Cosmic Ray Veto(CRV) R&D for Mu2e experiment

Yuri Oksuzian on behalf of CRV Mu2e

Outline

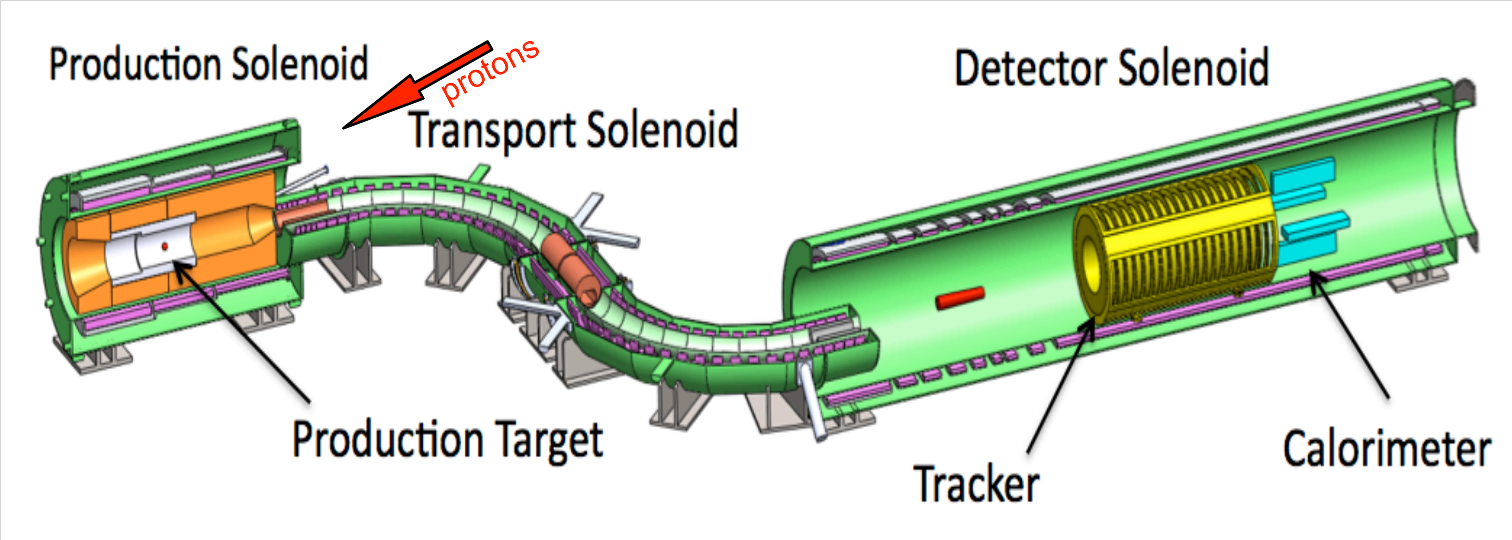
- Mu2e overview and motivation
- Cosmic Ray Veto(CRV) overview
- Cosmic rays(CR) background
- CRV
  - PMT based prototype
  - SiPM based single counter test beam studies
- Summary

Goal is 99.99% CR veto efficiency

Mu2e overview

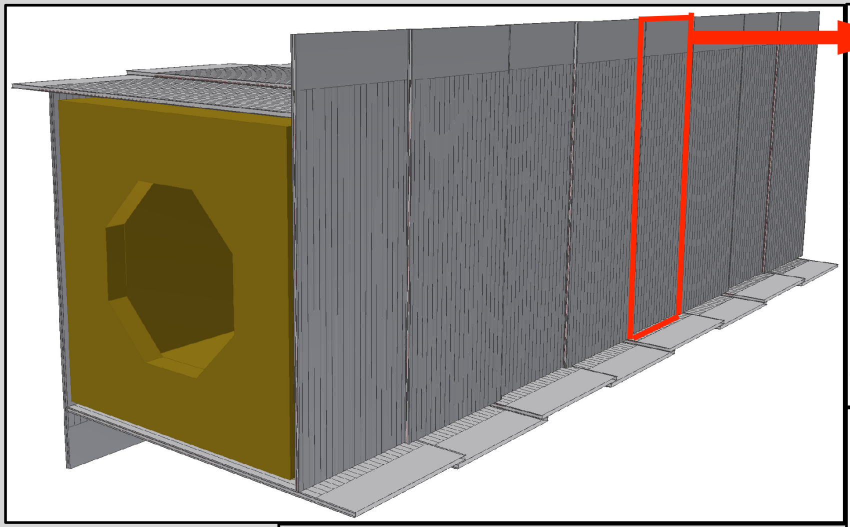
- Mu2e is the muon-to-electron conversion experiment
  - Proposed start date of 2018 and two years of data taking.
- Goal:
  - Search for neutrino-less muon decay in the field of nucleus
  - Single event sensitivity!
  - Measure $R_{\mu e} = \frac{\Gamma(\mu^- + (A,Z) \rightarrow e^- + (A,Z))}{\Gamma(\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1))}$
  - Designed sensitivity of $R_{\mu e} < 6\times10^{-17}$ at 90% CL
  - 4 orders of magnitude more sensitive than existing limit.
- WHY?
  - Any signal is a sign of new physics
  - Both complementing and extending LHC
  - Testing mass scales at 10^4 TeV, not directly reachable on any collider
  - Many models beyond Standard Model predict CLFV at observable rates for Mu2e

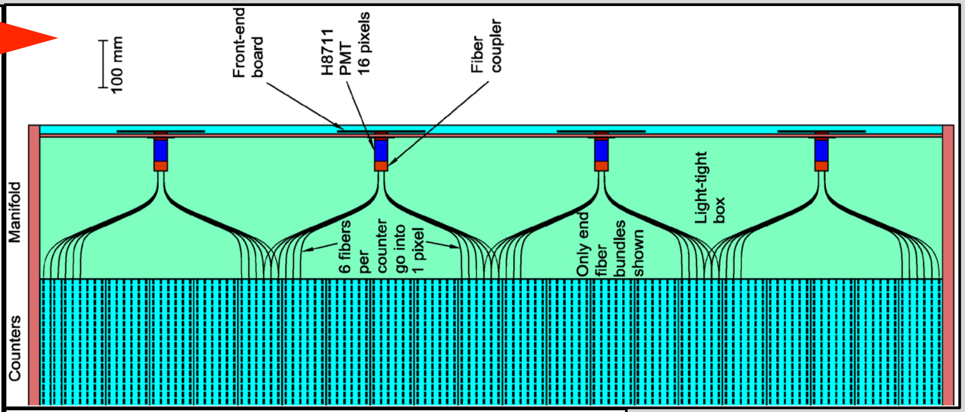
Mu2e overview



- Protons produce pions in the production target
- Pions transported in the transport solenoid. Pions decay to muons
- Muons captured in the stopping target
- Conversion electrons are detected and measured in the tracker
- CRV system(not shown) surrounds detector solenoid and rejects events associated with cosmic rays
- To achieve required sensitivity we need CR induced background under control

