Scintillator-ECAL beam tests

Satoru Uozumi, Kobe University

for Daniel Jeans, Miho Nishiyama

and all the ScECAL group

1. DESY Beam Test (Mar 2007) … First test of ScECAL
2. KEK Beam Test (Nov 2007) … To establish extruded scintillator strip
3. FNAL Beam Test (Sep 2008) … Final test with larger prototype and various type & energy of beams

CALICE
Calorimeter for ILC

KOBE UNIVERSITY

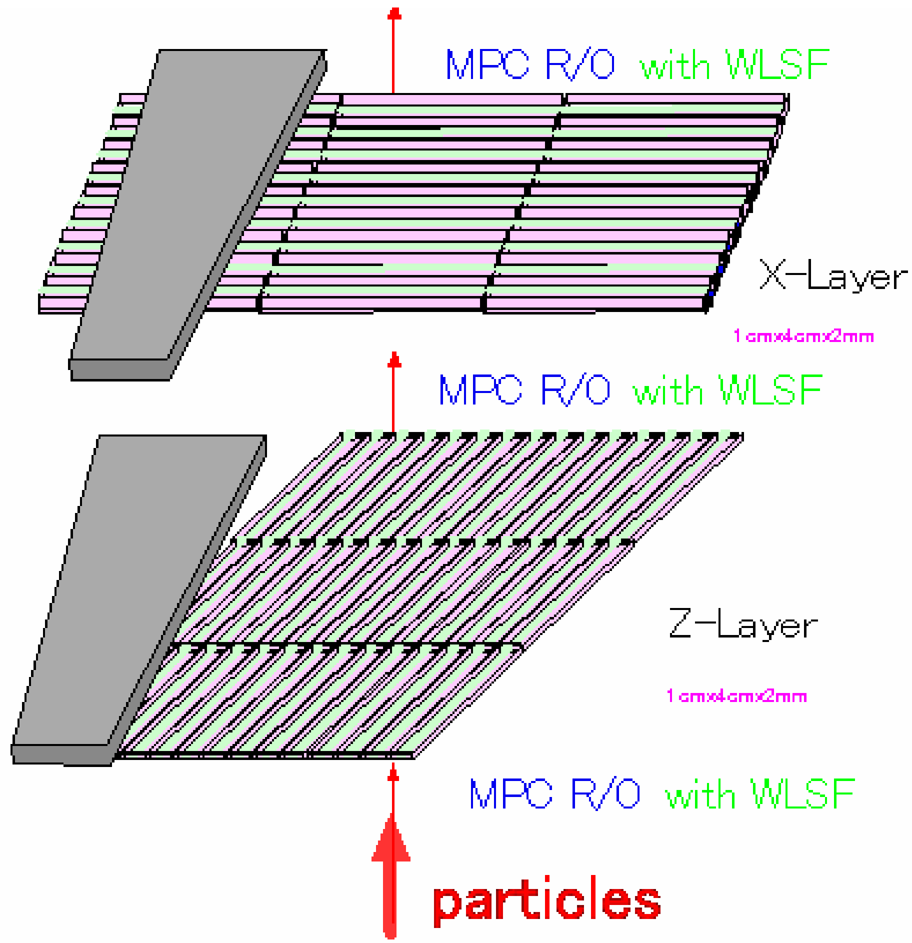
strip scintillator calorimeter

sampling calorimeter
- active material: scintillator
- absorber: W/Fe/Pb

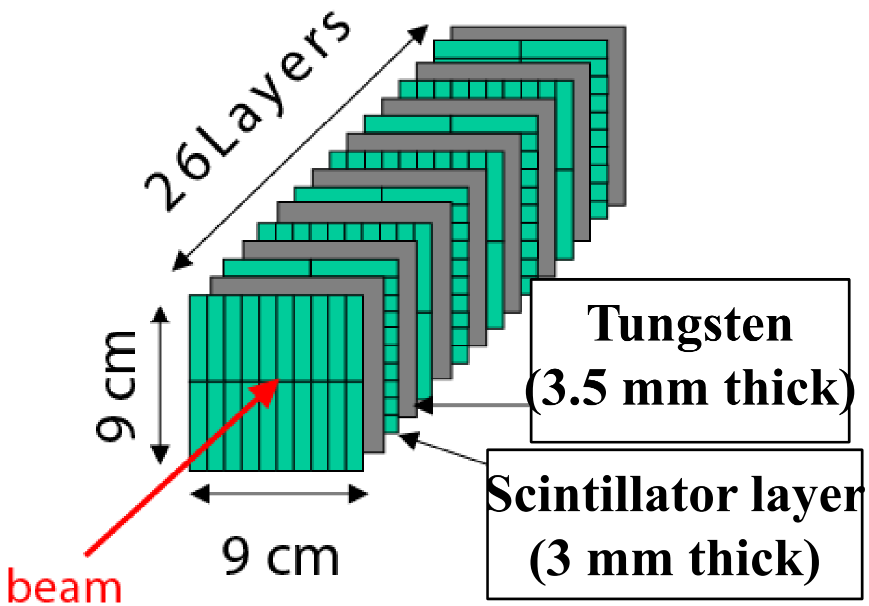
designed for PFA: fine segmentation
- scintillator strips ~1x4 cm^2
- orthogonal layers

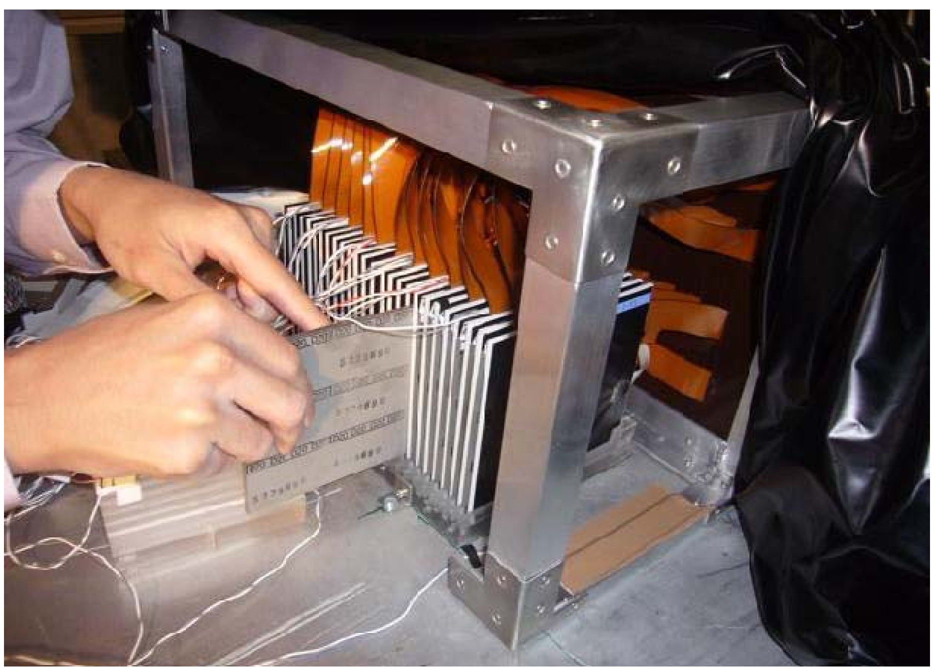
each strip read out by MPPC
- photon counting device

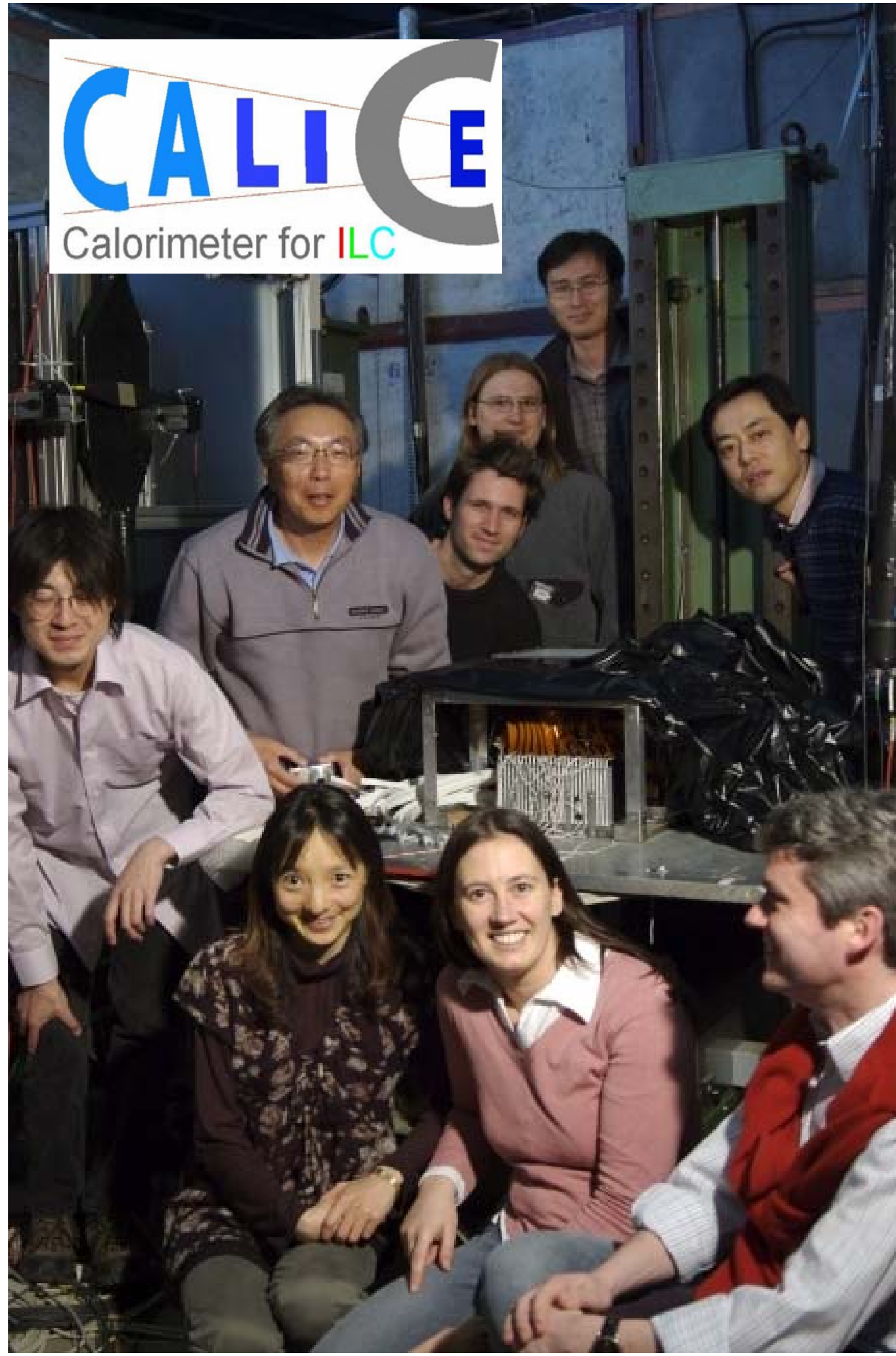
built and tested small prototype
- first test for scintillator + MPPC (
- check suitability for ILC ECAL



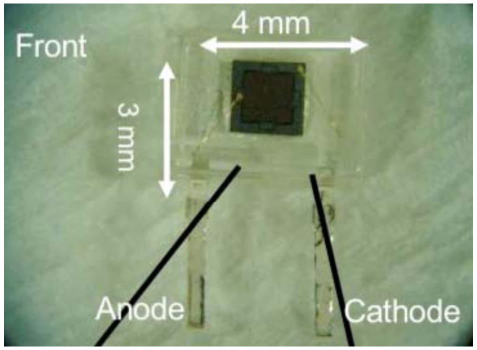
exposed to 1-6 GeV e+ beam
at DESY 03/07

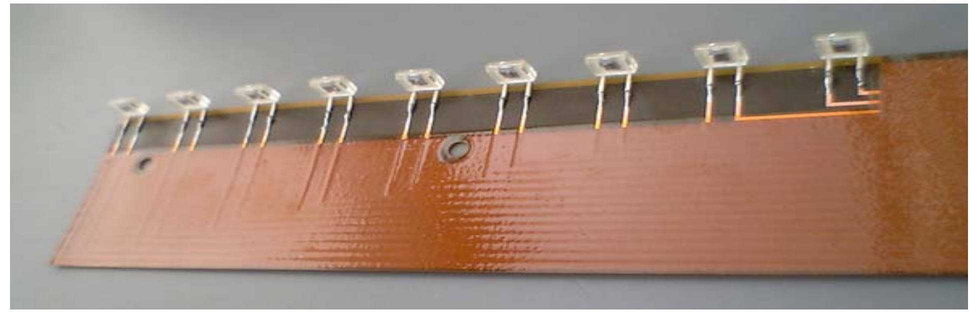


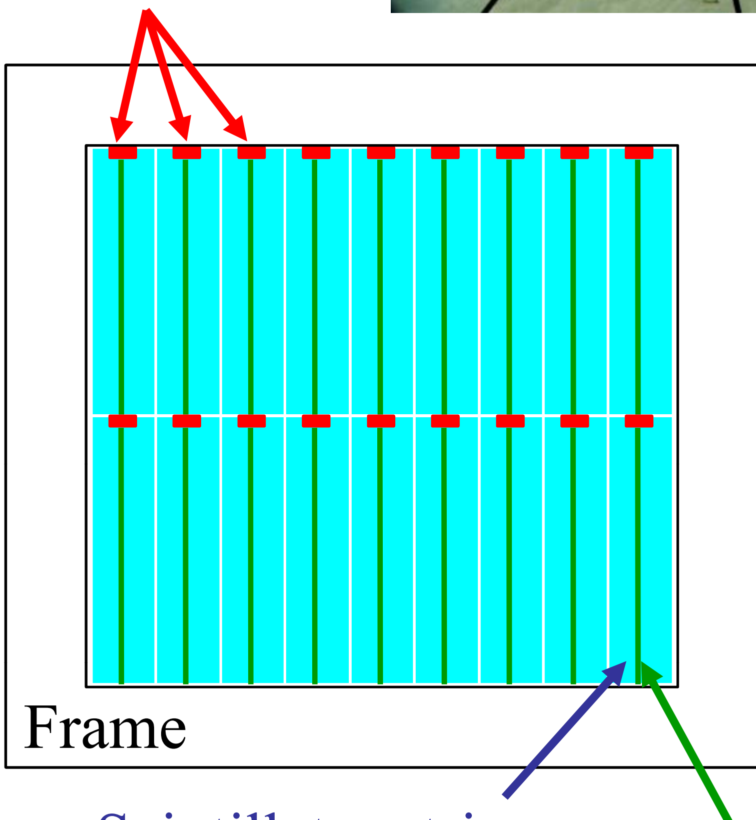




Detector setup, scintillator types







3 types of scintillator strips:

Kuraray (Megastrip)
- WLSF readout
- direct readout (simpler)

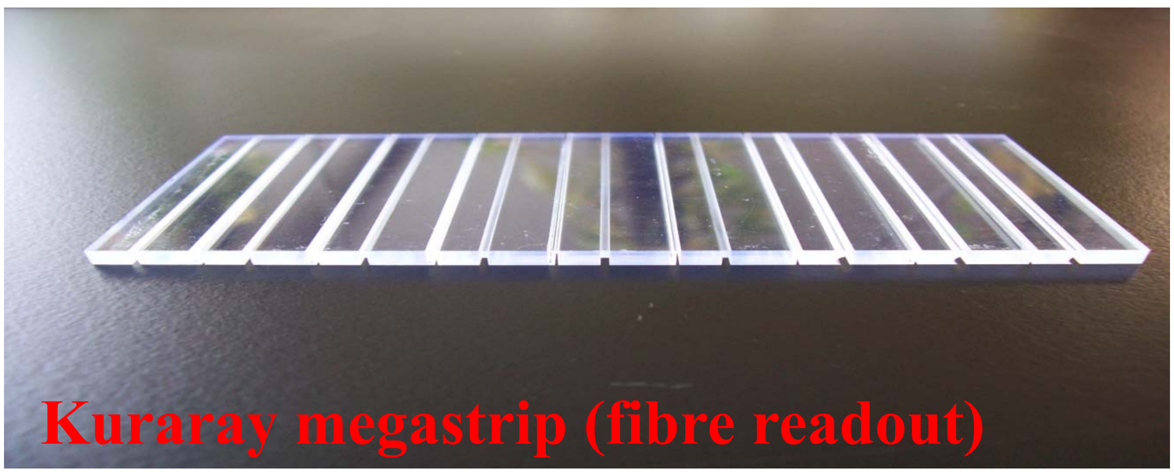
KNU/Korea (separate strips)
- extruded scintillator (inexpensive)
- WLSF readout

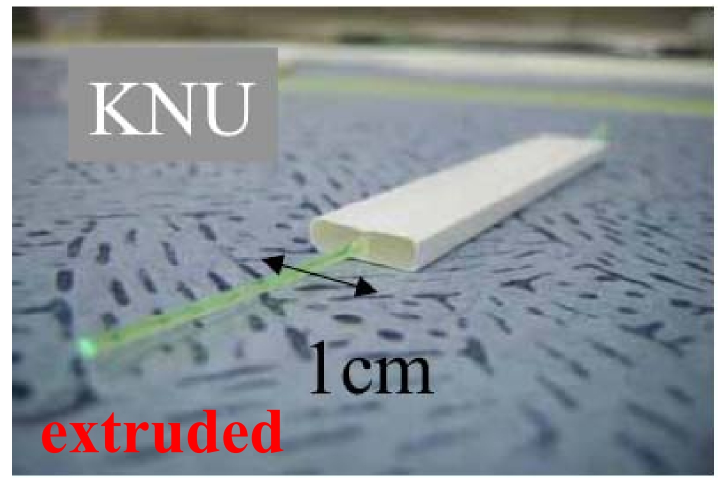
CALICE readout electronics (LAL-Orsay) borrowed from DESY CALICE A-HCAL group

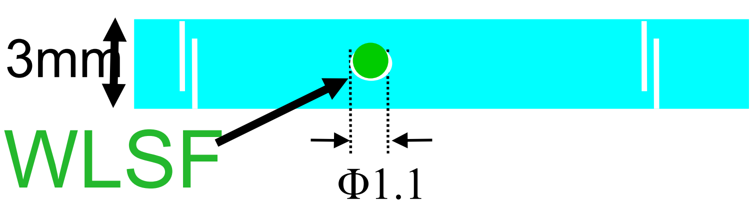
produced 3 half-modules (13 layers each)
with different scintillator types

tested 3 configurations

Kuraray (fibre) + Kuraray (direct)
Kuraray (direct) + Kuraray (fibre)
Extruded (fibre) + Kuraray (fibre)

