Volcano Radiography with GRPCs

Samuel Béné
LPC Clermont-Ferrand
On behalf of the Tomuvol Collaboration

ToMuVol

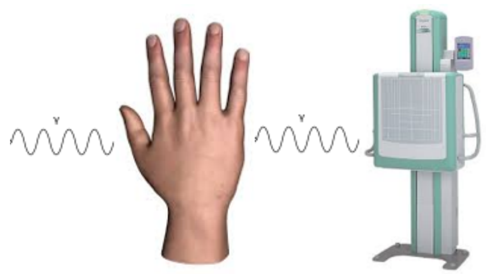
cnrs IN2P3 Les deux infinis

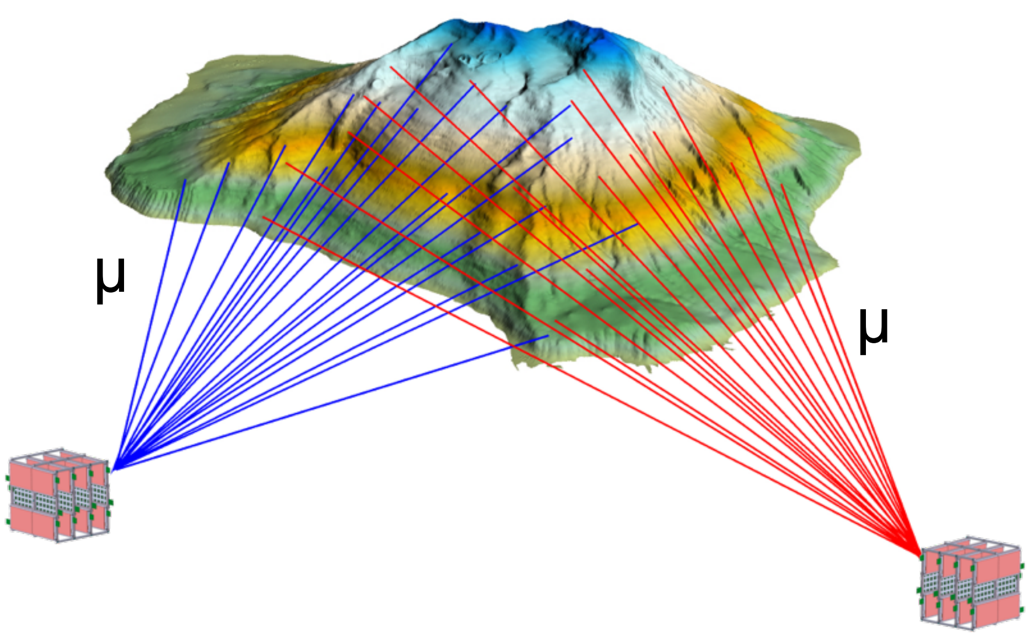
UNIVERSITE BLAISE PASCAL CLERMONT-FERRAND

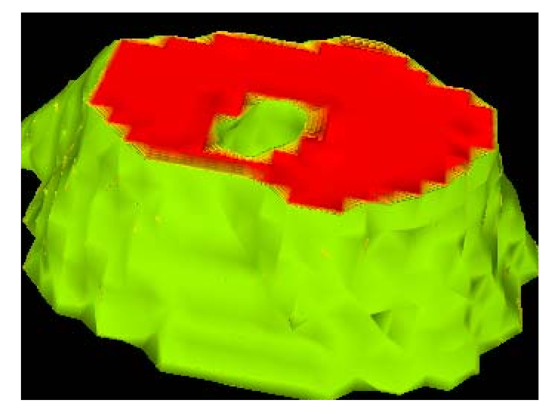
Density imaging with Cosmic Rays Muons

Basic principle :

- Probe the inner structure of a volcano using muons in terms of density.
- Combine images from different viewpoints for 3D “tomographic” reconstructions.







Three-dimensional computational axial tomography scan of a volcano with cosmic ray muon radiography

Hiroyuki K. M. Tanaka,[1] Hideaki Taira,[2] Tomihisa Uchida,[3] Manobu Tanaka,[3] Minoru Takeo,[1] Takao Ohminato,[1] Yosuke Aoki,[1] Ryuichi Nishitama,[1] Daigo Shoji,[1] and Hiroshi Tsuiji[1]

JGR,vol. 115, 2010

Possible since :

- Muons are very penetrating : 0.1~1TeV muons can pass through 0.1~1 km of rocks
- High energy muons are naturally produced in air showers.

The Tomuvol collaboration

*Proof of principle for the "**To**mographie with **Mu**ons of the **Vol**canoes"*

Interdisciplinary collaboration, emerged end 2009: particle physicists (IPNL, LPC) and volcanologists (LMV, OPGC).

Phase 1 : 2010-2014

- Extensive studies of the Puy-de-Dôme.
- Comparison to geophysical techniques.

Phase 2 : 2014➠

- Design, construction and validation of an autonomous and easily transportable radiographic device.

Base design of the detector :

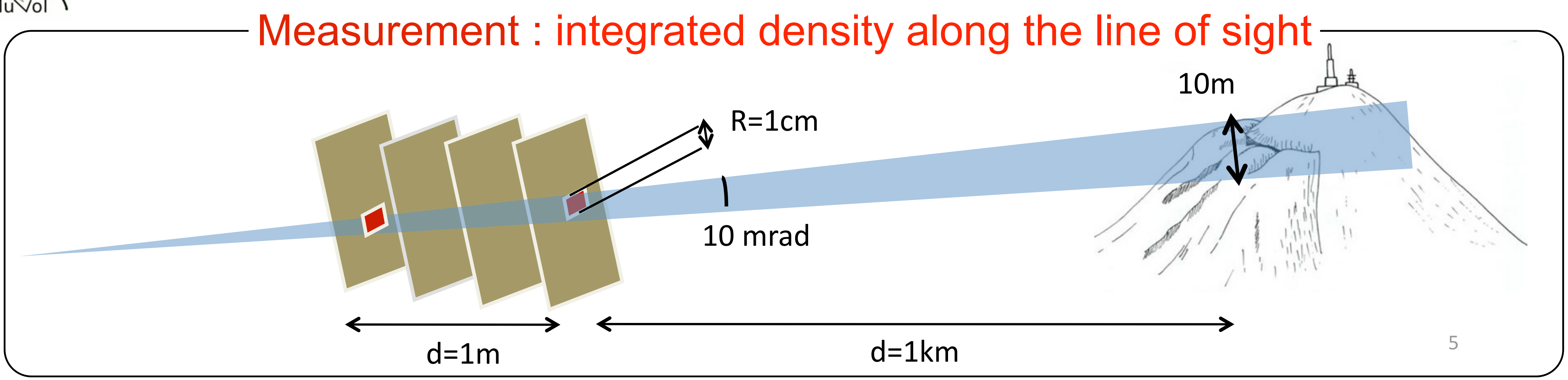
Muon tracker composed of four planes made of CALICE Glass Resistive Plate Chambers.

➥extensively described at this conference:

Gerald Grenier on the SDHCAL technological prototype,

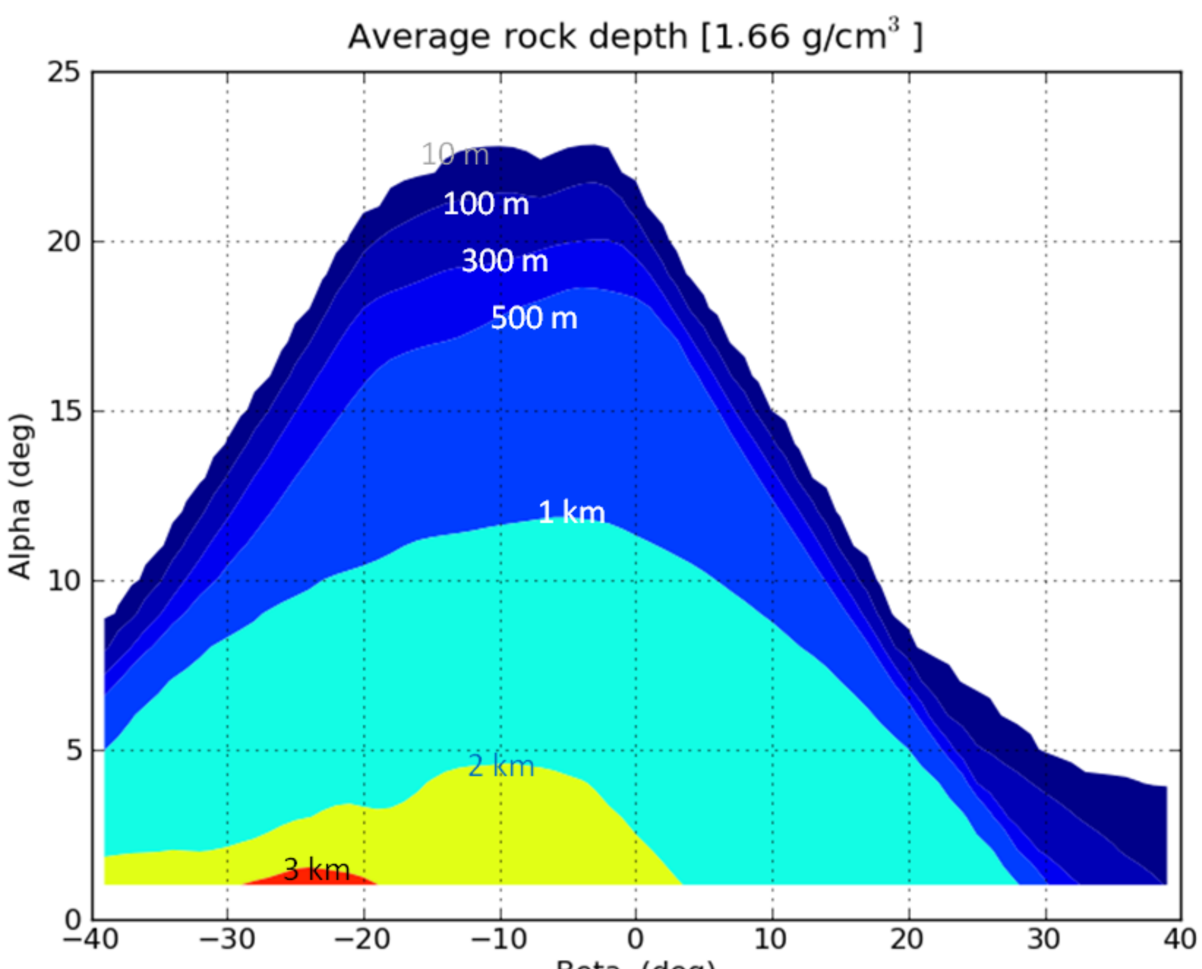
Nathalie Séguin on the readout ASICs (Hardrock 2)

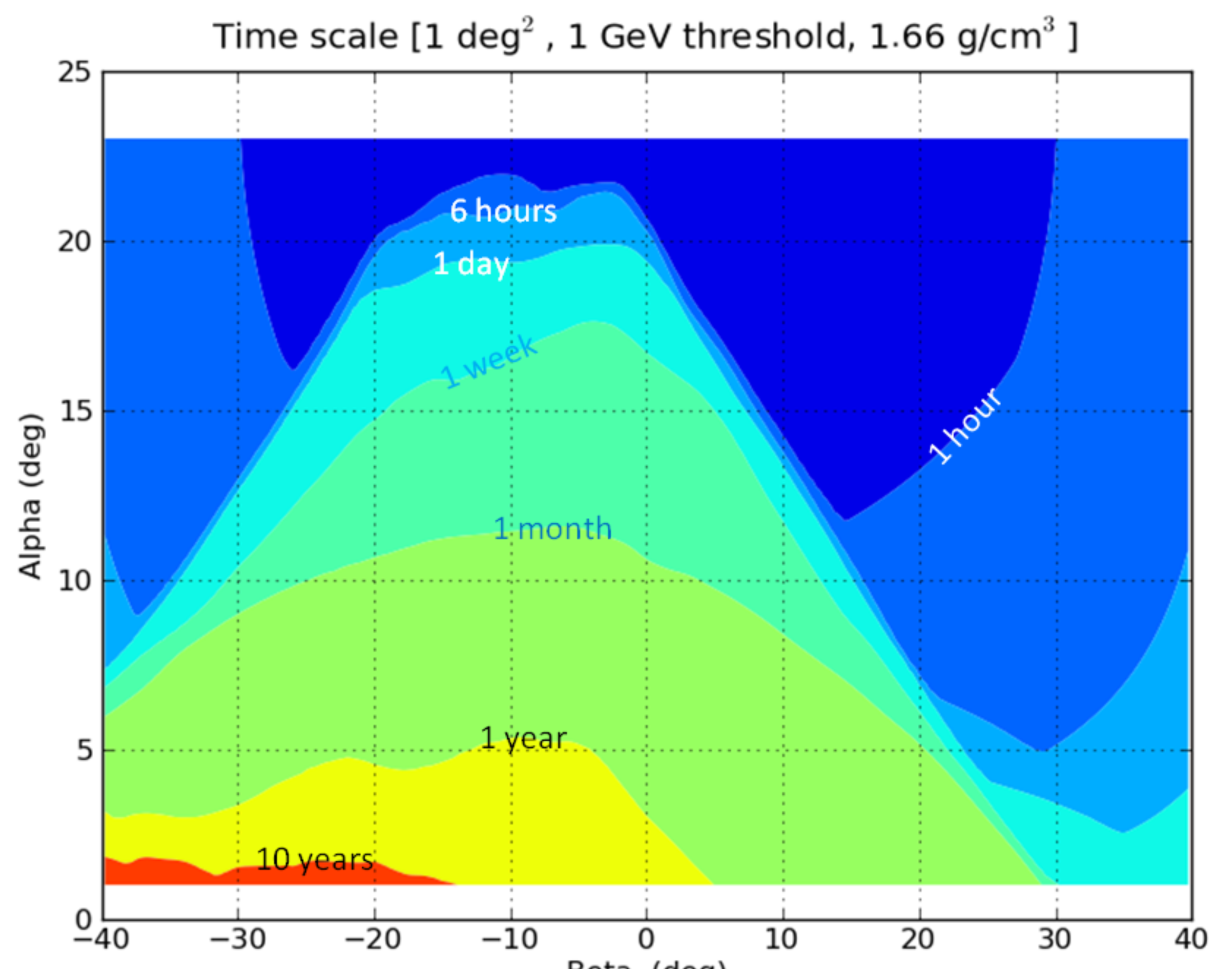
Detectors for volcano radiography



- ~0.5º track resolution - 10 m spatial res. for a detector ~km away
- Attainable density contrast driven by the detector effective surface

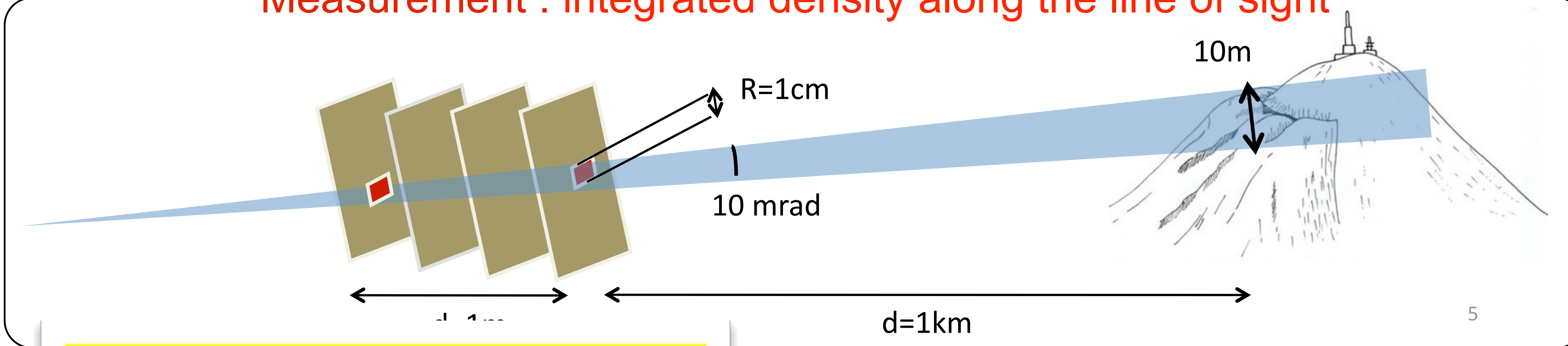
High energy muons rather scarce at high θ : 1~10/m^{2}deg^{2}day near the horizontal.





Detectors for volcano radiography

Measurement : integrated density along the line of sight



A good detector

- ✓large, upscalable surface
- ✓(very) good angular resolution
- ✓high efficiency
- ✓low noise

