
# Muon g-2 from the source

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USPAS Winter 2018

# Outline

Fermilab

- Motivation
- Experiment requirements
- Big Move
- FNAL
- Ring components

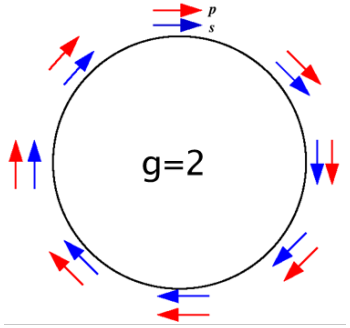
# g-2 experiment

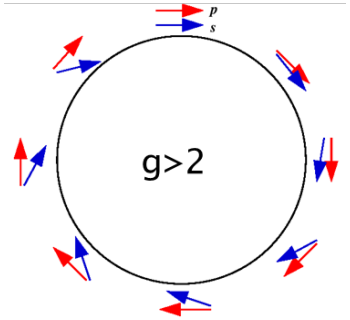
$$a_\mu = g-2/2$$

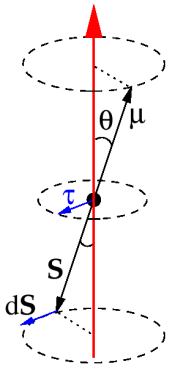
Fermilab

Magnetic moment of the muon is coupled to spin and gyromagnetic ratio g

$$\mu = ge/2m_\mu c\, s$$




Muons in a magnetic field:

Cyclotron frequency

$$\omega_C = eB/\gamma mc$$

Spin precession frequency

$$\omega_s = geB/2mc + (1-\gamma)eB/\gamma$$

$$\omega_a = \omega_s - \omega_C = -(g-2/2)eB/mc$$

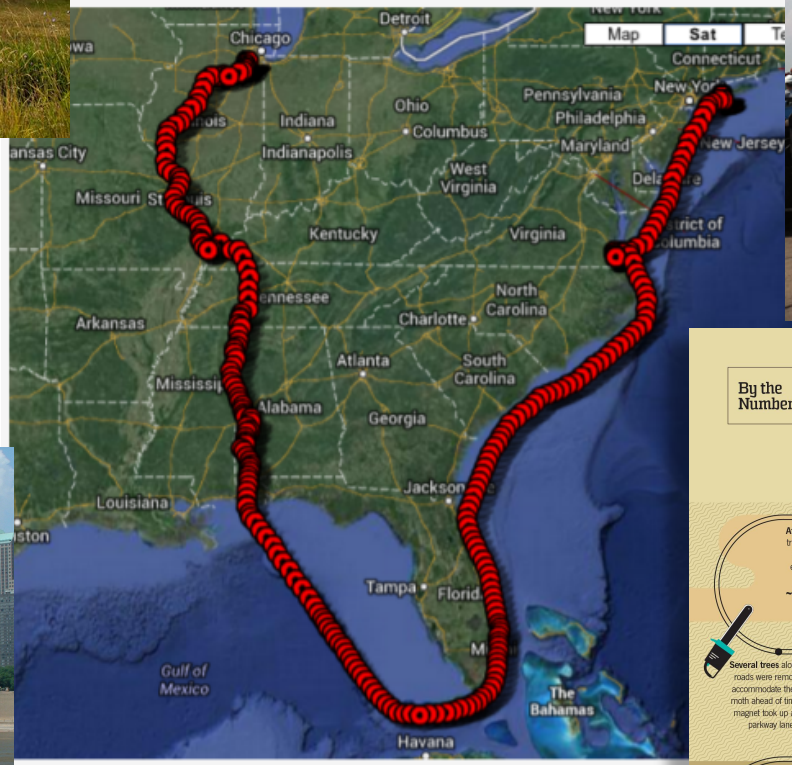
# Requirements for FNAL g-2

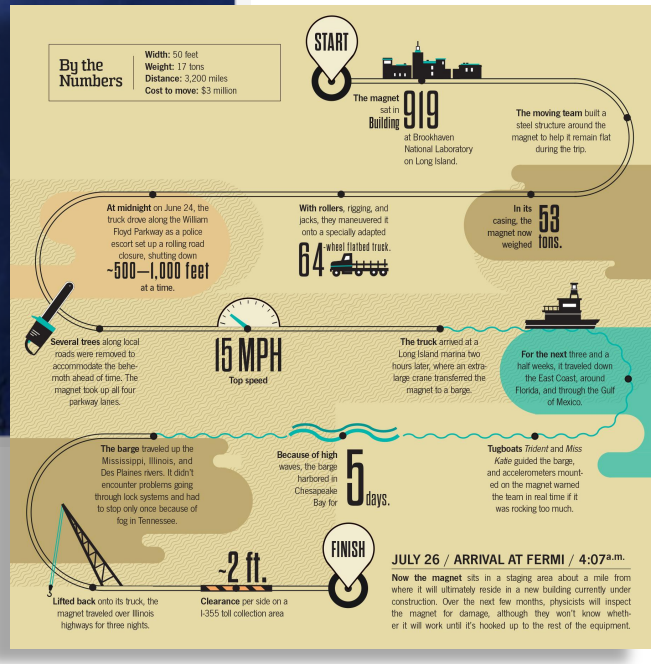
Fermilab

- Muons at “magic momentum” 3.09 GeV
  - $\Delta p/p$ =+/- 2%
- BNL was statistics limited- more muons
  - At least 7x10$^{-7}$ muons per POT
- Uniform field to within ppm

# Big Move


Driving Discovery in Particle Physics

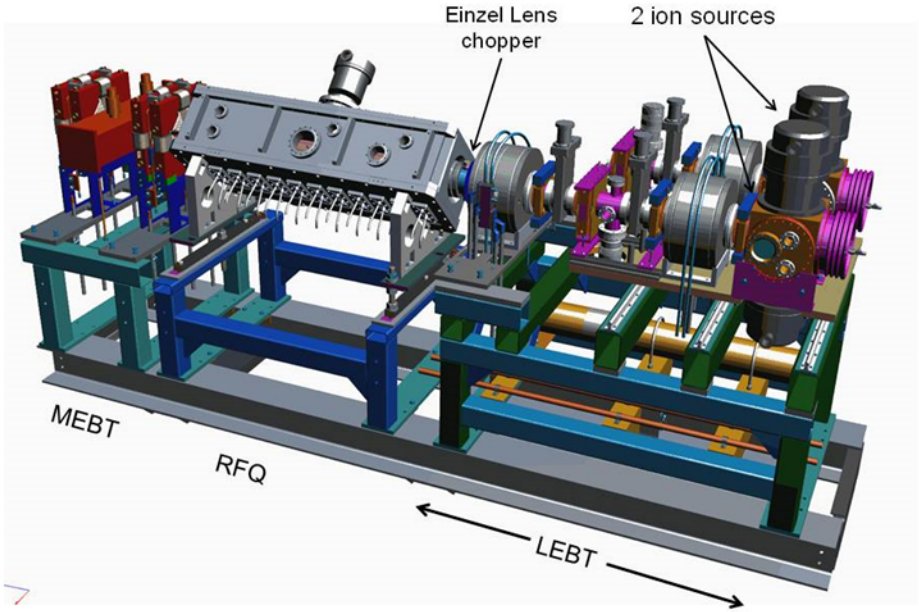

Map
Sat
Chicago
Detroit
Connecticut
Pennsylvania
Philadelphia
Ohio
Columbus
Indiana
Indianapolis
Maryland
West Virginia
Kentucky
Virginia
Tennessee
North Carolina
Charlotte
Arkansas
Atlanta
South Carolina
Alabama
Georgia
Louisiana
Jackson
Tampa
Gulf of Mexico
The Bahamas
Havana

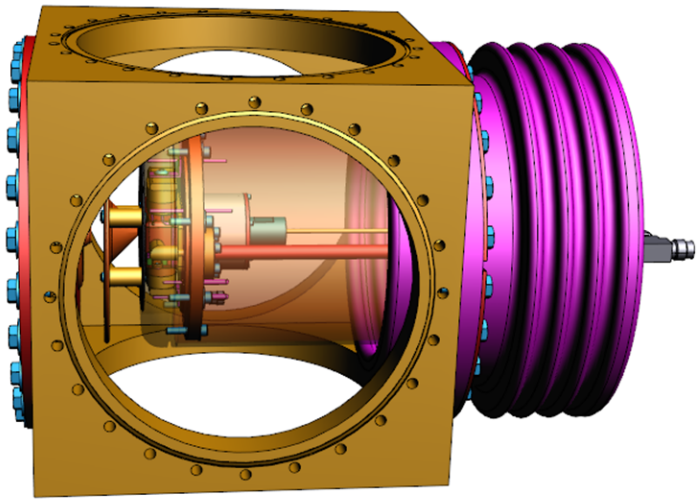

By the Numbers
Width: 50 feet
Weight: 17 tons
Distance: 3,200 miles
Cost to move: $3 million
START
The magnet sat in Building 919 at Brookhaven National Laboratory on Long Island.
The moving team built a steel structure around the magnet to help it remain flat during the trip.
At midnight on June 24, the truck drove along the William Floyd Parkway as a police escort set up a rolling road closure, shutting down ~500–1,000 feet at a time.
With rollers, rigging, and jacks, they maneuvered it onto a specially adapted 64-wheel flatbed truck.
In its casing, the magnet now weighed 53 tons.
Several trees along local roads were removed to accommodate the behemoth ahead of time. The magnet took up all four parkway lanes.
15 MPH Top speed
The truck arrived at a Long Island marina two hours later, where an extra-large crane transferred the magnet to a barge.
For the next three and a half weeks, it traveled down the East Coast, around Florida, and through the Gulf of Mexico.
The barge traveled up the Mississippi, Illinois, and Des Plaines rivers. It didn't encounter problems going through lock systems and had to stop only once because of fog in Tennessee.
Because of high waves, the barge harbored in Chesapeake Bay for 5 days.
Tugboats Trident and Miss Kate guided the barge, and accelerometers mounted on the magnet warned the team in real time if it was rocking too much.
~2 ft. Clearance per side on a I-355 toll collection area
FINISH
Lifted back onto its truck, the magnet traveled over Illinois highways for three nights.
JULY 26 / ARRIVAL AT FERMI / 4:07a.m.
Now the magnet sits in a staging area about a mile from where it will ultimately reside in a new building currently under construction. Over the next few months, physicists will inspect the magnet for damage, although they won't know whether it will work until it's hooked up to the rest of the equipment.

