

# Systematics on ScECAL

## 1<sup>st</sup> prototype test @ DESY

Apr 18-21 2015, CALICE meeting@KEK  
Satoru Uozumi *for the CALICE collaboration*

NIM A, 763 (2014) 278

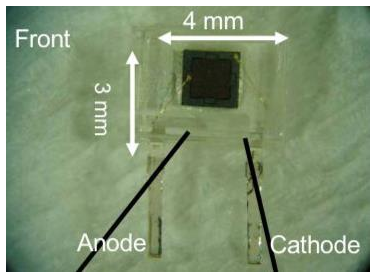


### Performance of the first prototype of the CALICE scintillator strip electromagnetic calorimeter

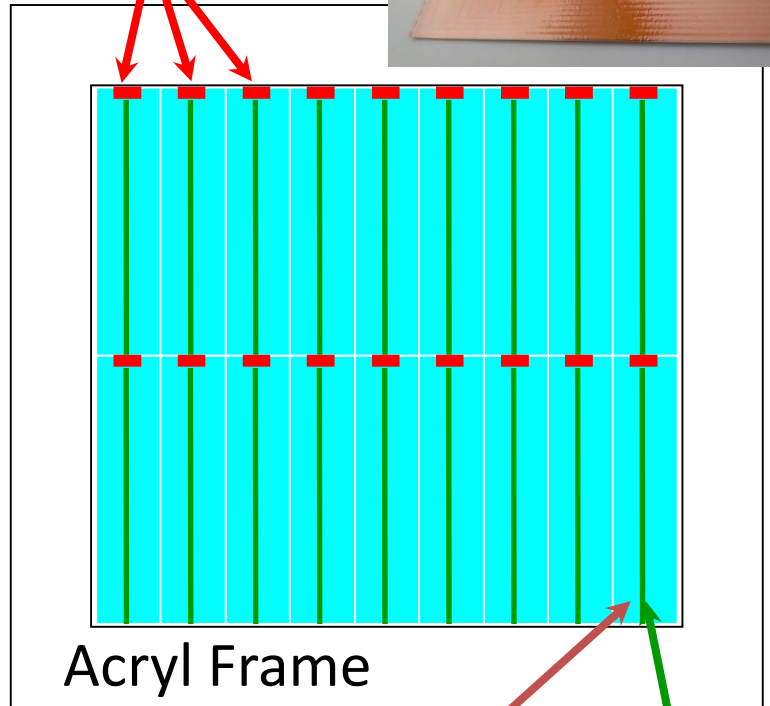
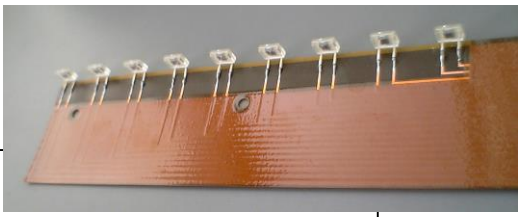


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# The ScECAL 1<sup>st</sup> prototype

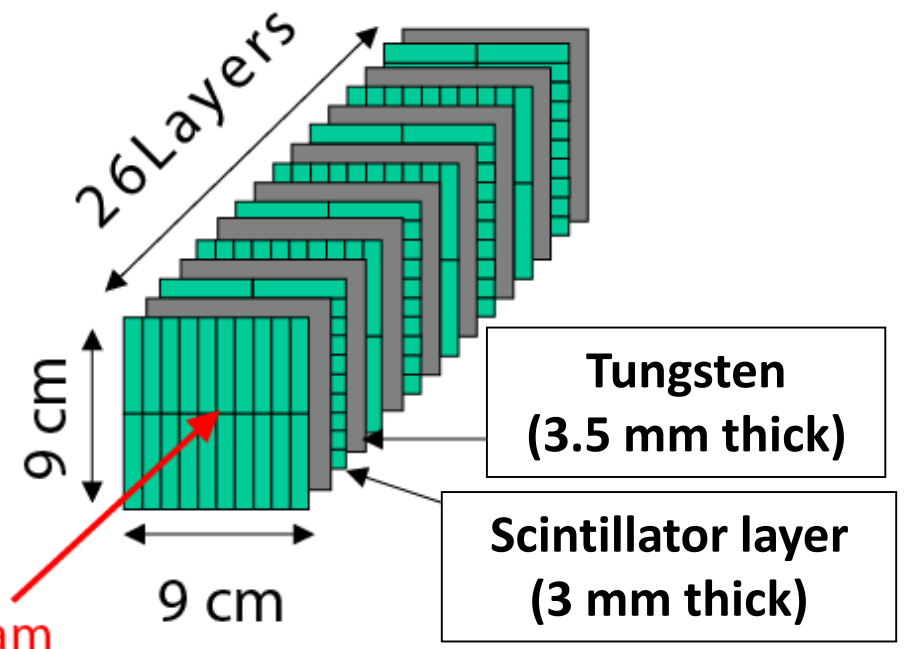


MPPCs  
(1600 pixels)

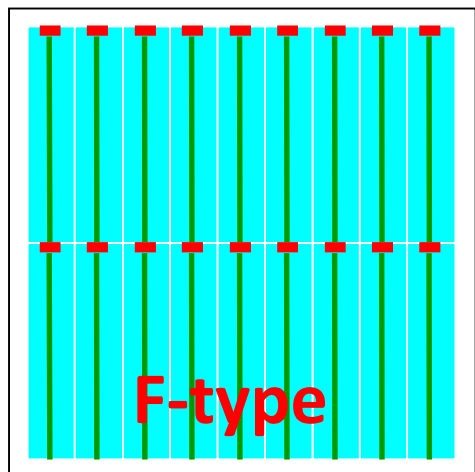


Scintillator strip  
(1 x 4.5 x 0.3 cm)

WLS fiber

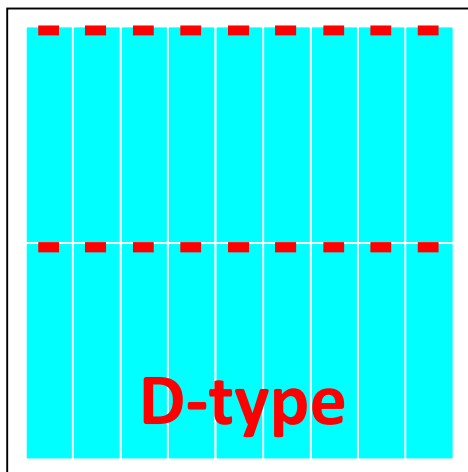


# Fibre and Direct readout Modules



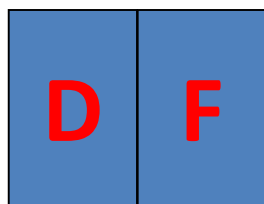
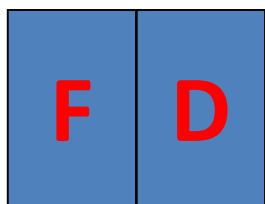
① WLSF readout

