APPEC Technology Forum 2015 - Low light-level detection in astroparticle physics and in medical application

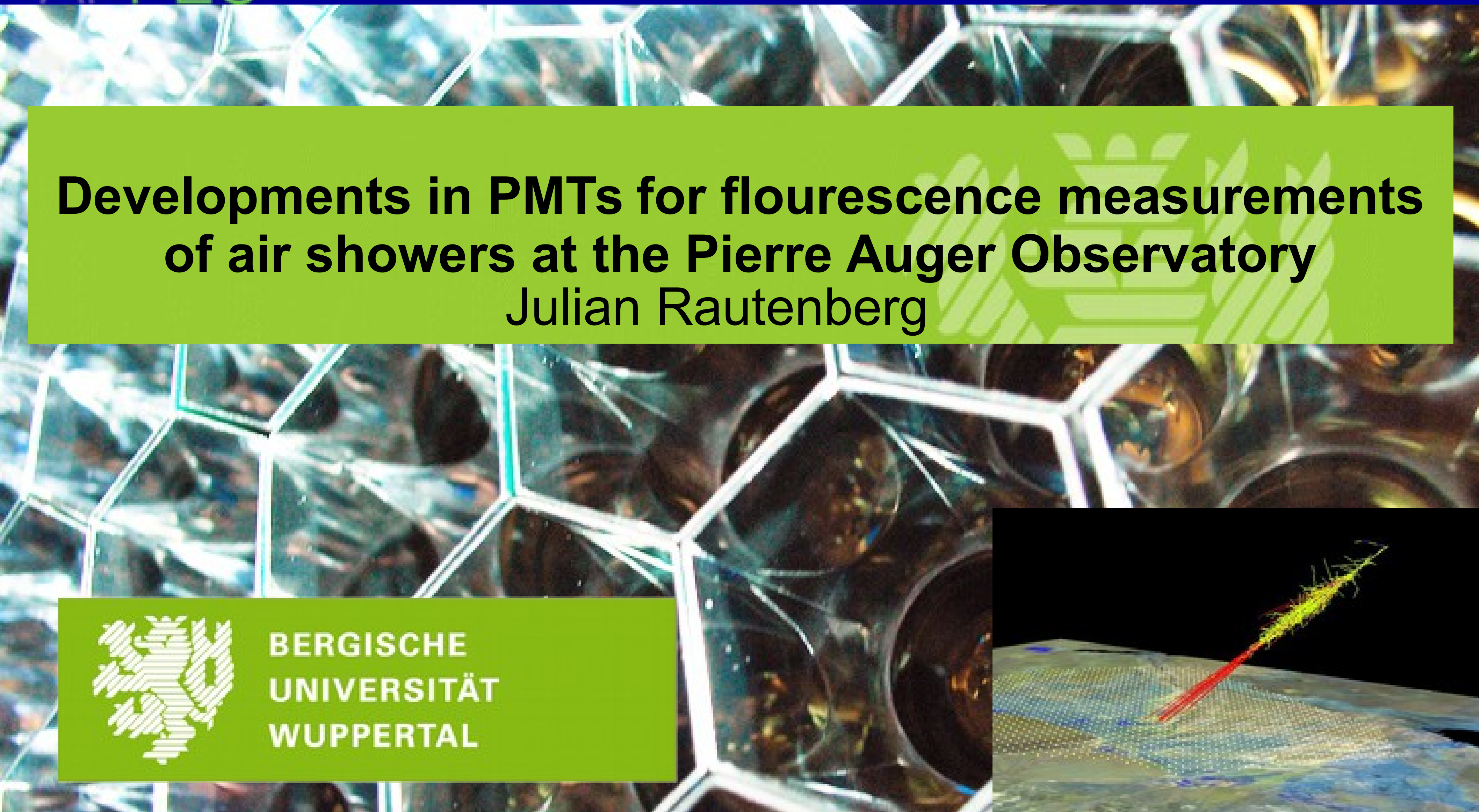
22-23 April 2015 *Carl Friedrich von Siemens Foundation*
Europe/Berlin timezone

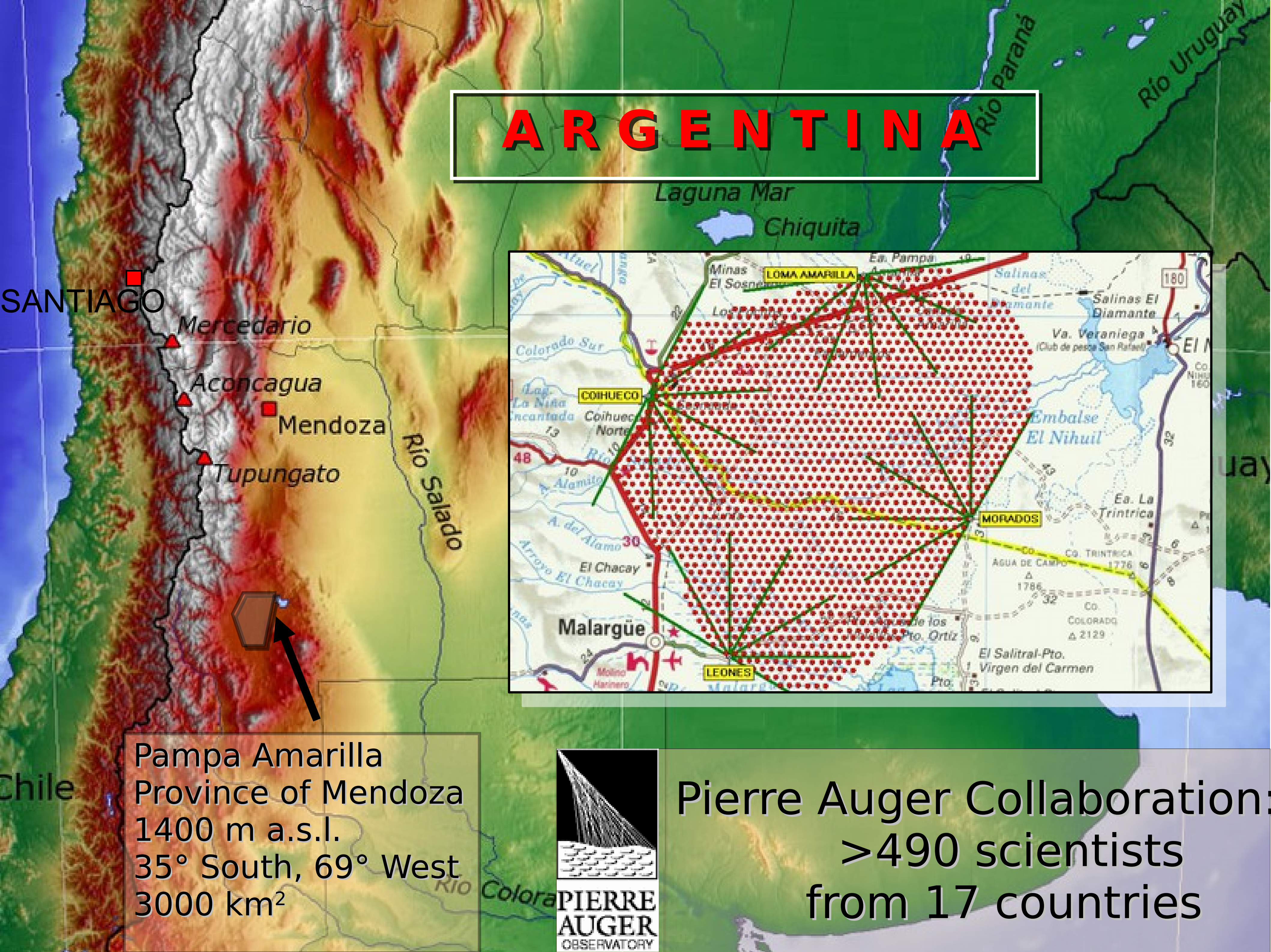
APPEC

# Developments in PMTs for flourescence measurements of air showers at the Pierre Auger Observatory

Julian Rautenberg

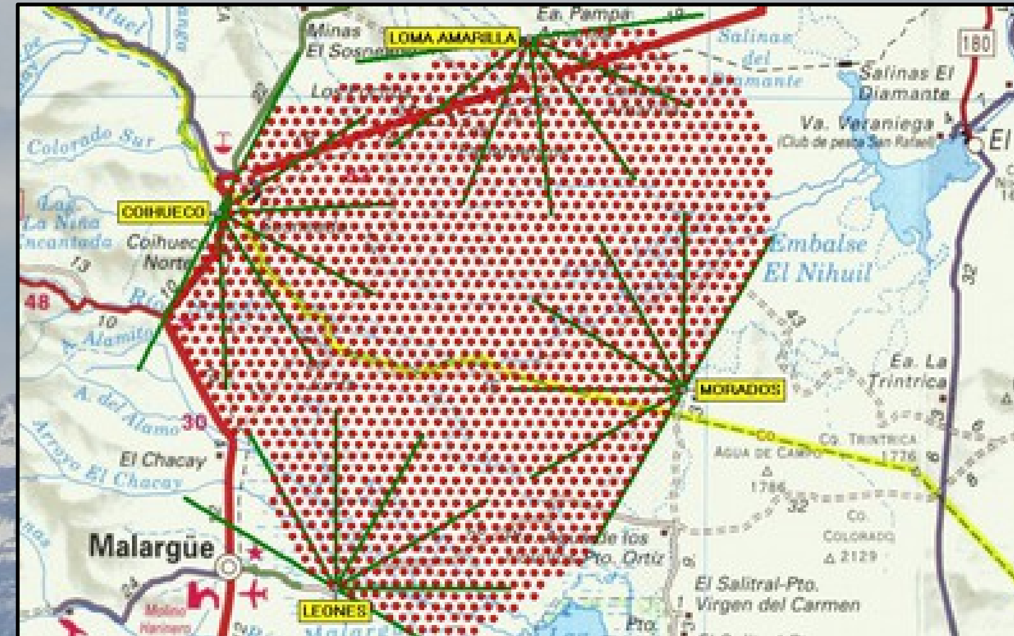
BERGISCHE UNIVERSITÄT WUPPERTAL



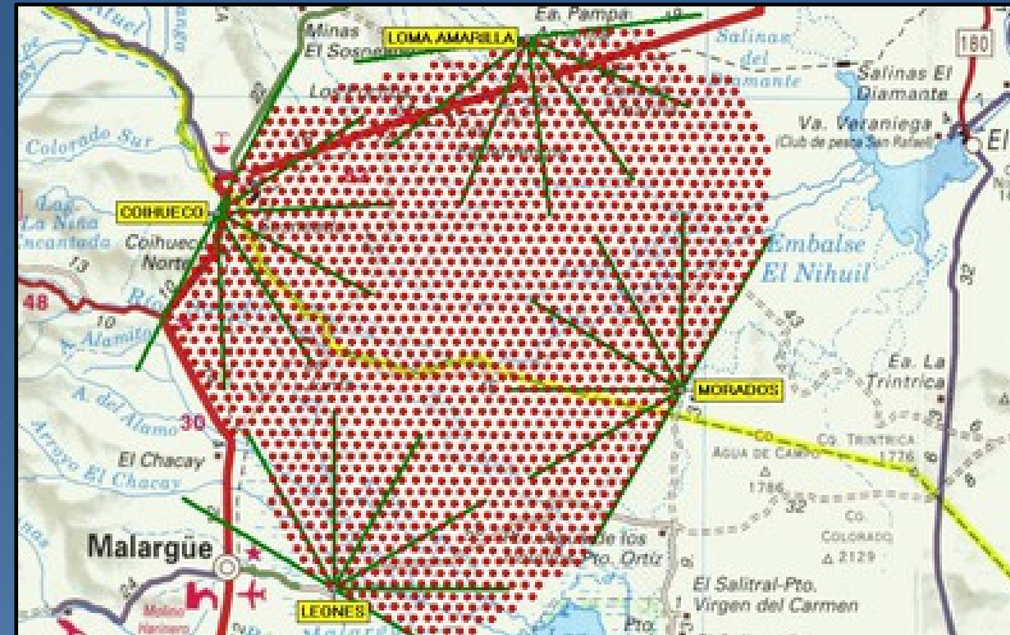


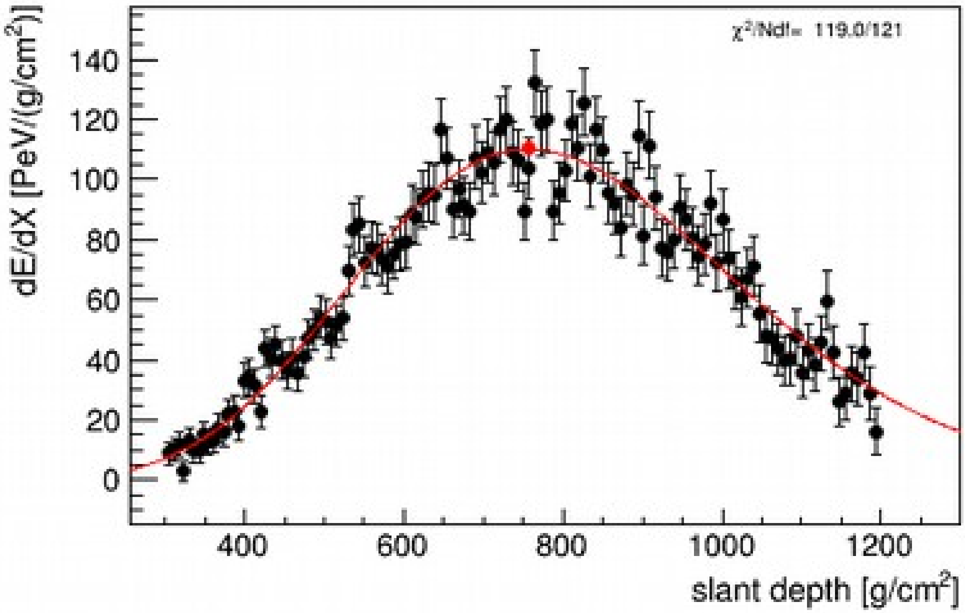
ARGENTINA
SANTIAGO
Mercedario
Aconcagua
Mendoza
Tupungato
Río Salado
Laguna Mar Chiquita
Río Paraná
Río Uruguay
Chile
Río Colora
LOMA AMARILLA
COIHUECO
MORADOS
LEONES
Malargüe
Embalse El Nihuil
Salinas El Diamante
Pampa Amarilla
Province of Mendoza
1400 m a.s.l.
35° South, 69° West
3000 km²
PIERRE AUGER OBSERVATORY
Pierre Auger Collaboration:
>490 scientists
from 17 countries

