FNAL Intensity Frontier: LBNF/DUNE and Muon Campus

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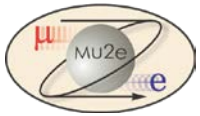
Presentation to Accelerator Safety Workshop, August 15, 2017

Scope: Status of the Fermilab Intensity Program

The Fermilab Intensity Frontier Program implements the recommendations of the Particle Physics Project Prioritization Panel, i.e., the “P5” recommendations.

From the perspective of accelerator safety this talk covers:

- Brief Summary of Accelerator Safety Order Implementation at Fermilab
- Status of Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) Project
- Status of Muon Campus Facility
  - Muon g-2 Experiment
  - Muons to Electrons (Mu2E) Experiment



Fermilab Approach to Accelerator Safety Implementation

- ESH&Q Section Leads Program
  - Maintains the Safety Assessment Document (one SAD).
    - ✓Projects write SAD chapters aided by subject matter experts (SMEs).
  - Maintains the stand-alone Shielding Assessments (SAs) referenced by the SAD.
    - ✓Projects write SAs, with SME help. SRSO approves SAs.
  - Supervises compliance with the DOE-approved Accelerator Safety Envelope (ASE).
    - ✓Coordinated with Accelerator Division Operations Department.
- SADs & SAs are reviewed by Fermilab ESH Committee (FESHCom) Subcommittees and Panels
  - SADs are Director-approved, sent to DOE-FSO for concurrence, ASEs are approved by DOE-FSO.
- ESH&Q Hosts *timely* Accelerator Readiness Reviews (ARRs).

Fermilab Approach to Accelerator Safety Implementation

Fermilab ES&H Committee (FESHCom) Subcommittees

Cryogenic Safety	Electrical Safety
Emergency Management	Environmental Protection
Ecological Land Management	Subcontractor Safety
Fire Safety	Industrial Hygiene
Incident Prevention	Mechanical Safety
Quality Assurance	
Safety Assessment Document Review Subcommittee	Radiation Safety Subcommittee – • Shielding Assessment Review Panel

- Fermilab has long had an integrated safety committee structure; Fermilab ES&H Committee (FESHCom), chaired by the Director.
- The SAD Review Subcommittee and the Shielding Assessment Review Panel have “citizen”, DOE-FSO, and SME members. It’s far from being just SMEs.
- Subcommittee Chairs provide periodic reports to FESHCom monthly meetings.

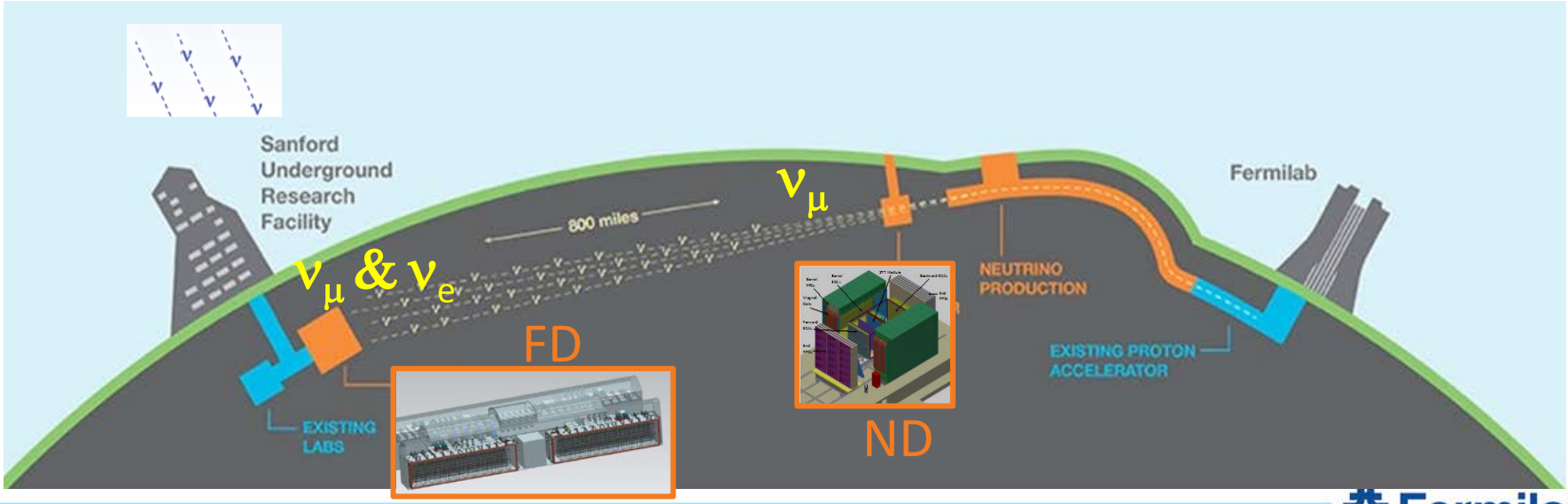
LBNF/DUNE (Info from Vaia Papadimitriou)

