Istituto Nazionale di Fisica Nucleare

Photodetectors for BelleII calorimeter

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JENNIFER Consortium General Meeting
10-12 June 2015

What we need

- R&D program to develop an electromagnetic calorimeter based on Pure CsI crystals
- Pure CsI Crystal
  - Low Light yield
  - Emission time ~25ns (also a slow component ~1200ns)
  - Peak emission (fast component). 310nm
- What characteristics of the readout sensor are required:
  - Good QE at 310nm
  - Large active surface
  - Work inside B field (~1Tesla)
- Goal: noise below 1MeV on single channel

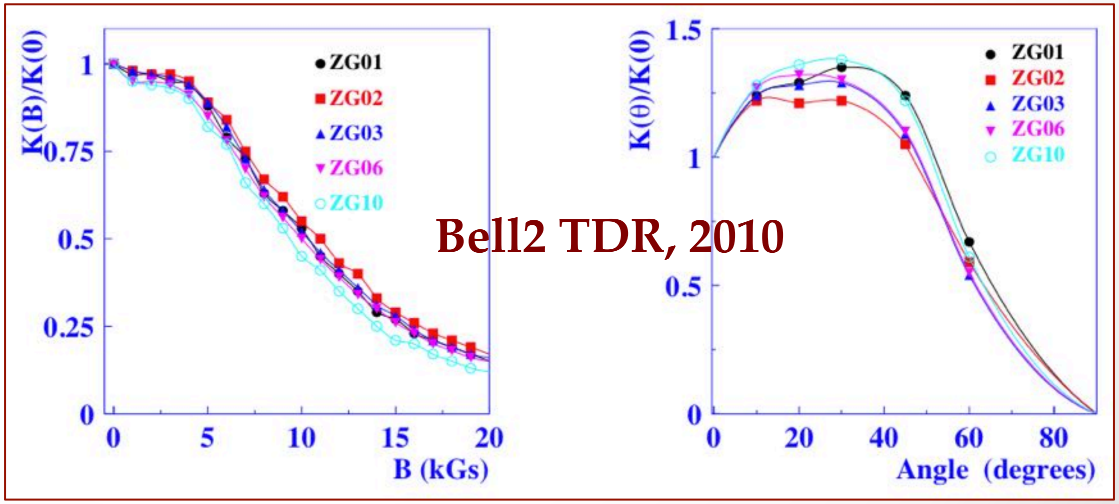
What we studied

- During the R&D we studied different photodetectors
  - Hamamatsu 1-inch Photopentode
  - Hamamatsu 2-inch Photopentode (Belle2/Hamamatsu jonied R&D)
  - Hamamatsu S8664-55 Avalanche PhotoDiode (APD)
  - Hamamatsu S8664-1010 APD
  - Excelitas C30739ECERH-2 APD
  - Advance Photonix SD630-70-73-500 APD
  - FBK UV SiPM (prototype)

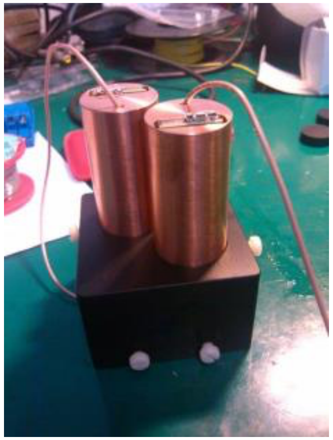
- All the material shows in this presentation is the result of the work of the Belle2 ECL Italian group
  - INFN Frascati
  - University and INFN Roma3
  - University and INFN Napoli
  - University and INFN Perugia
  - ENEA Casaccia

Photopentode

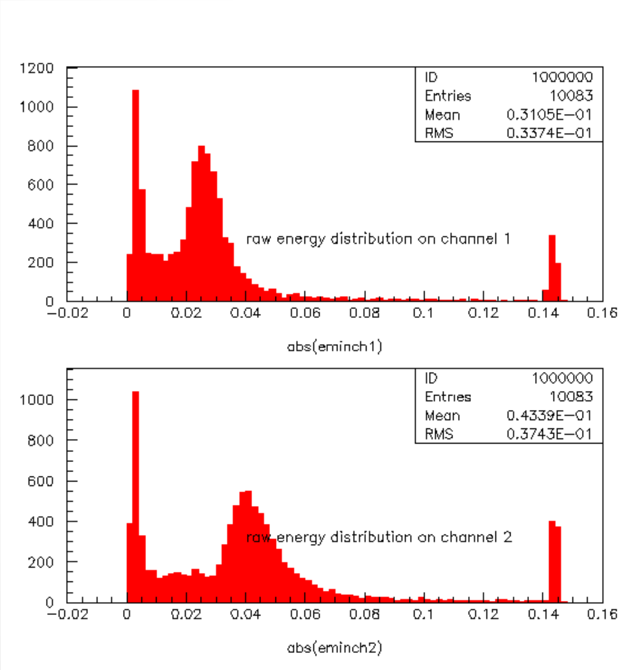
- 5 amplification stage PMT
- Low capacitance ~10pF
- QE at 310nm 25-30%
- Gain factor 150-200 in 0 magnetic field
- Gain reduction due to the magnetic field 30-40% (depend on angle between PP and B)



1-inch Photopentode



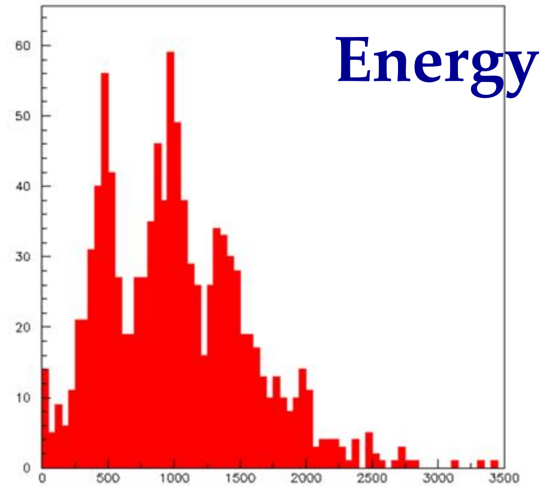
- 1-inch photopentode (standard Hamamatsu product)
- PP 1inch double read-out
  - Total Active area: ~10cm^2

