Muon beam options at Fermilab: a collection of information for discussion

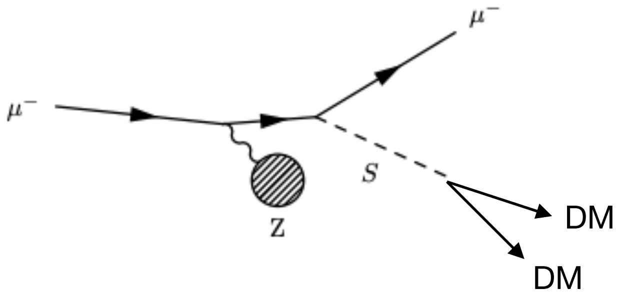
Nhan Tran, Fermilab + inputs from many people!

June 22, 2021

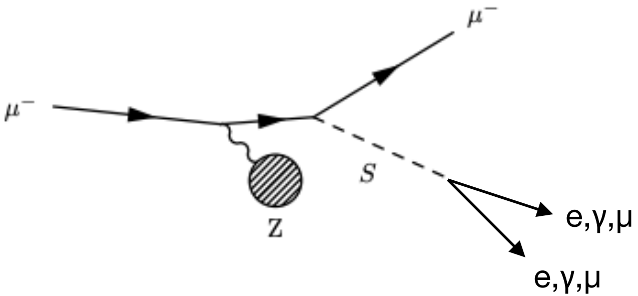
Experimental assumptions

Types of signatures

Invisible



Visible

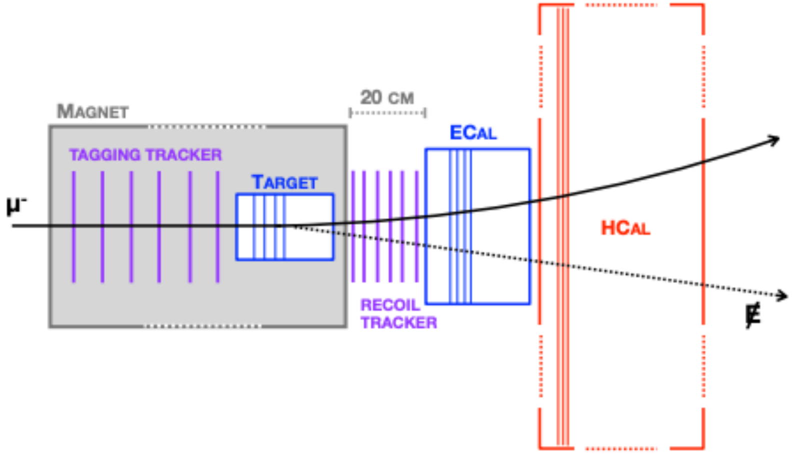


Experimental technique is
missing momentum

Experimental technique is
muon beam dump
** either direct or indirect, will discuss more*

The signature depends on the properties of S (spin, mass, couplings), but performing **both** types of these searches will be sensitive to any light new physics related to g-2

Muon missing momentum



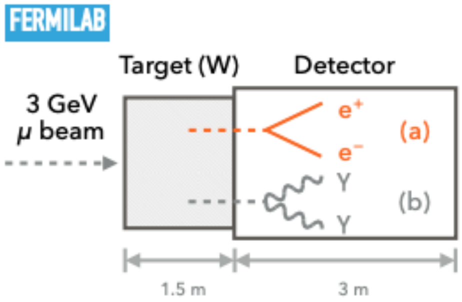
Beam Requirements

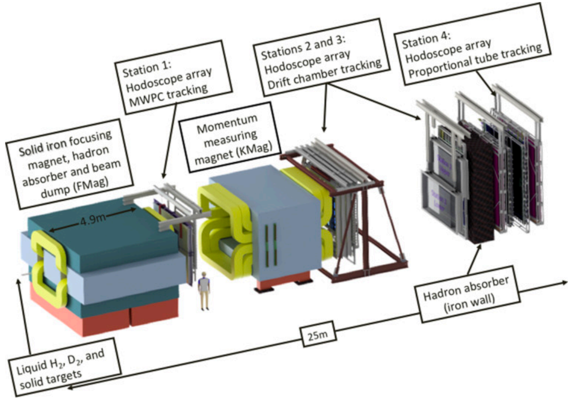
- **Individually** identify incoming muons
  - i.e. low current, high repetition rate
  - Need O(1e10) muons on target
- Beam energy > ~5 GeV