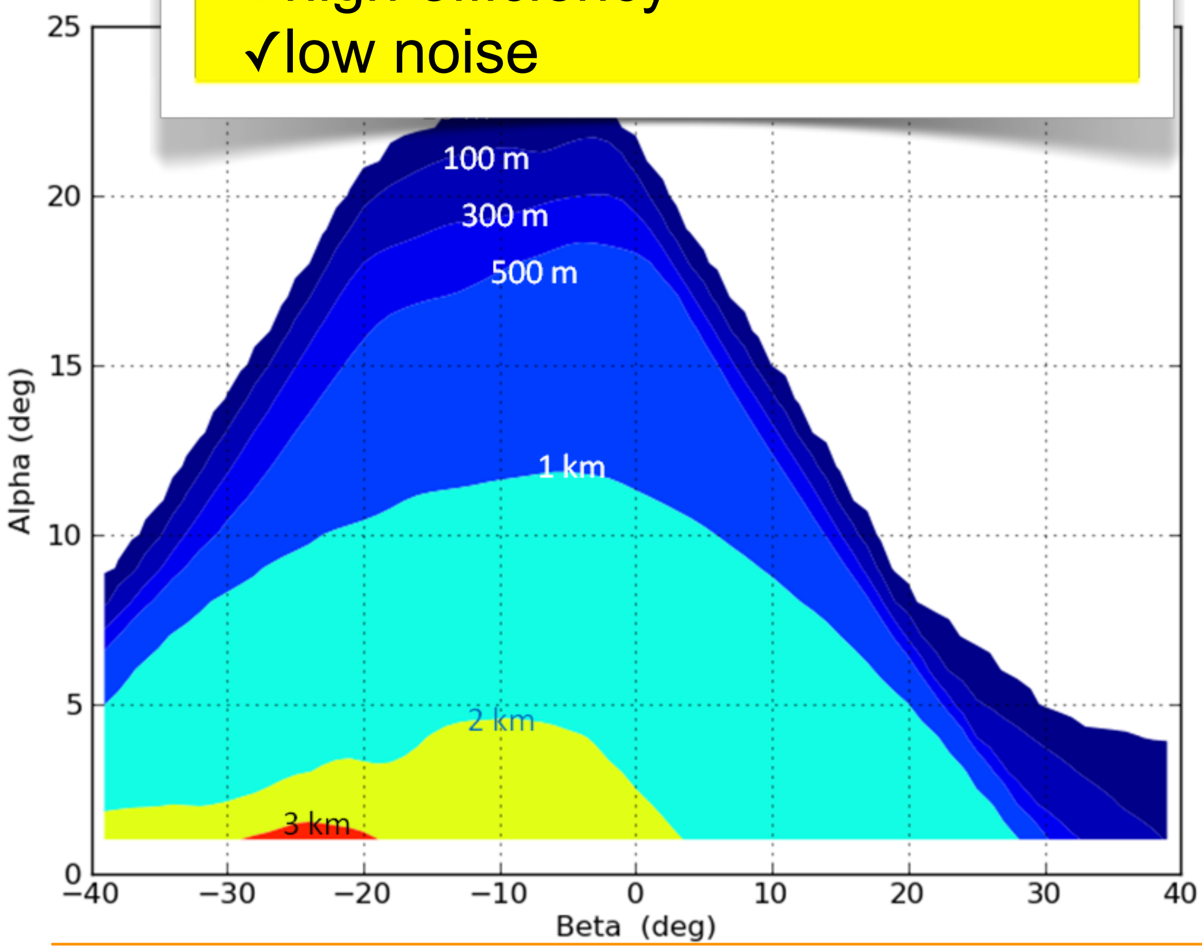
10 m sp

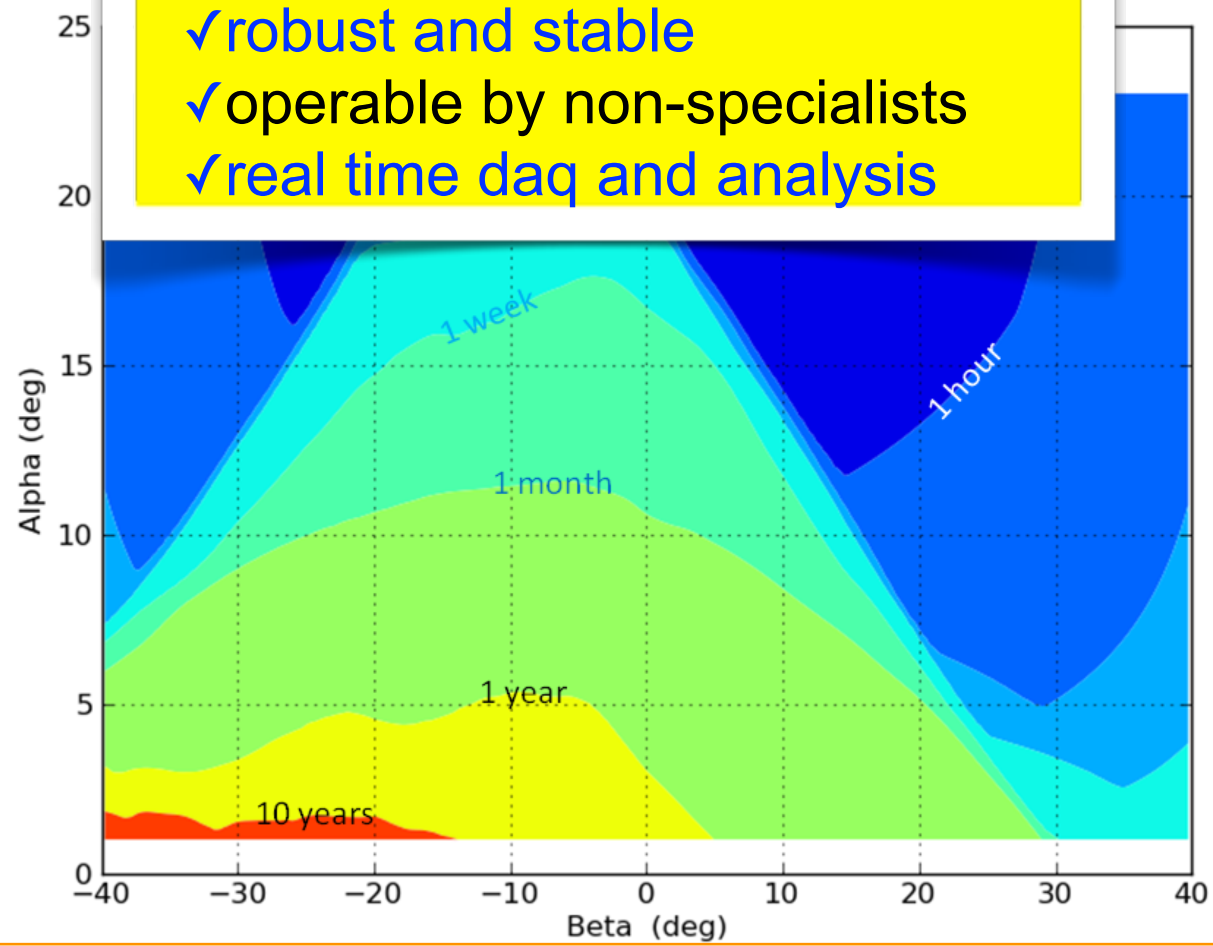
ast drive

high θ : 1

... and some more

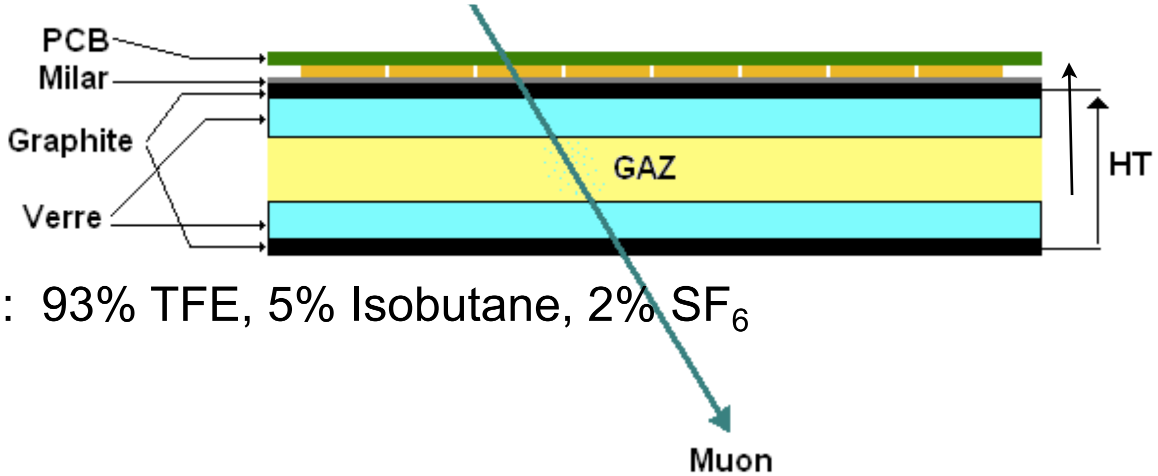
- ✓low power consumption
- ✓robust and stable
- ✓operable by non-specialists
- ✓real time daq and analysis





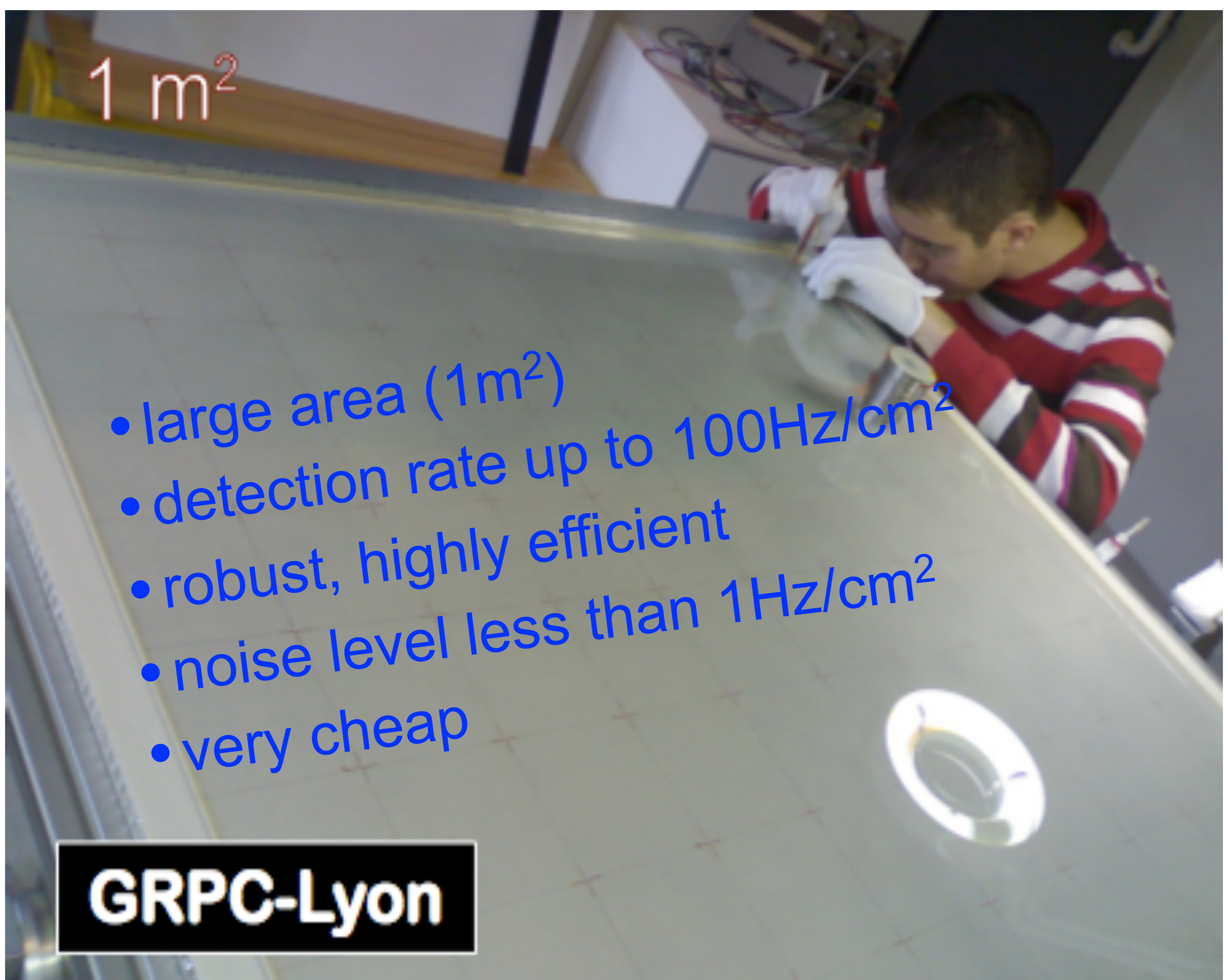
CALICE GRPC's

Avalanche mode: total mean MIP charge 2.6pC, RMS: 1.6pC



Gas: 93% TFE, 5% Isobutane, 2% SF_6

M. Bedjidian et al, "Performance of Glass Resistive Plate Chambers for a high granularity semi-digital calorimeter", JINST 6:P02001,2011



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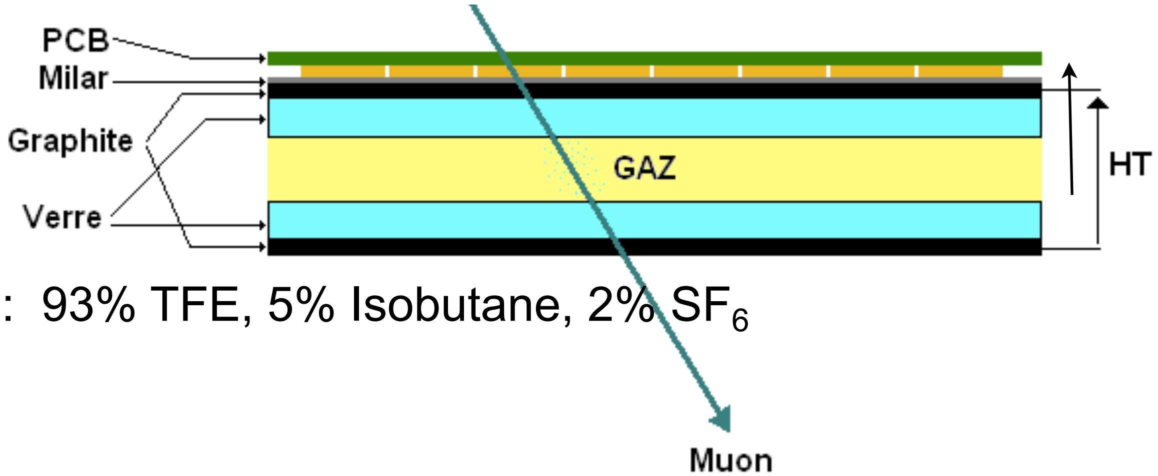

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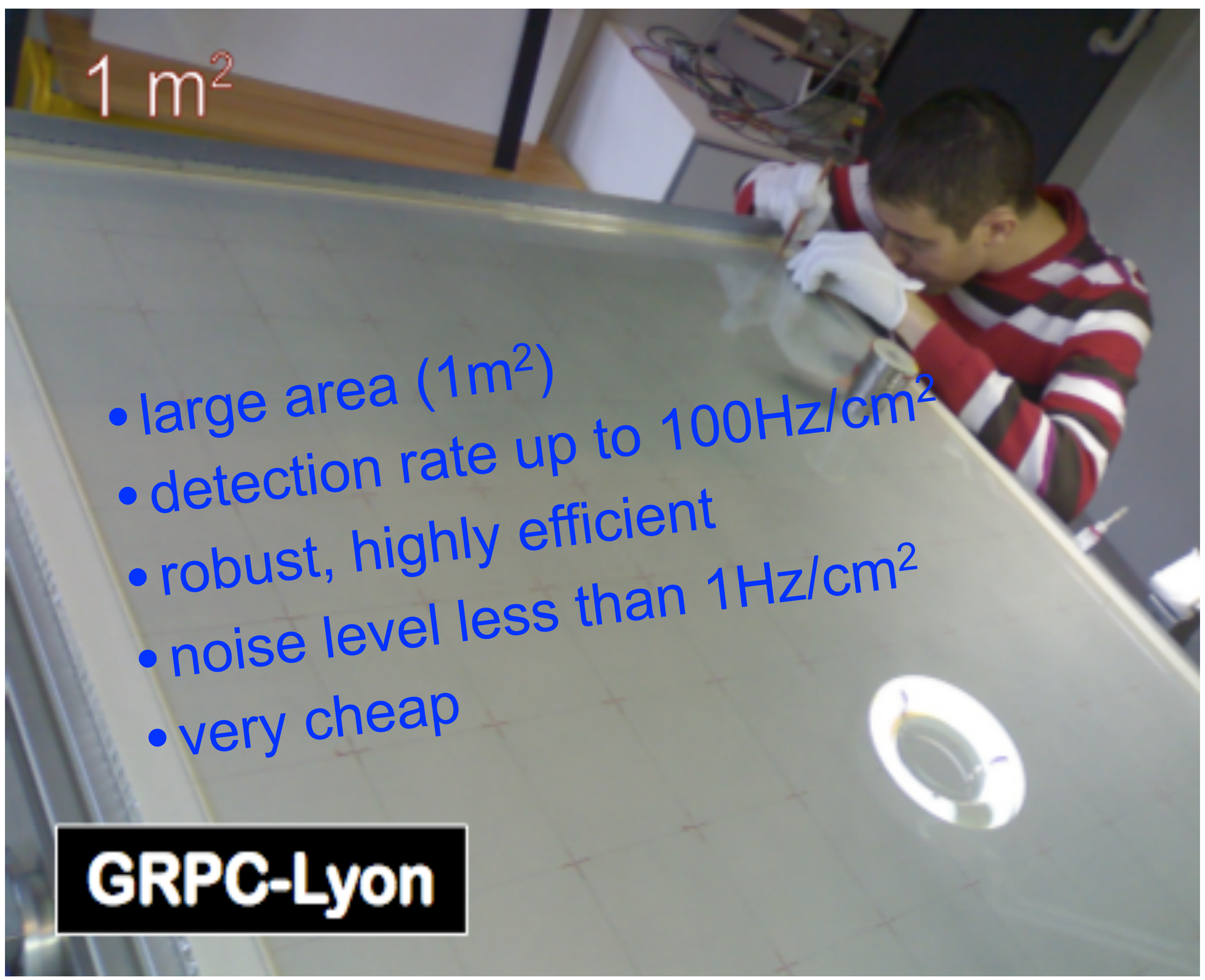
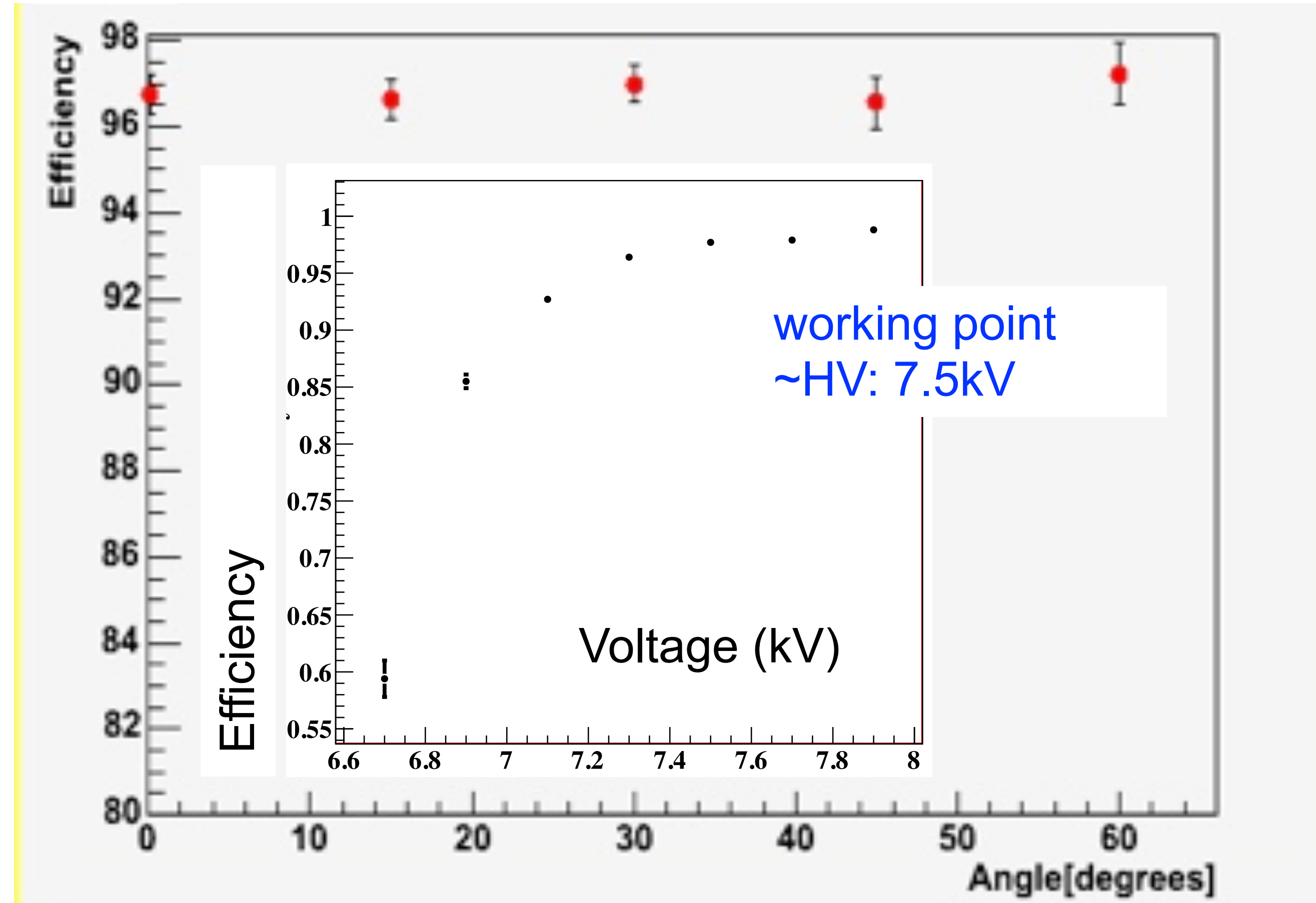


Efficiency vs. HV & track incident angle



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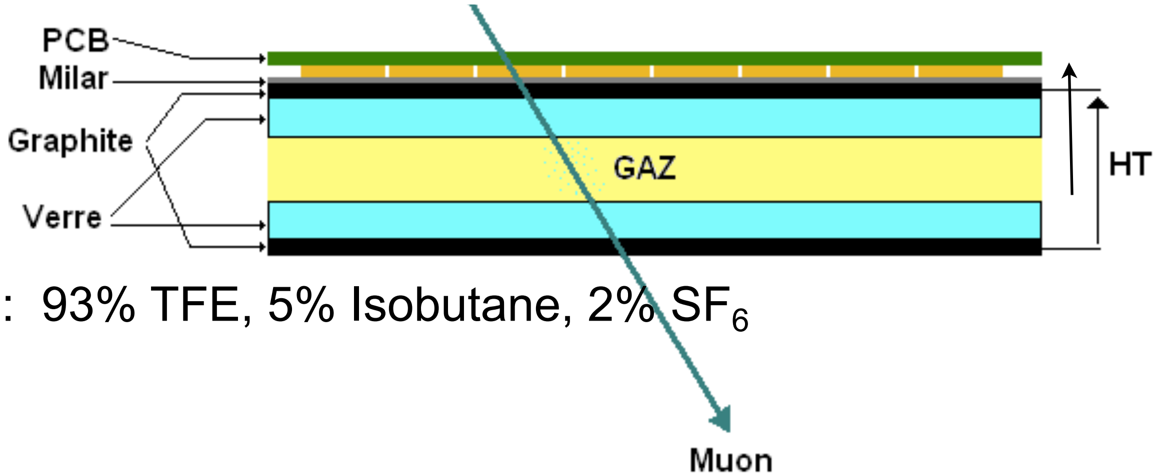

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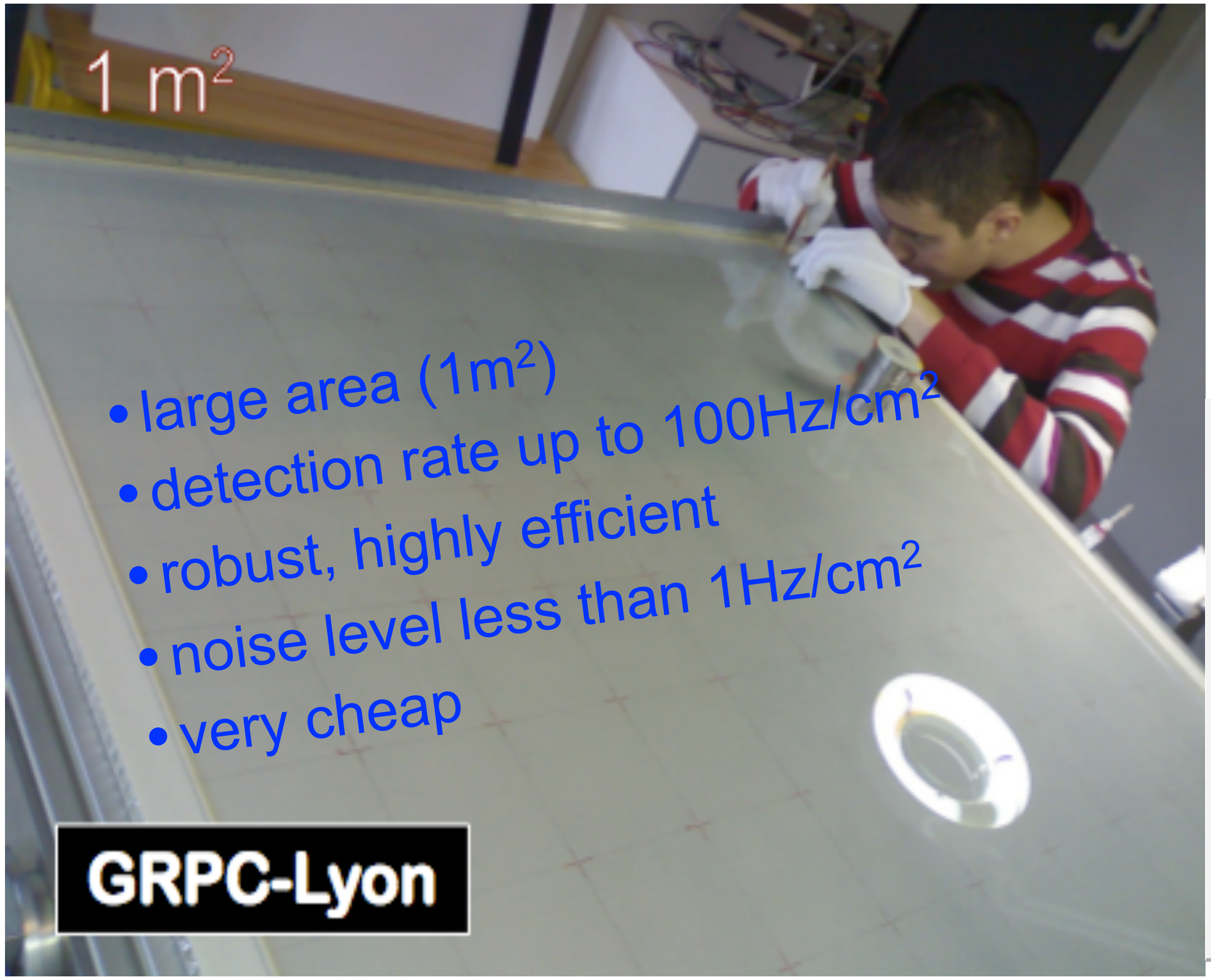

