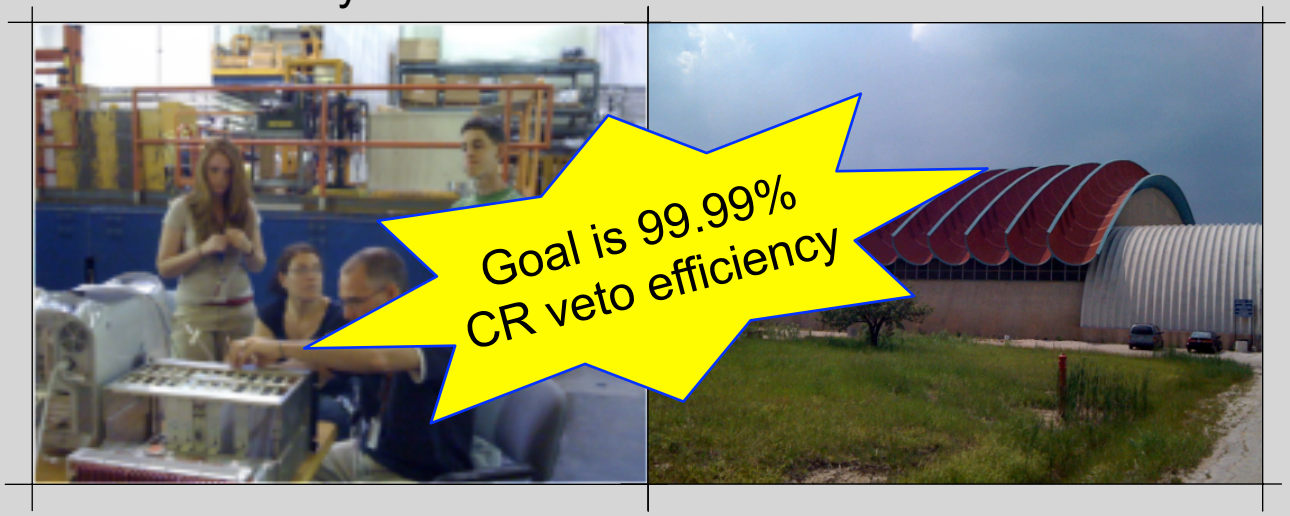
Cosmic Ray Veto(CRV) R&D for Mu2e experiment

Yuri Oksuzian on behalf of CRV Mu2e

Outline

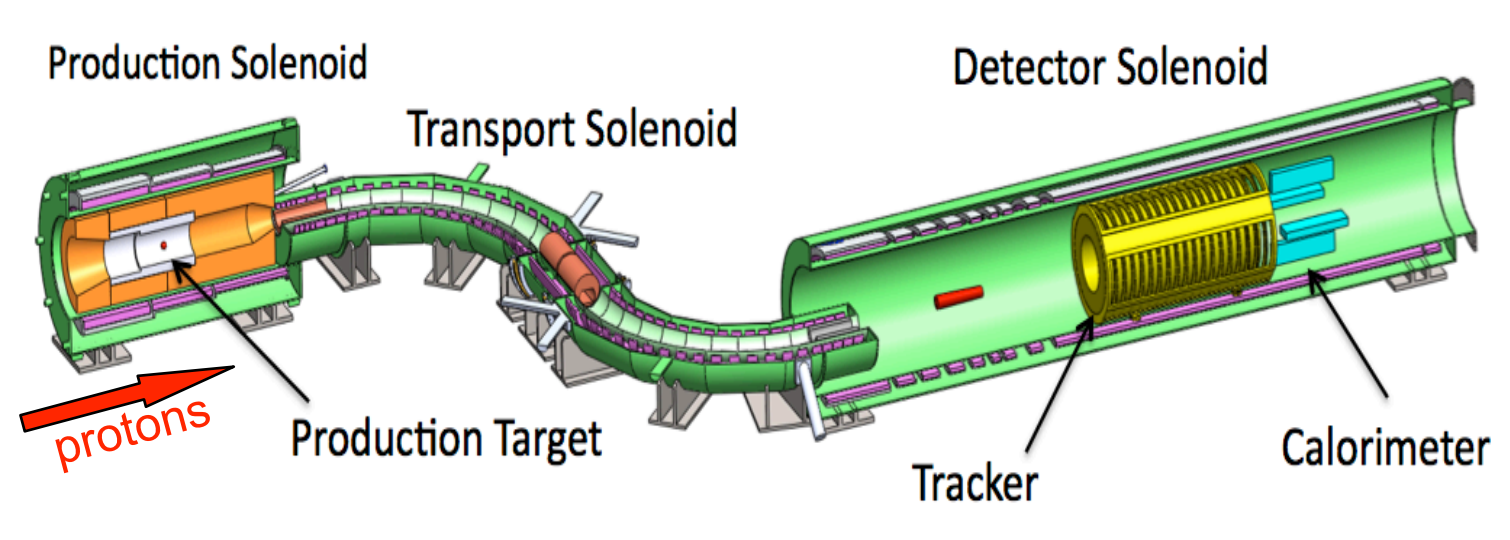
- Mu2e overview and motivation
- CRV overview
- Cosmic rays background
- Cosmic ray veto
  - PMT based half module prototype
  - SiPM based single counter test beam studies
- Summary



Mu2e overview

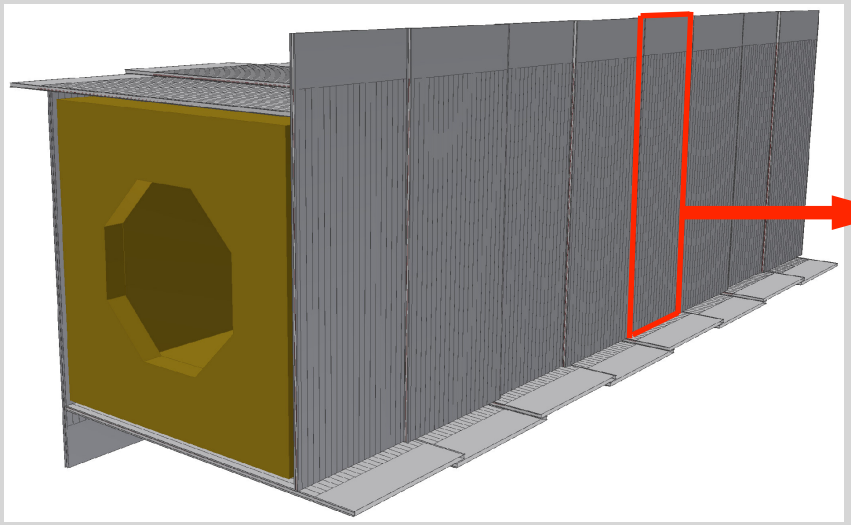
- Mu2e is the stopping target experiment
  - Proposed start date of 2017 and two years of data taking.
- Goal:
  - Search for neutrino-less muon decay in the field of nucleus
  - Single event sensitivity!
  - Measure $R_{\mu e} = \frac{\Gamma(\mu^- + (A,Z) \rightarrow e^- + (A,Z))}{\Gamma(\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1))}$
  - Designed sensitivity of $R_{\mu e}$<6x10^{-17} at 90% CL
  - 4 orders of magnitude more sensitive than existing limit.
- WHY?
  - Any signal like signature is the sign of new physics
  - Both complimenting and extending LHC
  - Testing scales at 10^4 TeV, not reachable on any collider
  - Many models beyond Standard Model predict CLFV at observable rates for Mu2e

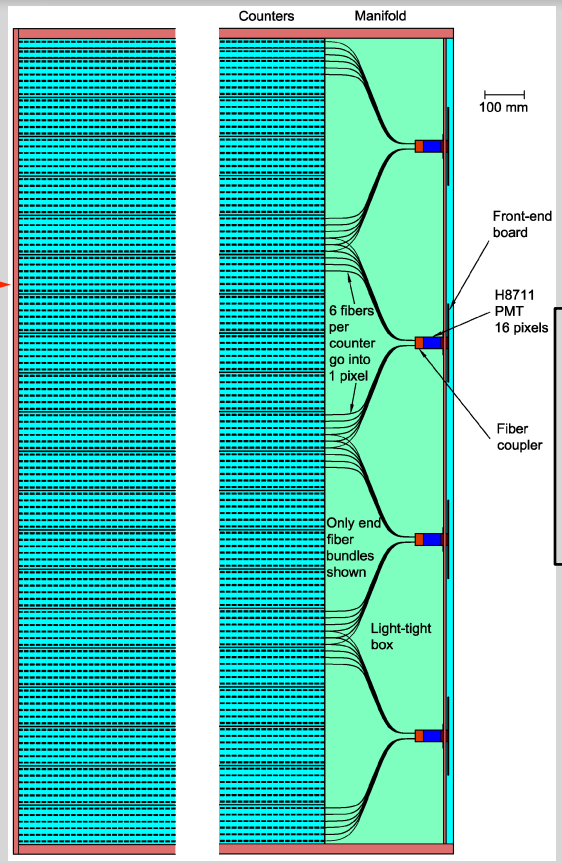
Mu2e overview



- Protons knock out pions from 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

