Geophysical density tomography using cosmic rays

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Y.Déclais[1], J.Marteau[1], D.Gibert[2], N.Lesparre[2], F.Nicollin[2]

B.Carlus[1], S.Gardien[1], C.Girerd[1], F.Mounier[1], S.Vanzetto[1], B.Kergosien[3], P.Rolland[2]

[1] *Institut de Physique Nucléaire de Lyon (IPNL)*
[2] *Institut de Physique du Globe de Paris (IPGP)*
[3] *Géosciences Rennes*

Outline

- Introduction
- Muon tomography
- Muon telescopes
- Local tests setup
- Synergies with other projects
- Conclusions & perspectives

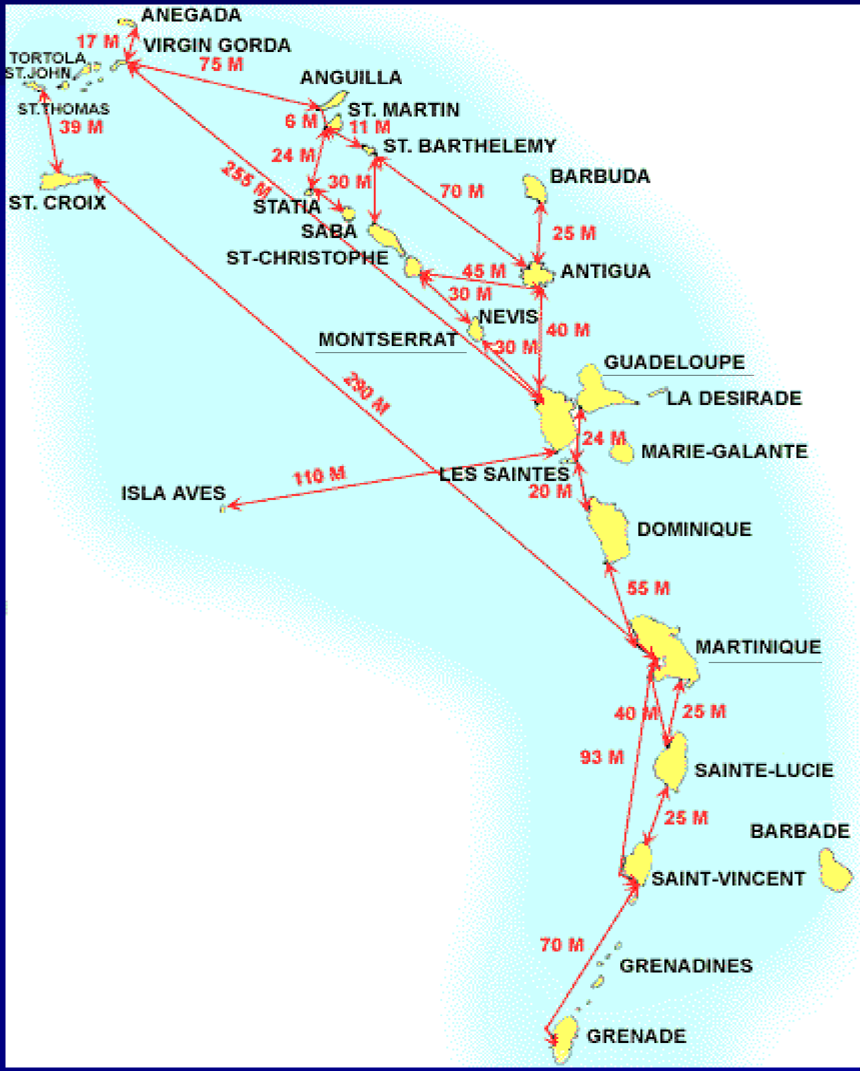
Introduction

Observations in the Lesser Antilles, 3 volcanoes under the IPGP responsibility :

- **<u>Montagne Pelée</u>, Martinique :**
  no sign of activity

- **<u>La Soufrière</u>, Guadeloupe :**
  risks of phreatic eruption and flank destabilization

- **<u>The Soufrière Hills</u>, Montserrat :**
  long-lasting magmatic eruption since 1995, risks of pyroclastic flows, dome collapse, magmatic explosions...



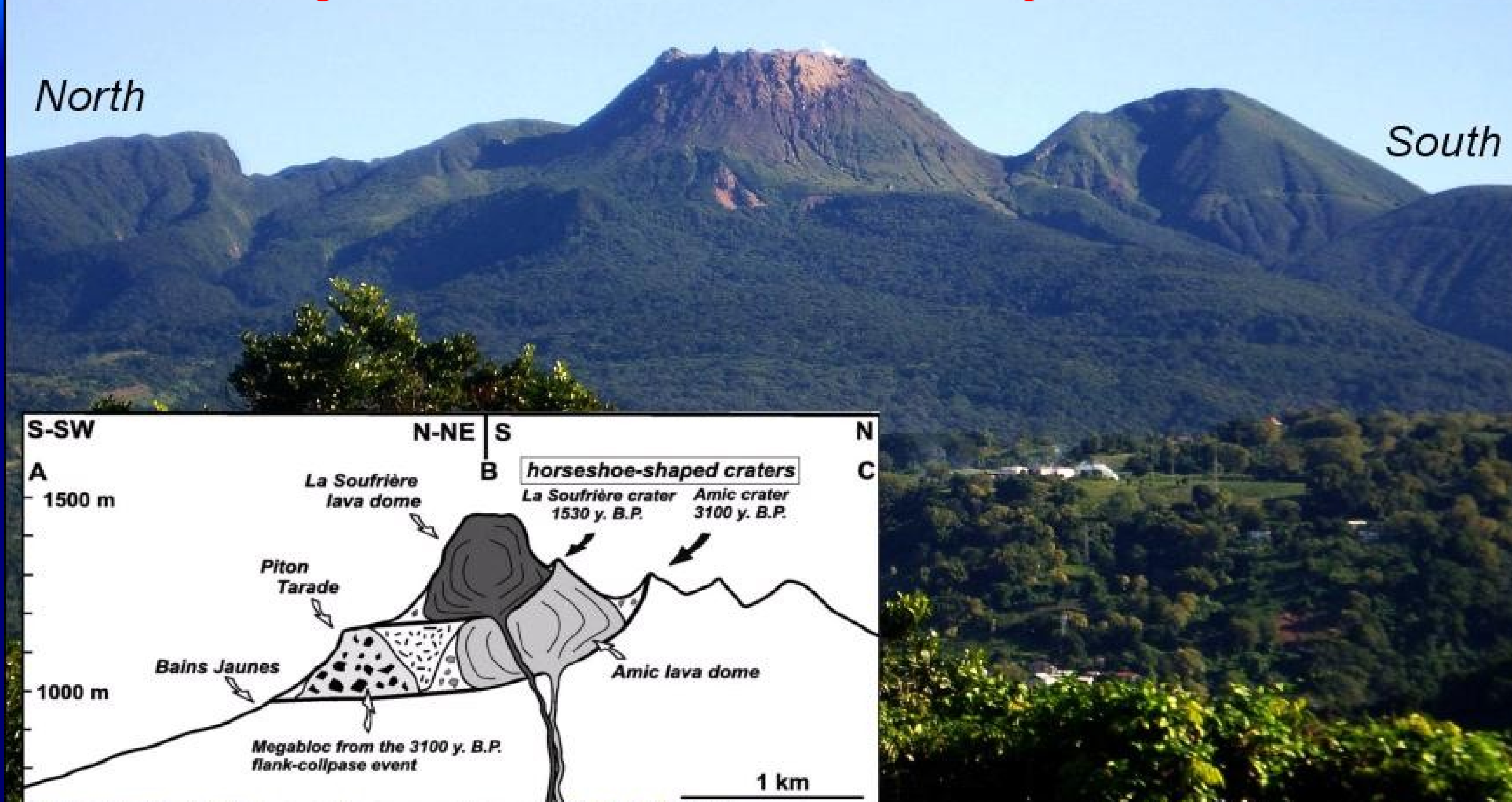
J.Marteau

Introduction

"La Soufrière" presents many risks due to :

- **the geological structure : the dome "sits" on an N-S 15° inclined plane**
- **the presence of hot liquid acid which may vaporize after a sudden decompression (phreatic eruption which may also provoke a magmatic explosion)**

