Current status and prospects of the FNAL muon g-2 storage ring

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Argonne National Laboratory
8/5/15 DPF 2015

Today

- g-2 reminder
- Storage ring
  - overview
  - injection systems
  - magnetic field systems
- Current status, path forward

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Experimental technique overview

Principle

(J. Mott's previous talk)

- Muons in magnetic field:

  1. Cyclotron motion

$$\frac{d\vec{p}}{dt} = e\vec{v} \times \vec{B} \quad \Rightarrow \quad \omega_c = \frac{eB}{\gamma mc}$$

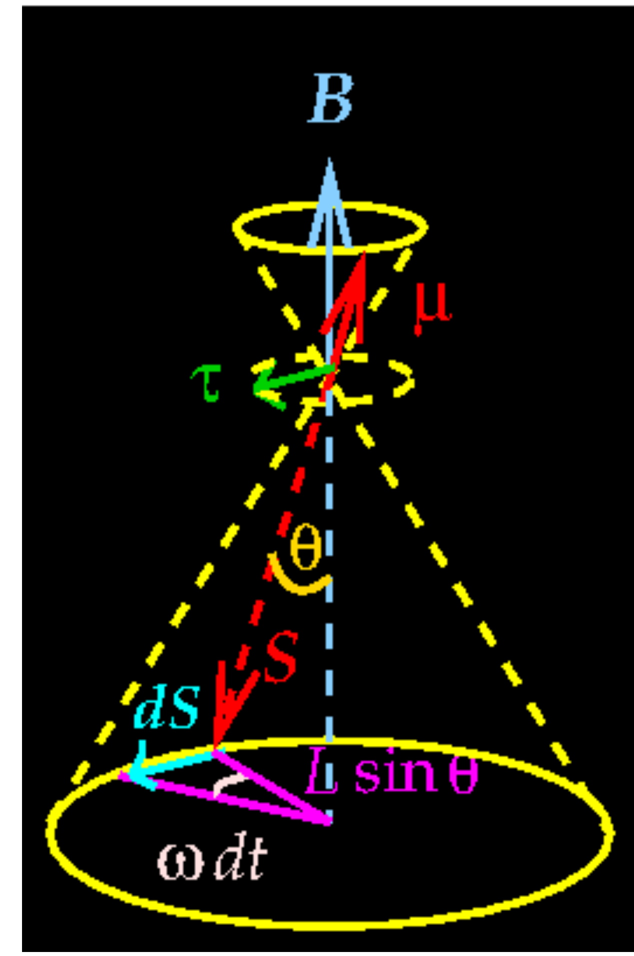
$$(\vec{v} \cdot \vec{B} = 0)$$

  2. Spin precession

$$\frac{d\vec{S}}{dt} = \vec{\mu} \times \vec{B} \quad \Rightarrow \quad \omega_s = \frac{geB}{2mc} + (1-\gamma)\frac{eB}{\gamma mc}$$

Larmor precession

Thomas precession



Difference frequency:

$$\omega_a \equiv \omega_s - \omega_c = a_\mu \frac{eB}{mc}$$

Precision measurements of ω_a, B ⇒ a_μ

$$a_\mu \equiv \frac{g-2}{2}$$

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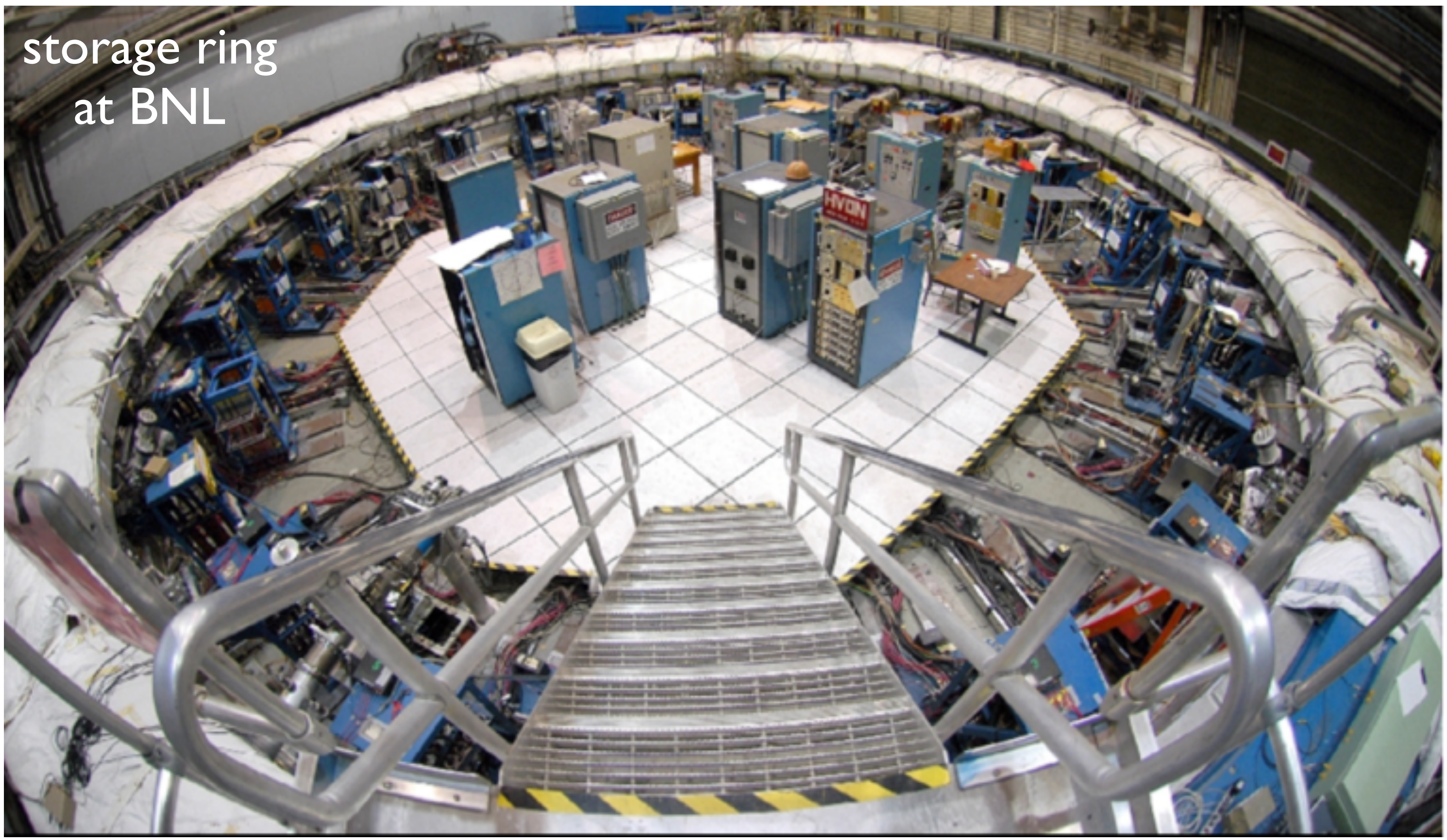
Overview

- C-shaped 7.1-m radius superconducting magnet excites 1.45 T magnetic field in storage volume



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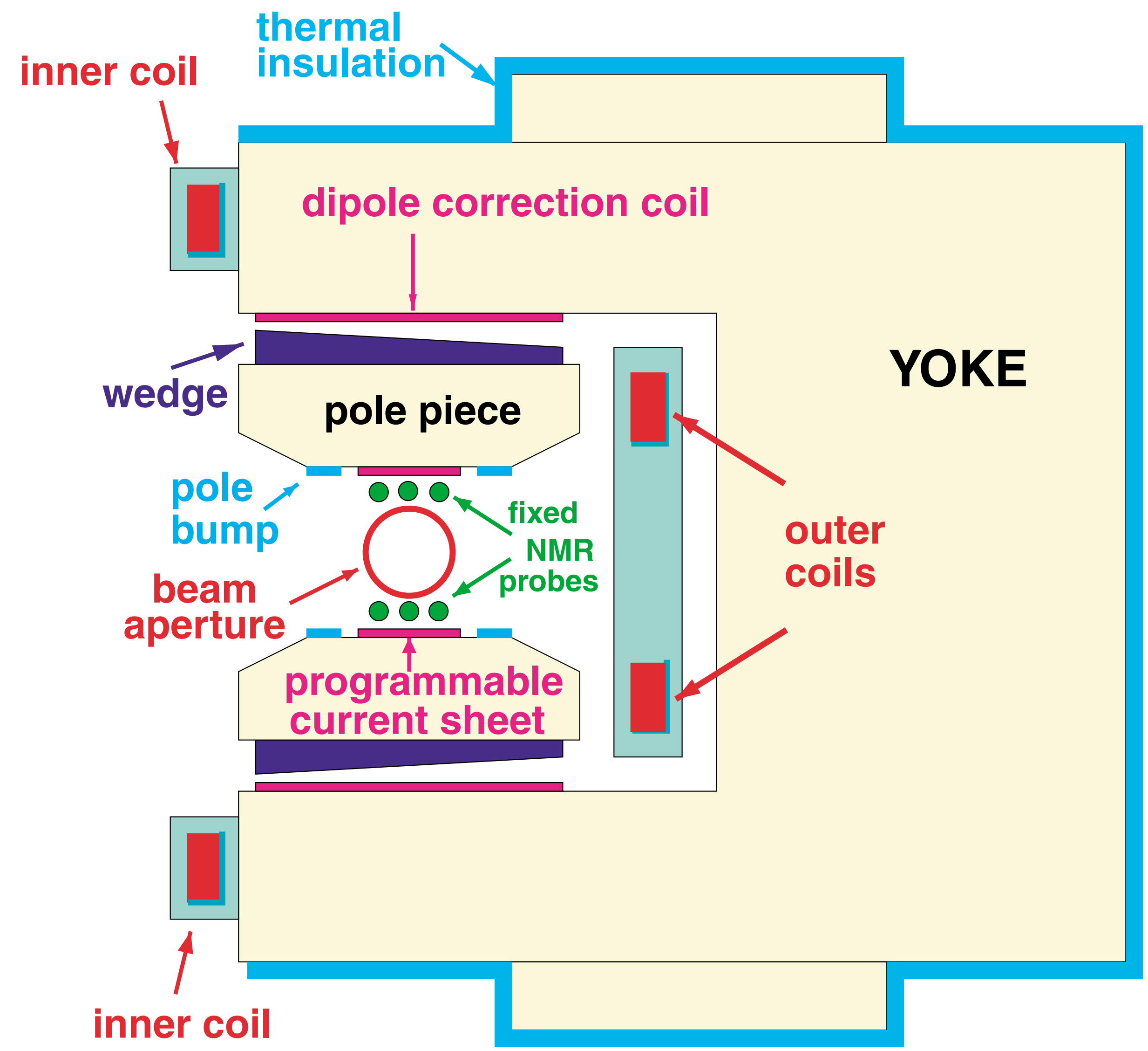
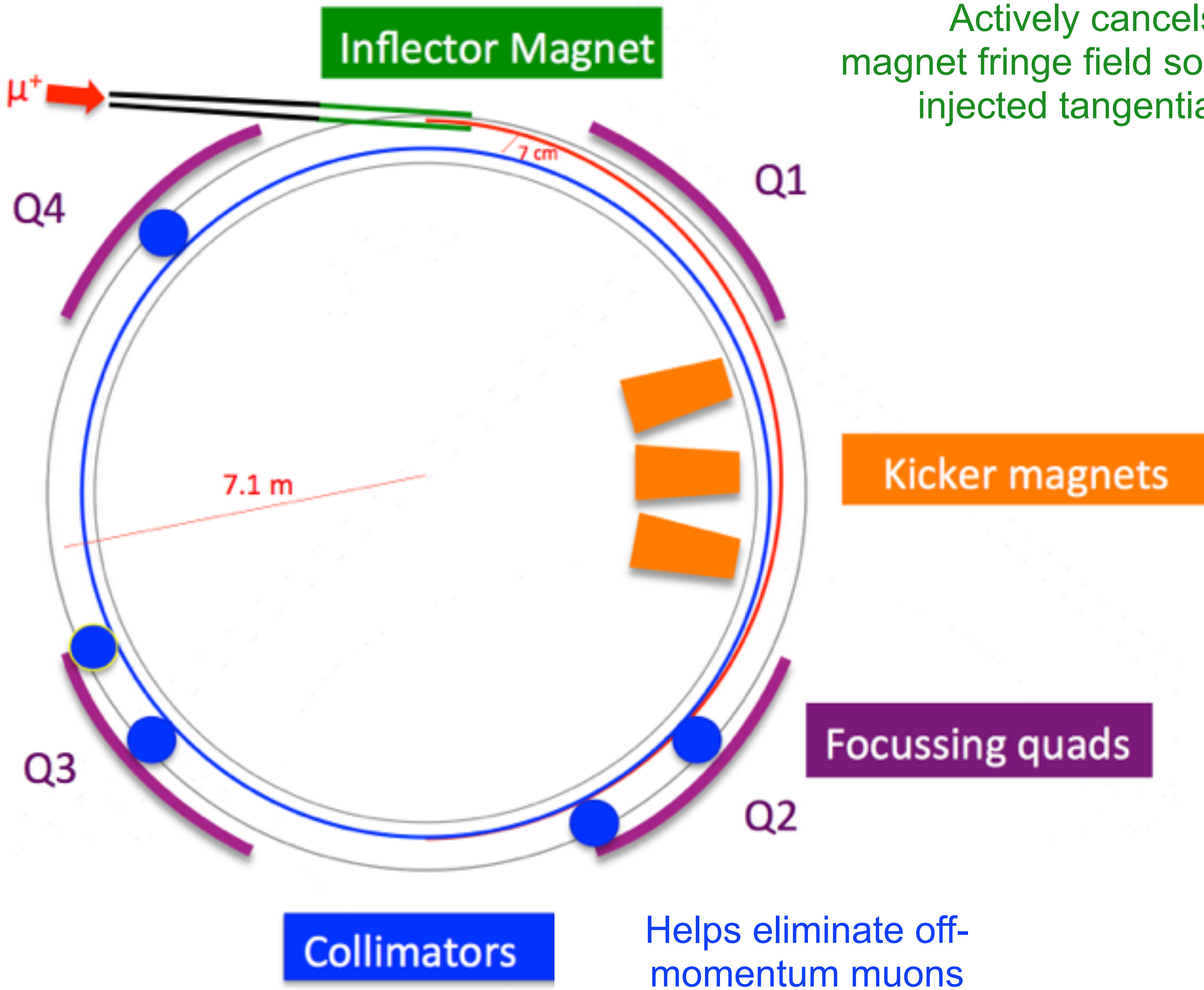


