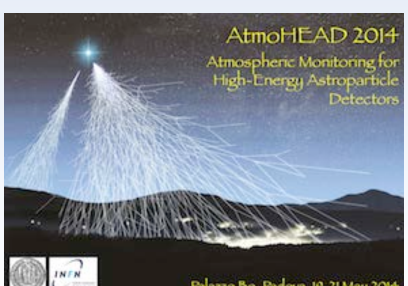
Science and More with Lasers and Astroparticle Observatories



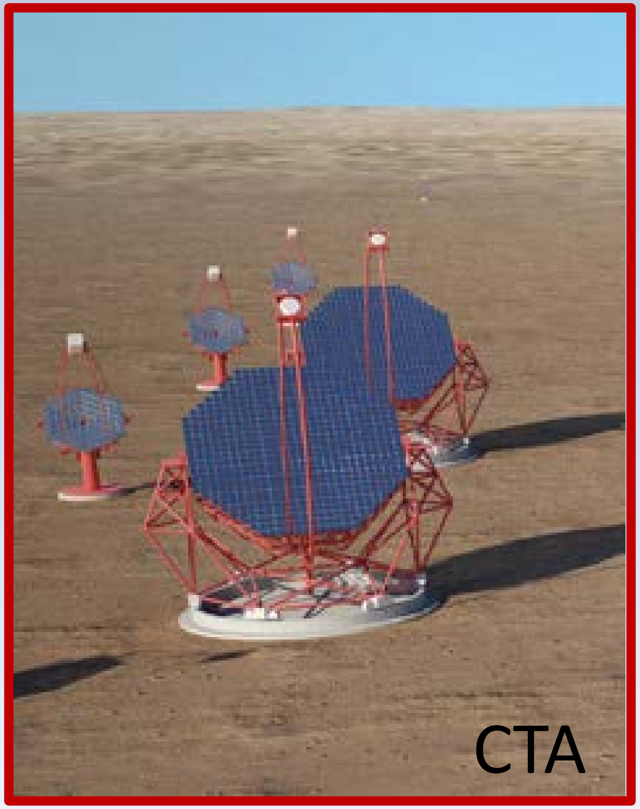
Lawrence Wiencke
Colorado School of Mines
AtmoHEAD May 19 2015
Padua Italy
lwiencke@mines.edu

International Workshop on
Interdisciplinary Science and Astroparticle Detectors

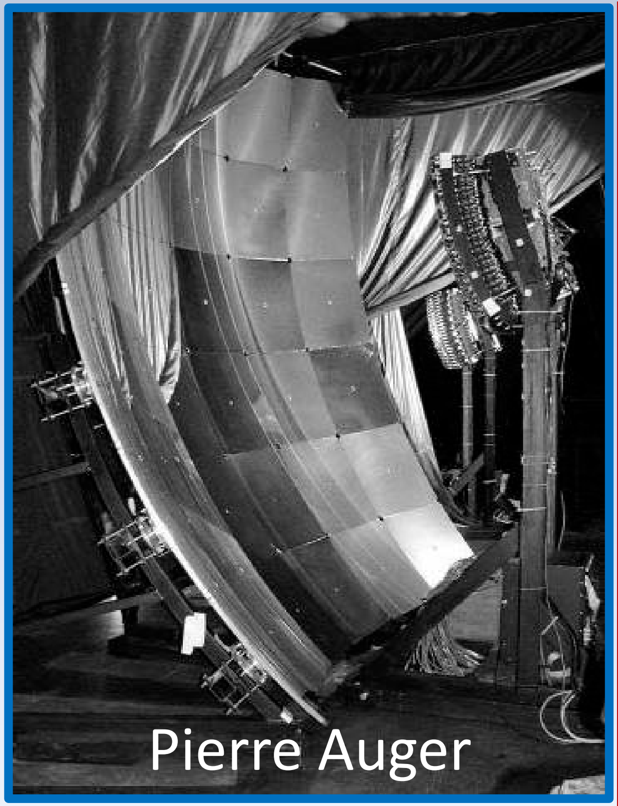
- **Atmospherics**
- **Elves**
- **Lightning**
- **Climate**

Colorado School of Mines   Golden Colorado   June 2015

Examples of Remarkable Observatories in operation and planned

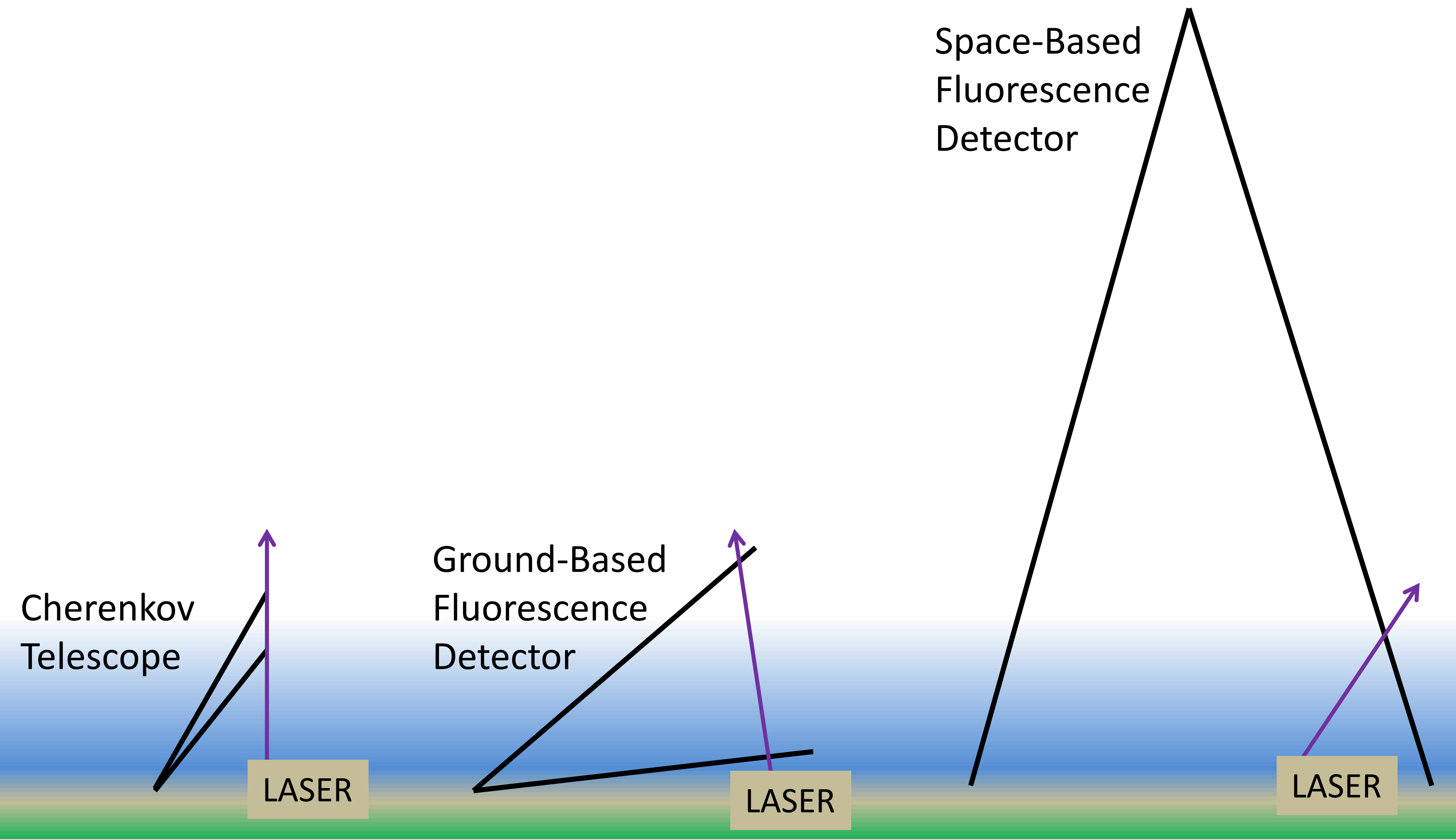


Air Cherenkov



Ground-based
Fluorescence
+ Surface Detector

Space-based
Fluorescence


Space-Based
Fluorescence
Detector
Cherenkov
Telescope
Ground-Based
Fluorescence
Detector
LASER
LASER
LASER

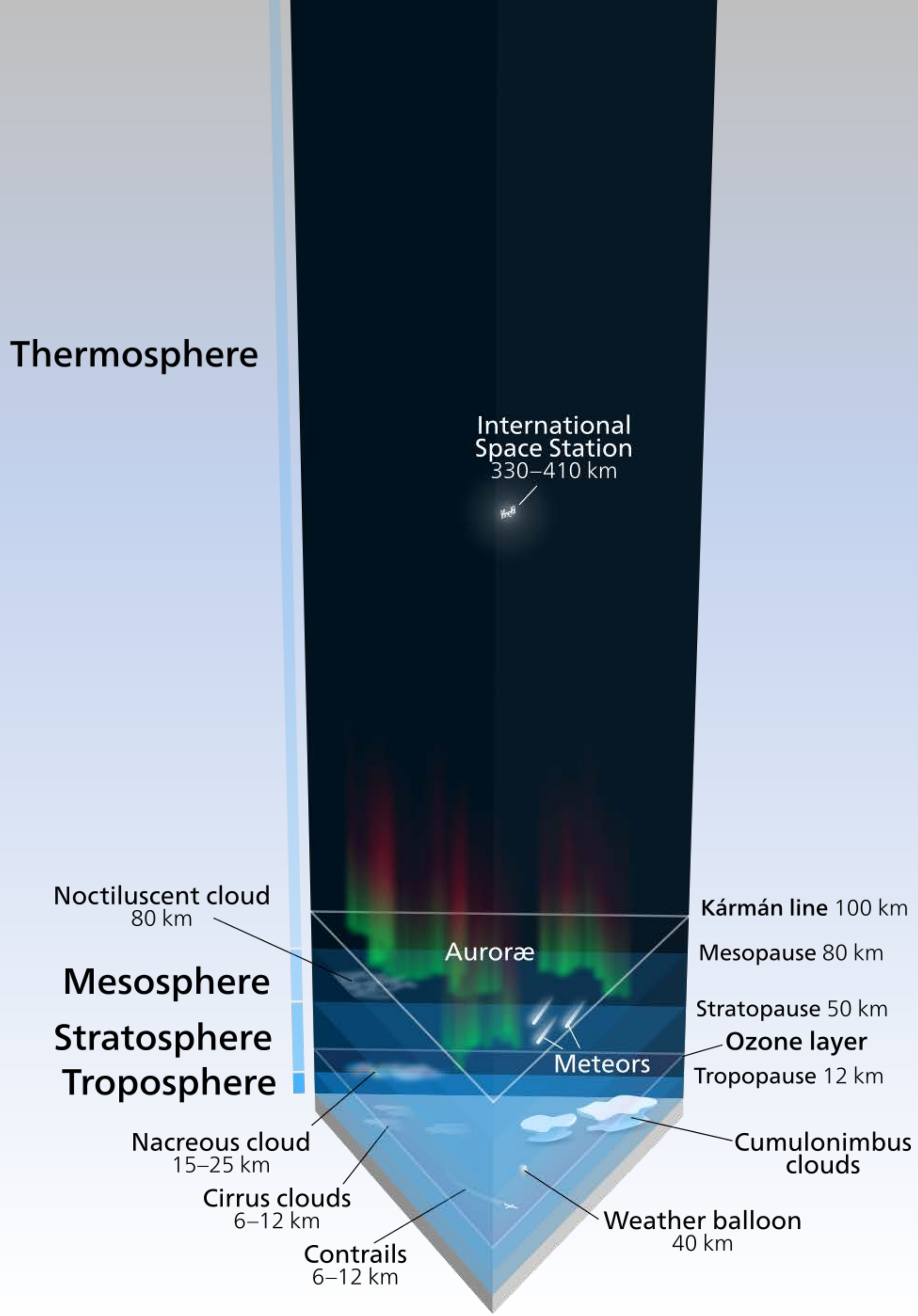
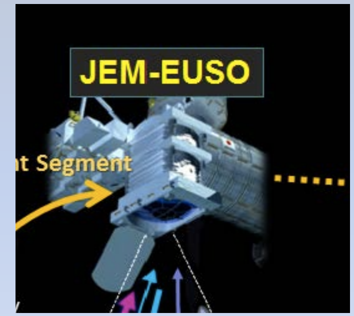


Image credit:
Wikimedia Commons
user Kelvinsong.

Optical Test Beams and Optical Cosmic Ray Detectors

Fly's Eye (1980-1993)	High Resolution Fly's Eye 1992-2004	Pierre Auger Observatory 2003-Present	JEM-EUSO 2017->



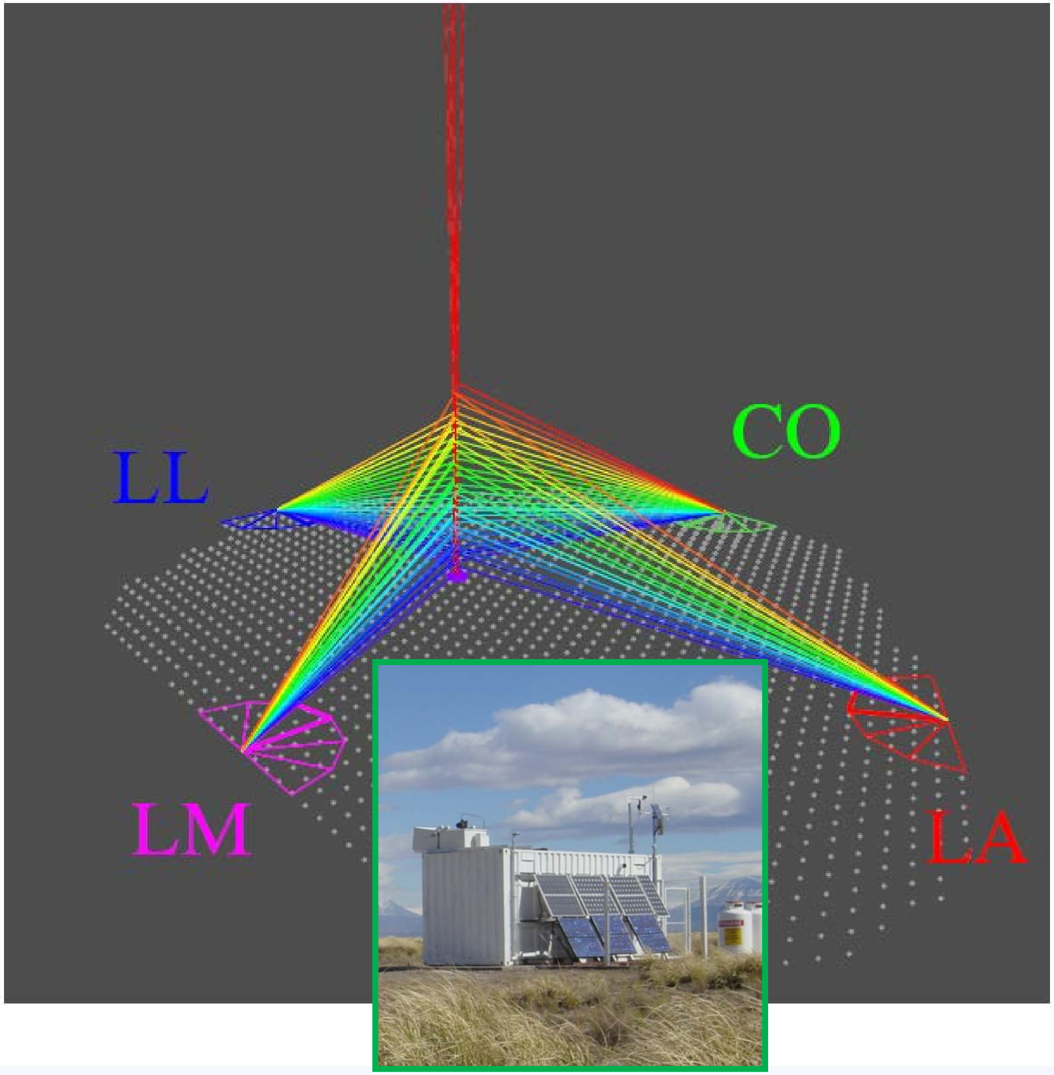
2 km	**13 km**	**27-40 km**	**350-400 km**

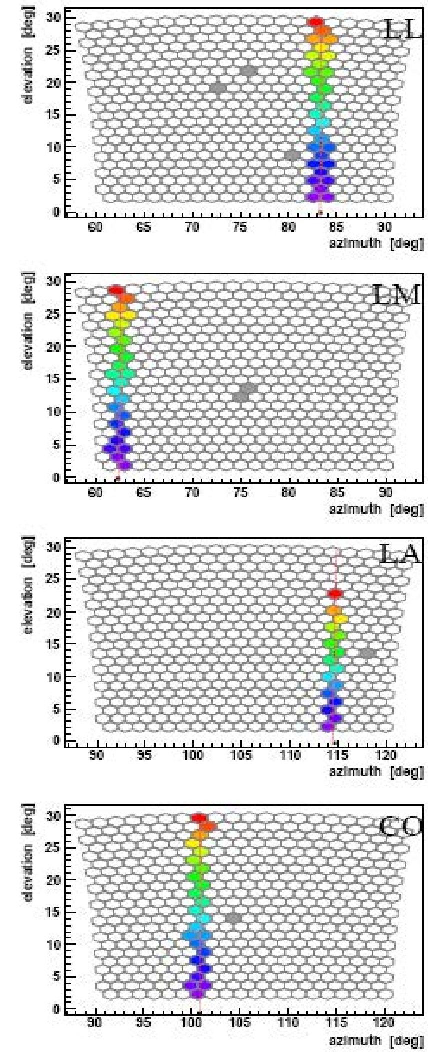



GLS

Calibration Atmospheric Clarity	Aerosol Optical Depth Clouds, Diagnostics	Aerosol Profiles, Clouds, Timing, Calibration ……	Pointing, Timing, Calibration tests ….

