Calorimeter for c-τ -factory based on pure CsI crystals.

May 13, 2010

A.Kuzmin

Outline:

- Pure CsI
- Belle calorimeter
- Photodetectors
- Beam test
- Radiation tests
- Calorimeter design
- Electronics
- Summary

- **To detect photons and measure their energy and coordinates from 10 MeV upto 4 GeV**
  - **Thick enough active material to have good energy resolution in wide energy range**
  - **Fast scintilator to have small pile-up noise**
  - **Good time resolution to suppress beam background**
  - **As thin passive material in front of the calorimeter as possible**
- e/**hadron-separation**

Background?

Similar to B-factory: 1.5 $A \times 1.5\ A$ 3.5, 8 GeV

Crystals with short decay time.

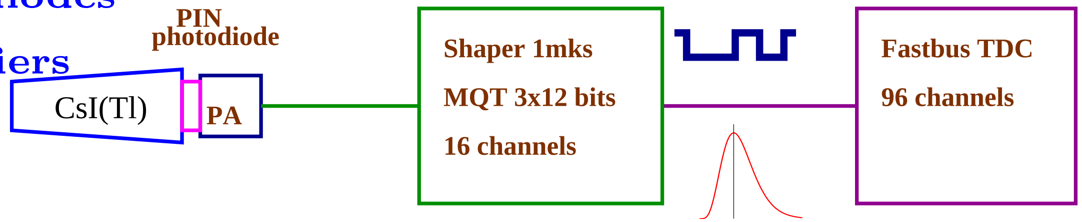
crystal	ρ, g/cm^3	X_0, cm	λ_{em}, nm	n	N_{ph}/MeV	τ, ns
CsI(Tl)	4.51	1.86	550	1.8	52000	1000
CsI	4.51	1.86	305/400	2	5000	30/1000
BaF_2	4.89	2.03	220/310	1.56	2500/6500	0.6/620
CeF_3	6.16	1.65	310	1.62	600	3
$PbWO_4$	8.28	0.89	430	2.2	25	10
$LuAlO_3$(Ce)	8.34	1.08	365	1.94	20500	18
$Lu_3Al_5O_{12}$(Ce)	7.13	1.37	510	1.8	5600	60
Lu_2SiO_5(Ce)	7.41	1.2	420	1.82	26000	12/40

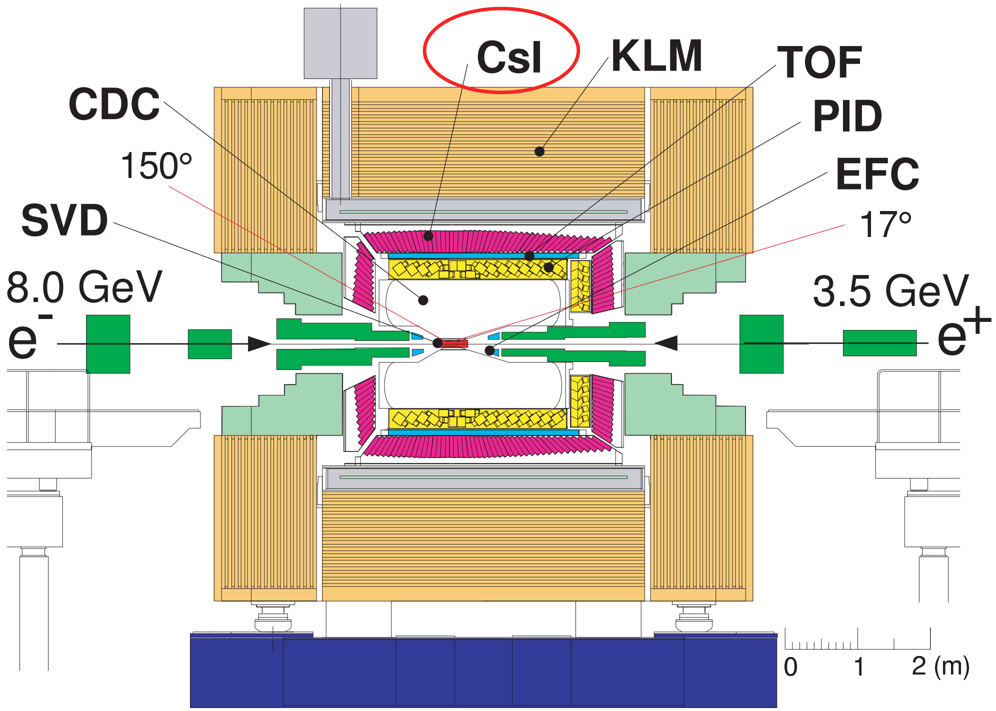
$LuAlO_3$(Ce) and Lu_2SiO_5(Ce) are good but very expensive.

Pure CsI scintillator has shorter decay time and is a good candidate as material for the Belle endcap calorimeter.

Additional test with pure CsI

- Crystals 300x(50-80)x(50-80) mm
- Wrapping 200μm teflon+50 μm Al mylar
- Readout 2 10x20 mm PIN diodes
- 2 charge sensitive preamplifiers
- Shaper CR-(RC)^4, τ=1μs
- Lightoutput 5000 p.e./MeV
- Electronic noise $1000e \approx 200$ keV





- Calorimeter based on CsI(Tl) scintillating crystals
- Thickness – 16.1 X_0(30 cm)
- Calorimeter is inside magnetic coil
- CDC+ACC is about 0.3 X_0
- 8736 counters (40 tons of CsI(Tl))

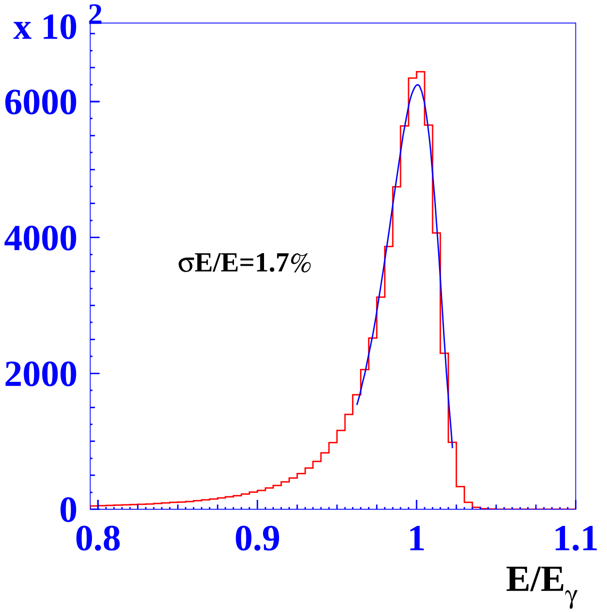
ECL performance

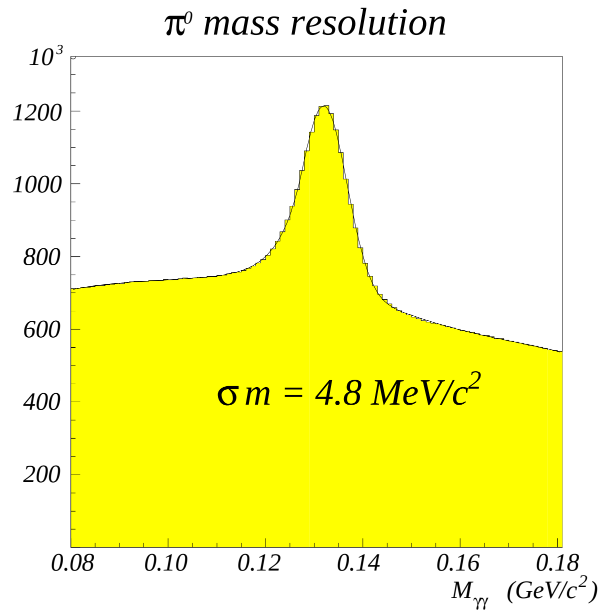
- Calorimeter has succefully been working for 10 years
- Only one channel died during this period
- Good performance