Fermilab's largest, most "international", time-lengthy project

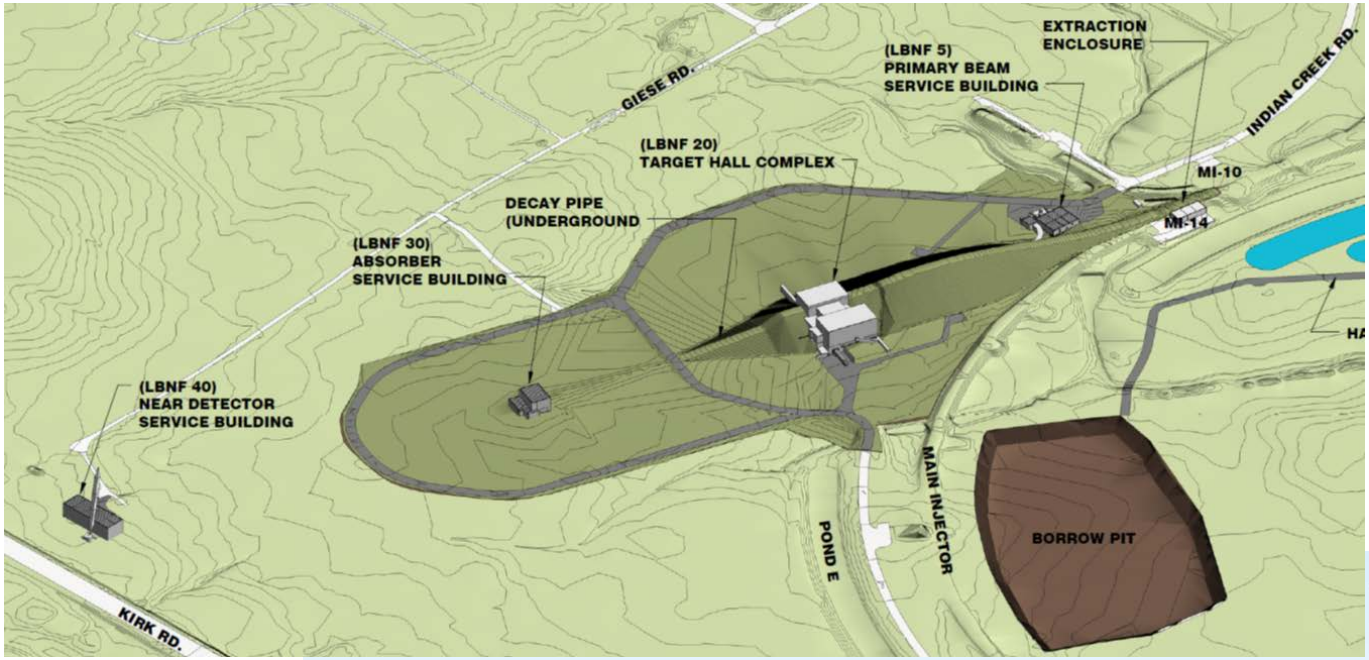
- DUNE Experiment (its BIG!: 964 persons, 164 institutions, 30 nations.)
  - LBNF: far (Sanford Underground Research Facility (SURF) Lead, SD) and near (Fermilab) site facilities include, conventional facilities, cryogenics and beamline at Fermilab.
  - DUNE: far and near detectors. DUNE far detector will be 4850 ft (1480 m) below surface.
- Physics Objectives
  - Measure neutrino oscillations (CP violation, CP phase, mass hierarchy,…, in a single experiment).
  - Study other fundamental physics enabled by a massive underground detector (nucleon decay, atmospheric neutrinos, neutrinos from galactic core collapse supernovae).
- DUNE far detector will be in underground DOE-leased space within SURF in South Dakota and operated by Fermilab.
  - The Challenge: Build and operate a huge detector in leased space within another laboratory at a remote location deep underground in the Black Hills!

