Highlights of Astroparticle Physics

Symposium in Memory of Gianni Navarra

Torino, 20 September 2010

'The Birth and Promise of the Auger Observatory'

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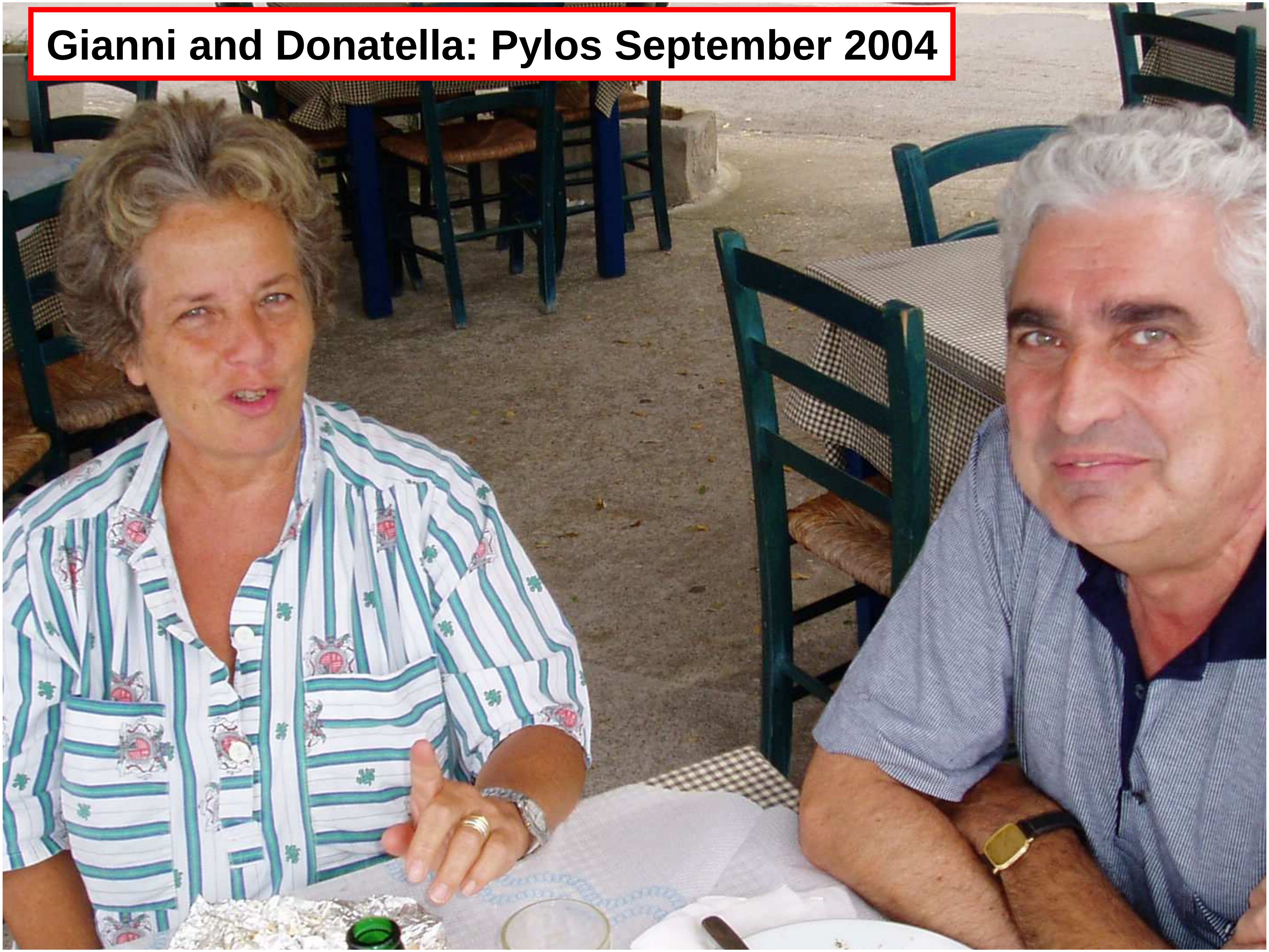


Gianni and Donatella: Pylos September 2004

Malargüe, 16 November 2003

My first visit to Torino, and only visit to Plateau Rosa, was sometime around 1980

Gianni was using micro-processors to measure shower directions ON-LINE with times determined with small scintillator array

Searching for signals from Crab Nebula

Impressive technical feat: far ahead of what any other shower physicists were doing

Detection of EAS Čerenkov Light Reflected from Mountain Snow.

C. CASTAGNOLI and G. NAVARRA

Istituto di Cosmo-Geofisica del C.N.R. - Torino, Italia
Istituto di Fisica Generale dell'Università - Torino, Italia

C. MORELLO

Istituto di Cosmo-Geofisica del C.N.R. - Torino, Italia

(ricevuto il 3 Maggio 1983)

Summary. — Fast (typical duration (400 ÷ 500) ns) light pulses are detected pointing three mirrors at a snowy mountain surface. The characteristics of the pulses are in agreement with expectations from EAS Čerenkov light reflected from the snow. The technique can be applied to the study of the cosmic-ray primary spectrum at high energies.

PACS. 94.40. – Cosmic rays.

Nuovo Cimento 1983 (based on an idea of Chudakov, 1972)

First discussion about a giant array

“The problem is lack of exposure: while it has been clear for many years that 1000 km^2 of instrumented area is needed, but progress towards getting this has been slow.”

“The experimental problems are challenging and subtle but certainly soluble. All that is need is dedication, money and patience.”

AAW Nottingham ECRS 1980

Jim Cronin: Dublin ICRC August 1991

"You're not nearly ambitious enough:

We should build 5000 km^2"

This was the starting point of what has become the Pierre Auger Observatory

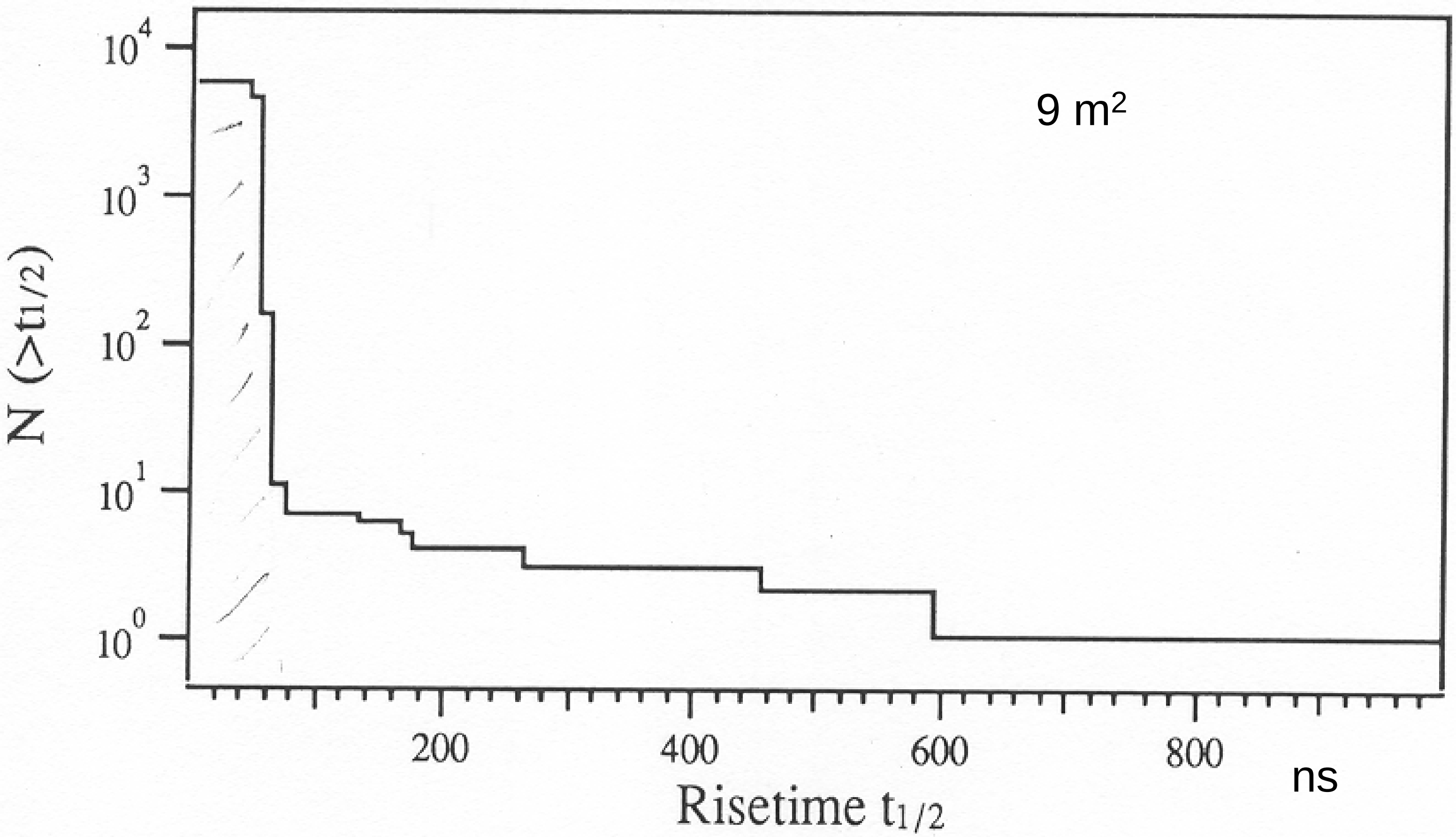
Early name – P5000

Naming the Observatory, Auger, came from efforts to woo John Linsley, and hence Palermo, into joining the project.

