Beam dynamics study for the Muon Campus at Fermilab

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Physics with muons beyond g-2 and Mu2e, Fermilab, Batavia, IL
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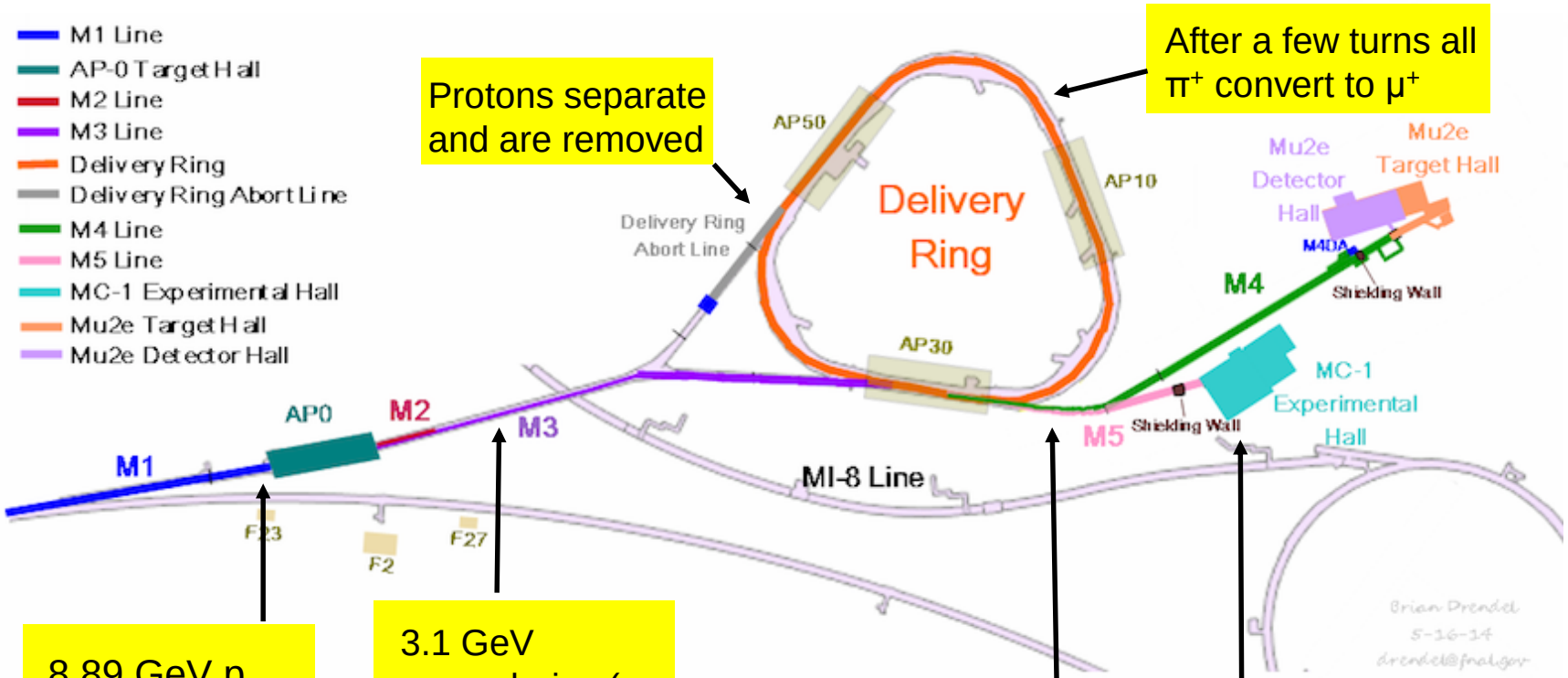
Outline

- Overview of the Fermilab Muon Campus
- Simulation model & results
  - Target and M2-M3 beamlines
  - Delivery ring
  - M4-M5 beamlines
- Delivery ring for neutrino research
- Conclusion & Future work

Muon Campus overview



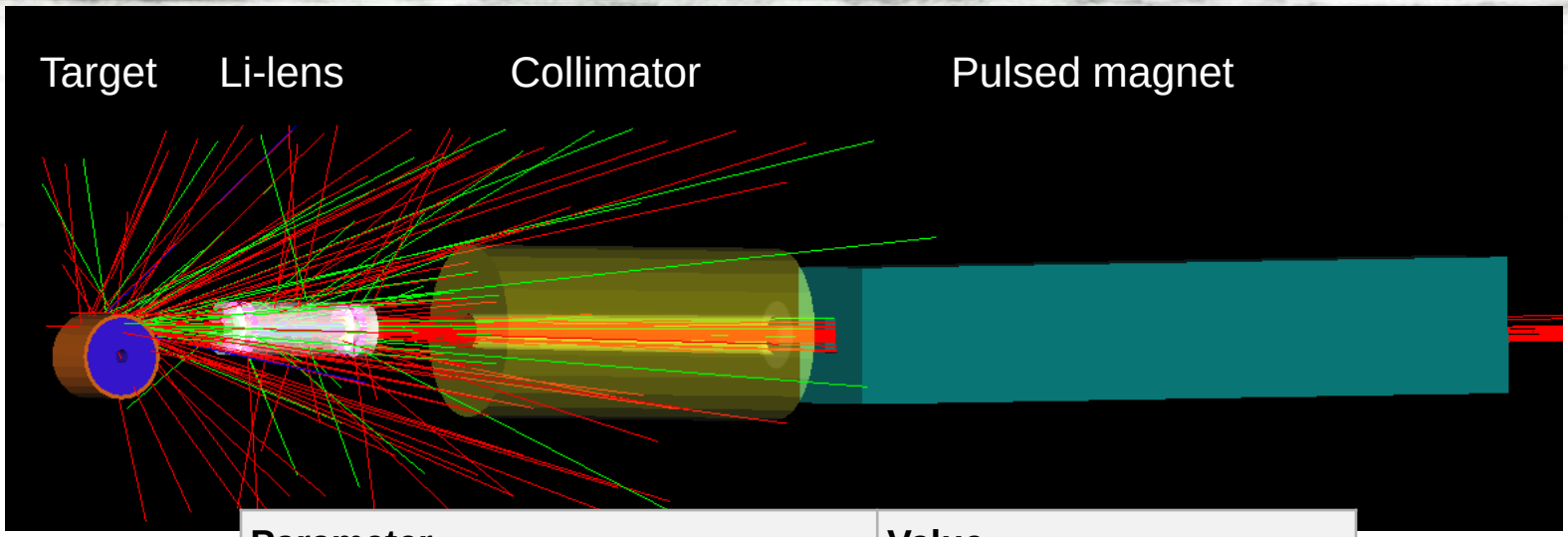
Challenges

- Beam requirements at the g-2 ring entrance:
  - At least 7x10^{-7} muons per POT within ±2% $\Delta p/p$
  - Maintain an average polarization 90% or better
- At the same time, the beamlines have bends, elevation changes, complex injection and extraction schemes:
  - Can cause severe particle loss
  - Trigger spin correlations that could increase systematic error
- At the same time most beamlines need to be compatible with the Mu2e experiment

Approach

- The aim of this work is to deliver an end-to-end simulation for g-2 so that the above issues can be addressed
- To achieve this we have developed simulation models for different parts of the lines
  - Targetry: MARS & GEANT4
  - Beamline optics: MADX
  - Beam and spin tracking: BMAD, GEANT4, G4Beamline
- Validated our results against:
  - Theoretical models
  - Independent simulation codes

