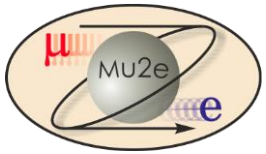
Fermilab

Mu2e CD-2 Review
Extinction Monitoring



Peter Kasper

L4 Manager for the Extinction Monitor

10/22/2014

Extinction Monitor Requirements

- Monitor the extinction of beam **hitting** the target.
  - That is the final extinction of interest to the analysis
  - Out of time beam that misses the target does not easily produce background tracks
- Requirements are discussed in Mu2e-DOC-894
  - Should be operating at all times during data acquisition.
  - Data should be available for online monitoring.
  - Data must be synchronized to the spill, so time evolution of out-of-time beam can be studied.
  - Should measure the proton pulse characteristics in addition to the extinction.

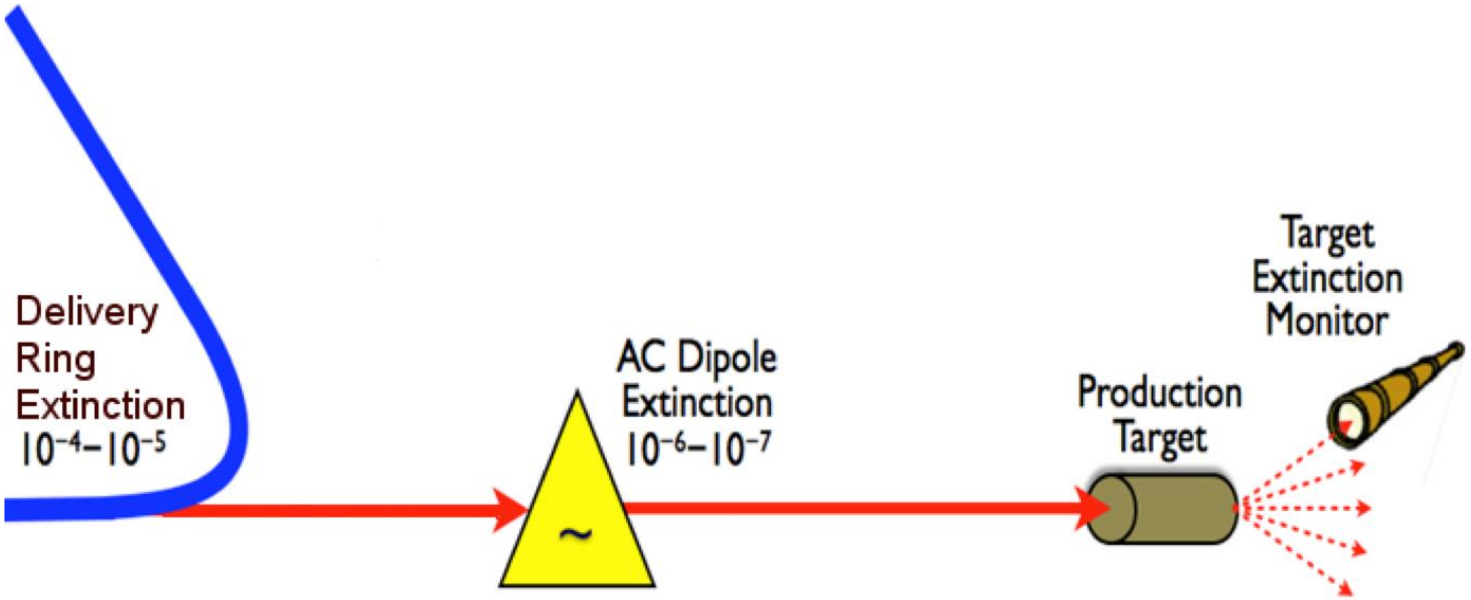
Extinction Monitor Requirements (cont'd)

- From Mu2e-DOC-894:

Specification	Value
Sensitivity (90% C.L.)	10^{-10}
Extinction accuracy	10%
Integration time	6×10^{16} POT (~3 hours at design intensity)
Timing resolution (RMS)	<10 ns
Dead-time	<10 ns
Rate-dependent error over dynamic range	<10%
Initial readiness	When the production target is ready
Access time (assuming monthly access is needed)	4 hrs
Radiation hardness (minimum protons delivered before replacement is required)	4×10^{20} POT

Principle of Operation

- Since we are only interested in protons hitting the target we monitor the rate of secondary particles produced by interactions on the target
- With ≈ 3 x 10^{7} protons/bunch it is not possible to measure a 10^{-10} extinction with a single bunch, nor is it feasible to count every proton.. Hence we must integrate over many bunches.