CRV overview





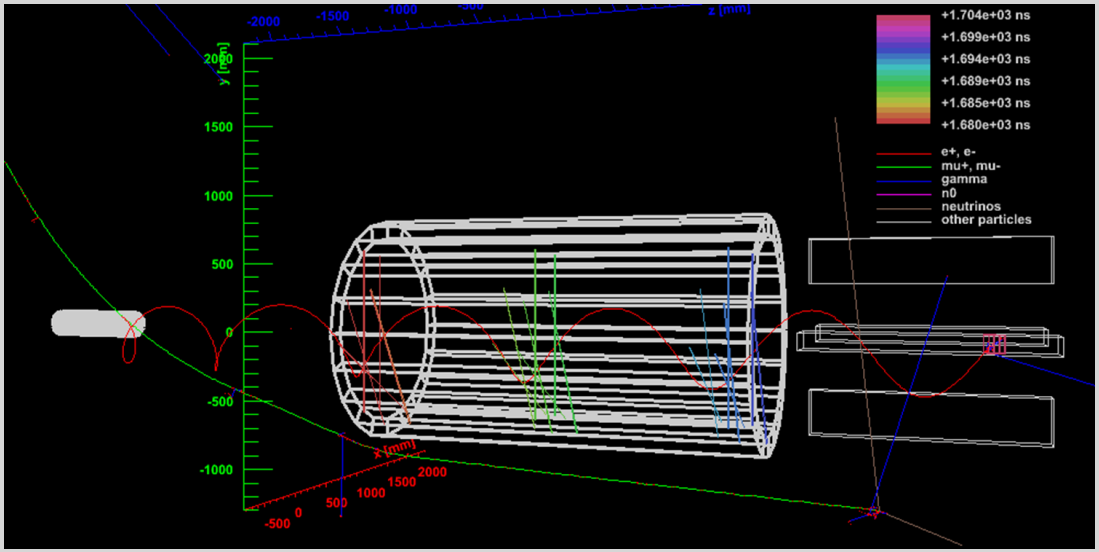
Full size BASELINE module
- 3 layers
- 3 x 20 = 60 counters
- counter: 100 x 10 x 4700 mm^3
- 6 fibers/counter
- 16 anodes PMT or SiPM's

Half-size module has 30 counters and 2 PMTs

- Cosmic Ray Veto(CRV) system:
  - Covers detectors solenoid.
  - Has a purpose to veto a conversion like events produced by cosmic muons
  - Proposed design of three layers of plastic scintillator read out by wavelength shifting(WLS) fibers and photomultipliers

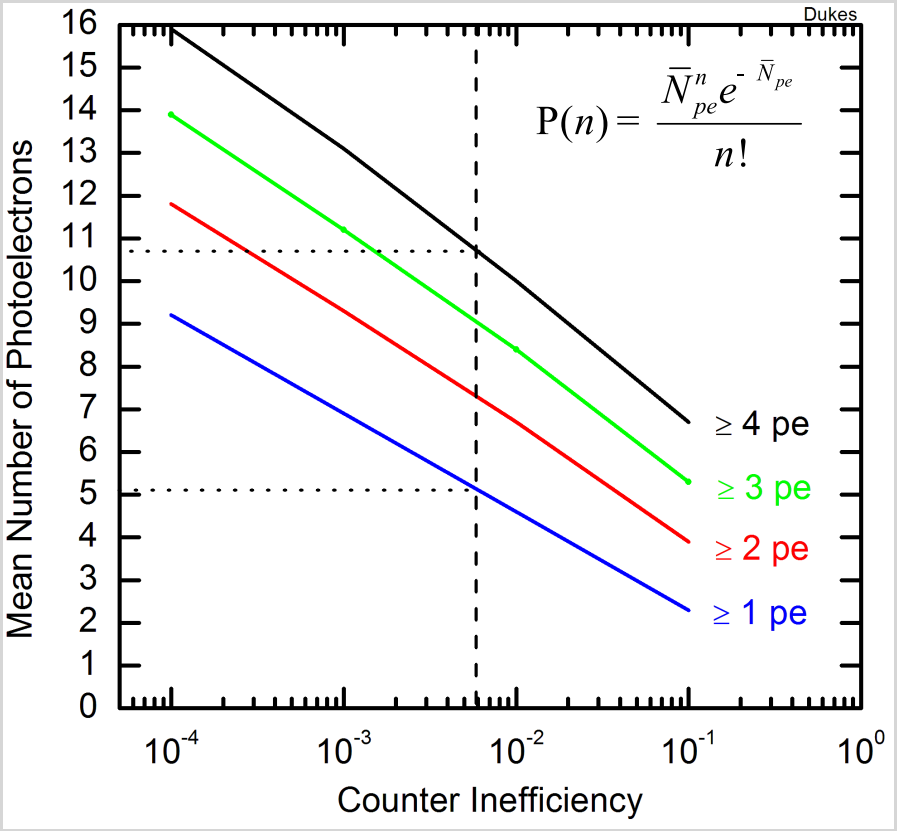
CRV requirement

- Using GEANT4 detector simulation and Daya Bay package to generate cosmic rays.
  - Generated 502×10^6 muons cosmic ray in [3-300] GeV window
  - Only 2 events survive final event selection cuts
  - To reject events on 0.05 CR background level we will need an inefficiency of 2×10^{-4} or better



- Perfect cosmic background event example
  - Muon knocks off electron from the stopping target
  - Decays before entering bottom CRV – one chance to veto.

Required photo-statistics



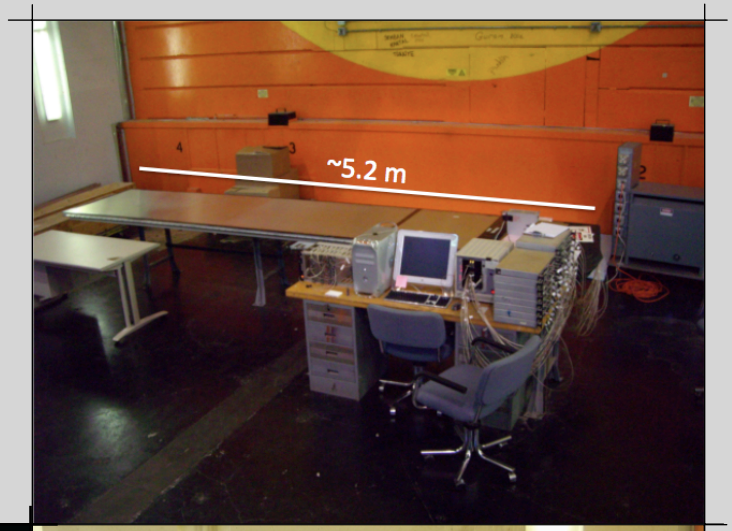
- To achieve desired inefficiency we will require 2 out 3 coincidence in CRV module
- Assuming each layer is independent, it will result in single layer efficiency of 99.4%

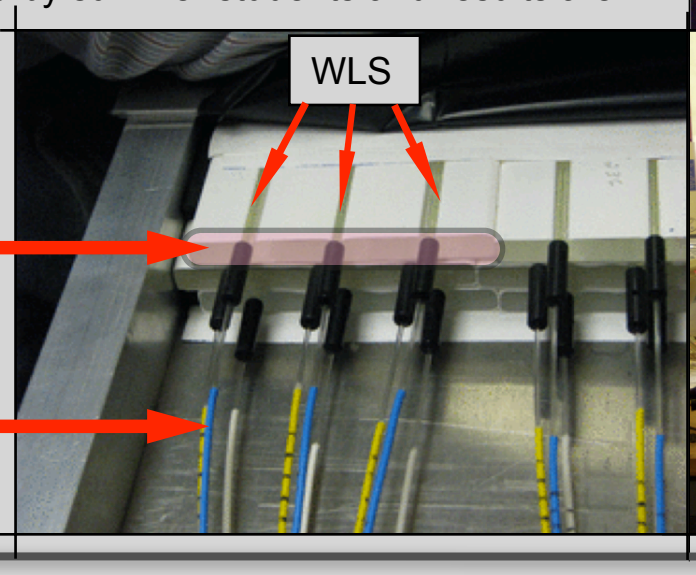
$$\varepsilon(2\text{of}3) = \varepsilon_{SL}^{3} + 3\varepsilon_{SL}^{2}(1-\varepsilon_{SL})$$

