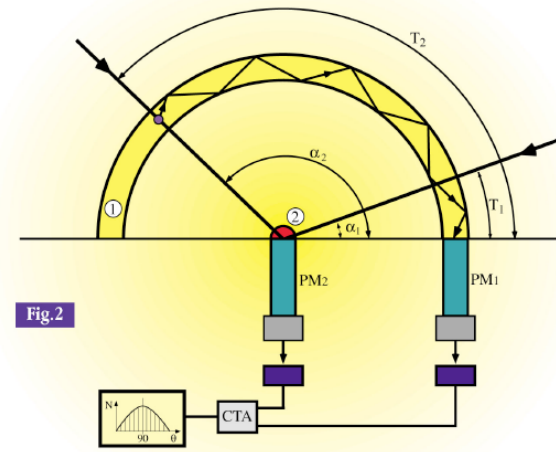


Three French educational projects based on cosmic muon detection

15-16 February 2017 Centro Fermi, Roma
Workshop high school cosmic ray experiments

Nicolas Arnaud (narnaud@lal.in2p3.fr)

Laboratoire de l'Accélérateur Linéaire (CNRS/IN2P3 & Université Paris-Sud)
European Gravitational Observatory (CNRS & INFN Consortium)





Sciences à l'École



« Cosmos à l'École »

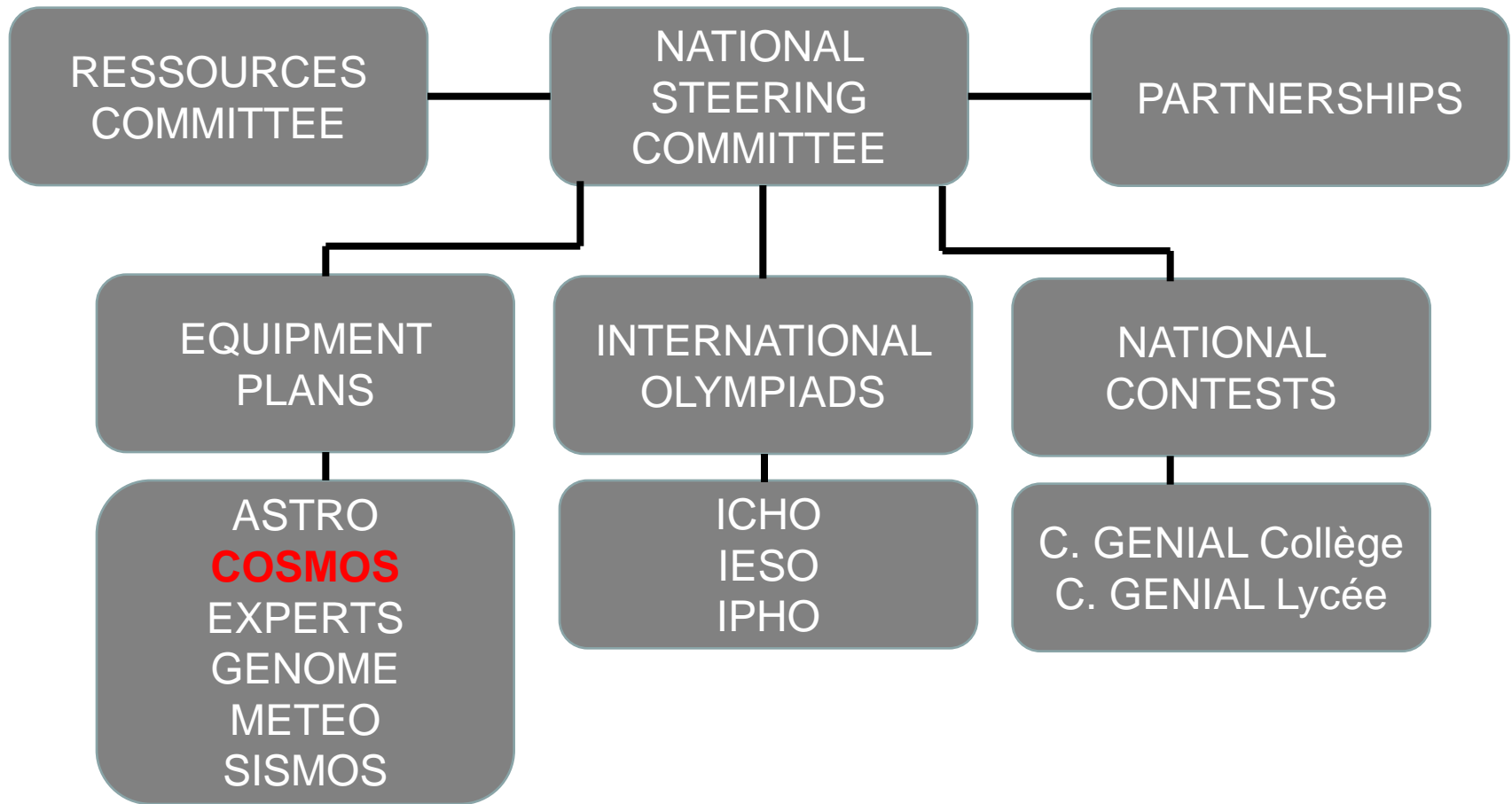
Claire Bonnoit-Chevalier (claire.bonnoit@obspm.fr)

Nicolas Arnaud



Sciences à l'École

- « Sciences à l'École » is a project from the French Education ministry which is promoting Science in high schools and higher education
- Founded in 2004
- Located in Observatoire de Paris





ministère
éducation
nationale



COSMOS à l'École

COSMOS à l'École



- 46 educational institutions sharing 30 muon detectors
- From 25 regional education authorities (/30)
- 1700 pupils
- Once they have been trained, teachers train colleagues from their high school or from the local area (during dedicated teacher training sessions)
- Teachers get a « Cosmodétecteur» for 3 years (renewable) and usually make it circulate in their school and locally



SCIENTIFIC COMMITTEE

| | Equipment | Education |
|-----------------------|--|---|
| Preparation | <p>Designed and built by José Busto and his team at the CNRS/IN2P3 « Centre de Physique des Particules de Marseille » (CPPM)</p> | <ul style="list-style-type: none"> • Pedagogical resources: elaboration and collection Creation of a website, of an exercise book, • Calls to get a cosmodetector (2008, 2014, 2017) • Selection of the teacher teams |
| Implementation | <ul style="list-style-type: none"> • Preparation and delivery of the detector in the schools • Teacher network | <ul style="list-style-type: none"> • 1 week of training period in CERN for teachers (French Teacher Programme) • 1 week of training period in CPPM for teachers • Mutualisation of knowledge <i>through a dedicated website:</i> http://www.sciencesalecole.org/plan-cosmos-a-lecole-presentation/ • Advices from CNRS/IN2P3 physicists who act as mentors |



