the LIMADOU experiment on the CSES satellite

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With great contribution from R. Battiston, W. J. Burger, F. Nozzoli, E. Ricci and the LIMADOU collaboration

Topics

particle detection in space

- objectives
- constraints
- methods

the Limadou experiment on board the CSES satellite

- HEPD-01 description
- event reconstruction
- preliminary results

space weather and Earth remote sensing

- trapped particles
- particle bursts

the HEPD-02 tracker

- needs
- concept
- spatialize a new technology: how to

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Topics

particle detection in space

- objectives
- constraints
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space weather and Earth remote sensing

- trapped particles
- particle bursts

lecture 1

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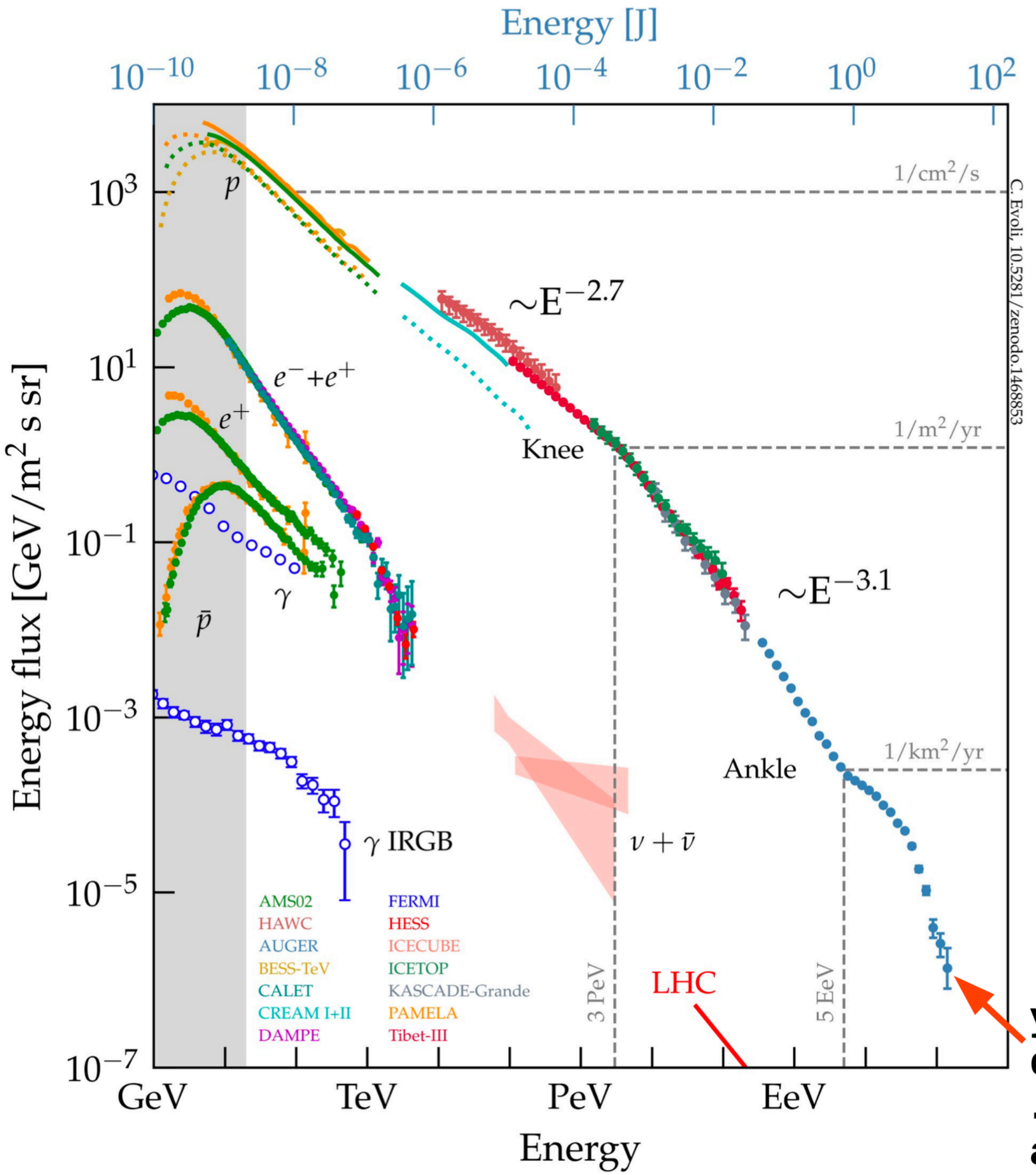
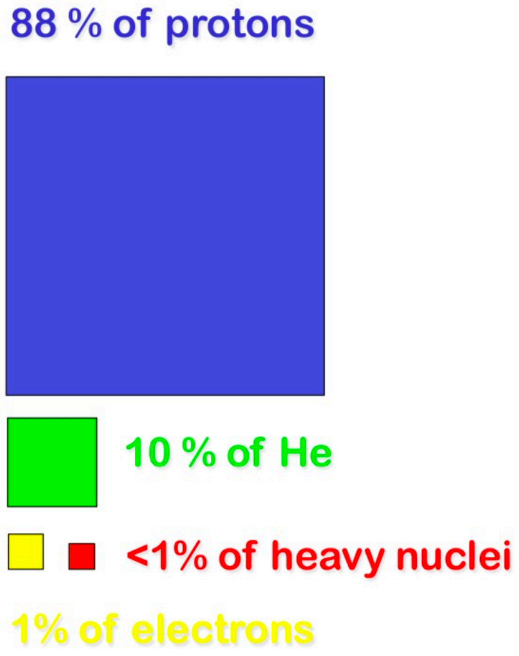
Cosmic-ray spectrum





rare components

$\bar{p}/p \sim 10^{-4}$

$e^{+}/e^{-} \sim 10^{-1}$

your kinetic energy during a quiet walking (3km/h) … but the momentum of just a single eyelash hair ...

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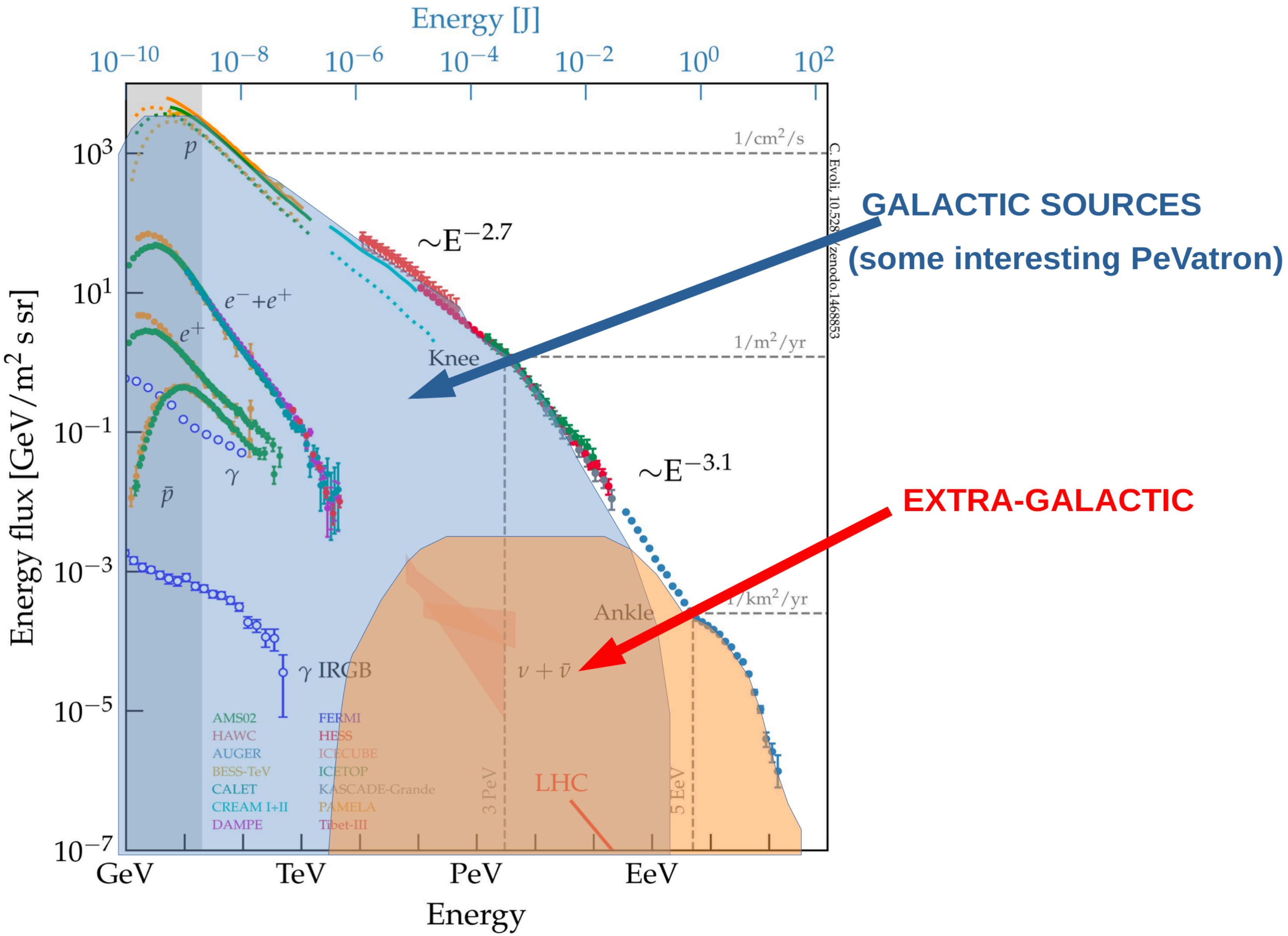
Cosmic-ray spectrum



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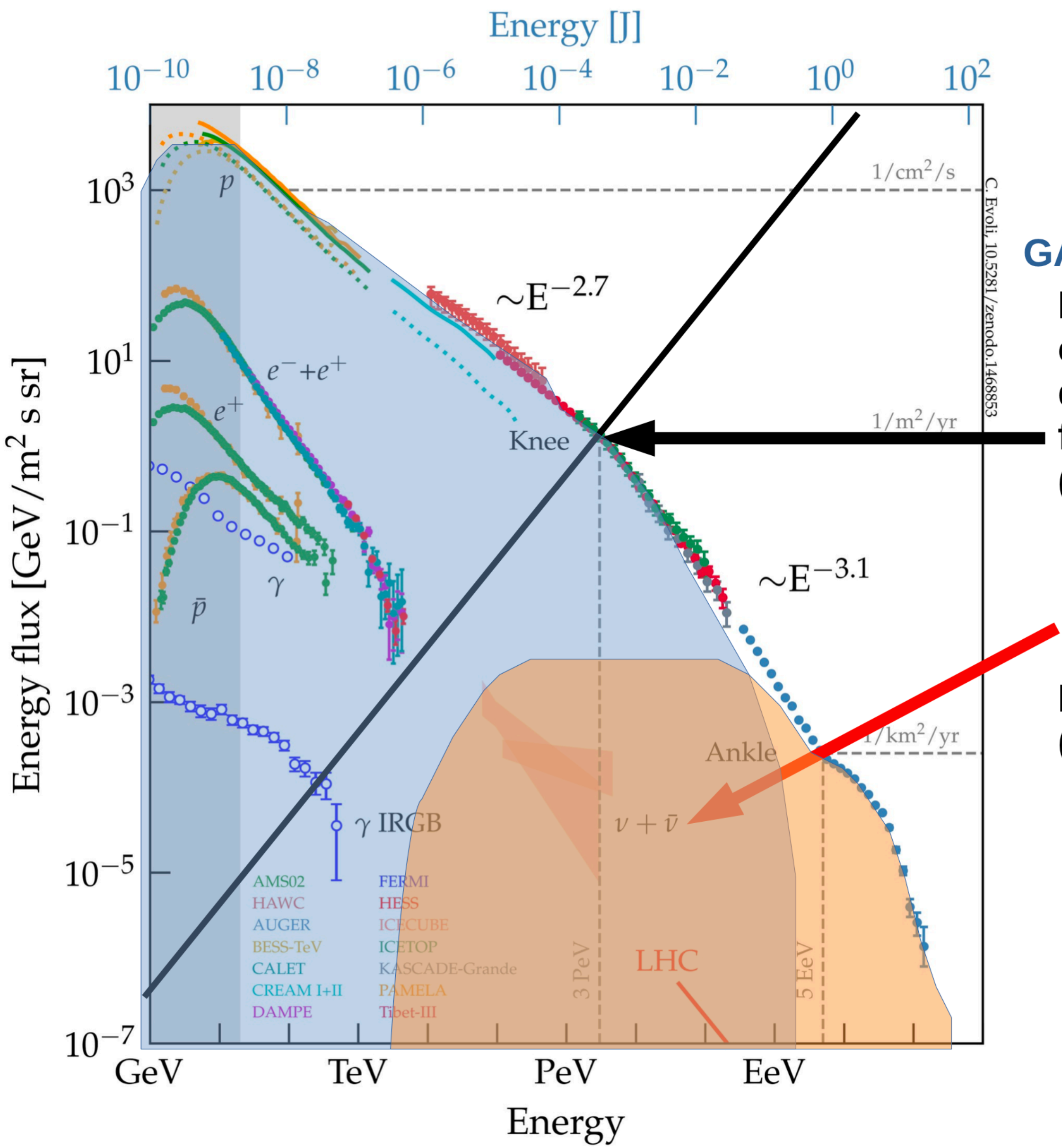
Direct measurements



GALACTIC SOURCES

Direct measurement of cosmic rays with a detector in space are feasible above this line (m^2 acceptance x year)

EXTRA-GALACTIC

Indirect measurements (next lectures …)

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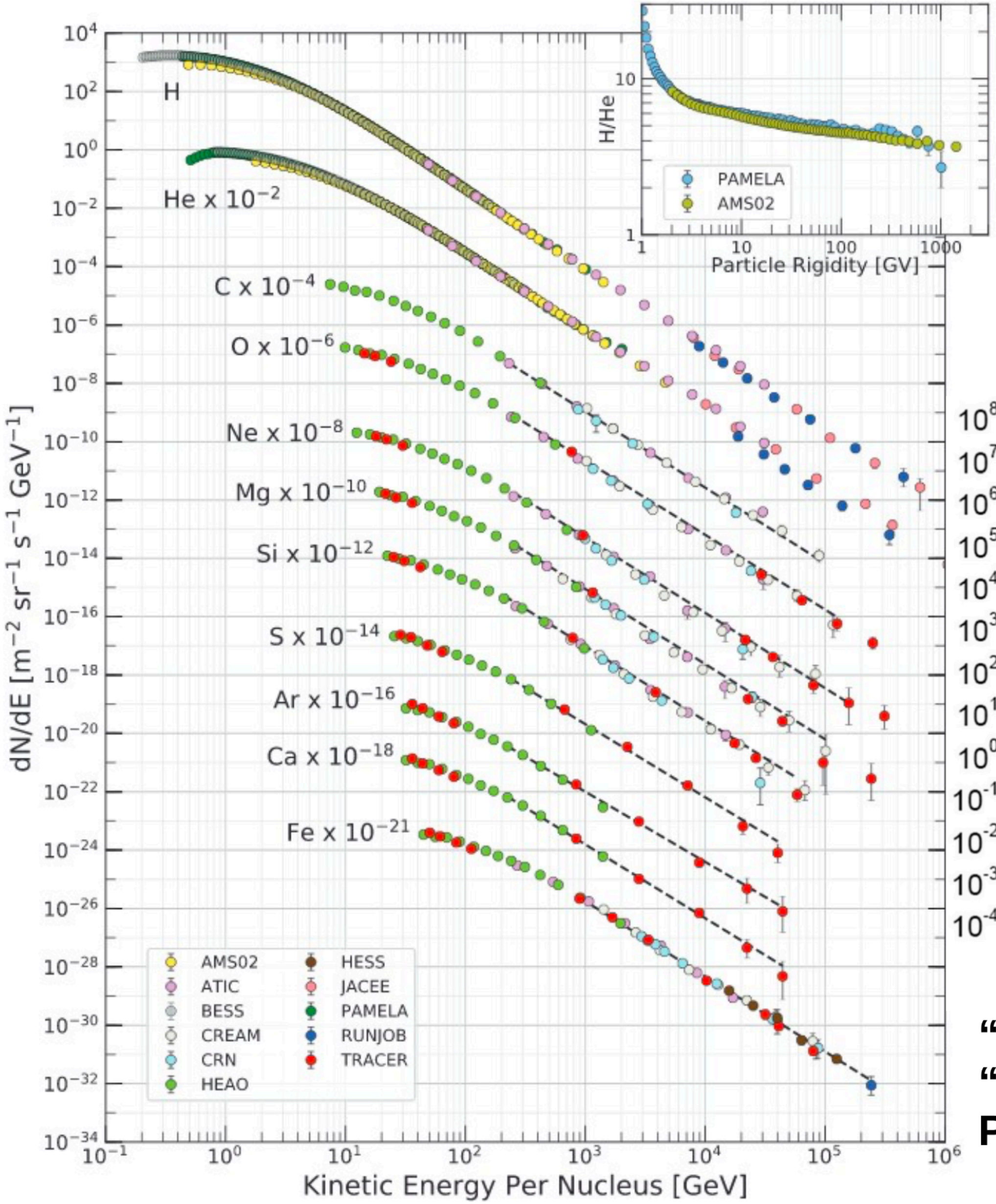
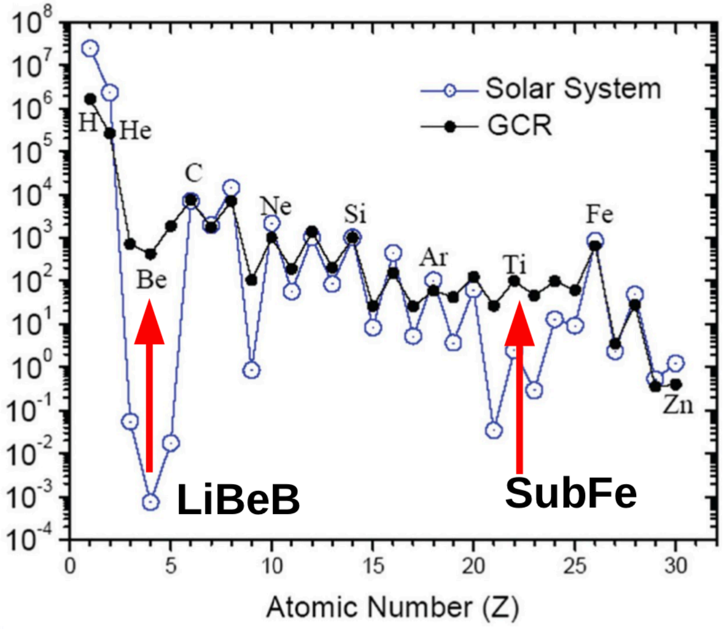
Cosmic ray composition



Cosmic Ray composition:

NUCLEI composition:
- particle charge
- particle "Energy"



"High" abundances of "secondary nuclei" Production by Fragmentation

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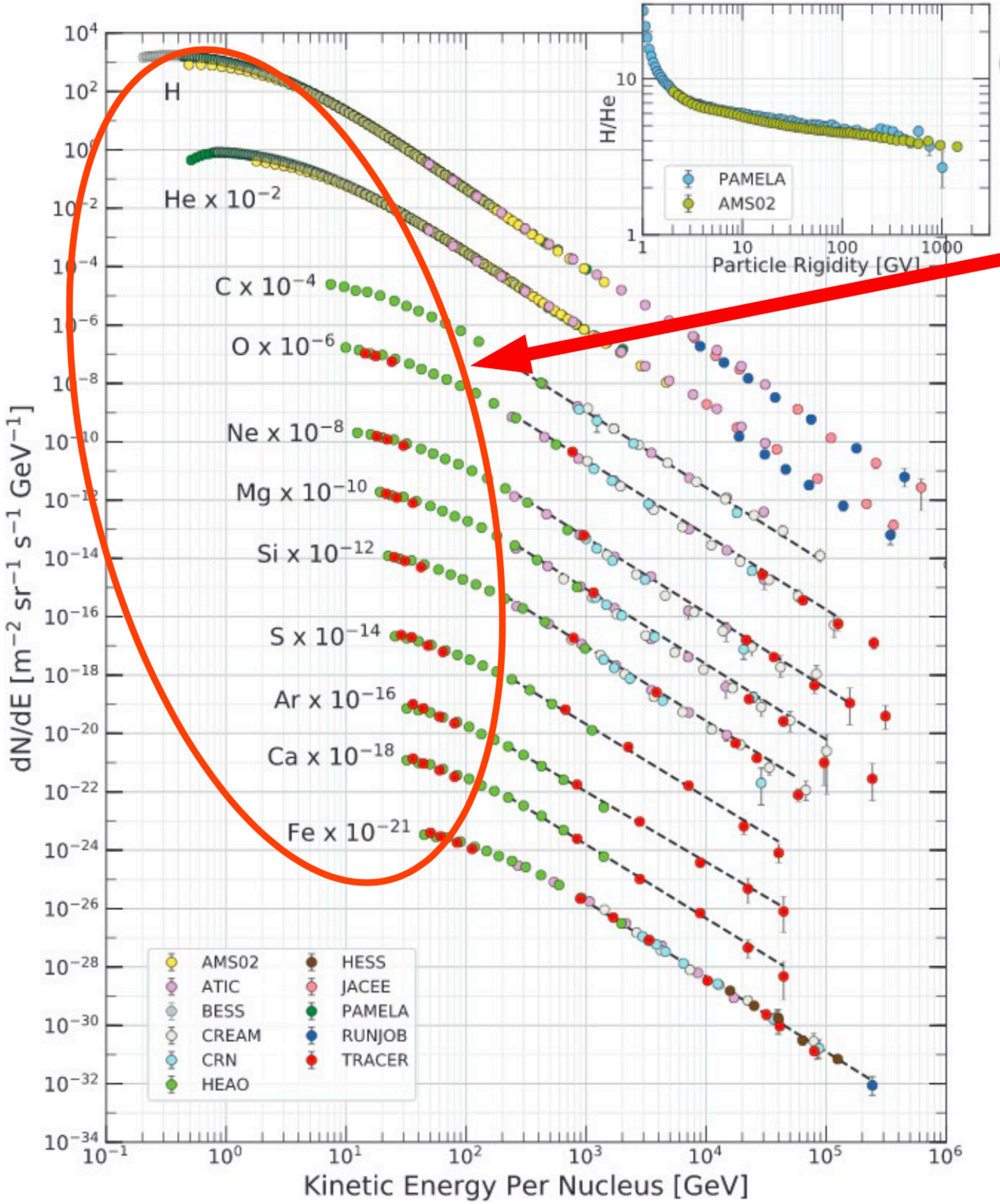
Cosmic ray composition



Cosmic Ray composition:

NUCLEI composition:
- **particle charge**
- **particle "Energy"**

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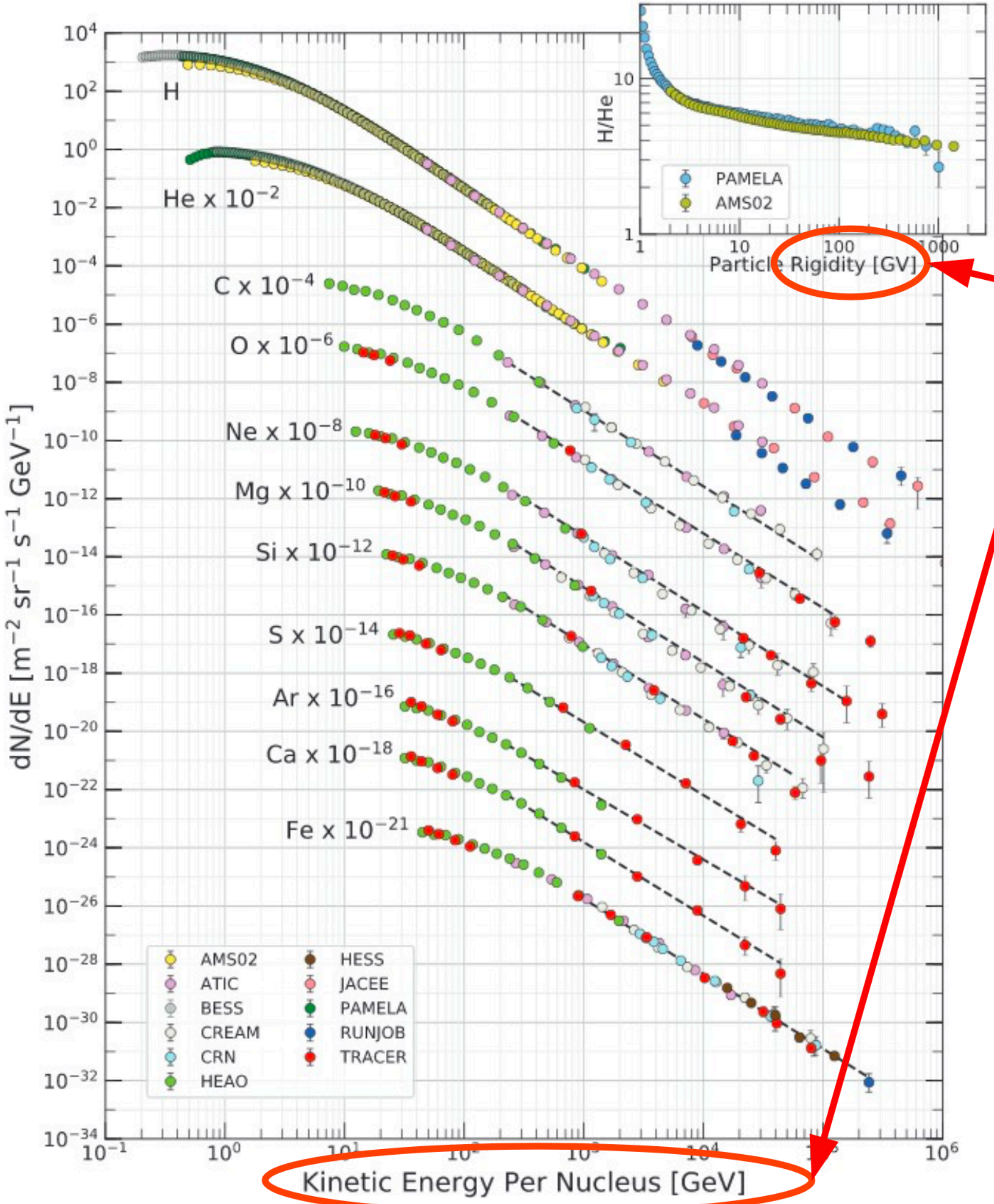
Cosmic ray composition



Cosmic Ray composition:

NUCLEI composition:
- particle charge
- particle "Energy"

which "Energy"?

