A summary of the R&D for the FWD ECL upgrade

G. Finocchiaro

Riunione Belle II Italia — Pisa, 20 novembre 2017

Outline

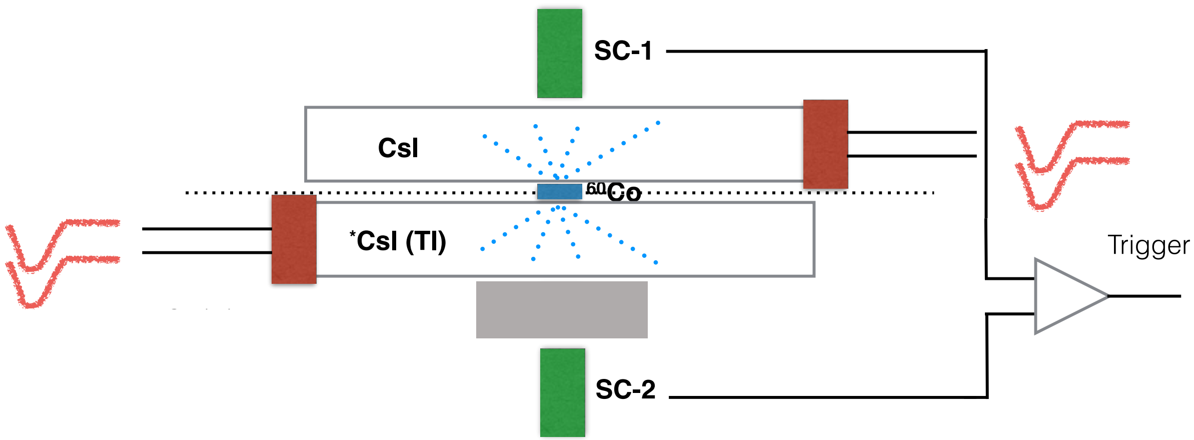
- Pure CsI with LAAPD readout
  I. bare crystal
  II. + UV11S filter
  III. + UV11S filter + NOL9 WLS
  IV. + UV5S filter + NOL9 WLS

- Pure CsI with photopentode readout

- CsI(Tl)
  I. pin-diode readout
  II. pin-diode + APD readout (transimpedance amplifier)
  III. pin-diode + APD readout (charge integrating amplifier)

The setup

- We studied several detector configurations with our cosmic ray telescope, and a high-intensity (~3MBq) ^{60}Co source



- Two crystals, up to 8 channels recorded, scintillators and lead to trigger straight tracks

- The ^{60}Co source corresponds to ~2-2.5 times the average background in the FWD endcap predicted by MC 12

Reducing the CsI slow light components: optical filters

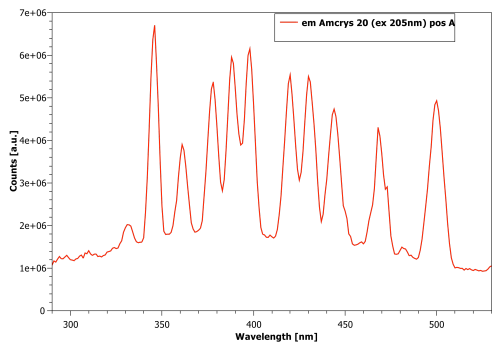


FIG. 1. Emission spectrum of pure CsI.

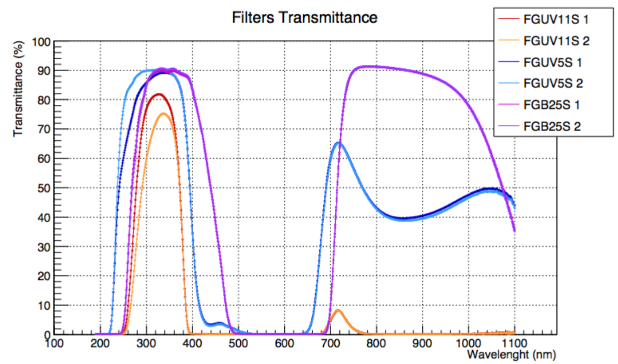


FIG. 2. Transmittance of the optical filters used.

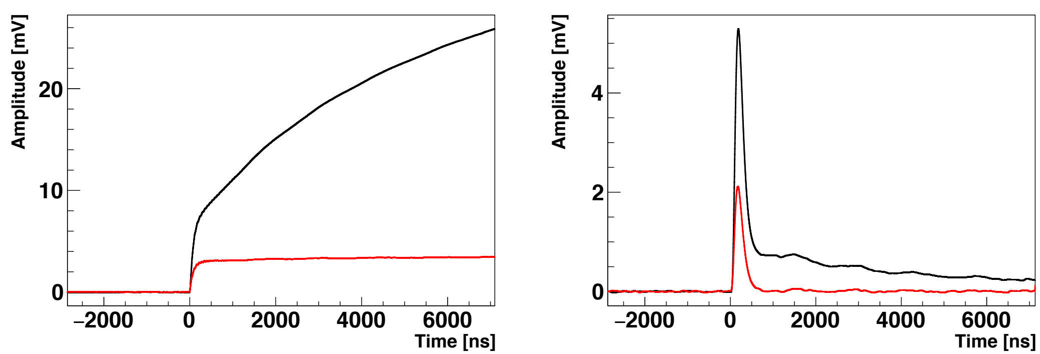
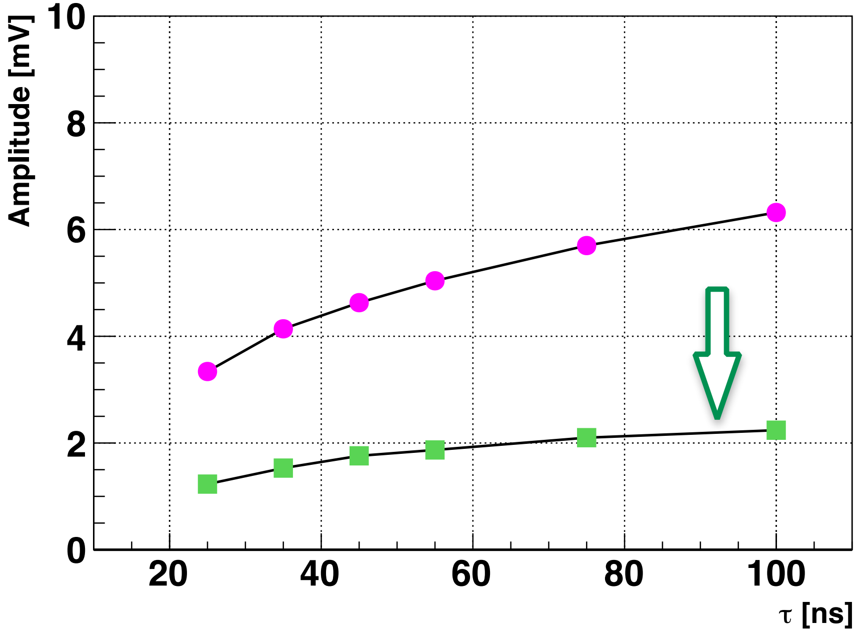
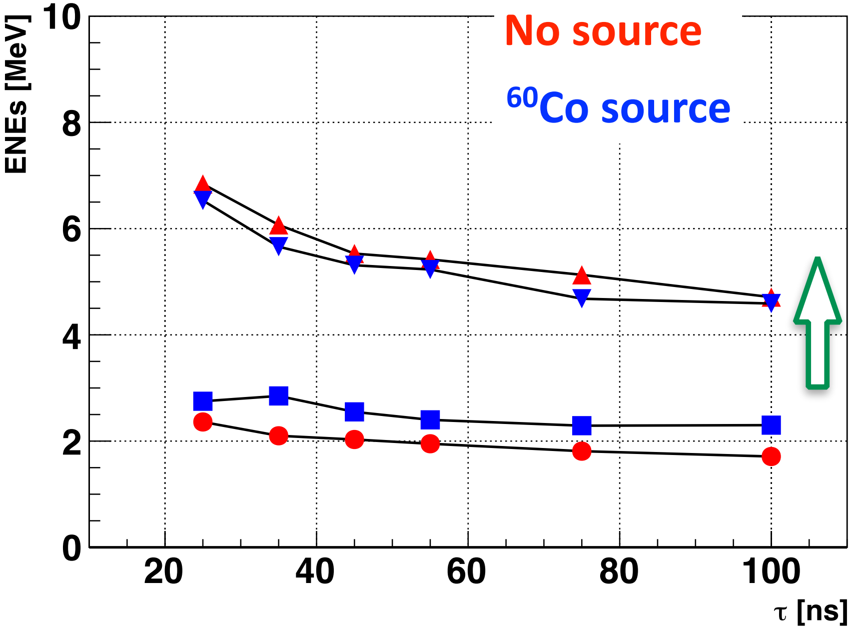


FIG. 3. Pure CsI crystal waveform without (black curve) and with the UV11S filter (red curve). The left plot shows the output of the CR110 preamplifier, the right plot the result of a CR-(RC)^4 filter with time constant of 50 ns.