- Candidates at Fermilab
  - MCenter
  - NM4

Kahn,Krnjaic,Tran,Whitbeck, arXiv:1804.03144

Muon beam dump





Low energy muon beam requirements

- As many muons as possible
  - Results assume 3e14 MoT
- Candidates at Fermilab
  - Muon Campus

Chen,Pospelov,Zhong, arXiv:1701.07437

High energy muon beam requirements

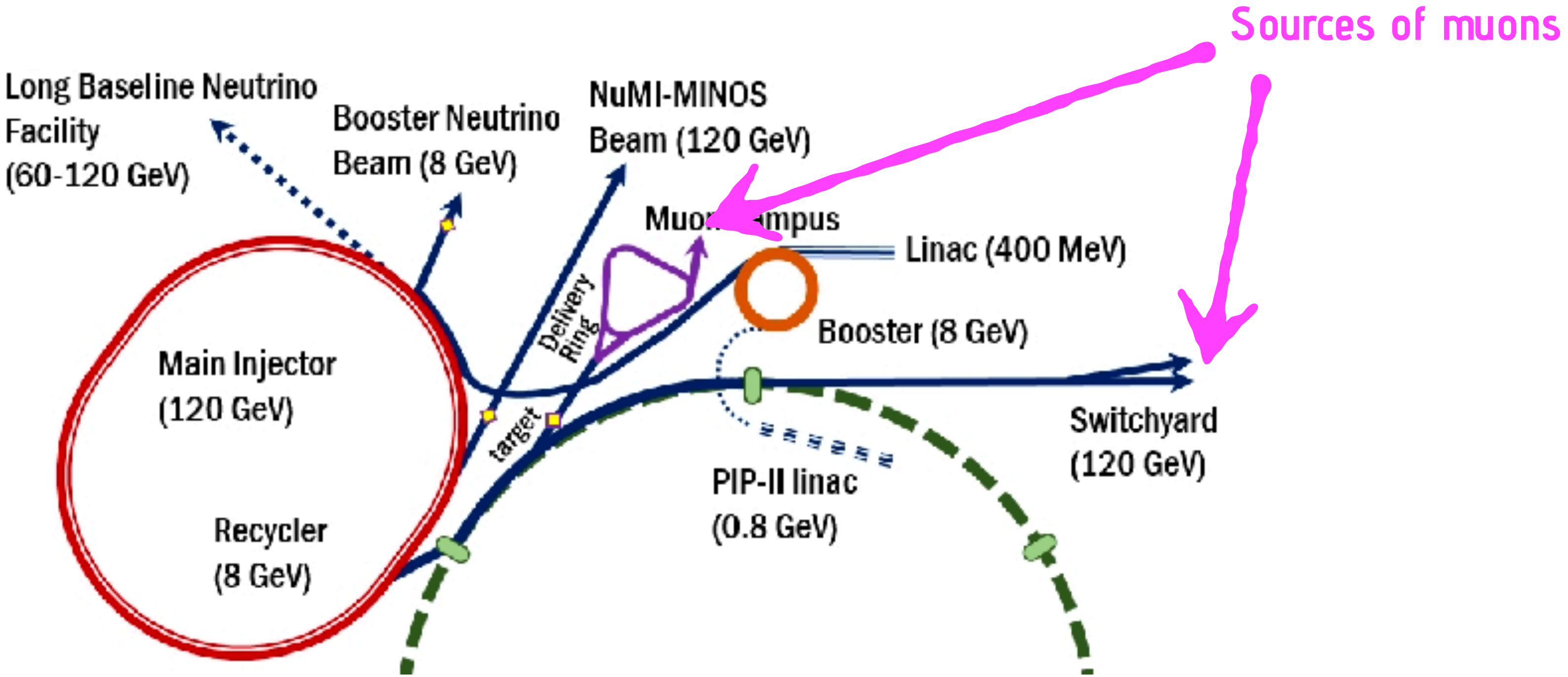
- 120 GeV protons make secondary muons in beam dump, as many protons as possible
  - Near-term results assume 1e18 PoT
- Candidates at Fermilab
  - SpinQuest/DarkQuest @ NM4

SpinQuest, arXiv:1901.09994
Berlin, Gori, Schuster, Toro, arXiv:1804.00661

Muon production at Fermilab

Disclaimer: I’m not an expert — this is a collection of inputs to seed discussion about what is possible at the accelerator complex

