High precision, low disturbance calibration of the High Voltage system of the CMS Barrel Electromagnetic Calorimeter

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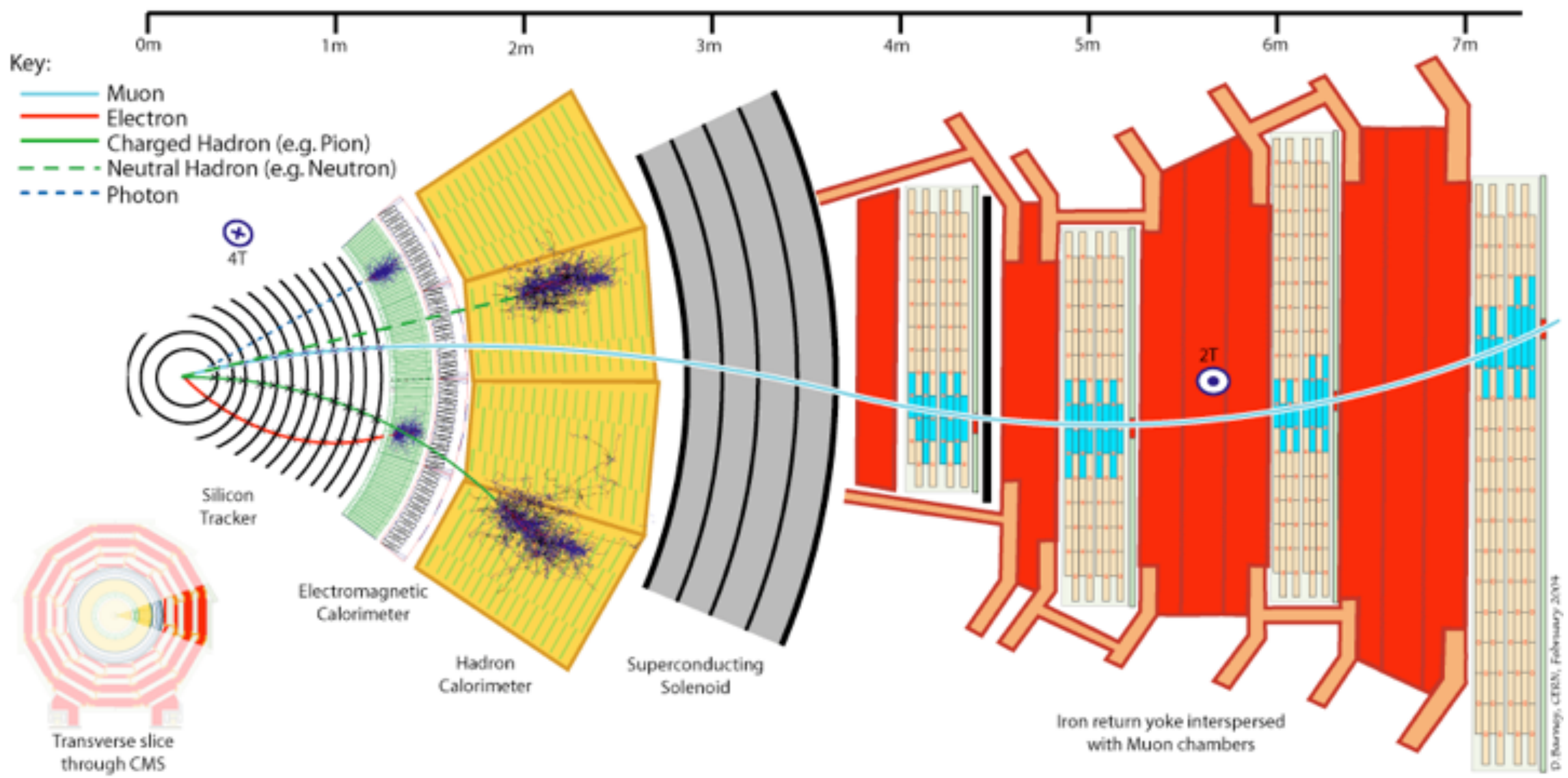
Outline

- LHC and CMS description
- ECAL description
- Readout electronics
- ECAL Barrel HV system
- Calibration Description

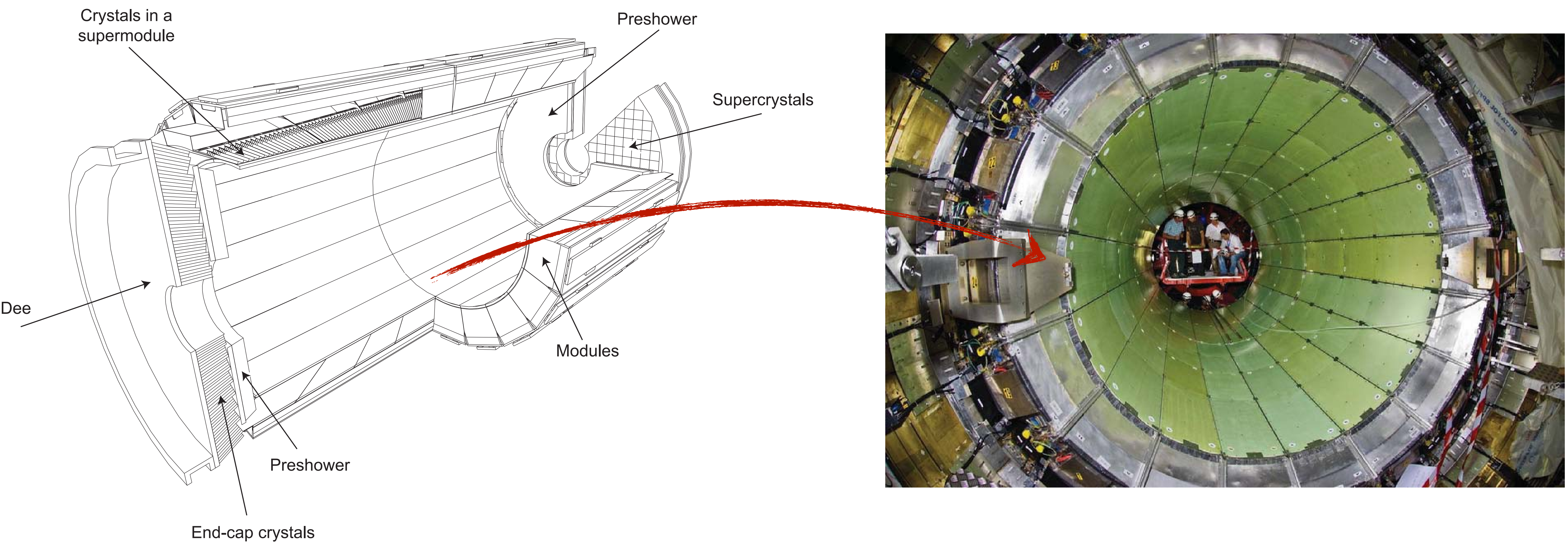
Compact Muon Solenoid (CMS)

