Status and Progress of LDRD to Improve Stopped Muon Yield for Mu2e-II

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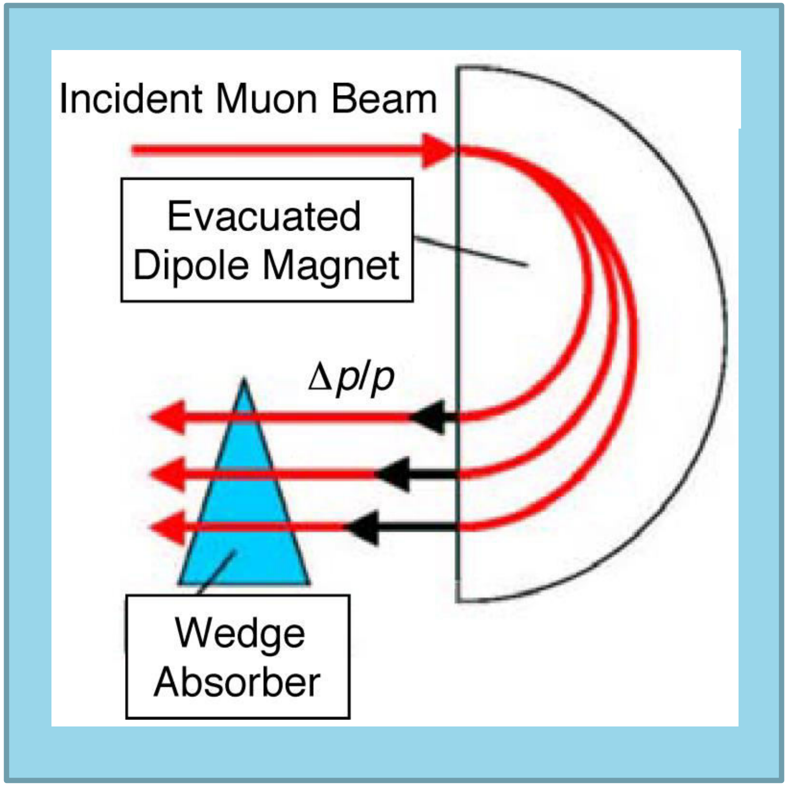
Outline

- Ionization cooling principle
- Fermilab Muon g-2 experiment
  - Motivation for cooling with wedges
  - Expected gain in performance
  - Current status
- Fermilab Mu2e-II experiment
  - Motivation for cooling with wedges
  - Criteria for wedge selection
  - Expected benefits for the experiment
- Summary and ideas for the future

Ionization cooling

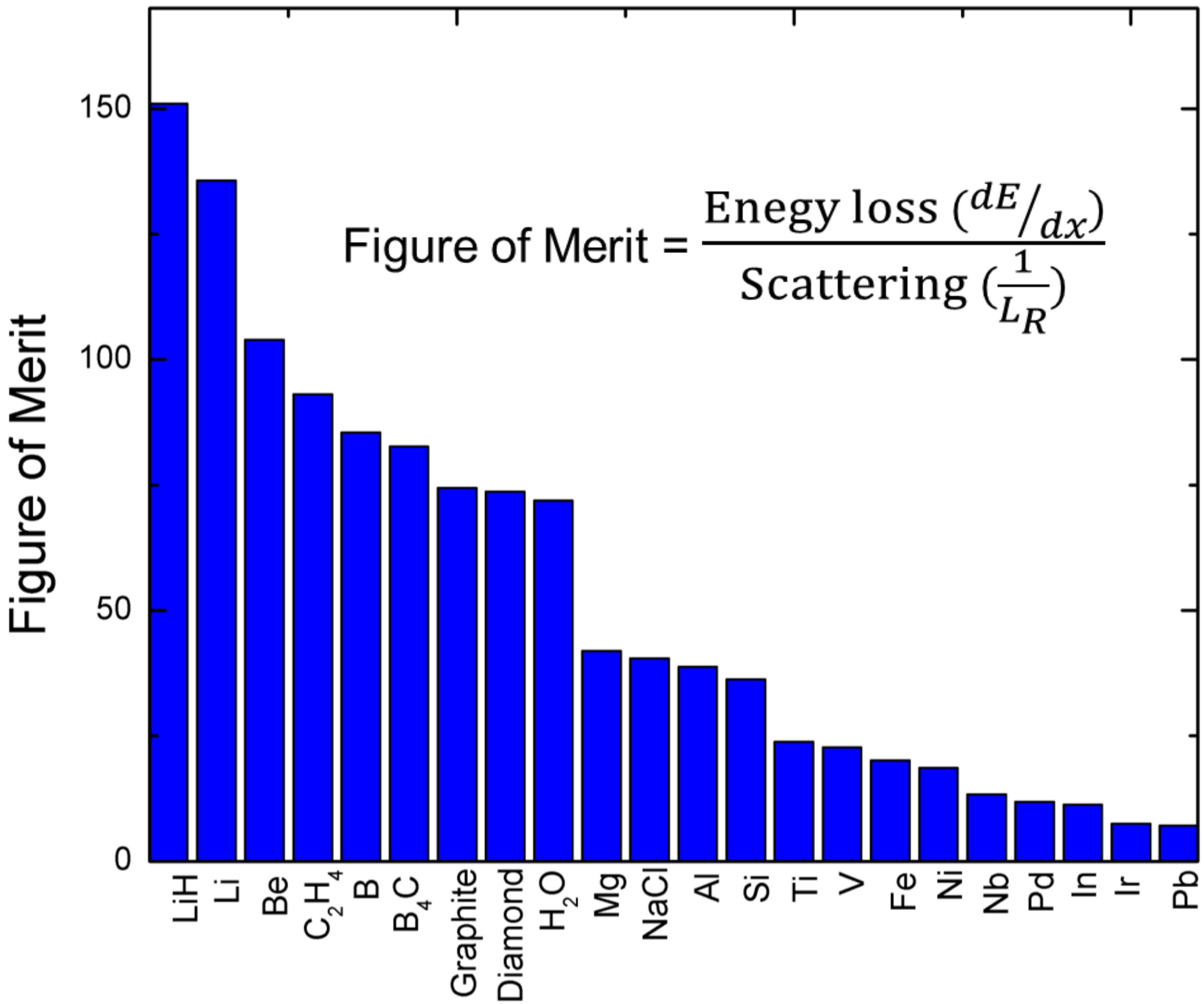
- The idea is to guide muons through a dispersive area, which separates the beam by momentum

- Subsequently the particles pass through a wedge absorber to reshape their momentum distribution



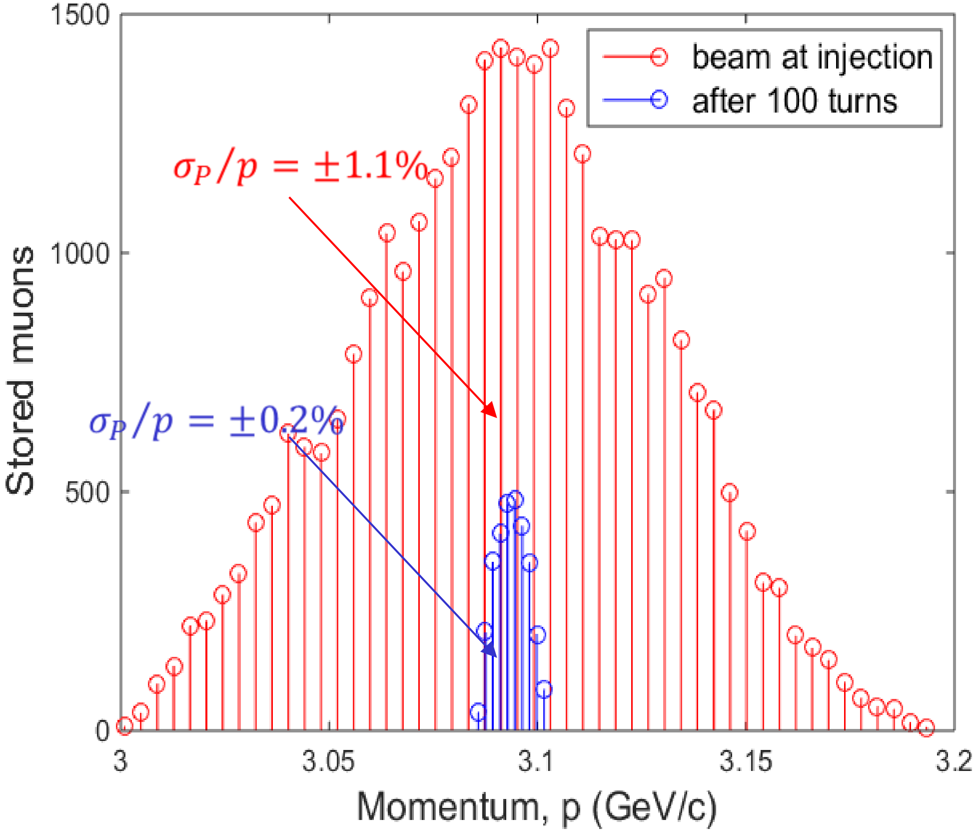
D. Neuffer, D. Stratakis, J. Bradley, *Muon Intensity Increase by Wedge Absorbers for low-E Muon Experiments,* Fermilab 2017