Big thanks to folks who gave inputs (recently and not so recently): Carol Johnstone, Mandy Kiburg, Tom Kobilarcik, Jim Morgan, Evan Niner, Jason St. John, Diktys Stratakis, Adam Watts

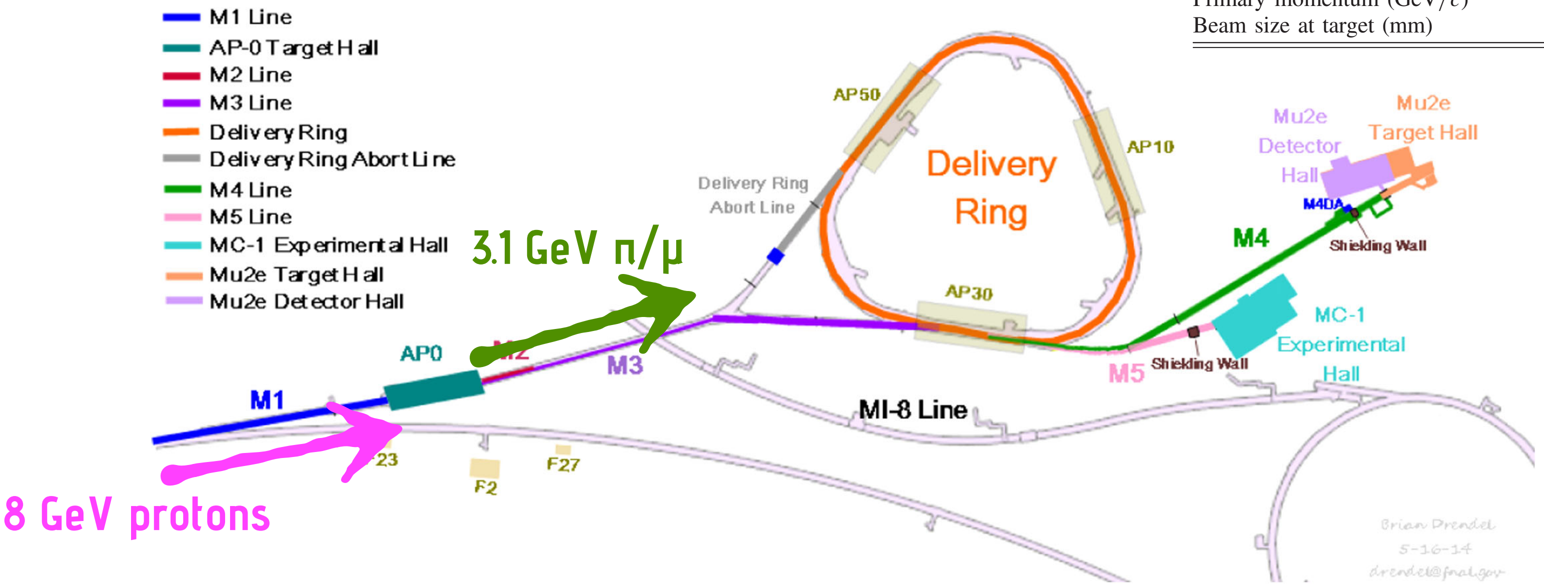


https://arxiv.org/abs/1803.00597
https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.22.011001

Muon campus: g-2

TABLE I. Primary beam parameters.

Parameter	Value
Intensity per pulse	10^{12}
Total POT per cycle	16×10^{12}
Number of pulses per cycle	16
Cycle length (s)	1.4 s
Primary momentum (GeV/c)	8.89
Beam size at target (mm)	0.15

