



Can you put  $M^3$  into  
SpinQuest?

P. Harris

w/help from D. Hoang, C. Mantilla, B. Ramson

# Where do you place M<sup>3</sup>?



# Where do you place M<sup>3</sup>?



Playing Cops and Robbers  
in the Park



Playing Cops and Robbers  
in the Bank

# Disclaimer

This work is just an idea

The hope is to discuss the pros and cons of  
this idea

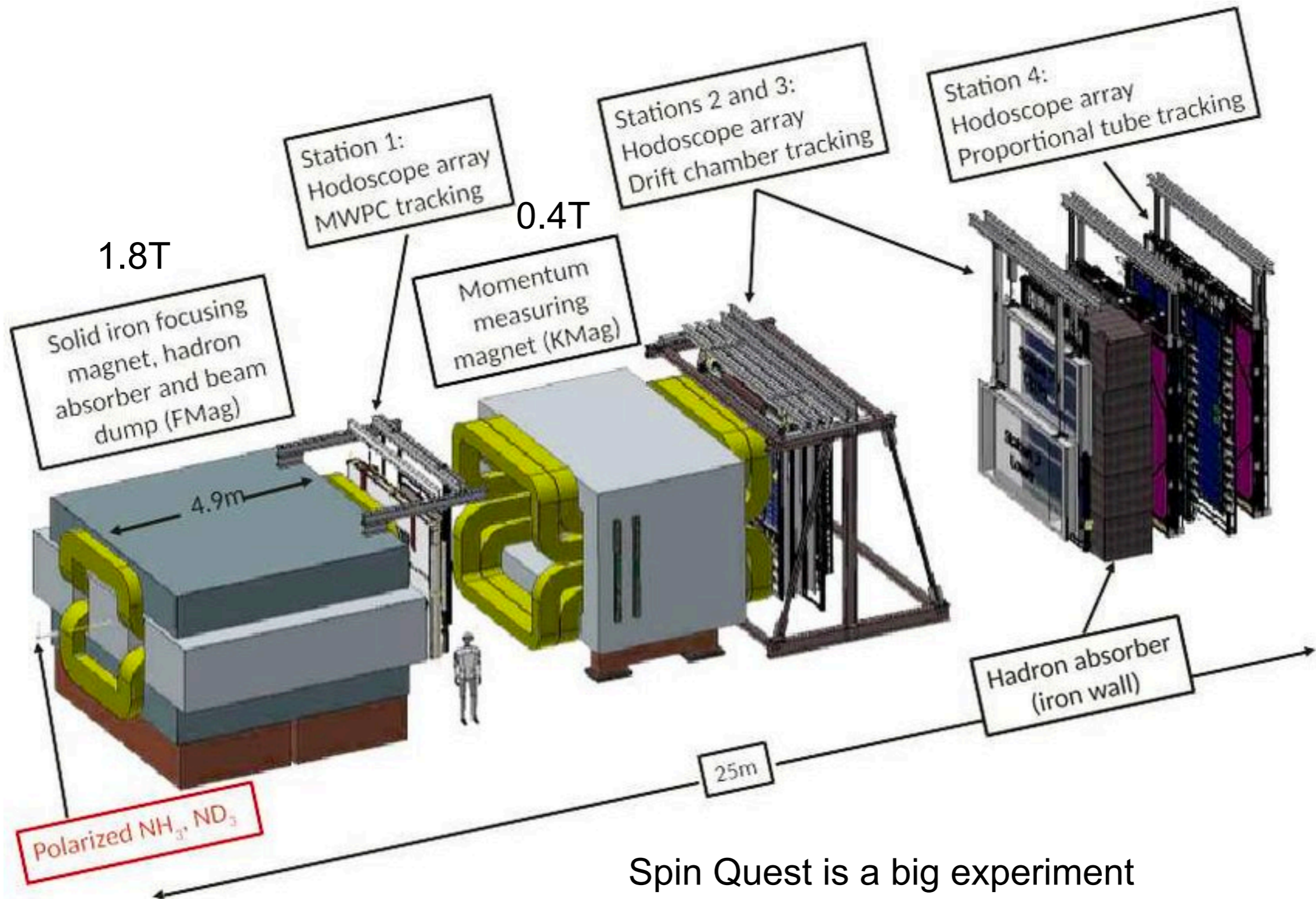
I am not yet sure this is a

good idea

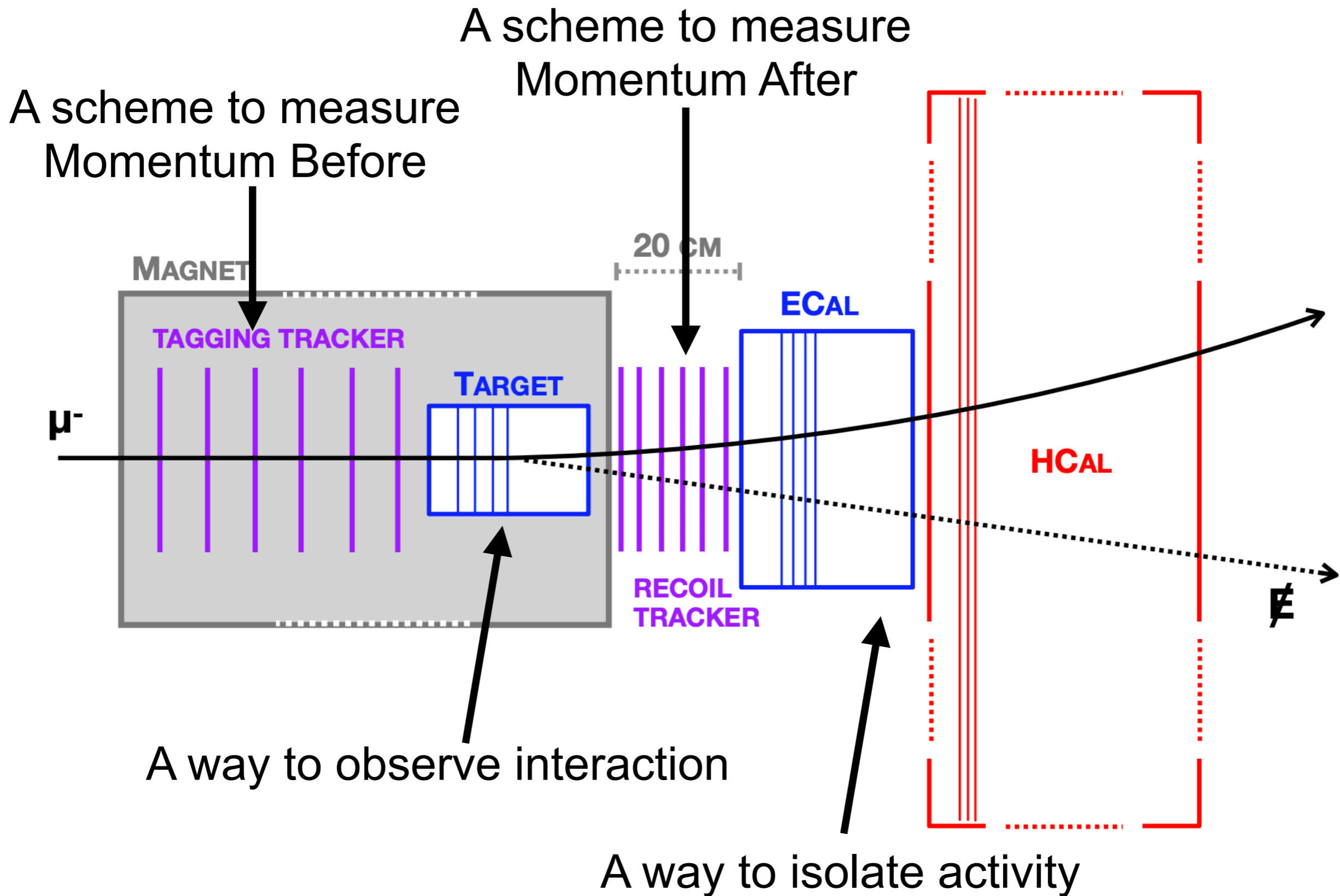
or a

bad idea

# Spin Quest



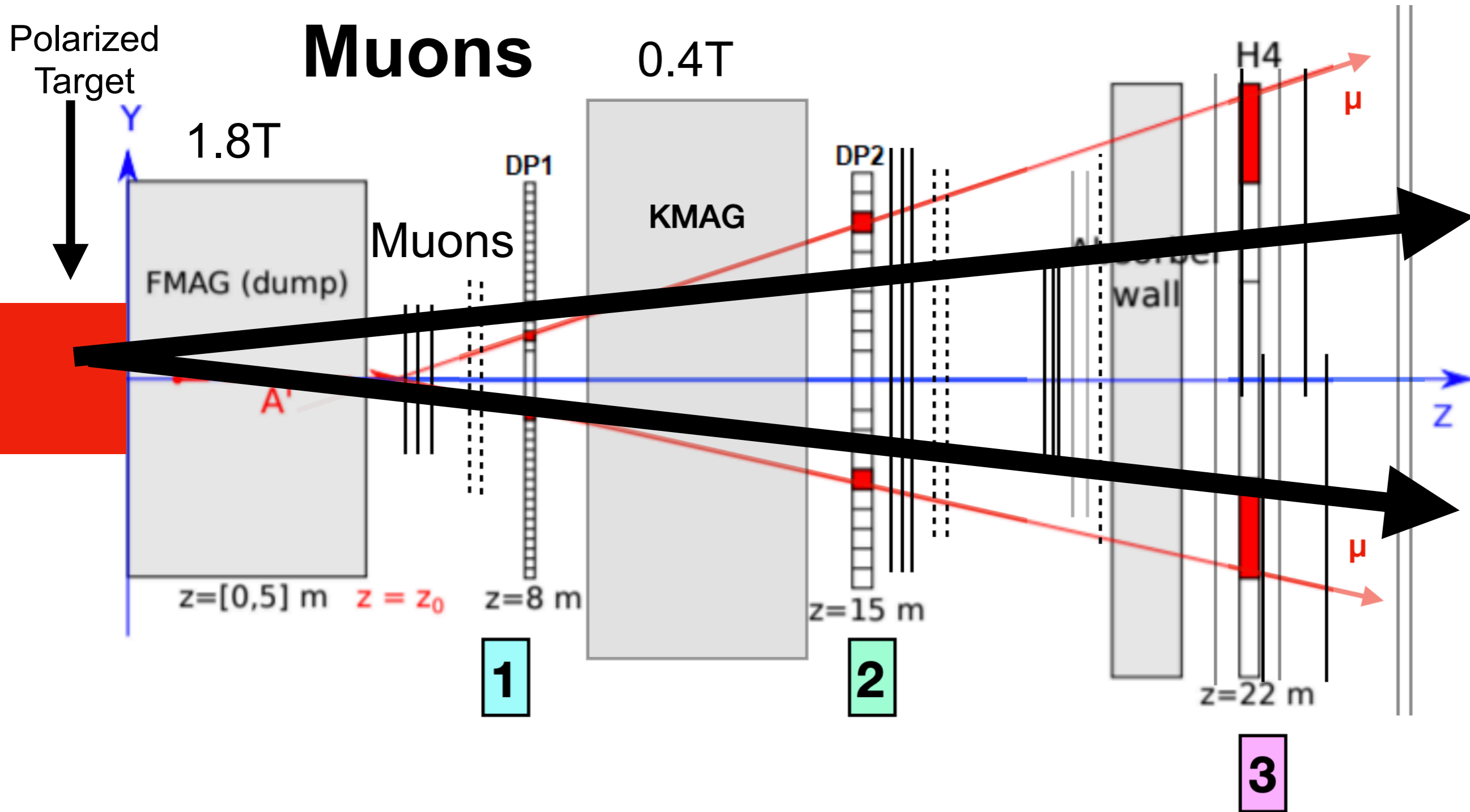
Spin Quest is a big experiment  
 Its goal is to measure muons on the edge of detector



# What do we need?

- Preserve physics for SpinQuest
- Enough Muons to do  $M^3$
- Upgraded detector do  $M^3$  (and improve DQ/SQ)

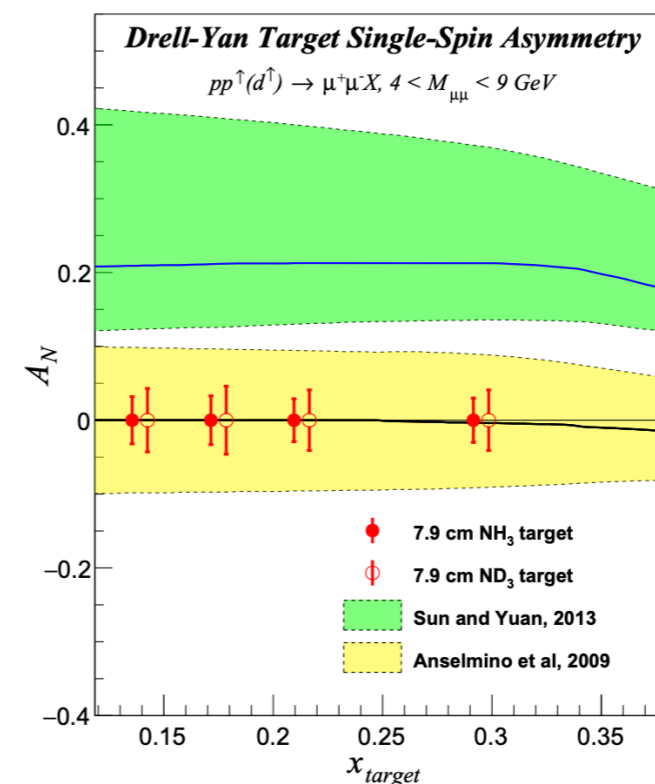
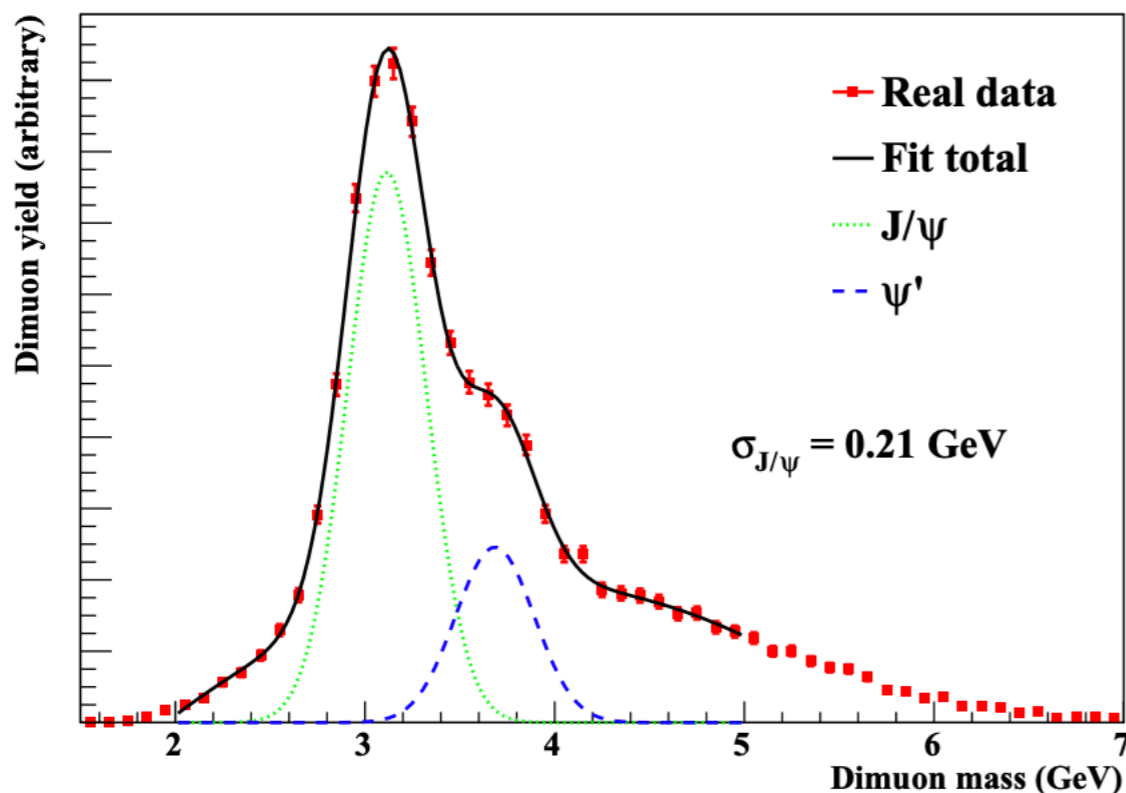
# SpinQuest



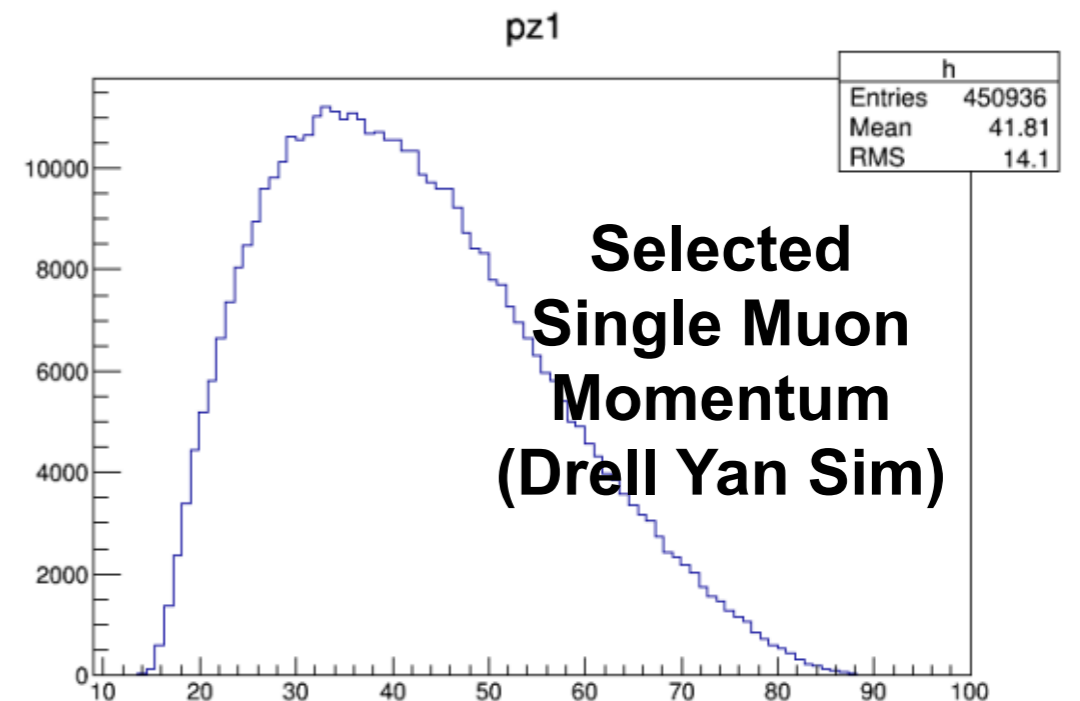
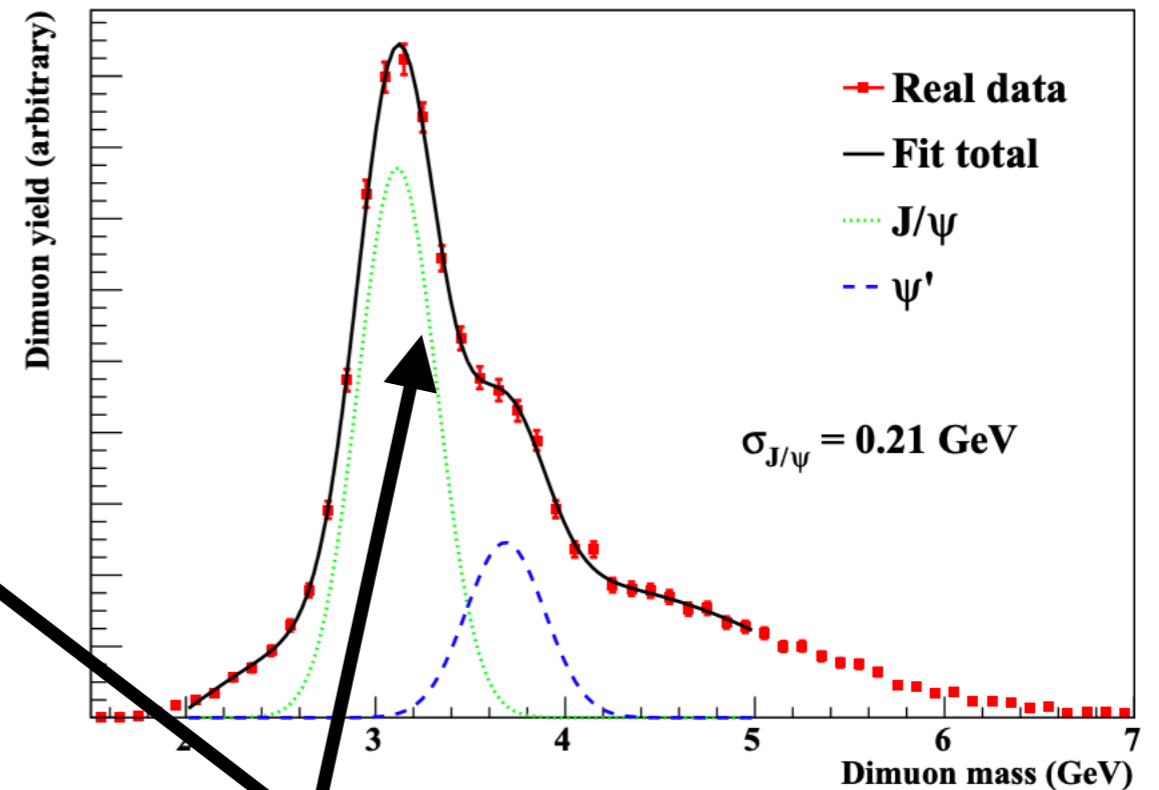
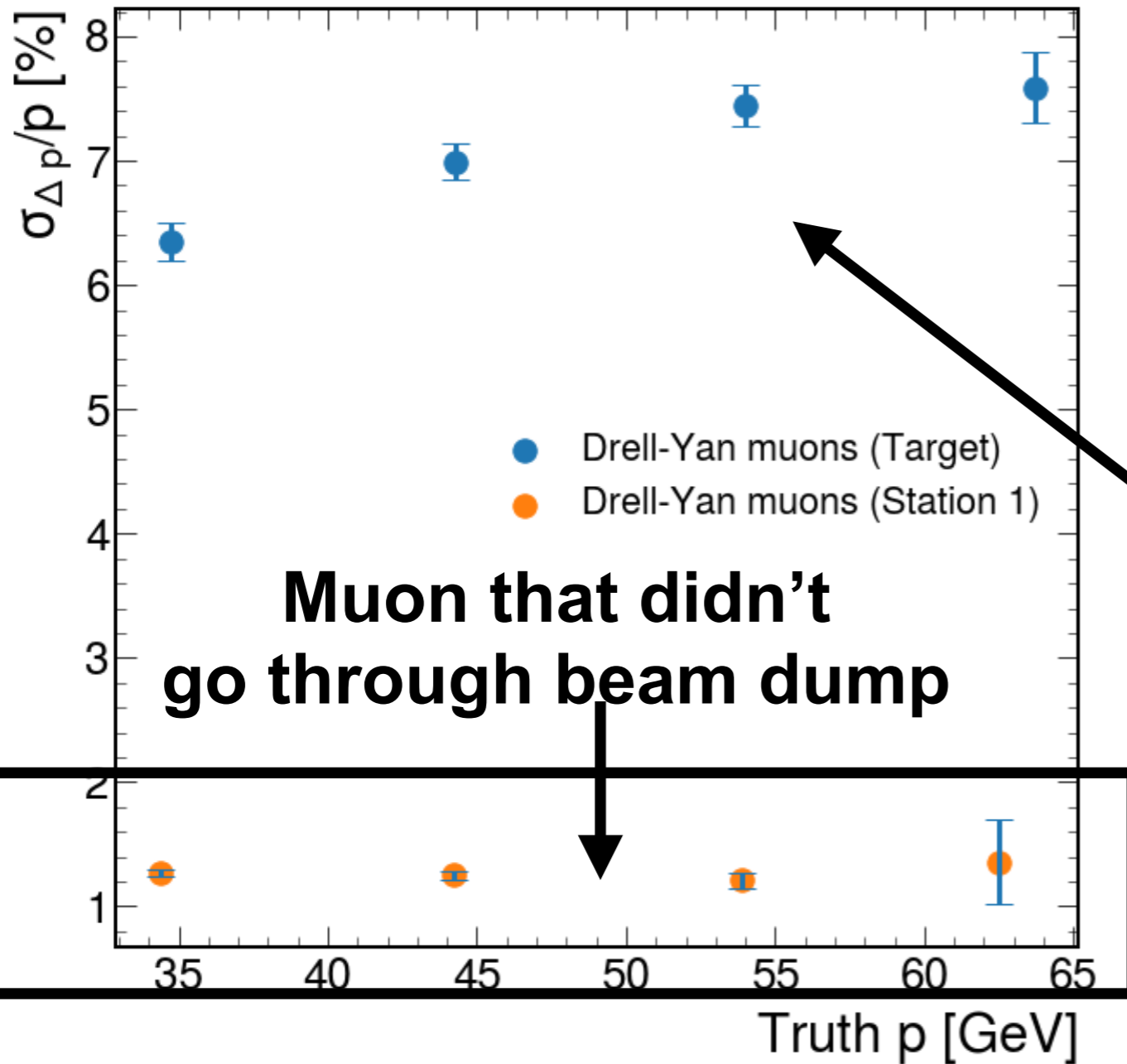


