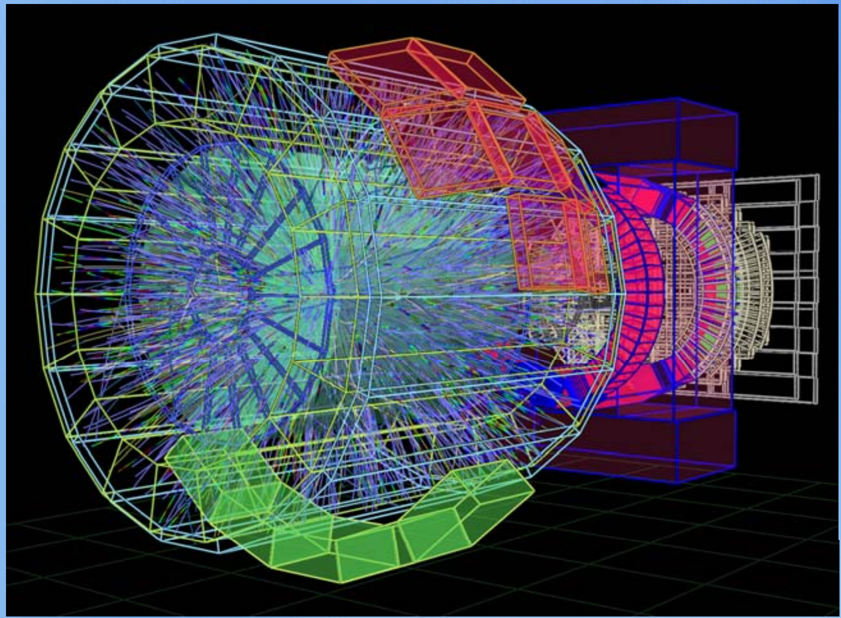
RD07

Florence, 29th June 07



Characterization of Avalanche Photo Diodes (APDs) for the Electromagnetic Calorimeter in the ALICE experiment

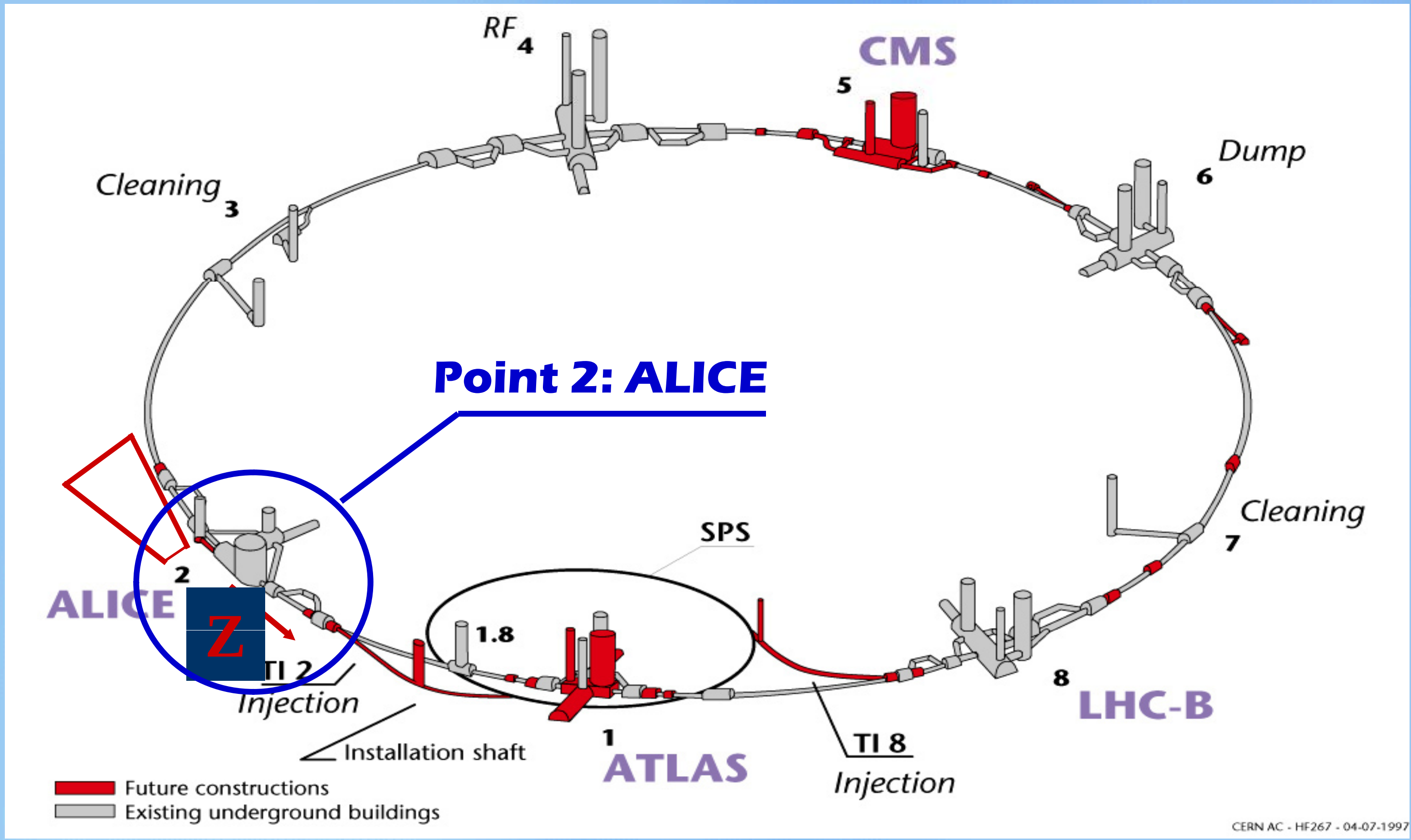
Paola La Rocca

University and INFN Catania

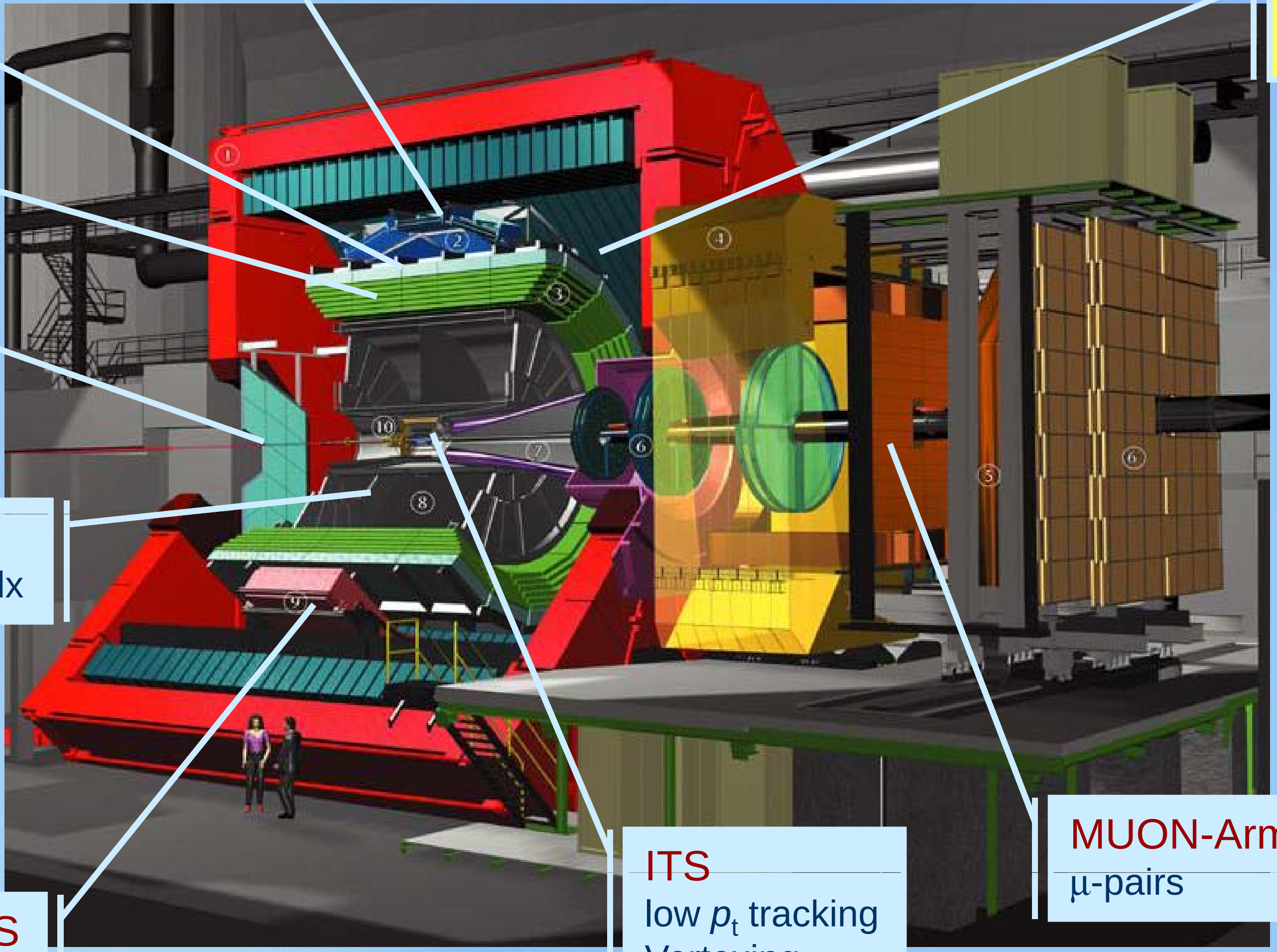
Outline

- The ALICE experiment at LHC
- ALICE ElectroMagnetic CALorimeter
- APD testing station in Catania
- Test results
- Conclusions and Perspectives

The Large Hadron Collider (LHC) @ CERN



Layout of the ALICE detector



Alice Physics

ALICE will track and identify products from pp and nucleus-nucleus collisions in a large multiplicity environment (dN_{ch}/dy up to 8000).

Main tasks:

- ***studying* QCD matter under extreme conditions**
- **studying the phase transition between confined matter and Quark-Gluon Plasma (QGP)**

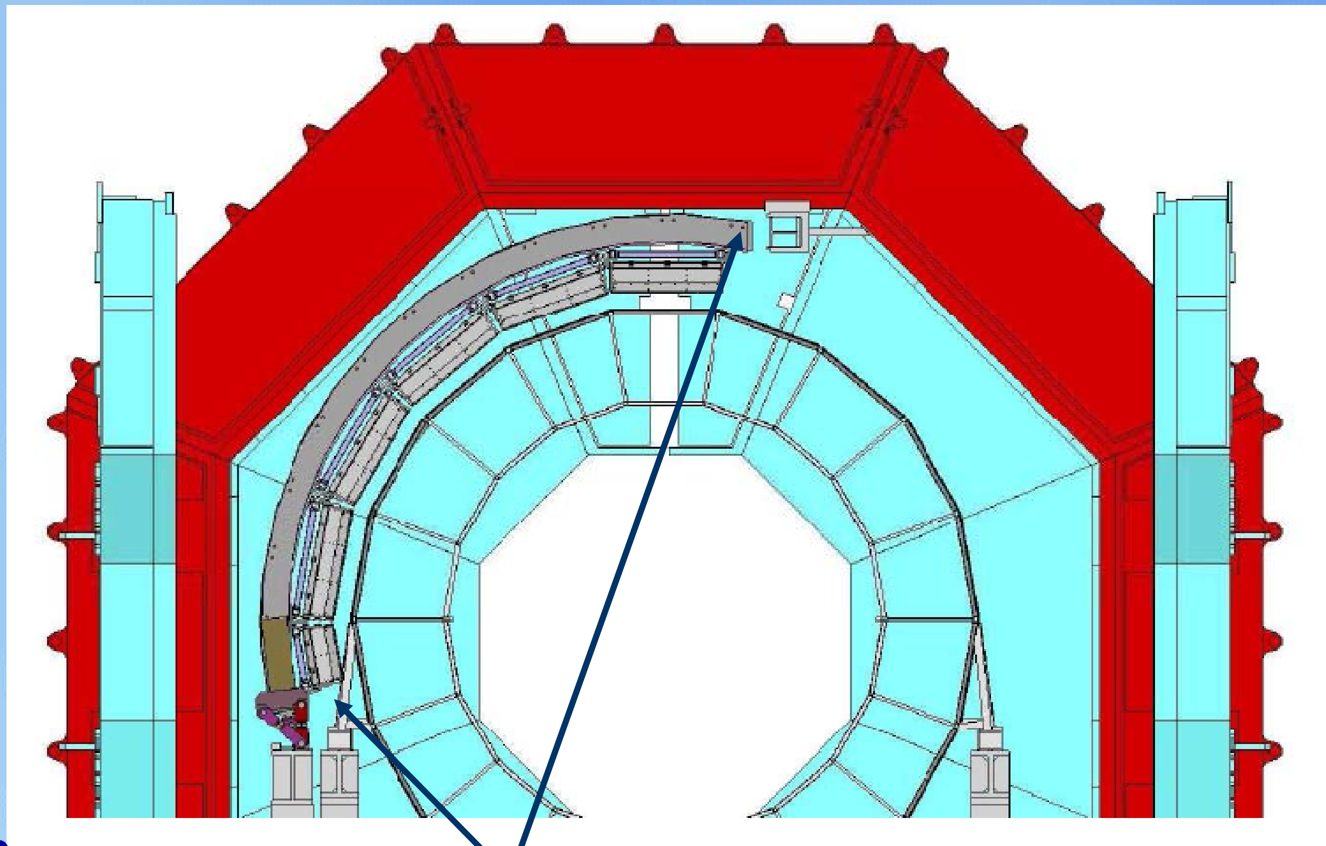
The ElectroMagnetic CALorimeter

ALICE Calorimeters:

PHOS & EMCal

EMCal design is heavily influenced by its integration within the magnet

It provides a partial back-to-back coverage with the PHOS Spectrometer



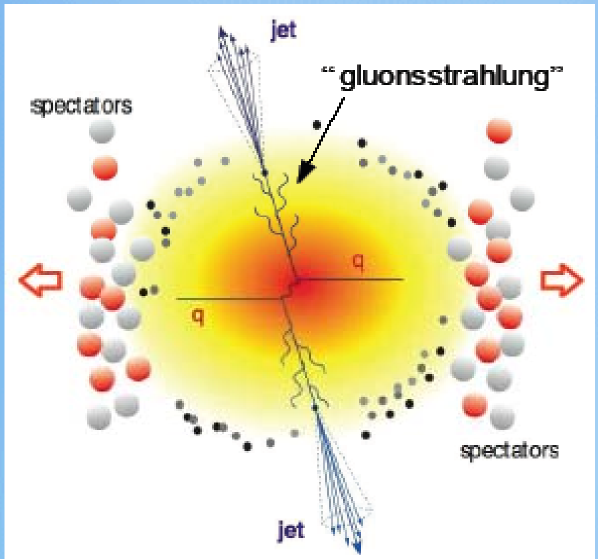
Total Coverage

$\Delta\Phi = 110^\circ \quad -0.7 < \eta < 0.7$

EMCal Physics Motivation: jet study

The combination of the EMCal with the unique tracking and particle ID capabilities of ALICE enable the most extensive measurements of jet *quenching* at the LHC

Jet : A fast quark or gluon plus its radiation (theory).
Collimated bundle of particles with high p_T (experiment).

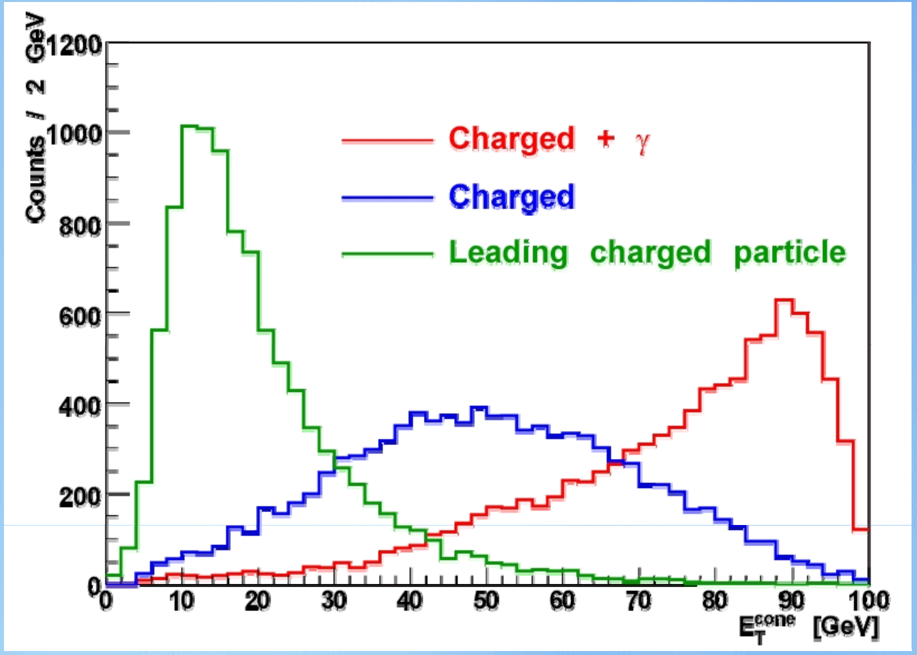


Jet quenching : Change of the jet properties when traversing a colored medium with respect to those in vacuum.

EMCal Physics Performance / 1

EMCal provides :

- **High p_T trigger**
- **Improved jet reconstruction up to 200 GeV**



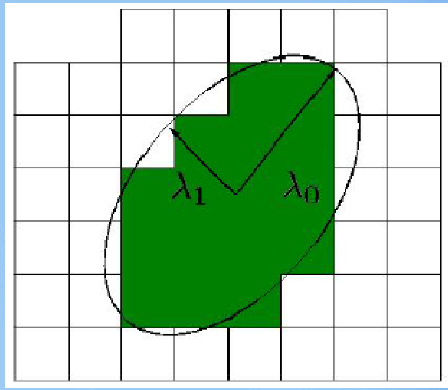
Most probable measured fraction of jet energy:

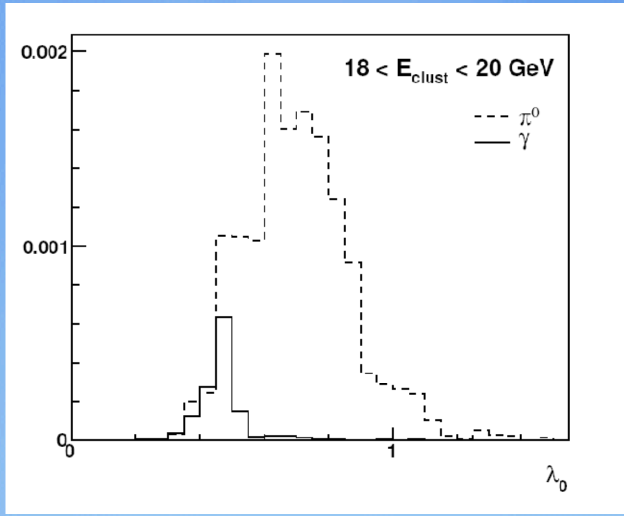
- below 20%
- about 50%
- about 90%

EMCal Physics Performance /2

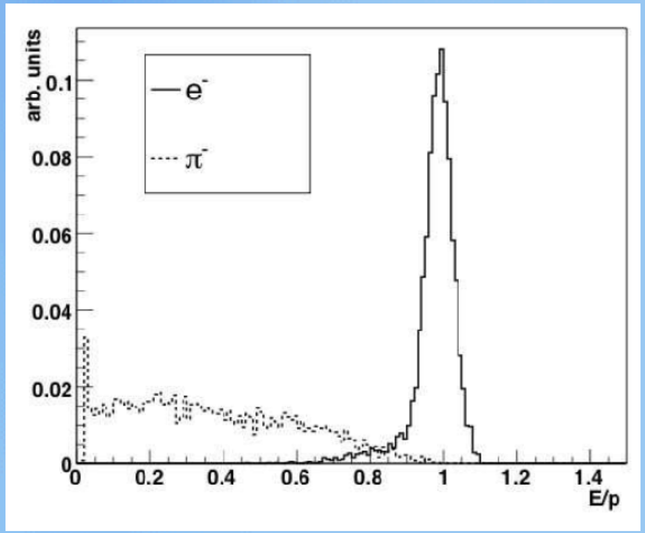
- γ/π^0 discrimination (direct photon measurements)

Shape analysis + invariant mass

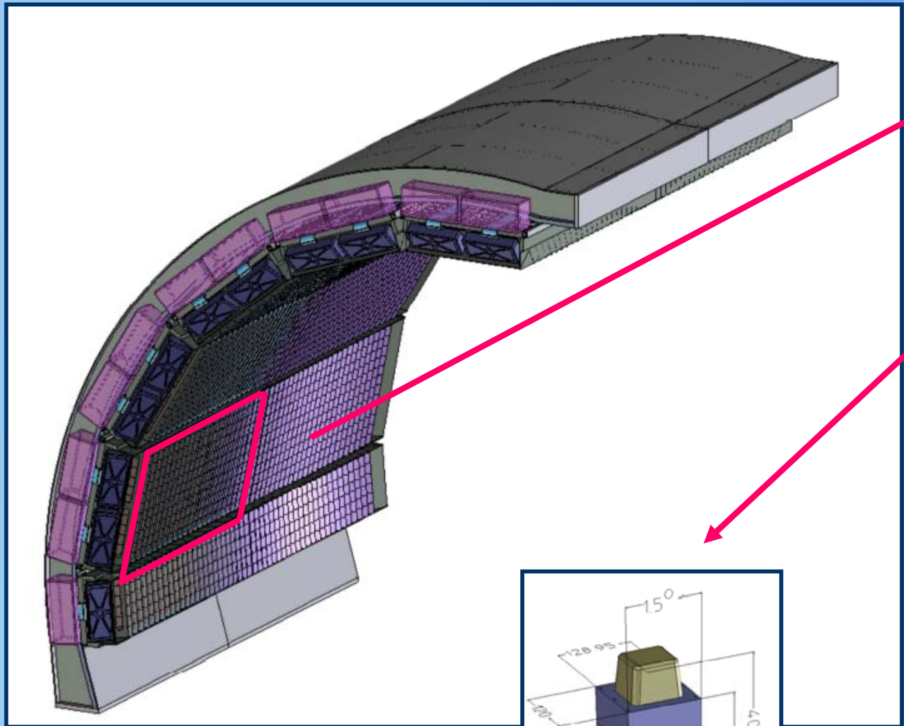


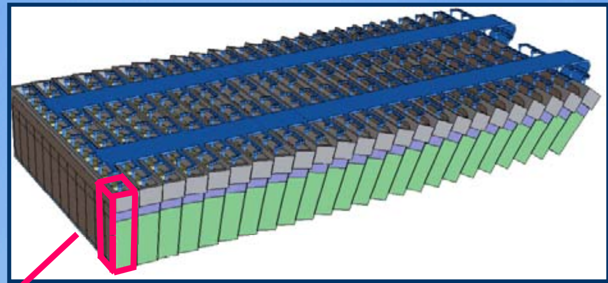


- e^-/π^- discrimination (Heavy Quark Jets)



