Fermilab

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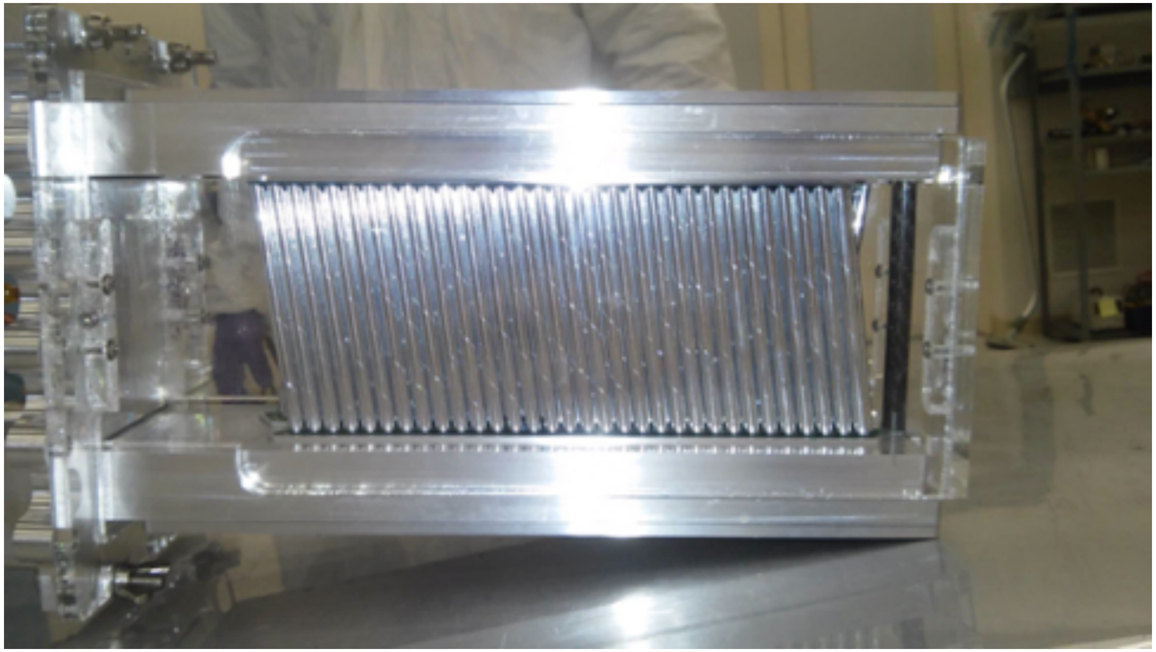
Muon g-2 Tracker Overview



Brendan Casey
L3 Manager
21 October 2015

Outline

- Physics/Requirements
- Team and Design
- Current issues/problems
- Schedule

Muon g-2

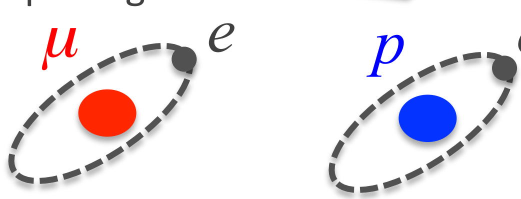
- g-factor is the ratio of a particle's spin to its magnetic moment in units of the Bohr magenton. =2 for point-like Dirac particles
- g-2 differs from zero due to quantum fluctuations in the vacuum
- These corrections can be calculated to sub-ppm precision
- A measurement of muon g-2 to sub-ppm precision required to test these calculations

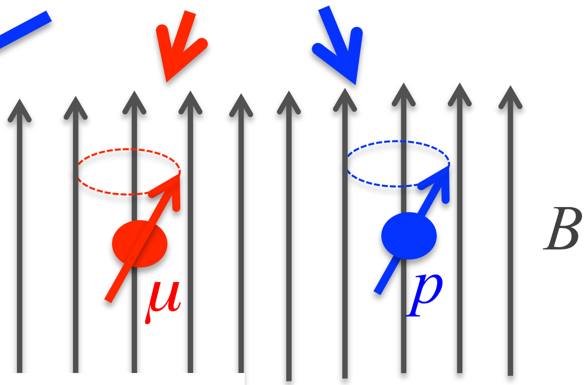
Muon g-2

Experimental goal is a measurement of muon g-2 to 140 ppb precision

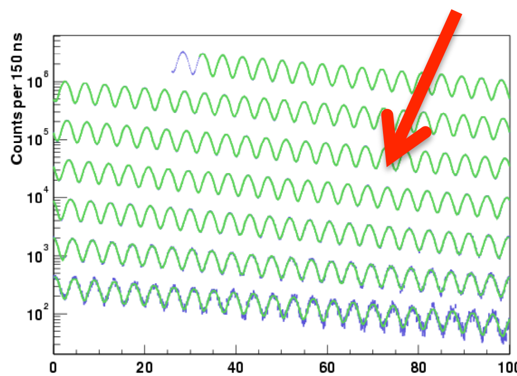
$$\frac{(g-2)_\mu}{2} = a_\mu = -\frac{m}{q}\frac{\omega_a}{B} = \frac{\omega_a/\omega_p}{\mu_\mu/\mu_p - \omega_a/\omega_p}$$

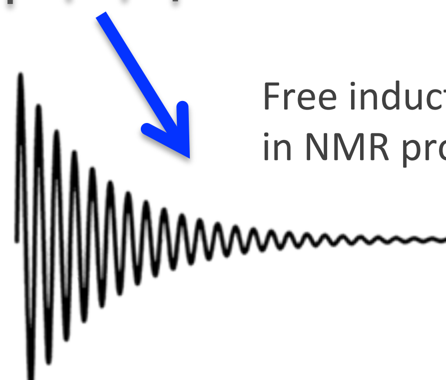
Muonium and hydrogen hyperfile splitting





high energy positrons versus time from the stored muon beam





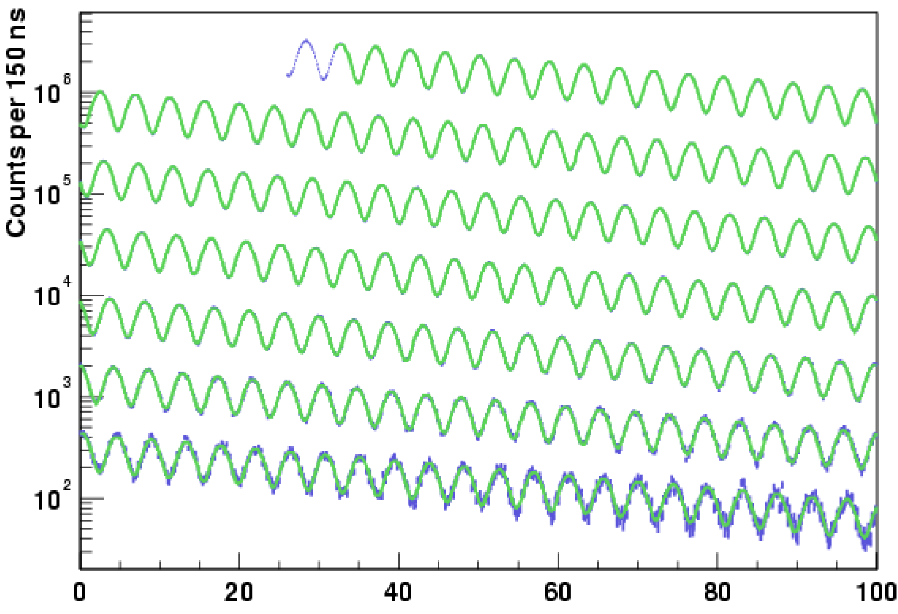
Free induction decay in NMR probes

Detector L2

The L2 detector branch of the WBS contains all instrumentation required to measure the muon precession frequency

