A MINIMAL MUON MISSING MOMENTUM EXPERIMENT: M^4

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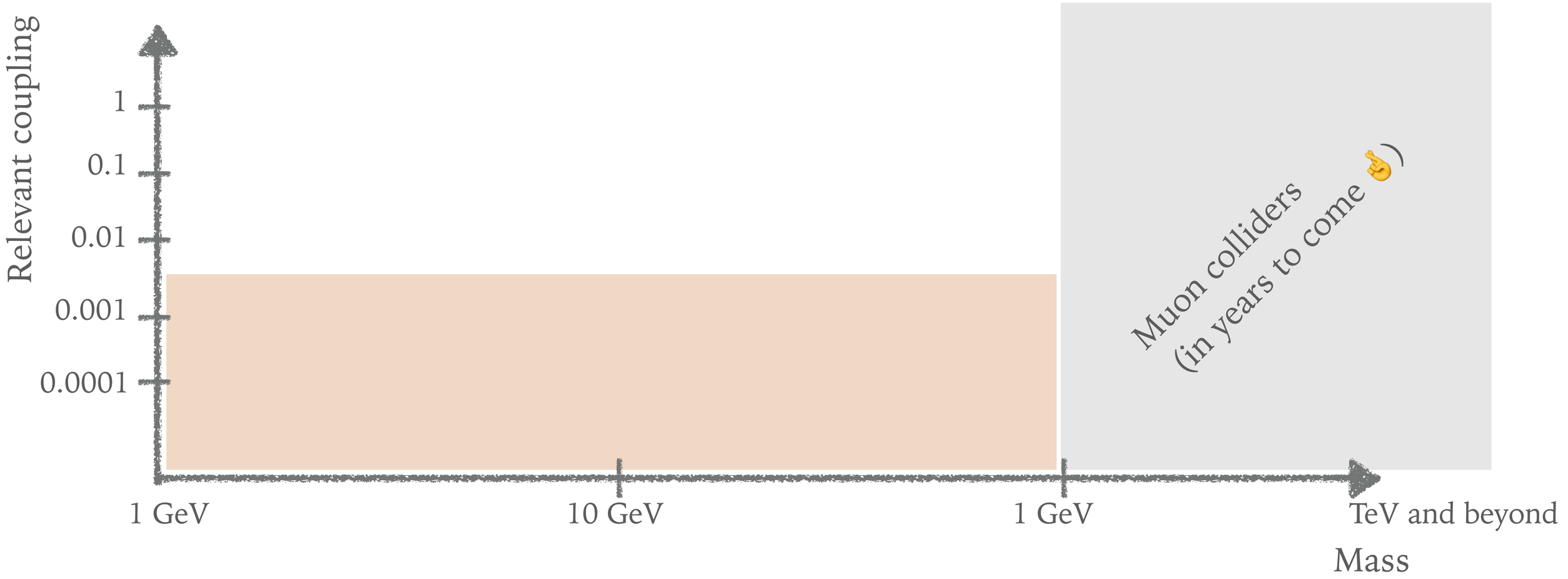
Discovering the new physics of g-2 with fixed target muon facilities @ FNAL
June 22nd 2021