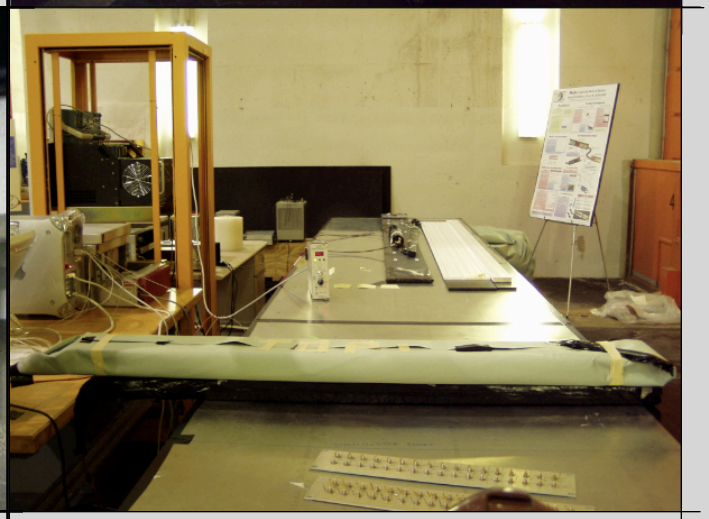
ε(layer)	ε(2of3)	1-ε(2of3)
99.4%	99.99%	0.0001
99.0%	99.97%	0.0003
98.0%	99.88%	0.0012
97.0%	99.74%	0.0026

Half module test stand

- Mid 2009 shipped CRV prototype from W&M
- Commissioned CRV test stand at CDF
- Does not meet 99.99% veto efficiency requirement
- Set up two trigger paddles above and below CRV prototype:
  - Improved trigger purity
- Perform various measurements:
  - Light yield at various points from RO end
  - Efficiency as the angle of incidence
- Studies are performed by summer students and results are documented

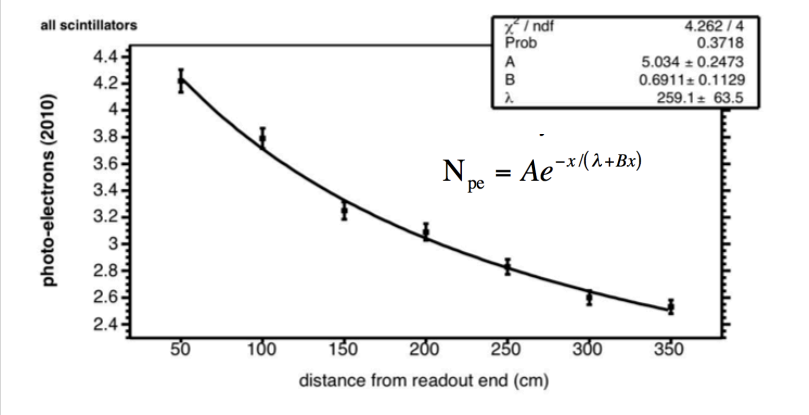






Half module results

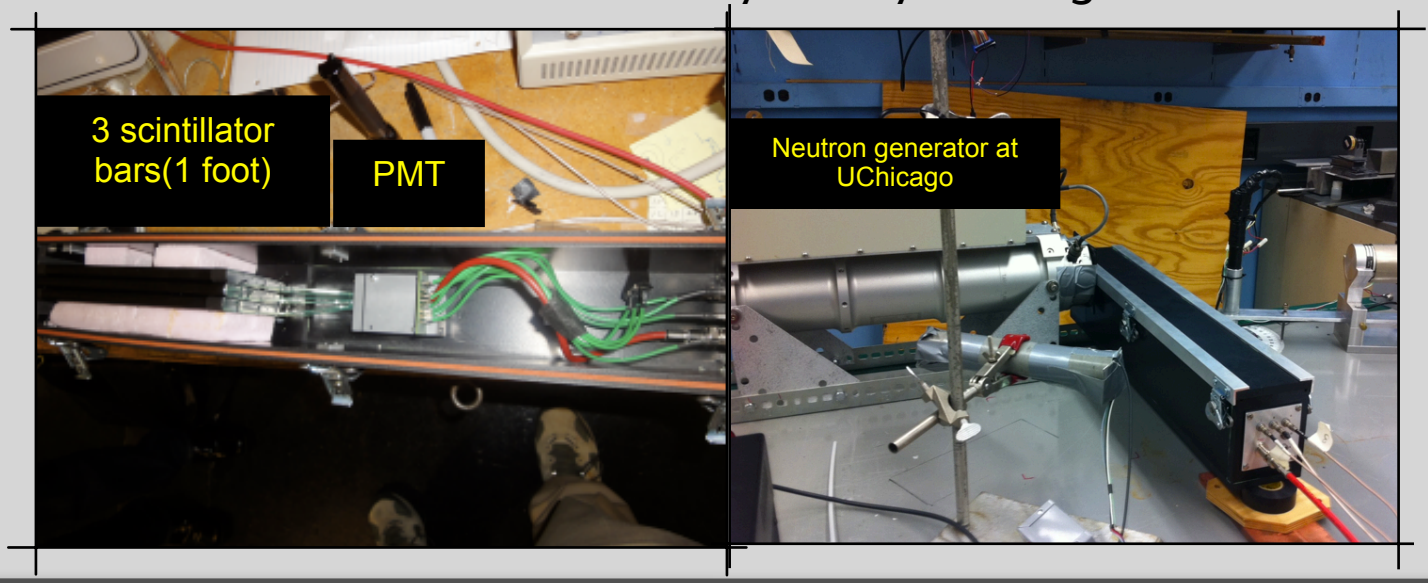
- To meet the requirements of 99.99% efficiency we will need an improved light yield
- Various improvements will be considered
  - Higher number of channel per counter
  - Thicker type of scintillator. Already produced
  - Holes instead of groves
  - Different type of WLS fiber
  - SiPM instead of PMTs
- All these studies will be made during this summer with the help of summer students