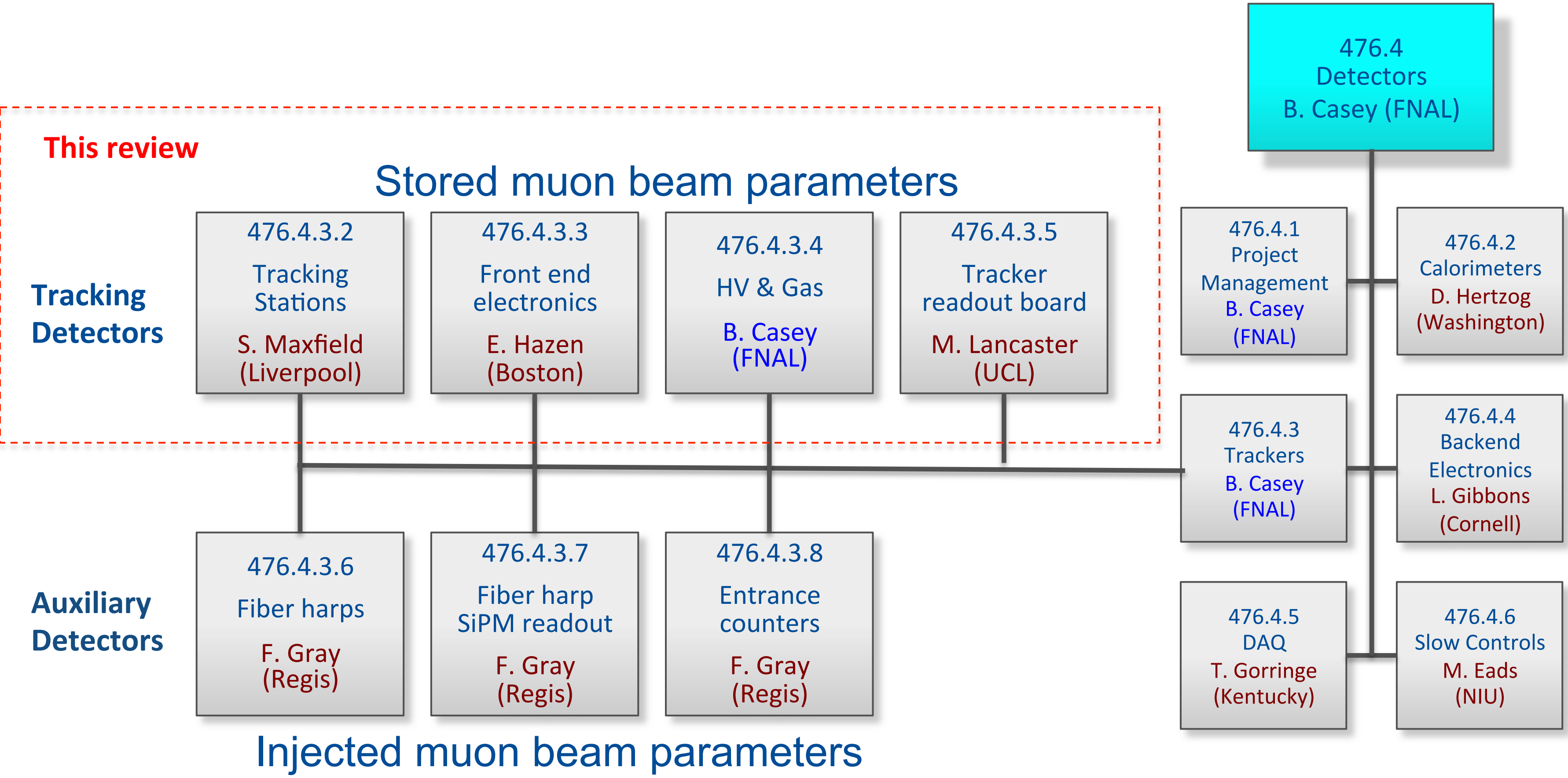
- This includes:
  - Calorimeters to measure positron energy and time
    - This data is fit to extract the precession frequency
  - Tracking detectors to measure characteristics of the muon beam
    - This data is used to make corrections to the extracted precession frequency and help constrain systematics
  - Readout electronics, data acquisition, and slow controls

\# of high energy positrons versus time



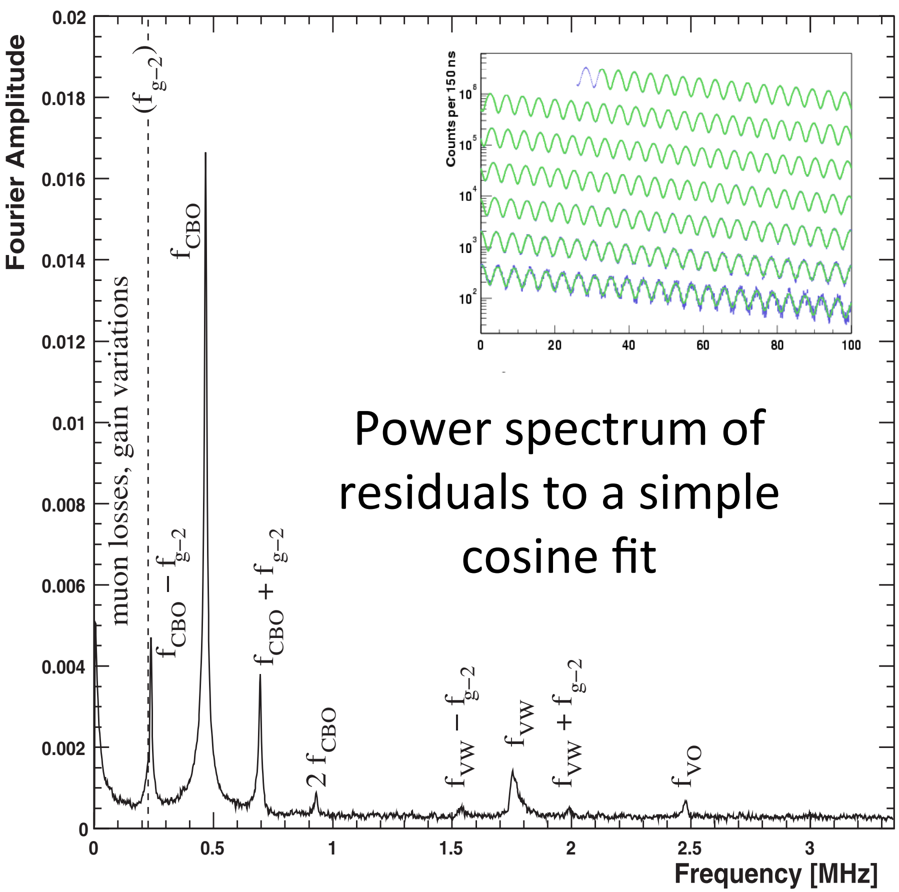
BNL 2001 run. This plot x 40

Tracker L3



- This L3 resides under B. Casey (Control Account Manager) in the detector WBS.
- Encompasses the tracking detectors and the auxiliary detectors

Beam Dynamics



- We need to know everything about the stored muon beam
  - Arrival time
  - Injected profile
  - Stored profile
  - Motion throughout the fill

Physics Goals

- Measure the beam profile in multiple locations around the ring.
  - Validates our model of beam dynamics needed to
    - Understand calorimeter acceptance changes due to beam breathing
    - Determine ppm level corrections to ω_a due momentum spread and betatron oscillations
    - Determine effective magnetic field map seen by the muons
    - Limit the size or radial and longitudinal magnetic fields

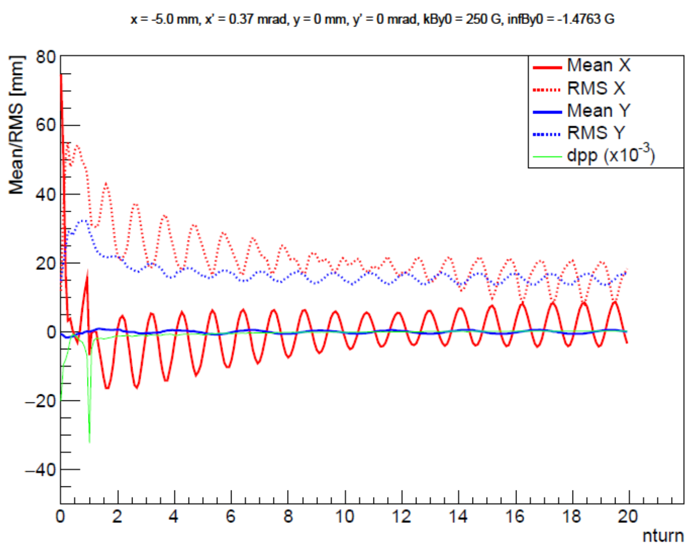
- Make an independent measurement of positron momentum
  - Can be used to validate calorimeter-only methods of determining pileup and gain systematic uncertainties in regions where tracker and calorimeter acceptance overlap

