Astroparticle Physics
(Where are we going?)

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University of Michigan

Vulcano Workshop on Frontier Objects in Astrophysics and Particle Physics

26 May 2008

Outline

1. Cosmic Rays

   High (EeV) energies: AUGER - sources, GZK, etc.

   Medium (PeV) energies: GAMMA spectrum

   Lower (TeV) energies: AMS, Pamela

2. Forward Physics at the LHC; TOTEM workshop, etc.

3. High energy neutrinos: Auger and Ice Cube

4. Dark matter: COUPP, Xe10, and DAMA/LIBRE

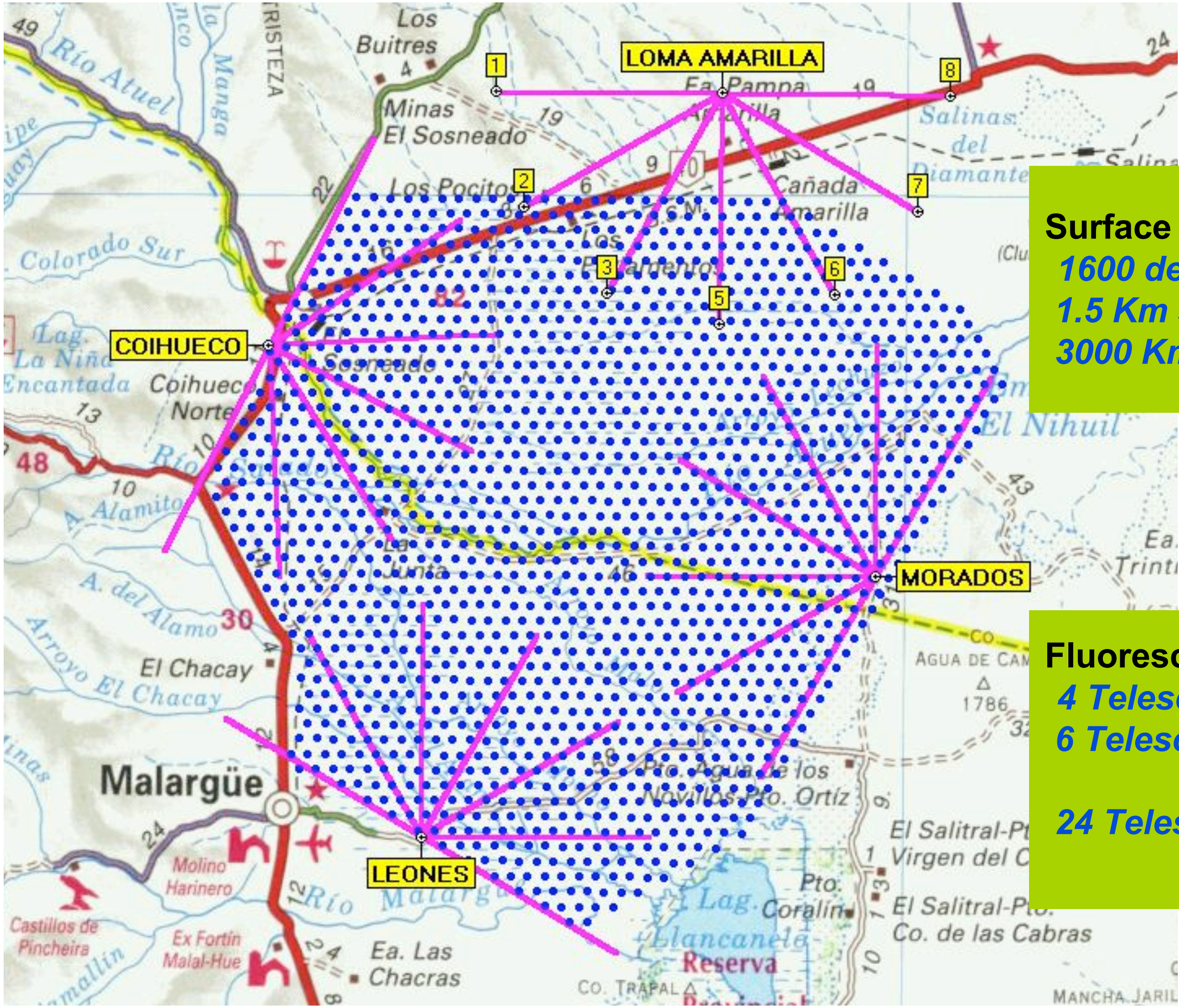
5. Activities; conferences, workshops, etc.

6. The future - where are we going?

High energy - EeV - cosmic rays; first results from AUGER

Probably most of you have seen the first results from AUGER; and later this week you will hear more details, I am sure, from Gianni Navarra, Claudio di Giulio, and Aurelio Grillo (who are members of the collaboration). Let me note some of the highlights, and then point to some future directions.

The AUGER array, nearing completion, has been actively taking data since 2004 (during its construction). There are ~1600 surface (water Cherenkov tanks) detectors, spaced 1.5 km, covering ~3000 km^2 plus 24 telescopes (located in 4 buildings) to image the atmospheric scintillation light from air showers.



