Calorimeter for ILC

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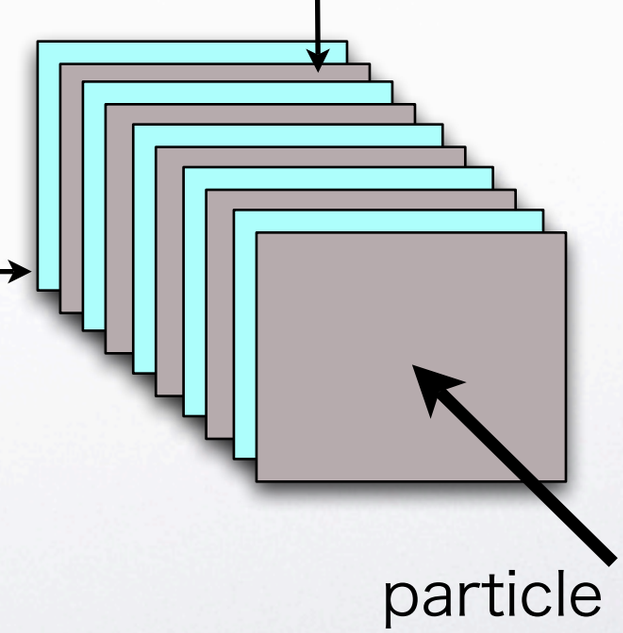
scintillator

scintillator calorimeter

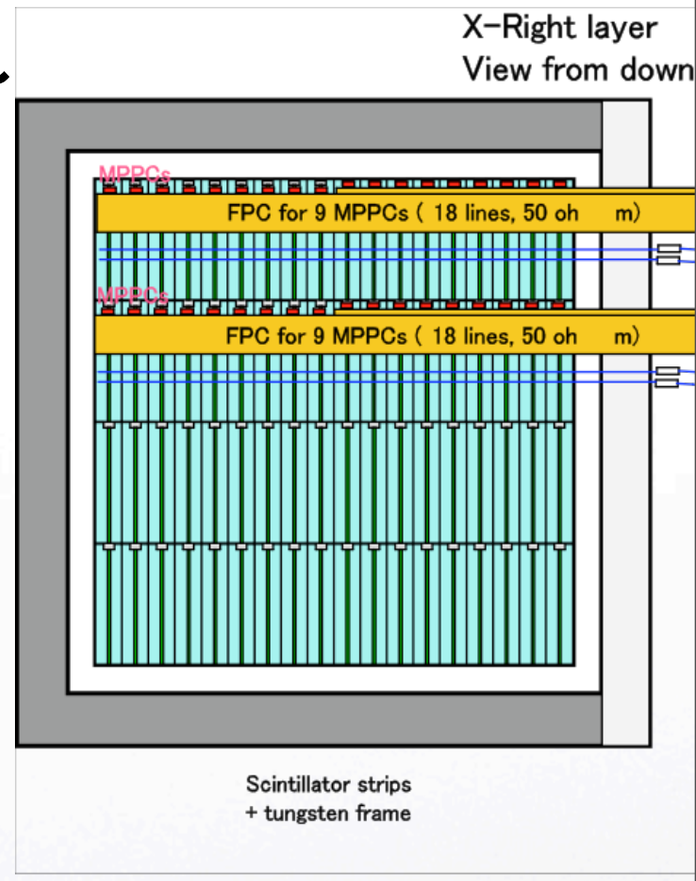
scintillator cal.

- sandwich calorimeter
- absorber : Tungsten
  - short X_0=3.5mm, λ_{int}=20cm, $R_{Moliere}$~9mm (90% of EMshower)
- active material : scintillator
- scintillator (organic)
- fast but small light output
- stable , reliable, robust, cheap
- scintillation light detection > sensor



sandwich cal.

- measured energy in scintillator ~ dE/dX
- sum of dE/dX ~ $E_{incident}$
- follow shower development
- need separation layer by layer
- PFA requires fine segmentation
- to reduce # of channels
- strip structure



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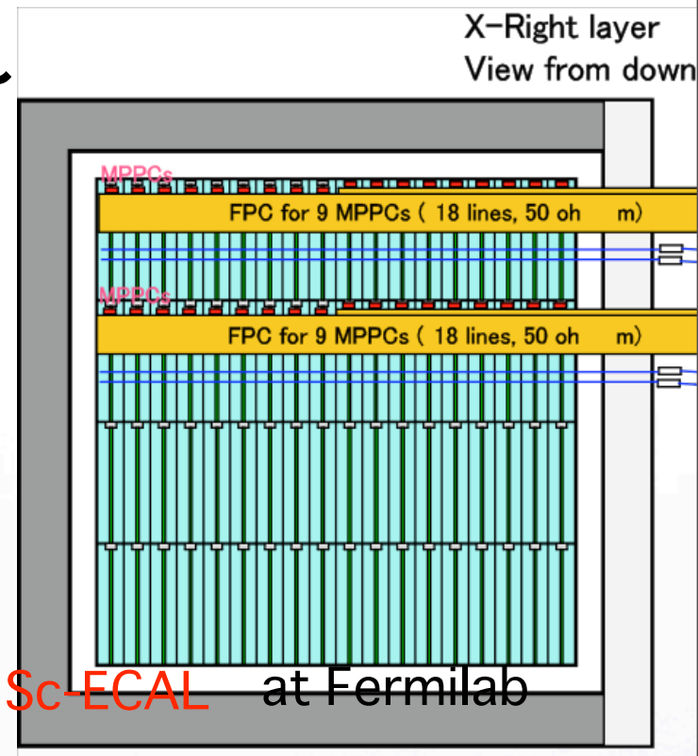
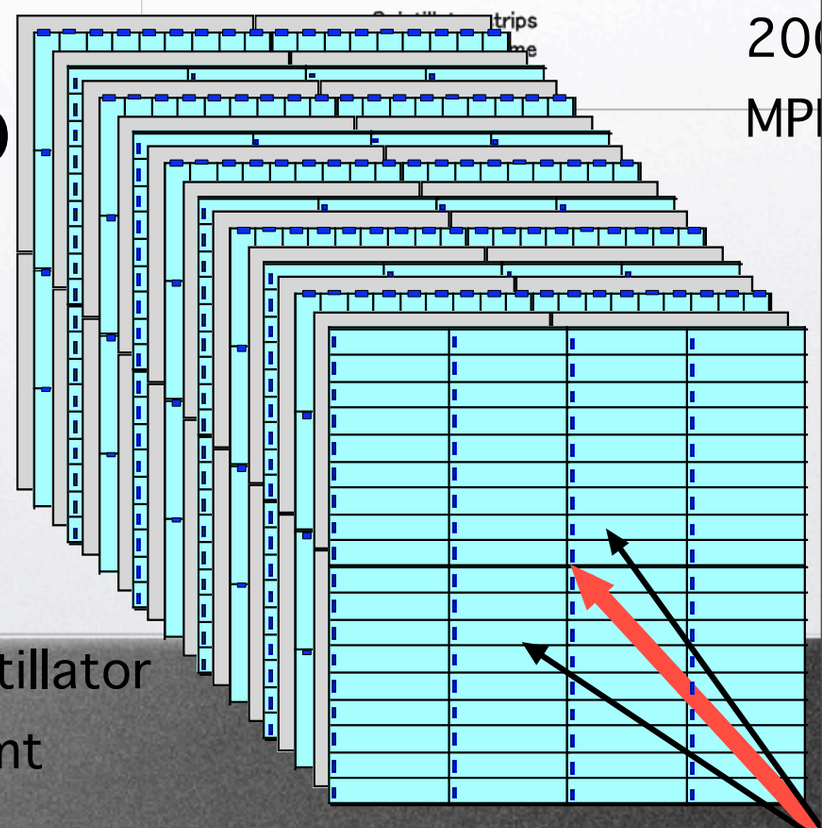


CALICE Sc-ECAL at Fermilab

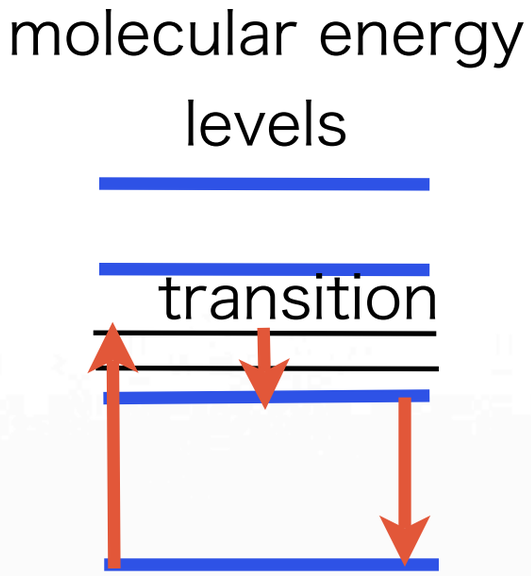


scintillator

- transparent material : poly-styrol
- with dopant like PT, POPOP
- charged particles deposit energy as dE/dx

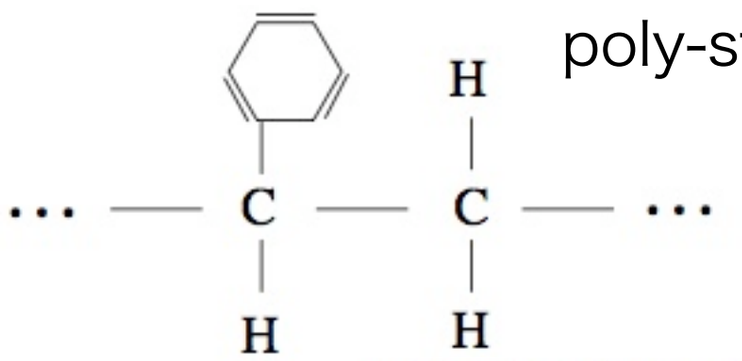
excitation → transition → emission

- scintillation light ~300-400nm



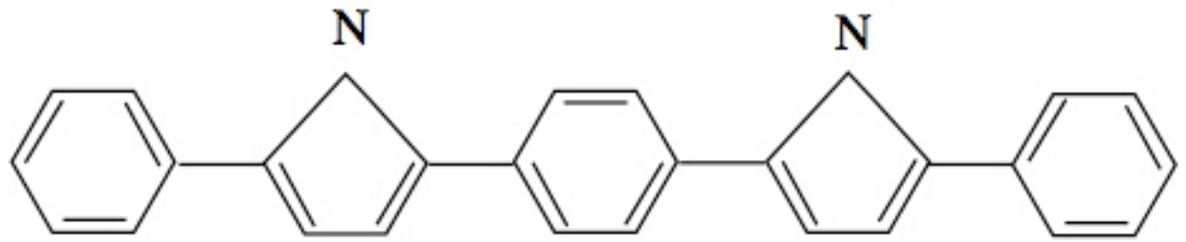
~ns

poly-styrol



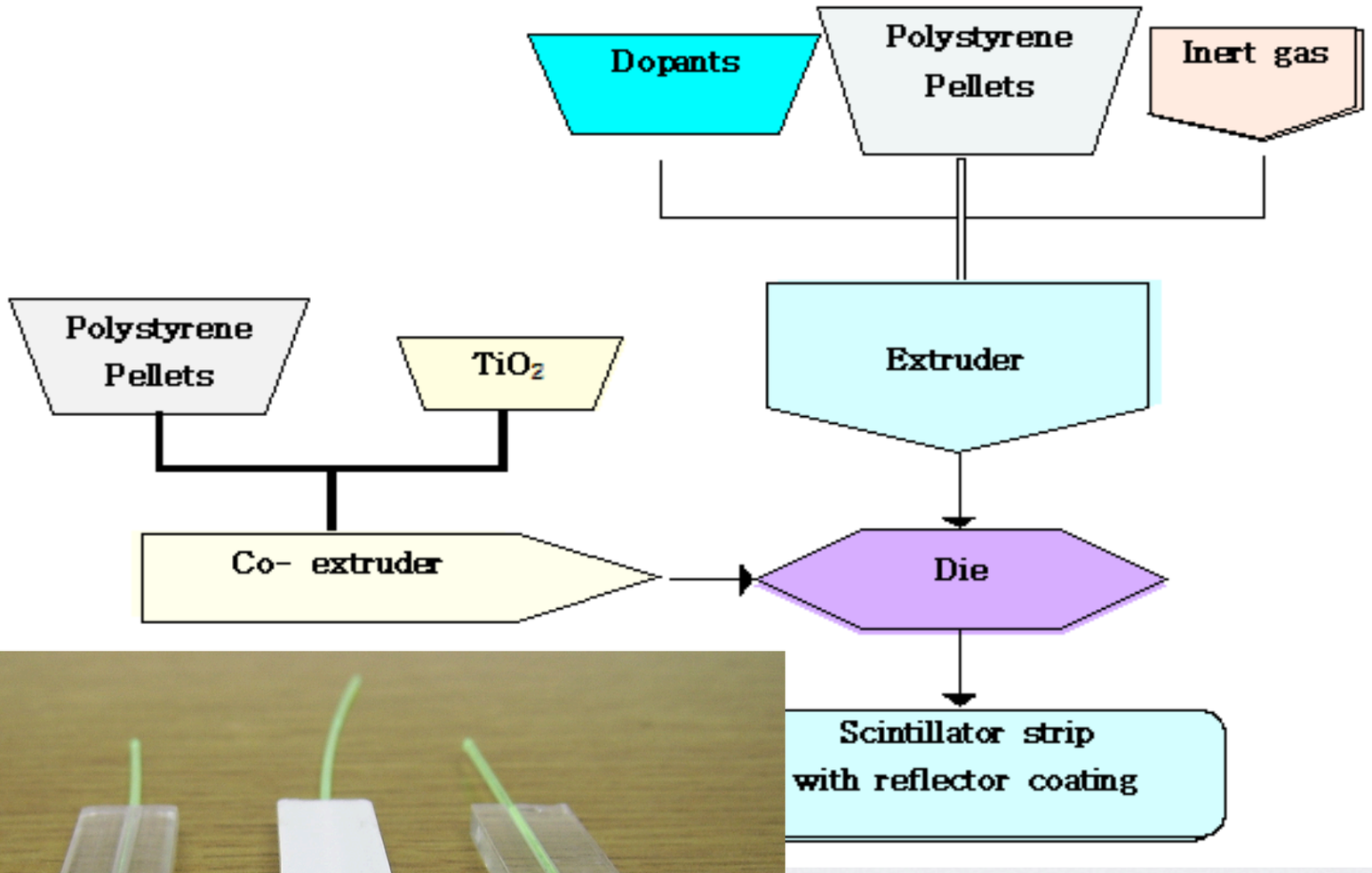
p–Terphenyl ($C_{18}H_{14}$, 1 %)

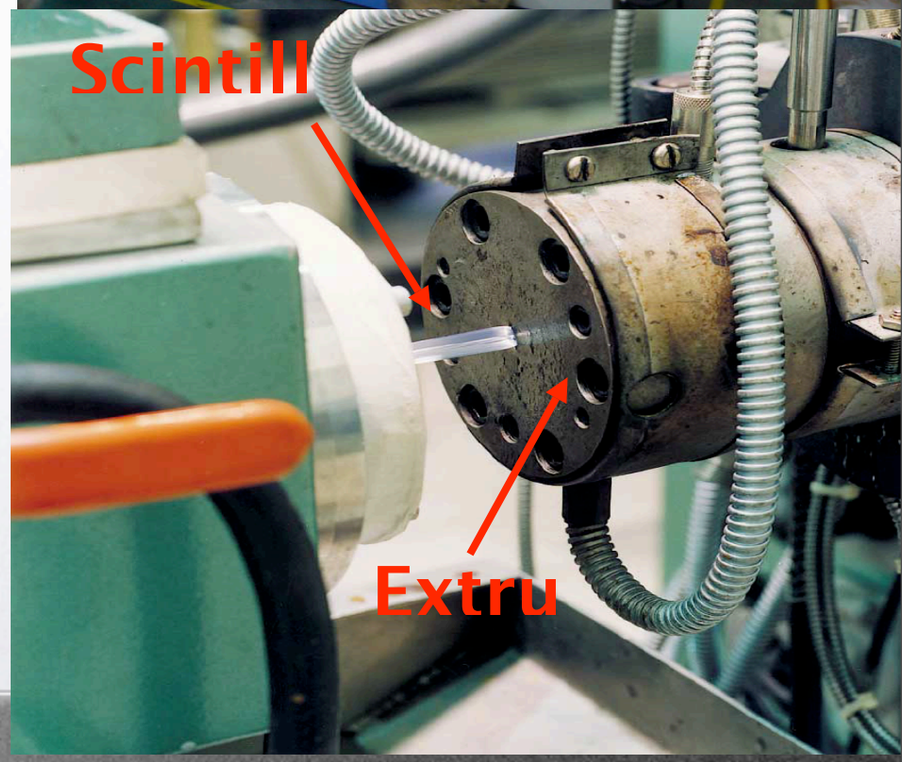
POPOP $C_{24}H_{16}N_2O_2$

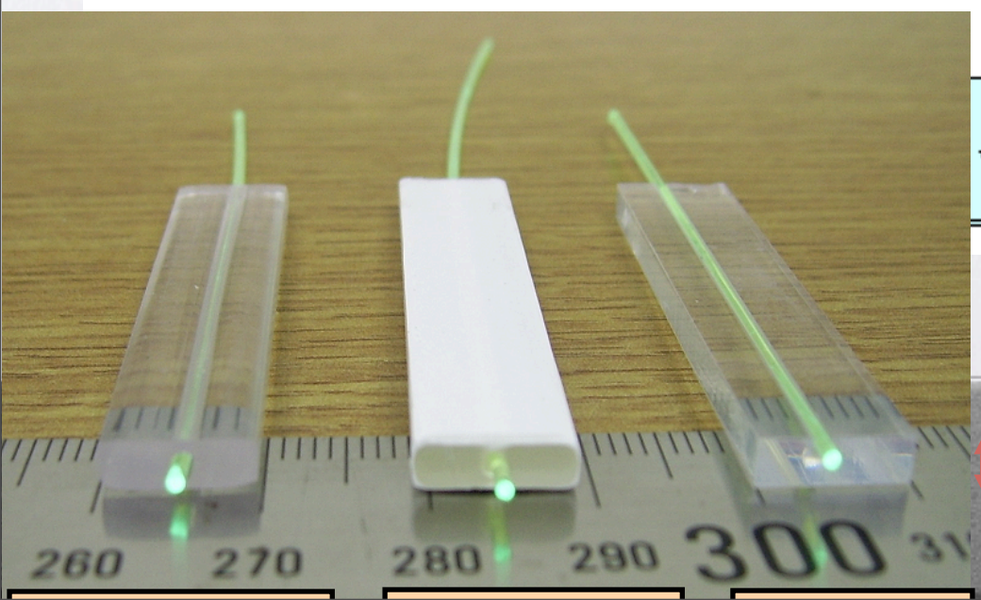


scintillator strip

- Extrusion method
- suitable for strip scintillator



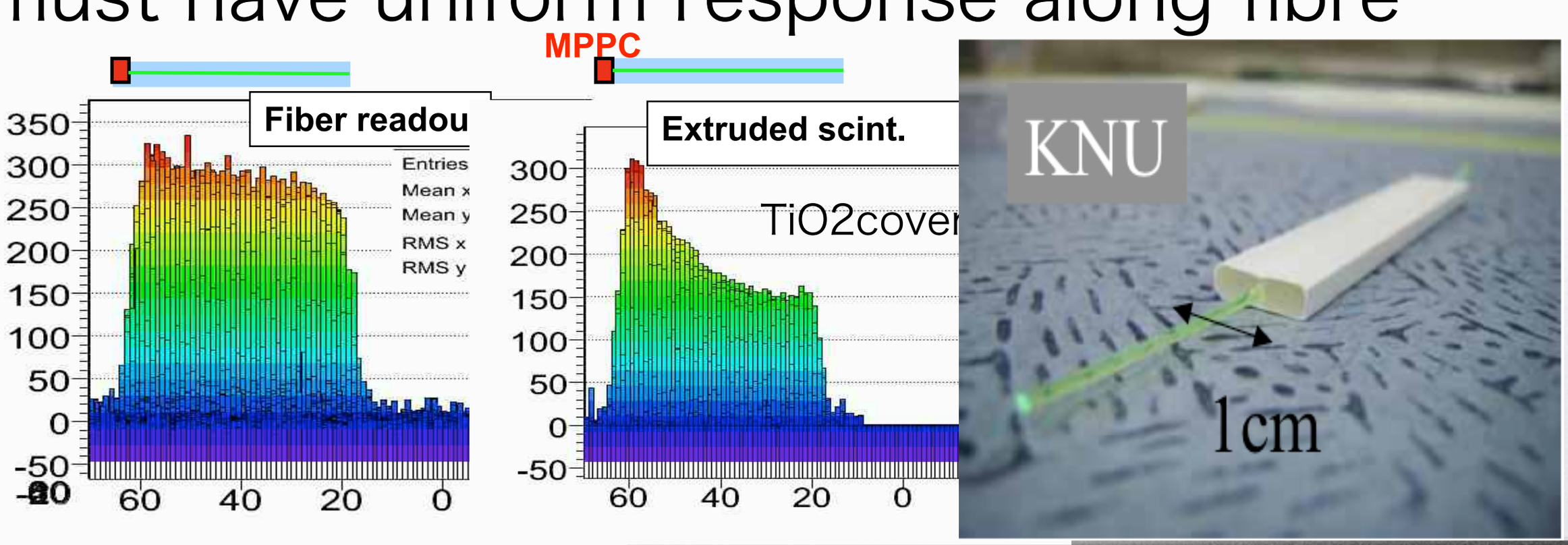




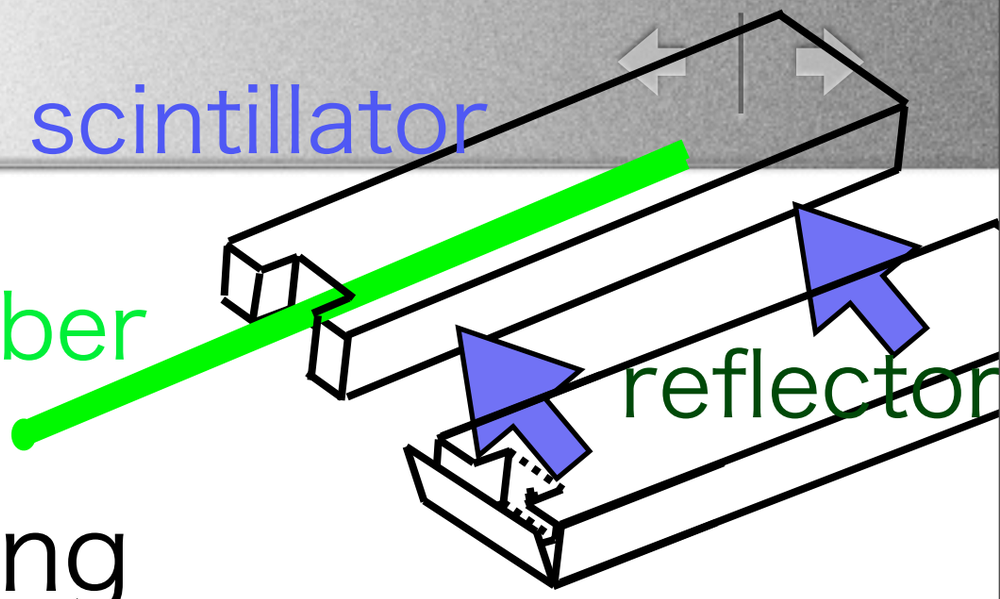
3m

scintillator strip 2

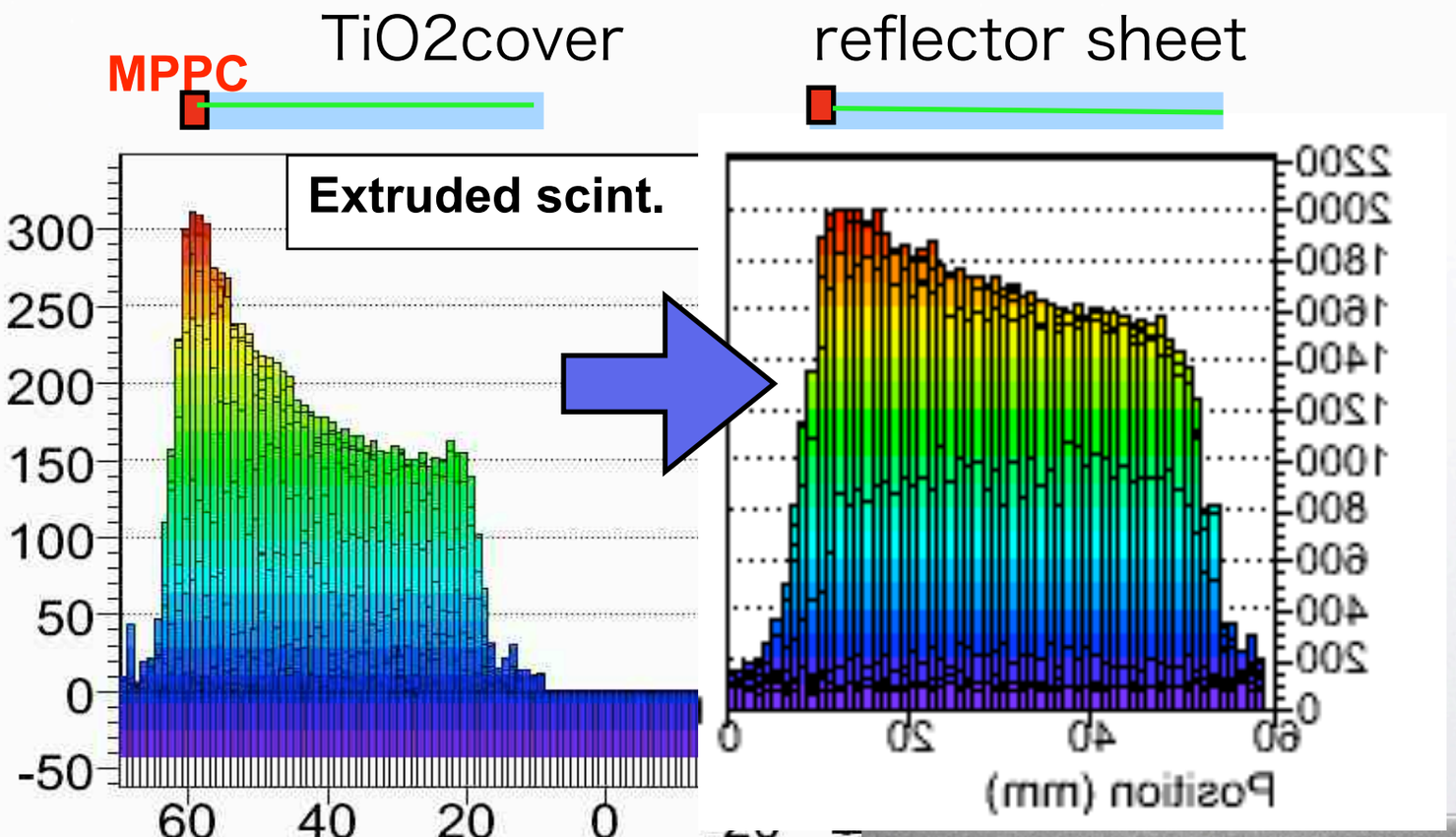
- extrusion method has TiO2 cover & hole for WLSF
- WLSF : once absorb blue light
- then emit green light in uniform direction in 1ns
- must have uniform response along fibre