The EMCal Project





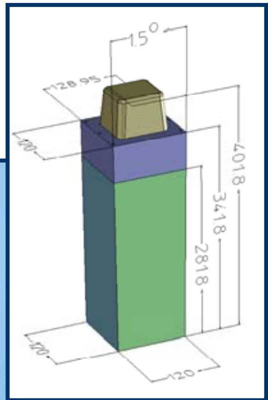
10 super modules
with 12 x 24 modules

$\Delta\Phi = 20°$ $\Delta\eta = 0.7$

2 super modules
with 6 x 24 modules

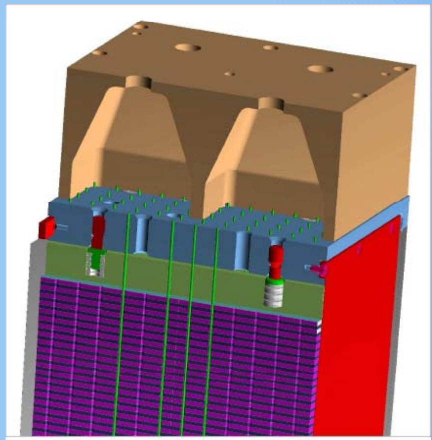
$\Delta\Phi = 20°$ $\Delta\eta = 0.7$

Modules with
2 x 2 towers



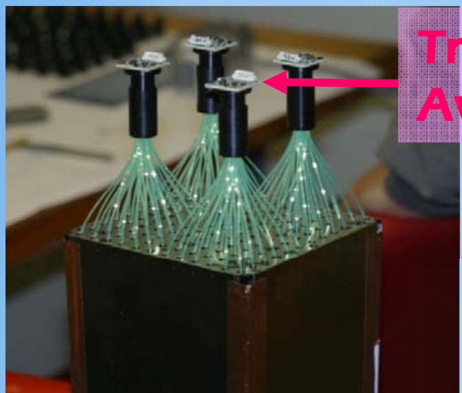
Total Number of
Towers: 12672

Elementary Module : Towers

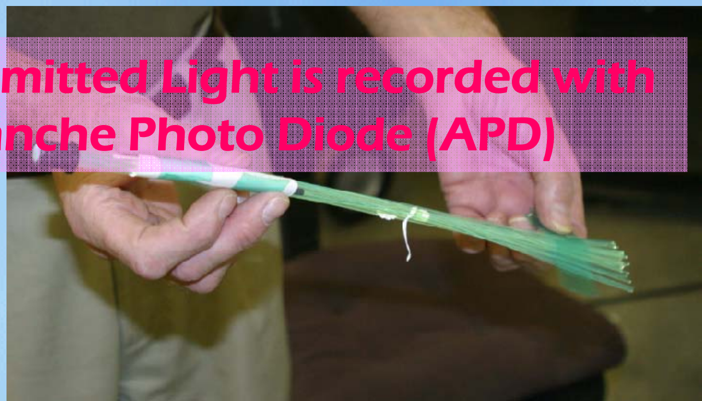


- 77 alternating layers of Pb and polystyrene based scintillator
- Radiation Length ~ 20 X_0
- Front dimensions 6×6 cm^2
- Design resolution: $\sigma_E/E \sim 1\% + 8\%/\sqrt{E}$

Scintillation photons produced in each tower are collected by an array of 36 optical fibres (Shashlik fiber geometry)



Transmitted Light is recorded with Avalanche Photo Diode (APD)



EMCal Planning and Organization

- Several US and EU institutes involved in the EMCal project

(Italy : Frascati, Catania)

- Current expectations : Sept - Oct 2007 beam tests at PS and SPS

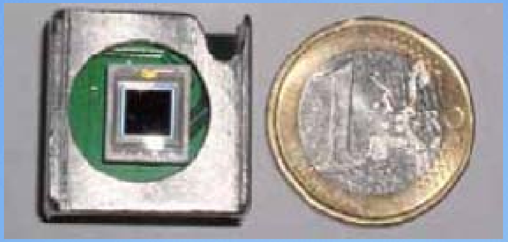
- Catania Task : testing activity on ~3000 APDs

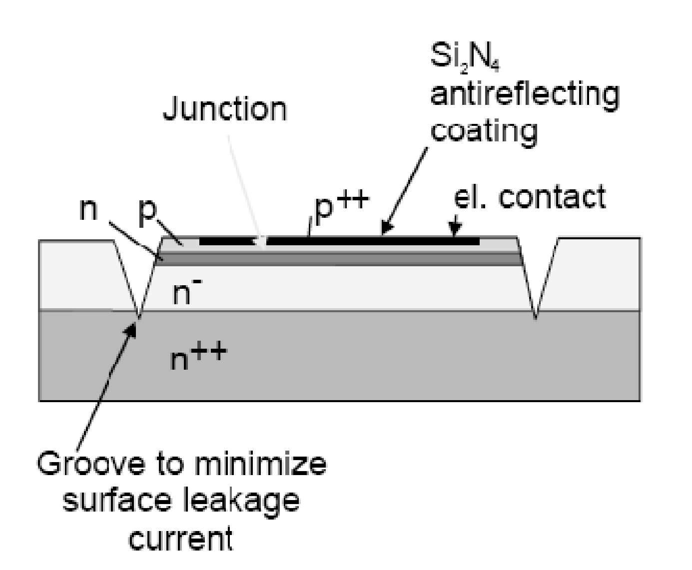
- Actually tested a batch of 80 APDs

Hamamatsu APDs Si APS S8664 series

R&D Activity by the CMS Coll. & Hamamatsu Photonics

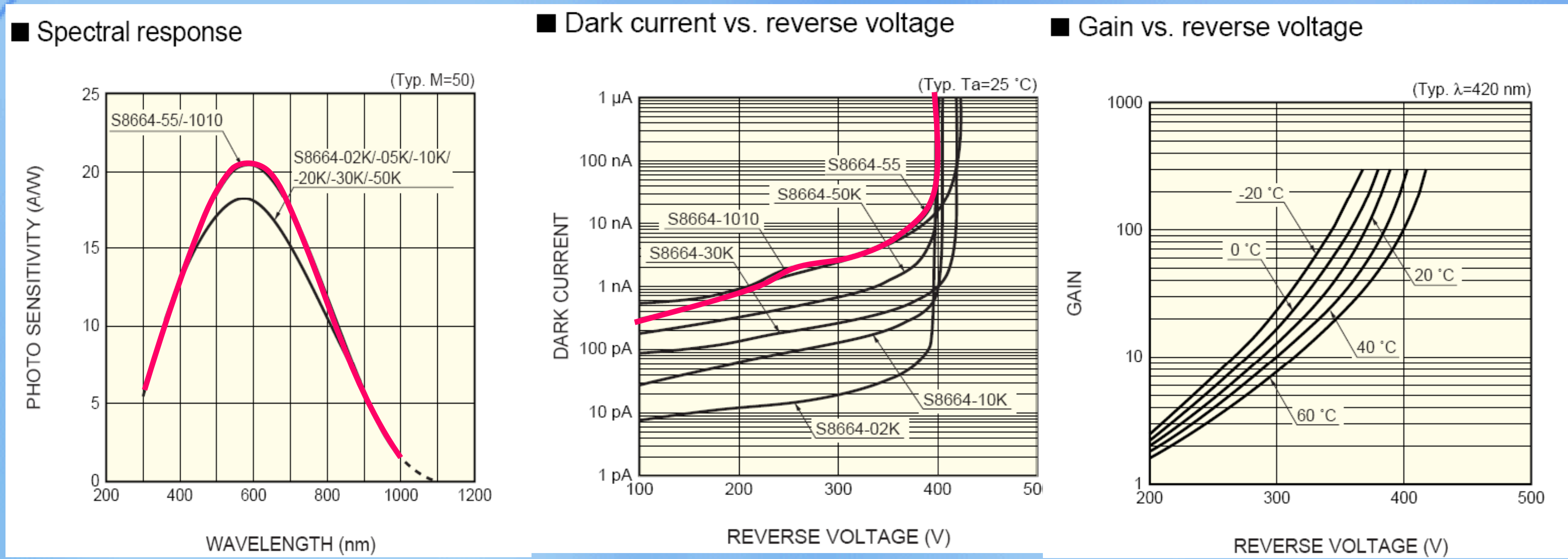
To be used in EMCal calorimeter in a similar way that is already used by PHOS (different temperature and gain)





Parameter	S8664-55 APD
Active area	5×5 mm^2
Op. voltage	~ 380 V
Capacitance	70 pF
Serial resist.	3 Ω
Dark current	< 10 nA
Quantum eff.	72% for 420 nm
$\mathrm{d}M/\mathrm{d}V \times 1/M$	3%/V
$\mathrm{d}M/\mathrm{d}T \times 1/M$	$-2.2\%/^{\circ}$C

Hamamatsu APDs Si APS S8664 series



EMCal Readout Electronics

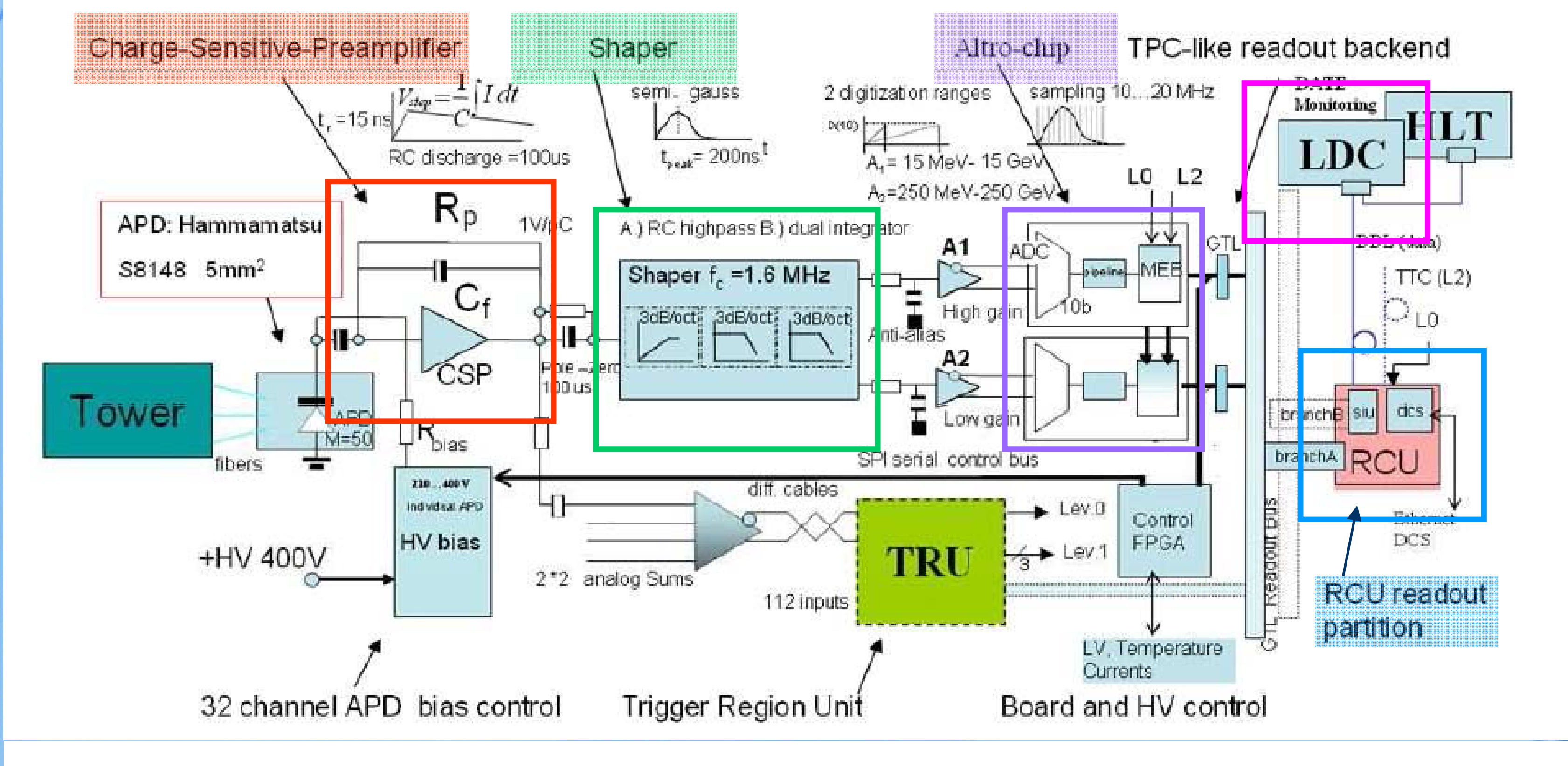
EmCal electronic requirements are quite similar to those of PHOS

$\Rightarrow$ PHOS readout electronics has been adopted for the EmCal readout (with minor modifications)

DESIGN SPECIFICATIONS:

- Large dynamic range ~14bits: dual gain range shapers, flash ADC
- Fast trigger input based on overlapping tower energy sums
- Individual APD bias control for gain matching
- Appropriate timing for low energy neutron / antineutron rejection