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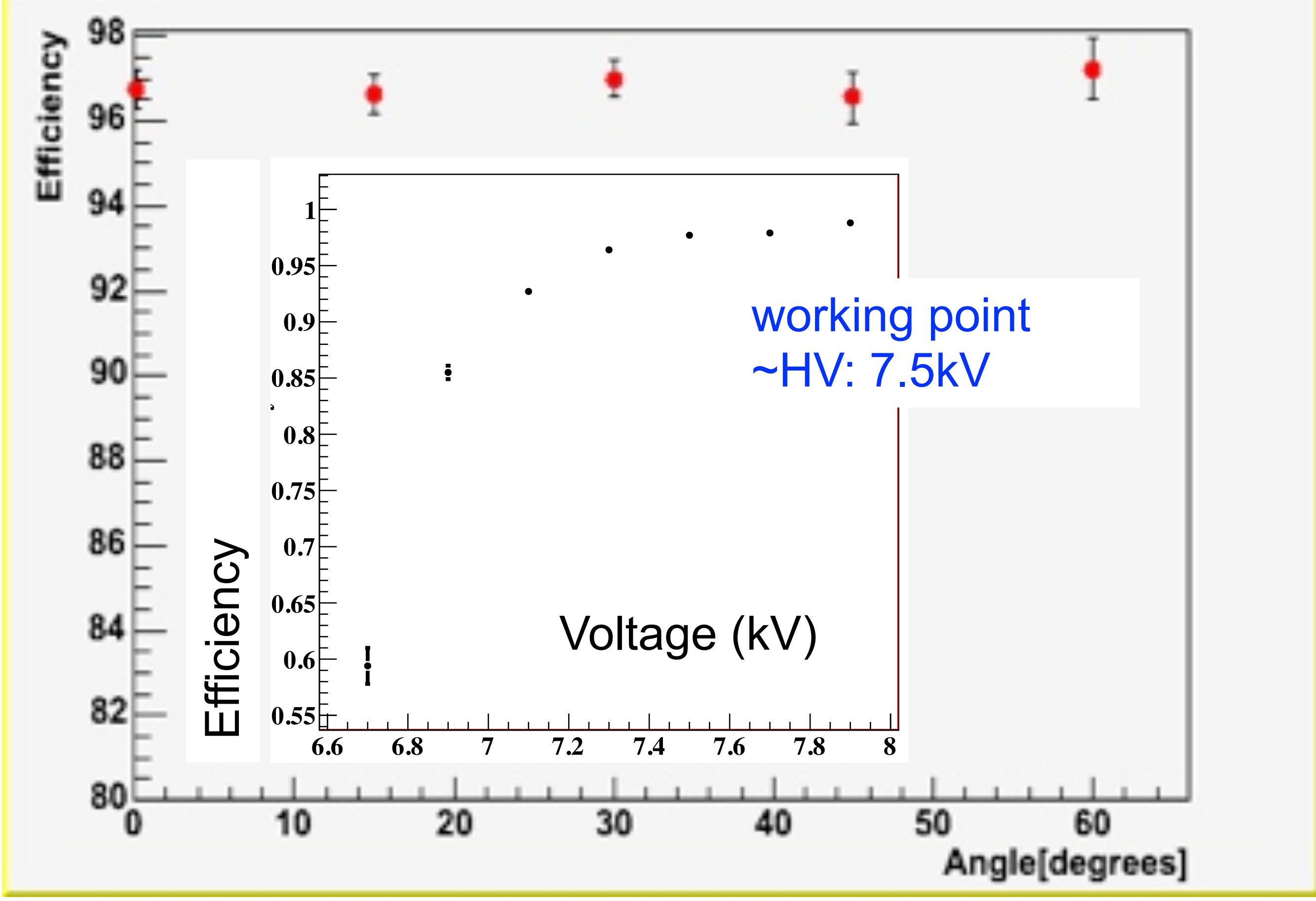
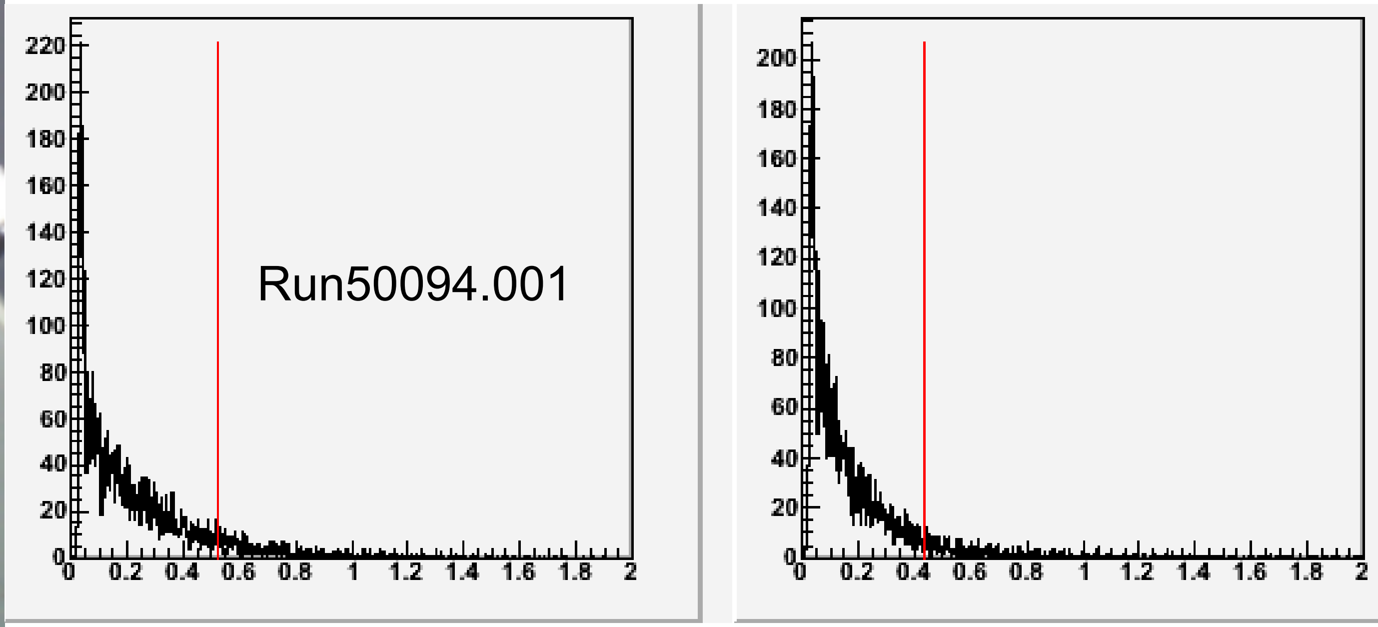
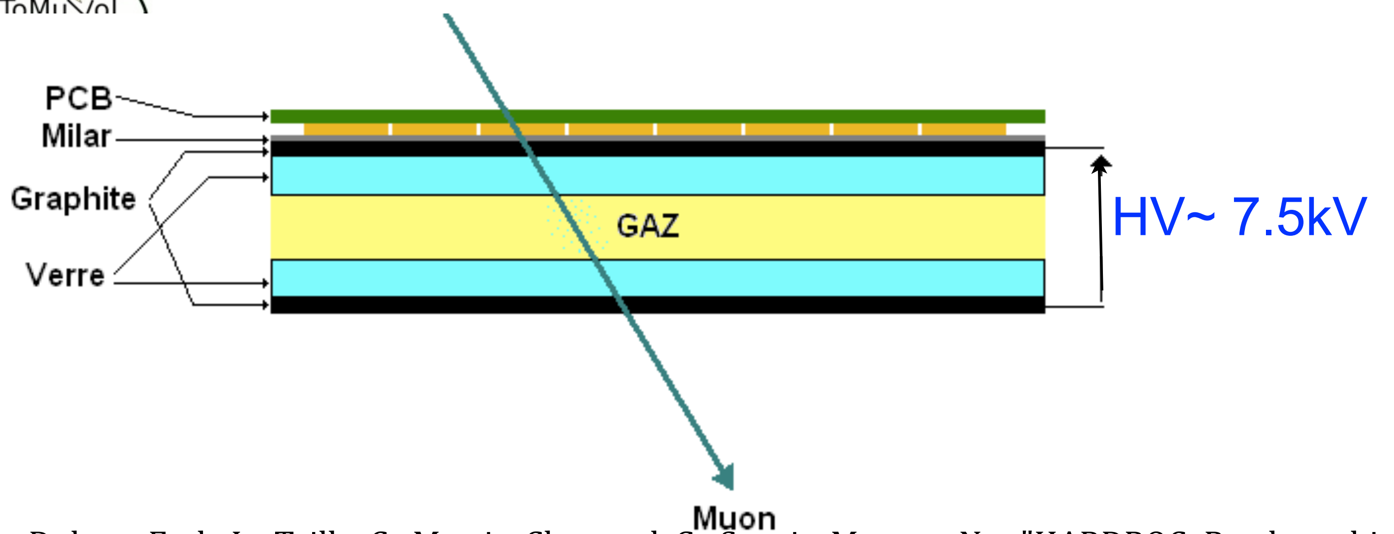
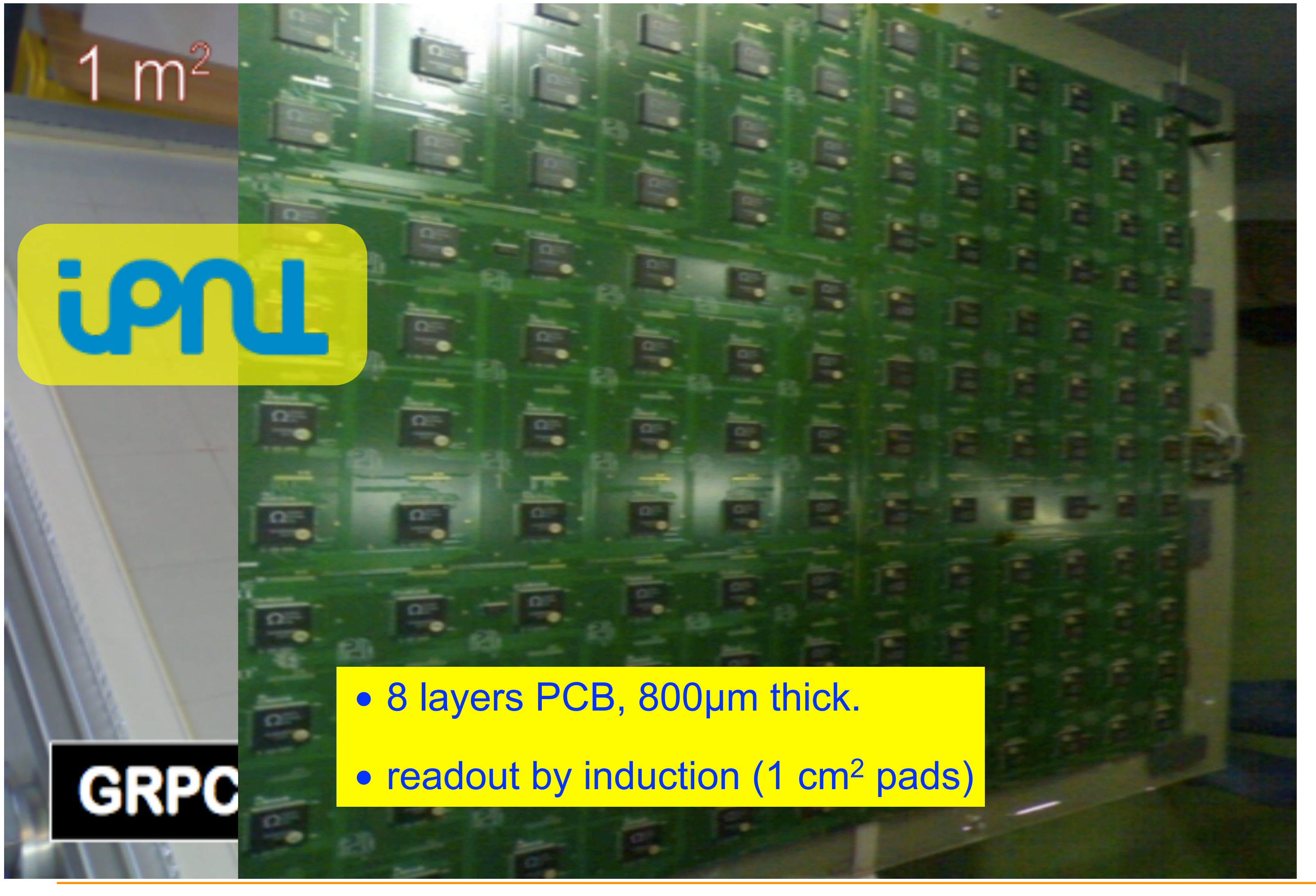


Noise rate (Hz)

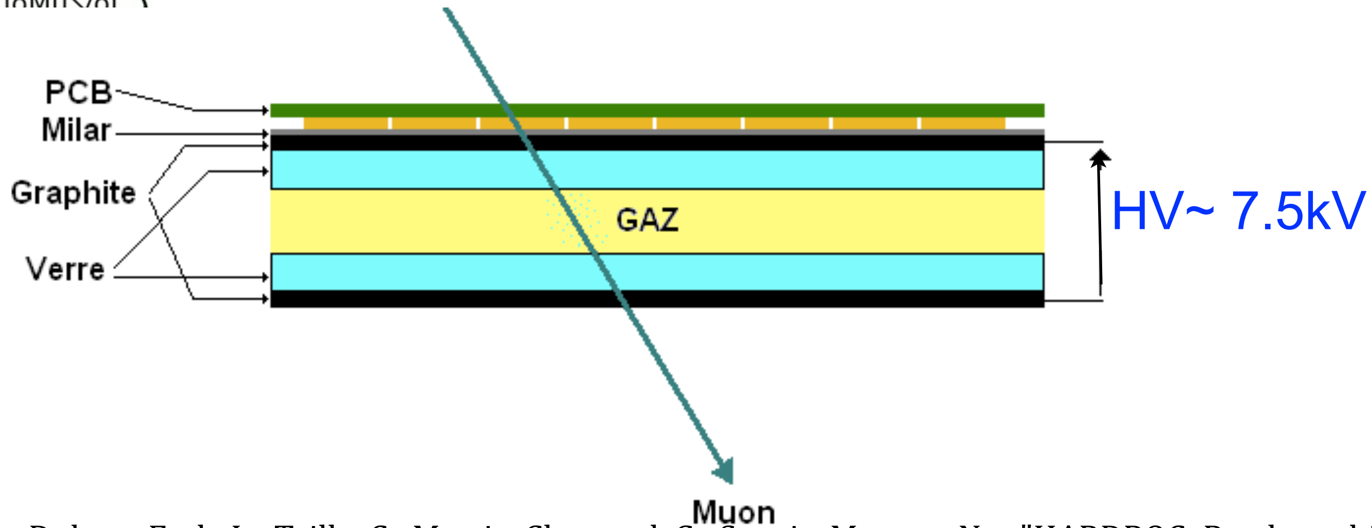




Dulucq, F.; de La Taille, C.; Martin-Chassard, G.; Seguin-Moreau, N.; , "HARDROC: Readout chip for CALICE/EUDET Digital Hadronic Calorimeter," *Nuclear Science Symposium Conference Record (NSS/MIC), 2010 IEEE*



Muon Tracker : CALICE Electronics



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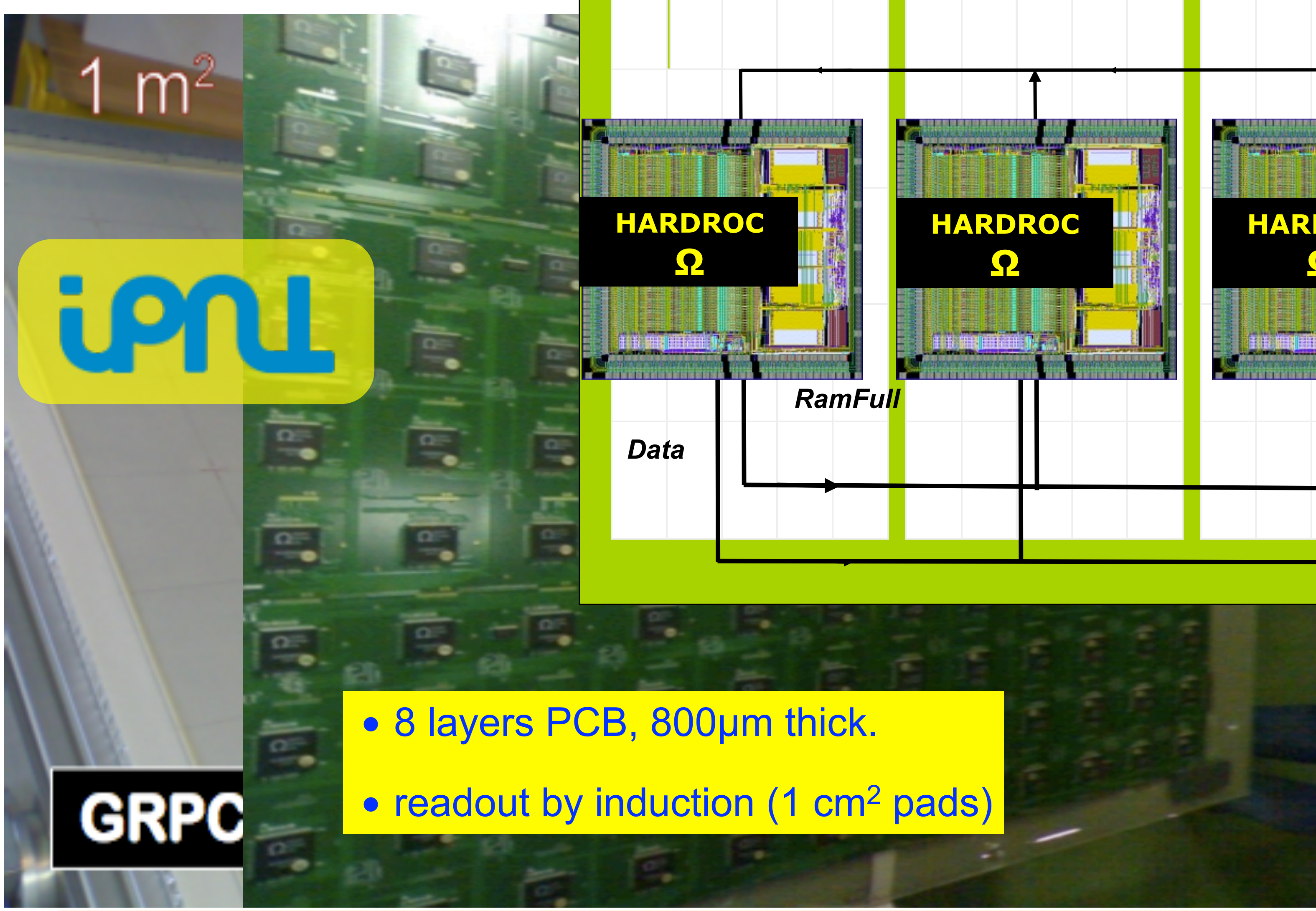
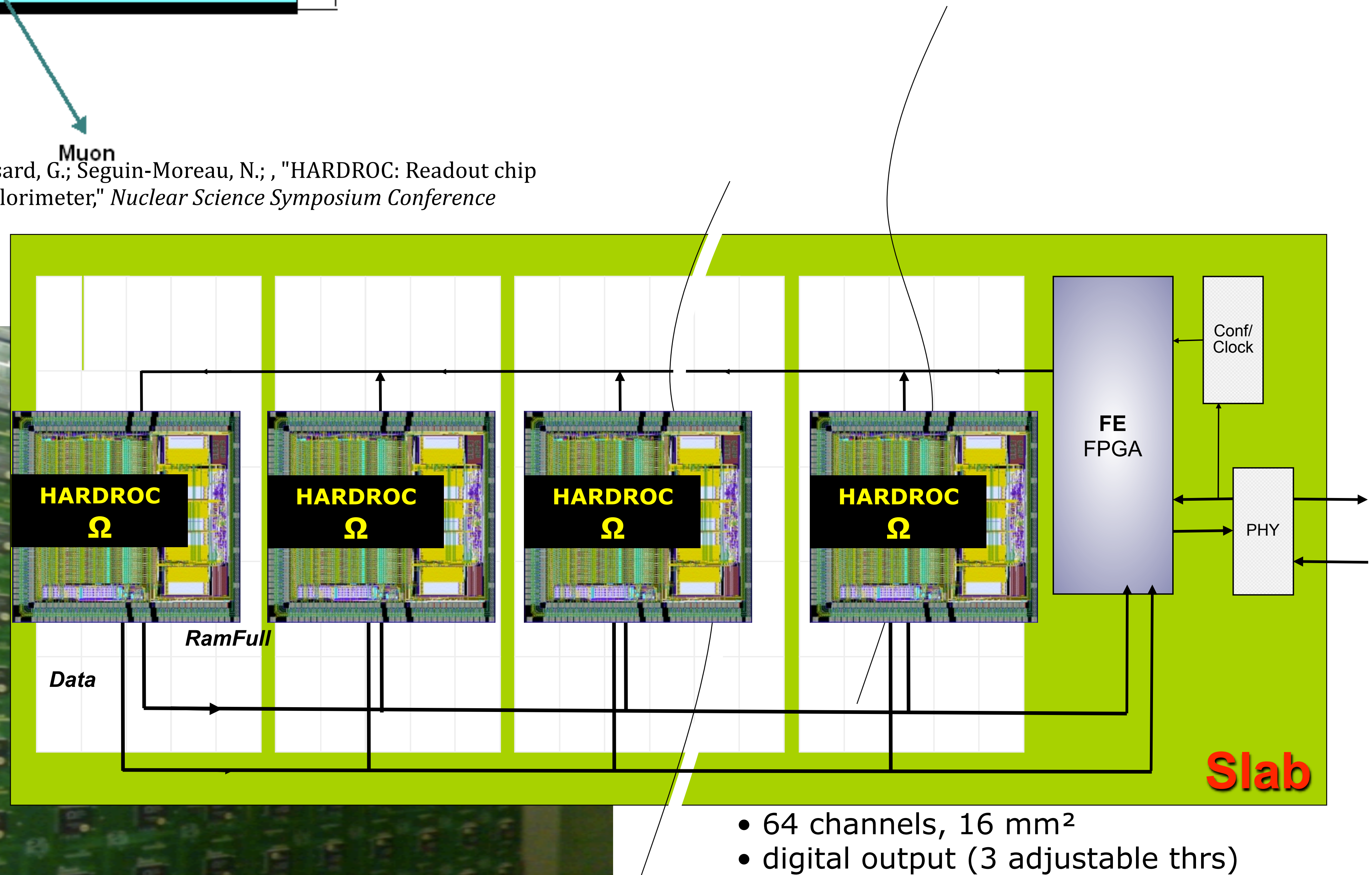