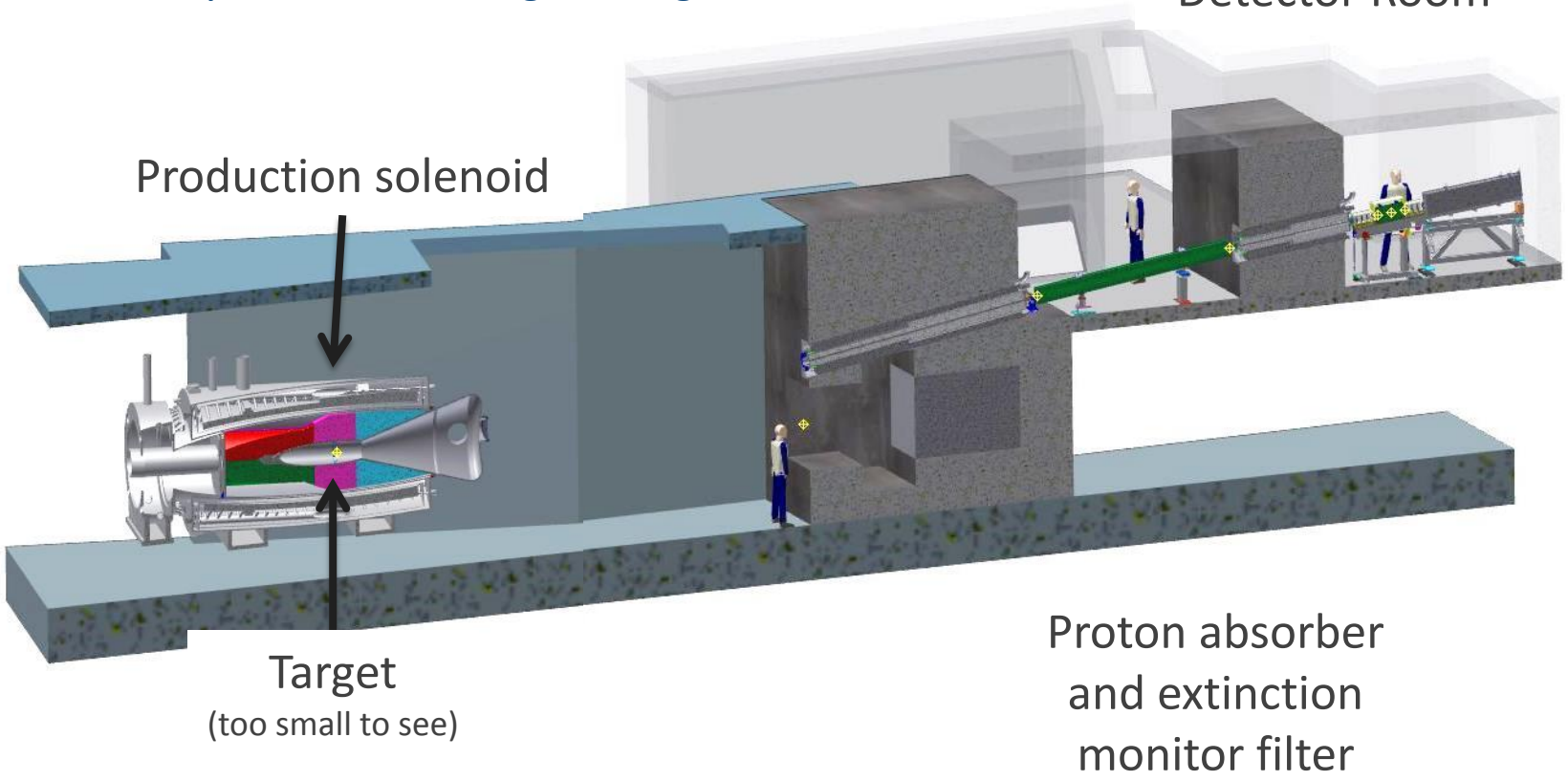
Principle of Operation … Filter + Detector