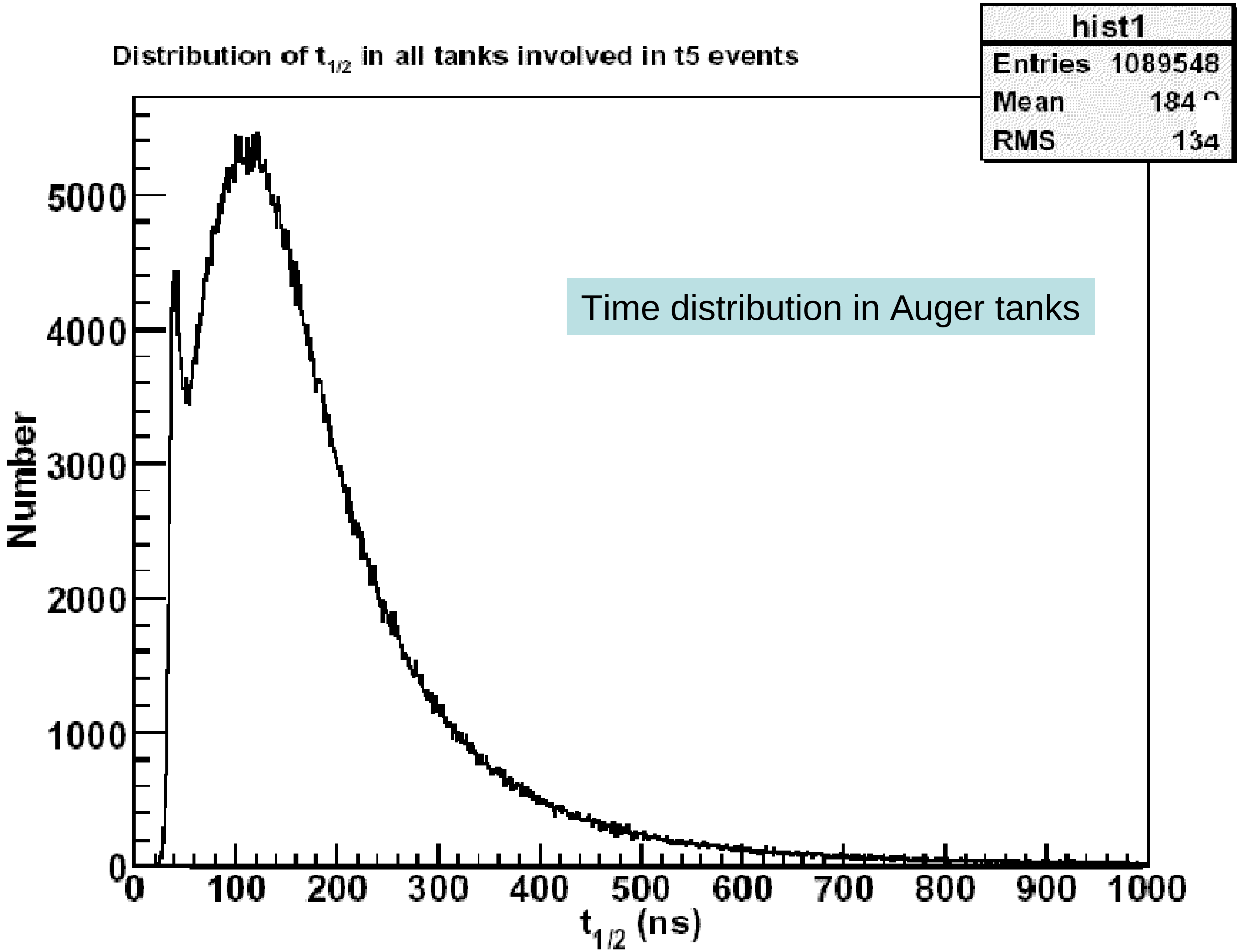
Jim had sabbatical leave in Leeds for 4 months in late 1991.

Most of the time was spent on early planning for what became the Auger Observatory. Some test measurements were made at Haverah Park and contacts were developed with our Electronic Engineers (led to GPS studies, largely by Clem Pryke) and eventually to Paul Clark

Figure **3.1** The integral risetime spectrum of pulses from the water Čerenkov detector.



Simon Hart: MSc thesis, University of Leeds 1992


Distribution of $t_{1/2}$ in all tanks involved in t5 events
hist1
Entries 1089548
Mean 184
RMS 134
Time distribution in Auger tanks
Number
0
1000
2000
3000
4000
5000
0
100
200
300
400
500
600
700
800
900
1000
$t_{1/2}$ (ns)

The Paris Workshop

April 1962

Some reflections post-Paris

- **Really the French were not very keen**
- **German situation was very complicated**
- **Italian groups (mainly Palermo and Naples) were rather reluctant to get involved under Jim's leadership as John Linsley had different ideas as to how things should be done: at this time John and Jim had a difficult relationship**
- **From UK perspective, this was our only hope!**

MAJOR PROBLEMS TO BE OVERCOME

- **LACK OF MONEY TO DO ANYTHING**

- **Fight for recognition that the project was worthy of attention**

- **Site surveys**

- **Develop a collaboration of critical mass and competence and withmoney to build a capital project of ~$100M**

- **How was the worth of the project to be assessed?**

- **A vulnerability, as with neutrino astronomy was that there were no hard theoretical numbers demanding the construction of an instrumentof a certain size**

Coping with the lack of Money

Small amounts of money for travel and limited R&D from budgets of interested laboratories (e.g. Leeds: sale of lead previously used for muon shielding and Aluminium lids)

UNESCO: Jim, with Murat Boratav, persuaded Director General to give significant support for three years (travel, visits by scientists from developing countries to design studies)

Private donors whom Jim knew:

Robert Galvin, Motorola
David Grainger, benefactor of University of Chicago

Jim could get through doors that I could never even have knocked on!

The Design Study: Jan – July 1995

- Studies of various surface detector designs:

RPCs, water-Cherenkov, scintillators, radio….
"Let a thousand flowers bloom…."

- Hybrid approach: ground array and fluorescence detectors - chose water as surface detector

- Very extensive Monte Carlo calculations

- Two sites to give all sky coverage

- Each site ~3000 km^2 : site survey was contemporaneous

Approximate cost ~$100M

Design Study document completed in October 1995

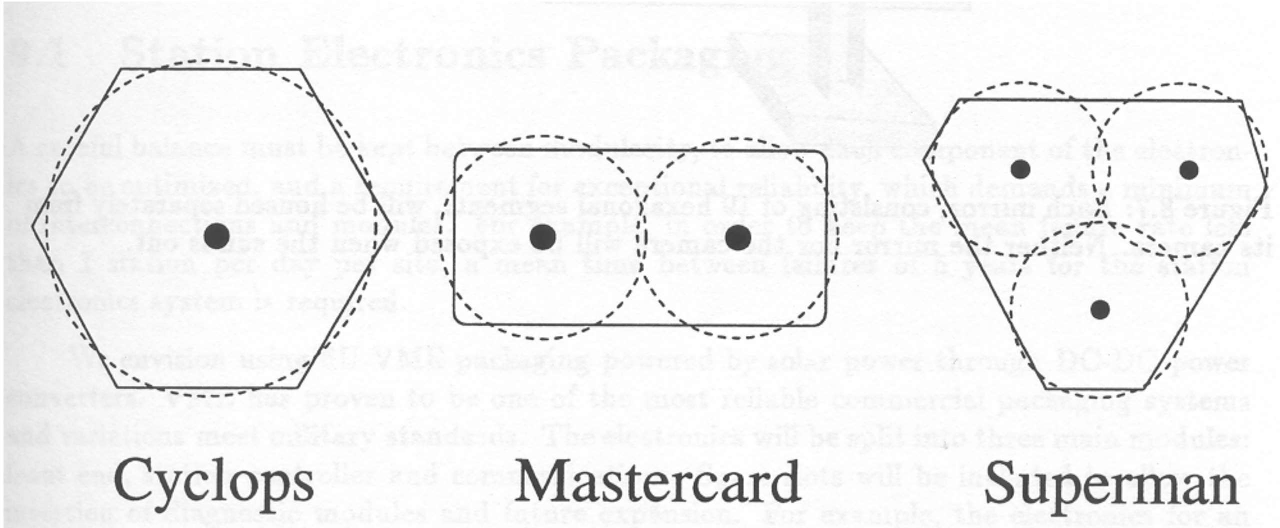
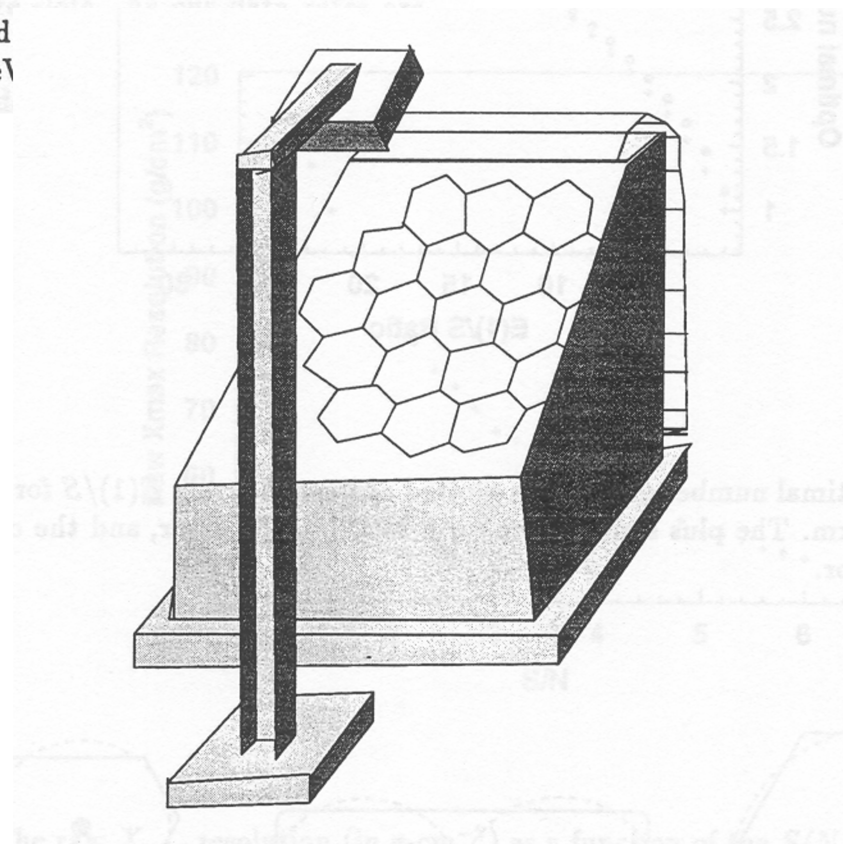


