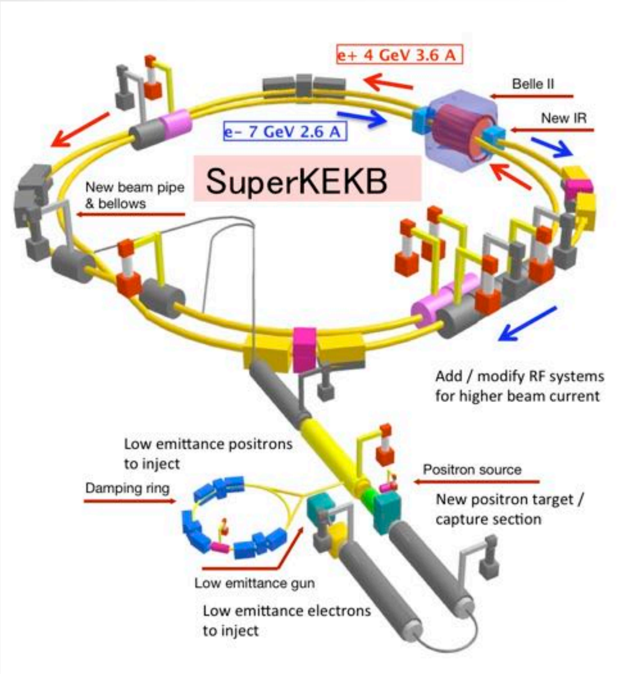
A pure CsI Calorimeter for the BelleII experiment at SuperKEKB

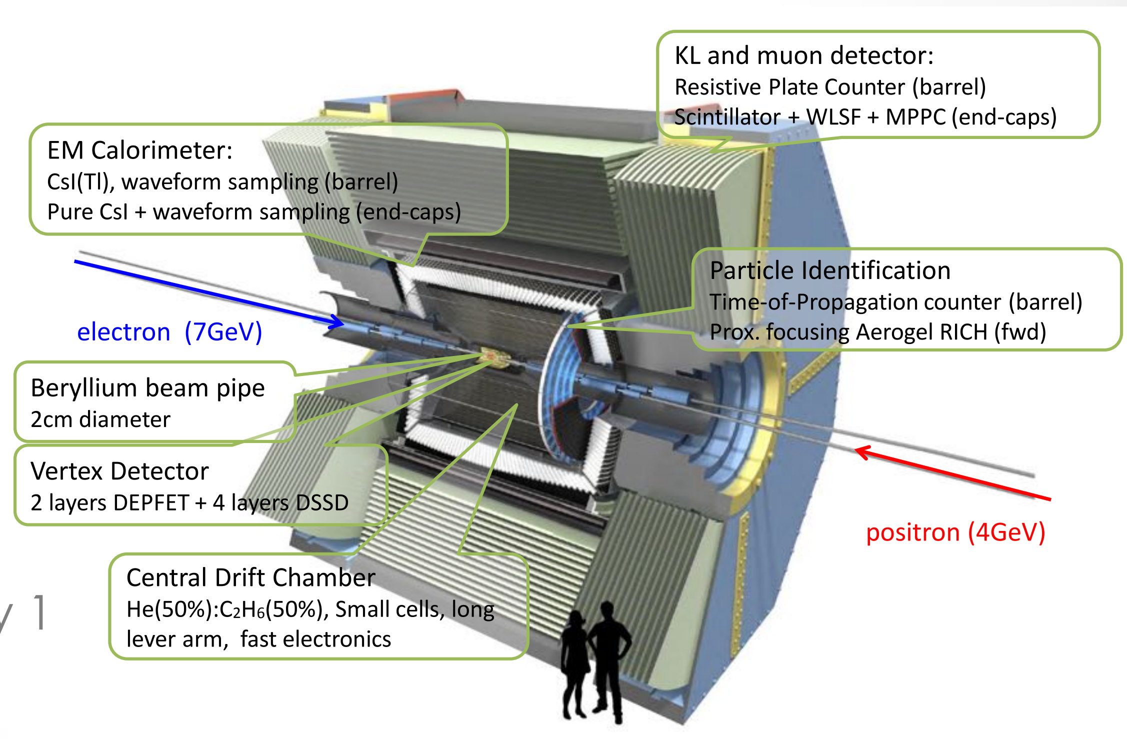
A. Rossi for the Italian BelleII-ECL group

Frontier Detector for Frontier Physics
13th Pisa meeting on Advanced Detectors

BelleII at SuperKEKB

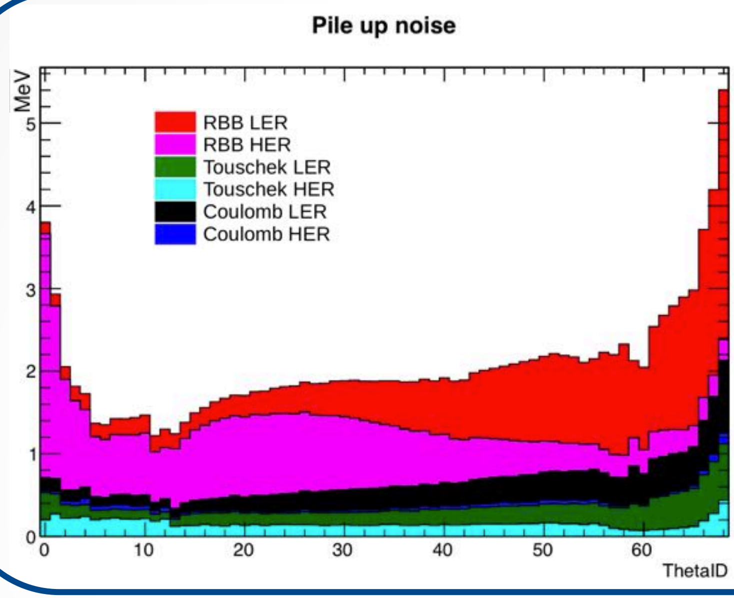


- Luminosity goal: 8×10^{35} cm^{-2} s^{-1}
  - using a large crossing-angle at IP
  - squeezing the beams to nanometre-scale
- ~50ab^{-1} in 10 years operation



- Redesign of all subdetectors
- Add 2 pixel layers as vertex detector
- Add Fwd PID
- Pure CsI upgrade not for day 1