- Filter
  - Selects a sample of suitable secondary particles and delivers them to the detector
  - Sets the per proton signal rate in the detector
  - Shields the detector from unwanted interaction products
- Detector
  - Measure “in-time” and “out-of-time” signal rates with equal or known relative efficiency
  - Must have LOW “out-of-time” backgrounds compared to “out-of-time” signal rate

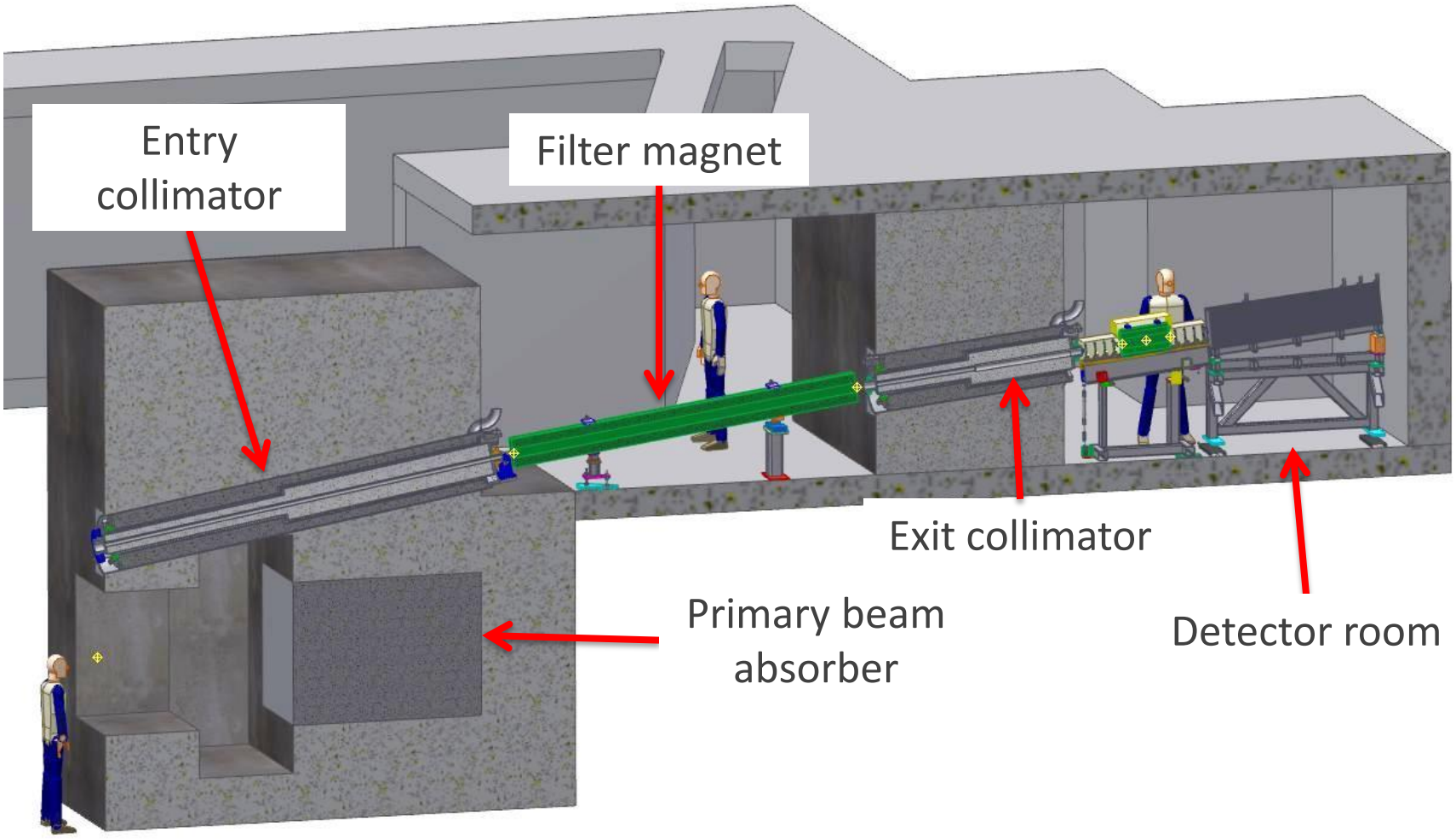
Location

- Detector room is located above and behind the beam dumpz

3D model courtesy of Bartoszek Engineering



