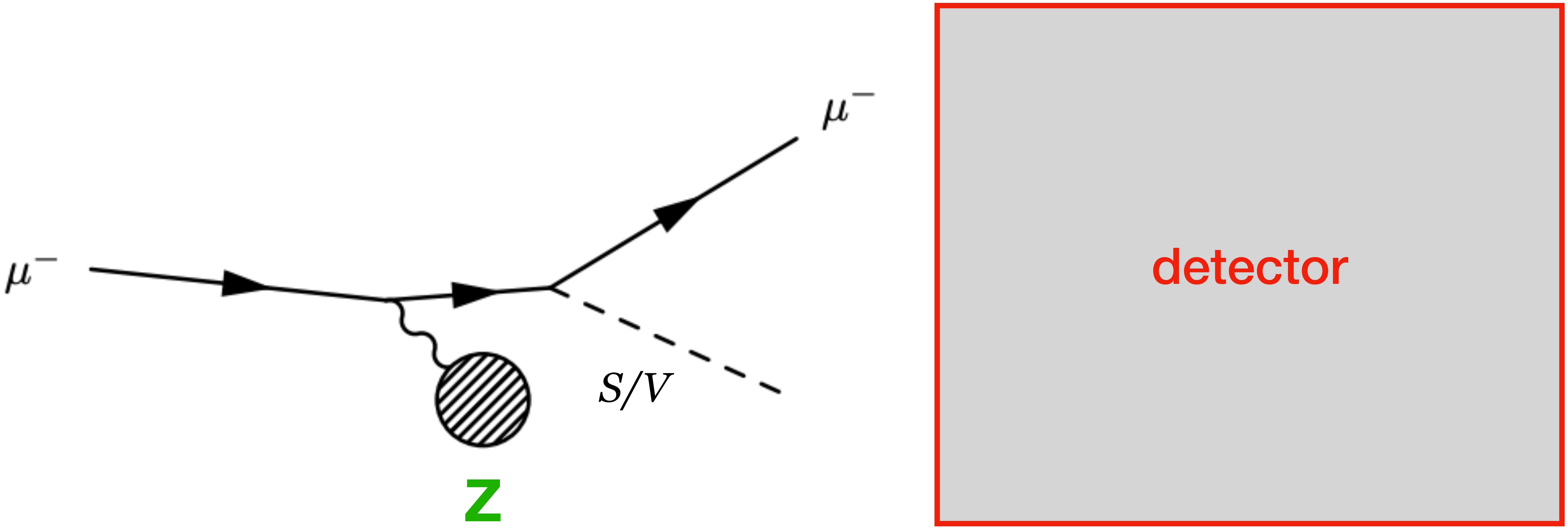
Beam Dump (or Missing Momentum)

