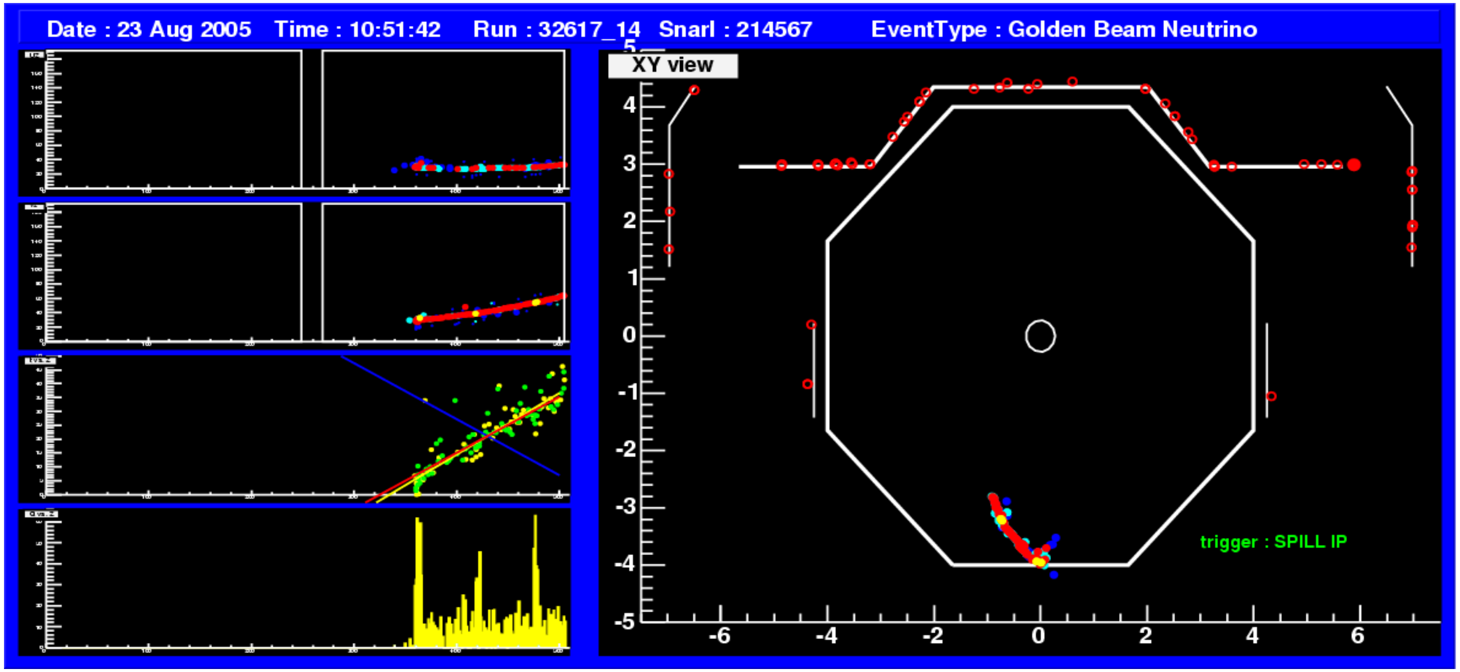
MINOS Technology for the ILC Muon Chambers ?