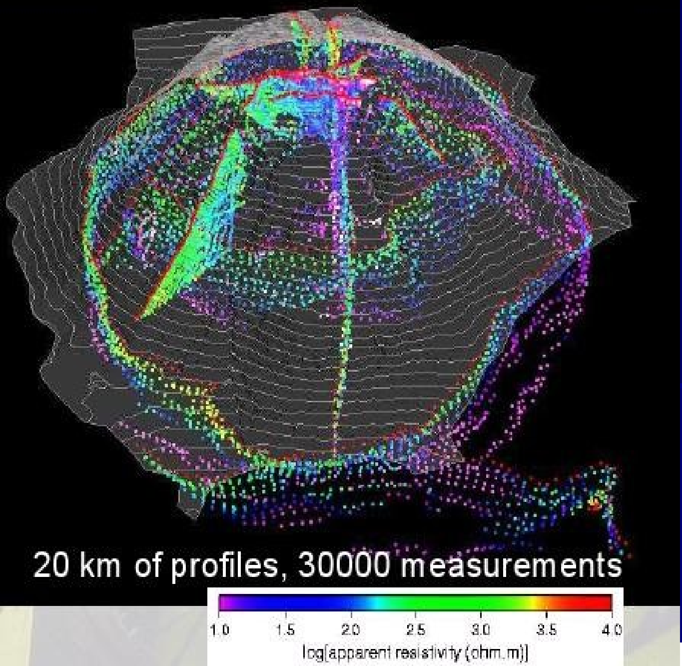
=> the knowledge of the internal structure of the dome is important...



Sketch from Boudon et al., J. Volcanol. Geotherm. Res. (2008), doi:10.1016/j.jvolgeores.2008.03.006

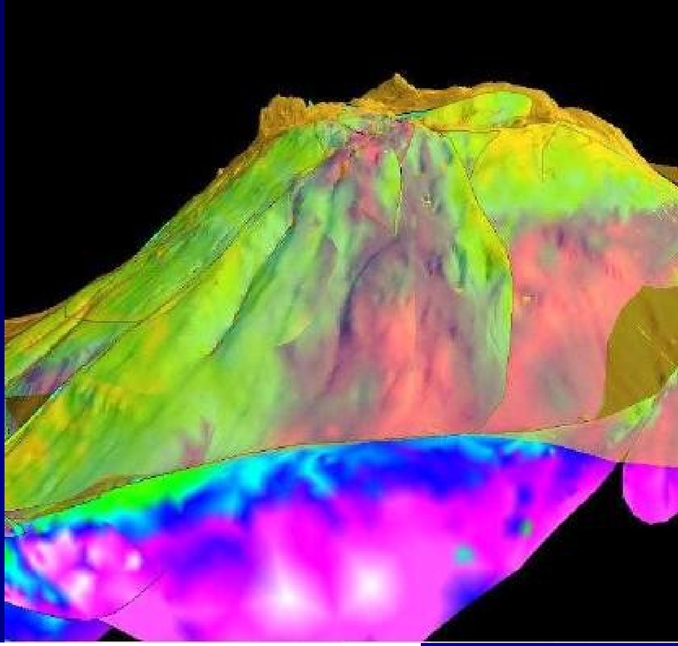
Muon tomography

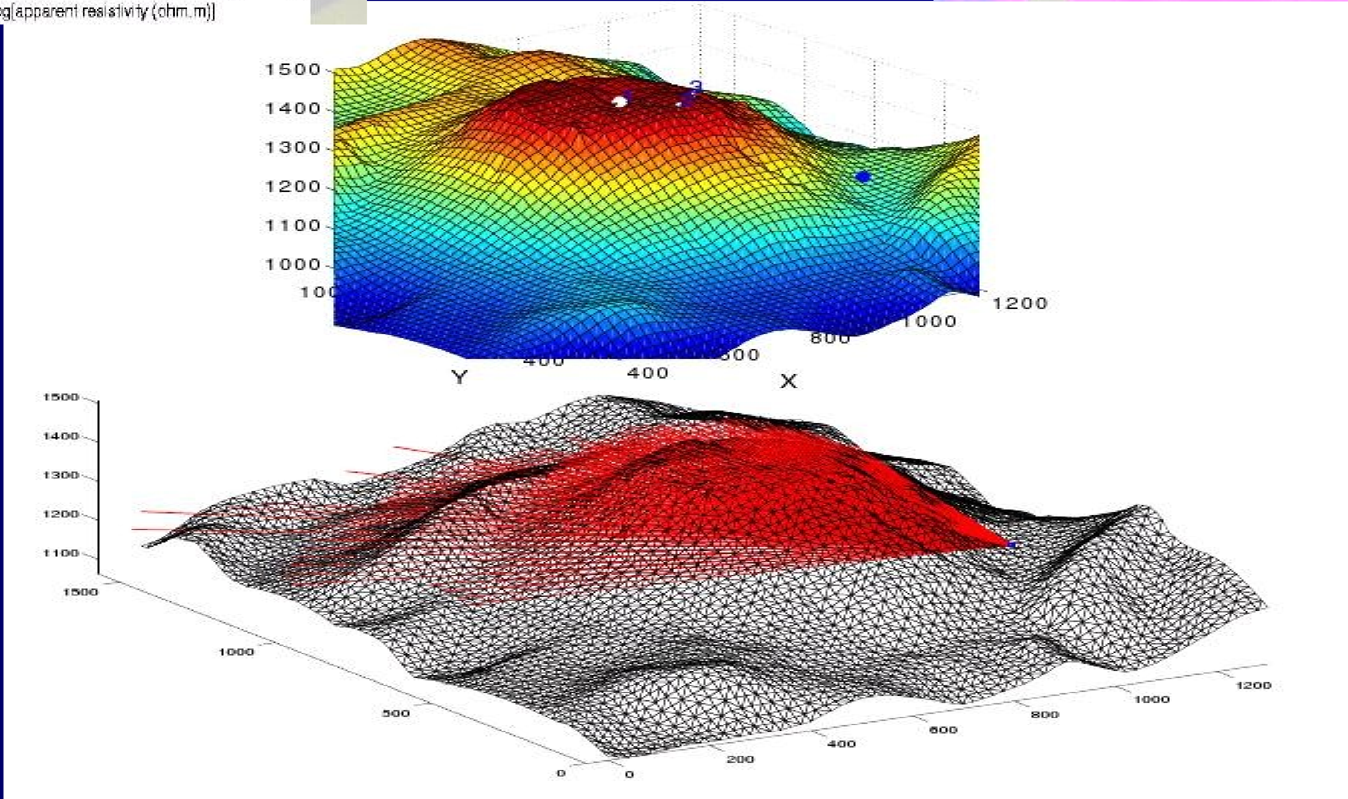
Muons tomography provides density profiles information after deconvolution of the known topography by direct measurement of the muons flux/attenuation.



Muon tomography

Muons tomography may be combined with other techniques (electrical tomography, seismic tomography) which may give mainly "surface" indications on the nature of the rocks.





Muon tomography

Importance of the environmental constraints : access, weather & power...

