SAFETY PLAN – February 9, 2013

FOR THE KICKER MAGNET TESTING SYSTEM in ROOM 373 PSB.

1. Introduction

The new g-2 experiment is designed to measure the anomalous magnetic moment of the muon with a precision of 0.14 ppm. The experiment is planned for data taking at Fermilab beginning in 2015-2016. The goal of the new experiment is to refine the results of a similar experiment performed at Brookhaven Experiment (E-821) a decade ago. The aim of the Fermilab experiment is to reduce both statistical and systematic errors by a factor of at least four with respect to the BNL experiment. The 14m diameter muon storage ring built for the Brookhaven experiment will be transported to Fermilab, where a new muon beam line is under construction. The purpose of the kicker magnet is to direct injected muons onto the axis of the central orbit of the storage ring. In the BNL experiment, the kicker failed to generate the requisite amplitude. The result was poor capture efficiency and significant betatron oscillation of the muons that were stored. Another characteristic of the BNL kicker was significant variation in amplitude over the length of the injected bunch. We aim to remedy the limitations of the BNL kicker with a redesign of both pulser and kicker magnet.

2. Kicker

The BNL kicker stripline magnets consist of three, 1.7m long sets of parallel plates. The plates are separated by about 10cm. The height of the plates is also about 10cm. The plates are installed inside the storage ring vacuum chamber and the current pulse is timed to be coincident with the traversal of the muon bunch. In the Brookhaven experiment, the current pulse was generated by discharging a capacitor, via a thyratron switch, through a load resistor and the kicker magnet. The capacitor was charged to about 60-100kV by a 1.5 kV DC supply through a high voltage transformer with turns ratio of 1:85. The shape of the current pulse corresponded to an overdamped RLC circuit.

In order to improve the temporal quality and overall magnitude of the pulse we plan to replace the storage capacitor with a Blumlein transmission line (see section 5). On discharge, the transmission line will ideally deliver a rectangular pulse, of duration corresponding to the $\tau = 2L/v_{group}$ in the line, where L is the length of the line and v_{group} the group velocity. In addition we plan to optimize the shape of the kicker plates to reduce the ratio of magnetic field to current in the plates.

3. Prototype chamber and kicker

The prototype vacuum chamber, kicker plates, pulser, and drive electronics used to develop the system for the BNL experiment have been delivered to Cornell and are set up in PSB 373. The vacuum chamber is shown in Figure 1. The E-821 style kicker plates visible inside the chamber in Figure 1 right will be replaced with plates as shown in Figure 2.

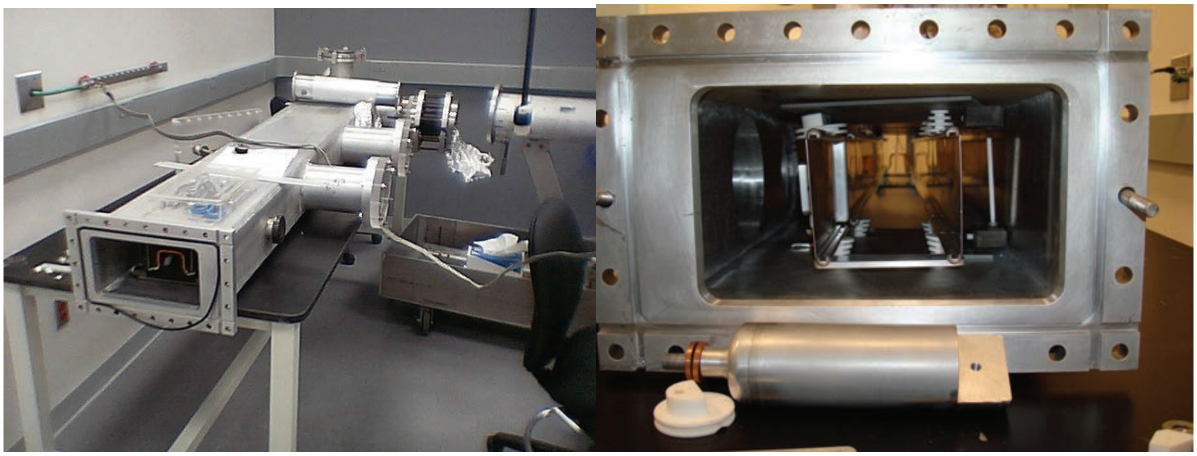


Figure 1. Prototype vacuum chamber. The strip line kicker plates are visible (right) in the open end of the vacuum chamber. The plates couple to the pulser through the bellows at the far end of the chamber (left). The chamber is connected to the building ground terminal on the wall to the left. The kicker plates, which will attain high voltage for tens of nanseconds during the pulse, are isolated from the vacuum chamber by Macor© standoffs.

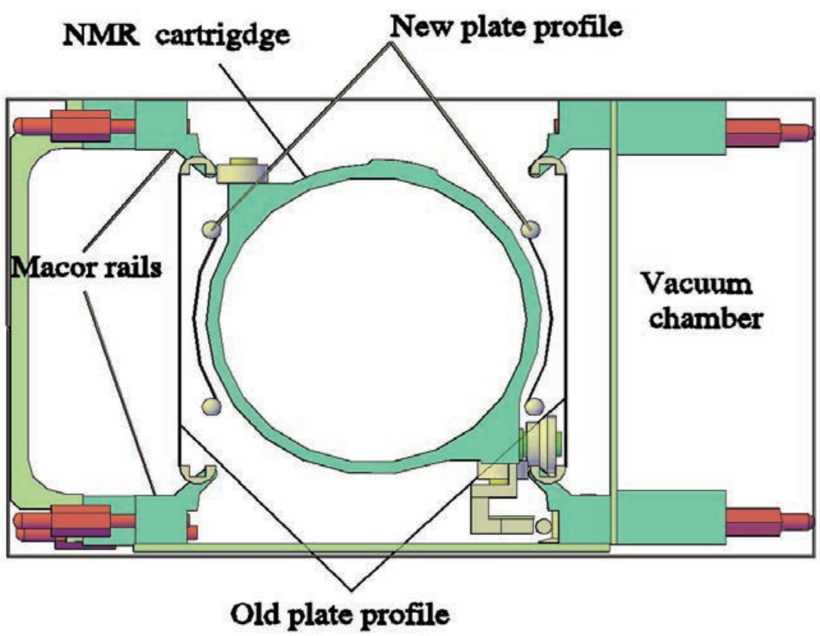


Figure 2. Old kicker plate profile (as in the photograph above) and the new profile.

