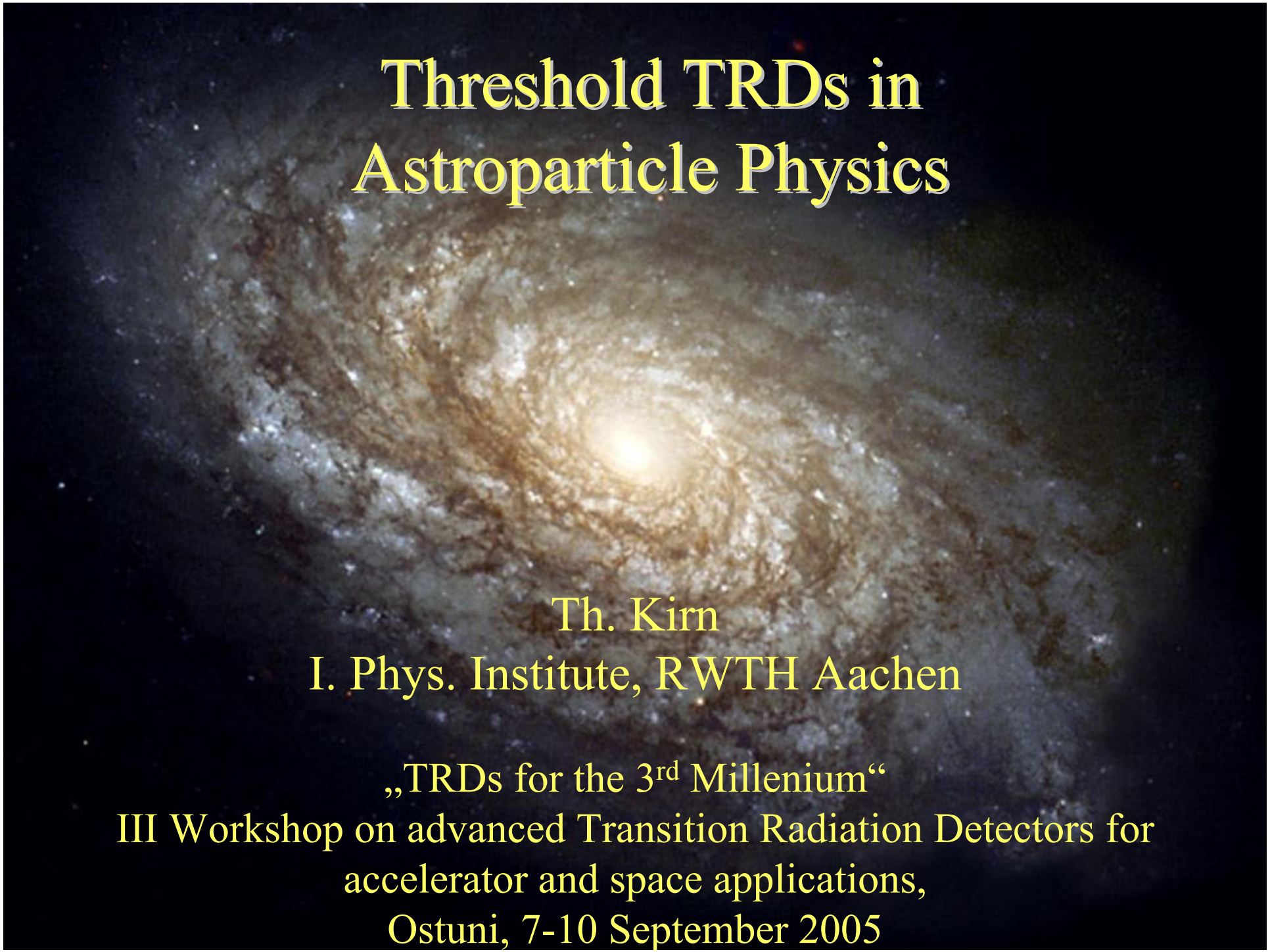


Threshold TRDs in Astroparticle Physics

Th. Kirn
I. Phys. Institute, RWTH Aachen

„TRDs for the 3rd Millenium“
III Workshop on advanced Transition Radiation Detectors for accelerator and space applications,
Ostuni, 7-10 September 2005

Cosmic Rays

p

$\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$

CR-Sources
Production, Acceleration

Galactic : SNRs, Pulsars,
Extragalactic : AGN, ..
Exotic : GRBs, ..
DarkMatter : WIMPs
$\chi\chi \rightarrow e^{+}$, p^{-} , γ, ν, ..

p, He, γ, e^{-},
C, N, O, ...

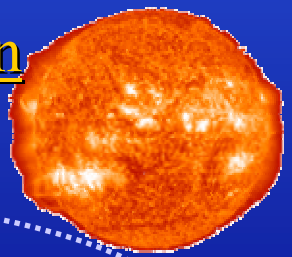
CR-Propagation

- Interaction with ISM and fields
- Reacceleration

→

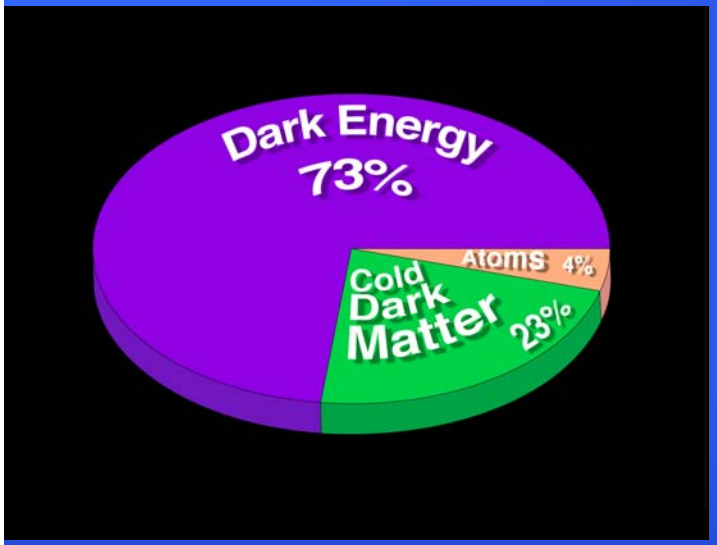
p, p^{-}, He, γ, e^{-}, e^{+},
μ^{-}, μ^{+}, Li, Be, B,
C, N, O, isotopes, …