CsI + UV11S

1 APD



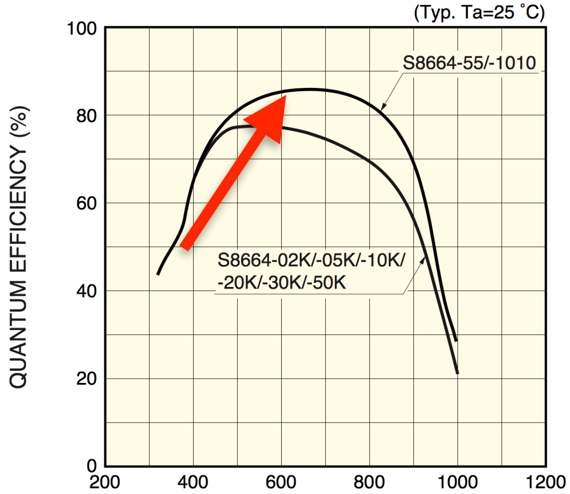


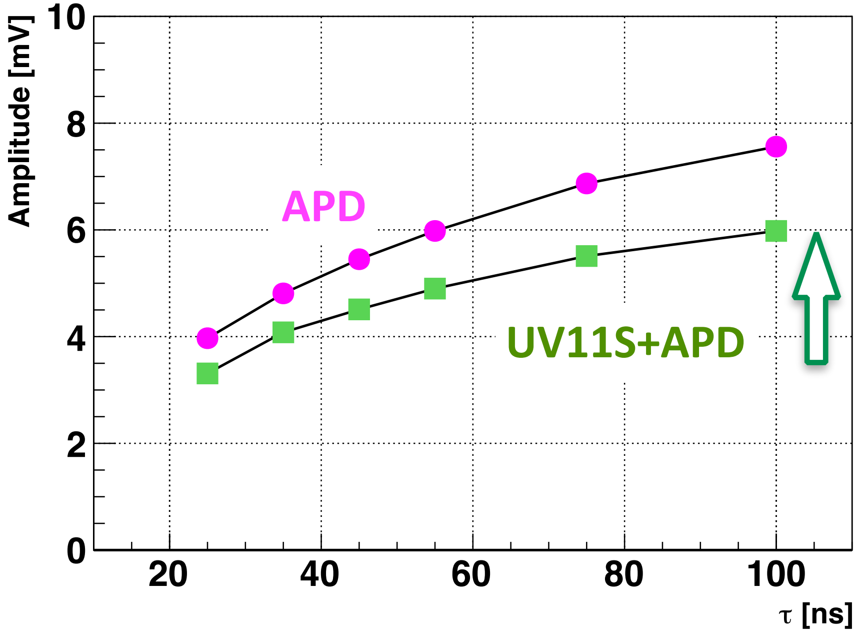
Gain~150

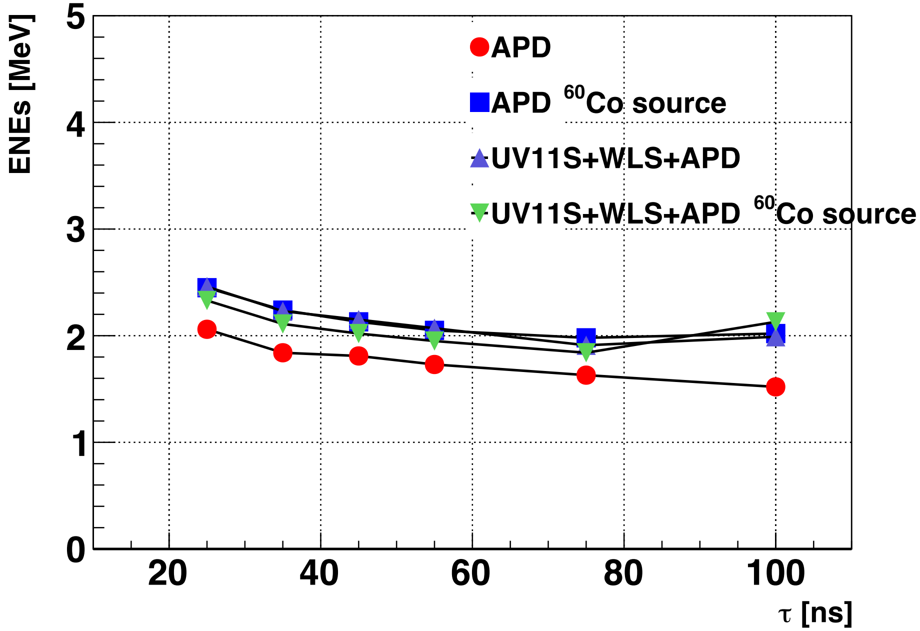
CsI + UV11S +**WLS**

1 APD

■ Quantum efficiency vs. wavelength



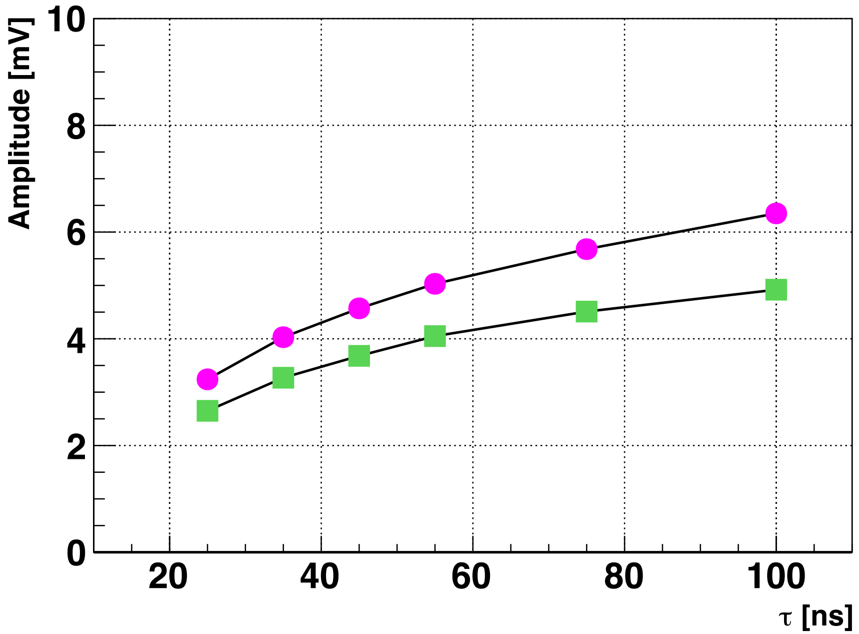


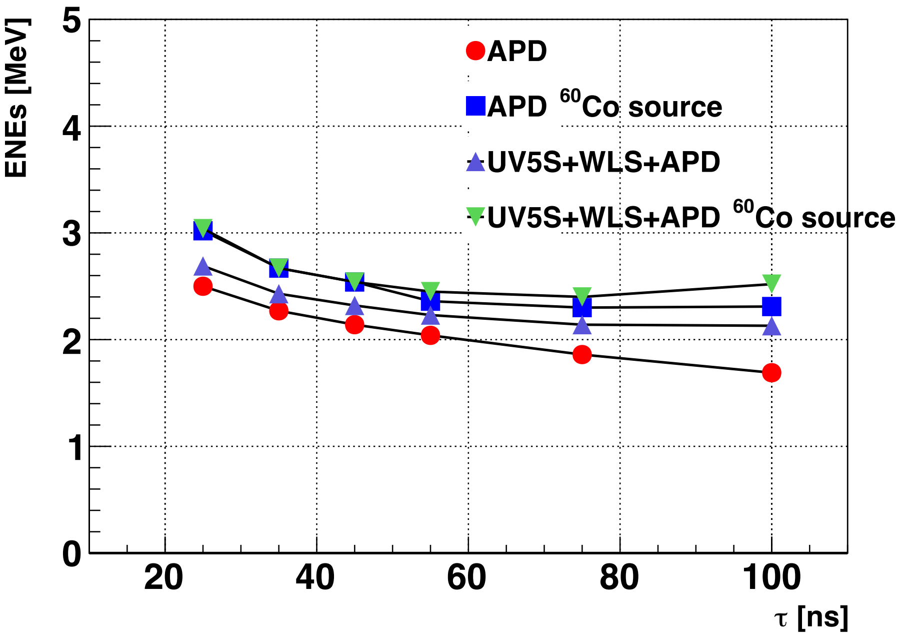


Gain~200

CsI + UV5S +WLS

1 APD

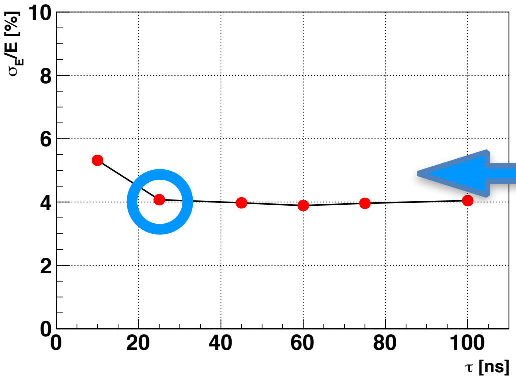


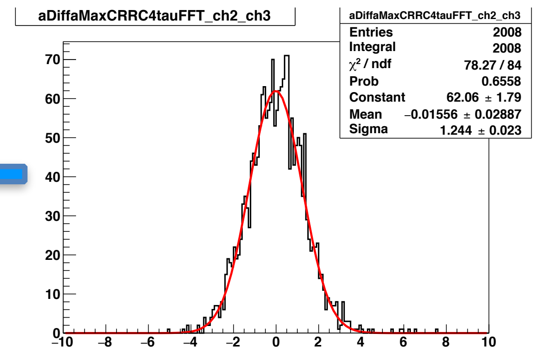


Gain~150

Photo-pentode

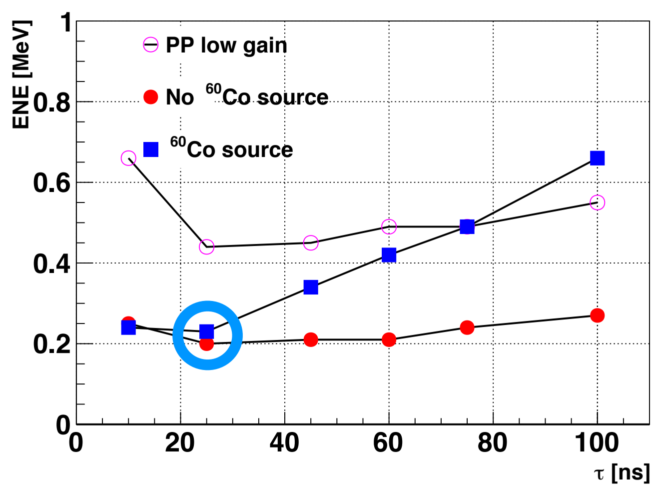
Energy resolution





- Resolution derived from the difference of signal of the two PP at the crystal ends. Gain of PPs was equalised in this run, but relatively small (~50)
- Did *not* correct for the light lost because absorbed by the second PP: the quoted resolution is an *upper limit*

