PhotoDet 2015
International Conference on New Photo-detectors
July 6-9, 2015, Moscow, Troitsk, Russia

Belle II

東京大学
THE UNIVERSITY OF TOKYO

Study of scintillation counter consisting of a pure CsI crystal and APD

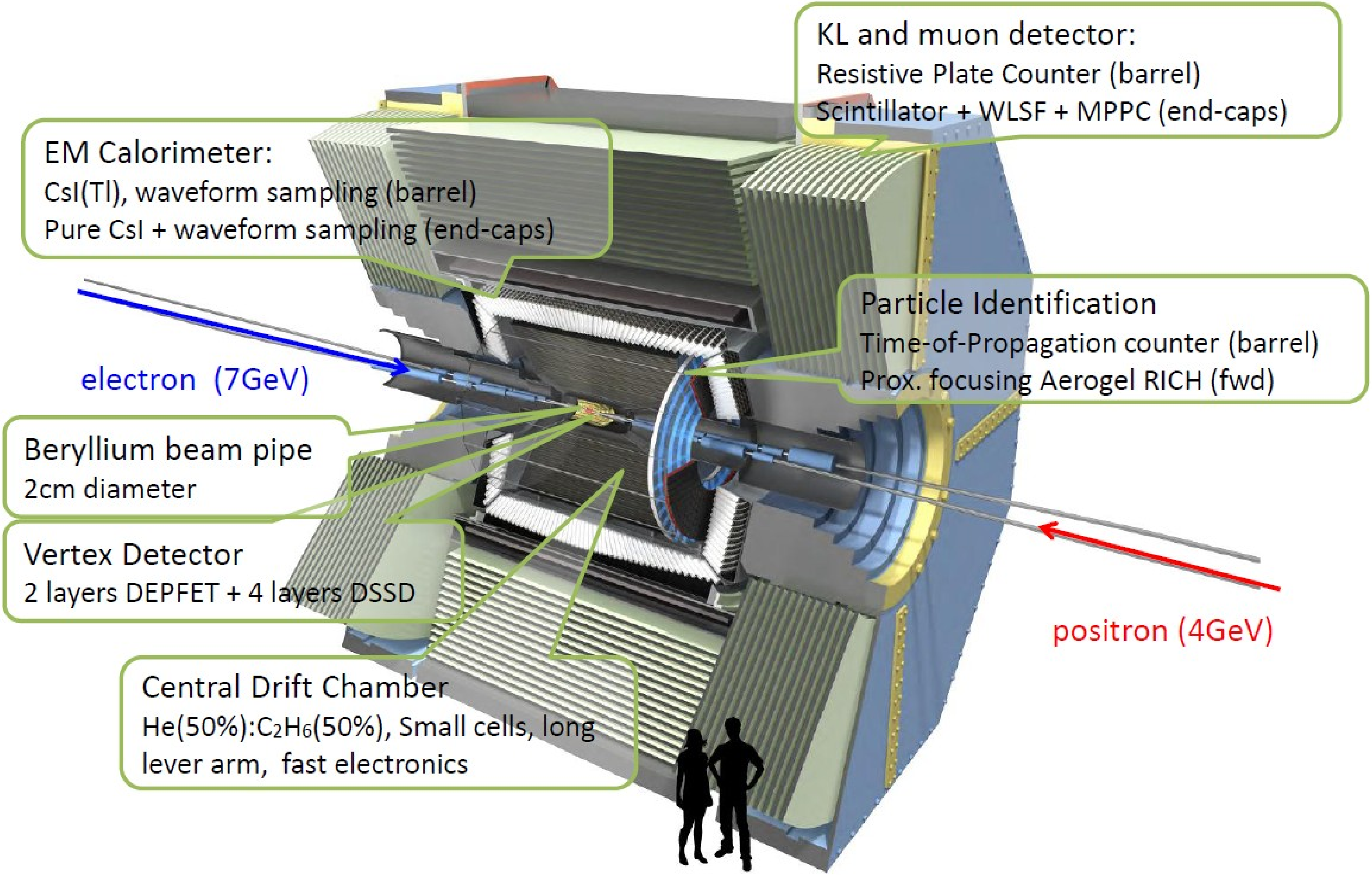
D. Epifanov (The University of Tokyo)
on behalf of Belle II collaboration
July 9th, 2015

Outline:

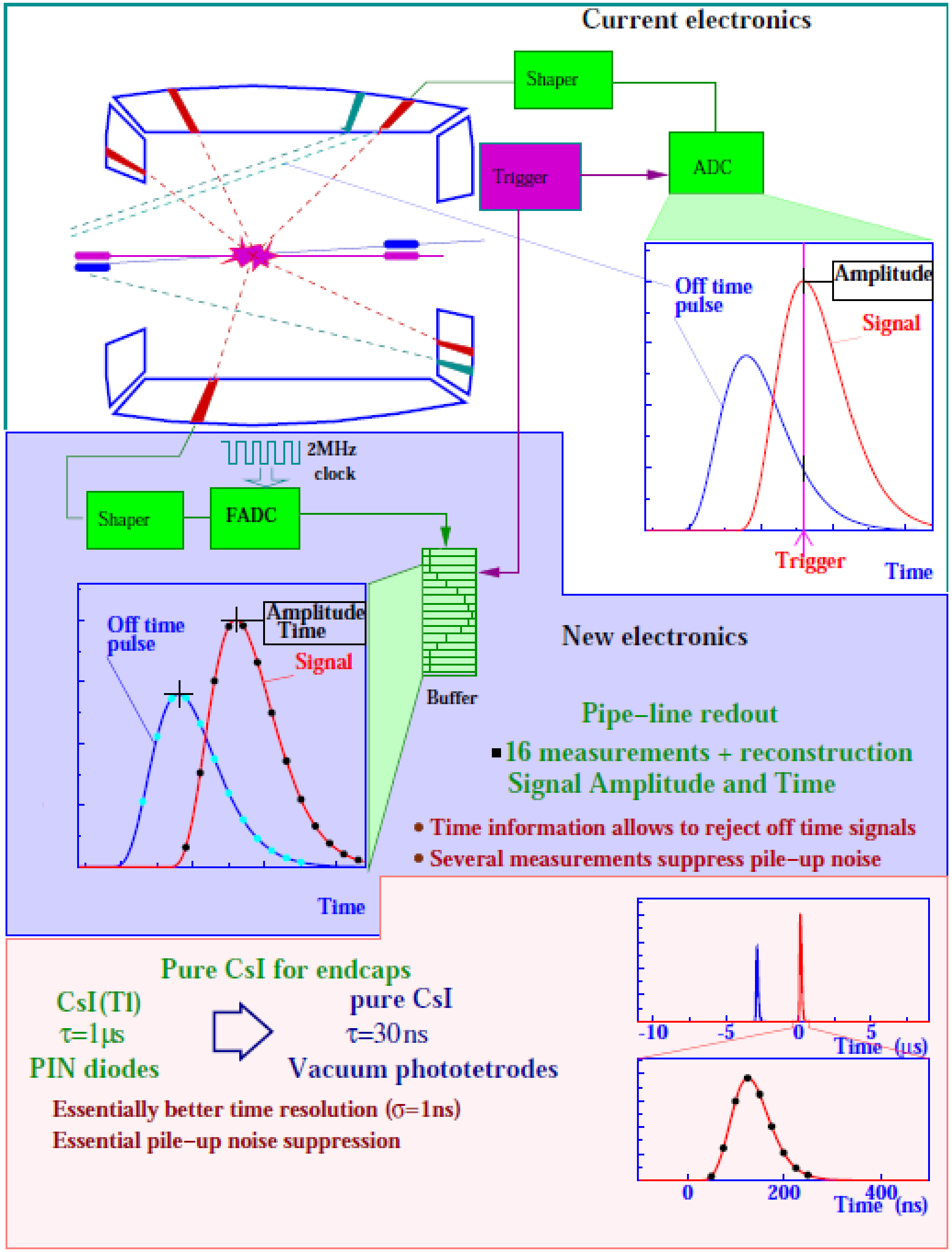
- Belle II calorimeter upgrade
- Electronic noise in the scheme with APD
- CsI(pure)+(1-4)APDs light output and equivalent noise energy
- Improvement of the light output
- Wavelength shifters with organosilicon luminophores
- Characteristics of APD
- Summary