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

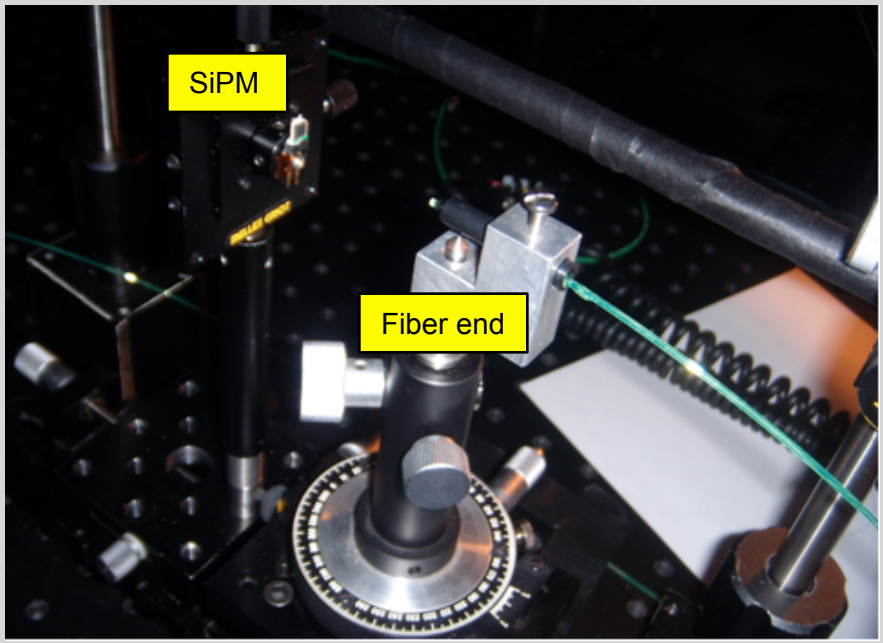
Neutron Sensitivity

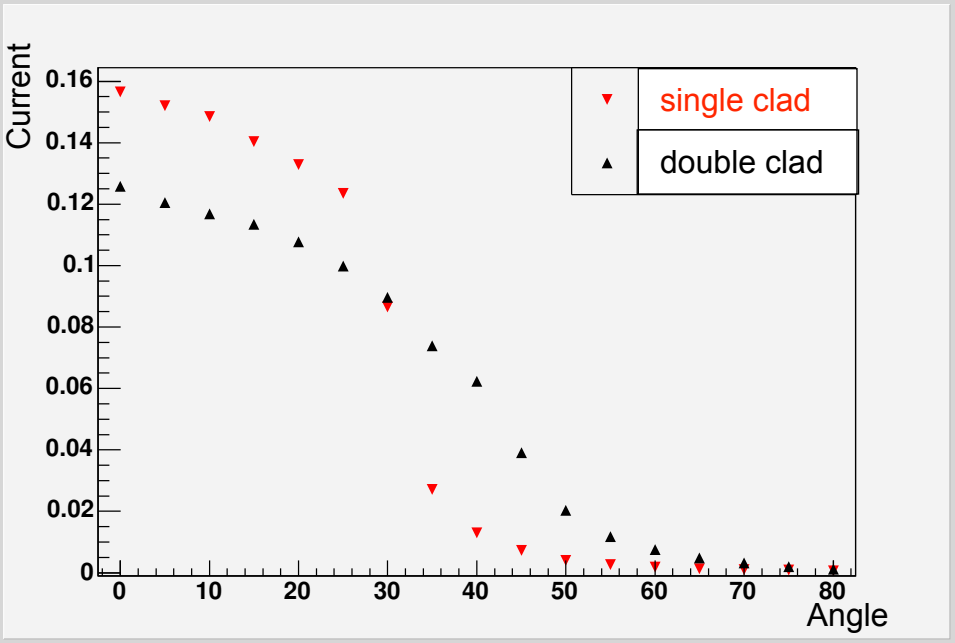
- The neutron flux in mu2e cavern is expected to be high
  - Make sure the neutron flux is not significant source of fake BG in CRV
- Portable CRV prototype to test the sensitivity to neutrons
  - BCF-92 WLS fiber and Hamamatsu PMT
  - Box commissioned and 10-15 <PE> achieved
- DD neutron generator
  - few MeV neutrons with ~10^6 n/s flux
- Data collected and will be analyzed by undergraduate student



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



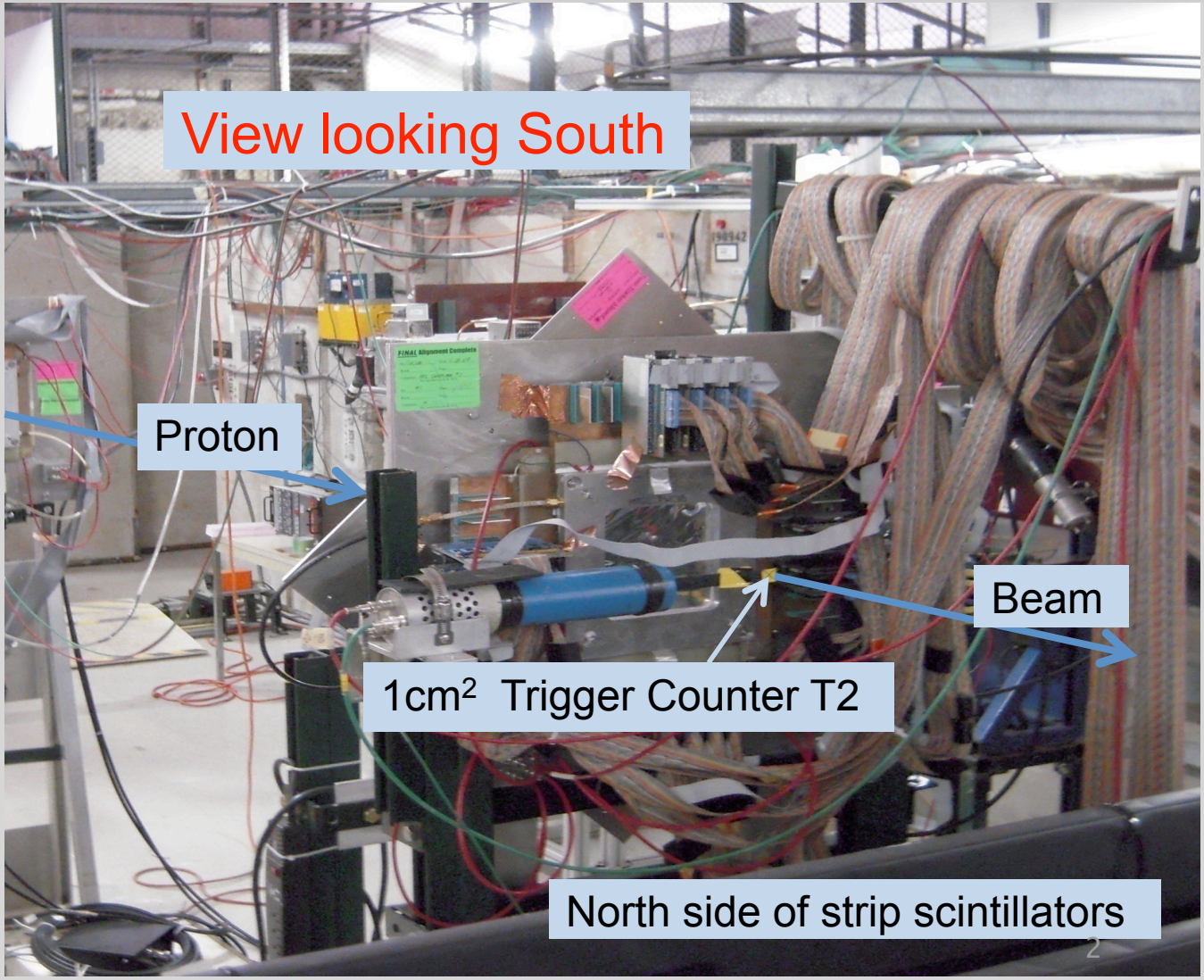


As expected, more light is trapped at higher angles for 1.2mm multi-clad fiber

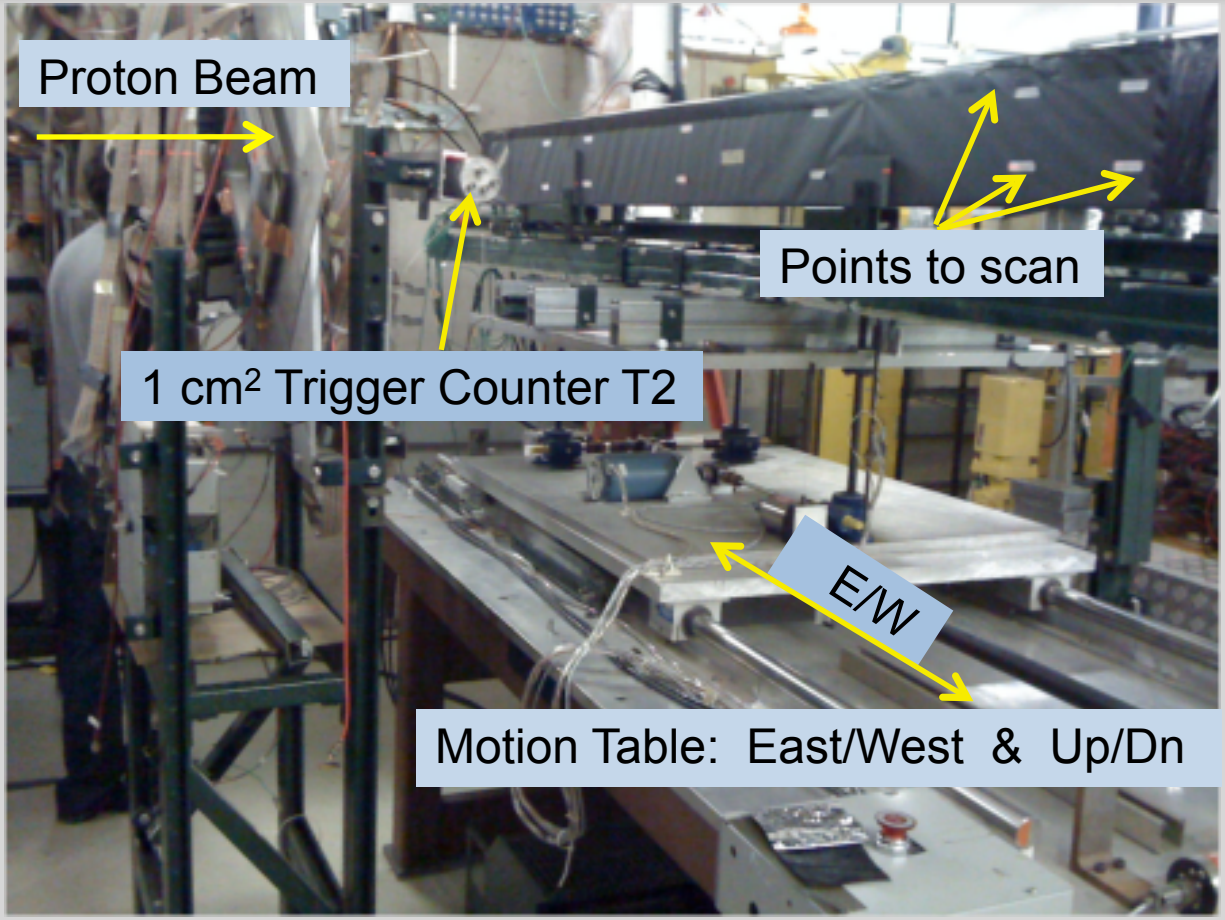
Test Beam Studies

- Joined T995 task force in May, working together with:
- Use proton beam at MTest to study scintillator strip
  - 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