Filter Layout

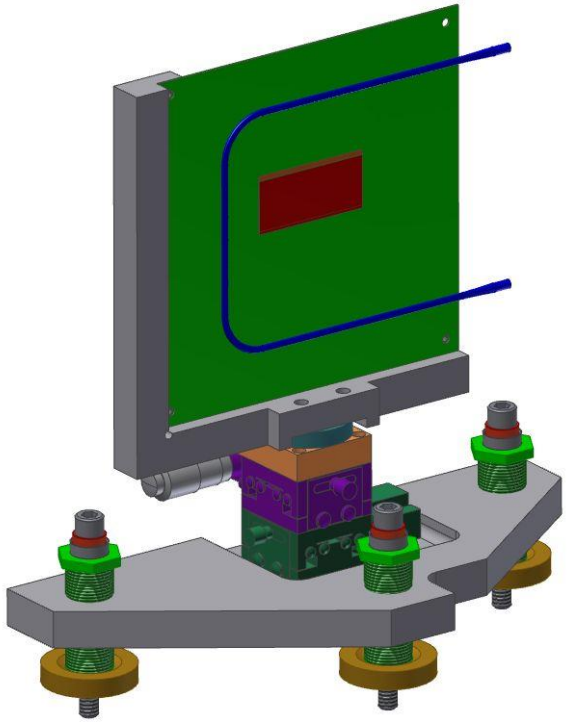


Filter Design

- Locates detector outside target hall
  - Easy access for detector maintenance
  - Lots of room for shielding
  - Low radiation levels for detector + electronics
- Entry collimator
  - Located in concrete above the primary beam dump
  - Admits forward produced high momentum secondaries
- Filter magnet
  - Permanent dipole oriented to transmit ~4.5 GeV/c secondaries
- Exit collimator
  - Admits signal particles through a 2m thick shield wall