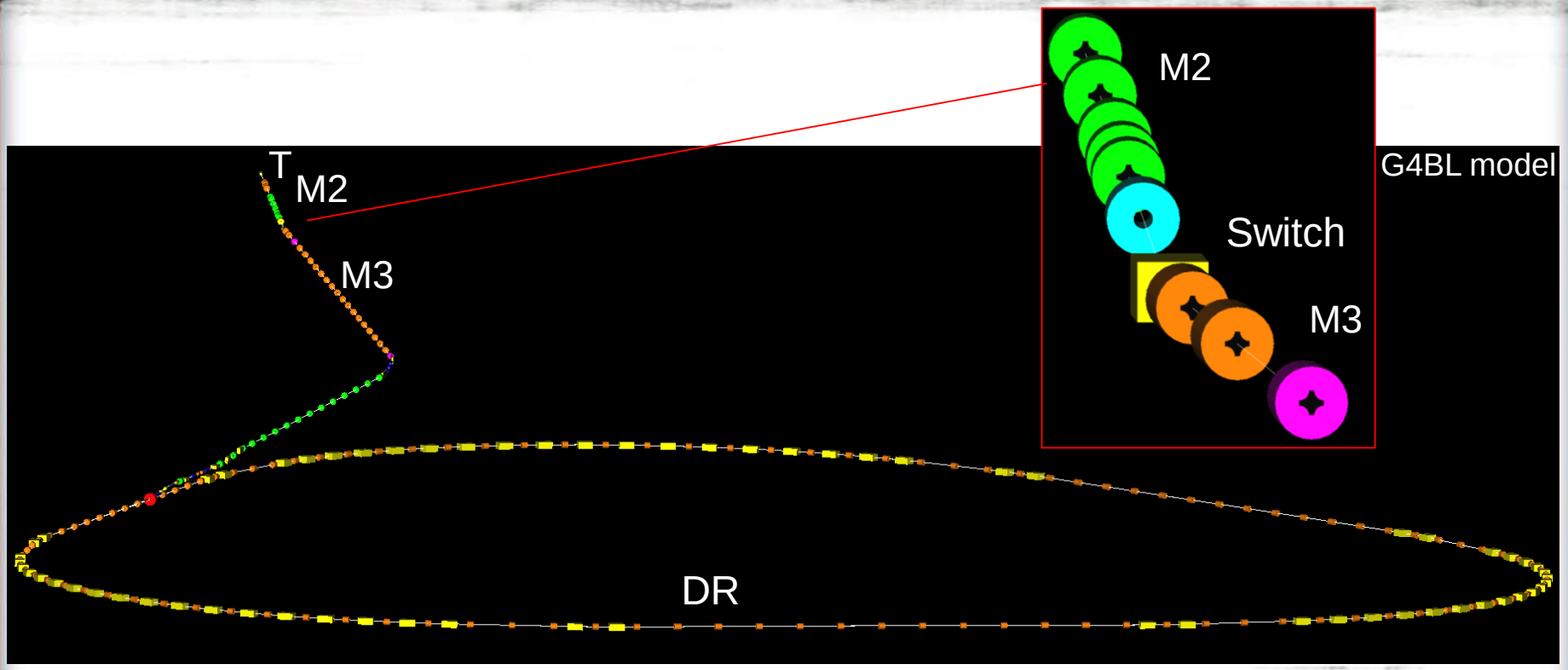
Beam production target



Parameter	Value
Intensity per pulse	10^{12}
Proton energy	8.0 GeV
Secondary energy	3.1 GeV
Selected particle	π^+
Beam size at target	0.15 mm
Distance between Li-lens and target	31.0 cm
Focusing field gradient of Li-lens	232 T/m

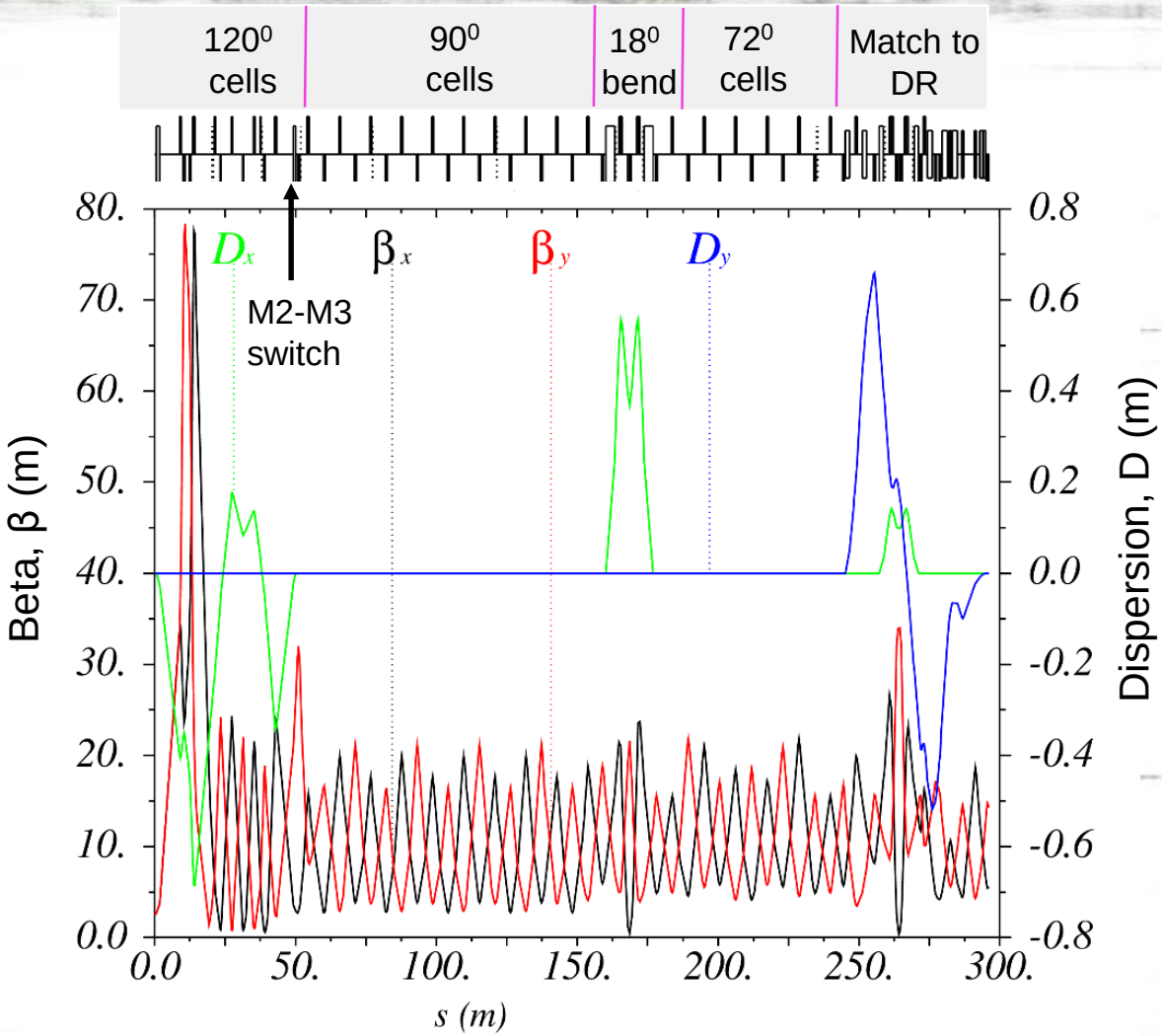
Grange et al., Muon Technical Design Report (2015)

Secondary beam transport lines



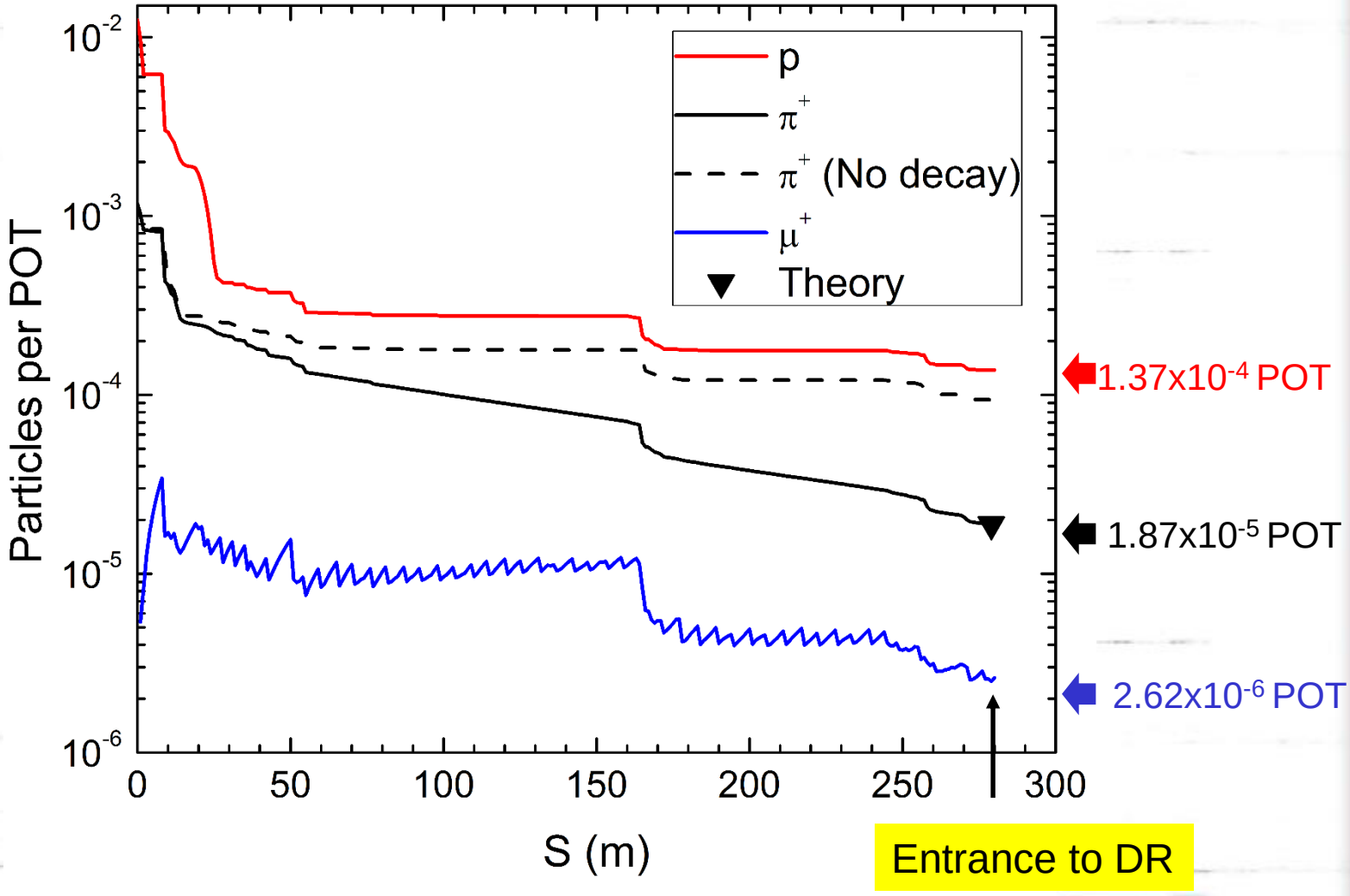
- M2 & M3 lines will carry the secondary beam from the target (T) to the delivery ring (DR)
- Loop four times until μ^+ yield peaks and all p are removed