Kinetic Energy: calorimeters (ATIC, JACEE, RUNJOB)

E/nucleon: TRD, Cherenkov (CRN-Spacelab, HEAO, CREAM, TRACER, HESS)

Rigidity (P/Z): Spectrometers (AMS02, Pamela, Bess)

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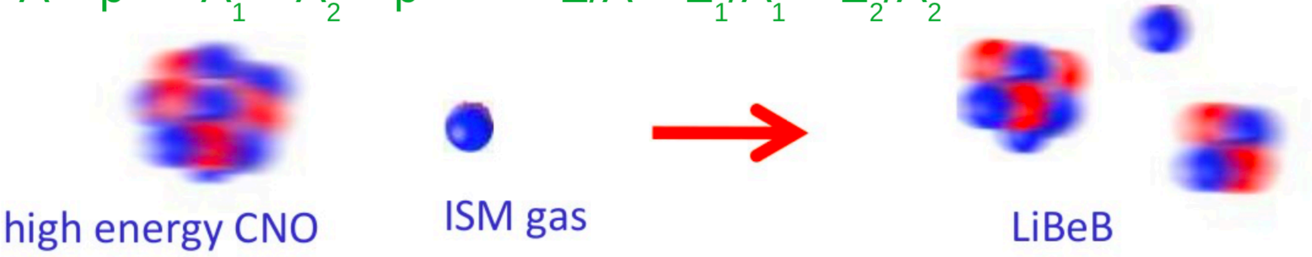
Energy/nucleon and rigidity

RIGIDITY: GV (Giga-Volt)
MEASUREMENT: P/Z is the quantity related to the trajectory in magnetic field
(easily converted to Momentum knowing the particle charge Z)

PHYSICS:
Different particles with same rigidity follow the same trajectory in magnetic fields
(in the Galaxy, in the Heliosphere, in the Earth magnetic field, in the detector field)
Main effects of propagation in the magnetic field (and the main time dependent solar modulation effects) would cancel out in <Flux Ratio> vs <Rigidity>

Energy/nucleon: GeV/n (usually average isotopic composition is assumed)
MEASUREMENT: is a quantity related to velocity (ToF, RICH, TRD)
(they measure GeV/M and cannot be converted to Energy if mass is unknown)

PHYSICS:
Fragmentation of nuclei roughly conserve E/n in spallation processes
(when a relativistic CR nuclei during propagation interacts on a proton of ISM)
$A + p \Rightarrow A_1 + A_2 + p$ $E/A \sim E_1/A_1 \sim E_2/A_2$



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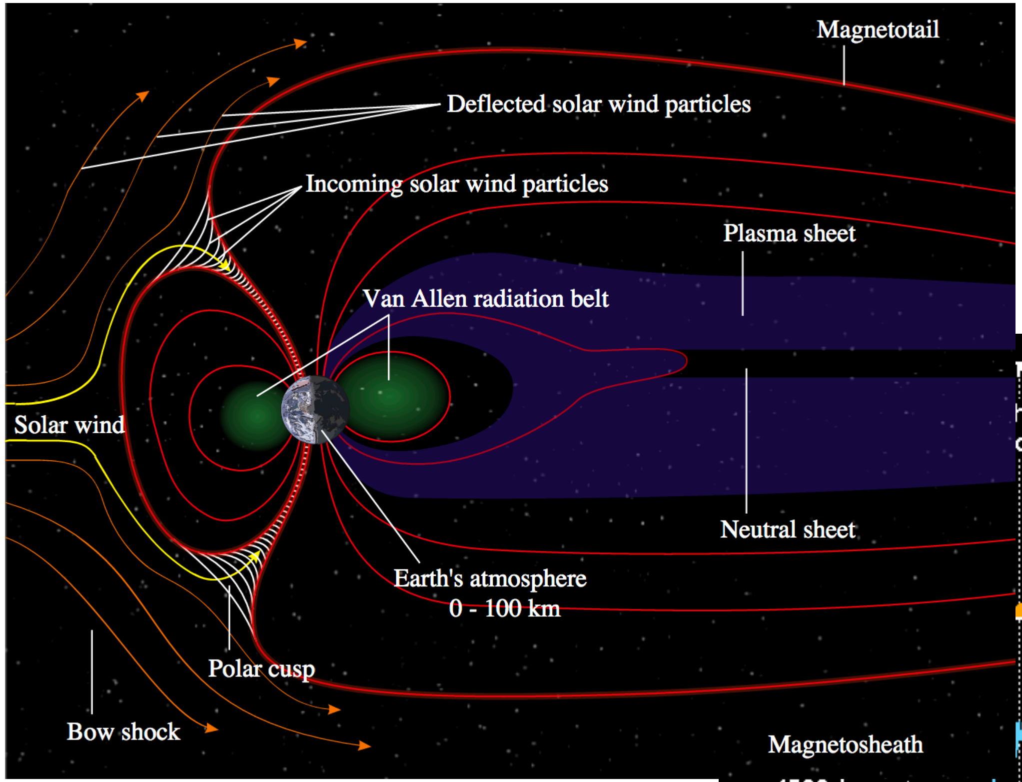
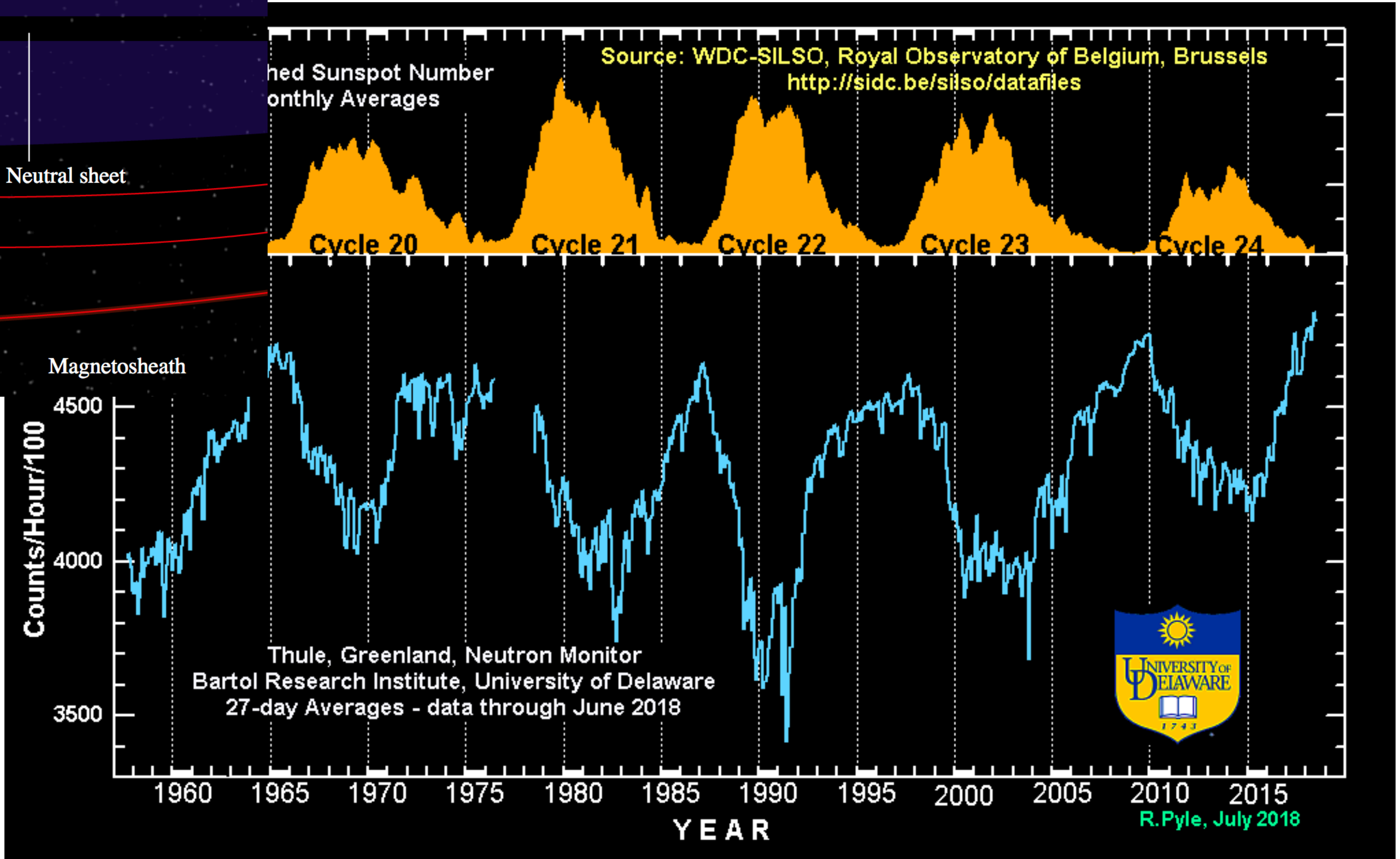
Solar activity





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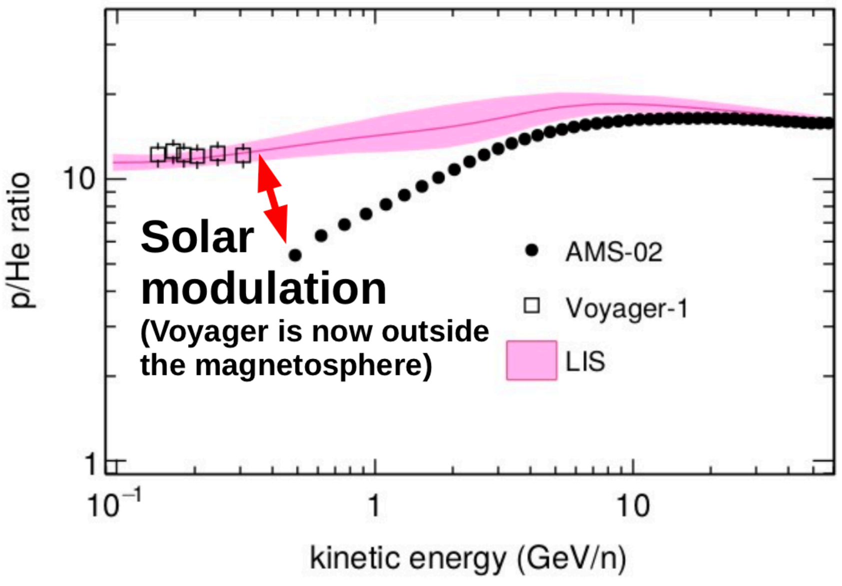
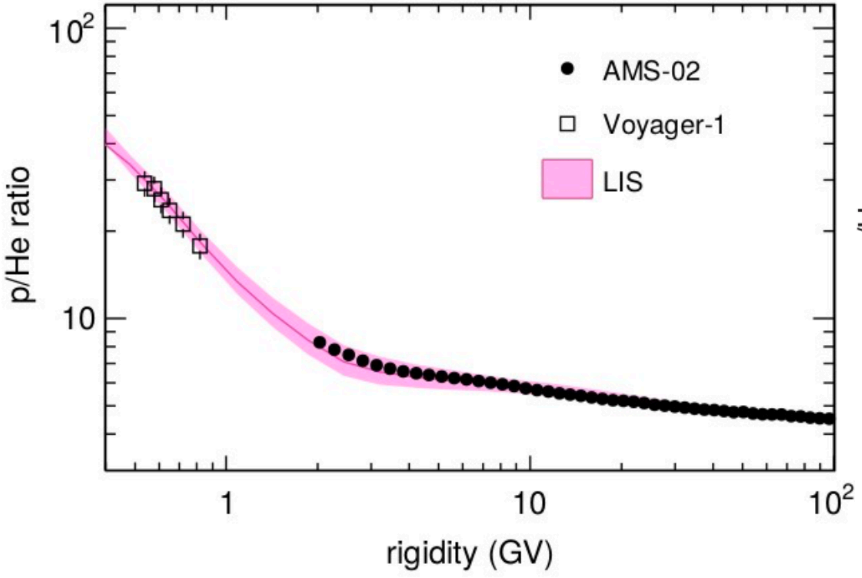
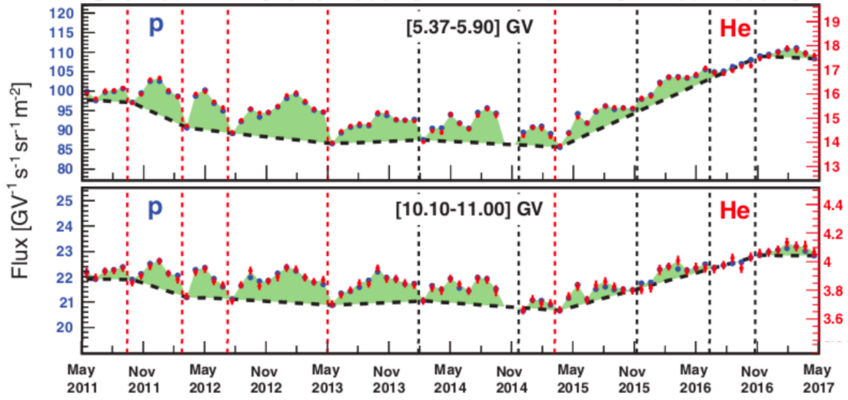
Solar modulation

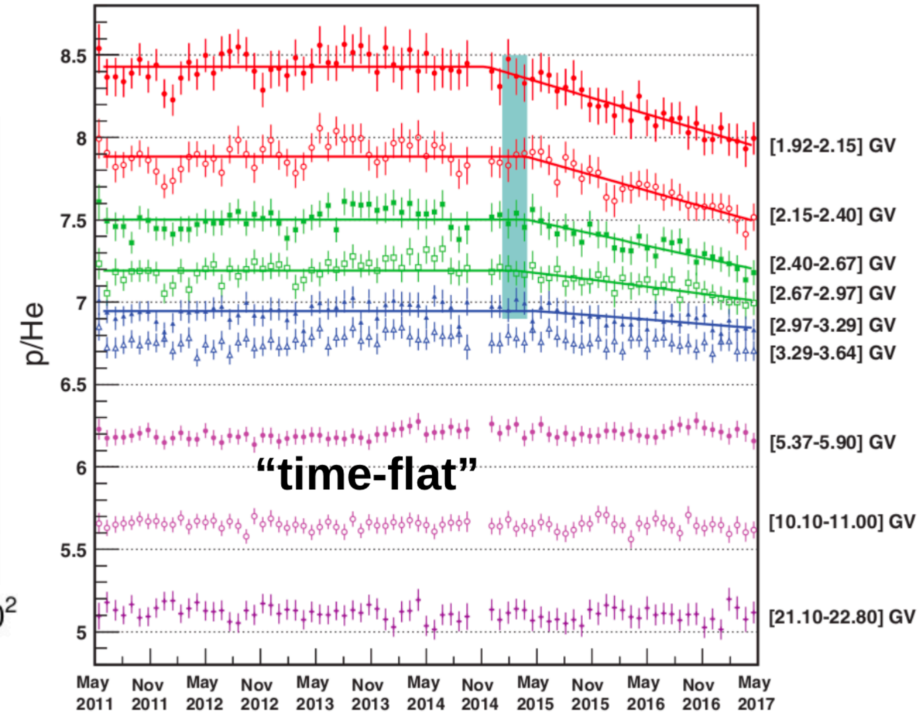




Solar modulation => time variation



Flux ratio vs R



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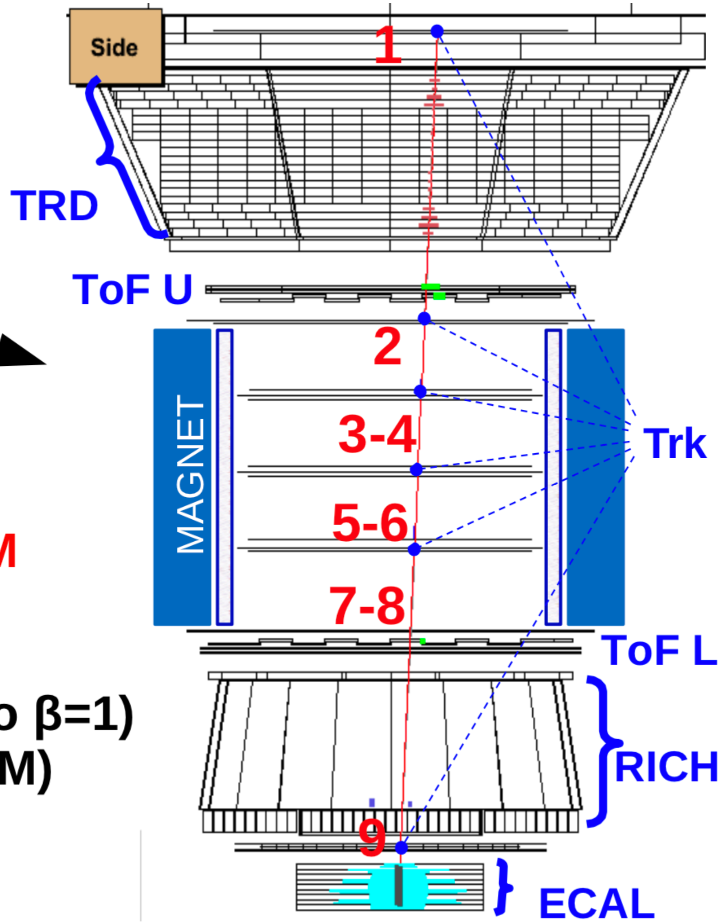
Particle detection in space: the champion (AMS-02)

AMS02: 7.5 Tons – 5x4x3m
B=0.15T in space since 2011
able to identify few antinuclei over 150G events (0.5m^2 sr)
is shown for PID examples



- **Absolute value of charge: VERY SIMPLE**
- **Particle Mass: easy for E<M, very difficult for E>>M (typically evaluated by "velocity" vs Energy)**
- **Particle Velocity: "easy" at few % (but saturation to β=1) (TRD measuring γ = E/M to avoid saturation for E>>M)**
- **Particle direction: VERY SIMPLE**
- **Particle Momentum: hard to do better than few %, very difficult for P>TV**
- **Charge sign: (up to now) impossible for R>TV**
- **Particle Energy: feasible down to few %, but large systematics for E>>TeV**

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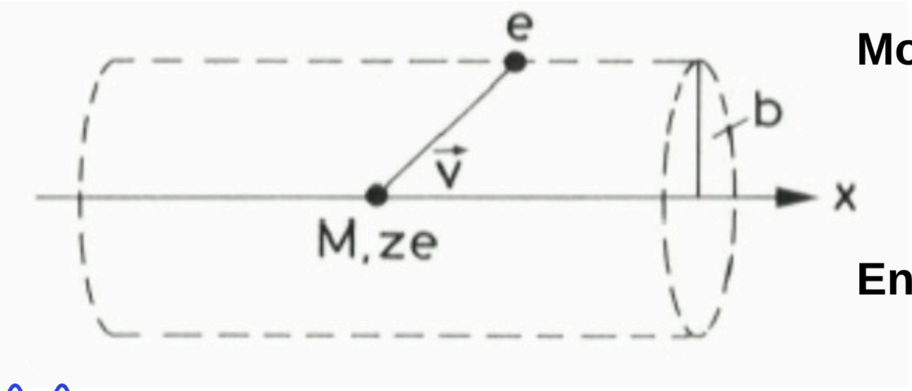
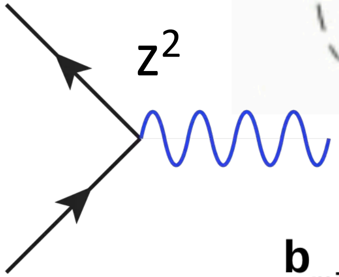
Energy loss via ionisation





Momentum transferred to an electron:

$$\Delta P = \int F\,dt = \int eE_\perp \frac{dx}{v} = \frac{ze^2}{2\pi\epsilon_0 b v}$$

Gauss th. $\Phi_E = \frac{Q}{\epsilon_0}$

Energy loss in dV = 2πb db dx : $n_e = \rho N_A Z/A$

$$-dE = \frac{(\Delta P)^2}{2m_e} n_e dV = \frac{1}{(4\pi\epsilon_0)^2}\frac{4\pi z^2 e^4}{m_e v^2} n_e \frac{db}{b} dx$$

b_{min}: head on collision (v_e = 2 v) $\Delta E_{max} = 2\gamma^2 m_e v^2$ $\quad b_{min} = \frac{1}{4\pi\epsilon_0}\frac{ze^2}{\gamma m_e v^2}$

b_{max}: This approach assumes electrons "at rest" that is Tcollision << Trevolution

Tcollision ≈ b/(γv) and Trevolution ≈ 1/ν => b_{max} ≈ γv/ν (then integrate over b)

Bohr formula:

$$-\frac{dE}{dx} = \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{4\pi N_A}{m_e}\frac{z^2}{v^2}\rho\frac{Z}{A}\ln\left(\frac{\gamma^2 m_e v^3}{z e^2 \bar{\nu}}\right)$$

Full quantum mechanical: Bethe-Block

$$-\frac{dE}{\rho dx} = K z^2 \frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_e c^2\beta^2\gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

projectile

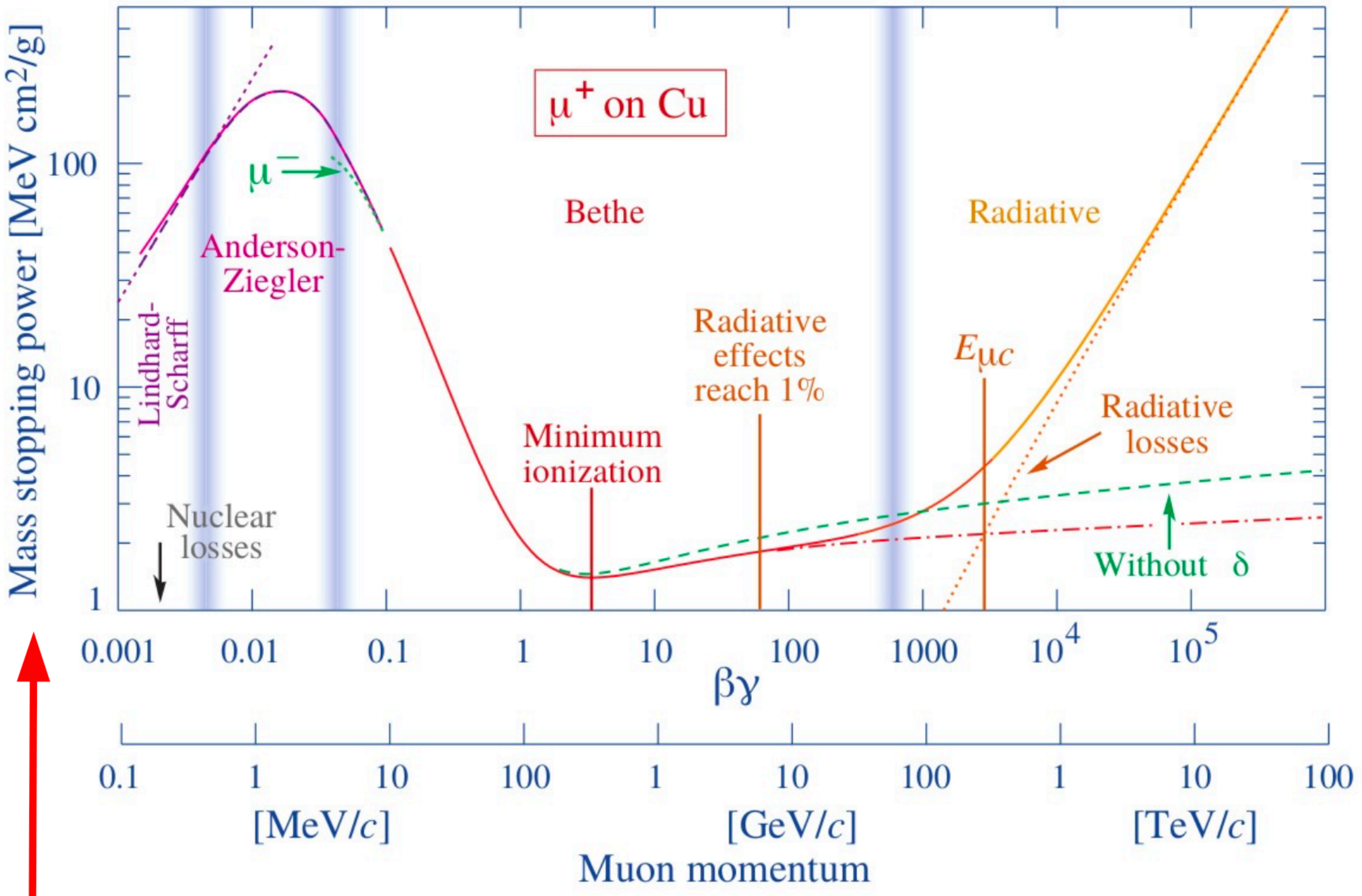
Target material

relativistic rise (E>>M)

"minor" corrections

Z/A quite similar in all materials main material effect from density

Charged particles energy loss in material



$$-\frac{dE}{\rho dx} = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

The main effect of target material (due to the density) can be factorized out.

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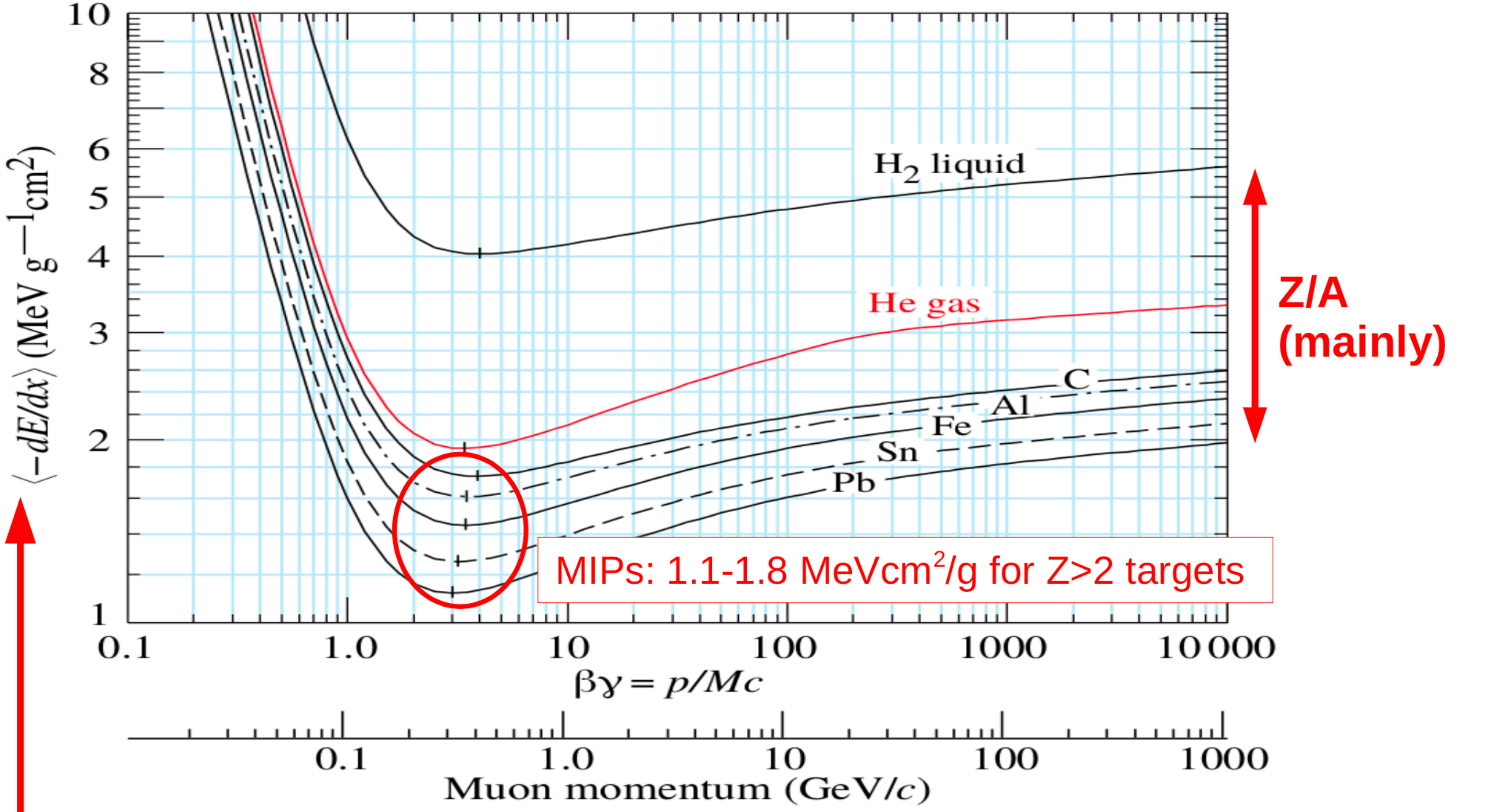
The importance of the material



$$-\frac{dE}{\rho\, dx} = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

The main effect of target material (due to the density) can be factorized out.

MIPs (Minimum Ionizing Particles) are “calibration sources” for detectors.