Beam storage systems



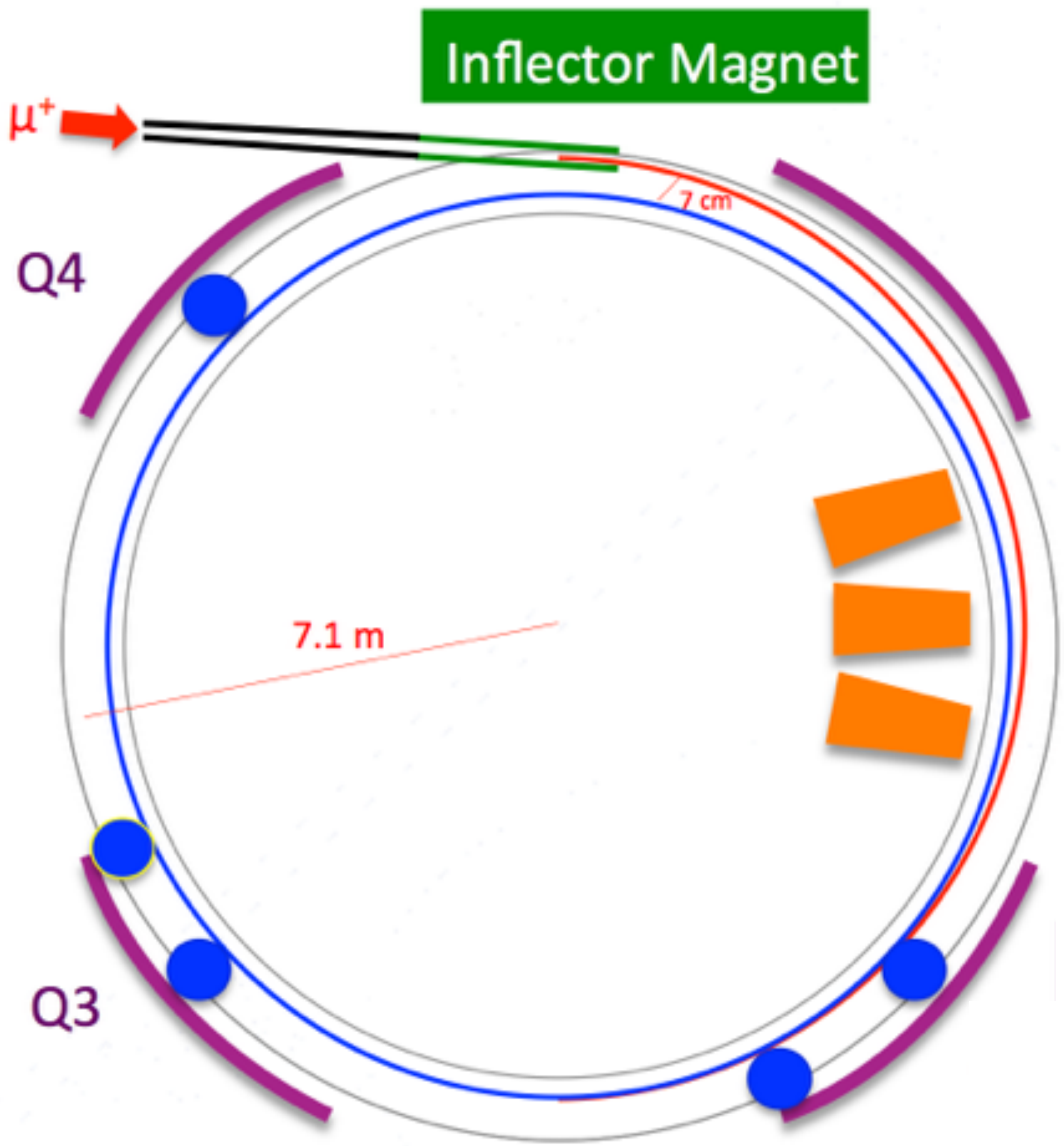
Actively cancels magnet fringe field so muons injected tangentially

Injected muons off-orbit. "Kicks" muons onto correct path

Statistics, statistics, statistics…

Helps eliminate off-momentum muons

Beam storage systems



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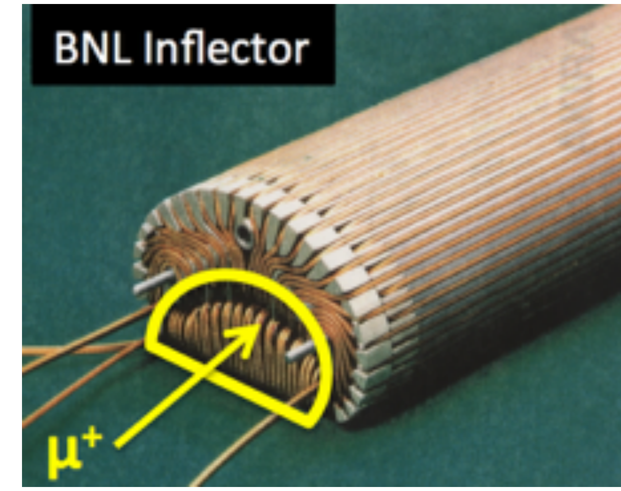
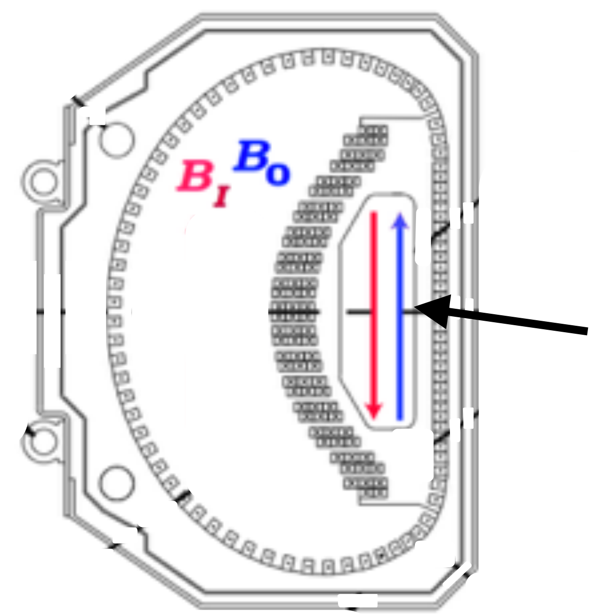
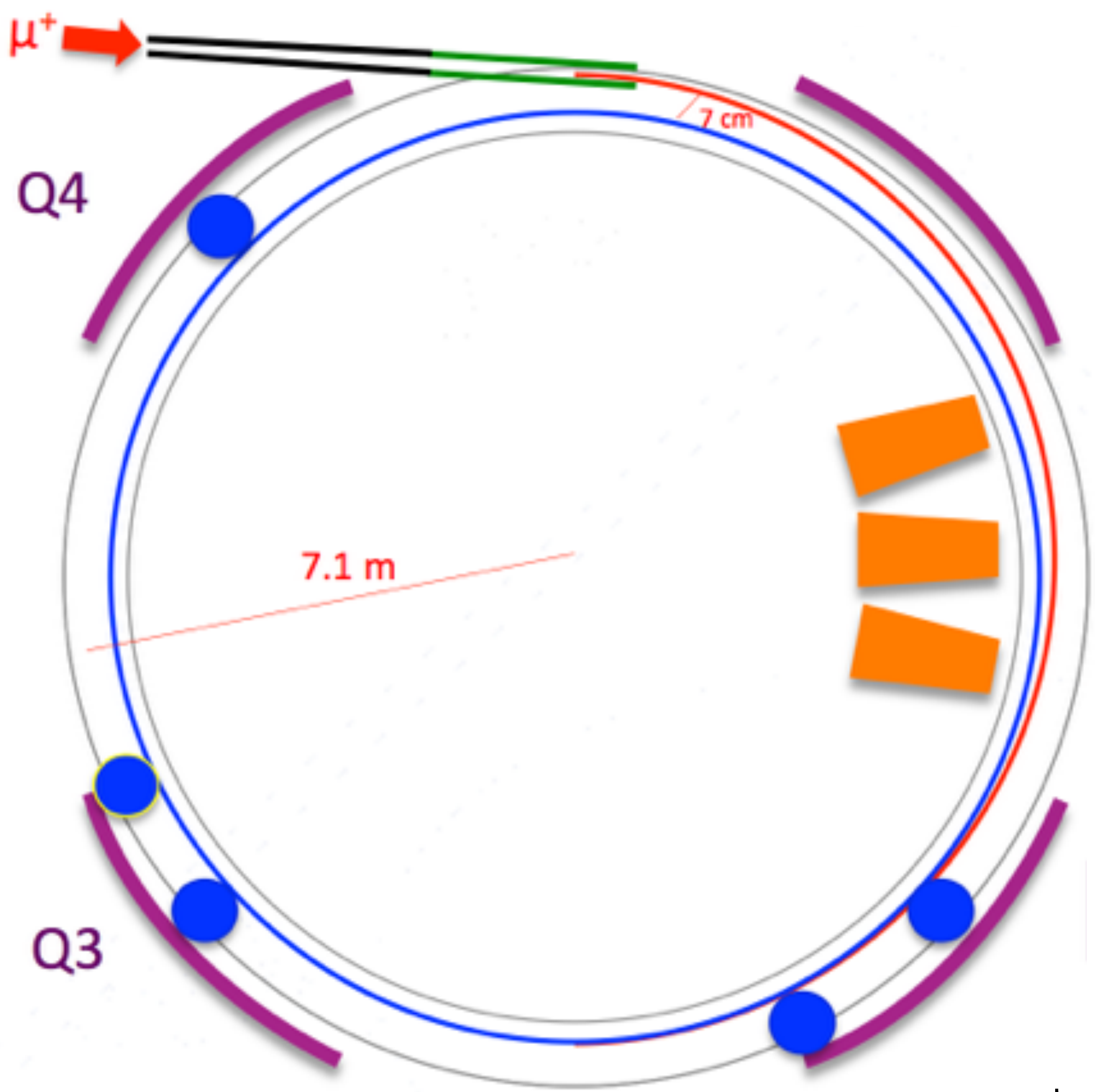
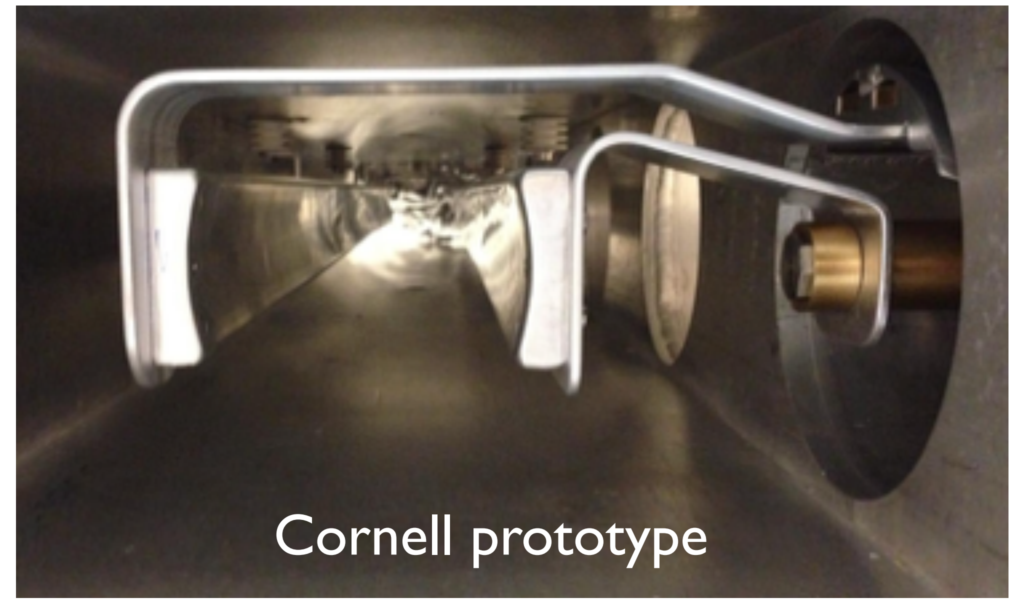