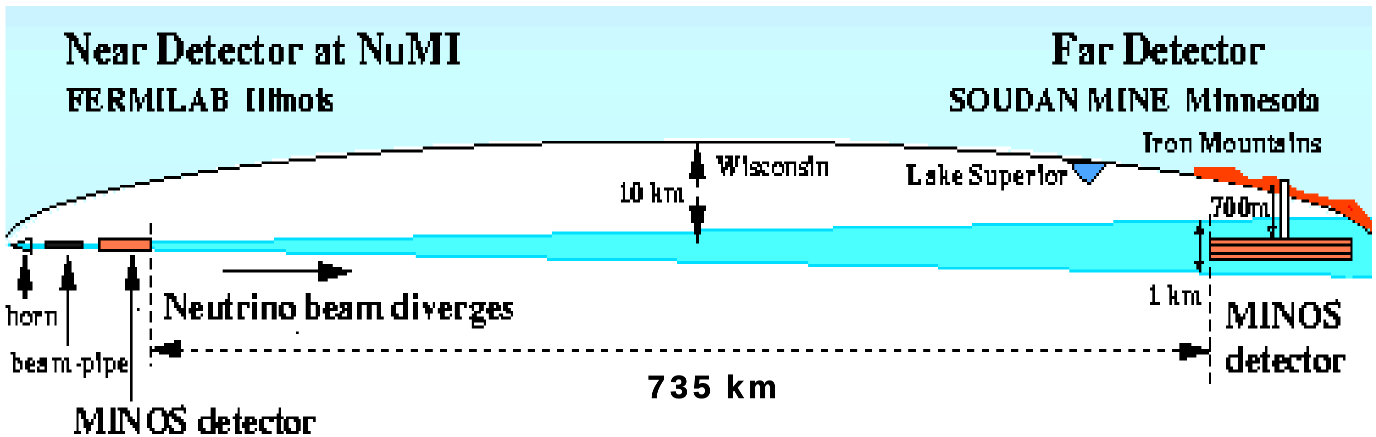
Mark Thomson
University of Cambridge



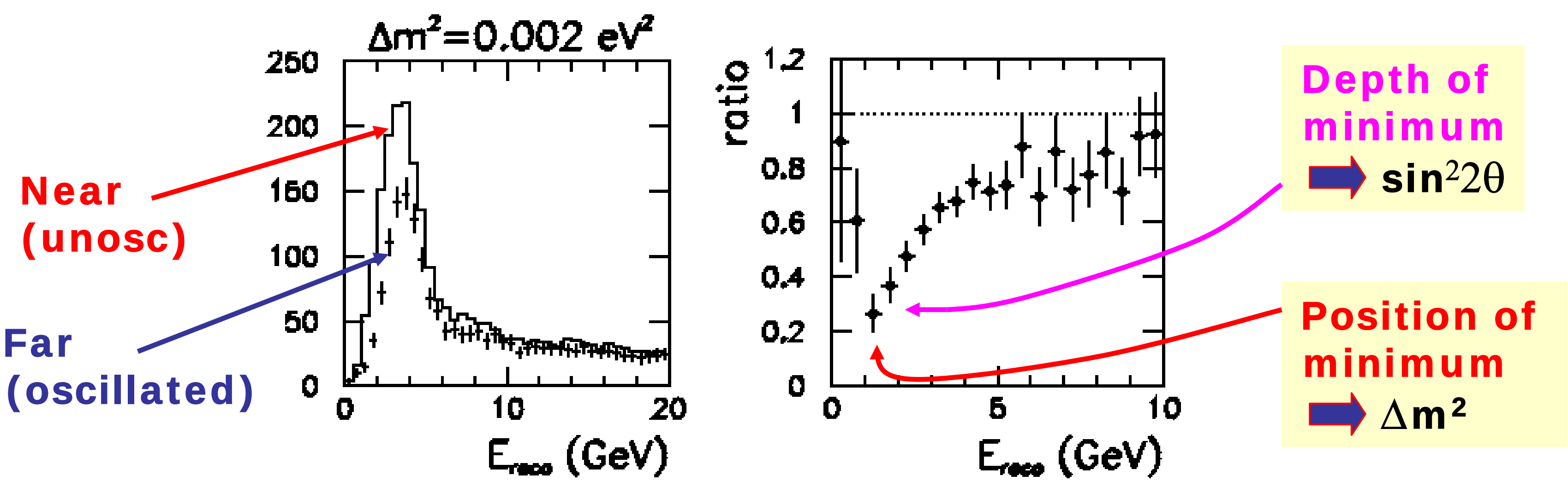
THIS TALK:

- The MINOS detector
- MINOS scintillator system
- Performance
- Conclusion

MINOS : Basic Idea



- **Measure ratio of neutrino energy spectrum in far detector (oscillated) to that in the near detector (unoscillated)**
- **Partial cancellation of systematics**



MINOS Far Detector

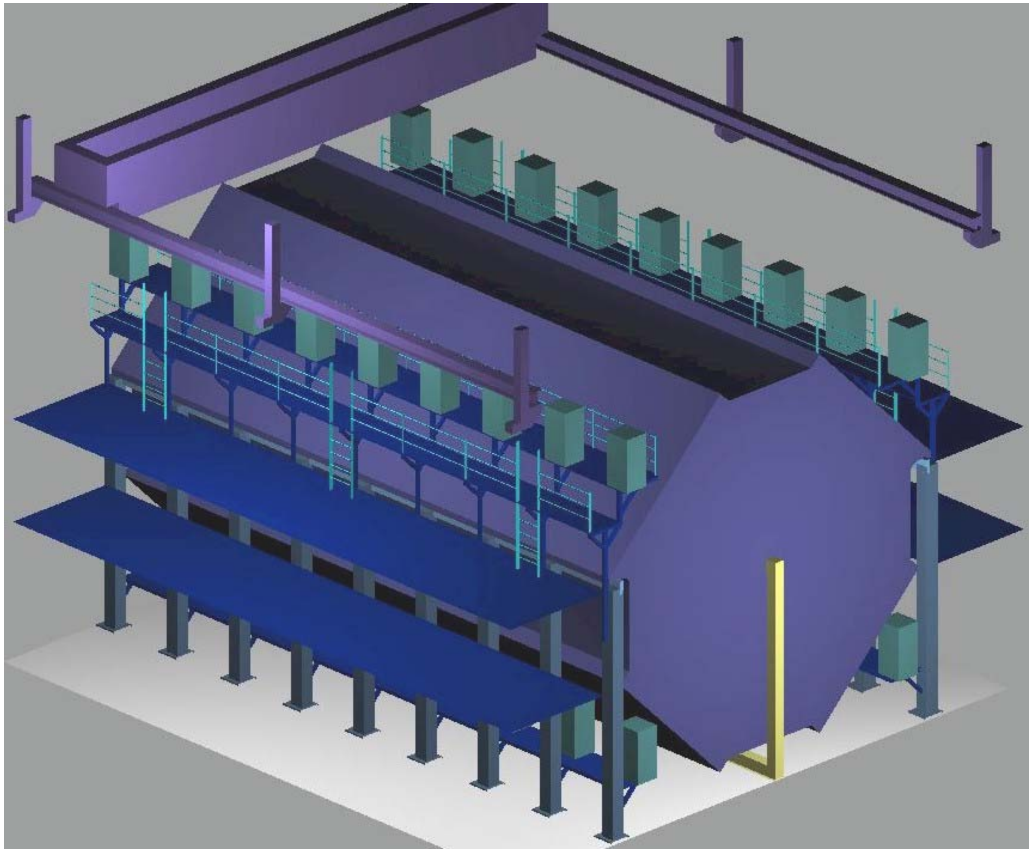
(will only describe Far Detector in this short talk)

8m octagonal steel & scintillator tracking calorimeter

- 2 sections, 15m each
- 5.4 kton total mass
- 55% / √E for hadrons
- 23% / √E for electrons

Magnetized Iron (B~1.5T)