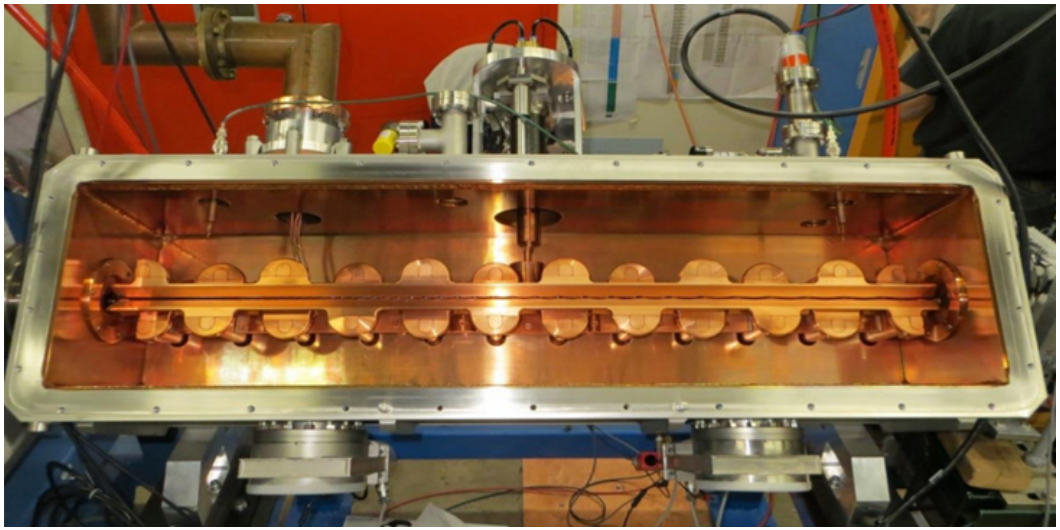
# FNAL

Fermilab


| Section | Extraction E |
|---|---|
| Source | 0-35 keV |
| RFQ | 750 keV |
| Linac | 400 MeV |
| Booster | 8 GeV |
| Target | ~3 GeV |





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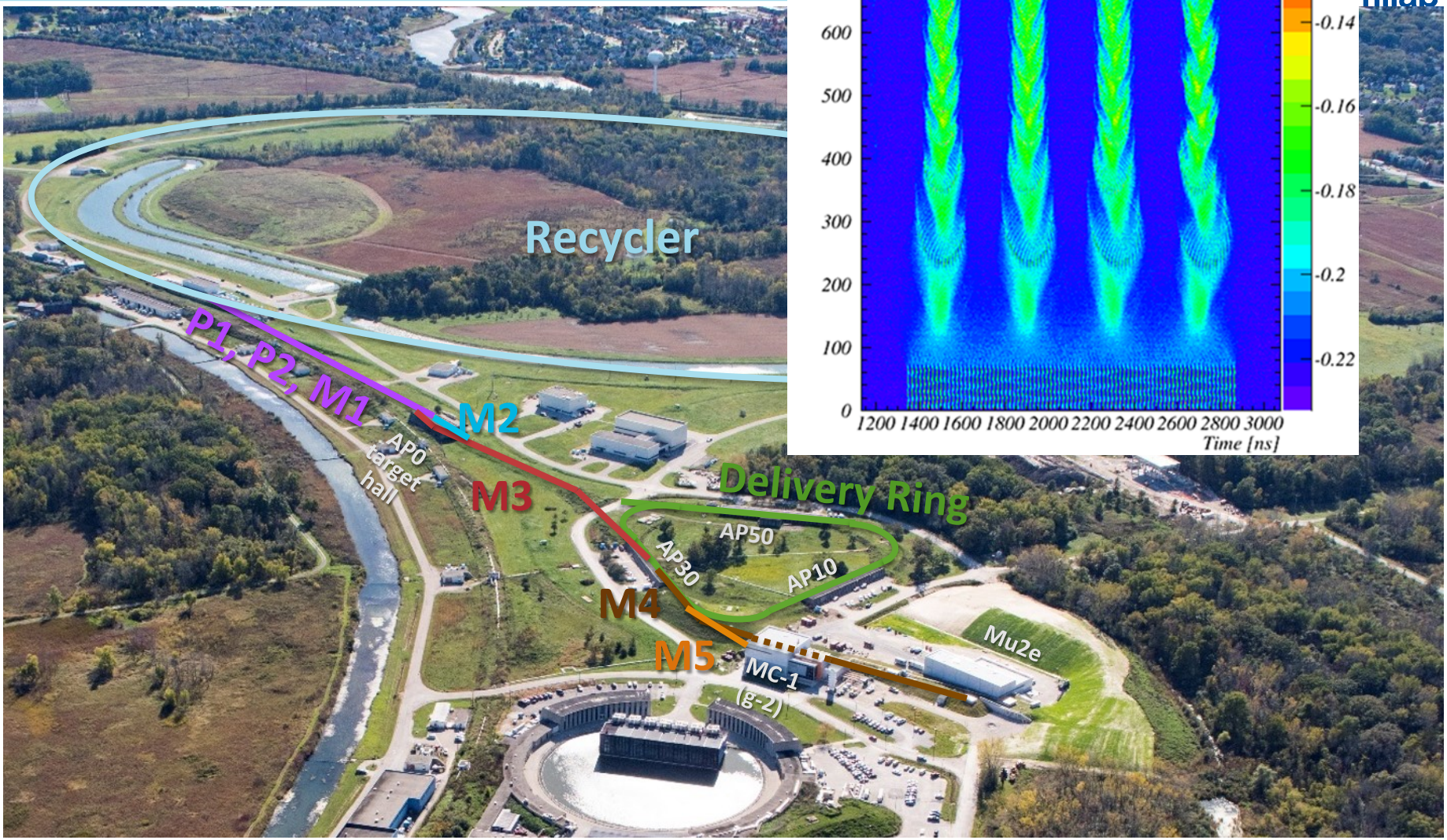
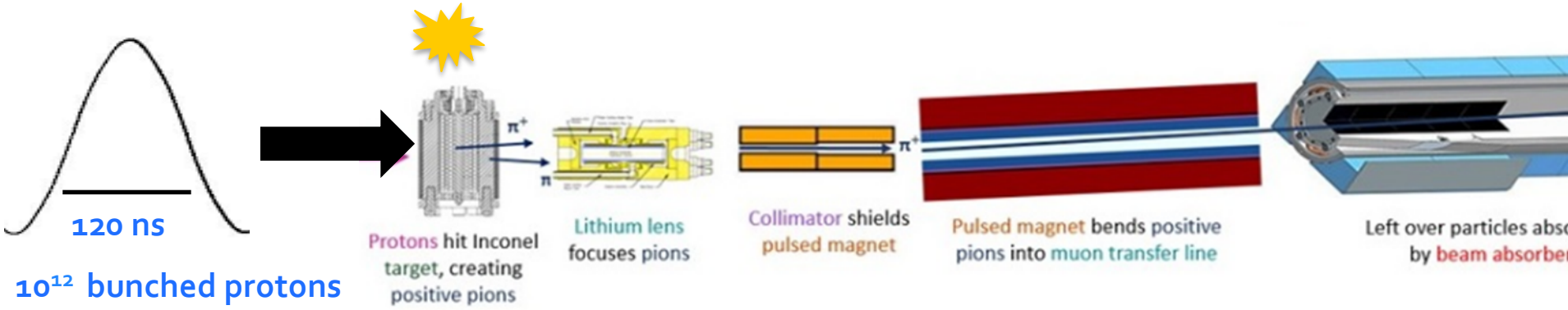
# Muon Campus overview