EMCal Readout Electronics

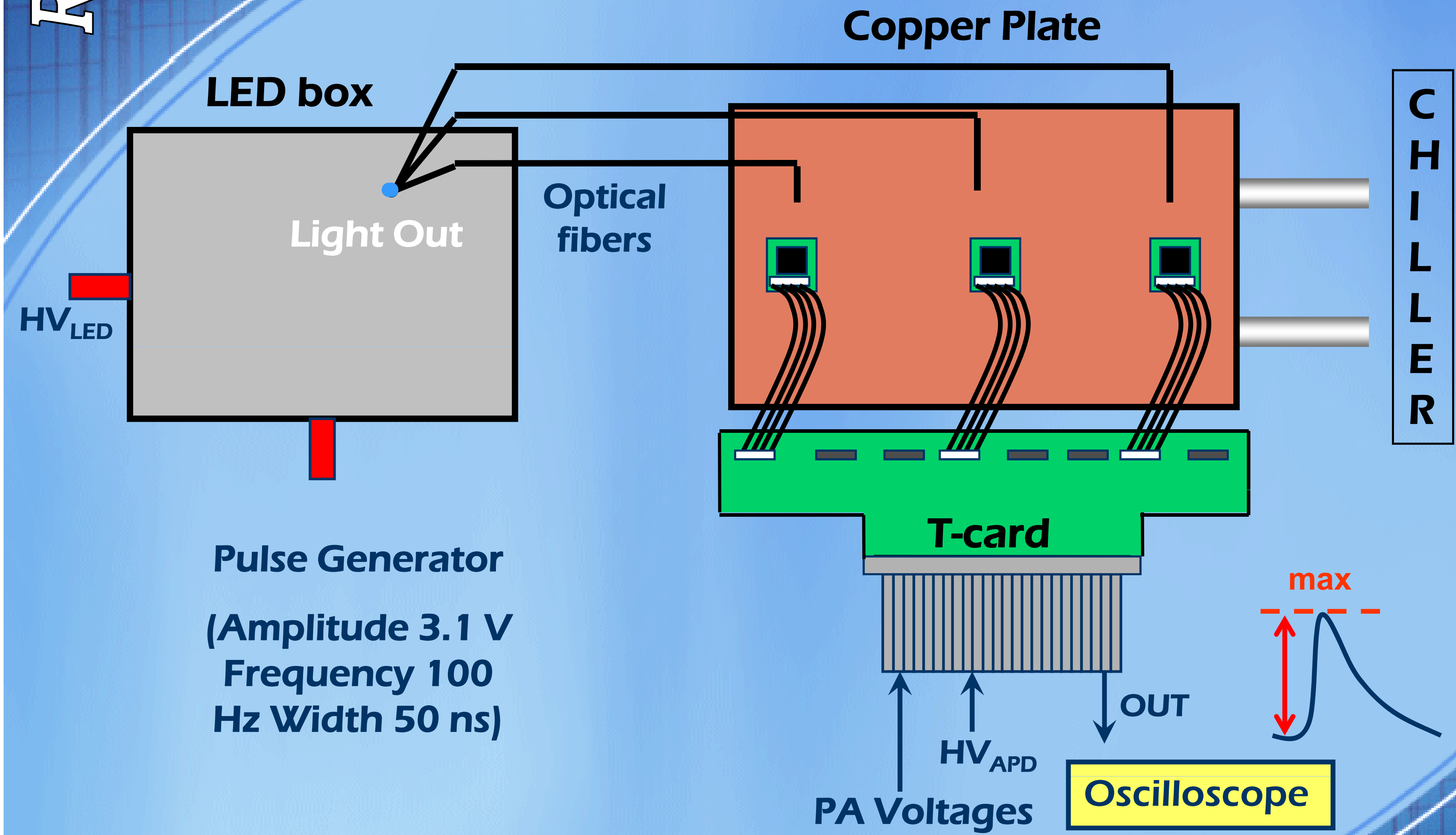


APDs Testing Activity

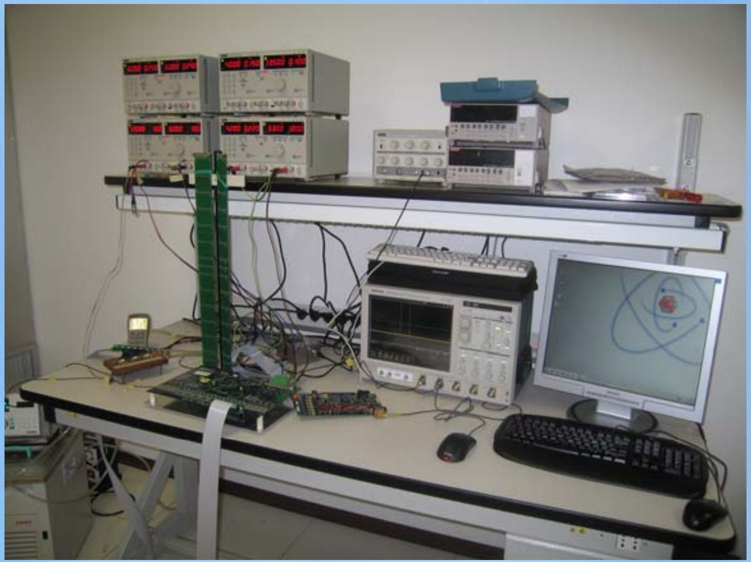
- **APD Calibration is important to:**
  - **Improve the EMCal energy resolution**
  - **Provide a good L0 and L1 trigger**

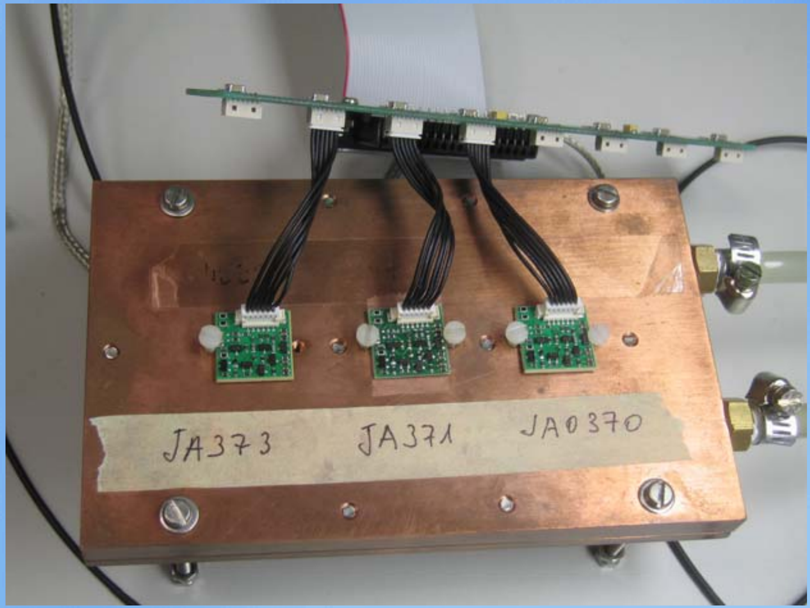
- **Tasks:**
  - **Selecting APDs according to their performances**
  - **Measuring the APD gain dependence on the bias voltage (Voltage Coefficient dM/dV × 1/M)**
  - **Evaluating the nominal voltage setting for the APD to obtain gain M=30 (instead of 50 as for PHOS)**
  - **Measuring the APD gain dependence on the operating temperature (Temperature Coefficient dM/dT × 1/M)**

Testing set-up / 1

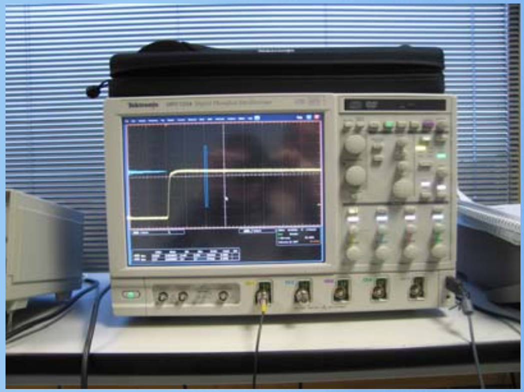


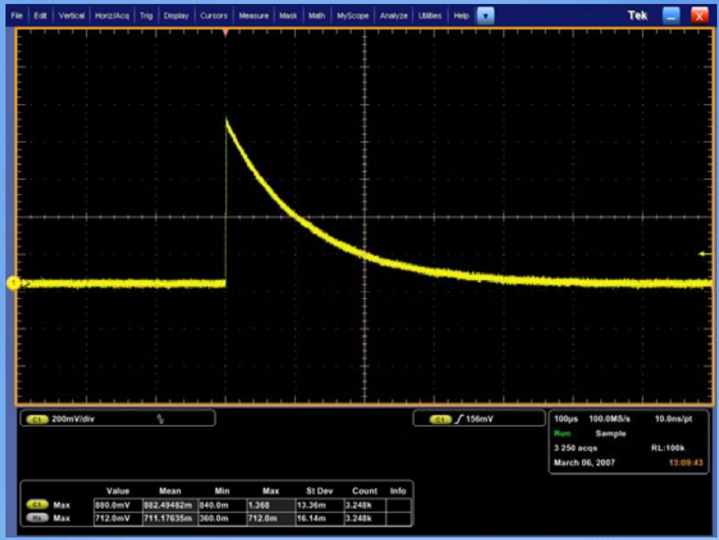
Testing set-up / 2

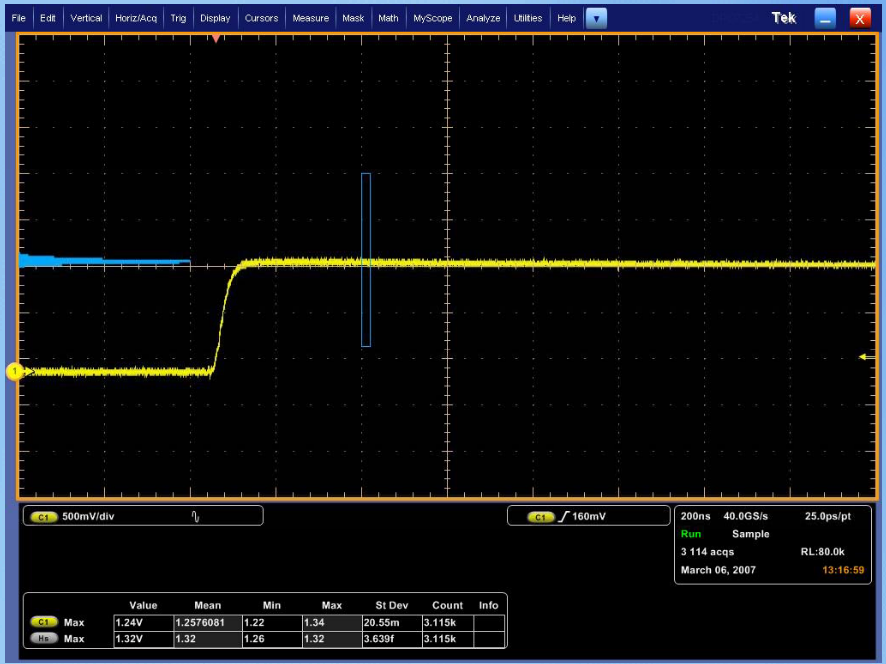




Oscilloscope Measurements







Use of oscilloscope *histogramming capabilities* to perform *measurements*

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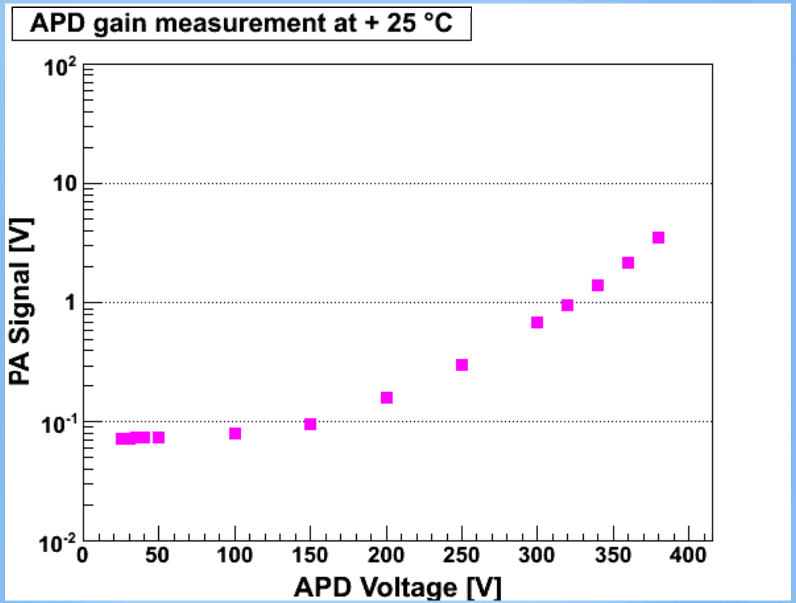
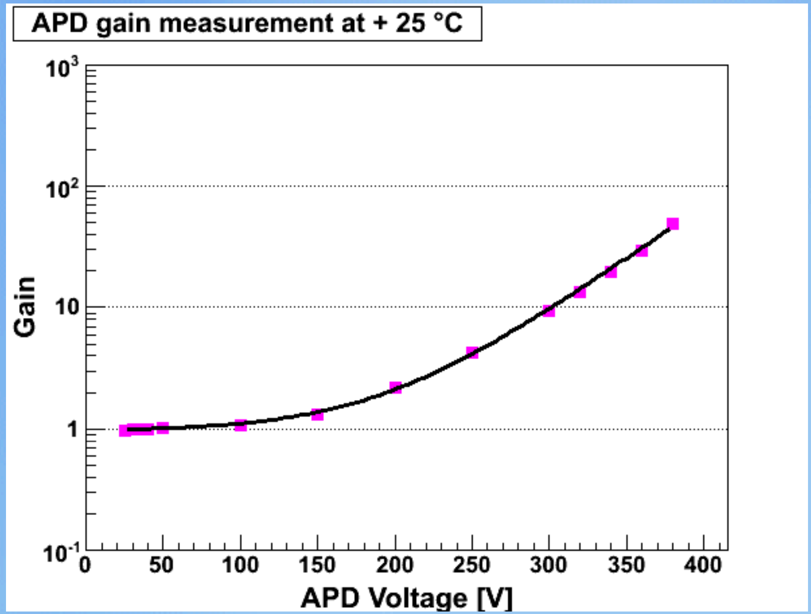
APD Gain dependence on bias voltage

