Belle calorimeter upgrade

B.Shwartz,

on behalf of BELLE calorimeter group

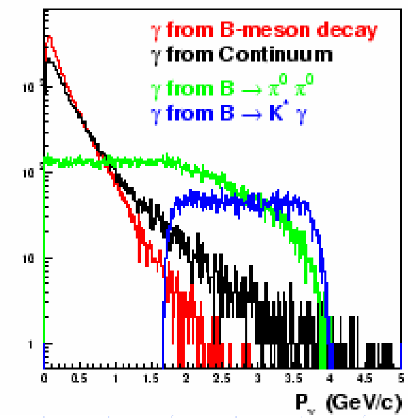
Role of the electromagnetic calorimeter

Measurement of

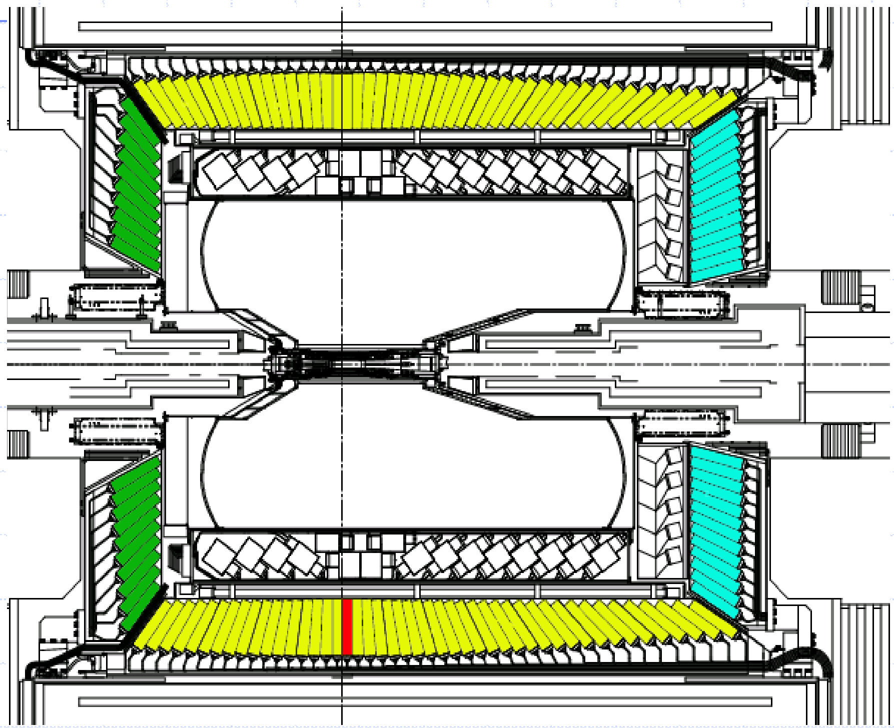
- *Energy/angle of photon* (20MeV~8GeV)
- *Electron identification*
- *K_L detection together with KLM*
- *Redundant trigger*
- *Neutral trigger*

Measurement of the luminosity

- *Online/offline luminosity*

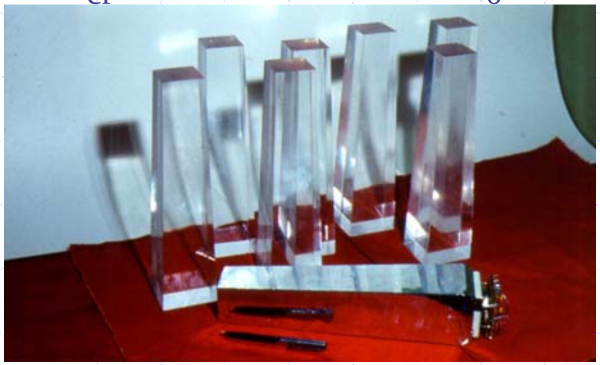


BELLE Electromagnetic Calorimeter for KEKB energy asymmetric B-factory

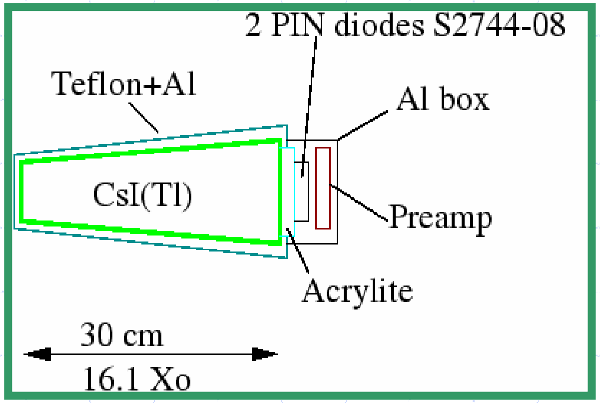


3 m

L_{cr} = 30 cm = 16.2X_0



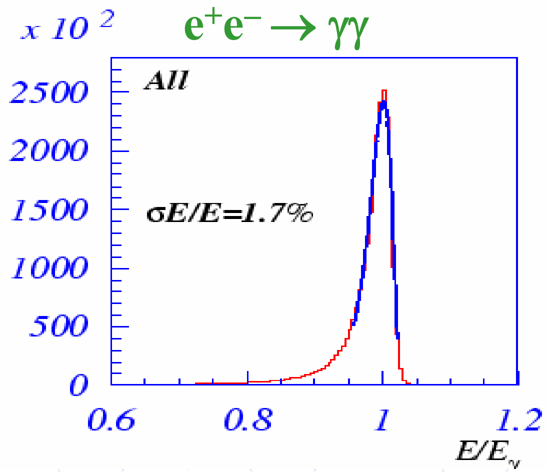
Light output - 5000 ph.el./MeV
electronics noise σ~200 keV



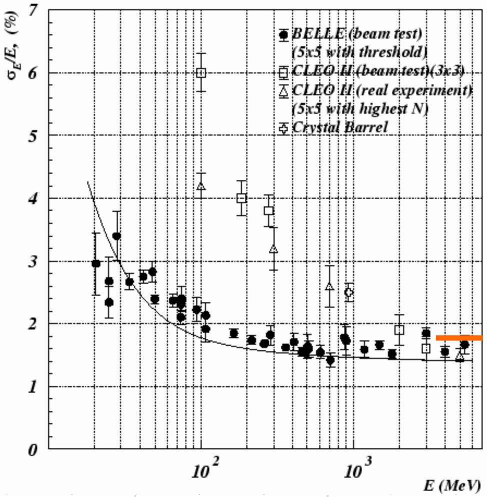
Number of crystal: 8736
Total weight is ~43ton

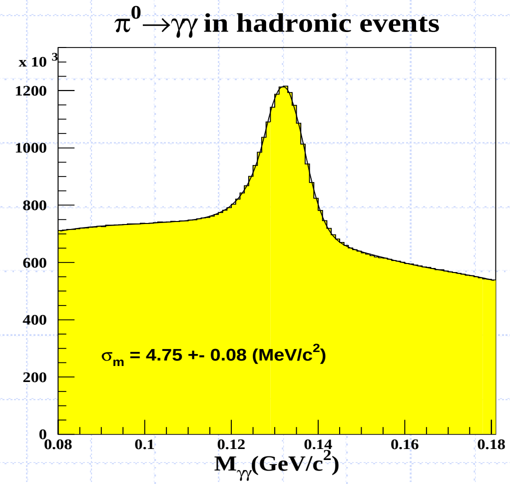
BELLE calorimeter performance

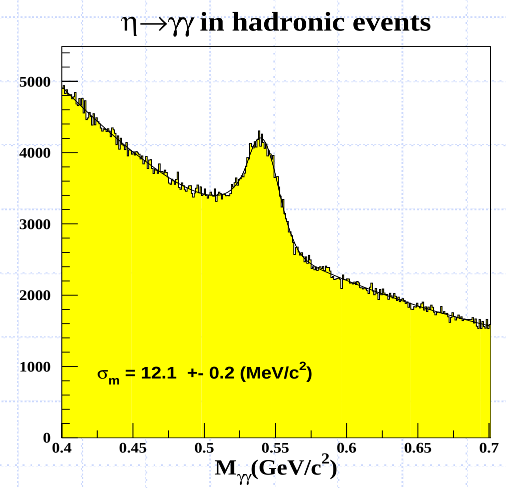
The Belle calorimeter has been exploited from 1999 up to now. It demonstrates high resolution and good performance.



Test beam



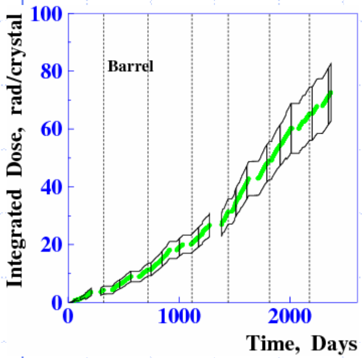


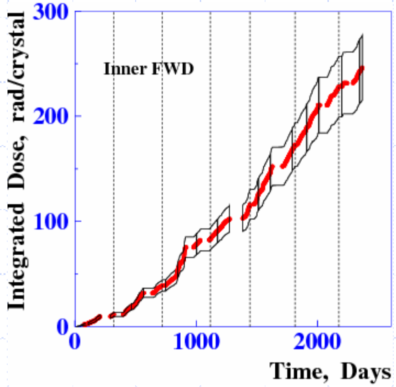


Calorimeter performance in a view of the luminosity increase.