MTest enclosure



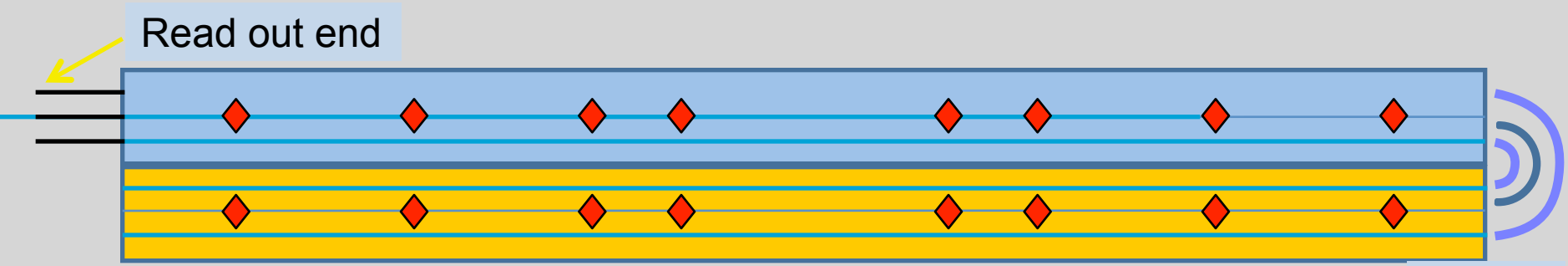
Setup



Points we measure:
horizontal: 0, 300, 600, 750 mm
vertical: 0, 180 mm

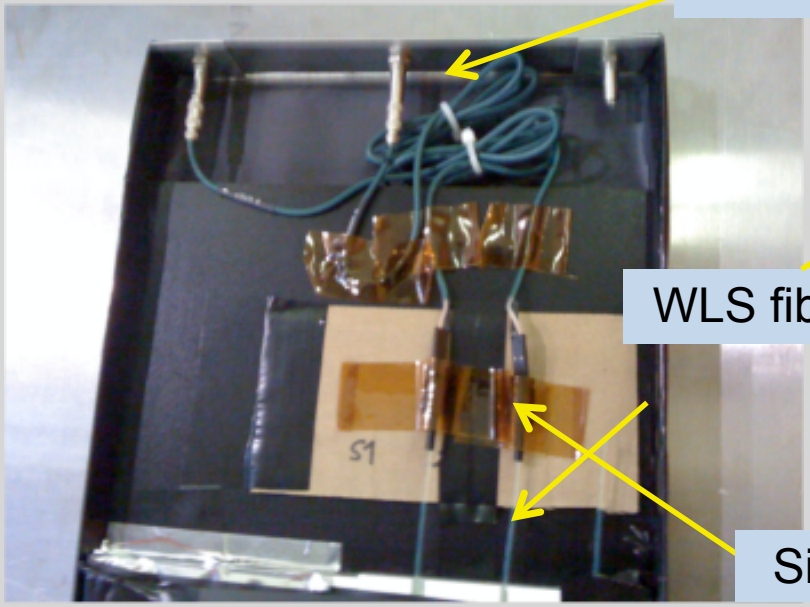
→ Flip the scintillator and repeat the procedure

