CHAPTER 1

E989 EXPERIMENT AT FERMILAB

This Chapter will explain the experimental apparatus used for the E989 experiment at Fermilab. It will also cover the improvements from the previous E821 experiment at BrookHaven National laboratory and the current status of this experiment.

1.1 Explanation of Experimental Apparatus

The GM2 experiment is a complicated project with many different subsystems to improve the results from previous experiments.[?] The experiment is re-using the storage magnet and the superconducting inflector that was used in E821, with a refurbished NMR trolley and magnetic field measurement system. Mainly, the new features to E989 are that a pure muon beam has been designed and commissioned minimizing hadronic components, segmented calorimeters consisting of a 6×9 array of lead fluoride crystals to minimize ionizing particle such as lost muons, a new fast muon kicker, improved magnetic shimming to improve field variations by a factor of two, two straw tracker arrays located in the vacuum and behind the calorimeters, and a more rapid rate of data taking provided by Fermi Lab accelerator facility. The goal is to generate 21 times more data than Brookhaven and to improve the systematic errors by a factor of three and the overall uncertainty of the measurement. [?]

To produce muons in the experiment an 8 GeV pulsed proton beam coming from the recycler ring at Fermi Lab is collided with a target, producing pions. The pions are the selected by their energy and the beam is then transported into the delivery ring. During

Figure 1.1: Illustration of the Muon Campus at Fermi Lab Ref. [?]

this transportation the pions then decay into a polarized muon beam. These muons are then transported to the storage ring in the experimental hall on the muon campus. Refer to Fig.**??** for a visual representation. [?]

The muon are injected through the inflector magnet which provides a region free of magnetic fields for the muon to pass through and into the storage ring at the MC1 building housing the storage ring. The muons are then centered in the ring using a kicker. The kicker is a series of three long plate that are able to produce a pulsed magnetic field. The magnetic field in the ring is produced by super conducting coils surrounded by iron yokes as to maintain uniformity of the magnetic field. Refer to Fig. **??** for a cross section schematic of the ring. As the polarized muons pass through this magnetic field they precess according to the ω_a frequency as covered in previous sections. The muon then decays into a positron preferentially in the direction of it's spin and is detected by the calorimeters and the tracker

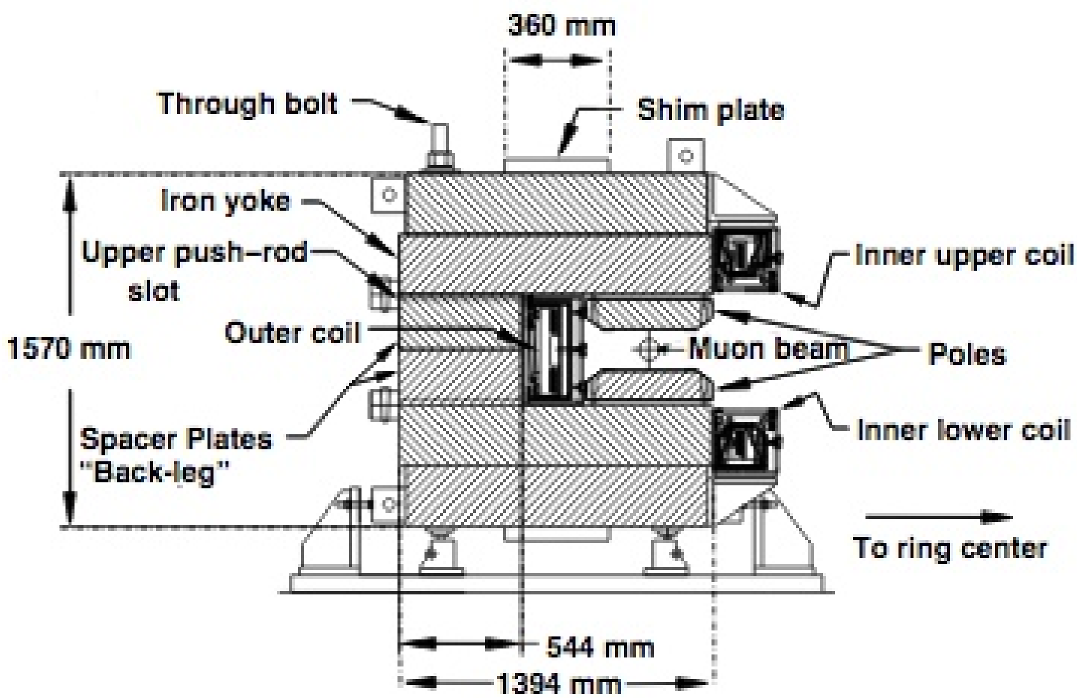

Figure 1.2: Illustration of the cross section of the storage ring Ref. [?]

stations on the inside of the ring. Shown in Fig. ?? is a birds eye view representation of the storage ring and the position of the kickers, inflector, tracker stations, and calorimeter stations. The detectors consist of 24 calorimeters and two tracker stations that each consist of 8 trackers.