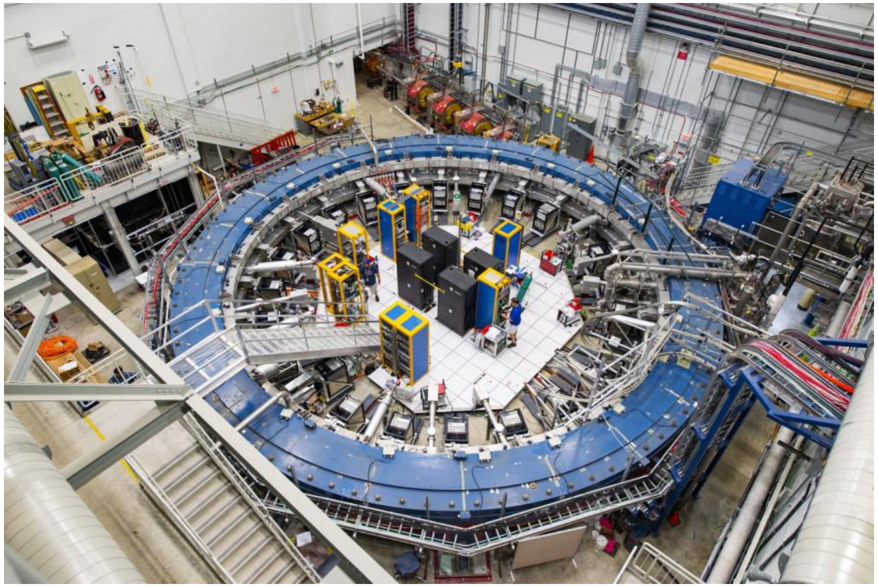
Choice of wedge material



Muon g-2 experiment

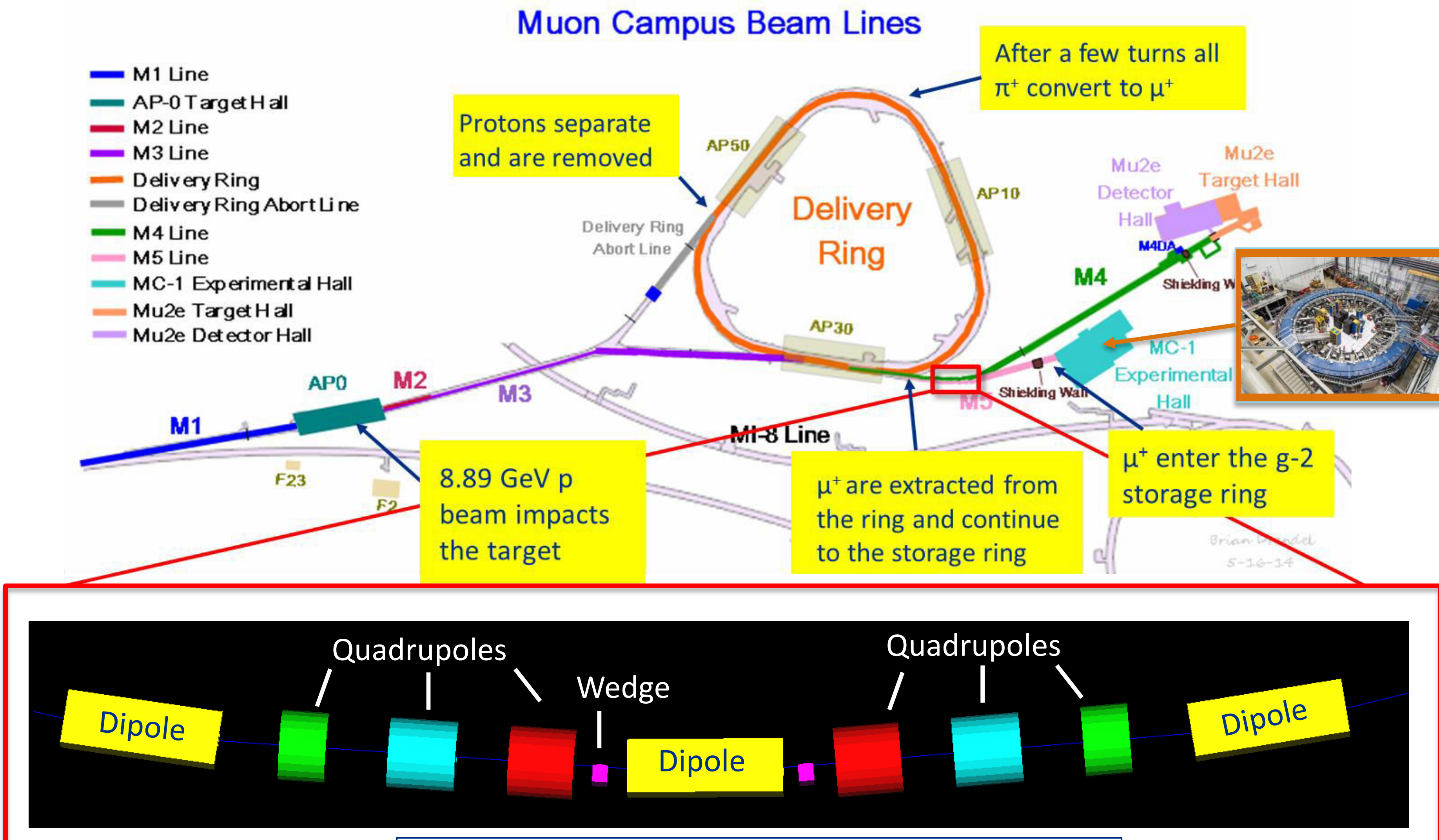
Muon g-2 motivation for muon cooling





- The upstream beamline delivers muons to the ring with a very broad momentum spectrum

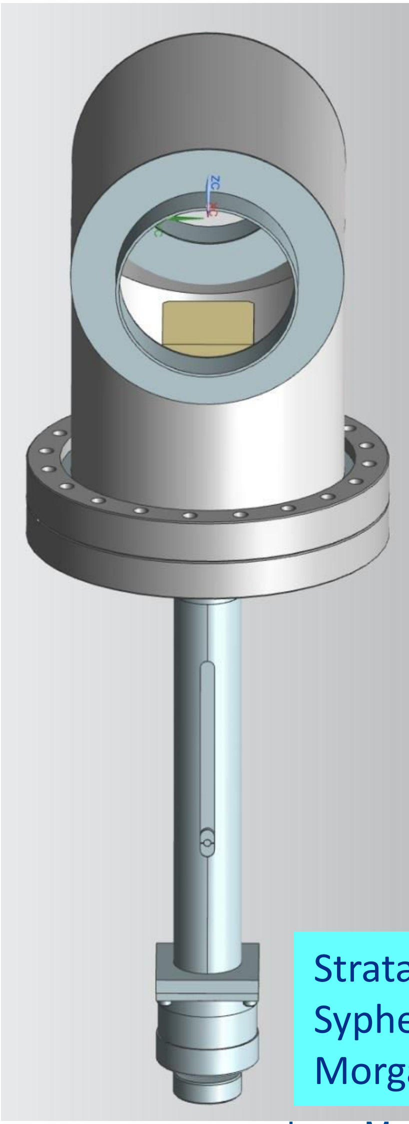
Muon g-2 wedge location along the Muon Campus

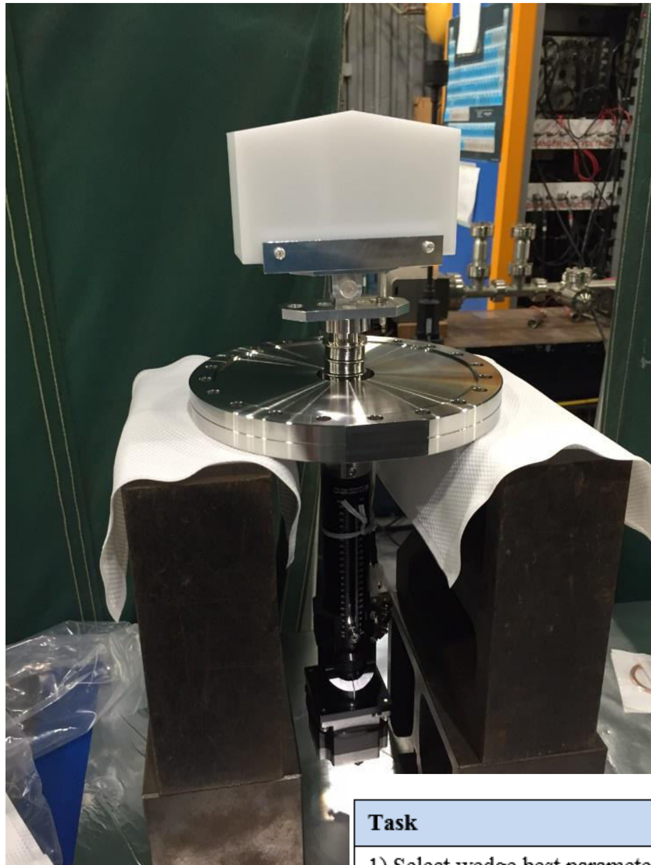


J. Bradley, Fermilab Intern, H. Edwards (2017)

Fully funded proposal to study wedge cooling for Muon g-2

LDRD at Fermilab
Laboratory Directed Research and Development

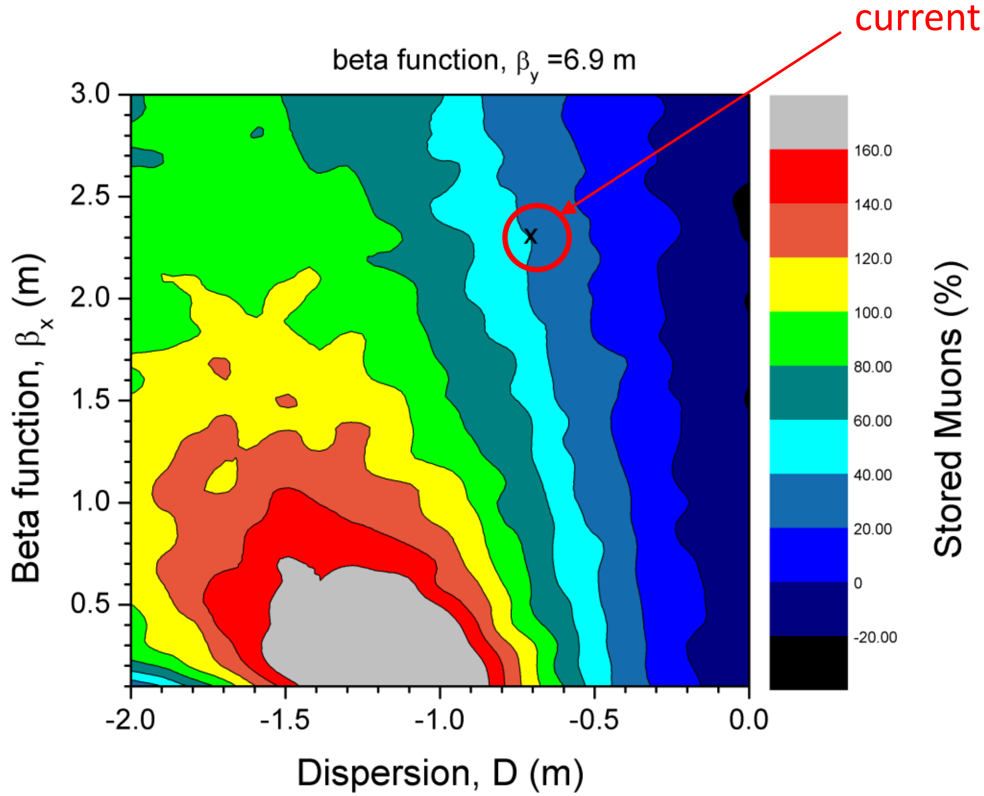




Task	M-18	A-18	M-18	J-18	J-18	A-18	S-18	O-18	N-18
1) Select wedge best parameters	x	x							
2) M4-M5 optics optimization		x	x						
3) Engineering drawings		x	x						
4) Order parts			x	x					
5) Fabrication				x	x				
6) Installing system					x	x	x		
7) Test system							x	x	x

Stratakis (PI)
Syphers (co-PI)
Morgan (coordinator)

Expected performance

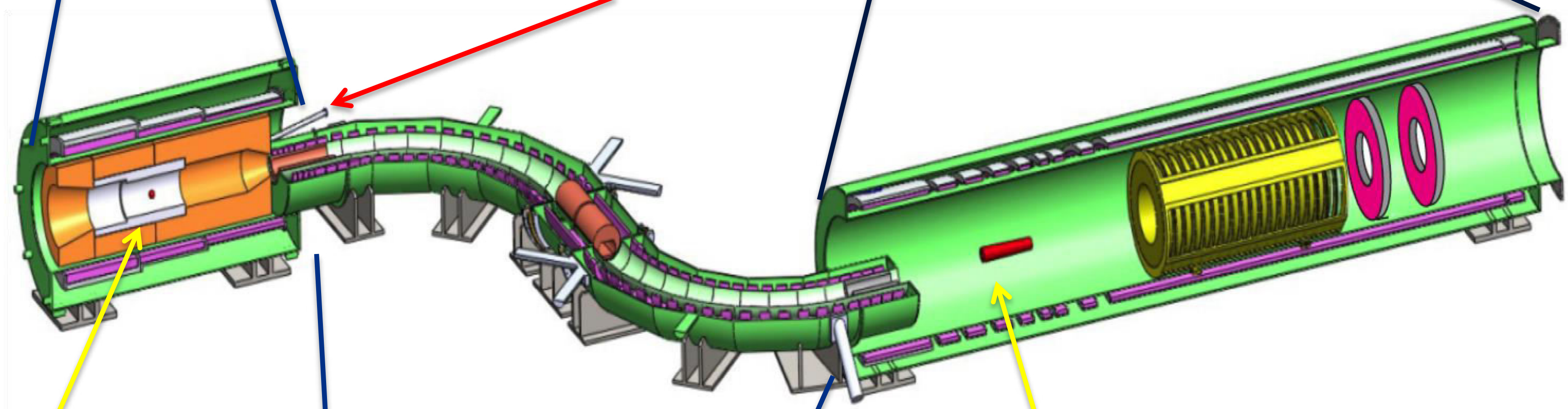


- Colormaps indicate the potential to increase the number of stored muons by more than 20%

J. Bradley et. al., *Initial studies into longitudinal ionization cooling for the muon g-2 experiment,* proceedings of IPAC2018, Vancouver Canada

Mu2e-II experiment

Mu2e apparatus



- For this study, the Mu2e beamline has been used as a baseline with some small modifications