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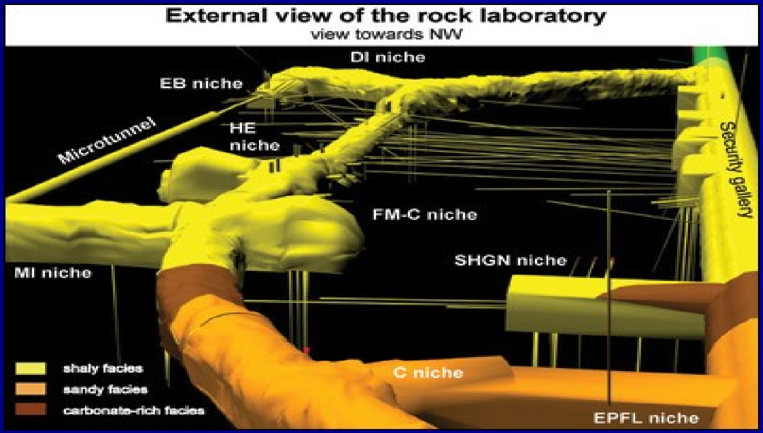
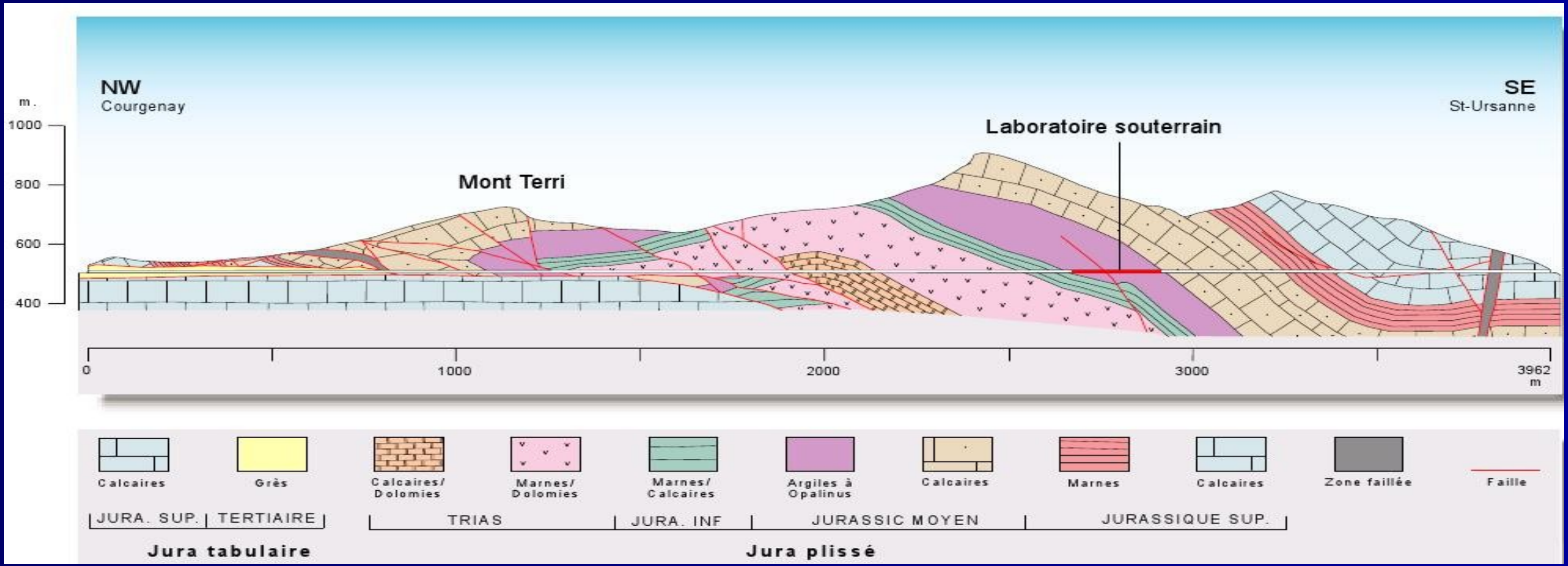
Muon tomography

Applications : study of other vulcanic activities (Soufrière Hills, Etna) and studies of underground geological storage candidate sites (Mont-Terri project)





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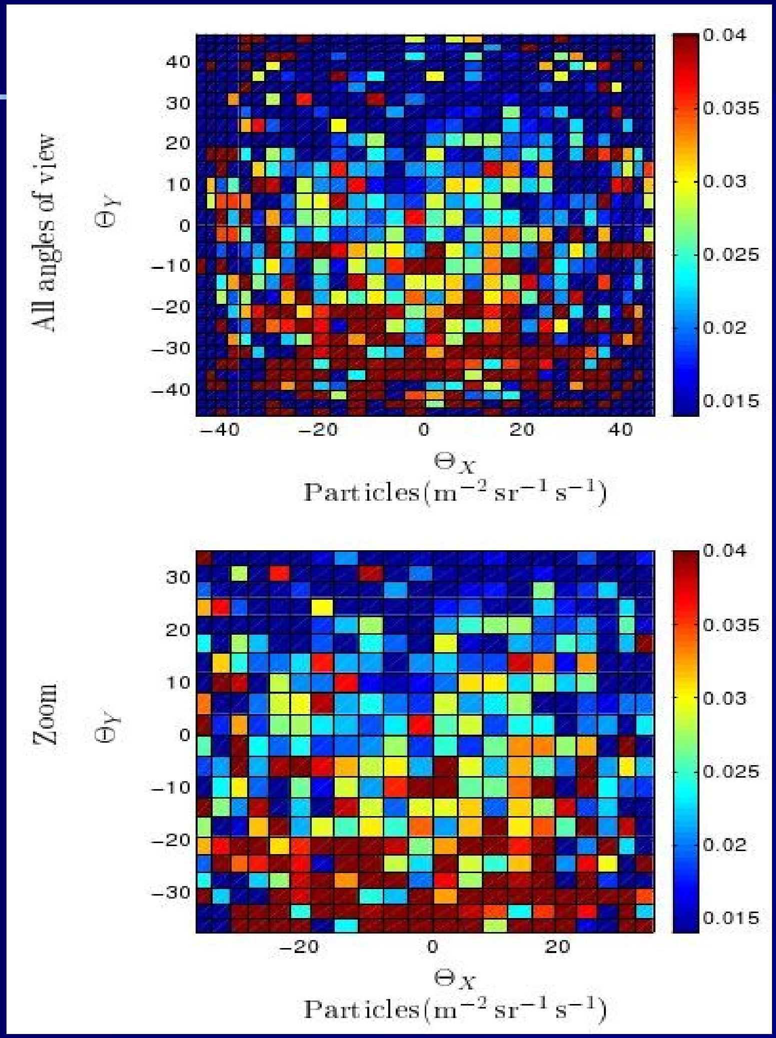
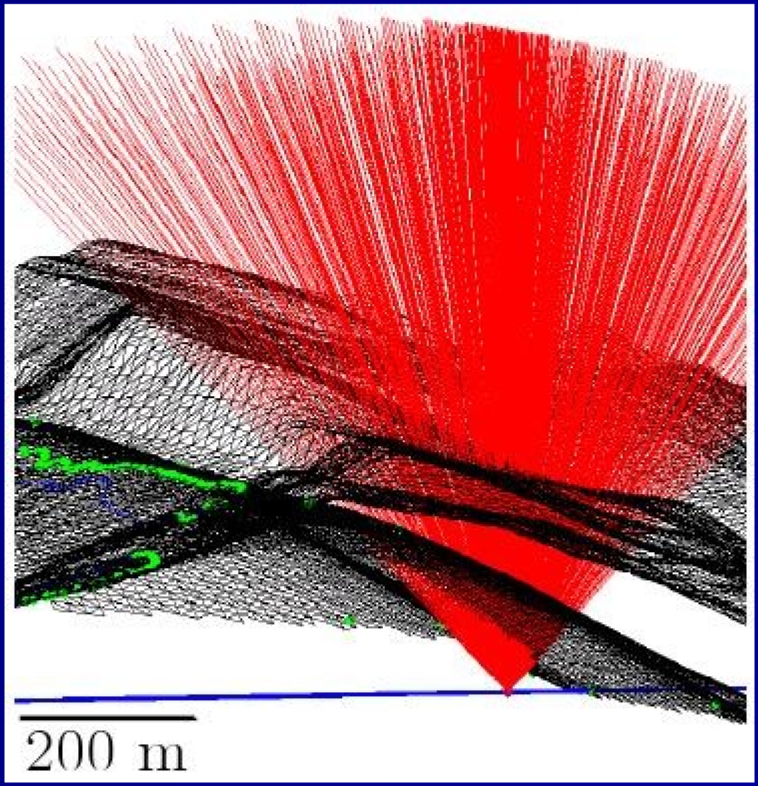
Muon tomography

1st data recorded (comparison with MUSIC[1] code on-going) :





[1] *MUon SImulation Code*

Muon telescopes

Proposal to cope with the environmental constraints :

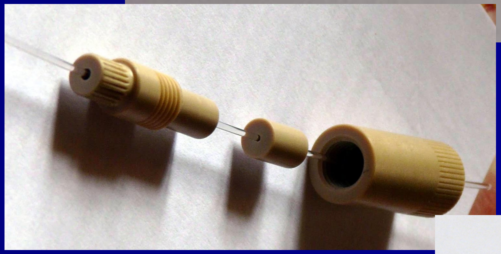
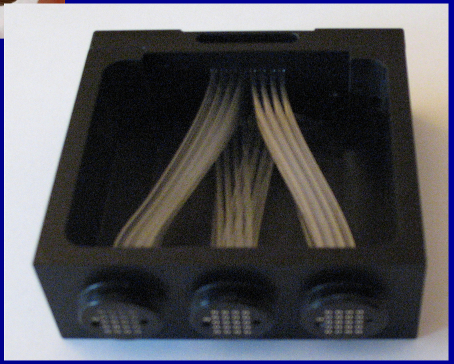
- choice of a robust technology
- ... modular, scalable, cheap
- low power consumption
- ... easy to move
- compatible with network/wifi communication
- embedded local processing

