Overview of AMF conversion experiments

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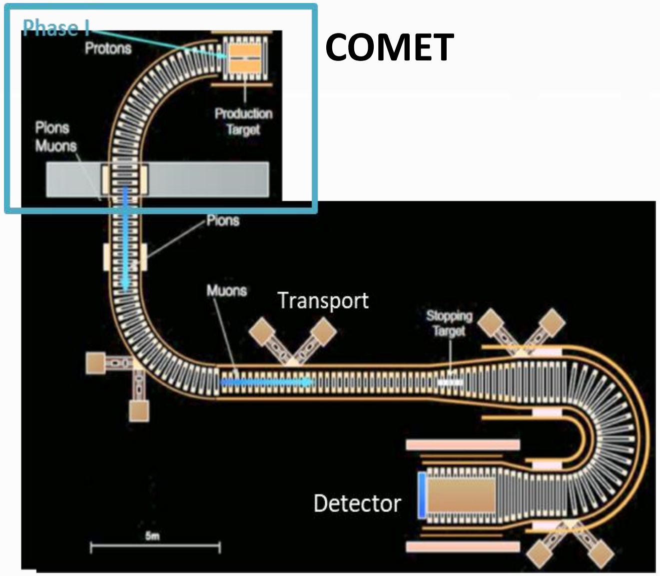
with input from many people

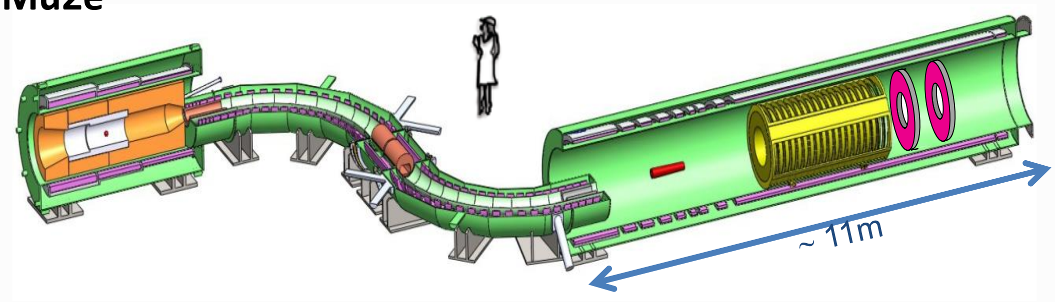
Workshop on future muon program at FNAL
Caltech – March 2023

Two different approaches – COMET and MU2E

COMET



Mu2e



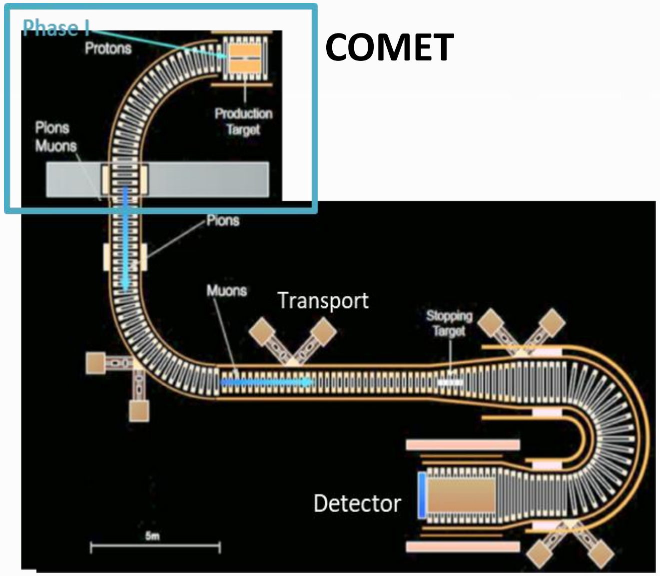
Comet has a C-shape magnetic spectrometer after the stopping target

- Filter out low-energy and “wrong charge” particles
- Filter out neutrals
- Lower occupancy / radiation dose in detector
- Charge asymmetric - only positive or negative at a given time

$$D = \frac{p}{qB}\theta_{bend}\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