The Pierre Auger Observatory: A Quad-Quasi-Static LIDAR system





http://astroserve.mines.edu/lasers

COLORADOSCHOOLOFMINES
EARTH • ENERGY • ENVIRONMENT

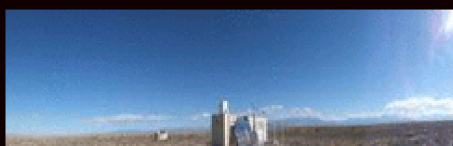
Atmospheric Laser Test Beams for the Pierre Auger High Energy Cosmic Ray Observatory and JEM-EUSO

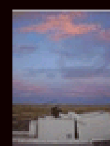
Locations: Malargüe Argentina and Colorado USA (R&D) and Global (JEM-EUSO GLS)

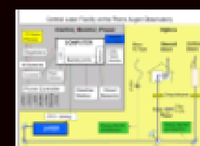
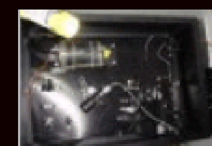
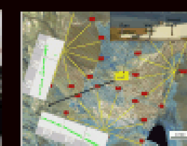
Applications: Atmospheric Measurements, Targeting Astrophysical Objects, Upward-Going Events, Cosmic Ray Detector Performance Monitoring, GPS Timing, Photometric Calibration

Contacts: Lawrence Wiencke Carlos Medina

Pierre Auger Central Laser Facility *Latest Plots*





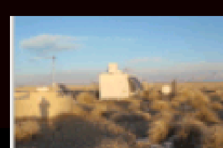




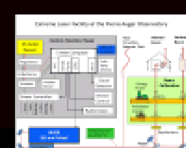
CLF (2003-2013(March): *Autolog AGN* Cal (*YY*, *MM*, *DD*)

CRLF (June 2013 - Present): Autologs (YY, MM) Cal (YY, MM) Vtmon (YY, MM)

IR Cloud Mon. (2005-Present) Volts - Temps Mon. (2003-Present)

Pierre Auger eXtreme Laser Facility *Latest Plots*



XLF (2008-Present) Autologs (YY, MM, DD) Cal Const Cal (YY, MM, DD) Root Cal (YY, MM)

Beam Calibration Plots Polarization Plots plottingprograms.pdf

IR Cloud Mon. (2008-Present) (YY, MM, DD) Volts-Temperatures (2008-Present) (YY, MM, DD)

Some References

Techniques for measuring aerosol attenuation using the Central Laser Facility at the Pierre Auger Observatory Pierre Auger Collaboration *JINST* 8 P04009 (2013).

Atmospheric Super Test Beam for the Pierre Auger Observatory, L. Wiencke for the Pierre Auger Collaboration et al Proc 32nd ICRC(August, 2011).

The Rapid Atmospheric Monitoring System of the Pierre Auger Observatory, The Pierre Auger Collaboration, JINST 7 (2012) P09001

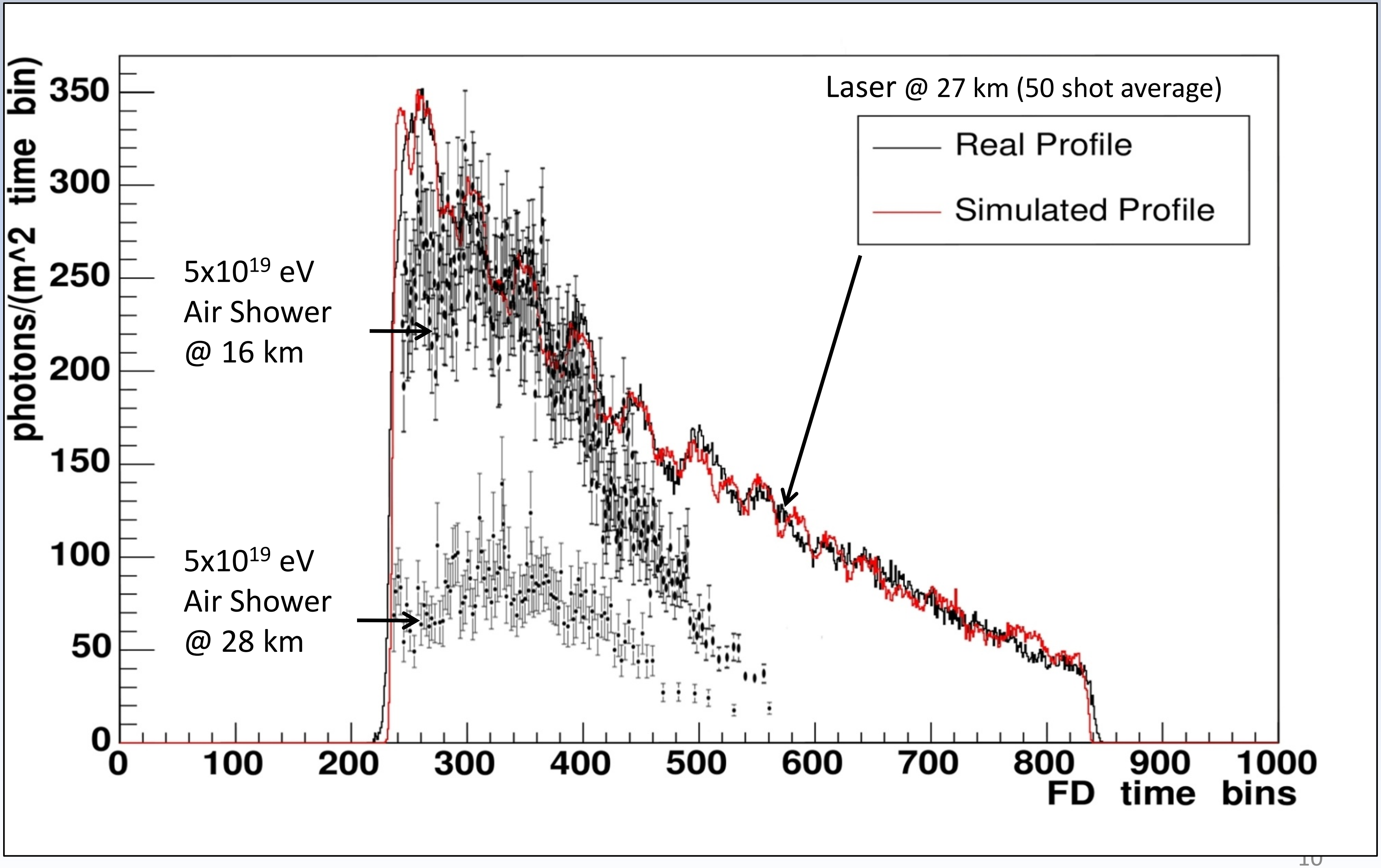
Description of Atmospheric Conditions at the Pierre Auger Observatory using the Global Data Assimilation System (GDAS) The Pierre Auger Collaboration, Astroparticle Physics, 35 (2012), 591-607

A study of the effect of molecular and aerosol conditions in the atmosphere on air fluorescence measurements at the Pierre Auger Observatory, The Pierre Auger Collaboration, Astroparticle Physics 33, 108 (2010).

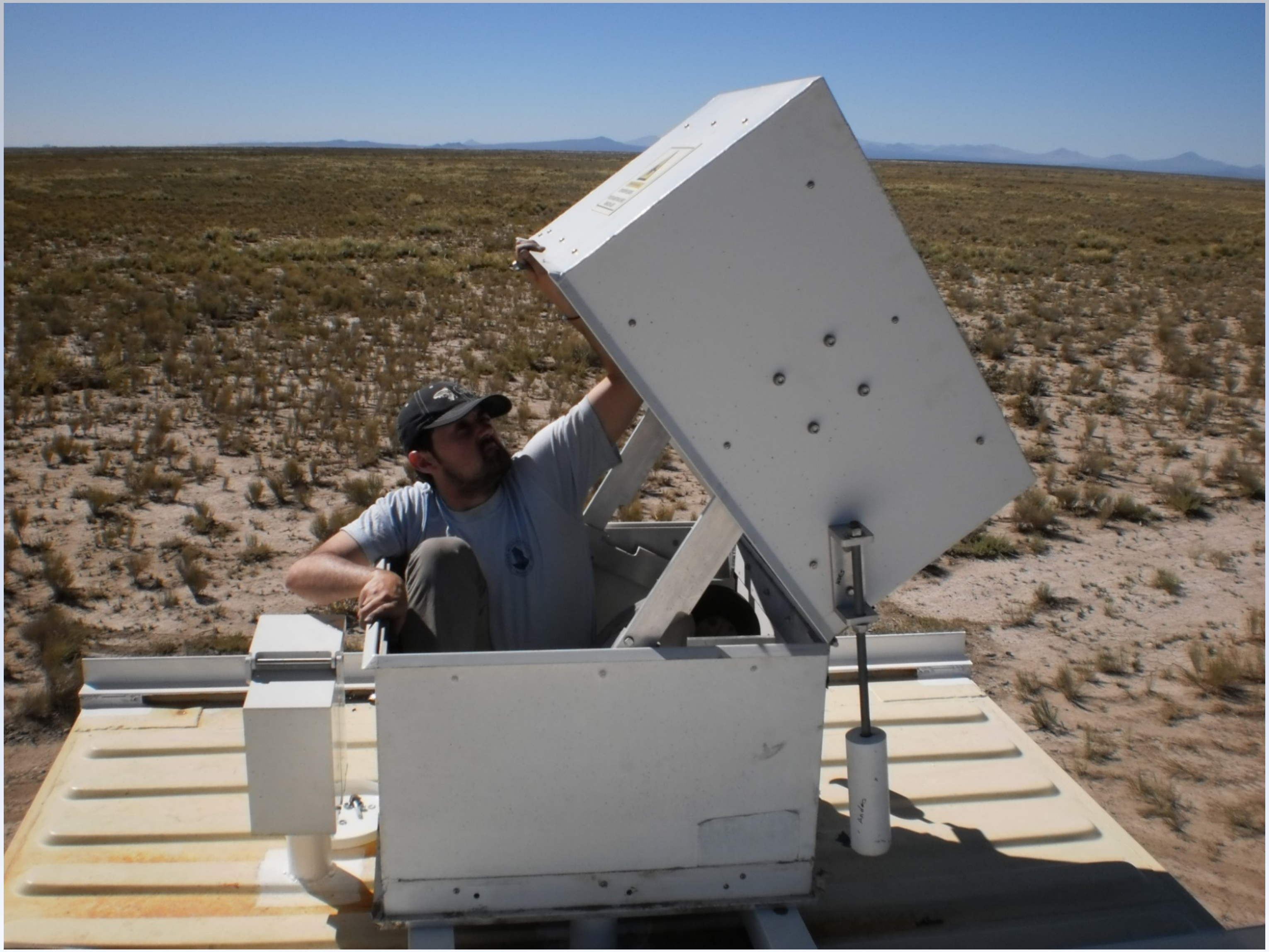
The Fluorescence Detector of the Pierre Auger Observatory, The Pierre Auger Collaboration, NIMA, 620 p227 (2010).

The Central Laser Facility at the Pierre Auger Observatory, B. Fick et al., JINST 1, p11003 (2006).

Laser – Air Shower Equivalence



Laser System – Many fun knobs to turn!

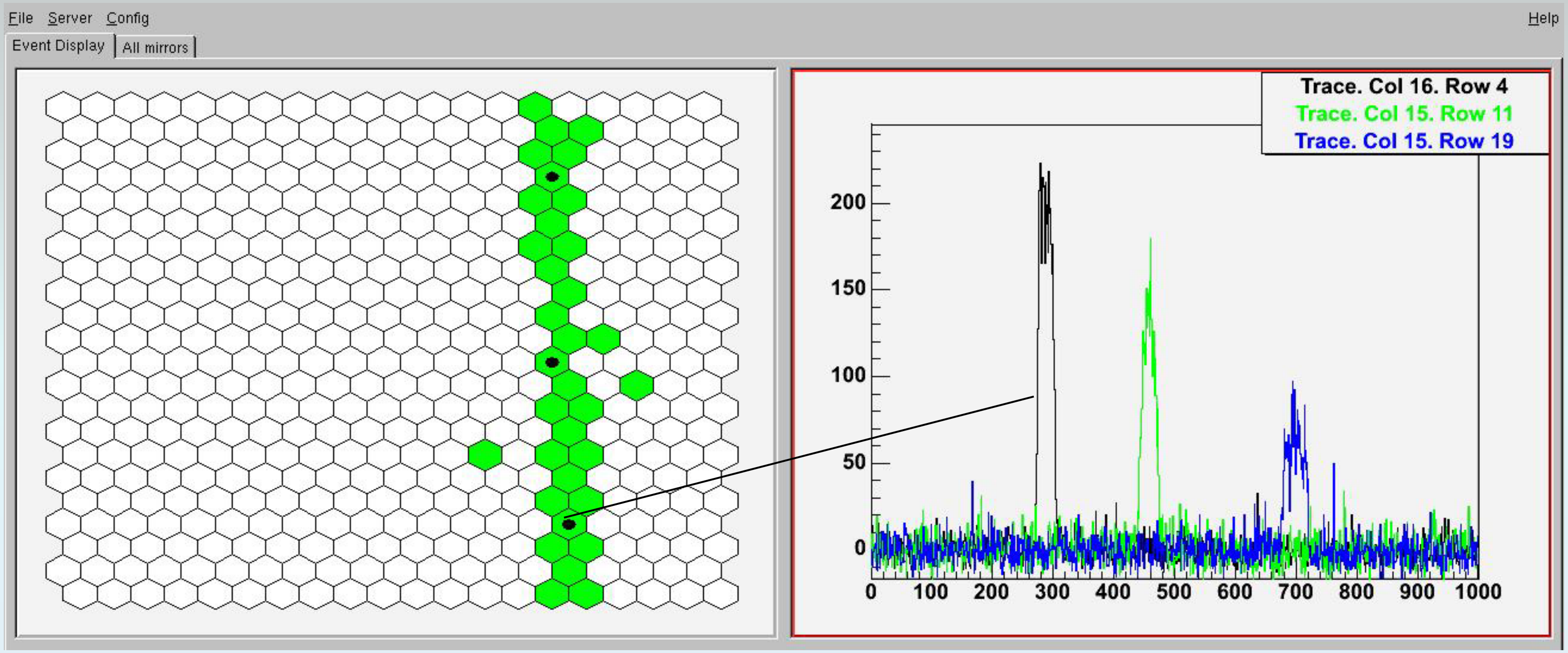


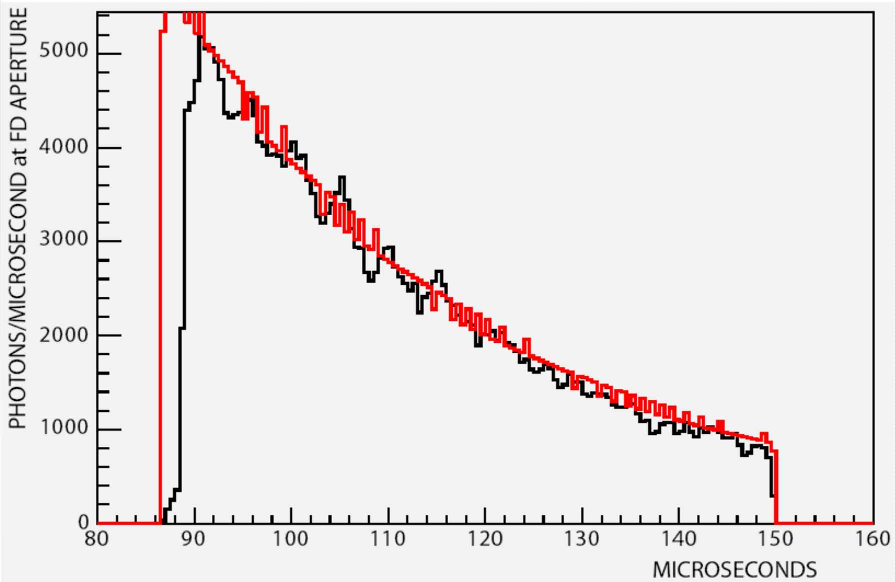
PhD Student Eric Mayotte Auger – CRLF March 2013

Laser System – Fun knobs to turn

- Number of Pulses
- Energy per pulse $E=hc/\lambda$ -> $N\gamma$
- Absolute time (GPS second, Nanosecond)
- Direction (two angles)
- Position (x,y)
- Position (z) not so easy
- Polarization
  - Randomized is best
- Pulse duration (~10 ns typical)
- Wavelength
  - 1064, 532, 355 nm YAG, 337 nm Nitrogen
    variable wavelength much harder

