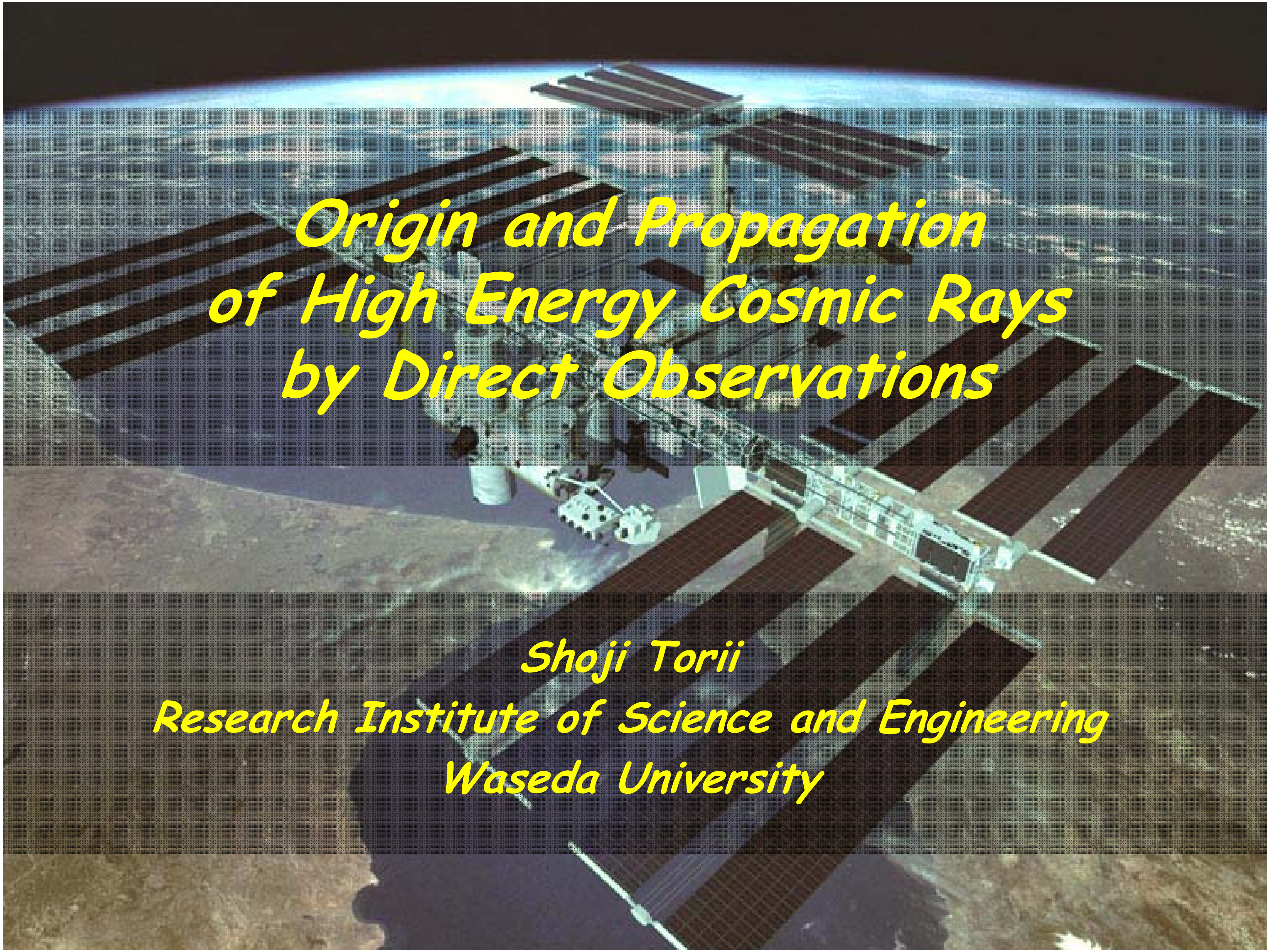
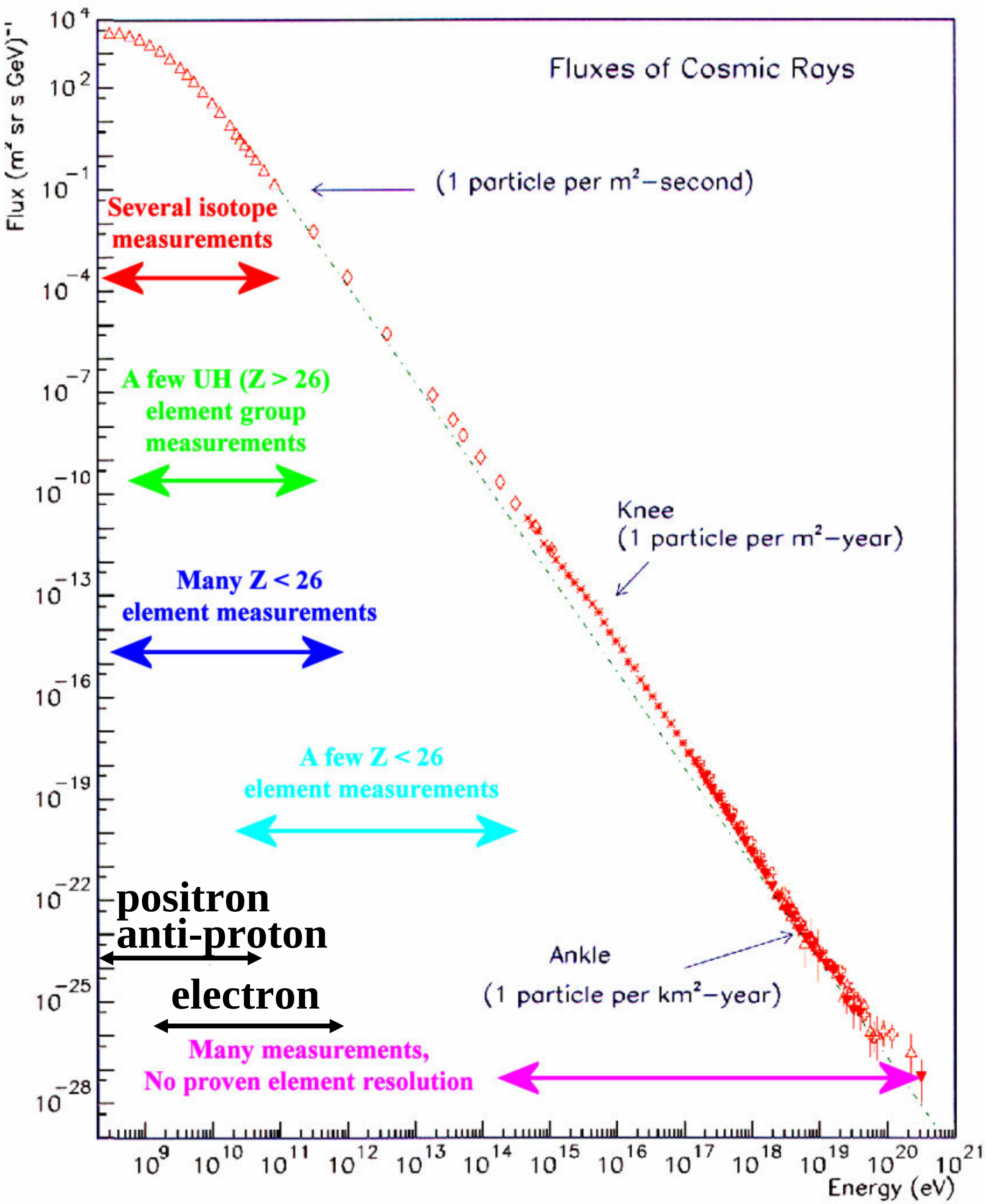


Origin and Propagation of High Energy Cosmic Rays by Direct Observations

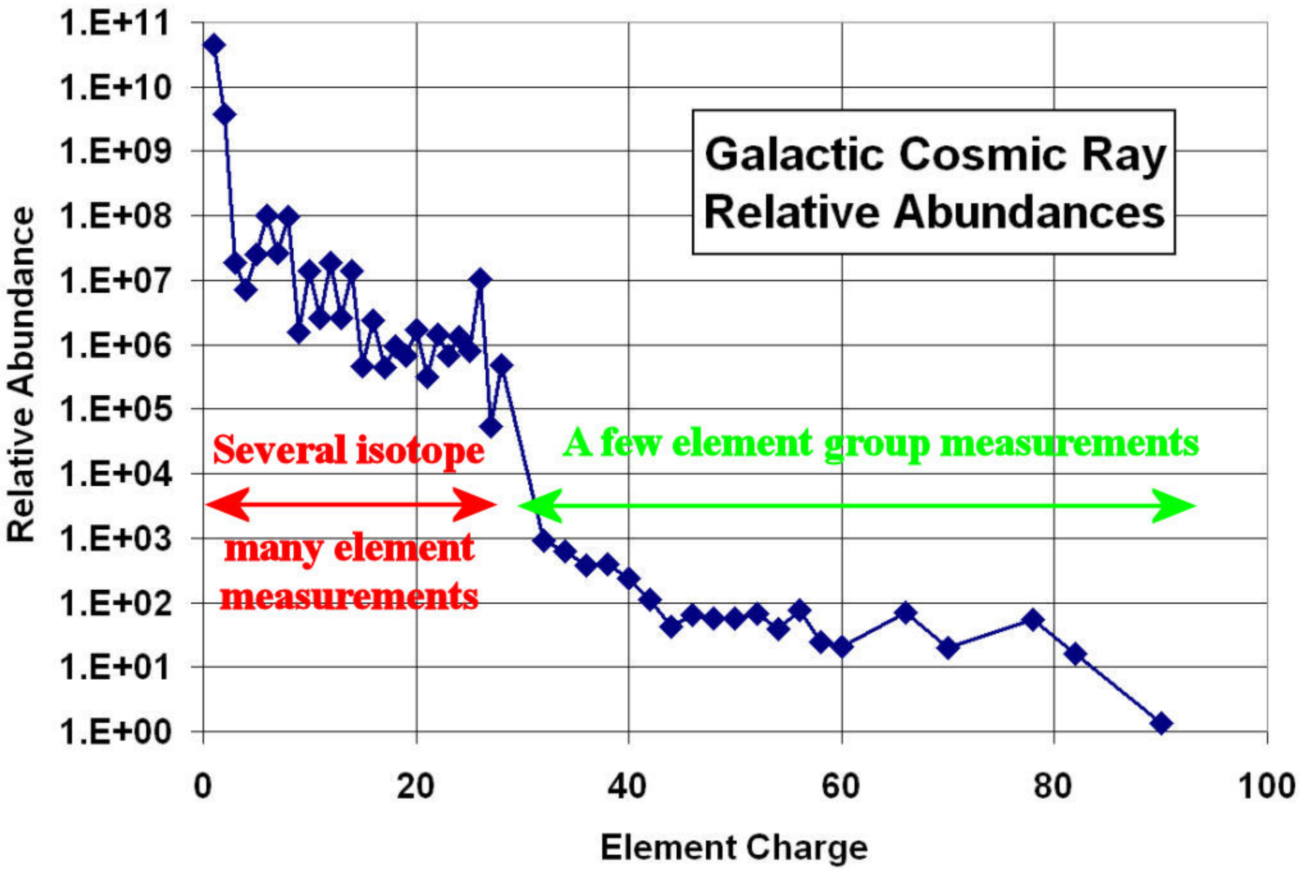
Shoji Torii
Research Institute of Science and Engineering
Waseda University

Energy Spectrum

- Covers more than 20 orders of magnitude
- Flux varies by more than 30 orders of magnitude
- Required detector size varies greatly over this range
  - Satellites limited to low energy (< 100 GeV)
  - Balloons can approach the "knee" (~ 1 PeV)
  - Air shower measurements for highest energy
- Most detailed measure-ments are at low energy
- Little composition knowledge above 1 PeV



Composition measurements cover the full element range

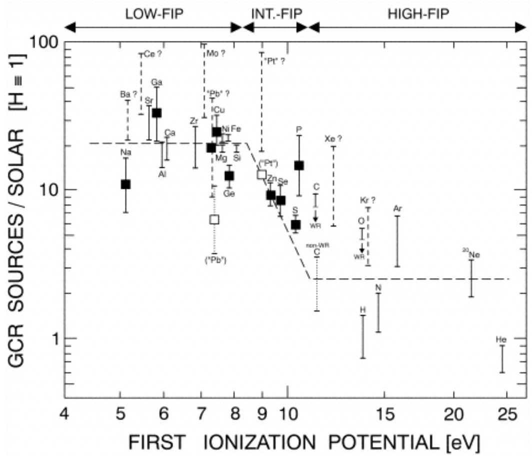


- Relative abundances range over 11 orders of magnitude
- Detailed composition limited to less than ~ 10 GeV/nucleon

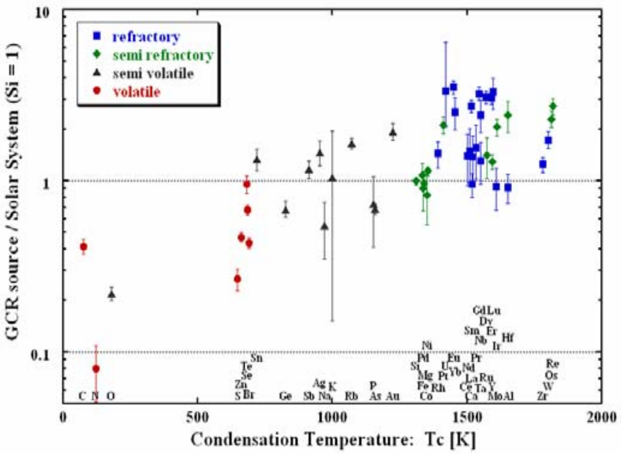
Origin and Acceleration of Cosmic Rays :A Standard Scenario

- **Origin**

FIP (hot gas) **or** **Volatility (dust・grain)**



Ellison et al., ApJ 1997



Hasebe et al., Nucl. Phys. A 2005

ISM or SN ejecta

- **Acceleration by Supernova Shock Wave (Fermi Acceleration)**

$$Q(E) = \frac{dI}{dE} \propto E^{-\alpha}, \quad \alpha = \frac{3}{R-1} + 1 \qquad R = \frac{\rho_2}{\rho_1} \leq 4 \quad \Rightarrow \quad \alpha \geq 2$$

- **Maximum Energy**

$$E_{max} \sim 100\ Z\ \mathrm{TeV}$$

oblique shock, diffusive shock, multiple shocks, different SN types…

Propagation of Galactic Cosmic Rays: Leaky Box Model

- **Leaky Box Model for Protons & Nucleus**

$$\frac{N_i(E)}{\tau_e(E)} = Q_i(E) - \left(\frac{\beta c\rho}{\lambda_i} + \frac{1}{\gamma\tau_i}\right) N_i(E) + \frac{\beta c\rho}{m}\sum_{k\geq i}\sigma_{i,k}N_k(E)$$

1 ry component

$$\frac{N_P}{\tau_e} = Q_P(E) - \frac{\beta c\rho}{\lambda_P}N_P \quad \Rightarrow \quad N_P = \frac{Q_P\tau_e}{1+\frac{\beta c\rho\tau_e}{\lambda_P}} = \frac{Q_P\tau_e}{1+\frac{\lambda_e}{\lambda_P}}$$

Protons $\frac{\lambda_e}{\lambda_p} << 1 \quad \Rightarrow \quad N_p \approx Q_p\tau_e \propto E^{-\alpha-\delta}$

Heavy Nuclei $\lambda_e \approx \lambda_p \quad \Rightarrow \quad N_p \sim E^{-\alpha-\delta+\varepsilon}, \varepsilon \leq \delta$ *(harder than protons)*

2ry component

$$\frac{N_s}{N_P} = \frac{\sigma_{P\to S}}{\sigma_P}\frac{\lambda_e}{\lambda_p\{1+\lambda_e/\lambda_S + \tau_e/(\gamma\tau_S)\}} \quad \Rightarrow \quad \frac{N_s}{N_p} \propto E^{-\delta}, \frac{\lambda_e}{\lambda_s} << 1 \text{ (Light Nuclei)}$$

Propagation of Electrons

- **Diffusion Equation**

$$\frac{dN}{dt} = D\nabla^2 N + \frac{\partial}{\partial E}\{b(E)N(E)\} + Q(E)$$

However, since high energy electrons can not propagate so far from the source due to the energy loss (~E^2), the density is not uniform.

⇒ **Leaky Box is not a good model at higher energies.**

The diffusion equation is analytically solved by Kobayashi et al.
ApJ 601 (2004) 340-351.

Effects of Nearby Sources bring:

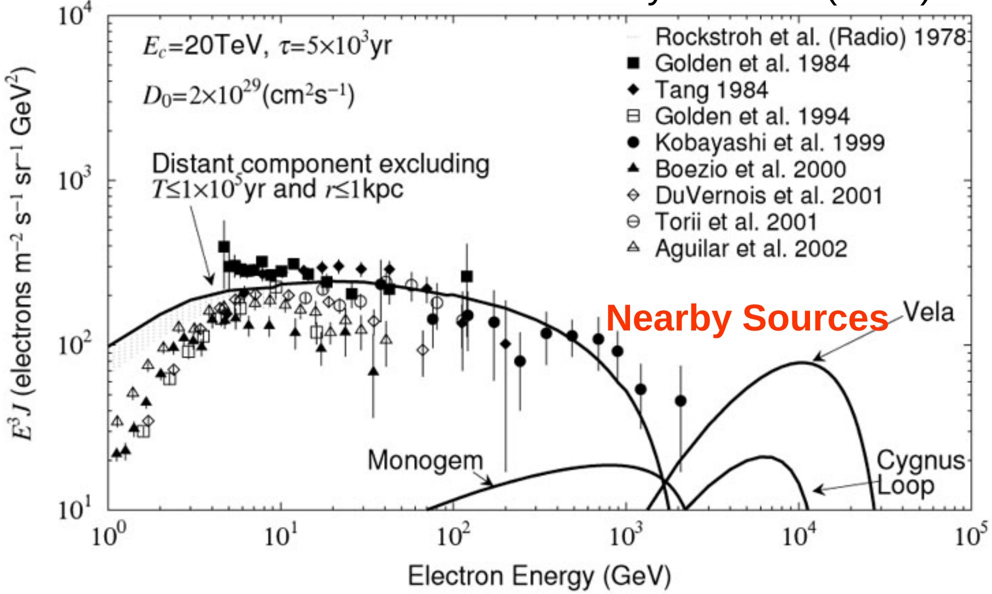
- **Structure in energy spectrum**
- **Anisotropy of arrival direction**

Electrons can provide additional information about the GCR source

- High energy electrons have a high energy loss rate $\propto E^2$
  - Lifetime of ~10^5 years for >1 TeV electrons
- Transport of GCR through interstellar space is a diffusive process
  - Implies that source of high energy electrons are < 1 kpc away

- Electrons <u>are</u> accelerated in SNR
- Only a handful of SNR meet the lifetime & distance criteria

Kobayashi et al (2004)



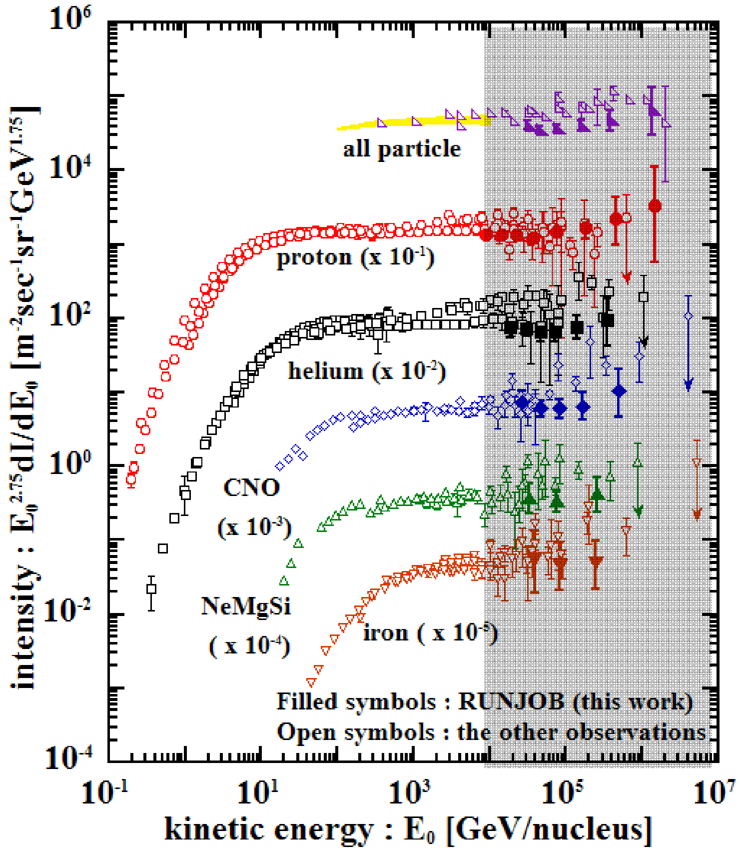
Proton & Nucleus Observation before 2000

“Supernova remnant pradigm”

- **Cosmic Rays are accelerated by Fermi acceleration at SNR shocks**

- **Power laws of the type $E^{-\gamma}$ are usually assumed to be generated naturally, with slope around $\gamma=2$**

- **The spectra observed at the Earth are modified by diffusive propagation in the Galaxy**



Due to poor statistics, it is difficult to know details of energy spectra of each component over 10 TeV/ nucleus.