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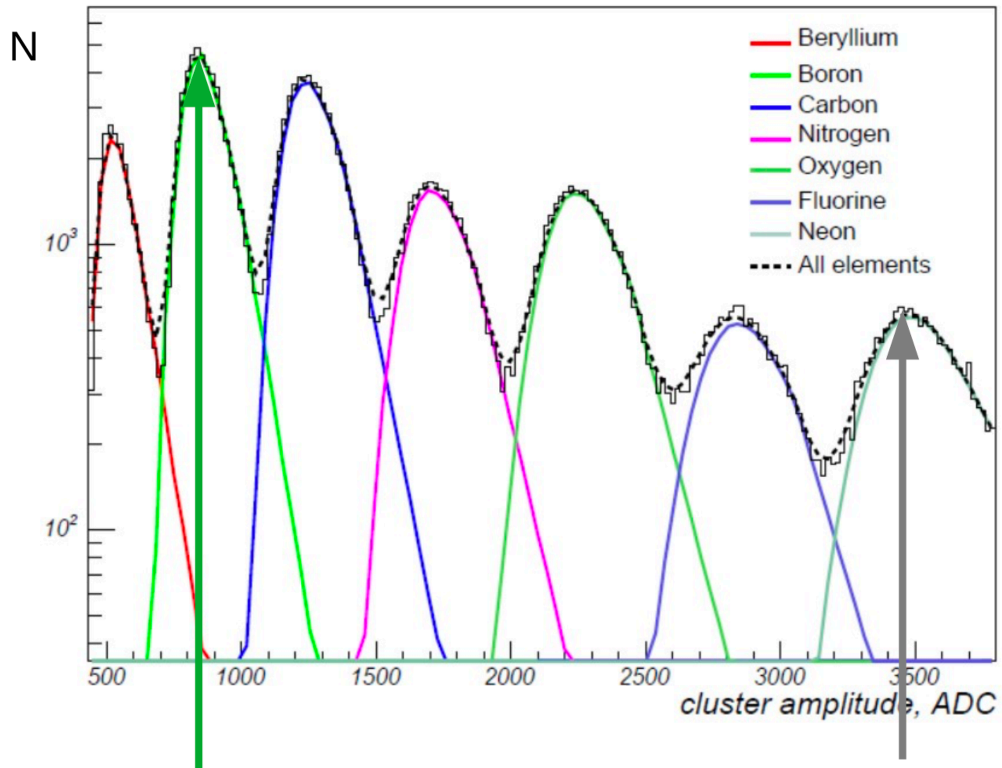
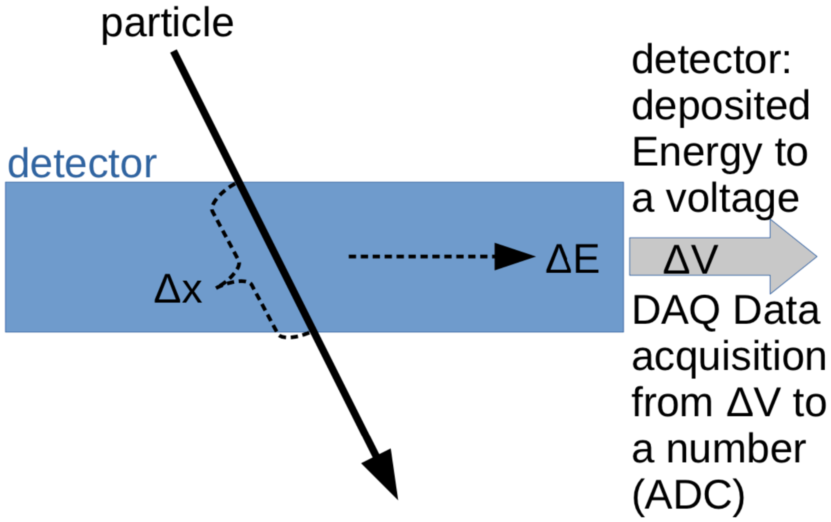
Measurement of charge





(Analog to Digital Converter)
(from the voltage to a number)

Boron z=5
Signal amplitude: 860 ADC channels

Neon z=5**x2**=10
Signal amplitude: 860**x4** = 3440 ADC channels

$$-\frac{dE}{\rho dx} = K z^2 \frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_e c^2\beta^2\gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

to measure dE/dx also some tracking to measure dx is necessary…
(and to get a good charge measurement also some value for velocity is needed)

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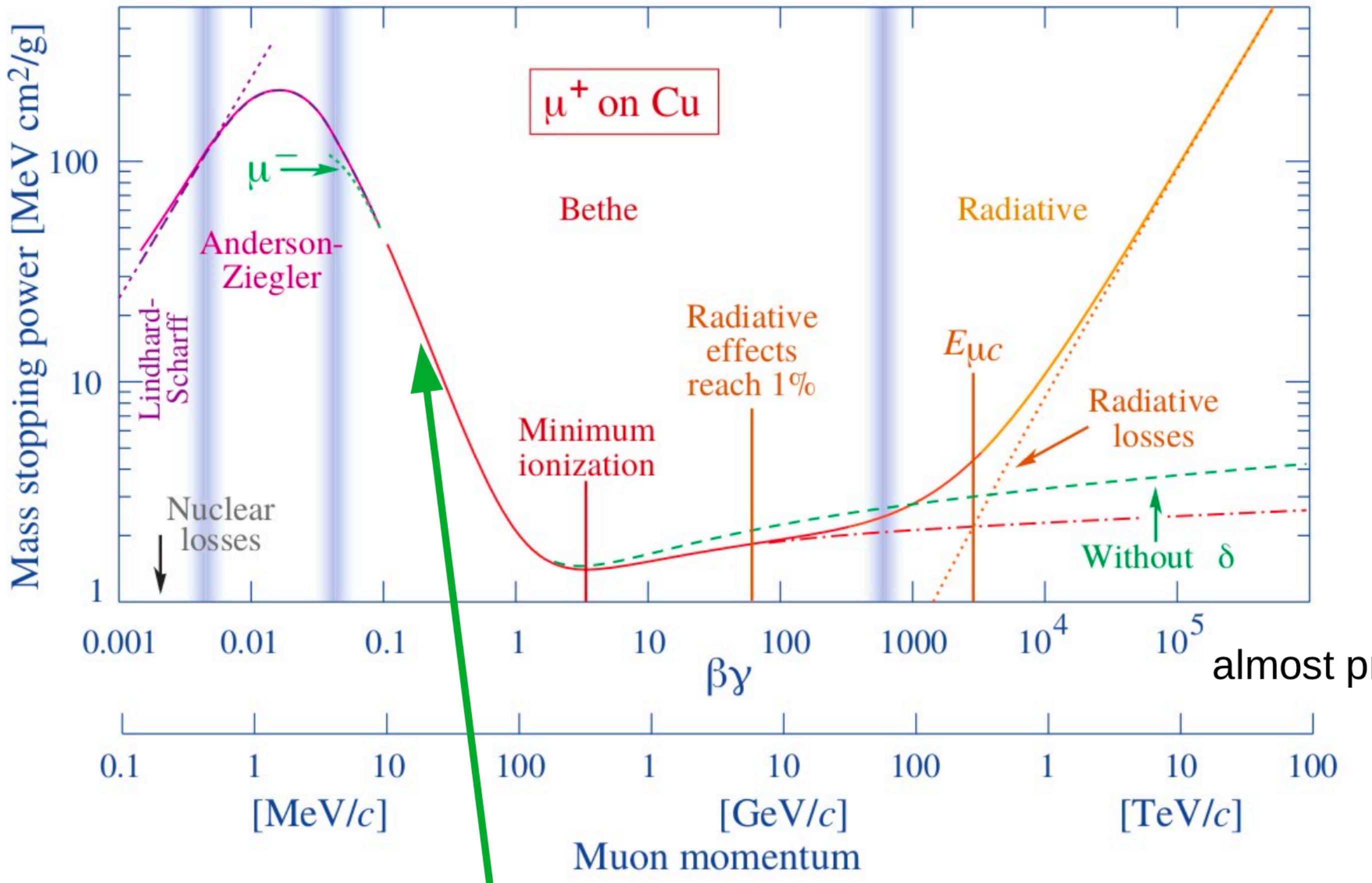
Measurement of velocity (1)



almost proton Momentum(GeV/c)

$$-\frac{dE}{\rho\, dx} = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

If charge is known, the energy loss allows a reasonable velocity measurement for γ<1
(possible but hard to exploit the relativistic rise for γ measurement)
On the other hand correction for this effect is required for precise charge measurements.

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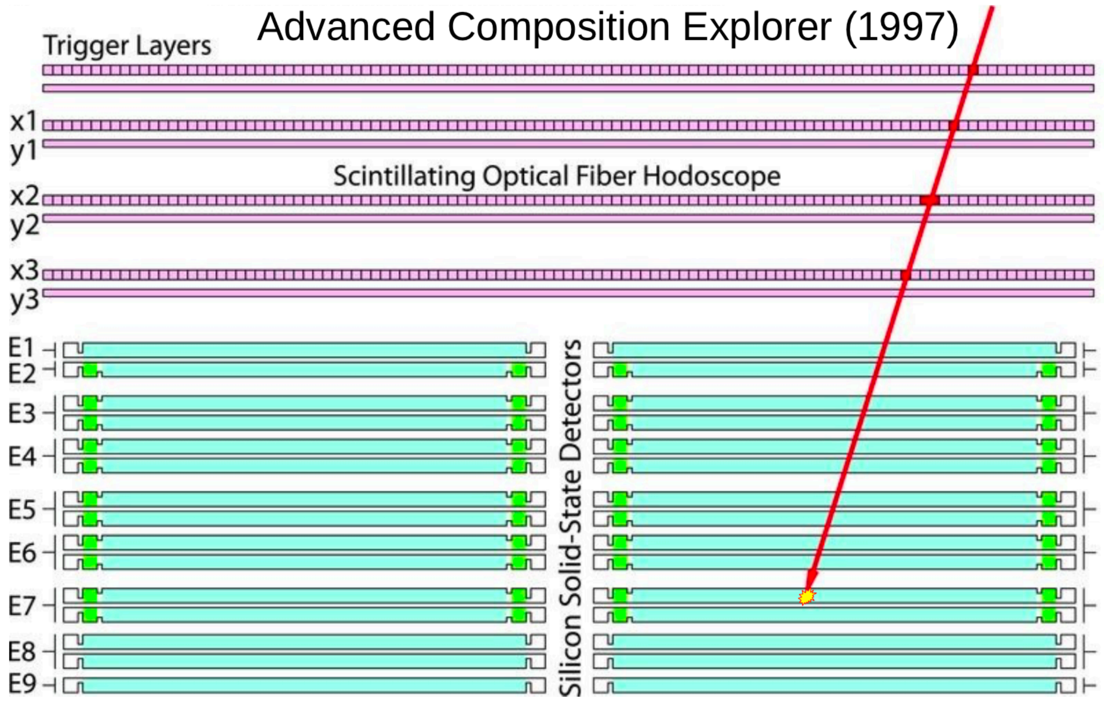
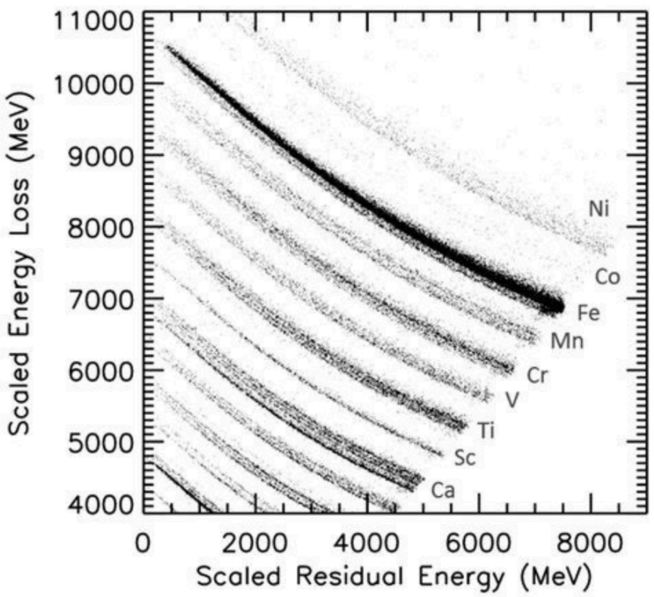
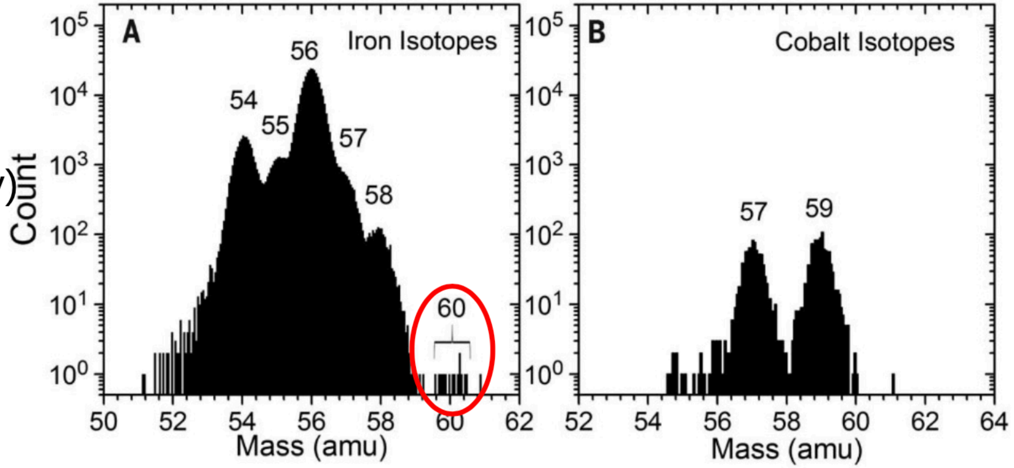
Measurement of mass: dE/dx + E





ACE-CRIS evidence for ^{60}Fe ($T_{1/2} \approx 2.6$My)
200<E<500 MeV/n
=> PRODUCED BY A NEARBY SN



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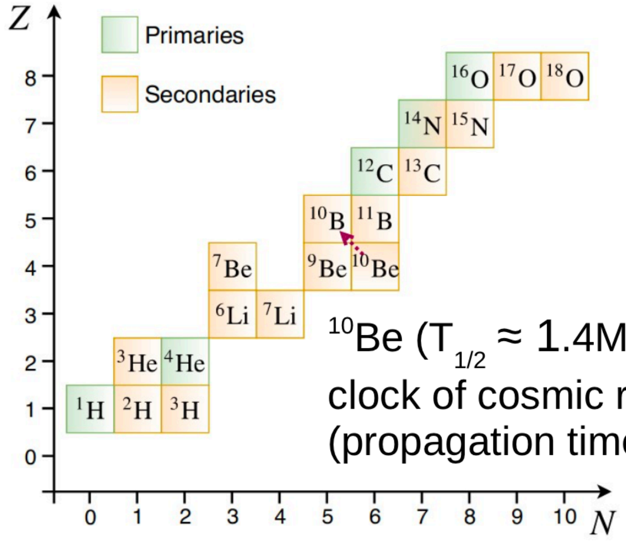
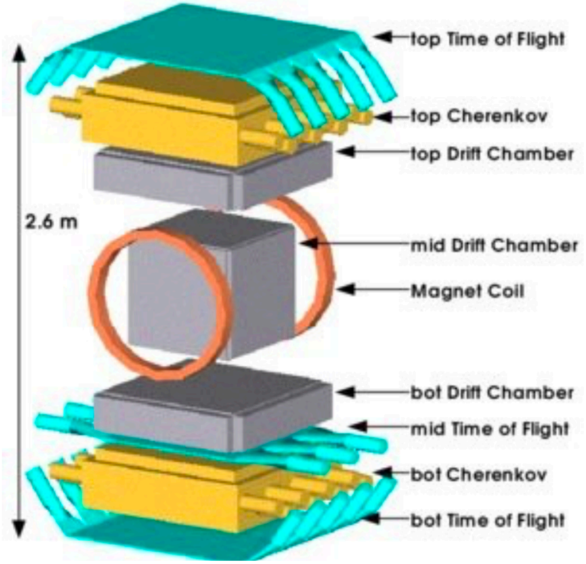
Measurement of mass: momentum + velocity

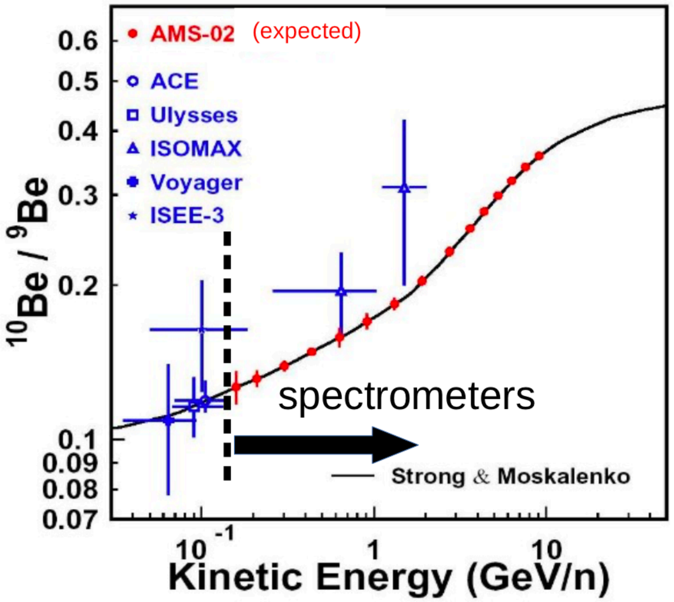
Isotopes in light cosmic rays:



^{10}Be ($T_{1/2}$ ≈ 1.4My) is the clock of cosmic rays (propagation times)

ISOMAX: Balloon (1998)





$$M = \frac{RZ}{\gamma\beta} \Rightarrow \frac{\Delta M}{M} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\gamma^2 \frac{\Delta\beta}{\beta}\right)^2}$$

DETECTOR COMPLEXITY INCREASES

Velocity direct measurement:
Time of Flight
Cherenkov Detector

Momentum measurement: (R = P/z)
Magnet + tracker

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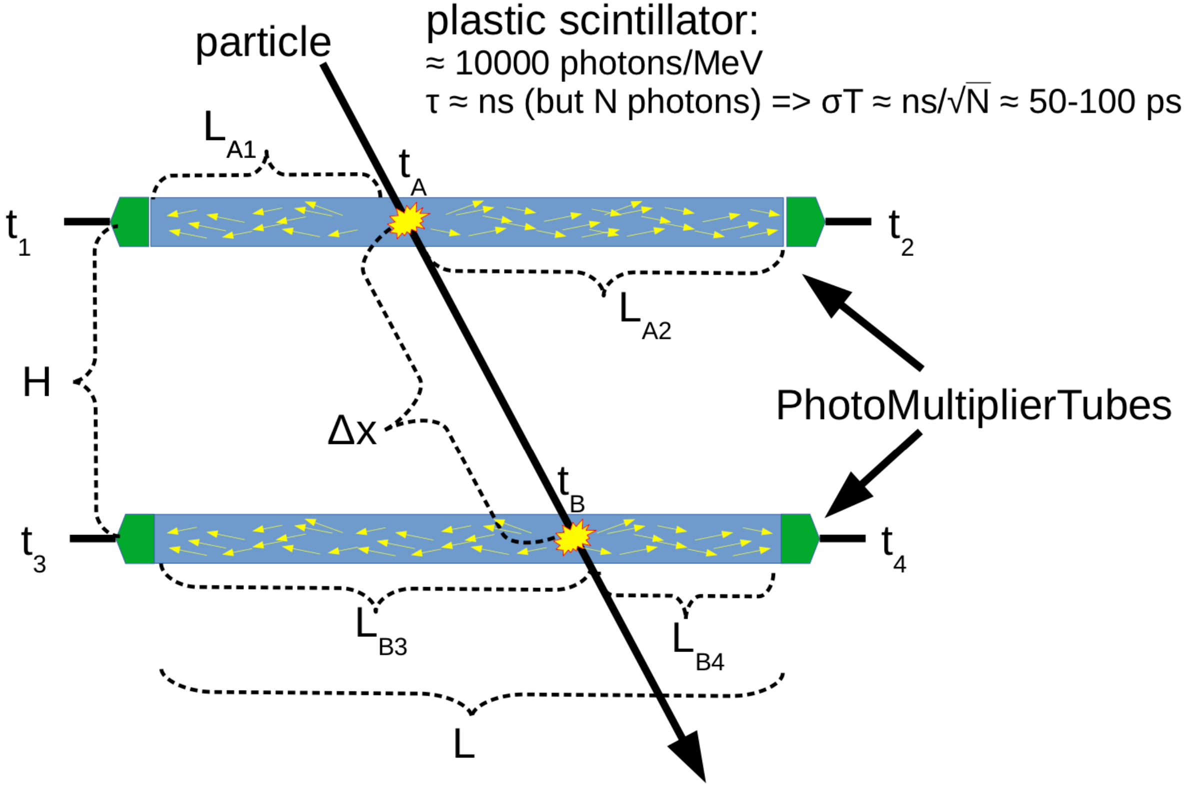
Measurement of velocity 1: time of flight



Velocity resolution:
$\Delta\beta/\beta \approx \Delta ToF/ToF \approx 100$ ps c/H
H=1m => $\Delta\beta/\beta \approx 3\%$
Energy up to ≈ GeV/n

Position resolution (along the bar) from time difference ≈ few cm

c = 30cm/ns (speed of light)
n ≈ 1.6 (plastic scint. refr. index)

$t_1 = t_A + L_{A1} n/c$

$t_2 = t_A + L_{A2} n/c$

$t_A = (t_1 + t_2)/2 + L\, n/(2c)$

$t_B = (t_3 + t_4)/2 + L\, n/(2c)$

$ToF = t_B - t_A = (t_3 + t_4 - t_1 - t_2)/2$

$\beta = \Delta x/(ToF\ c)$

some tracking is required

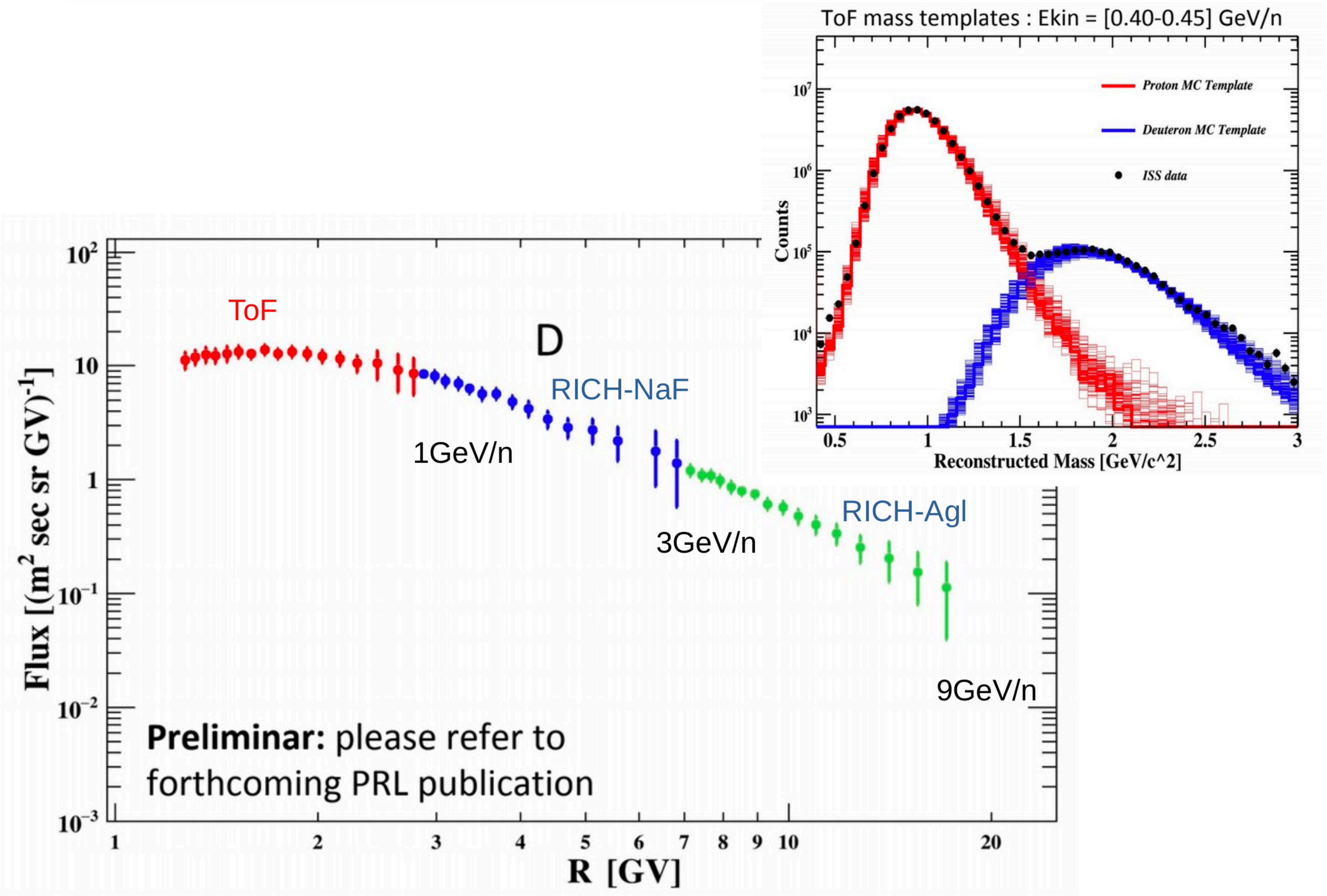
Some "self tracking" capability:

$t_2 - t_1 = (L_{A2} - L_{A1}) n/c = \Delta L_A n/c$

$t_4 - t_3 = (L_{B4} - L_{B3}) n/c = \Delta L_B n/c$

$(\Delta x)^2 = H^2 + (\Delta L_A - \Delta L_B)^2/4$

Example: AMS-02 measurement of deuterium flux



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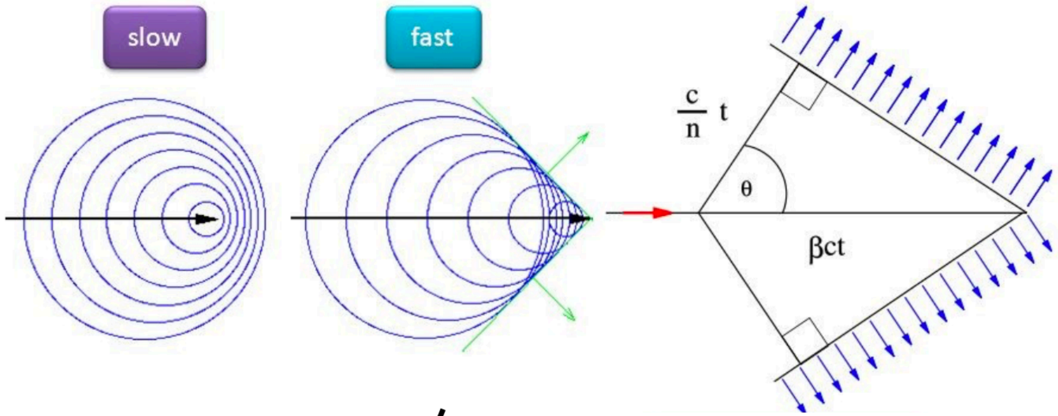
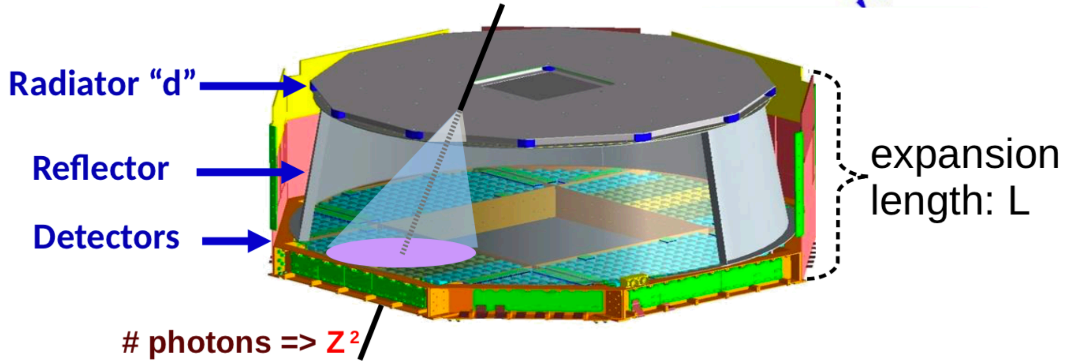
Measurement of velocity 2: Cherenkov light



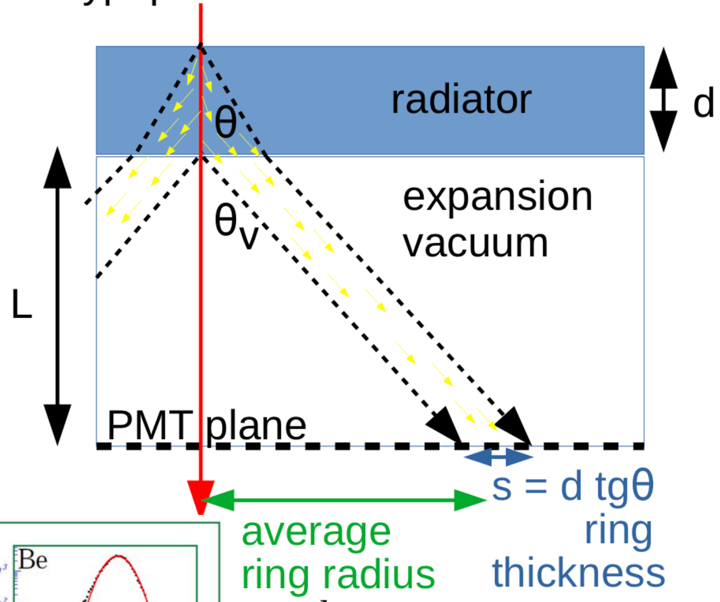


Basic equations:
1) $\cos\theta = 1/(n\beta)$ [Cherenkov]
2) $n \sin\theta = \sin\theta_V$ [Snell]

3) $N_{ph} \simeq \epsilon\, d\, 2\pi\alpha Z^2 \sin^2\theta \frac{\lambda_2-\lambda_1}{\lambda_2\lambda_1}$

$N_{ph} \simeq \epsilon\, d\, K Z^2 \sin^2\theta$

Typically K 500-1000 photons/cm:
Typ. photon coll.eff. 0.01-0.3



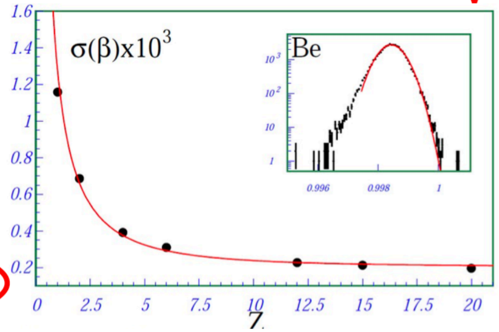
$\bar{r} = \frac{d}{2} tg\,\theta + L\, tg\,\theta_v$

some tracking helps a lot to find the ring center

Example of AMS02 RICH: L = 45cm
AeroGel n = 1.05 $\beta_{min} = 0.95$ $\sin\theta \approx 0.3$ d=2.5cm
NaF: n = 1.33 $\beta_{min} = 0.75$ $\sin\theta \approx 0.65$ d=0.5cm

$$\sigma_\beta = \sigma_r \frac{d\beta}{dr} = \frac{s}{\sqrt{12(N_{ph}-2)}} \frac{d\beta}{dr} \sim \frac{d}{L}\frac{\beta}{n} \frac{\sin^2\theta}{\sqrt{12(N_{ph}-2)}}$$

AMS02: $\langle N_{ph}\rangle \approx 3 x z^2$; $\frac{\sigma_\beta}{\beta} \sim \frac{1.2\,x\,10^{-3}}{z} \Rightarrow 10\, GeV/n$



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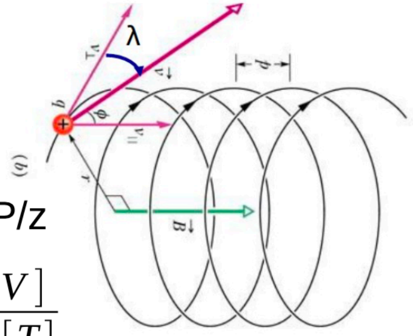
13/02/20

Measurement of momentum

Lorentz force

$$\frac{d\mathbf{P}}{dt} = z\,e\,\mathbf{v} \times \mathbf{B}$$



Helix trajectory: R=P/z

$$\rho = \frac{P_\perp}{zeB} \Rightarrow \rho[m] = \frac{R[GV]}{0.3\,B[T]}$$

Rigidity resolution:

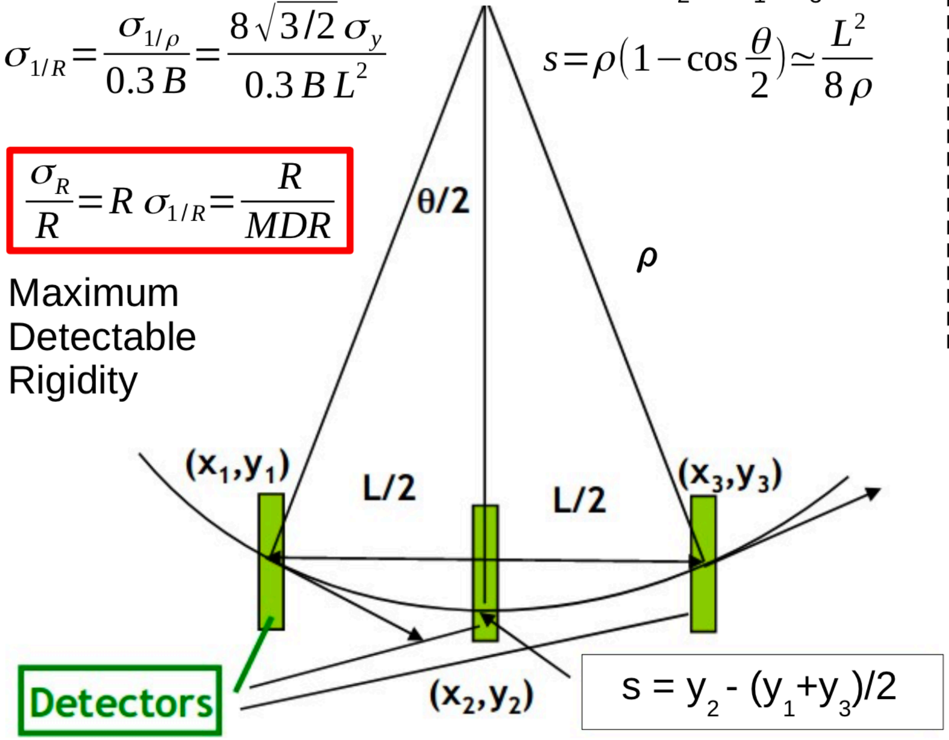
$$\sigma_{1/R} = \frac{\sigma_{1/\rho}}{0.3\,B} = \frac{8\sqrt{3/2}\,\sigma_y}{0.3\,B\,L^2}$$

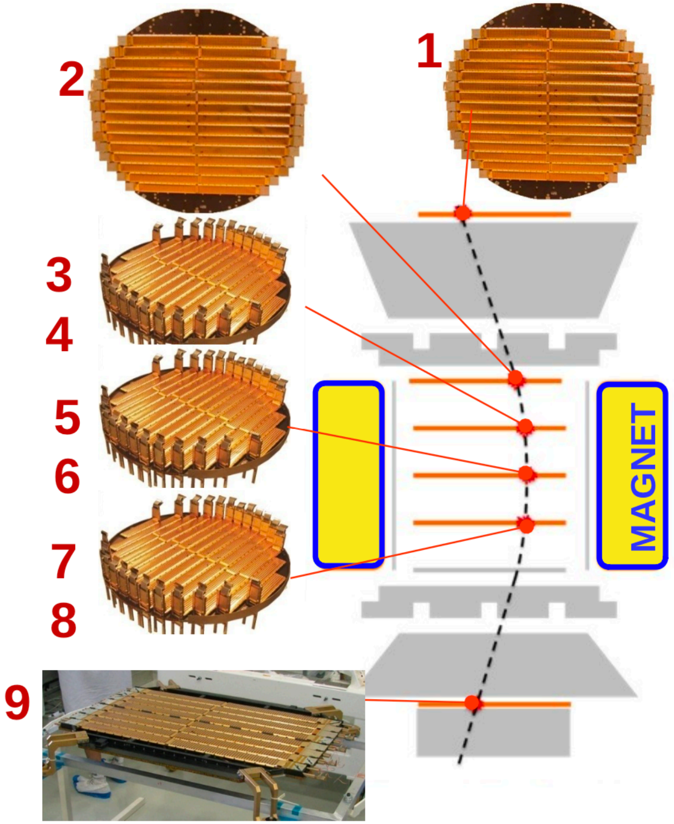
$$\frac{\sigma_R}{R} = R\,\sigma_{1/R} = \frac{R}{MDR}$$

Maximum Detectable Rigidity

Sagitta: $y_2 - (y_1+y_3)/2$

$$s = \rho\left(1-\cos\frac{\theta}{2}\right) \simeq \frac{L^2}{8\rho}$$





For a Tracker with N>>3 layers:

$$\frac{1}{MDR} = \sigma_{1/R} \simeq \sqrt{\frac{720}{N+4}}\,\frac{\sigma_y}{0.3\,B\,L^2}$$

AMS02: z=1 σ_y=10um MDR$_{(z=1)}$= 2 TV

z=2 σ_y = 5um (larger S/N)

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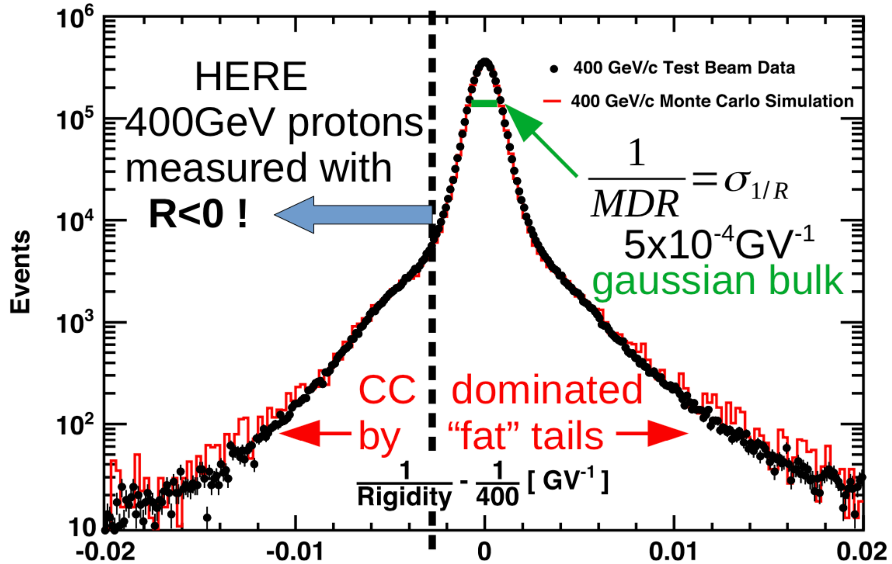
Measurement of charge-sign

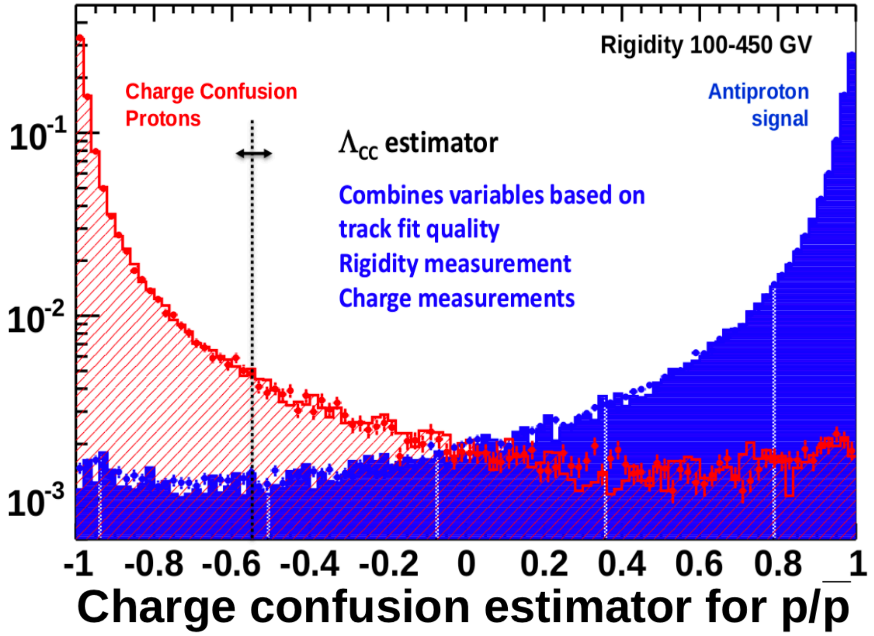


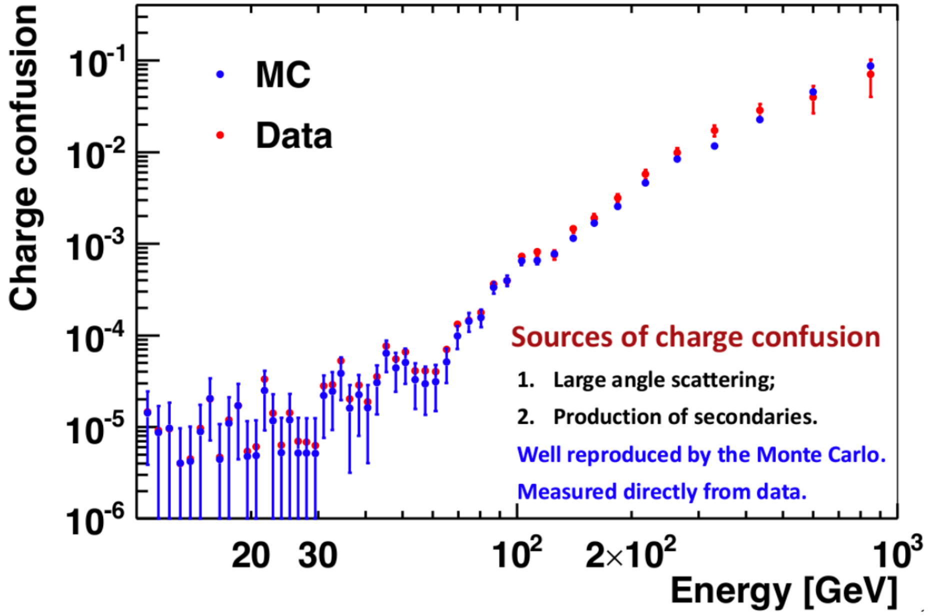
Tracker MDR = 2 TV for Z=1 particles

Charge confusion = probability of wrong charge sign measurement

<1% up to 300 GeV
<10% up to TeV

Reduction/identification by MC based multivariate analysis.





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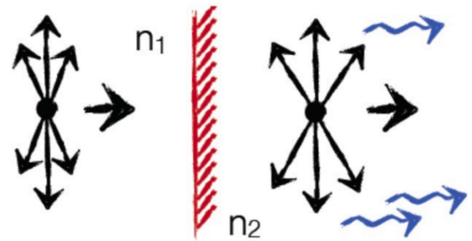
The LIMADOU Experiment on the CSES Satellite

13/02/20

Detection of transition radiation

Particle crossing an interface.



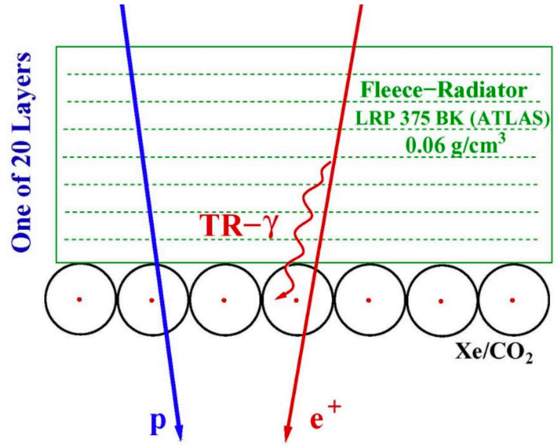
Radiated energy/crossing:

$$W = \frac{1}{3}\alpha\hbar\omega_p\gamma \qquad E_\gamma^{max} \simeq \gamma\hbar\omega_p$$

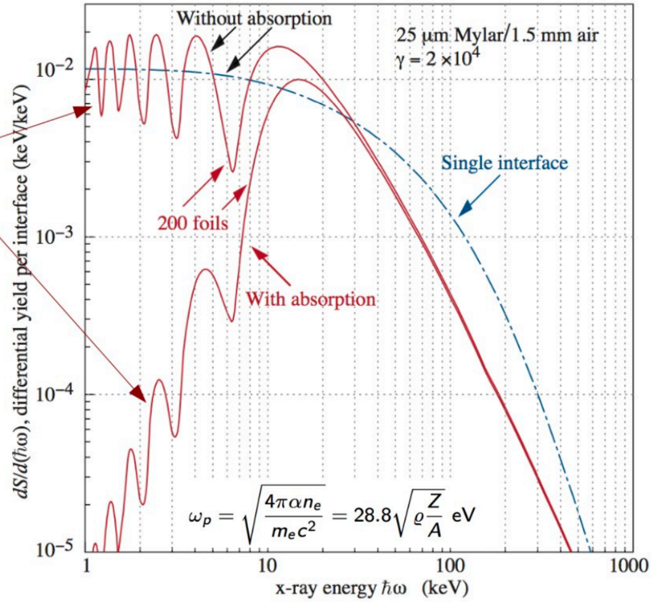
#radiated photons/crossing:

$$N \sim \frac{W}{\hbar\omega} \sim \alpha = \frac{1}{137}$$

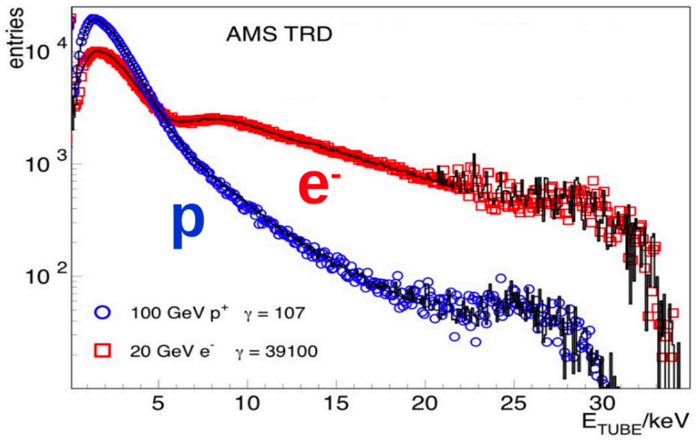
Needs a lot of interfaces!



Oscillations are due to interference between successive boundaries



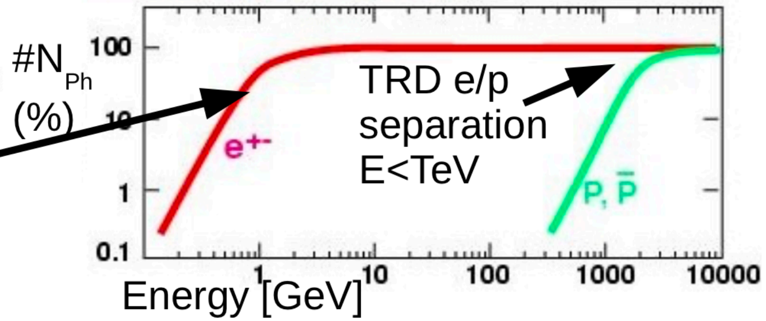
X-ray photon energy spectra for a radiator consisting of 200 25 μm thick foils of Mylar and for a single surface



Saturation of number of TRD photons $\gamma > \gamma_{sat} \sim 2000$

Not easy to perform isotopic separation…

Usually Likelihood technique adopted to do PID



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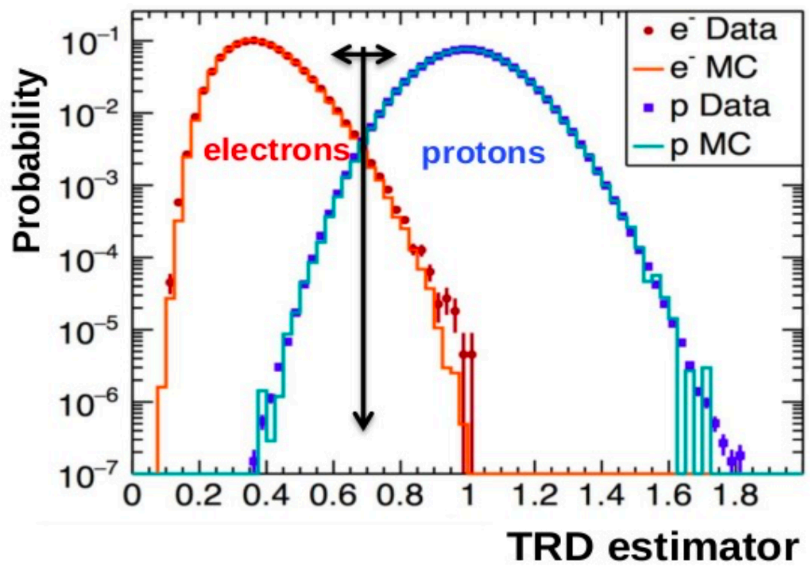
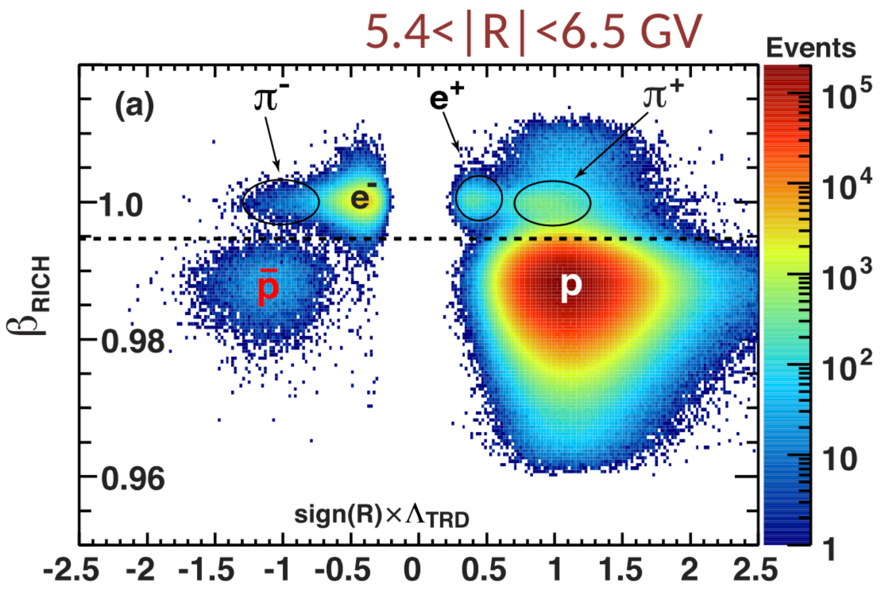
Electron/proton separation with TRD

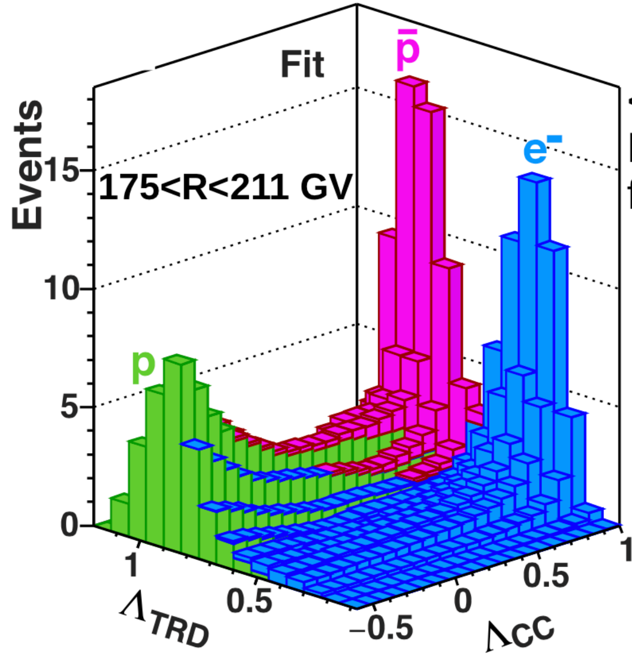
N = 20 layers

$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)} \qquad P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

TRD estimator = $-\ln(P_e/(P_e+P_p))$







<= TRD:
Mass separation
for E>>M

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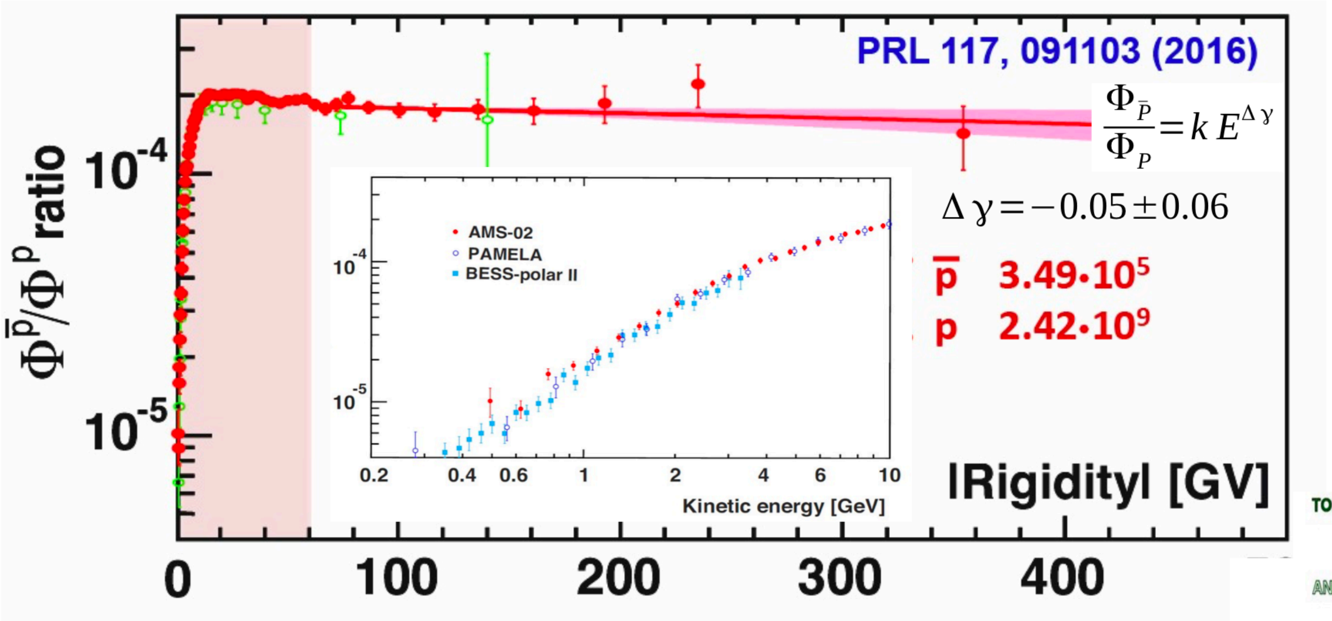
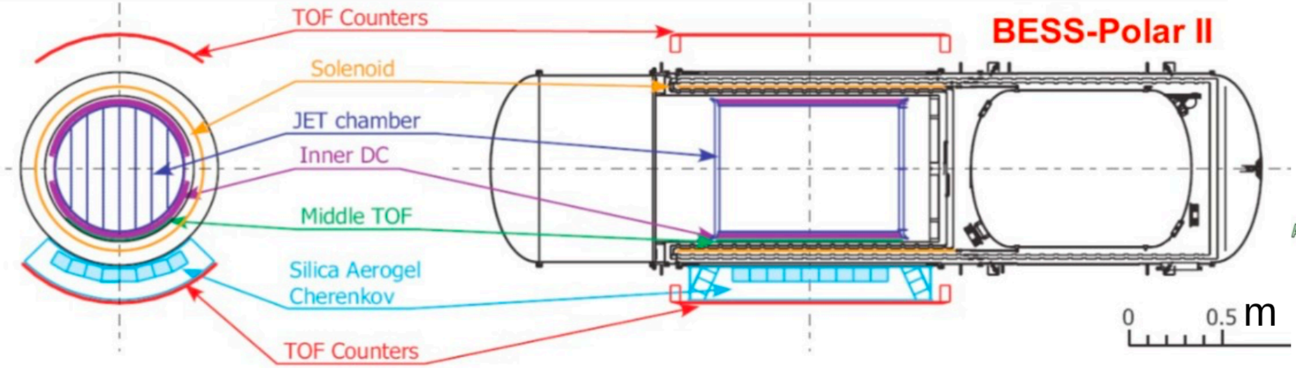
Measurement of antimatter in CRs

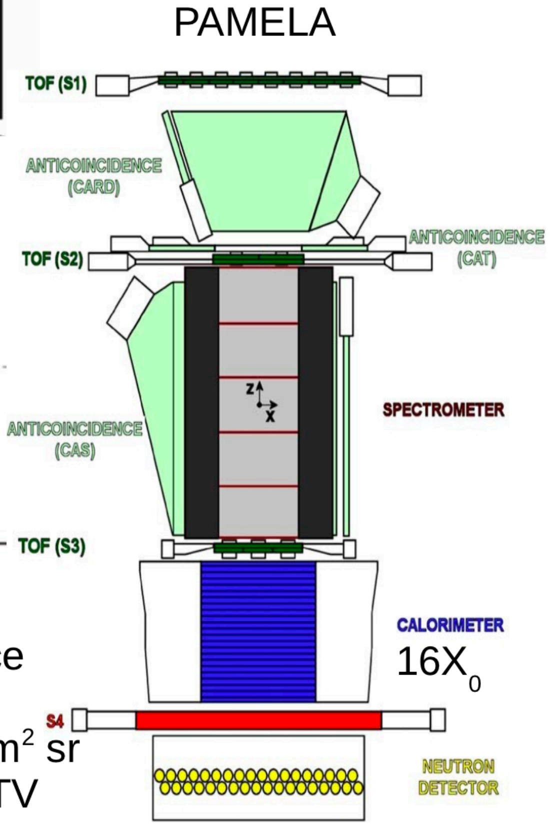


Flat antiproton ratio.

“exotic” sources?
Background model still uncertain (next slides...)