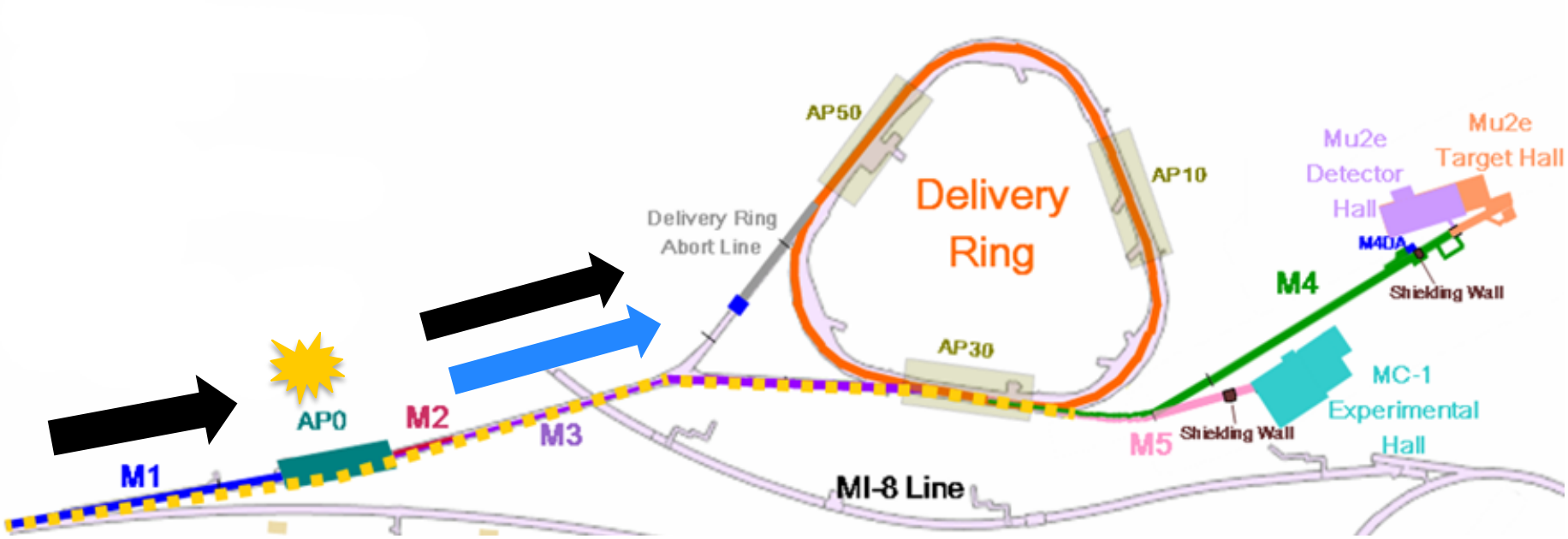
# Muon production

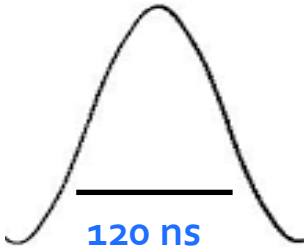
Fermilab

# Muon production

Fermilab



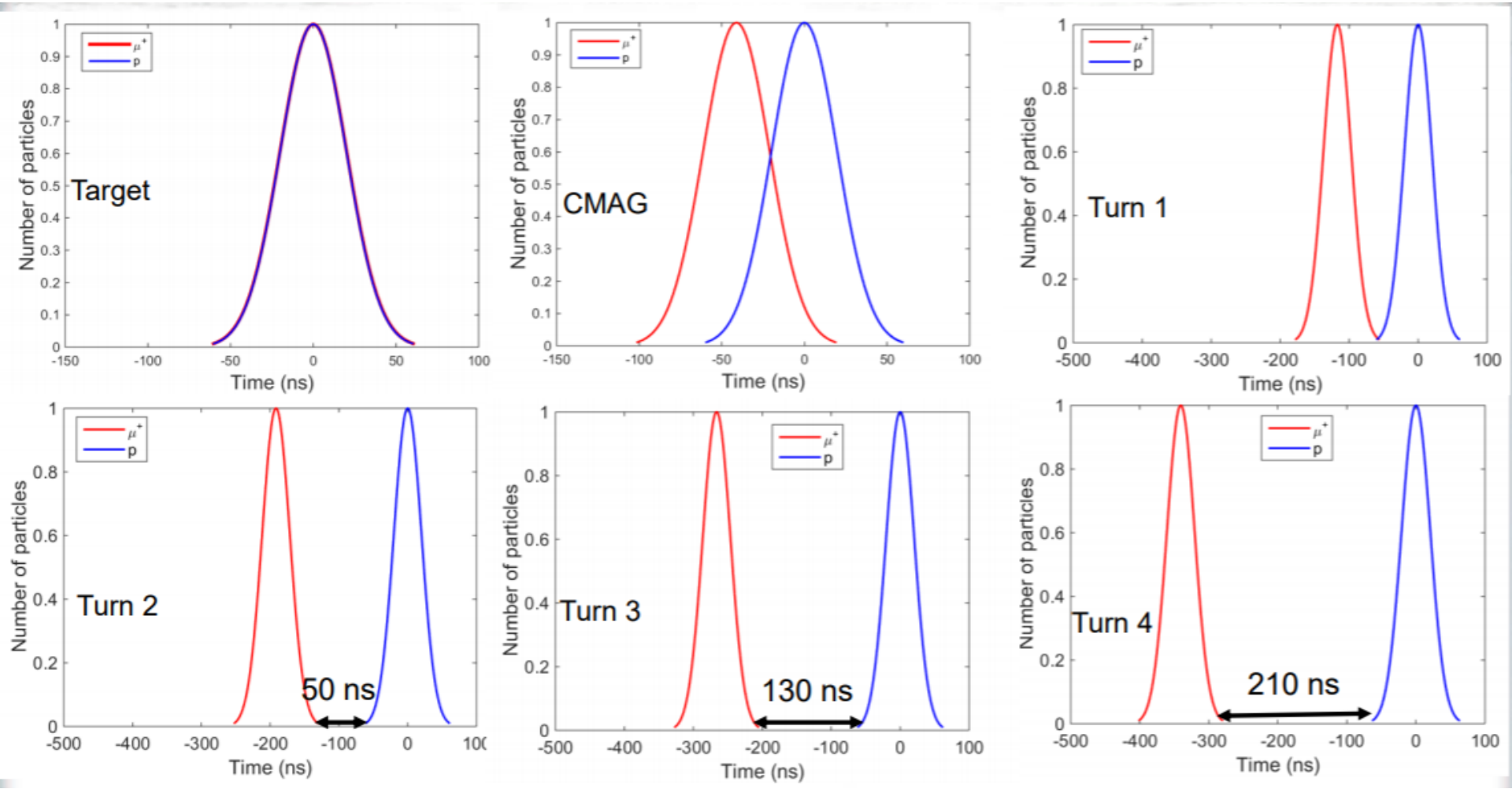

collide protons with target to produce pions

