ASTROPARTICLES

Vulcano Workshop 2006

May 22, 2006

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Outline

- Definition of Astroparticles
- Low Energy Nuclei; <~20 TeV
- Space Travel- Radiation Safety
- Intermediate Energy;~100 TeV-PeV
- C2CR,CMS,GAMMA,ANI…..
- High Energy;~100 PeV-1ZeV
- Neutrino Physics, H.E. Gammas, Gravity Waves
- Dark Matter- Dark Energy
- Conclusions

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Cosmic-ray physics in the space age

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Cosmic rays are primarily nuclear particles ranging in energy over about 10 orders of magnitude, from GeV to EeV. The current research activities in each of three broad energy regions of these primary particles are discussed, and outstanding current problems noted. Neutrino and gamma ray astrophysics are also discussed, as are the problems of space travel related to cosmic rays.

What are “Astroparticles”? Cosmic Rays?

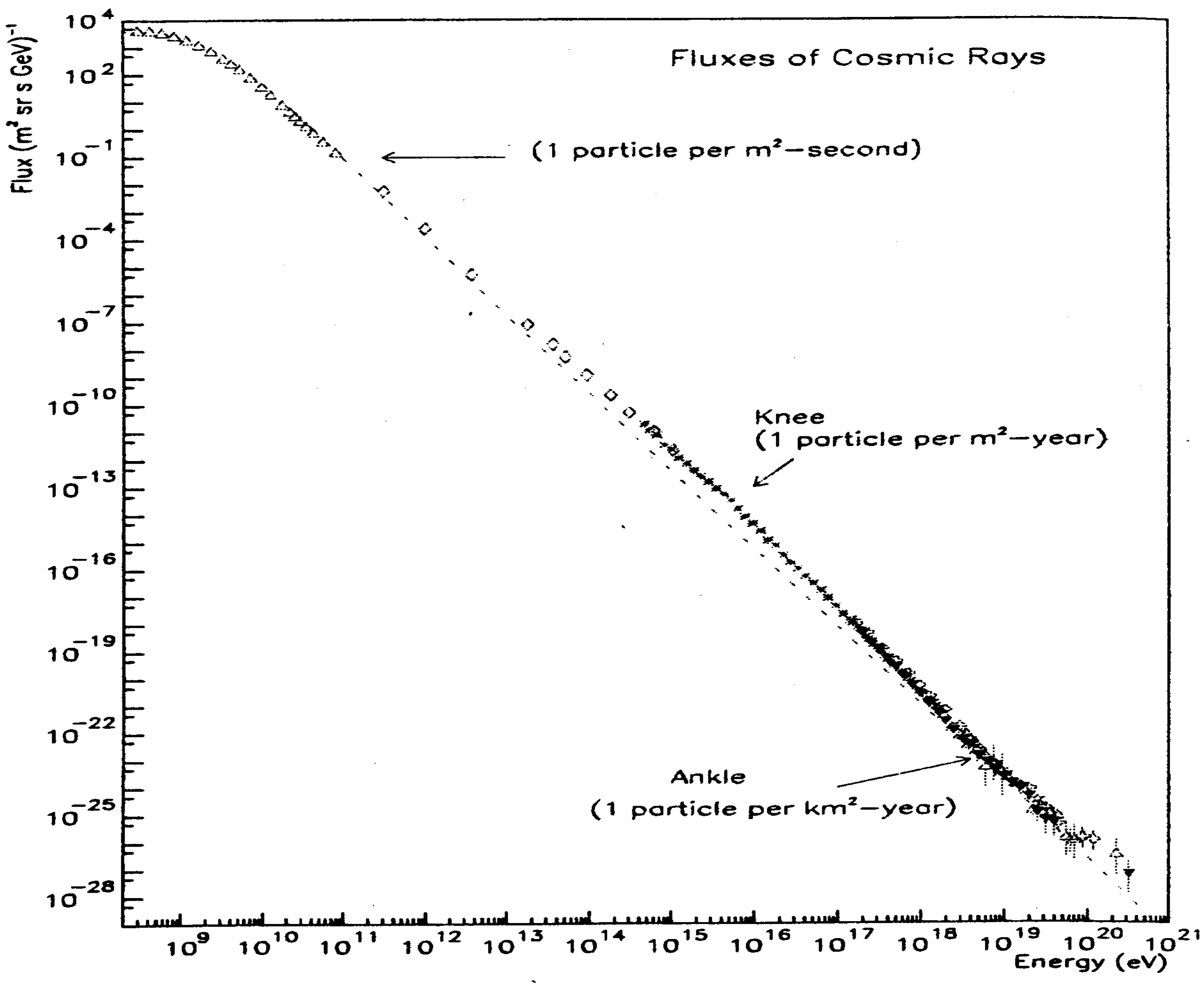
Anything which reaches the earth from outer space {except EM radiation with energies below ~ GeV, plasma, neutral gas, meteors, and asteroids}.

- Nuclei (p, He,…Fe, etc.)
- Neutrons
- Anti- nuclei
- Anti Protons
- Electrons and Positrons
- High Energy Gammas (E>GeV)
- Neutrinos
- Gravity Waves
- Dark Matter (?)
- Dark Energy (?)

Note:

A few years ago the American Physical Society decided to form a new Division in this area of physics. There are other Divisions in the Physical Society; in Atomic-Molecular –Optical Physics, Nuclear Physics, Elementary Particle Physics, etc. It was first proposed to call this new Division the Division of Cosmic Ray Physics. However people objected, and (after considerable discussion) instead it became named the Division of Astrophysics.