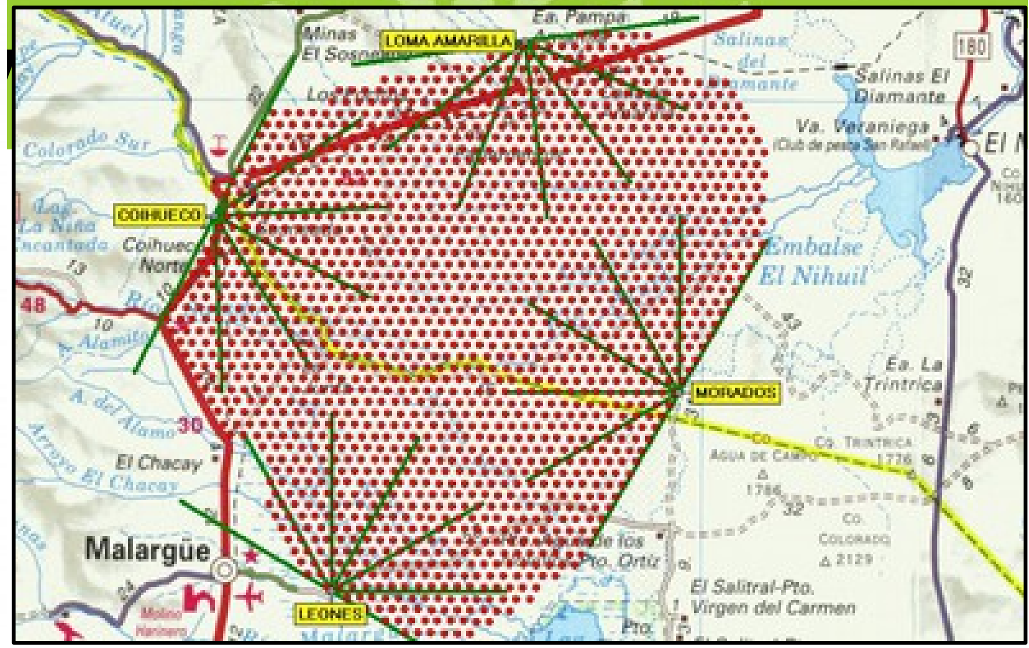
# Surface Detector (SD)



# Fluorescence Detector (FD)



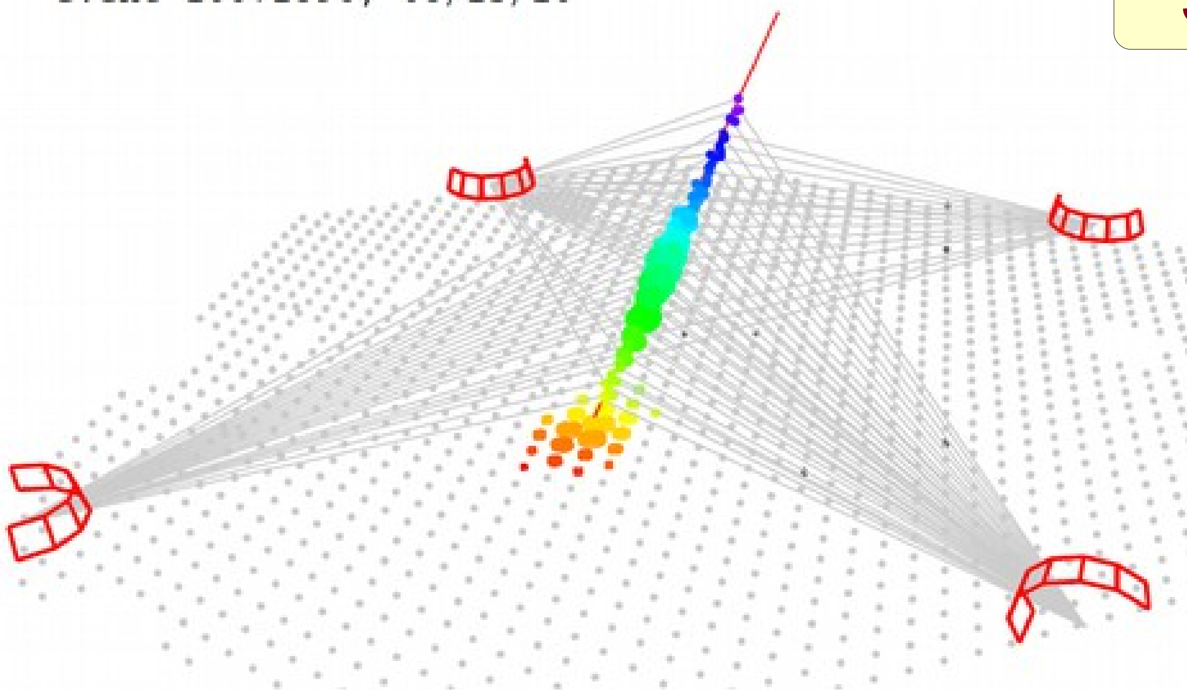


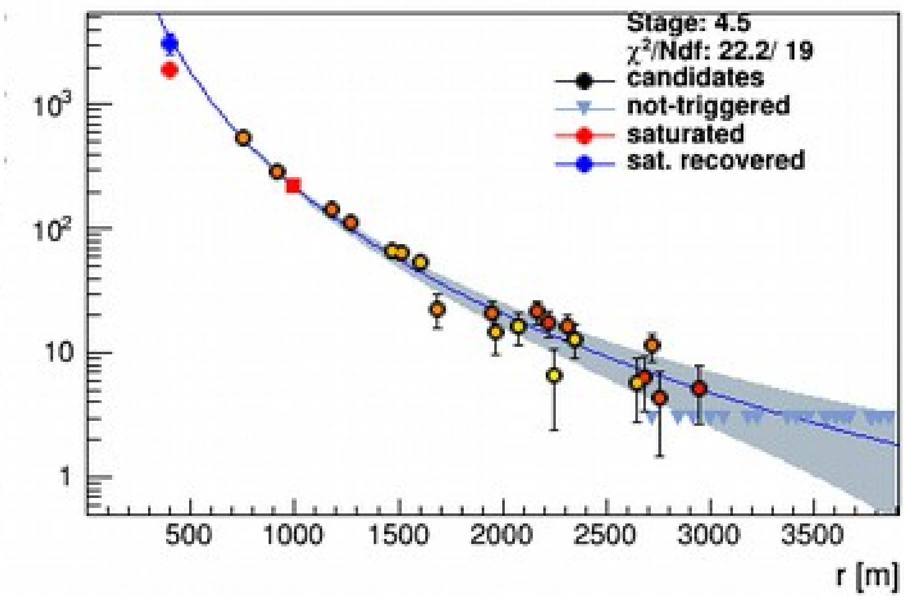




FD: longitudinal development

SD: lateral distribution

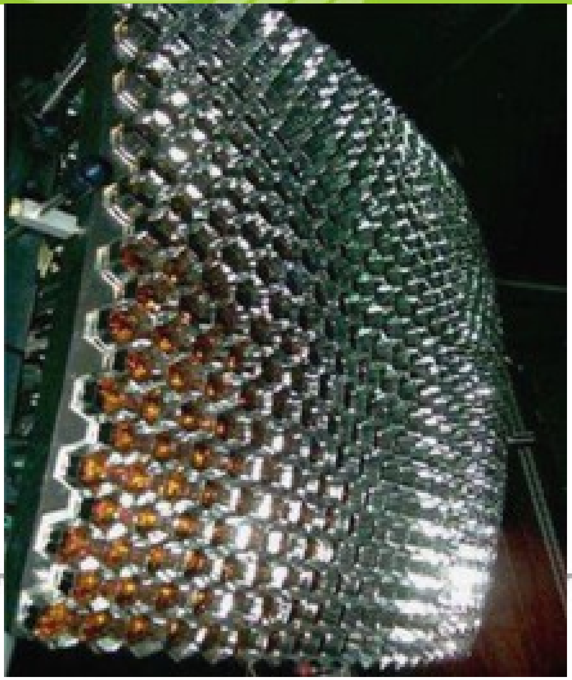
event 10071896, 08/15/10

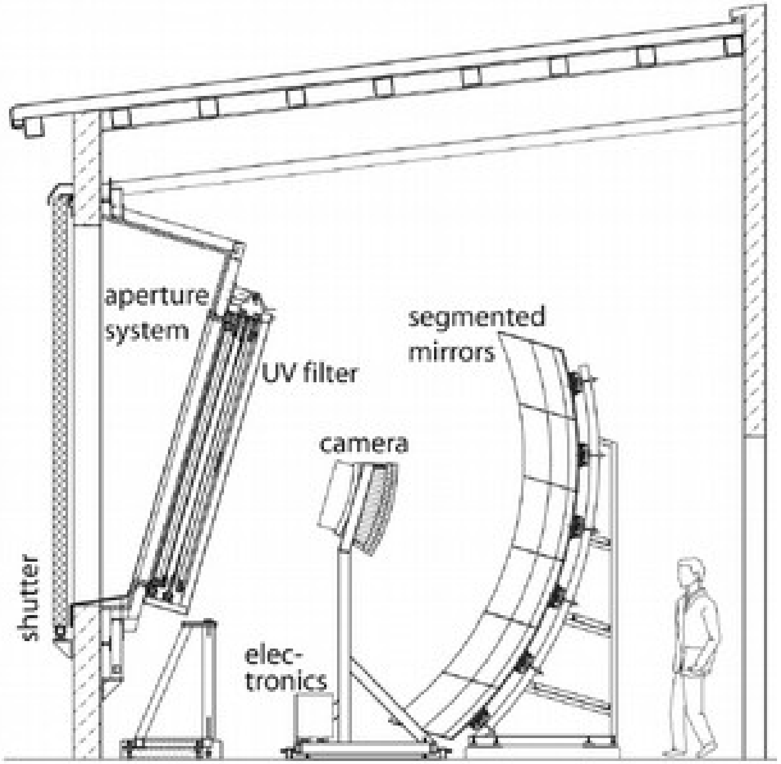


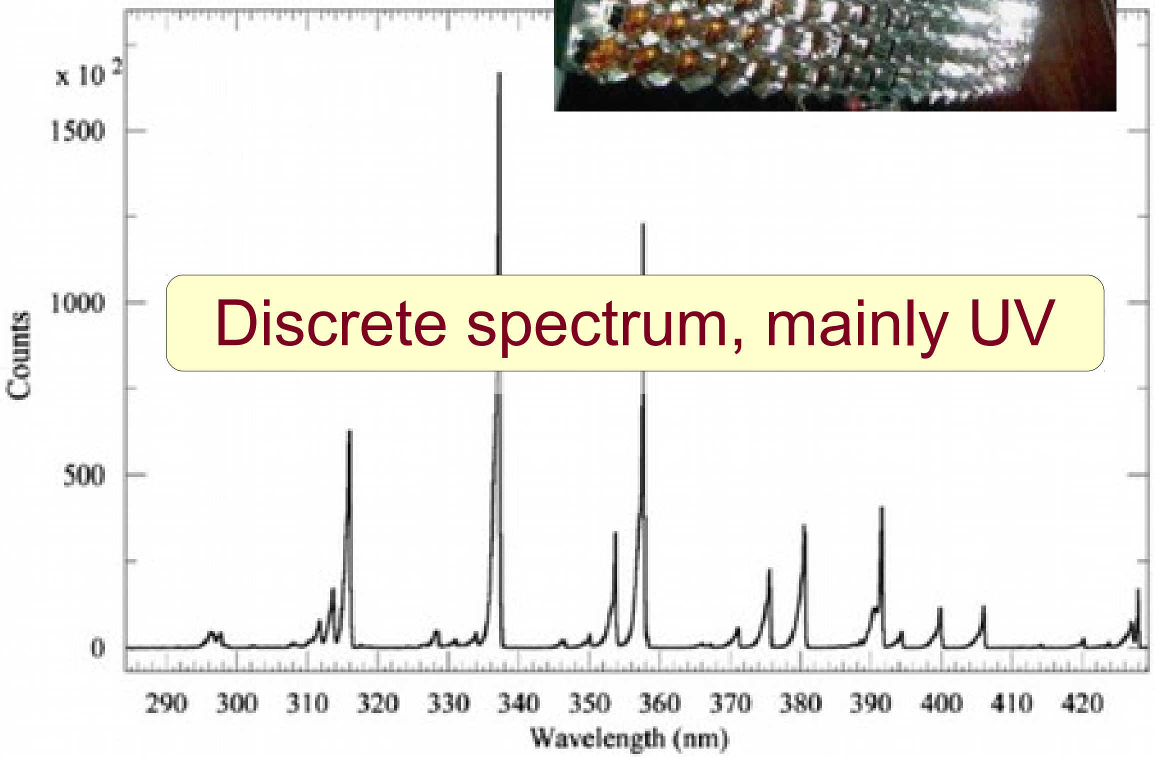


# First Part: PMTs for Fluorescence Detection

- optimized for fluorescence light between 300 nm and 400 nm
- camera: 440 photomultiplier (PMT), Photonis hexagonal XP 3062
- transition between PMTs is covered by light guides