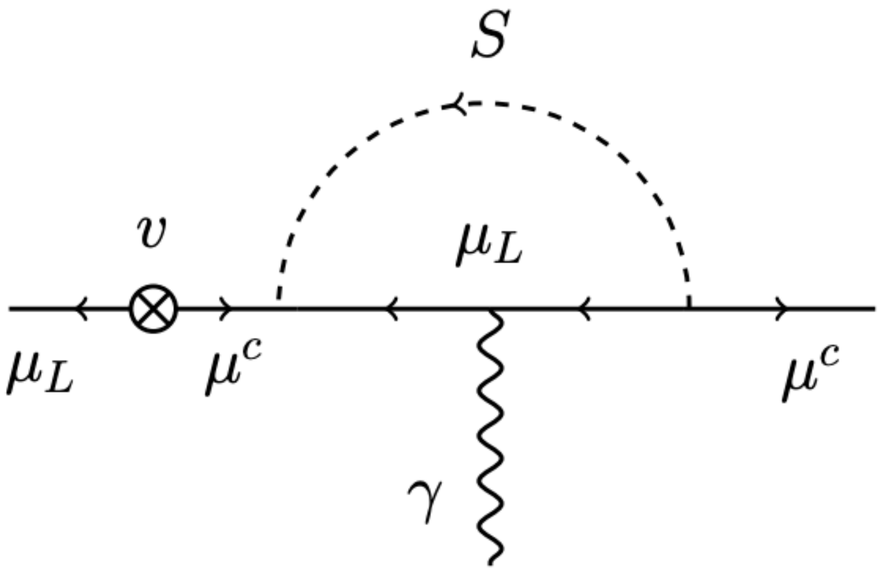
NEW PARTICLES AND Δa_μ^{exp}

from D. Curtin's colloquim

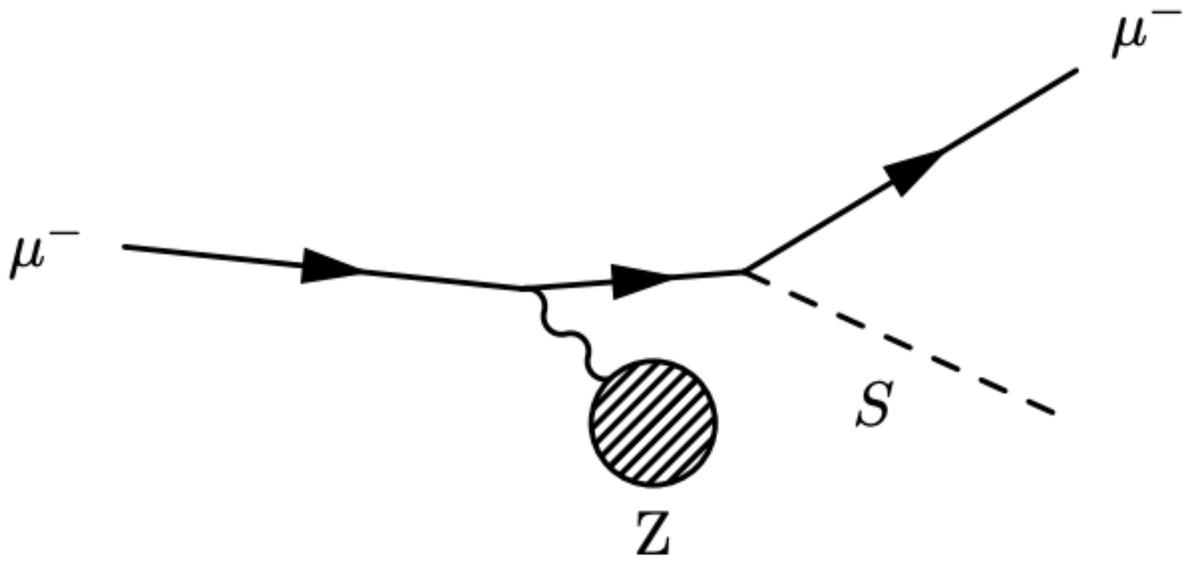


Big opportunity to probe $\lesssim$ GeV regime @ Fermilab

NEW PHYSICS IN $(g-2)_\mu$: E.G. A SINGLET SCALAR*