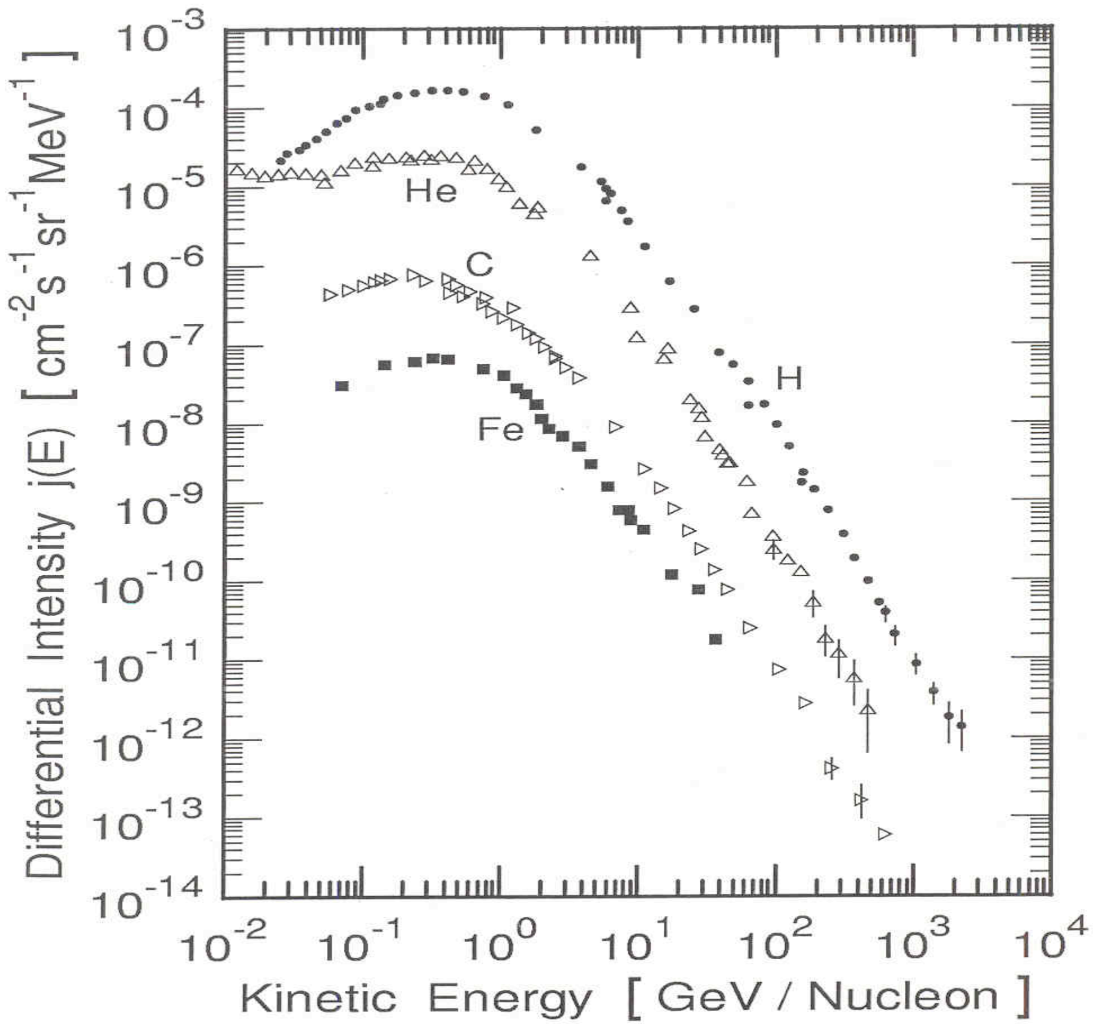
It seems that the term “Cosmic Rays” has become unpopular; instead, this area of physics is increasingly called: Astrophysics, Astroparticle Physics, or Particle Astrophysics.



Fluxes of Cosmic Rays
Flux (m² sr s GeV)⁻¹
(1 particle per m²-second)
Knee
(1 particle per m²-year)
Ankle
(1 particle per km²-year)
Energy (eV)
10^4
10^2
10^-1
10^-4
10^-7
10^-10
10^-13
10^-16
10^-19
10^-22
10^-25
10^-28
10^9
10^10
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21

“Low” Energy Primary Cosmic Rays” Tens of Mev<E<Tens of TeV Nuclei

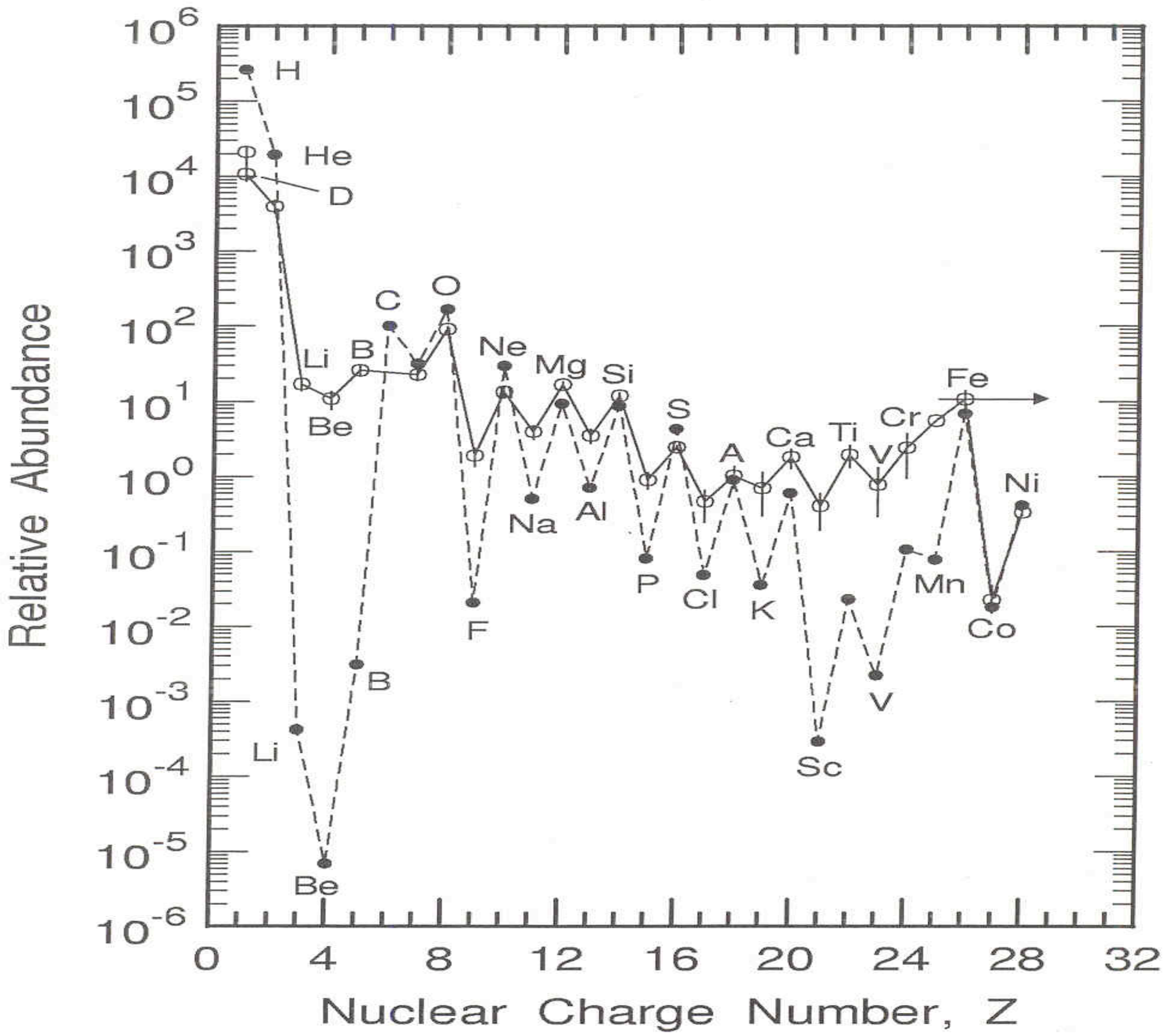
This is the range of energies studied by direct observation from balloon- and satellite – borne detectors above the atmosphere. The detectors include magnetic spectrometers, ionization calorimeters, etc. and typically have exposures on the order of square meter – steradian – weeks. The upper limit to the energy range of primaries studied is determined by the rapid falloff of flux with energy. It is worth noting a few of the instruments/programs which have contributed in this area: BESS, HEAT, AMS, CAPRICE, JACEE, CREAM, PAMELA, and MASS (to name only a few).



H
He
C
Fe
Differential Intensity j(E) [cm^{-2}s^{-1}sr^{-1}MeV^{-1}]
Kinetic Energy [GeV / Nucleon]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

“Low” Energy Primary Cosmic Rays” Tens of Mev<E<Tens of TeV Nuclei

It is now generally agreed that the source of most of these primaries is shock wave acceleration associated with supernovas, although lower energy primaries are also produced from solar flares. The nuclear composition of these cosmic rays generally reflects stellar (“universal”) composition, although some nuclei (Li, Be, and B for example) are significantly more abundant in cosmic rays than in stars. This is almost certainly due to the spallation of C, O, etc. nuclei on interstellar matter.