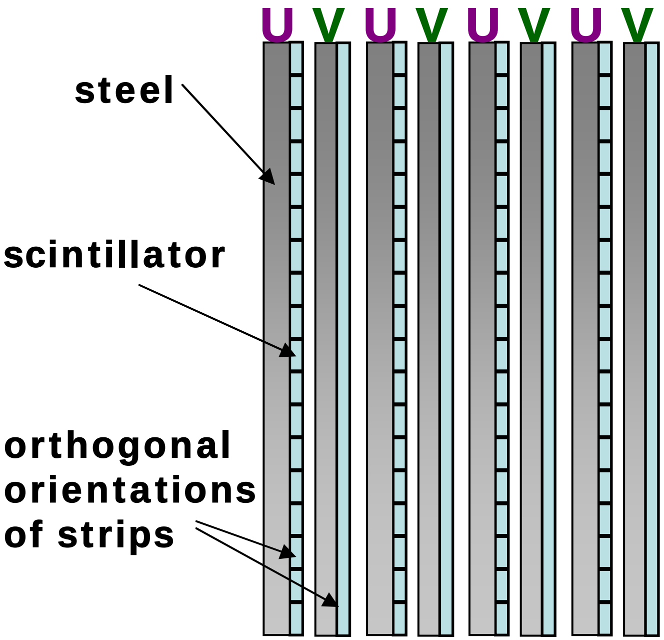
484 planes of scintillator



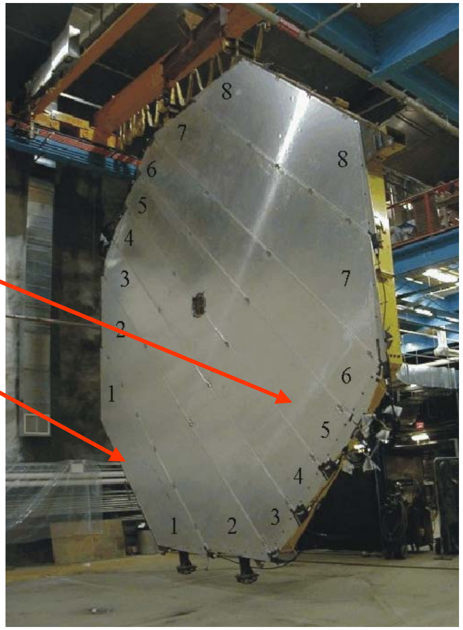
**One Supermodule of the Far Detector…
Two Supermodules total.**

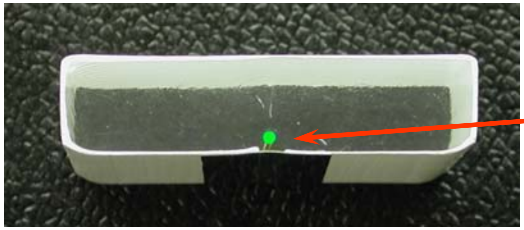
Detector Elements

- ★ Steel-Scintillator sandwich : **SAMPLING CALORIMETER**
- ★ Each plane consists of a **2.54 cm** steel + **1 cm** scintillator
- ★ Each scintillator plane divided into **192 x 4.1cm** wide strips
- ★ Alternate planes have **orthogonal** strip orientations (U and V)



Scintillator Length:
4m - 8m

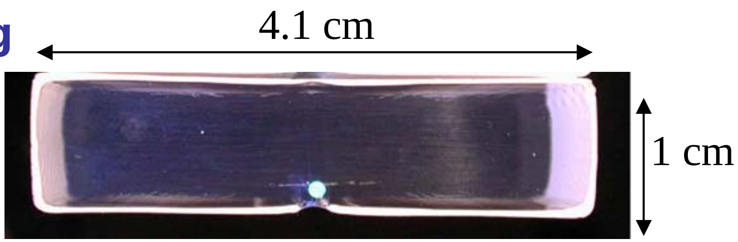


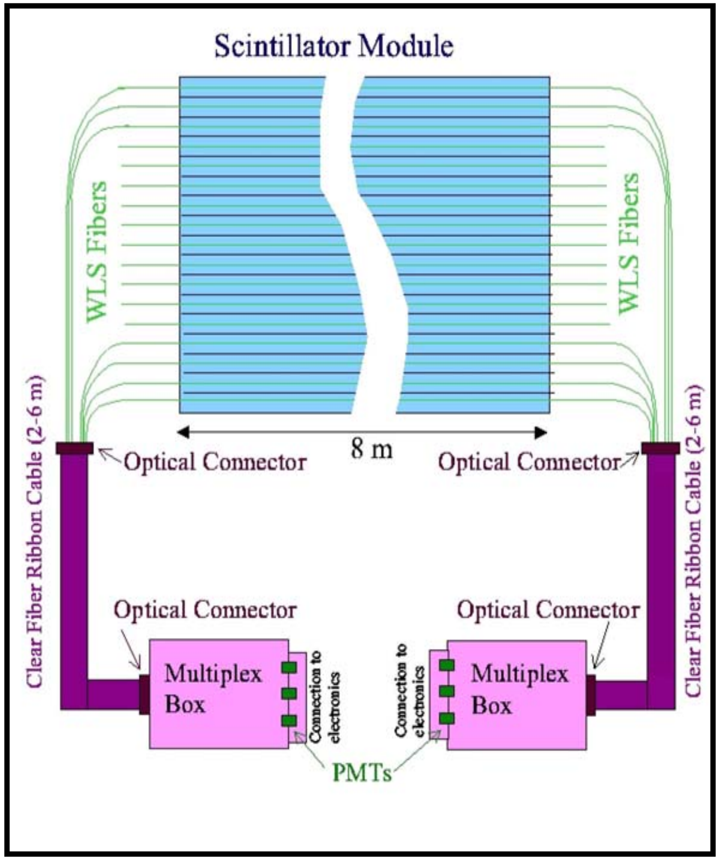


- ✦ Scintillation light collected by **WLS** fibre glued into groove
- ✦ Readout by multi-pixel PMTs