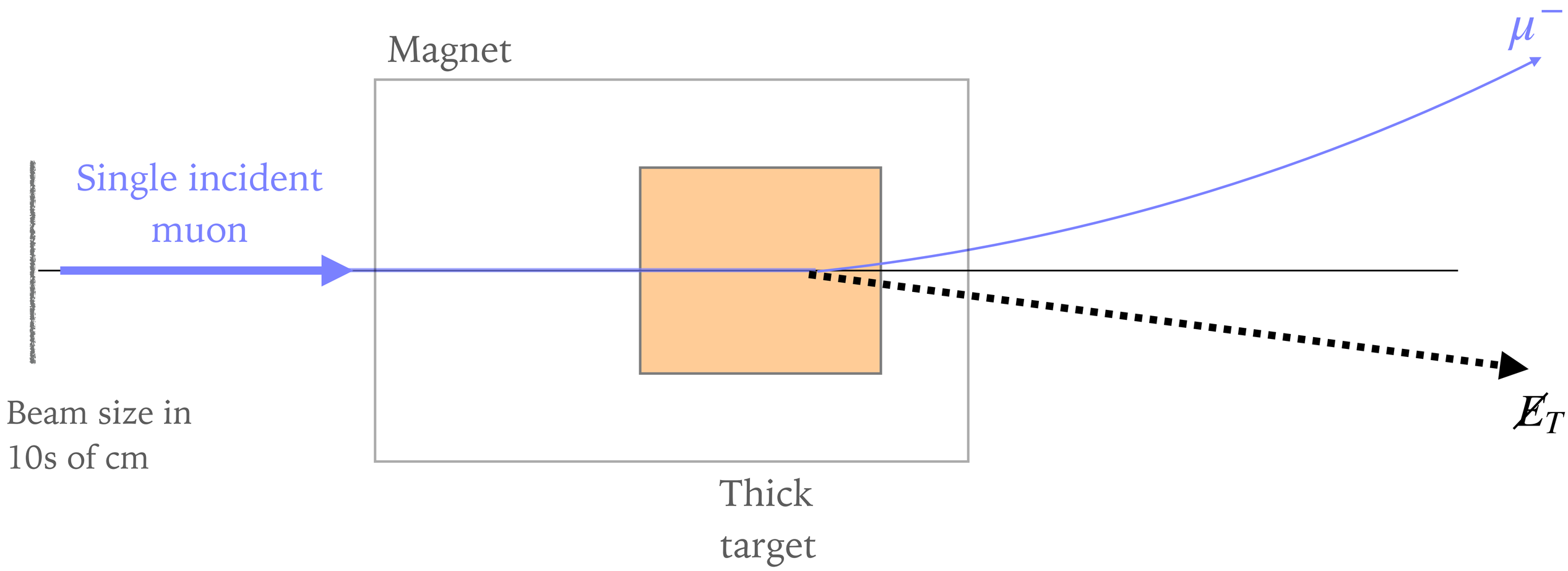


$$\mu + N \to \mu + N + S$$

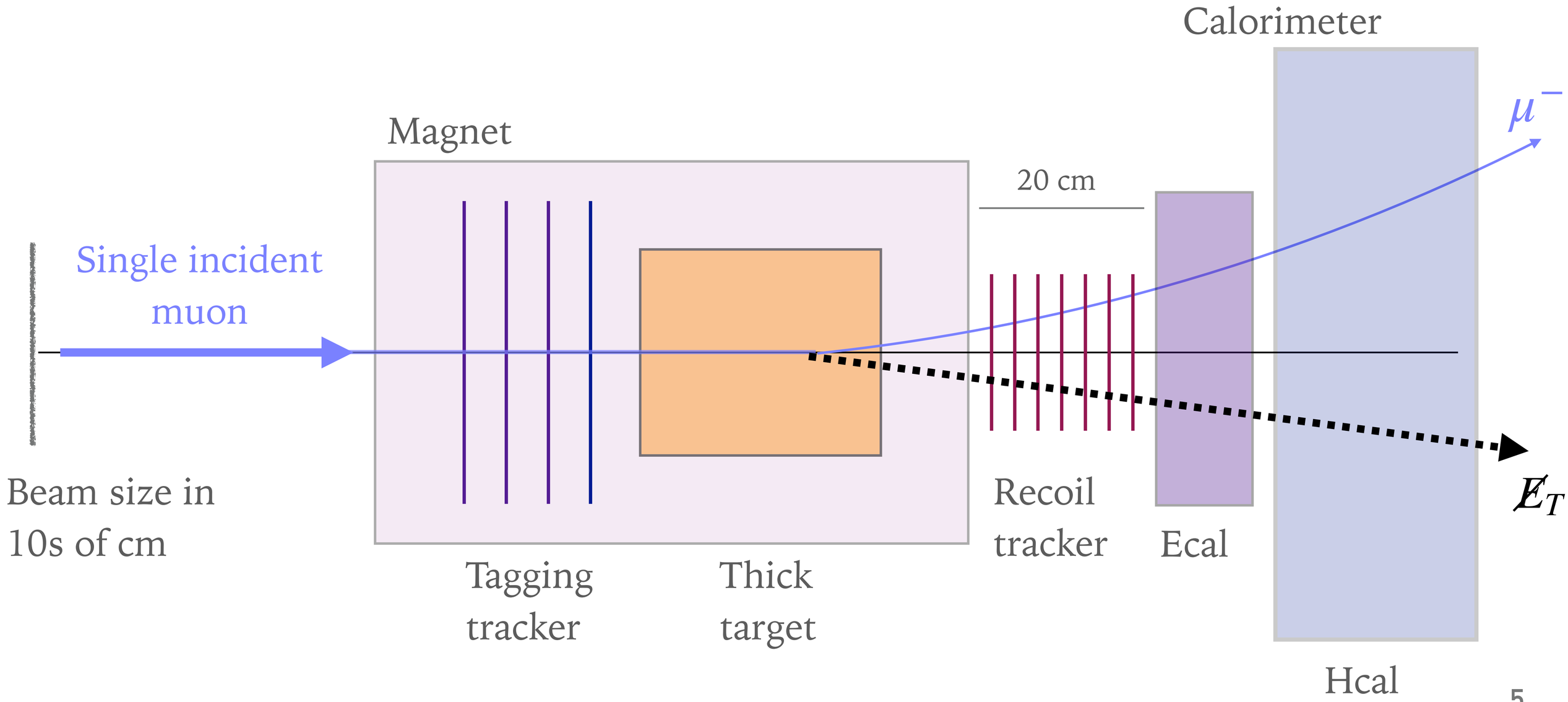


* And similarly for a singlet vector

MEASURING THE MISSING MOMENTUM OF THE MUON



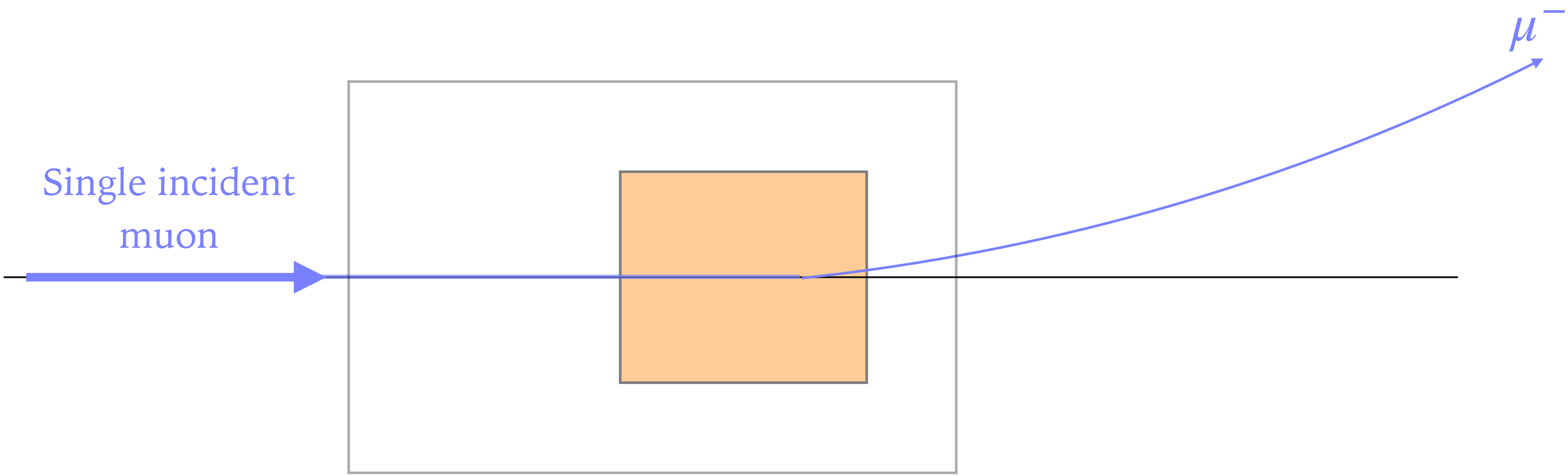
M3 SCHEMATIC (LDMX-LIKE)