Pile-up & electronics noise

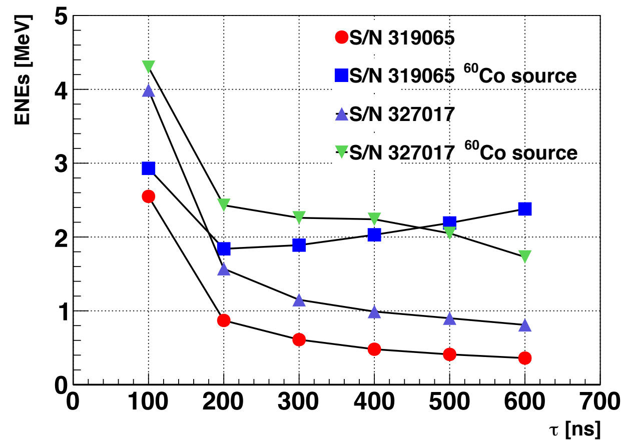


319065 reference
327017 700 Gy

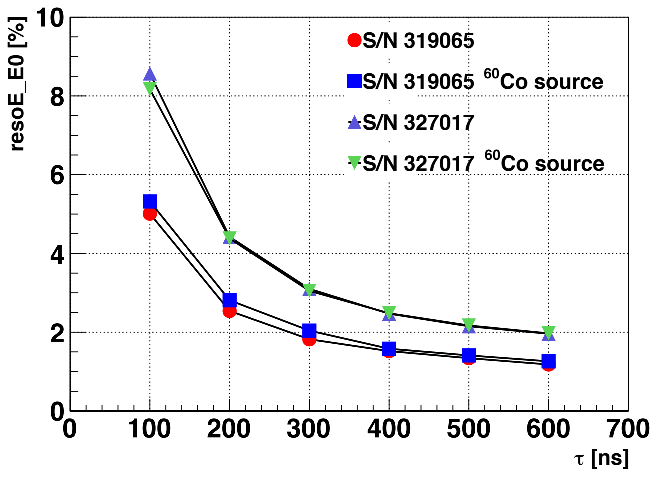
CsI(Tl) - reference crystal

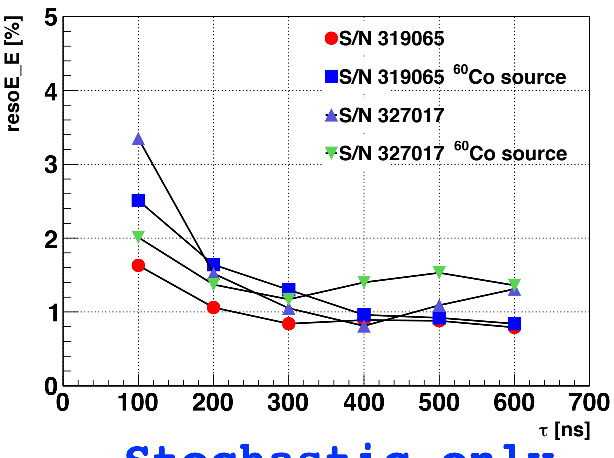
2 pin diodes

Pile-up & electronics noise



Energy resolution



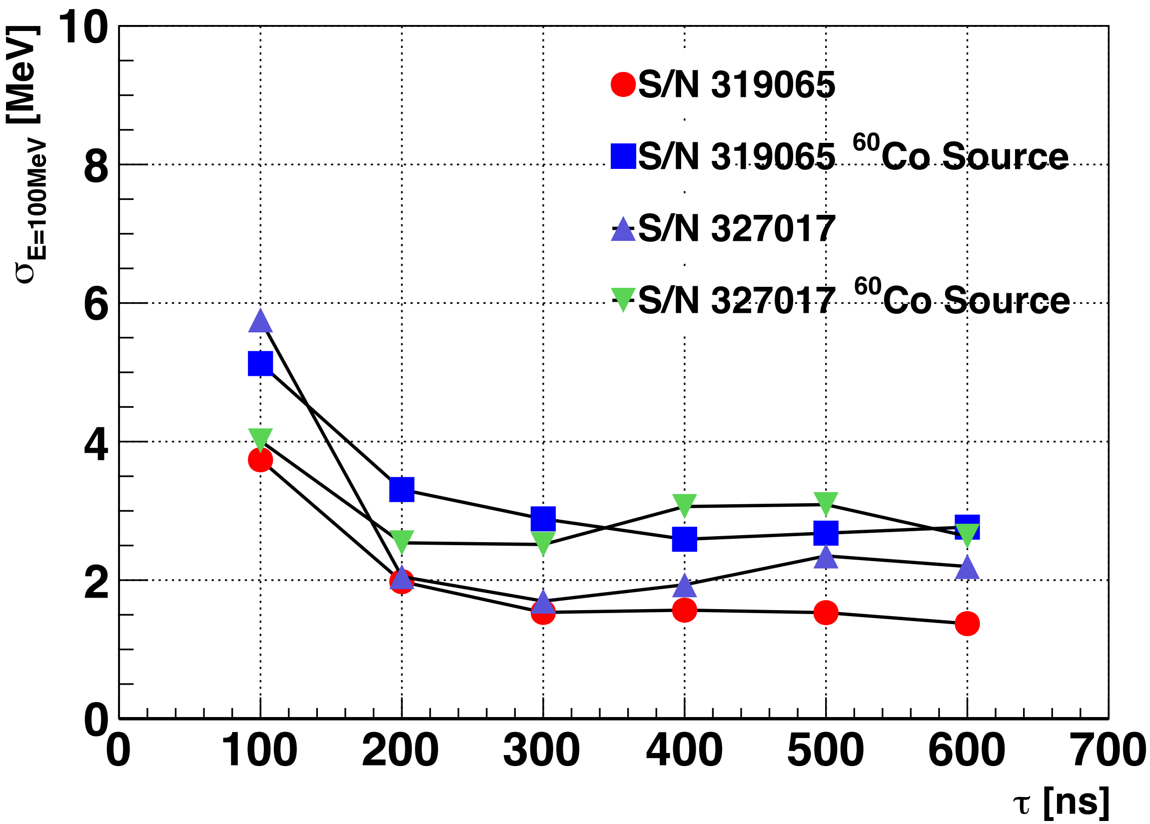


Stochastic only

319065 reference
327017 700 Gy

CsI(Tl) - reference crystal

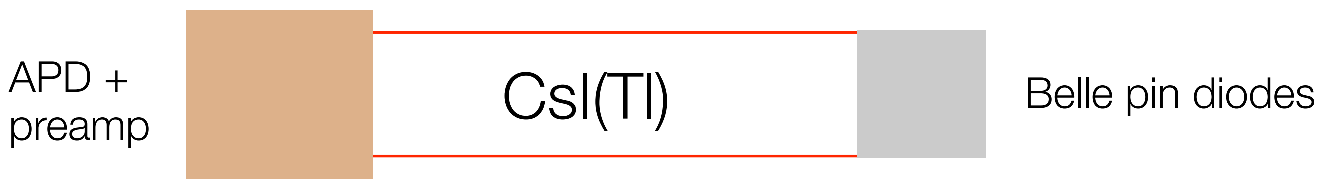
2 pin diodes



ENERGY ERROR (PILE-UP + STATISTICS) AT 100 MEV

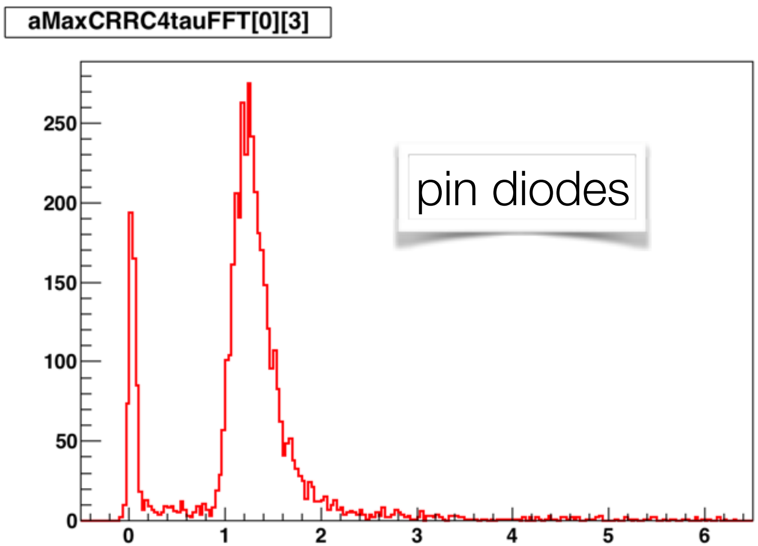
APD on CsI(Tl)

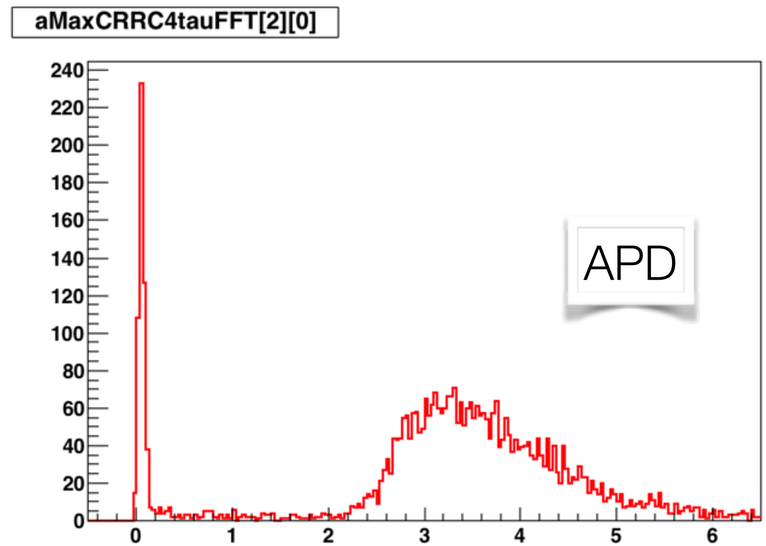
- A possible background mitigation strategy
- We aim to study the effect of an additional photosensor on the CsI(Tl) crystal
- For practical reasons, we equipped the Belle crystal with APDs on the *front size*



  - remind, CR track cross the side faces of the crystal
- We used both transimpedance and charge-integrating amplifiers

APD vs pin diode signal





Very high S/N for APDs

- τ_{APD}=25ns τ_{pin}=500ns

CsI(Tl) + APD

Transimpedance amplifier

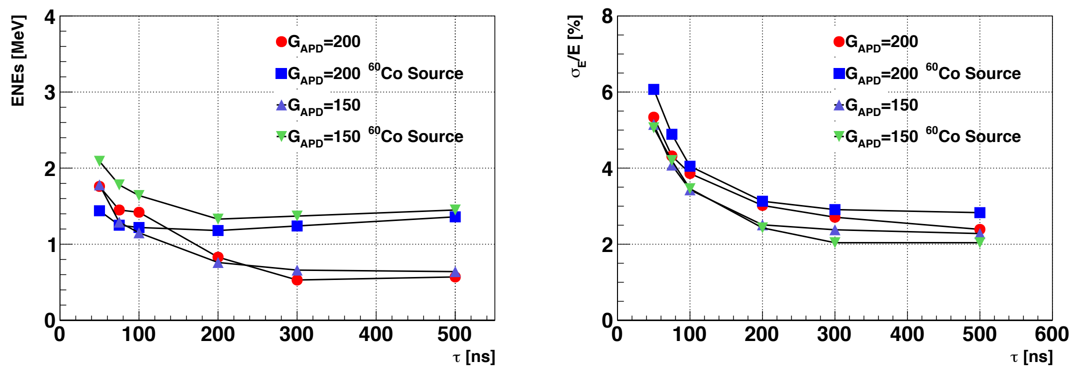
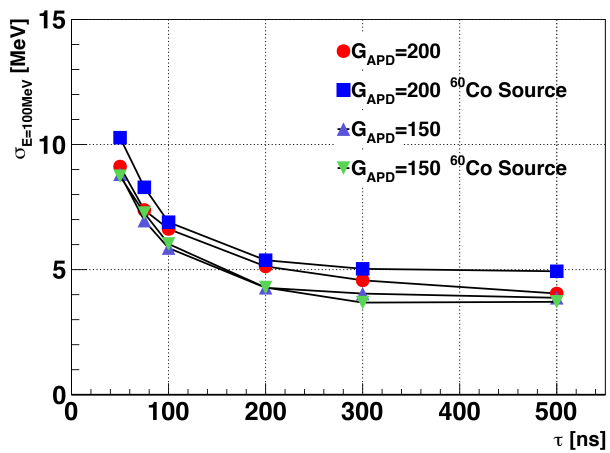


FIG. 14. ENE (left) and photostatistics energy resolution (right) of the sum of two APDs with TZA readout as a function of the CR-(RC)^4 filter shaping time.