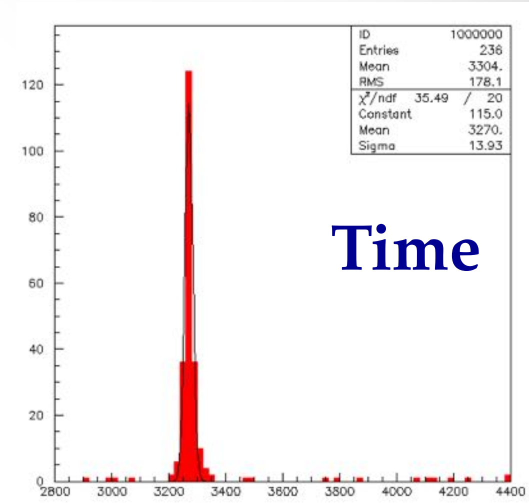


- Test with cosmics
  - MPV deposited energy ~30MeV on Pure CsI crysal (5x5x30cm^3)
- Combining the two channel we have S/N~78
- **Noise level ~400KeV**

2-inch Photopentode

- Special Hamamatsu product
- Active area: $20cm^2$





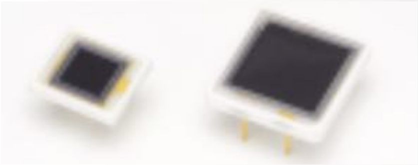
- Tested with 100MeV electron beam on a single crystal (~80MeV energy contained)
- Energy and time resolution exploited
- **Noise level ~200KeV**
- **Time resolution ~1.5ns**

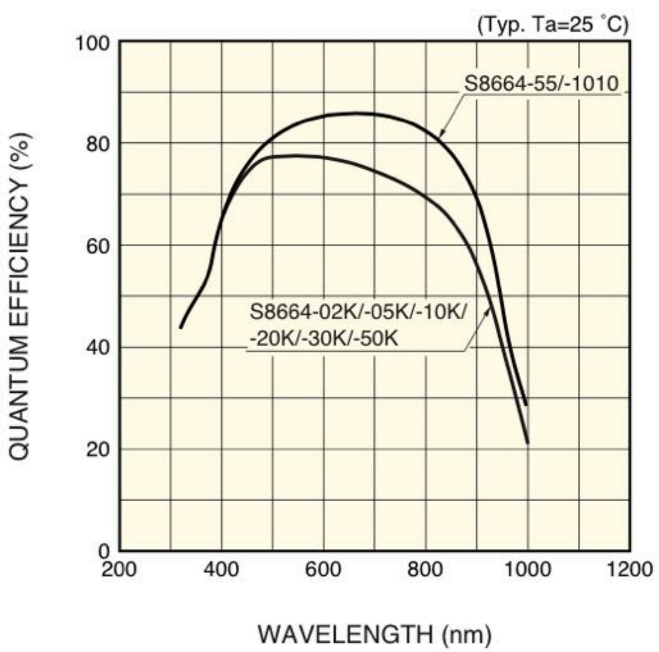
Vop PP	Peak (A.U.)	sigma (ns)	Noise (KeV)
750	380	1.4	270
850	450	1.5	230
1000	560	1.6	190

Very good performances with PP
Main problem: sensor depth (58mm) → mechanical structure backpannel replacement

APD Hamamatsu

- S8664-55
  - Active area 5x5 mm^2
  - Capacitance 80pF
- S8664-1010
  - Active area 10x10 mm^2
  - Capacitance 270pF
- Typical Gain 50
- Special product for S8664-1010
  - Gain 200 with $\Delta V > 20V$
- Inverse Bias ~400V





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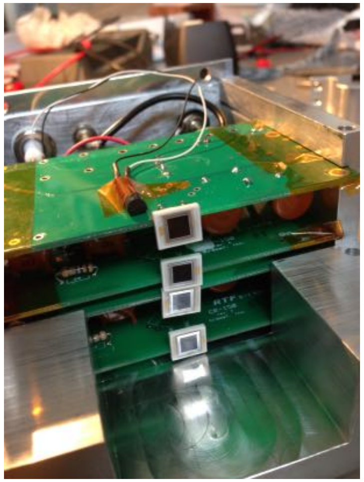
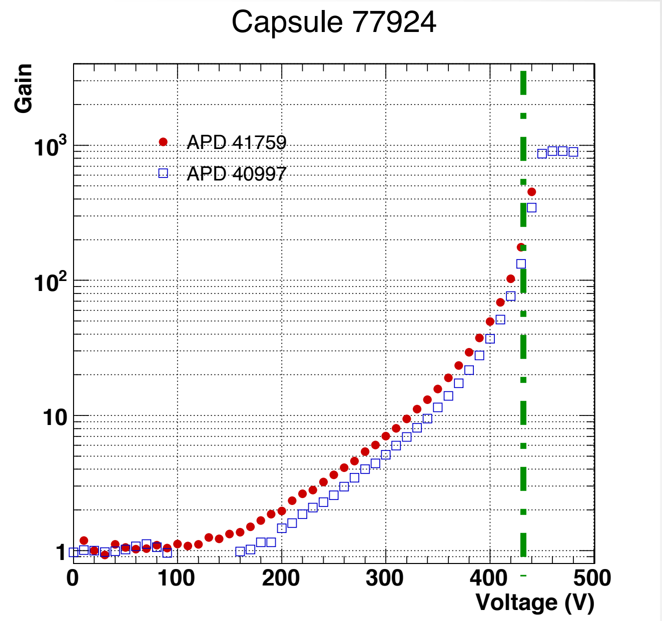
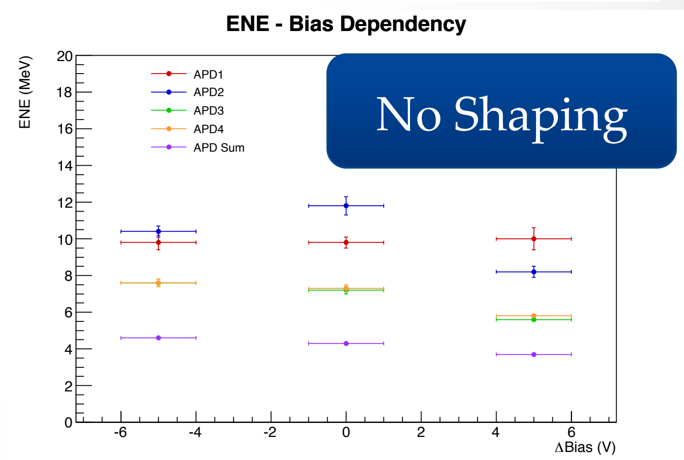
Small APD Hamamatsu