Fwd ECL Upgrade



Last results from BelleII MC simulations

Samuel de Jong (UVic)
20th BelleII General Meeting

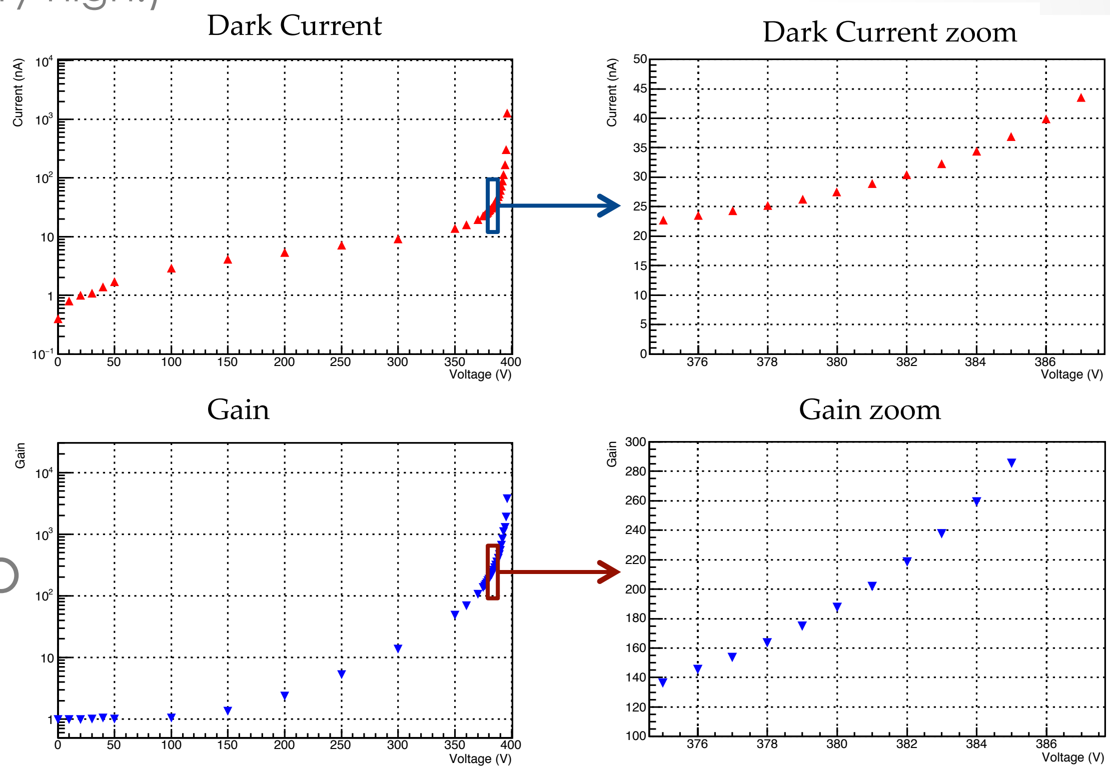
- Pile up greater than 2MeV on fwd and bwd region
  - High background rate expected
  - CsI(Tl) slow crystal (500ns shaping for BelleII)
- A faster crystal would decrease pile up considerably

Pure CsI vs CsI(Tl)

- Pure CsI crystal has been proposed to replace CsI(Tl) in the forward region
- Pure CsI Pros
  - Same density (i.e Molier Radius, X0 …) of CsI(Tl), no mechanical structure replacement needed
  - Fast response, ~25ns vs 1200ns of CsI(Tl)
- Pure CsI Cons
  - Low light yield, ~4% of CsI(Tl)
  - Near UV emission (315nm)
- Two type of sensors have been proposed:
  - Photopentode:
    - PMT with 5 amplification stage (G~180 in B field of ~1T)
    - big cathode surface (2inch diameter) and a good QE at 315nm (~40%) but for this option the back plane of the mechanical structure need to be replaced
  - Large Area APD:
    - 1x1 cm2 with G~200
    - mechanical structure can be used as it is but reaching a good S/N is challenging

Preliminary Test on APD (I)

- Special Large Area APD from Hamamatsu
  - Standard design gain is 50, we use only selected APDs in order to work at G=200 with $\Delta V > 20V$
  - Typical I_{dark}~30nA
  - Capicitance 270pF (very high!)
  - QE at 315nm ~ 40%

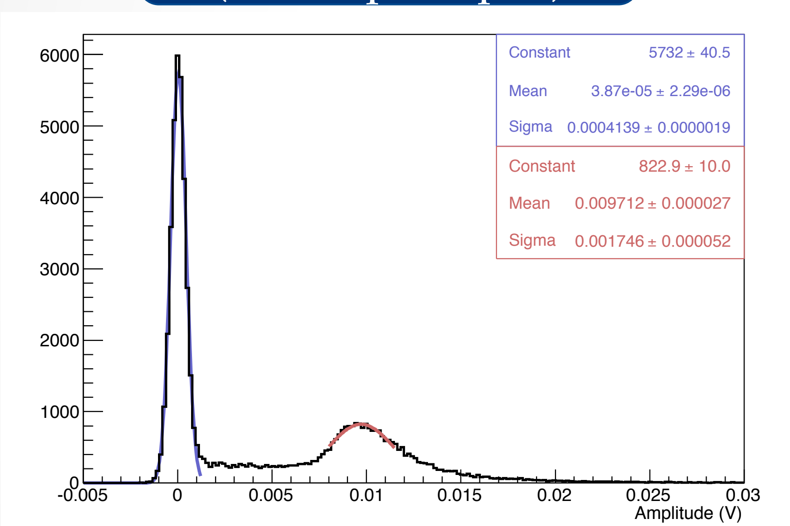


- 2 APDs for each crystal with separate readout electronics
- Cosmic rays test to optimize the S/N

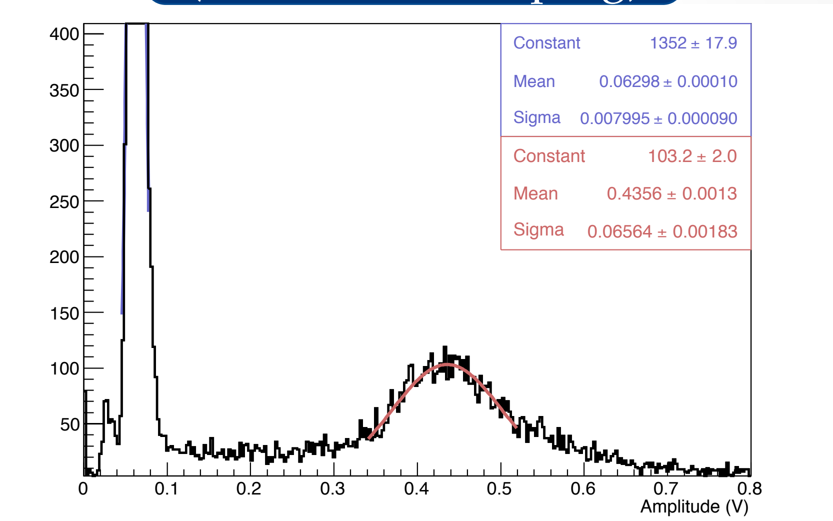
Preliminary Test on APD (II)

- 2 APDs for each crystal with separate readout electronics
- Cosmic rays test to optimize the S/N

2APD combined (Preamp output)



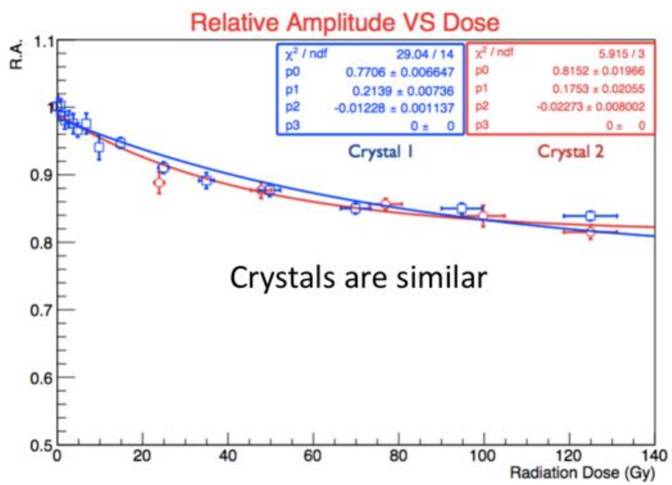
2APD combined (After 100ns shaping)

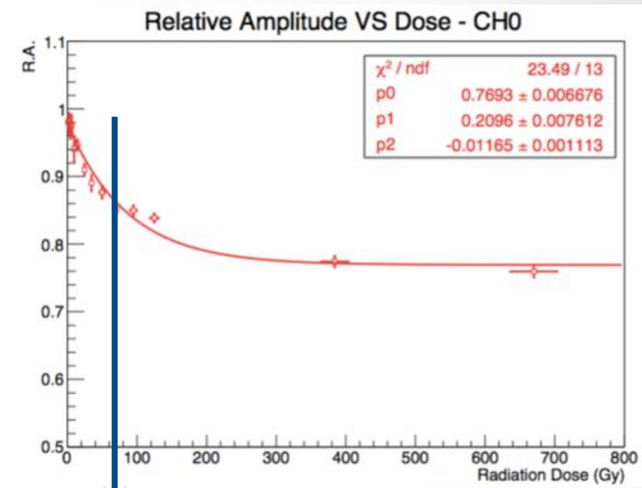


- Cosmic deposited energy 30MeV
- Equivalent Noise Energy
  - Preamp output 1.3MeV
  - Shaper output 0.7MeV