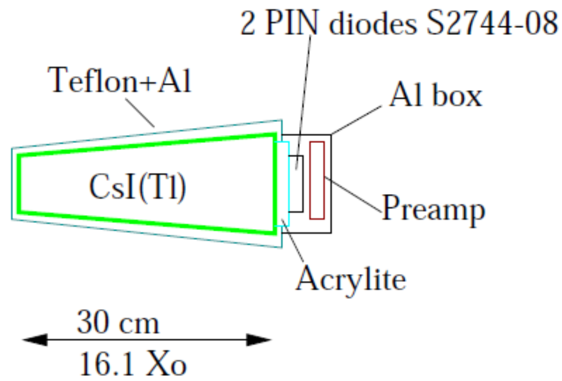
Belle II at SuperKEKB

Belle II at SuperKEKB is the only e^+e^- Super Flavor Factory in the nearest future, which is competitive/complementary to the current and coming energy/intensity frontier experiments

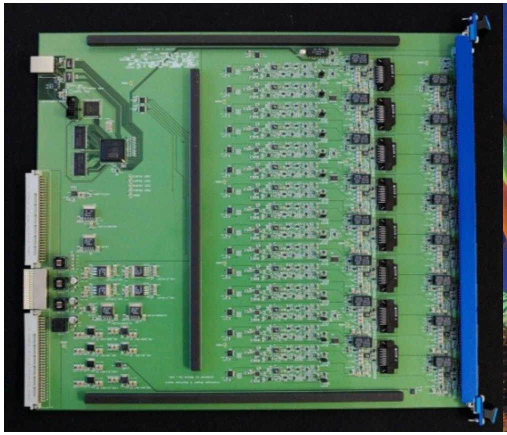


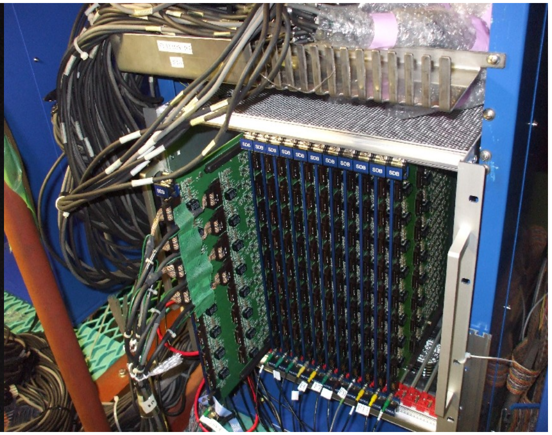
Barrel ECL



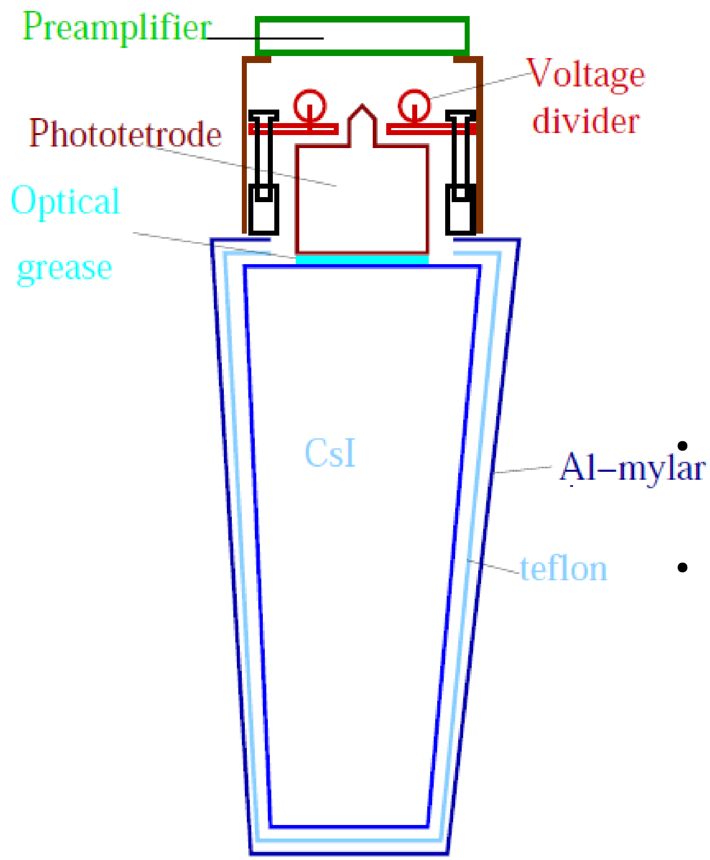


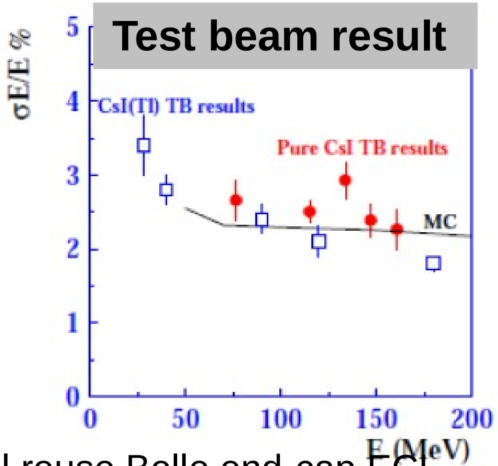
- **Barrel ECL** will be reused, new electronics with pipe-line readout and waveform analysis (16 ch Shaper-DSP board) has been developed and tested. All Shaper-DSP boards were produced, tested, delivered to KEK and installed in the detector.
- Belle II DAQ electronics has been tested in the ECL data transfer runs with the frequency up to 30 kHz.
- **Cosmic runs with barrel ECL are ongoing.**





End cap ECL upgrade

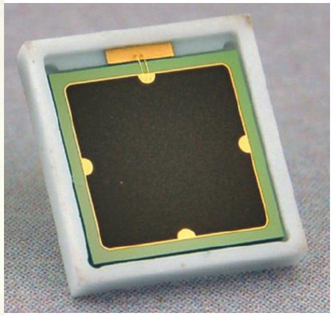




- At the first stage of the Belle II experiment we will reuse Belle end-cap ECL (1152 + 960 channels) (with new preamplifiers and readout electronics).
- **The main end-cap ECL upgrade option is to use CsI(pure) crystals and Hamamatsu photopentodes R11283MOD-A** (dedicated R&D showed good results):
  - Low pile-up noise and good energy and spatial resolution
  - Similar physical characteristics (as for CsI(Tl)), better radiation hardness
  - There are several crystal producers, acceptable price
- **However there are some difficulties:** *no redundancy, notable dependence on magnetic field, long term stability, new mechanical support is needed.*
- **In the CsI(pure) + Si APD option** we are investigating APDs from two producers: *EXCELITAS*, *Hamamatsu Photonics.* ***The main problem here is to reach admissible level of electronic noise.***
- **With the actual size crystal and 1 APD (1 x 1 cm^2) Hamamatsu S8664-1010 we obtained ENE ≈ 2 MeV, while the required ENE ≤ 0.5 MeV**

Hamamatsu APD S8664-1010

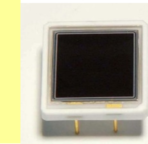
EXCELITAS APD C30739ECERH-2



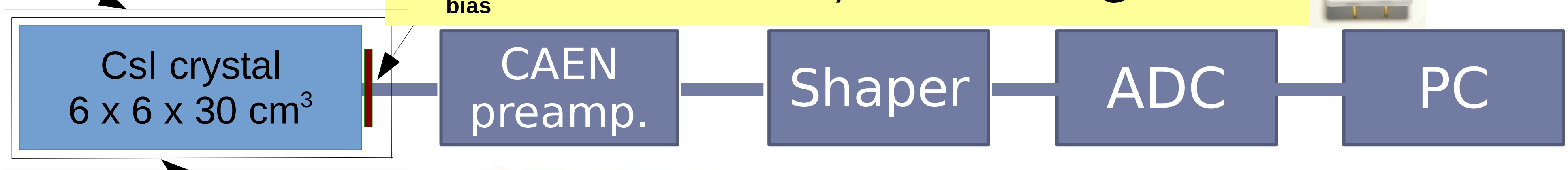
Study of electronic noise

APD Hamamatsu S8664-1010

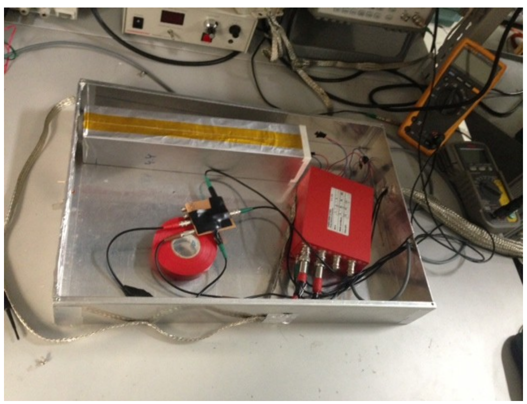
U_{bias} = 394 V: Gain = 50, Idark = 8 nA @ T=25 °C