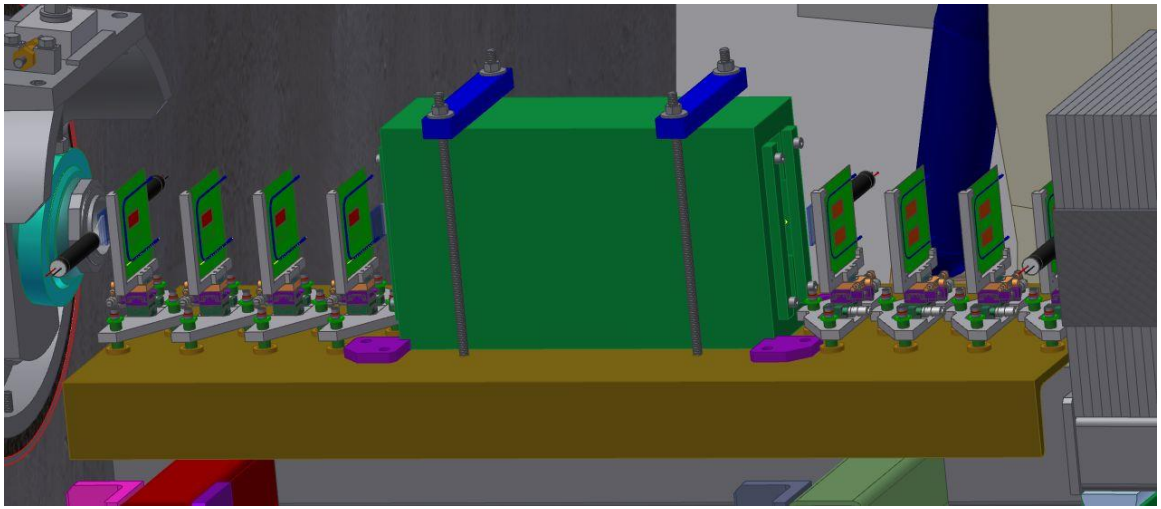
Pixels: the Basis of the Measurement

- High granularity
  - Atlas style FE-14 sensor chips with 26,880 pixels per chip
  - Pixel size is 250 x 50 μm
  - 4 upstream planes with 4 x 3.5 cm active area
  - 4 downstream planes with 4 x 5.1 cm active area
- Low Noise
  - Signal/noise = 15,000 / 121 electrons
- Radiation hard to 300 Mrad (expect <1 Mrad/yr)
- Huge cost saving by “piggy-backing” on LHC R&D and production



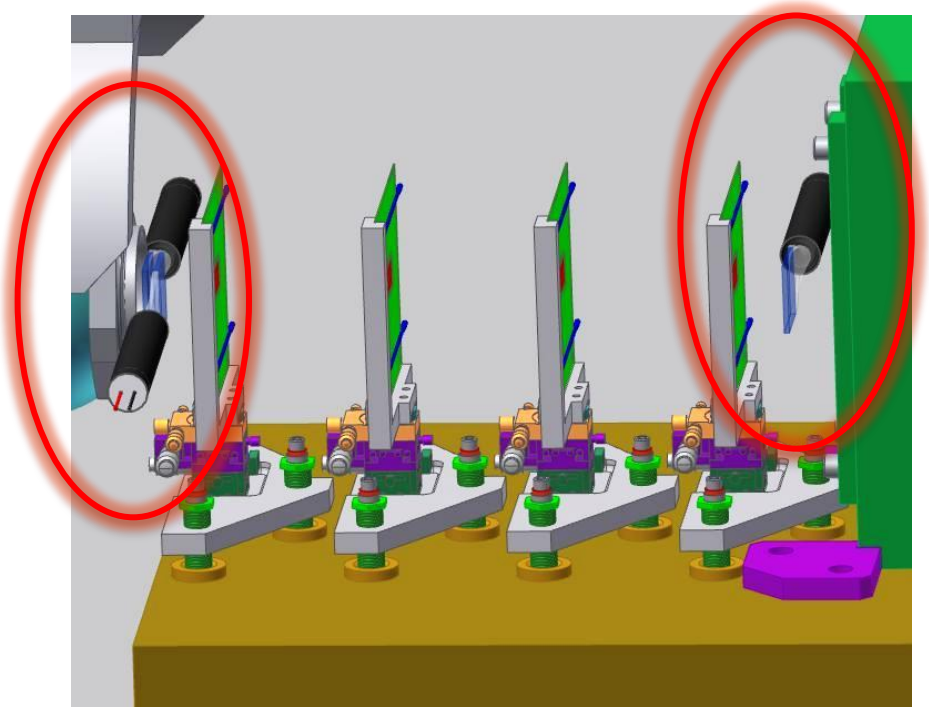
Detector Magnet

- Magnet
  - Permanent dipole 0.14 T.m.
  - Main purpose is to prevent electrons produced in stopped muon decays from forming tracks



Trigger Counters

- 6 fast scintillator counters
  - Provide a trigger for the pixels
  - Also measure the time structure of the beam