CsI(Tl) Radiation Hardness

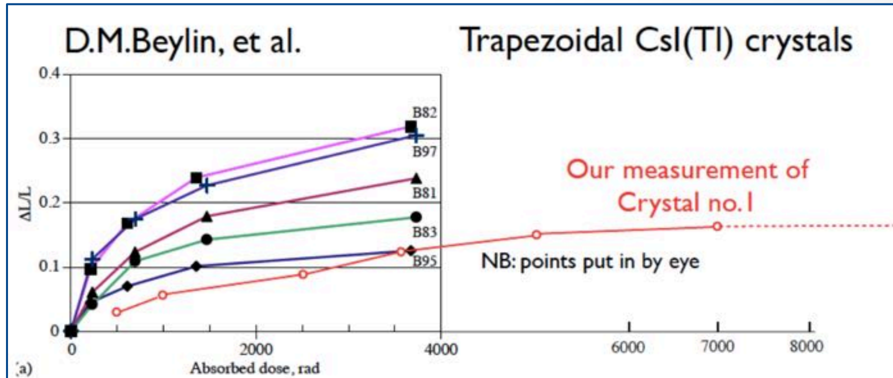
2 Belle spare crystals has been used to test CsI(Tl) radiation hardness





Expected dose after 10y at BelleII

- Irradiation at Calliope facility at ENEA Casaccia
  - Co60 source
- 20% Light Yield loss after 150Gy
- Saturation after 400Gy

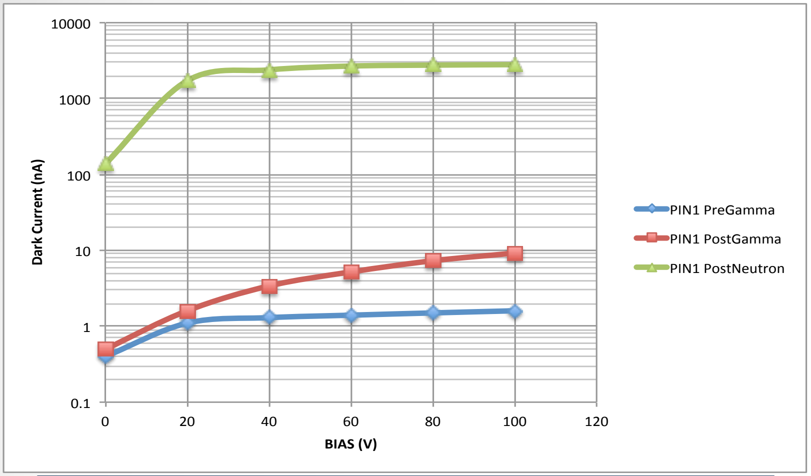


Nuclear Instruments and Methods in Physics Research A 541 (2005) 501–515

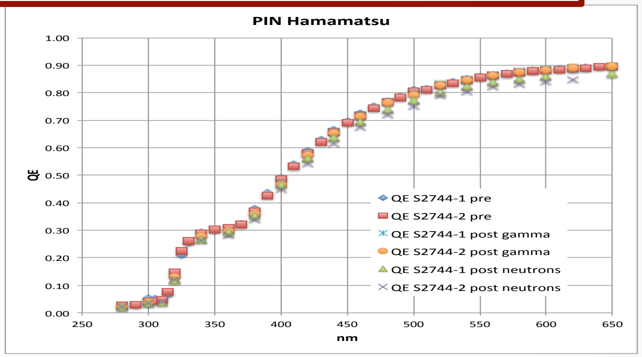
PiN/APD Radiation Hardness

- 250Gy with gamma at ENEA Casaccia
  - x4 expected dose
- 10^{12} neutrons/cm^2 at ENEA Frascati
  - x4 expected dose

- **HAMAMATSU PIN S2744-08**

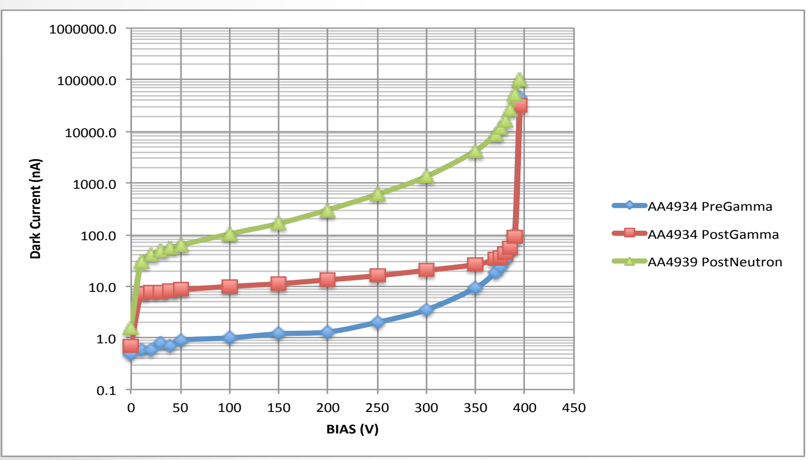


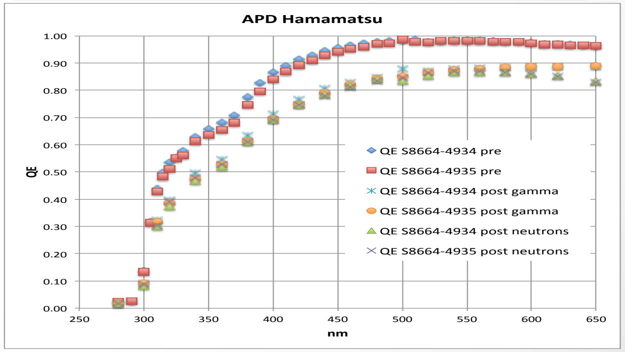
Orders of magnitude increase after neutrons



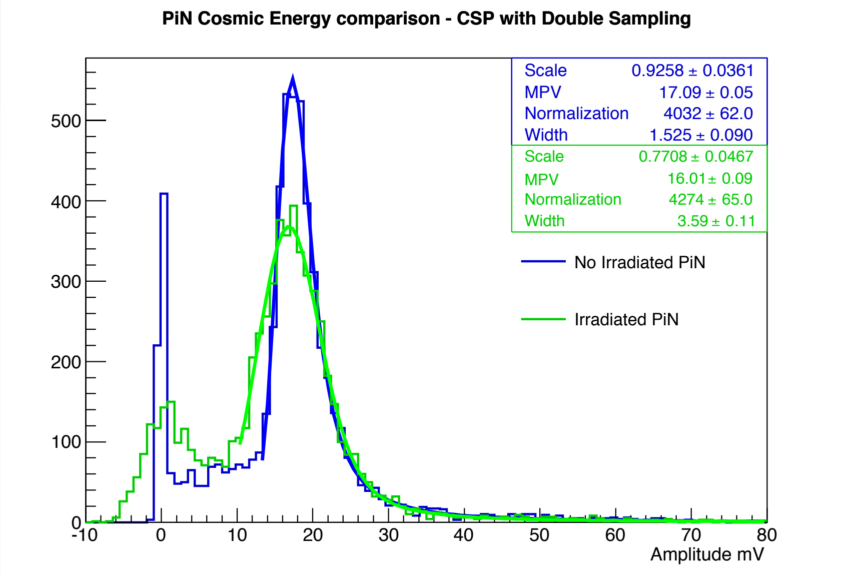
Stable QE for PIN
QE decrease for APDs after gamma, no further effects by neutrons