- Beam incident on **target (Z)**



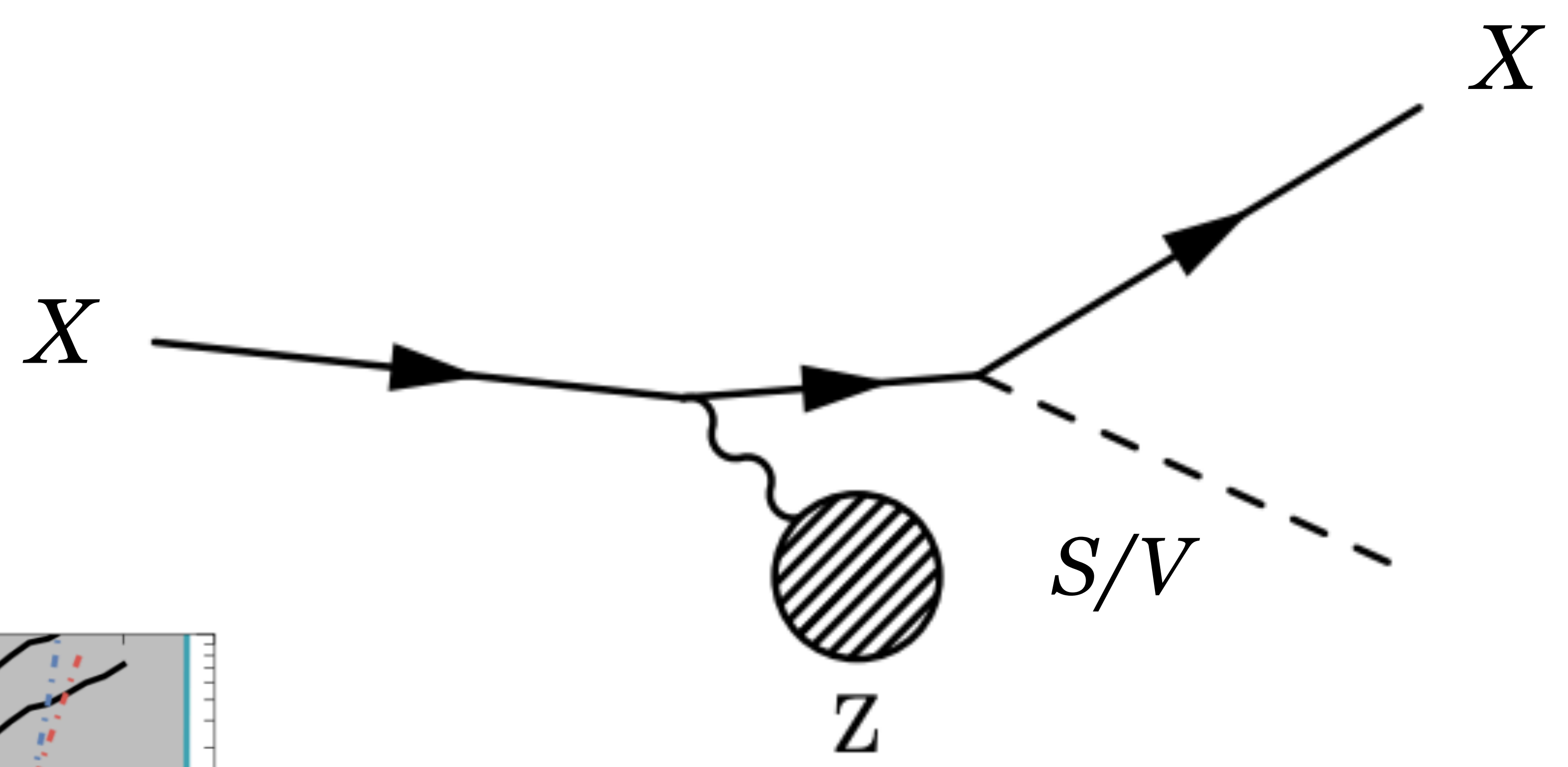
Muon Beam Dump

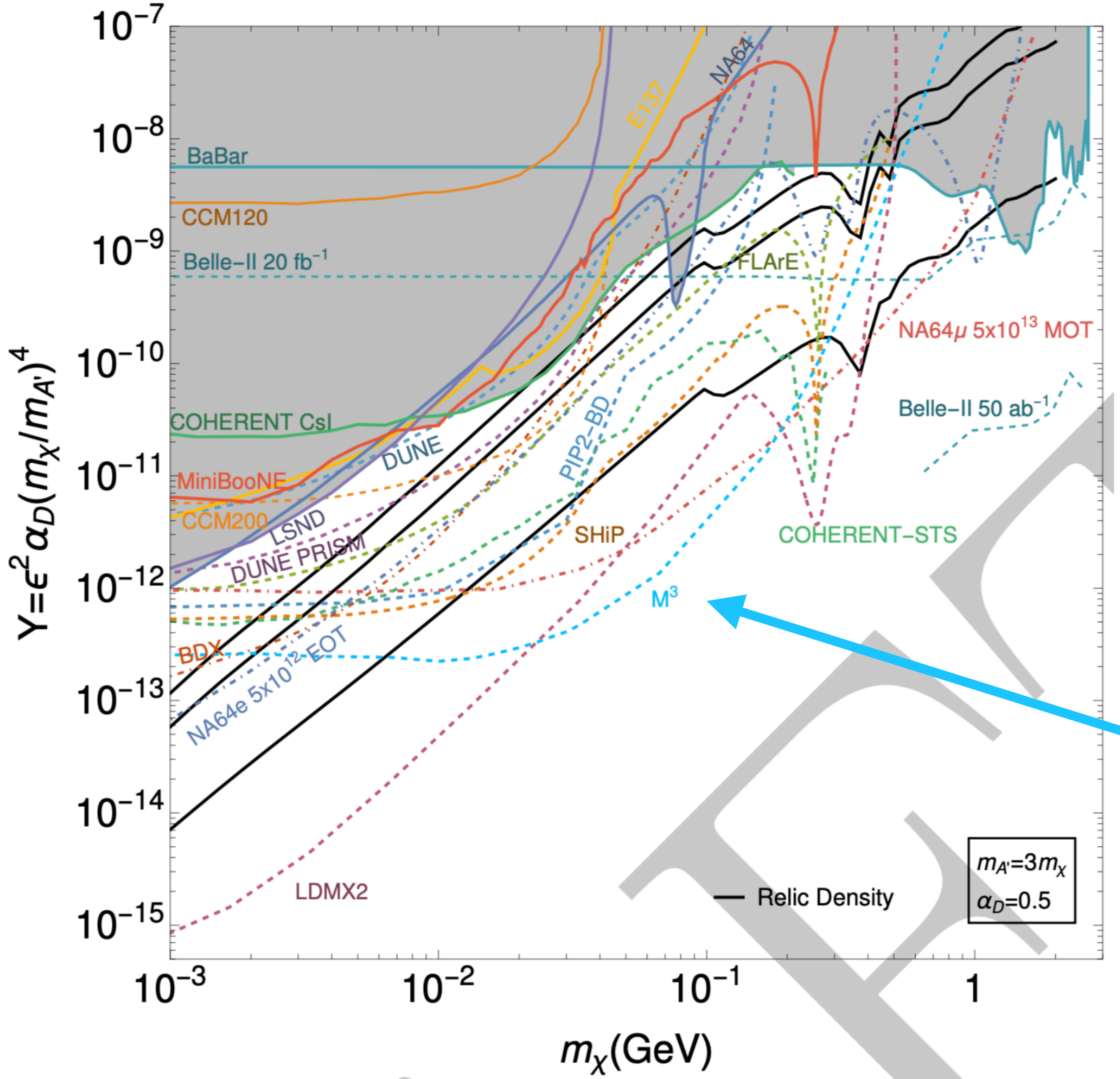
- Muon Beam incident on **target (Z)**



Why a Beam Dump?

- Dark matter

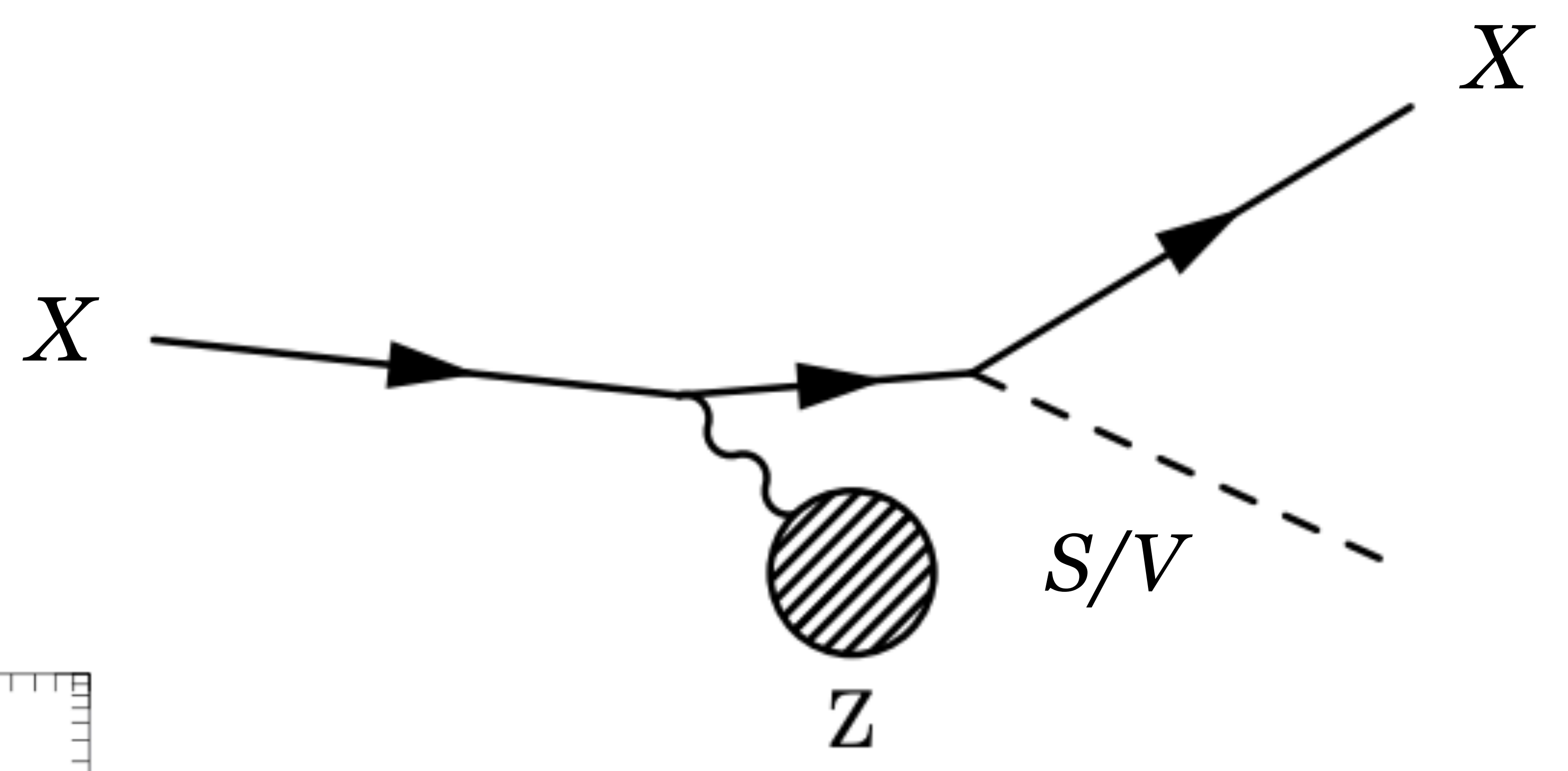


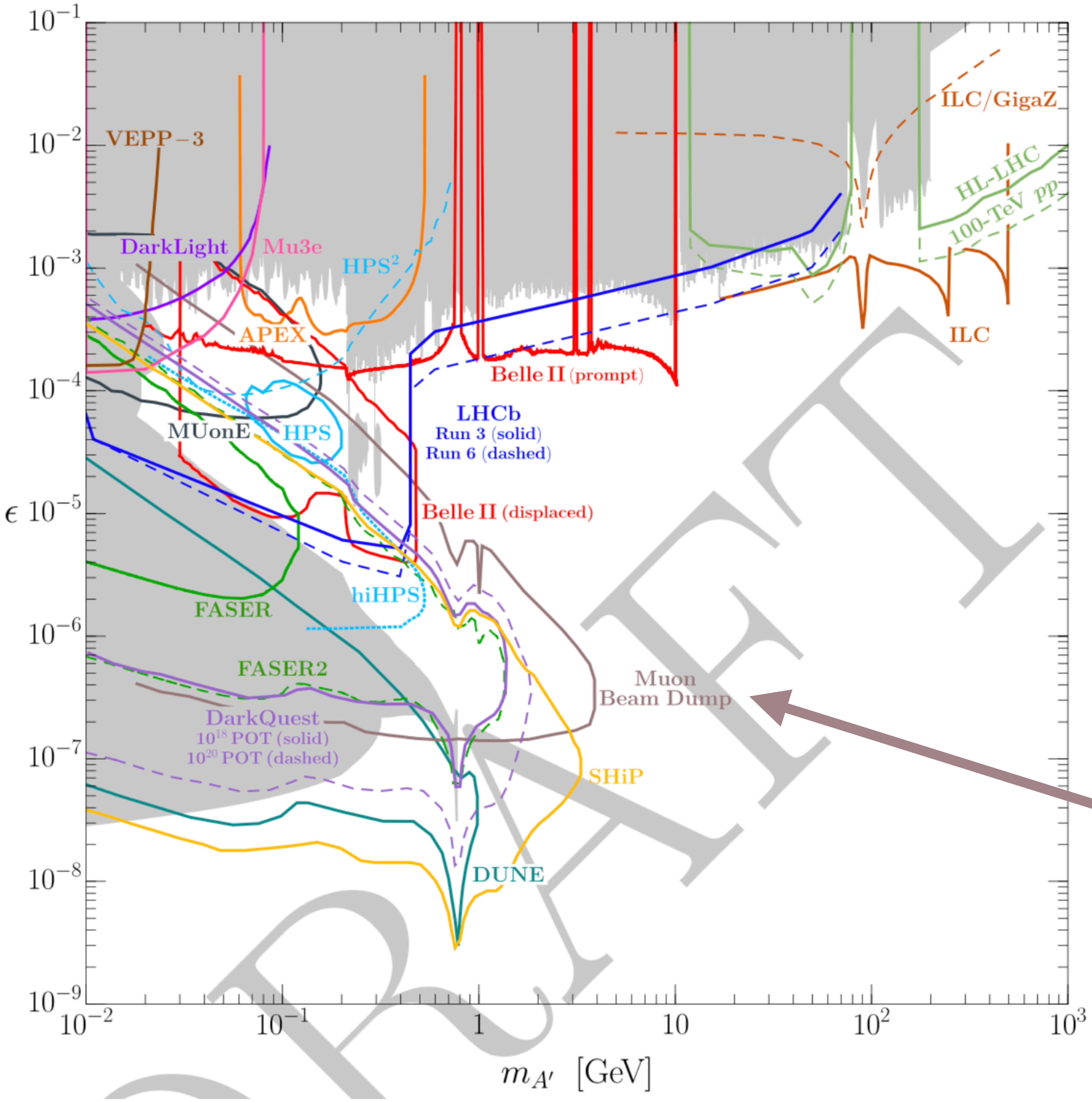


Muon beam dumps

Why a Beam Dump?