$$M(V) = H(V) / H(plateau)$$

Parameterization with an exponential plus a constant:

$$M(V) = p_0 + p_1 \exp(p_2 V)$$





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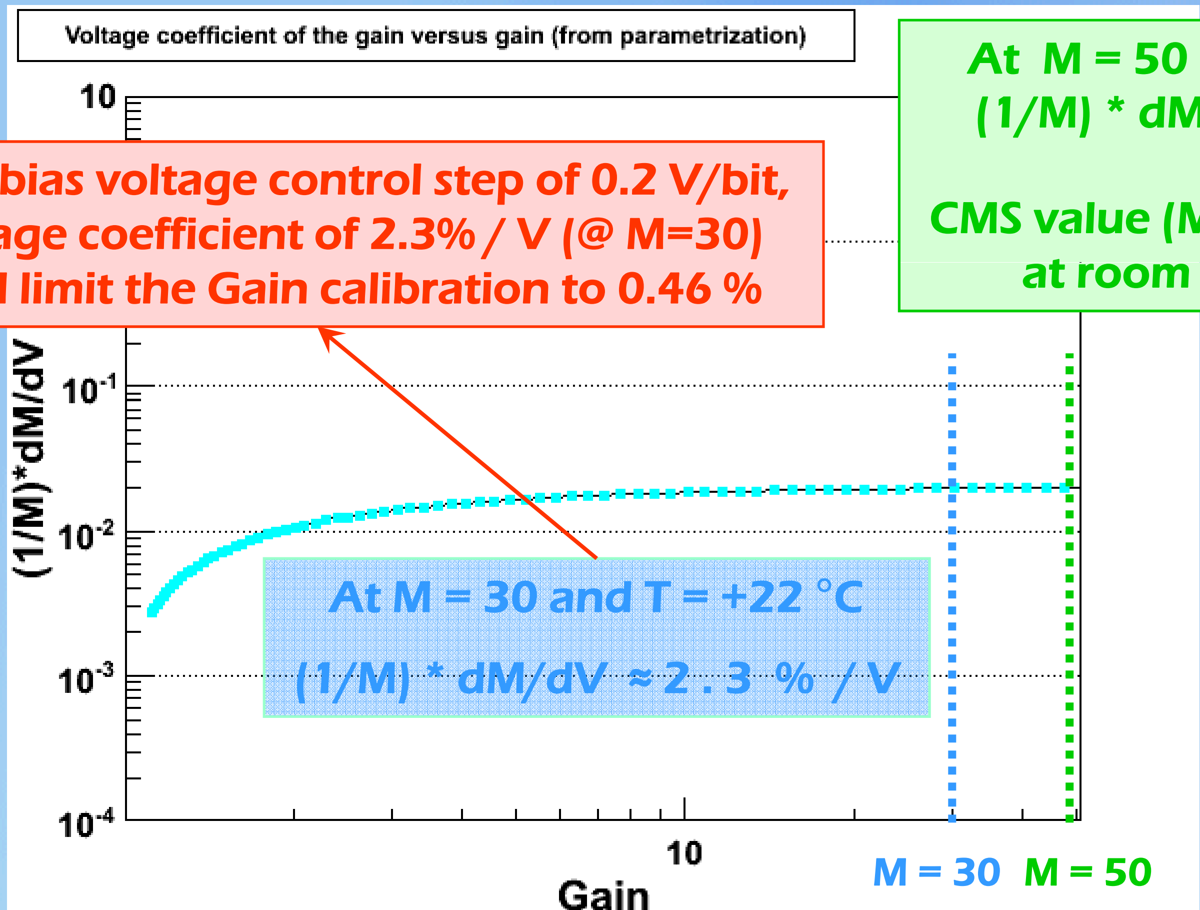
Voltage coefficient of the gain versus gain

(1/M)*dM/dV from parameterization at room temperature (T = + 25 °C)

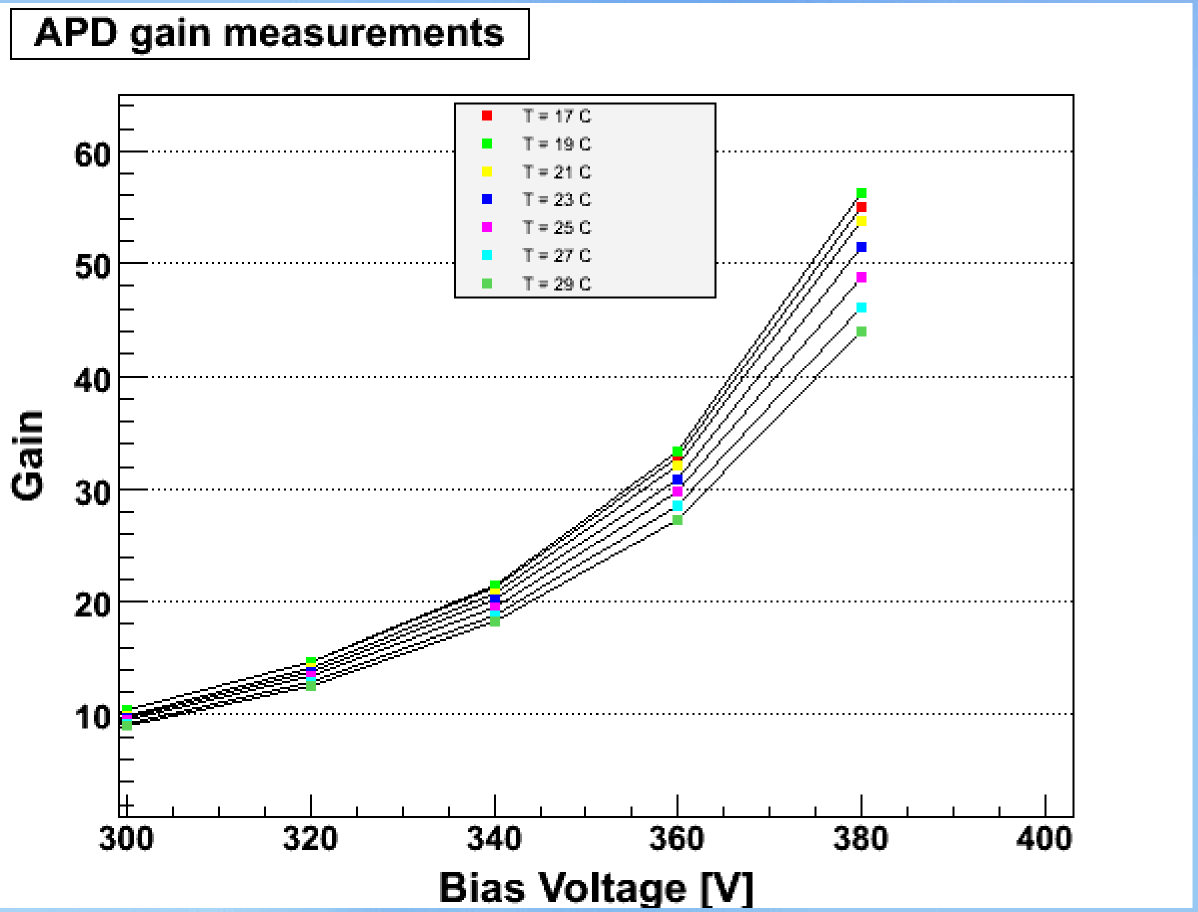


With a bias voltage control step of 0.2 V/bit, a voltage coefficient of 2.3% / V (@ M=30) would limit the Gain calibration to 0.46 %

At M = 50 and T = +25 °C
(1/M) * dM/dV ≈ 3 % / V

CMS value (M = 50): 3 . 3 % /V at room temperature

APD Gain dependence on temperature /1



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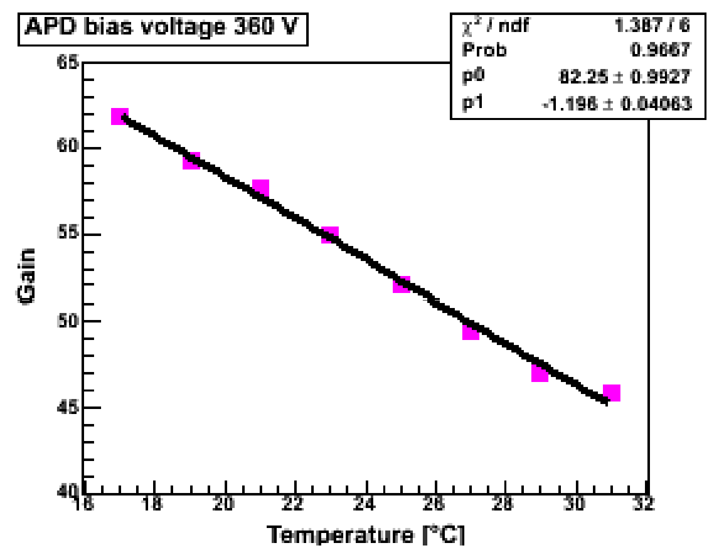
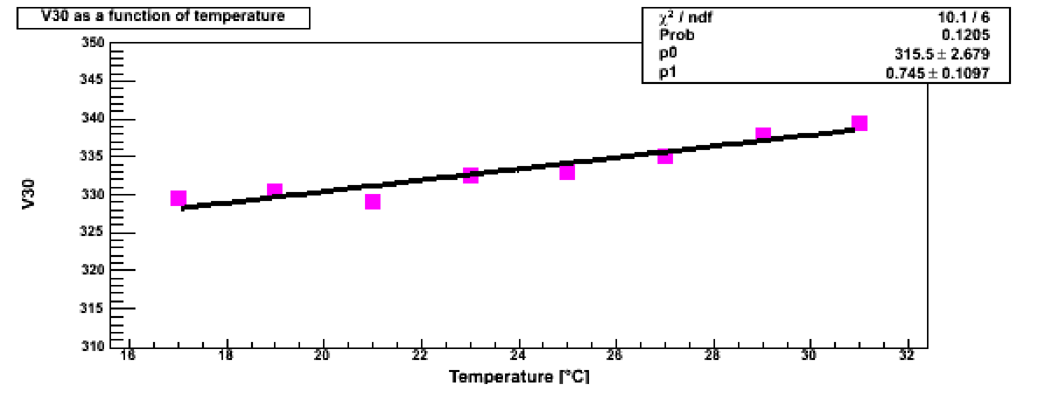
APD Gain dependence on temperature/2

The gain decreases when the temperature increases.