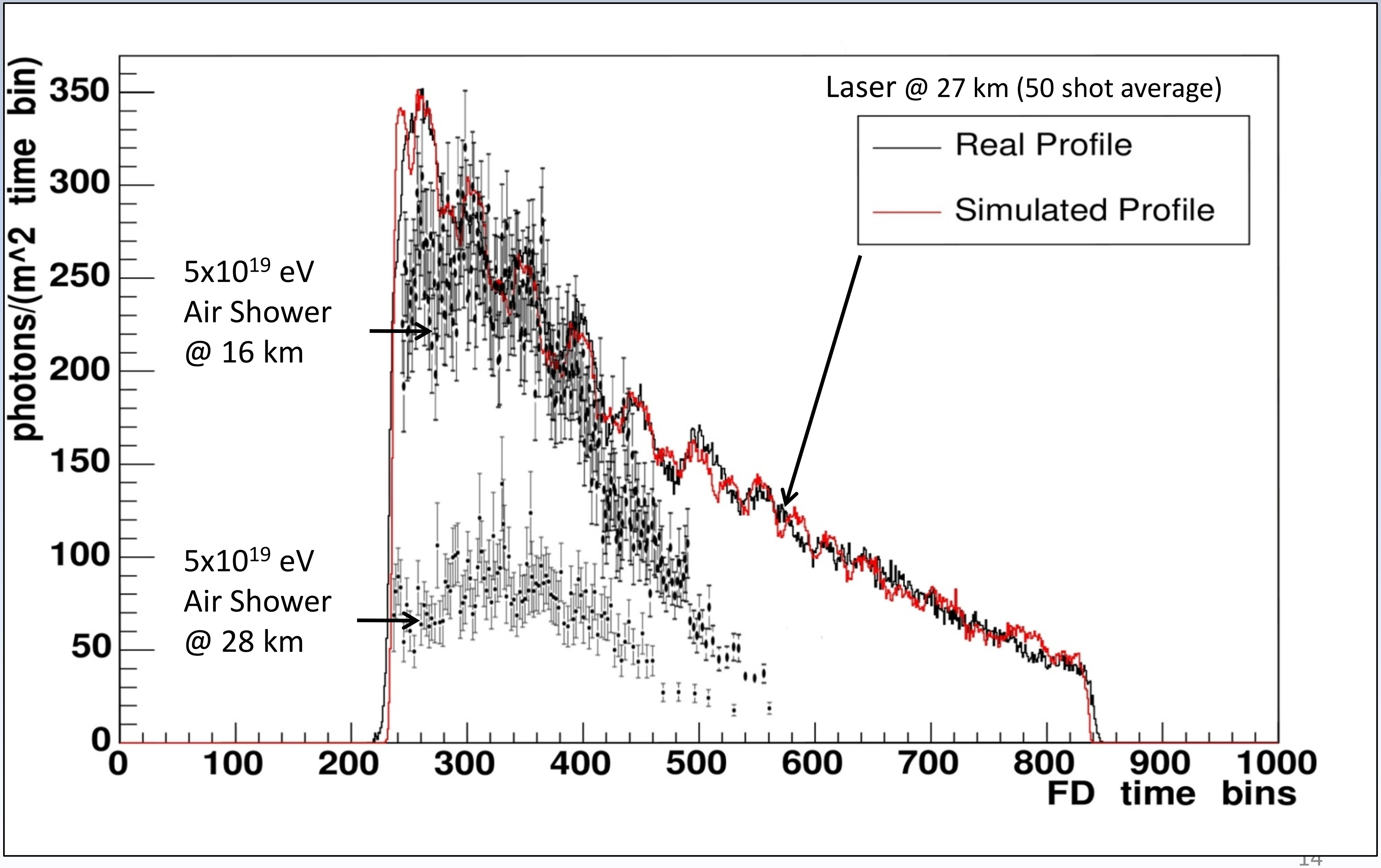
Central Laser Measurements



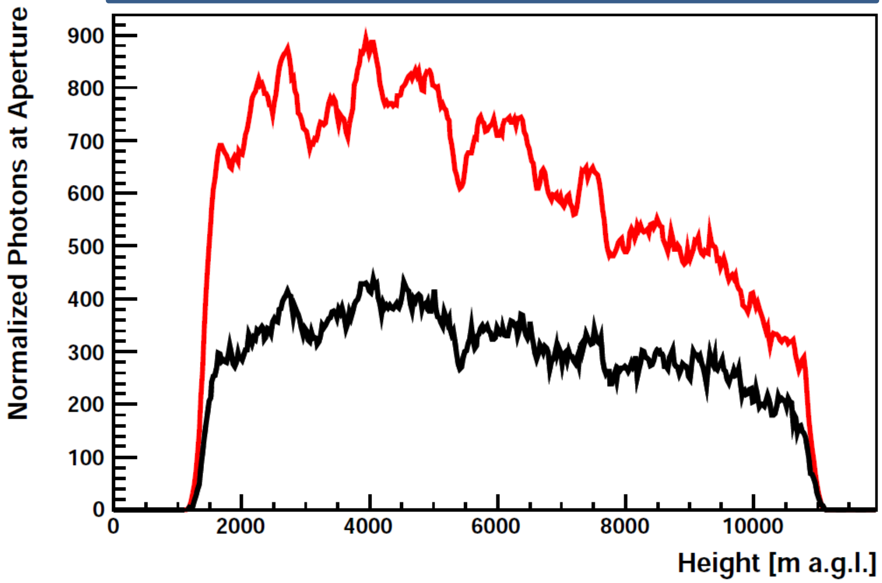


Photons at Los Leones Aperture
Black: Data
Red: Simulation
clear atmosphere
laser energy&polarization

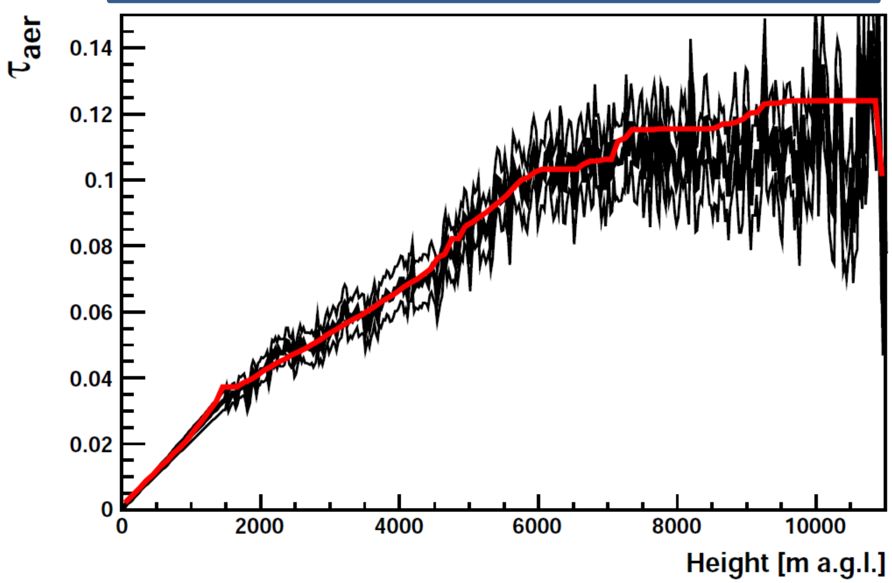
Laser Knobs: Number of pulses, Energy



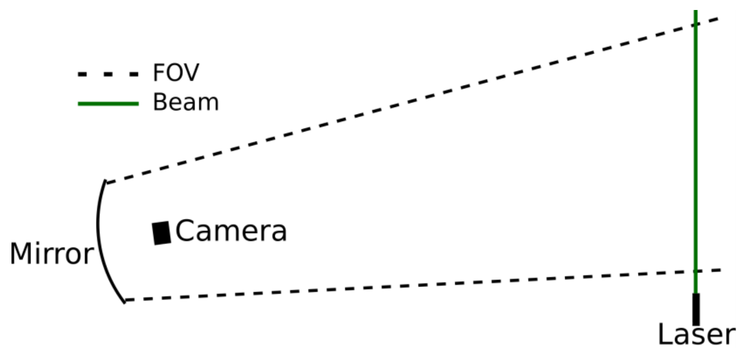
Return Signal & Clear night Rayleigh signal

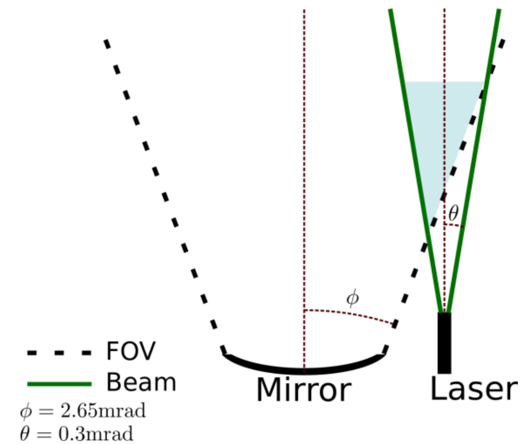


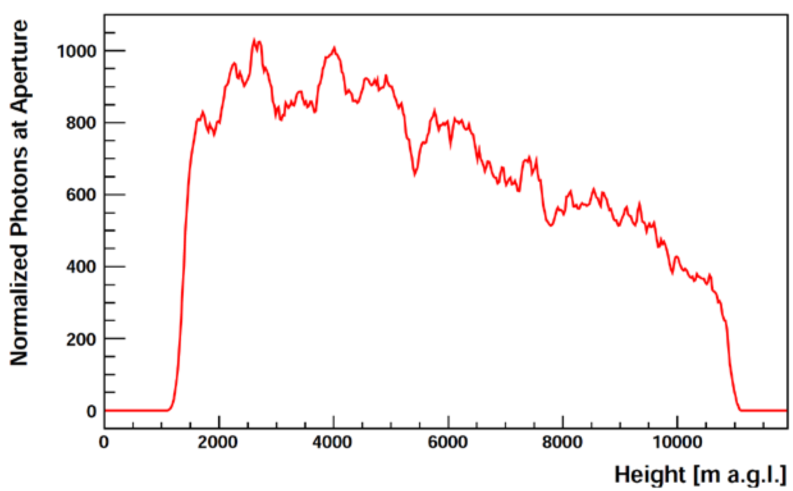
VAOD



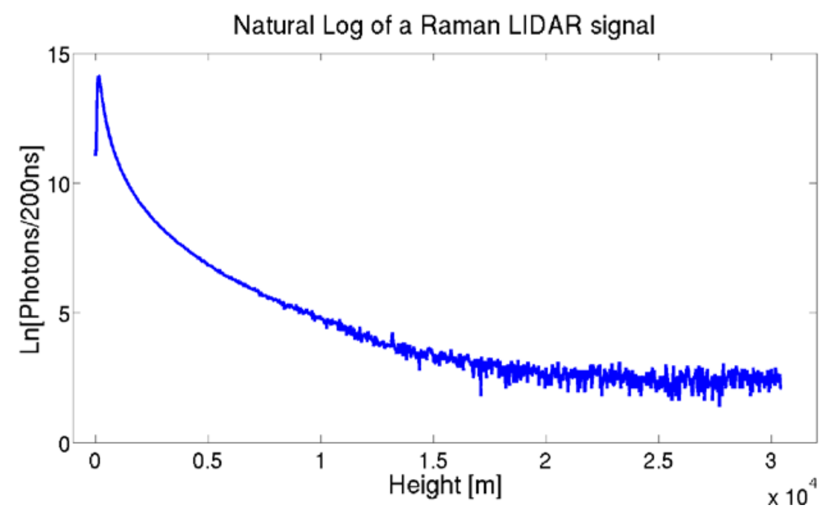
	Elastic Bi-Static LIDAR	Raman LIDAR
Field of View		
Dynamic Range		





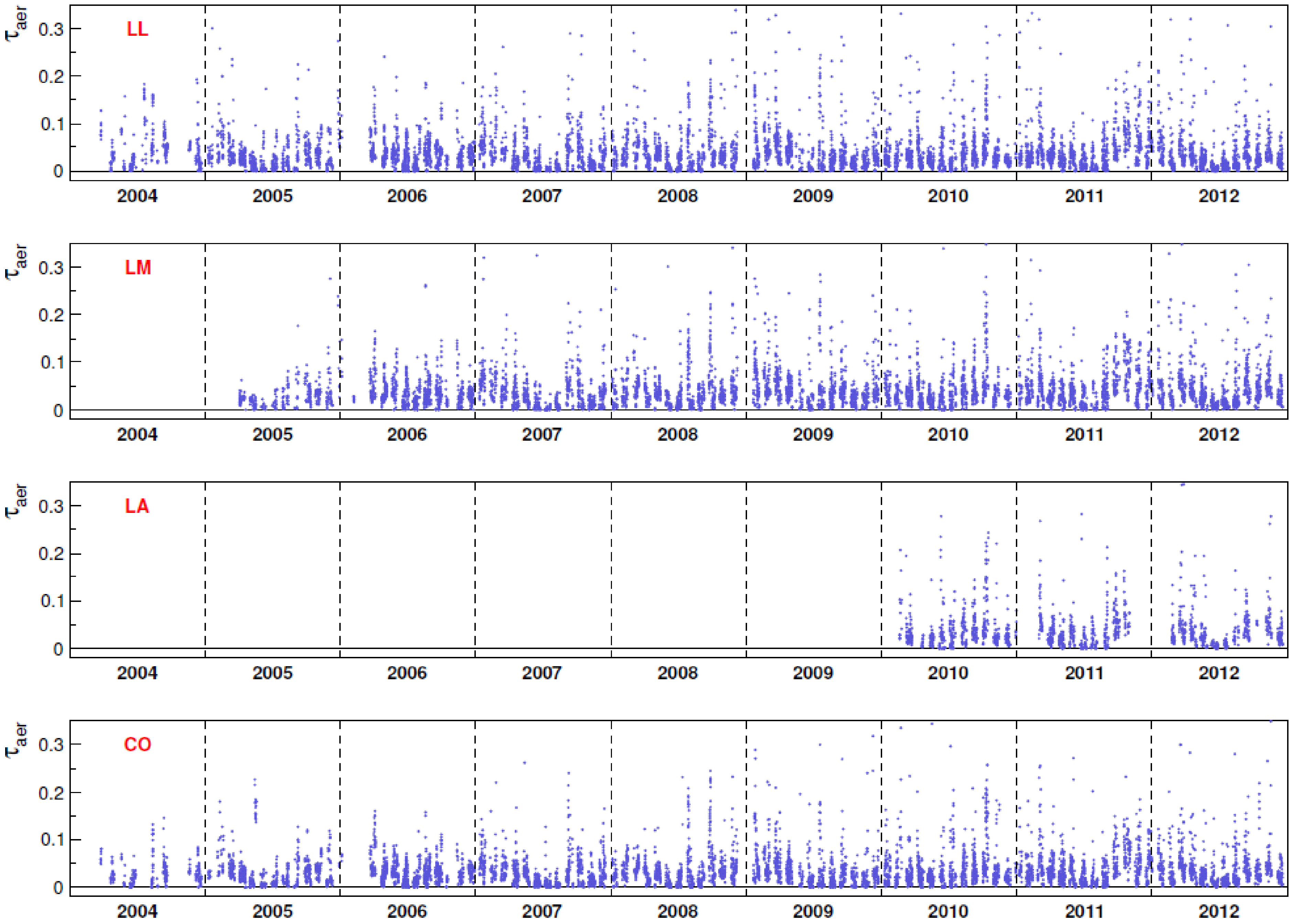


Dynamic range ≈ 600

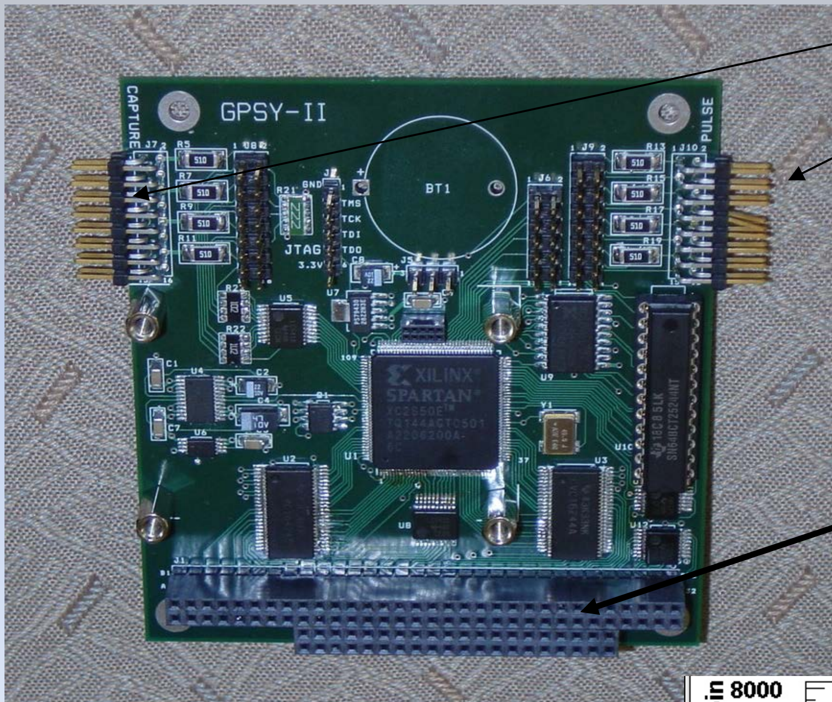


Dynamic range ≈ 10^6

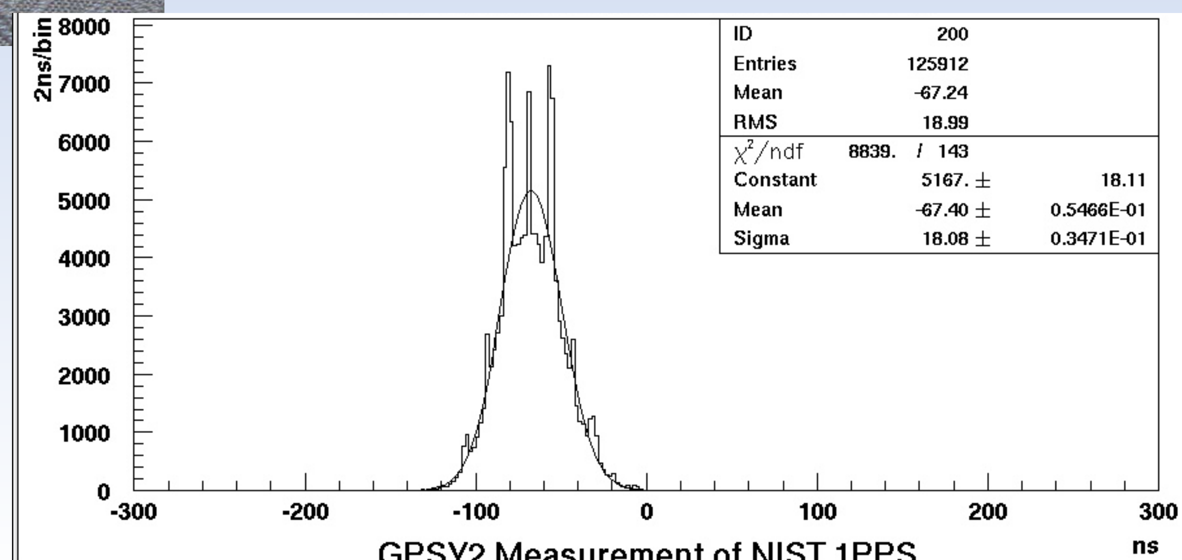
Aerosol Optical Depth (Hourly)