- 4 APDs with separate readout
  - Total active area 1cm^2
- Working point G=200
- Tested with cosmics
- Combining the 4 channels
  - **<u>Noise level ~4MeV</u>**







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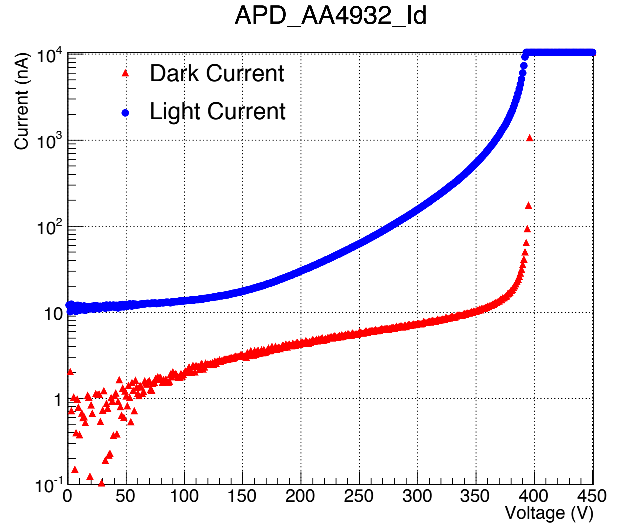
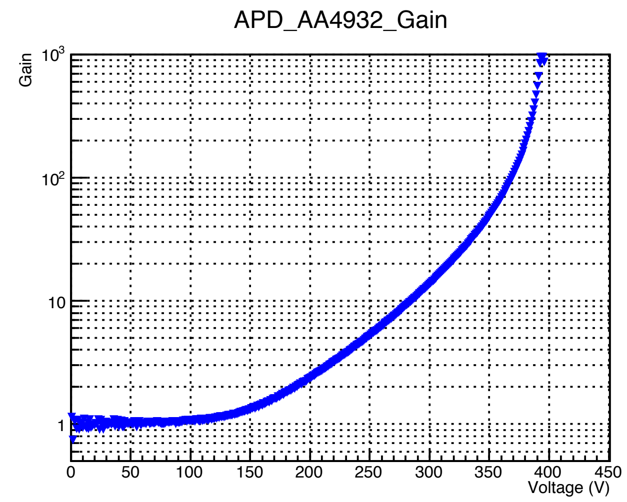
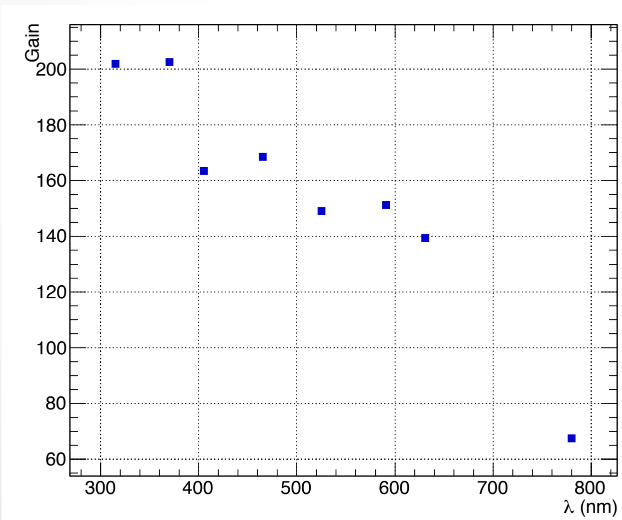
Large APD Hamamatsu

- Selected APD
  - G=200
  - Idark ~ 30nA (>50nA with non selected APDs)
- Better performance in terms of noise
- Gain is not λ independent