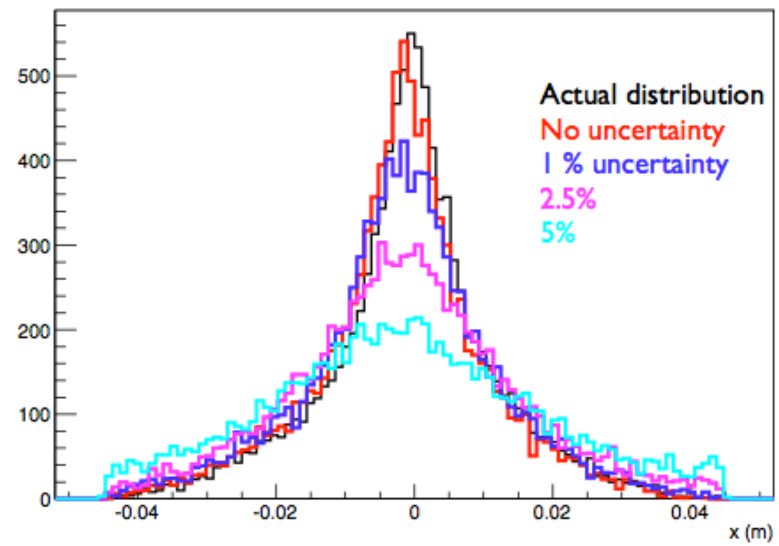
- For commissioning, determine position (x,y) and angle (x',y') distributions at injection and during the kick and scraping.

- Characterize position and width CBO modulations, horizontal and vertical.

Requirements

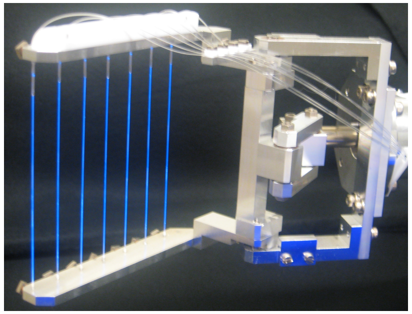
- Need to measure beam profile with mm level accuracy
- Large extrapolation back to decay position requires percent level uncertainty on curvature and minimal material
- Requires better than 300 micron uncertainty on individual position measurements