4. Electronics

The circuit diagram for the pulser used in the BNL experiment is shown in Figure 3. There is a high voltage power supply, high voltage charging circuit, high voltage transformer, thyratron driver and thyratron tube, and thyratron trigger amplifier. The 10 nf capacitor is charged through a resistance of 5.75 ohms and the kicker magnet (M) to near 100kV. The capacitor is discharged through 11.5 ohms and the kicker magnet when the thyratron switch is triggered.

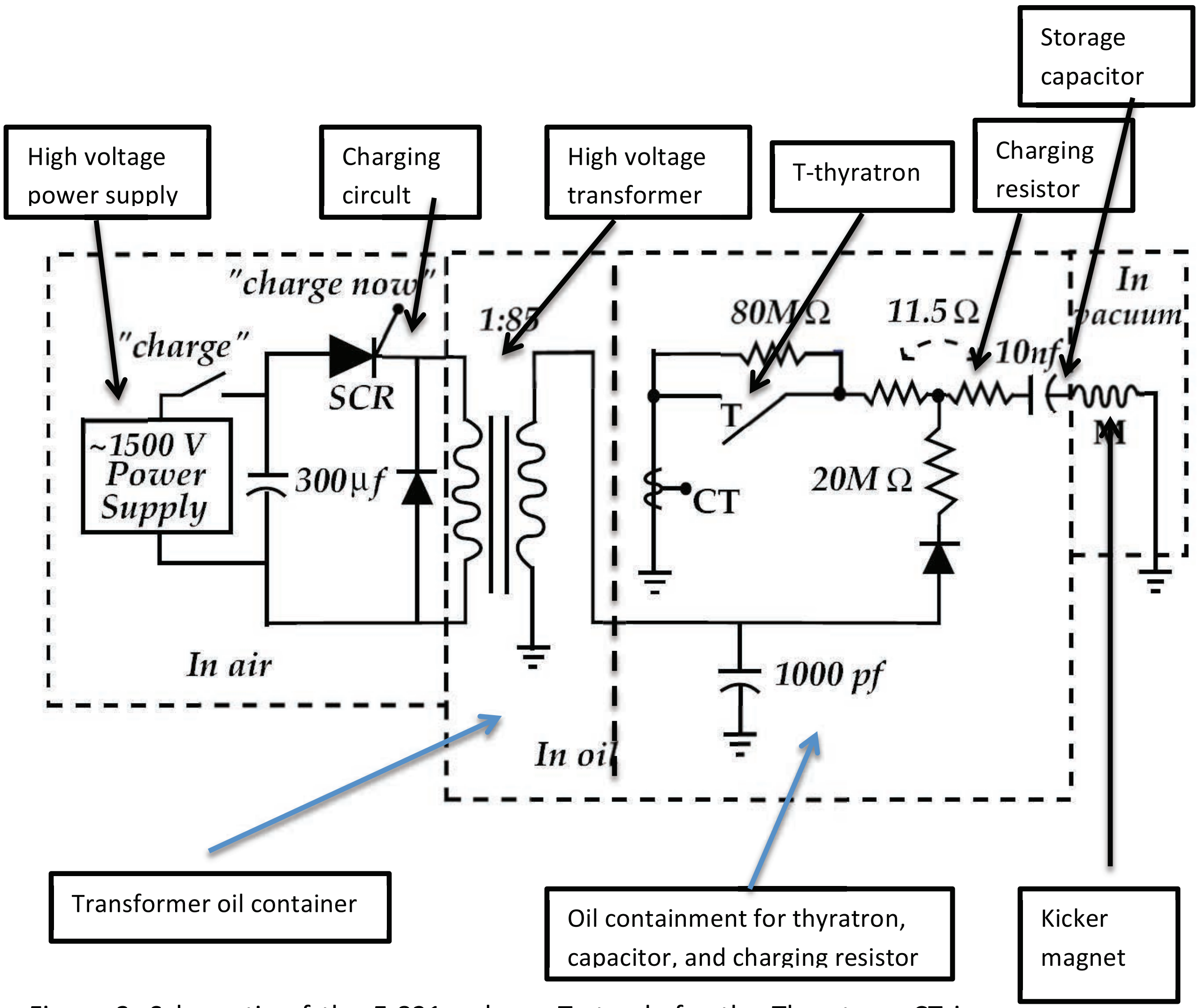


Figure 3. Schematic of the E-821 pulser. T stands for the Thyratron. CT is a current monitor. M is the strip line kicker magnet. In the new experiment, the 10nf storage capacitor will be replaced by a blumlein.

1. High voltage supply (**A.L.E., HV P.S.**)

   The input AC power to the high voltage supply is three phase 208 V AC. The output is 1500 V. A trigger closes the "charge" switch (see Figure 3) that connects output of the supply to the charging storage unit. The high voltage supply is mounted in the rack shown in Figure 8.

2. High voltage charging unit (**g-2 Kickers, 1kV Charging P.S.**)
   The charging unit contains a 300 microfarad capacitor bank, an SCR switch and diode. The SCR is triggered to initiate the current flow to the high voltage transformer. The charging unit is immediately above the high voltage supply in the rack in Figure 8.
3. High voltage transformer (in oil tank)
   The high voltage transformer with a turns ratio of 1:85 is shown in Figure 4. It is housed in the oil tank. The input to the transformer tank is at 1500 V. The output, (the high voltage coax connected through the top of the transformer oil tank) maximum is 130kV.

