

# AMF Conversion Experiments

## Summary

### CalTech Workshop

**Cole Kampa**<sup>1</sup>, Craig Group<sup>2</sup>

<sup>1</sup> Northwestern University, <sup>2</sup> University of Virginia

March 29, 2023

# Session Goals

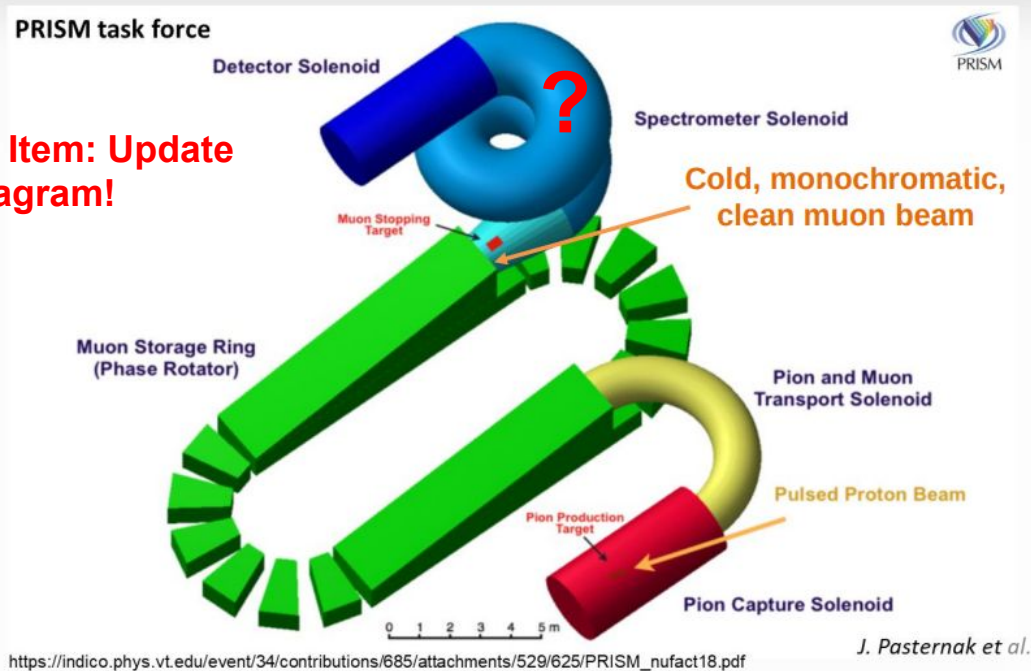
- Where we are picking up from Snowmass is basically a sketch of an experiment. Design concept drawing from PRISM/PRIME concept.
- Now is the time to move from a sketch to a conceptual design report – by the next Snowmass (~10 years). **We need to start now!**
- Once we make some progress along these lines, we would like to have an updated AMF conversion experiment publication (~2 years ?)
- Determine synergies in the muon community (and beyond?)
- Make a list of action items, and determine who can contribute where

We had a lot of great discussion, which I can't fully capture here, but I will do my best to summarize.

# Overview of AMF Conversion Experiment (B. Echenard)

- General discussion of conversion experiments and what are the main shortcomings and difficulties in the current generation of experiments.  
→ Many of these problems can be solved using an FFA!
- We assume in this session that we get a phase rotated beam from an FFA (see Bob's talk for details on the FFA session)
- High muon stopping rate will be a blessing and a curse
  - The good: higher statistical power (among many other benefits with FFA)
  - The bad: very high occupancy in detectors
- This is the motivation for the “Guggenheim” scheme (a spectrometer between the stopping target and the detectors)