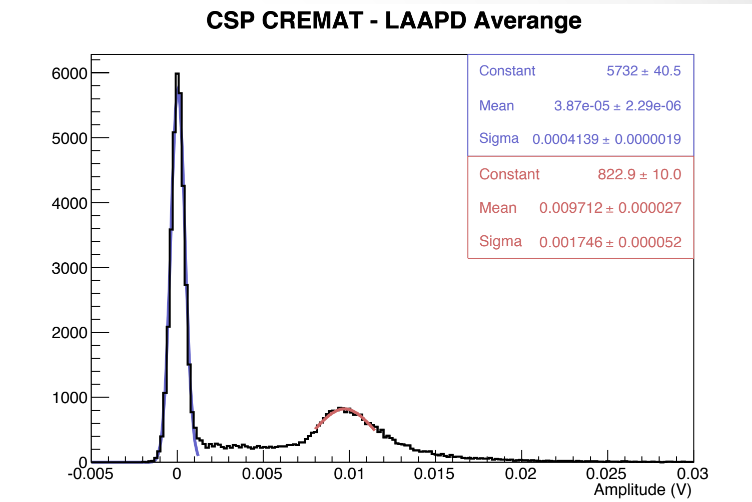


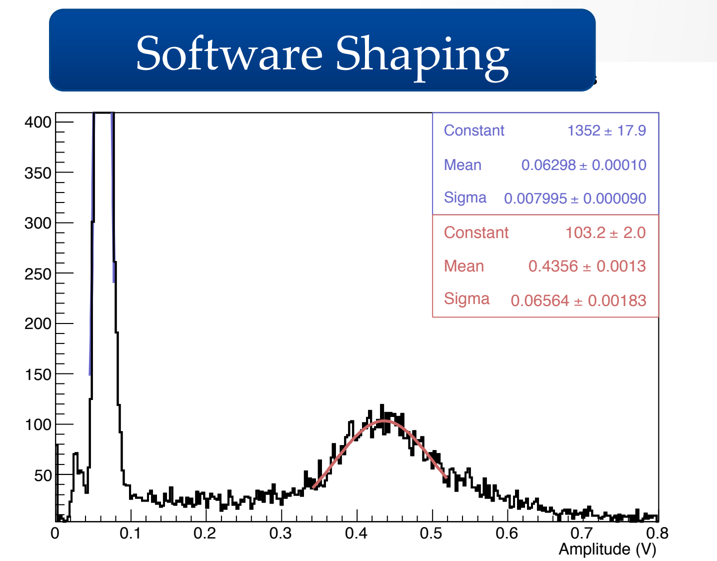




Large APD Hamamatsu

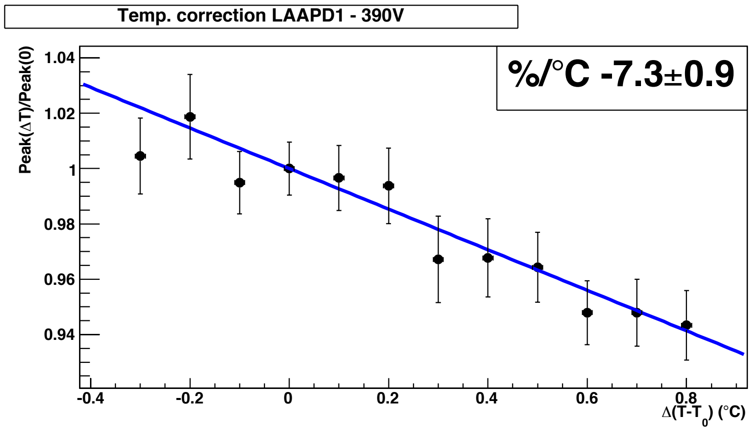
- 2 Large APDs with separate readout
  - Total active area $2 cm^2$
- Software shaping applied in order to simulate a $CR-RC^4$ filter
- Tested with cosmics
- Noise level combining the 2 APDs
  - **<u>After preamp : 1.3MeV</u>**
  - **<u>After shaping : 0.7MeV</u>**