Surface Array

1600 detector stations

1.5 Km spacing

3000 Km^2

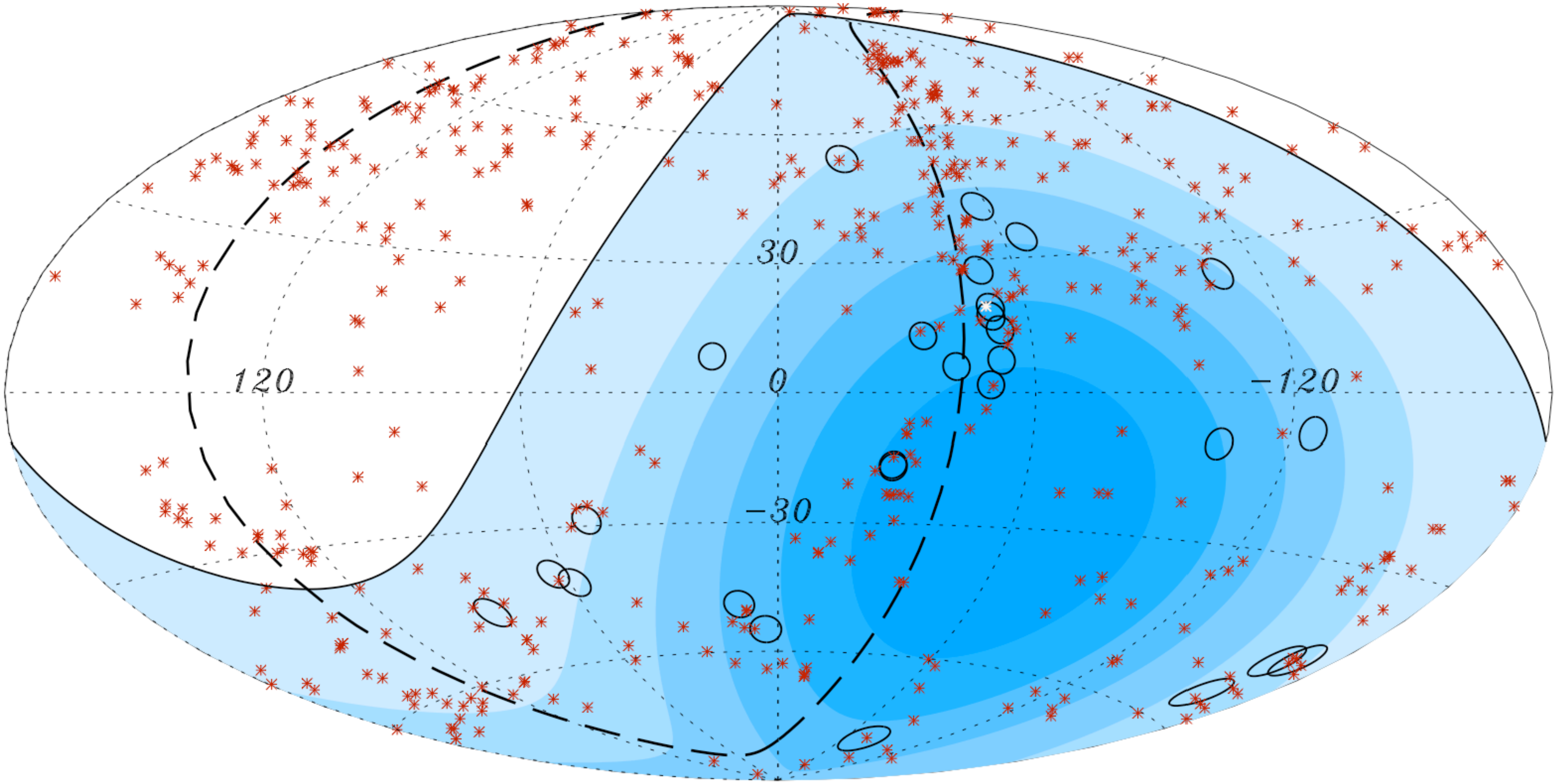
Fluorescence Detectors

4 Telescope enclosures

6 Telescopes per enclosure

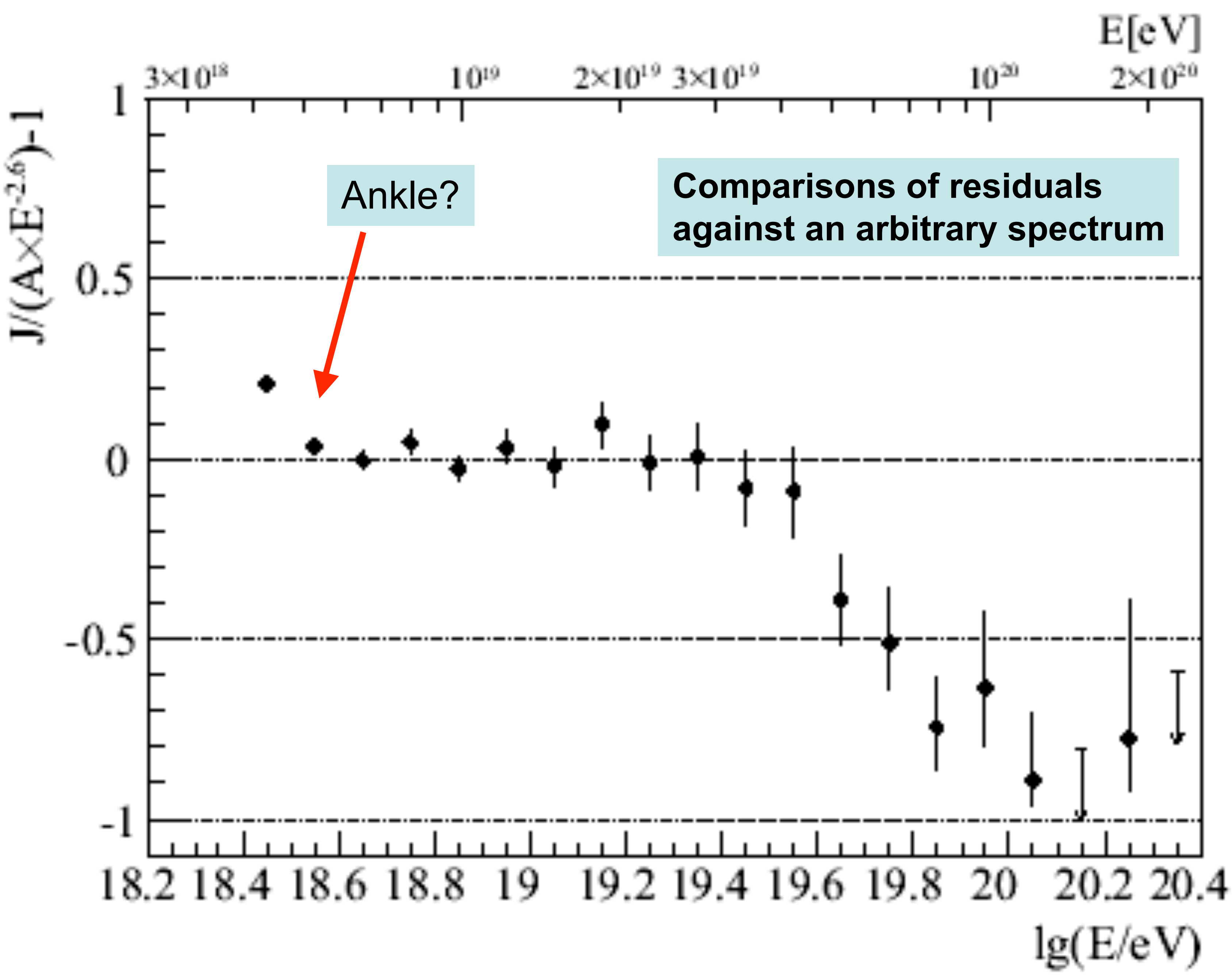
24 Telescopes total

- As I am sure you have heard, the most significant result from AUGER is the correlation of the location of most of the events of over 57 PeV (~20 out of 27) with active galactic nuclei (AGNs), which are less than 100 Mpc distant.



Events and AGN (Galactic Coordinates)

- The other most notable result is the confirmation of the “GZK cutoff”, i.e. a break in the spectrum at about 30 EeV, confirming the attenuation of more energetic primaries by interaction with the 2.7K microwave background radiation, producing mesons, and hence reducing the energies of the primary protons.



E[eV]
3×10^18
10^19
2×10^19 3×10^19
10^20
2×10^20
J/(A×E^-2.6)-1
1
0.5
0
-0.5
-1
Ankle?
Comparisons of residuals
against an arbitrary spectrum
18.2 18.4 18.6 18.8 19 19.2 19.4 19.6 19.8 20 20.2 20.4
lg(E/eV)

- Note that the AUGER group has also studied their showers for evidence of gamma primaries, and – from the character of the shower; e.g. signal rise time and curvature of the shower front – they have set limits of 2% on the fraction of photon primaries above 10 EeV (95% C.L.).

- They also argue, from the height of shower maximum, that the primaries are consistent with protons – perhaps with other light nuclei – and inconsistent with iron (and/or other heavier nuclei).

What’s next?

- Clearly the AUGER group is eager to continue collecting data at the Argentine site, to better identify the AGN sources, to seek tau neutrino signals from GZK pion decays, etc.
- The AUGER group is also still very eager to construct a Northern Hemisphere array – to be located in Colorado (U.S.).
- And, of course, the EUSO (satellite observation of EAS atmospheric scintillation images) would add significant data. We will hear more about this from Andrea Santangelo on Saturday

Intermediate – PeV - Energies

- At these energies – 10^{14} to 10^{17} eV - there is still confusion concerning the composition, although most observers agree that the primary composition becomes heavier through the “knee” region (~ 1 – 10 PeV), which is, of course, a natural consequence of a rigidity-dependent or mass-dependent upper limit to the acceleration or galactic containment of these cosmic rays.

- One interesting piece of new data from the Armenian GAMMA experiment is the observation of a possible “bump” in the spectrum at about 70 PeV. This could be evidence for an iron peak, in accord with a model of Erlykin and Wolfendale of nearby, recent supernova sources.

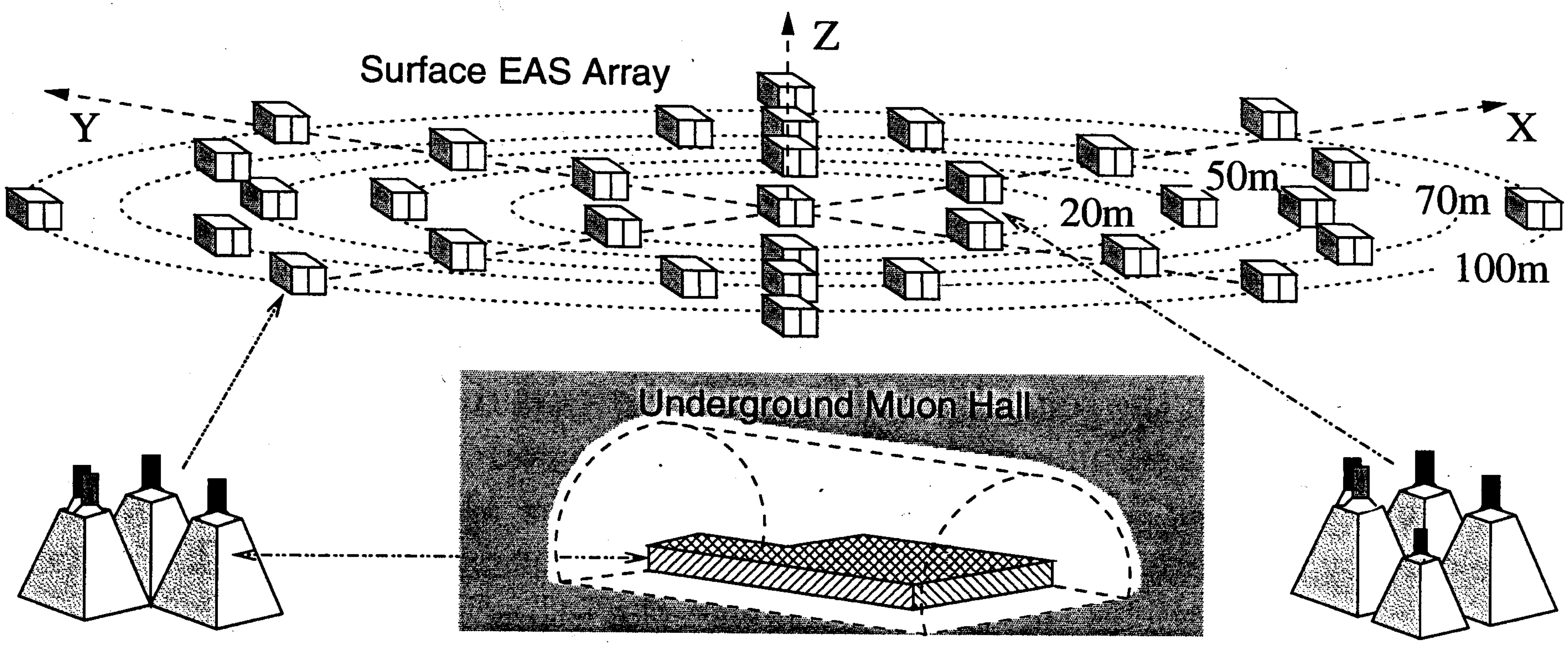


Fig. 1. Diagrammatic layout of the GAMMA facility.