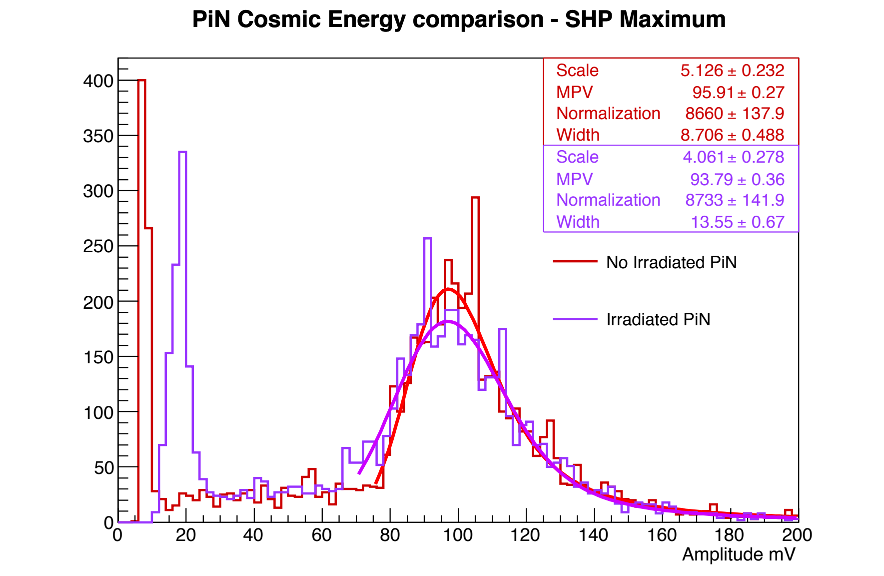
- **HAMAMATSU LAAPD S8664-1010**





PiN Noise after Irradiation





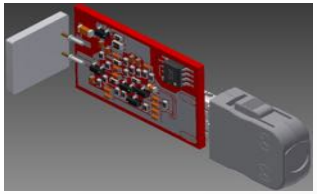
- **After Charge Sensitive Preamplifier (CSP)**
  - ENE : NoIrr. **~630KeV** → Irr. **~4.9MeV**
- **After Shaping (SHP)**
  - ENE : NoIrr. **~220KeV** → Irr. **~1.14MeV**

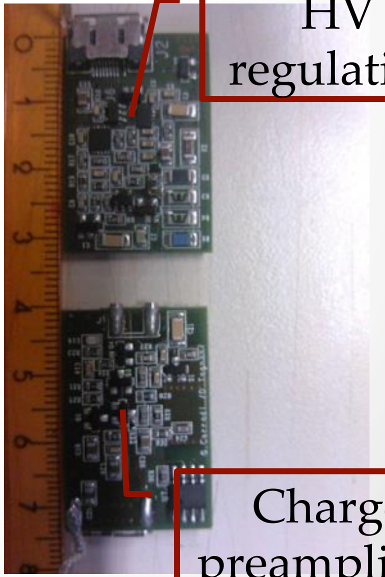
Same studies have to be done for APDs

Matrix Prototype

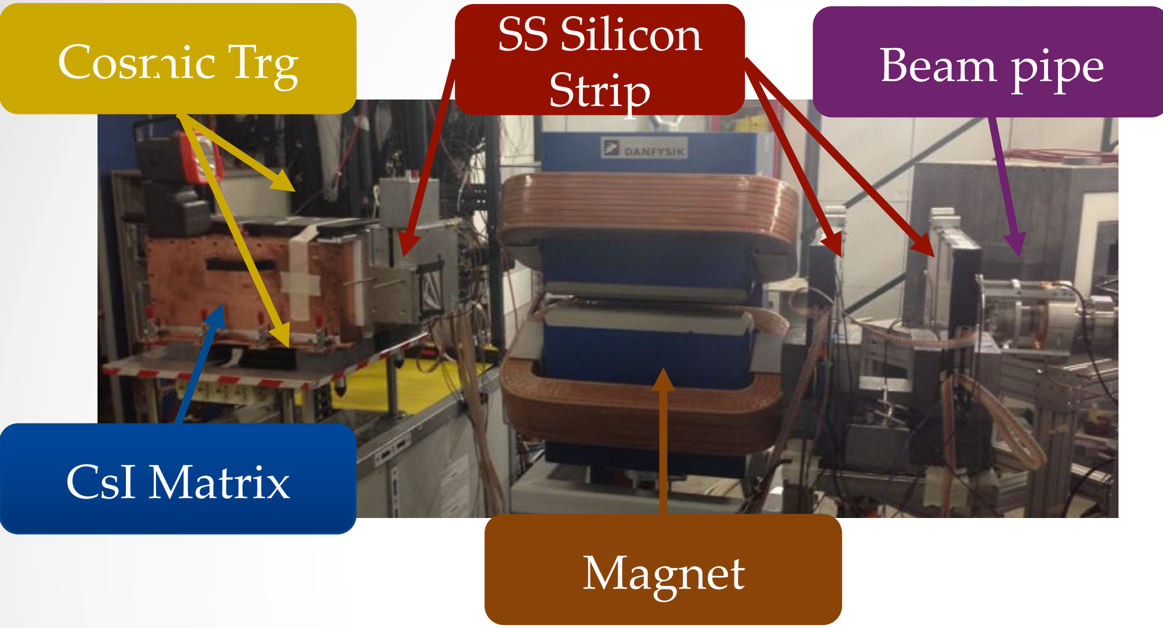
- 4x4 CsI Pure crystals (all produced by Amcrys)
  - Qualification of an Italian producer (Optomaterials) is ongoing
  - First preliminary results shows a very good quality
- Each crystal equipped with 2 Hamamatsu LA-APD
- Each APD is readout with 1 Charge preamplifier
- Single channel HV regulation on frontend board
- 1 temperature sensor (Maxim 1-wire) for each channel

Charge – Preamplifier
Custom discrete amplifier at BJT transistor.
Gain = 1.4V/pC
Power dissipation = 16mW
Single power = 6V to GND
Dynamic Range 2.2V
Tau IN = 40ns





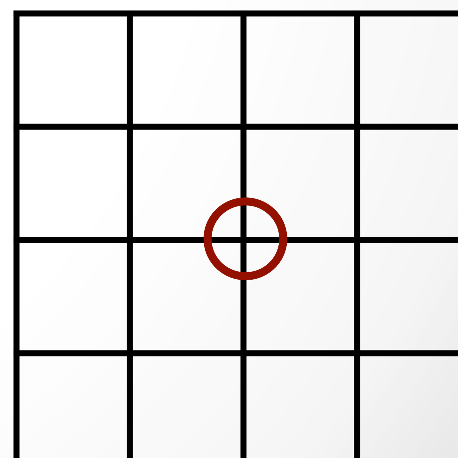
Beam Test @ LNF



Beam Test Facility (BTF) @ LNF

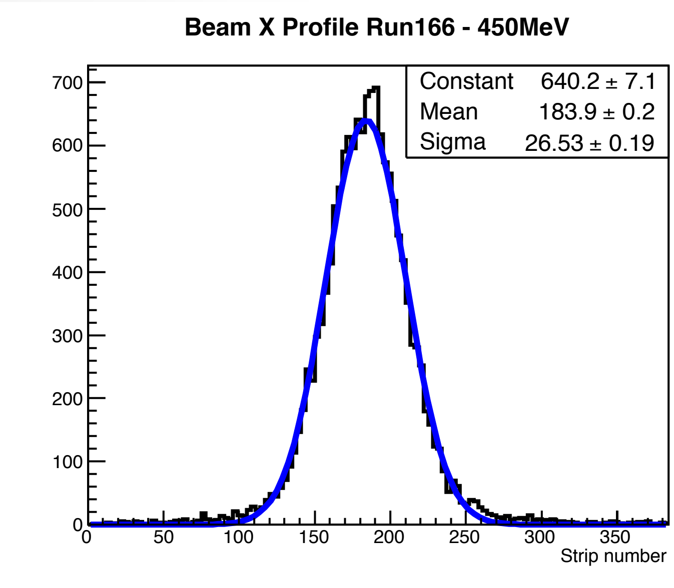
- LINAC electron (500MeV) on tungsten target
- Energy selection of secondary electrons with 2 dipole magnets
  - From ~480MeV down to 50MeV
- Multiplicity selected with slits
  - $1\text{-}10^{9}$ electrons/spill

