Characterization and Quality Control of Avalanche Photodiode Arrays for the Clear-PEM Detector Module

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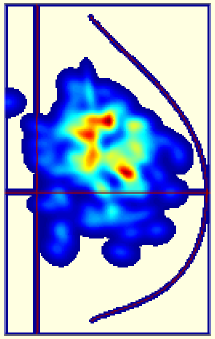
8th International Workshop in Radiation Imaging Detectors
2-6 July 2006, Pisa, Italy

Summary

1. **Clear-PEM Project**
2. **Clear-PEM Detector Requirements**
3. **Clear-PEM Detector**
4. **Quality Control (QC) of APDs in Clear-PEM**
   1. QC of Gain and Dark Current
   2. QC of Relative Gain
5. **Conclusions**

1. Clear-PEM Project

The main goal of the **Clear-PEM project** is the development of a
Positron Emission Mammography (PEM) Scanner
in the framework of the Crystal Clear Collaboration (CCC) at CERN.

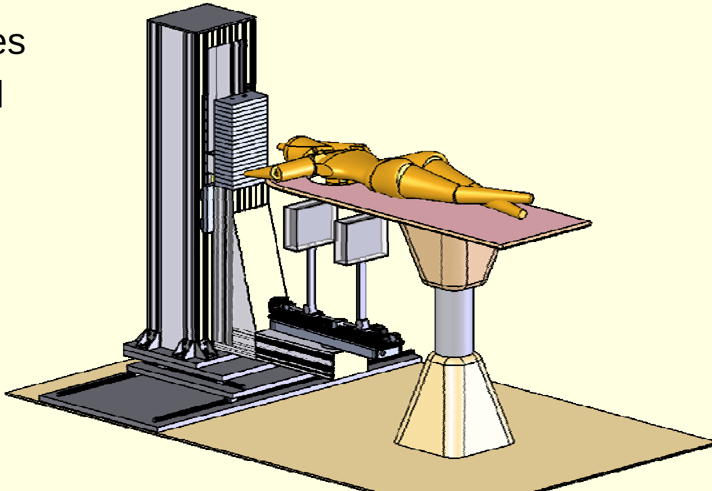


- **Consortium PET-Mammography (Portugal)**

  TAGUSPARK – Parque de Ciência e Tecnologia
  LIP - Laboratório de Instrumentação e Partículas
  Hospital Garcia Orta - Serviço Medicina Nuclear
  IBEB - Instituto Biofisica e Engenharia Biomédica
  IBILI - Instituto Biomédico de Investigação da Luz e Imagem
  INESC - Instituto de Engenharia de Sistemas e Computadores
  INEGI - Instituto de Engenharia Mecânica e Gestão Industrial

~ 40 People

- **CERN Geneva**
- **VUB Brussels**



2. Clear-PEM Detector Requirements

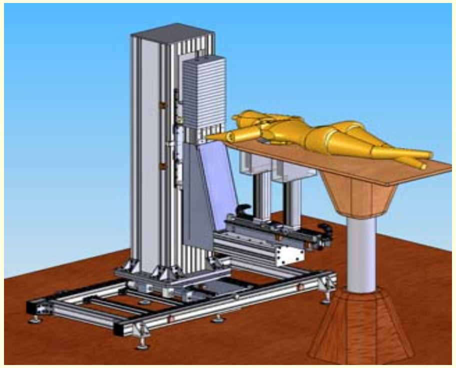
Good spatial resolution (~2 mm): Fine crystal segmentation (2x2 mm)

Depth of Interaction measurement with resolution FWHM ~2 mm

High Sensitivity: High photon interaction probability (20 mm long crystals)

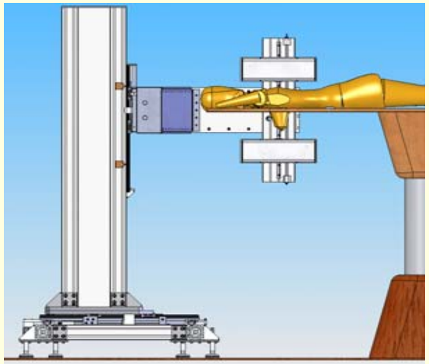
High efficiency to Compton events in the detector (> 75%)

Low Random Background: Good time resolution (~ 1 ns)



Breast and axilla exams:

- Breast exams with the patient in prone position
- The plates rotate around the breast
- PEM plates can be rotated for axilla exams