Relative Abundance
Nuclear Charge Number, Z
H
He
D
Li
Be
B
C
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
A
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni

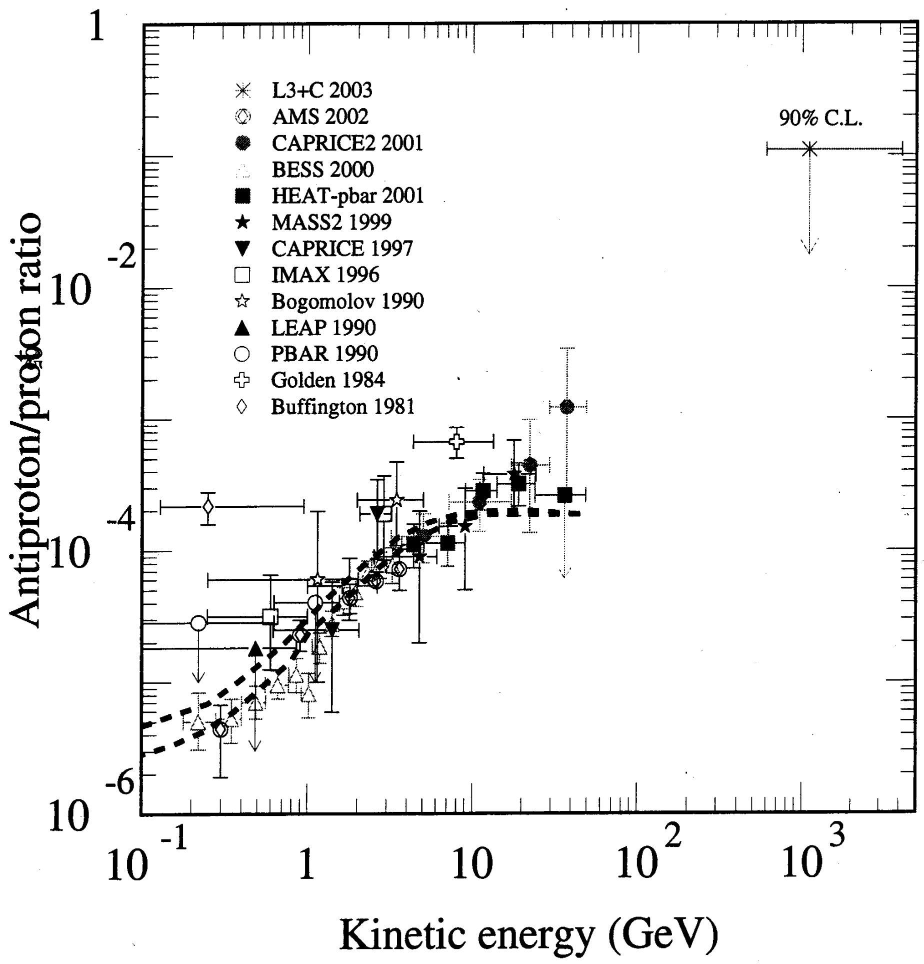
Antimatter?

The apparent asymmetry of the universe, the lack of primordial antimatter, remains an unresolved mystery. The Standard Model suggests that a Big Bang origin of the Universe should have resulted in as much antimatter as matter. Why we have a matter-dominated Universe is a mystery. Perhaps due to CP non-conservation?

Antimatter?

Primary antiprotons are observed at about the abundance expected from high-energy interactions of primaries with interstellar matter (up to the extent of existing data). Of course, higher energy data will be welcome (e.g. from PAMELA).

Final result



Antimatter?

Heavier cosmic ray antinuclei could provide evidence of primordial antimatter. Within our galaxy, an antimatter star or star cluster would be apparent from matter – antimatter annihilation in its vicinity, with (for example) an abundant 70 MeV gamma flux from the resulting π^0 production.

Antimatter?

If there were antimatter galaxies or galactic clusters, anti-baryonic cosmic rays from them might diffuse to the vicinity of our galaxy. However, for GeV-TeV energies, the local galactic magnetic field contains cosmic ray nuclei for millions of years (determined by the abundance of Be), and this galactic "bottle" will be difficult for GeV – TeV cosmic rays from outside the galaxy to penetrate. Therefore even with sensitivities of 10^{-10}, it may be difficult to detect an extragalactic anti-nucleus in this energy range. Nevertheless, the AMS program is proceeding with a magnetic spectrometer detector (to be mounted on the International Space Station) designed to search for such anti-nuclei among primary cosmic rays (B. Alpat talk, Saturday).

Radiation Safety

An interesting sidelight in the discussion of primary cosmic rays in this energy region is the matter of the radiation exposure to astronauts who might spend two or three years outside the Earth's atmosphere. The energy flux of cosmic rays is peaked in the hundreds of MeV – few GeV energy range, and the particle flux incident on the Earth is (order of magnitude) about a nucleon per (cm^2 second steradian). As many are in nuclei – with an ionization proportional to Z^2 – the effective biological dose rate is of the order of 100 REM, or 1 Sievert, per year.

Radiation Safety

This flux can suddenly fluctuate upwards due to Solar activity. A safe radiation exposure level (defined for radiation workers at high energy labs, nuclear facilities, etc.) is at most a few REM per year. Thus, for an astronaut on a mission of a few weeks, the exposure is not too serious. However, for the ~3 year journey to Mars and return, this cosmic ray flux is a significant problem. NASA has held biennial workshops on this topic. NASA recommends, for example, that a 3 year space flight should not increase an astronaut's probability of subsequently developing cancer by more than 3%.

Note: A short-term dose of 400 REM is 50% fatal.

Radiation Safety

There are 3 primary possible shielding scenarios:

1.) Passive bulk absorber (> a meter of low-Z material surrounding the space craft)

2.) A toroidal magnetic field (with no field inside, where the astronauts are)

3.) An electrostatic shield; charging the space craft to about $+10^9$ Volts

All three of these appear difficult, costly, and would add significant weight to the space craft. Cosmic rays will not prohibit future extended human space exploration, but they do add to the engineering challenges to be faced.

Radiation Safety

Note: when at a very high elevation, have you ever wondered what happens when a primary GeV iron nucleus hits you in the head? Do you have a bad dream (if asleep at night)? Or a brilliant idea?

Another interesting discussion concerning low energy cosmic rays, specifically those associated with solar flares, concerns the correlation between the solar 11-year cycle with the weather on Earth (e.g. average global temperature). Students of this topic observe a positive correlation. The physical source of this correlation is reasonable. An increase of cosmic rays from solar flares impinging on the atmosphere should lead to more ions in the upper atmosphere. These ions can then be nuclei for water-vapor droplet – hence, cloud – formation. An increase in the global cloud cover then would increase the Earth’s albido, and hence reduce the heat absorbed from the sun.