Need More Observation with Large Scale and Long Duration for accurate measurement of the spectra and abundances of elements in cosmic rays

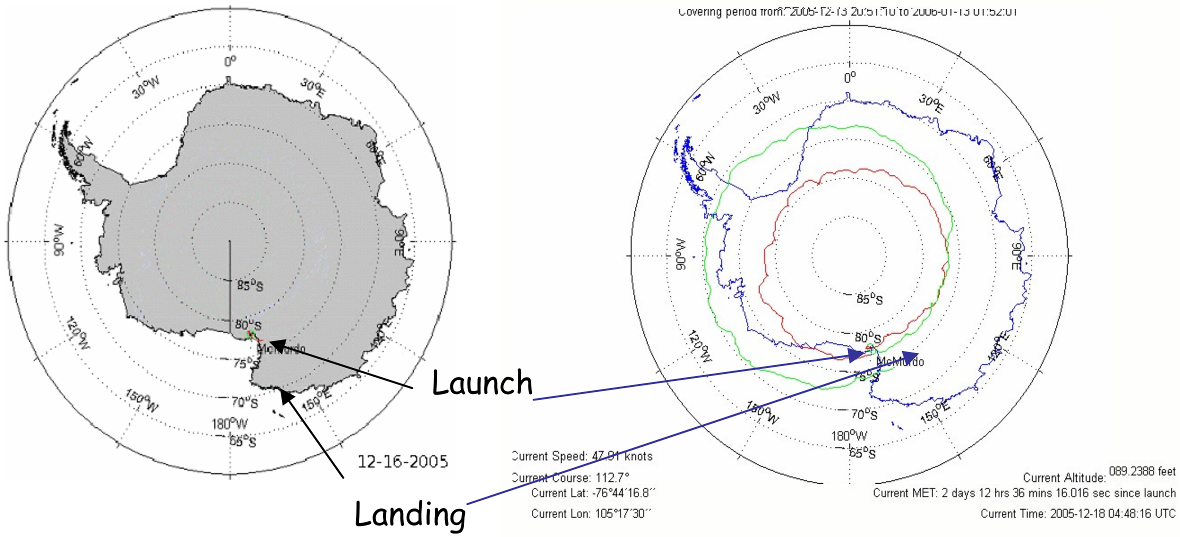
New Technology and Long Duration Ballooning for Precise Measurments

70 days of flight from 2 launches

- CREAM
- ATIC
- Tracer
- TIGER
- BESS-Polar
- PPB-BETS

CREAM-I
12/16/04 – 1/27/05
Record breaking 42 days

CREAM-II
12/16/05-1/13/06
28 days



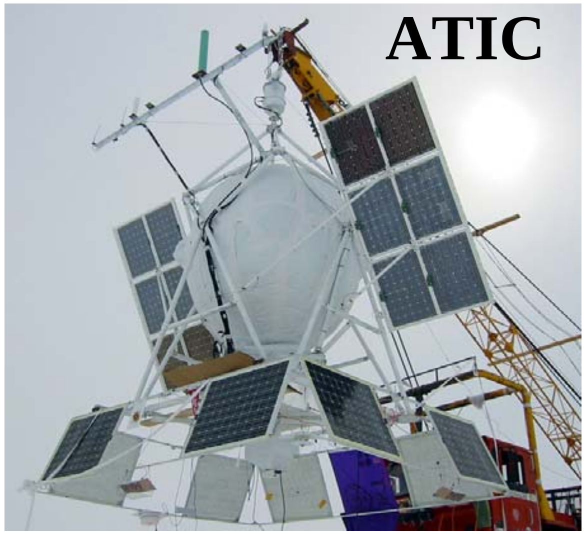
Cosmic ray balloon payloads (1)

Cosmic Ray Energetics and Mass (CREAM)

- GCR nuclei from H to Fe for energies from ~1 TeV to ~500 TeV
- 1141 kg (2526 lbs)
- Flights in 2004 and 2005 (70 days)
- Anticipated flights in 2007 and 2008

Advanced Thin Ionization Calorimeter (ATIC)

- GCR nuclei from H to Fe from 50 GeV to ~100 TeV; GCR electrons from ~20 GeV to several TeV
- 1636 kg (3600 lbs)
- Flights in 2000, 2002 (30 days), launch failure in 2005
- Anticipate flight in 2007



Cosmic ray balloon payloads(2)

Transition Radiation Array for Cosmic Energetic Radiation (TRACER)

- Direct measurements of O to Fe from ~50 GeV to several 100 TeV; 5 m^2 sr
- 1614 kg (3550 lbs)
- Flights in 2003, 2006 (14 days)
- Proposing for more flights

Trans-Iron Galactic Element Recorder (TIGER)

- GCR nuclei heaver than iron (26 < Z < 40) for energies ranging from 0.3 to ~100 GeV/nucleon
- 700 kg (1543 lbs)
- Flights in 2001 and 2003 (50 days)
- Unrecovered after 2003 flight

Cosmic ray balloon payloads(3)

Anti-Electron Sub-Orbital Payload / Low Energy Electronics (AESOP/LEE)

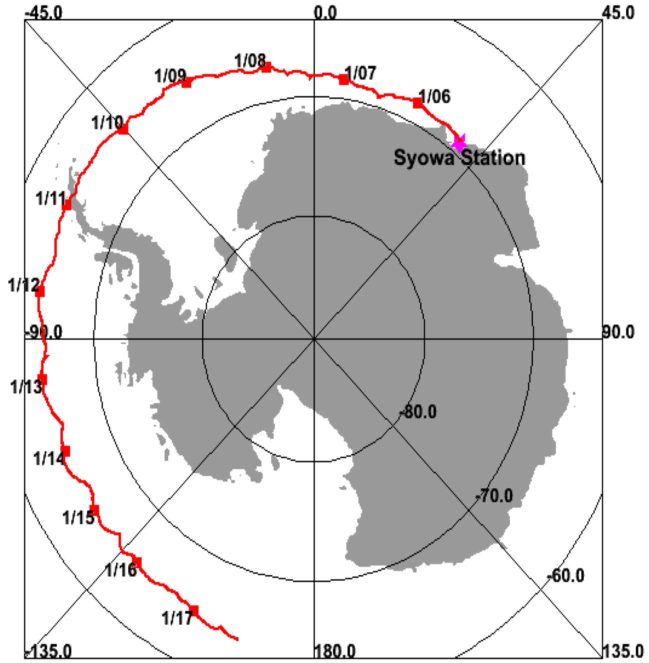
- Study solar modulation of electrons up to 20 GeV; resolve positrons and negatrons up to 6 GV
- 934 kg (2060 lbs)
- Flights in 97, 98, 99, 00 (120 hours)
- Still operational

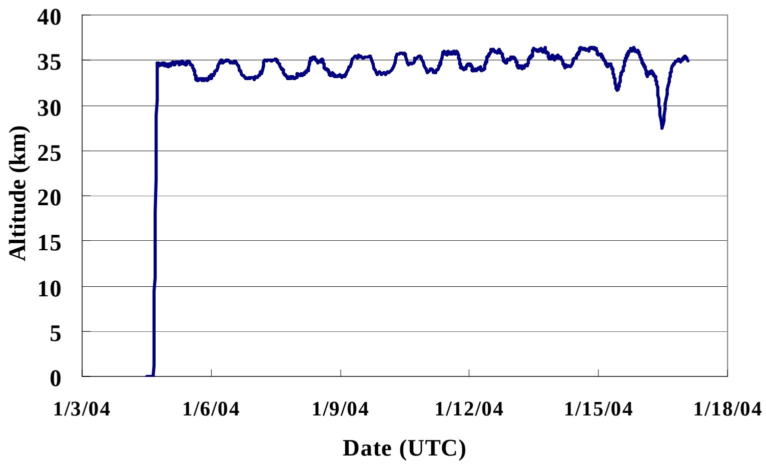
Balloon Experiment Superconducting Spectrometer (BESS)

- Anti-protons and isotopes of light nuclei from 0.18 to 4.20 GeV; search for anti-deuterium, anti-helium
- 2,070 kg (4400 lbs)
- 9 “ConUS” Flights 1993 – 2002; LDB flight in 2004 (8.5 days)
- Anticipate flight in 2007

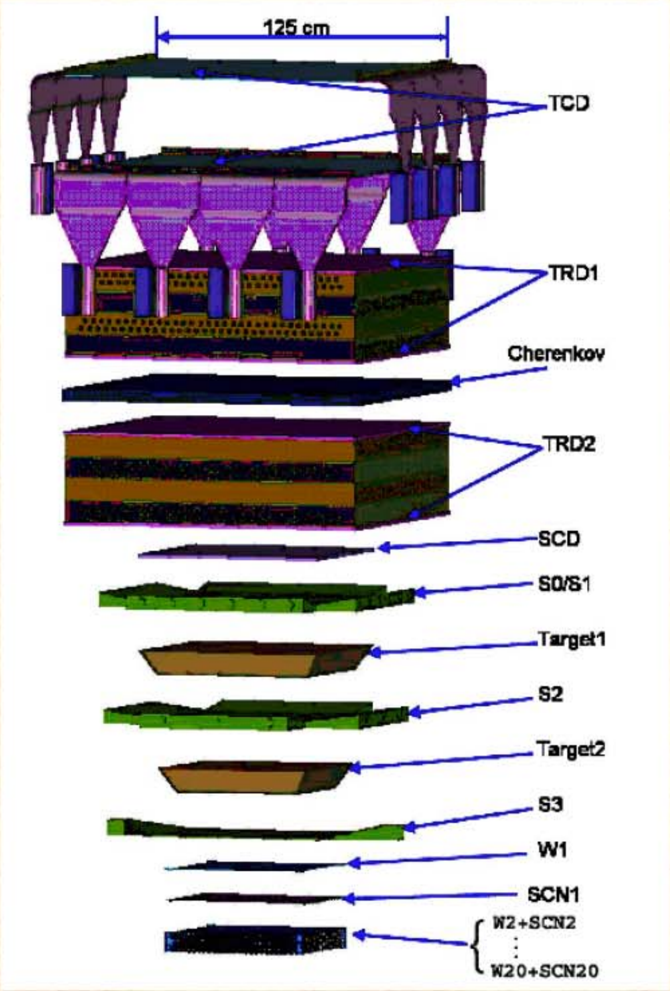
PPB-BETS for Electron Observation

- Direct measurements of Electrons ~10 GeV to 1000 GeV
- 600 cm^{2}sr
- ~500 kg
- Flights in 2004 (13 days)
- Detector was not recovered





CREAM Instrument

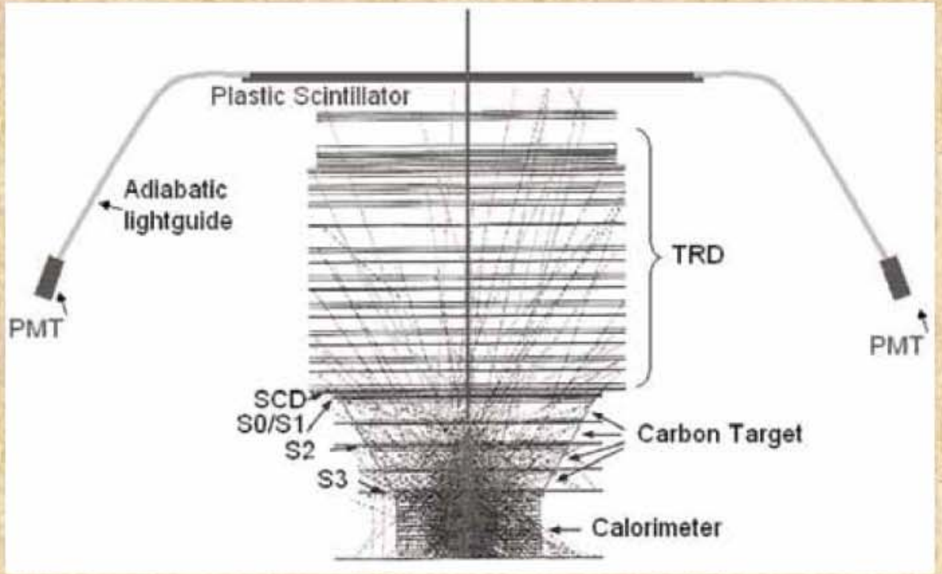


A key feature of the instrument: Simultaneous measurements of the energy and charge of a subset of nuclei by the complementary calorimeter and TRD techniques, thereby allowing in-flight inter-calibration of their energy scales.

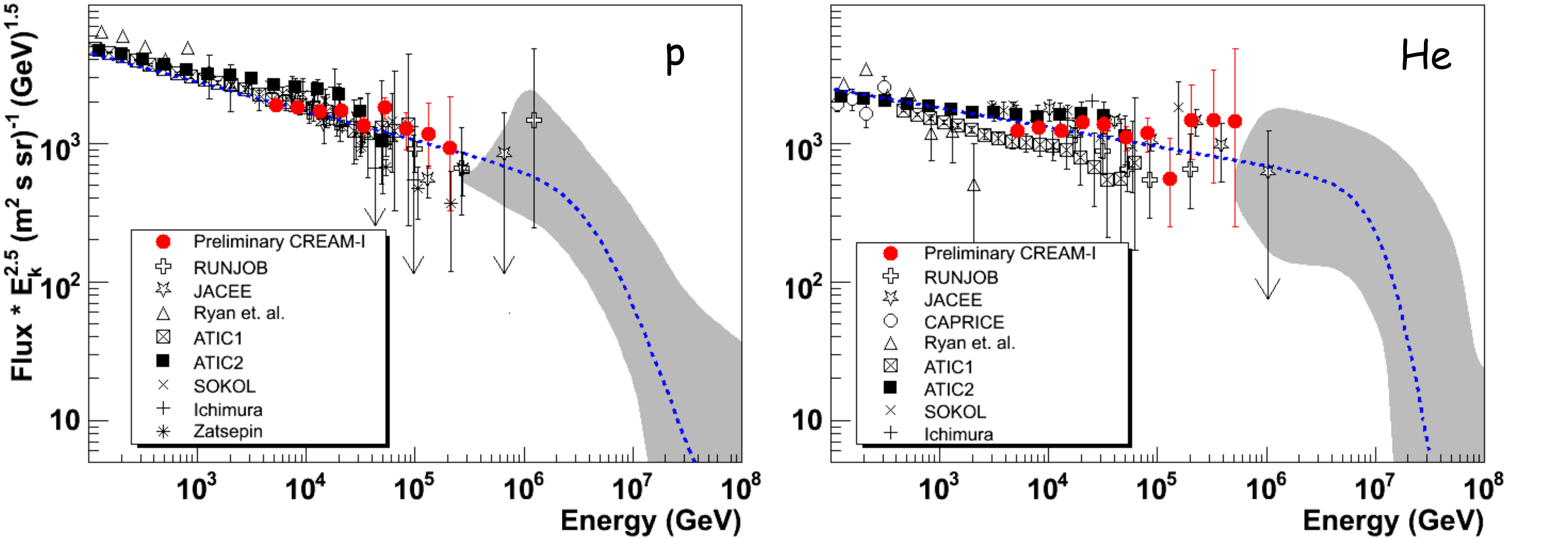
Timing-Based Charge Detector
- Identify incoming particle
- Penn State U

Transition Radiation Detector
- Measure velocity for Z ≥ 3
- U of Chicago

Tungsten-SCN Calorimeter
- Measure energy for Z ≥ 1
- U of Maryland



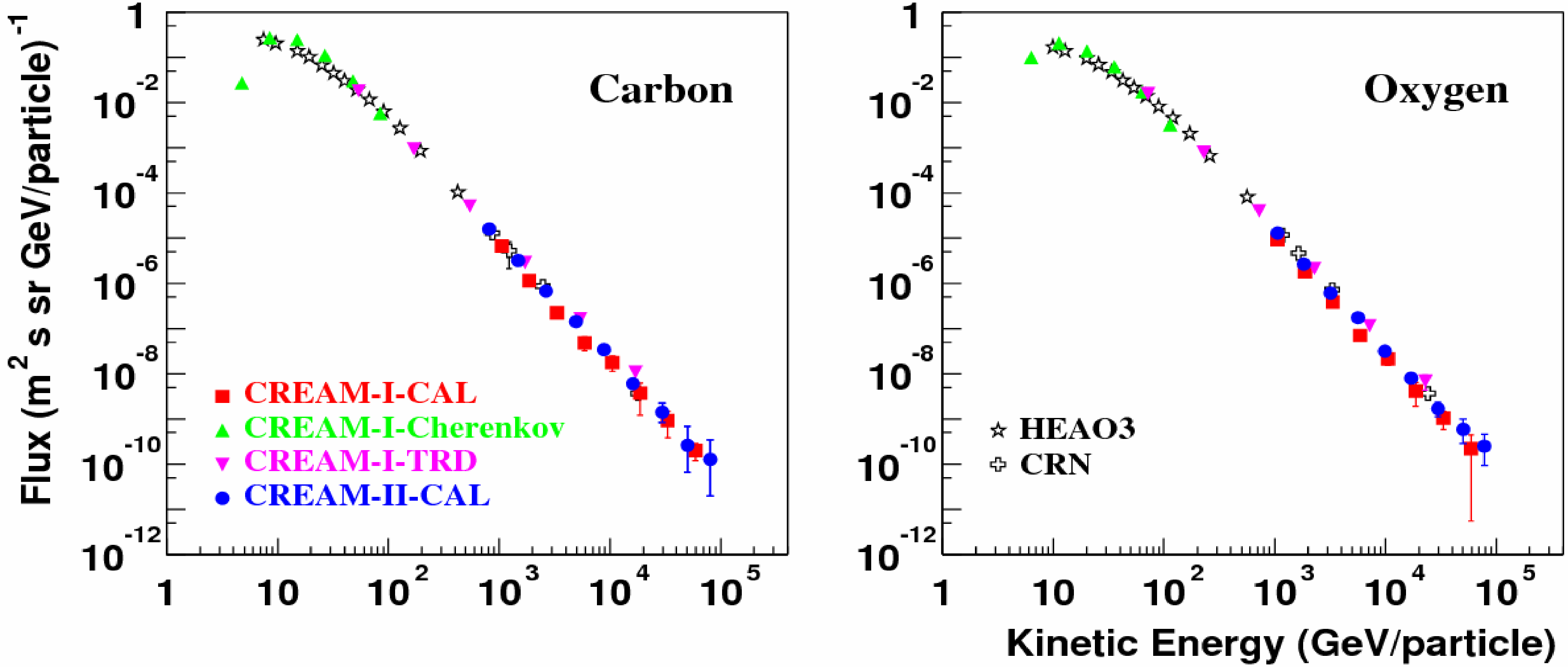
Approaching the “knee”



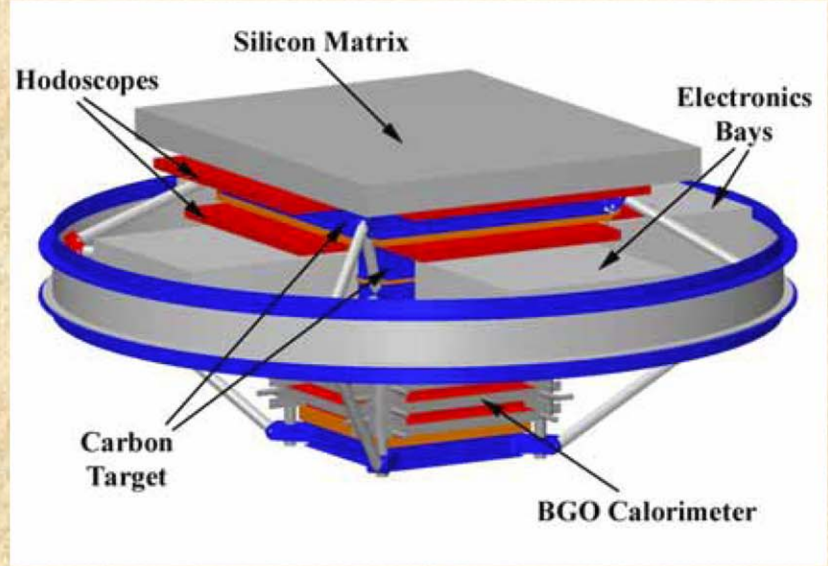
- The proton spectrum follows a power law with little change up to ~ 100 TeV.
- The He spectrum seems harder than the proton spectrum.
  - If this continues, the “knee” composition could be dominated by He
  - He/p ratio is about a factor of 2 higher at ~10TeV/n than 10-100 GeV/n
- Future flights will extend the CREAM energy reach to higher energies and distinguish hadronic interaction models such as QGSJET and SIBYLL used for ground based data.