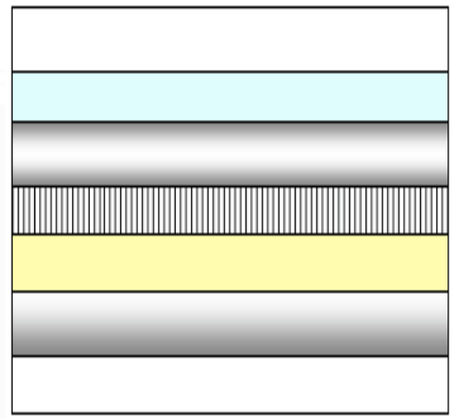


strip

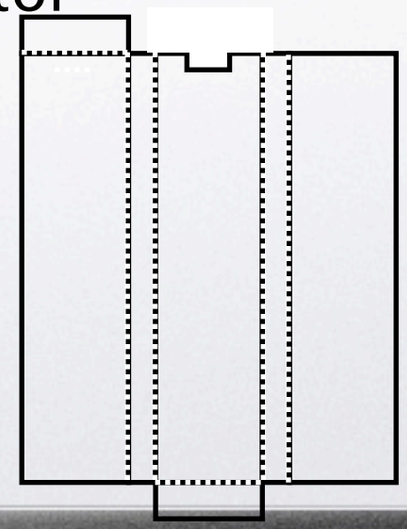


- improvement of uniformity
- by removing TiO2 and putting reflector film



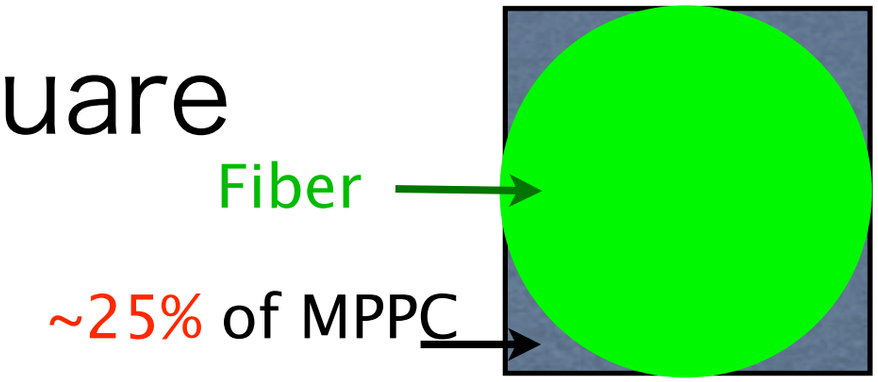


Total 57μm thickness Kimoto reflector

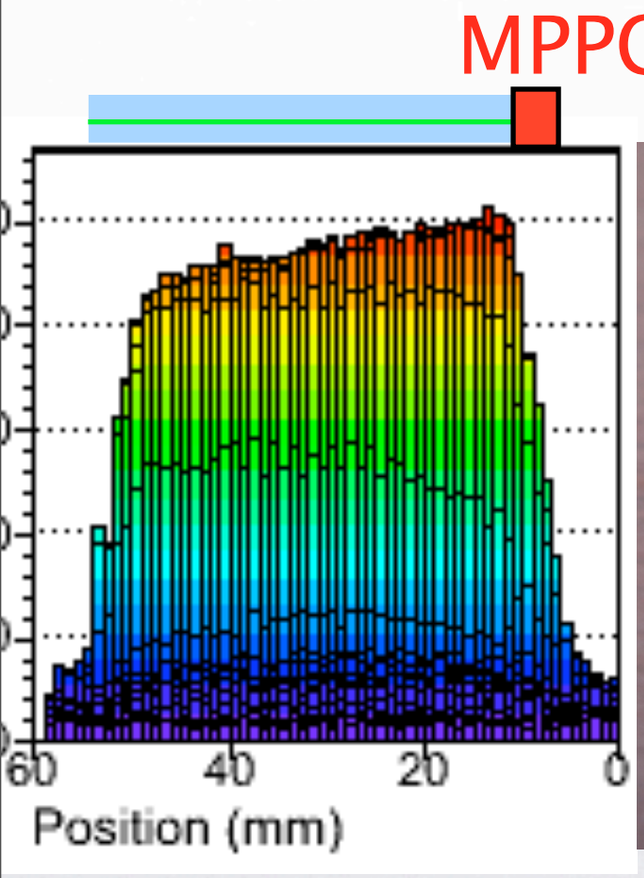


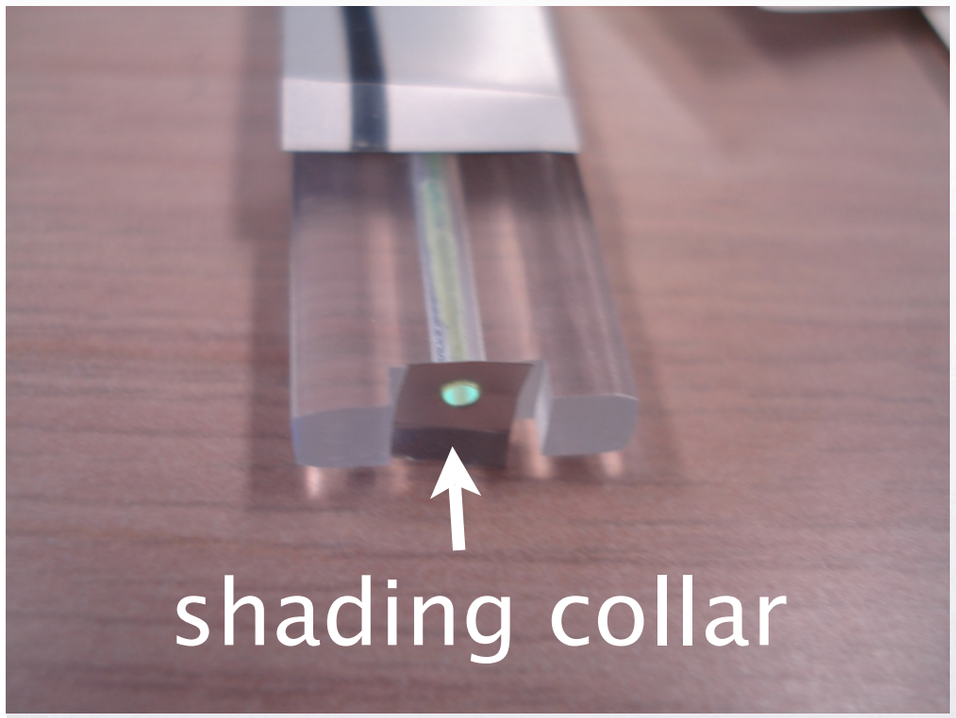
strip

- MPPC : 1mm x 1mm square
- WLSF : 1mm diam.
- add shading collar

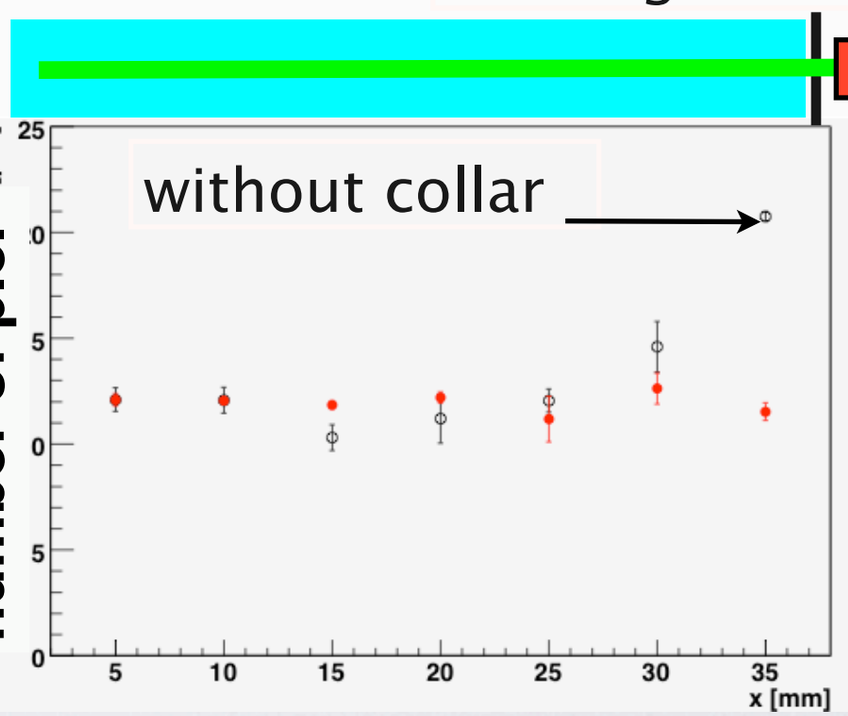


reflector





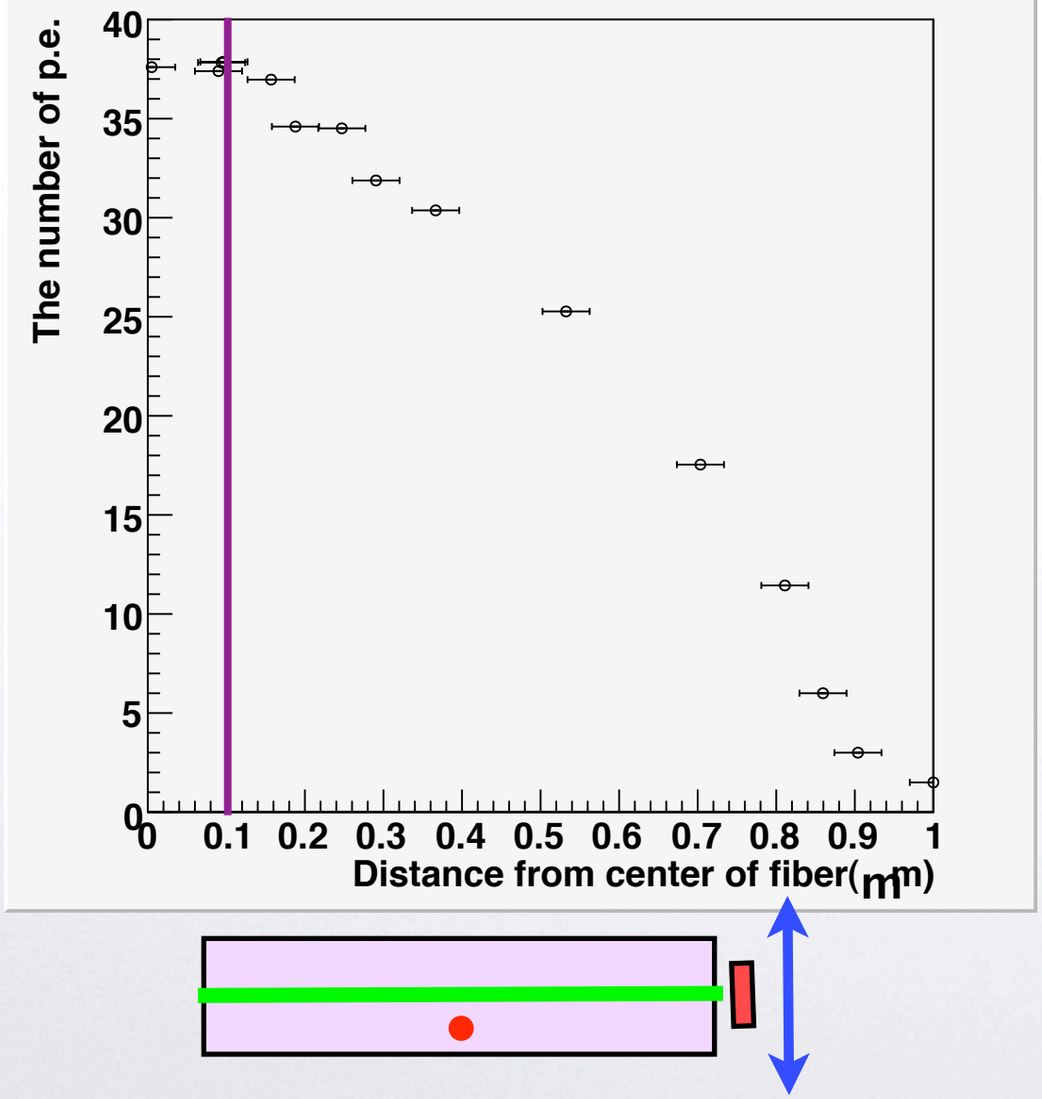
MPPC
Position dep. of light
shading collar



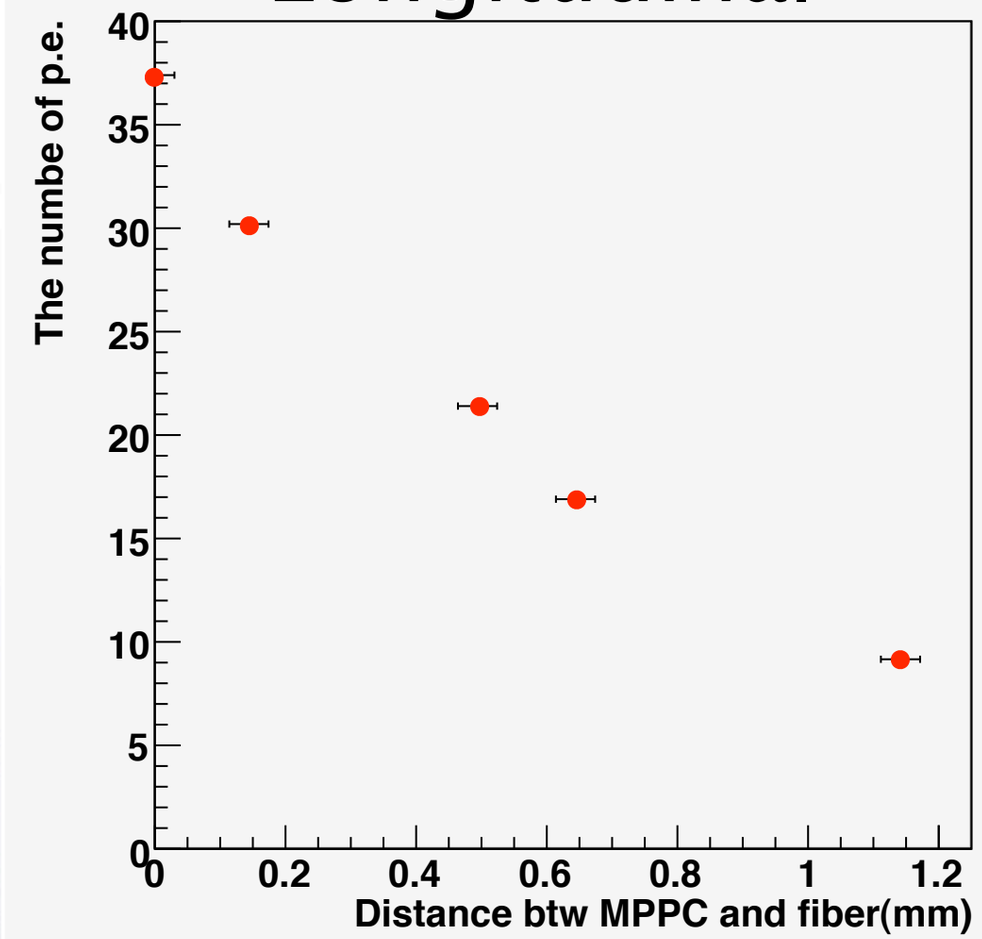
WLSF and strip

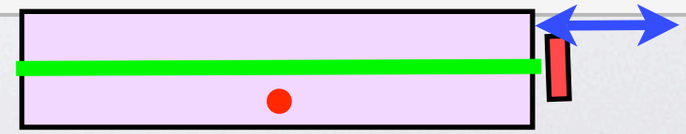
- relative position precision
- 0.1μm required

Transverse

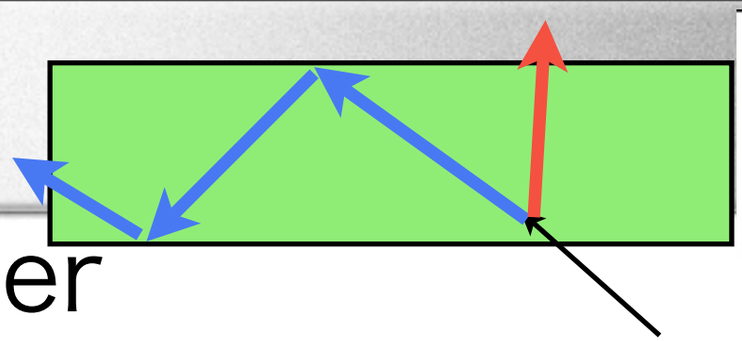


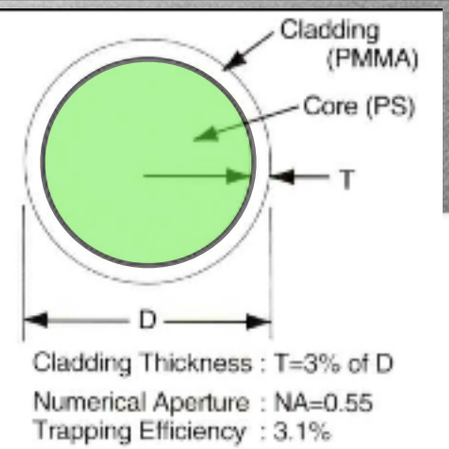
Longitudinal





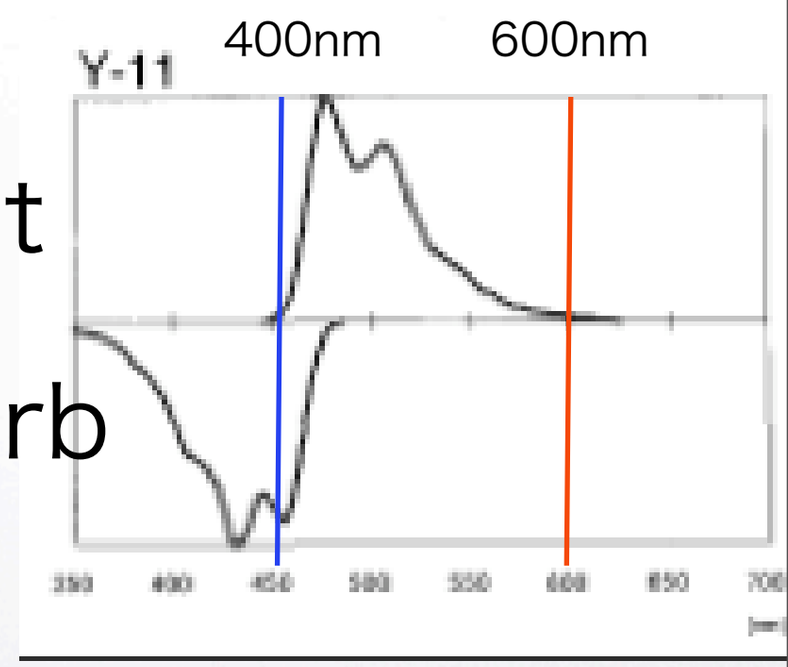
WLSF





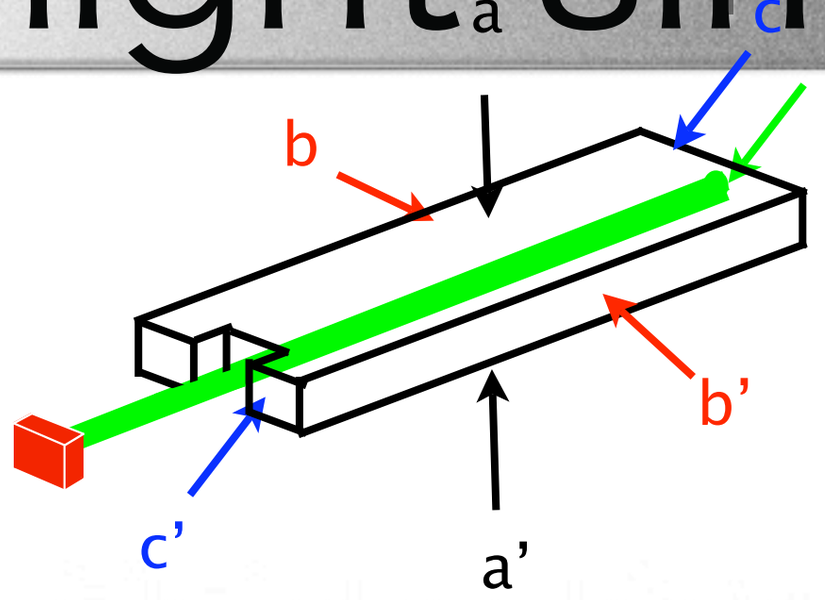
Wave Length Shifting Fiber

- wave length shifting fiber
- absorb shorter wavelength
- emit rather longer wavelength
- Kuraray Y11
- absorption length ~ 10μm
- emit light in uniform direction

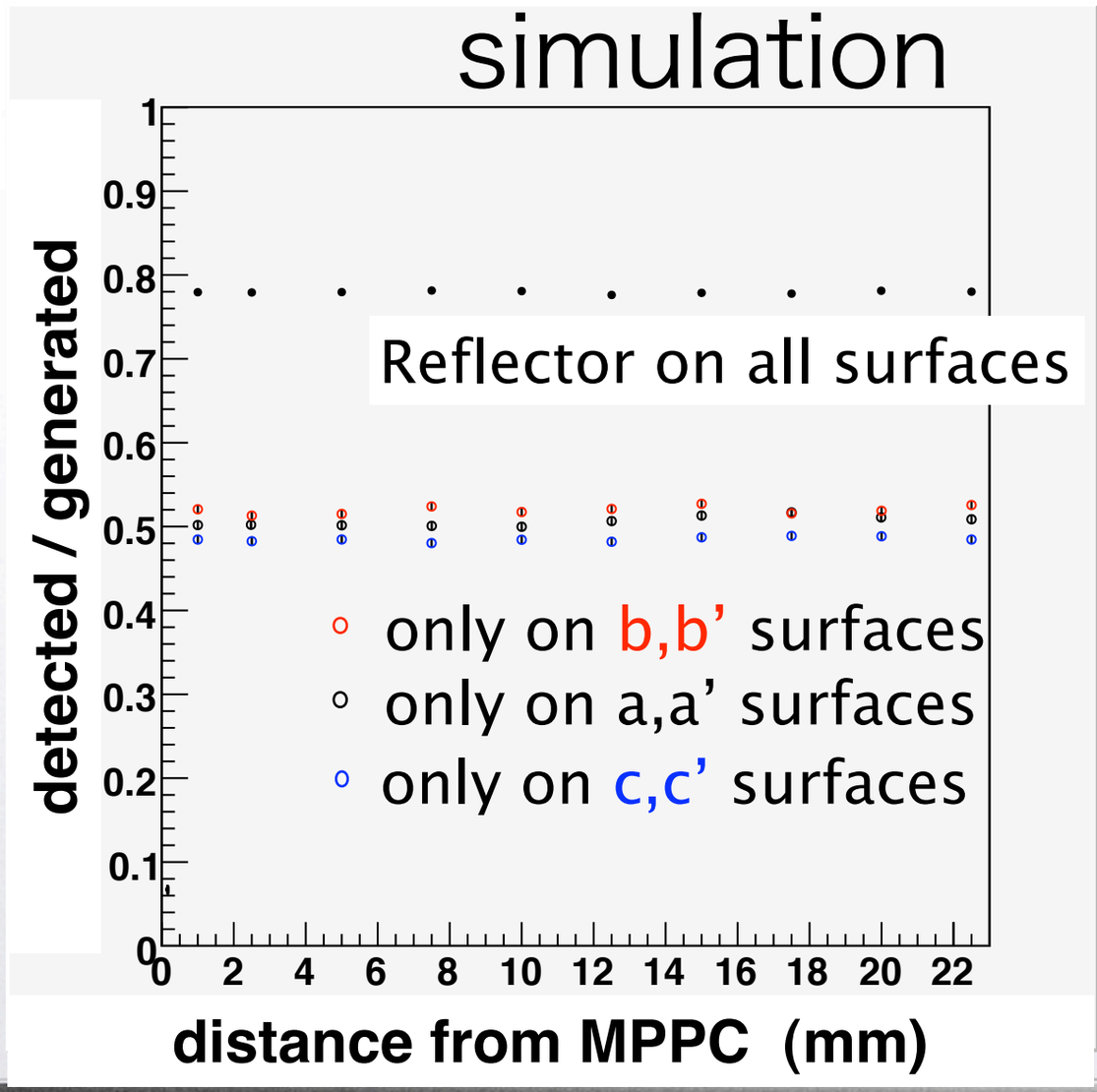


scintillation light sim.