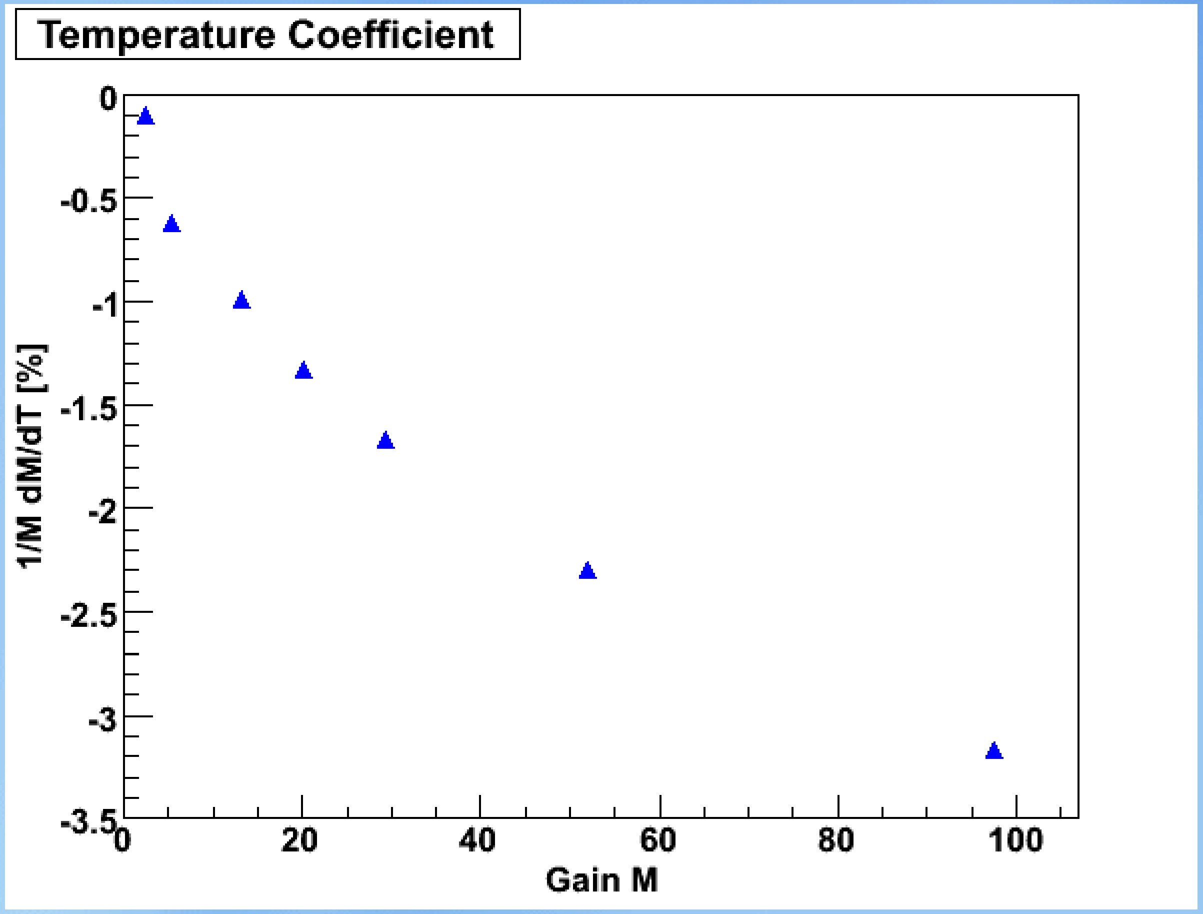




- Small fluctuations from APD to APD

- Realistic measurement of the temperature (thermal equilibrium and thermocouple position)

Temperature coefficient



1/M dM/dT = -1.7 %
(@ M = 30)

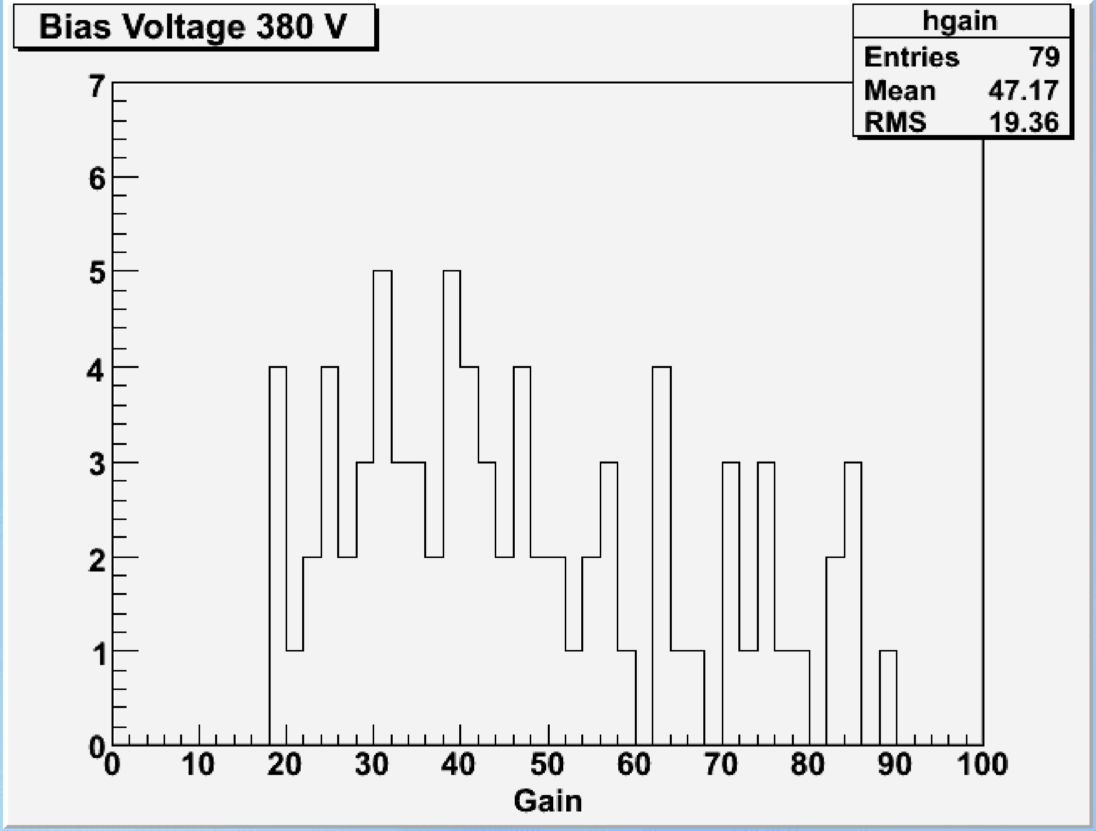
Example:

$\Delta T = \pm 1°$ C

$M = 30 \pm 0.5$

Gain of 80 APDs for a fixed HV

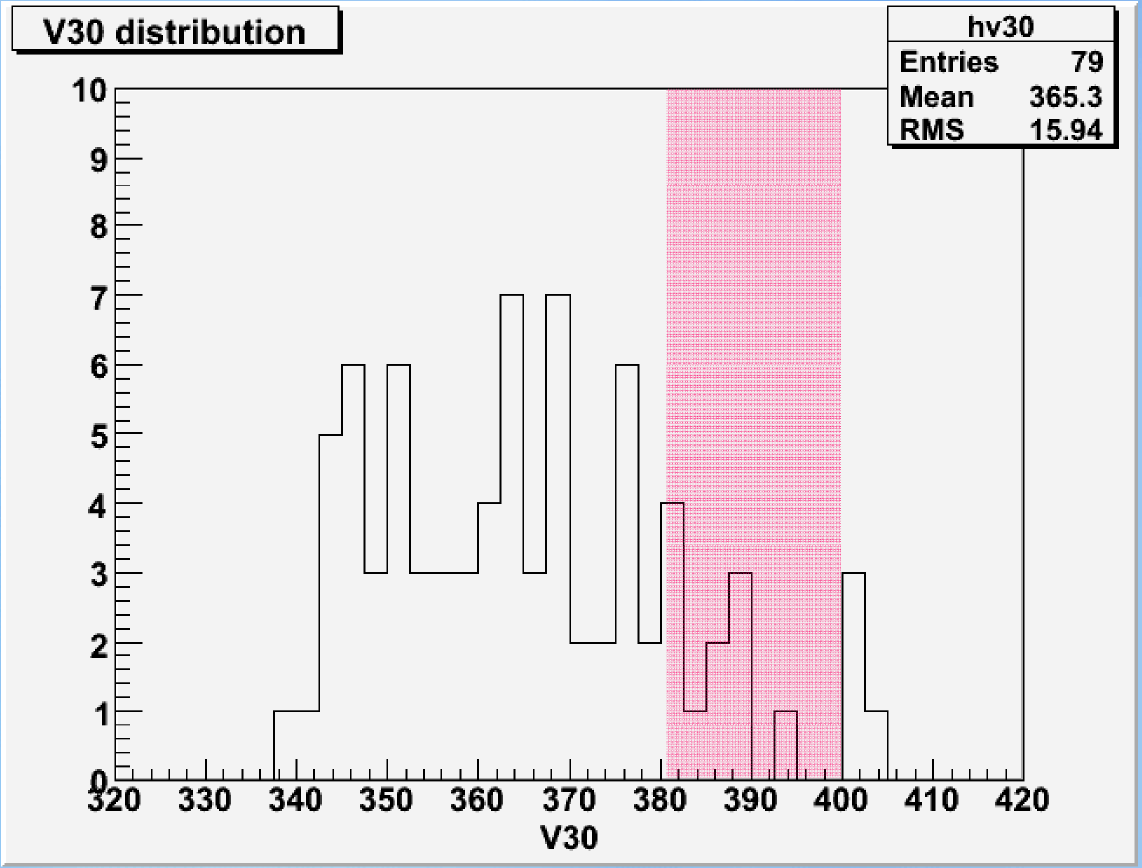
Considerable differences in individual APD gain exist for production batches when the same reverse-bias voltage is applied at an operating temperature of +25° C



Distribution V_{30}

V_{30}: Voltage at which gain M = 30

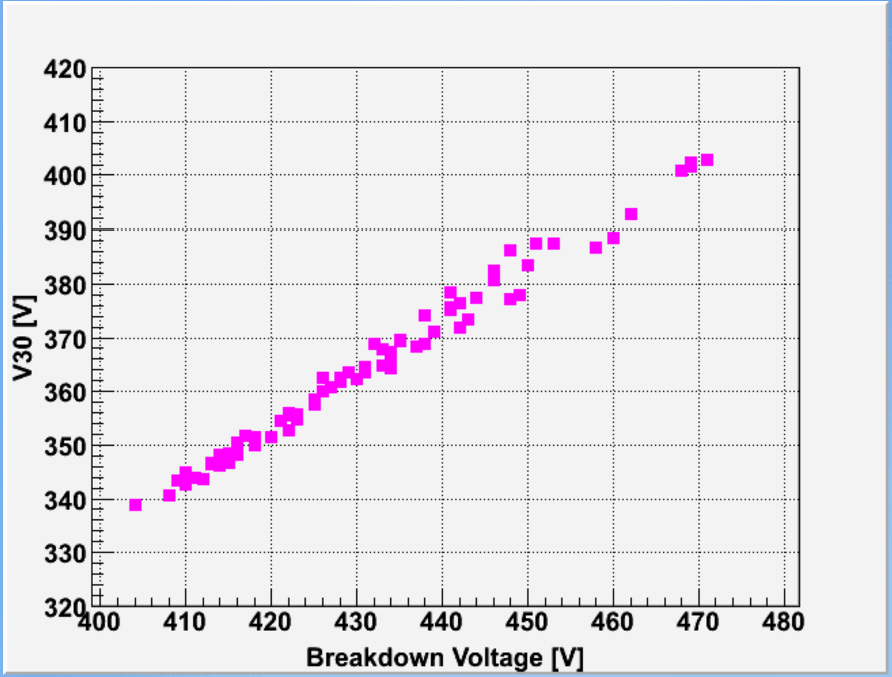
At room temperature (+25° C) V_{30} value should be lower than 400 V