- 8 layers PCB, 800µm thick.
- readout by induction (1 cm^2 pads)



- 64 channels, 16 mm²
- digital output (3 adjustable thrs)
- low power consumption (1.5 mW/ch)
- large gain range
- xtalk <2%
- ajustable gain for each channel

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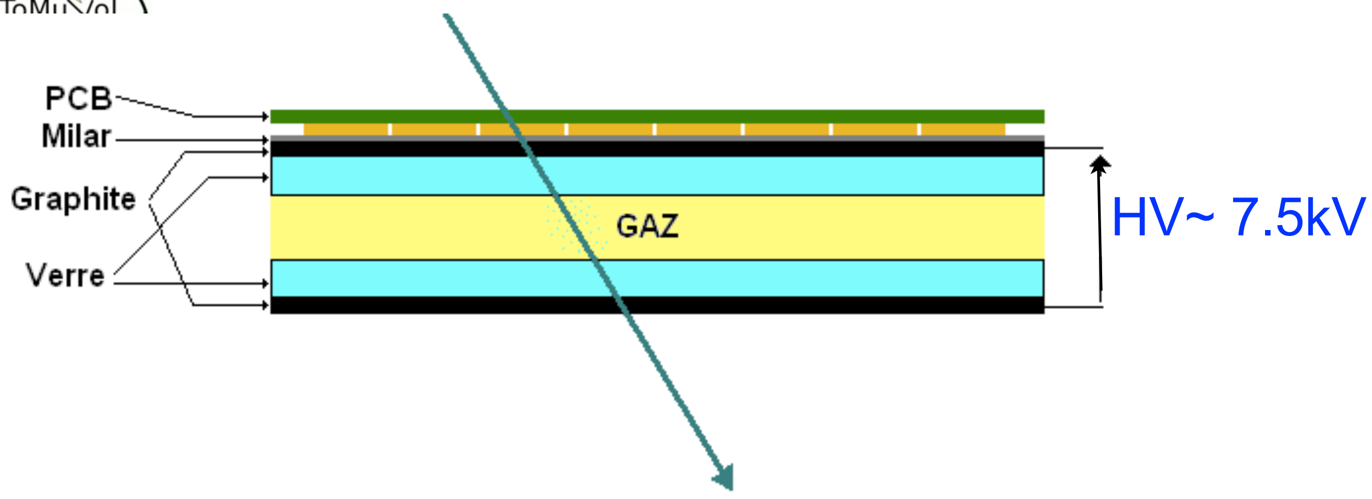

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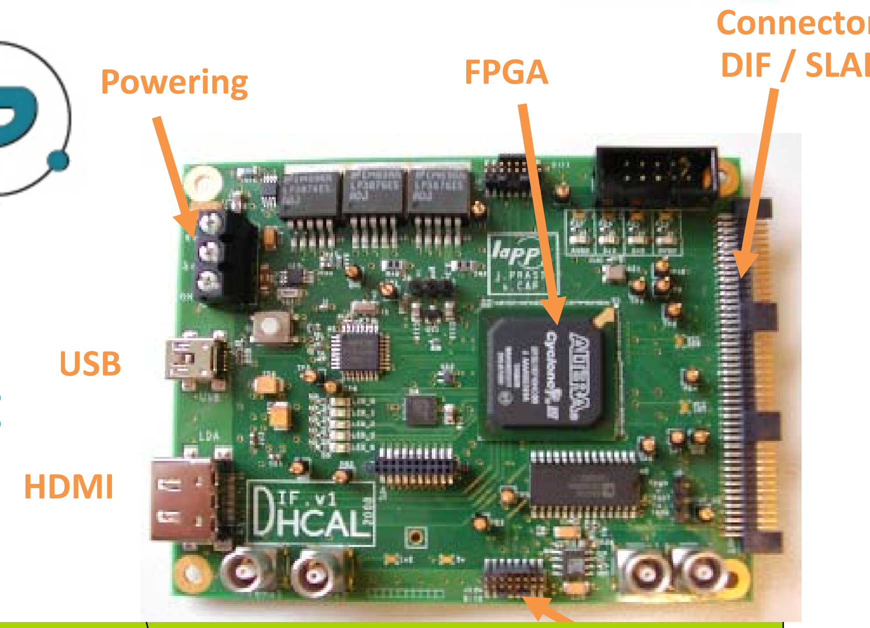

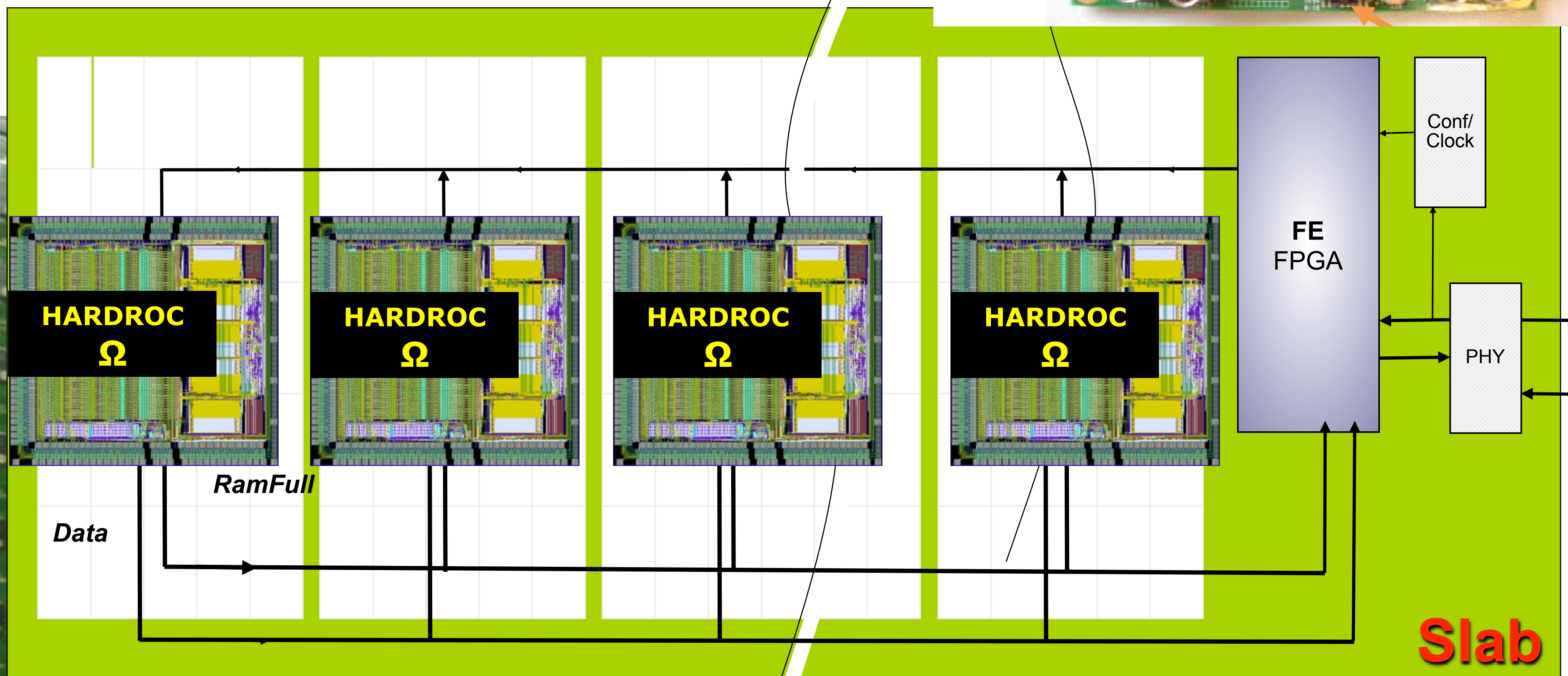

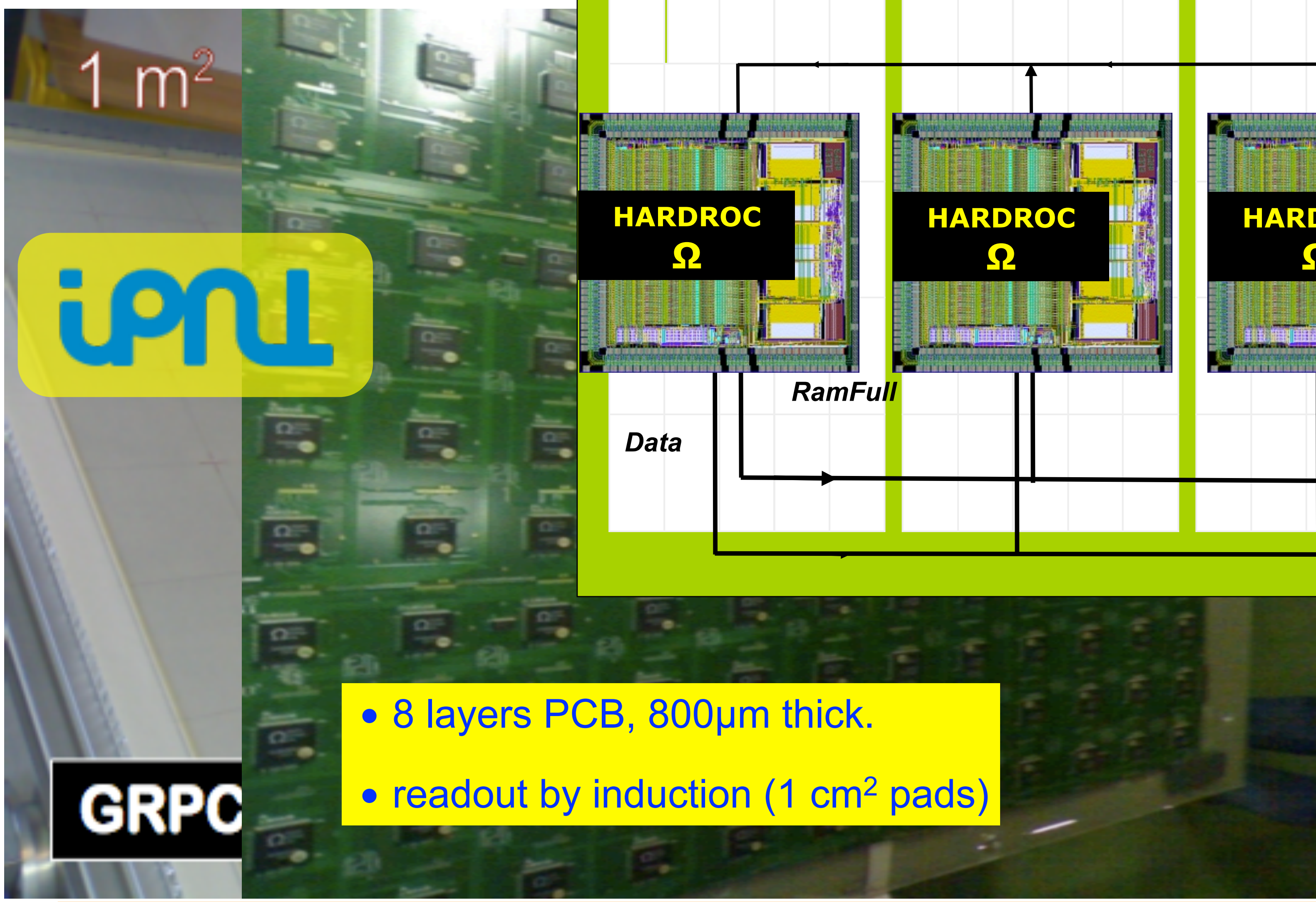

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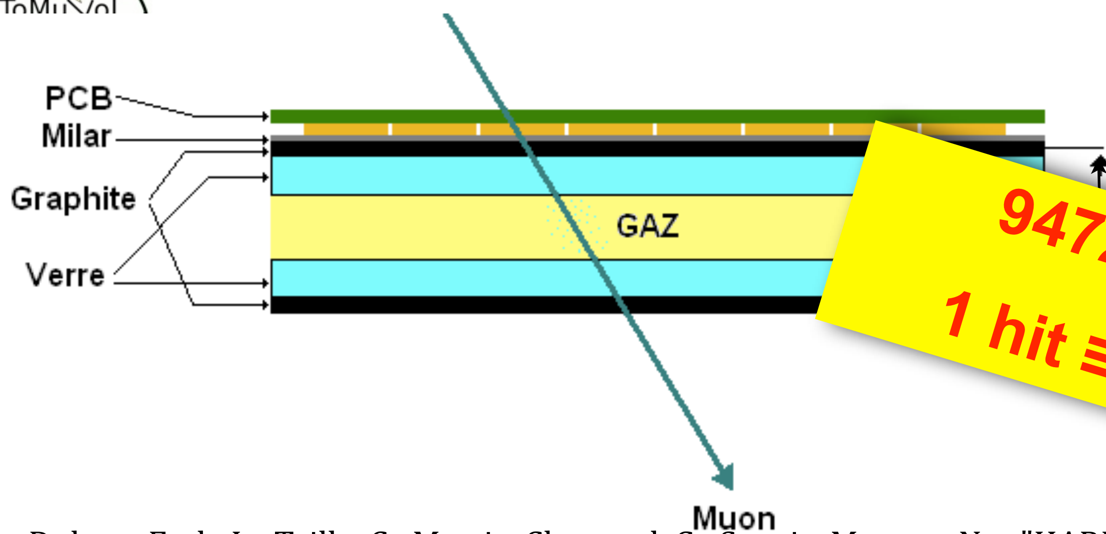

9472 channels/m2

1 hit ≡ time + thresh

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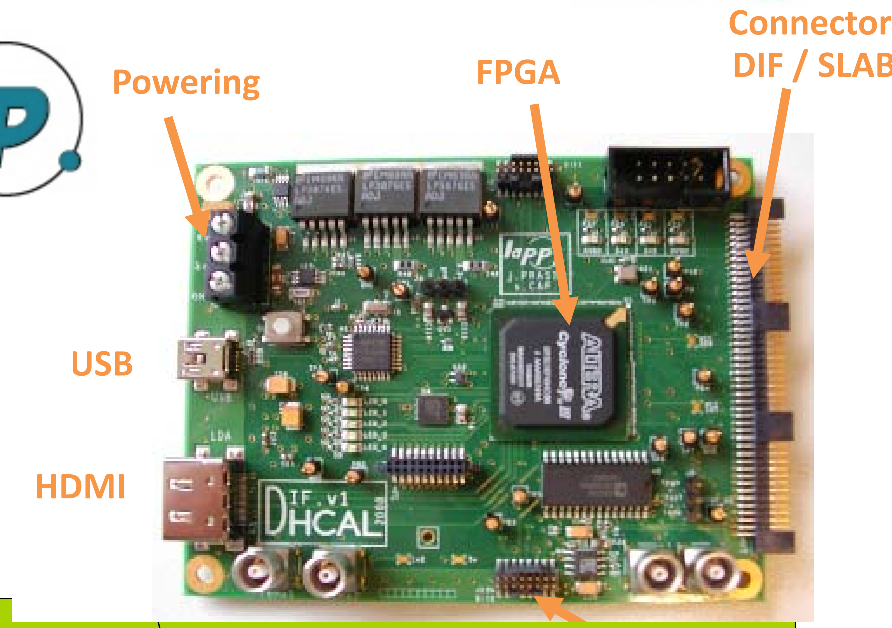

