Astroparticle – laboratory
Measurement of the Positron Fraction in the Cosmic Rays with the PAMELA Experiment

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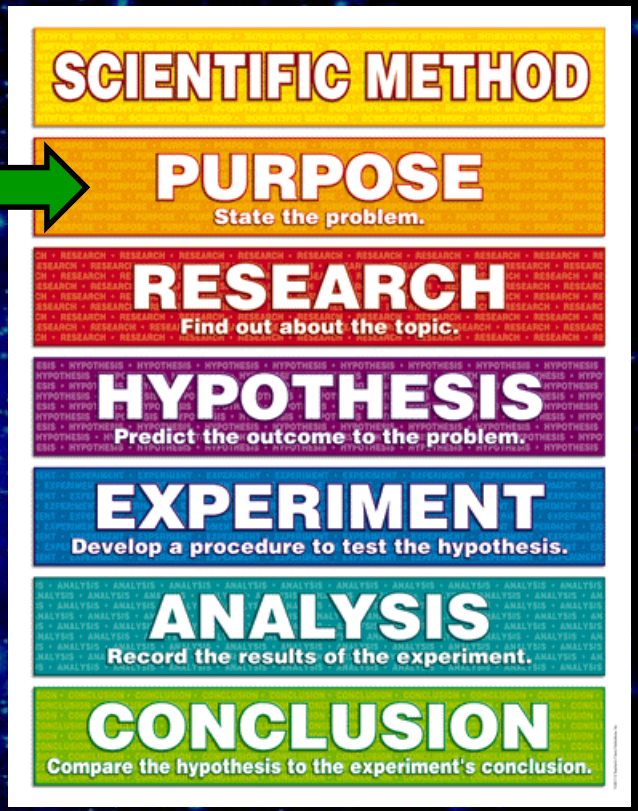
On behalf of the PAMELA collaboration

C++ course 2016/2017 – Università degli Studi di Trieste

~~***December 21st 2012***~~

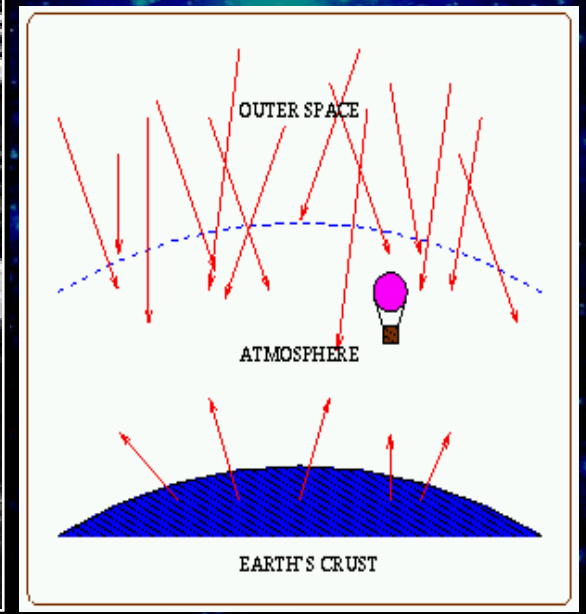
Presentation outline

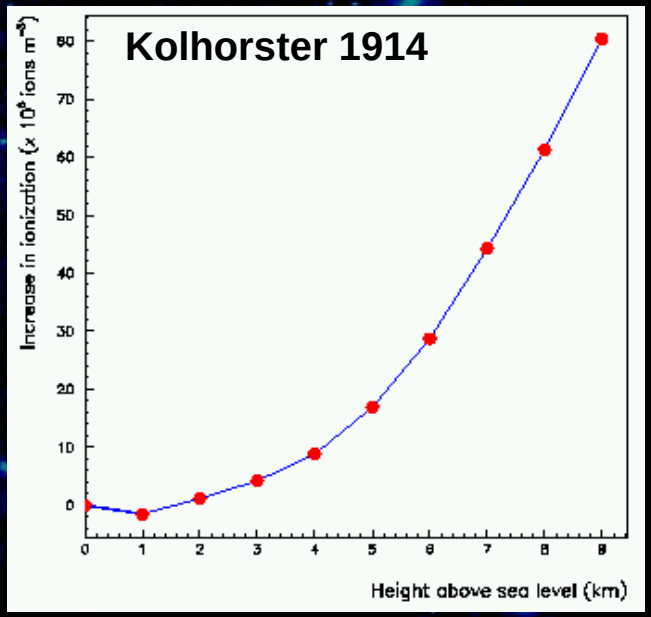
- Introduction
- Comic rays
- PAMELA apparatus
- Positron selection
- Positrons with PAMELA



The discovery of cosmic rays

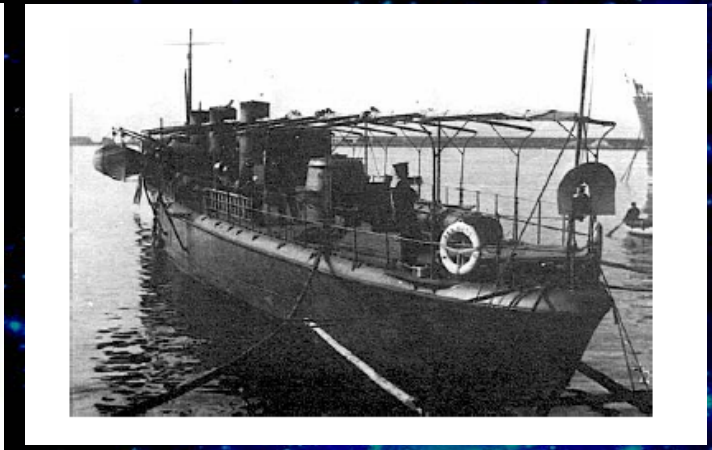
- Victor Hess ascended to 5000 m in a balloon in 1912
- ... and noticed that his electroscope discharged more rapidly as altitude increased
- Not expected, as background radiation was thought to be terrestrial
- NPP 1936 (with Carl 'e+' Anderson)





The discovery of cosmic rays

Domenico Pacini
1878 – 1934



- **Domenico Pacini in 1911 placed his electroscopes underwater...**
- **... and noticed that his electroscopes discharged more slowly as sea depth increased**

- **He concluded that "*a sizable cause of ionization exists in the atmosphere, originating from penetrating radiation, independent of the direct action of radioactive substances in the soil*" [Il Nuovo Cimento VI/III, 93 (1912) - arXiv: 1002.1810v1]**

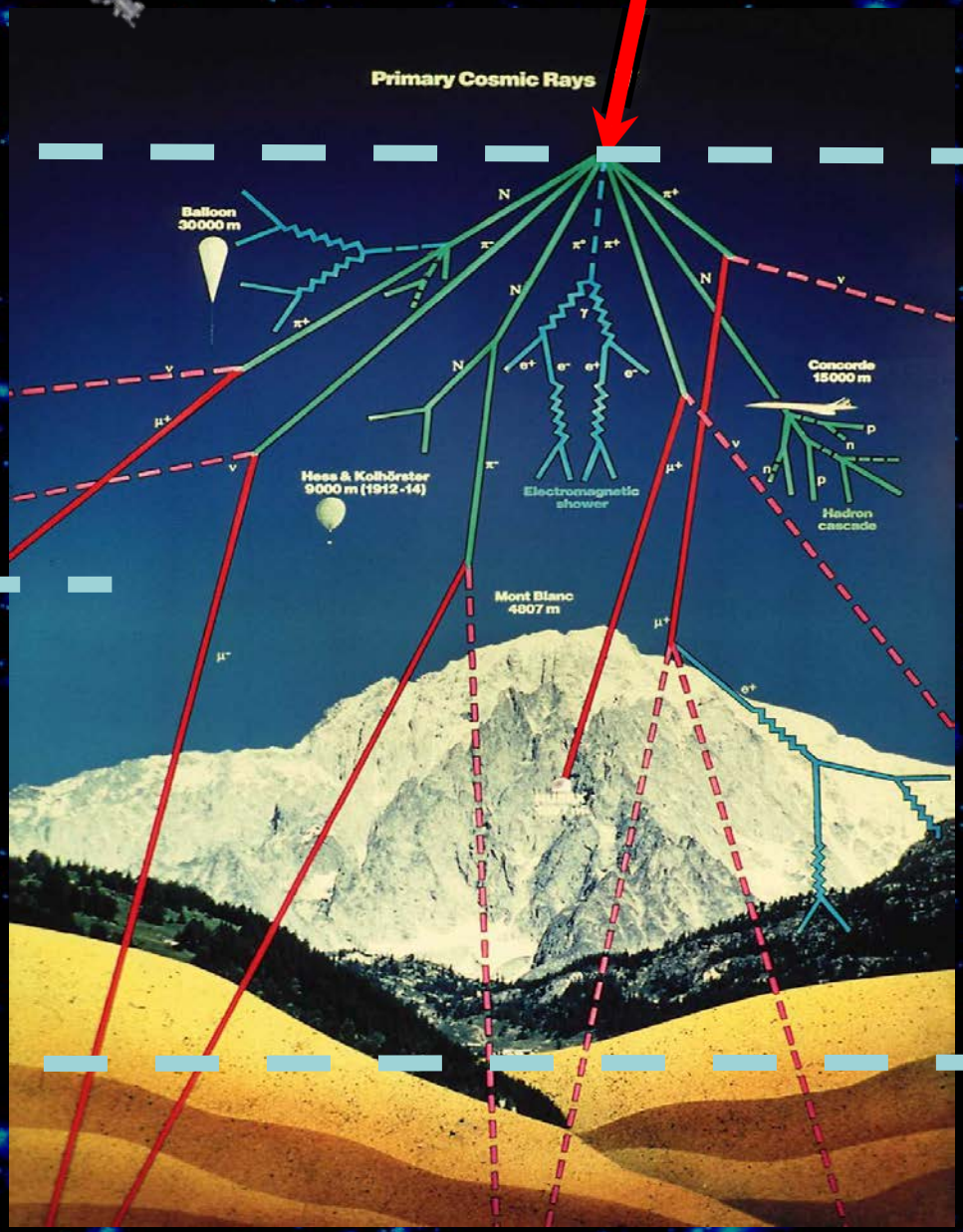
My short paper "Die Frage der durchdring. Strahlung ausserterrestrischen Ursprunges" is a report of a public conference, and therefore has no claim of completeness. Since it reported the first balloon measurements, I did not provide an in-depth explanation of your sea measurements, which are well known to me. Therefore please excuse me for my unkind omission, that was truly far from my aim ... - V. Hess [arXiv: 1002.2888v2]

~500 km

Smaller detectors but long duration - PAMELA!

