MINOS Technology for the ILC Muon Chambers ?

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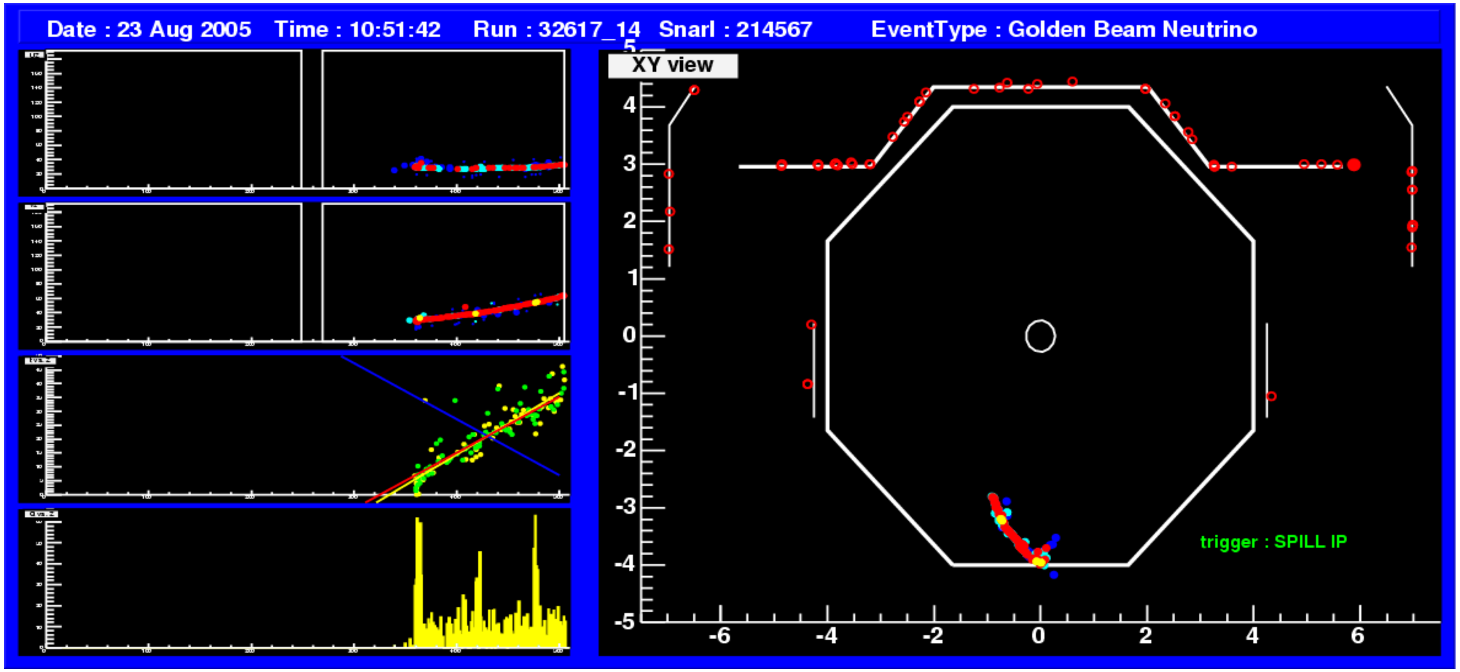
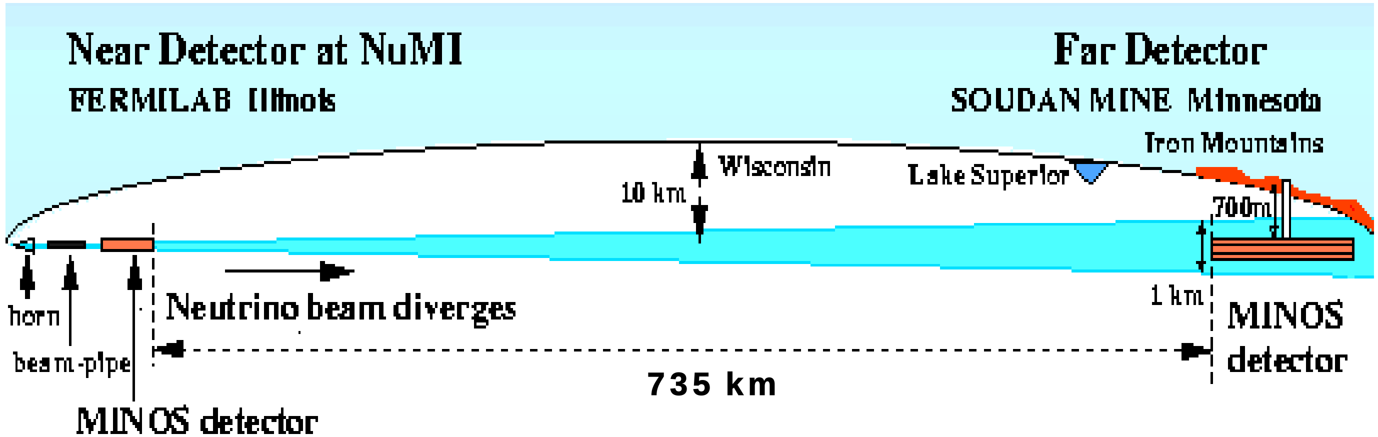