Aluminized mylar



Teflon



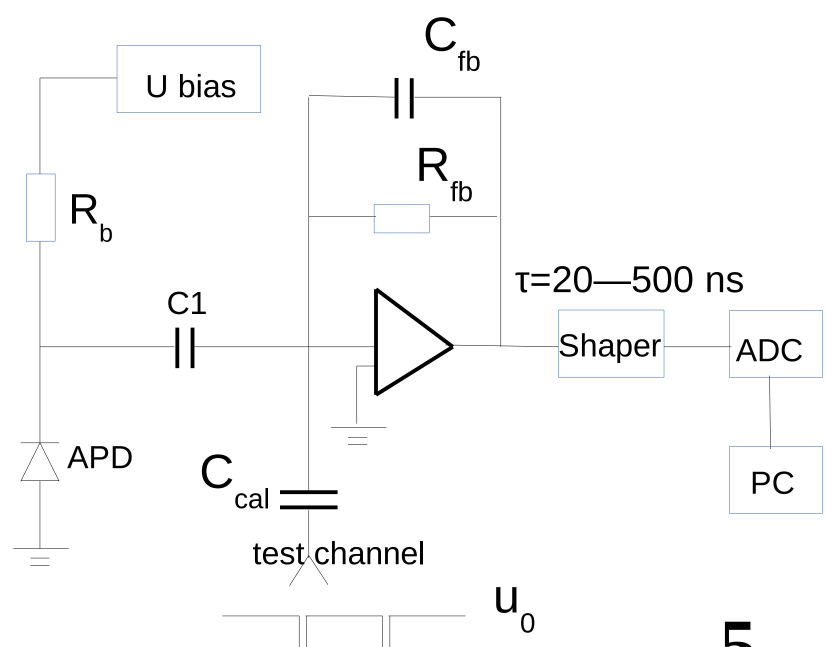
4ch preamplifier
CAEN A1422B045F3
45 mV/MeV (1 V/pC)

CP 4467A
Fast Shaping Amplifier (NIM)
τ = (20—500) ns

Hoshin C008
16ch peak hold
ADC (CAMAC)

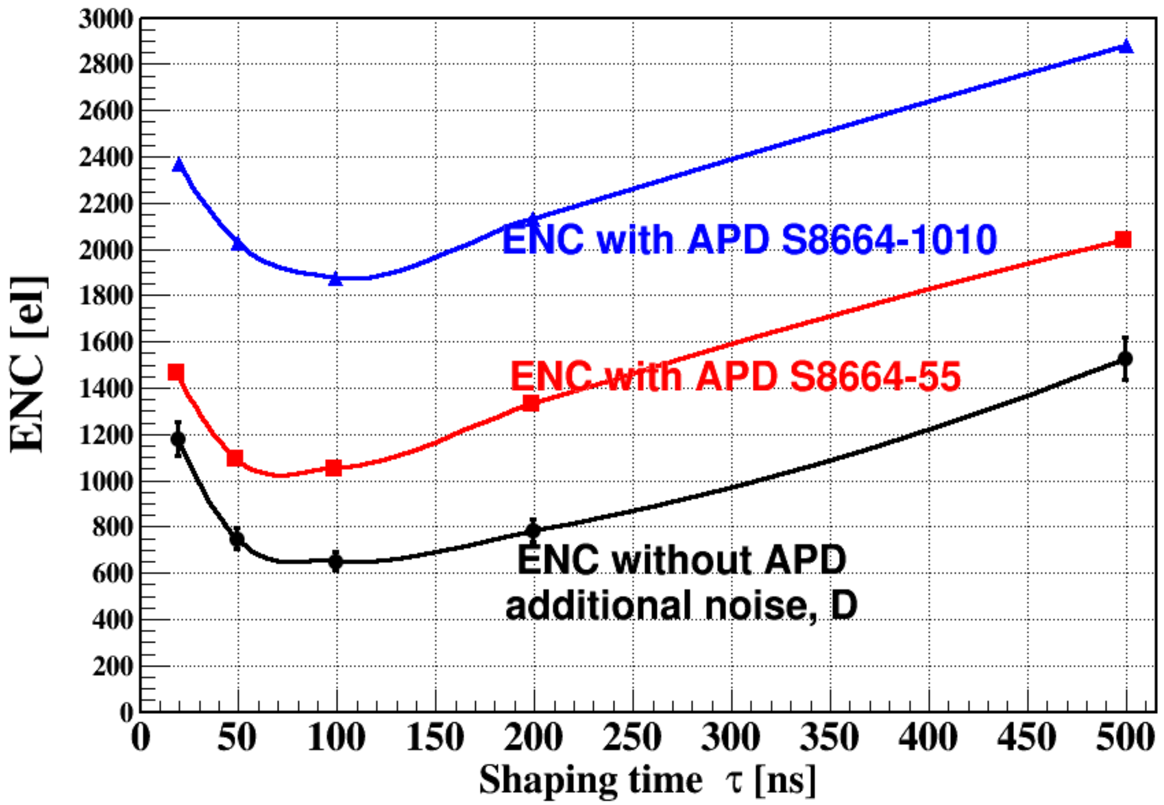
$$ENC^2 = \frac{2 I_d K g F \tau}{e} + \left(\frac{B^2}{\tau} + E^2\right) C^2 + D^2$$

Shot noise — *Thermal noise* — *Additional noise*



- **e** – positron charge;
- **I_d** – dark current;
- **g** – APD gain;
- **τ** – shaping time;
- **K** – shaper factor;
- **F** – excess noise factor;
- **C** – APD junction capacitance;
- **B** – thermal noise coefficient;
- **E** – 1/f noise coefficient;
- **D** – additional noise.

Measurement of **D**



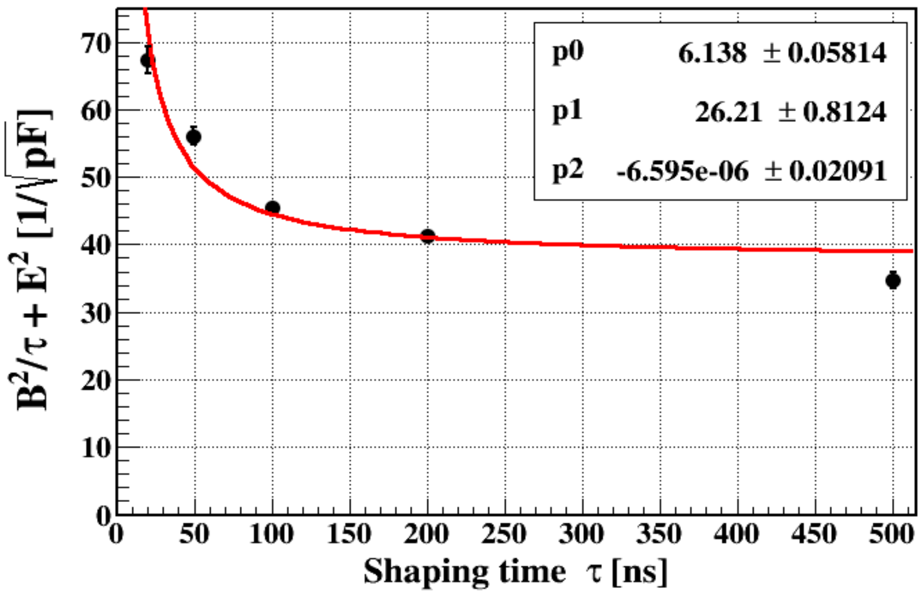
- At the shaping times from 20 ns to 500 ns, **D** is not constant. It varies strongly, which is explained by the relatively large additional parallel (i_{na}) and serial (e_{na}) noises.
- Fast shaper of better quality (like ORTEC 474, 579) might be helpful to decrease **D**

$$ENC^2 = (2eI_d + \frac{4k_bT}{R_b} + i_{na}^2)K_iT_s + (4k_bTR_s + e_{na}^2)K_\nu\frac{C^2}{T_s} + K_{\nu f}A_fC^2$$