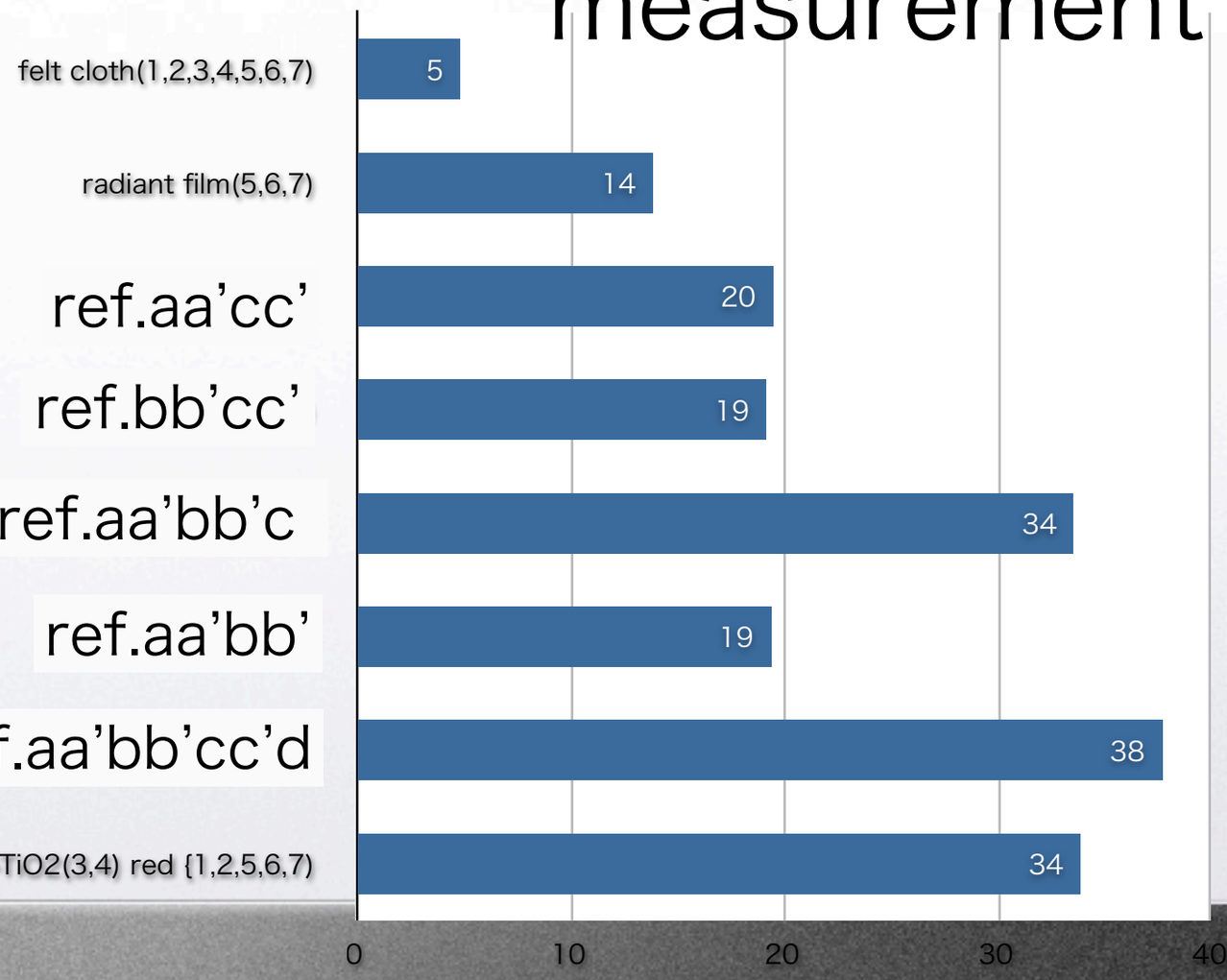
- reflector effect
- relevant for all surface



simulation

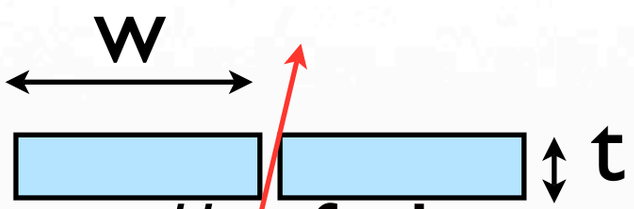


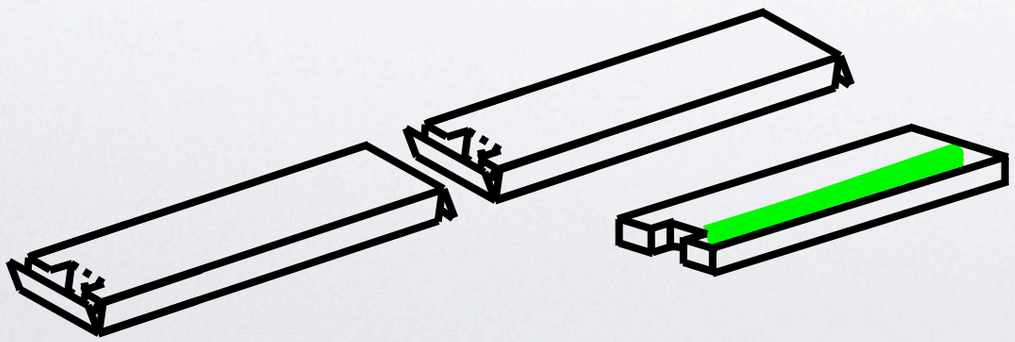
measurement

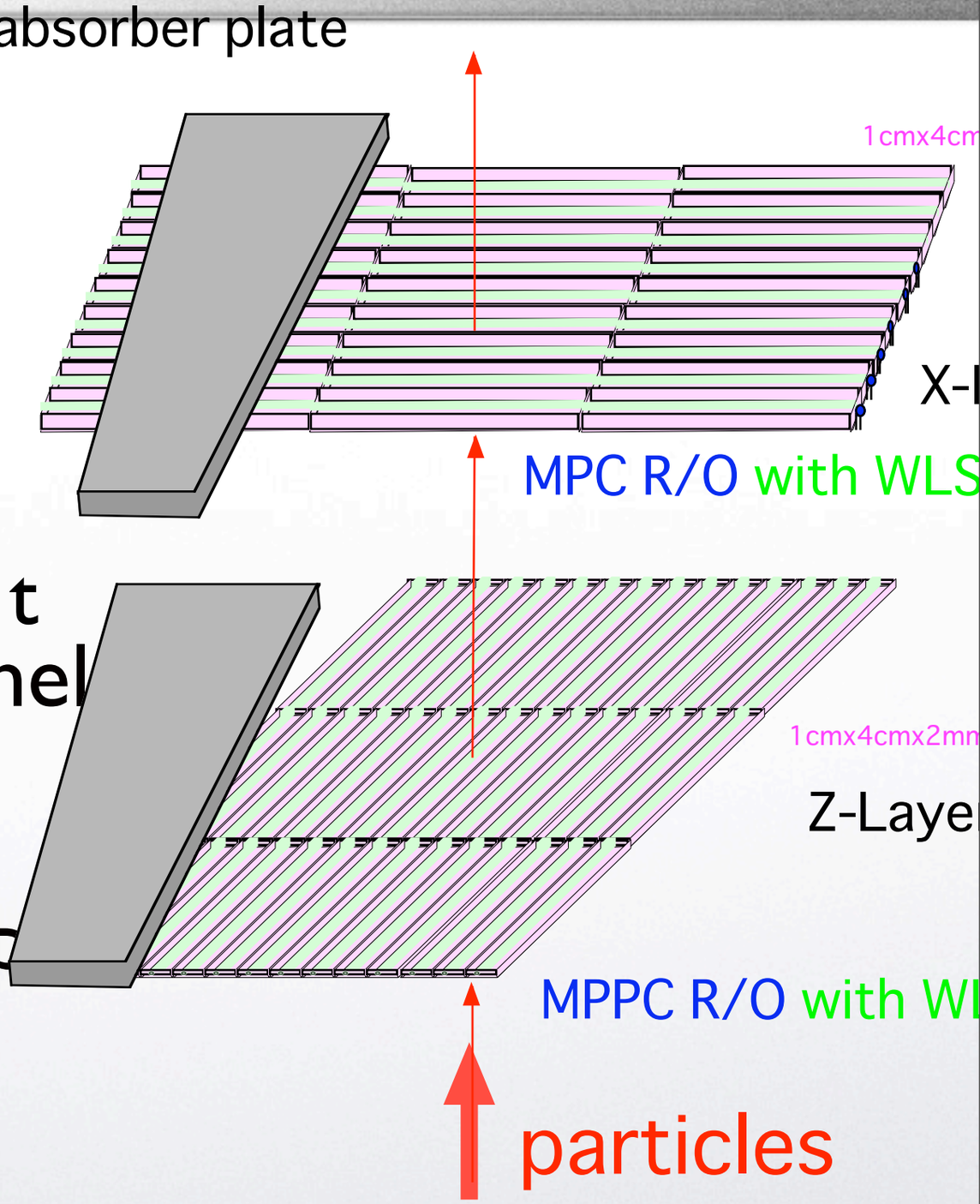


Strip scECAL

- strip
  - width : segmentation
  - thickness : charged track insensitive
  - length : to reduce # of channel but not so long
  - reflector sheet for each strip



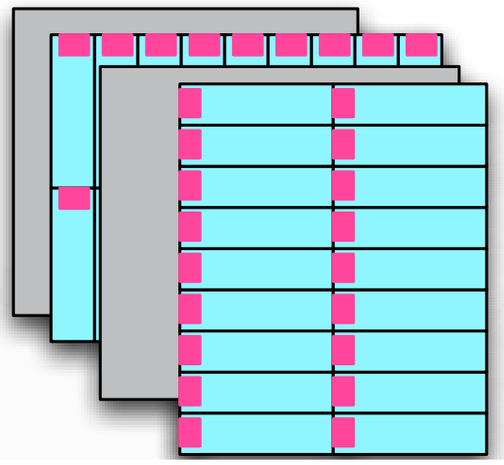


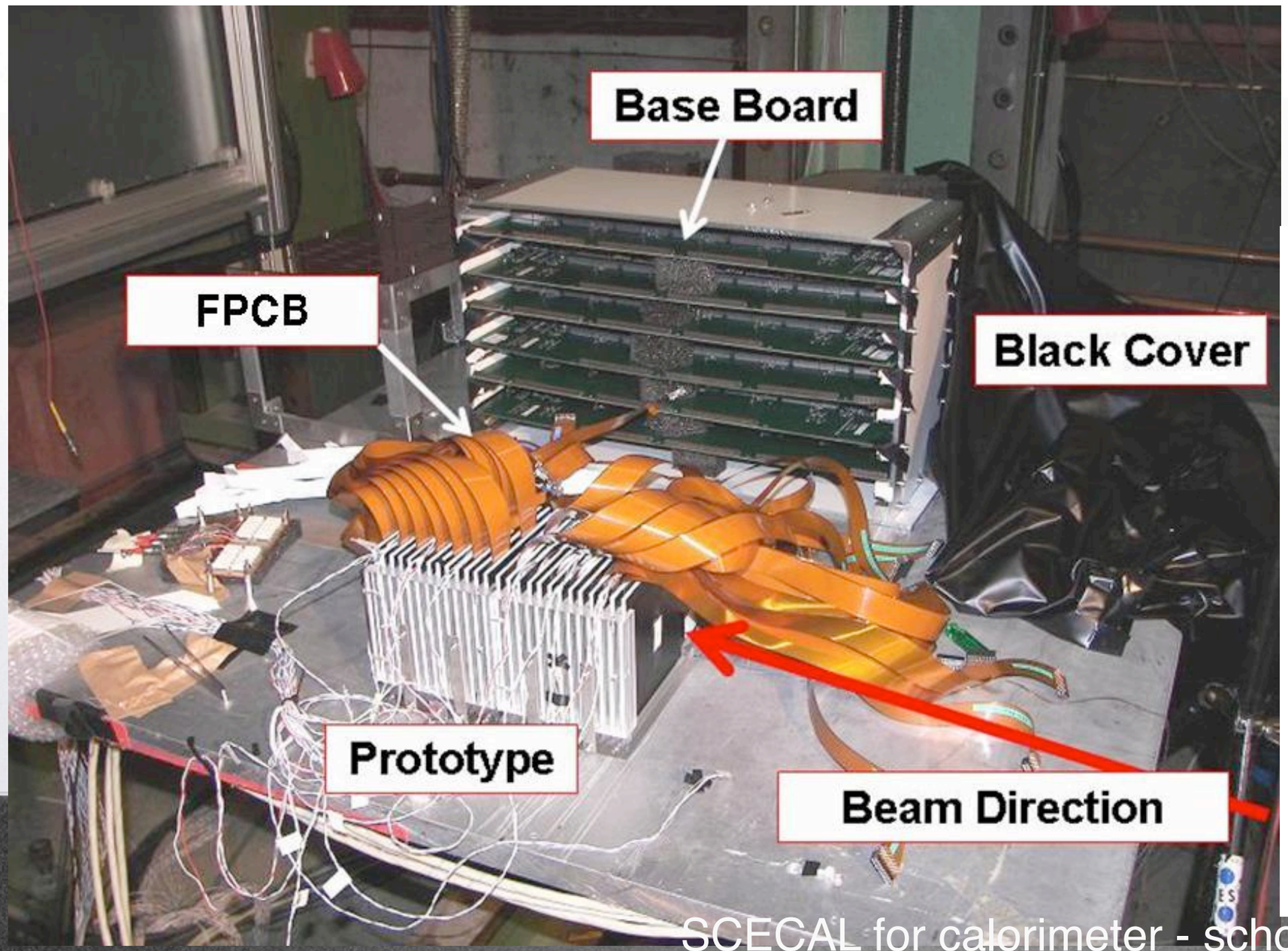


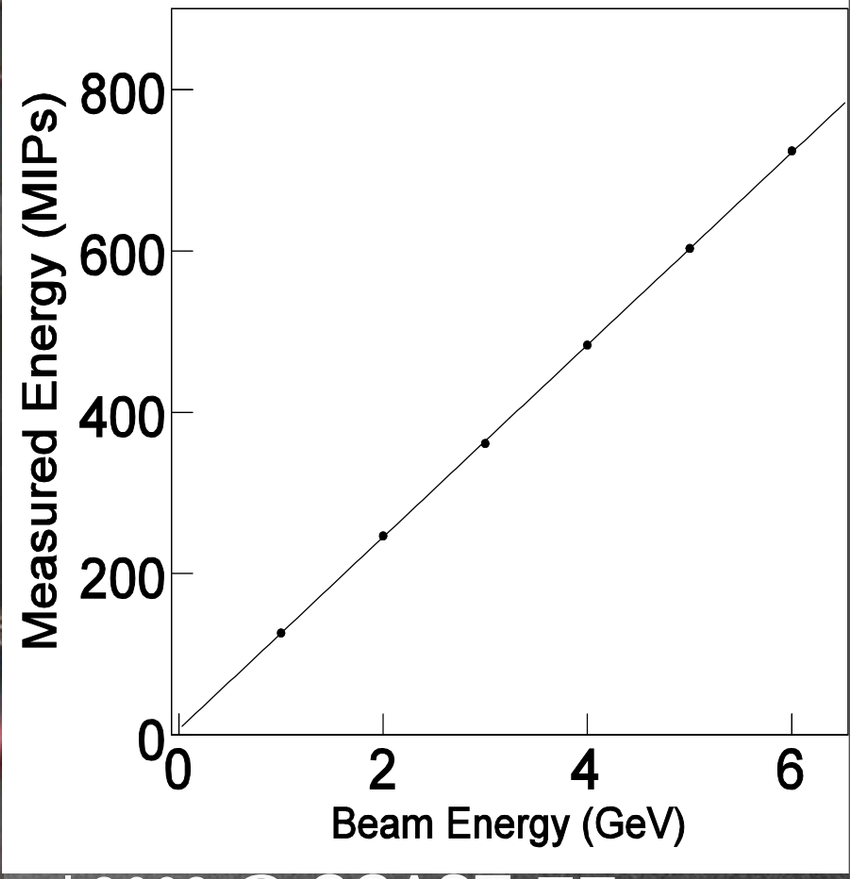
scintillator ECAL 1

- small prototype of 500 strips
  9x9 cm^2
- tested at DESY 1-6 GeV

26 layers

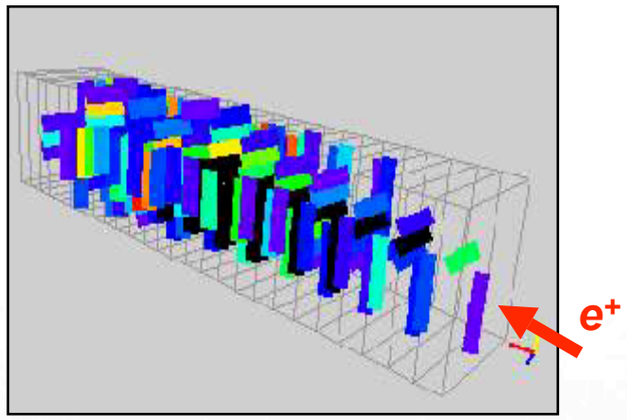


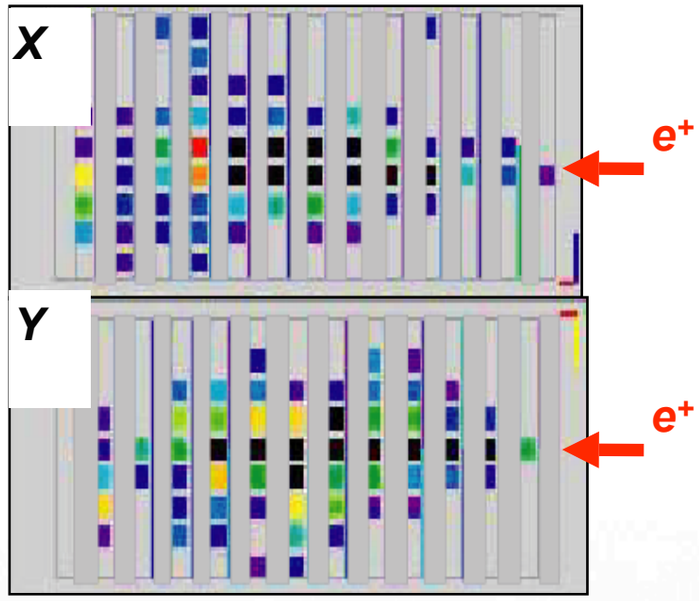




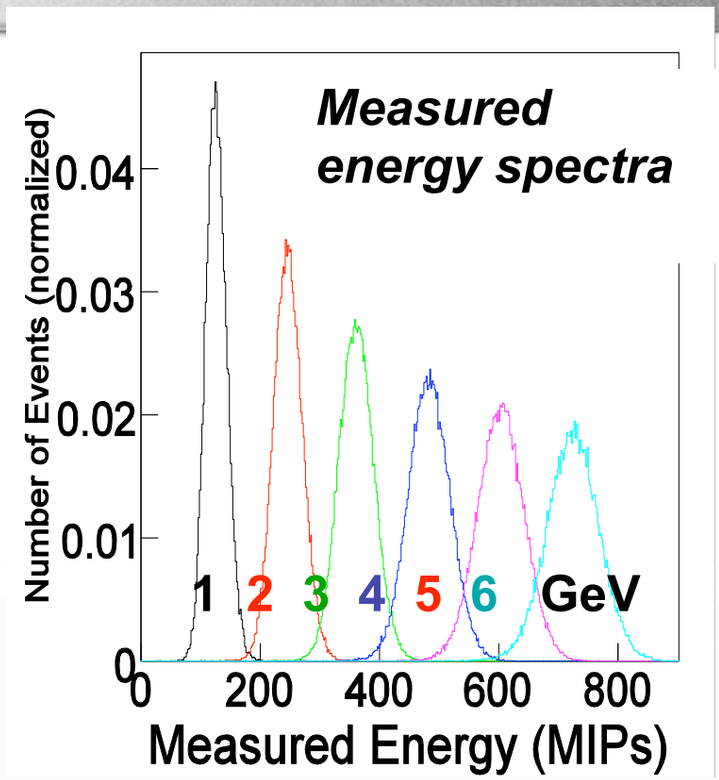
scinti-ECAL BT results

Event display
6 GeV e⁺

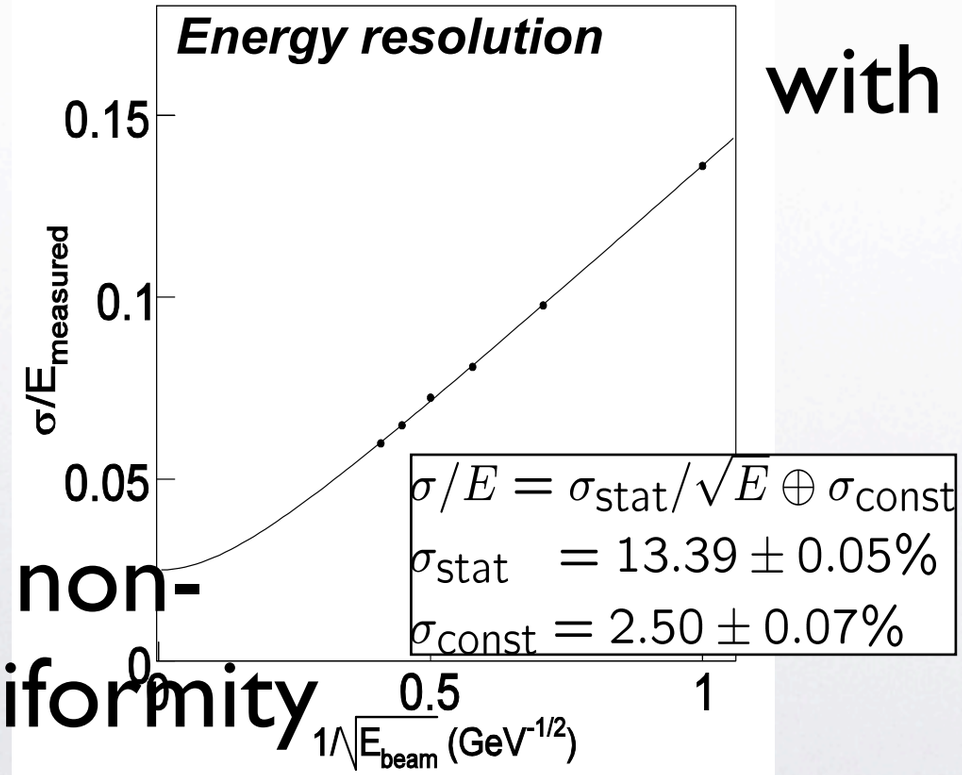




DESY BT
with small proto.

