ISAPP 2004

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Observations of Cosmic Rays

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Why to Study Cosmic Rays ?

✓Cosmic rays span over an enormous range of energies, up to 10^{20} eV

✓They are abundant and serve an important role in the energy balance of galaxy. Their energy density 1 $eVcm^{-3}$ is comparable to that contained in the galactic magnetic field or in the cosmic microwave background.

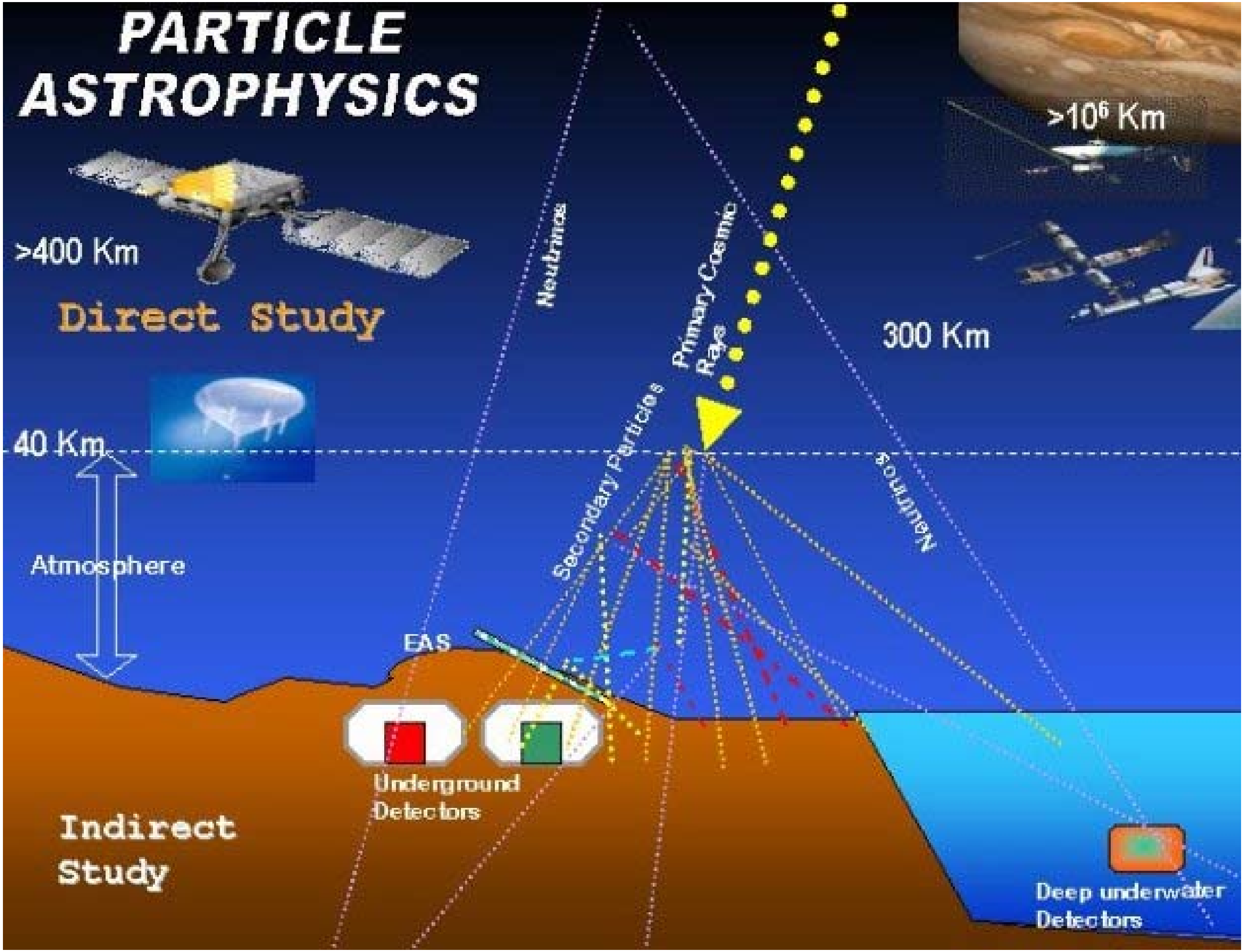
✓They are evidence of powerful astrophysical accelerators (supernovae, active galactic nuclei…) and can be used to study these accelerators

✓They propagate through universe and can give information on properties of cosmic environment (magnetic fields, matter densities…)

✓Their chemical composition, modulated by propagation, reflects the nucleosynthetic processes occurring at their origin and can also be used to measure age of astrophysical objects (cosmic ray clocks: ^{10}Be $t_{1/2} = 1.5\ 10^6 y$)

✓They can be used to study the validity of physical laws in extreme conditions (violation of Lorentz invariance?)

✓They can be messengers of « new physics » or yet unknown particles


PARTICLE
ASTROPHYSICS
>400 Km
Direct Study
>10⁶ Km
300 Km
Neutrinos
Primary Cosmic Rays
Secondary Particles
Neutrinos
40 Km
Atmosphere
EAS
Underground Detectors
Indirect Study
Deep underwater Detectors

Outline

- A Brief History of Cosmic Ray Physics
- Direct Detection
- Air Shower Detection Techniques
- Air Shower Detectors

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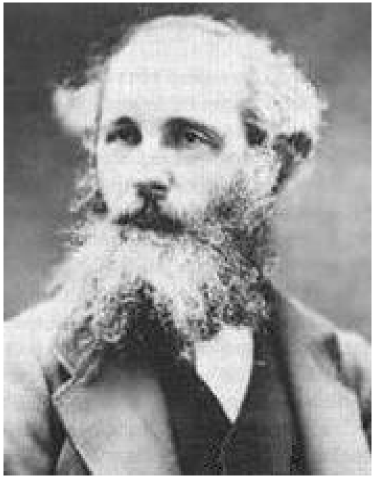
Observations of Cosmic Rays

- A Brief History of Cosmic Ray Physics

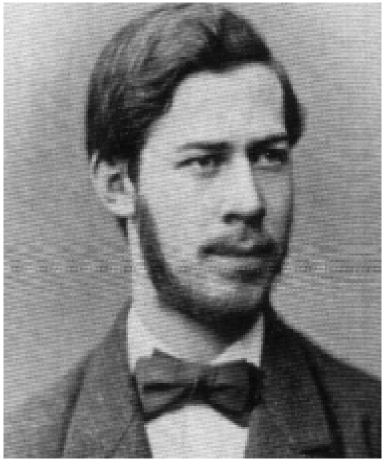
A brief history of Cosmic Ray Physics

Great triumphs of 19th century



J.C. Maxwell

Unification of electricity and magnetism
Maxwell 1864



H.R. Hertz

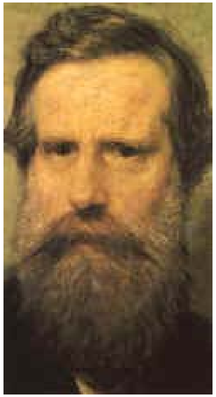
20 years later experiments of Hertz confirmed that the light is a form of electromagnetic radiation

Experiments in electricity and magnetism were the major growth area in physics

Conduction of electricity through gases:
Good vacuum tubes and high voltages between the positive and negative electrodes