Figure 8.6: Possible array layouts for 1, 2 or 3 eyes. The solid
and the dotted circles the limits of their apertures for 10 EeV



The concept of the layout following the design study (October 1995)

-But Nature does not provide hills so strategically placed!

“High quality report”: Jan Ridky

Entrance of Italy

One of the people who heard about the project - by chance - was Giorgio Matthiae. In late 1993 (?) he was in Tokyo where he been invited by M Nagano and M Teshima to present data on elastic scattering and total cross section at high-energy (p-pbar collider at CERN). This is a topic that Giorgio had studied for many years.

Giorgio recalls presenting the extrapolation of the accelerator data to higher energy using dispersion relations in a plot that included cosmic ray data.

Giorgio heard Jim Cronin give a talk on

'A Surface Array for the Highest Energy Cosmic Rays'

but he was much more excited by Bruce Dawson's talk,

'Some notes on the Hybrid Array concept'

Giorgio told me "It was the first time I heard about this idea (I found it very appealing indeed!)"

CERN: 9 – 11 November 1997

But it was after the Ground Breaking Ceremony in March 1999 that Gianni's Group joined Auger

However it was not until 1999/2000 that Italian CR groups became fully involved in the project after further efforts by Giorgio, Jim and myself

It was a great disappointment to me that I was not able to persuade my old cosmic ray friends, Gianni and John Linsley, Livio Scarsi and Osvaldo Catalano in Palermo, to join the project

Gianni was leading the excellent experiment, EAS TOP, above Gran Sasso, and did not find a very large collaboration particularly appealing while John Linsley was driving the Palermo group towards what became the EUSO project.

Gianni and his group eventually joined ~2000

The Search for Funding in the USA

All countries watched what the US was doing

Significant promises of funding from Argentina, Brasil and Mexico

US assessment by SAGENAP committee:

DIFFICULT! Third time lucky (April 1998)

BUT:

BUILD ONLY ONE ARRAY and GO SOUTH

At the second meeting we ran into difficulties when a scientist* from the HiRes group advocated a completely different approach

provocatively named ‘El Cheapo’

based on an idea that he had proposed some years before to use solar cells as collectors of Cherenkov light produced in the air. This was a notion with no experimental evidence to justify it displacing the careful design of the Collaboration. I made this clear in no uncertain terms but my reaction did more harm than good: the proposal was turned down again.

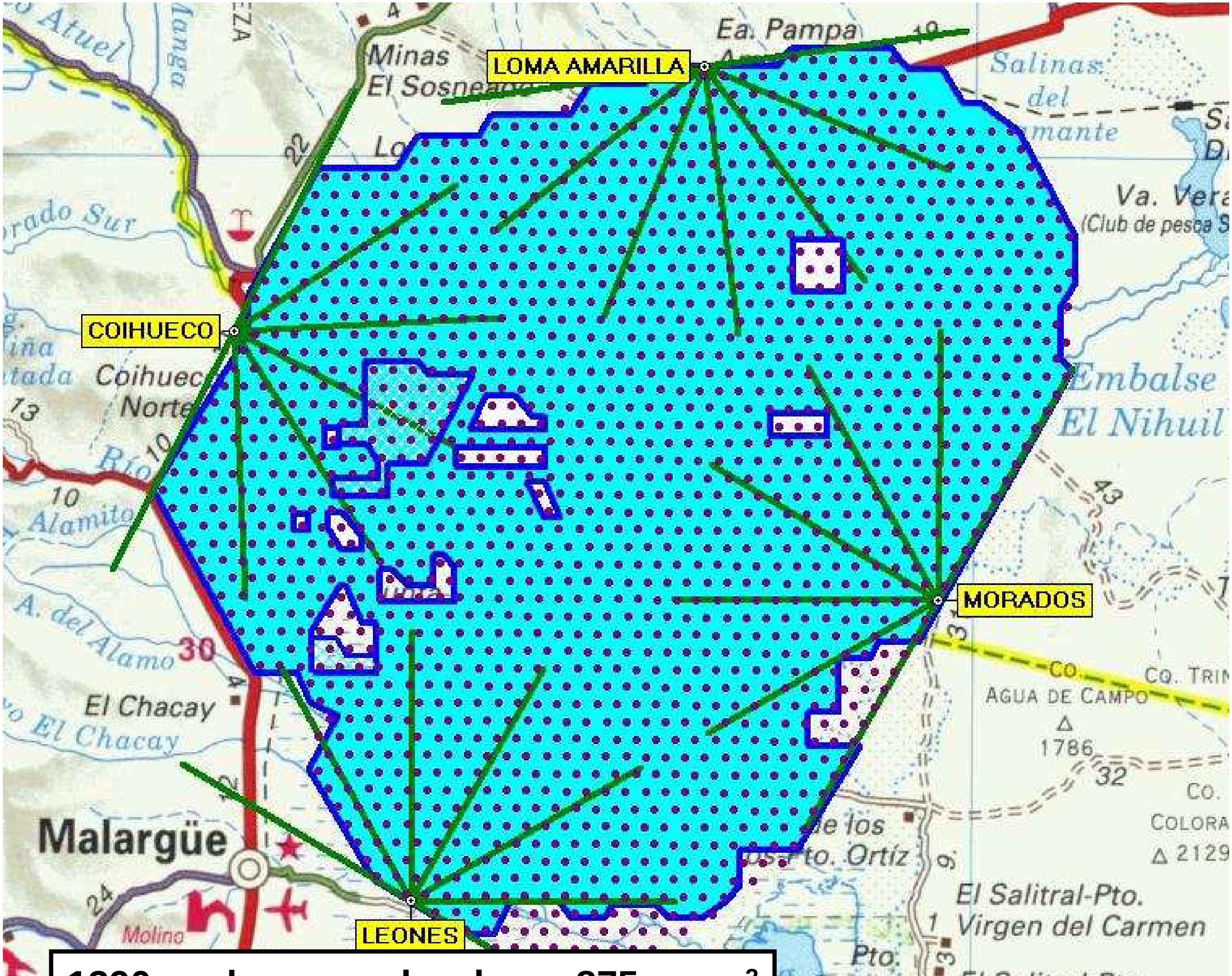
(Jim was advised not to bring me to the third meeting)

***** It was a young guy wanting tenure who was set up by his bosses to kill us. I got an apology about 10 years later!***

After US funding announced in 1998, funding from European Countries came relatively quickly.