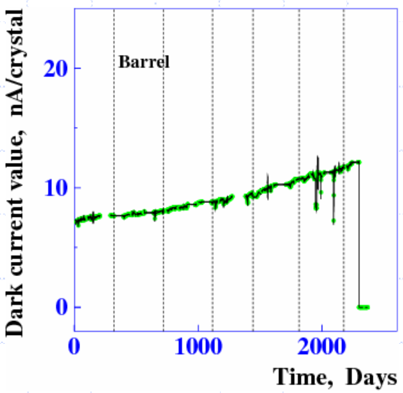
At L ~ 10^{34} $cm^{-2}s^{-1}$ and $\int L dt \sim 700 fb^{-1}$

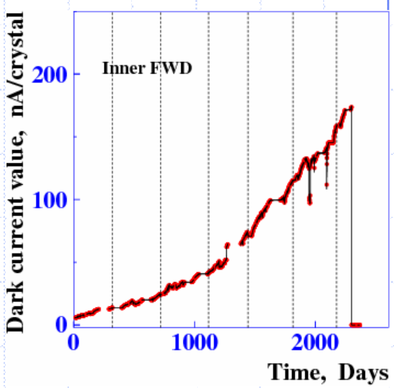
Radiation damage of the crystals

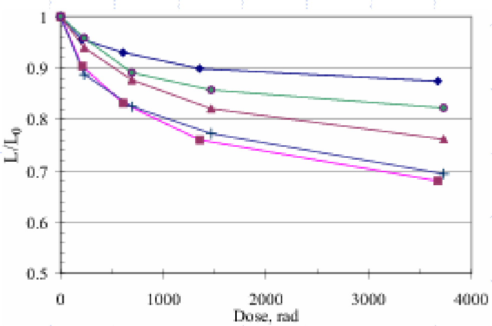




Increase of the PD dark current







In the most loaded part the light output degradation is about 10%

Basically – no problem.

Small increase of the dark current in the barrel

Essential increase of the dark current in endcaps

Caused by neutron flux ($\Phi \sim 10^{10}$ cm^{-2})

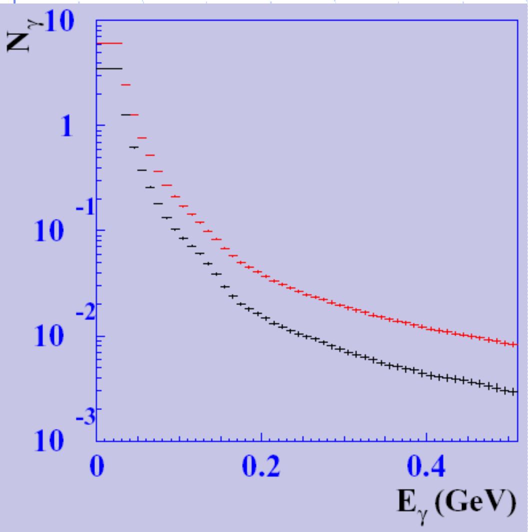
Results in $\sigma_d \sim 0.2$-0.3 MeV, still not the most annoying problem.

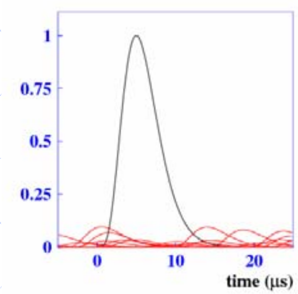
Pile up effect

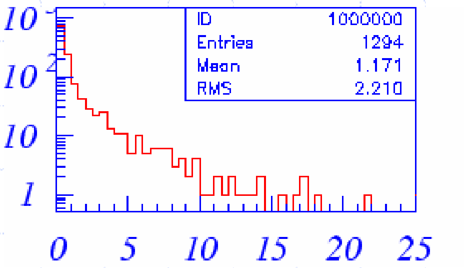
Pile-up noise

$$\sigma_{pile-up} = \overline{E_\gamma}\sqrt{f_{bkg}\cdot\tau_{eff}} \propto \sqrt{I\cdot P}$$

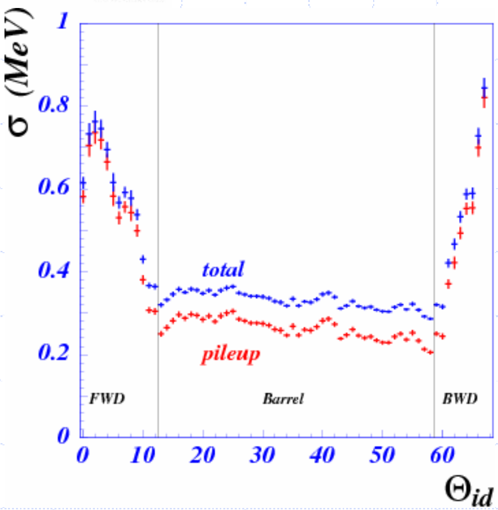
Fake clusters







ε_γ, MeV



(E>20 MeV) 6 fake clusters, 3 in barrel 3 in endcaps background

The obvious solution is to replace CsI(Tl) crystals by the other scintillators with

$L \sim L_{CsI(Tl)}$, $\tau \sim \tau_{CsI(Tl)}/10$ and zero afterglowing.

Lu_2SiO_5(Ce), $LuAlO_5$(Ce), $LaBr_3$(Ce) ……. ?

Problems - cost and mass production

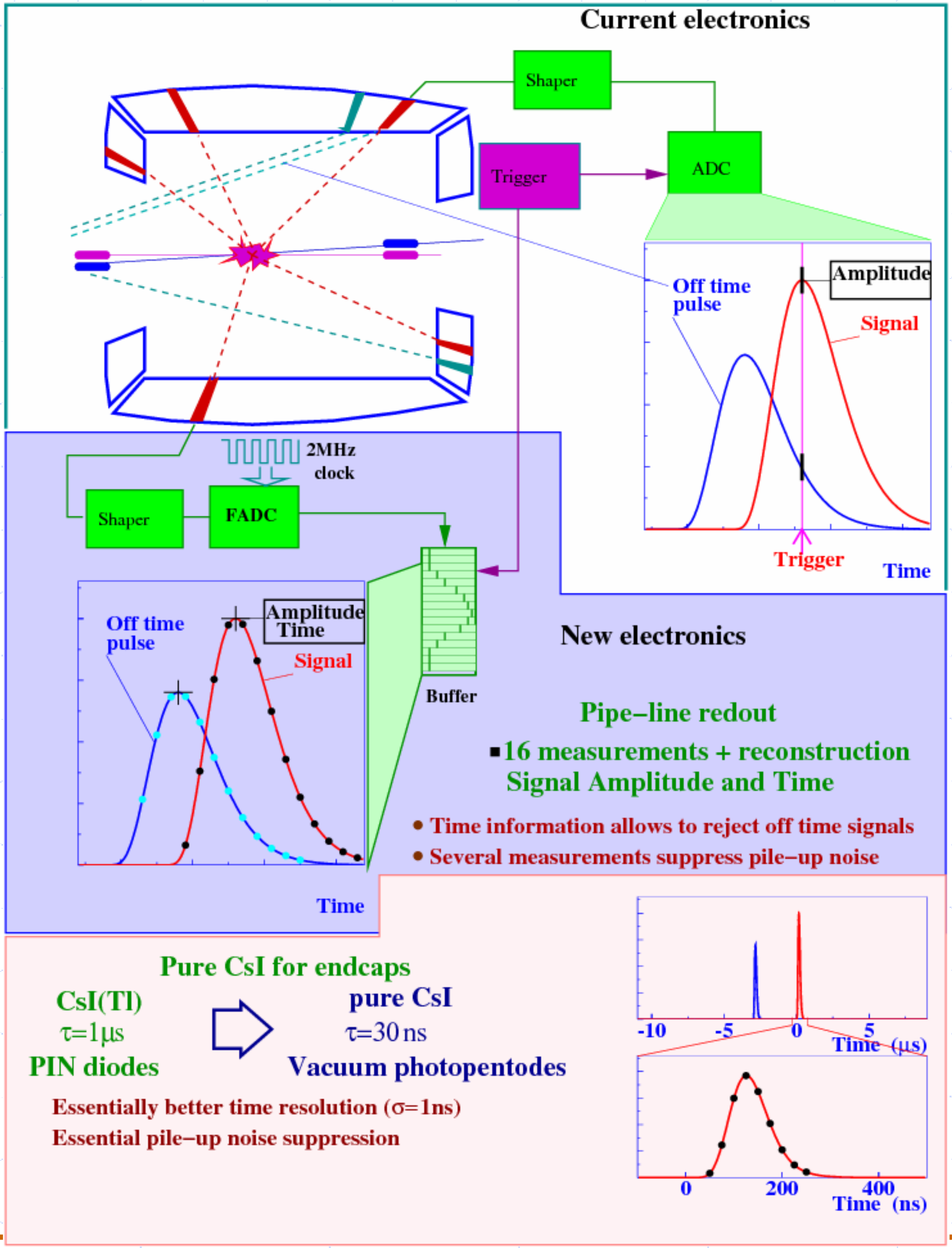
We needed in a reasonable compromise…

- To keep existing CsI(Tl) crystals in the barrel part.
- To replace CsI(Tl) to pure CsI crystals in the end caps.
- To modify all readout electronics.
- To keep the present mechanical structure.