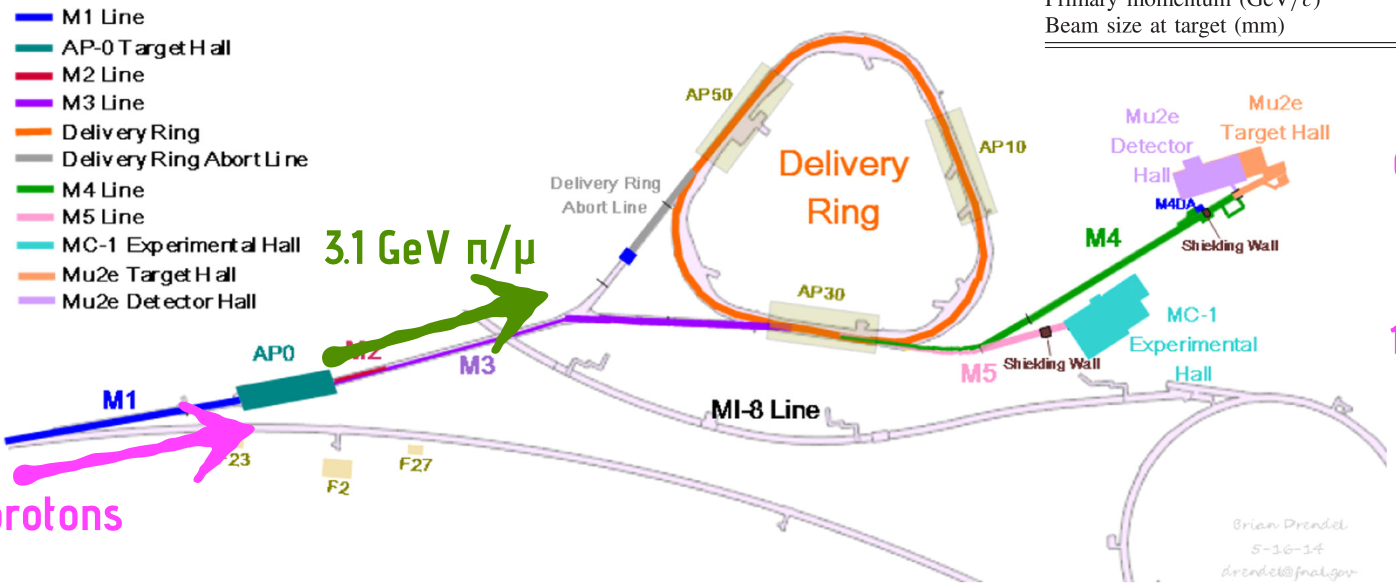


https://arxiv.org/abs/1803.00597
https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.22.011001

Muon campus: g-2

TABLE I. Primary beam parameters. (protons)

Parameter	Value
Intensity per pulse	10^{12}
Total POT per cycle	16×10^{12}
Number of pulses per cycle	16
Cycle length (s)	1.4 s
Primary momentum (GeV/c)	8.89
Beam size at target (mm)	0.15



8 GeV protons

6.8e5 muons/fill
16 fills/cycle

g-2 requires ~ 1e14 muons/year

https://arxiv.org/abs/1803.00597
https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.22.011001