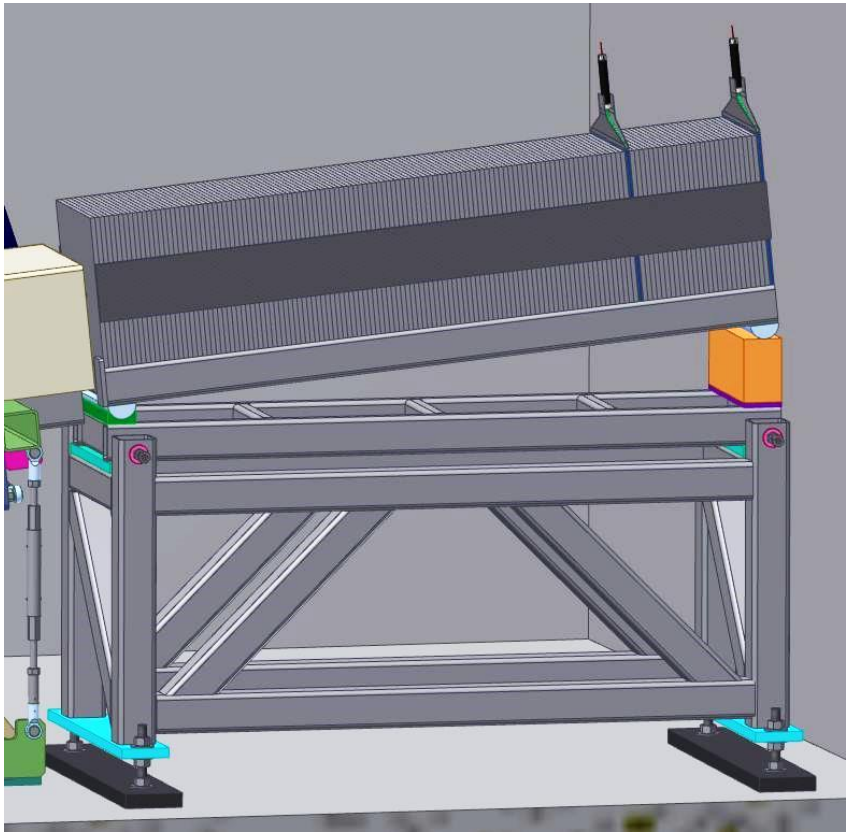


Location of upstream trigger counters with respect to the pixel planes

The layout downstream of the magnet is a mirror image of the upstream

Muon ID Detector

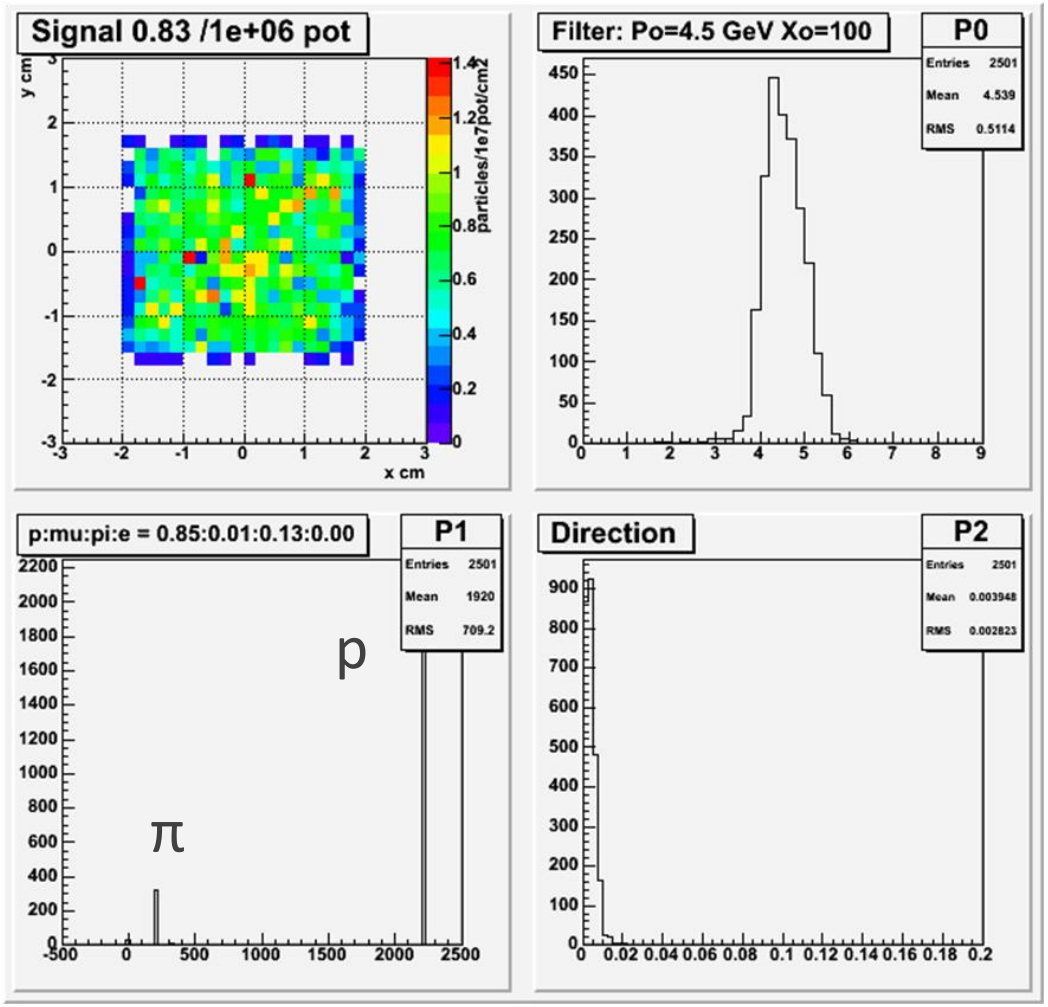
- Added in response to the down select review (discussed shortly)
- Measures the muon content of the extinction signal
- Muon content expected to be small for a real signal but backgrounds from cosmic rays or from interactions upstream of the production solenoid will be largely muons