# What can SQ do?

- Spinqwest is designed to **measure muons from a target**
  - The momentum resolution is not perfect
  - But it is pretty good
- Strategy for SpinQuest in one line:
  - **Measure di-muon asymmetry from Drell-Yan or J/ψ**

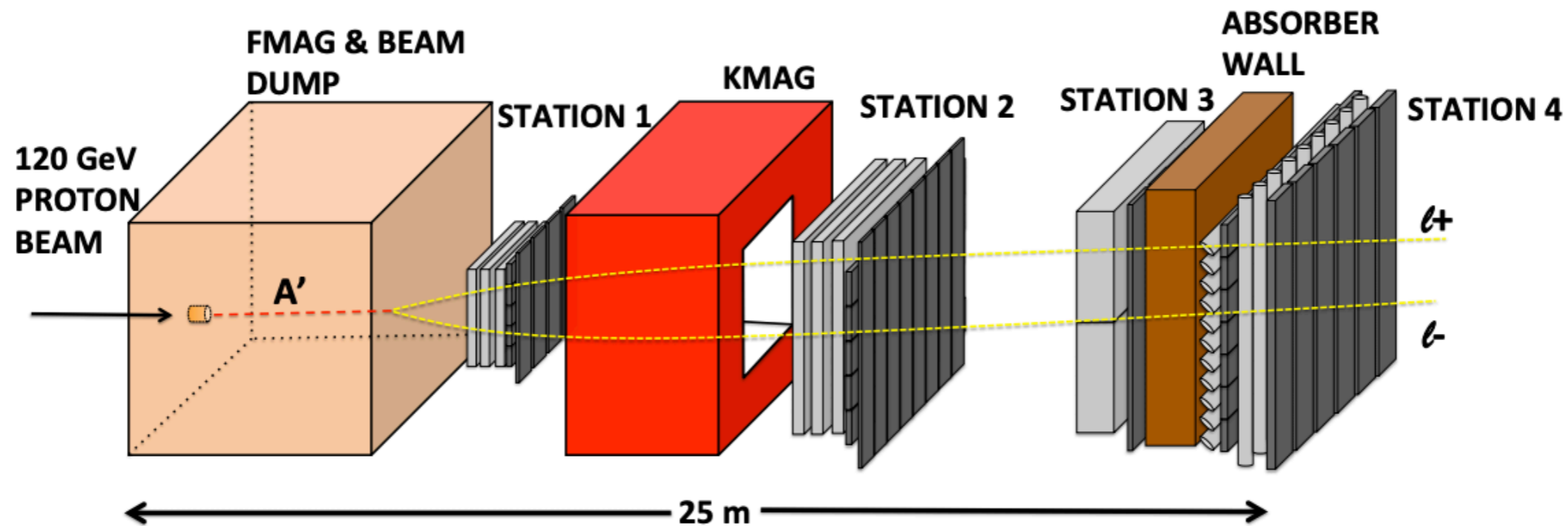


# Spin Quest Resolution

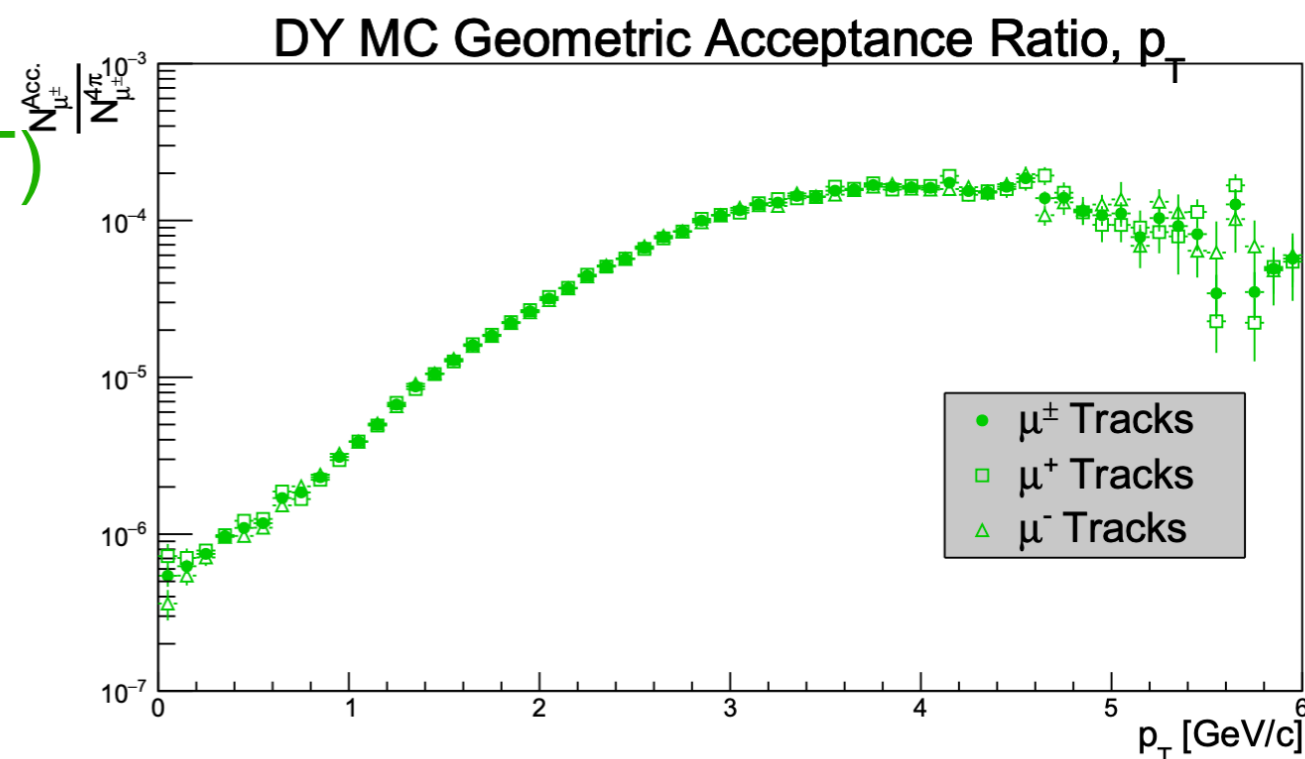


Spin Quest Targets muons  
 in 9 to 60 GeV range  
 But most above 30 GeV

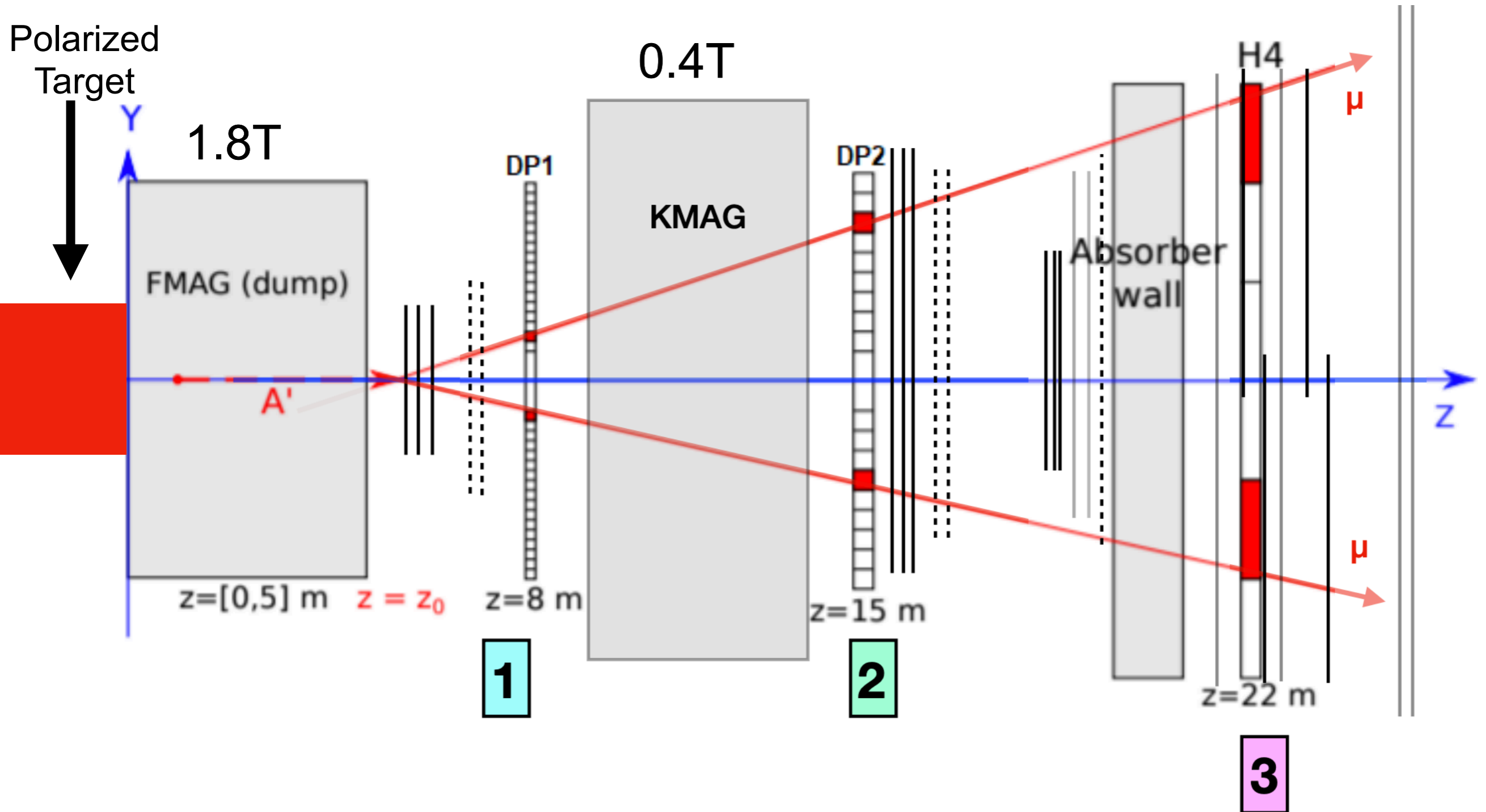
# Spin Quest Event Acceptance



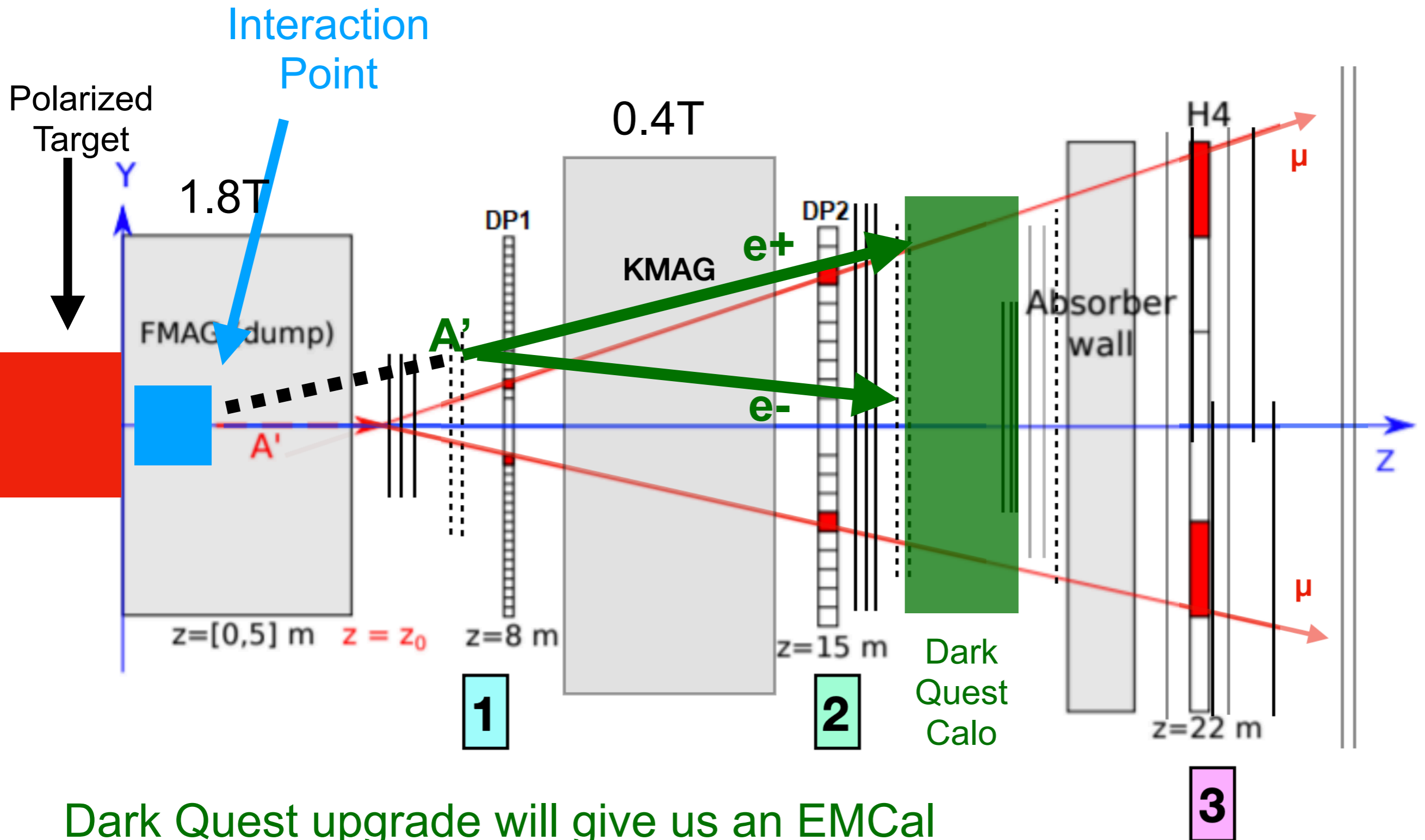
- Spin Quest aims for dimuon
  - Wide di-muons are best (high  $p_T$ )
  - Not so much in center
- Room to gain with
  - More and better instrumentation



# SpinQuest to DarkQuest

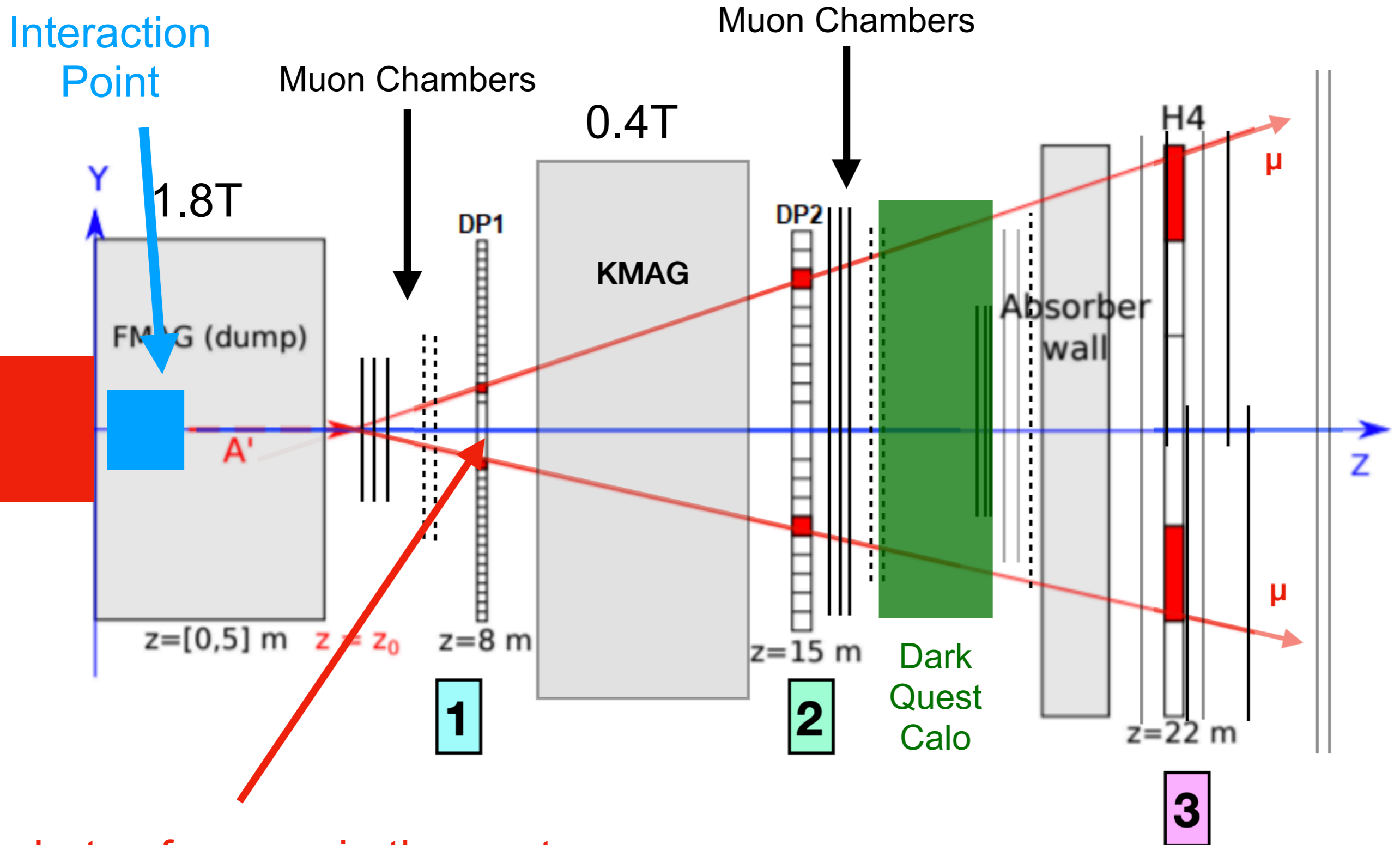


# SpinQuest to DarkQuest



Dark Quest upgrade will give us an EMCAL  
This can enable dark photon to electrons