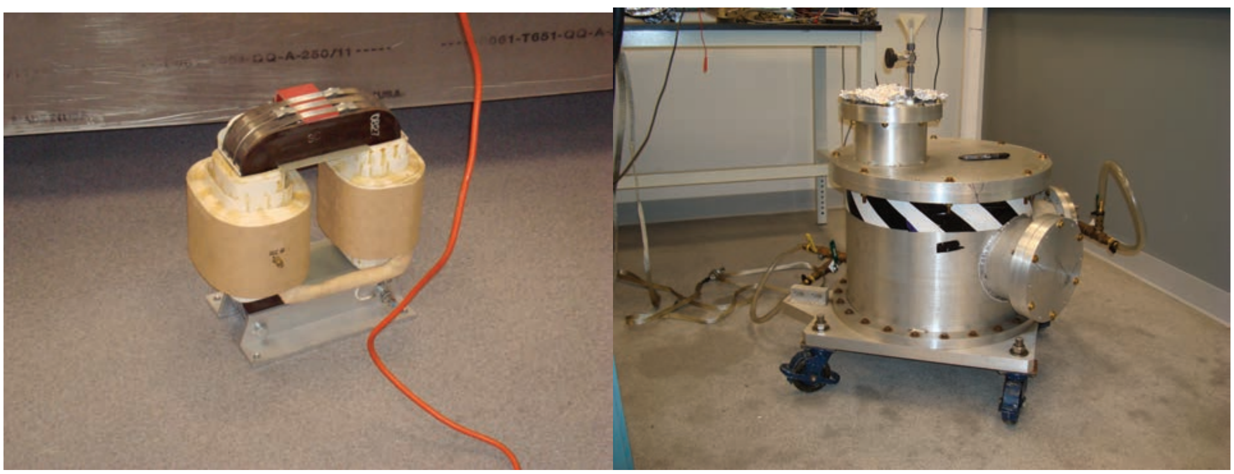


Figure 4. High voltage transformer (left) and high voltage transformer oil tank (right). The high voltage 50 ohm transmission line connects the transformer secondary to the 11.5 ohm charging resistor shown in Figure 3.

4. Thyratron (in aluminum housing)
   A deuterium thyratron CX 1699 is appointed as the switch. (Maximum voltage 130kV, max forward current up to 10kA). The thyratron is mounted inside the aluminum structure shown in Figure 5. For high voltage operation, the structure is filled with transformer oil. The thyratron stands off the up to 130 kV charging voltage. When triggered, it conducts up to 10kA through the load. The aluminum housing is tied to the building ground.
5. Thyratron driver (**g-2 Kicker Thyratron, Station driver**)
   The thyratron driver provides power to the hydrogen reservoir (6V, 8A), the heater filament (6.3V, 25A) and bias voltages to the first (100V, 150mA) as well as the primary triggering grid (100V, 150mA). Voltage and current monitors are mounted in the panel labeled **Kicker A.C. Aux. & meter.** The driver is mounted just below the high voltage

supply in the electronics rack, and the thyratron voltage and current monitors above the charging supply.

6. The thyratron trigger amplifier delivers a 500-1kV pulse through a 50 ohm cable to the primary grid of the thyratron.

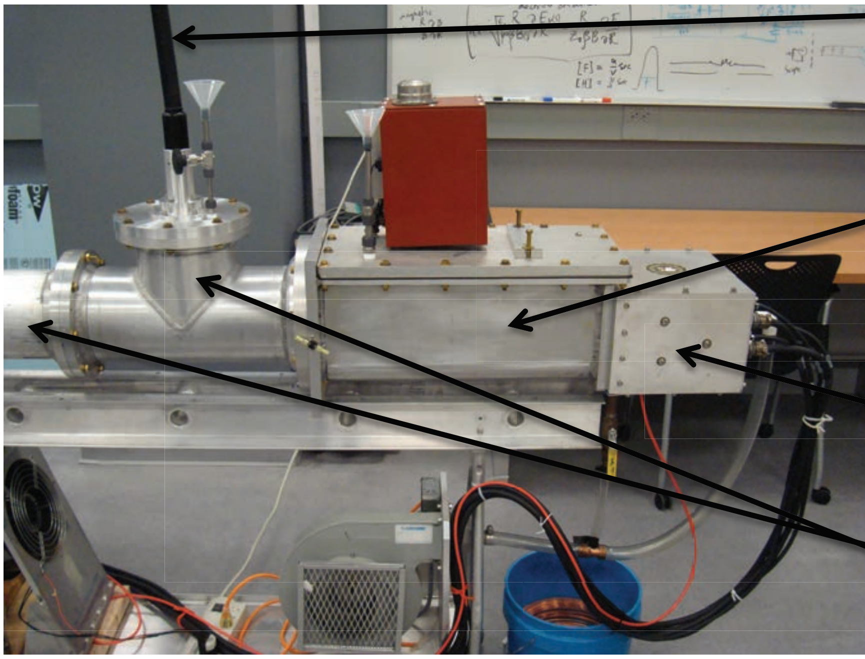


Figure 5. The ~40cm long, cylindrical thyratron tube is mounted inside the aluminum housing in the center of the picture. When operating at high voltage the housing is filled with transformer oil. Connections to the thyratron are through the right most assembly. There is no exposed high voltage. The red box on the top of the housing is an oil reservoir. The high voltage transmission line couples to the high voltage end of the blumlein (to left) and thyratron (to right).

5. Blumlein generator

The Blumlein type generator is shown in Figures 6 and 7.