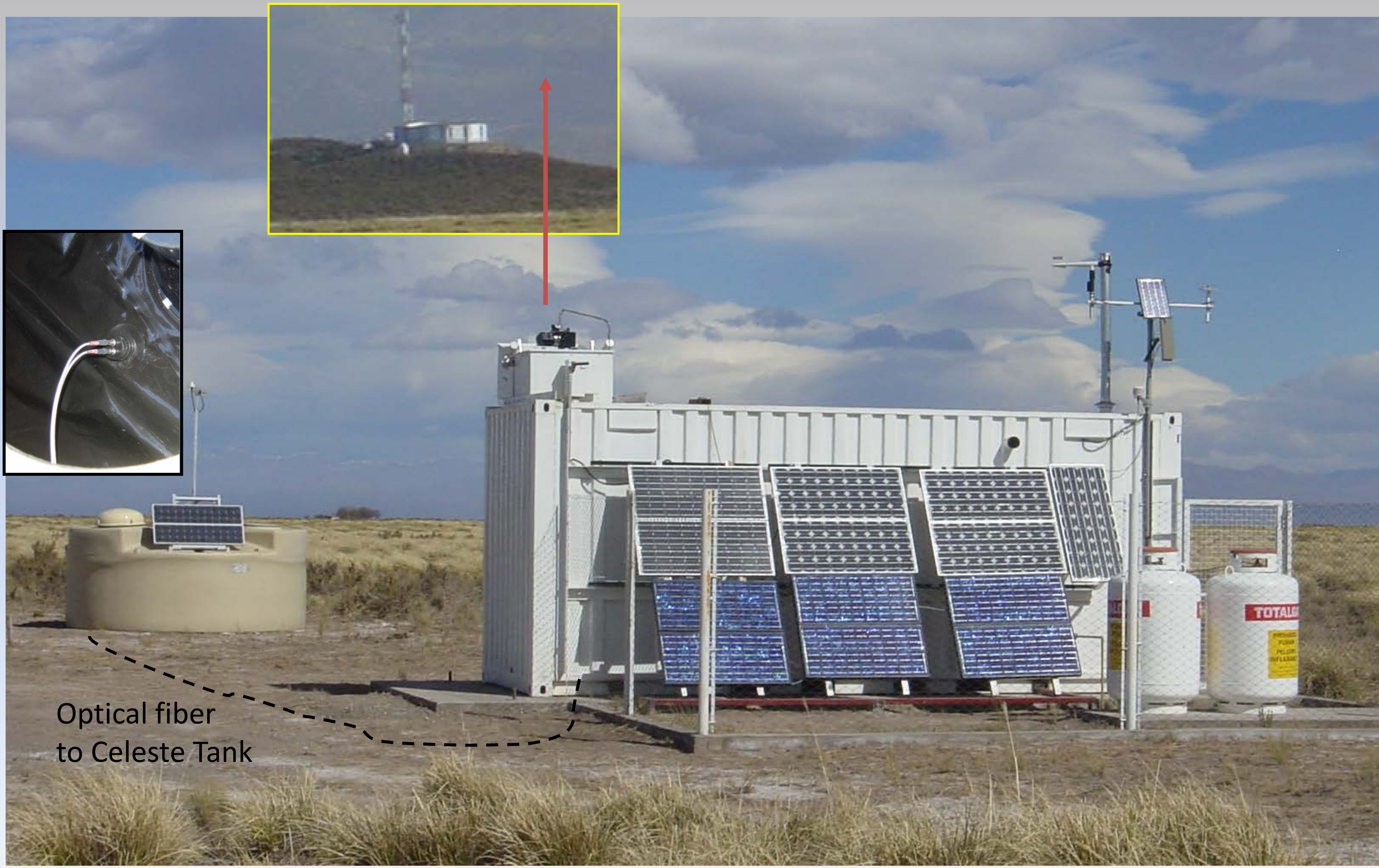
Laser Knobs: Absolute time (GPS second, Nanosecond)



- 8 input channels
  - Time-Stamp digital pulses (25 ns resolution)
- 8 output channels
  - Generate pulses at specific absolute times
- SoftCapt Register (5 bit)
  - Record the absolute time the register is written
  - Profile application programs in absolute time
- On-board GPS reciever
  - Record times and locations
- Industry Standard PC104 board profile
- Software Driver for Linux
  - More than 30 user functions
- Lotus M12 GPS engine (not shown)



US Patent (J. Smith, S. Thomas, J. Thomas, L. Wiencke)

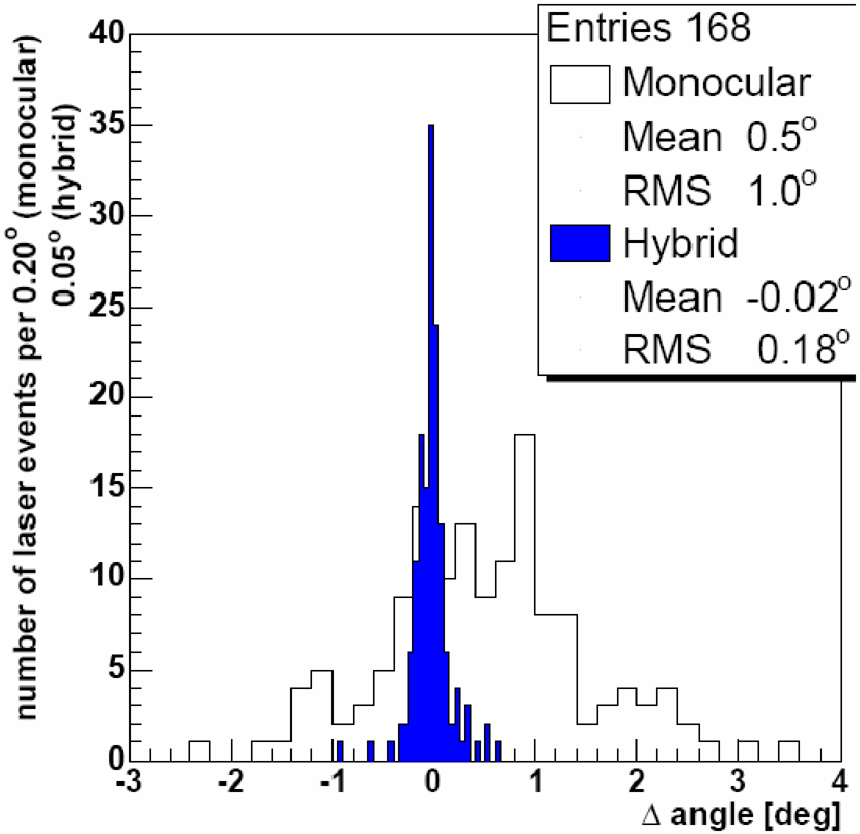


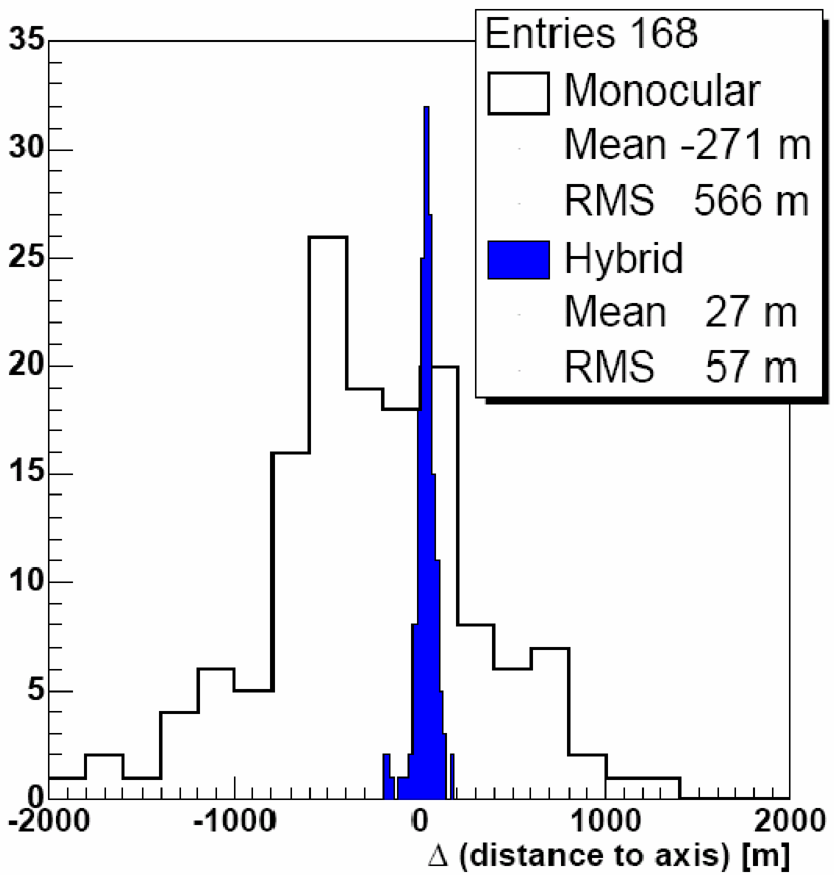
The Cental Laser Facility provides a simulated “Test Beam”

7 mJ uV pulsed laser - optically equivalent to 100 EeV Air-Shower

http://astroserve.mines

Angular and Spatial Resolution from Central Laser Facility





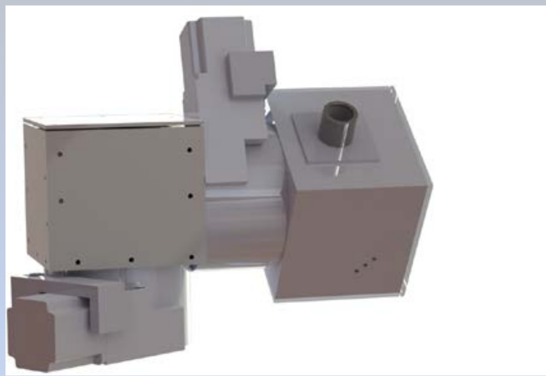
Angle in laser beam /FD detector plane

Laser position – Hybrid and FD only (m)

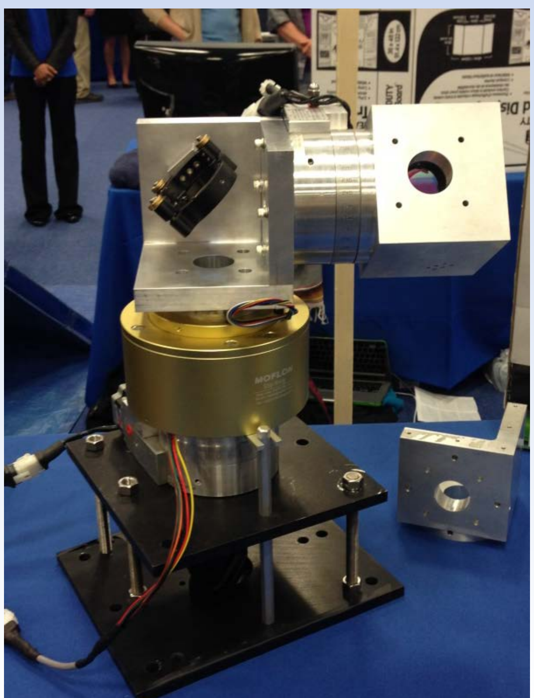
Mono/hybrid rms: 1.0°/0.18°

Mono/hybrid rms: 566 m/57 m

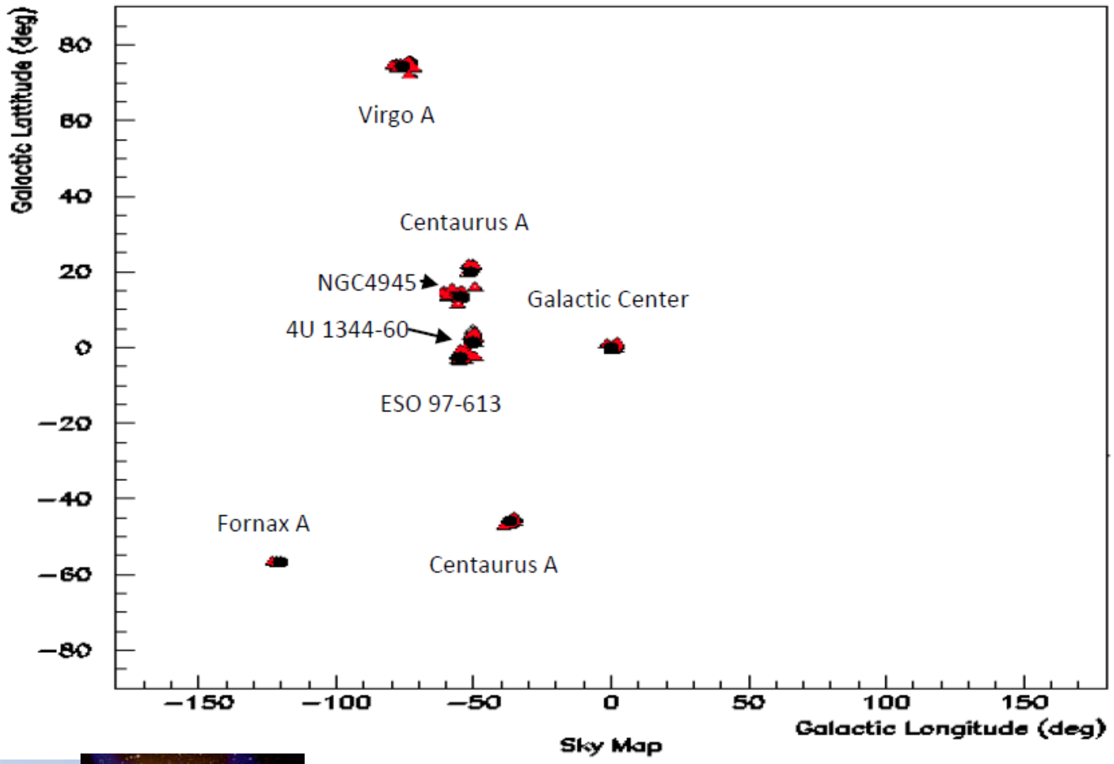
Laser Knobs: Direction

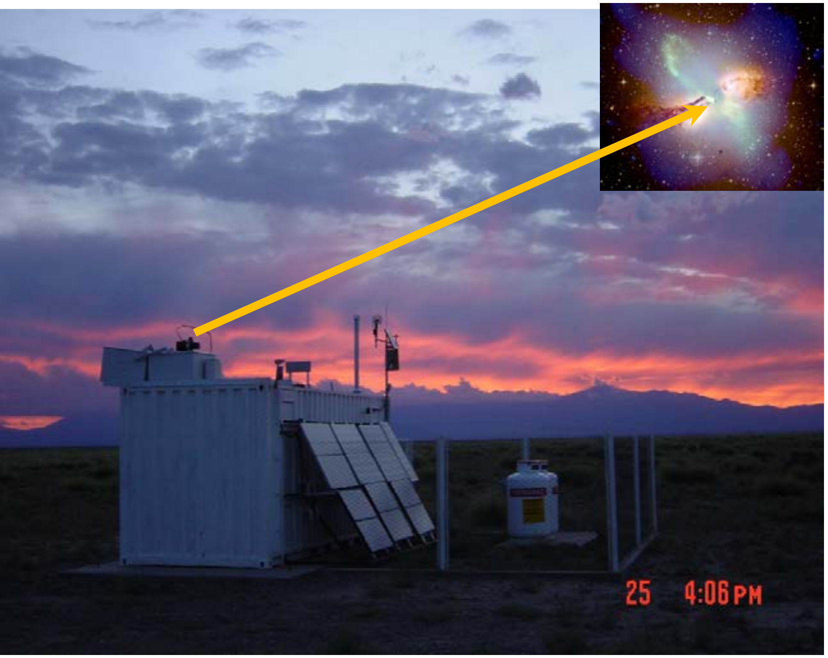


Jeremy Bogulski and Tyler Horvath
Mines Sept 2012-April 2013



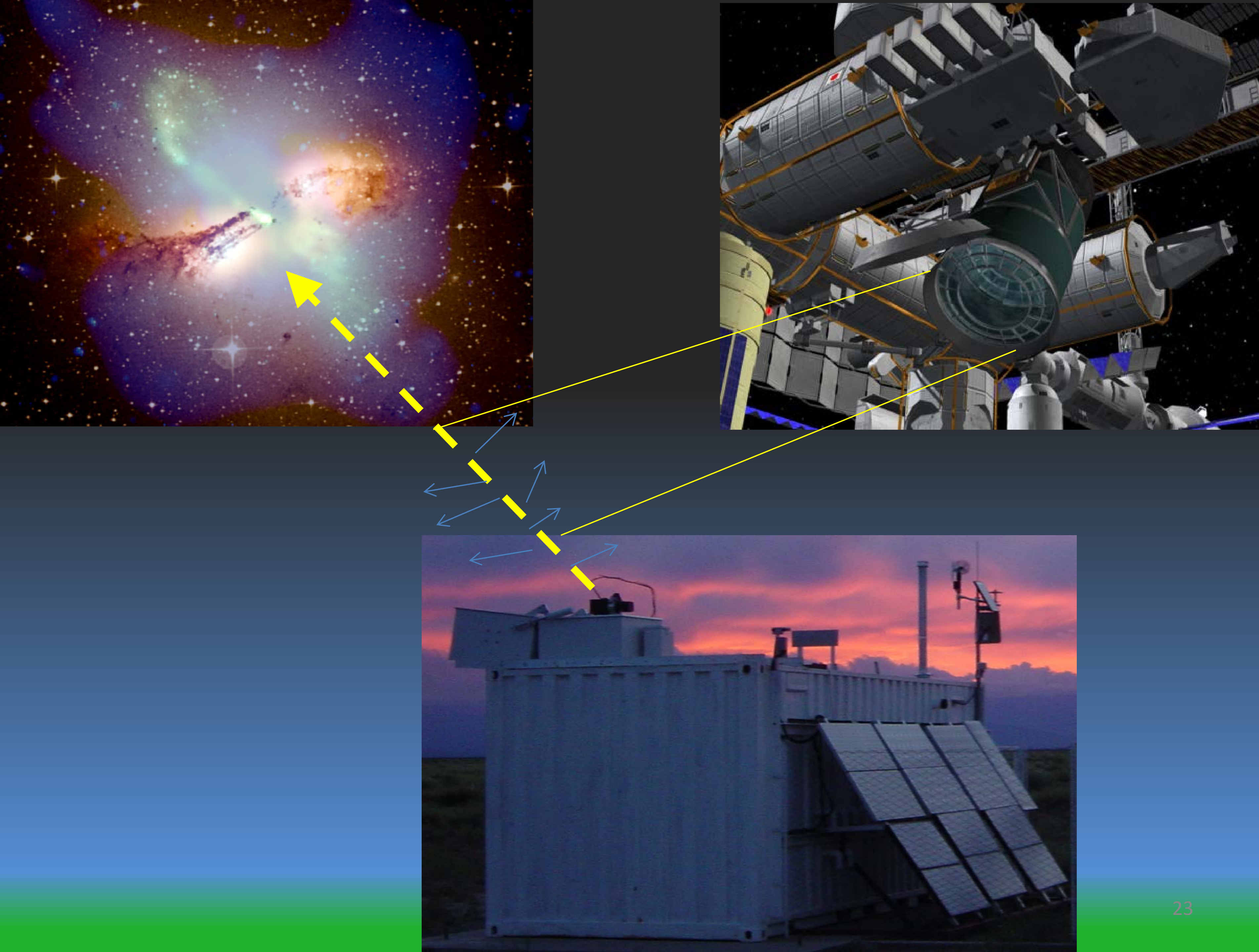
Pierre Auger System





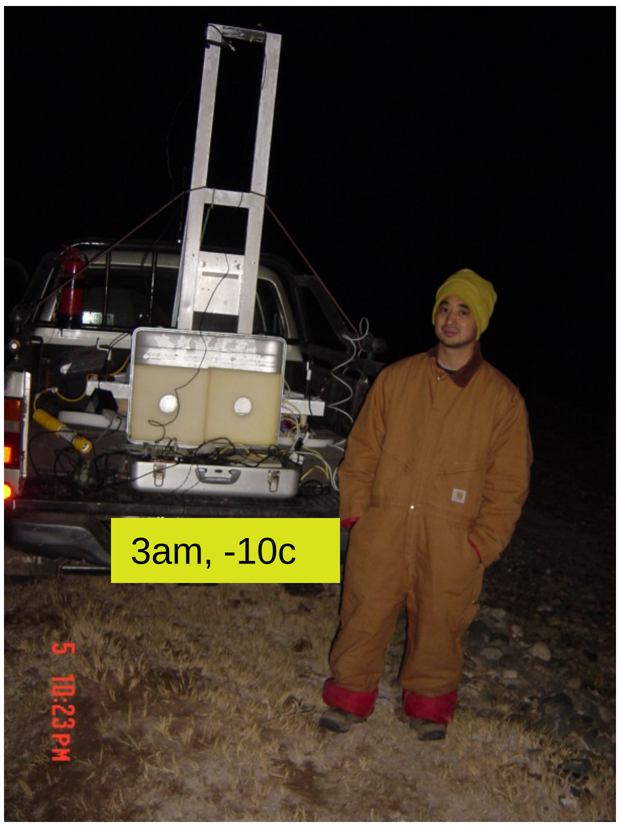
Sky Map of Laser Tracks as Measured by the Pierre Auger Fluorescence Detector