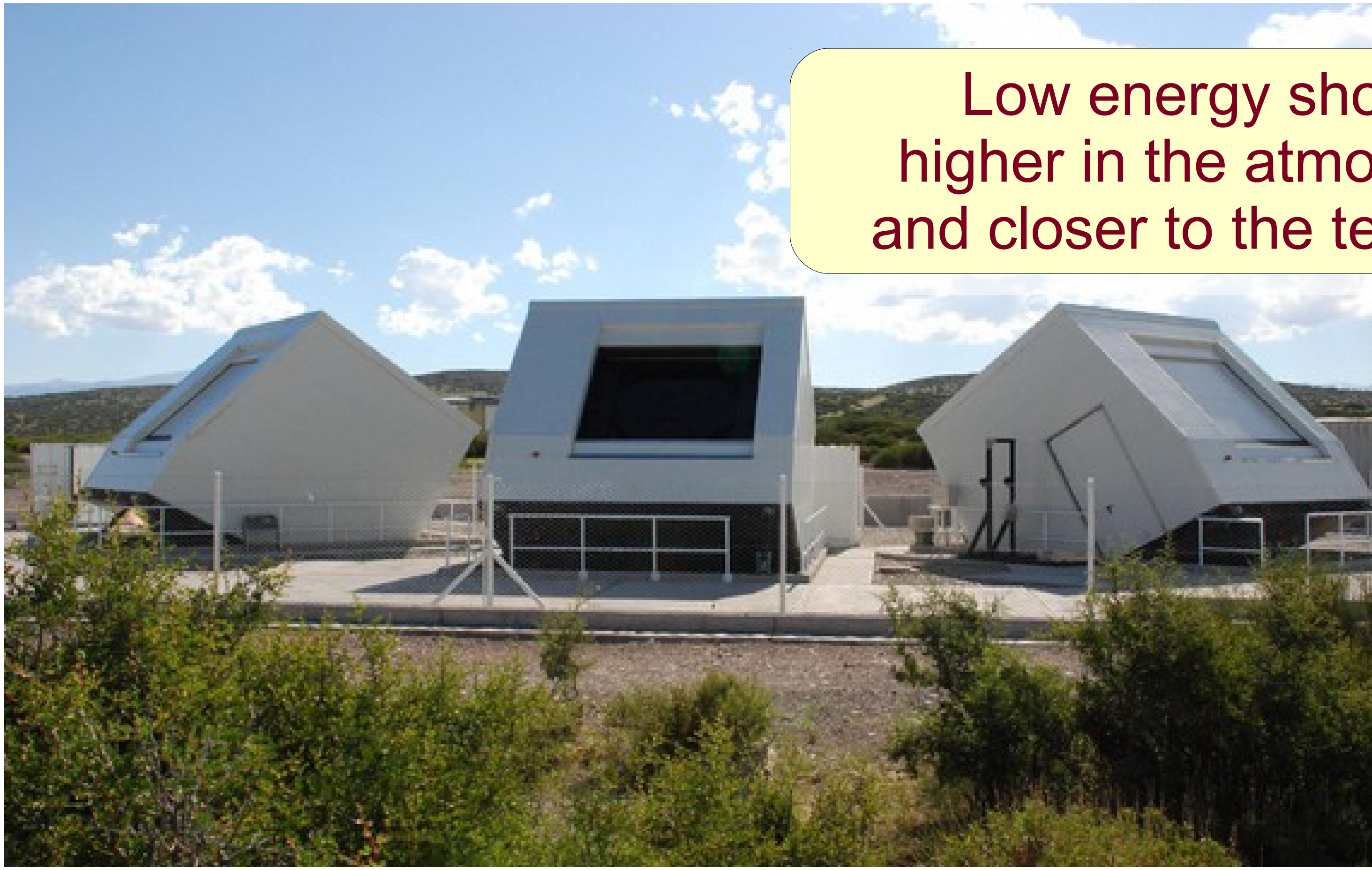





Discrete spectrum, mainly UV

# First Part: PMTs for Fluorescence Detection

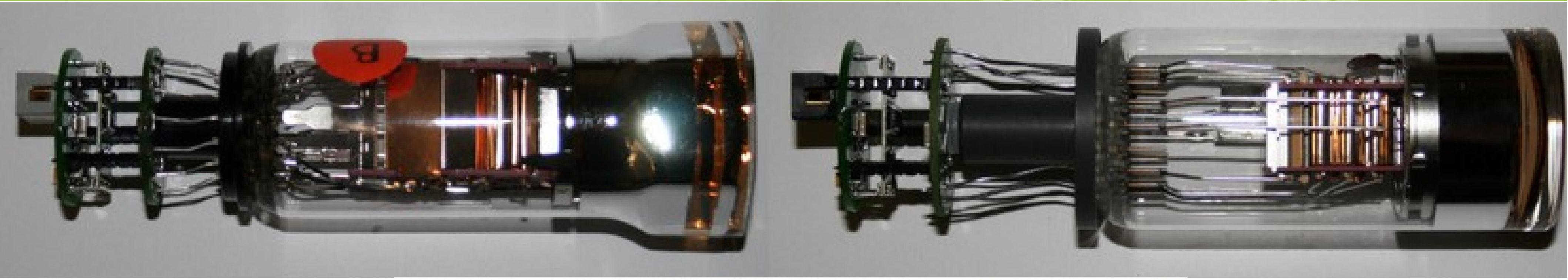


Low energy shower:
higher in the atmosphere
and closer to the teleskope

High Elevation Auger Telescopes (HEAT)

- Photonis stopped delivery of ordered XP 3062 (hexagonal)
- Replacement of one camera (440 PMTs) with round entry window

# First Part: PMTs for Fluorescence Detection



| | XP3062 | Ham. R9420-100 |
|---|---|---|
| Faceplate | hexagonal | round |
| Photocathode | bialkali | super-bialkali |
| Window | lime glass | borosilicate |
| Dynode structure/stages | lin. focused/ 8 | lin. focused/ 8 |
| Gain | $2.6 \times 10^5$ | $3.7 \times 10^5$ |
| Supply Voltage [V] typ. | 1100 | 1300 |
| max. | 1300 | 1500 |
| Dark current [nA] typ. | 1 | 10 |
| max. | 20 | 100 |
| Cathode sens. [mA/W] | 90 | 110 |
| Q.E.at peak wavelength | 27% | 35% |
| Rise Time [ns] | 3 | 1.6 |

High Elevation Auger Telescopes (HEAT)

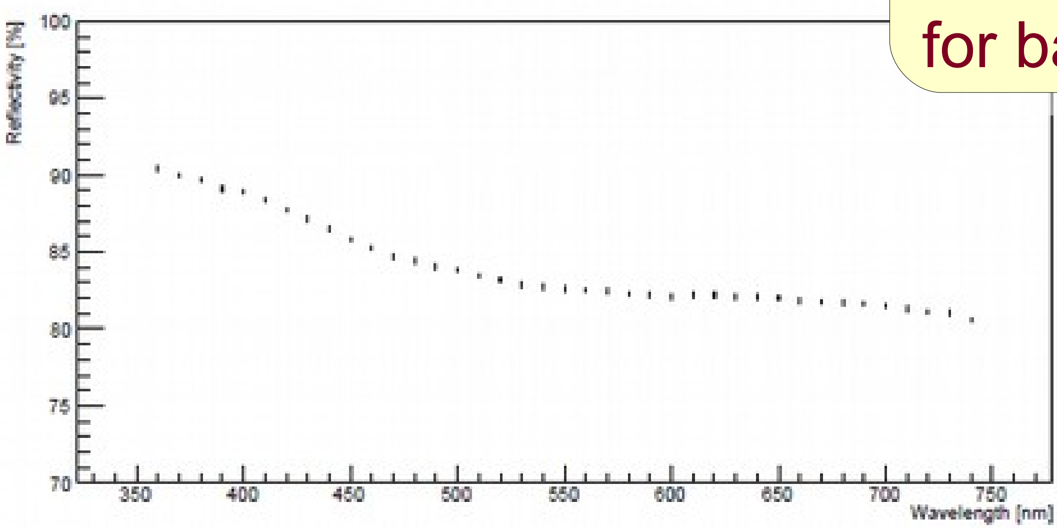
- Photonis stopped delivery of ordered XP 3062 (hexagonal)
- Replacement of one camera (440 PMTs) with round entry window

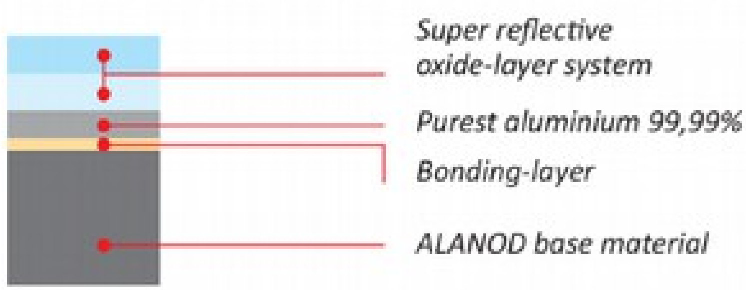
# Winston Cones: Material

- light collectors to cover dead space between PMTs
- transition from hexagonal to round structure
- material: Alanod 4300UP (high reflectivity in UV range, HISCORE)
- manufacurer of segmented cone: Alux Luxar (Langenfeld, GER)

alanod

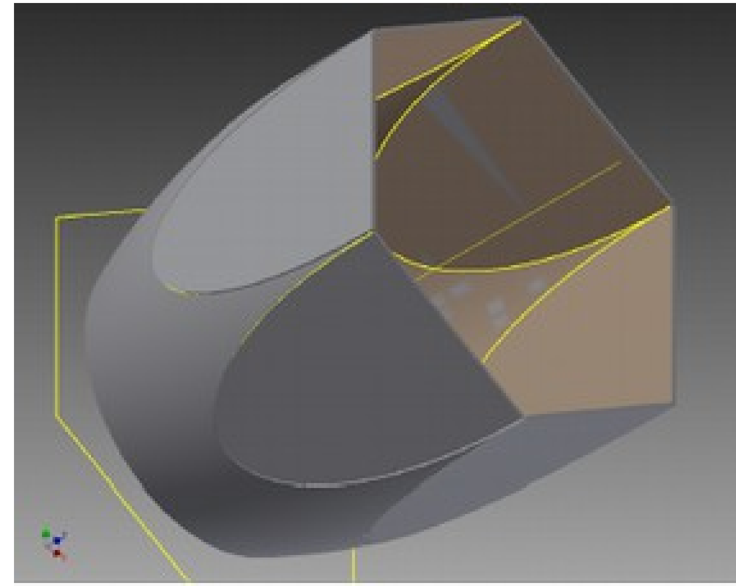
World-market leader
for band-anodized aluminium

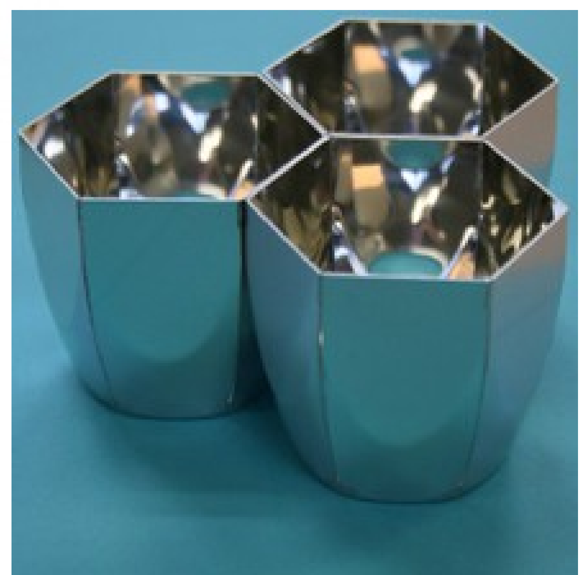


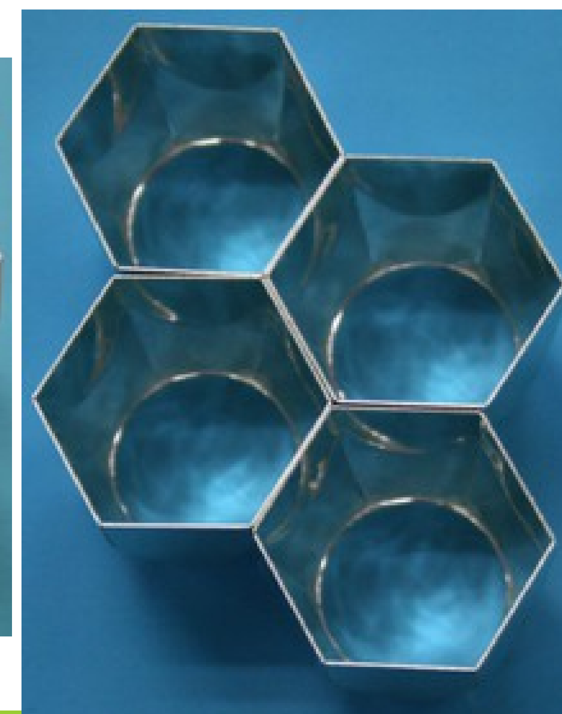



# Winston Cones: Design

- winston cone geometry given by aperture size
- modification for hexagonal entrance aperture
- problem 1: material only bendable in 2D
  - else loss of reflectivity
- problem 2: hexagon shape on sphere varies up to 1mm