Optics in M2 & M3 beamlines



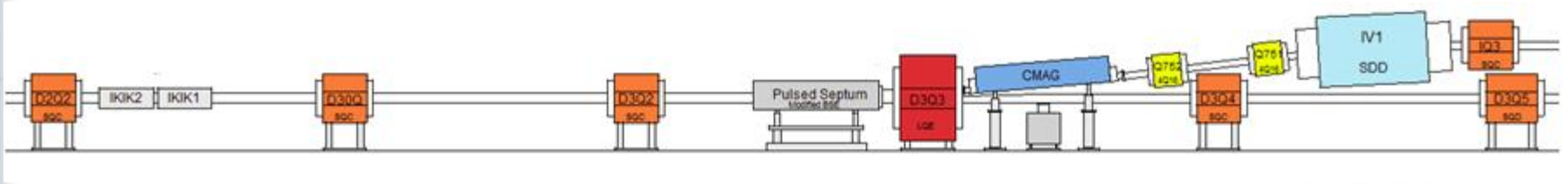
Johnstone, GM2-doc-700-v13 (2014)

Tracking in M2 & M3 beamlines



Injection: Conceptual design & model

- Conceptual design

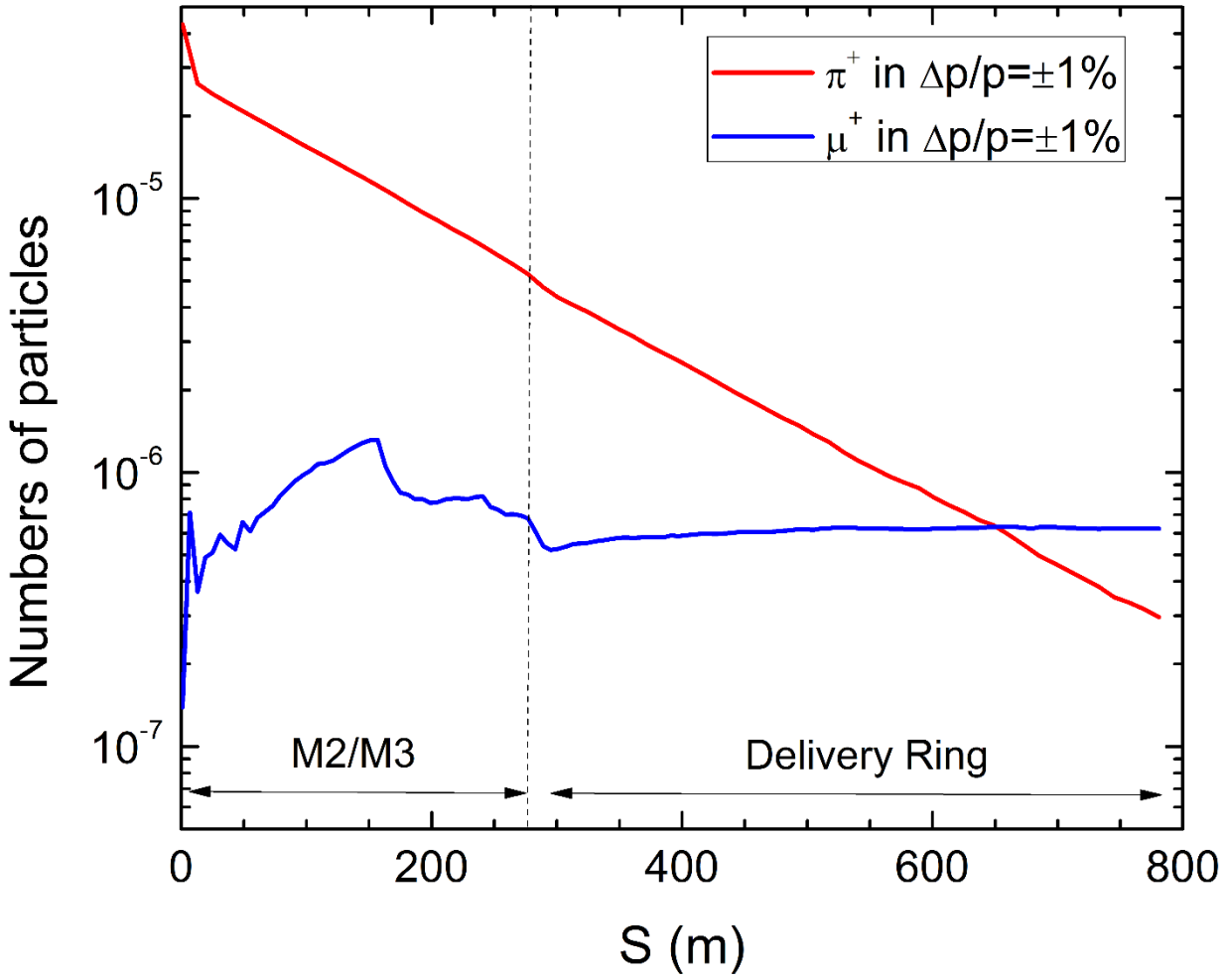


- Simulation model

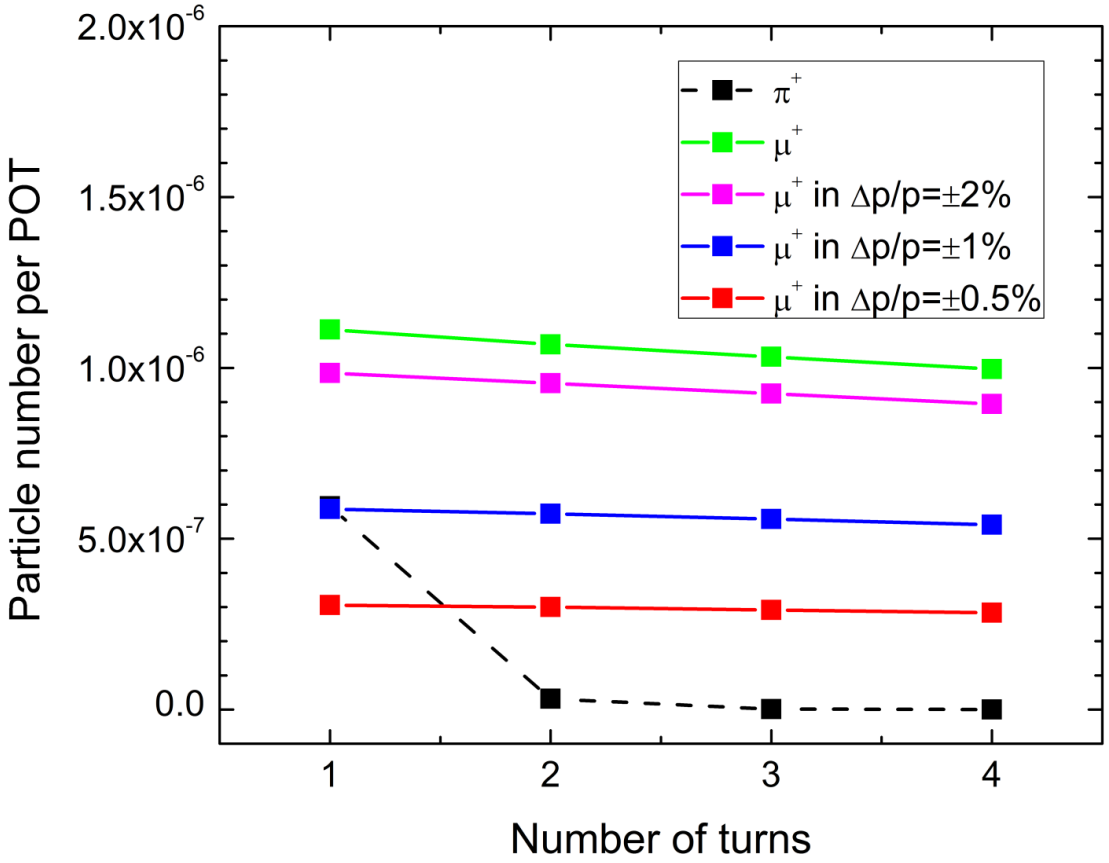
- Vertical injection with a combination of a C-magnet, 303 quadrupole, magnetic septum and kicker magnets