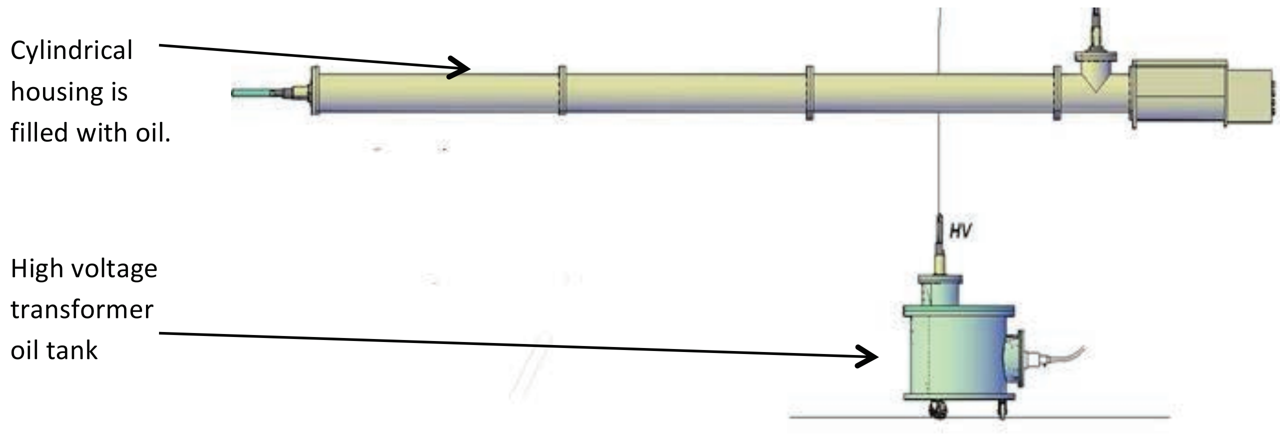


Figure 6. The Blumlein generator concept. Thyratron is mounted in the housing at the right. The output of the line will be coupled to the kicker magnet via the high voltage coax at the left. The Blumlein generator is a triaxial transmission line.

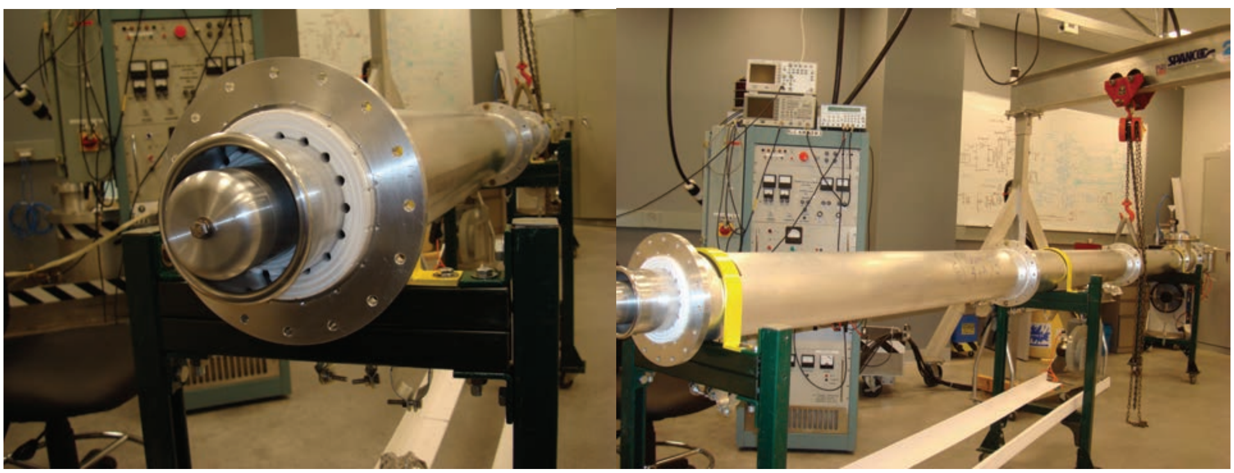


Figure 7. (Left) Business end of blumlein. The central conductor will be connected to a 25 ohm load resistor. The middle conductor is charged to about 60kV via the high voltage cable at the far end. (Right) Assembled line.