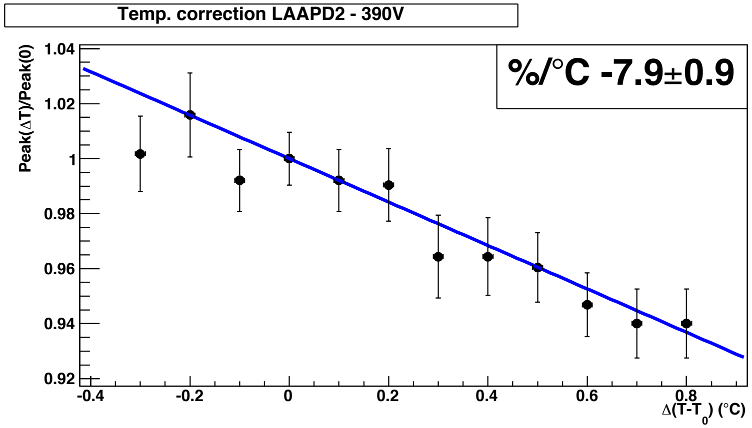




Large APD Hamamatsu

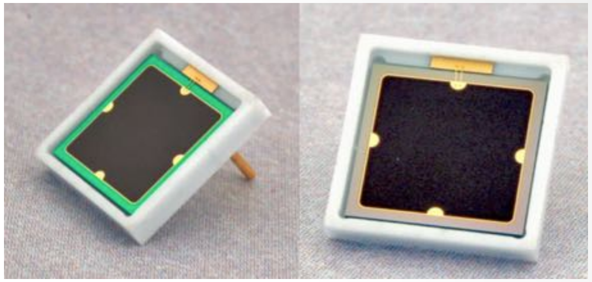
- Temperature dependency -7.5%/°C

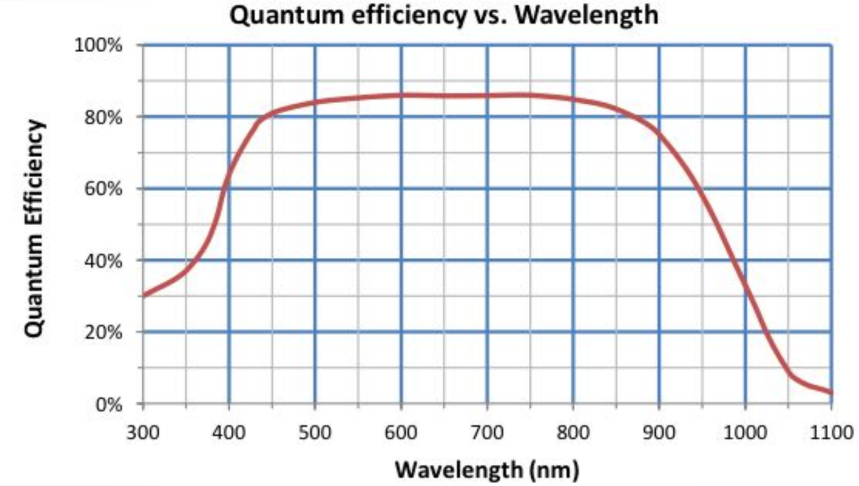


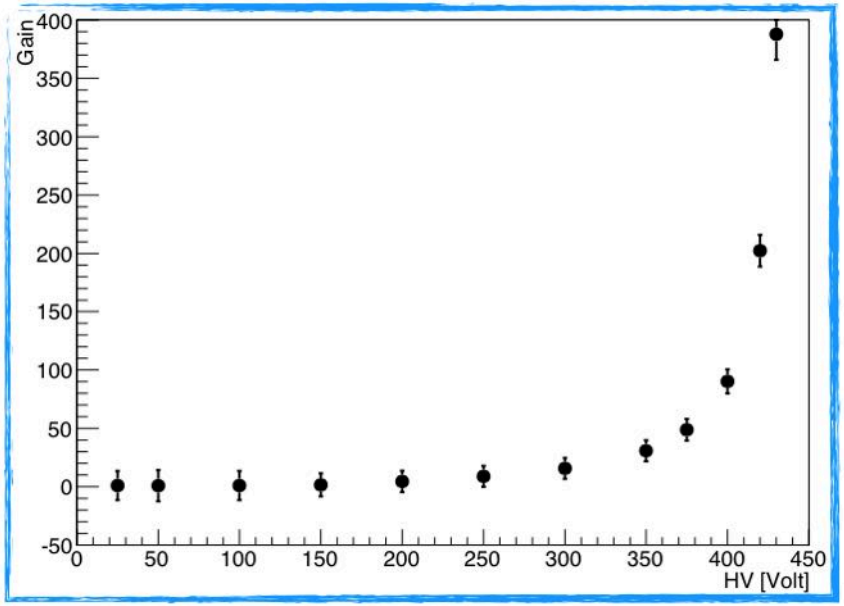


APD Excelitas

- C30739ECERH-2
  - Active Area 5.6x5.6mm2
  - Capacitance 60pF (low!)
  - Dark Current ~3nA (very low!)
  - Typical Gain 200
  - Typical ΔV ~15V
- Typical Bias ~410V

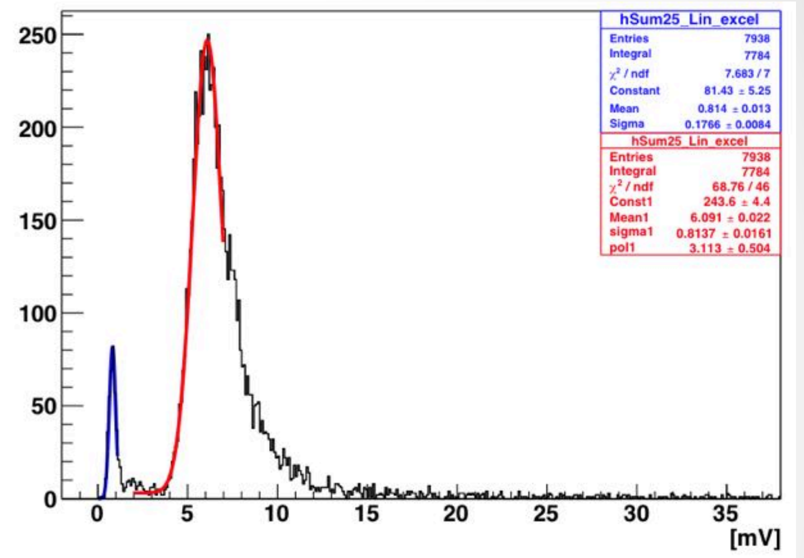






APD Excelitas

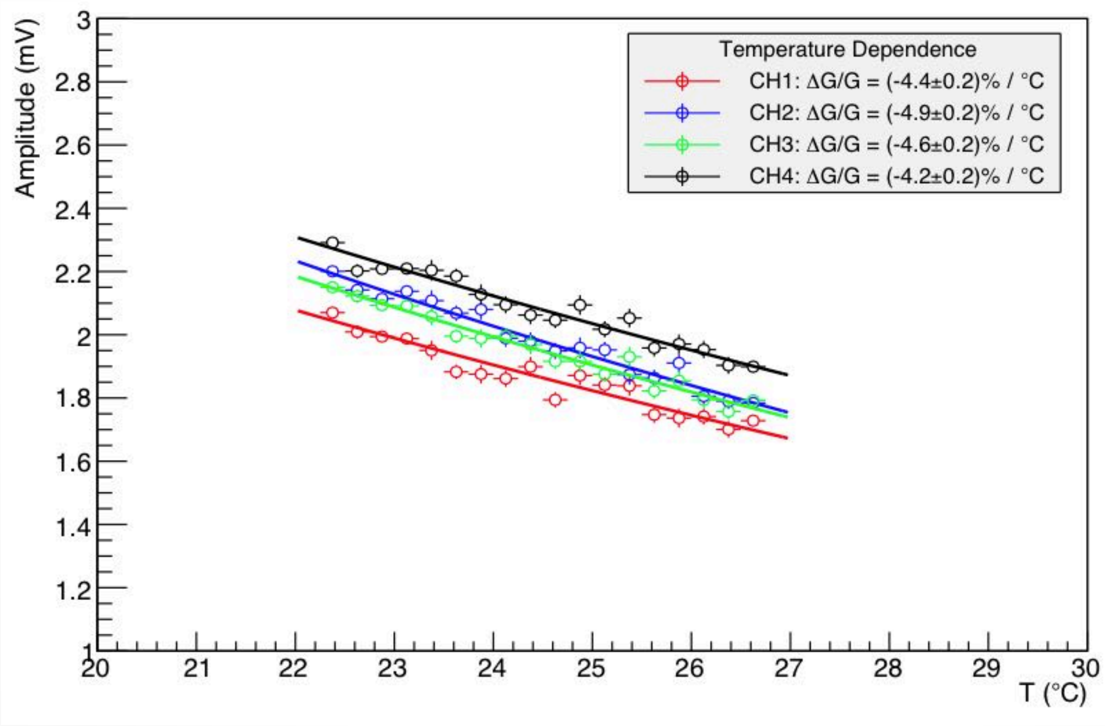
- 4 APDs with separate readout
  - Total active area 1cm^2
- Working point G=200
- Tested with cosmics
- Combining the 4 channels after software shaping
  - **<u>Noise level ~1MeV</u>**