Morgan, GM2-doc-3312 (2015) & Morgan, GM2-doc-2244 (2014)

Performance

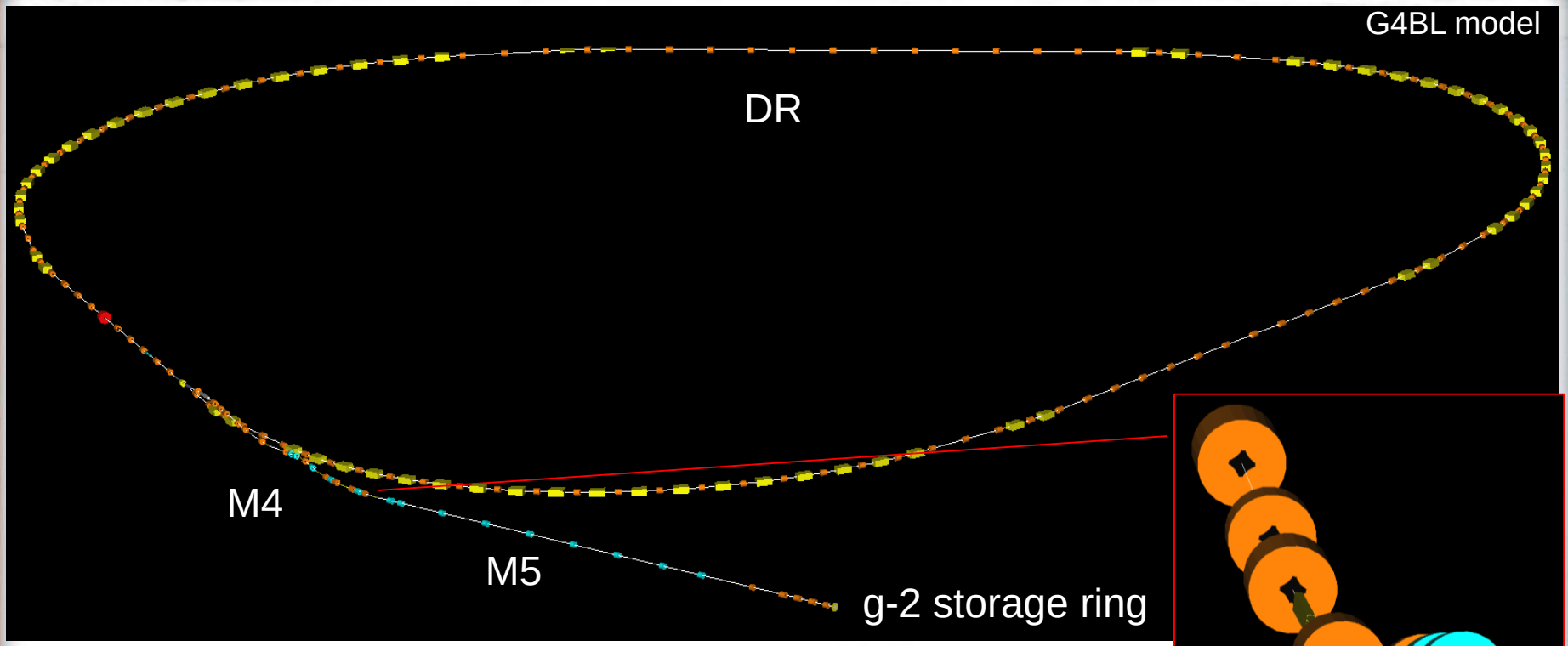


Performance along the DR



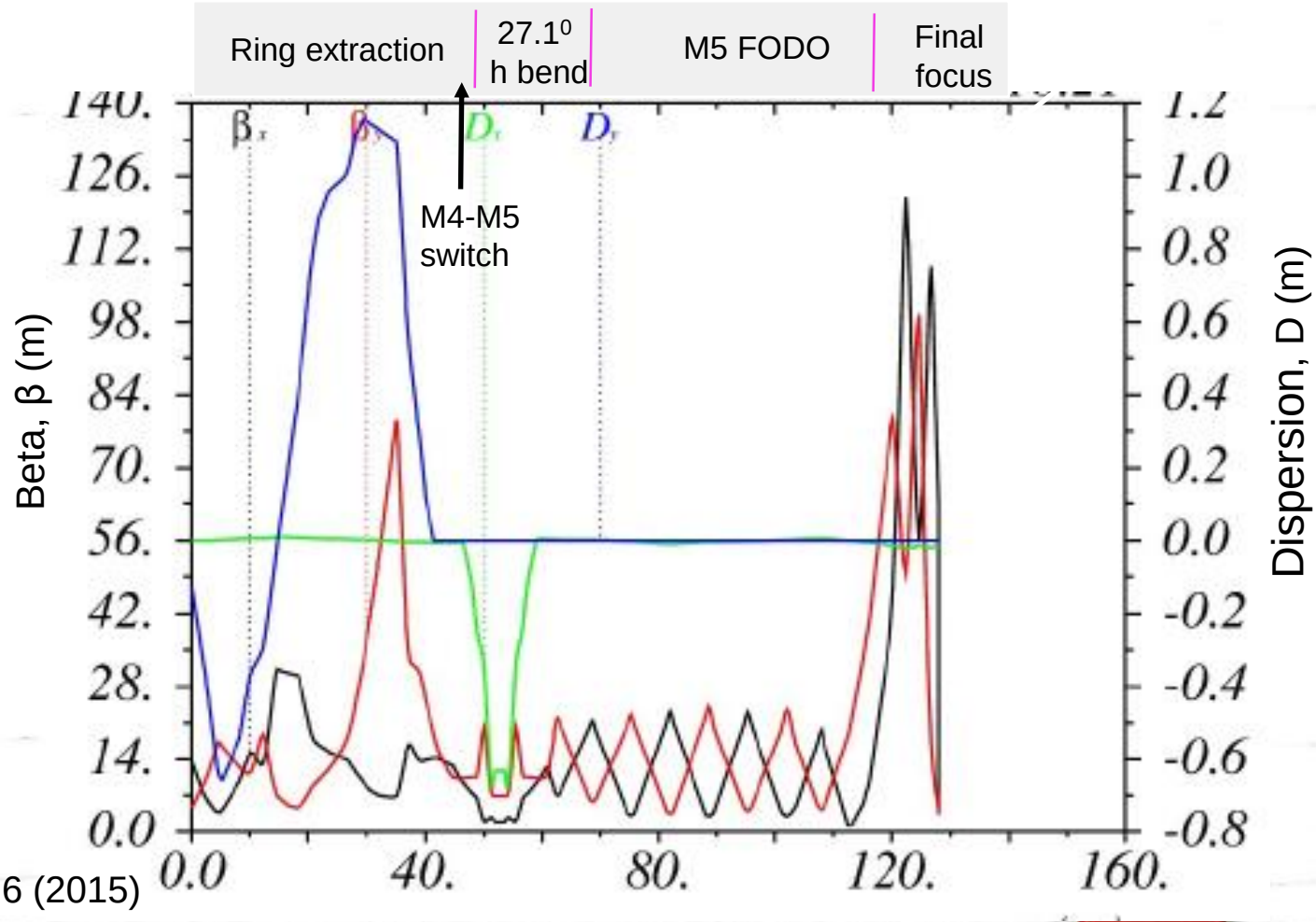
- After 4 turns near 90% of muons are transmitted towards the extraction line