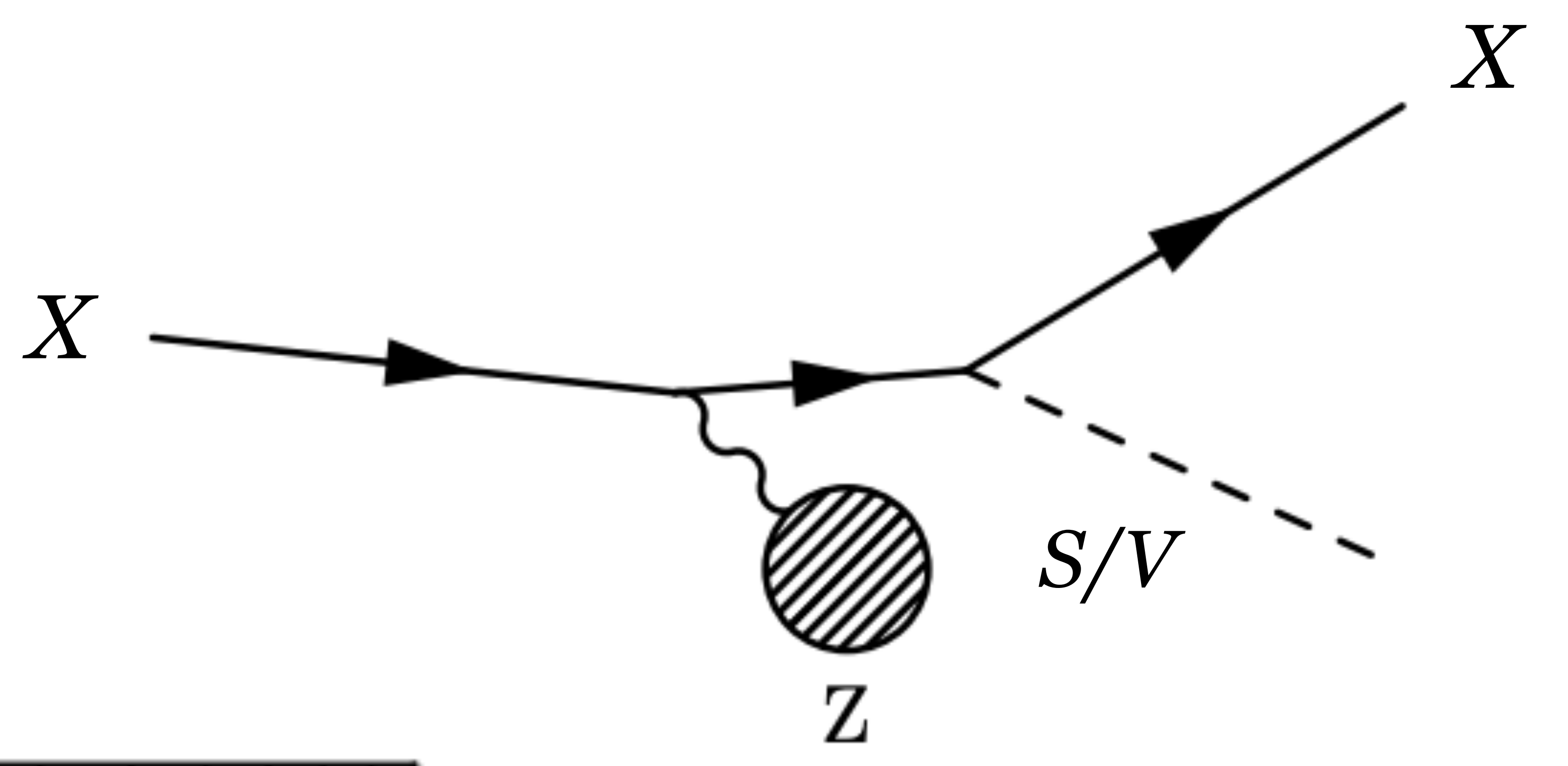
- Dark photon



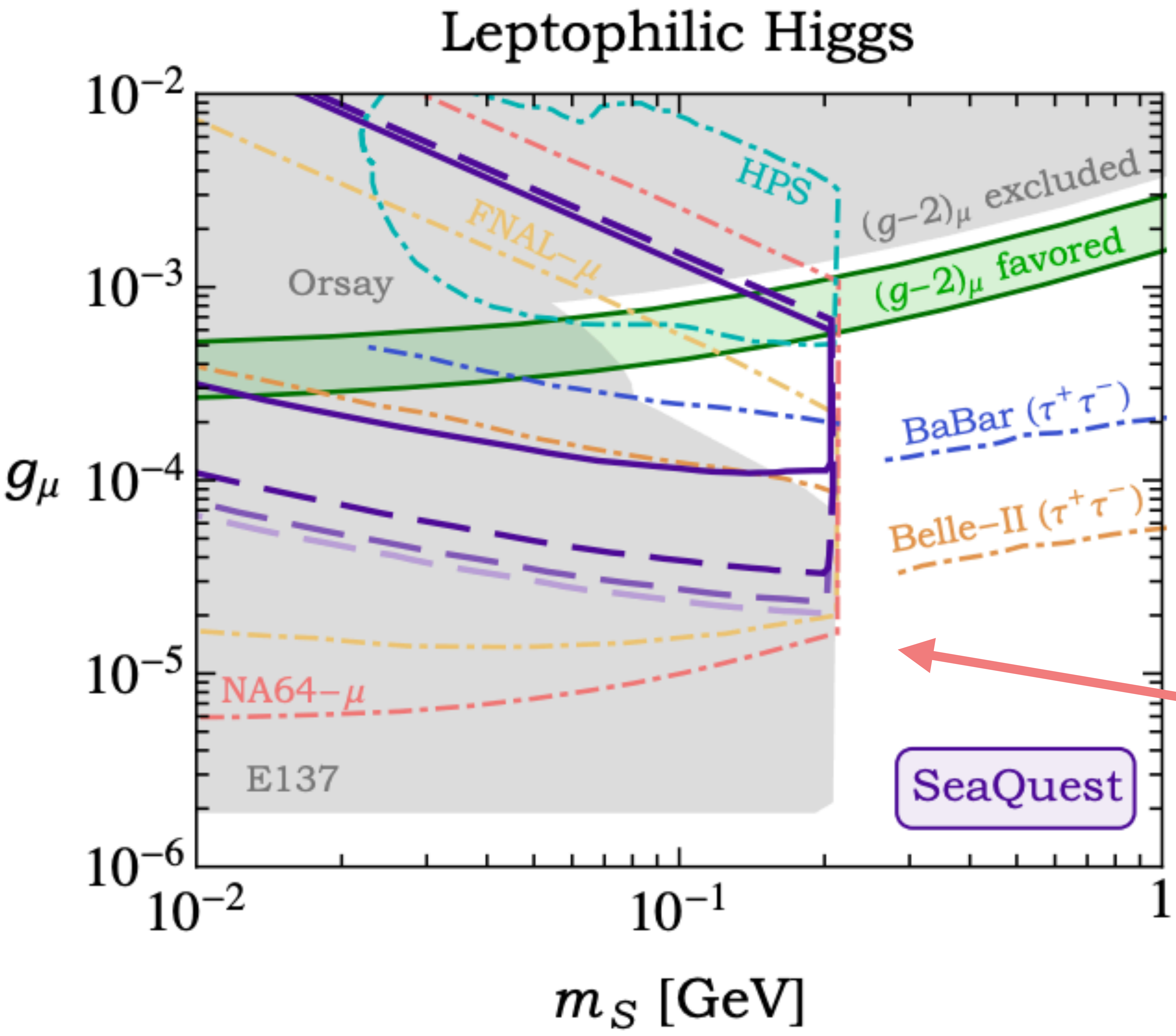


Muon beam dump

Why a Beam Dump?