**Action Item: Update this diagram!**



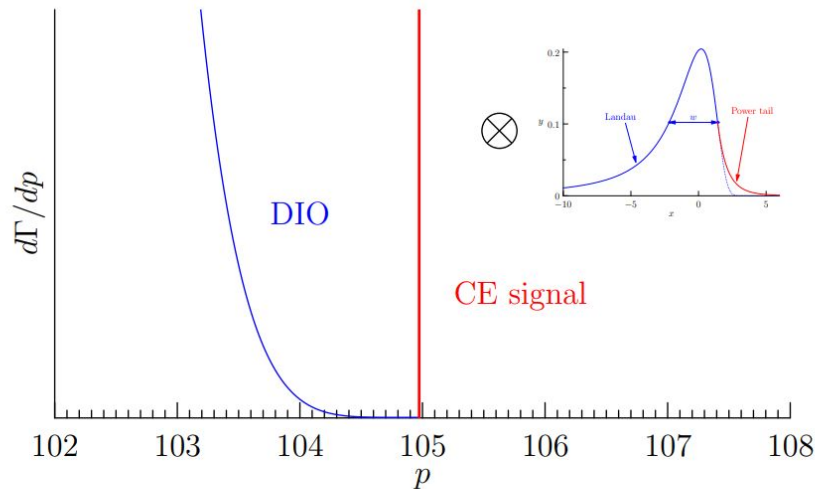
- We spent a lot of time staring at this cartoon and discussing...
- Emphasized importance of thinking about  $\mu^-$  and  $\mu^+$ .
- Lots of questions about all of the blue parts – one common theme, is “Guggenheim” really the best? Why a “C” shaped config? Could an “S” shaped config work?
- Short discussion on the annular design, but it seems that the general feeling is a desire to pursue the spectrometer option.
- **Action Item: Map out acceptance of different configurations.**

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

# Signal Resolution Requirements (A. Gaponenko)

- Developed a tool for estimating relationship between physics reach and detector momentum resolution.
- Motivation: DIO likely to be a driving background of AMF experiment that can only be reduced by improving detector resolution.
- Using a simple detector momentum resolution function:
  - Landau function (core + radiative tail) – parameter  $\sigma$
  - Power law (high side tail) – parameter  $s$
- Procedure for a choice of  $\sigma$  and  $s$ :
  - Using theoretical signal and background spectra, convolve with resolution function to estimate detector response.
  - Cut & count analysis to estimate sensitivity ( $5\sigma$  discovery reach)

## Theoretical spectra



Czarnecki, Tormo PRD84(2011)013006

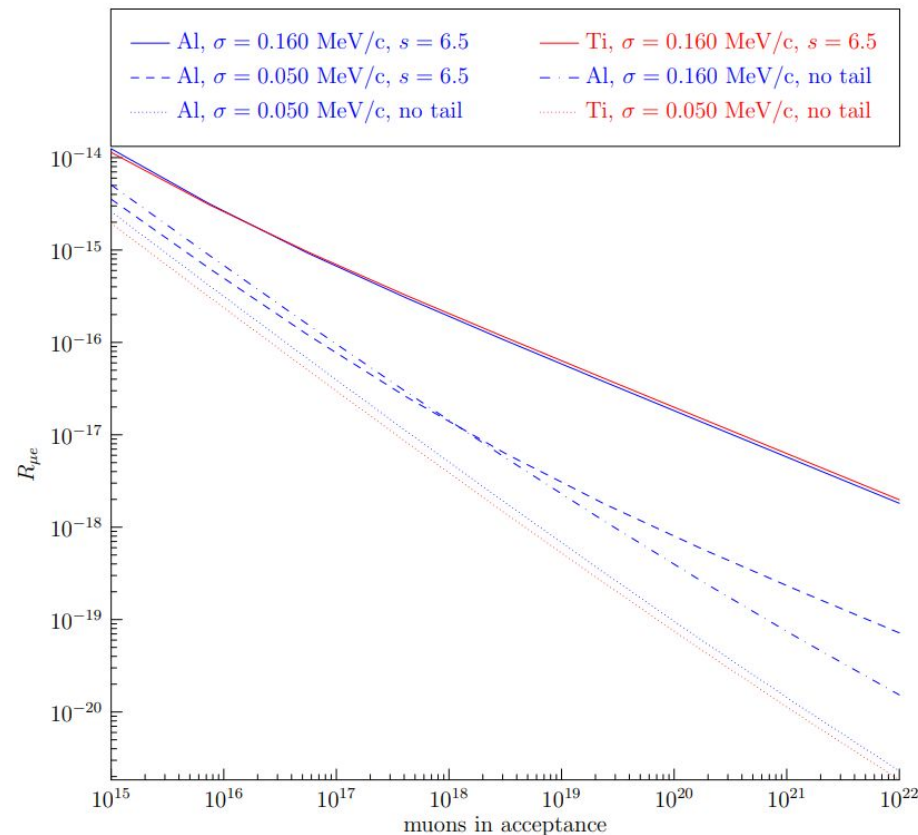
Andrei Gaponenko

8

2023-03-28 Future muons

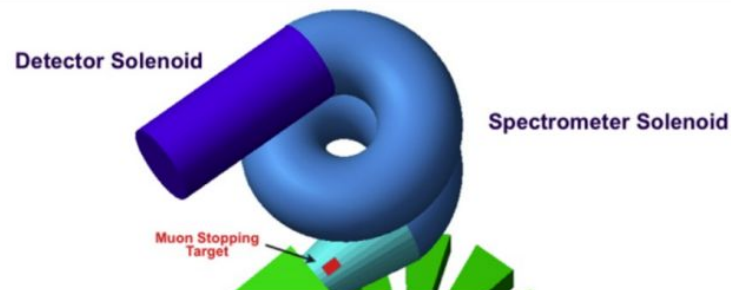
→ To get to  $O(10^{-20})$ , it will be important to reduce both the core and the tail