Performance … Sensitivity

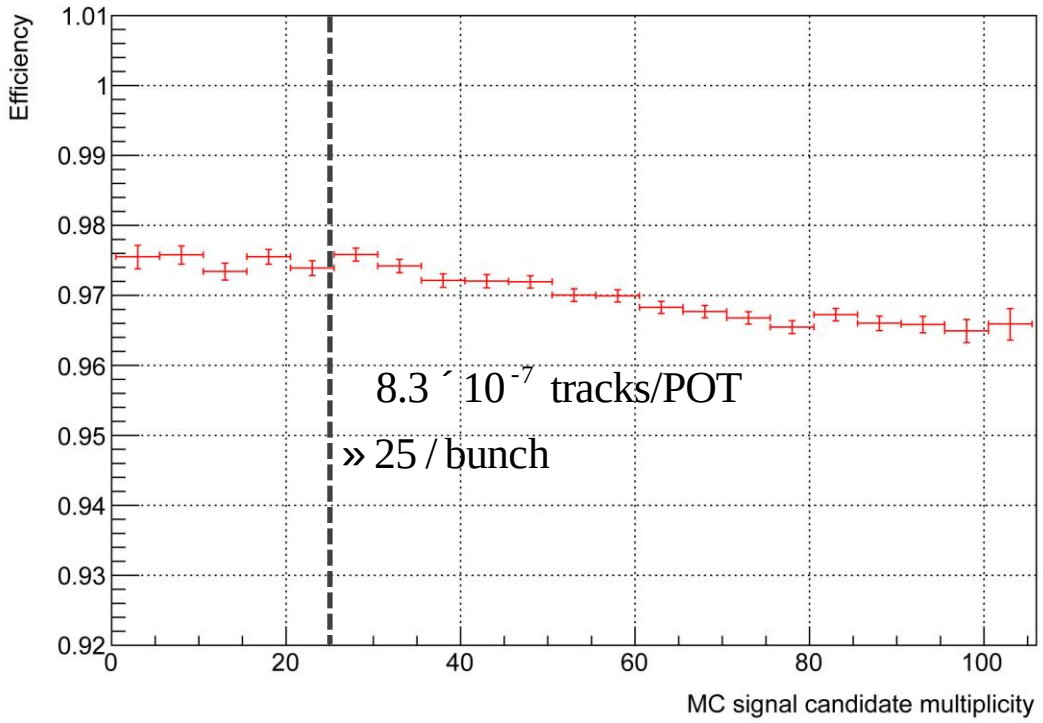
- To set a 90% CL upper limit of $1x10^{-10}$ extinction after $6x10^{16}$ POT requires a signal rate of $5x10^{-7}$ tracks/POT
- The expected rate of $8.3x10^{-7}$ tracks/POT (≈ 25 tracks/bunch) meets this requirement
- Background (cosmics, noise, etc) < .03 tracks/hour
  - ~ .1 track/($6x10^{16}$ POT)
  - ~ $2x10^{-12}$ extinction
  - this can be measured and subtracted!

Track distributions surviving filter



Performance … linearity

Track reconstruction efficiency:



- The track reconstruction efficiency is expected vary by < 1% over a generous range of bunch intensities
- The linearity requirement of 10% is comfortably met.