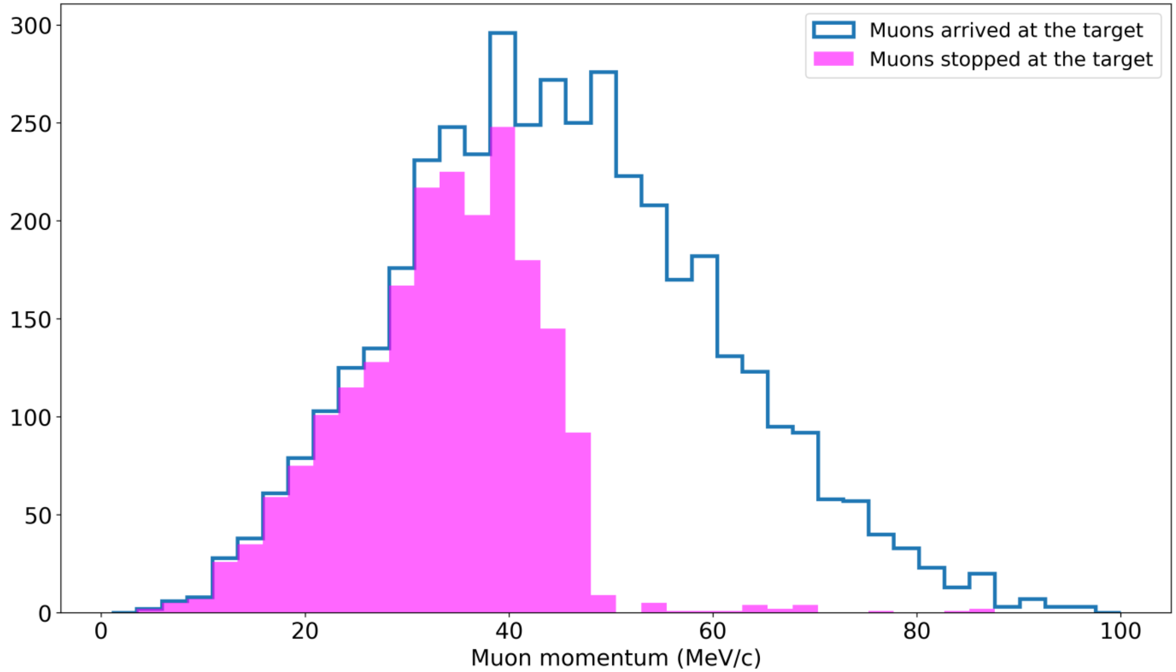
Mu2e Collaboration, *Mu2e Technical Design Report,* arXiv 1501.05241, October 2014

My simulation setup

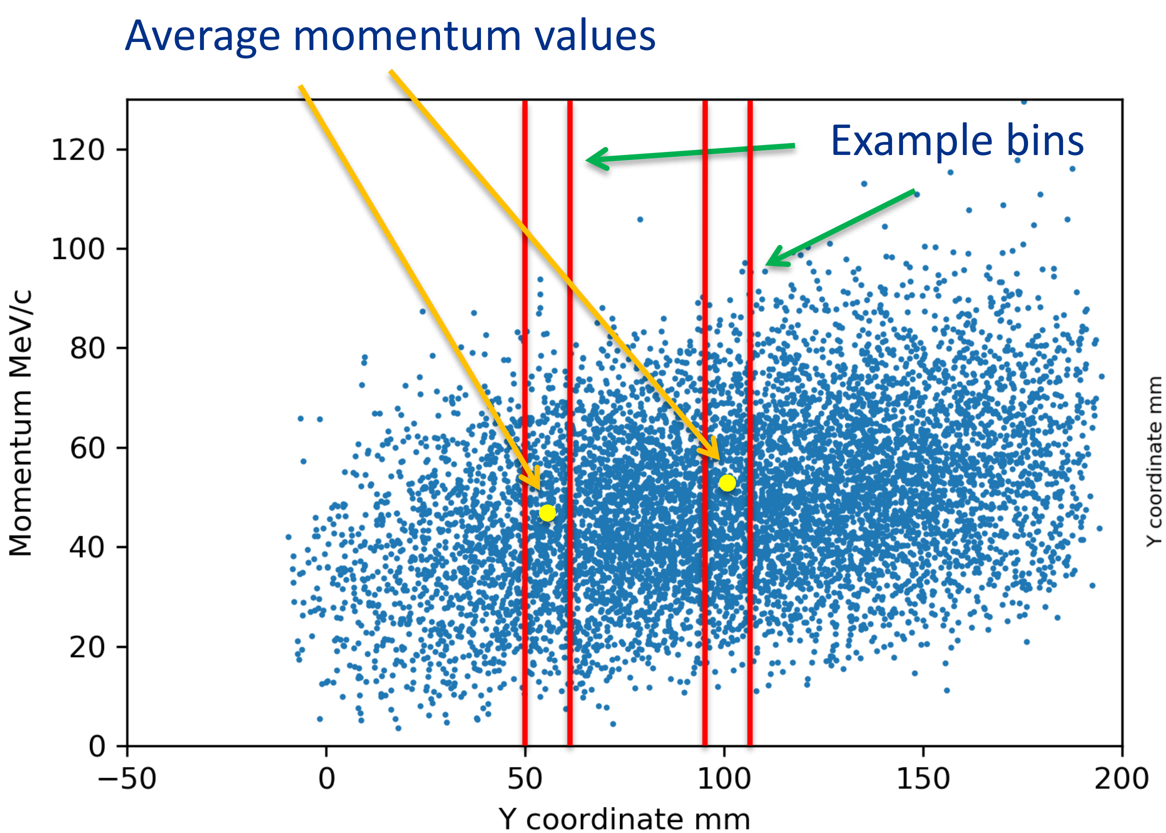
- G4Beamline deck provided by Y. Oksuzian
- Tracking starts upstream the Collimator 1 – I don't generate interactions at the proton target
- Particles distribution is provided by D. Hedin for **800 MeV** input proton beam
- All the simulations were run at NERSC-Edison cluster, which allows to process several millions of particles in a few minutes

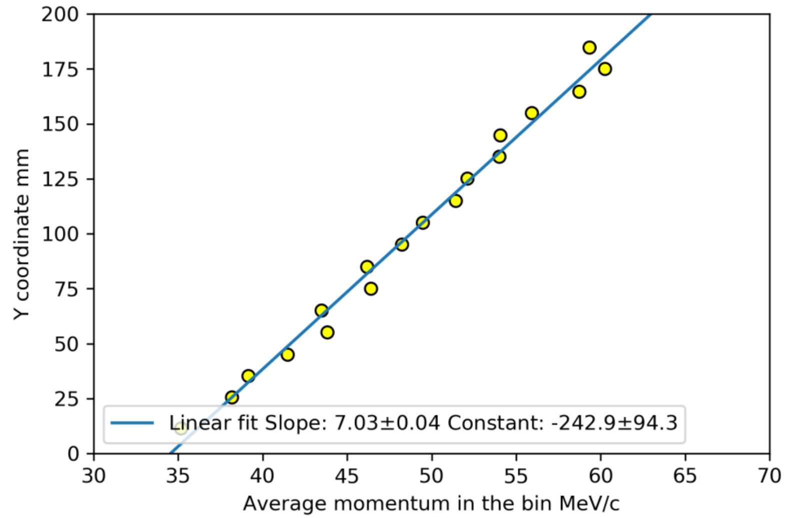
Ionization cooling for Mu2e-II

- The muon beam at the stopping target has a momentum spread up to 100 Mev/c
- Our goal is to increase the number of muons stopped inside the target
- Using the wedge, we want to cool down as many muons as possible to P < ~40 MeV/c



The Wedge – how it is created





- Y corresponds to the vertical distance from the beam center (Y=0 mm)
- The idea is to calculate the average momentum in the chosen bins in Y

Defining the width of the wedge

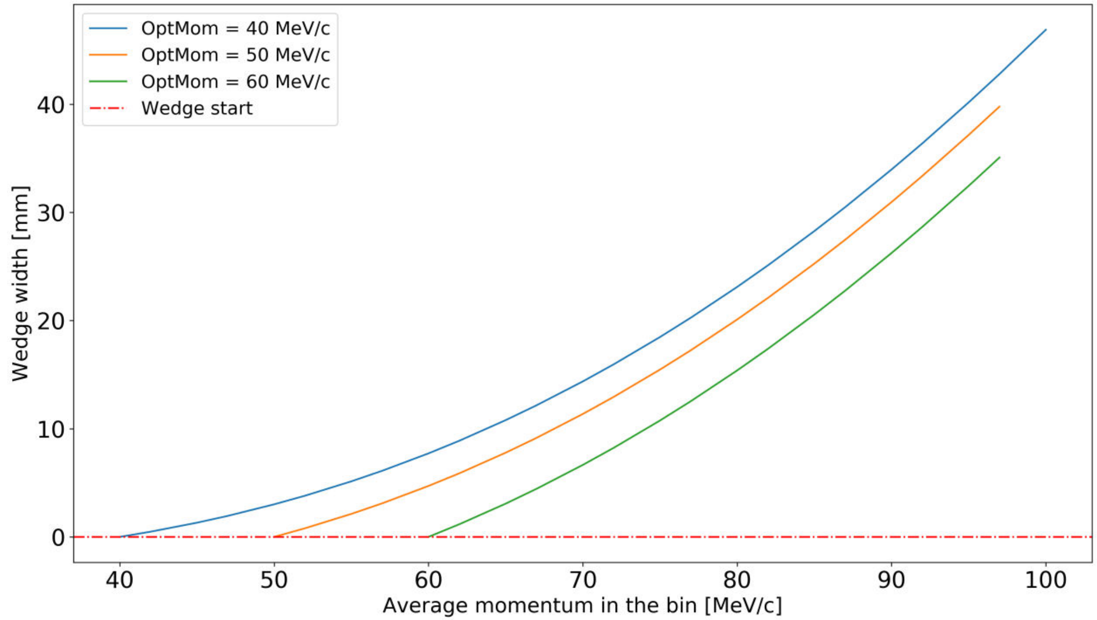
$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 \rho \frac{Z}{A}\left(\frac{1}{\beta^2}\ln\left(\frac{2m_e c^2\gamma^2\beta}{I}\right) - 1 - \frac{\delta}{2\beta^2}\right)$$