C & O spectra from CREAM

- CREAM results span ~ 4 decades in energy: ~ 10 GeV to ~ 100 TeV
- Spectra were obtained by 3 independent groups, UC, INFN & UMD
- TCD/CD/TRD results are consistent with SCD/CAL results
- CREAM-I & II SCD/CAL results are consistent
- C & O spectral shape/fluxes agree with previous measurements

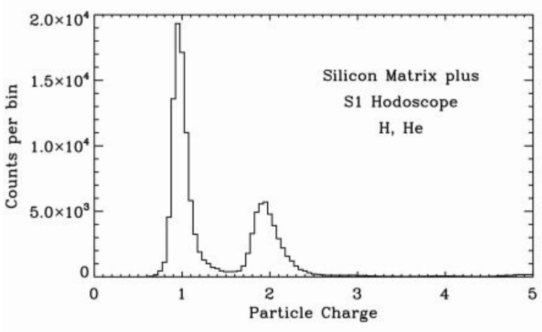


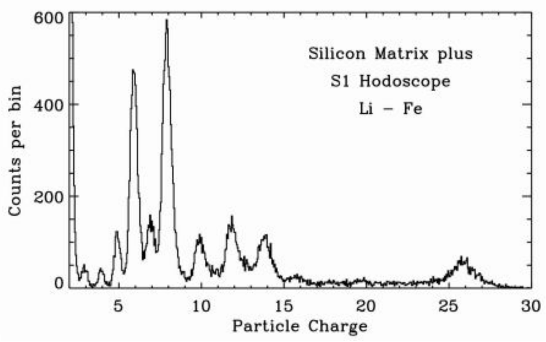
ATIC Instrument

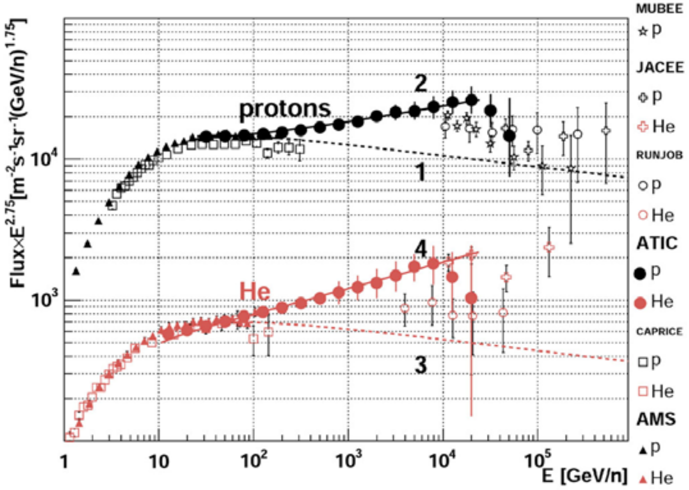


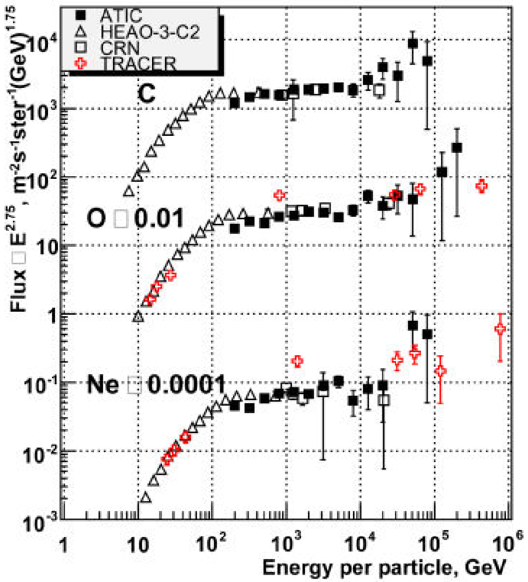
Total weight :
 ～1,500 kg (3,300 lbs),
Total power consumed :
 ＜ 350 Watts (including power conversion efficiency)
Balloon Alititude:
 ~36km
Geometrical factor :
 0.45 m^2 sr (calorimeter top) ～ 0.24 m^2 sr (calorimeter bottom).

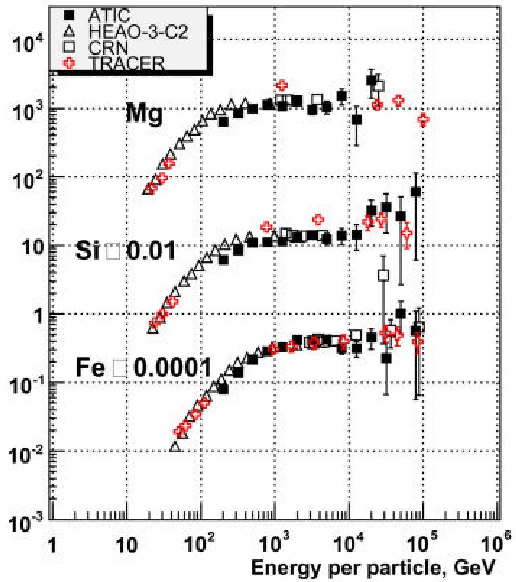
Preliminary ATIC-2 Results

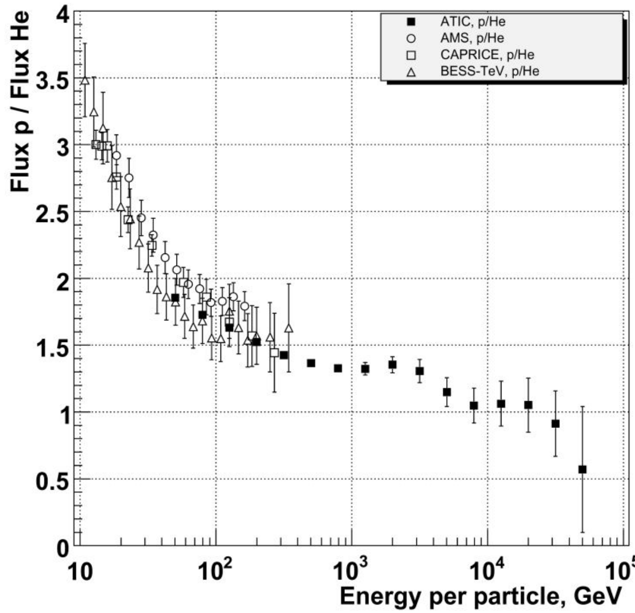




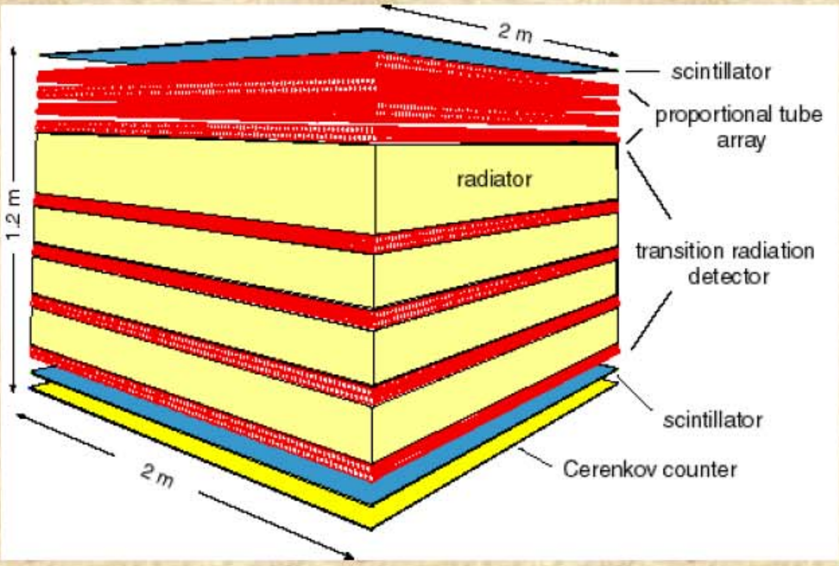




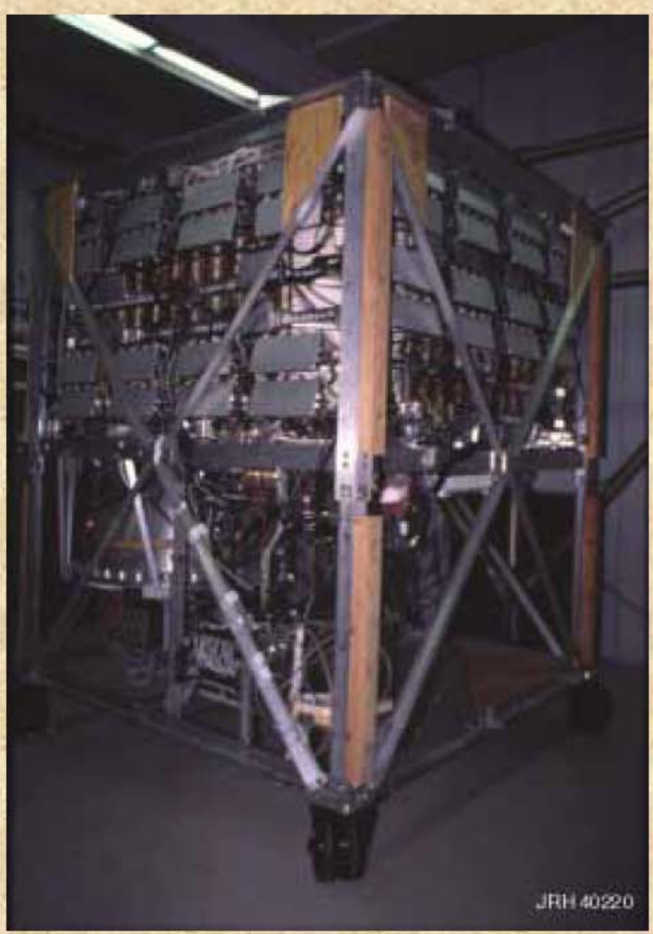




TRACER Instrument



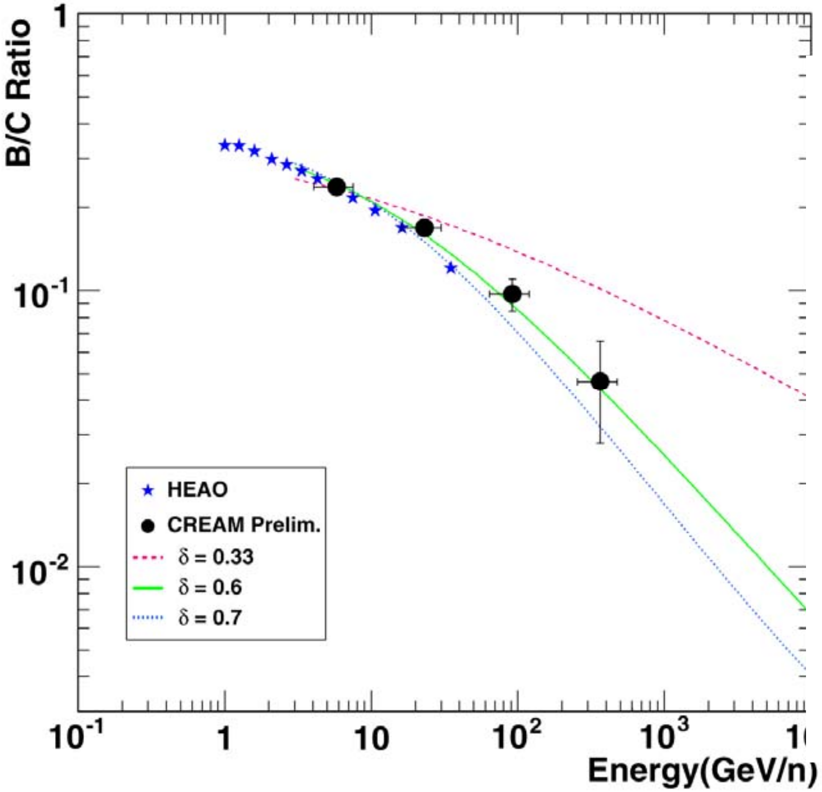
The whole detector is mounted inside a 2.5 x 2.5 x 3 m ^{3} aluminum structure without a surrounding pressurized shell.



- Detector:
  Two layers of plastic scintillators (2 x 2 m^2),
  One Cerenkov counter (2 x 2 m^2)
  Transition radiation detector system which determines the Lorentz factor.
- Oxygen to iron in 10^{13} to several 10^{14} eV per nucleus
- 60 m^2 sr days for 12 days flight
- Altitude 37.5 km

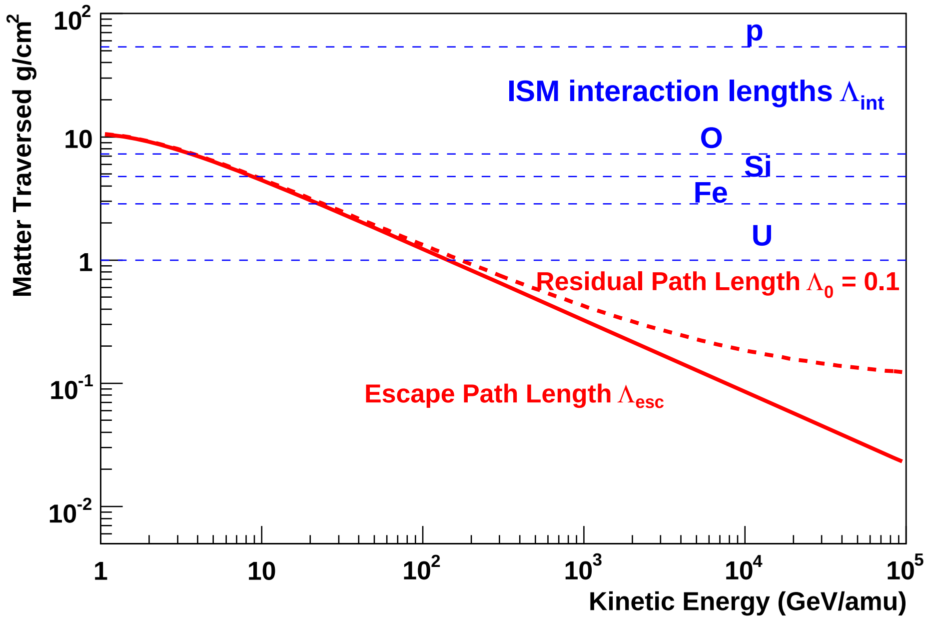
B/C Ratio and Matter Traversed

CREAM **B/C Ratio**



Propagation Pathlength Λ

$$\frac{1}{\Lambda} = \frac{1}{\Lambda_{esc}(E)} + \frac{1}{\Lambda_{int}(Z)}$$



TRACER Results

The TRACER results, extending to about 10^{14} eV per particle, represent the highest energy cosmic-ray data currently available with single element resolution.

The data can be described by a simple propagation model with

- **δ : 0.6** ***energy dependent path length***
- **α : 2.3** ***power law source index***
- **Λ_0 :0.1 g/cm^2** ***residual path length***

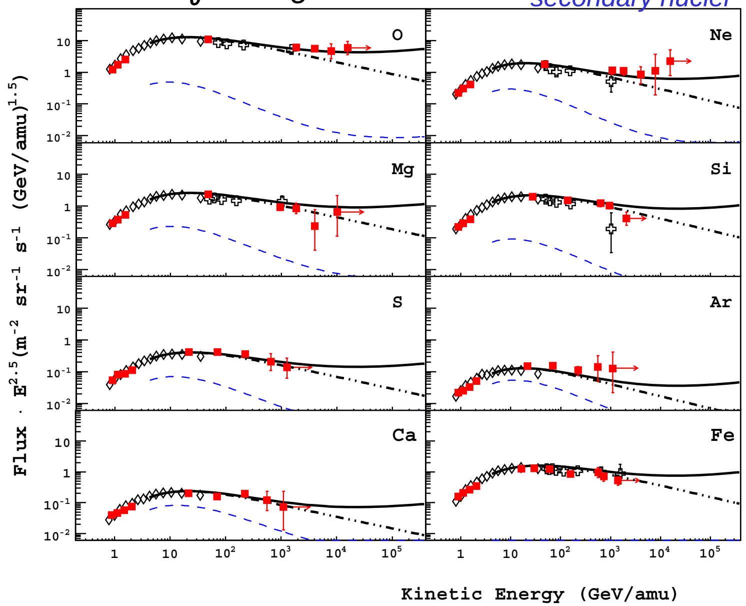
The TRACER data indicate a common origin and mode of propagation for all species. They are consistent with predictions of commonly accepted shock acceleration models.

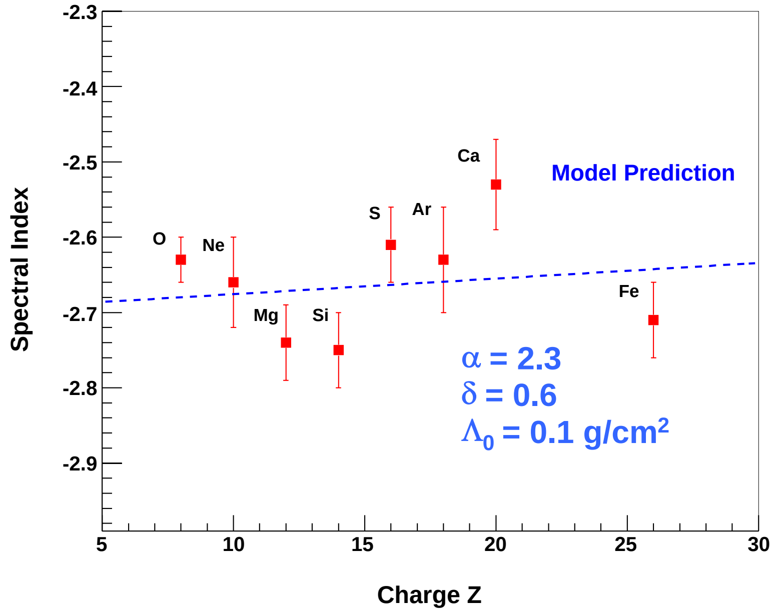
The relative source abundances of cosmic rays confirm the anti-correlation with the first ionization potential, or volatility at high energy.

TRACER + Propagation Model

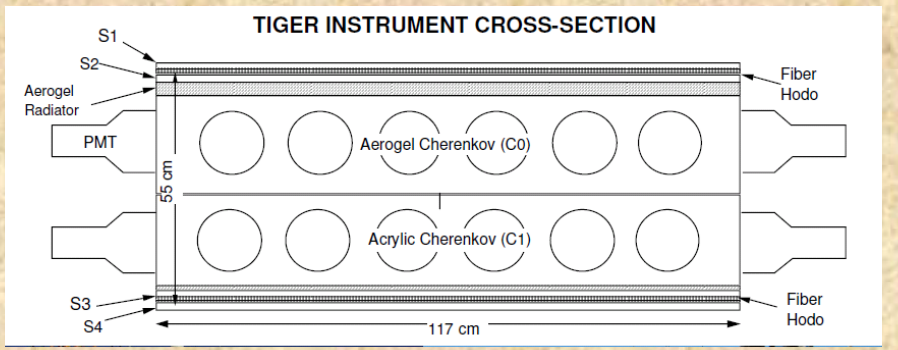
α = 2.3
Λ_0 = 0.1 g/cm^2

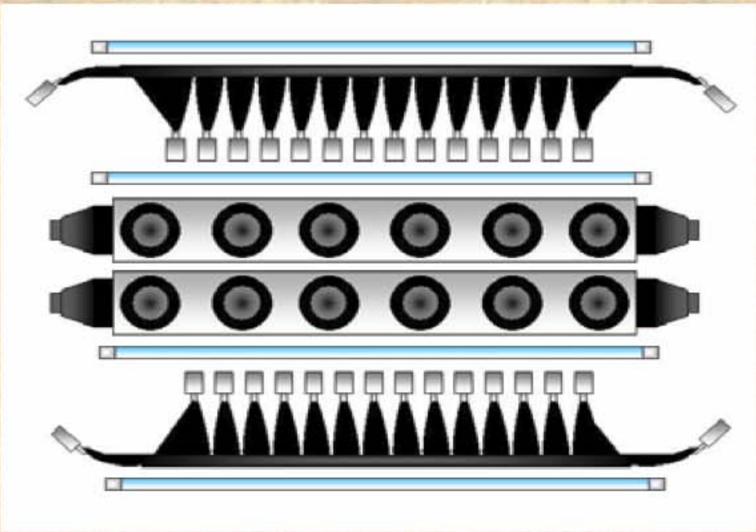
Dashed Line *Contribution from secondary nuclei*





TIGER Instrument



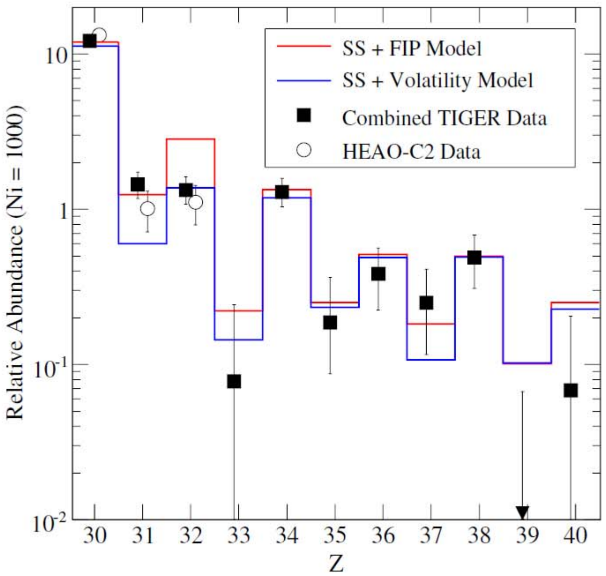


- Experiment Weight : ~1050kg
- Balloon Altitude: > 35.5 km
- Measurement of the elemental abundances of nuclei with 26 < Z < 40
- Energy measurement in 0.3-10 GeV/n.

TIGER Results

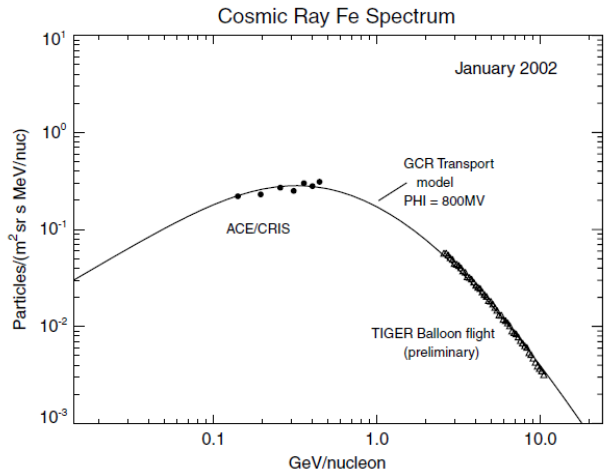
Volatility or FIP Fractionation or ??