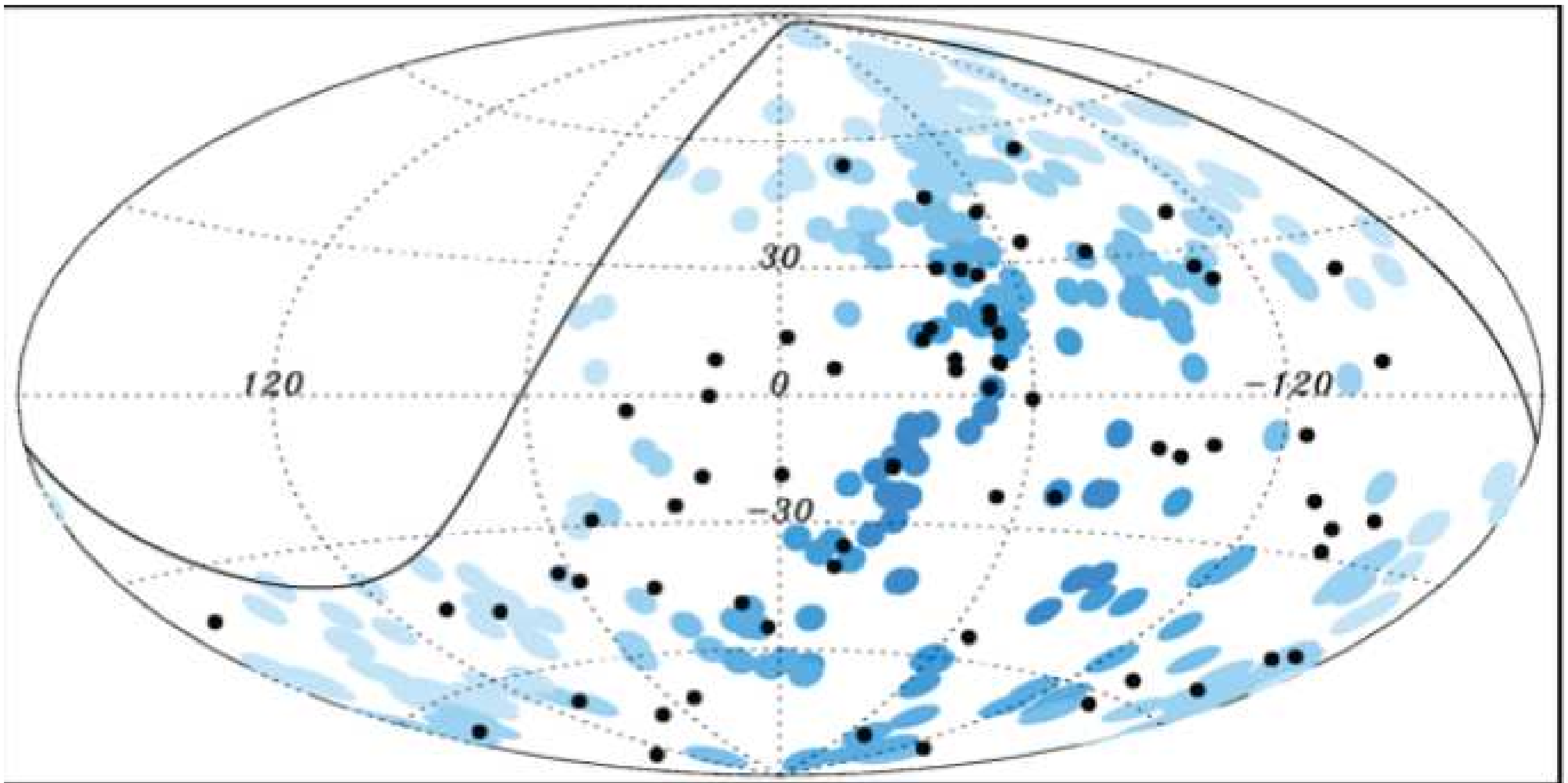
This allowed International Agreements to be signed

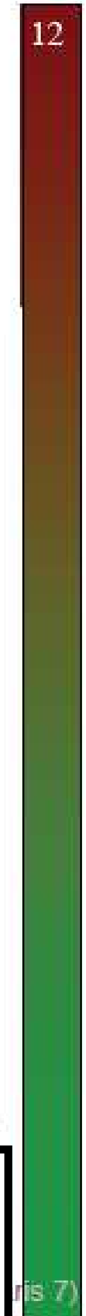
Ground breaking Ceremony in March 1999



1390 m above sea-level or ~ 875 g cm^{-2}

- Anisotropy





Directions and energies of top 69 events now available

There will surely be many who search: many will see 'clouds'

Arrival Directions

Auger effect is only at highest energies, >5 x 10^{19} eV,

where a comparison of observations is extremely difficult

Exposures of Auger and HiRes are now rather different

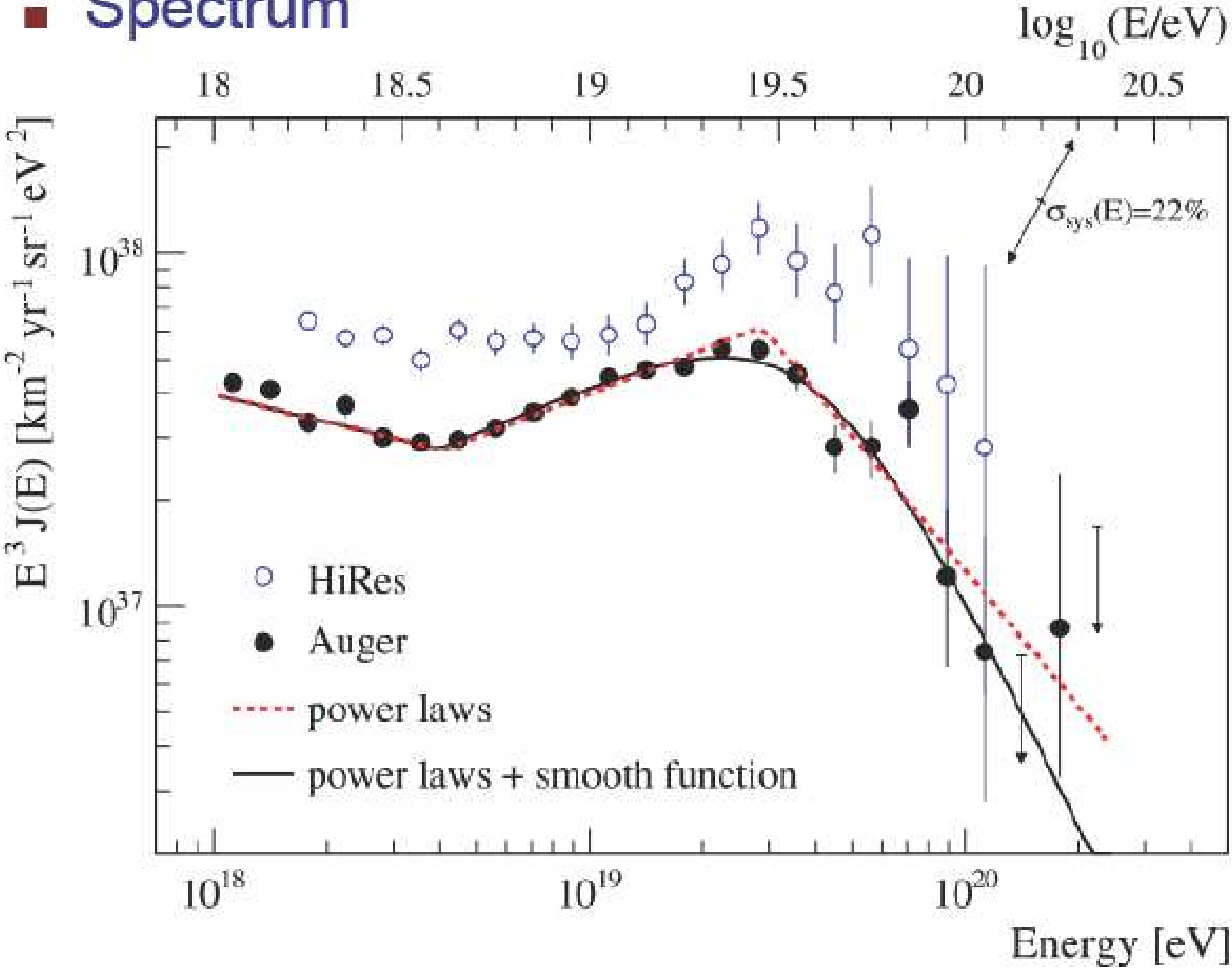
Auger > 10^{19} eV:	**4440**	**(HiRes stereo: 307**
> 5 x 10^{19} eV:	**59**	**: 19**
> 10^{20} eV:	**3**	**: 1)**

based on 12,790 km^2 sr yr (recent spectrum PRL)

Now growing at ~7000 km^2 sr yr per year

TA Exposure: ~ 700 km^2 X 1.84 sr (to 45°)

- Spectrum



log10(E/eV)
18
18.5
19
19.5
20
20.5
E³ J(E) [km⁻² yr⁻¹ sr⁻¹ eV²]
10³⁸
10³⁷
σsys(E)=22%
HiRes
Auger
power laws
power laws + smooth function
10¹⁸
10¹⁹
10²⁰
Energy [eV]

- **Differences are quite small but a fundamental question is:-**

'Are there North/South differences in slope and amplitude of spectra?'

Could there be fine structure?

- **Also better estimates of energy might help to illuminate composition debate**

- **Groups should understand each other's conversion to energy rather better and also the different atmospheric models**

- **Fluorescence yields used – is there need for compromise?**

Progress may be made in Portugal this week

Corrections for energy resolution?

Have 'final adjustments' all been made?