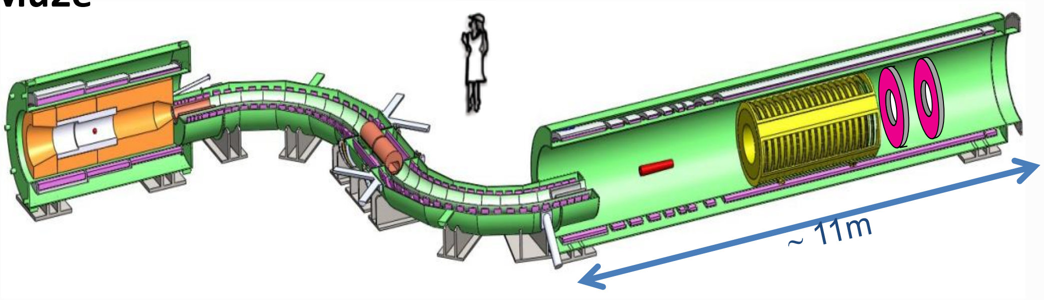
D : drift distance
B : Solenoid field
θ_{bend} : Bending angle of the solenoid channel
p : Momentum of the particle
q : Charge of the particle
θ : $atan(P_T/P_L)$

Two different approaches – COMET and MU2E



COMET

Mu2e

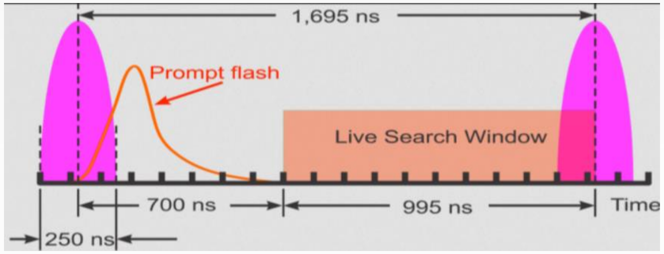


Mu2e has the detector in front of the stopping target

- Annular design to be insensitive to low-energy particles
- Large occupancy and radiation dose
- Track reconstruction more challenging
- Charge symmetric – in-situ calibration with positrons and $\mu^- \rightarrow e^+$ search

Muon conversion – limiting factors

Current approach (COMET / Mu2e / Mu2e-II)