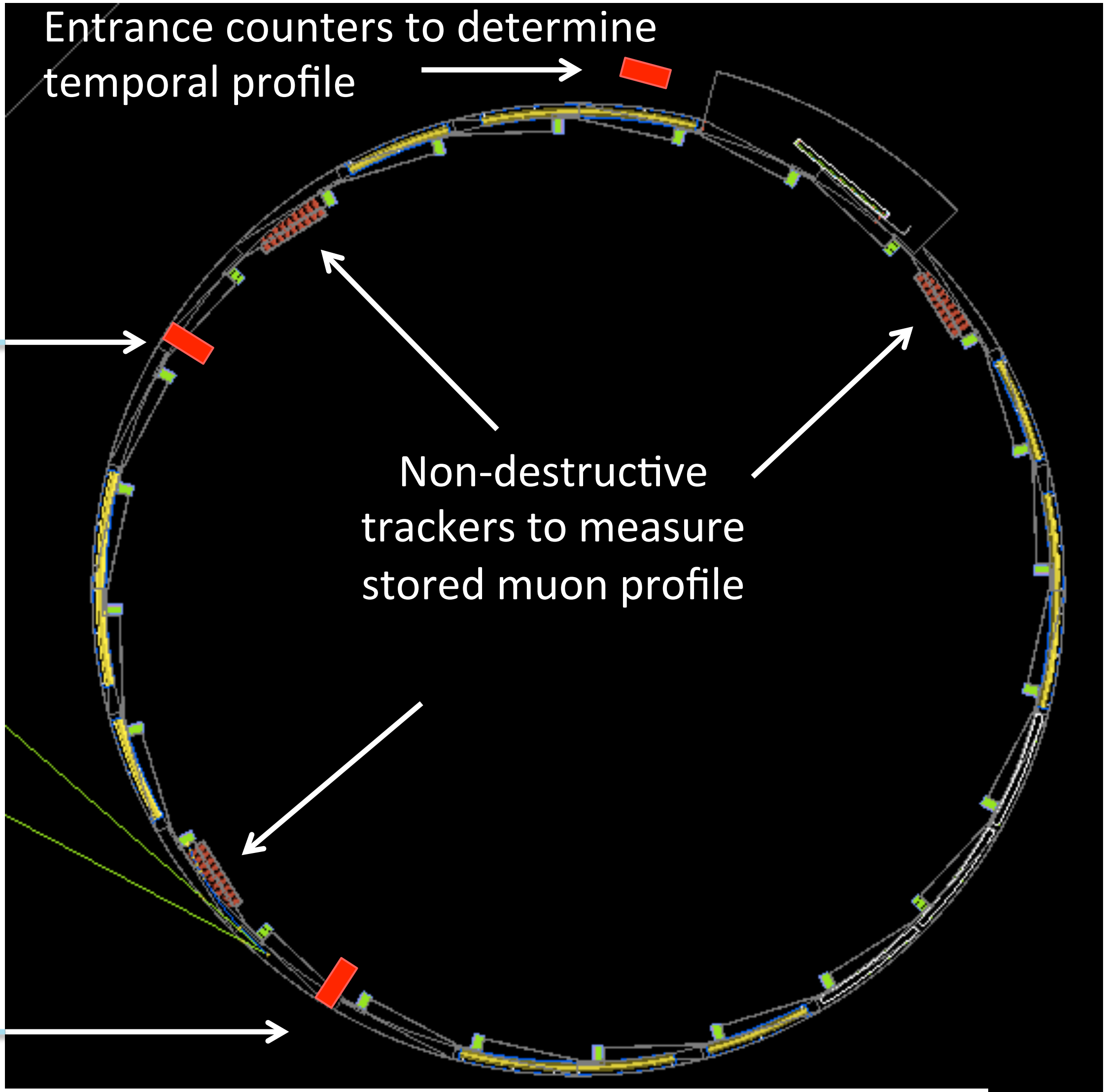
Technical design: Trackers

Systems primarily funded by
the STFC and ECA



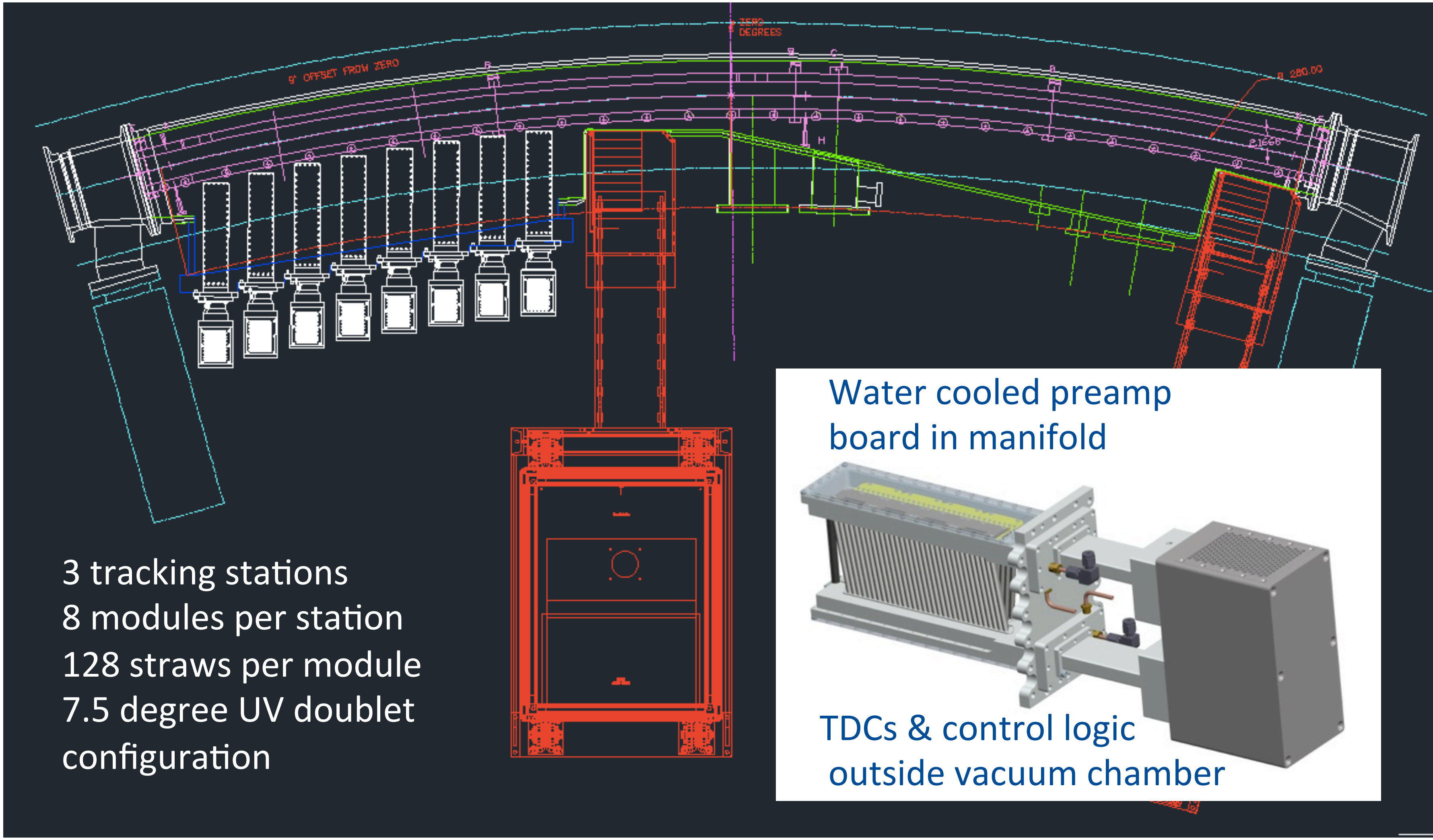
Recycled from BNL

Destructive fiber
harps to measure
injected muon profile



Muon g-2   In-vacuo. >factor of 5 improvement to similar system on BNL

Design



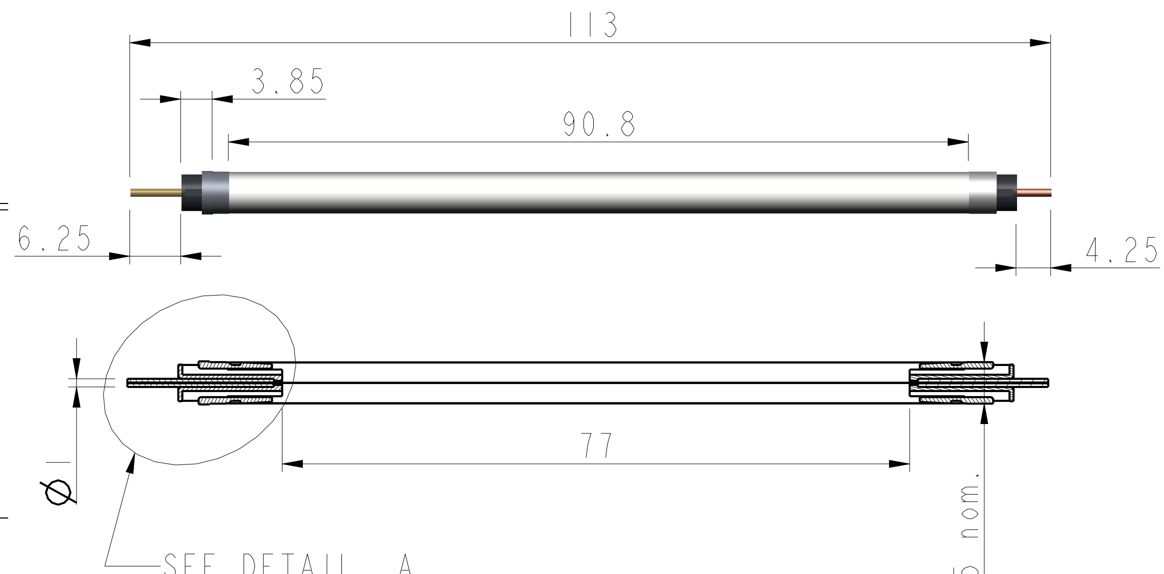
3 tracking stations
8 modules per station
128 straws per module
7.5 degree UV doublet configuration

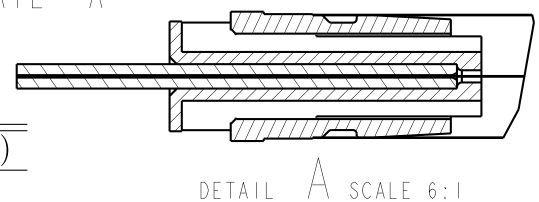
Water cooled preamp board in manifold

TDCs & control logic outside vacuum chamber

Mu2e Straws

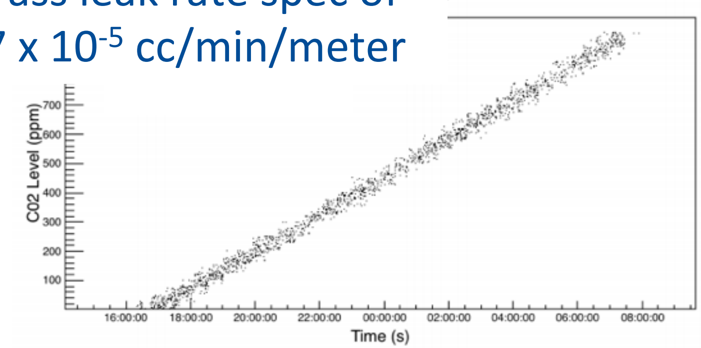
Straw material	Aluminized Mylar
Straw wall thickness	15 μm
Wire	25 μm gold-plated tungsten
Straw length	~~10 cm~~ 9 cm
Stereo angle	$\pm$ 7.5° from vertical
Gas	50:50 Argon:Ethane
Pressure	1 Atm
Operating voltage	1800 V





Material	Thickness	radiation Length (cm)	X/X_0 (%)
Gold	200 Å	0.3	6×10^{-4}
Aluminum	500+500 Å	8.9	1×10^{-4}
Adhesive	3 μm	17.6	2×10^{-3}
Mylar	6 + 6 μm	38.4	3×10^{-3}
Ar:Ethane	5 cm	1×10^5	4×10^{-2}
Total per straw			0.05
Total per station			0.11
Tungsten	25 μm	0.35	0.7
Total after hitting 1 wire			0.82