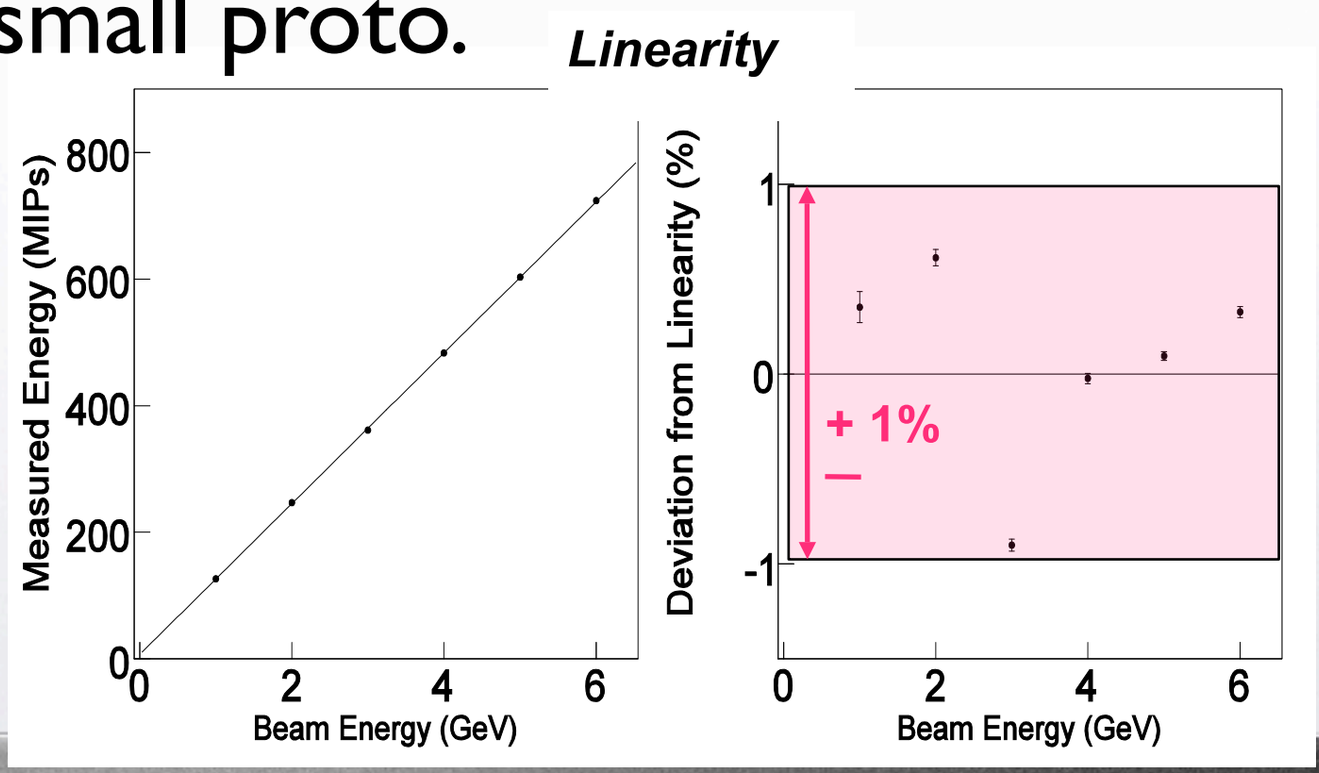


Energy resolution



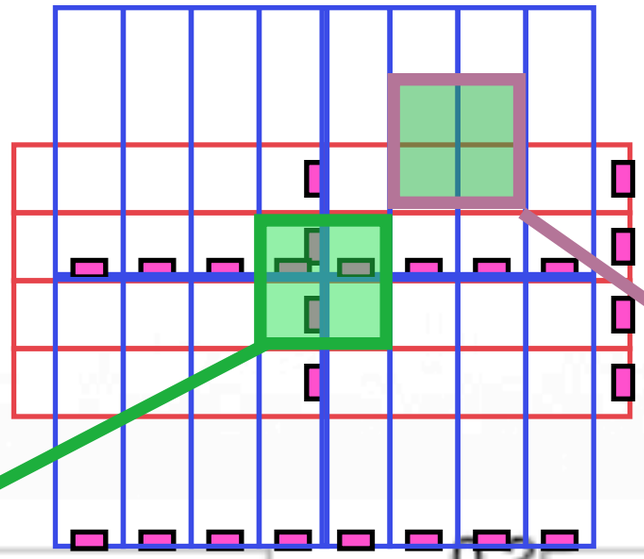
non-
uniformity

Linearity

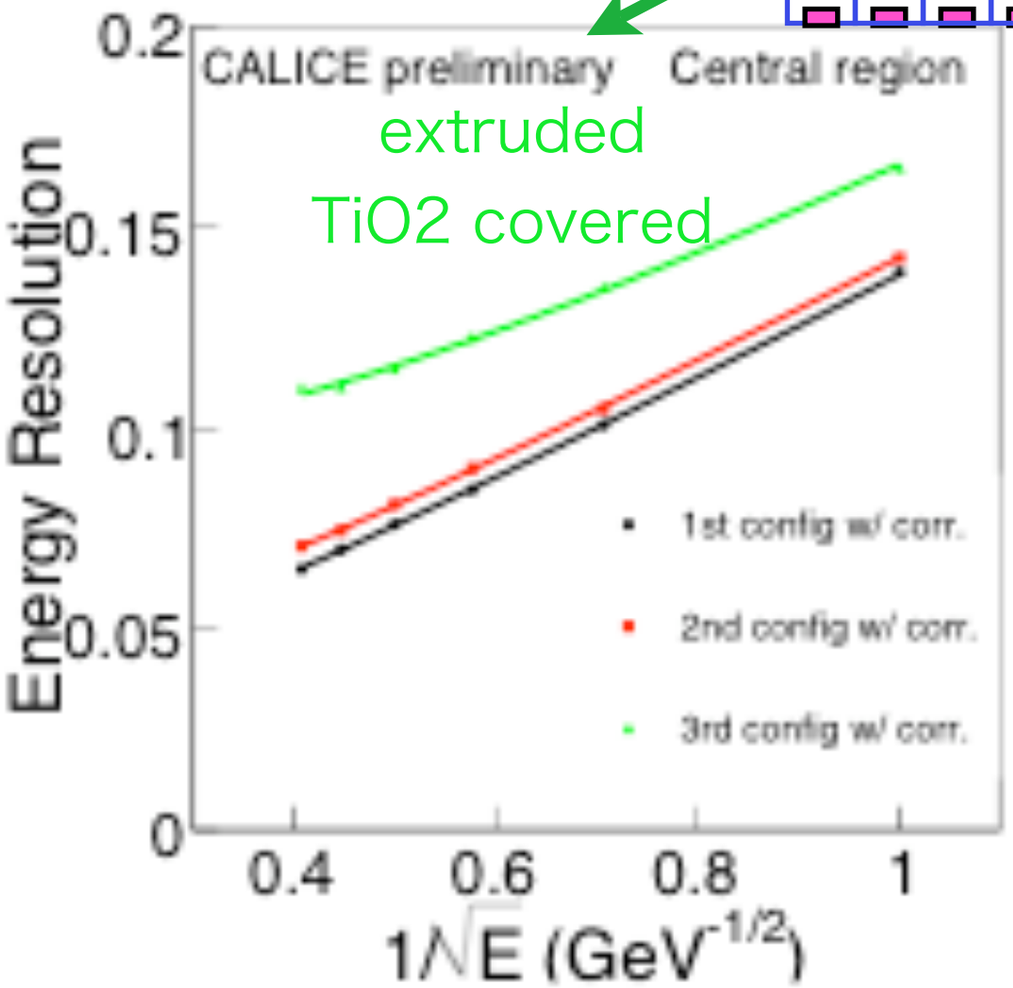


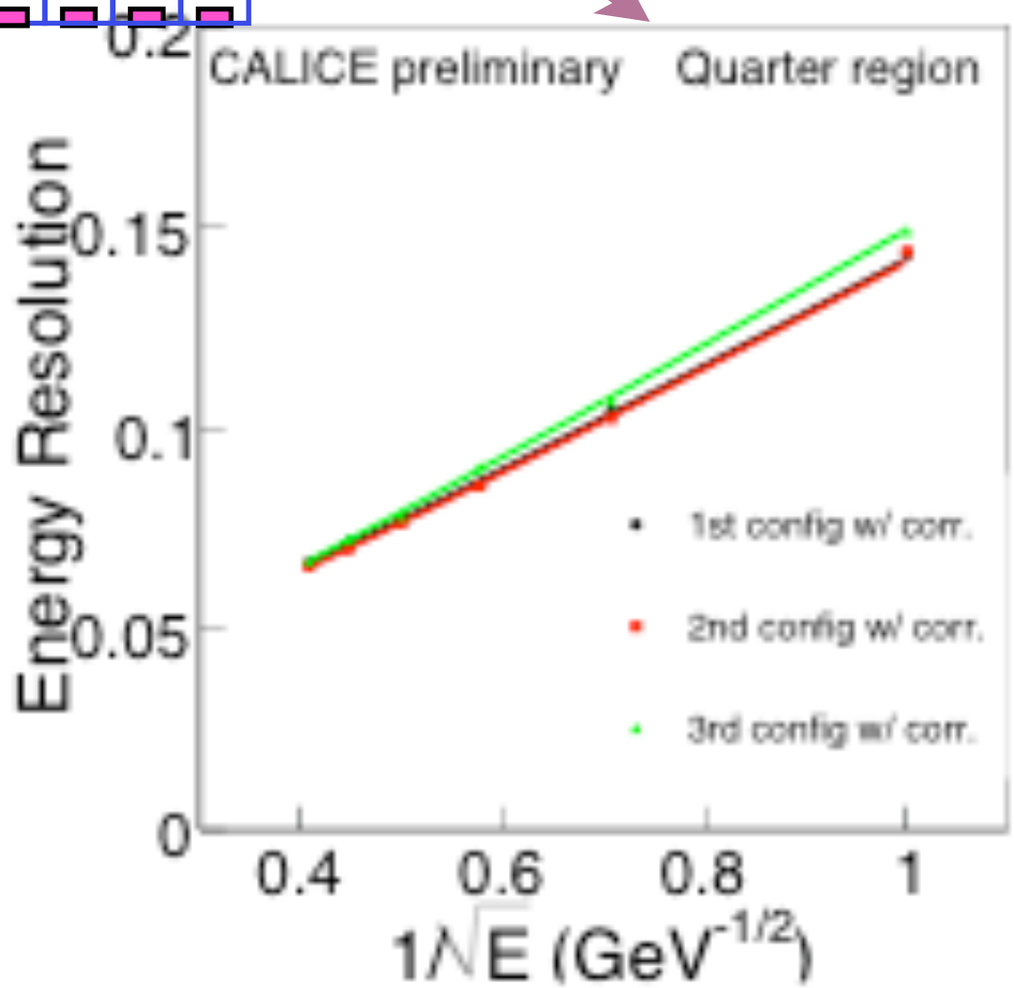
uniformity of a strip

- non-uniformity gives rise const. term in ER
- DESY BT



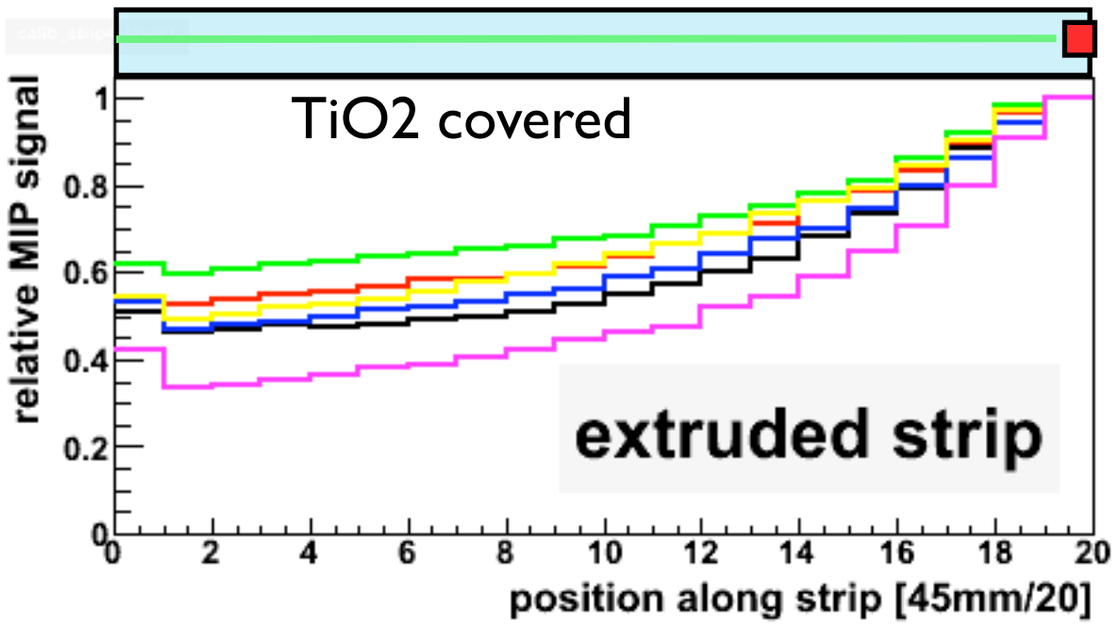
$$\frac{13\%}{\sqrt{E(GeV)}} \oplus 3\%$$

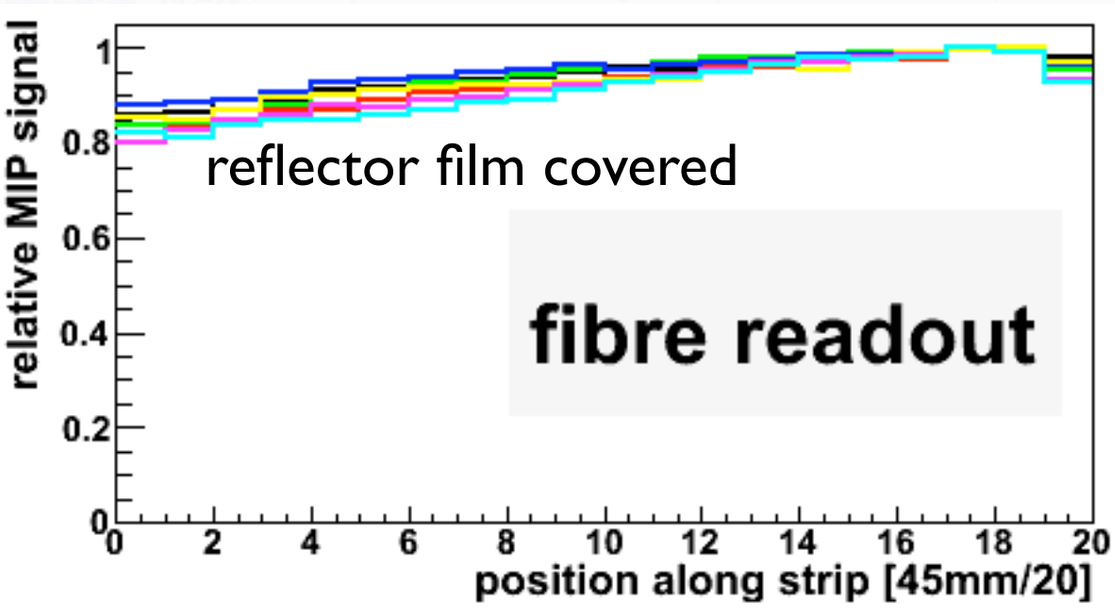


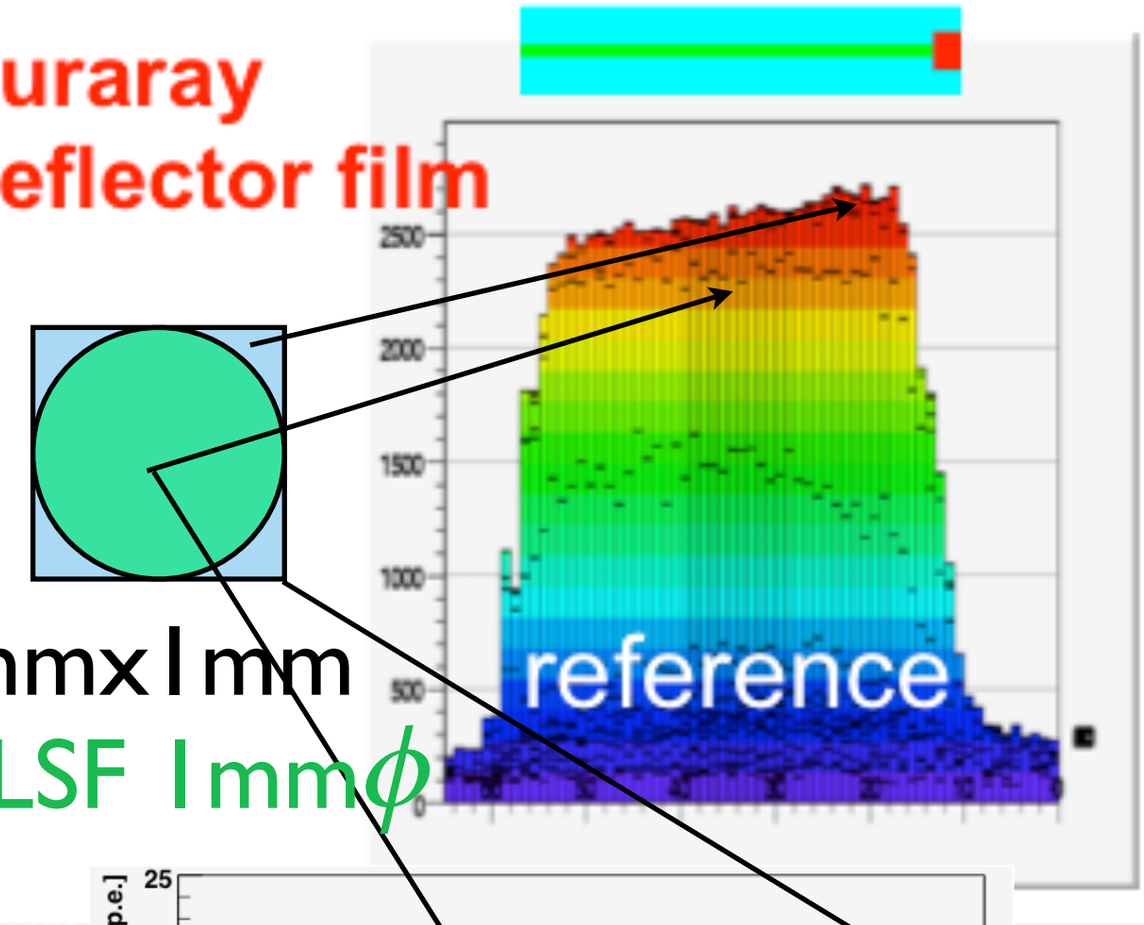


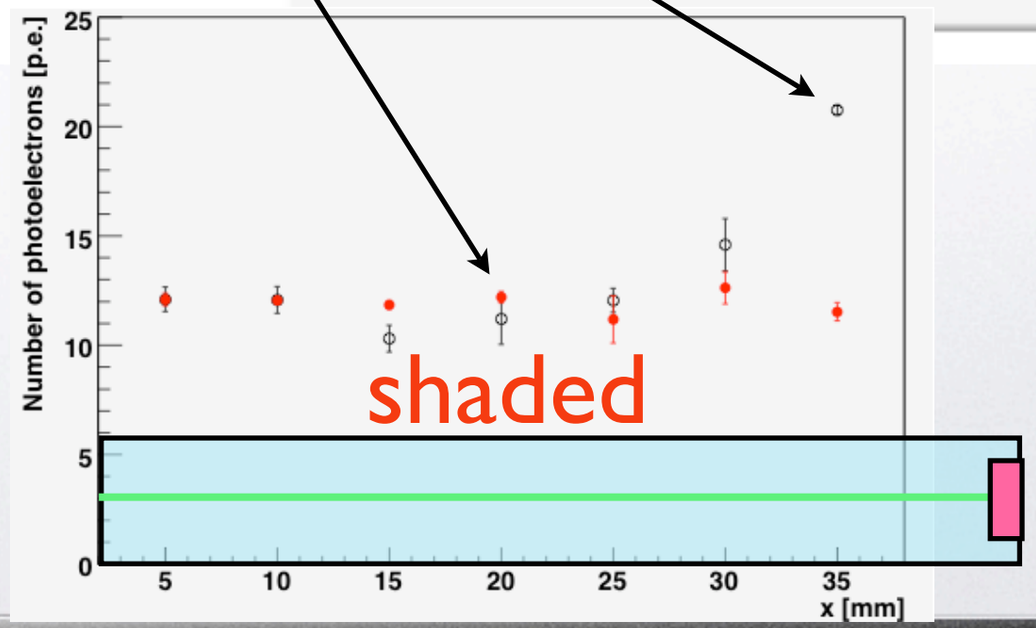
uniformity of a strip 2

- uniformity tested by MIPs



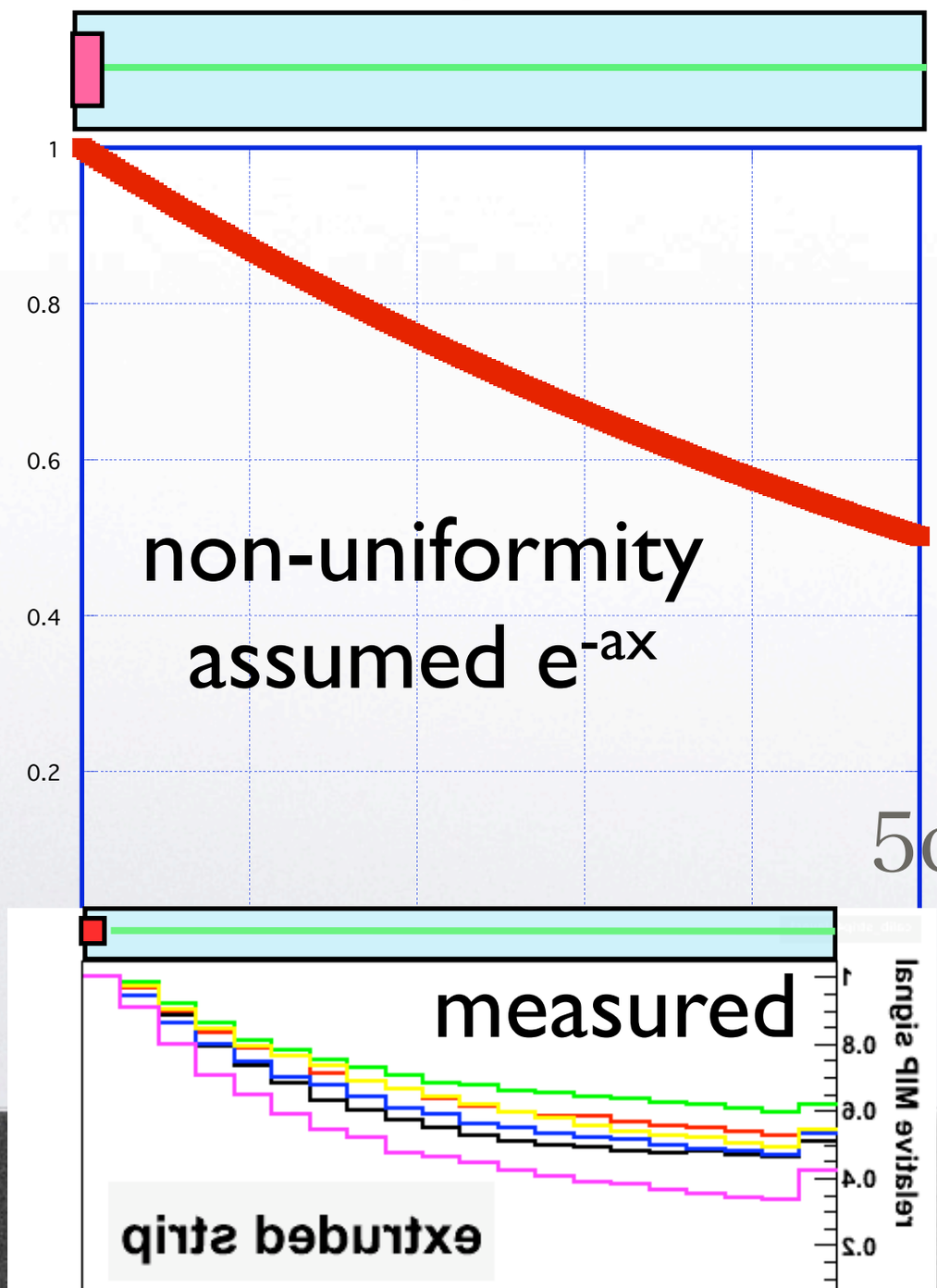


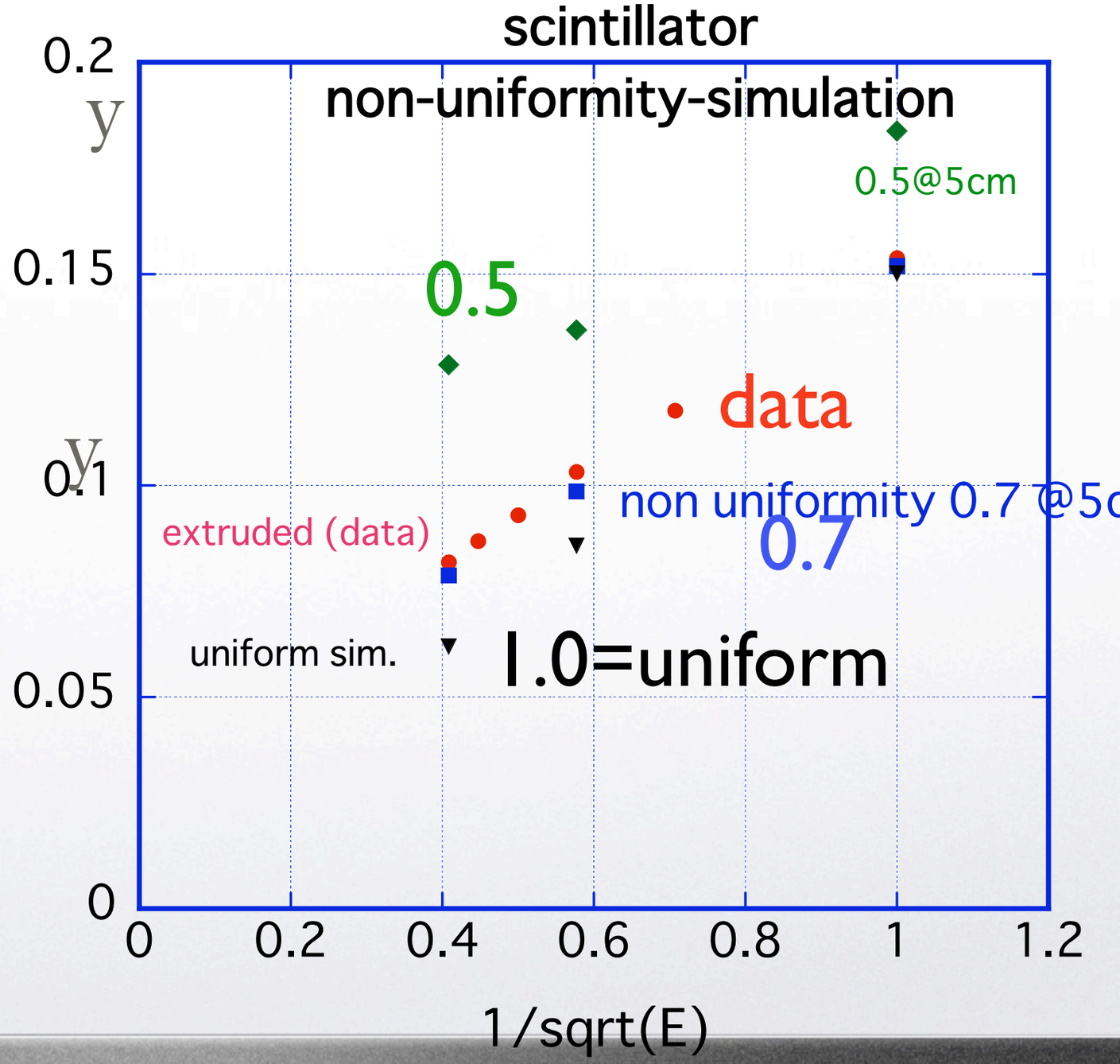




uniformity of a strip 3

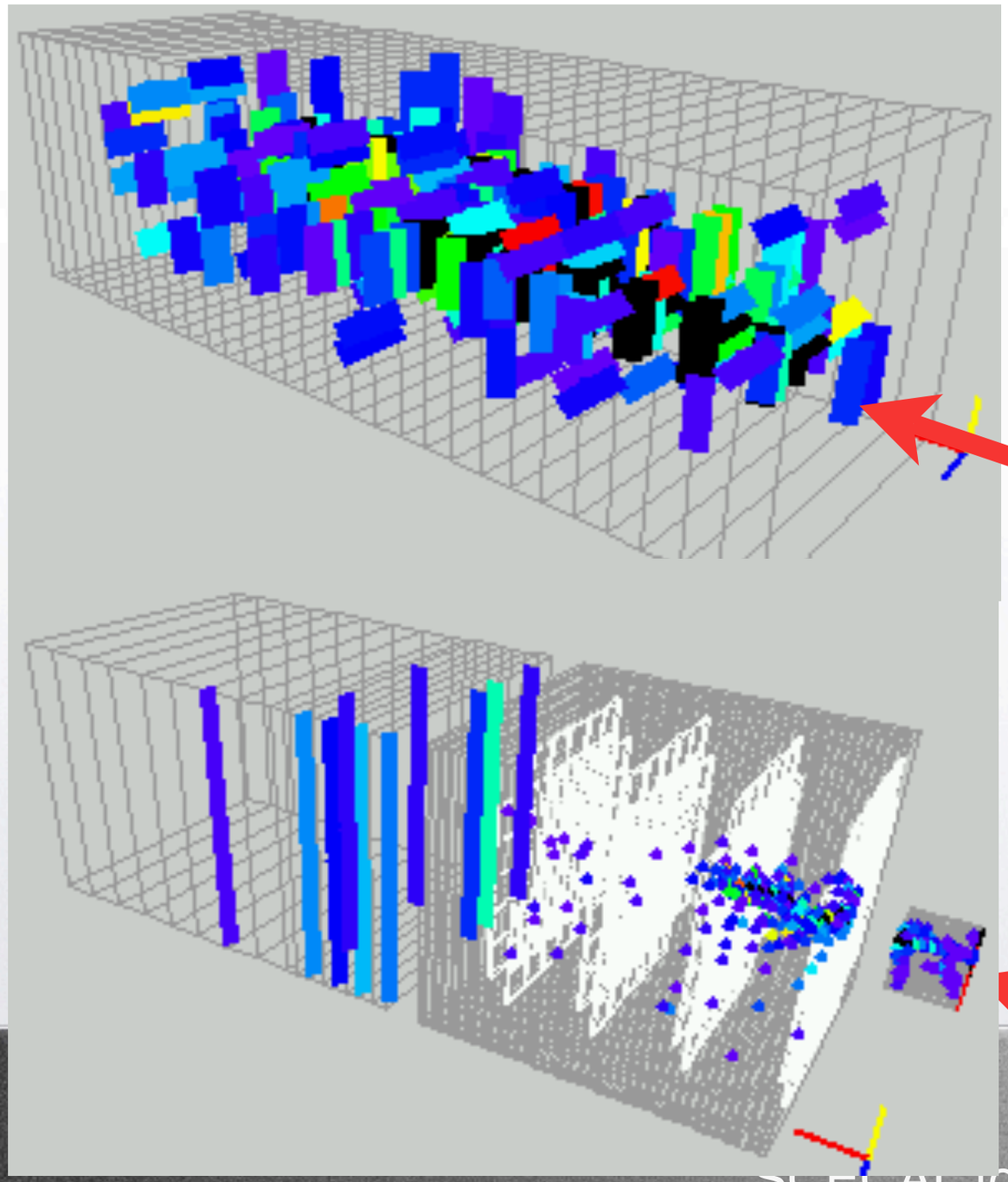
- simulation with uniform and non-uniform strips