- Multi-purpose detector
  - length: 21 m; height: 15 m; weight: >10 kt
- Subdetectors:
  - Tracker (+pixel)
  - Calorimeters: **<u>e.m.</u>** and hadronic
  - Solenoid magnet: 3.8 Tesla
  - Muon chambers



Electromagnetic Calorimeter

- The electromagnetic calorimeter of CMS (ECAL) is a hermetic homogeneous calorimeter made of 61200 lead tungstate ($PbWO_4$) crystals mounted in the central barrel part, closed by 7324 crystals in each of the two endcaps

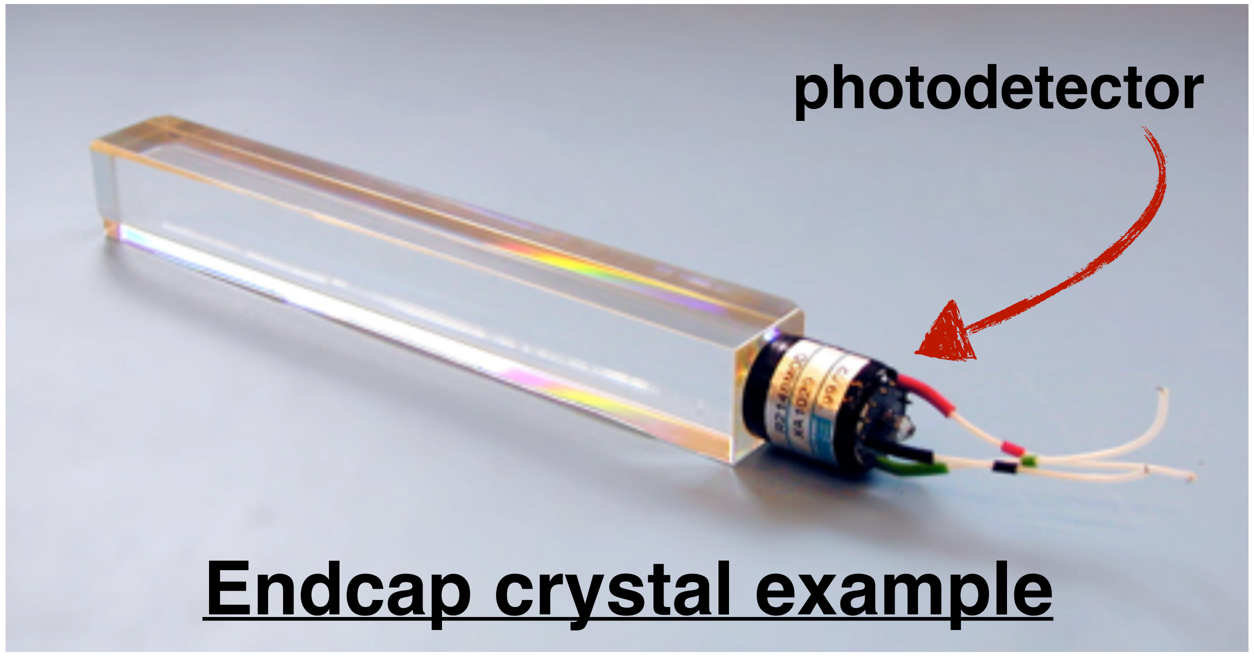


- Barrel is divided in 36 Supermodules of 1700 crystals each (two sides EB+ and EB-)
- Endcaps divided into Dees (138 5x5 matrices of crystals)

Lead Tungstate Crystals

- The $PbWO_4$ has been chosen for its particular characteristics:

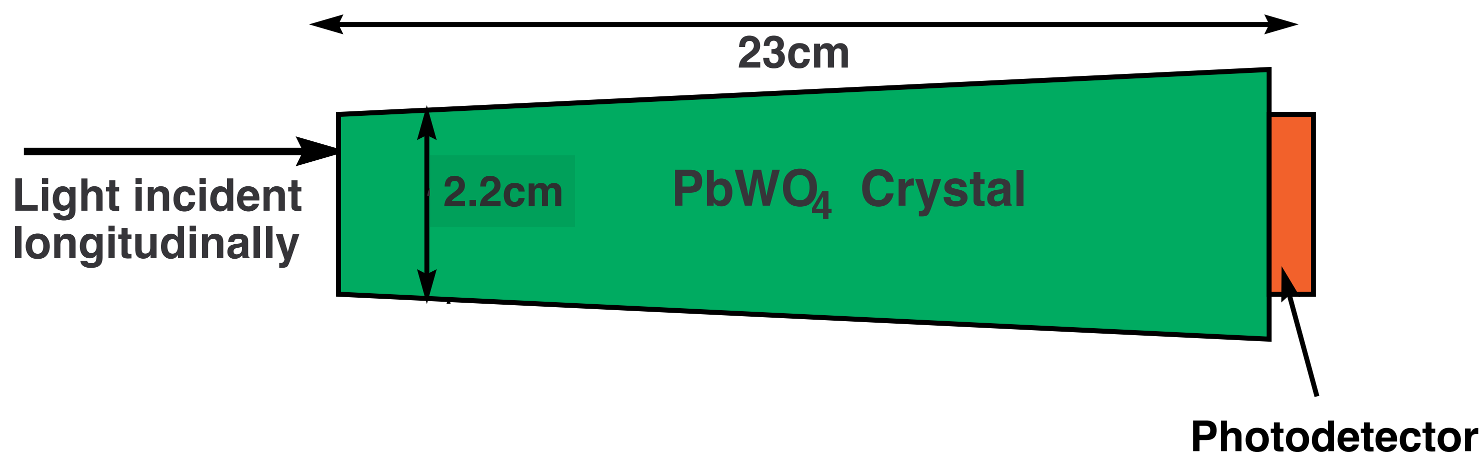
ρ [g/cm³]	8.28
Molière radius [cm]	2.2
Radiation Length [cm]	0.89
Wavelength [nm]	420-430
p.e. emission [MeV^{-1}]	4.5



- Low p.e. emission ⇒ photodetector with internal gain (gain=50) needed

Detection System

- Each crystal is coupled to one (Endcap) or two (Barrel) photodetectors:
  - Barrel: 2 Avalanche Photodiodes (APD)
  - Endcap: 1 Vacuum Phototriodes (VPT)