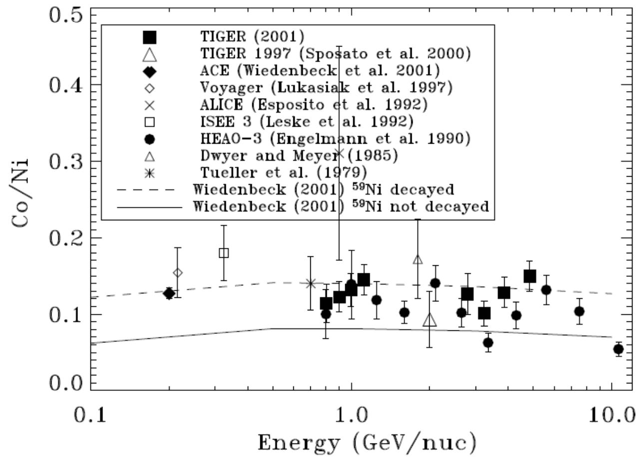
Top-of-atmosphere abundances



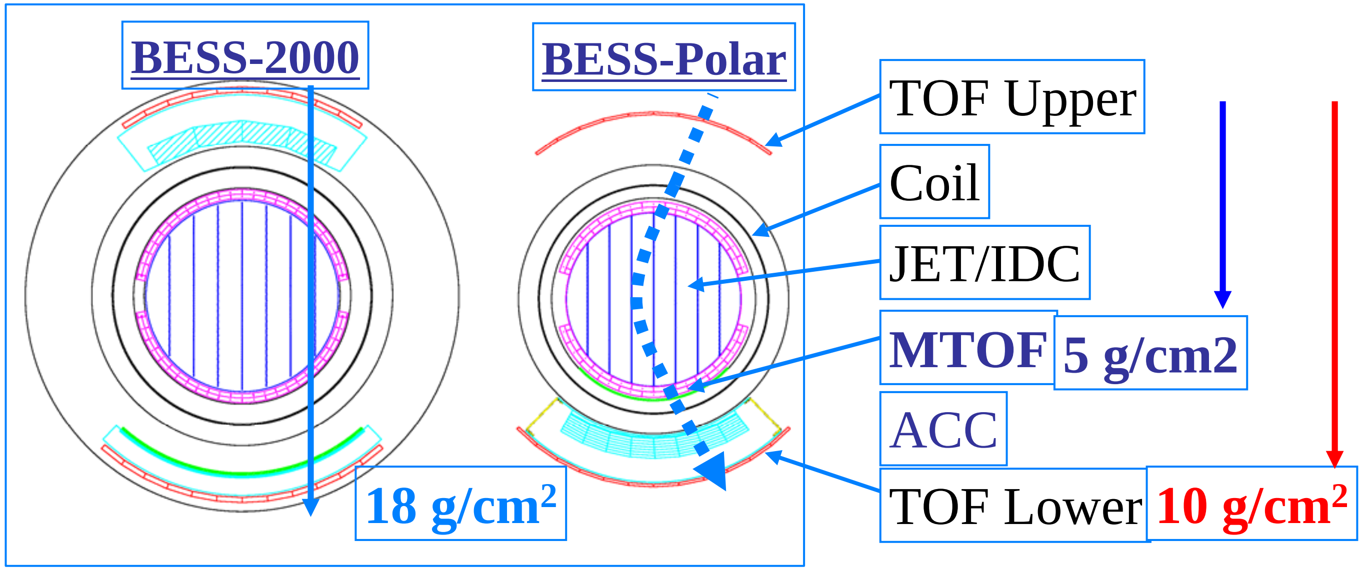
- $_{31}$Ga agrees with SS+FIP.
- $_{32}$Ge agrees with SS+Volatility.
- The disagreement suggests that the source abundances are not SS.
- TIGER results for Ga and Ge are consistent with HEAO-C2.

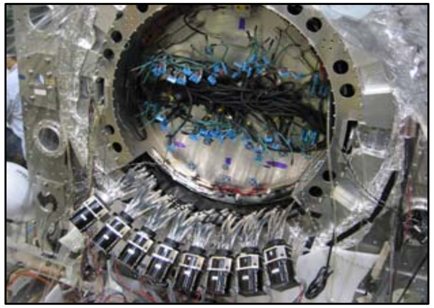
ACE/CRIS & TIGER





BESS-Polar Spectrometer
with Minimizing Material in Detectors



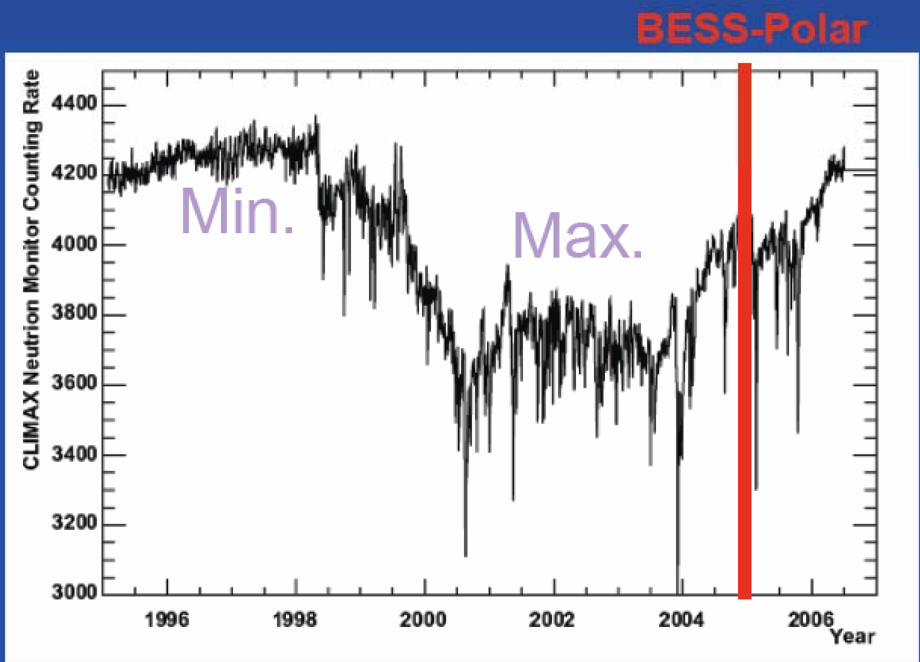


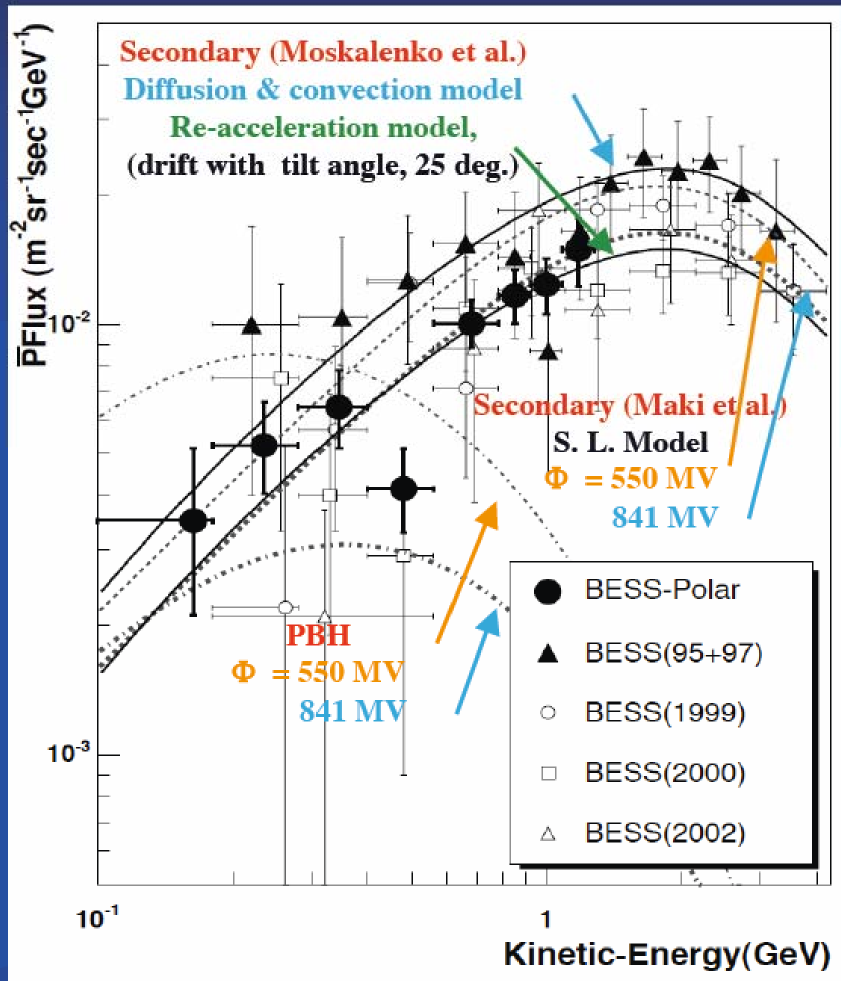
Minimize material &
New detector (Middle TOF) ➡ **Energy range extended down to 0.1 GeV**

Low power electronics
Solar Power System, Longer Cryogen Life ➡ **Long duration flight in Antarctica**

Antiproton Spectra with BESS

- BESS Polar I, 2004, before Solar-minimum,
- Results updated.





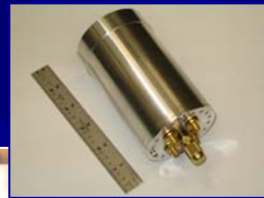
Re-acceleration model and S.L. model more consistent with BESS-Polar -I (before solar minimum)

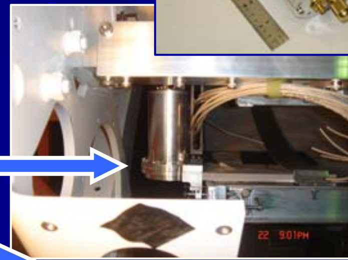
31

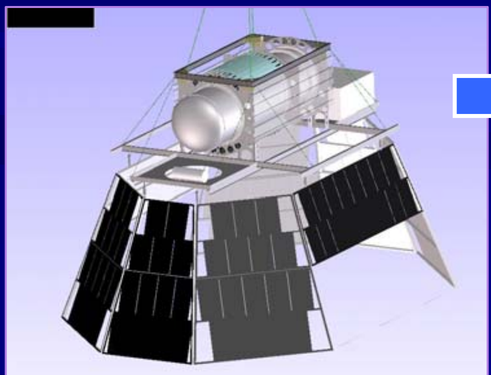
Upgrade for BESS-Polar-II

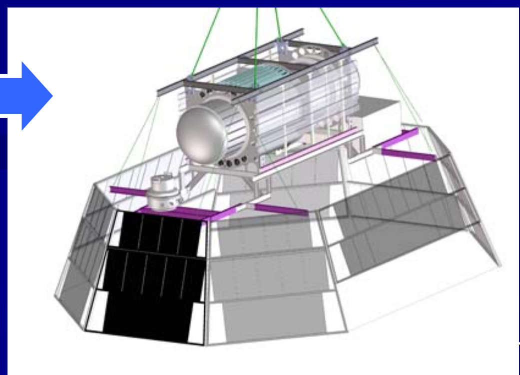
to realize 20 days observation in Solar Minimum

Subject	(BESS-Polar I)	(BESS-Polar II)
Magnet Cryogen Life	**~ 11 days**	**> 22 days**
Track detector (JET) gas quality	~ 10 days	**> 22 days**
TOF-PMT housing	Resin potting	Pressurized housing
ACC Particle ID	Rejection ~ 630	**>> 1000**
Solar-power gen.	4 stage 900 W	**3 stage 675 W**
Effective Acceptance	**0.2 m^2sr**	**0.3 m^2sr**
Observation time	**8.5 days**	**> 20 days**
Statistics Data storage	4 x BESS97 2 of 3.6 TB	**20 x BESS97** **12 ~ 16 TB**

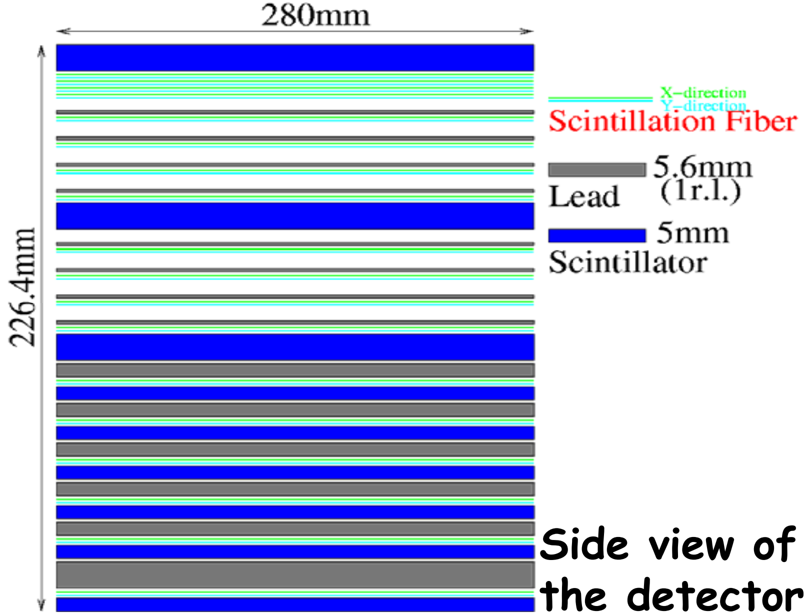




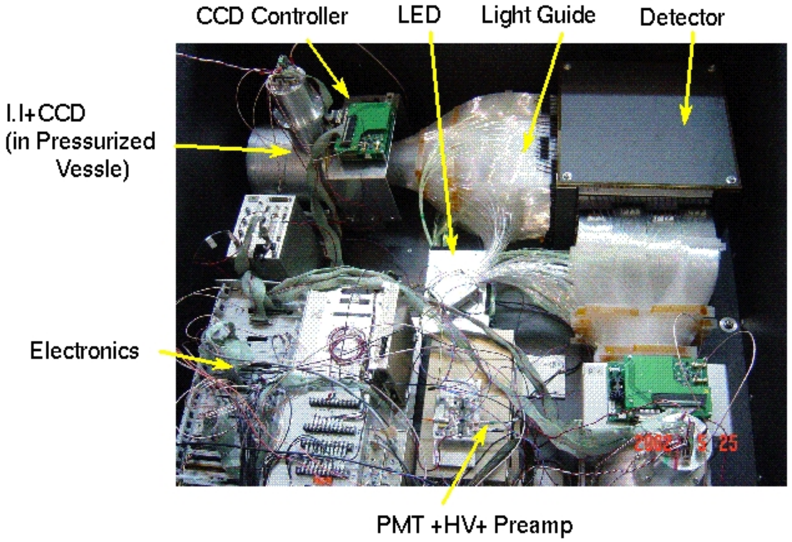




PPB-BETS Detector
"Imaging Calorimeter"

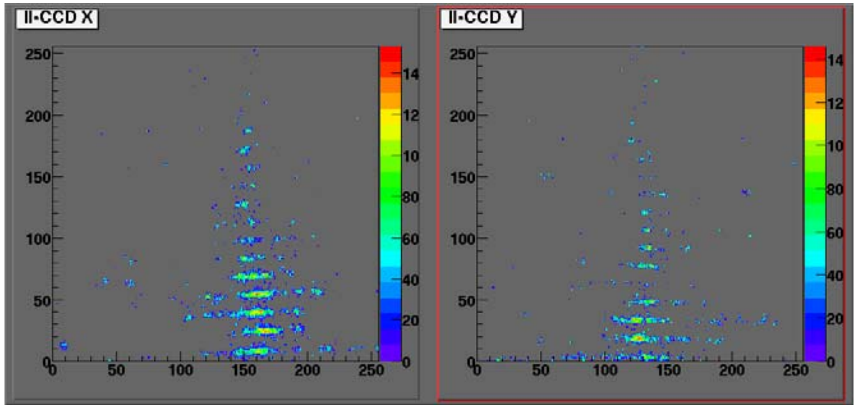


Side view of the detector

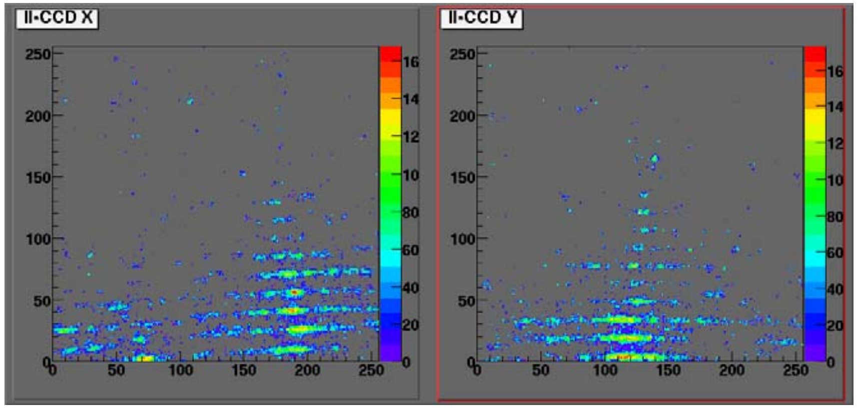


Imaging of cascade shower:
- Electron selection
- Energy measurement
- Angular measurement

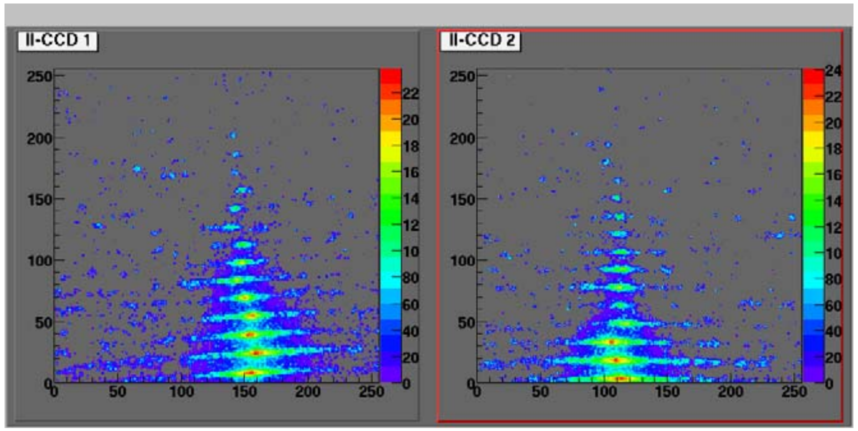
Calibration at Accelerator Beam @ CERN-SPS