REDUCIBLE BACKGROUNDS: OUTGOING MUON

Phase-I mis-id: 10^{-8}

Phase-I rate/muon: 1

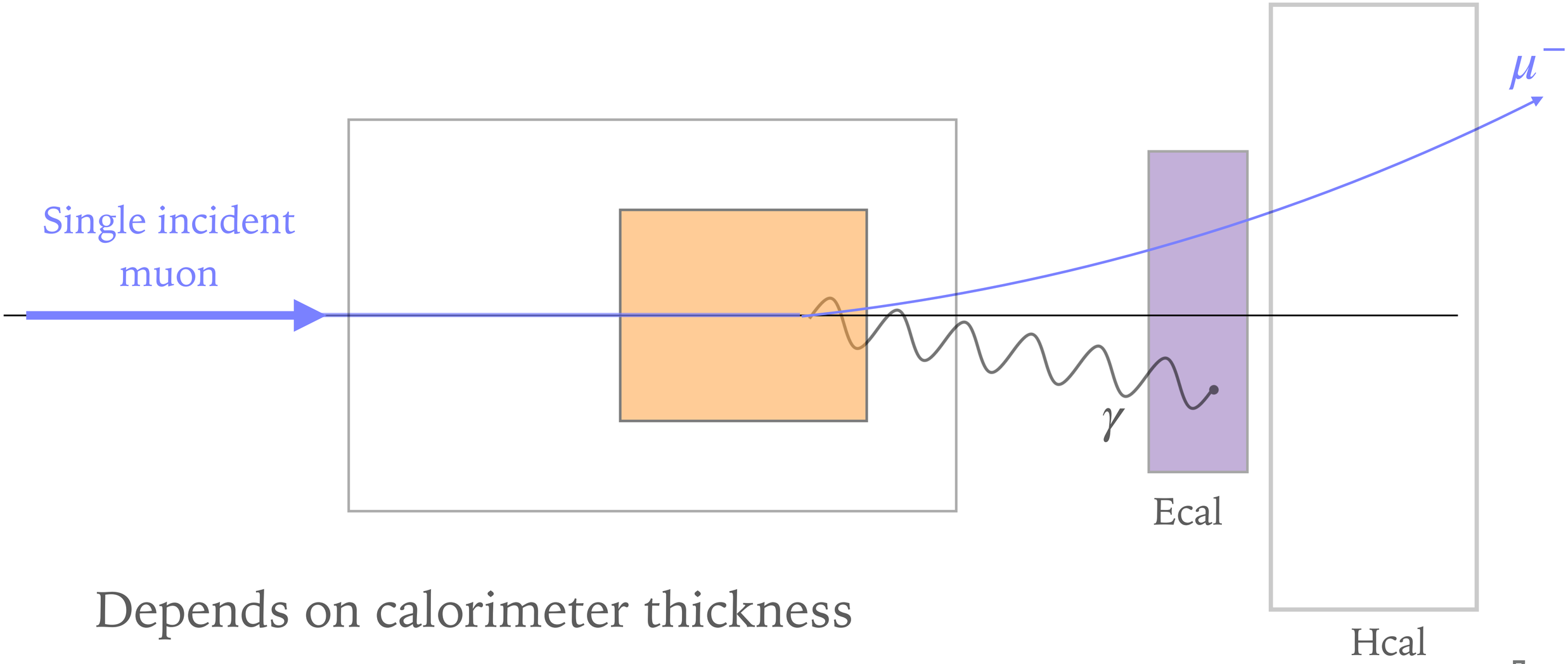


Easy to veto with muon E_{recoil} requirement

HARD BREMSSTRAGHLUNG

Phase-I mis-id: 10^{-8}

Phase-I rate/muon: 10^{-2}

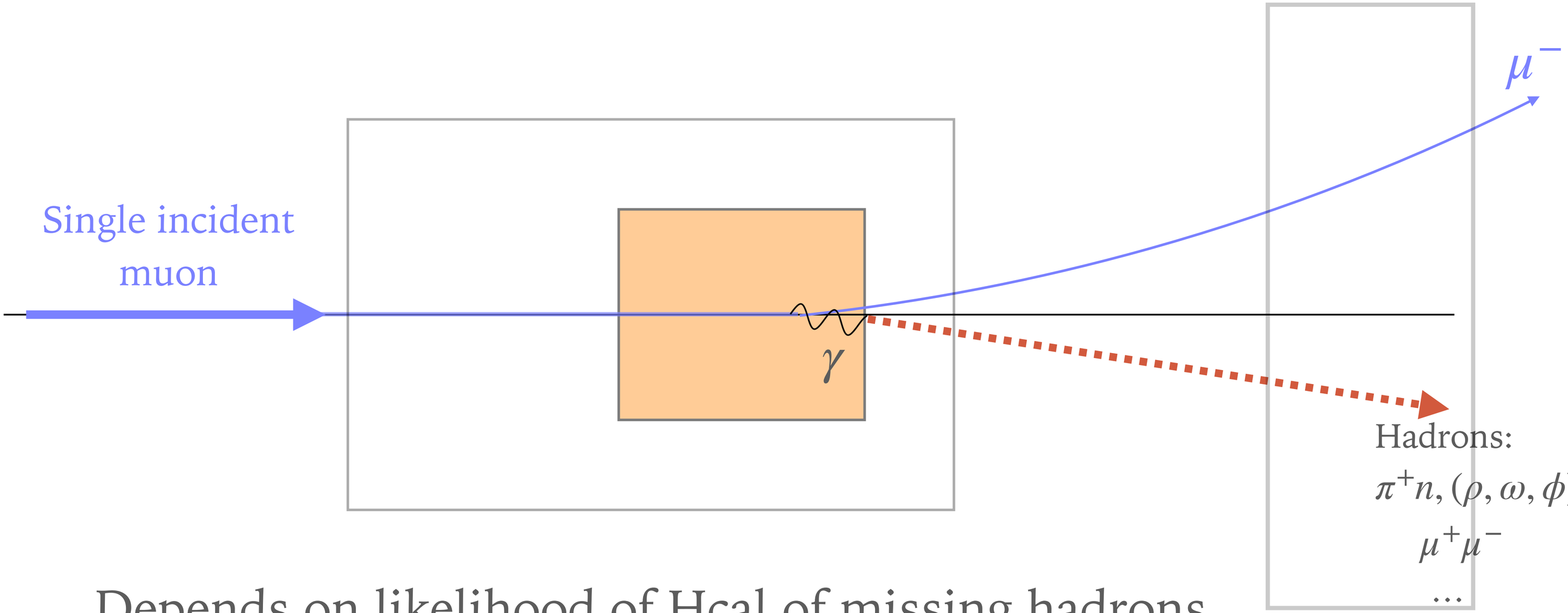


Depends on calorimeter thickness

BREMSSTRAGHLUNG INITIATED EVENTS

Phase-I mis-id: 10^{-2}

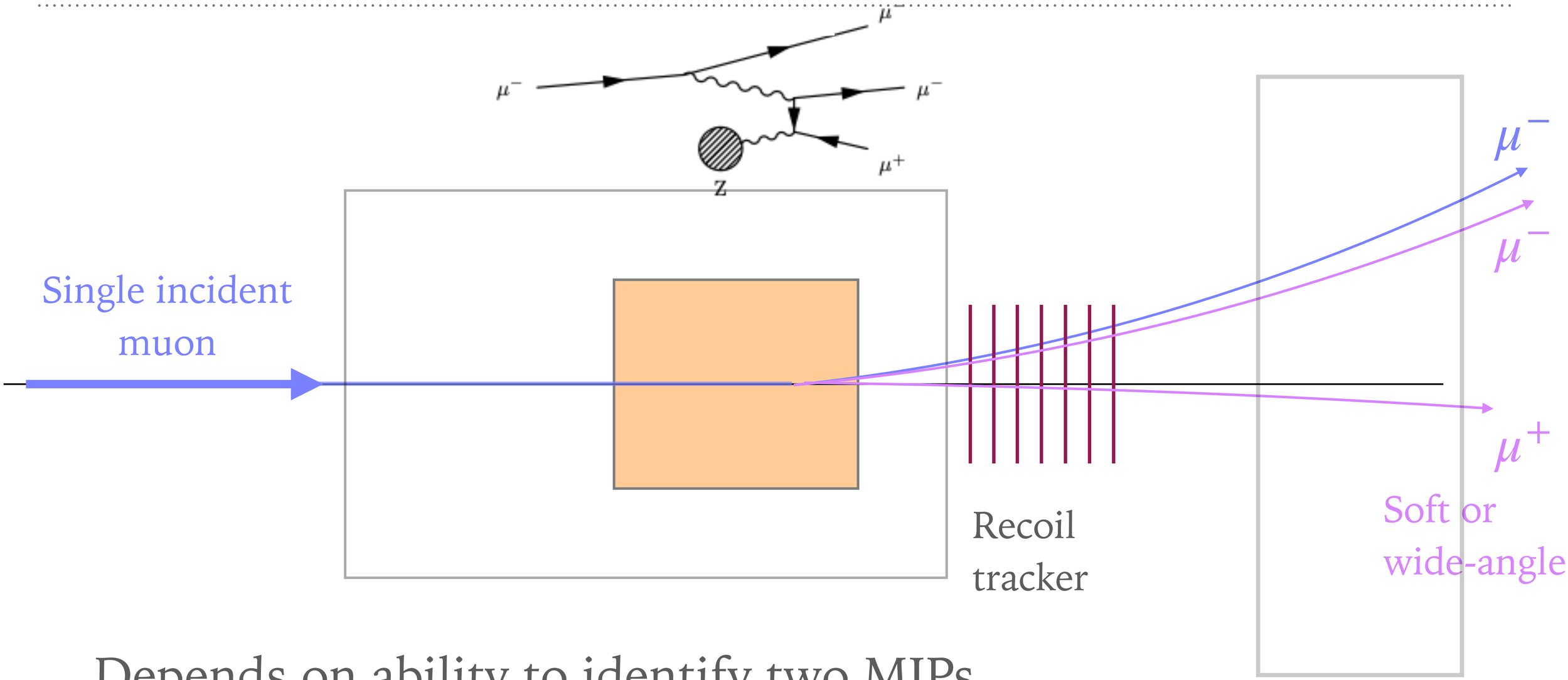
Phase-I rate/muon: $10^{-6 \text{ to } -10}$