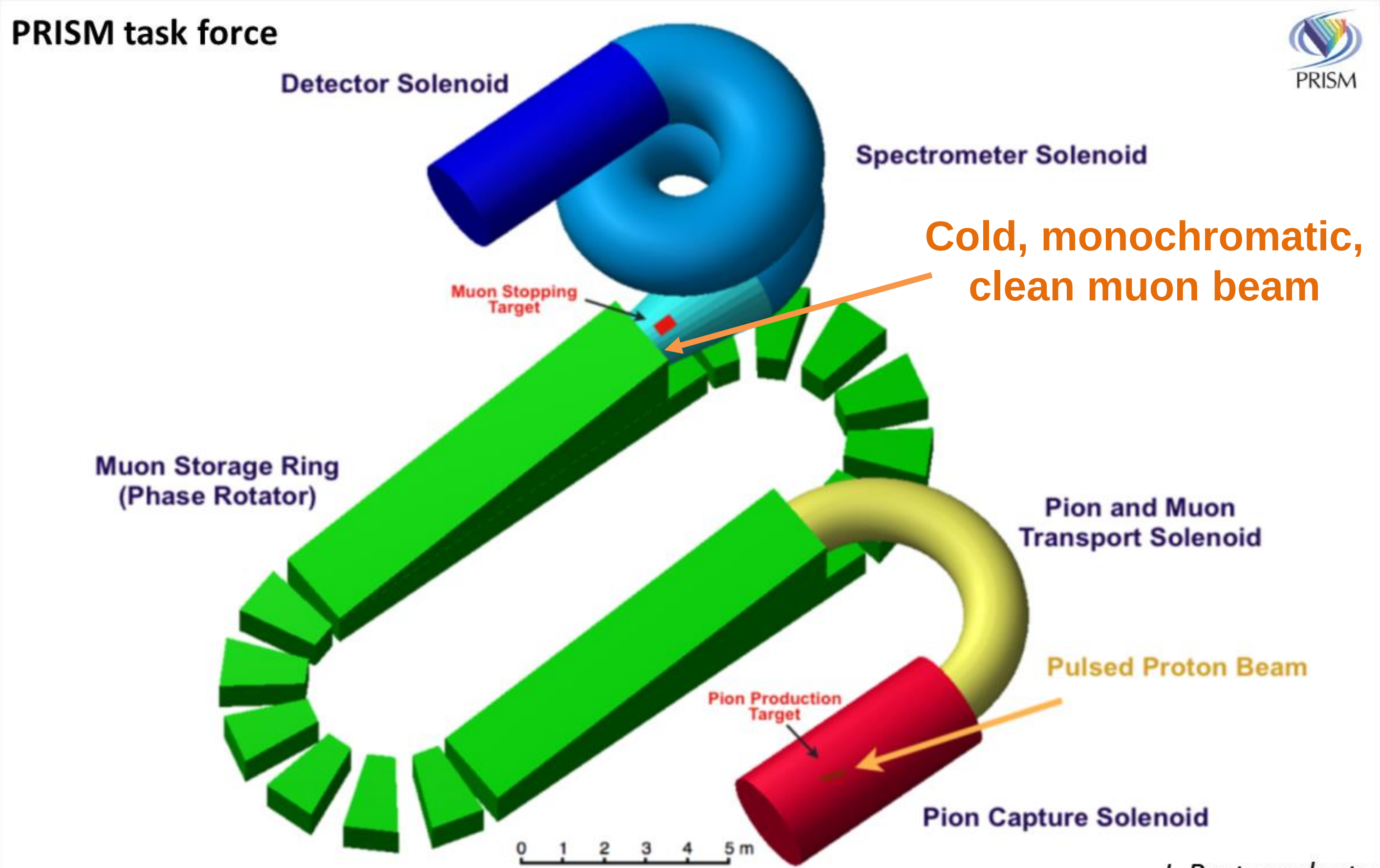


- Protons hit the production target, pions $\rightarrow$ muons captured by production solenoid (pulsed beam)
- Muons transported towards stopping target
- Muon conversion or decay products measured by detector (tracker + calorimeter)

Going beyond Mu2e(-II) requires overcoming the following limiting factors

- Background due to beam flash and pion decays – also prevent measurements with high-Z targets
- Background from out of time protons – beam extinction performance
- Momentum resolution to reduce DIO background – target and tracker performance
- Cosmic-induced background – CRV performance
- Radiation – detector and readout electronics
- Trigger latency – rate

AMF conceptual design



https://indico.phys.vt.edu/event/34/contributions/685/attachments/529/625/PRISM_nufact18.pdf

J. Pasternak et al.

We will assume that the FFA is delivering the muon beam we need and focus on the conversion experiment design

Take advantage of cold, monochromatic, pure muon beam at the exit of the FFA

No beam-induced background – notably pion contamination

- No need to wait for pions to decay anymore, RPC is extremely suppressed
- No background from antiprotons, delayed electrons,…
- Can measure short muonic atom lifetime $\rightarrow$ high Z material (e.g. Au)
- No stringent requirements on out-of-time protons
- Less radiation in the detector

Cold beam

- Use thinner stopping target to stop muons $\rightarrow$ reduce energy loss fluctuations in target material, which improves momentum resolution

Still need to handle DIO background, cosmic induced background and secondary particles produced from muon captures, i.e. all the “stuff” produce in the stopping target

Spectrometer solenoid + detector (aka Guggenheim scheme, à la PRIME concept)

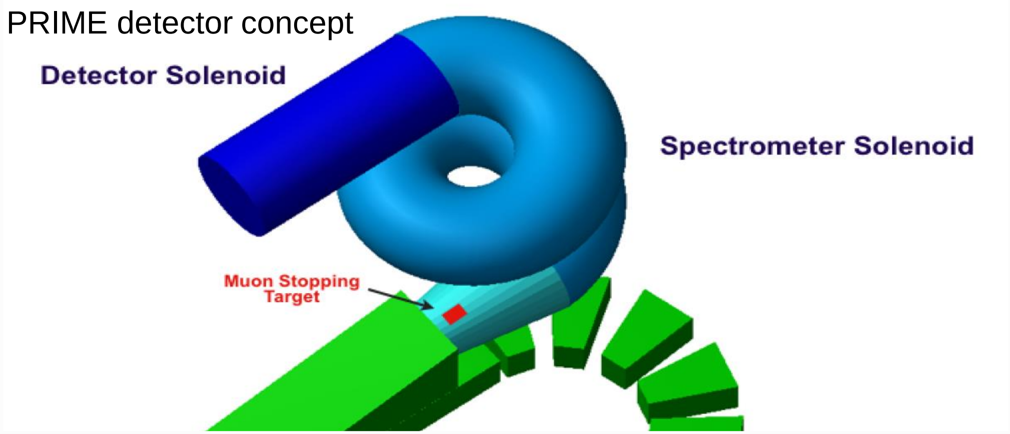
+ Greatly reduce muon capture induced background with beam blocker (including neutrals)