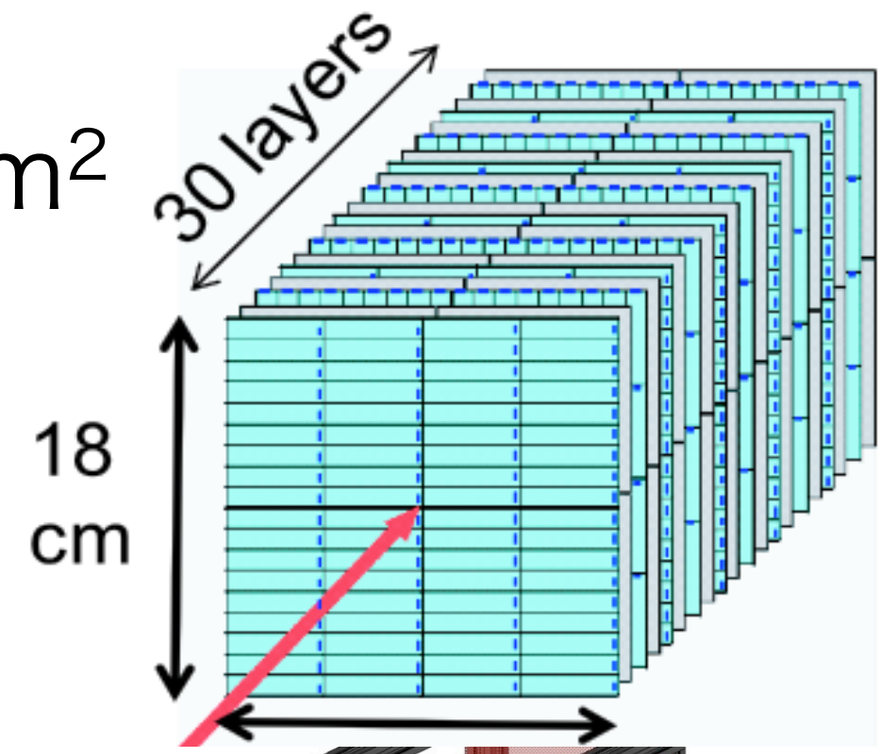


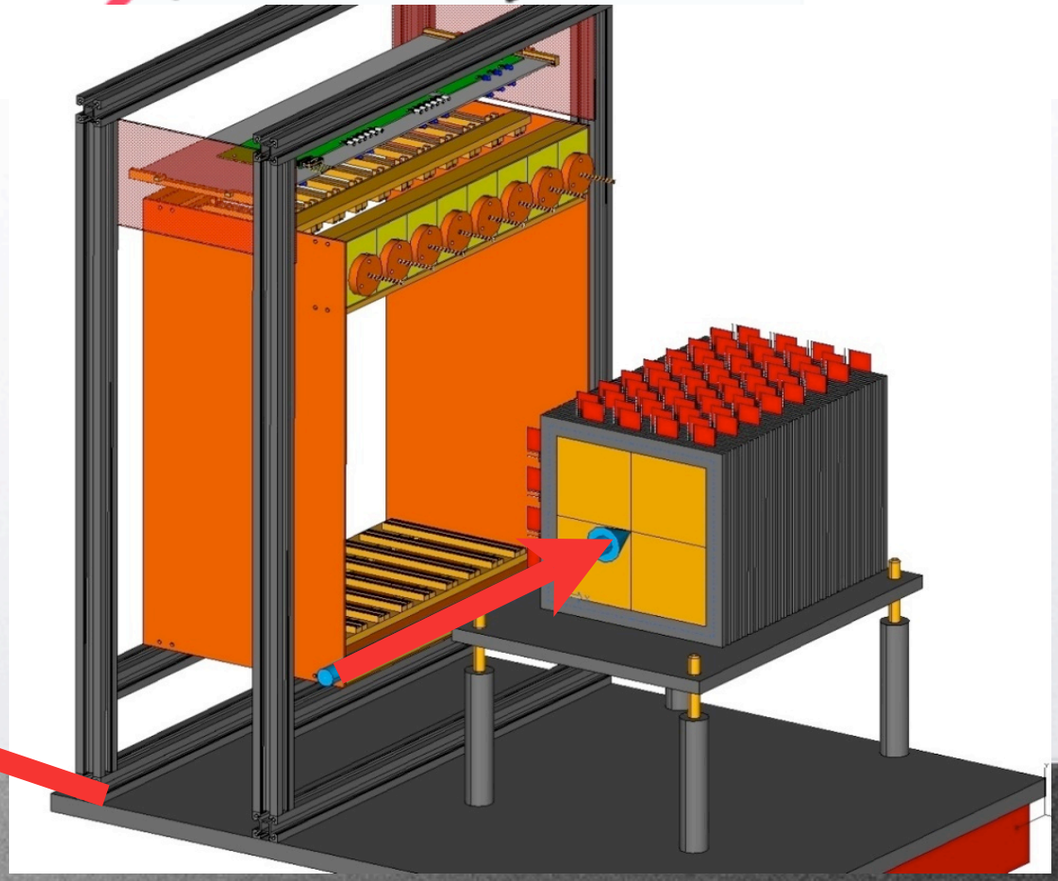


scintillator ECAL 2

- strip ECAL 2000 ch
  18x18 cm^2
- tested at Fermilab







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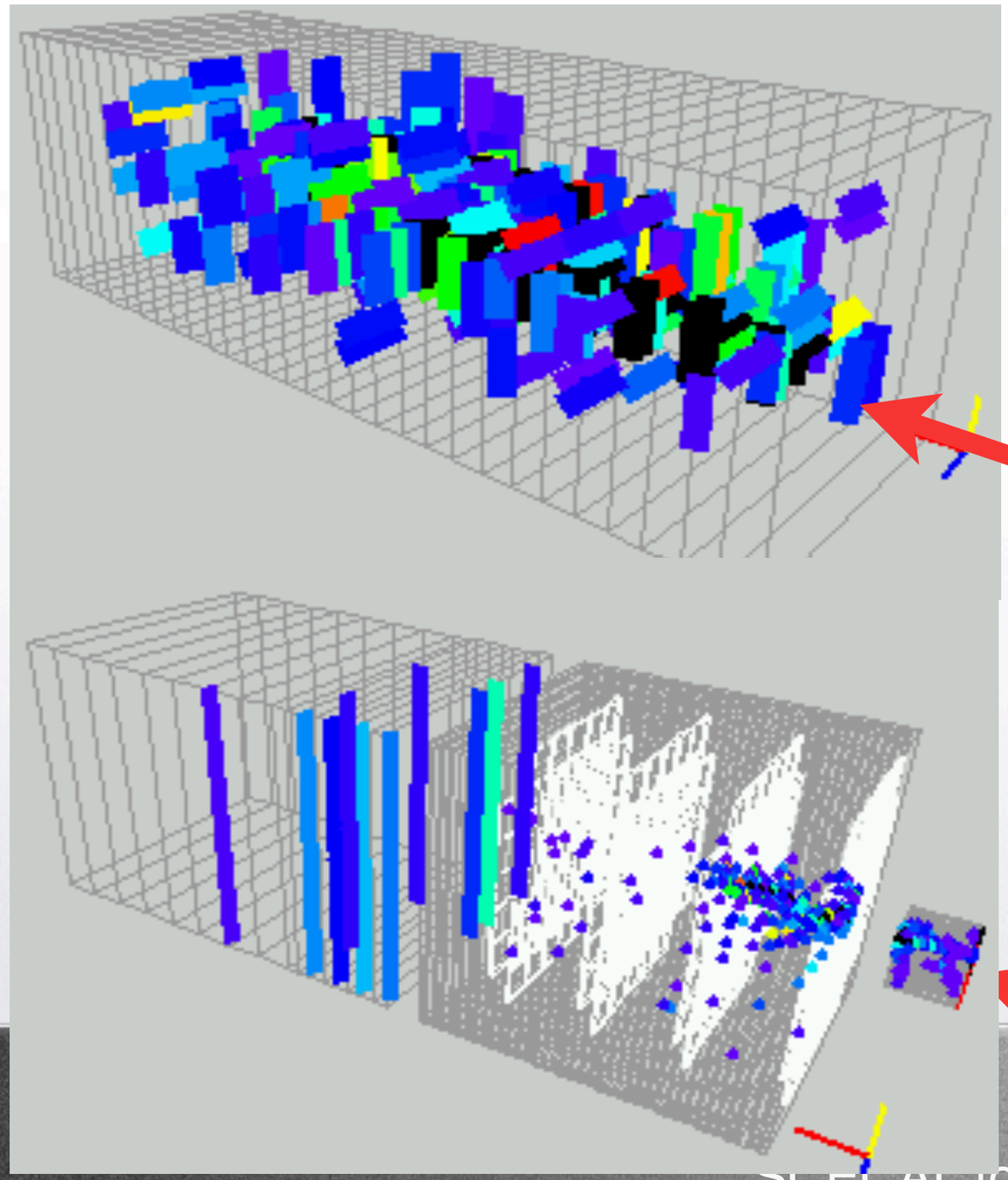
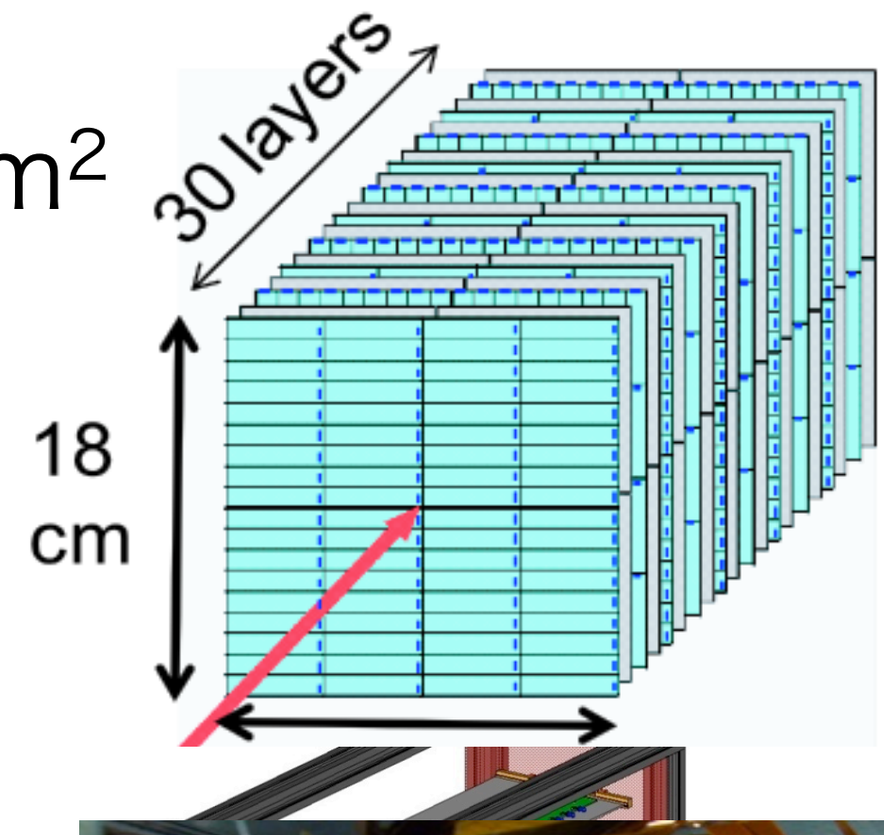
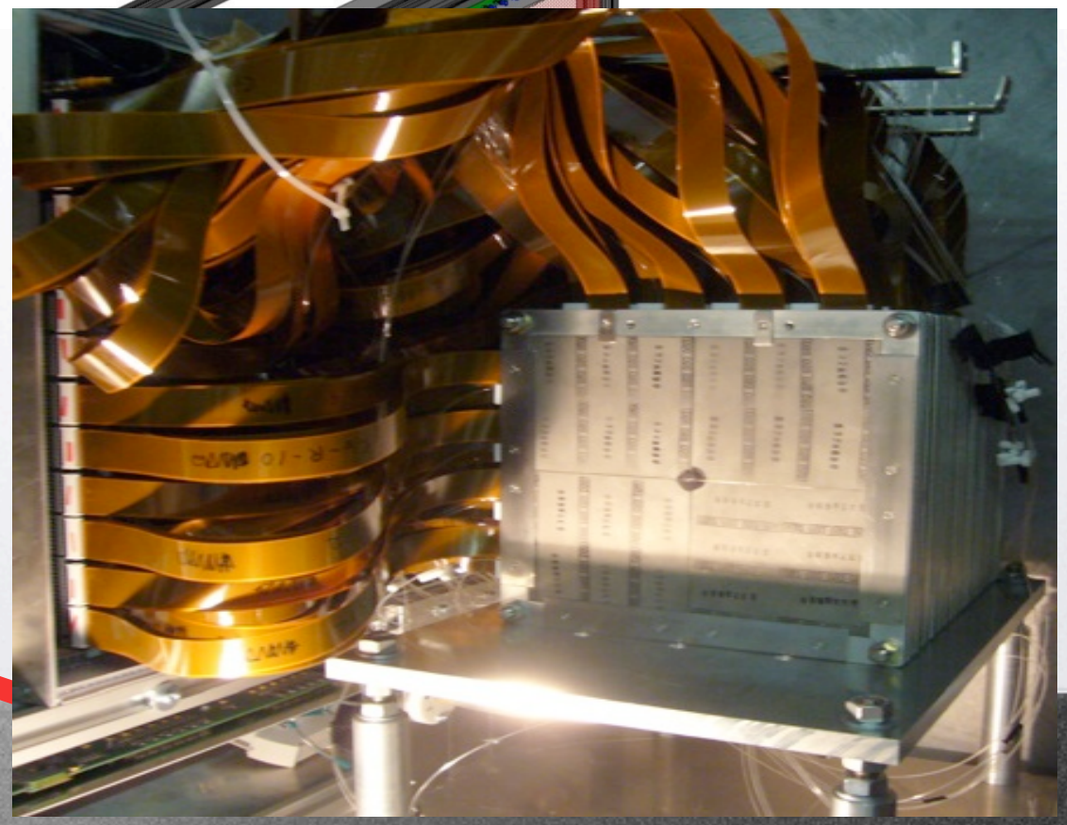
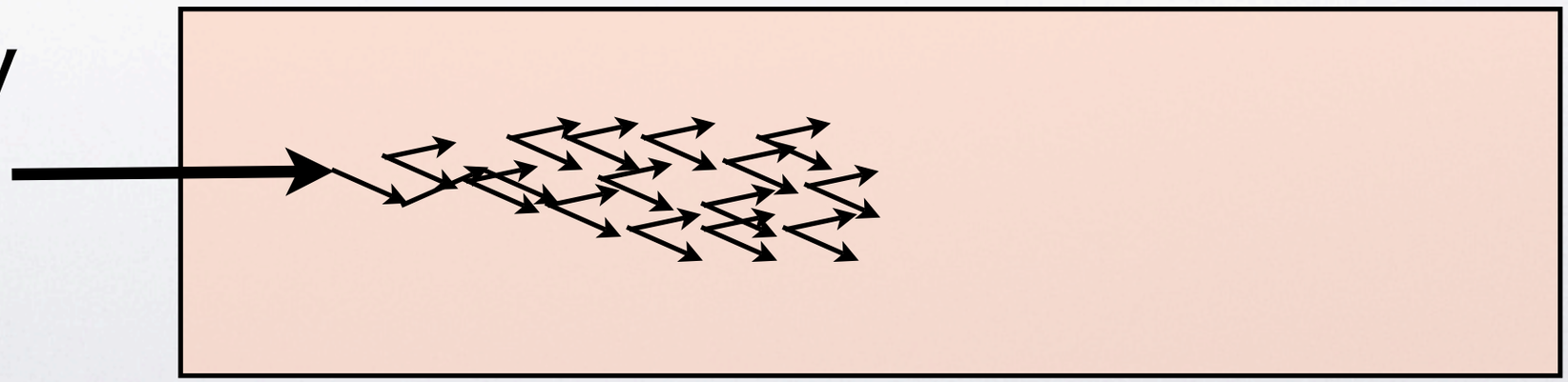






How to calculate energy

- sandwich calorimeter measures part of the incident energy
- we need factor to go back the actual energy
- MIP will be used as a constant unit
- 1 MIP : particle passing absorber & scintillator pair
- count number of MIP by 1GeV electrons
- ~24 MIP/GeV



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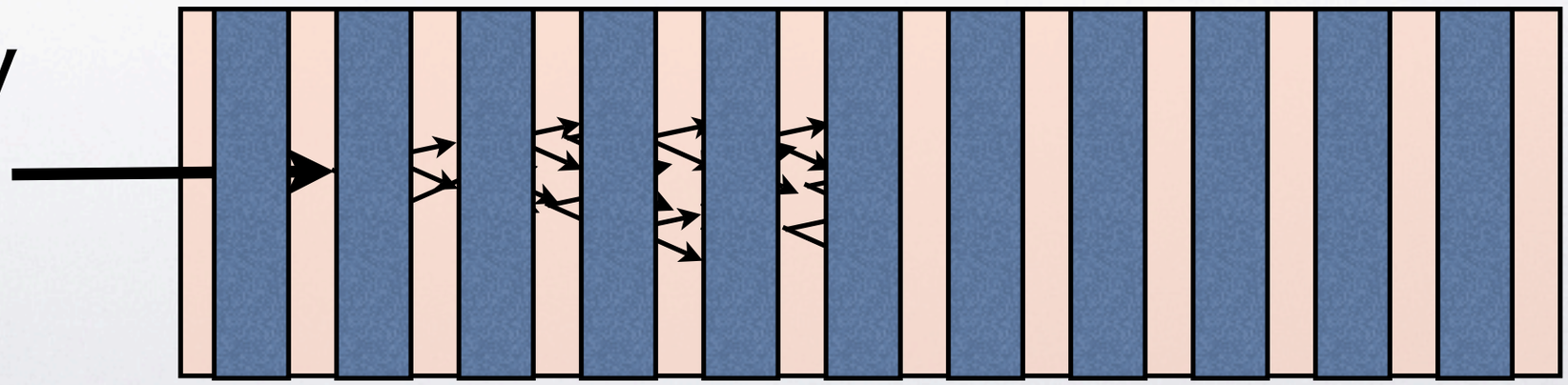
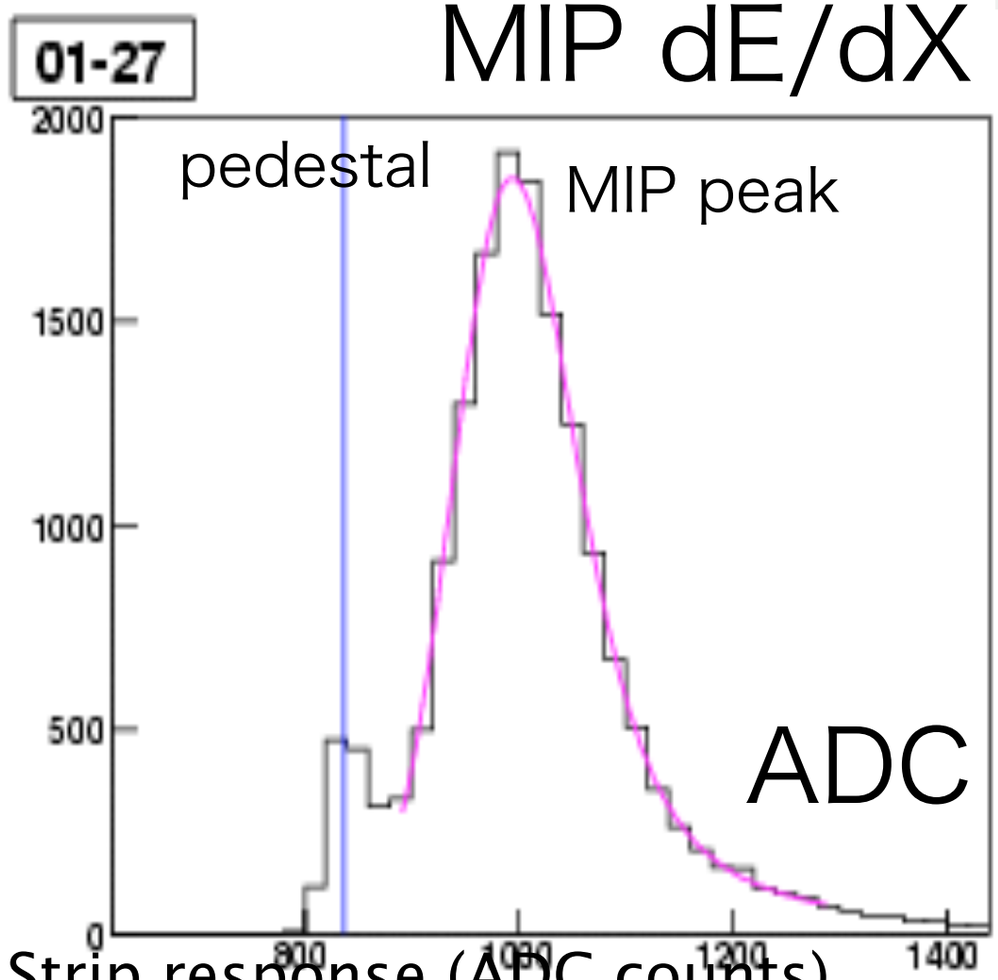
- we need factor to go back the actual energy
- MIP will be used as a constant unit
- 1 MIP : particle passing absorber & scintillator pair
- count number of MIP by 1GeV electrons
- ~24 MIP/GeV

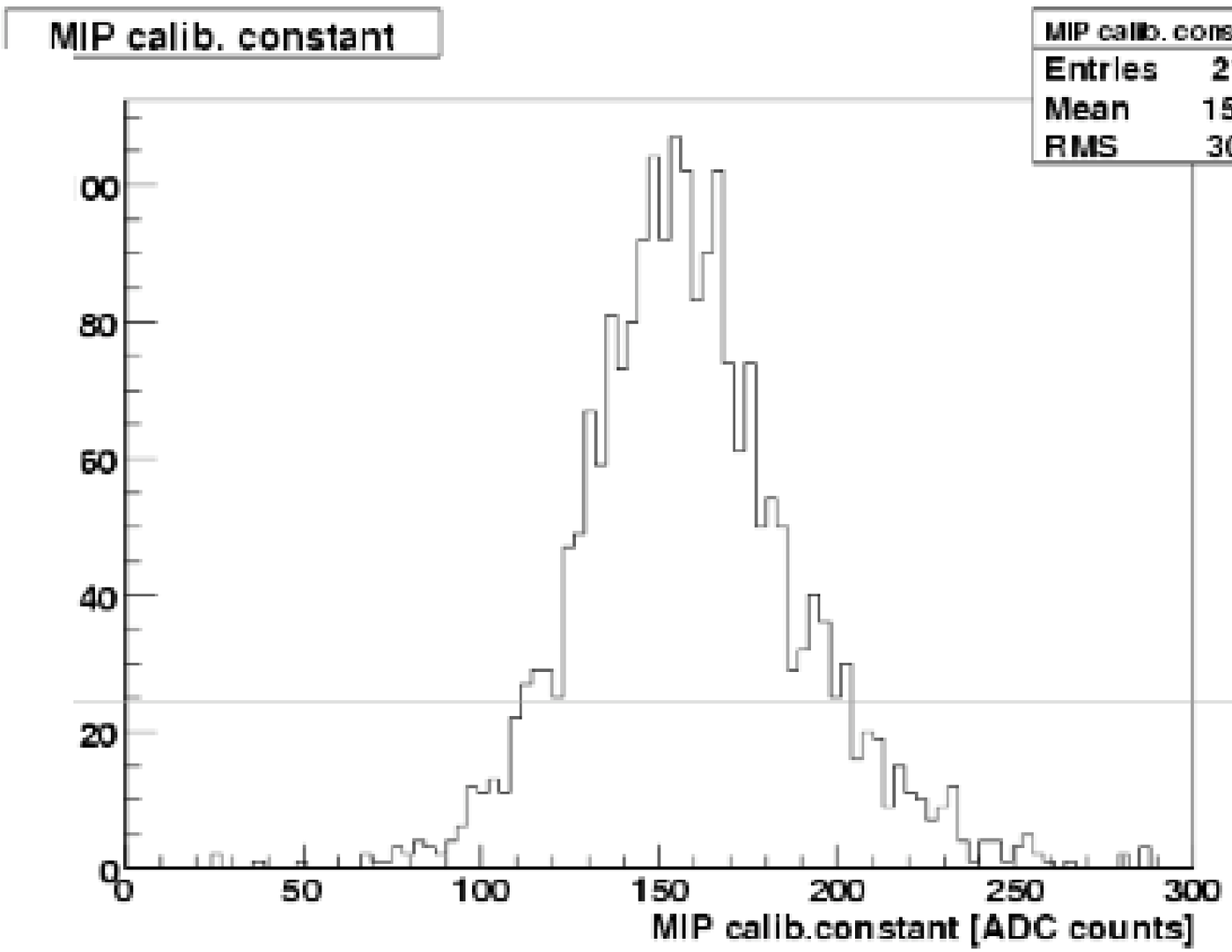


How to meas. MIP

- particle traverse the strip without interaction except dE/dX by ADC
- at FNAL : muons, at DESY positrons

MIP dE/dX

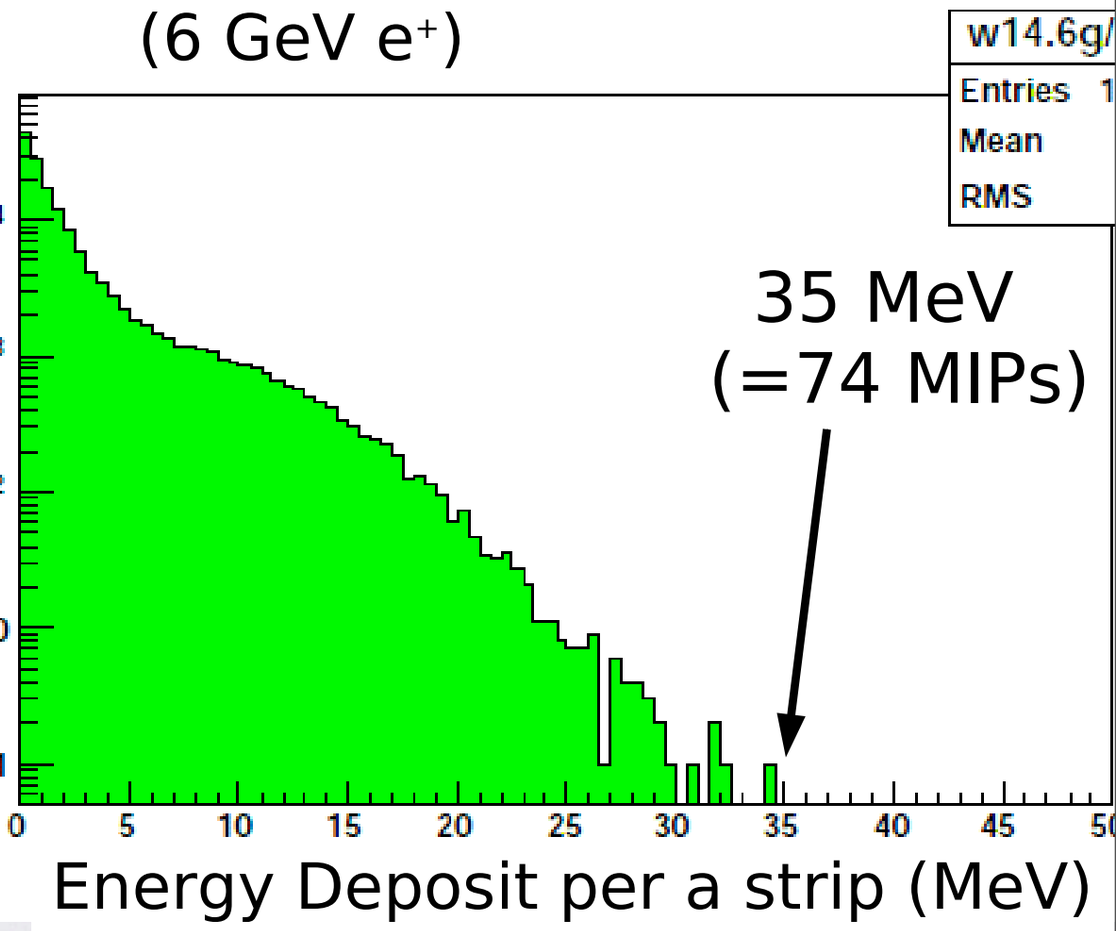




ECal saturation

- MPPCs saturate with limited number of pixels, when it receive many lights
- calorimeter response may suffer
- dE/dX of each strip
- for 6GeV 74MIPS
- maximum energy / strip
- correct the effect
- with response curve