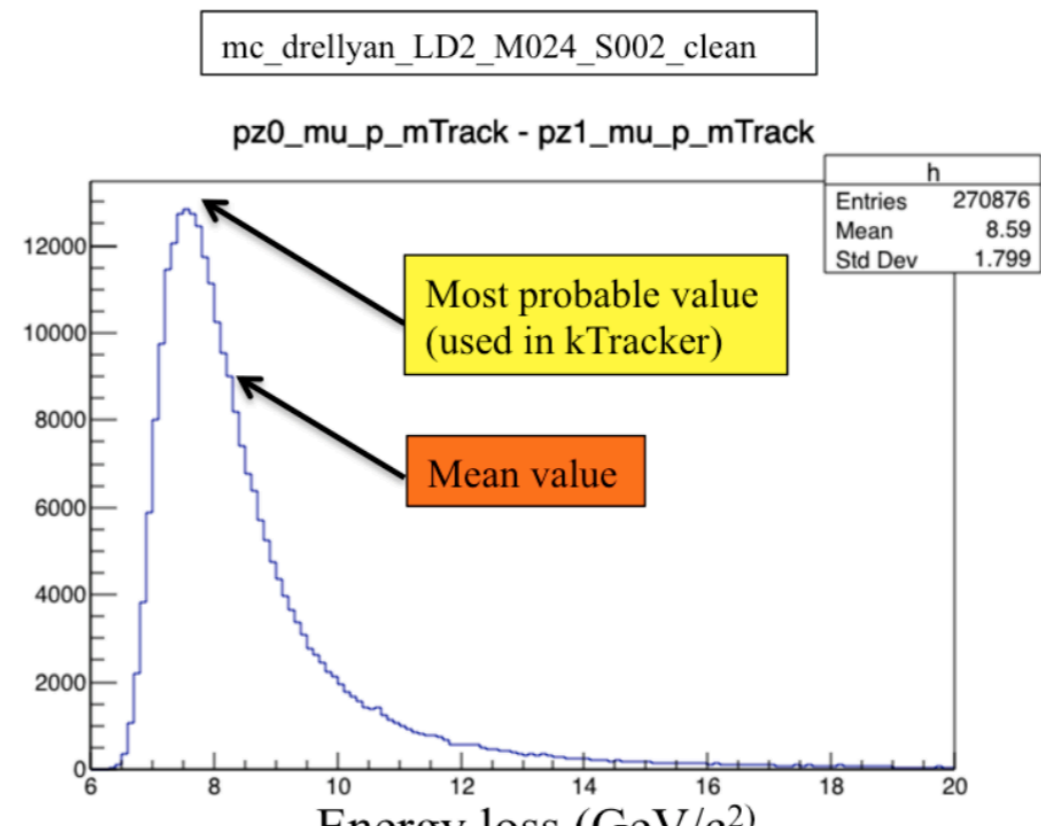
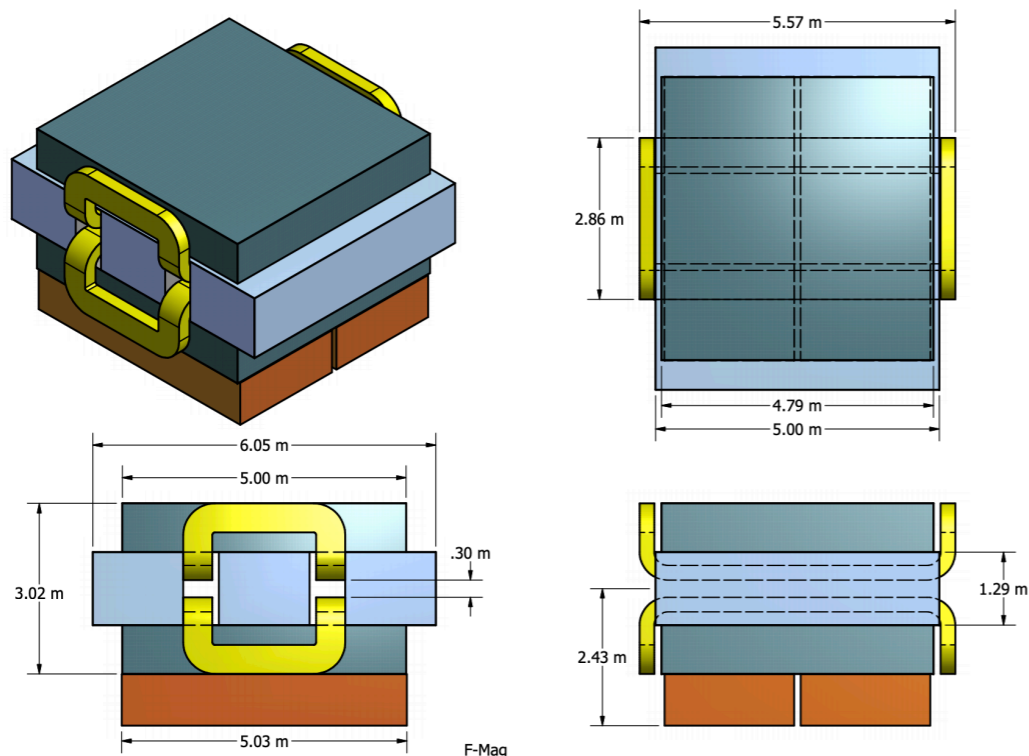
# Can SpinQuest do M<sup>3</sup>



Lots of muons in the center

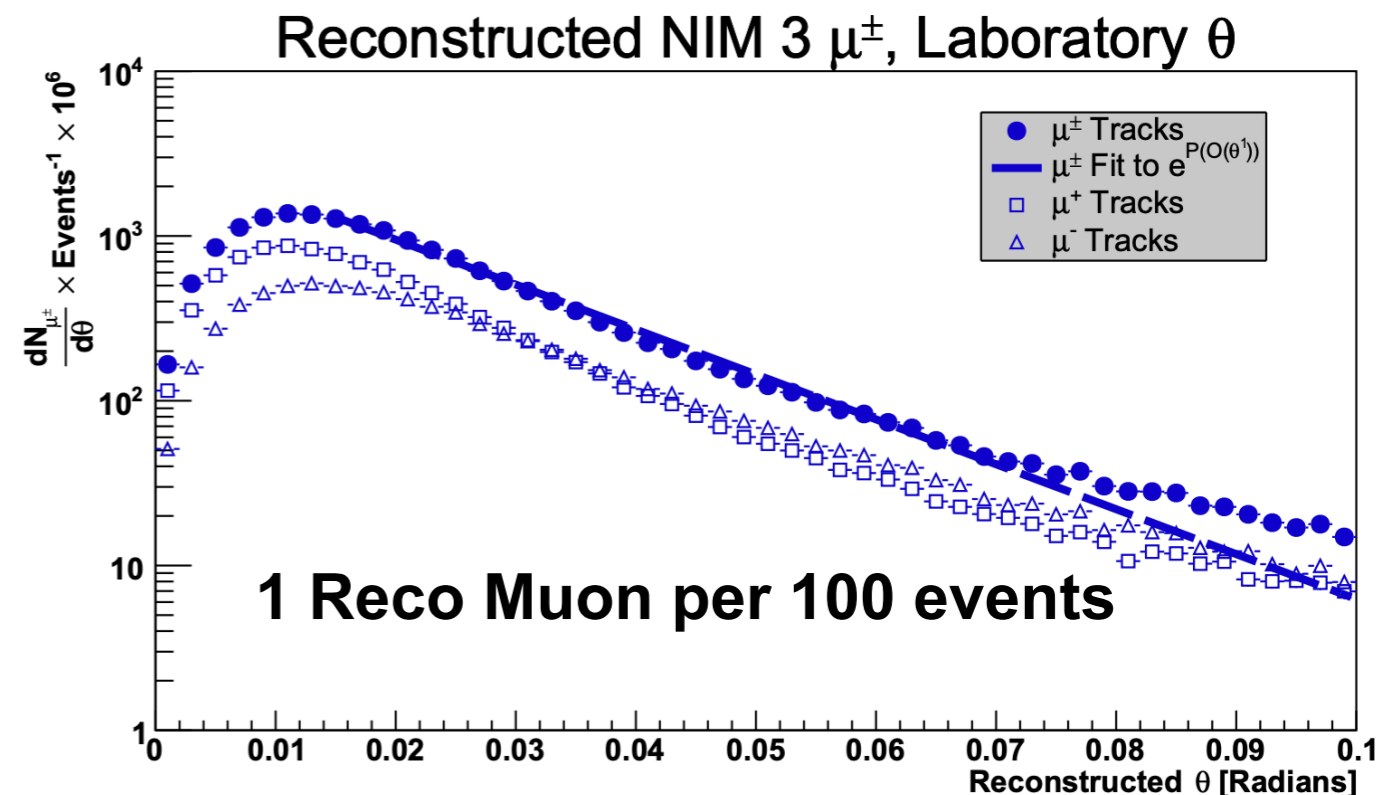
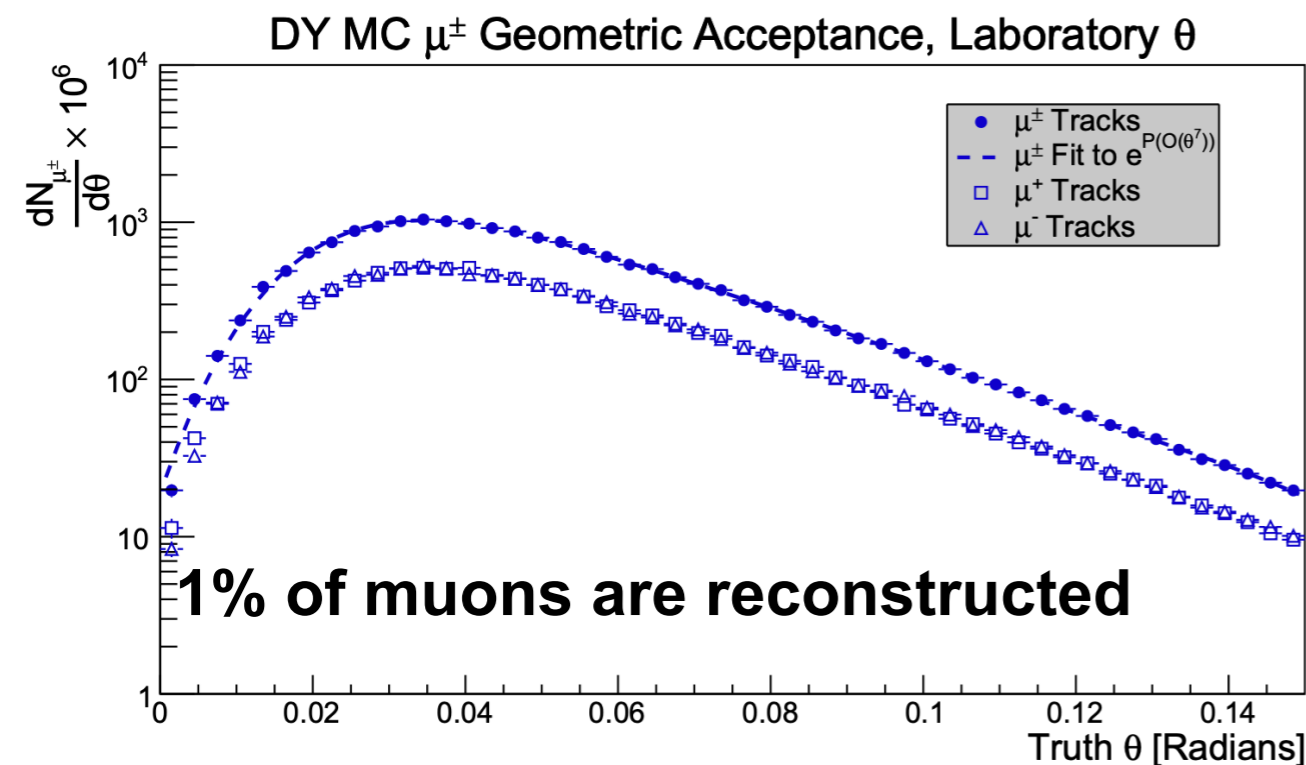
# Muon Beam in SpinQuest

- Muons get bent out of the FMag
  - To survive the FMag you need 8 GeV
- Gets rid of the pions produced in the beam dump
  - Puts some energy limit on good muons (>10 GeV)
- ▶ After all this expect at least one good muon per beam



# Muon Beam in SpinQuest

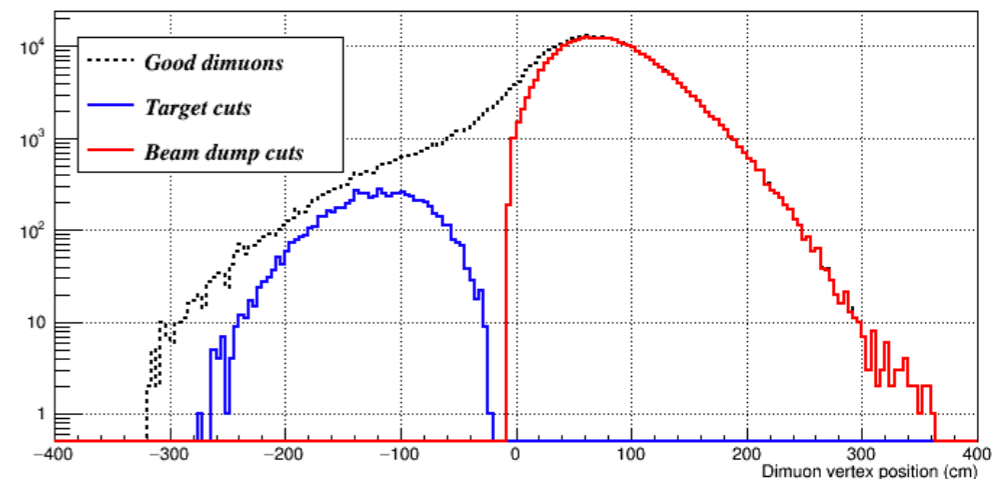
- The SpinQuest beam has a lot of protons on target:  $10^5$ 
  - For every proton on target
    - ▶ Roughly get a muon out of it in the beam dump
  - Question: How many muons leave the beam dump?
- Of those, how many muons do we reconstruct?



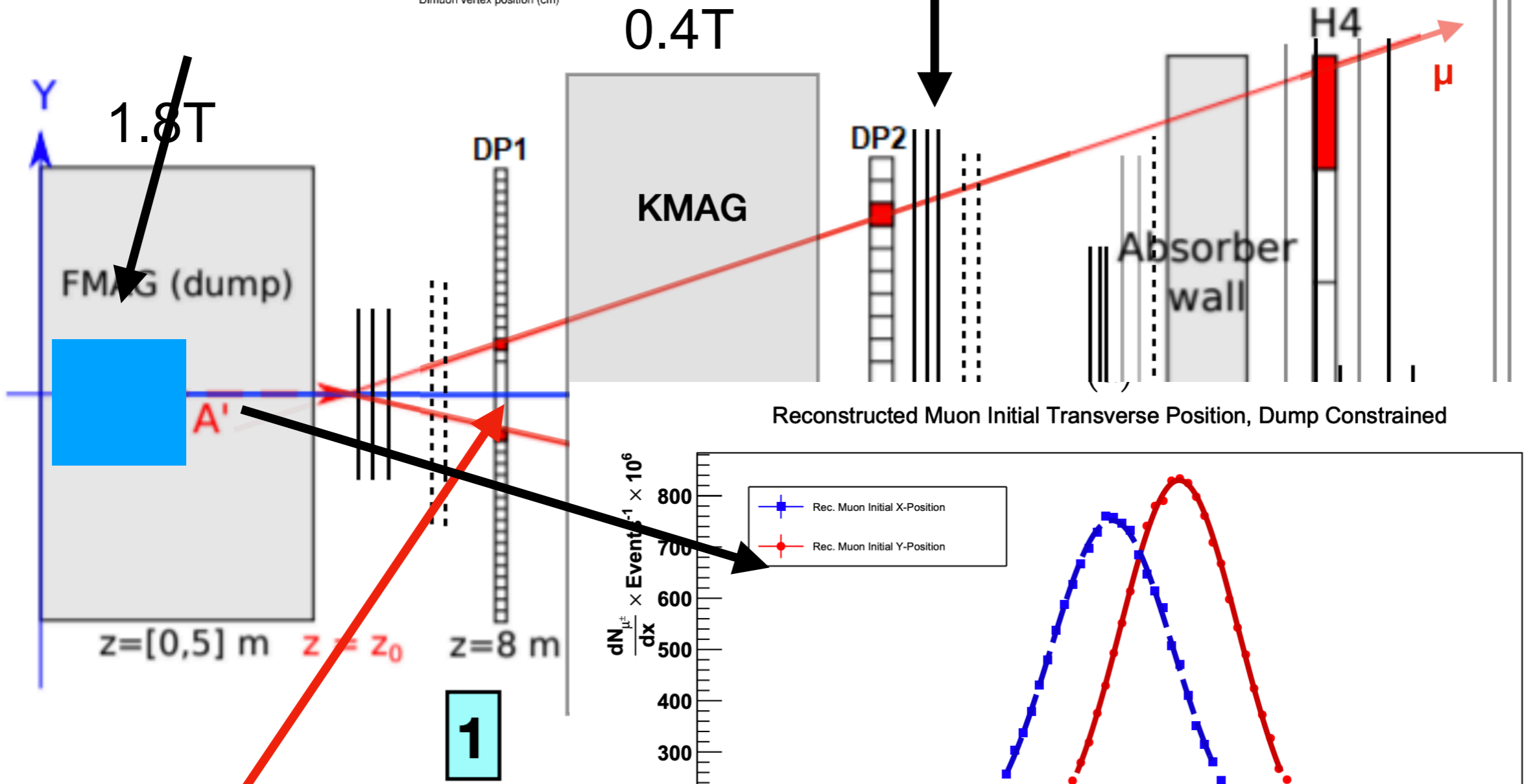
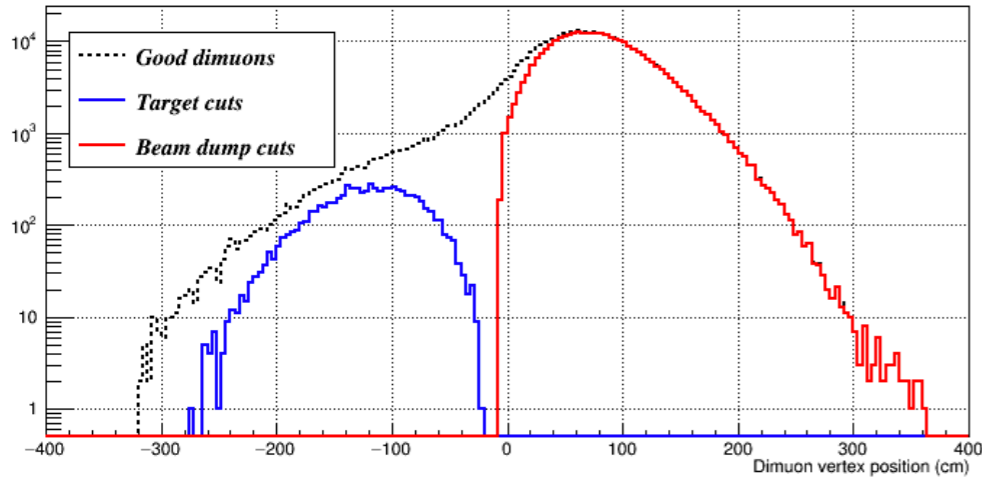


# Numerology

- We need to get  $10^{10}$  muons
- Beam is :
  - $10^5$  protons at 52 MHz for 4s **every minute**
  - 100 total days of running gives
    - ▶  $3000 \times 10^{10}$  events
- Per event we get  $10^{-2}$  muons per event
  - Making it out of the beam dump
  - We need a fiducial area that is 1/30th SQ
    - ▶ Assuming normal spinquest reconstruction to get muon
- More muons from more detectors makes it easier