2 APD modules

to the readout electronics

APD specifications

sensitive area	5x5 mm^2	rise time	<2 ns
operating voltage	340-430 V	dark current	≈3 nA
effective thickness	6 ± 0.5 μm	quantum efficiency	75 ± 2%
series resistance	<10 Ω	gain sensitivity (V)	3.1 ± 0.1%/V
capacitance	80 ± 2 pF	gain sensitivity (T)	-2.4 ± 0.2%/°C

Energy Resolution

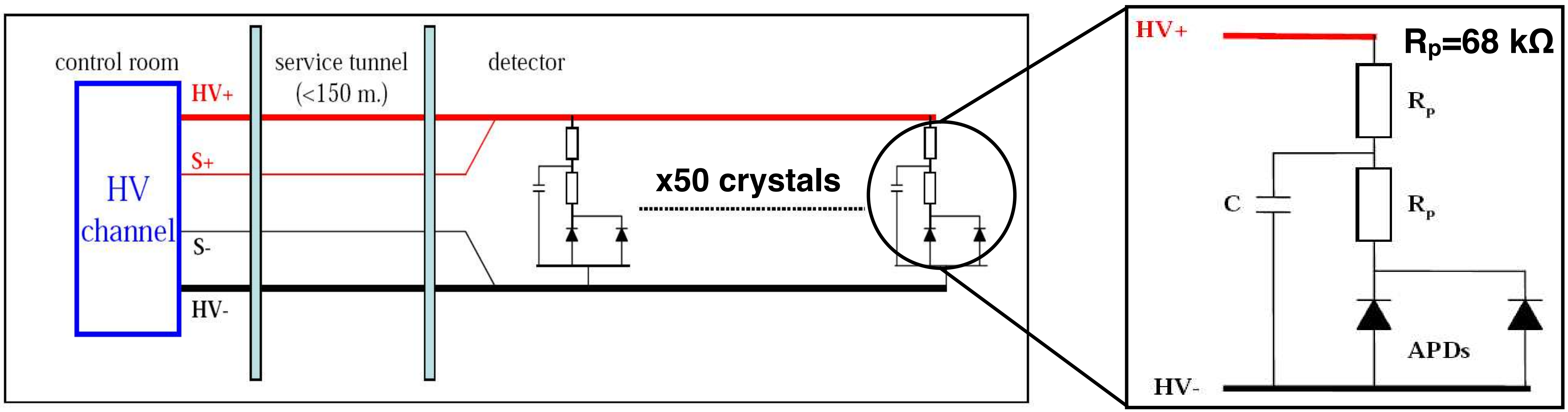
- Three contributions in the energy resolution:
  - stochastic
  - noise
  - **constant**

$$\frac{\sigma(E)}{E} = \frac{a_{stoc}}{\sqrt{E}} \oplus \frac{b_n}{E} \oplus c$$

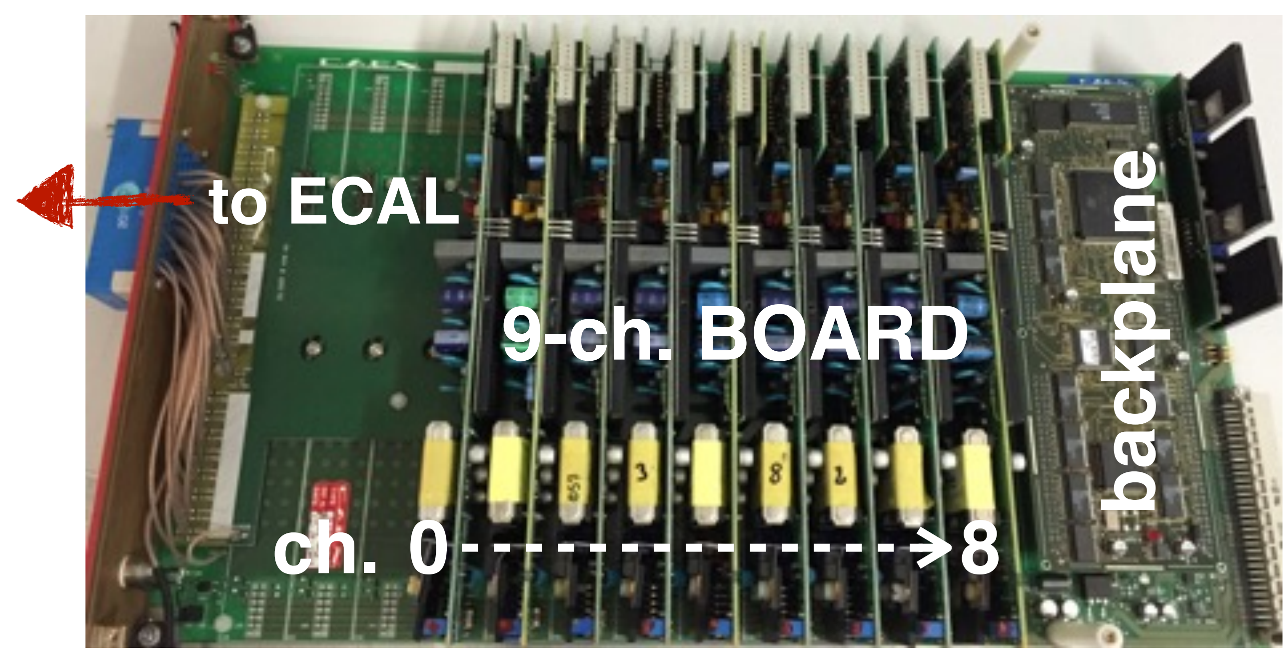
- The HV system affects the constant (c) term
  - to have 3% gain sensitive, we need better than **60mV HV stability** to keep small contribution to energy resolution constant term

Power supply scheme

- All the 122400 APDs need a stable and accurate High Voltage power supply to guarantee a correct response of the calorimeter
- Each HV channel is connected with a ~150m long cable (equipped also with a 'sense' line) to the detector



- 144 boards of 8 or 9 HV ch. "CAEN A1520PE 9-channels"
- 8 boards are inserted in a "CAEN SY4527 Mainframe" (# 18, divided into 3 racks EB+ side and 3 racks EB- side)