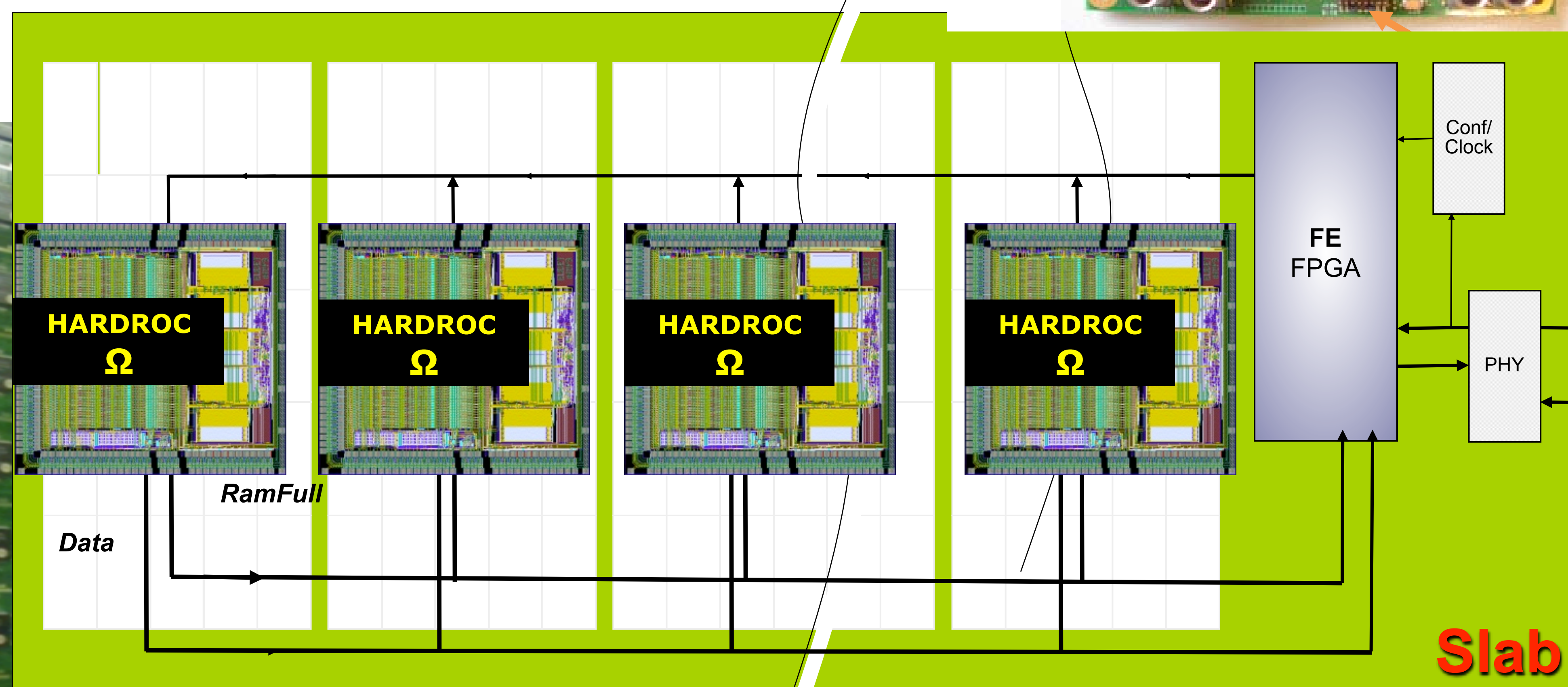

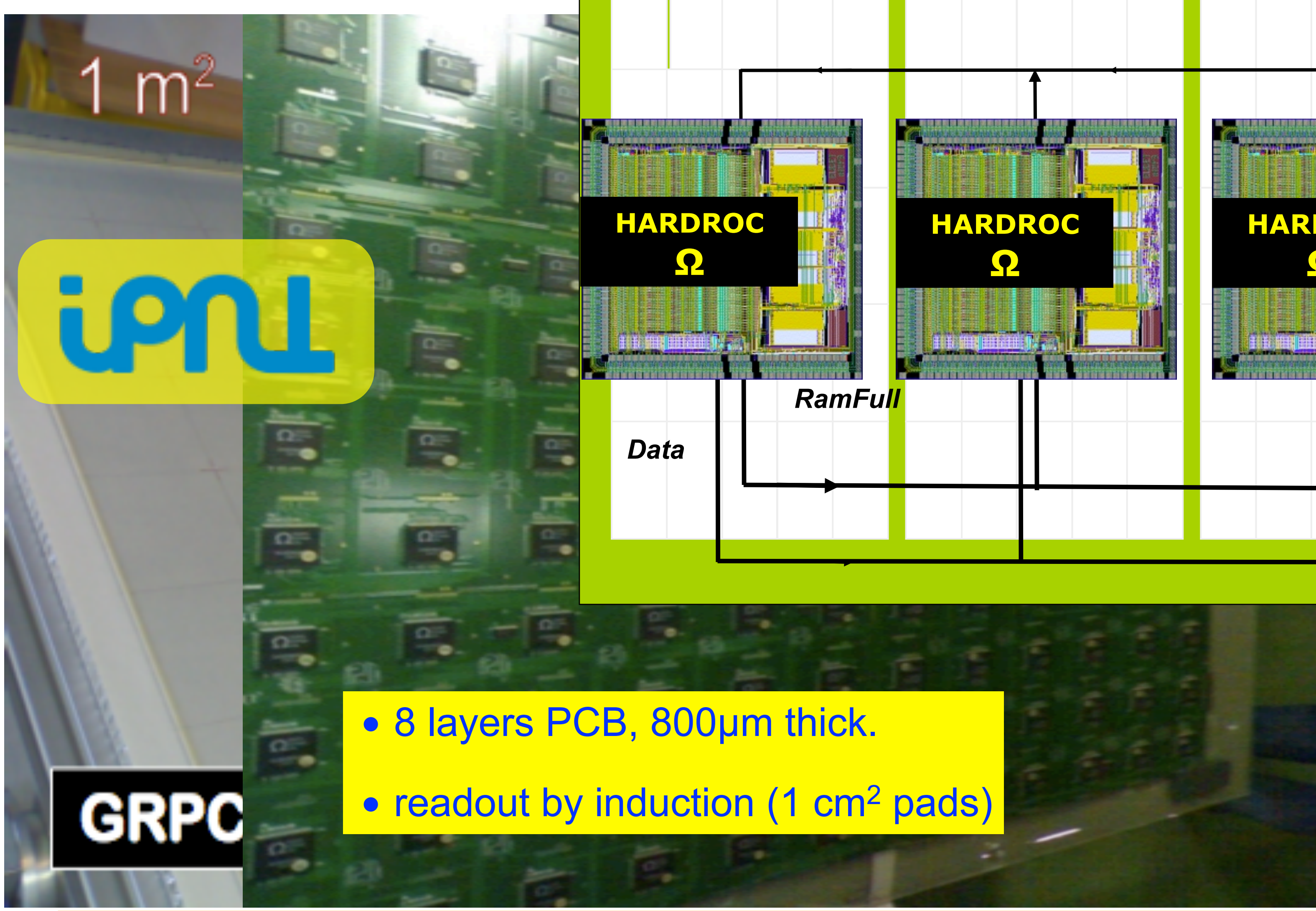

- 8 layers PCB, 800µm thick.
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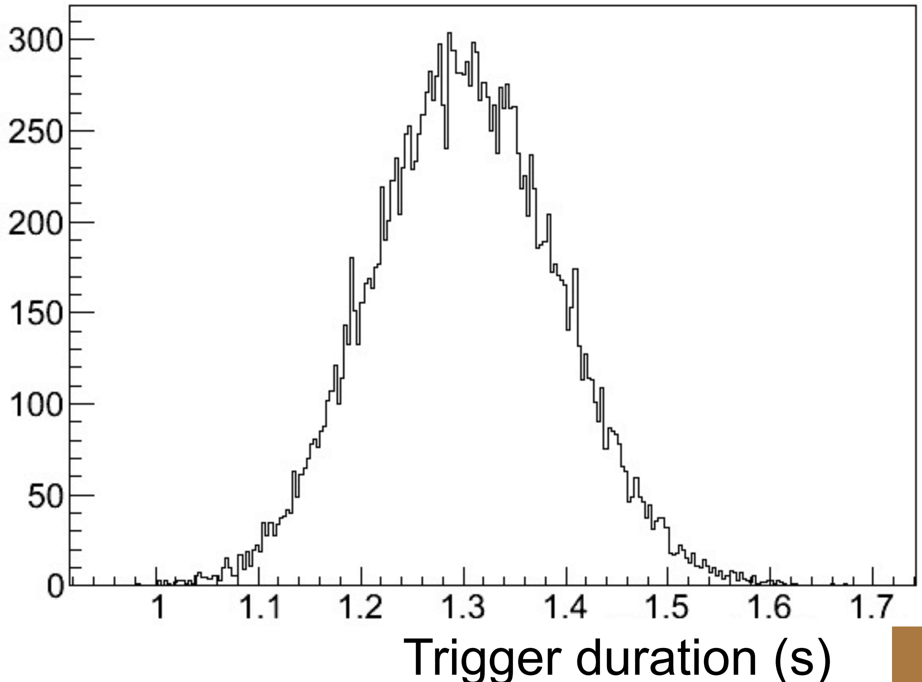
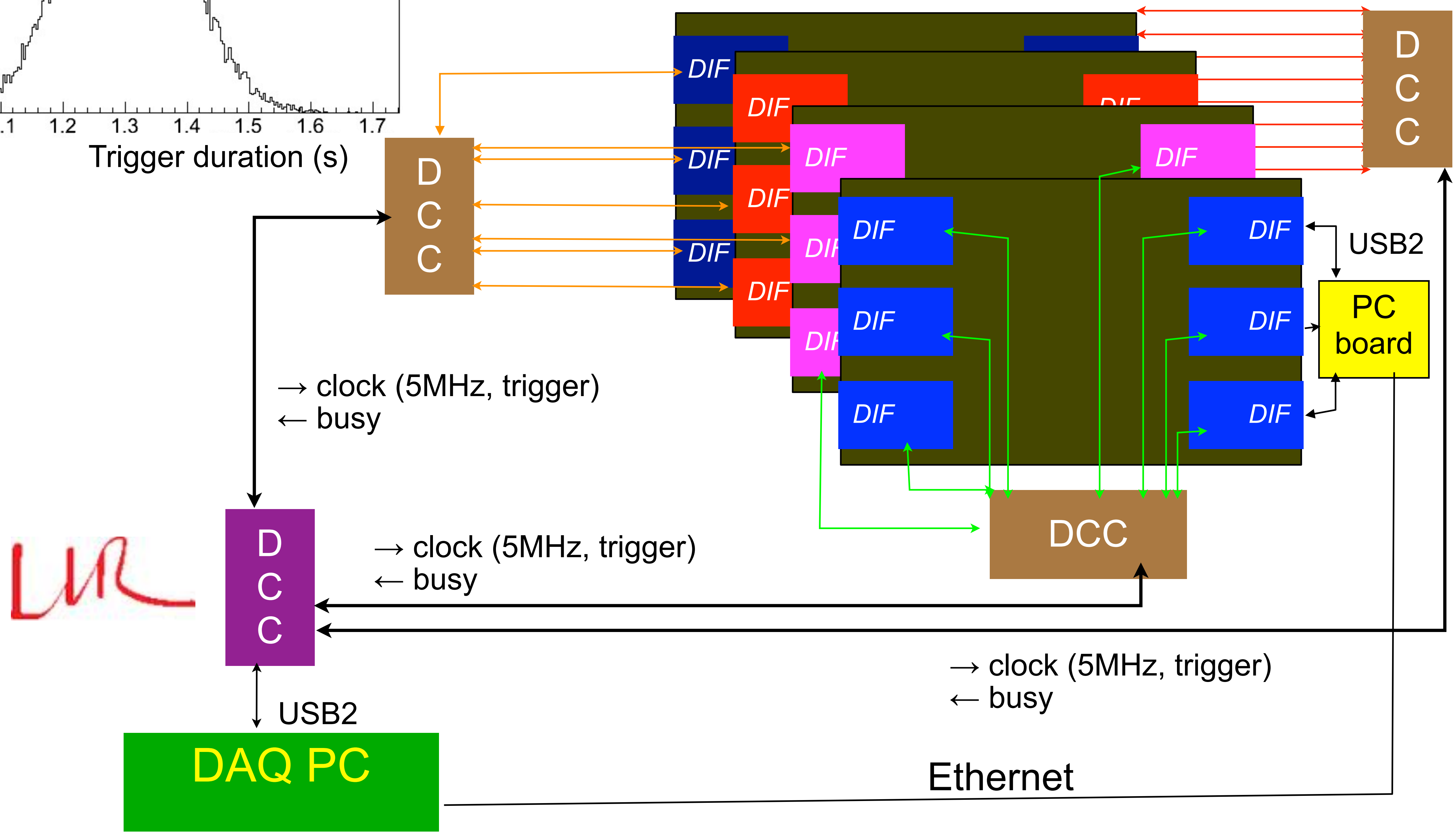
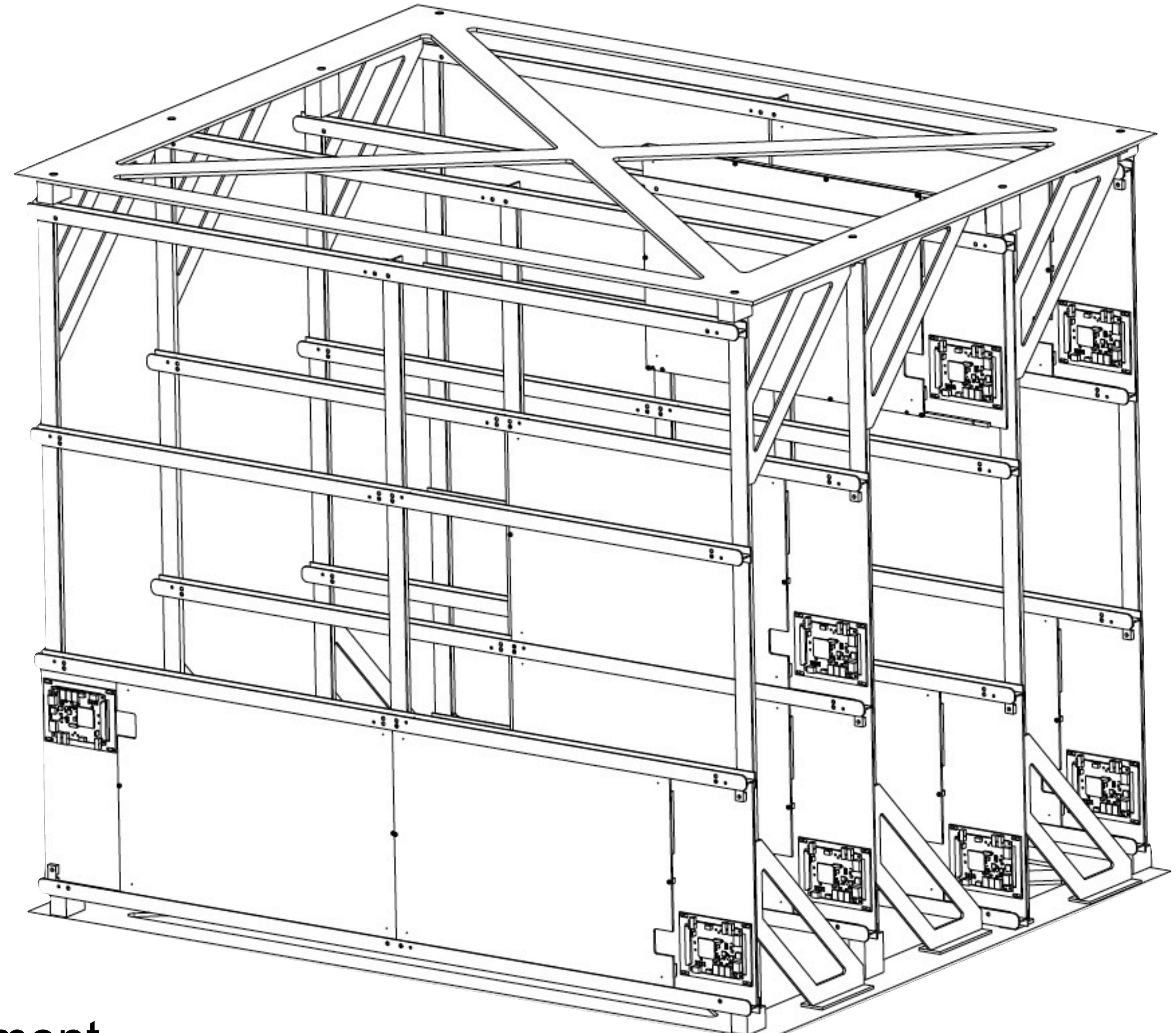


- system operated synchronously @ 5 MHz
- each DIF reads/controls 48 HARDROC2 ASICS (autotrigged and with internal RAM holding 128 consecutive events)
- first full RAM triggers the readout of the whole detector



The Tomuvol detector design

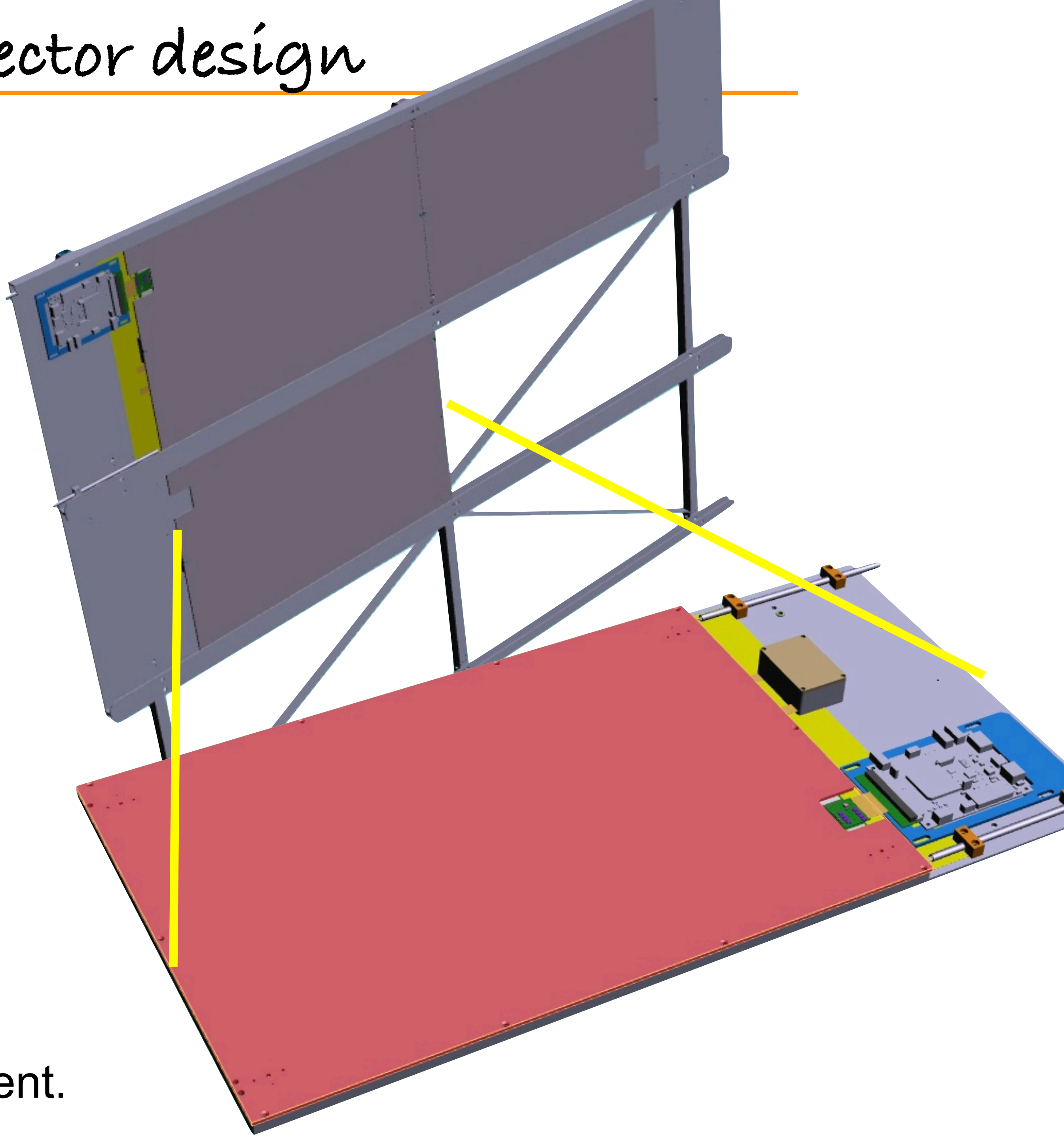


- $1m^2$ chambers not really suited for field deployment.
- Difficult to transport (heavy, fragile).
- Price/unit too high to produce enough spares.

➡ **$1m^2$ made out of 6 chambers $50x33\ cm^2$**

- easy to transport
- price/unit compatible with spare production
- special care in designing the structure for precise alignment

The Tomuvol detector design



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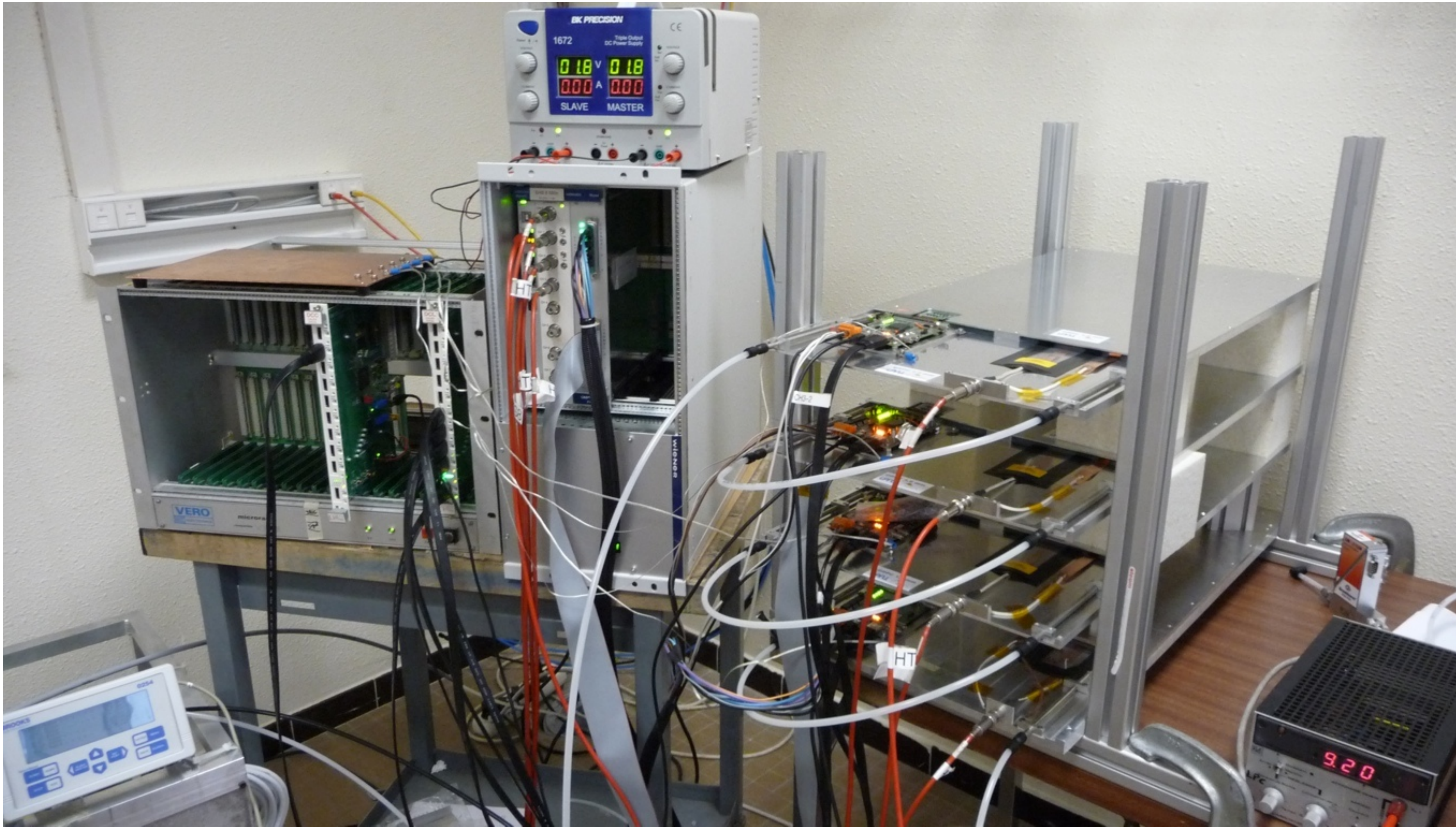
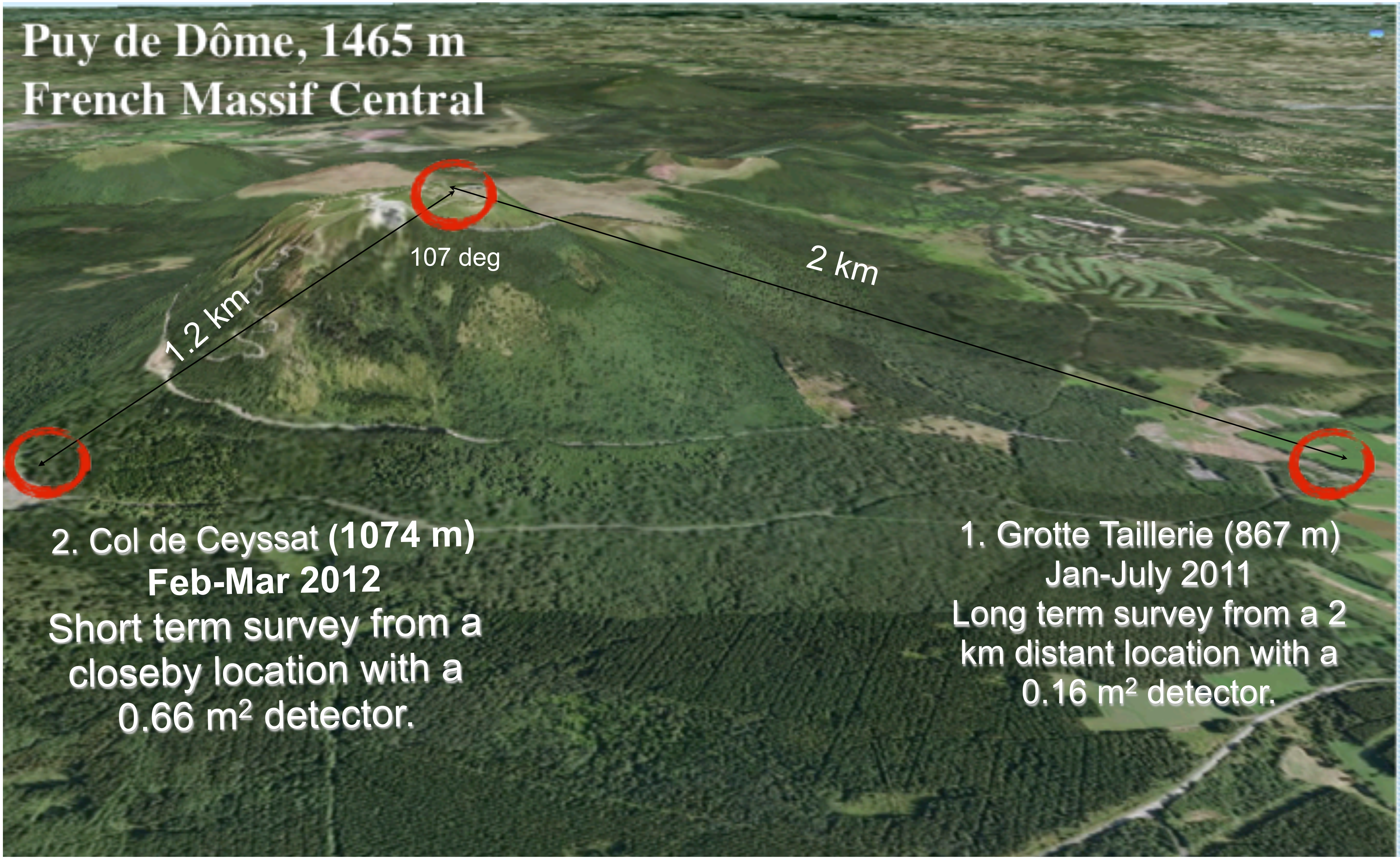
Test bench @ LPC last November