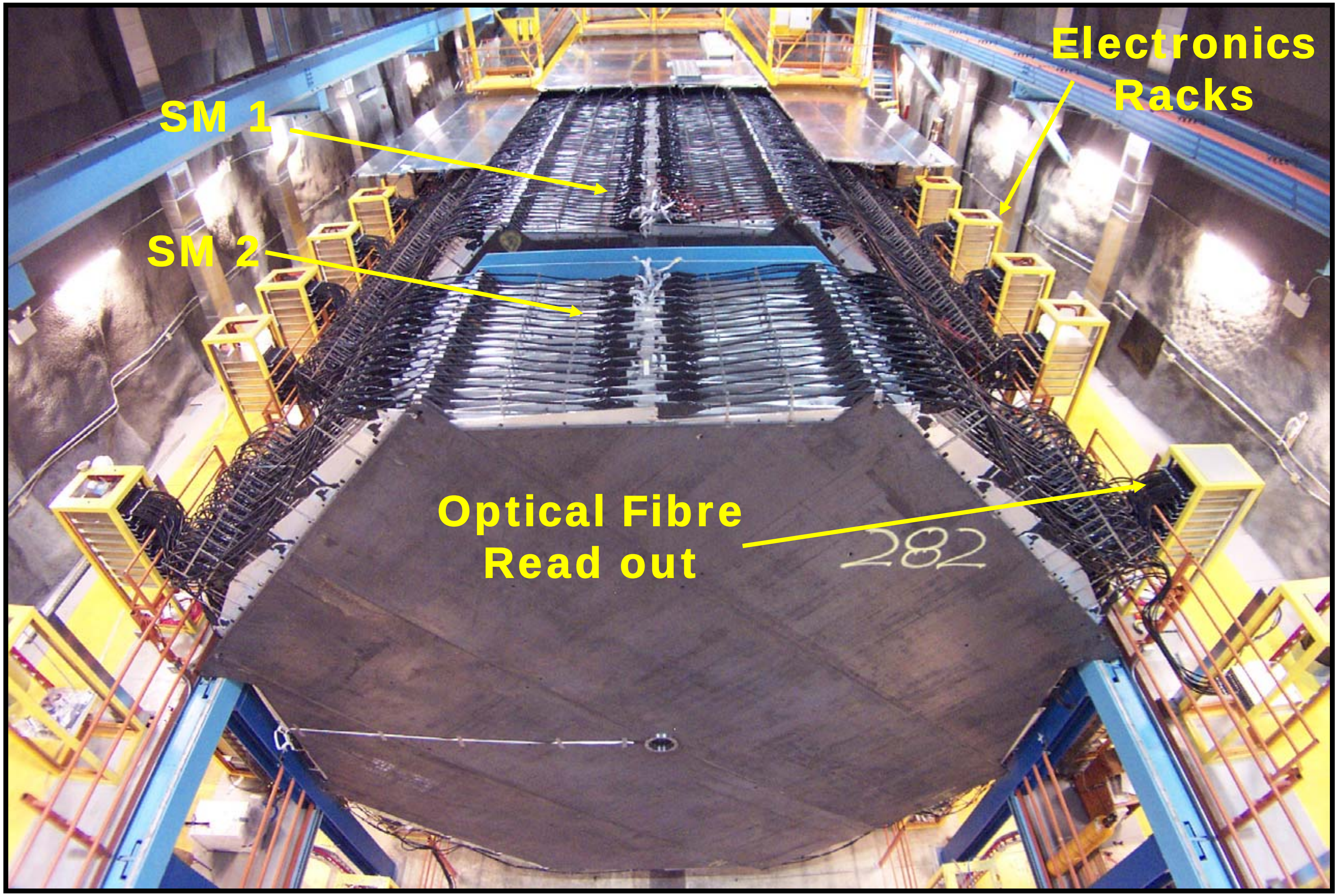
Scintillator / Fibres

- ★ **4.1 x 1cm scintillator strips, up to 8m long**
  - Extruded polystyrene (co-extruded TiO_2 coating)
  - PPO (1%), POPOP (0.03%) fluors
- ★ **Readout via wavelength shifting fibres**
  - Kuraray 1.2mm fibre (Y-11 fluor, 175 ppm)
- ★ **Optical connection via clear fibres**





MINOS FarDet during installation



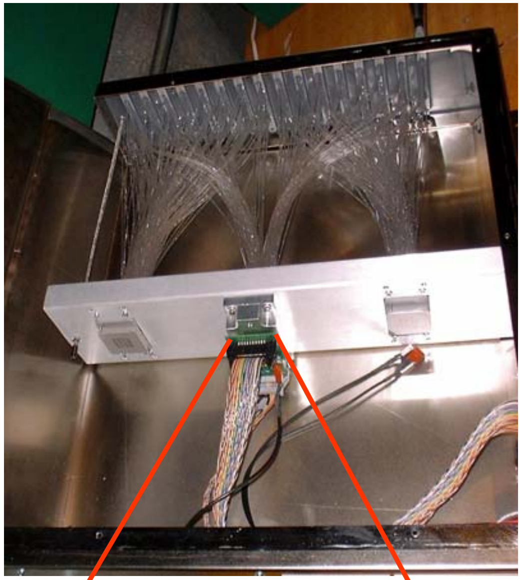
Readout / Multiplexing

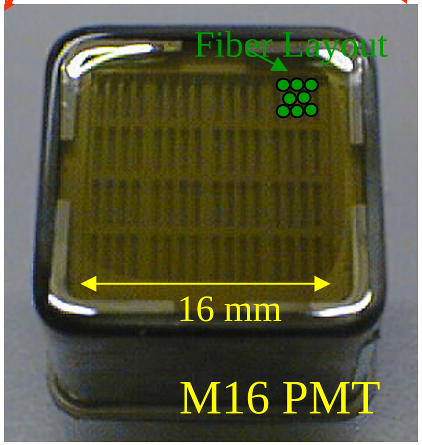
Light Detection:

- ★ Hamamatsu 16 pixel PMTs
  R5900-00-M16
- ★ QE ~ 15 %
- ★ Strips read out at both ends
- ★ Readout by VA chip (IDEAS ASA)

Optical Multiplexing:

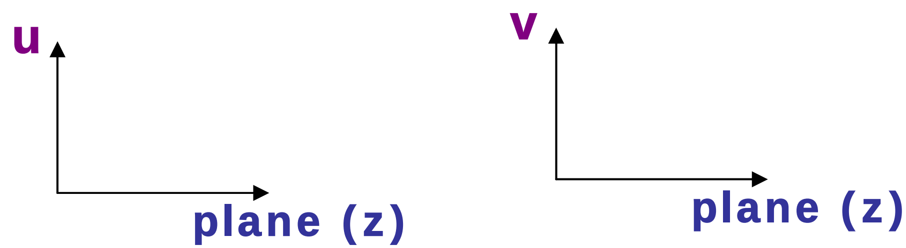
- ★ 8 fibres connected to each pixel
- ★ Different multiplexing pattern
  for both detector sides
- ★ Ambiguities removed in software