Measurement of thermal noise (B, E)

Two well known capacitors C_1 and C_2 were used to measure **B** and **E**.

$$\mathbf{B}^2/\tau + \mathbf{E}^2 = (\overline{Q}_1^{\,2} - \overline{Q}_2^{\,2})/(C_1^2 - C_2^2)$$



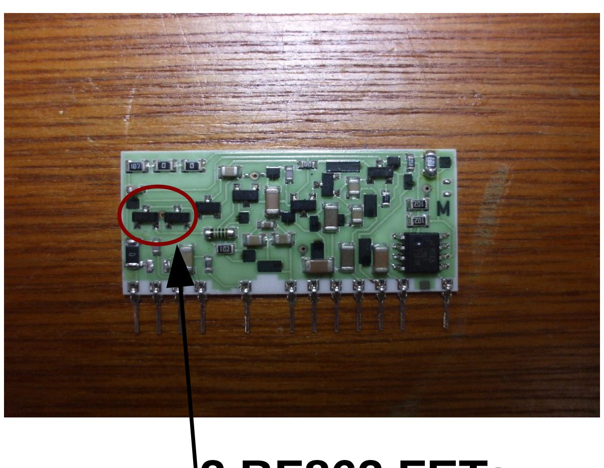
$\mathbf{B} = (26.2 \pm 0.8 \pm 4.8)\ \sqrt{ns}/pF$

$\mathbf{E} = (6.1 \pm 0.1 \pm 0.4)\ 1/pF$

$\mathbf{B}^2/\tau = (4k_B T \mathbf{R_s} \Delta f)/e^2$

$\mathbf{R_s}$, equivalent serial resistance, it is dominated by reversal transconductance of the CAEN preamp. FET (BF862)

$R_s \approx 50\ \Omega$ was also measured with additional serial resistance at the CAEN preamp. input



2 BF862 FETs

We also tried FET **2SK932-23,** at short shaping times thermal noise is almost the same.

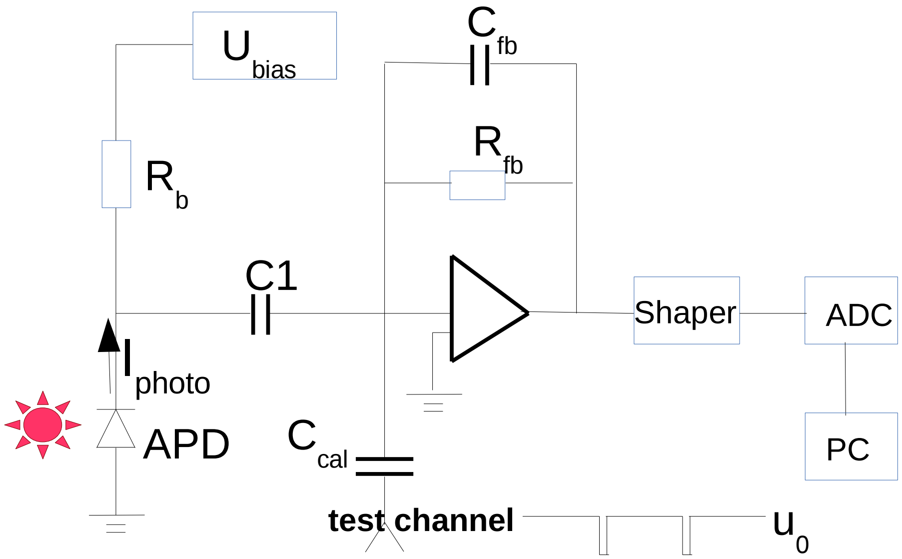
Shot noise, excess noise factor **F**

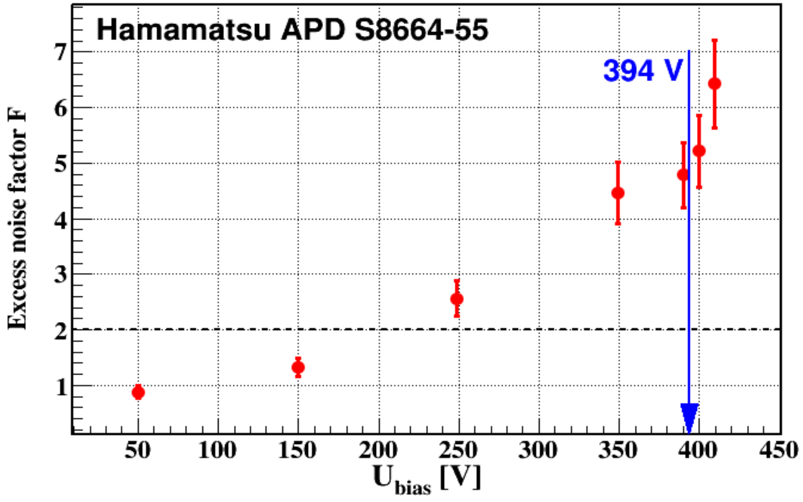
$$\overline{Q}^2_{\text{no Iphoto}} = 2\cdot e\cdot I_d\cdot \tau\cdot g\cdot F\cdot K + (B^2/\tau + E)\cdot C_d^{\,2} + D^2$$

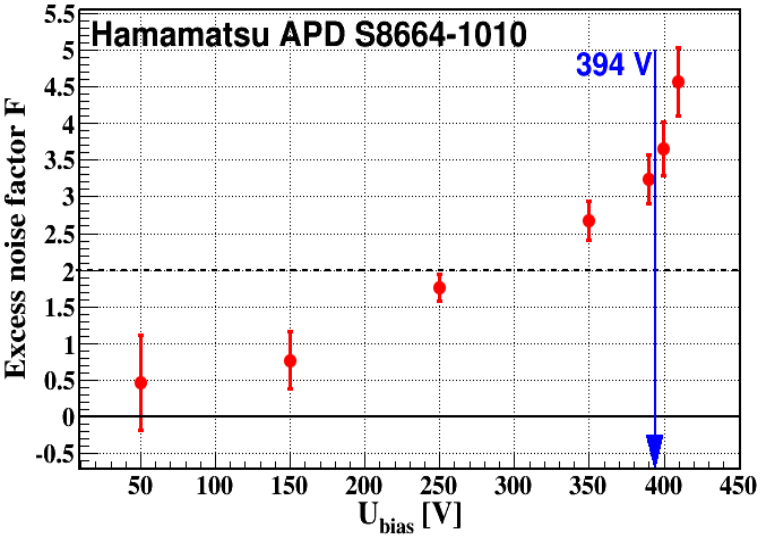
$$\overline{Q}^2_{\text{with Iphoto}} = 2\cdot e\cdot (I_d + I_{\text{photo}})\cdot \tau\cdot g\cdot F\cdot K + (B^2/\tau + E)\cdot C_d^{\,2} + D^2$$

$$F = (\overline{Q}^2_{\text{with Iphoto}} - \overline{Q}^2_{\text{no Iphoto}})/(2\cdot e\cdot I_{\text{photo}}\cdot \tau\cdot g\cdot K)$$