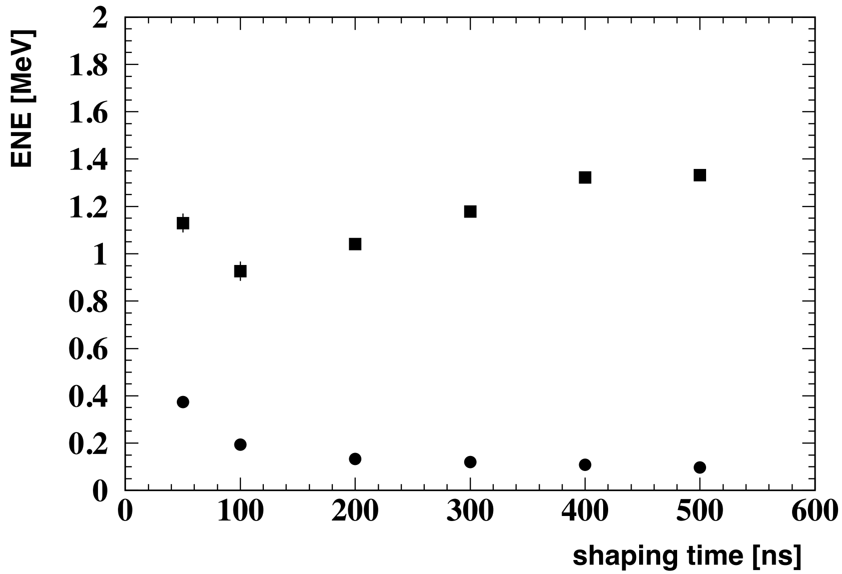


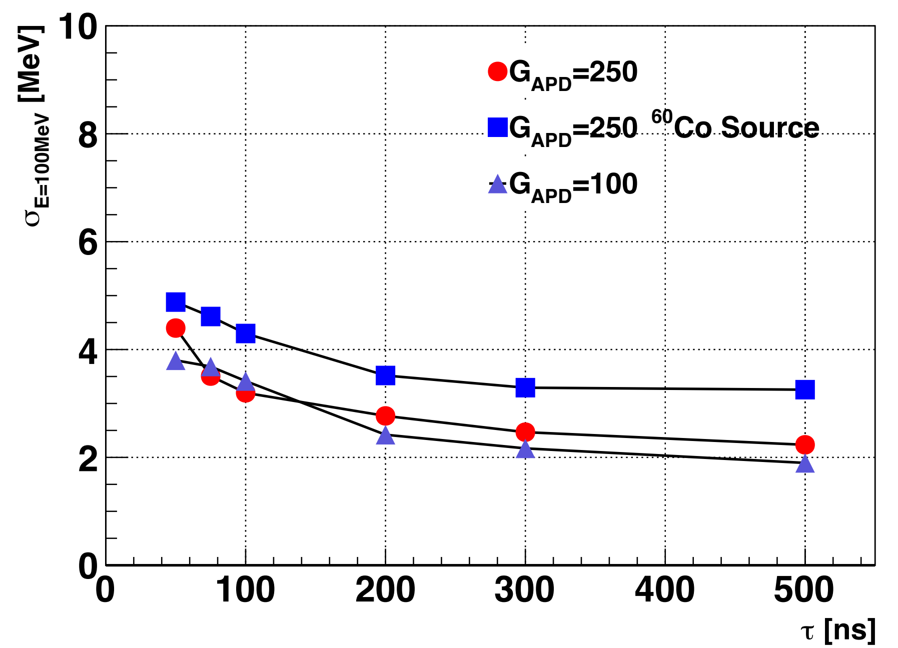
σ(E) AT 100 MEV

FIG. 15. Energy error at 100 MeV energy from photostatistics and pile up and electronics noise, as a function of the CR-(RC)^4 filter shaping time.

CsI(Tl) + APD

CR110 charge-integrating amplifier





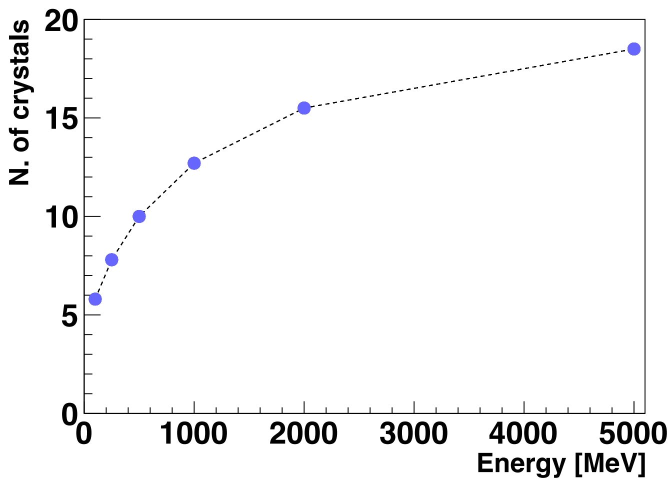
σ(E) AT 100 MEV

Relative energy resolution

- Parameterised as

$$\frac{\sigma_E}{E} = \frac{a}{E} \oplus \frac{b}{\sqrt{E}} \oplus \frac{c}{\sqrt[4]{E}} \oplus d$$

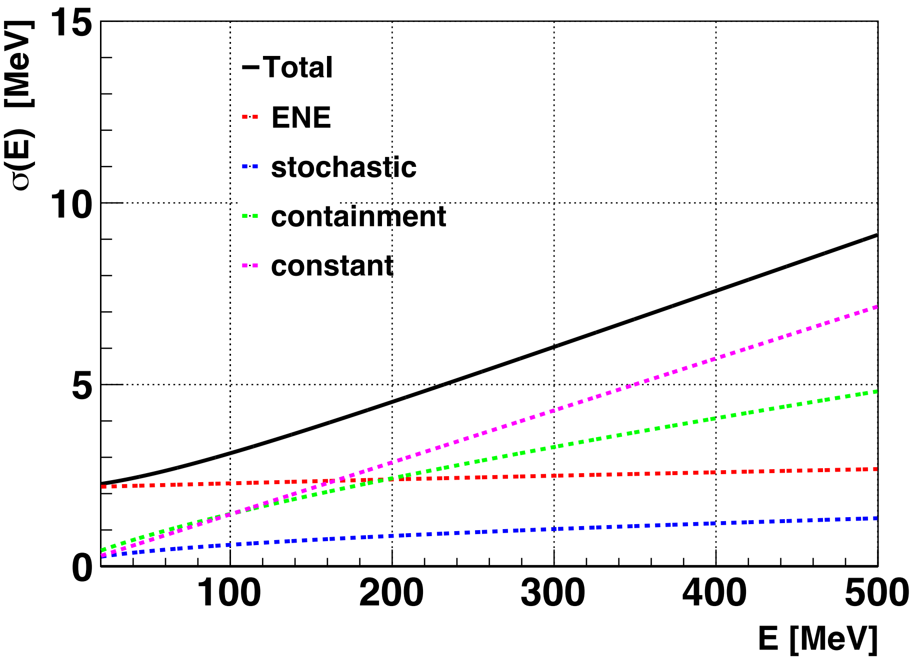
- We use the values of the Belle II TDR for the constant term **d=1.43%**, and for the one related to shower containment **c=0.81%**.
- For the other terms, we use measurements on single crystals from the cosmic muon setup

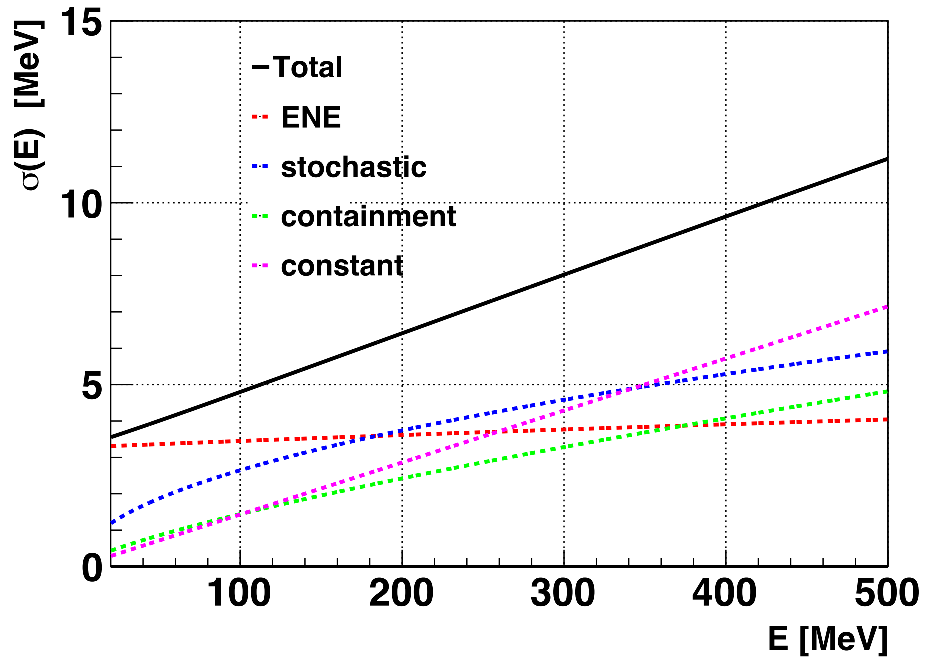


Use parameterisation of n. of crystals vs. E in single photon events.