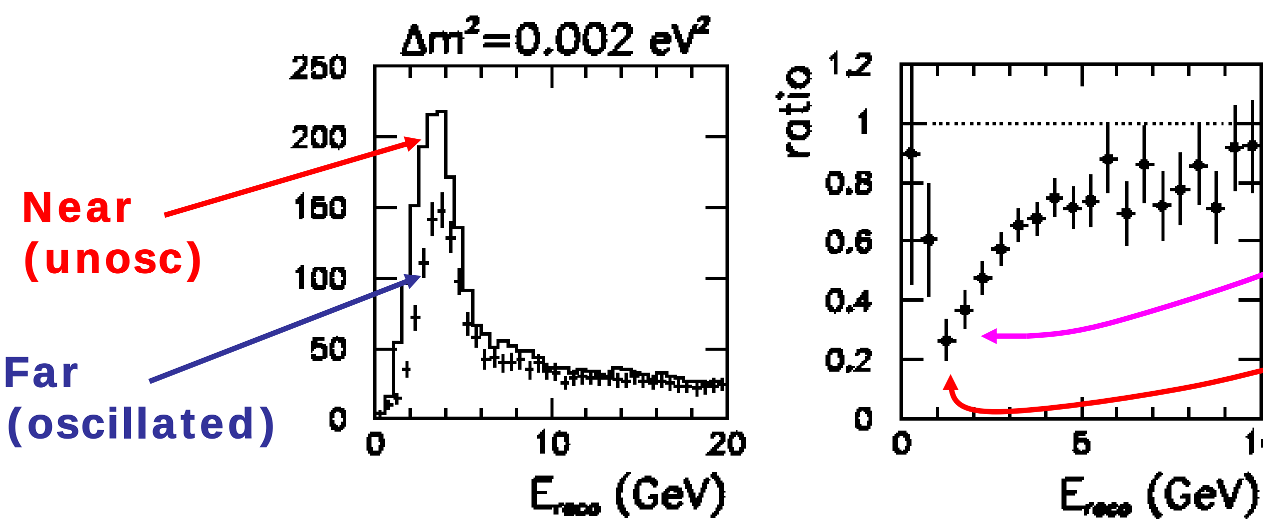
THIS TALK:

- 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**



Depth of minimum ➡ $\sin^2 2\theta$

Position of minimum ➡ Δm^2

MINOS Far Detector

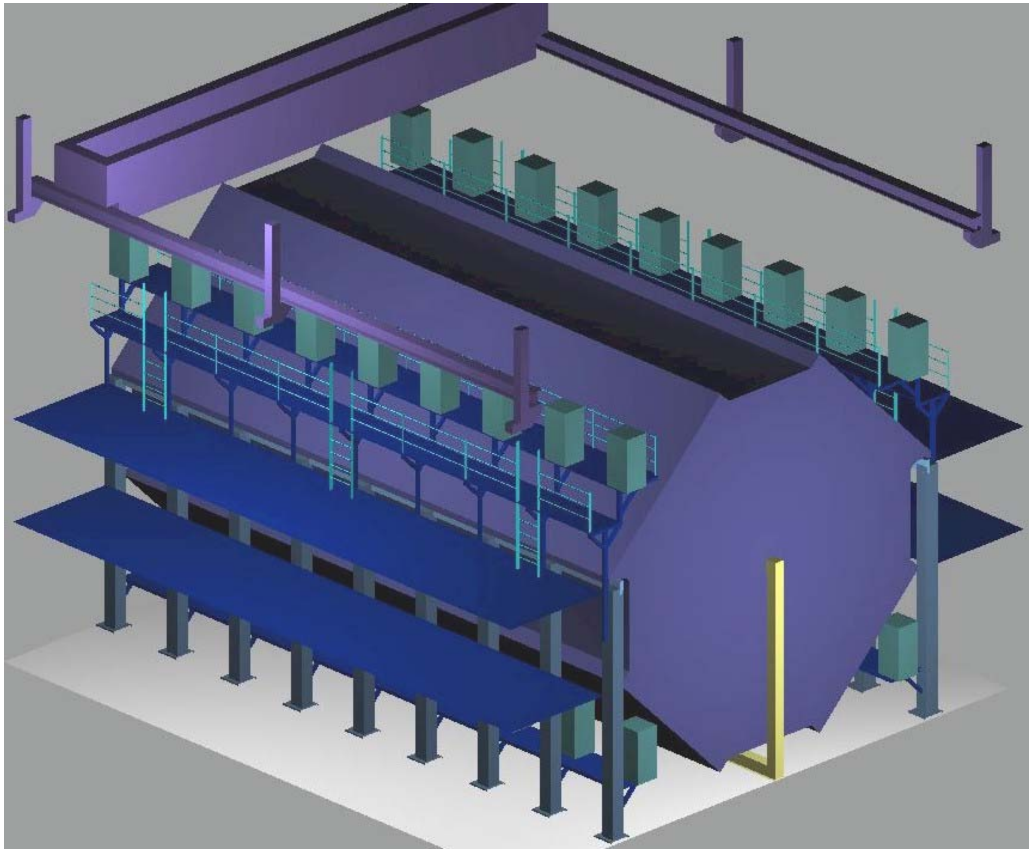
(will only describe Far Detector in this short talk)

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)