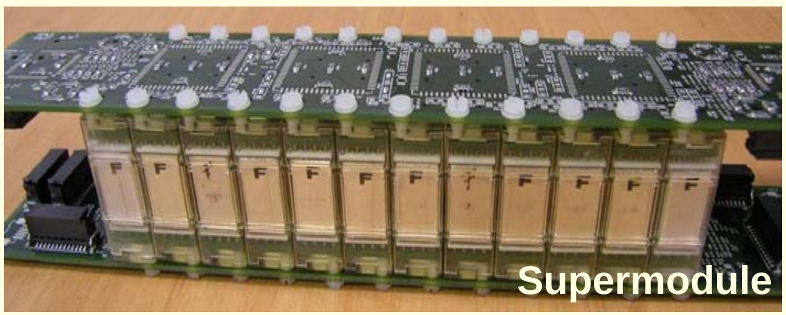


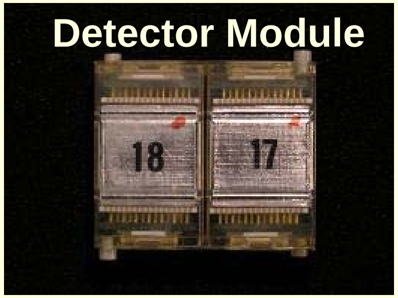
3. Clear-PEM Detector

2 **Detection Plates**

4 **Supermodules** per Plate

Each Supermodule composed by 12 **Detector Modules**

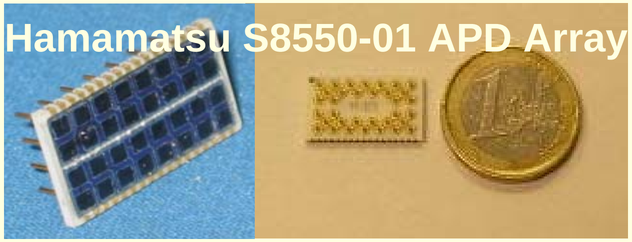




Each Detector Module is composed by:

- 2 **Hamamatsu S8550-01 APD arrays** (4x8 APD pixels)
- 1 **LYSO:Ce** 4x8 Crystal matrix (2x2x20mm^3) – Peaks at 420 nm light

Totals:
6144 Crystals
398 APD arrays
12 734 APD Pixels



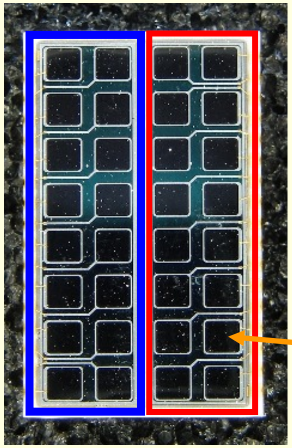
4. Quality Control of APDs in Clear-PEM

Hamamatsu S8550-01 APD Array

Properties:

- 32 APD pixels 1.6x1.6 mm^2
- Typical gain 50
- Optimal Spectral Response for 420 nm (QE ~70%)
- Dark Current ~10 nA per pixel
- Ceramic Package
- Epoxy Window
- Dedicated packaging for our project

The Quality Control (QC) of the APD Arrays is important for the overall performance of the detector!



Quality Control done in 2 phases:

1) QC of Gain and Dark Current (per sub-Array)

2) QC of Relative Gain (per pixel)

4.1 QC of Gain and Dark Current

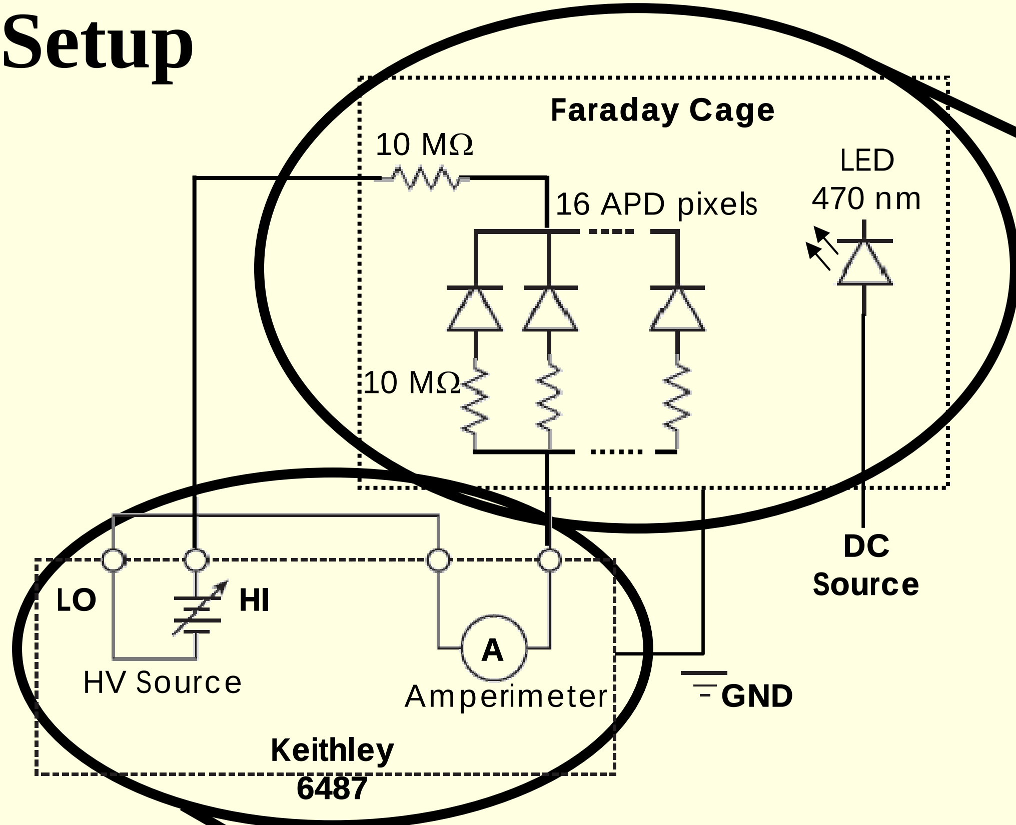
Using a Picoammeter / Voltage Source Keithley 6487 and a blue LED (470 nm) to simulate the scintillation light, the following parameters were measured for 398 APD Arrays at constant temperature of ~24ºC:

- Bias Voltage (HV) for Gains 50, 100 and 200
- Dark Current at Gains 50, 100 and 200
- Gain Gradient per volt at Gains 50, 100 and 200

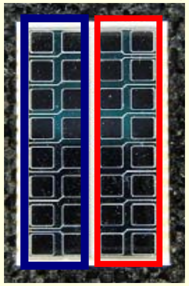
A reference APD array is also measured everyday in order to control systematic errors! (mostly temperature variation)

4.1 QC of Gain and Dark Current

Setup



Hamamatsu S8550 APD Array



Sub-array 1 (16 APD Pixels)

Sub-array 2 (16 APD Pixels)

4.1 QC of Gain and Dark Current

Bias Voltage (HV)

Protocol:

- Bias the first APD sub-array with **30V** (**M=1**)
- Regulate the intensity of the LED in order to read 10 nA in the picoammeter
- Raise bias voltage in order to have:
  - I (30V) x 50
  - I (30V) x 100
  - I (30V) x 200
- Repeat Process for the next sub-array

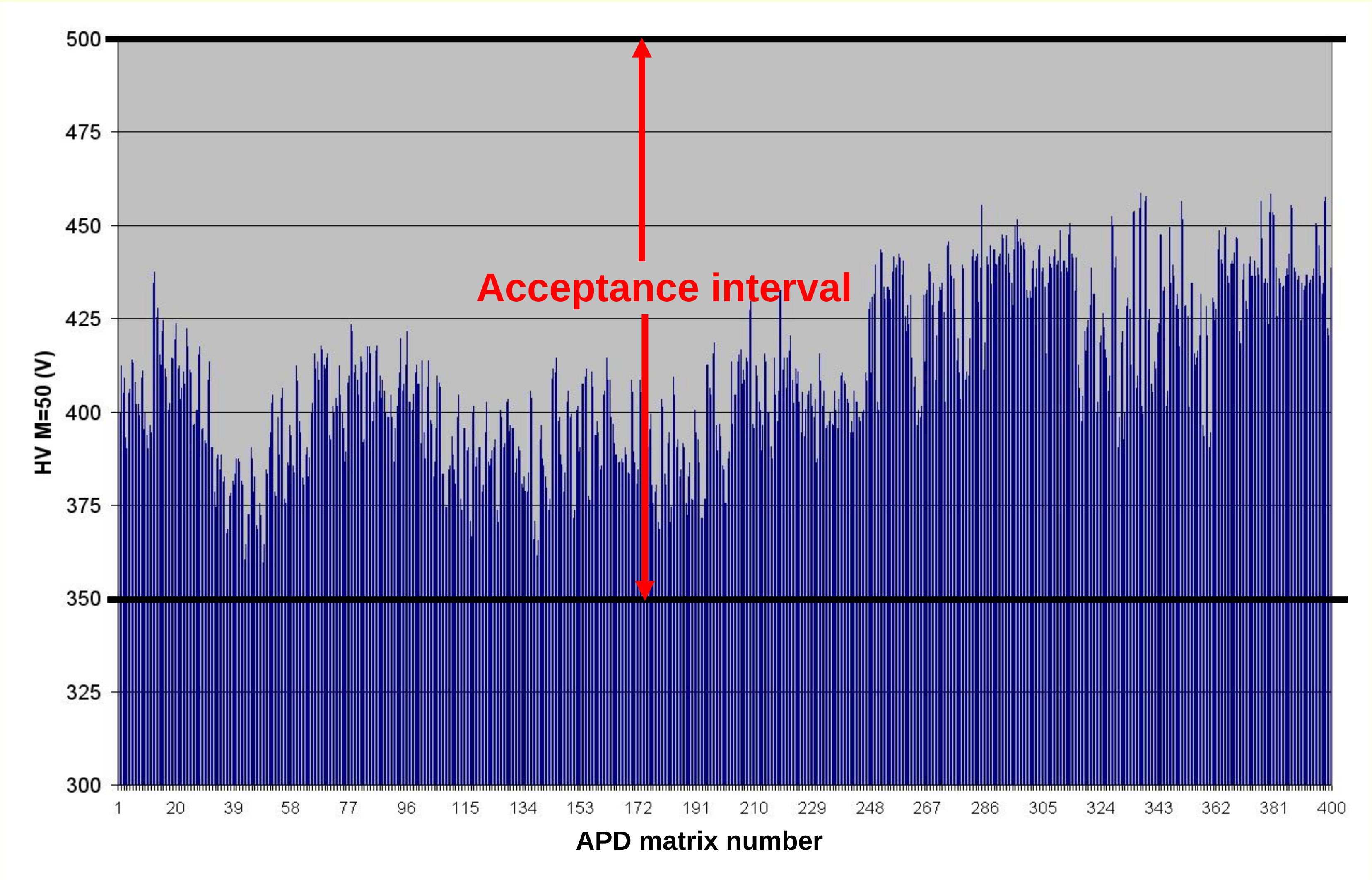
Results (398 APDs)	**Bias Voltage (V)**	
	Sub-array 1	Sub-array 2
Gain 50	**410 ± 22**	**410 ± 22**
Gain 100	426 ± 22	426 ± 22
Gain 200	434 ± 22	434 ± 21

