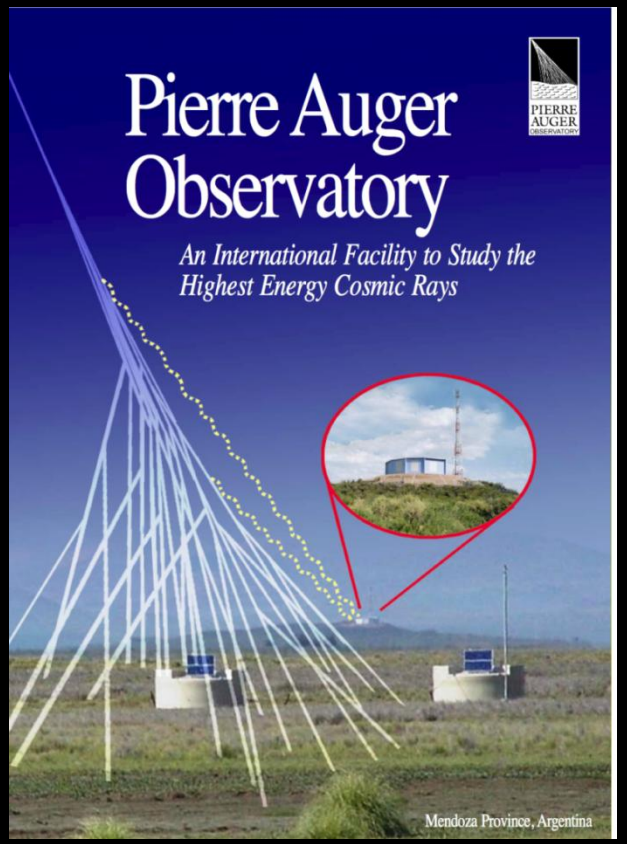
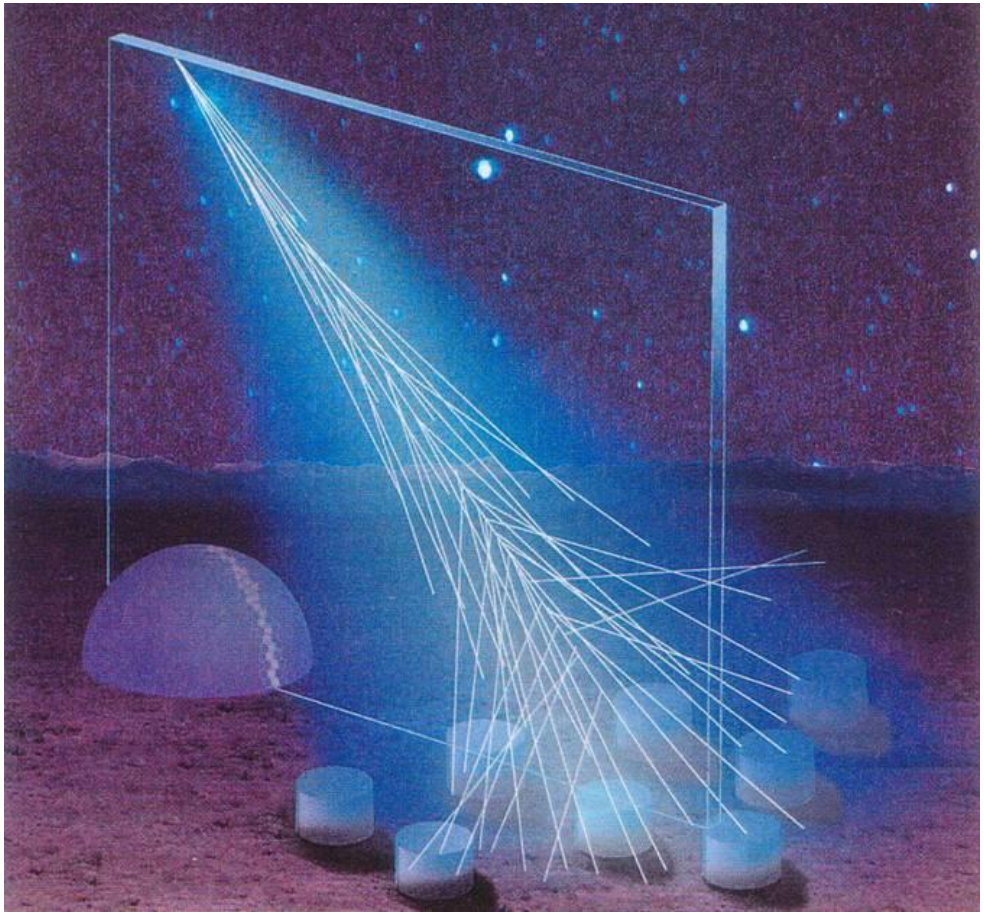
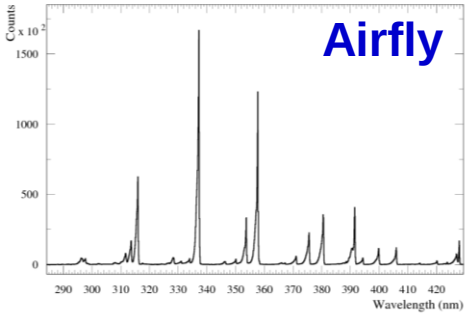
Atmospheric Calorimetry above 10^{19} eV: Shooting Lasers at the Pierre Auger Observatory



Lawrence Wiencke
Colorado School of Mines
Calor 2008 May 28th Pavia

The hybrid nature of Auger





300-400 nm light from de-excitation of atmospheric nitrogen (fluorescence light)
≈ 4 γ's / m /electron

10^{19} eV ⇨ 10^{10} e

Fluorescence Detector

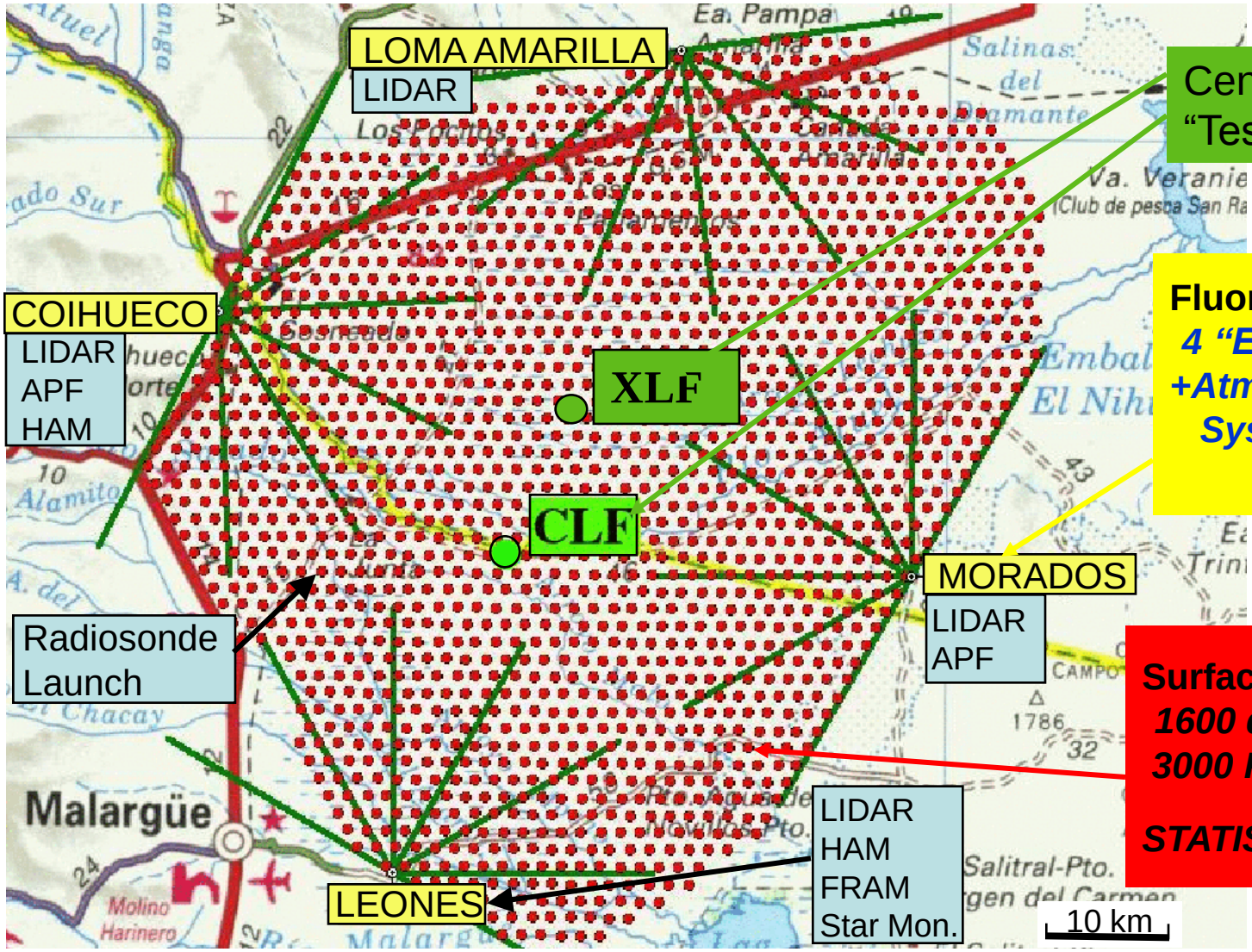
- E + longitudinal development
- Time ≈ direction
- ≈ 10% duty cycle

Trigger efficiency
Energy-direction calibration,
syst. errors

Surface Detector

- Shower size ≈ E
- Time ≈ direction
- 100% duty cycle

Detector Configuration (Almost Completed)



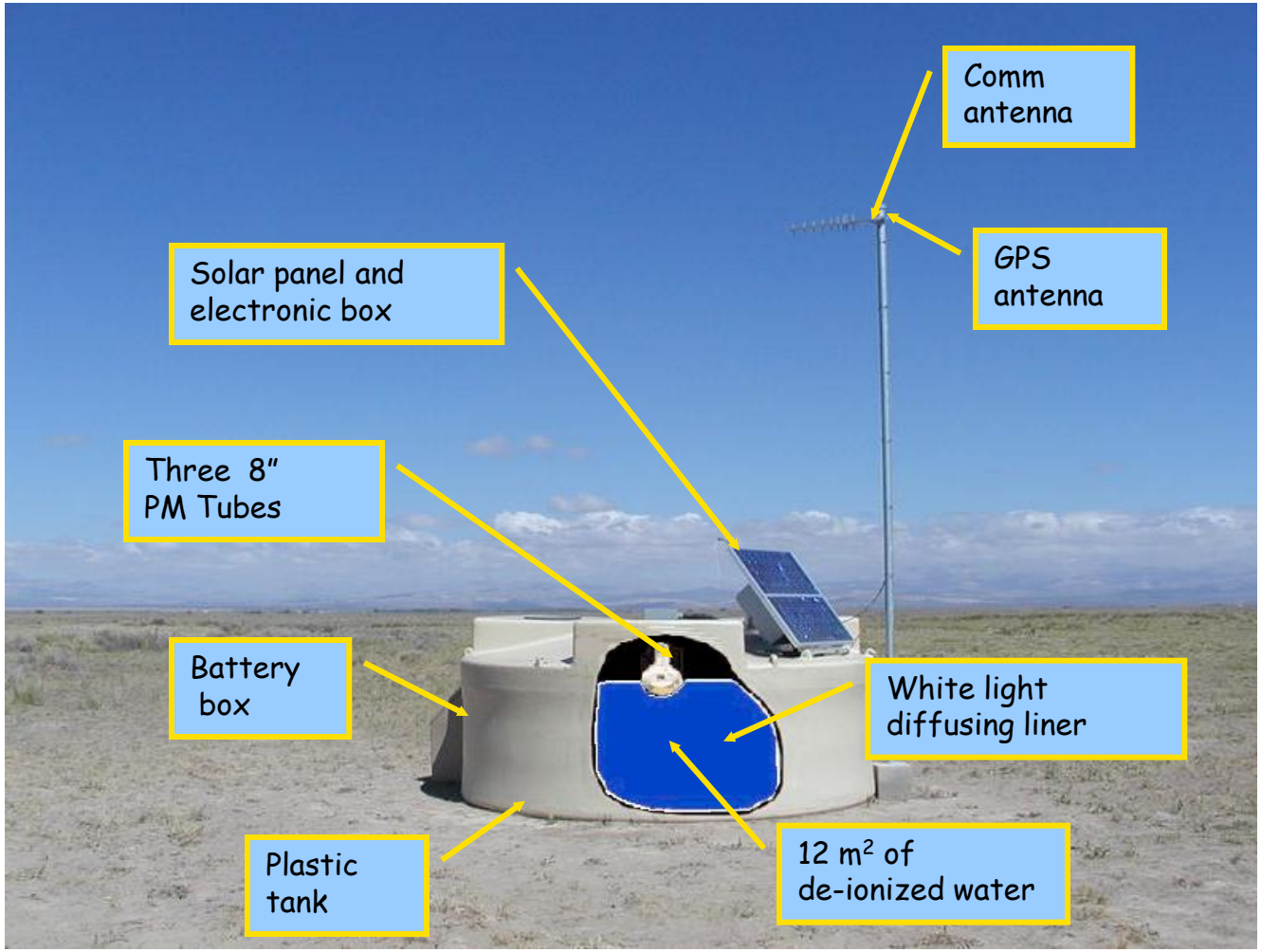
Central Laser Facilities
"Test Beams"