Top of atmosphere

Cosmic ray

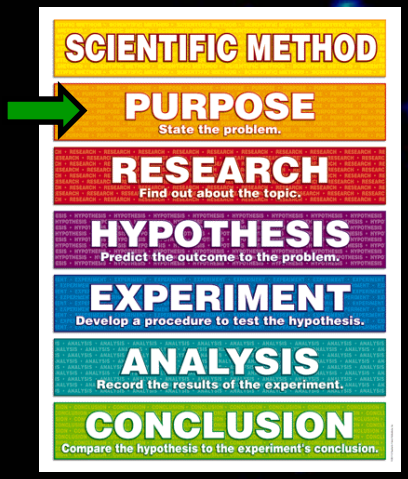


~40 km

Large detectors but short duration. Atmospheric overburden ~5 g/cm^2.

Almost all data on cosmic antiparticles from here.

~5 km



Ground

0 m

Cosmic Rays

p, He, C
N, O

e^-

γ_s

ISM gas

p, He, C,
N, O, Li,
Be, B, ...

π^+, π^- decay

π_0 decay

γ_s

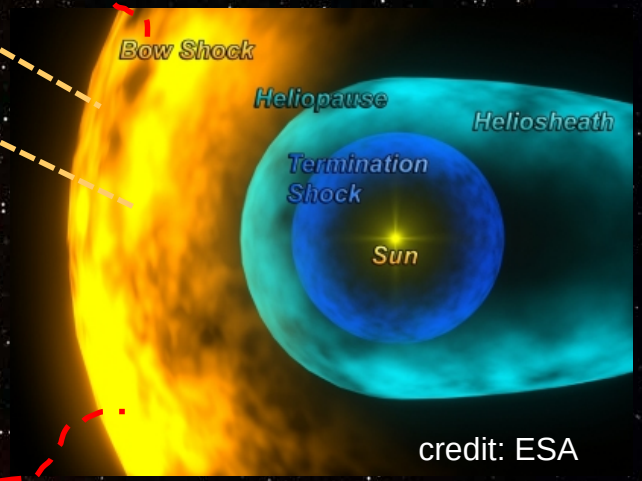
$\bar{p}$

e^- e^+

γ_s

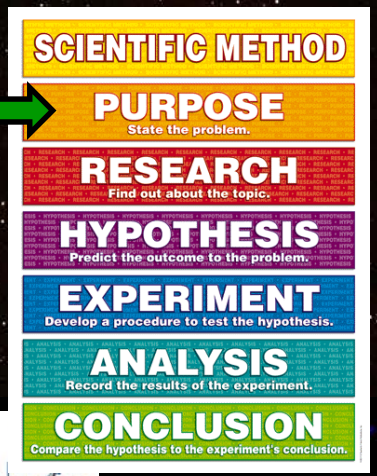
Bremsstrahlung, Synchrotron, Inverse Compton

Solar Modulation, lower interstellar cosmic ray spectra

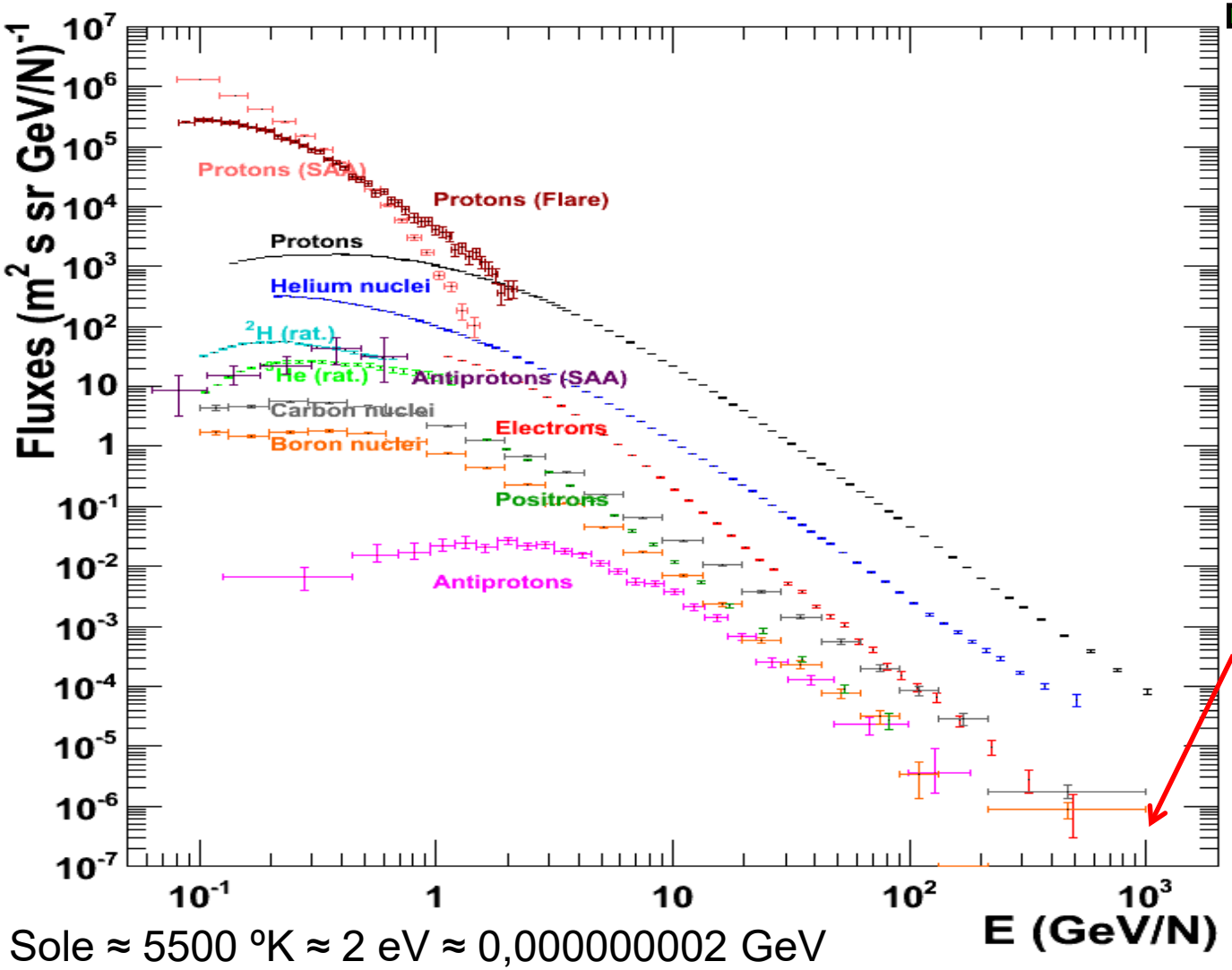


credit: ESA

CR secondary production (pp → X)



PAMELA Fluxes Measurements



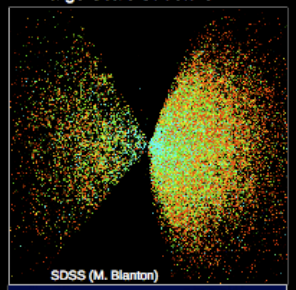
500 mila milioni di volte la temperatura del Sole

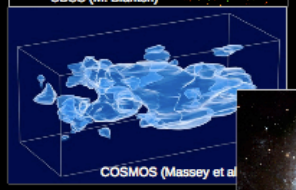
10^9 GeV/N

Sole ≈ 5500 ºK ≈ 2 eV ≈ 0,000000002 GeV

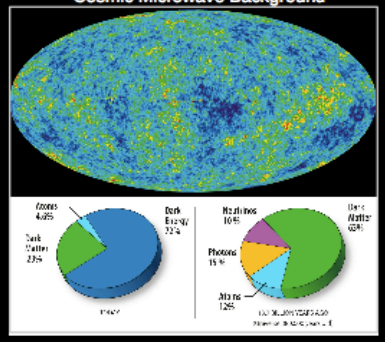
There's evidence for dark matter on many scales...