Intermediate Energies, 100 TeV- 100 PeV

These are energies beyond the range of direct observation, where our knowledge is based on surface observations of air showers. Within this energy range lies the “knee”, where the primary spectrum displays a break in slope, and where the composition changes. As noted frequently, the interpretation of the air shower observations is difficult, due to the extrapolation back to the primary interaction at the top of the atmosphere, and the uncertainty in the inclusive distributions in the primary interaction. This has been discussed extensively (e.g. my talk at the 2004 Vulcano Workshop). Let me note a few updates. The Prague conference “From Colliders to Cosmic Rays” last September included good discussions of relevant topics, for example

HOME

TOPICS

INTERNATIONAL ADVISORY COMMITTEE

MEETING SITE

ACCOMMODATION

REGISTRATION

CONTRIBUTED PAPERS

PROGRAMME

REGISTERED PARTICIPANTS

CONFERENCE POSTER

TRAVELLING

LOCAL ORGANISING COMMITTEE

CONTACT

GENERAL INFO

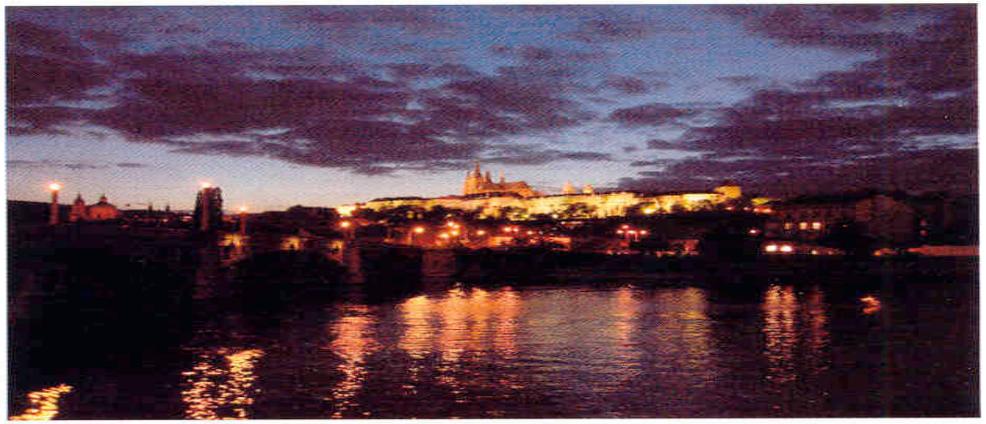
! NEW !

Prague, Czech Republic

From Colliders to Cosmic Rays

7-13 September 2005

CONFERENCE PHOTO (0.5 Mb)
or larger version (4.8 Mb)



International conference on interconnection between high energy physics and astroparticle physics

The aim of the conference is presentation and discussion of recent research activities and open questions in the fields of cosmic rays and high energy physics. Emphasis is put on topics that have considerable overlap in research aims and methods applied to

Cross section and ρ-value predictions for pp and pbar-p

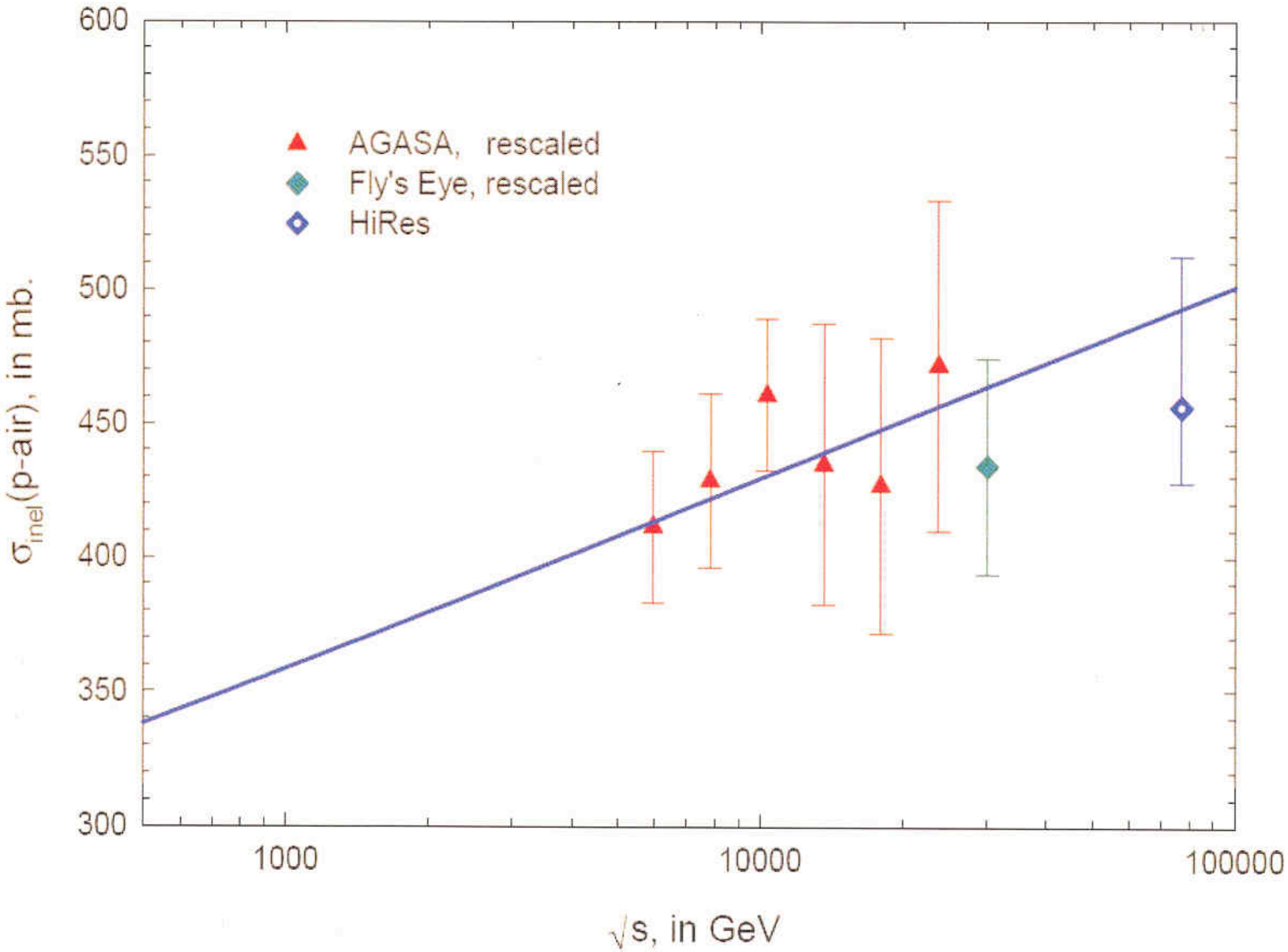
$\sqrt{s}$, in GeV	$\sigma_{\bar{p}p}$, in mb	$\rho_{\bar{p}p}$	σ_{pp}, in mb	ρ_{pp}
[illegible]	60.81 ± 0.29	0.137 ± 0.002	60.76 ± 0.29	[illegible]
1,800	75.19 ± 0.55	0.139 ± 0.001	75.18 ± 0.55	0.139 ± 0.001
14,000	107.3 ± 1.2	0.132 ± 0.001	107.3 ± 1.2	0.132 ± 0.001
50,000	132.1 ± 1.7	0.124 ± 0.001	132.1 ± 1.7	0.124 ± 0.001

LHC prediction

Cosmic Ray Prediction

The errors are due to the statistical uncertainties in the fitted parameters

$\sigma_{p\text{-}air}$ as a function of $\sqrt{s}$, with inelastic screening



- Jim Matthews' Rapporteur talk at Pune contains a good summary of the status of knowledge of primary cosmic rays in the vicinity of the "knee", the different results of different groups, and the uncertainties in the primary interaction Monte Carlos.