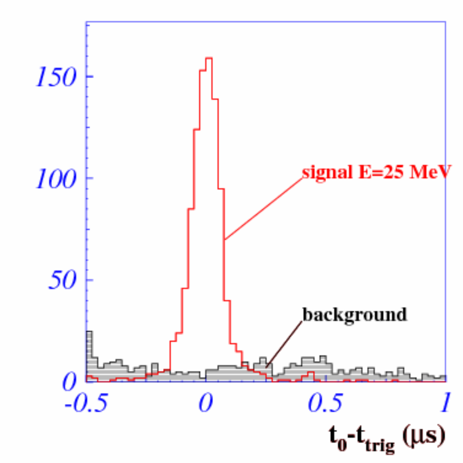
Modification of the electronics.

- Pipe-line readout with waveform analysis:
- 16 points within the signal are fitted by the signal function F(t): $F(t) = H \cdot f(t-t_0)$
- Both amplitude (H) and time (t_0) are obtained by the on-line shape fit:

$$\chi^2 = \sum_{i,j} (A_i - F(t_i)) S_{ij} (A_j - F(t_j))$$



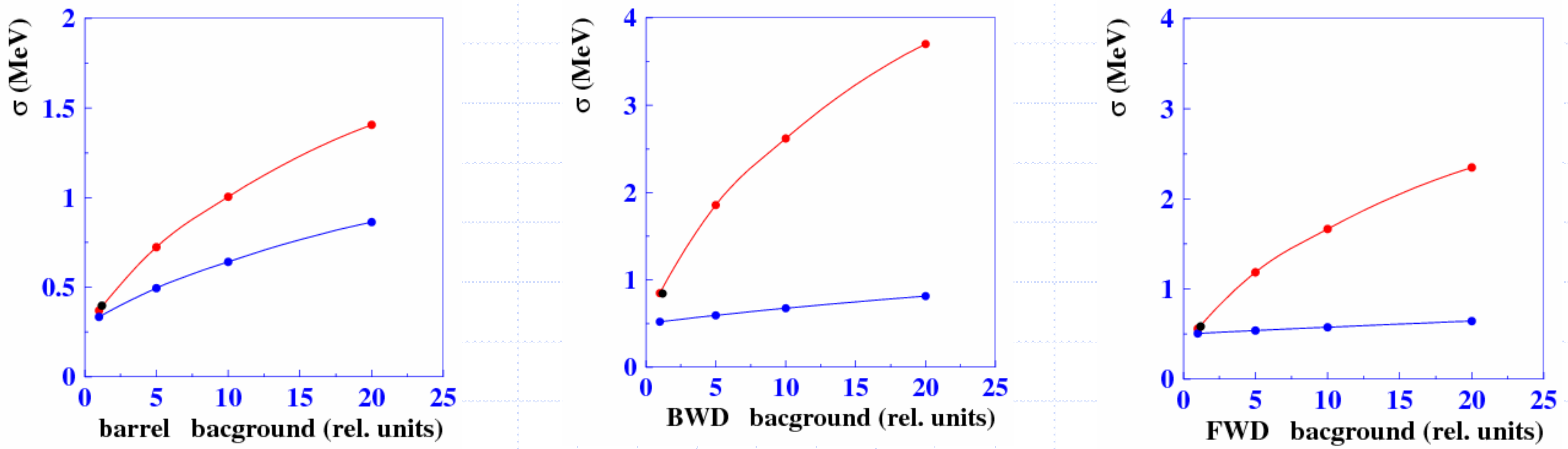
Expected improvement



Time information allows to suppress the fake clusters by 7 times for the barrel by rejecting wrong time clusters.

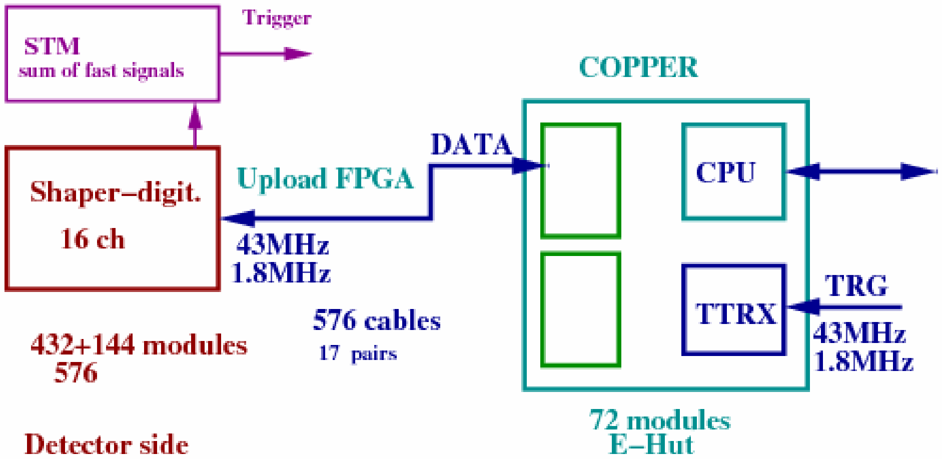
For endcaps the suppression factor is about $7 \times 30 = 200$ due to the shorter decay time of the pure CsI

The pileup noise will be reduced by factor ~1.5 for barrel and factor ~5 for endcaps:



New and new+ ECL electronics

New electronics

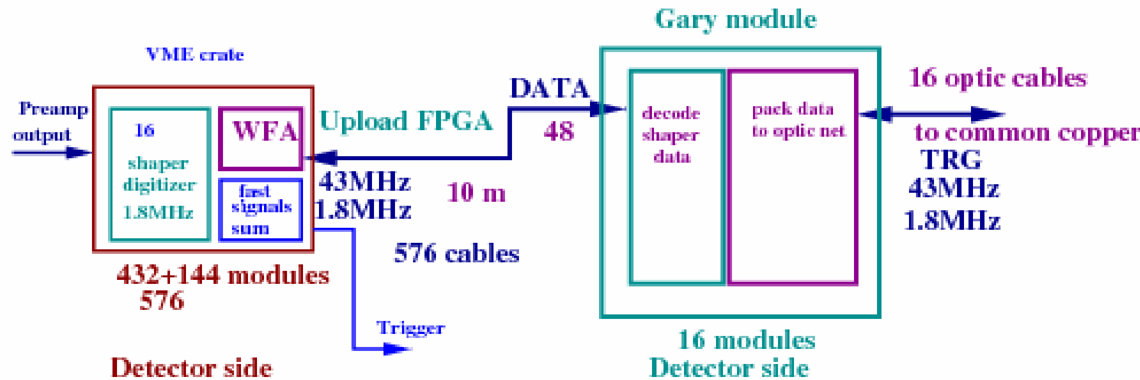


576 cables(x 17 pair)

72 copper modules 2 FINNESSE×4 channels

many cables, many copper crates

Very New electronics



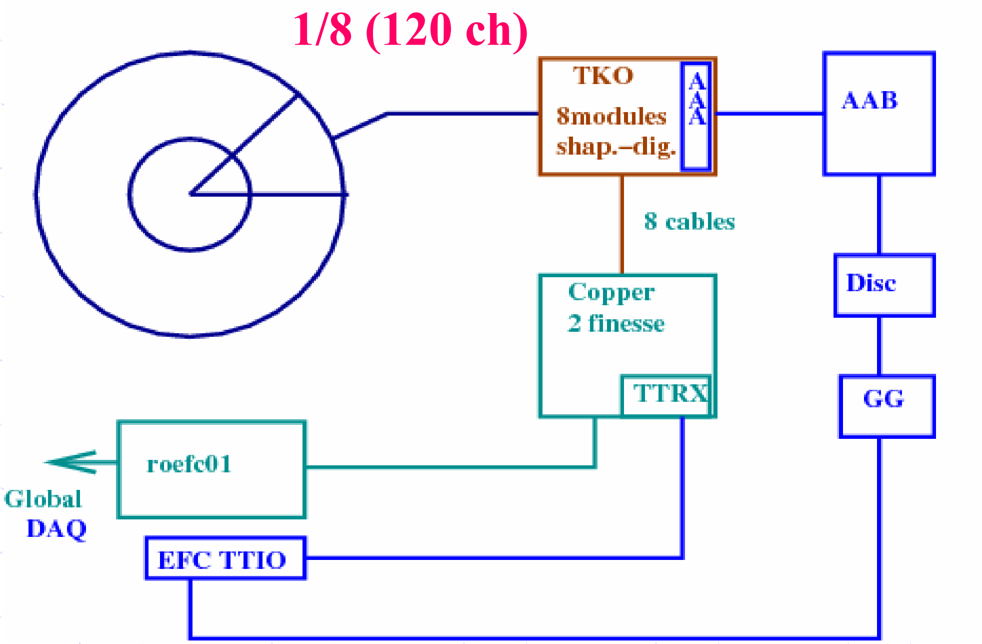
16 cables(optical)

16 Gary modules×(48) channels

Trigger, uploading, protocol..? under design

Readout scheme for summer and autumn tests

ECL BE



Obtained at the summer tests with cosmic rays

Incoherent noises :
5.7 channels(330keV) (outer layers)
7.1 channels(410keV) (inner layers)
10% higher than expected