+ Greatly reduce lower energy DIO contribution

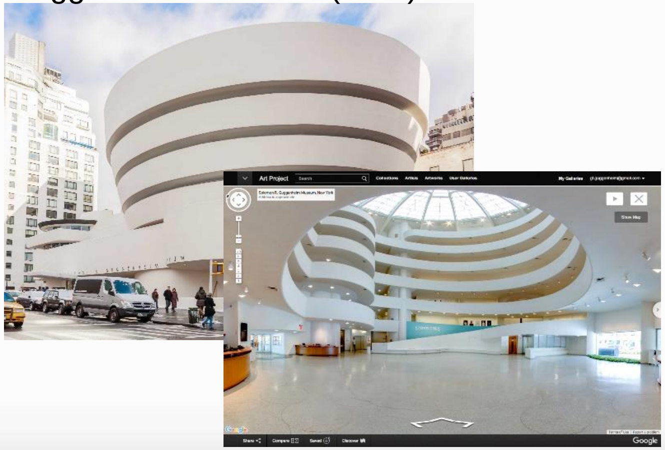
+ Detector occupancy is much lower and could be leveraged to design detector with improved momentum resolution and faster trigger system

- Not charge symmetric, so cannot measure simultaneously $\mu^- \rightarrow e^-$ and $\mu^- \rightarrow e^+$, but no need to measure in-situ background with positrons since RPC background is negligible. Can measure $\mu^- \rightarrow e^+$ with separate run.

PRIME detector concept

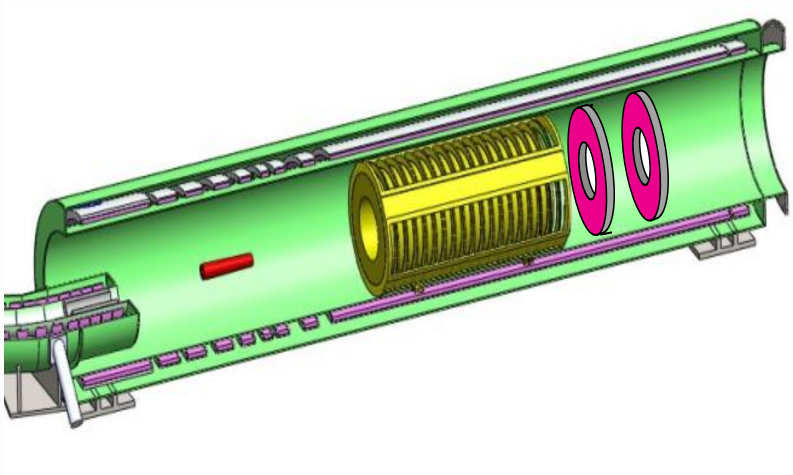


Guggenheim museum (NYC)



Annular detector (à la Mu2e)

- \+ Simpler solenoid system - we (almost) know how to do this
- \+ Charge symmetric detector, simultaneously in-situ measure $\mu^- \rightarrow e^-$ and $\mu^- \rightarrow e^+$
- \- Large detector occupancy, track reconstruction more challenging and more stringent constraints on radiation hardness
- \- More difficult for trigger



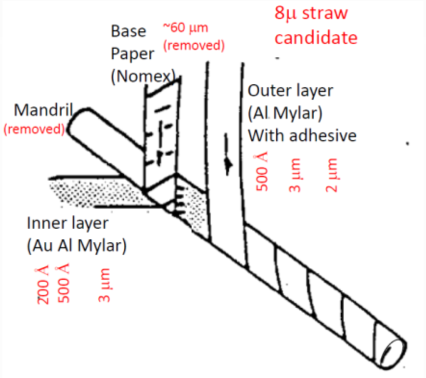
Comments on these two approaches?