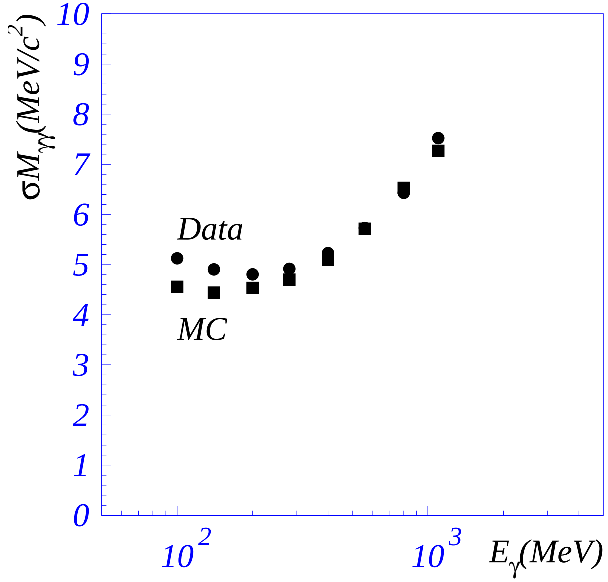
π^0 mass resolution

$m^2 = 2E_{\gamma 1}E_{\gamma 2}(1 - \cos\psi)$

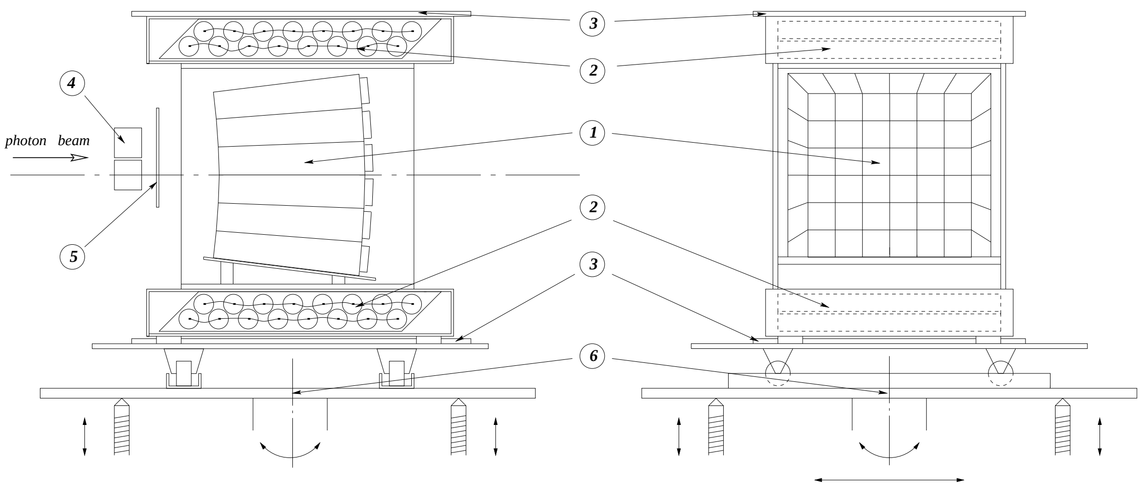
$e^+e^- \to \gamma\gamma$

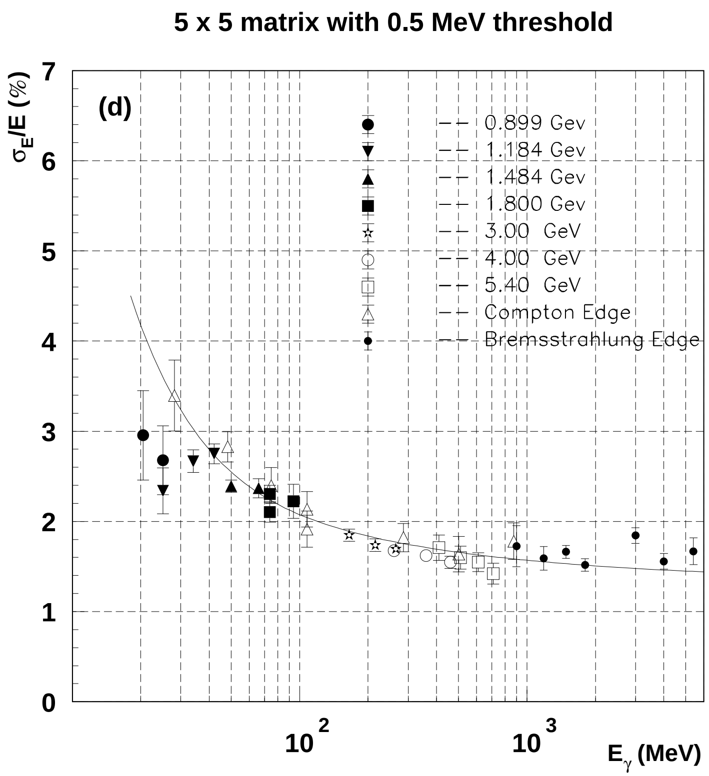






Test photon beam.





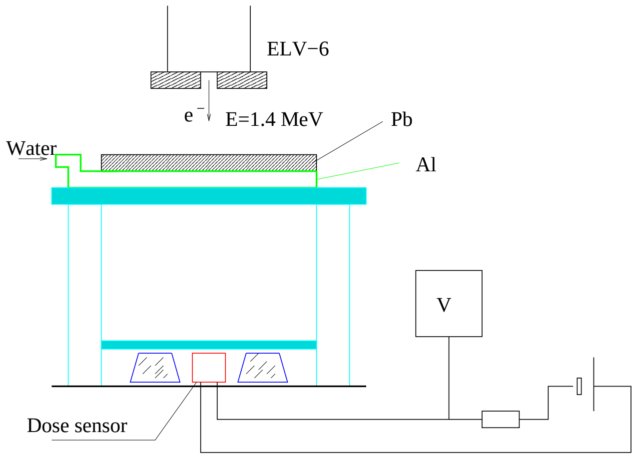
$$\frac{\sigma E}{E} = \frac{0.066(\%)}{E} \oplus \frac{0.81(\%)}{E^{1/4}} \oplus 1.39(\%)$$

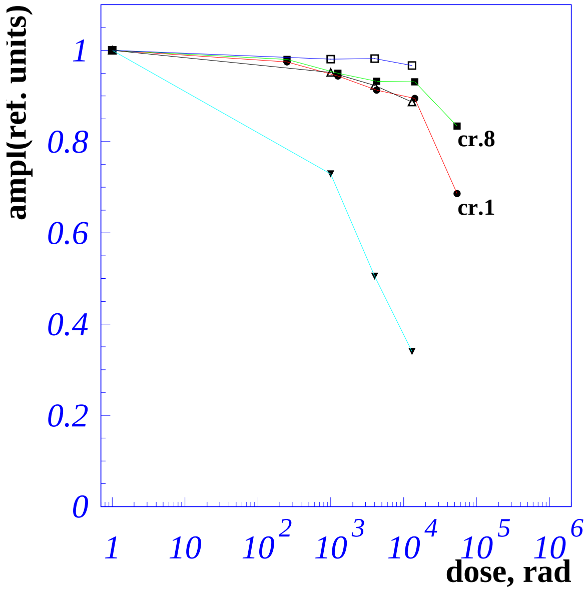
Radiation hardness test with photons.