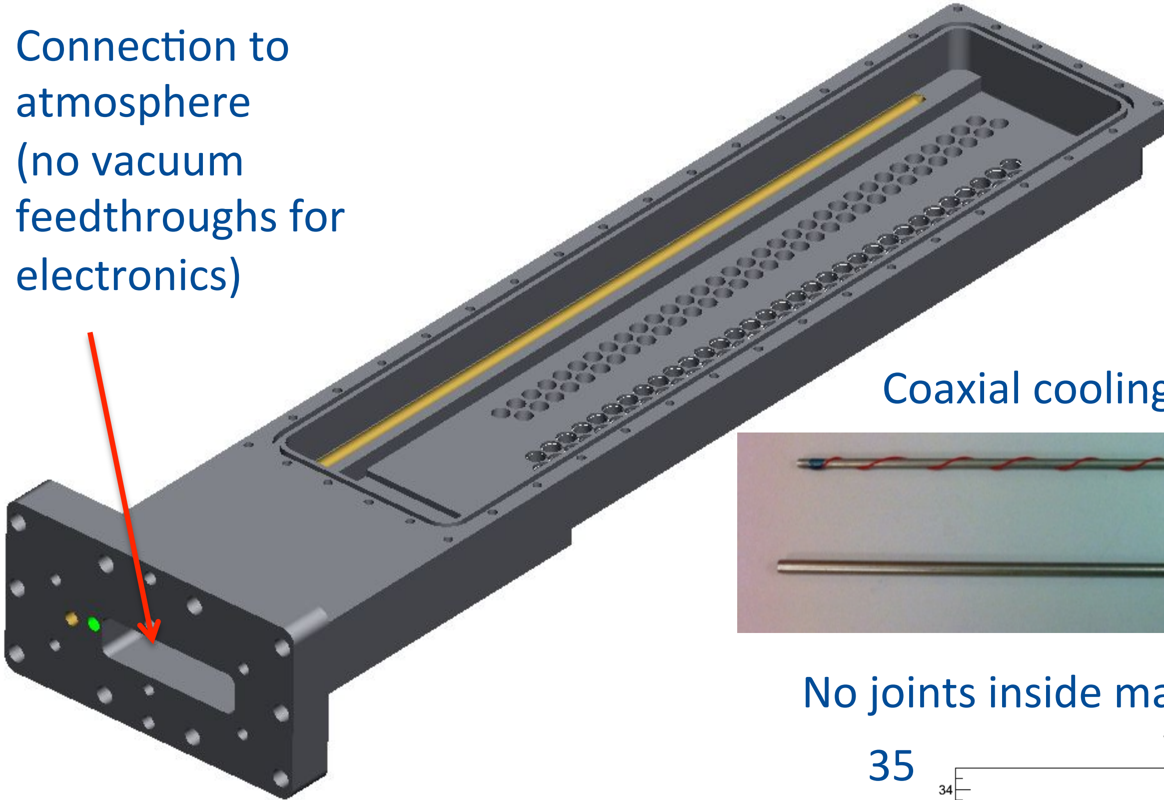
Pass leak rate spec of 7×10^{-5} cc/min/meter



Unique characteristics: very short, very thin

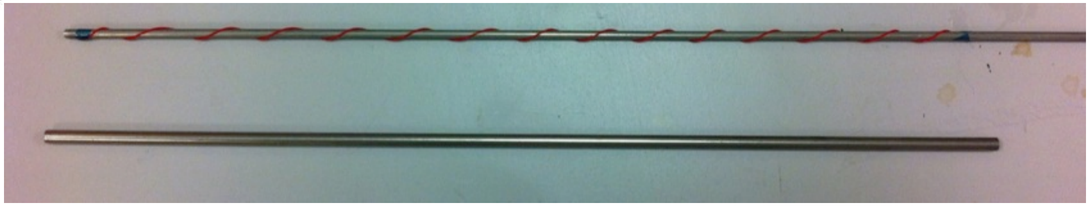
Manifolds

Connection to atmosphere (no vacuum feedthroughs for electronics)

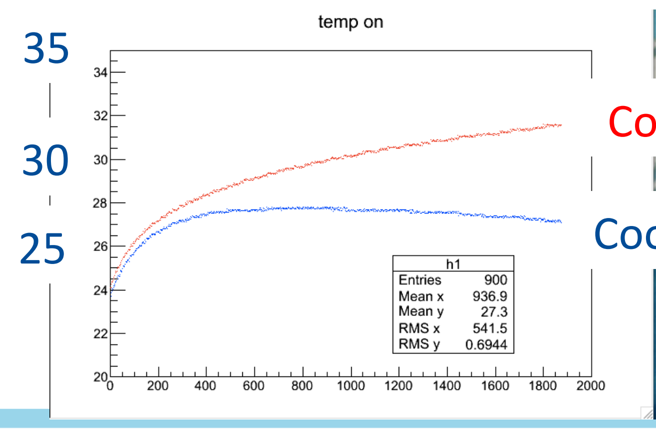


Preamp boards inside

Coaxial cooling channel embedded in manifold



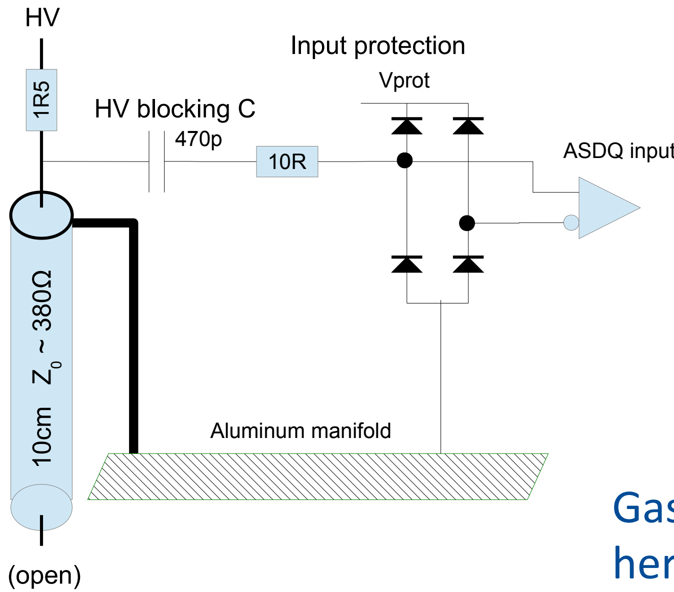
No joints inside manifold or in contact with vacuum



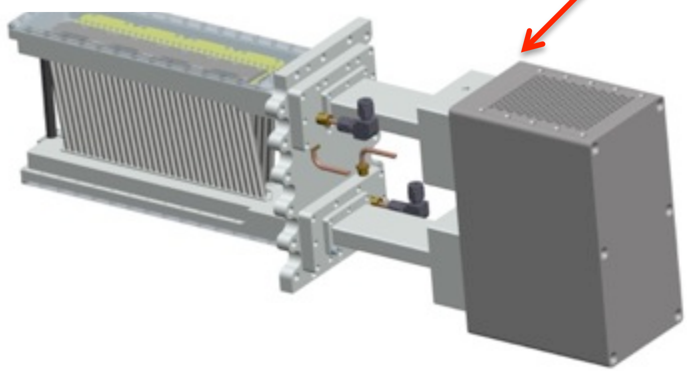
Cooling off

Cooling on

Front end electronics



Gas interface here



Crate outside vacuum houses
FPGA based TDC boards, voltage regulation, control logic

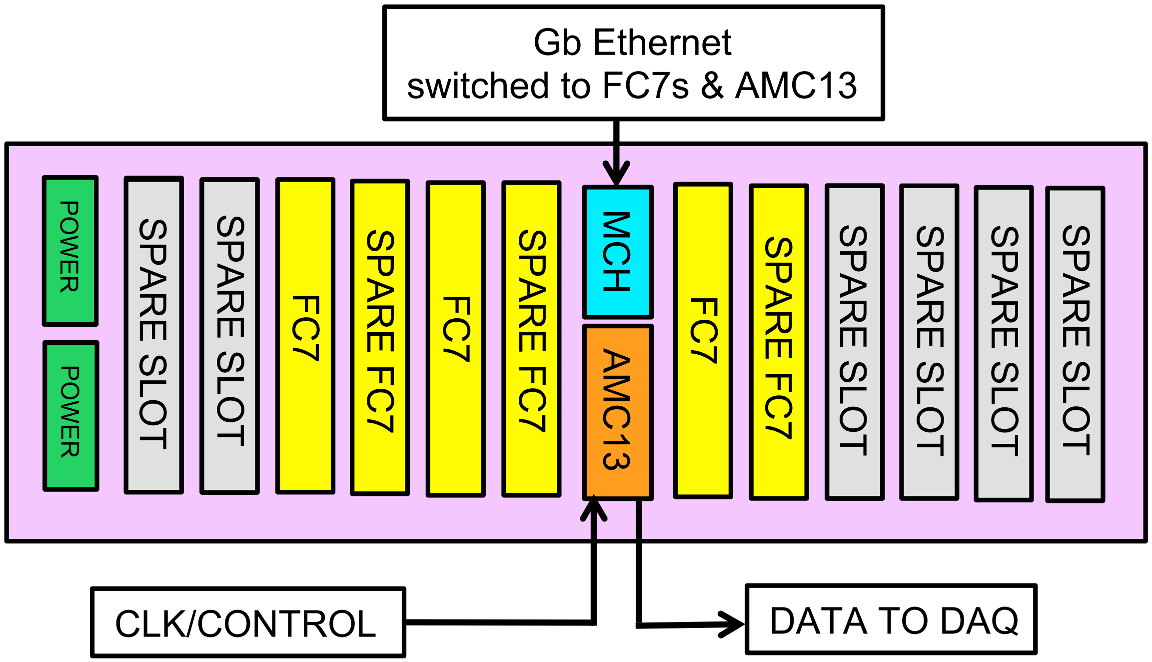
Back end electronics

Micro TCA based system common to all g-2 detector systems

Uses CMS backplane and crate controller

Specs are set by the calorimeter

For tracker, this is basically a pass through for the data and an interface with the clock