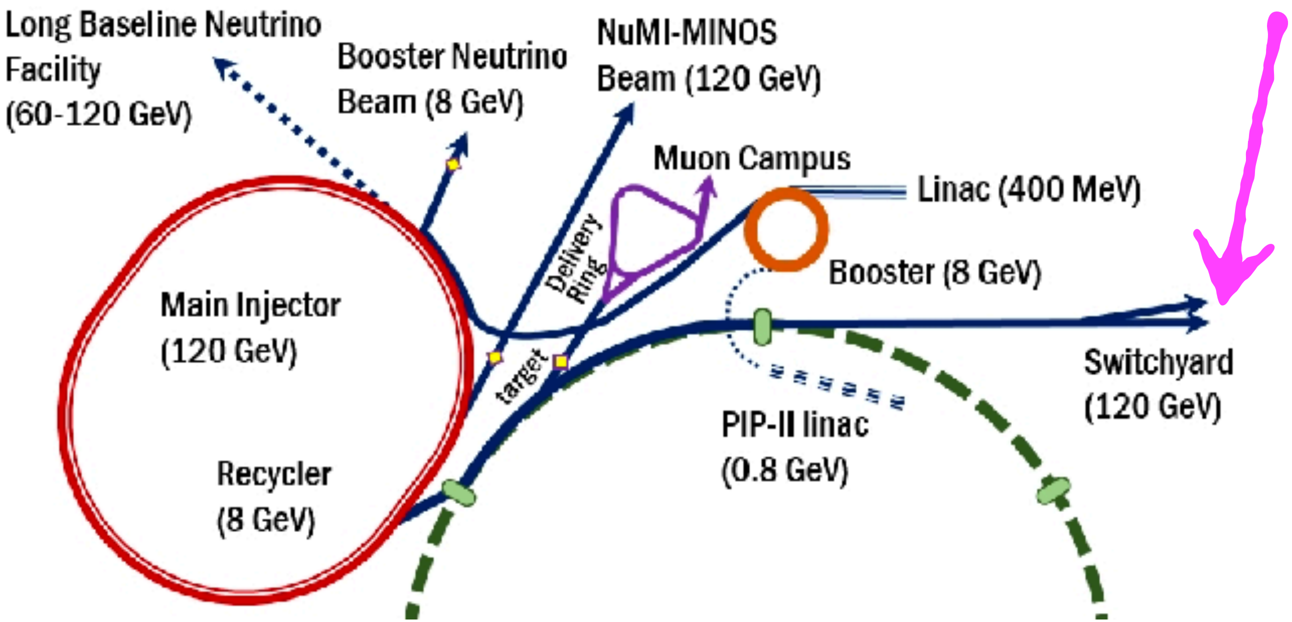
Fermilab

Muon campus: Mu2e

TABLE I. Primary beam parameters.

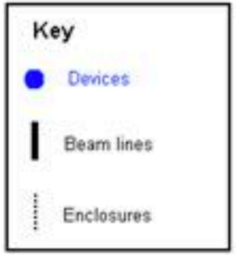
Parameter	Value
Intensity per pulse	10^{12}
Total POT per cycle	16×10^{12}
Number of pulses per cycle	16
Cycle length (s)	1.4 s
Primary momentum (GeV/c)	8.89
Beam size at target (mm)	0.15

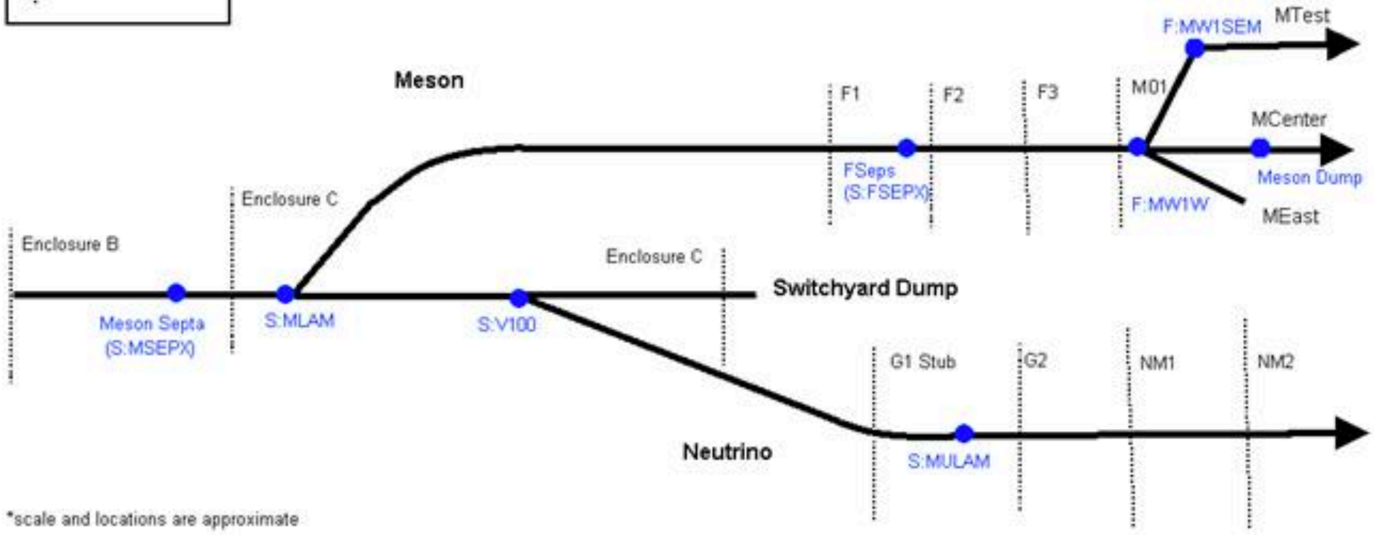
For Mu2e, 8 GeV protons are slow-extracted to Mu2e muon production target



https://arxiv.org/abs/1803.00597
https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.22.011001