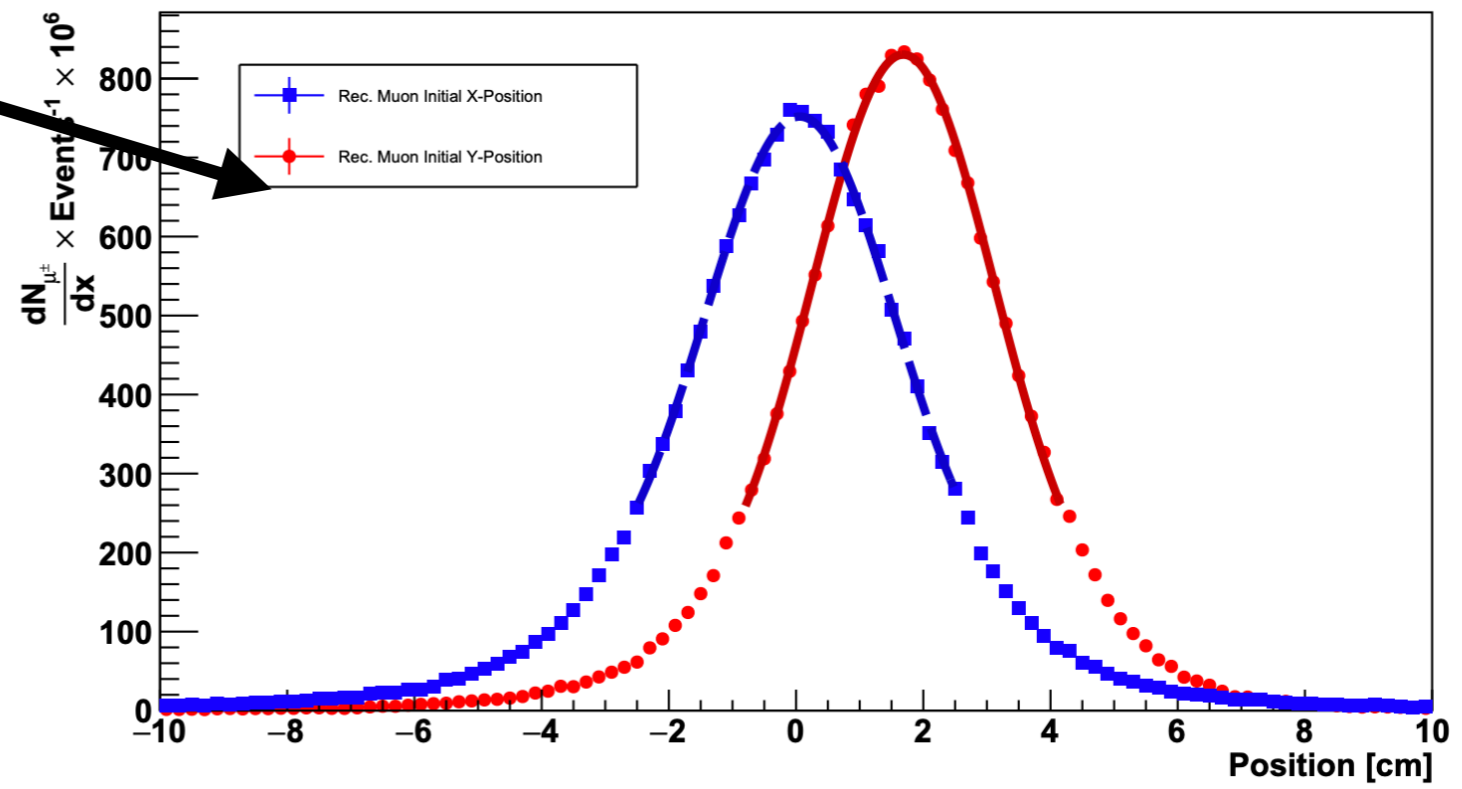


# The Beam

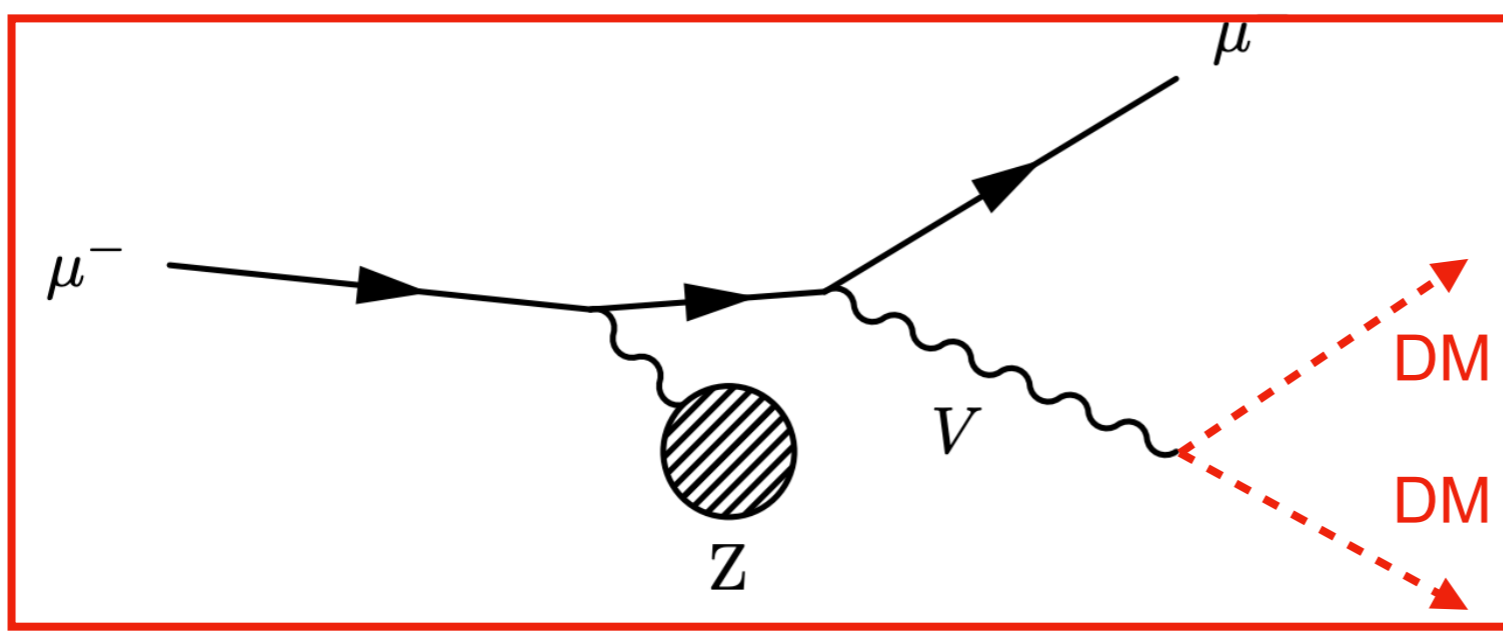


Lots of muons

Reconstructed Muon Initial Transverse Position, Dump Constrained

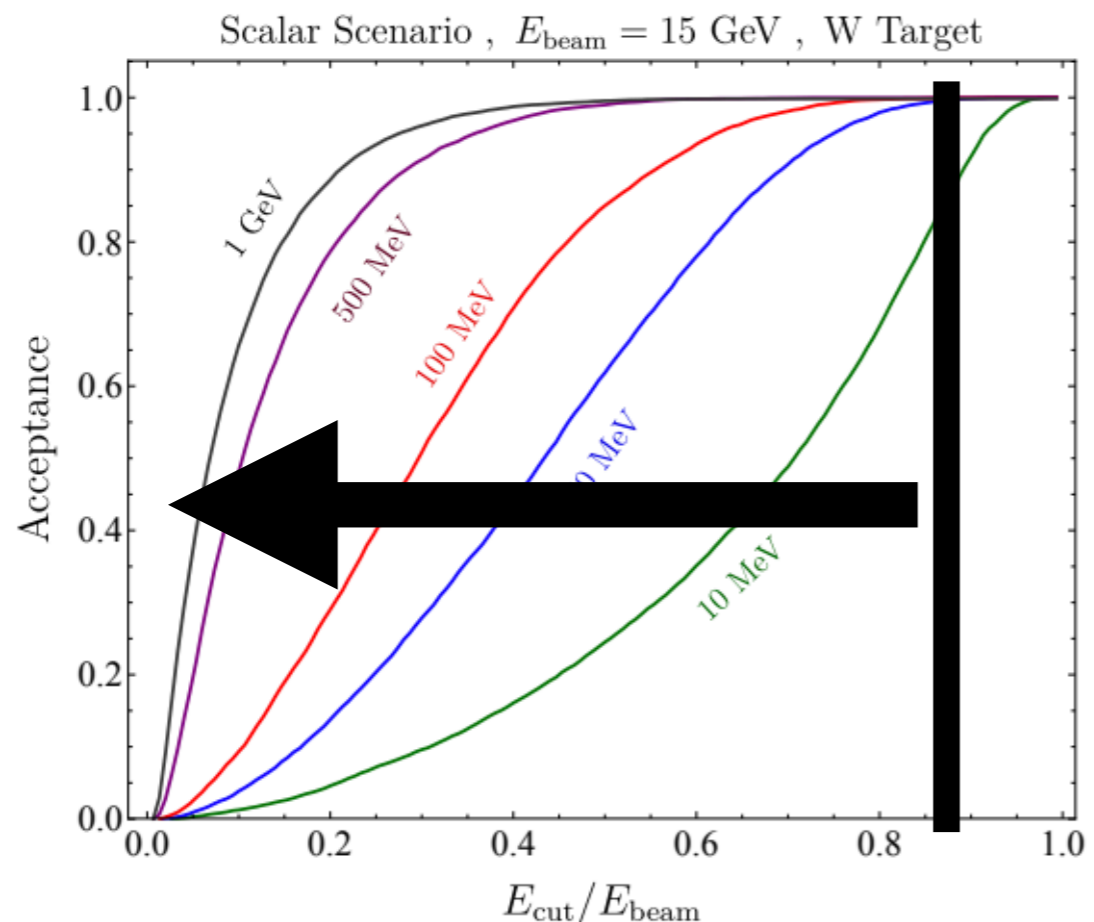


# g-2 related Signatures

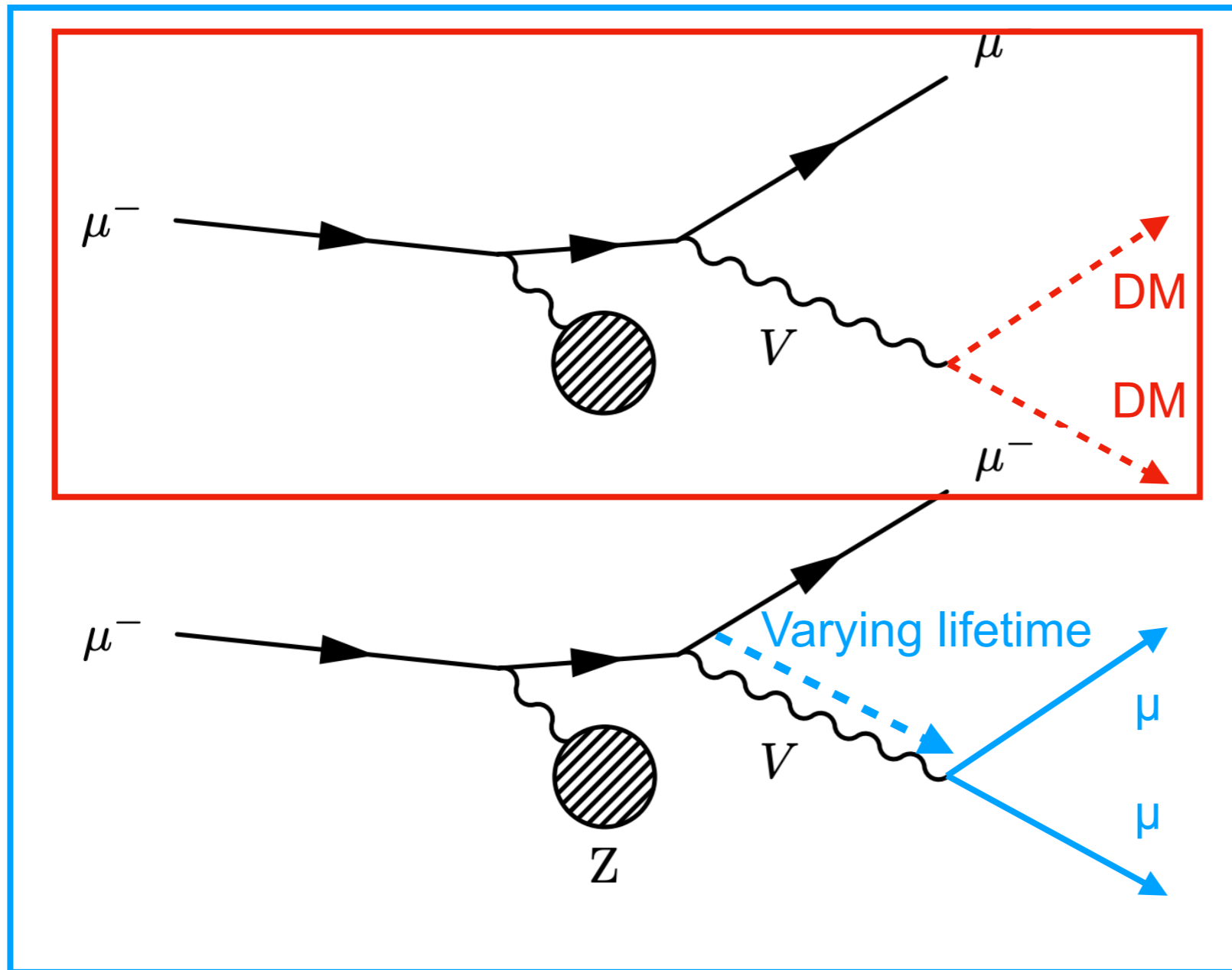


Invisible Signature  
Mediator decays to DM  
Look for kink

$\Delta p > 10\%$  (note current res is *in p* 1%)



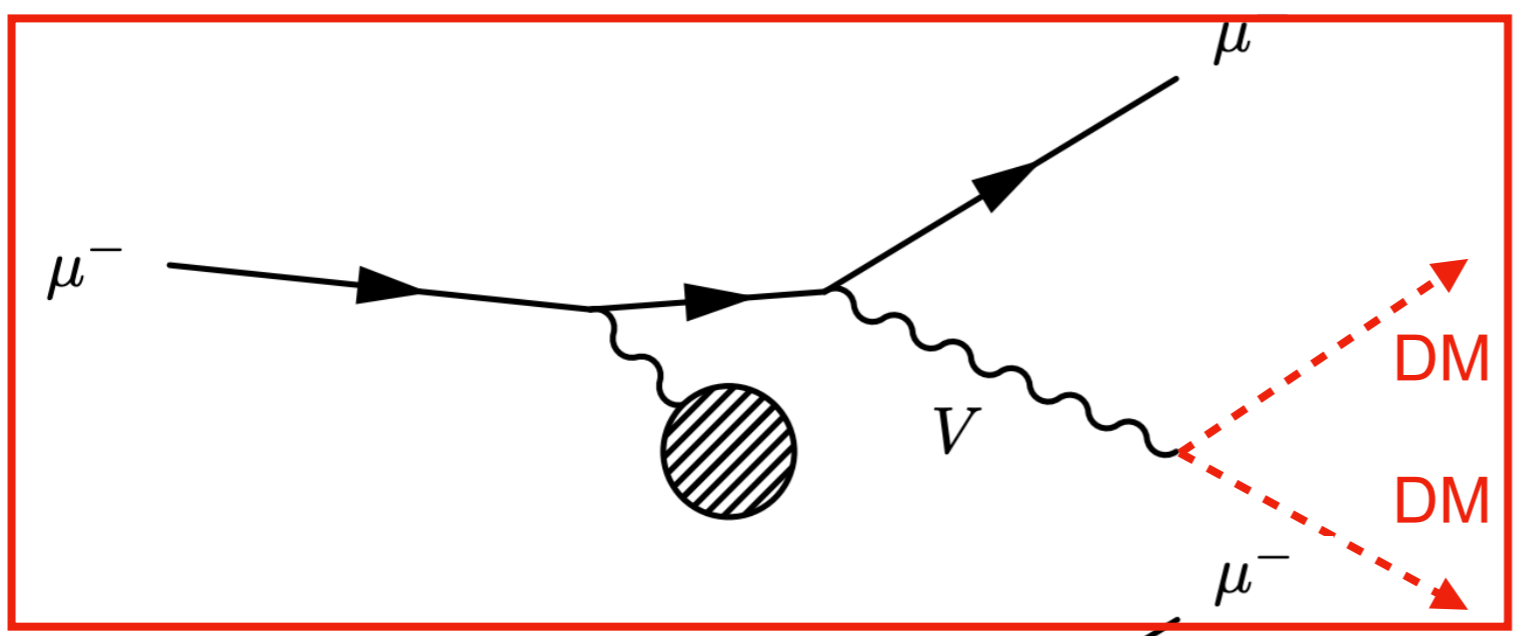
# $g-2$ related Signatures



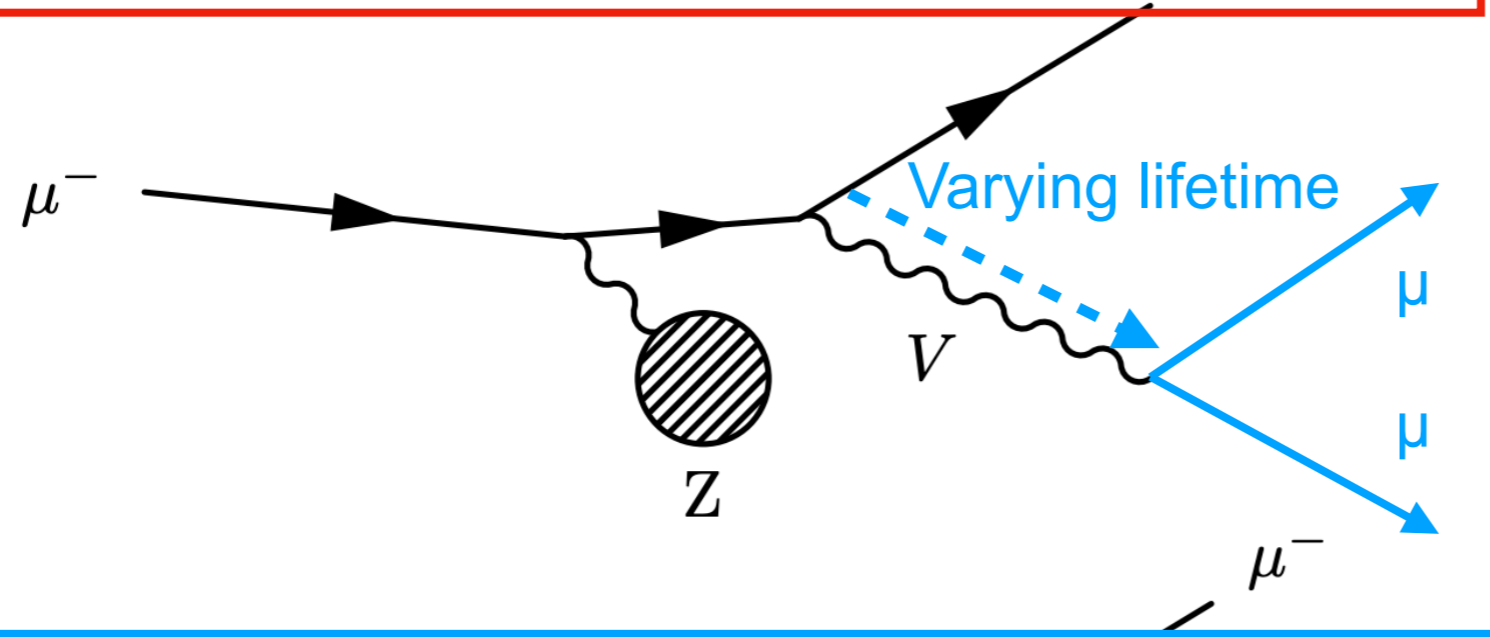
Invisible Signature  
 Mediator decays to DM  
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Tri-muon events  
 Di-muon can be displaced