σ [μV]	Signal [mV]	S/N	ENE [MeV]
177±8	5.27±0.03	30±1	1.00±0.05

APD Excelitas

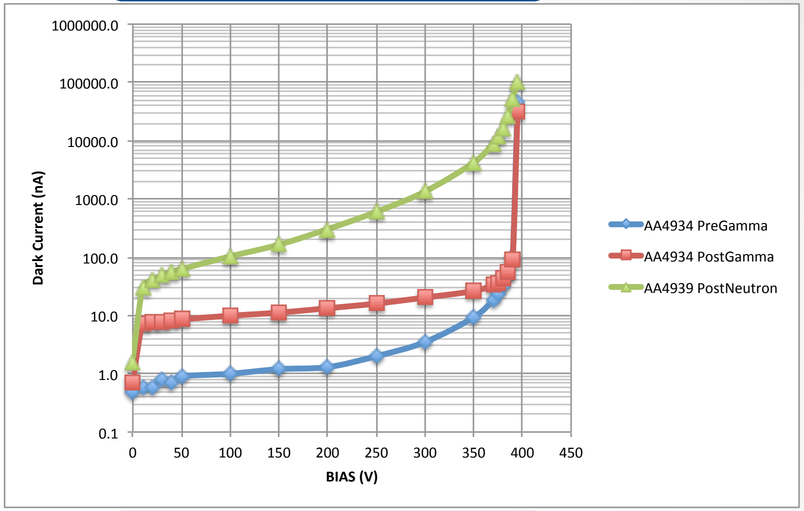
- Temperature dependency -4.5%/°C



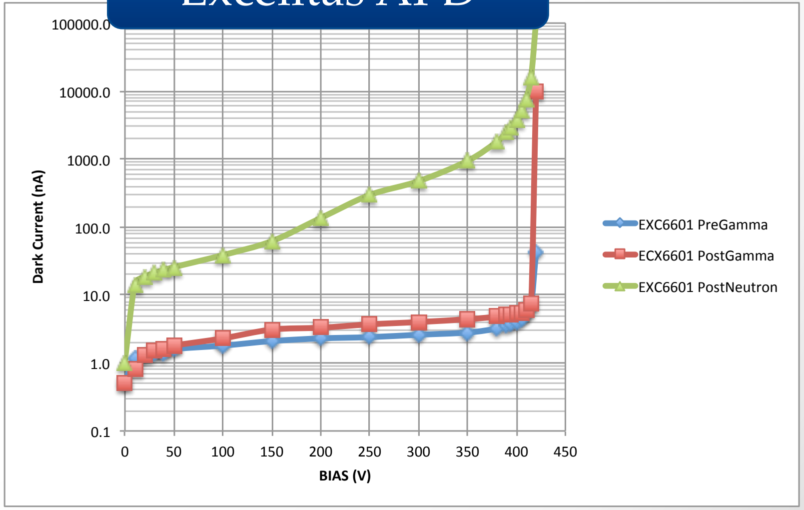
APD Radiation Hardness test

- Hamamatsu and Excelitas APD tested
- 250Gy with γs
- 10^{12} neutrons/cm^2
- Monitored parameters
  - Gain
  - Dark current
  - QE
- Gain → Stable
- Dark current
  - Small effect after gamma
  - Orders of magnitude increase after neutrons
  - Stable dark current after 1 month at RT (40% recover)