Large Scale Structure

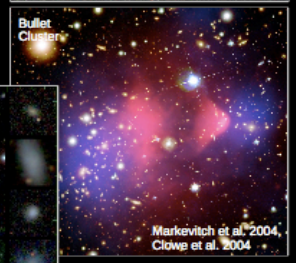




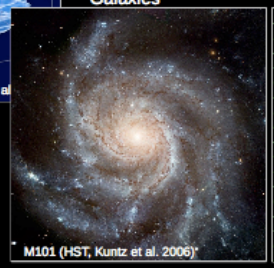
Cosmic Microwave Background



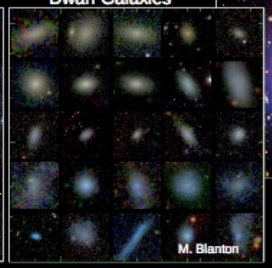
Galaxy Clusters



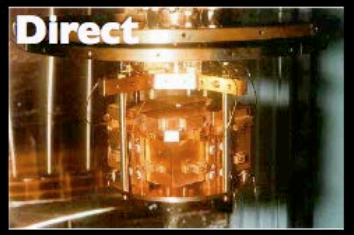
Galaxies



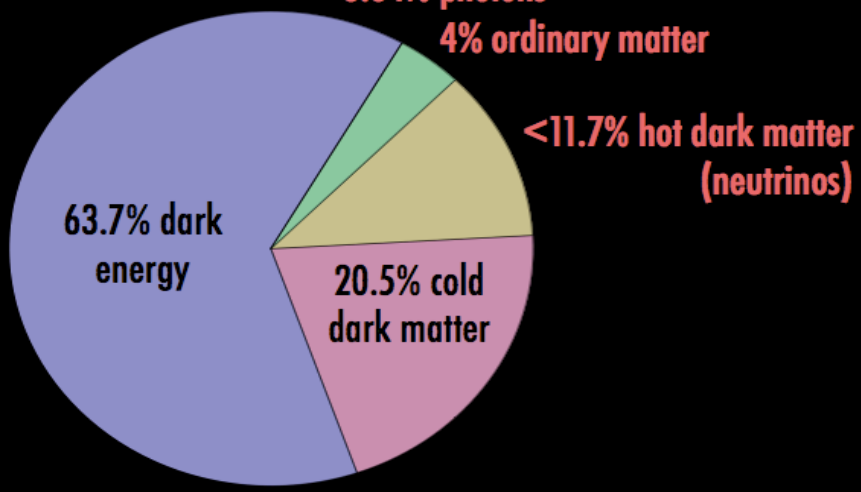
Dwarf Galaxies



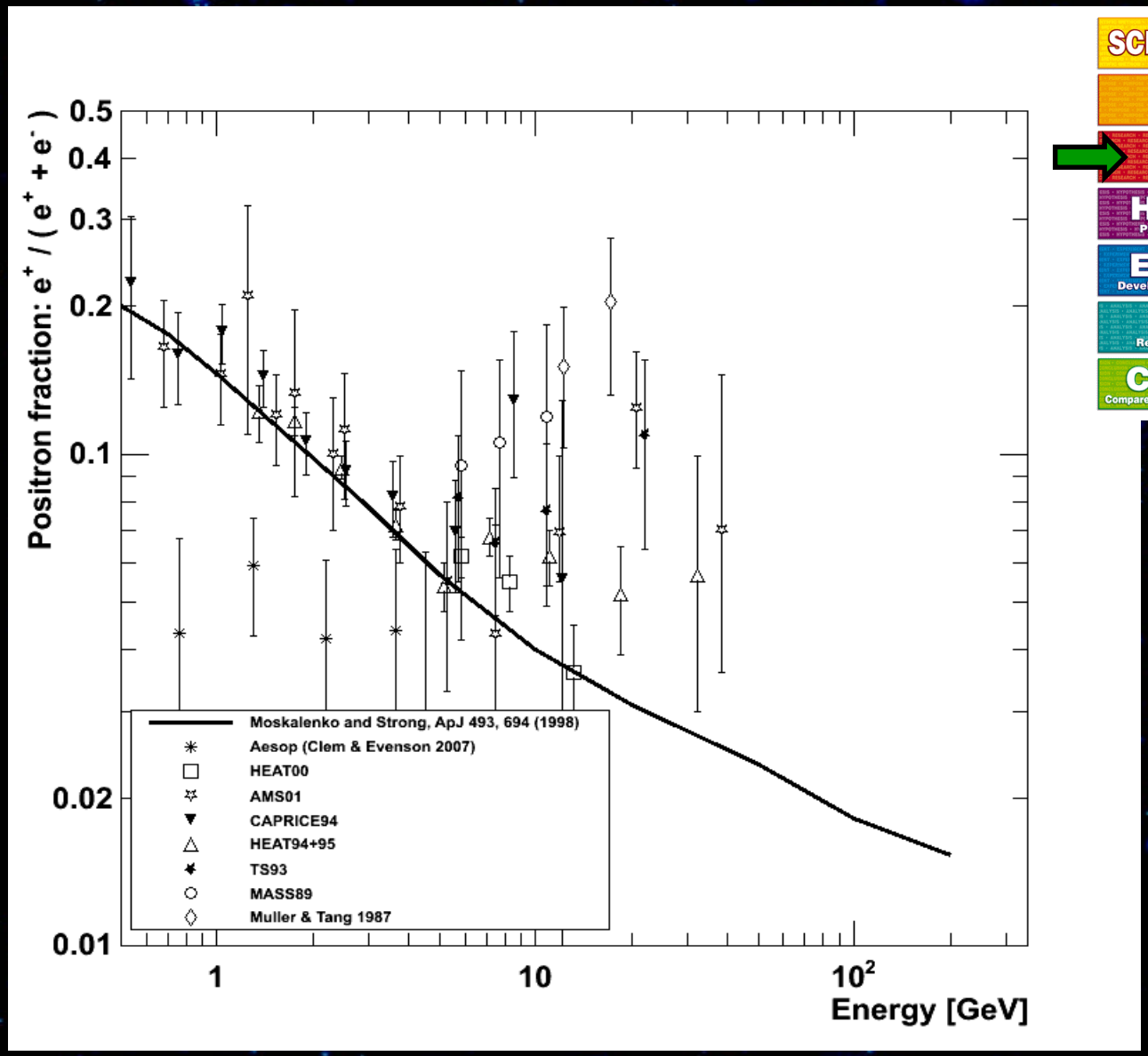
Searches for WIMP Dark Matter

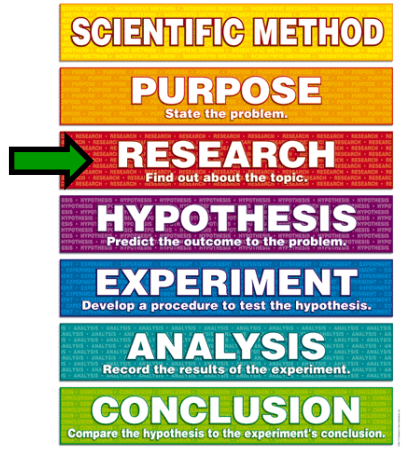


The current content of the Universe

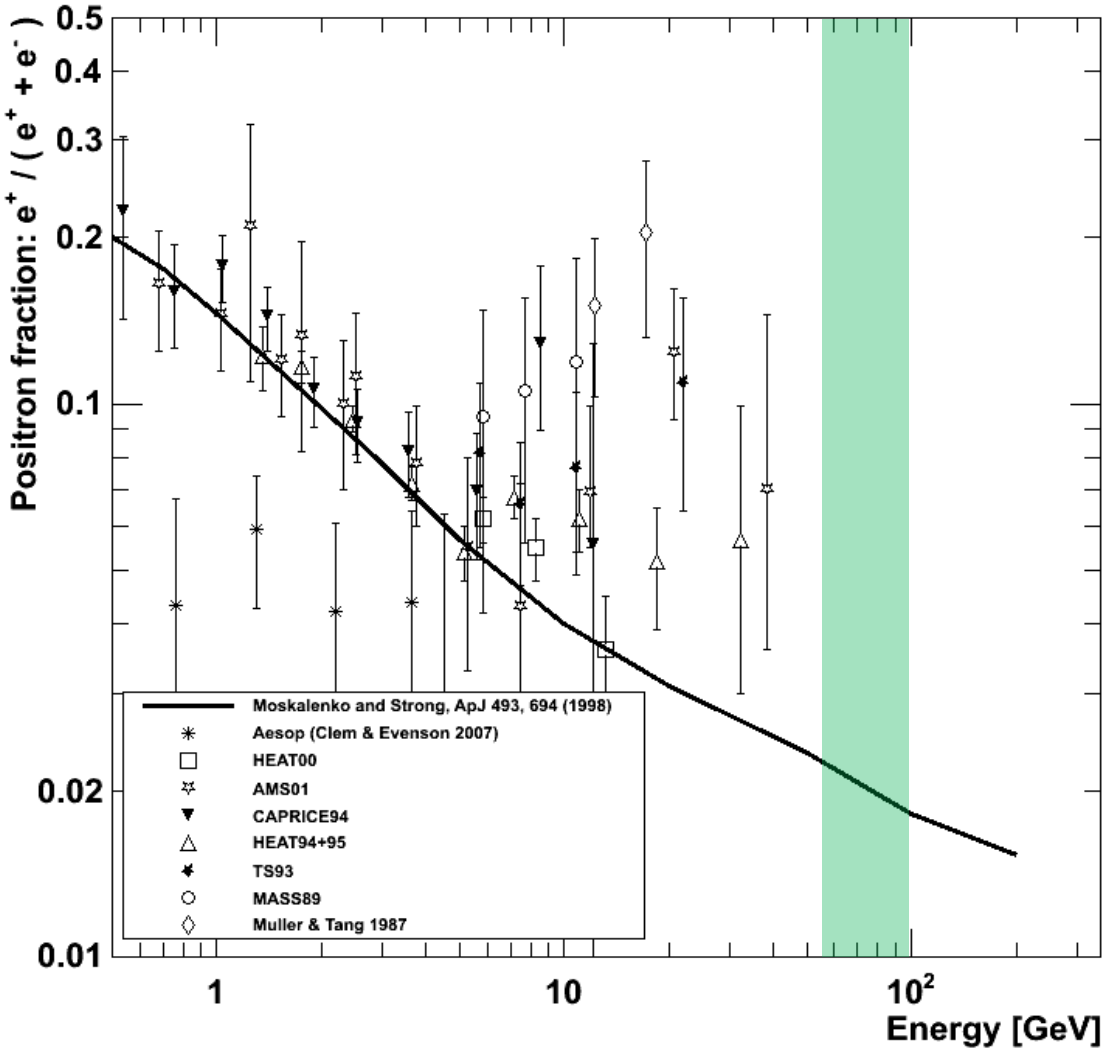


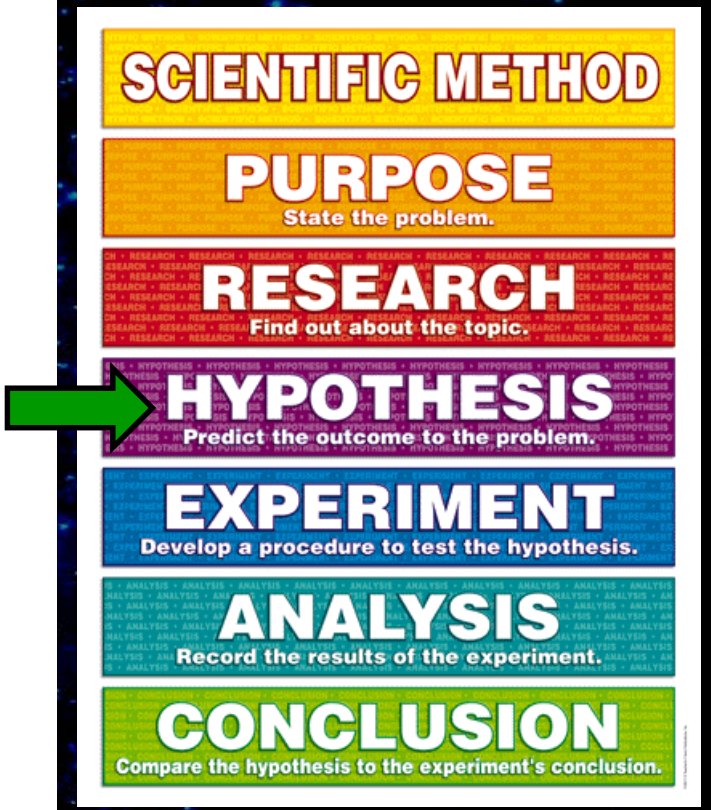
CR Positrons: available data before PAMELA