13 layers

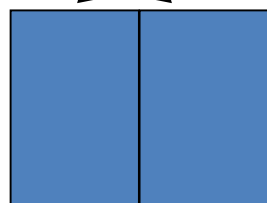


② Direct readout

13 layers

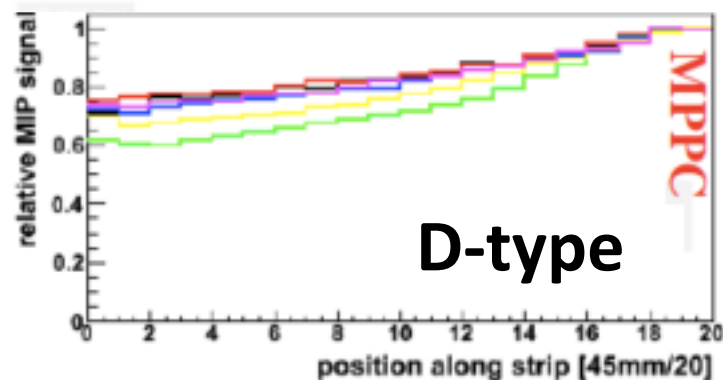
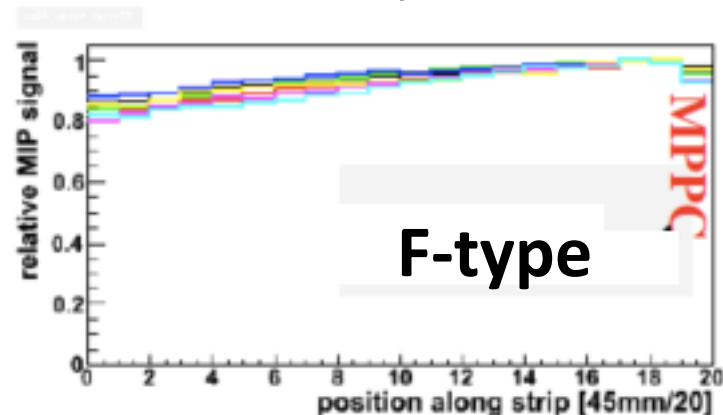


*Beam* →



13 + 13 layers

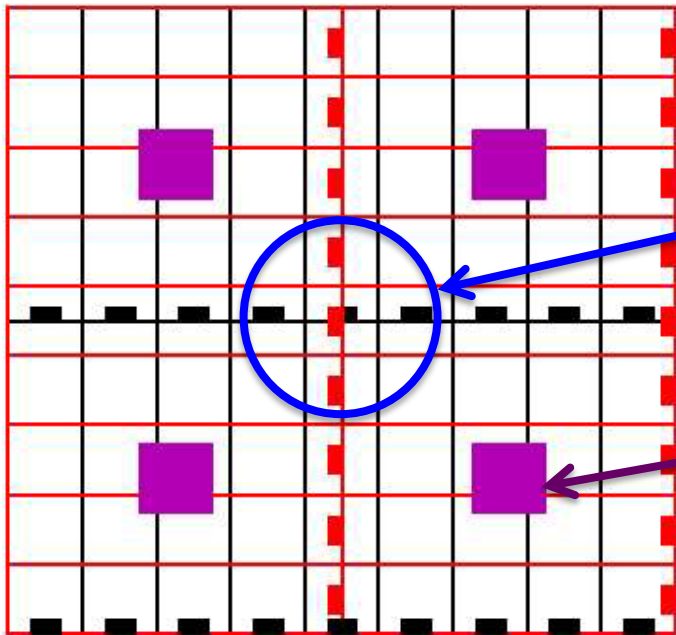
Longitudinal response  
uniformity for MIP



# 1-6 GeV $e^+$ beams into Central & Uniform regions

At DESY, 1<sup>st</sup> prototype had  
Been tested on 2007 using  
1-6 GeV  $e^+$  beam.