Strip components

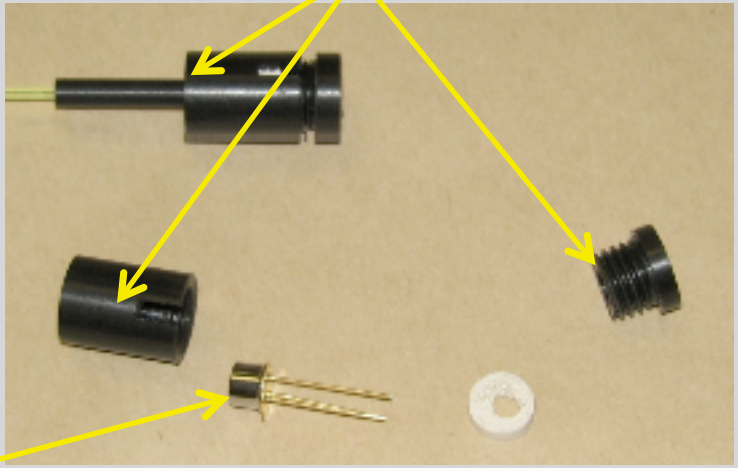


limo/signal connectors

SiPM housing



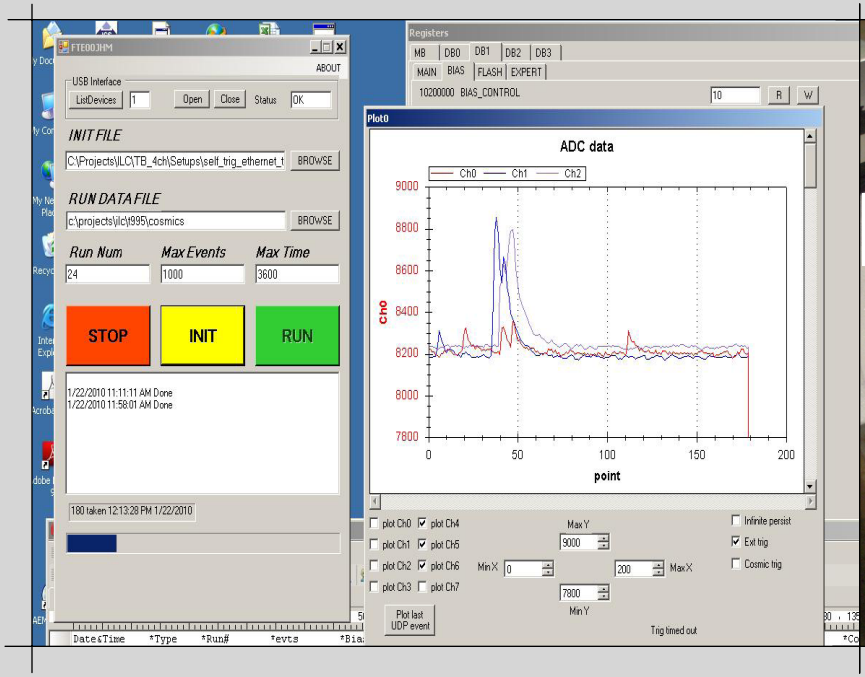
WLS fibers

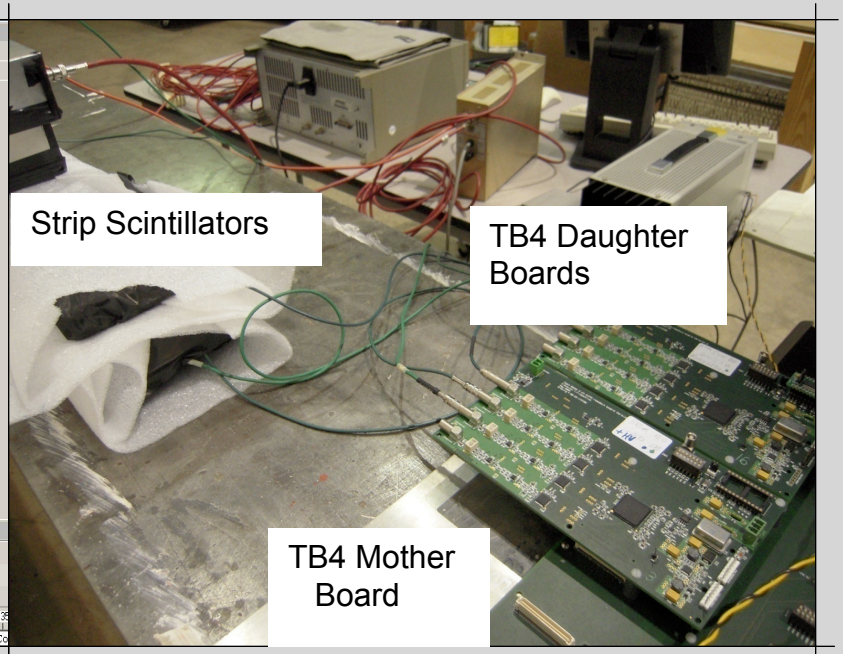


SiPM

DAQ

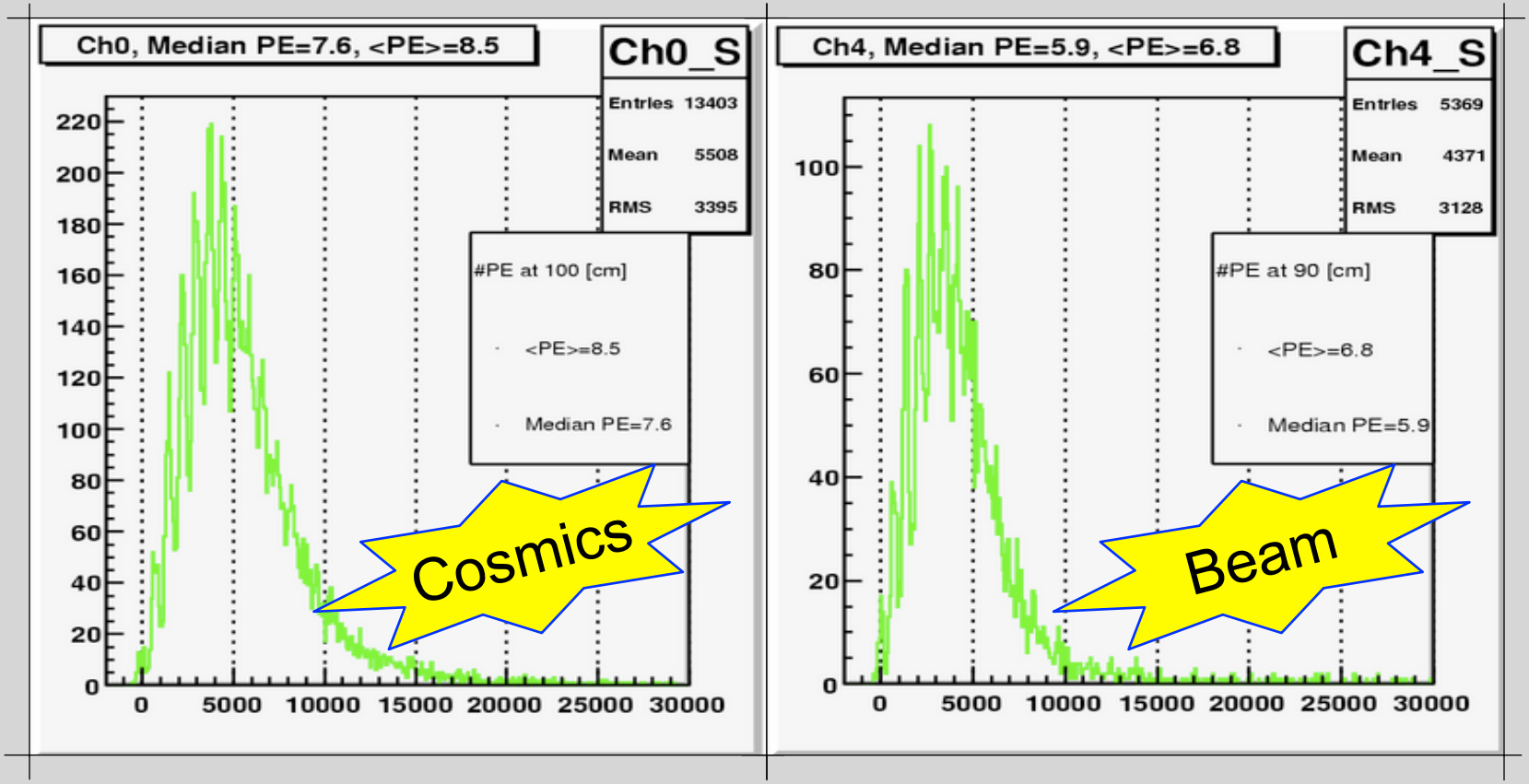
- Fermilab-based TB4 FE electronics
- 300 digitization/sampling x 4.7ns
- 12-bit ADC
  - Sample input signal at 4.7ns interval
  - ADC in time knowledge
  - Dark current and signal pulses on the picture below





Cosmics vs Beam

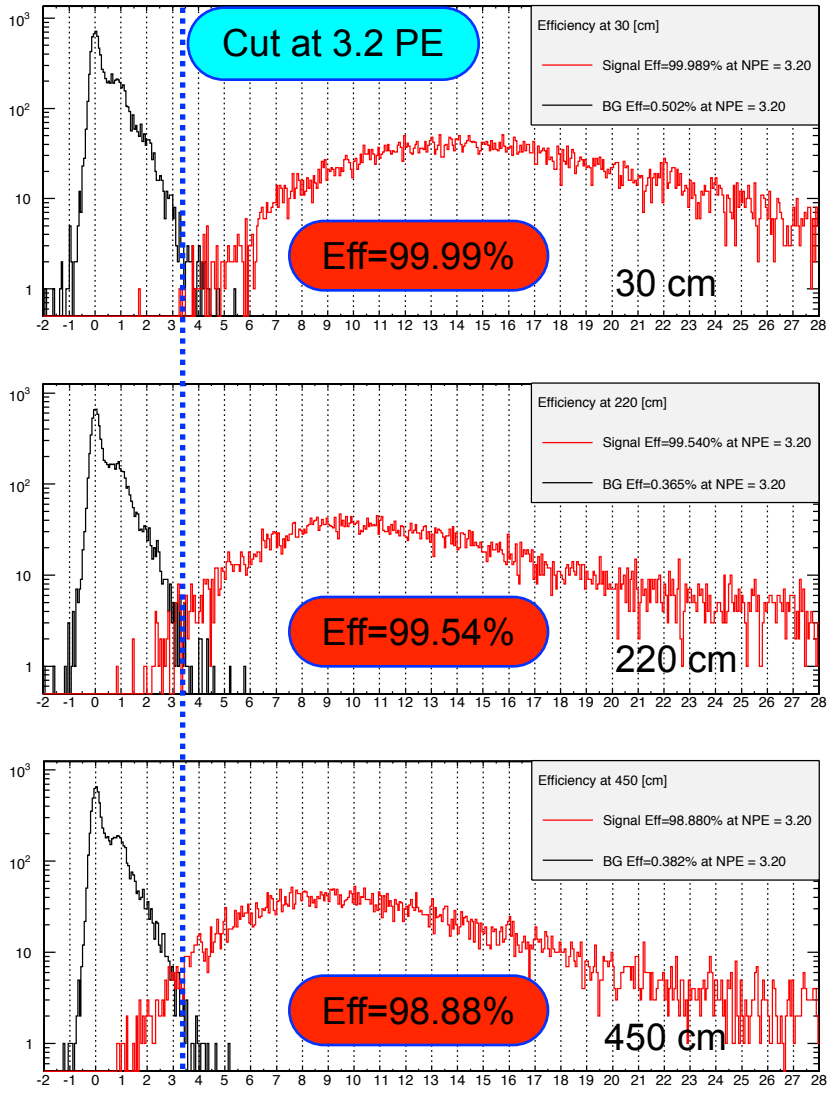
- Less <PE> from test beam data expected:
  - Test beam protons hit head on. Cosmic muons have wide range of angle of incidence and travel longer distance



Sum

- Using 3 layers of scintillator, we need CR veto efficiency of 99.99%
- Need 99.4% single layer efficiency
- We can achieve required efficiency
- Not the final result and room to improve