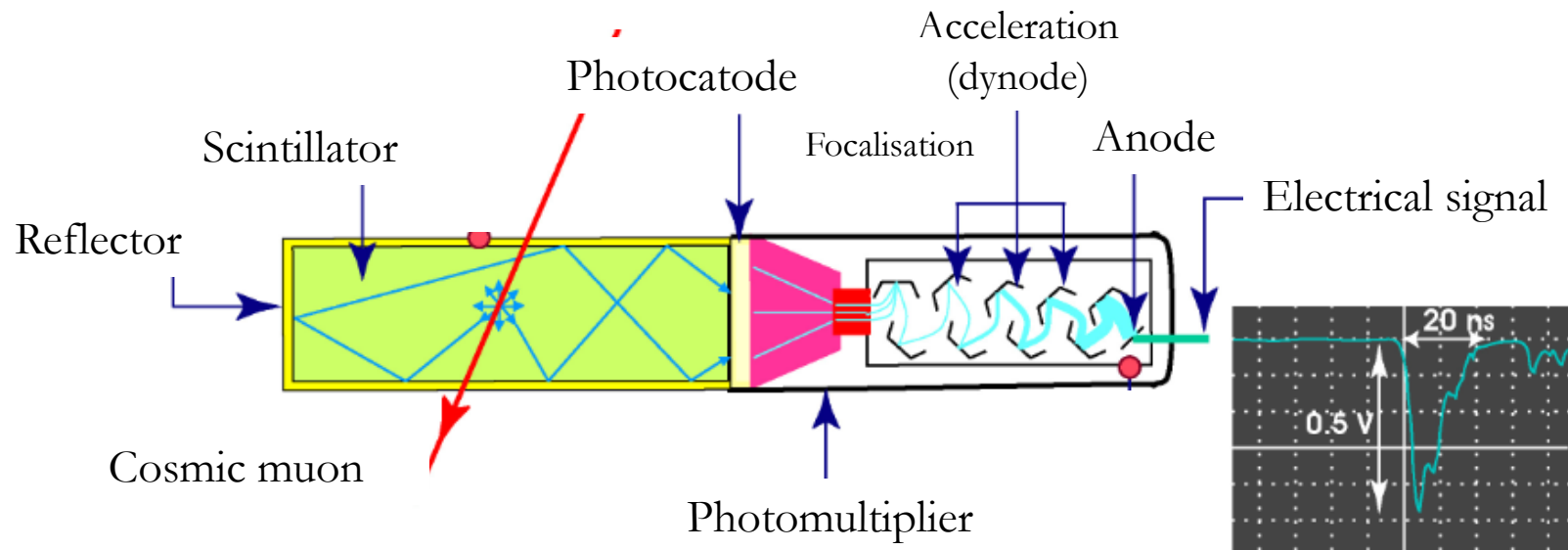
The cosmodetector apparatus

- 3 scintillator plates with a photomultiplier (PM) on top
- A DAQ system to trigger on 2-fold or 3-fold coincidences to remove background
- A Labview interface to steer the detector, monitor data taking and record data (ascii format, no GPS/accurate timing information)
- A movable « cosmic wheel » to look at the cosmic muon zenithal distribution

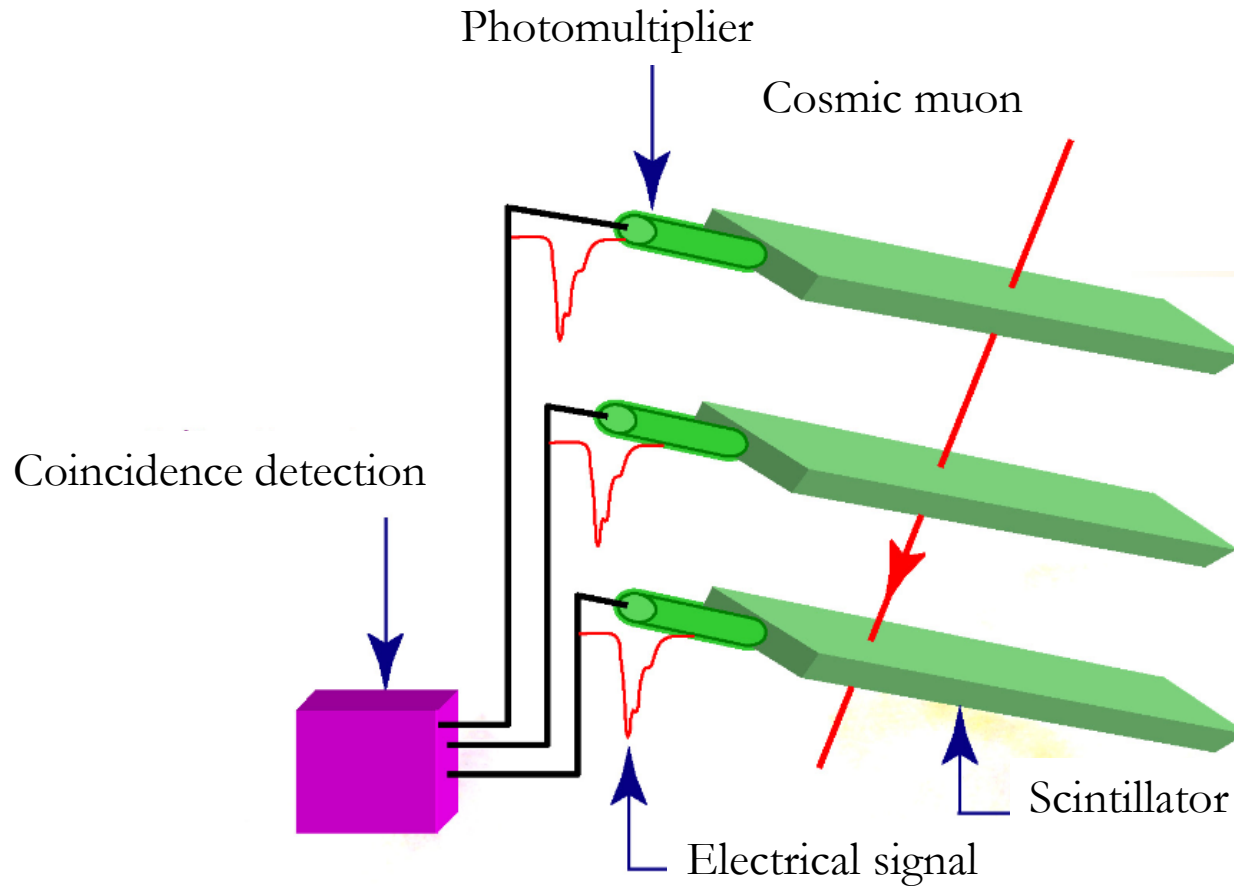


Laptop included – unit price: ~6-7 k€

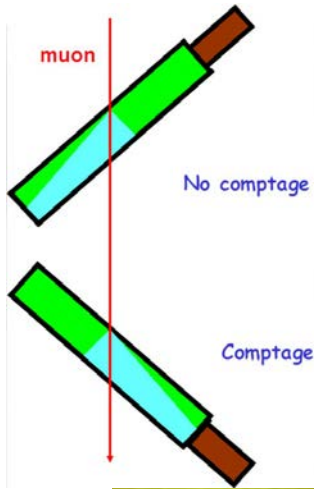
Muon detection



Muon detection



Additional detector elements



A Cherenkov radiator

Muons come from above!



**A scintillator to measure
the muon lifetime**

A muon enters the scintillator
(1st signal) and stops.

An electron is emitted when the
muon decays (2nd signal)