CRV overview



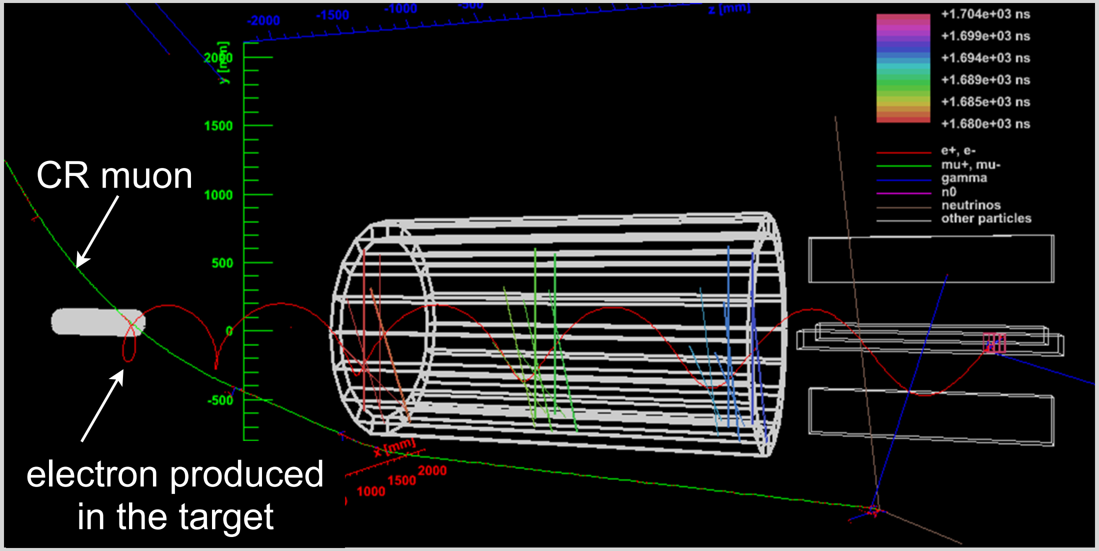


Baseline module
- 3 layers
- 3 x 20 = 60 counters
- counter: 100 x 10 x 4700 mm^3
- 6 fibers/counter
- 16 anodes PMT or SiPM's

- CRV system:
  - Covers detector solenoid
    - more than 1000m^2 needs to be covered
    - Challenge: outstanding veto efficiency at reasonable cost
  - Purpose is to veto conversion-like events produced by cosmic muons
  - Proposed design of three layers of plastic scintillators read out by wavelength shifting(WLS) fibers and photomultipliers

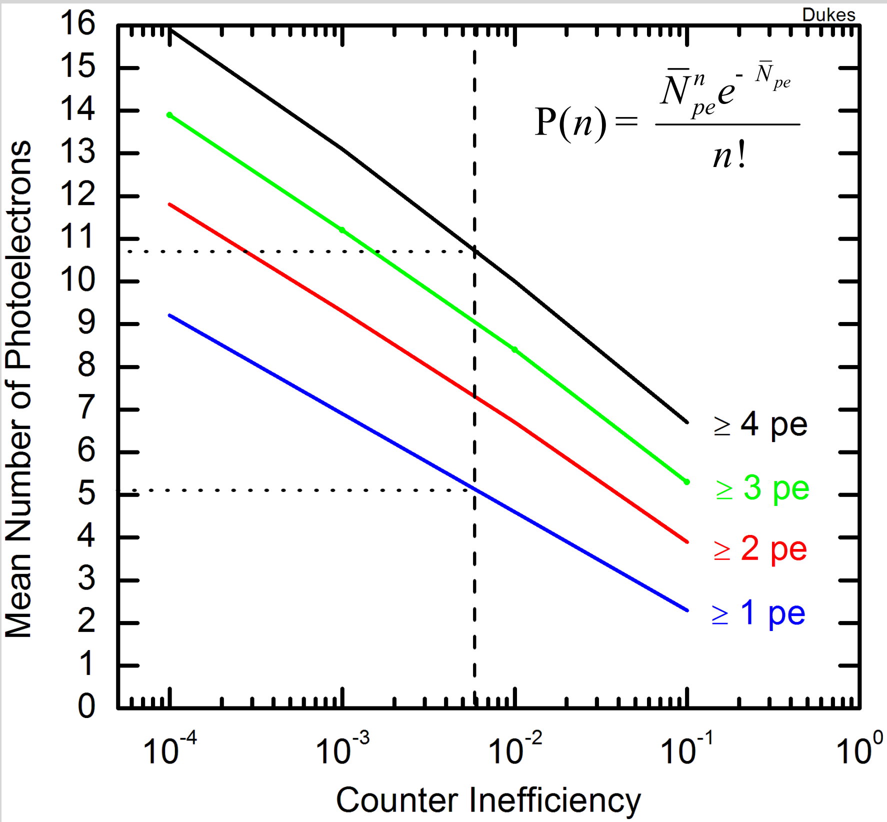
CRV requirement

- Using GEANT4 detector simulation and Daya Bay package to generate cosmic rays
  - Generated 0.5×10^9 CR muons in [3-300] GeV window
  - Only 2 events survive final event selection cuts
  - To limit CR background events to less than 0.05 events, we need an inefficiency of 2×10^{-4} or better



- Perfect CR background event example
  - Muon produces an electron in the stopping target
  - Decays before entering bottom CRV - one chance to veto.

Required photo-statistics



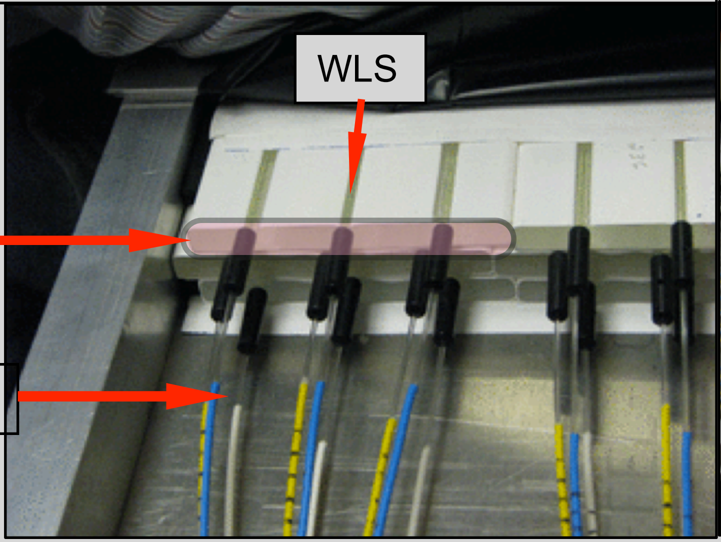
- To achieve desired inefficiency we will require 2 out 3 coincidence in CRV module
- Assuming each layer is independent, it will result in single layer efficiency of 99.4%