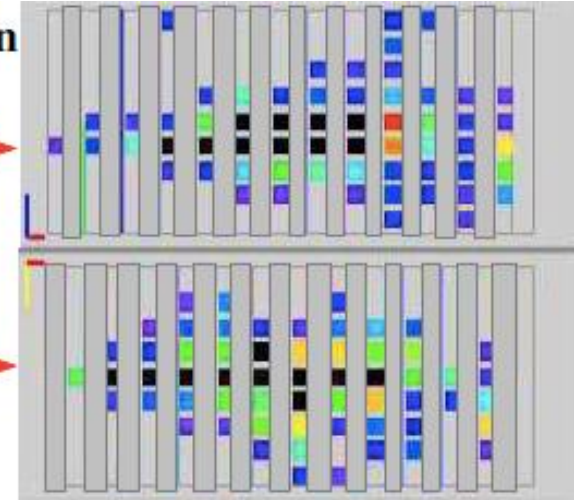
**Detector front view**



6 GeV  $e^+$ , center injection

x projection →

y projection →



Detector surface are categorized into

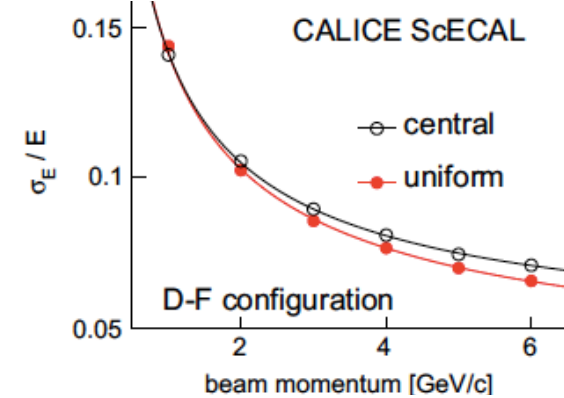
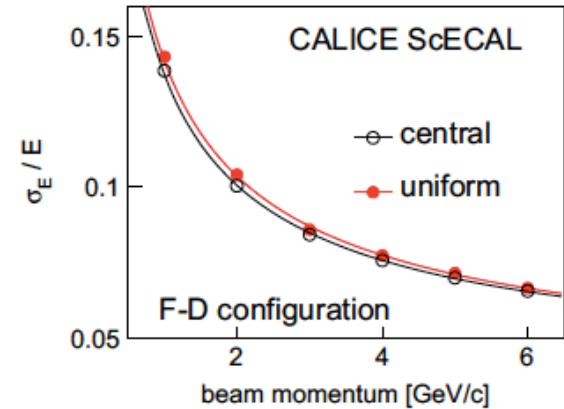
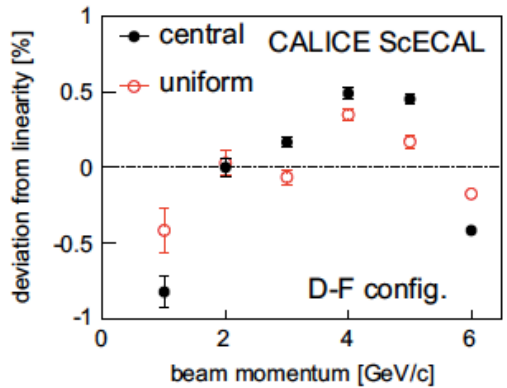
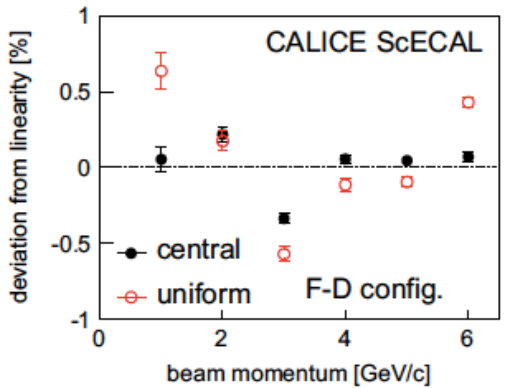
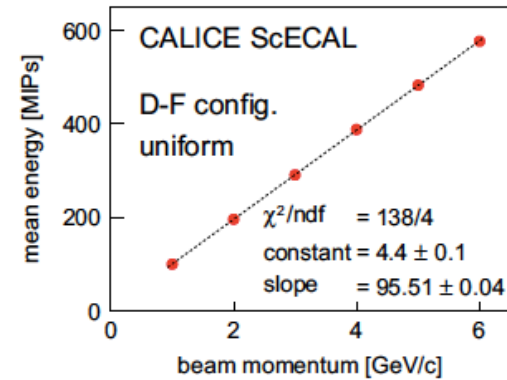
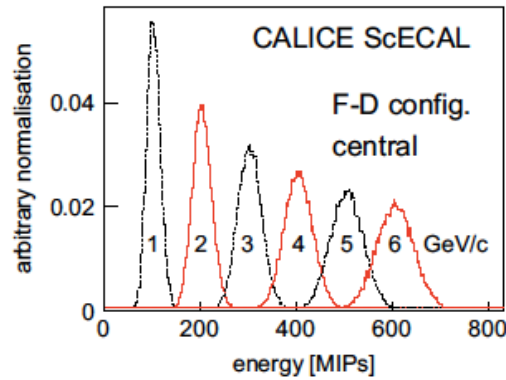
**Central region**

less EM shower leak,  
more effect of response non-uniformity

**Uniform region (all violet squares)**

little shower leak  
less effect of non-uniformity

# Linearity & Energy resolution



$$\frac{\sigma_E}{E} = \sqrt{\frac{\sigma_{\text{stochastic}}^2}{E_{\text{beam}}[\text{GeV}]} + \sigma_{\text{constant}}^2}$$

Configuration	Region	Contribution	(%)	Statistical	Systematic
F-D	Central	Stochastic	13.24	$\pm 0.05$	$\pm 0.20^{+0}_{-1.66}$
		Constant	3.65	$\pm 0.05$	$\pm 0.47^{+0}_{-3.65}$
	Uniform	Stochastic	13.76	$\pm 0.07$	$\pm 0.21^{+0}_{-1.86}$
		Constant	3.52	$\pm 0.07$	$\pm 0.47^{+0}_{-3.52}$
D-F	Central	Stochastic	13.43	$\pm 0.06$	$\pm 0.07^{+0}_{-0.80}$
		Constant	4.45	$\pm 0.04$	$\pm 0.22^{+0}_{-4.45}$
	Uniform	Stochastic	13.73	$\pm 0.08$	$\pm 0.07^{+0}_{-2.34}$
		Constant	3.35	$\pm 0.07$	$\pm 0.22^{+0}_{-3.35}$

# Resolution on Systematics : Breakdown

Source	Configuration	Region	$\delta\sigma_{\text{stochastic}}$	$\delta\sigma_{\text{constant}}$
MIP calibration	F-D	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
	D-F	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
Temperature correction	F-D	Central	$\pm 0.02$	$\pm 0.01$
		Uniform	$\pm 0.04$	$\pm 0.02$
	D-F	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
Cross-talk correction	Both	Both	$\pm 0.03$	$\pm 0.12$
Single pixel signal	Both	Both	$\pm 0.06$	$\pm 0.17$
Effective pixel number	F-D	Both	$\pm 0.19$	$\pm 0.42$
	D-F	Both	$\pm 0.01$	$\pm 0.07$
Total (not including beam energy spread)	F-D	Central	$\pm 0.20$	$\pm 0.47$
		Uniform	$\pm 0.21$	$\pm 0.47$
	D-F	Central	$\pm 0.07$	$\pm 0.22$
		Uniform	$\pm 0.07$	$\pm 0.22$
Beam energy spread (assumed to be 5%)	F-D	Central	$+0$ $-1.66$	$+0$ $-3.65$
		Uniform	$+0$ $-1.86$	$+0$ $-3.52$
	D-F	Central	$+0$ $-0.80$	$+0$ $-4.45$
		Uniform	$+0$ $-2.34$	$+0$ $-3.35$