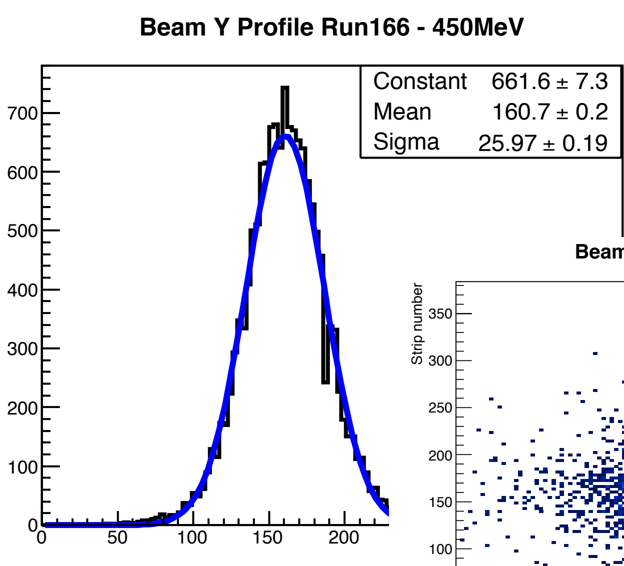
- Data collected at different energies
  - 100, 200,300,400,450 MeV
  - From MC best position is in a circle with R=1.5cm from center
- Night acquisitions with cosmic trigger for calibration
- Data acquired also with magnet between silicon boxes ON but not analyzed yet (not in this talk)

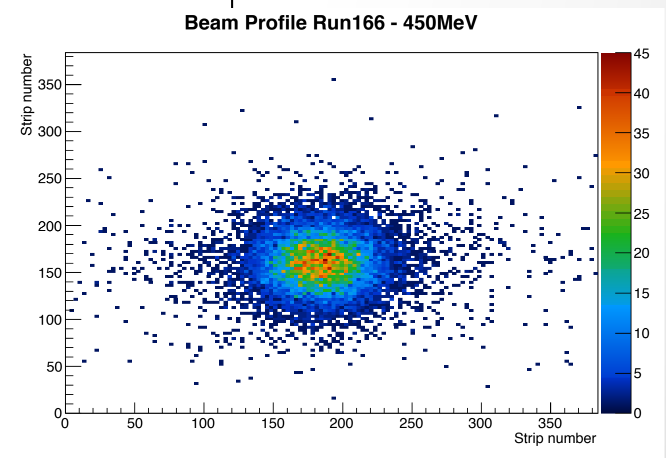


Position Selection

- For each run two cuts are applied:
  - Only 1 cluster reconstructed on each plane
  - Position selection of ½ σ around the mean value
    - Mean value change slightly between different run



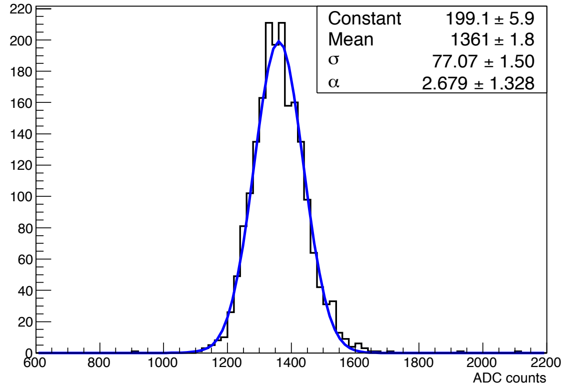




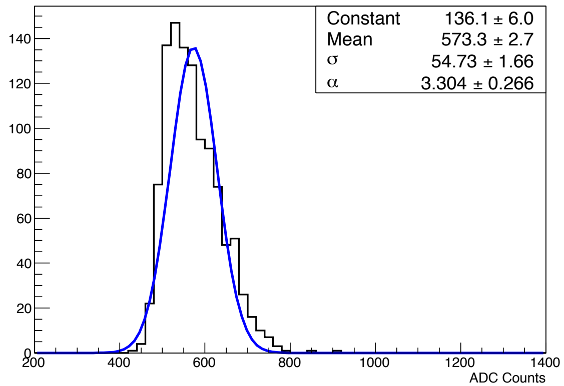
Beam Test results (I)

INFN Istituto Nazionale di Fisica Nucleare

450MeV – CSP output

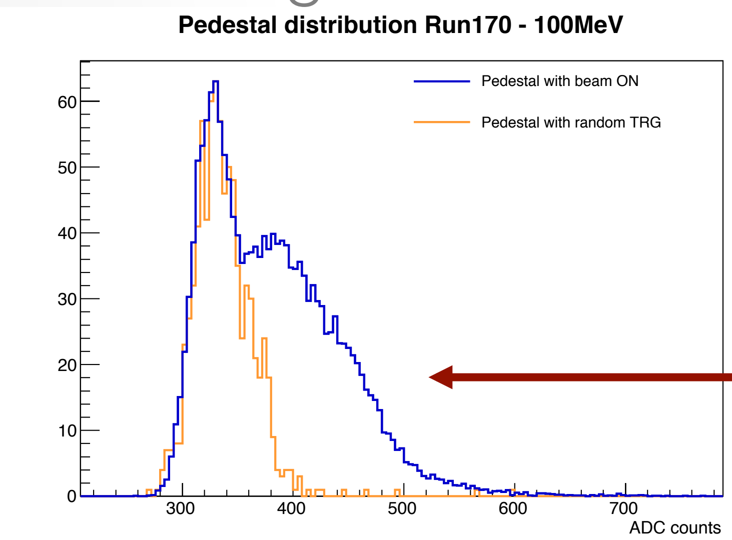


100MeV – CSP output



Calibration and temperature correction parameter extracted from cosmic data and applied event-by-event

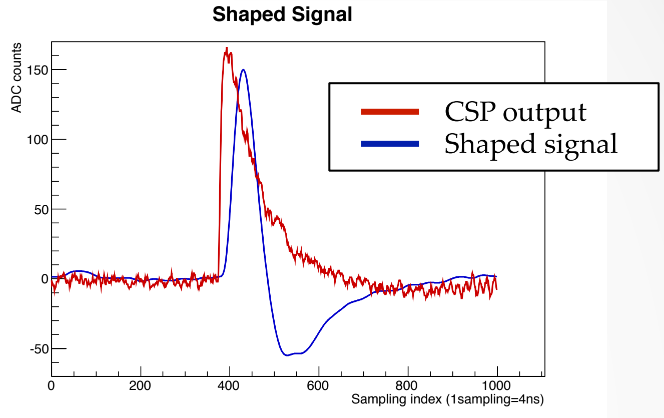
We found some distortion on energy distribution mainly at low energies