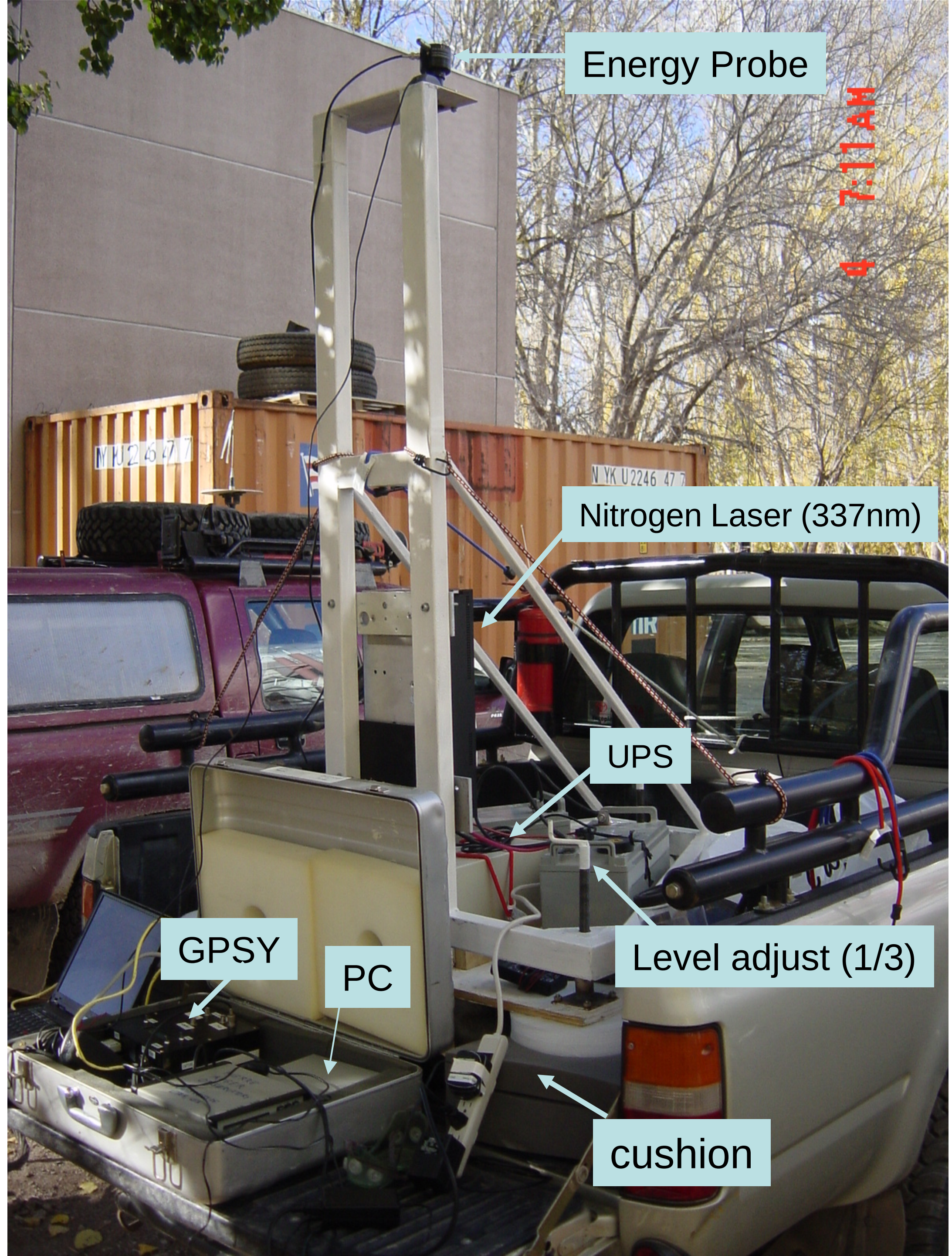
L. Patterson, A. Woolman, S. Hackenburg,

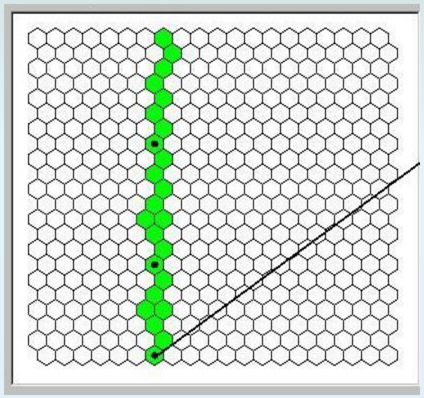


Laser Knob:

Position (x,y)







Roving Laser @ 4km

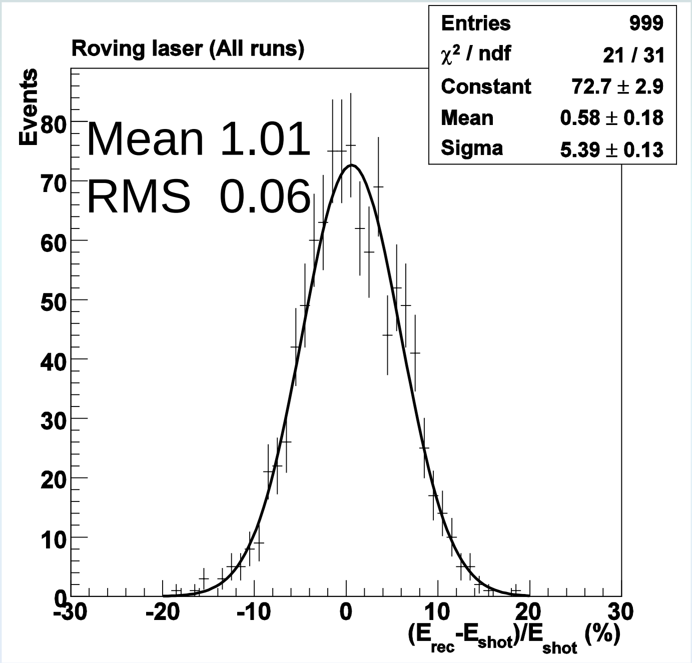
Central Laser @ 27km

Measure Laser Energy by reconstructing track seen in calibrated FD

Measure Laser Energy Locally with a calibrated pyroelectric energy probe

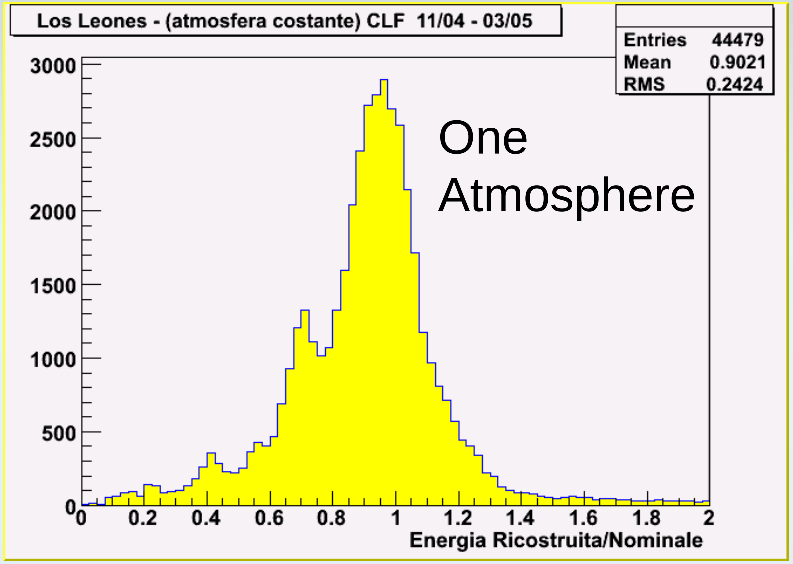
Laser Tests of Photometric Calibration

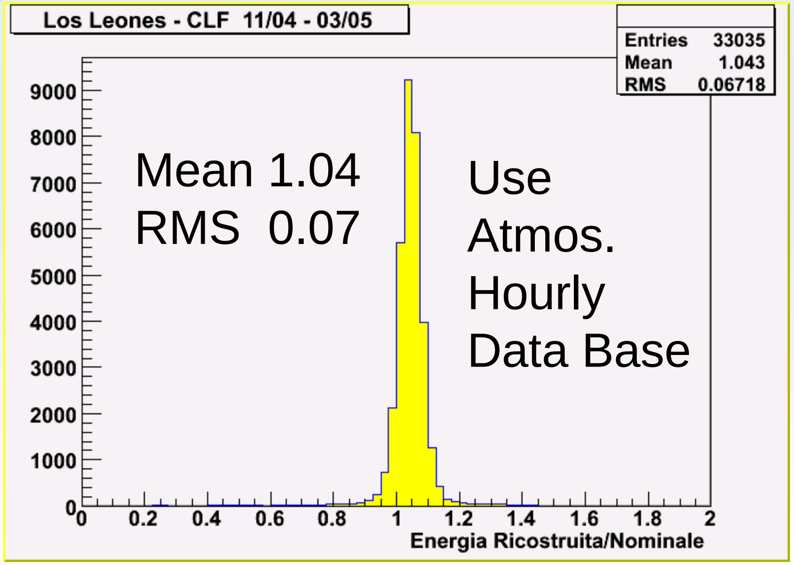
Roving Laser @ 4km
analysis-V. Verzi (Roma)

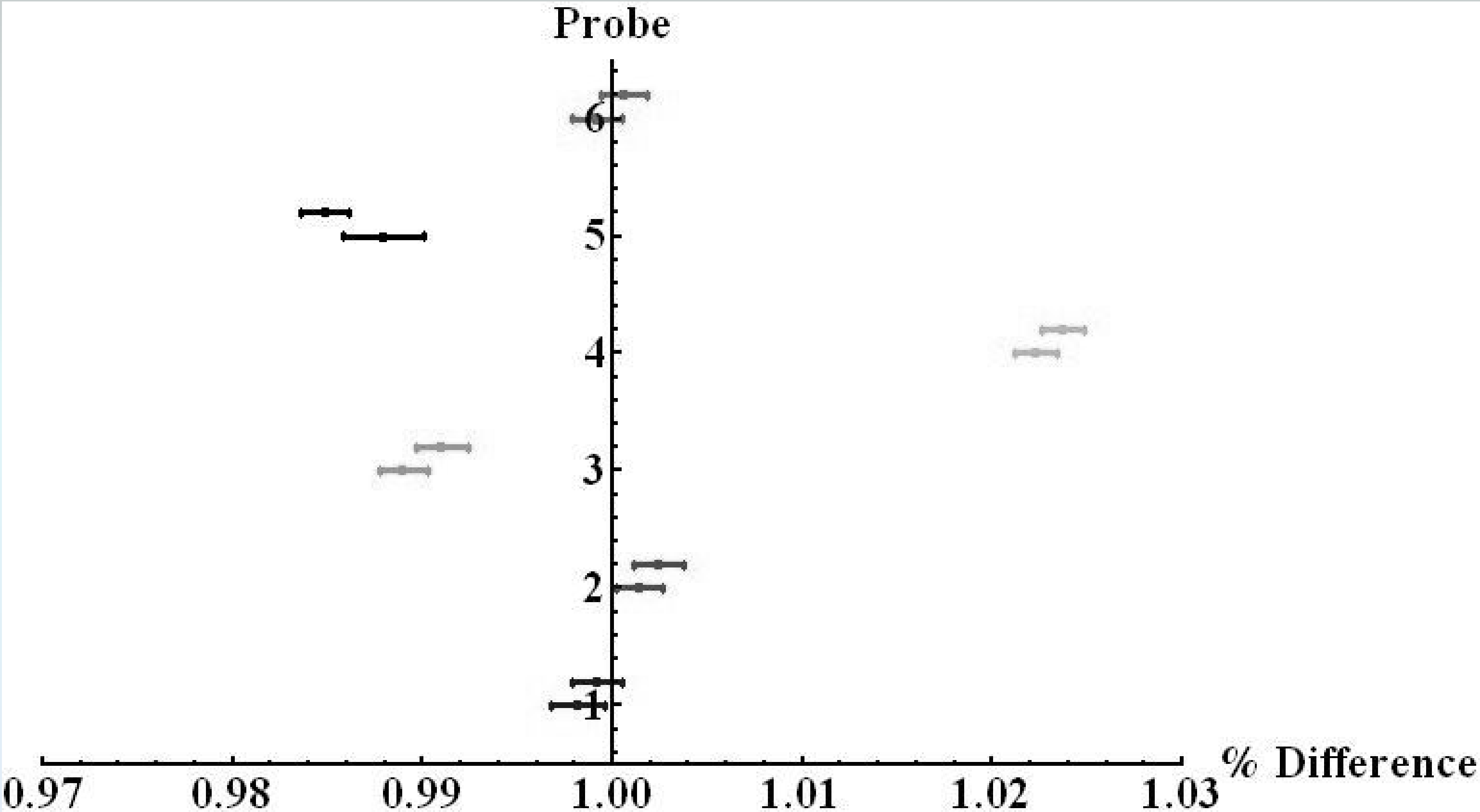


$(E_{rec}-E_{laser})/E_{laser}$

"CLF @ 27 km"
Analysis -L. Valore (Napoli)







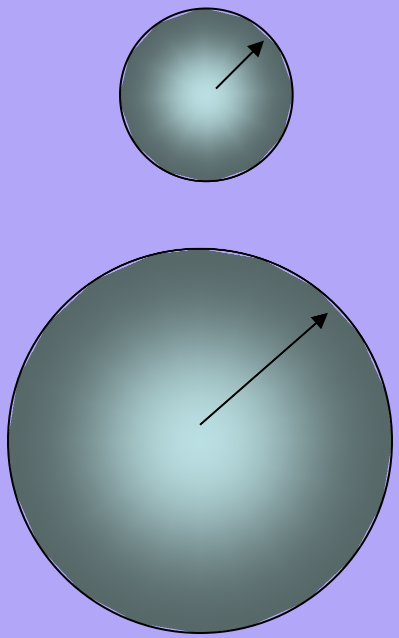
Cross-Calibration of 6 Pyroelectric Laser Energy Probes
Wiencke et al. ICRC 2009

One Motivation for Energy Calibration

$\Delta E/E$ 25%

$\Delta V/V$ >10

(for protons in CMBR)



8×10^{19} eV
90 MPC

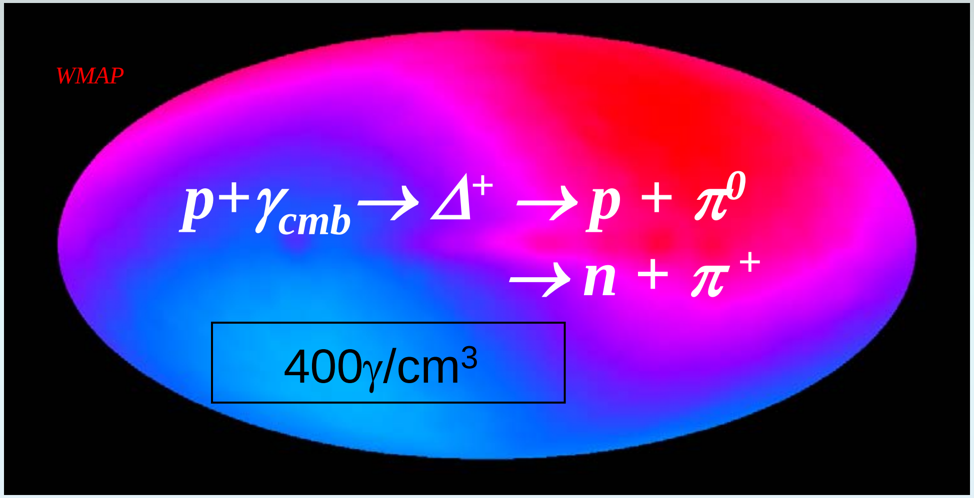
6×10^{19} eV
200 MPC

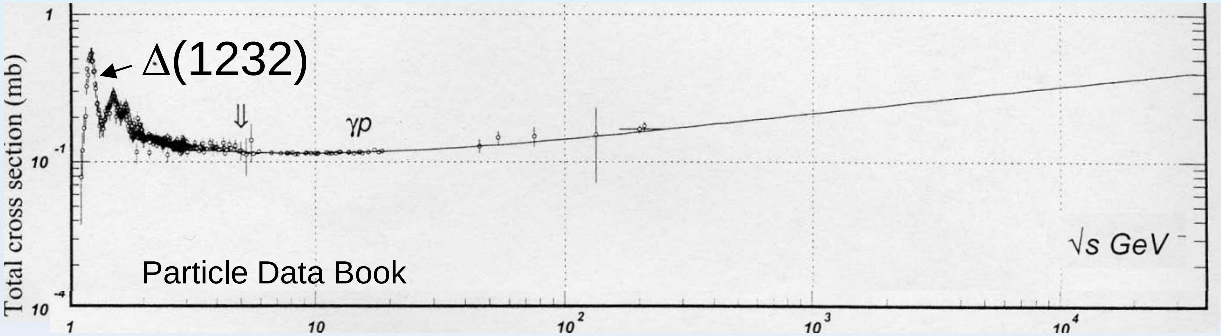
$\Delta E/E$ of 1% corresponds to a change in volume of ~10^6 MPC^3