Pions decay into muons

$10^{12}$ bunched protons

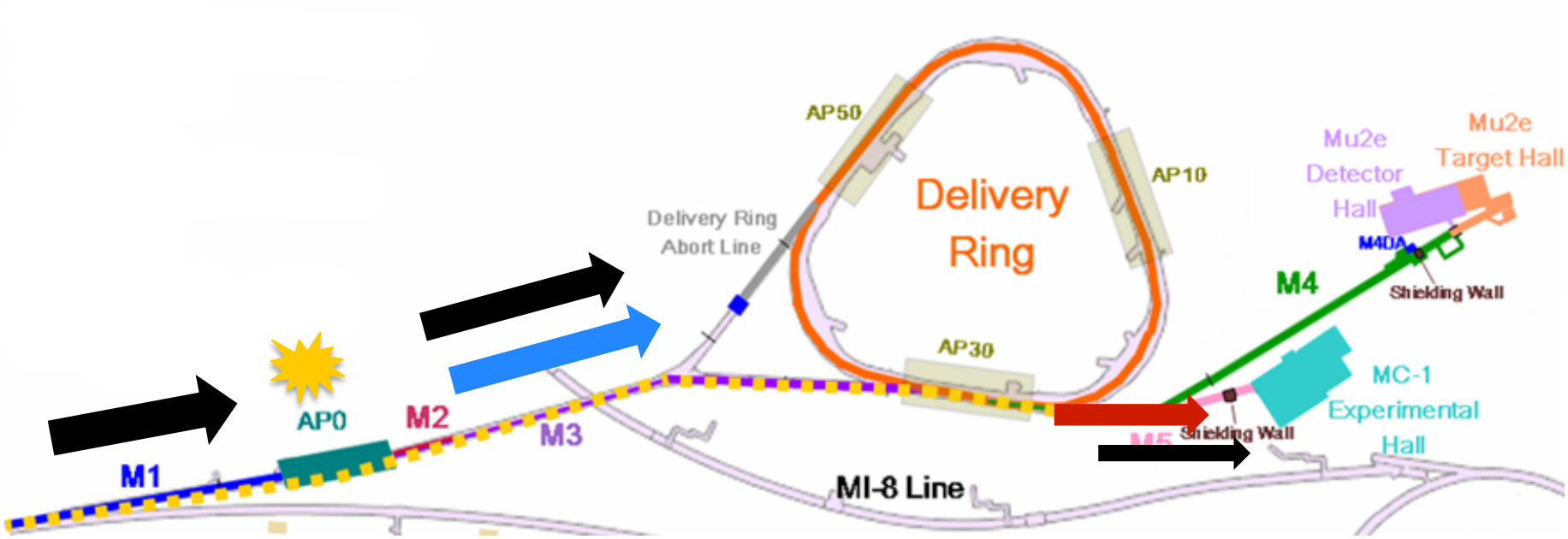
# Proton separation in DR

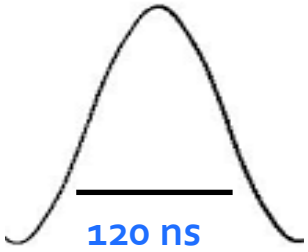
Fermilab



# Muon production

Fermilab




collide protons with target to produce pions