Coherent noises :
1.2 channels(70 keV) for 16 channels (1 module)
0.6 channels(30keV) for 120 modules

The time resolution per counter is $17/\sqrt{2}=12$ns as expected for 35 MeV energy deposition

8 Shaper digitizer were connected to ECL B3 sector (120 channels)
Copper module installed in the crate near FB rack
The Copper is readout by EFC PC roefc01

A test of the new ECL electronics in the experiment

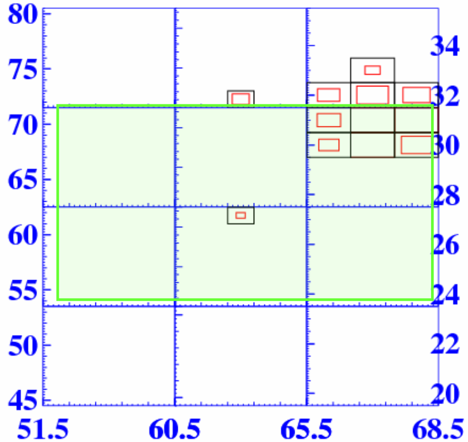
Since beginning of this experiment (exp.67) up to Oct.23, morning, ECL was running with 120 channels (1/8 of the BE) connected to 8 new shaper-digitizer boards, read out by the copper module. Other ECL channels were in the usual status. In this configuration we collected about 965 pb^{-1} of the statistics.

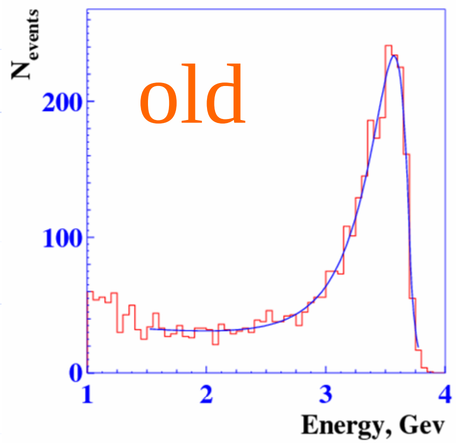
From this data 4 runs with 26 pb^{-1} was recorded without injection veto.

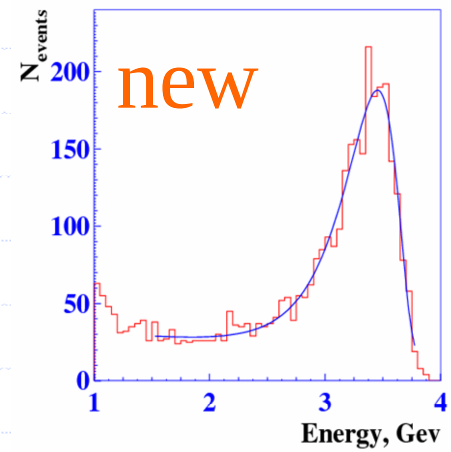
On Oct.23, during the maintenance time, we replaced the new electronics with the old one. Nakamura-san analized the data from the local run performed after replacement and confirmed that all changed channels are alive.

First results

over 1/8 of backward endcap

4






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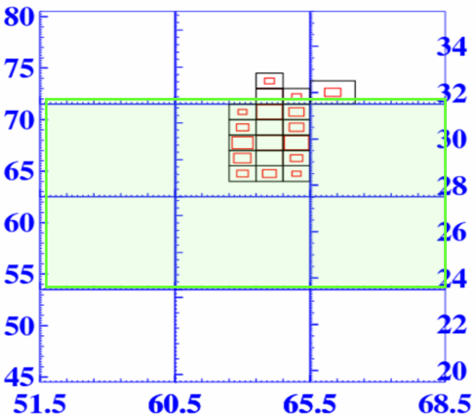
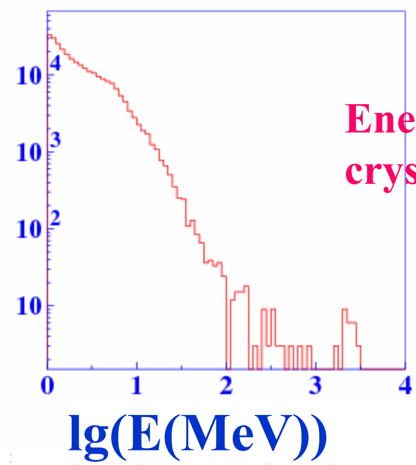
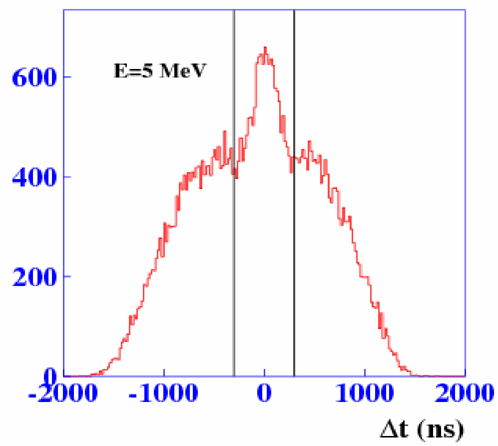