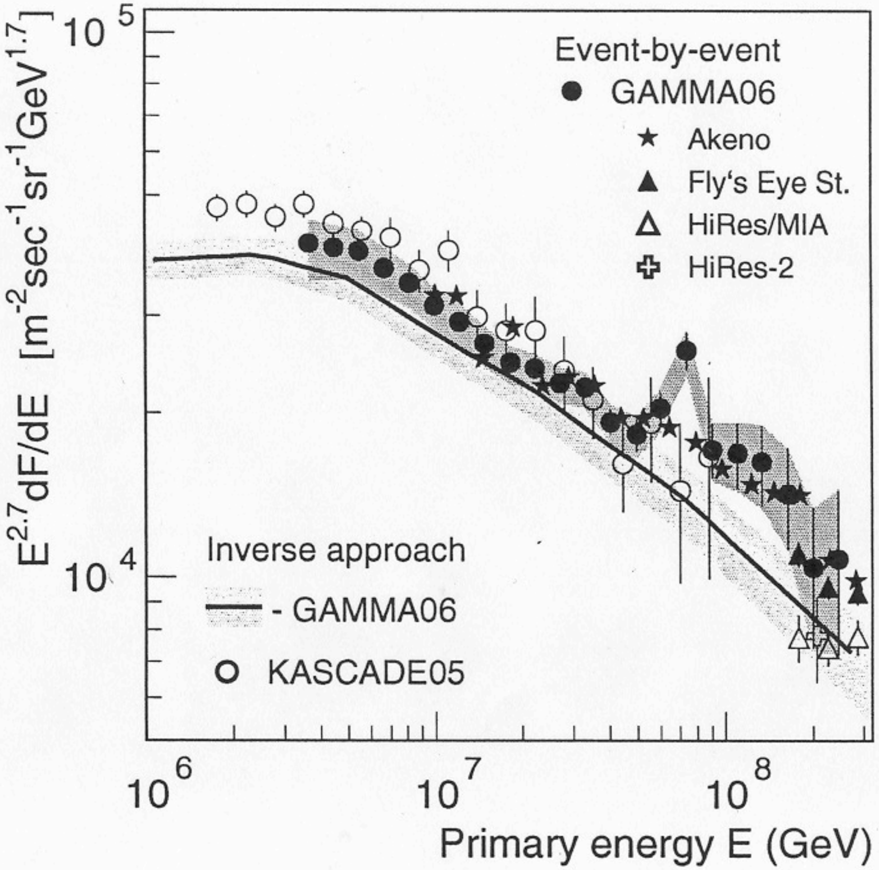


Fig. 5. All-particle energy spectrum obtained using event-by-event method in comparison with the results of EAS inverse approach [2–4].

- Indeed, this is an experiment in which I have been involved; the other authors are from Armenia, Russia, and France. Yes, the group is capable and intelligent. Of course, this "bump" may be a statistical fluctuation; although it is statistically ~4σ above the smooth curve, the fact that it is just one of about 20 data points somewhat reduces its statistical significance.

Neutrons

- As an incidental note, let me recall an observation I made some years ago. In high-energy nuclear collisions, the final-state most energetic baryon is a neutron about ¼ of the time; in proton-nucleus collisions, these neutrons have energies up to almost the full energy of the incident proton.
- If some h.e. protons from a supernova source interact in the supenova environment, they will produce energetic neutrons. The mean free path of a 10 PeV neutron is:

$$L \approx 10^3 \text{s} \times c \times (10^{16}/10^9) \approx 100 \text{ parsec.}$$

Hence, it is not unreasonable to seek air showers of those energies which might point to a nearby source in our galaxy.

Low – TeV - energies

- In this energy range, below ~100 TeV, direct observation of primary cosmic rays is practical, with balloon- and satellite-borne detectors. I look forward to learning of the latest results from Pamela.
- The other major facility for the study of these energies is AMS-02, discussed at this 2004 Workshop by Benchet Alpat. Regrettably, the current director of NASA has argued that there are not sufficient funds to launch AMS-02 (which is engineered to be attached to the International Space Station). However Sam Ting, the head of the AMS collaboration has not given up, and is gathering political support for the introduction of the necessary funding legislation. I believe that he will be successful.

Models and LHC Studies

- In earlier Workshops I have noted the need for accelerator measurements, particularly in the forward direction (high η, or pseudorapidity), in order to improve the Monte Carlo models of the primary cosmic ray interactions in the PeV energy range, which are critical to the interpretation of air shower data, e.g. in terms of primary mass.
- Of course the LHC will provide the possibility to collect exactly this data; the 14 TeV c.m. energy is equivalent to a 10^{17} eV (100 PeV) proton on a stationary proton.
- Is there a program to make these measurements?

Yes!

Karsten Eggert, during the 1990s, proposed an LHC experiment, FELIX, which would cover the forward regions very well, but which was rejected.

This proposal, its contents and its fate, was discussed more extensively in my talk at the 1998 Vulcano Workshop.

Eggert subsequently became spokesman for the TOTEM experiment, which was originally only an elastic scattering experiment (with Roman Pots for observing the scattered protons). He has expanded this to a more comprehensive forward-physics experiment, which, with CMS and CASTOR, should be able to provide the comprehensive, inclusive data desired to refine the cosmic ray Monte Carlos.

F E L I X

A full acceptance detector at the LHC

Letter of Intent

Abstract

The FELIX Collaboration proposes the construction of a full acceptance detector for the LHC, to be located at Intersection Region 4, and to be commissioned concurrently with the LHC. The primary mission of FELIX is the study of QCD: to provide comprehensive and definitive observations of a very broad range of strong-interaction processes. This document contains a description of the detector concept including details of the individual detector elements and their performance characteristics, an extensive discussion of the physics menu, and the plans for integration of FELIX into the collider lattice and physical environment.

Spokespersons:

CMS Note-2007/002
TOTEM Note 06-5
21 December 2006

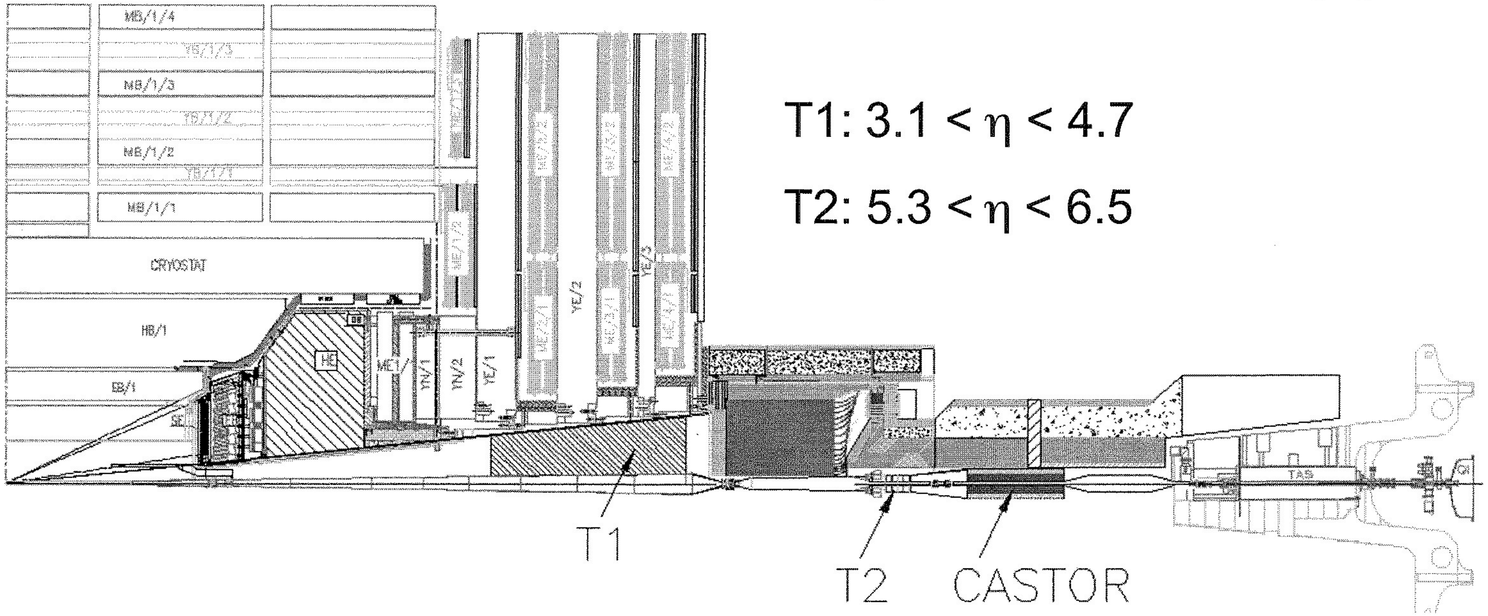
Prospects for Diffractive and Forward Physics at the LHC

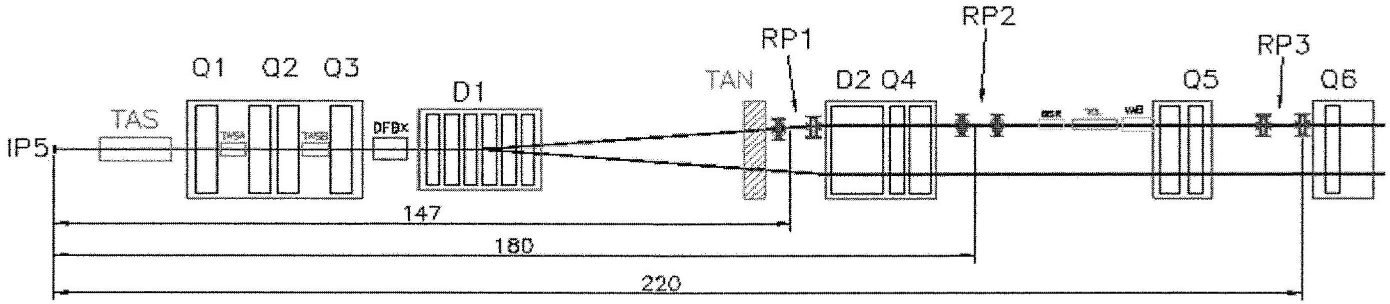
The CMS and TOTEM
diffractive and forward physics
working group