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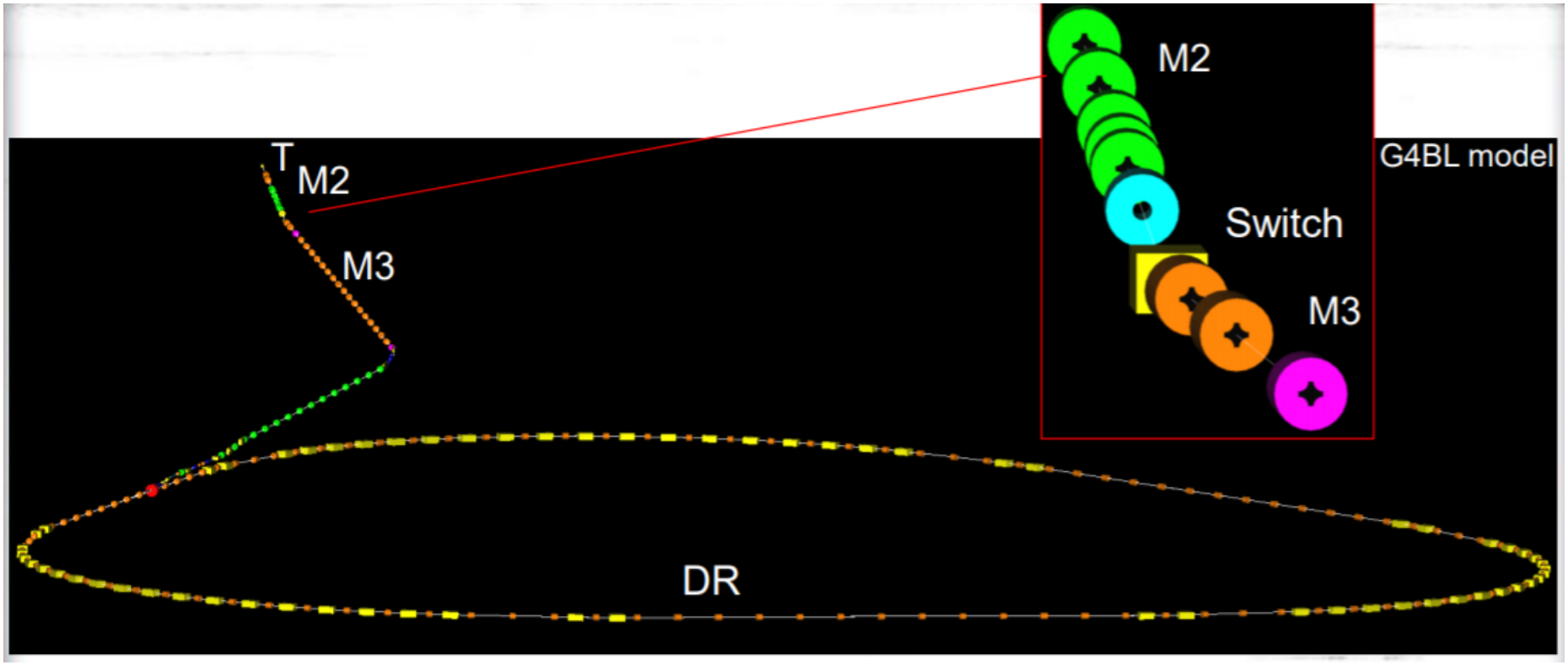
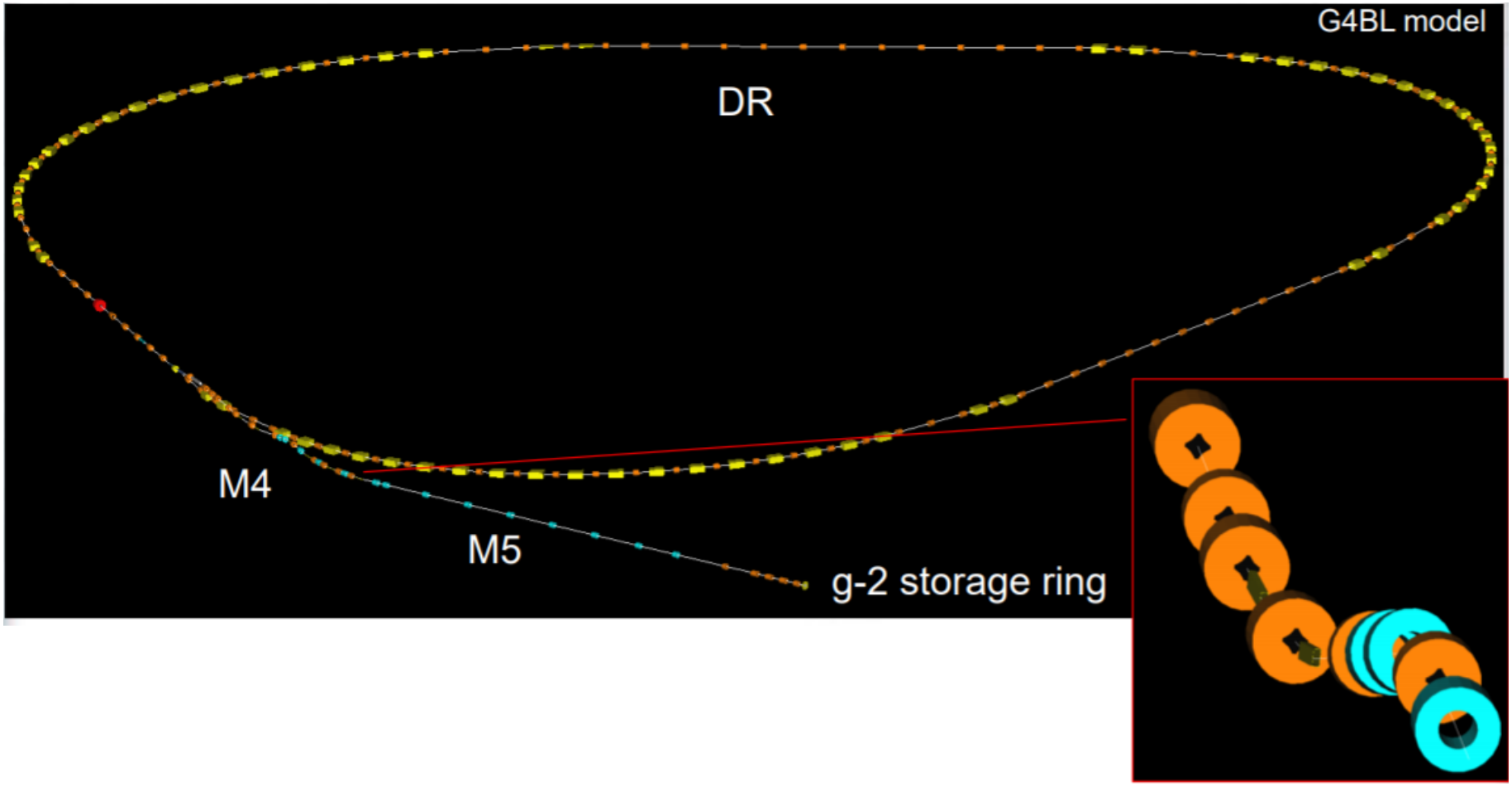
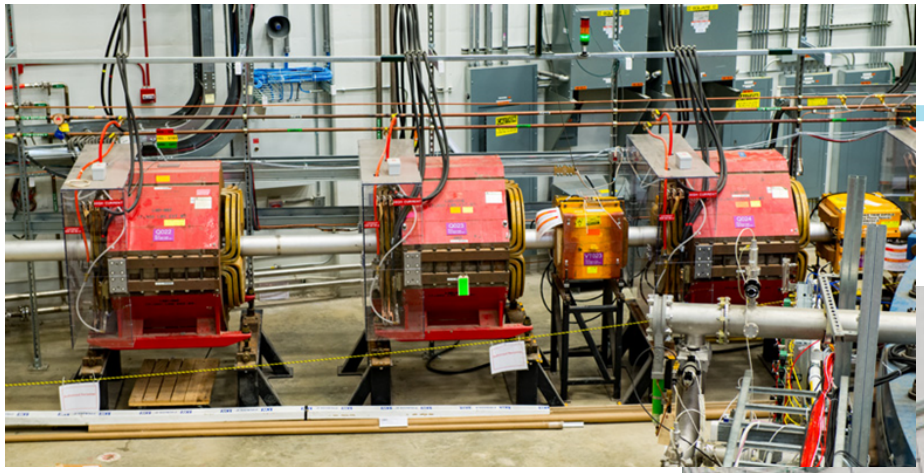
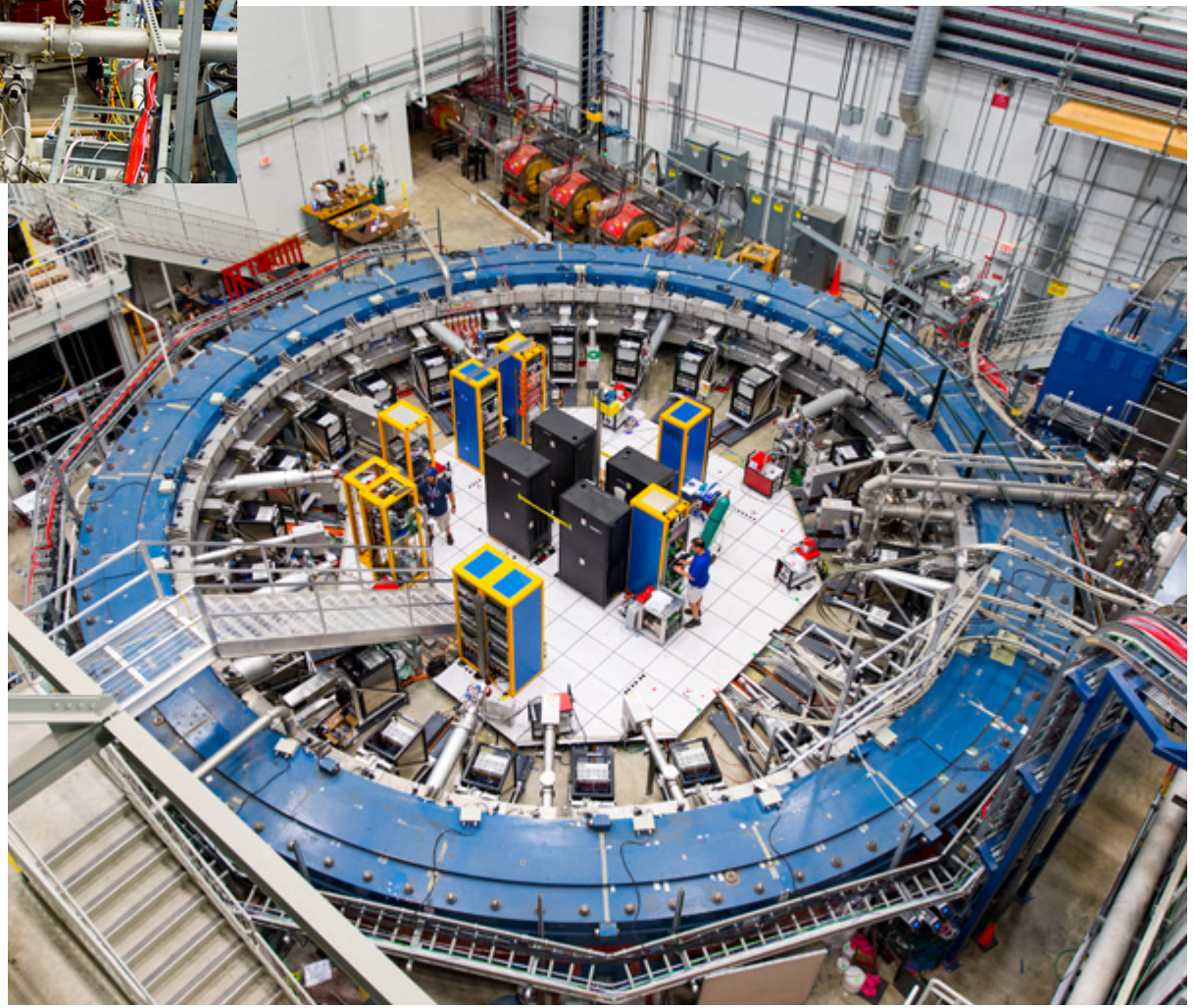
# Simulation