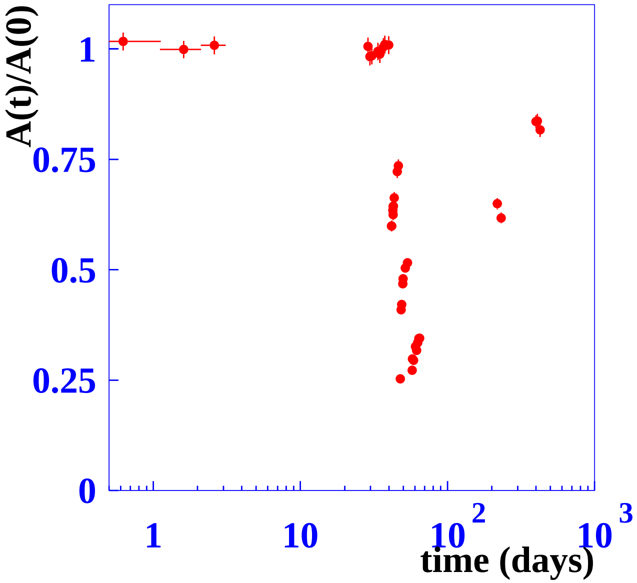
- **Radiation hardness of 4 pure CsI crystals and one counter (pure CsI crystal+ photopentode) were tested with γ-quantum irradiation.**
- **For 15 krad dose the degradation of the lightoutput for 3 crystals and counter was less than 10%, but one counter about 60%. However it was recovered for about 80% within an year.**

Bremsstrahlung γ ($E_\gamma < 1.4\ MeV$)

Dose 0.250, 1 , 4 , 10 , 30 krad







Pure CsI crystals were irradiated by neutrons.
Neutron irradiation up to $10^{12} cm^{-2}$ did not reveal a degradation within 5%.

Photodetector

Requirements for photodetectors

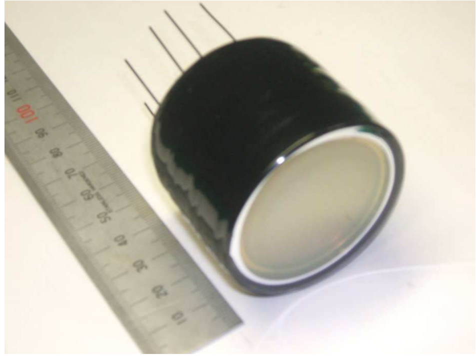
- UV-sensitive
- large sensitive area
- low capacity($\sigma_{noise} \sim \frac{C}{\sqrt{\tau}}$)
- gain factor more than 30 in magnetic field
- good stability, compact, not expensive...

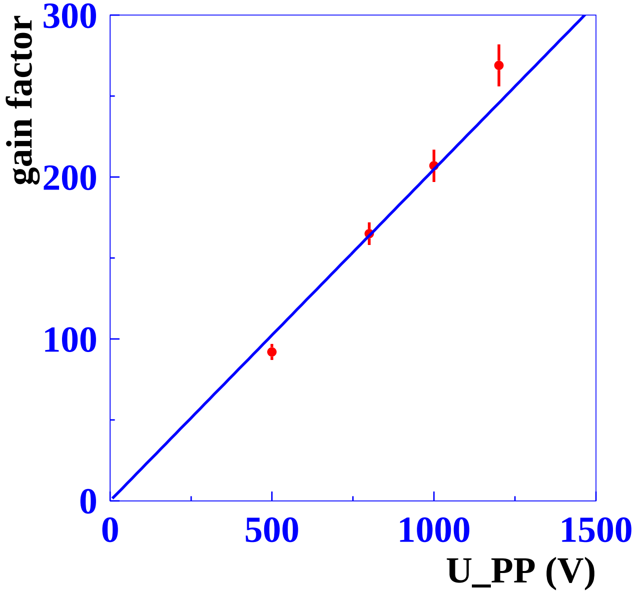
CsI(Tl) → pure CsI

- Lightoutput ten times less
- Decay time 30 ns
- 300 nm – UV-light

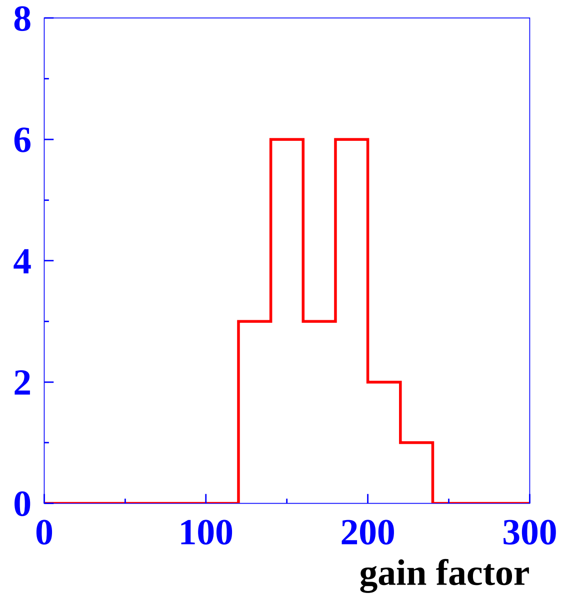
PIN diode - large noise/signal
APD - large noise/signal due to capacity

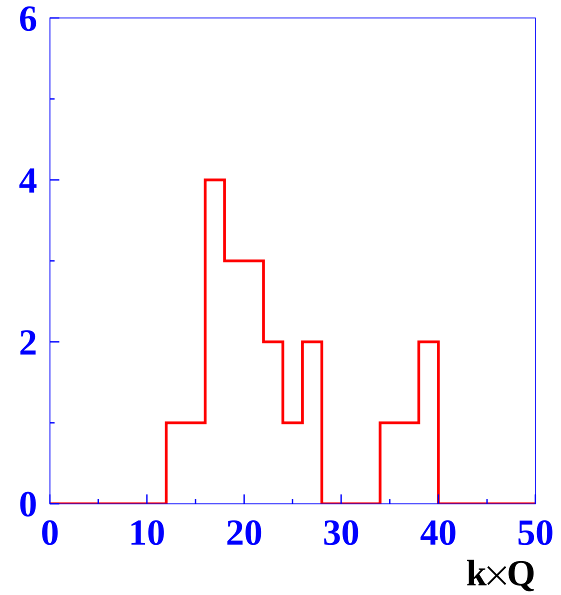
Hamamatsu developed the 2' UV sensitive phototriodes, phototetrodes, photopentods $C \approx 10\ pF$.
Dependence of gain factor on voltage is close to linear.