QC acceptance interval (Gain 50):

350V < HV < 500V

4.1 QC of Gain and Dark Current

Bias Voltage (M=50)



4.1 QC of Gain and Dark Current

Dark Current (Id)

Protocol:

- APD in the dark (no external light or radiation source)
- Measure the current, with the picoammeter, for:
  - APD sub-array biased for M=50
  - APD sub-array biased for M=100
  - APD sub-array biased for M=200
- Repeat for next APD sub-array

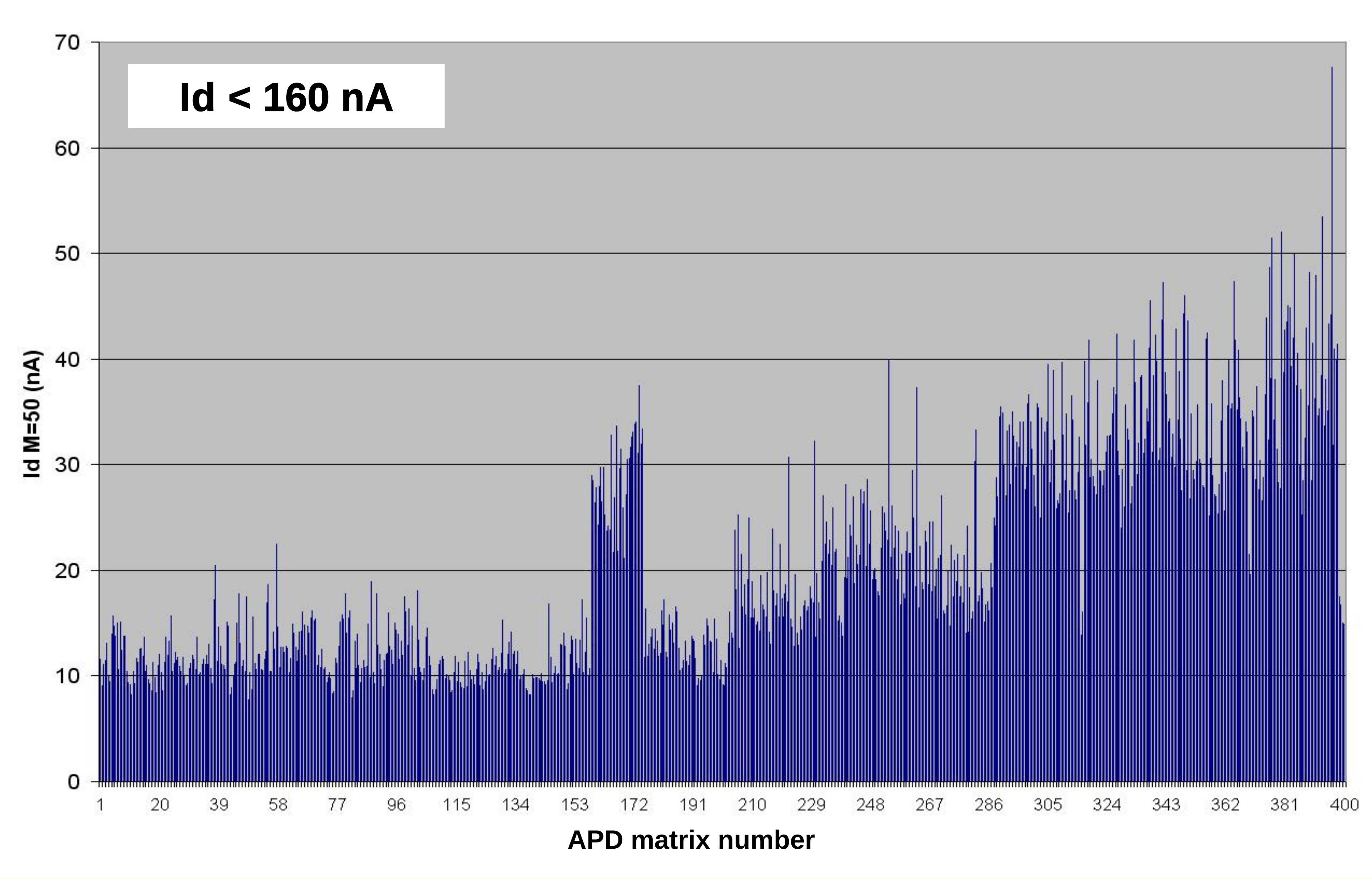
Results (398 APDs)	**Dark Current Average Values (nA)**	
	Sub-array 1	Sub-array 2
Gain 50	**19.8 ± 9.7**	**21.2 ± 11.1**
Gain 100	31.1 ± 16.5	33.4 ± 22.3
Gain 200	79.7 ± 56.3	90.4 ± 69.6

QC acceptance limit (Gain 50):

Id < 160 nA
(10 nA per pixel)