Bethe Bloch formula

$$\int_{OptMom}^{AvgMom} \frac{dE}{dx}(P)dp = \text{wedge width}$$

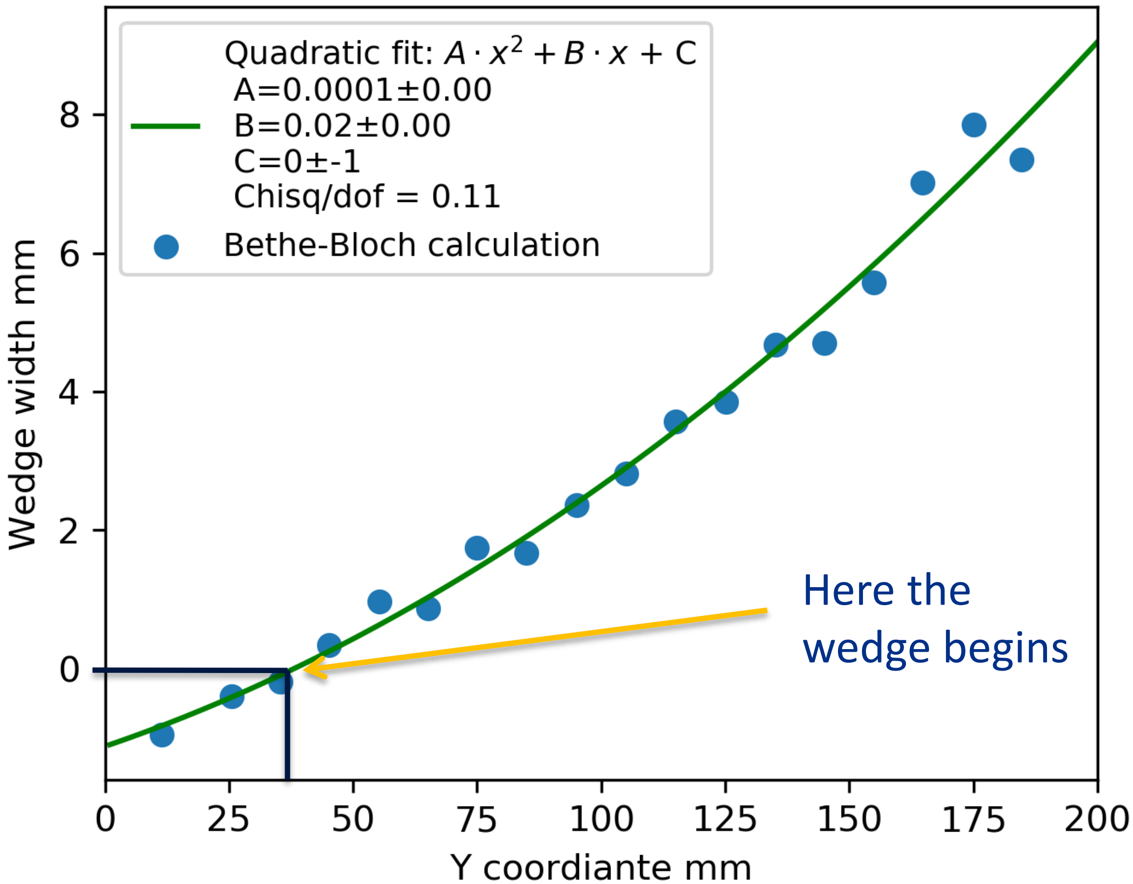
OptMom – Optimization momentum

AvgMom – Average momentum in the bin

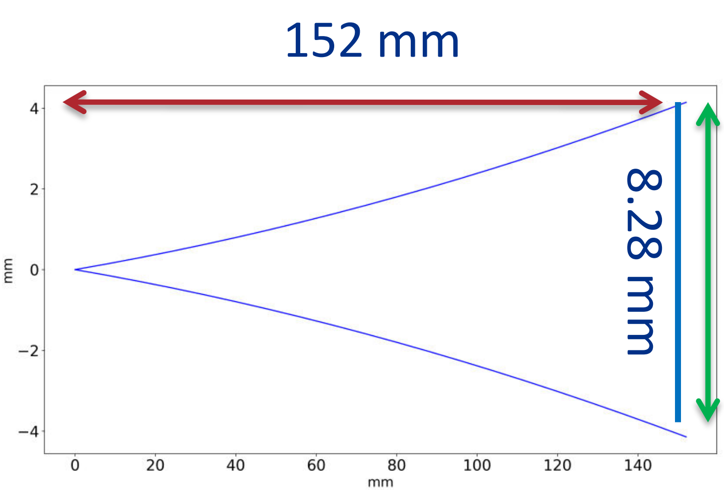


- OptMom is the desired final average energy that we want to obtain with the wedge
- OptMom values between 40-70 MeV/c were tried in the simulations

Mu2e-II wedge – how it is created

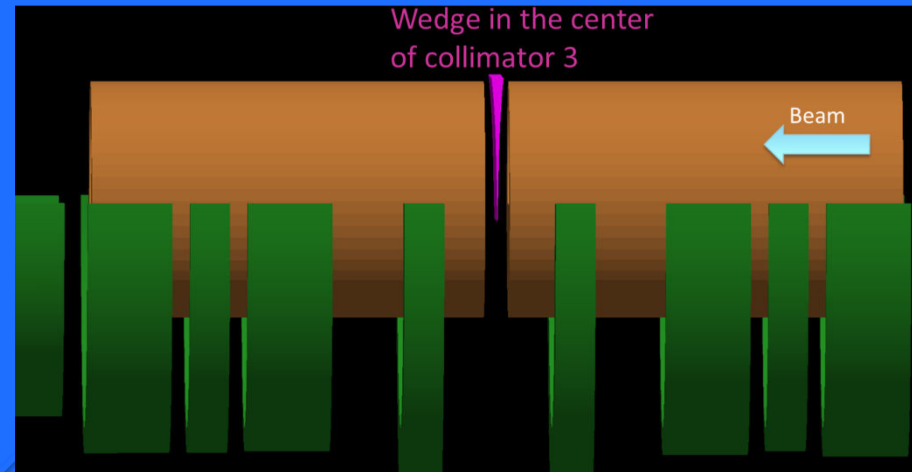


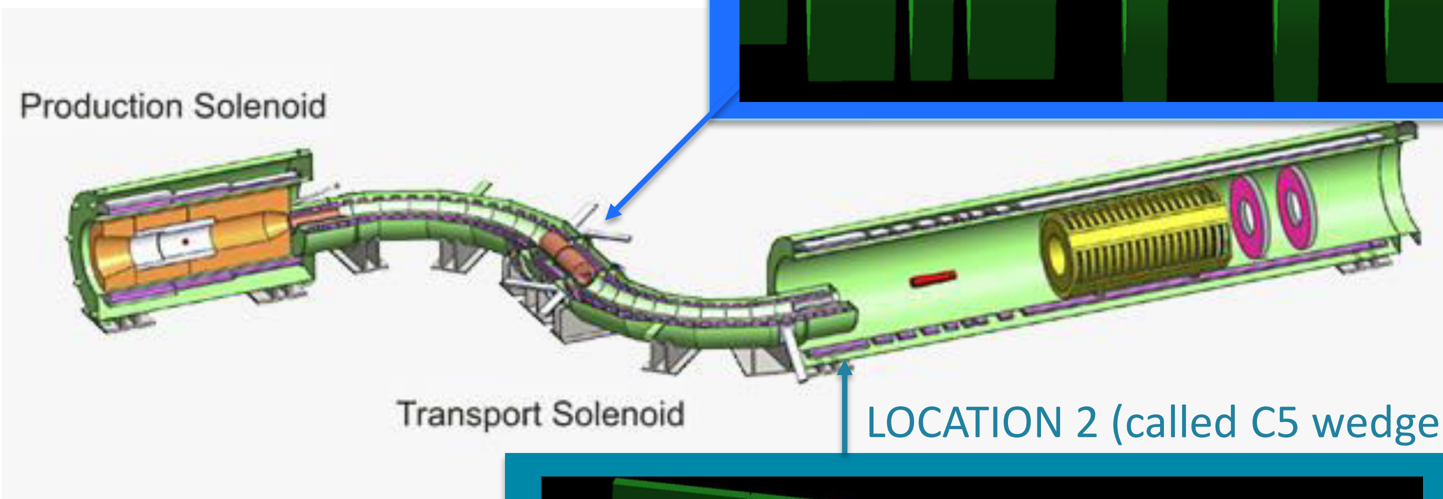
Wedge dimensions for berylium



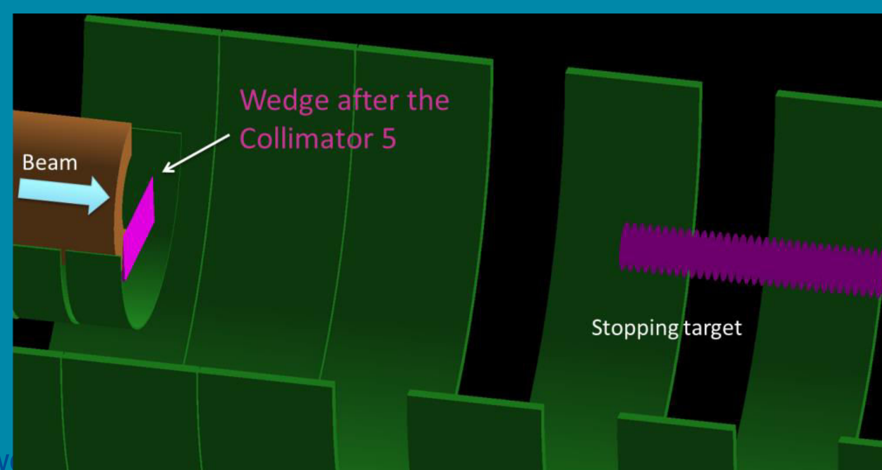
Wedge position

LOCATION 1 (called C3 wedge)



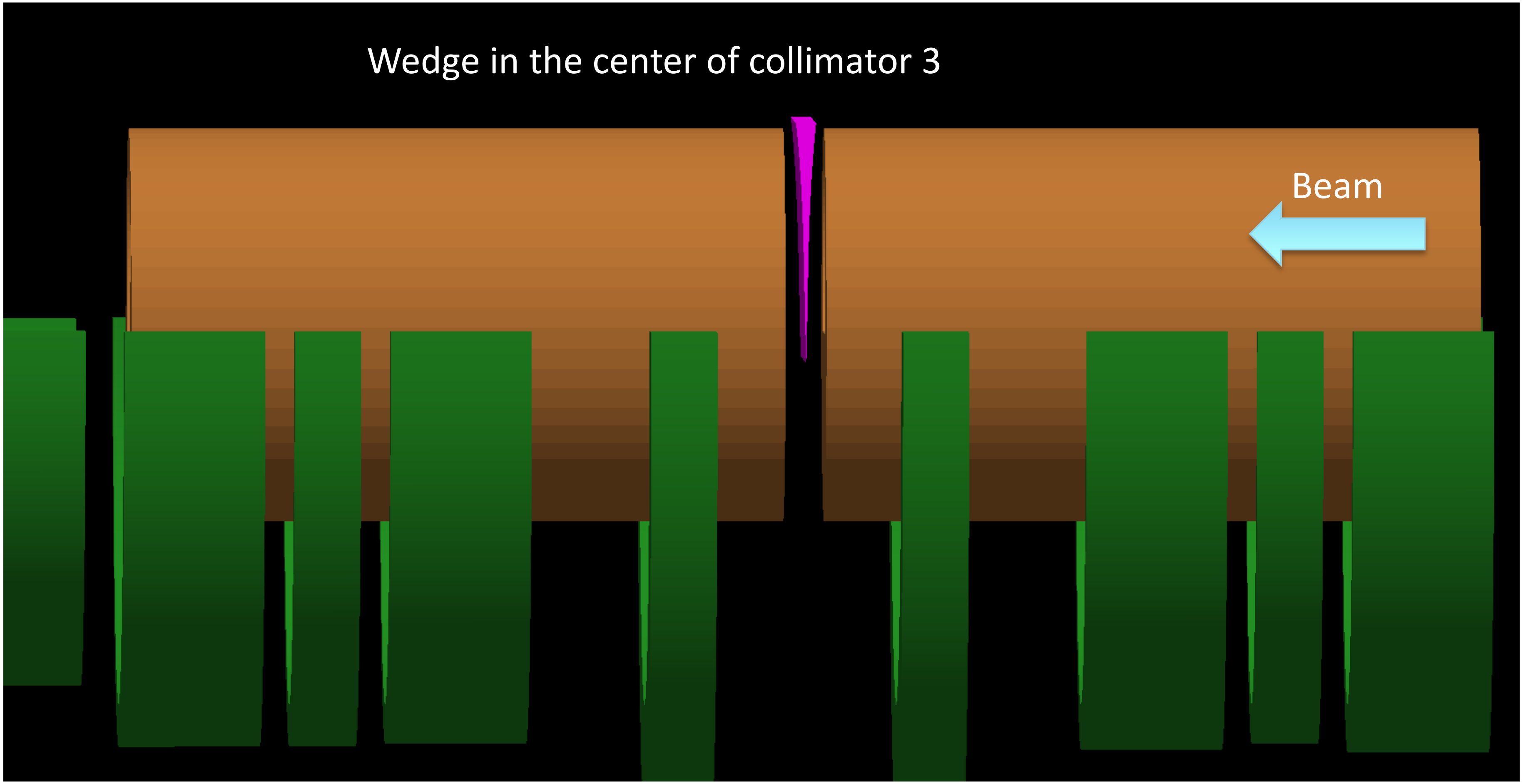


LOCATION 2 (called C5 wedge)