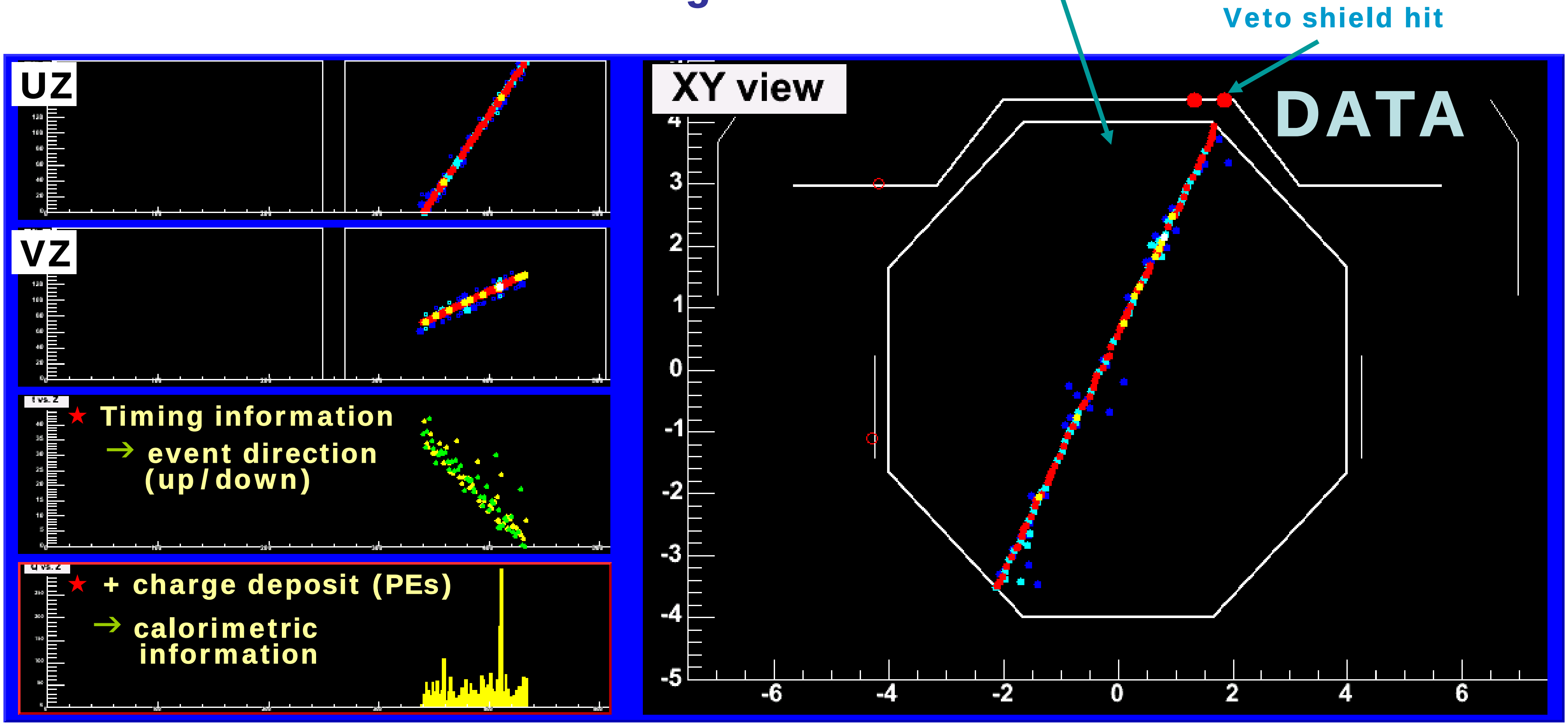


Event Information (typical muon)

★ **Two 2D views of event**



★ **Software combination to get `3D' event**



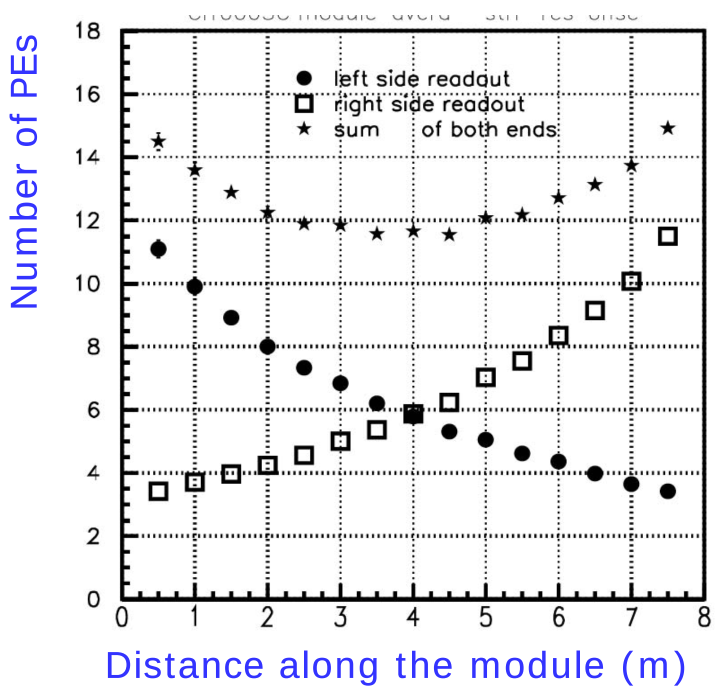
Performance

Light Output
Efficiency
Cross-talk
Noise
Timing / Timing Calibration
Detector Calibration
Detector Performance

Light Output

Light at PMT depends on:

- Path-length in strip
- Attenuation in WLS fibre
  - 30 % self-absorbtion of green light $\lambda \sim 1$m
  - Most important component : 70 % $\lambda \sim 7$m
- Attenuation in clear fibres : $\lambda \sim 10$m
- Optical connection efficiency
- Typically **8-10 PEs/strip** for a normal incidence MIP



Note: in addition to WLS in strip, on average **~0.8m** WLS in pigtail and **~3m** Clear fibre