Plastic scintillator hodoscope
+ WLS fibres
+ clear fibres connectors
+ MaPMT
+ OPERA readout electronics (analogic/digital)

Muon telescopes

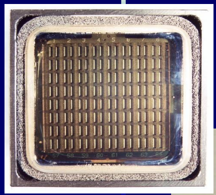
- 2 XY biplanes (32 channels per biplane)
- Fermilab scintillator bars + 1mm WLS + 1mm clear fibres (Bicron)
- Hamamatsu MaPMT (H8804)

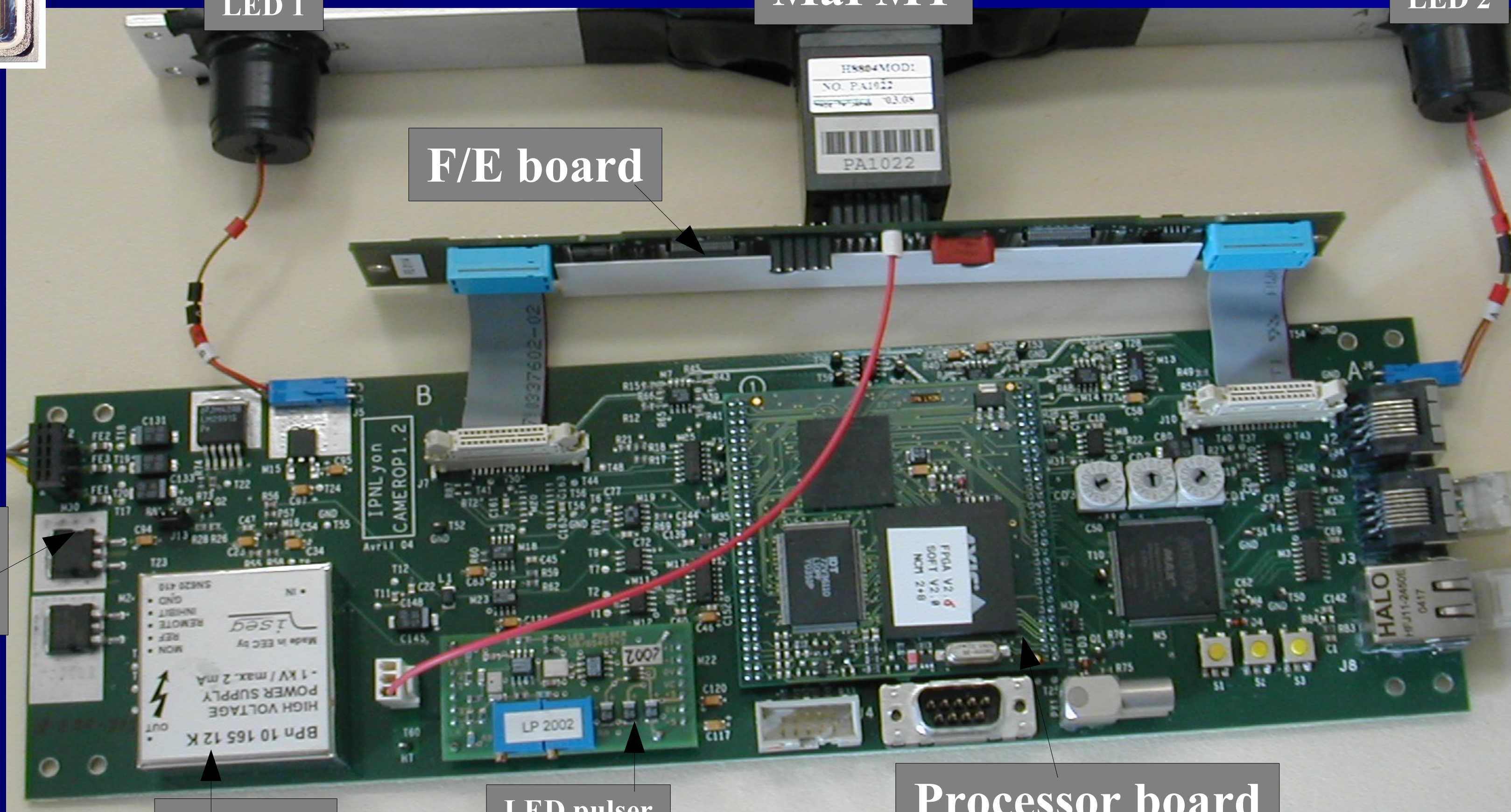


Muon telescopes

- Hamamatsu “H8804mod1”, 64 2mm×2mm pixels, <10Hz dc at 0.5 pe
- Auto-triggerable F/E with channel-to-channel gain compensation (1→ 4)
- Ethernet DAQ system with embedded Linux
- Motherboard hosting HV module, LED pulser. ADC: 12 bits, 5MHz
- Event timestamp with 10ns accuracy, locked on GPS