LBNF/DUNE (Info from Vaia Papadimitriou)

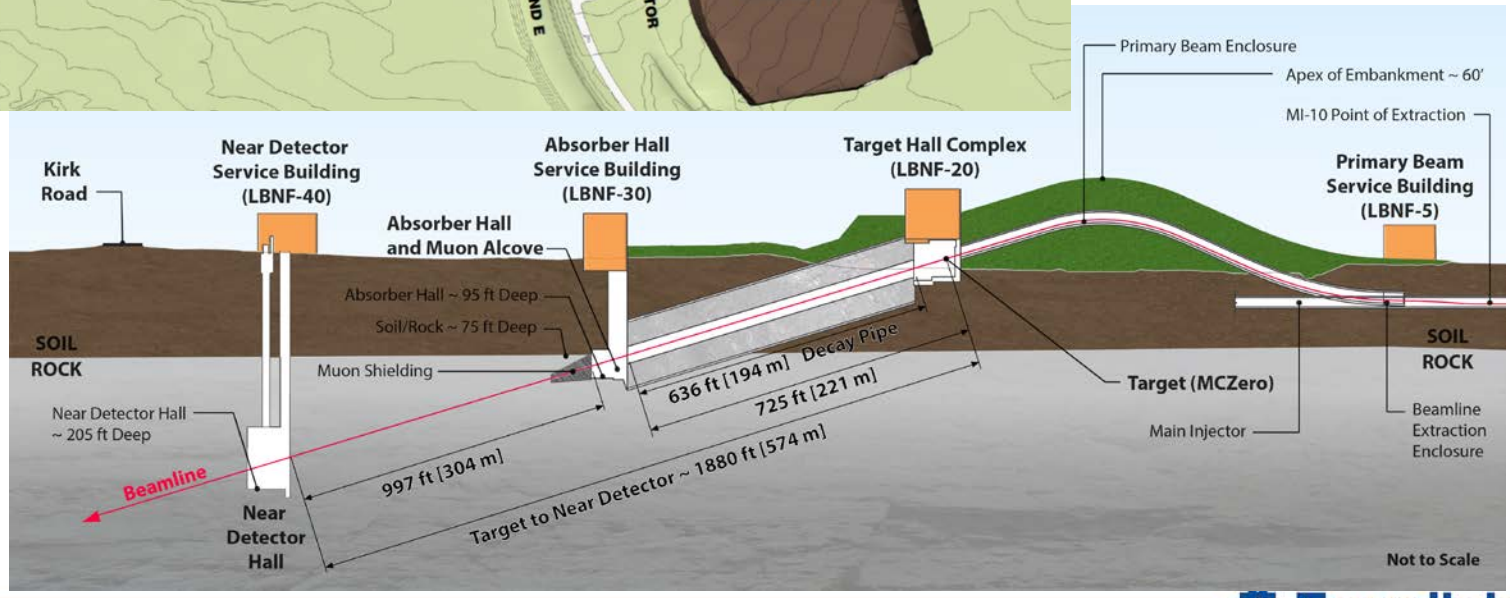
- Milestones:
  - CD-1R approval, Nov. 5, 2015; CD-3a approval, Sep. 1, 2016 (far site CF).
  - Finalize conceptual beamline design in September 2017.
  - Commission 1st 10 kTon far detector in **2024,** 2nd 10 kTon far detector and the near detector by **2026.** The detection medium is liquid argon.
  - Produce neutrino beam in **2026.** No ARR is planned in 2017! ☺
  - Accelerator safety challenges are all on Fermilab site, not in South Dakota.
  - DUNE Far detector has numerous “non-accelerator” challenges such as tunnel safety, underground cryogenic/ODH areas, etc.