1879 : Crookes tube

Discovery of cathode rays



Crookes

1897 : Thomson measured the charge to mass ratio of cathode rays by deflection the radiation by crossed electric and magnetic fields: Discovery of the first sub-atomic particle, electron

Thomson

New discoveries

1895 Röntgen discovered X-rays: Photographic plates left close to Crookes tubes were darkened

Search for other sources of X-ray emission

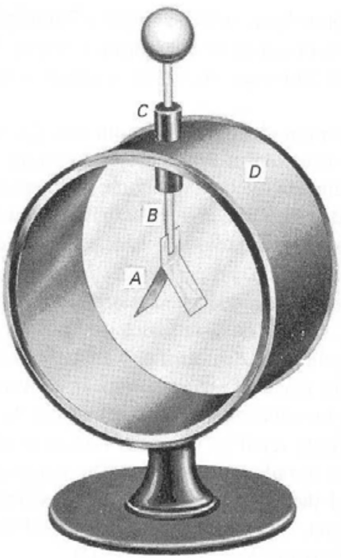
1896 Becquerel discovered natural radioactivity by studying uranium samples

1898-1900 Rutherford, P. et M. Curie and Villard understood that there were several types of radioactivity: α, β, γ

The discovery of Cosmic Rays

Early experiments in radioactivity used electroscope

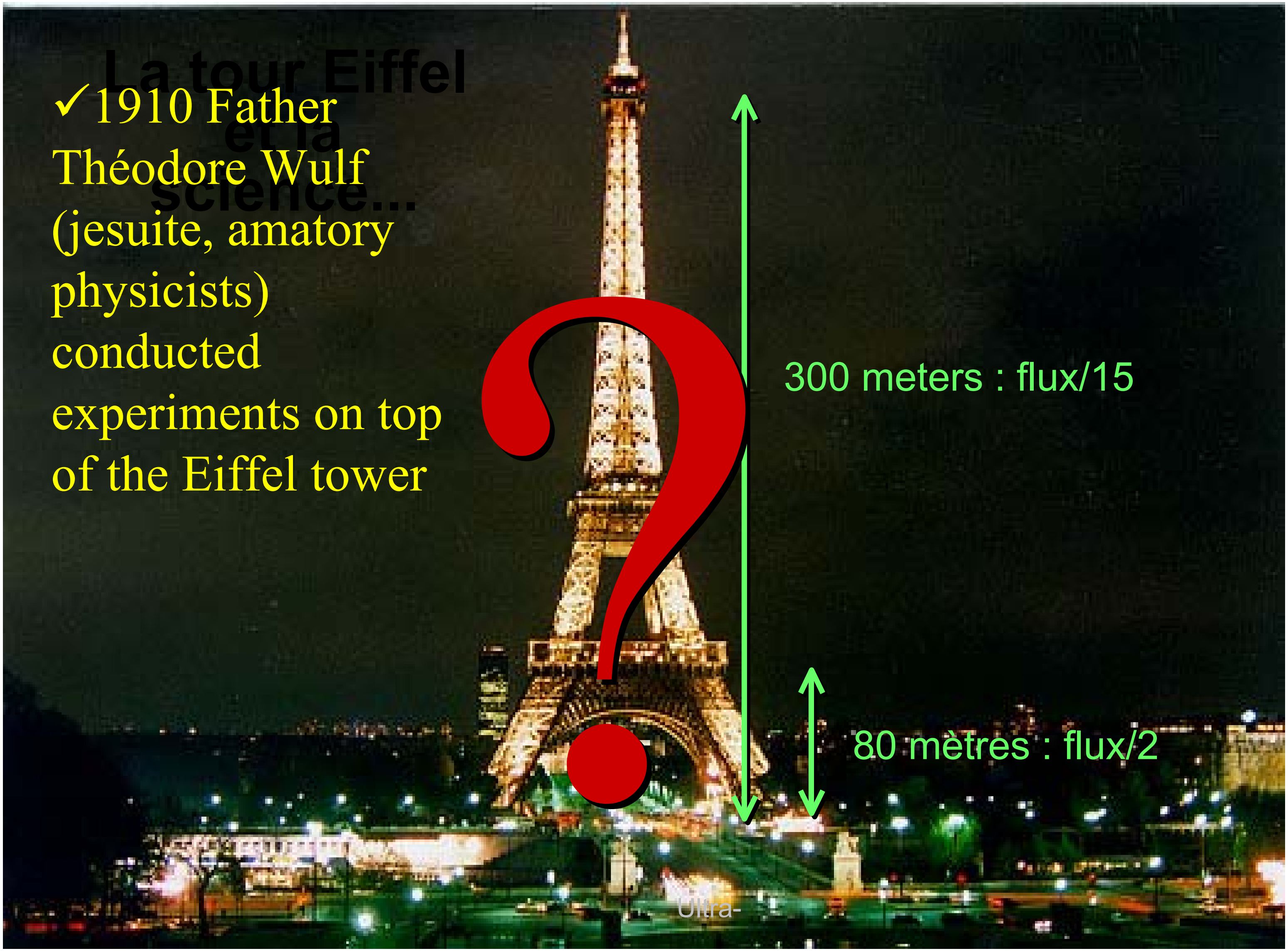
✓When electroscope is charged, the leaves (A) are pushed apart
✓The ionisation of the gas inside discharge the electroscope and the leaves move towards each other
✓The rate at which the leaves came together measured the amount of ionisation



Spontaneous discharge of the electroscope !

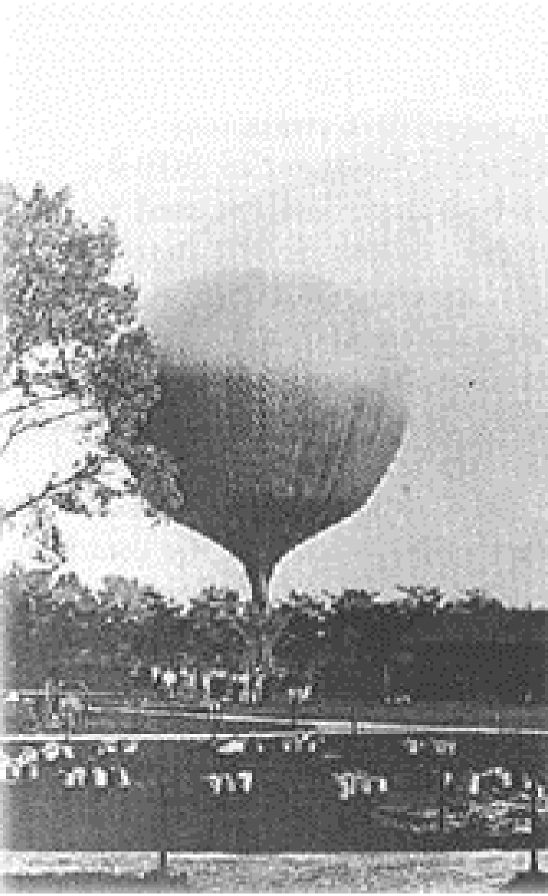
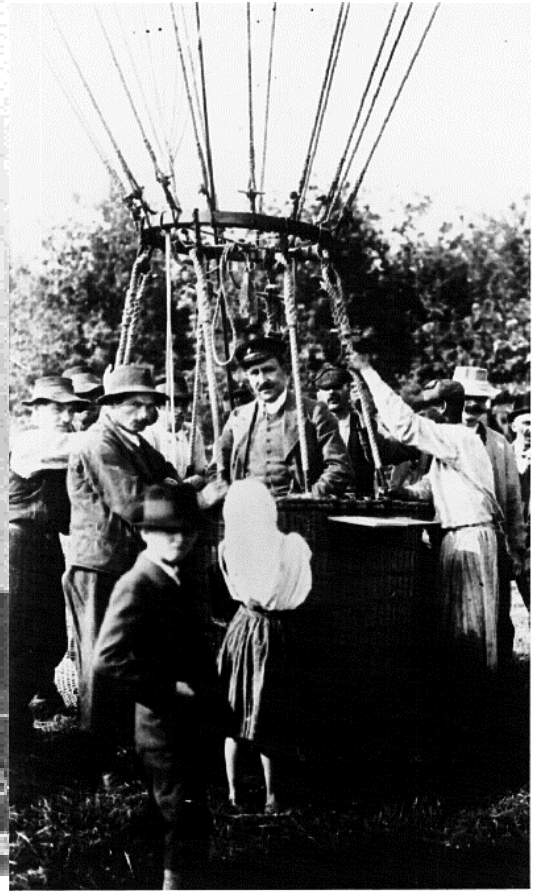
✓1901 Wilson observes that the discharge is identical on the ground and in a tunnel
✓Rutherford shows that this is due to the natural radioactivity