Beam
channel

Beam storage systems





Kicker magnets

Injected muons off-orbit.
"Kicks" muons onto correct path

New kicker will feature stronger kick, faster rise/fall time

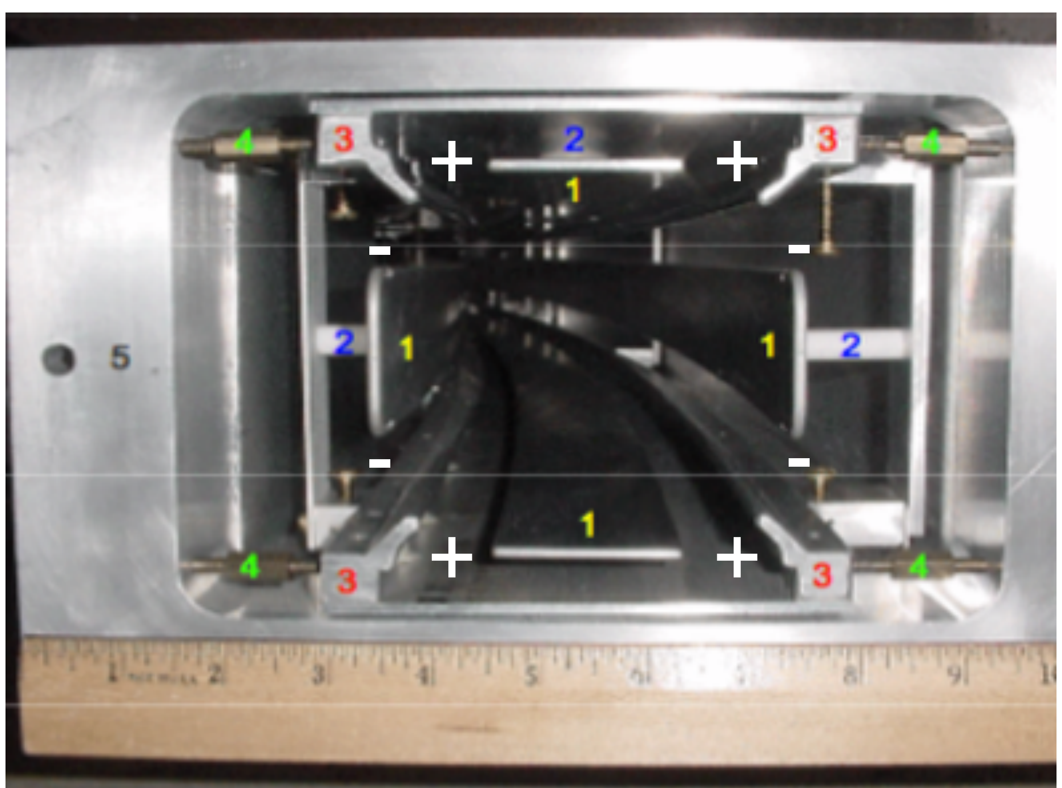
➥ **Improved storage efficiency, systematics**

Focussing quadrupoles

- Around 40% of storage volume equipped with electric focusing quadrupoles for vertical confinement
  - dramatically increases storage efficiency

- Complicates the physics, but fortunately…

$$\vec{\omega}_a \equiv \vec{\omega}_s - \vec{\omega}_c = \frac{e}{mc}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)(\vec{\beta} \times \vec{E})\right]$$



(1) plates, (2) HV standoffs, (3) trolley rails, (4) adjustment screws, (5) vacuum chamber

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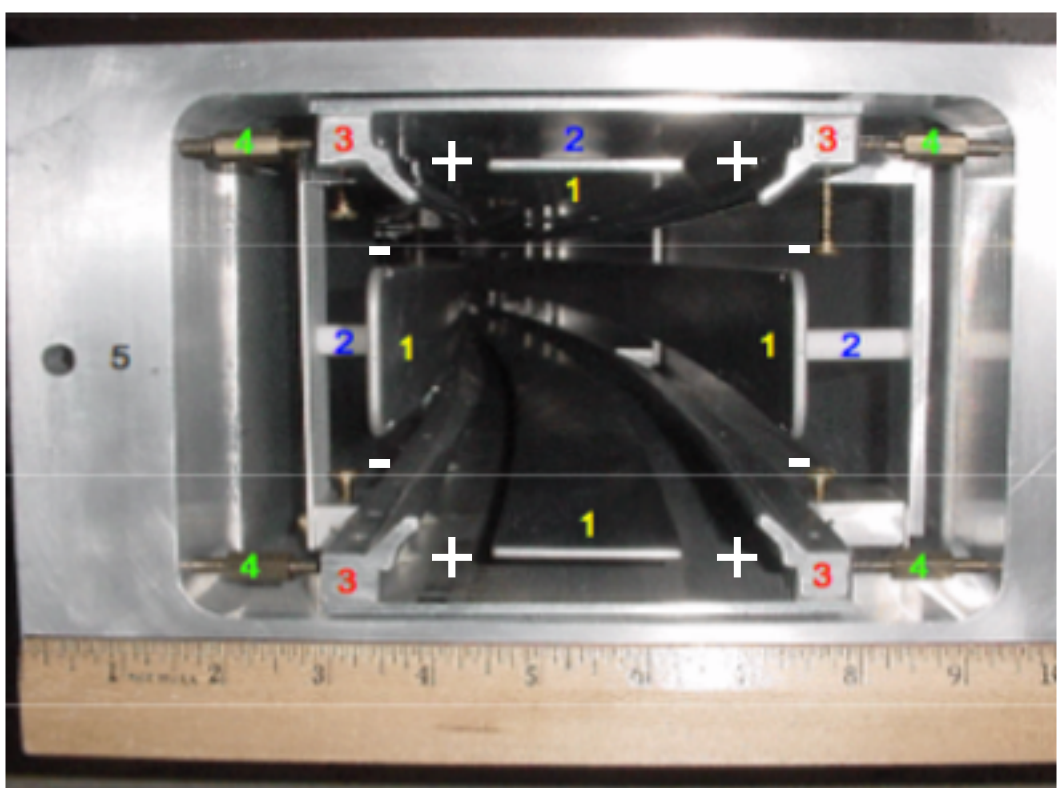
$\emptyset$ for γ = 29.3
finite γ spread leads to small correction