Experimental apparatus

T1: $3.1 < \eta < 4.7$

T2: $5.3 < \eta < 6.5$





$$L\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN}{dt}\right|_{t=0}$$

$$L\sigma_{tot} = N_{elastic} + N_{inelastic}$$

Optical Theorem

$$\boxed{\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{\left.(dN/dt)\right|_{t=0}}{N_{el} + N_{inel}}}$$

TOTEM Physics

- σ tot
- elastic scattering
- diffraction (together with CMS)

Karsten Eggert
CERN, PH Department

on behalf of the

TOTEM Collaboration

http://totem.web.cern.ch/Totem/

Politecnico di Bari and Sezione INFN
Bari, Italy

Case Western Reserve University
Cleveland, Ohio,USA

Institut für Luft- und Kältetechnik,
Dresden, Germany

CERN, **Geneva, Switzerland**

Università di Genova and Sezione INFN
Genova, Italy

University of Helsinki and HIP,
Helsinki, Finland

Academy of Sciences,
Praha, Czech Republic

Penn State University
University Park, USA

Brunel University, **Uxbridge, UK**

TOTEM TDR is fully approved by the LHCC and the Research Board

Last month (April 28 – 30) there was a TOTEM Workshop at State College, Pennsylvania on "Forward Physics at LHC with TOTEM", organized by Karsten Eggert, with about 20 participants. There were three days of very interesting – and relevant – talks.

One item discussed was the Zero Degree Calorimeter (ZDC) a small calorimeter located 140 m from the interaction region for studying forward neutrons and gammas.

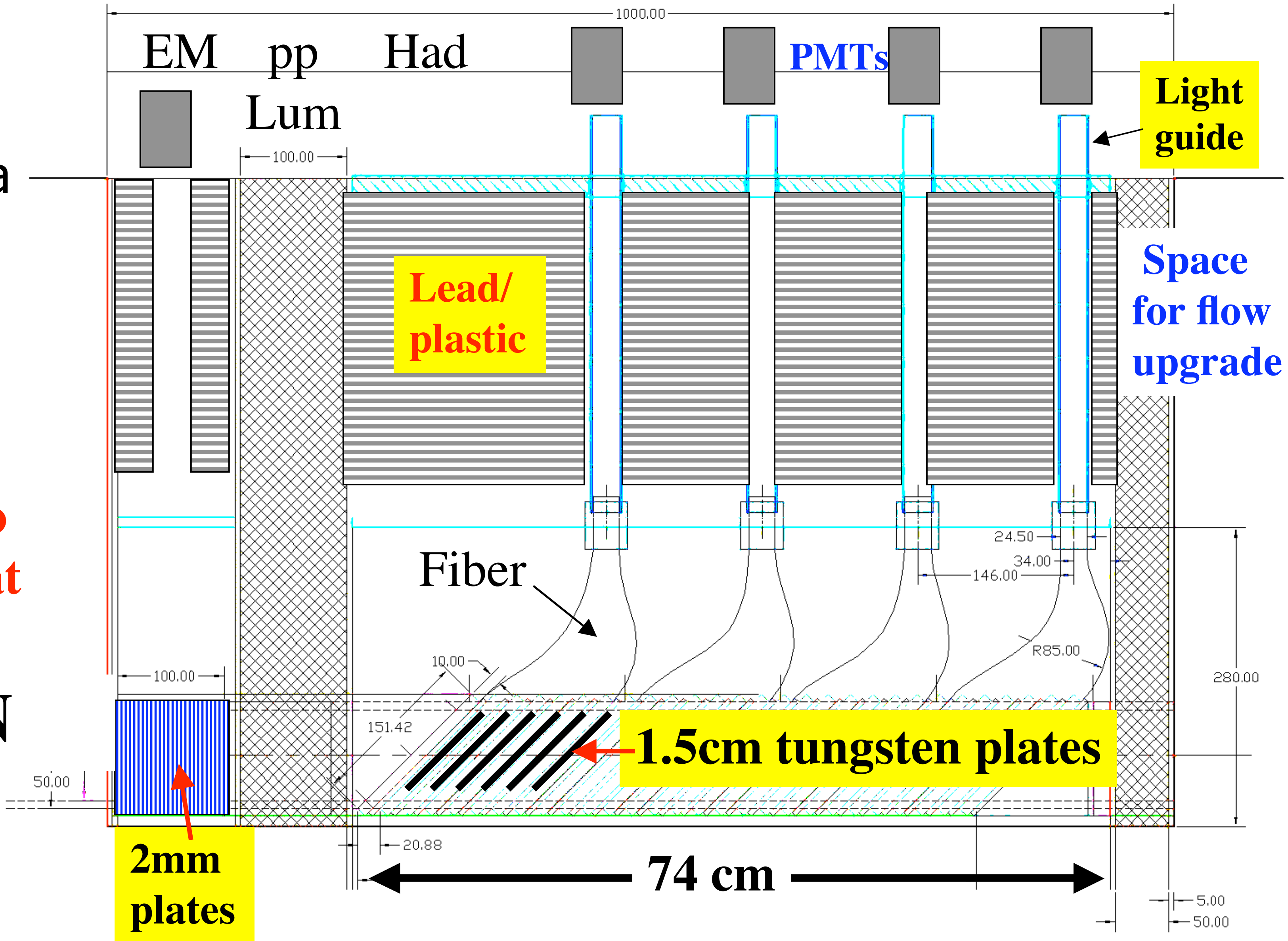
I am involved as a collaborator in this ZDC. The head of the ZDC is Michael Murray (University of Kansas,U.S.)