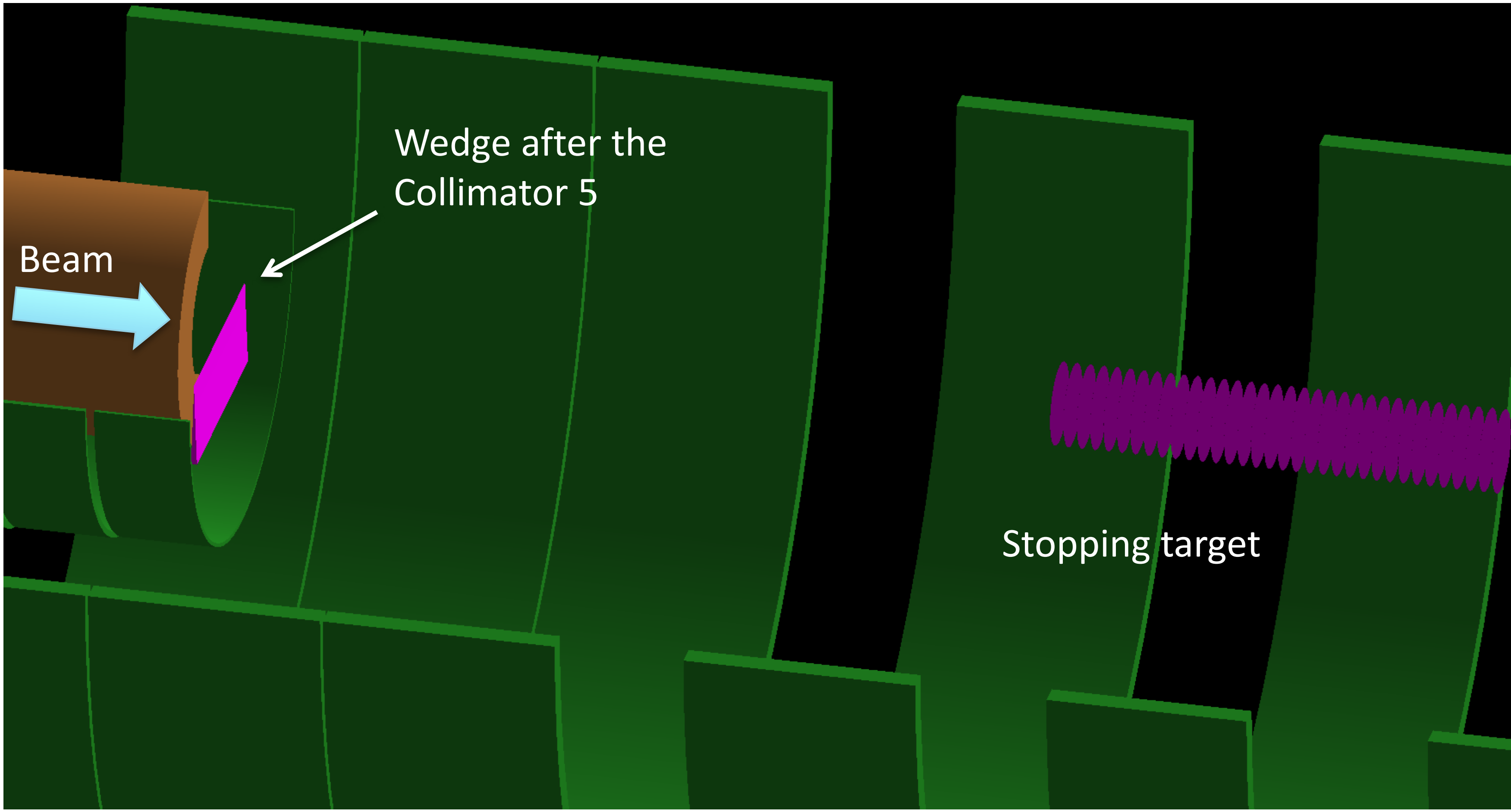


Fermilab

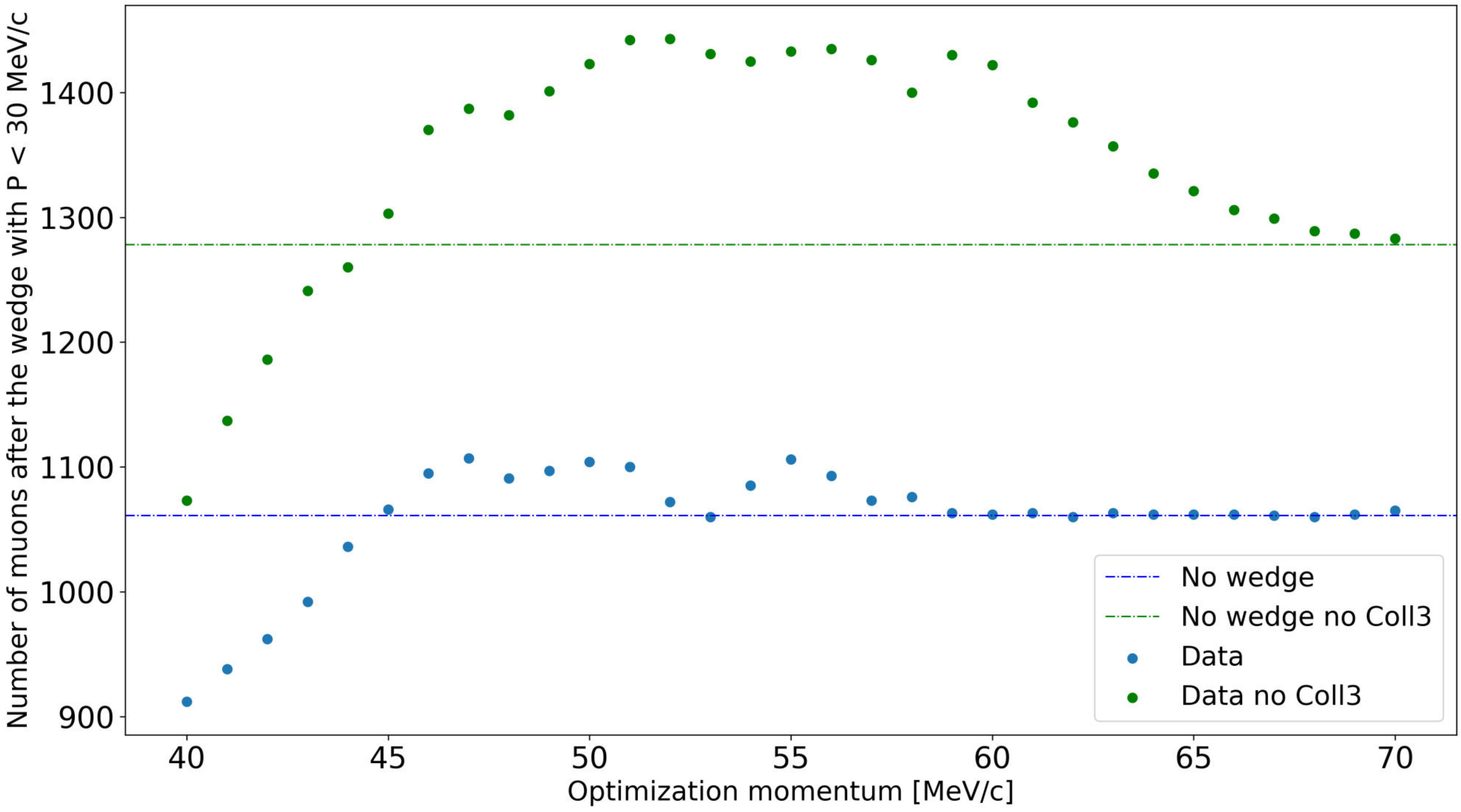
C3 wedge position zoomed in



C5 wedge position zoomed in

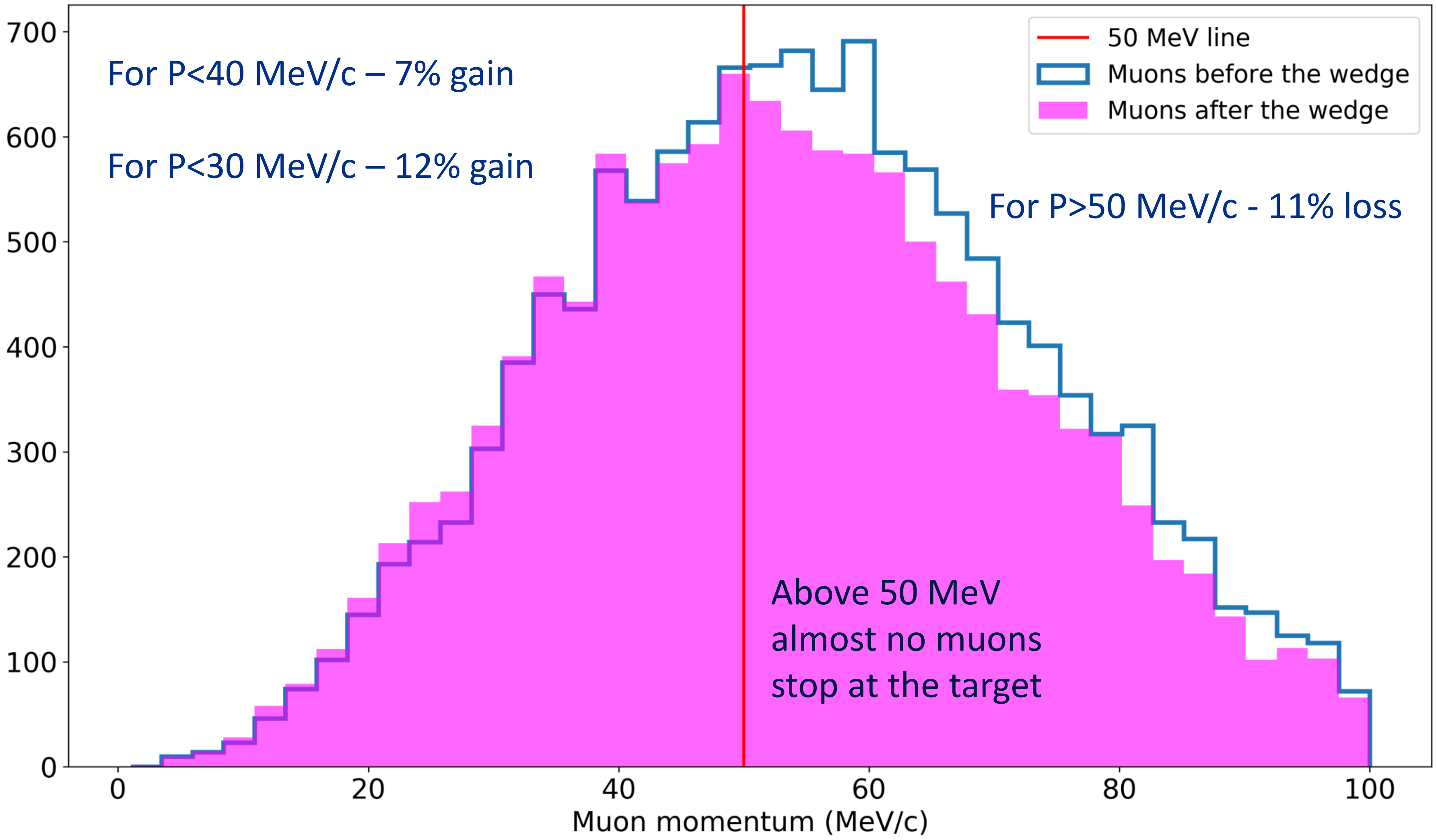


C3 wedge results

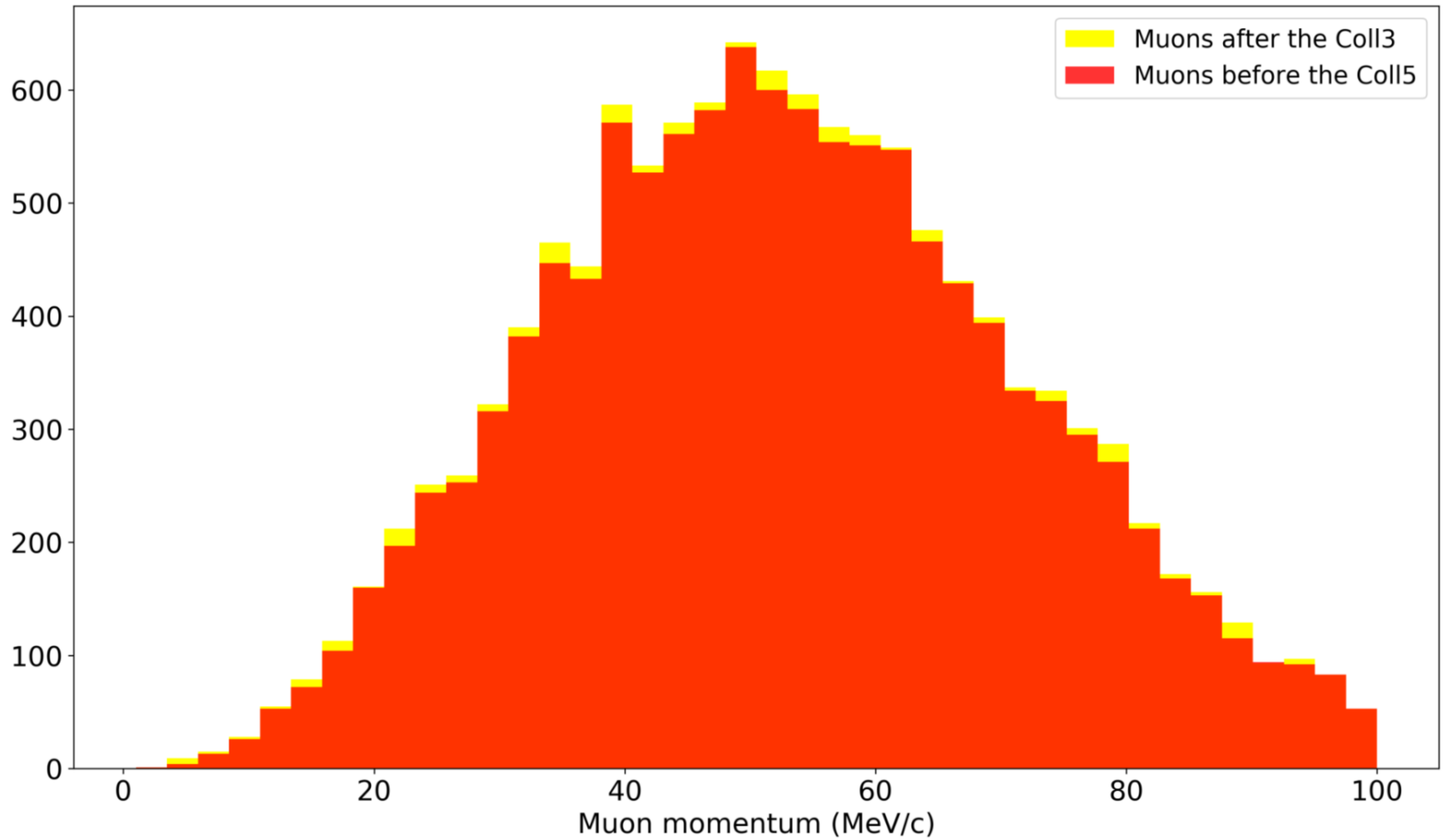


- This plot indicates that for optimum performance of a wedge the collimators may need to be redesigned

Performance of C3 wedge – 59 MeV OptMom, noC3

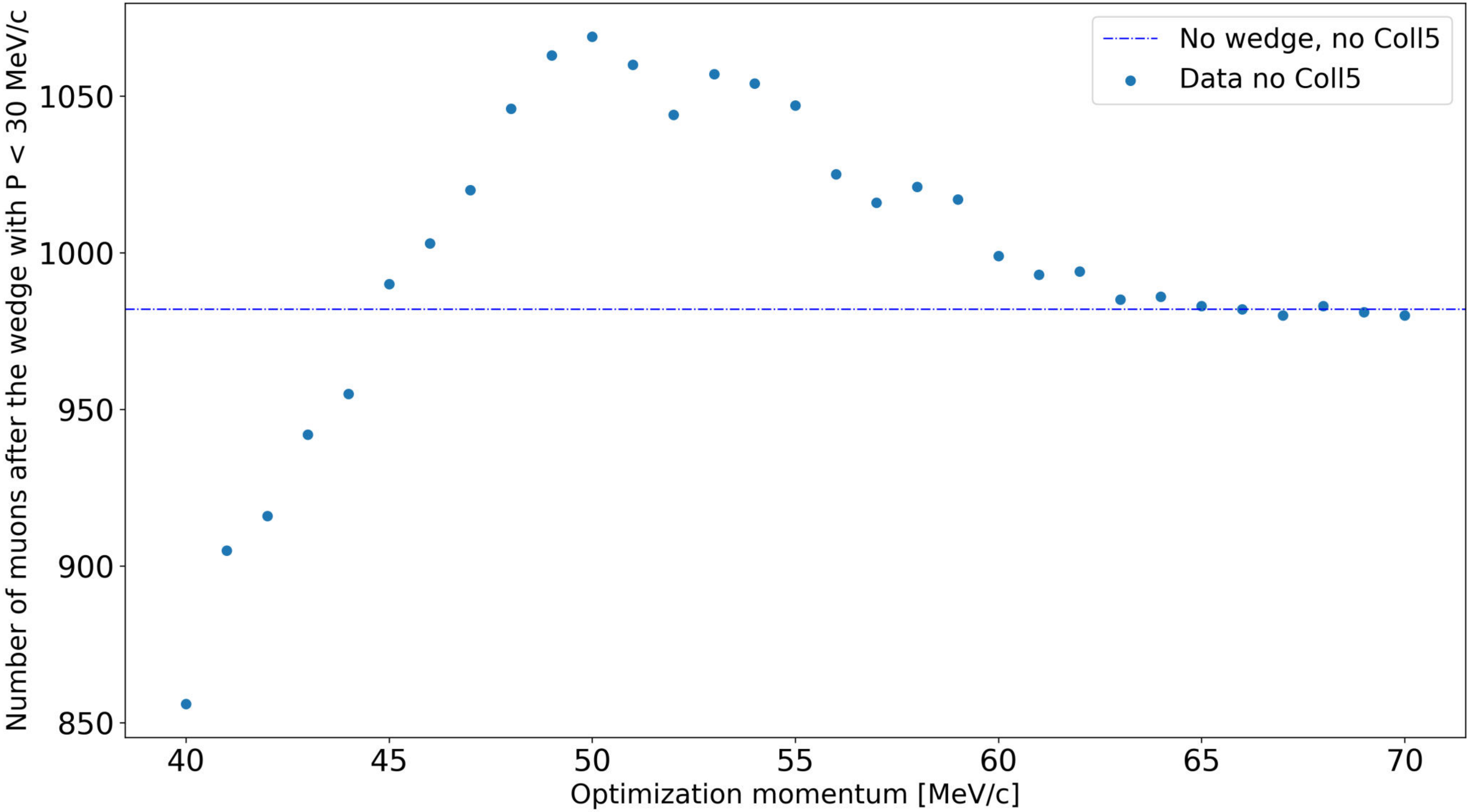


Beam propagation downstream the C3 wedge

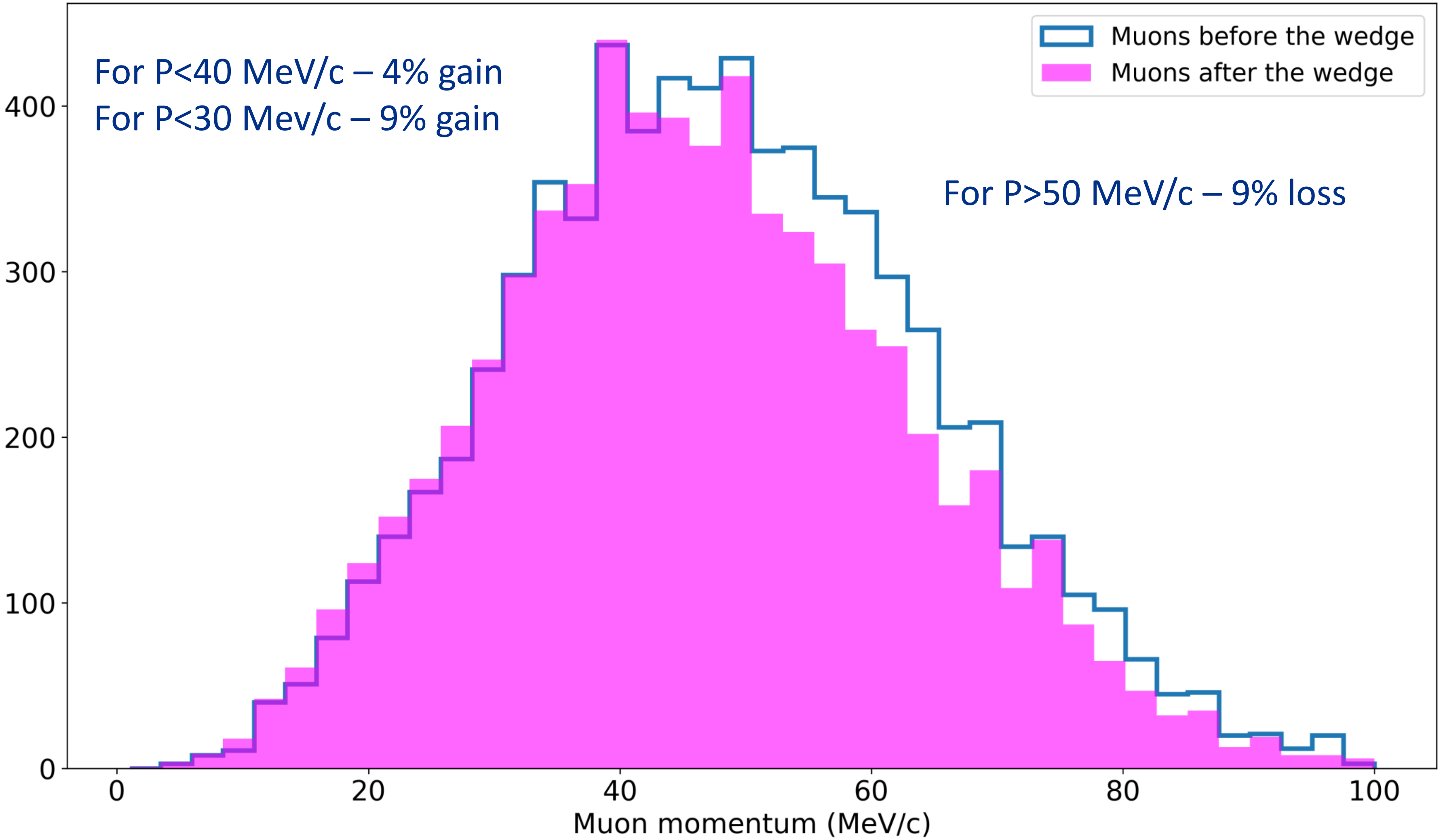


- We don't see significant losses as the beam propagates the transport solenoid downstream the C3 wedge. However, some retuning might be necessary for full recovery

C5 wedge results



C5 wedge results, OptMom 50 MeV/c



Results summary

- We showed that a wedge absorber has the potential to benefit the Mu2e-II Experiment in two ways:
  - More muons <40 MeV/c (more stopped muons)
  - Less muons > 50 MeV/c (less background)
- Two sweet spots have been identified. One between C3up and C3dn and one downstream of C5.
- Devices are relatively inexpensive and the benefits to the Experiment potentially can be high for a fairly modest investment
- A current LDRD program to test the principle is underway for the Muon g-2 Experiment. First results are expected in FY 2019

Future studies

- Investigate the sensitivity in performance with the field of the detector solenoid (not yet done).
- Reshape collimators and identify their optimum aperture provides the best performance when the wedge is inserted. The possibility of using a wedge for collimation AND momentum tailoring will be explored.
- Optimize the stopping target. Since we gain low energy muons with the wedge, it is likely that we can use a thinner stopping target. Consider extending the target radius
- Check if 2 wedges can improve the results
- Explore other materials. For instance, use B_4C which theoretical calculations indicate that it can achieve the same performance as Be with 2/3 of its length.