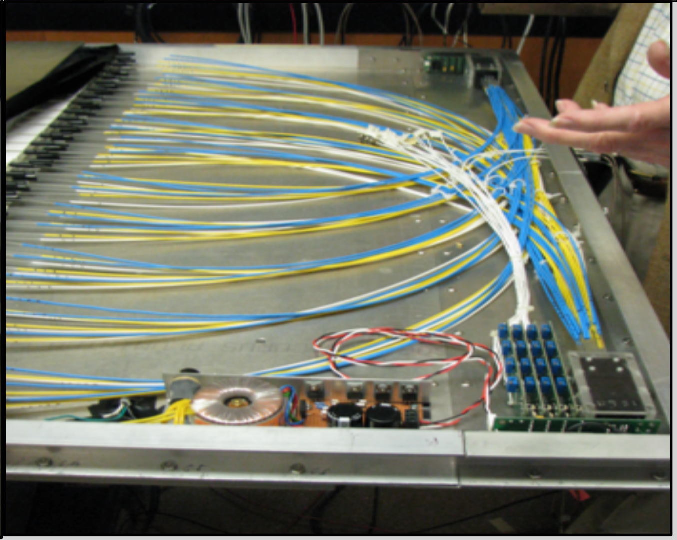
$$\varepsilon(2of3) = \varepsilon_{SL}^{3} + 3\varepsilon_{SL}^{2}(1-\varepsilon_{SL})$$

ε(layer)	ε(2of3)	1-ε(2of3)
99.4%	99.99%	0.0001
99.0%	99.97%	0.0003
98.0%	99.88%	0.0012
97.0%	99.74%	0.0026

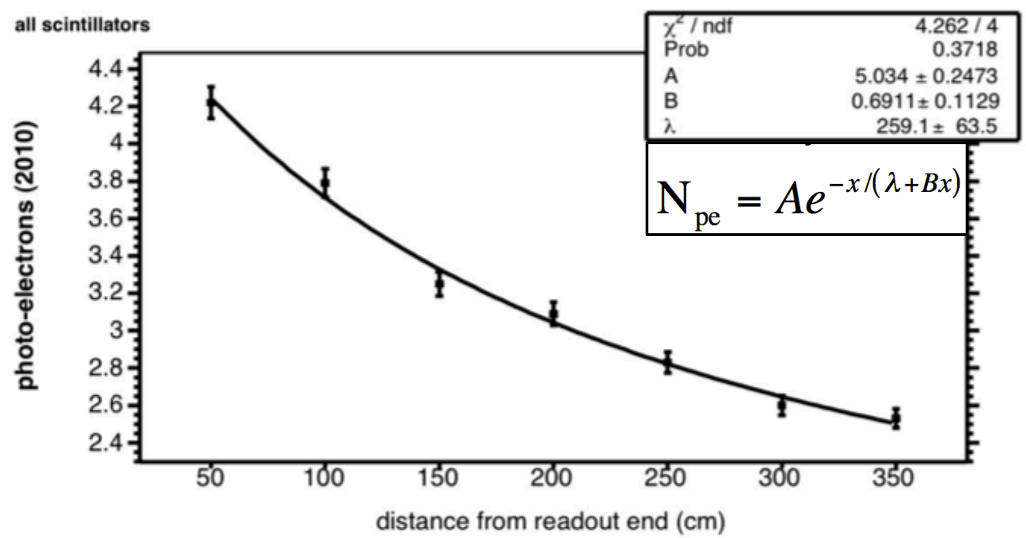
Prototype test stand

- Mid 2009 shipped CRV prototype from William & Mary
- Commissioned CRV test stand at CDF
- Does not meet 99.99% veto efficiency requirement
- Set up two trigger paddles above and below CRV prototype
- Perform various measurements:
  - Light yield at various points from readout(RO) end
  - Efficiency versus the angle of incidence
- Studies are performed by summer students





CRV prototype results



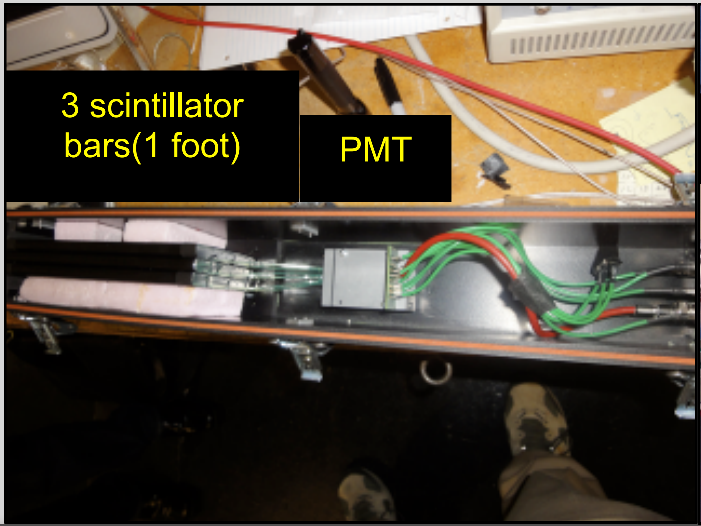
$$N_{pe} = Ae^{-x/(\lambda + Bx)}$$

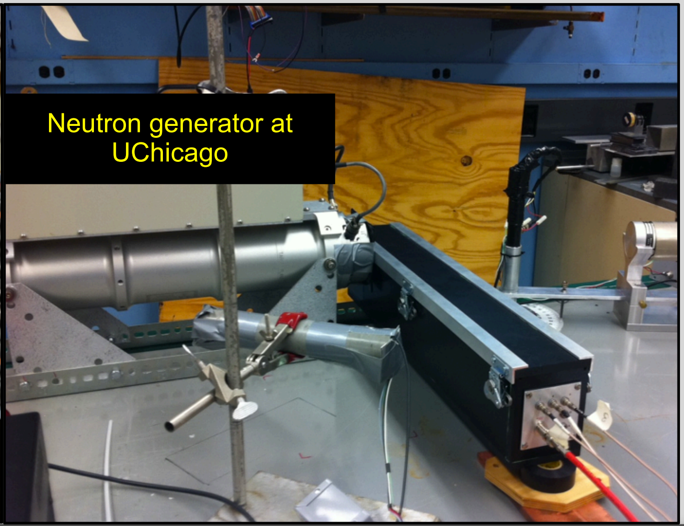
100 cm from RO	98.9%
200 cm from RO	97.8%
300 cm from RO	96.8%

- To meet the requirements of 99.99% efficiency we will need an improved light yield
- Various improvements will be considered
  - More fibers per counter
  - Thicker scintillator. Already produced
  - Holes instead of grooves
  - Different type of WLS fiber
  - Photomultiplier with higher Quantum Efficiency. SiPM?