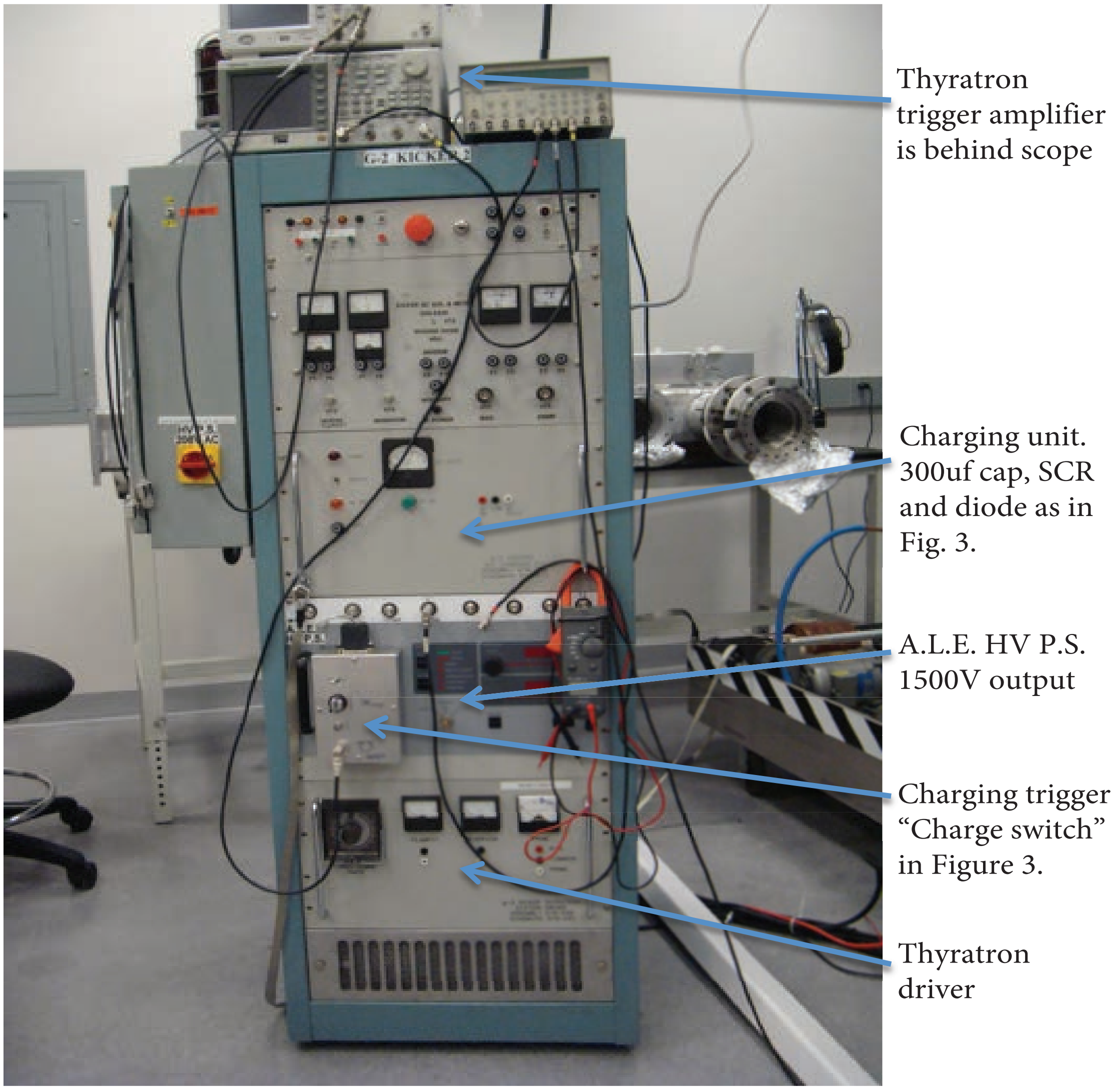


Figure 8. Electronics rack

6. Activity

The activity in a room 373 will be associated with assembly and test of the HV pulser and kicker magnet that will be installed in the vacuum chamber. The tests will include measurements of the fields in the kicker magnet, measurements of HV amplitude and the current running through the kicker. Both-the optical magnetic field measurements and traditional techniques with a short induction loop will be used to measure the field.

7. Hazards – High voltage

Maximum voltage is ~130 kV, with 5kA in ~100 ns pulse. This HV pulse will be applied to the kicker magnet located inside Aluminum vacuum chamber. The equipment is arranged so there is no open exposure to the HV; the HV electrodes and components are inside the vacuum chamber. Exposed surfaces including the vacuum chamber, the outer cylinder of the Blumlein generator, the thyratron housing as well as the electronics rack are all secured to the building ground. The middle cylinder of the blumlein is charged to ~ 60kV. It is discharged via the thyratron switch to the outer grounded cylinder of the line. If the middle cylinder is charged and the thyratron fails to fire, the cylinder will discharge through the 80M-ohm resistive divider in parallel with the thyratron with time constant of < 1 second.

8. Transformer oil

The HV generator is a Blumlein type and consisting of a triaxial line filled with Dow Corning 561 oil. The total amount of liquid is ~75 Liters total (~20 gallons). A spill kit is located next to the oil drum. The transformer oil is non toxic and non flammable. Absence of oil will result in internal breakdown at “low” voltage that does not constitute a personnel hazard.

9. Magnetic field

The magnetic field generated between the plates of the strip line kicker has a peak field of about 200 G. The ½ inch thick aluminum vacuum chamber attenuates the field so that the magnetic field is negligible outside the chamber. The pulse width is at most 100 ns with frequency content greater than 1MHz. The skin depth for aluminum at 1MHz Is less than 0.1 mm. The magnetic field outside the chamber is many orders of magnitude smaller than the peak field near the kicker plates, and so presents no magnetic field hazard.

10. Hazards – thyratron

The thyratron will be bathed in transformer oil that circulates through a heat exchanger to keep it cool. If it is operated without oil it will be hot. The tube is evacuated and there is a small risk of implosion. Note that the tube is fully enclosed in a heavy aluminum housing. x-rays?

11. Protocol

When the system is fully assembled, there will be no exposed high voltage. A flashing red light indicates that voltage is applied to the transformer primary. If testing is required during assembly, while there remains a risk of exposure to high voltage, a two man rule will be in effect. Both individuals will be trained in the operation of the electronics. A sign will indicate whether or not the system is energized. The system will be de-energized by shutting off the charging voltage. All accessible electrodes, not permanently attached to ground will be grounded with a grounding stick.

12. Emergency shutoff

An emergency shut off switch is located to the right of the exit from the lab. The red button will shut off all power including high voltage to the blumlein, all power to the thyratron, and the thyratron trigger. The middle cylinder of the blumlein may remain charged. It is only discharged through the thyratron. Prior to handling, a grounding stick will be used to discharge all components that are not tied directly to ground.

Emergency shut off .
Red button to right of door

13. Ground

The “vacuum chamber”, thyratron housing, blumlein outer conductor, electronics rack will all be grounded with grounding strap to the building ground indicated in Figures 9, 10 and 11.

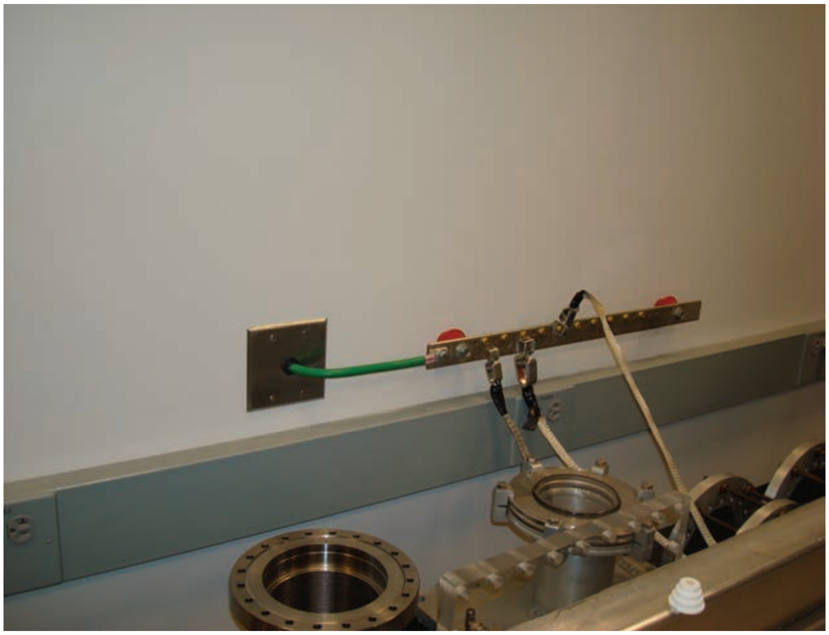


Figure 9. Terminal strip connected to building ground as in Figures 10 and 11.