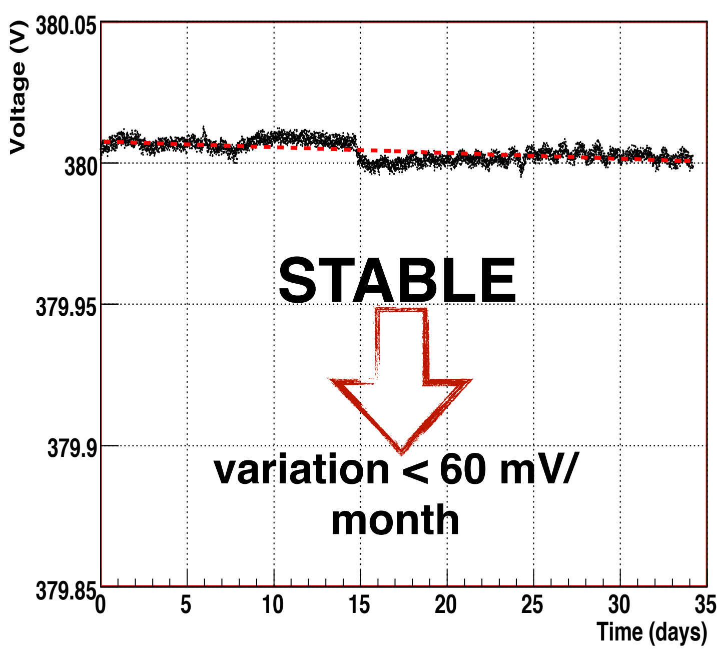


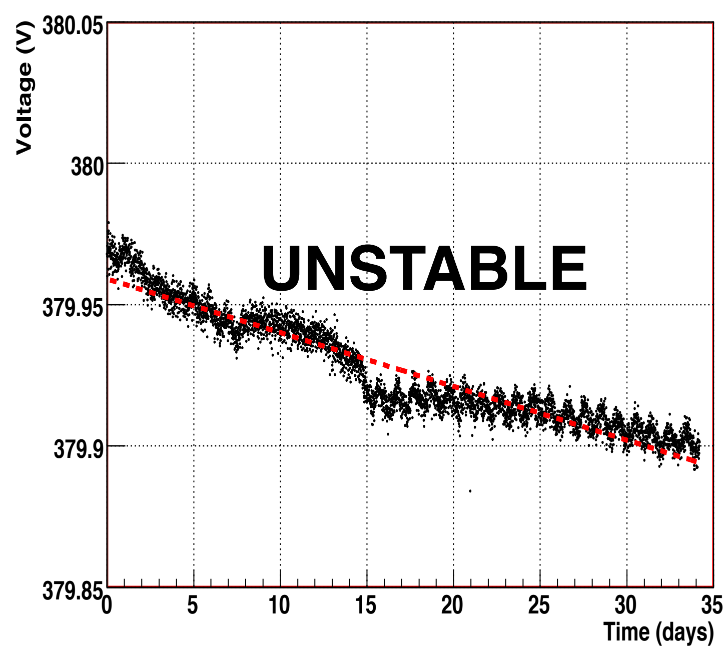
HV channel characteristics

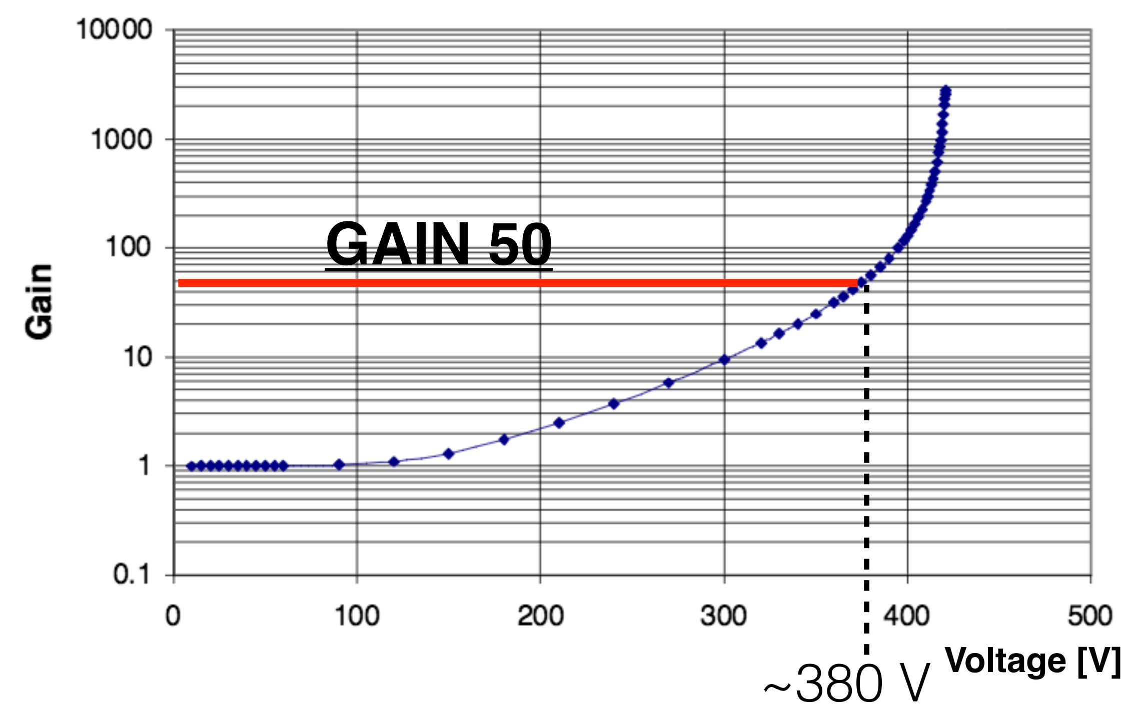
- Each channel specifications are:

voltage range	0-500 V	high freq. noise (>100 kHz)	< ±20 mV
programmable steps	20 mV	operating temperature	15-40 °C
DC regulation	< ±20 mV	current limit	15 mA
DC stability (3 months)	< ±20 mV	max ramp rate	50V/s
low freq. noise (<100 kHz)	< ±20 mV	external calibration	< ±20 mV

- In total the ECAL Barrel HV system consists in 1224 HV channels that must provide a stable and accurate voltage to the APDs of the detector which operate at Gain 50







Calibration Procedure (fw)

- The calibration is currently done <u>once per year</u> (Jan. - March after the LHC Winter shutdown)
  - to maintain the same response of the detector