Schematic Side View of Detector

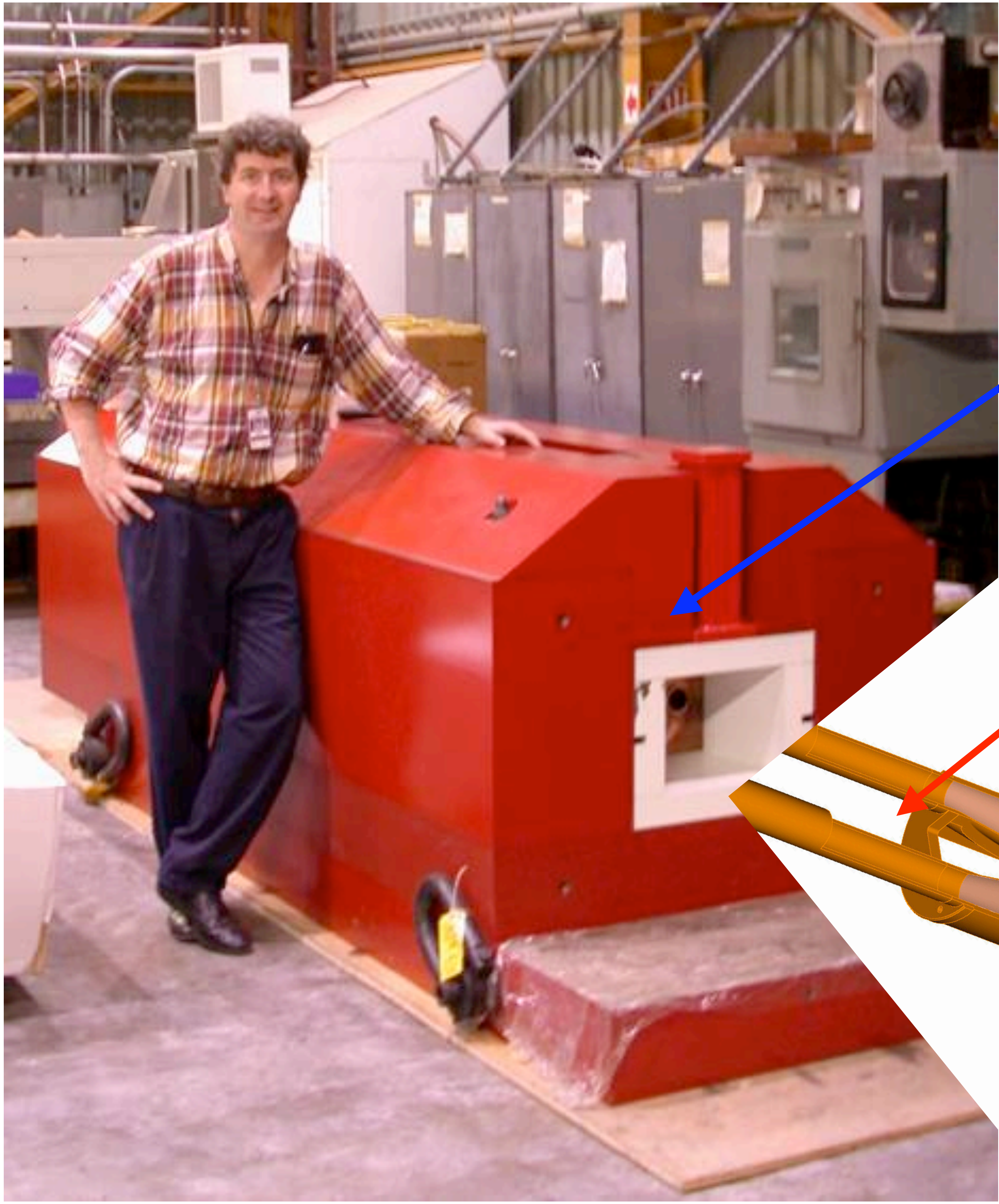
Lum data available in HLT & offline

Copper frame to take heat out

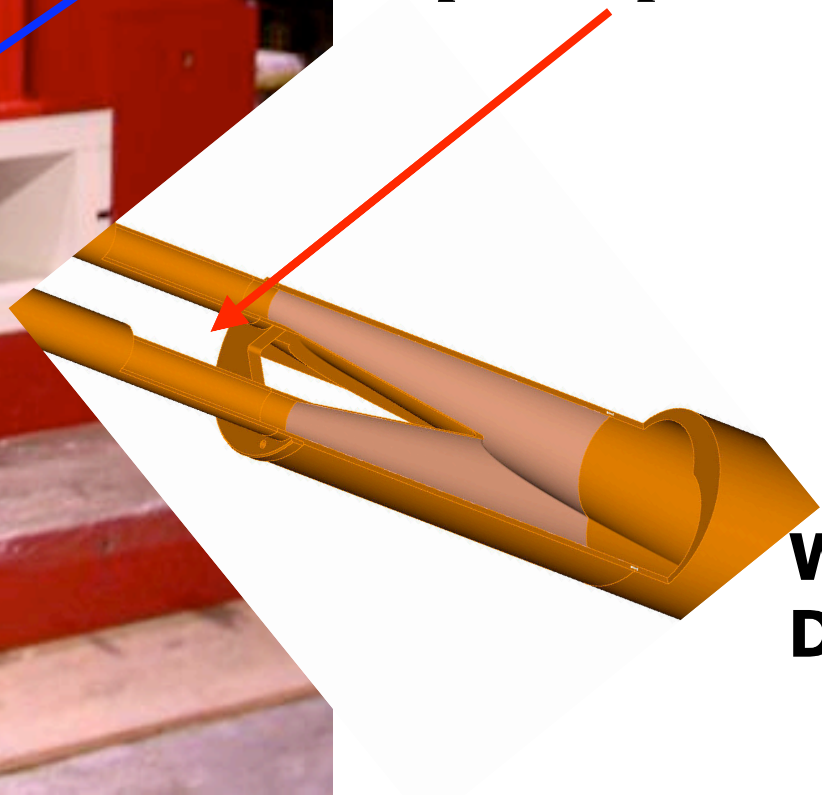
γ, π_o N



Where we sit



We are at Z = ± 140m inside the TAN just behind the "pair of pants."



Warm Dipole

Neutrinos

- A very busy area of particle physics/astrophysics these days is neutrino physics.

- One recent development is the result from the Fermilab MiniBooNE which proves that the “Sterile neutrino” (invented to explain a result from Los Alamos) does not exist. Indeed there are other problems in low energy neutrino physics, but I will not address them here.

- Let us focus instead on the highest end of the neutrino spectrum; neutrinos in the EeV energy range.

GZK neutrinos

The GZK break in the primary spectrum is due to the energetic primary protons interacting with the 2.7K radiation to produce mesons, hence degrading the proton energies. Of course, the pions will decay to muons and neutrinos; thus a 30 EeV proton may produce a pion of ~3 EeV and hence a neutrino of ~1 EeV. These neutrinos would travel easily through Mpcs of space, undeflected by any magnetic fields, and would thus enable the study of more distant VHE sources of cosmic rays. Although created as muon neutrinos (and, from the subsequent muon decays, also as electron neutrinos), over their journey through space they would be expected to oscillate between the three (electron, muon, and tau) neutrinos varieties.

- Let us focus on just two experiments; the South Pole “Ice Cube” and AUGER.

- Following are some slides from a seminar at Michigan given by Anna Franckowiak of Humboldt Universitat (Berlin) on the Antarctic “Ice Cube” program.

Sources: GRBs

- **Fireball Shock Model (Meszaros, Rees 1994)**
  - Relativistic Jets with variations ~ 1s
  - Internal Shocks: Collisions within Jets -> Gamma radiation
  - External Shocks: Collisions with interstellar medium -> Afterglow (radio, x-ray, optical)

$$p\gamma \longrightarrow \Delta^+ \longrightarrow n\pi^+$$

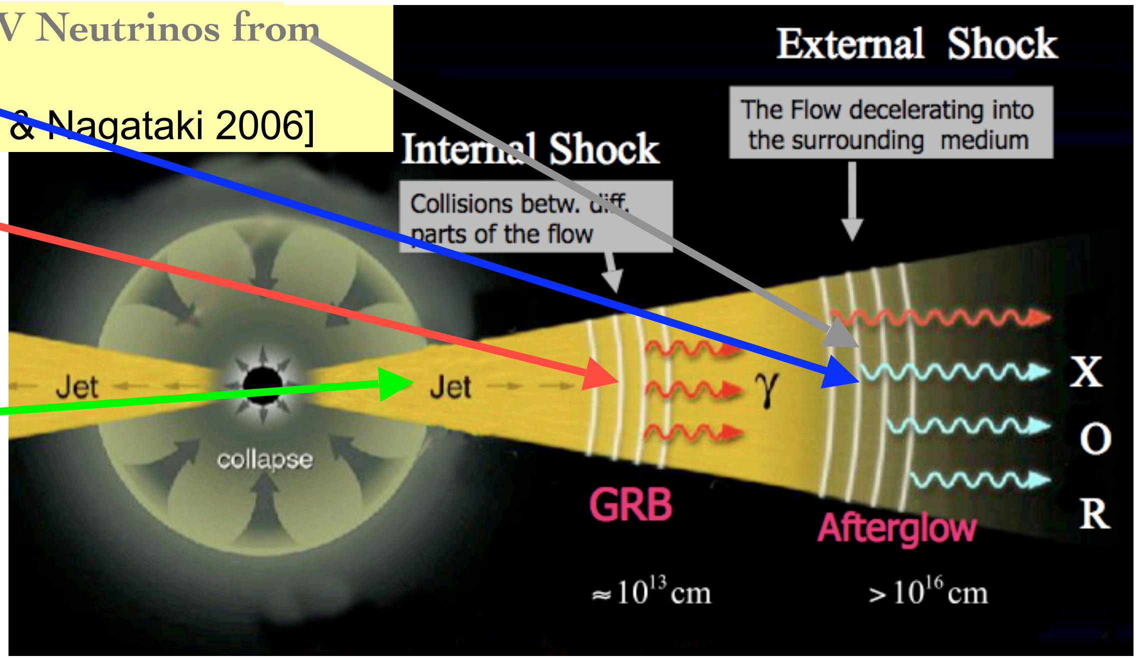
$$\pi^+ \longrightarrow \nu_\mu \mu^+ \longrightarrow \nu_\mu e^+ \nu_e \bar{\nu}_\mu$$

EeV Neutrinos from external Shocks
[Dermer 2001]
[Waxman & Bahcall, 2000]

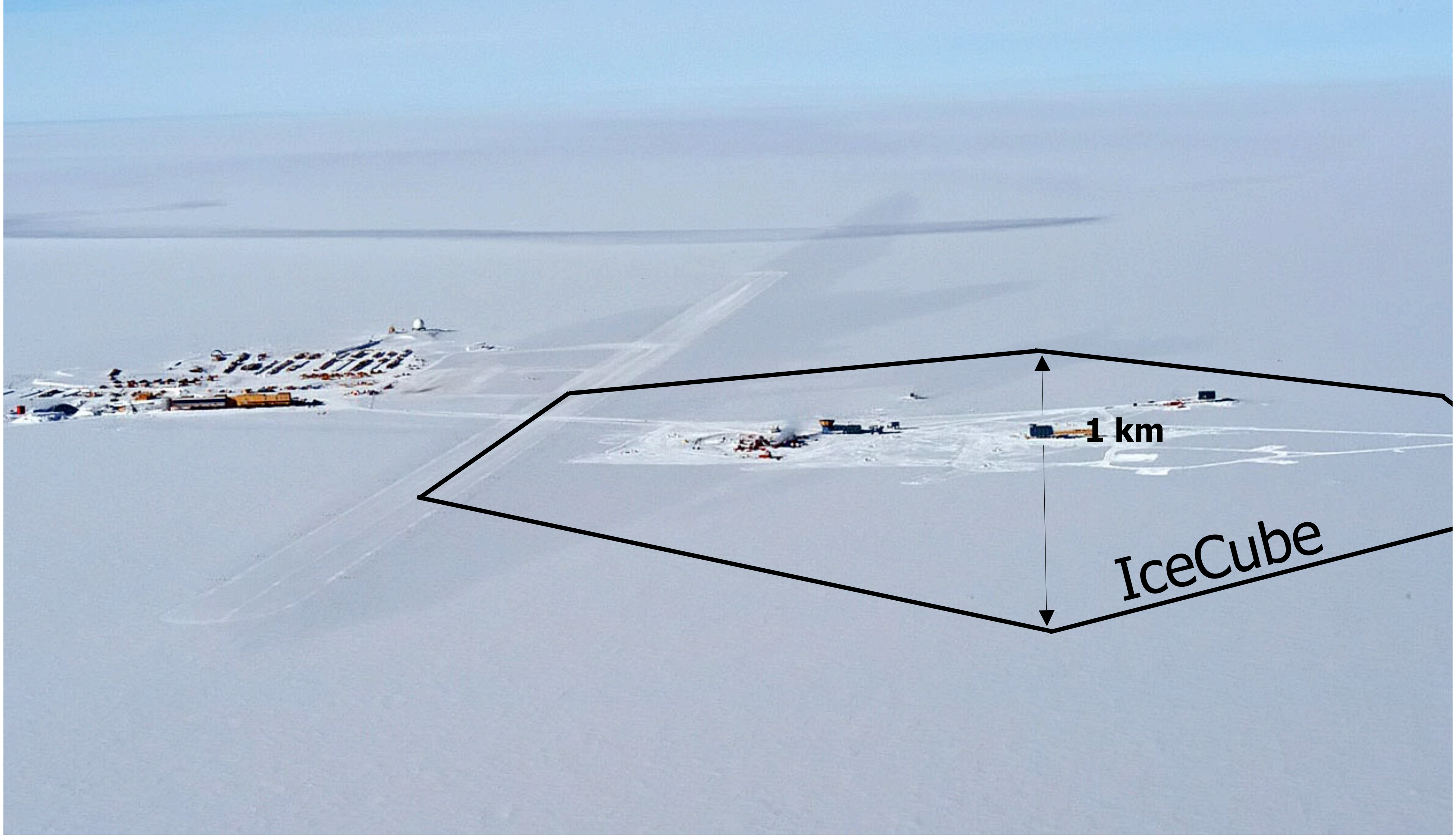
PeV Neutrinos from internal Shocks
[Waxman & Bahcall 1997]
[Gupta & Zhang, 2006]
[Murase & Nagataki 2006]