Fluorescence Detectors
4 "Eyes"
+Atmospheric Monitoring Systems

Surface Detector Array
1600 detector stations
3000 Km²

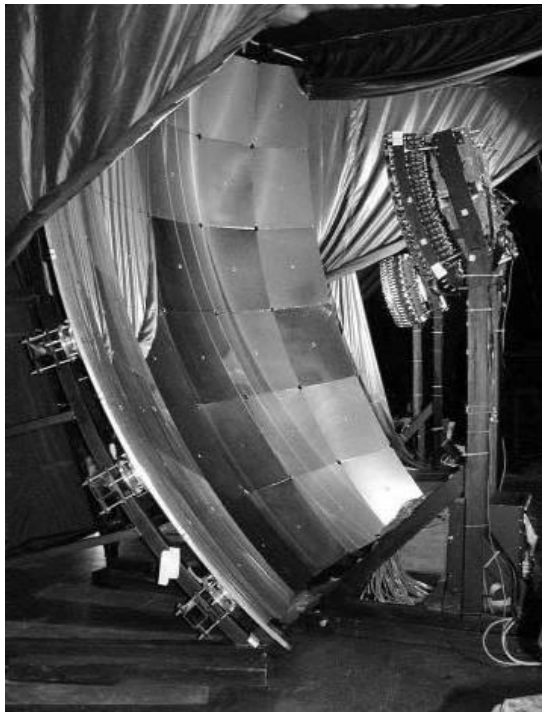
STATISTICS ENGINE

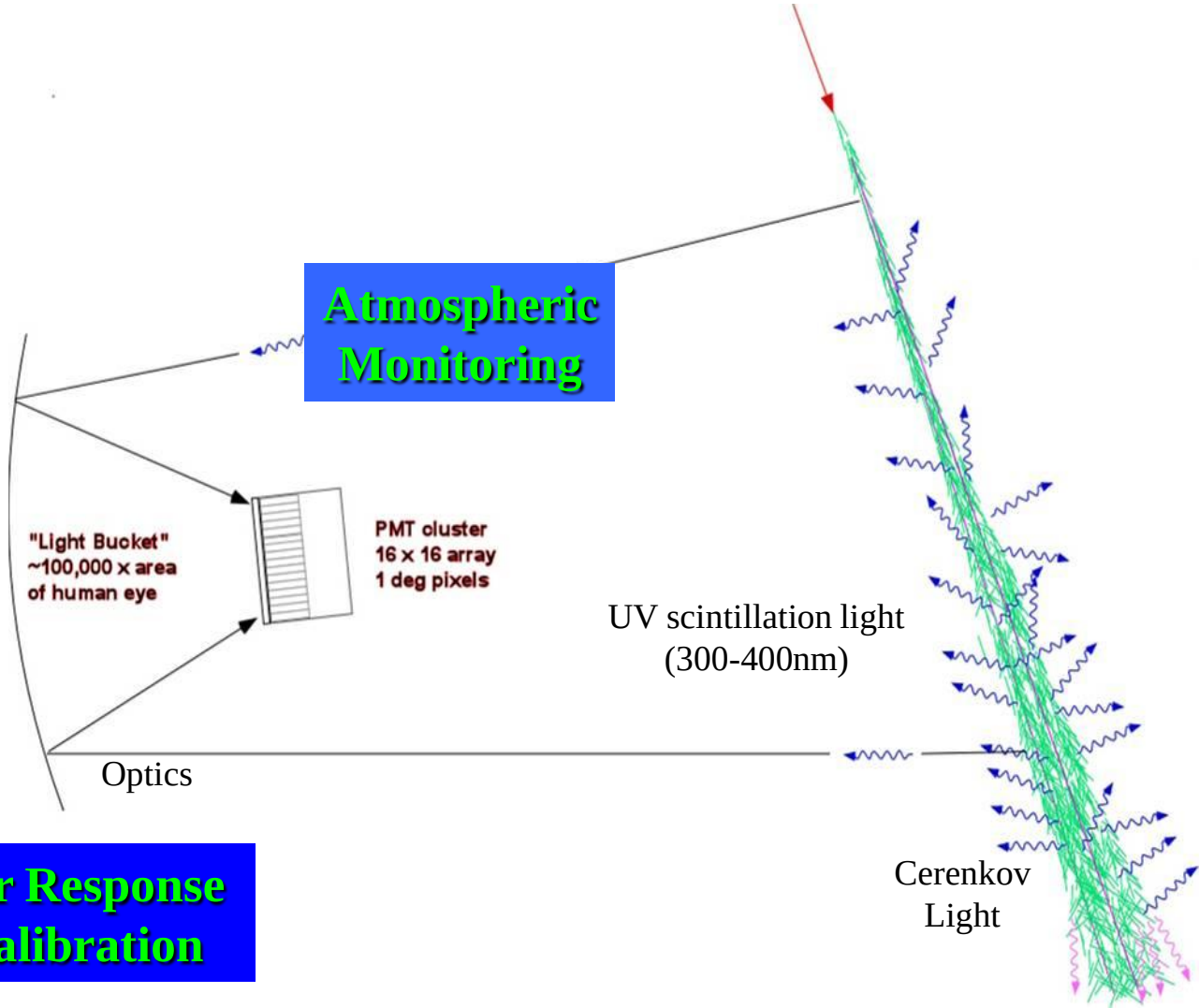
An Auger Surface Detector Station (1 of 1600, 1.5 km spacing)



view of Los Leones Fluorescence Eye

The Air Fluorescence Technique





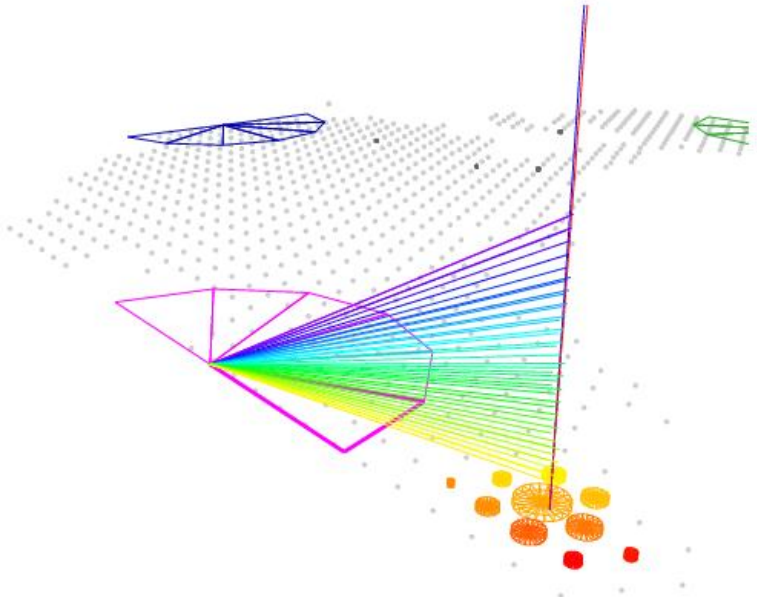
Detector Response and Calibration

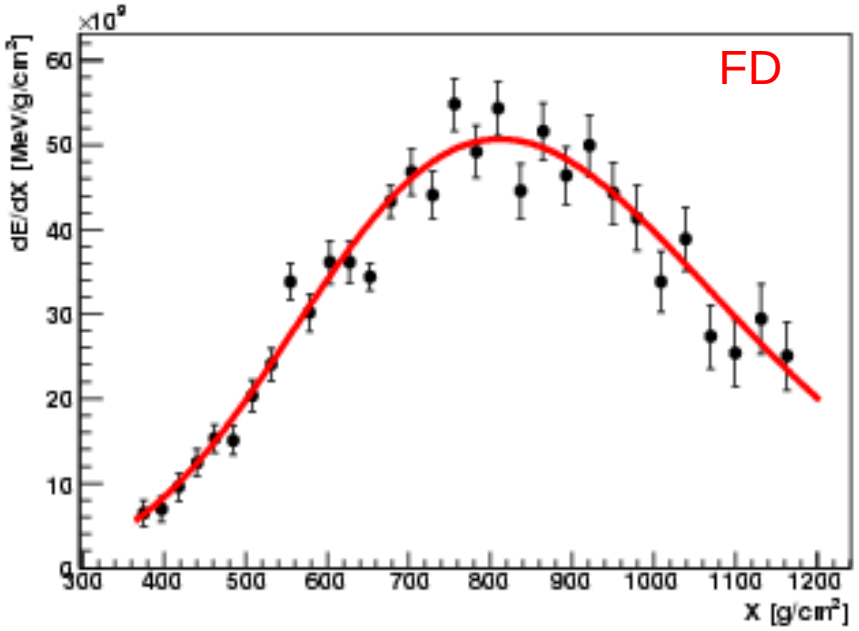
Use the Atmosphere as a Calorimeter

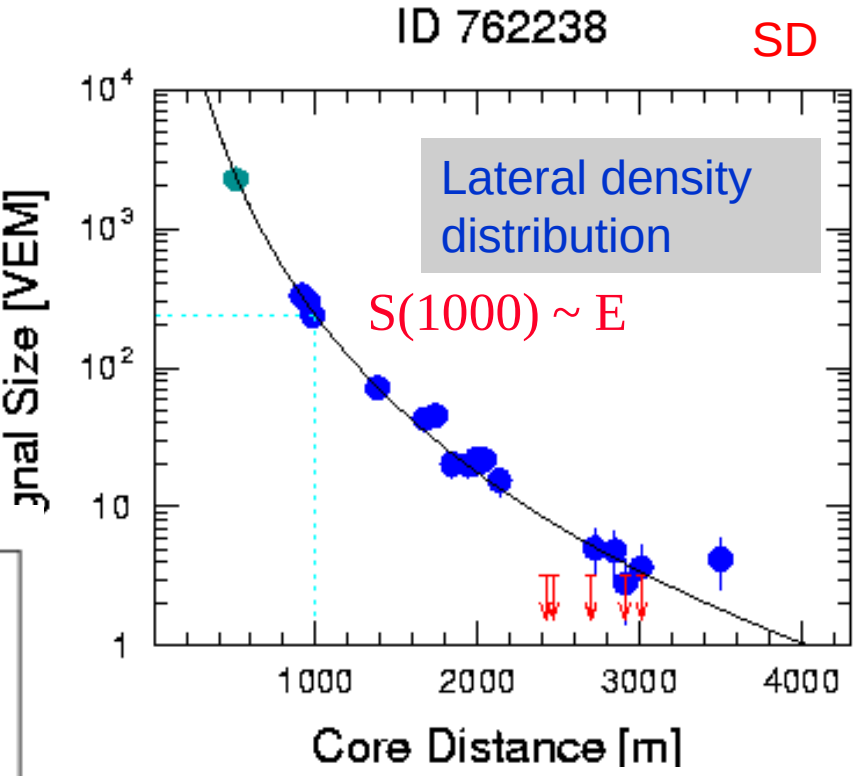
Total amount of scintillation light proportional to shower energy

Measurement of UHECR Energy

SD events, $\theta < 60$

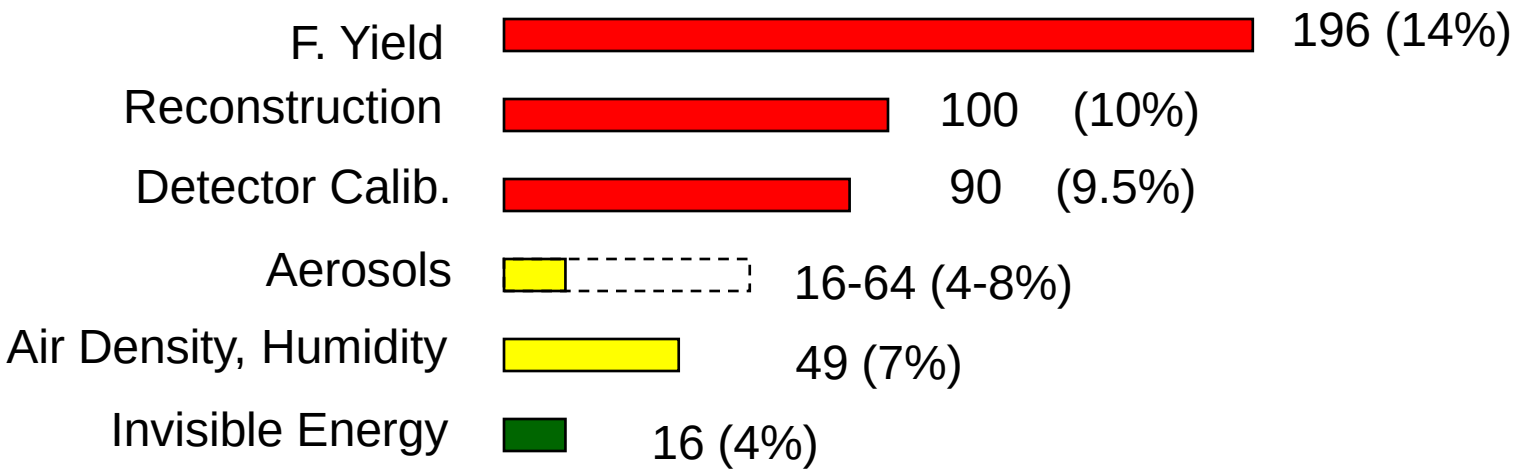






SD energy estimator calibrated by calorimetric measurement from Fluorescence Detector in Hybrid Events