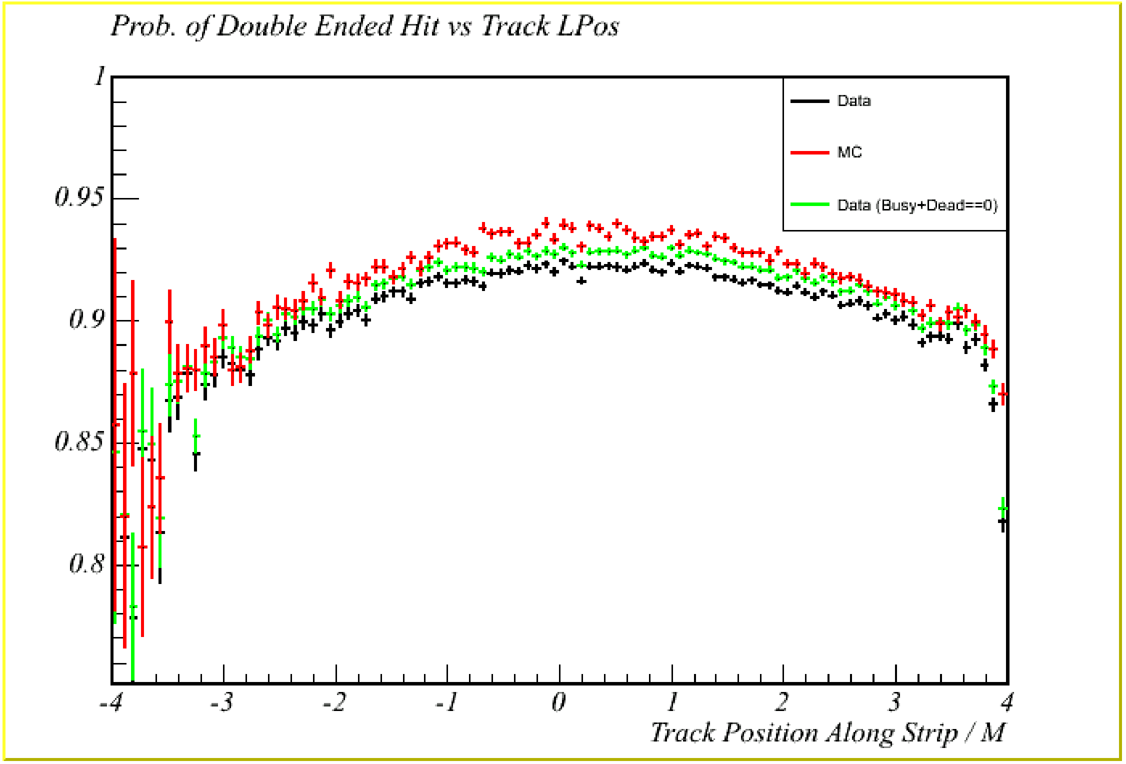
Efficiency

Achieve very high efficiency (>99%)

- biggest loss due to readout deadtime

Efficiency for double-ended hit ~ 90 %

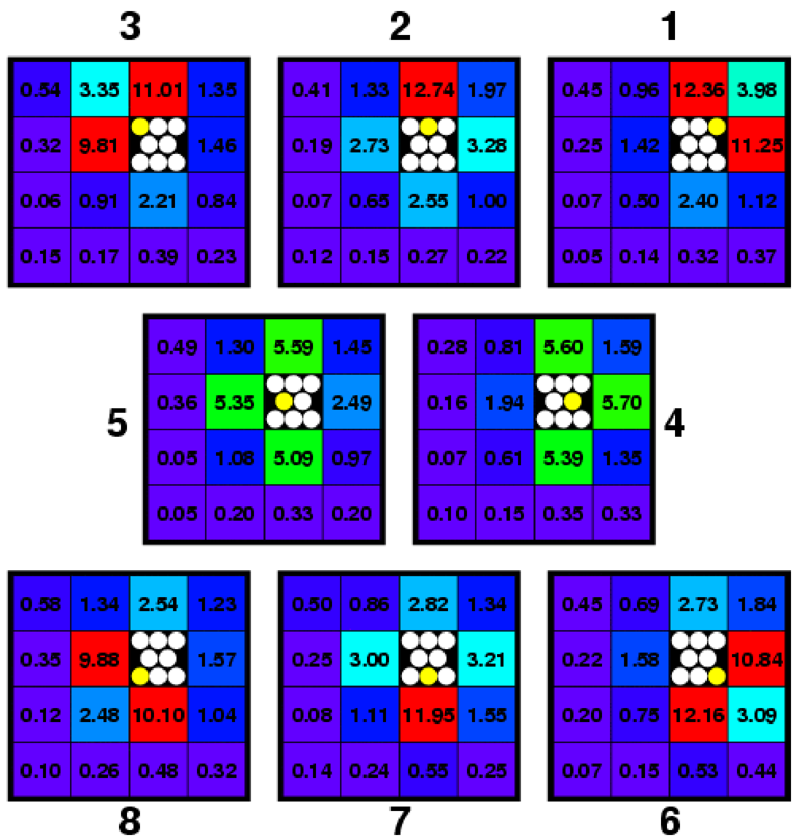
- PE statistics



Cross-talk

- ★ Optical cross-talk measured in test setup and in data
- ★ Depends on PMT pixel and fibre in bundle of 8

Cross-talk fractions ($\times 10^{-3}$)



"For a typical cosmic muon approx 25 % chance of cross-talk hit"

Noise

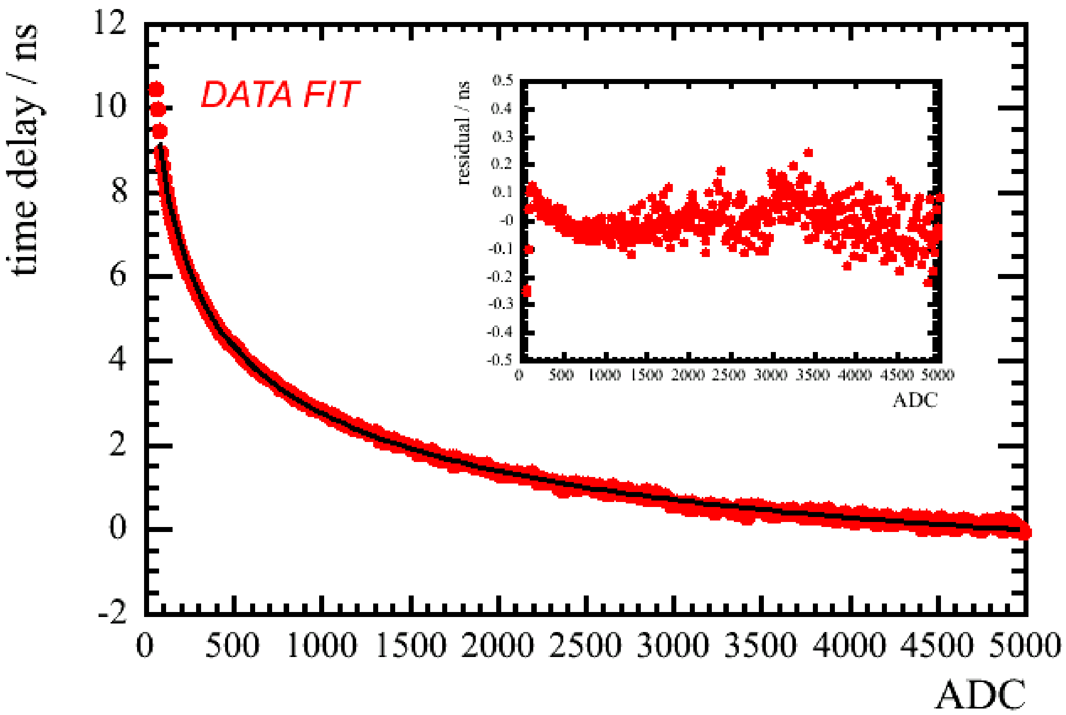
Noise some numbers:

Radioactivity : 6 Hz (per stripend)
PMT Dark count rate : ~350 Hz per PMT
Spontaneous emmission from WLS fibres : ~ 50 Hz (stripend)
~ 1-5 Hz per meter of WLS

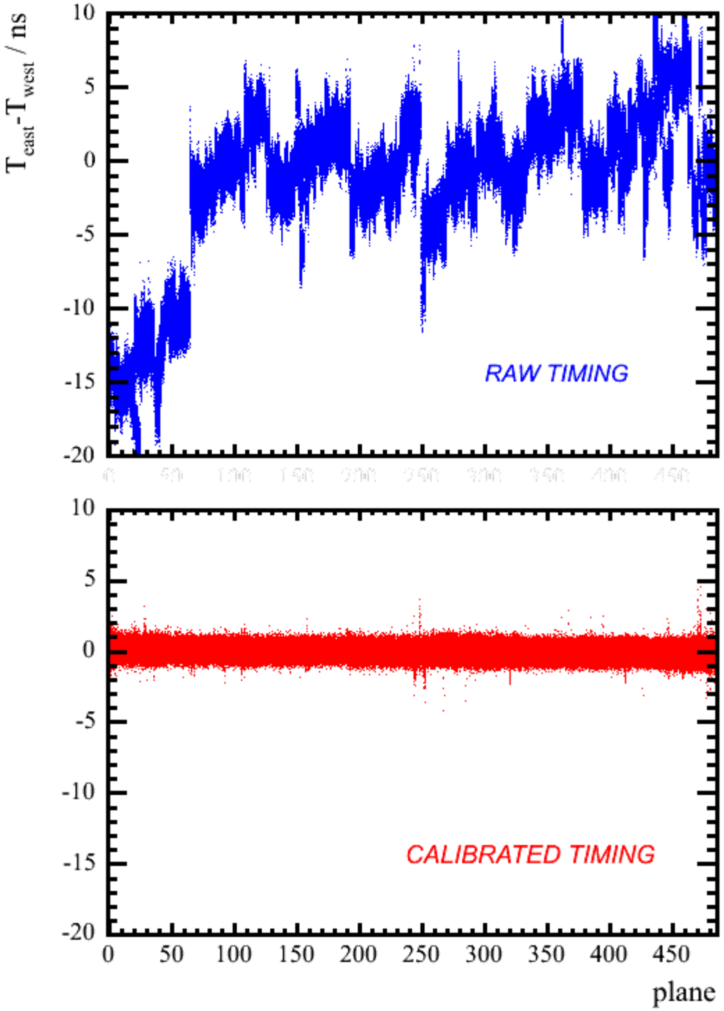
For more info : NIMA 545 (2005) 145-155

Timing Resolution

- ★ Timing resolution determined by decay time of Y-11 fluor in WLS fibre ~8ns
- ★ Resolution of 2.4 ns achieved for data cosmics
- ★ Limitted by convolution of exponential decay, PE statistics and electronics threshold

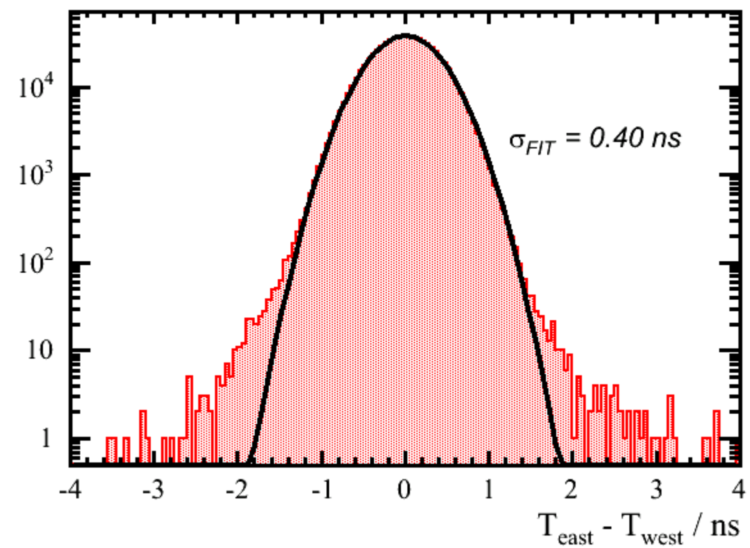


Timing Calibration



Use cosmic muons:

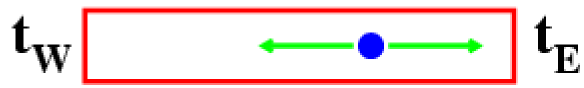
★ Remove electronics and fibre length offsets