Histogram: $\Delta t = t_2 - t_1$

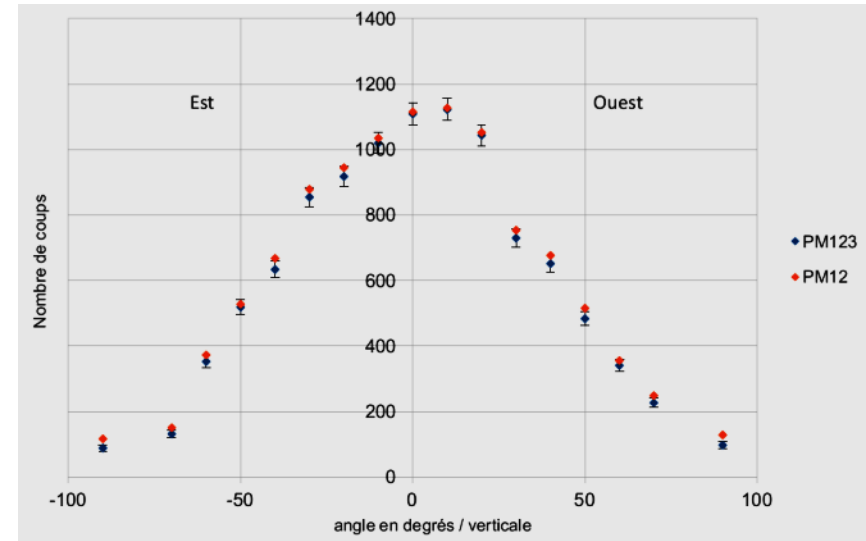
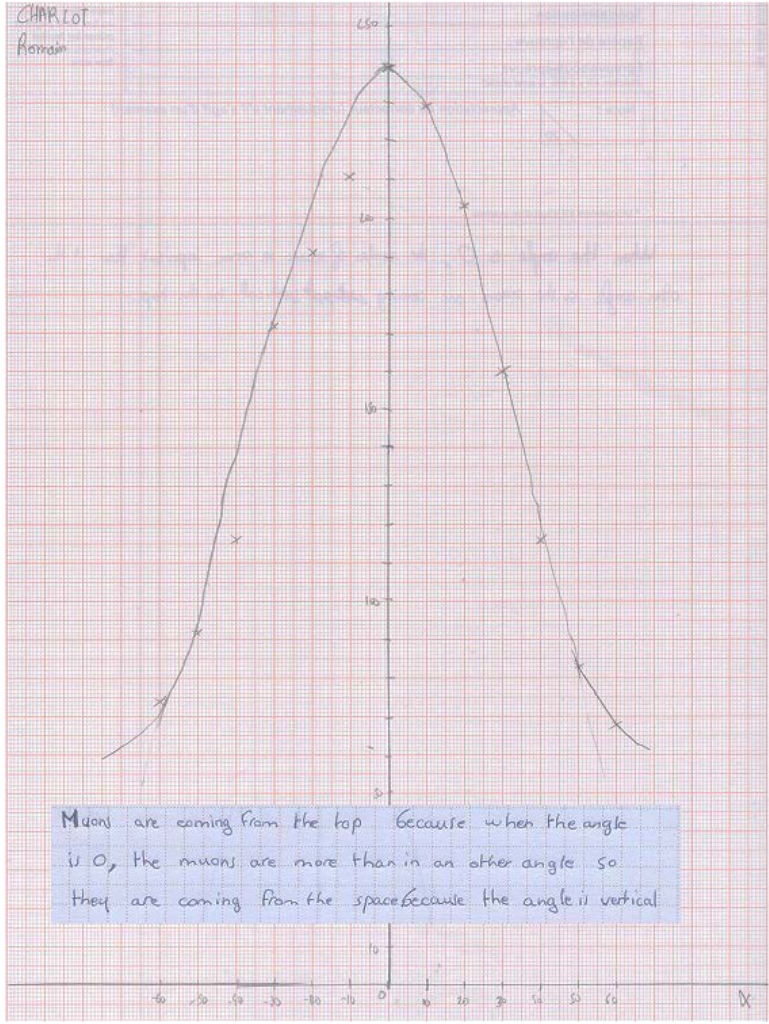
Educational activities based on the « Cosmodécteur »

- Measure the angular distribution of muons
- Measure the muon lifetime
- Highlight the radioactivity of some materials (^{40}K , etc.)
- Use the Cherenkov effect to find the muon direction
- Study particle showers
- Study how matter interacts with particles

+ A hands-on experience

- Calibration
- Discrimination
- Coincidence

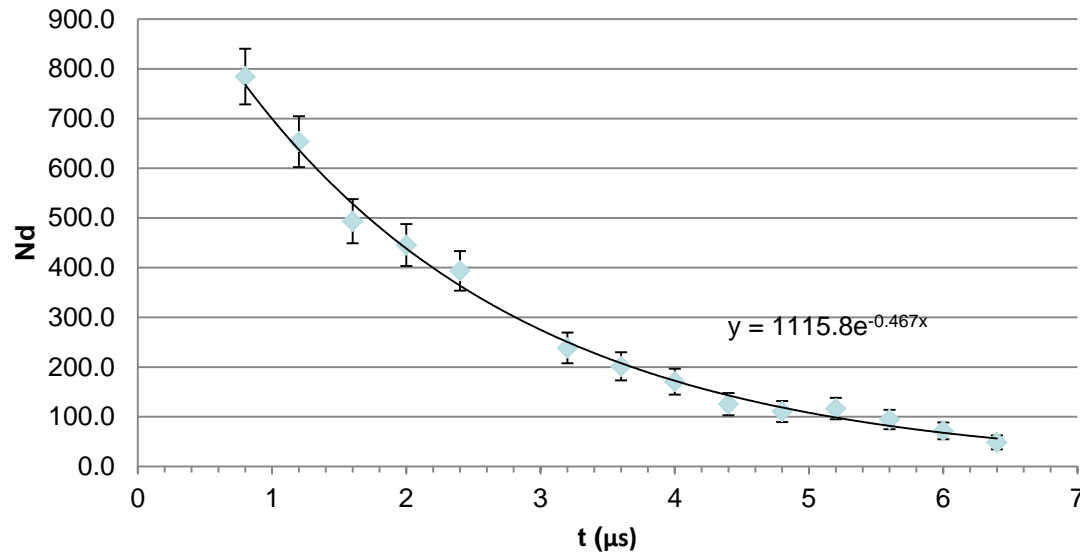




Raw muon angular distribution
Asymetry due to nearby buildings



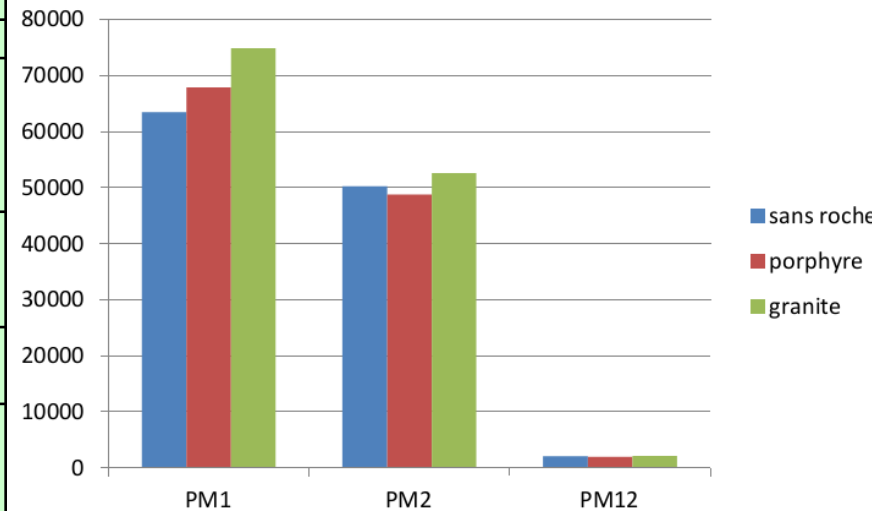
Lifetime measurements



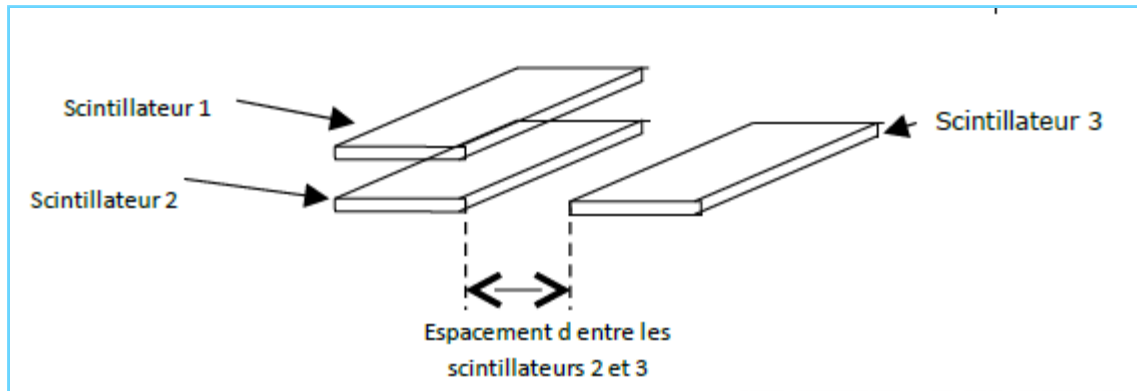
Fitted lifetime: $\sim 2.1 \mu\text{s}$ (PDG: $2.2 \mu\text{s}$)



| Matériau | Conditions | PM1 seul Nbre de détections | Détections PM1+PM2 en coïncidence |
|--|---|-----------------------------------|---|
| Rien | | 1898 | 657 |
| Une roche du Limousin ramenée de Bessines (?) | Posée sur PM1 sans rien | 14 989 | 716 |
| Idem | Posée sur 5 écrans de plomb du CRAB | 8619 | 702 |
| Potasse solide | Dans un bécher posé sur PM1 | 1970 | 648 |
| Echantillon de Césium 131 du CRAB | Posé sur PM1 sans rien | 2078 | 707 |
| 2 Roches de granit, empruntées au labo de SVT, origine inconnue. | Posées sur PM1 sans rien, l'une après l'autre (pas en même temps) | 1943 | 706 |
| | | 1849 | 627 |