FD Energy Calibration

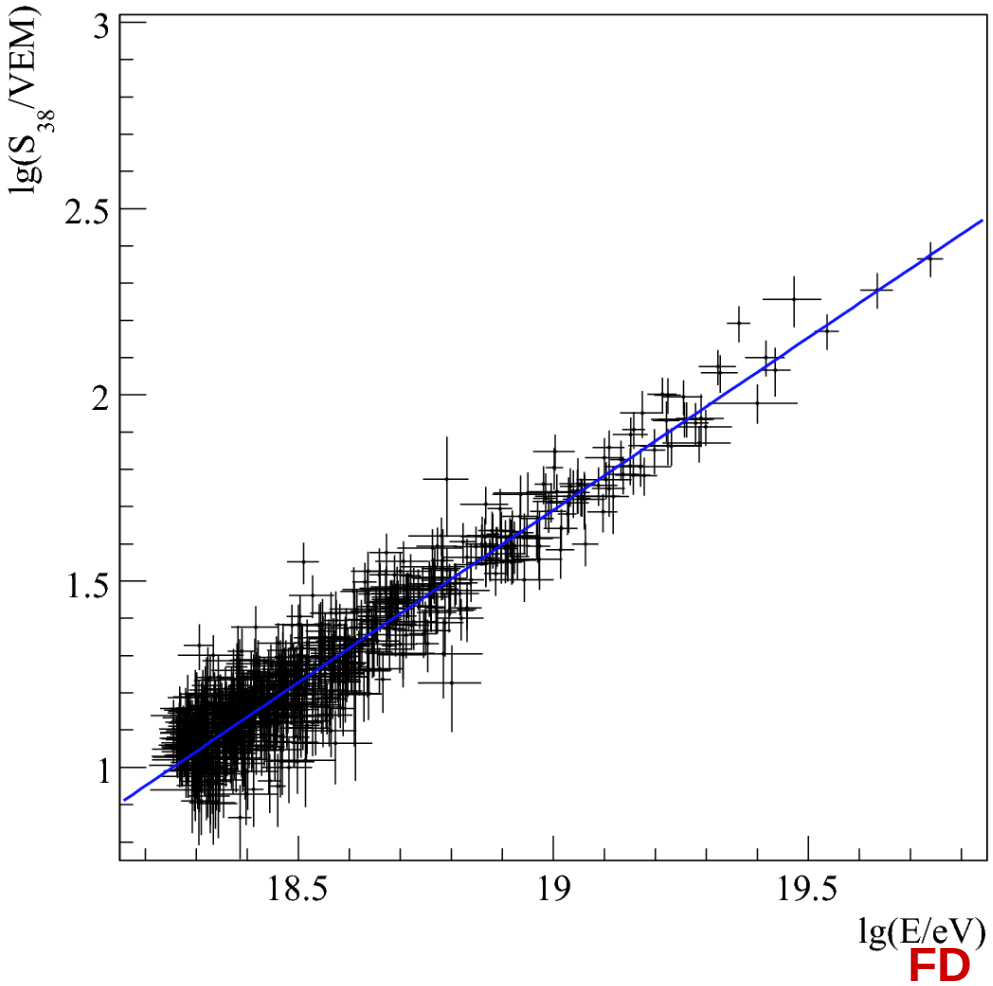


Quadrature Sum (22%)

(Assumes terms are uncorrelated)

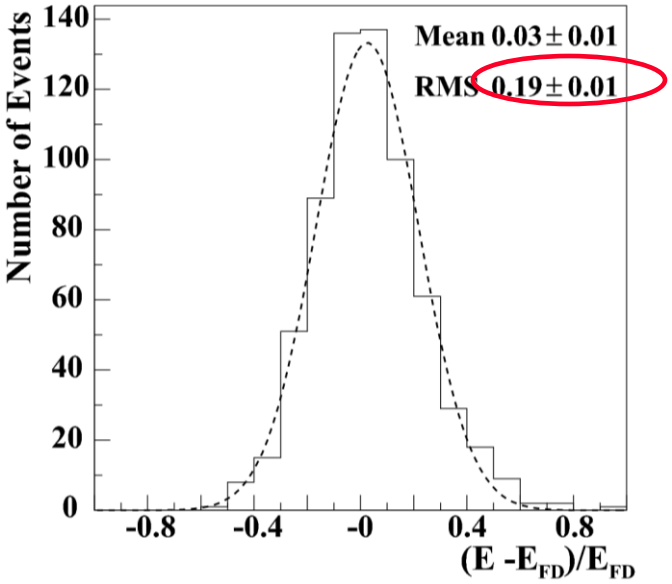
Energy Calibration with Fluorescence Detector

SD



FD

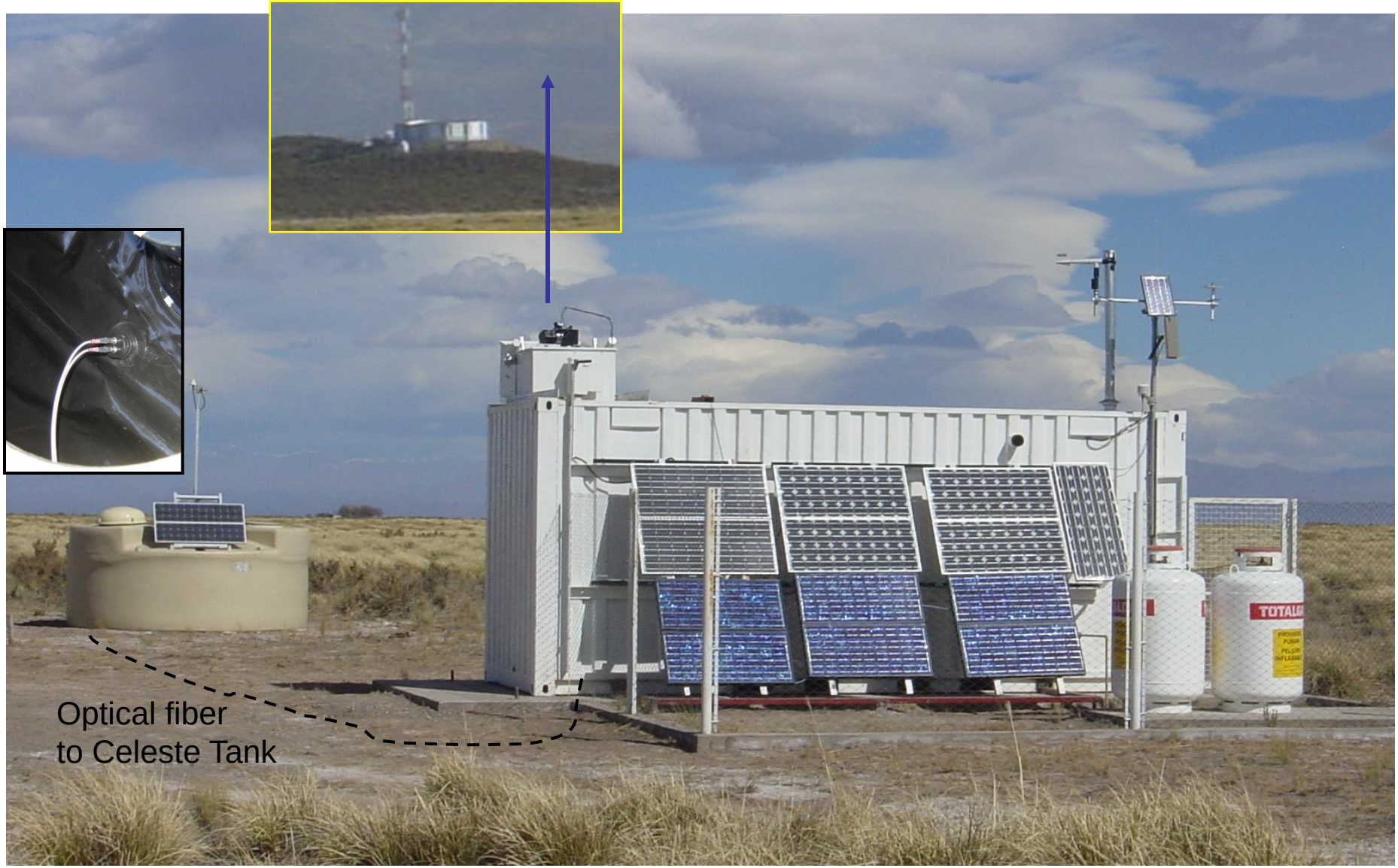
Energy resolution better than 20%



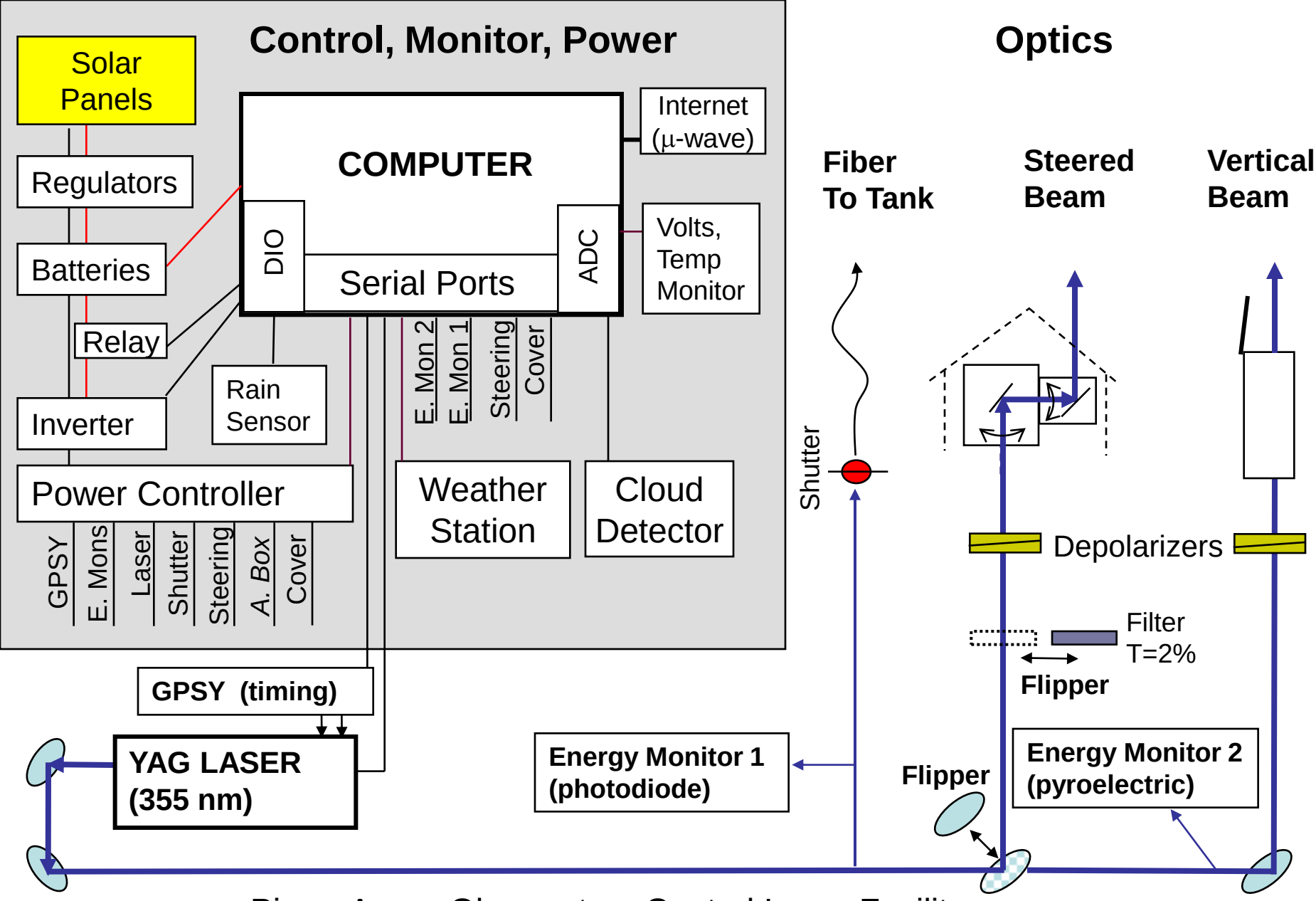
$$E_{SD} = A\,(S_{38})^{b}$$

$$b \sim 1$$

NOTE: Both S_{38} and E_{SD} are determined experimentally. We DO NOT rely on shower simulation!