Preliminary measurement campaigns

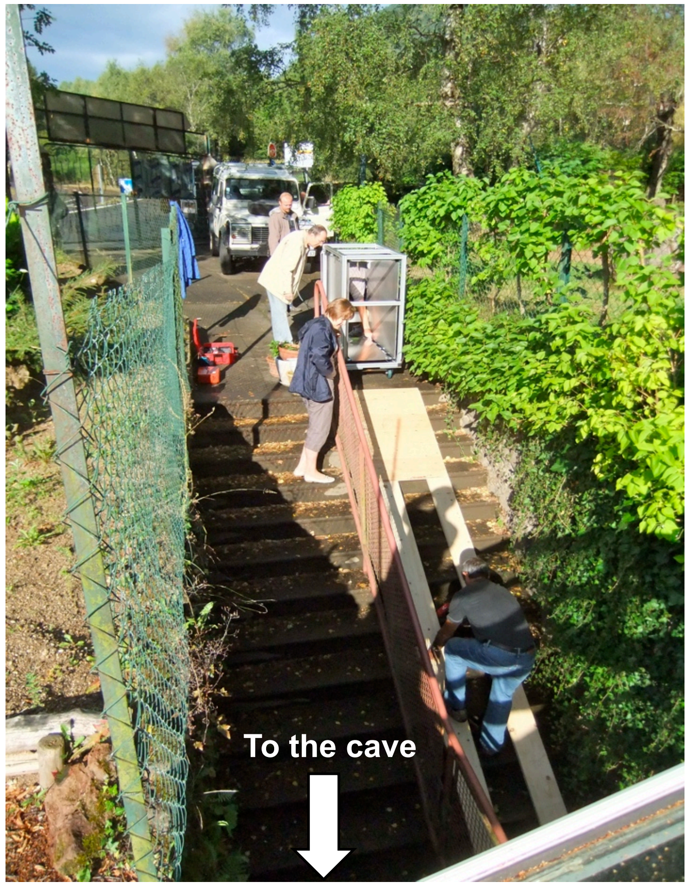


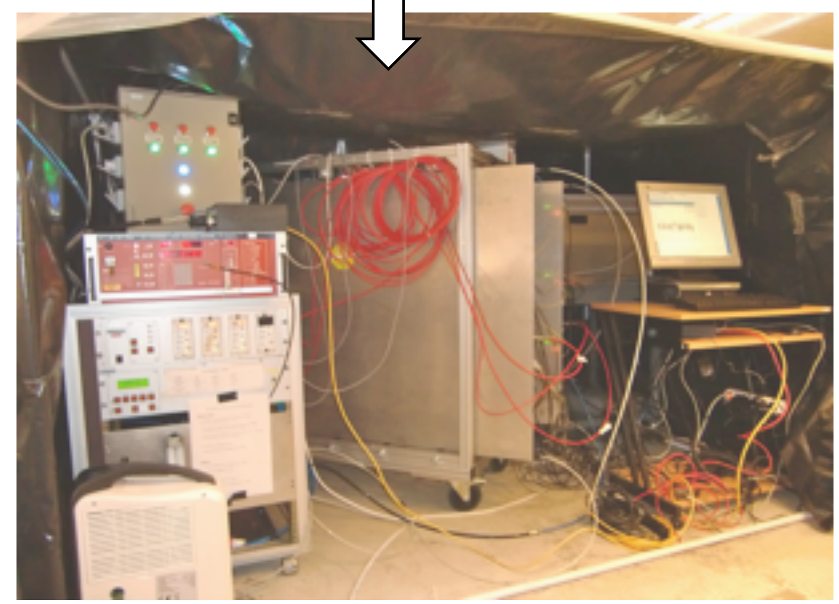
Prototype detector, using GRPCs borrowed from IPNL

The Taillerie campaign

Jan-July 2011

Detector installation at La Taillerie





Setup of the detector :

- 3 plans of 1m^2 x 1m^2 x 0.16 m^2 or 1 m^2.
- Spacing : 0.5m (Jan-May) or 1m (May-July).

Detector in an artificial cave, shielded partially by ~60cm concrete :
➥ Should be visible in the data ...

Alignment performed in collaboration with ESGT Le Mans.
➥ Obtained accuracy on the absolute position : better than 5 mm.

The Col de Ceyssat campaign

Feb-Mar 2012

Setup at Col de Ceyssat

Setup of the detector :

- 4 plans of $1m^2$ x $1m^2$ x $1m^2$ x $0.66\ m^2$.
- Spacing : 1m.

Detector partially shielded by buildings around.

Absolute alignment more difficult due to the detector being in a small room with little openings.

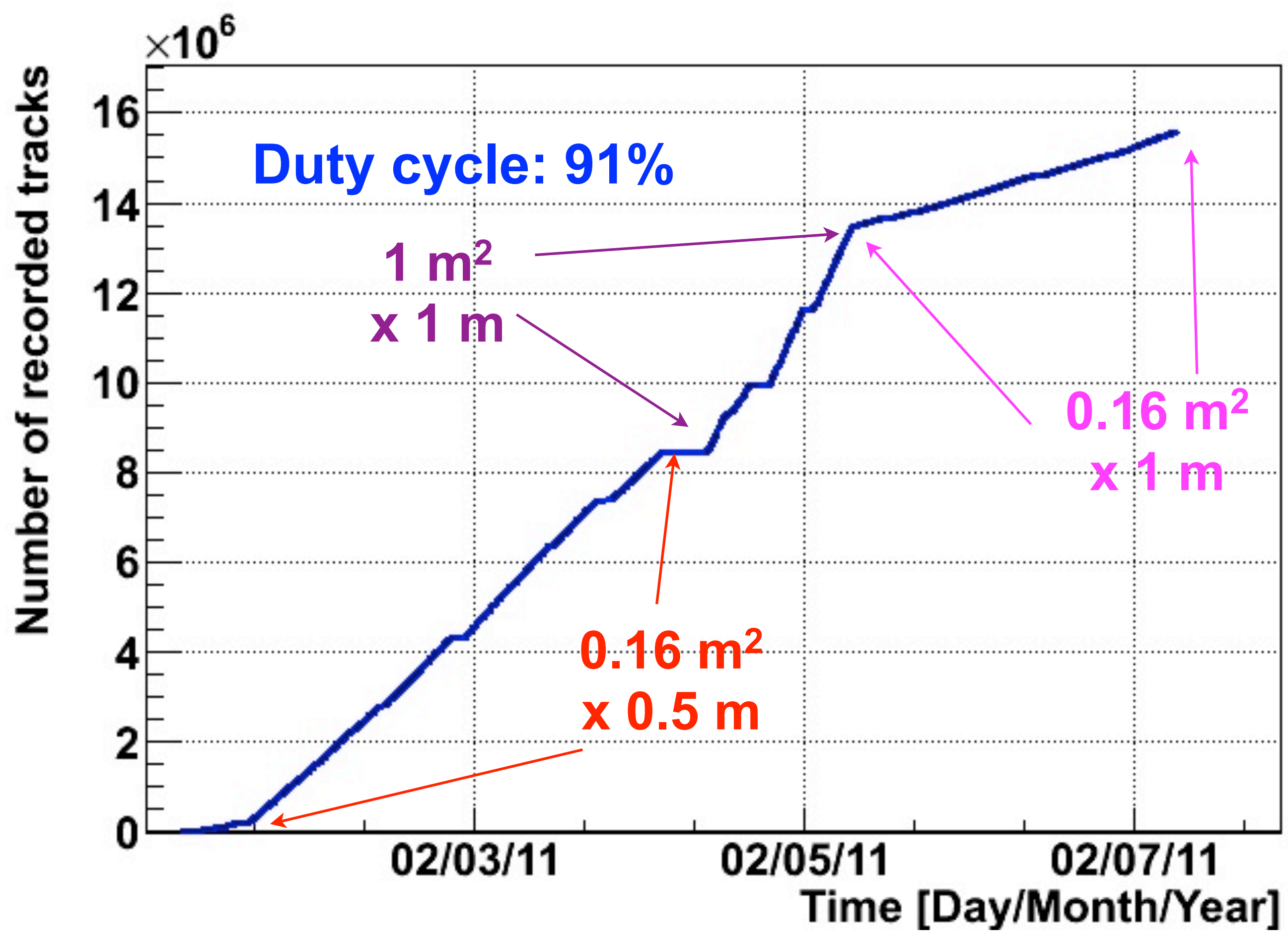
➥ Obtained accuracy : ~10 mm.

Network :

- La Taillerie : using wifi antenna, relayed by the Puy-de-Dôme.
- Col de Ceyssat : “regular” Internet Service Provider.

17 M μ candidates (w/o any selection).

Thanks to 2 x 8h daily shifts 7/7 + very dedicated experts.



Remote control and data taking

Network :

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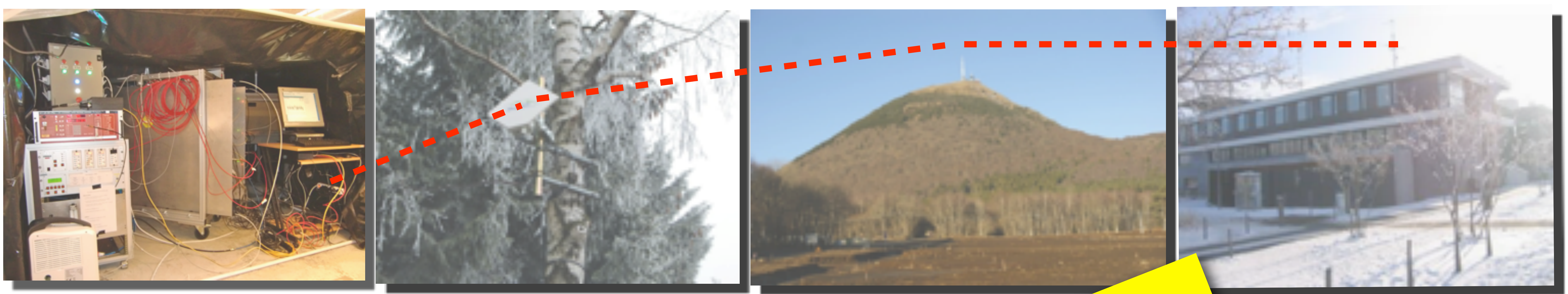

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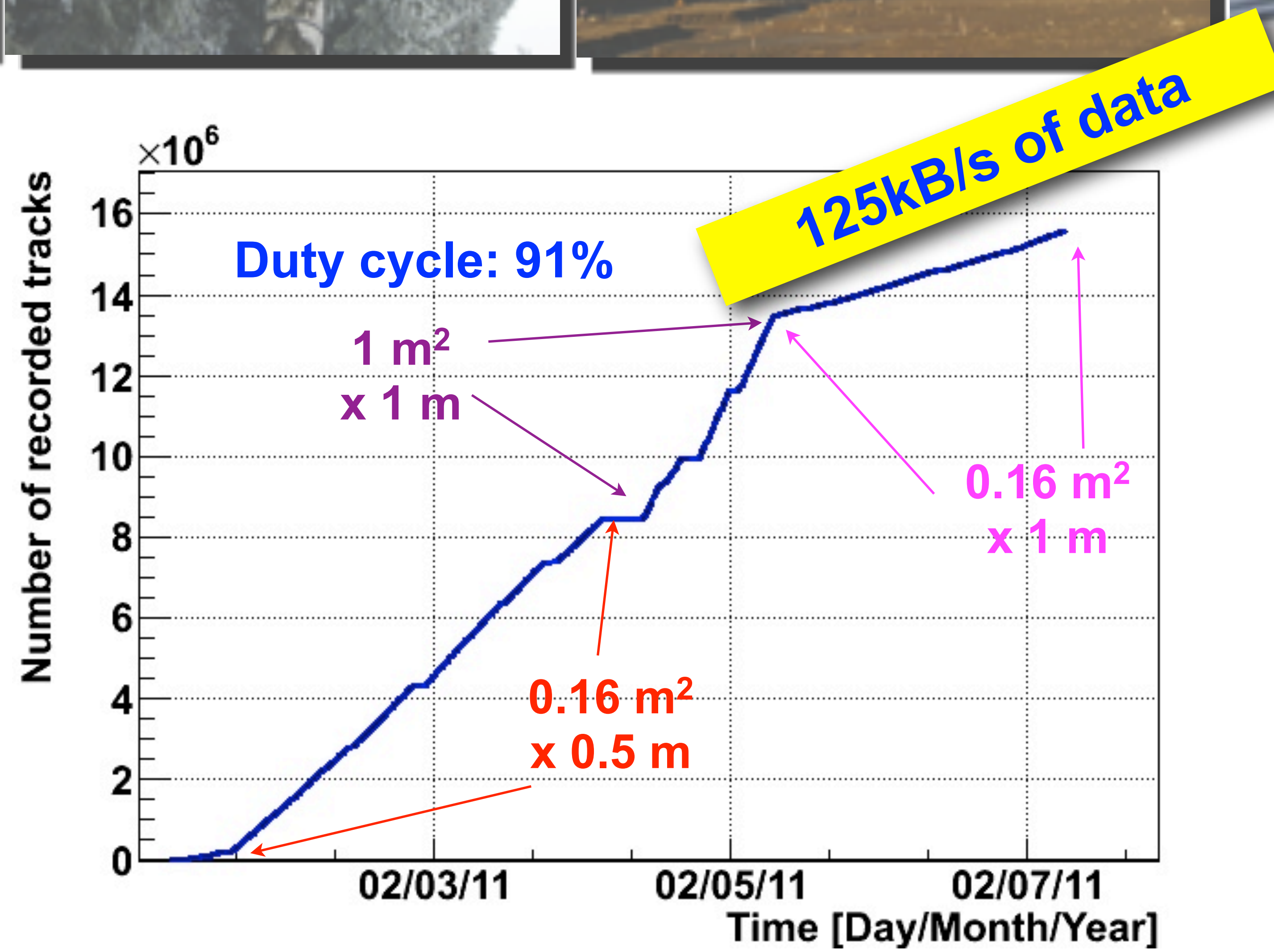
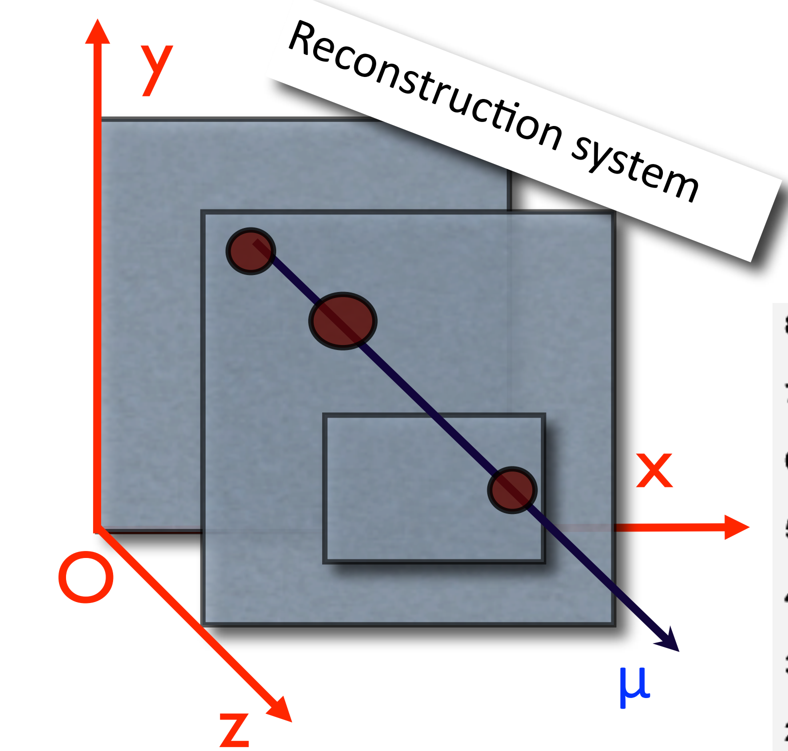