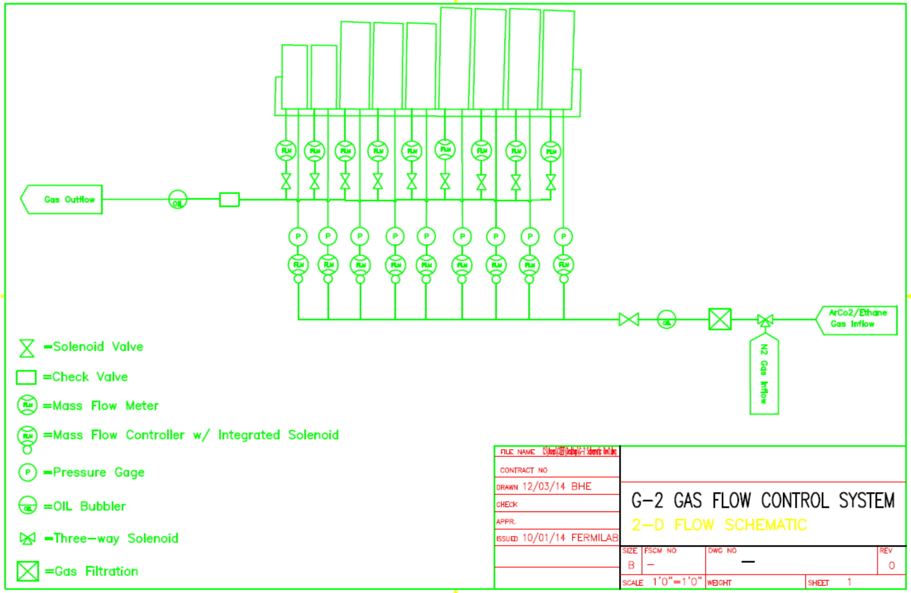
Gas

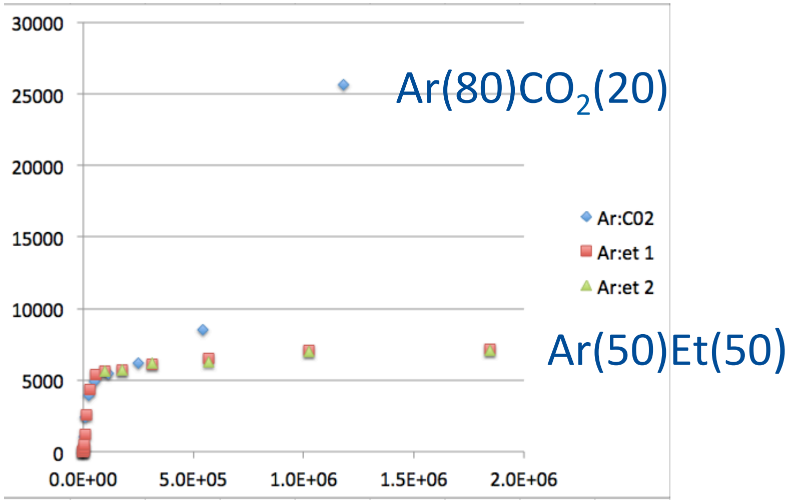
Gas system designed to work with Ar:Et (50:50) or Ar:CO_2(80:20)

With Ar:Et @ 1800V gain is 2 x 10^6
-Total charge on wire is 3mC/cm
-20% lose of gain without additive
-No loss with 0.1% O_2 added based on CDF experience

Rate at beginning of fill is few hundred kHz for the hottest straw
-few % gain sag at 2 x 10^6 gain
-not an issue with sufficient S/N

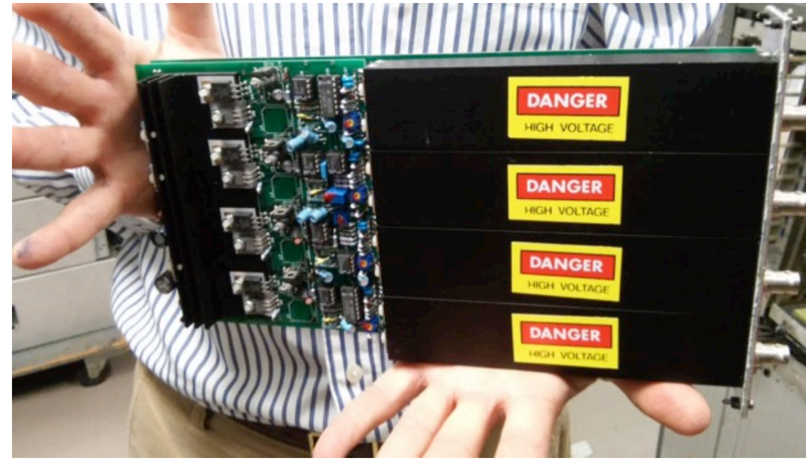
Likely that we will not run with this high a gain but designed for it (everything rated for 3kV)