The CLF sends light simultaneously to
the Surface Detector and to the Fluorescence Detector

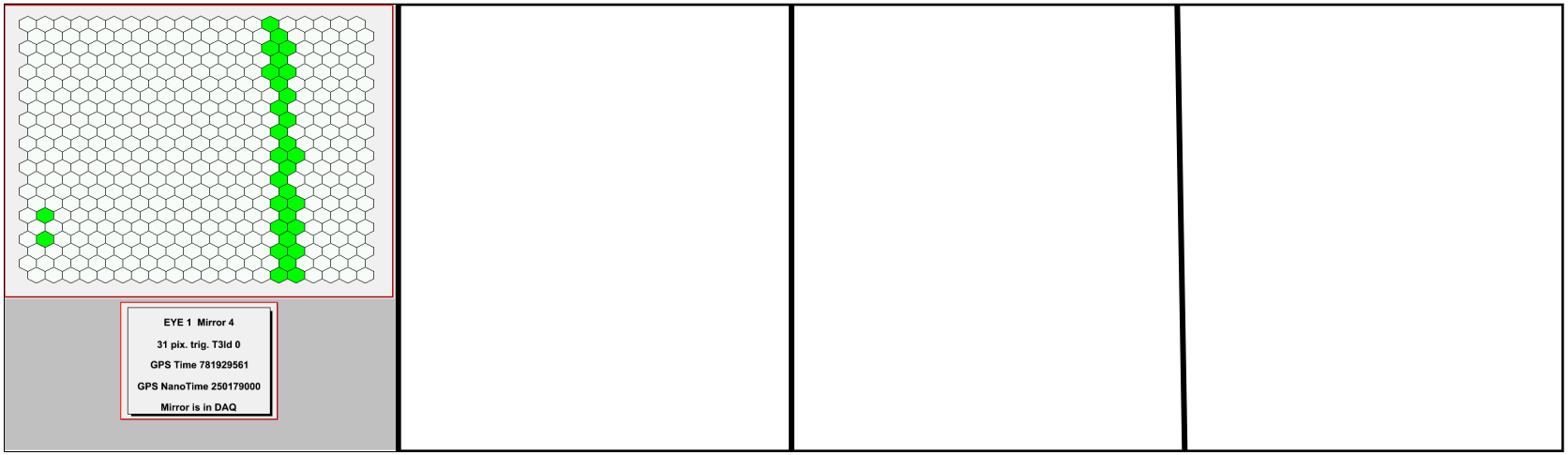


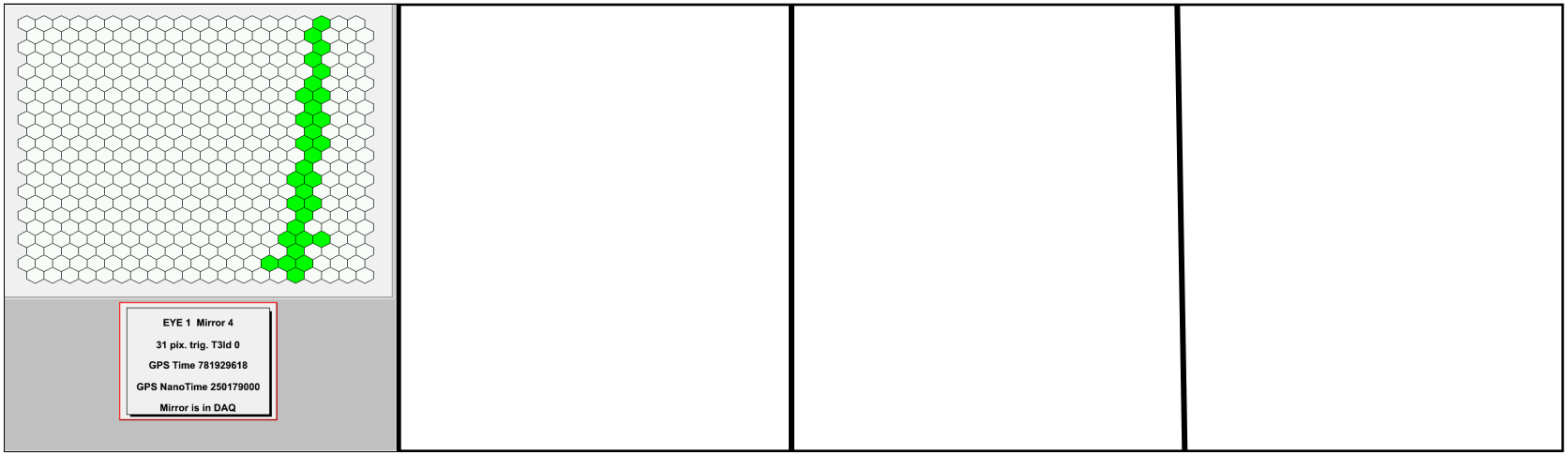
Pierre Auger Observatory Central Laser Facility

JINST 1 P11003 (2006)


RADIACIÓN LASER
LA EXPOSICIÓN DE LOS OJOS O PIEL A LA RADIACIÓN DEL HAZ ES PELIGROSA
ATENCIÓN
NO SE SUBA AL TECHO

Examples of steered shots (as seen by Los Leones)