Delivery ring & M4/M5 lines



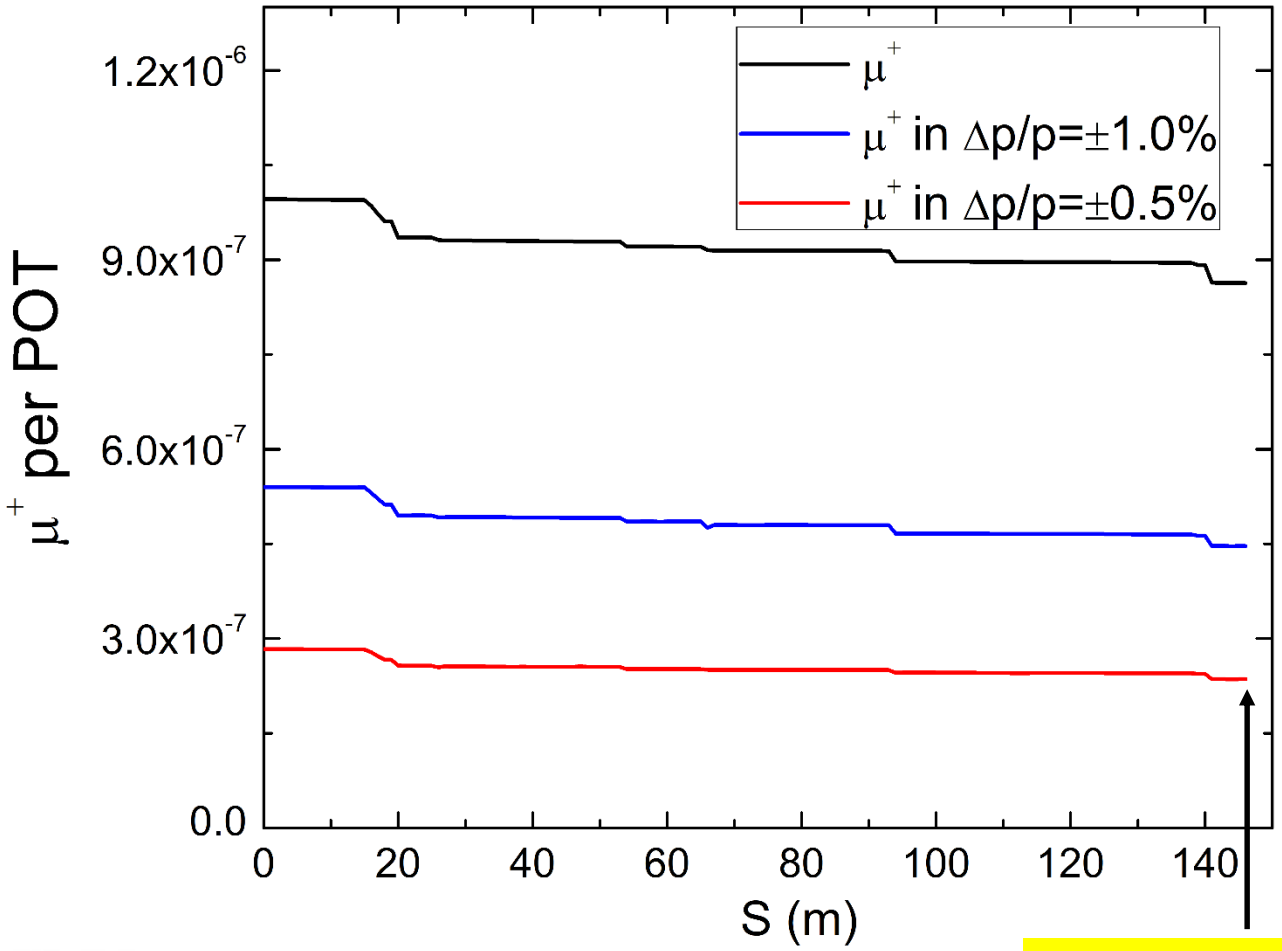
- Near magic momentum μ^+ are extracted into the M4 line and bent into M5 for transport to the g-2 storage ring

Optics of M4 & M5 beamlines

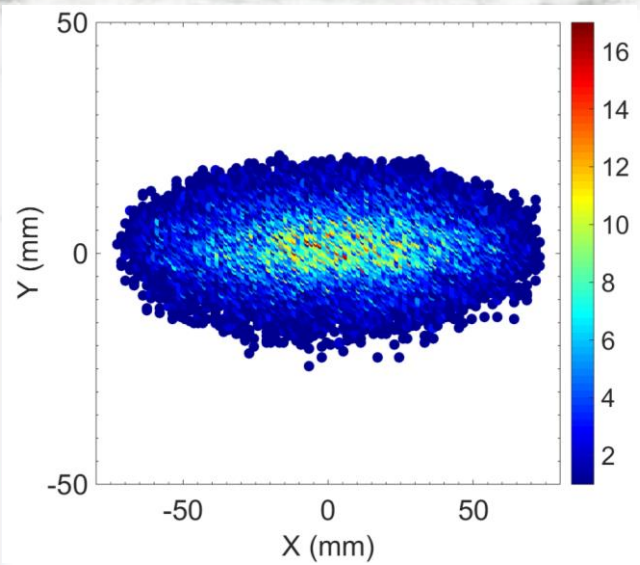


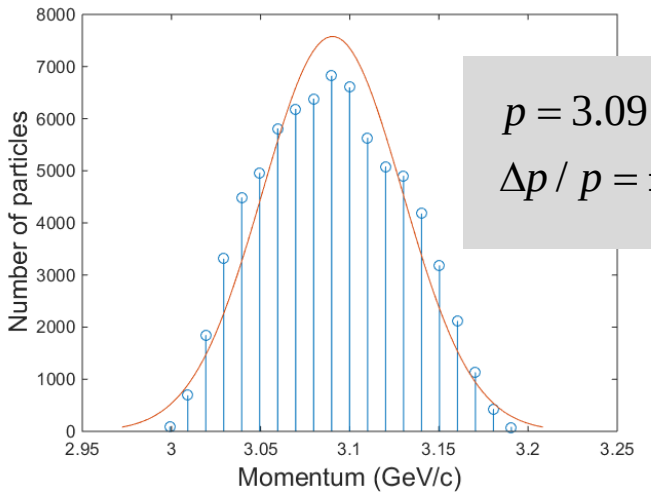
Johnstone, GM2-doc-1568-v16 (2015)

Tracking in M4 & M5 beamlines



Beam at the storage ring entrance

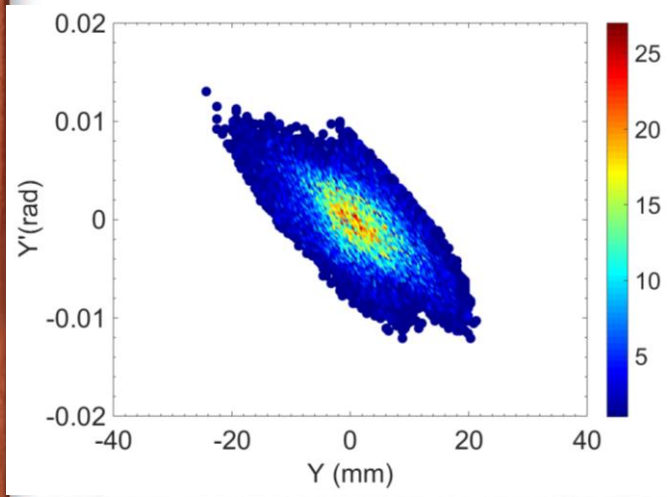


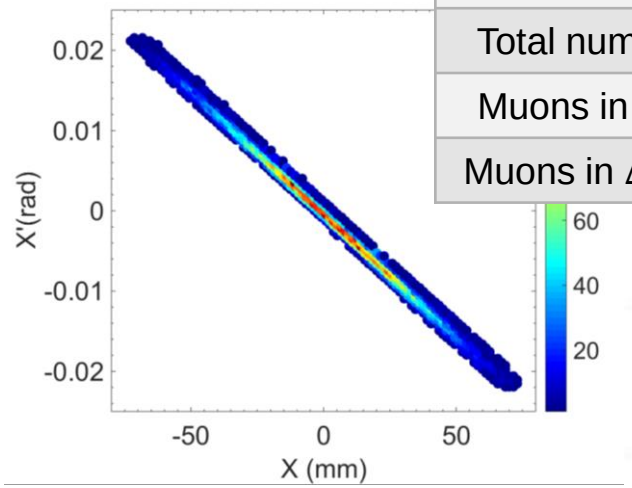


$p = 3.091\,\mathrm{GeV/c}$

$\Delta p / p = \pm 0.012$

Particles	Value
Total number of muons	8.7x10^{-7} POT
Muons in $\Delta p/p = \pm 1\%$	4.4x10^{-7} POT
Muons in $\Delta p/p = \pm 0.5\%$	2.4x10^{-7} POT