Neutron Sensitivity

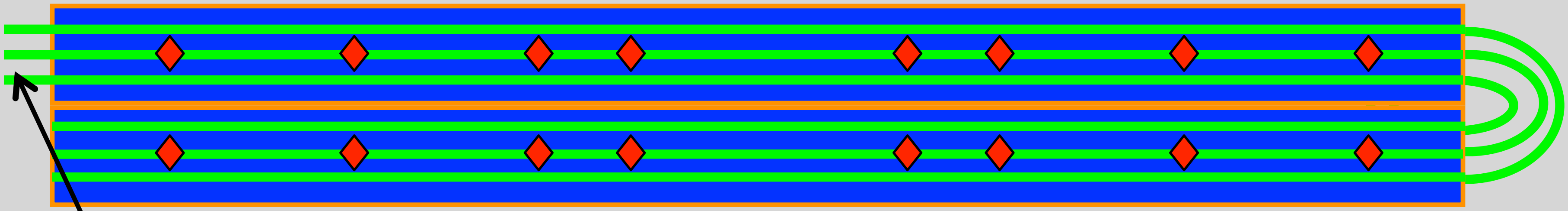
- The neutron flux in mu2e cavern is expected to be high
  - Make sure the neutron flux is not significant source of fake BG in CRV
  - CRV not more than 1% deadtime
- Portable CRV prototype to test the sensitivity to neutrons
  - BCF-92 WLS fiber and Hamamatsu PMT
  - Box commissioned and 10-15 <PE> achieved
- Neutron generator
  - ~2.8 MeV neutrons with flux of ~10^6 n/s
- Data collected and needs to be analyzed.

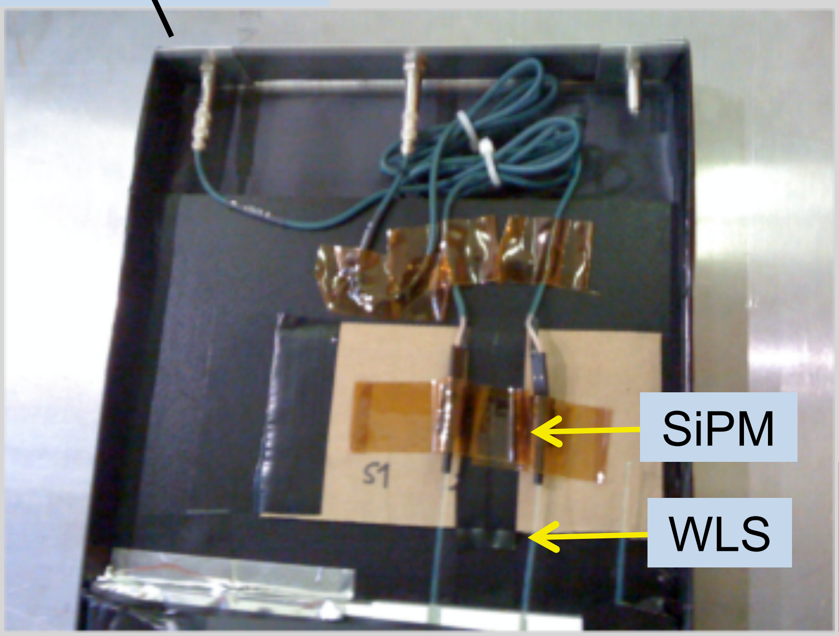




Single Counter

To improve the photo electron statistics we built and tested single counter strip



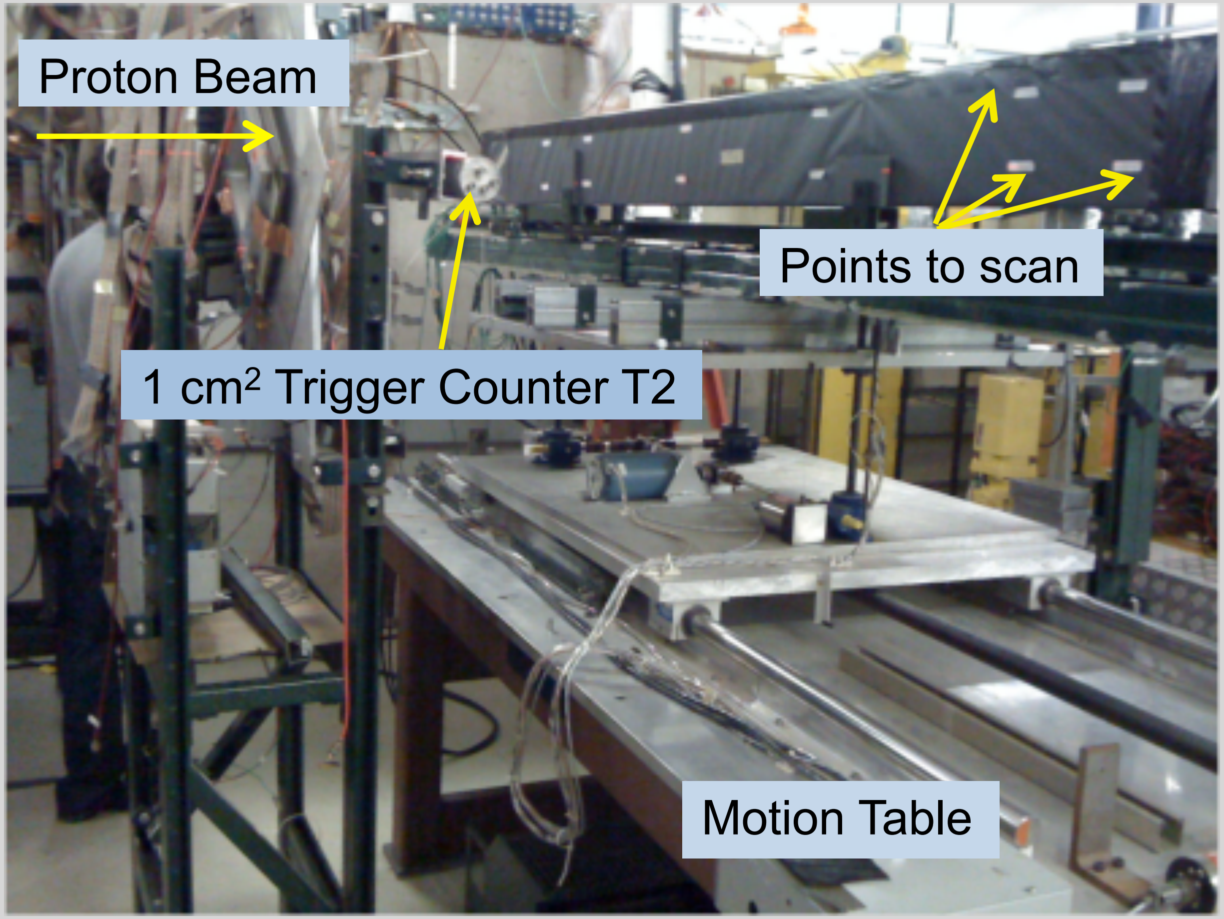


	WLS(multi-clad)	Photo Multiplier
CRV prototype	1.4mm Bicron BCF-92	4x4 Hammamatsu H8711 PMT
Single counter	1.2 mm Kuraray Y-11 1500 ppm	1.2mm diameter IRST SiPM
Difference	Y-11 has longer attenuation length and better match for scintillator light emission	SiPM has higher Photo Detection Efficiency