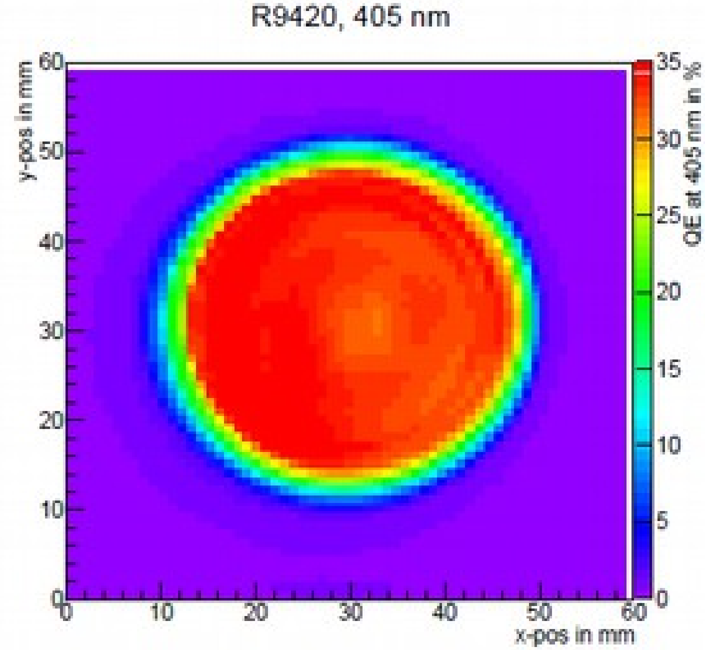


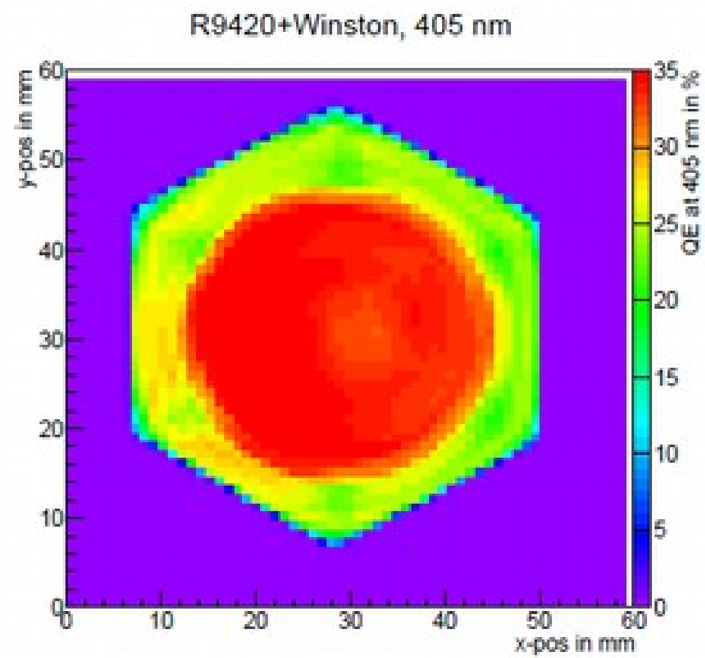




# Winston Cones: Lab Measurements

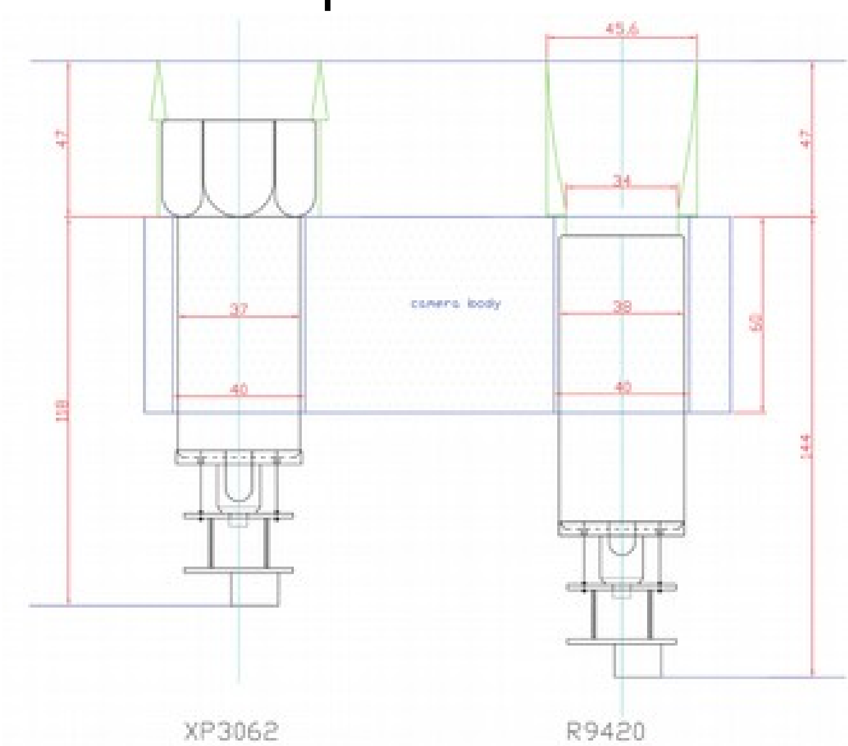
- first measurements with new Winston Cones
- scan of QE with 405 nm laser
- stepsize 1 mm, spotsize < 1.1 mm
- efficiency increase of ~ 20%



# Winston Cones: Test Installation

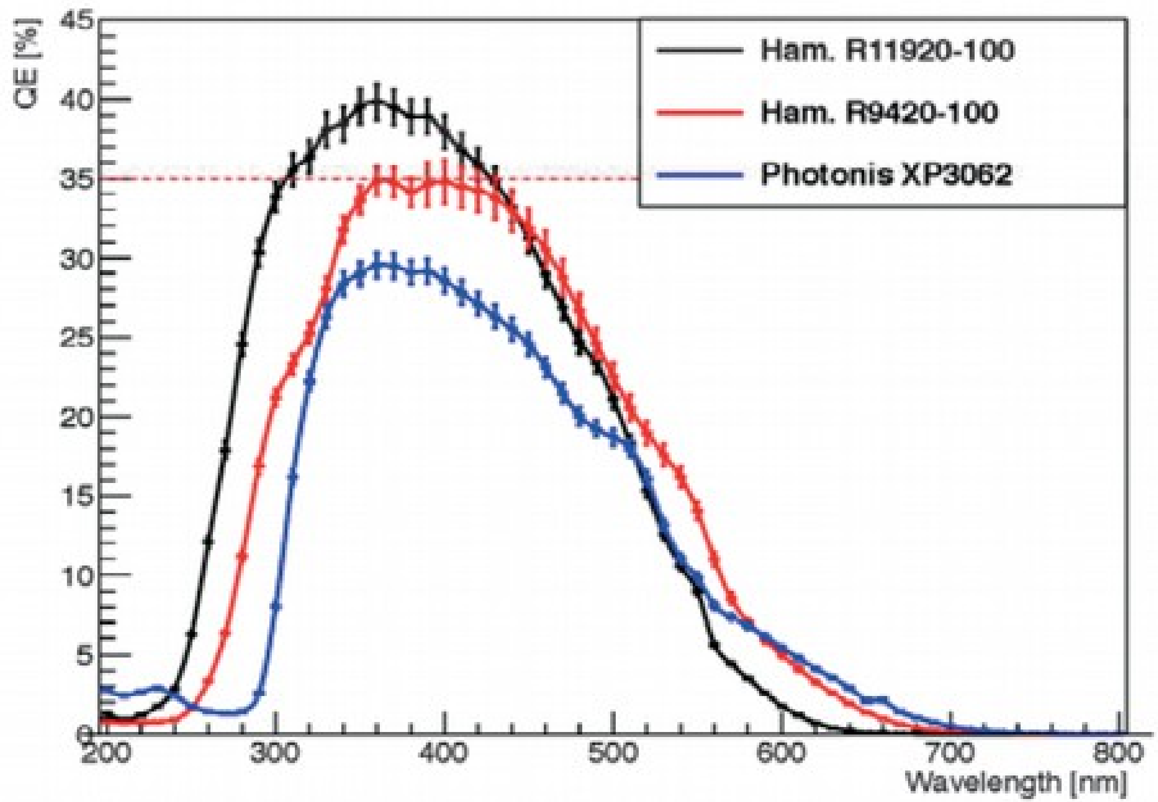
- prototype with 48 PMTs + Winston Cones installed in one camera
- plastic plate to hold Winston cones
  - produced with 3D printer to fit
  - camera body shape
  - screwed to camara body
  - Winston cones glued with epoxy
- same focal plane

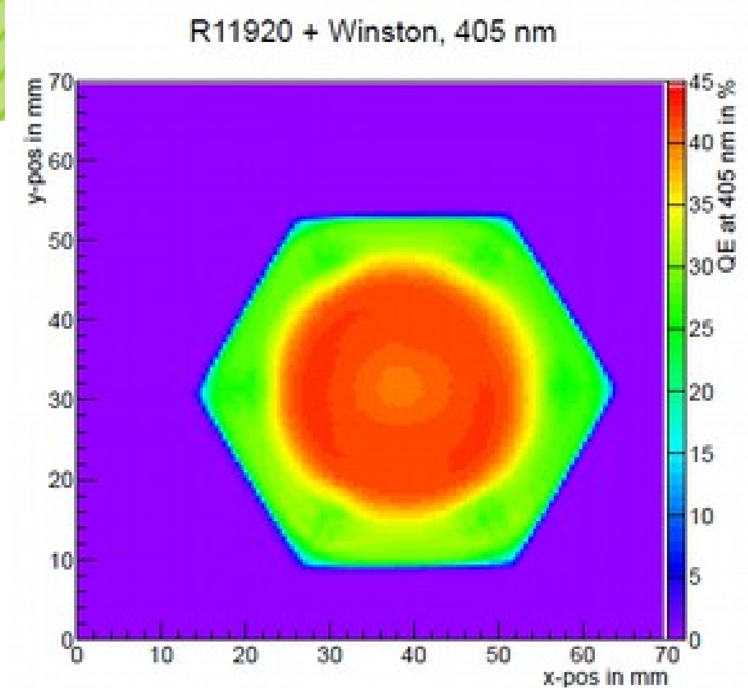


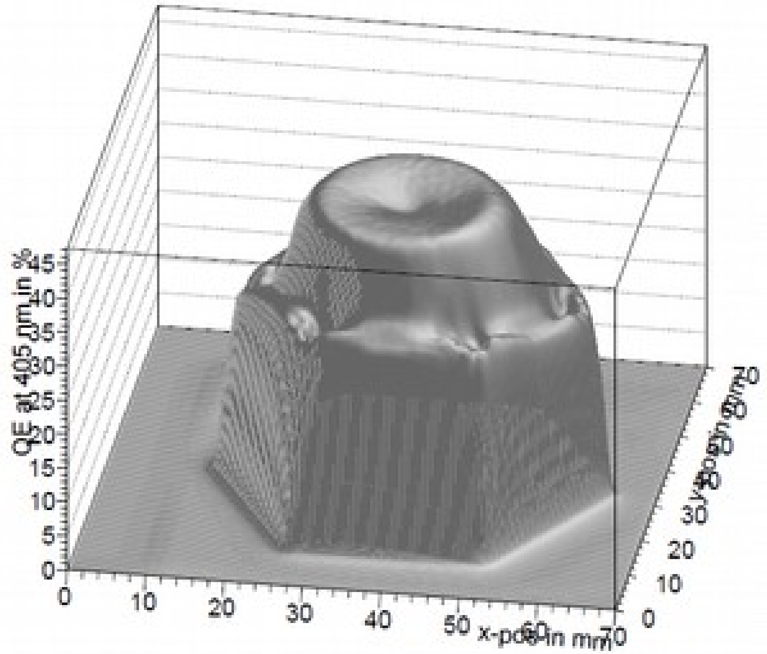

# New PMTs

| | Phot. XP3062 | Ham. R9420-100 | R11920-100 |
|---|---|---|---|
| Faceplate | hexagonal | round | hem./frosted |
| Photocathode | bialkali | super-bialkali | super-bialkali |
| Window | lime glass | borosilicate | borosilicate |
| Dynode structure/stages | lin. focused/ 8 | lin. focused/ 8 | lin. focused/ 8 |
| Gain | $2.6 \times 10^5$ | $3.7 \times 10^5$ | $4 \times 10^4$ |
| Supply Voltage [V] typ. | 1100 | 1300 | 1300 |
| max. | 1300 | 1500 | 1500 |
| Dark current [nA] typ. | 1 | 10 | 5 |
| max. | 20 | 100 | 20 |
| Cathode sens. [mA/W] | 90 | 110 | 110 |
| Q.E.$_{\text{at peak wavelength}}$ | 27% | 35% | 35% |
| Rise Time [ns] | 3 | 1.6 | 2.6 |