Depends on likelihood of Hcal of missing hadrons

TRIDENT PRODUCTION

Phase-I mis-id: N/A

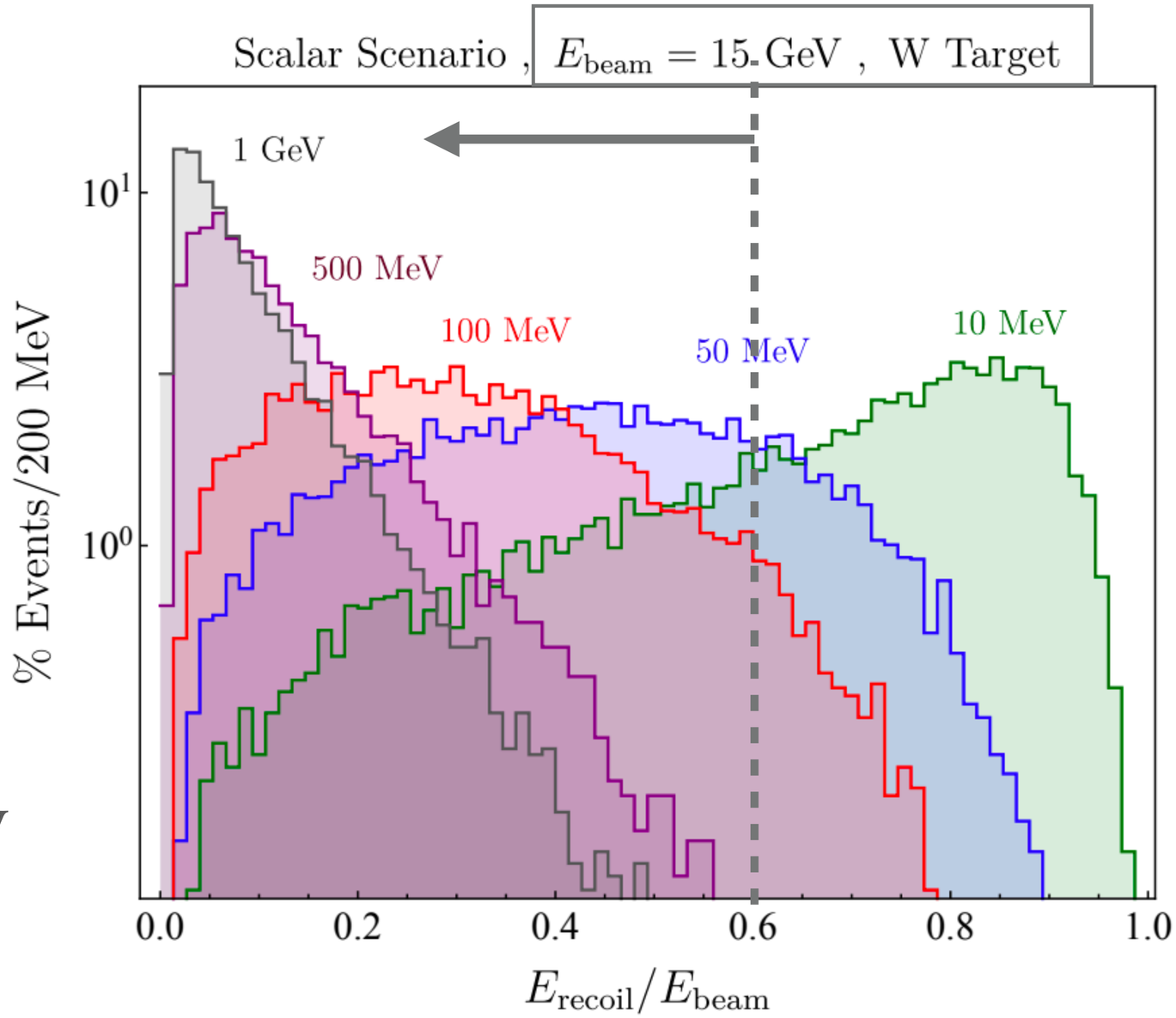


Depends on ability to identify two MIPs

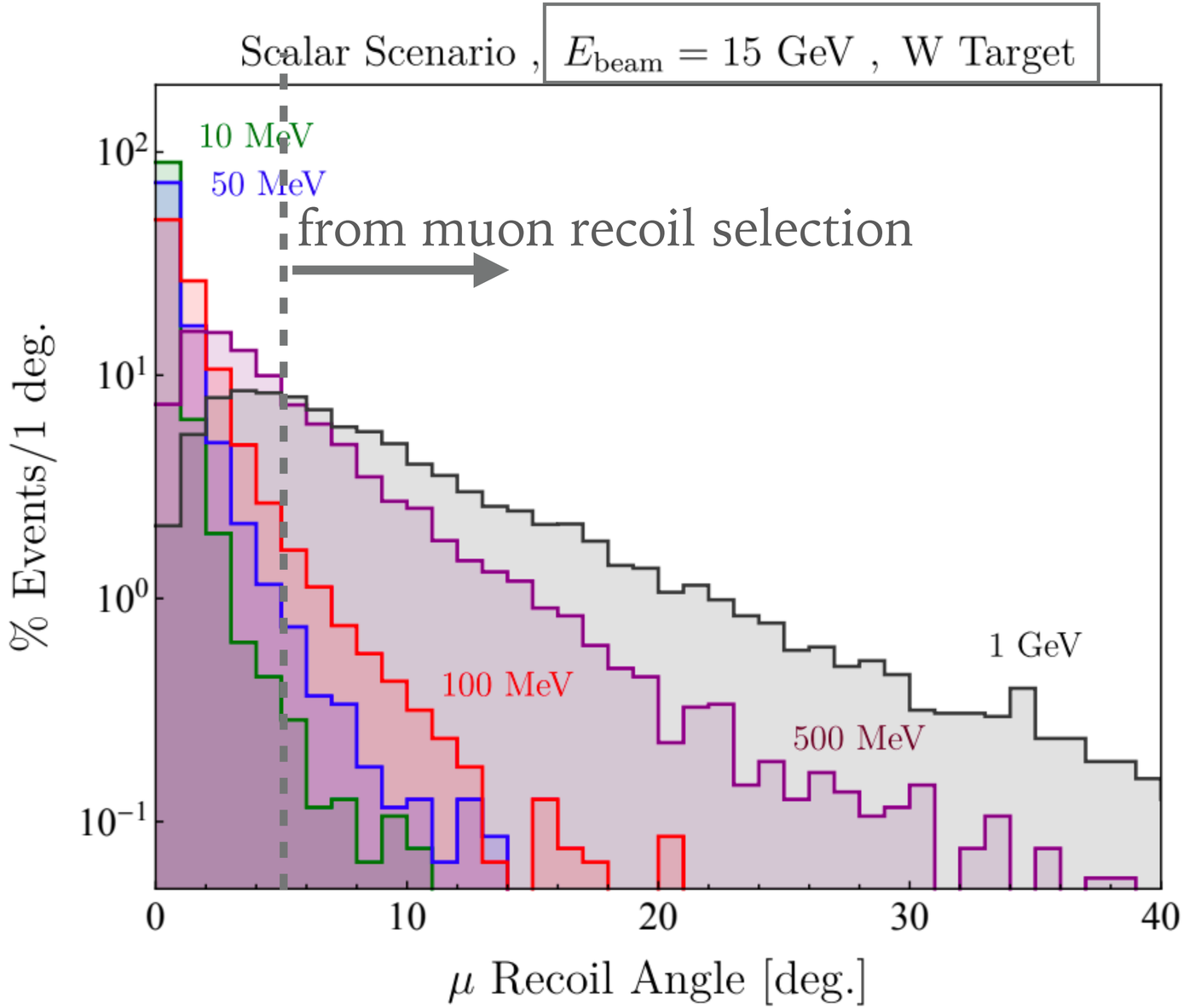
SIGNAL ENERGY SPECTRUM IS LARGELY DEPENDENT ON BEAM'S ENERGY

Selecting on muon recoil energy:

@ $E_{recoil} < 9$ GeV and $E_{beam} = 15$ GeV



MOSTLY FORWARD OUTGOING MUONS FOR LIGHTER MASSES

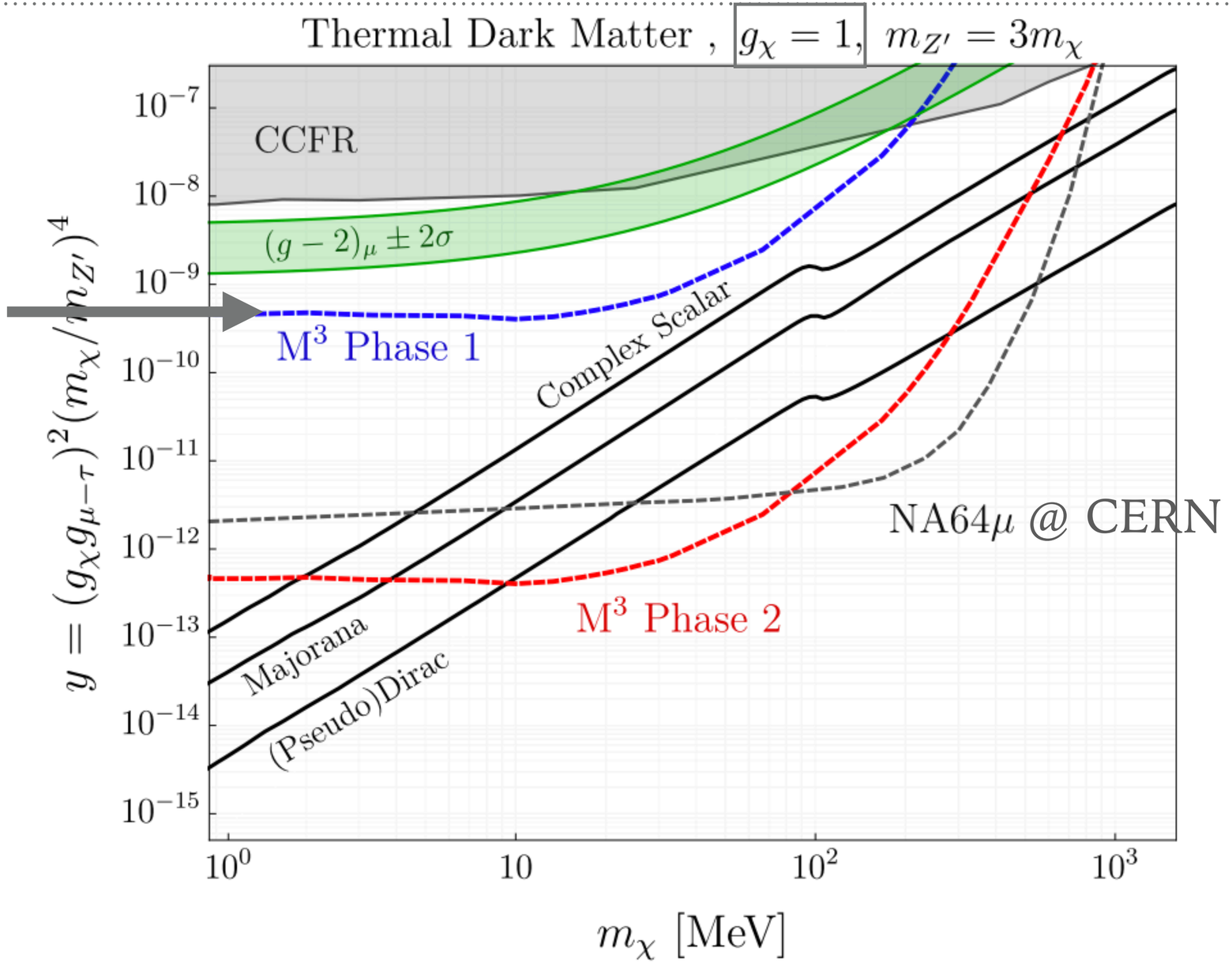


SENSITIVITY REACH

Kahn Y., Krnjaic G et. al.

Already gives us **complete coverage of g-2 region**! (for any invisibly decaying particle lighter than the muon)

Not mentioned but equally important: **M³ can also do visible $S \to \mu^-\mu^+$ (being studied by D. Forbes)**



Suppose we were to do this experiment today:

- What are the experimental requirements?
- How minimal can we get?

EXPERIMENT REQUIREMENTS:

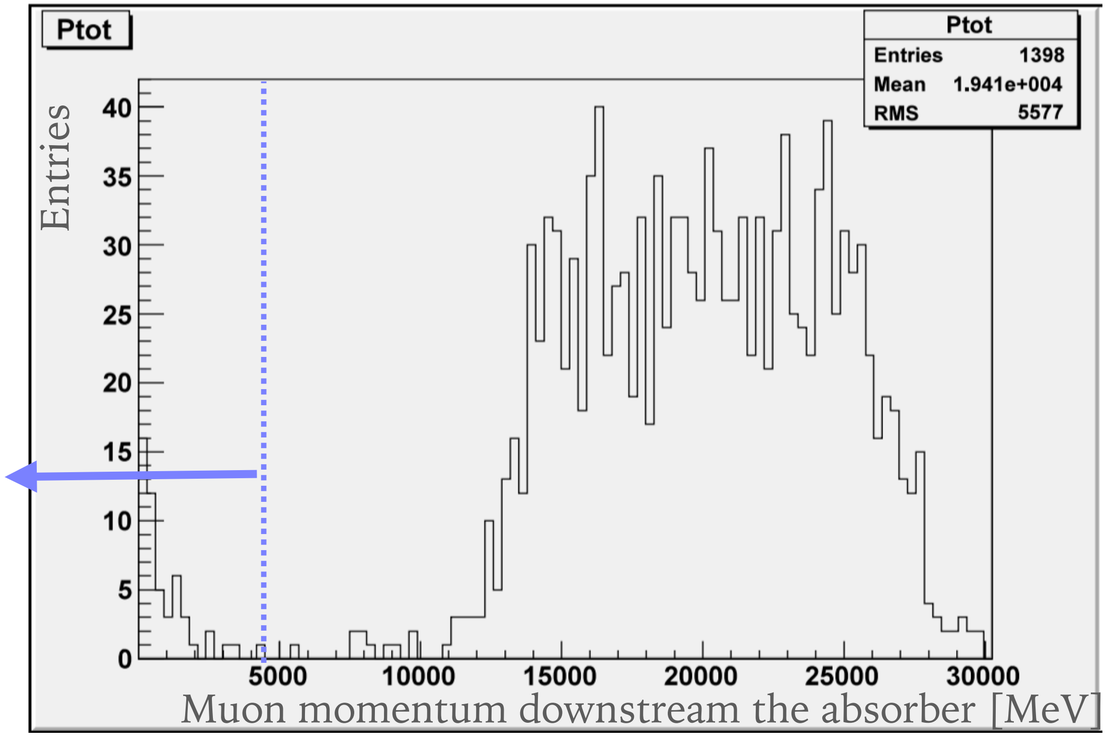
- Transverse size needs to catch **muon beam spread**
- Fast LHC-like **readout**: from beam bunch structure (does not need to be 53 MHz)
- **Target depth** that allows for large production rate
- **1% momentum resolution** to measure muon missing momentum
- Downstream and target veto: **calorimeter layers**