EYE 1 Mirror 4
31 pix. trig. T3Id 0
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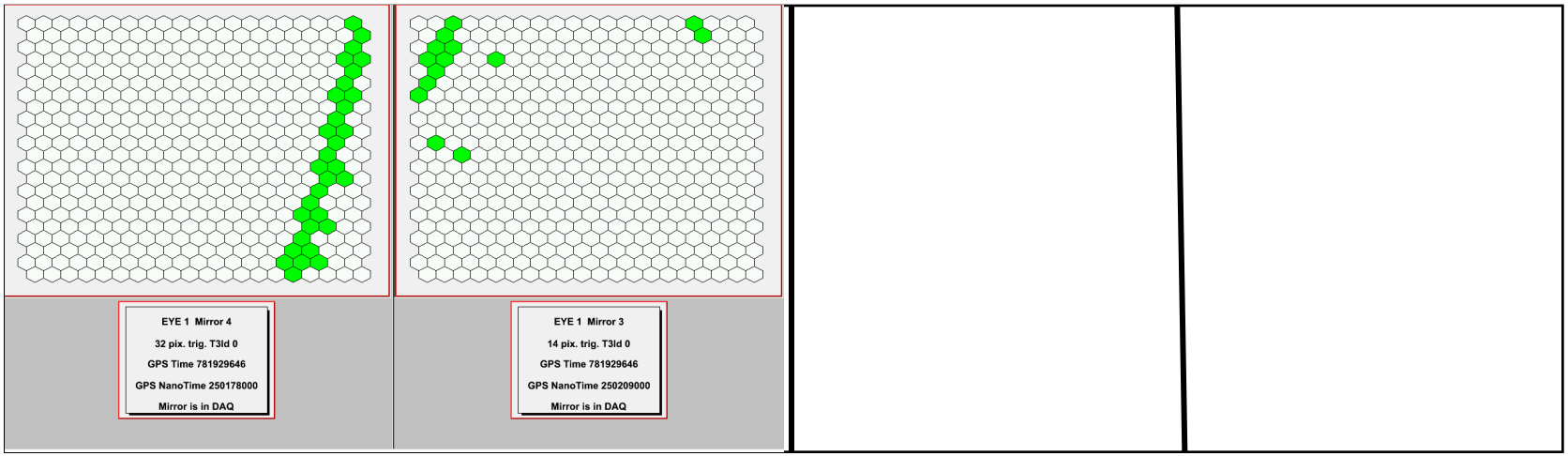
GPS NanoTime 250179000
Mirror is in DAQ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EYE 1 Mirror 3
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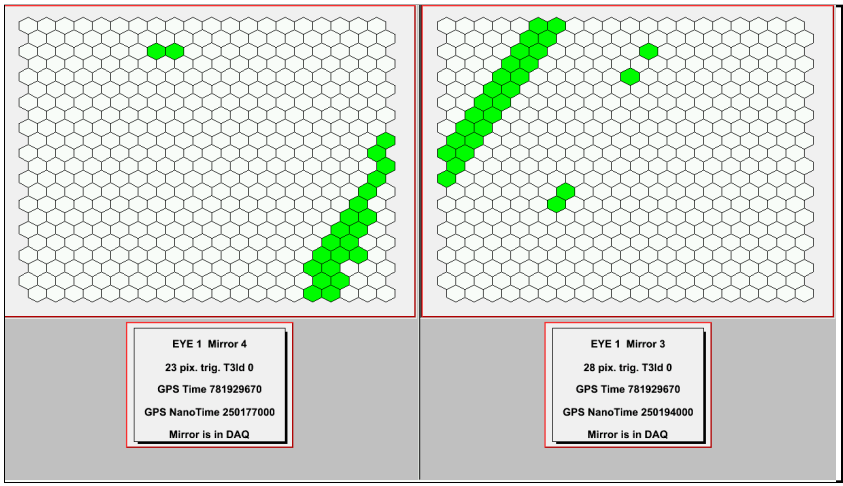
GPS Time 781929646
GPS NanoTime 250209000
Mirror is in DAQ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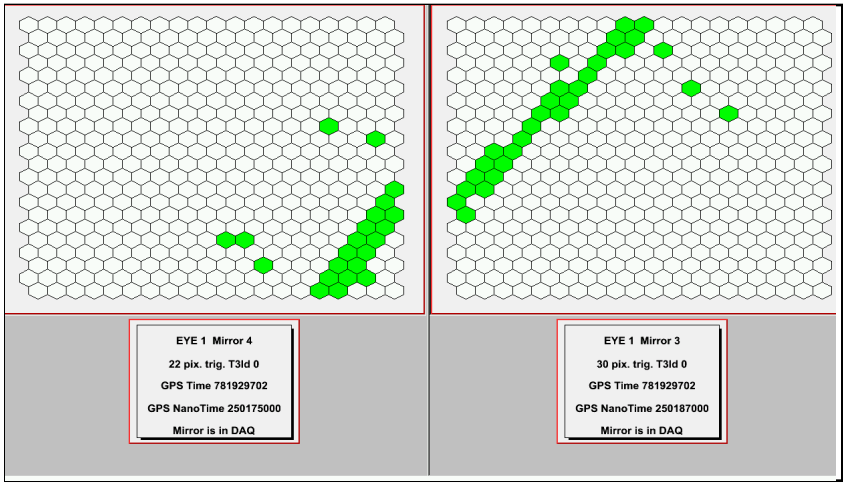
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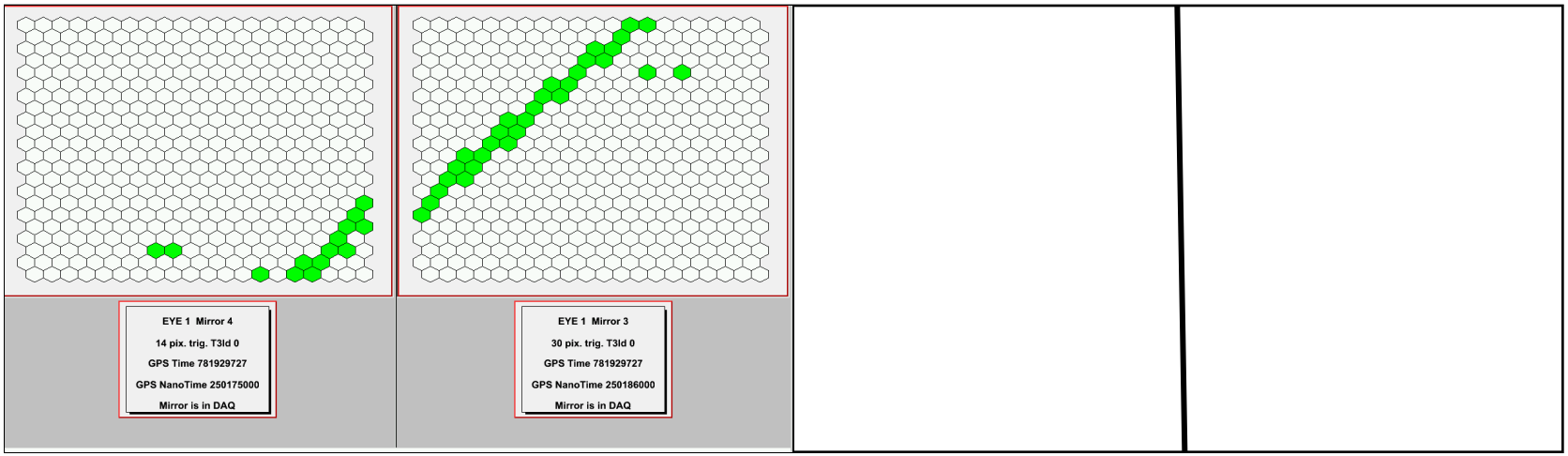
Mirror is in DAQ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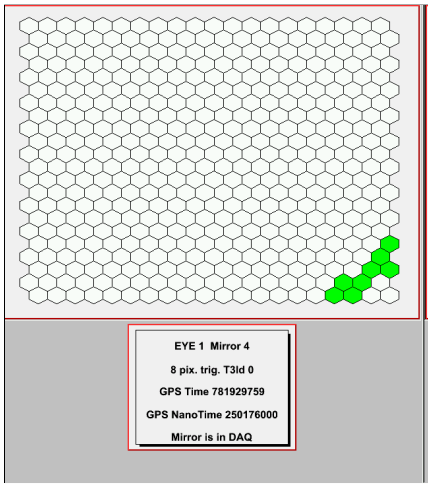
GPS Time 781929727
GPS NanoTime 250186000
Mirror is in DAQ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GPS Time 781929759
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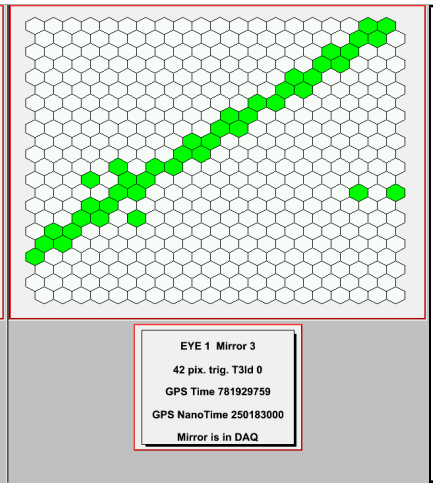
Mirror is in DAQ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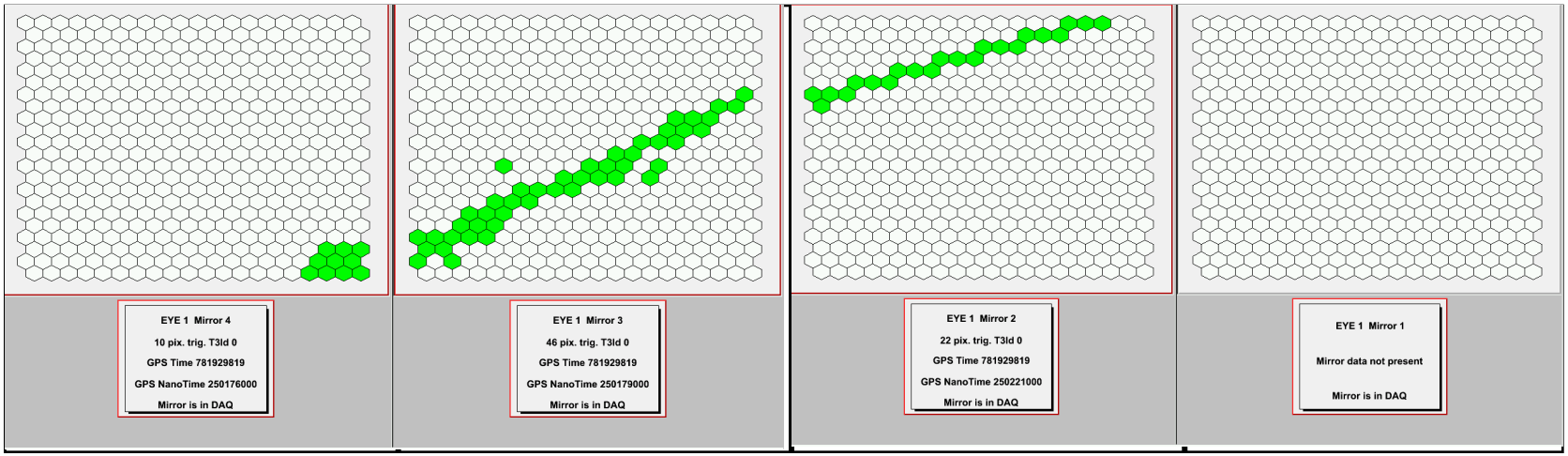
Mirror is in DAQ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Mirror is in DAQ
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GPS NanoTime 250179000
Mirror is in DAQ
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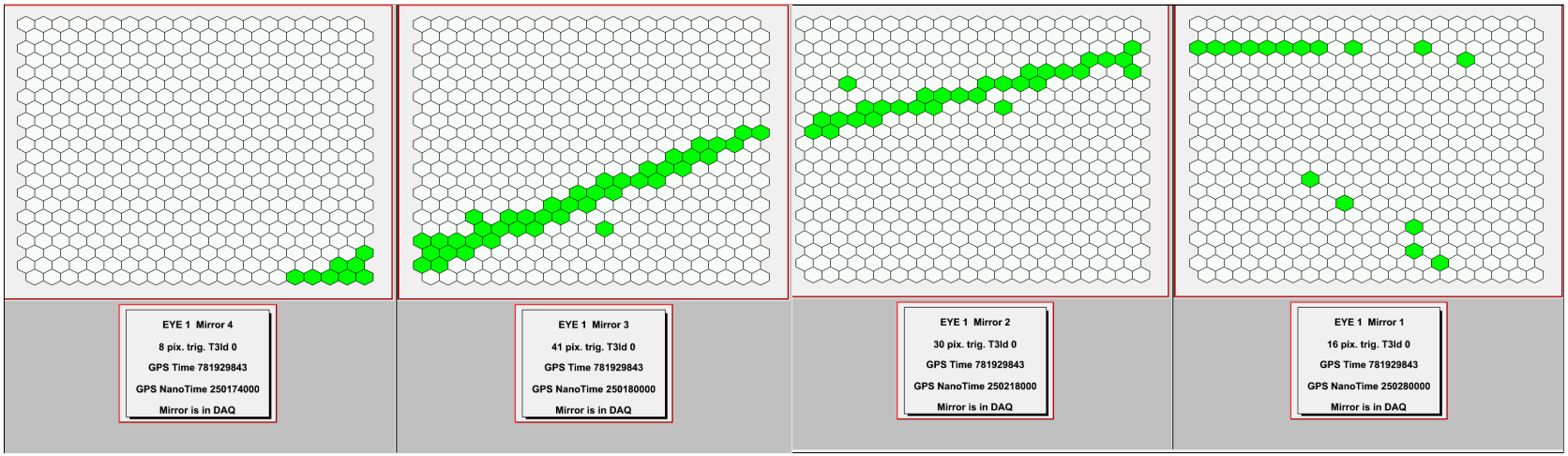
EYE 1 Mirror 1
Mirror data not present
Mirror is in DAQ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EYE 1 Mirror 3
41 pix. trig. T3ld 0
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GPS NanoTime 250180000
Mirror is in DAQ
EYE 1 Mirror 2
30 pix. trig. T3ld 0
GPS Time 781929843
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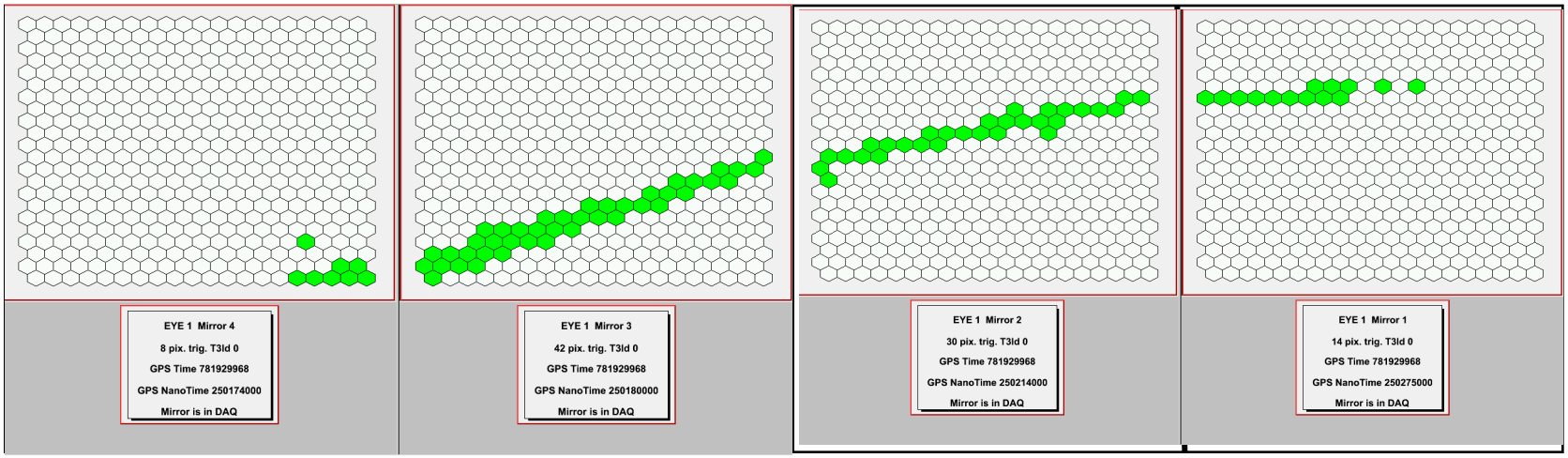
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GPS Time 781929968
GPS NanoTime 250180000
Mirror is in DAQ
EYE 1 Mirror 2
30 pix. trig. T3ld 0
GPS Time 781929968
GPS NanoTime 250214000
Mirror is in DAQ
EYE 1 Mirror 1
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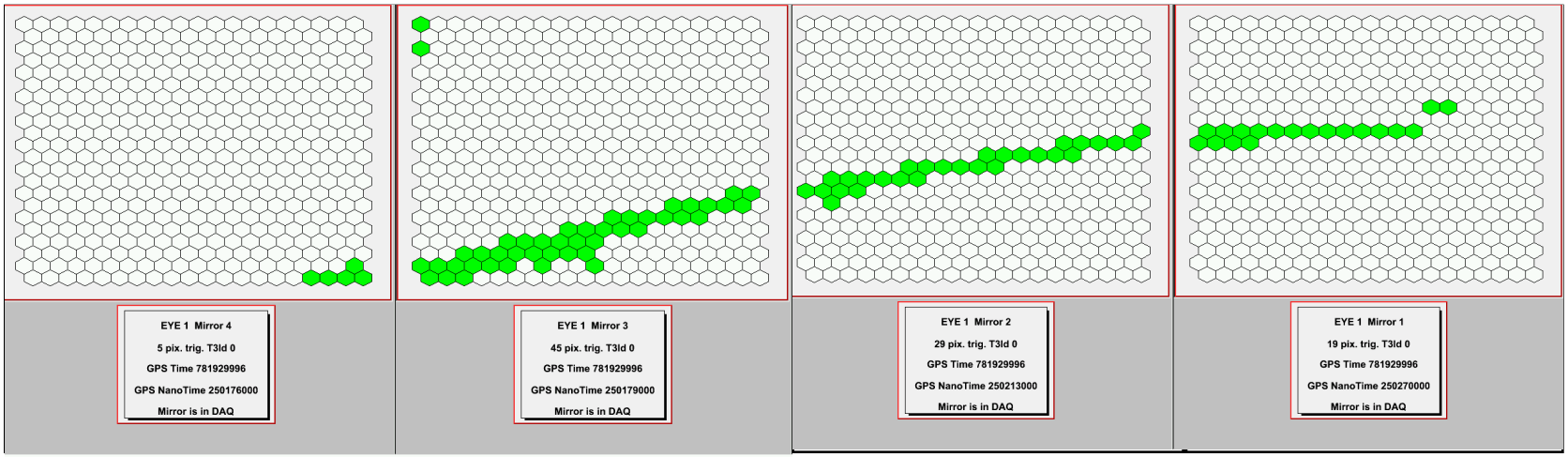
Mirror is in DAQ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GPS Time 781929996
GPS NanoTime 250179000
Mirror is in DAQ
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29 pix. trig. T3ld 0
GPS Time 781929996
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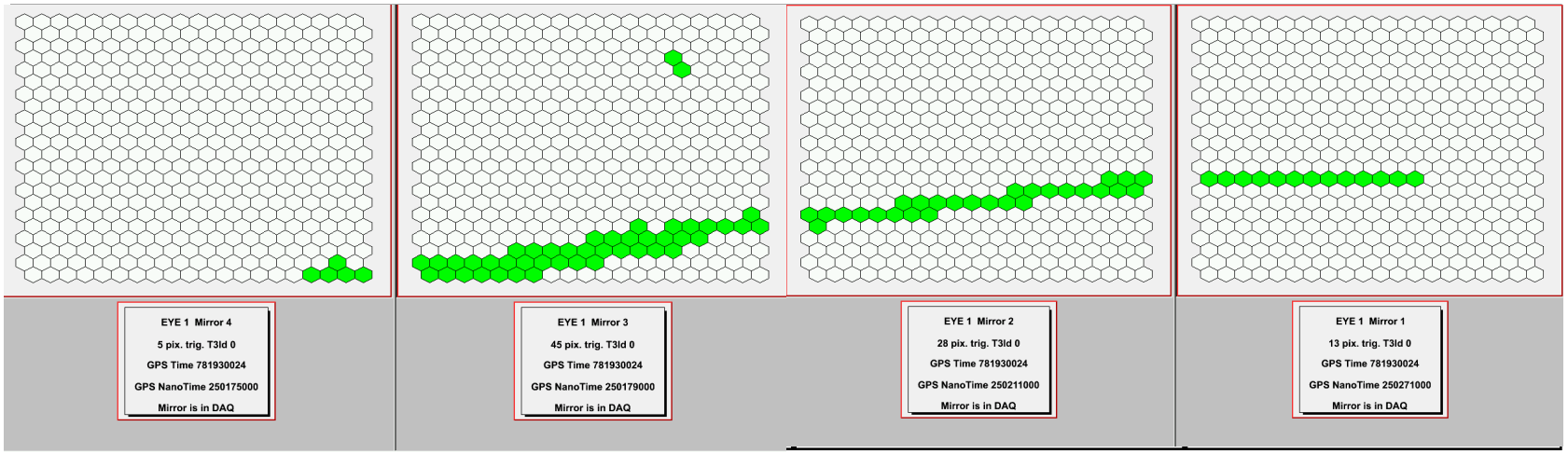
Mirror is in DAQ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Mirror is in DAQ
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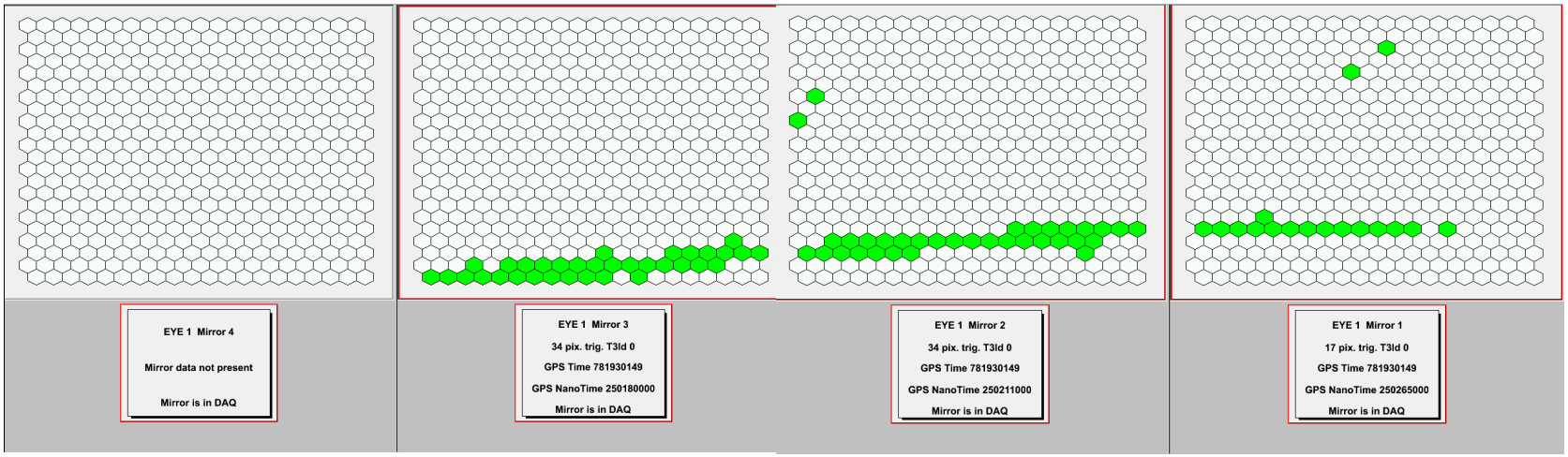
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34 pix. trig. T3ld 0
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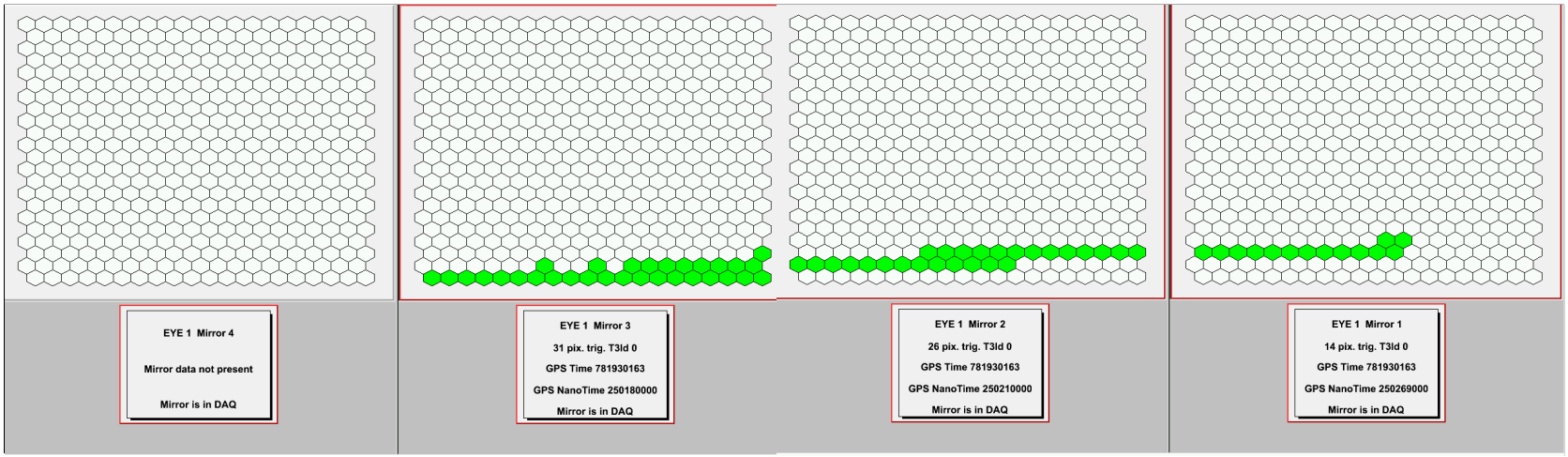
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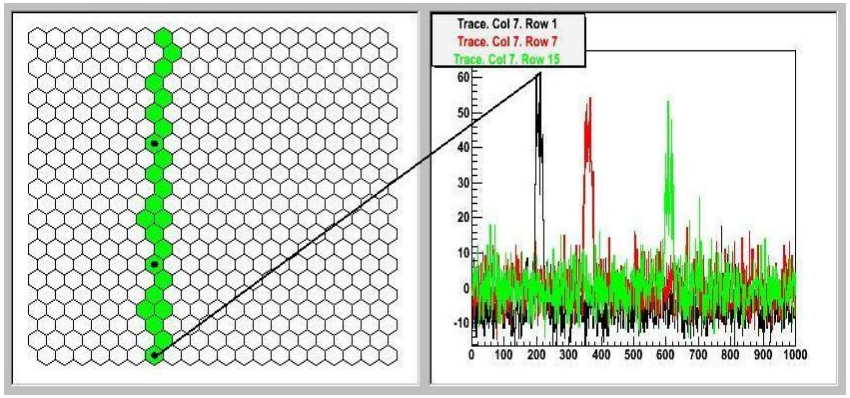
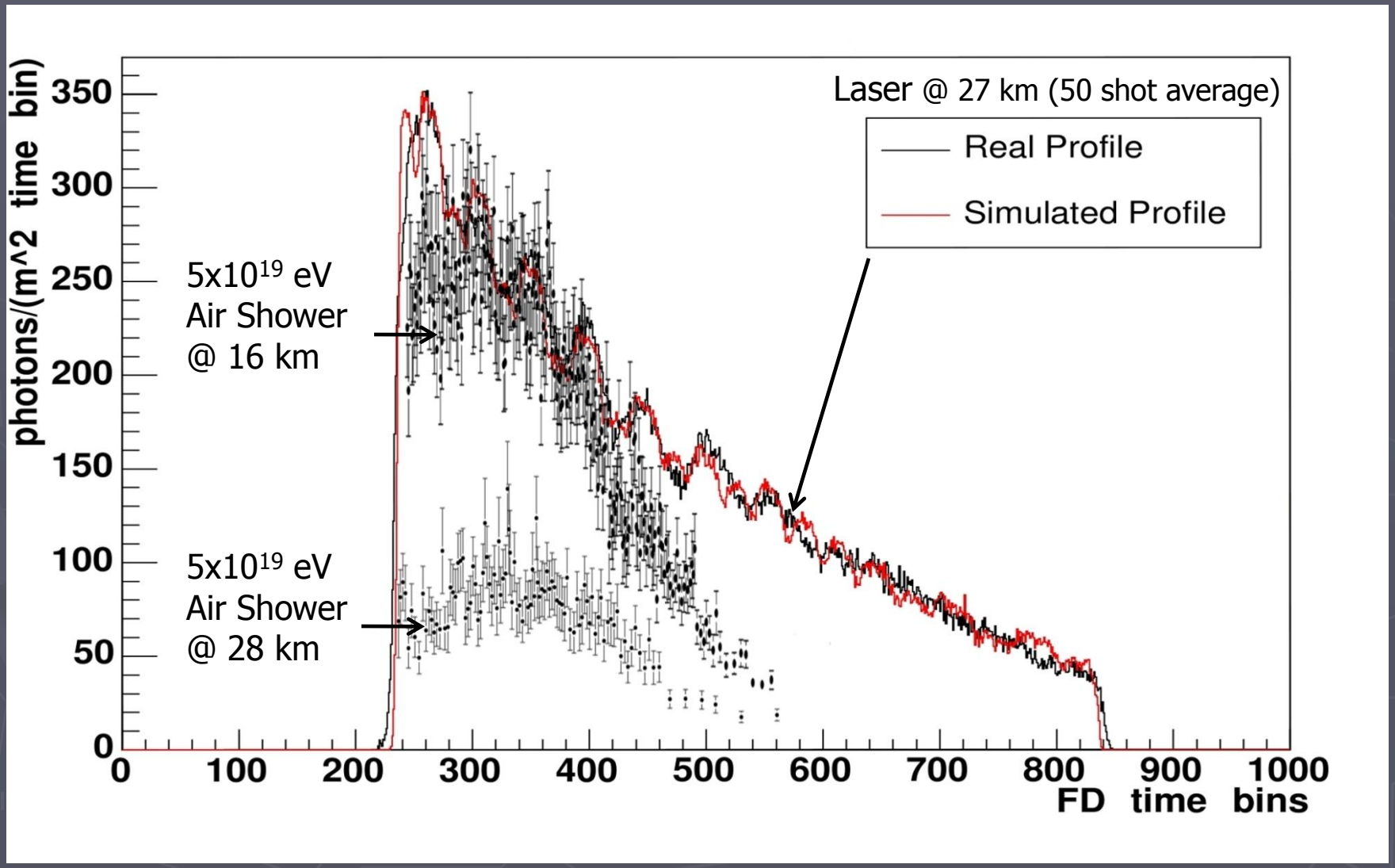
GPS Time 781930163
GPS NanoTime 250210000
Mirror is in DAQ
EYE 1 Mirror 1
14 pix. trig. T3ld 0
GPS Time 781930163
GPS NanoTime 250269000
Mirror is in DAQ