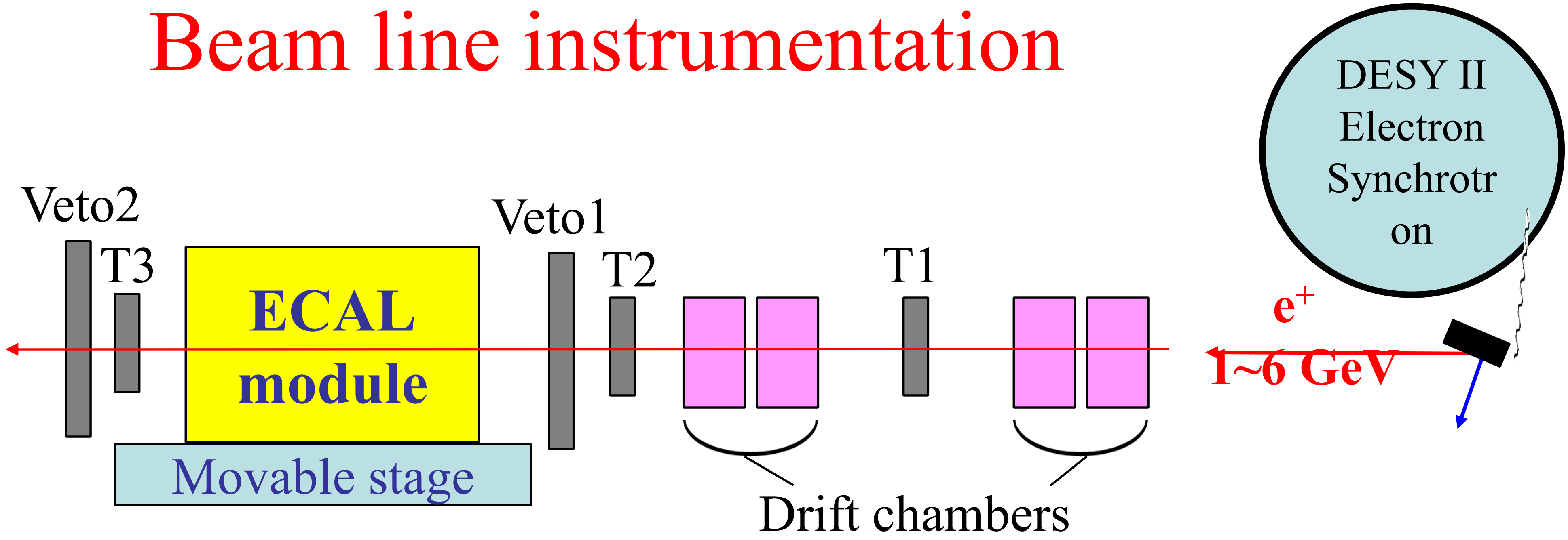


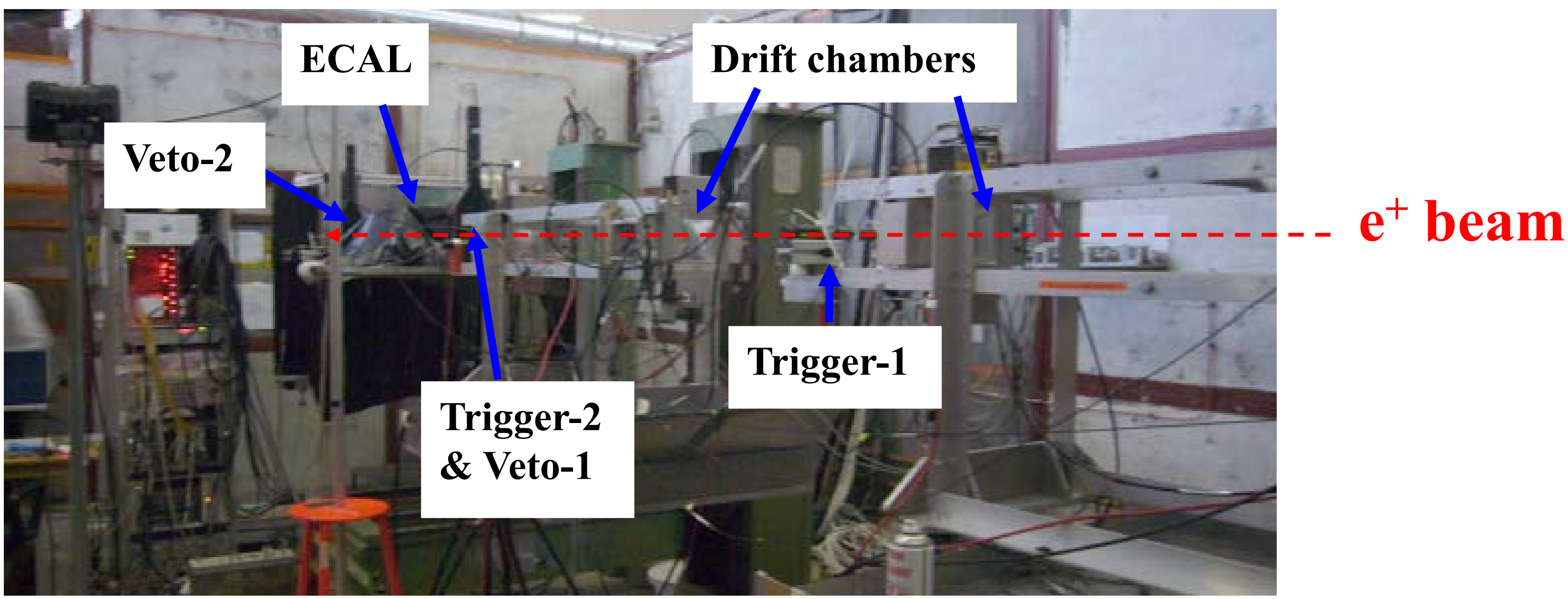




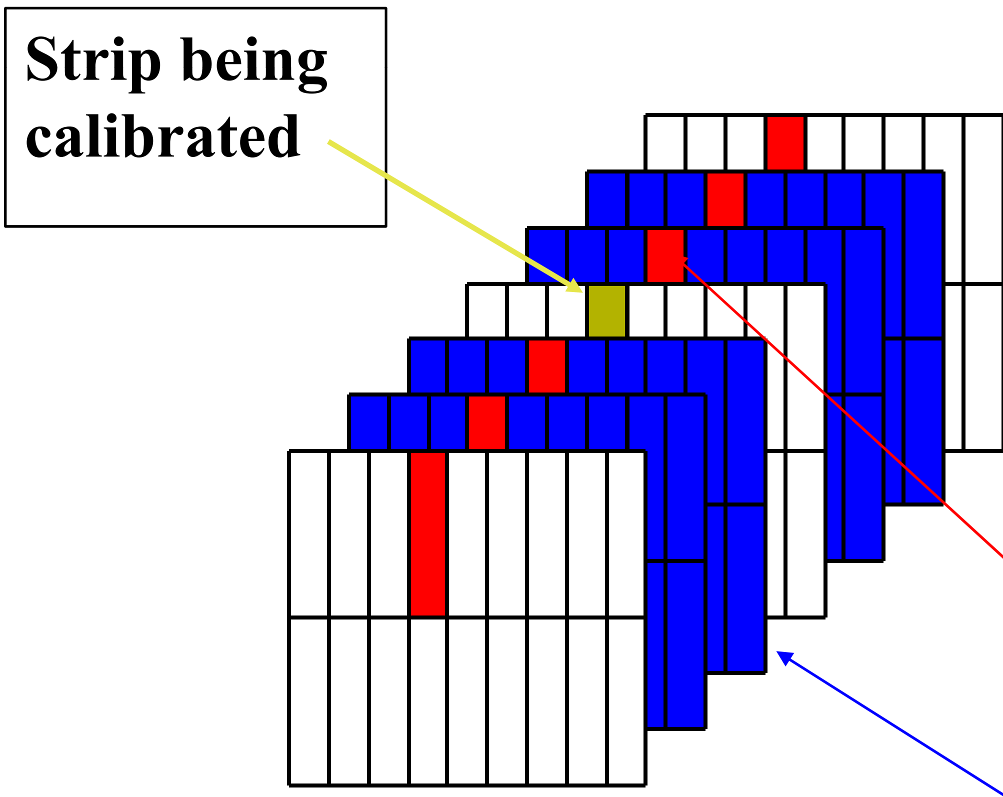
Compare performance of 3 configurations

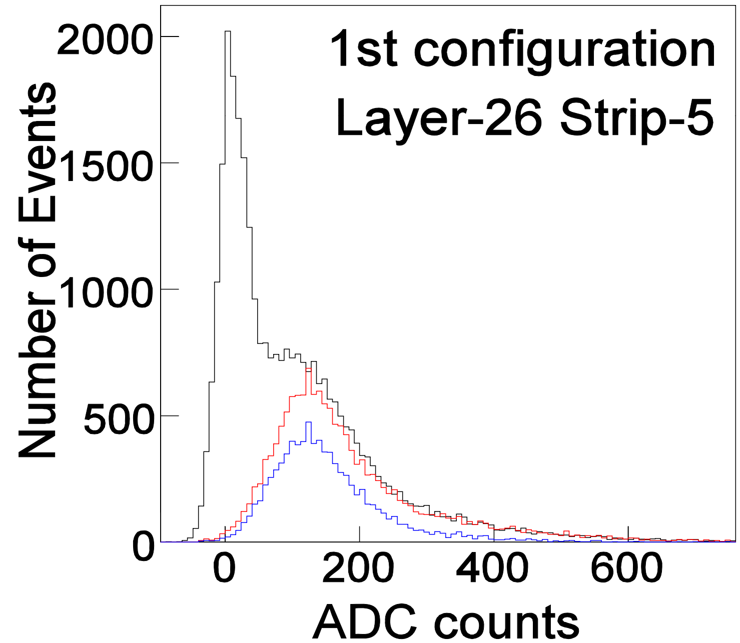
Beam line instrumentation





MIP calibration

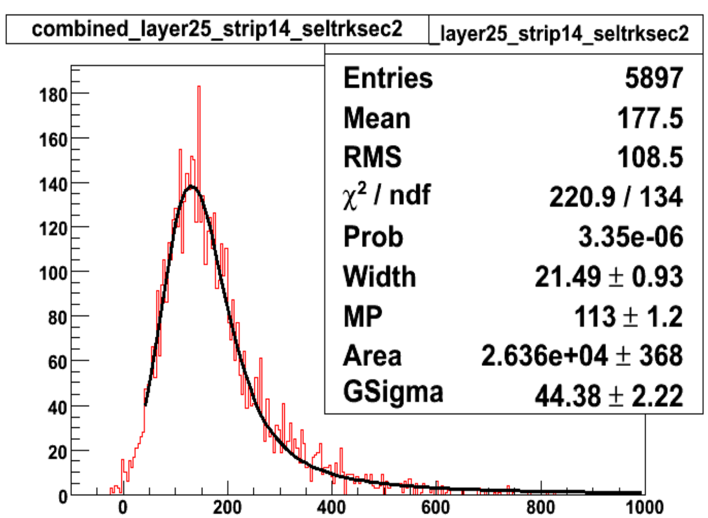




Trigger only

Red strips have non-pedestal signal

Blue strips have only pedestal signal

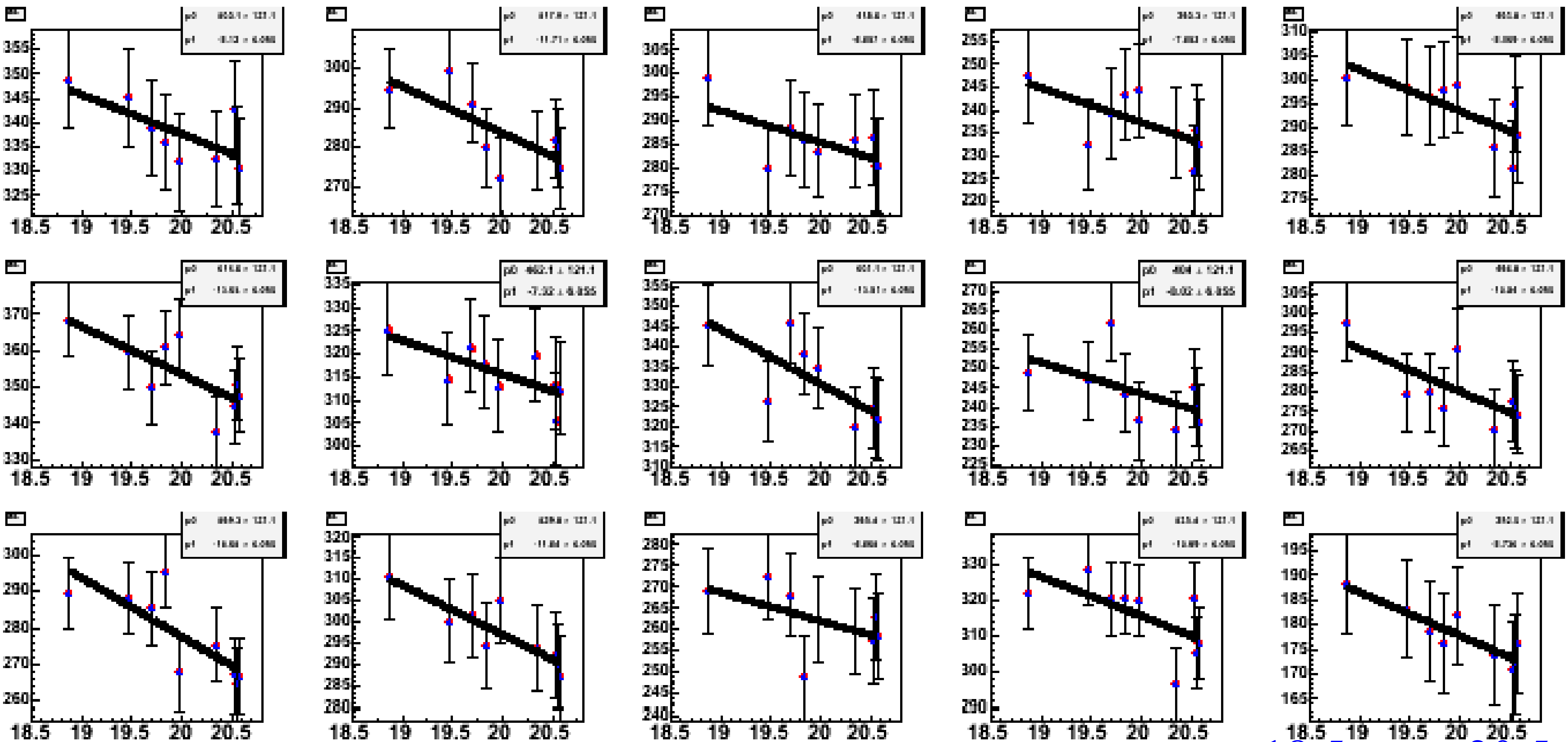


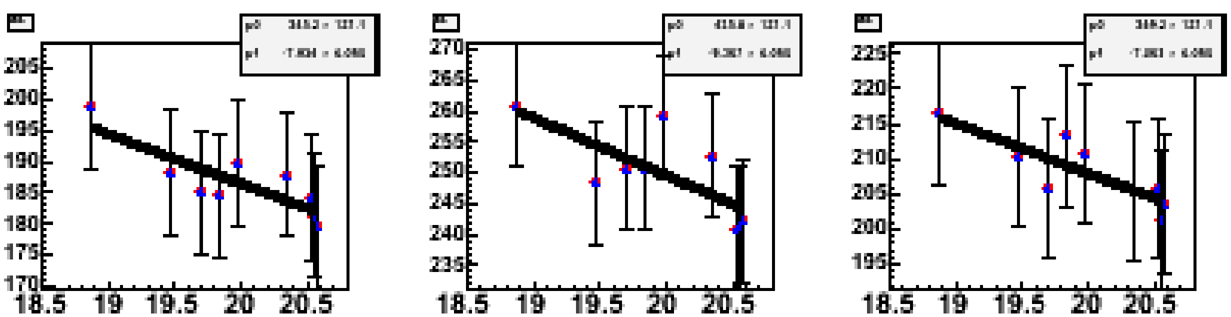
fit to Gaussian-convoluted Landau

MIP response temperature dependence

MPPC gain changes with temperature

example: 18 strips in one layer





18.5 20.5

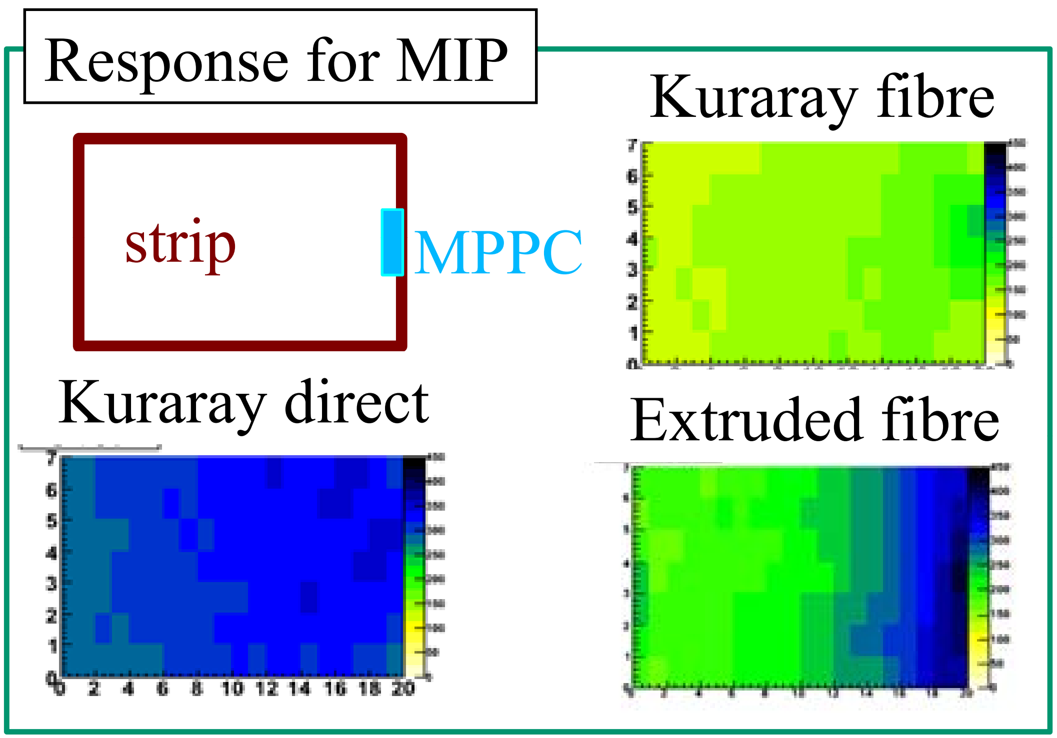
temperature

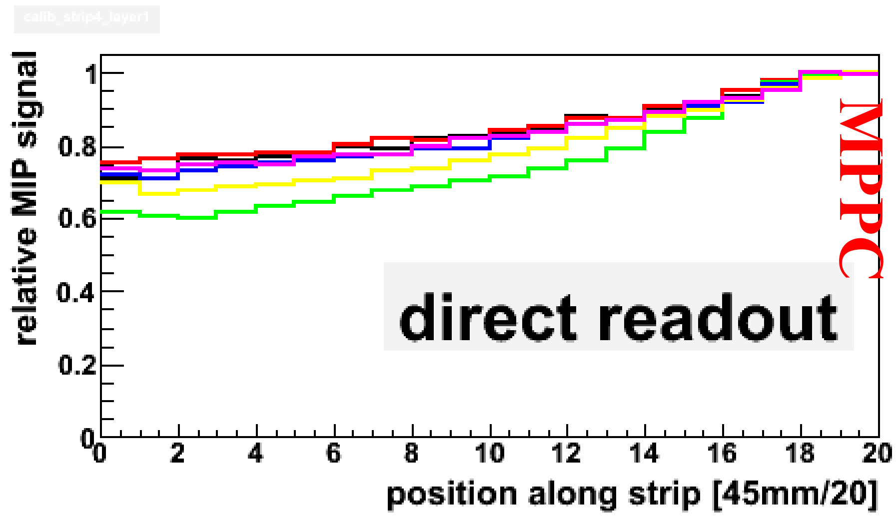
consistent for all channels

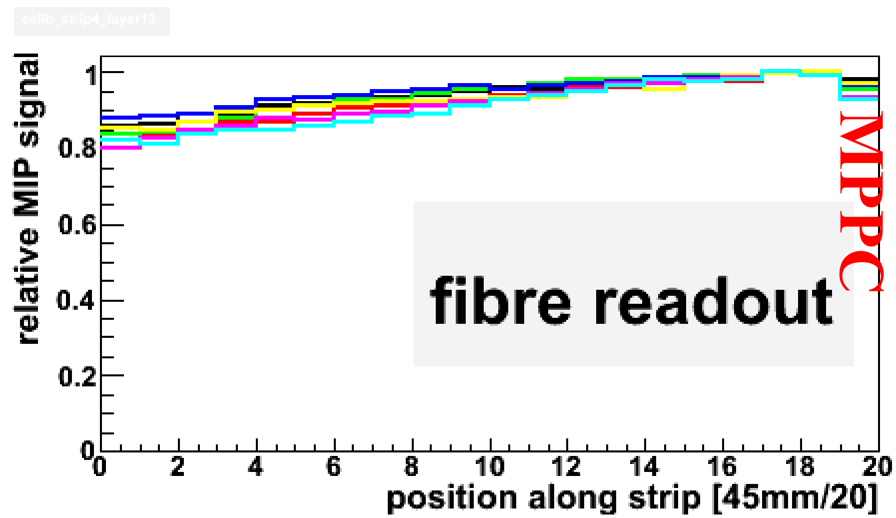
apply common correction

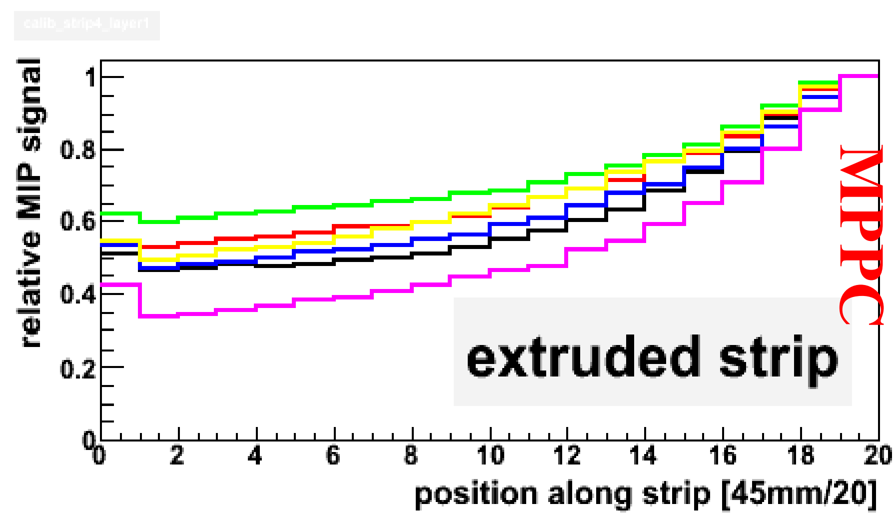
MIP response uniformity:
detailed scan across single strip