# New PMTs

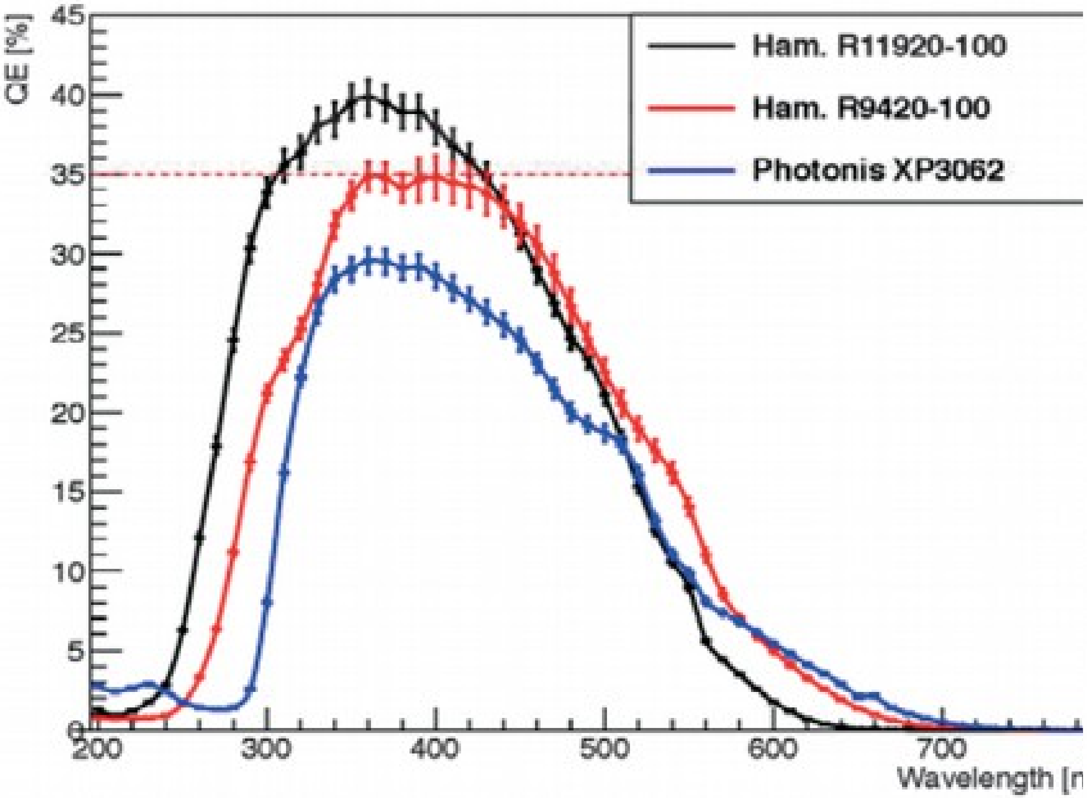


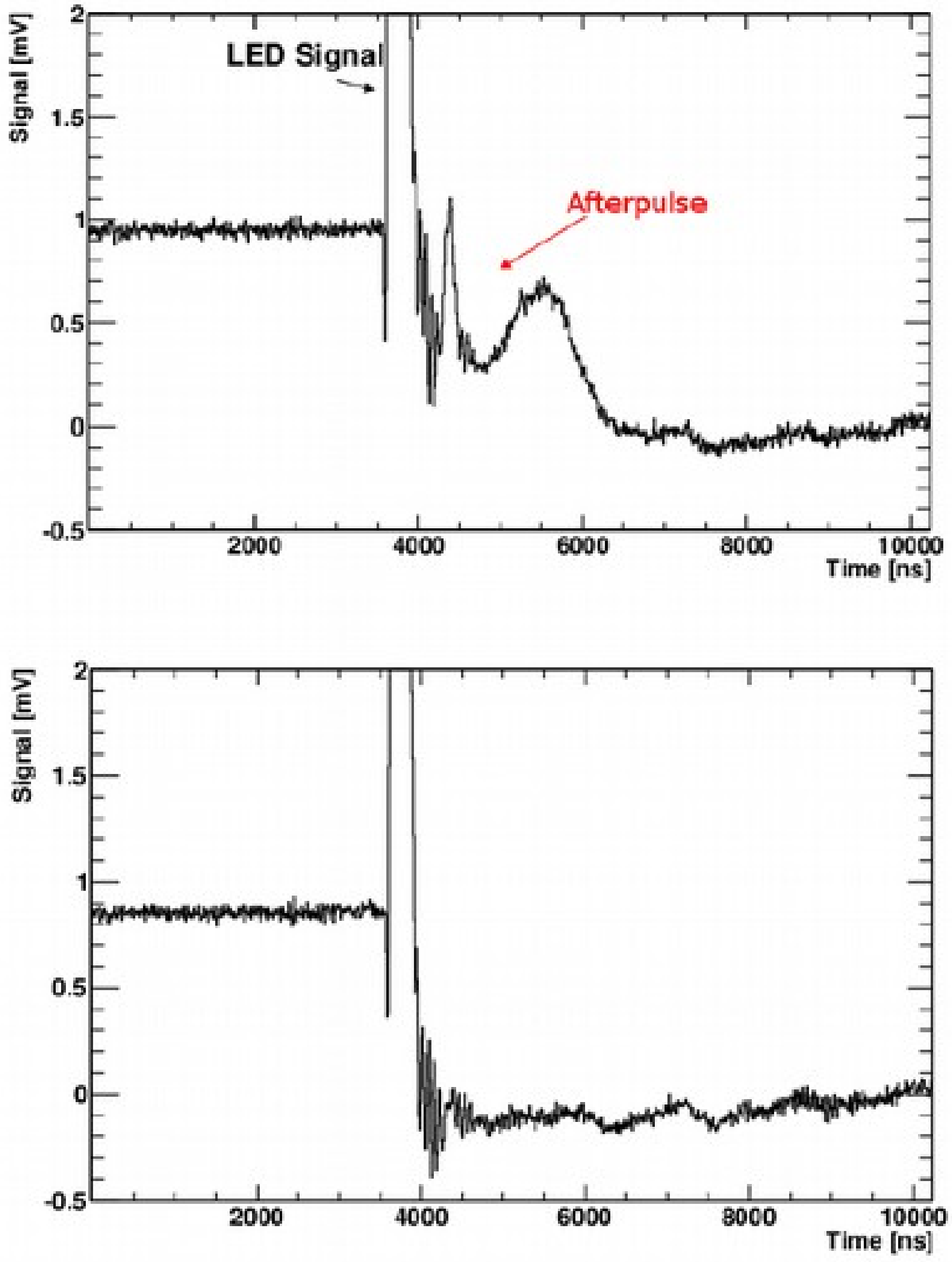




- Higher QE of 40% (R11920-100) compared to 35% (R9420-100)
- Spherical window increases homogenity of winston-cone efficiency

# New PMTs

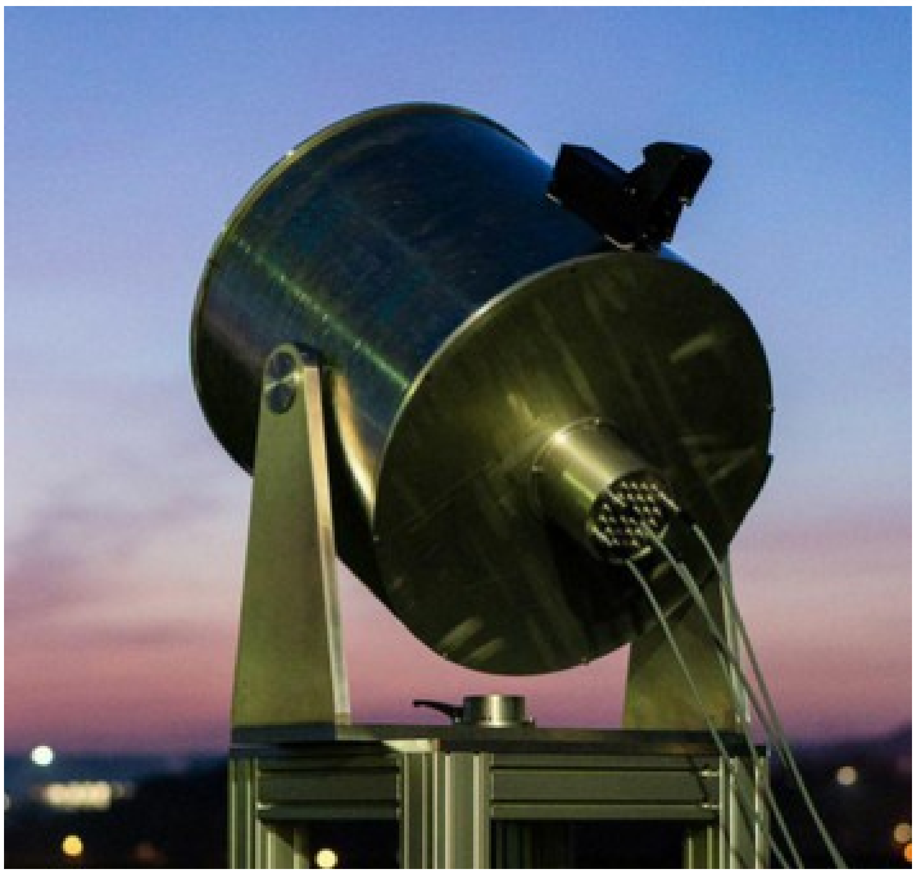


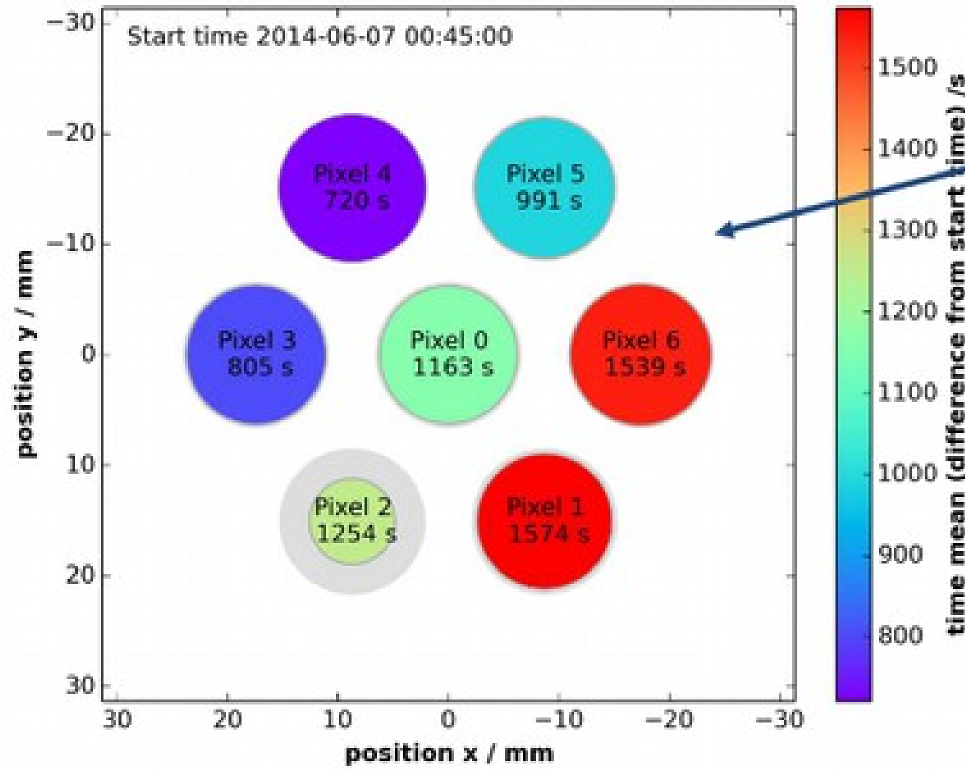




- Improved Afterpulsing
- To be tested with ca. 100 PMTs in one camera

# Fluorescence with SiPM

FAMOUS

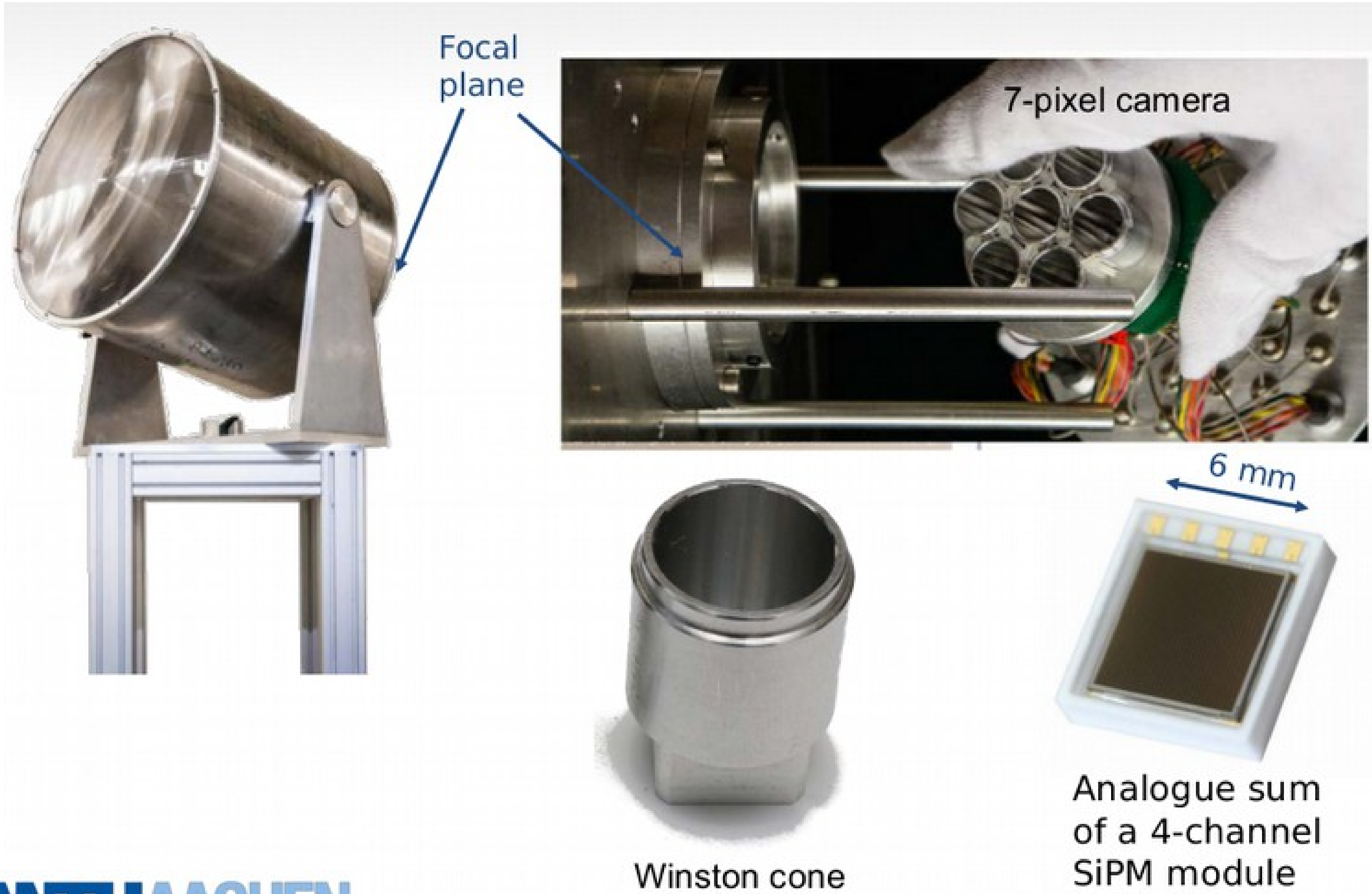





Pro: insensitivity!
Test-measurements with moon
Future for FD?