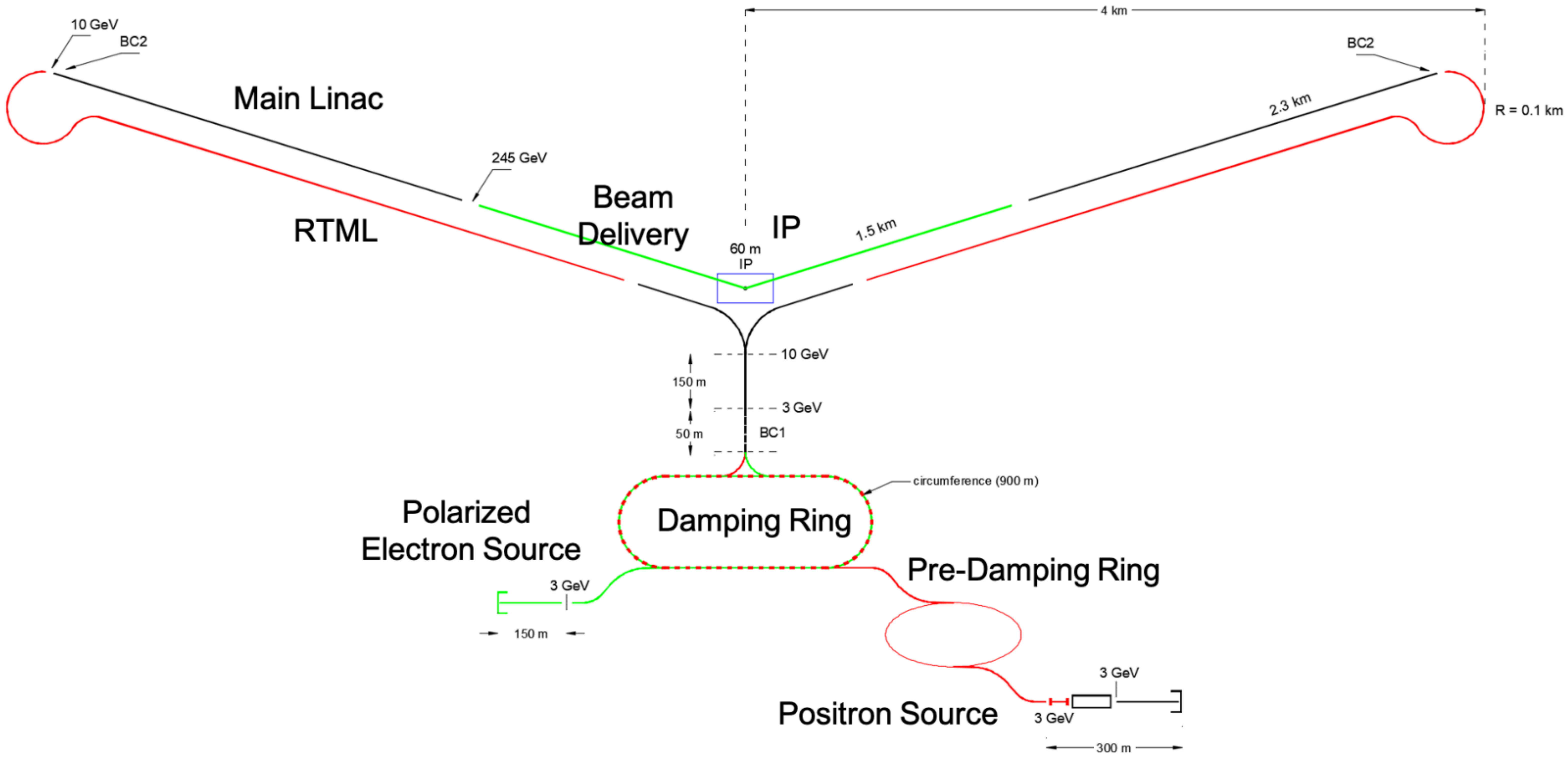
- Weakly coupled scalars
  - eg. $U(1)_{L_\mu - L_\tau}$



Muon beam dump

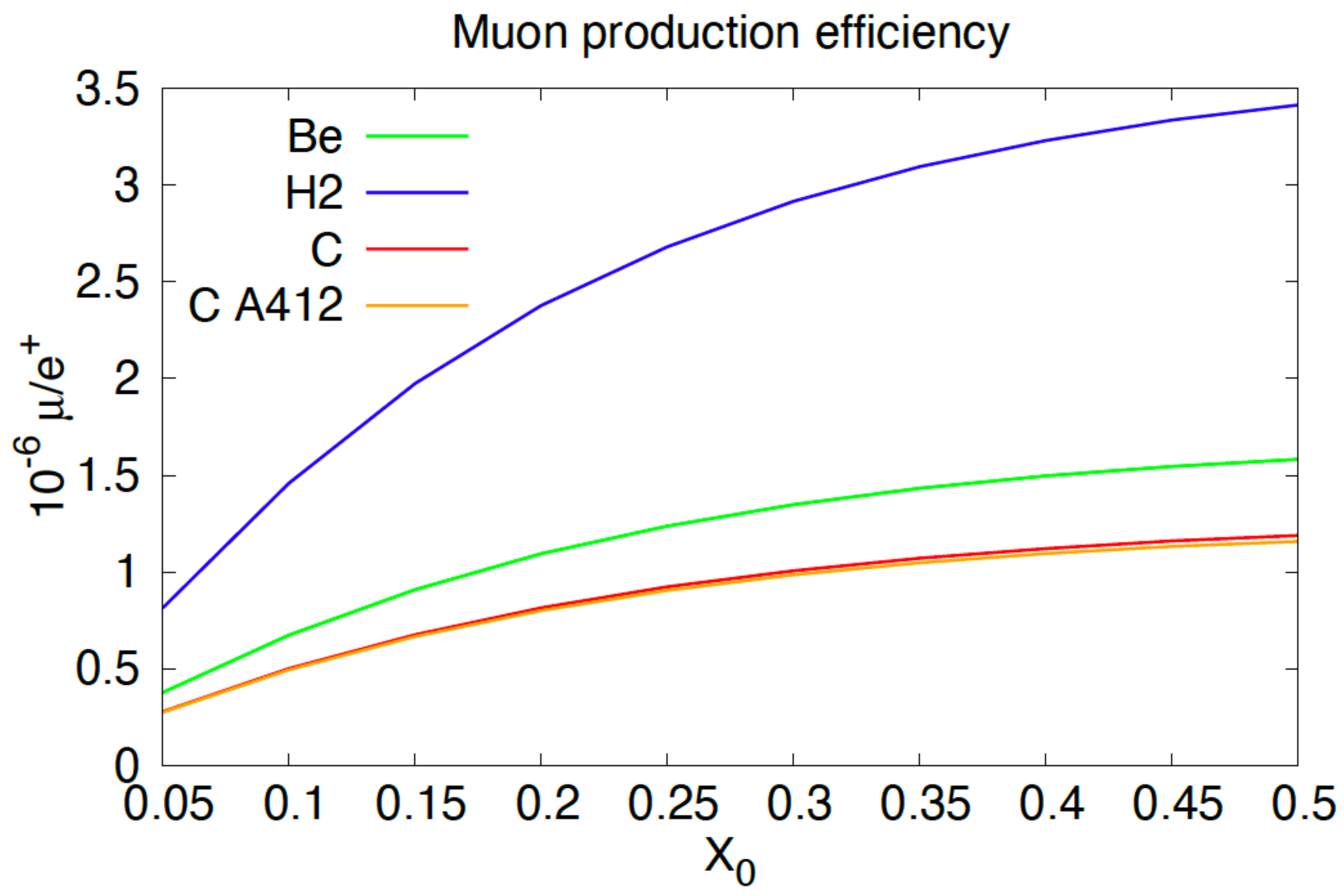
Physics During C^3 Construction

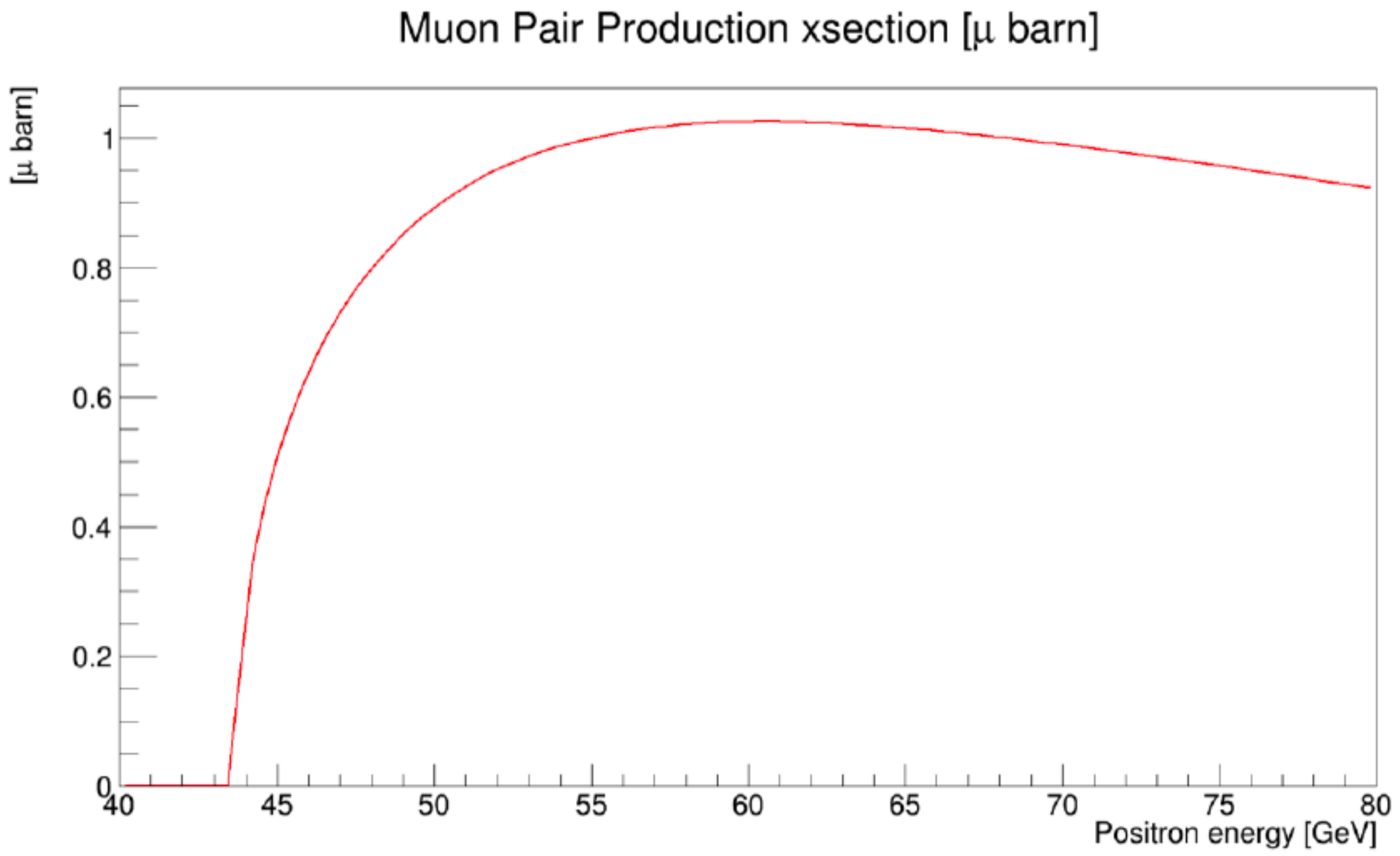
- Necessary elements:
  - Positron Source – Few GeV electron linac, positron target, positron capture
  - Damping ring?
  - Main linac to 45 GeV – ~550-700 m
(low to high current),
1 cryo plant