extruded strips show significant non-uniformity

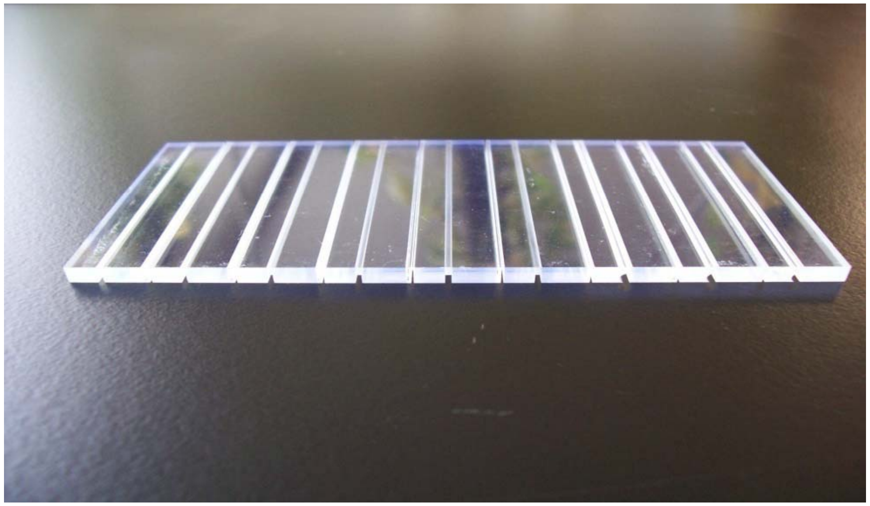


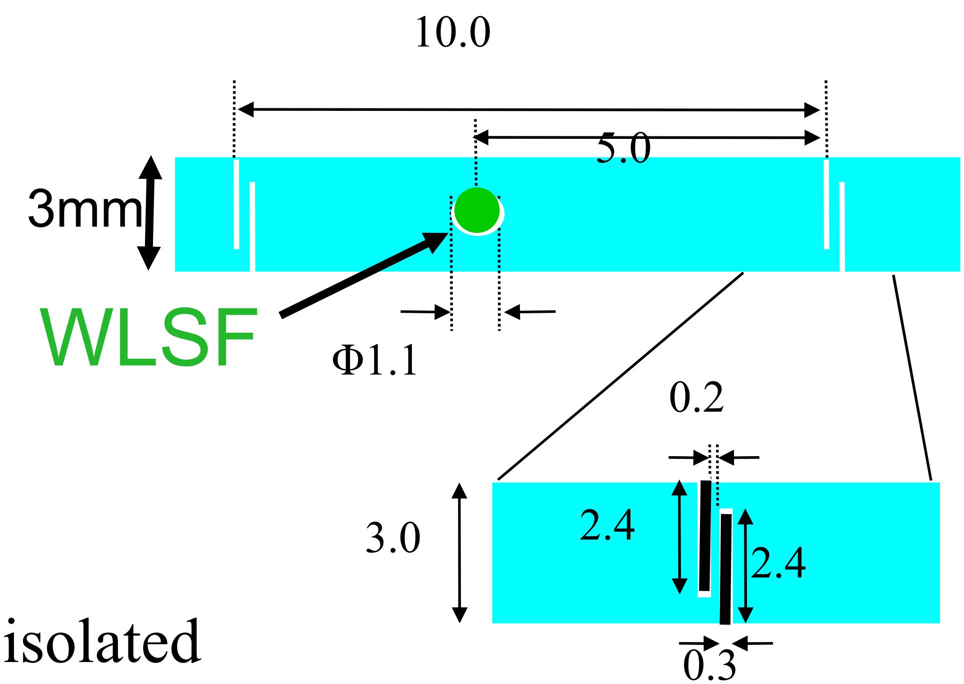




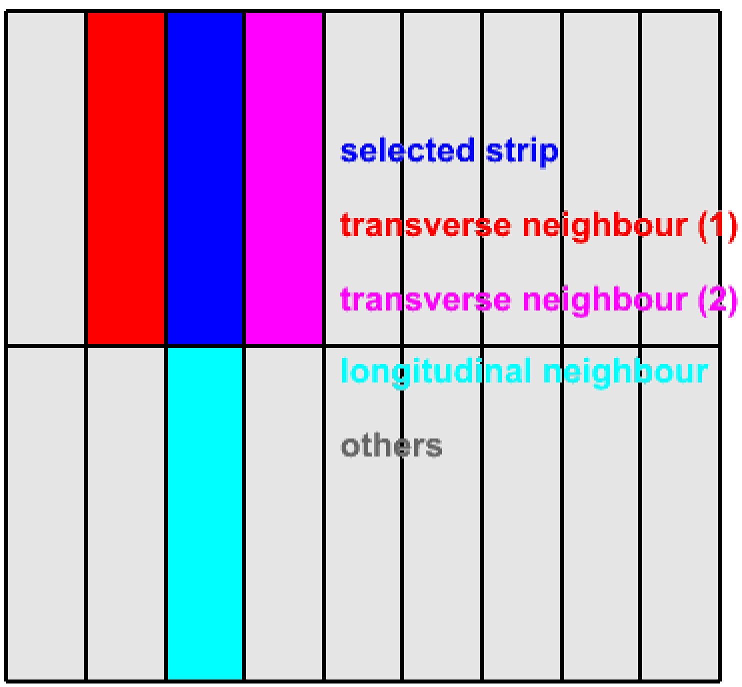


light cross-talk between adjacent strips

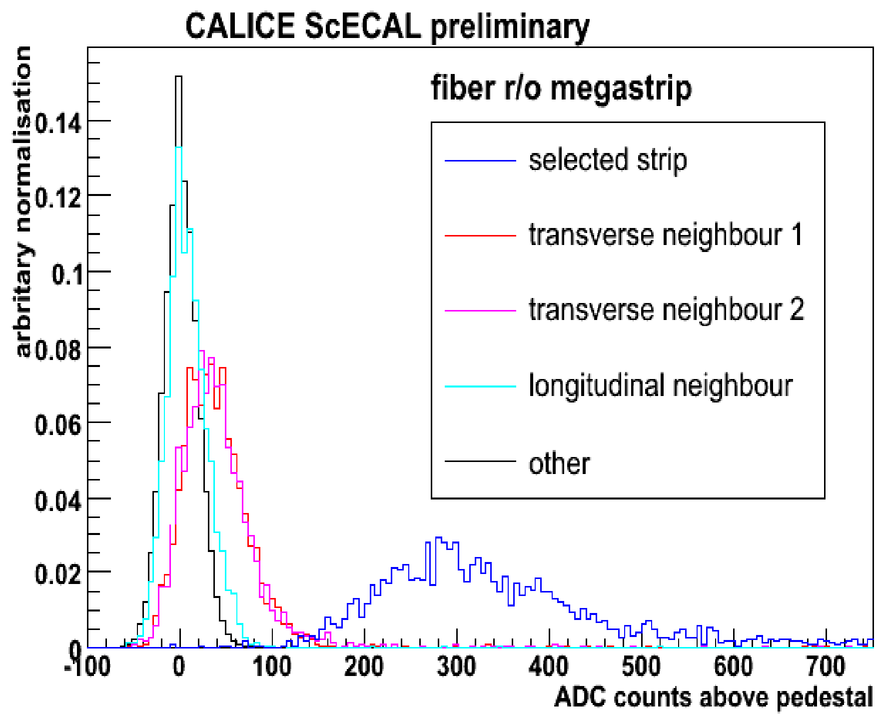




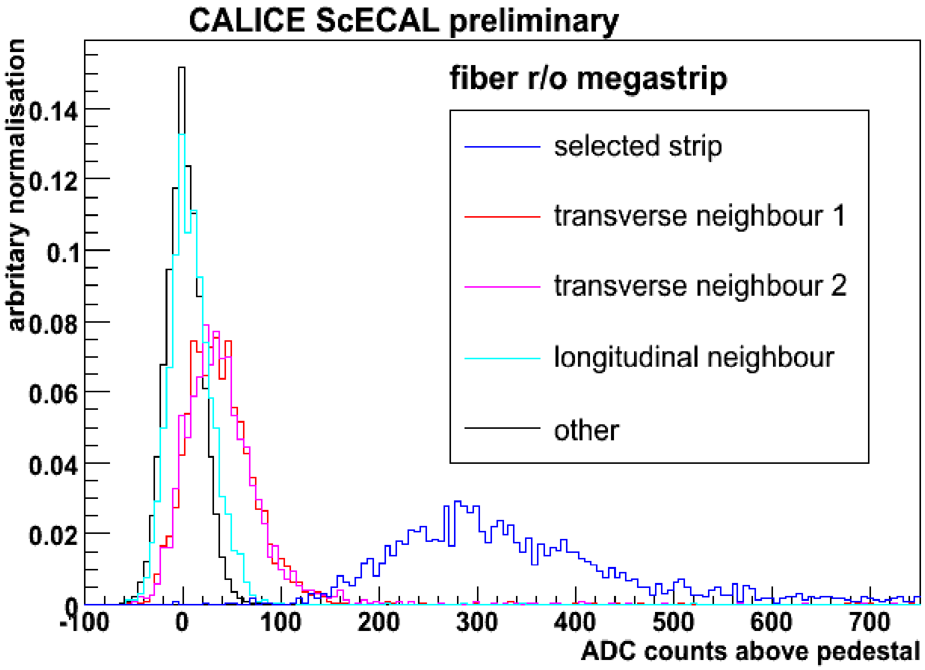
Mega-strip structure: strips not perfectly isolated

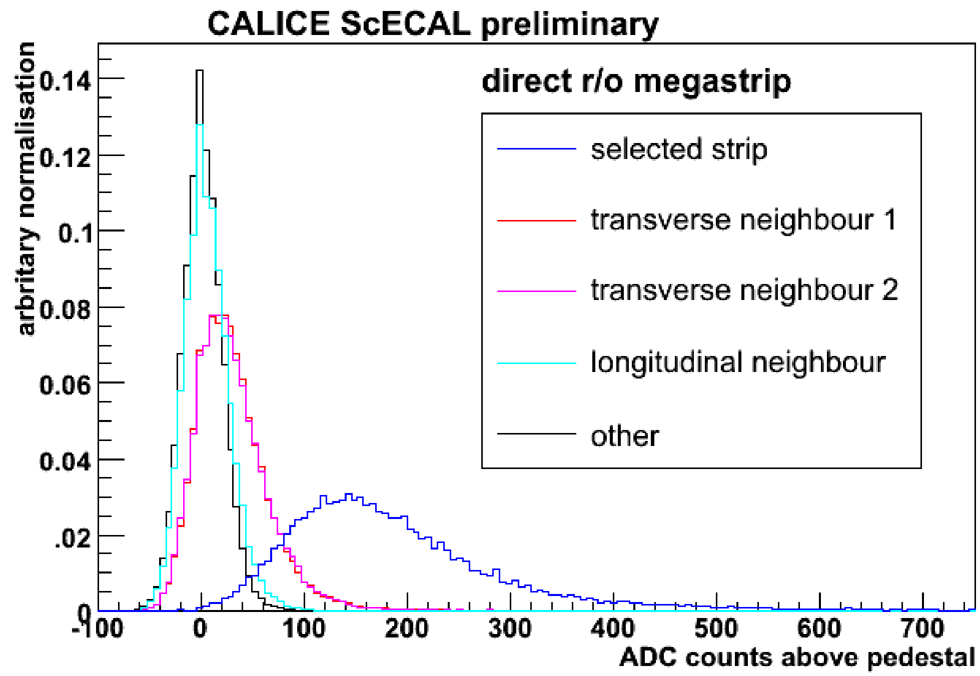


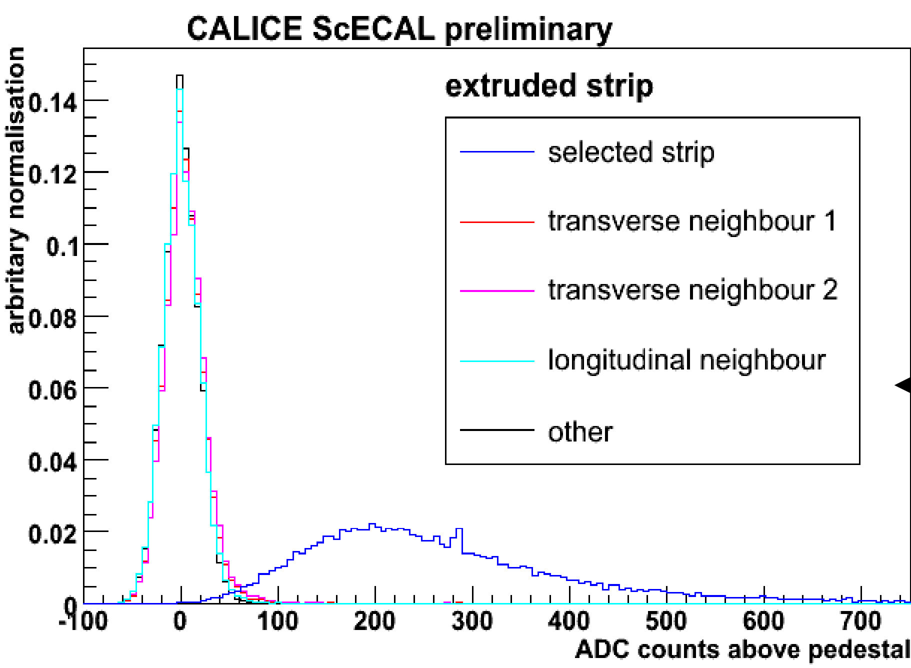
look at signal when MIP hits adjacent strips



light xtalk: different configurations

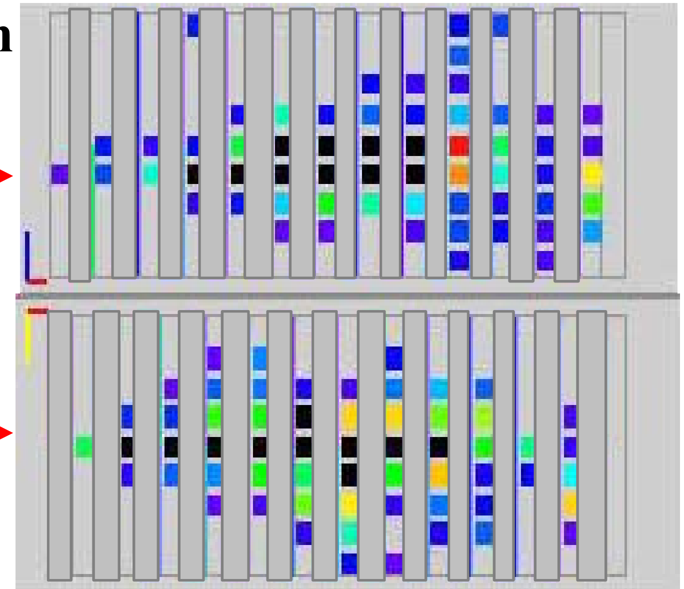






much less light cross-talk
in extruded strips

runs with tungsten plates



range of e+ beam momentum: 1->6 GeV/c

scanned front face of detector

apply calibration constants

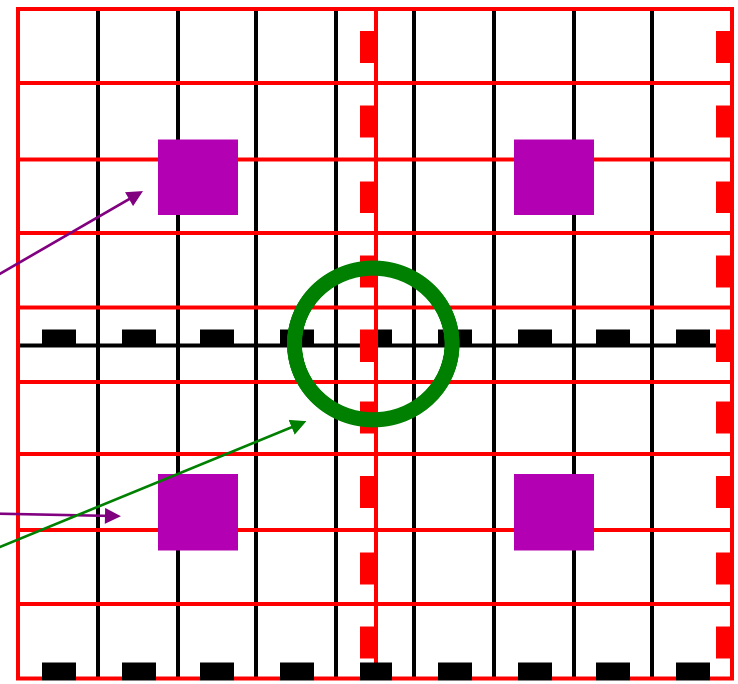
temperature correction

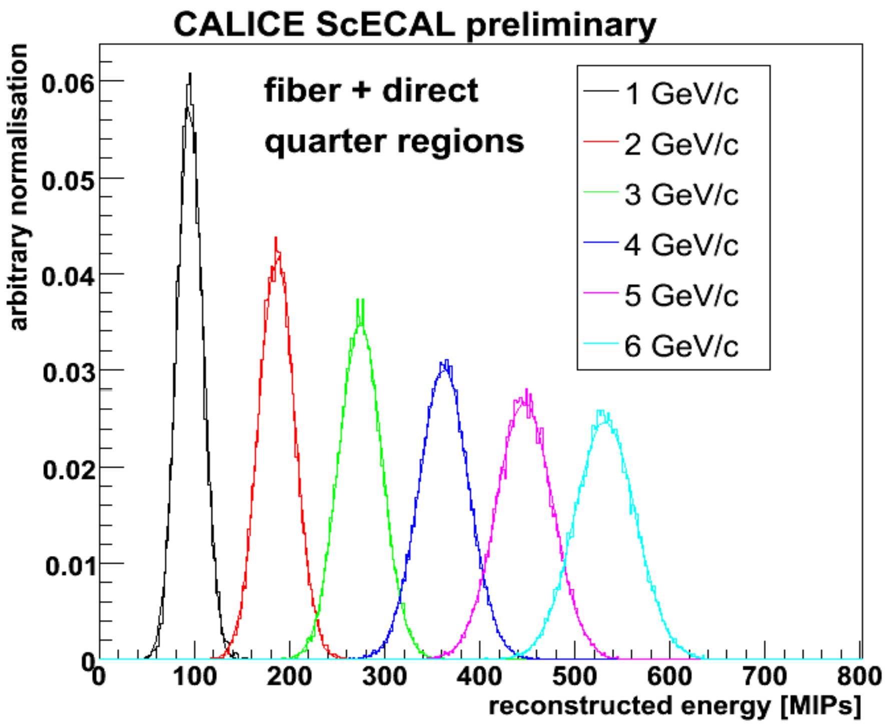
cross-talk correction

look at different detector regions

quarter regions – most uniform

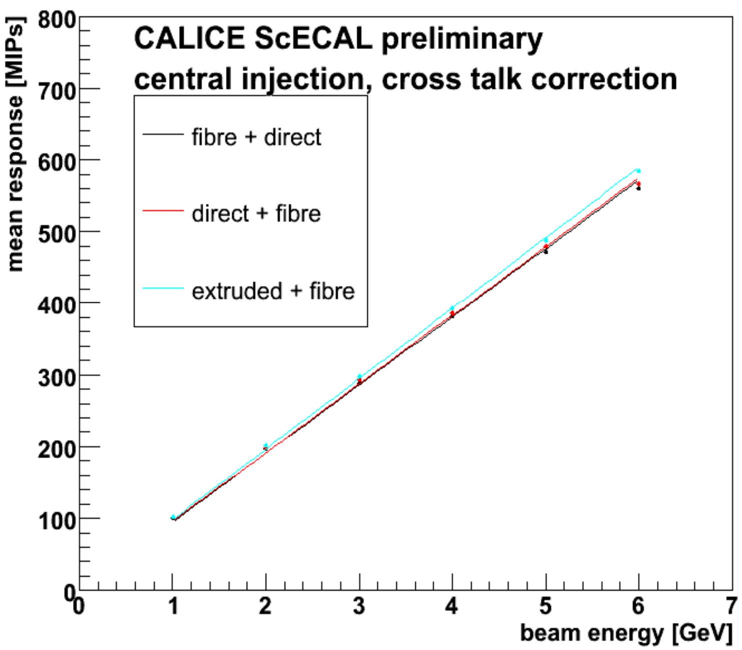
central region – least uniform, least leakage