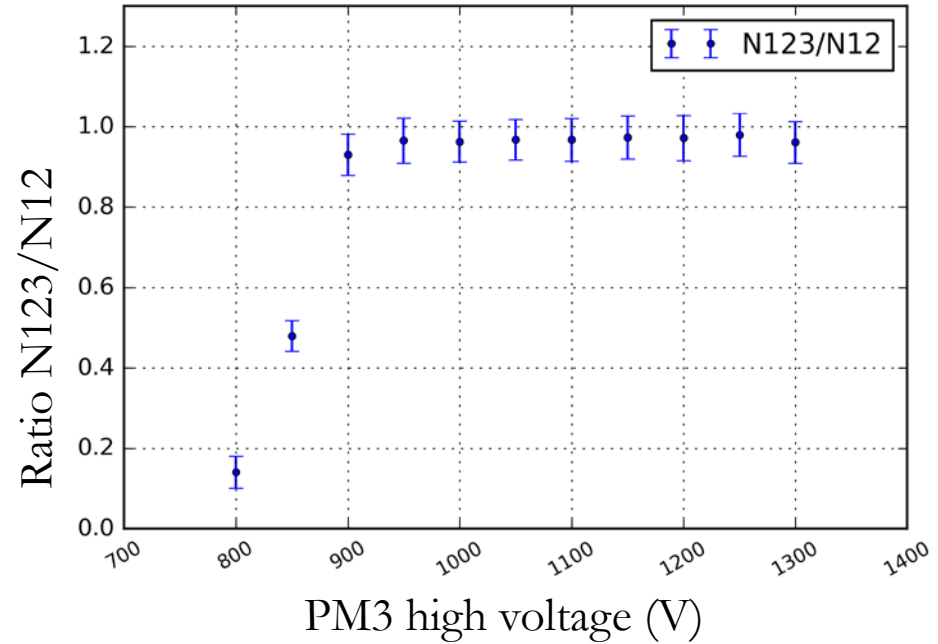
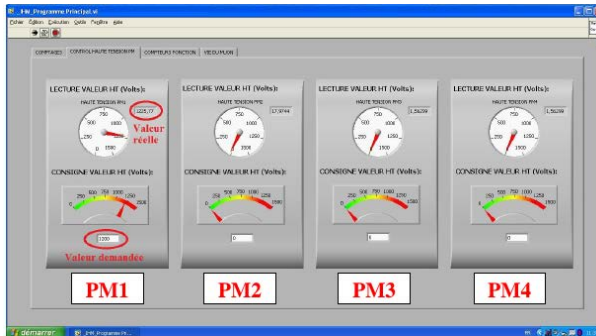
Rock radioactivity



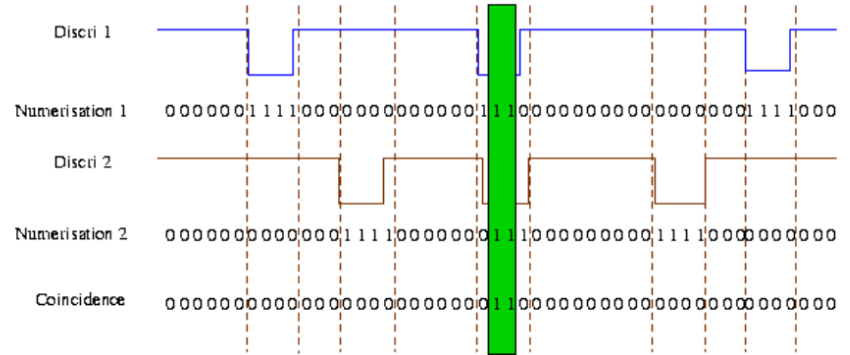
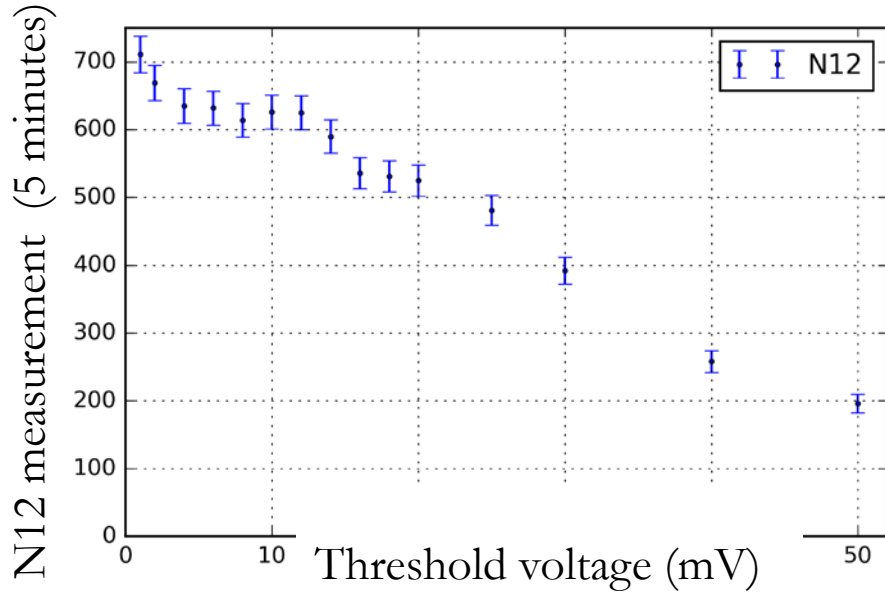
Particle showers

Calibration

Configuration



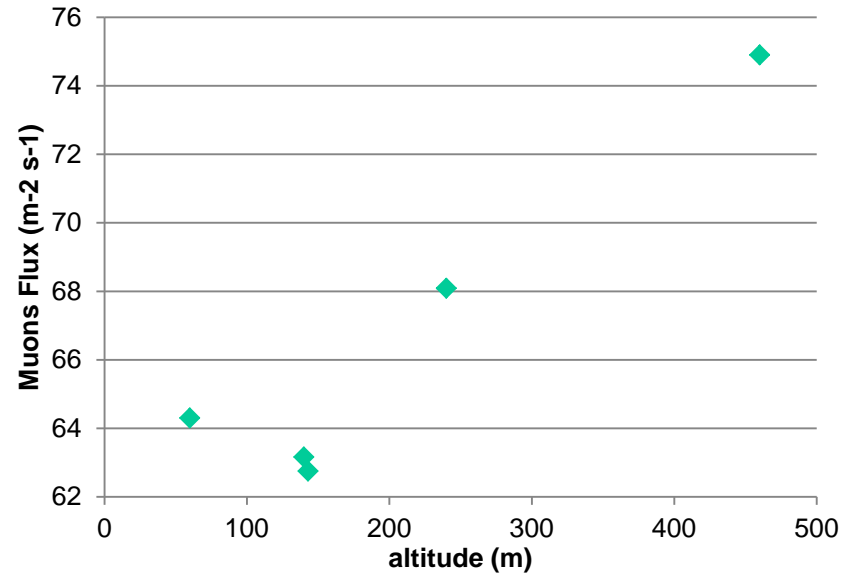
Discrimination



Configuration



Network measurements



| altitude (m) | Muons Flux (m ⁻² s ⁻¹) | lycee |
|--------------|---|---------------------|
| 143 | 62,75 | Rudloff, Strasbourg |
| 240 | 68,09 | Perrier, Tulle |
| 60 | 64,3 | Einstein, Bagnols |
| 140 | 63,16 | Déodat, Toulouse |
| 460 | 74,9 | Cassin, Tarare |