Test Beam Studies

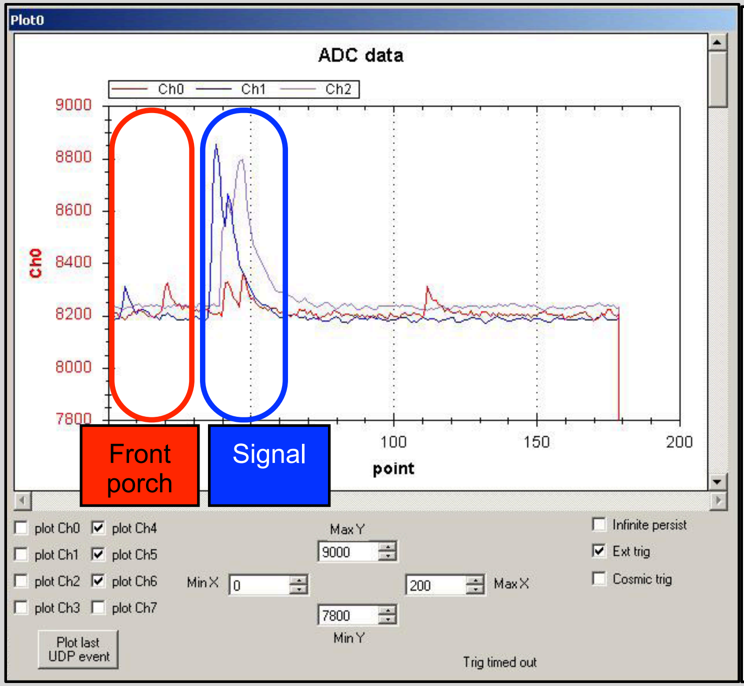
- Joined T995 collaboration in May
- Use proton beam at MTest to study single scintillator counter
  - 120 GeV protons, 4s spill every minute, 1-10KHz intensity
  - Trigger on coincidence 1x1 cm^2 upstream and 10x10 cm^2 downstream
- Advantages:
  - 1000 ev/spill: 15 minutes(beam) vs 2 days(cosmics)
  - Known beam position. Take vertical scans
  - Known angle of incidence
- 2 test beam runs in May and Sep of 2010

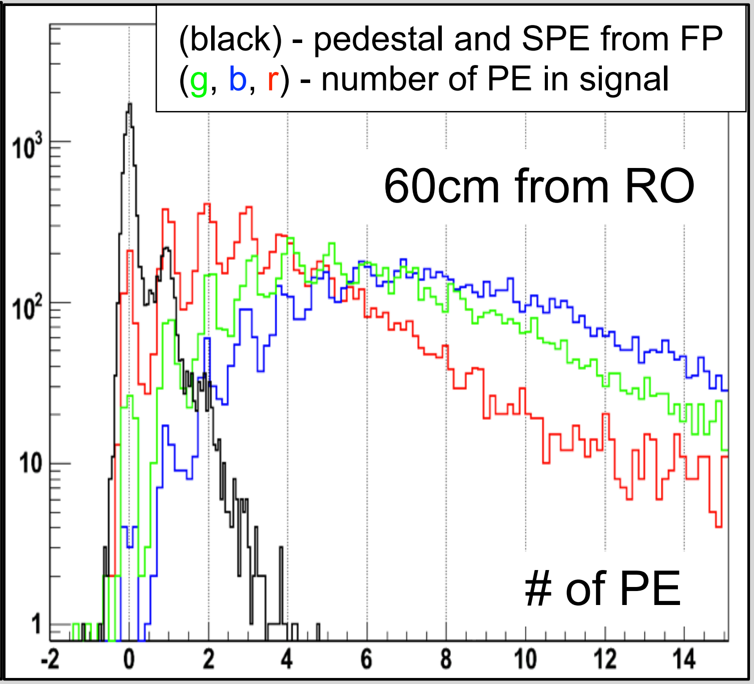
Setup


Proton Beam
Points to scan
1 cm² Trigger Counter T2
Motion Table

DAQ

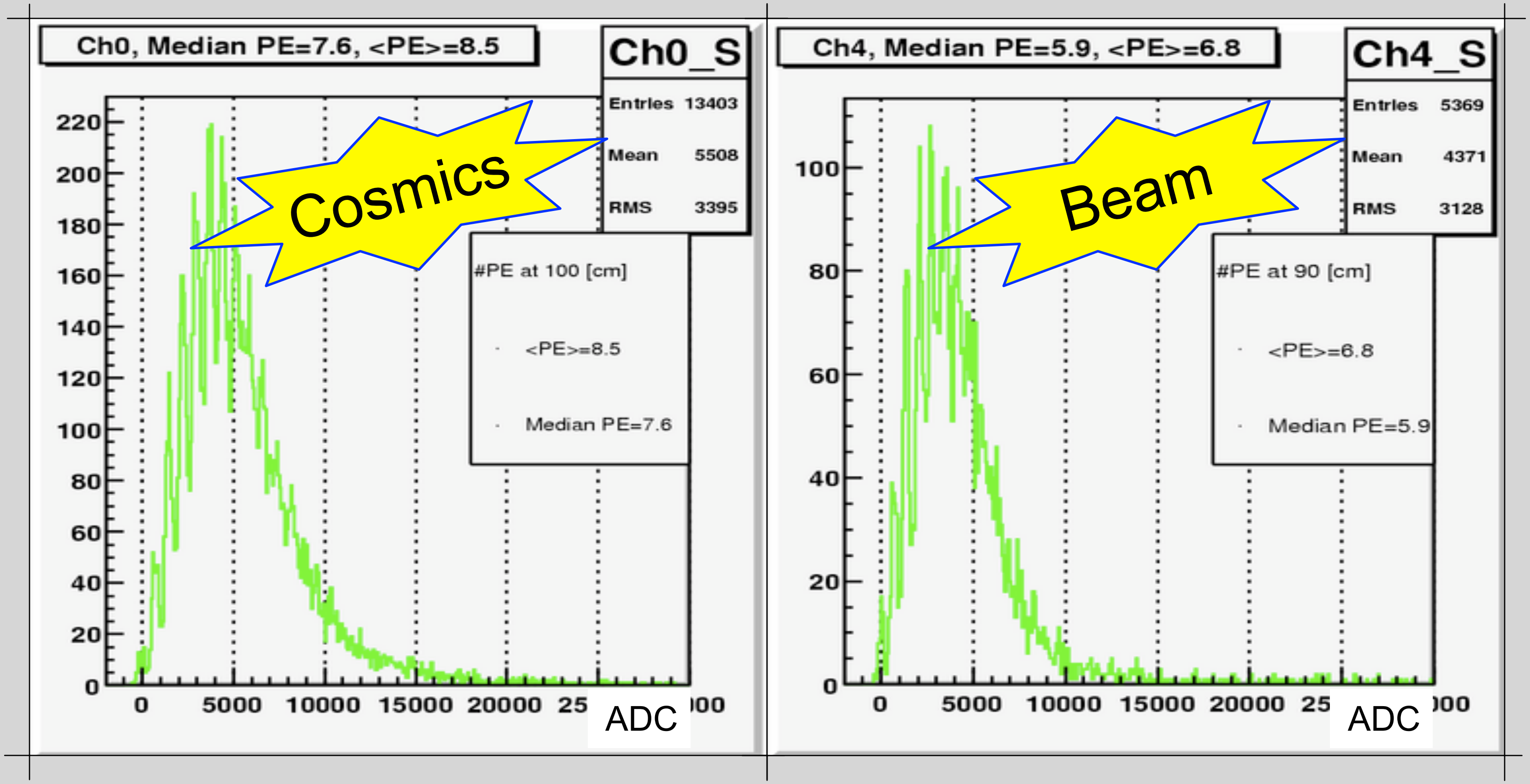
- Fermilab-based electronics
- 300 digitization/sampling
- 12-bit ADC
  - Sample input signal at 4.7ns interval
  - ADC in time information
  - Dark current and signal pulses on the left picture
- Total charge is calculated in the signal region
- Front porch(FP) region is used for self calibration: to extract pedestal and single PE value