BESS-Polar II (2008-2010)
Balloon: ≈ 30gg 4.7x10^9 events
Acceptance: 3000 cm^2 sr 1500kg
1T superconducting magnet
drift chambers => MDR = 270 GV



PAMELA:
(2006-2016) in space
1.3m x 460kg
Acceptance: 21.5 cm^2 sr
0.43T => MDR = 1 TV

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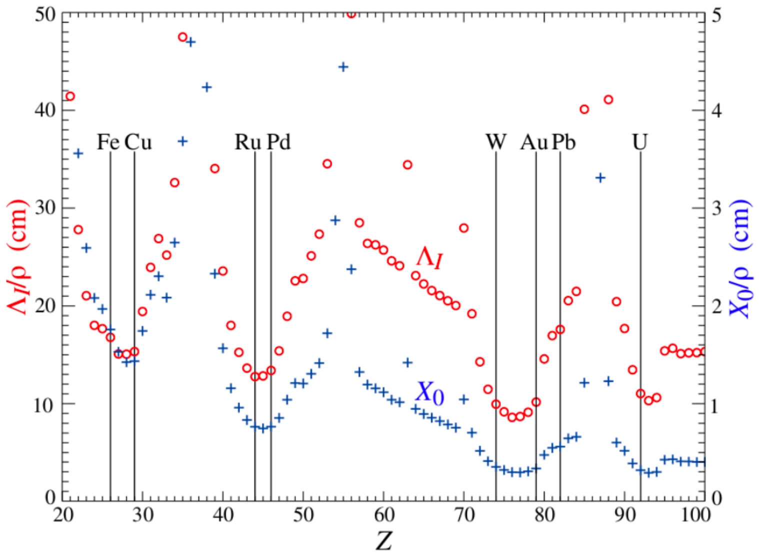
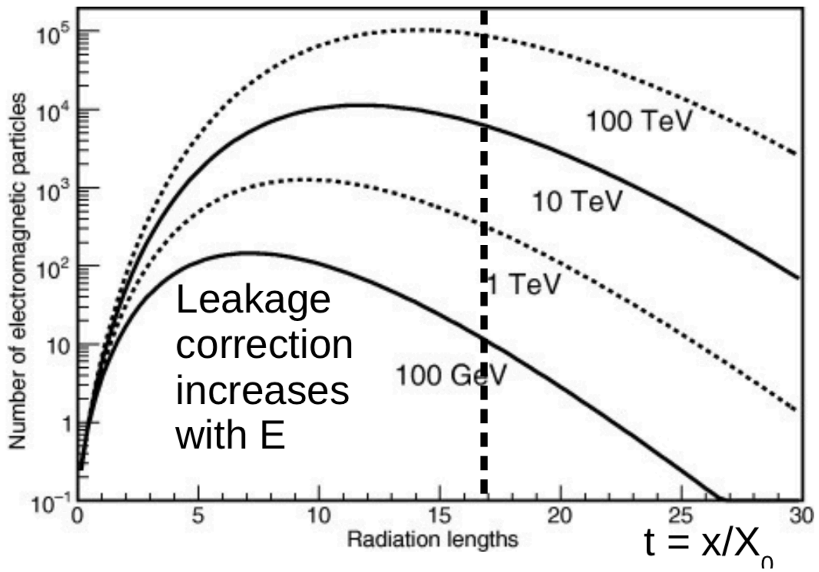
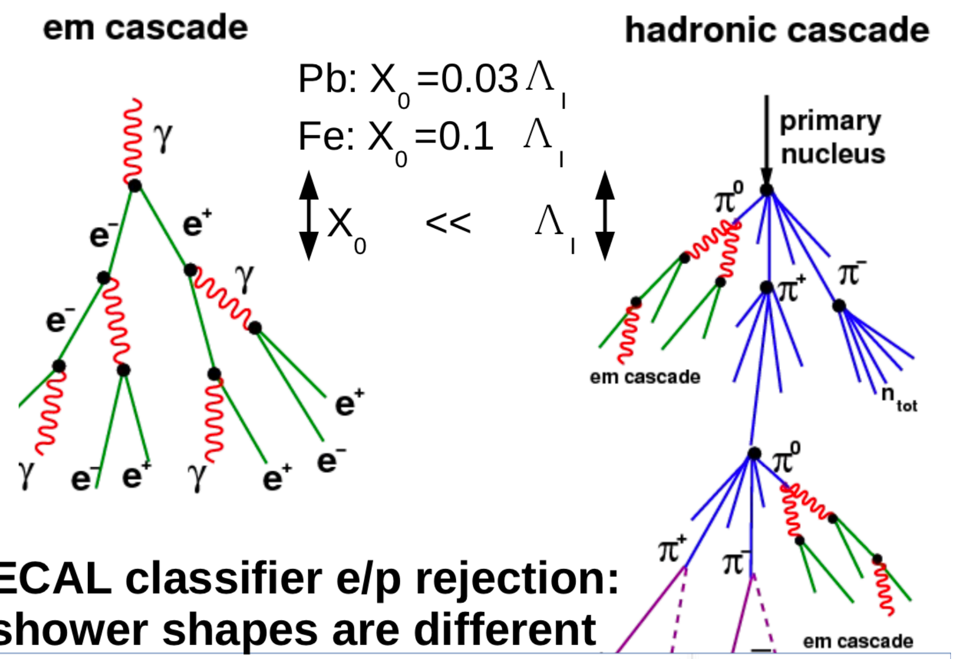
Calorimeters

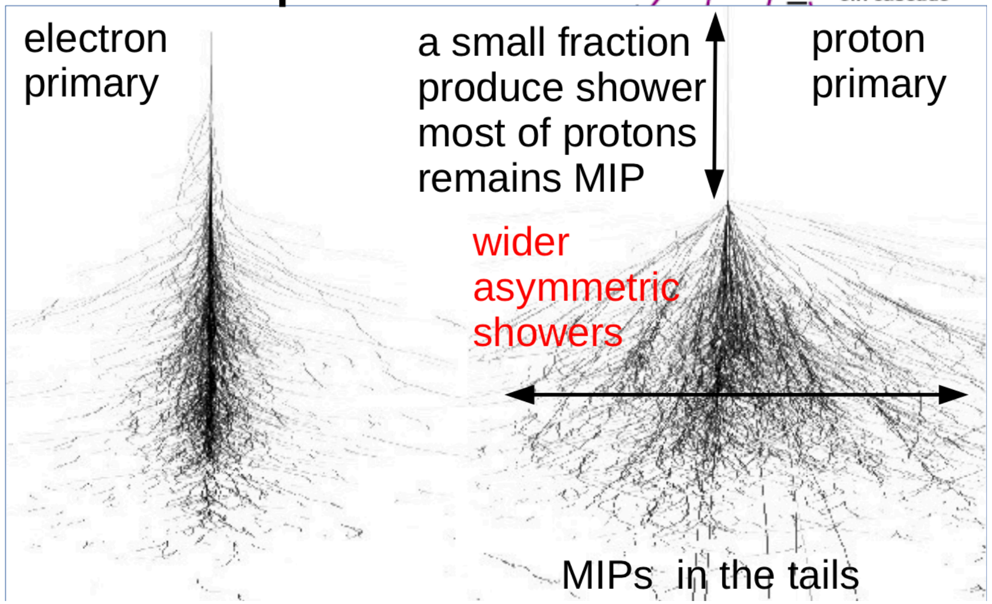


$$\frac{dE}{dt} = E_0\, b\, \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)} \qquad t_{max} = \ln\left(\frac{E}{E_c}\right) \pm 0.5$$





ECAL classifier e/p rejection: shower shapes are different



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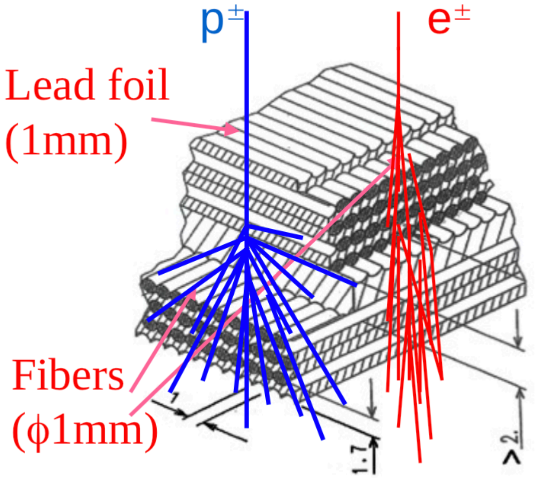
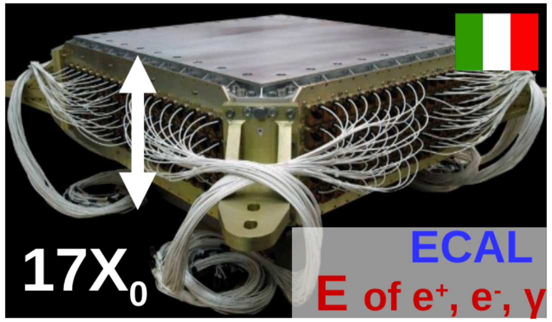
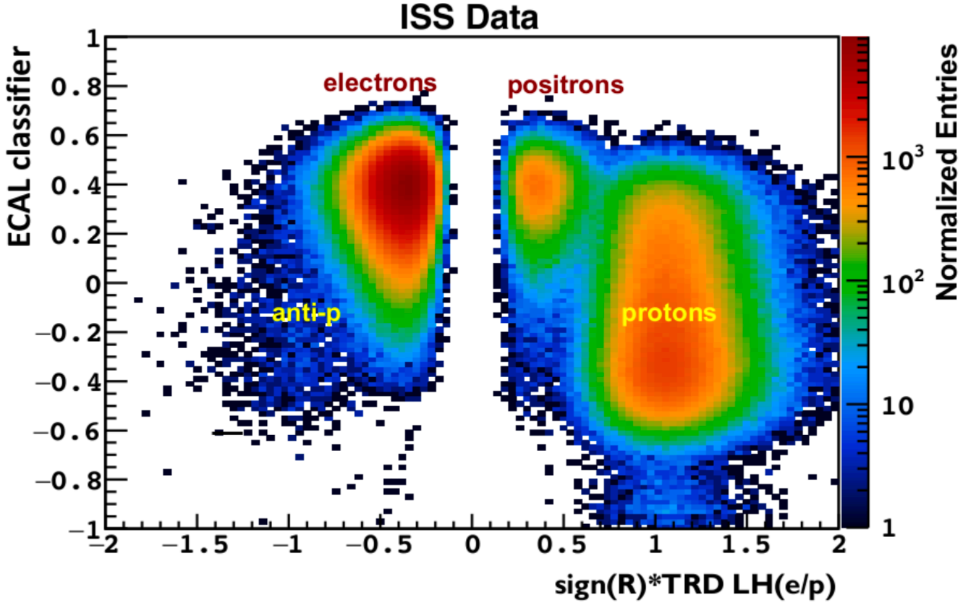
Electron/proton separation with E/P method

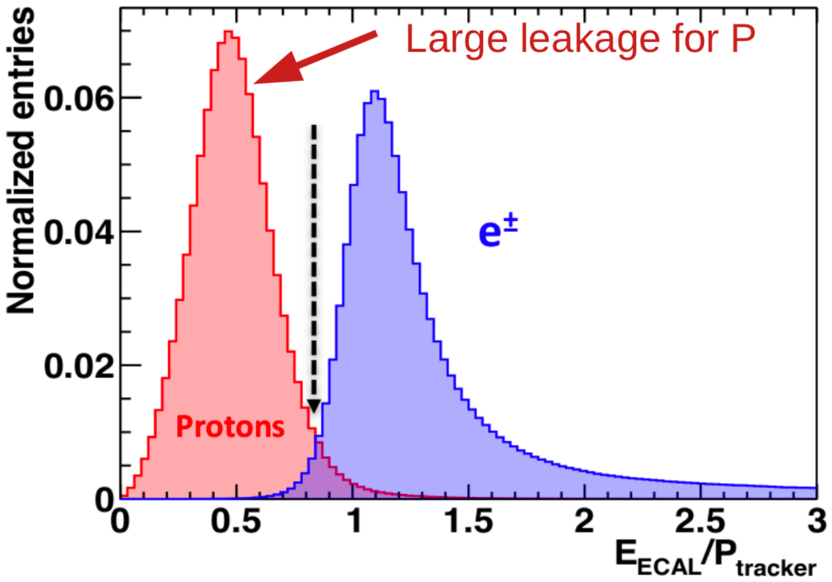
50,000 fibers, $\phi = 1$ mm
Inside 600 kg of lead





ECAL energy resolution ~2% at HE
ECAL energy absolute scale tested during test beams on ground + E/R
MIP ionization used to cross-calibrate the energy scale in flight





30

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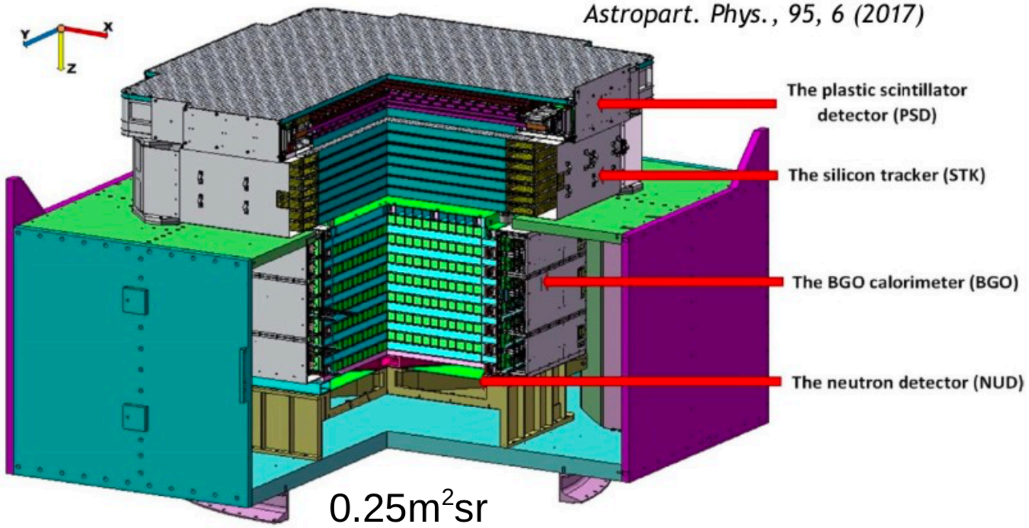
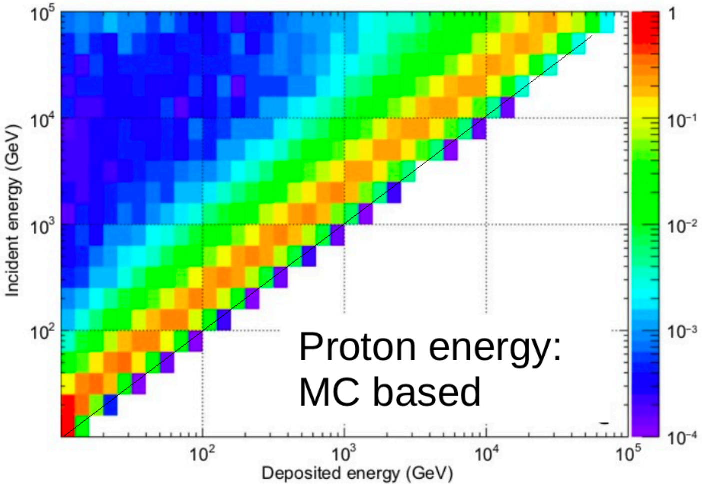
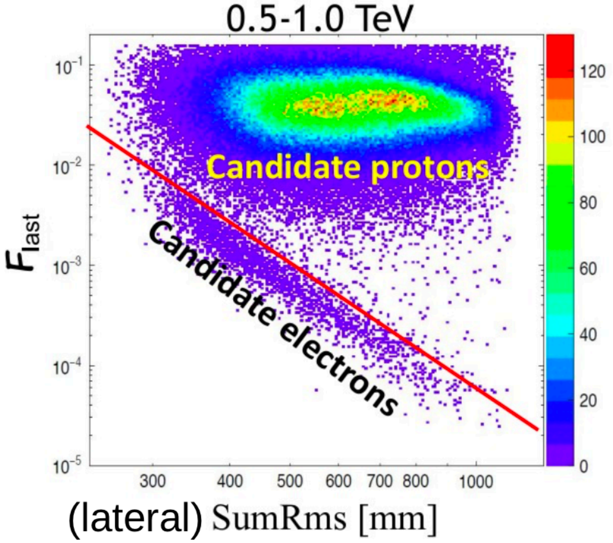
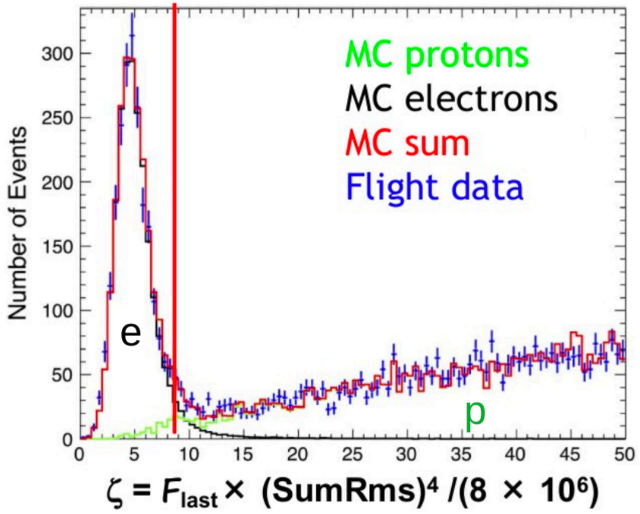
Higher energy? DAMPE



Electron: Test Beam up to 243 GeV
MC extrapolated to 5 TeV
Proton: Test Beam up to 400 GeV
MC extrapolated to 100 TeV







Proton Energy resolution:
100 GeV => 10 TeV
25% => 35%

No redundancy of
Energy scale :(

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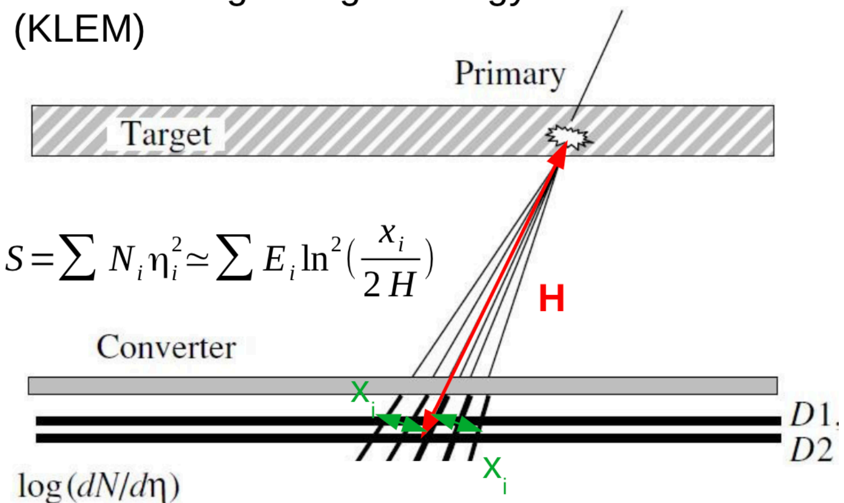
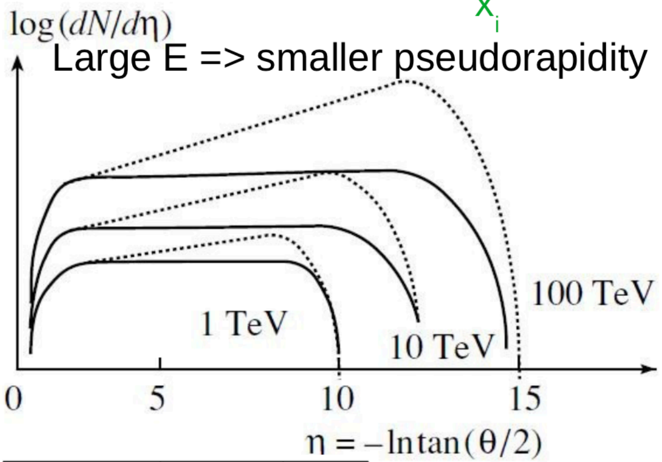
Higher energy? NUCLEON

Kinematic Lightweight Energy Method (KLEM)



$$S = \sum N_i \eta_i^2 \simeq \sum E_i \ln^2\left(\frac{x_i}{2H}\right)$$

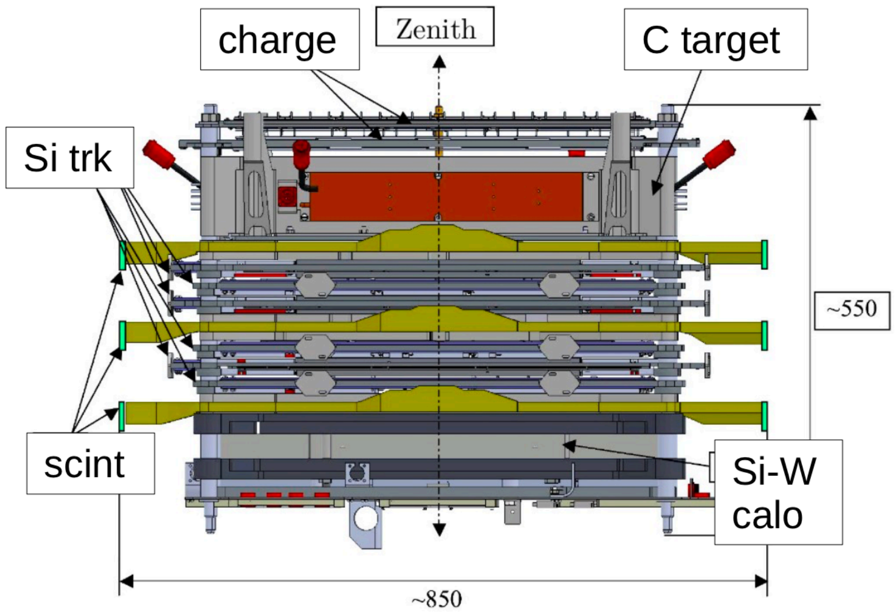
Large E => smaller pseudorapidity

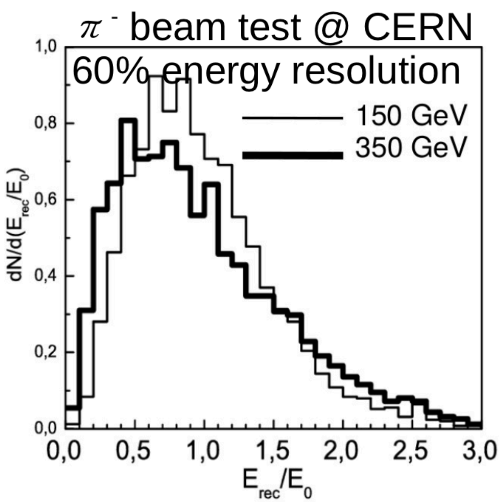


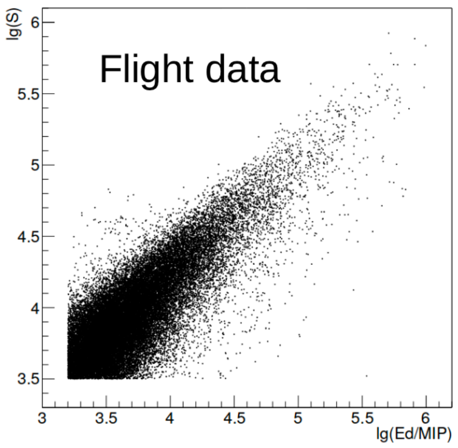
Projectile	a, GeV	b
p	1651	1.36
He	2556	1.27
C	3514	1.18
S	4163	1.14
Fe	4362	1.12

$$E_{primary} \simeq a S^b$$

Thin Calorimeter 12 X_0 350kg 0.2m^{2}sr (2017)







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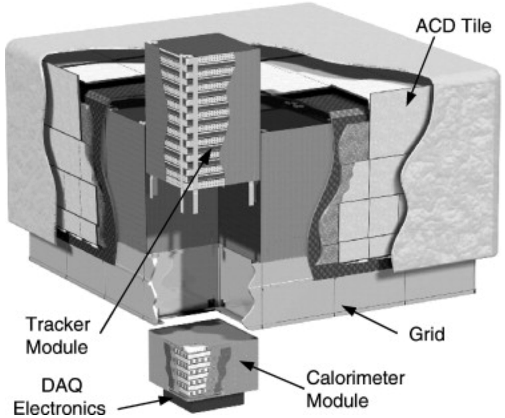
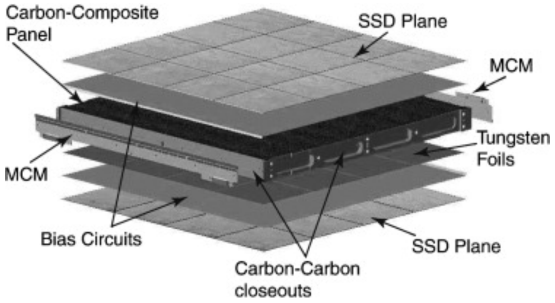
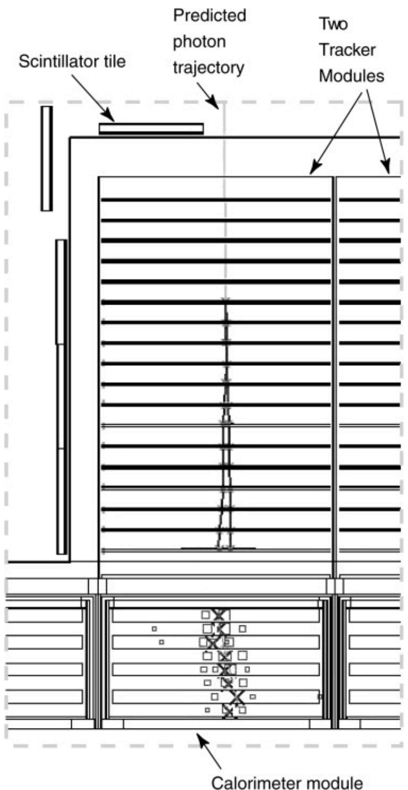
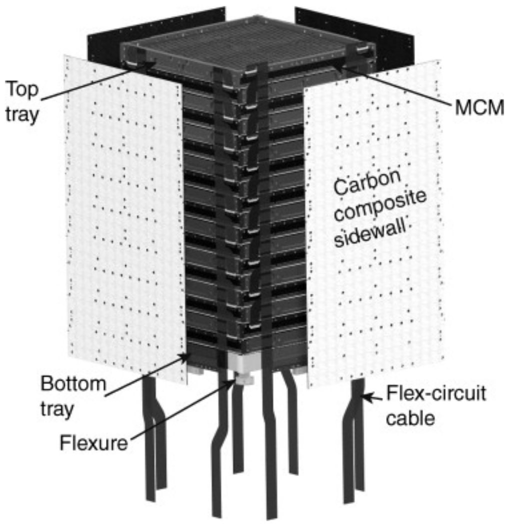
Particle detection and GeV-TeV astronomy

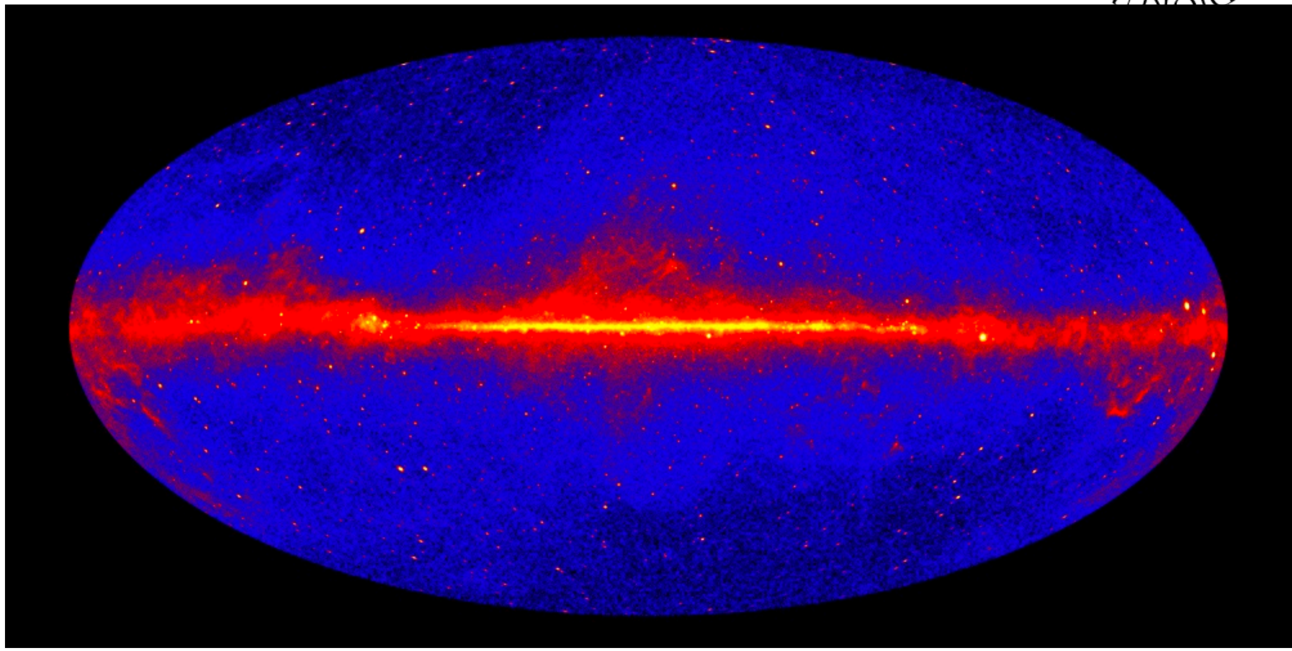


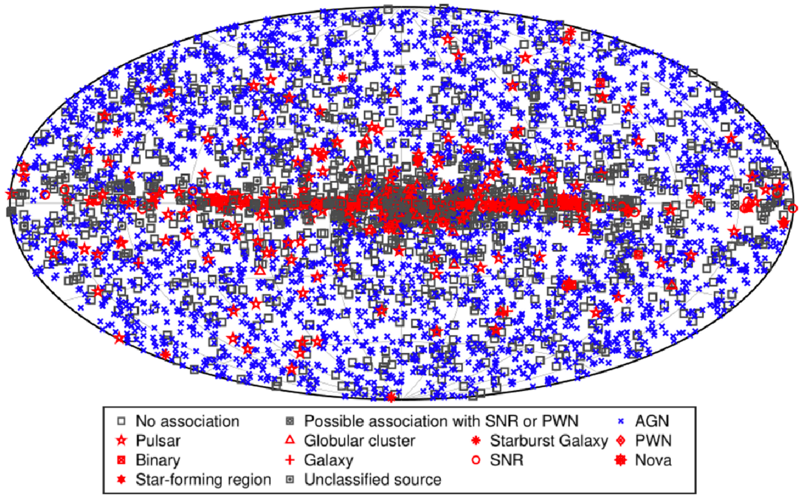






Astroparticle Physics
Volume 28, Issues 4–5, December 2007, Pages 422-434





0.1 – 10 TeV

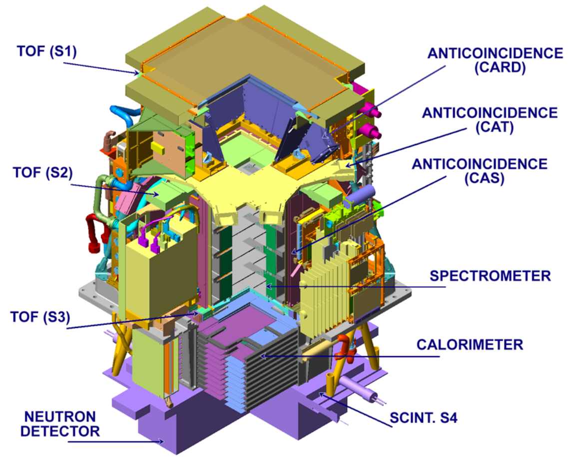
< 100 GeV

< 1 TeV

< 10 TeV

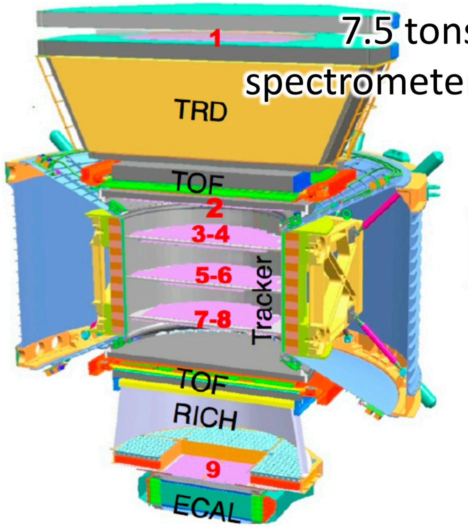
PAMELA

2006-2016
0.47 tons
spectrometer



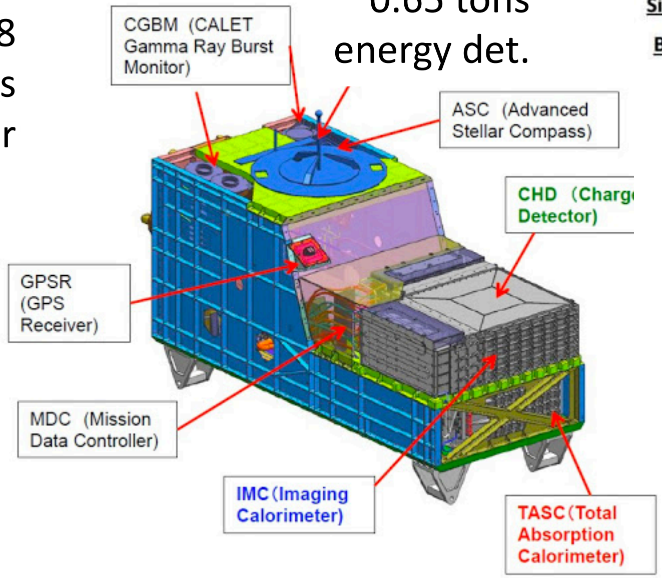
AMS-02

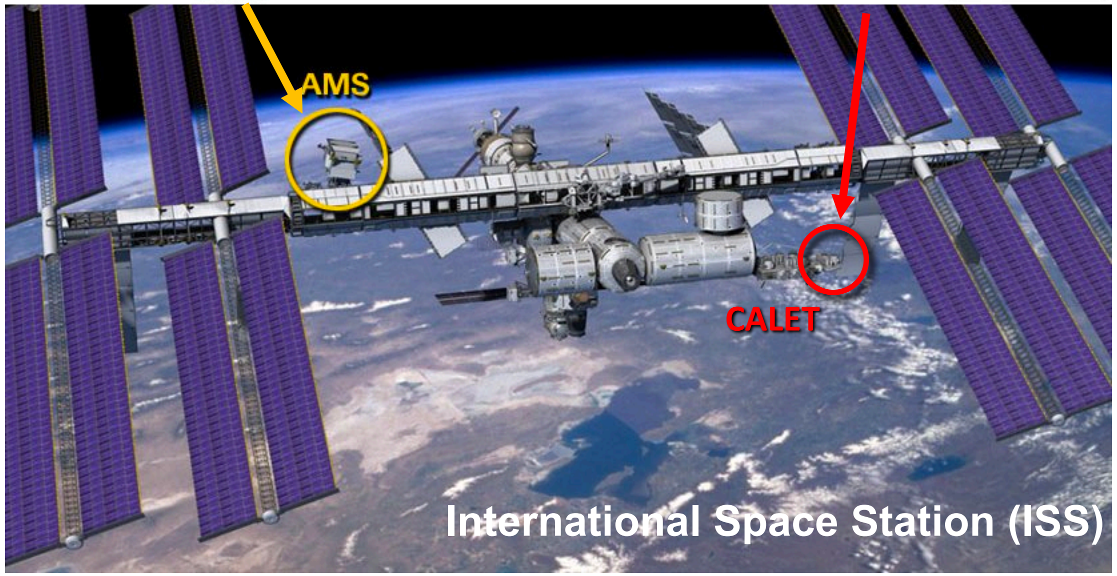
2008-2028
7.5 tons
spectrometer

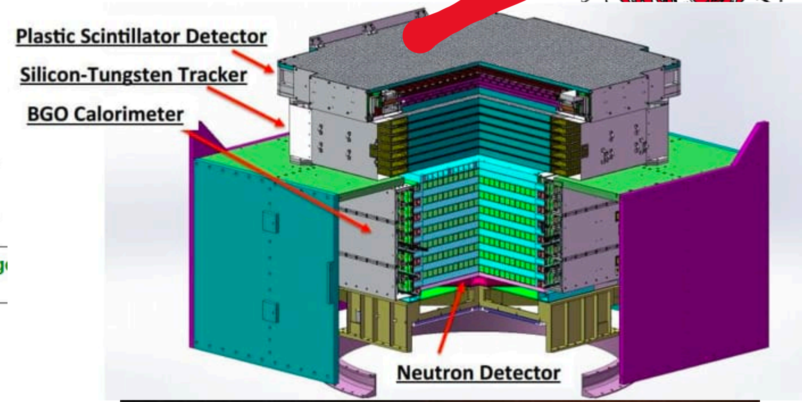


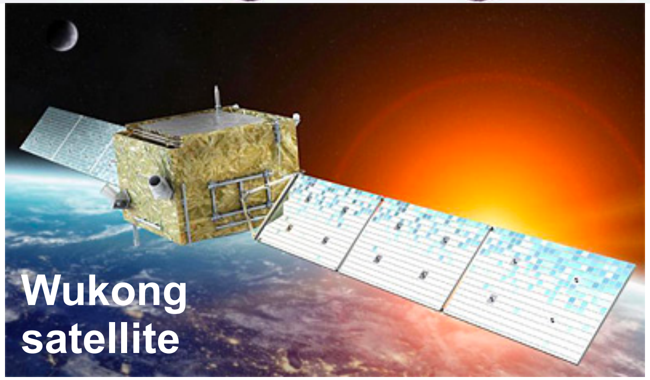
CALET

2015-2020
0.65 tons
energy det.