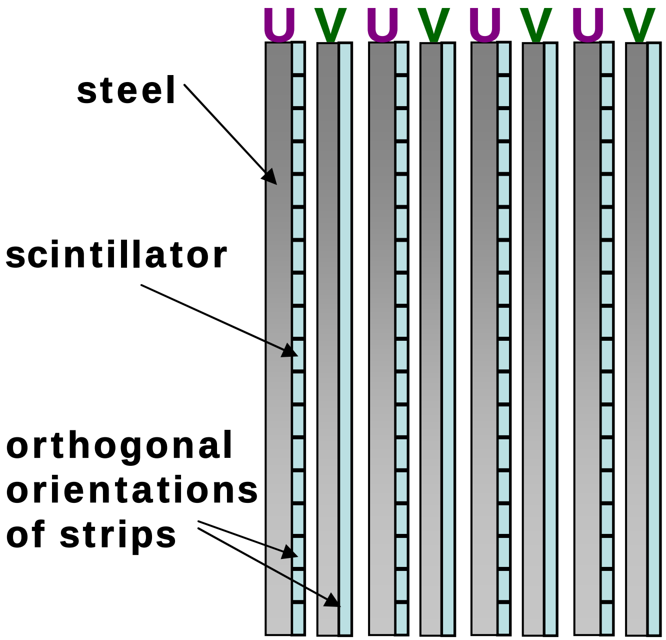
484 planes of scintillator



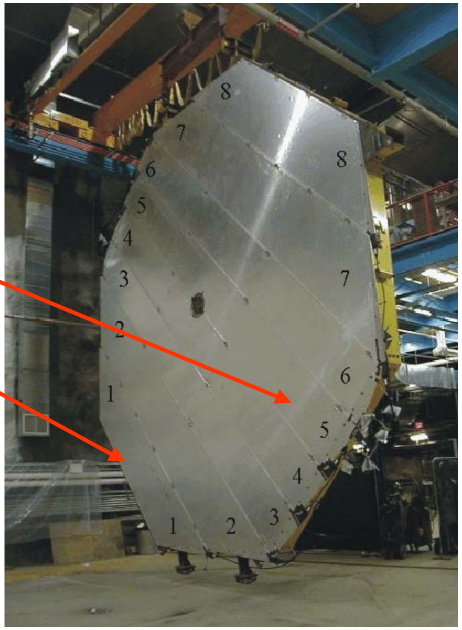
One Supermodule of the Far Detector...
Two Supermodules total.

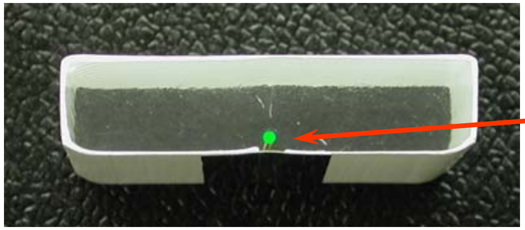
Detector Elements

- ★ 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

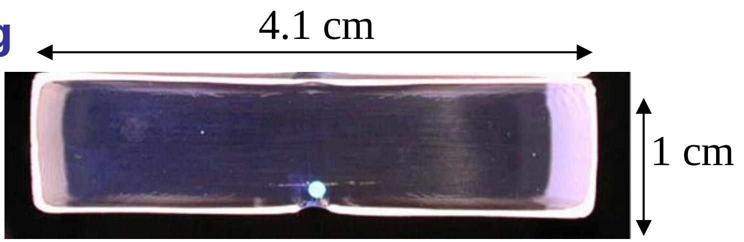


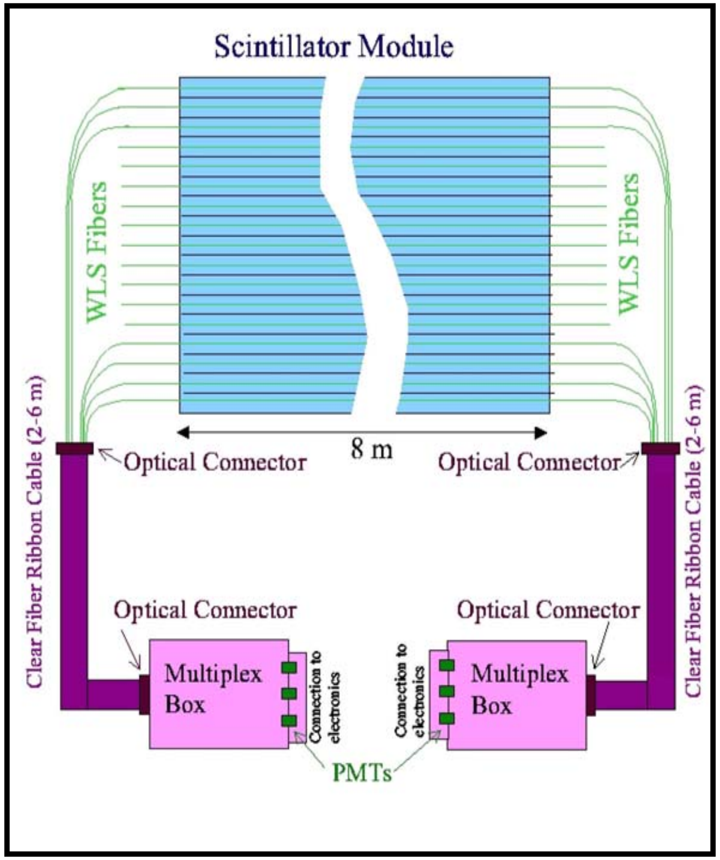


- ✦ Scintillation light collected by **WLS** fibre glued into groove
- ✦ Readout by multi-pixel PMTs