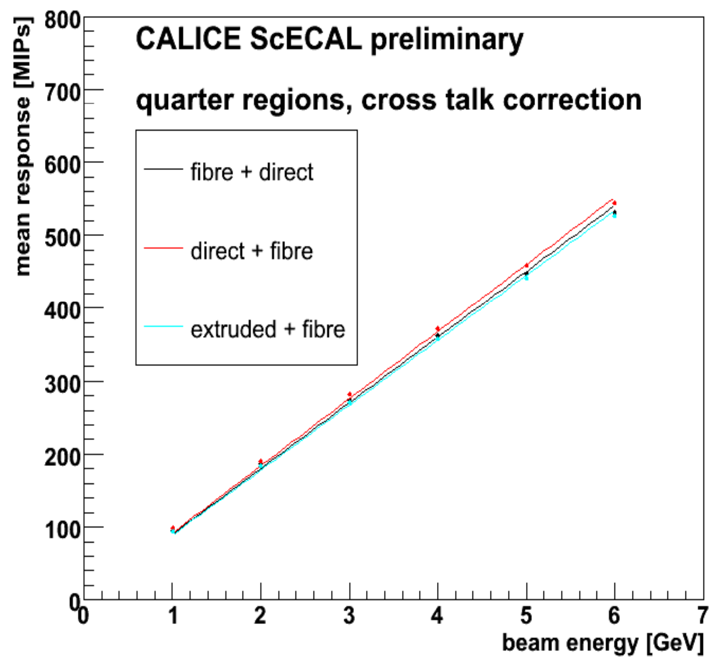




energy response

reconstruct total energy deposited in calorimeter

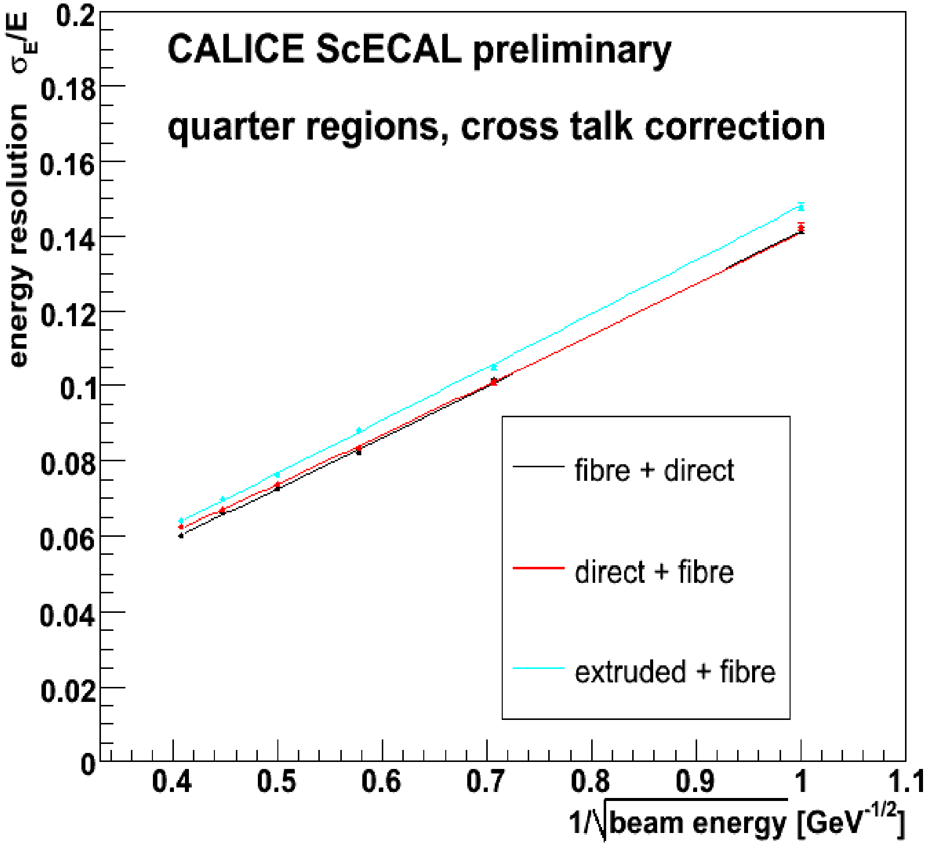


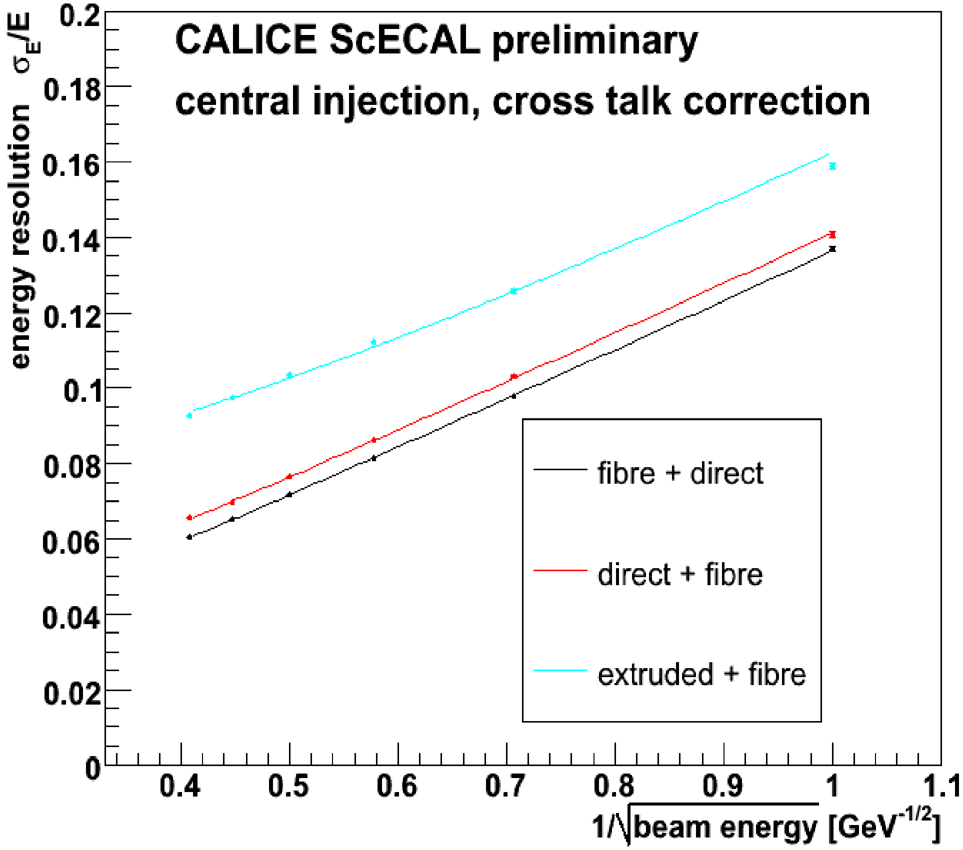


linear response

no strong effect of MPPC saturation has been seen

Energy resolution of 3 configurations





resolution of configurations similar in quarter regions

at centre of detector, extruded+fibre much worse:
strip uniformity improtant in this region

Conclusion of the DESY Beam Test

Analysis of DESY testbeam data in good shape

In uniform regions, detector works well
sufficient energy resolution for ILC ECAL ($\sigma/E \sim 14\%/\sqrt{E} \oplus 2\%$)

Non-uniformity and small light yield of extruded strips significantly degrades performance.

In progress...

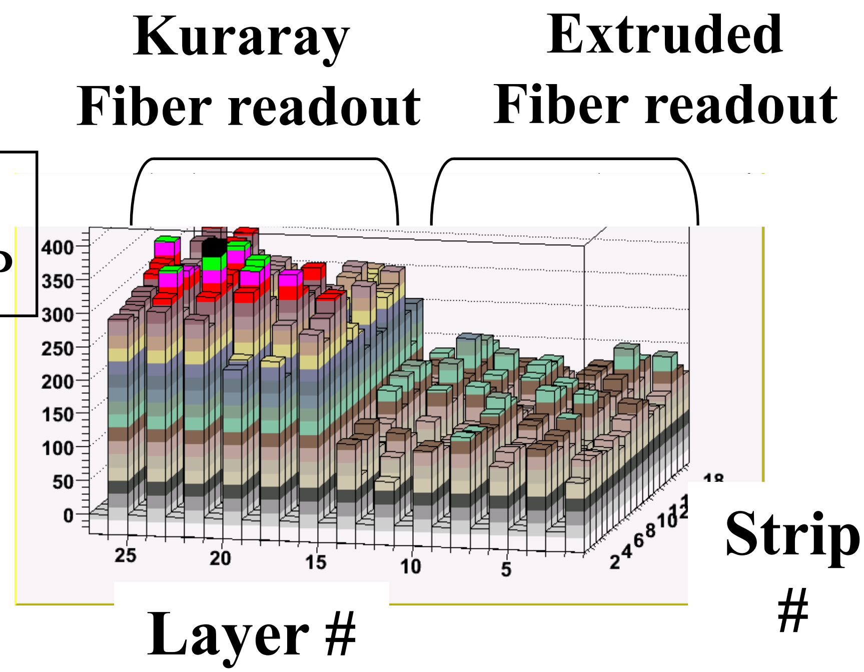
Some further data analysis (MPPC saturation correction...)
Detailed simulation
Proceed to publication

At the last DESY Beam Test…

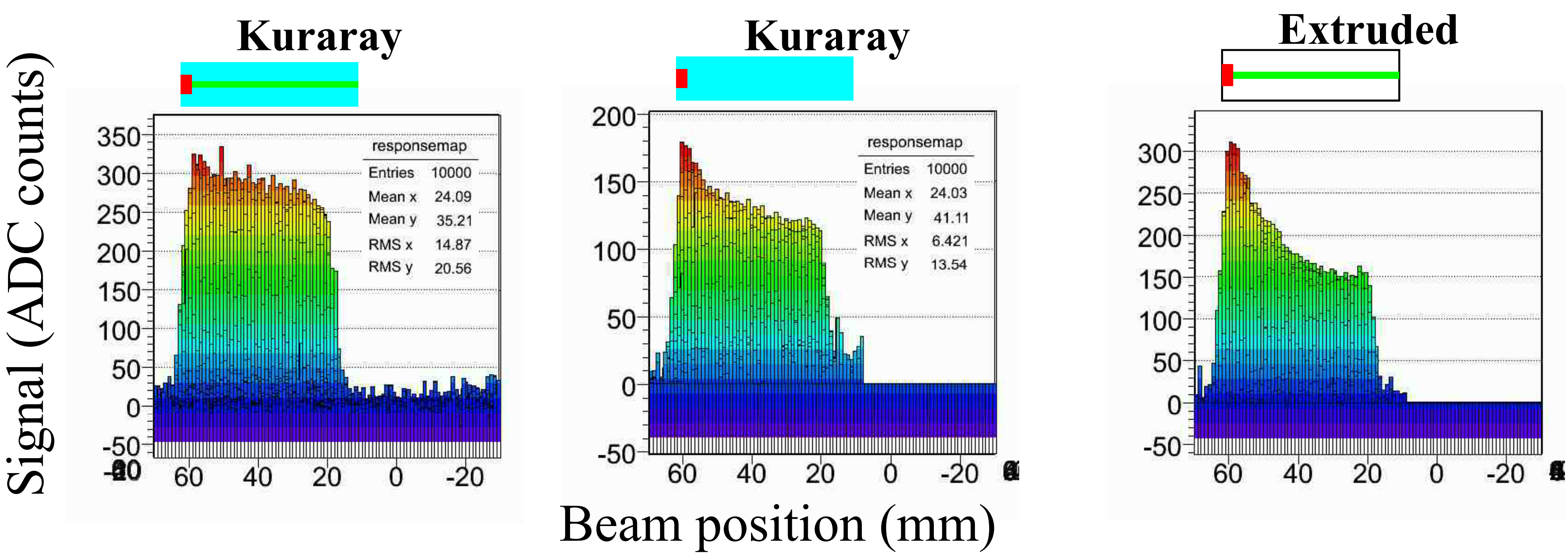
Extruded scintillator strips show

- Low light yield
- Large non-uniformity

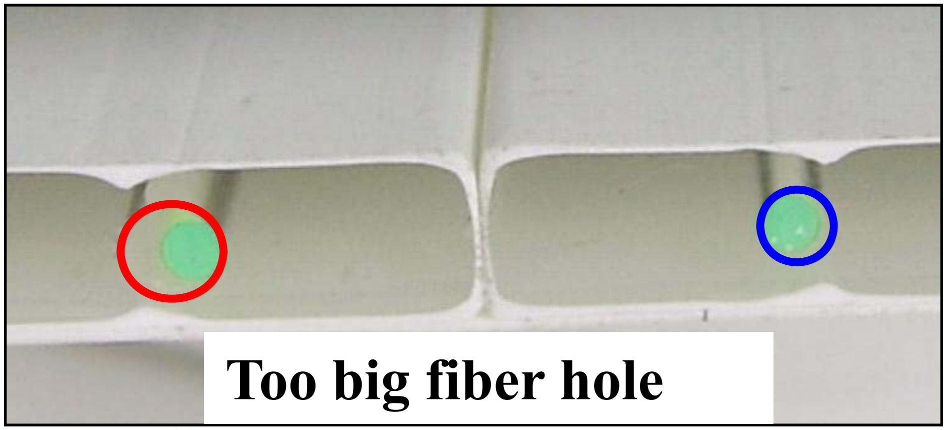
Response for MIP

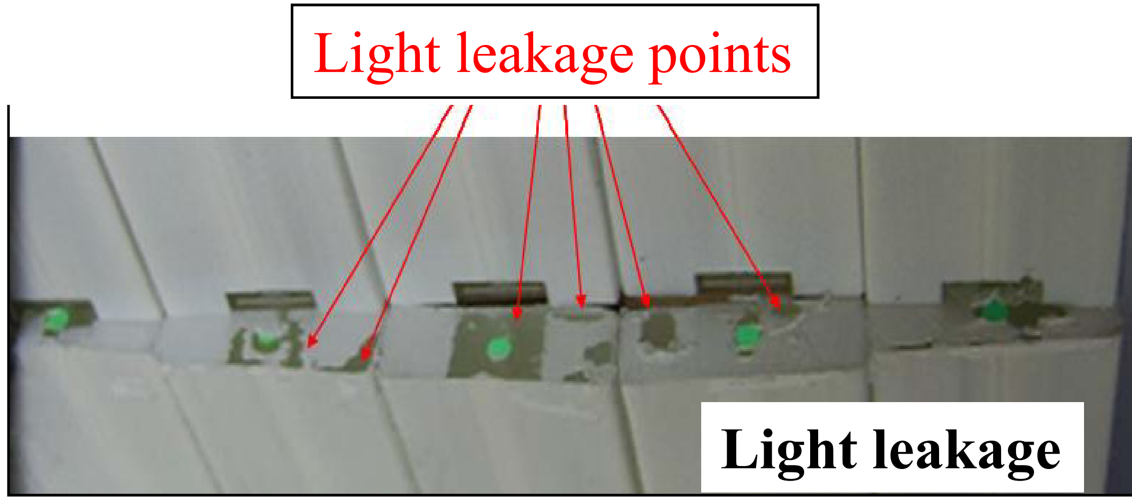


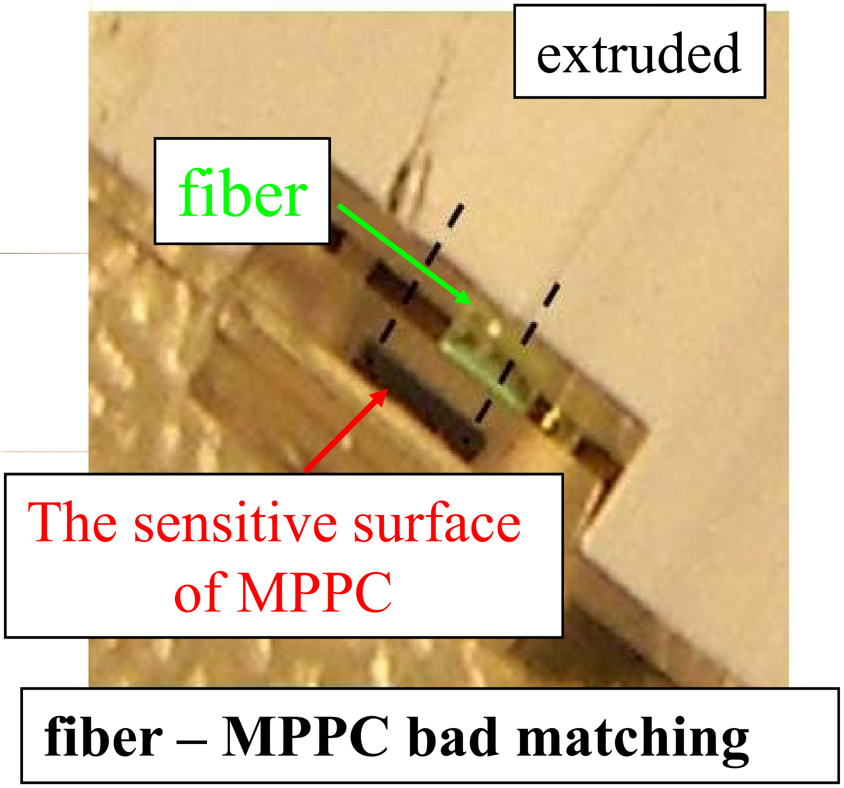
Uniformity of 3 different types of scintillators



Why the extruded scintillator showed such low light yield and non-uniformity?







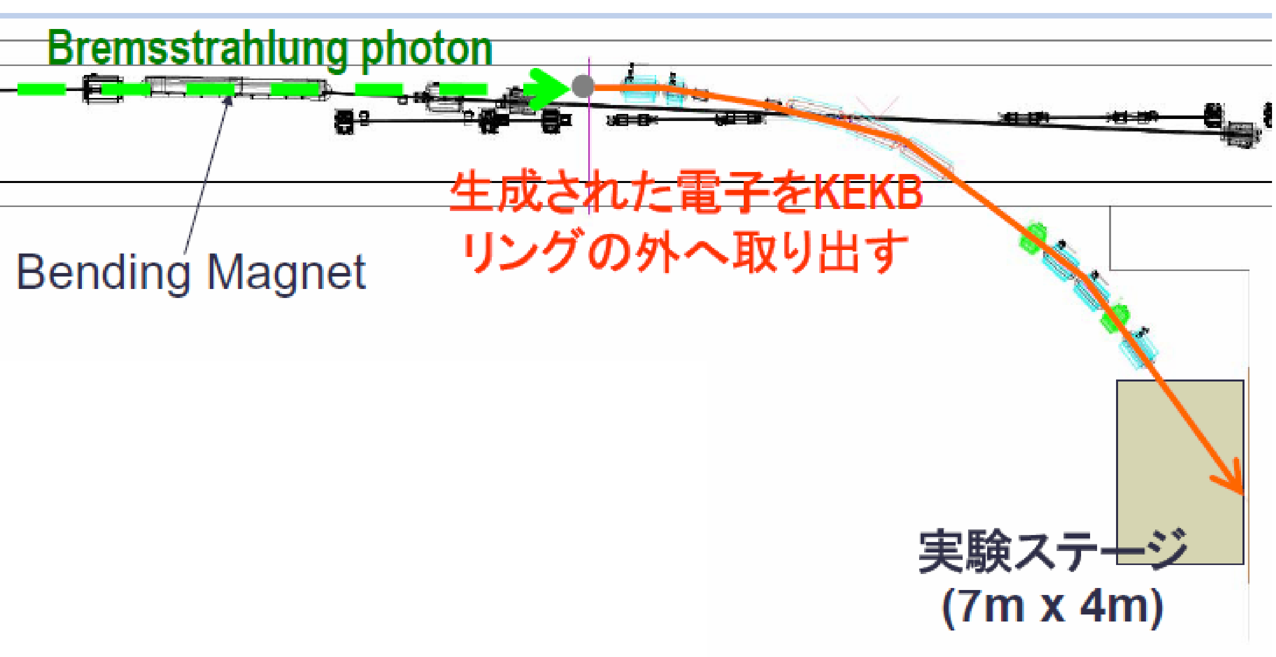
- **Some extruded scintillator strips have a bigger hole.**
- **Sometimes the hole isn't correctly centerd.**
- **Some extruded scintillator strips have leakage points.**

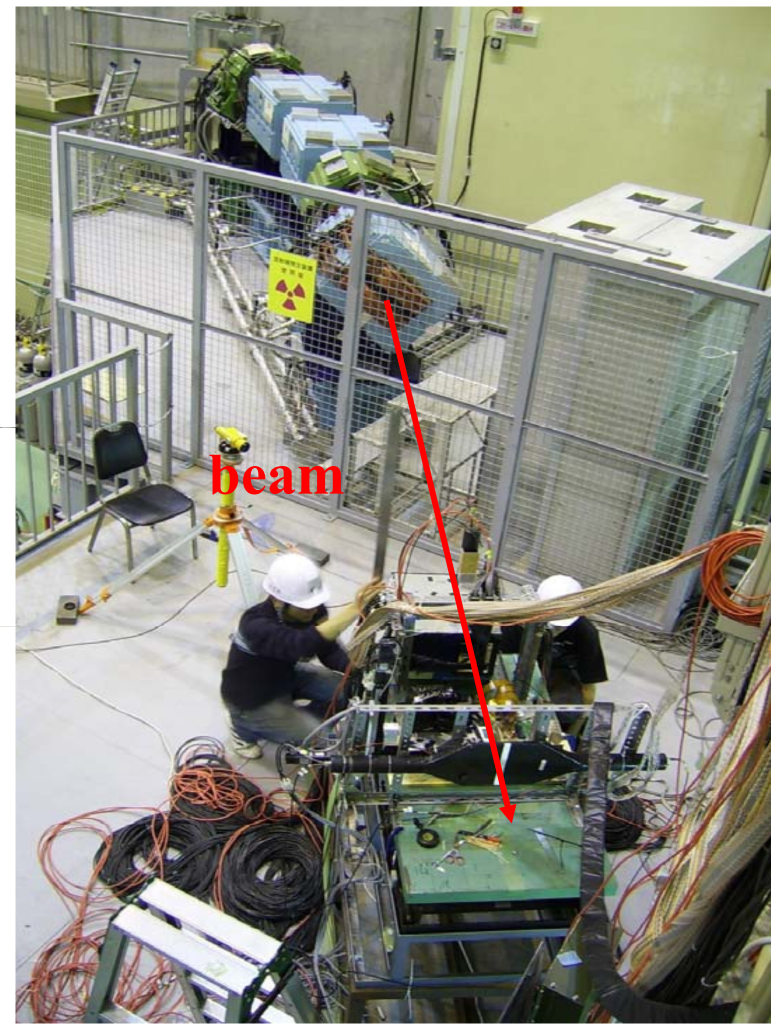
KEK Beam Test
(Nov-2007 at KEK Fuji electron beamline)

- Extruded scintillator R&D is very important for reduction of scintillator production cost.
- Need to perform deeper study of improved extruded scintillator strips by 2D scanning with MIPs.
- Evaluate light yield, position dependence, strip-by-strip variation, and compare various extruded strips with Kuraray strips.