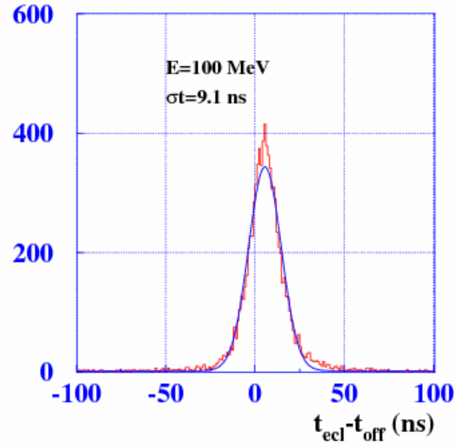


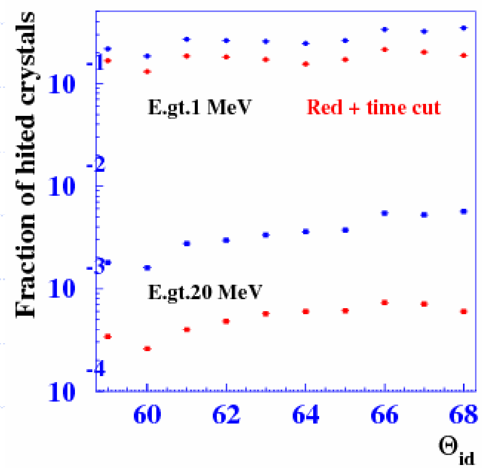
Energy deposited in one crystal

Shaded area – new electronics

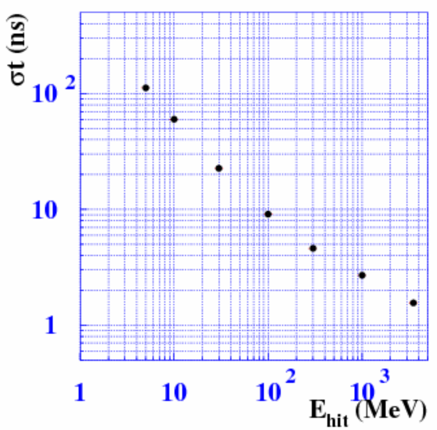
Timing and background

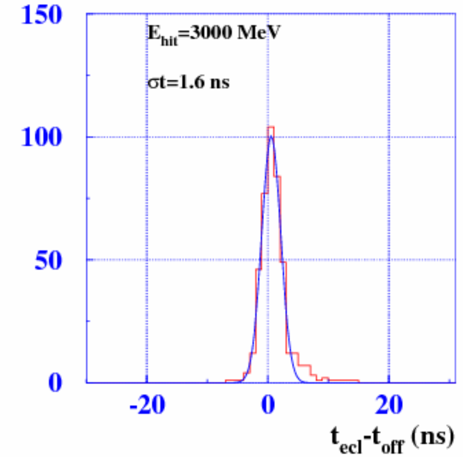


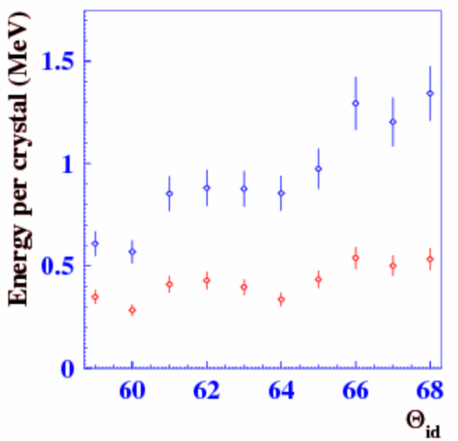




One channel time distribution



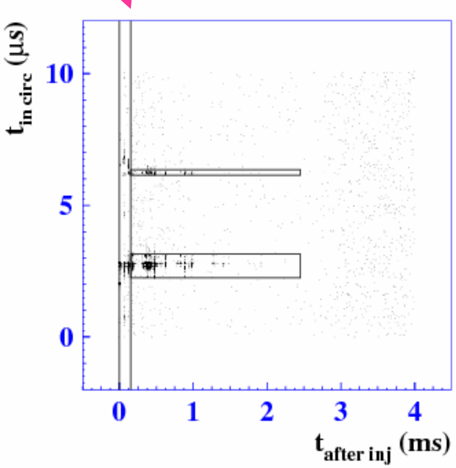


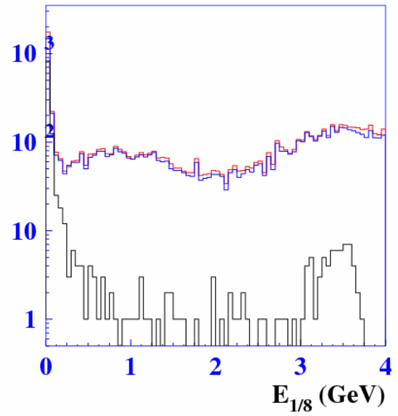


Injection study

150 μs

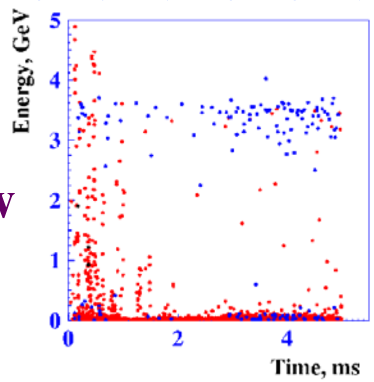
HER





HER

new

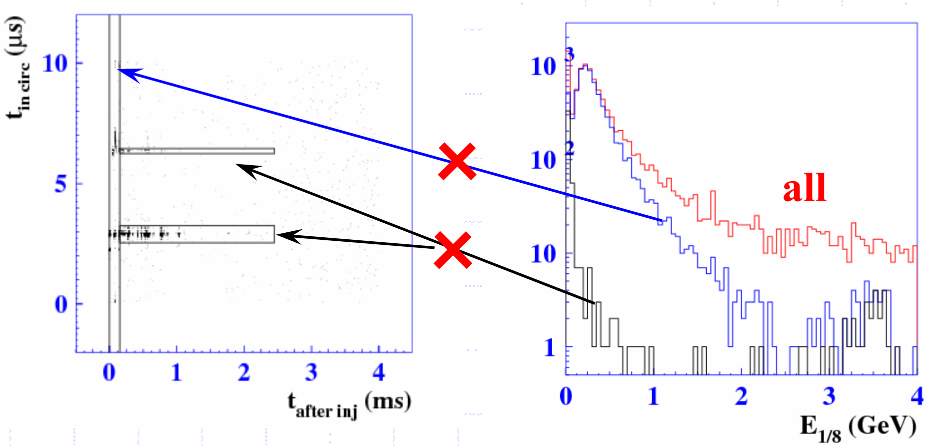


all events

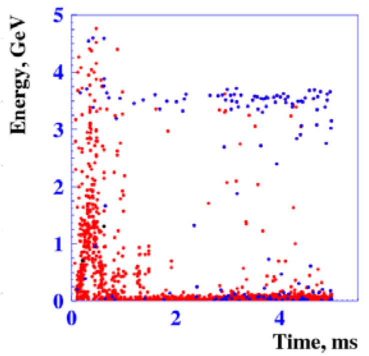
FE.and.BE

bad inj.time

LER



old

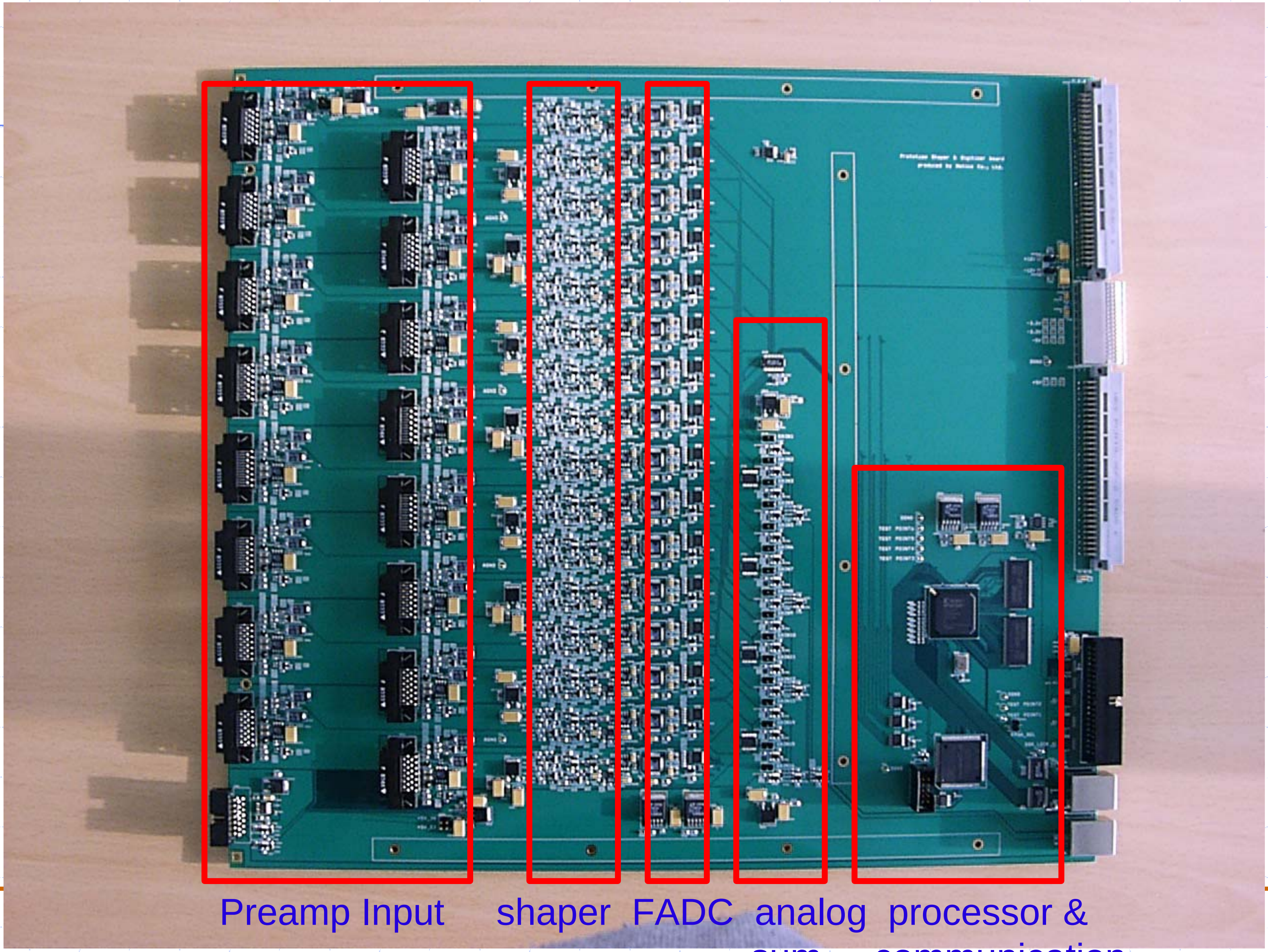


Current Status

B.G. Cheon (Hanyang U)

- A schematic design had been based on TKO version.
- Some modifications were performed after the discussion with Y.Usov.
- Purchase of all the parts was done in Oct.
- Board layout (9U-size, 6-layers) was finished in Nov.
- Schedule of the 1st prototype board production/test
  - ✓ PCB production : done in Nov.
  - ✓ Soldering : done in this week.
  - ✓ Basic test : 2 weeks (power line and analog part w/ pulse gen.)
  - ✓ Shipping to KEK : End of December (if no mistake is found)
  - ✓ Detail test : from Jan/2009 @ KEK
- Revision of the board (production of the 2nd prototype) will take much short term because we already have all parts and much less effort is necessary.

New VME Shaper board



Pure CsI in the end caps

Properties of pure CsI and CsI(Tl) scintillation crystals

	ρ, g/cm^3	X_0, cm	λ_{em}, nm	N(λ_{em}, nm)	N_{ph}/MeV	T, ns	dL/dT, %/° @20°C
Pure CsI	4.51	1.85	305	2	2000	20/1000	- 1.3
CsI(Tl)	4.51	1.85	550	1.8	52000	1000	0.4

To use pure CsI crystals in the end caps we had to answer several important questions:

- ✓ **To find proper photodetector with a gain, large area and low capacity;**
- ✓ **To prove the radiation resistance of the crystals;**
- ✓ **To demonstrate the possibility to obtain the desirable characteristics.**

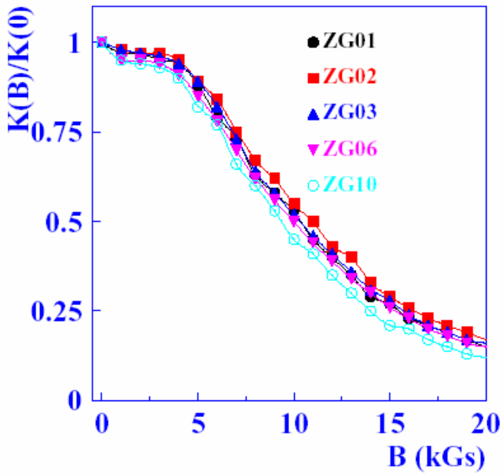
Photodetector

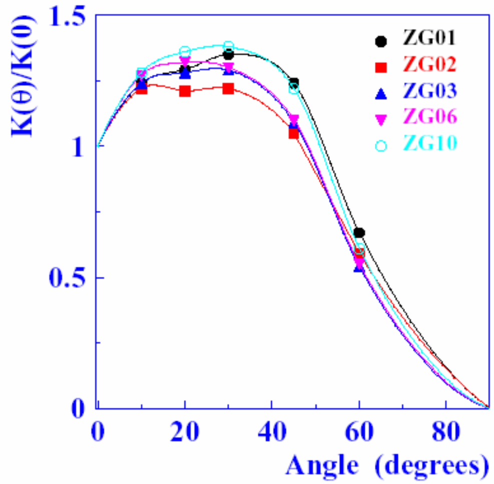
2" UV sensitive photopentods (PP), Hamamatsu Photonics