Expect this to be an upper limit in real physics events

Energy error — no ^{60}Co source

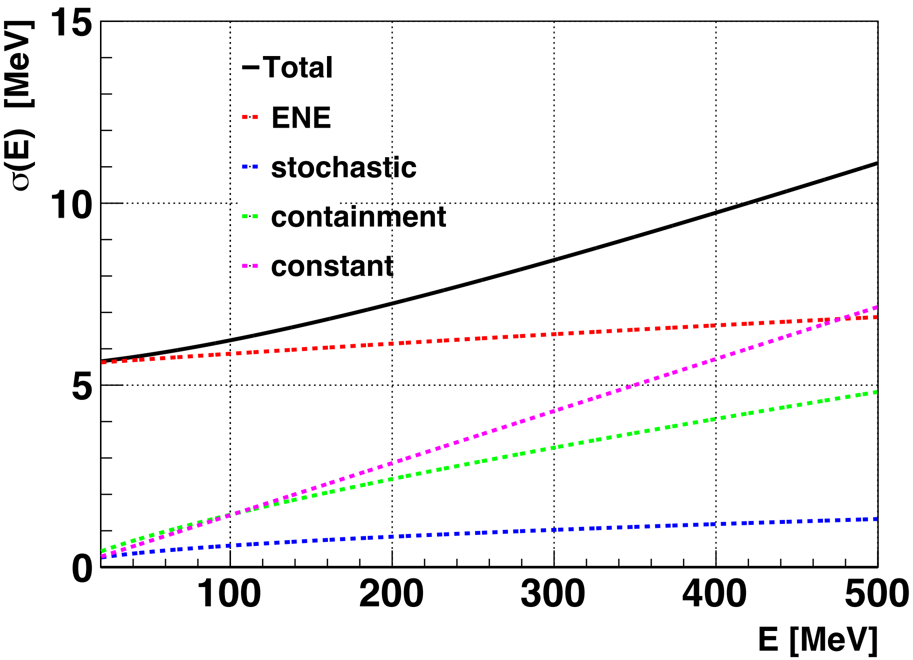


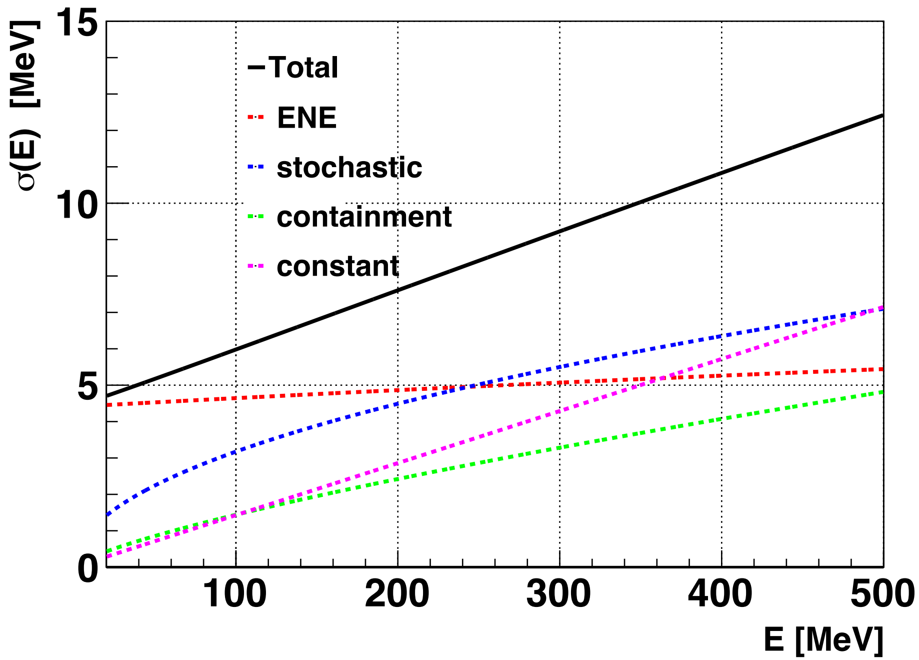


CsI(Tl)+pin diodes

CsI + APD

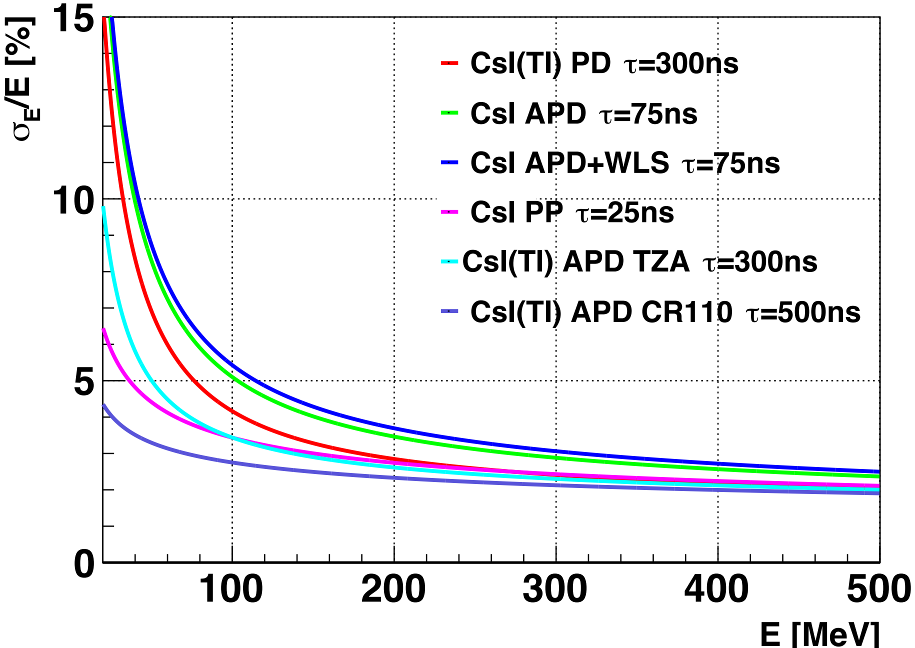
Energy error — ^{60}Co source



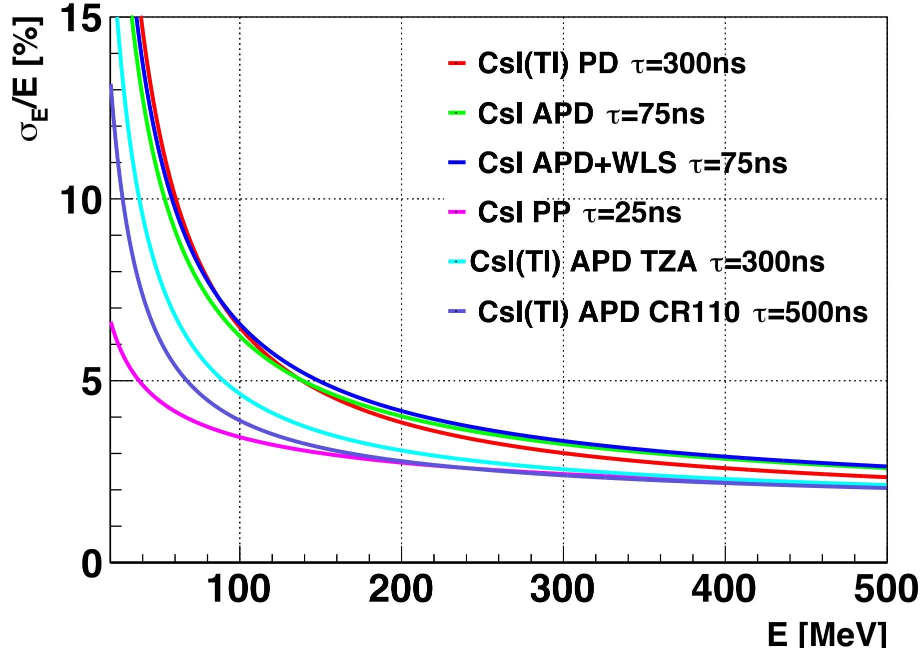


CsI(Tl)+pin diodes **CsI + APD**

ECL energy resolution with and w/o ^{60}Co source

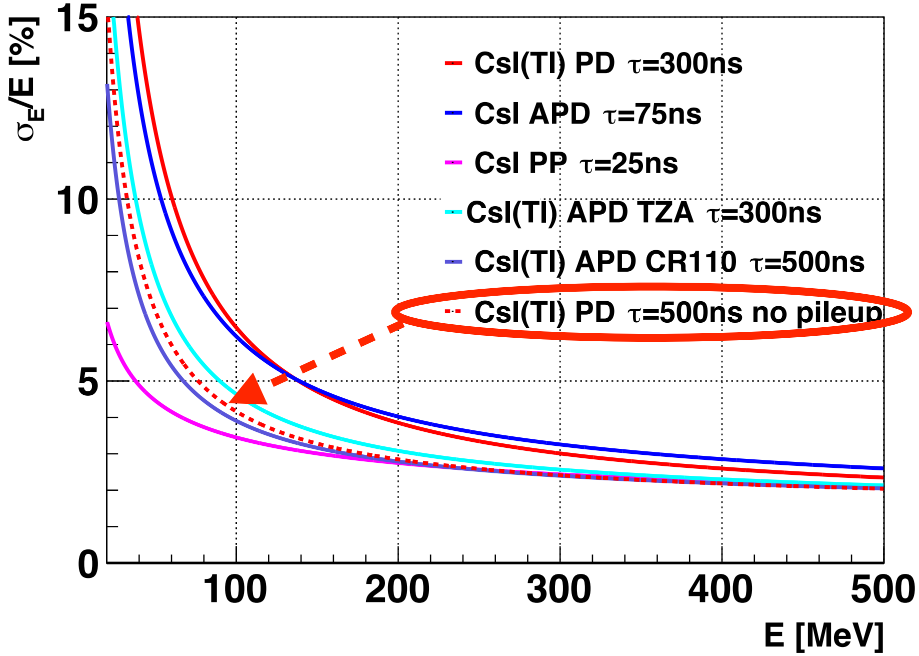


No ^{60}Co source

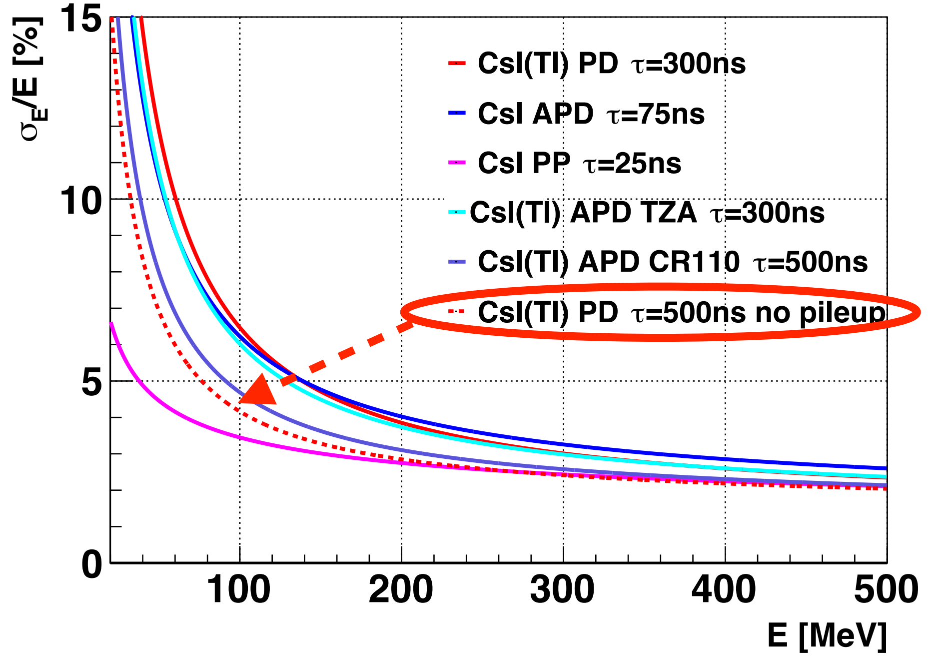


With ^{60}Co source

ECL energy resolution w/ pileup, 1 or 2 APDs

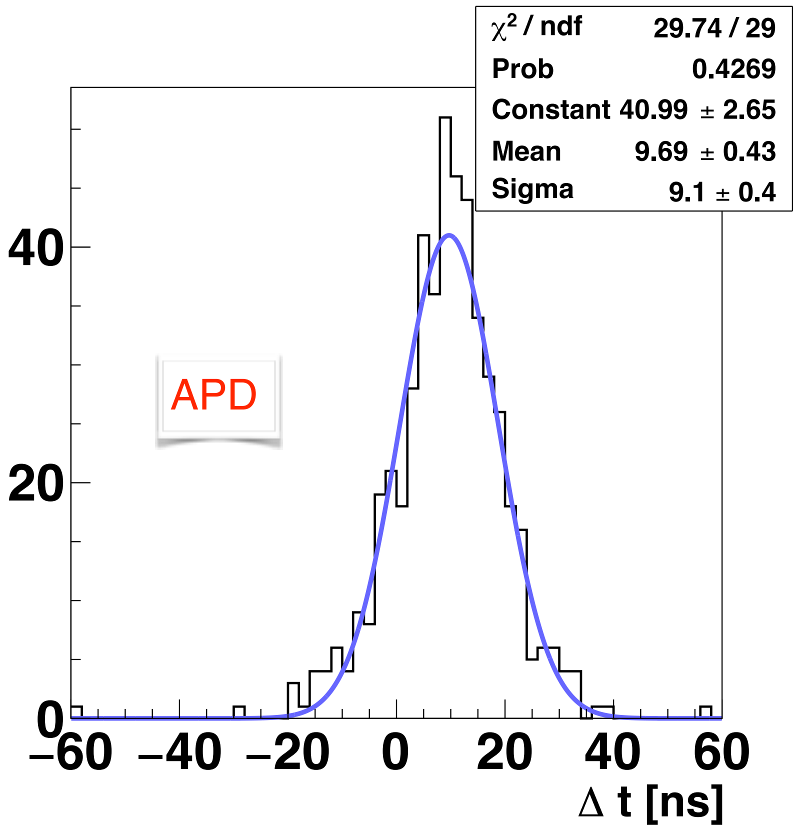