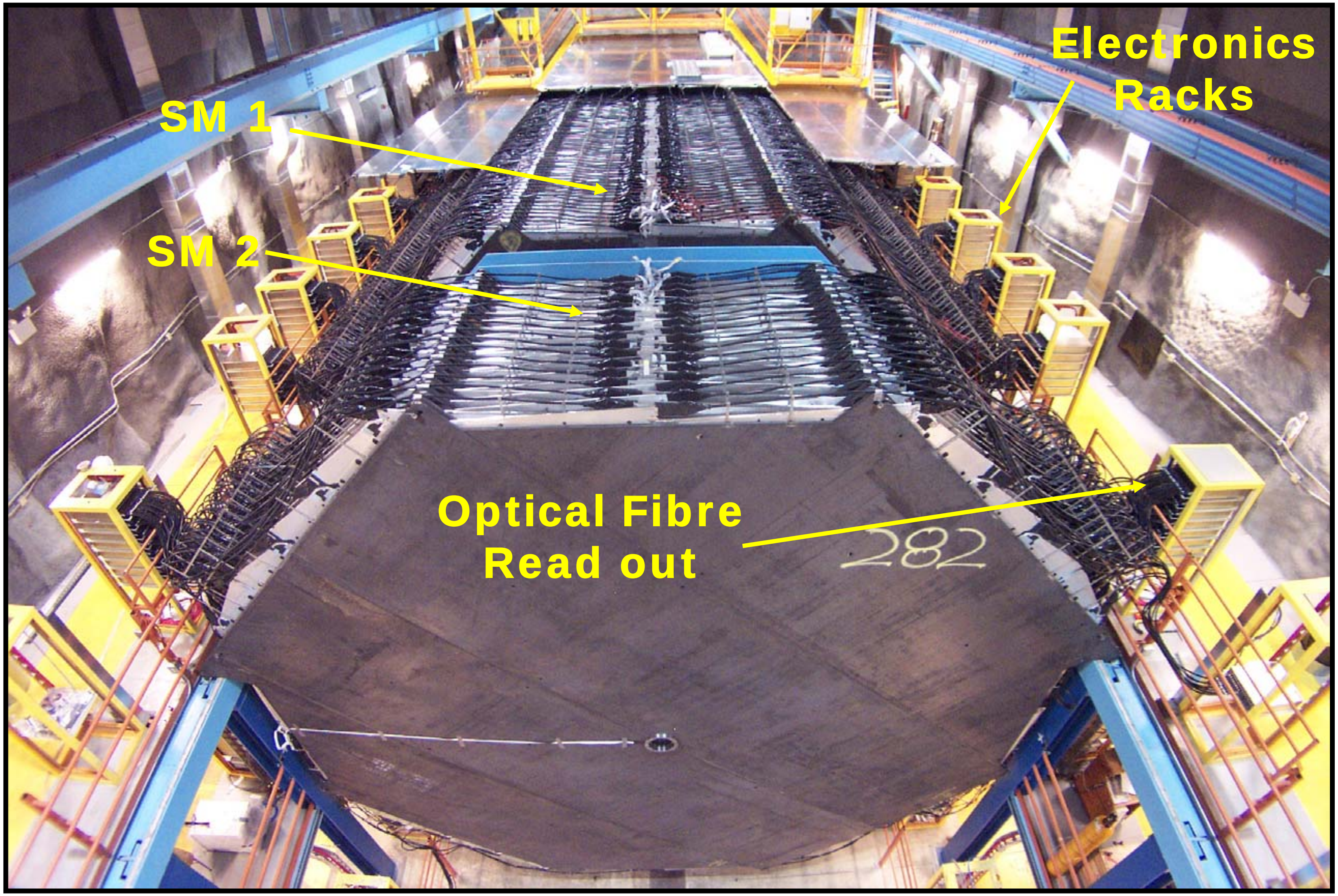
Scintillator / Fibres

- **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**





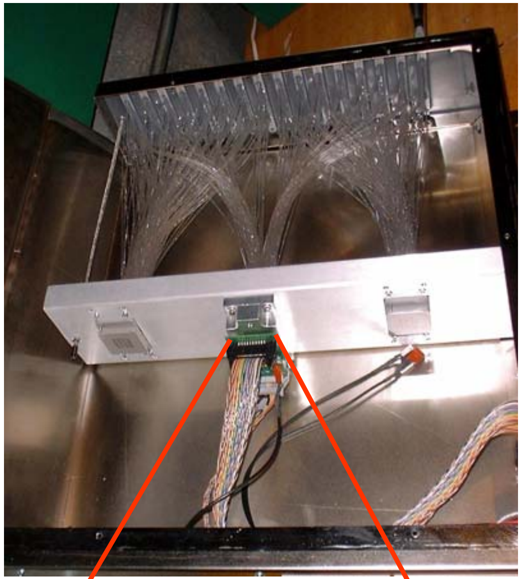
MINOS FarDet during installation

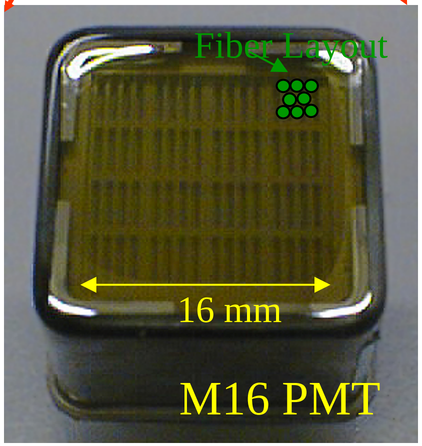


Readout / Multiplexing

Light Detection:

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



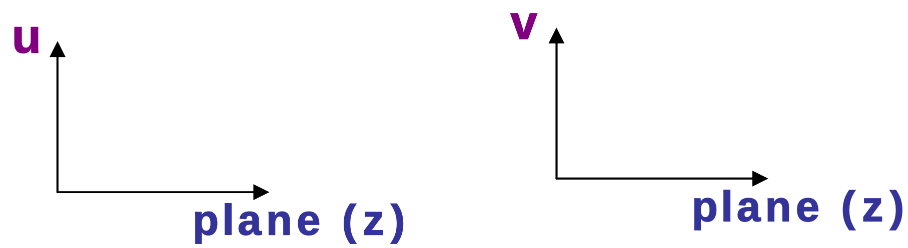


Optical Multiplexing:

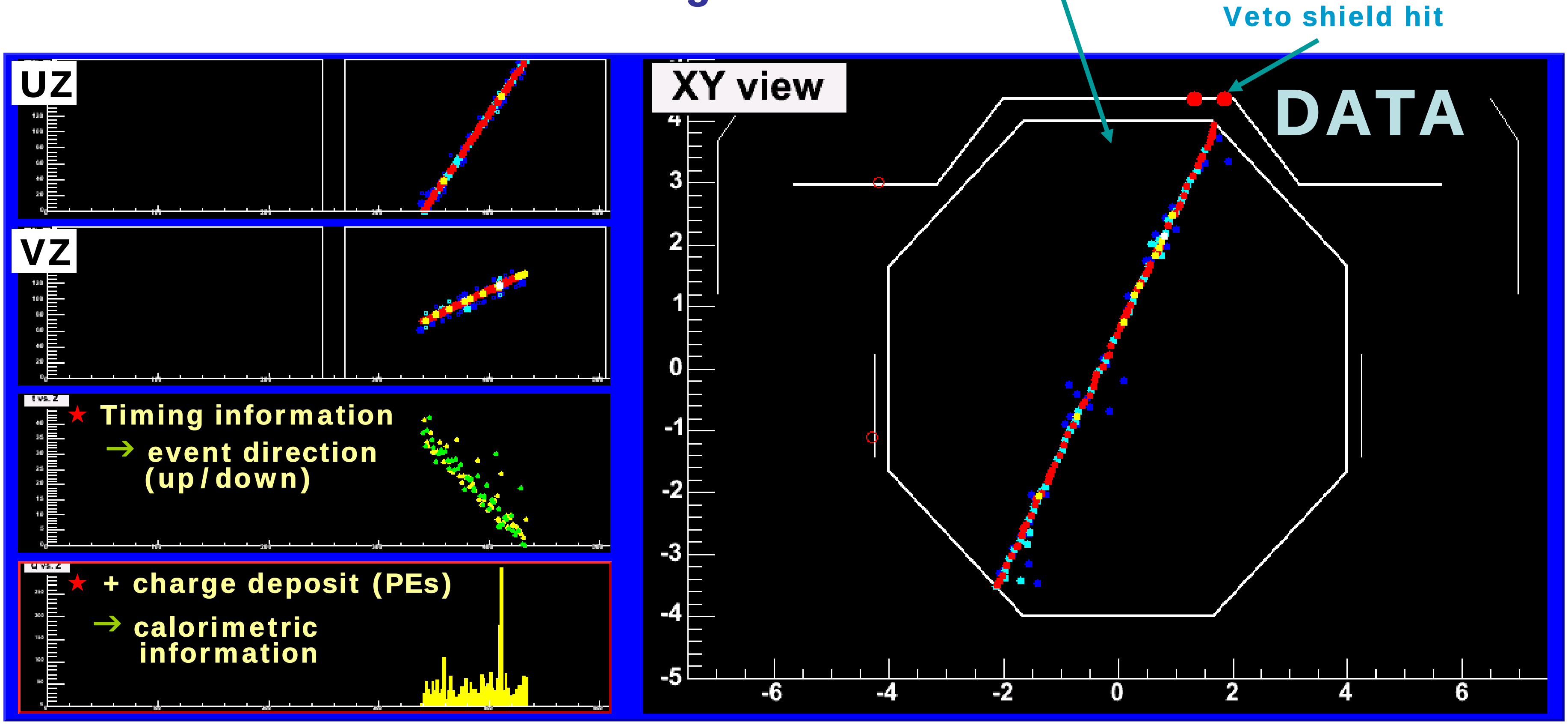
- ★ 8 fibres connected to each pixel
- ★ Different multiplexing pattern
  for both detector sides
- ★ Ambiguities removed in software

Event Information (typical muon)

★ Two 2D views of event



★ Software combination to get `3D' event



Performance

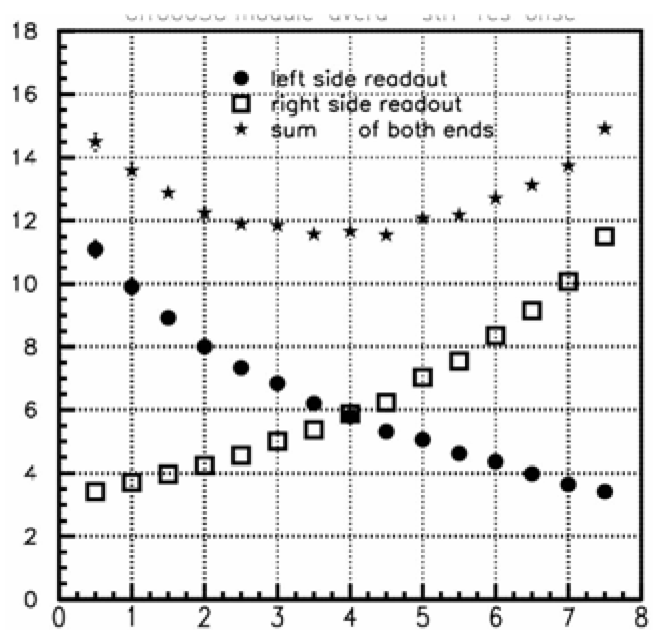
Light Output
Efficiency
Cross-talk
Noise
Timing / Timing Calibration
Detector Calibration
Detector Performance

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

Number of PEs



Distance along the module (m)