TeV neutrinos from inside the star
[Meszaros & Waxman, 2001]
[Razzaque et al. 2003]

PeV-EeV Neutrinos from Flares
[Murase & Nagataki 2006]



IceCube:
A cubic kilometer neutrino detector



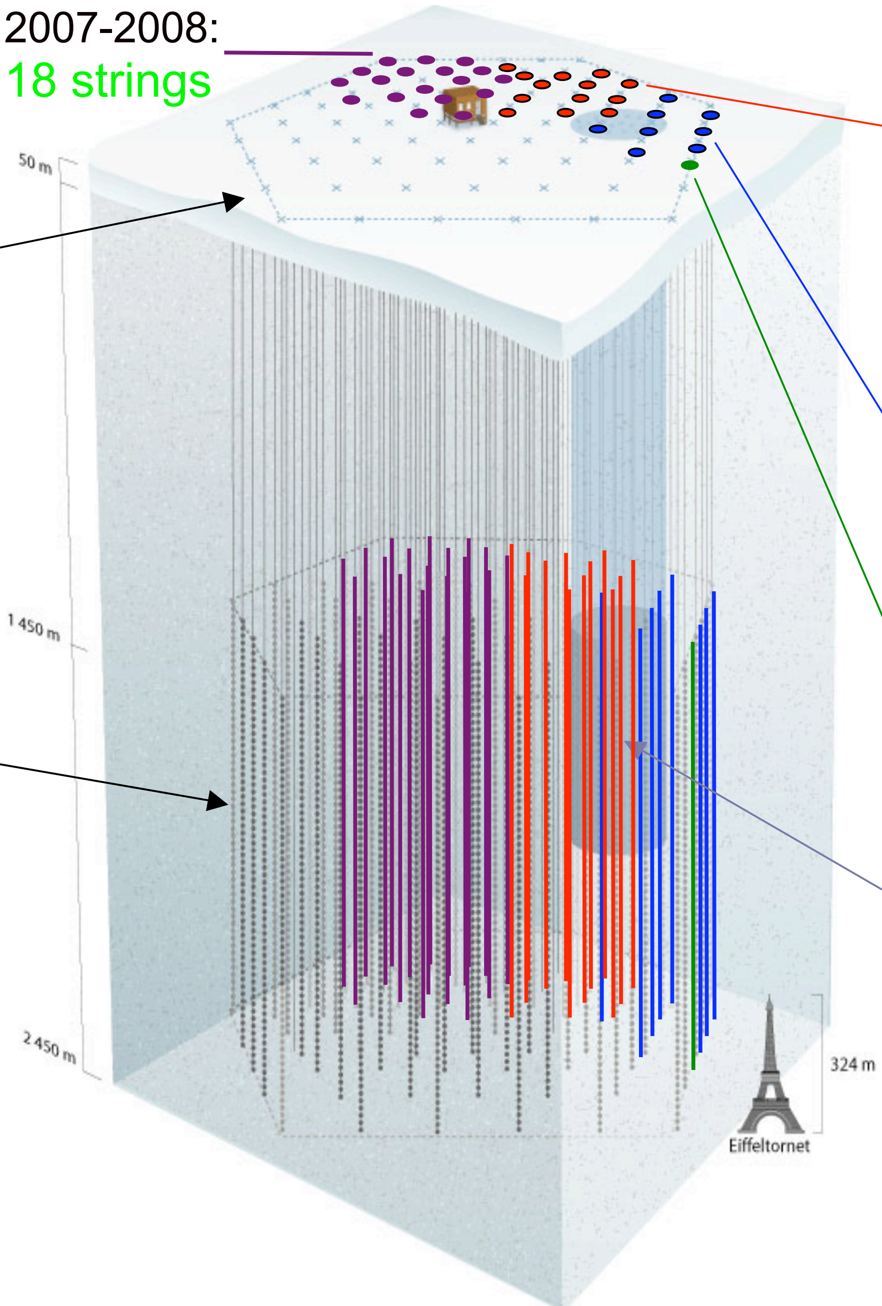
2007-2008:
18 strings

2006-2007:
13 Strings

IceTop

Air shower detetor

threshold ~ 300 TeV



2005-2006: 8 Strings

2004-2005 : 1 String

InIce

70-80 Strings ,

60 Optical Modules

17 m between Modules

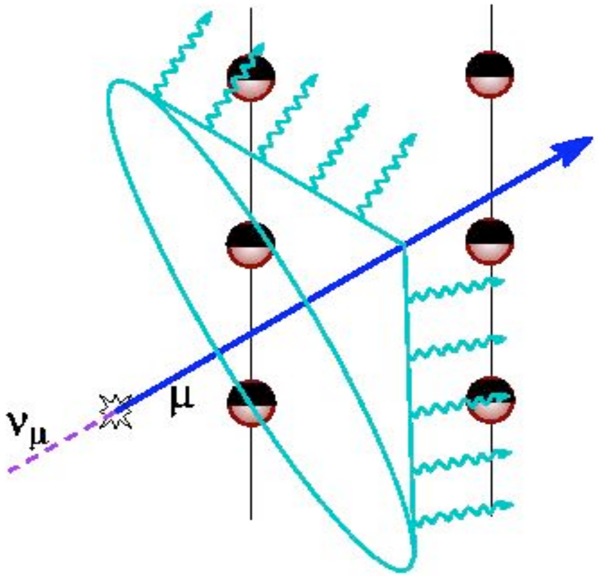
125 m between Strings

AMANDA

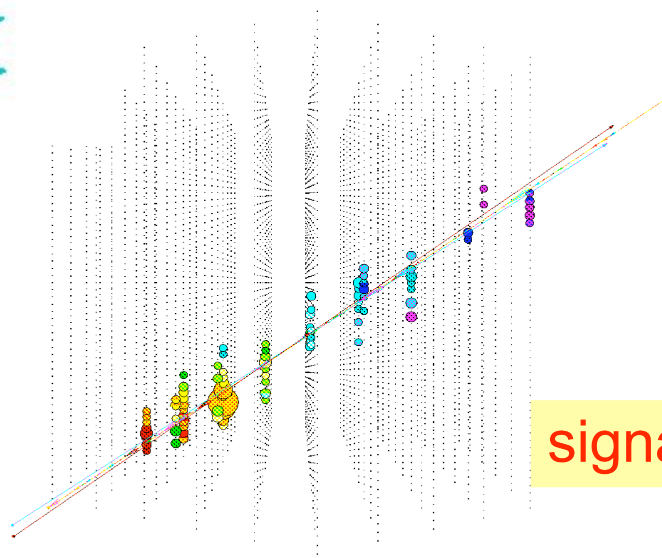
19 Strings

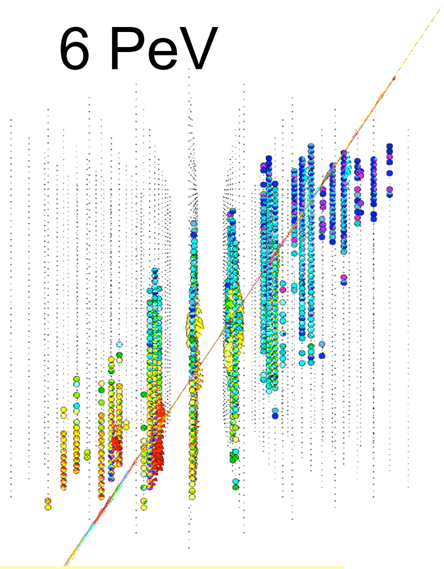
677 Modules

Neutrino Signature



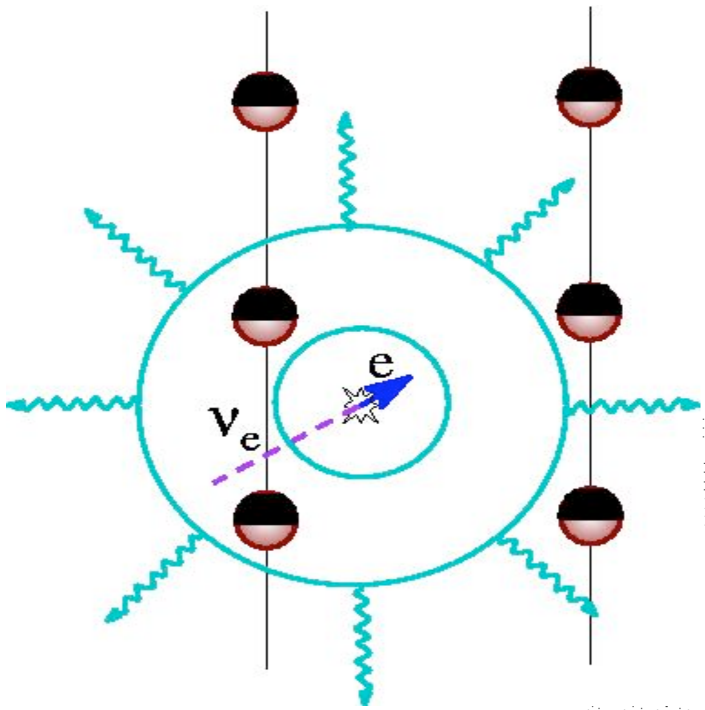
Muon-tracks:
+ good pointing
+ large event rates due long muon range