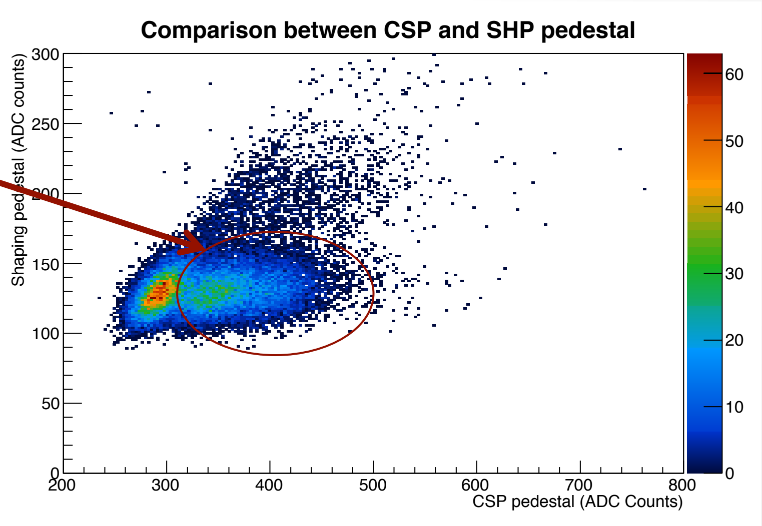
- This is due to pickup noise synchronous to BTF RF trigger
- This is evident when a comparison between pedestal with random trigger and pedestal with BTF RF trigger is performed

Software Shaping

- We apply a software shaping in order to "simulate" the effect of a CR-RC^4 shaping with time constant 100ns



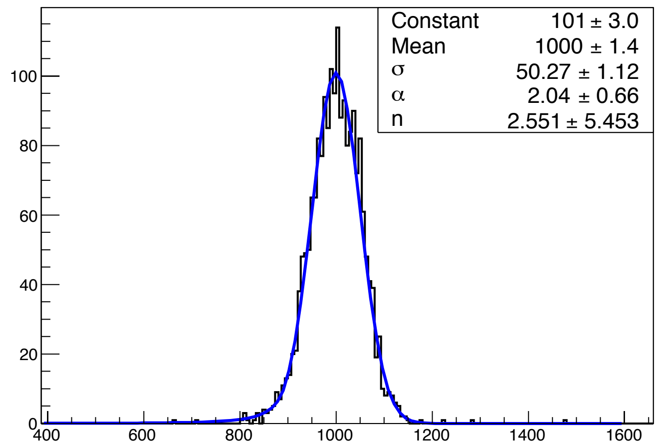
- The CR-RC filter cut the frequency of the pickup noise (or at least the noise is attenuated)



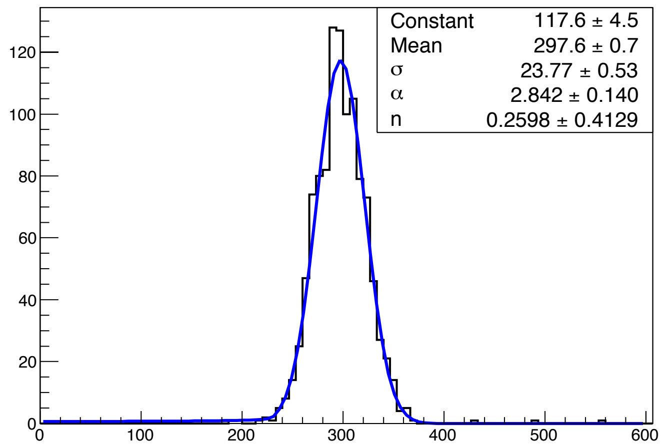
Beam Test results (II)

Energy distribution fit to shaped signals

450MeV – SHP 100ns

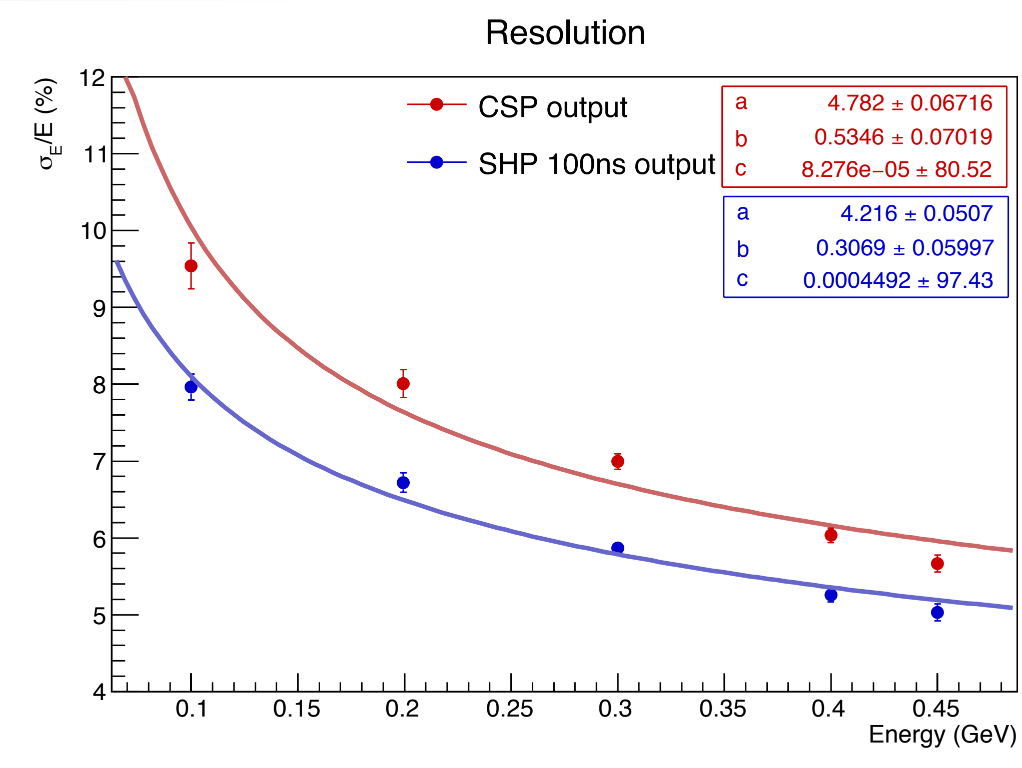


100MeV – SHP 100ns



- Energy distribution with expected shape
- Better results wrt the CSP output

Beam Test results (III)



Fit function: $\sigma(E)/E = \frac{a}{\sqrt[4]{E}} \oplus \frac{b}{E} \oplus c$

- Resolution compromised by the pickup noise
- Another effect is the beam degradation due to multiple scattering
  - Matrix – Beam pipe distance ~1.7m
  - 8 silicon layer 400 μ m each
- constant parameter c not extracted correctly
  - Probably due to the few energy points

Conclusions

- BelleII calorimetry upgrade in the forward region is under study
- Pure CsI crystal with large area APDs has been proposed as possible upgrade
  - Fast crystal but low light yield
  - With APDs all mechanical structure don't need to be replaced
- With APD readout reaching a good S/N is challenging
- Lab. test show the an ENE of ~0.7MeV is feasible
- CsI(Tl) gamma irradiation shows a Light loss of 20% and then saturation
- PiN/APD after irradiation shows a dark current increase of 2 order of magnitude
  - ENE of CsI(Tl)+PiN increase of a factor 6
- First beam test with 4x4 crystal matrix
  - Resolution higher than expected
  - Some problems with pickup noise
  - Beam degradation due to multiple scattering
- New beam test at Mainz at the end of July
  - Tagged photon facility