4.1 QC of Gain and Dark Current

Dark Current (M=50)



4.1 QC of Gain and Dark Current

Gain Gradient (dM/dV)

Protocol:

- Bias the APD Sub-array for M=50 with the LED on and measure the current
- Regulate the bias voltage and measure the current again for :
  - HV1 = HV(M=50) + 3V
  - HV2 = HV(M=50) - 3V
- Calculate the gains for HV1 and HV2 (M1 and M2 respectively) and the Gain Gradient through: $$dM / dV = \frac{M1 - M2}{(HV1 - HV2)M}$$
- Repeat for M=100 and 200
- Repeat the all process for next sub-array

Results (398 APDs)	**dM/dV Average Values (%/V)**	
	Sub-array 1	Sub-array 2
Gain 50	**3.60 ± 0.09**	**3.64 ± 0.96**
Gain 100	5.83 ± 0.26	5.88 ± 0.33
Gain 200	13.41 ± 4.17	12.91 ± 3.62

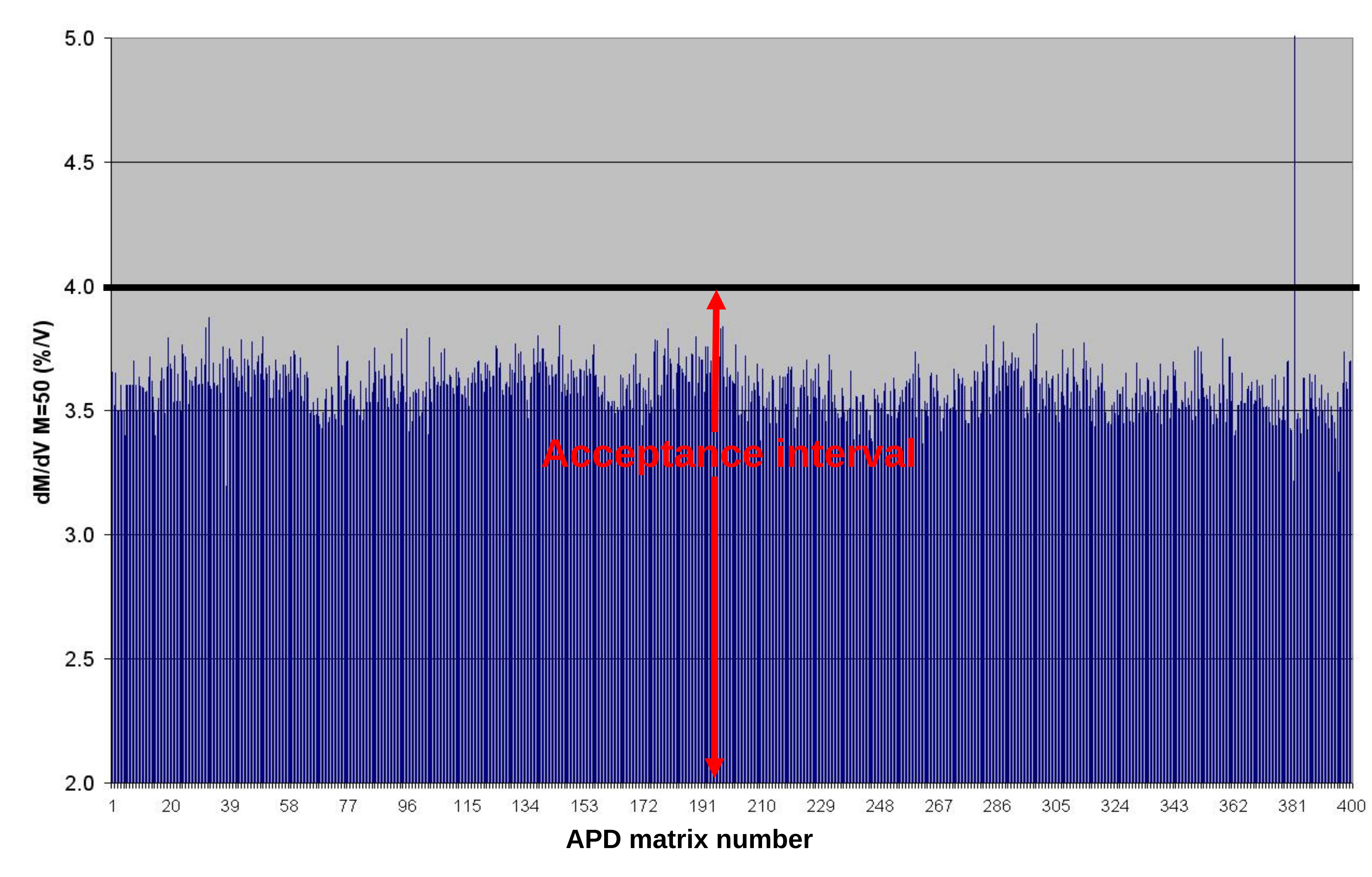
QC acceptance limits (Gain 50):

dM/dV < 4%/V

(Hamamatsu establishes 3.5%/V)

4.1 QC of Gain and Dark Current

Gain Gradient (M=50)



4.1 QC of Gain and Dark Current

First Conclusion:

From all 398 APDs, only 1 was rejected!