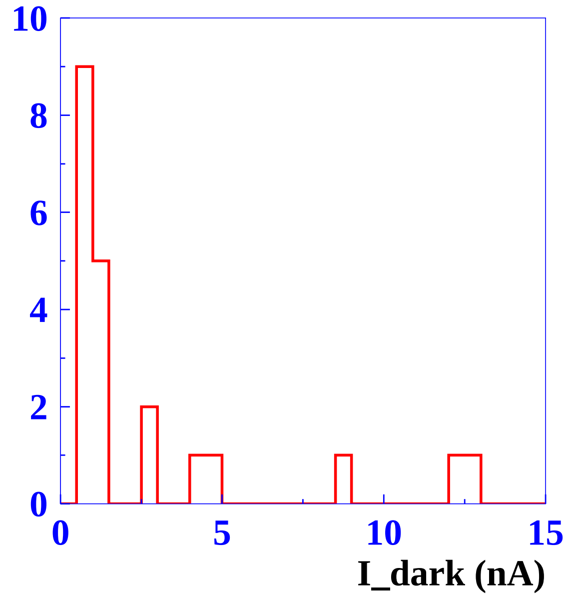


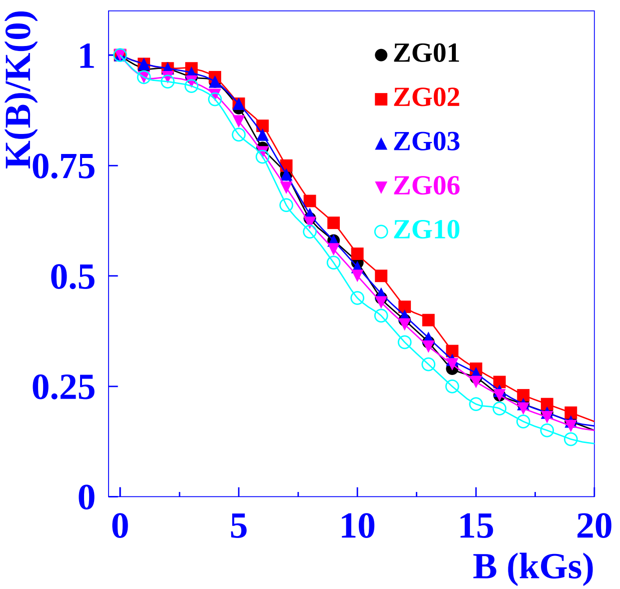


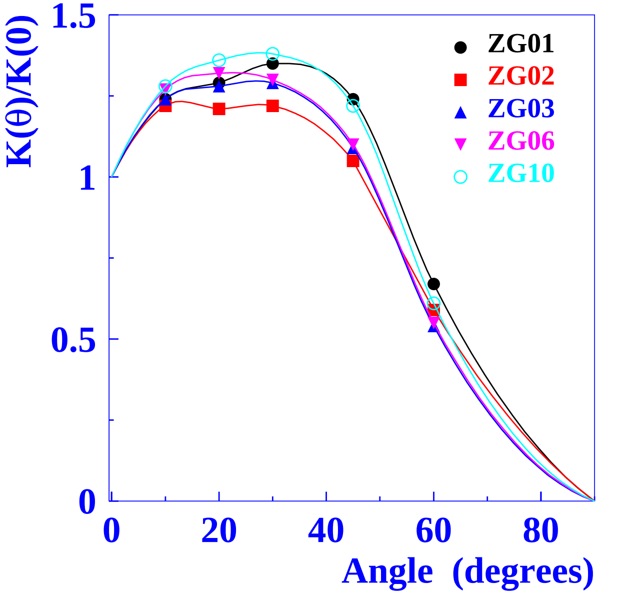
Magnetic field



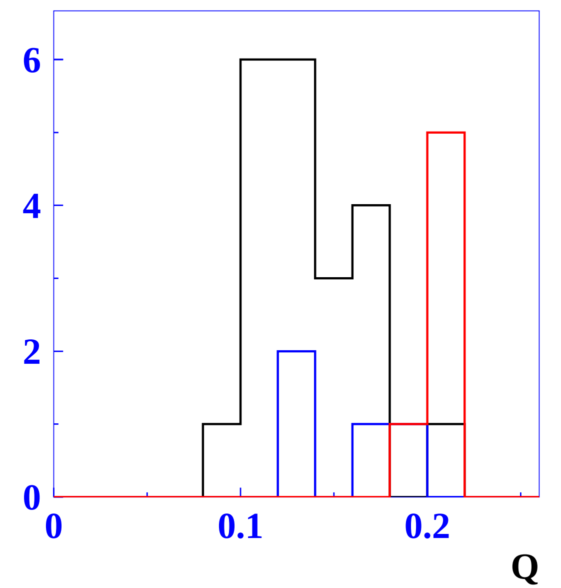


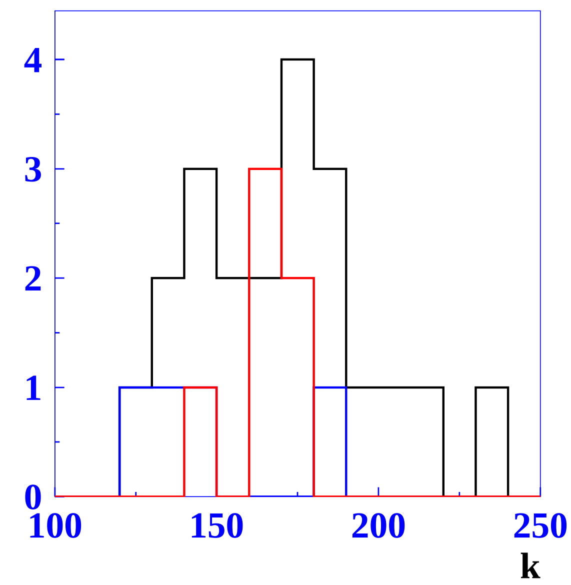


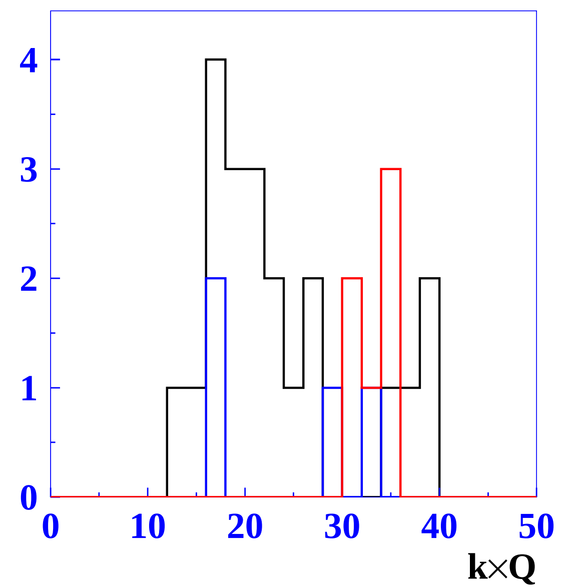


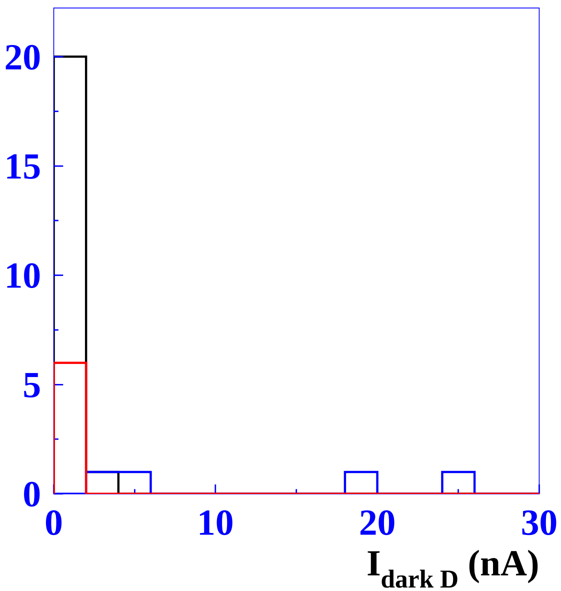


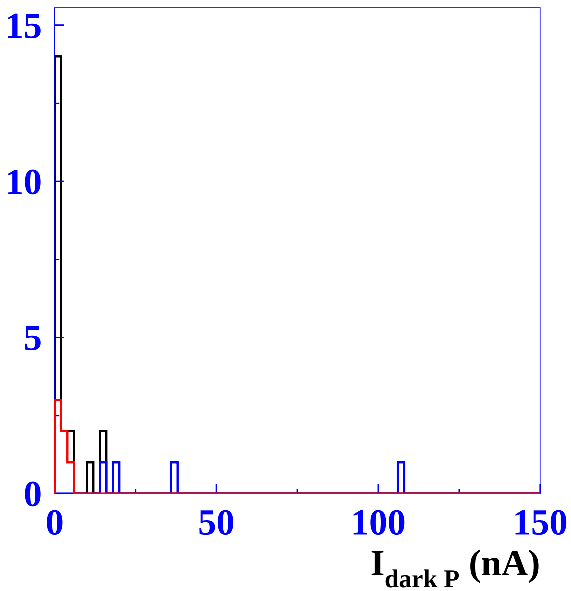
- Gain factor without magnetic field is 150-250
- The gain factor drops down ∼3.5 times for B=15 kGs
- About 20-30 % improvement for angle 20-45°