K(EXP) = 0.44 ± 0.02 K(CR-4RC) = 0.45



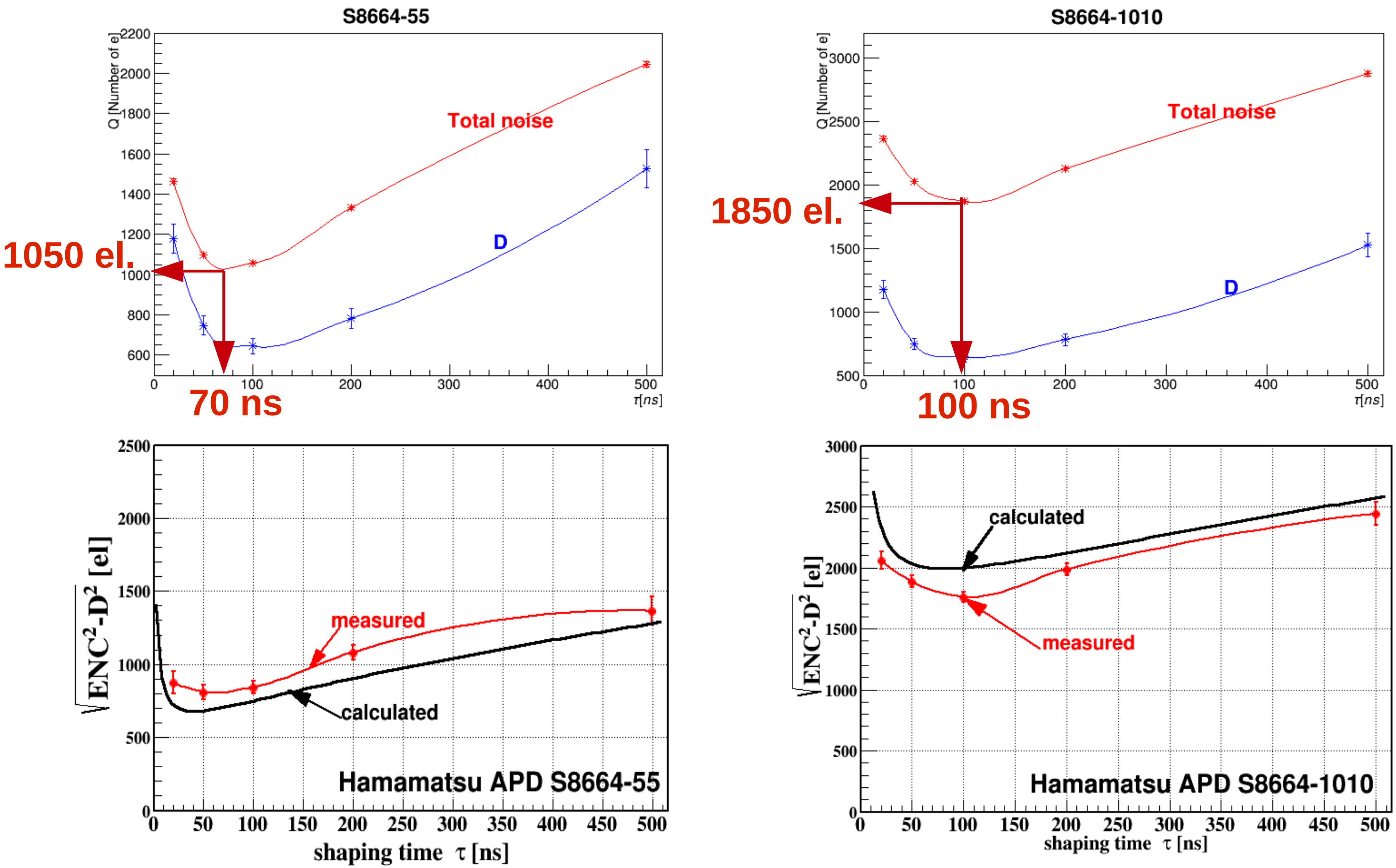




S8664-55: g = 50, F = 5.1 ± 0.5

S8664-1010: g = 50, F = 3.4 ± 0.4

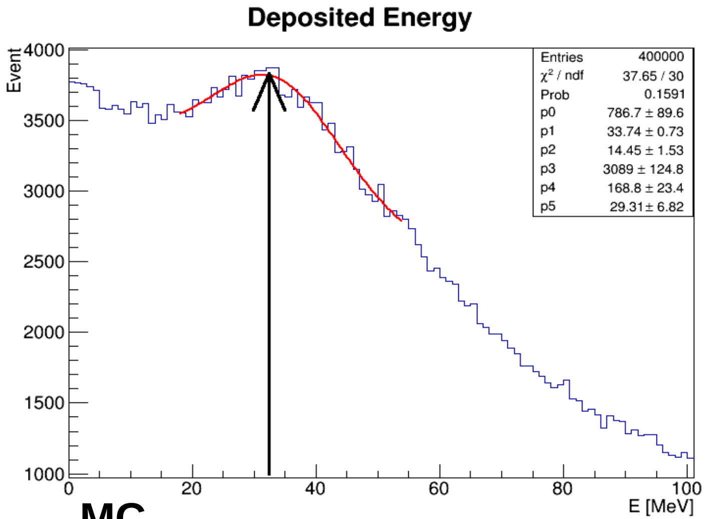
ENC vs. shaping time

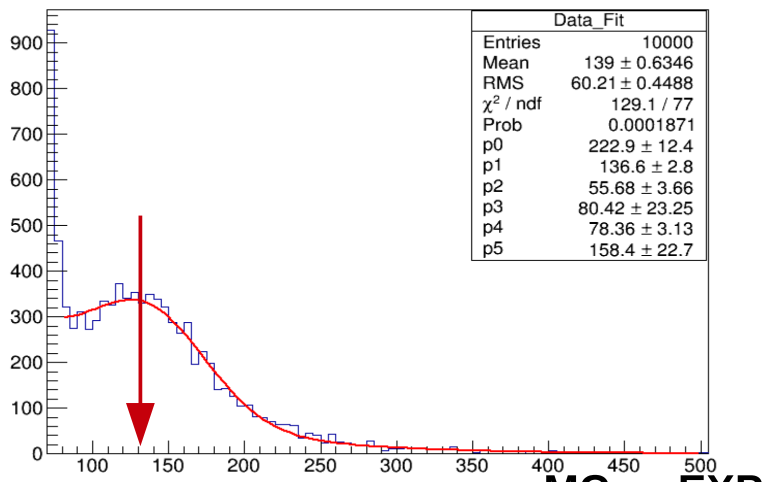


Discrepancy between **calculated** and **measured**
$\sqrt{ENC^2 - D^2}$ is due to the uncertainty in $\mathbf{C_{APD}}$

Light output (LO) and ENE

Cosmic muons are used to calibrate ADC channels in units of energy (MeV)





E^{MC}_{peak}(cosmic) ≈ 33 MeV

$Price_{ADC}$(MeV/ch) = $E^{MC}_{peak} / A^{EXP}_{peak}$

ENE = $\sigma_{cal} \times Price_{ADC}$

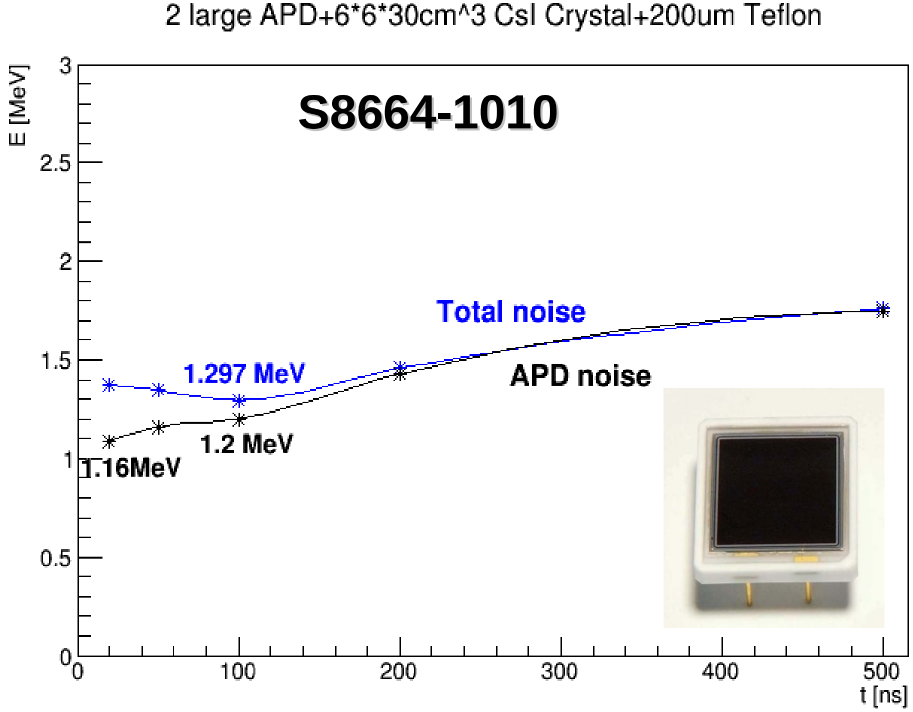
The light output is measured by comparison of the signal from cosmic muons (A_{cosm}) with calibration signal (A_{cal}) (gain is eliminated)