COSMIX

Benoit Lott & Denis Dumora

CENBG (CNRS/IN2P3 et Université de Bordeaux)

cosmix@cenbg.in2p3.fr

Nicolas Arnaud

The « COSMIX » detector

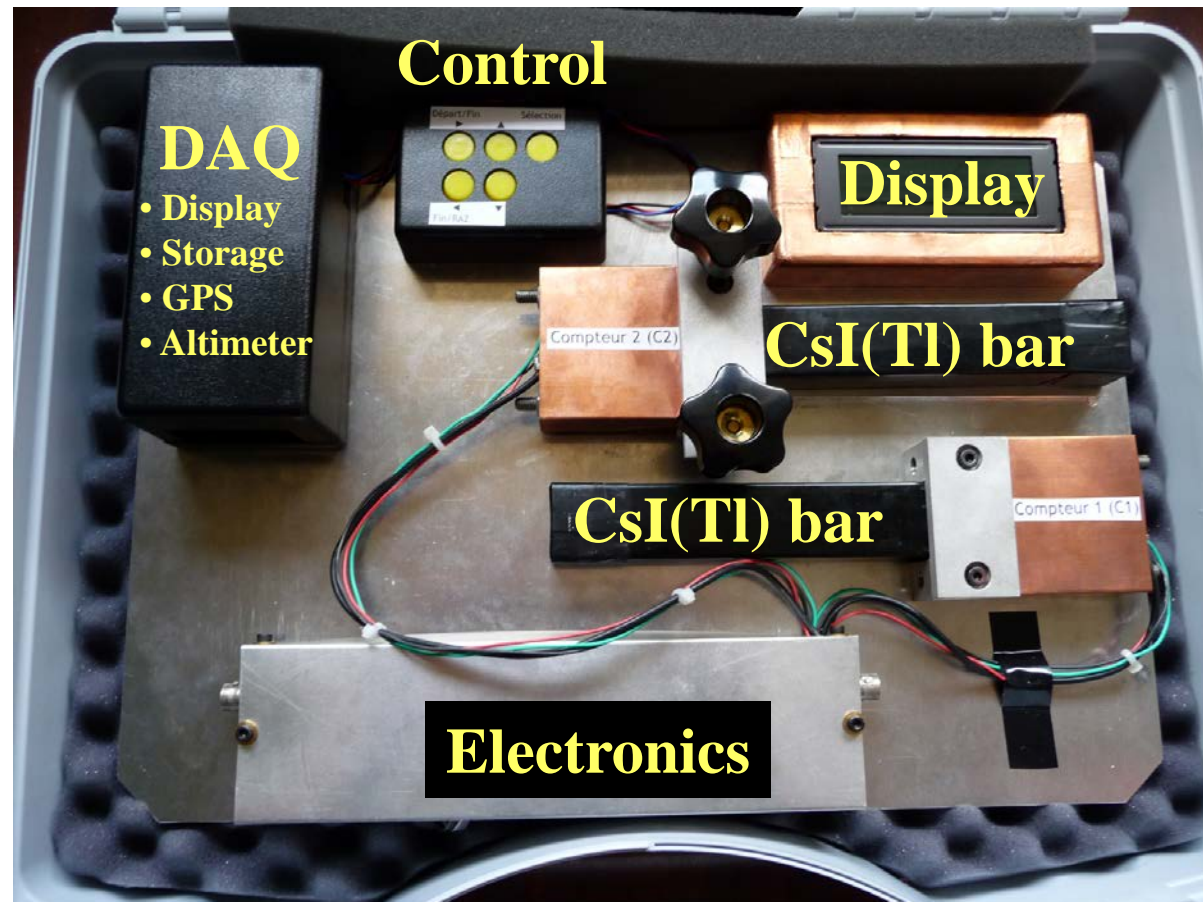
- A portable cosmic muon detector
 - Compact and light
 - Plug-and-play
 - Robust
 - Background-free data
- Developed at a CNRS/IN2P3 lab, the « Centre Etudes Nucléaires de Bordeaux Gradignan », (CENBG) by Benoit Lott and Denis Dumora
- Quick and easy introduction to cosmic rays to audiences which do not have access to a « cosmodétecteur »
- Various applications
 - High schools
 - Outreach talks
 - Museums, laboratory open days, etc.



The « COSMIX » case

- Two $l \times w \times h = 16 \times 3 \times 2 \text{ cm}^3$ CsI(Tl) bars from Amcrys
- Hamamatsu PIN diodes
- Consumption $\sim 300 \text{ mA}$
- **5V power** (e.g. from laptop)
 - 7000 mAh battery for mobile measurements
- **Unit cost $\sim 2 \text{ k€}$**
 - Half for the scintillator bars alone

→ First detectors built using Fermi-GLAST spares
- **Case**
 - **Weight $< 4 \text{ kg}$**
 - **Dimensions: $\sim 44 \times 36 \times 12 \text{ cm}^3$**



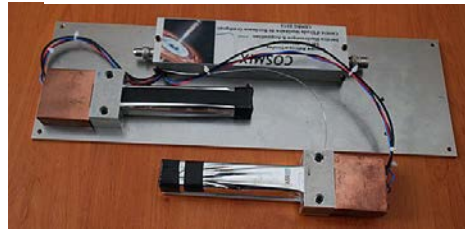
Experiments

- Energy deposit: ~ 12 MeV for cosmic muons \gg background particles
→ All analog signals come from muons

- Two data-taking modes:

Single rate

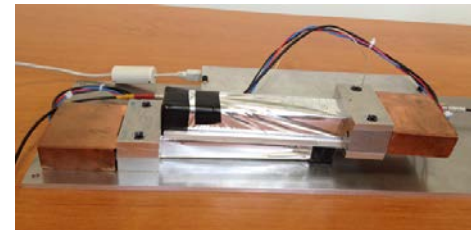
~ 1 evt/s



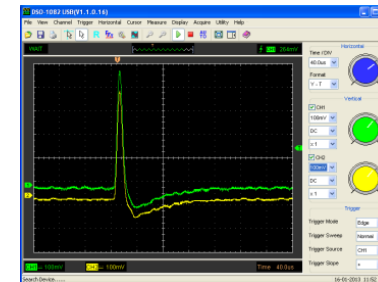
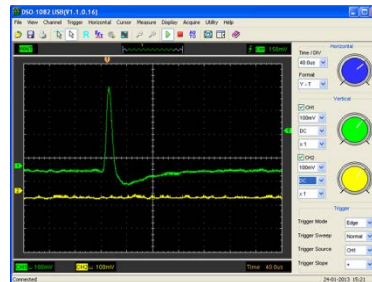
Coincidences

[One bar is movable]