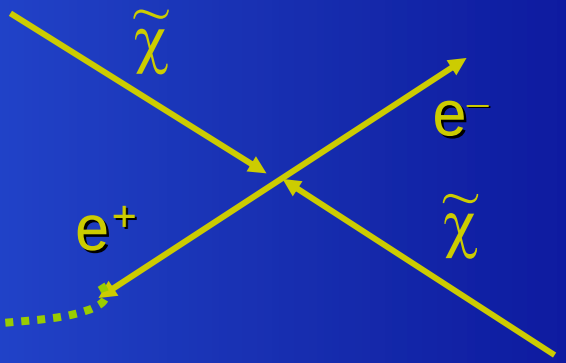
Solar Modulation



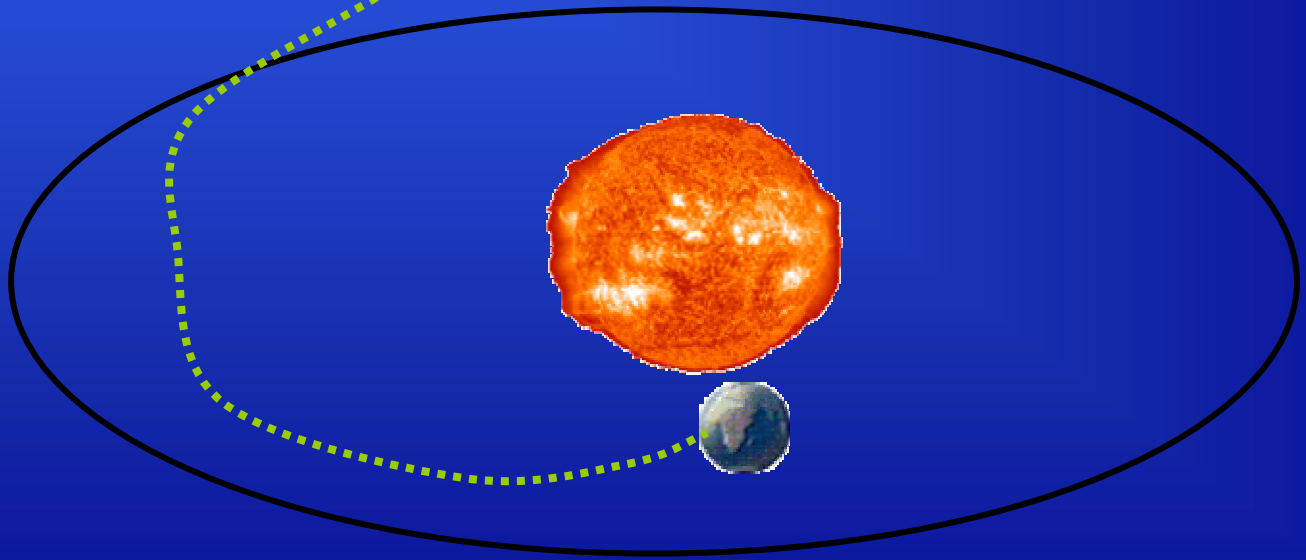
Geomagnetic Cutoff
Atmospheric Interactions