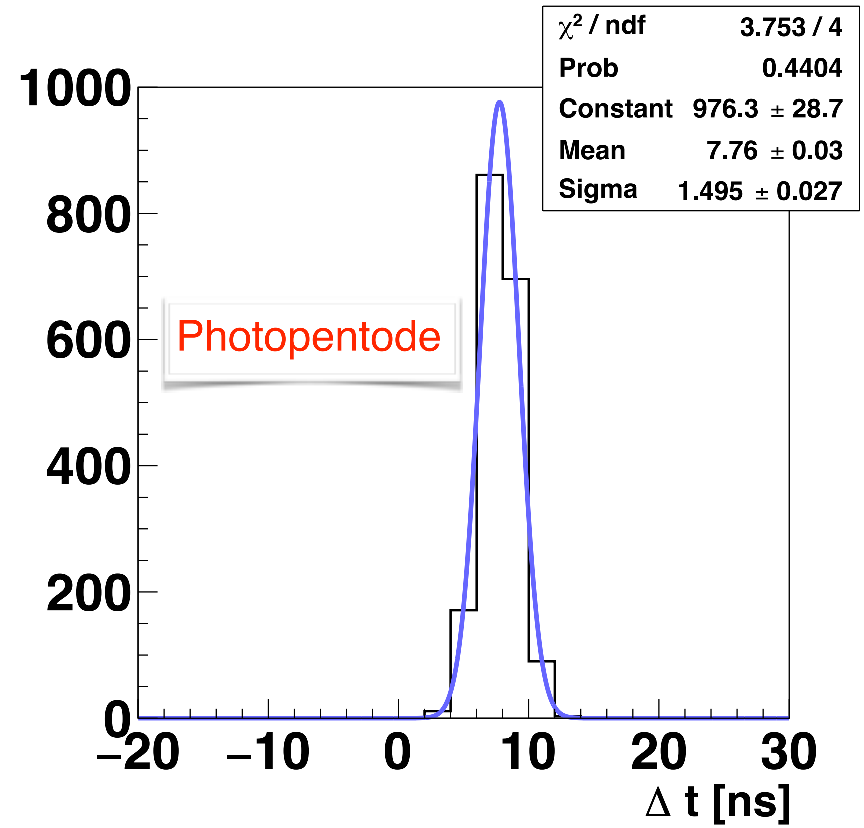
2 APDs on CsI(Tl)crystal



1 APD on CsI(Tl)crystal

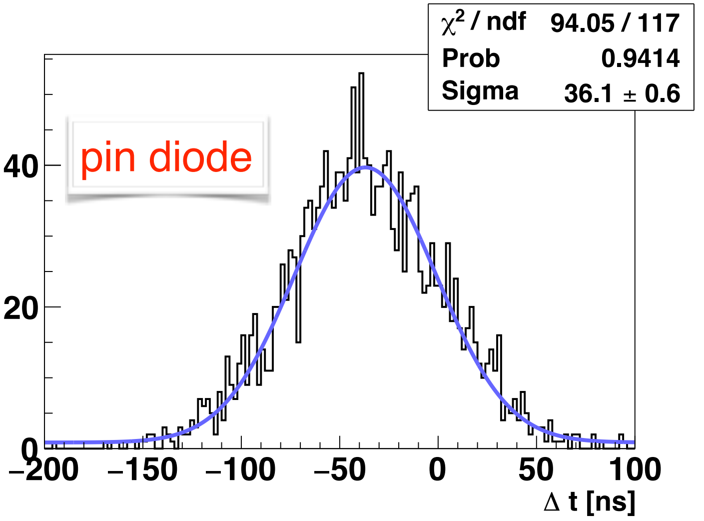
Time resolution — pure CsI

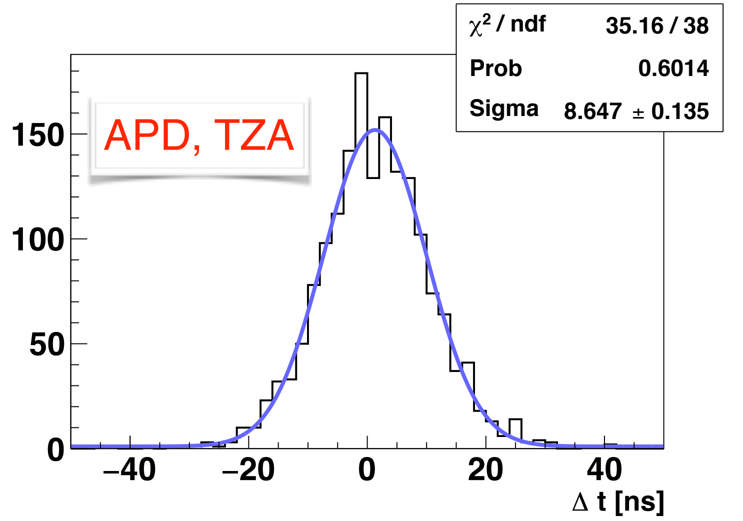


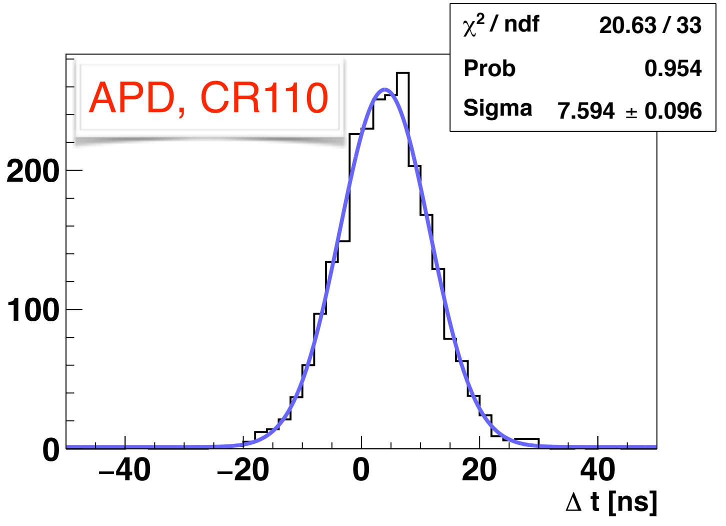


- $\sigma_t(E=100MeV)_{APD}$ = 1.2ns
- $\sigma_t(E=100MeV)_{PP}$ = 0.3ns

Time resolution — CsI(Tl)







- $\sigma_t(E=100MeV)_{PD}$ = 6.4ns
- $\sigma_t(E=100MeV)_{APD\text{-}TZA}$ = 1.5ns
- $\sigma_t(E=100MeV)_{APD\text{-}CR110}$ = 1.4ns

Improvement in time resolution will help background rejection in cluster reconstruction

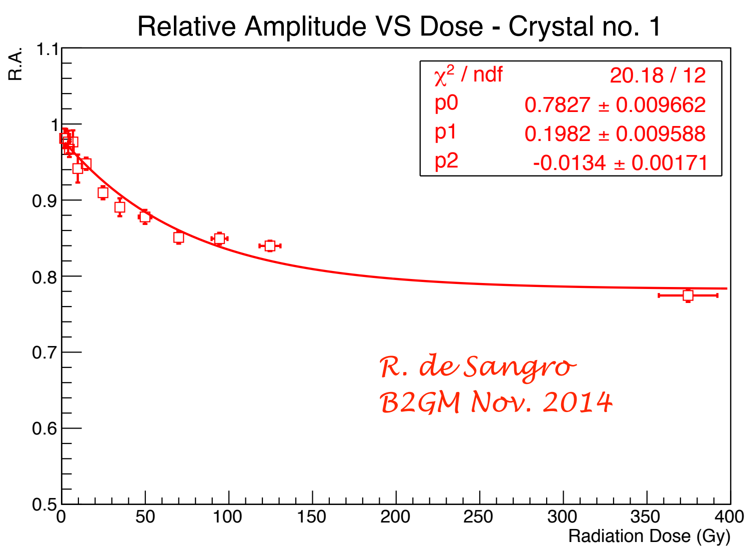
Summary and outlook (I)