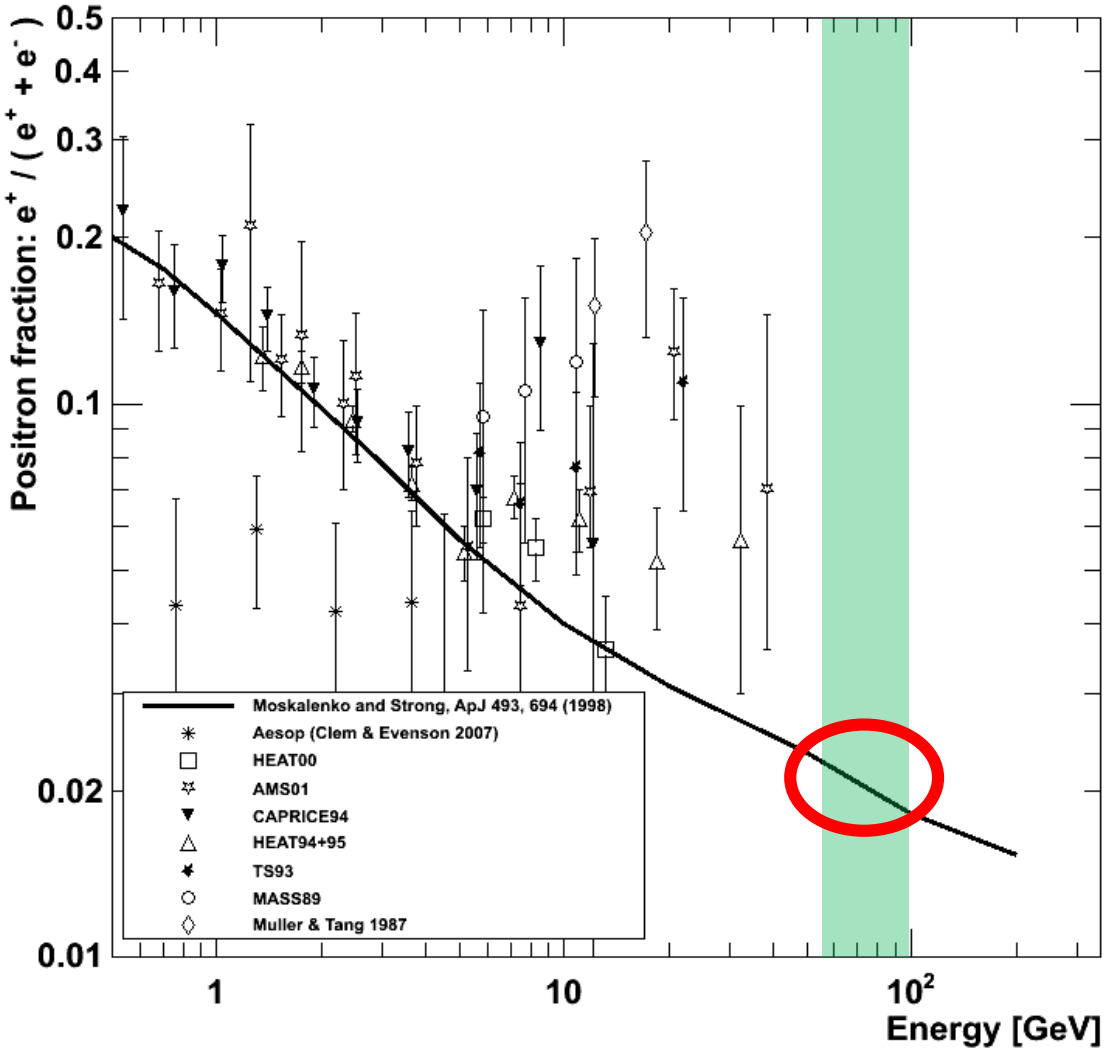


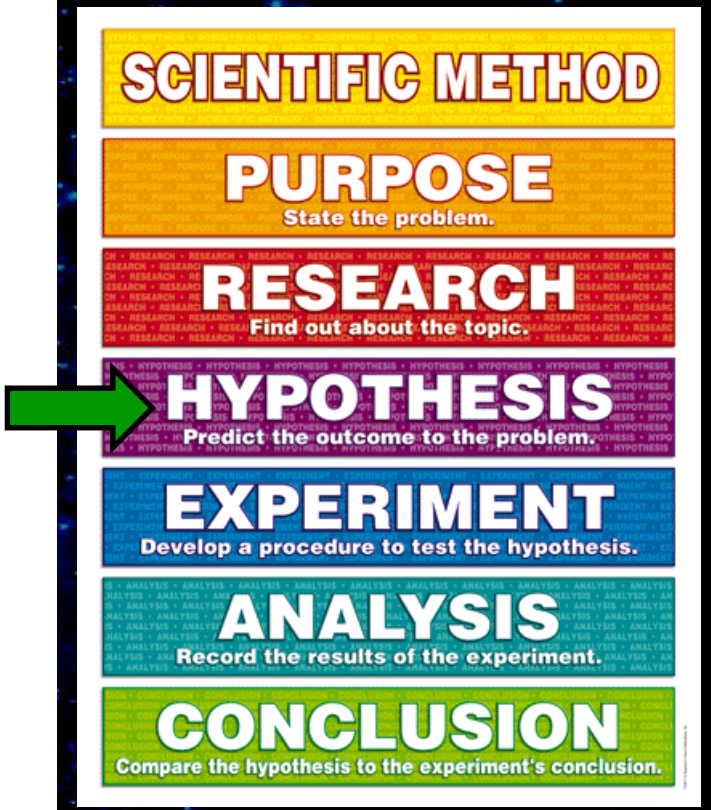
CR Positrons: available data before PAMELA





CR Positrons: available data before PAMELA





PAMELA Collaboration

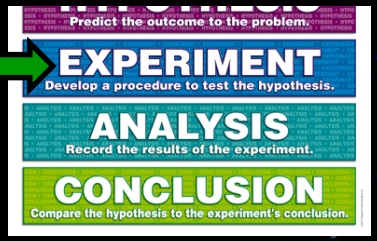
Italy

Bari, Florence, Frascati, Naples, Rome, Trieste, CNR, Florence

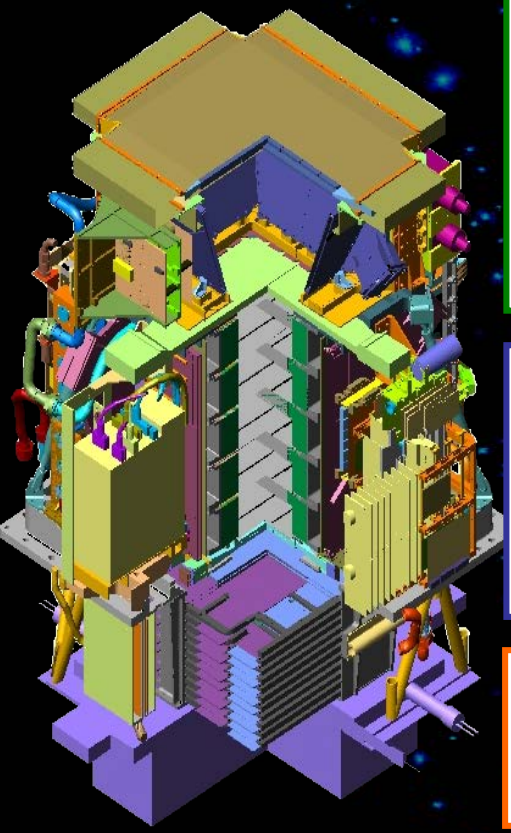
Germany: Siegen

Sweden: KTH, Stockholm

Russia: Moscow / St. Petersburg



PAMELA detectors

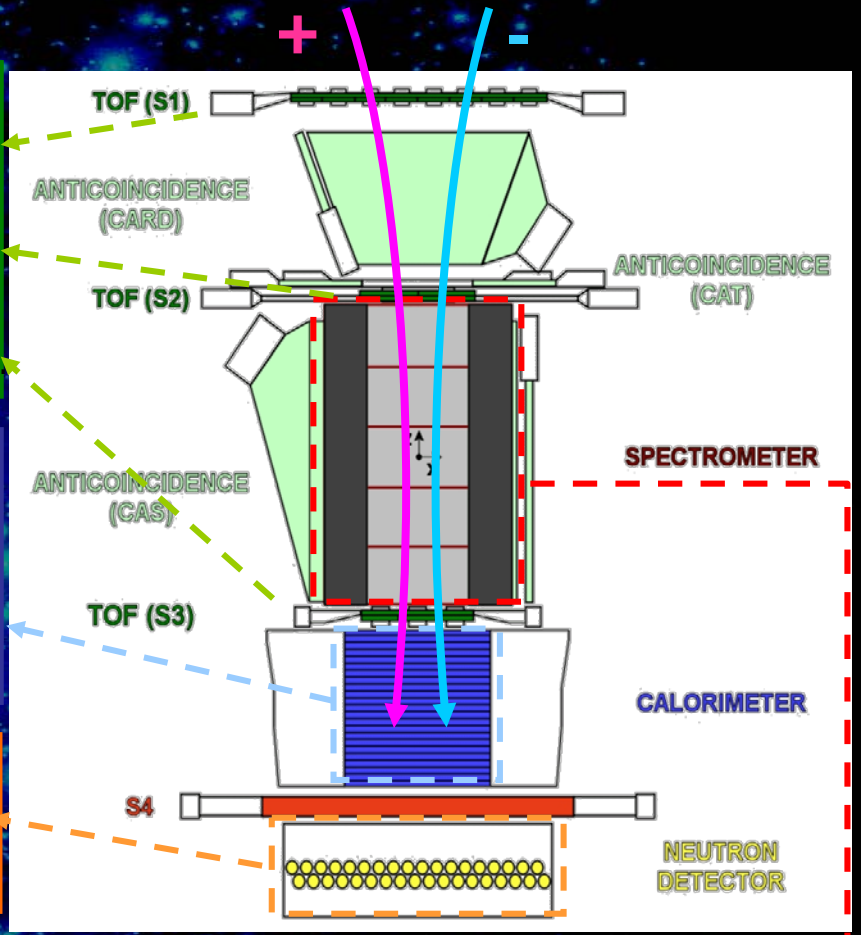


GF: 21.5 cm² sr
Mass: 470 kg
Size: 130x70x70 cm³
Power Budget: 360W

Time-Of-Flight
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX

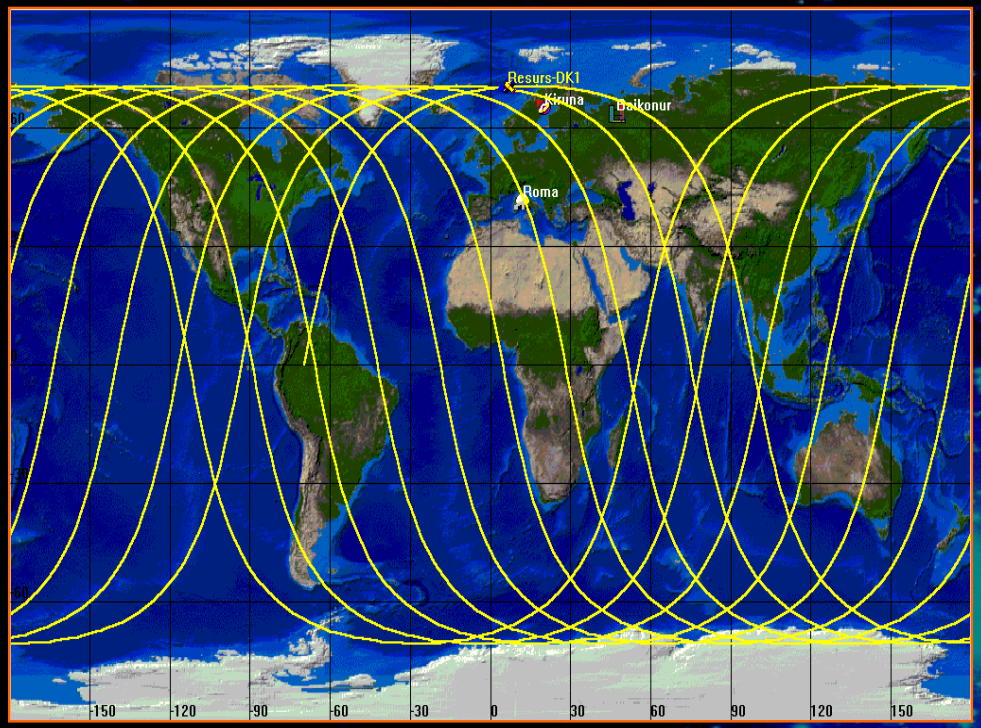
Electromagnetic calorimeter
W/Si sampling (16.3 X_0, **0.6 λ_I**)
- Discrimination e^+ / p, p-bar / e^- (shower topology)
- Direct E measurement for e^-