Acknowledgements

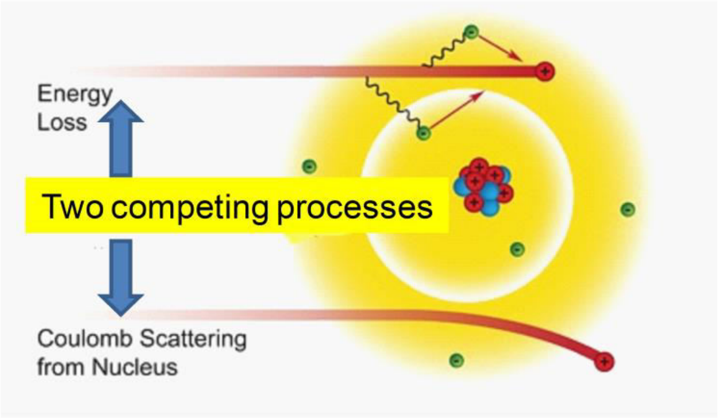
I would like to thank the follwing people for guiding me throughout my project:

- **Diktys Stratakis** and **David Neuffer** – for providing a great working atmoshpere and outstanding support
- **Mike Syphers –** for leading the summer student meetings
- **Alexander Valishev** – for allowing me to take part in the Helen Edwards Summer Internship and gain invaluable experience while working at Fermilab

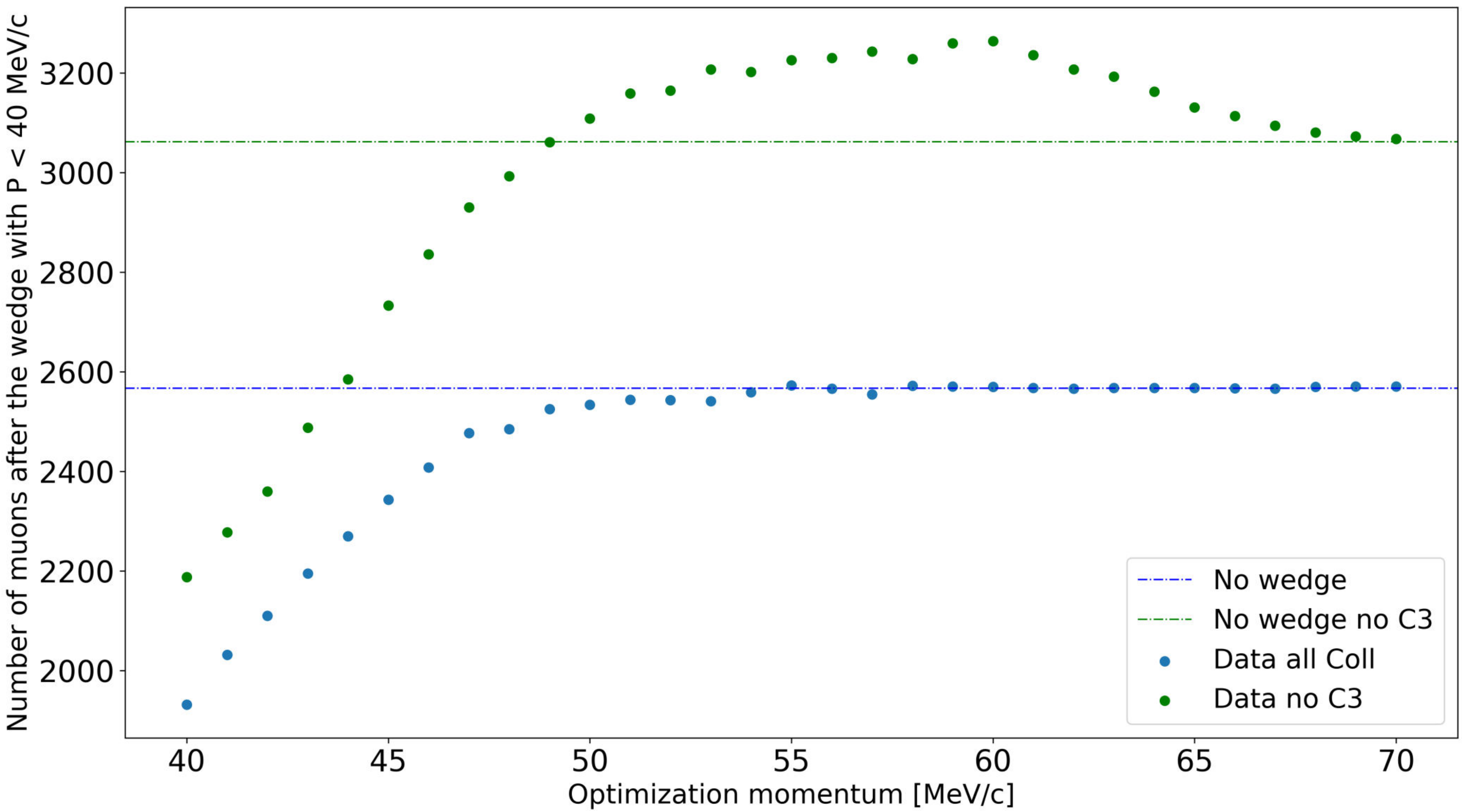
Backup slides

Requirements for wedge material

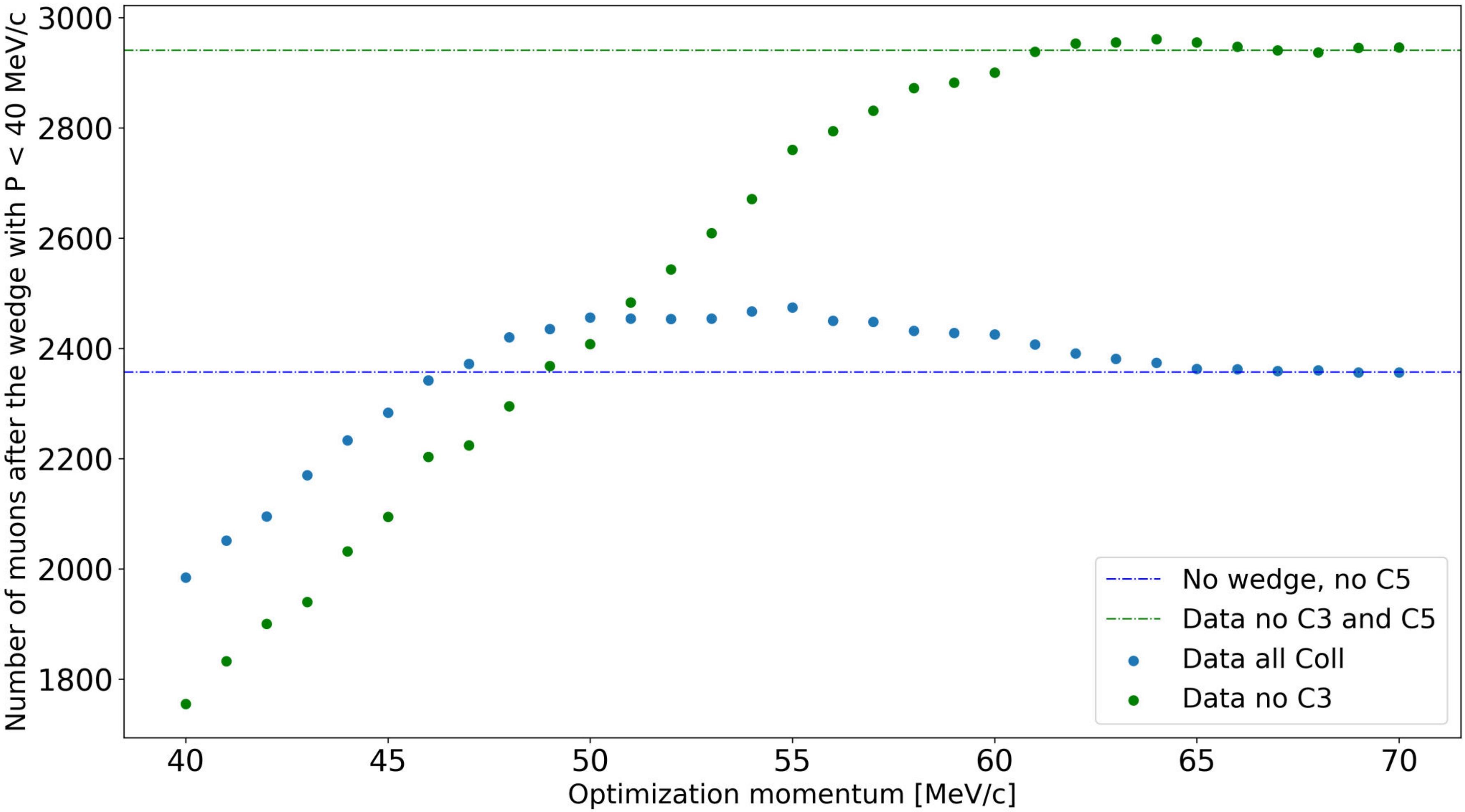
- There are competing processes involved in the ionization cooling
  - Cooling from ionization of the material
  - Heating from Coulomb scattering
- We need a material with:
  - Large *dE/dx*
  - Lardge radiation lenght L_R
- We require a location with:
  - High dispersion
  - Low beta function