Fermilab




G4BL model
DR
M4
M5
g-2 storage ring

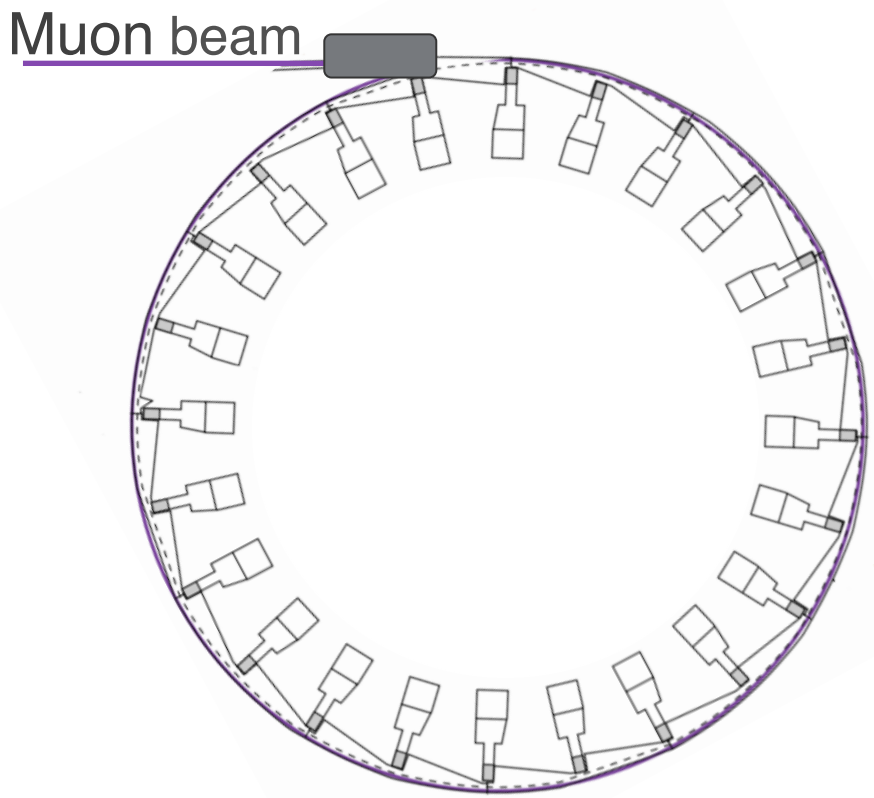


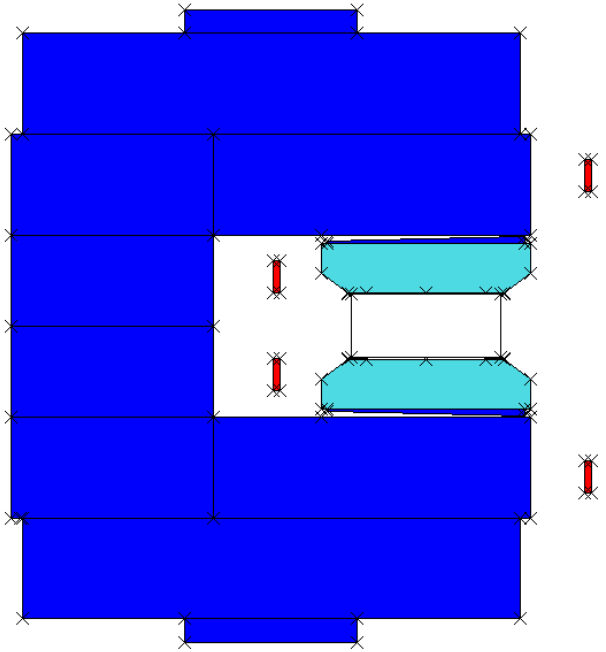


# g-2 ring

B= 1.45 T

Fermilab



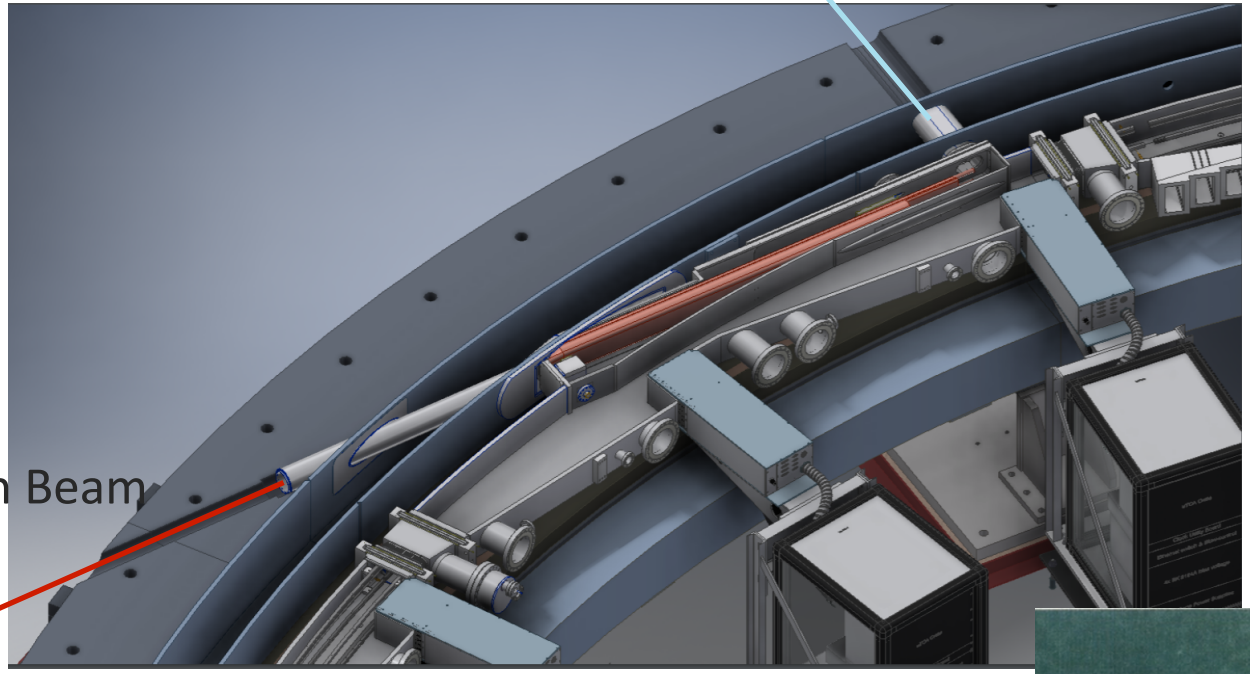
Inflector Magnet

R= 7.112 m

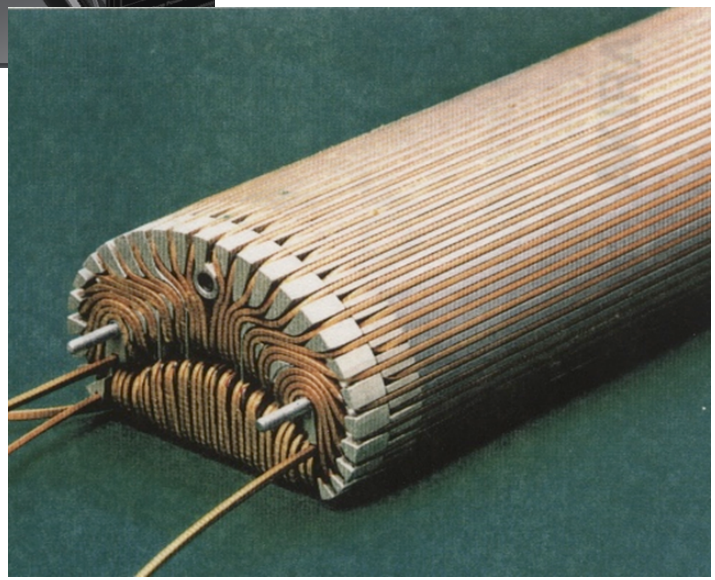
# Inflector magnet

Lead and Cryo

Fermilab



Muon Beam



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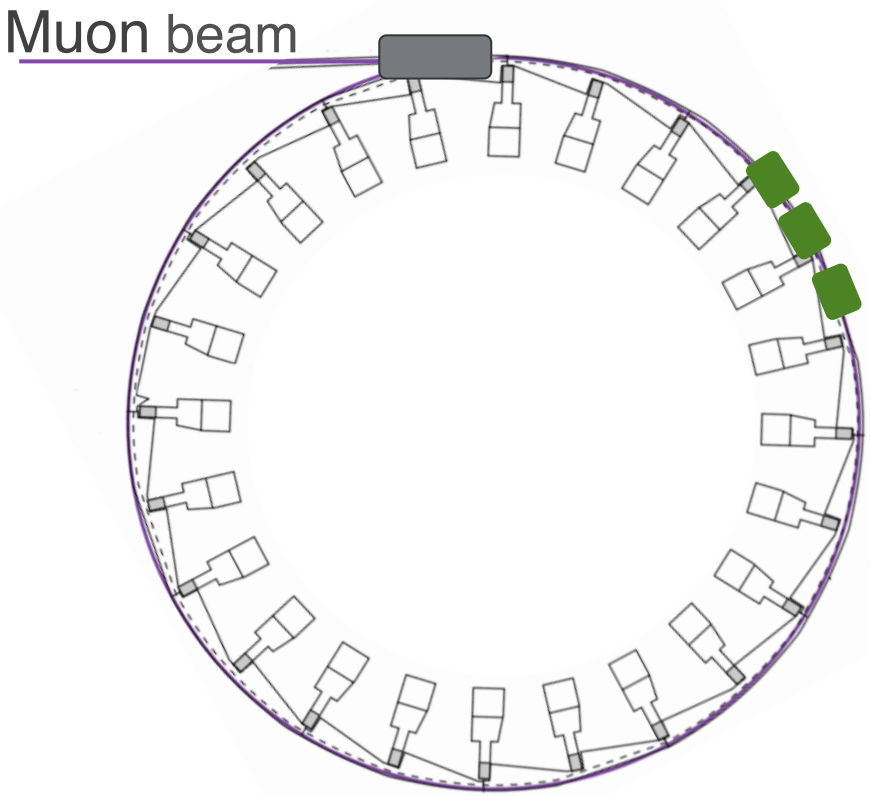
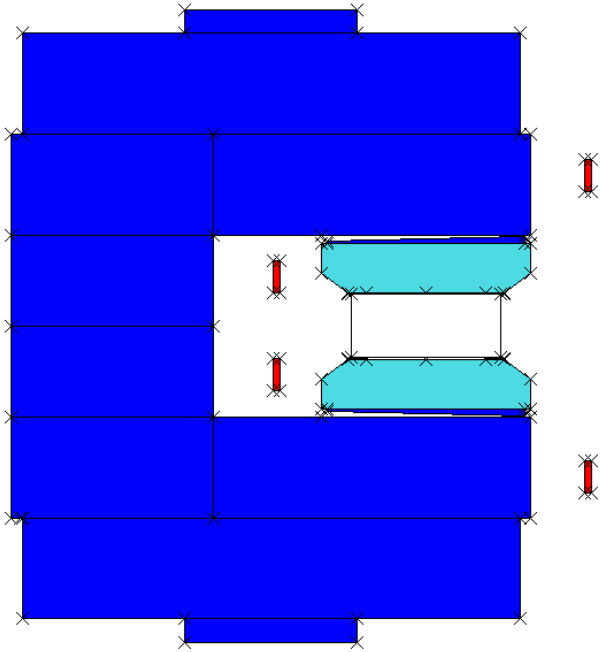