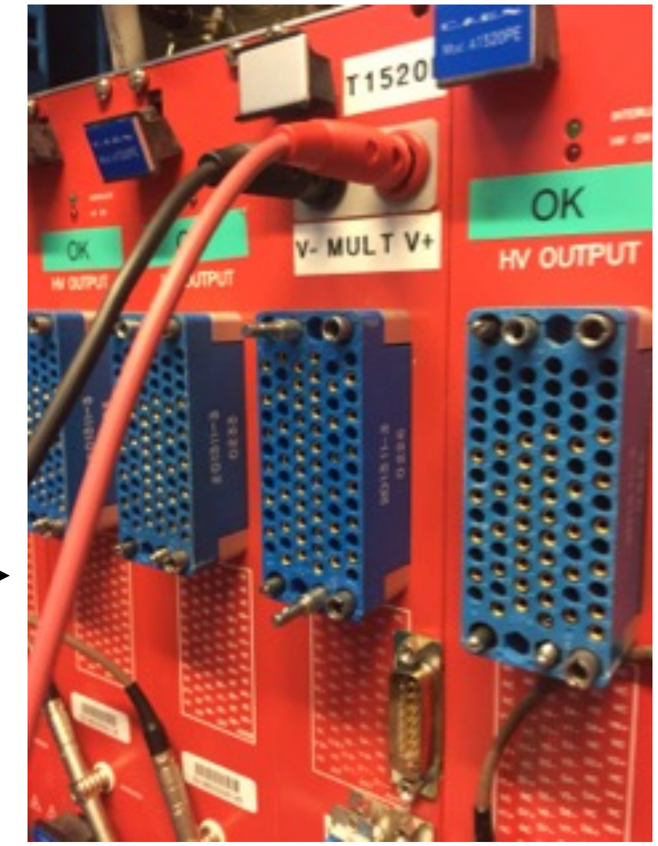
- Each channel is calibrated with a fixed load of 33 kΩ using 10 voltage points:
  - each Digital MultiMeter (DMM) reading is written in the channel buffer
  - an internal interpolation is done ⟹ the channel extrapolates the calibration corrections changing its internal settings

- In the following two calibrations will be described: “old” used since 2008 and “new” introduced in 2017;
  - **<u>this fw procedure is common for both calibrations</u>**

Old calibration procedure

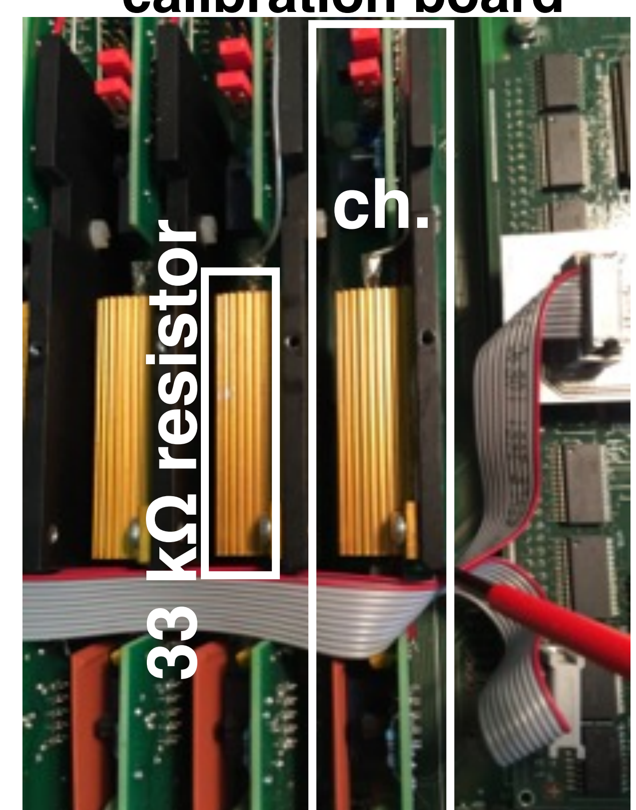
- It was a fully-manual procedure

- Hardware used (for each EB± side):
  - 1 digital multimeter (6 digis)
  - 1 9-ch. calibration board developed by CAEN →
  - HV board-to-calibration board-to-DMM connectors



- Expert operations:
  - unscrew one HV board and replace it with the calibration one
  - connect the cables to the DMM and the board that has to be calibrated
  - launch the calibration program (loaded in the fw)
  launch a "verify" routine (check the channel after
  - calibration)
  - calibrate the HV board unplugged

Internal view of the calibration board



Old procedure pros&cons

- Pros:
  - *fully validated* procedure
  - machinery and steps *very well known by experts*

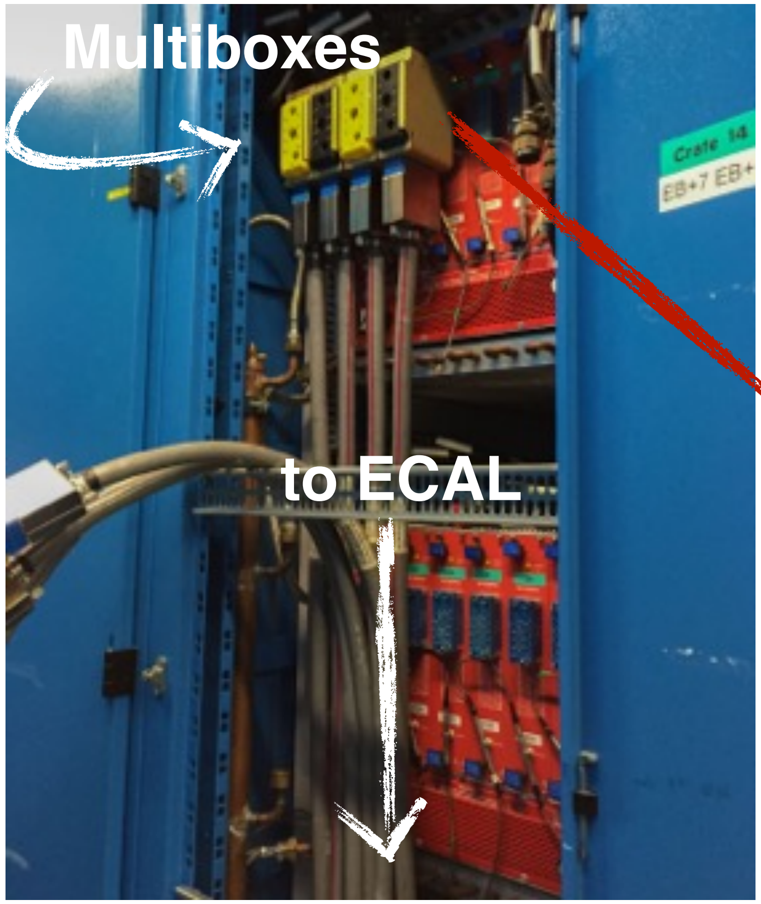
- Cons:
  - *time consuming* (>3 weeks)
  - a lot of manpower needed (>10 people - 2 FTE shifts)
  - *could stress the hardware*: all the procedures and steps have to be performed plugging and unplugging delicate boards thus stressing their backplanes
  - the value of the verify and the one written in the channel buffer is taken after a fixed delay time. In principle the channel could be stable in less time (can we improve this?)
  - the plugging and unplugging procedures *prevent us to perform periodically verify or calibration* during Technical Stops of LHC

New calibration procedure (HW)

- During 2015 a new set of hardware equipment has been installed in USC to permit new procedures of calibration