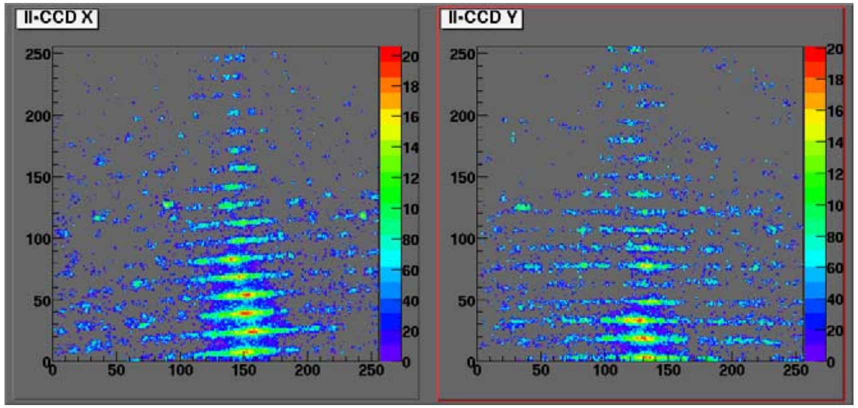
50 GeV electron



150 GeV proton



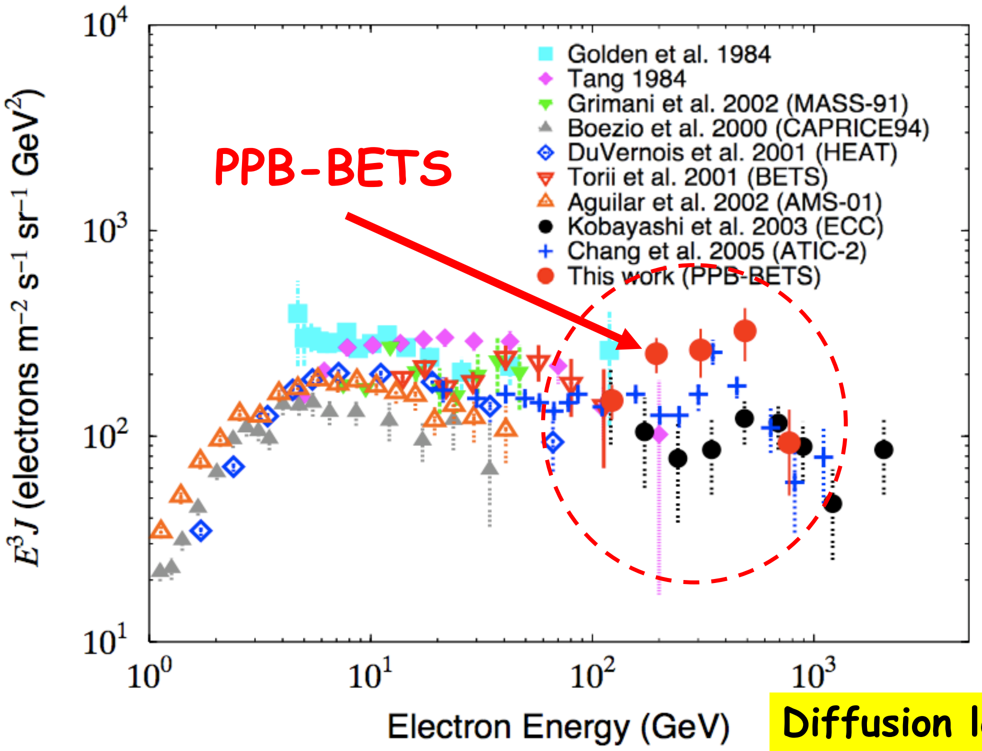
200 GeV electron



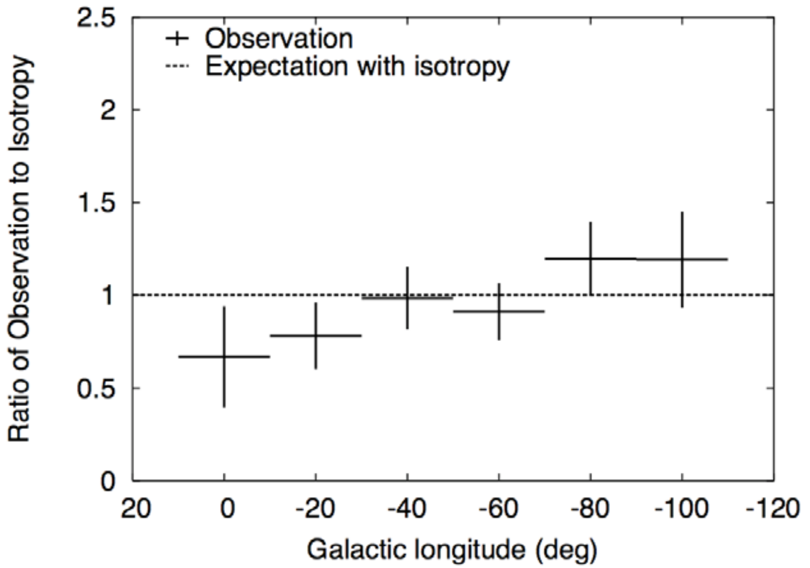
350 GeV proton

BETS Results

Energy spectrum of electrons in the energy range of 100GeV to ~1TeV



Ratio of observation to isotropic distribution along Galactic longitude



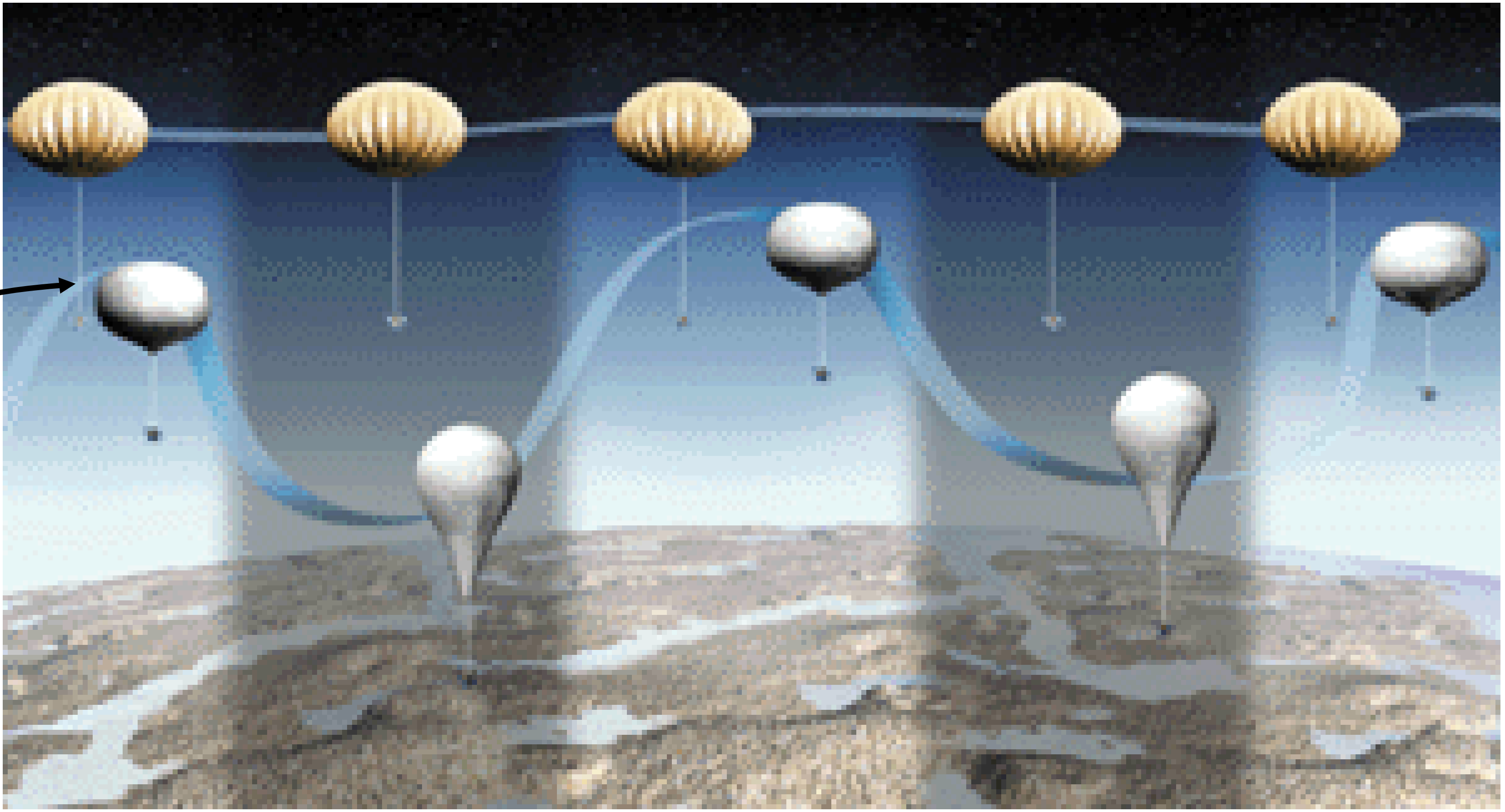
(Expected anisotropy by a model: ~1% >200GeV)

Diffusion length during the loss Time: $[4D(E)T_{loss}]^{1/2}$=1-2 kpc

Possible bump at 300 – 800 GeV seen by both ATIC and PPB-BETS may be a source signature?

Super-pressure Balloons:
A New Capability for Advanced Observations

Super-Pressure : Ultra Long Duration Balloon (ULDB) “Pumpkin”

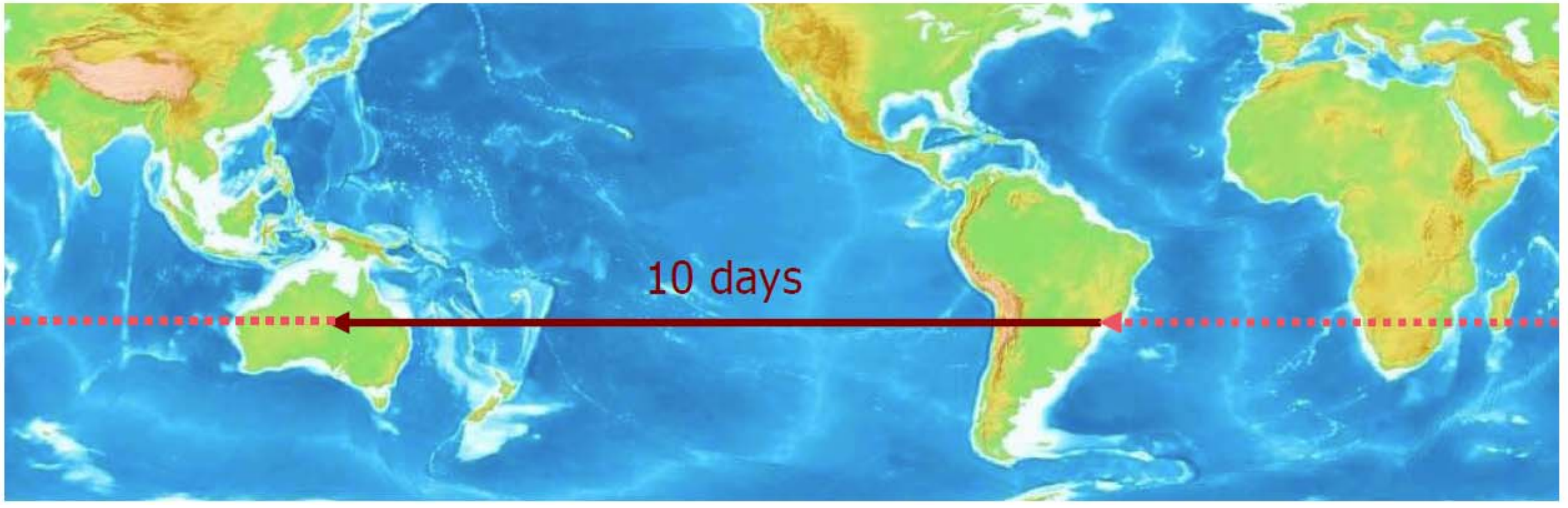


Zero-Pressure Balloon

Prospect of SPB development

in Japan

- 300,000 m^3 SPB in fabrication
  - Balloon weight ~ 1,200 kg
  - Suspend 450 kg @ 37 km (Payload ~ 350 kg)
  - Technical flight within 2007 at Brazil
- Brazil—Australia flight (~ 10 days), planned in 2008
- World-around (~ 1 month), hopefully in 2010
- Telemetry by INMARSAT BGAN (492 kbps max. IP packet)



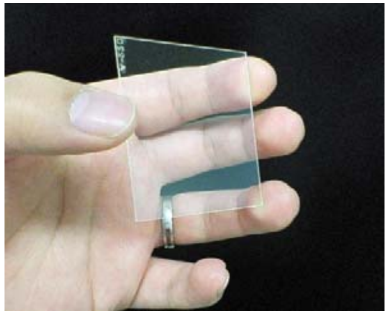
Ultra-Heavy Cosmic Ray Observation Program for High Energy Nuclear Astrophysics

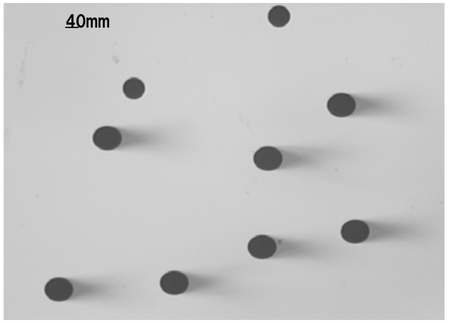
N.Hasebe et al.　Waseda University

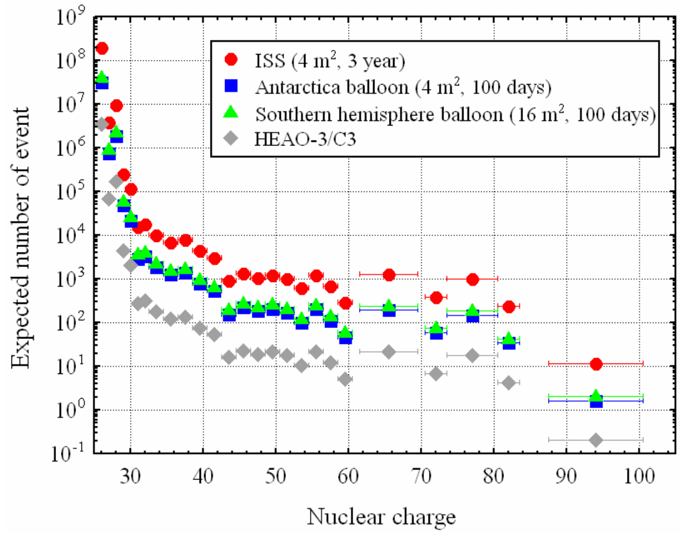
□ Solid-State Track Detector（SSTD）

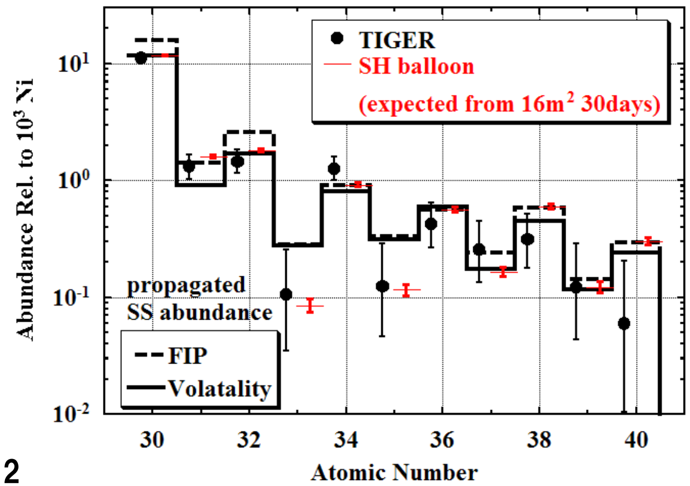
◎ CR-39 plastic detector　(performances already tested)

◎ BP-1 glass detector　(Now under development)









□ Advantage of SSTD

- Large collecting power（ > a few m²)
- High mass and charge resolutions
- Low cost & Easy to handle the detector
- Not sensitive for X-ray, γ-ray, β-ray and light nuclei

12

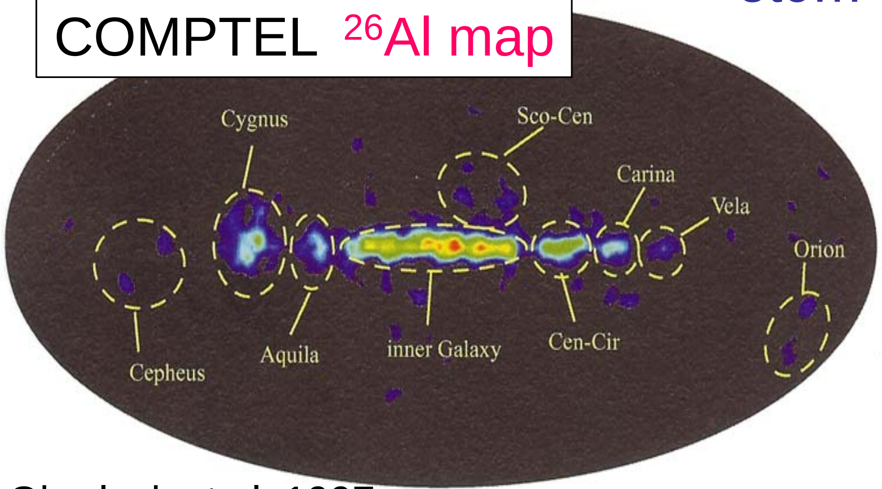
MeV γ Observation for Nuclear Emission

T.Tanimori et al.　Kyoto University

	Energy [keV]	Decay
^{56}Ni	158,270,480,759,812	6.10d
^{56}Co	847,1238,2598	77.2d
^{57}Co	122,136	271.7d
^{44}Ti	1157	63yr
^{26}Al	1809	7.4×10^{5} yr

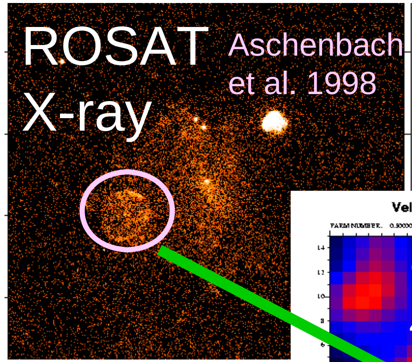
etc…

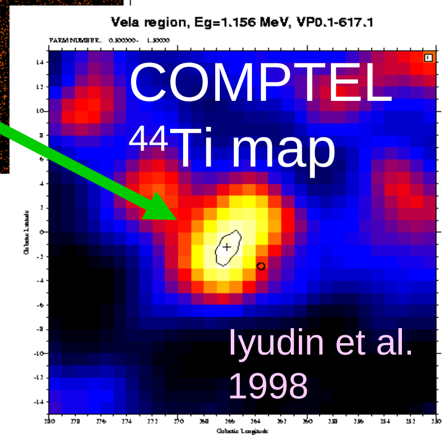
COMPTEL ^{26}Al map

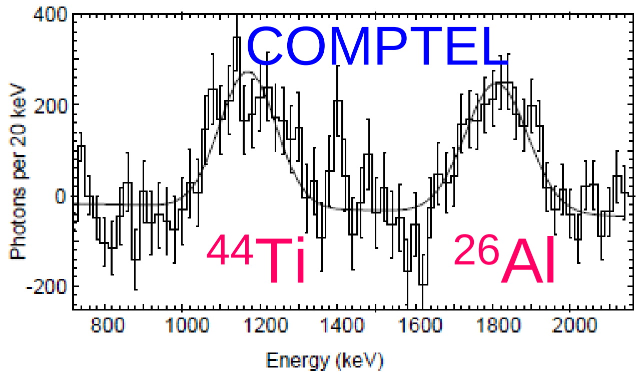


Oberlack et al.,1997

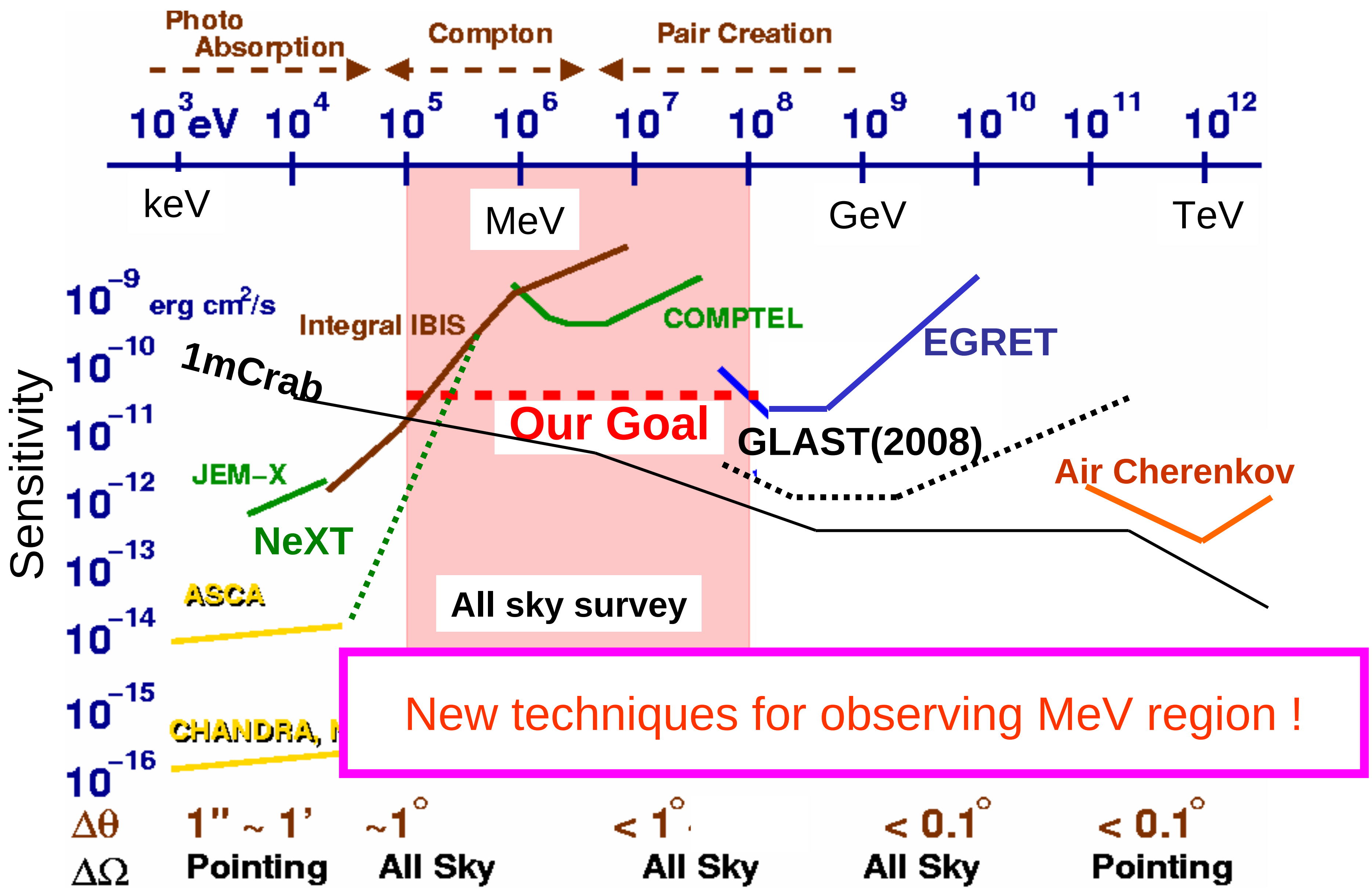
Discovery of SNR





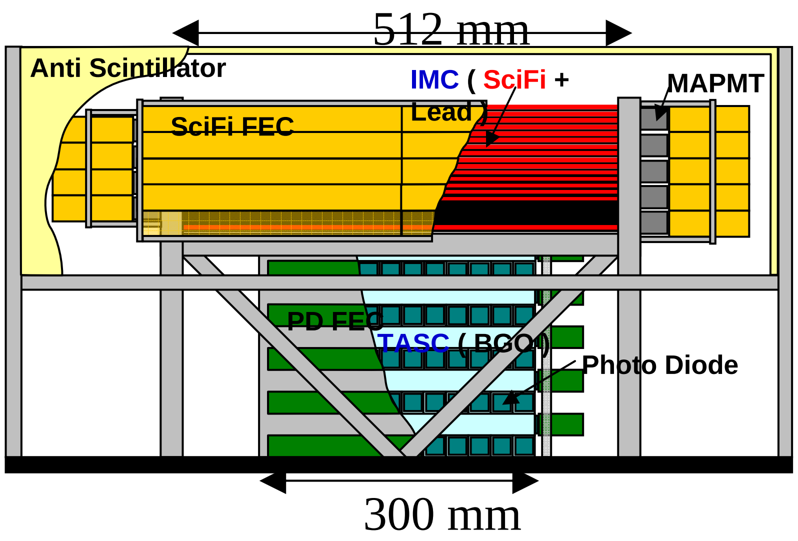


SMILE Instrument

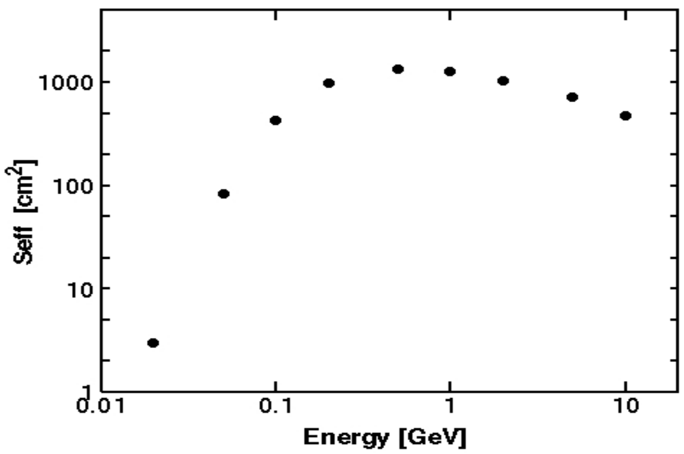


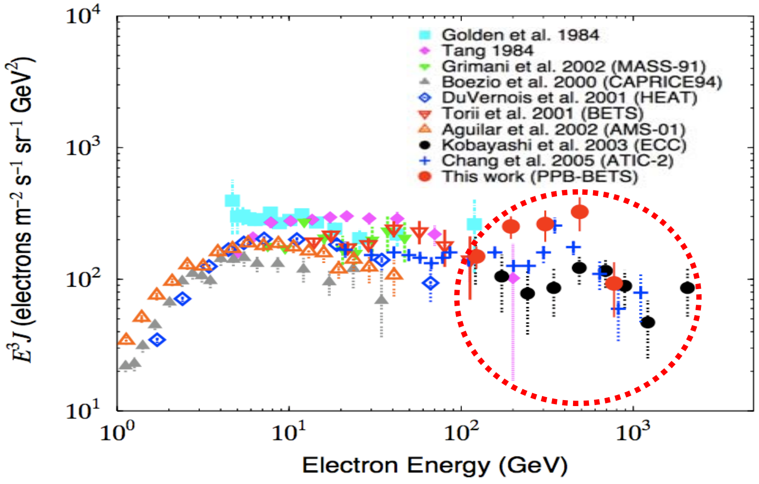
Electron Observation by ULDB

S.Torii et al. Waseda University



Effective Area





Observation of electron energy spectrum up to a few TeV

Cut-off of energy spectrum and/or Enhancement

We need space experiments for:

- Very high-statistics observation for define modeling of acceleration and propagation
- Very high-energy observation for resolving the origin of Knee
- Observation free from atmospheric effects
- Search for exotic origins as Dark Matter

Present and Expected Missions for Cosmic Ray Observation

PAMELA: Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics
AMS02: Alpha Magnetic Spectrometer
CALET: Calorimetric Electron Telescope

PAMELA nominal capabilities

	energy range	particles in 3 years
• Antiproton flux	80 MeV - 190 GeV	~ 10^4
• Positron flux	50 MeV – 270 GeV	~ 10^5
• Electron flux	up to 400 GeV	~ 10^6
• Proton flux	up to 700 GeV	~ 10^8
• Electron/positron flux	up to 2 TeV (from calorimeter)	
• Light Nuclei	up to 200 GeV/n He/Be/C:	~$10^{7/4/5}$
• AntiNuclei search	sensitivity of $3x10^{-8}$ in He/He	

→ Simultaneous measurement of many cosmic-ray species

→ New energy range

→ Unprecedented statistics

Taking into account live time and geometrical factor:

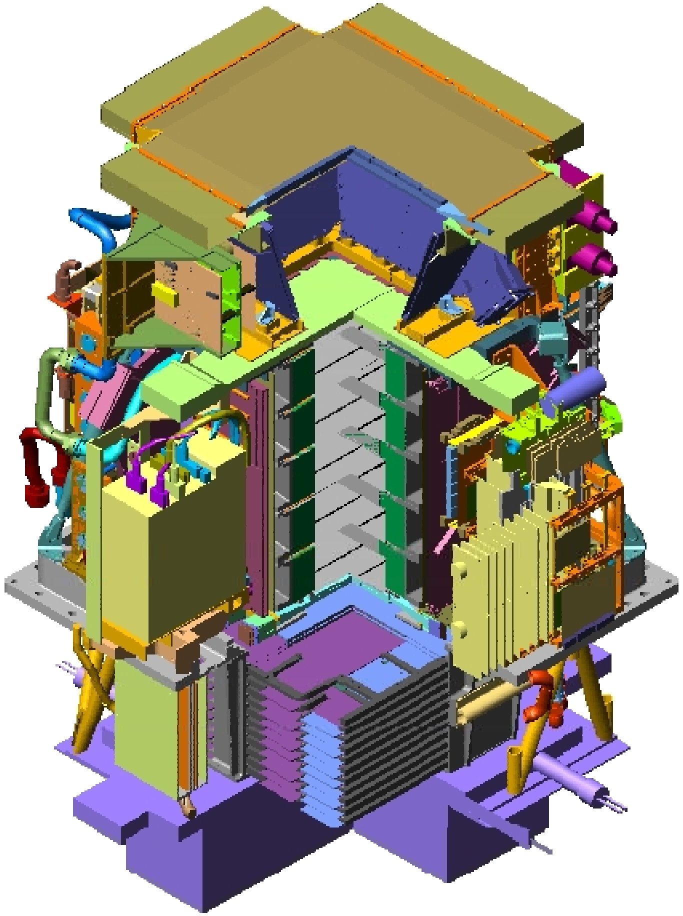
1 HEAT-PBAR flight ~ 22.4 days PAMELA data

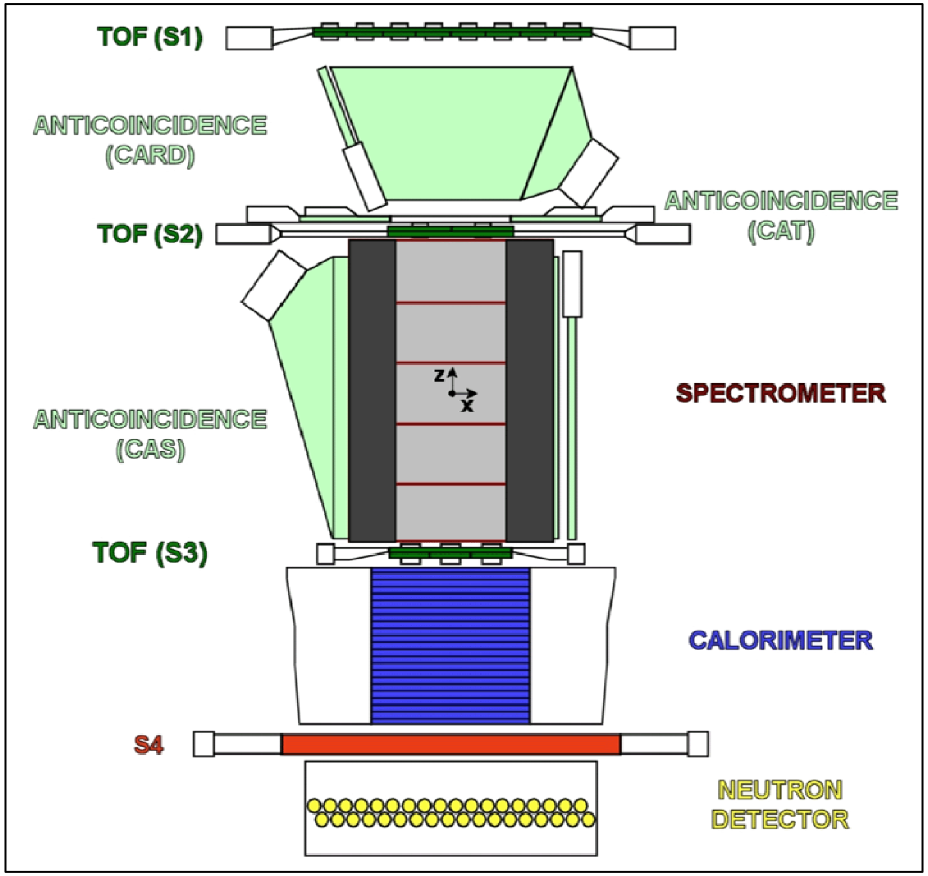
1 CAPRICE98 flight ~ 3.9 days PAMELA data

PAMELA science

- Search for antimatter
- Search for dark matter
- Study of cosmic-ray propagation
- Study solar physics and solar modulation
- Study of electron spectrum (local sources?)
- Study terrestrial magnetosphere

PAMELA apparatus





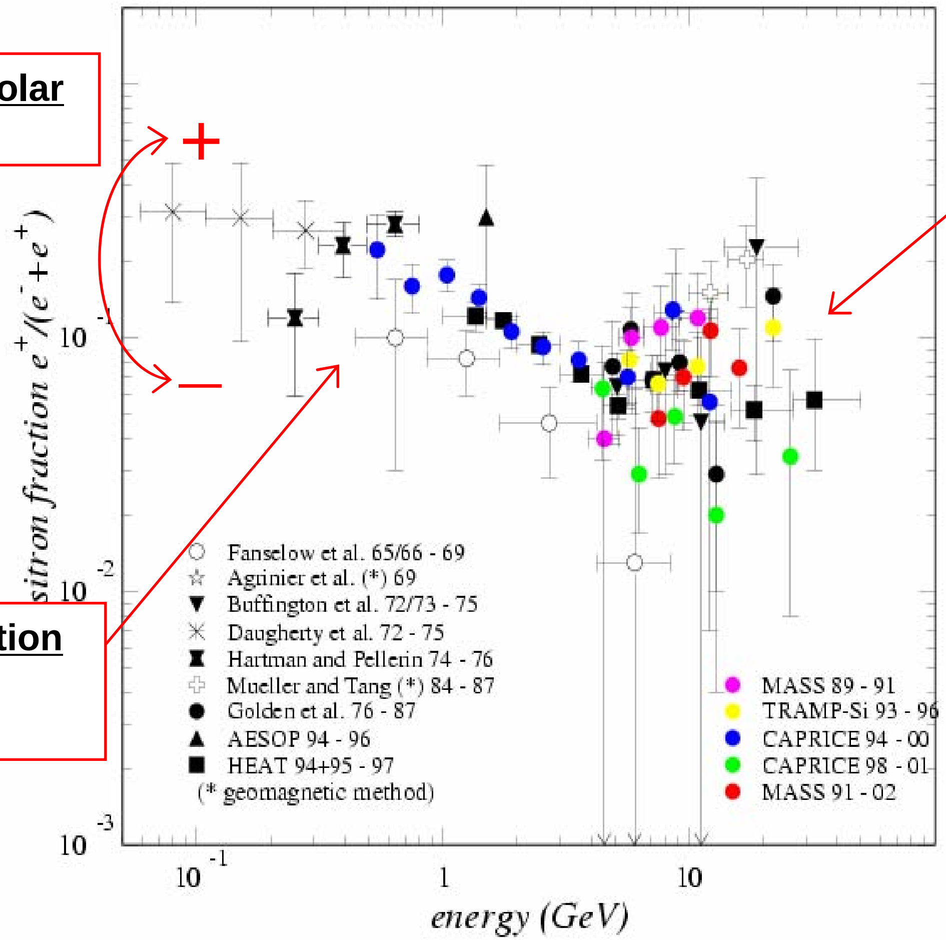
GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W

Positrons

Experimental scenario until 90s

Charge-dependent solar modulation

Atmospheric correction (balloon-borne experiments)

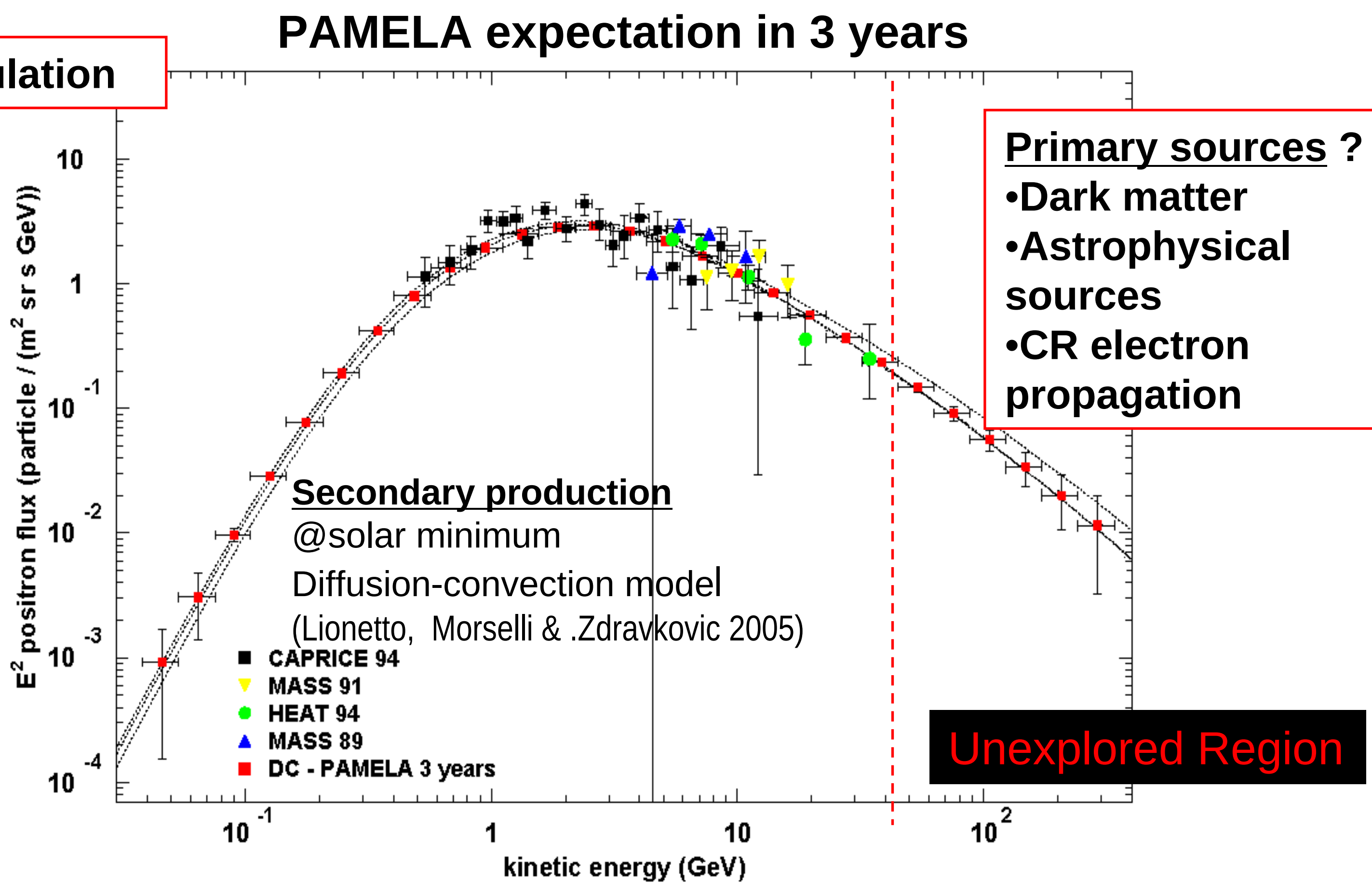


…?…

Difficult interpretation due to large uncertainties in propagation models

Positrons

• Solar modulation



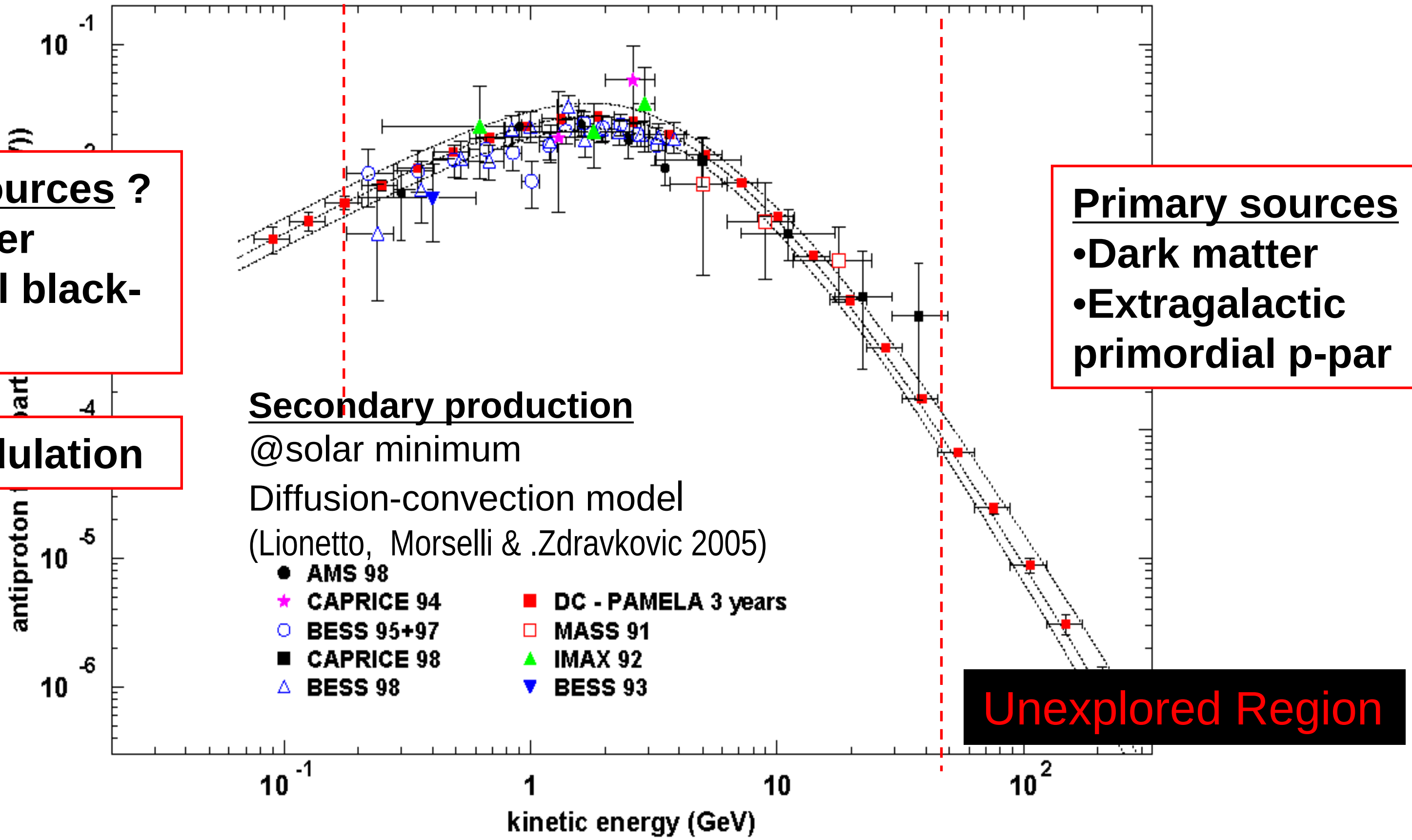
Primary sources ?
- **Dark matter**
- **Astrophysical sources**
- **CR electron propagation**

Antiprotons

PAMELA expectation in 3 years

Primary sources ?
- **Dark matter**
- **Primordial black-holes**

- **Solar modulation**



Primary sources ?
- **Dark matter**
- **Extragalactic primordial p-par**

Cosmic-ray Antimatter from Dark Matter annihilation

A plausible dark matter candidate is neutralino (χ), the lightest SUSY particle.