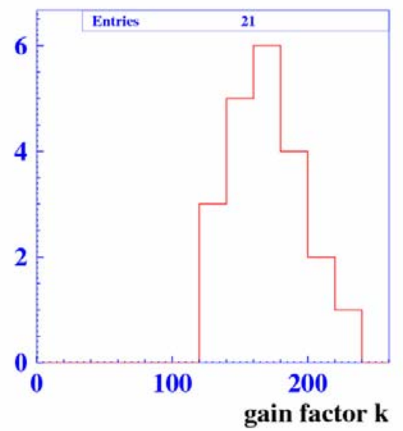
C ≈ 10 pF.

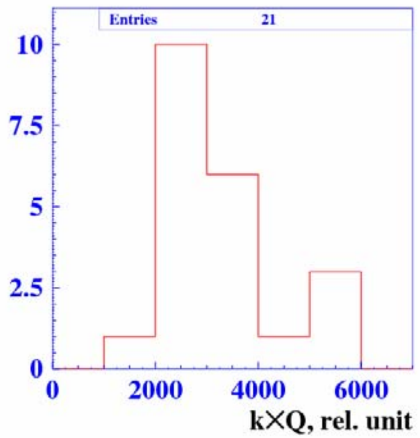
PP gain factor 120-240.

(we need > 30 in mag.eld)









The gain factor drops down 3.5 times for B=15 kGs

About 20-30 % improvement for angle 20-45°

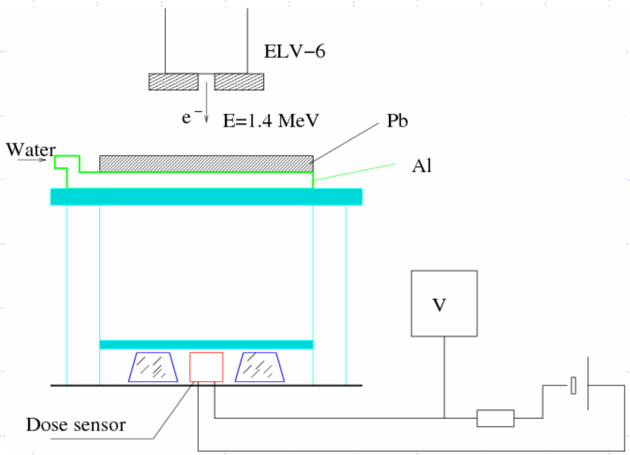
Radiation hardness test with photons

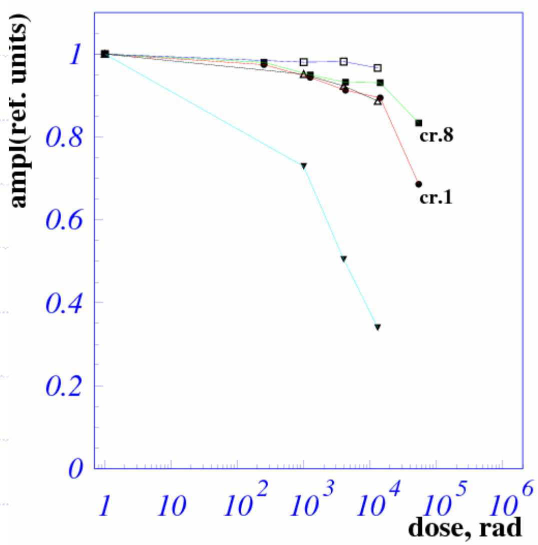
Radiation hardness of 4 pure CsI crystals (Kharkov) and one counter (pure CsI Crystal + photopentode) were tested with gamma irradiation.

For 15 krad dose the degradation of the lightoutput for 3 crystals and counter was less than 10%, but one counter lightoutput reduction was about 60%

(→ all crystals should be tested before assembling).

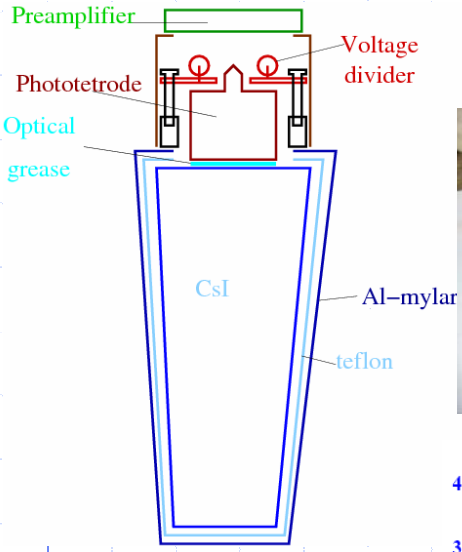
Bremsstrahlung photons,
E = 0 ÷ 1.4 MeV from
ELV-6, BINP
Absorbed doses
0.250, 1 , 4 , 10 , 30 krad

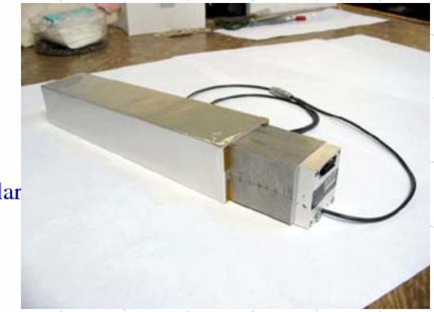


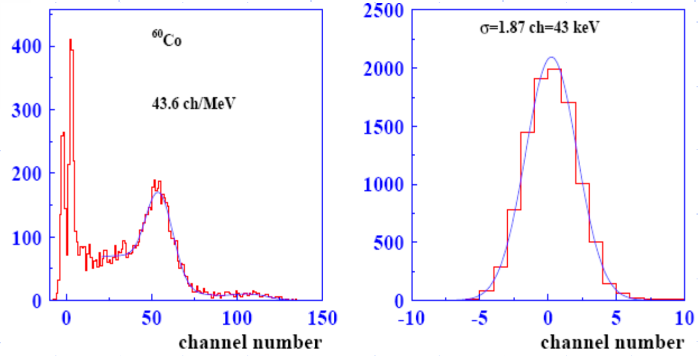


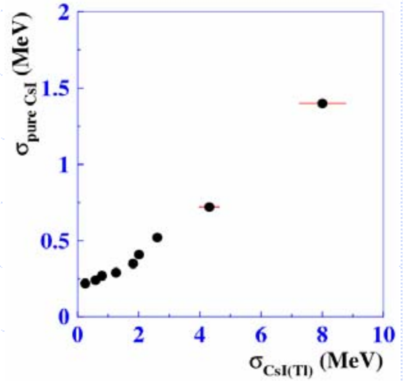
Neutron irradiation up to 10^{12}cm^{-2} did not reveal a degradation within 5%

Counters design and properties







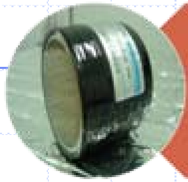


Electronics for pure CsI crystals are developed under the same general scheme as for the barrel part but:

- **shaping time is shorten to 30 ns;**
- **clock frequency increases from 2 MHz to 43 MHz**

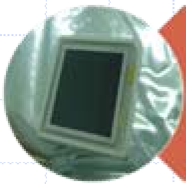
The prototype of the shaper-digitizer module are developed, produced and demonstrated a good performance.

Are there alternatives for light readout and fast crystals?



P.P. x3

Nara W's Uni group



APD x2

Ken Jery,
FU JEN CATHOLIC UNIVERSITY

Pr:LuAG scintillator

- Pr^{3+} 5d-4f transition scintillating
- Pr^{3+} scintillation decay time, wavelength change by host material.
- LuAG:$Lu_3Al_5O_{12}$:host material
- Yoshikawa group in Tohoku developed.
- Original motivation is next generation PET.
- Furukawa Co. has been doing R&D of crystal growth.