Clearly not yet in case of Auger

HiRes? Thomson at Delaware Dec 2010:talked of shift down in eneergy of 10%

- **Look at same part of sky and compare flux?**

(was planned in 1971 for Haverah Park and Sydney arrays)

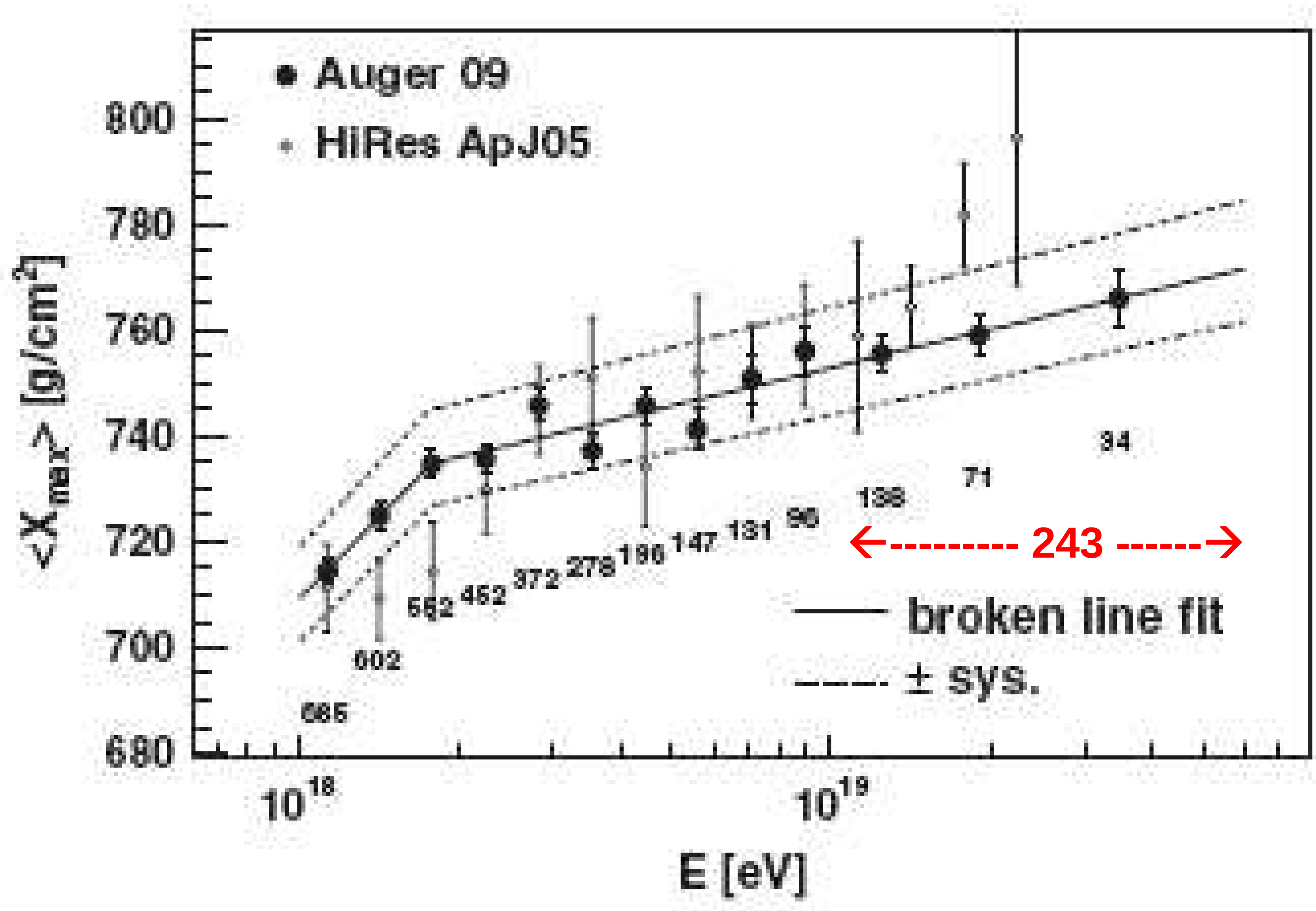
But event numbers are low from HiRes and cannot be increased.

Little overlap with TA and small exposure

Mass Composition

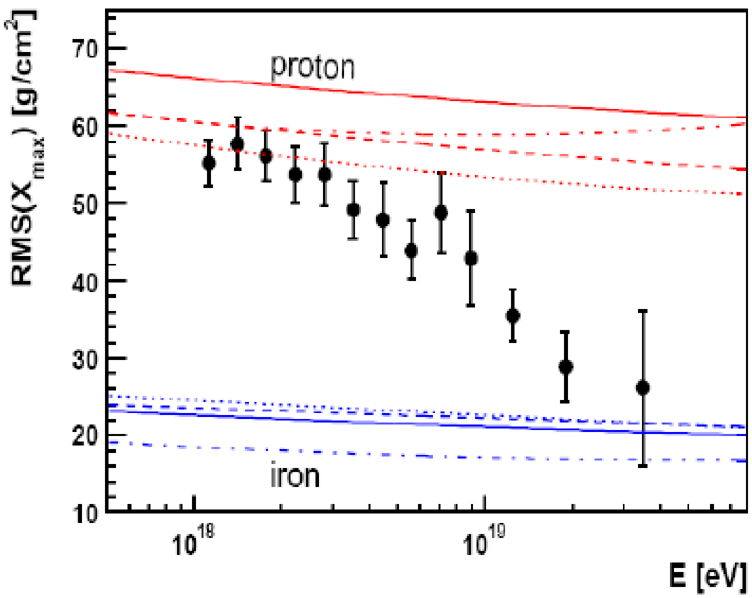
- **Extremely important for interpreting data in astrophysical context**

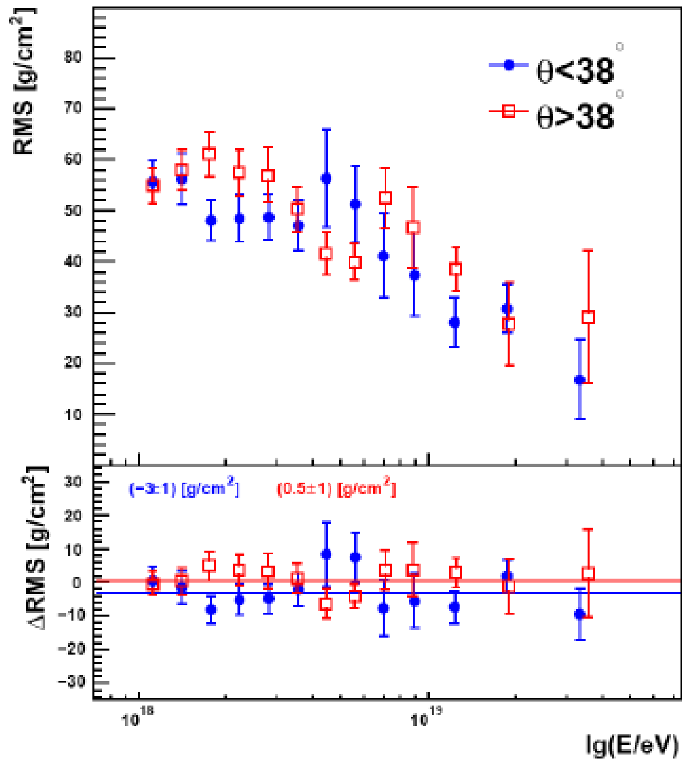
- **Important connection for neutrino astronomy**