**Action item: use tool on a few higher-Z stopping targets (e.g. Au).**



# Discussing an AMF Tracker (D. Ambrose)

## Evolution of Requirements



### Mu2e's Requirements

- **No mass  $r < 38$  cm, Low mass  $38 \text{ cm} < r < 70$  cm** —————> No longer relevant
- **Electron momentum resolution:  $< 180$  keV/c at 105 MeV/c** —————> Optimize for resolution, Needs improvement for DIO discrimination. Sub 100 keV/c range
- **Efficiency for acceptance and reconstruction of 105 MeV/c electron tracks:  $>20\%$**  —————> This is more dependent on optimizing the spectrometer solenoid. Expect high efficiency of electrons that enter tracker.
- **Outgassing rate :  $< 6$  sccm** —————> Leak rate is an issue but wider range of technology available
- **Hit rate:  $> 5\text{MHz/channel}$ , 500 ns after proton bunch hits production target** —————> No beam flash, significantly less radiation, more room for shielding. Spectrometer solenoid curates the electron spectrum.
- **Access :  $< \text{once per year}$**  —————> Possibly harder to access with more shielding in place.
- **Operation time:  $> 10$  yrs**

→ Environment imposes far fewer constraints than those on the Mu2e/Mu2e-II tracker.

3/28/23

D. Ambrose, Future Muon Program at Fermilab Workshop

6

# Track to the Drawing Board

D. Ambrose

Straw Tube Proportional Tracker	Multi-wire Proportional Chamber Tracker	Gas Electron Multiplier (GEM) Tracker	Newer Technologies
Pros: Highly segmented  Good intrinsic momentum resolution  A lot of experience on hand  Cons: Many small gas volumes and surfaces to leak  Hard to manufacture	Pros: Less intrinsic mass -Helium?  One large gas volume  Easier to manufacture  Plenty of experience on hand  Cons : Less segmented than straws	Pros: Very easy to manufacture  Variable geometry  One large gas volume  Cons: Limited experience on hand(?)  Intrinsic Mass(?)	"Novel Sensors for Particle Tracking: A Contribution to the Snowmass Community Planning Exercise of 2021"  <a href="https://arxiv.org/pdf/2202.11828.pdf">https://arxiv.org/pdf/2202.11828.pdf</a>  We have time to do some R&D

"low-mass silicon sensors, such as HVMaps or micro-pattern gas detectors proposed for the Belle-II tracking TPC"

**Action item(s): Which options are people interested in pursuing? What is the necessary R&D?**

3/28/23

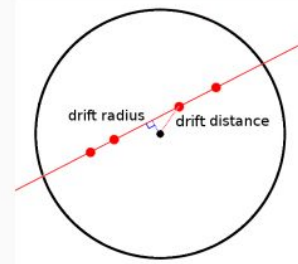
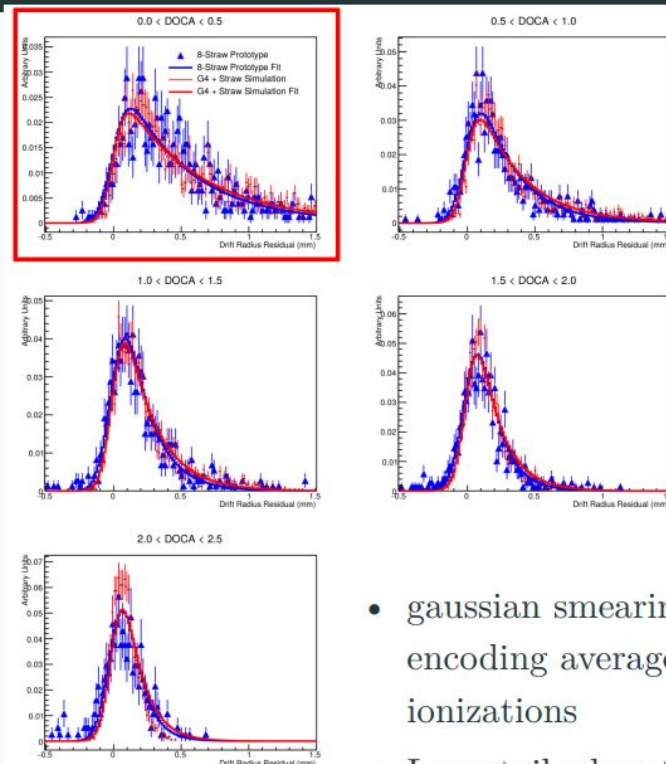
D. Ambrose, Future Muon Program at Fermilab Workshop