Crystal with Pr doping in 0.25 atomic%.
2in. diameter ingot

Nara W's Uni group

Summary

- **To keep good performance of the calorimeter at high background conditions we need to upgrade the electronics for the barrel and to replace both crystals and electronics in the endcaps .**

- **The work for barrel electronics upgrade is in progress. The working version of the electronics has been developed.**

- **At the next step we need in a detail test of the electronics integrated to DAQ of the Belle detector during the continuous run.**

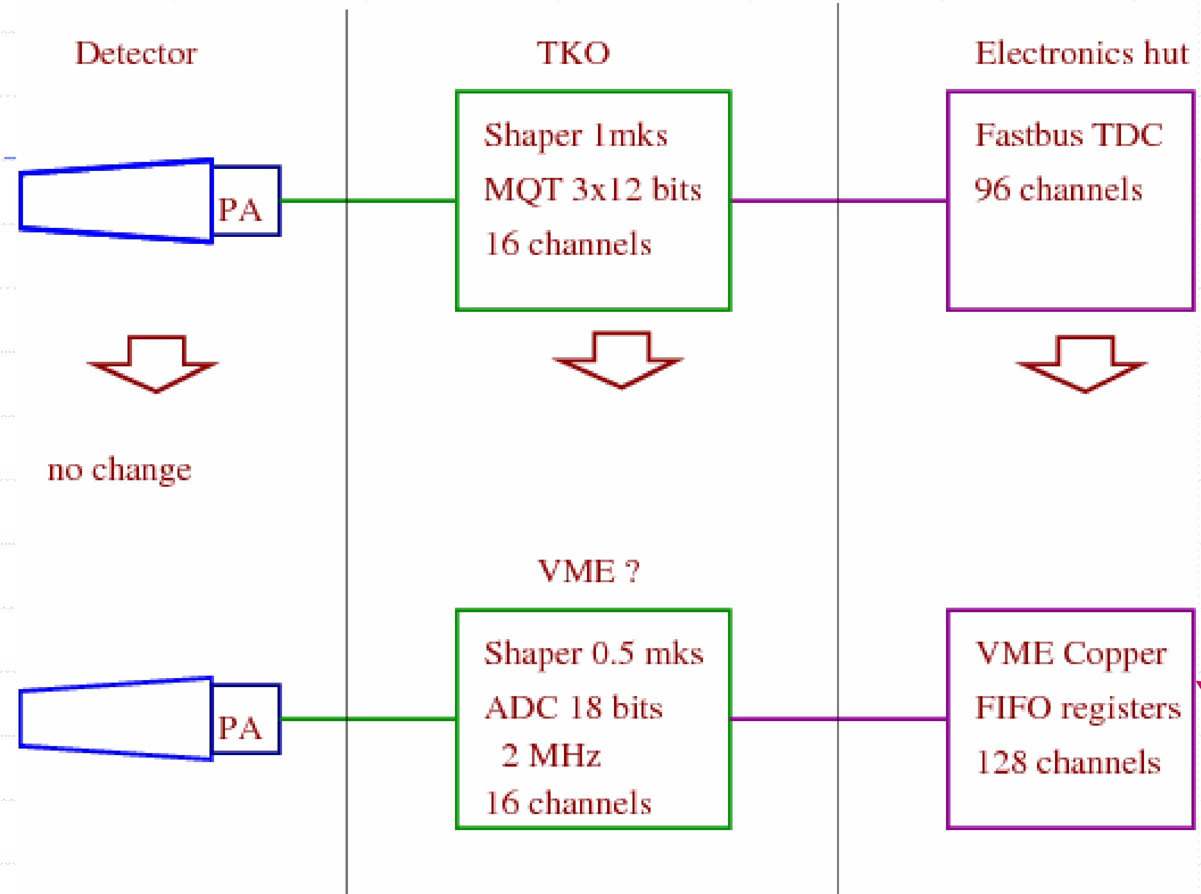
- **The prototype of the endcap calorimeter based on pure CsI counters with modified electronics was tested with a beam and provided the expected pile-up suppression.**

  - **More people are highly needed!**

- **We are waiting for a decision and budget to start the crystal and electronics production.**

back up

Electronics modication (barrel)



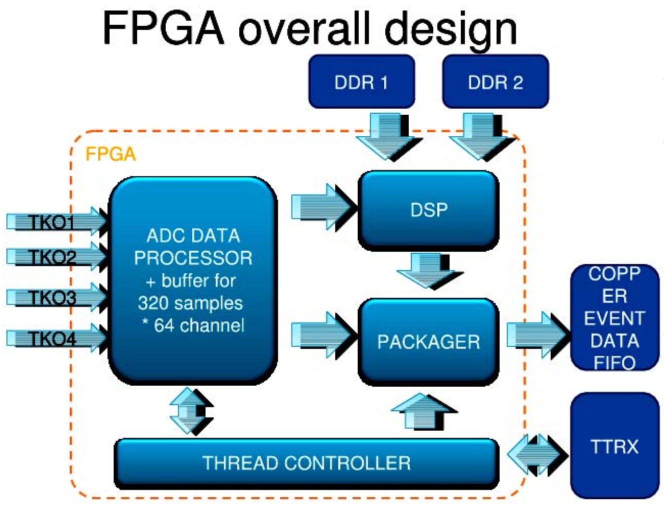
COmmon **P**ipelined **P**latform for **E**lectronics **R**edout,

Front-end **IN**strumentation **E**ntity for **S**ub-detector **S**pecific **E**lectronics

Contains boards (FINESSE) where the signal is processed

Present status: for both, shaper-digitizer and COPPER (with FINNESE), prototypes have been tested and the expected parameters have been obtained.

Parameters determination

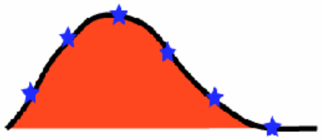


Algorithm details

$$\chi^2(A,p,t_0)=\sum_{i,j}\left(y_i-Af(t_i-t_0)-p\right)S_{ij}^{-1}\left(y_j-Af(t_j-t_0)-p\right)\to \min$$

$$S_{ij}=\overline{(y_i-\bar{y})(y_j-\bar{y})}$$

$f(t)$ – counter response



$$Af(t_i-t_1-\Delta t)=Af(t_i-t_1)-A\Delta t f'(t_i-t_1)=Af(t_i-t_1)+Bf'(t_i-t_1)$$

where t_1 – initial time (trigger time)

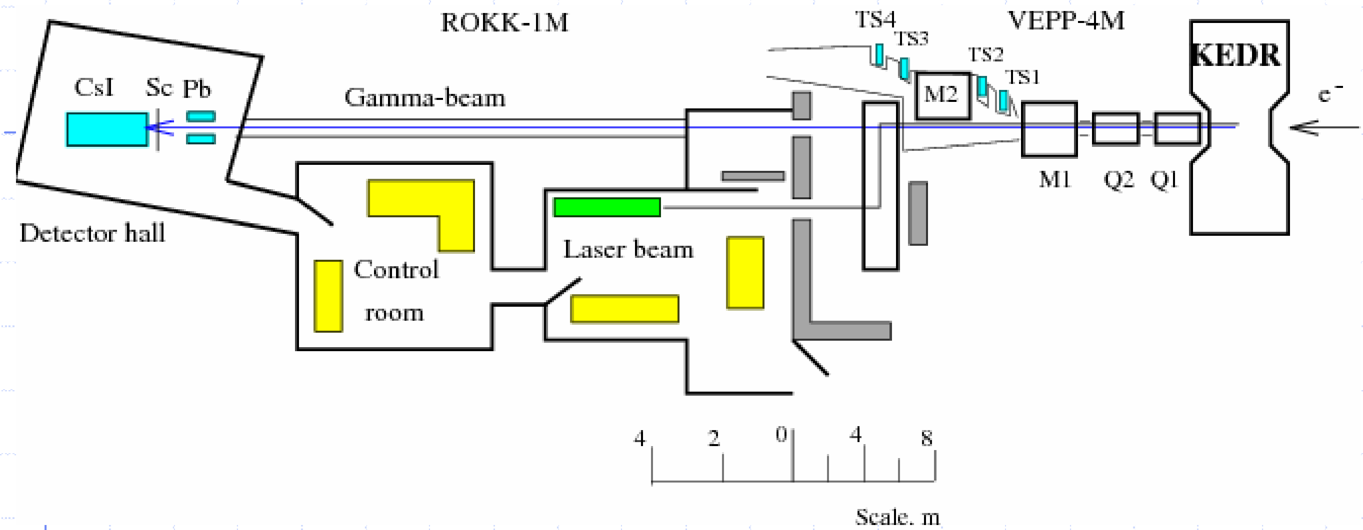
$$\begin{cases}\sum_{i,j} f_i S_{ij}^{-1}\left(y_j-Af_j-Bf'_j-p\right)=0\\ \sum_{i,j} f'_i S_{ij}^{-1}\left(y_j-Af_j-Bf'_j-p\right)=0\\ \sum_{i,j} S_{ij}^{-1}\left(y_j-Af_j-Bf'_j-p\right)=0\end{cases} \Rightarrow \begin{aligned} A&=\sum_i \alpha_i y_i\\ B&=\sum_i \beta_i y_i \Rightarrow \Delta t=-B/A\\ p&=\sum_i \gamma_i y_i\end{aligned}$$

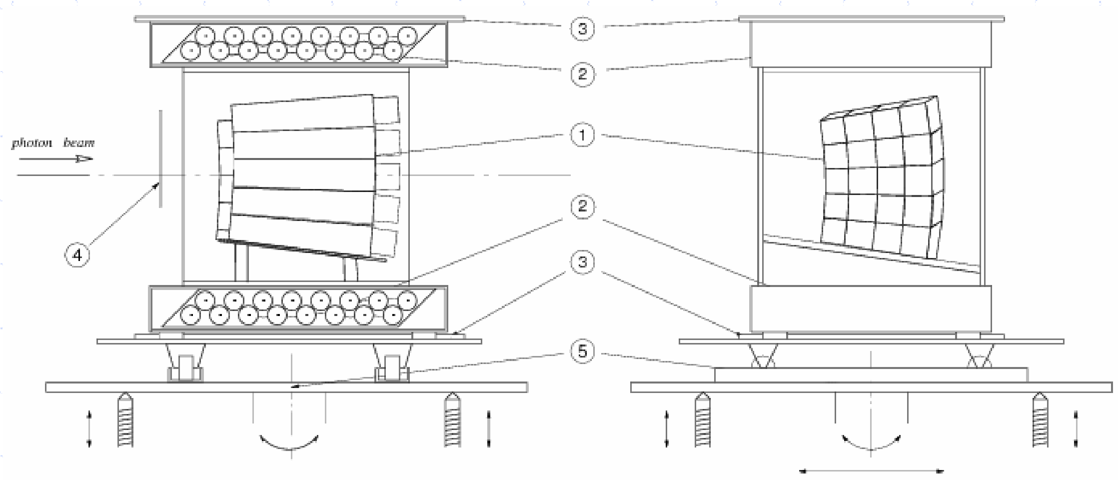
FPGA are located at FINNESE module
The algorithm of energy and time reconstruction was implemented.