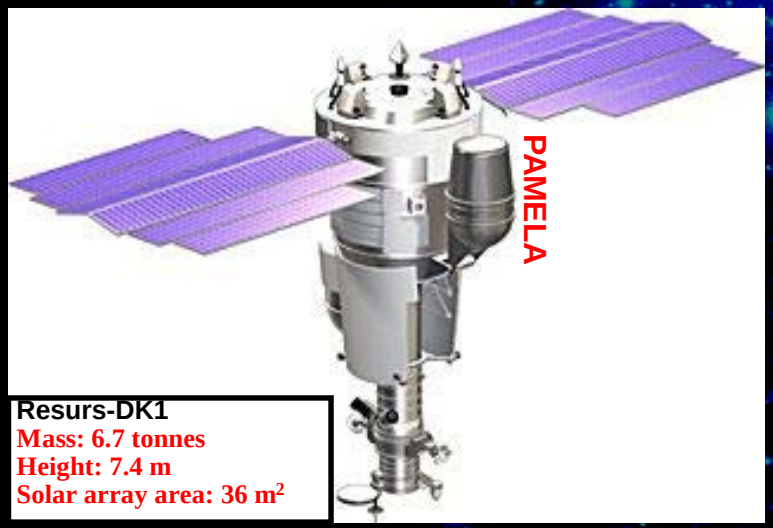
Neutron detector
^{3}He tubes + polyethylene moderator:
- High-energy e/h discrimination



Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- Magnetic rigidity → R = pc/Ze
- Charge sign
- Charge value from dE/dx

Resurs-DK1 satellite and orbit





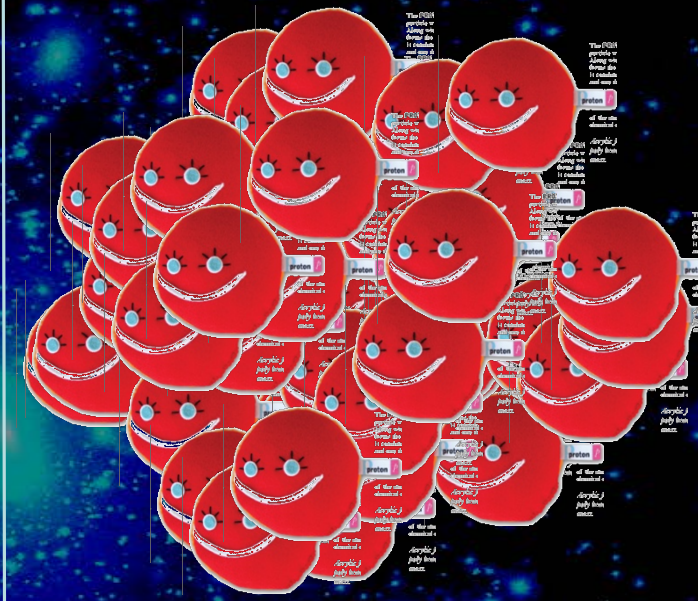
- Resurs-DK1: multi-spectral imaging of earth's surface
- PAMELA mounted inside a pressurized container
- Launch 15/06/2006 - lifetime >3 years (assisted), extended till end of satellite operations
- Data transmitted to NTsOMZ, Moscow via high-speed radio downlink. ~16 GB per day
- Quasi-polar and elliptical orbit (70.0°, 350 km - 600 km) – from 2010 circular orbit (70.0°, 600 km)
- Traverses the South Atlantic Anomaly
- Crosses the outer (electron) Van Allen belt at south pole

Cosmic rays Z=1 particles

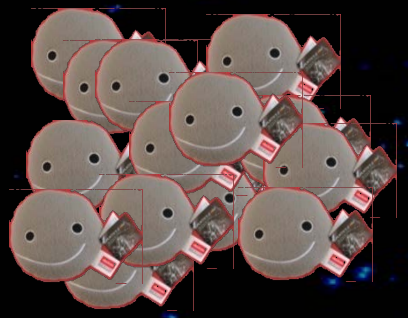
CHARGE ONE NEGATIVE

CHARGE ONE POSITIVE

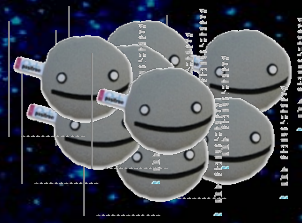
1 $\overline{p}$



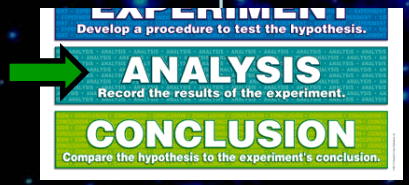
10000 p



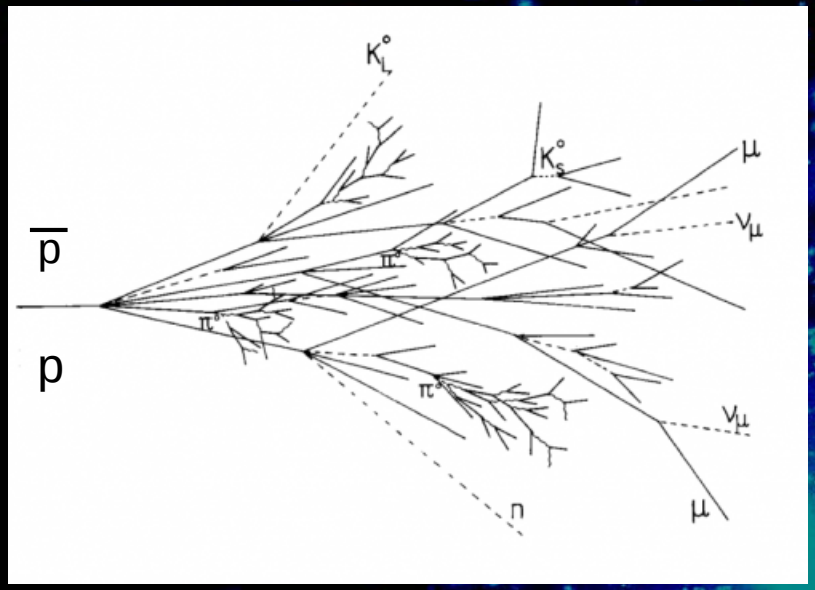
100 e^-



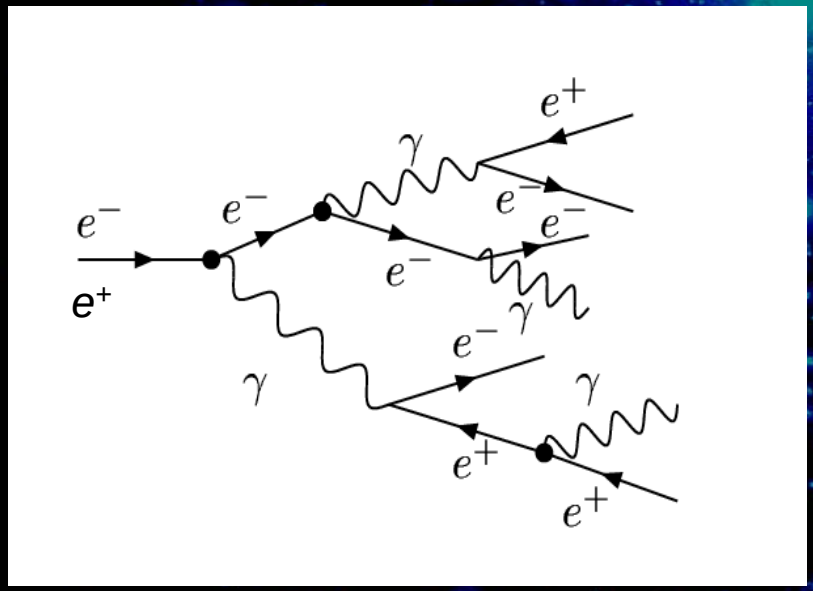
10 e^+



Protons and Electrons showers

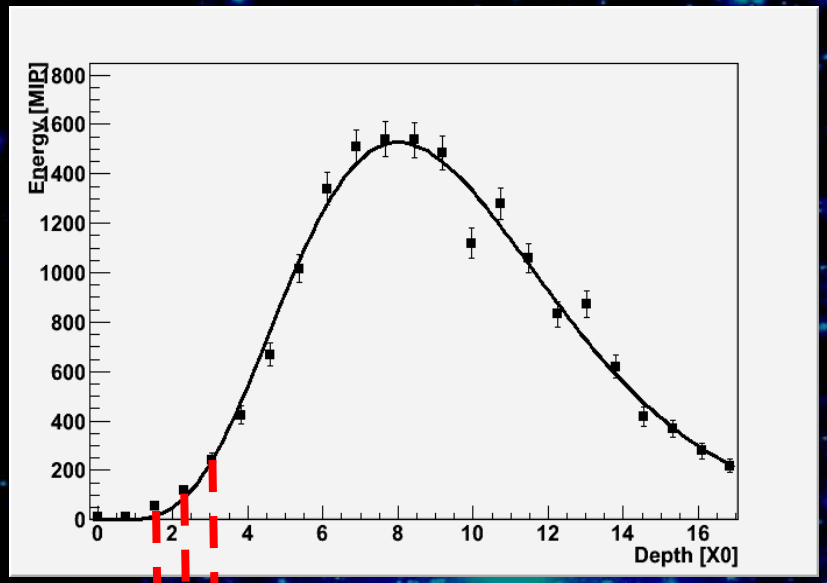


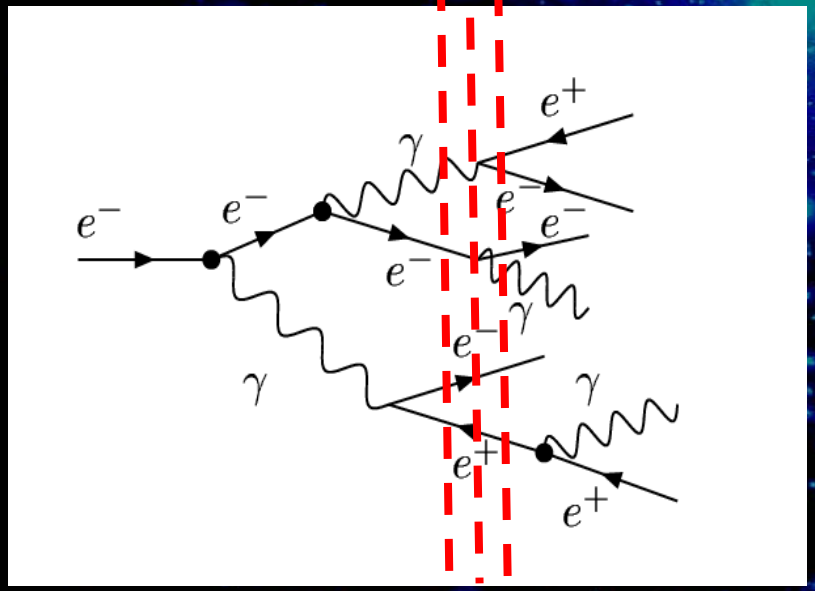
protons and anti-protons:
- deeper interaction
- wide shower
- uneven longitudinal profile
- ≈ 1/3 of primary energy into EM showers