Since uncertainties are extremely important in this experiment measurement and evaluation of the uniformity of the magnetic field is necessary. One system used for this are fixed NMR probes at several locations around the ring. A trolley system was developed that can travel throughout the ring and measure the magnetic field.

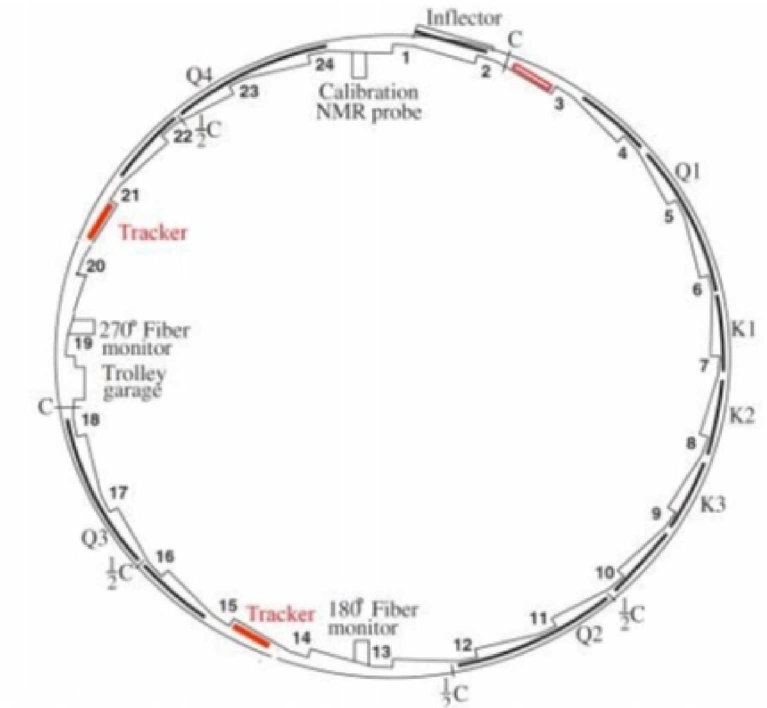

Figure 1.3: Birds Eye View of the Ring Ref. [?]

1.2 Requirements of the E989 Experiment

To meet the goal of an experimental precision of 140 ppb, 21 times more data needs to be collected than the E821 experiment. This will result in a 100 ppb statistical uncertainty in the a_μ measurement. The measurement of ω_a and ω_p have a total proposed uncertainty of 70 ppb. The proposed limits for the expected uncertainty of the experiment can be found in Fig. ?? and Fig.??.

Category	E821 [ppb]	E989 Improvement Plans	Goal [ppb]
Gain changes	120	Better laser calibration	
		low-energy threshold	20
Pileup	80	Low-energy samples recorded	
		calorimeter segmentation	40
Lost muons	90	Better collimation in ring	20
CBO	70	Higher n value (frequency)	
		Better match of beamline to ring	< 30
E and pitch	50	Improved tracker	
		Precise storage ring simulations	30
Total	180	Quadrature sum	70

Figure 1.4: Expected Improvement in the systematic uncertainties for ω_a . Ref [?]

Category	E821 [ppb]	Main E989 Improvement Plans	Goal [ppb]
Absolute field calibration	50	Special 1.45 T calibration magnet with thermal enclosure; additional probes; better electronics	35
Trolley probe calibrations	90	Plunging probes that can cross calibrate off-central probes; better position accuracy by physical stops and/or optical survey; more frequent calibrations	30
Trolley measurements of B_0	50	Reduced position uncertainty by factor of 2; improved rail irregularities; stabilized magnet field during measurements*	30
Fixed probe interpolation	70	Better temperature stability of the magnet; more frequent trolley runs	30
Muon distribution	30	Additional probes at larger radii; improved field uniformity; improved muon tracking	10
Time-dependent external magnetic fields	–	Direct measurement of external fields; simulations of impact; active feedback	5
Others †	100	Improved trolley power supply; trolley probes extended to larger radii; reduced temperature effects on trolley; measure kicker field transients	30
Total systematic error on ω_p	170		70

Figure 1.5: Expected Improvement in the systematic uncertainties for ω_p. Ref. [?]