Track Fit and Chambers Inter-alignment

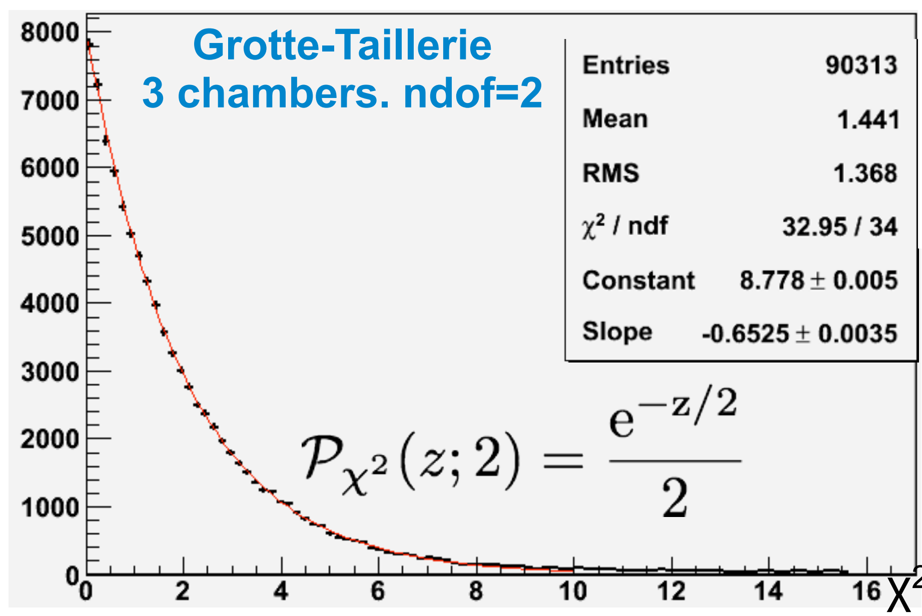


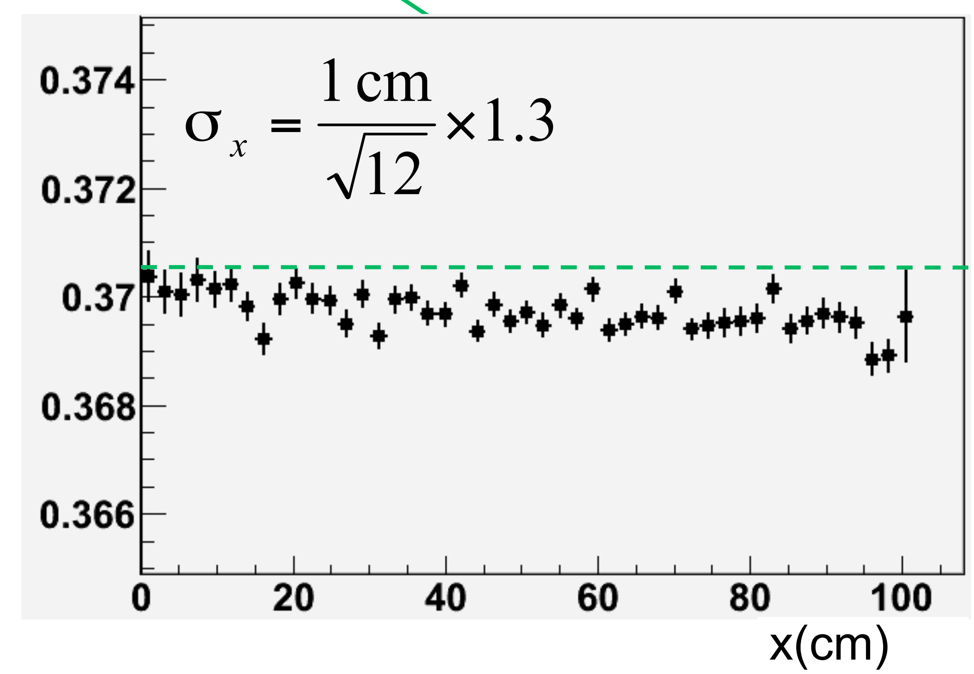
⇒ Detector inter-alignment

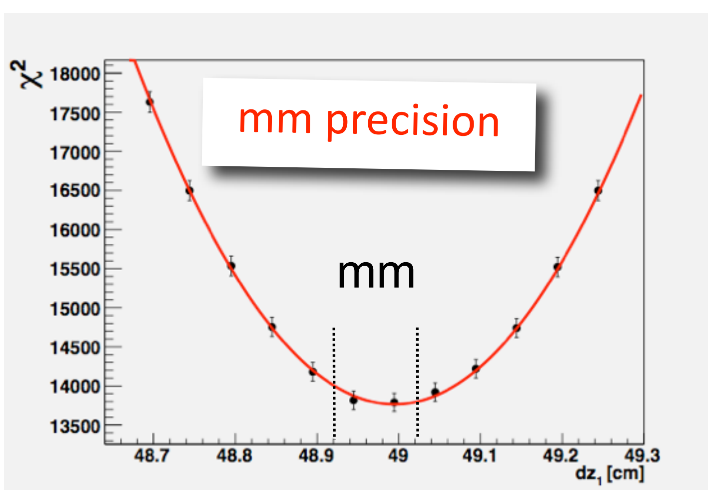
Track reconstruction

Clusterise the coincident hits in the chambers

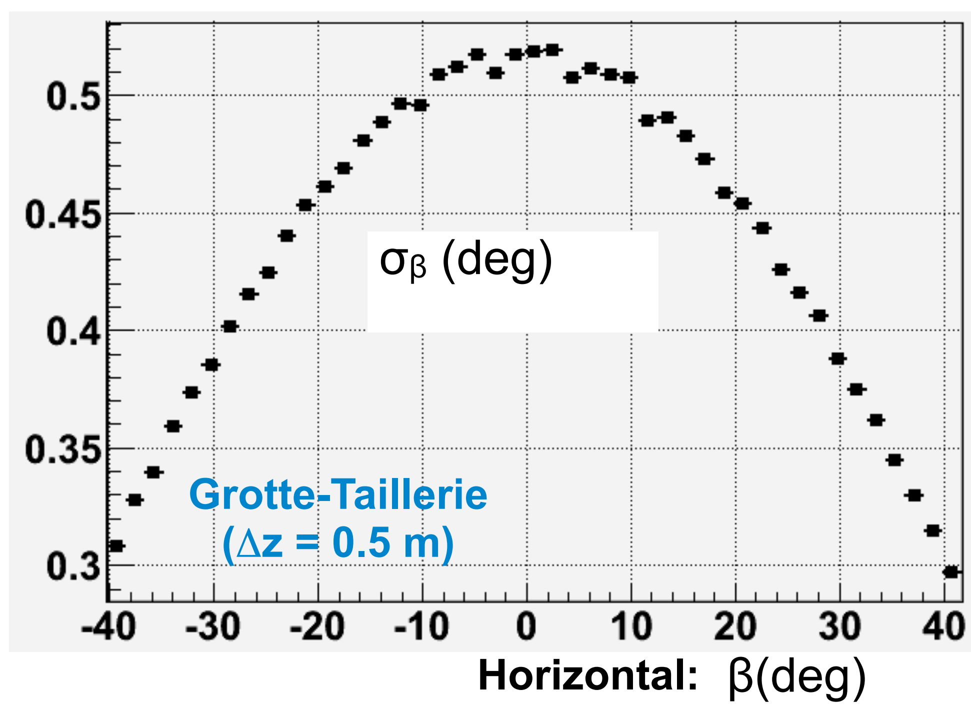
Analytically minimise χ^2 w.r.t. 4 track parameters using the cluster barycentres in each chamber. N.B.: the **average cluster** size is **1.3 cell**.

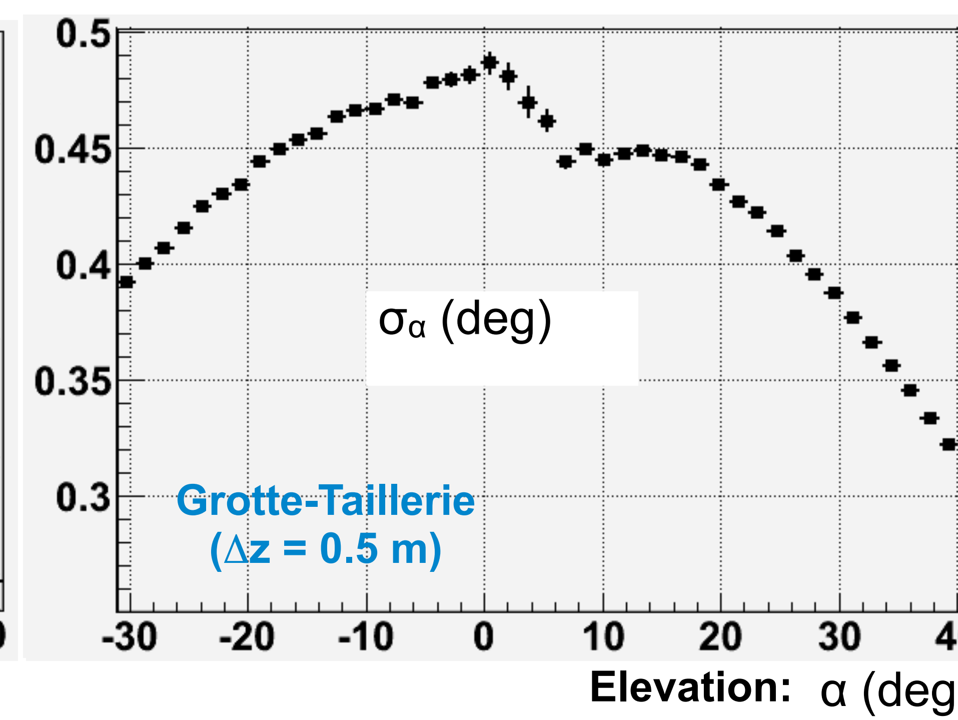






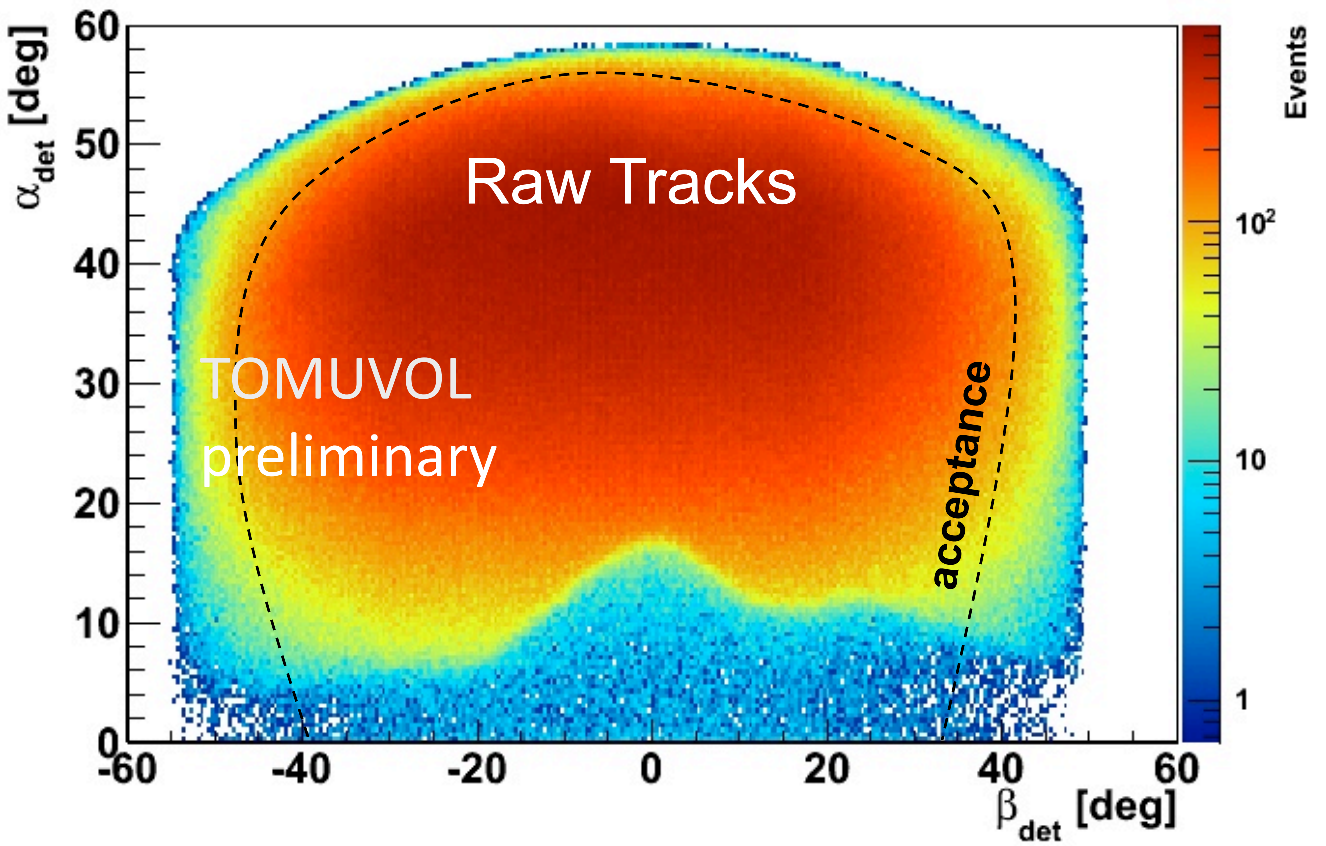
Track χ^2 optimal when detector well aligned

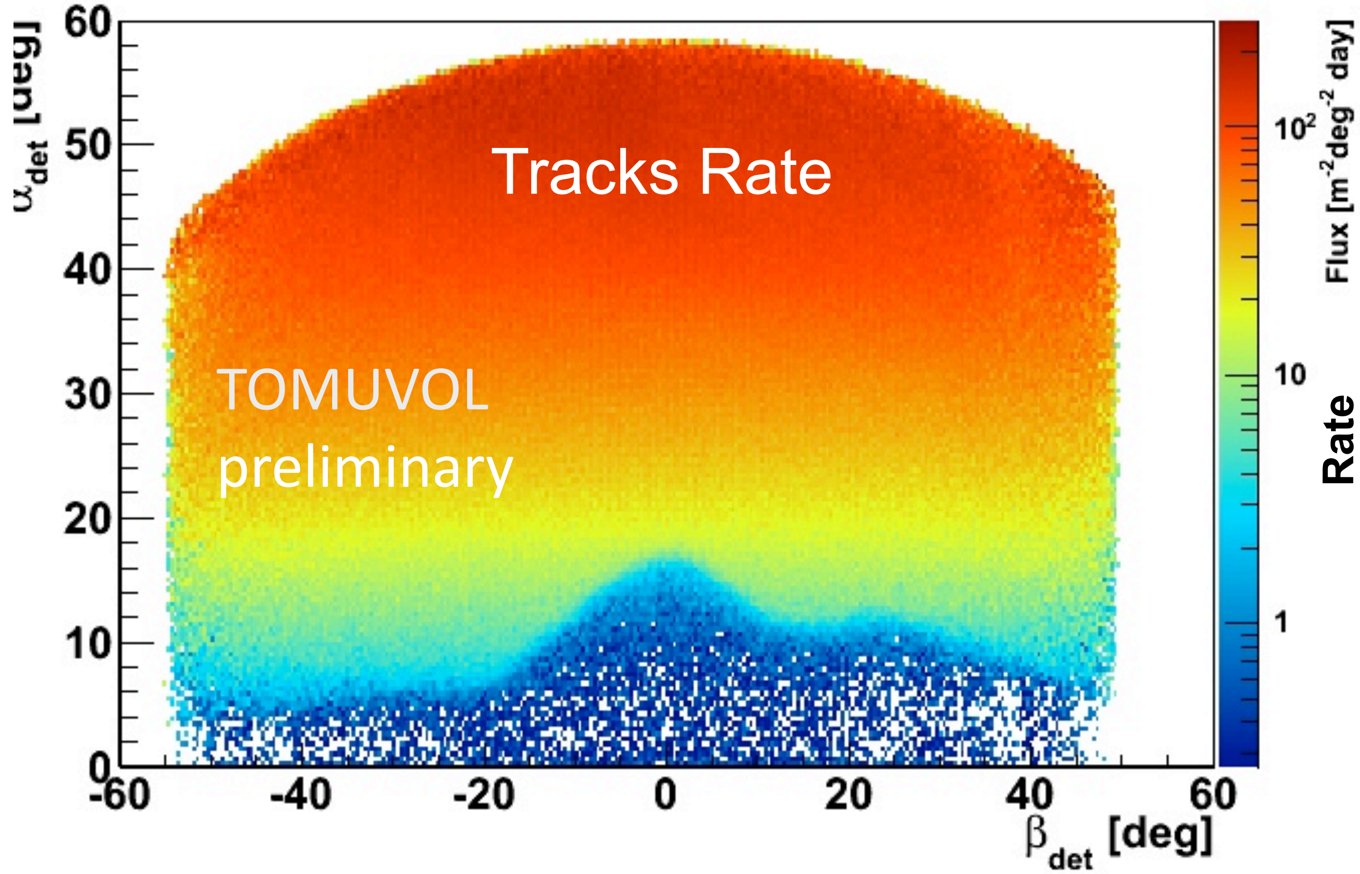




From raw-data to radiographic measurement

Grotte Taillerie: 21/01/2011 - 06/04/2011, 65.8 days of data taking, 0.16 m^2 x 0.5 m

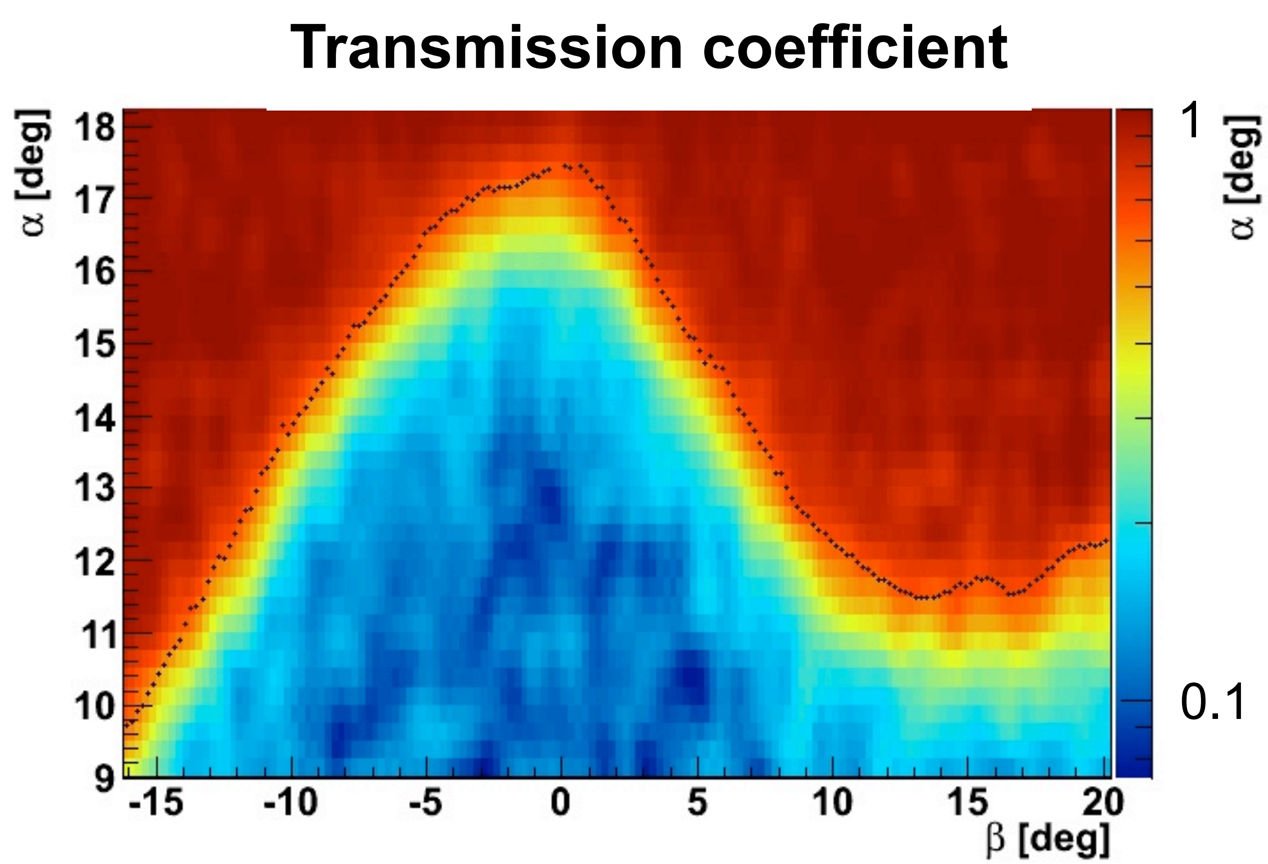


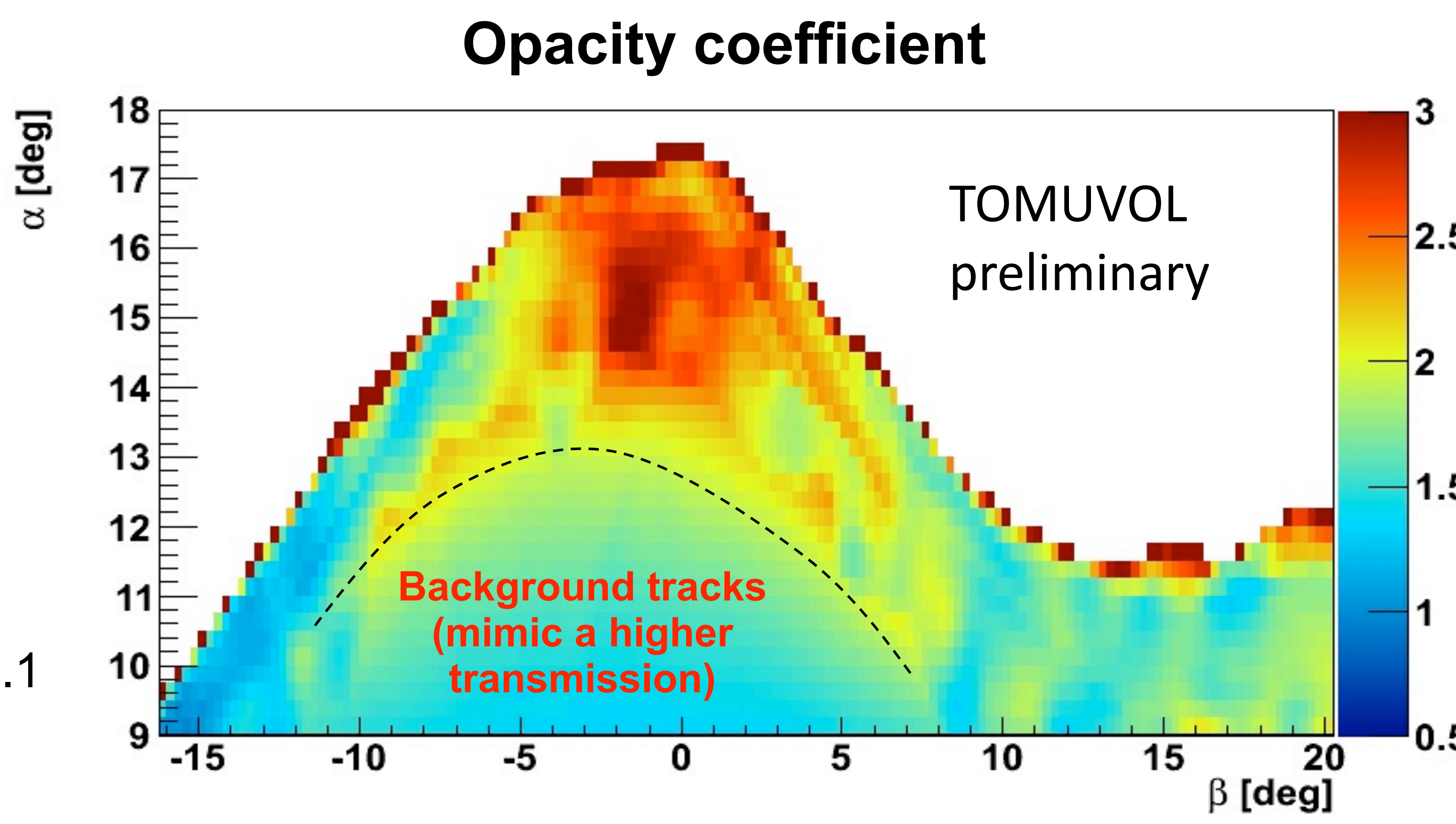


❑ **Preliminary map** by converting the aligned tracks to **a track rate** per m^2 per solid angle and unit time.

- **Correct** for the detector geometrical **acceptance** and dead cells.
- **No correction** from individual chambers detection **efficiency** yet. Additional factor ~ (0.90-0.95)$^{N=3,4}$.
- **No correction** for the **dead time** yet.