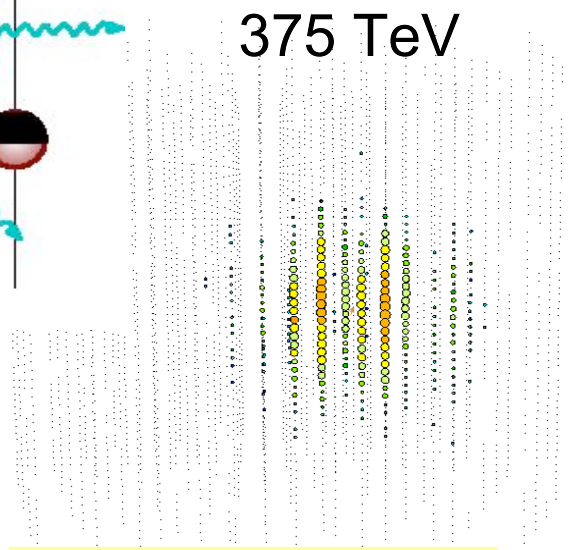
signature of ν_μ

Neutrino Signature

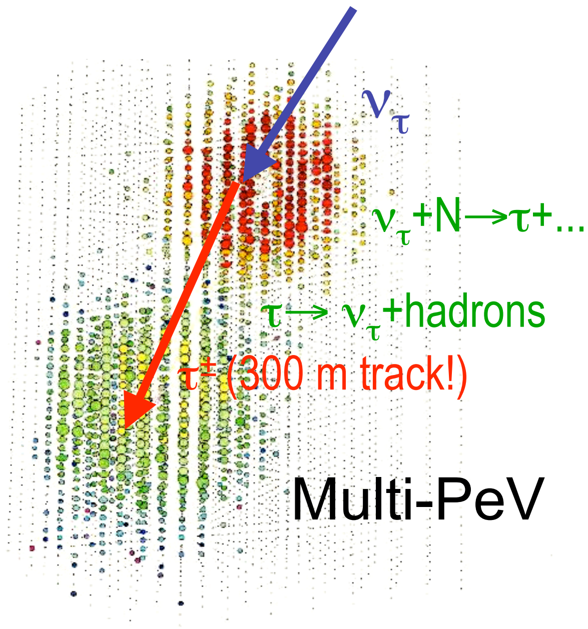


Particle shower (cascade)

+ $\nu_e, \nu_\tau, (\nu_\mu)$
+ good energy resolution (~0.2 in logE)
+ little background

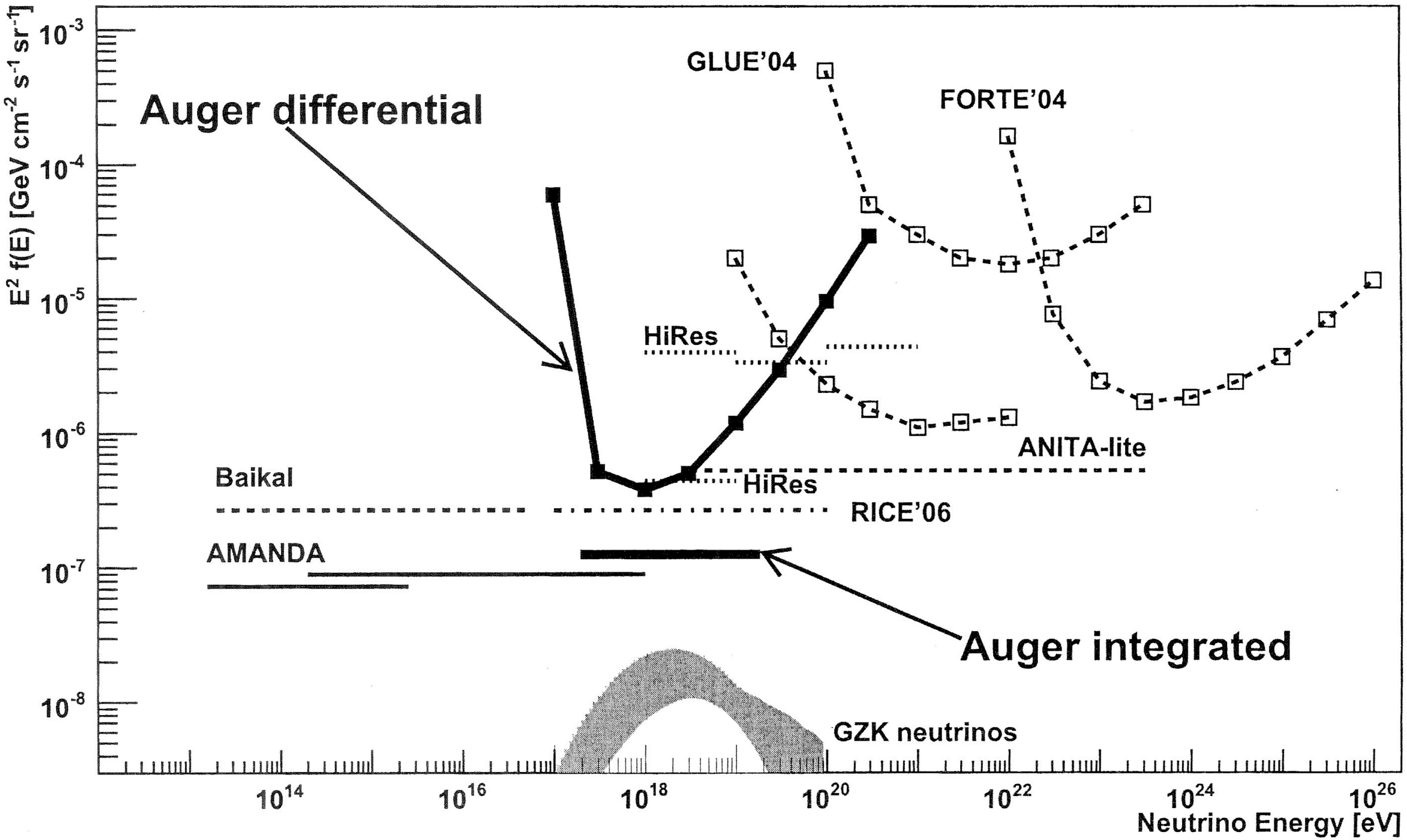


signature of ν_e



signature of ν_τ

- The other significant search for EeV neutrino signals is from AUGER. They are able to search for air showers moving almost tangent to the horizon, but somewhat upward (zenith angles between 90.1º and 95.9º); these would be produced by tau neutrinos incident almost tangent to the Earth’s crust and undergoing a charge exchange; resulting taus decaying in the atmosphere and generating an air shower.



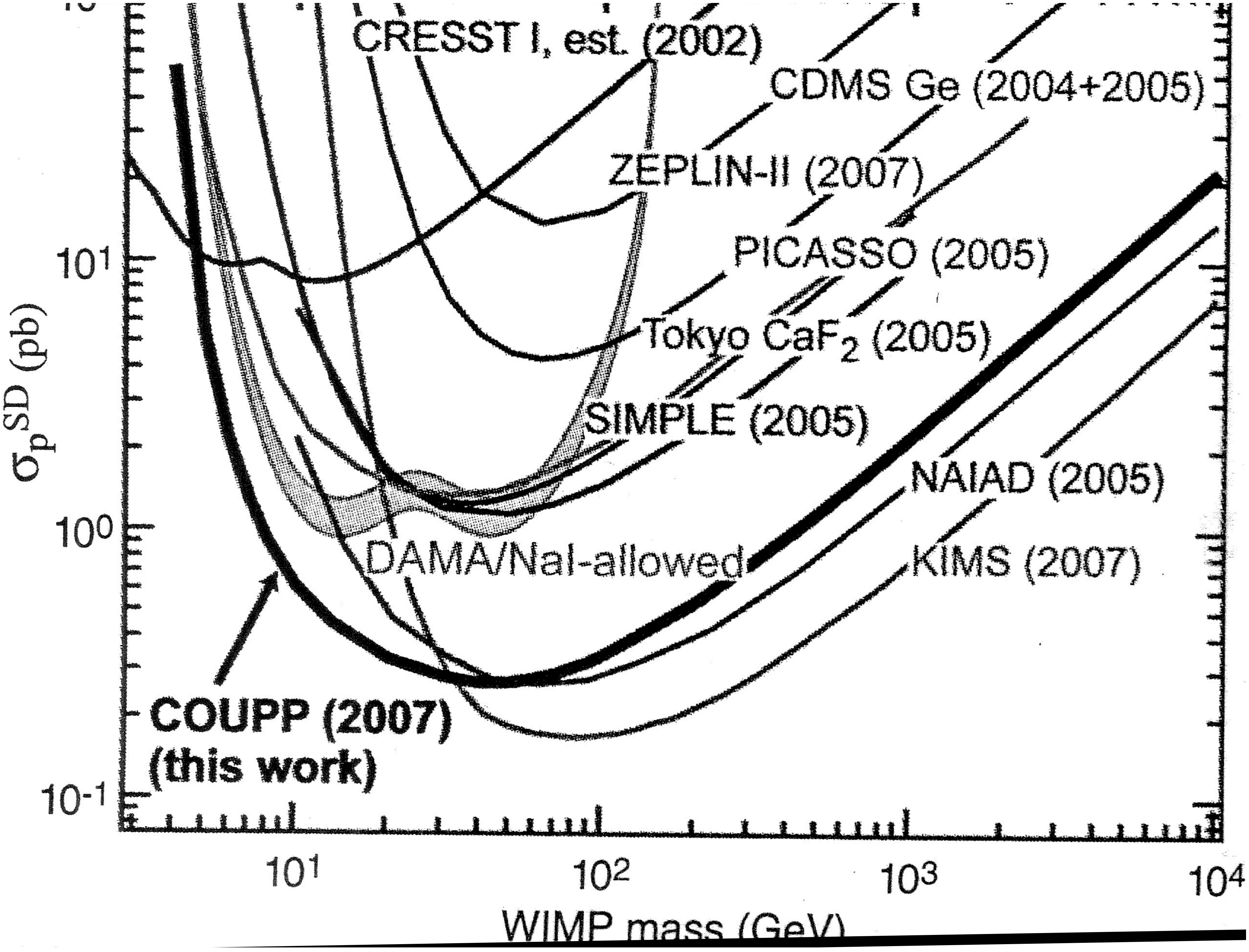
E^2 f(E) [GeV cm^{-2} s^{-1} sr^{-1}]
Auger differential
GLUE'04
FORTE'04
HiRes
ANITA-lite
Baikal
HiRes
RICE'06
AMANDA
Auger integrated
GZK neutrinos
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{14}
10^{16}
10^{18}
10^{20}
10^{22}
10^{24}
10^{26}
Neutrino Energy [eV]