Annihilation of relic χ gravitationally confined in the galactic halo

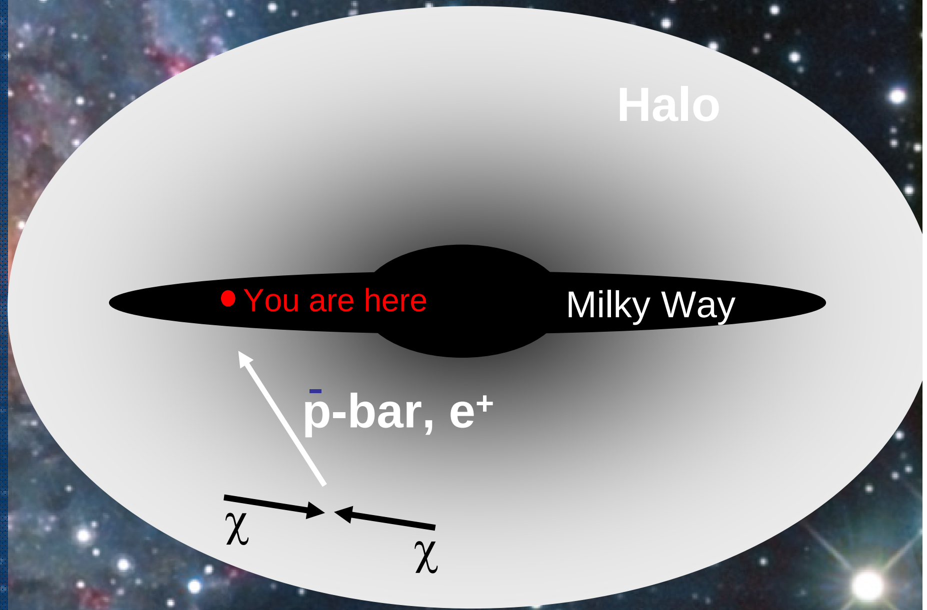
→ Distortion of antiproton and positron spectra from purely secondary production

Most likely processes:

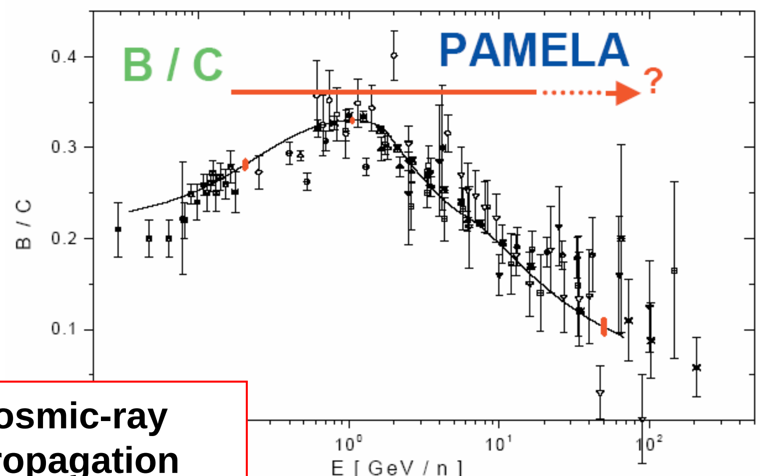
- $\chi\chi \rightarrow qq \rightarrow$ hadrons $\rightarrow$ anti-p, e^+,…
- $\chi\chi \rightarrow W^+W^-, Z^0Z^0, \ldots \rightarrow e^+, \ldots$

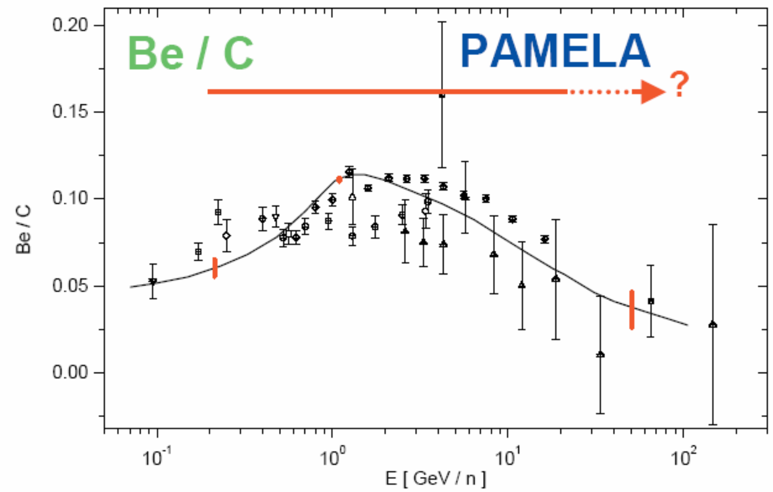
direct dicay ⇒ positron peak $E_{e+} \sim M_\chi/2$

other processed ⇒ positron continuum $E_{e+} \sim M_\chi/20$

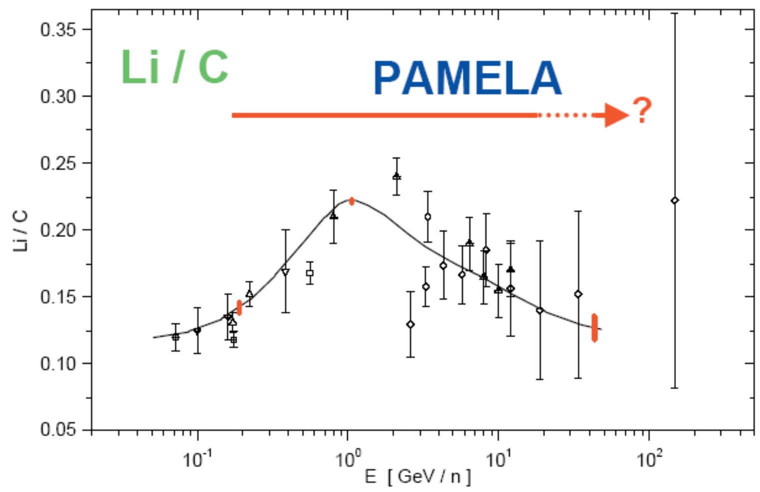


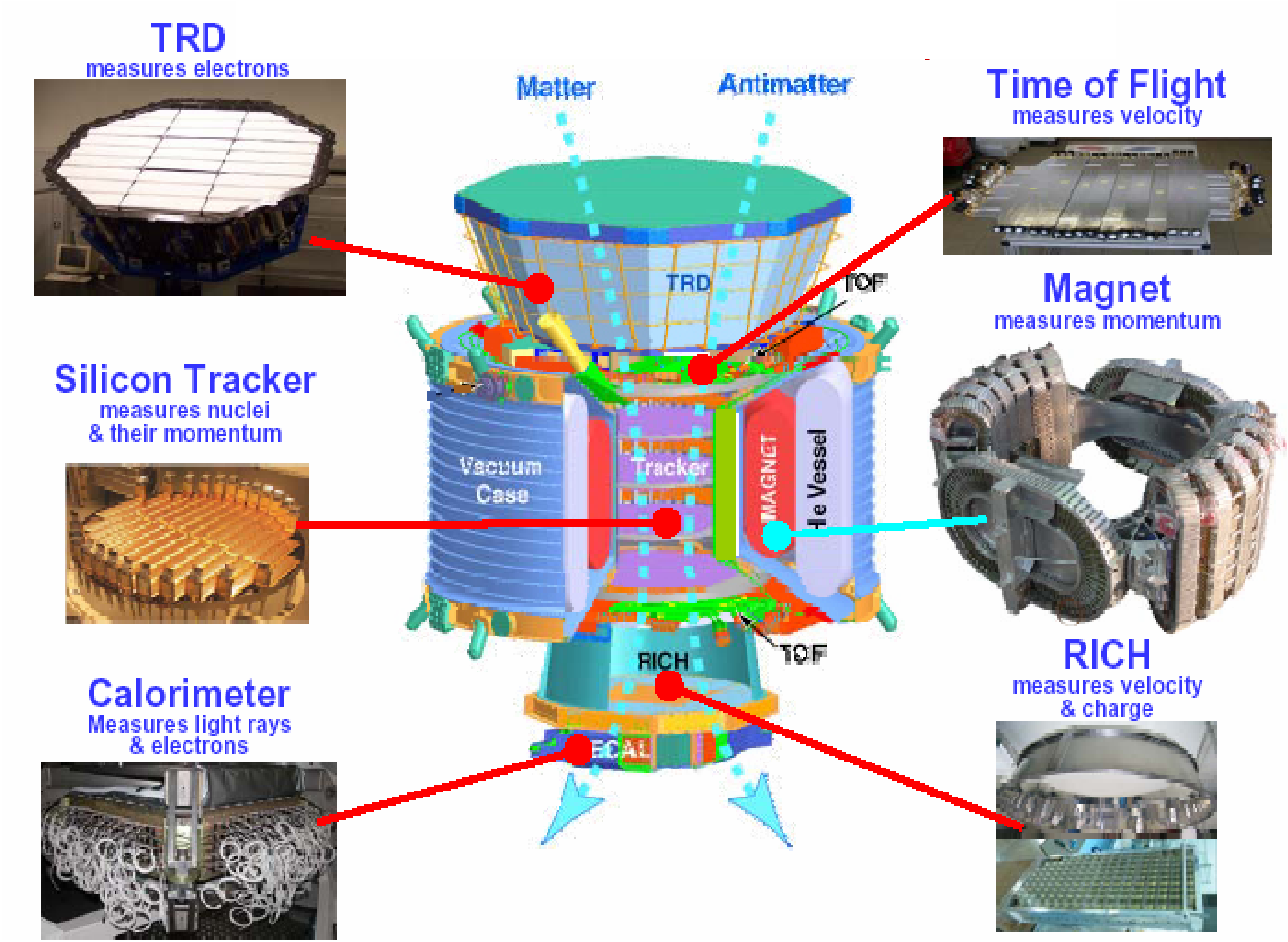
Secondary-to-primary ratio





Cosmic-ray propagation parameters often tuned on B/C data





TRD
measures electrons
Matter
Antimatter
Time of Flight
measures velocity
TRD
TOF
Magnet
measures momentum
Silicon Tracker
measures nuclei
& their momentum
Vacuum
Case
Tracker
MAGNET
He Vessel
TOF
RICH
RICH
measures velocity
& charge
Calorimeter
Measures light rays
& electrons
ECAL

Expected data statistics for AMS on ISS

Above	> 1 GeV/c	>5 GeV/c	>10 GeV/c	>100 GeV	> 1 TeV
Protons			6.1×10^9	1.5×10^8	2.5×10^6
Electrons	1.4×10^8	7.3×10^7	6.8×10^6	7.2×10^4	5.4×10^2
Positrons	9×10^6	3.8×10^6	3×10^5	1.6×10^3	6
Antiprotons	1.5×10^6	1.1×10^6	1.4×10^4	3.2×10^3	5.8×10^2
Helium	6.4×10^8	4.3×10^8	2.1×10^8	7.3×10^6	1.7×10^5

AMS-02 goals and capabilities

Cosmic rays spectra and chemical composition up to 1 TeV

Search for Antimatter in Space

Search for Dark Matter

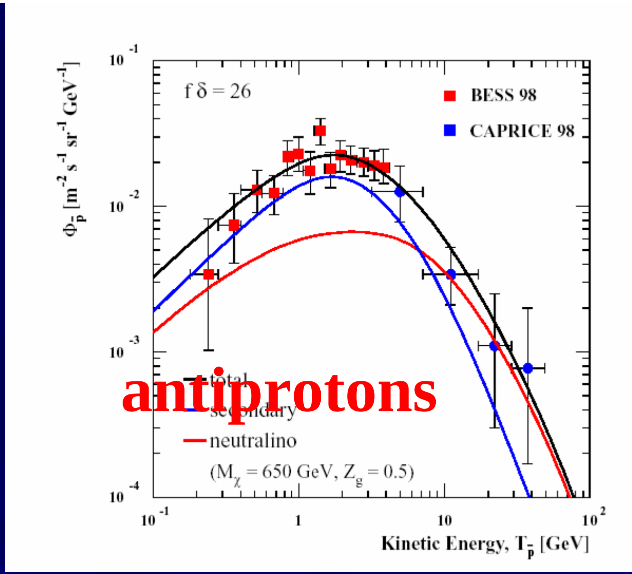
↓

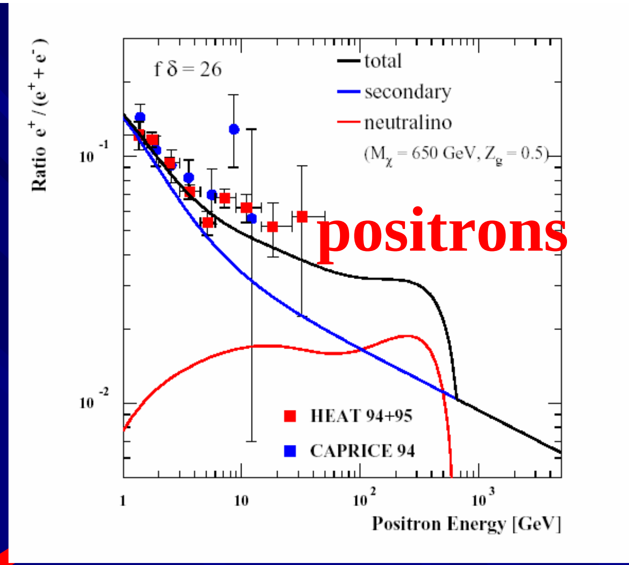
AMS will identify and measure the fluxes for:

- **p for E < 1 TeV with unprecedented precision**
- **e+ for E < 300 GeV and e– for E < 1 TeV (unprecedented precision)**
- **Light Isotopes for E < 10 GeV/n**
- **Individual elements up to Z = 26 for E < 1 TeV/n**

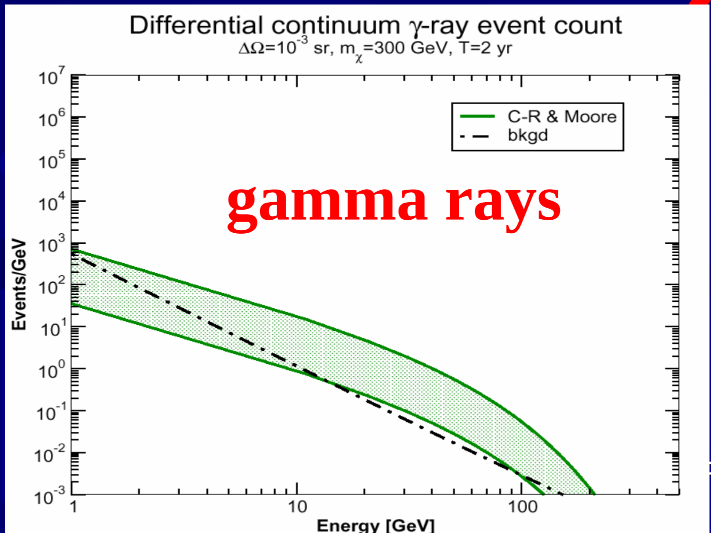
Absolute fluxes and spectrum shapes of protons and helium are important for calculation of atmospheric neutrino fluxes

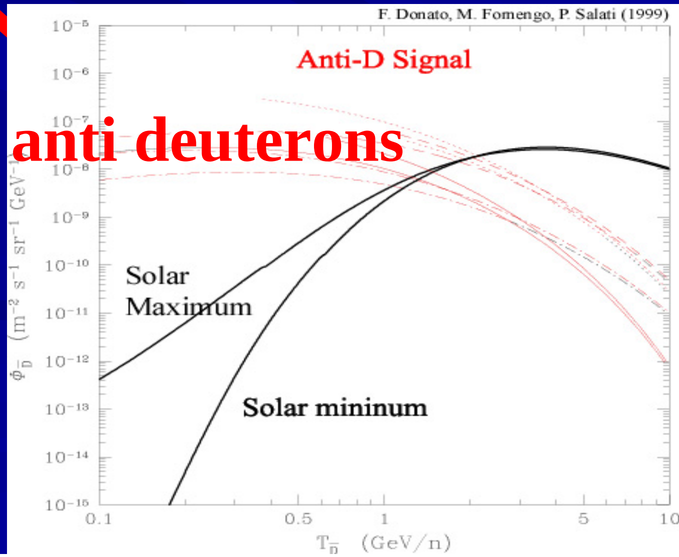
Unique Feature Of AMS





Combining searches in different channels could give (much) higher sensitiviy to SUSY DM signals





CALET: CALorimetric Electron Telescope

CALET Mission Concept

● **Instrument:**
  High Energy Electron and Gamma-Ray Telescope Consisted of
  - Imaging Calorimeter (IMC)
  - Total Absorption Calorimeter (TASC)

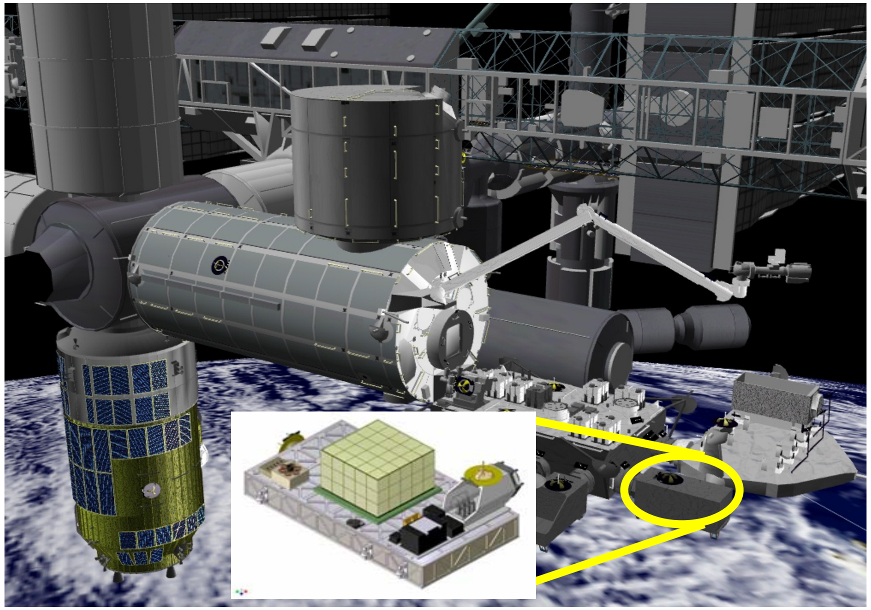
● **Launch:**
  HTV: H-IIA Transfer Vehicle

● **Attach Point on the ISS:**
  Exposed Facility of Japanese Experiment Module (JEM-EF)

● **Nominal Orbit:**
  407 km, 51.6^{o} inclination

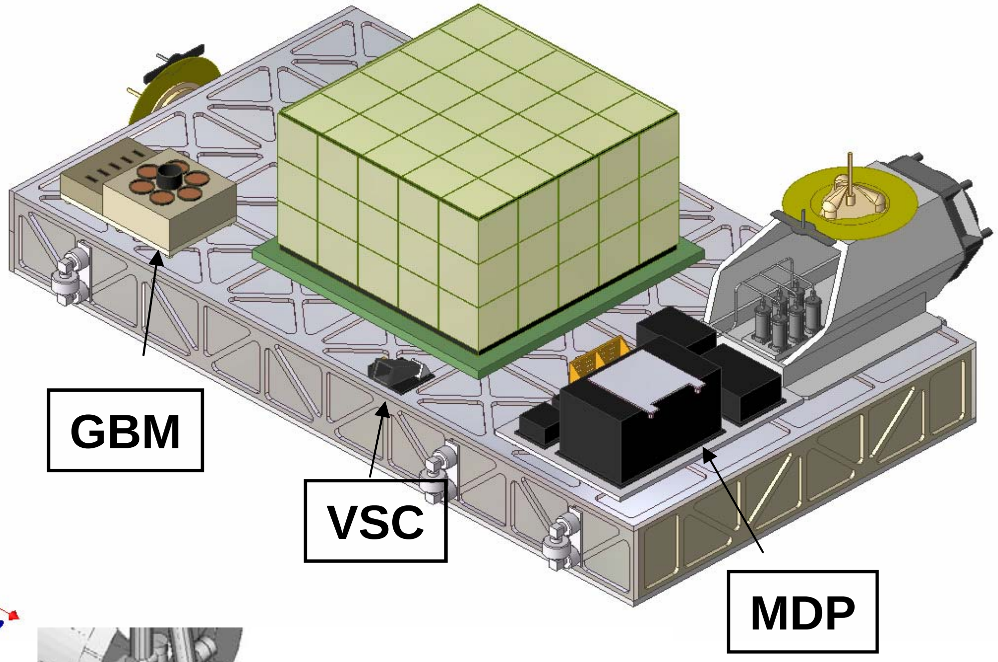
● **Life Time:**
  3(Minimum)-5 years

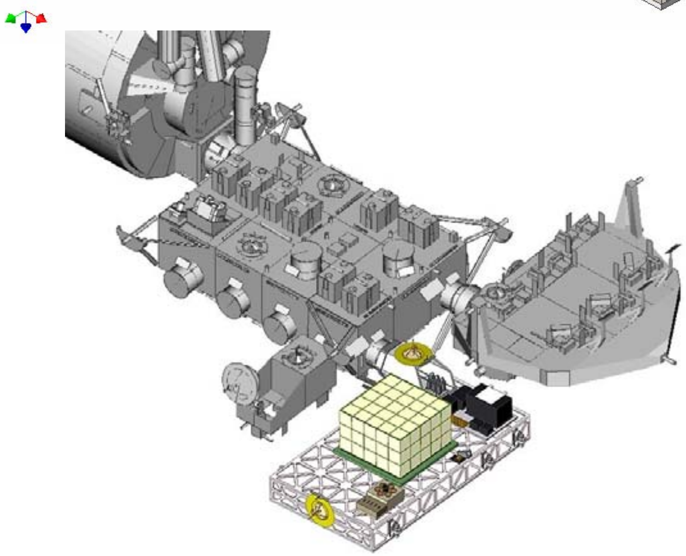
● **Mission Status**
  Phase A/B Study
  Launch around 2013 in Plan

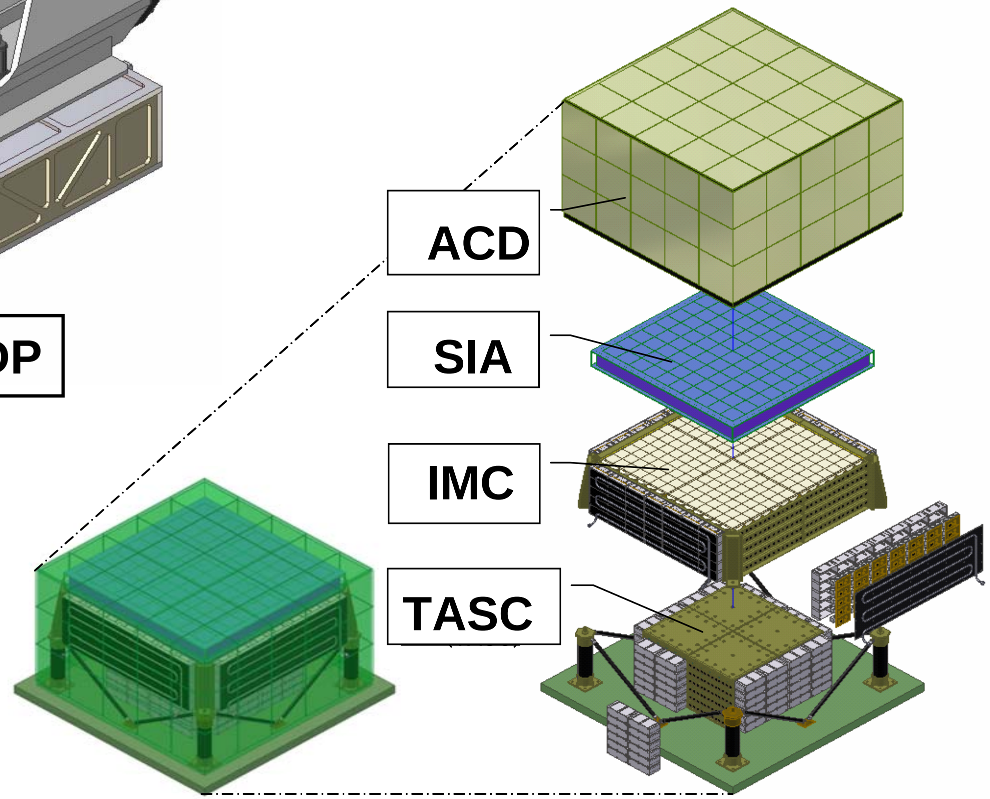


CALET Payload:
- 1GeV ~ 10 TeV for electrons
- 20 MeV ~ several TeV for gamma-rays
  + Gamma-ray bursts in 7 keV~20 MeV
- several 10GeV ~ 1000 TeV for p & nuclei
- Weight: 2000 kg
- Geometrical Factor: ~0.7 m^2sr
- Power Consumption: 640 W
- Data Rate: 300 kbps