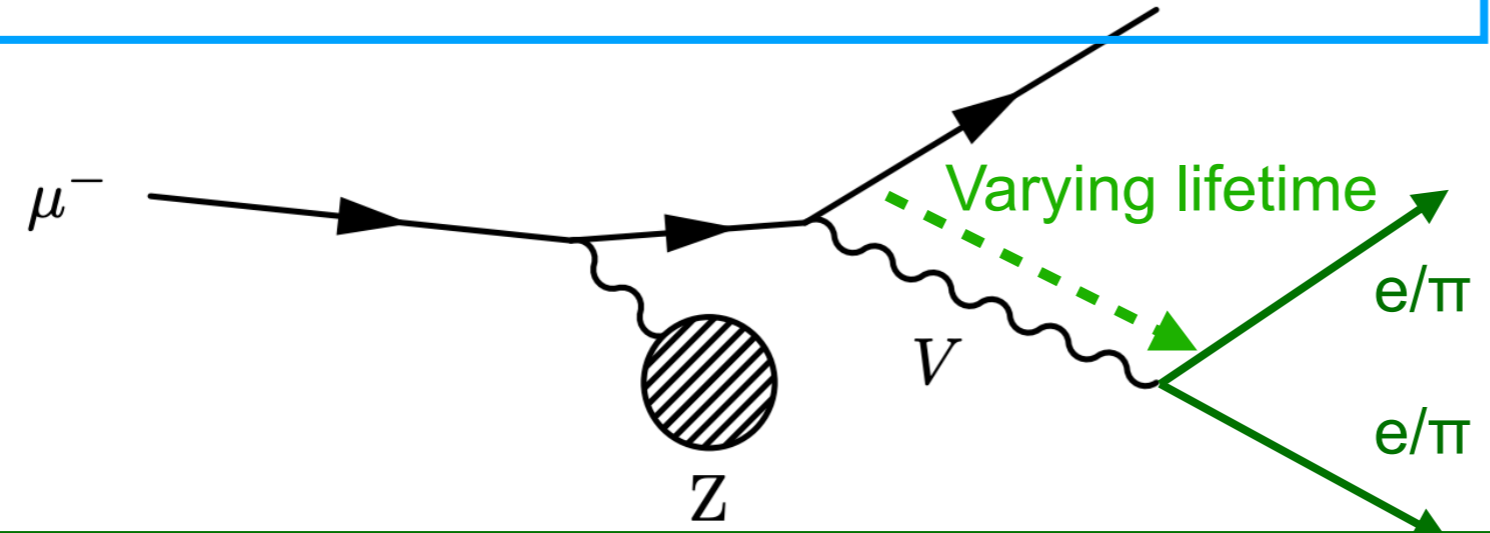
# g-2 related Signatures



Invisible Signature  
Mediator decays to DM  
Look for kink

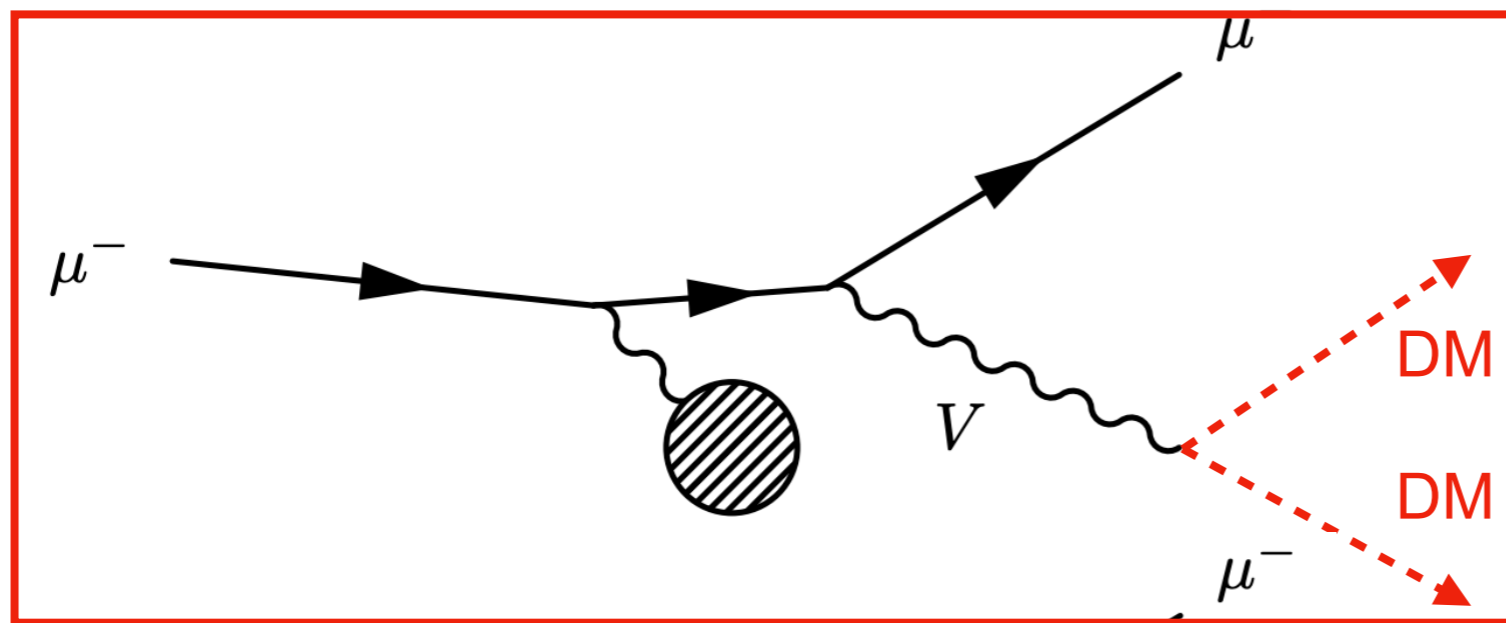


Tri-muon events  
Di-muon can be displaced

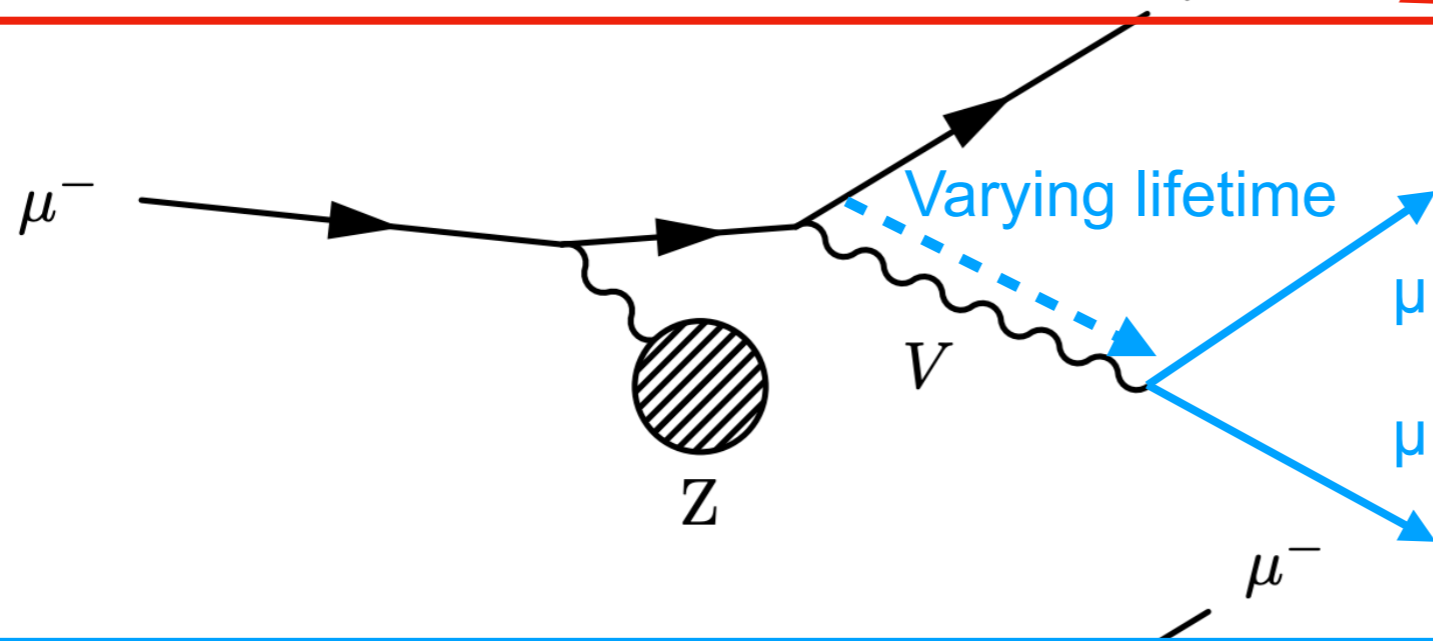


Decays to electrons  
and hadrons  
displaced

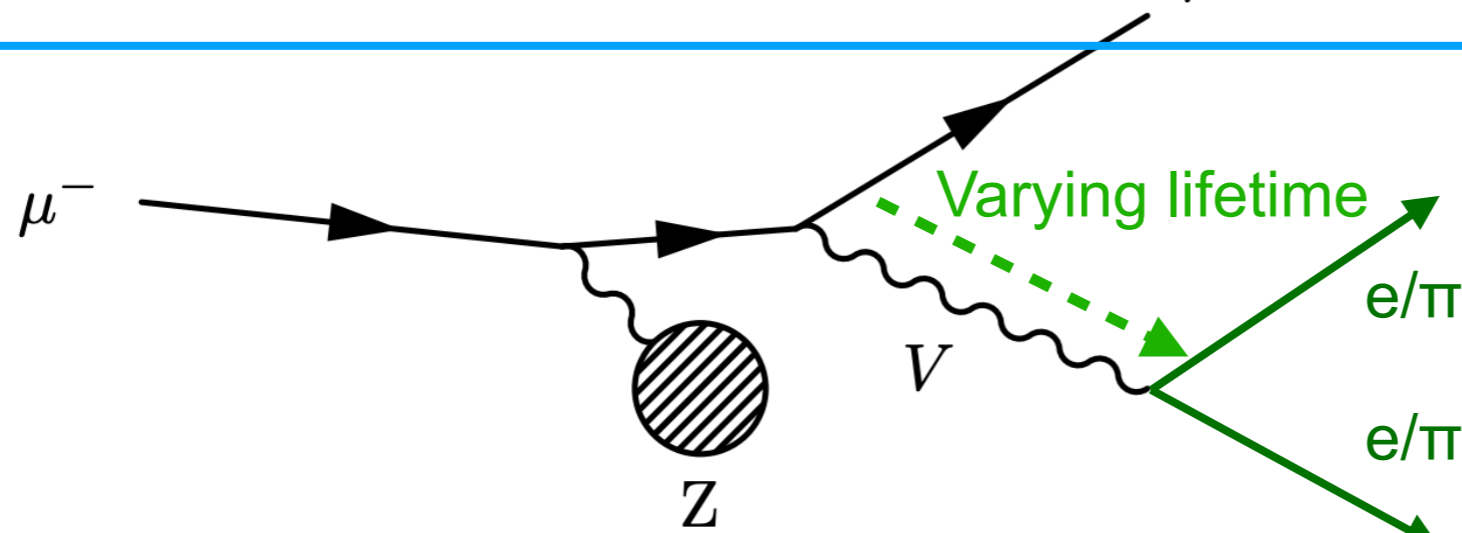
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Invisible Signature  
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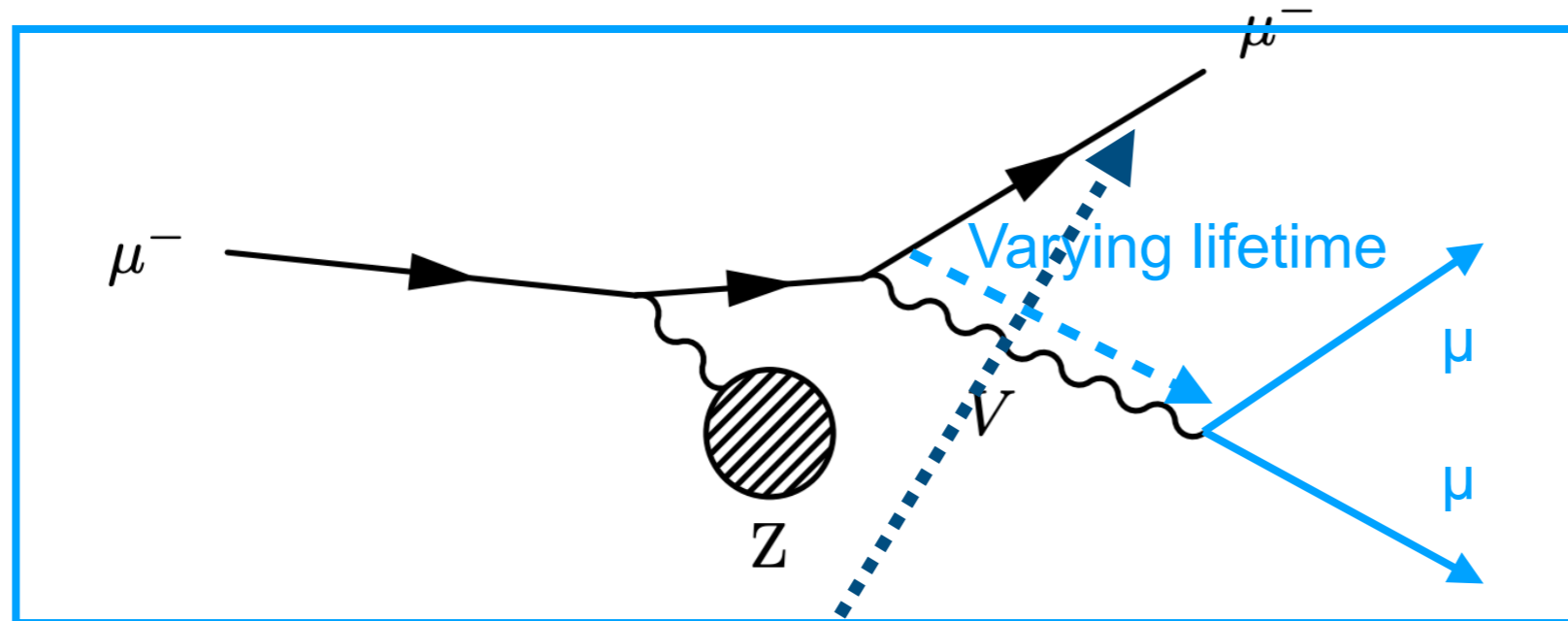
Tri-muon events  
Di-muon can be displaced



Decays to electrons  
and hadrons  
displaced

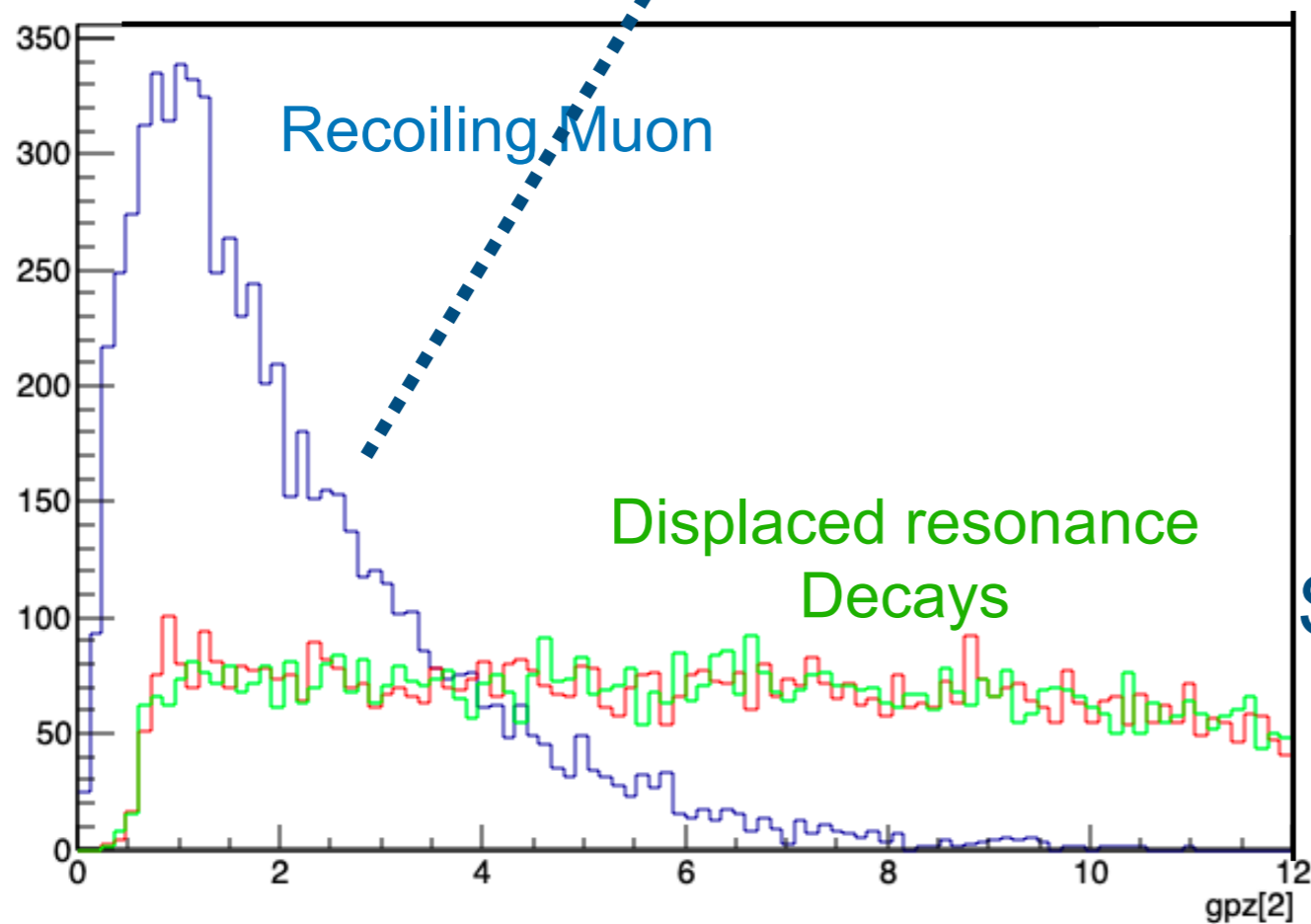
**What about  
semi-visible?**

# Tri-Muon Signature



Tri-muon events  
Di-muon can be  
displaced

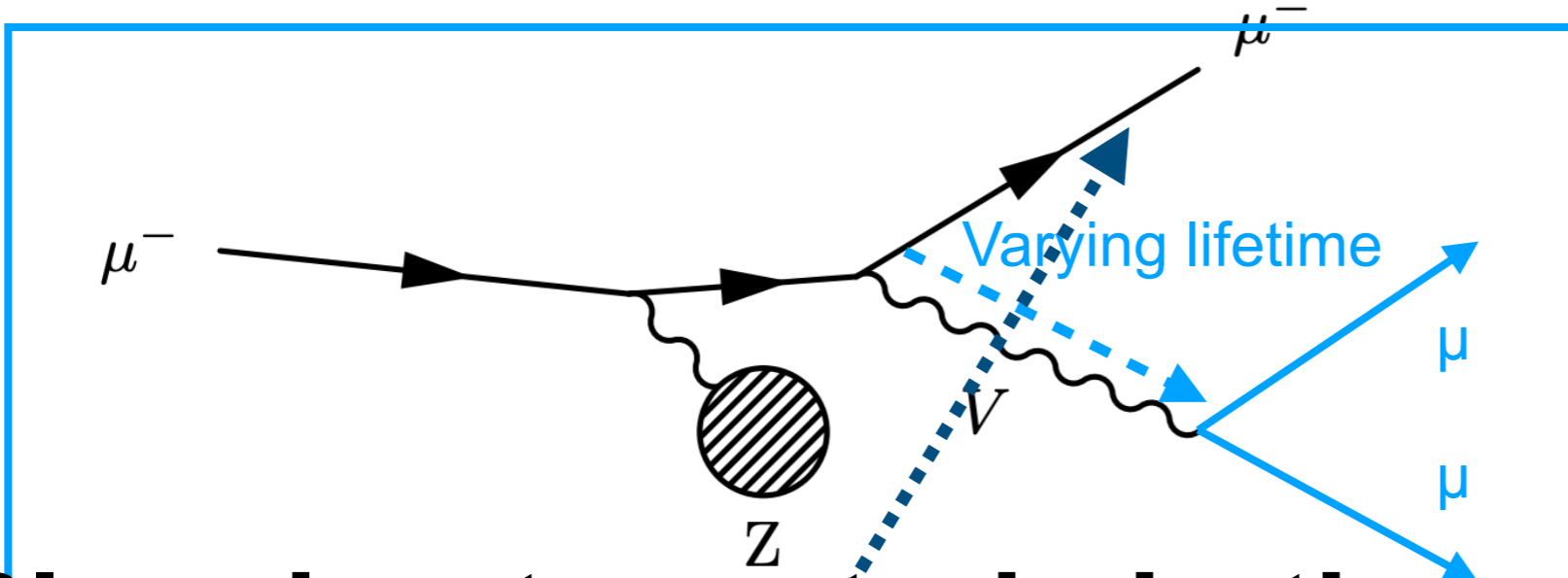
Thanks to Cristina!



We have run a Tri-muon event  
in SpinQuest

Small recoiling muon will require  
interaction after beam dump

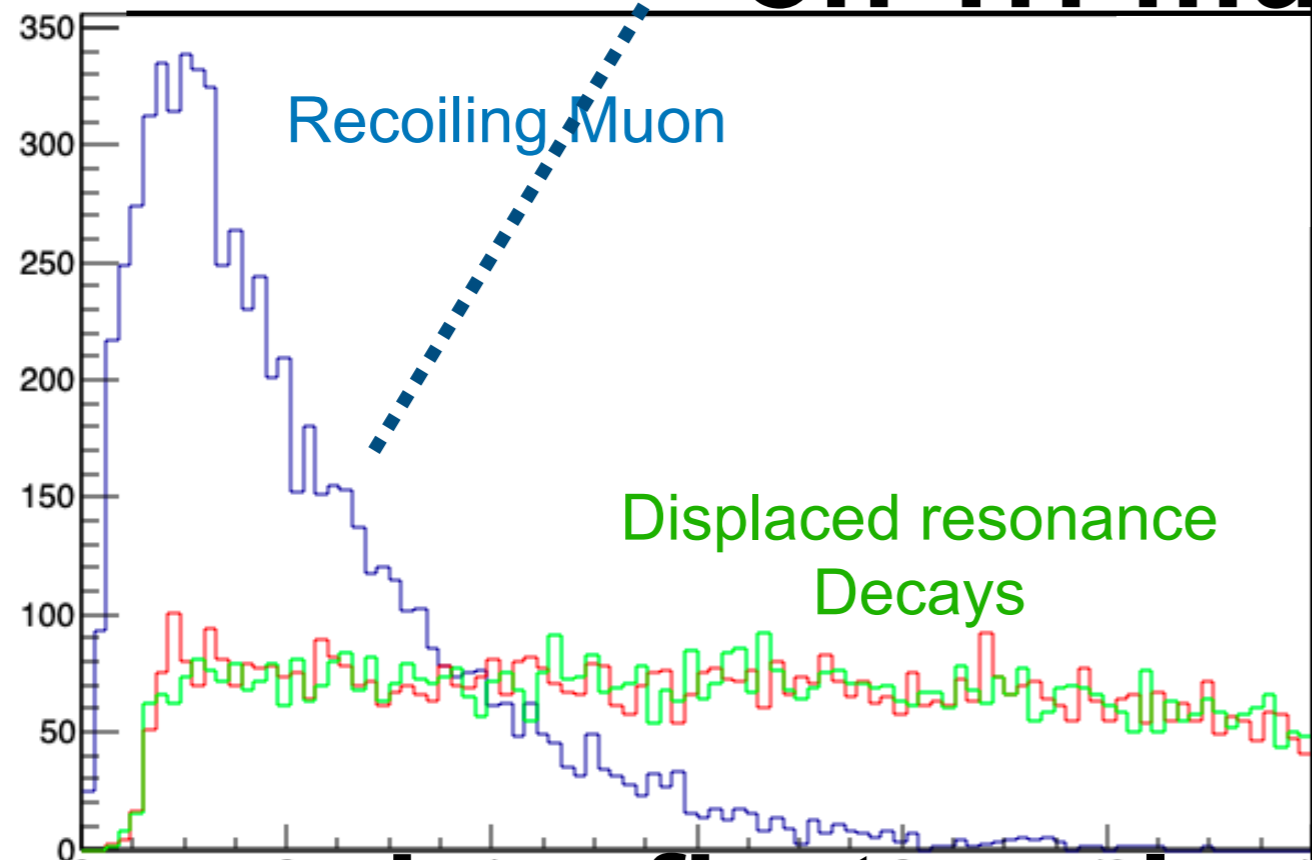
# Tri-Muon Signature



Tri-muon events  
 Di-muon can be displaced

**Planning to a study in the next few weeks on Tri-muon**

Thanks to Cristina!