Eiffel tower and the science



- ✓1910 Father Théodore Wulf (jesuite, amatory physicists) conducted experiments on top of the Eiffel tower

Up to the sky

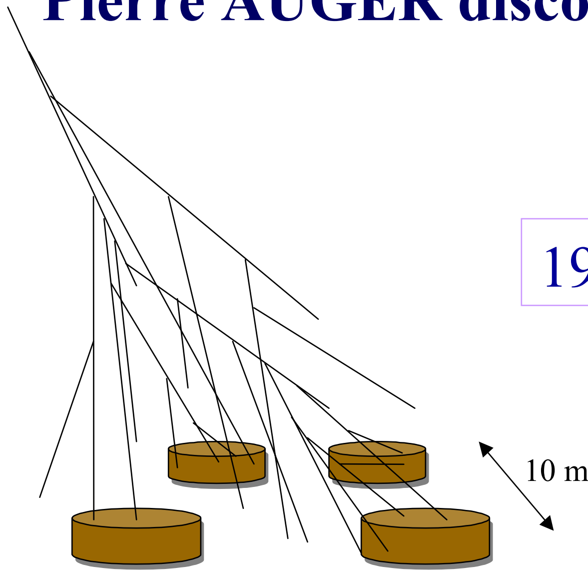
Average ionisation increase with increasing altitude

1912 and 1913 : Hess and Kolhörster made manned balloon flights to measure the ionisation of the atmosphere with increasing altitude

Source of the ionisation must be located above the earth's atmosphere !

Towards extreme energies

Pierre AUGER discovers Cosmic Ray showers



1938

Two particle detectors positioned high in the Alps signaled arrival of particles at exactly the same time

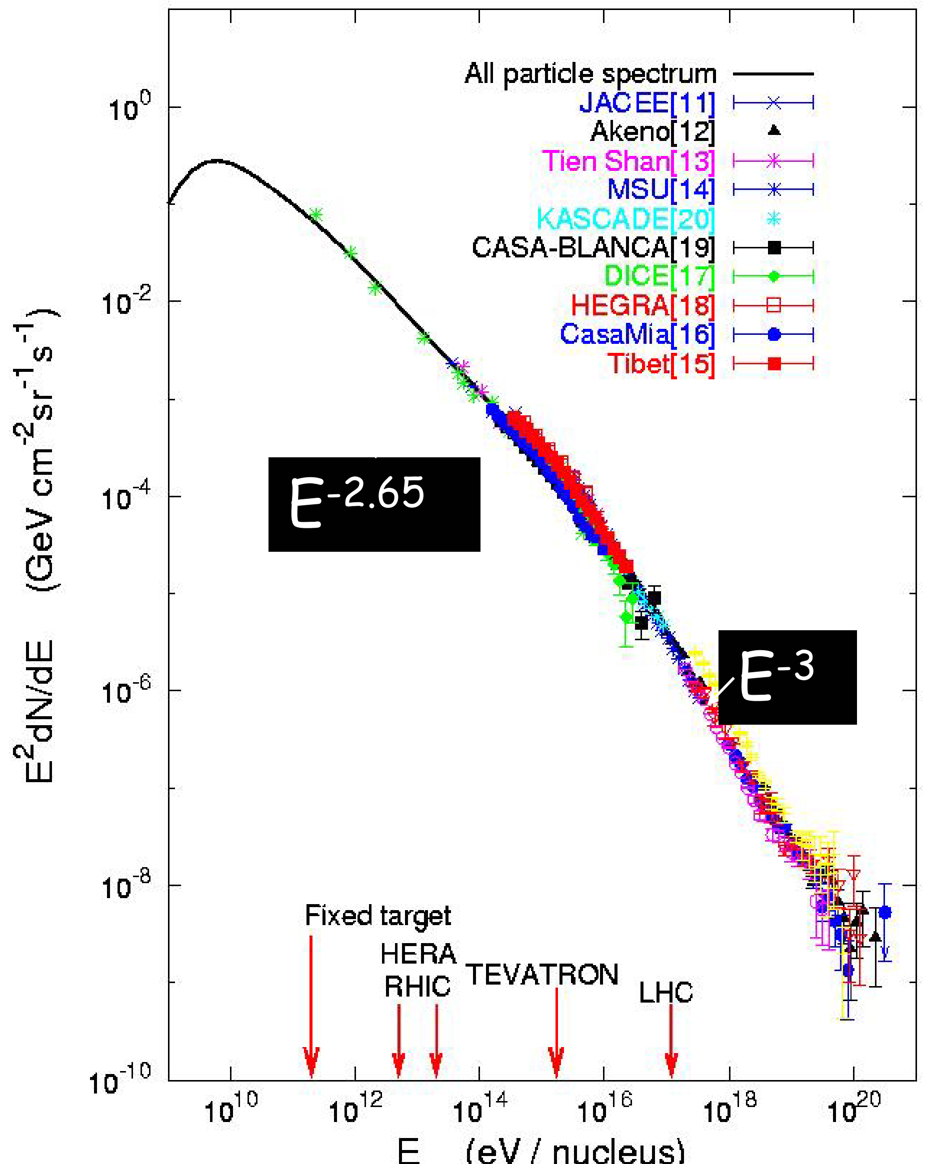
$E > 10^{15}$ eV

The beginning of Particle Physics !