- Note, ANITA is another Antarctic program with the goal of observing PeV neutrinos. A neutrino incident almost tangent to the earth’s surface, after charge-exchange in the ice, produces an energetic tau or electron which initiates an EM shower in the ice. The radio frequency Cherenkov radiation from this shower, where the wavelength is longer than the dimensions of the charged-particle cluster, is coherent. ANITA is a balloon-borne rf antenna complex to detect these EM-generated radio signals.

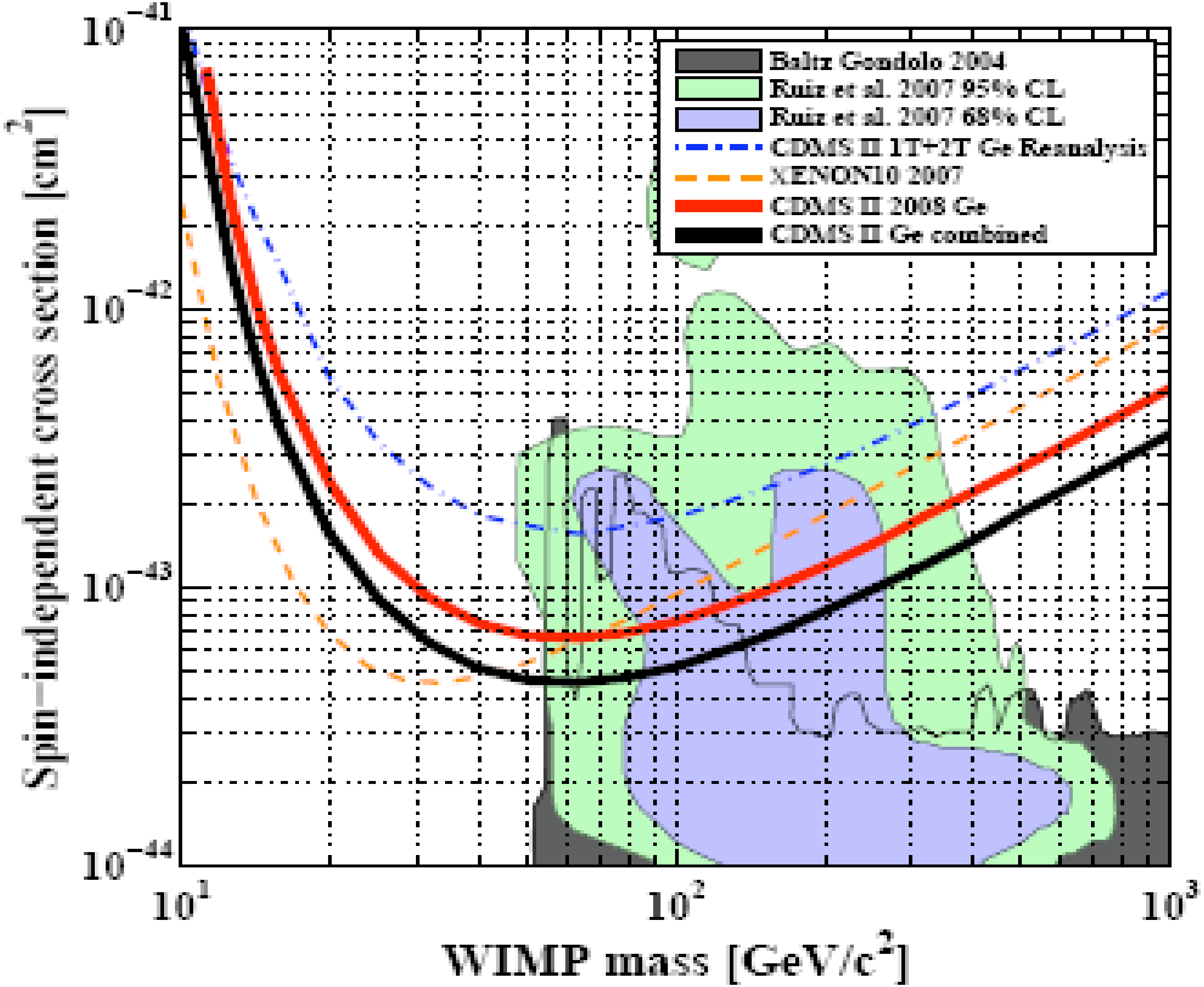
Dark Matter

In closing this discussion of “Where are we going?”, it is most appropriate to comment on the searches for Dark Matter. There have been several intensive searches for evidence of Dark Matter. This week we shall hear from Rita Bernabei on the very interesting positive results from DAMA/LIBRA.

However it is also appropriate to note the several very sensitive negative searches; CDMS, COUPP, KIMS, Xe10, etc. The COUPP experiment, a bubble chamber using CF_3 I, has a negative result which was recently publicized in articles in Science, the CERN Courier, and Physics Today. The next slide is from the COUPP reports.


CRESST I, est. (2002)
CDMS Ge (2004+2005)
ZEPLIN-II (2007)
PICASSO (2005)
Tokyo CaF_2 (2005)
SIMPLE (2005)
NAIAD (2005)
KIMS (2007)
DAMA/NaI-allowed
COUPP (2007)
(this work)
10^1
10^0
10^{-1}
σ_p^{SD} (pb)
10^1
10^2
10^3
10^4
WIMP mass (GeV)

The next slide is from a CDMS preprint; this "Cold Dark Matter Search" uses Ge and Si, cooled to ~50 mK. Also on the slide are results from Xe10, a liquid Xenon detector. Both report negative results.



Baltz Gondolo 2004
Ruiz et al. 2007 95% CL
Ruiz et al. 2007 68% CL
CDMS II 1T+2T Ge Reanalysis
XENON10 2007
CDMS II 2008 Ge
CDMS II Ge combined
10^{-41}
10^{-42}
10^{-43}
10^{-44}
Spin-independent cross section [cm^2]
10^{1}
10^{2}
10^{3}
WIMP mass [GeV/c^2]

- It is significant that these other WIMP searches claim greater sensitivity than DAMA and report no evidence for WIMP events.
- It is also perhaps relevant that the MACRO muon measurements also display a ±2% seasonal flux variation, peaked in June or July (within the uncertainties, in phase with the DAMA oscillation).
- Possibly, photo-neutrons from the muons' electromagnetic photonuclear interactions could create a background in DAMA, although in the DAMA/LIBRA paper, this is explored and rejected.
- Certainly more work must be done, and indeed serious searches are in progress.

Since the last Vulcano Workshop in 2006, there have been a number of meetings and conferences where this physics/astrophysics has been discussed.

XIV ISVHECRI 2006 (Weihai, China)

Tien Shan “Int’l C.R. Workshop” 2006 (Kazakhstan)

20^{th} European C.R. Symposium 2006 (Lisbon)

Colliders to Cosmic Rays 07 (Granlibakken, CA)

Aragats “Int’l C. R. Workshop” 2007 (Armenia)

XXX ICRC 2007 (Merida, Mexico)

“Forward Physics at LHC with TOTEM” 2008 (Penn.)

“Int’l Astroparticle Physics Symp.” 2008 (Colorado)

XXth Rencountres de Blois, 2008 (Blois, France)

Conclusions

Indeed, the future of cosmic ray "Astroparticle" physics will continue to be very active. Neutrino physics, Dark Matter searches, and the continued studies of the spectrum, composition, and sources of primaries over the full range of energies (~12 orders of magnitude) will keep us occupied. The search for Dark Energy is a continuing challenge. This field of science remains lively, interesting, and a great pleasure to work in.