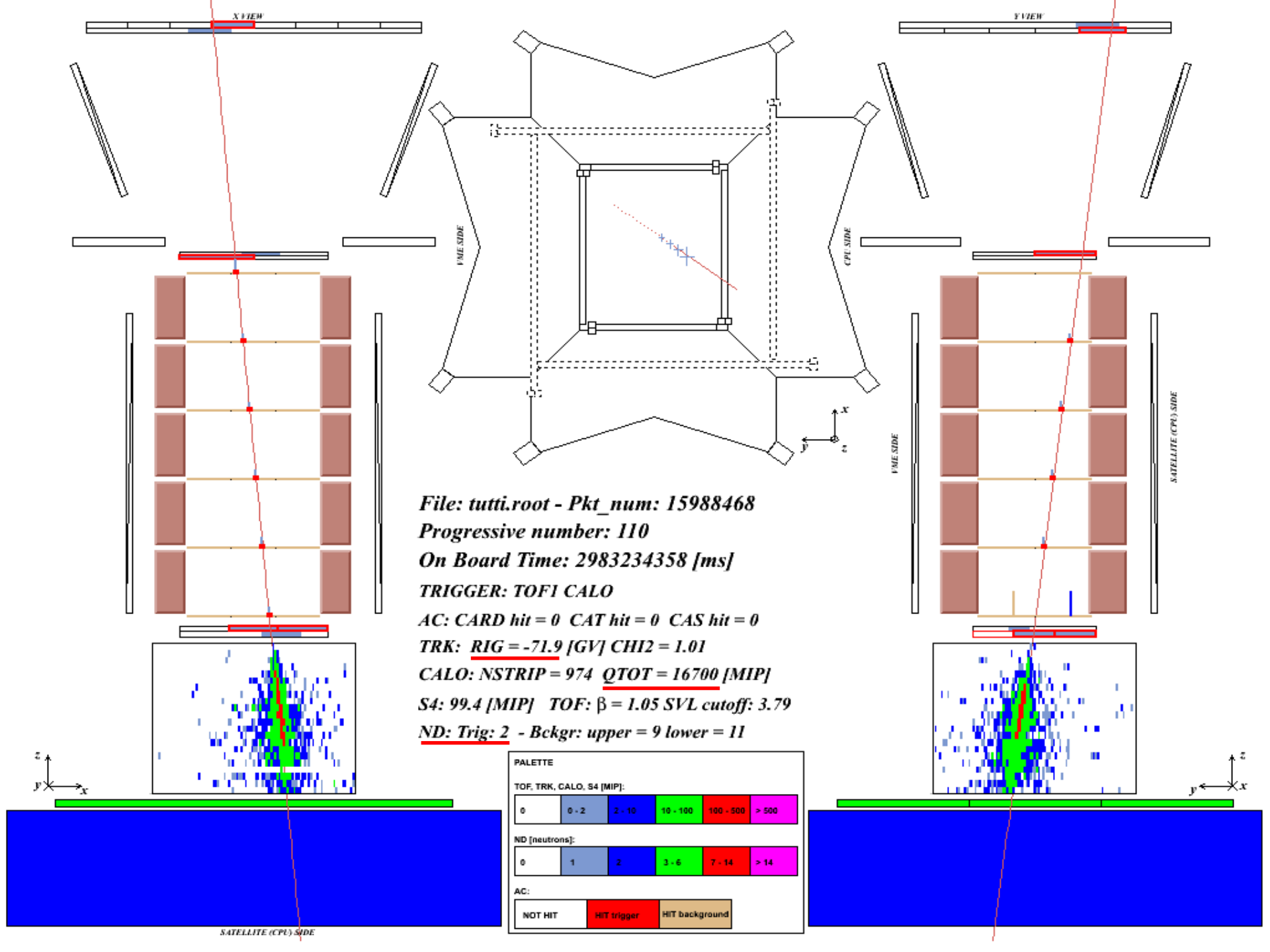
electrons and positrons:
- prompt interaction
- collimated shower
- smooth longitudinal profile
- primary energy proportional to measured energy

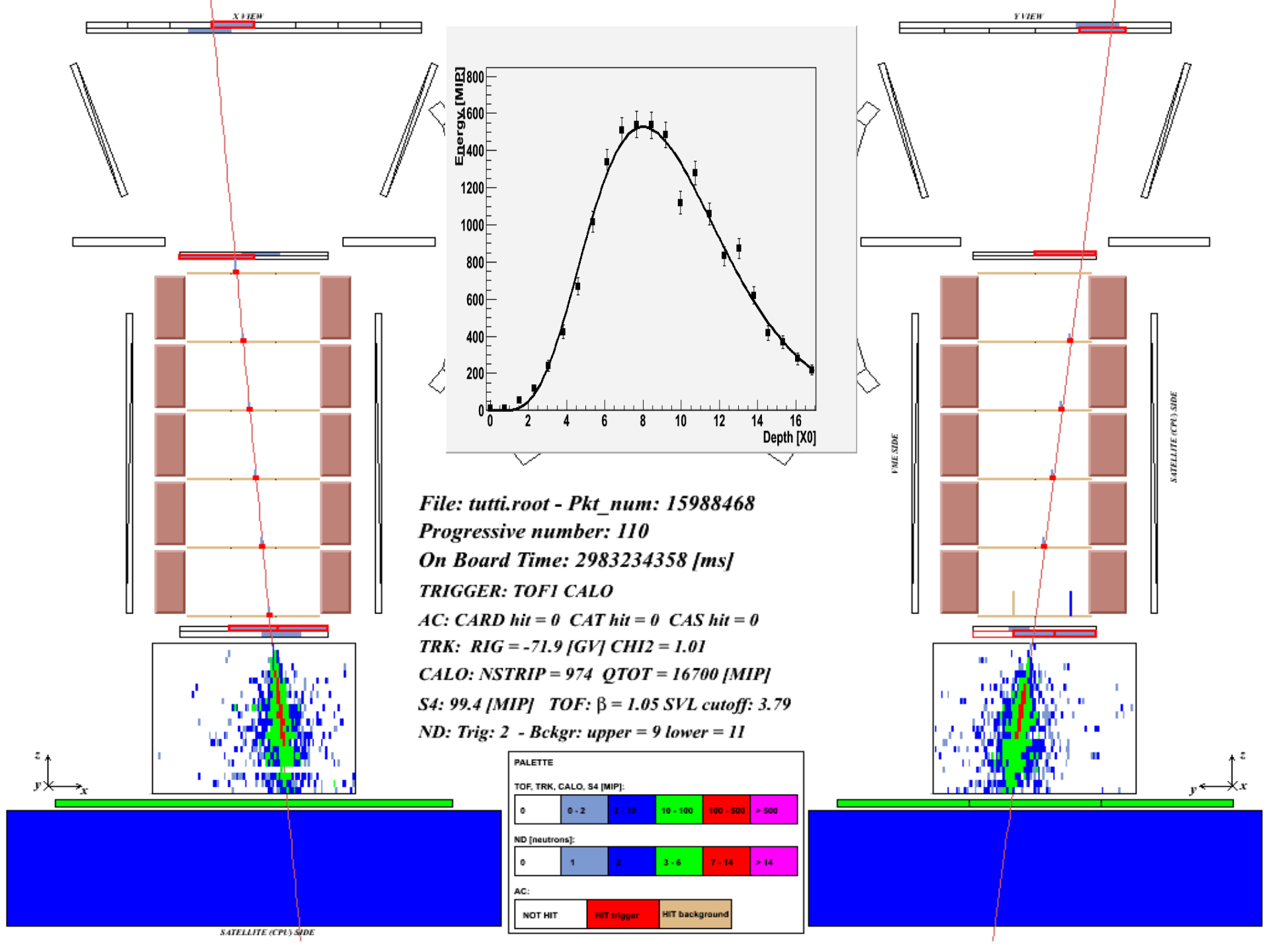
Longitudinal profile





electrons and positrons:
- **prompt interaction**
- **collimated shower**
- **smooth longitudinal profile**
- **primary energy proportional to measured energy**


X VIEW
Y VIEW
VME SIDE
CPU SIDE
VME SIDE
SATELLITE (CPU) SIDE
SATELLITE (CPU) SIDE
File: tutti.root - Pkt_num: 15988468
Progressive number: 110
On Board Time: 2983234358 [ms]
TRIGGER: TOF1 CALO
AC: CARD hit = 0 CAT hit = 0 CAS hit = 0
TRK: RIG = -71.9 [GV] CHI2 = 1.01
CALO: NSTRIP = 974 QTOT = 16700 [MIP]
S4: 99.4 [MIP] TOF: β = 1.05 SVL cutoff: 3.79
ND: Trig: 2 - Bckgr: upper = 9 lower = 11
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background