1930-50 the cosmic radiation provided a natural high energy beam allowing to study sub-nuclear particles

1932	◆ Positon ⇒ antimatter!
1936	◆ Muon
1947	◆ Pions : π^0, π^+, π^-
1949	◆ Kaons (K)
1949	◆ Lambda (Λ)
1952	◆ Xi (Ξ)
1953	◆ Sigma (Σ)

Cosmic ray energy spectrum



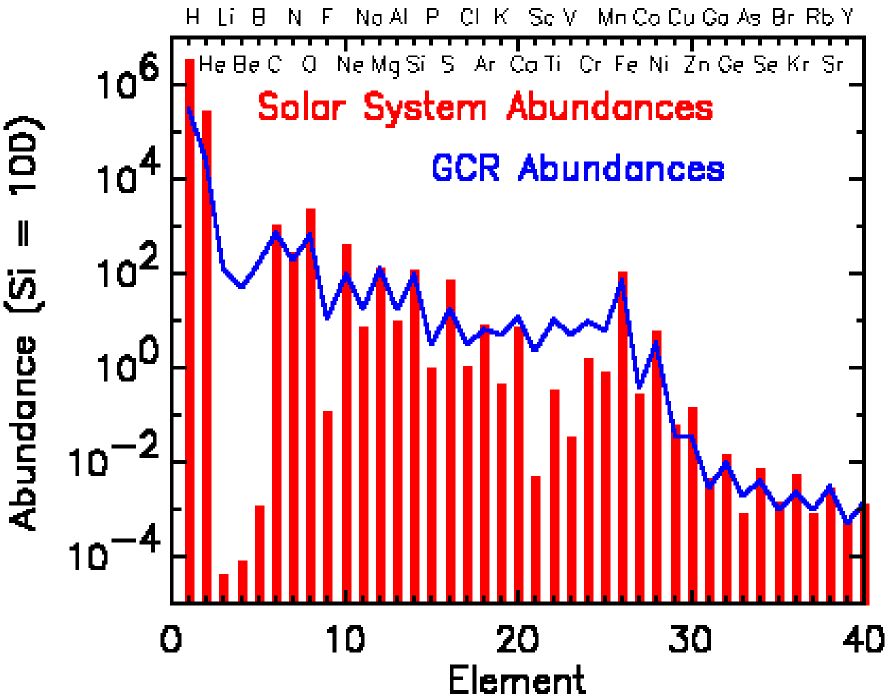
>10^{12} eV: 1 per (m^2 second sr)

>10^{16} eV: 1 per (m^2 year sr)

>10^{19} eV: 1 per (km^2 year sr)

>10^{20} eV: 1 par (km^2 century sr)

Cosmic ray composition



- Composition (at ~GeV):

  85% H (p)

  12% He (α)

  1% heavier nuclei

  2% $e^{\pm}$ (≥90% e^-)

  10^{-5}-10^{-4} antiprotons.

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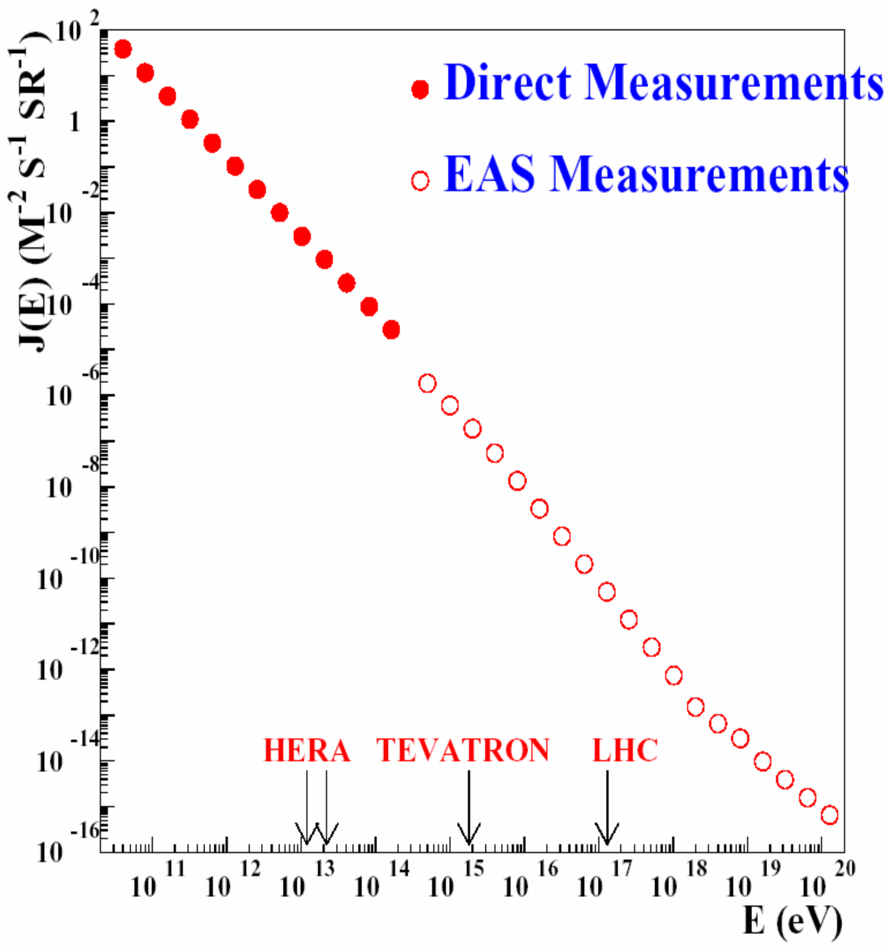
Observations of Cosmic Rays

- Direct detection : Balloon and Satellite Experiments

Direct detection: balloons and satellites

At $<10^{14}$ eV: flux is large enough to allow direct measurements on balloons, satellites, shuttle missions

At $> 10^{17}$ eV: flux $< 10^{-10}$ /m^{2}sr s
a 1m^2, 2π sr detector sees < 1 event / 50 yrs !