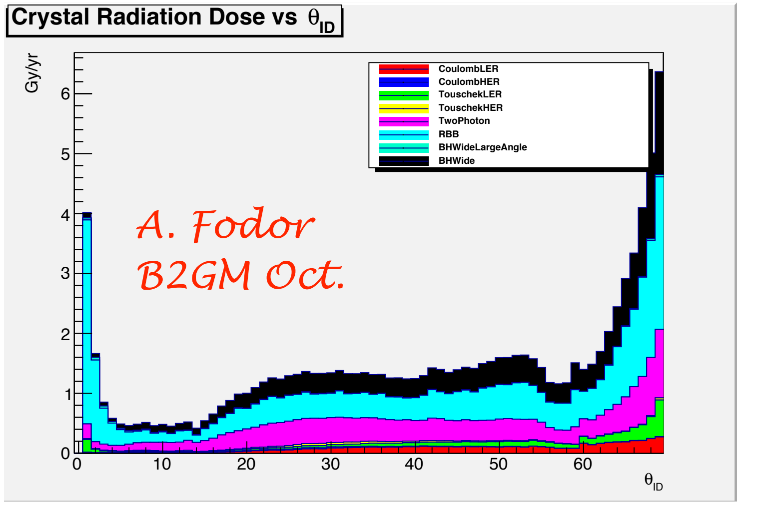
- As expected, the best performance with the expected backgrounds is obtained by pure CsI with photopentode readout
- Interestingly, we found that the capabilities of the present Belle calorimeter can be fully recovered by adding two APD photosensors to the CsI(Tl) crystals

Summary and outlook (II)

- We know that CsI(Tl) crystals are sufficiently radiation hard to survive for several Belle II lifetimes
- Background simulations predict larger (x3) backgrounds in the barrel than in the forward endcap

Irradiation Results





Summary and outlook (III)

- If backgrounds turn out to be too high, *the whole ECL will be affected,* making the replacement of the crystals *de facto* impossible

- Adding APDs to the present calorimeter may well become the only concrete solution

Summary and outlook (IV)

A 5h Belle2 note is in preparation

BELLE2-NOTE-TE-2017-015
Version 0.0
November 20, 2017

Comparison of cosmic-ray data results for different forward ECL upgrade options

R. de Sangro, G. Finocchiaro, B. Oberhof, P. Patteri, I. Peruzzi, M. Piccolo, A. Russo

Laboratori Nazionali di Frascati dell'INFN,
Via Enrico Fermi 40, 00044 Frascati, Italy

A. Aloisio, G. De Nardo, R. Giordano, M. Merola, C. Sciacca

Università Federico II e INFN Sezione di Napoli

C. Cecchi, E. Manoni, A. Rossi, G. Scolieri

Università di Perugia e INFN Sezione di Perugia

F. Ameli, S. Baccaro, A. Cemmi, S. Fiore, M. Montecchi

INFN Sezione di Roma "La Sapienza"

E. Bernieri, P. Branchini, A. Budano, F. Budano, E. Graziani, A. Passeri, D. Tagnani

INFN Sezione di RomaTre Via Della Vasca Navale 84 00146, Italy

Abstract

In this note we discuss results from cosmic ray data collected in a number of different configurations, corresponding to possible options proposed for the upgrade of the Belle II forward electromagnetic calorimeter. In particular, we consider a pure CsI calorimeter with photopentode or large-area APD (LAAPD) readout. The use of optical filters and wavelength shifters with LAAPDs is also studied. Finally, we investigate the possibility of retaining the CsI(Tl) crystals with pin diode photosensors of the present Belle calorimeter, adding two LAAPDs with either transconduttance or charge integrating amplifier readout. Finally, a comparison of the performance of the various options in terms of energy and time resolution is presented.

BELLE2-NOTE-TE-2017-005
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May 31, 2017

Performance study of CsI(Tl) and pure CsI crystals with cosmic rays

R. de Sangro, G. Finocchiaro, B. Oberhof, P. Patteri, I. Peruzzi, M. Piccolo, A. Russo

Laboratori Nazionali di Frascati dell'INFN,
Via Enrico Fermi 40, 00044 Frascati, Italy

A. Aloisio, G. De Nardo, R. Giordano, M. Merola, C. Sciacca

Università Federico II e INFN Sezione di Napoli

C. Cecchi, E. Manoni, A. Rossi, G. Scolieri

Università di Perugia e INFN Sezione di Perugia

F. Ameli, S. Baccaro, A. Cemmi, S. Fiore, M. Montecchi

INFN Sezione di Roma "La Sapienza"

E. Bernieri, P. Branchini, A. Budano, F. Budano, E. Graziani, A. Passeri, D. Tagnani

INFN Sezione di RomaTre Via Della Vasca Navale 84 00146, Italy

Abstract

In this note we report results obtained on characterization of CsI(Tl) and pure CsI scintillating crystals with cosmic rays. Relevant observable as number of photoelectrons, equivalent noise energy and energy resolution were measured. Comparisons of performances are presented.

BELLE2-NOTE-TE-2017-006
Version 1.0
May 31, 2017

Characterization of Large Area APD

R. de Sangro, G. Finocchiaro, B. Oberhof, P. Patteri, I. Peruzzi, M. Piccolo, A. Russo

Laboratori Nazionali di Frascati dell'INFN,
Via Enrico Fermi 40, 00044 Frascati, Italy

A. Aloisio, G. De Nardo, R. Giordano, M. Merola, C. Sciacca

Università Federico II e INFN Sezione di Napoli

C. Cecchi, E. Manoni, A. Rossi, G. Scolieri

Università di Perugia e INFN Sezione di Perugia

F. Ameli, S. Baccaro, A. Cemmi, S. Fiore, M. Montecchi

INFN Sezione di Roma "La Sapienza"

E. Bernieri, P. Branchini, A. Budano, F. Budano, E. Graziani, A. Passeri, D. Tagnani

INFN Sezione di RomaTre Via Della Vasca Navale 84 00146, Italy

Abstract

Analysis of the data collected at LNF with our cosmic ray set-up is presented: a novel and direct method to measure the gain of Large Area APDs used to read out pure CsI crystals is discussed in detail. Based on this gain measurement performed in the actual APD working conditions, we present results for the APD excess noise factor.

BELLE2-NOTE-TE-2017-007
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April 15, 2017

Study of pile-up effect on CsI(Tl) and pure CsI crystals performance

R. de Sangro, G. Finocchiaro, B. Oberhof, P. Patteri, I. Peruzzi, M. Piccolo, A. Russo

Laboratori Nazionali di Frascati dell'INFN,
Via Enrico Fermi 40, 00044 Frascati, Italy

A. Aloisio, G. De Nardo, R. Giordano, M. Merola, C. Sciacca

Università Federico II e INFN Sezione di Napoli

C. Cecchi, E. Manoni, A. Rossi, G. Scolieri

Università di Perugia e INFN Sezione di Perugia

F. Ameli, S. Baccaro, A. Cemmi, S. Fiore, M. Montecchi

INFN Sezione di Roma "La Sapienza"

E. Bernieri, P. Branchini, A. Budano, F. Budano, E. Graziani, A. Passeri, D. Tagnani

INFN Sezione di RomaTre Via Della Vasca Navale 84 00146, Italy

Abstract

The effect of pile-up from low-energy photons on the response of pure CsI and CsI(Tl) crystals in cosmic rays is studied using a data-driven and a Toy MC background simulation, and a high-intensity ^{60}Co radioactive source. Results for the Equivalent Noise Energy and the stochastic fluctuations in the energy measurement are presented as a function of the background level.

Version 1.0
June 19, 2017

A low noise front-end for the Belle II forward electromagnetic calorimeter upgrade

G. Corradi

Laboratori Nazionali di Frascati dell'INFN,
Via Enrico Fermi 40, 00044 Frascati, Italy

A. Aloisio, G. De Nardo, R. Giordano, M. Merola, C. Sciacca

Università Federico II e INFN Sezione di Napoli

C. Cecchi, E. Manoni, A. Rossi, G. Scolieri

Università di Perugia e INFN Sezione di Perugia

F. Ameli, S. Baccaro, A. Cemmi, S. Fiore, M. Montecchi

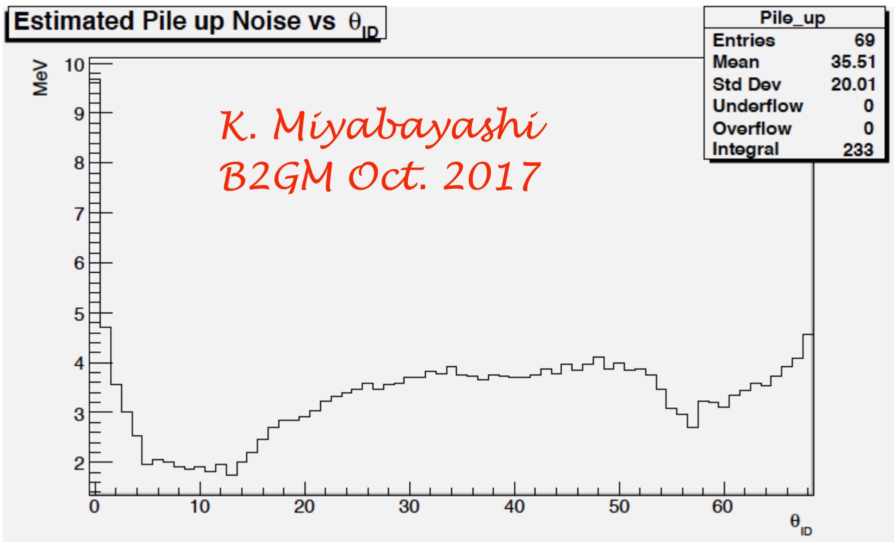
INFN Sezione di Roma "La Sapienza"

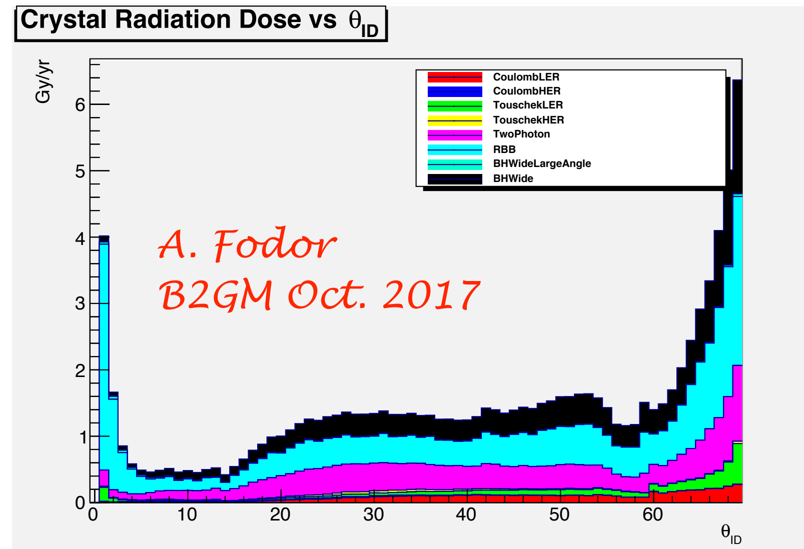
E. Bernieri, P. Branchini, A. Budano, F. Budano, E. Graziani, A. Passeri, D. Tagnani