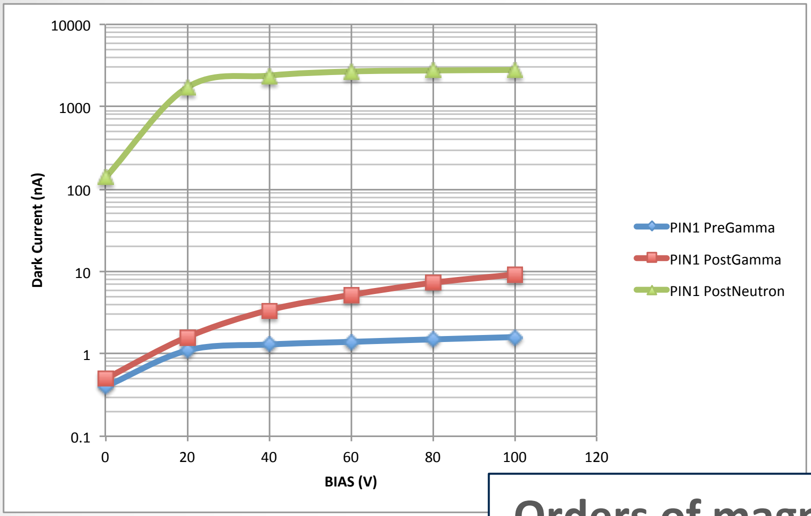
Backup

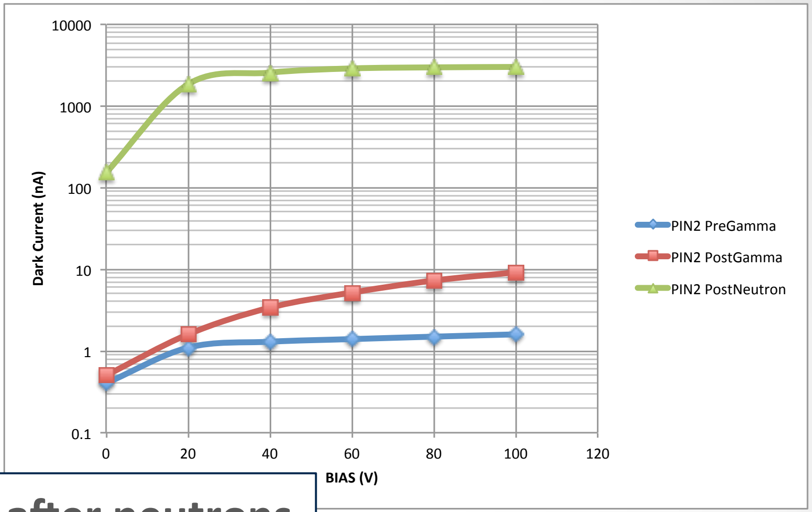
Readout sensor for Pure CsI

- The low light yield implies a "on sensor" gain factor
- Two type of sensors have been proposed:
  - Photopentode: PMT with 5 amplification stage (G~180 in B field of ~1T)
  - Large Area APD: 1x1 cm2 with G~200
- Photopentode have a big cathode surface (2inch diameter) and a good QE at 315nm (~40%) but for this option the back plane of the mechanical structure need to be replaced
- With APDs the mechanical structure can be used as it is but reaching a good S/N is challenging