DAMPE

2015-2020
1.4 tons
energy detector

calorimeters:
cosmic rays (acceleration and propagation), Dark Matter (indirect detection)

spectrometers:
calorimeters+antimatter

>10 TeV (future projects)

<10 TeV (electrons)
<10 PeV/n

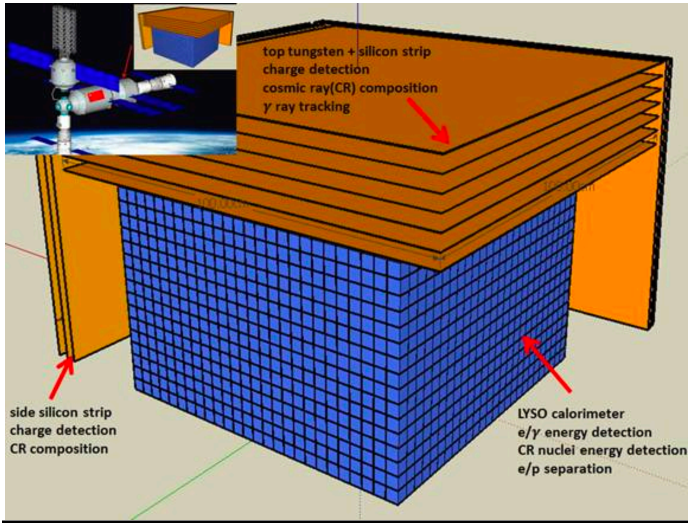
<20 TeV/e

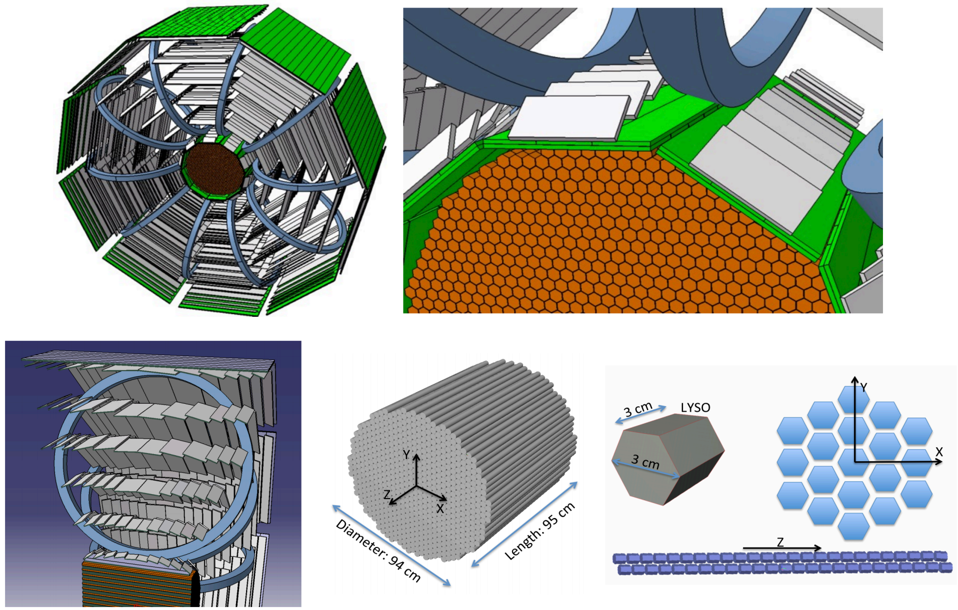
<100 TeV/e

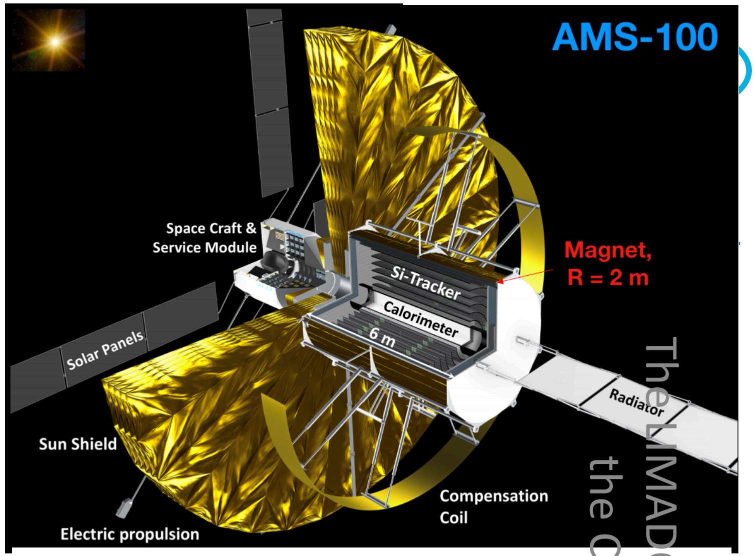
AMS-100 2035-2050?
40 tons
spectrometer

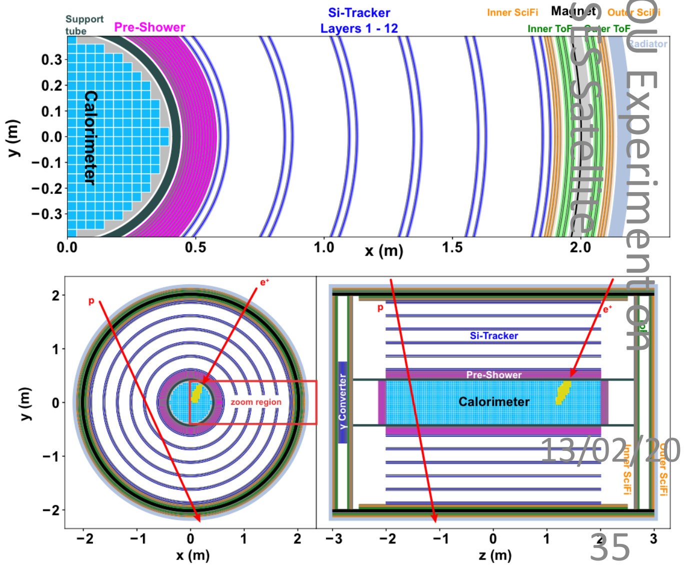
ALADINO 2030-2040?
7 tons
spectrometer

HERD 2026-2036?
4 tons
energy detector









calorimeters:
cosmic rays (origin, acceleration and propagation), Dark Matter (indirect detection)
spectrometers:
calorimeters+antimatter

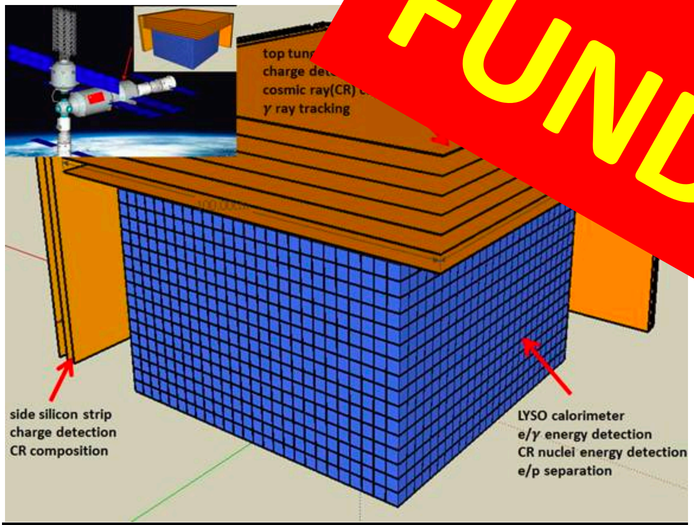
The LIMADOU Experiment on the CSES Satellite

>10 TeV (future projects)

<10 TeV (electron

<10 PeV/n

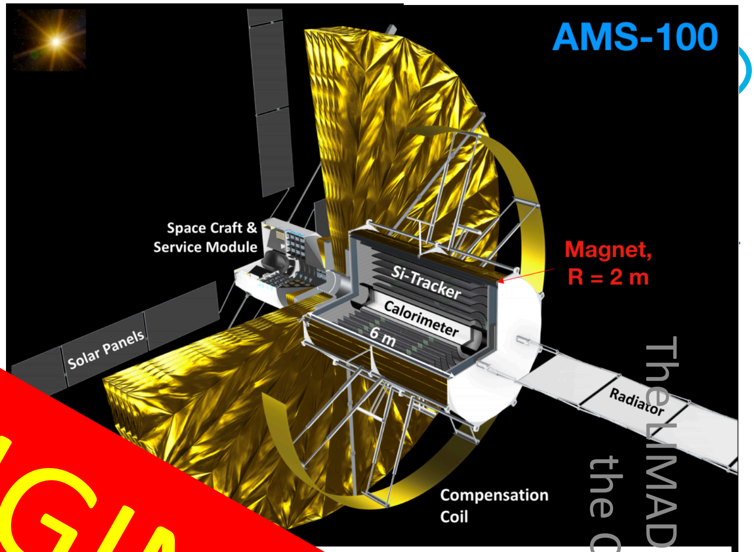
HERD

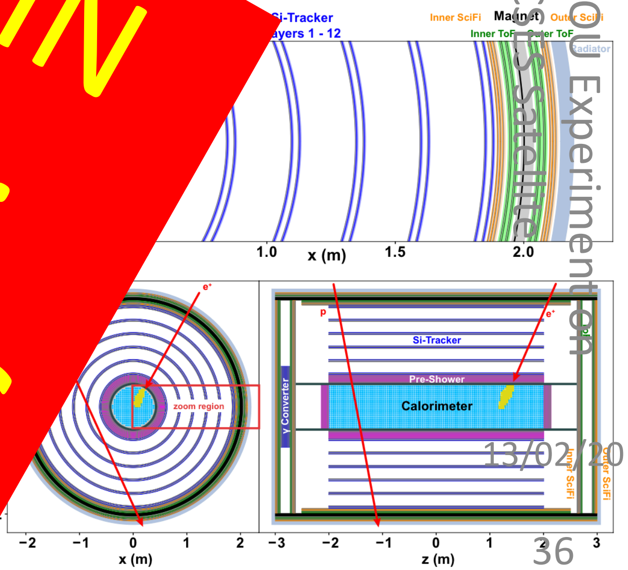


<20 TeV/e

ADINO 2030-2040?
7 tons
spectrometer

<100 TeV/e **AMS-100** 2035-2050?
40 tons
spectrometer





calorimeters:
cosmic rays (origin, acceleration a...
propagation), Dark Matter (indirect de...

spectrometers:
calorimeters+antimatter

DARK MATTER, ORIGIN OF CRs, ANITMATTER: FUNDAMENTAL PHYSICS

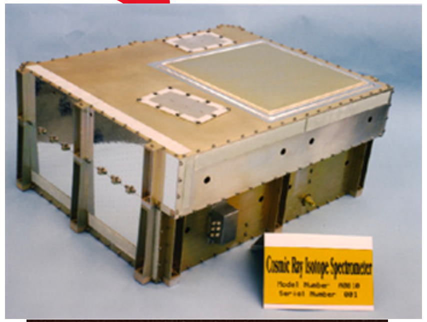
The LIMADOU Experiment on the CSS Satellite

< 100 MeV

>0.05 MeV

CRIS, EPAM, etc...

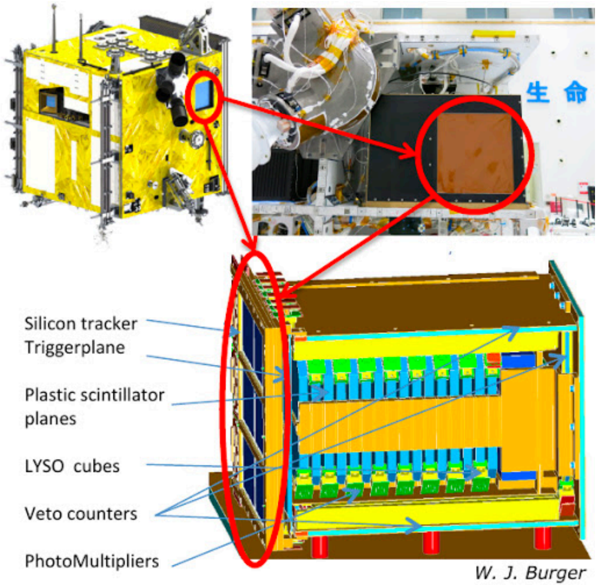
1997-2026
CRIS 30 kg
energy detector

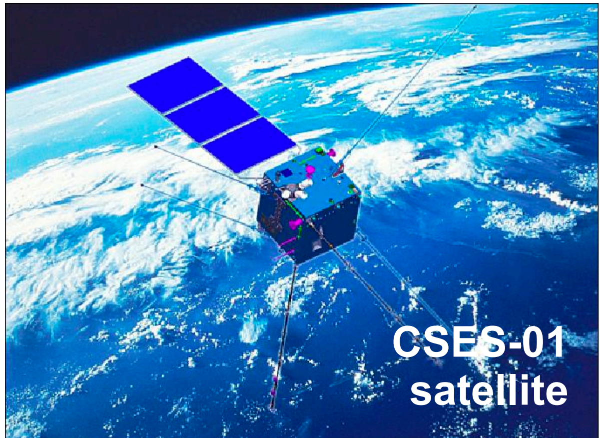


>3 MeV

HEPP/HEPD

2018-2034
HEPD 45 kg
energy detector

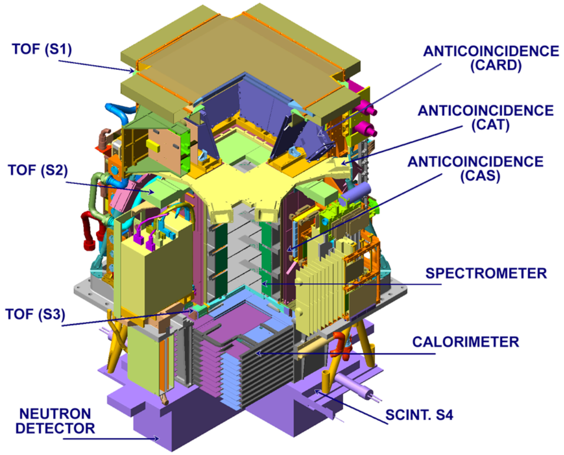




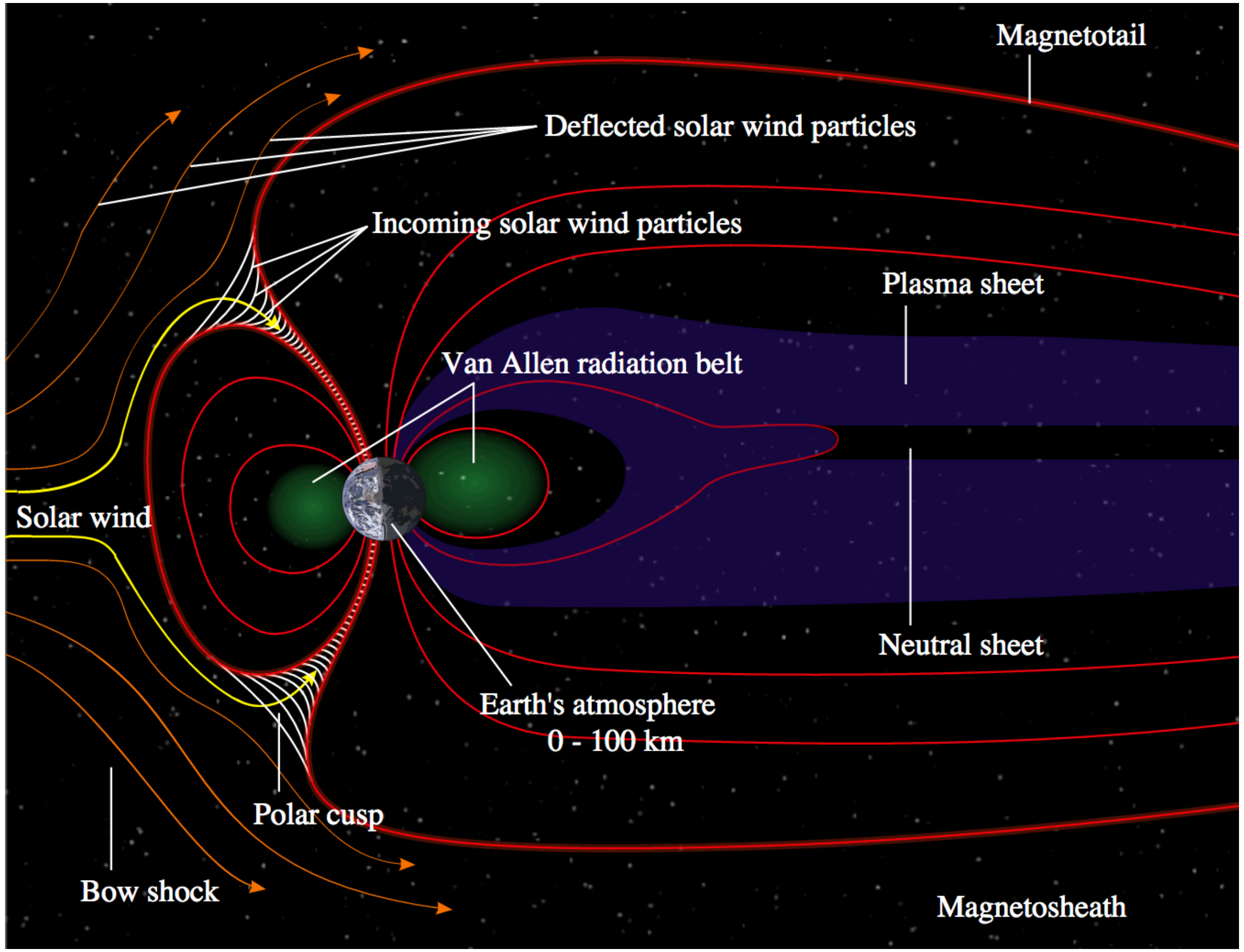
>70 MeV

PAMELA

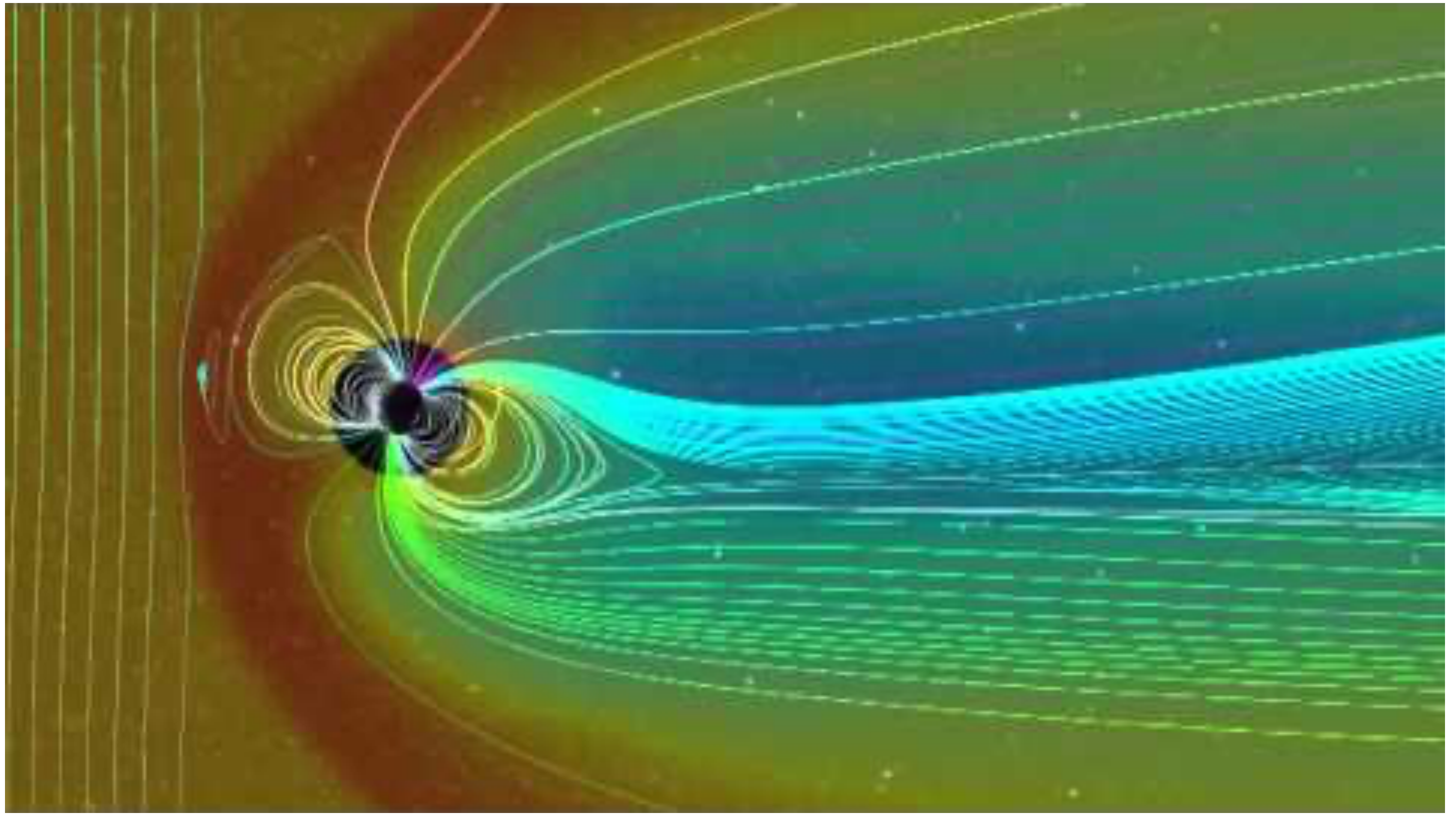
2006-2016
470 kg
spectrometer



The magnetosphere and the solar wind



“Space weather”



NASA/CP–2012-216003

Workshop Report on
Space Weather Risks and Society

Dr. Stephanie Langhoff
Chief Scientist
Ames Research Center, Moffett Field, California

Dr. Tore Straume
NASA Space Weather Working Group
Ames Research Center, Moffett Field, California

< 100 MeV

>3 MeV

>0.05 MeV

CRIS, EPAM, etc…

1997-…
CRIS…
energy d…

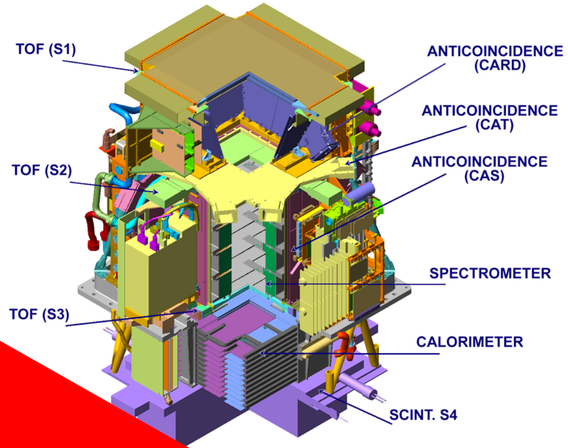
HEPP/HEPD

2018-2034
HEPD 45 kg
energy detector

>70 MeV

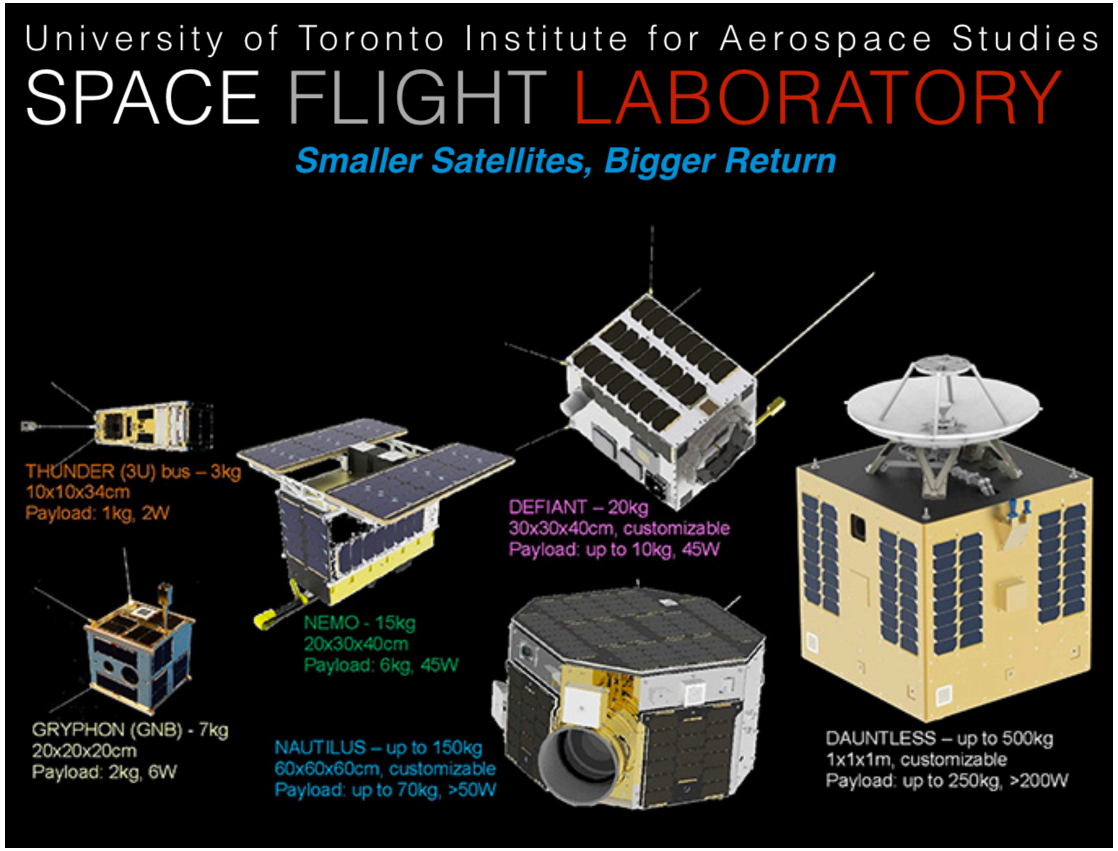
PAMELA

2006-2016
470 kg
spectrometer



**SPACE WEATHER,
EARTH SENSING:
"APPLIED" PHYSICS**

Choose your platform

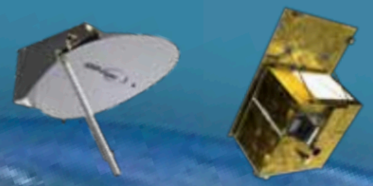


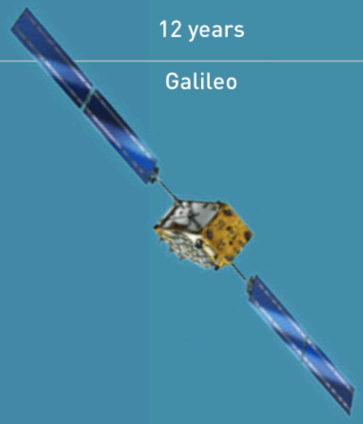
Typical Specifications – Customization Possible – Specifications Subject to Change