Dark Matter

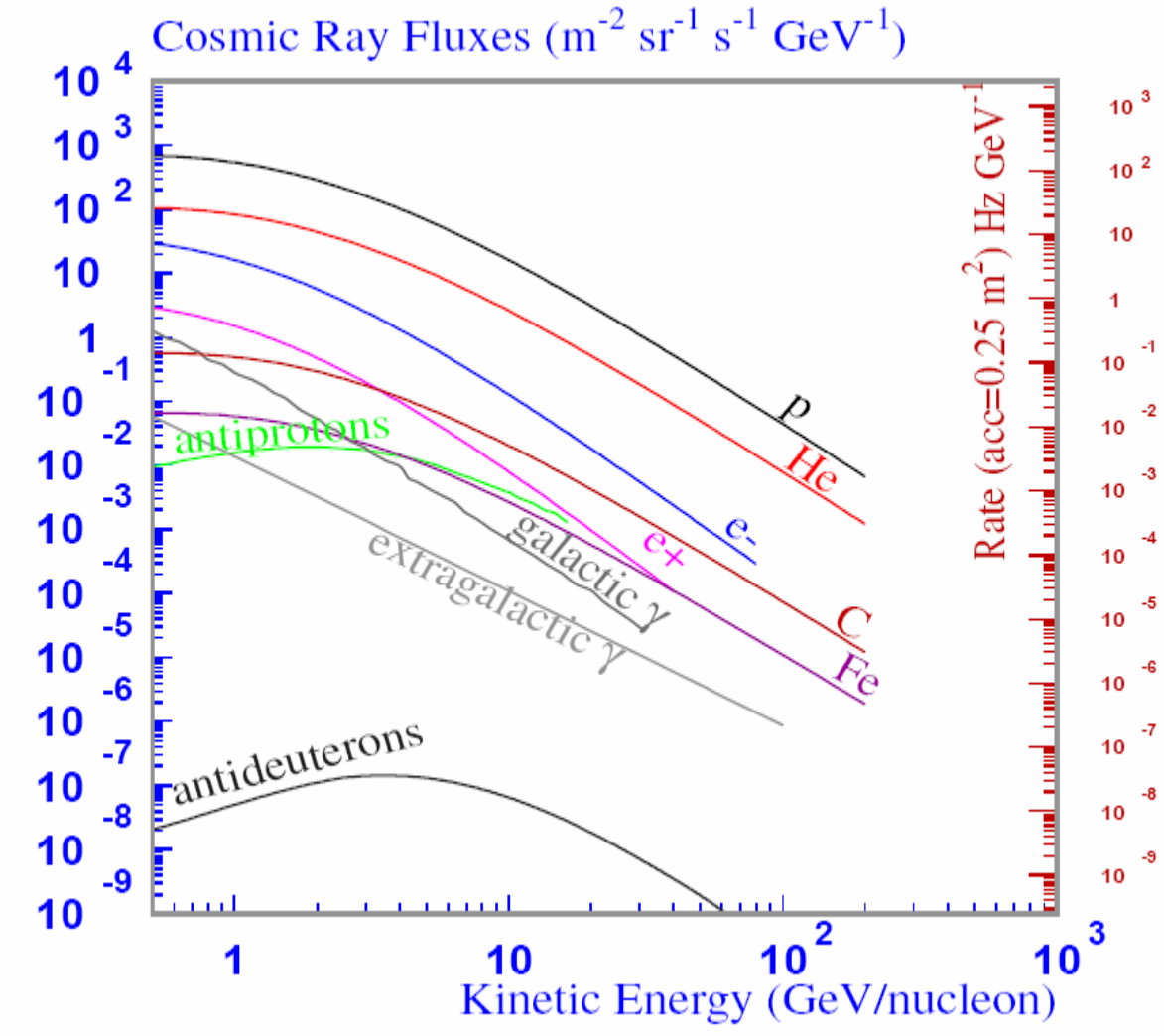




$\chi + \bar{\chi} \rightarrow X + \bar{e}, \bar{p}, \bar{D}$



Cosmic Ray Fluxes



- **Cosmic Ray Composition:**

  Protons 88 %

  Helium 10 %

  e^- 1 %

  e^+ 0.03 %

- **e^+ / p: 1 / 3000**
- **Primary Cosmic Rays:**

  (p, He, C, O, Fe)

  ⟶ Important for Secondary Production
- **Secondary/Primary Nuclei:**

  (B/C, ^{10}Be/^{9}Be)

  ⟶ Constraints on CR Propagation & Diffusion Models
- **γ-Ray Astrophysics**
- **Secondary Anti-Particles**

  CR nuclei + ISM⟶ $\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$

  $\chi\chi \rightarrow \bar{b}b$, W^+W^-, $Z^0Z^0 \rightarrow e^{\pm}$

  ⟶ Indirect Dark Matter Detection

Detector Requirements:
Antimatter Dark Matter Astrophysics

Signal from neutralino annihilation

Spectra: $\bar{e}$, $\bar{p}$, γ

Proton supression by 10^6
Electron supression by 10^4
Gamma reconstruction (energy / angle)

Galactic models (secondaries + propagation)

Nuclear abundance: B, C, ^{10}Be, ^{9}Be, ...
Standard particles: e, p

Tracking and charge / isotope separation

- **Charge identification**
- **Rigidity measurement**
- **Velocity measurement**
- **e.m. energy measurement**
- **e/p separation**
- **Albedo rejection**
- **Strong system redundancy**

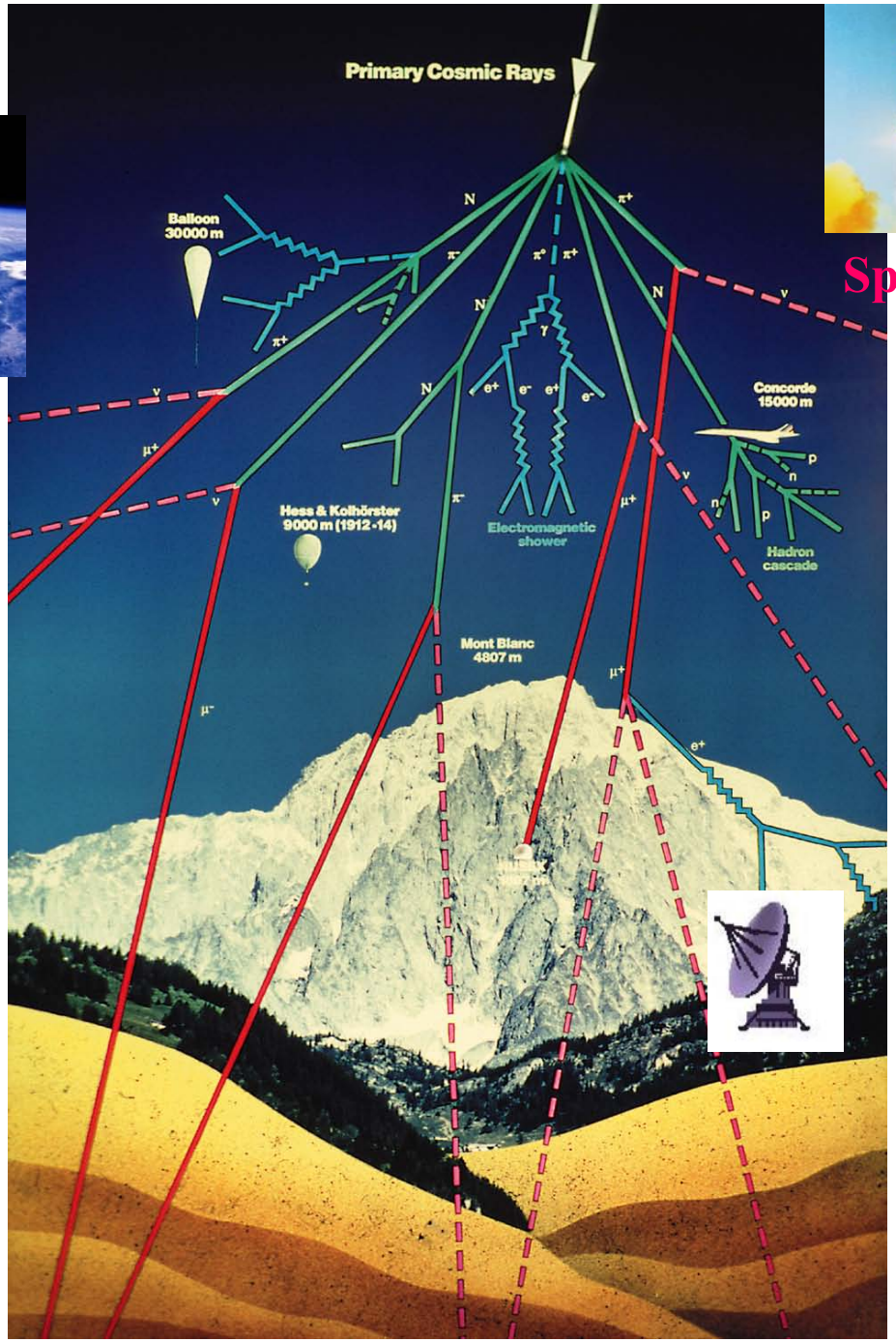
Ballon Experiments:

TS93

HEAT

TRACER

CREAM



Space Experiments:

CRN

AMS

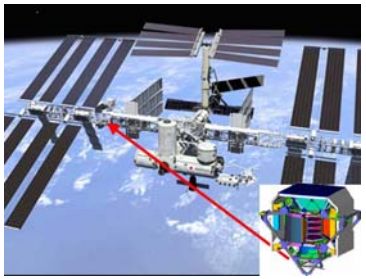
PAMELA

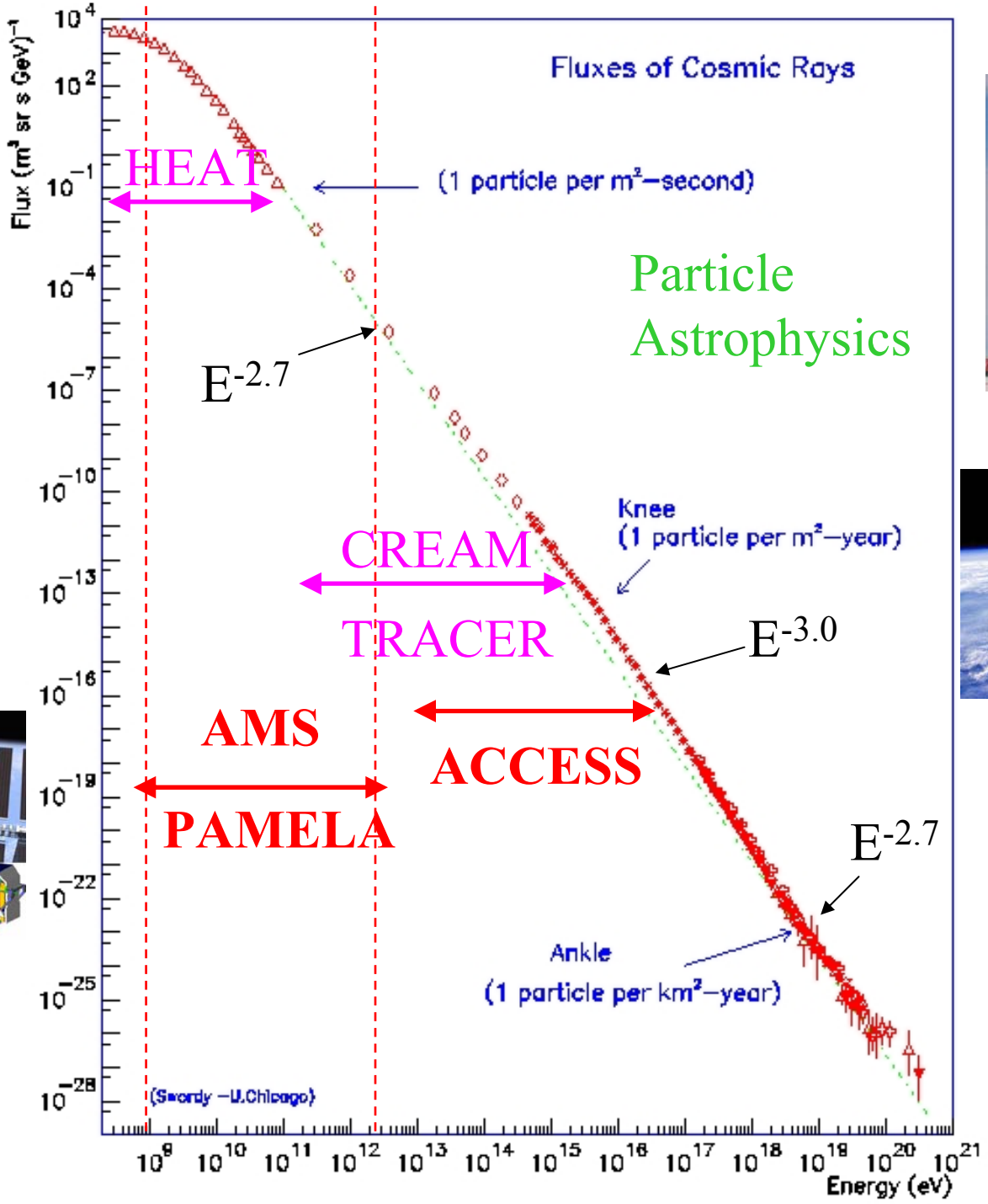
ACCESS

Underground Experiments:

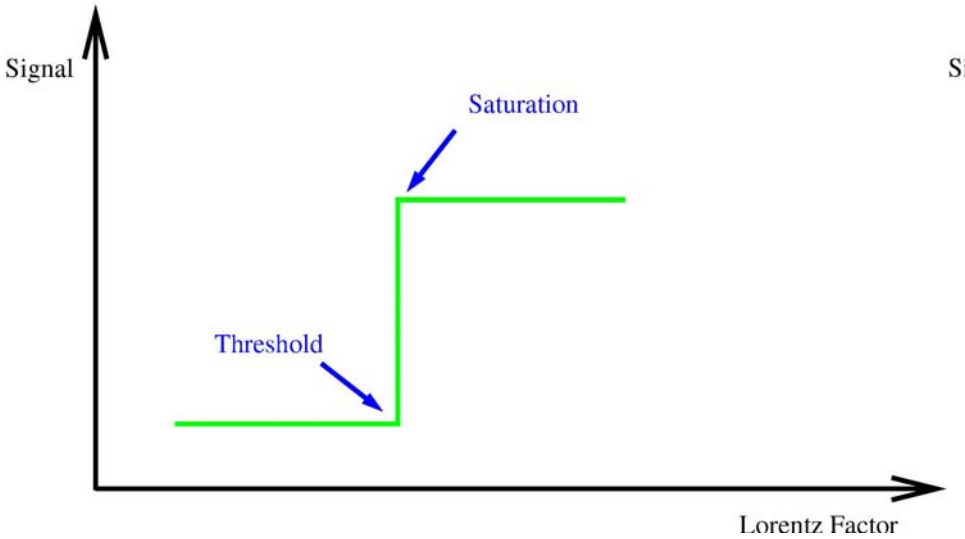
MACRO

$$\frac{dN}{dE} \propto E^{-\gamma}$$



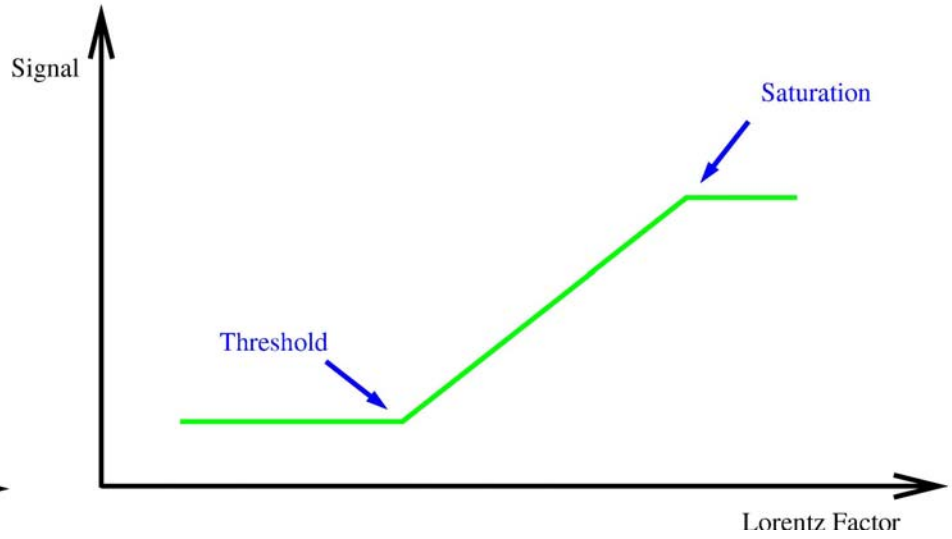


Threshold TRDs



TS93
HEAT
PAMELA
AMS

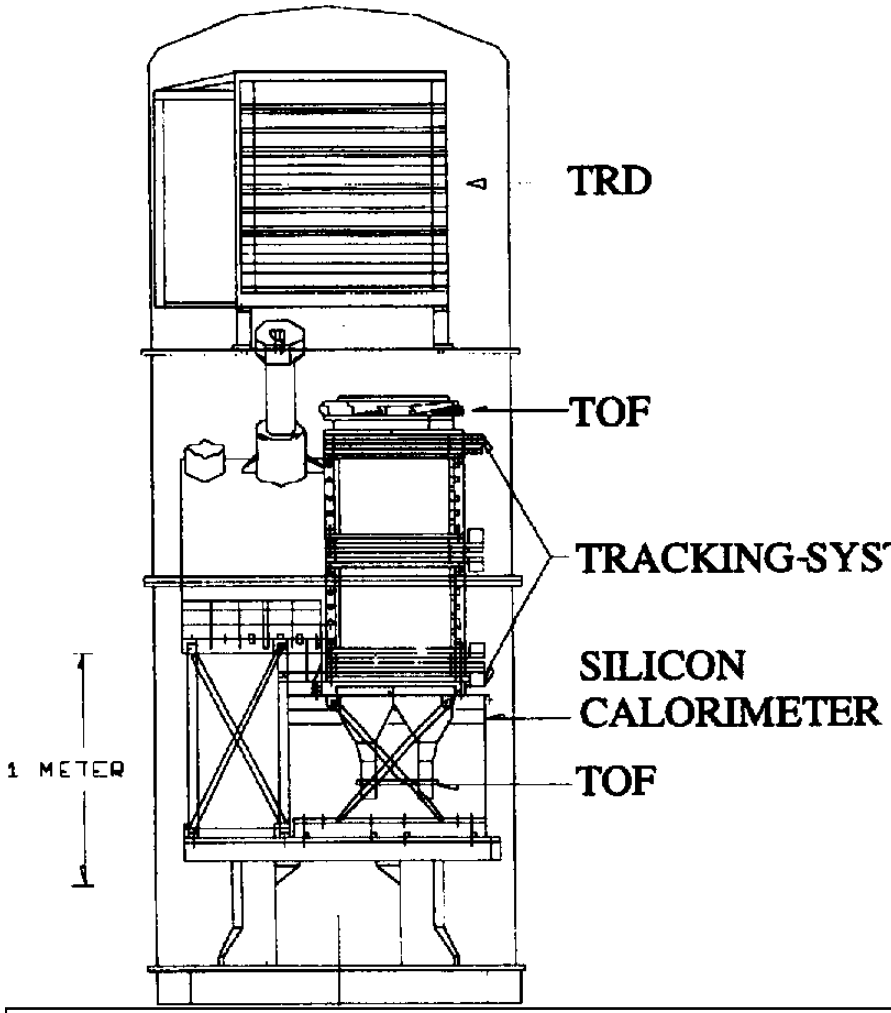
Precision TRDs



CRN
TRACER
CREAM

Threshold TRDs

TS93-Apparatus



Bellotti et.al. Astroparticle Physics 7 (1997) 219-230,
Golden et al. Astrophysical Journey 457, (1996) 103-106

- Balloon mission September 8th **1993**

  Ft. Sumner, 34°N latitude, **36 km** altitude, **25h**
- Measurements of:

  e^-, e^+ 4-50 GeV, e^+/e^- 10 GeV
- **T**ransition **R**adiation **D**etector

  e^+/p-discrimination, active area 76·80 cm^2

  Weight: 237 kg, Power: 100 W → 2560 ch.