~ 0.4 evt/s



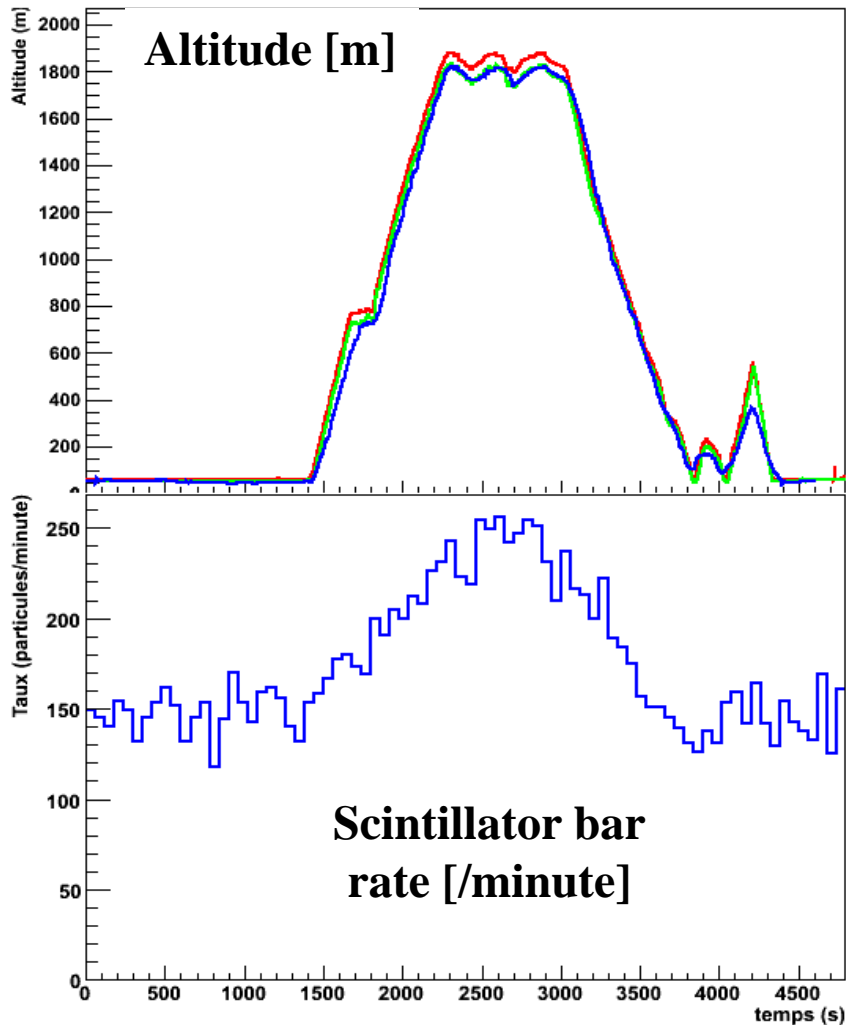
- All high schools have scopes nowadays



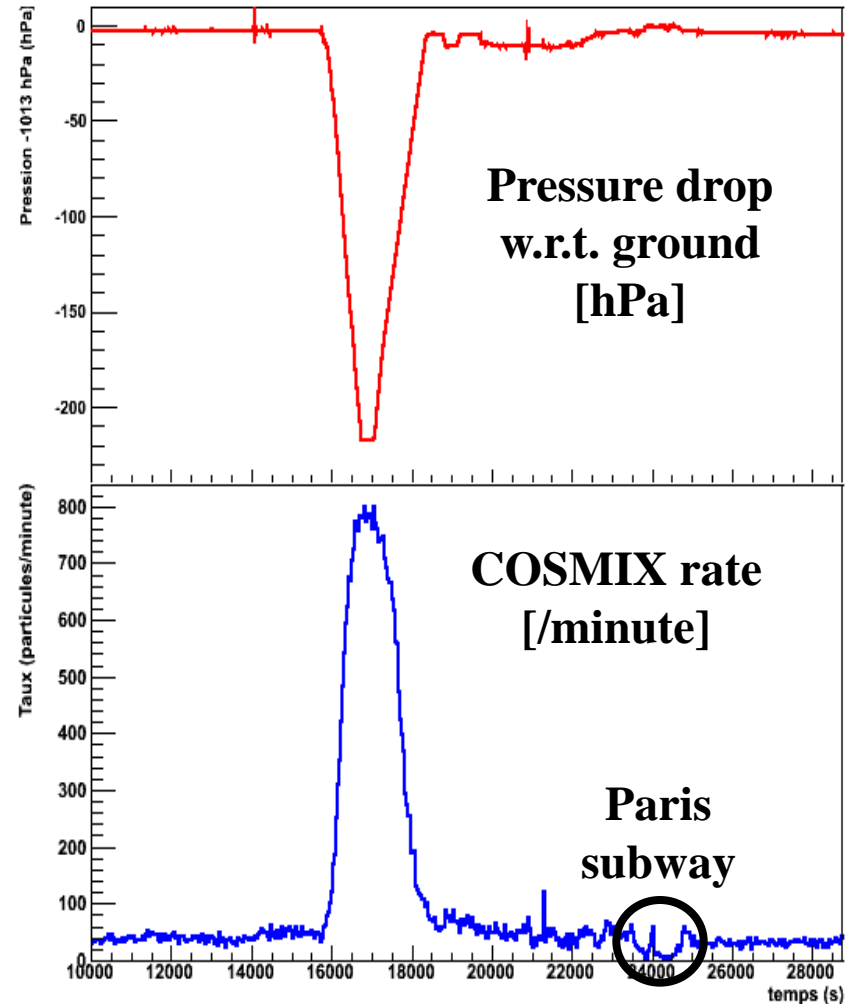
- DAQ system based on an Arduino micro-controller and a SD memory card
 - Event counting + data recording (ascii format → easy offline analysis)