Auger PRL 104 091101 2010

X_{max} RMS





→ Increase of the average mass up to 59 EeV

→ No zenith angle bias

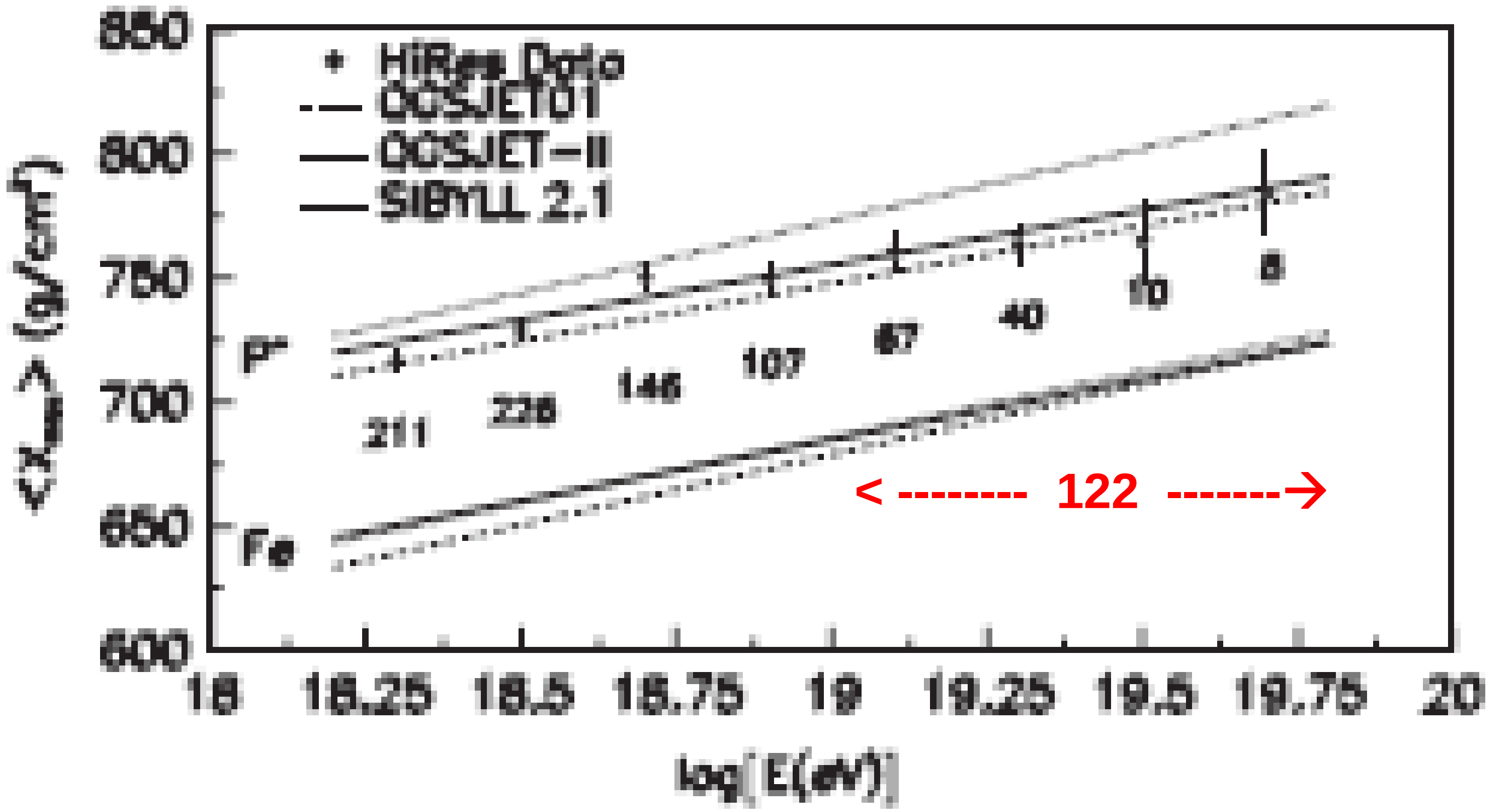
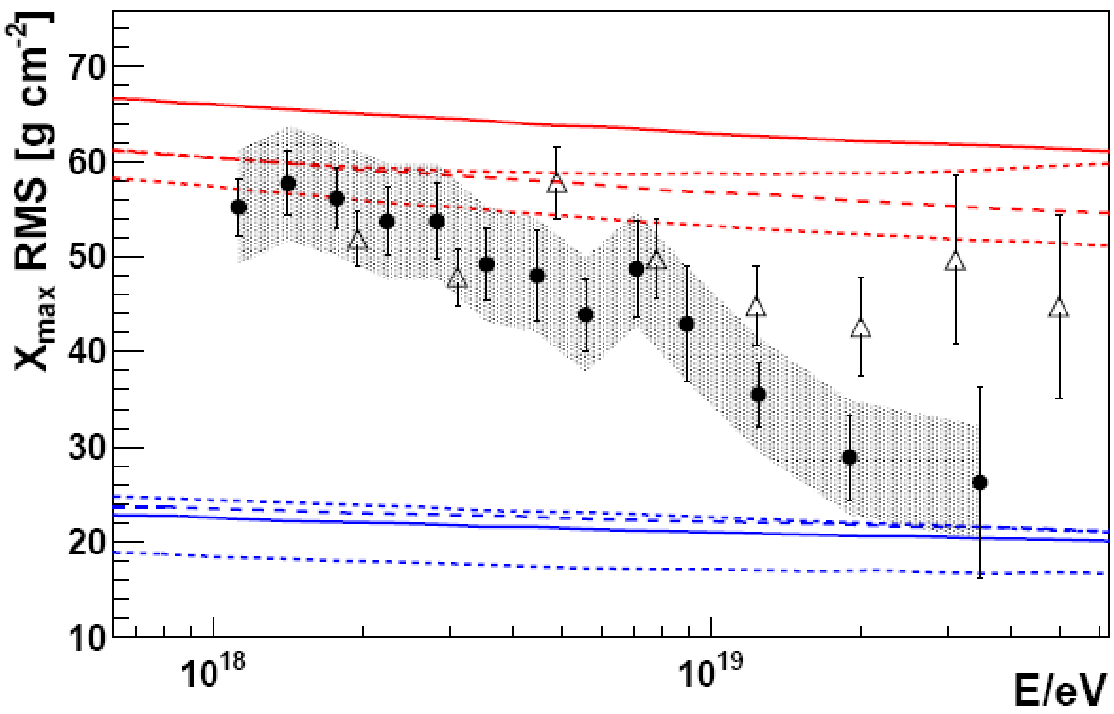


FIG. 3. HiRes stereo $\langle X_{max} \rangle$ compared with the predictions for QGSJET01, QGSJET-II, and SIBYLL protons and iron after full detector simulation. The number of events in each energy bin is displayed below the data point.

HiRes PRL 104 1611012010

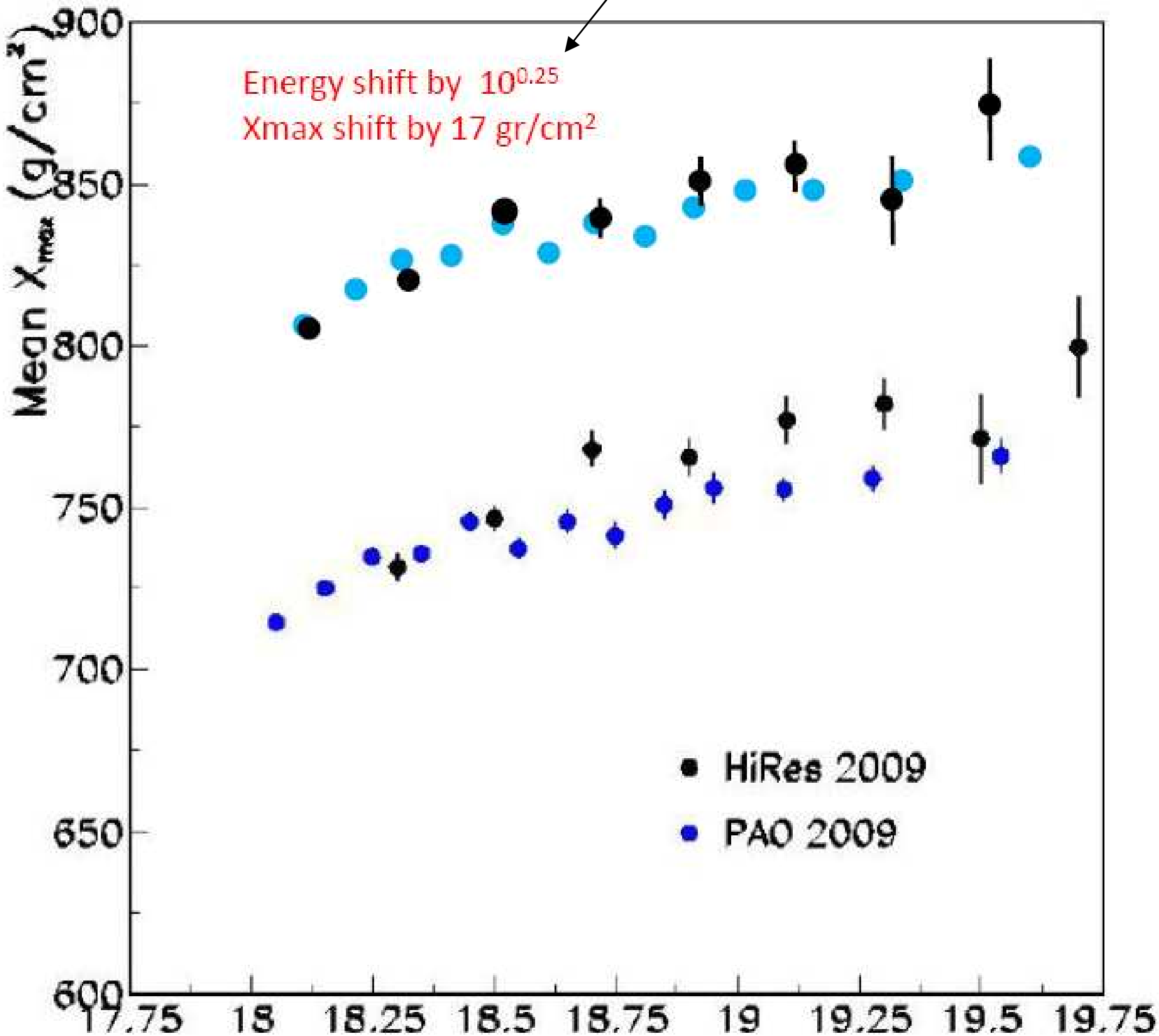
X_{max} RMS



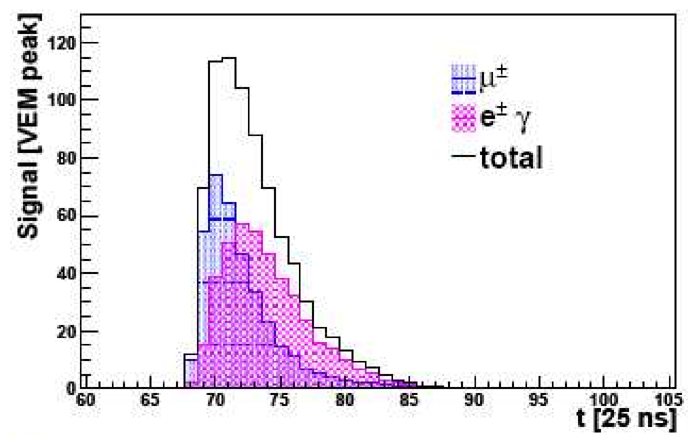
→ AUGER and HIRES results compatible within systematics