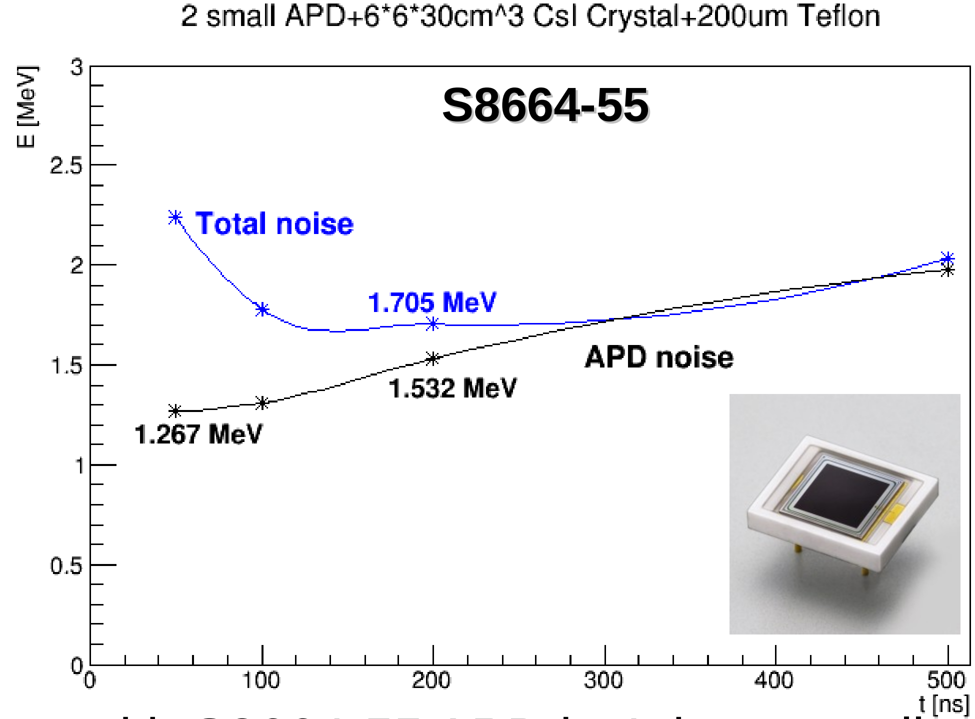
$$N_{cosm}(\text{ph.e.}) = (C_{cal} \times U_0 / e) \times (A_{cosm} / A_{cal})$$

$$LO = N_{cosm} / E^{MC}_{peak} / (\text{APD gain} = 50) / (S_{APD}\ [\text{cm}^2])$$

LO = 26 ph.e. / MeV / cm²

ENE, several APDs per crystal





Light collection efficiency for the counter with S8664-55 APD is 4 times smaller, than for the counter with S8664-1010, but the thermal noise component is also smaller by a factor of C_{APD}(large) / C_{APD}(small) ≈ 3.5

1 APD S8664-1010 has essentially larger dark current (26 nA) in comparison with the average one (8 nA), we introduce correction to ENE

ENE(2 S8664-1010 APDs (same I_{dark})) = 1.1 MeV

ENE(4 S8664-1010 APDs (same I_{dark})) = 0.8 MeV

ENE(2 S8664-55 APDs) = 1.7 MeV

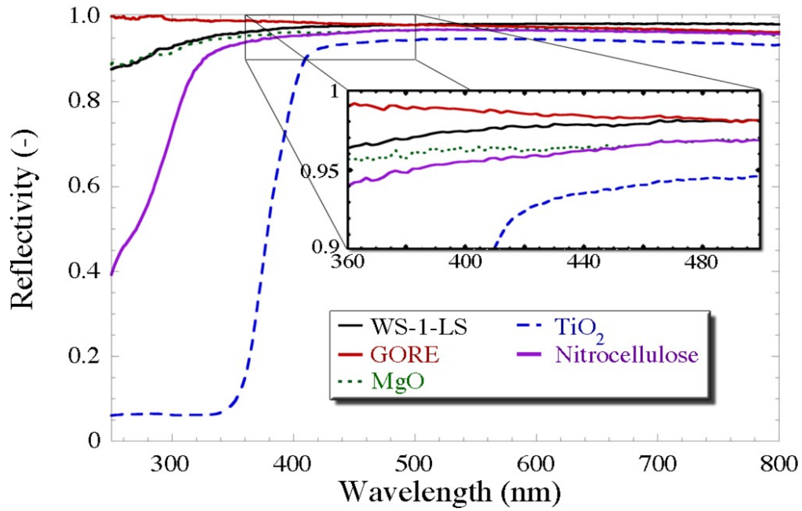
ENE(4 S8664-55 APDs) = 1.2 MeV

Improvement of the LO

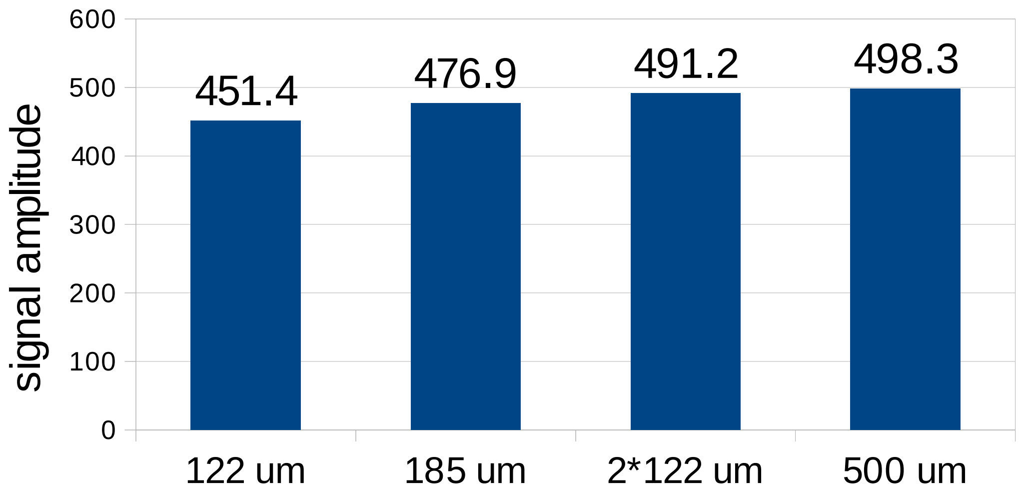
	Refraction index	Transparency @315 nm from the producer	Light collection efficiency
OKEN-6262A	1.453 (@ 590 nm)	85%	**1.00**
TSF451-50M	1.404 (@ 590 nm)	98%	**0.85**
BC-630	1.465	95%	**0.95**

Three types of optical grease were tested (Δ = 100 μm),
OKEN-6262A provide the largest light output

Effect of the thickness of white porous Gore-Tex teflon was studied,
thickness of **200 μm** was found to be optimal.

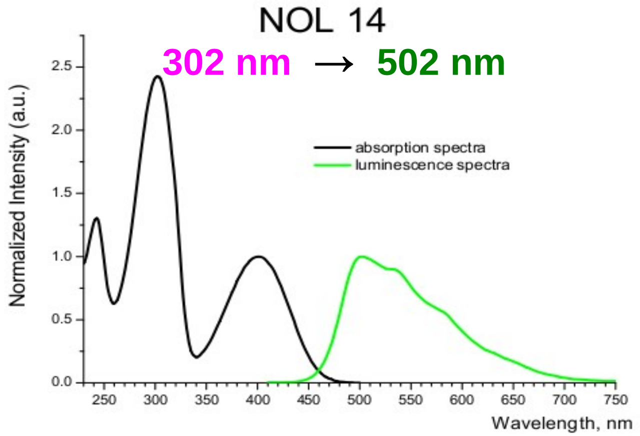


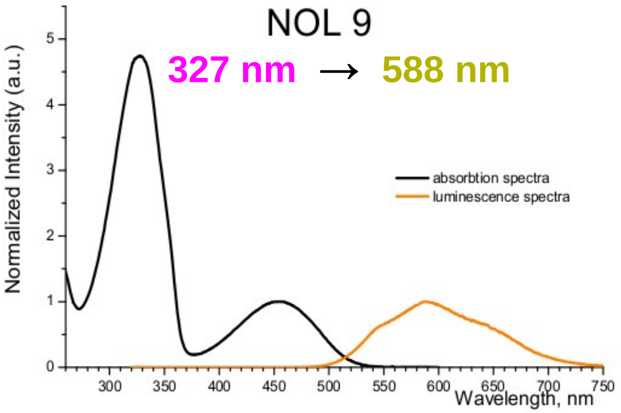
M.Janecek, IEEE Trans. Nucl. Sci. 59.3 (2012) 490.