Opacity Coefficient





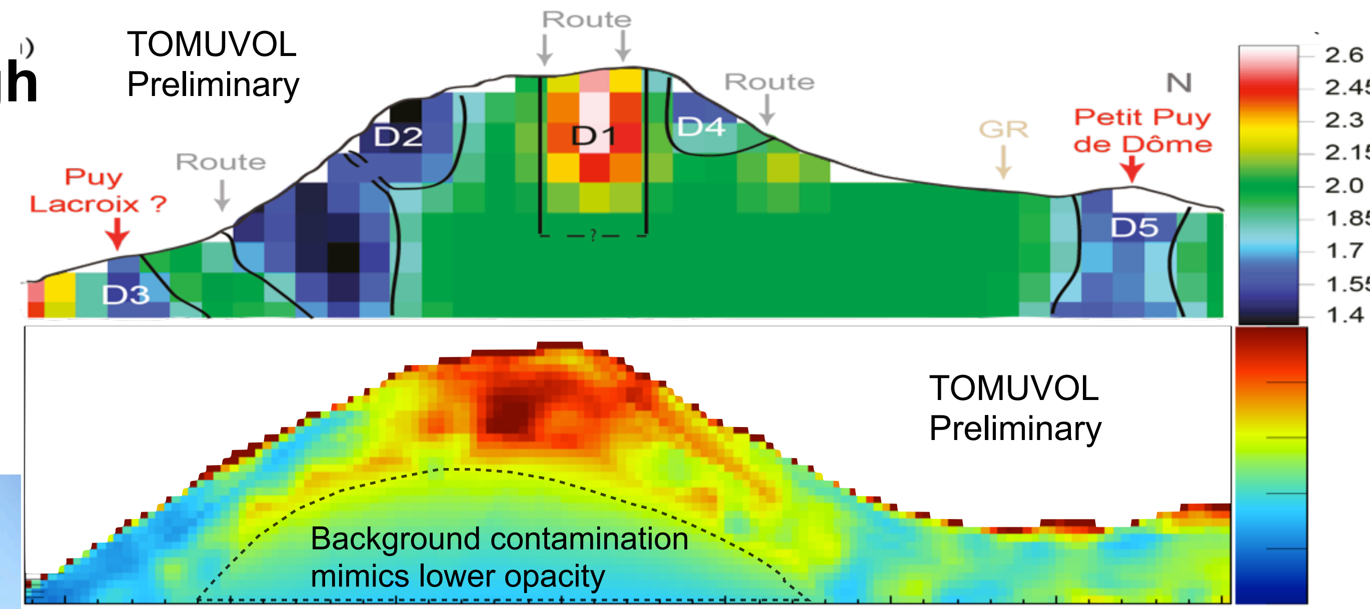
- Opacity coefficient:
  - Compute the transmission through the rocks normalised by the measured open sky flux.
  - Report the **absorption coefficient divided by the rock depth** for each line of sight as given by the topography (LiDAR measurements).

- **Hints** of a structural contrast in the **somital area**. In the **base**, **background tracks mimic a higher transmission**.

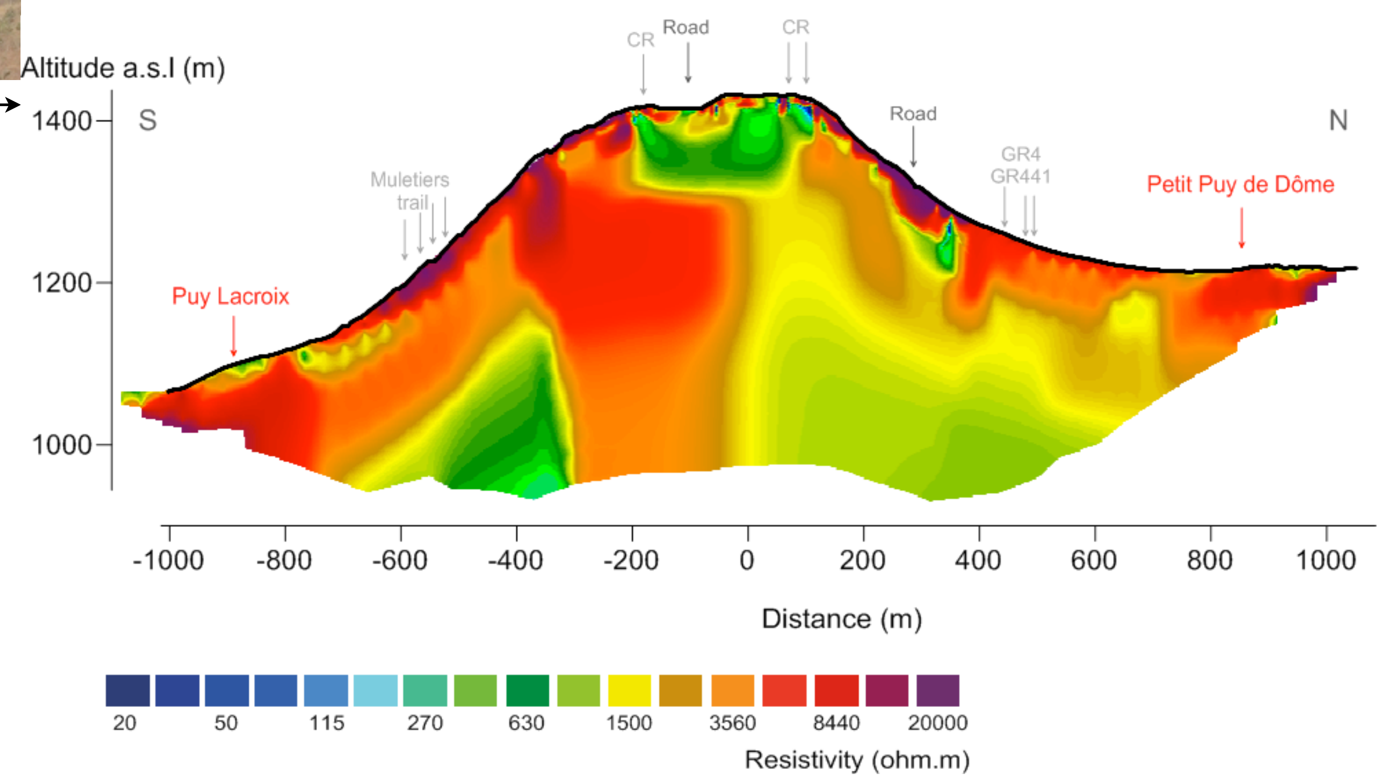
Comparison with geophysical methods

Puy-de-Dôme inner structure, imaged through gravimetric tomography, with atmospheric muons and by electrical restivity :

Density ($10^3 kg/m^3$)



Linear opacity to atmospheric muons



➥ Notable agreement between gravimetric and muonic tomographies on the presence of a dense core near the top of the volcano.

The simulation tools

Another step is needed before converting muon data into density imaging.

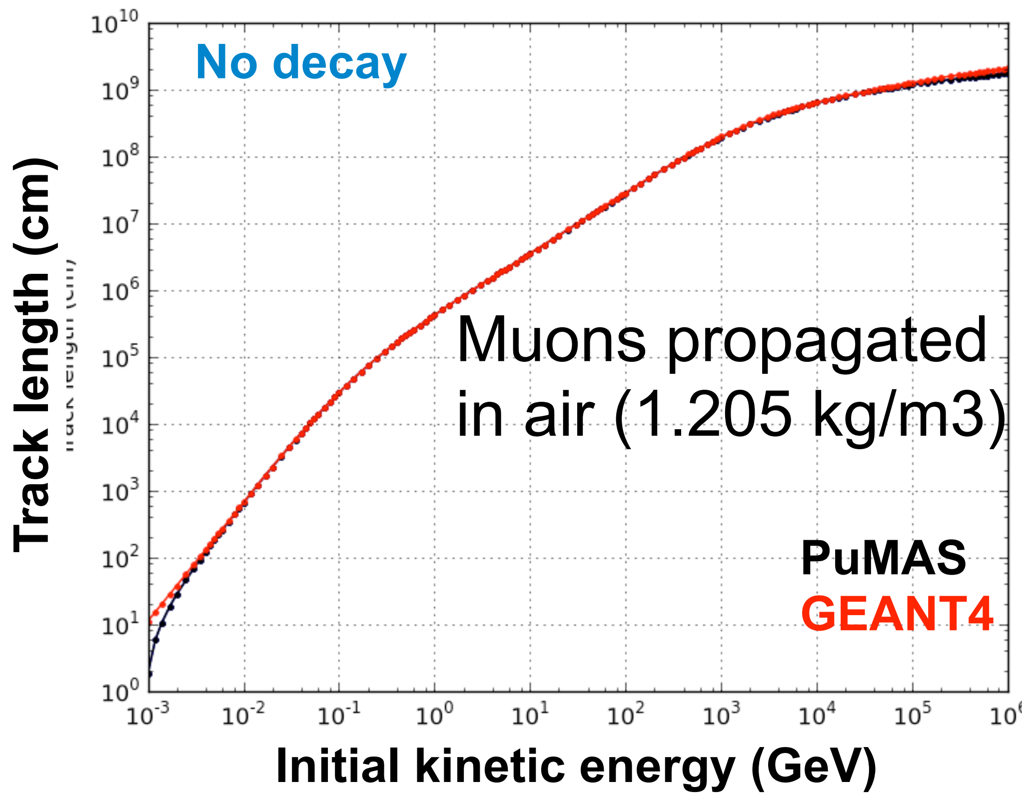
Remember that we need a model for the atmospheric muons flux and their interaction in the volcano.

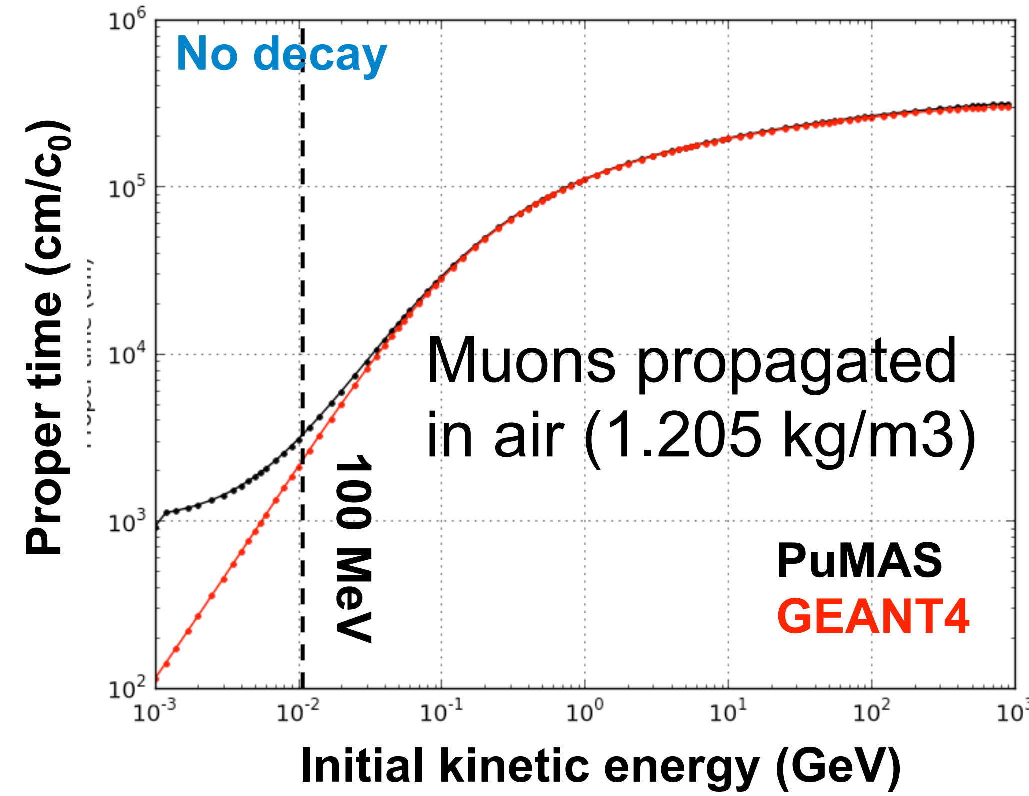
Simulation of the detector also needed to compute detector acceptance, and to estimate background due to fake tracks created by downgoing showers.

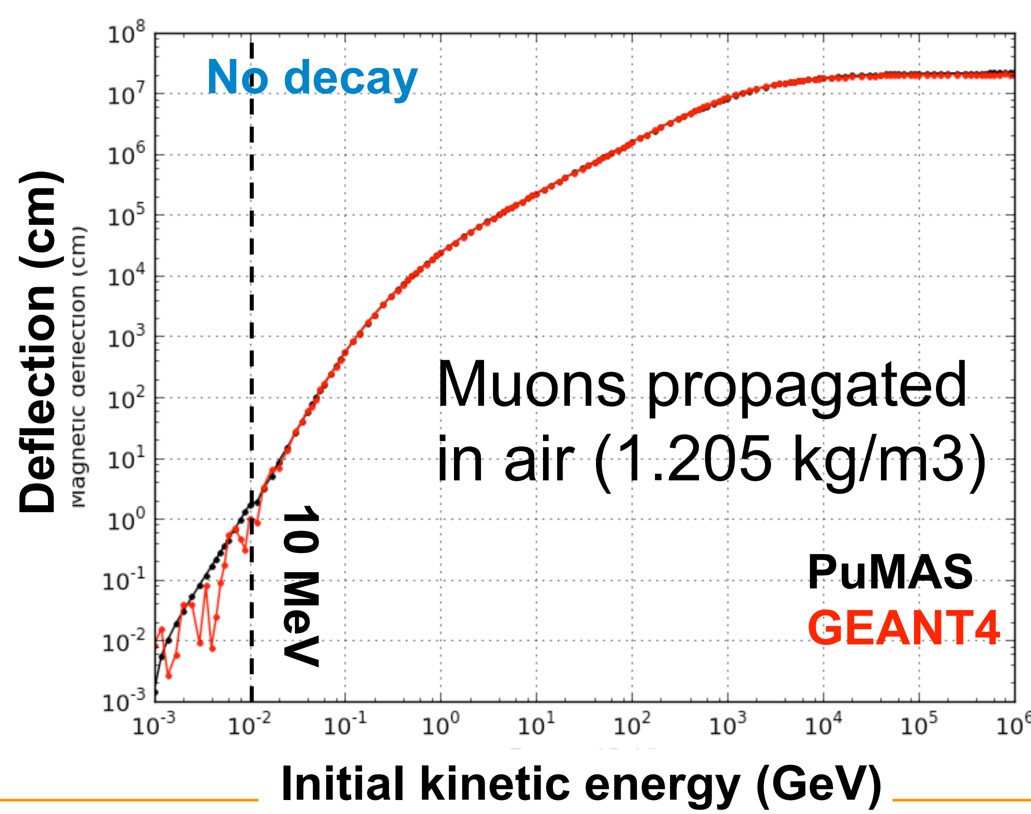
Geant4 simulations of air showers and of the detector are in construction:
- Powerful tool to describe detector and environment geometry.
- Particle interaction with matter well described up to ~TeV.

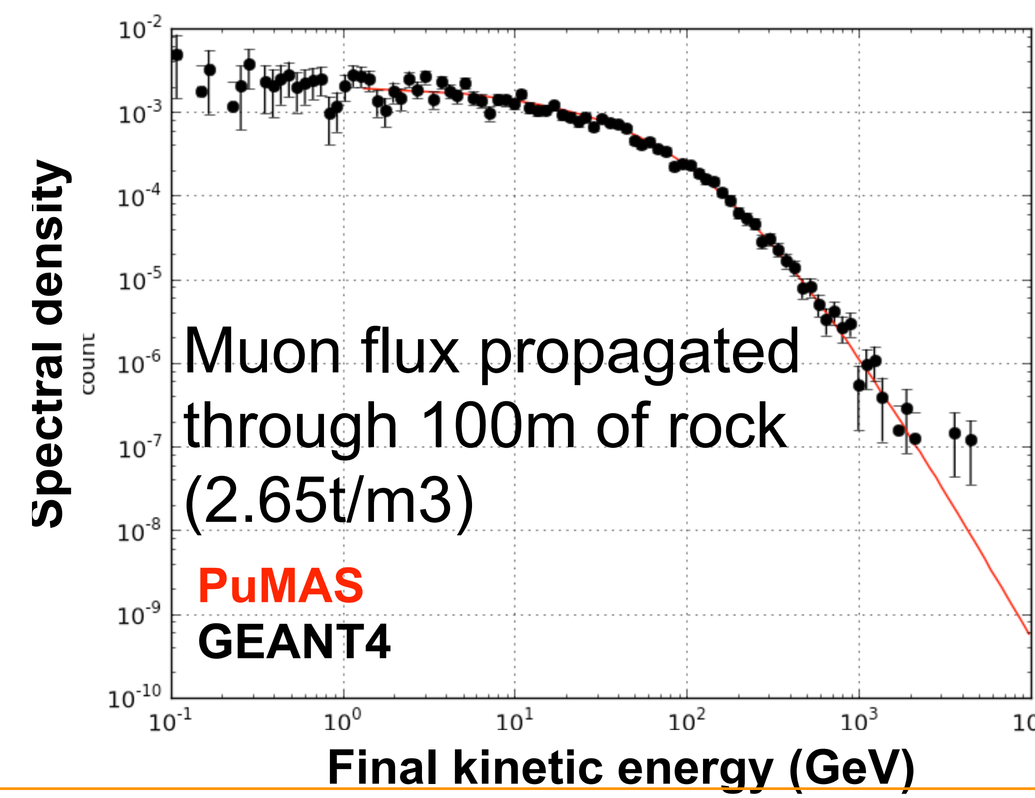
Custom program : PuMAS, using cosmic muon flux measurements and semi analytical formulas for muon propagation also in development:
- Much faster then a Monte-Carlo approach.
- Deterministic
- Allows cross checking the Geant results.

Comparison Geant4/PuMAS

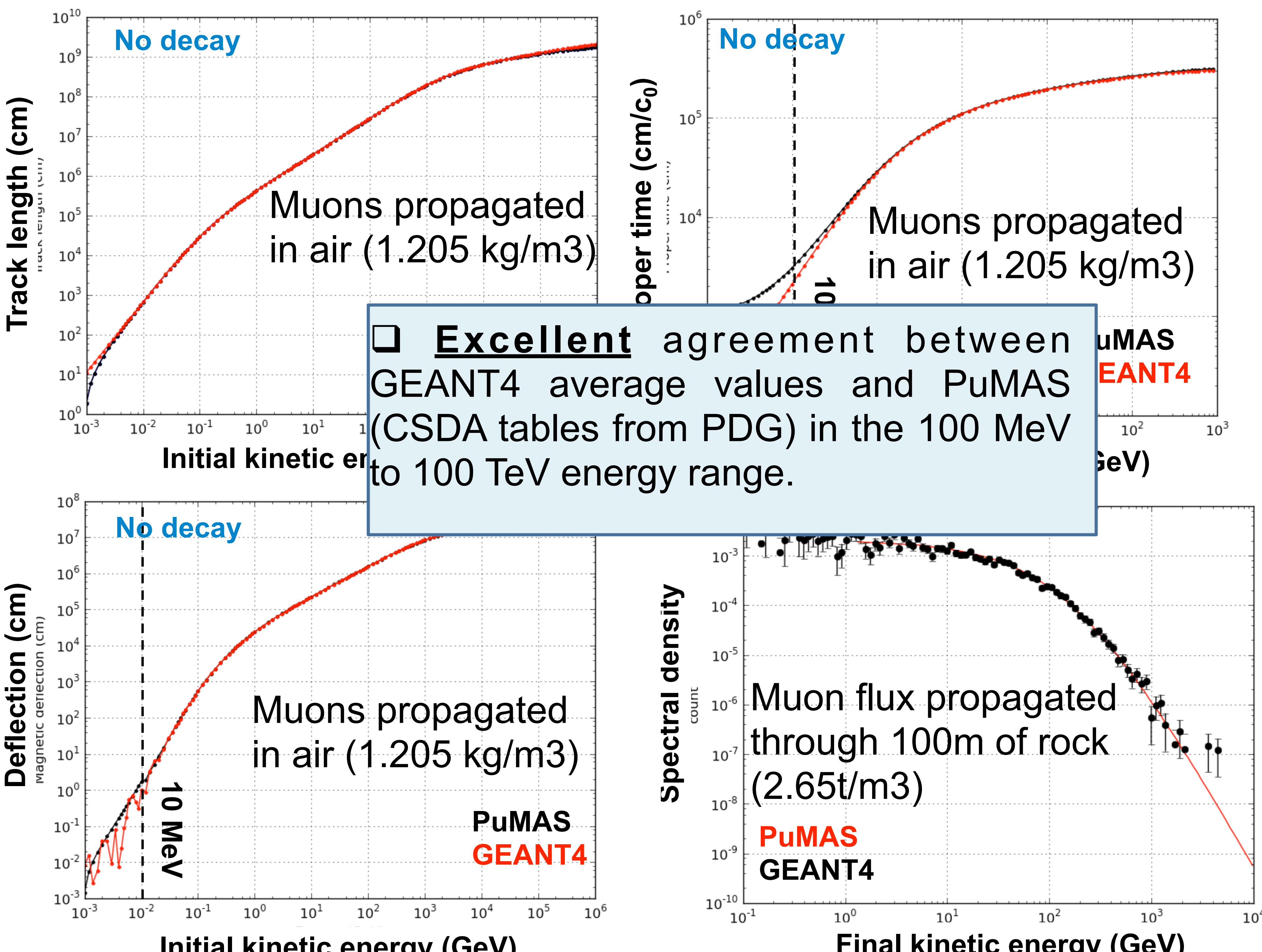








Comparison Geant4/PuMAS



- **Excellent** agreement between GEANT4 average values and PuMAS (CSDA tables from PDG) in the 100 MeV to 100 TeV energy range.

Present day situation – Near future expectations

First measurements on the Puy-de-Dôme :

- Encouraging results with 17+11M tracks candidate at 2 ~orthogonal positions.
- Preliminary data confirm the potential of the method.
- Borrowed detector working as prototype allowed us to define a good muon telescope (slightly optimised version of CALICE GRPC chambers for field deployment).

Building the TOMUVOL detector -> First data taking scheduled in June 2013:

- With a better data quality and the knowledge acquired from preliminary measurement campaigns, a very accurate image of the Puy-de-Dôme can be expected within 1 year.
- Until then, need to work on the simulations and evaluate model-dependent systematics.

Tomographic campaign on Puy de Dôme during summer 2013:

- 2 x 1m2 detectors : MURAY (scintillators+SiPMs, NAPLES) + TOMUVOL with additional Bristol chambers.
- expect very interesting results in the near future!

Longer term perspectives :

- Design and construction of an autonomous and portable radiographic device.
- Validation of the detector on an active site (and a much less “cosy” environment).