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

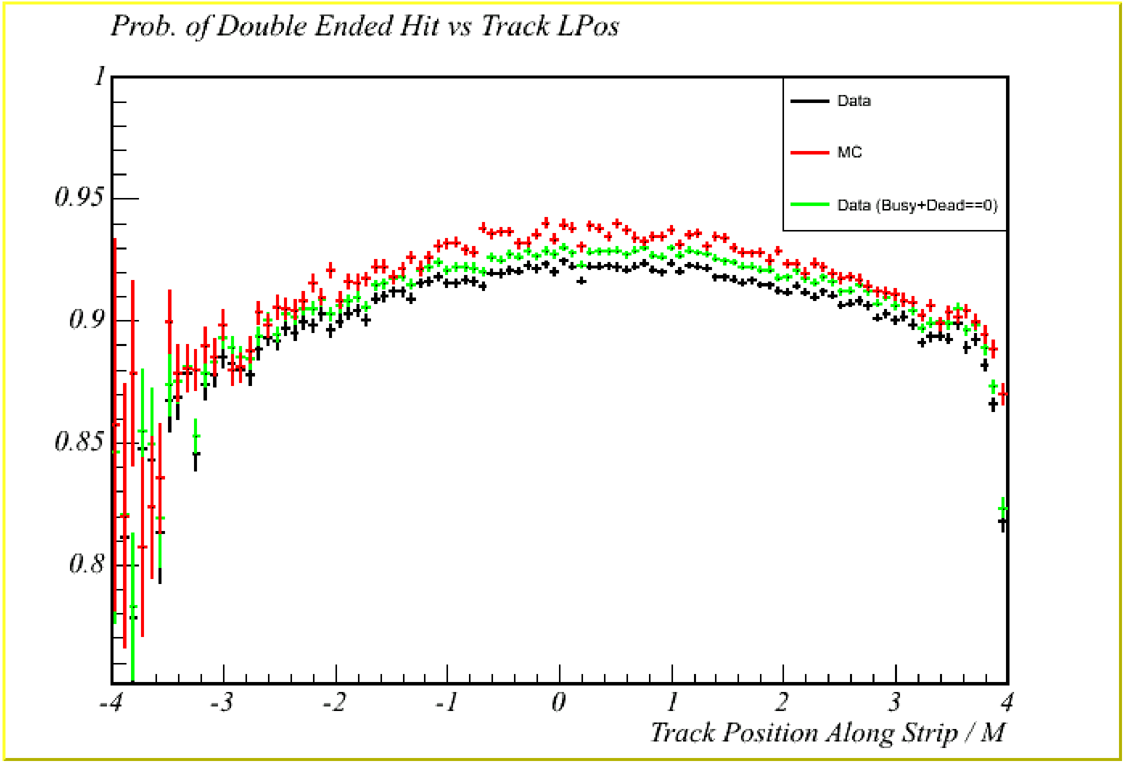
Efficiency

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 ($\times 10^{-3}$)

3

0.54	3.35	11.01	1.35
0.32	9.81		1.46
0.06	0.91	2.21	0.84
0.15	0.17	0.39	0.23

2

0.41	1.33	12.74	1.97
0.19	2.73		3.28
0.07	0.65	2.55	1.00
0.12	0.15	0.27	0.22

1

0.45	0.96	12.36	3.98
0.25	1.42		11.25
0.07	0.50	2.40	1.12
0.05	0.14	0.32	0.37

5

0.49	1.30	5.59	1.45
0.36	5.35		2.49
0.05	1.08	5.09	0.97
0.05	0.20	0.33	0.20

4

0.28	0.81	5.60	1.59
0.16	1.94		5.70
0.07	0.61	5.39	1.35
0.10	0.15	0.35	0.33

8

0.58	1.34	2.54	1.23
0.35	9.88		1.57
0.12	2.48	10.10	1.04
0.10	0.26	0.48	0.32

7

0.50	0.86	2.82	1.34
0.25	3.00		3.21
0.08	1.11	11.95	1.55
0.14	0.24	0.55	0.25

6

0.45	0.69	2.73	1.84
0.22	1.58		10.84
0.20	0.75	12.16	3.09
0.07	0.15	0.53	0.44

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

Noise

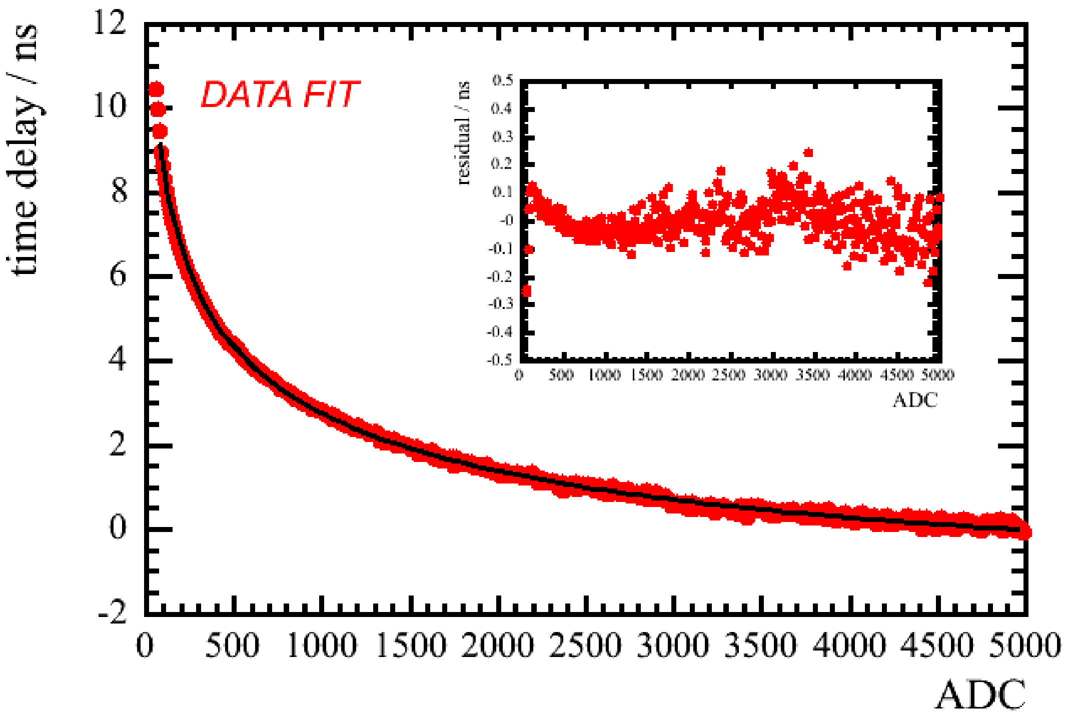
Noise some numbers:

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

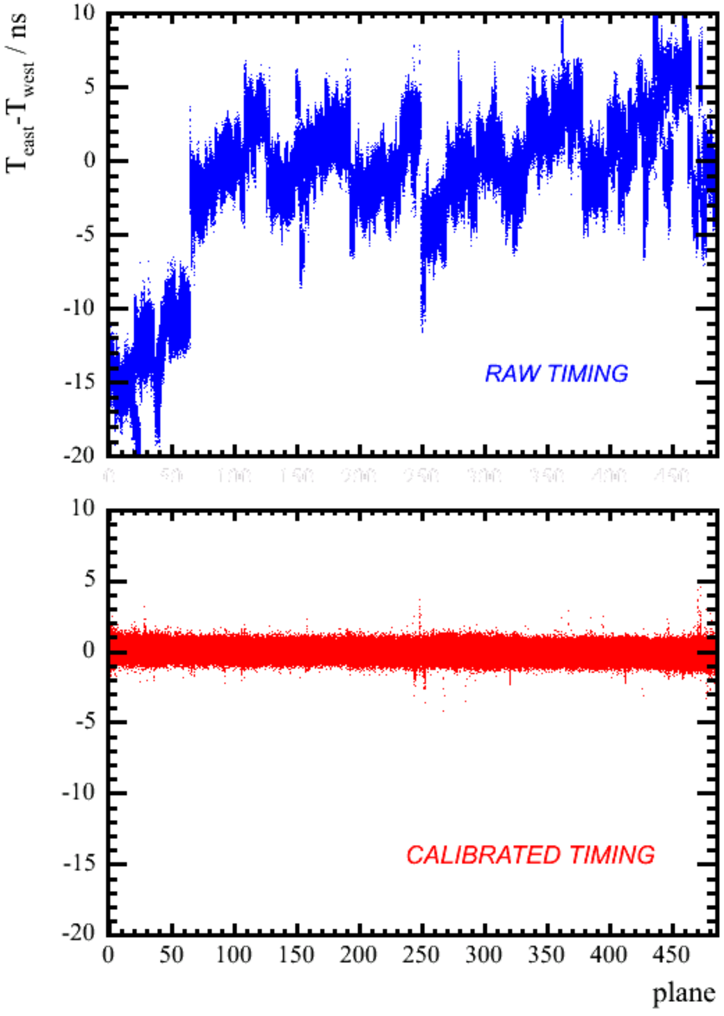
For more info : NIMA 545 (2005) 145-155

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

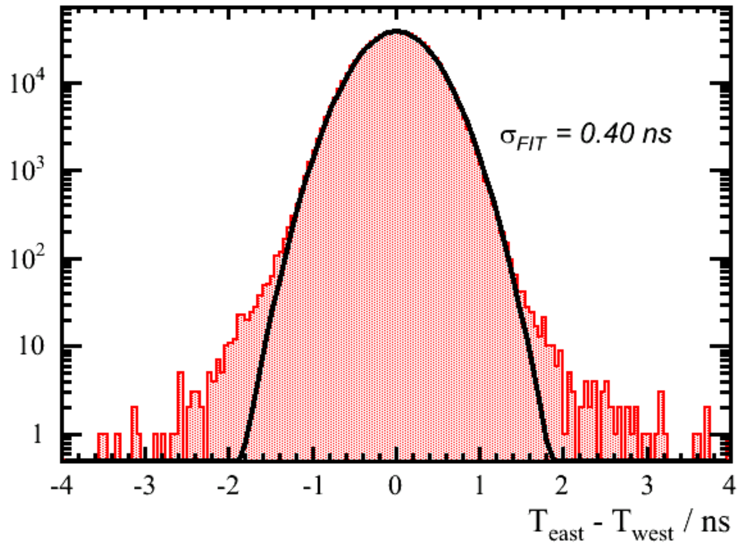


Timing Calibration



Use cosmic muons:

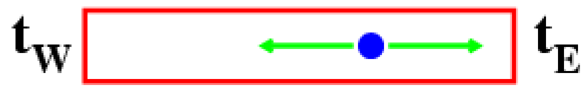
★ Remove electronics and fibre length offsets