Cosmics vs Beam

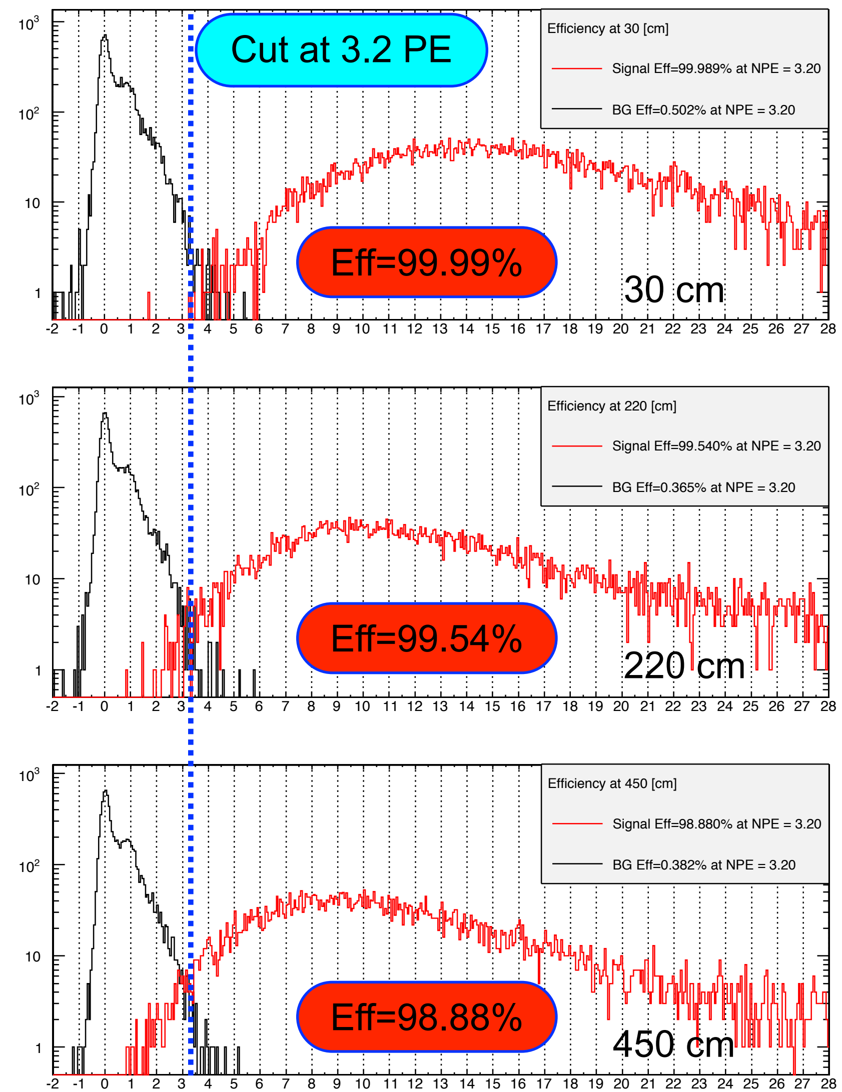
- Fewer <PE> from test beam data expected:
  - Test beam protons hit head on. Cosmic muons have wide range of angle of incidence



Sum

- Reminder:
  - Using 3 layers of scintillator, we need CR veto efficiency of 99.99%
  - Translates into 99.4% single layer efficiency
- Plots on the right show:
  - Sum of PE from three fibers in the **signal region**
  - Sum of PE from three fibers in the **Front Porch(FP) background region**
  - Signal and noise(dark current) rejection efficiency at 3.2 PE
- We can achieve required efficiency
- Not the final result and room to improve