  10 Layers carbon fiber radiators + MWPC

  (Xe 80% / CH4 20%)
- **T**ime **o**f **F**light System

  Plastic scintillator 2cm → (dE/dx),

  Resolution: 400 ps (1.4 m path)
- Superconducting Magnet

  Multiwire Proportional Chambers, Drift Chambers
- ECAL

  EM showers for $e^{\pm}$, 5 xy-layers Si+tungsten

TS93-TRD

e^+/p-discrimination, active area 76·80 cm^2

Weight: 237 kg, Power: 100 W → 2560 ch.

10 Layers Carbon Fiber Radiator + MWPC

→ X_0=0.13

10 Layers in aluminium box

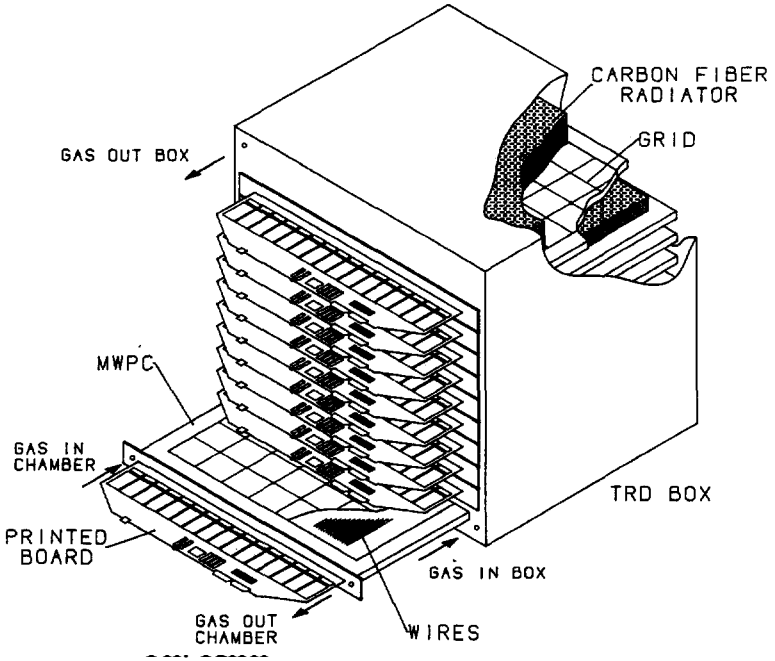
→ 10 G shock protection

Radiator:

1 Layer → aluminium frame → 4 poly-ethylene bags → Carbon fiber segments

1. Layer → 1 additional radiator

Density: 0.06 g/cm^3



MWPC (Xe/CH_4 80/20):