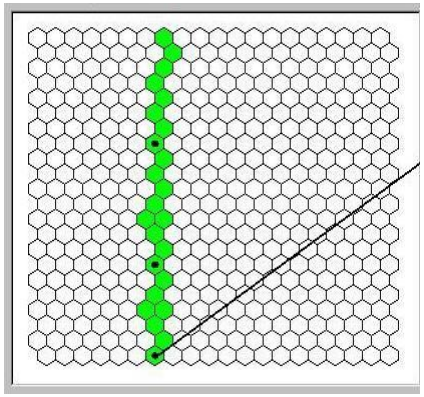
Many Uses of Laser “Test Beams”



- Check Cabling of FD
- FD-SD Clock offsets
- Check Pointing of FD
- Study FD Angular resolution
- Atmospheric Clarity (Time, Eye)
- Clouds
- Up-Time & Triggering Studies
- Measure speed of the Laser track
- End to End test of Absolute Photometric Calibration

Laser – Air Shower Equivalence





Roving Laser @ 4km

Central Laser @ 27km

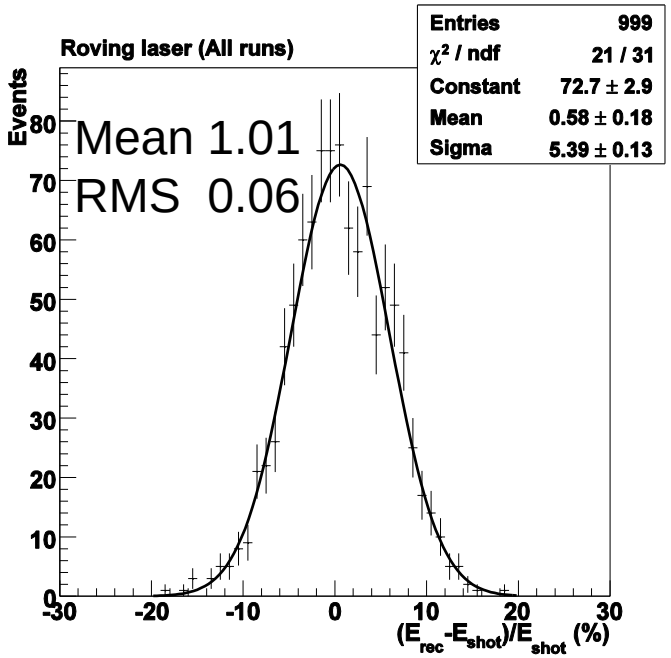
Measure Laser Energy by reconstructing track seen in calibrated FD