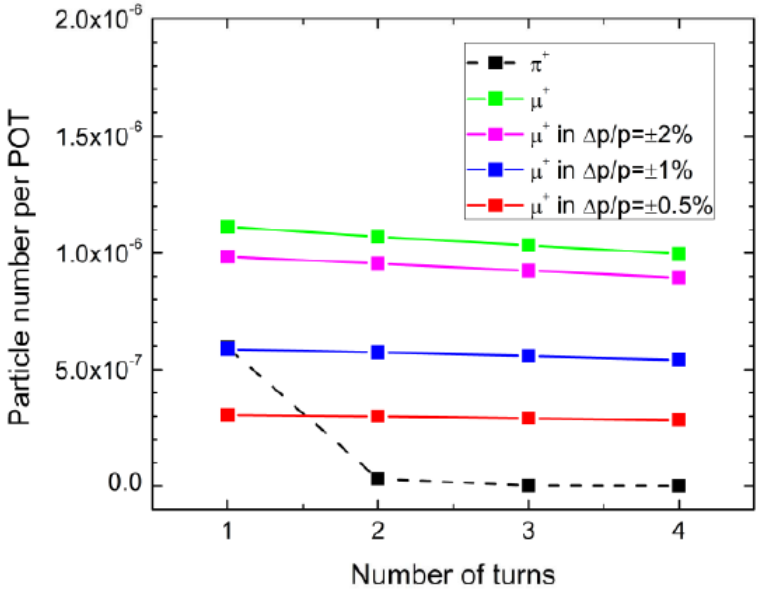




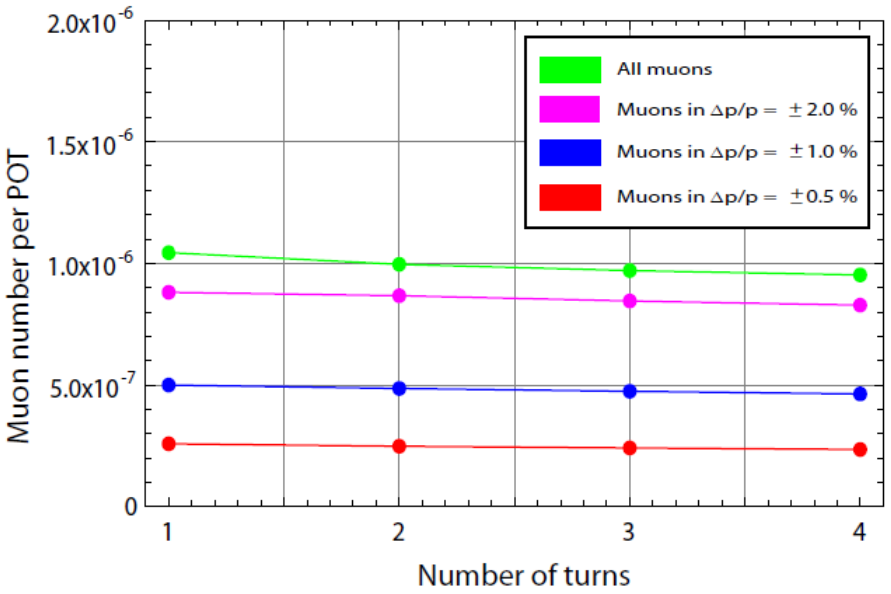
Benchmarking results

- Our G4Beamline results were cross-checked against independent simulation codes

G4Beamline results

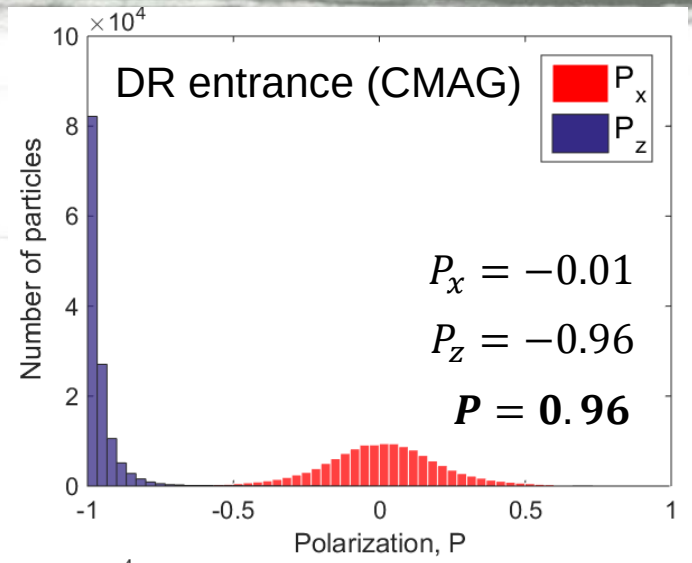


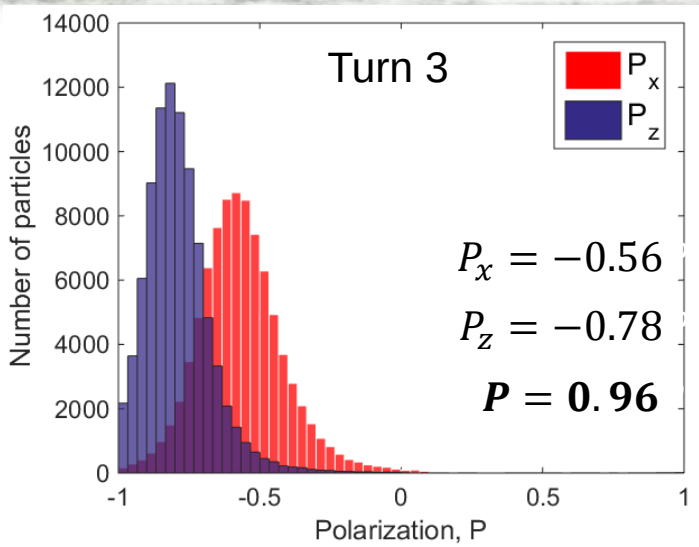
BMAD results

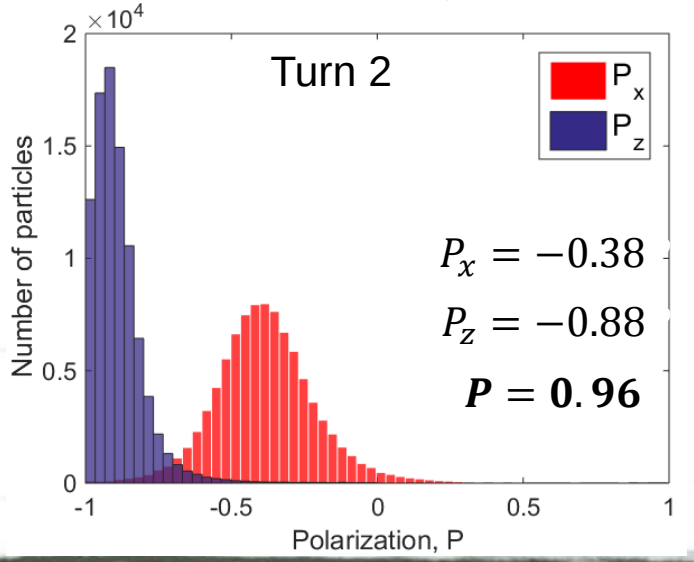


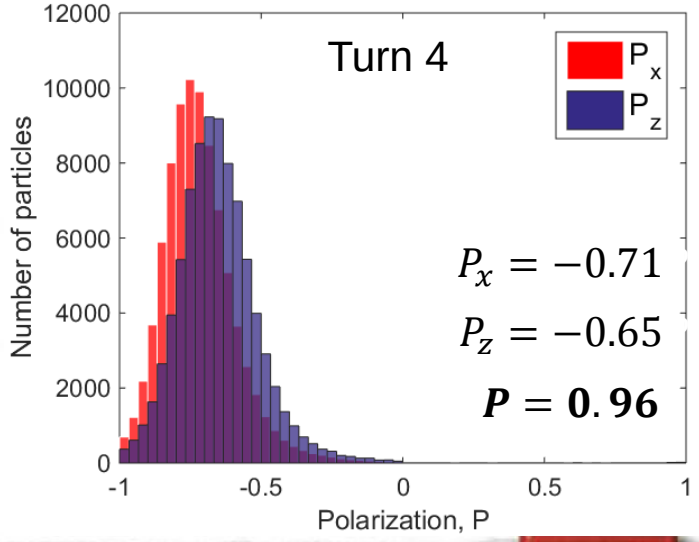
Work done by: M. Korostelev (Cockcroft, Lancaster) & D. Stratakis (FNAL)