BNL/FNAL approach



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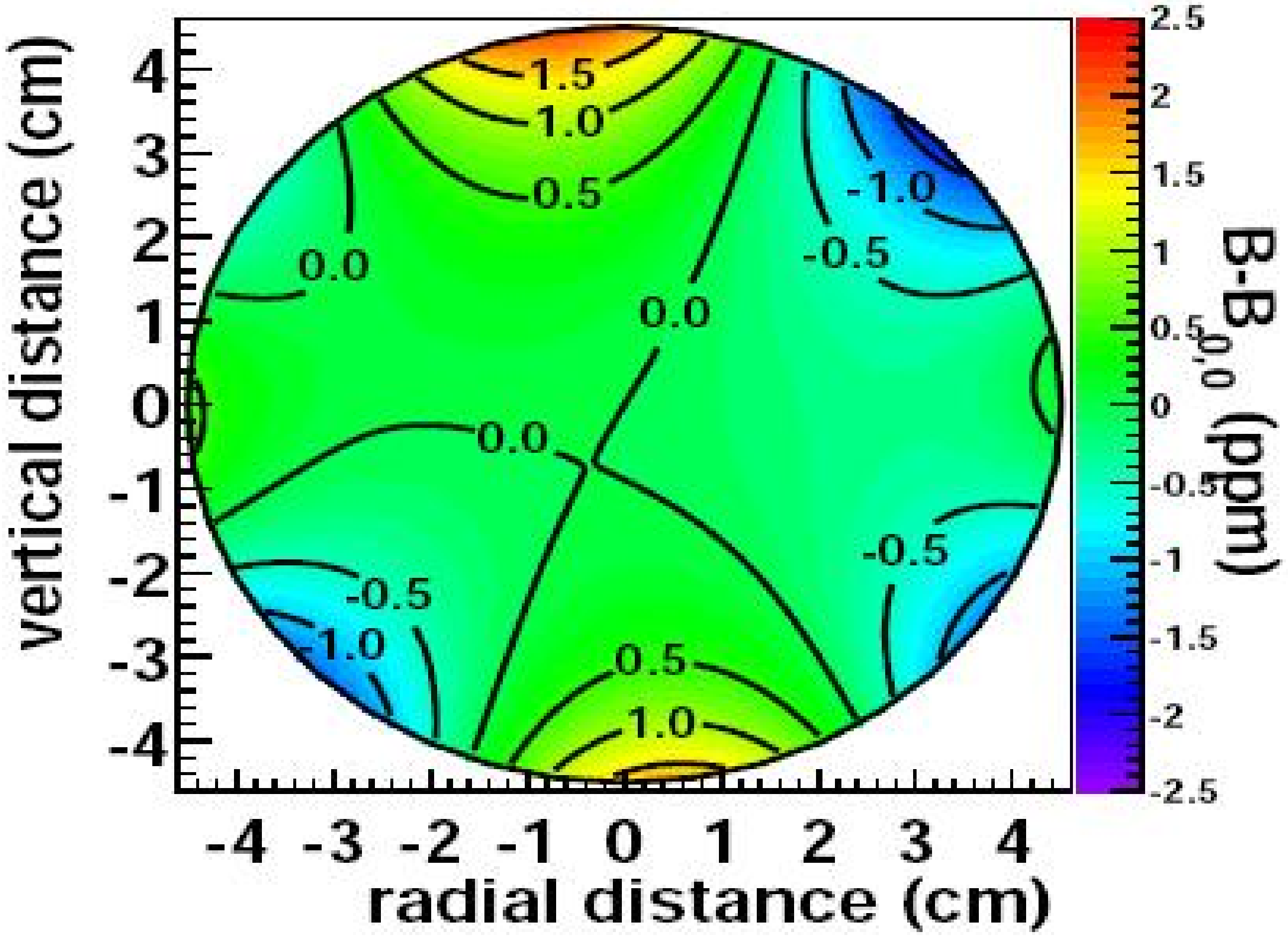
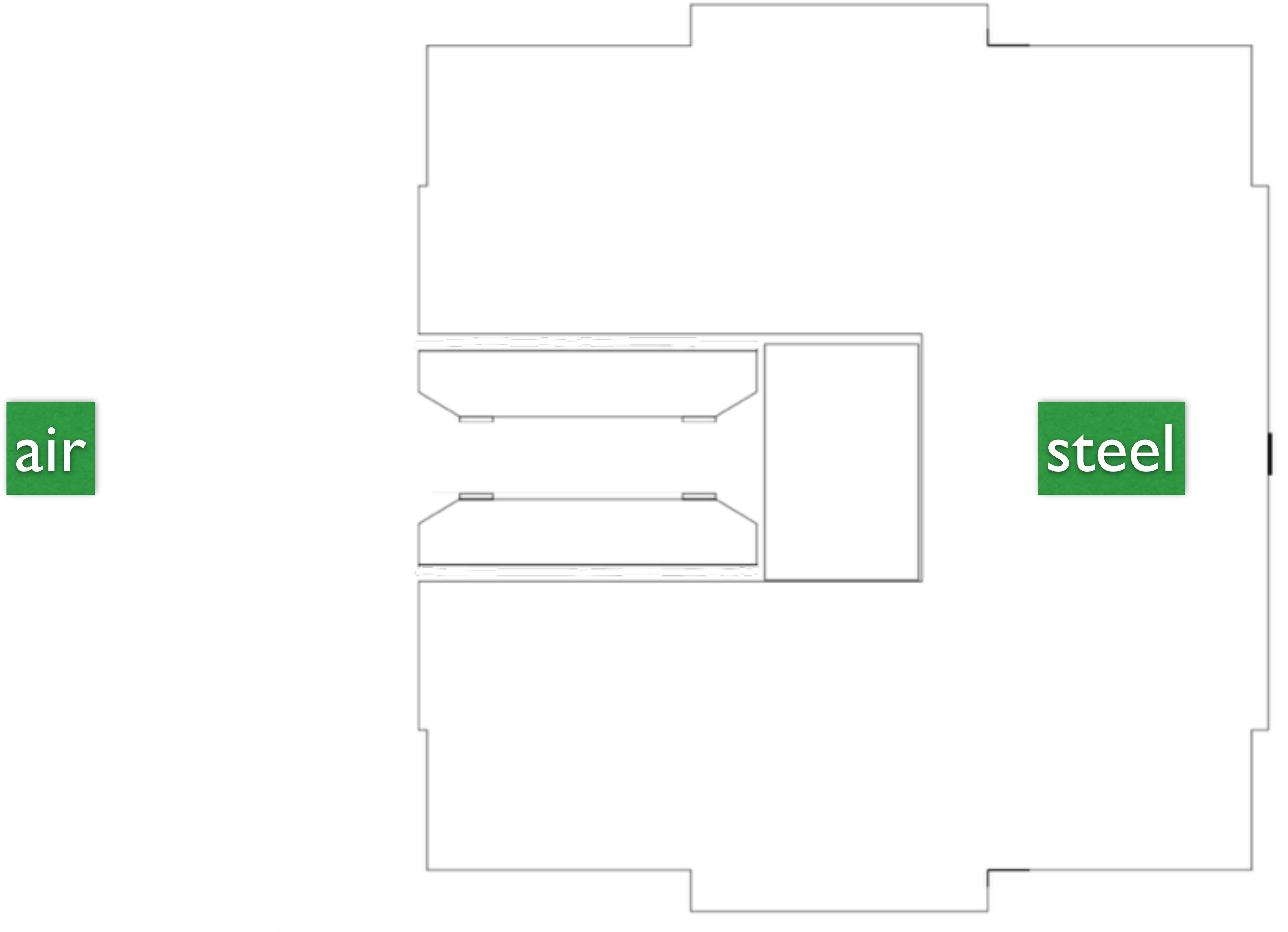
Magnetic field

- Challenge is to measure field *experienced by the muons* to 70 ppb. Enormously challenging. Many many systematic effects enter. Our best tool to reduce their effect is to make the field as homogeneous as possible.



Azimuthally-averaged magnetic field achieved in BNL g-2

Magnetic field



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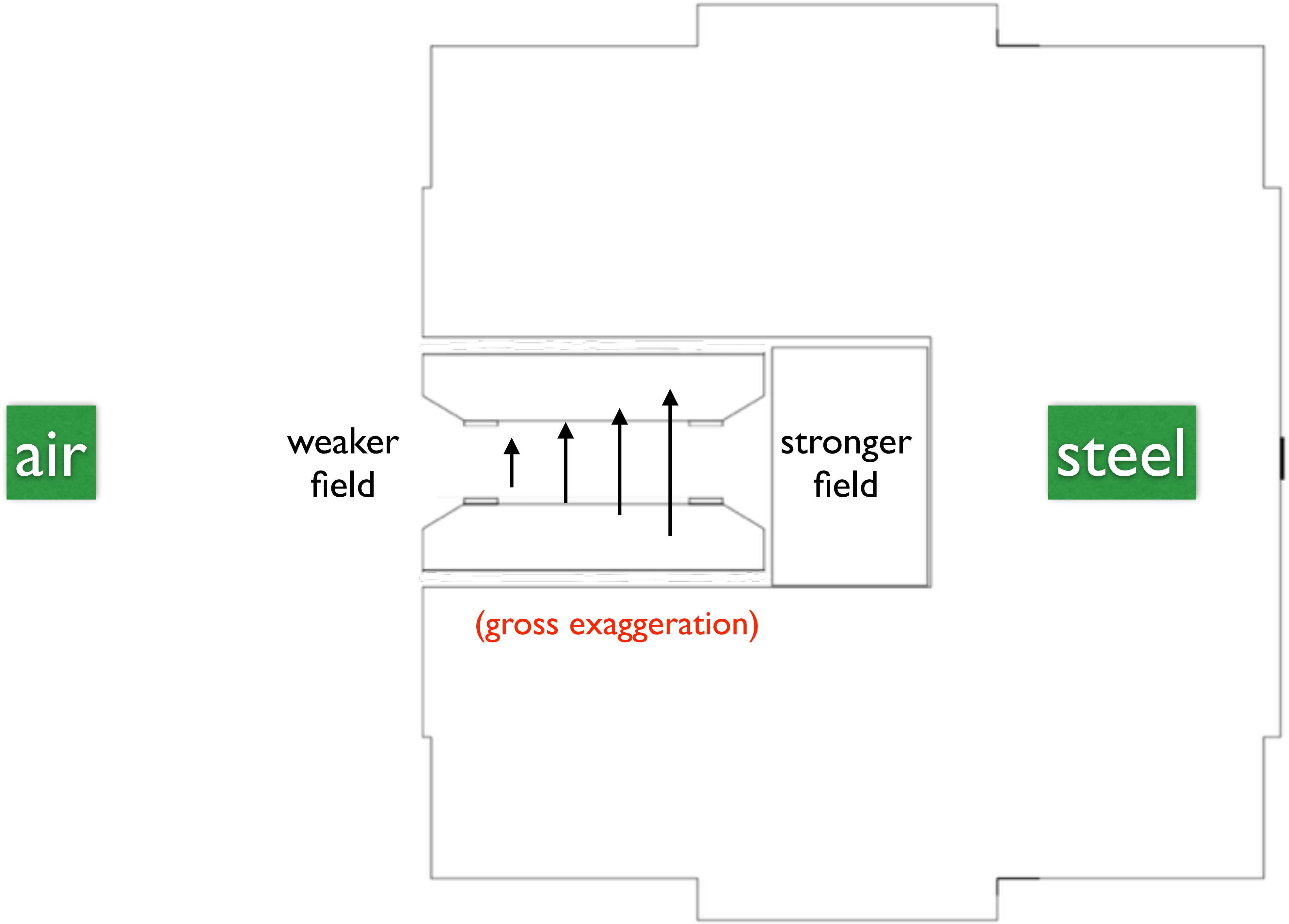