Hamamatsu APD

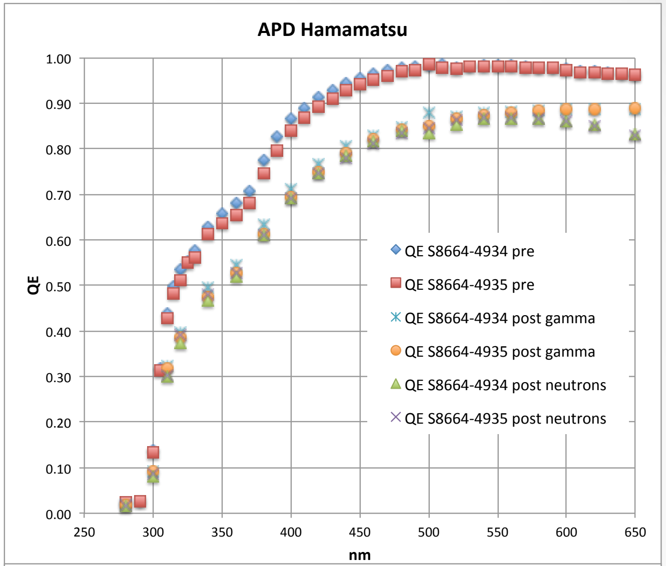


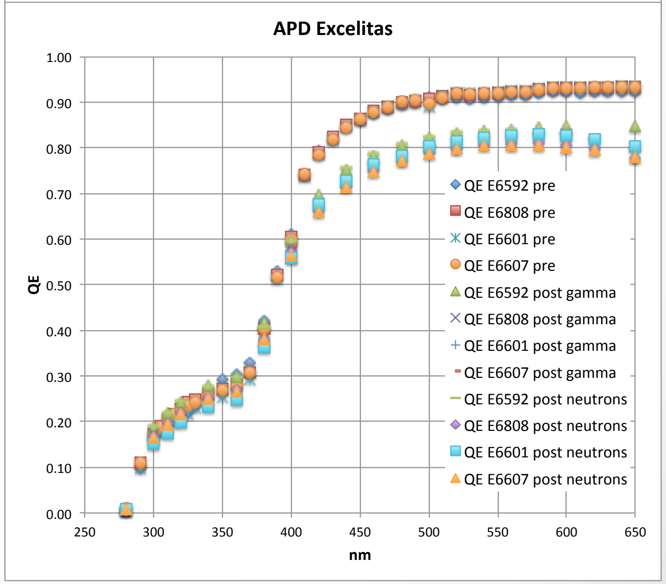
Excelitas APD



APD Radiation Hardness test

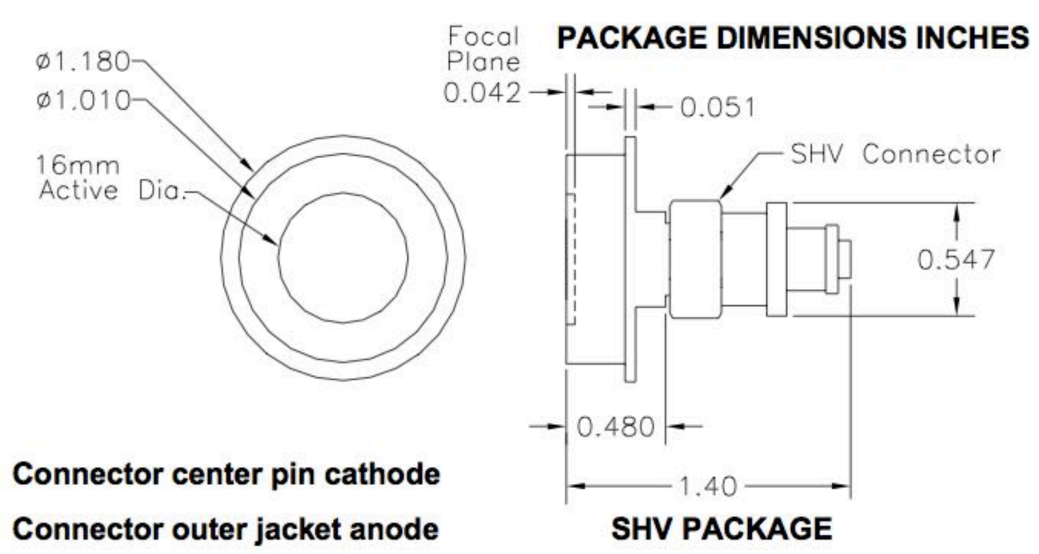
- Small decrease in QE after γs (~10%)
- QE remains stable after neutrons irradiation

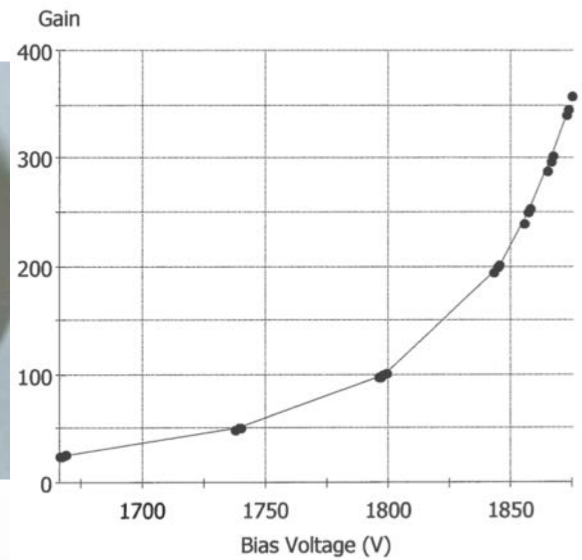




APD Advanced Photonix

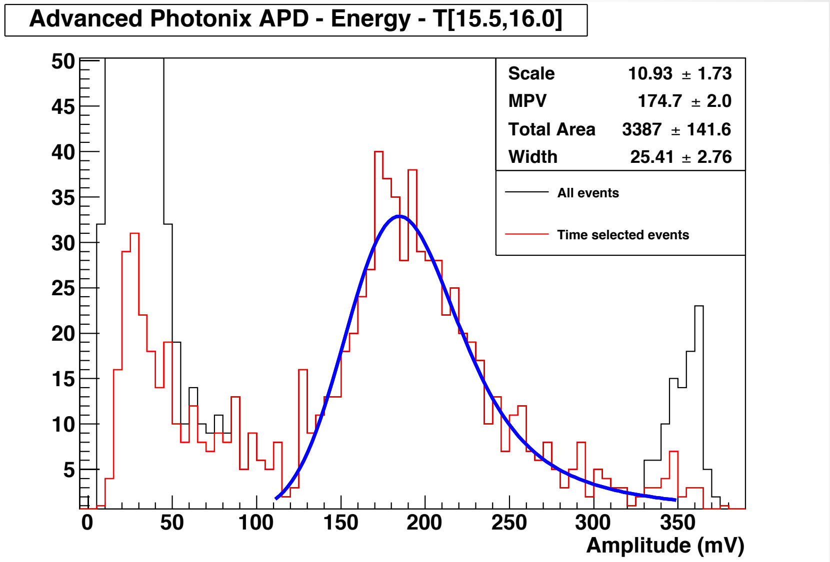
- SD630-70-73-500
  - Active Area 2cm^2
  - Capacitance 130pF
  - Idark ~500nA (high!)
  - Gain 250
- Typical bias 1800V
- 1mm gap between Si surface and crystal



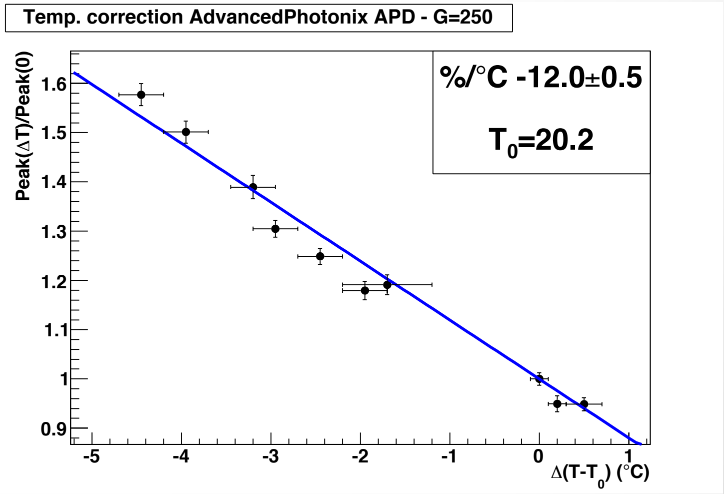


APD Advanced Photonix

- 1 APD used
- Test with cosmics
- After shaping
  - **Noise Level 2MeV**



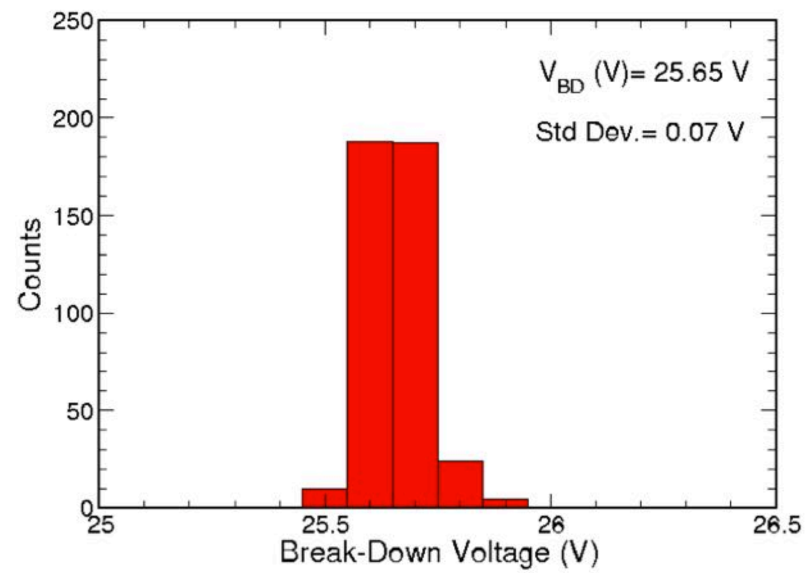
- High temperature dependency
  - -12%/°C