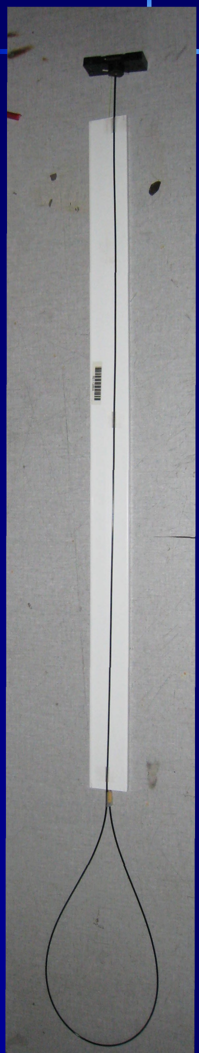


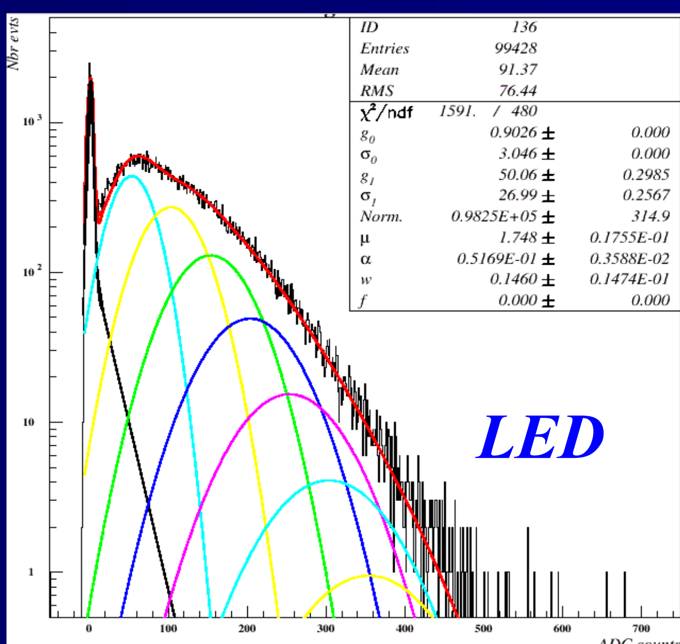


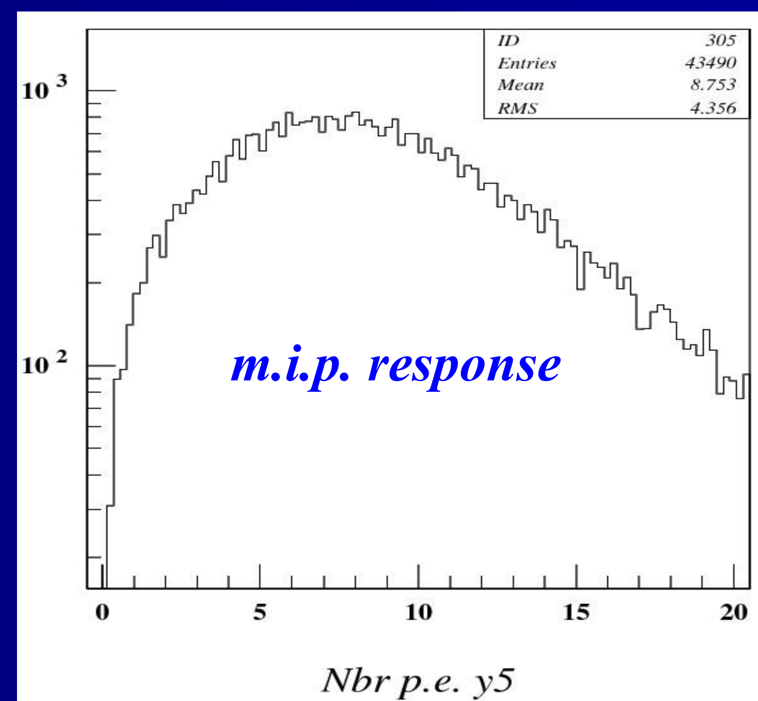
Muon telescopes

Local tests setup

- Many tests performed on the opto-electronics chain :
  - MaPMT characterization (gain uniformity before/after correction, cross-talk, absolute amplification gain, photocathode performance)
  - Light yield measurements to check performances of :
    - fibre-to-fibre connections (various diameters and types)
    - fibre-to-scintillator gluing
    - optical box transmission
    - polishing quality etc







Local tests setup

- **Tests results : possible improvements wrt 1st prototypes**

  • ~30% increase by gluing WLS fibres

  • ~35% increase by using the new MaPMT (extended PC)

  • ~25% increase with new optical connectors

  • => >12 p.e. achievable with our present test setup (~roughly 100% muon detection efficiency with a threshold <0.3 p.e.)

- **Other developments :**

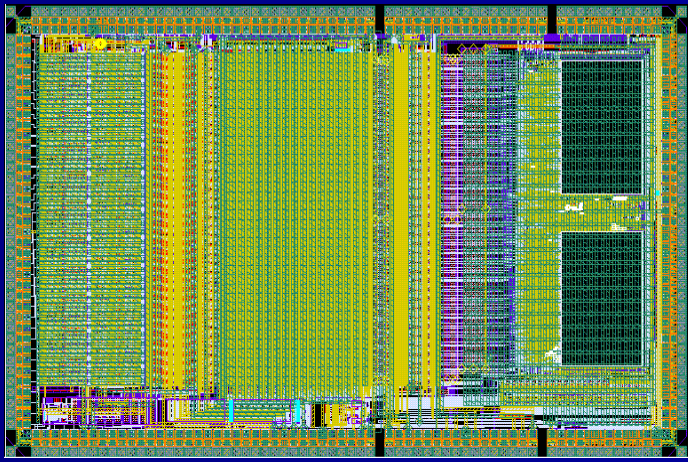
  • XY hardware coincidence logic in the FPGA (reduction of background)

  • OPERA Target Tracker software adaptation

R&D in electronics

- **Upgrade the number of photo-electrons/mip :**

  - **from MaPMT to SiPM (15% => 80% Q.E.)**



  - **from OPERAROC to SPIROC (LAL) with comparable features** (preampli, gain correction, auto-trigger)

  - **keeping the same digital part (mezzanines)**

R&D in electronics

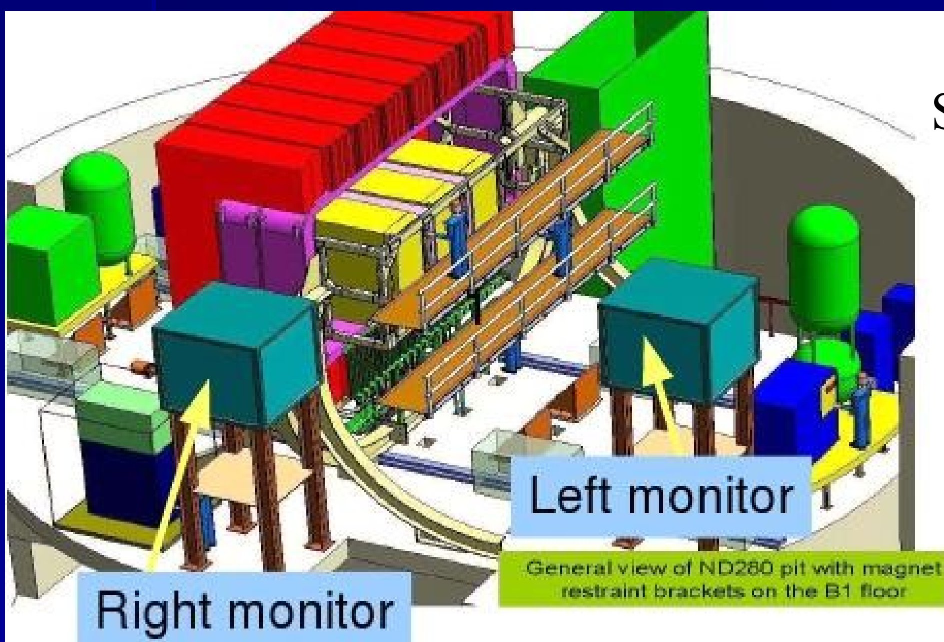
- **1st prototype board designed, to be produced**
- **Various SiPM samples purchased**
  - S10362-13-050C (baseline)
  - S10362-11-050C
  - S10362-11-100C

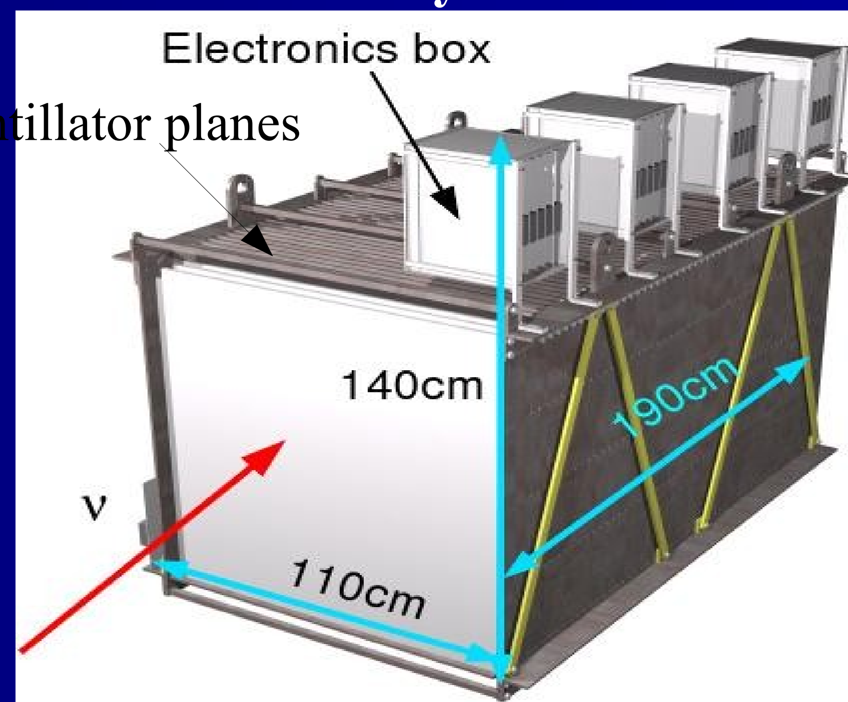
Parameter	Symbol	S10362-11 series			Unit
		-025U, -025C, -025P	-050U, -050C, -050P	-100U, -100C, -100P	
Effective active area	-	1 × 1			mm
Number of pixels	-	1600	400	100	-
Pixel size	-	25 × 25	50 × 50	100 × 100	μm
Fill factor *1	-	30.8	61.5	78.5	%
Spectral response range	λ	320 to 900			nm
Peak sensitivity wavelength	λp	440			nm
Photon detection efficiency *2 (λ=λp)	PDE	25	50	65	%
Operating voltage range	-	70 ± 10 *3			V
Dark count *4	-	300	400	600	kcps
Dark count Max. *4	-	600	800	1000	kcps
Terminal capacitance	Ct	35			pF
Time resolution (FWHM) *5	-	200 to 300			ps
Temperature coefficient of reverse voltage	-	56			mV/°C
Gain	M	2.75×10^5	7.5×10^5	2.4×10^6	-