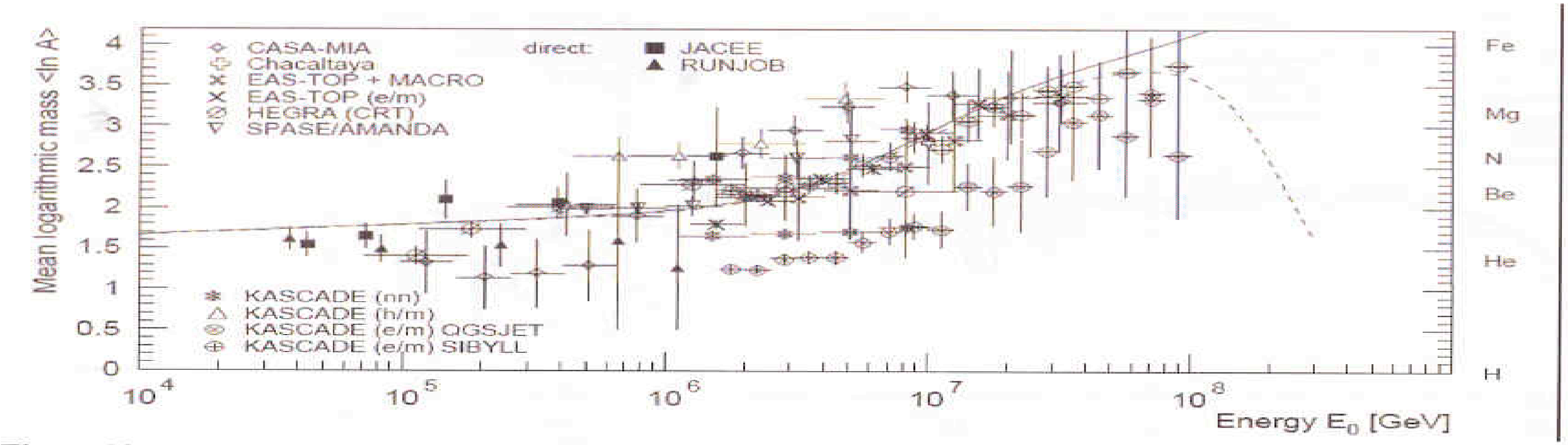


Figure 14: Mean logarithmic mass of cosmic rays derived from measurements of air shower particles at ground level.

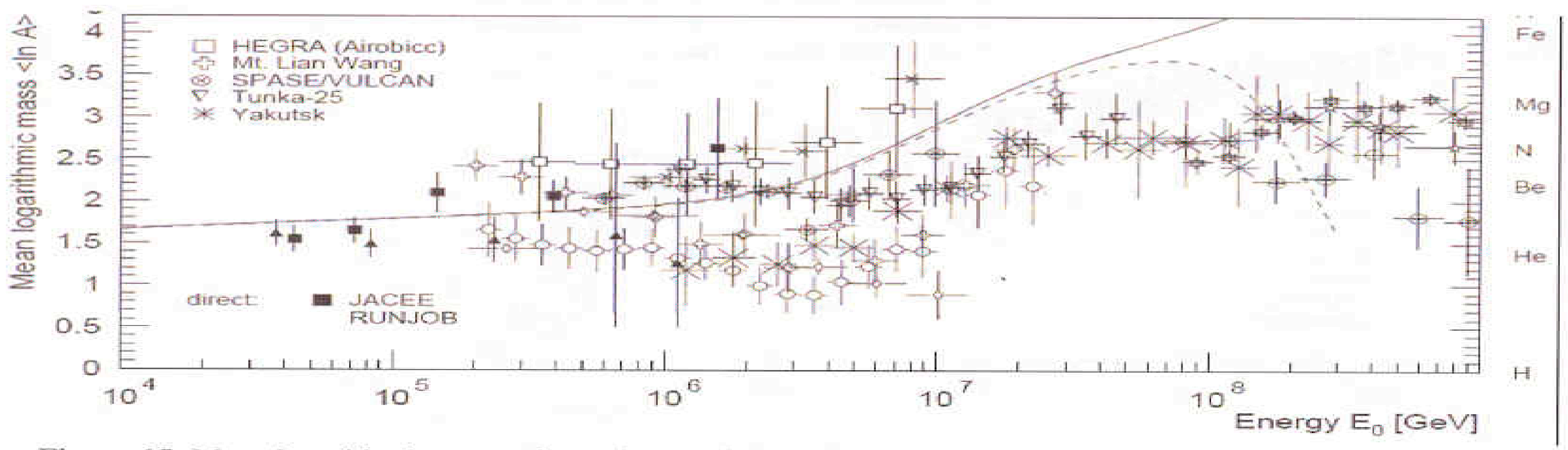


Figure 15: Mean logarithmic mass of cosmic rays derived from the depth of shower maximum measured by optical devices. These have been analyzed using QGSJET02 [17].

It is clear that using the new interaction modeling (either QGSJet02 or SIBYLL, which give very similar results), there is, perhaps for the first time, a strong consistency between the two approaches. Differences remain, but the trend toward higher mass primaries through the knee is seen in most experiments when analyzed using the same models. Those analyses which looked at spectra from individual or groupings of primaries mostly see evidence for individual knee features, appearing at larger energies for higher Z particles, as expected for SNR origins.

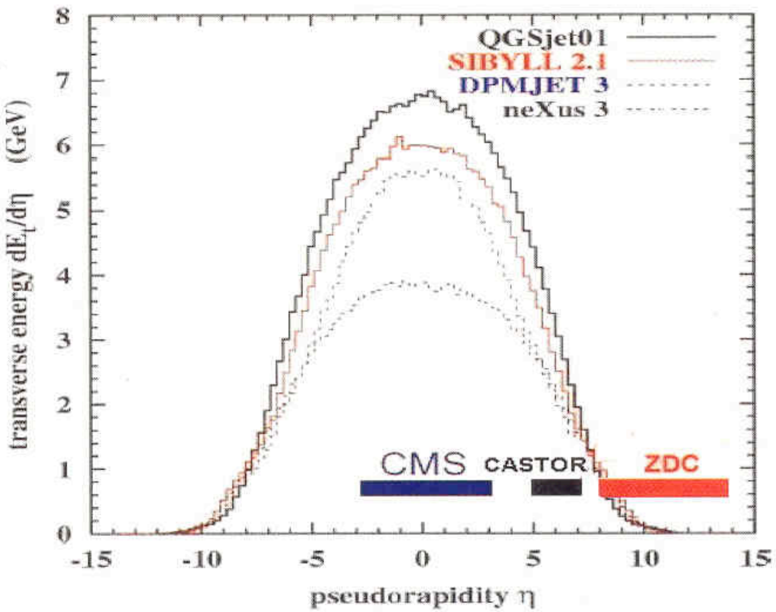
It is tempting now to wonder whether the differences at extreme energy between AGASA (a surface array) and HiRes (an optical device) can be reconciled using the improved simulations. These new interaction