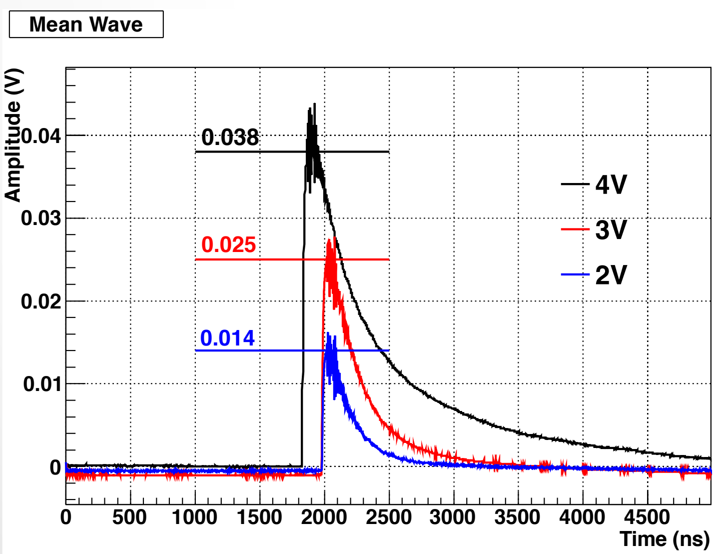


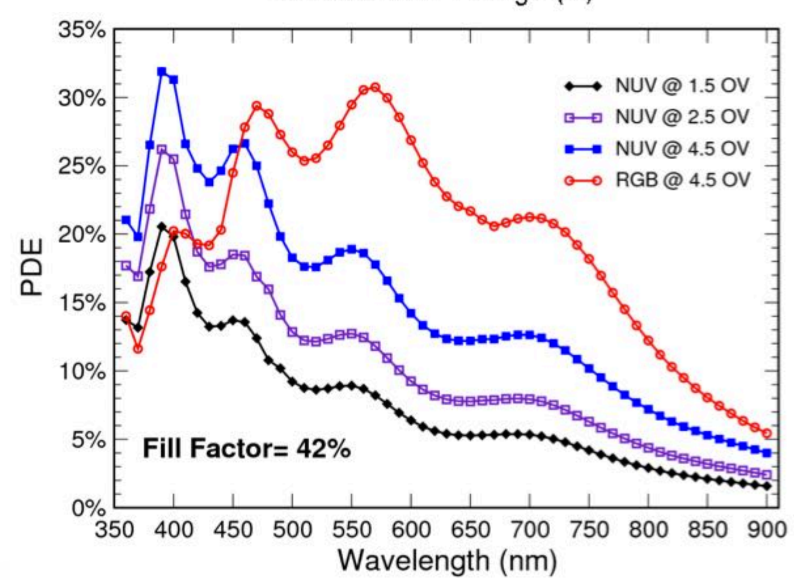
- No coating above silicon
- Very delicate structure
  - 3 broken APD out of 4

SiPM

- FBK UV-SiPM
  - Prototype
  - Active area 0.4x0.4 mm^2
  - 50 μ m cells



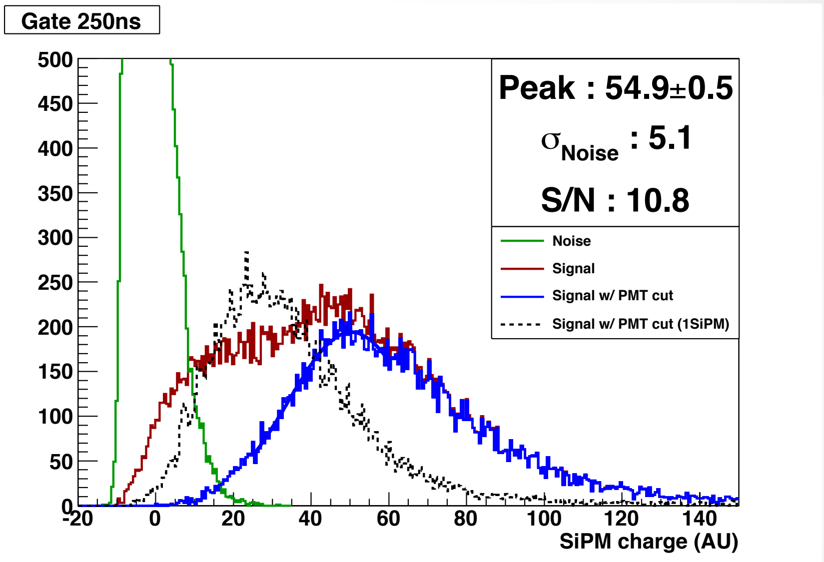




SiPM

- 2 SiPM in parallel
  - Total active area 0.32 cm^2
- Preamp amplification 50db
- Test with cosmics
- Noise Level 2.8MeV

- Extrapolation with a 4x4 SiPM matrix
  - Noise level ~ 1MeV
- Limitation on dynamical range
- Radiation hardness (neutrons) is an issue



Summary

- Several photodetectors have been tested
- Photopentonde gives very good results: ~200KeV
  - Main problems: B field, mechanical structure replacement, no redundancy
- APD solution have been deep investigated
  - Good S/N is challenging due to the high detector capacitance
  - Noise level below 1MeV has been reached with 2 products
    - 2x Hamamatsu S8664-1010 APD
    - 4x Excelitas C30739ECERH-2
- Sensor used for the calorimeter prototype is the Hamamatsu APD