R= 7.112 m

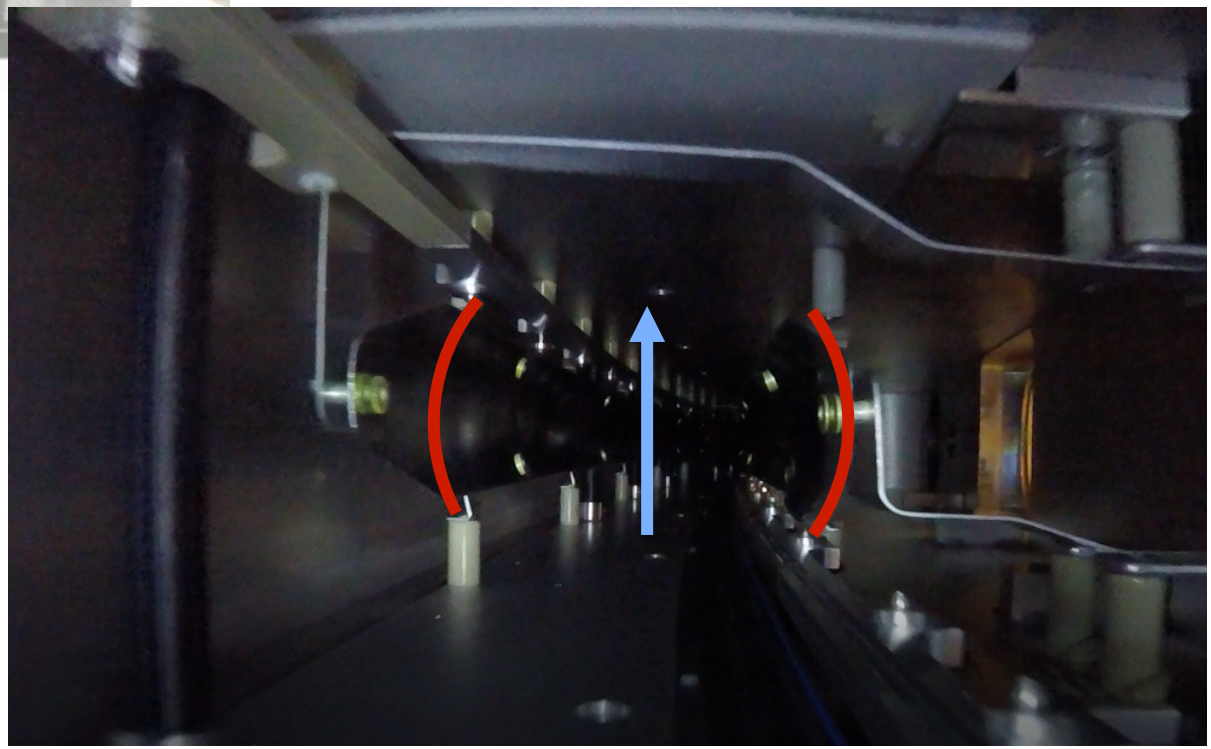


Inflector Magnet

Kicker Magnet

# Kicker Magnet

Fermilab

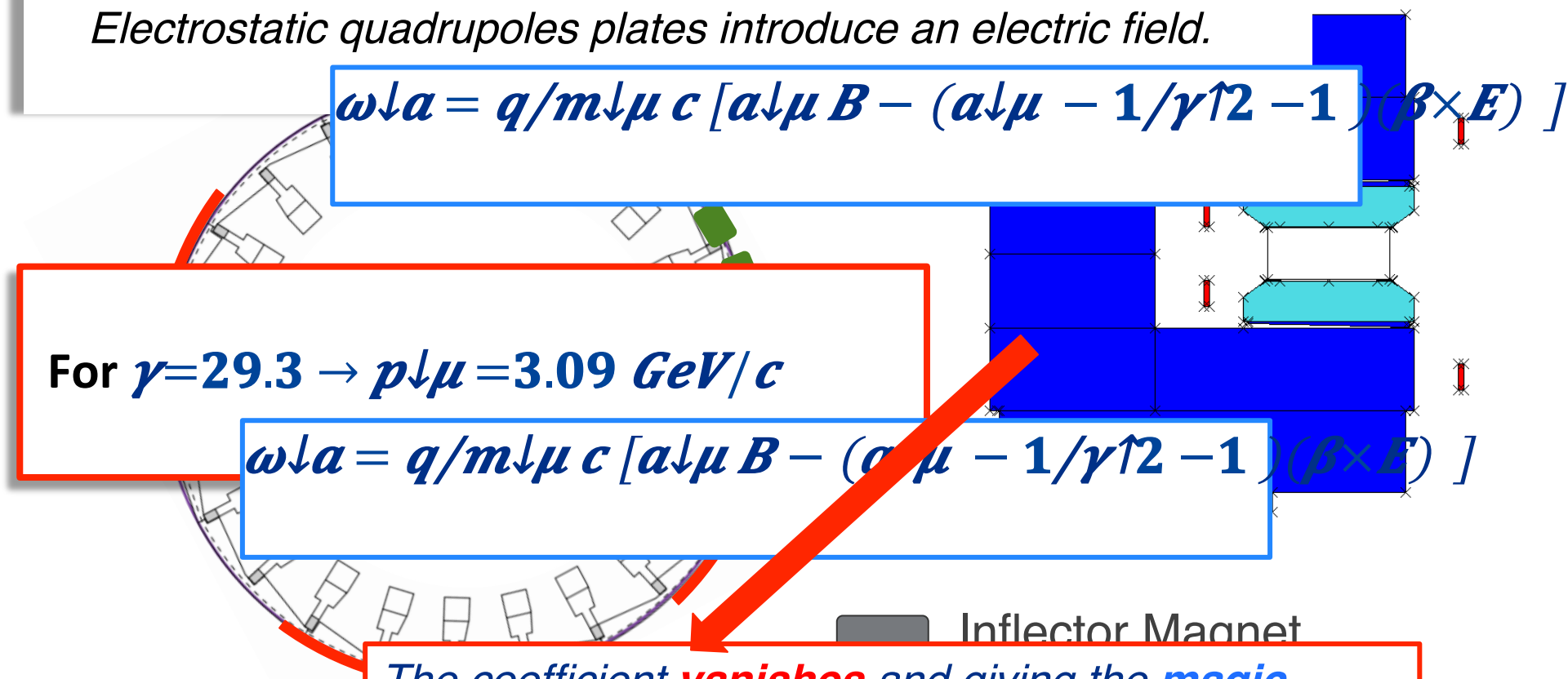


# g-2 ring

Fermilab

*Electrostatic quadrupoles plates introduce an electric field.*

$$\omega\downarrow a = q/m\downarrow\mu\, c\,[a\downarrow\mu\, B - (a\downarrow\mu - 1/\gamma\uparrow 2 - 1)(\beta\times E)\,]$$



For $\gamma = 29.3 \rightarrow p\downarrow\mu = 3.09\ GeV/c$

$$\omega\downarrow a = q/m\downarrow\mu\, c\,[a\downarrow\mu\, B - (a\downarrow\mu - 1/\gamma\uparrow 2 - 1)(\beta\times E)\,]$$

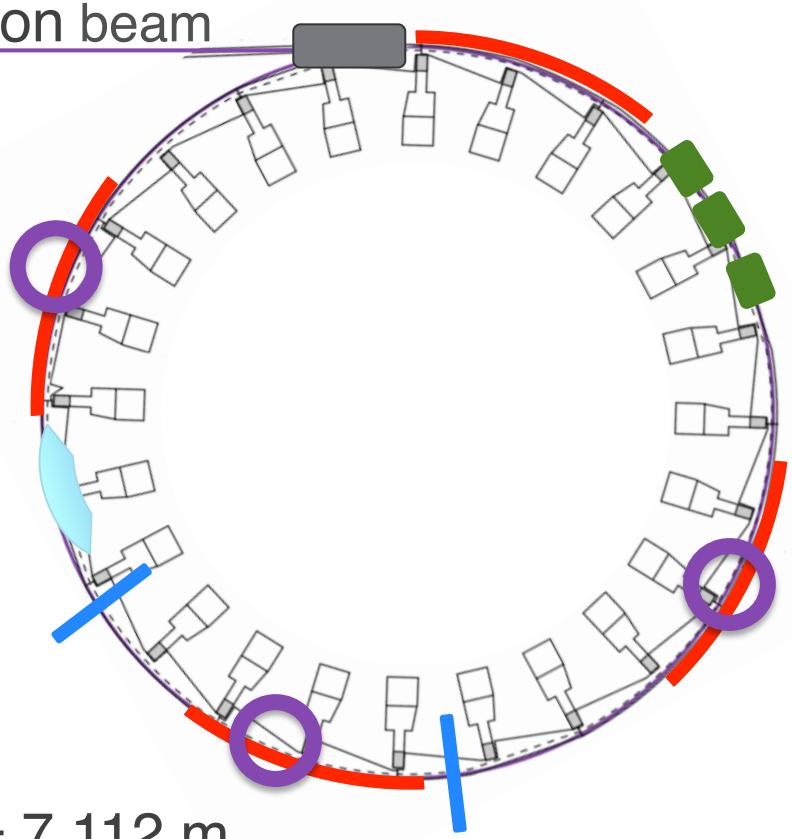
Inflector Magnet

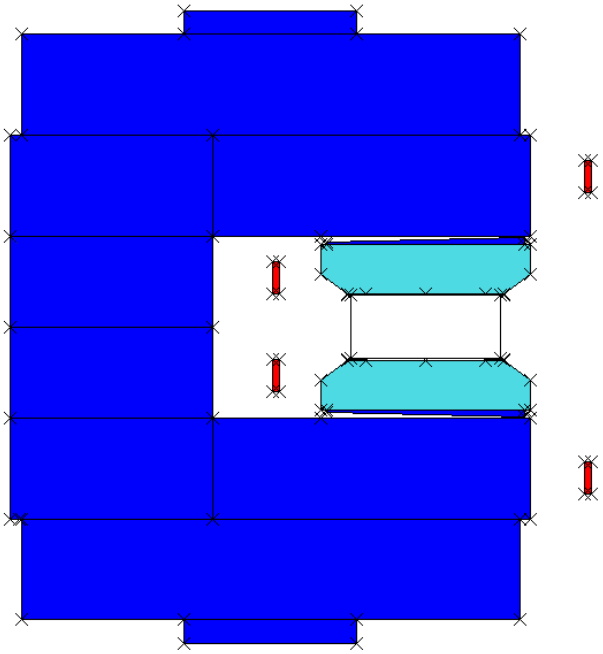
R= 7.112 m

*The coefficient **vanishes** and giving the **magic momentum** of **3.09 GeV/c**!!*