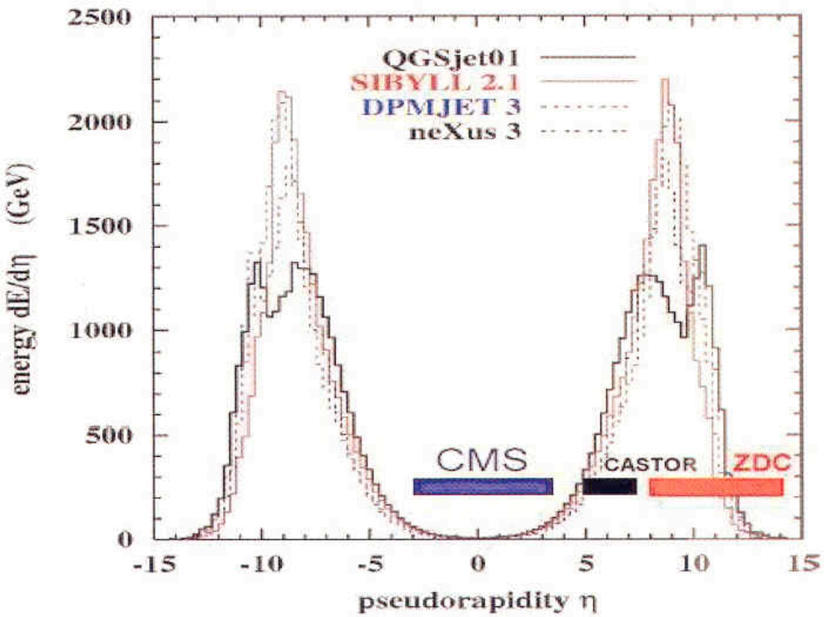
- My own interests at the LHC have been with the group constructing a Zero Degree Calorimeter for the CMS detector complex.

- At Prague, Dr. de Roeck discussed the LHC experiment capabilities for "Diffraction and Forward Physics …". We will next hear from Dr. Denegri, who, at this Workshop two years ago, also discussed the LHC potentials in this area.

(4.3) Calibration and tuning of hadronic models

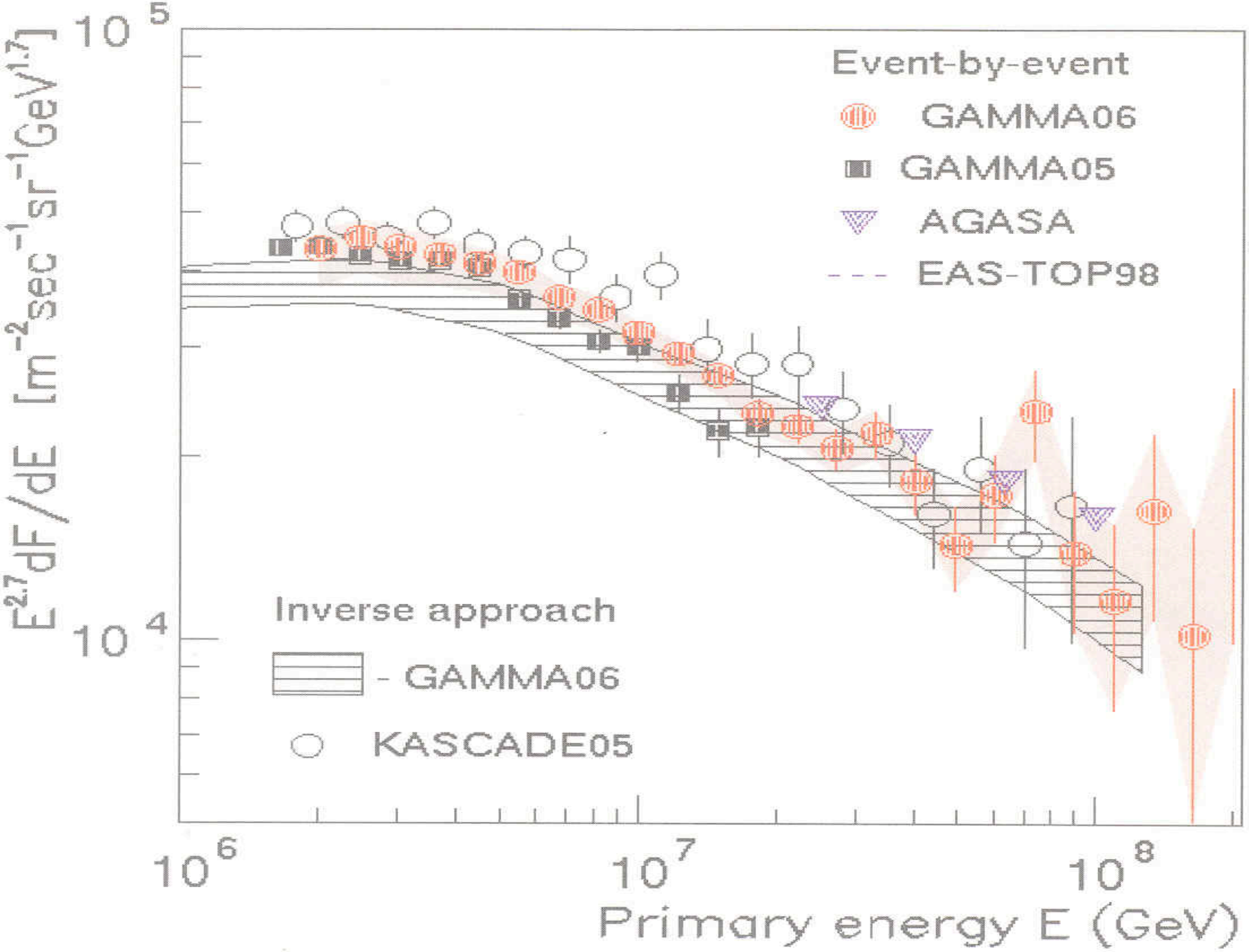
- Model predictions of particle multiplicity & energy flow at LHC:



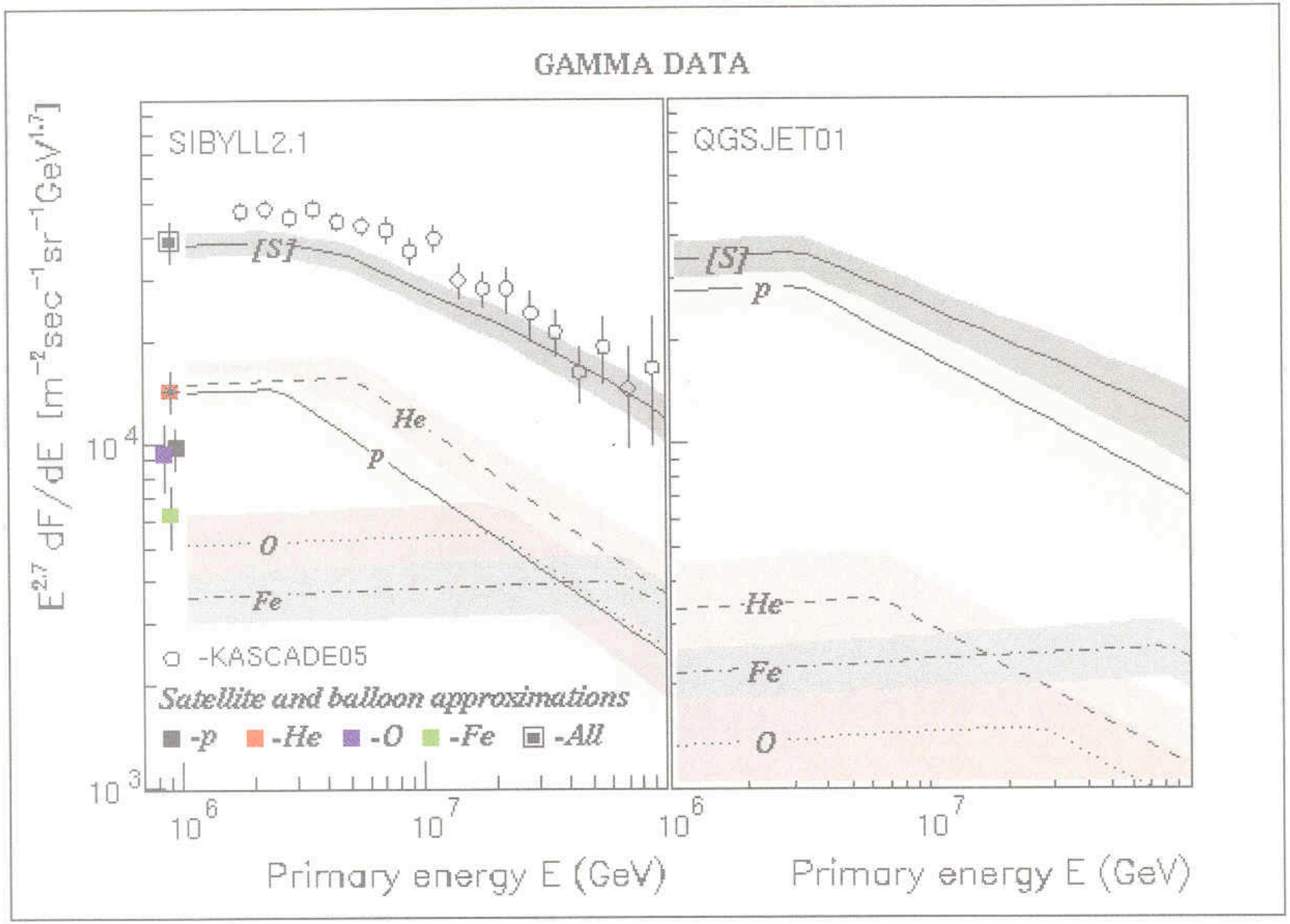


- ZDC: Direct measurement of forward leading baryon (neutron) and π^0 cross-sections & energy in pp,pA,AA at E_{lab} ~ 100 PeV ! (strong model constraint)

I am also involved with the Yerevan Physics Institute, which is operating the GAMMA air shower facility on Mt. Aragats (3200 m) in Armenia (about which I spoke at the last meeting of this Workshop).

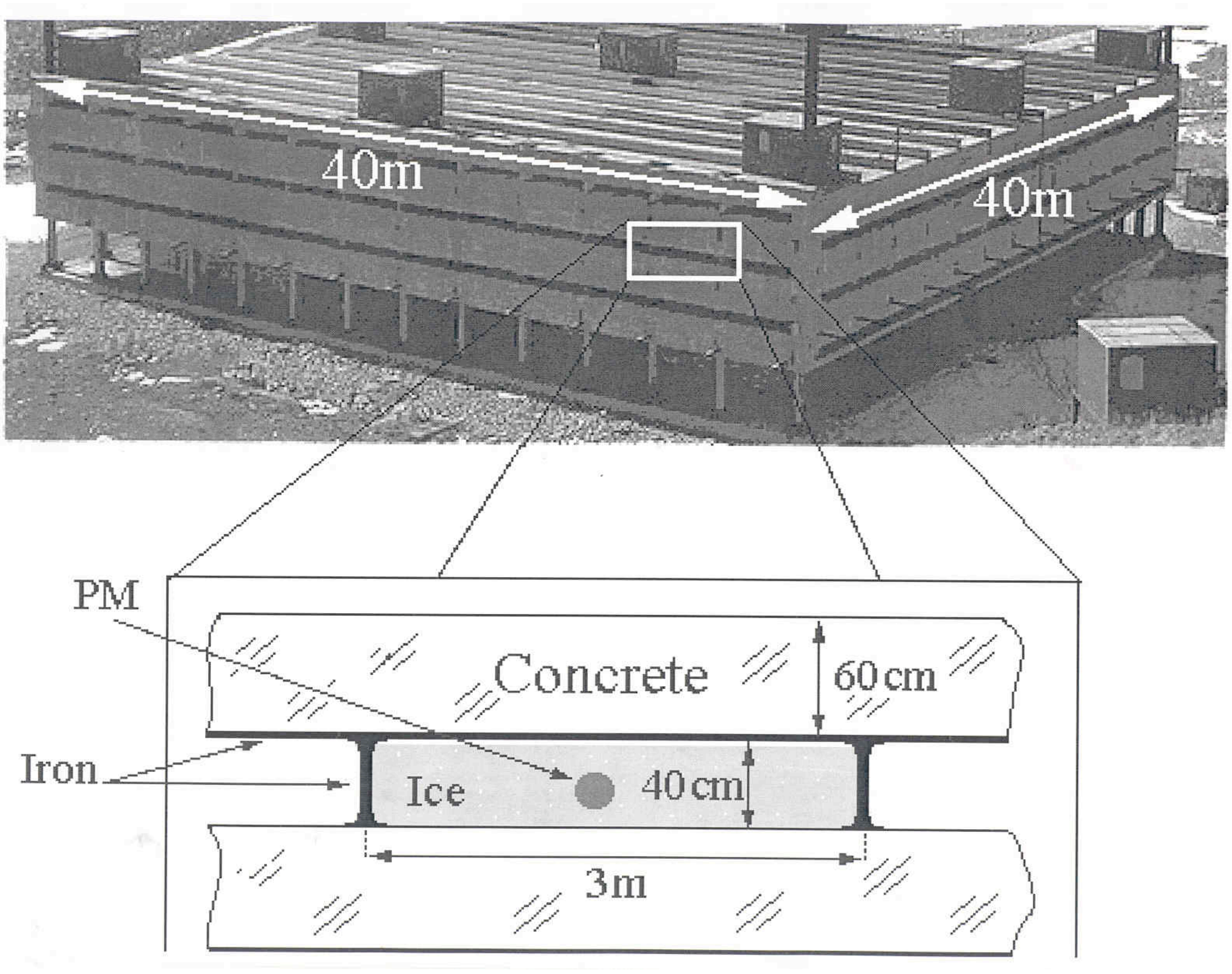


$E^{2.7}dF/dE$ [$m^{-2}sec^{-1}sr^{-1}GeV^{1.7}$]
10^5
10^4
Event-by-event
GAMMA06
GAMMA05
AGASA
EAS-TOP98
Inverse approach
- GAMMA06
KASCADE05
10^6
10^7
10^8
Primary energy E (GeV)



GAMMA DATA
SIBYLL2.1
QGSJET01
[S]
p
He
O
Fe
o -KASCADE05
Satellite and balloon approximations
■ -p ■ -He ■ -O ■ -Fe ▣ -All
E^2.7 dF / dE [m^-2 sec^-1 sr^-1 GeV^1.7]
10^4
10^3
10^6
10^7
Primary energy E (GeV)

A conspicuous feature of this GAMMA array is the 40 X 40 meter concrete structure at the center of the array. Below this are located the muon array of 150 square meters of counters, with a threshold of ~5 GeV. This structure was built about 25 years ago by Nikolsky (of the Lebedev Institute) to house a hadron calorimeter, which was never completed. We are now proposing (to a U.S. funding agency) a study and prototype tests of detectors, and hope to subsequently (following these studies) to finally build this calorimeter. The KASCADE group has shown the value of such a calorimeter, and it would be a valuable addition to this GAMMA array, especially considering the 3200 m elevation of this station.