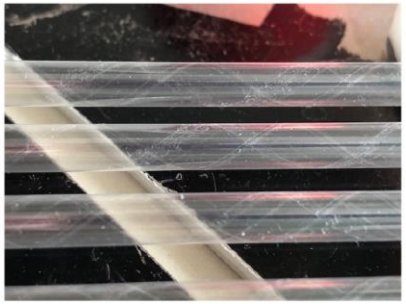
Any other idea?

Need to improve tracking resolution to reject DIO by a "large factor" - see Andrei's talk for the definition of "large factor"

Straw tracker with thinner straws – see Dan's talk

- LDRD to develop 8 μm Mylar straws using 3.5 μm Mylar + 1 μm adhesive + 3.5 μm Mylar double helical wrap
- Held 15 PSI for multiple days and 400 g tension without visible distortion
- Handling straws with internal outward force without causing obvious damage
- Almost no compression force can be applied, making the installation of straw termination challenging





Pressurized 8 μm Mylar Straws

What is the ultimate performance? Limiting factors (thickness, length)?

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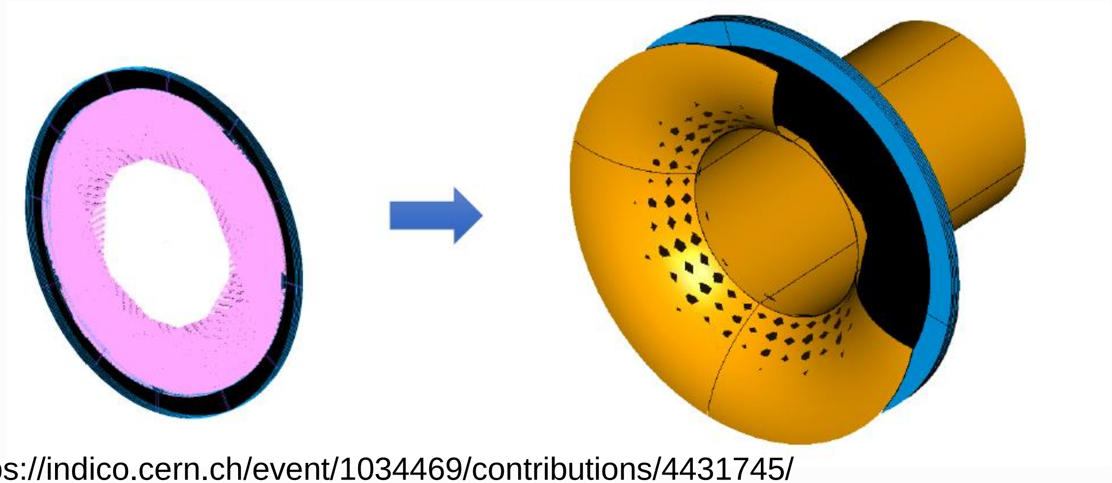
Alternative designs

- ultra-light pressure vessel to ease requirements on straw leakage while keeping Mu2e straw layout, i.e panel geometry (G. Tassielli)



https://indico.cern.ch/event/1034469/contributions/4431745/

Tracker considerations

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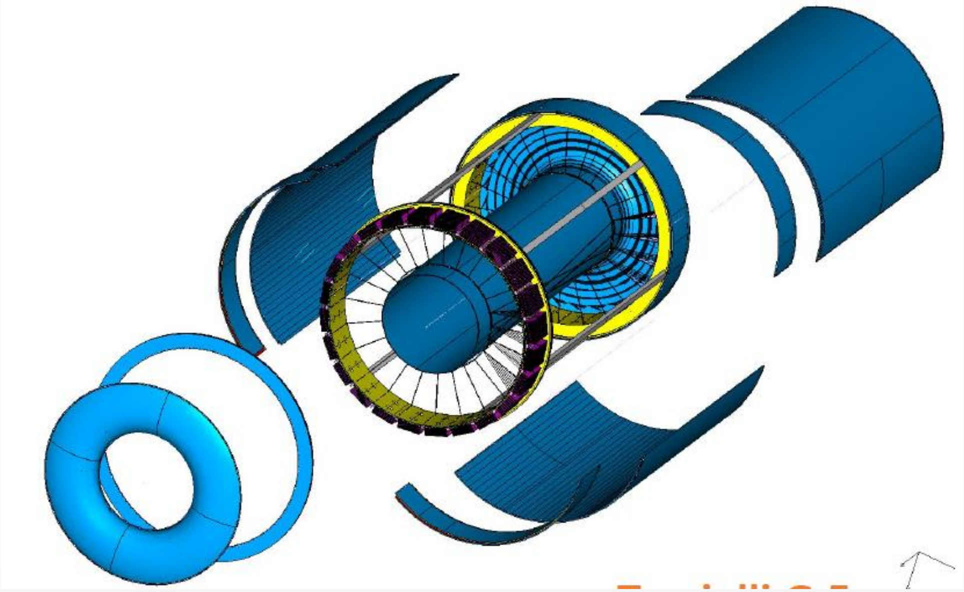
- ultra-light pressure vessel to ease requirements on straw leakage while keeping Mu2e straw layout, i.e panel geometry (G. Tassielli)
- Construct a high granularity and high transparency drift chamber à la MEG II (G. Tassielli)