Measure Laser Energy Locally with a calibrated pyroelectric energy probe

Laser Tests of Photometric Calibration – *In Progress*

Roving Laser @ 4km

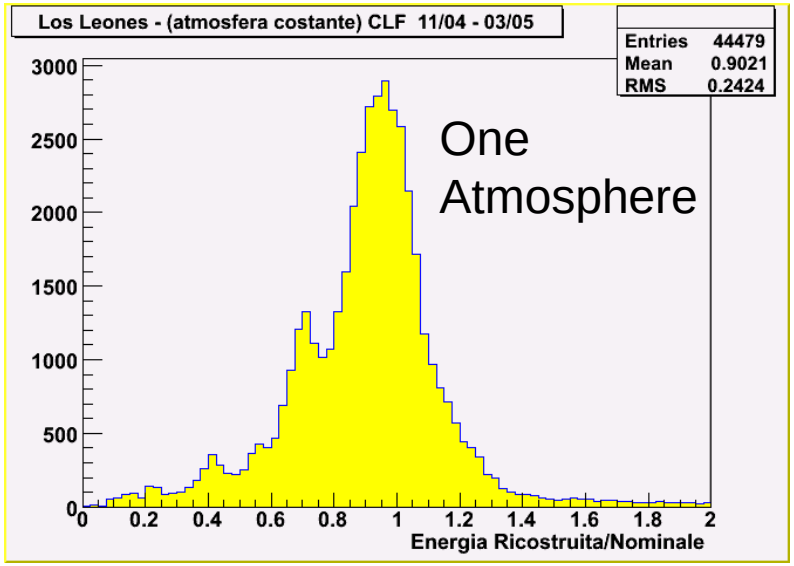
analysis-V. Verzi (Roma)

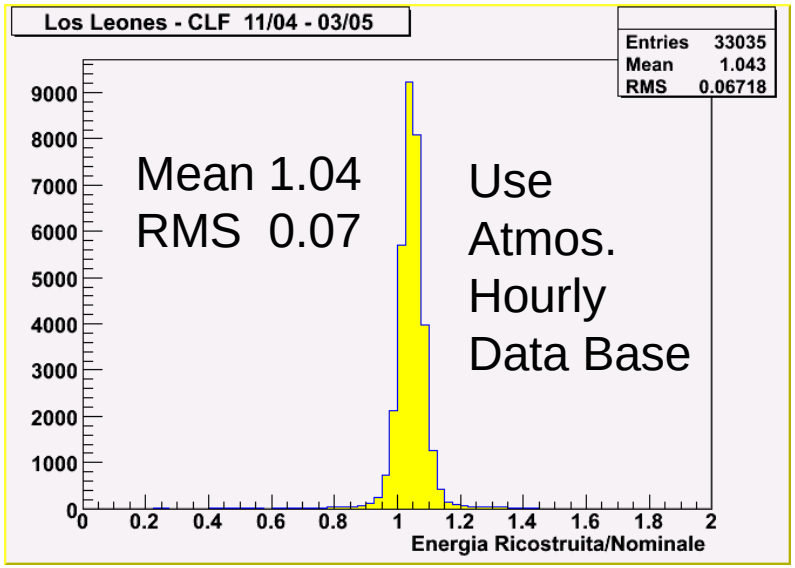


$(E_{rec}-E_{laser})/E_{laser}$

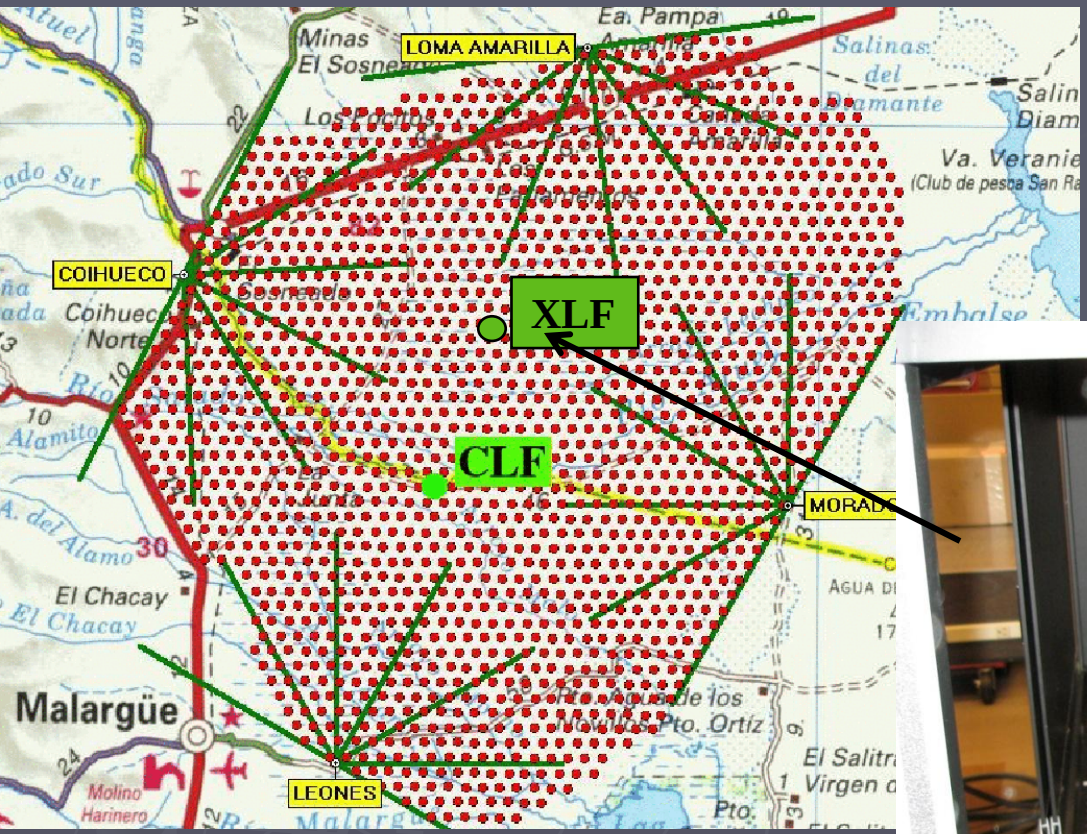
"CLF @ 27 km"

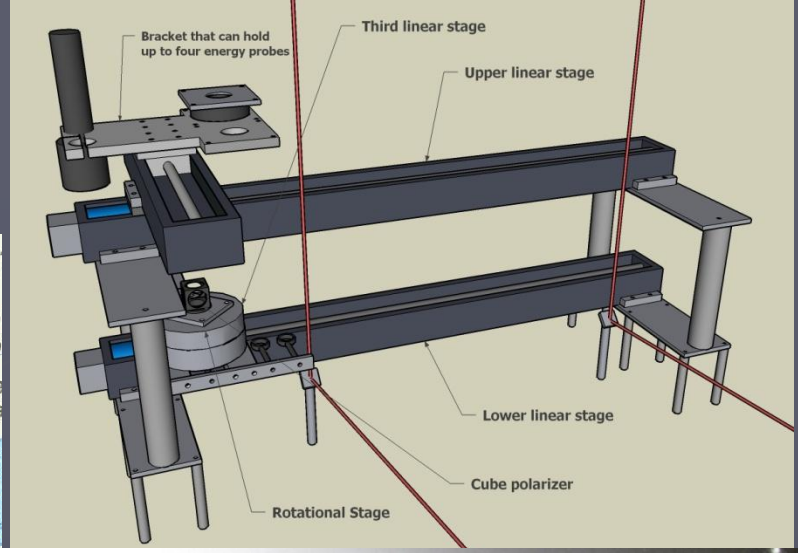
Analysis -L. Valore (Napoli)





eXtreme Laser Facility to be installed October 2008,





The Pierre Auger Observatory of Ultra-High Energy Cosmic Rays

Northern site : Colorado

21000 km^2

(Planned)

> 300 PhD scientists from
> 70 Institutions
and 17 countries

Argentina
Australia
Brazil
Bolivia*
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
UK
USA
Vietnam*

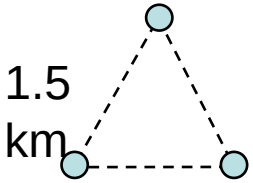
Associate Countries

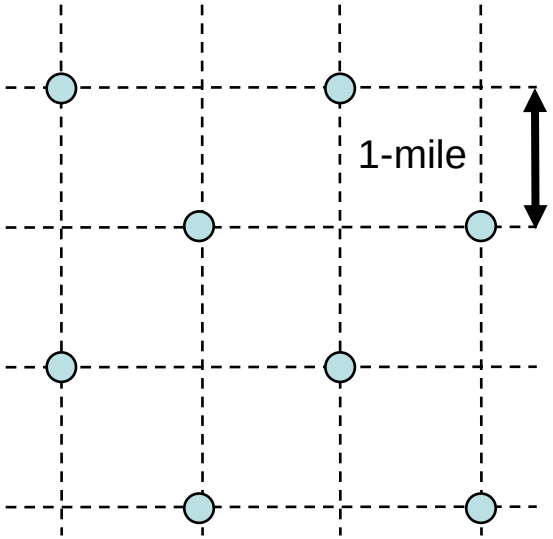
Southern site: Argentina

3000 km^2 1x provencia Pavia

(Operational)

	South	North
SD units	1,600	4,400
SD area	3,000 km^2	21,000 km^2
	3 light sensors	1 light sensor
	Non-insulated	Insulated
	tank→center comms	tank→tank





	4 buildings with 6 telescopes each	≈ 7 buildings with 6 telescopes each
	large stereo coverage	little stereo coverage

Conclusion

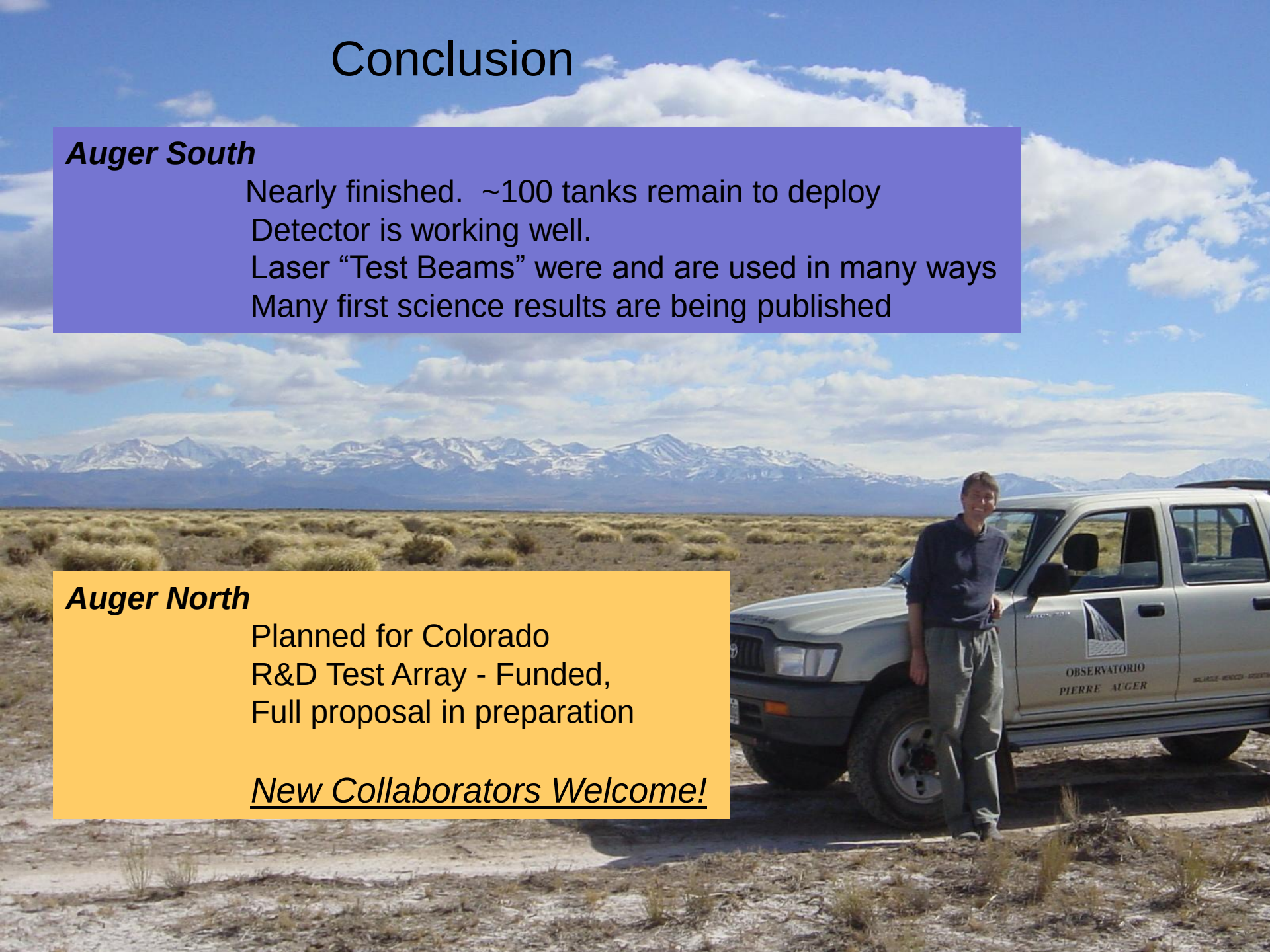
Auger South

Nearly finished. ~100 tanks remain to deploy
Detector is working well.
Laser “Test Beams” were and are used in many ways
Many first science results are being published

Auger North

Planned for Colorado
R&D Test Array - Funded,
Full proposal in preparation

New Collaborators Welcome!