→ Reasonably small

→ Improved in 2<sup>nd</sup> prototype

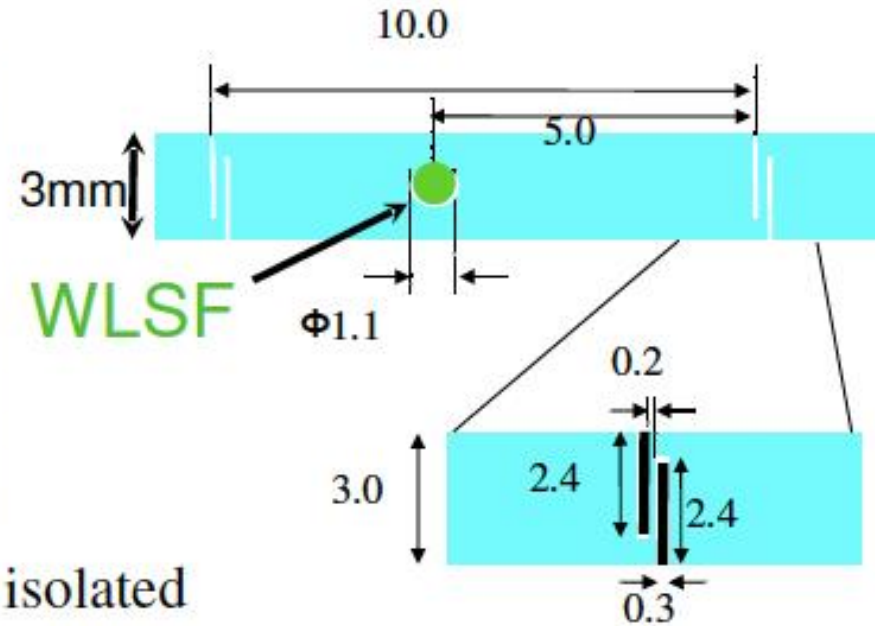
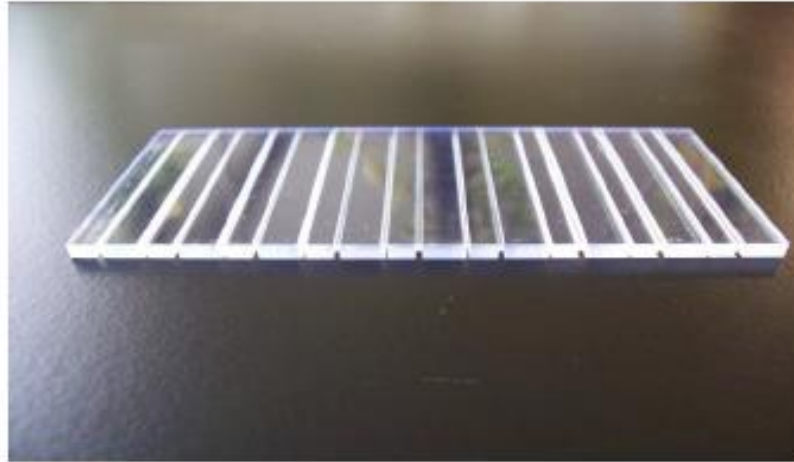
→ Non-trivial

→ Derived from the e<sup>+</sup> beam : Not easy to estimate  
The beam momentum spread precisely

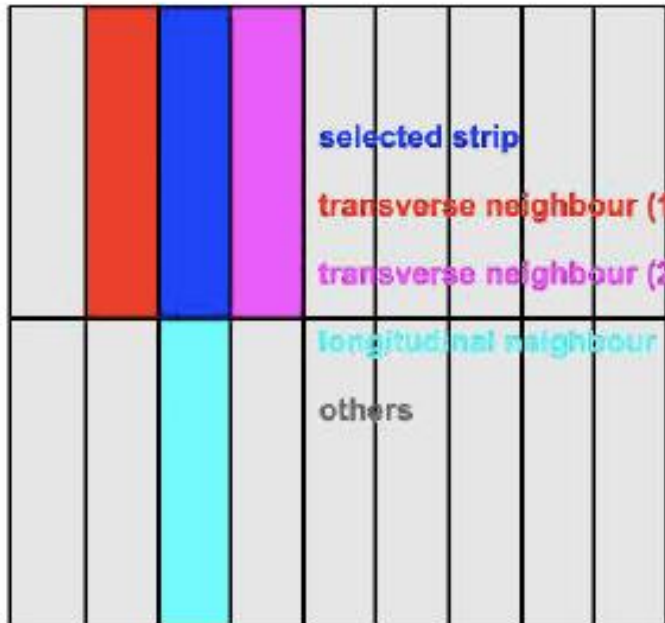
# Systematics : Optical cross-talk

Source	Configuration	Region	$\delta\sigma_{\text{stochastic}}$	$\delta\sigma_{\text{constant}}$
MIP calibration	F-D	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
	D-F	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
Temperature correction	F-D	Central	$\pm 0.02$	$\pm 0.01$
		Uniform	$\pm 0.04$	$\pm 0.02$
	D-F	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
Cross-talk correction	Both	Both	$\pm 0.03$	$\pm 0.12$
Single pixel signal	Both	Both	$\pm 0.06$	$\pm 0.17$
Effective pixel number	F-D	Both	$\pm 0.19$	$\pm 0.42$
	D-F	Both	$\pm 0.01$	$\pm 0.07$
Total (not including	F-D	Central	$\pm 0.20$	$\pm 0.47$
		Uniform	$\pm 0.21$	$\pm 0.47$
beam energy spread)	D-F	Central	$\pm 0.07$	$\pm 0.22$
		Uniform	$\pm 0.07$	$\pm 0.22$
Beam energy spread (assumed to be 5%)	F-D	Central	+0 -1.66	+0 -3.65
		Uniform	+0 -1.86	+0 -3.52
	D-F	Central	+0 -0.80	+0 -4.45
		Uniform	+0 -2.34	+0 -3.35

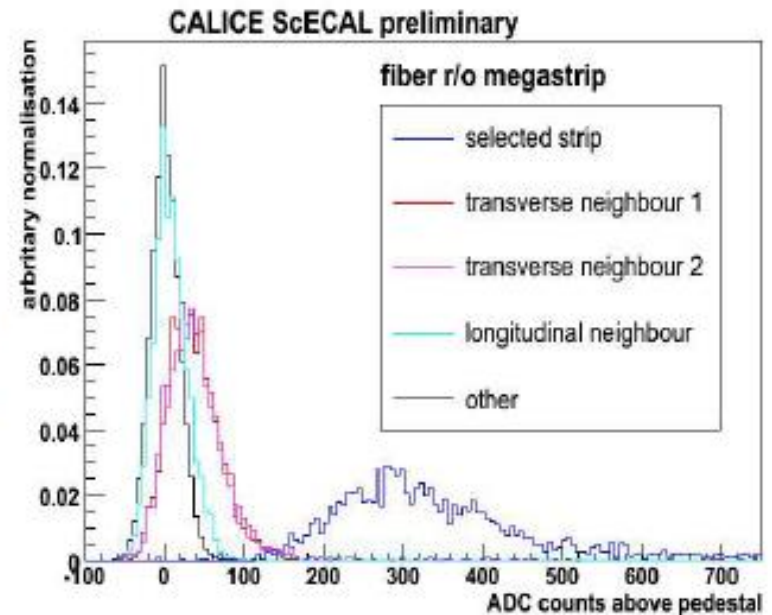
# light cross-talk between adjacent strips