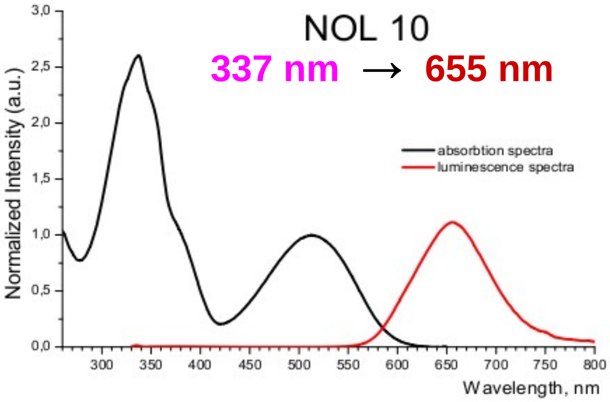


Wavelength shifters with organosilicon luminophores

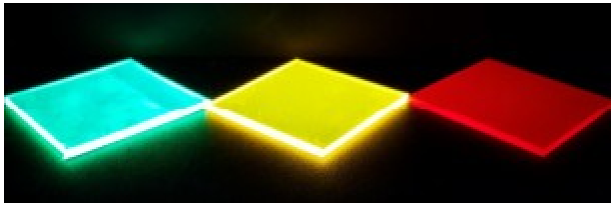
Based on the nanostructured organosilicon luminophores (NOL-9,10,14) from **LumInnoTech Co.**, the WLS plates were developed ((60 x 60 x 2) mm^3).



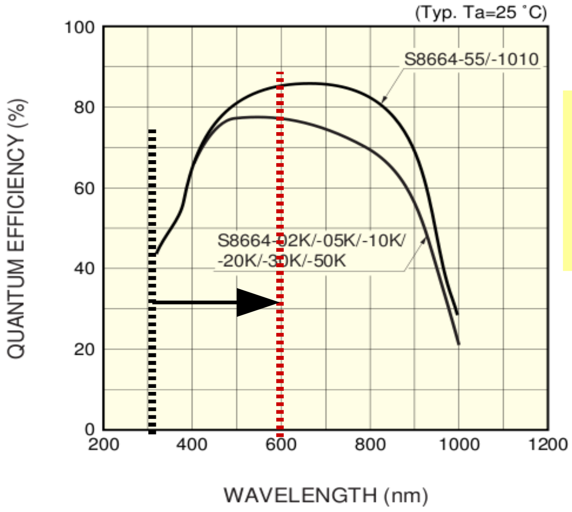




The absorption and emission spectra of these NOL's match our needs very well (**λ_{CsI} = 320 nm**). The improvement of the APD QE is by a factor of 2–3.



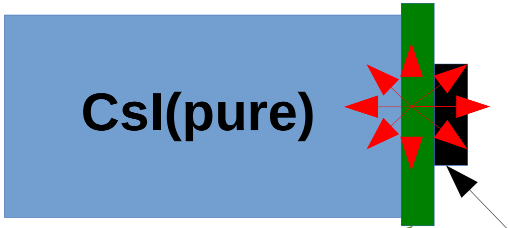
■ Quantum efficiency vs. wavelength

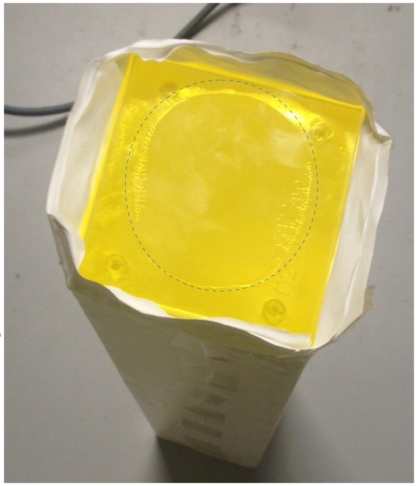


See also poster at this conference:

O. V. Borshchev et al., (ISPM RAS)
Nanostructured organosilicon luminophores as effective spectral shifters in a wide spectral region