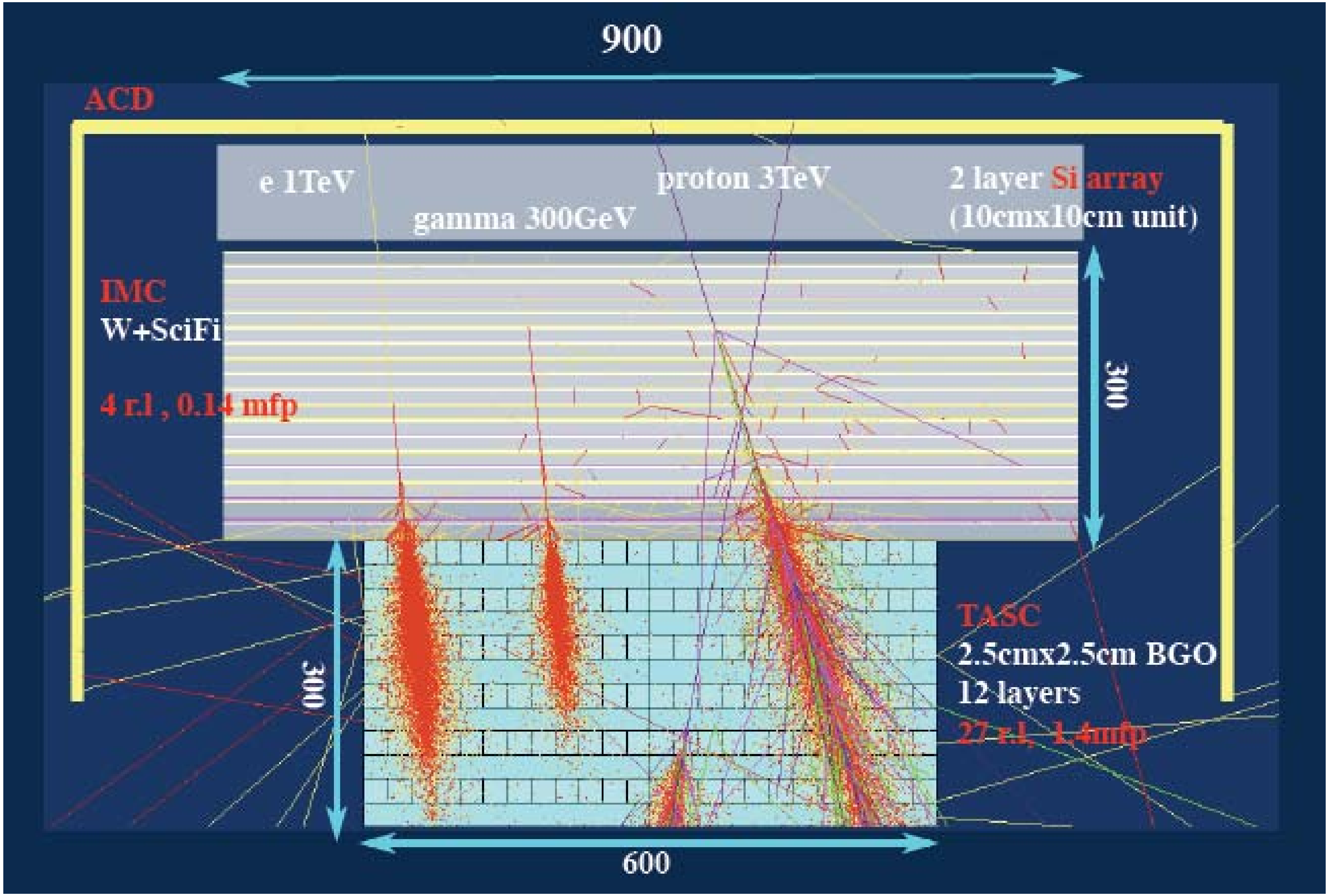
Schematic Structure of the CALET Payload





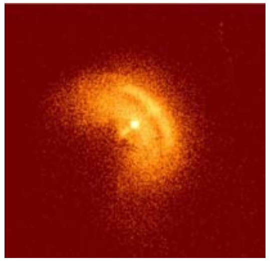


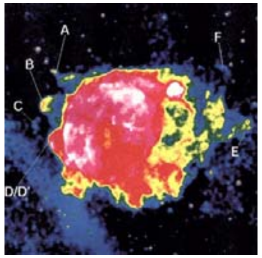
Examples of Simulation Events

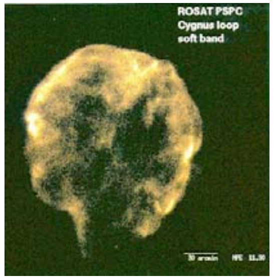


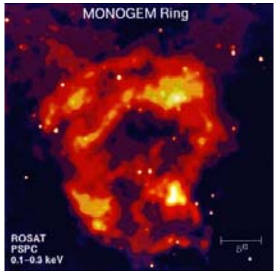
Purposes of Electron Observation

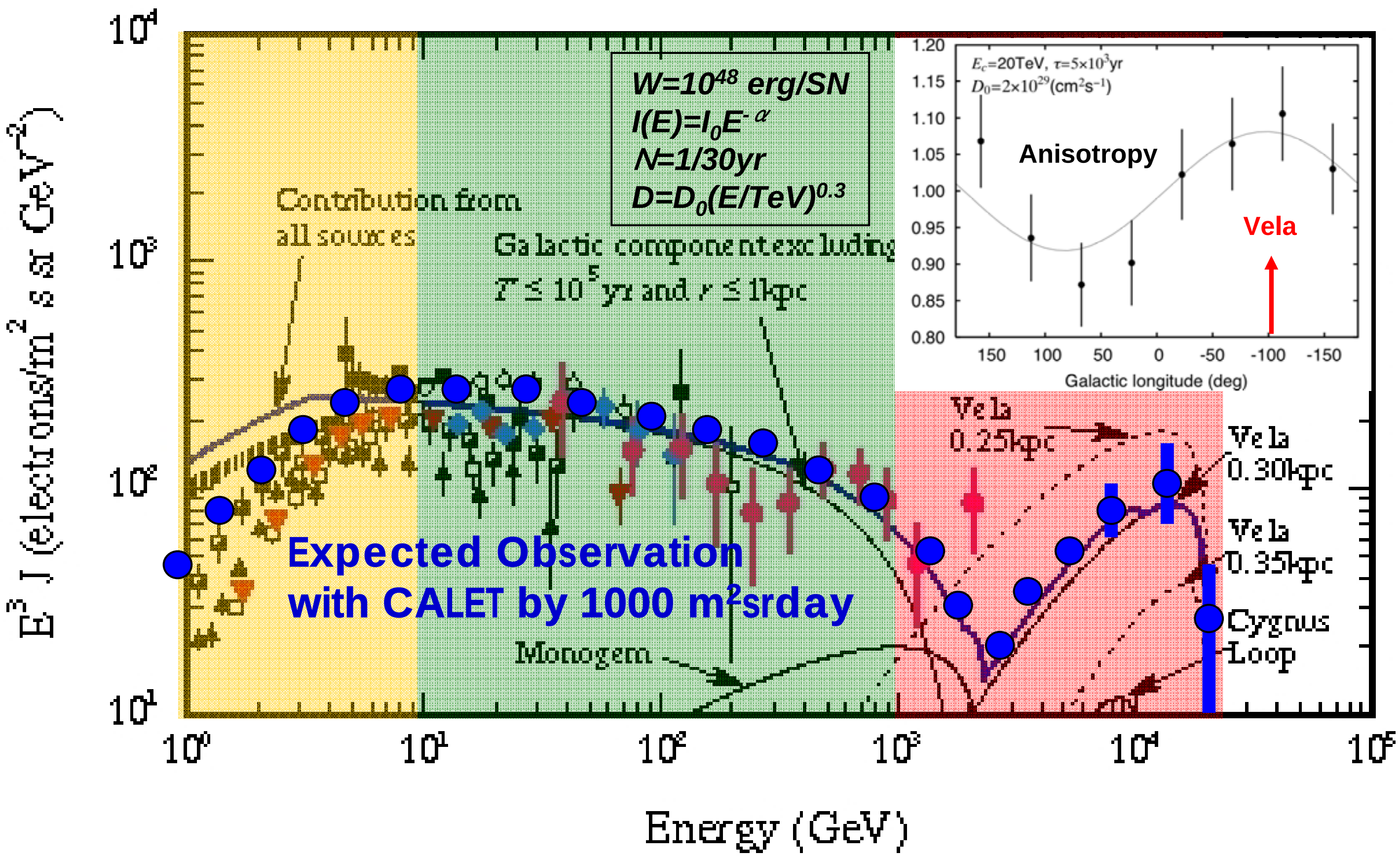
- *Detection of Nearby Sources*
- *Electron Propagation in Our Galaxy*
- *Acceleration by Supernova Shock Wave*
- *Solar Modulation*











Origin and Propagation of Proton and Nucleus

- *Supernova Shock Acceleration*
  Change of power spectrum index depending on Z ?
- *Propagation in the Galaxy*
  Leaky box model ?

Measurements of proton and heavy ion flux in the energy region exceeding 1 TeV, in which magnet spectrometer is not capable.

For proton measurement:

$S\Omega_{eff} \sim 0.2\ m^2\ sr$ (for p)

Exposure factor for 3 years:

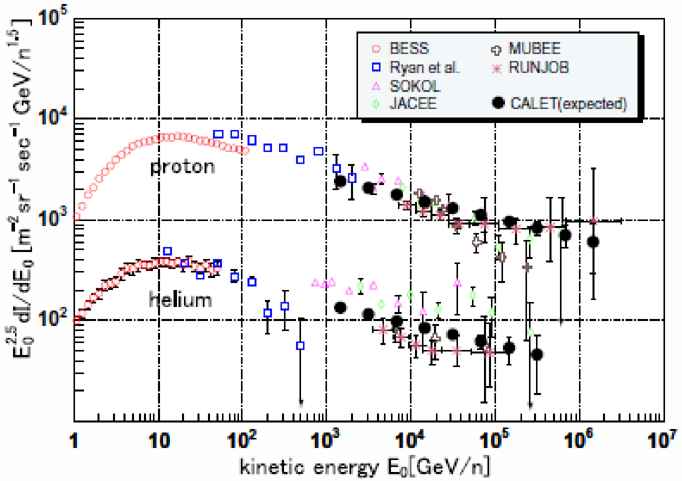
$220\ m^2\ sr\ day \sim 1.9 \times 10^7\ m^2\ sr\ sec$

Expected numbers of protons:

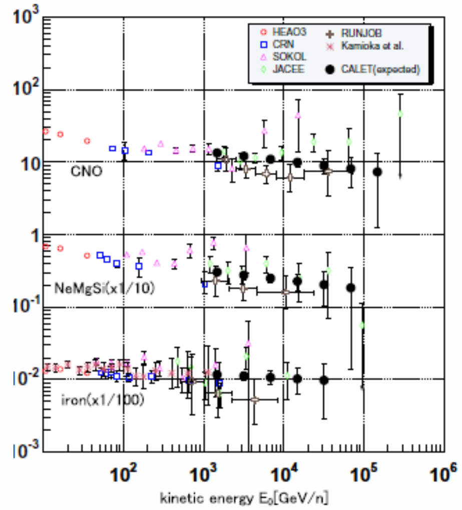
Energy (TeV)	Number
1	$\sim 10^6$
10	2.3×10^4
100	4.1×10^2
1000	~ 10

Energy Resolution: ~30% , E > 100 GeV

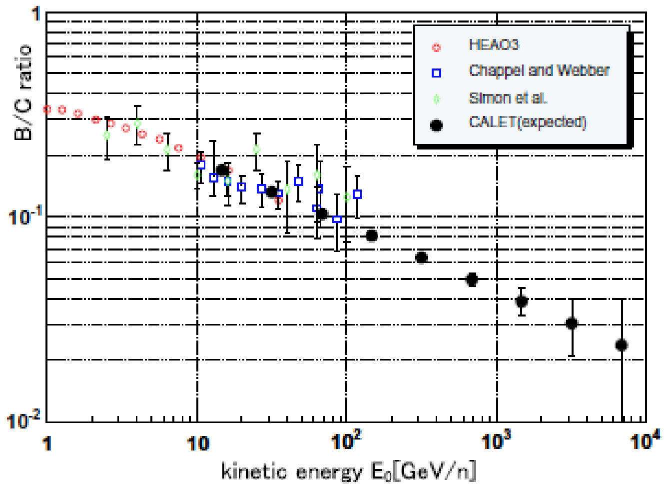
P & He



Heavy Nuclei

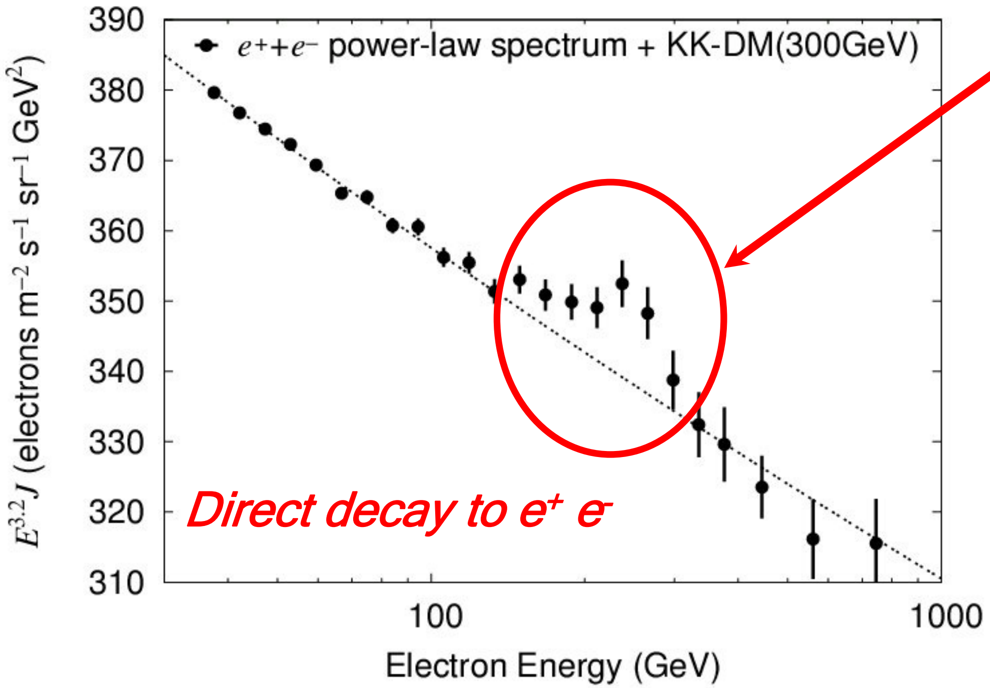


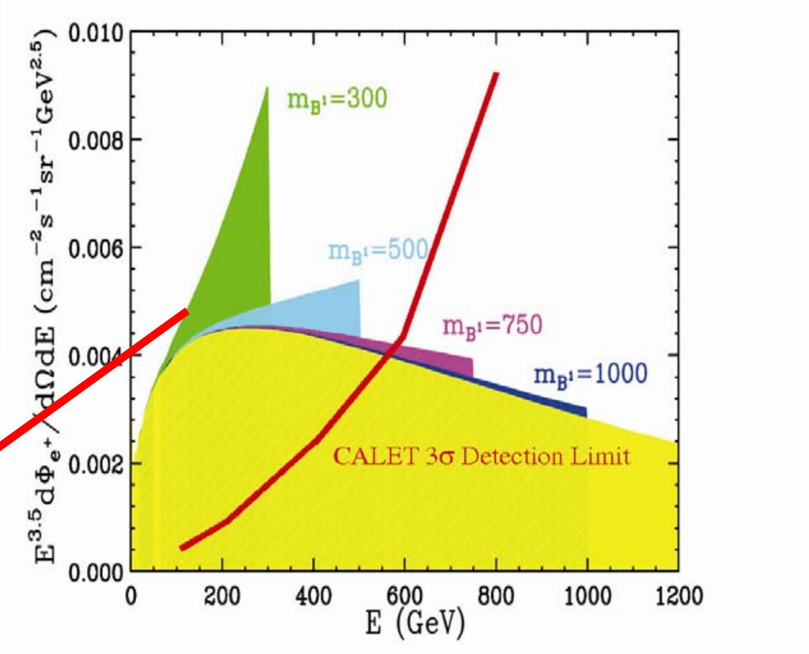
B/C Ratio



Dark Matter Search by Positrons (& Electrons)

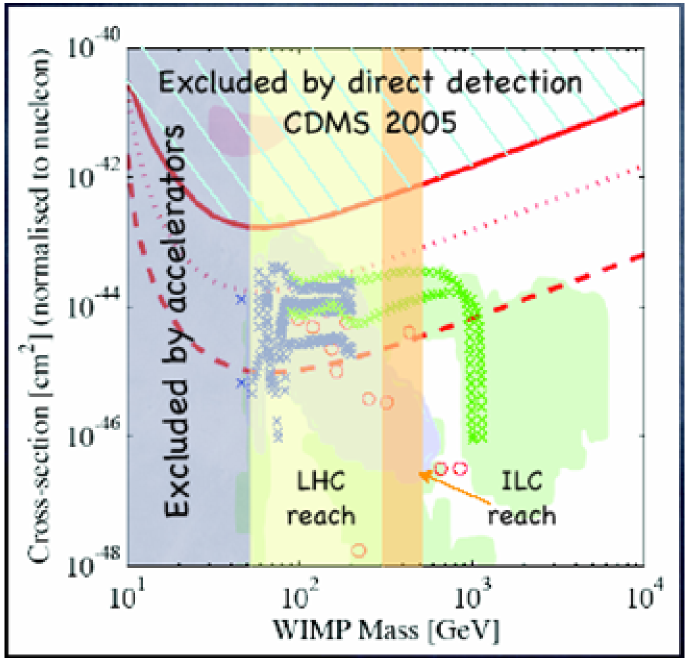
Positron will be measured by
- **PAMELA flying**
- **AMS to be launched on ISS**
- **CALET on ISS (can not separate e+ and e-)**
  Simulation for 300 GeV KK DM





H.C. Cheng et al., PRL 2002.

SUSY Dark Matter Search by Gamma-ray Line



WIMP Mass Limit from Direct Observation

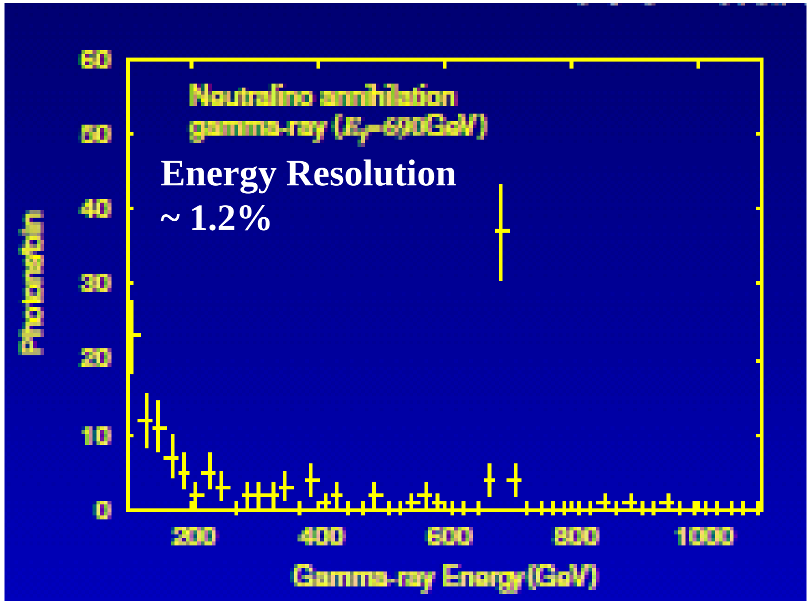
- WIMP mass is likely heavier than 100 GeV
- Future accelerator experiments will cover the mass range in 100~1000 GeV
- Indirect observation is very promising to see gamma-ray line according to WIMP mass.

- 690 GeV neutralino annihilating to $\gamma\gamma$
- Clumpy halo as realized in N-body simulation of Moore et al. (ApJL 1999)

$$\Phi_\gamma = \frac{N_\gamma \sigma v}{m_\chi^2} \frac{1}{4\pi} \int \int_{line\ of\ sight} \rho^2(\ell) d\ell d\Omega$$

- $m_\chi = 690\mathrm{GeV}$
- $N_\gamma \sigma v = 1.5 \times 10^{-28} \mathrm{cm}^3 \mathrm{s}^{-1}$

Simulated Signal in CALET for 3 years



SUMMARY

- Very impressive improvements in the quality of the measurements has be brought by the LDB flights since 2000.
- Much more progress within a few years is expected to realize a precise measurement for acceleration and propagation model; B/C ratio, spectral index of p ~Fe, UH particles … , also in collaboration with X-ray and gamma-ray observations.
- Measurements in the electron spectrum might tell us about nearby sources or more likely put limits on diffusion.
- The ULDB flights by super pressure balloons will make possible the observations for ~100 days to cover the Knee region and to distinguish the models in origin, acceleration and propagation.
- New erra of astroparticle physics should arrive in next decade by the crucial observations in space of various kinds of cosmic rays and the possible detection of dark matter.

Most Exciting Period of Cosmic-Ray Science !!!