Fukushima speculates:-

Unreasonably large E shift



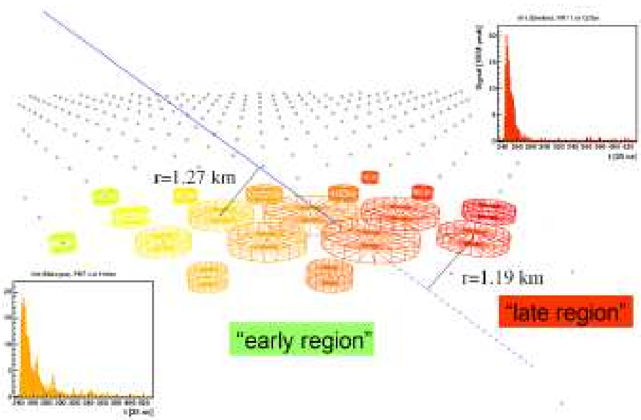
Rise time $t_{1/2}$ in surface stations



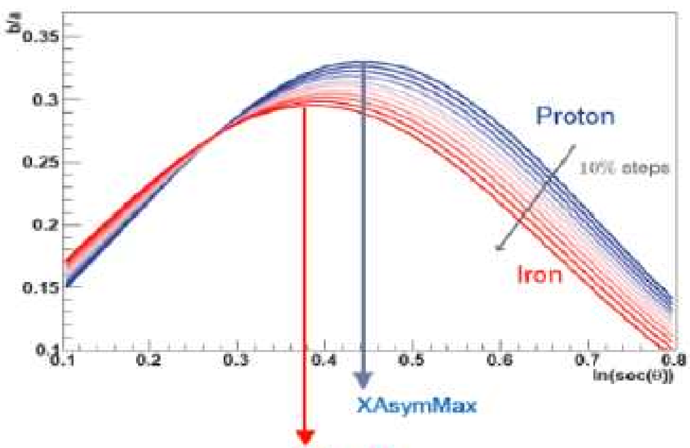
- $t_{1/2}$ sensitive to shower development
  higher particle production heights (shallow showers) → narrow time pulses (smaller $t_{1/2}$)
- $t_{1/2}$ sensitive to electron/muon content
  muons produce narrow pulses in tanks → muon-rich showers (nuclei) have smaller $t_{1/2}$
- $t_{1/2}$ linearly correlates with X_{max}

$$\textit{benchmark} \quad \langle\Delta\rangle = \frac{1}{N}\sum_{i=1}^{N}\frac{t^i_{1/2} - t_{1/2}(r,\theta,E_{ref})}{\sigma^i_{1/2}(r,\theta,S)}$$

Asymmetry of rise time in surface stations



- em component absorption in late region
  - → *early-late asymmetry (dependence on azimuth ξ)*
  - → *muons dominate in late regions*
  - → *smaller $t_{1/2}$ in late regions*
- em absorption increases with zenith θ
  - → *muon component almost asymmetry-free*
  - → *asymmetry decreases with θ*



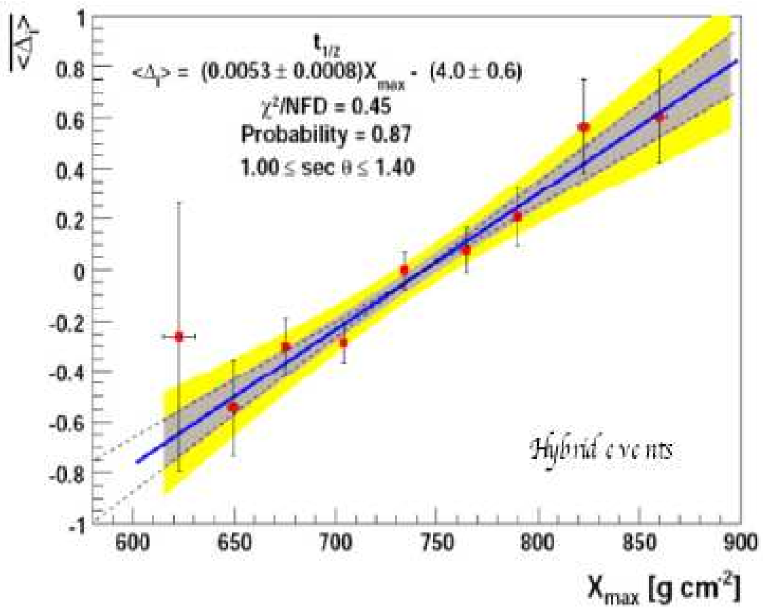
- Asymmetry profile maximum as composition indicator

$$\left\langle \frac{t_{1/2}}{r} \right\rangle = \mathrm{a+bcos}\,\xi$$

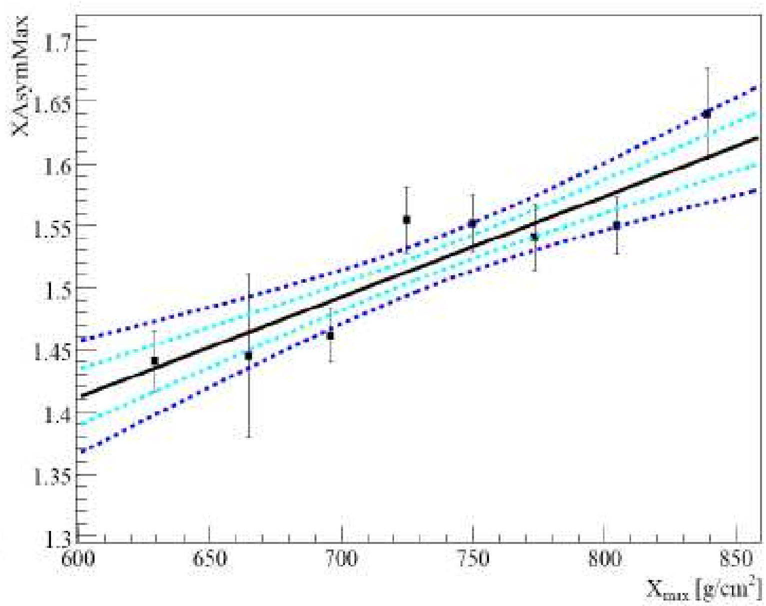
→ *asymmetry profile* $\frac{b}{a}(\sec\theta)$

→ *asymmetry maximum linearly correlates to* X_{max}

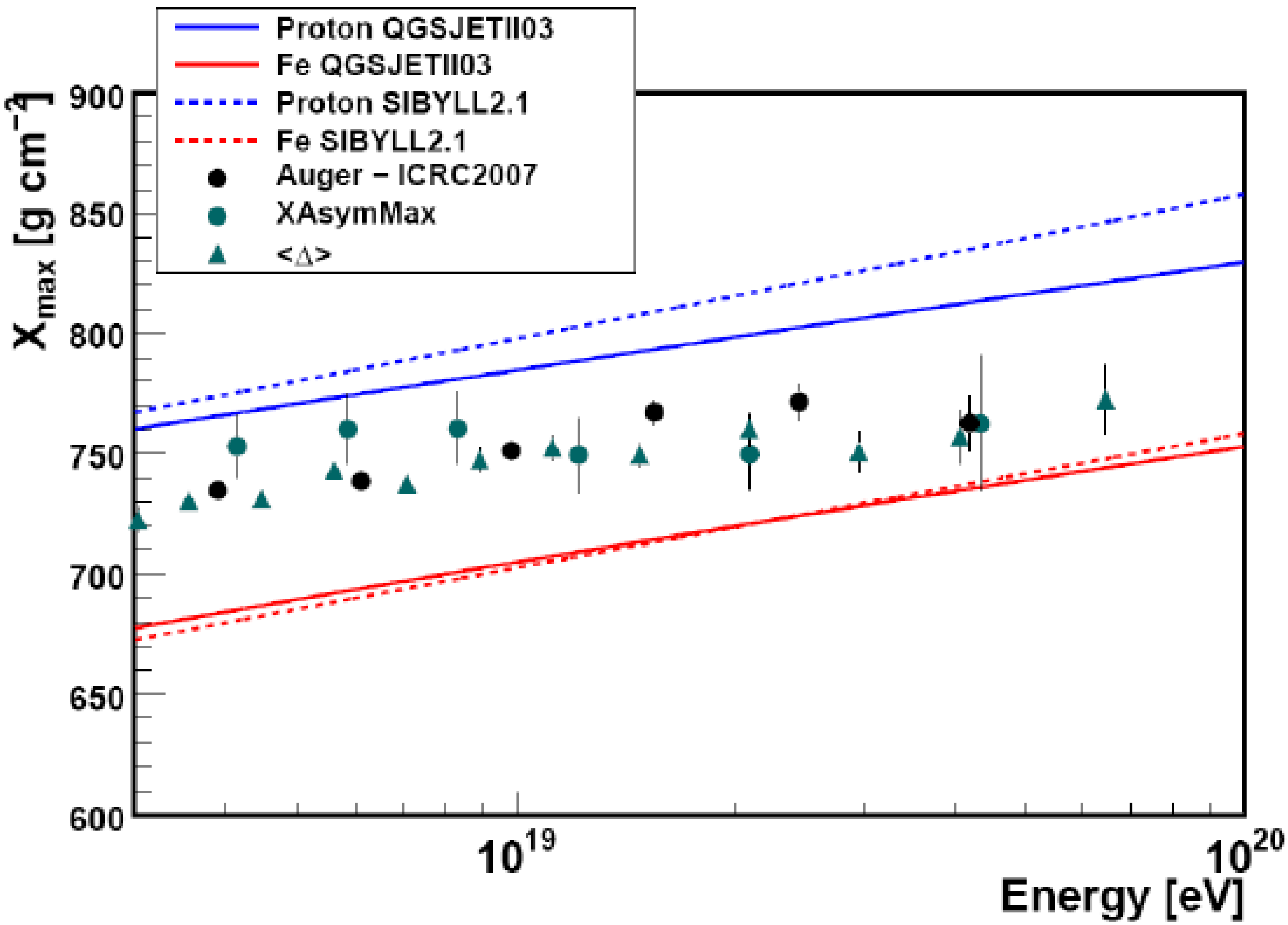
Use hybrids to calibrate $t_{1/2}$ & AsymmMax with X_{max}