KEK Fuji Beam-Line

- Electron beam-line from bremsstrahlung photons of KEKB
- Beam spot size: ~ 3 cm x 4 cm
- Beam energy : 1-4 GeV
- Rate: 15Hz @ 3 GeV

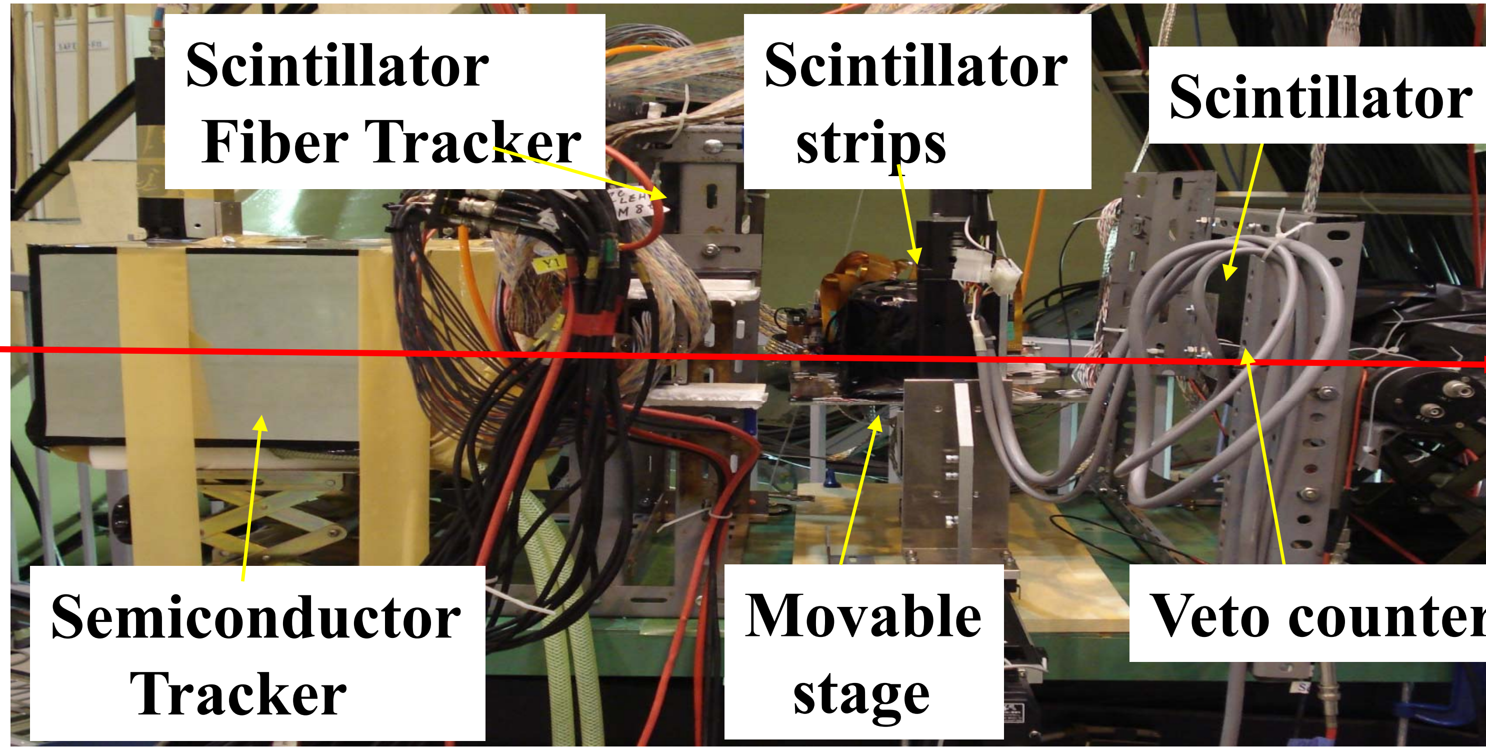




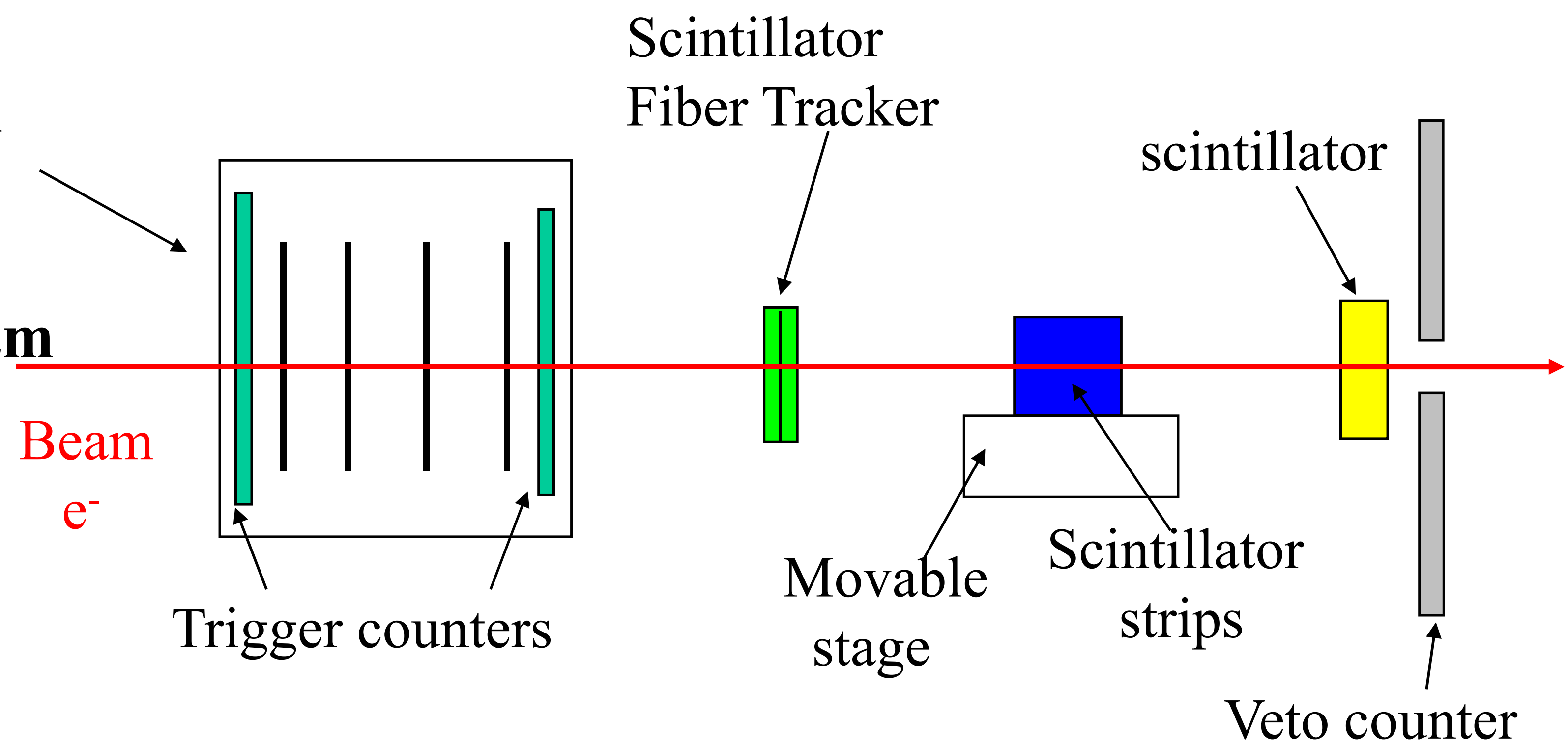
Setup

Beam
e^-

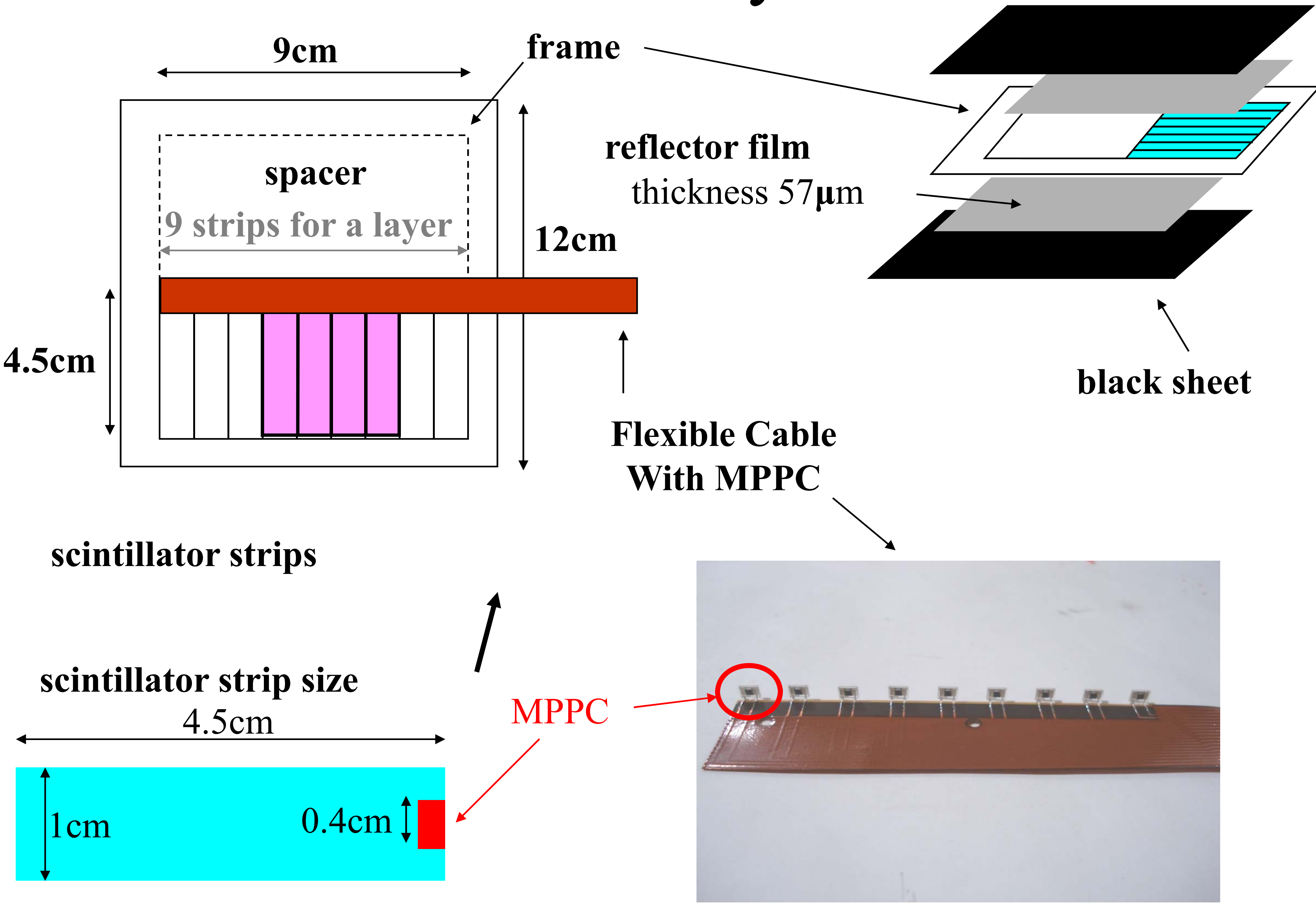
Setup of side view



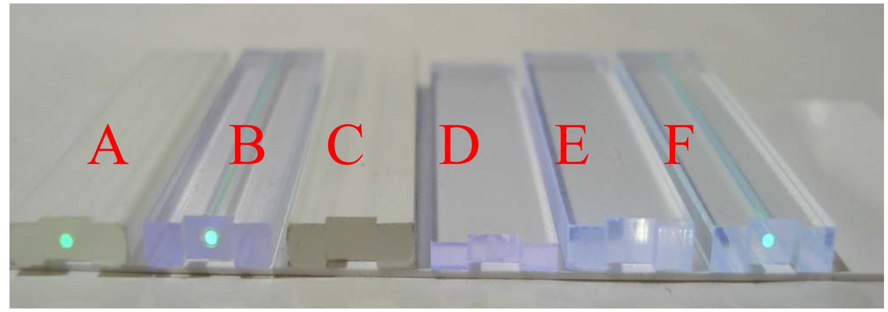
Semiconductor Tracker
(ATLAS TGC)
12cm×6cm
Resolution
vertical : 23µm
horizontal: 580µm



Scintillator Assembly

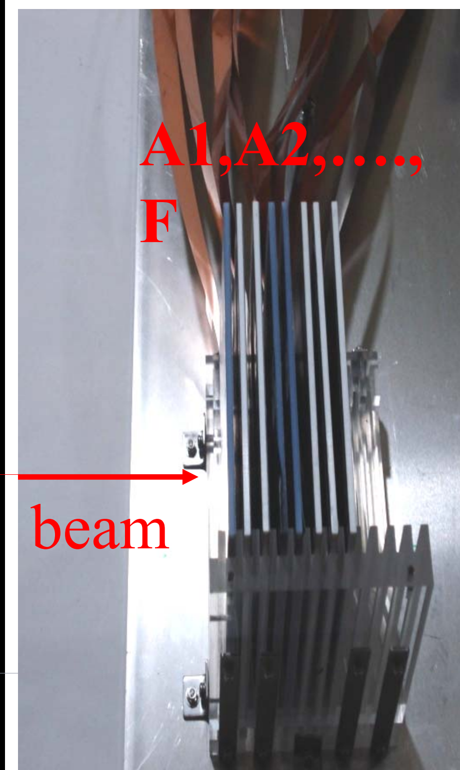


Scintillator Strips



- 8 layers with different types of strips
- 4 strips per one layer were read out.

type	Method	Read-out	Cover	Thickness (mm)	
A1	Extruded	Fiber	TiO_2	3	No fiber
A2					good matching
B1			Reflector		big fiber hole
B2					matched hole
C		Direct	TiO_2		
D	Kuraray	Direct	Reflector	2	
E				3	
F		Fiber			reference



Extruded scintillator strip with a fiber hole (A,B)