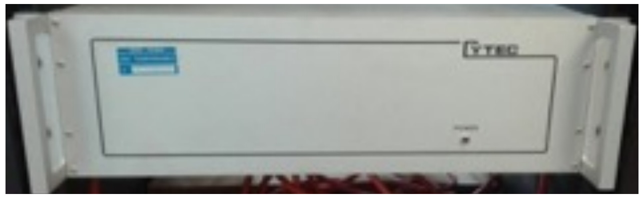
- **<u>Multiboxes</u>** have been designed and tested at CERN by the CMS Rome group
  - HV and High Current resistant relays that can decouple the HV system from the ECAL detector (the HV can be ON with the LV OFF without damaging the APDs)

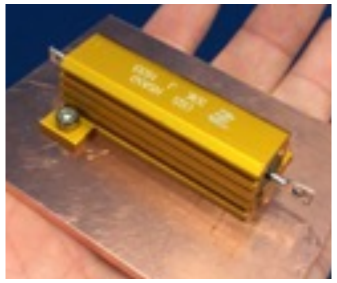
New Calibration HW scheme connections



Multiboxes
CMS ON: HV to detector
CMS OFF: HV to DMM

Cytec Multiplexer





33 kΩ resistor with a copper plate to dissipate heat

+

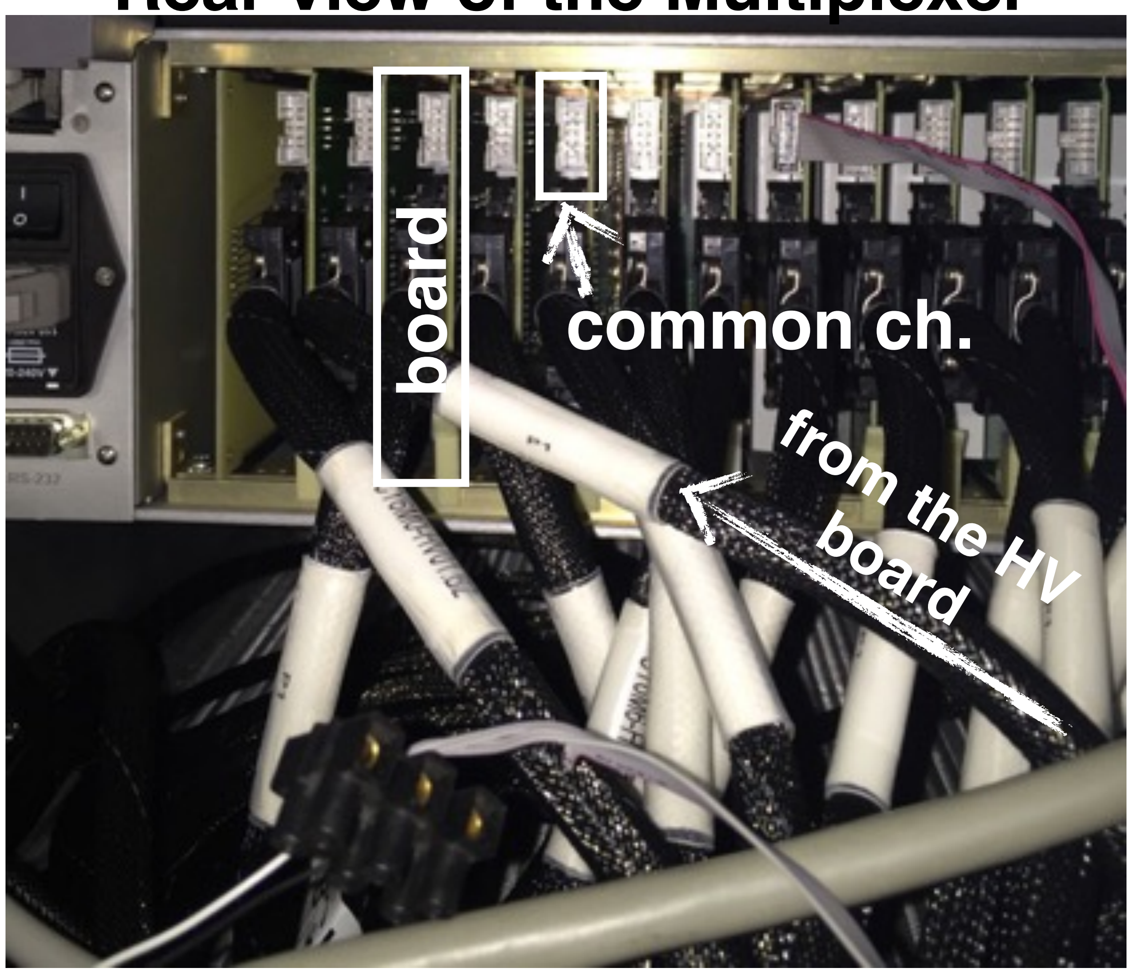
<u>8 1/2 digis</u> DMM

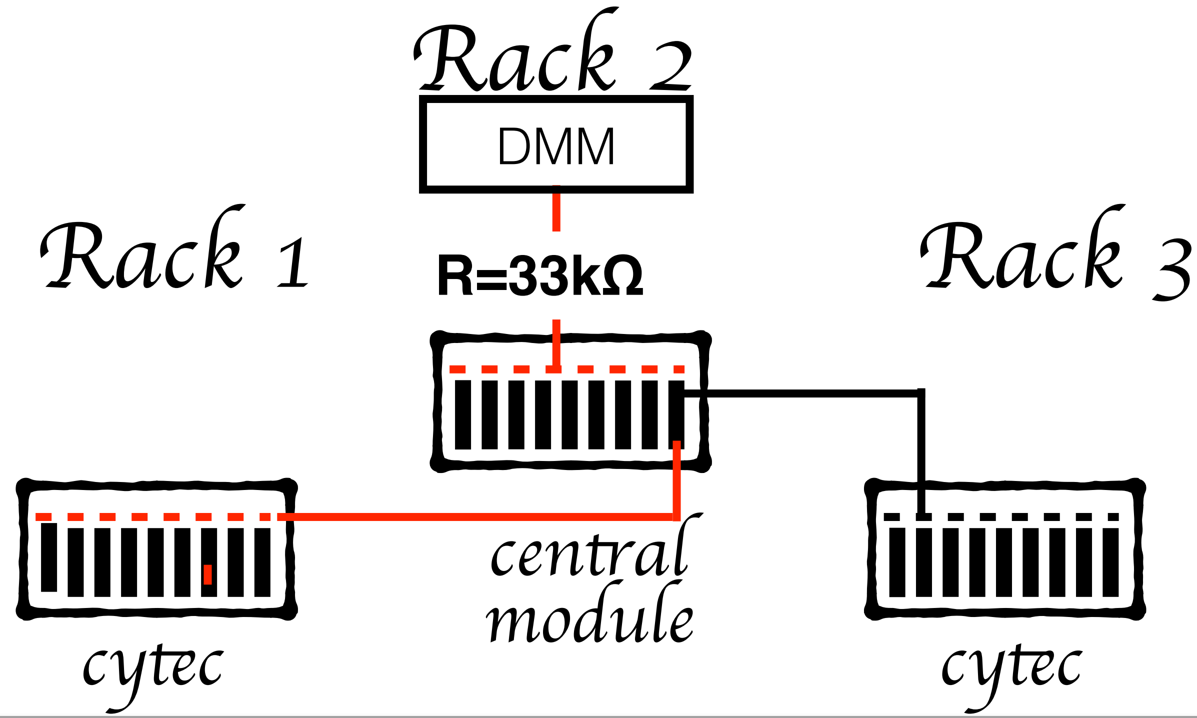
Multiplexer connections

- The multiplexer enables us to use only one DMM (for each side) and without unplugging any of the HV boards
  - made of many boards containing one channel (just a switch) corresponding each to a HV one (latched=HV ch. connected; unlatched= HV ch. disconnected)