Synergies with other projects

- OPERA : valorization of the readout system (hardware/software)

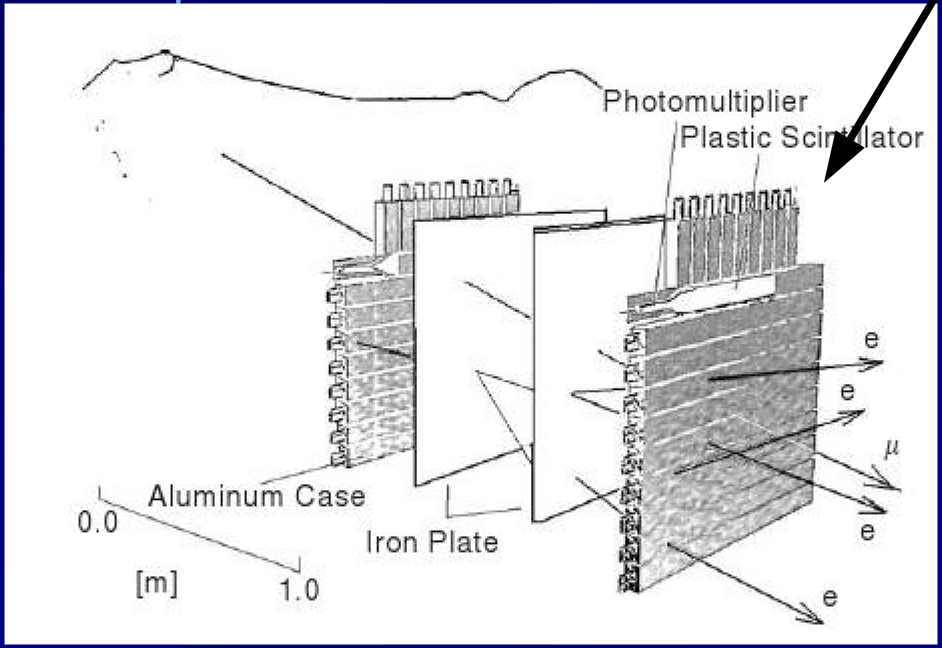
- T2K : proposal of a Left-Right beam asymmetry monitor using the <u>same</u> technology (collaboration approval under process)
=> all optimization tests available
=> common purchase (reduced cost) for all electronics
=> "recycling" of the know-how accumulated locally

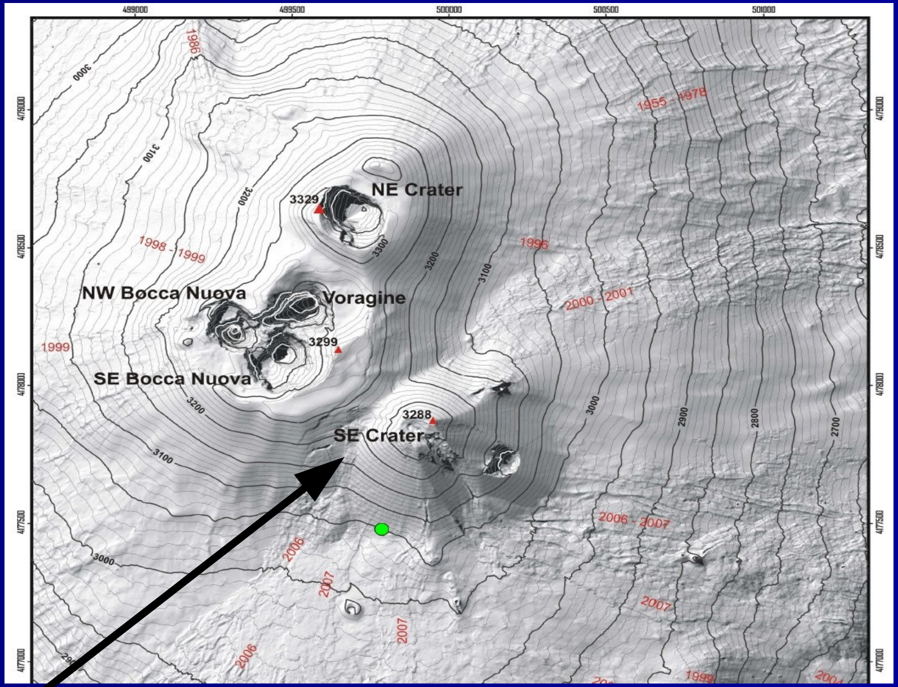




Synergies with other projects

- Volcanoes tomography : Tanaka et al (Japan), this project is a natural upgrade of the early prototypes





- Volcanoes tomography : Italy (collaboration with D.Carbone on the Etna => telescope on the South-East crater june-october 2010)

Conclusions and perspectives

- **Funding issues :**
  - **2008 : BQR IPG ~ 30k€**
  - **2009 : IN2P3-astroparticules ~ 30k€**
  - **2009-2010 : Mont-Terri project ~ 6k€**
  - **2009-2011 : ANR domoscan ~ 100k€**

- **Responsabilities sharing :**
  - **telescopes design, drawings, raw material purchase : all** ← ***completed***
  - **scintillator planes production : IPGP, Rennes**
  - **opto-electronics chain production and tests : IPNL** ←
  - **on-site installation, commissioning : all**
  - **data quality check, data acquisition shift, data transfer : IPNL** ←
  - **data analysis : all**
  - **R&D in electronics : IPNL**

to be transferred to IPGP

Conclusions and perspectives

Who?	What?	%FTE 2009	%FTE 2010
J.MARTEAU	detector designs tests MaPMT/SiPM DAQ, soft. developments installation&commissioning	20	15
Y.DECLAIS	detector designs installation&commissioning	10	10
B.CARLUS	DAQ, soft. developments computing setup installation&commissioning	10	5
S.GARDIEN	R&D electronics SiPM	80	80
C.GIRERD	hardware XY coincidence FPGA adaptation to SiPM	5	10
F.MOUNIER	opto-mechanical design optical box prod.		
S.VANZETTO	optical connection design optical fibres polishing	20	20
Electronics service	boards design		
Mechanical service	small machining work		

Conclusions and perspectives

- Valorization project applied to vulcanos tomography
- Interesting field... not only for fundamental science
- Mature detection technology and readout scheme
- Generic R&D for a widely-used new device (SiPM)
- 1st 3D-tomography in perspective: requires the production of other telescopes (scaled by × 2), mainly in IPGP (know-how transfer)
- IPNL concentrates on R&D and contributes to the detector(s) commissioning and data analysis

Appendix : tests results

Gain computation/equalization

- Different gain fit function compared from simple PoissonxGauss to full Bellamy et al. function:

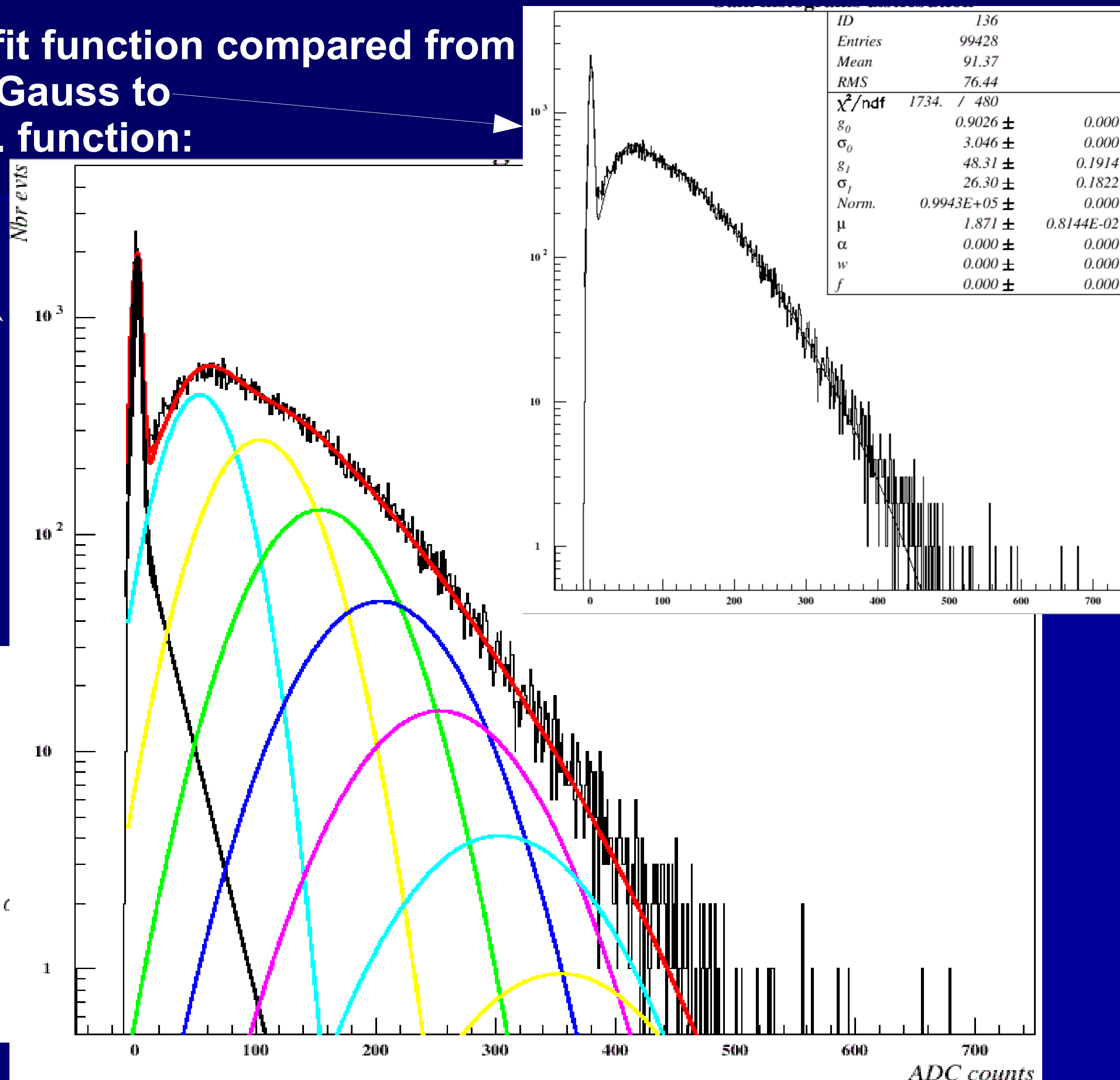
$$S_{fit}(q) =$$

$$\sum_{n=0} \frac{\mu^n e^{-\mu}}{n!} \left\{ (1-w) \frac{1}{\sqrt{2\pi}\sigma_n} e^{-\frac{(q-Q_n)^2}{2\sigma_n^2}} \right.$$

$$+ w.\frac{\alpha}{2} e^{-\alpha(q-Q_n-\alpha.\sigma_n^2)}$$

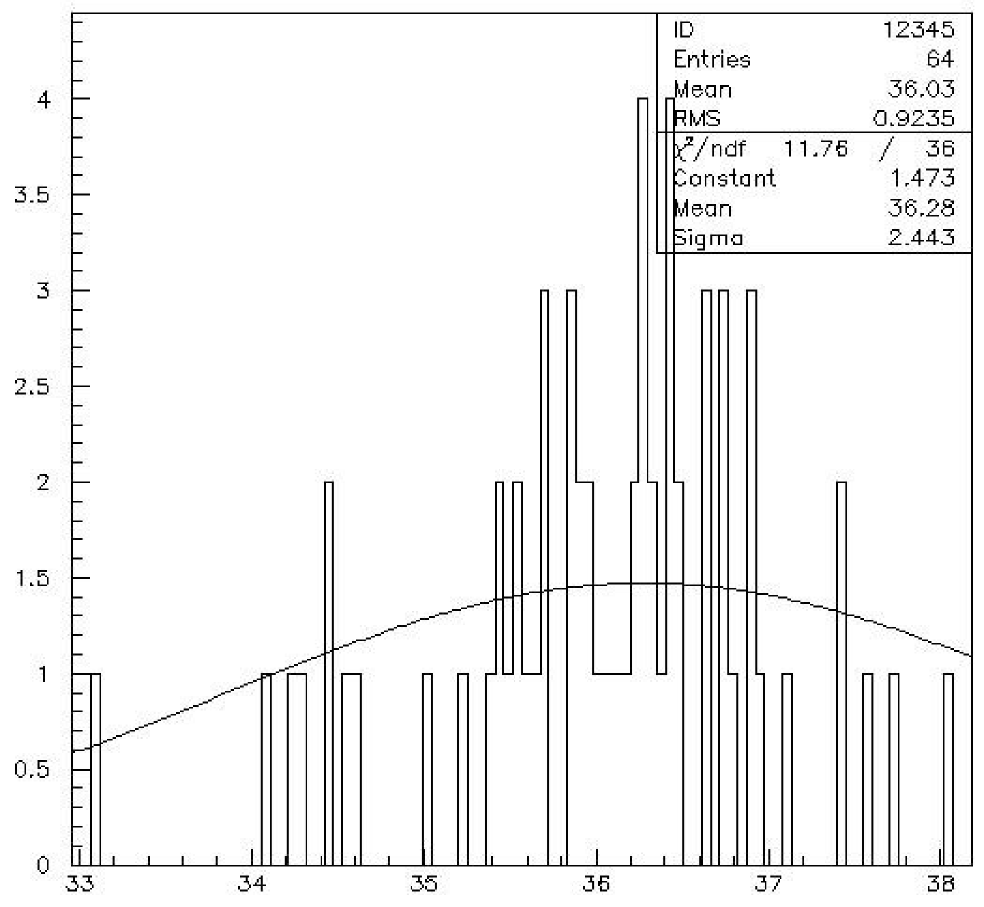
$$.\left[erf\left(\frac{|Q_0 - Q_n - \alpha.\sigma_n^2|}{\sigma_n\sqrt{2}} \right) + sign(q - Q_n - \alpha.\right.$$

$$\left. \left. .erf\left(\frac{|q - Q_n - \alpha.\sigma_n^2|}{\sigma_n\sqrt{2}} \right) \right] \right\},$$



Gain computation/equalization

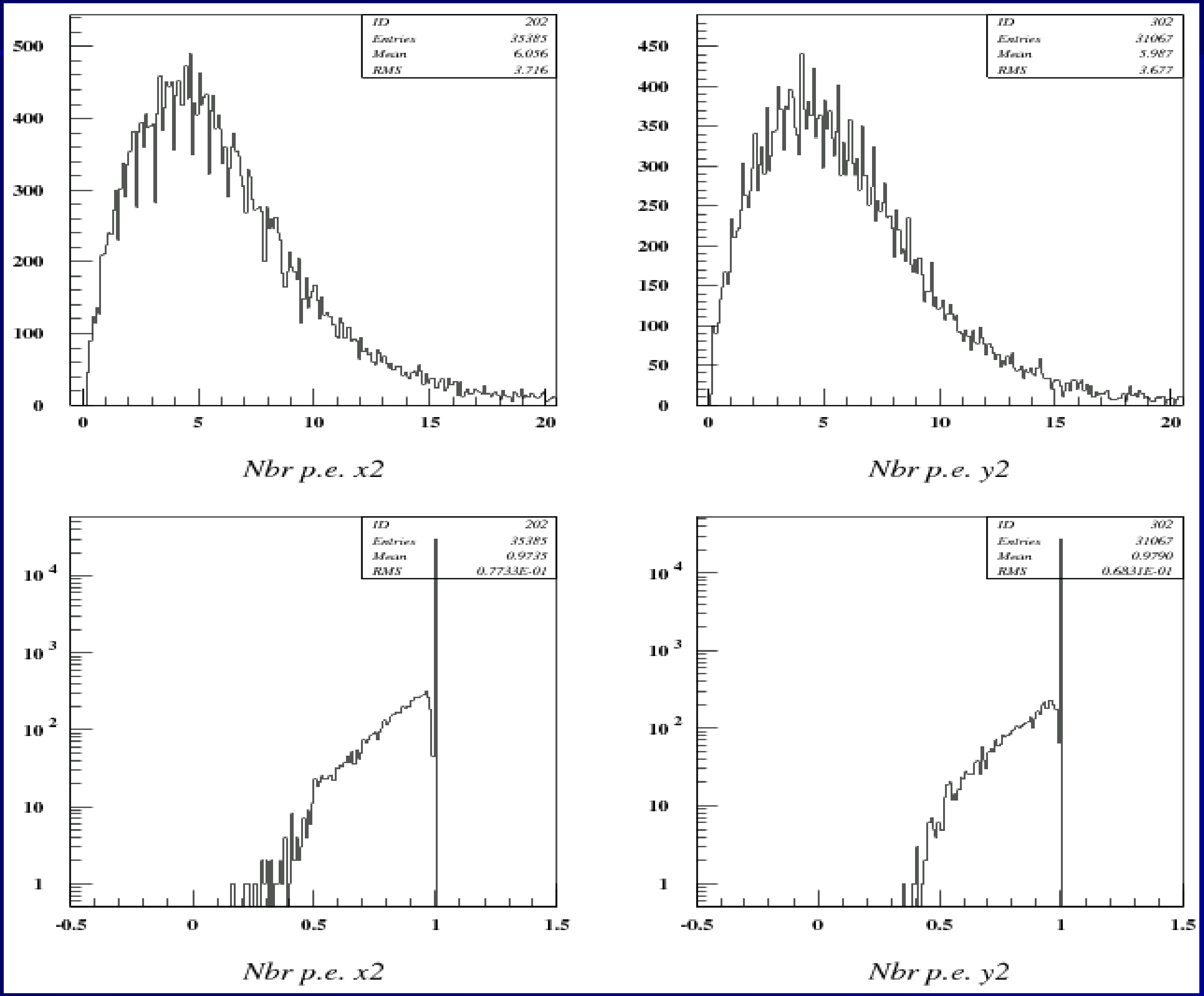
- Gain equalization on 1 MaPMT : 1 example
- σ/mean ~ 7% (N.B. MaPMT gain spread 1:3)