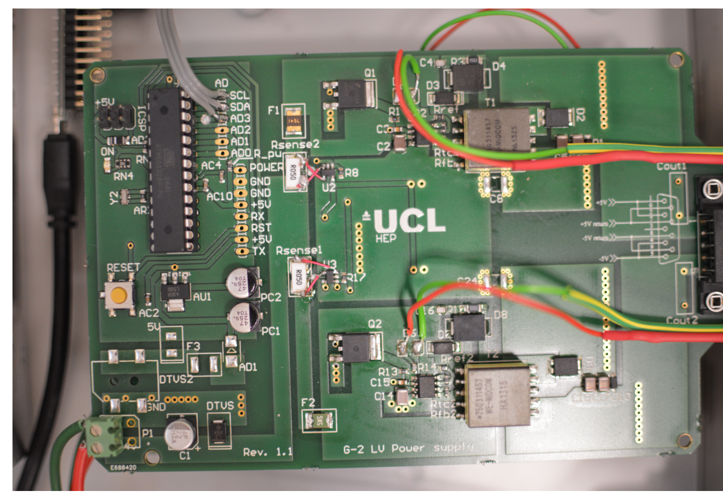




LV/HV

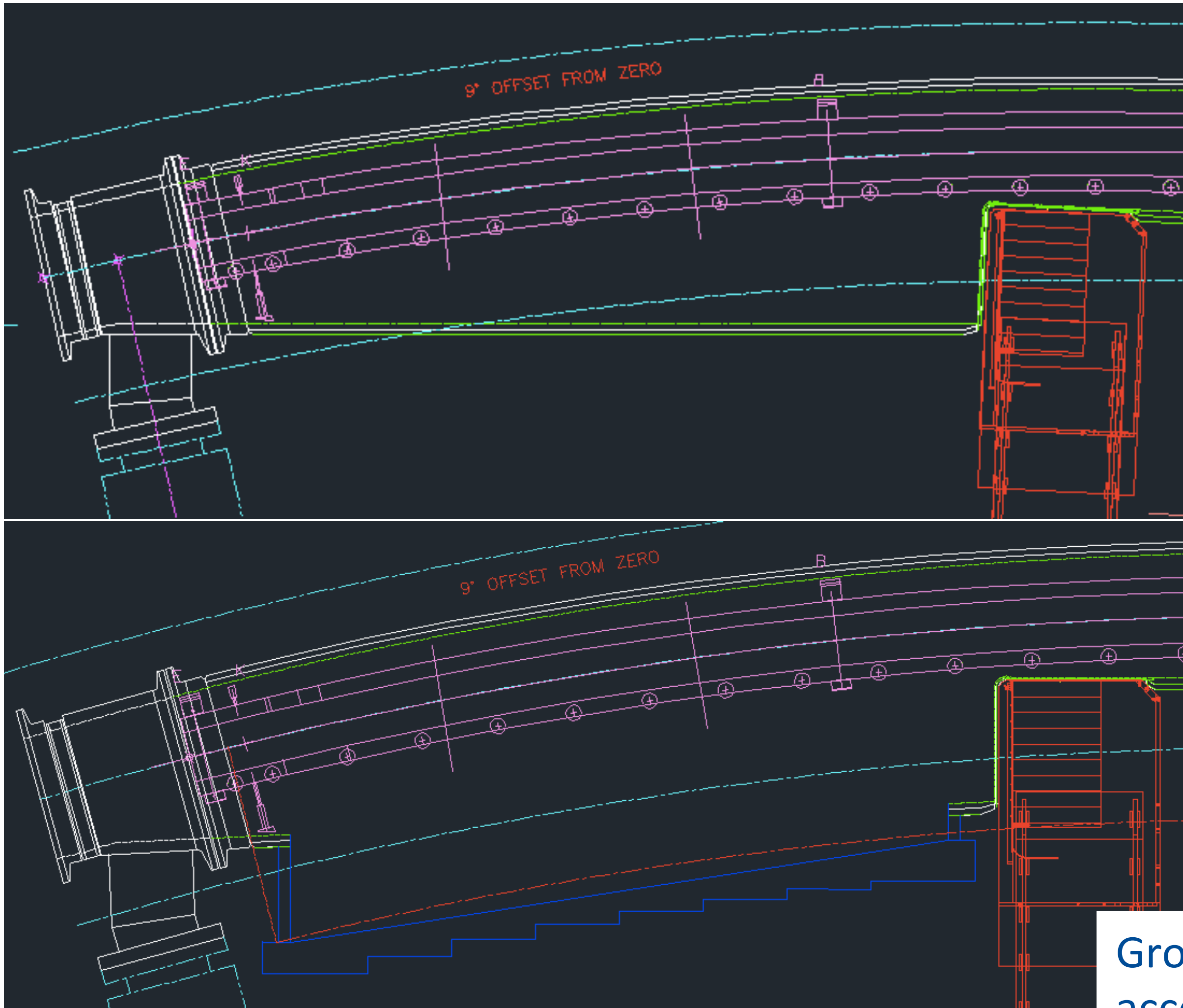
- HV: Evaluating 3 commercial units
  - CAEN, ISIG/Veiner, CAEN system recycled from CDF
  - Based on CDF and LHC experience, we would need 50% spares for new systems and significant human resources for burn in and communication with vendors
  - CDF system has factor of 2 more channels than we need already burned in. Started testing it this week
- LV: Custom board from UCL designed and prototyped
- HV/LV independent for three trackers with racks located about 2 meters away

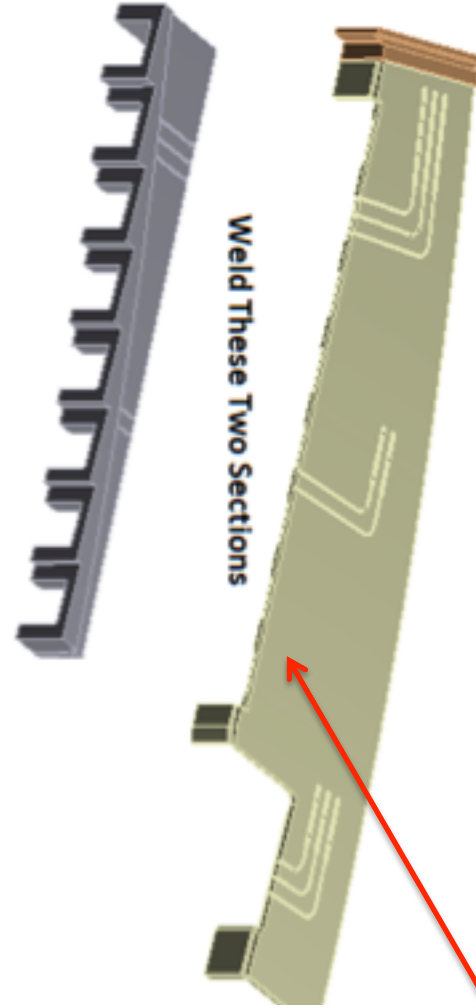




Vacuum chamber modifications

Carved out of single piece of Al

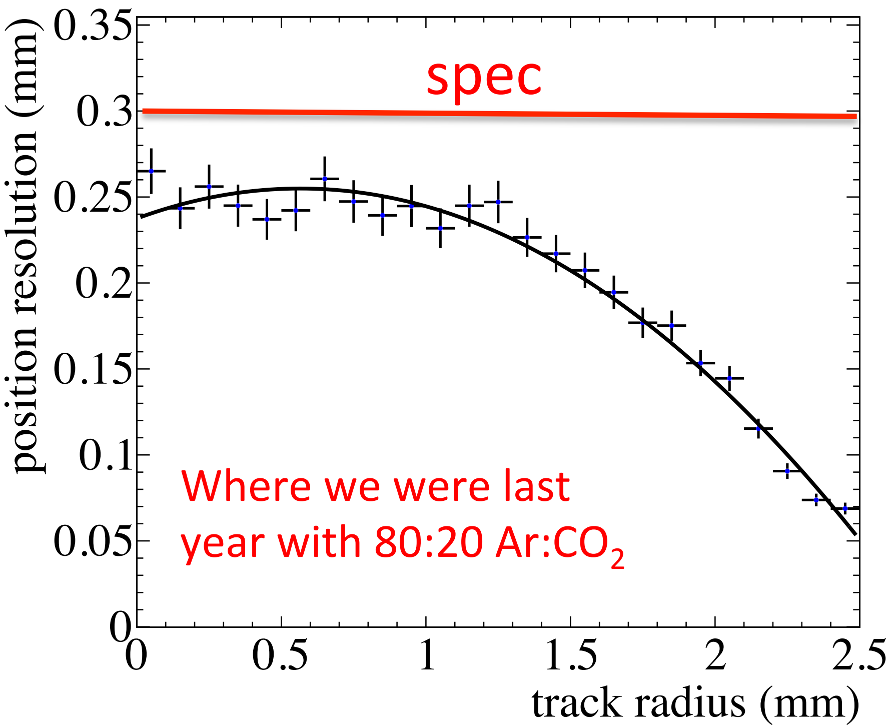


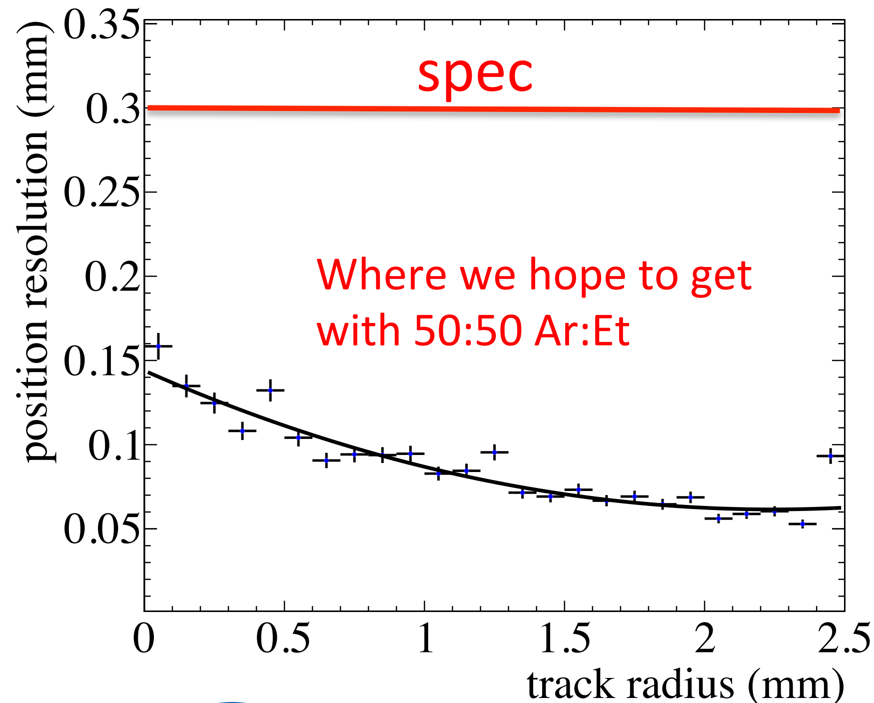


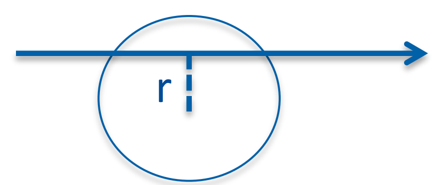
Grooves cut into existing chamber to account for weld deformation and deflection under vacuum