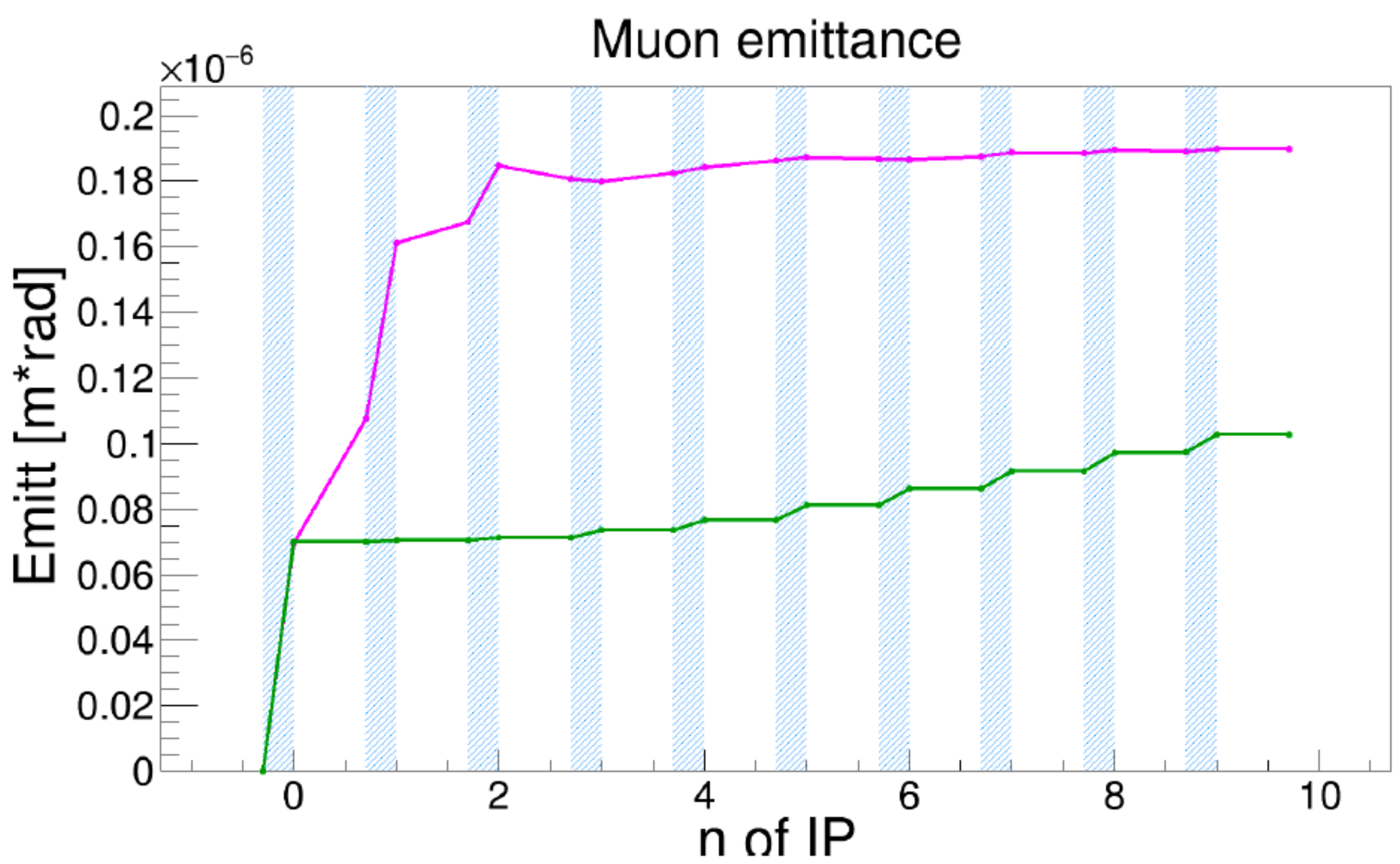


Muon Production with Positrons at 45 GeV

- 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 C^3

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 Singe Pass

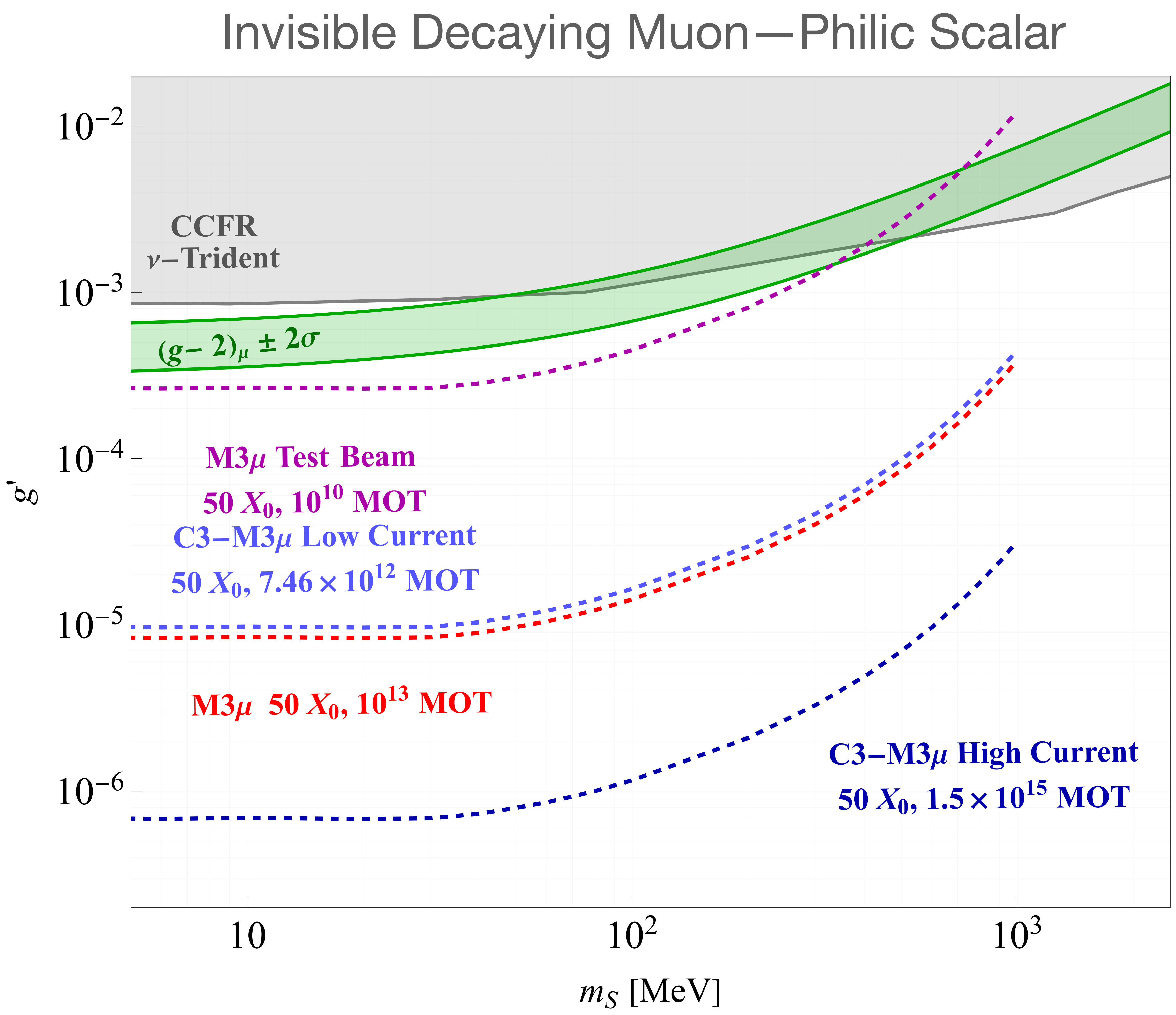
Includes 10^{-6} efficiency for e^+ conversion