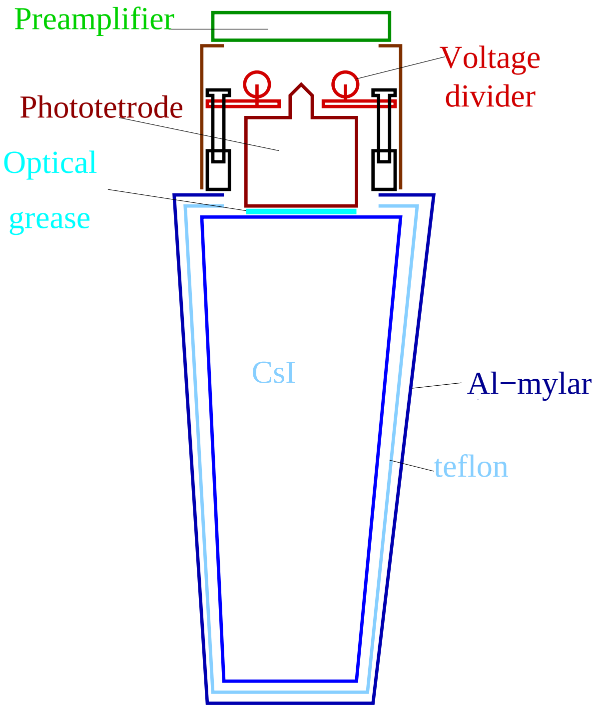


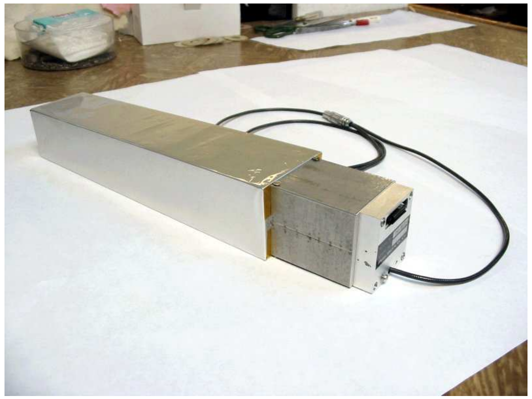
New High quantum efficiency photodetectors

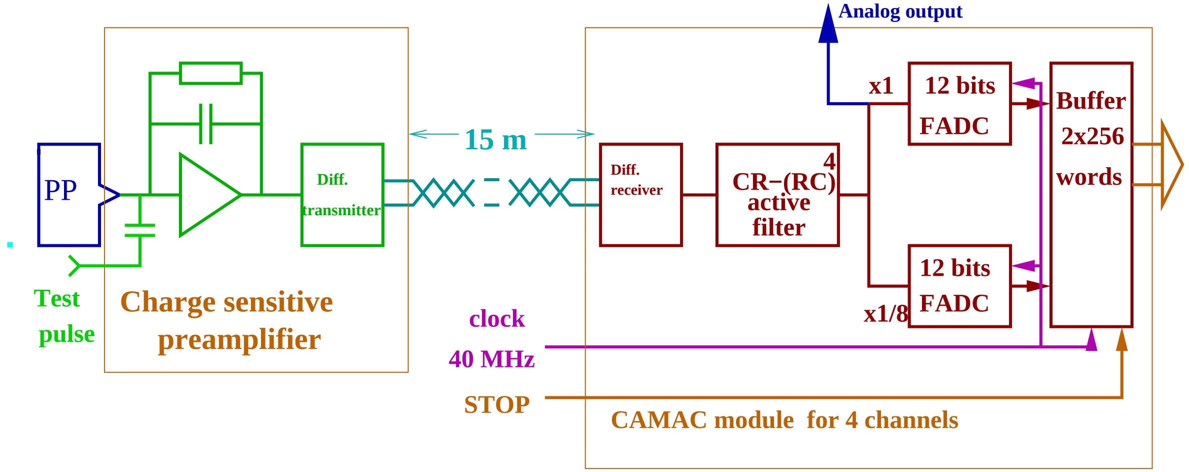
4 pcs produced in June 2009

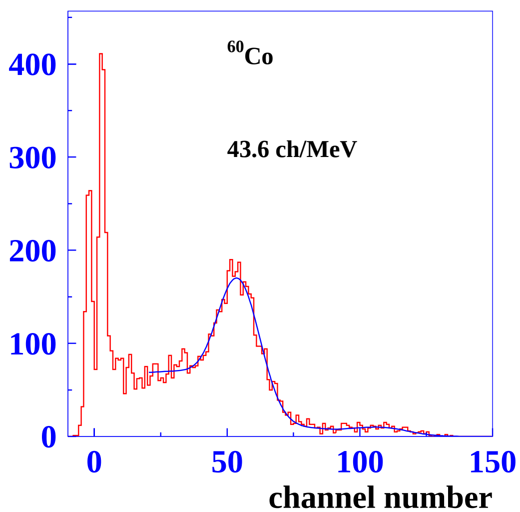
6 pcs produced in July 2009

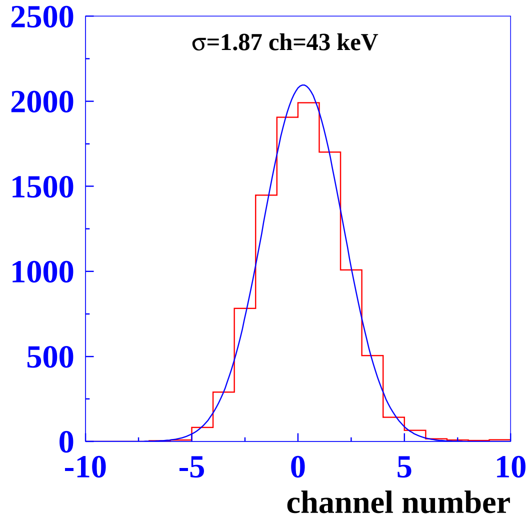
Counters design





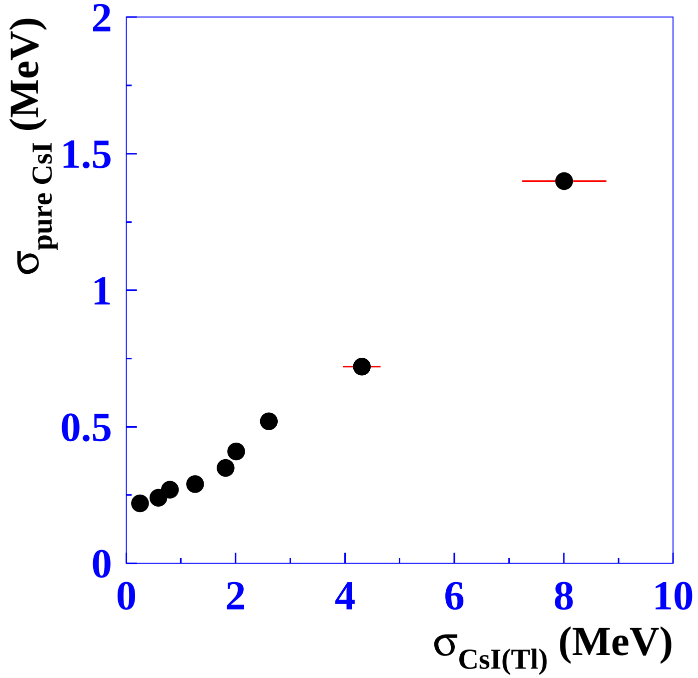




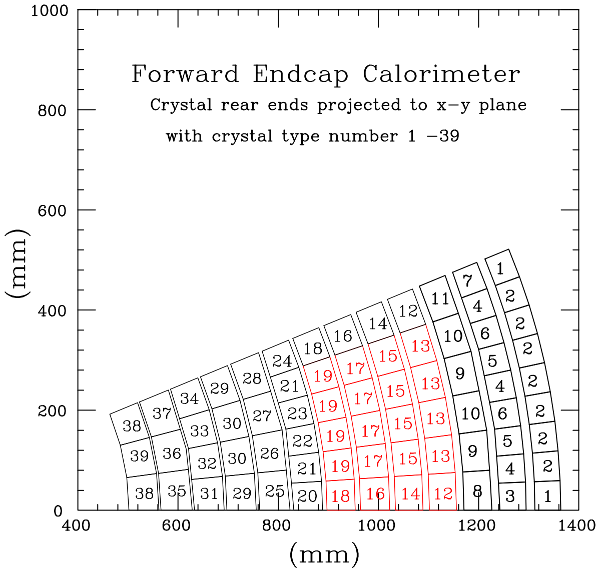


Pileup noise measurement.