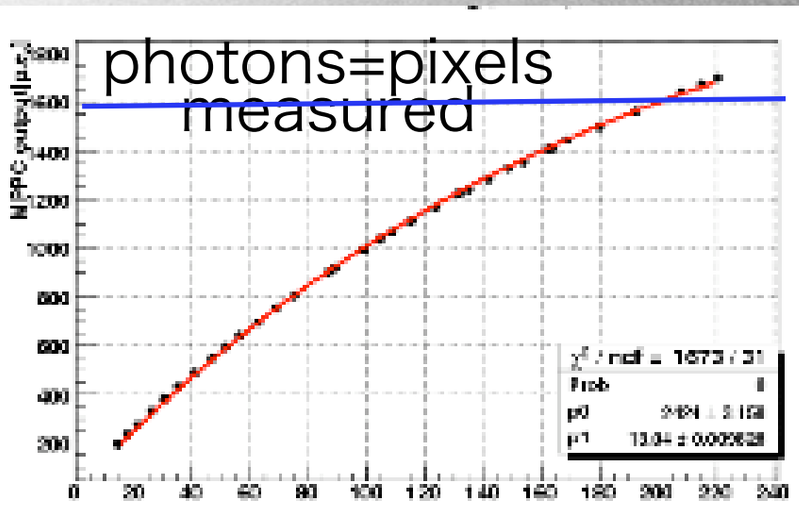
Result of GEANT4 simulation
(6 GeV e^+)



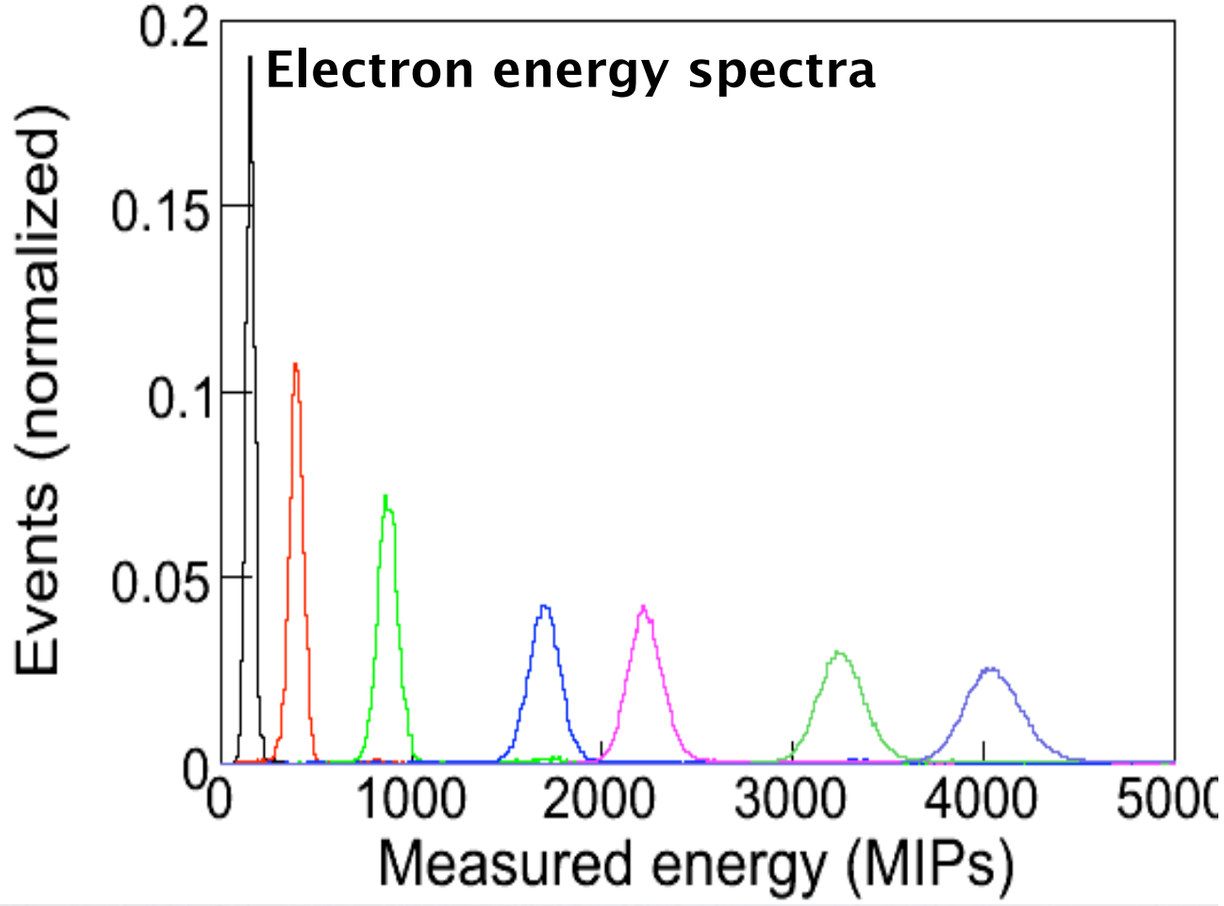
74 MIPs ~ 1554 pixels

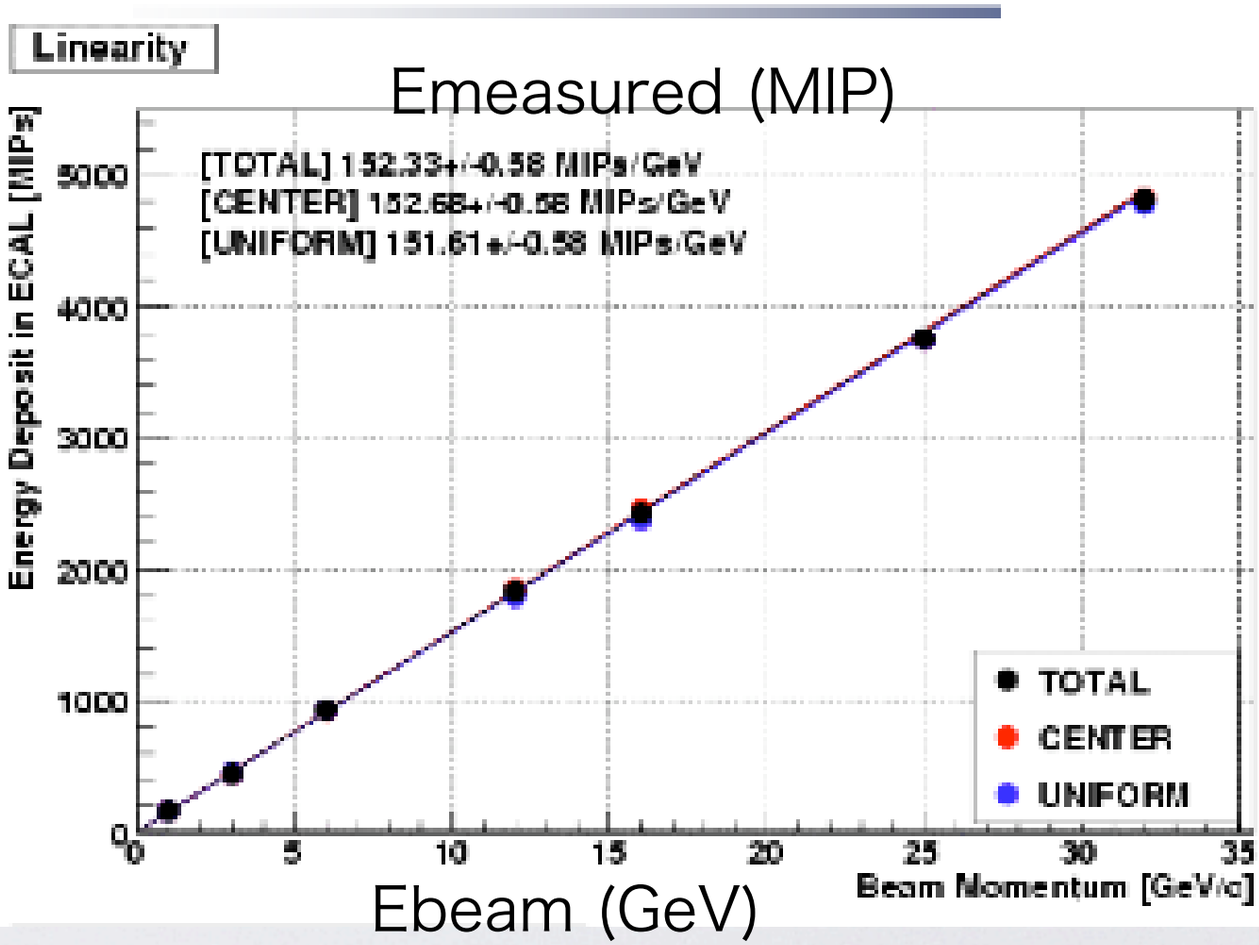
ECal results

- electron response
- linearity corrected
- response curve

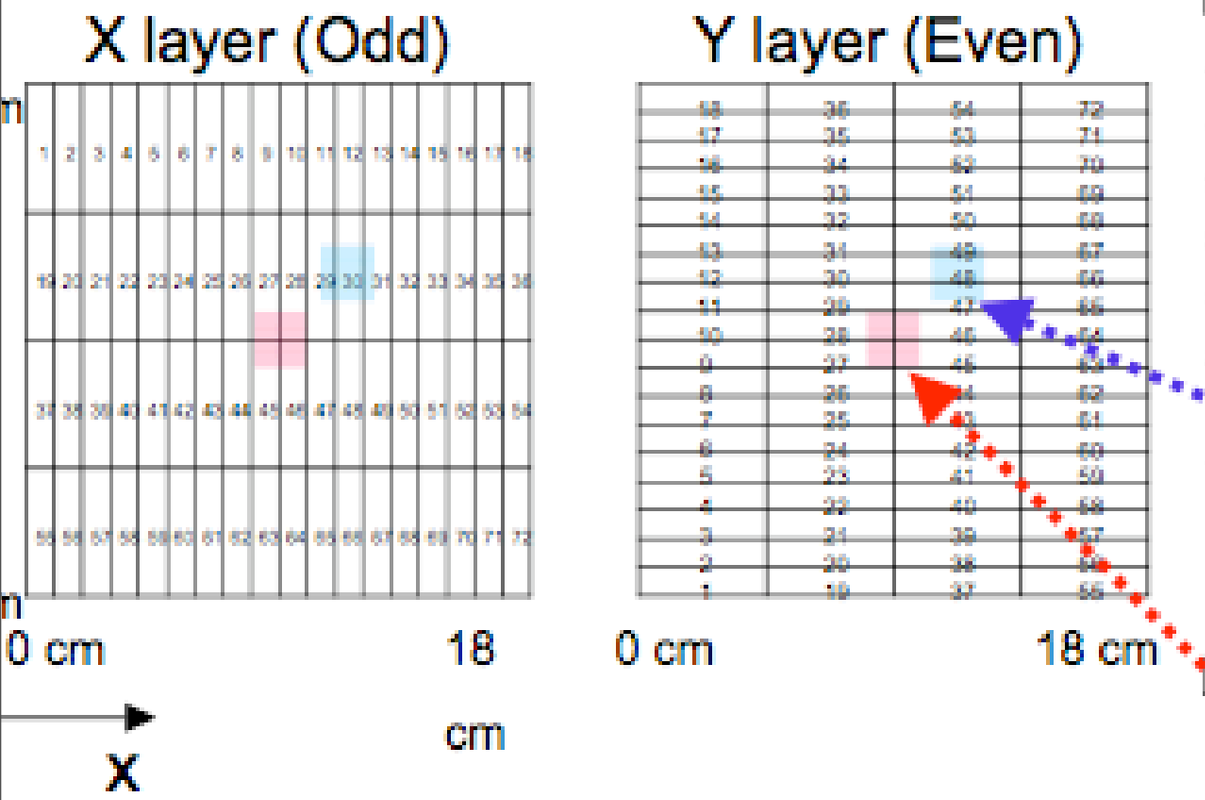


N_{true} photons in

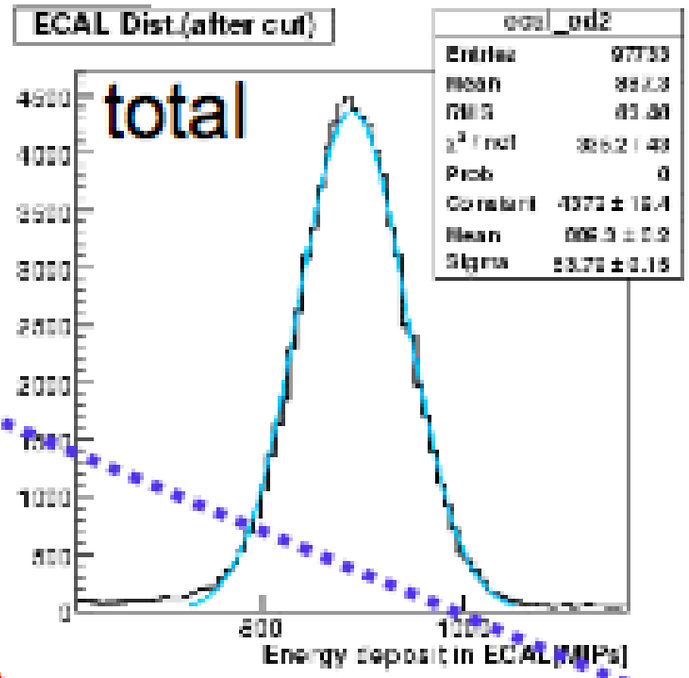


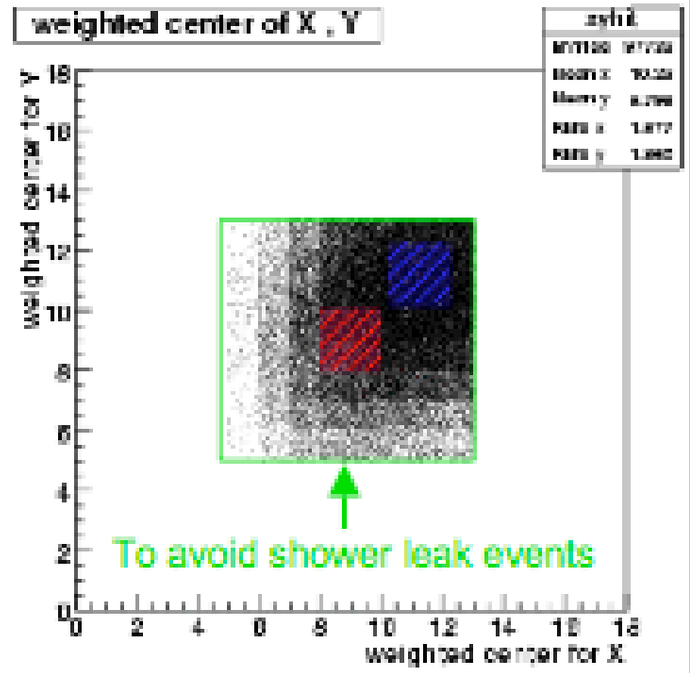


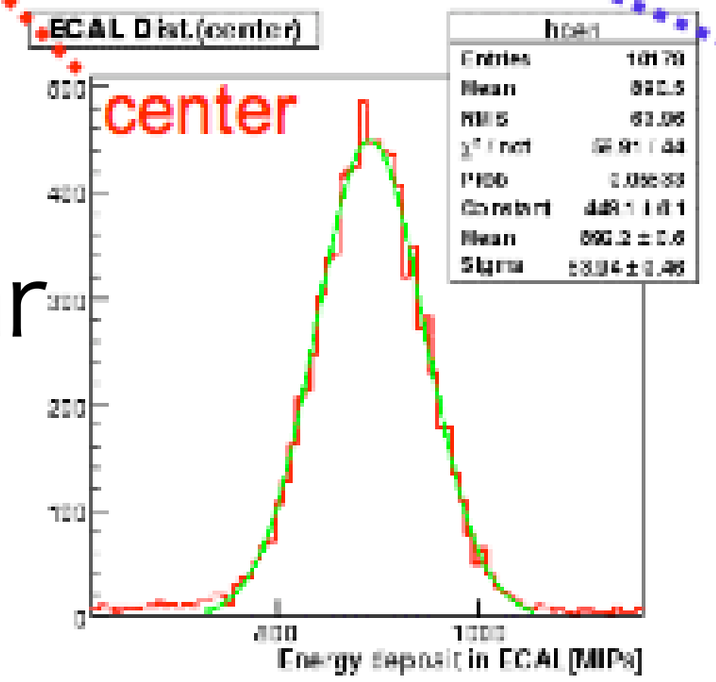
ECal uniformity

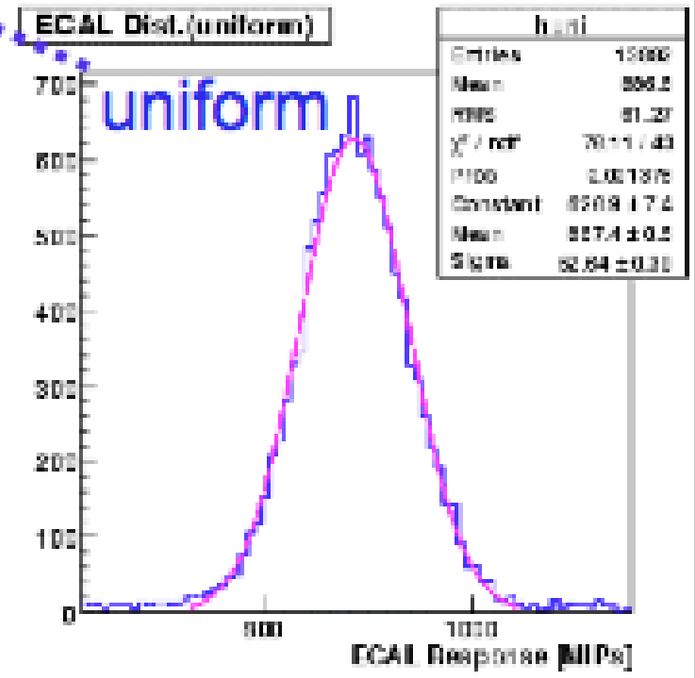


resolutions are similar





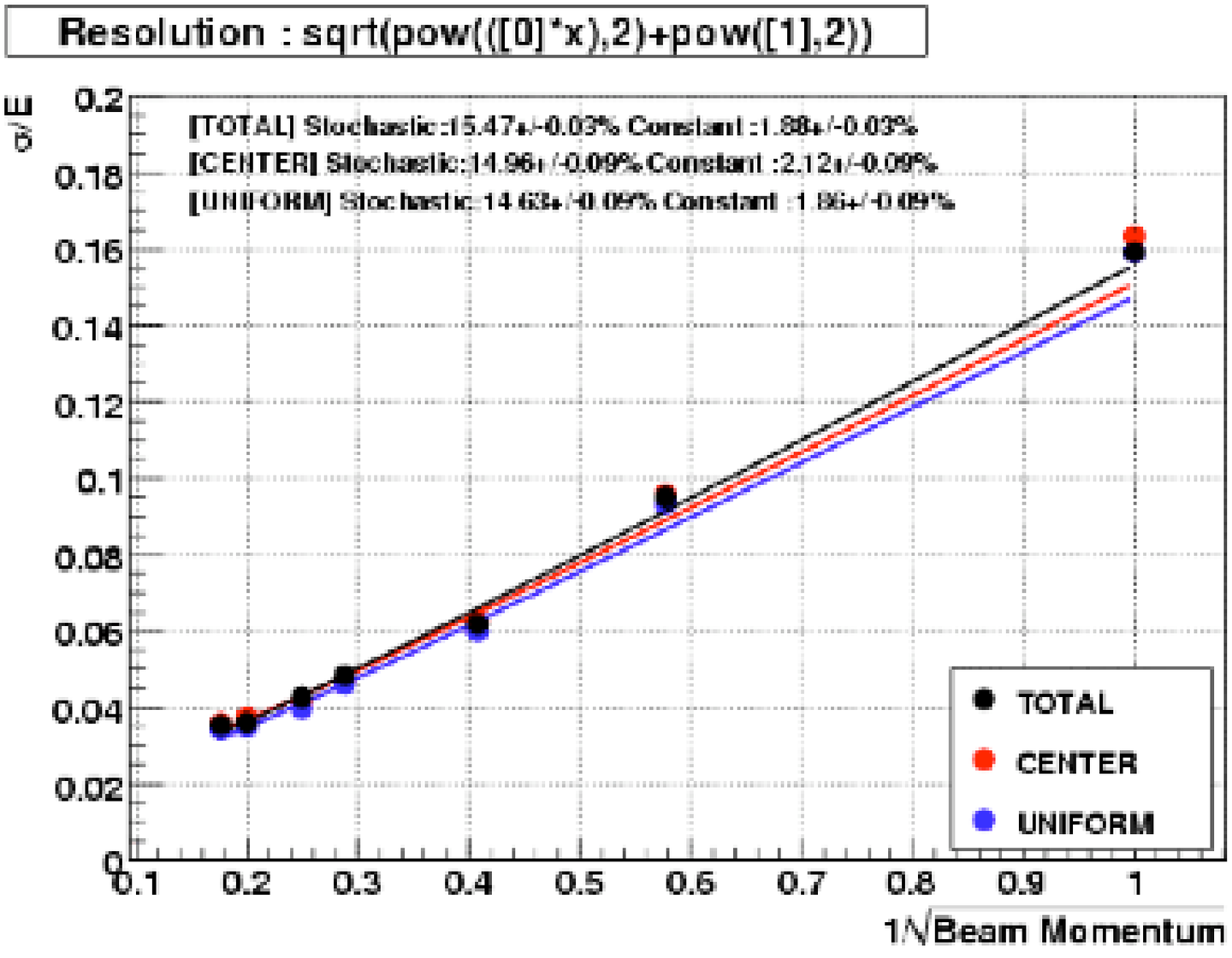




ECal uniformity cont.