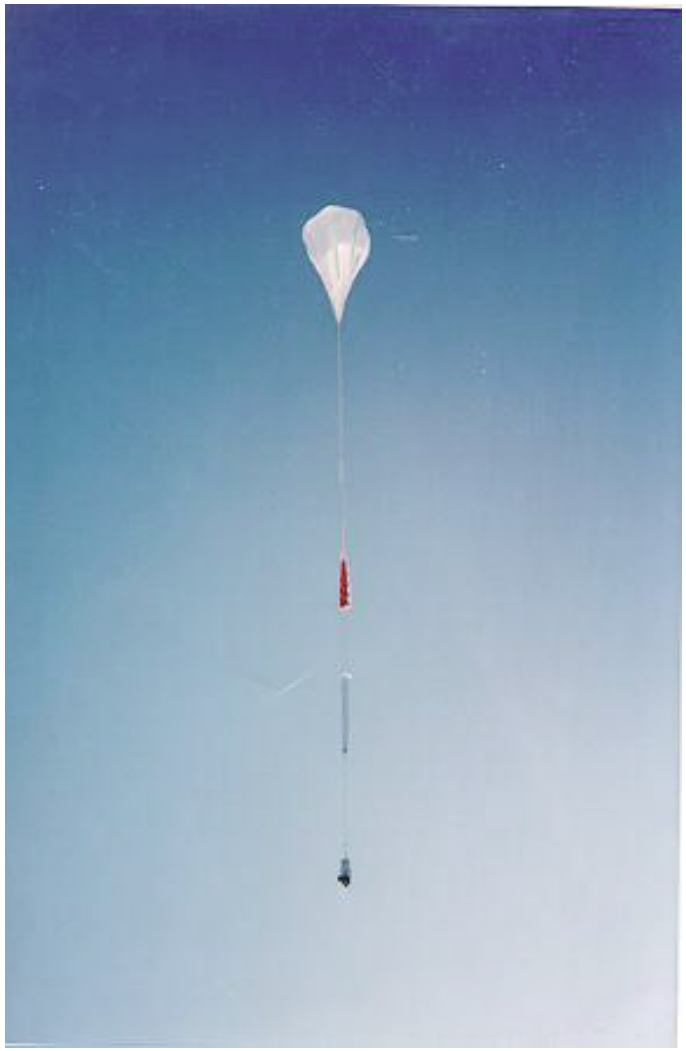
Anode – Cathode 8mm

1 Anode plane → 256 gold plated tungsten wires, Ø 25µm , tension: 70g, 3mm spacing

HV: 2950 V → Gasgain 10^4, Fe^{55} – Monitoring

Overpressure in box 50 µbar, 870-1000 mbar

TS93 Results



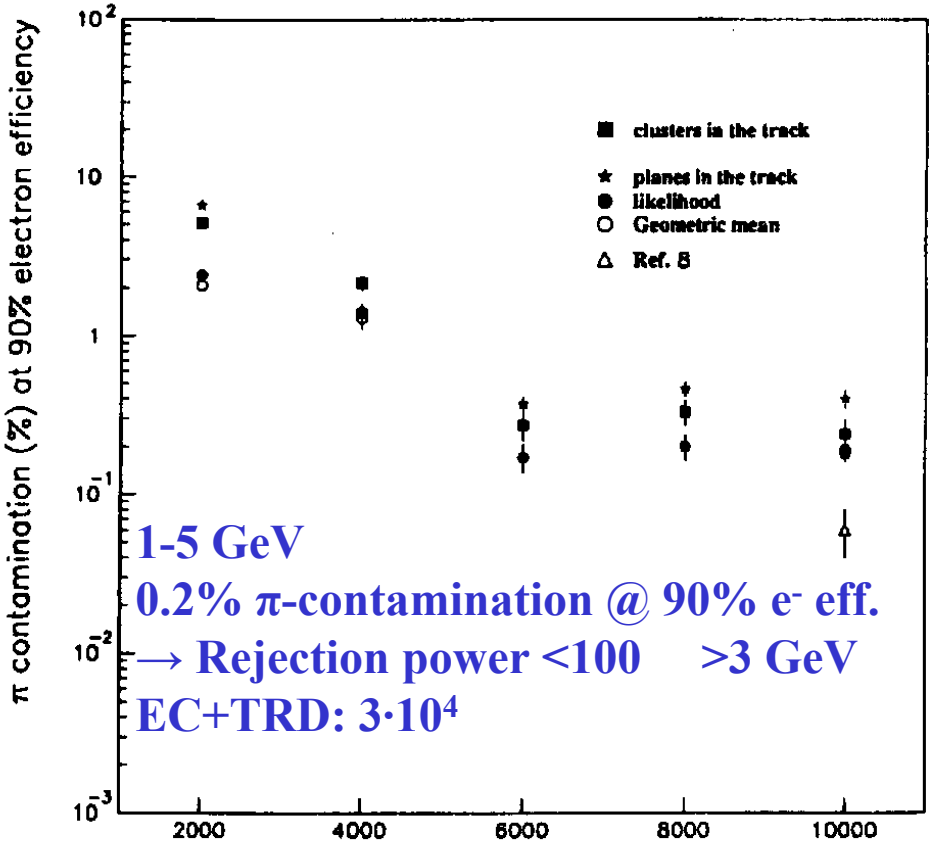


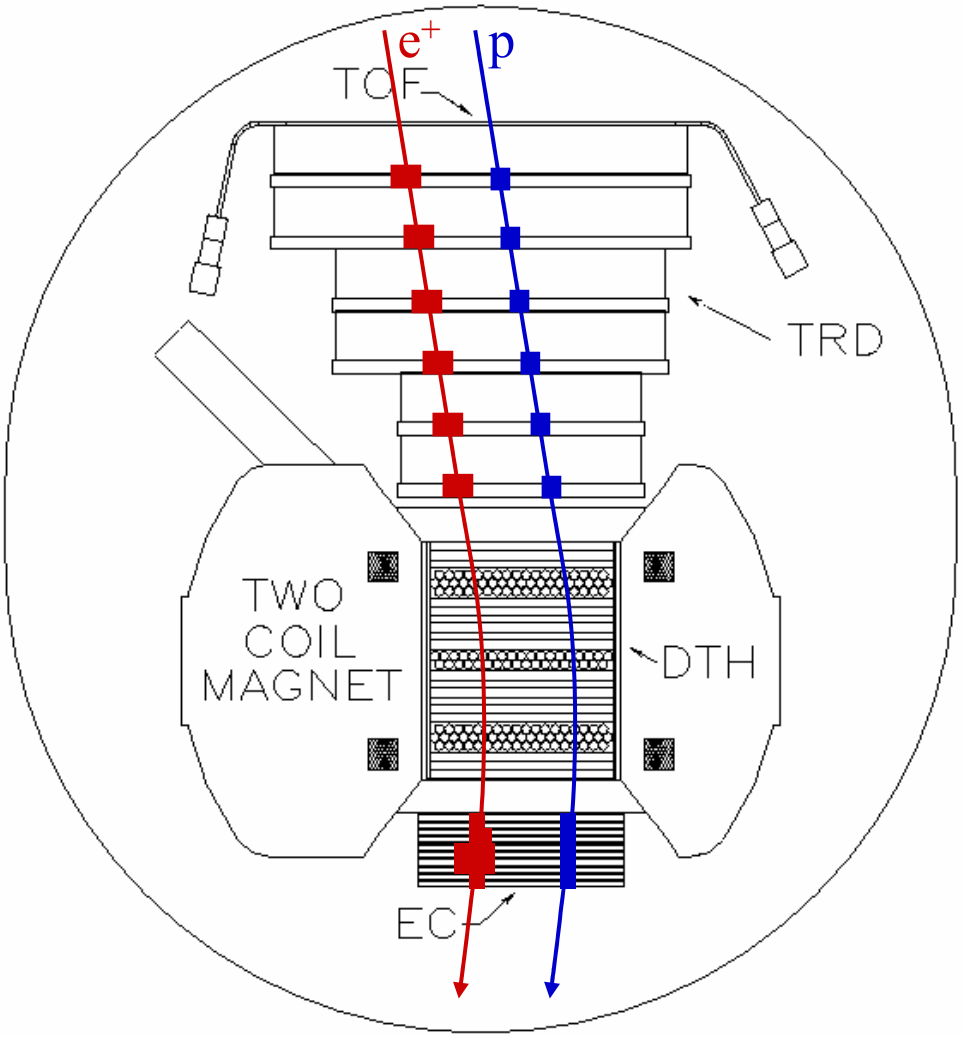
TABLE 1

SUMMARY OF ELECTRON–POSITRON RESULTS

ENERGY BIN AT SPECTROMETER (GeV) (1)	OBSERVED NUMBER OF EVENTS[a] e^- (2)	OBSERVED NUMBER OF EVENTS[a] e^+ (3)	MEDIAN ENERGY AT TOA (4)	CORRECTED NUMBER AT TOA e^- (5)	CORRECTED NUMBER AT TOA e^+ (6)	$[e^+/(e^+ + e^-)]$ (7)
4.0–5.0.....	109	14 (0.9)	5.71	129.0 ± 12.6	11.50 ± 4.0	0.082 ± 0.027
5.0–7.0.....	165	17 (1.5)	7.49	163.6 ± 13.0	11.56 ± 3.54	0.066 ± 0.019
7.0–11.....	97	11 (1.3)	10.8	78.4 ± 8.08	6.57 ± 2.47	0.077 ± 0.028
11–50	56	10 (1.3)	22.0	40.5 ± 5.70	5.01 ± 2.25	0.110 ± 0.046

[a] The numbers shown in the parentheses are the residual proton contamination.