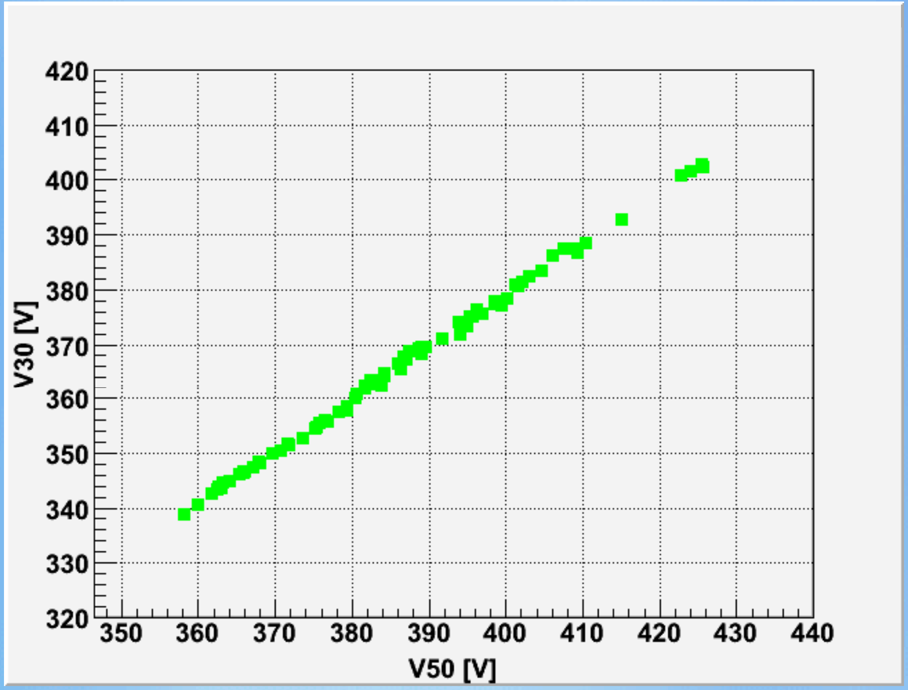


The safety limit changes depending on the operating temperature

V_{30}–$V_{Breakdown}$ Correlation

V30 voltage is highly correlated with V50 and with $V_{Breakdown}$



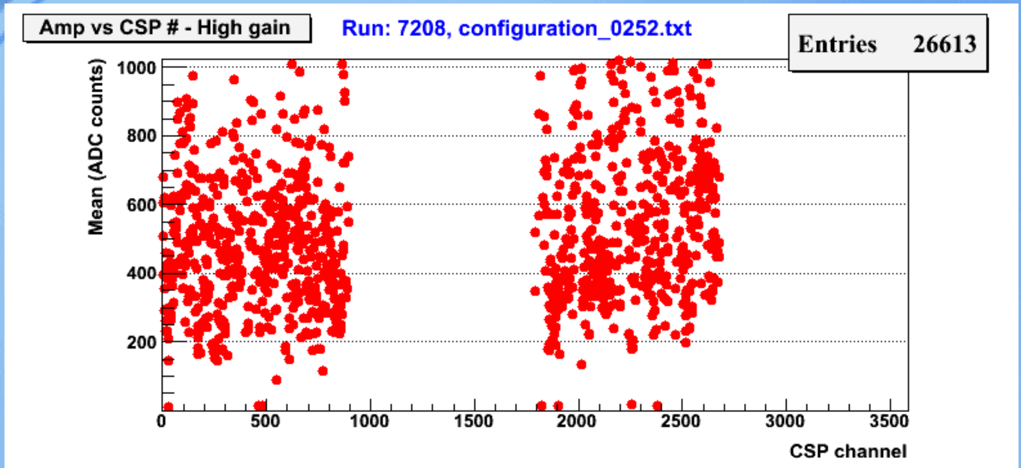


It should be safe to operate the APDs up to 400V without too much care about possible breakdown.

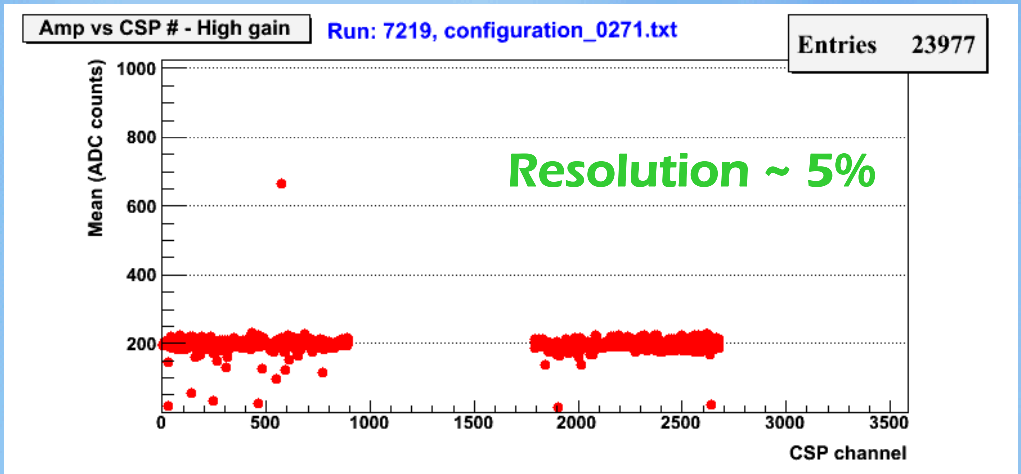
EMCal Calibration

1. APD pre-Calibration

An example: the PHOS Calibration (H. Müller, J. Hamblen, L. Benhabib)



Before calibration

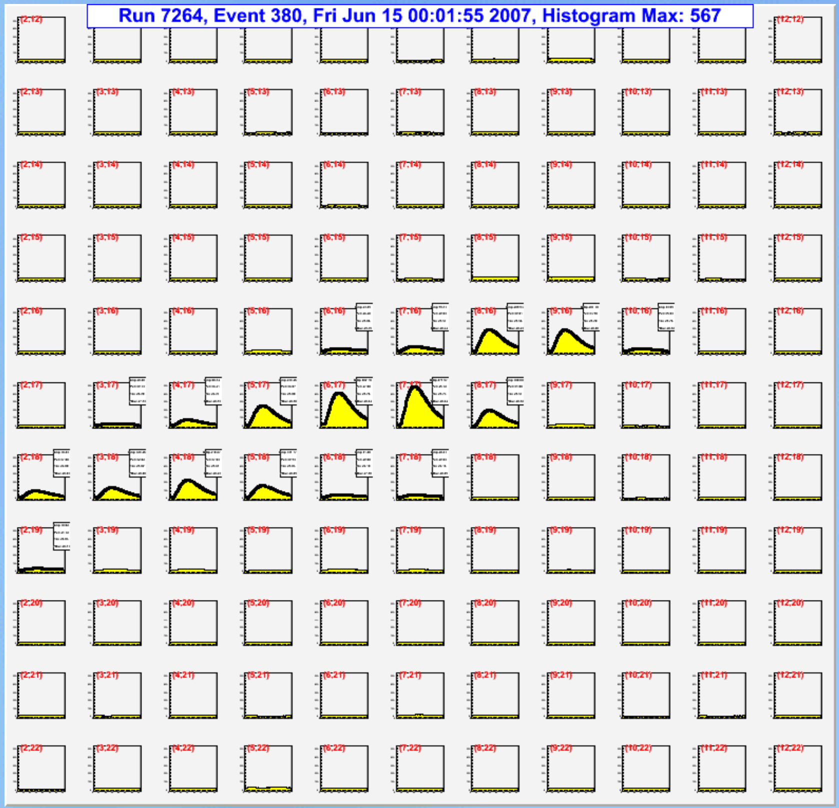


After calibration

EMCal Calibration

2. Cosmic Ray Calibration

(relative calibration of individual module better than 5%)



(H. Müller, J. Hamblen, L. Benhabib)

3. In-beam MIP, Electron and π^0 Calibrations

Conclusions and Perspectives

Present Status:

- *A working testing station has been set up*
- *First results of the APD characteristics fits the experimental requirements of the EMCal*
- *A first batch of 80 APDs analyzed*

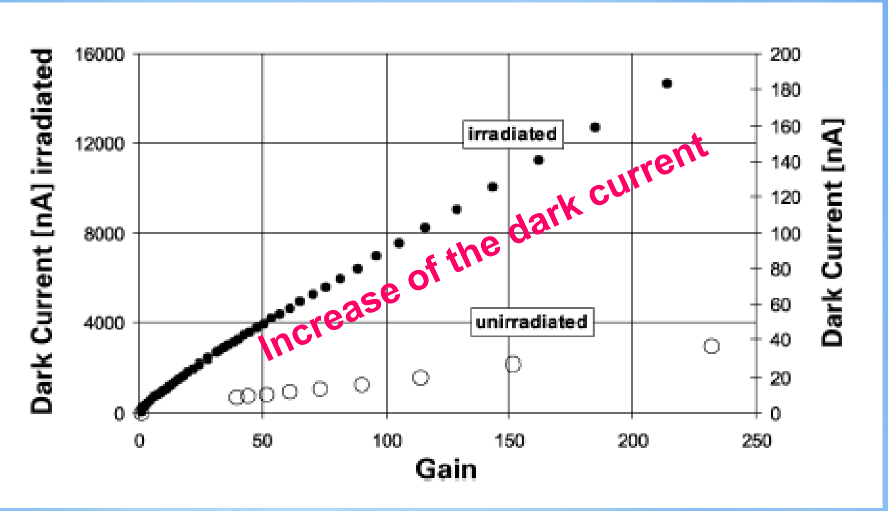
In the future:

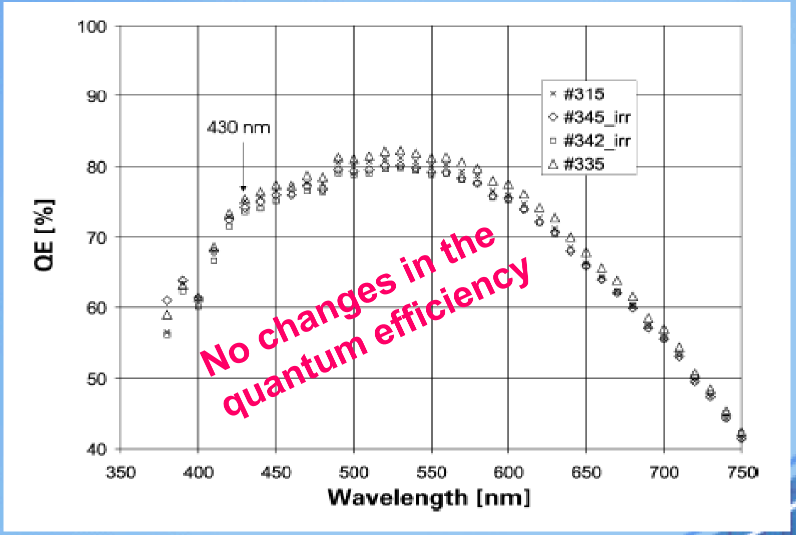
- *Sept - Oct beam tests*
- *Writing a common protocol for the preparation and testing of APDs*
- *Starting the testing activity for APD mass production*

Radiation Hardness /1

CMS collaboration studied extensively the radiation damage in S8664 APDs

- **Irradiation for about 2 h with a 2 nA beam of 64 MeV protons (equivalent to a neutron flux of about 2×10^{13} neutrons/cm^2 – the expected total neutron fluence after 10 years of LHC operation in the central section of the calorimeter)**
- ***annealing for a week at a temperature of 90°C and***
- ***all parameters re-measured***