Fluorescence Detector Photometric Calibration

Drum for uniform illumination of each fluorescence camera

Calibrated Roving Nitrogen Laser: Deliver known light flux via scattering

Atmospheric Monitoring

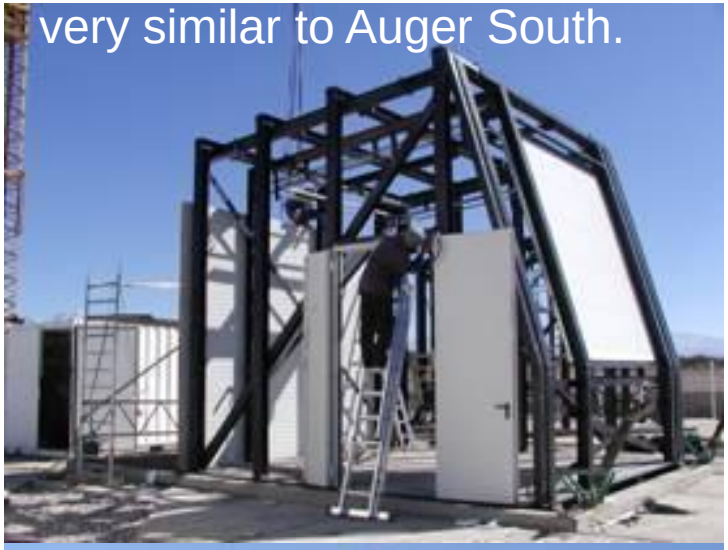
LIDAR at each fluorescence eye for atmospheric profiling - “shooting the shower”

Radiosondes for air density profile

R&D for Auger North

HEAT = **R&D for northern FD**
Being installed at Auger South.

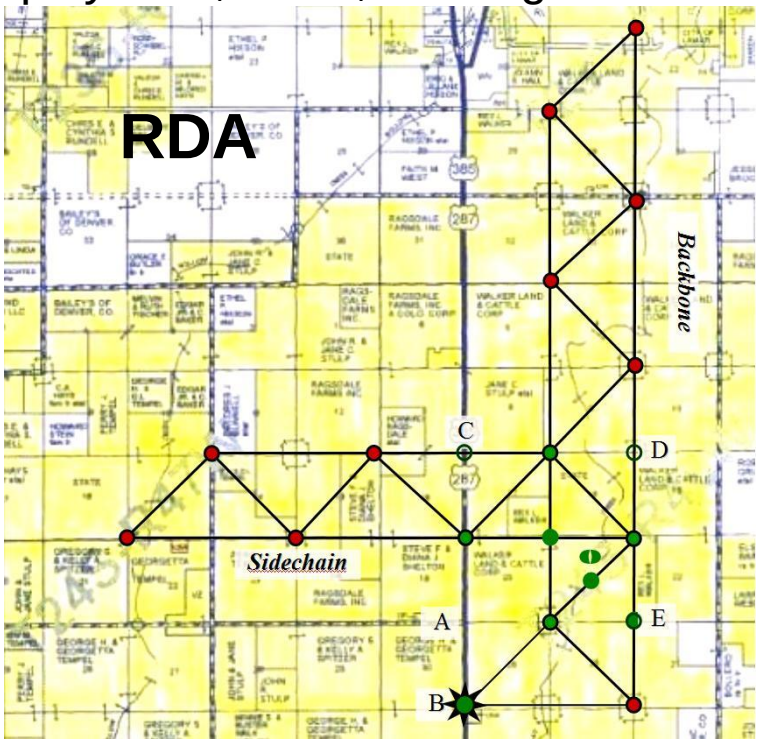
Mostly European effort.
New electronics. Telescopes very similar to Auger South.



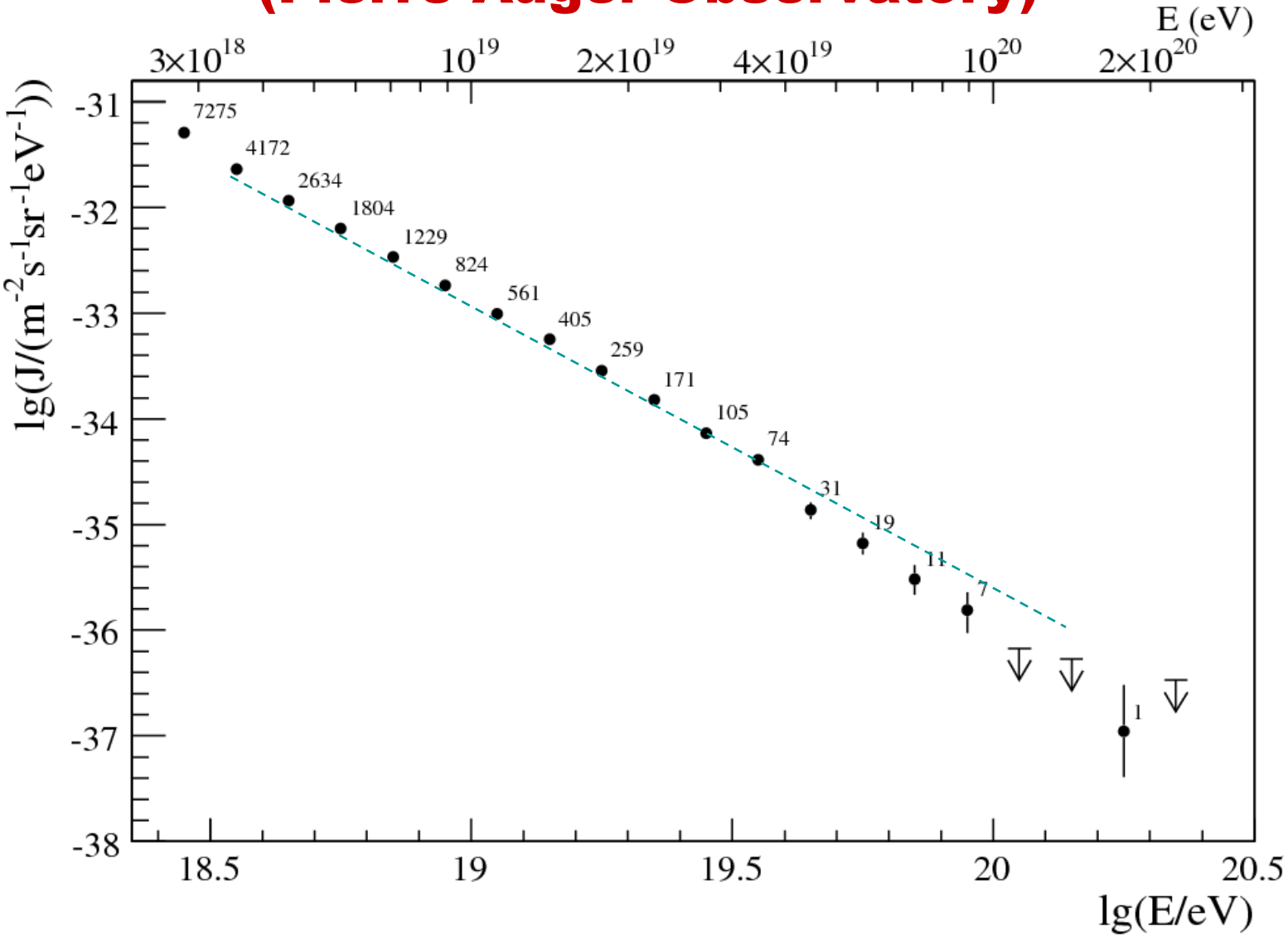
R&D Array (RDA) south of Lamar for **SD and Comms systems.**

10 SD units + 10 additional comms-only stations. US + European effort

New tank – freezing challenge
New comms – rolling terrain
End-to-end test of SD w/ comms
Deployment, water, working in SE CO

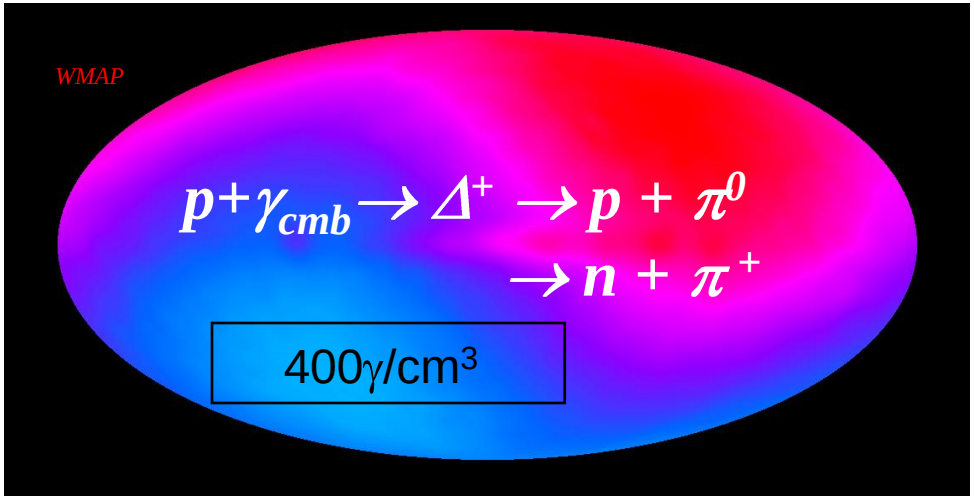


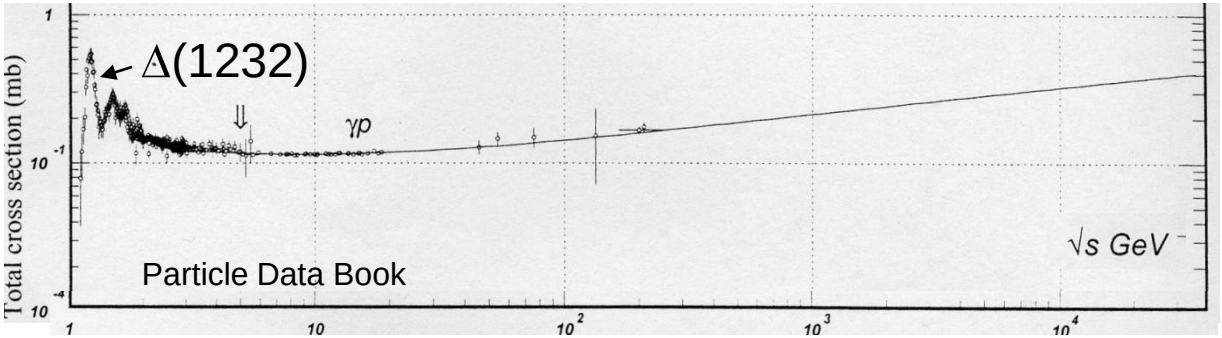
Cosmic Ray Energy Spectrum
(Pierre Auger Observatory)



SD events, $\theta < 60$ 20000 events $> 3 \cdot 10^{18}$ eV submitted to PR

Cosmic Rays Loose Energy in the Cosmic Microwave Background Radiation





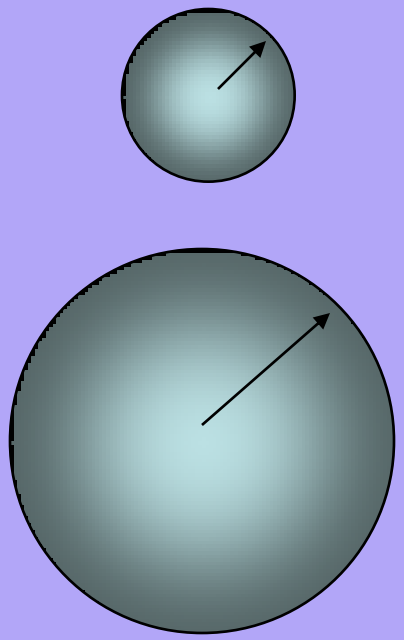
Energy Threshold ~ 5 x 10^{19} eV

Distance Scale is a strong function of Energy

One Motivation for Energy Calibration

$\Delta E/E$ 25%
$\Delta V/V$ >10

(for protons in CMBR)



8×10^{19} eV
90 MPC

6×10^{19} eV
200 MPC

$\Delta E/E$ of 1% corresponds to a change in volume of ~10^6 MPC^3

Our local supercluster of galaxies occupies 10^5 MPC^3

1 MPC = 1 Million parsecs = 3 Million Light Years