MUON BEAM

* Taken from FTBT study

- High intensity: 10^{10} MOT (phase-I) - 10^{13} MOT (phase-II)
- **Beam energy** in tens of GeV

e.g. for muons from 32 GeV pion in flight decays (at MCenter *)



These events need to be discarded (recoil tracker needs to identify them)

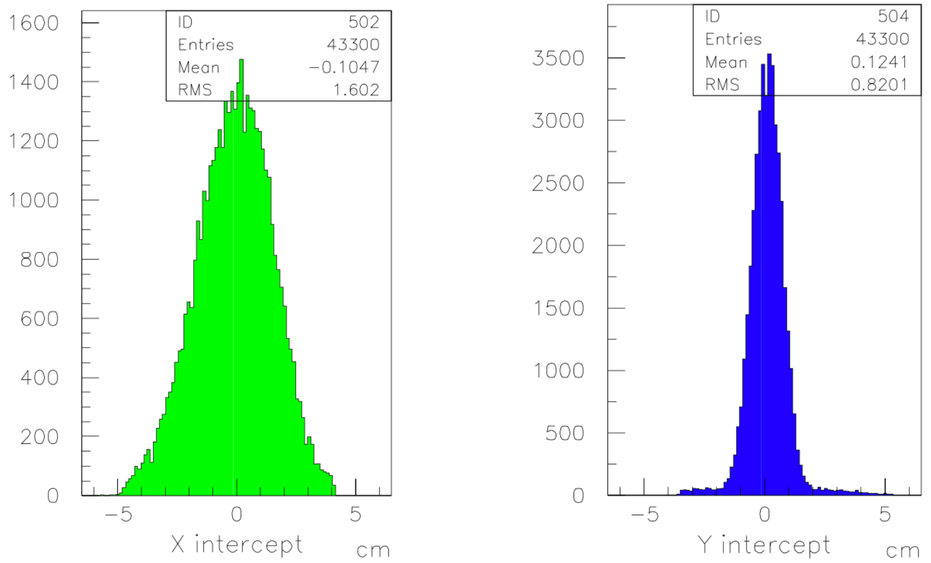
Muon **beam size ~ 20 cm**

MUON BEAM FROM PION IN FLIGHT DECAYS

* Taken from FTBT study

- Also need to worry about π^- **contamination:**
  - Those that make it through the absorber (e.g. iron for MTest) - it's also possible to add absorber upstream the magnet.

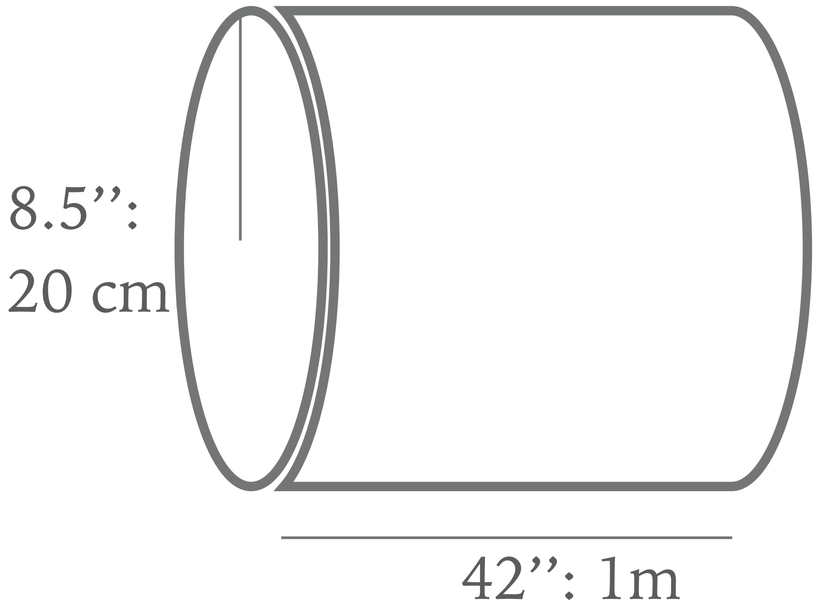
Pion beam size at
Mtest ~ 10 cm
(before Fe absorber)

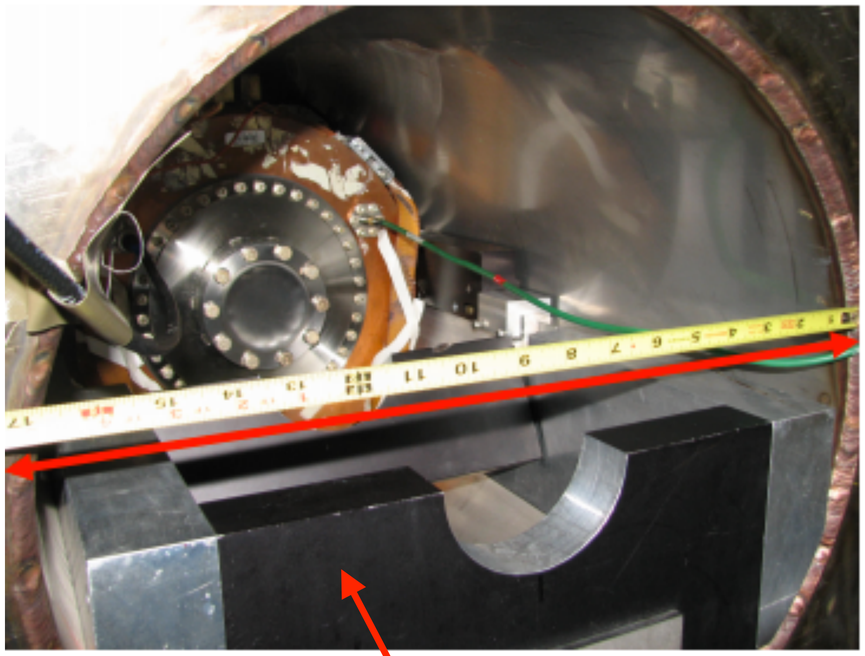


  - Those that decay in target region: hopefully produce a soft muon that can be vetoed

THE MAGNET: FROM MUCOOL TEST AREA

- Cylindrical superconducting magnet available ~@ MTest
- 4 Tesla with 44 cm bore hole: need to think of support structure, cooling etc for tracking modules