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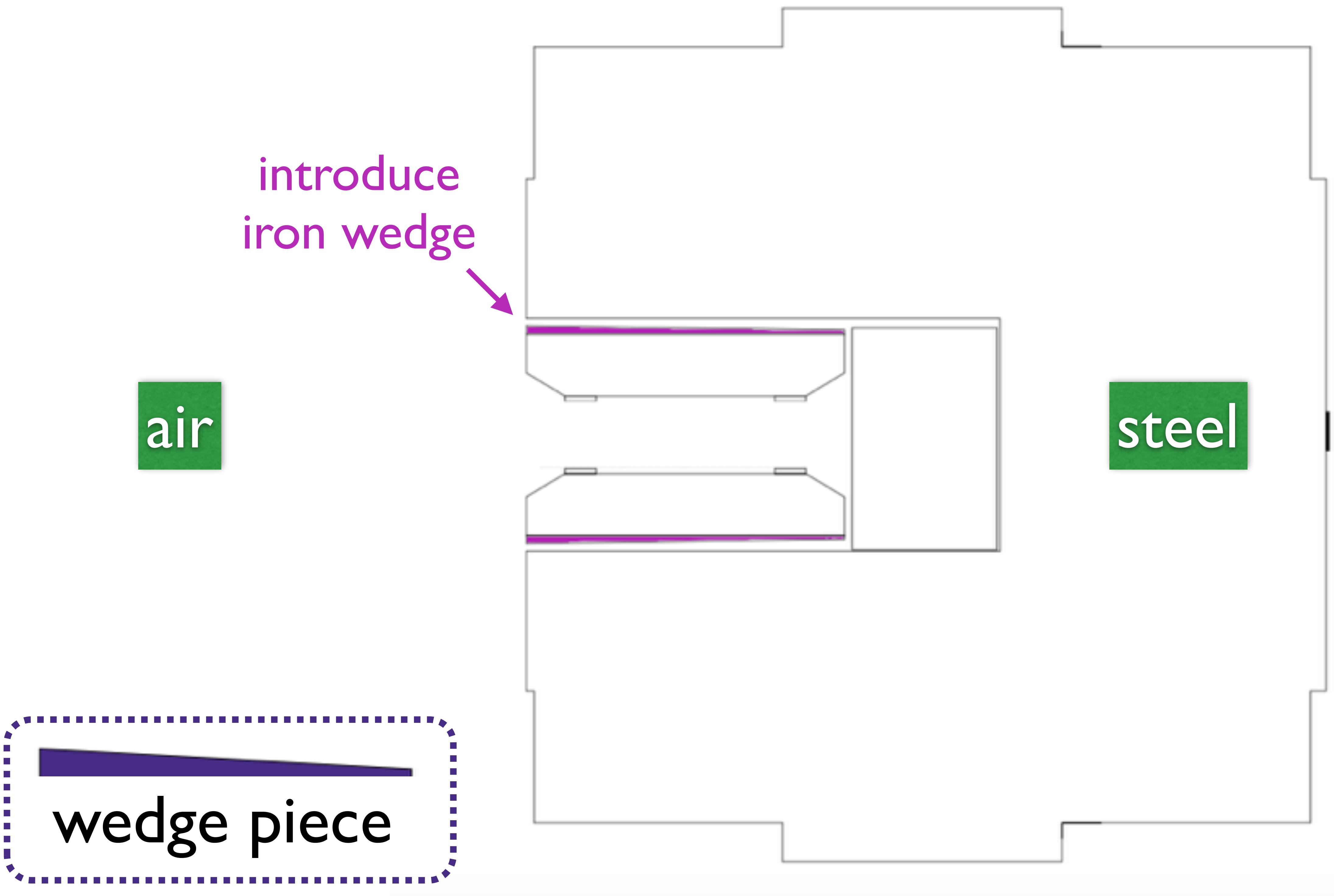
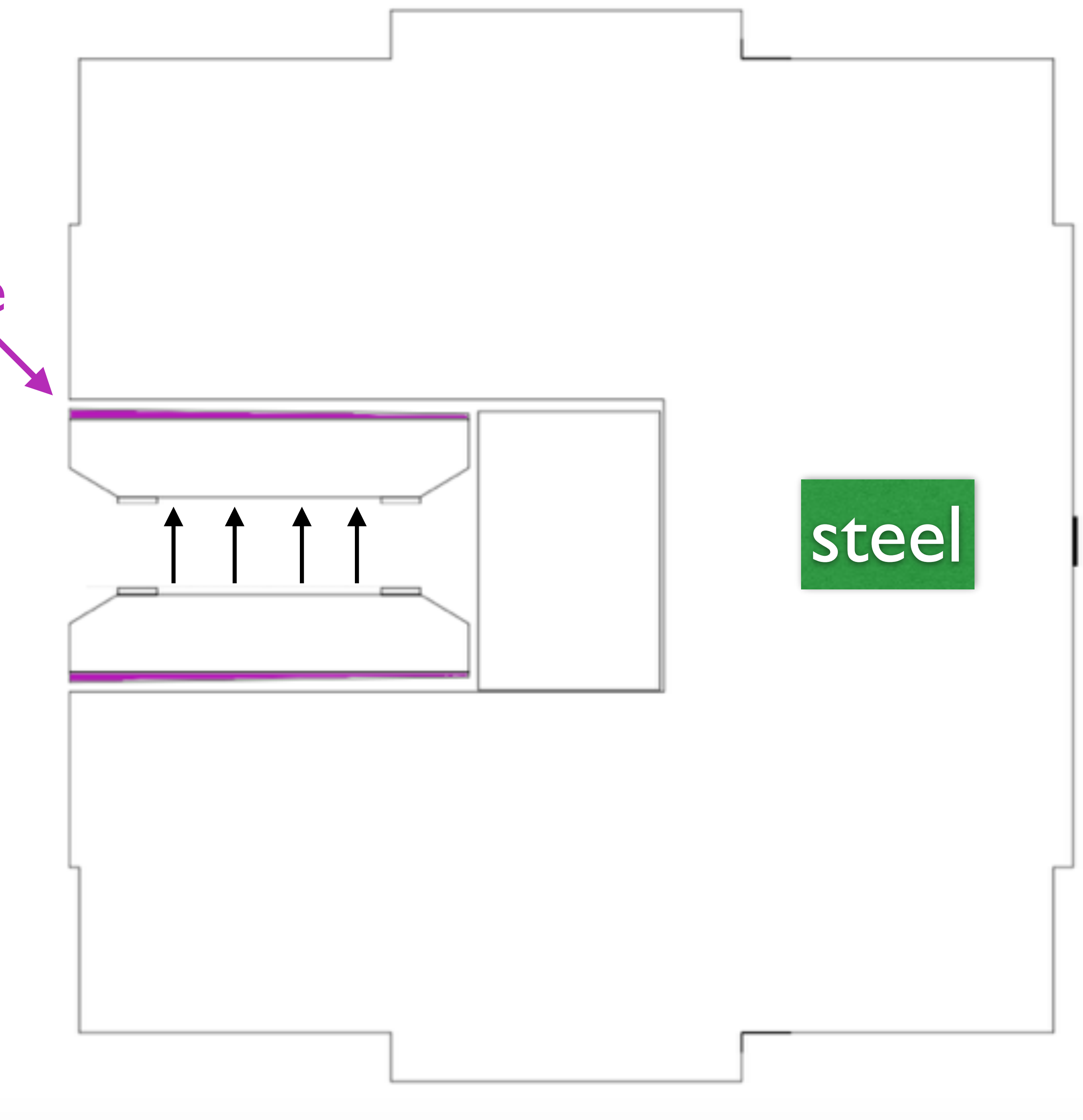


Magnetic field

introduce
iron wedge

air



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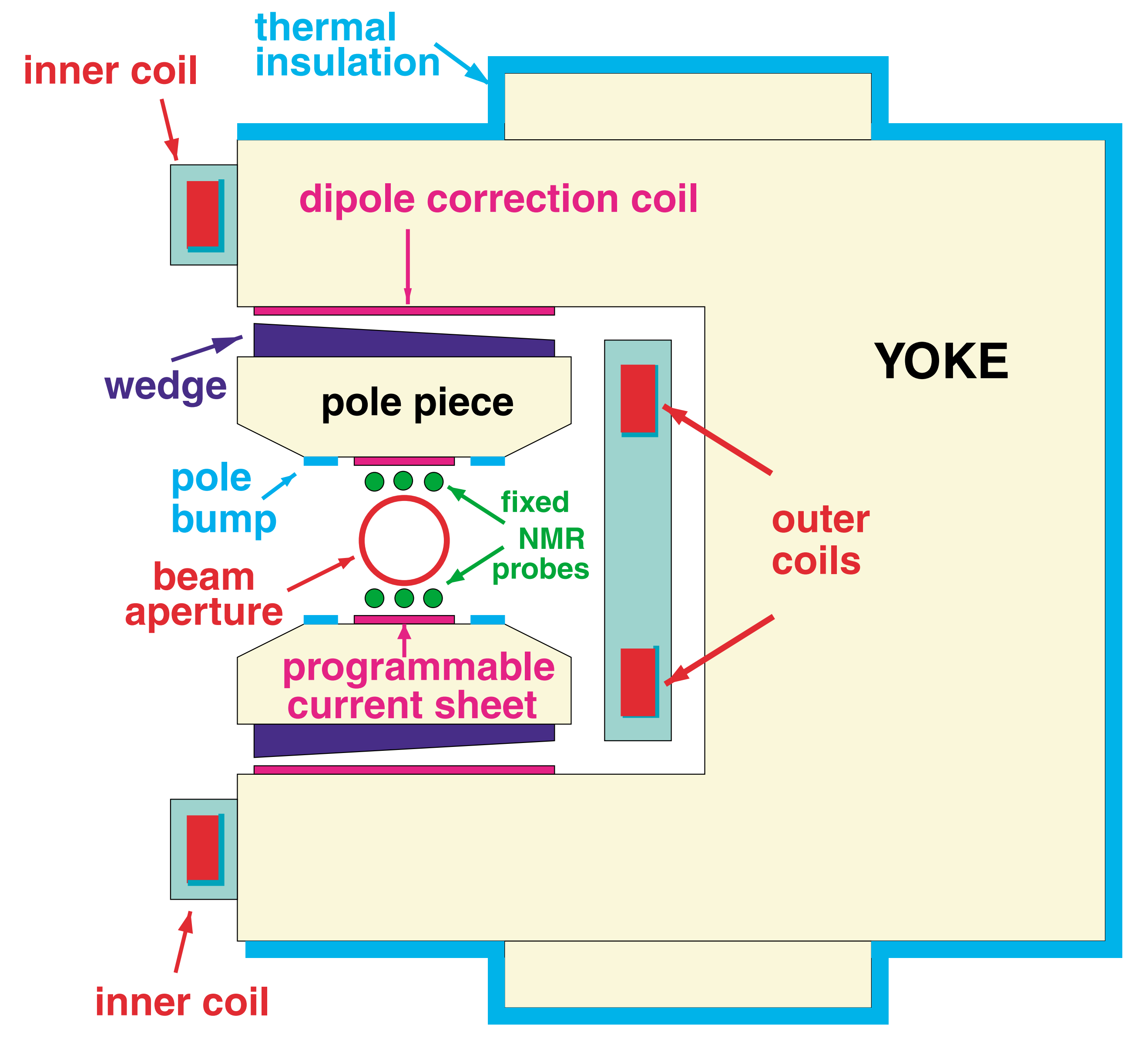
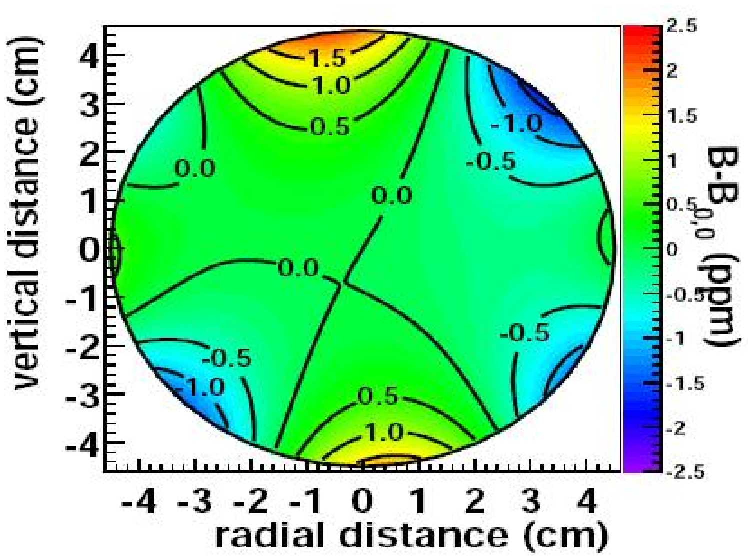