X VIEW
Y VIEW
Energy [MIP]
Depth [X0]
File: tutti.root - Pkt_num: 15988468
Progressive number: 110
On Board Time: 2983234358 [ms]
TRIGGER: TOF1 CALO
AC: CARD hit = 0 CAT hit = 0 CAS hit = 0
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PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
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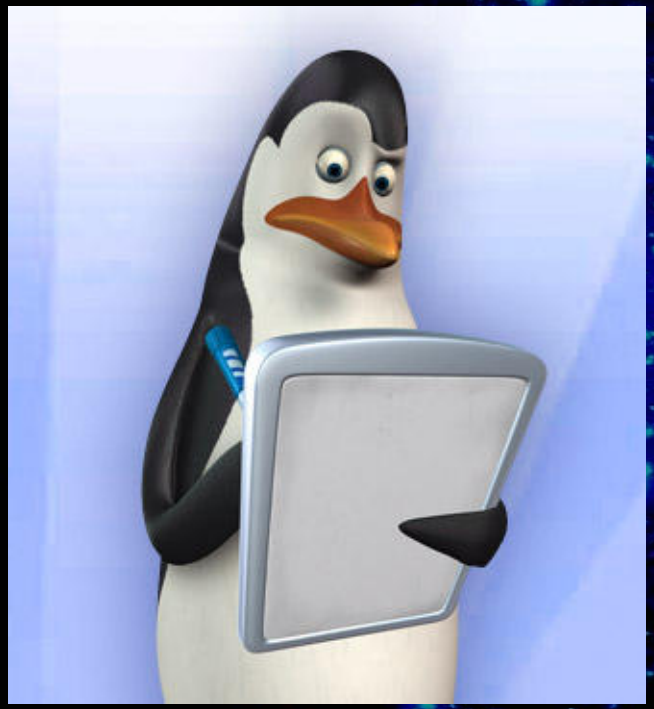
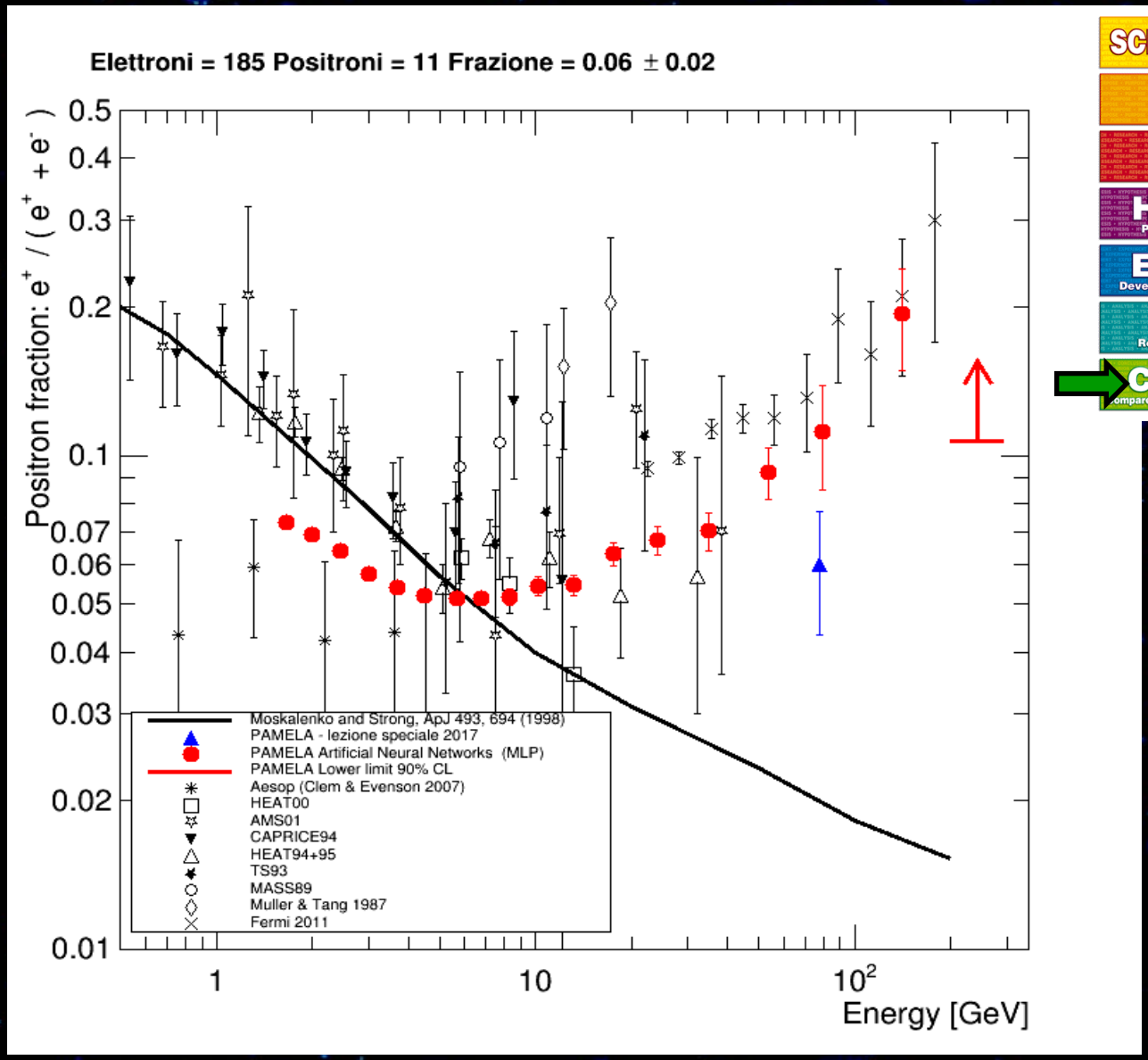
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background
VME SIDE
SATELLITE (CPU) SIDE
SATELLITE (CPU) SIDE

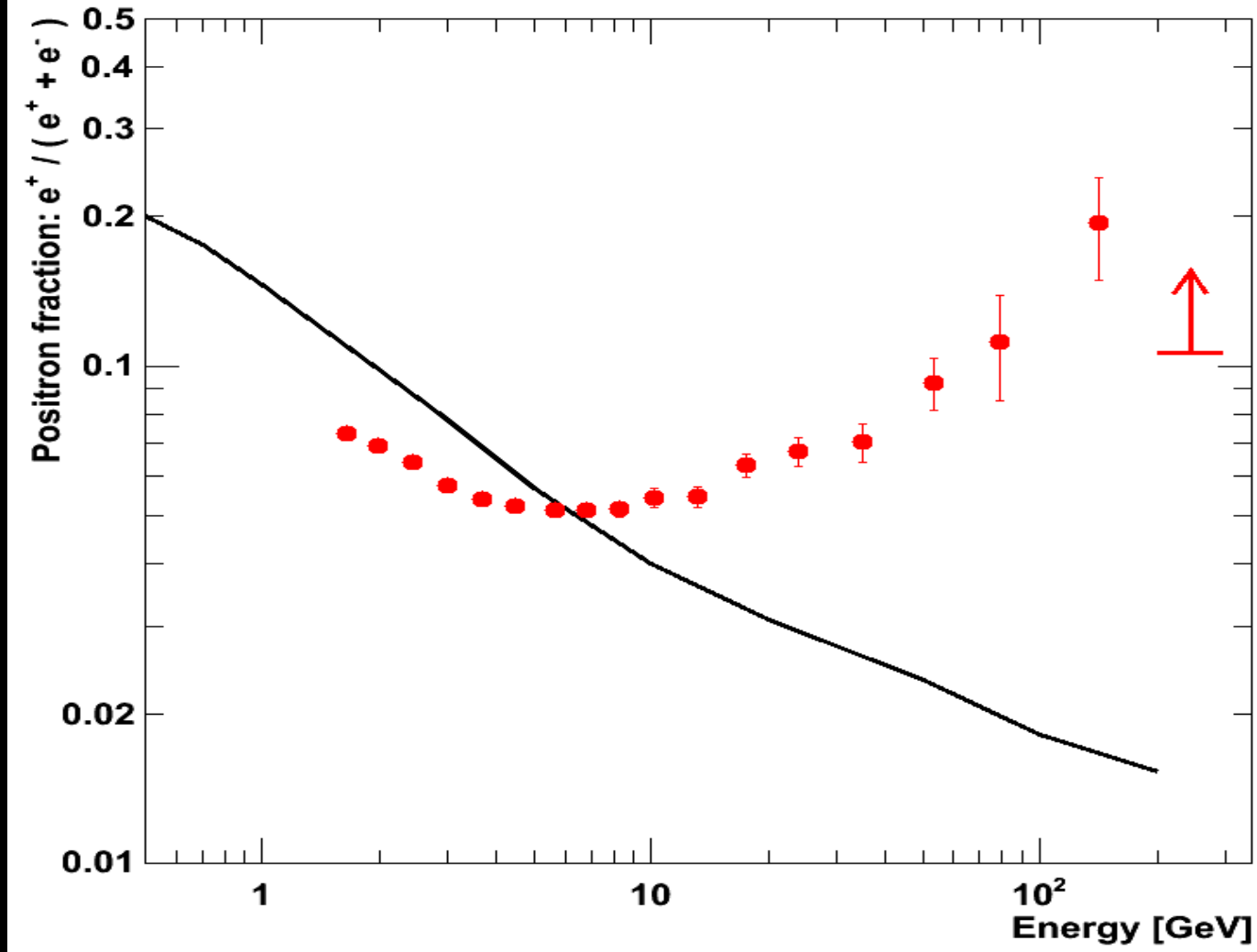


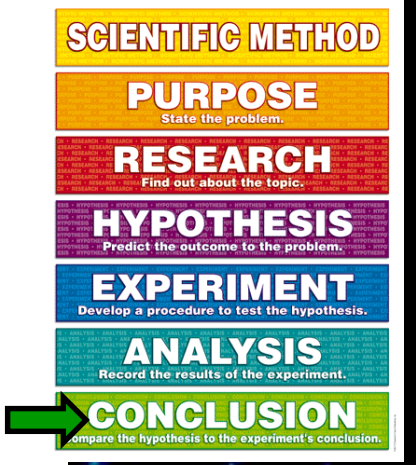

SCIENTIFIC METHOD
PURPOSE
State the problem.
RESEARCH
Find out about the topic.
HYPOTHESIS
Predict the outcome to the problem.
EXPERIMENT
Develop a procedure to test the hypothesis.
ANALYSIS
Record the results of the experiment.
CONCLUSION
Compare the hypothesis to the experiment's conclusion.