- All the multiplexers are connected in a "star" configuration
  - one (central module) multiplexer is connected to the DMM
  - the other multiplexers "common channel" are connected to a board of the central module (each to a different channel)

Rear view of the Multiplexer





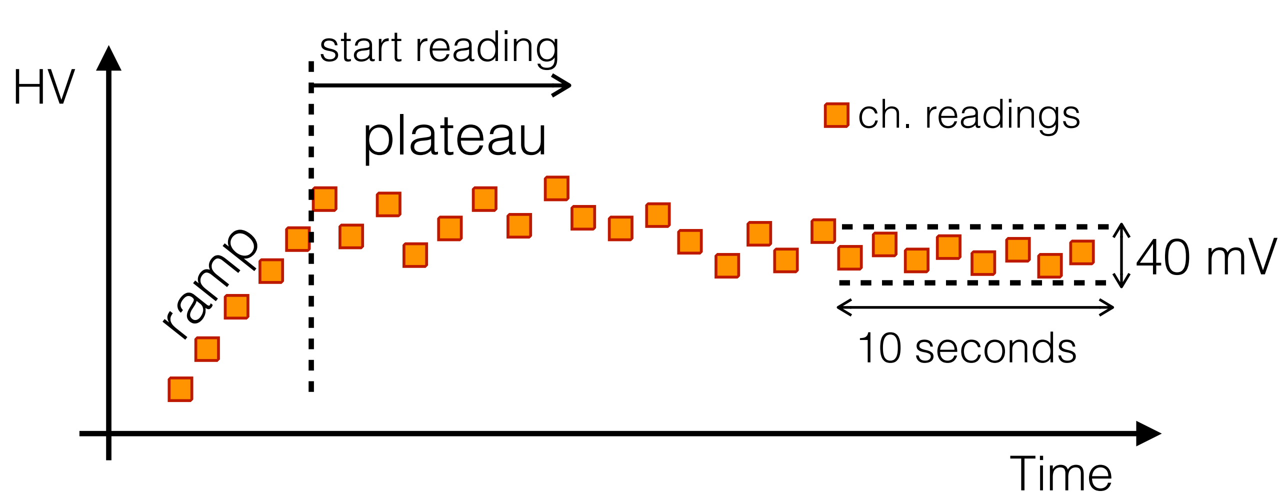
- - - - - - **common channel**:
it is a short circuit connected to all the cytec channels that are latched

I latched channel and connection

New calibration procedure

- It uses a C++ program with the CAEN HWrapper.h and visa/r232 libraries to communicate with the whole system
- Sequence of the calibration:
  - Set the Multiboxes on CMS OFF (decouple the detector): this is the **only manual operation**
  - enter which rack/crate/board/channel number to calibrate
  - launch the calibration (the system automatically checks the status of the calibration apparatus and running protection routines to verify that the HV is completely OFF preventing any possible short-circuit and checking the network connection)
  - it calibrates a channel if it differs from the correct value by 10 mV
- How does it decides when the channel is stable?

"signal follower routine"