Didn't pass the GAIN GRADIENT QC!

4.2 QC of Relative Gain

Measurement parameters:

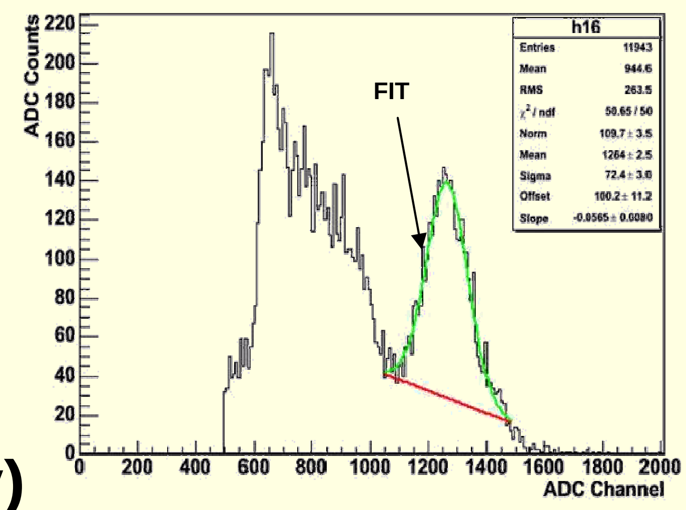
- Discrete amplification electronics
- Cesium radioactive source (^{137}Cs, 662 keV, 93 µCi)
- 32 LYSO:Ce polished crystals matrix wrapped in Tyvek
- APDs polarized at **gain 50**
- Stable temperature

The same reference APD array was measured everyday in order to control systematic errors!

The following parameters were measured for 397* APDs:

- 662 keV Peak Position per APD pixel
- Pedestal positions per acquisition run

*1APD failed previous QC



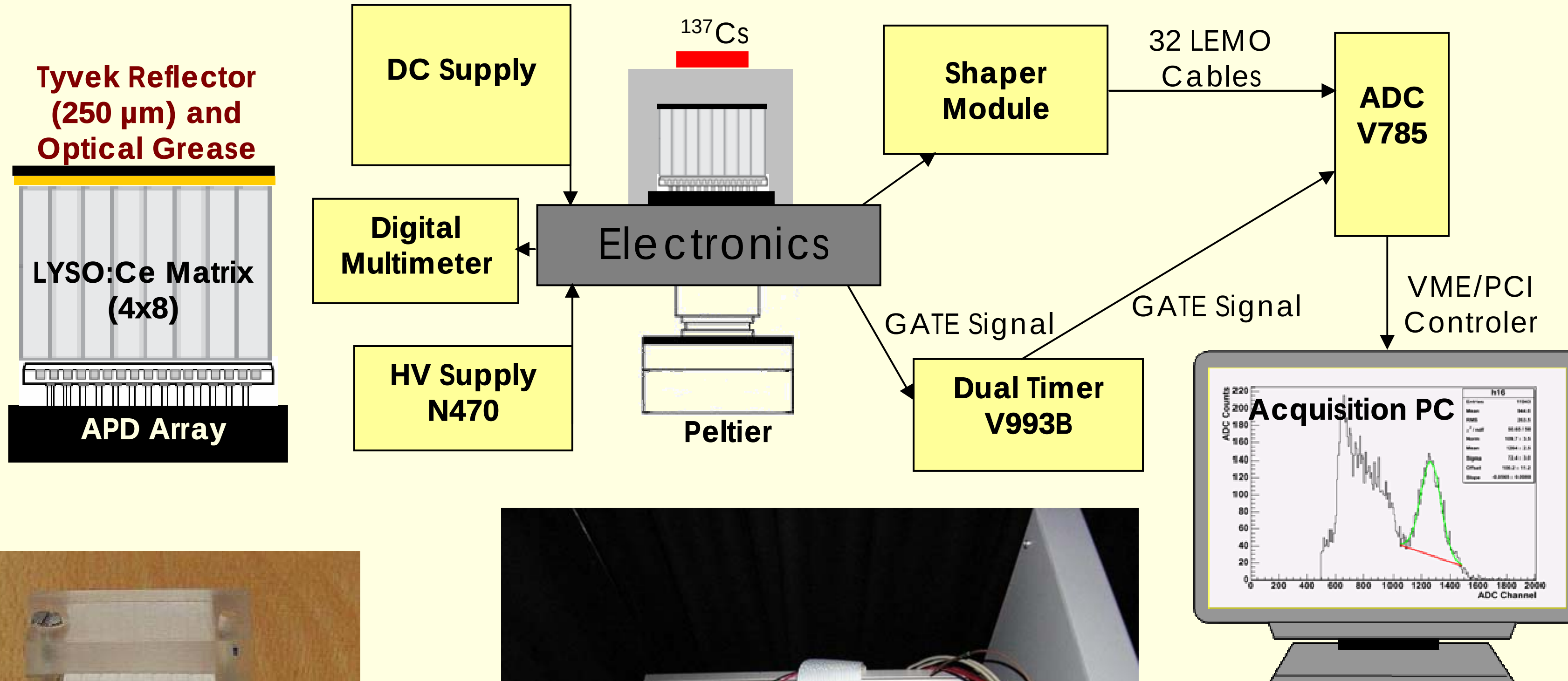
Data treatment done in order to obtain:

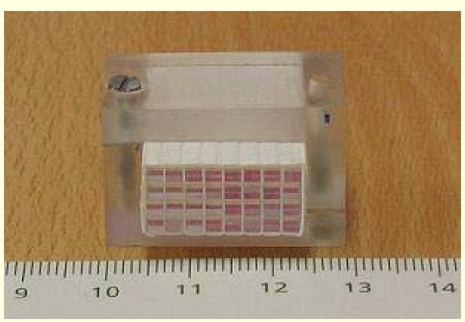
- Relative Gain variation

- Relative gain variation (within sub-array)

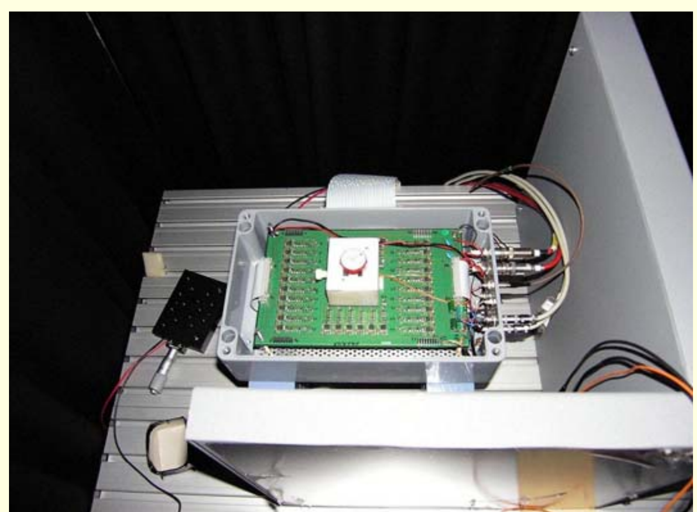
4.2 QC of Relative Gain

Setup





32 LYSO:Ce polished Crystals with Tyvek Wrapping

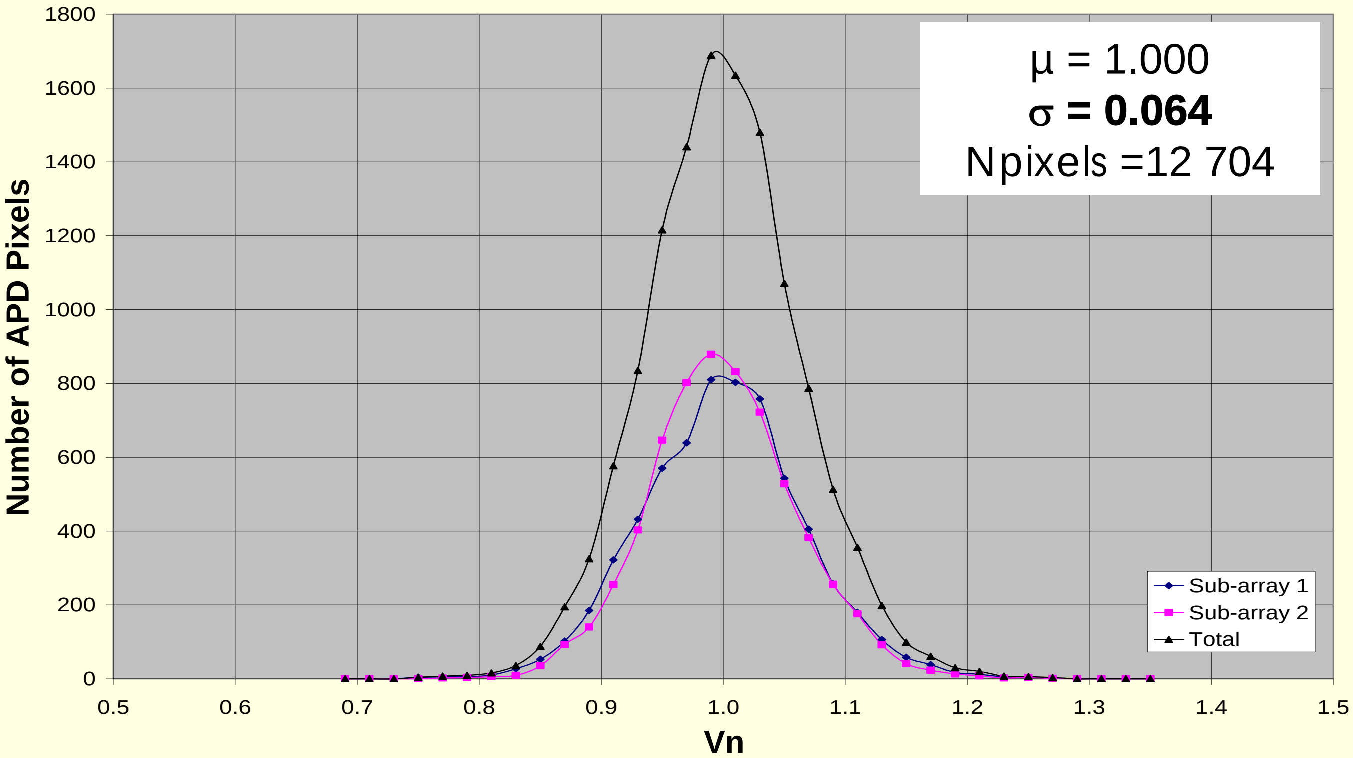


4.2 QC of Relative Gain

Relative Gain (Vn)

$$Vn = \frac{Fit\ Peak\ Position - Pedestal\ (Vpp)}{Average\ Vpp\ per\ Pixel\ (Va)}$$