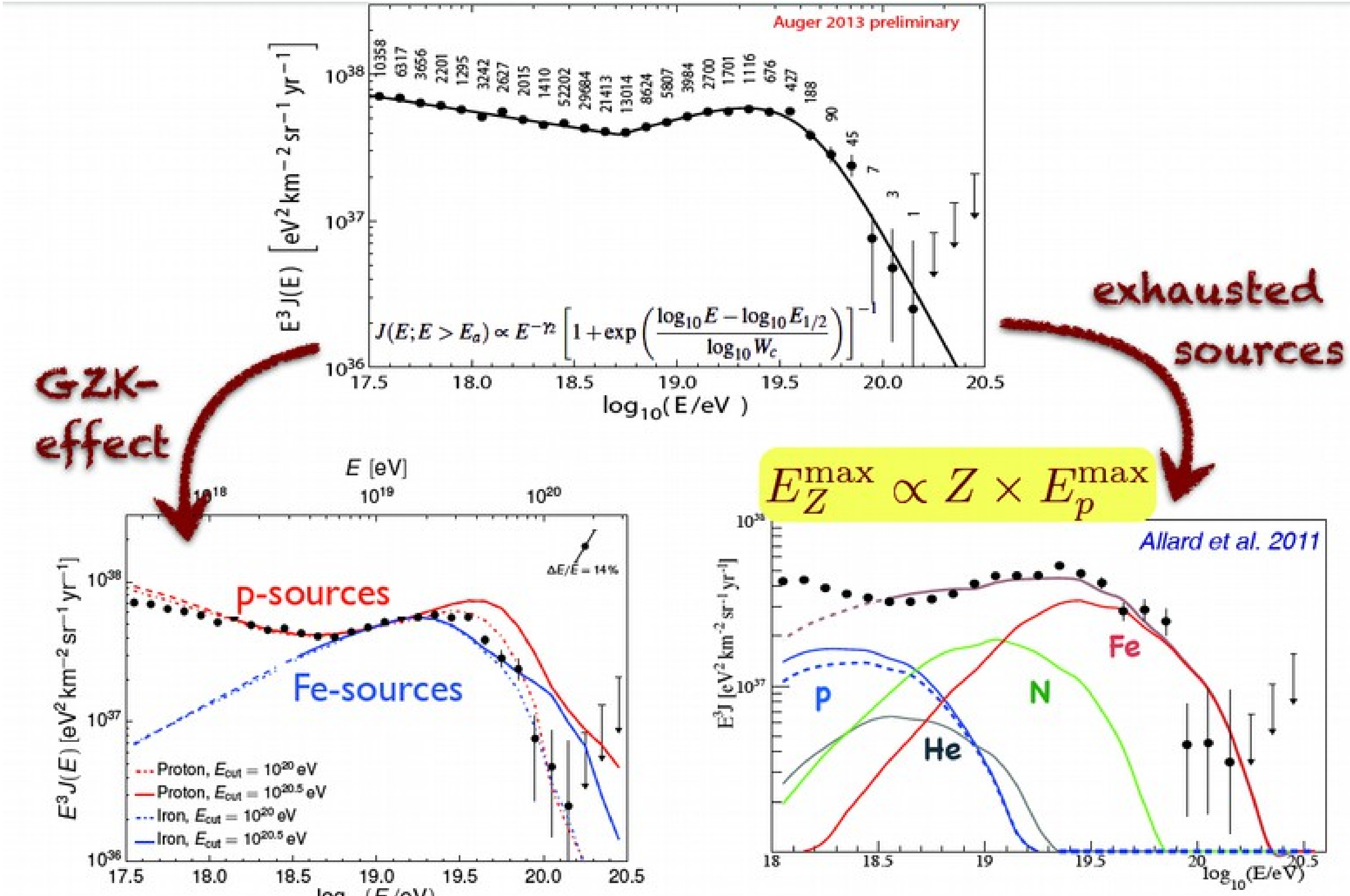
RWTH AACHEN UNIVERSITY

# Fluorescence with SiPM

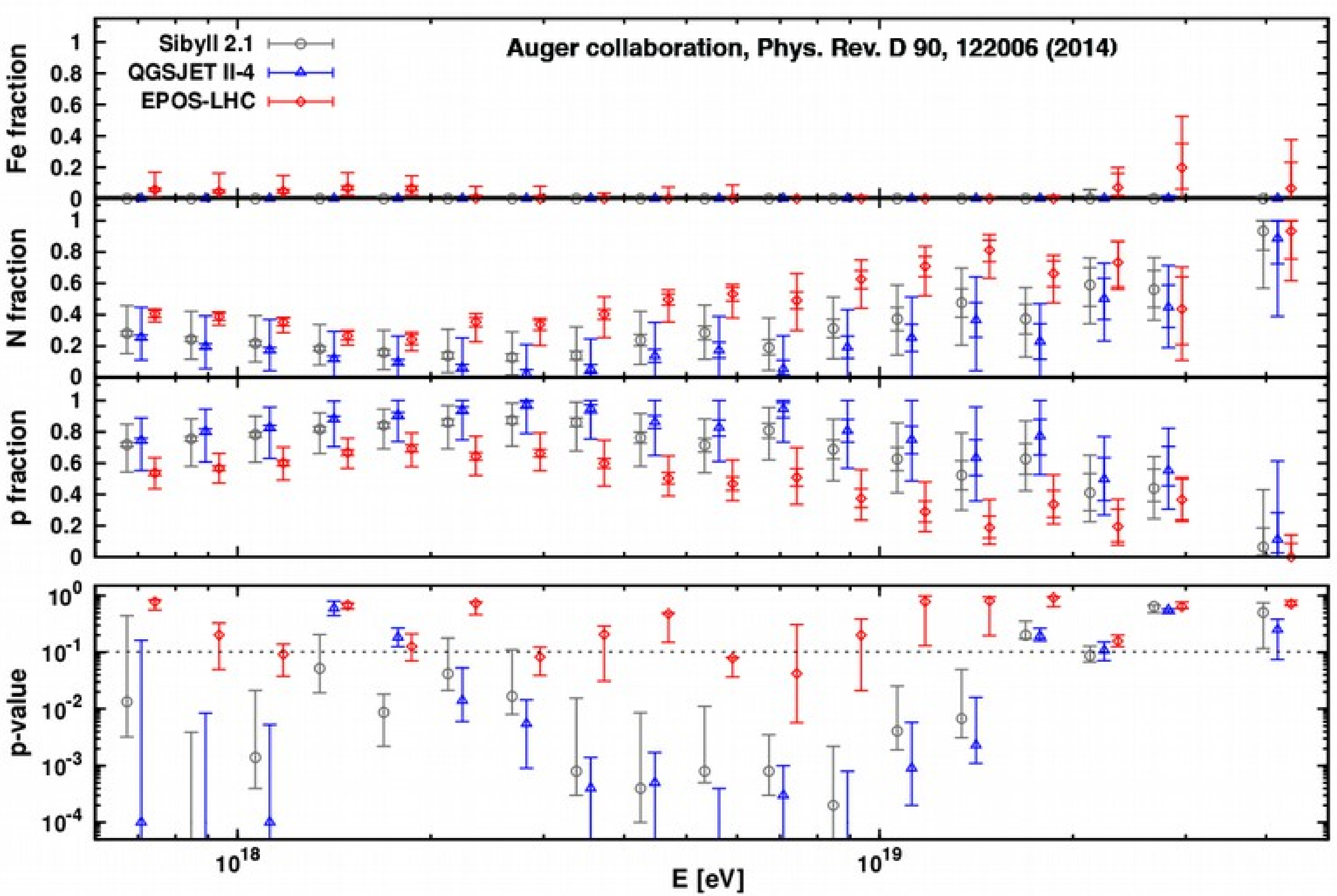



Auger-Upgrade

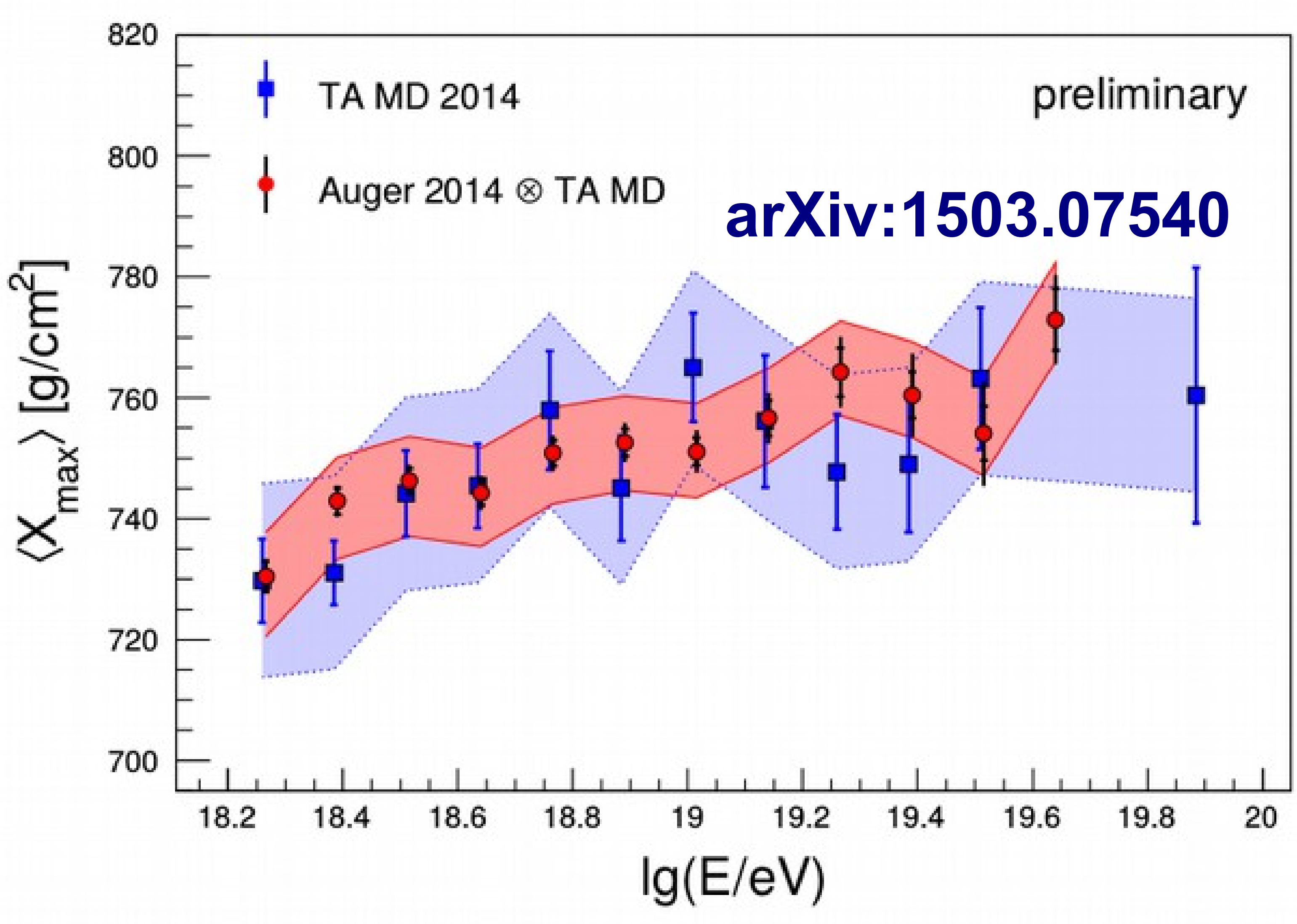
# Auger Key Question:



# Auger Key Question:

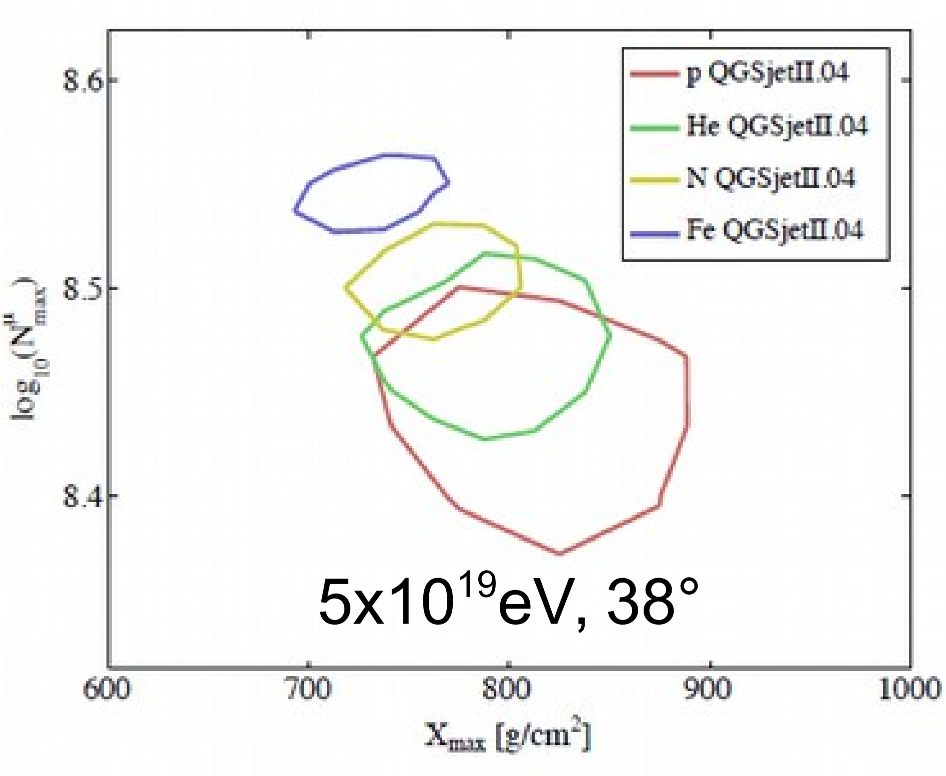


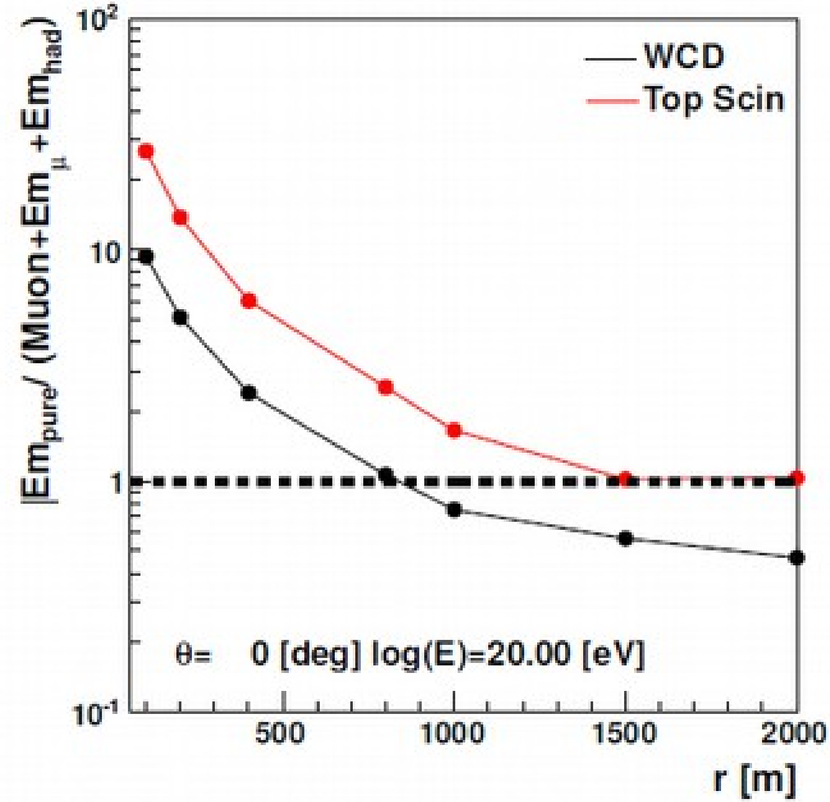
# Auger Key Question:




Report of the Working Group on the Composition of Ultra High Energy Cosmic Rays (UHECR 2014)

# Auger-Upgrade:
# Event-Wise Composition Sensitivity at highest Energies



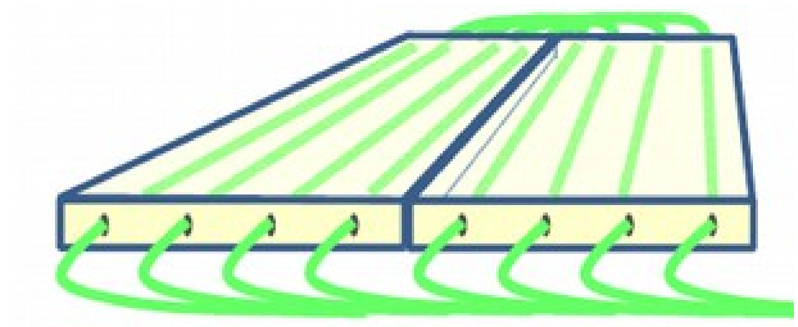




- Add (thin) Scintillator on top of Surface Detectors for EM component
- Dynamic Range:
  peak signal in a 4m$^2$ SSD at 200m from the core of a shower at $10^{20}$ eV and 38 degrees zenith angle is expected around 12,000 MIPs

# Auger Upgrade

# Auger Upgrade:

- Small Scintillator with wace-length shifting fiber to one PMT
- Main requierement:
  - sensitivity above 500nm
  - Large dynamic range, linearity
- Candidates so far:
  - R9420
  - R8916

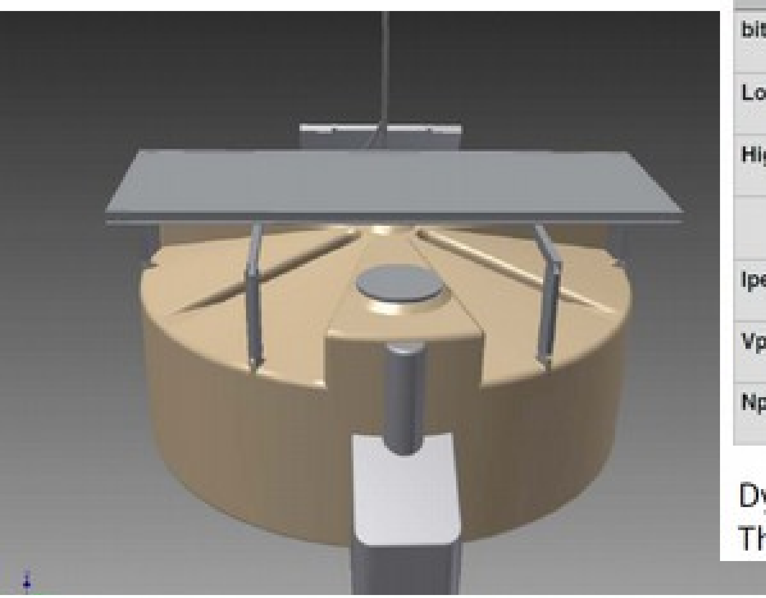


Noise-level on FE-Board

| Range | Intent | Dynamic range | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| bits | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| LowGain | MIP | AnodeX32 | | | | | | | | | | | | | | | | | | |
| HighGain | Showers | | | | | | | | Anode/4 | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| Ipeak (mA) | | 0.0006 | | | | 0.01 | | | 0.1 | | | | 1.25 | | | 10 | | | | 160 |
| Vpeak (mV) | | 0.03 | | | | 0.5 | | | 4 | | | | 62.5 | | | 500 | | | | 8000 |
| Npart (MIP) | | 0.07 | | | | 1.2 | | | 10 | | | | 156 | | | 1250 | | | | 20000 |

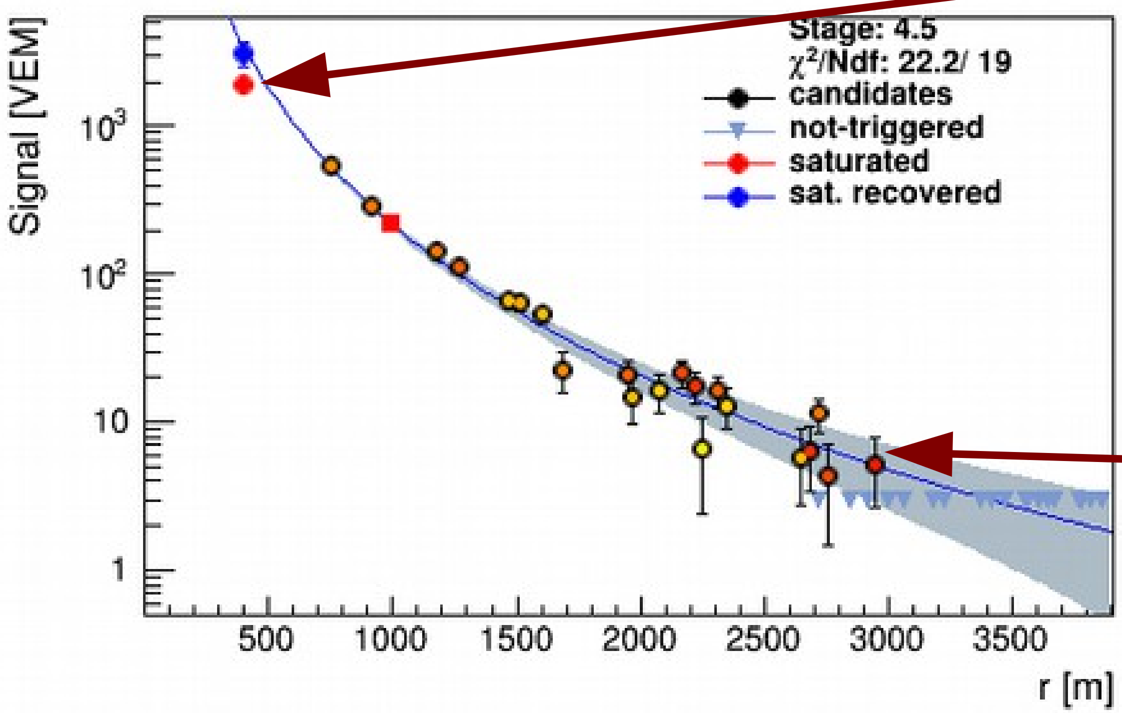
Dynamic range required: 20000 MIP

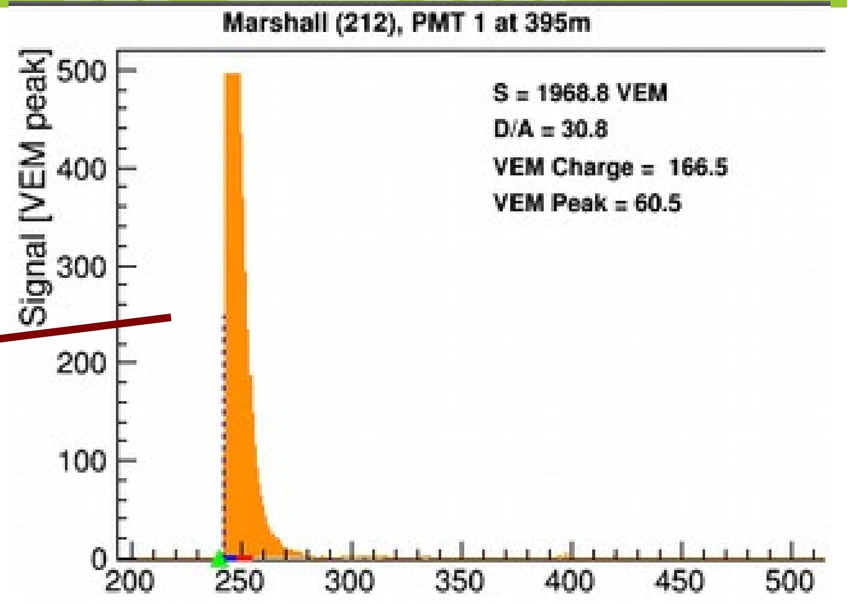
This can be achieved with two channels and a PMT linear up to 160 mA