LBNF/DUNE (Info from Vaia Papadimitriou)



Zoom in on Fermilab Site



LBNF/DUNE Challenges (Info from Vaia Papadimitriou)

60 or 120 GeV Protons to the LBNF target. 1.2 MW initial proton beam power, upgradeable to 2.4 MW beam power – a lot of beam! Intense design effort is underway to address:

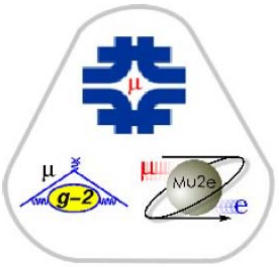
- Groundwater and surface water activation
- Prompt radiation
- Residual radiation/handling of activated components
- Radionuclide air emissions
- Shielding of enclosures on slopes to prevent unacceptable muon penetration.
- Construction QA for installation of protective features such as a large geomembrane system to keep water out
- Dose to workers and dose to members of the public onsite & offsite

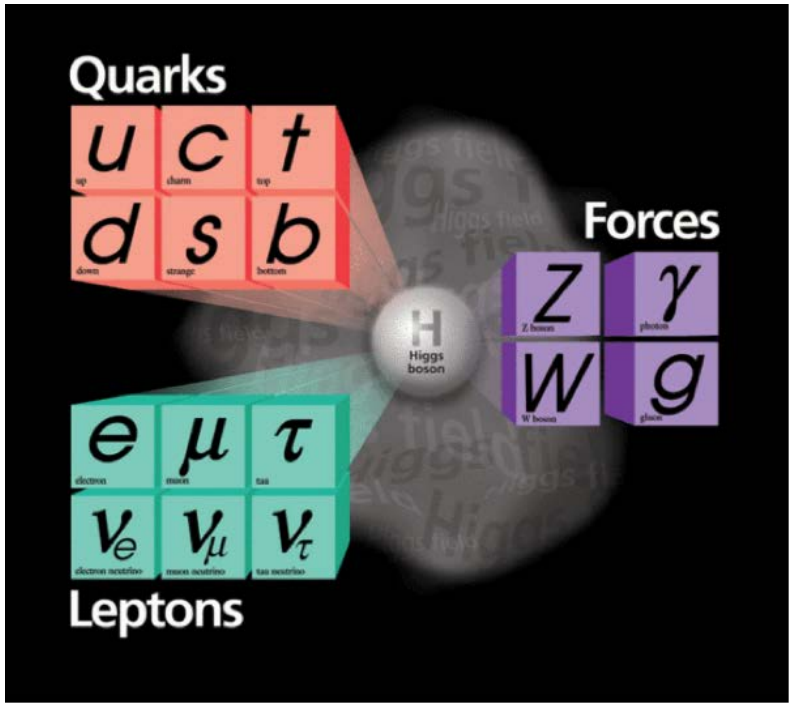
Many peer reviews on these topics already!

- Many accelerator improvements needed to get to 2.4 MW $\Rightarrow$ SAD, SA, & ASE upgrades along the way.
- Development of LBNF Shielding Assessment, SAD, ASE and conduct of ARRs will happen in early 2020s.

The Muon Campus (Info from Steve Werkema, Chris Polly, and Ron Ray)

- Why Muons?
  - $\pi^{\pm} \rightarrow \mu^{\pm}\nu$ 99.9877% of the time
  - Decay ≈ pure weak force, nearly no nuclear force
  - 2.2 μs lifetime (64 μs @ 8 GeV)
  - Heavy, $(m_\mu/m_e) \approx 206.8$, radiate far less than do electrons in circular orbits
- Two experiments being built:
  - Muon g-2 (Precisely measure μ gyromagnetic ratio)
  - Mu2e (Finding direct $\mu \rightarrow e$)
  - Others in the future?