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

1 MPC = 1 Million parsecs = 3 Million Light Years

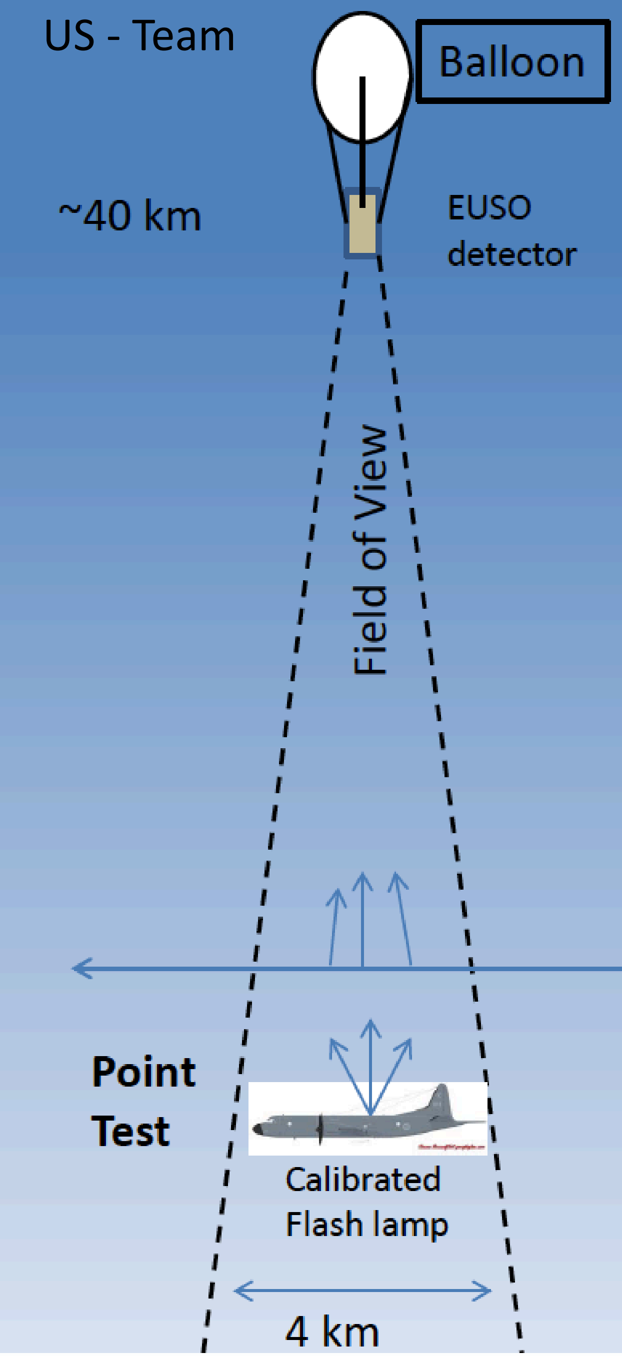
Cosmic Rays Loose Energy in the Cosmic Microwave Background Radiation





Energy Threshold ~ 5 x 10^{19} eV

Distance Scale is a strong function of Energy



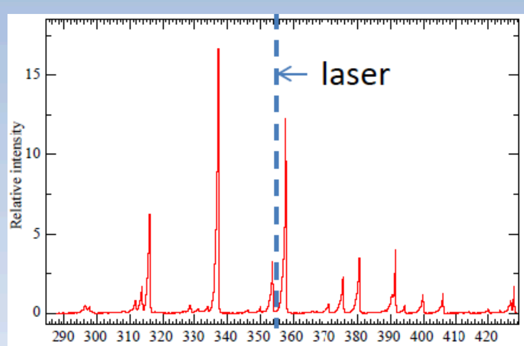
Testing EUSO-Balloon

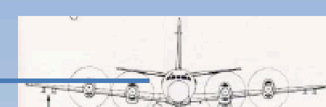
Fly one aircraft equipped with
two types of calibrated pulsed UV light sources.

Point Test: Fly airplane in field of view and fire **flash lamp**. Light travels directly from lamp to detector

Track Test: Fly airplane outside field of view and shoot a UV pulsed **laser** across field of view. Light scatters out of the beam to the detector.
(5 mJ Laser ~100 EeV Cosmic Ray)

Fly aircraft at altitudes between 1-5 km.





Calibrated UV laser

Track Test

EUSO-Balloon
Flight Planned for 2014, Timmins Canada

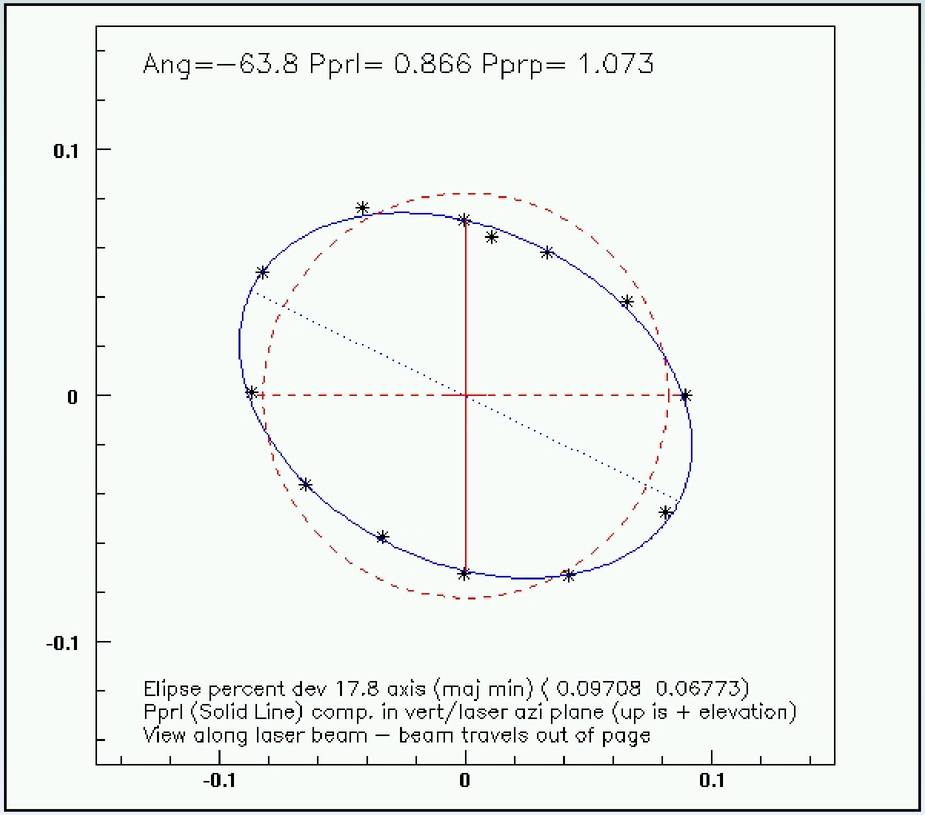
http://euso-balloon.lal.in2p3.fr/

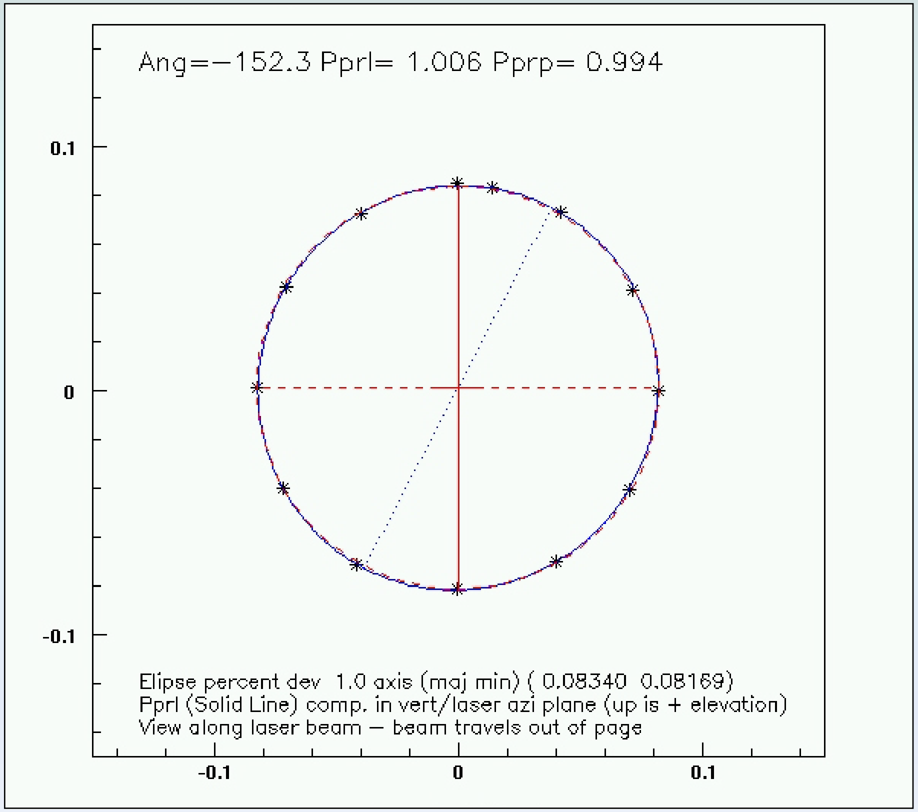
Laser Knob: x,y, **z**

Jim Wright (pilot, XP Services), Doug Houi (XP), Johannes Eser (Mines) Matt Rodencal (UAH) Evgeny Kuznetsov Mark Christl (NASA), Steve Csorna – not shown (Vanderbilt) photo – L. Wiencke


S22 8403

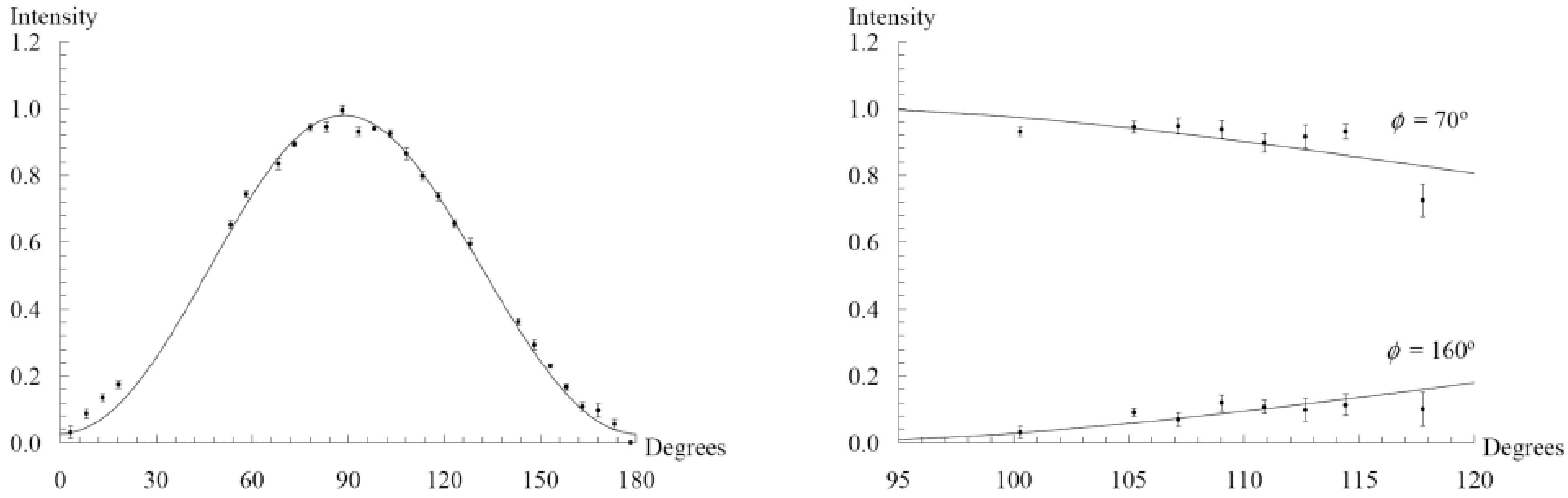
Laser Knob: Polarization





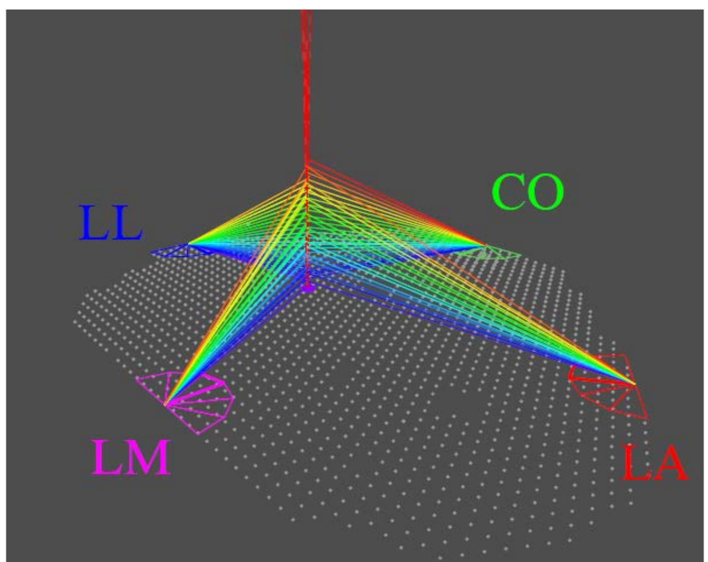
Initial setting based on “Hearing Test method”

Setting based on iterations of energy probe measurements



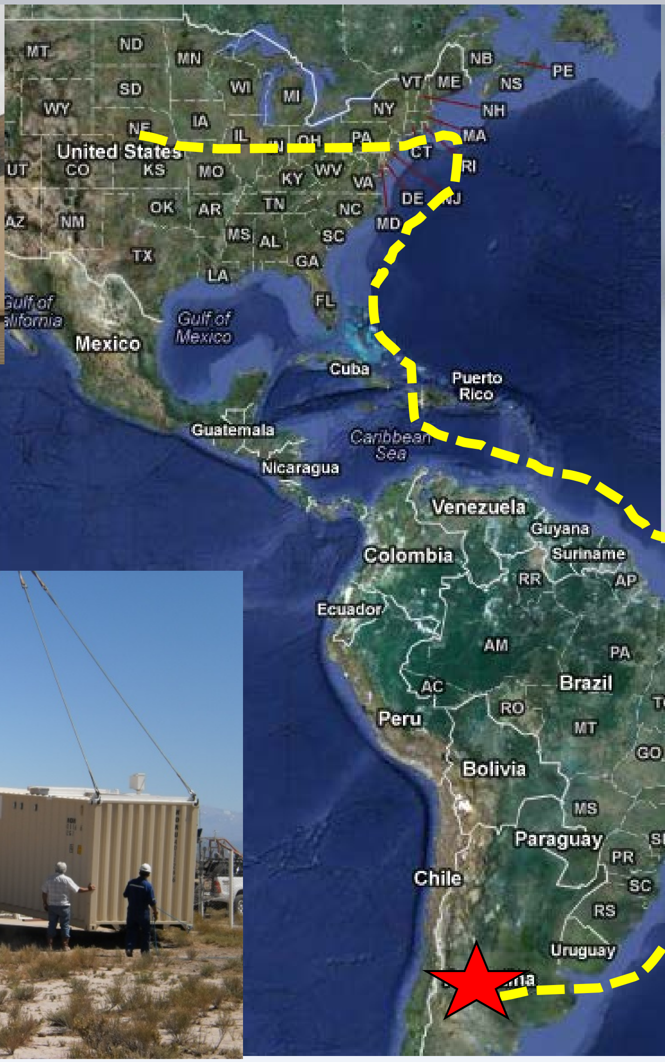
(a) Polarization Angle (b) Scattering Angle

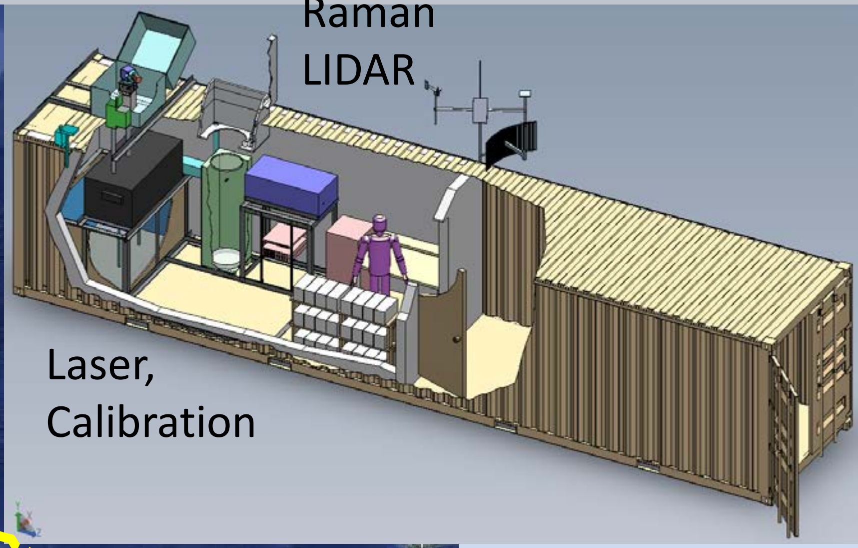
Fig. 7: Intensity of scattered light from vertical linearly polarized beams recorded by a fluorescence telescope normalized to measurements of unpolarized beam under the same atmospheric conditions. Data is shown as a function of the polarization rotation angle of the beam (a) and of the scattering angle (b). The curves show the Rayleigh scattering prediction for polarized light. Error bars correspond only to statistical uncertainties.