PiN/APD Radiation Hardness

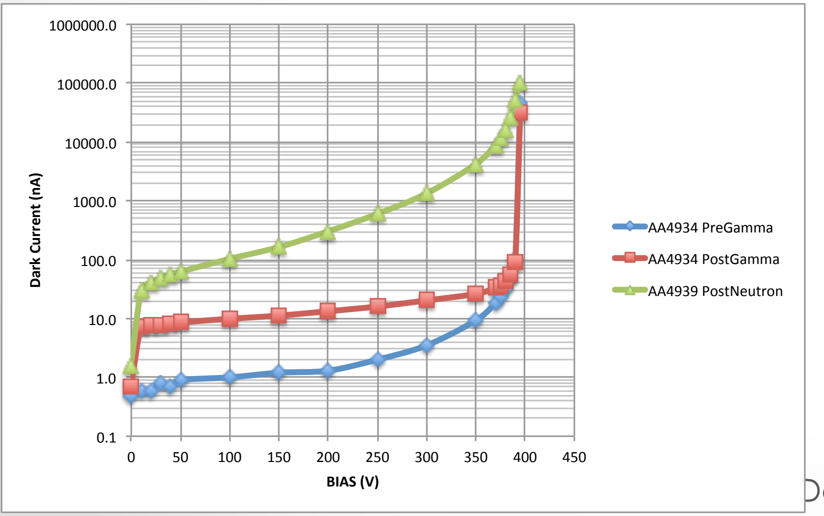
HAMAMATSU PIN S2744-08

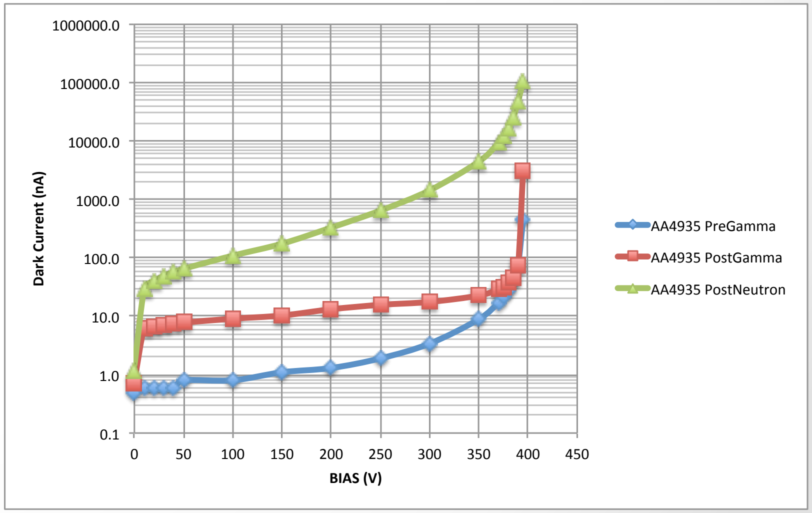




Orders of magnitude increase after neutrons

HAMAMATSU LAAPD S8664-1010

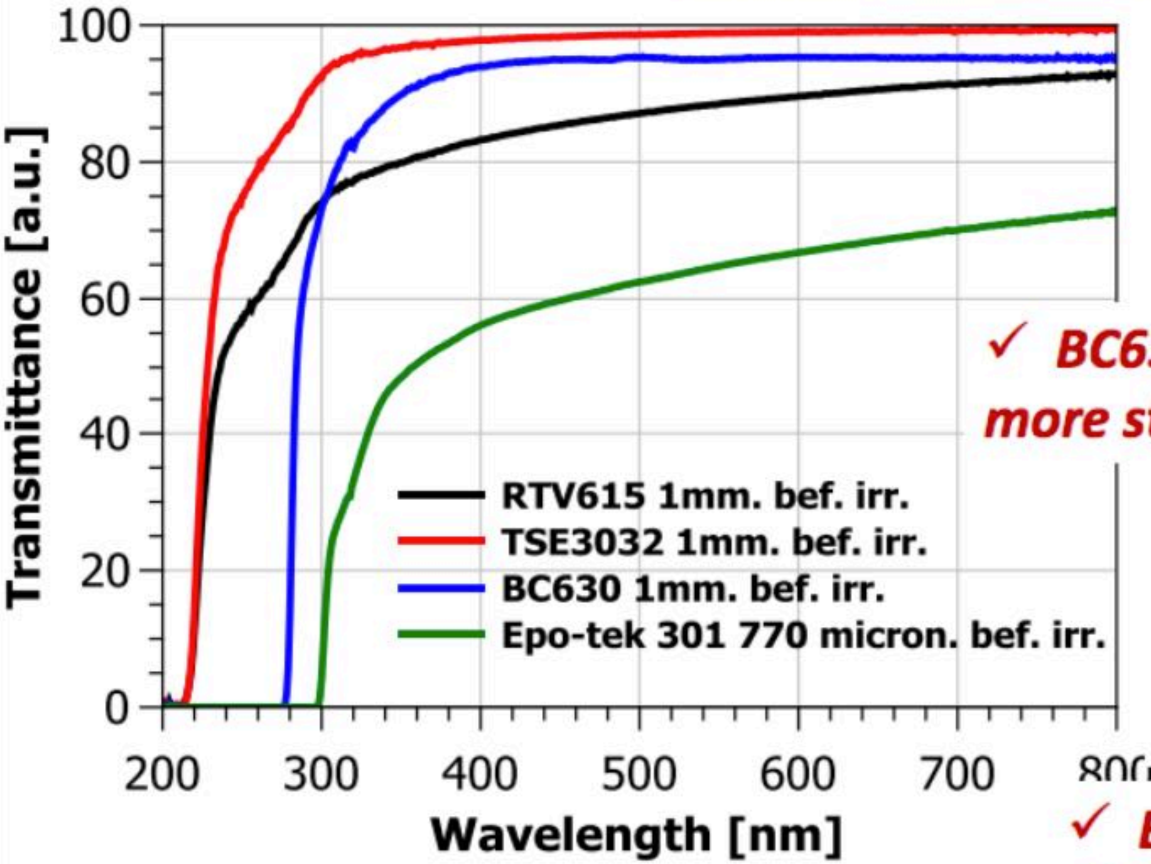




Optical Coupling Materials

Transmittance curves
Range: 200-800 nm

Dose rate: **5 Gy_{air}/h**
Total absorbed doses: **up to 44 Gy in air, at RT**



under irradiation (13.2Gy):

- ✓ ***BC630 and RTV615:*** ***more stable*** *(ΔT% @ 315 nm = - 2%)*

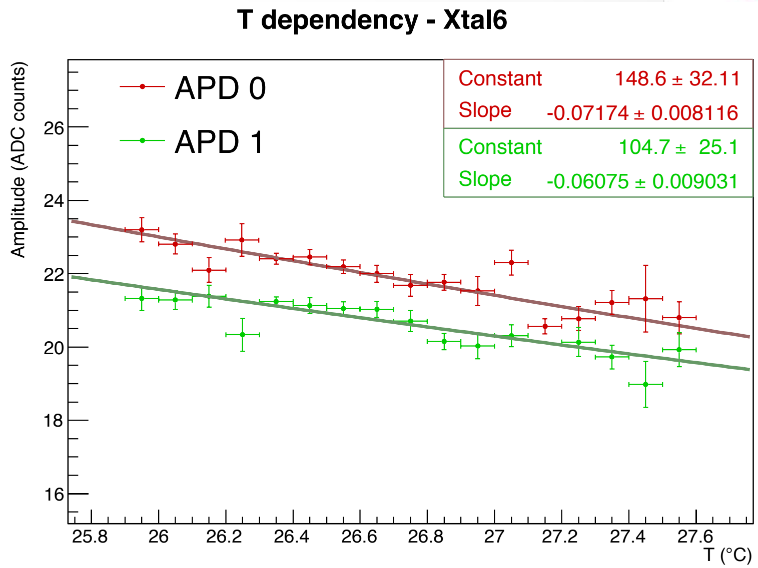
after irradiation
(stability ~ 30 days) :

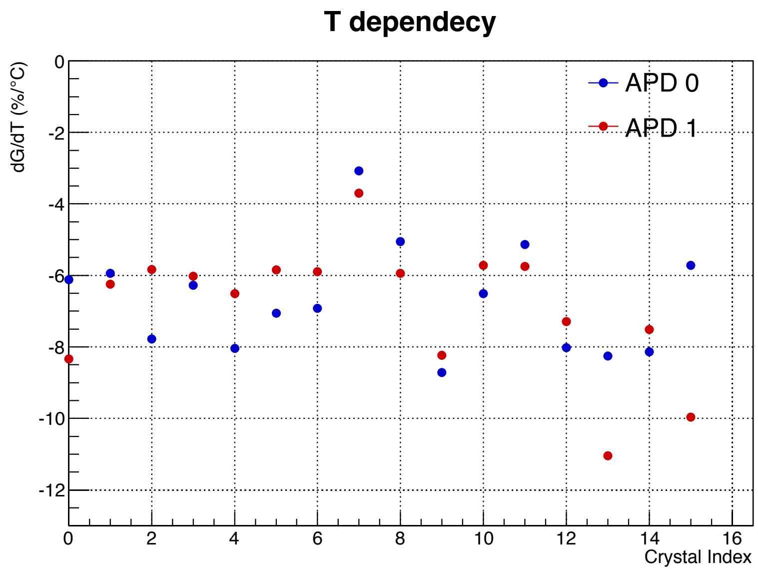
- ✓ ***BC630: the best performances***
- ✓ ***Resins:*** *ΔT% @ 315 nm = - 5%)*

All test performed at ENEA Casaccia

Temperature Correction

- APD gain has an high dependency with temperature
- Cosmic data used to study Gain vs T channel-by-channel dependence
- Store functions parameters for correction
- Mean dG/dT -7%/°C



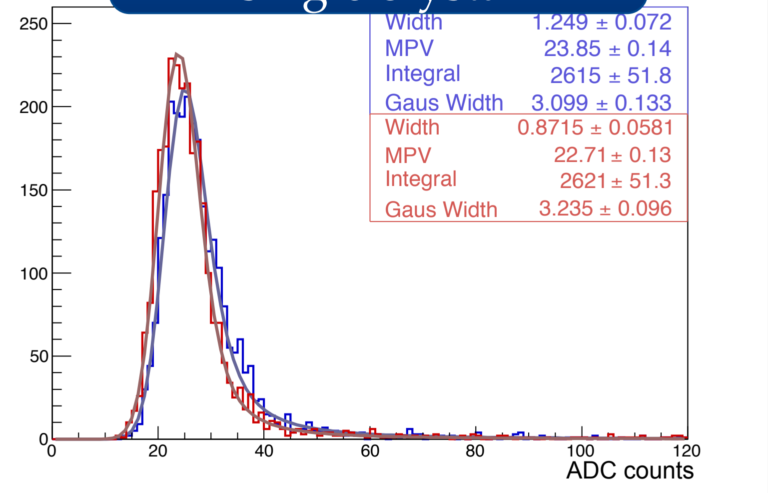


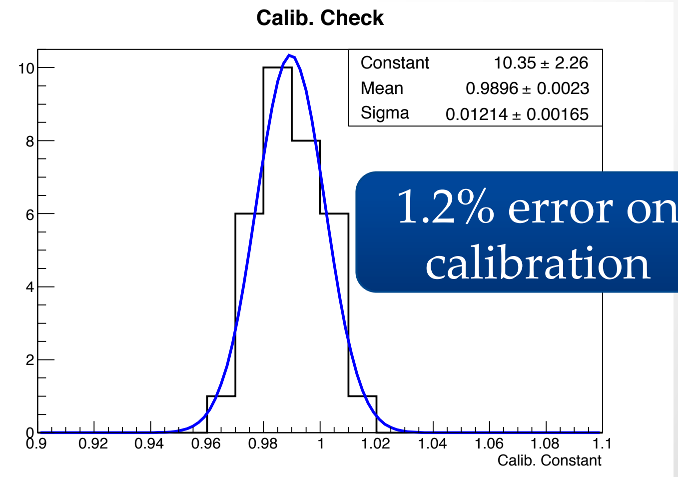
Calibration

- Selected cosmic events which pass through one matrix column
- Event-by-event dG/dT correction applied
- Fit with Landau with Gaussian convolution function and MPV extraction

- A couple of cosmic runs are not used to extract calibration constant
  - Check calibration stability and precision

Cosmic signal on single crystal





1.2% error on calibration