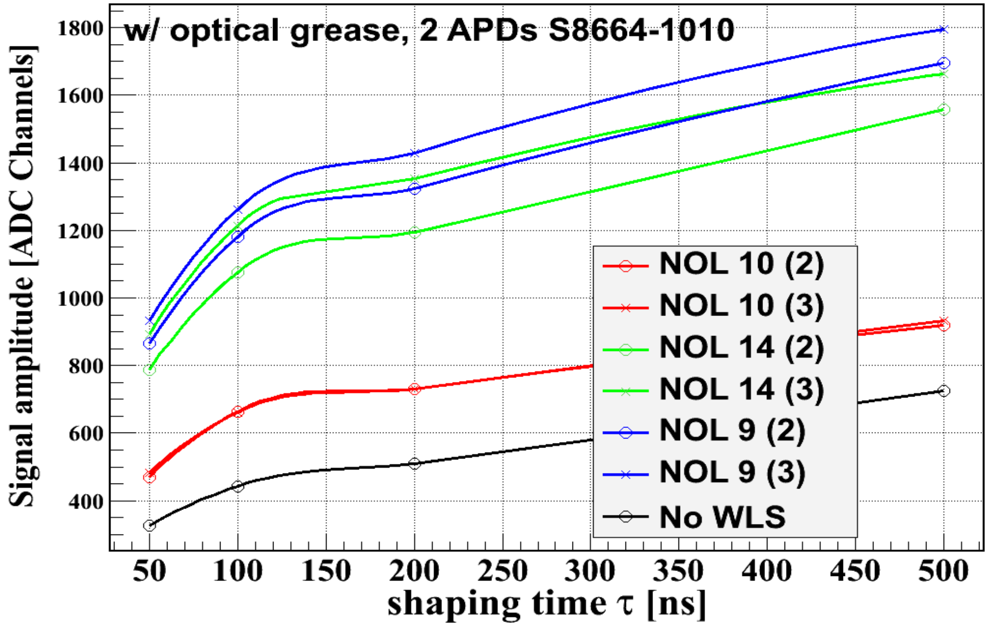
Results with WLS plates

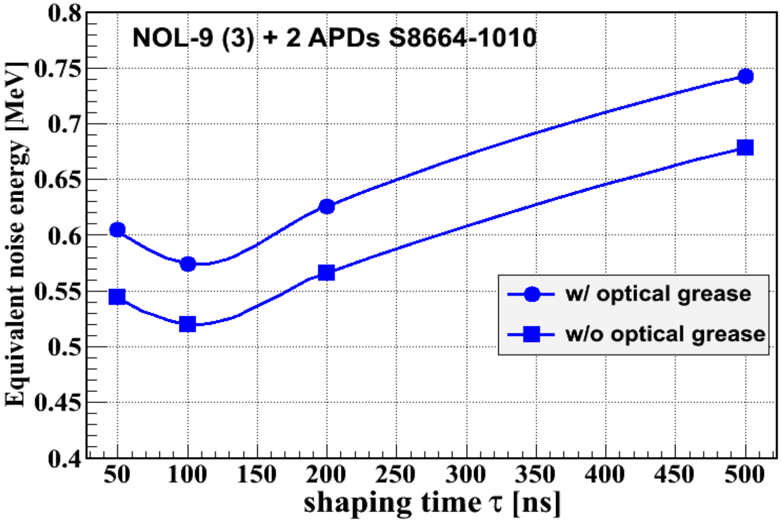


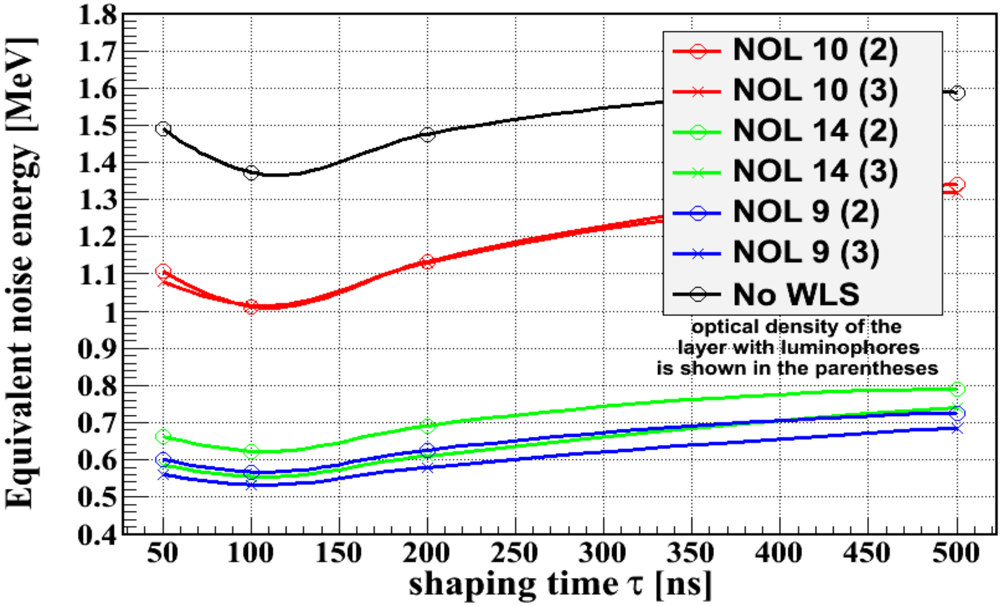


It is important to cover the whole 6 x 6 cm^2 plate by optical grease

However, the largest signal is achieved w/o optical grease between crystal and WLS plate



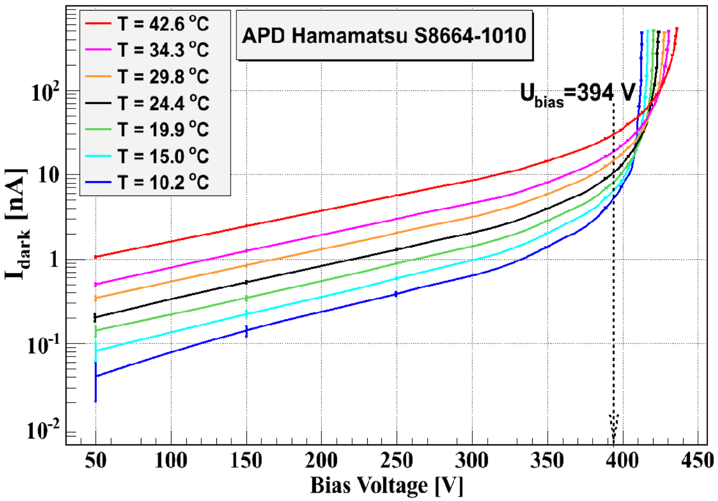


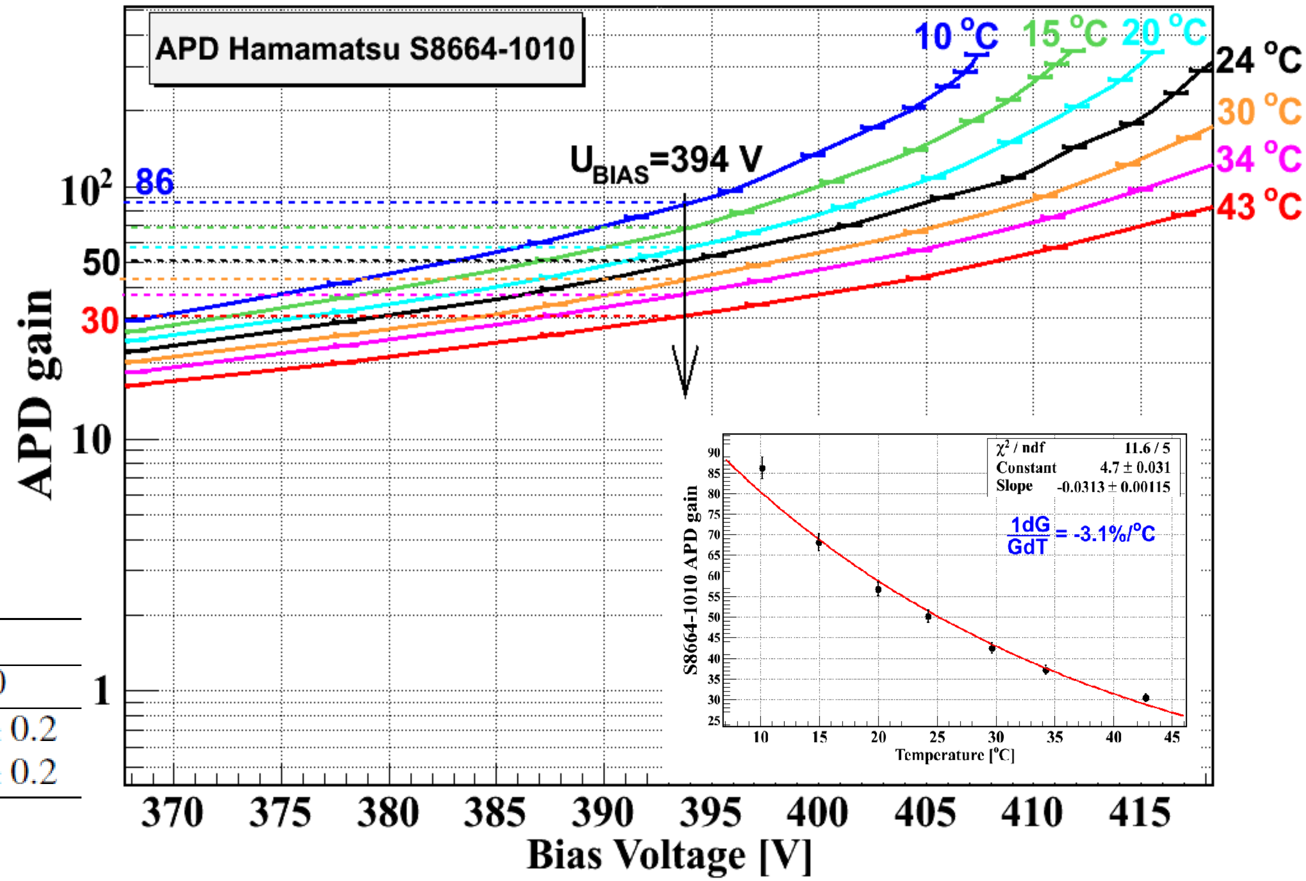


ENE(2 S8664-1010) = (0.55 ± 0.05) MeV
ENE(4 S8664-55) = (0.45 ± 0.05) MeV

Characteristics of APD

APD is a dominant source of the signal temperature variations, which have to be compensated





(1/G)(dG/dT)[%/°C]

APD type	APD gain		
	30	50	100
S8664-55	-2.4 ± 0.1	-3.3 ± 0.1	-5.0 ± 0.2
S8664-1010	-2.3 ± 0.1	-3.1 ± 0.1	-4.9 ± 0.2

To compensate temperature variations of APD gain, we can organize temperature sensor - bias voltage feedback.

Summary

- Hamamatsu APDs of S8664 series provide promising option for Belle II end cap ECL upgrade
- Essential increase of the light output of the CsI(pure)+APD(s) counter was achieved with WLS plates based on the nanostructured organosilicon luminophores (NOL-9)
- Several APDs per crystal allow us to decrease further ENE and provide readout redundancy
- The ENE of the counter with 4 S8664-55 APDs was measured to be ENE = (0.45 ± 0.05) MeV, which satisfies project requirements
- Radiation hardness of WLS plates is under investigation
- We are working to optimize the readout scheme from WLS plates