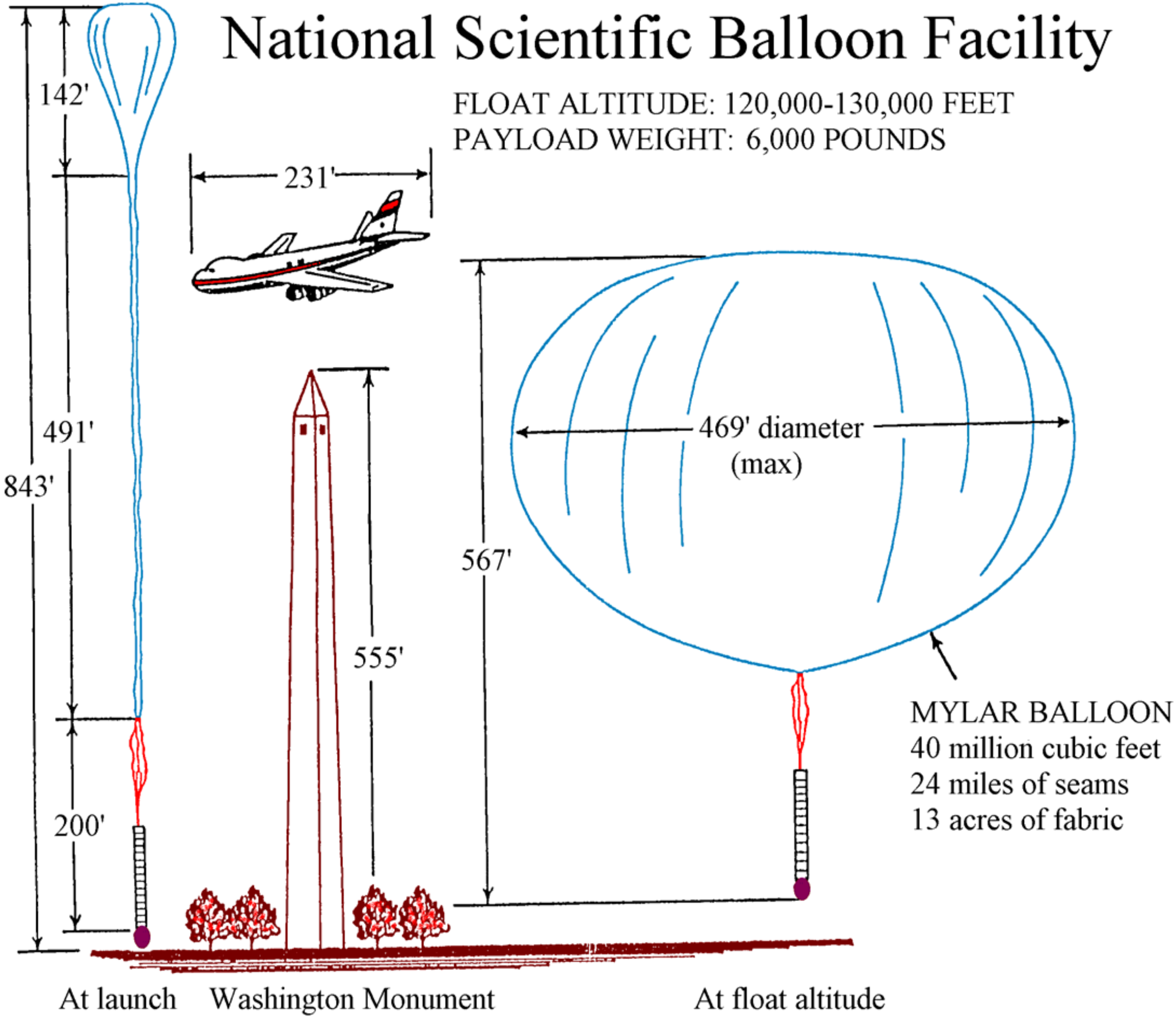
Experimental Goals

- Antimatter: Positrons, Antiprotons : Primary or secondary ?
- Searches for heavy antimatter (e.g., Anti-Helium)
- Composition of Cosmic Rays (Z, A)
- Propagation

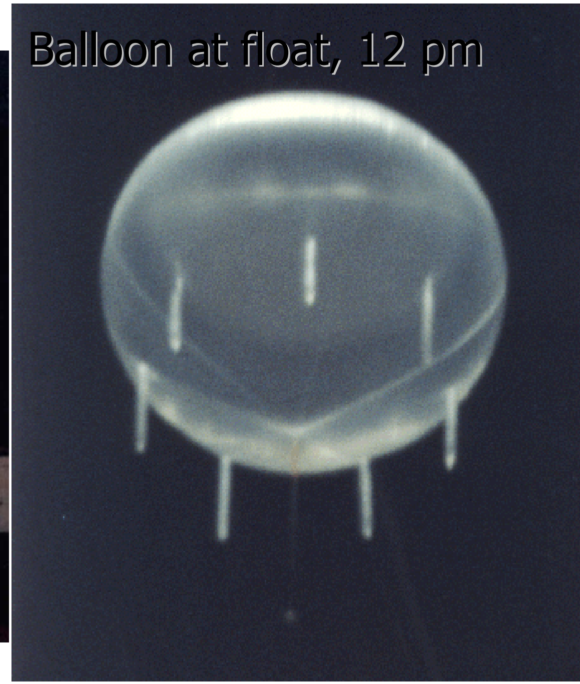
- Primary p, e^- produced at CR acceleration sites (e.g. supernova shocks);
- Secondary $e^\pm$ produced in equal numbers in the ISM:
  CR nuclei + ISM $\Rightarrow \pi^\pm \rightarrow \mu^\pm \rightarrow e^\pm$;
- Secondary pbars also produced in the ISM;