Magnetic field

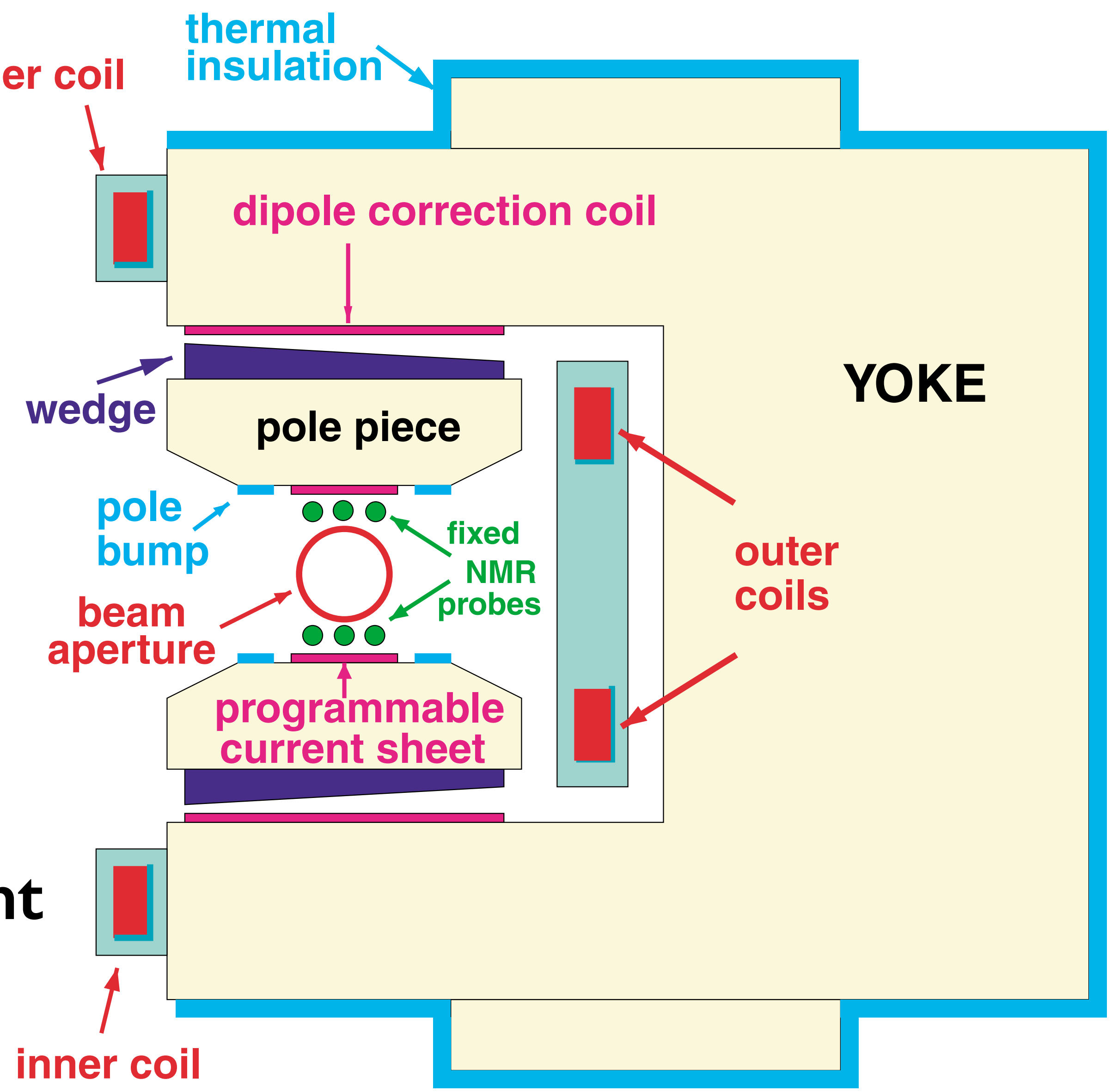
- Many more passive and active tools that control strength of various multipoles

<u>Passive shims</u>
- Iron wedges
- Pole tilt
- Iron pole bumps
- Thermal insulation

<u>Active shims</u>
- Dipole correction coils
- Surface correction coils



FNAL g-2 goal is x2 improvement in homogeneity



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Courtesy Fermilab Visual Media Services

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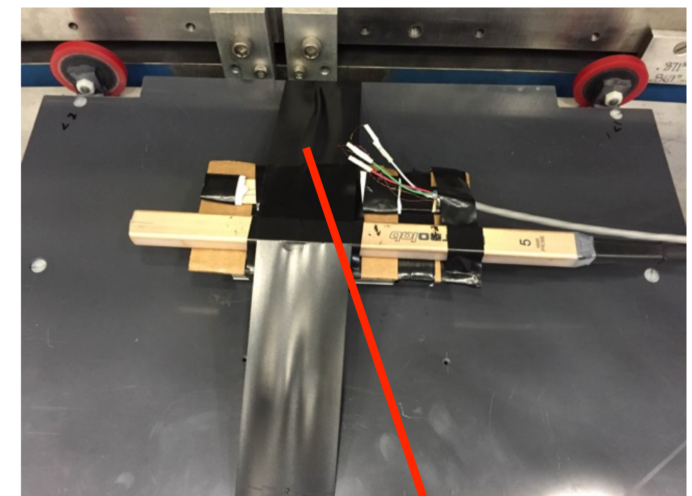
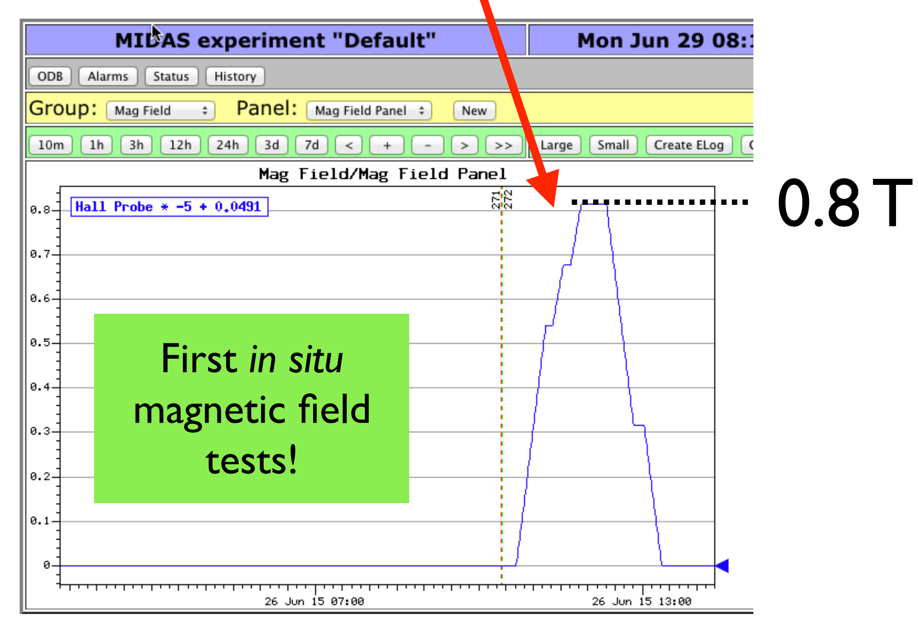
Since reaching 5K

- Began injecting small amounts of current, monitored many many circuit elements for resistance, voltage drops
  - consistently measured nΩ range, magnet is superconducting!
- Mounted hall probe and wide-band NMR device to roughly monitor field as we ramp to full power (5200A)
- During slow ramp-ups, noticed anomalously high resistance (~μΩ) at particular joint along with temperature rise
- Well understood and mundane mechanical issue. Repair happening as I speak!





Summary

- The muon g-2 magnet is an enormously powerful tool for physics exploration designed and built 20 years ago and is still being improved upon
- Various upgrades to the injection systems will increase storage efficiency
- Built in magnetic field "shim kit" will help understanding the field experienced by stored muons
  - 1/2 of the observables in the experiment!
- The Brookhaven g-2 measurement is arguably the strongest existing hint for new physics. With recently recommissioned storage ring and strong new collaboration, the muon g-2 experiment has a bright future

Thanks for your attention!

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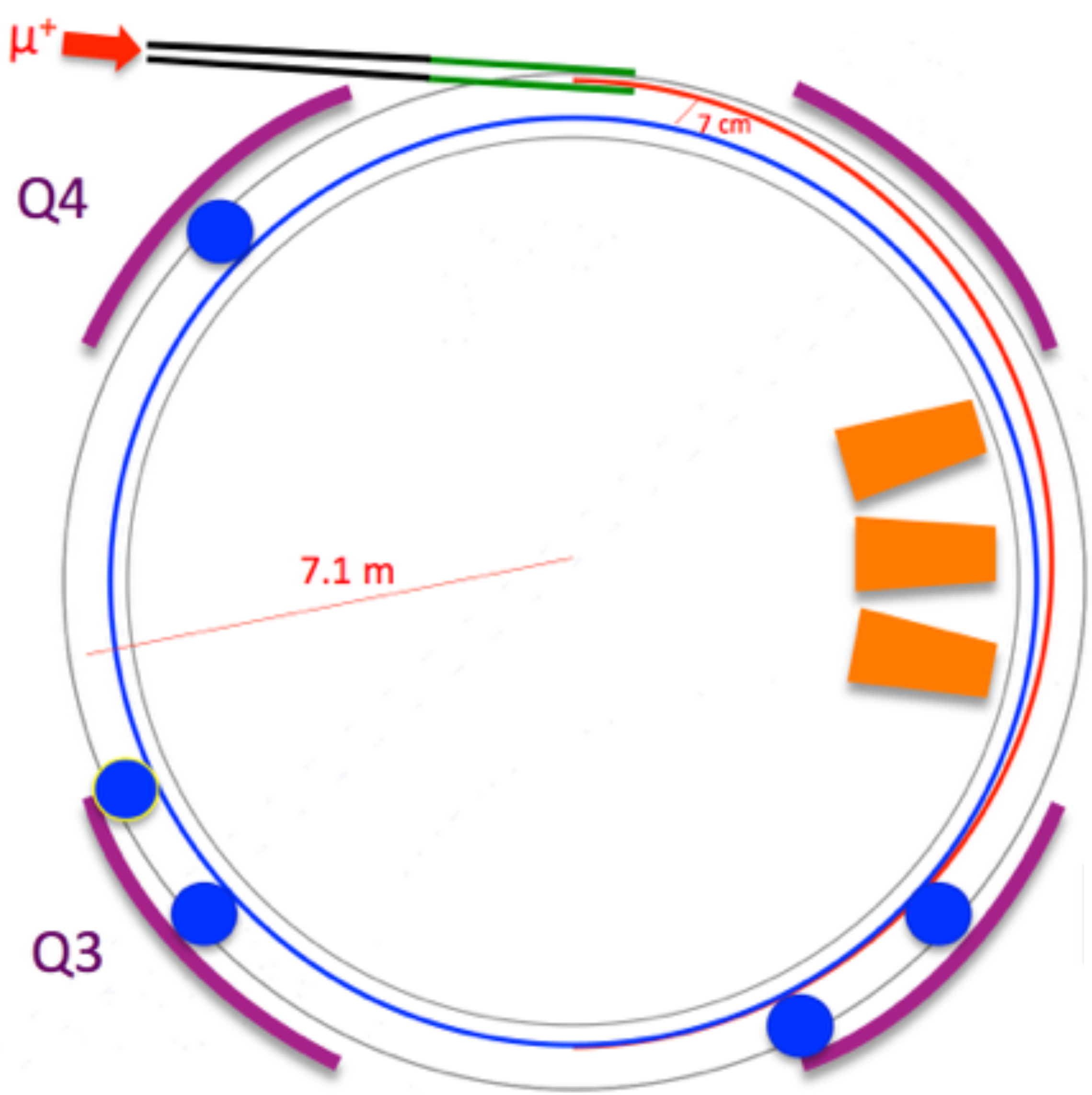
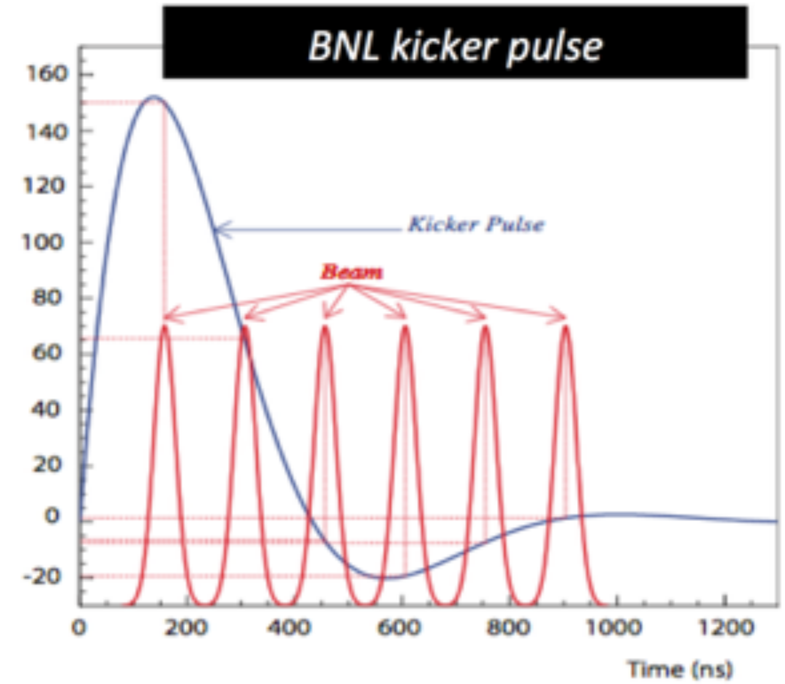
Spare