Spin Tracking



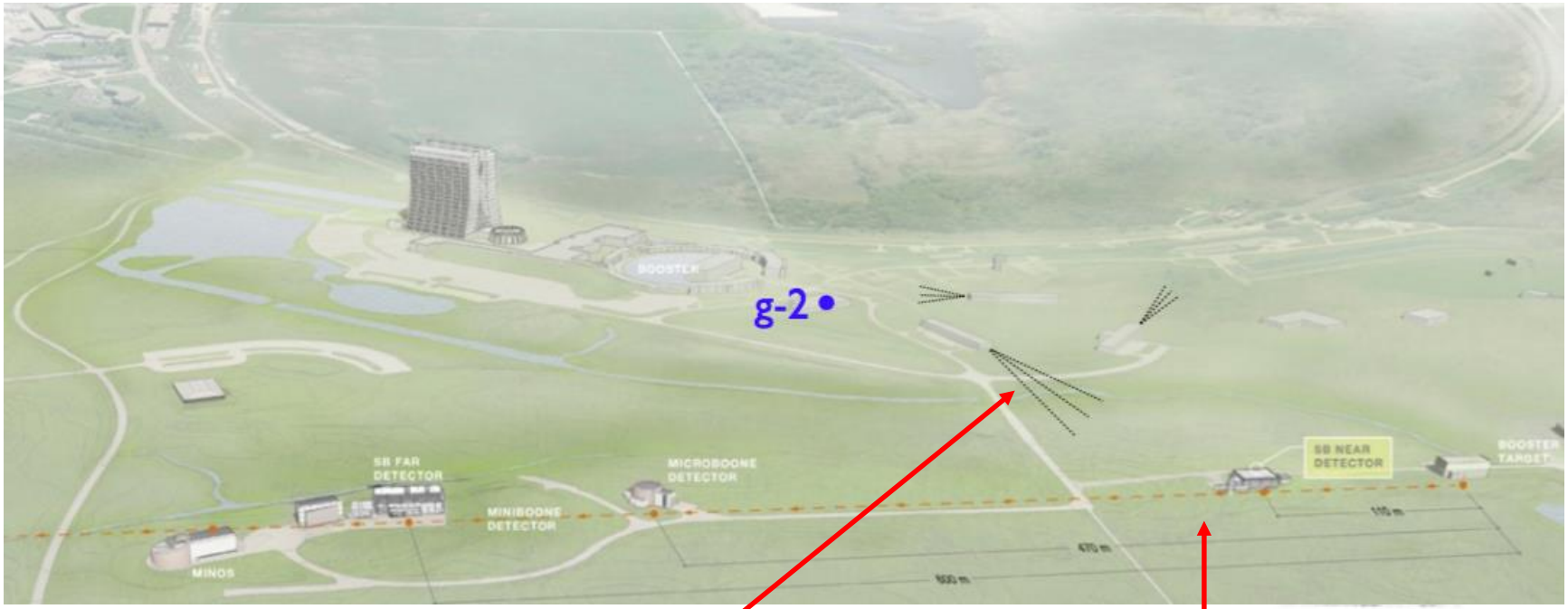






New projects

- Potential of using Muon Campus for neutrino research



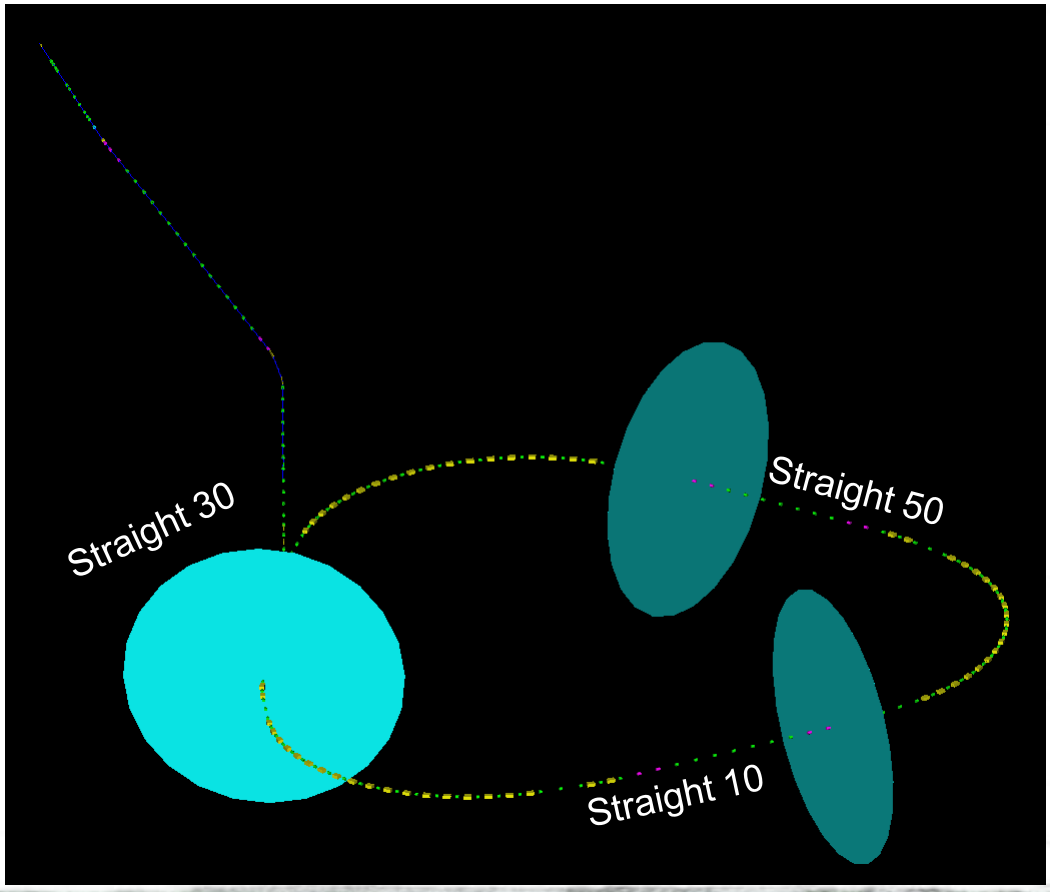
It is a long the neutrino path of sector 10 of the Muon campus delivery ring

Short-Baseline Near Detector (SBND) will be one of three liquid argon neutrino detectors sitting in the Booster Neutrino Beam (BNB) at Fermilab as part of the Short-Baseline Neutrino Program.

Collaboration with: J. Grange (ANL), J. Zennamo (UChicago) and Z. Pavlovic (FNAL)

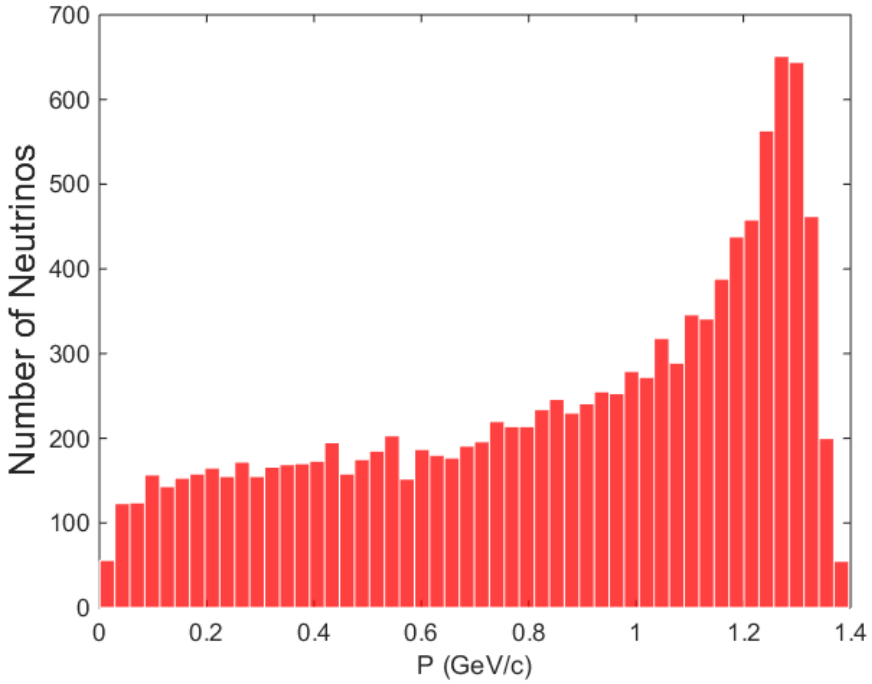
Neutrino Detector

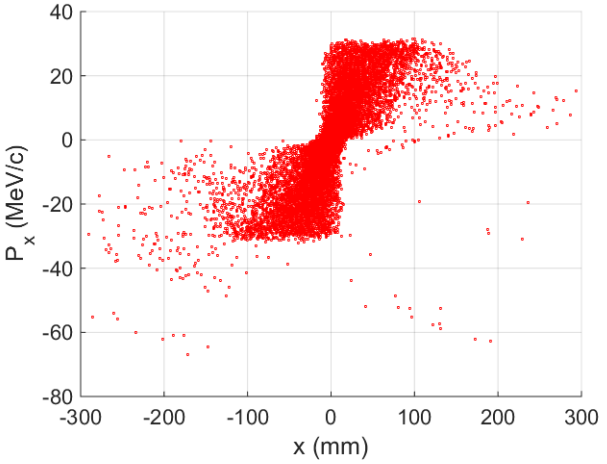
- Three virtual detectors are placed at the end of straight sections 10, 30, and 50. Results for turn 1 only.