Mega-strip structure: strips not perfectly isolated



look at signal when MIP hits adjacent strips

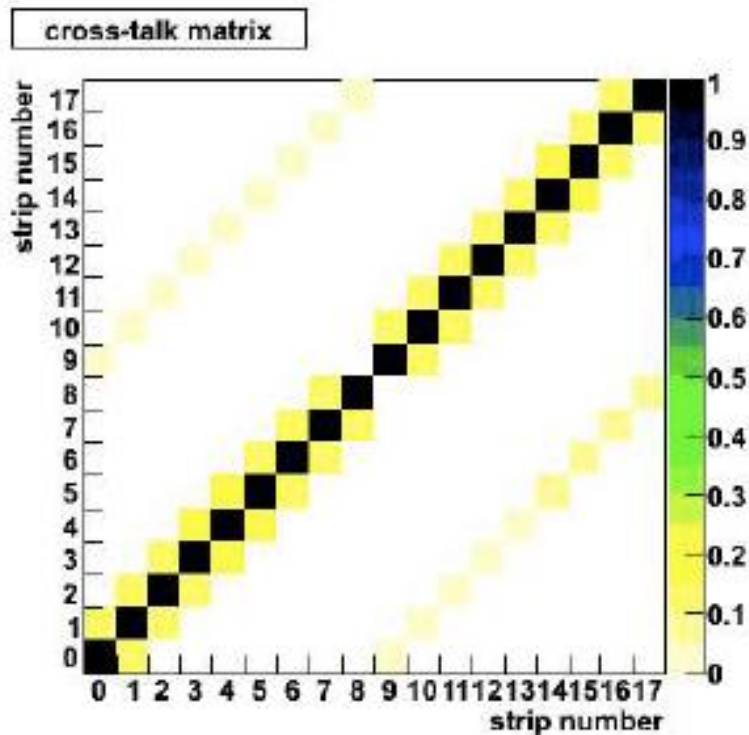




measure xtalk across each strip boundary

correction of cross-talk

in each layer, define matrix with measured xtalk probabilities ( $\sim 10\%$ )



use this matrix to unfold the cross-talk

The Mega-strip structure had been Replaced with separated strips after 2<sup>nd</sup> prototype.

# Systematics : Single Pixel signal

Source	Configuration	Region	$\delta\sigma_{\text{stochastic}}$	$\delta\sigma_{\text{constant}}$
MIP calibration	F-D	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
	D-F	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
Temperature correction	F-D	Central	$\pm 0.02$	$\pm 0.01$
		Uniform	$\pm 0.04$	$\pm 0.02$
	D-F	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
Cross-talk correction	Both	Both	$\pm 0.03$	$\pm 0.12$
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	D-F	Both	$\pm 0.01$	$\pm 0.07$
Total (not including beam energy spread)	F-D	Central	$\pm 0.20$	$\pm 0.47$
		Uniform	$\pm 0.21$	$\pm 0.47$
	D-F	Central	$\pm 0.07$	$\pm 0.22$
		Uniform	$\pm 0.07$	$\pm 0.22$
Beam energy spread (assumed to be 5%)	F-D	Central	+0 -1.66	+0 -3.65
		Uniform	+0 -1.86	+0 -3.52
	D-F	Central	+0 -0.80	+0 -4.45
		Uniform	+0 -2.34	+0 -3.35

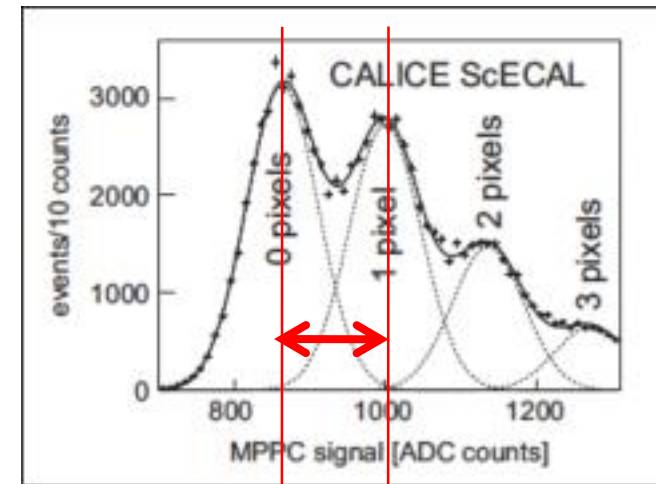
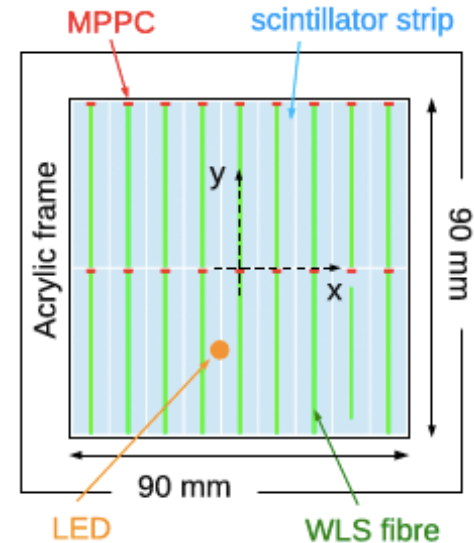
# Systematics : Single Pixel signal

- AHCAL electronics has 2 gain modes.
- LED calibration has been done in 2 steps in order to obtain the single pixel equivalent signal.

**Step 1** : Measure single-photoelectron peak in high gain mode,

**Step 2** : Measure gain ratio of low/high-gain mode (=inter-calibration factor).

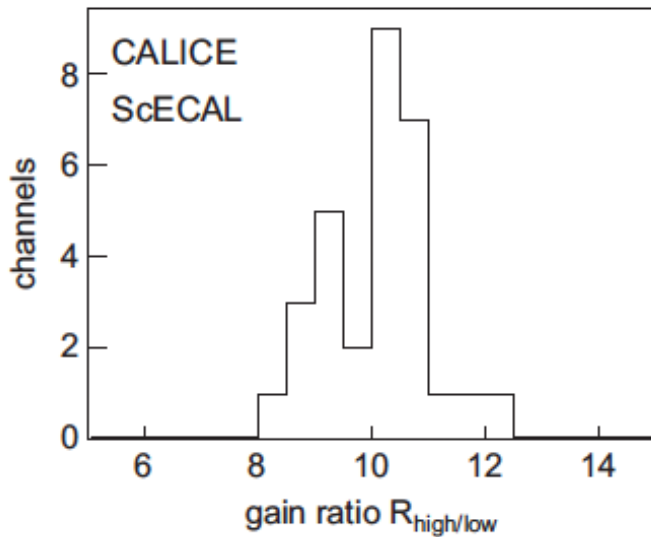
**Note** : LED runs are done just for a limited number of channels



**d-value**

# Systematics : Single Pixel signal

Inter-calib factor for 30 channels (out of 468).