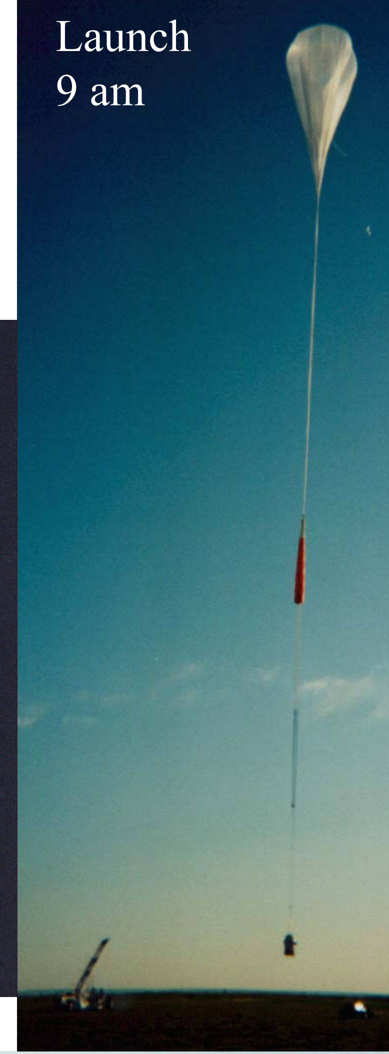
National Scientific Balloon Facility

FLOAT ALTITUDE: 120,000-130,000 FEET
PAYLOAD WEIGHT: 6,000 POUNDS



Scientific Ballooning

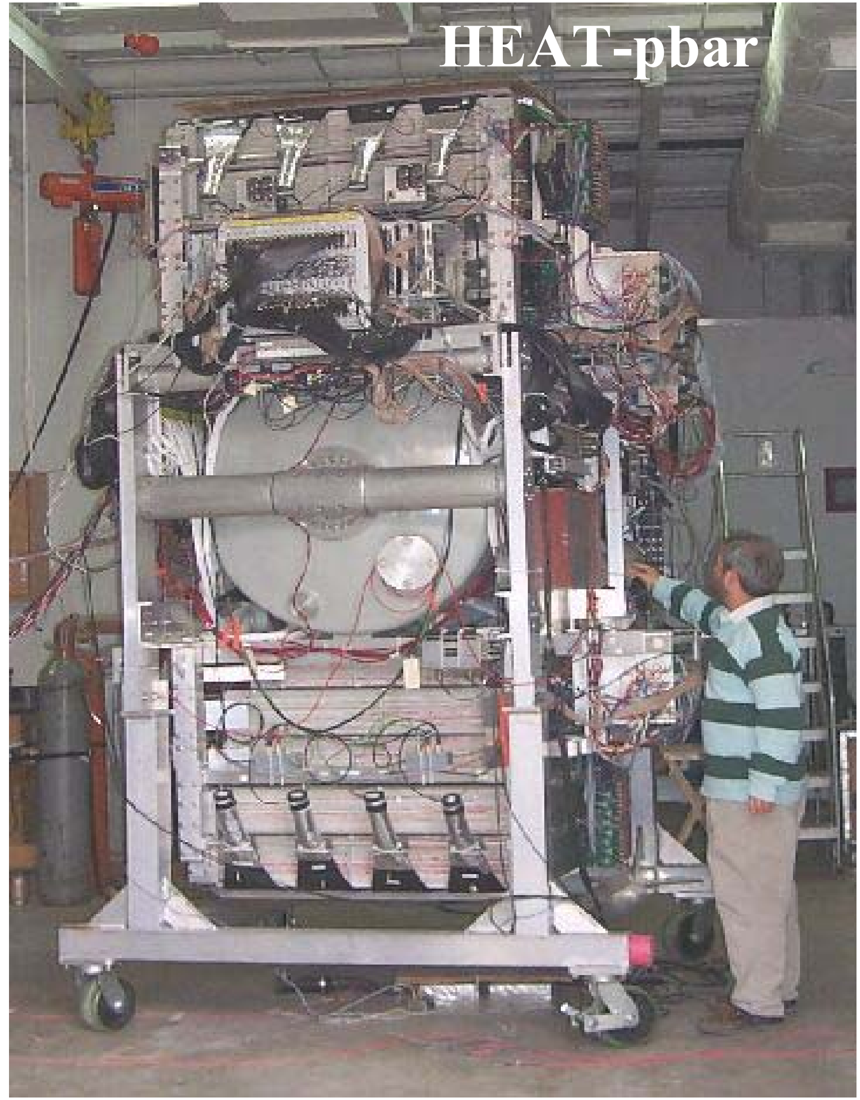




HEAT-pbar (High Energy Antimatter Telescope)

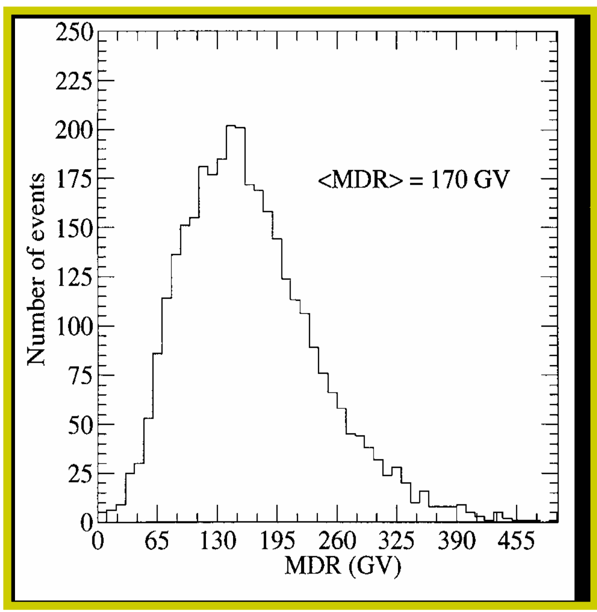
Complex detectors

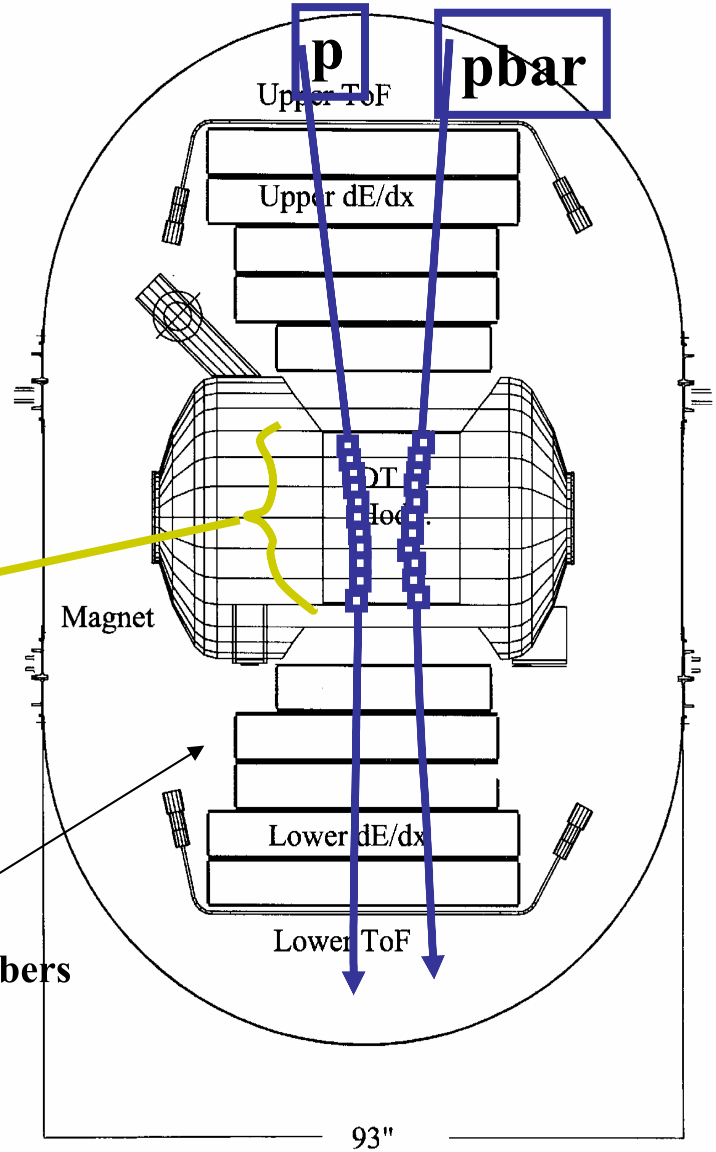
- Superconducting Magnet Spectrometer with Drift Tube Hodoscope (DTH), Multiple Ionization (dE/dx) Detector and Time-of-Flight (TOF) system.
- 1) Jun. 2000 flight from Ft. Sumner, NM (22 hour flight)
  2) May 2002 flight from Ft. Sumner, NM (6 hour flight; failed balloon)



Identifying Antiprotons with HEAT-pbar

- Drift Tube Hodoscope:
  - p from amount of bending in B=1T
  - Sign of Z from direction