Type : A

covered with TiO2

A1 : fiber - MPPC bad matching

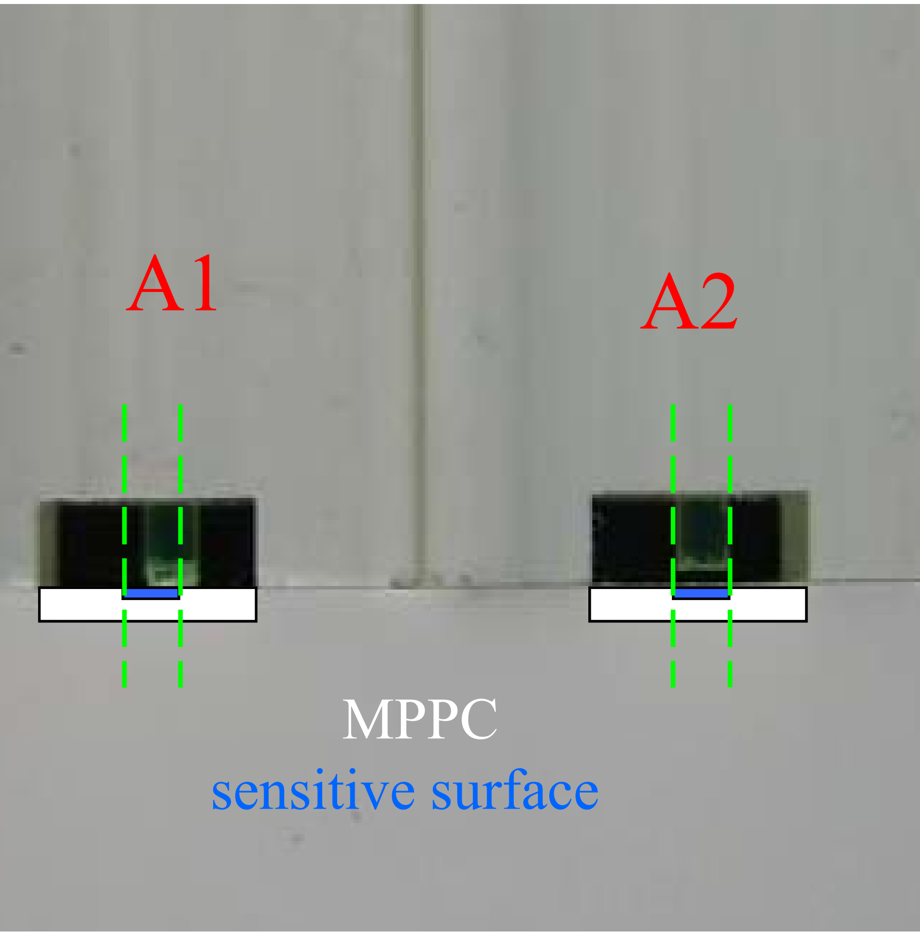
A2 : fiber – MPPC good matching

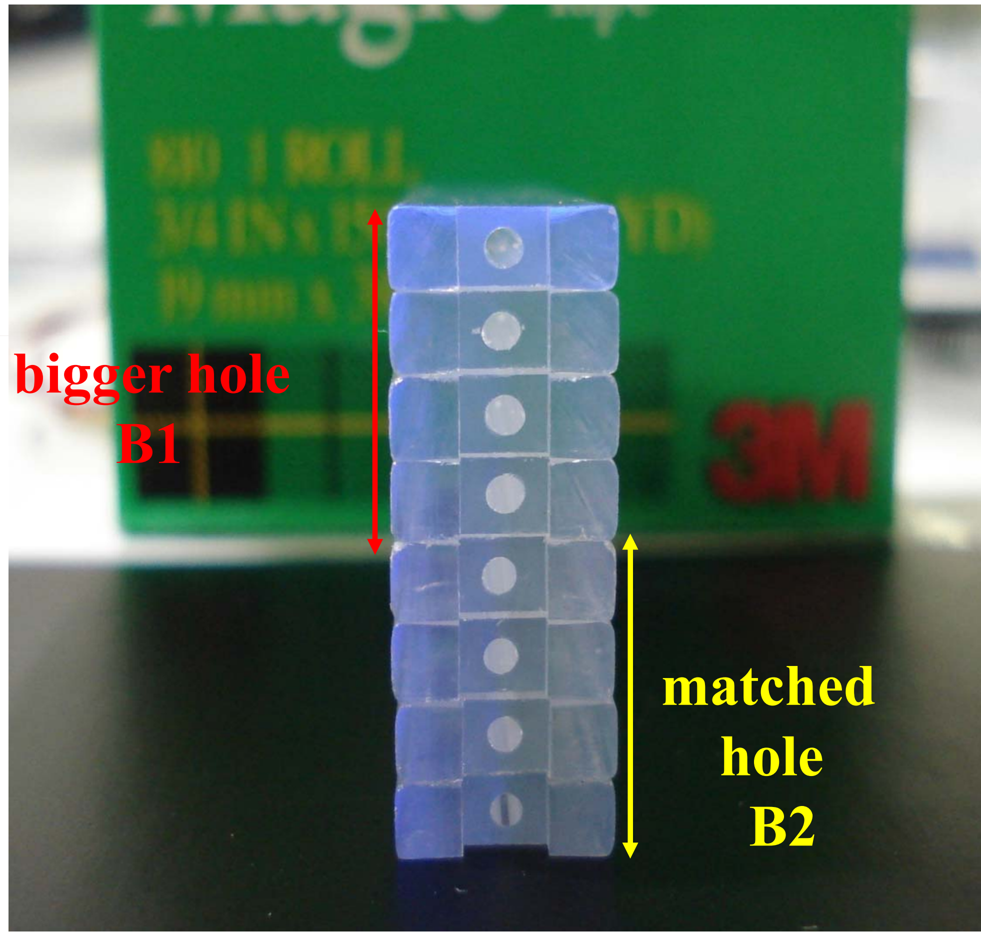
Type : B

covered with KIMOTO reflector film

B1 : bigger hole

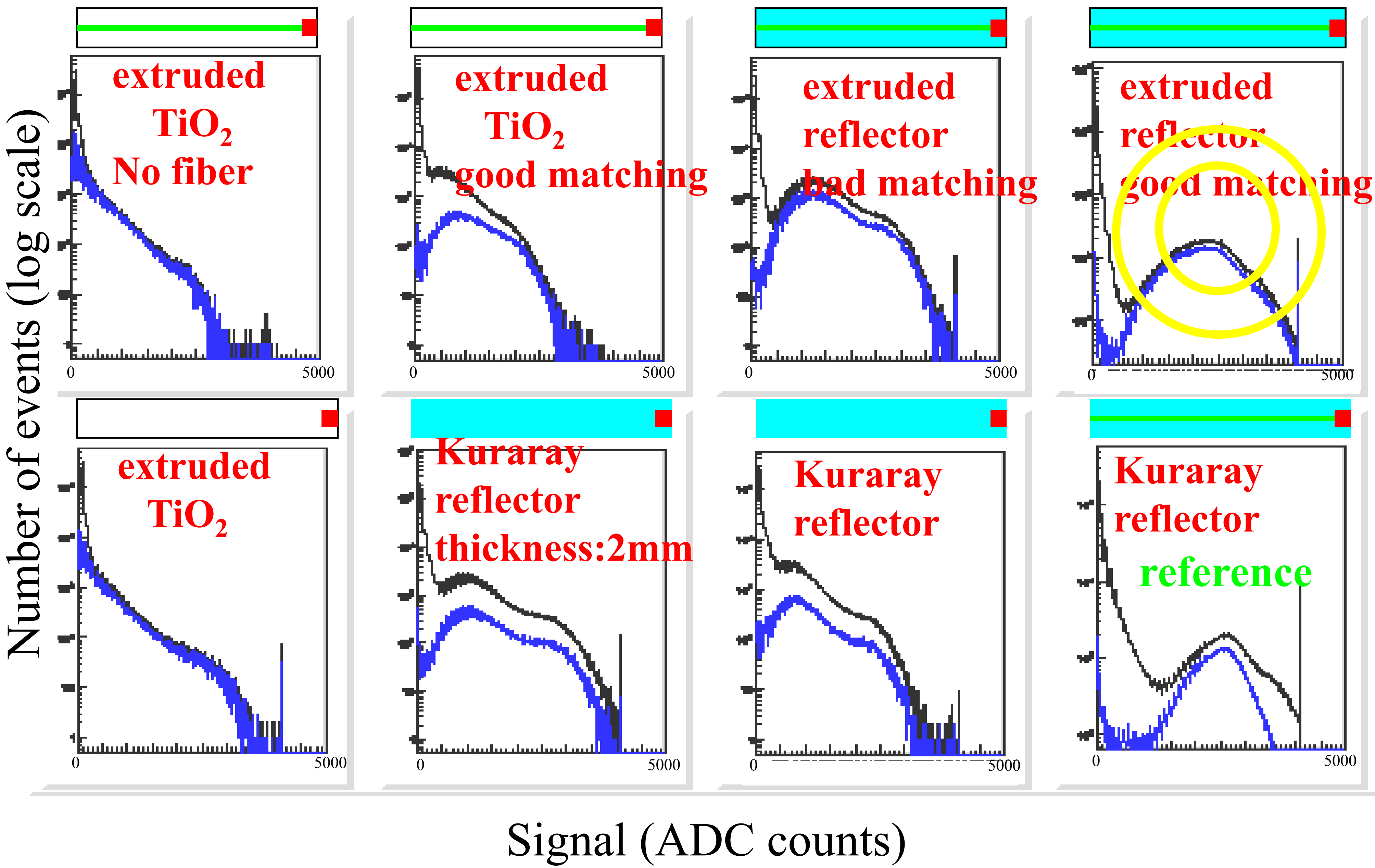
B2 : matched hole



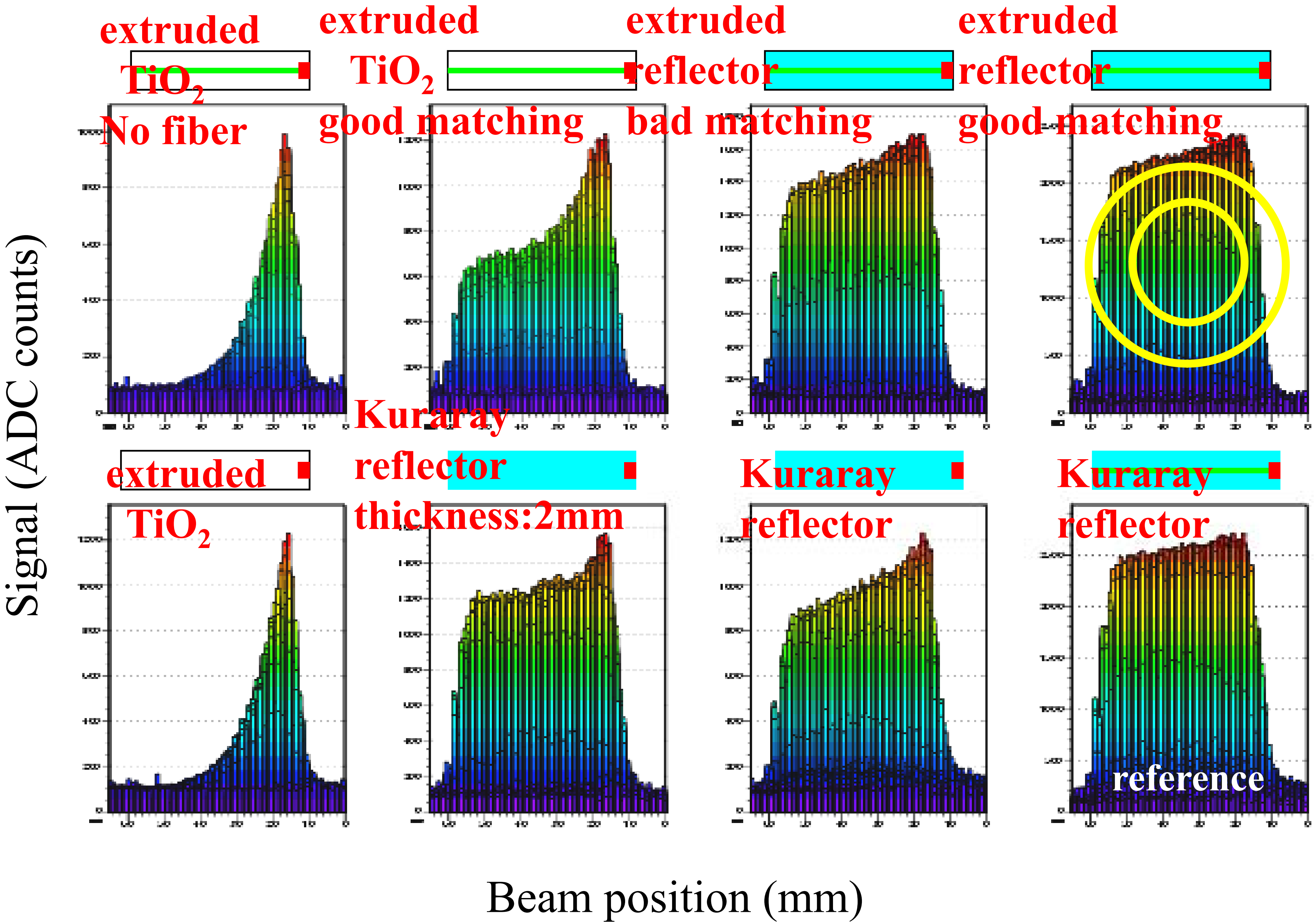


Response for MIP

All collected events
MIP events



Uniformity


extruded
TiO2
No fiber
extruded
TiO2
good matching
extruded
reflector
bad matching
extruded
reflector
good matching
extruded
TiO2
Kuraray
reflector
thickness:2mm
Kuraray
reflector
Kuraray
reflector
reference
Signal (ADC counts)
Beam position (mm)

Conclusion of the KEK Beam Test

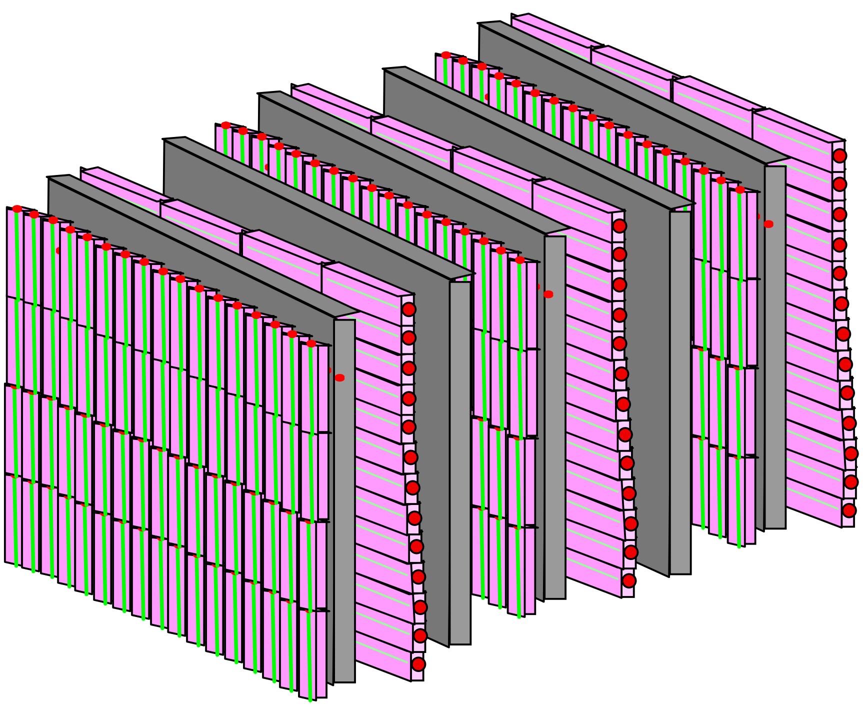
- Result shows acceptable performance of the extruded scintillator strips.
  - Type of reflector and position matching between fiber and MPPC are very important.
  - Extruded strip without fiber is not useful, since attenuation length is so short.
- More detailed analysis will follow.
  - Comparison of absolute light yield
  - Bias voltage dependence
- Feedbacks are provided to KNU colleagus.

Quality of the extruded scintillator will be improved for FNAL BT.

The FNAL beam test in Sep 2008

- Establish the Scintillator-strip ECAL technology
  - Test linearity of the ScECAL with high energy beam.
  - Evaluate all the necessary performances

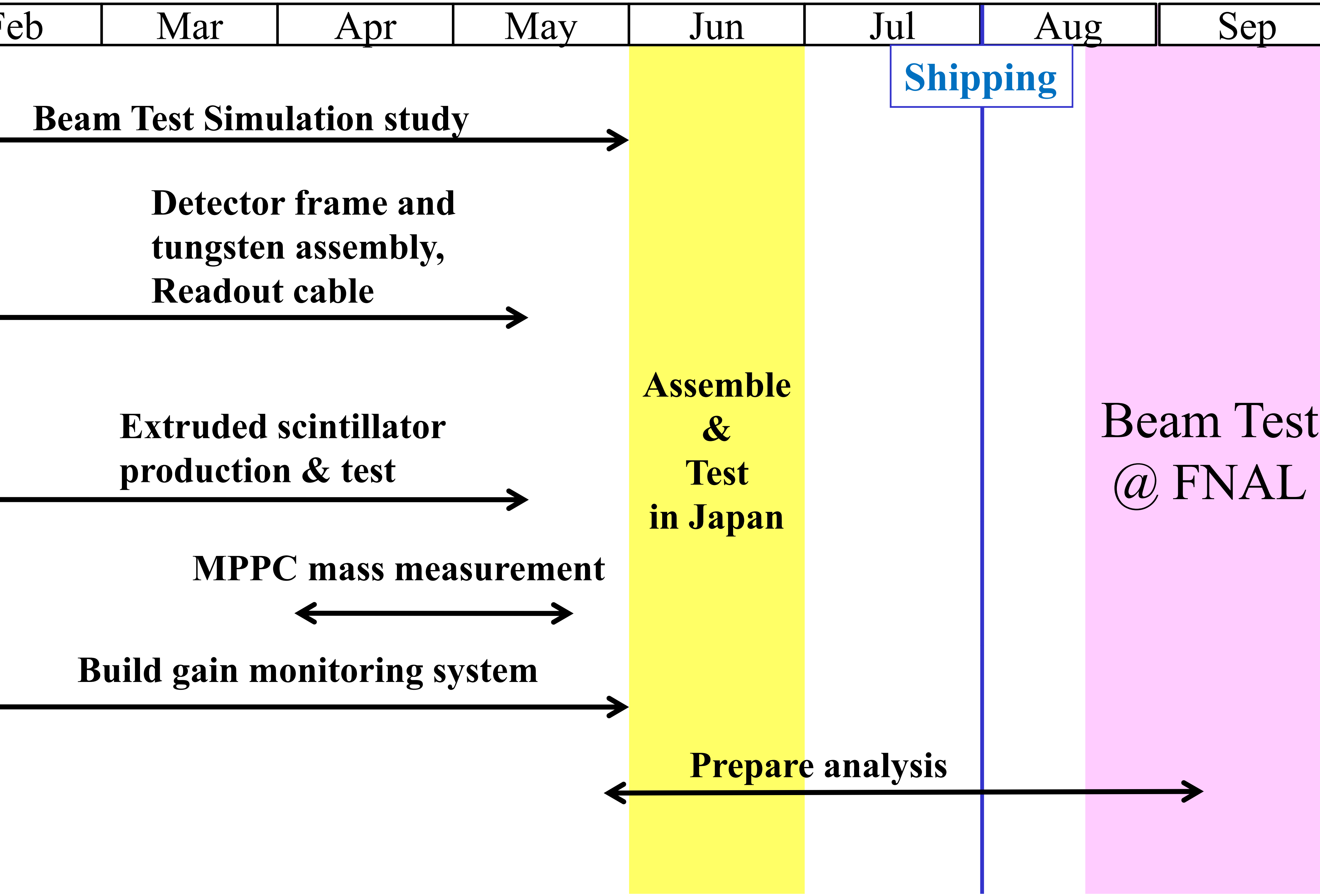
    using various beams (π,K,e,μ….) with wider energy range
- Combined test with the Analog HCAL
- Test π^0 -> 2γ reconstruction (hopefully)
- Measure hadron shower to test simulation model



- The 2nd prototype will be 4 times larger than the DESY BT module.

  (20 x 20 cm, ~30 layers)
- Fully adopt the extruded scintillators.
- Expect > 2000 readout channels.

Schedule toward the FNAL BT



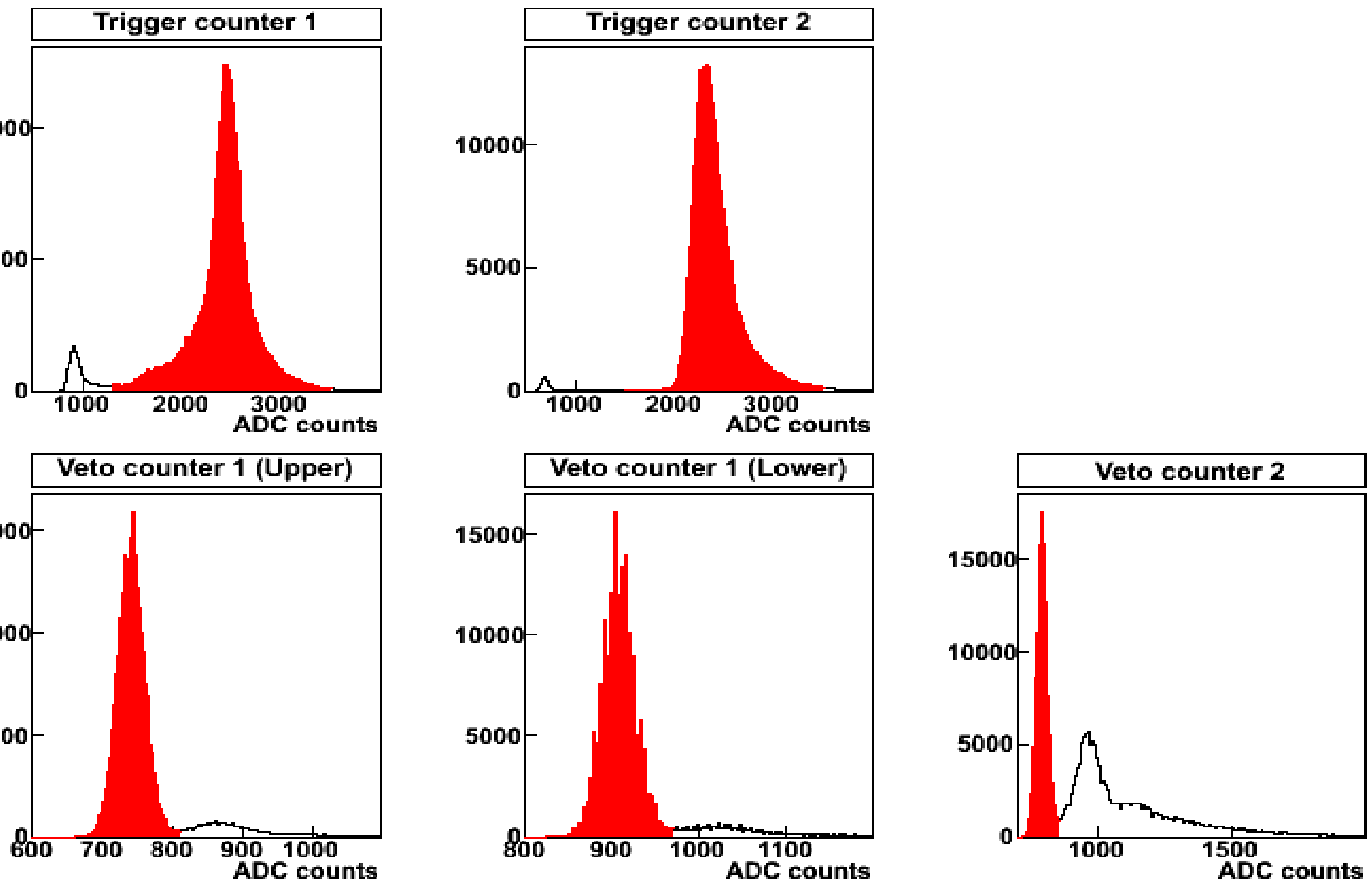
Concusion

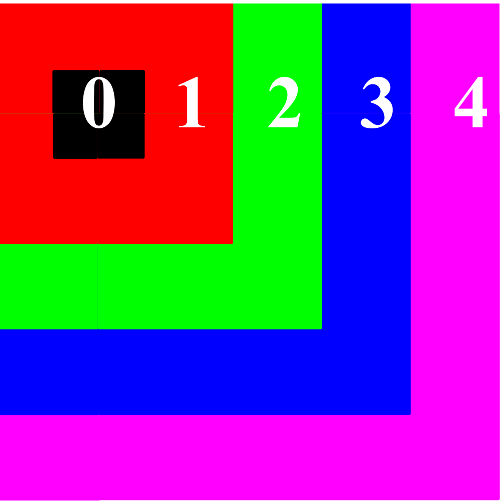
- Scintillator-ECAL R&D is ongoing in good shape.
- The DESY beam test proves performance of ScECAL and gave lots of experiences to us.

  Analysis of the data is in almost a final phase.
- The result of KEK beam test told us how to improve performance of extruded scintillator strips.
- At the FNAL beam test, various tests will be done to technically establish the ScECAL.