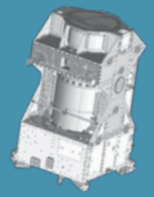
	THUNDER (3U)	GRYPHON (GNB)	NEMO	DEFIANT	NAUTILUS (NEMO-150)	DAUNTLESS
Spacecraft Mass	3.5 kg	7 kg	15 kg	20-30 kg	up to 150 kg	up to 500 kg
Spacecraft Volume	10 x 10 x 34cm	20 x 20 x 20 cm	20 x 30 x 40 cm	30 x 30 x 40 cm	60 x 60 x 60 cm	1 x 1 x 1 m
Peak Power 25°C,BOL	2-7 W	7 – 9 W	50 – 100 W	50 – 100 W	up to 500W	up to 1kW
Payload Mass	1 kg	2 kg	6 kg	6-10 kg	up to 70 kg	up to 250 kg
Payload Volume	1,000 cm^3	1,700 cm^3	8,000 cm^3	11,000 cm^3	up to 108,000 cm^3	up to 0.5 m^3
Payload Power @ duty cycle	1-2 W @100%	3-4 W @100%, 6 W max.	45 W @40% min., 65 W max.	45 W @ 40% min, 65 W max	50W or higher	200 W or higher
ACS stability	~2° (1)	~2° (2) ~60″ (3)	~2° (2) ~10-60″ (3)	~2° (2) ~10-60″ (3)	~2° (2) ~10-20″ (3)	~2° (2) ~10-20″ (3)
Downlink	32 kbps – 1 Mbps	32 kbsp – 2 Mbps	32 kbps – 2 Mbps	32 kbsp – 50 Mbps	32kbps – 50Mbps	32kbps – 200Mbps
Propulsion	cold gas	cold gas	cold gas, resistojet, monopropulsion	cold gas, resistojet, monopropulsion	cold gas, resistojet, monopropulsion, Hall thruster	cold gas, resistojet, monopropulsion, Hall thruster
Navigation	GPS, 5-10m	GPS, 5-10m	GPS, 5-10m	GPS, 5-10m	GPS, 5-10m	GPS, 5-10m
Launch Interface	XPOD-Triple	XPOD GNB	XPOD Duo, XPOD Delta	Separation System	Separation System	Separation System
Mission Heritage	CanX-2, NTS, CanX-7	NTS, AISSat Constellation, BRITE Constellation, EV9, CanX-4, CanX-5	NEMO-AM, GHGSat-D, NORSAT-1, NORSAT-2, DMSat-1	Gray Jay	NEMO-HD	LEO 2

Choose your platform

OHB	SmartLEO	SmartLEO Agile	SmartMEO	SmallGEO	Interplanetary
Orbit	Low Earth Orbit	Low Earth Orbit	Medium Earth Orbit, Low Earth Orbit	Geostationary Orbit, High Earth Orbit	Interplanetary, Sun/Earth Langrange Points
Typical Applications	Earth Observation, Reconnaissance and Science	Agile (multi-targeting, fast slewing) Earth Observation, Reconnaissance and Science	Navigation and Series Production	Telecommunication, Earth Observation and Meteorology	Interplanetary Transfer, Carrying of Lander and Mars Orbiting
Launch Mass	600 – 1,100 kg	1,900 – 2,100 kg	700 – 800 kg	2,400 – 3,800 kg	up to 4,400 kg
Payload Mass	up to 400 kg	up to 600 kg	up to 300 kg	up to 900 kg	up to 800 kg
Payload Power	up to 500 W	up to 1 kW	up to 1,1 kW	up to 10 kW	up to 2 kW
Lifetime	3 – 12 years	3 – 12 years	12 years	8 – 15 years	2 – 8 years
Heritage	SAR-Lupe, EnMAP	SARah	Galileo	Hispasat 36W-1, EDRS-C, Electra, MTG	ExoMars TGO







Choose your platform (not necessarily big)

The CubeSat standard was created by California Polytechnic State University, San Luis Obispo and Stanford University's Space Systems Development Lab in 1999 to facilitate access to space for university students. Since then the standard has been adopted by hundreds of organizations worldwide. CubeSat developers include not only universities and educational institutions, but also private firms and government organizations.

2010

Planet Founded

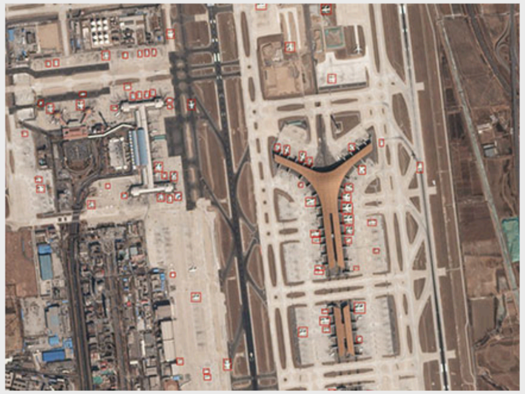
December 29, 2010

Planet Labs is founded by ex-NASA scientists, Will Marshall, Robbie Schingler, and Chris Boshuizen, with a goal to use space to help life on Earth. The founders and a small group of physicists and engineers began building Planet's first satellite in a garage in Cupertino, California.

2014

Mission 1 Established

CEO Will Marshall takes the stage at TED to announce Planet's Mission 1 - to image the entire Earth's surface every day and make global change visible, accessible, and actionable.



2018

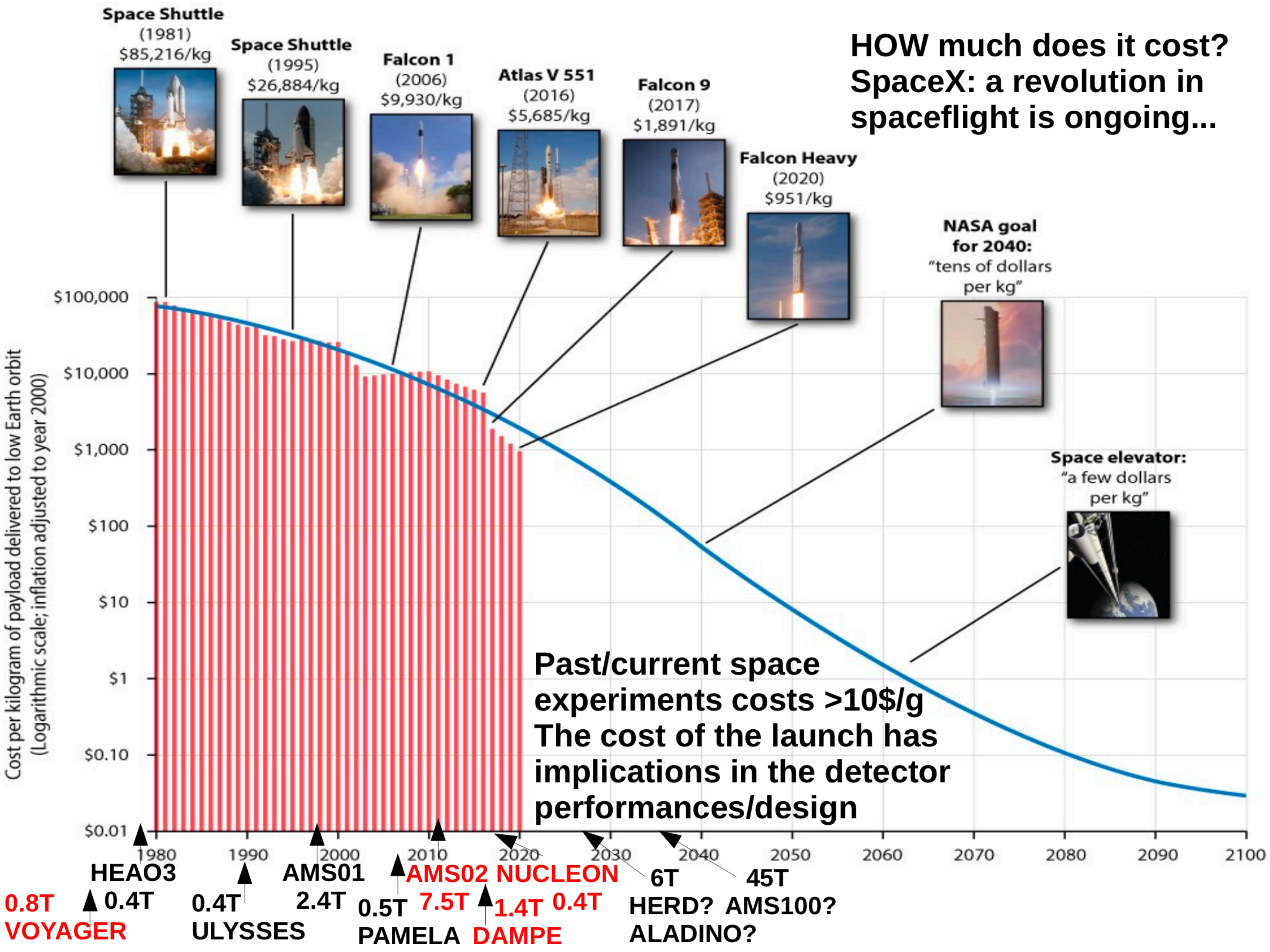
Planet Analytics Beta Launched

July 18, 2018

Planet unveils the beta release of Planet Analytics, a product suite that leverages machine learning to transform global, daily satellite imagery into information feeds that detect and classify objects, identify geographic features, and monitor change over time.

Choose your launcher

HOW much does it cost?
SpaceX: a revolution in spaceflight is ongoing...



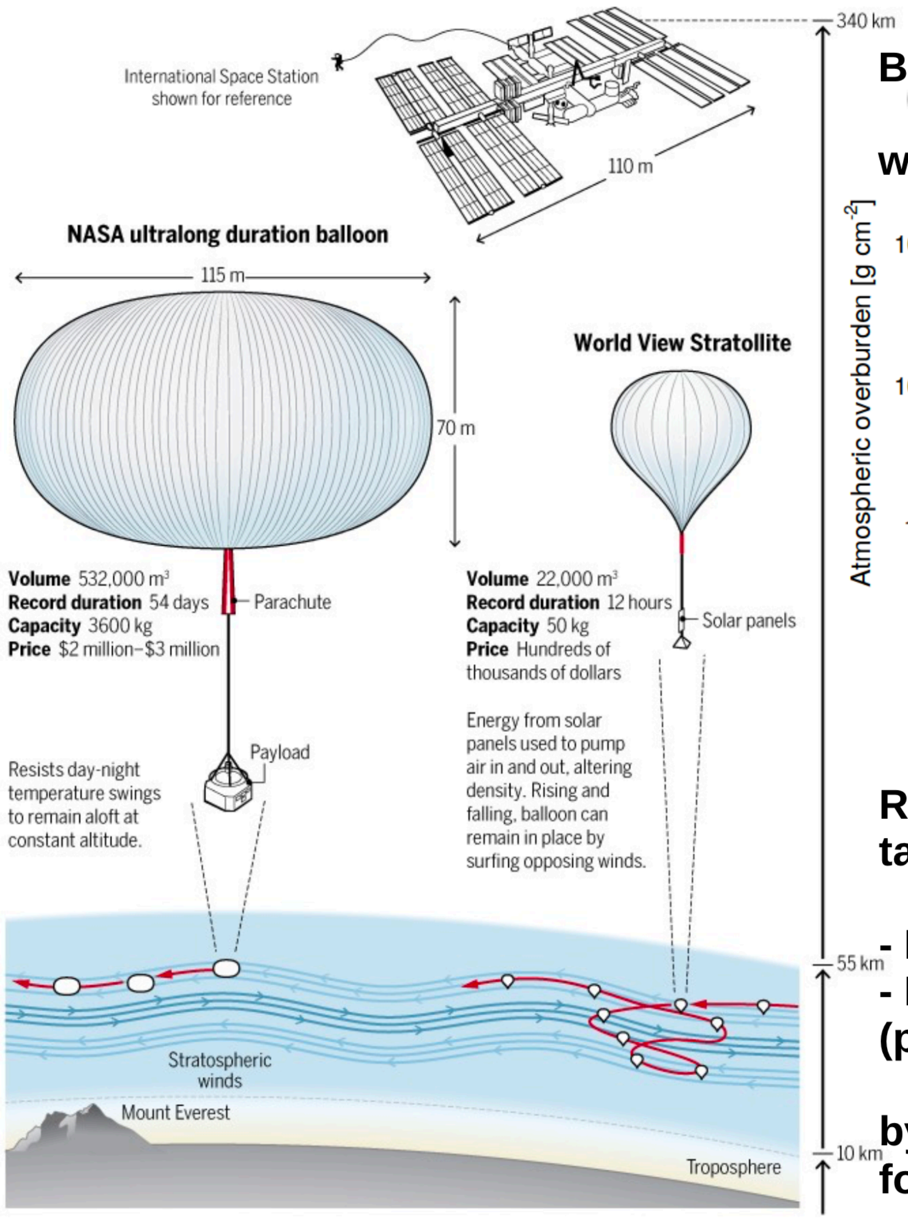
Past/current space experiments costs >10$/g
The cost of the launch has implications in the detector performances/design

Roberto Iuppa

The LIMADOU Experiment on the CSES Satellite

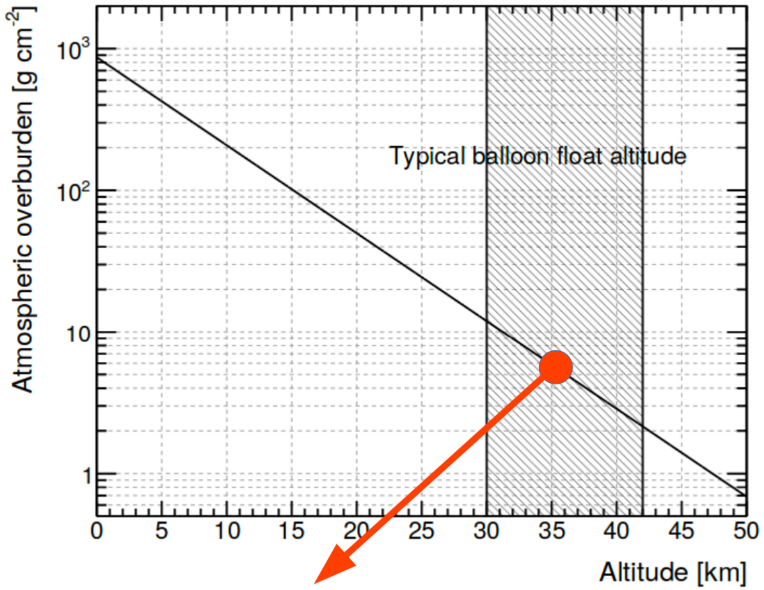
13/02/20

Balloons are an option…



Balloons? Not really cheaper now …

was an option for past experiments



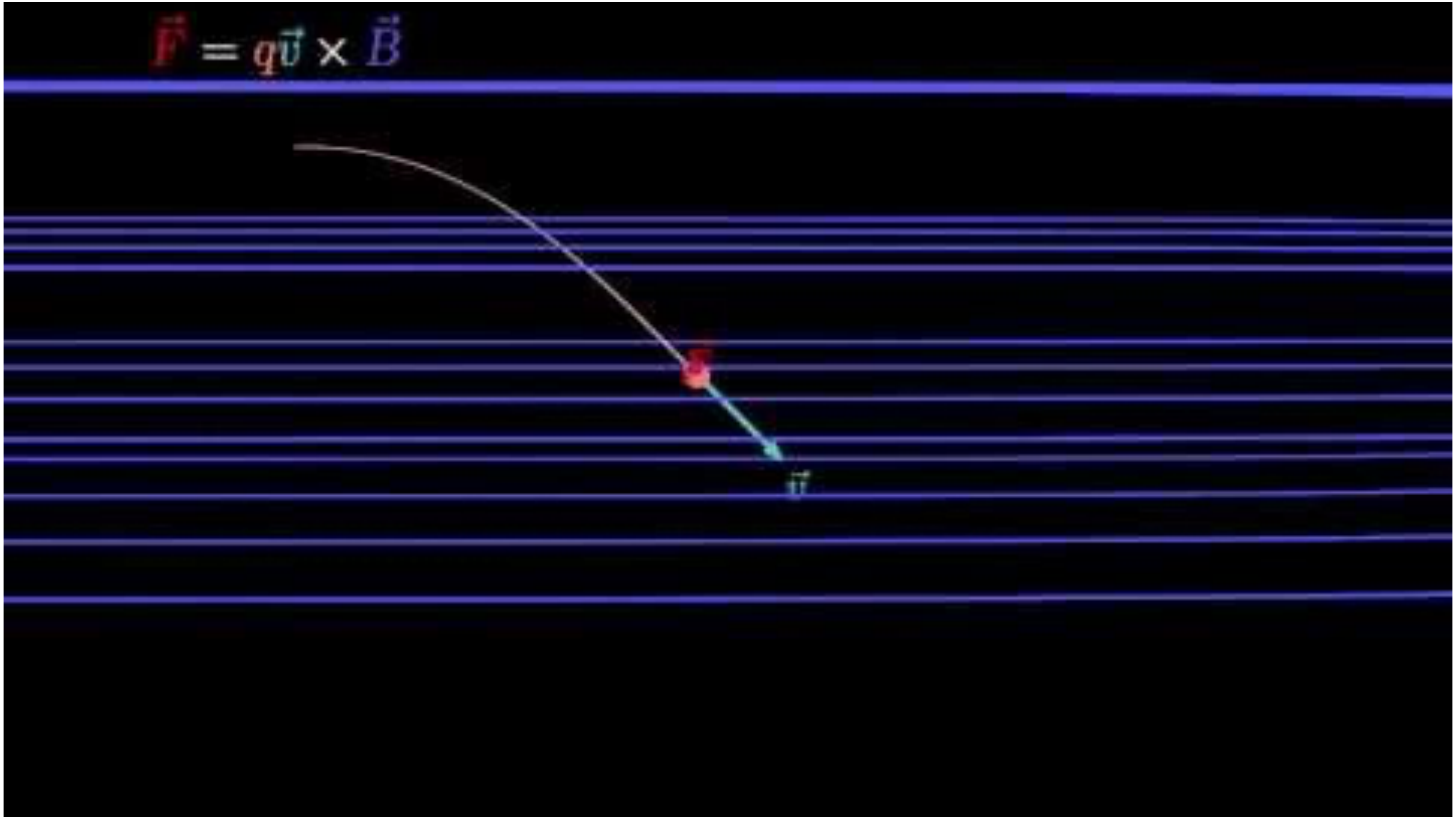
Residual atmosphere is a passive target: the same of 5 cm of plastic

- Fragmentation effects
- Production of secondary particles (problem for antimatter search)

by comparison Galaxy grammage for CR typ. path lenght is ~2 g/cm^2

Roberto Iuppa

Magnetic bottles and Van Allen belts



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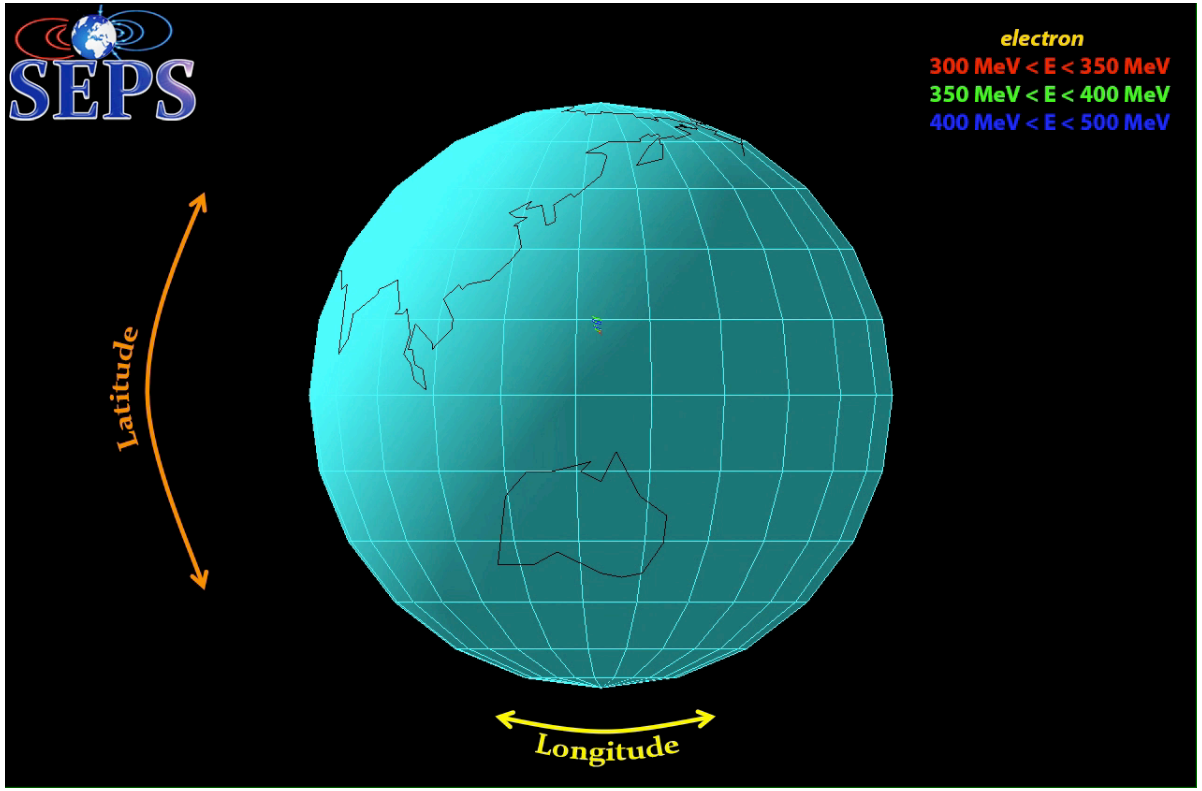
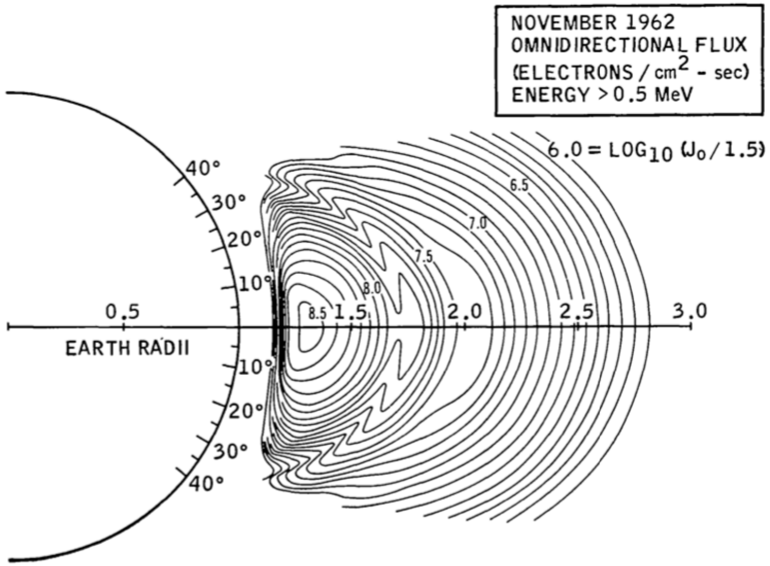
Van Allen belts





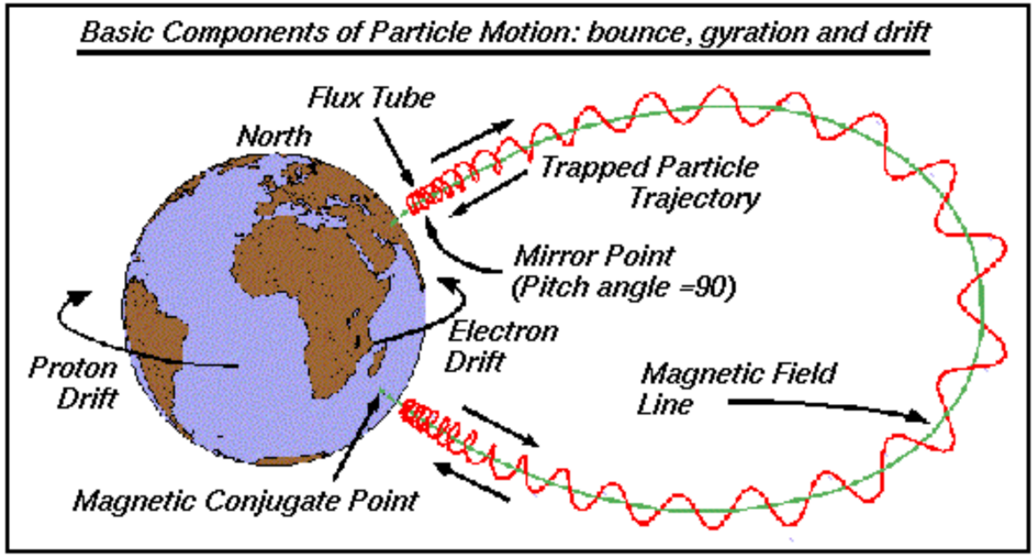
L - shell

Fig. 18. Contours of constant omnidirectional intensity of electrons greater than 0.5 MeV in November 1962 plotted in R-λ space. The horizontal line represents the magnetic equator (McIlwain, 1966b).

courtesy of W.J. Burger

Trapped particles: adiabatic invariants

Roberto Iuppa



Three adiabatic invariants:

$$J_1 = \frac{\pi p_\perp^2}{qB} \Rightarrow \frac{p^2 \sin^2 90^o}{2 m_o B_m} = \frac{p^2 \sin^2 \alpha}{2 m_o B}$$

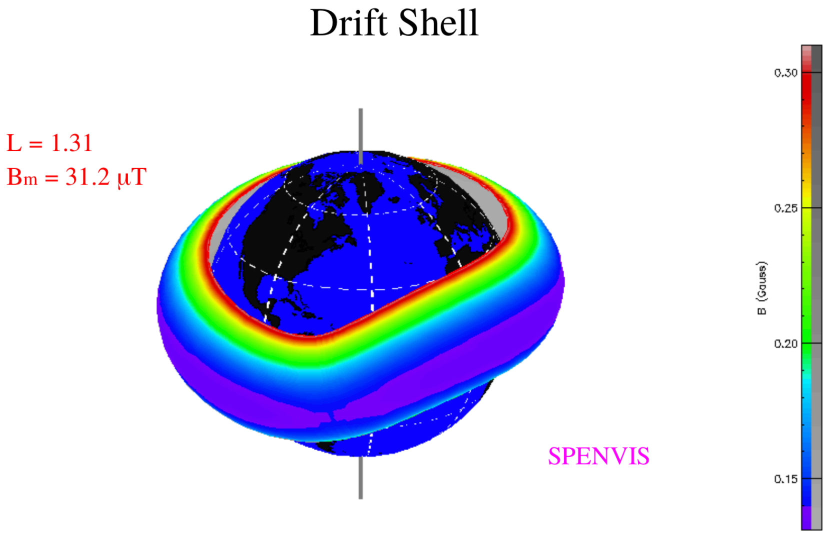
Gyration orbit (pitch angle)
constant magnetic moment

$$\frac{J_2}{2p} = \frac{1}{2}\oint \cos\alpha \, ds = \int_{s_m}^{s'_m} \sqrt{1 - \frac{B(s)}{B_m}} \, ds$$