Simulated Performance

- Design meets specifications with significant head room
  - Simulations backed up by preliminary beam test results







What is ready

- Straw and manifold designed and prototyped
- Front end preamp boards designed and prototyped
- Backend link to DAQ designed, prototyping in progress
- Low voltage designed and prototyped
- Gas system designed, building first ‘channel’

What is not ready

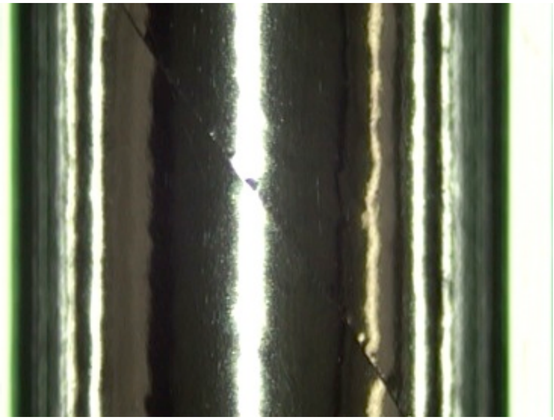
- Having QC problems with straw vendor
- Demonstrated that straws pass leak rate spec but havent demonstrated it with a complete module
- Have to do another design iteration on the TDC do to space conflicts
- Still prototyping the modifications to the vacuum chambers
- Over our material budget

Straw vendor

- We piggybacked off a Mu2e purchase
- Large variation batch to batch in ID
  - Vendor didn't keep the mandrel
- Feathering at the seams
  - Looks like the cutting tool got dull
  - Causes OD problems
- Straws damaged in shipping
- In the end, ~50% useable

Feathering

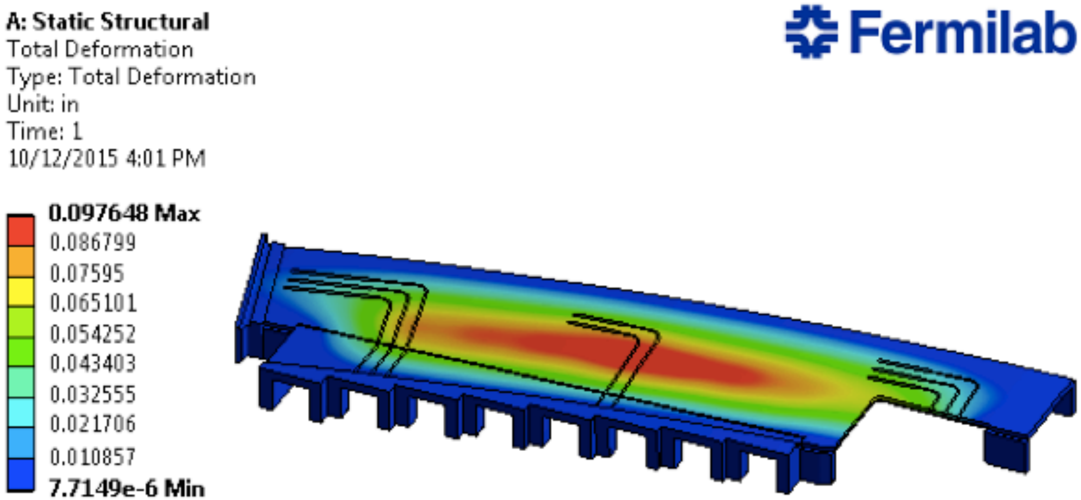
No feathering



Straw vendor

- Buying a new batch of straws
  - Minimum order is about 4x what we need
- Working directly with vendor and have renegotiated specs on ID and OD
  - They claim to have solved the feathering problem
- Purchasing up to 4 setup charges
  - We will do QC on the straws during production and will adjust setup if needed
- We are getting the mandrel
- We are supplying the shipping material and will do the shipping

Vacuum chamber modifications



- Have a very tight tolerance on space between vacuum chamber floor and ceiling and the manifolds
  - 0.5 mm at ATM, 0.1mm at 10^{-6} T
- Engineers realized we could no keep these specs if we are welding aluminum
- Solution is to machine pockets into the floor and ceiling of the chambers
  - Prototyping weld this week

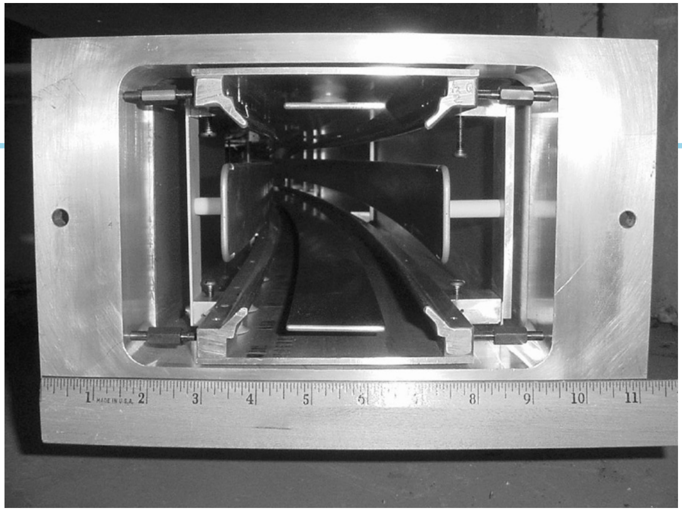
Material budget

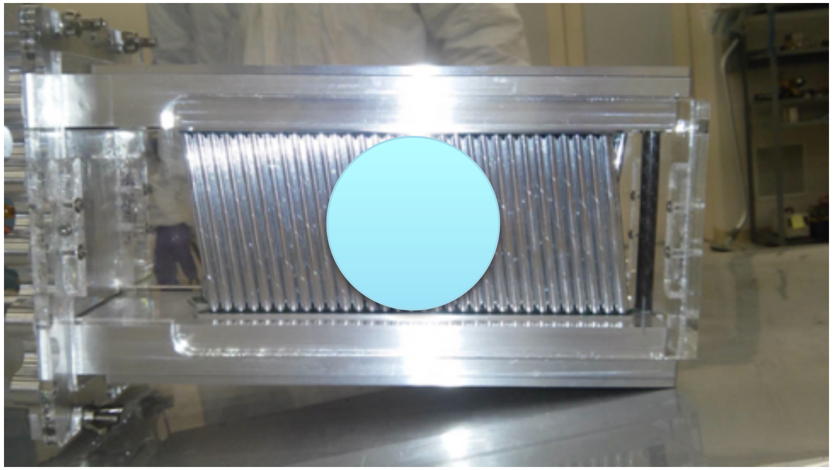
- About 60% of the ring is instrumented with electrostatic quadrupoles and kickers that shadow the calorimeters
  - Calorimeters can live with this

- Our goal has been to keep our material budget << than this material so we know the calorimeters can live with us

- Muon beam envelope is contained within 9cm

- Our goal has been to have passive material outside this area





Material budget

- Problems with our assumptions
  - Brem photons created in the quads/kickers in general do not hit the calorimeters
  - Brem photons created in tracker in general hit the calorimeters
  - Divergence in decay angle has positrons hitting manifolds

- About 2% of positrons going through the tracker get reconstructed as two showers
  - Can probably reduce this by a factor of 2 by shrinking the carbon fiber post but we don't think we can shrink the manifold any more
  - Still investigating the effects on downstream analysis
  - Systematic uncertainty budget for understanding pileup is 40 ppb

- Worst case would be that the calorimeters behind the trackers could not be used for analysis
  - In this case, we would not deploy all three trackers

Schedule from 10,000 ft

- Final prototyping of modules, refining of QC procedures now
- Construction readiness review 4th week of January
- Module production starts in February and takes 15 months
- First trackers worth of equipment at Fermilab ~summer 2016.
- Final equipment arriving late spring 2017
- Beamline scheduled to be complete early spring 2017 so if that stays on schedule, third tracker would be installed in summer 2017 shutdown