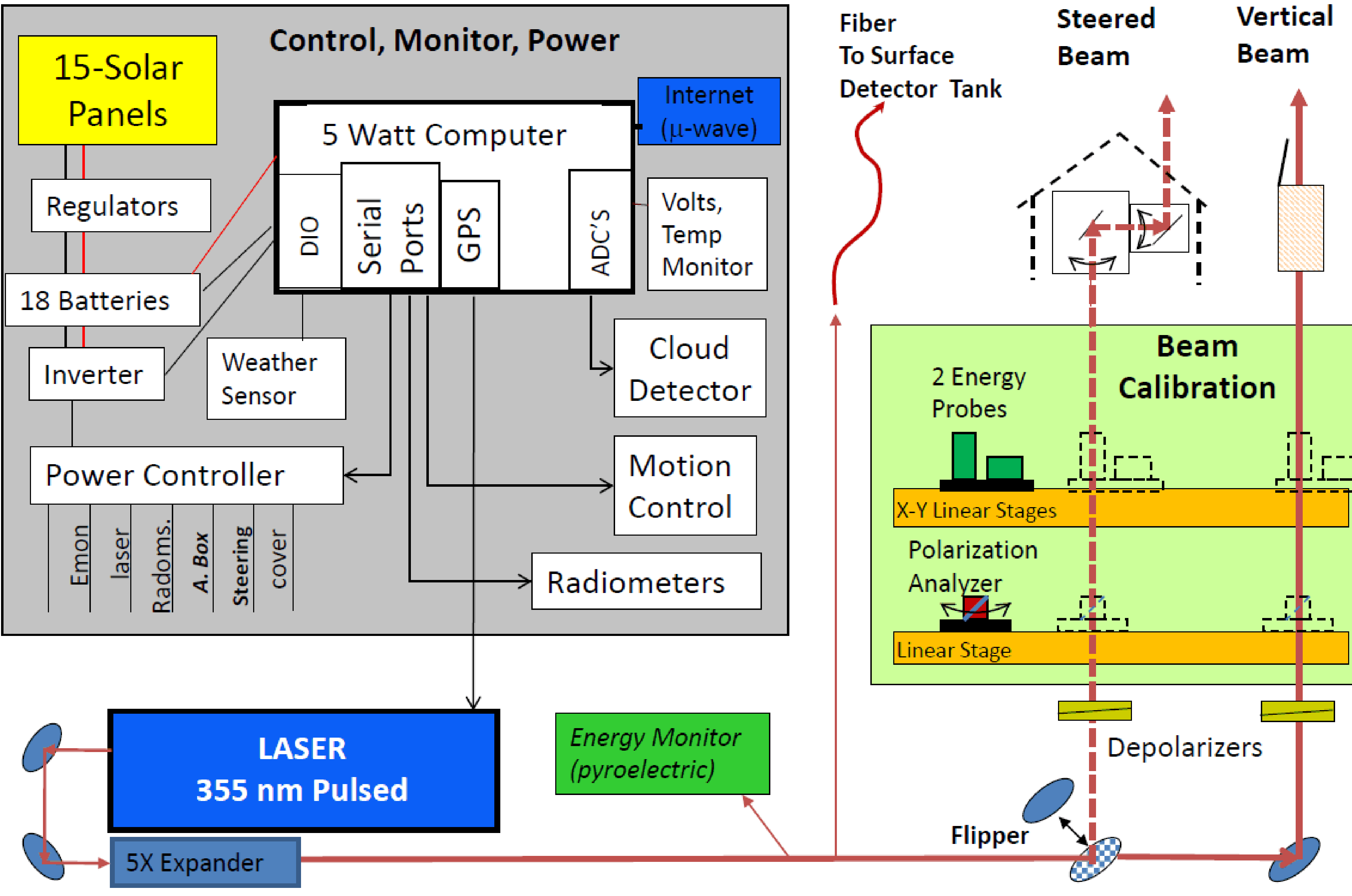
Wiencke et. al ICRC 2009

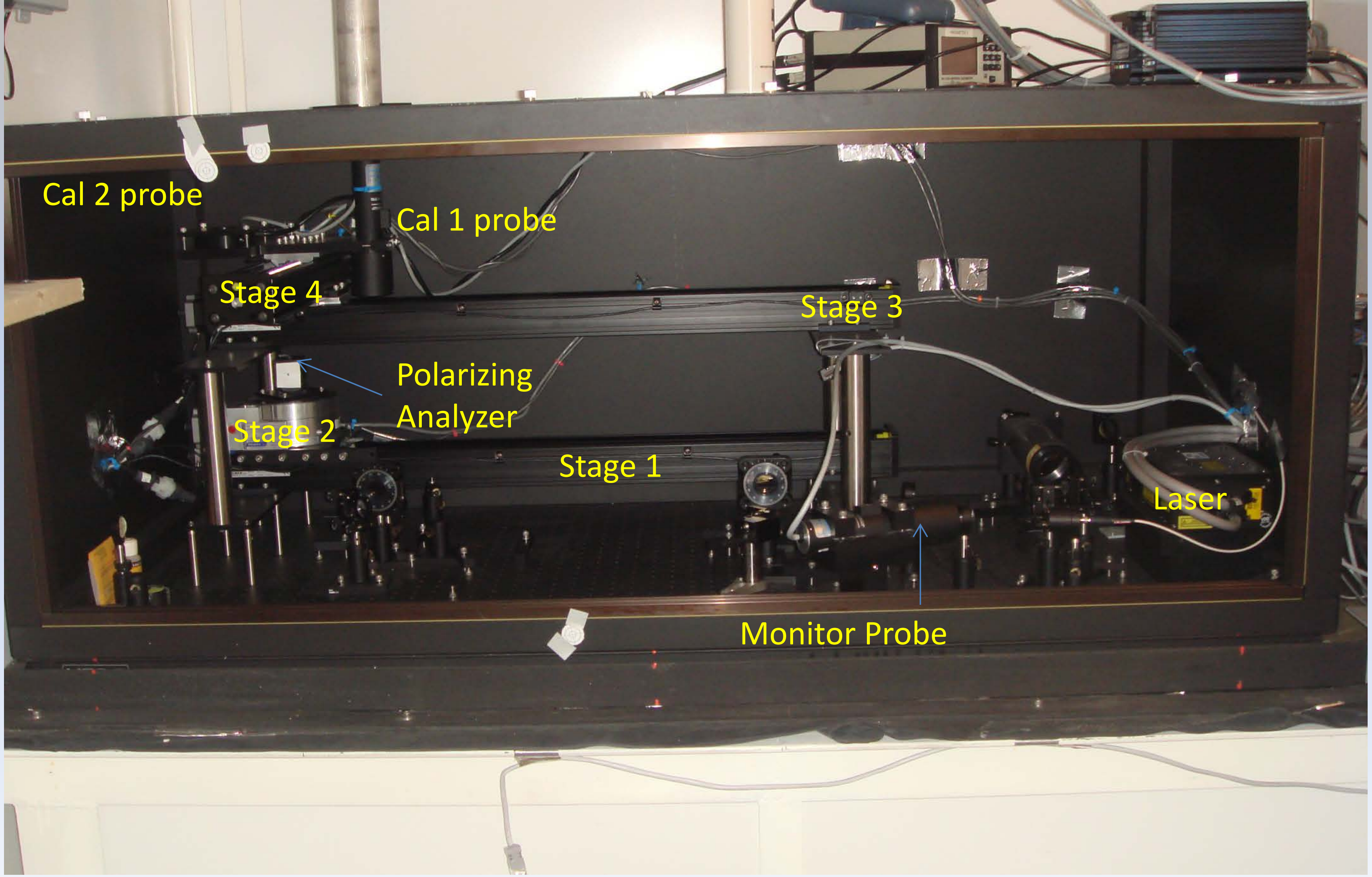
Pierre Auger: Laser Facility Upgrade





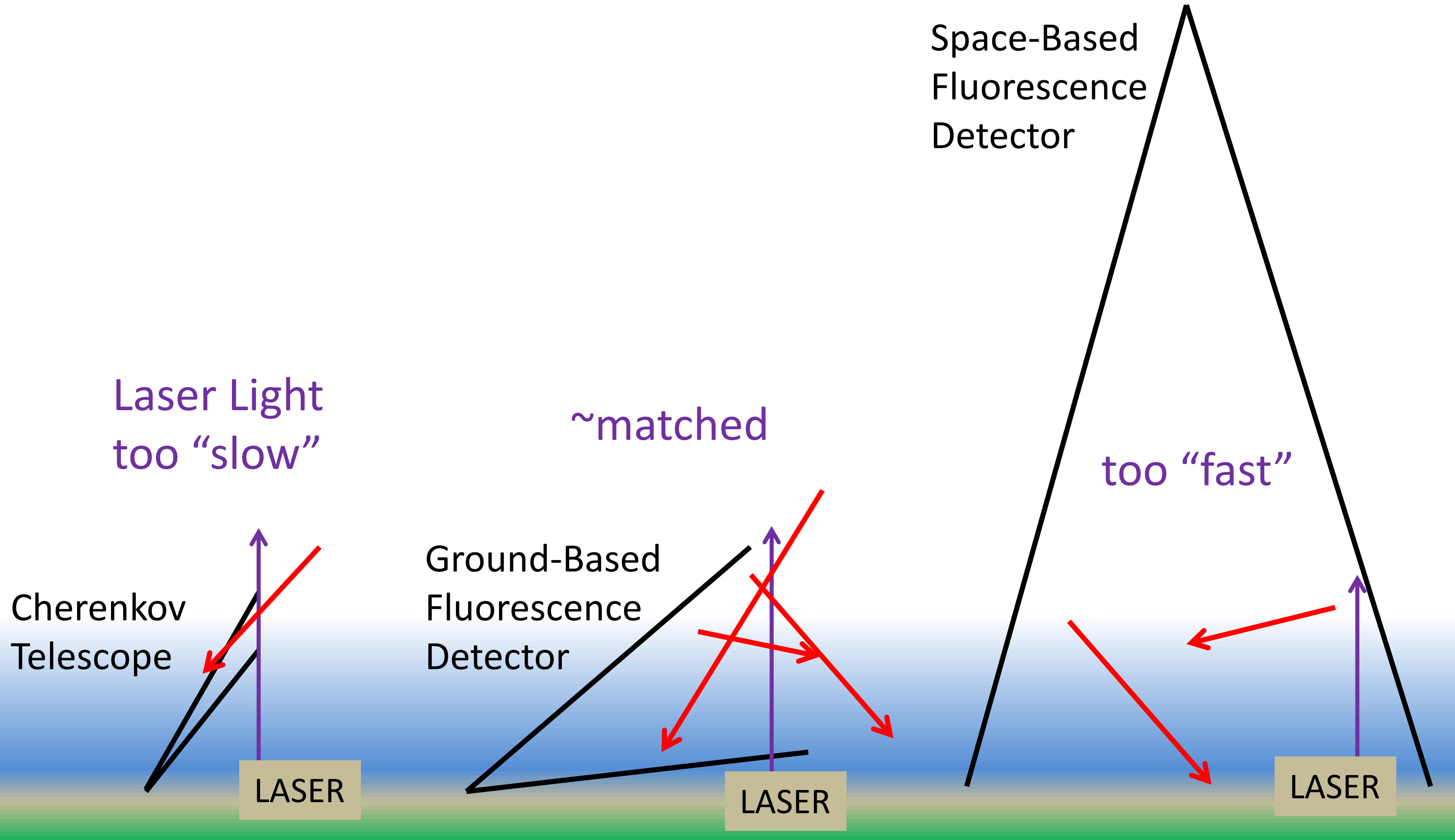
Extreme Laser Facility at the Pierre Auger Observatory



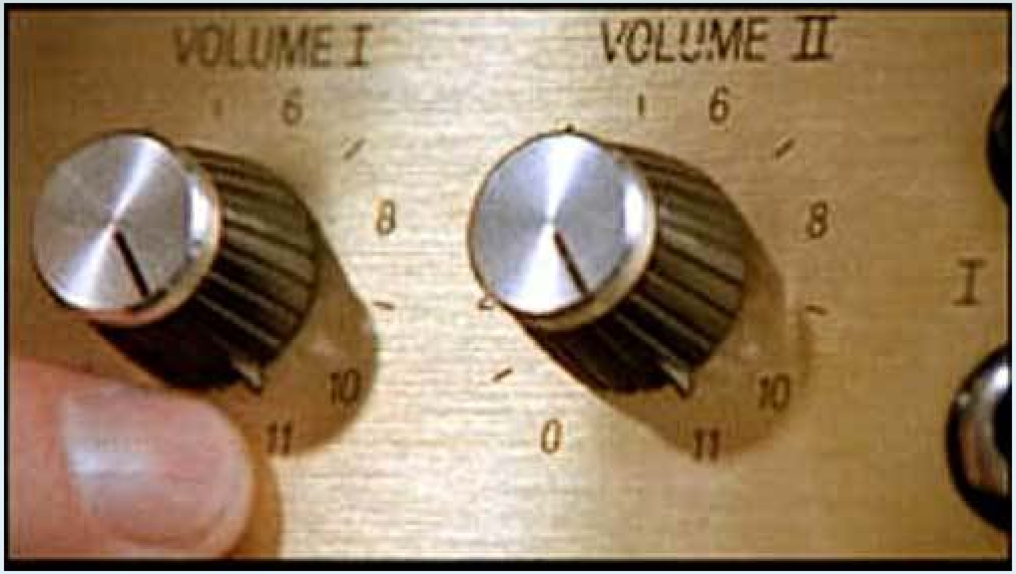


Cal 2 probe
Cal 1 probe
Stage 4
Stage 3
Polarizing
Analyzer
Stage 2
Stage 1
Laser
Monitor Probe