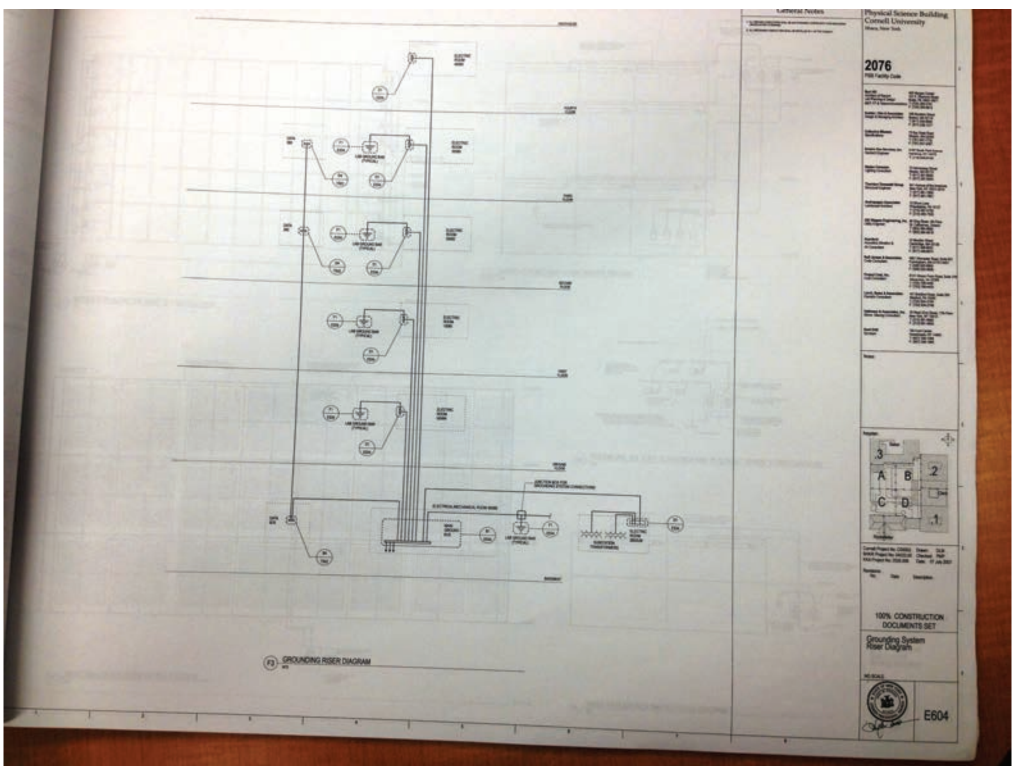


Figure 10. PSB Electrical Drawing E604 shows the riser diagram for the lab grounds.

Figure 11. Photograph of detail D1 on the drawing in Figure 7 that shows how the grounds on each floor are tied together in the electric room.

14. Crane

A two man rule applies to use of the crane.

15. Fire and spill hazard

A dry chemical extinguisher is located adjacent to the door to the room. A spill kit is located beside the oil drum. Secondary oil containment ?

16. Location

Experimental work will be carried out in room 373 of Physical Sciences Building (PSB). The plan of the third floor is represented in Fig. 12 and evacuation routes in Fig. 13.