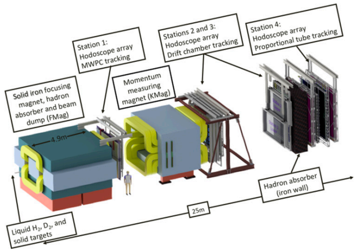
Switchyard





*scale and locations are approximate

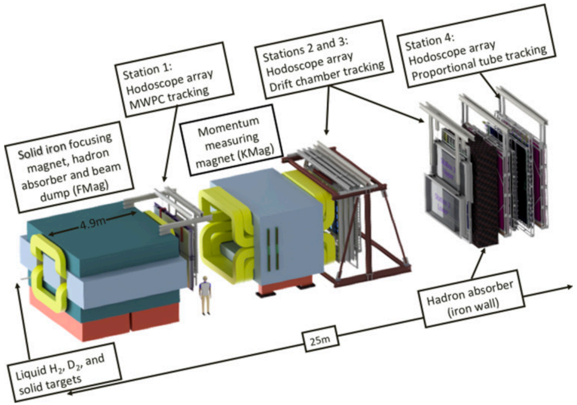
NM4



Fermilab

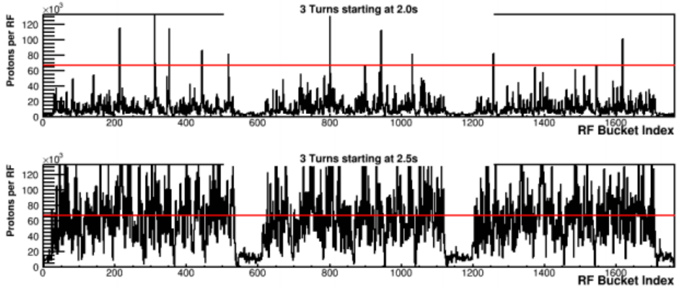
Protons at SeaQuest, SpinQuest, etc.

NM4 can provide 1e13 protons/spill



e.g. beam intensity variations from slow extraction at main injector can saturate triggers

For running with SpinQuest (w.r.t. SeaQuest), we also expect some decrease in uptime due to polarized target running efficiency

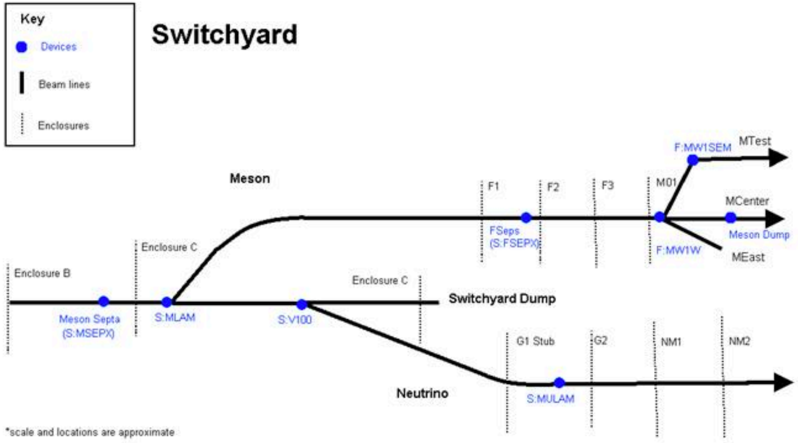


A number of effects reduce the total amount of protons on target including beam quality factor and target uptime