- energy resolution
- different location of det.

$$\frac{\sigma}{E} = \frac{\sigma_{stochastic}}{\sqrt{E}} \oplus \sigma_{constant}$$



center

$\sigma_{stochastic}$=14.96±0.09%

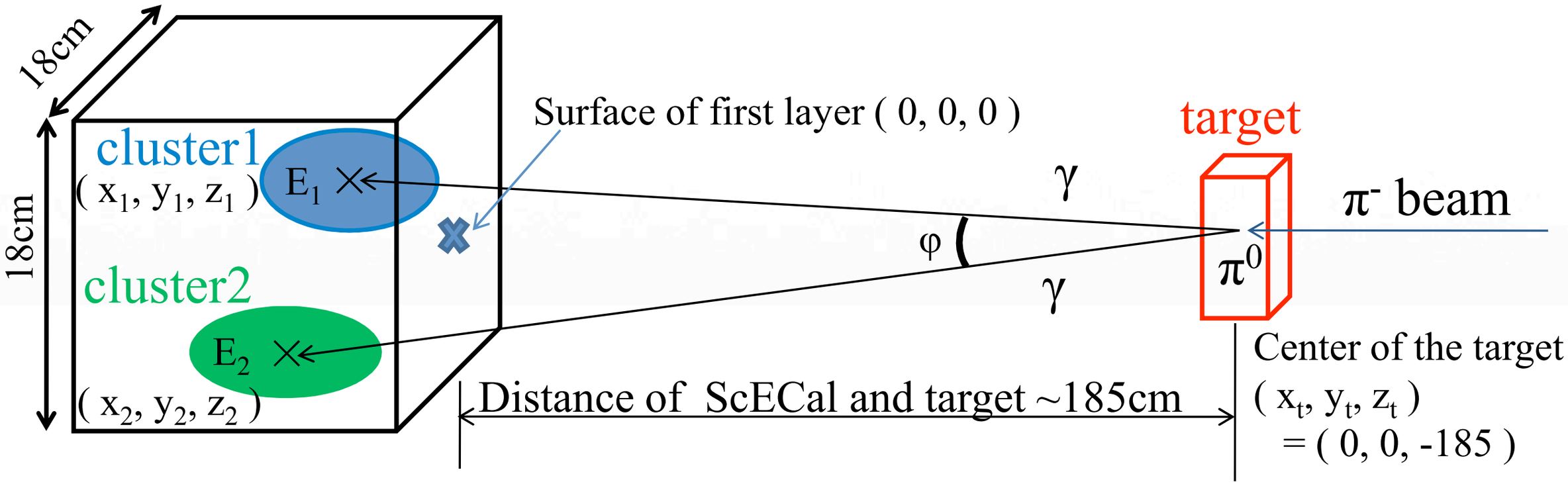
$\sigma_{constant}$=2.12±0.09%

aside

$\sigma_{stochastic}$=14.63±0.09%

$\sigma_{constant}$=1.86±0.09%

Reconstruction of Invariant Mass in 2 γ system



$$(\text{Invariant Mass}) = \text{sqrt}(2*E_1*E_2*(1-\cos(\varphi)))$$

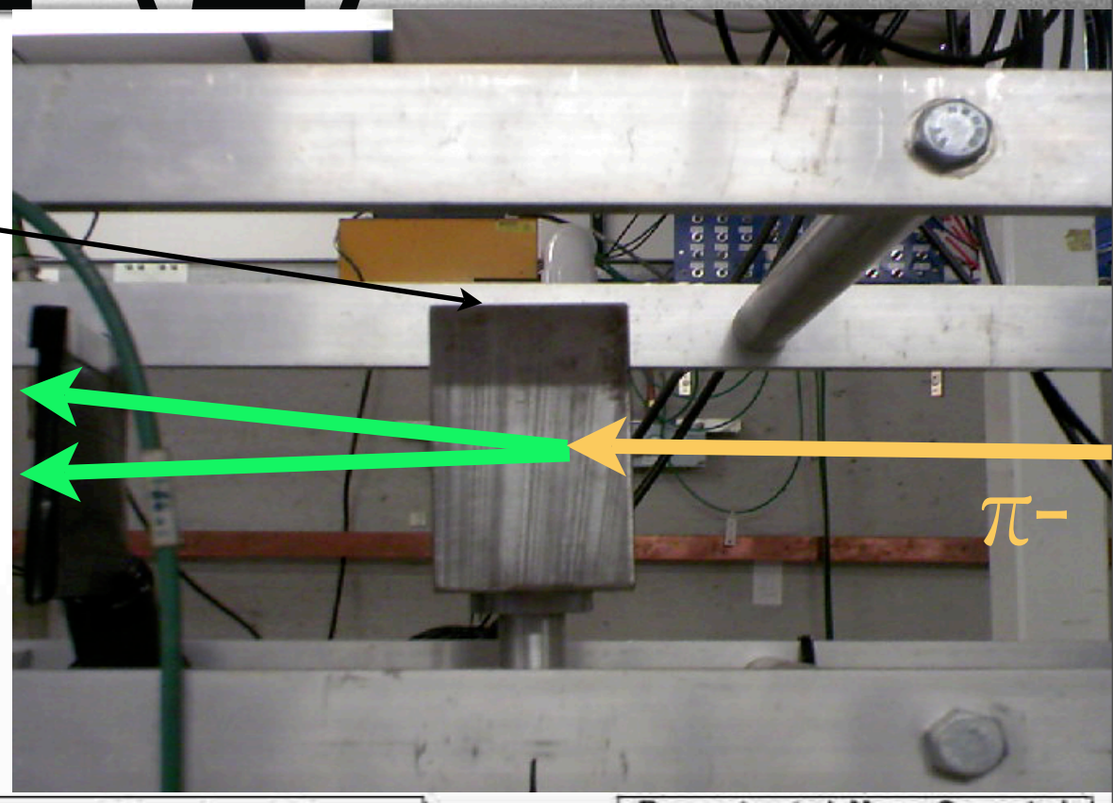
In case two gammas have equal energy,

Energy of π^0 (GeV)	3	4	5	10	15
Distance of two clusters (cm)	16.7	12.5	10.0	5.0	3.3

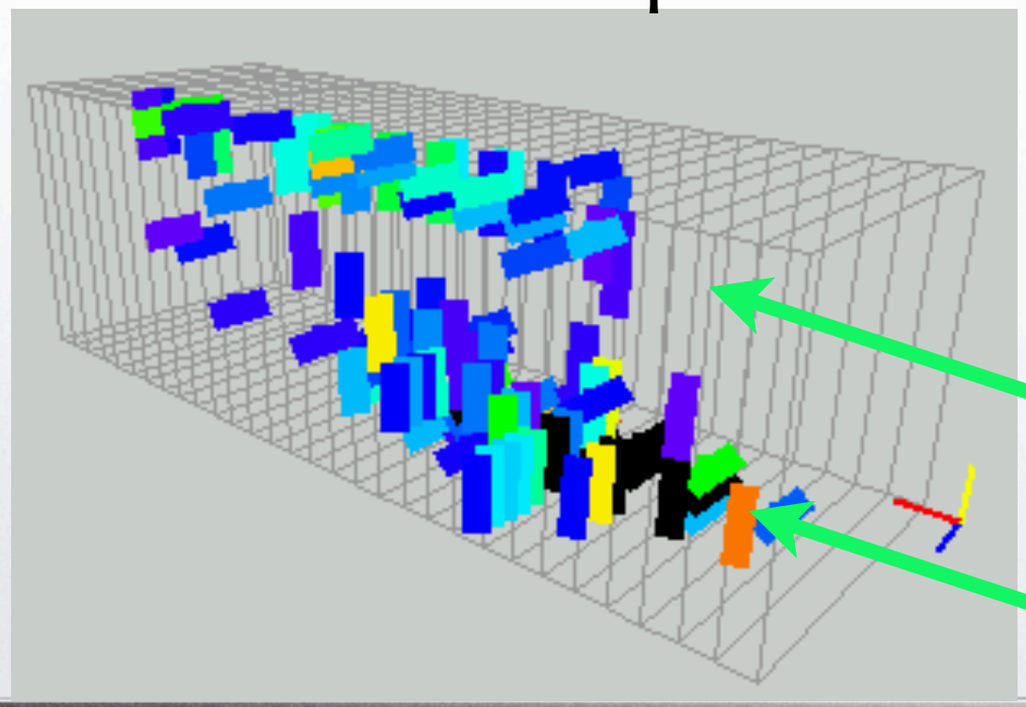
scECAL (2)

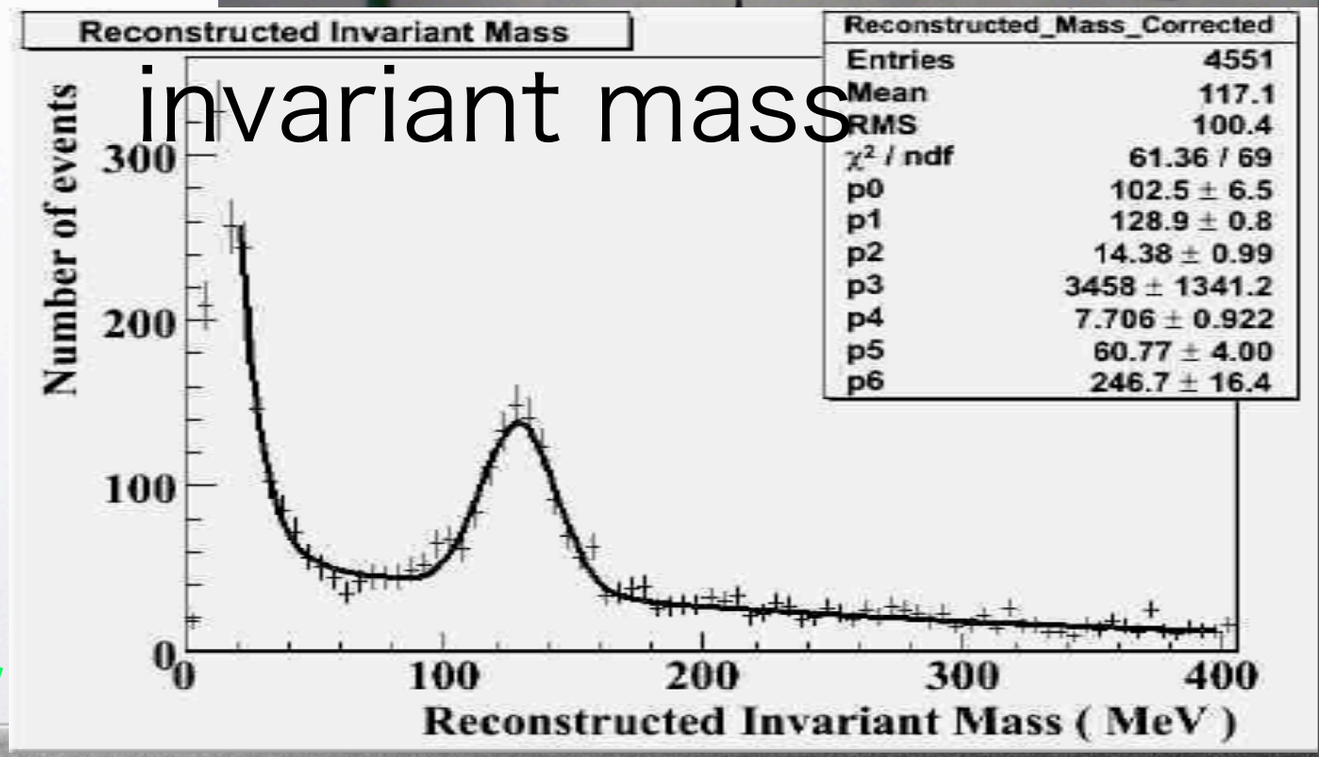
pi-zero production

target to produce pi-zero



an event of pi-zero

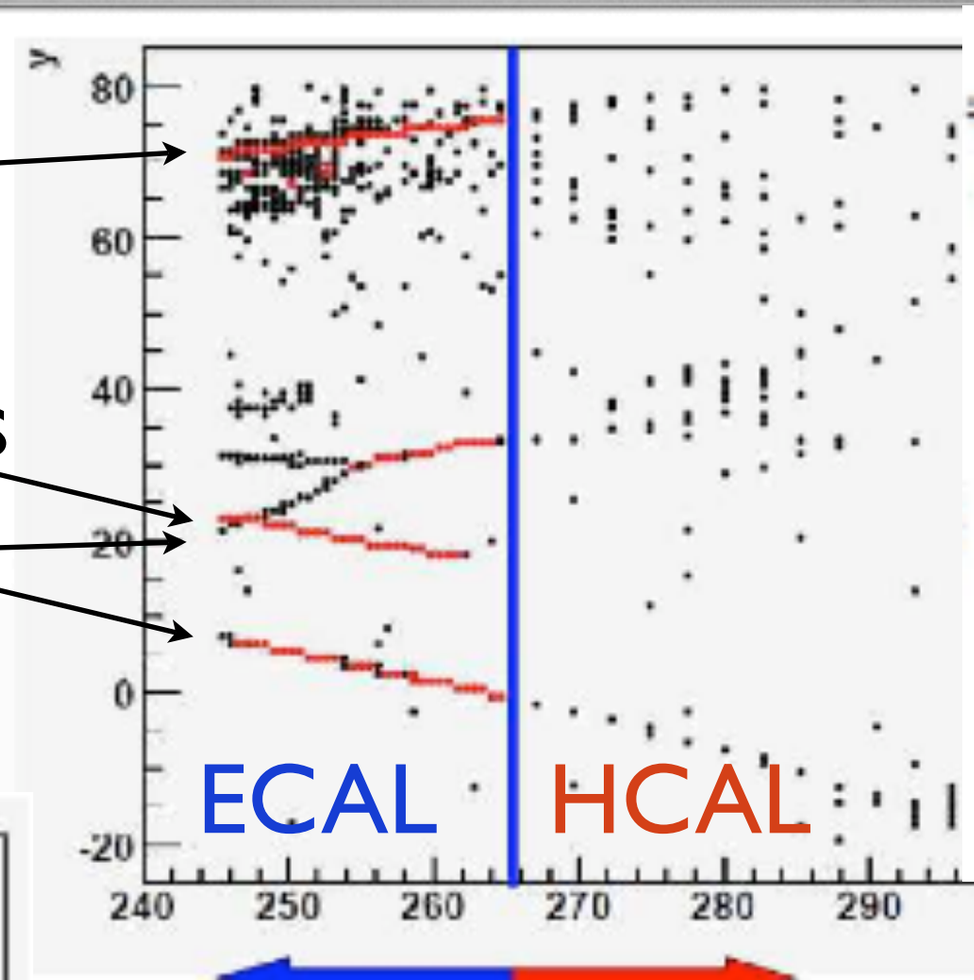


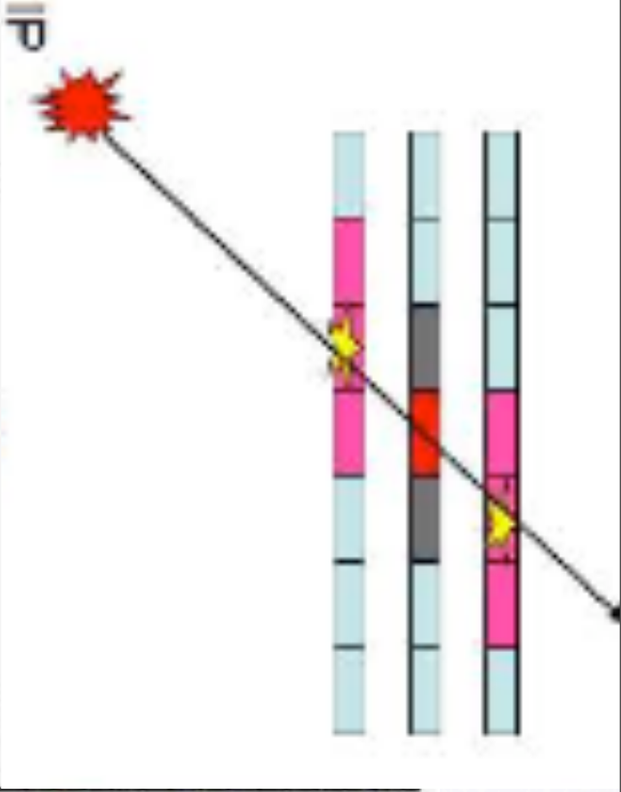


invariant mass

Calibration & monitor

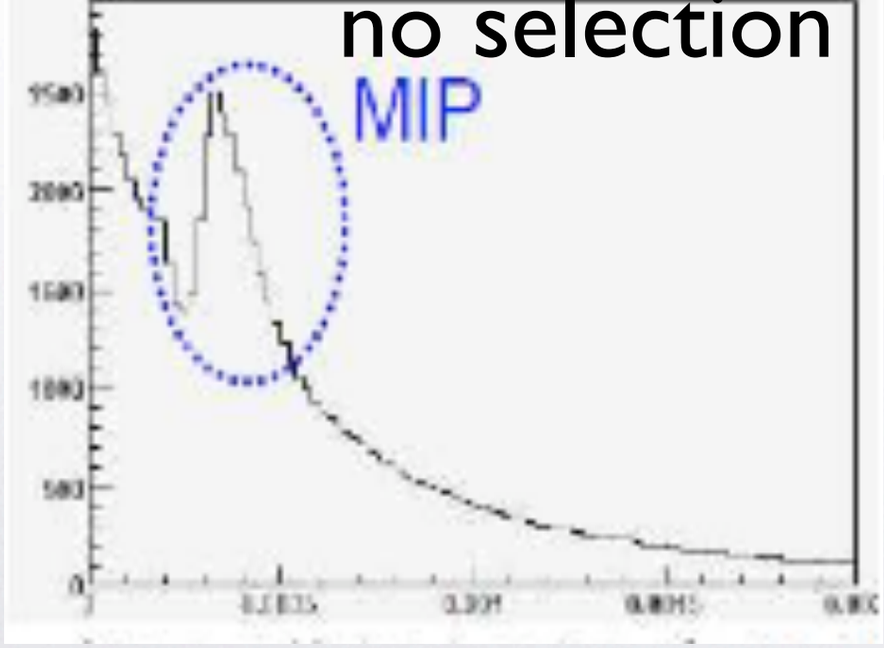
- in situ calibration
- other than CRs
- by hadrons as MIPs
- tracks in jets

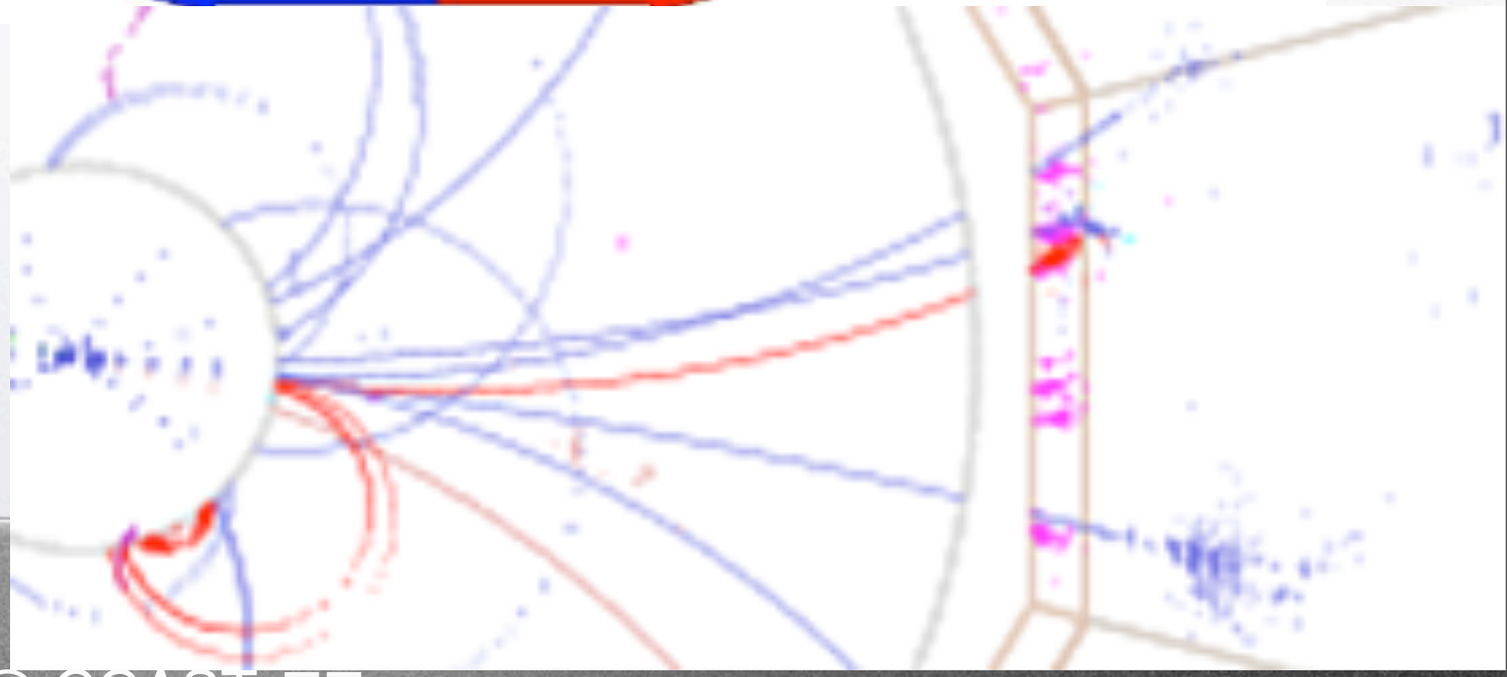




dE/dx /strip

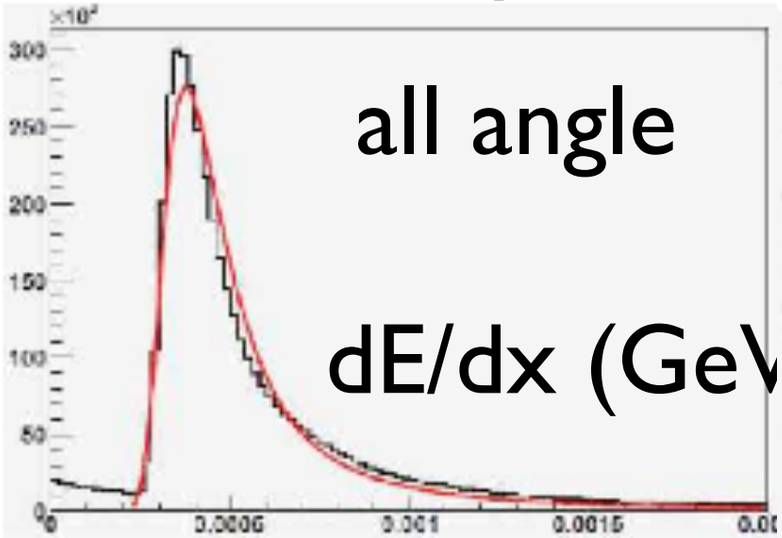
no selection

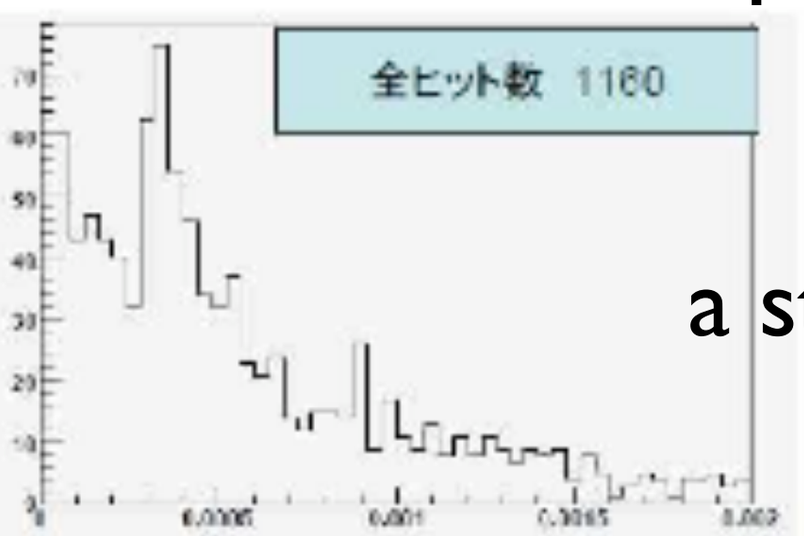




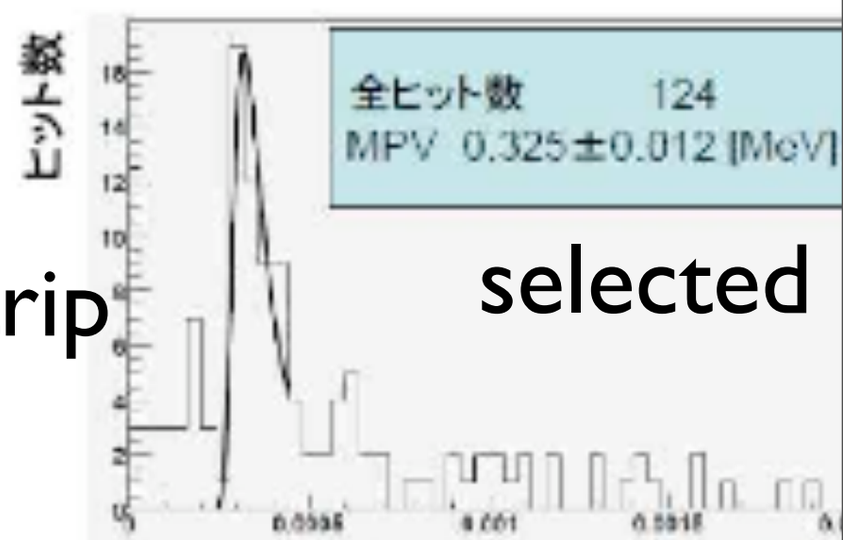
Calibration & monitor

- selection of hadronic MIP tracks
- each strip needs 100 hits for 5% precision

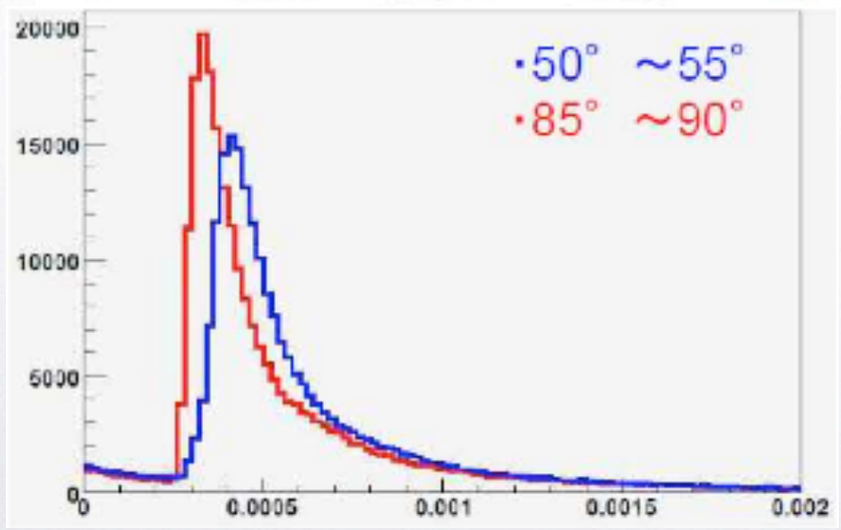




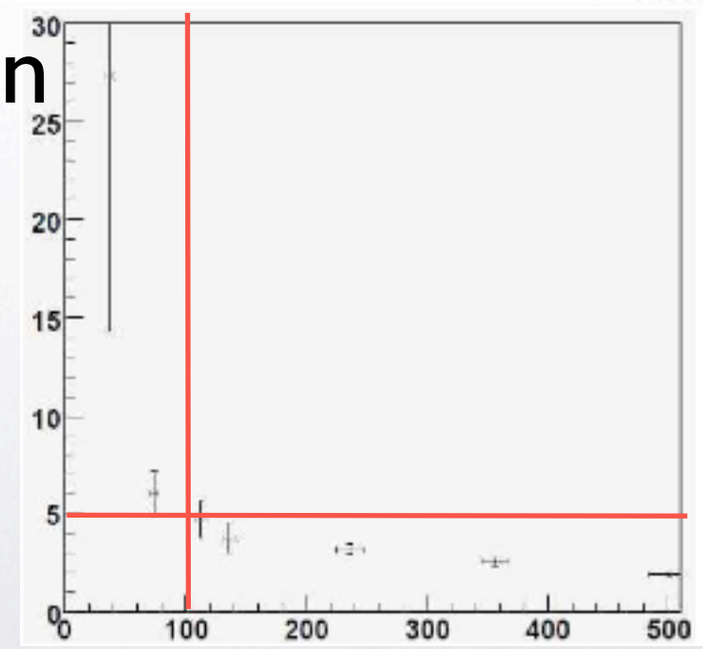
a strip



selected



precision (%)