- Cross-talk correction : signal(pixel) += ∑_8 neighbours

Typical spectra (p.e. / cross-talk)

- **Around 6-7 p.e. (very low zero-suppress and threshold)**
- **Cross-talk : *F = (Nbr p.e. (central pixel)) / (Nbr p.e. (9 pixels))***



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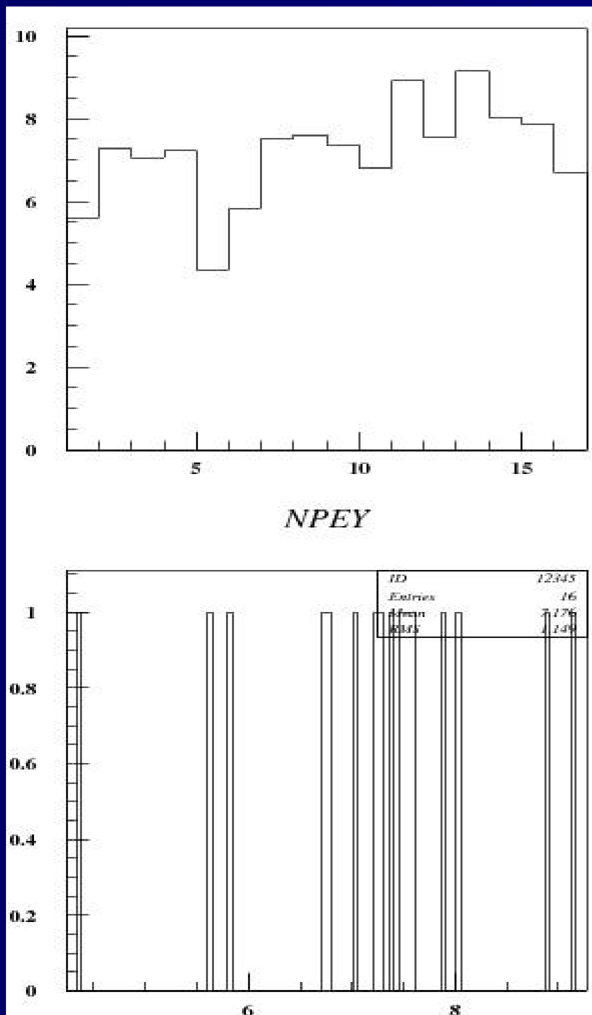
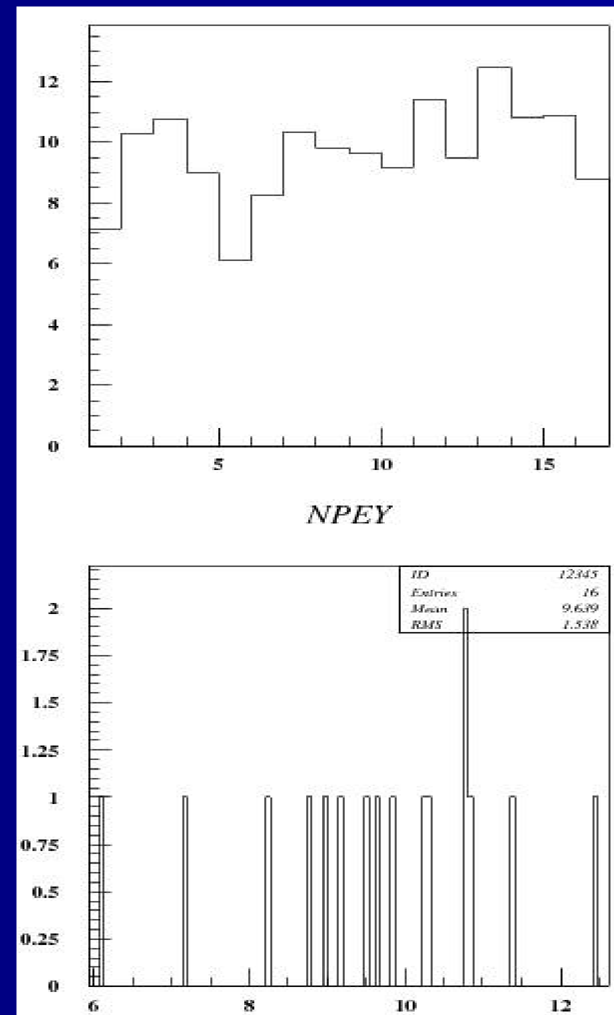
Glued .vs. unglued option

- Tests of 2 bars with or without glue for the inside WLS (glue mixed under vacuum to avoid bubbles)
- Overall gain of 28-30% light for the glued bar

Extended-PC MaPMT tests

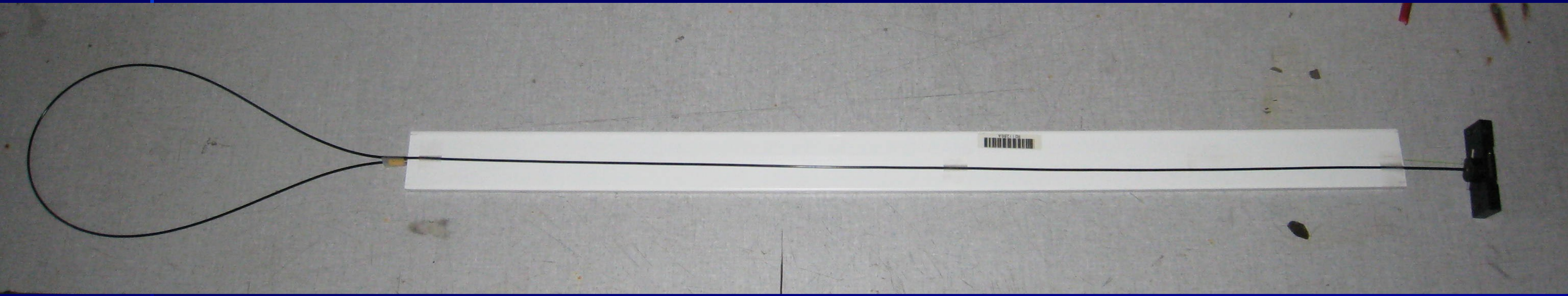
- F/E electronics has been produced, adapted to the new Hamamatsu pinout (same chips, different PCB)
- Comparison over the same 16 bars, same electronics (just PMT swap)
- Same pattern => overall gain 34%





Optical connection tests

- Setup : single bar (WLS unglued) with 1 end readout directly and the opposite end readout through clear fiber connection on the same PMT



- 2 different optical connectors tested :
  - "Bern" standard one (brass connector) => T ~ 50-60%
  - new PEEK connector (longer guideline) => T ~ 80%