C3 String Test High Muon Current

Parameter	Value
Number of RF Pulses Per Year (180 days)	1.87×10^9
RF Pulse Length	700 ns
Positron Bunch Charge	1 nC
# 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 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
- **C^3 low current and high current**



https://arxiv.org/pdf/1804.03144.pdf

M^3 (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 x 10^{10} MOT / yr**

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M^3 (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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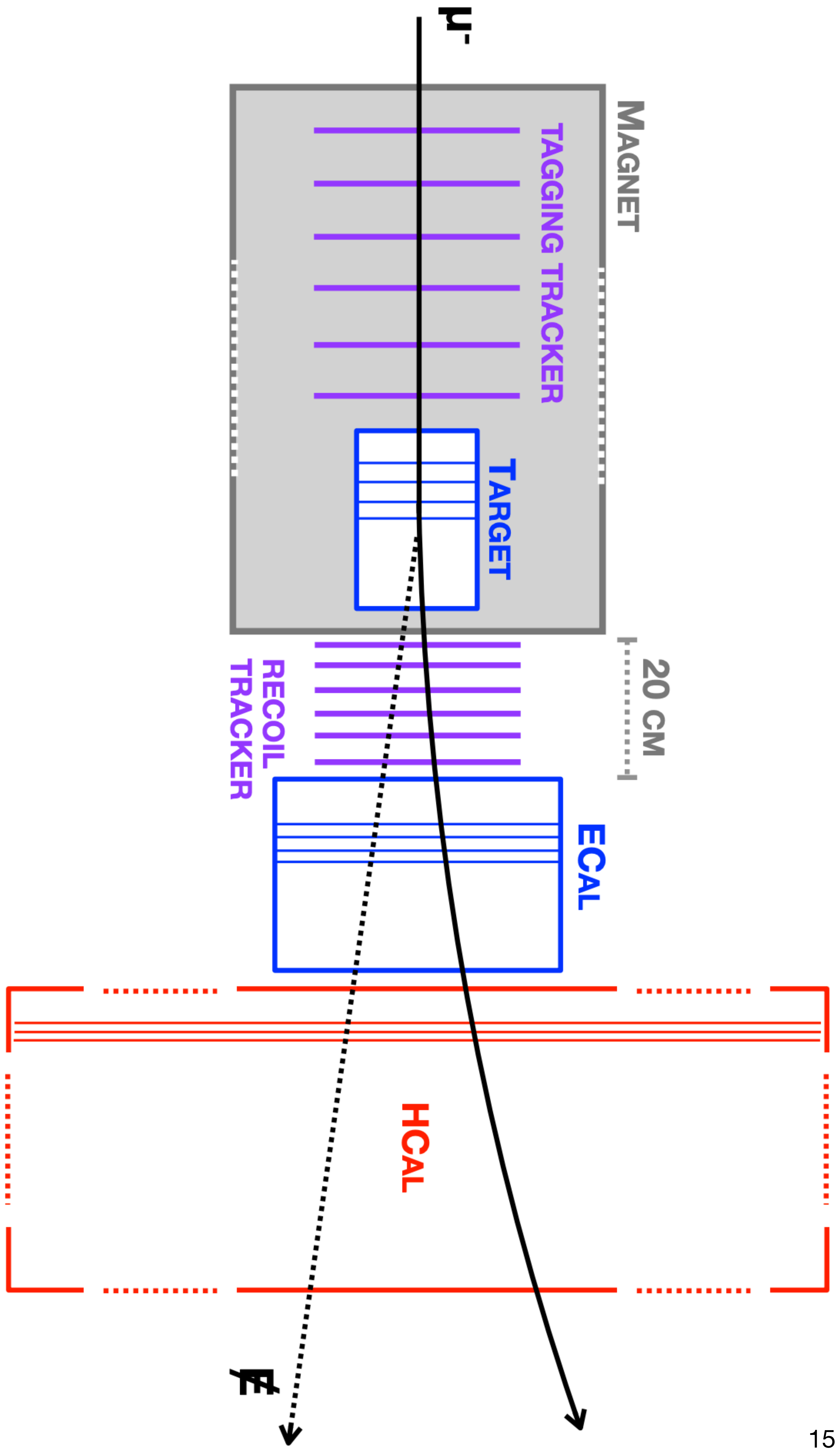
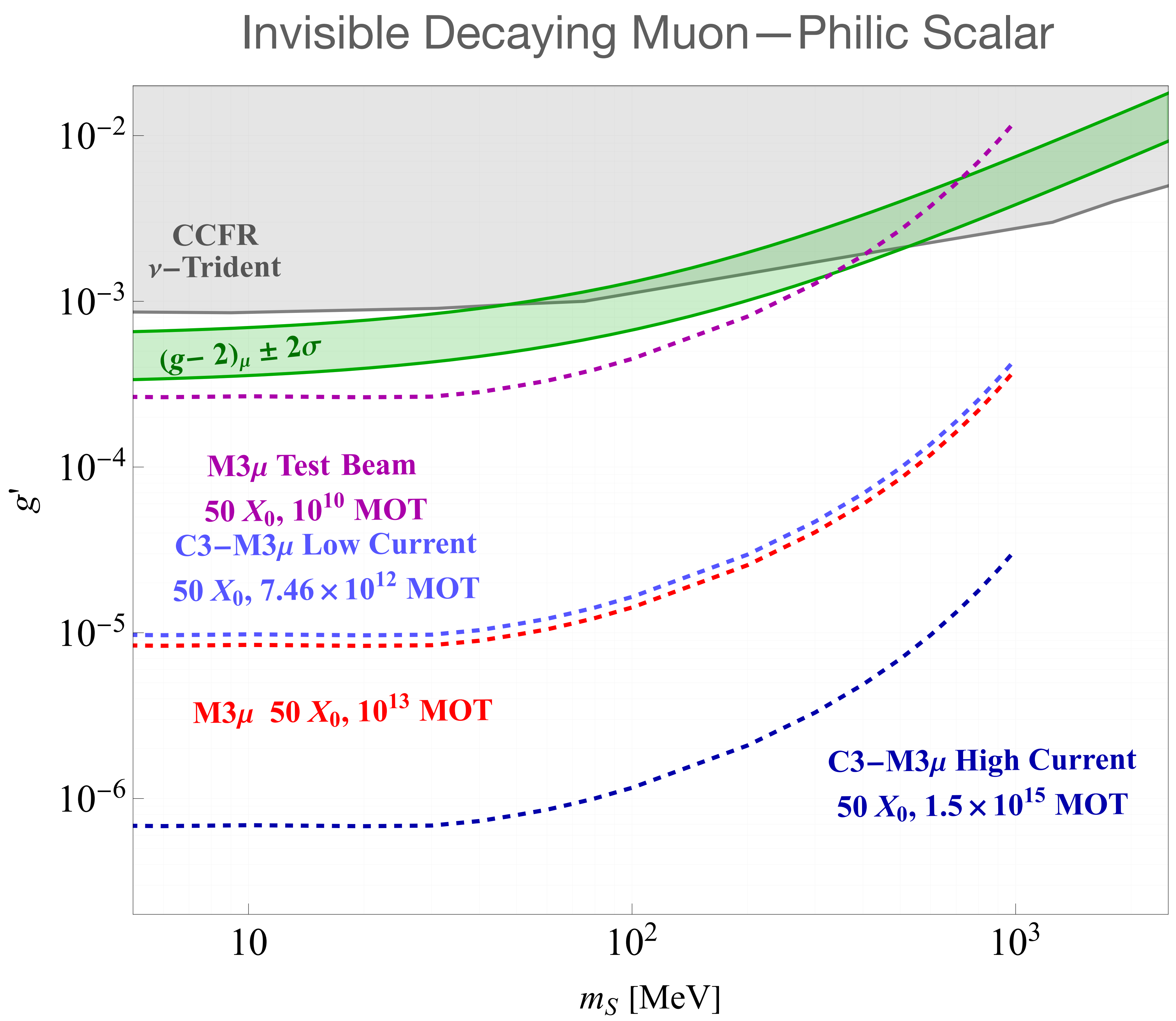
To Be Understood:

- From M^3 (based on LDMX):
  - Detector:
    - Silicon microstrip tagging tracker
    - 1T magnet
    - Tungsten-silicon sample calorimeter (ECal) [similar to CMS HGCal]
    - Steel-scintillator sampling HCal
  - Target = ECal (~50 X_0)
- For a beam dump don't need to tag incoming particles
- C^3 low and high current scenarios are very different beasts