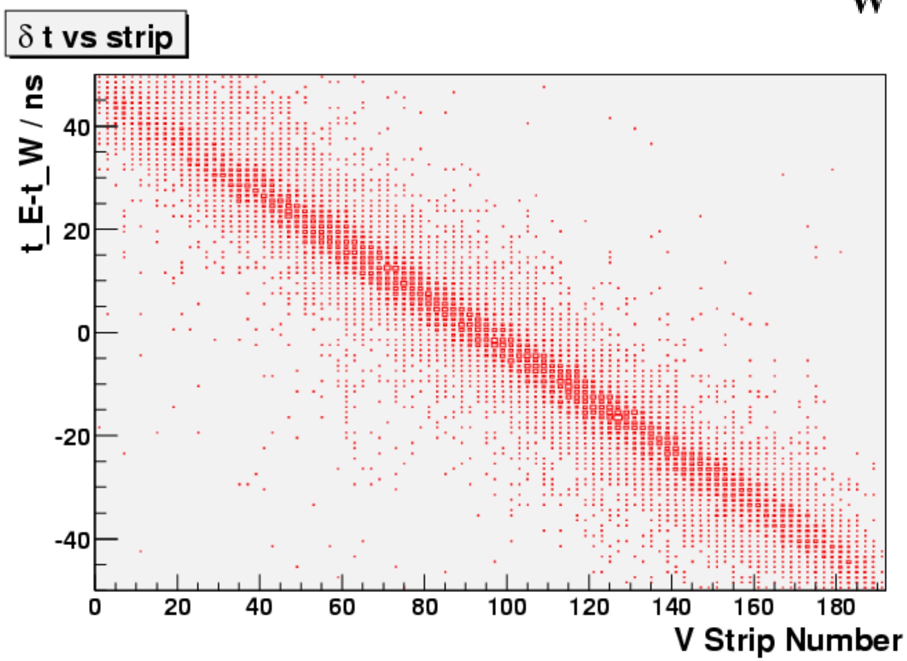
One use of timing

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

e.g. U Strip



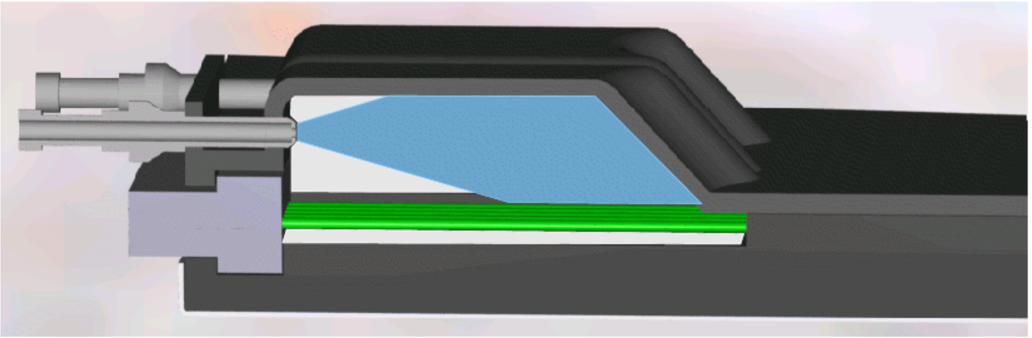
$t_W - t_E \rightarrow V$



★ 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

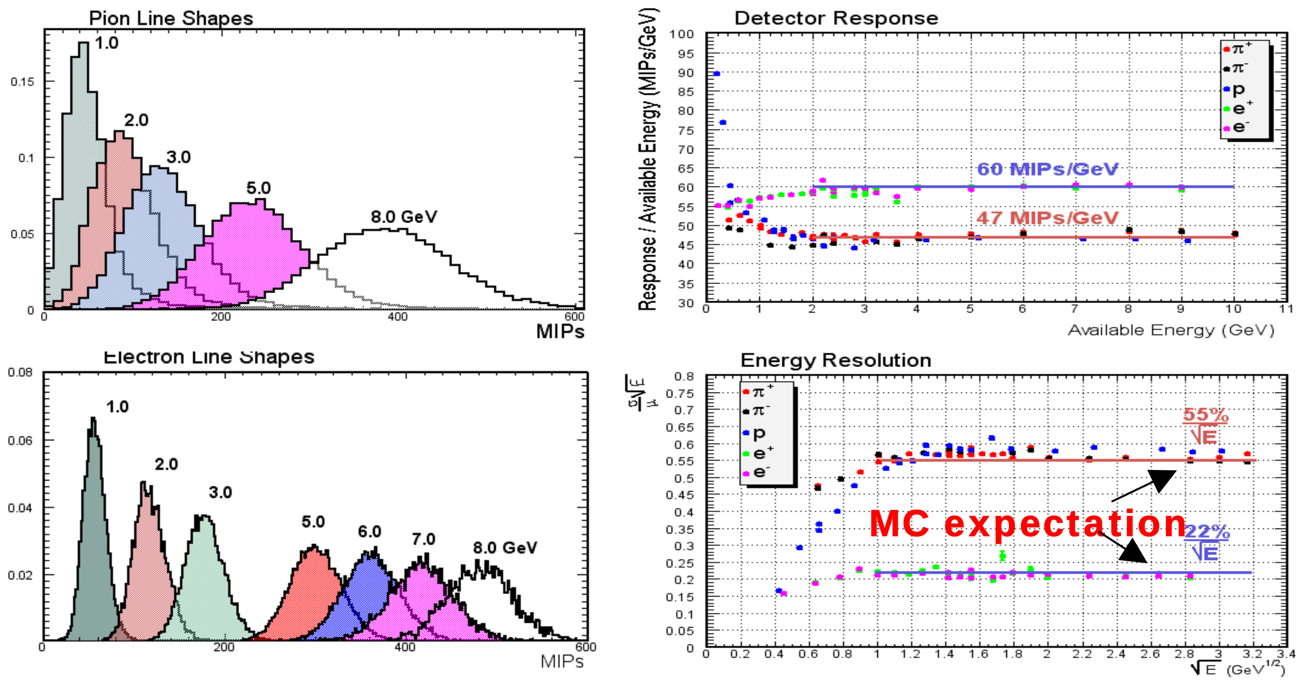
II) Cosmic Muons (VERY POWERFUL):

- ✦ 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…