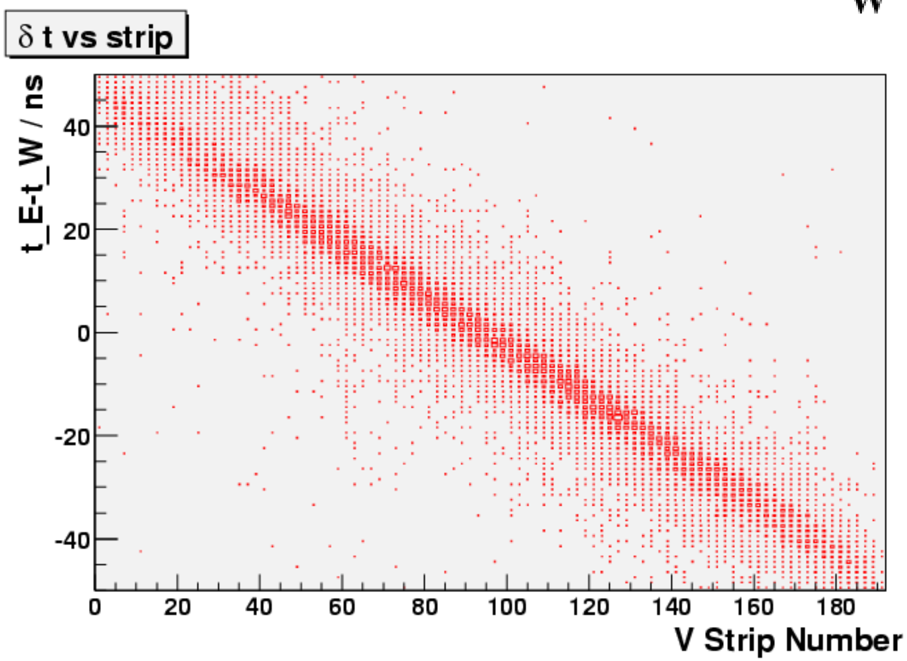
One use of timing

- ★ Use times at the two end of strip to find distance along strip

e.g. U Strip



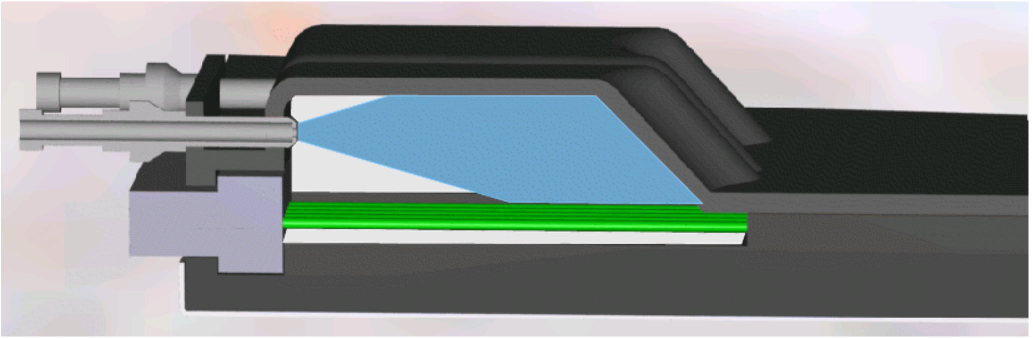
$t_W - t_E \to V$



- ★ Δt resolution ~ 4 ns
  - corresponds to ~ 30 cm

Calibration I

I) LED LIGHT INJECTION:



Light from calibration fibers illuminating ends of fibers from the scintillator where they are bundled

- Linearity of electronics
- Short-term drift of calibration
- PMT gains (low led light level : 1 PE)
- Check optical integrity

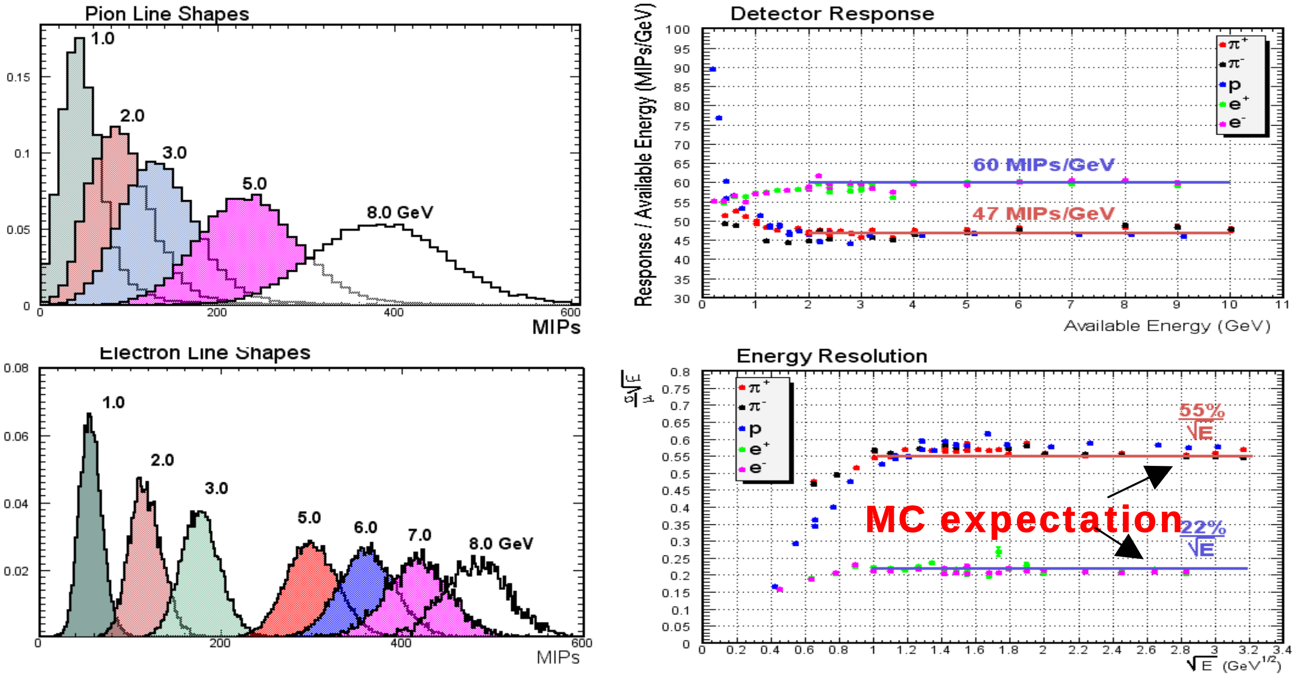
II) Cosmic Muons (VERY POWERFUL):

- 1000 muons/strip/month [half mile underground]
- Determine strip-to-strip MIP response
- Determine overall calibration

★**Confident that we will achieve MINOS goal of 2 %**

Calibration II : Test Beam

Response measured in CERN test beam using a MINI-MINOS



	Response	Resolution
Hadrons	**47 MIPs/GeV**	**55% / √E**
Electrons	**60 MIPs/GeV**	**22% / √E**

- **Provides calibration information**
- **Test of MC simulation of low energy hadronic interactions**

Concluding Comments

- MINOS detectors are performing very well
- Extremely robust detector operation

MINOS style muon chambers for ILC ?

- Even with relatively thin scintillator (1cm) + modest QE get very high MIP efficiency
- what about timing requirements ?
- what about aging ? (no evidence yet)
- other issues ?
- Looks like a very promising technological choice…