Changes since CD-1

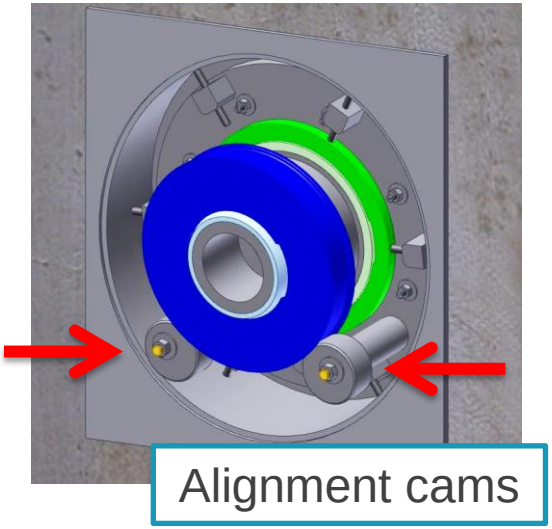
- At the time of CD-1, we were considering two possible designs for the monitor:
  - The pixel-tracking based design presented here.
  - A design proposed by UC Irvine, based on scintillators
- An independent review committee was appointed by the spokespersons
- The committee concluded that both designs could in principle satisfy the specification, but that the pixel-based design entailed lower risk.
- The "Muon catcher" calorimeter was also added to this design to measure the muon content of the out of time signal as a test for false positives.

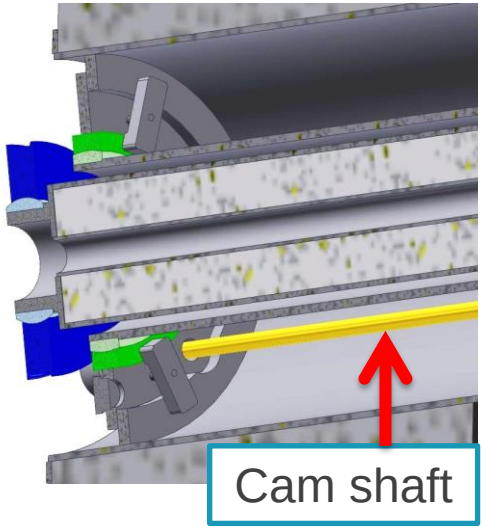
Quality Assurance

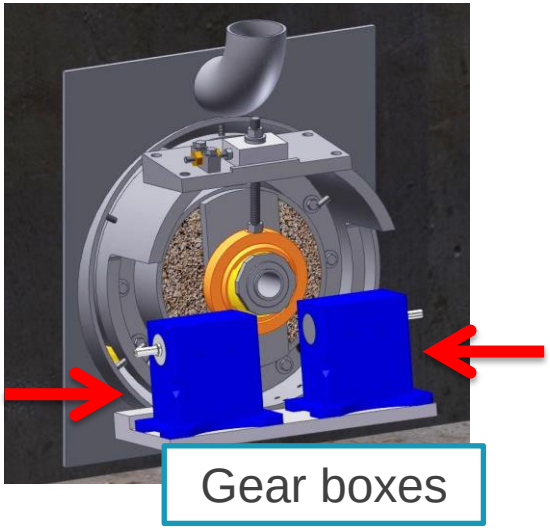
- The most important issue in the construction is alignment, which will be monitored continuously throughout the civil construction and detector installation tasks.
- Fabrication will be largely subcontracted, and will adhere to the subcontractor requirements in the “Fermilab Quality Assurance Plan”.
- The pixels themselves will be qualified according to the standard ATLAS quality control procedure
  - (See JINST Vol 7. p. 11010 (2012)).

ES&H

- The external monitor will not be accessible during operation, but simulations show there will not be any significant activation present when beam is off.
- The target hall will however, not be easy to access and hence the entry collimator has been designed so that any necessary alignment adjustments can be done from the downstream end







Summary

- We have designed an extinction monitoring system that meets the requirements of the Mu2e experiment.
- We are confident that we have met the requirements for CD-2 approval of this system.
  - Preliminary design complete
  - Project ready to baseline