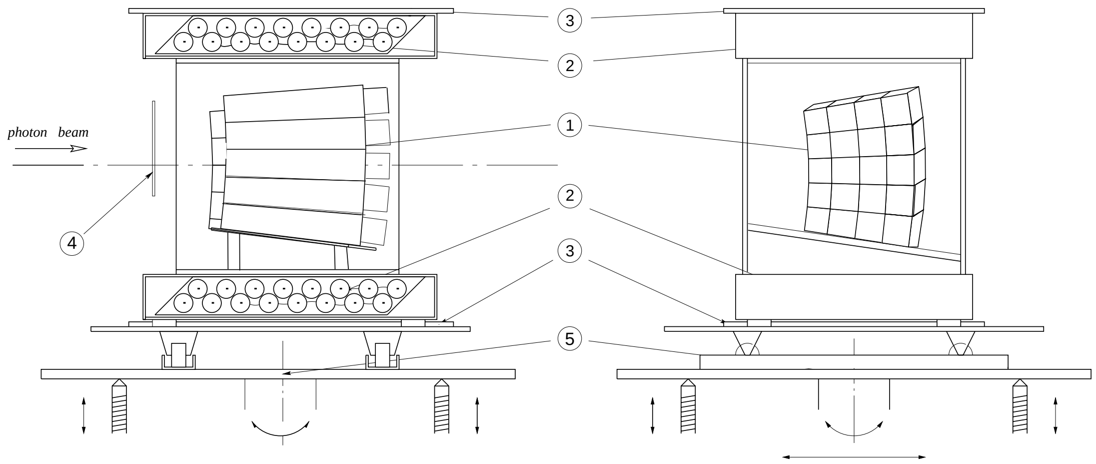
- **Pile-up noise was imitated by $^{60}Co(E_\gamma = 1.17/1.33\ MeV)$ at different distances from counters.**
- **The pure CsI counter with new electronics and CsI(Tl) Belle counter were tested**
- **The measurements are in agreement with estimations: pileup noise of pure CsI is factor 5.5 less than for Tl doped crystals.**



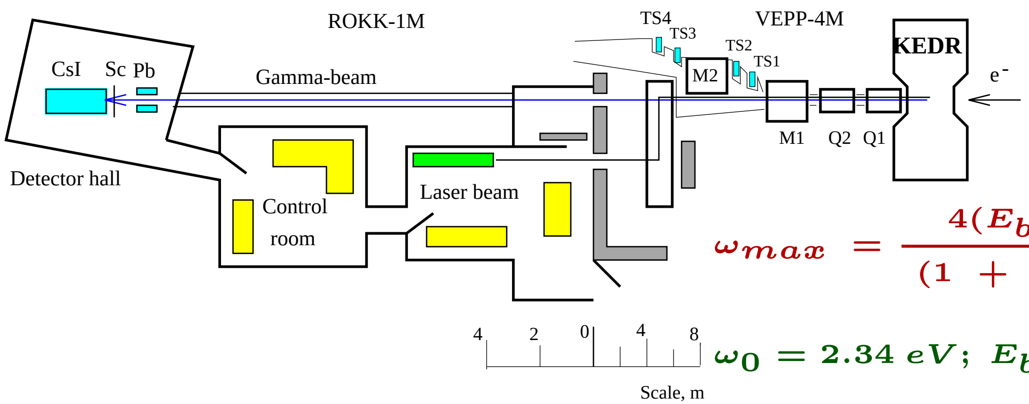
Beam test



20 crystals of 8 geometrical types(part of FWD) produced in Kharkov, coupled with Hamamatsu phototetrodes.



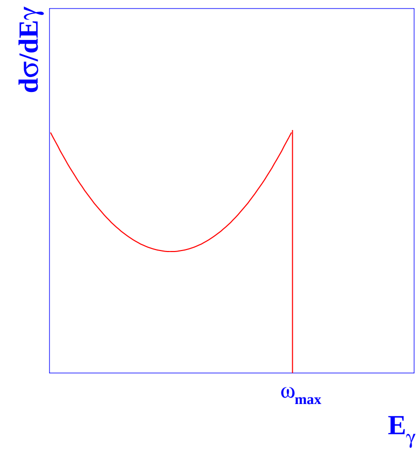
ROKK-1M at Novosibirsk



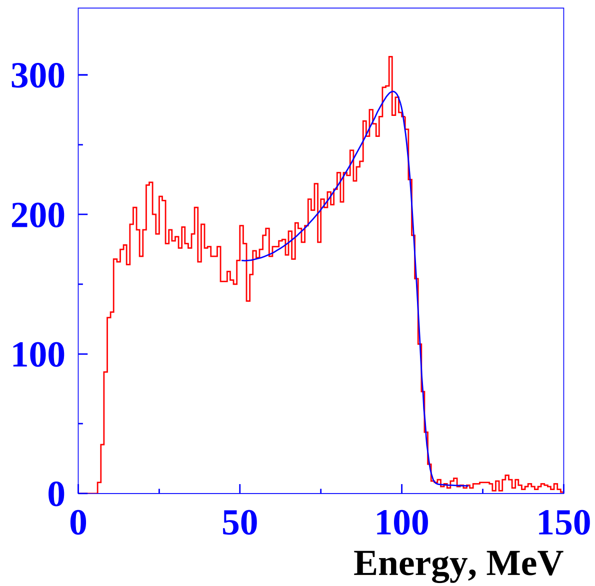
$$\omega_{max} = \frac{4(E_{beam}/m_e)^2\omega_0}{(1 + 4E_{beam}\omega_0/m_e^2)}$$