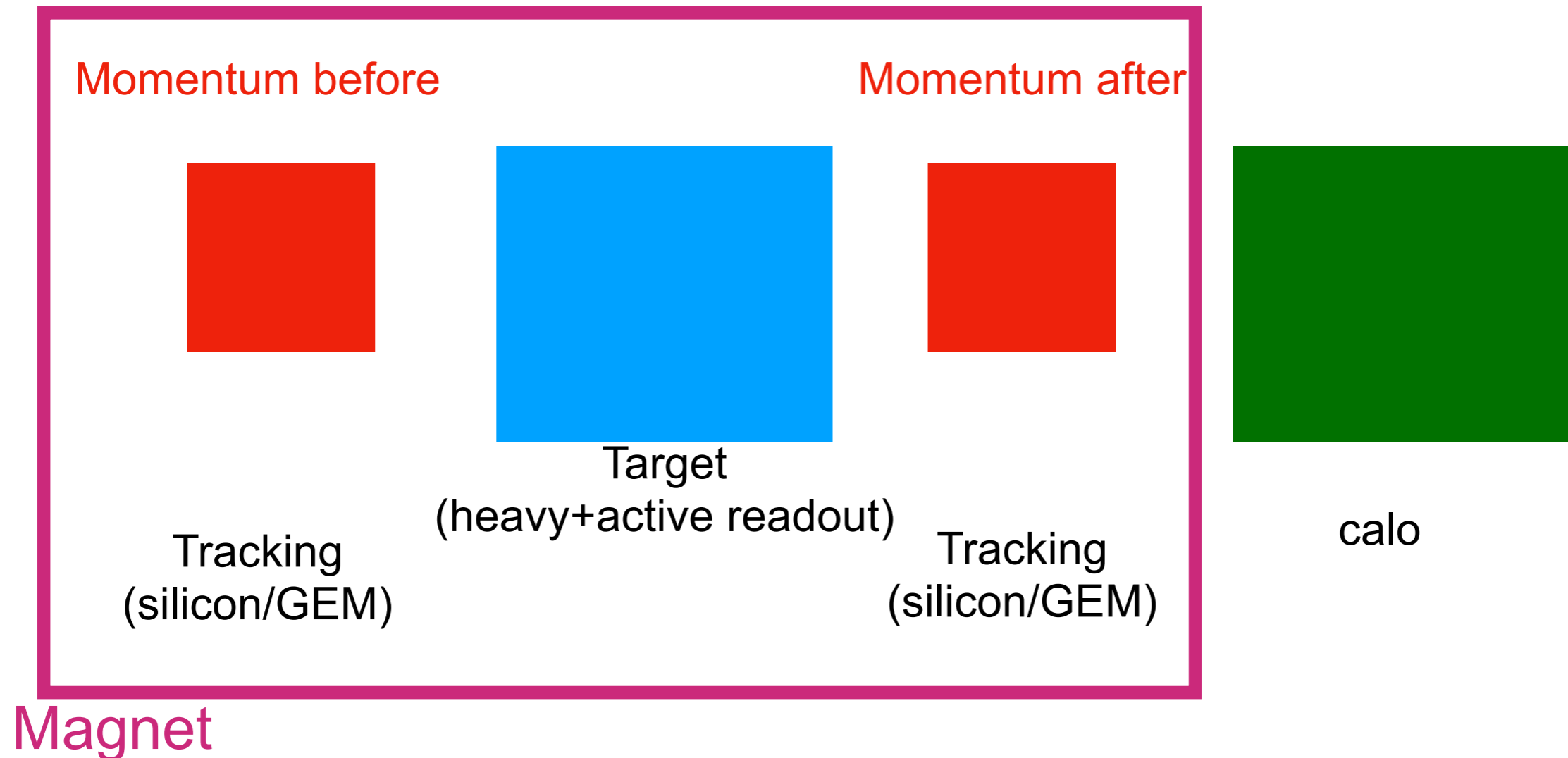
We have run a Tri-muon event in SpinQuest

Small recoiling muon will require interaction after beam dump

**We can do a first analysis on SQ Data(NOW)**



# What is critical for M<sup>3</sup>

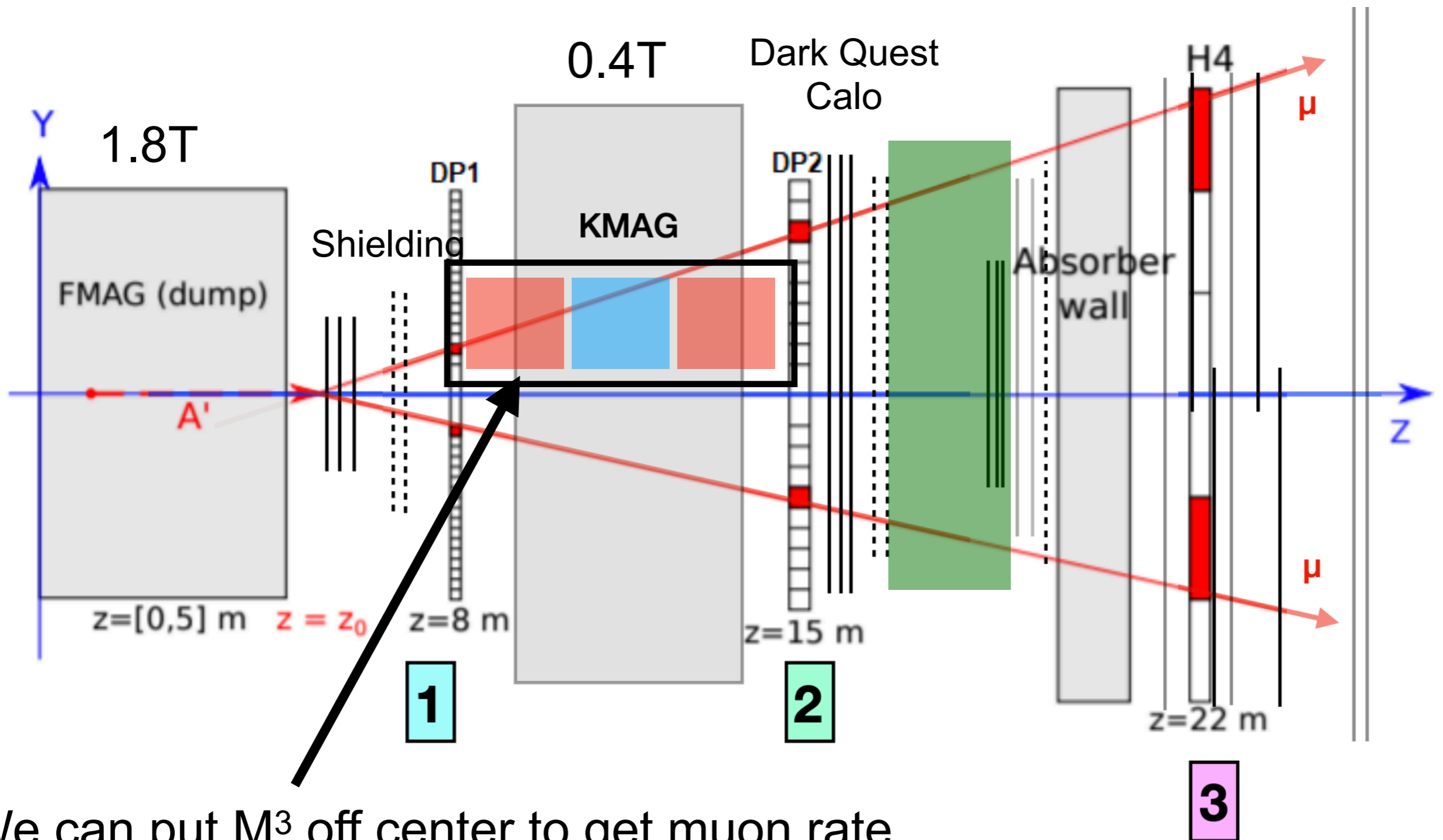


**Lets use these shapes as a key**

Note: M<sup>3</sup> propose silicon and a fancy target,  
we don't necessarily need that

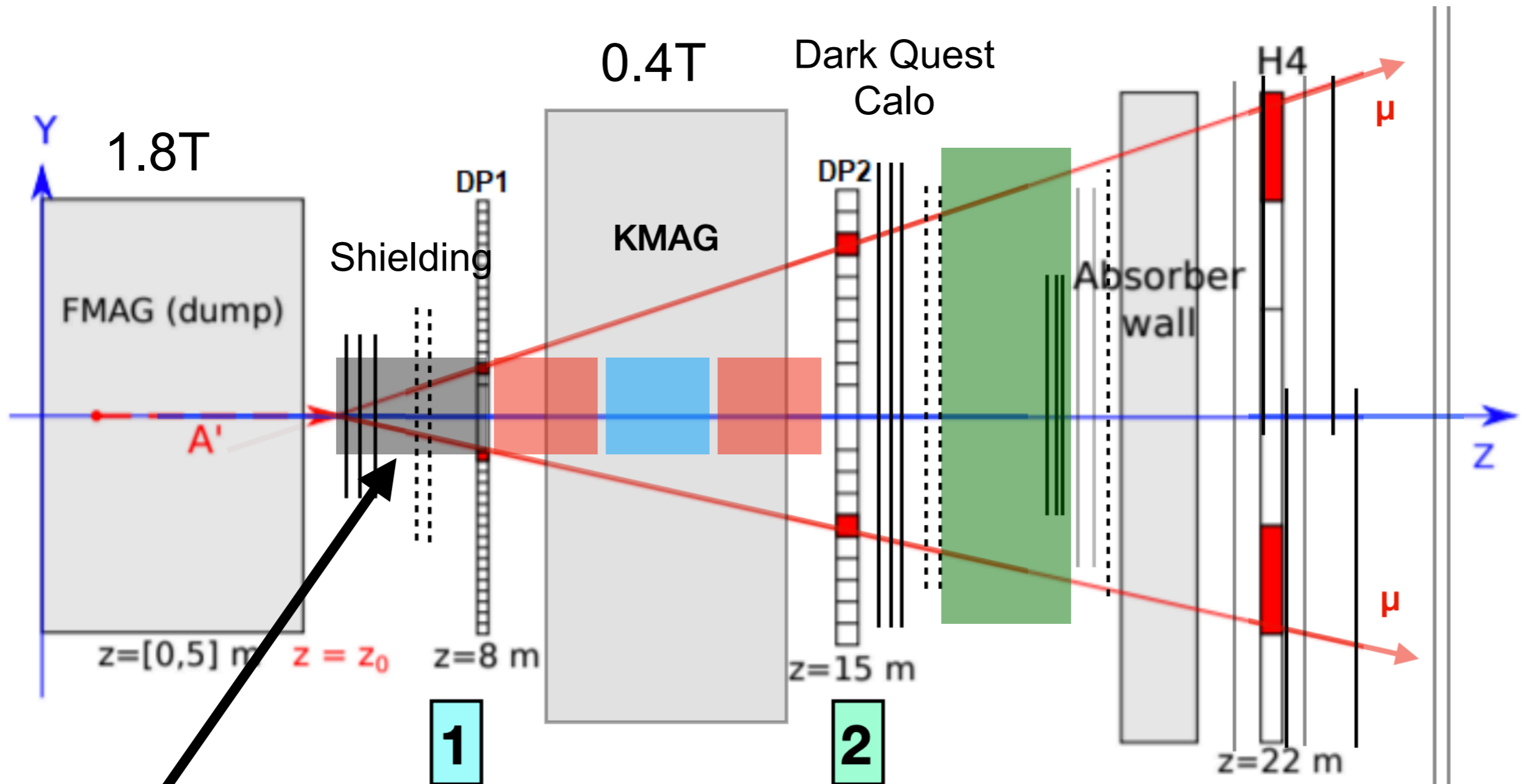
Same deal for tracking can make it larger and/or cheaper

# Can SpinQuest do M<sup>3</sup>



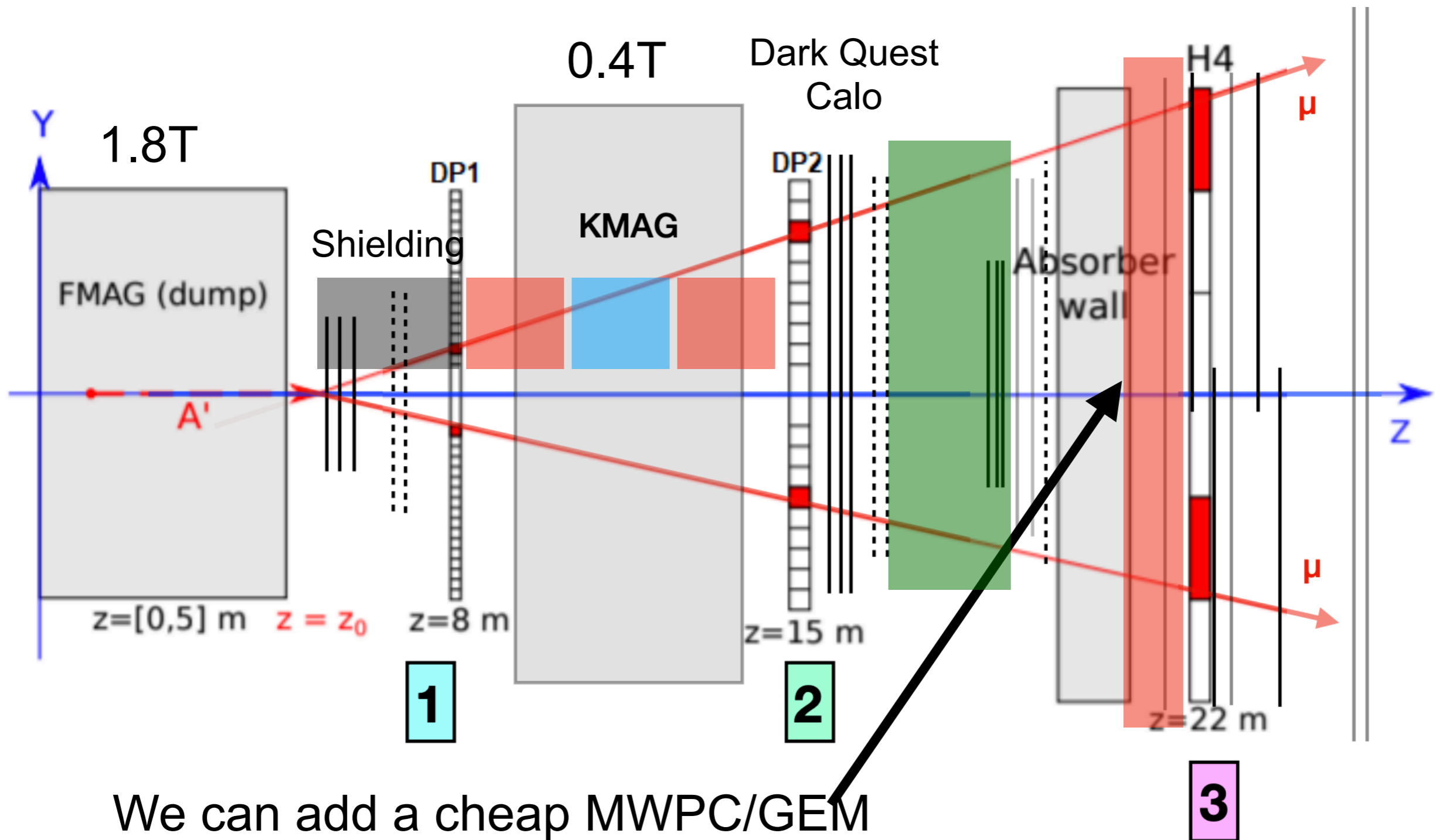
We can put M<sup>3</sup> off center to get muon rate

# Can SpinQuest do M<sup>3</sup>



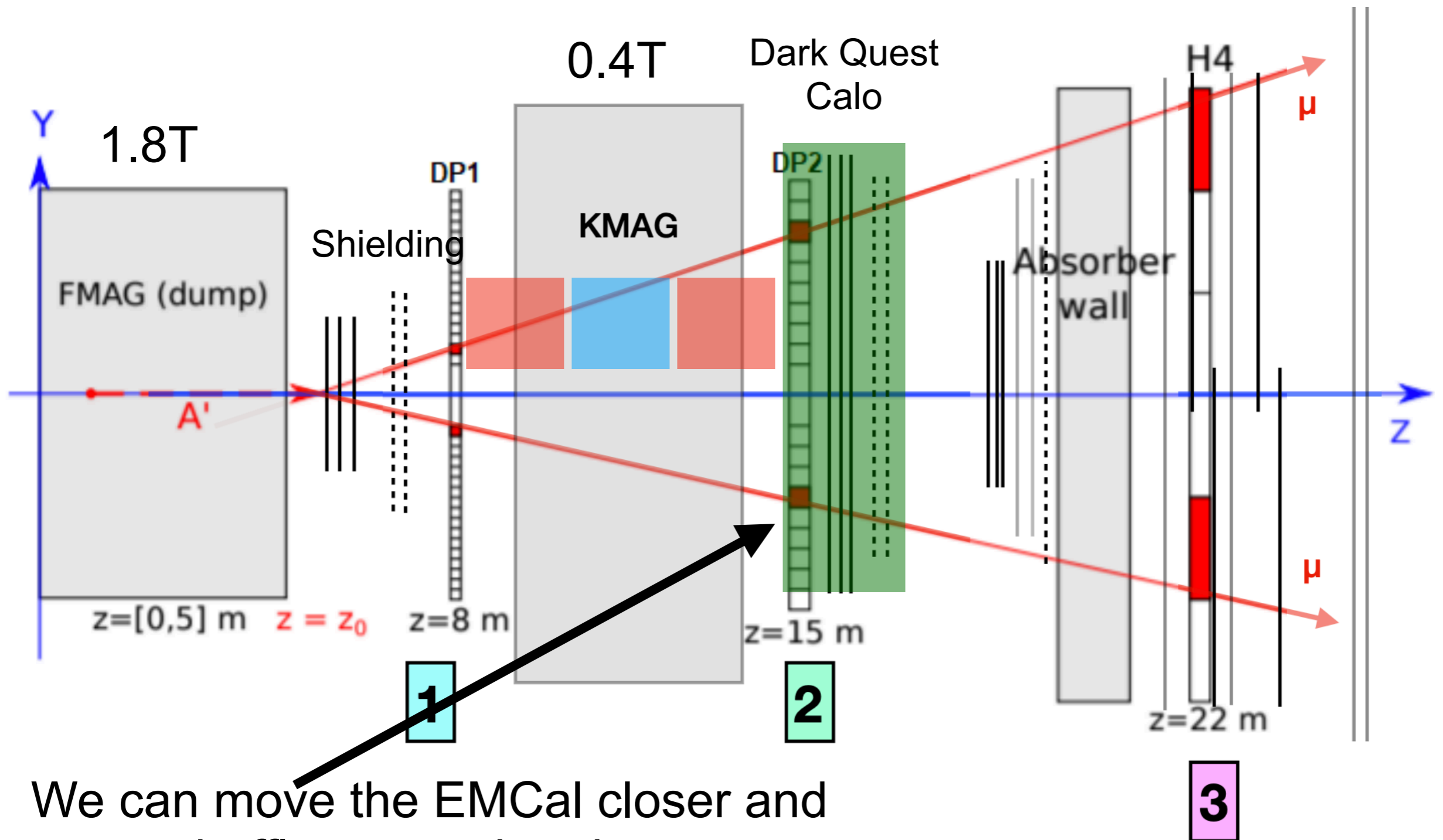
We can add shielding to reduce rate  
Should add small impact on SpinQuest

# Can SpinQuest do M<sup>3</sup>



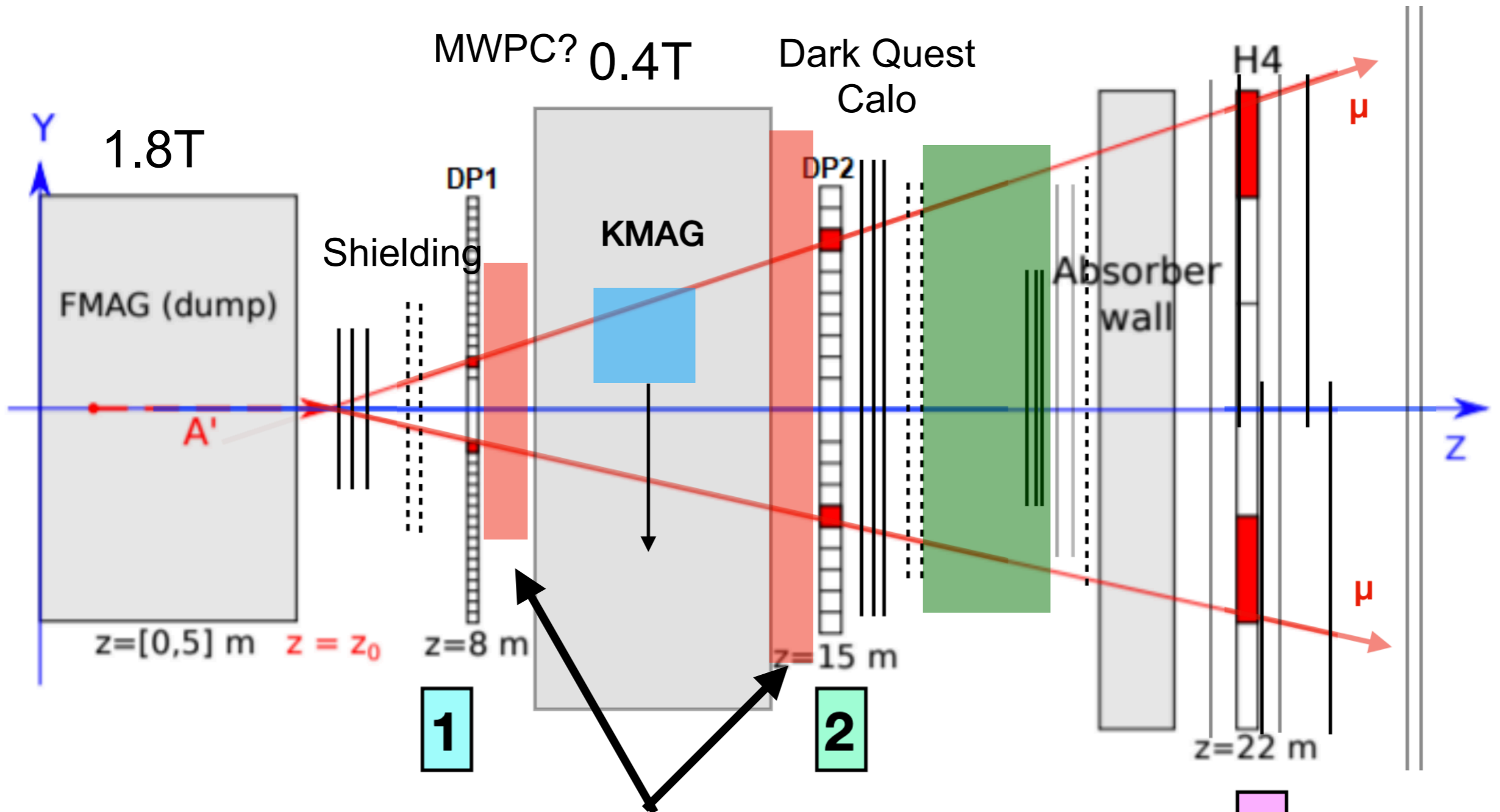
We can add a cheap MWPC/GEM  
for large lever arm (improved muons for everybody)