- Due to a lack of available time, Inter-calibration had been done just for small fraction of whole channels.
- This incompleteness of LED runs induces non-negligible systematic uncertainties.
- **It tells the necessity of well-arranged LED system & runs.**

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Module type	$d_{\text{low-gain}}$ (ADC counts)
type-F	$14.4 \pm 1.5$
type-D	$15.8 \pm 1.7$

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**~10% of uncertainty**

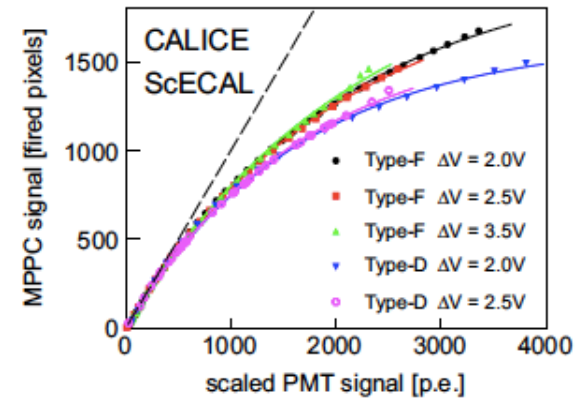
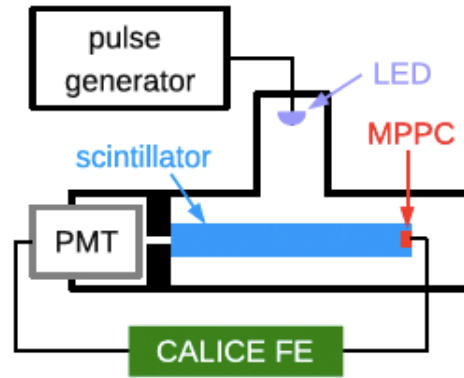
# Systematics : Effective Pixel Number

Source	Configuration	Region	$\delta\sigma_{\text{stochastic}}$	$\delta\sigma_{\text{constant}}$
MIP calibration	F-D	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
	D-F	Central	$\pm 0.01$	$\pm 0.02$
		Uniform	$\pm 0.02$	$\pm 0.02$
Temperature correction	F-D	Central	$\pm 0.02$	$\pm 0.01$
		Uniform	$\pm 0.04$	$\pm 0.02$
	D-F	Central	$\pm 0.01$	$\pm 0.02$
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Beam energy spread (assumed to be 5%)	F-D	Central	+0 -1.66	+0 -3.65
		Uniform	+0 -1.86	+0 -3.52
	D-F	Central	+0 -0.80	+0 -4.45
		Uniform	+0 -2.34	+0 -3.35

# Systematics : effective pixel number

- Non-uniform response of the MPPC is corrected using correction curve (measured separately) :

$$N_{\text{fired}} = N_{\text{pix}}^{\text{eff}} (1 - e^{-p \cdot \text{ADC}_{\text{PMT}} / N_{\text{pix}}^{\text{eff}}})$$



- Thanks to quick recovery ( $\sim 4\text{ns}$ ) of the MPPC, num. of effective pixels is enhanced.
- The enhancement depends on input light length.

Module type	$N_{\text{pix}}^{\text{eff}}$
type-F	2073
type-D	1677

Difference of those  
Is taken as the source  
of systematic uncertainty

- This tells that larger dynamic range and knowledge on response of the MPPC is important.

# Summary & Conclusion

From the viewpoint of irreducible systematics,

- Beam momentum spread gives dominant effect
- Understanding non-linear response of the MPPC is important
- Single-pixel & electronics calibrations are of 2<sup>nd</sup> importance (balance with technology & cost)
- Strip response non-uniformity also gives non-trivial effect
- MIP calibration, temperature dependence of the MPPCs are rather OK