We can reach 99.4% single layer efficiency



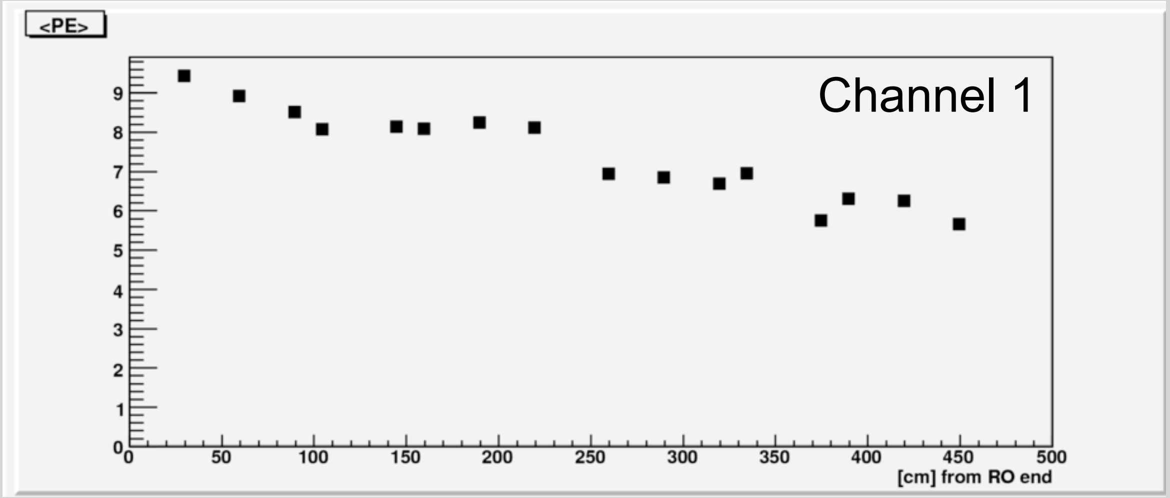
Summary

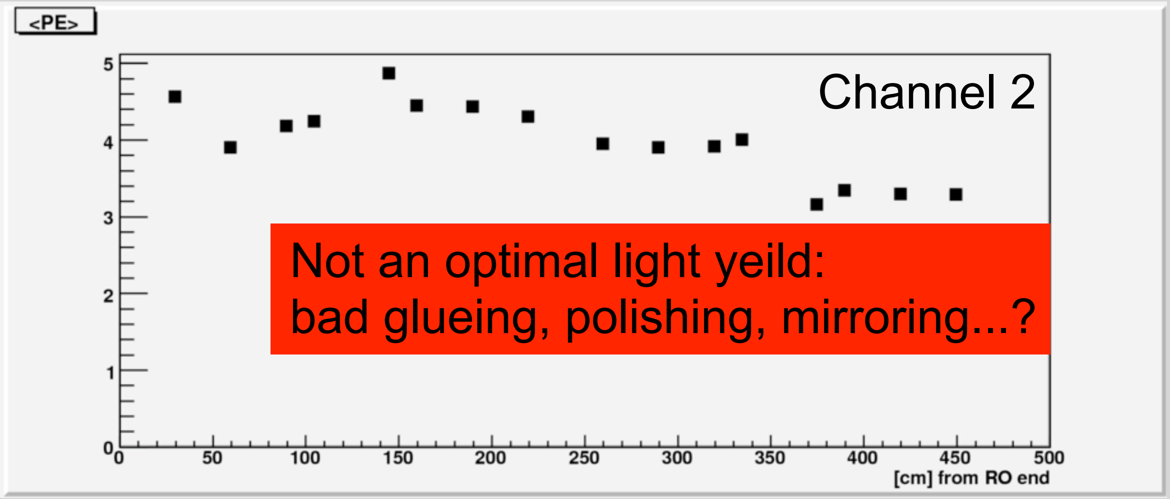
- Mu2e will perform a measurement 4 orders of magnitude better than the current limits
  - Complements and extends LHC results and probes physics at mass scales up to 10^4 TeV
- Plan to have an approved Conceptual Design Report by the end of 2011
- CRV prototypes studies
  - Does not meet required efficiency yet, but room for improvement.
- Test beam studies
  - Observe promising increase in PE statistics, using SiPMs
  - 99.4% single layer efficiency seems achievable