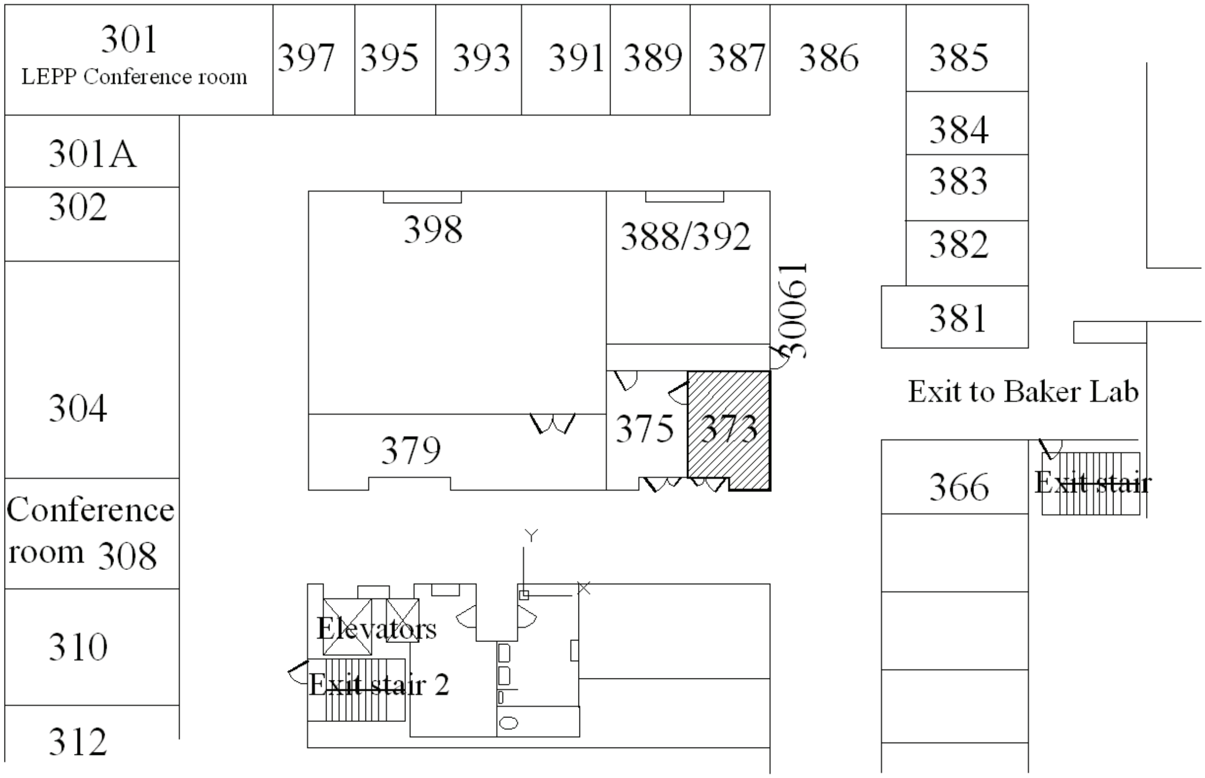


Figure 12. The third floor PSB General plan. Room 373 is hatched.

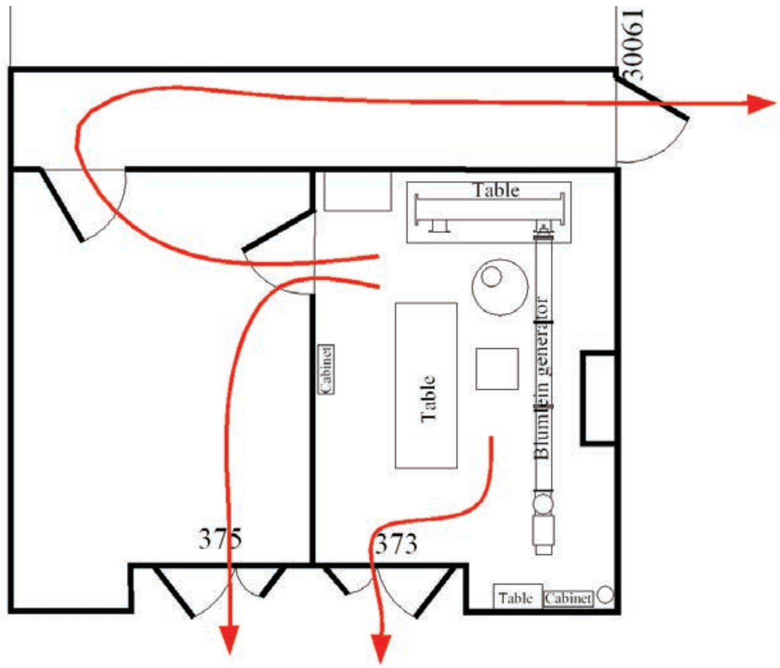


Figure 13. Possible evacuation ways in a case of emergency.

SUMMARY

Maximal voltage: up to 130 kV
Maximal current: up to 5 kA
Dow Corning 561 liquid content ~100 Liters total (~26.5 gallons).
Other voltages required for thyratron operation:
Heater: 6.3 V, 25 A
Reservoir: 6 V, 8 A
Prime voltage: up to 100 V, 150 mA
Bias: up to 100V, 150 mA
Triggering voltage: 500-1kV on 50 Ω

REFERENCES

[1] G.W.Bennet *et.al.,* " Final report of the Muon E821 Anomalous Magnetc Moment Measurement at BNL", arXiv:hep-ex/0602035v1, 20 Feb. 2006; Dated: August 9, 2009.

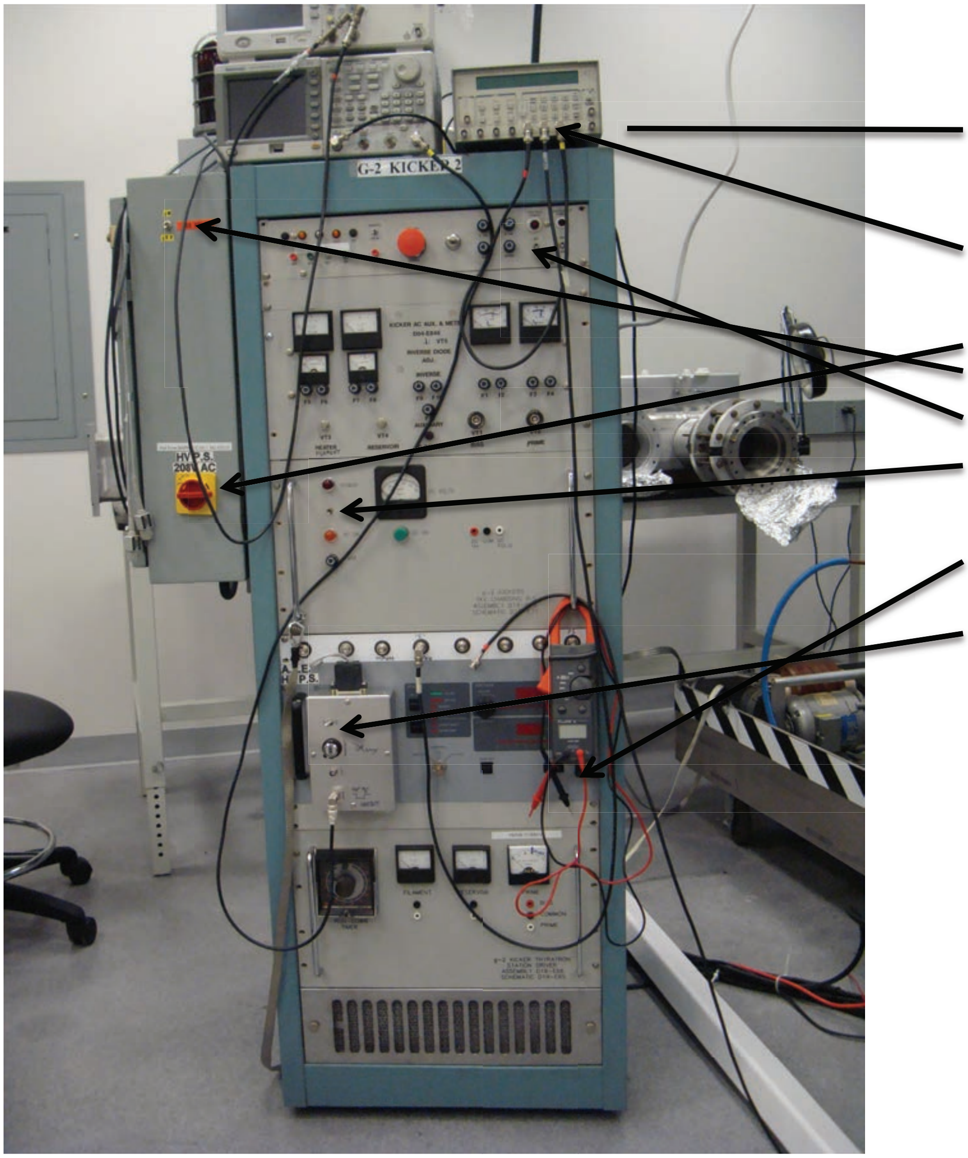
[2] X.Fei, V.W.Huges, R.Prigl, Nucl.Inst. and Meth. **A 374**(1994), 118.