40m
40m
PM
Concrete
60cm
Iron
Ice
40cm
3m

Two Comments Concerning the Confusion of the Spectrum and Composition near the “Knee”.

1. Since the spectrum is steeply falling, ~E , a 25% error in normalization of the energy leads to about a factor of 2 error in the flux at a given energy. At these energies, the flux of gammas at the elevation of typical EAS arrays is about 5 times the flux of electrons, hence a 5% uncertainty in the gamma conversion probability in the detector array can lead to a 25% error in the electron flux, hence to a factor of 2 error in primary flux.

- A way to resolve this problem would be to construct a “standard detector”, e.g. a square meter scintillator, with appropriate photo-detector and electronics, and take it to the different arrays to “calibrate” the local detectors, so that their results could be compared with each other.

Two Comments Concerning the Confusion of the Spectrum and Composition near the "Knee".

2. Another suggestion: Each collaboration has (of course) a specific detector array configuration, and develops their own analysis procedures. All groups use the same first interaction Monte Carlos (Sibyll, QGSJet, etc.), and programs like GEANT for the shower development, for their analysis. It would be interesting to see what the difference would be if two groups (with quite different arrays, at different elevations, etc.) exchanged data, and each analyzed the other's data with their own programs. Whether the resulting spectra and compositions are a consequence of the location and details of the EAS arrays, the primary interaction Monte Carlos, or - the analysis procedures - would certainly be of interest!

Point Sources

- For decades there have been searches for point sources of observable cosmic rays, from muons (for example), e.g. the claims from Kiel and Soudan during the 1980s. In fact it was these observations which, in part, stimulated Cronin to build the MIA-CASA cosmic ray array.
- The L3-Cosmics collaboration looked for point sources of muons (of over 20 GeV) with the L3 detector (the study of muon spectra, etc. by this group has been previously reported extensively). This point source search and its negative results were reported at the 2004 Vulcano Workshop; 10 known gamma sources and 7 gamma-ray bursts were studied; no evidence of any statistically significant excess was observed from any of them.
- However, since that time, one of the L3 students studied the data files looking for new transient sources, and one significant transient was observed. The next transparencies are from Pierre LeCoultre's Pune report on this observation.

- **Significance:**
  - 6.356 σ (Li-Ma prescription)
- **Chance occurence:**
  - $< 2.6 \cdot 10^{-3}$
- **Excess:**
  - $N_S = 762$
  - $N_B = 562.3$
  - $N_S - N_B = 163.7.$
- **Cell position:**
  - $\alpha = 173^{\circ}$
  - $\delta =$ -1°
- **Time (UTC):**
  - MJD = 51773.489 - 51776.333
  - 11h44, 17/08/2000 - 08h00, 20/08/2000.

Fit results:

- Position:

  Right ascension: $\alpha = (172.53 \pm 0.17)^\circ$

  or: α = 11h30m07.2s

  Declination: $\delta = (-1.19 \pm 0.17)^\circ$

  Galactic longitude = $(265.02 \pm 0.42)^\circ$

  Galactic latitude = $(55.58 \pm 0.25)^\circ$

- Angular resolution: $(0.70 \pm 0.13)^\circ$

Point Sources

To be sure, the area of gamma ray astronomy is a rich and lively field. There will be discussions at this Workshop on Wednesday afternoon, hence I will not attempt to make further comments on this area.

I would, however, like to recall an earlier discussion of the possibility of point source astronomical objects being observed by high-energy neutrons. The point is that a neutron of, e.g., 100 PeV, would have a decay mean path of about a kiloparsec. And neutrons are produced abundantly in high energy nuclear interactions. I presented this discussion at the 1988 Vulcano Workshop.

Emulsion Chamber Anomalies

Members of the emulsion chamber community have perennially argued that there is new physics at and above PeV energies, based on their observations. One of the perennial candidates for this new physics has been the Centauro phenomenon, e.g. interactions where the final state displays a lack of $\pi^0{}_s$. However in recent years the most impressive Centauro candidate has been shown to be a superposition of two separate events, hence is not anomalous.

The "Long-Flying Component"

Another anomaly, discussed by Vladimir Yakovlev, is the "Long-Flying Component". He had observed, in emulsion chambers, events where a hadron penetrated well beyond the range expected for a nucleon or pion, leading to a hadron cascade deeper in the chamber. He and I.M. Dremin (also of the Lebedev Institute) have recently circulated a preprint in which they argue that this phenomenon is due to the rise in the cross section for the production of charmed hadrons, e.g. _$^{+}_{c}$ (a charm hyperon composed of a u, d, and c quark). These (and other charmed hyperons) have decay lifetimes of hundreds of femtoseconds, and masses of 2 – 3 GeV, hence would have a mean decay path length of meters at PeV energies. If it is also assumed that they have an anomalously low interaction cross section, or a very low inelasticity, and are produced with a high rapidity (very forward production), this might explain this long-flying component phenomenon. Clearly, good LHC data will be necessary to validate this explanation.

Charm in cosmic rays
(The long-flying component of EAS cores)

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Lebedev Physical Institute RAS, 119991 Moscow, Russia

Abstract

Experimental data on cosmic ray cascades with enlarged attenuation lengths (Tien-Shan effect) are presented and analyzed in terms of charm hadroproduction. The very first estimates of charm hadroproduction cross sections from experimental data at high energies are confirmed and compared with recent accelerator results.

High Energy Cosmic Rays, 100 PeV - ZeV; Gamma Ray Astronomy , and Neutrinos

These three topics are being discussed in many talks during this Workshop, and I shall not take time here to discuss them, except to note that all are most interesting areas in astroparticle physics, and I look forward to these presentations.

- Gravity Waves

I have been interested in noting that gravity waves discussions now have earned a place in cosmic ray and astroparticle physics discussions. Up to the present, it is my understanding that the LIGO and VIRGO detectors have not yet claimed to detect a true gravity wave signal, although LIGO has commenced some serious operation at close to its design sensitivity. I look forward to G. Pizzella's discussion following our coffee break to learn more.

- Dark Matter and Dark Energy

Again, this afternoon and tomorrow we will hear about Dark Matter and Dark Energy, certainly two of the exciting and very timely issues in our efforts to understand our Universe.

Conclusions

This is certainly a most lively and exciting period in our study of the Universe, and of those messenger objects which reach us on Earth. As noted two years ago, the more mysteries we solve, the more new problems arise. Some problems, like the physics of the "knee" in the primary cosmic ray spectrum, have been studied for some decades, but are still not clearly resolved. In this area, where good data from the LHC will be most valuable in understanding the primary nuclear interactions at the top of the atmosphere, and in neutrino physics, the interplay between accelerator data and cosmic ray observations is very relevant and necessary.

- I look forward to the broad spectrum of topics which we will be discussing this week.