C3 wedge results – P < 40 MeV

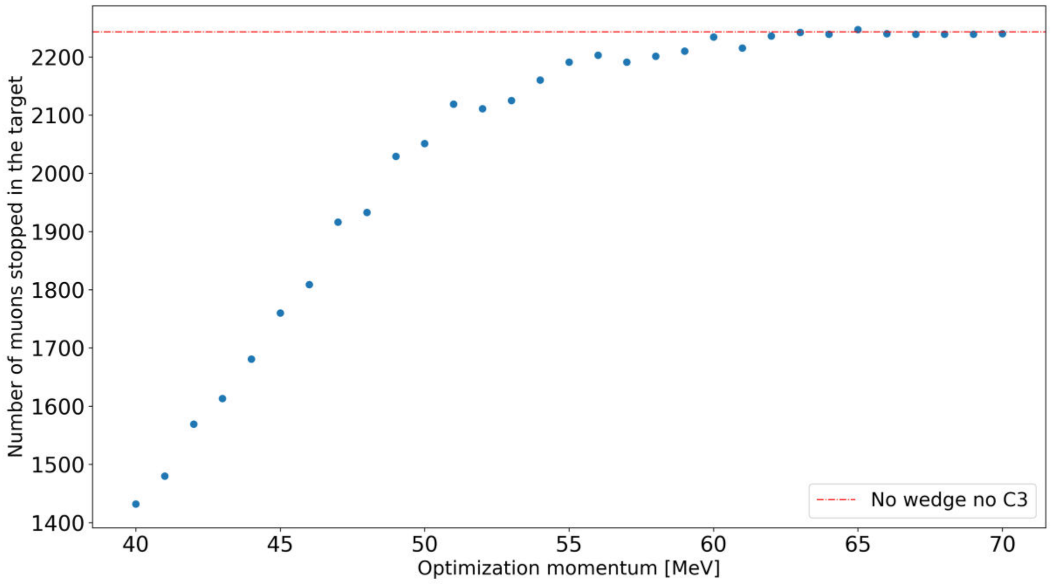


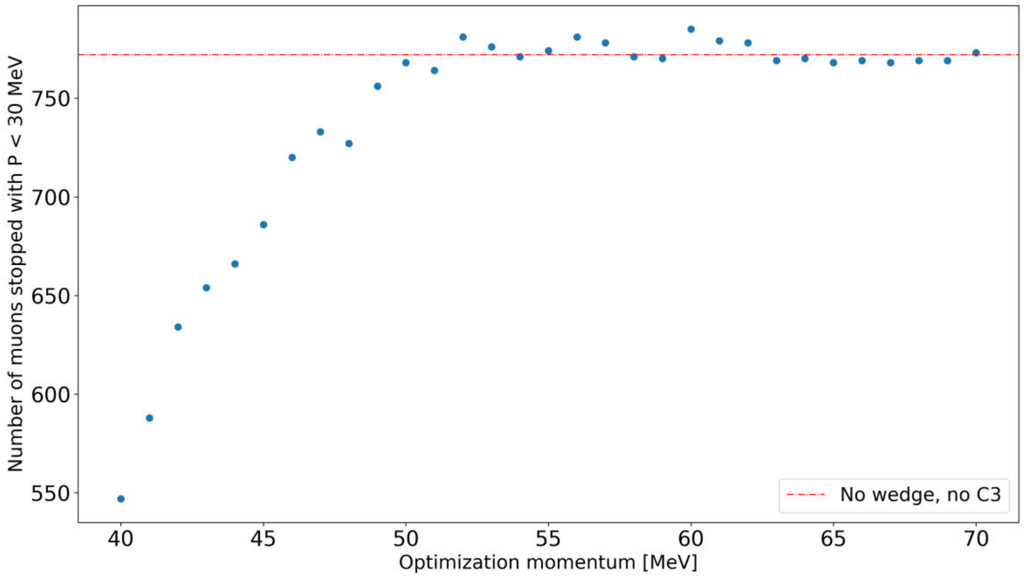
C5 wedge results – P < 40 MeV



C3 wedge results – no Coll 3

- No significant gain can be seen in muons stopped in the target

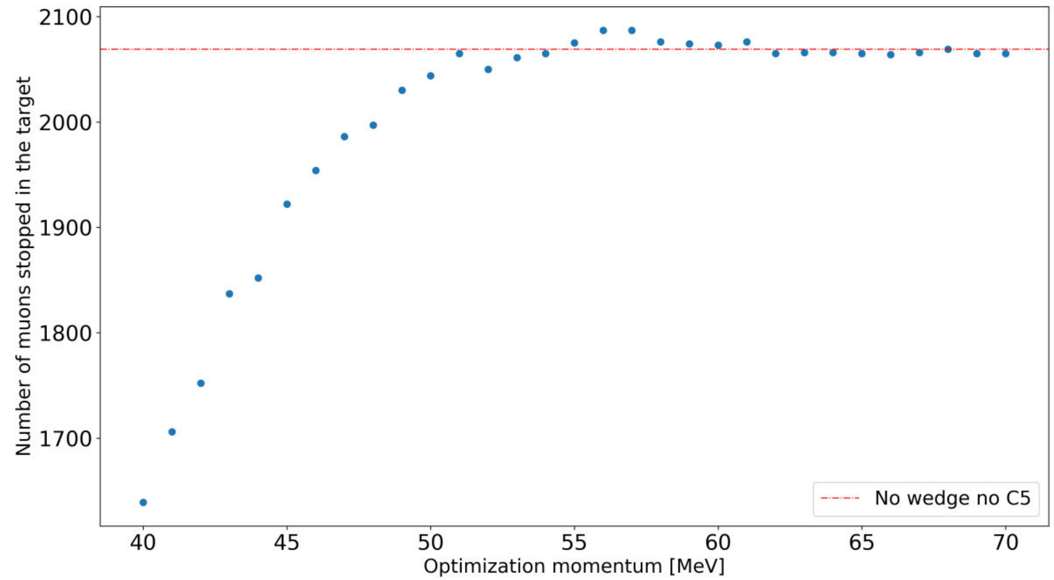


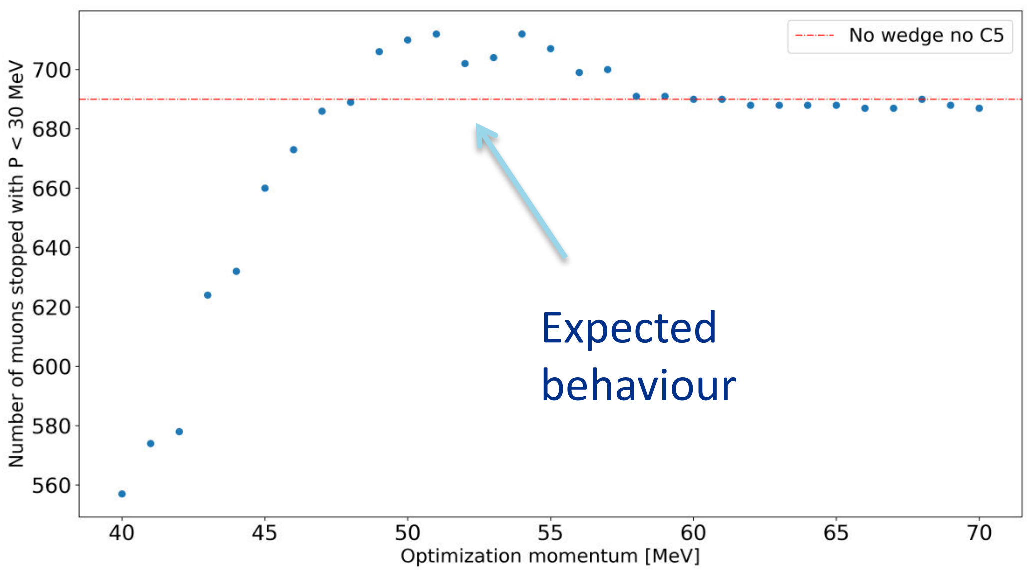


- Most of the good muons gained with the wedge are lost on the way to the target!

C5 wedge results – no Coll 5

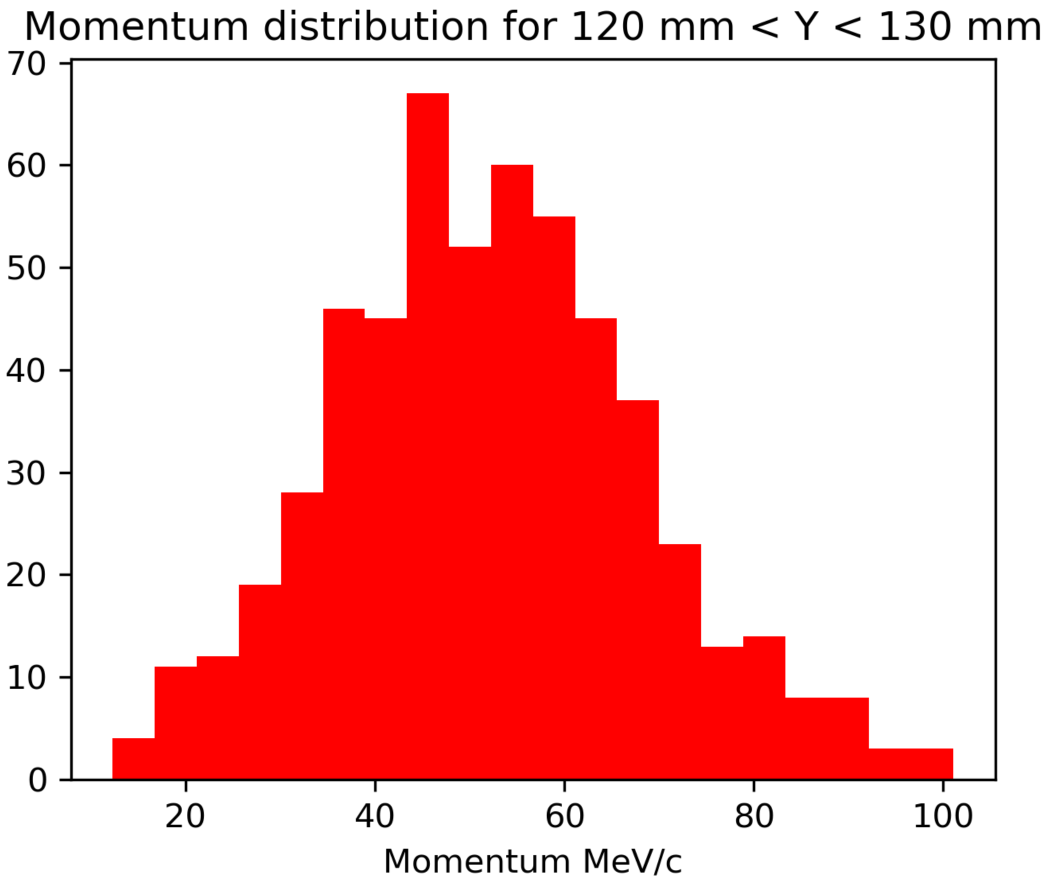
- No significant gain can be seen in total number of muons stopped in the target





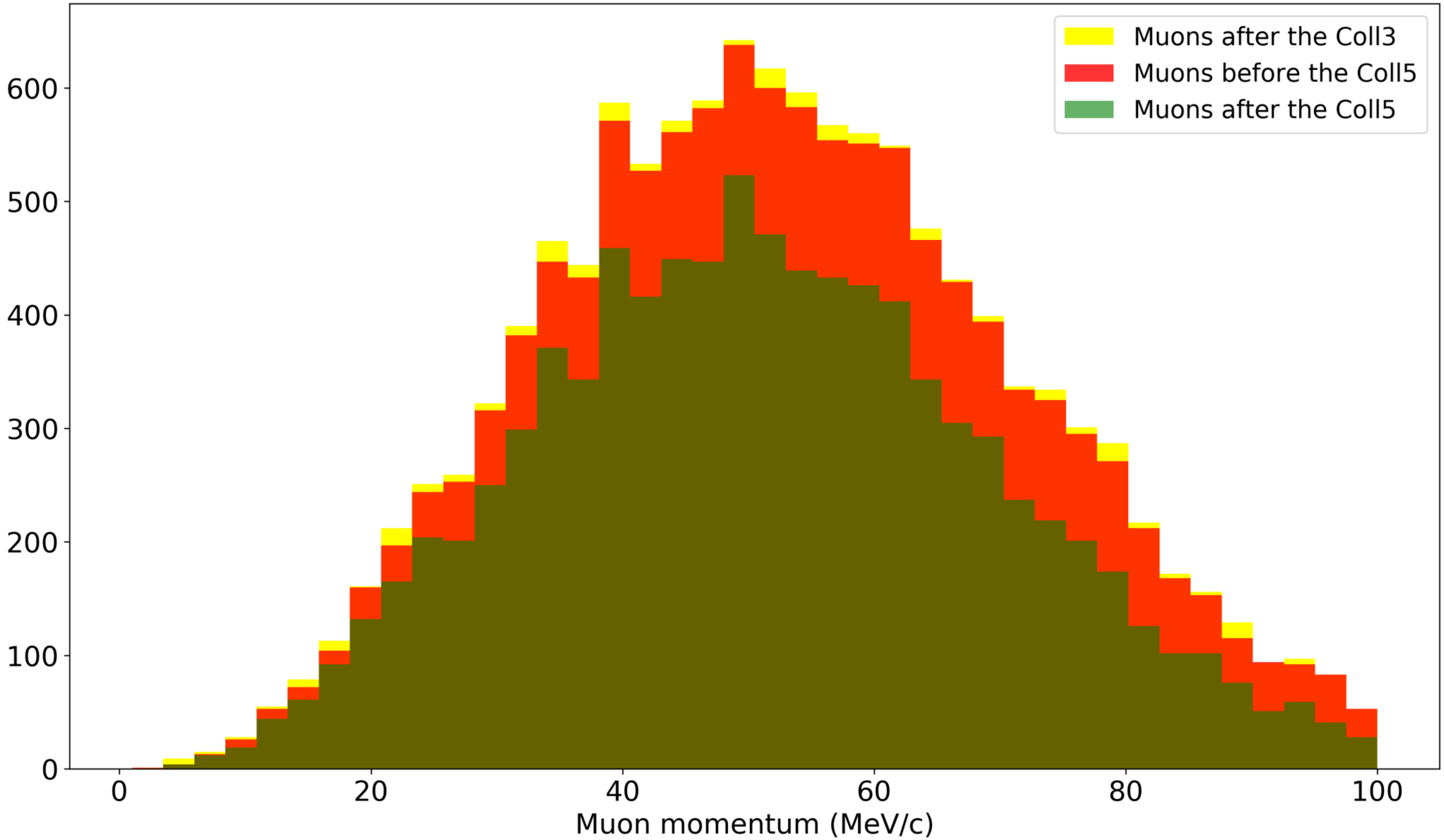
3.2% gain in muons stopped at the target with P<30 MeV

Mu2e wedge – how it is created



- The main problem is the momentum spread – the wedge is able to efficiently cool down only the average momentum in the bin

C3 wedge, no Coll 3



C3 wedge, Coll 3 only downstream part