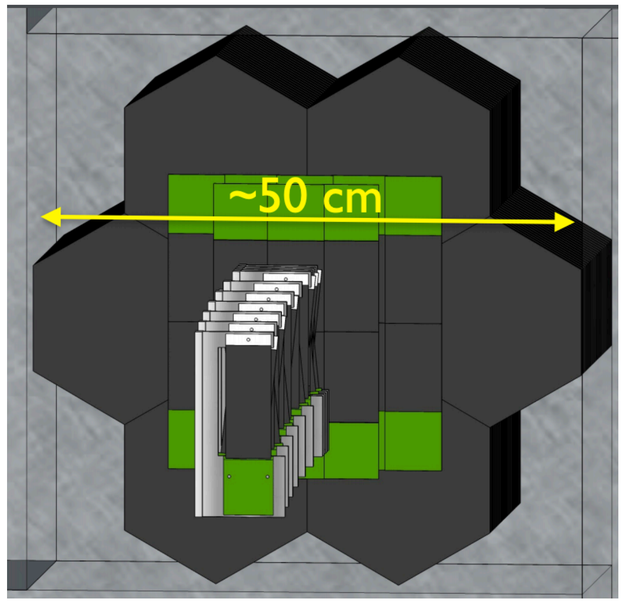


TARGET REQUIREMENTS

- Needs to be much **thicker** than LDMX (0.1 $X_0 \rightarrow 50\ X_0$) - about 25 cm of tungsten or silicon.
  - To allow for larger production rate.
  - Thickness $\propto 1/\mathrm{MOT}$
- Needs to be placed in **magnetic field** region: measure p_μ
- Needs to be **active**, e.g. high granularity silicon mocdules. To detect muon energy loss from SM interactions in the target (e.g. from electrons from hard $\mu e \rightarrow \mu e$ scattering or pion decays)

TARGET FROM HIGH GRANULARITY CALORIMETER

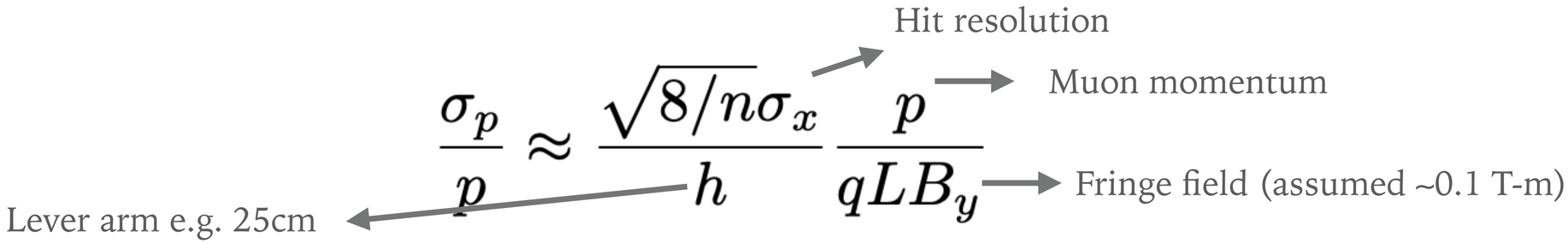
- Can we use high granularity Si(-W) modules as active target?
  - Piggy-back on sensors and electronics (for 40MHz) (LDMX or CMS)



LDMX: 17 double layers of Si(-W): $40X_{0,}$ (500 μm thick), 432 pads/module
CMS (EM): 28 layers of Si(-W): $26X_{0,}$ (300 μm thick) low and high density modules

RECOIL TRACKER

- Muon momentum resolution: drives the cut on muon recoil
- Can use available tracker strip sensors and electronics?

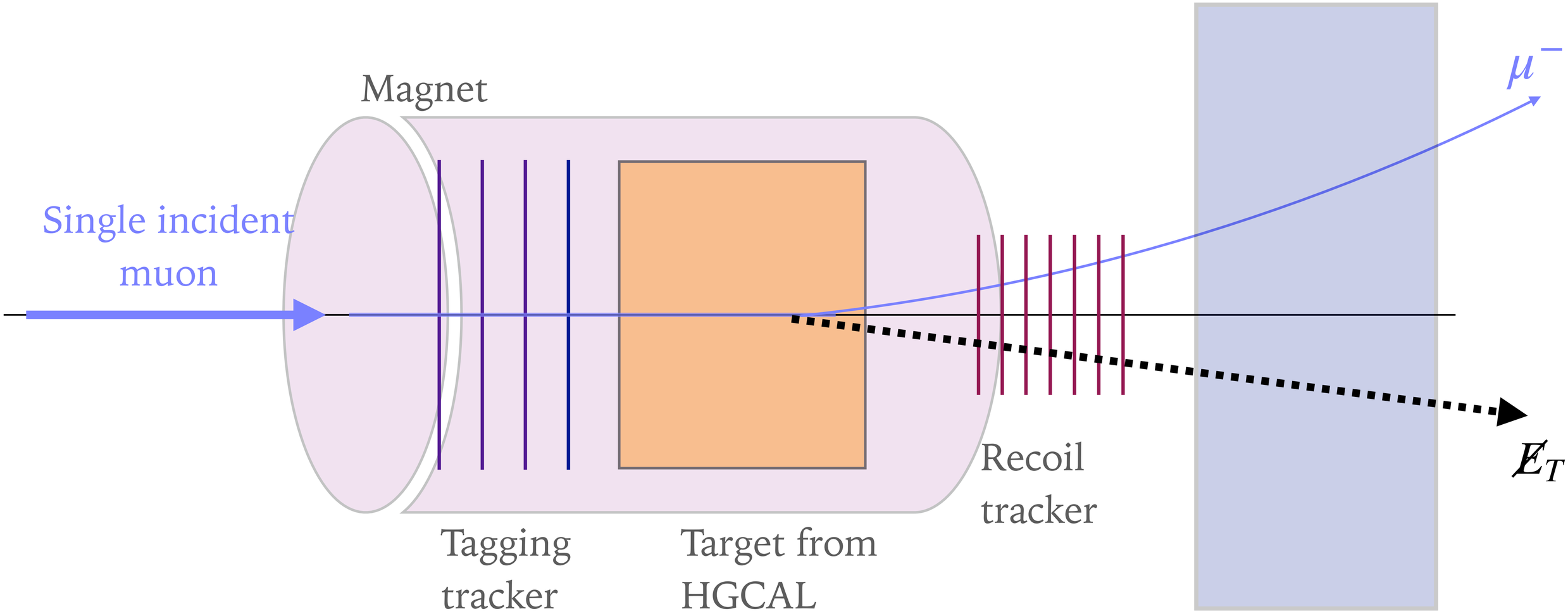


	Hit resolution	Number of planes	Fringe field	Momentum resolution	Dimensions
Pheno-studies	17μm	6	~0.1 T-m (1T)	~0.08%	4x10cm sensors and 60μm pitch
FTBF telescope technology and magnet	<14μm	6 (available)	>0.1 T-m (4T)	<0.08%?	Strip length: 9cm, 4x4cm^2 coverage, and 60μm pitch

maybe Lorenzo can build more \(゜ヮ゜)/)

M4 SCHEMATIC

*Need to study photo-nuclear backgrounds w/o an Ecal!



SUMMARY

- We have a unique beam campus @ FNAL. Let's use it to discover $(g-2)_\mu$ new physics!
  - M^3: pheno-study showing potential of FNAL facilities
  - M^4: let's build this ~now!
    - Needs a background study of: how well we can do w/o Ecal, how many layers of Hcal, and momentum resolution + study beam options.
    - What else are we missing?