# Can SpinQuest do M<sup>3</sup>



We can move the EMCal closer and shuffle muon chambers

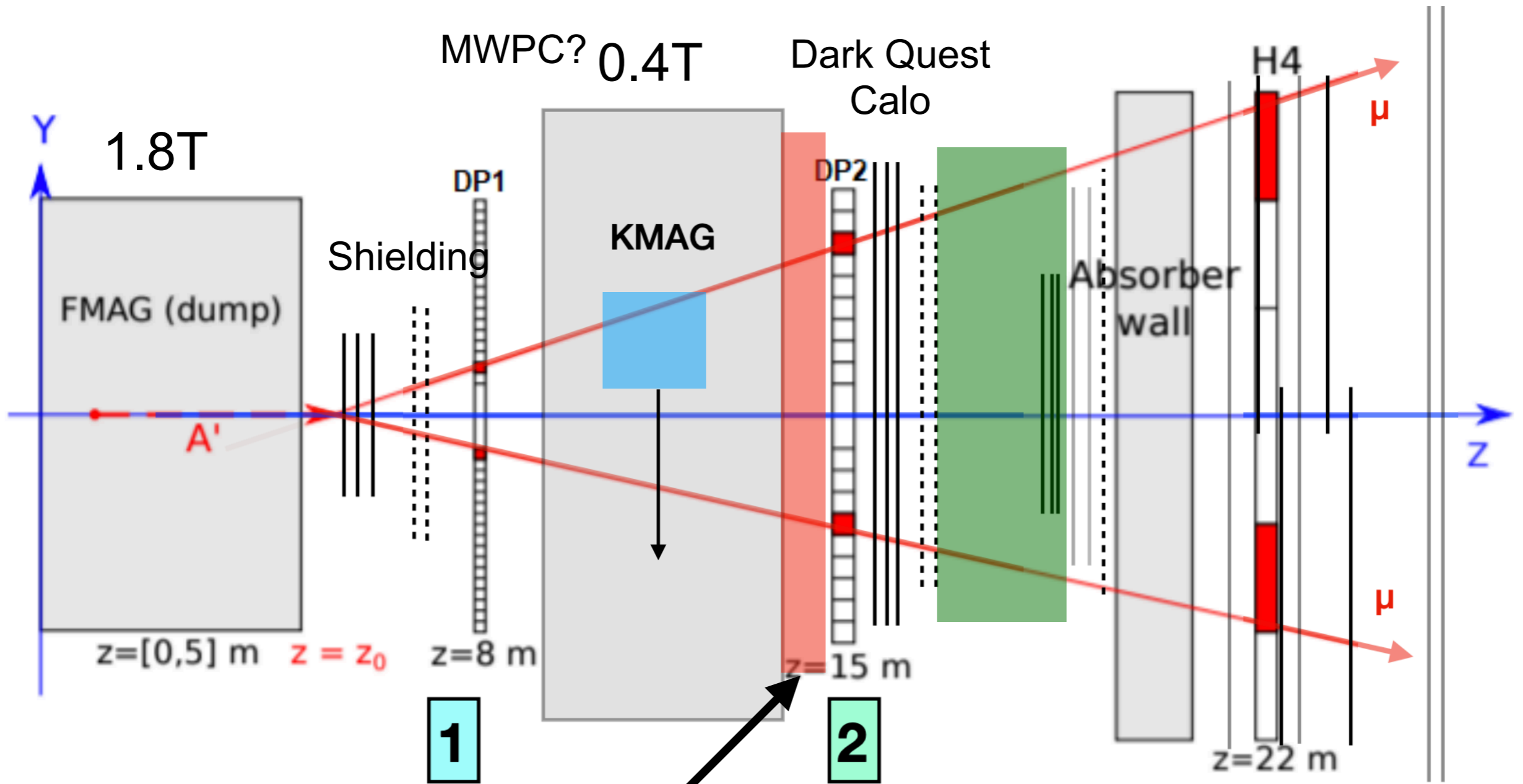
# Can SpinQuest do M<sup>3</sup>



Can put wire chambers/GEM outside of magnet **3**

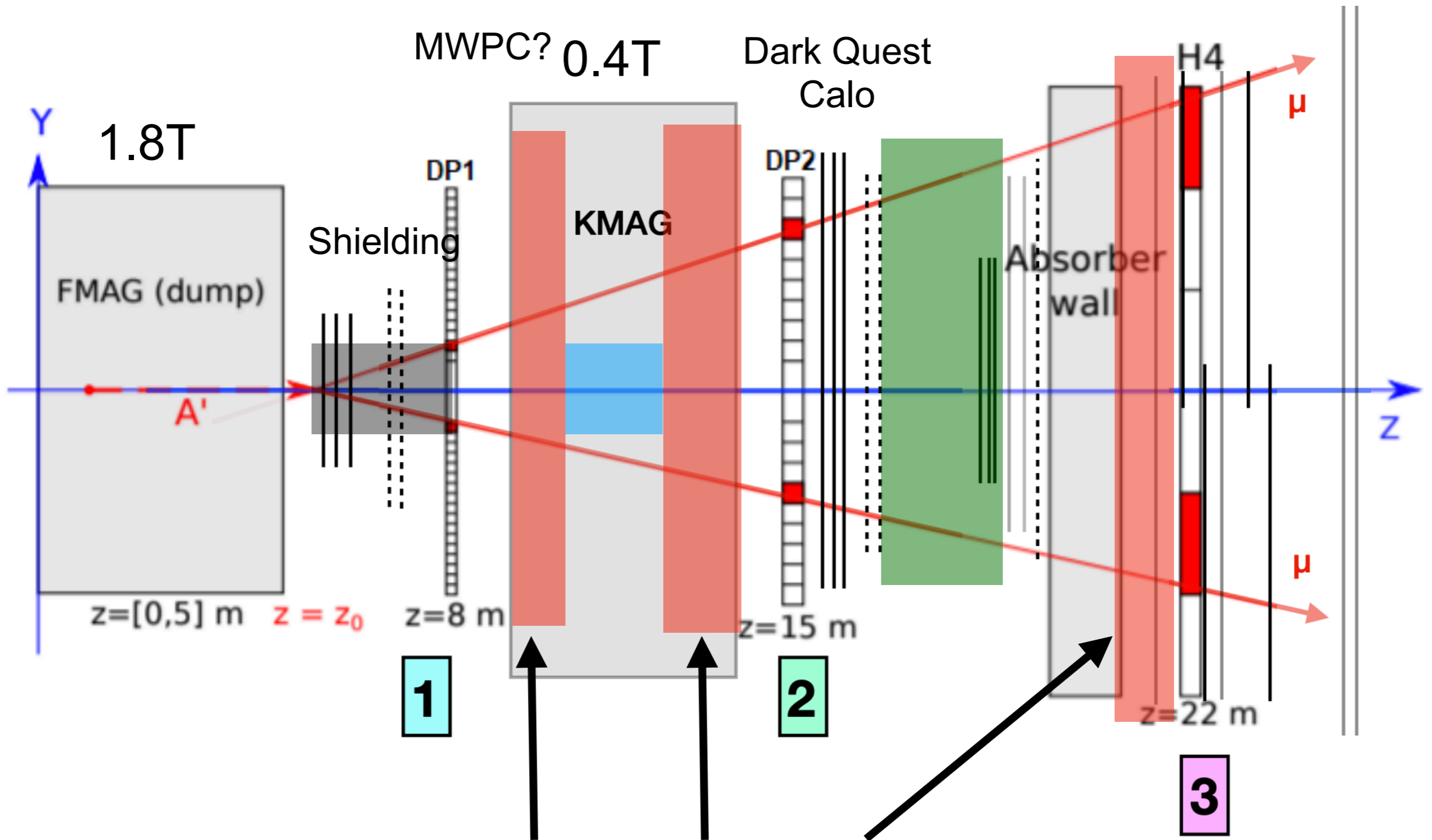
Big gain in acceptance for SpinQuest 1st Muon momentum harder

# Can SpinQuest do M<sup>3</sup>



Can put wire chambers/GEM outside of magnet **3**  
 Minimal approach

# Can SpinQuest do M<sup>3</sup>

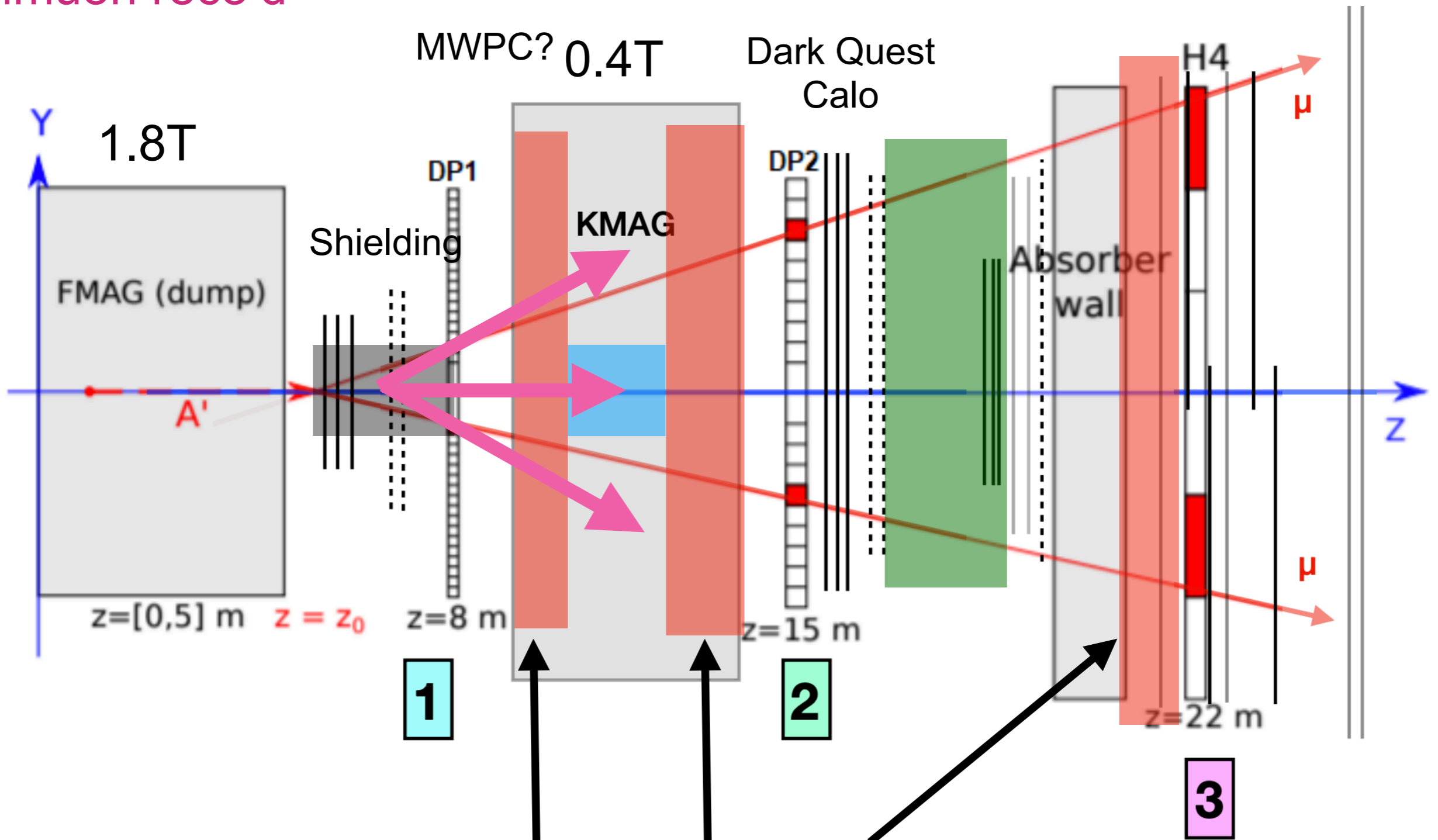


Ultimate Momentum Resolution + Acceptance gain



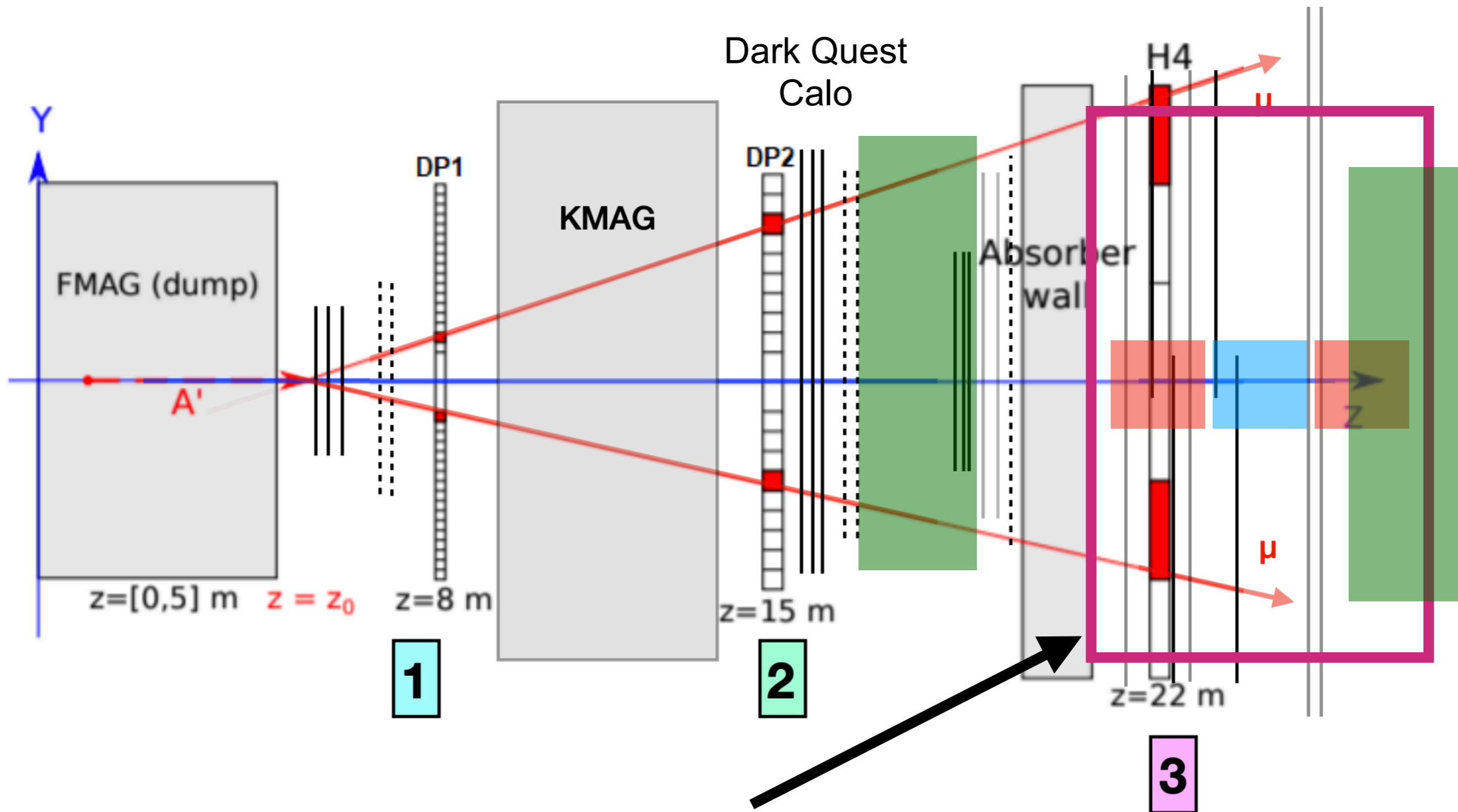
# Can SpinQuest do M<sup>3</sup>

Trimuon reco'd



Ultimate Momentum Resolution + Acceptance gain

# Can SpinQuest do M<sup>3</sup>



Long Quest Style upgrade (would need to check beam/should work)

# M<sup>3</sup>+SQ Advantages

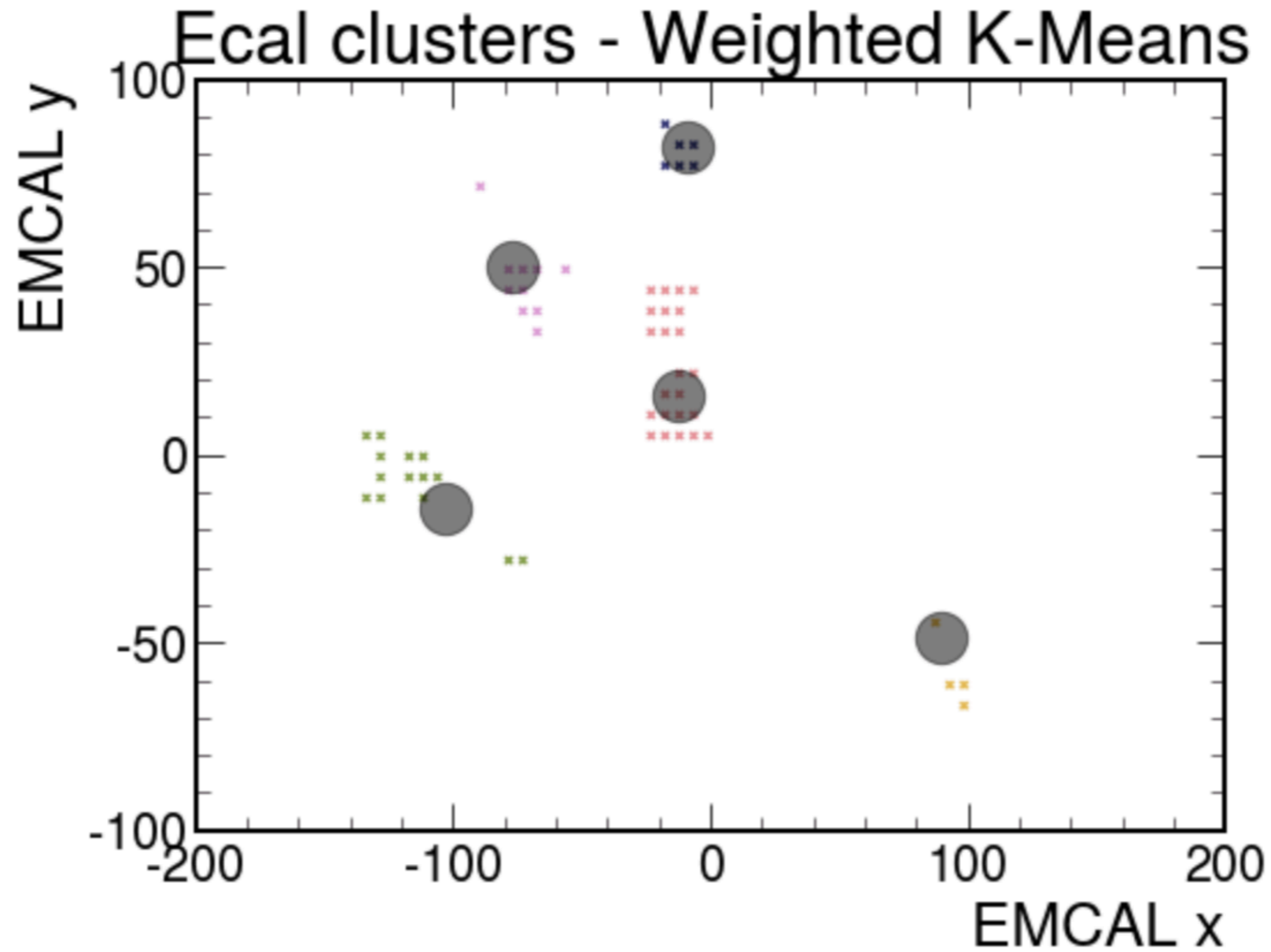
- Having one detector do all brings some advantages
  - Can reuse a lot of stuff
    - ▶ All of the core infrastructure is there
  - Same detector hall for everything
- Additionally brings together a bunch of measurements
  - Larger collaboration of people
  - Easier to present to funding agencies
  - New detectors upgrade SpinQuest/DarkQuest
    - ▶ Nice Spin physics program to complement Dark Matter
  - Probably other stuff we haven't thought about

# What do we need?

- Preserve physics for SpinQuest
  - Yes and improve it (need to keep  $> 20$  GeV muons)
- Enough Muons to do  $M^3$ 
  - Yes, and seems like we can reconstruct them
- Upgraded detector do  $M^3$  (and improve DQ/SQ)
  - We need a target and some more tracking
    - ▶ Don't need the fanciest thing in the world
- There is a lot of functionality we have not thought about

# Thanks!

## Dark Quest (6 photon event)



# Summary

- By merging SpinQuest with M3 we add a lot of functionality
  - Can search for all related decays in one fell swoop
  - Existing SpinQuest framework makes instrumentation easier
  - Removes need for calorimeter/perhaps a muon chamber
- Adds lots of acceptance of tri-muon events
  - Larger scale and instrumented detectors make it easier
  - Additionally can deal with displaced decays to electrons
- **Are there other things that we can do?**
  - Improved Spinquest measurements
  - Improved displaced object decays?