Conclusions

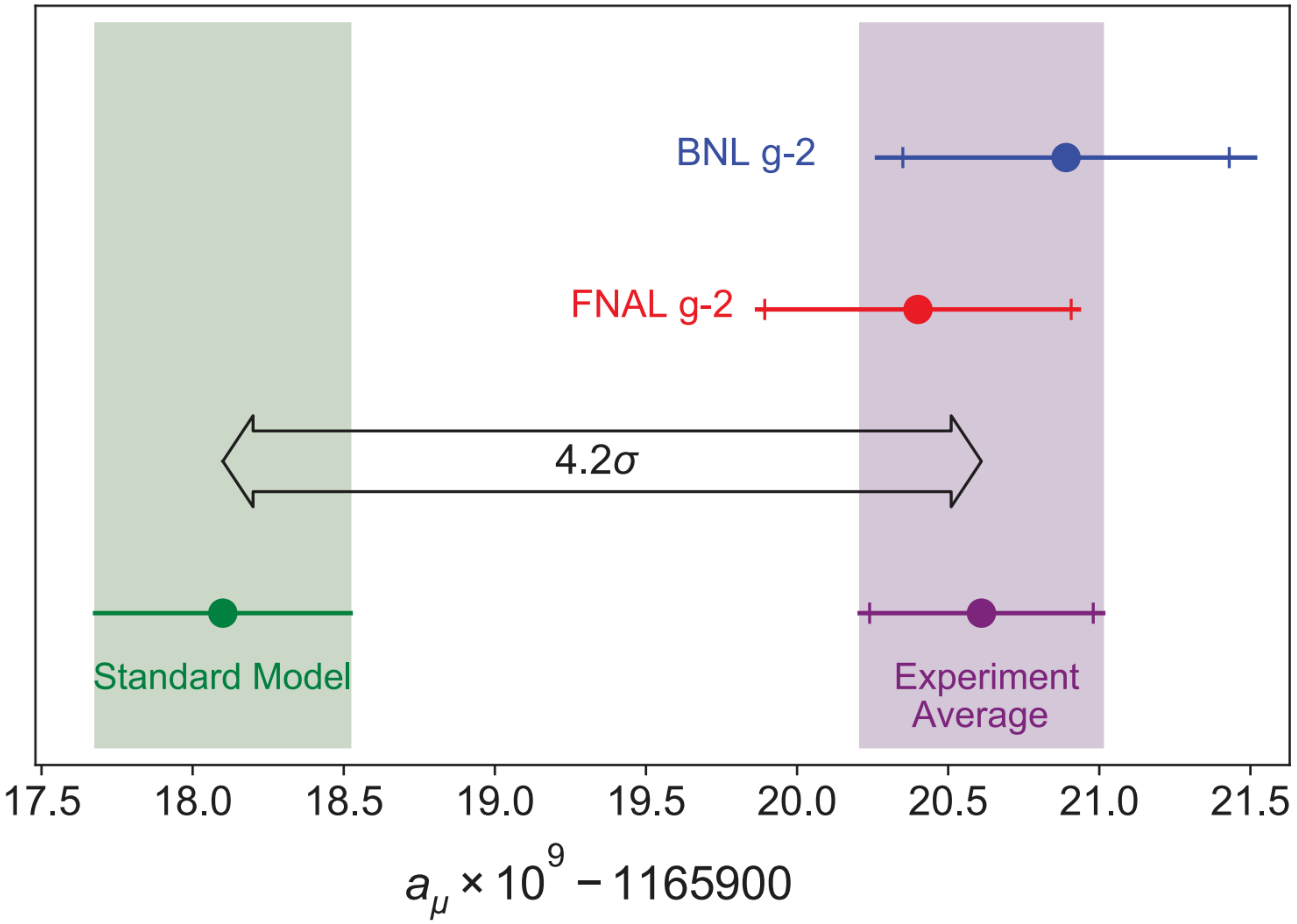
- C^3 construction period offers a real opportunity for exciting physics with beam dump experiments
- Muons are a very attractive possibility
  - Positron or even electron beam dump could also be explored
- Work needs to be done to understand how exactly this would look
  - Detector/target design
- Higher energy beam could also be considered
  - From physics perspective, adjust the probed parameter space



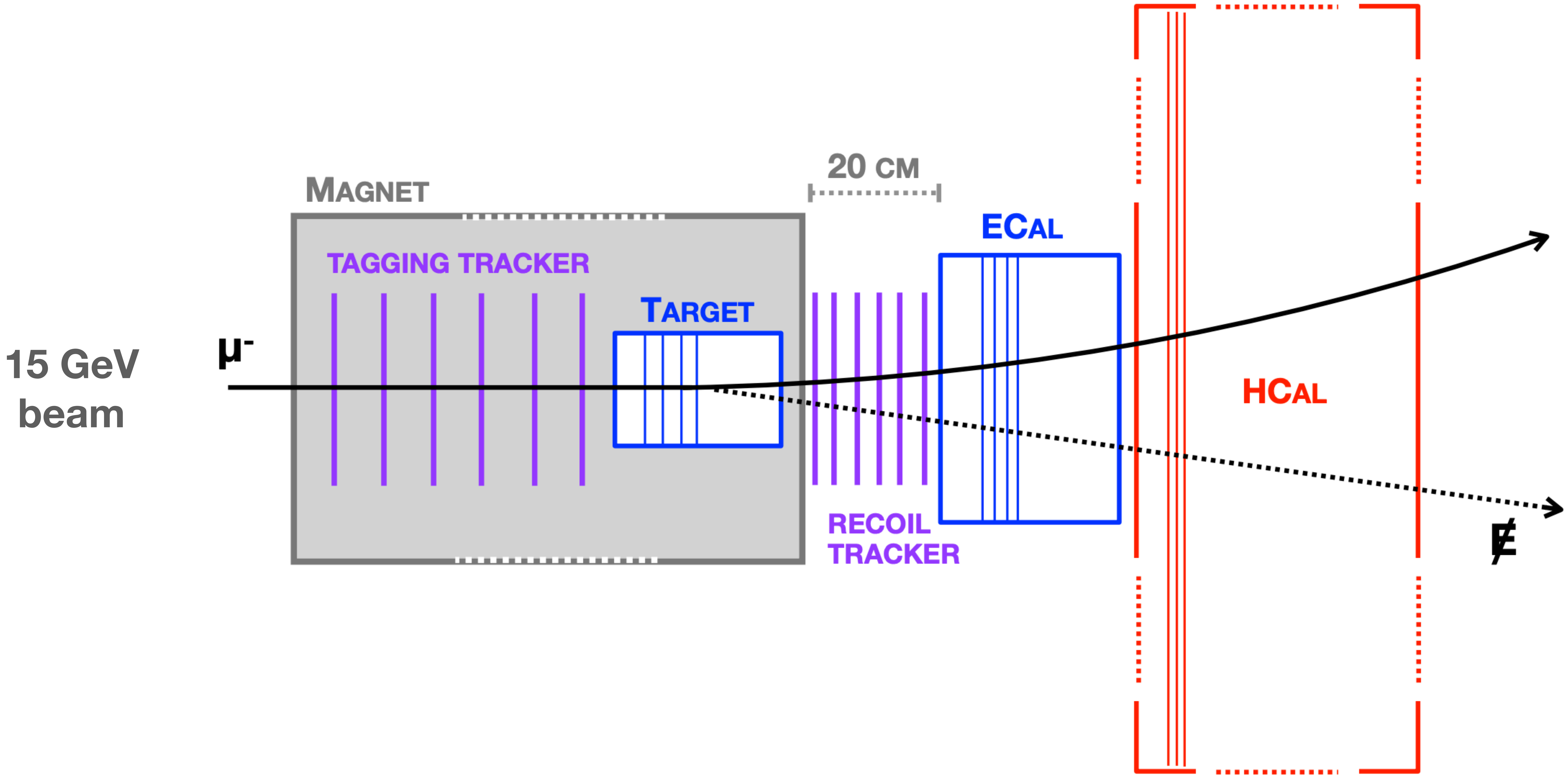
BACKUP

Theoretical Motivation

- 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?



Muon Missing Momentum (M^3)