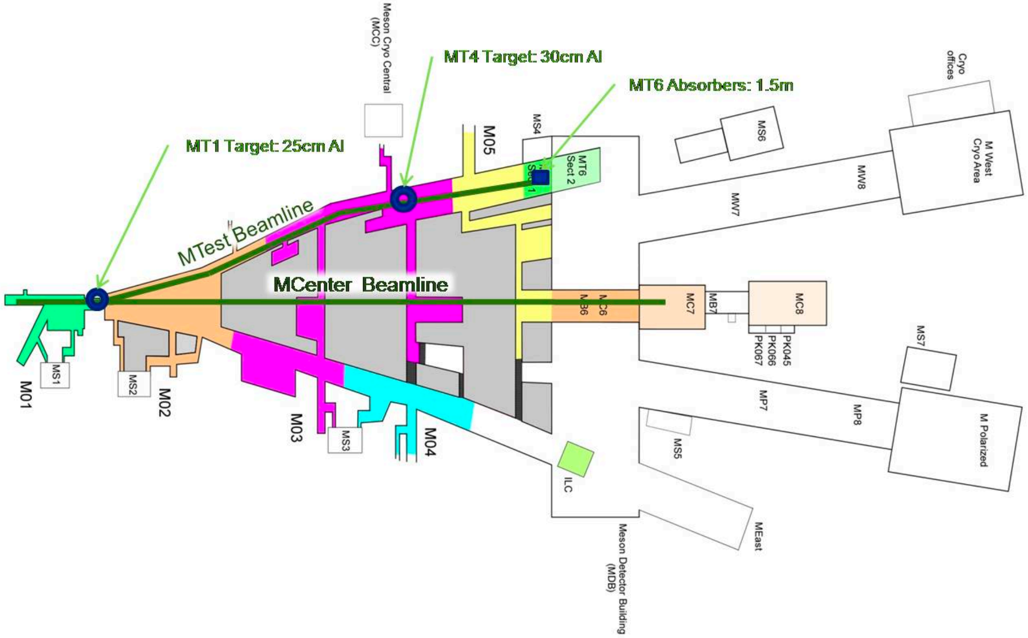
Expect around 1.5-2e12 PoT / spill

Into the unknown

- Rate of muons at g-2 and protons at NM4 is known
- Rate of muons are Meson Area or NM line are NOT well-known



Muons at Meson Area



Assorted Thoughts

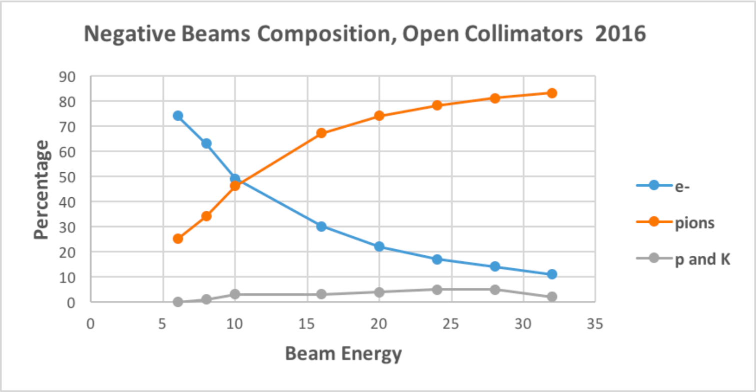
- Given how busy MTest is and nature of test beam experiments there, longer term experiments would have to be on the MCenter beamline
    - Could we have a longer term experiment at MTest?
    - MCenter beamline (being straight) can make muon production challenging (including beam halo)
- The rate of protons allowed at Meson Area is limited due to shielding requirements — what is the maximum?
- Is a setup available to make a relatively simple/fast measurement?

Muons at Meson Area

- We understand that FTBF can run up to 1e6 protons per spill
  - 4 second spill runs once every minute

- MTest has a muon mode by closing two several ft thick absorbers between MT6-1 and MT6-2
  - Is something similar at MCenter?
  - Muons can be up to 60 GeV but there is no reliable flux at any energy
    - This would need to be studied at FTBF

- Switchyard could also provide muons but this would need to be studied



Some input on muons at FTBF

Muons from 32 GeV/c pions

D. A. Jensen

Nov 30, 2015

DRAFT 0.5

This is just a brief note discussing the so called 32 GeV/c muon beam, so called because it is derived from a 32 GeV/c pion beam. The pions in the FTBF beam line decay in flight yielding muons. The muons penetrate an iron shield, loosing energy. The pions are absorbed in the steel.

To obtain an estimate of the momentum spectrum, the FTBF beam line was studied using G4_beamline. As expected, the muons arriving in the FTBF experimental area derive primarily from the decay of pions downstream of the final bend. To obtain higher statistics, just the downstream end of the beam line was simulated: a pencil pion beam was allowed to decay upstream of the nominal 3 meter long Fe absorber. Figure 1 shows the momentum spectrum just downstream of the Fe absorber. This spectrum is based on 50K pion decays.