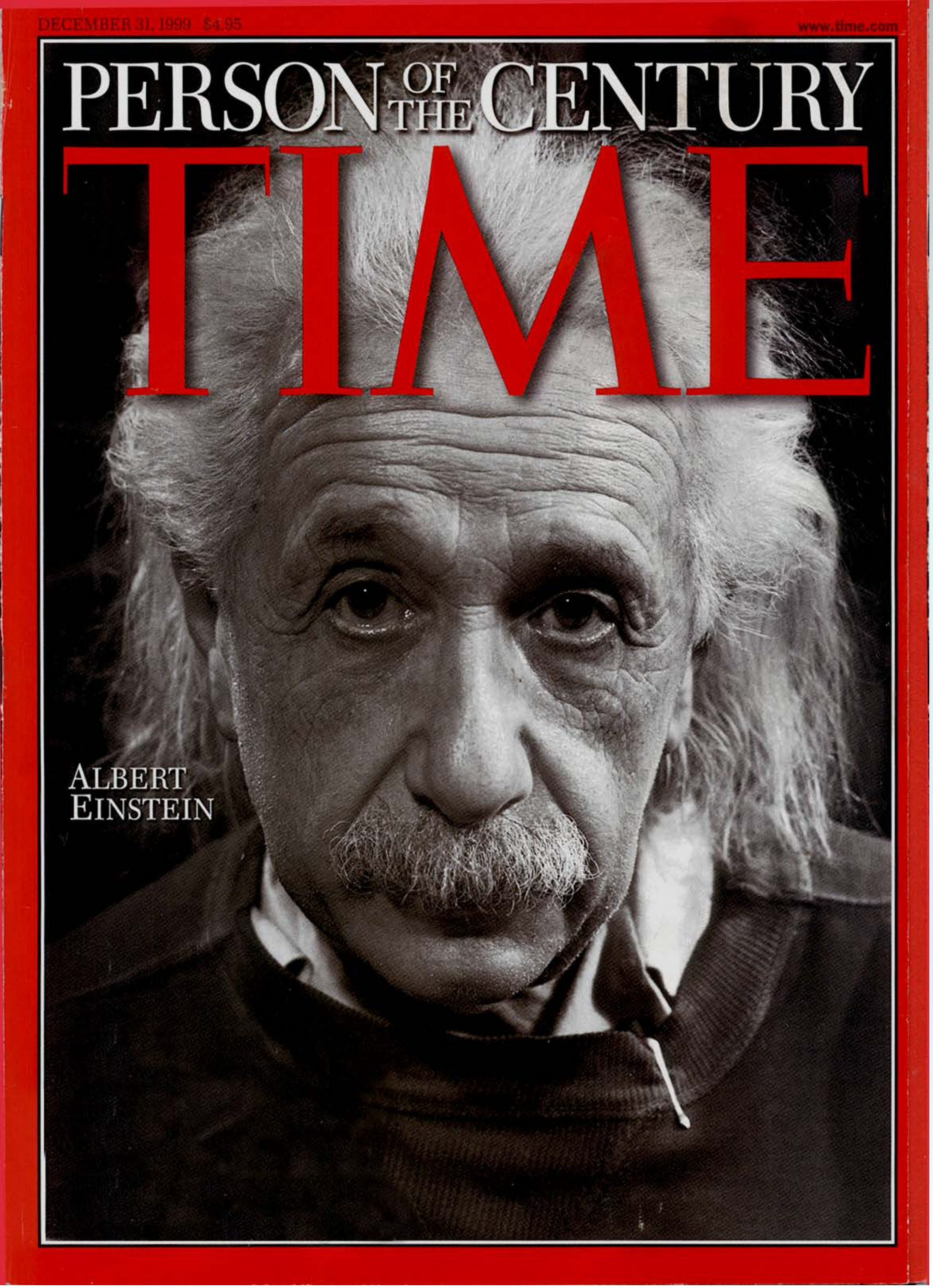
Geometry and Timing

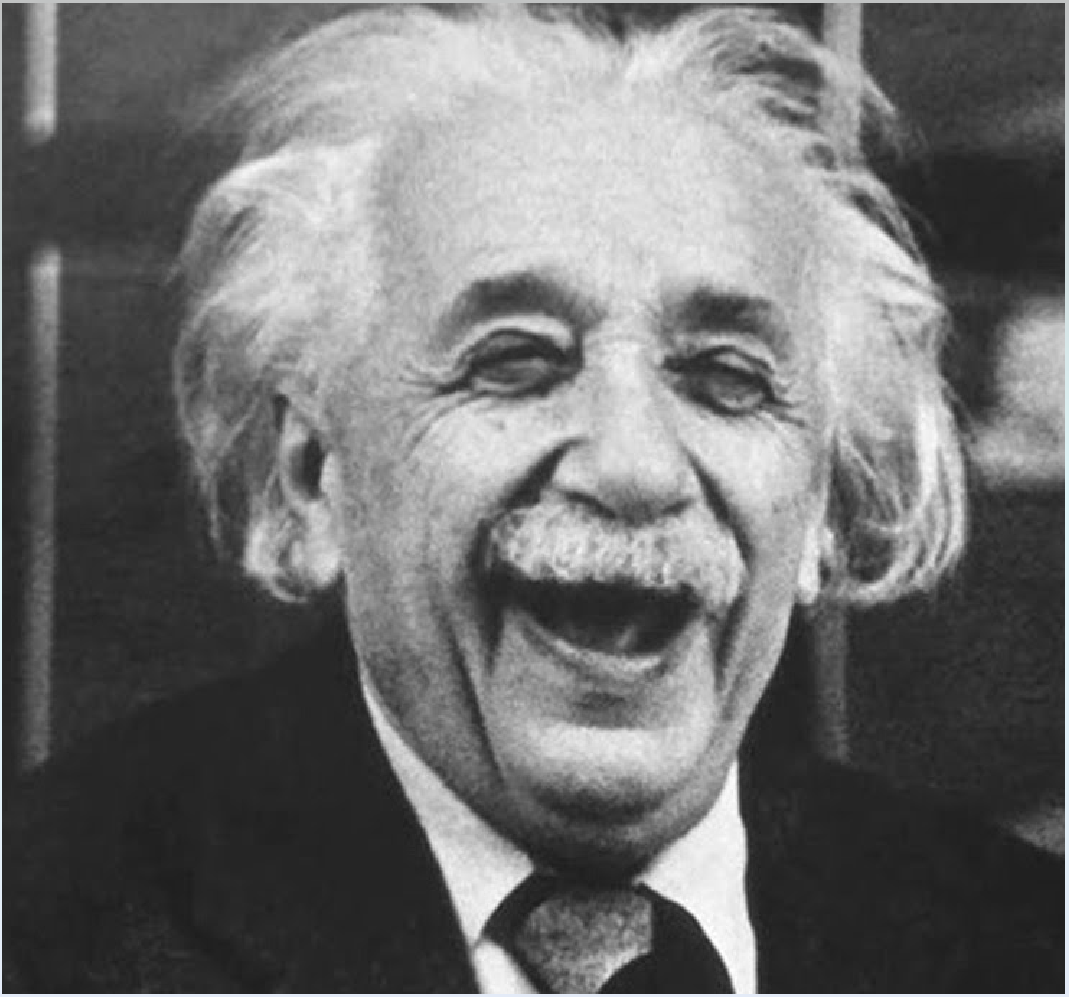


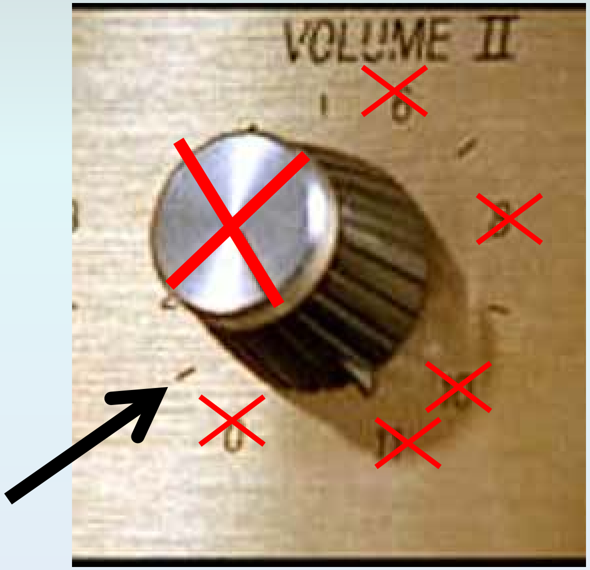
A laser knob we wish we had..



The v/c knob !?


DECEMBER 31, 1999 $4.95
www.time.com
PERSON OF THE CENTURY
TIME
ALBERT EINSTEIN





$$v_\gamma = c$$

Einstein (1905)

Search for Slow "Showers"

E. Mayotte, K. Gesterling, K. Kuhn

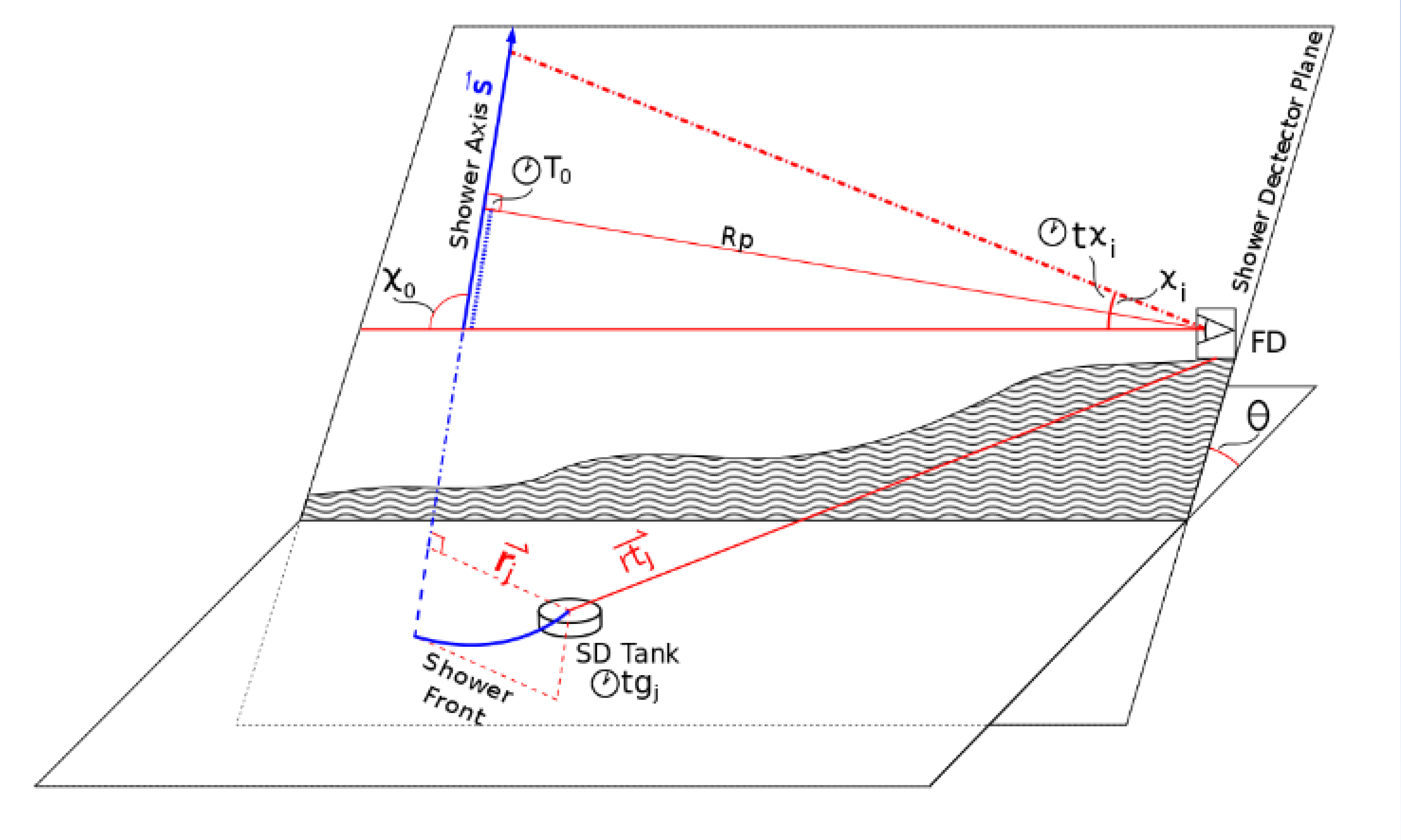
Reconstruct Events assuming V ≠ C
Use FD pixel timing techniques to calculate "shower" velocity

Possible Candidates…
atmospheric phenomena, macro scale events (micro meteorites)
Exotics: Magnetic Monopoles (SHMM, IMMM), Qballs $m>10^{19}$ Gev)

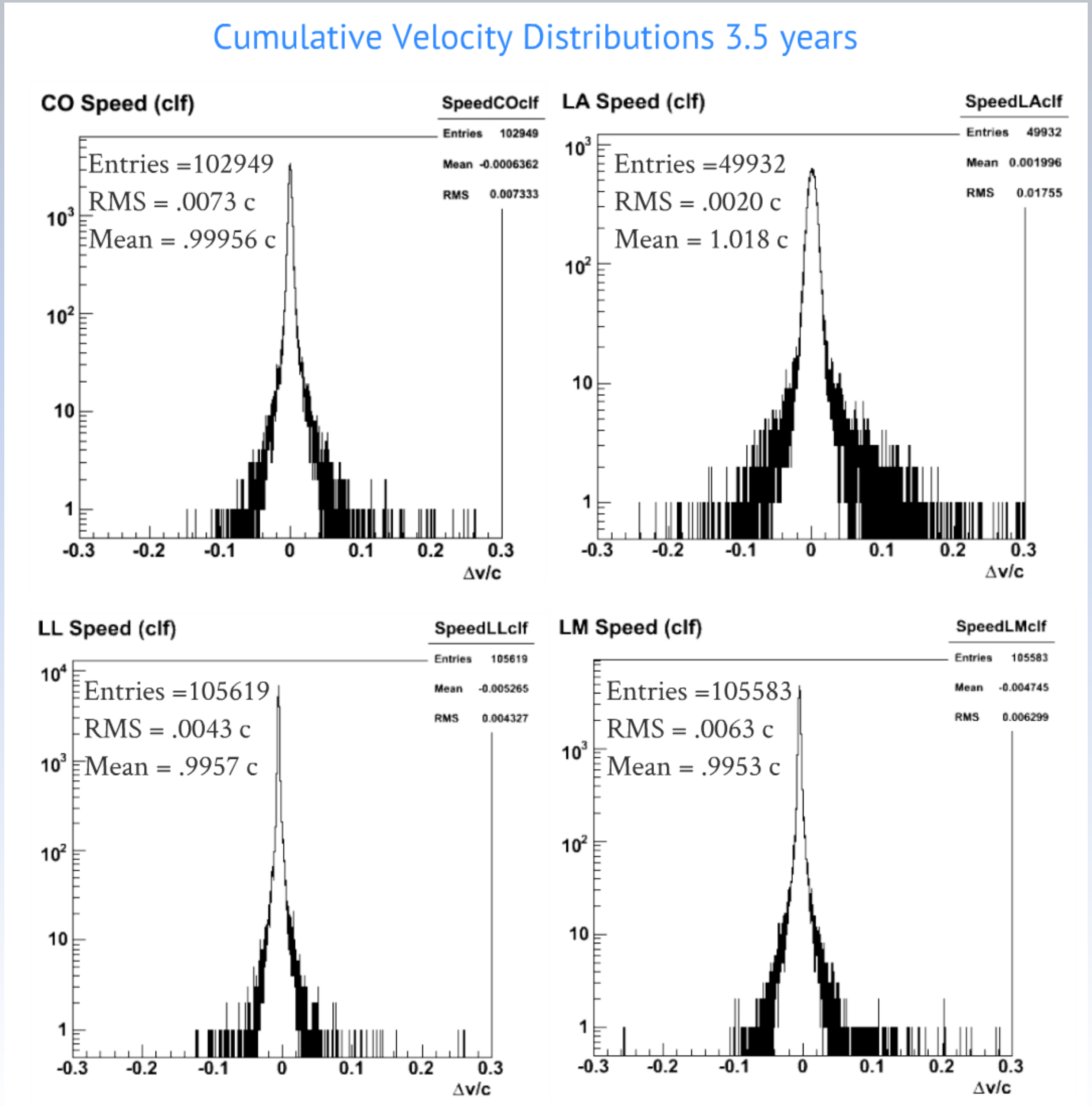
Any event with accurately measured sub-luminal velocity would be very interesting

Search for Slow "Showers"

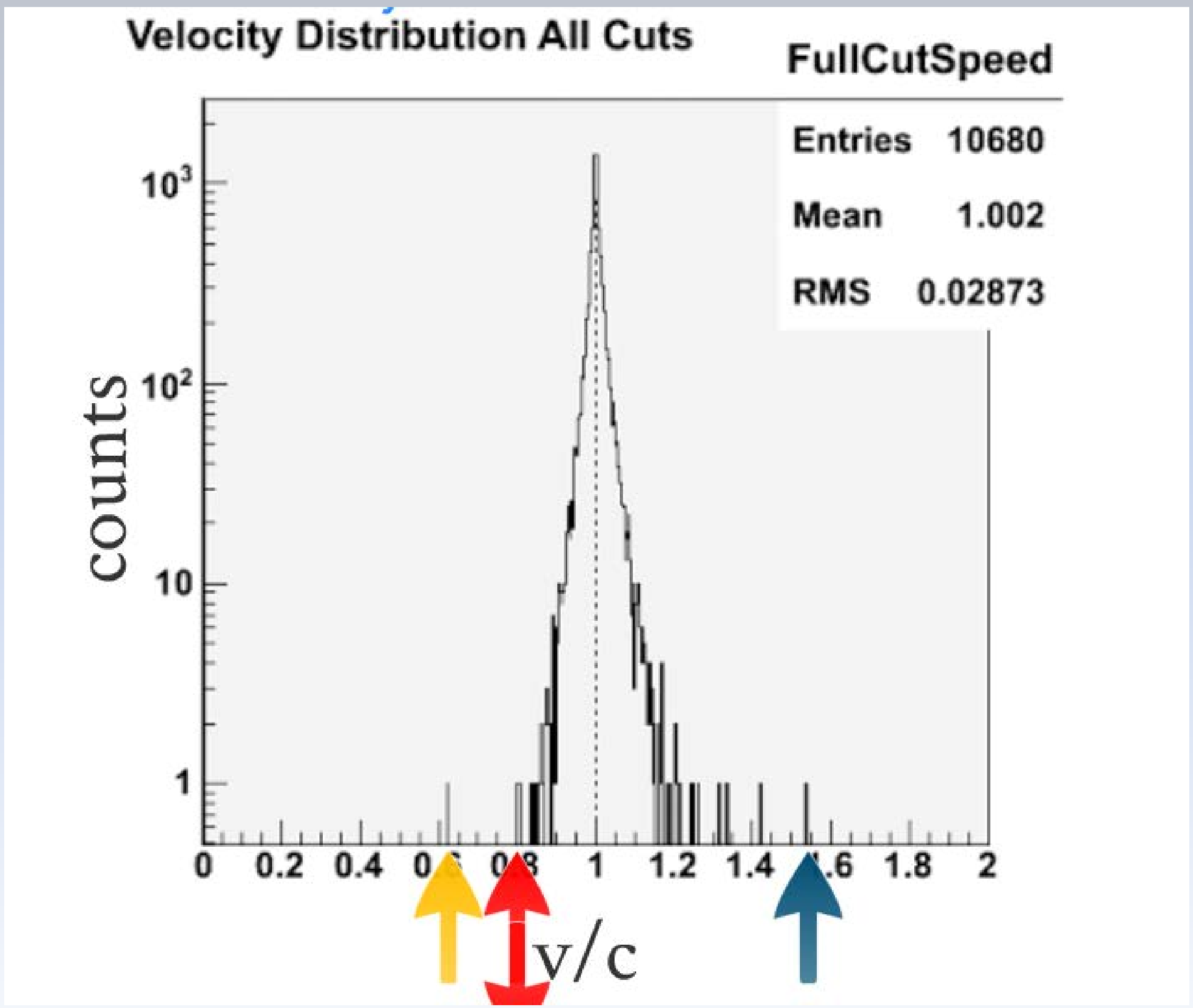
Separate shower propagation (free velocity) and light propagation (v=c/n)



Benchmark technique with laser data



Air Showers (Hybrid Method)



Astronomy & Lasers
Laser Guide Star: Adaptive Optics

Image credit: Yuri Beletsky / European Southern Observatory, of the VLT in Chile.

ESA OBSERVATORY BREAKS WORLD QUANTUM TELEPORTATION RECORD

Laser from Optical Ground Station on Tenerife

6 September 2012 An international research team using ESA's Optical Ground Station in the Canary Islands has set a new distance world record in 'quantum teleportation' by reproducing the characteristics of a light particle across 143 km of open air.

Funded by ESA, researchers from Austria, Canada, Germany and Norway transferred the physical properties of one particle of light – a photon – onto its 'entangled' partner via quantum teleportation, thereby bridging a distance of 143 km between the Jacobus Kapteyn Telescope on La Palma and ESA's Optical Ground Station on adjacent Tenerife.

Their results have been published in this week's Nature Magazine.

Once entangled, the measurement of a certain property – such as polarisation or spin – will yield the same result for both particles, no matter how far apart the particles are located, and without any further signal being physically passed between them.

Conclusion

- Lasers are essential tools for cosmic-ray observatories
- Techniques certainly extend to CTA, JEM-EUSO
- Challenge to community:
  - Observatory Detectors are amazing
  - Lasers are relatively inexpensive

Conclusion

- Lasers are essential tools for cosmic-ray observatories
- Techniques certainly extend to CTA, JEM-EUSO
- Challenge to community:
  - Observatory Detectors are amazing
  - Lasers are relatively inexpensive
  - **Also think beyond Laser “service”!**

International Workshop on
Interdisciplinary Science and Astroparticle Detectors

Colorado School of Mines Golden Colorado June 2015