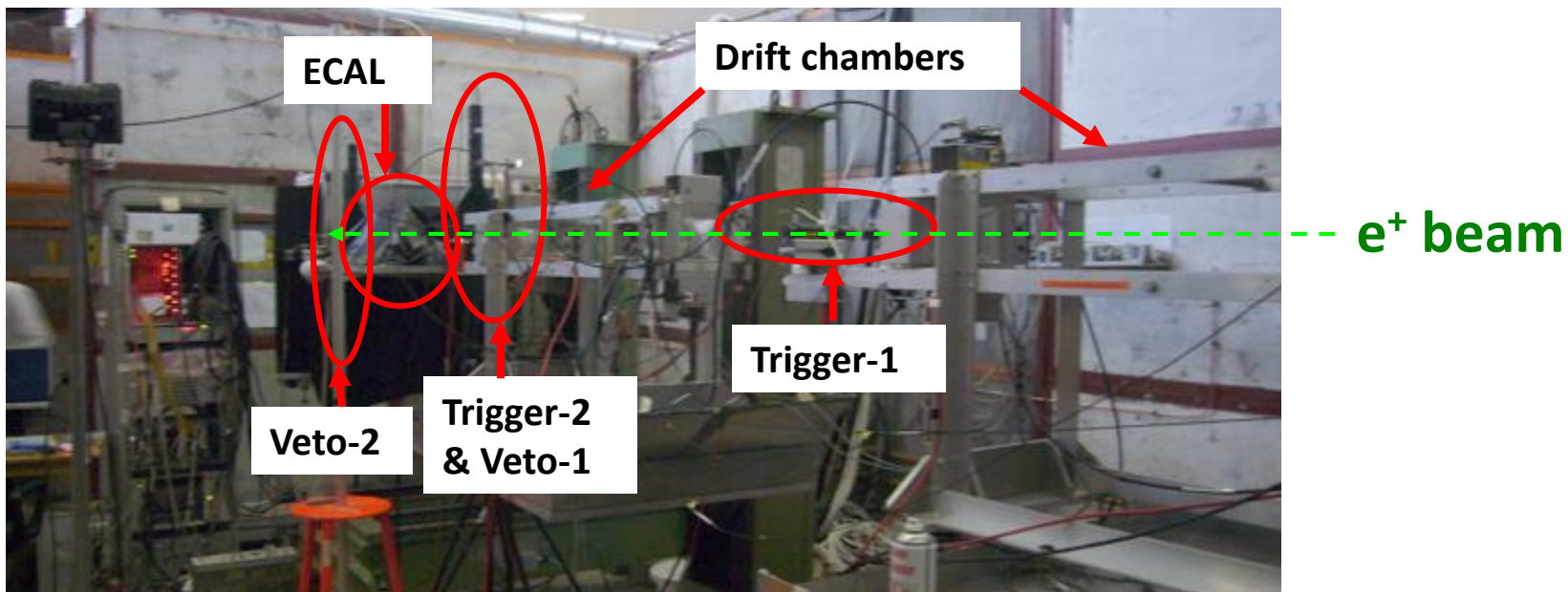
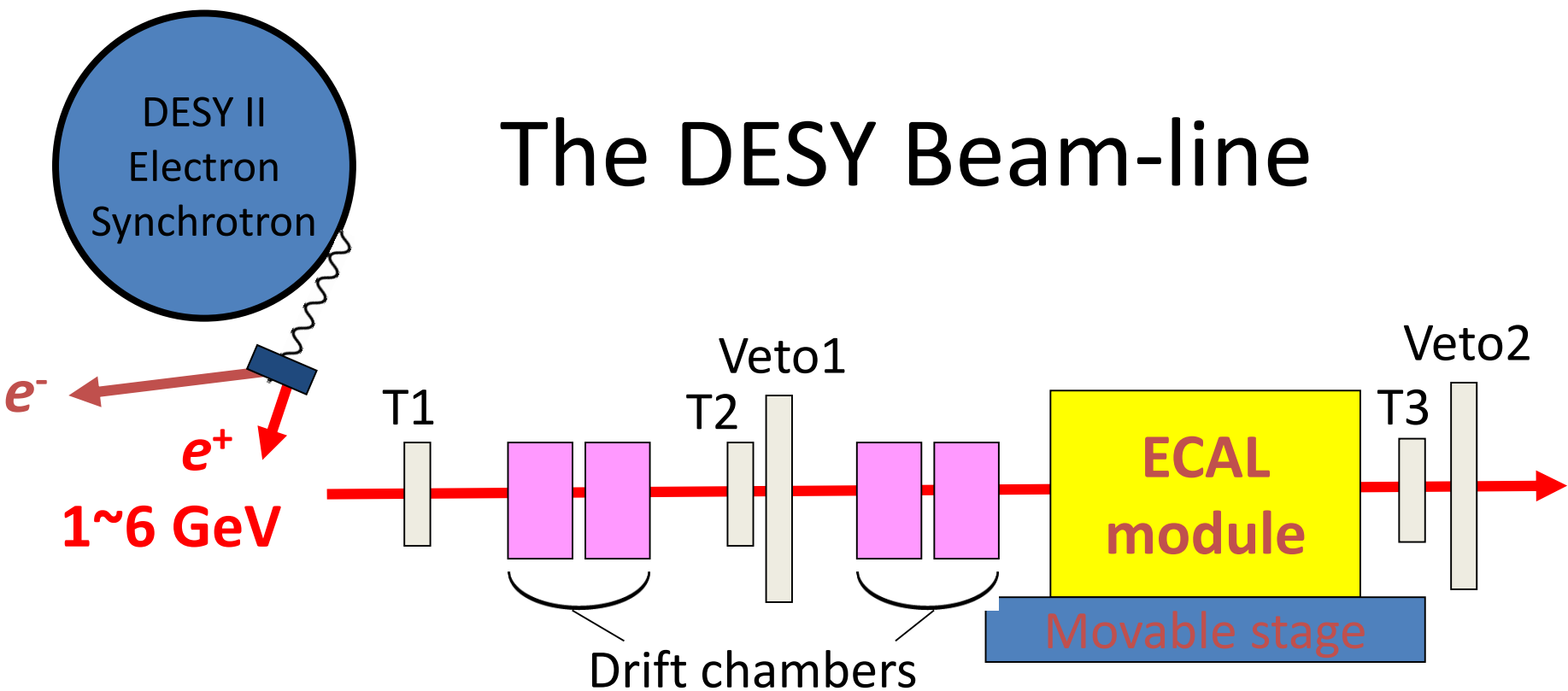
# Backups



# Feedbacks to 2<sup>nd</sup> & future prototypes

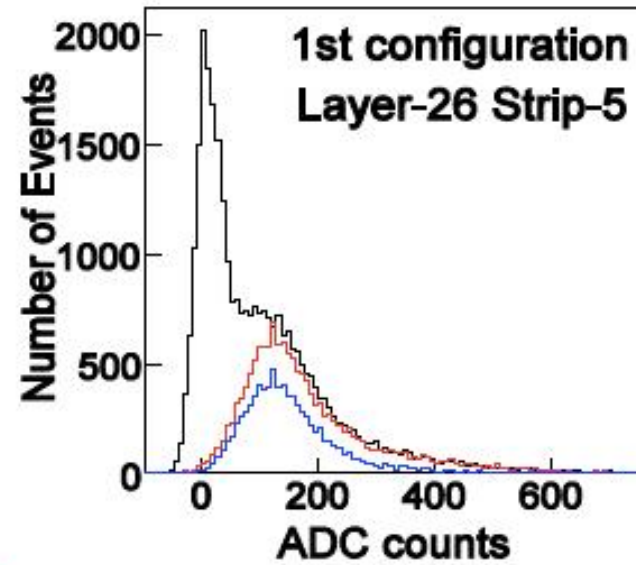
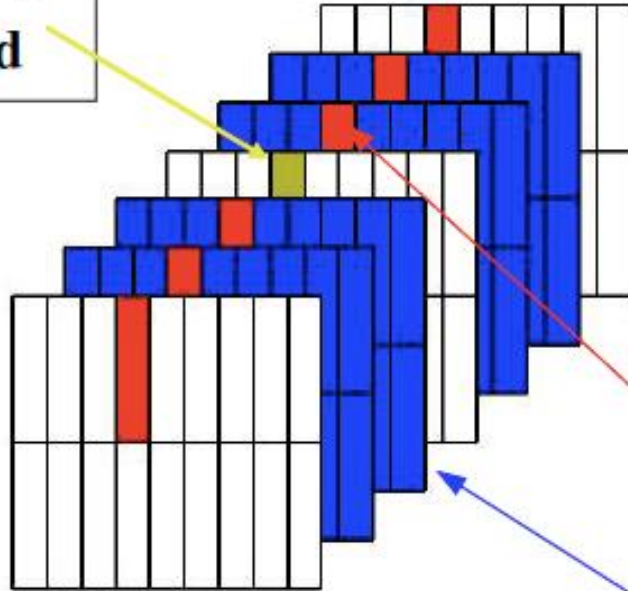
- The 2<sup>nd</sup> ScECAL prototype had been built and tested @ FNAL (1-32 GeV e-, p- and m)