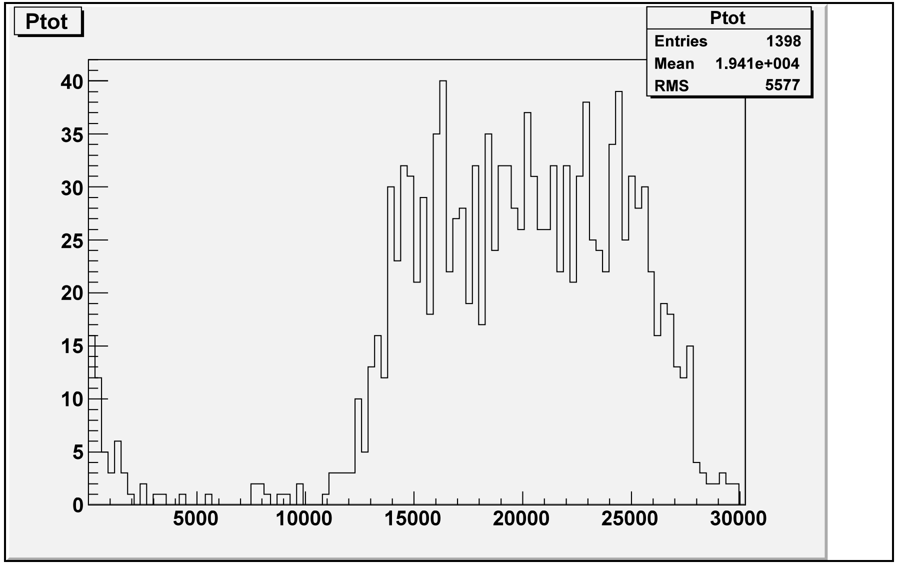


Figure 1 Momentum spectrum of muons from a 32 GeV/c pion beam

Fermilab

Some input on muons at FTBF

Muons from 32 GeV/c pions

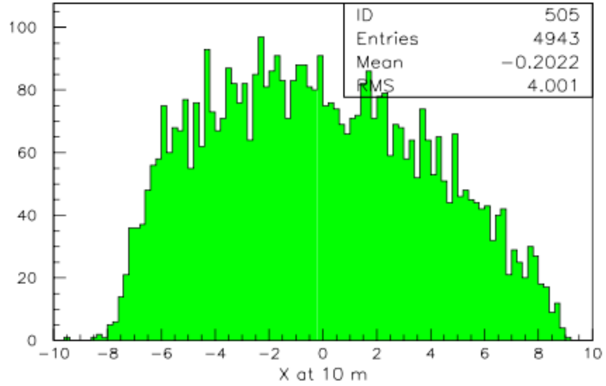
D. A. Jensen

Nov 30, 2015

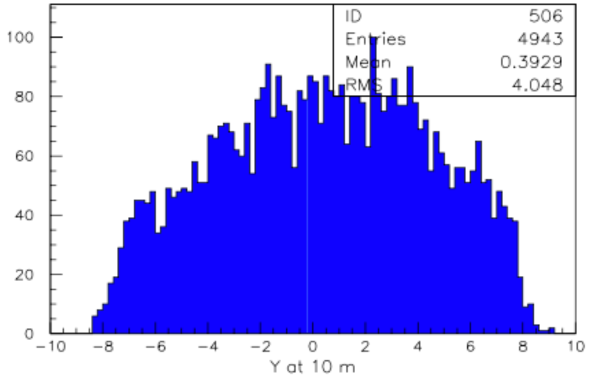
DRAFT 0.5

This is just a brief note discussing the so called 32 GeV/c muon beam, so called because it is derived from a 32 GeV/c pion beam. The pions in the FTBF beam line decay in flight yielding muons. The muons penetrate an iron shield, loosing energy. The pions are absorbed in the steel.

Early in 2015 data on the pion beam and muon beams were collected using the wire chamber system. Tracks were reconstructed and characterized by the slope and intercept at the upstream end of the 6.2 experimental hall in FTBF. The first plot shows the pion beam in X (horizontal, green) and Y(vertical, blue). It is this beam that is intercepted by the iron absorber leaving the decay muons. The second set of plots shows the muon beam, again at the upstream face of the experimental area. A final plot shows the muon beam 10 meters downsream of the upstream face of the experimental hall.



[cm]



[cm]

Evolving thinking, questions, discussion…

- Rates of muons for g-2, and thus a potential muon beam dump experiment, is well-understood
- Rates of protons at NM4 is well-understood
  - To understand a little better: efficiency for data-taking when running with SpinQuest

- Muons for a missing momentum experiment need to be understood better
  - Possible at FTBF, but will we get enough muons?
    - Could we run longer at MTest?
  - What about muons at NM3 or NM4?
    - Higher flux of protons is available there
    - How would that affect future experiments in NM4?