Radiation Hardness /2

Radiation in ALICE detectors in 10 years running scenario

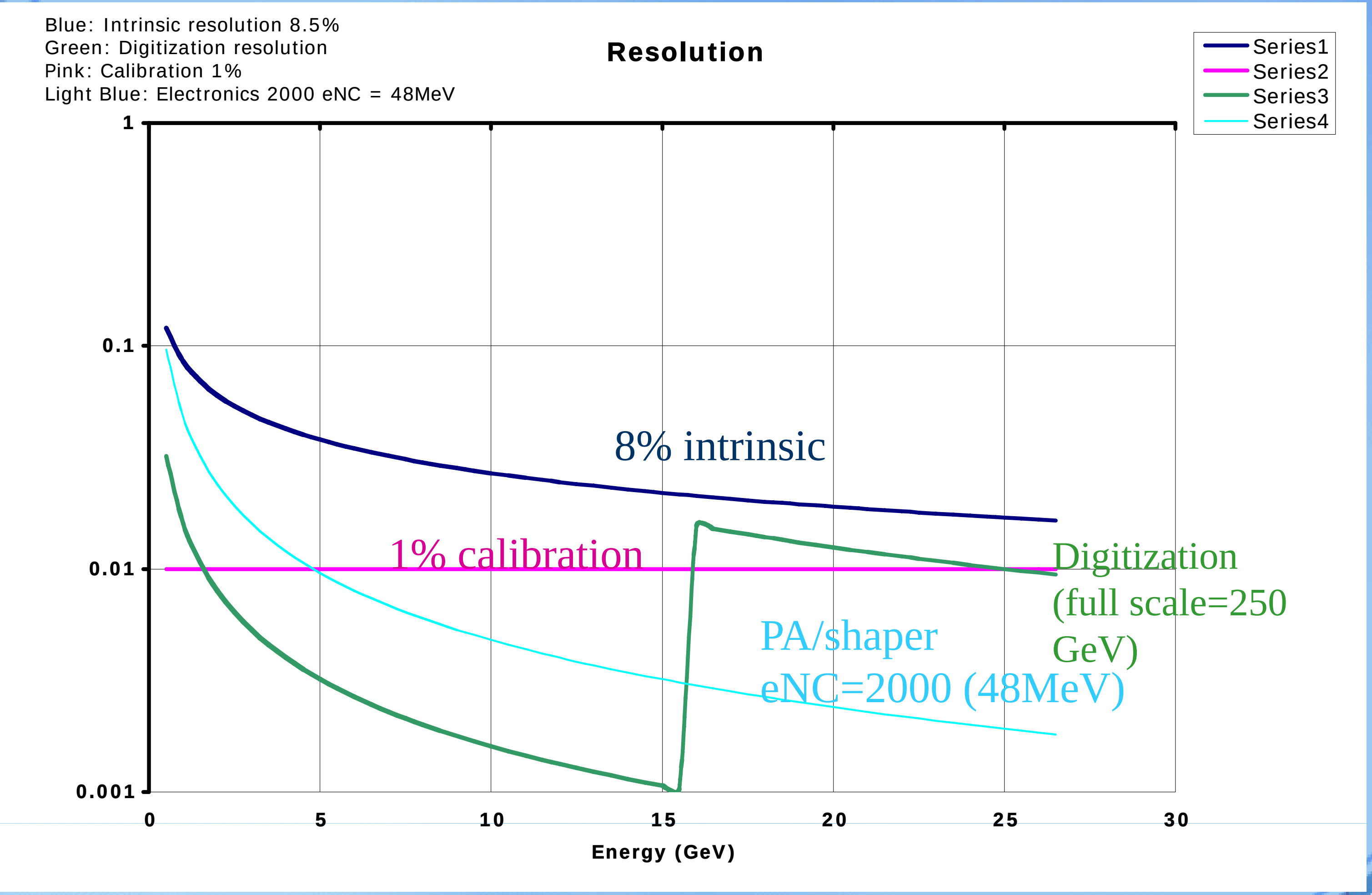
Table 5: Neutron fluence in mid-rapidity detectors.

Detector	n-Φ [cm^{-2}] IP Collisions	n-Φ [cm^{-2}] Beam-Gas	n-Φ [cm^{-2}] Halo	n-Φ [cm^{-2}] Total
SPD1	$8.0 \cdot 10^{11}$	$1.8 \cdot 10^{10}$	$3.1 \cdot 10^{10}$	$8.5 \cdot 10^{11}$
SPD2	$5.6 \cdot 10^{11}$	$1.4 \cdot 10^{10}$	$2.4 \cdot 10^{10}$	$6.0 \cdot 10^{11}$
SDD1	$4.5 \cdot 10^{11}$	$1.4 \cdot 10^{10}$	$2.2 \cdot 10^{10}$	$4.9 \cdot 10^{11}$
SDD2	$4.2 \cdot 10^{11}$	$1.4 \cdot 10^{10}$	$2.0 \cdot 10^{10}$	$4.5 \cdot 10^{11}$
SSD1	$4.0 \cdot 10^{11}$	$1.3 \cdot 10^{10}$	$2.0 \cdot 10^{10}$	$4.3 \cdot 10^{11}$
SSD2	$3.9 \cdot 10^{11}$	$1.2 \cdot 10^{10}$	$1.8 \cdot 10^{10}$	$4.2 \cdot 10^{11}$
TPC(in)	$3.6 \cdot 10^{11}$	$1.2 \cdot 10^{10}$	$1.7 \cdot 10^{10}$	$3.9 \cdot 10^{11}$
TPC(out)	$2.4 \cdot 10^{11}$	$9.0 \cdot 10^{9}$	$5.6 \cdot 10^{9}$	$2.5 \cdot 10^{11}$
TRD	$1.5 \cdot 10^{11}$	$6.0 \cdot 10^{9}$	$3.2 \cdot 10^{9}$	$1.6 \cdot 10^{11}$
TOF	$1.0 \cdot 10^{11}$	$4.7 \cdot 10^{9}$	$2.4 \cdot 10^{9}$	$1.1 \cdot 10^{11}$
PHOS	$8.0 \cdot 10^{10}$	$3.4 \cdot 10^{9}$	$2.2 \cdot 10^{9}$	$8.6 \cdot 10^{10}$
HMPID	$8.0 \cdot 10^{10}$	$3.4 \cdot 10^{9}$	$2.2 \cdot 10^{9}$	$8.6 \cdot 10^{10}$

Table 4: Doses in mid-rapidity detectors.

Detector	Dose [Gy] IP Collisions	Dose [Gy] Beam-Gas	Dose [Gy] Halo	Dose [Gy] Total
SPD1	2000	250	500	2750
SPD2	510	48	120	680
SDD1	190	12	45	250
SDD2	100	2.4	13	120
SSD1	40	1.2	7	50
SSD2	26	0.6	2.5	30
TPC(in)	13	0.25	2.9	16
TPC(out)	2	0.05	0.2	2.2
TRD	1.6	0.03	0.16	1.8
TOF	1.1	0.03	0.1	1.2
PHOS	0.5	0.01	0.04	0.5
HMPID	0.5	0.01	0.04	0.5

Energy Resolution



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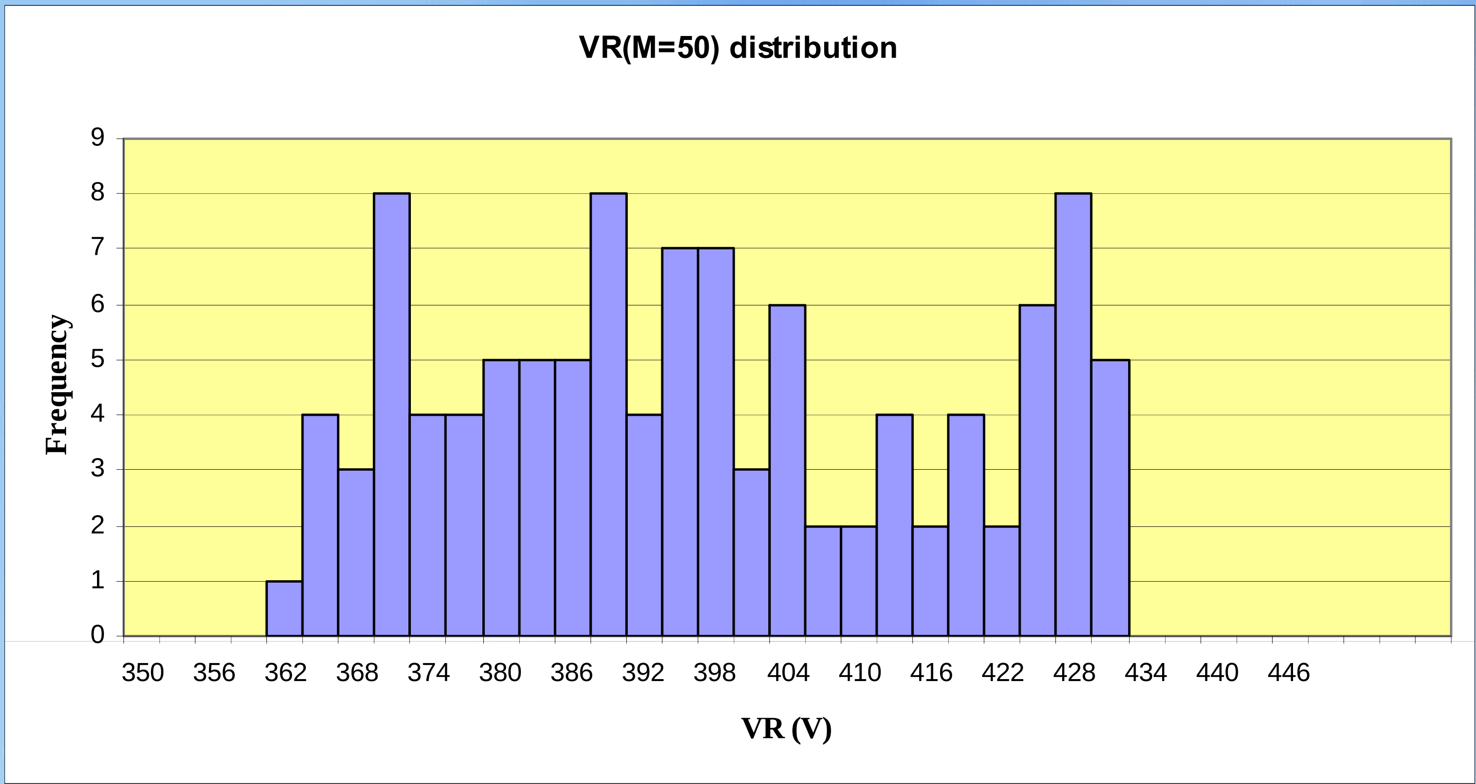
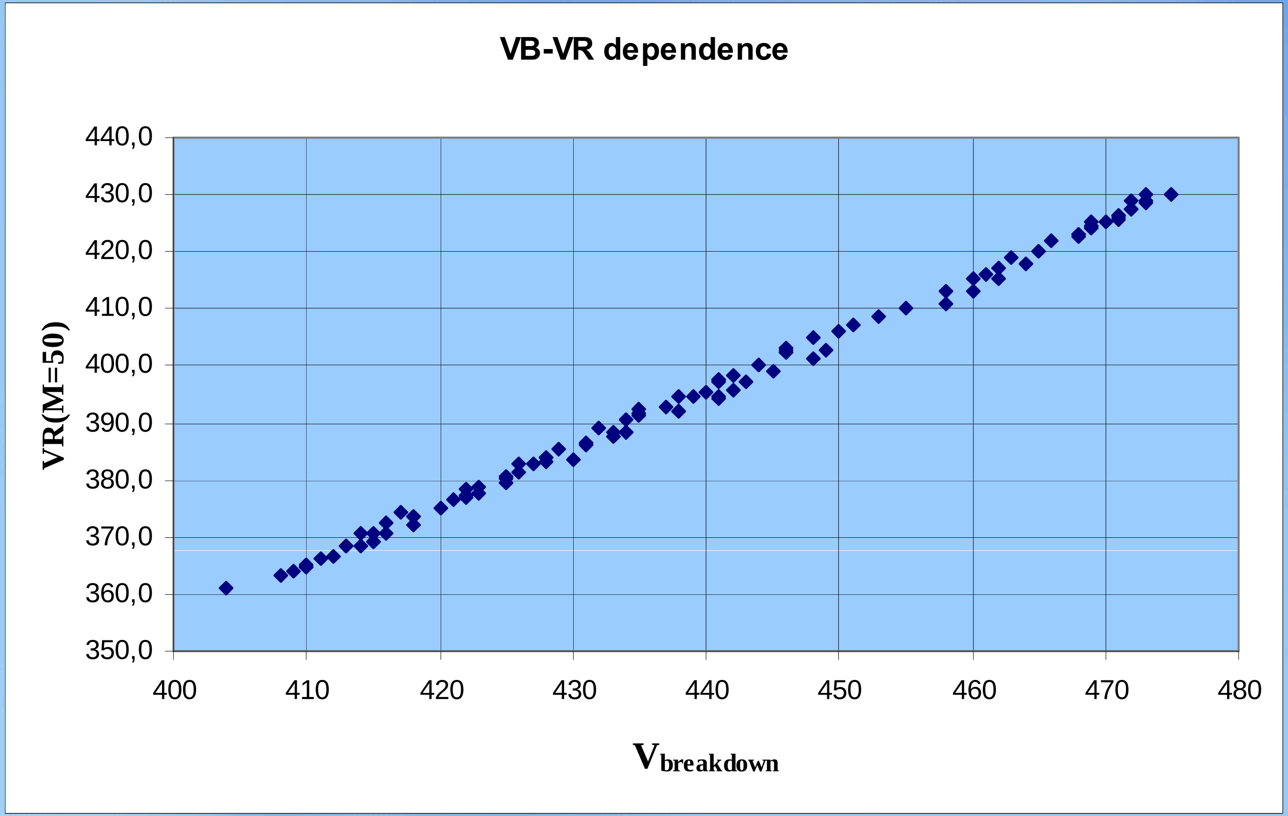
Statistics provided by Hamamatsu /1

1st batch of 100 APDs



Statistics provided by Hamamatsu /2



The breakdown voltage is highly correlated with V50

It should be safe to operate the APDs up to 400V without too much care about possible breakdown.