$$\omega_0 = 2.34\ eV;\ E_{beam} = 1.5 \sim 2.2\ GeV;$$

$$\omega_{max} = 70 \sim 160\ MeV$$

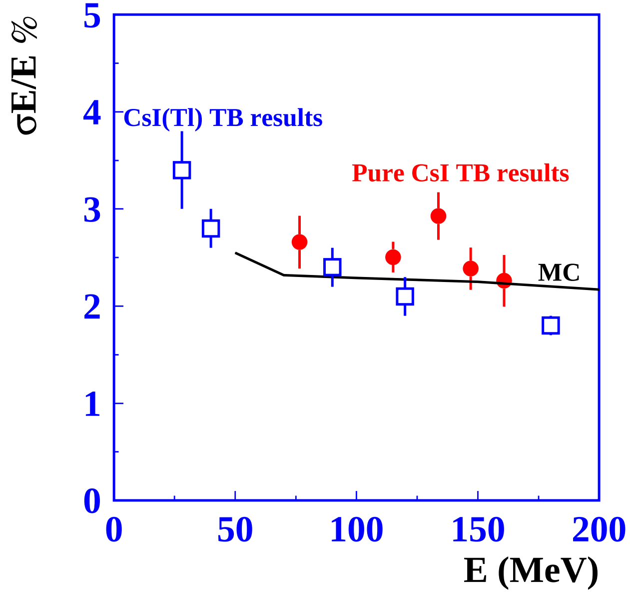


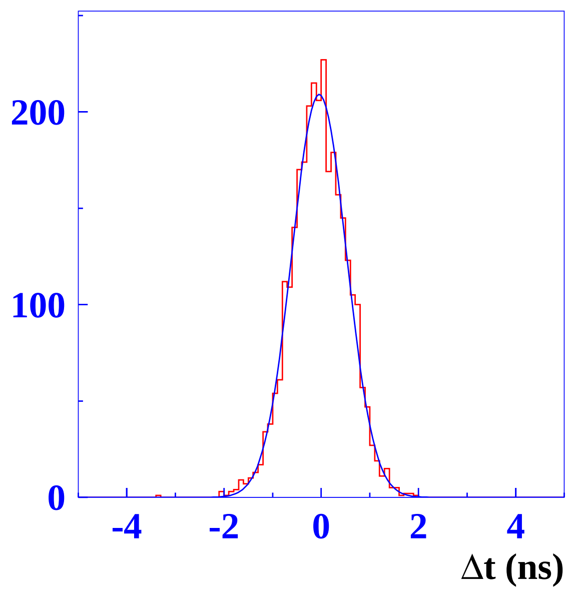
Beam test results.



Energy resolution is obtained from fit of the distributions by convolution of the Compton spectrum and logarithmic-Gaussian(σ).

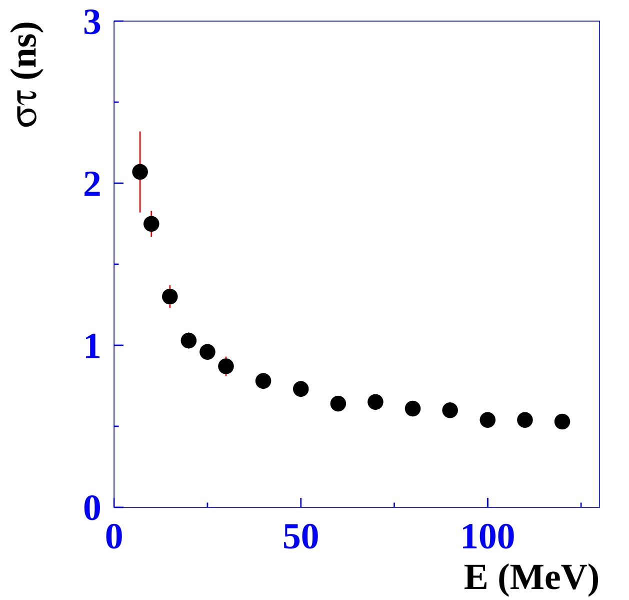
Energy resolution is consistent with MC and previous beam test results.





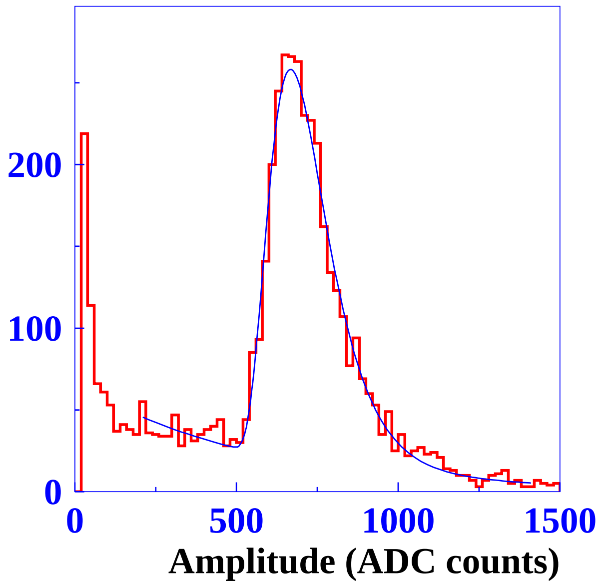
Time resolution

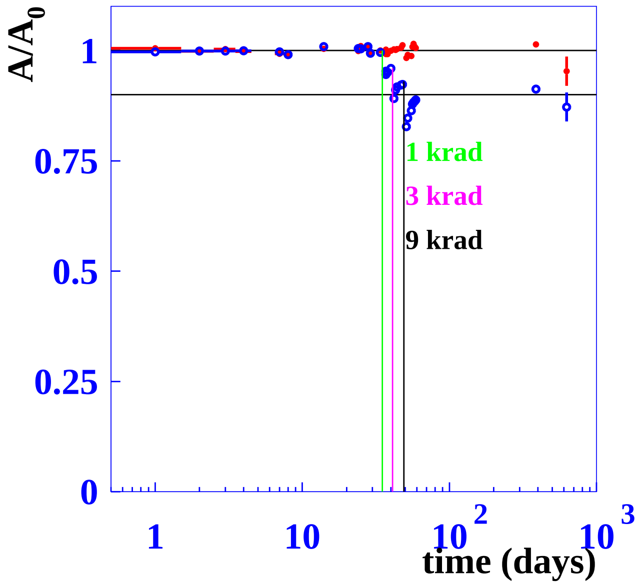
Wave form analysis allows to determine time with accuracy better then 1 ns for $E >$ 20 MeV(60 MeV in magnetic field).



Long-term stability

- Two counters (one which was irradiated) have been monitered for two years.
- Peak corresponding to cosmic energy deposition was measured.

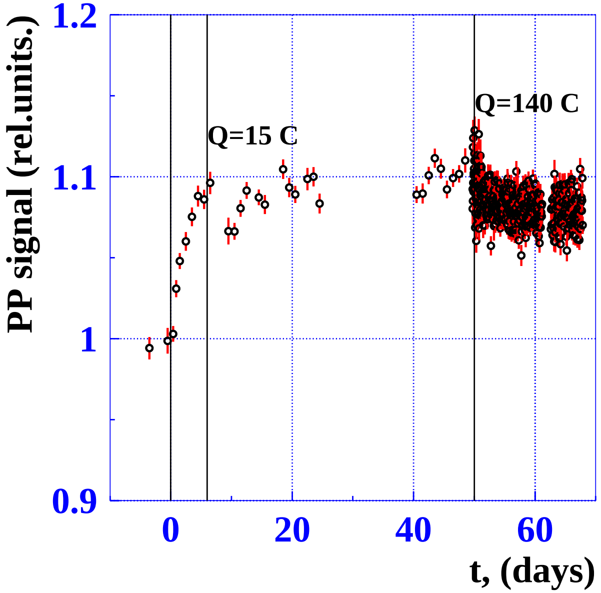




- The counter is stable within 2%.
- More long term study of Photopentodes in magnetic field is necessary.