Backups

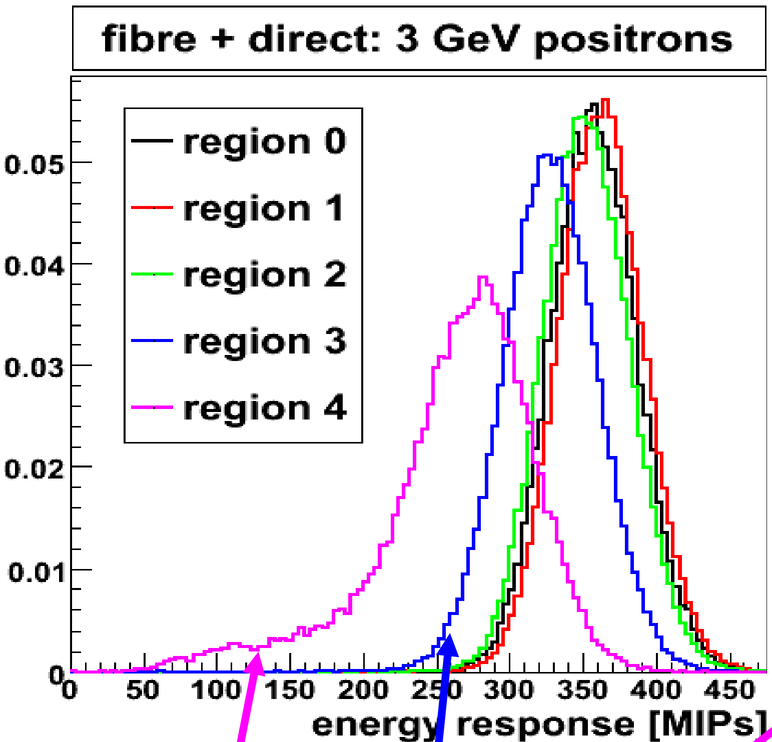
Trigger & Veto counter event selection

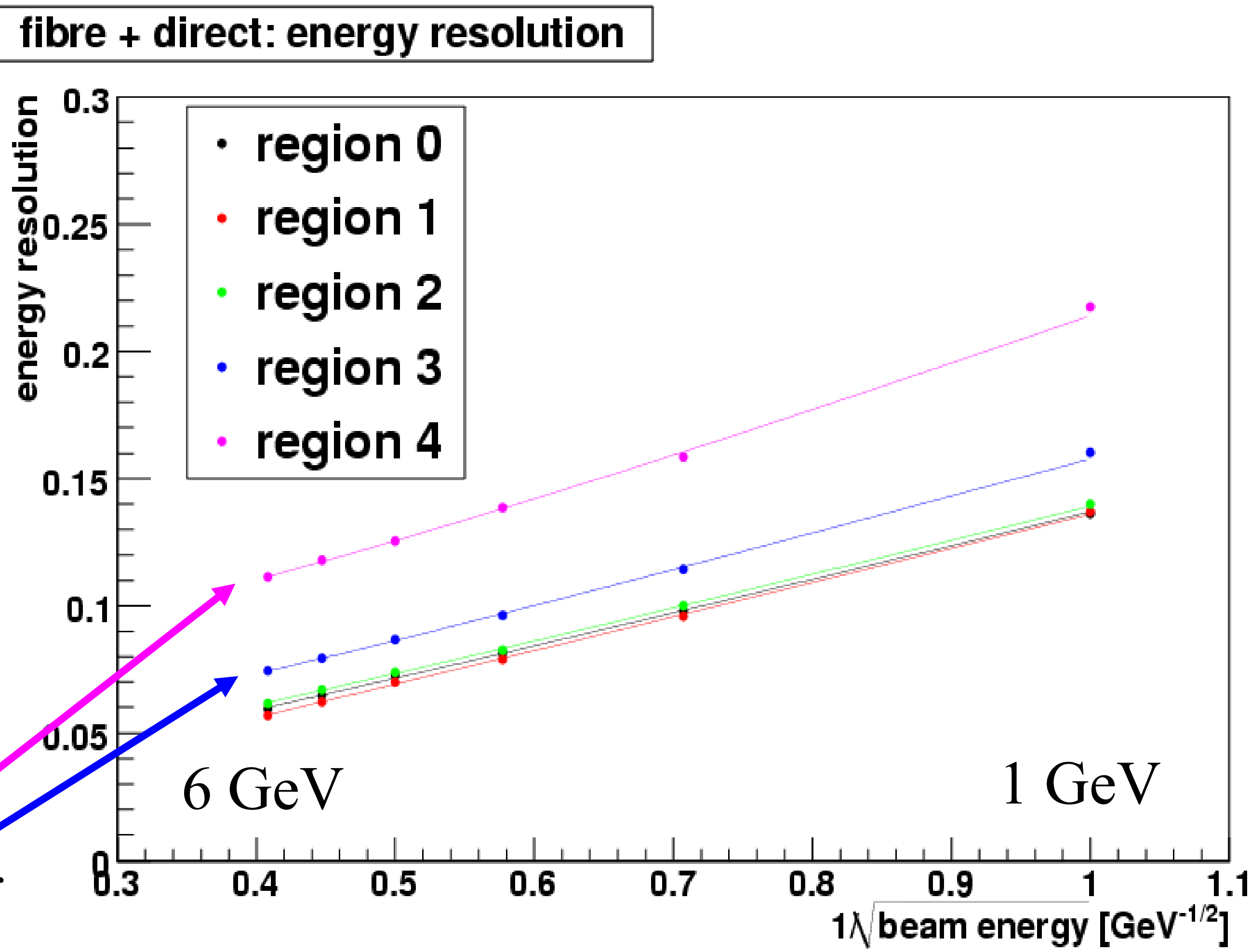




Energy resolution in different detector regions

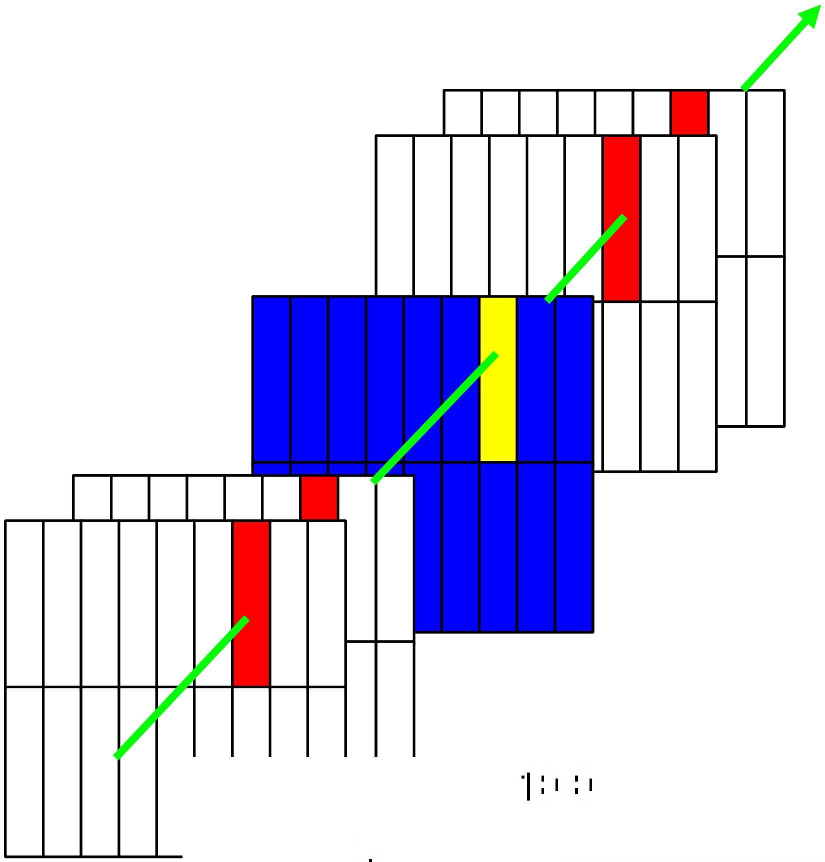
(fibre+direct, with absorber)

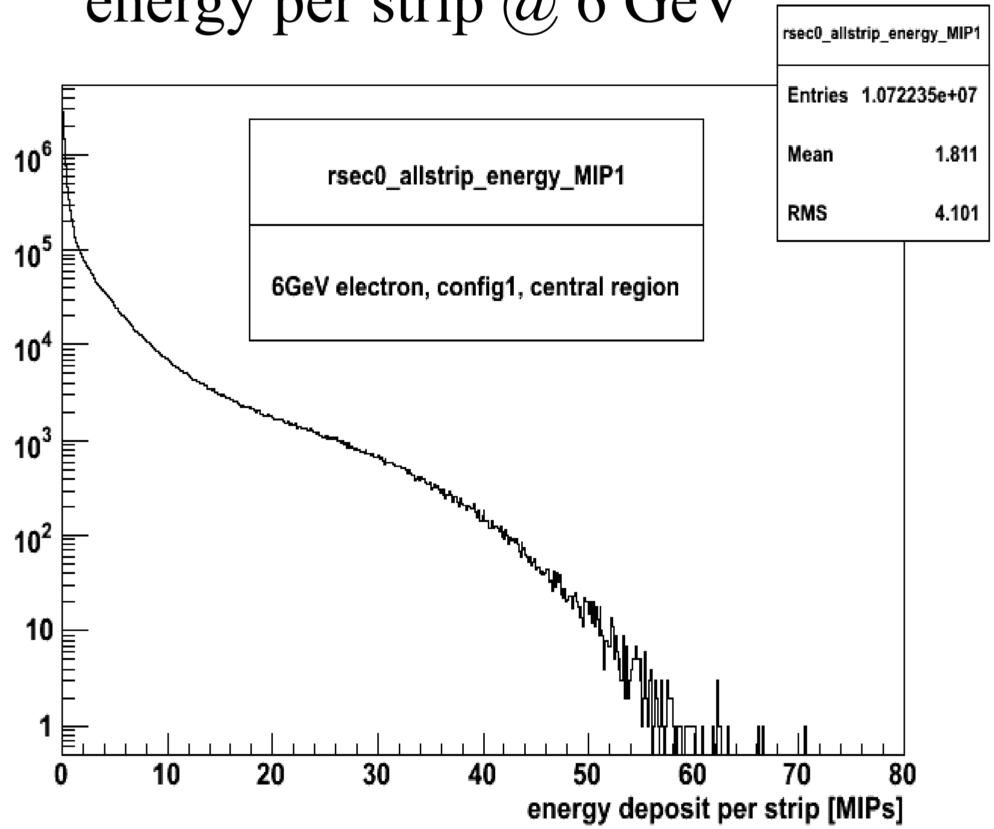


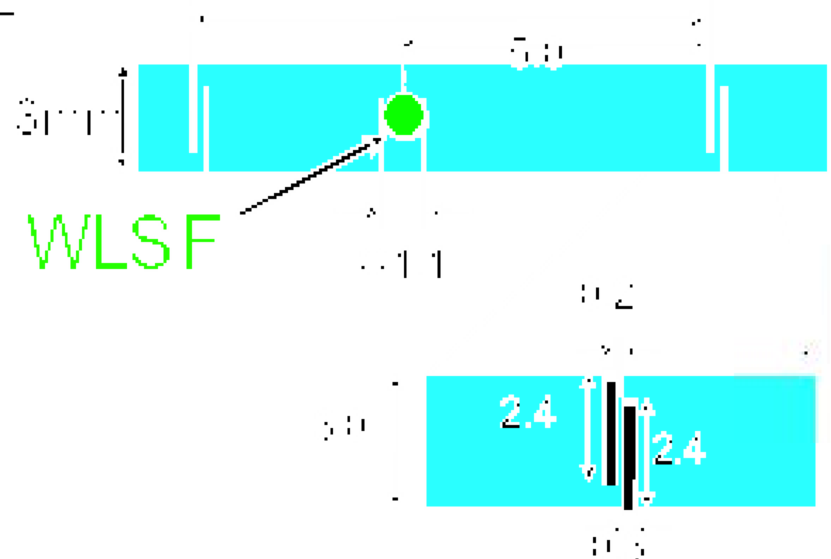


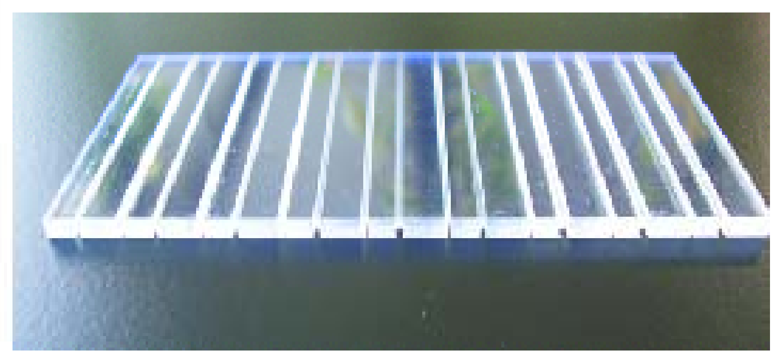
clear evidence of lateral shower leakage in outer two regions

energy per strip @ 6 GeV



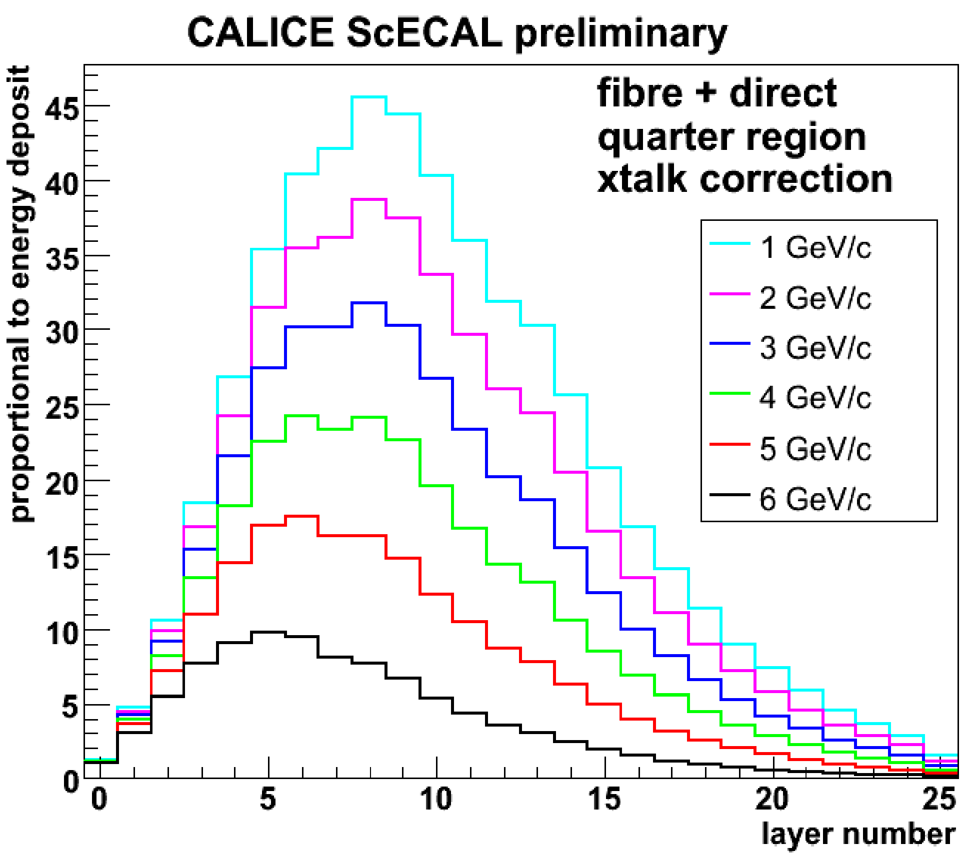


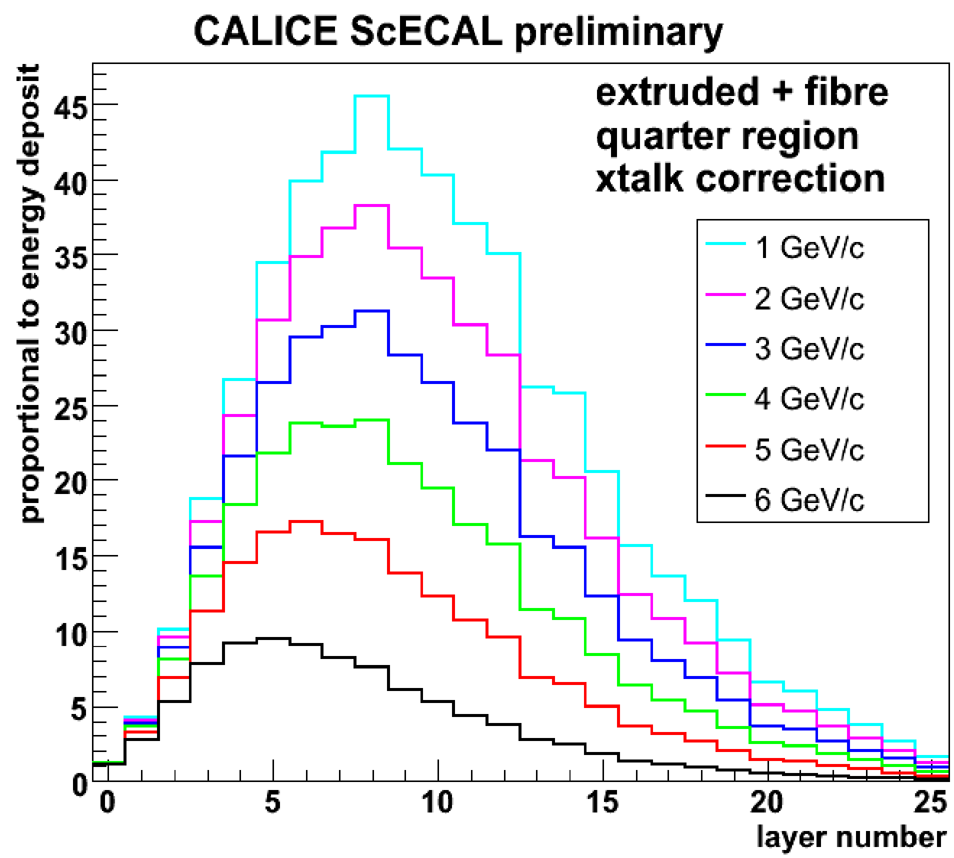




longitudinal shower profiles

quite smooth, a couple of smallish discontinuities
reason still under investigation





Energy resolution

	quarter regions		central region	
	stoch. term(%)	const term(%)	stoch. term(%)	const term(%)
fibre+direct:	13.98 +- 0.07	1.96 +- 0.12	13.39 +- 0.05	2.57 +- 0.07
direct+fibre:	13.83 +- 0.07	2.58 +- 0.09	13.70 +- 0.06	3.39 +- 0.05
extruded+fibre:	14.61 +- 0.08	2.35 +- 0.12	14.52 +- 0.09	7.26 +- 0.05

contribution
from shower leakage

non-uniformity

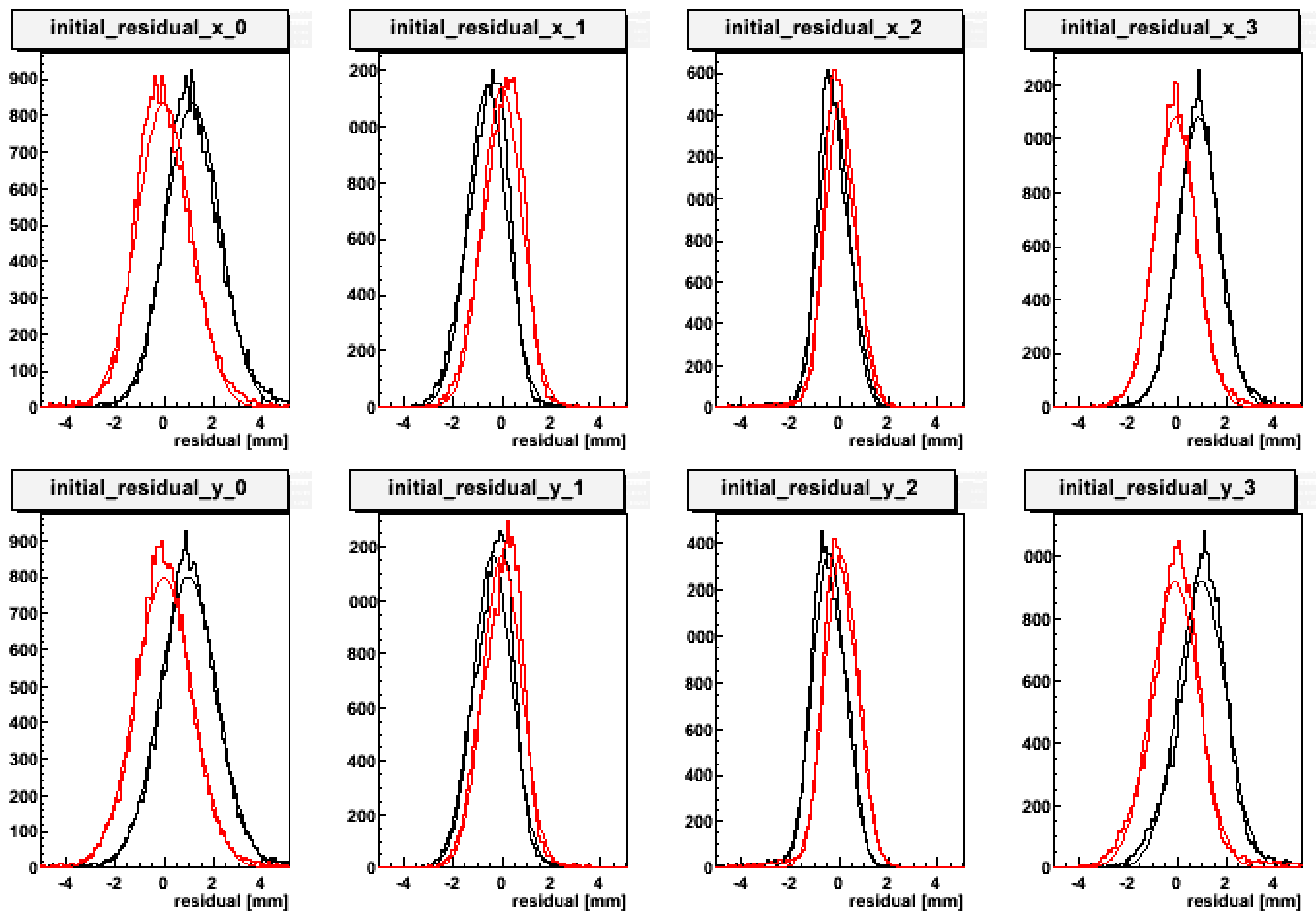
Tracking detector alignment

determine drift velocity and relative positions of 4 drift chambers
each chamber measures x,y position