APD \ Pixel	A1	B1	...	H4
10001	887,2	856,3	...	786,4
10002	857,2	894,7	...	864,3
...	...	...	...	...
60401	824,3	875,1	...	797,8
Average Peak position per pixel	853,1	885,4	...	799,8



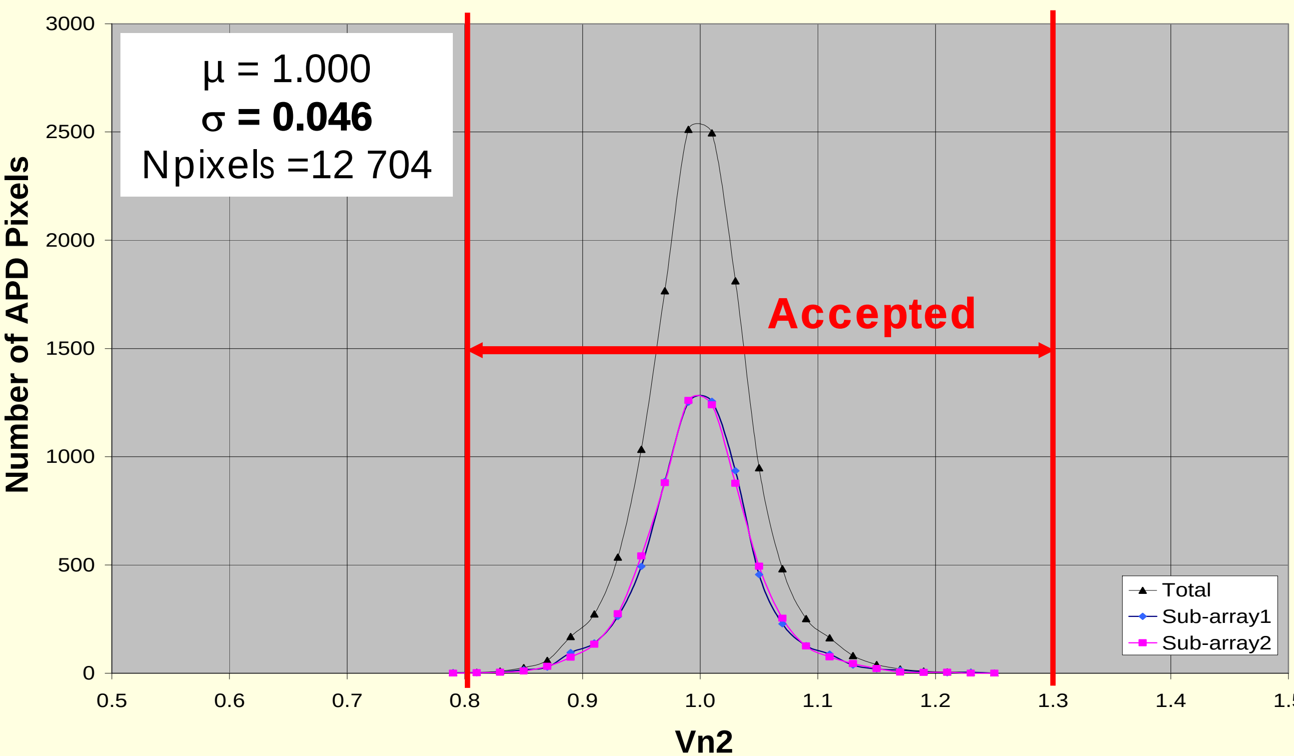
This normalization removes dependency on the electronic gain and crystal LY!

4.2 QC of Relative Gain

Relative Gain within sub-array (Vn2)

$$Vn_2 = \frac{Vn}{Vn\ Average\ \ per\ \ Array\ \ (Va_2)}$$

APD \ Pixel	Array 1: A1	Array 1: ...	Array 1: H2	Average Vn Array1	Array 2: ...
10001	1,075	...	0,965	1,046	...
10002	0,934	...	1,003	0,963	...
...	...	...	...	...	...
60401	1,023	...	1,011	1,056	...



This normalization further removes dependency on sub-array variation!

QC acceptance interval (Gain 50):

$0.8 < Vn2 < 1.3$

2. QC for Relative Gain

Second Conclusion:

From all 397 APDs, only 1 was rejected!

1 APD pixel had relative gain (within array) below 0.8

5. Conclusions

- Good Quality Control results (M=50):
  - Average Bias Voltage = 410 V
  - Average Dark Current = 20.5 nA
  - Average dM/dV = 3.62 %/V
  - Relative Gain within sub-array dispersion of 4.6 %
- From the total of 398 APD Arrays, 396 APD arrays (99%) can be used in the final prototype
- Due to this study, the S8550-01 APD Array is now being used by other Crystal Clear Collaboration groups