[3] R.Prigl *et.al*., Nucl.Inst. and Meth. **A** (1996) 349.

[4] The New (g-2) Experiment: A proposal to Measure the Muon Anomalous Magnetic Moment to ±0.14 ppm Precision, Submitted to DOE Office of High Energy Physics, April 5, 2010.

[5] E.Efstihadis, *et.al.*,"A Fast Non-Ferric Kicker for the Muon (g-2) experiment", Elsevier Sci., 15 July, 2002.

Operating procedure for **energizing**
PFN (pulse forming network – blumlein)

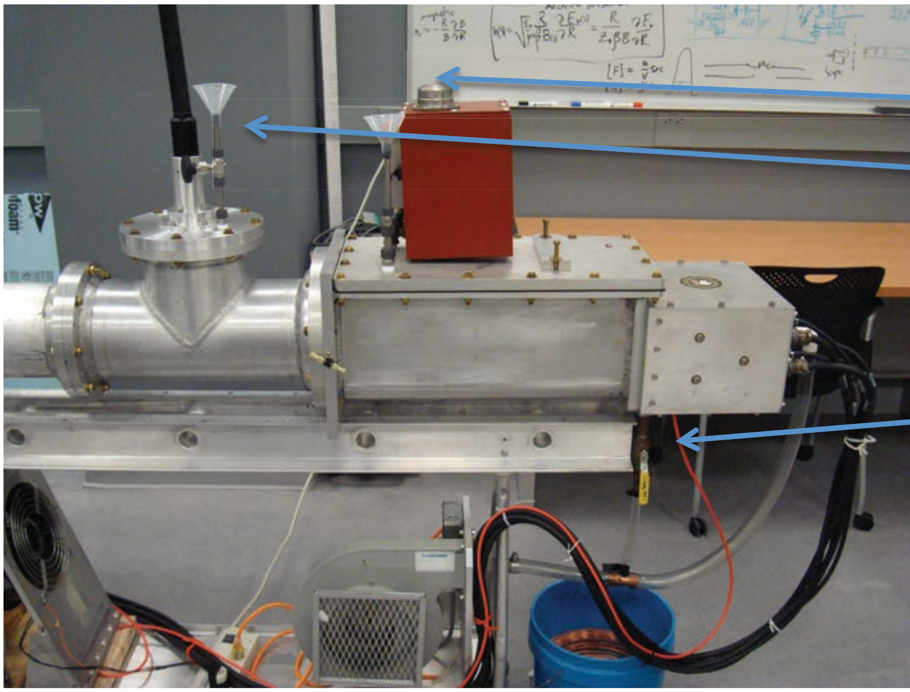


1. Switch on power strip (on top of G-2 Kicker rack, behind pulse generator)
2. Turn on pulse generator (on top of G-2 Kicker rack)
3. Turn RED switch on for 208
4. Toggle switch on
5. Thyratron driver on
6. Charging power supply toggle switch on
7. High Voltage power supply power on
8. Toggle switch for charging unit on

Thyratron requires at least 15 minutes to warm up

De-energize – switch off in reverse order
Use grounding stick to short out inner conductors of blumlein and capacitors and check with dvm before touching components.

Procedure for transferring oil to/from PFN and transformer tank

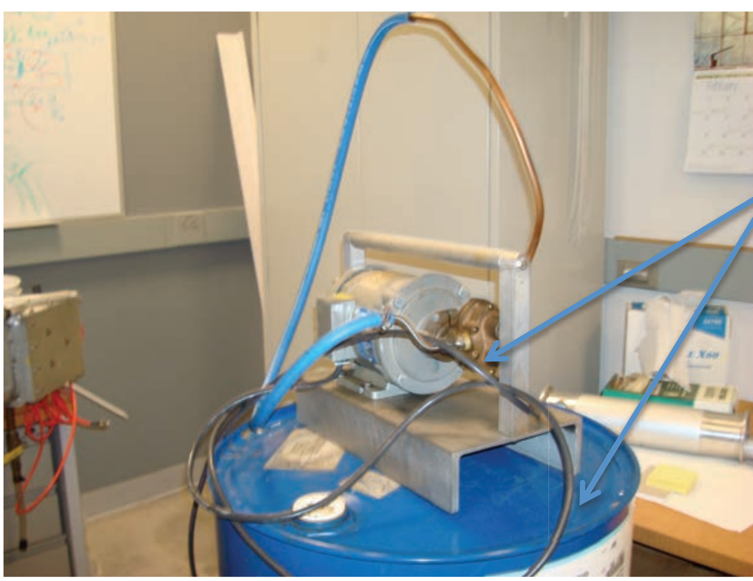


Filling

1. Oil in here (via pump from drum)
2. High point to release trapped air through funnel

Draining

1. Low point – to pump – to drum
2.



Oil drum

Oil pump