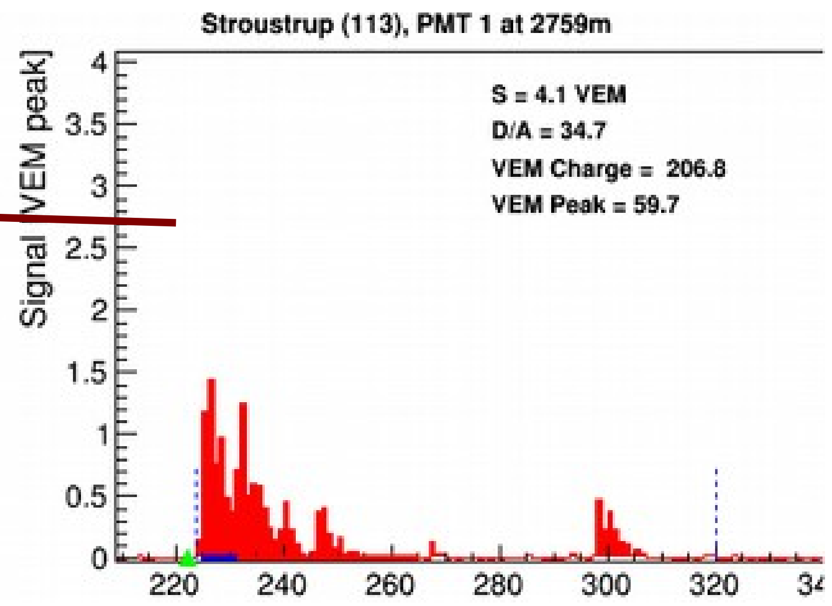


# Saturation of Surface Detectors

- Add a “small” PMT to increase dynamic range of linear response



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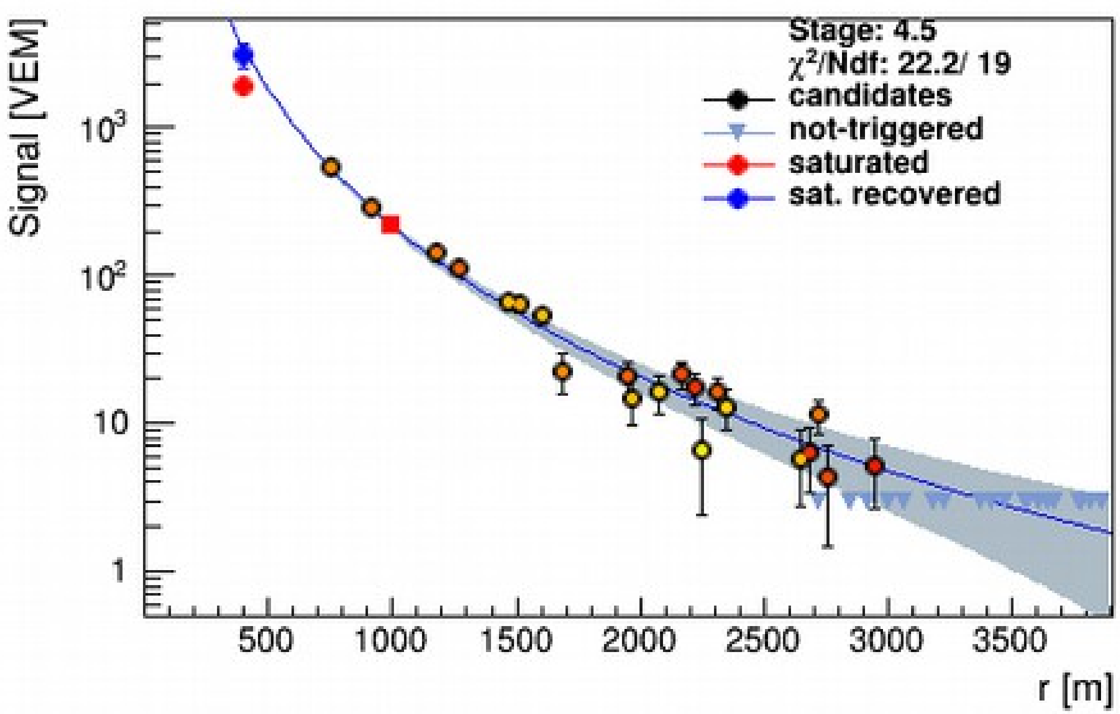
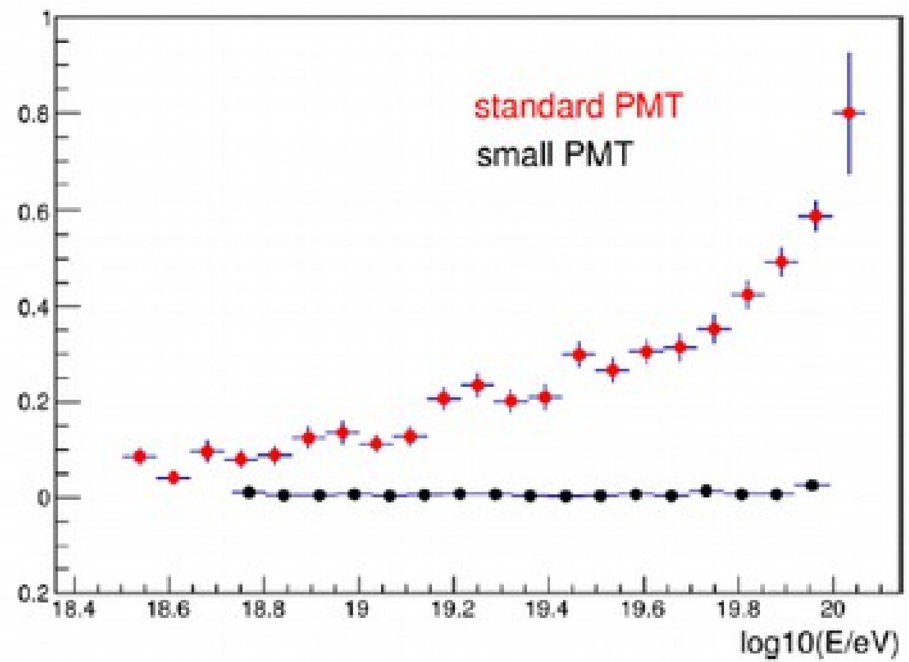
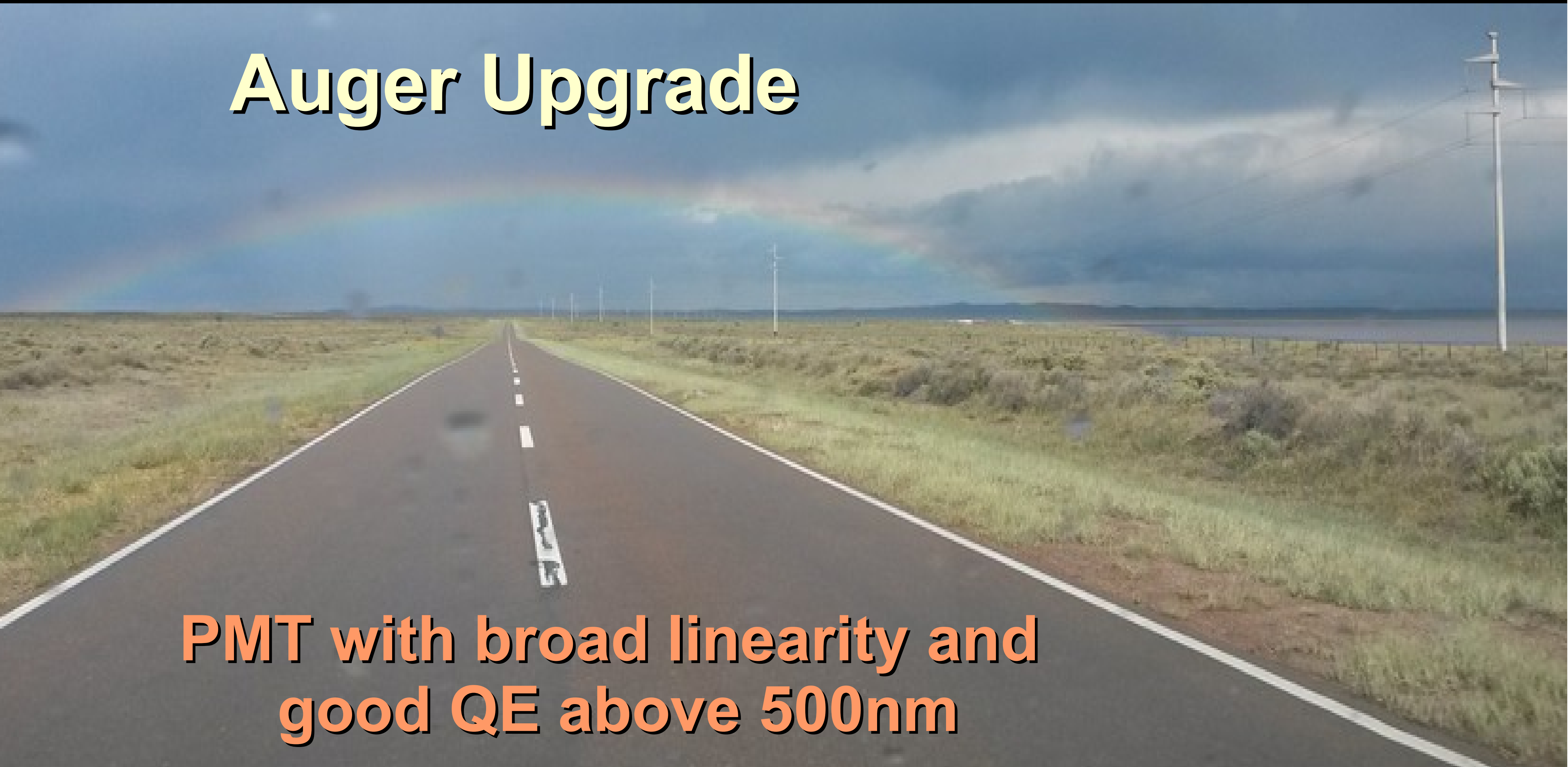


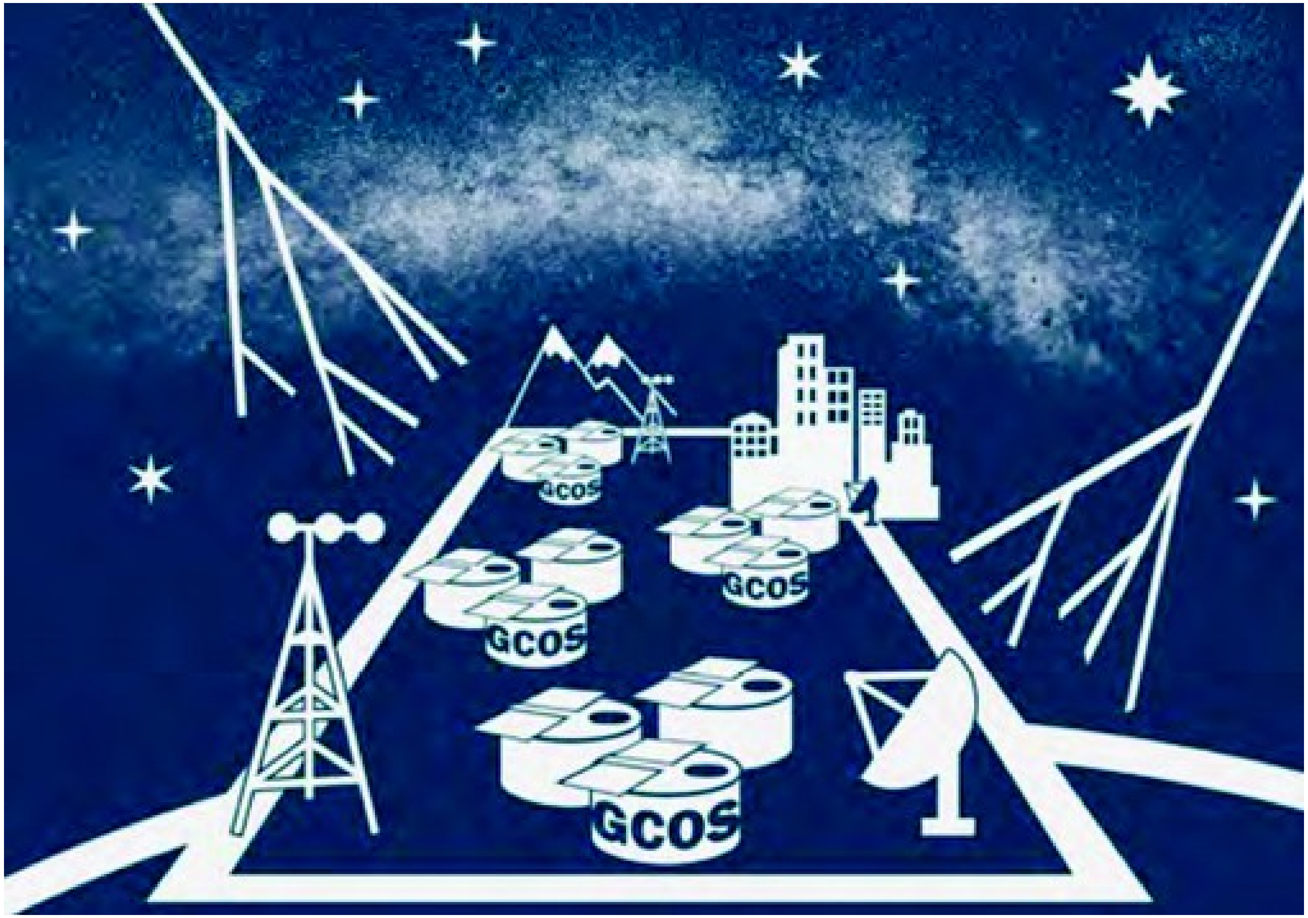

- New integrated SD-Electronic at higher sampling rate (120MHz)
- New HV also for existing 9” Photonis PMTs


Auger Upgrade
PMT with broad linearity and
good QE above 500nm

# Far future: GCOS

**p-astronomy with sources**

- Global, few sites, N+S
- ca. 90,000 km$^2$ (x30 Auger)
- FD with SiPMs?
- No FD at all?
- Optimal detector for composition-sensitivity?



# Schedule

## Specifications

1700 Photosensors 22–38 mm diameter for scintillator readout and 1700 Photosensors 22 mm diameter to increase dynamic range of WCD in addition to the three 9 inch PMTs per detector.

**Auxillary electronics**

Re-design of readout-electronics and replacement of 1700 times 3 HV modules for operation of the existing PMTs in WCDs as well as 3400 HV modules for the afore mentioned smaller PMTs.

## Requirements

**Design phase**

Immediate selection of optimal photo-detector

- for scintillator optimized for green light,
- for Cerenkov low priority on sensitivity since overlap with large PMTs.

Priority on high linearity.

**Prototyping phase**

- reliable and well tested products for prompt product readiness,
- interaction with companies for available prototypes or possible developments on short timescale.

## Schedule