# of hits

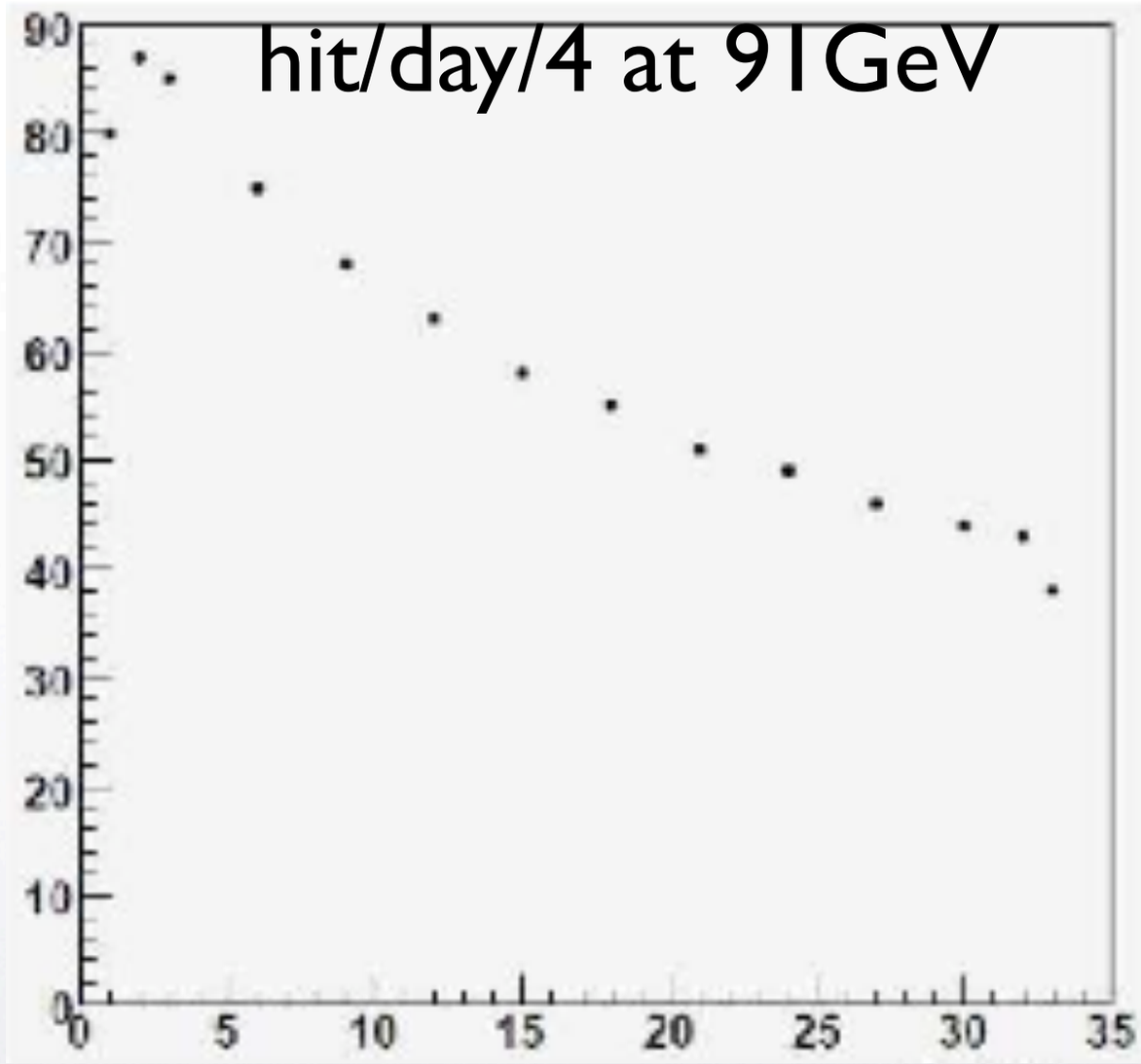
Calibration & monitor

- 100 hits / strip is achieved at Z pole

E_{cm}(GeV)	91	200	500
L $10^{33}cm^{-2}/s$	4	20	20
σ(nb)	31	0.02	0.003
hit/s	500	2	0.2

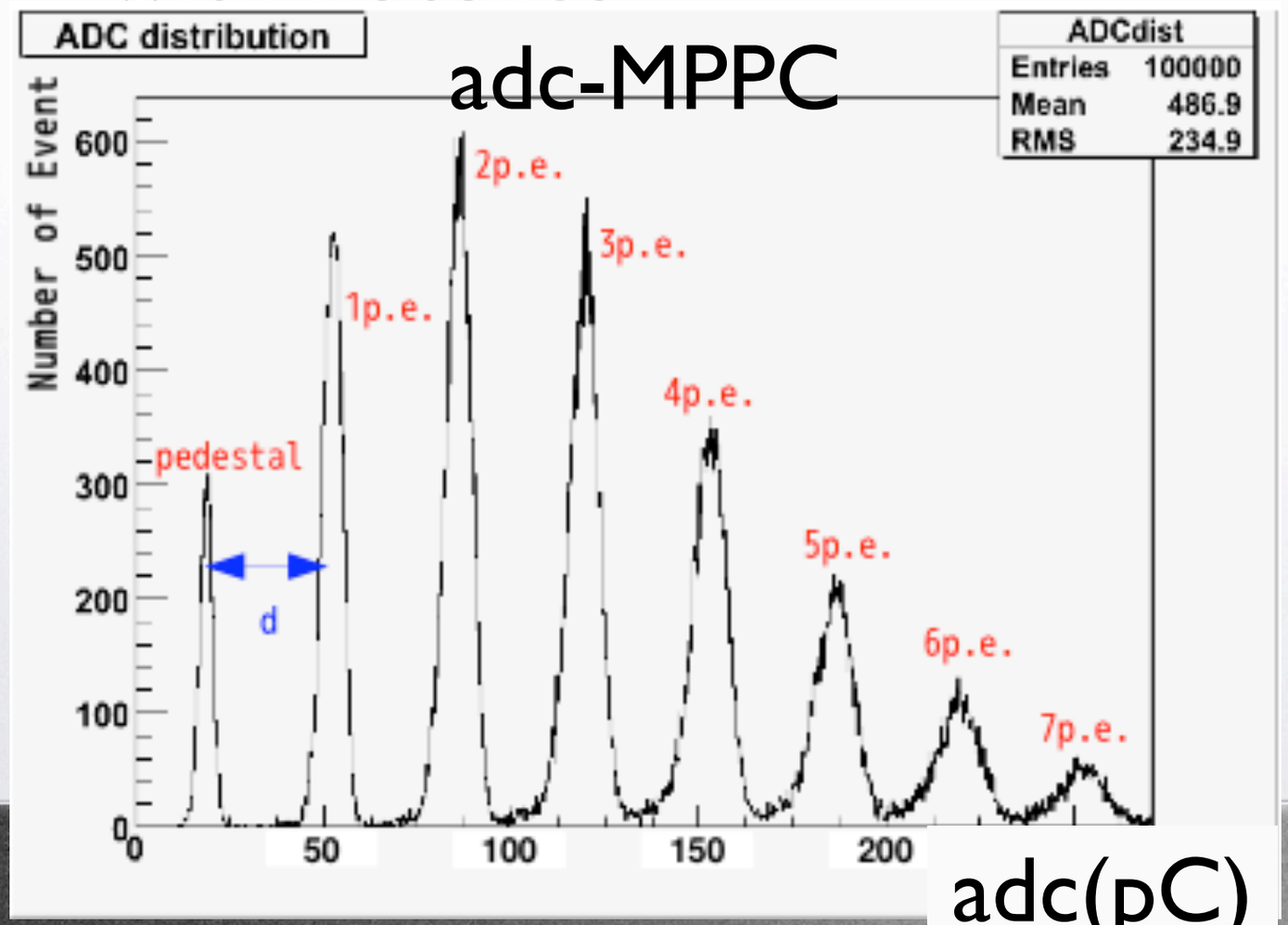
GigaZ

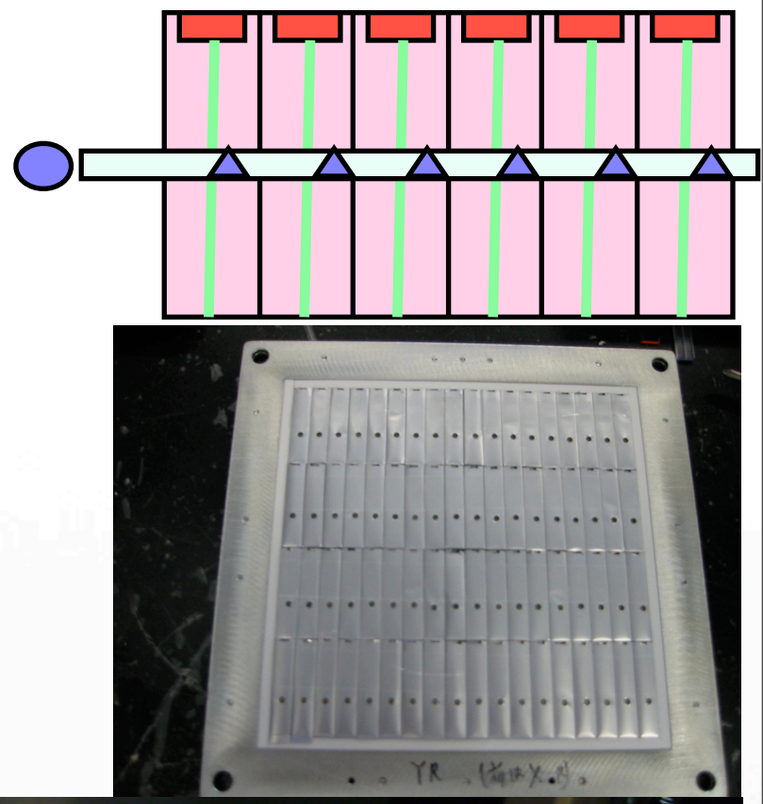
1 x 4 cm strip

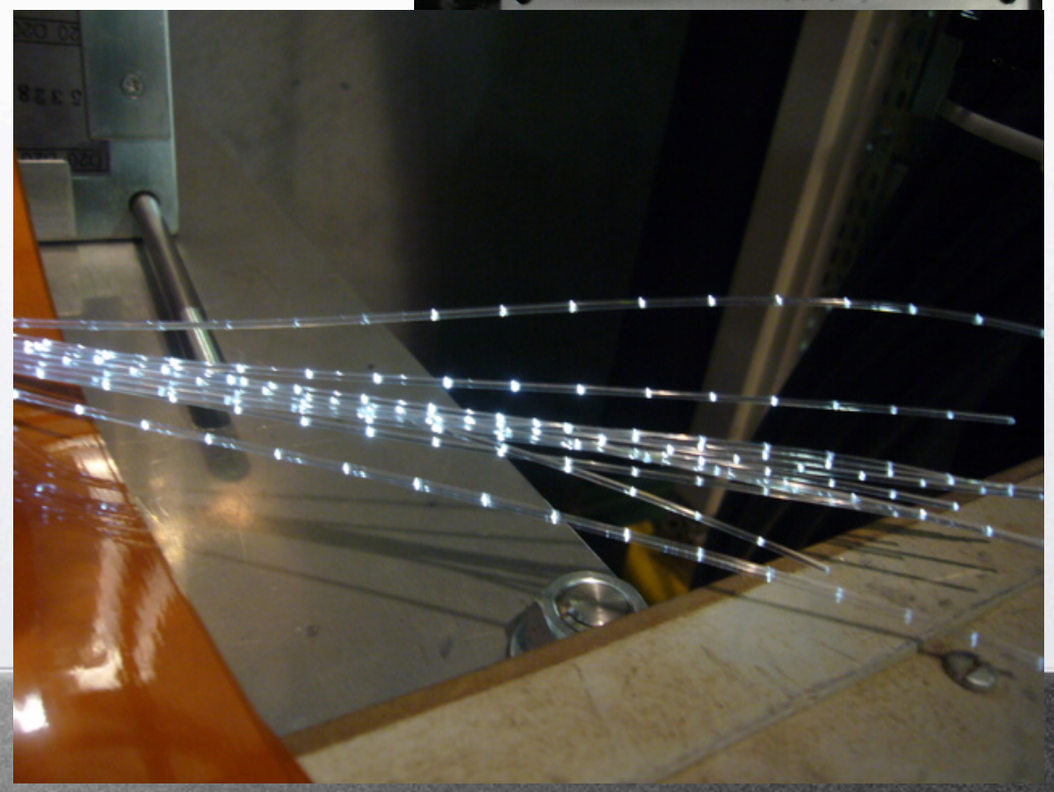


Calibration & monitor

- auto-calibration of MPPC gain at p.e.
- monitoring system of whole system
- LED lights distribution through clear fiber
- with notches

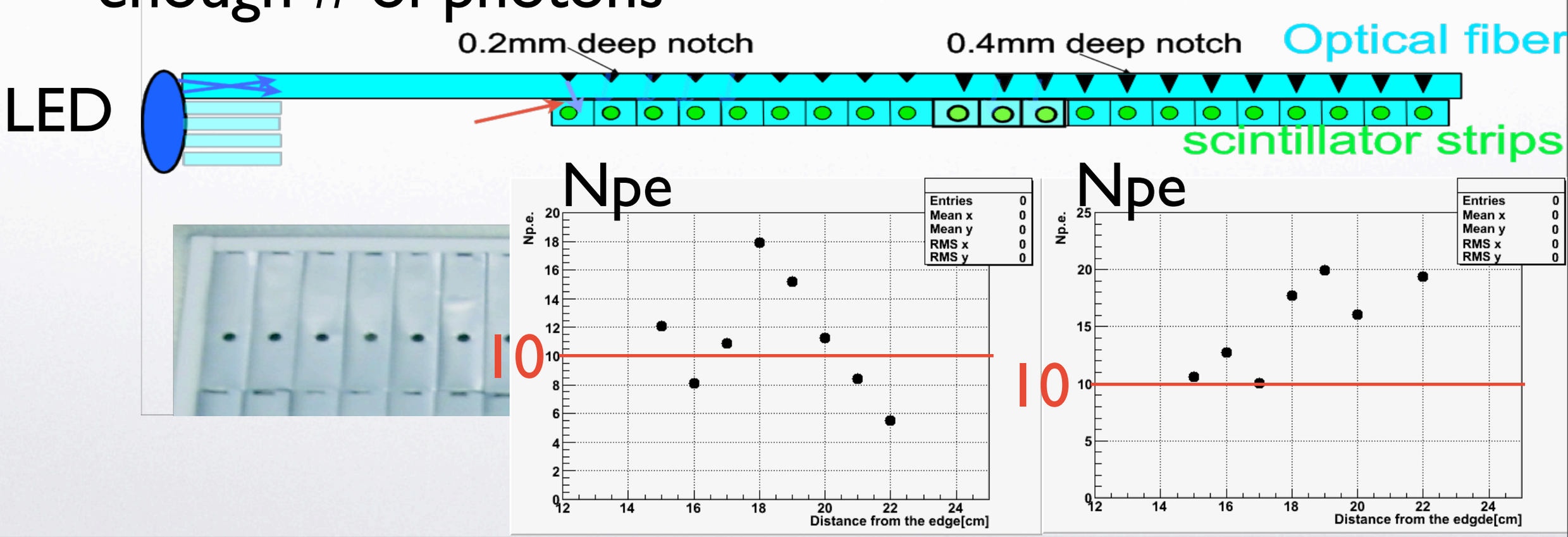






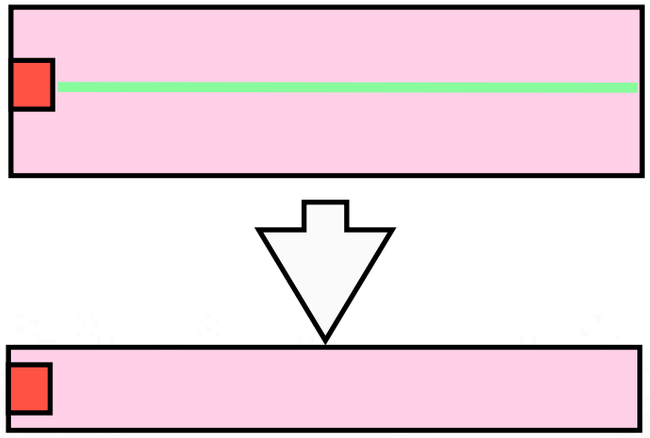
LED monitor

- triggered by LED flash timing
- can detect any shift scintillator, WLS fiber, MPPC, amp & electronics response
- enough # of photons

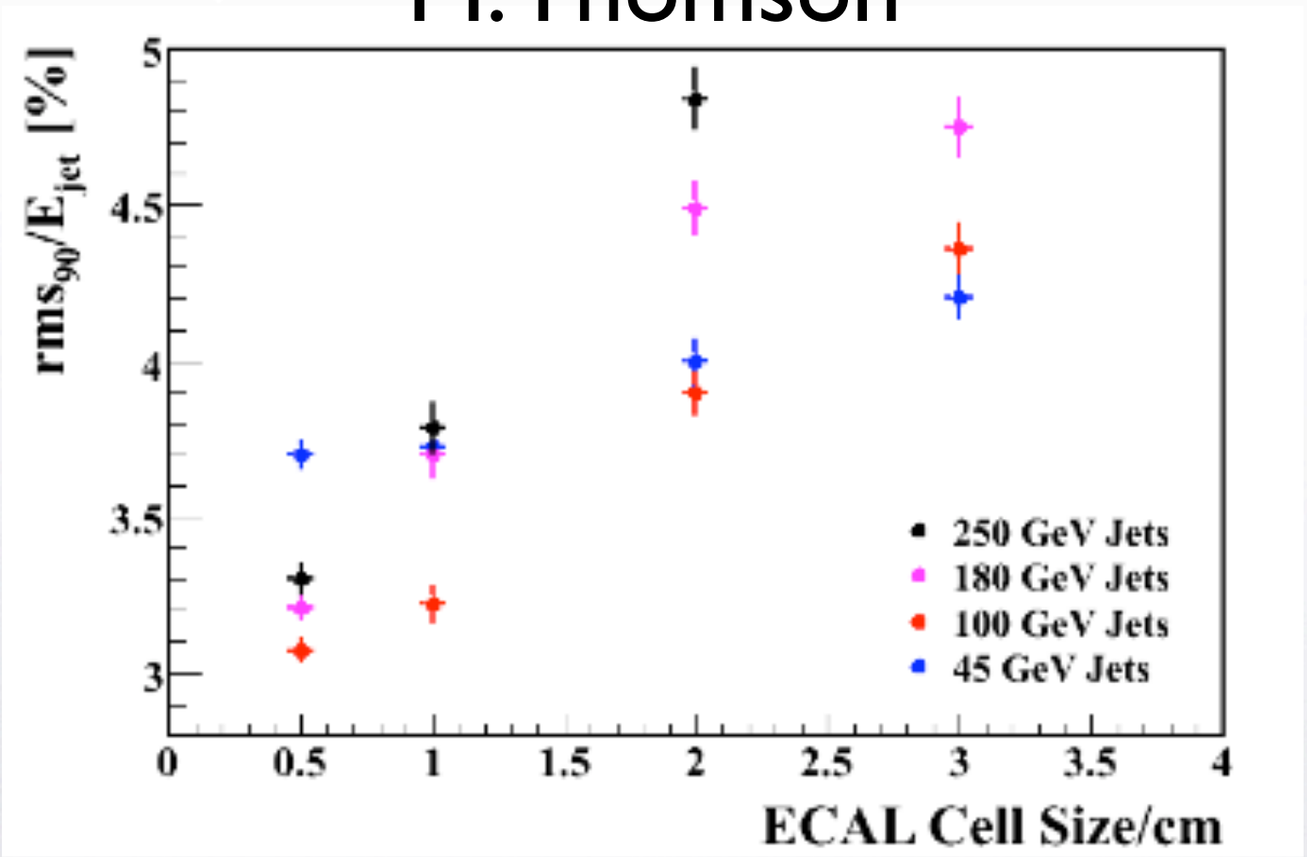


Further segmentation

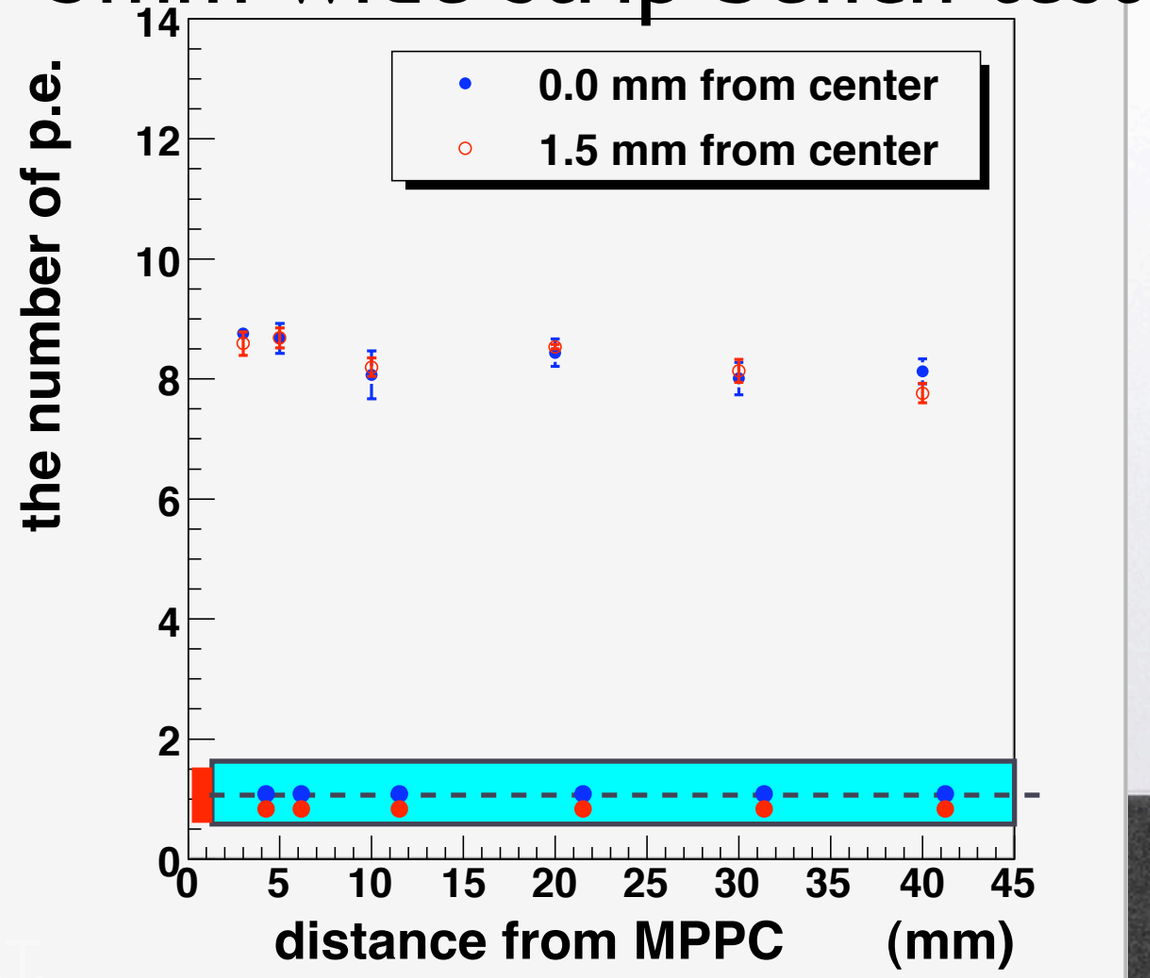
- 5mm width is favored by current PFA study
- WLSF-less configuration
- which looks promising



M. Thomson



5mm wide strip bench test



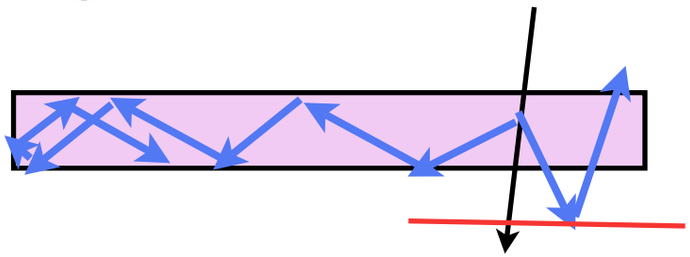
scintillator ECAL

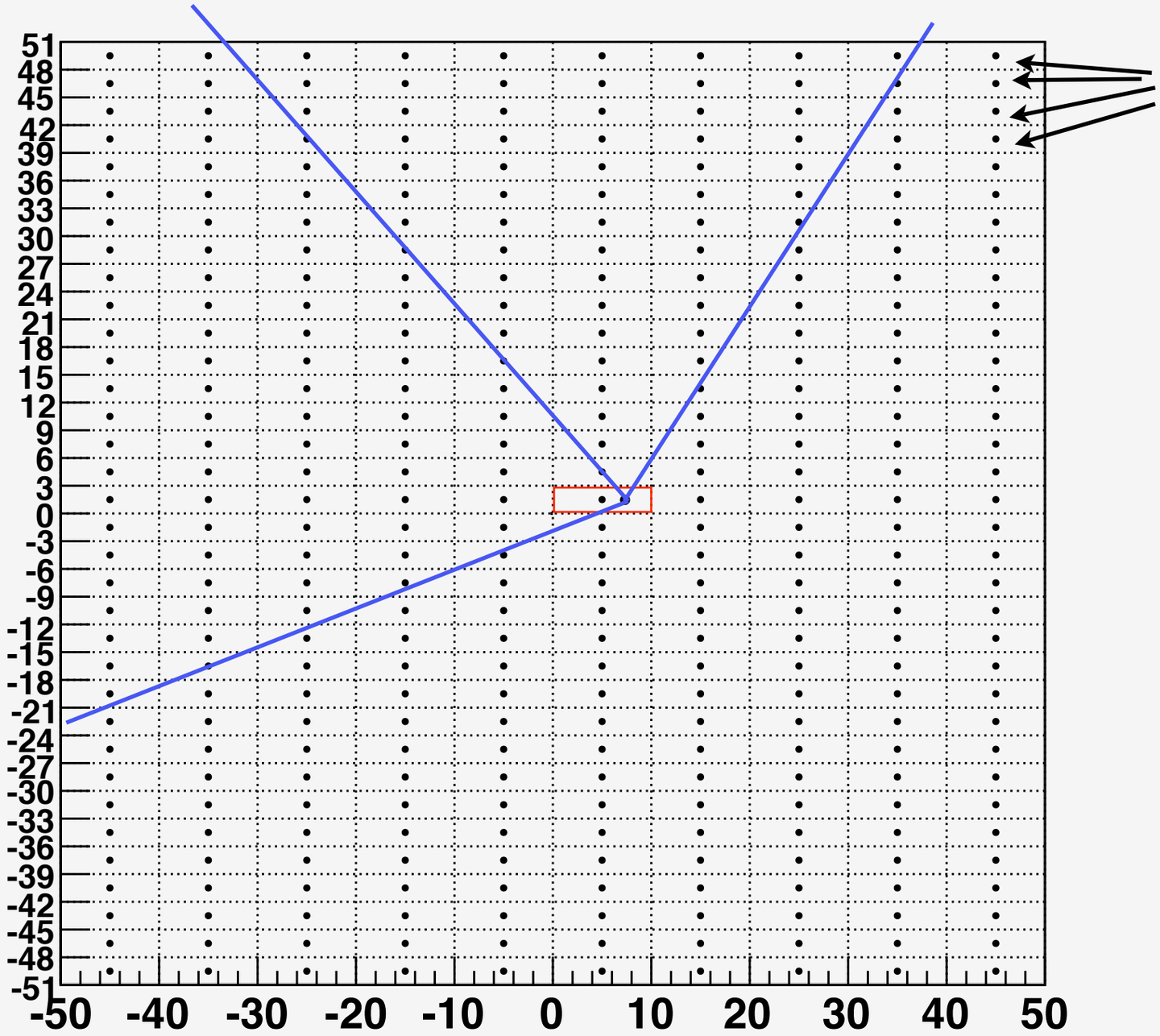
- scintillator is one of the key issue
- we need to understand its nature and light transition in the scintillator including reflection
- scintillator calorimeter is robust and reliable with fine segmentation
- good candidate of ILC detector

scintillation light

- if reflection of scintillation light occur very high efficiency,

simulation





mirror fibers

assume no absorption in scinti.

finally absorbed by fiber

good uniformity maintained