INFN Sezione di RomaTre Via Della Vasca Navale 84 00146, Italy

Backup

Belle II background predictions in ECL





i.e., with the exception of the first three rings,

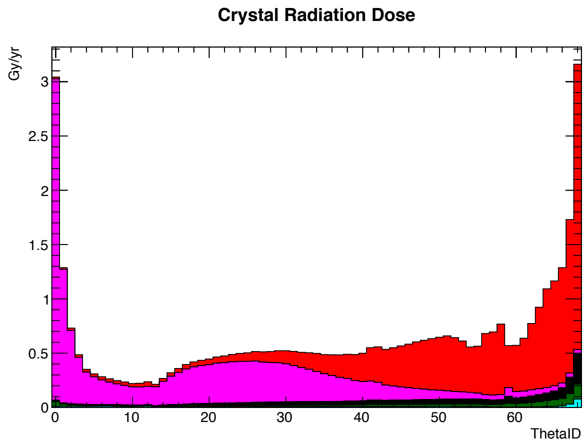
the pile-up noise is smaller in the FWD endcap

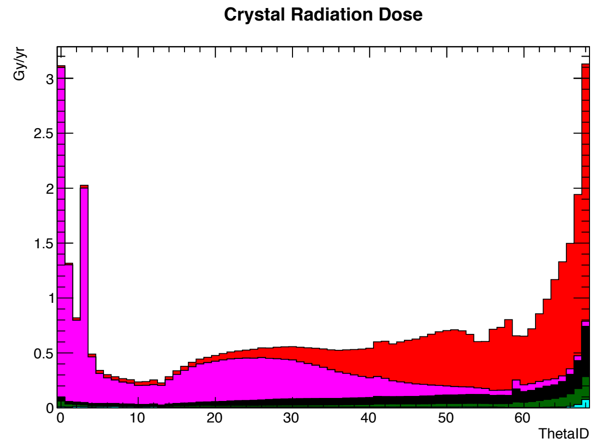
than elsewhere (the full MC says).

Belle II background predictions in ECL

Radiation Dose in Crystals

RBB LER
RBB HER
Touschek LER
Touschek HER
Coulomb LER
Coulomb HER



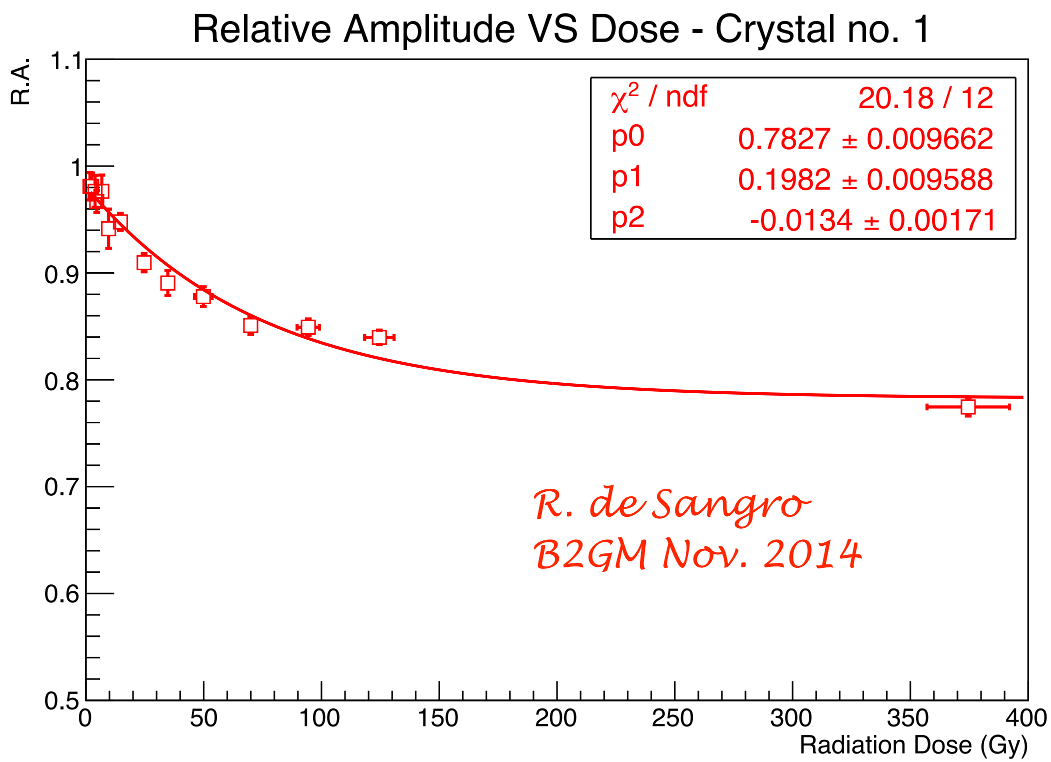


- 11th Campaign
- Maximum dose of 3.1 Gy/yr

- 10th Campaign
- Maximum dose of 3.1 Gy/yr

Crystal ageing

Irradiation Results

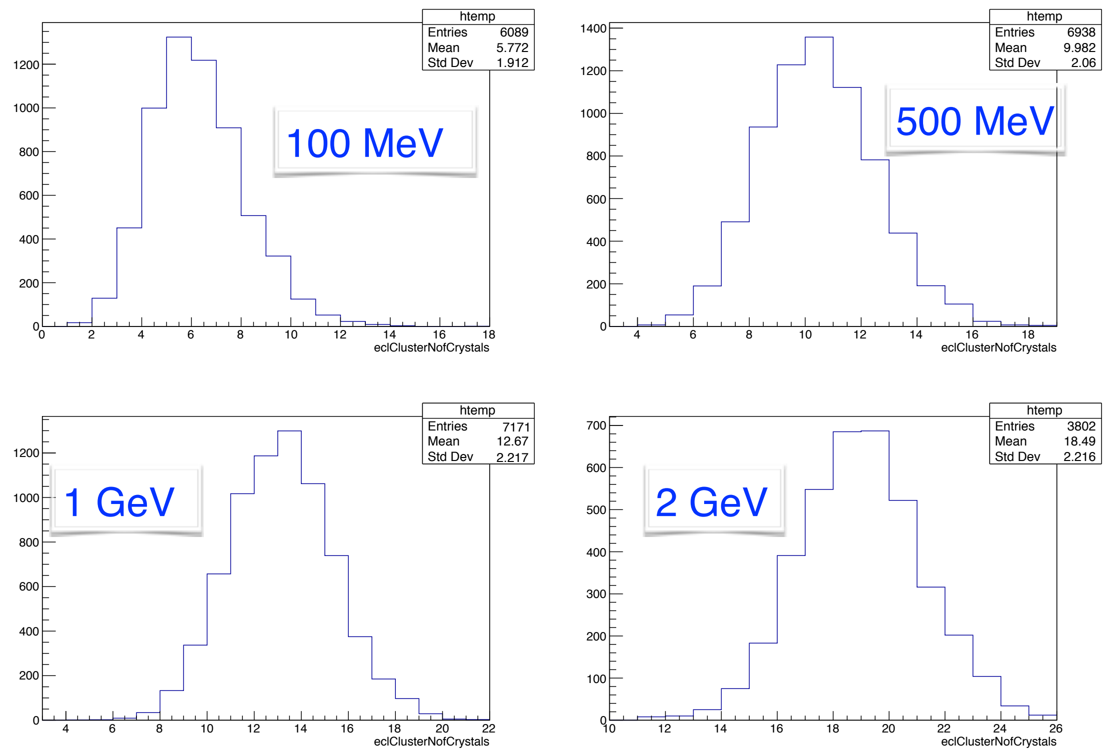


One additional point at 375 Gy for crystal 1

9

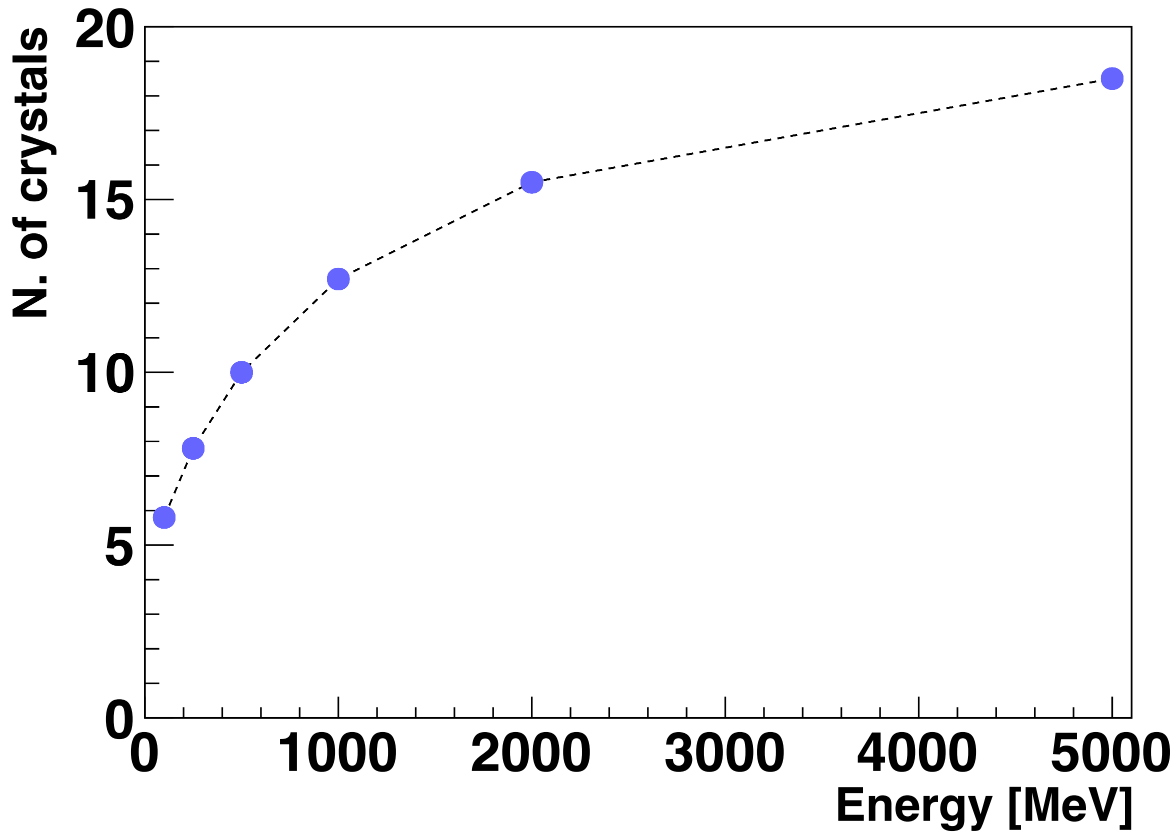
How many crystals in a cluster?

The electronics noise contribution **a** depends on the number of crystals in the cluster (energy threshold to include crystals in a cluster)



N. of crystals/cluster vs. photon energy from current clustering algorithm

How many crystals in a cluster?



Use parameterisation of n. of crystals vs. E in single photon events.

Expect this to be an upper limit in real physics events