Beam storage systems





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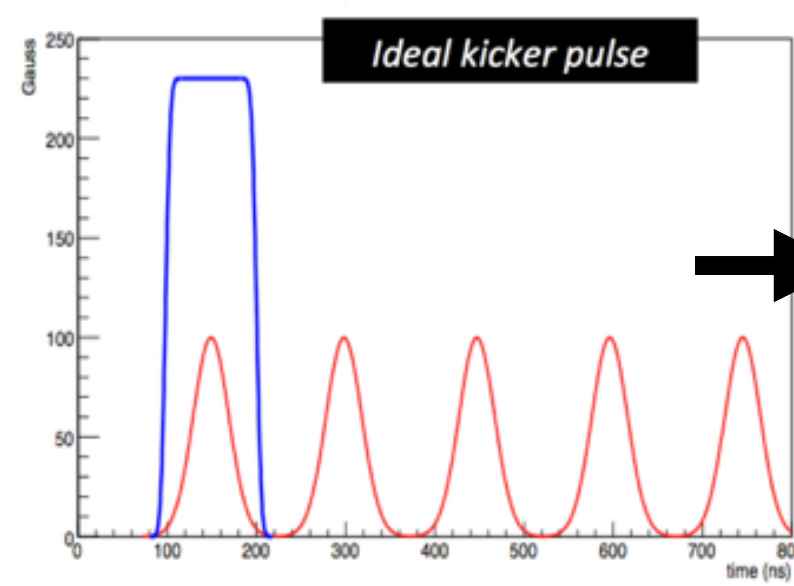
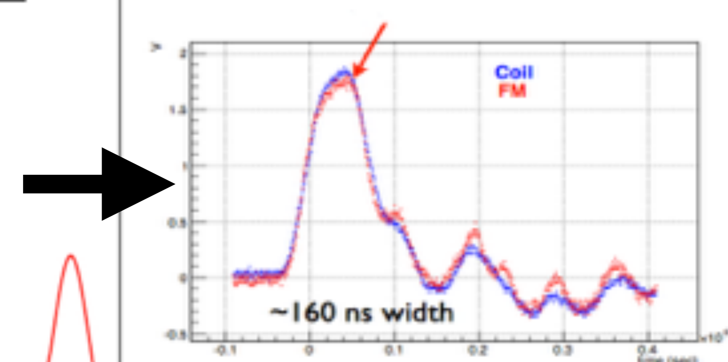
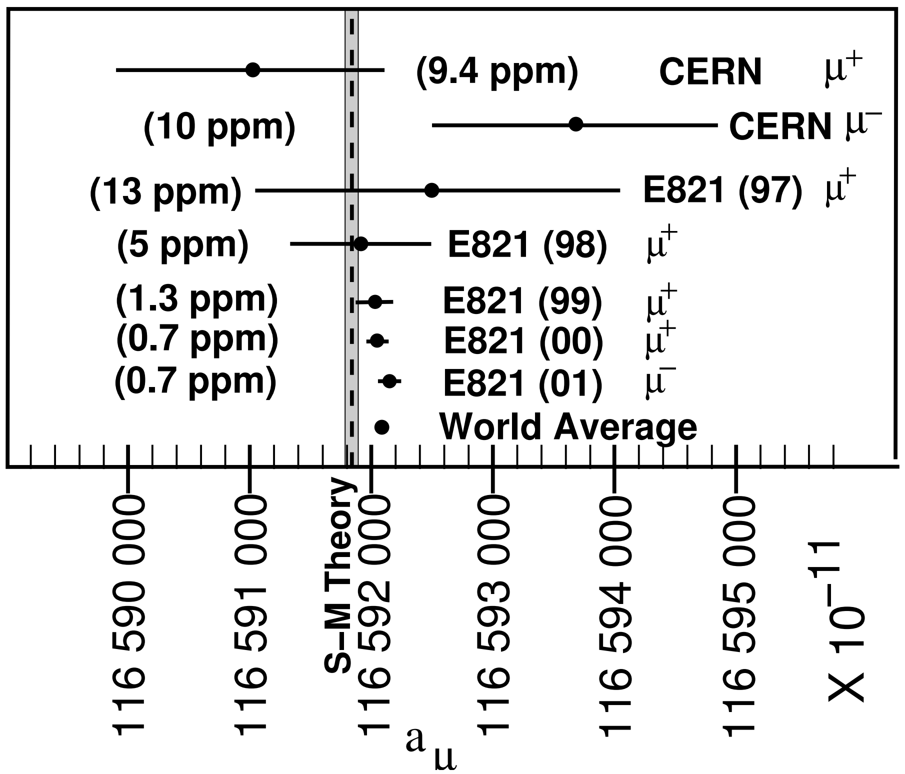




g-2 measurements, improvements for FNAL g-2



Brookhaven '04 measurement first to find robust discrepancy with SM value of ~3.6σ

- Long history of g-2 measurements, BNL first to find robust discrepancy (~3.65σ)
- To verify/refute, must test with better precision!

g-2 uncertainty source	BNL '01 (ppb)	FNAL goal (ppb)
ω_a statistics	480	100
ω_a systematics	180	70
magnetic field systematics	170	70
Total $g-2$ error	540	140

- Statistics by far largest improvement
- To test current g-2 hint at >5σ, need systematic improvement ~ factor 3

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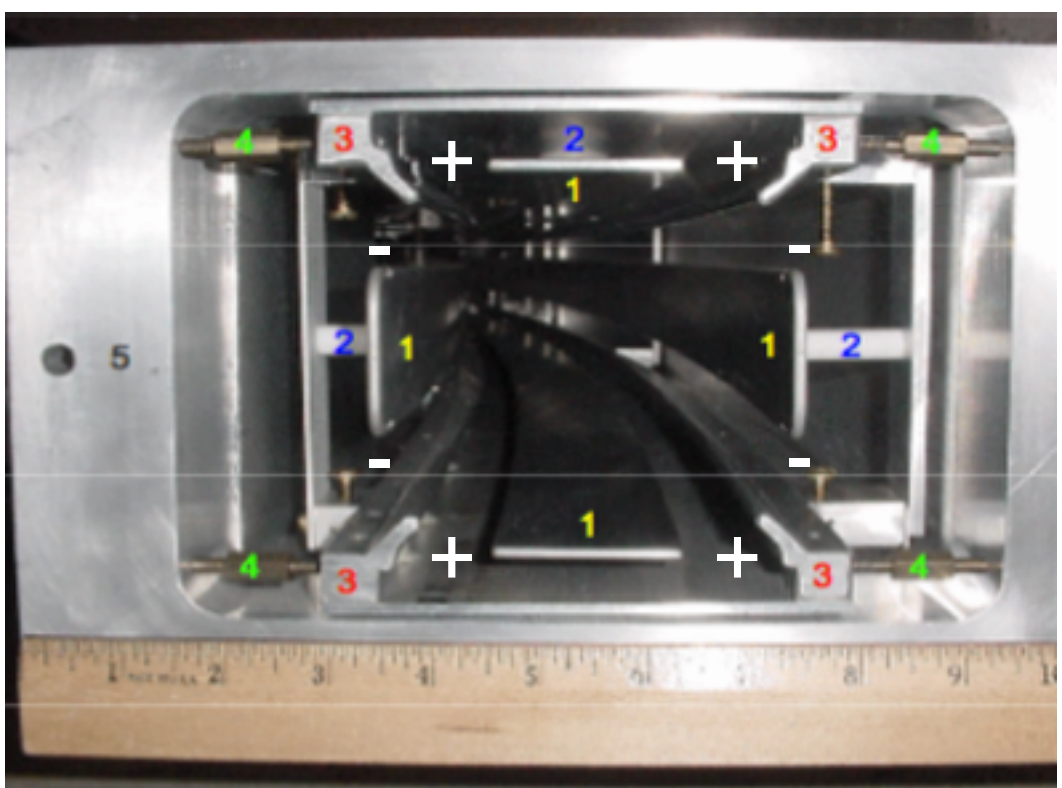