# The DESY Beam-line



# MIP calibration

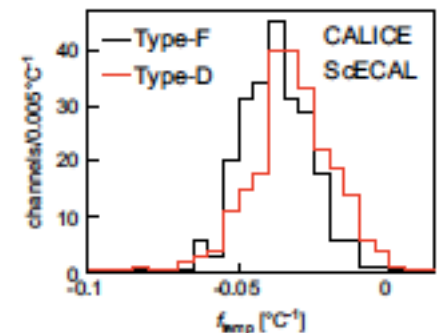
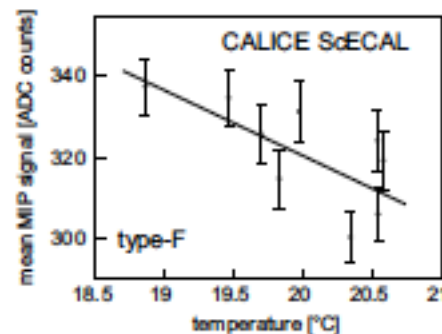
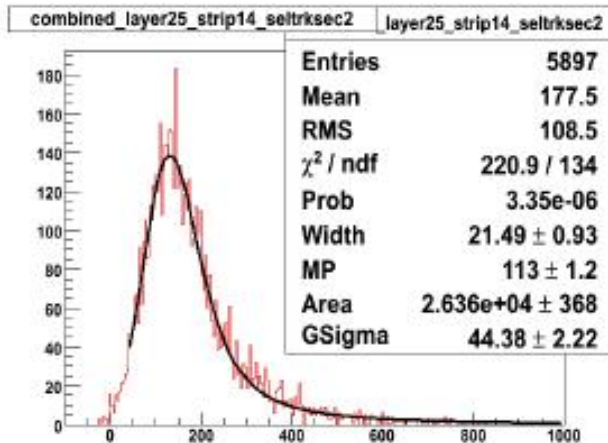
Strip being calibrated



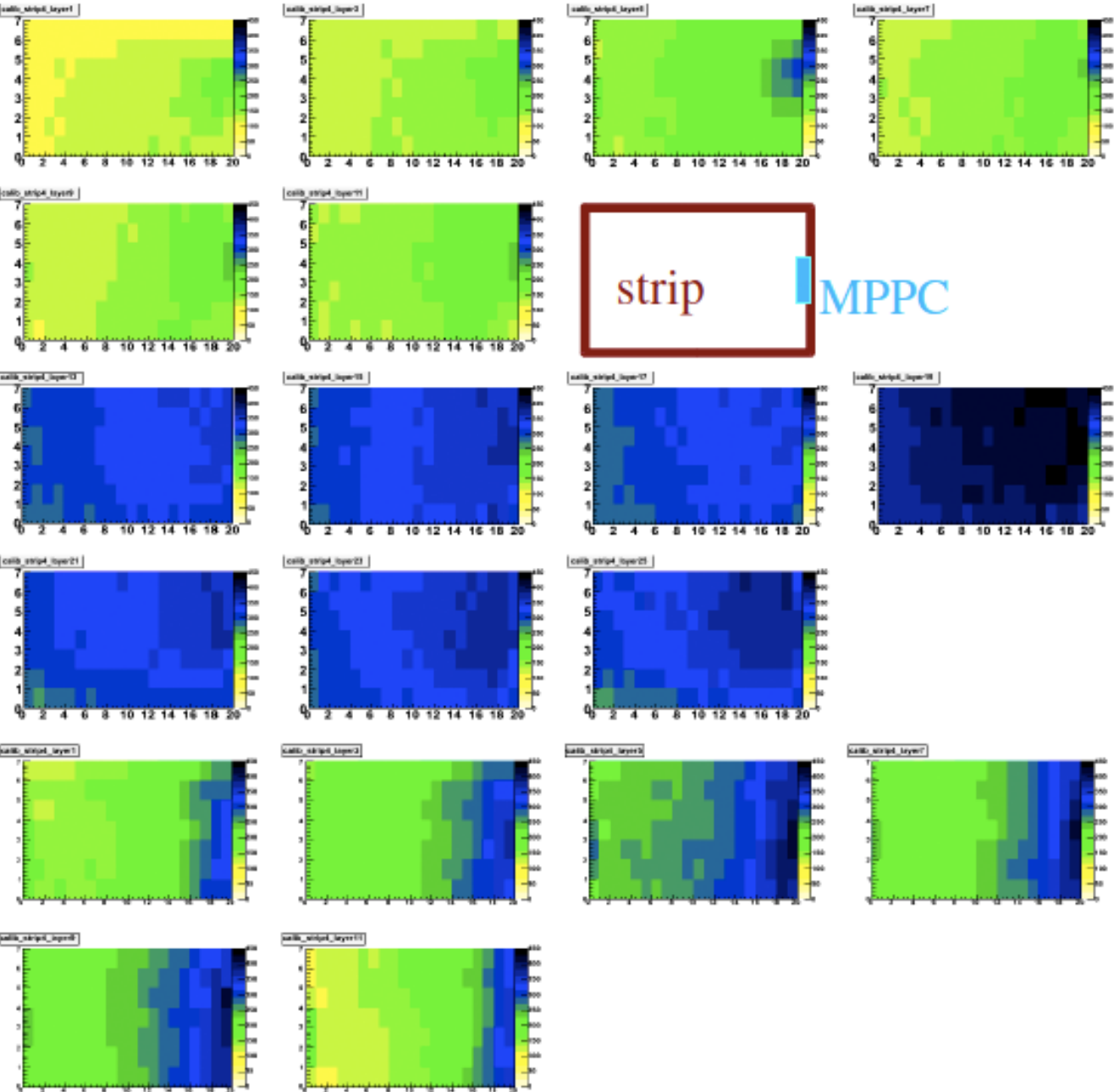
Trigger only

Red strips have  
non-pedestal signal

Blue strips have  
only pedestal signal



# MIP response uniformity: detailed scan across single strip



Kuraray  
direct readout

Kuraray  
fibre readout

KNU extruded  
fibre readout