Backup

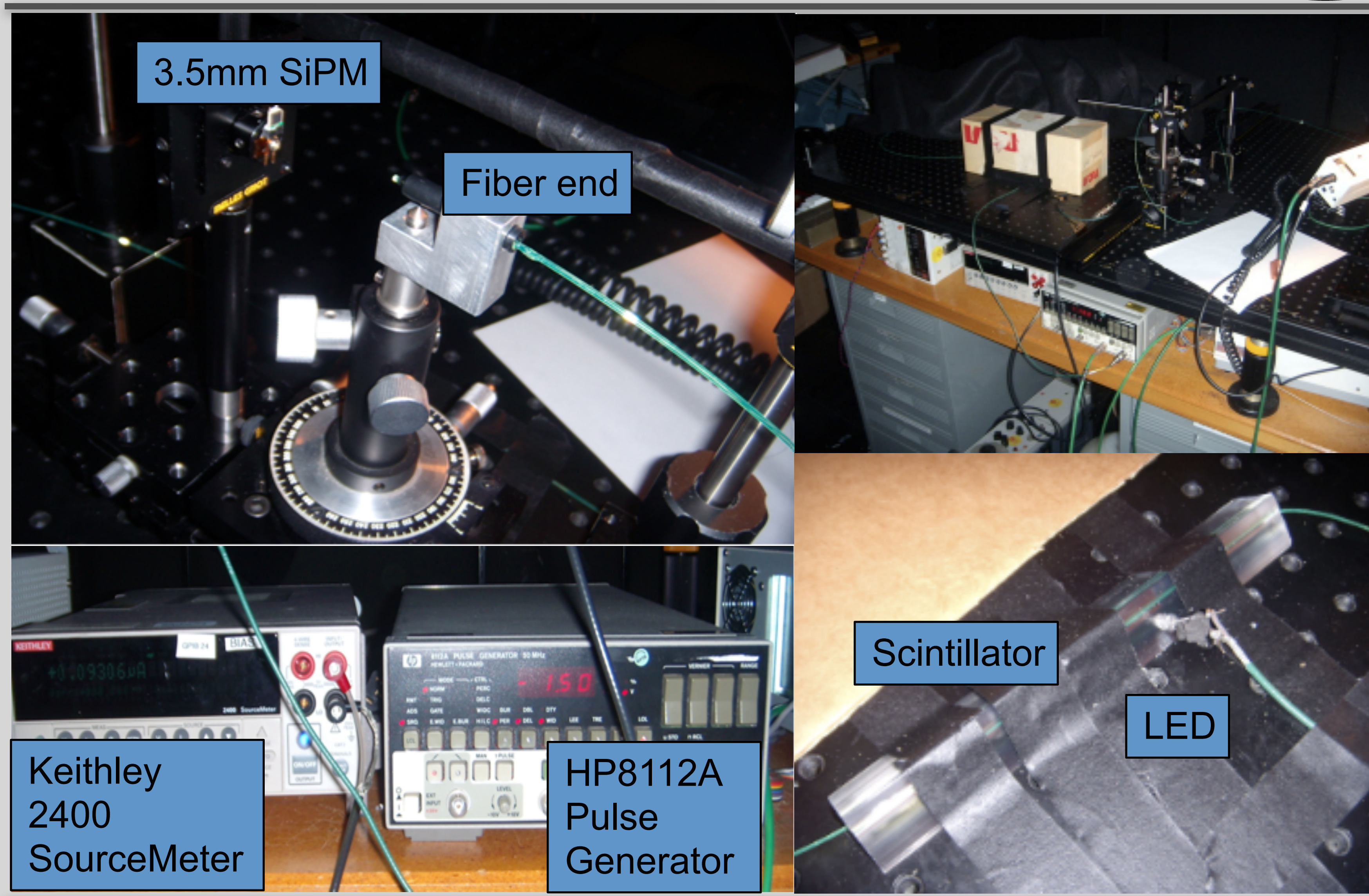
Yuri Oksuzian, UVa

Attenuation curve



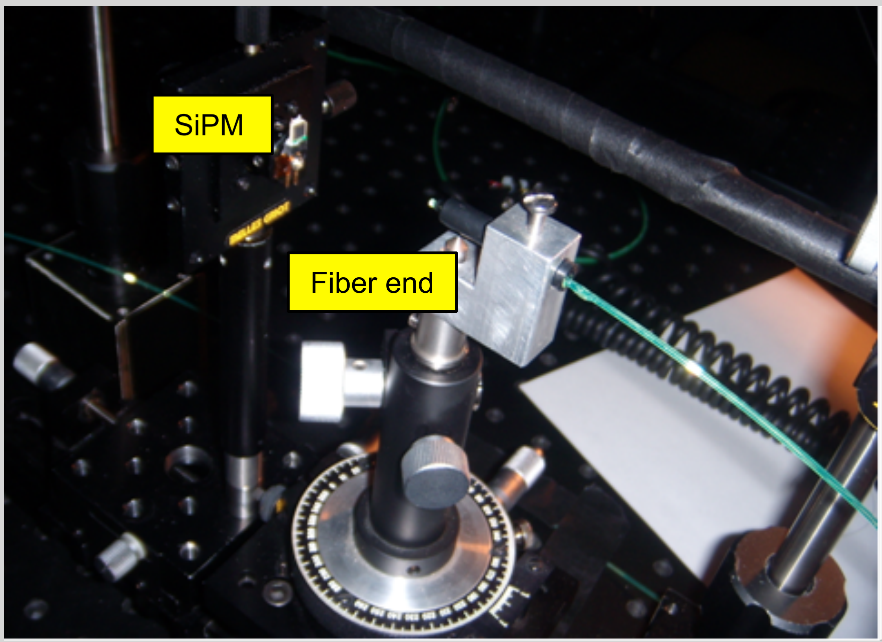


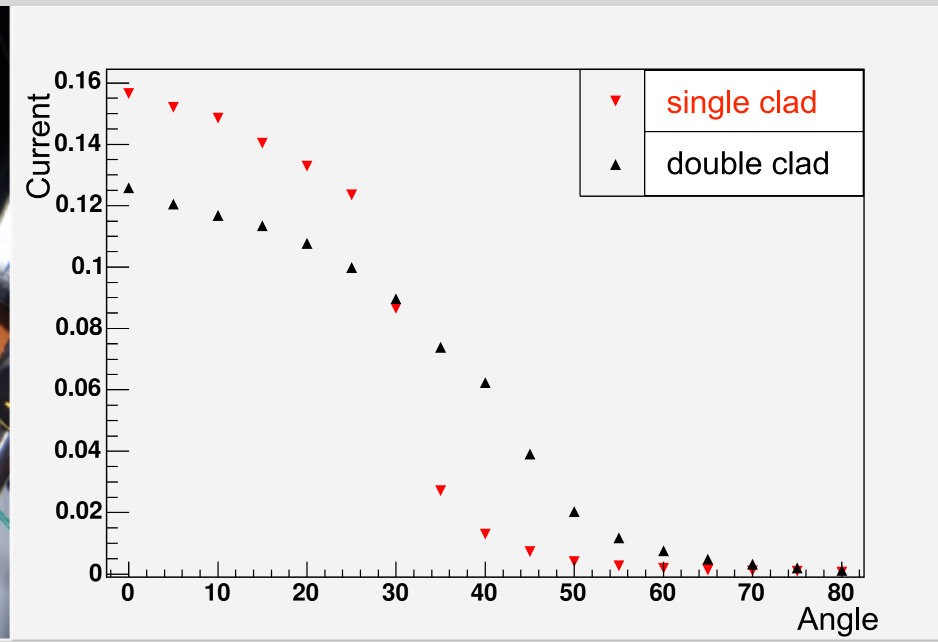
Setup at Lab 6



Fiber studies

- Study the angular light distribution from WLS fibers
  - Fiber/SiPM size matching
- Studies on
  - 1.2mm double-clad Kuraray(Y11) WLS Fiber
  - 1.4mm single-clad Bicron(BFC-92) WLS Fiber
- Summer student's project

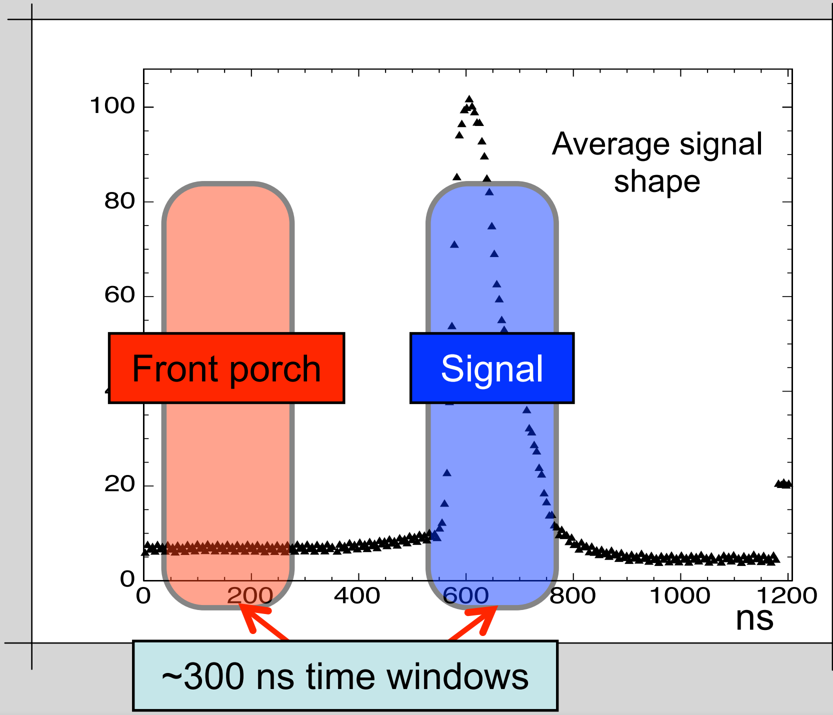


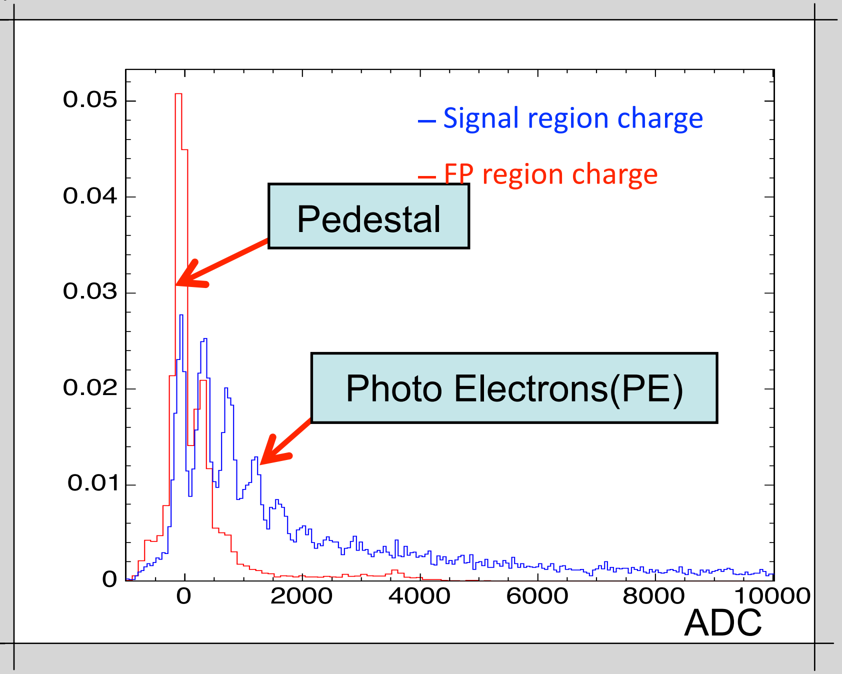


As expected, more light is trapped at higher angles for 1.2mm multi-clad fiber

Test beam in May

- Far from optimal scintillator strip in May:
- 1.4 mm BFC-92 single-clad fiber
  - Smaller trapping efficiency => smaller(50%) light yield
- 1.2 mm IRST SiPM
  - bad match for the fiber size
- Lower SiPM gain
  - Smaller quantum efficiency





PE yield at ~4m