We can reach 99.4% single layer efficiency



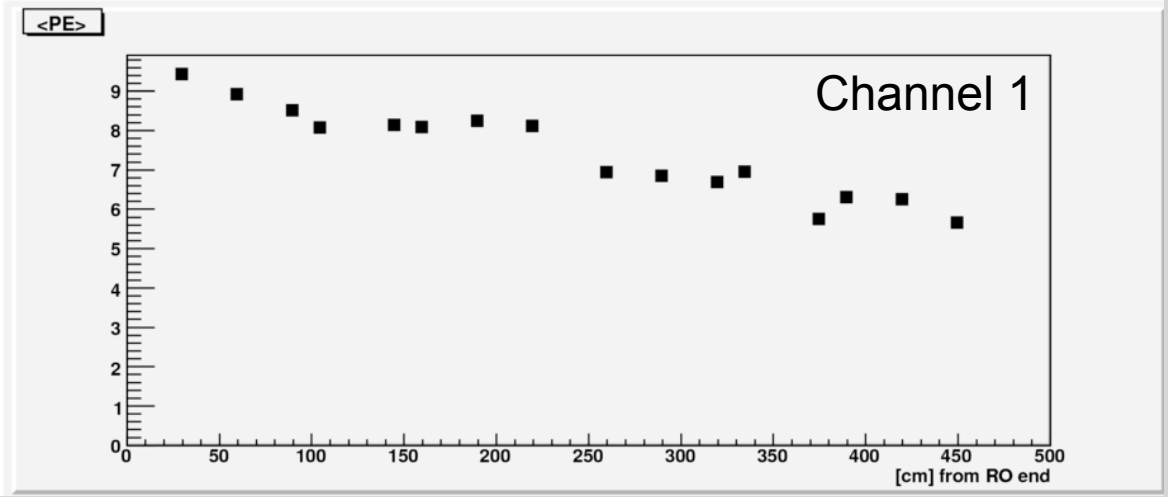
Summary

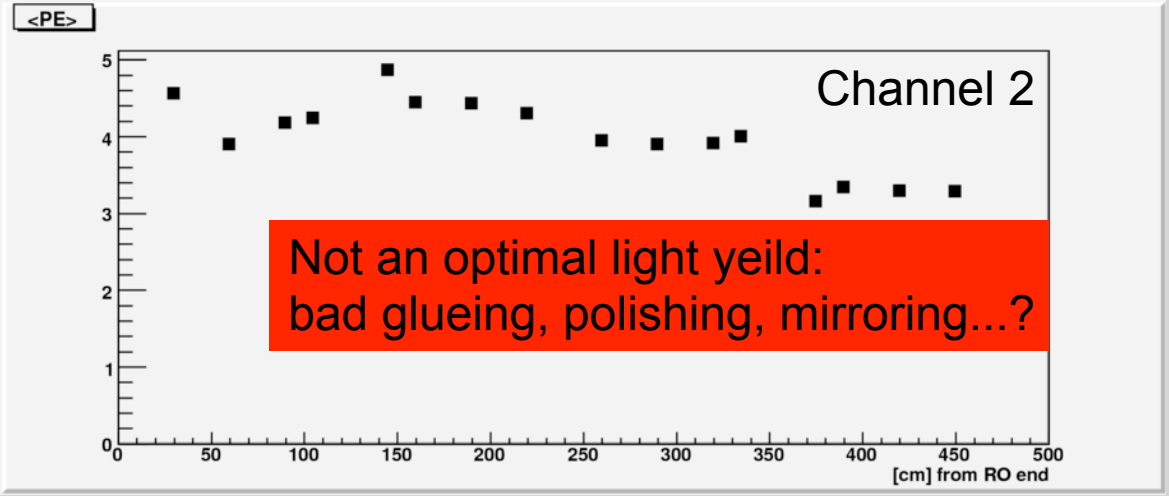
- Mu2e will perform a measurement 4 orders of magnitude better than the current limits
- It will be sensitive to mass scales orders of magnitude higher than LHC
- CRV sub-system had a successful Independent Design Review in the beginning of this month
- Plan to have an approved CDR by the end of 2011
- CRV prototypes studies
  - Various interesting measurements
  - 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 obtainable
- Interested?
  - Attend the presentation by C.Group tomorrow at User's meeting
  - Join collaboration of ~120 scientists