# Beams

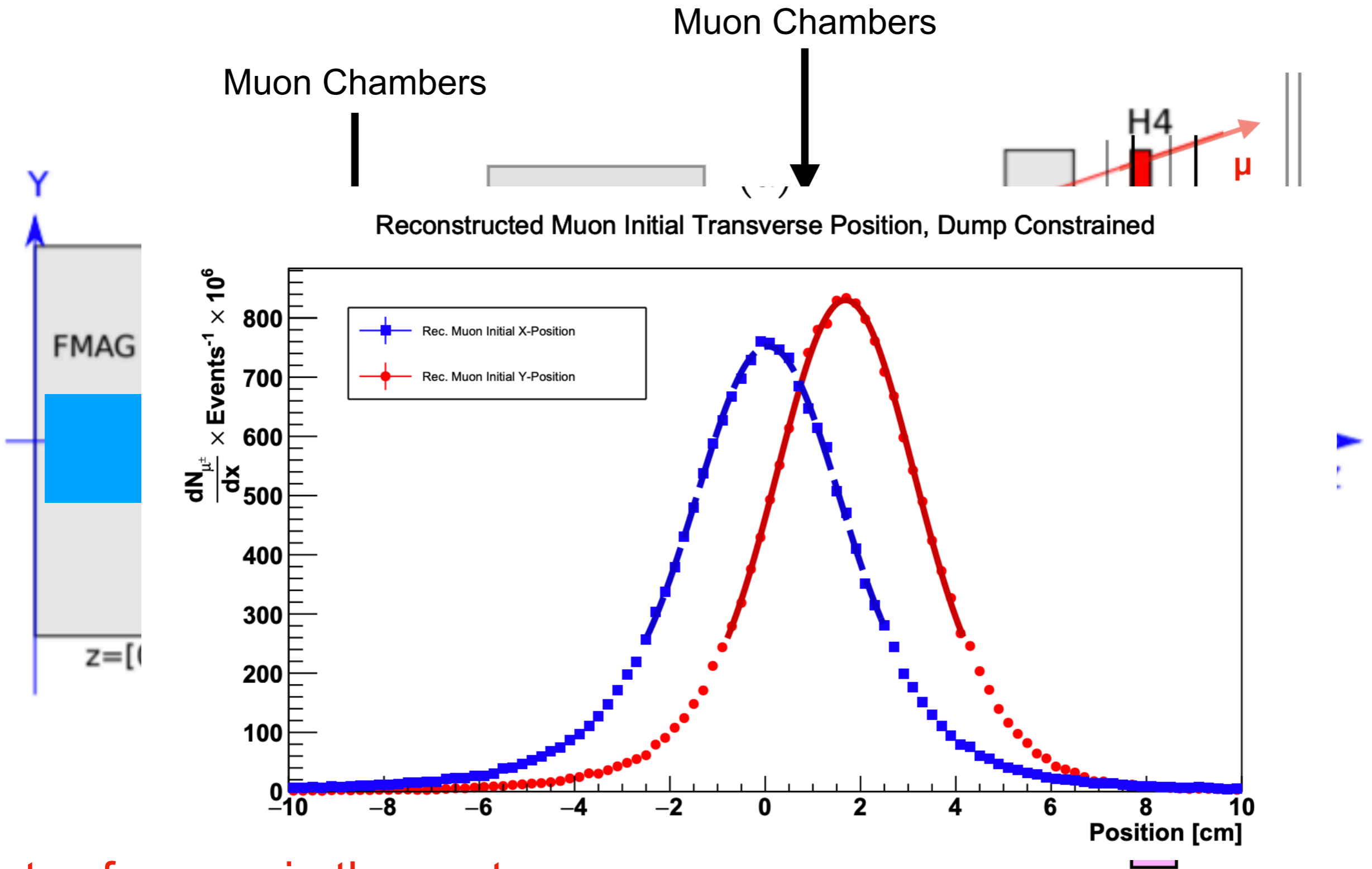
- Proposed M<sup>3</sup> uses the same beam as SpinQuest
  - Both use the switchyard
  - 4s pulses running at 52MHz 120 GeV proton beam
- SpinQuest produces muons from beam dump
- Proposed M<sup>3</sup> would use some other beam dump
  - I am not sure what the plan is
  - Does it exist?

# Supplies?

- According to Nhan :
  - There exists a 5 T Mu Cool magnet
  - A bunch of silicon lying around
  - HGcal?
  - There is also an MWPC lying around
- It would be good to know what is relatively cheap or not



# Can SpinQuest do M<sup>3</sup>



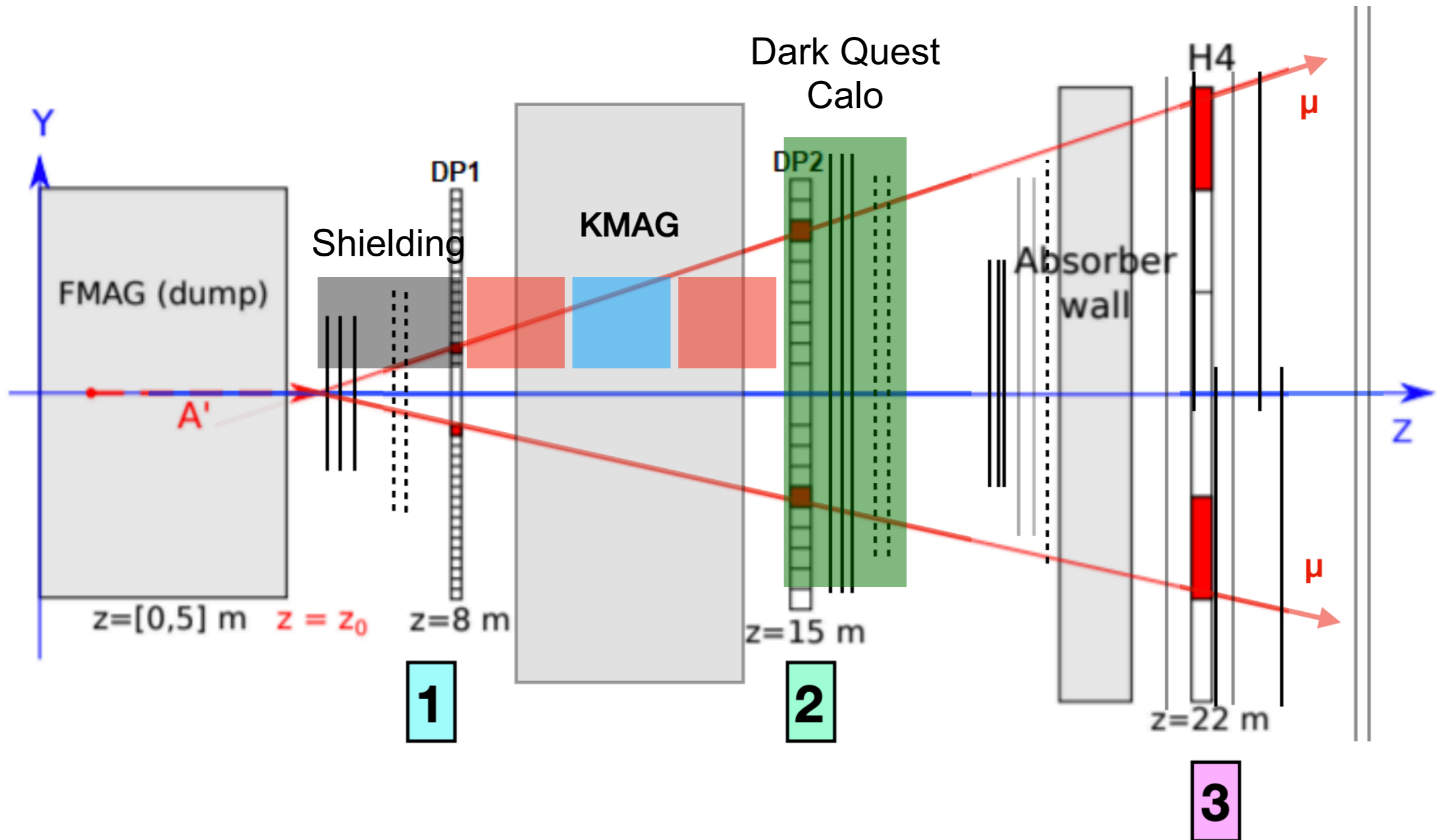
Lots of muons in the center

# What is critical for M3

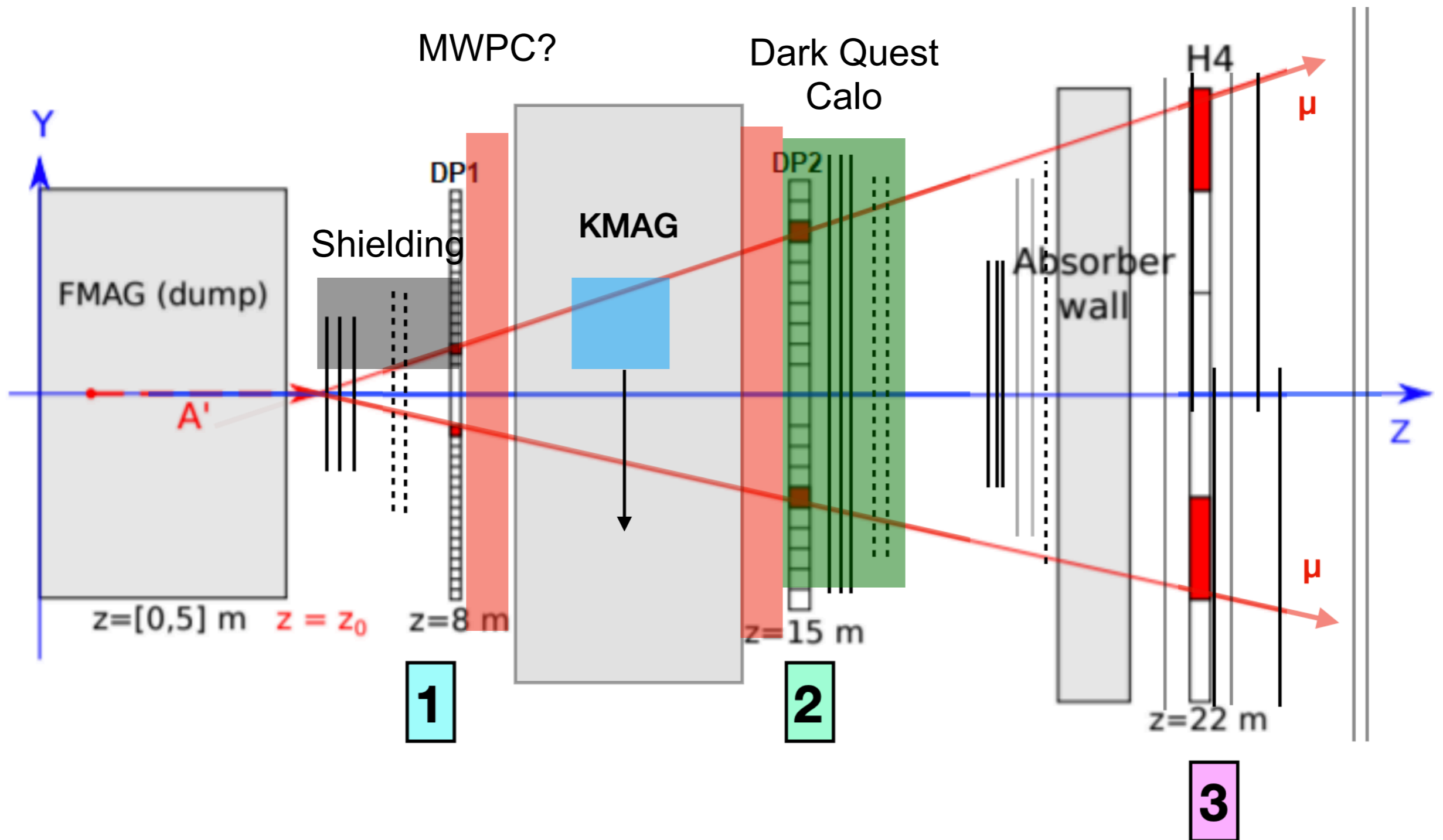


**Lets use these shapes as a eky**

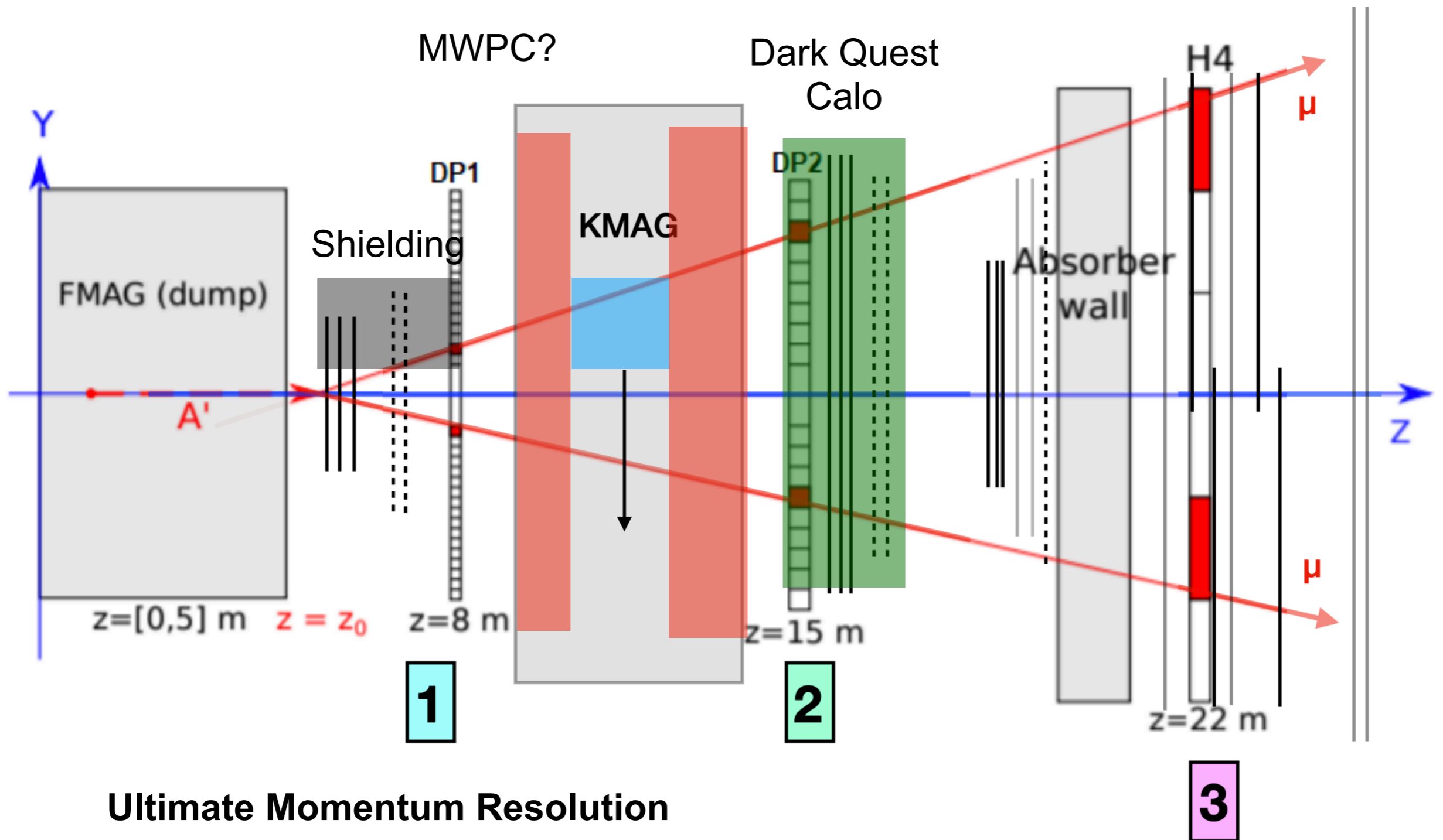
# Can SpinQuest do M<sup>3</sup>



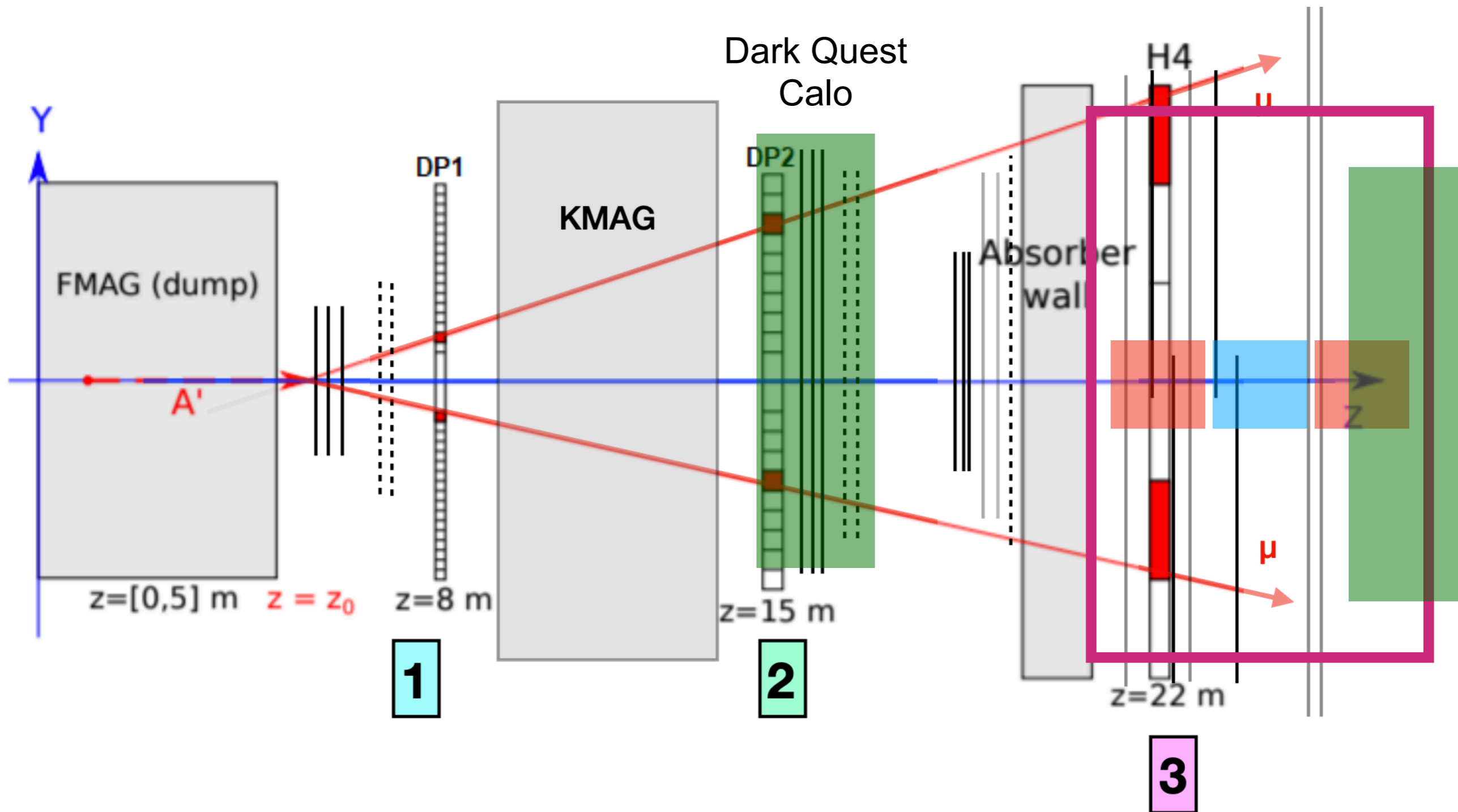
# Can SpinQuest do M<sup>3</sup>



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# Can SpinQuest do M<sup>3</sup>

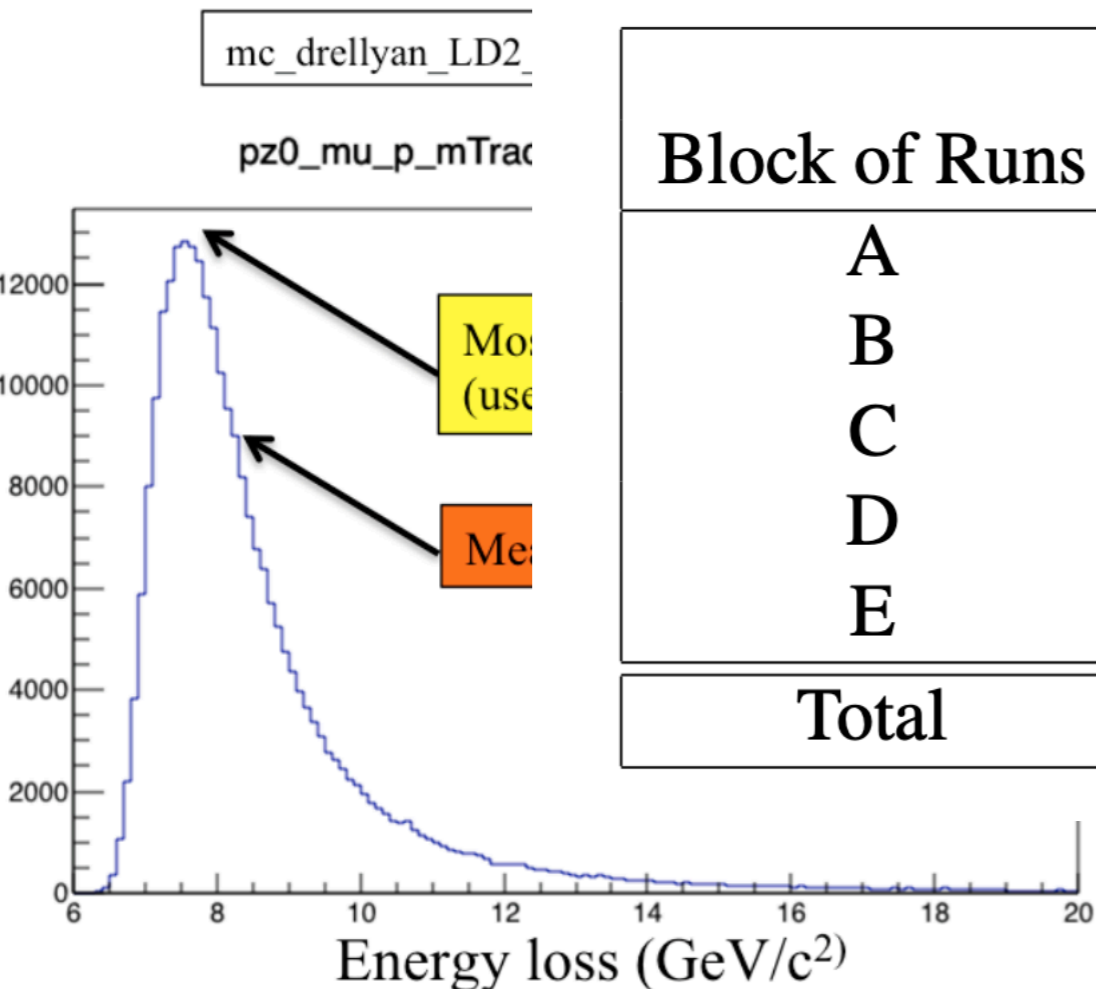


# Additional Points

- Can we generate muons from upstream?
- Muons from pion decays upstream can help
- Can add stuff upstream

# Muon Beam in SpinQuest

- The SpinQuest beam has a lot of protons on target:  $10^5$ 
  - For every proton on target
    - ▶ Roughly get a muon out of it



Block of Runs	Default data set		Seed data set		Increase 6 weeks $6 \times 10^{11}$	
	$\mu^+$	$\mu^-$	$\mu^+$	$\mu^-$	$\mu^+$	$\mu^-$
A	10653	12729	36271	35053	339%	274%
B	6274	6311	17508	19837	278%	313%
C	4928	4988	14096	15863	285%	317%
D	1896	2000	13351	13777	703%	688%
E	3168	3293	9952	10420	313%	315%
<b>Total</b>	<b>26919</b>	<b>29321</b>	<b>91178</b>	<b>94950</b>	<b>239%</b>	<b>224%</b>