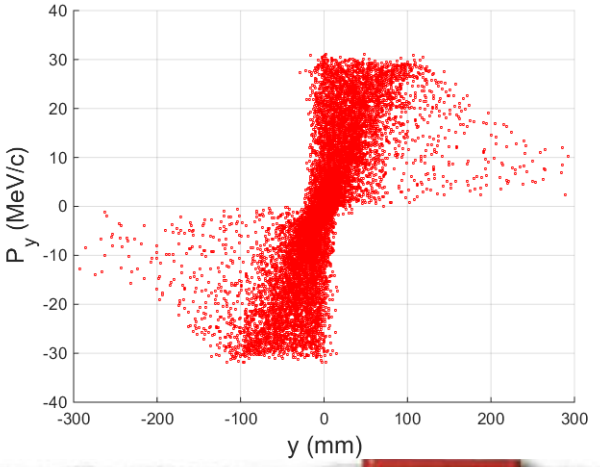


Straight 30

- At straight 30 the number of
  - ν_μ is 6x10^{-7} per POT
  - ν_e is 10^{-9} per POT

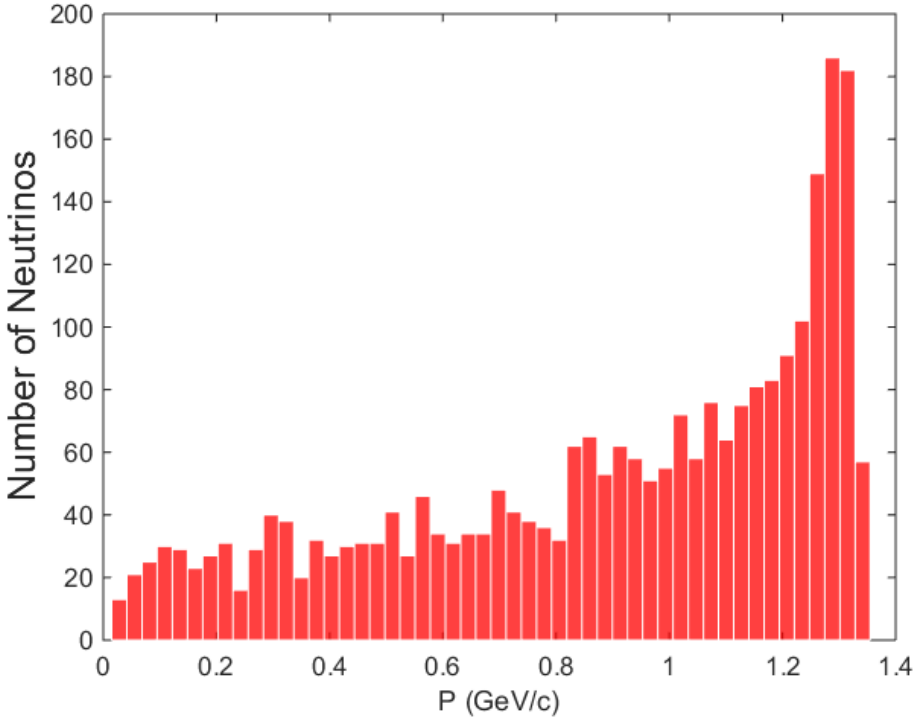


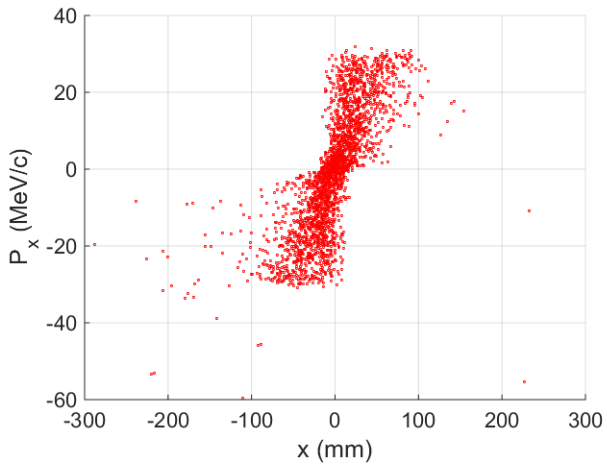


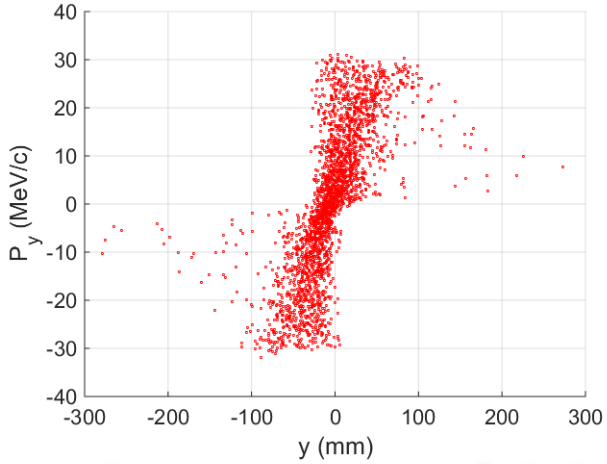


Straight 10

- At end of straight 10 the number of:
  - ν_μ is 1.3x10^{-7} per POT
  - ν_e is 10^{-9} per POT

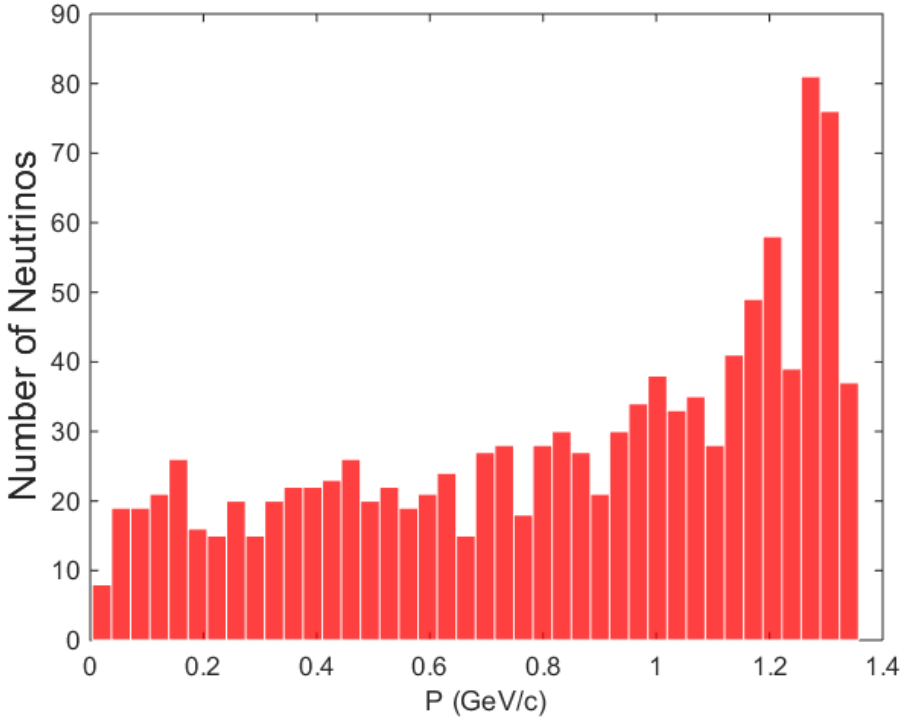


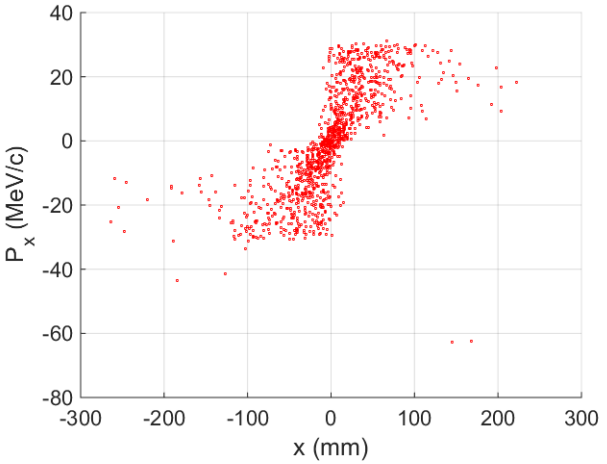


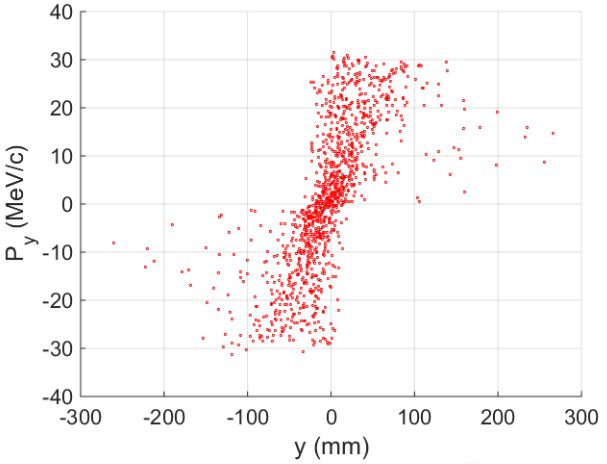


Straight 50

- At end of straight 10 the number of:
  - ν_μ is 5.8x10^{-8} per POT
  - ν_e is 10^{-9} per POT







Conclusion

- Developed a simulation model for the g-2 beam lines
- At the SR entrance parameters match the desired criteria:
  - The beam is >95% polarized
  - $\Delta p/p = \pm 1.2\%$ and centered near magic momentum
  - 8.4X10^{-7} muons per POT
- Our results agree well with independent simulation codes
- The number of neutrinos in the DR is estimated
- As a next step
  - Estimate the number of neutrinos in the SBND detector
  - Produce DR beam fluxes for a range of proton energies

Acknowledgment

- Thanks to Ao Liu (Fermilab) for allowing me to use his plotting program
- Thanks to Tom Roberts for helping me with G4Beamline
- Special thanks to: Bill Morse, Jason Crmkovic, Jean-Francois Ostiguy, Jim Morgan, Mary Convery, Maxim Korostelev, Mike Syphers, Nathan Froemming, Volodya Tishchenko for many discussions…