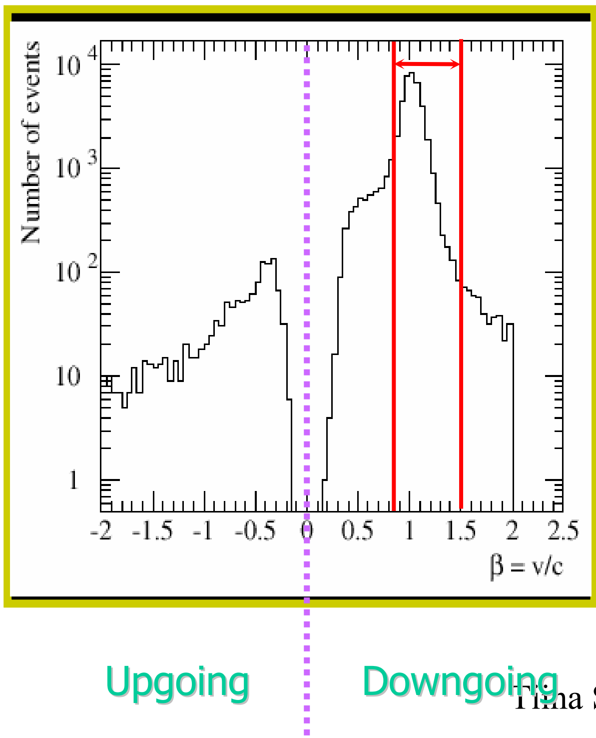


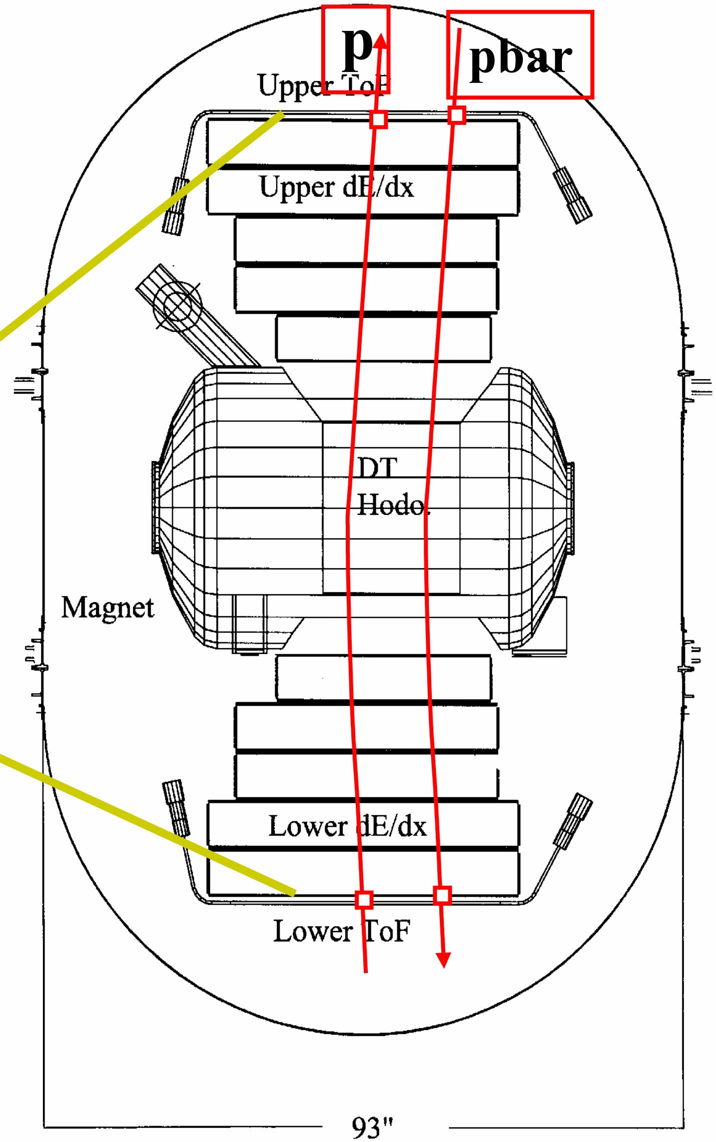


$$\mathrm{MDR} = \frac{3 \cdot d}{\sigma}\sqrt{(N+4)/720}\int \mathbf{B} \bullet \mathbf{dl}$$

Identifying Antiprotons with HEAT-pbar

Up going proton (albedo particles) looks like down going antiproton -> Need to know start and stop in the time-of-flight