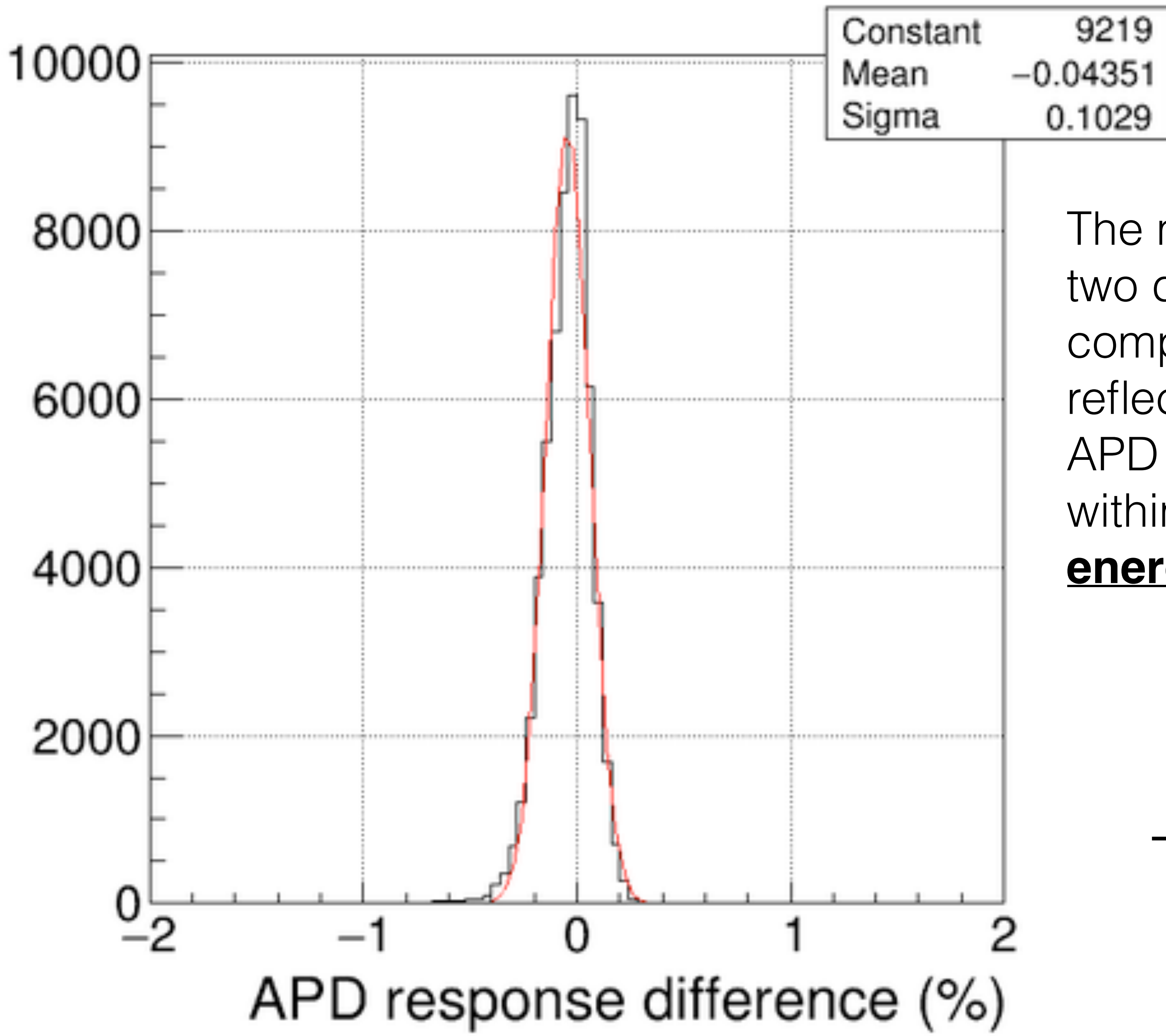


If the channel readings are in a 40 mV window for 10 seconds, **it is stable**

the value is written in the buffer

Calibration Comparison

- We calibrated the same channel with the two different calibration procedures



The mean shift from 0 is due to the use of two different DMMs, whose calibration is compatible at the 30 mV level, which reflects in a 0.1% systematic error on the APD gain. Almost 100% of the channels within +- 0.5% **maintaining the same energy resolution**

The two methods are **fully compatible**

New procedure pros&cons

- Pros:
  - *very fast* (no need of “manual” operations; overall time used<1 week) and less manpower needed (3-4 people; 2 FTE shifts)
  - procedure very intuitive (instructions appear on the screen) and *configurable* (no need to recompile if settings/hw addresses are changed)
  - no stress to the board screws as they are not unplugged for this calibration
  - introduction of the “signal follower” routine speeds up the procedures
  - it uses a 8 1/2 digis DMM (the 6 digis is just a backup)
  - *detector safe* (multiboxes decouple the system from ECAL)
  - a “verify” scan can be run during LHC Technical Stops
  - *fully compatible with the old calibration results*

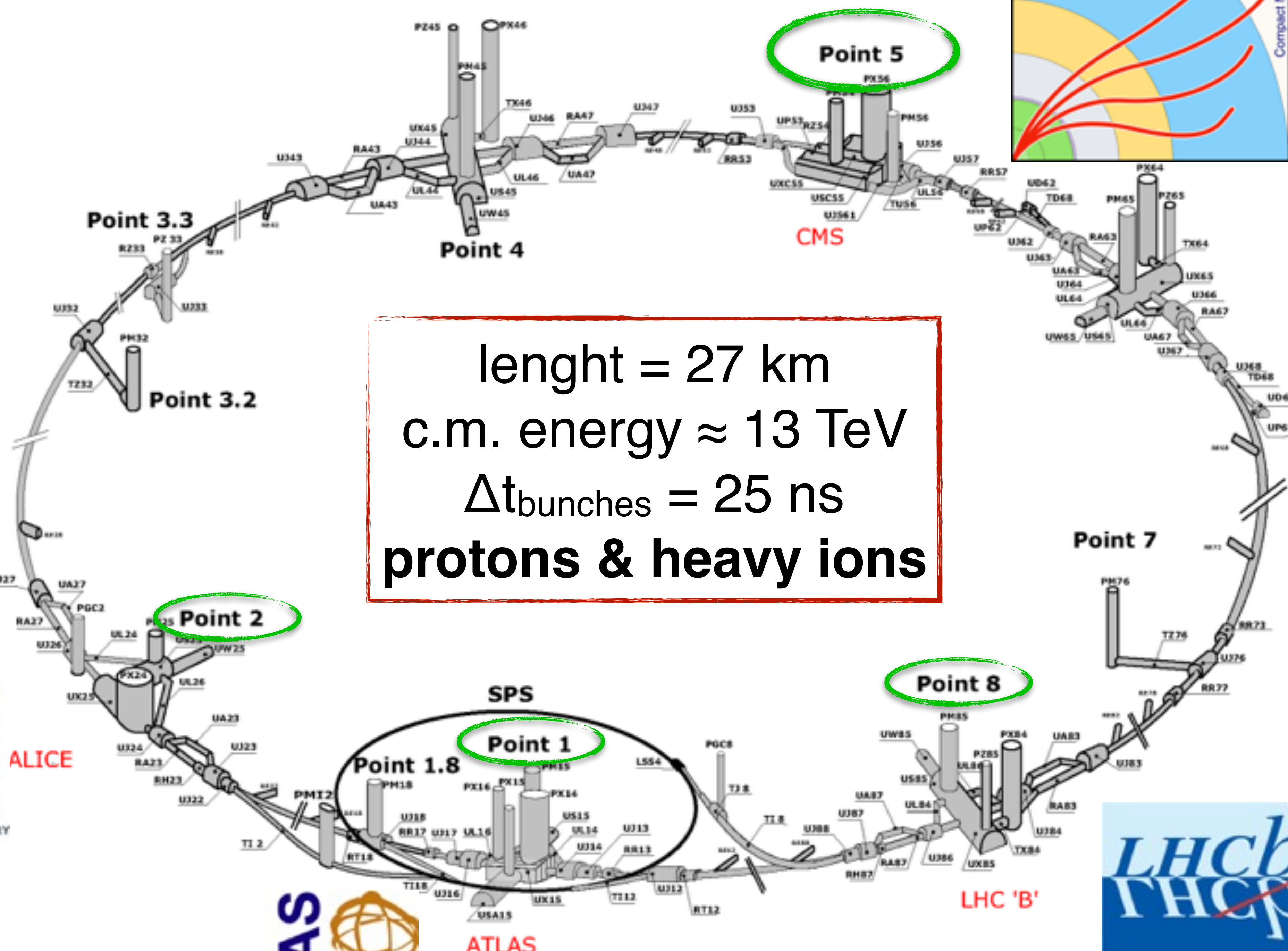
- Cons:
  - it needs a machine (also a VM) connected to the CMS service network

Conclusions

- Described the ECAL Barrel HV system of CMS
  - excellent stability is needed to maintain very good energy resolution
- Showed the Calibration procedure used from 2008
  - firstly what has been called “old” calibration used since the beginning of the experiment
  - the “new” calibration used this year showing the new hardware and techniques used
- The responses of the two calibration are <u>fully compatible</u>
- Major pros of the “new” calibration
  - less time consuming
  - completely automatic and configurable

BACKUP

Large Hadron Collider



lenght = 27 km
c.m. energy ≈ 13 TeV
$\Delta t_{bunches}$ = 25 ns
protons & heavy ions