*To satisfy the magic momentum condition, the orbit radius is **7.112 meters**.*

# g-2 ring




Inflector Magnet

Kicker Magnet

Electrostatic quadrupole

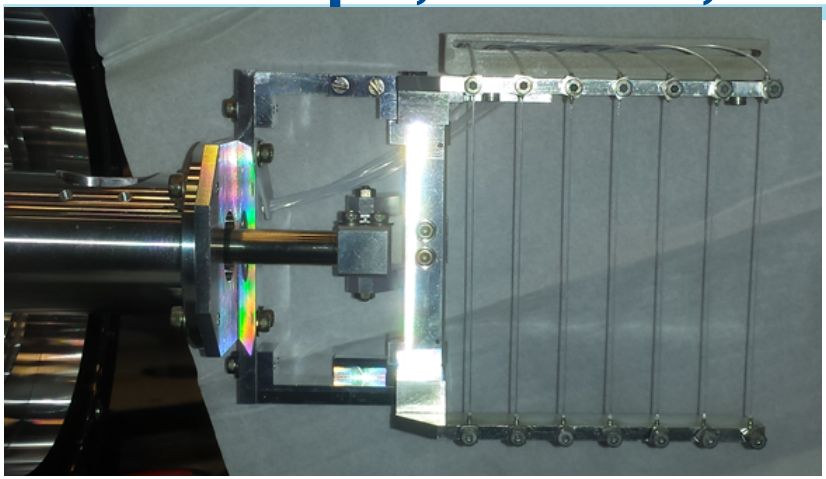
Tracker

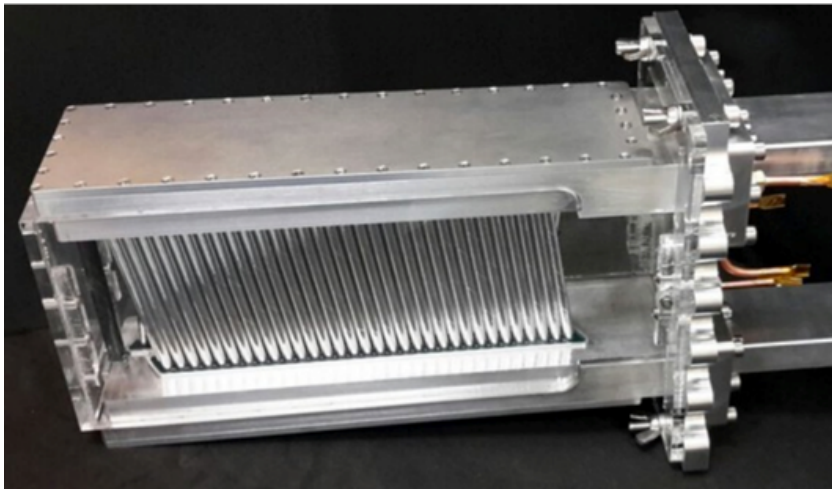
Fiber harps

Collimator

# Fiber harps, tracker, collimators

Fermilab

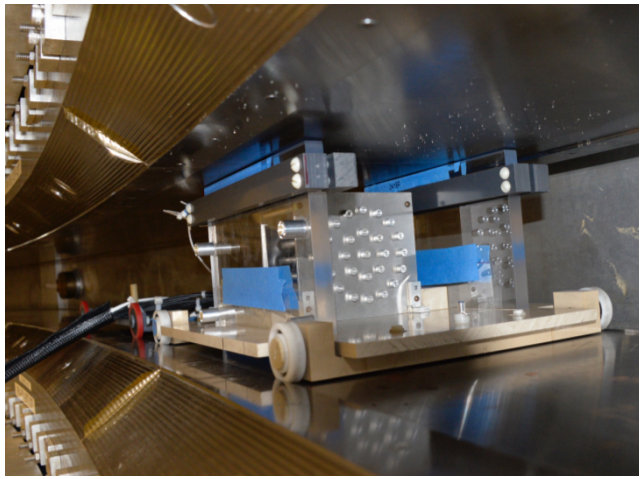


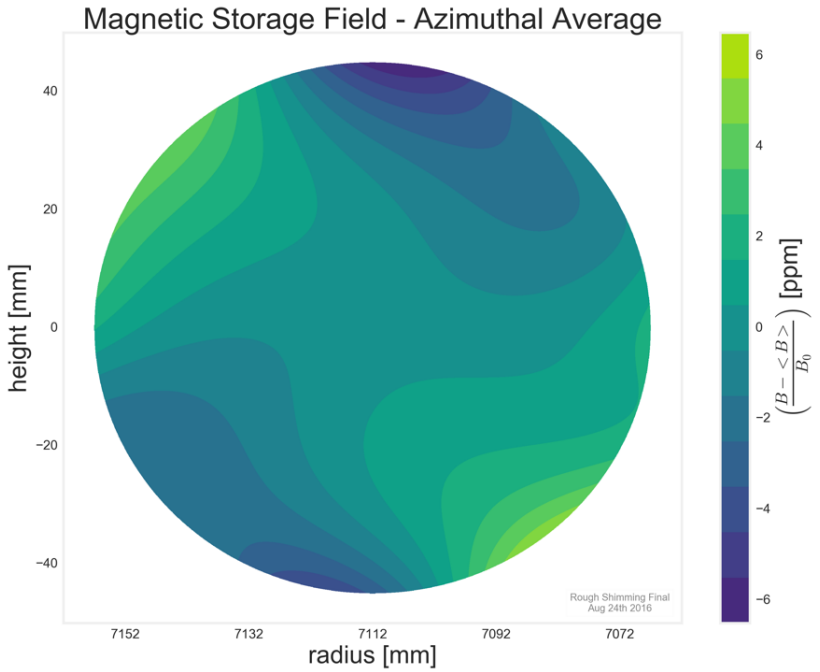


# Mechanical shimming of the main magnet

Fermilab

- After other mechanical knobs had been tuned, large shimming campaign with over 8000 foils (<10 ppm)
- Trolley with NMR probes to measure remaining field

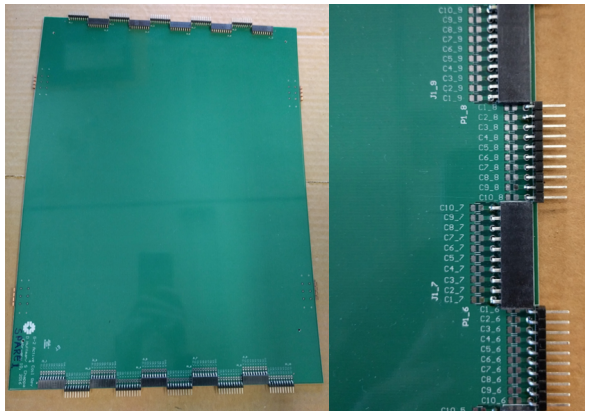


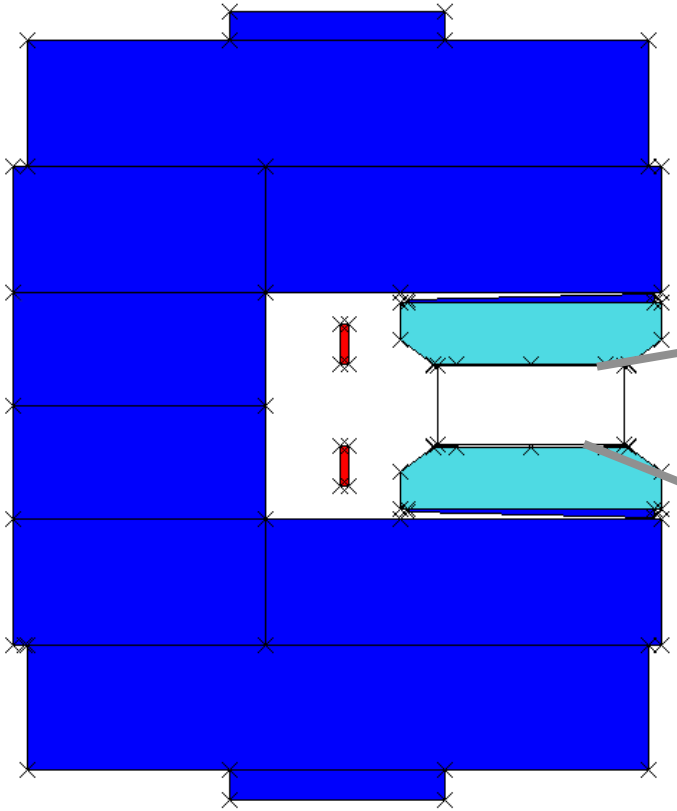


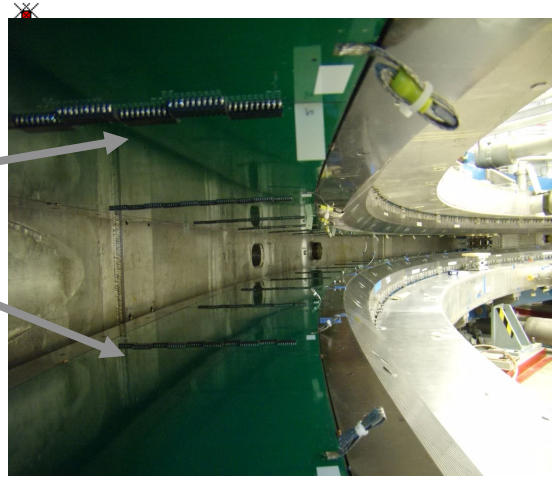

| Multipole (ppm) | Normal | Skew |
|---|---|---|
| n=1 | 0.02 | -0.56 |
| n=2 | -0.71 | -3.77 |
| n=3 | 0.75 | 0.62 |
| n=4 | 0.44 | 1.61 |

# Active correction coils

- 200 concentric coils -100 on top and bottom
- Independently controlled
- 36 boards on top and bottom, 10°







# Compensation coil modeling

Fermilab

- Previous BNL experiment proposed current distributions to cancel remaining multipoles

| Multipole | Normal | Skew |
|---|---|---|
| Dipole | - | 1 |
| Quadrupole | $h$ | $x$ |
| Sextupole | $h\uparrow 2 - x\uparrow 2$ | $x\uparrow 2 - h\uparrow 2$ |
| Octupole | $h\uparrow 3 - 3hx\uparrow 2$ | $x\uparrow 3 - 3h\uparrow 2\, x$ |
| Decapole | $h\uparrow 4 - 6h\uparrow 2\, x\uparrow 2 + x\uparrow 4$ | $4hx(h\uparrow 2 - x\uparrow 2\,)$ |

- h is the magnet half gap
- Normal currents are the same for the top and bottom, skew have opposite sign
- Did not account for asymmetry due to iron wedges

# Fields from current distributions

Fermilab

| Multipole | Normal | Skew |
|---|---|---|
| Dipole | | |
| Quadrupole | | |
| Sextupole | | |
| Octupole | | |
| Decapole | | |