9

# (Straw) Tracker intrinsic resolution, electronics, readout (R. Bonventre)

- Requirements on straws and readout will depend on which particles actually make it to the Tracker.
  - This will depend on the design we pursue for AMF.
- In Mu2e Tracker, drift resolution depends on impact parameter w.r.t. anode sense wire.

## Drift response in Mu2e



- gaussian smearing  $\times$  exponential encoding average spacing between ionizations
- Long tail when track near wire

- Lower gas pressure, lighter gas
  - worse ionization statistics, worse diffusion, higher gain
- Increase HV, thinner wire: increase gain, lower threshold
  - Trigger on single cluster?
  - Electrostatic stability, space charge effects?
- Slower gas
  - Better drift resolution, futher separate clusters, worse pileup
- Higher bandwidth
  - Better rise time, longitudinal resolution, more noise
- Better shaping, digitization for TOT
  - accurately measure end of pulse
  - improvement on  $t_0$  helps with pileup
- Cathode readout - additional measurement, 4x coincidence
- Cluster counting

# Sketching a Simulation Scheme (D. Brown)

## Action items:

**Discuss with Tom Roberts (Muons Inc.) about capabilities and status of G4Beamline and which stages we may use it in.**

**Develop a plan now for the connection between the pieces for our current needs (small studies to inform design)**

## Proposal: Compartmentalized Simulations

- G4Beamline for proton beamline
- G4/Mars for production target
- Standard accelerator simulation tools for FFA (?)
- G4 for muon stopping, daughter production
- G4Beamline for muon daughter transport (?)
- TrackToy for detector modeling
  - Fast, flexible
  - Needs upgrades
- How do we connect the pieces?

# Considerations for CRV (C. Group)

## Summary

My feeling is that significant work on an AMF CRV isn't critical at this time. The R&D plan for Mu2e-II will explore improvements to detector design and shielding.

While creating an experiment design:

- Care must be taken to allow for significant shielding between pion production target and the CRV, as well as the muon stopping target and the CRV.
- Significant overburden is required to keep the hadronic component of the cosmic rays low.
- Penetrations to the CRV must be considered carefully.

Once design geometry exists:

- Simulations must be run to understand particle fluence at CRV
- Shielding options can be considered
- CRV technologies can be considered

**Action items: make progress on design ideas so that we may work out the details of the CRV requirements and design.**

# A few action items I couldn't fit in previous slides

- Need to determine (working with our FFA colleagues) what the extracted muon beam may look like, and how much flexibility there is based on experiment needs. These details will play a large role in our design (e.g. stopping target)
  - Momentum & time spread
  - Physical size
- Want to understand more about what comes out of an FFA (e.g. acceptance of “junk” that we don't want and may generate backgrounds)
  - Also the downstream question along those lines: from a spectrometer before the detectors, what comes out? Hopefully it is a pure beam of high-energy electrons.
- Consider consequence of no  $e^+$  acceptance. i.e. how hard should we work to measure  $e^+$ 
  - $\mu^- \rightarrow e^+$  signal channel (LNV and CLFV)
  - Calibrations
- Explore more exotic solutions to measuring  $e^+$ 
  - Assay stopping target after the run
  - Split muon daughter beam with toroidal field or dipole field
- Additional considerations for back-extrapolation of tracks to stopping target.

# Planning for the future

- Summarize the session in a report (by Heidelberg CLFV – June 20-22 2023)
- Aggregate action items and prioritization
- Continue to explore synergies in the field
  - Detector R&D (Instrumentation Frontier)
  - MuCol

→ Get more people interested and contributing

→ Options for R&D funding (?)

**Thank you to all who contributed to this session. We had many great talks and discussions!**

**This workshop is just the first step. We need to make an effort to build on this momentum in the coming years. We encourage you to get involved!**

# Backups

# Annular Configuration (Mu2e)