Backup

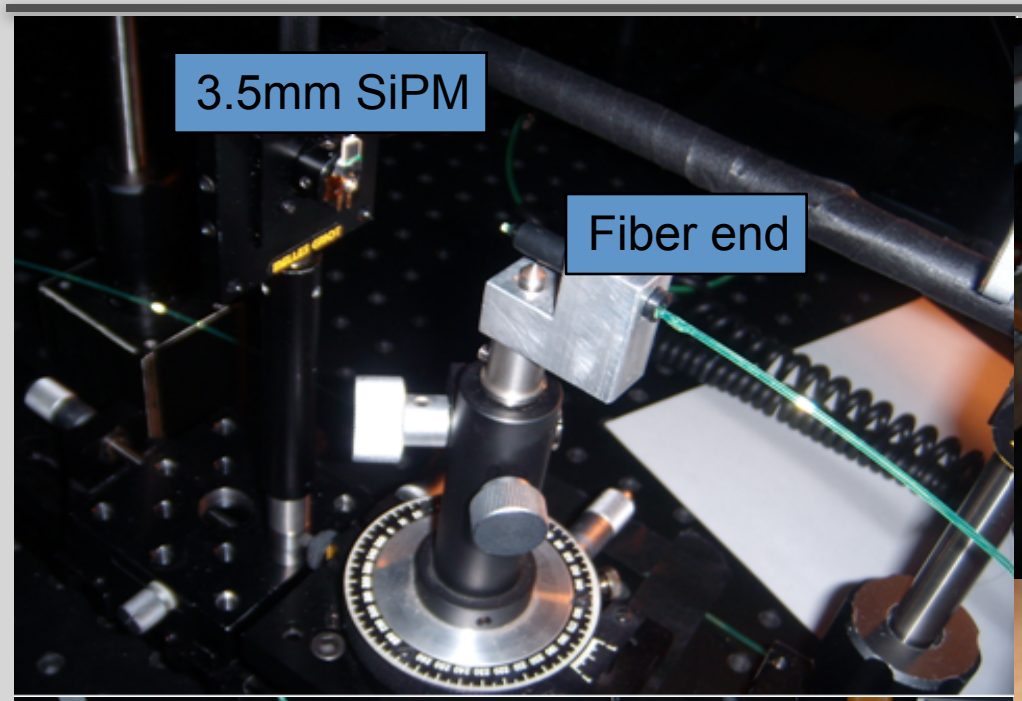
Yuri Oksuzian, UVa

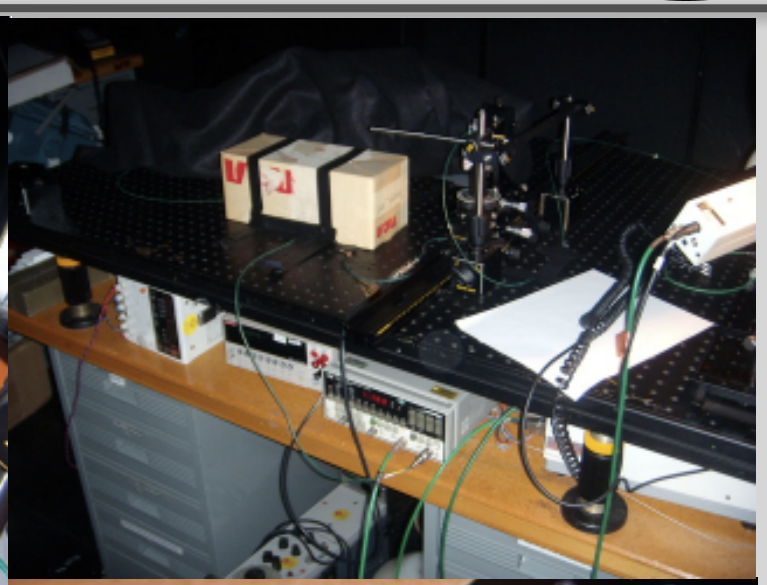
Attenuation curve

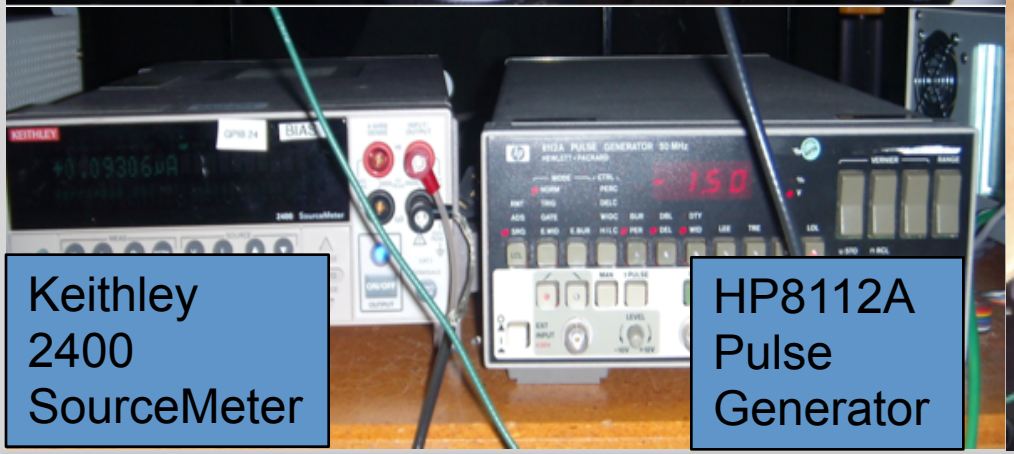


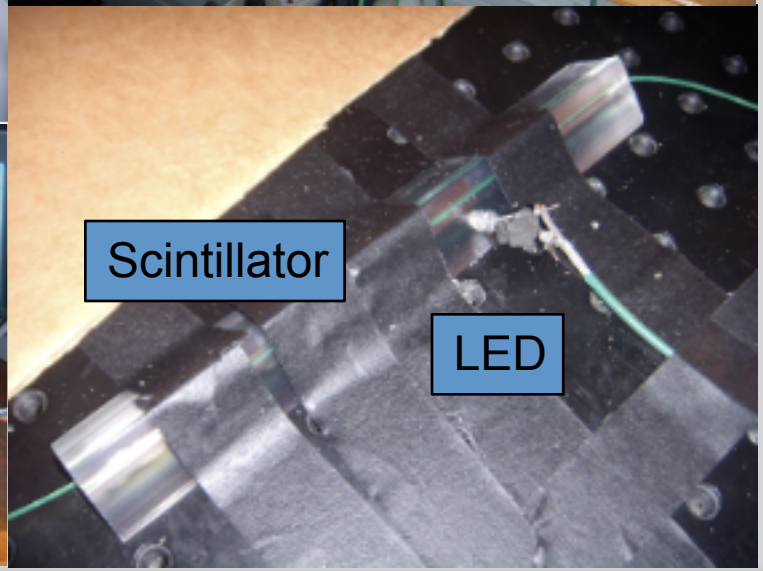


Setup at Lab 6



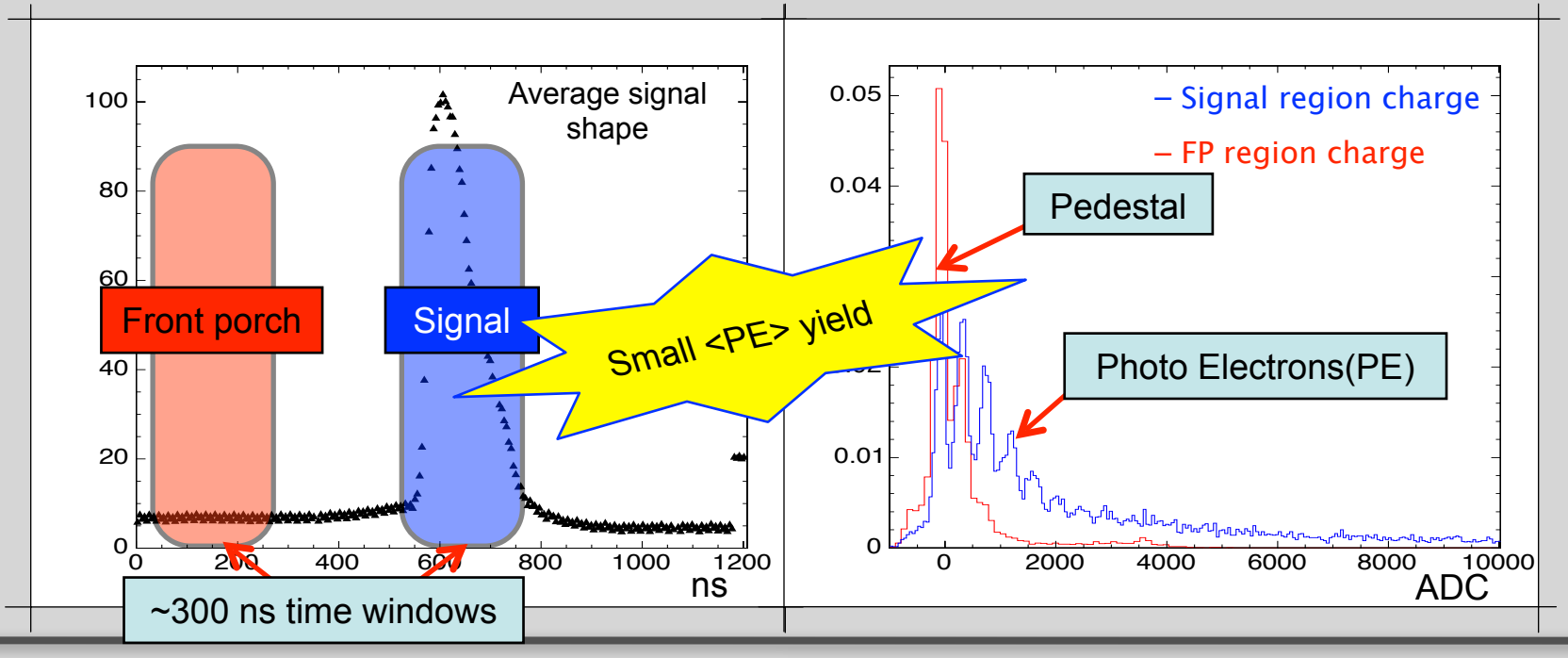




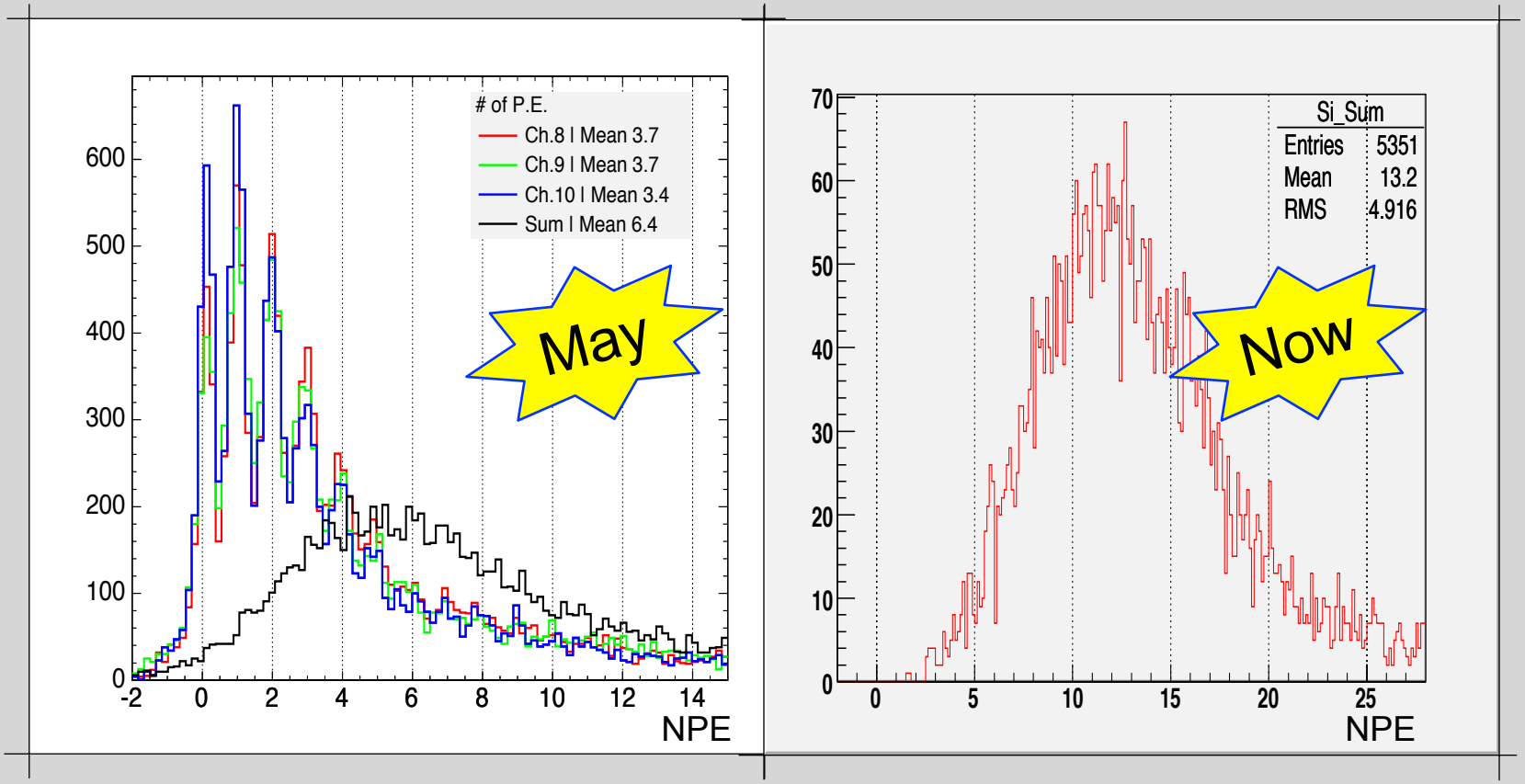


Test beam in May

- 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 yeild at ~4m



More than 2x PE yield now