Bounce motion between mirror points
integral invariant

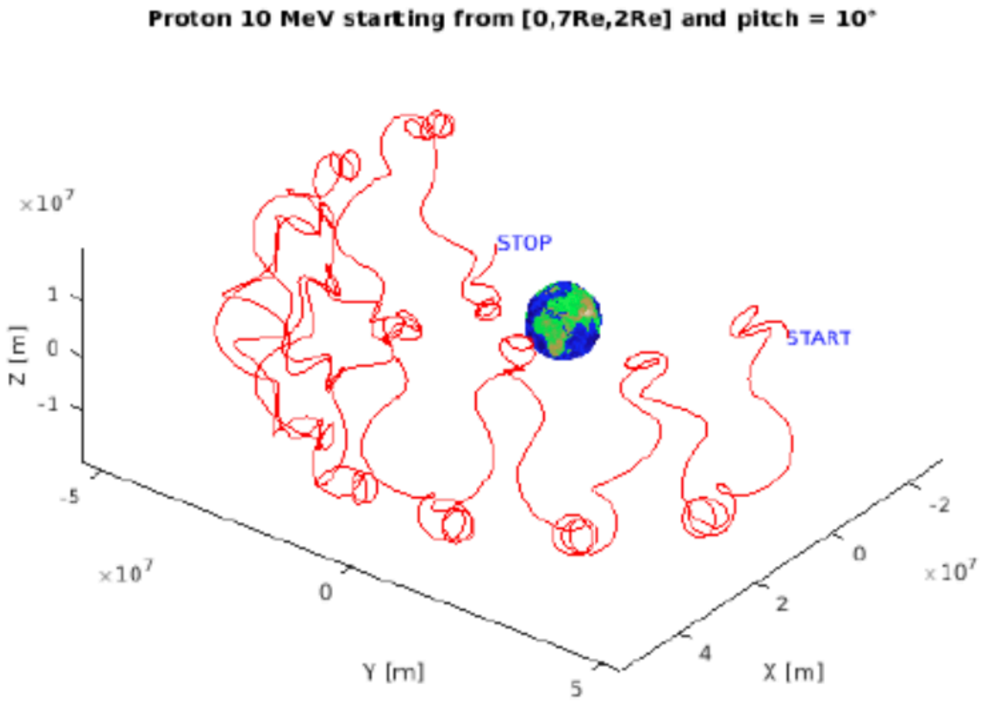
$$J_3 = q \oint \mathbf{B} \cdot \mathbf{dS} = q\Phi = q \int_{R_o}^{\infty} B_o \left(\frac{R_E}{r}\right)^3 2\pi r dr$$

Longitudinal Drift
flux invariant



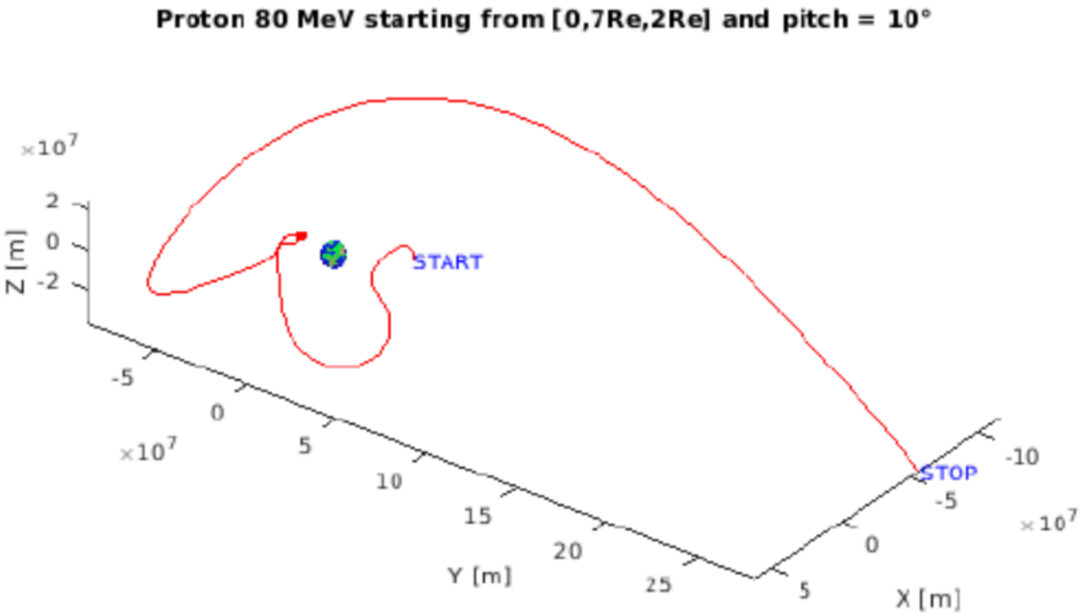
courtesy of W.J. Burger

Low energy untrapped



10 MeV trapped proton → NOT exiting the magnetosphere after *50 s*

L = 2.12 , altitude ~ 7000 km

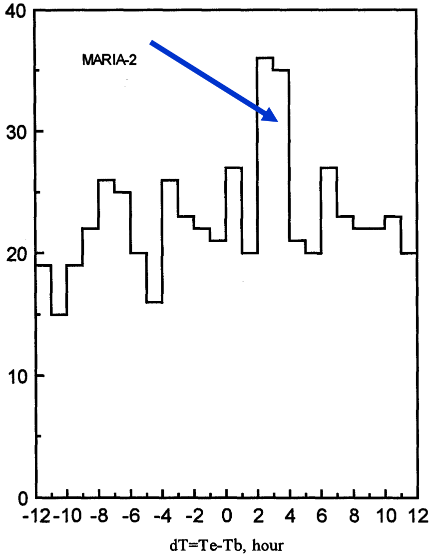


80 MeV galactic proton → exiting the magnetosphere after *50 s*

courtesy of M. Martucci

Roberto Iuppa

DT_{EQ-PB} distributions

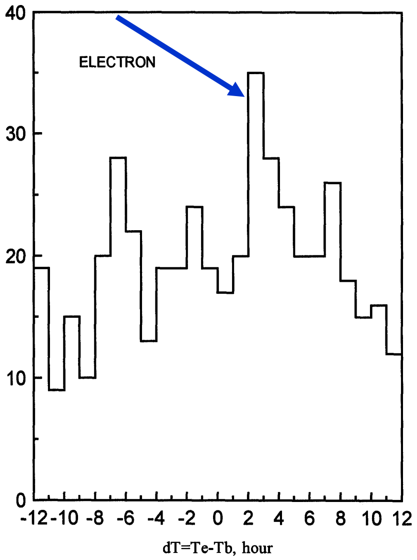


MIR mission
1985-2000

Altitude: 400 km

Inclination: 51°

E_e: 20 ÷ 200 MeV
E_p: 20 ÷ 200 MeV

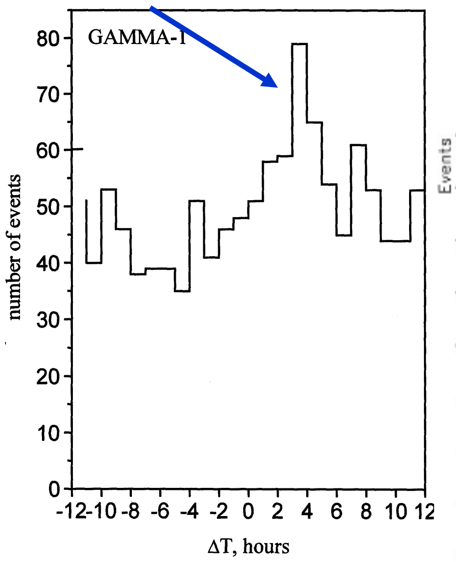


METEOR-3
1985-1986

Altitude: 1250 km

Inclination: 82°

E_e: ≤ 30 MeV

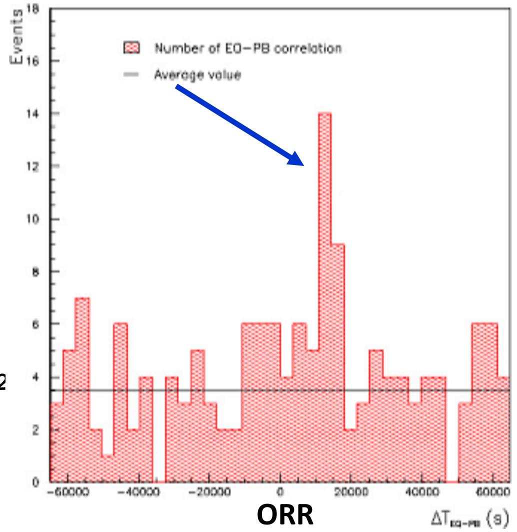


GAMMA

Altitude: 350km

Inclination: 51°

E_e: > 50 MeV



SAMPEX/PET

Altitude: 520 ÷ 740 km

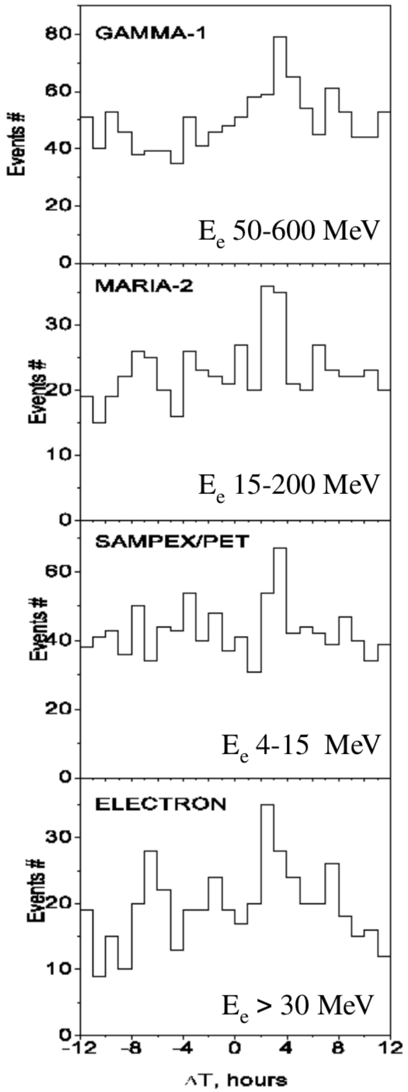
Inclination: 82°

4 ≤ E_e ≤ 15 MeV

Perturbation of Van Allen belts

External perturbations (e.g. solar events) already seen. Internal ones? The CSES mission was conceived to investigate the correlation of ionospheric perturbations with seismic events.

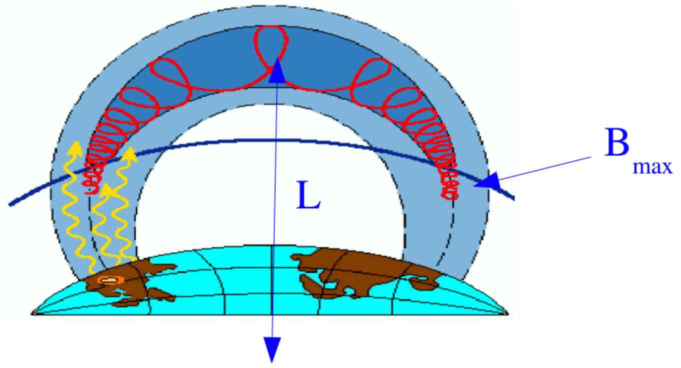
M > 4, |ΔL| < 0.1



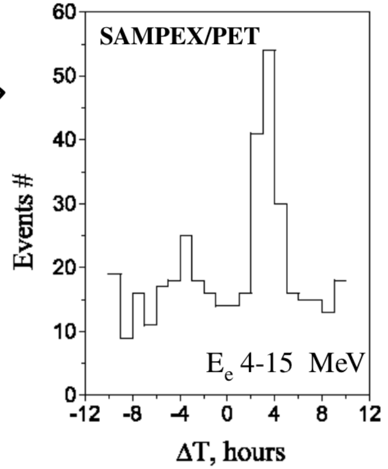
⇒

Particle Precipitation from the Inner Radiation Belts

S.Yu. Aleksandrin et al., Annales Geophysicae 21 (2009) 597



M > 5, |ΔL| < 0.07



Drift Shell Variables

L, B_{max}

$$\Delta T = T_{EQ} - T_{PB}$$

$$\Delta L = L_{EQ} - L_{PB}$$

L_{EQ} = L coordinate at an altitude of 300 km above the epicenter

courtesy of W.J. Burger

Roberto Iuppa

Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B (Proc. Suppl.) 243–244 (2013) 249–257
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
www.elsevier.com/locate/npbps

First evidence for correlations between electron fluxes measured by NOAA-POES satellites and large seismic events.

Roberto Battiston[a], Vincenzo Vitale[b]

[a]Dipartimento di Fisica and INFN-Trento Center for Fundamental Physics and Applications (TIPFA), Povo, Italy.
[b]Istituto Nazionale di Fisica Nucleare, sez. Perugia and ASI Science Data Center,Frascati, Italy.

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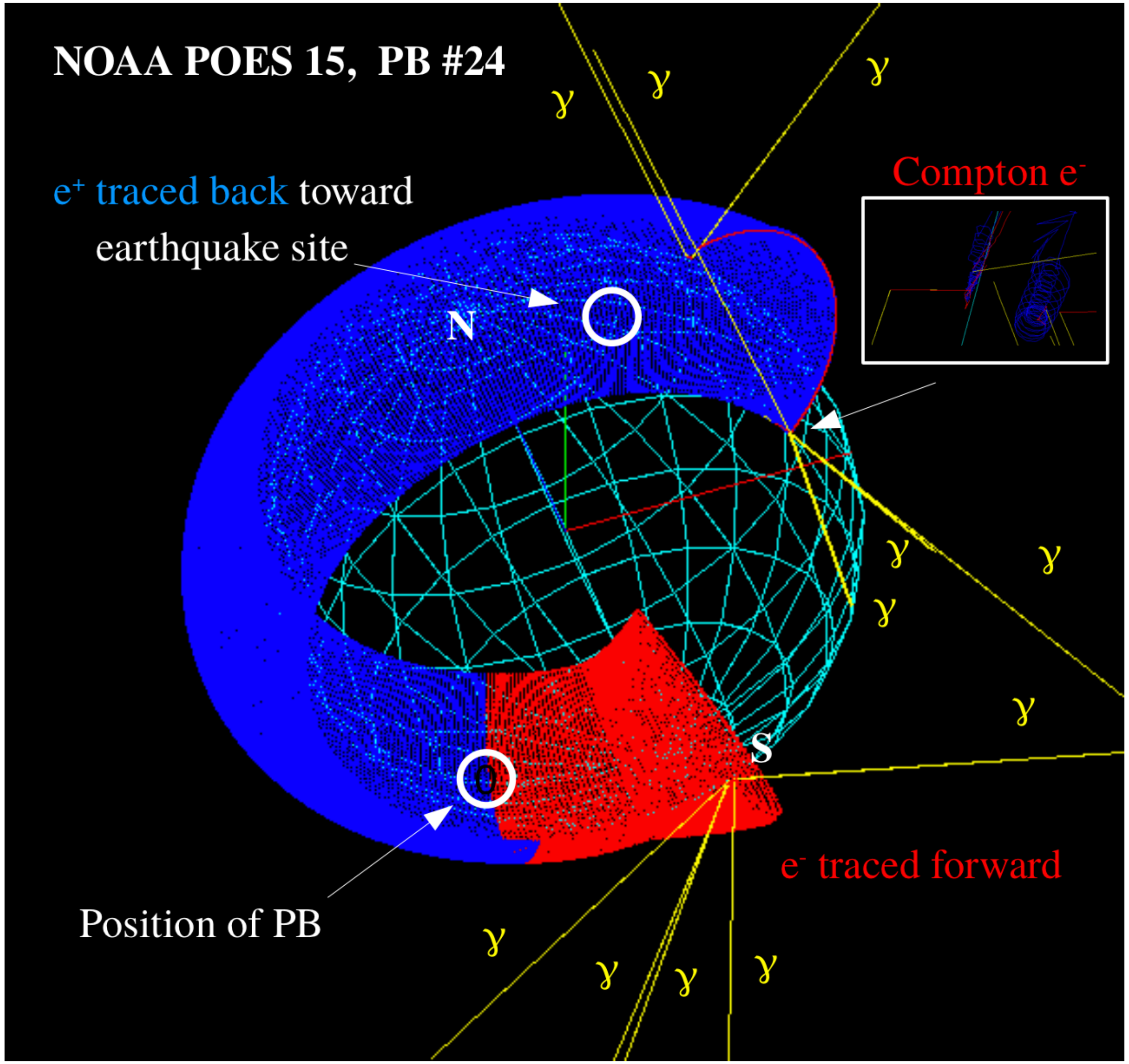
The

The seismic data are obtained from the National Earthquake Information Center (NEIC) PDE database of the U.S. Geological Survey, which has records on M2.5 and greater U.S. earthquakes and M4.5 and greater worldwide. Data from Fall 1998 from to the end of 2011 were downloaded from [29]. Earthquakes were required to have magnitude above 5, hypocenter depth smaller than 100 km and the earthquakes strains, which follow a major earthquake, were filtered accepting only 1 earthquake out of four, during 24 hours, within a region 0.7 degrees wide. **Among 170281 seismic events 17992 satisfy all the conditions.** **(10%)**

We defined an correlation height, e.g. an altitude at which the seismic electro-magnetic emissions can be associated with the electron belts. It was computed for each earthquake, as it was done also in previous works such as [2], [3]. **We have chosen a correlation height of 900km.** The related McIlwain L parameter for the seismic event was calculated by assuming the L parameter at the correlation height above the geographic location of the earthquake. The L parameter was calculated with the IGRF11 code (International Geomagnetic Reference Field model).

Back-tracing for spatial correlation



courtesy of W.J. Burger

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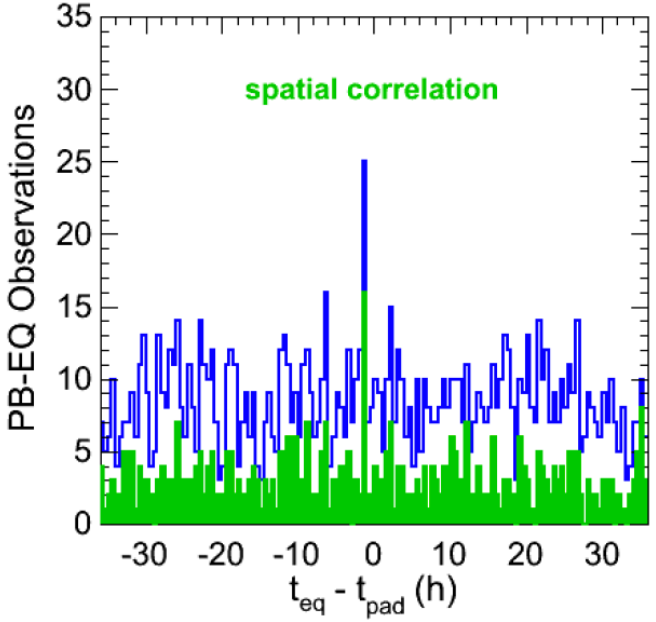
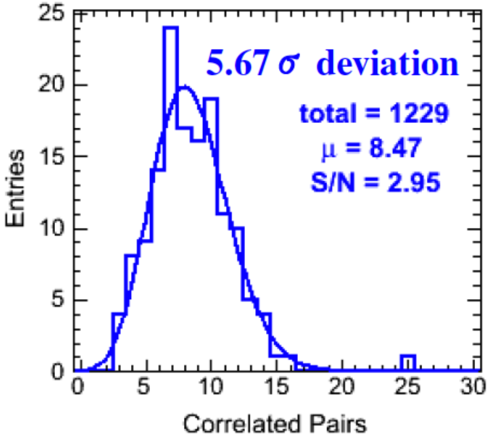
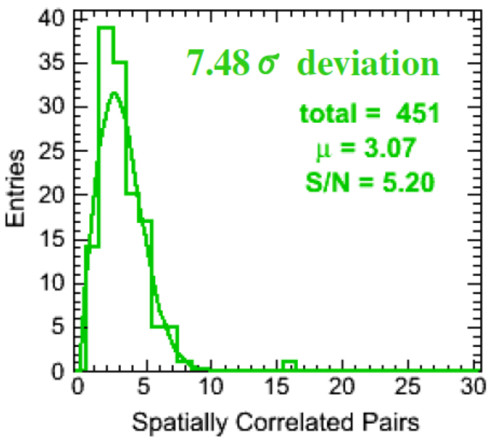
NOAA POES Time-Space-Correlated PB-EQ Pairs (16)

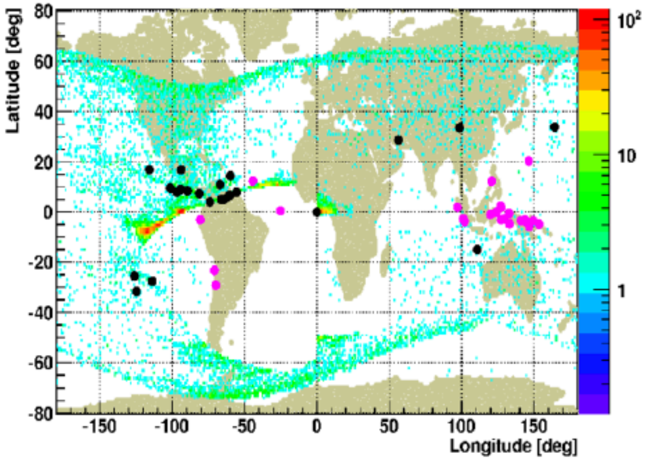


M > 5
|ΔL| < 0.1
L_{EQ} = 900 km
1.25 < L < 1,45





courtesy of W.J. Burger



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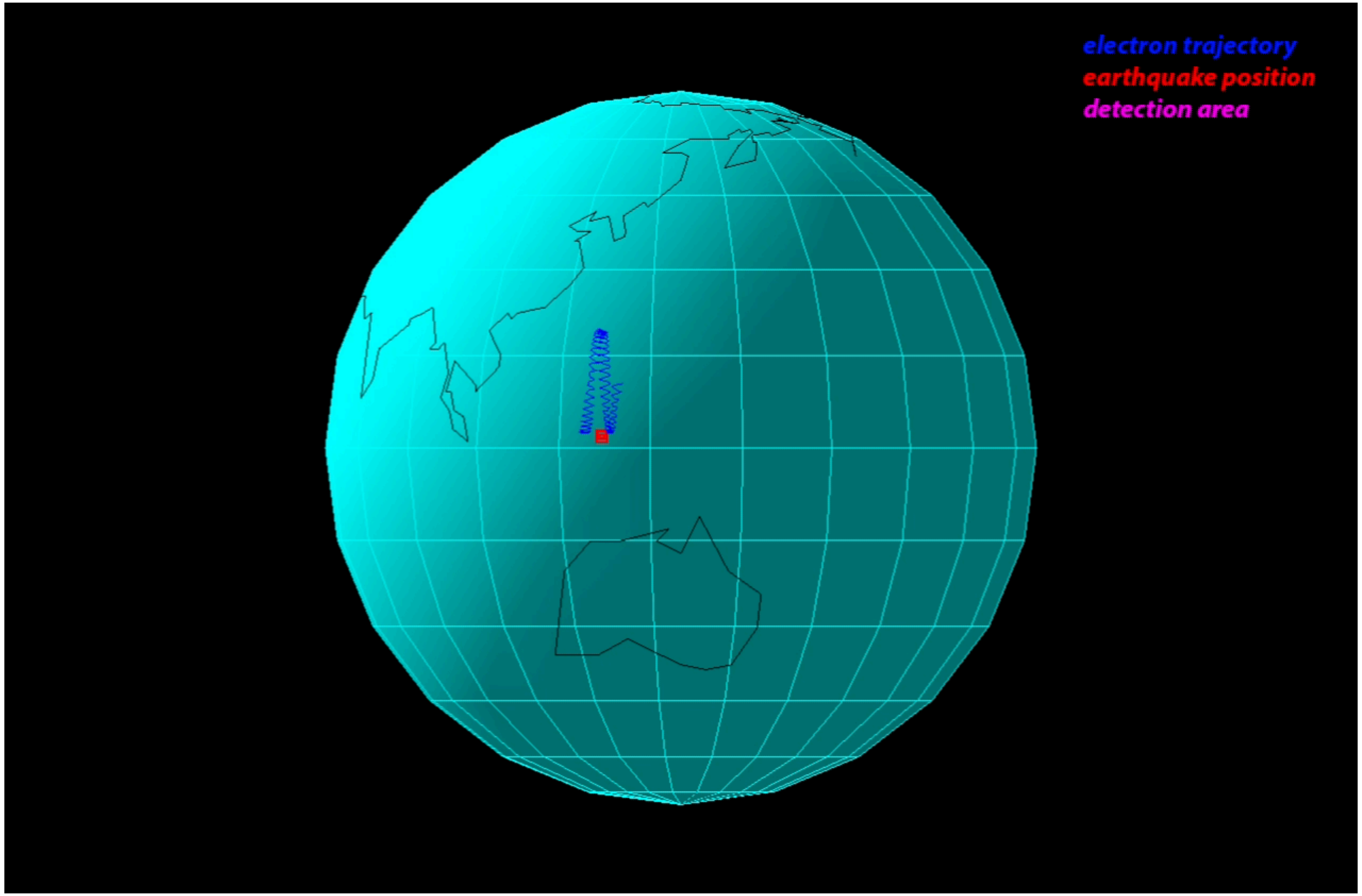
How could it happen?

Precipitation of energetic particles from the magnetosphere caused from electromagnetic emissions correlated to the earthquake.



Why should it happen?

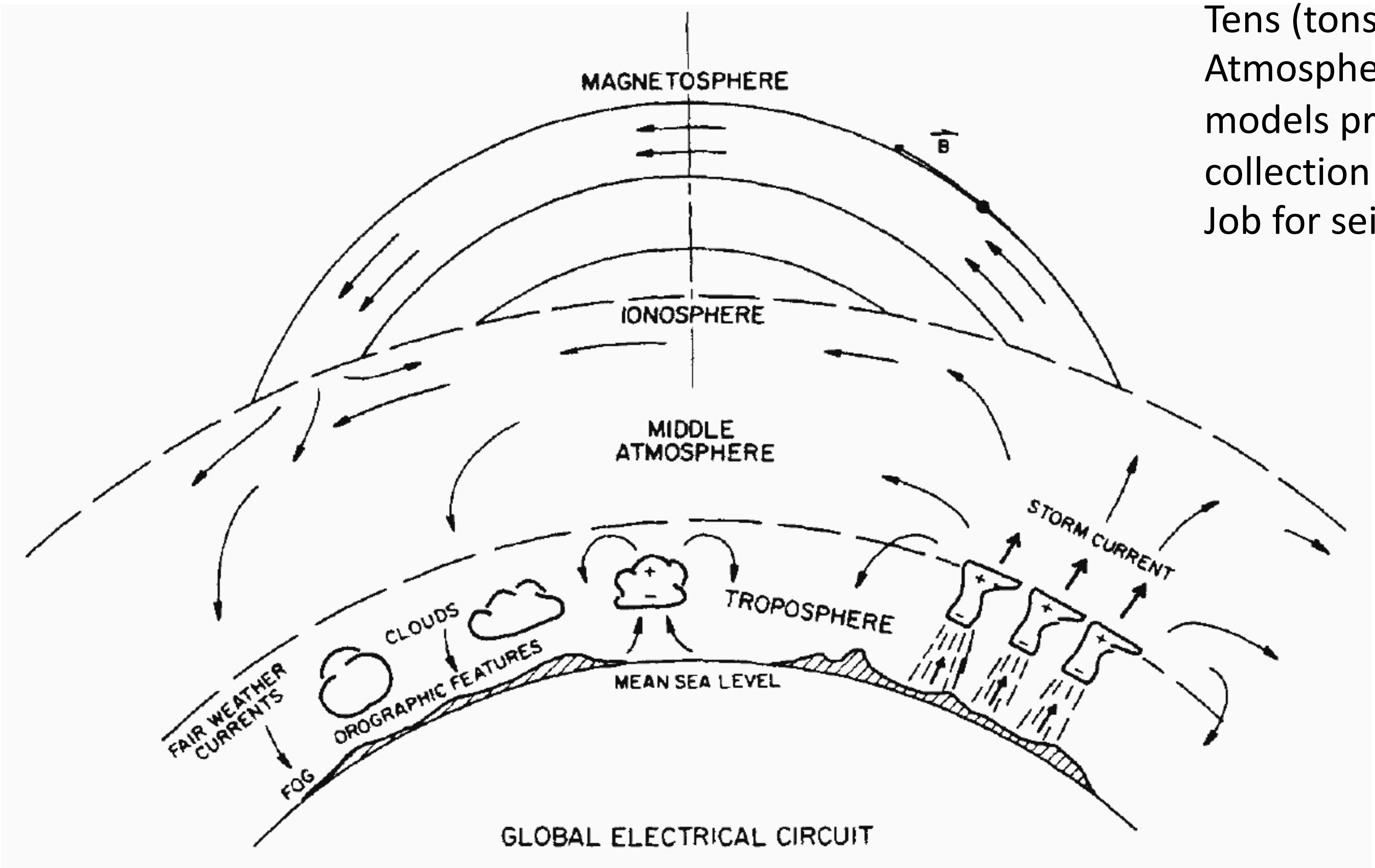


Fig. 1.22 Schematic presentation of the global electric circuit (After Roble and Tzur 1986)

Tens (tons!) of different Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) models proposed. Large statistics data collection and unbiased analysis needed. Job for seismologist and Earth scientists.

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Lithosphere–Atmosphere–Ionosphere Coupling (LAIC) model – An unified concept for earthquake precursors validation

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Journal of Asian Earth Sciences

Volume 188, February 2020, 104097

Full length article

Possible Lithosphere-Atmosphere-Ionosphere Coupling effects prior to the 2018 Mw=7.5 Indonesia earthquake from seismic, atmospheric and ionospheric data

Dedalo Marchetti [a, b], Angelo De Santis [b], Xuhui Shen [c], Saioa A. Campuzano [b], Loredana Perrone [b], Alessandro Piscini [b], Rita Di Giovambattista [b], Shuanggen Jin [a], Alessandro Ippolito [b, d], Gianfranco Cianchini [b], Claudio Cesaroni [b], Dario Sabbagh [b], Luca Spogli [b, e], Zeren Zhima [c], Jianping Huang [c]

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https://doi.org/10.1016/j.jseaes.2019.104097