PAMELA Positron Fraction

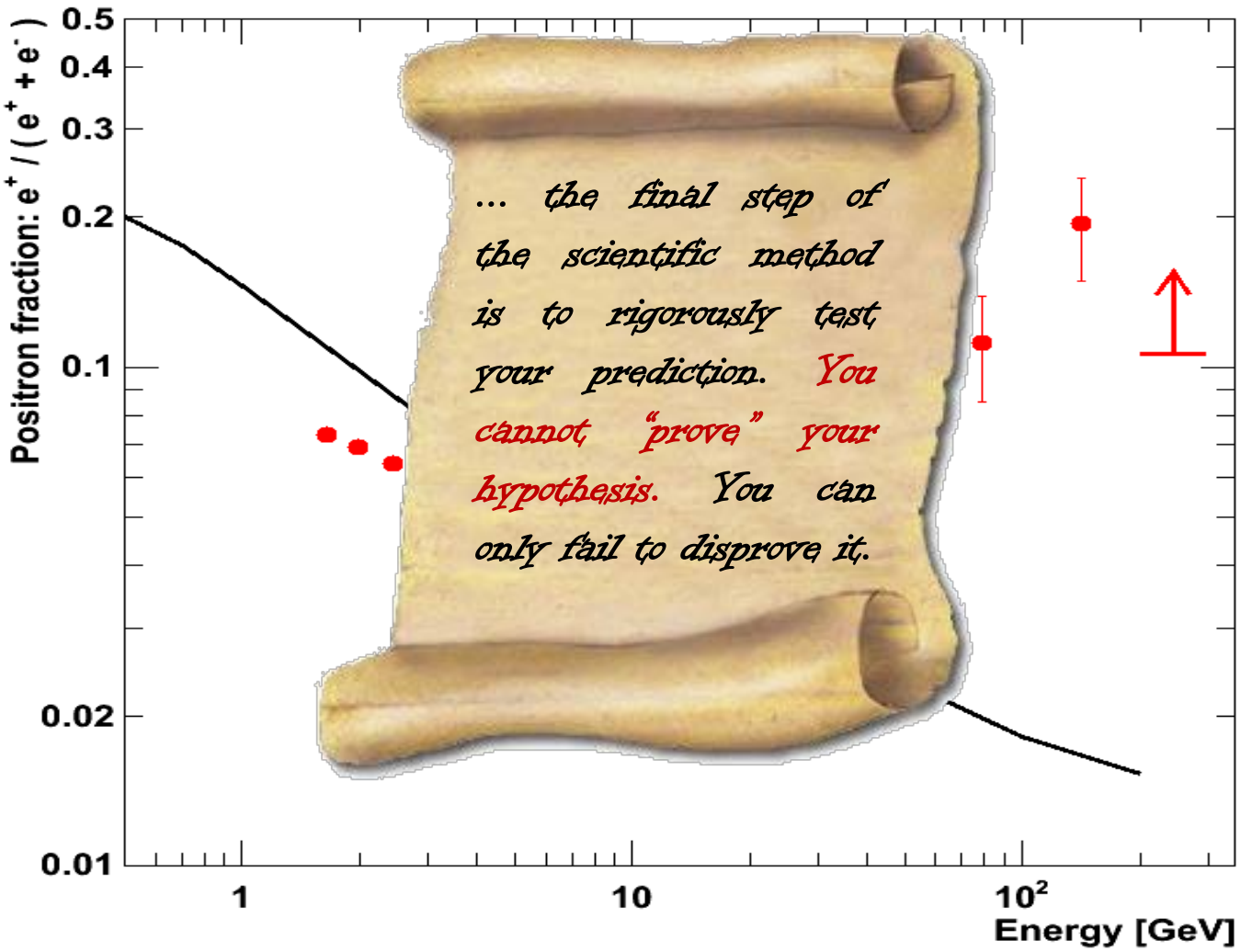


PAMELA Positron Fraction

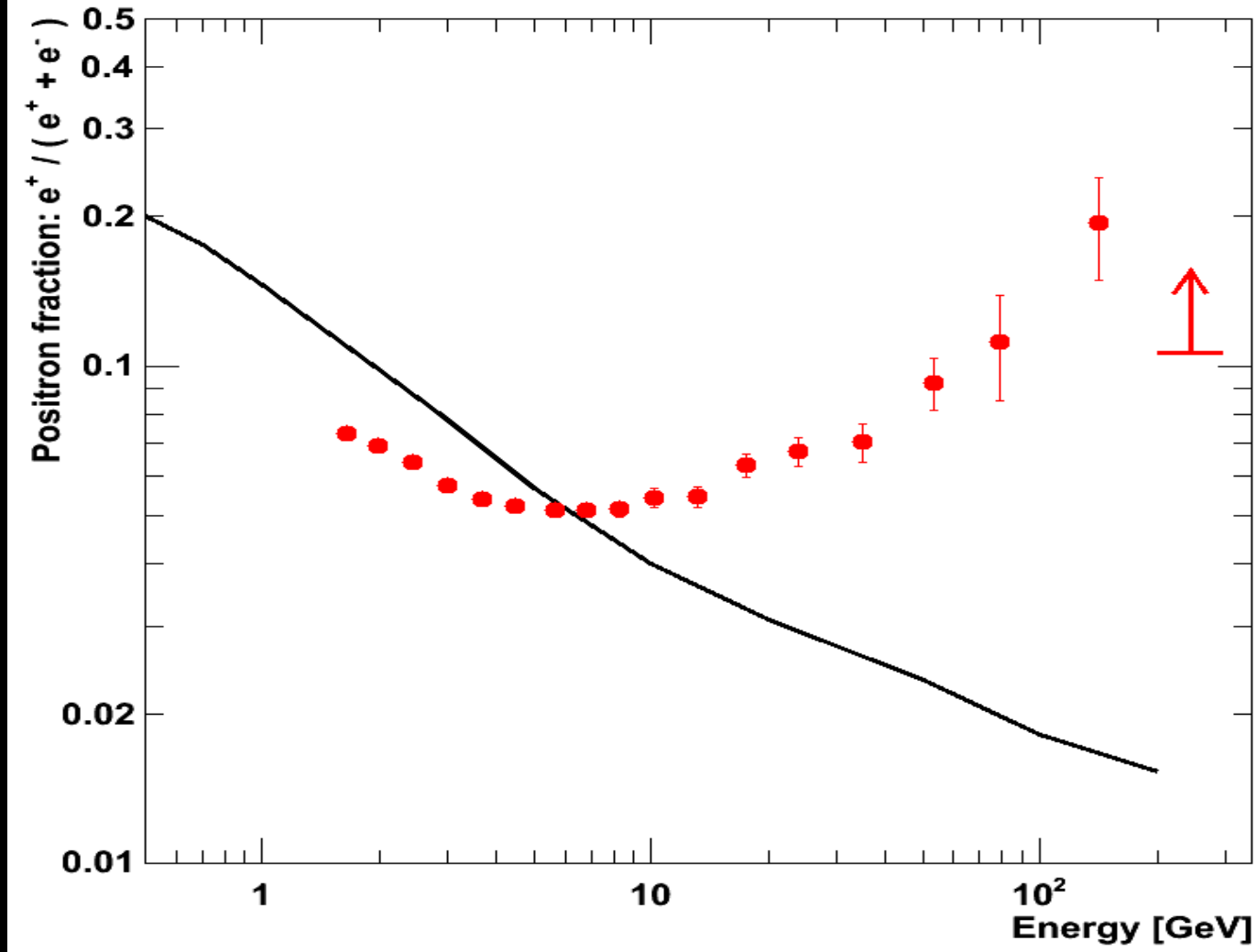


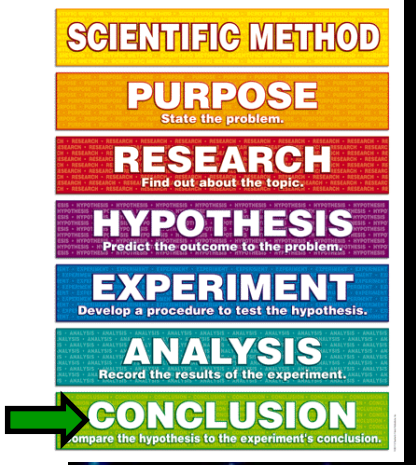


PAMELA Positron Fraction

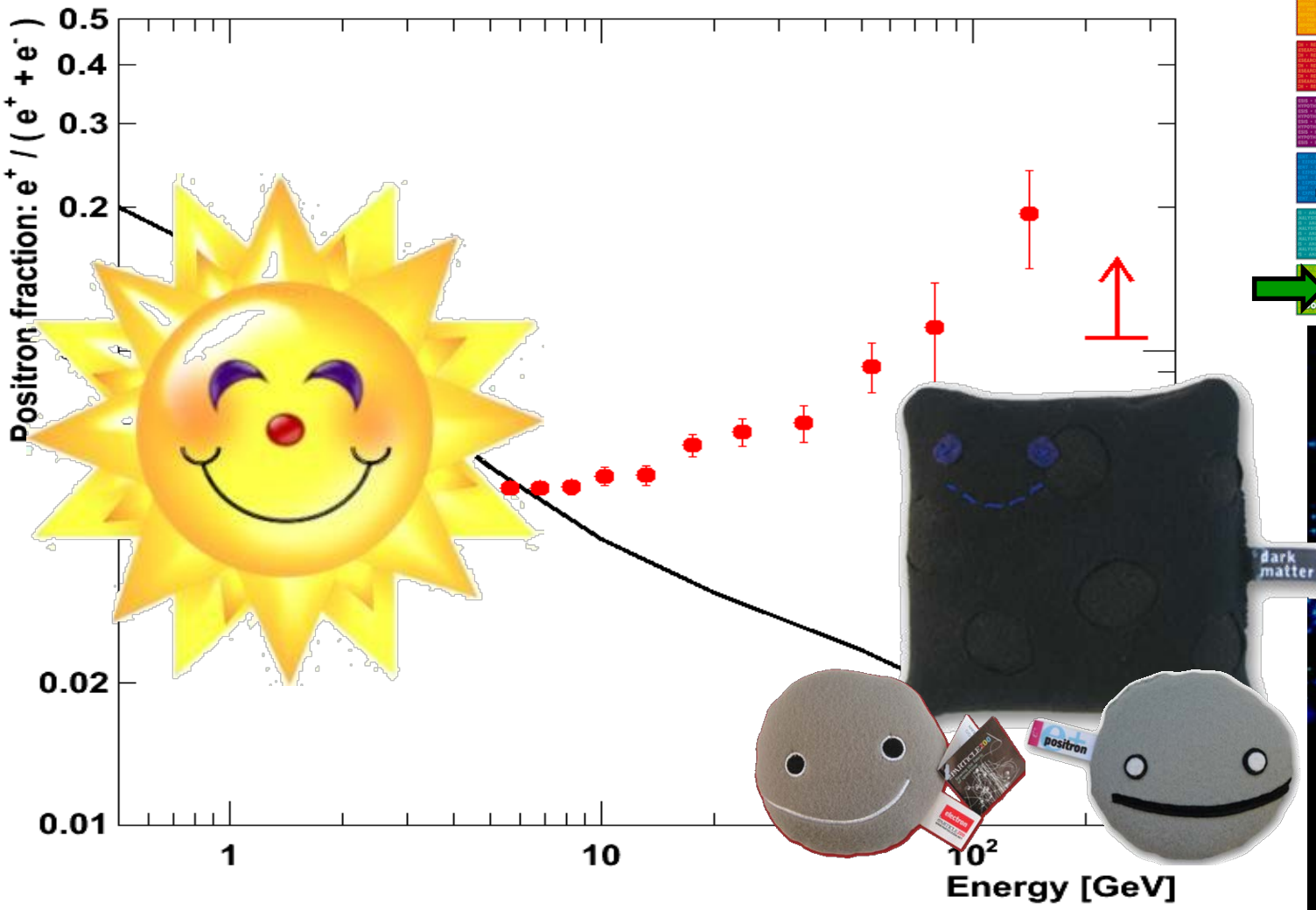


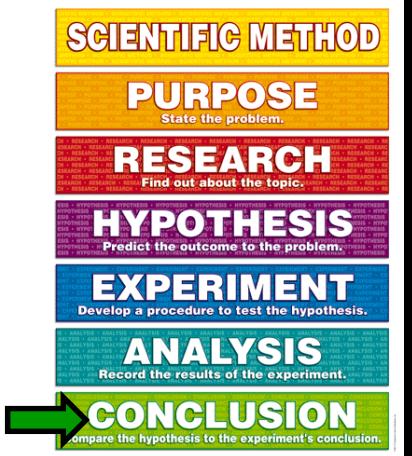
PAMELA Positron Fraction





PAMELA Positron Fraction





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Thanks!