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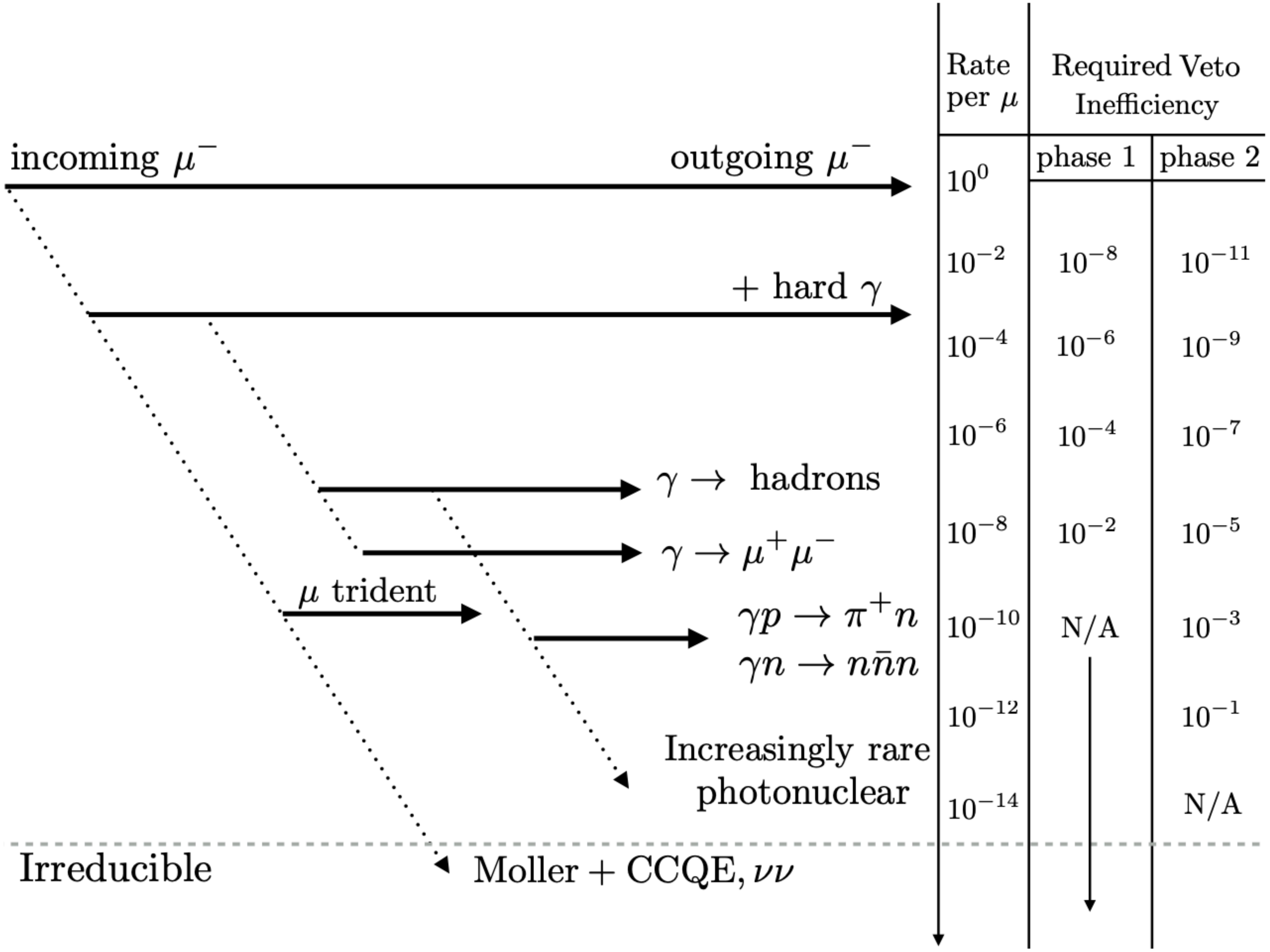
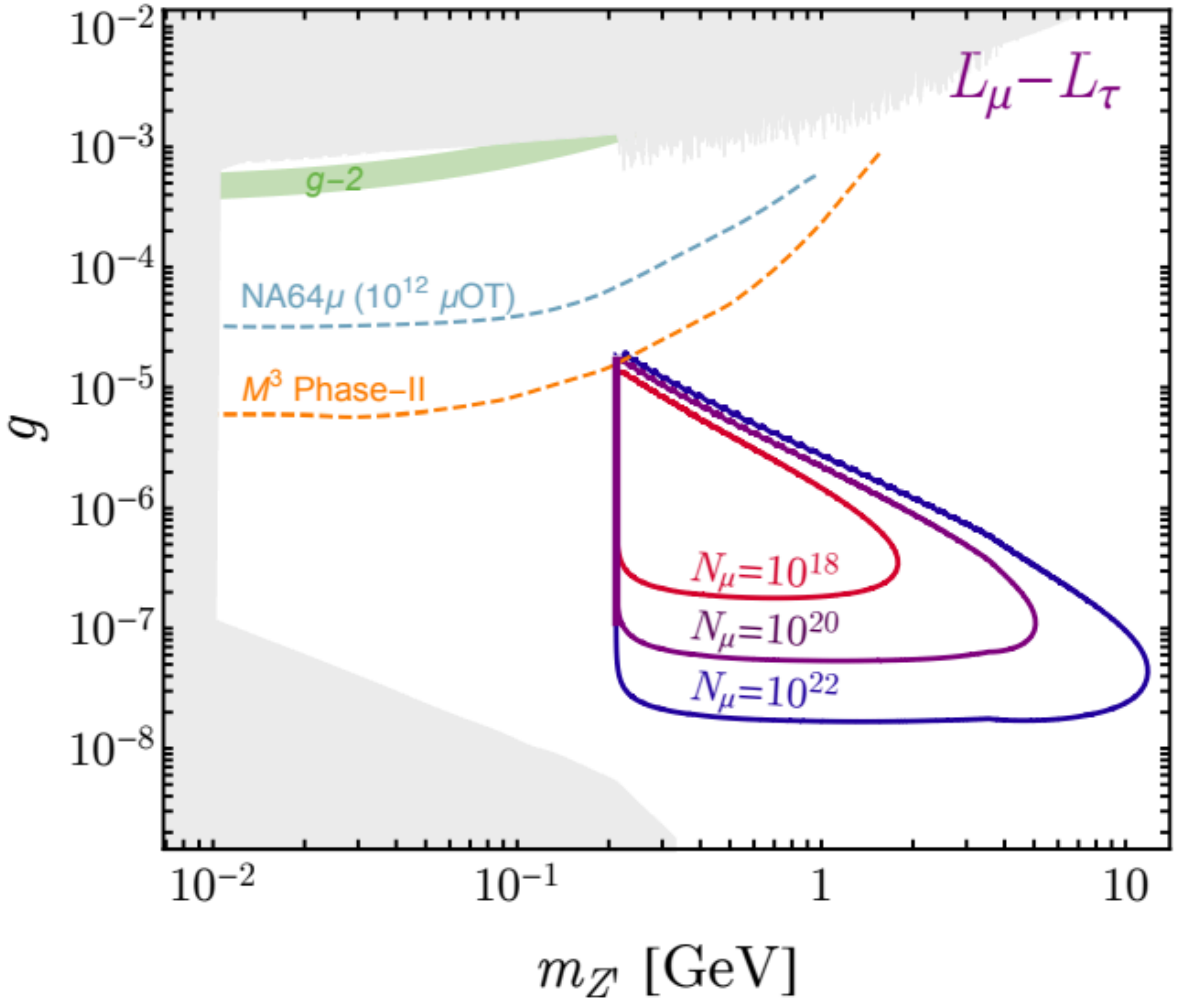
M^3 (Phase 2 +)

- 10^{15} MOT from C^3 gets to irreducible background floor for M^3
- Nice place to be
  - Increase in MOT would not improve limits significantly



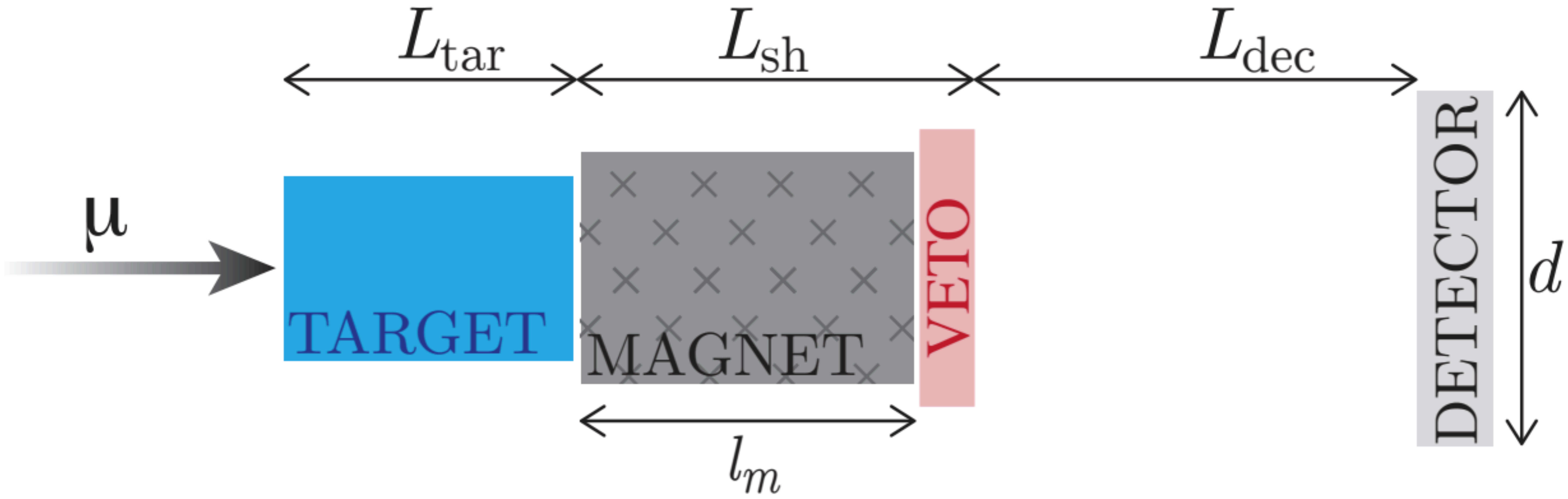
High-Energy Muon Beam Dump

- 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_μ → increased m_{med}
    - 500 GeV beam → 20 GeV m_{med}
    - 50 GeV beam → 5 GeV m_{med}



https://arxiv.org/pdf/2202.12302.pdf

High-Energy Muon Beam Dump



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