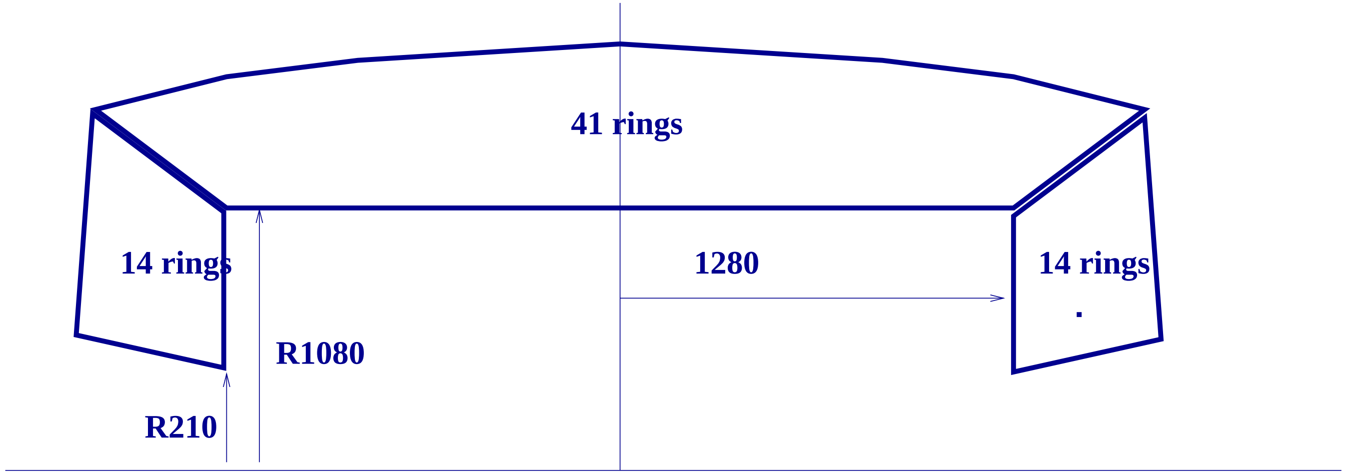
Long-term stability of PP depending on light illumination

- Counter was illuminated by LED to simulate 1 kRad/year
- Cosmic peak position was measured depending on the collected integral.



- No essential degradation up to 140 Q was observed

Possible $c = \tau$ Calorimeter design.



Crystal size: truncated pyramid with small size $\sim 5.5 \times 5.5\ cm^2$ and lenghth 30 cm (16.1 X_0)

In barrel it will correspond to 41 rings with 128 crystals in each of 21 types.

total barrel:= 5248 weight $\sim 26t$.

Endcaps: 14 rings($3 \times 128 + 4 \times 96 + 3 \times 64 + 2 \times 48 + 2 \times 32$

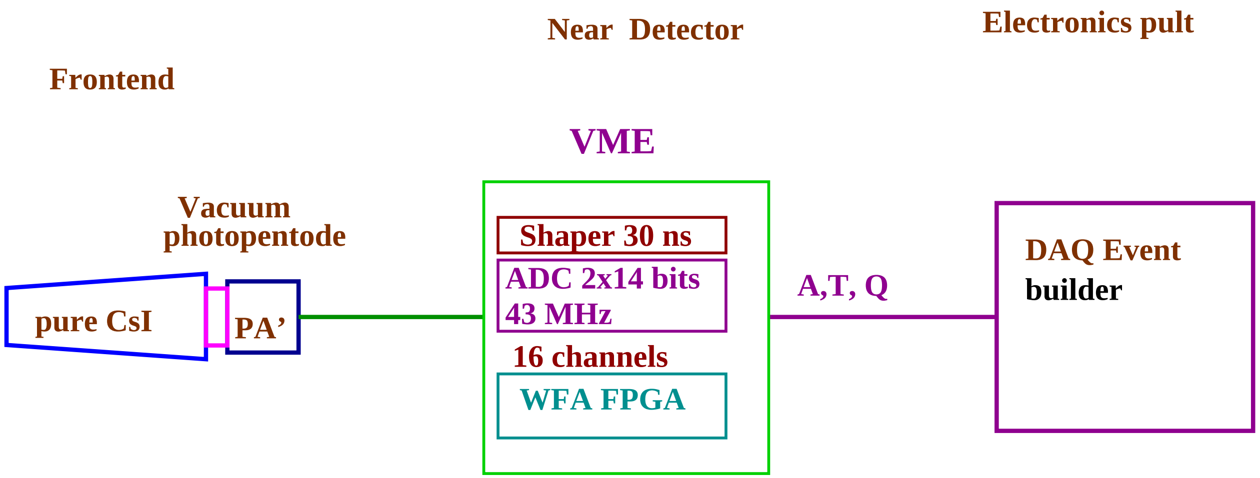
total endcaps: $= 1120 \times 2$ weight 5 $t \times 2$

Total: 7488 counters, 36 t. $\sim 35 M\$$

PP: 7488 $\sim 7\ M\$$

Electronics: 7488 channels $\sim 4\ M\$$

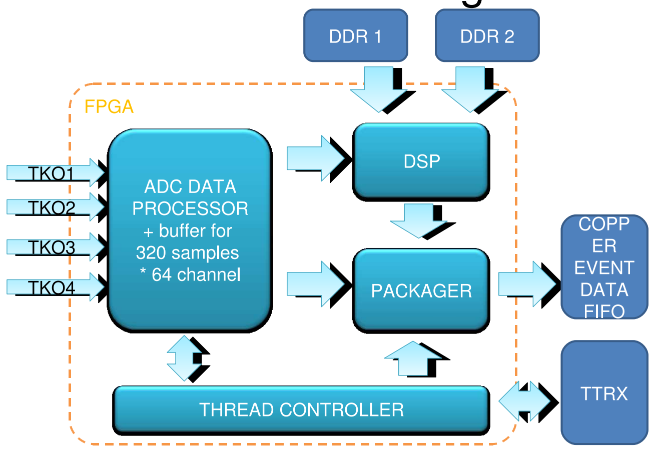
Electronics



- Belle II-like electronics
- Preamplifiers are located at counters
- Shaping, digitizing and fitting are done in Shaper DSP module located nearby detector
- Shaper $\tau = 30ns\ CR + (RC)^4$ (Integration active Bessel filter)
- Amplitude, Pedestal and time are fitted in FPGA

FPGA Electronics

FPGA overall design

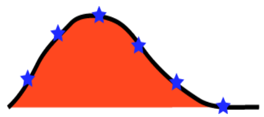


Algorithm details

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

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

$f(t)$ – counter response

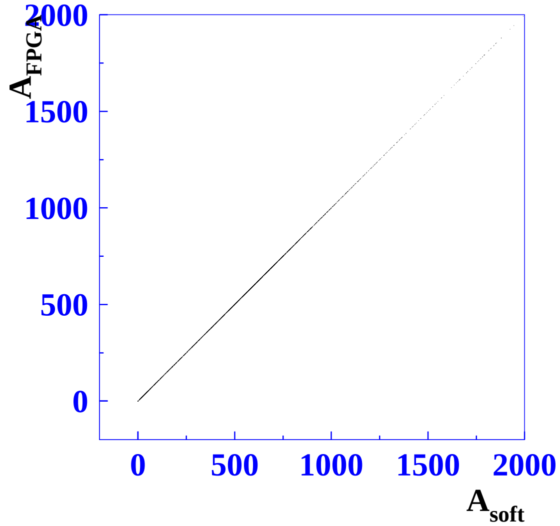


$$Af(t_i-t_1-\Delta t)=Af(t_i-t_1)-A\Delta t f'(t_i-t_1)=Af(t_i-t_1)+Bf'(t_i-t_1)$$

where t_1 – initial time (trigger time)

$$\sum_{i,j} f_i S^{-1}_{ij}\left(y_j-Af_j-Bf'_j-p\right)=0$$
$$\sum_{i,j} f'_i S^{-1}_{ij}\left(y_j-Af_j-Bf'_j-p\right)=0$$
$$\sum_{i,j} S^{-1}_{ij}\left(y_j-Af_j-Bf'_j-p\right)=0$$

$$A=\sum_i \alpha_i y_i$$
$$B=\sum_i \beta_i y_i \Rightarrow \Delta t=-B/A$$
$$p=\sum_i \gamma_i y_i$$



Tested with Belle calorimeter

Summary

- **Pure CsI + PP counters is a good candidate for $c-\tau$-factory calorimeter which provide high energy and position resolution**
- **Belle-II-type electronics can be adopted for this calorimeter**
- **The calorimeter provides good time resolution and can work in the high occupancy conditions.**