$t_{1/2}$ vs X_{max}



AsymmMax vs X_{max}

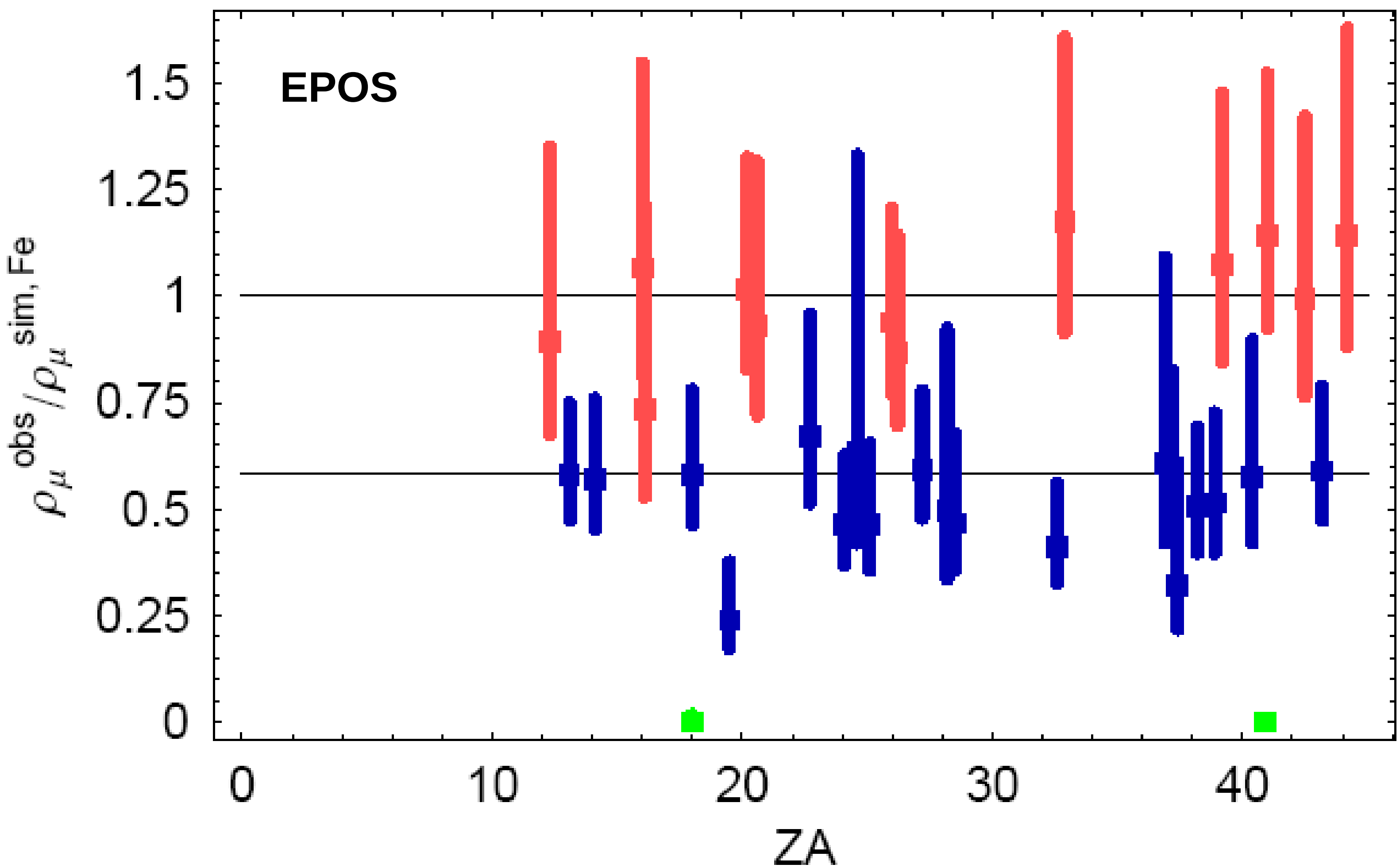


→ **Increase of the average mass with energy**

→ **Support FD results**

Yakutsk Muon Data: Glushkov et al JETP 87 190 2008

With EPOS, f_{proton} = 0.52 ± 0.2 and with SIBYLL ~ iron



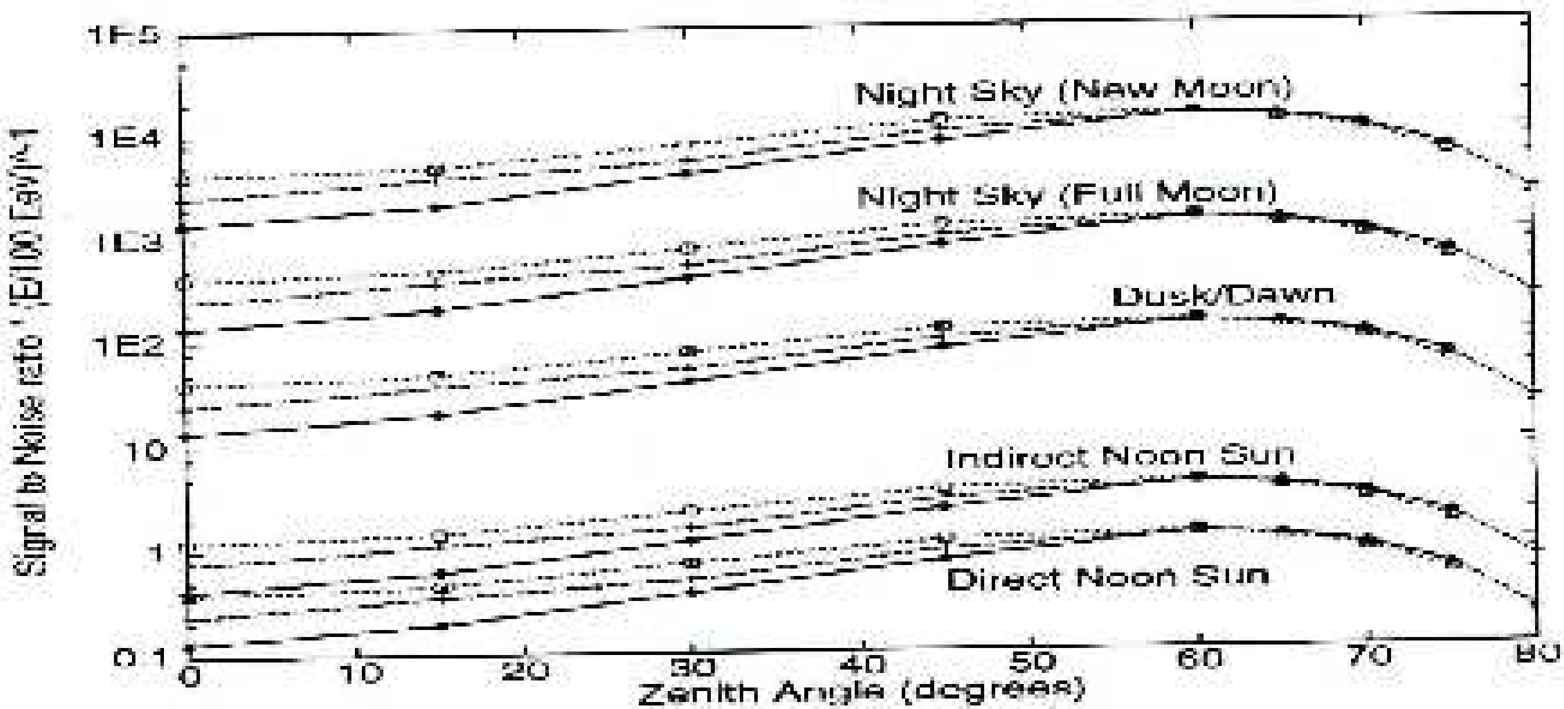


Figure A.1: Signal and Noise for Solar Panel detector at 1 km perpendicular distance from the shower axis as a function of zenith angle, primary energy, and various sky conditions. Primary Energies: Solid Lines with diamonds : 1000 EeV; Long Dash with Crosses: 100 EeV; Short Dashes with Boxes: 10 EeV. Horizontal Axis: Zenith angle (degrees); Vertical Axis: Energy scaled Signal-to-Noise ratio $S/N \times (E/100\ EeV)^{-1}$.

From Auger Observatory Design, Report, October 1995: Corbin Covault

Idea of Dave Kieda: Astroparticle Physics 4 133 1995

Studies are undertaken to see how to avoid birds sitting on the antennas (see figures below).

BUT!!

Figure: Bird droppings. Protecting the antenna does not work...

Gianni is much missed.

His input in scientific terms and his wise advice were very important to the Auger Observatory

Also his calmness, even when discussions were very heated

But he leaves a legacy of very well trained and imaginative people

His legacy will live on