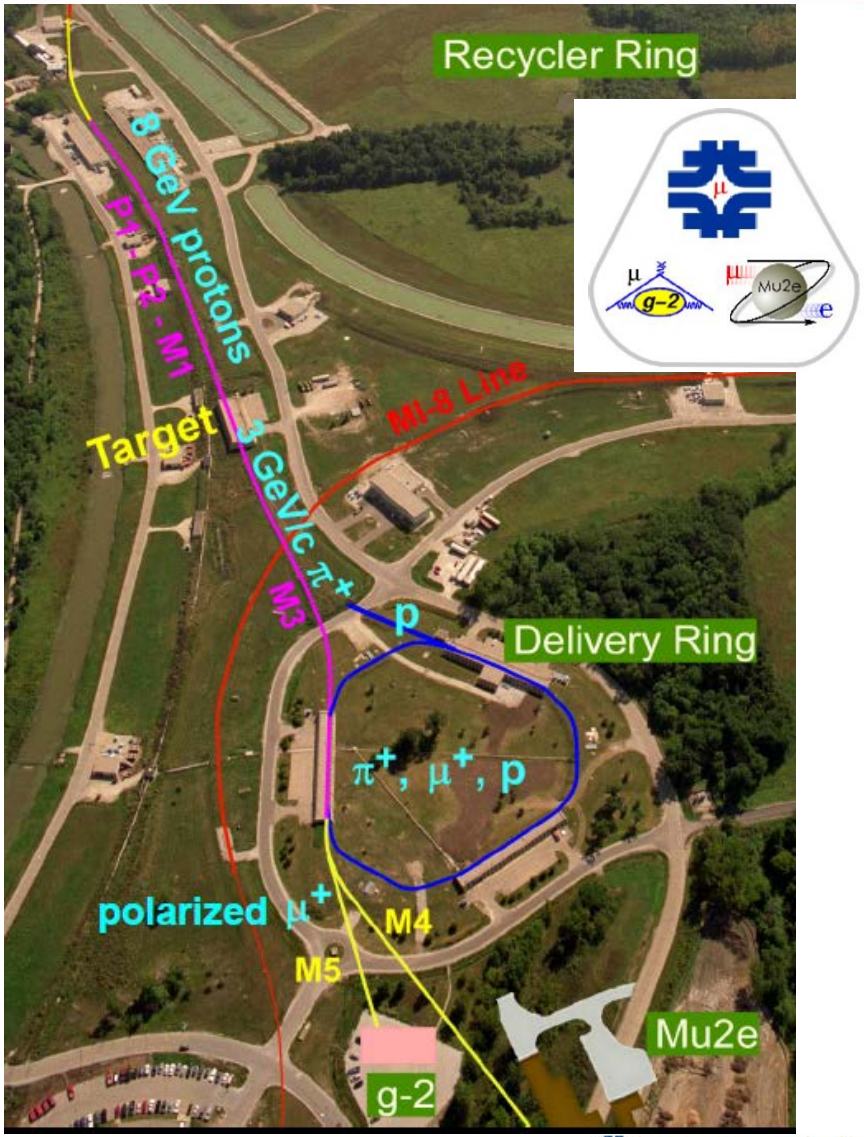




The Muon Campus (Info from Steve Werkema, Chris Polly and Ron Ray)

Repurposed old Antiproton Production Area

1. Remove Tevatron Collider antiproton production apparatus
2. Improve Recycler Ring (also for neutrino physics program)
3. "Reincarnation" of Antiproton Debuncher Storage Ring as <u>Delivery Ring</u> for storing:
   - Muons for Muon g-2; purifies beam by removing all but muons via decay and timing.
   - Protons for Mu2e; gets timing etc. optimum for experiment.
4. New conventional facilities, cryogenics, etc.



Muon g-2 (Info from Chris Polly and Steve Werkema)

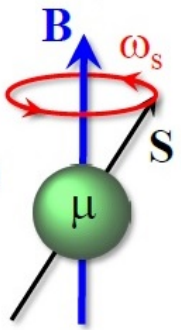
- Goal: Improve best measurement of “g-2”, BNL E821(2006) (5ppb!)
- “g” is the gyromagnetic ratio (magnetic moment/spin).
- Quantum mechanics: g = 2 for spin1/2 muons, without other effects.
- Previous experiments found g > 2, and by more than theory explains!
- Need better statistics, less systematic error, to see new physics.

Spin precession in a circular orbit

Two motions:

1) Larmor precession of the muon spin

$$\omega_s = g\frac{eB}{2m_\mu c}$$

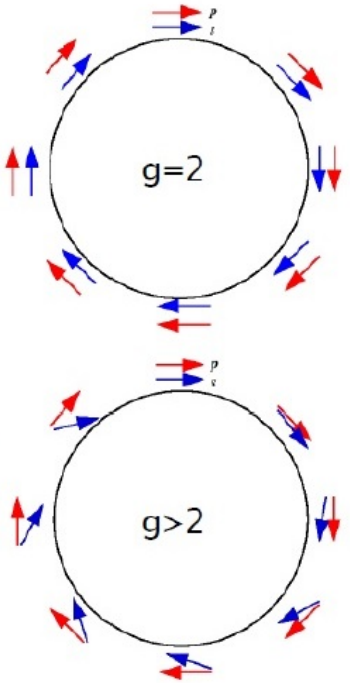


2) Cyclotron rotation of the muon momentum

$$\omega_c = \frac{eB}{m_\mu c}$$

The difference ($\omega_a \equiv \omega_s - \omega_c$) is proportional to g-2

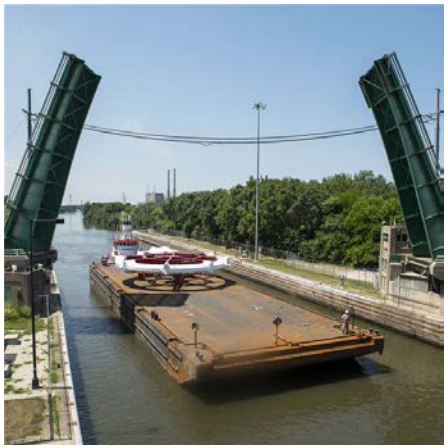
$$\omega_a = \omega_s - \omega_c = \left(\frac{g-2}{2}\right)\frac{eB}{m_\mu c} = a_\mu \frac{eB}{m_\mu c}$$

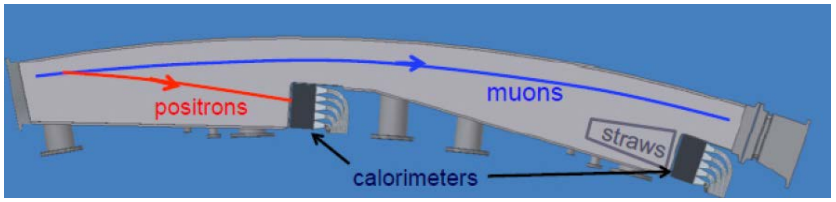


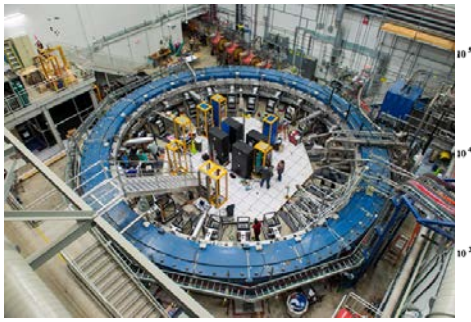
Muon g-2 (Info from Chris Polly and Steve Werkema)

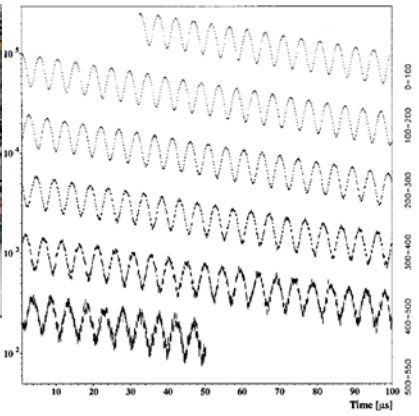
Goal: Improve measurement precision of g-2 by X4 (21X the beam)

- Using BNL superconducting magnet ring to store 3.094 GeV/c muons.
- Summer 2013: The Magnet Move of BNL's 15.2 m superconducting magnet saved $Ms.









- Measures the *frequency* modulation of the decay curve using Fourier analysis for result, some of error analysis.

SAD, ASE done; ARR (TJNAF, LBNL, FRIB team) done in March 2017. We have begun; initial "wiggle plots" seen – a long way to go!

Muon g-2 is to run through FY2019 with μ^+, may go longer with μ^-.

Mu2e (Info from Ron Ray and Steve Werkema)

- Very brief synopsis of physics
  - Looking for muons ⇒ electrons in nuclear field; “charged lepton flavor violation” (CLFV).
  - Standard Model forbids CLFV. CLFV is seen with neutrinos, this looks for it with muons.
  - Need factor of 10,000 over past searches; 10^{18} stopped muons (signal = 105.66 MeV)
- Numerous background sources
  - Neutrons, protons, photons
  - Unwanted processes that also make 105.66 MeV electrons
  - Low energy “normal” muon decays
  - Short lived particles that come “free” with 8 GeV protons on target (Delivery Ring needed allow for “extinction” time to remove those.)
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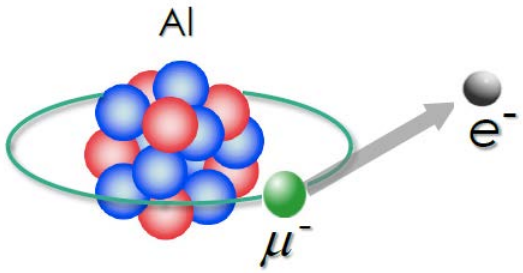


$$\mu^- N \rightarrow e^- N$$

L_μ:	1	0
L_e:	0	1

Both L_μ and L_e are not conserved in this process

Normal decay	$\mu^- \rightarrow e^-$	$\bar{\nu}_e$	ν_μ
L_μ:	1	0	0	1
L_e:	0	1	-1	0