The online software allows:

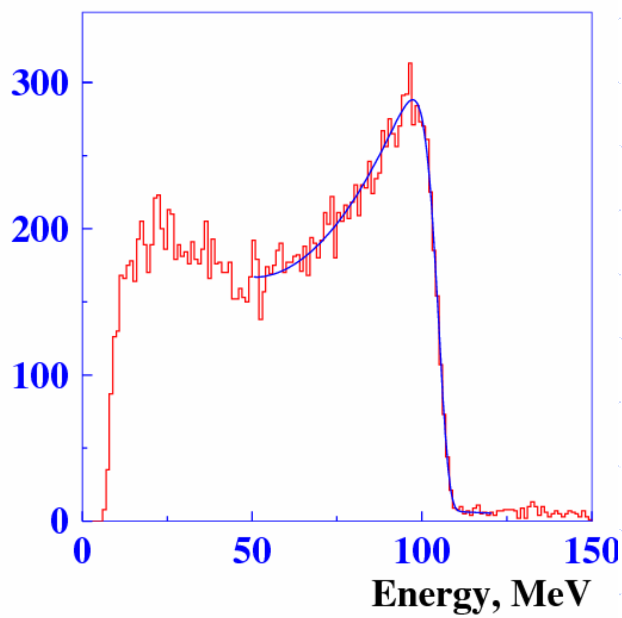
- ✓ To set preliminary sparsification threshold (before FPGA processing);
- ✓ To set output sparsification threshold (after FPGA processing), before recording to
- ✓ COPPER buffer;
- ✓ To record amplitude, time and quality, reconstructed at FPGA;
- ✓ To save raw sample informatin (amplitudes of 16 points) for each or some fraction of events.
- ✓ ~~According to simulation the algorithm works upto 50 kHz with occupancy < 1=3.~~

Beam test at BINP

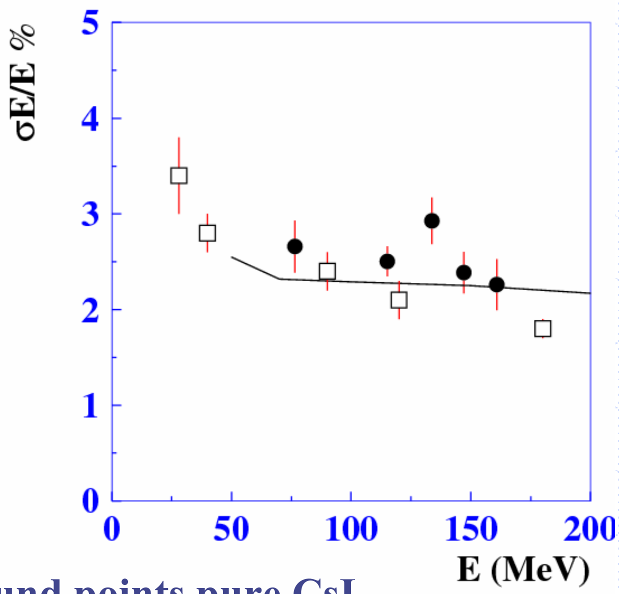




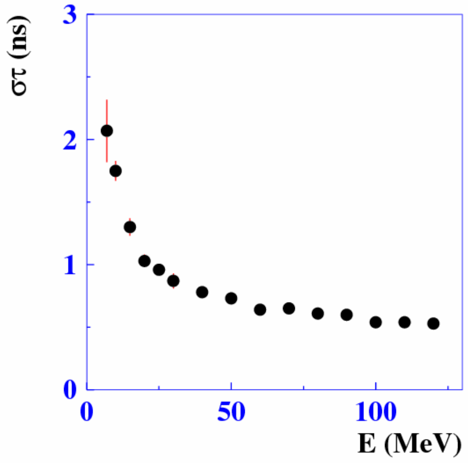
Energy and time resolution results.



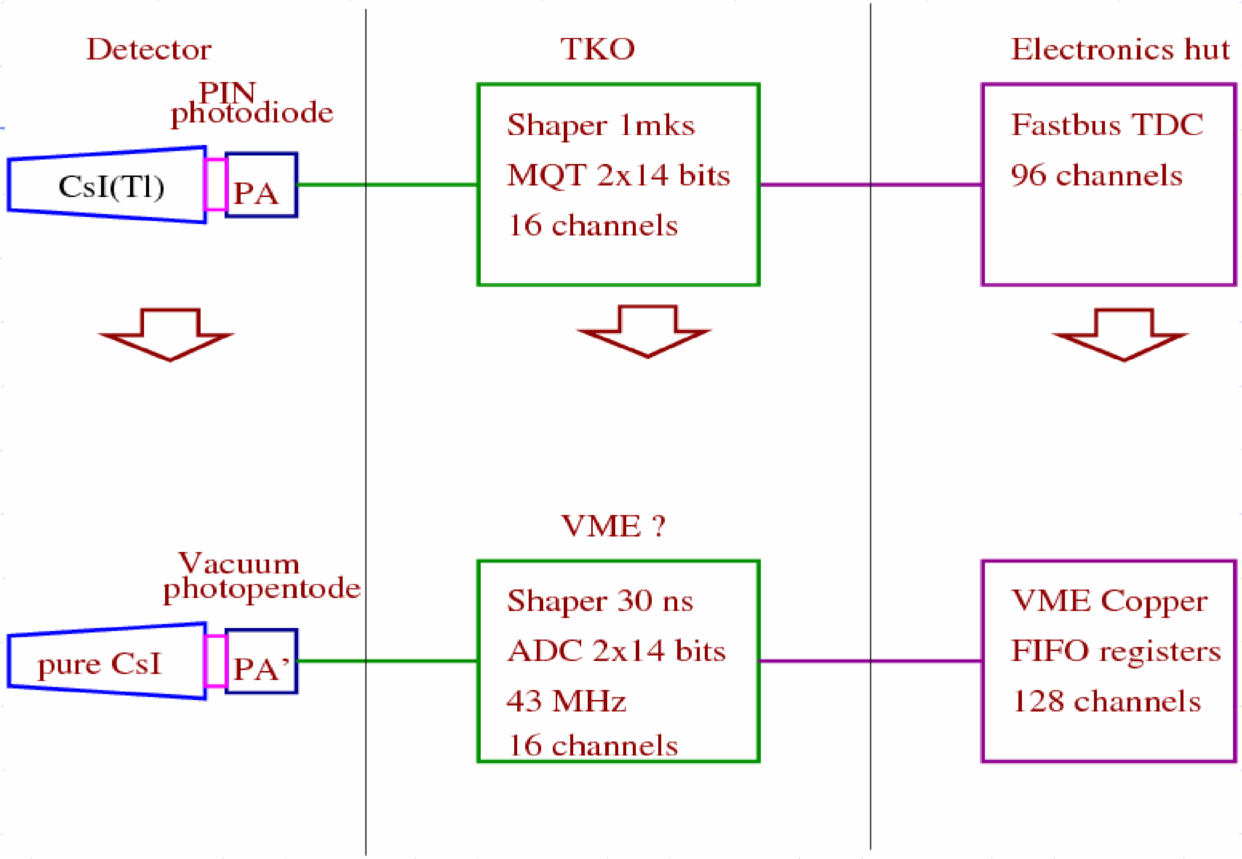
The distributions are fit by convolution of the Compton spectrum and logarithmic-Gaussian.



-round points pure CsI
-solid line MC
-rectangles CsI(Tl) beam test



Electronics modication(endcap)



Present status: modules were developed and first prototypes have been tested

Summary of the new electronics tests and plans

- System works and allows to record data from COPPER
- The data evaluated by FINNESSE are consistent with that taken by the old electronics
- The recorded data shows parameters close to expected.
- Data quality vs. injection time are studied. A decrease of veto gate looks to be possible.

Plans:

- Further study pile-up noise suppression
- To analyse data with sampling storage to get information about time noise correlation, as well as fit procedure and hardware reliability.
- To analyse run without injection veto.
- Implementation of the data from the new electronics to the standard data processing procedures: cluster reconstruction, Bhabha calibration etc.