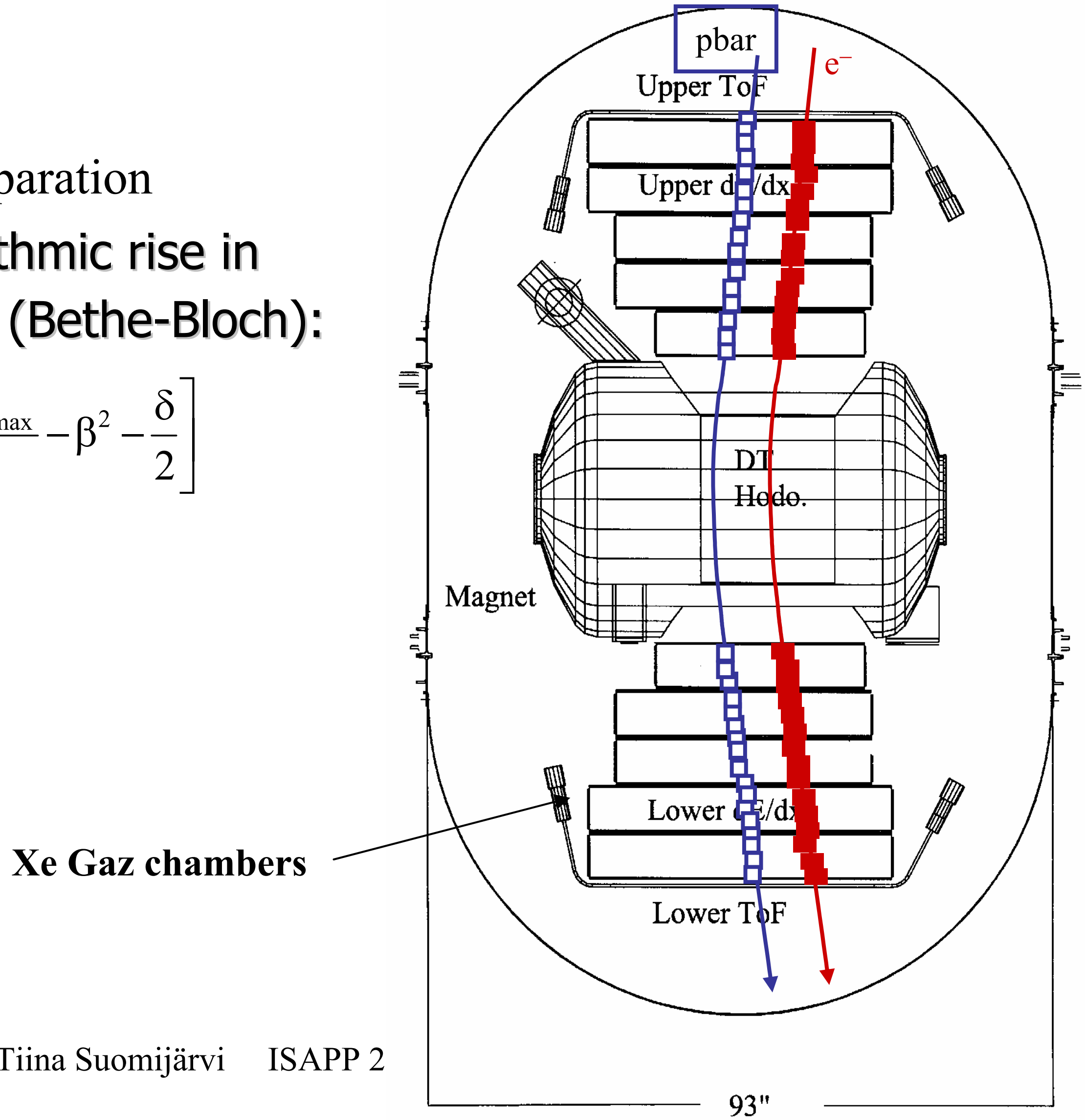


Identifying Antiprotons with HEAT-pbar

- Multiple dE/dx: p / π-μ / e separation

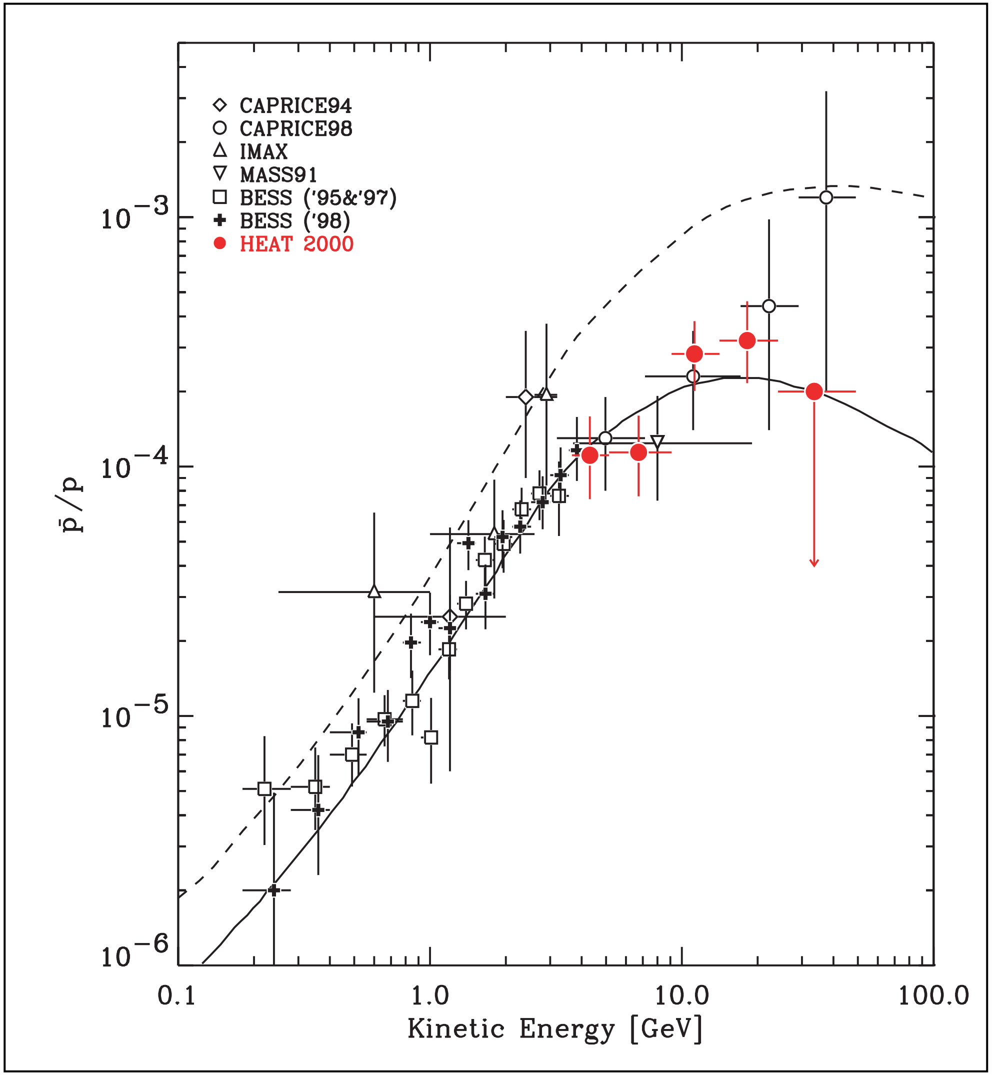
Technique exploits the logarithmic rise in the mean rate of energy loss (Bethe-Bloch):

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta}{2} \right]$$



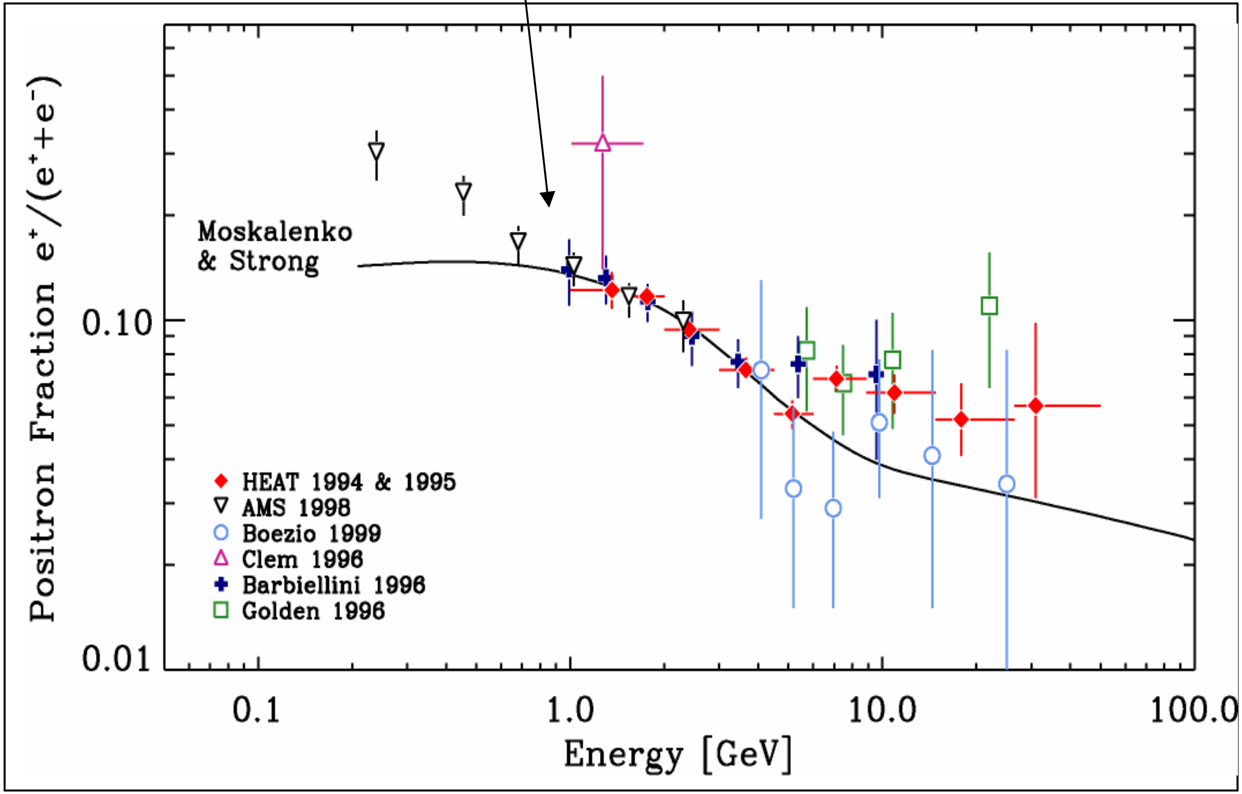
Experimental Results

- BESS, IMAX, MASS, CAPRICE and HEAT data in agreement with secondary production expectations



Positron Fraction since 1995

Effects of Solar modulation below GeV



- New detailed model predictions of e^+, pbar, γ production and propagation;
- Results much closer to secondary production expectations.

Outlook

- Continuing balloon spectrometer measurements: BESS, HEAT.
- New space experiments:
  - PAMELA (Satellite, 2004 launch from Baikonur, 3 year mission, 0.4–200 GeV?)
  - AMS (ISS, 2007 launch ? on STS, 3 year mission, 0.1 – 200 GeV?).

PAMELA   Russian-Italian Mission
2004 Baikonur launch
3 yrs: ~ 30 × balloon exposure

AMS
2007 STS launch ?
3 yrs: ~ 900 × balloon exposure