Mu2e (Info from Ron Ray and Steve Werkema)

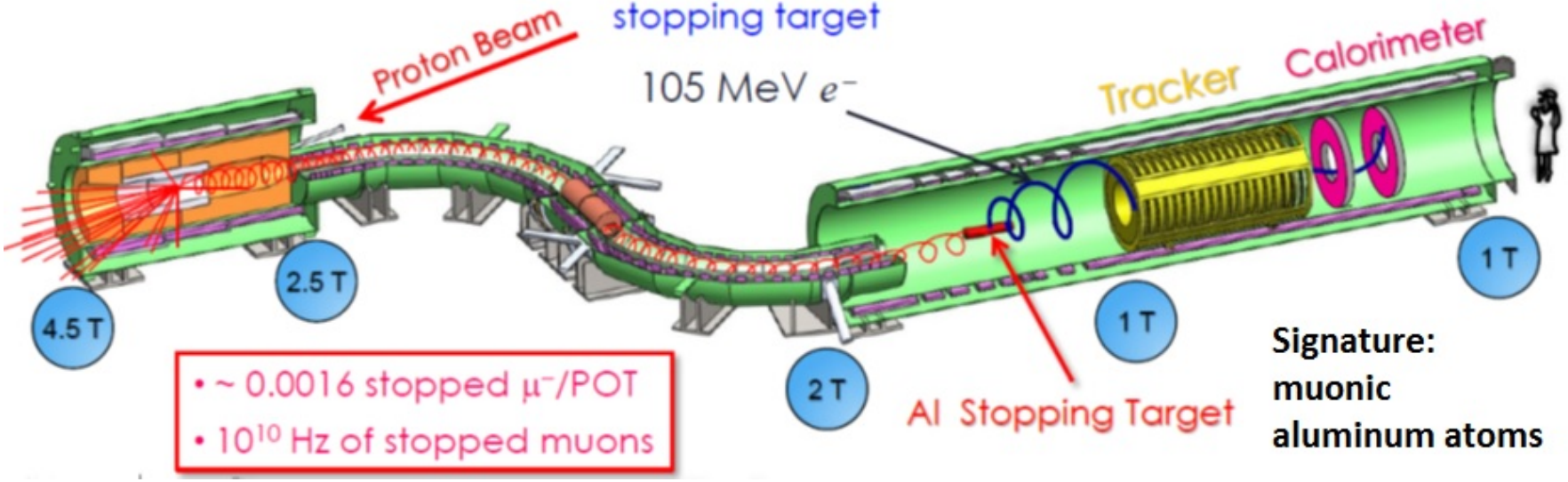
The Layout of Mu2e – Designed to Prevent Backgrounds!

- The muons being stopped go backwards from the beam.
- Superconducting solenoids are used extensively.

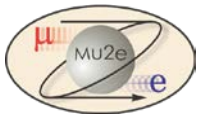
Production Solenoid
- Contains proton target
- Magnetic mirror – reflects secondaries back toward transport solenoid

Transport Solenoid
- Collimation
- Momentum and charge selection
- Transport to stopping target

Detector Solenoid
- Contains stopping target
- Tracker (straws)
- Calorimeter (BaF_2 crystals)



Mu2e Challenges (Info from Ron Ray and Steve Werkema)



"Repurposing" Antiproton Source for orders of magnitude more beam intensity poses challenges! These will be addressed in the Shielding Assessment and thus in the SAD. Ongoing work…

- Ground and surface water activation
- Prompt effective dose rate at north wall
- Prompt effective dose rate on shielding berm
- Air activation in the target hall
- Radiation skyshine
- Shielding of Production Solenoid
- High activated targets and focusing magnets

- Ongoing Reviews, internal, and external!
- Time scale: Mu2e received CD-3 approval in July 2016. CD-4 in FY21. Operations sometime in FY22.
- SAD, SA, ASE, & ARRs is work before us! We know it!