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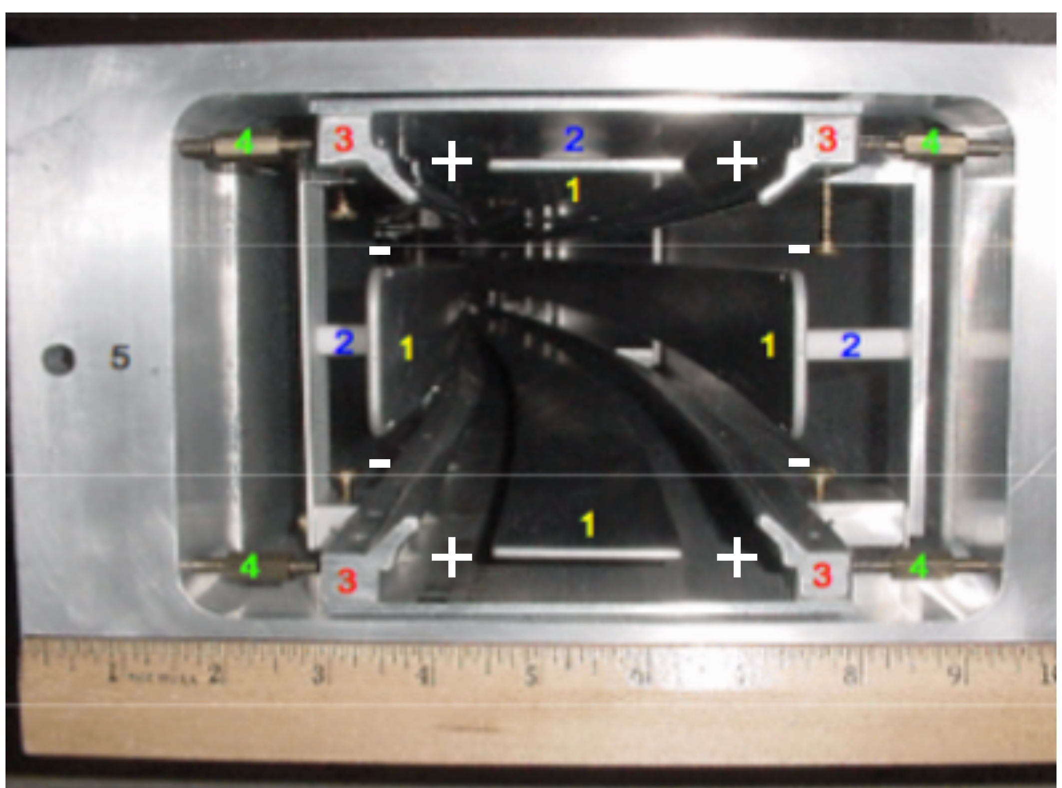

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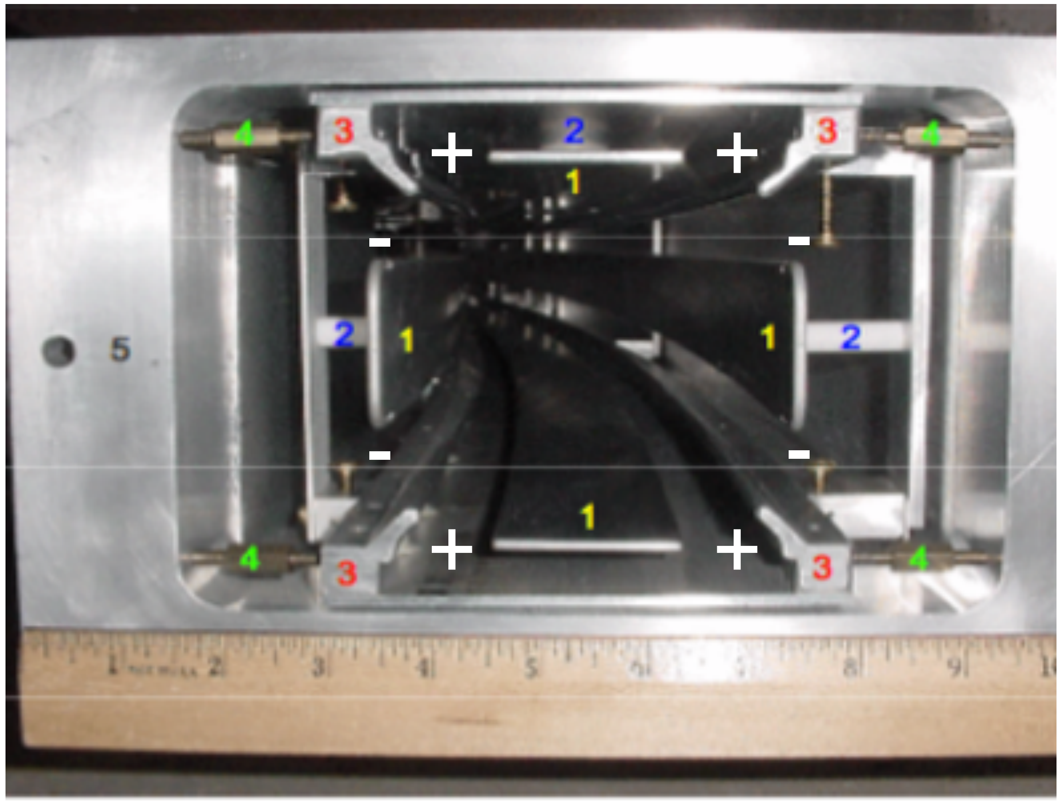

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∅ for γ = 29.3
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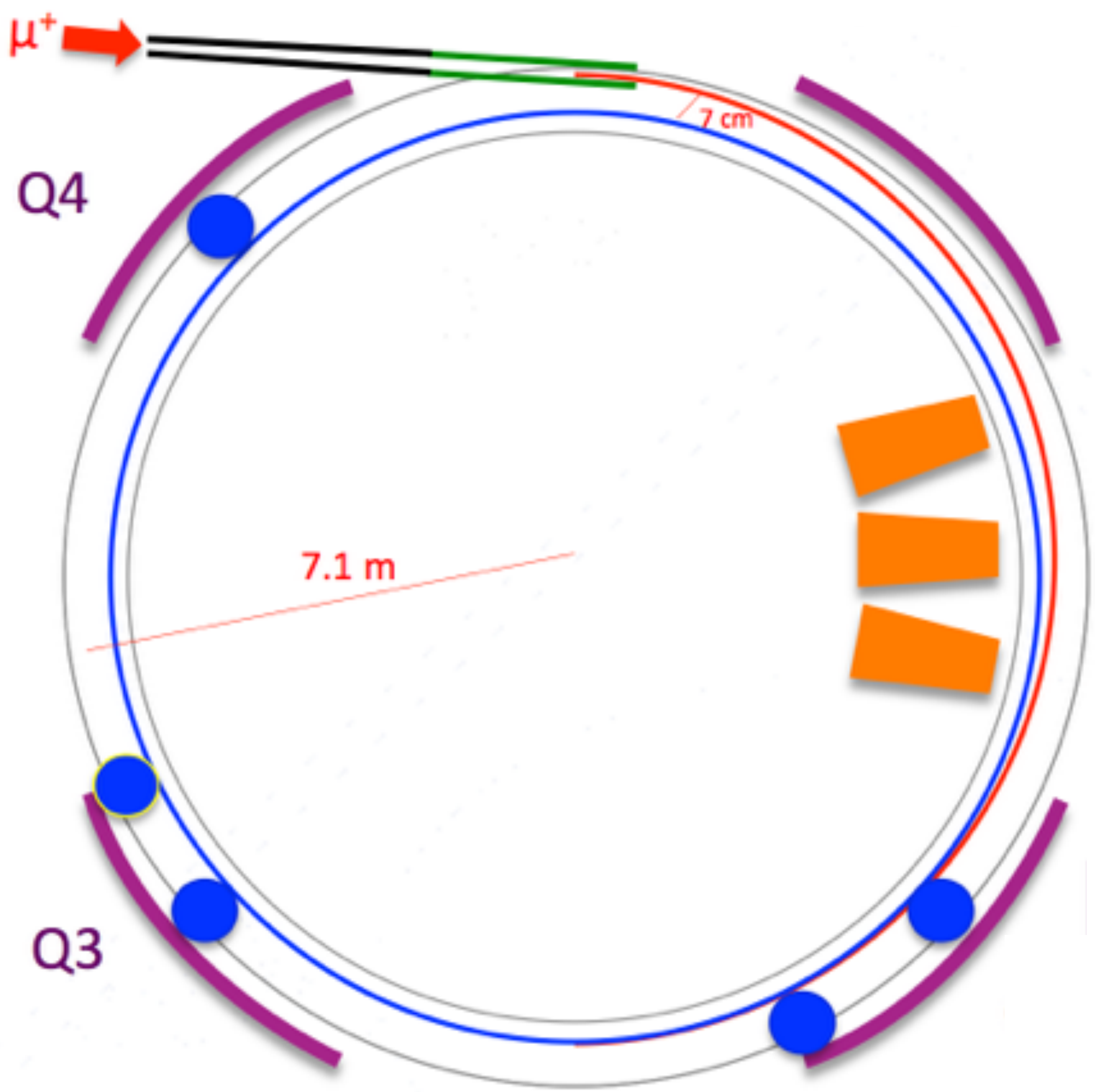
BNL/FNAL approach

∅

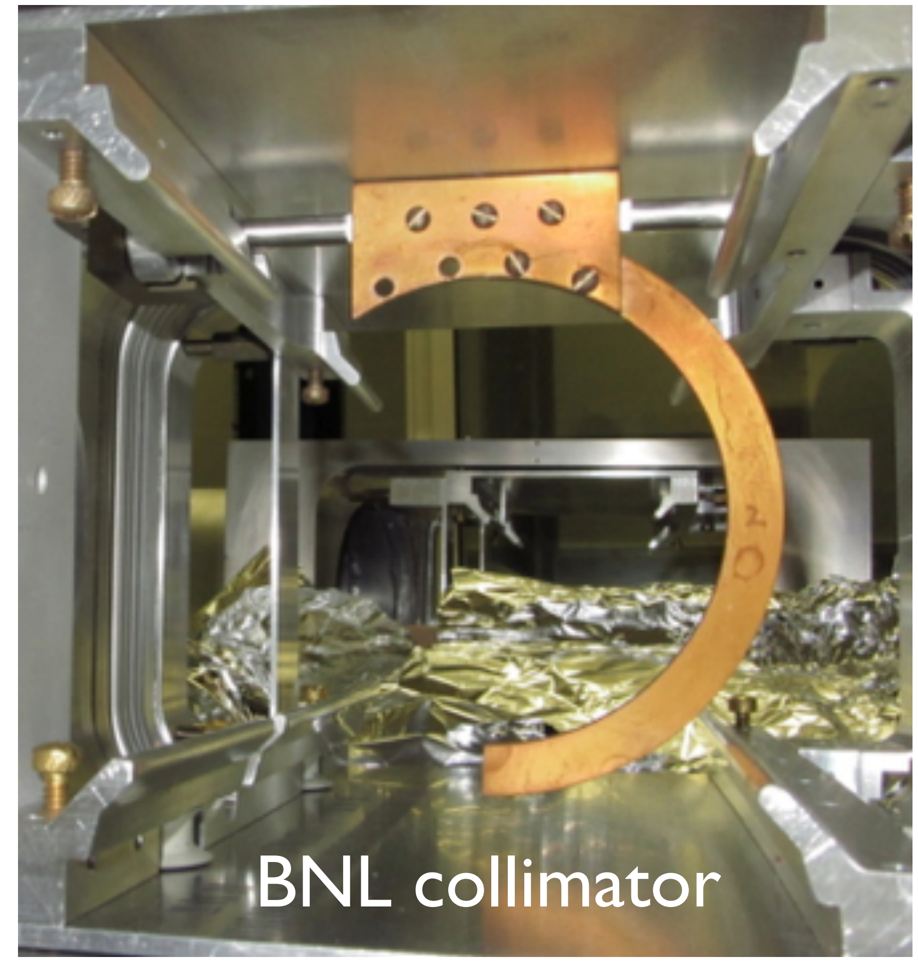
JPARC approach: 300 MeV muons, low dispersion; no E-field req'd

Beam storage systems



Collimators

Helps eliminate off-momentum muons



Produce new, thicker collimators for better beam cleaning efficiency