Cosmic ray rates vs. altitude

Private plane flight up to 1,800 m

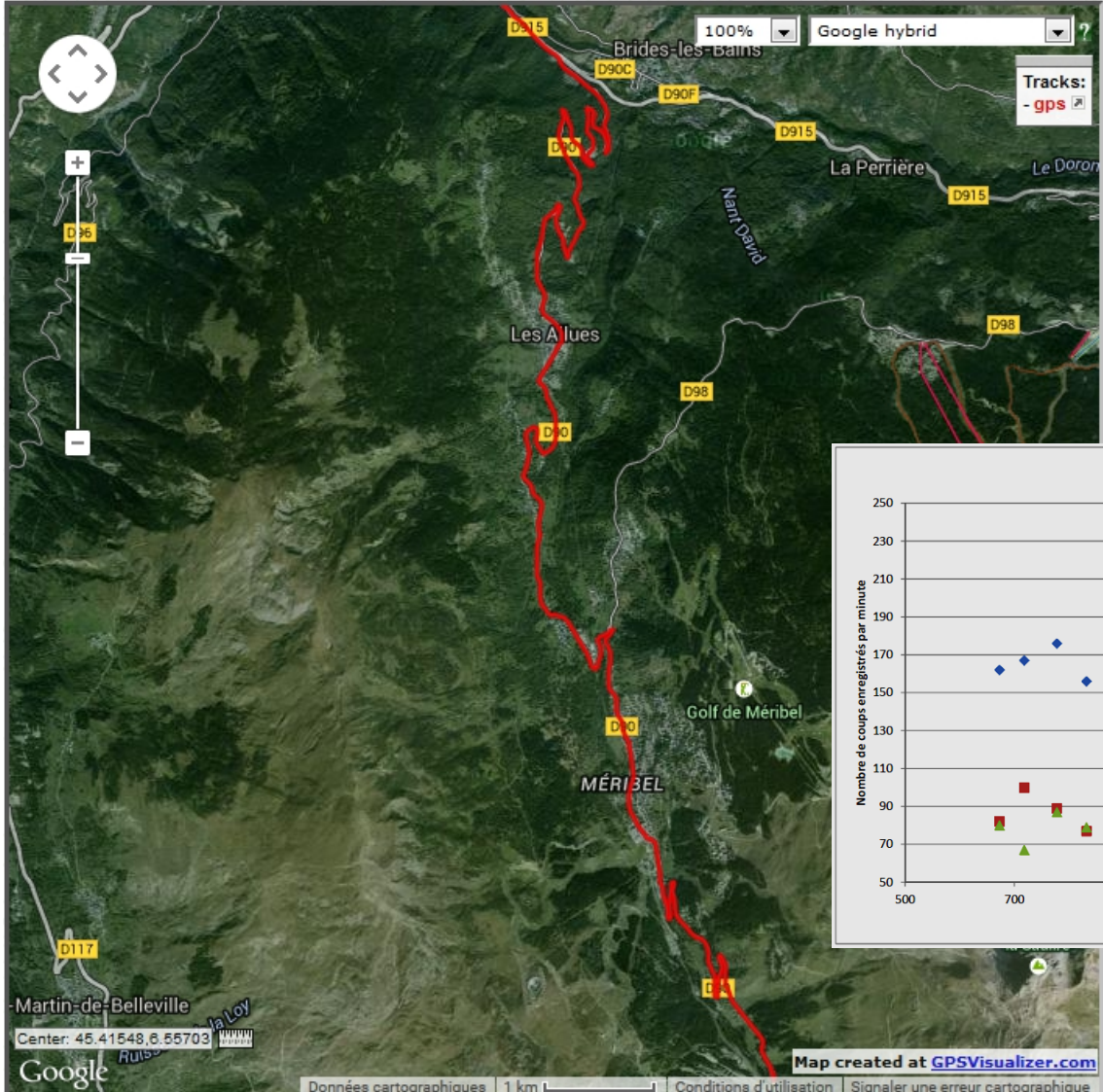


Commercial flight up to 10,000 m

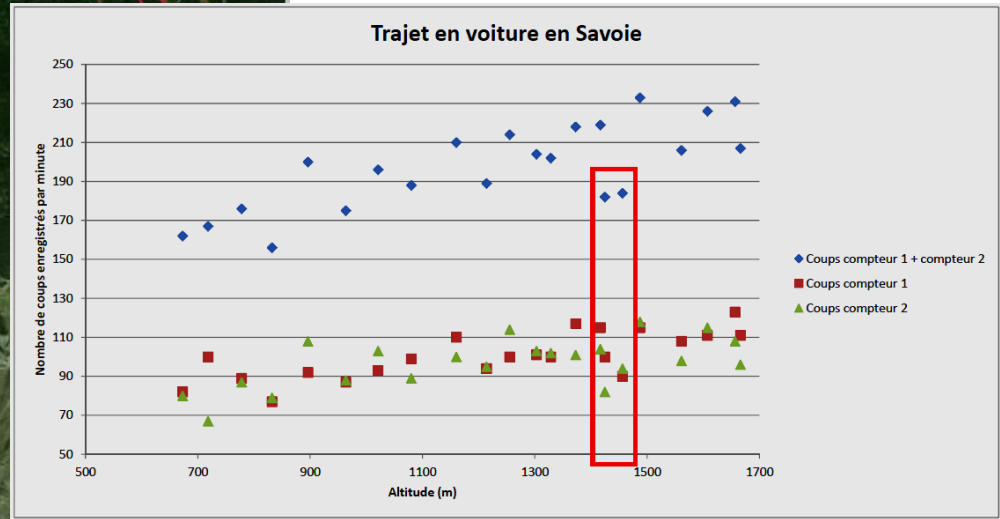


Example of a journey in mountains

- Detector ride monitored by GPS



- Rate increases with altitude



Circulation of « COSMIX » detectors

- **2013: 3 test cases** (2 funded by « Sciences à l'Ecole ») – circulated around Bordeaux
 - More than 1,000 students from 15 high schools used them
→ Feedbacks helped improving the design
 - One prototype sent to the Réunion island
- **2014: first « mass production » (~30 cases)**
 - Paris area
 - Bordeaux area
 - CNRS/IN2P3 Labs

} Educational projects
- **10 more or so produced the following year**
 - Using all Fermi-GLAST spares available
- **2017: production of 10 more cases**
- Most detectors are circulating in **French high-schools**
 - In particular: one in Corsica, one in the Reunion Island
 - Some are abroad: Canada, Switzerland (CERN S'Cool lab), Vietnam
→ Contact us if interested





Plateforme Éducative **Rayons cosmiques et muONs**



Workshop on cosmic ray education
15-16 February 2017
Rome, Italy



Contact

Cyrille BAUDOUIN

Outreach & education project coordinator (independant)

e-PERON coordinator

baudouin.cyr@gmail.com



The project

In a few words

A panel of experiments on
cosmic ray physics

Simple, robust and modular
detection system

Remote experiments and data
access
Virtual lab

From discovery (high school) to
deep studies (Universities)

To learn contemporary physics



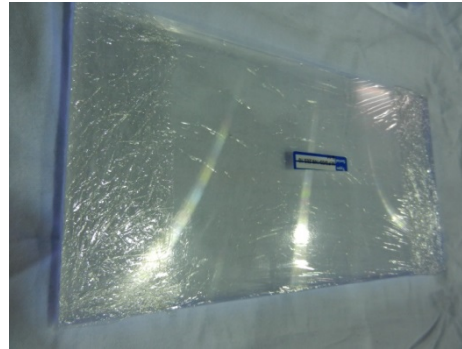
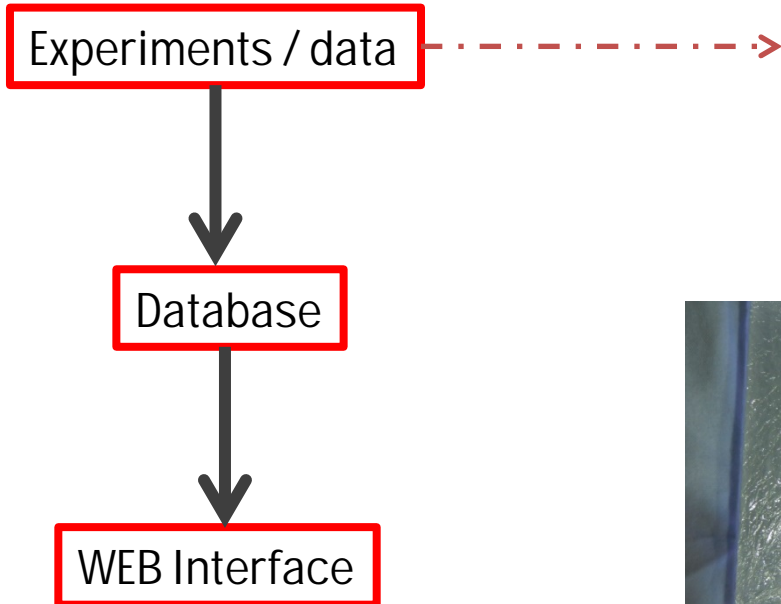
e-PÉRON virtual lab

Scintillation detection

20 detectors

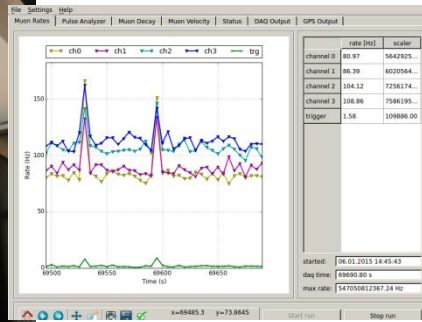
6 Quarknets

Experiments: *E/W effect, muon lifetime, Rossi experiment, cosmic ray array, environment correlations (T, P, radon, weather, solar activity...)*

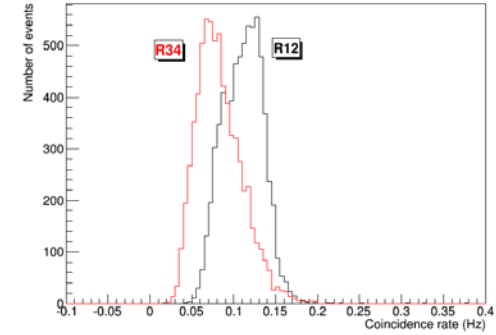
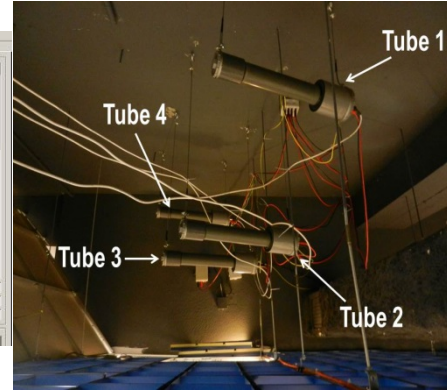


e-PÉRON virtual lab

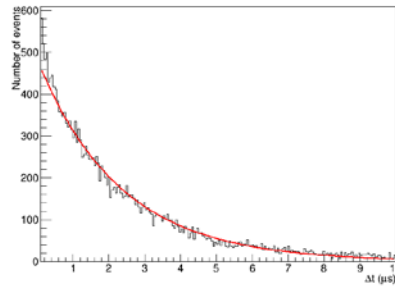
Cosmic ray array



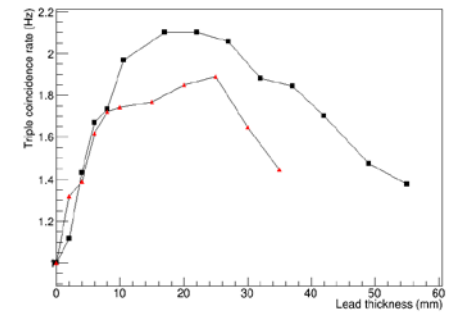
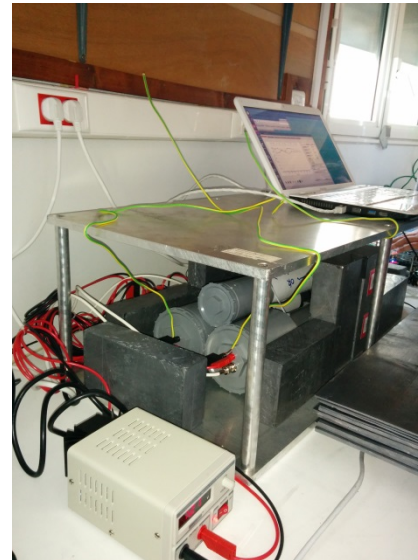
East/West effect