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MEG-II drift chamber 1801.04688

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- I-tracker?
- Investigate potential of low-mass silicon sensors (e.g. HVMaps), MPGD, ….
- Other ideas – see Dave's talk

Any other technology / idea? How do we assess performance?

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Other consideration – See Richie’s talk

- How does the reconstruction performance (i.e. momentum resolution) compare between an annular tracker and a full tracker? Need to consider effect of multiple scattering in target as well.

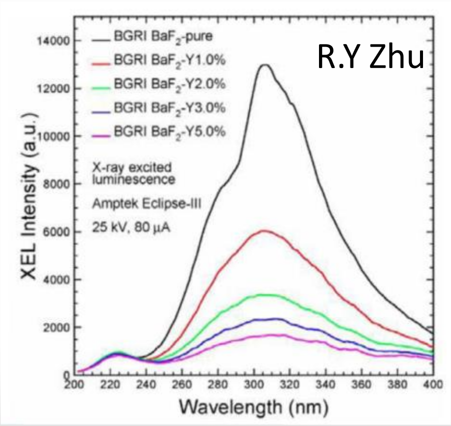
Any other technology / idea? How do we assess performance?

Calorimeter considerations

Calorimeter requirement strongly dependent on the type of detector

Annular detector (high occupancy)

- Need ultra-fast and radiation hard device in a setup like Mu2e
- BaF_2 calorimeter with UV-sensitive, solar blind photo-sensor?
    - Fast components (<1 ns) at 195 and 200 nm
    - Can support > 1 Mrad radiation dose
    - Yttrium doping can suppress slow component by factor x5 without reducing fast signal
    - Develop photo-sensor only sensitive to fast component: solar blind UV-sensitive SiPM /APD,…
    - *Discussed in the Mu2e-II calo session, along with other options*



Calorimeter considerations

Calorimeter requirement strongly dependent on the type of detector

Annular detector (high occupancy)

- Need ultra-fast and radiation hard device in a setup like Mu2e
- BaF_2 calorimeter with UV-sensitive, solar blind photo-sensor?

Full detector (low occupancy)

- Much less stringent requirements - a singe disk with moderate rate capabilities should suffice
- Could provide efficient, fast trigger

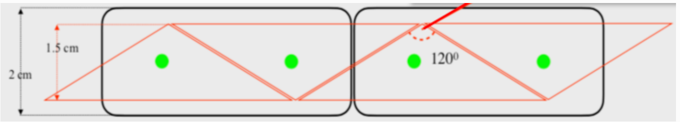
Any other technology / idea? How do we assess performance?

CRV considerations

Cosmic ray background must be vetoed with better efficiency

Veto performance – see Craig's talk

- Cosmic induced background scales with exposure, not instantaneous muon rate (good news!)
- Neutron production scales with instantaneous muon rate (bad news)
- Cosmic induced background is significant for Mu2e, need to reduce inefficiency
  - Triangular bar design
  - Minimize uncovered areas
  - Multi-system veto to reduce inefficiency
  - Investigate other technologies?
- Does neutron production from cosmic ray interaction become a problem?



Any other technology / idea? How do we assess performance?

Moving forward

At the start of the workshop, I set the (very) ambitious goal of having a conceptual design for the next Snowmass / P5

Given the available resources, progress will likely be slow, so we need to start now

How do we:

1) **Organize exploration of parameter space**
2) **Converge on a few concepts**
3) **Assess performance of detector capabilities**
4) **Coordinate the work**

It is not every day you get to design a new experiment from scratch.
This is a very interesting and very fun experience.

Do participate!