chamber 0 1 2 3

x

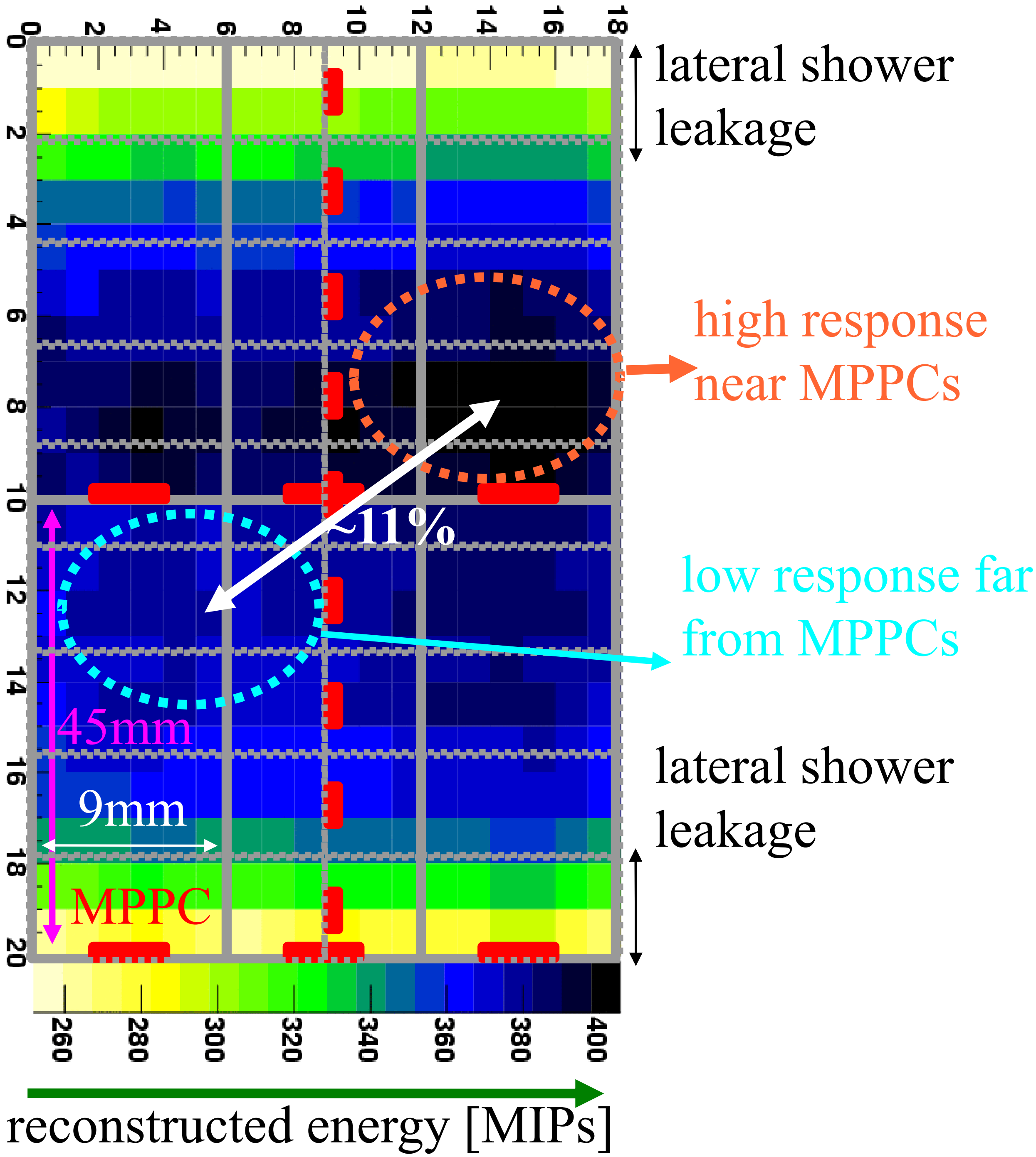
y

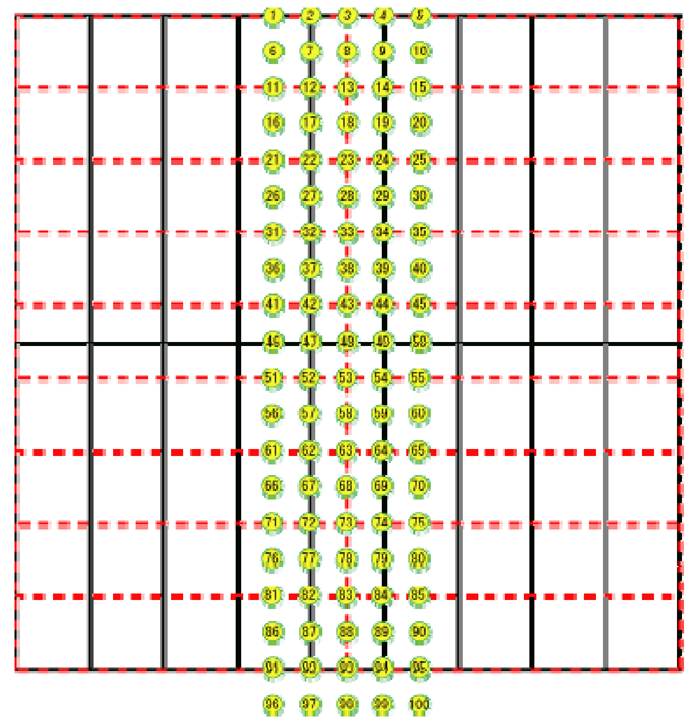


before
(after)
alignment

hit residual/mm

Energy response uniformity, direct+fibre, 3 GeV



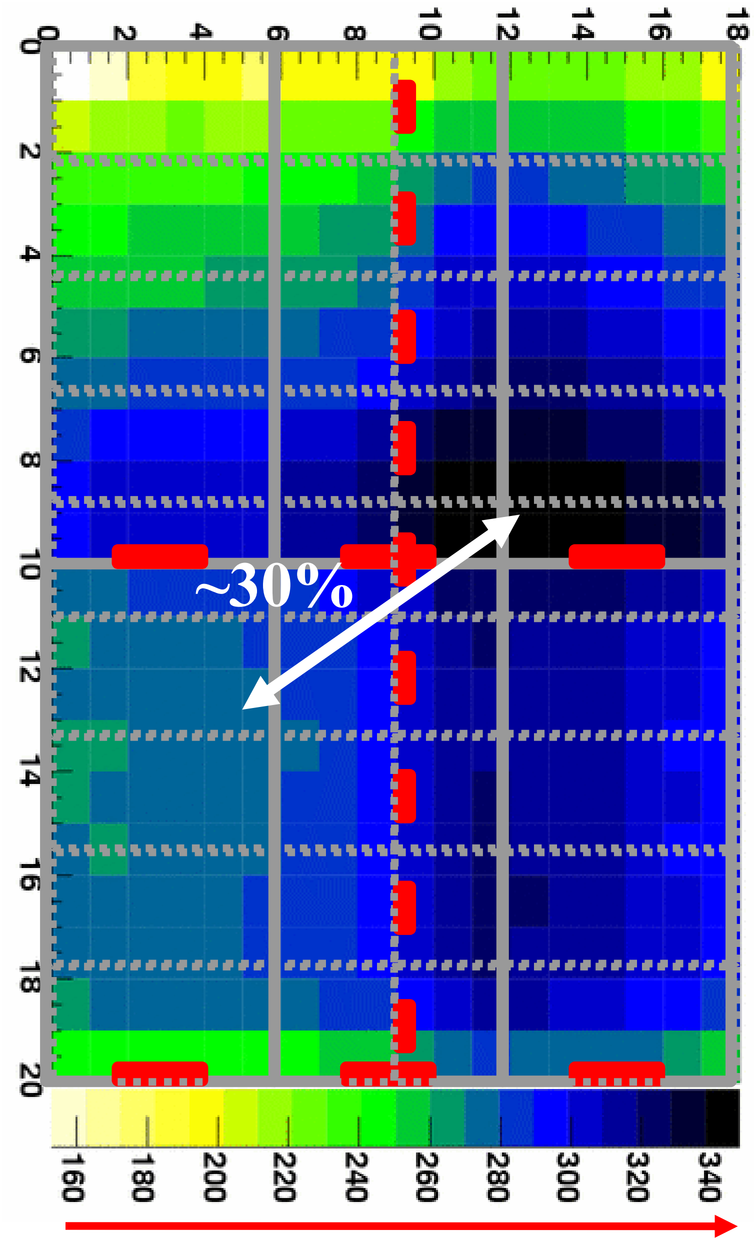


scanned 1/3 detector

can alternate orientation to minimise this effect

extruded+fibre @ 3 GeV: energy response vs. position

energy response



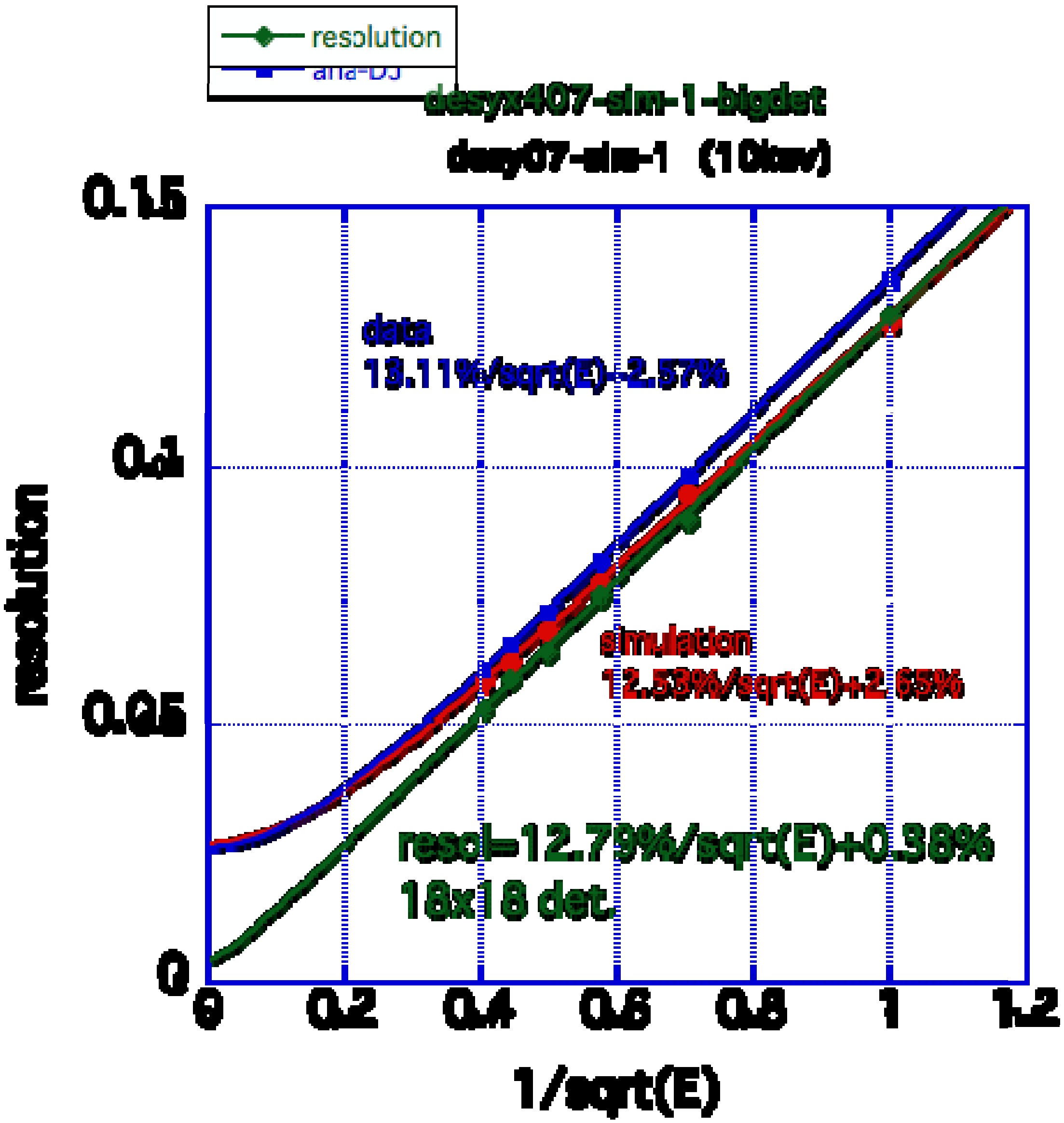
energy response [MIPs]

2-3 times more variation that direct+fibre configuration

extruded strips are less uniform

Simulation studies

simulation shows 4% lateral energy leakage, 1% longitudinal leakage
(central beam injection)



simulate a larger detector
(2x larger in each direction)

resolution of 1st configuration
(real data)

simulation of our detector
26 layers x 9x9cm^2

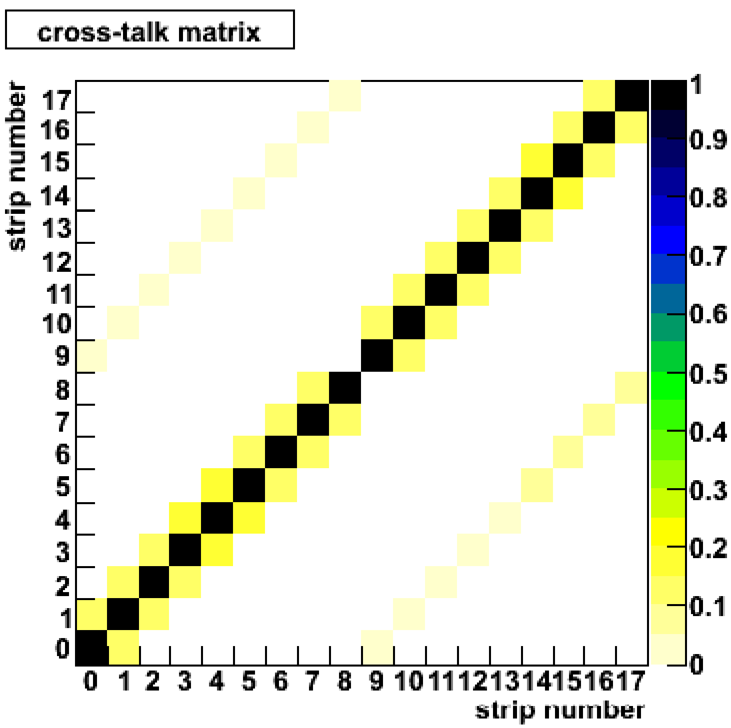
simulation of larger detector
52 layers x 18x18 cm^2:
no constant term!

shower leakage causes constant term of around 2.6%

measure xtalk across each strip boundary

correction of cross-talk

in each layer, define matrix with measured xtalk probabilities (~10%)



use this matrix to unfold the cross-talk

Comparison of Kuraray scintillator strips and KNU extruded

Kuraray

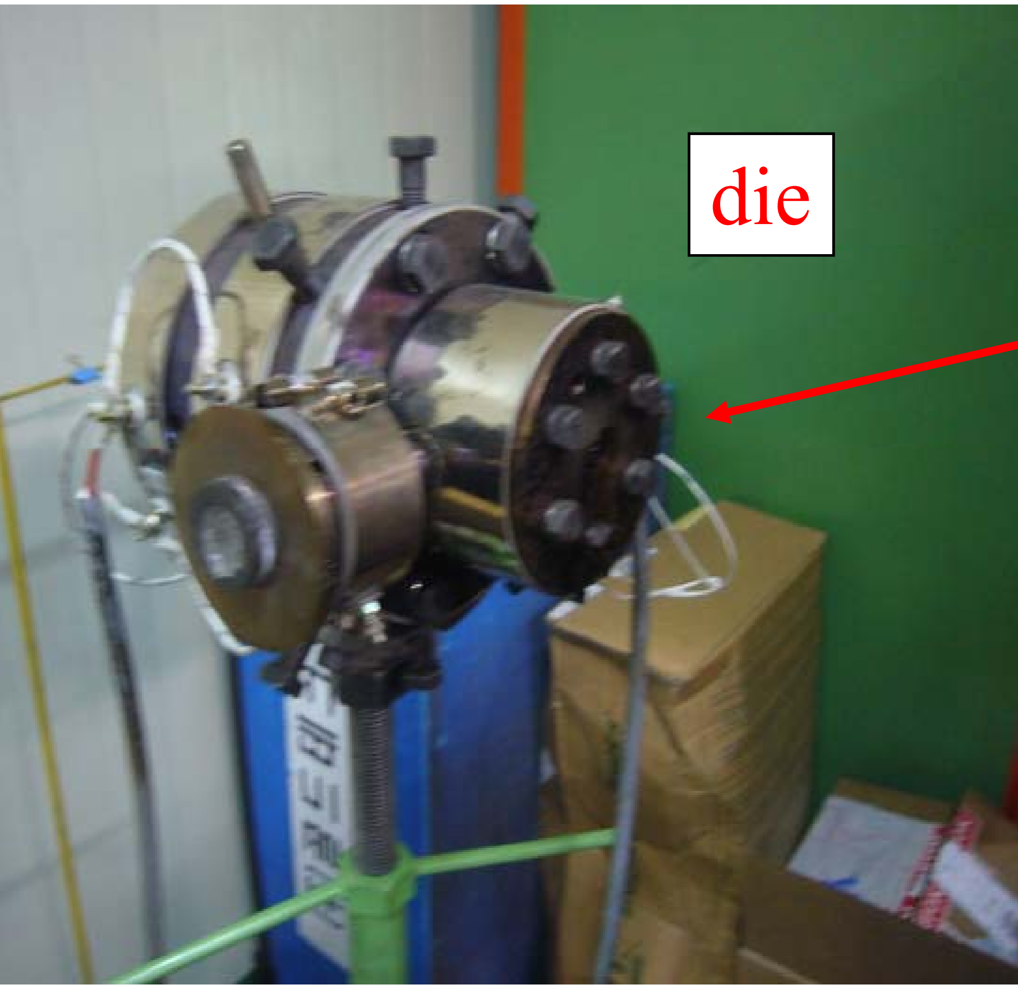
- Casted and machined
- High accuracy for the hole size and position
- Expensive

KNU Extruded

- Extrusion
- Simultaneously the fiber hole is made and scintillator strip.
- Can be covered with TiO_2 at the same time.
- Cheap
- Low accuracy for the fiber hole size and the position

Extruder

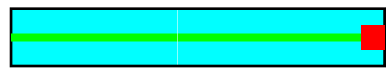
The pictures were taken
at Misung Chemical Company,
Korea.

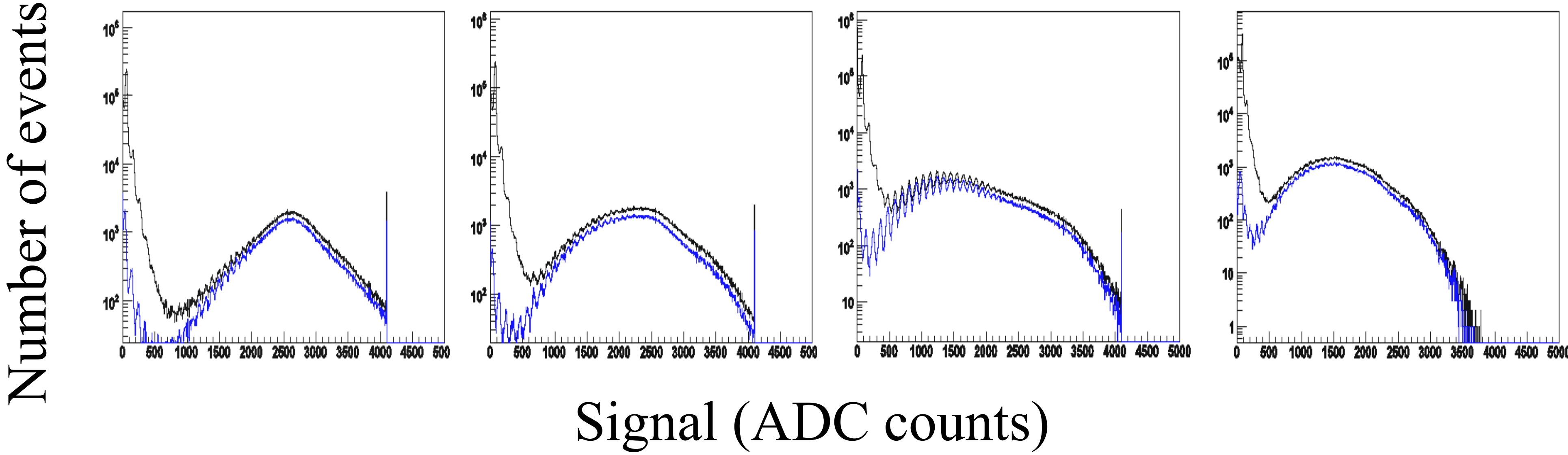


Response for MIP
Variation of strip by strip

Extruded scintillator strip + reflector film
good matching

All collected events
MIP events





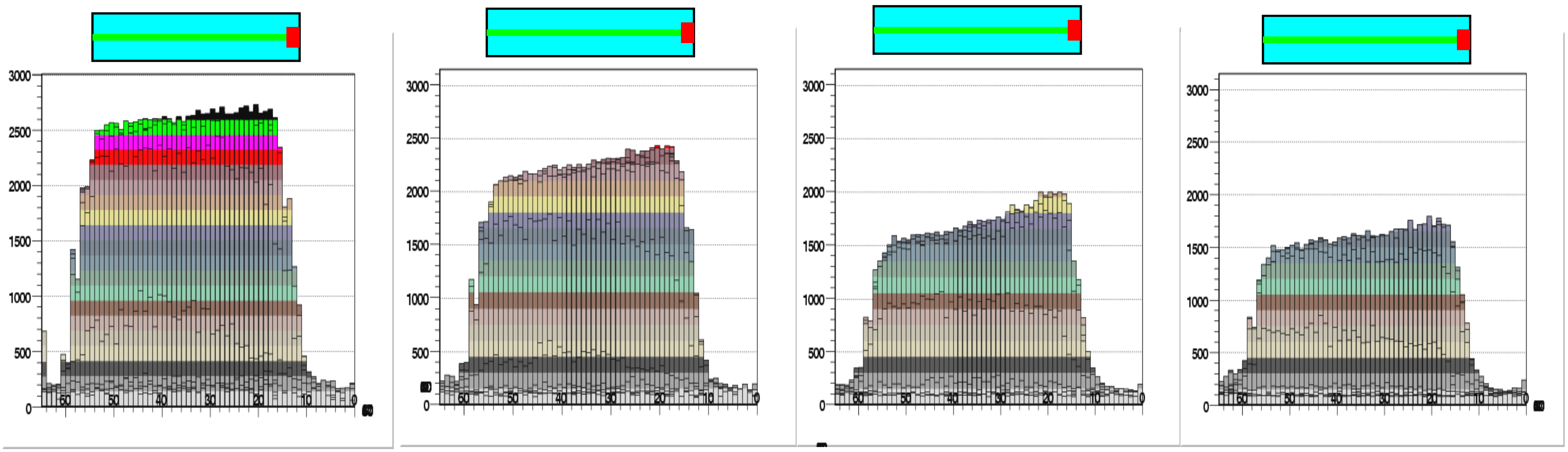
These plots show the variation of strip by strip is big.

Uniformity

Variation of strip by strip

Extruded scintilattor strip＋reflector film
good matching

Signal (ADC counts)



Beam position (mm)

These plots show the uniformity of these strips is not so big.
However light yields are not same.