Muon lifetime



Rossi experiment



e-PÉRON virtual lab

Experiments / data



Database

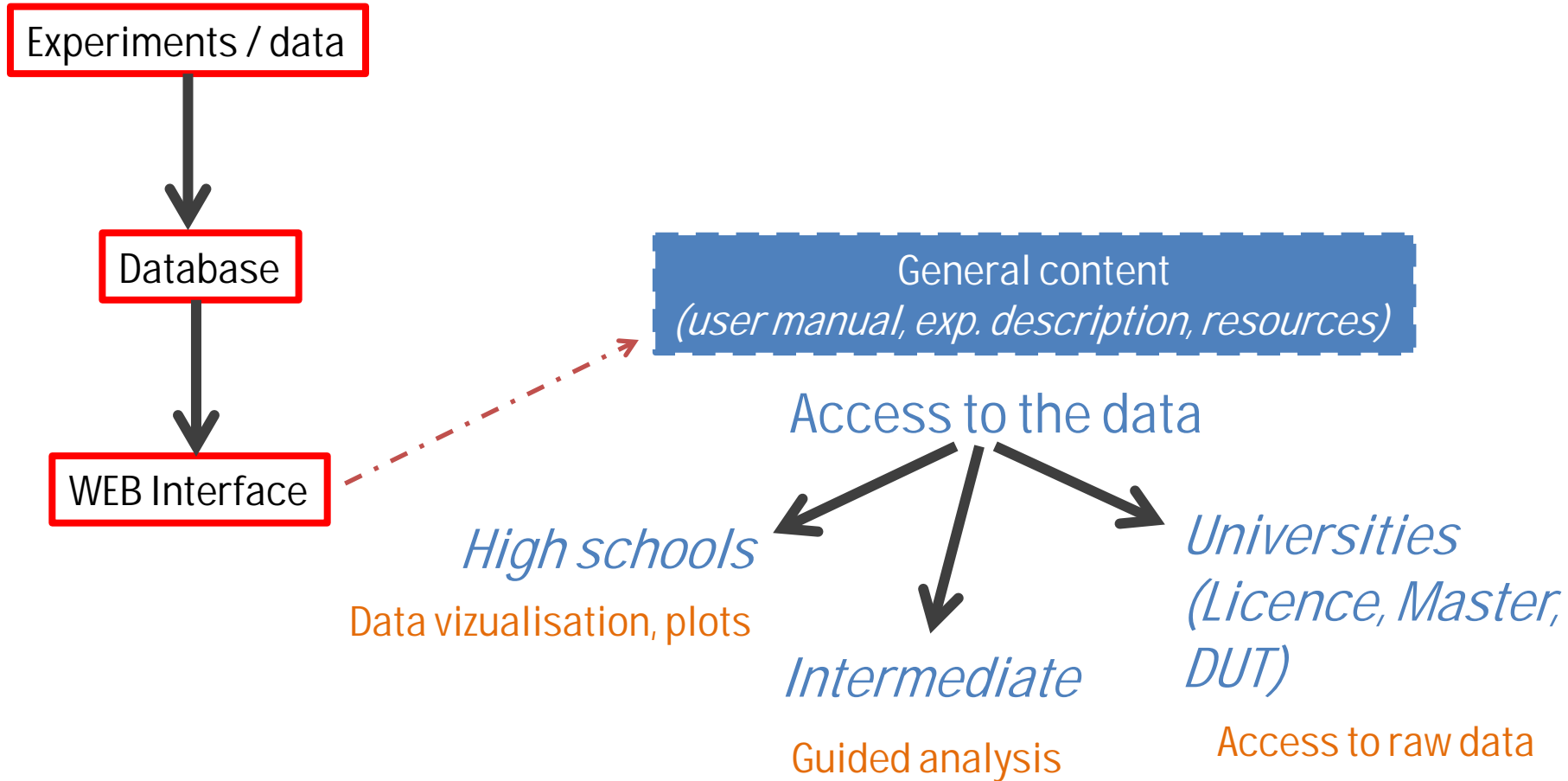


WEB Interface

Raw data in .txt

```
00141225 27.5 18.75 -1 -10.00143664 3.75 11.25 -1
00176512 20 18.75 -1 -10.00177882 35 25 -1 -10.0
0.0018701 43.75 28.75 28.75 -10.00191653 11.25 13.75
-1 8.75 16.250.0023599 35 45 -1 -10.00237539 15
-1 21.25 33.750.00304354 -1 -1 12.5 18.750.00306414
-1 -1 23.75 23.750.00381802 16.25 21.25 -1 -10.0
33.75 31.25 -1 -10.00427891 18.75 16.25 -1 -10.0
37.5 -1 -10.00505532 -1 -1 1.25 100.00506269 -1
28.750.00543754 2.5 -1 11.25 16.250.00543754 26.25
1 18.75 23.750.00556852 -1 -1 7.5 7.50.00558088 47
28.75 -1 -10.00594747 -1 56.25 35 33.750.00596162
00696296 22.5 -1 18.75 200.00702672 21.25 25 -1
-1 -1 6.25 2.50.00756663 38.75 47.5 -1 -10.0075696
572 -1 -1 36.25 36.250.00809119 -1 -1 37.5 46.25
2.50.00867255 1.25 2.5 -1 -10.00869837 30 10 17.5
83.75 -1 42.5 36.250.00899354 96.25 -1 66.25 83
3274 -1 -1 16.25 18.750.00913274 -1 -1 23.75 28.
37.50.00927987 1.25 3.75 -1 -10.00931307 10 13.75
37.5 -1 -10.0100199 36.25 18.75 -1 21.250.0100255
0 -1 -10.0106068 -1 -1 31.25 38.750.0106729 26.25
0111345 16.25 28.75 -1 -10.0111393 28.75 37.5 -1
1 -1 33.75 42.50.0119399 -1 -1 15 27.50.0119419
11.25 -1 -10.0122529 17.5 17.5 -1 -10.0122836 10
4 10 8.75 -1 -10.012942 12.5 15 -1 -10.0129639
```

e-PÉRON virtual lab



Organization

OCEVU funding

2012 – 2014: 40.5 k€

2015: 11.6 k€

2016: 6 k€

General coordination: Cyrille BAUDOIN

Scientific coordination: José BUSTO (CPPM) & Damien DORNIC (CPPM)

Technical and scientific support (data analysis, implementation, maintenance, network, web) :

Guillaume Chamak (OMP), Olivier Espagnet (OMP), Alain Klotz (IRAP), Aurore Mathieu (CPPM), Damien Turpin (IRAP), Pierre Vert (OMP)

+ Antoine Auvity (internship L3 AMU)

Technical teams (CPPM, OMP)



Implementation

Implementation plan



Phase I (12/2014): 12 scintillators array implementation

Phase II (05/2015): implementation of 3 new experiments

Muon lifetime, Rossi experiment, east/west effect

Phase III (01/2016): completion of the full array

Synchronicity card, remote radon detector

Phase IV (work in progress): web interface + database

Universities

- ✓ Data used in Physics License (Aix-Marseille University) in 2015/2016 and in 2016/2017
- ✓ Toulouse University in 2017/2018 (Master, Technical trainings)

High schools

- ✓ Work and tests with a group of teachers
- ✓ French physics school for teachers « Cosmos à l'école » (may 2017): 20 teachers

→ Sept. 2017 : national opening (high schools + universities)