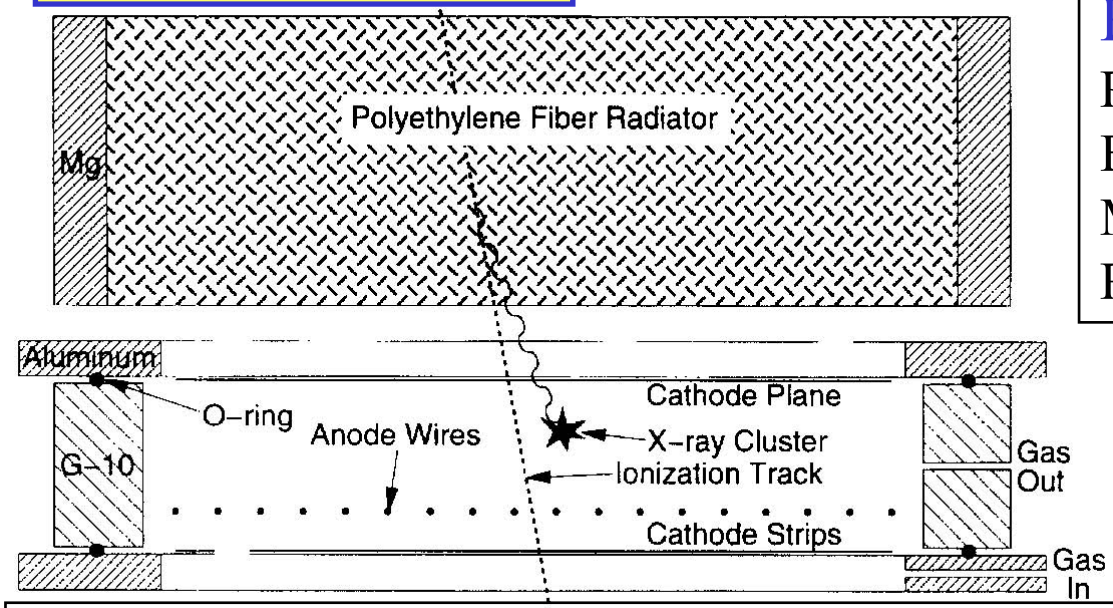
High Energy Antimatter Telescope



Barwick et.al. Phys. Rev. Lett. V75 (1995) 390-393,
Barwick et al. NIM A 400 (1997) 34-52,
J.J. Beatty et al. Astrophys. J. (2004)

- Balloon missions **1994 - 2002**
- Measurements of:
  e^-, e^+, p-rejection 10^5, CR-abundances
- **T**ime **o**f **F**light System
  → Z of particle $\frac{dE}{dx} \approx \frac{Z^2}{\beta^2 e^2}$
- **T**ransition **R**adiation **D**etector
  e^+/p-discrimination
  6 pairs of plastic fiber radiators
  + MWPC (Xe 70% / CH4 30%)
- Drift Tube Hodoscope (1T-field)
  $R=pc/Ze$, $p_{max} \sim 54\,GeV/c$
- ECAL
  EM showers for $e^{\pm}$, **TOF-Stop-Signal**
  10 layers lead + plastic scintillators

HEAT- TRD



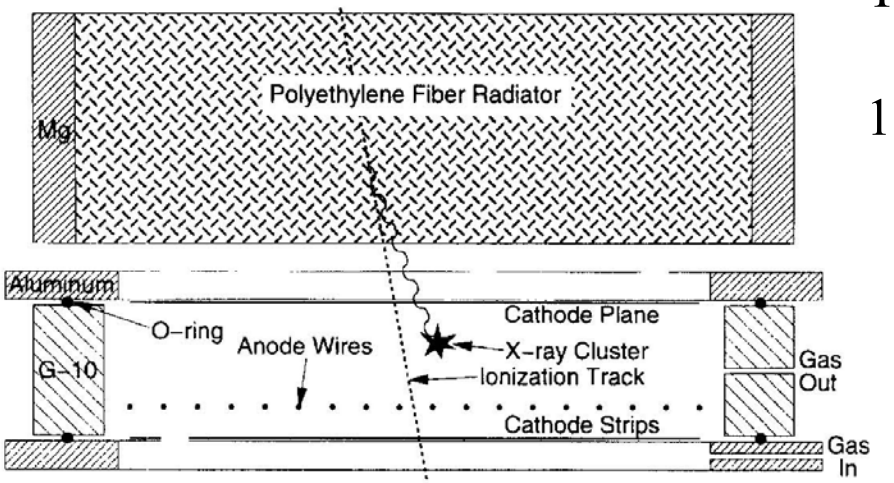
Radiator:

Polyethylene fiber blankets
Effective fiber diameter: 21 μm
Mean fiber spacing: 380 μm
Radiator thickness: 12.7 cm

MWPC:

Xe / CH4 (70 % / 30%), HV=3700V @ 1bar
Cathode windows: 50 μm aluminized mylar (tension 200 g/cm)
Windows are etched to form strips on mylar surface (7.8 cm wide, ⊥ wire)
Anode wire: 13 μm gold plated tungsten wires, 5 mm spacing
Anode wire plane offset from center → time profil widening of arriving charge @ wire
X-ray signal arrive later in time than start of ionization signal
8-10 wires → 1 electronic channel → spatial res. O(cm) → tracking → rejection δ-e^-

HEAT- TRD



TRD electronic:

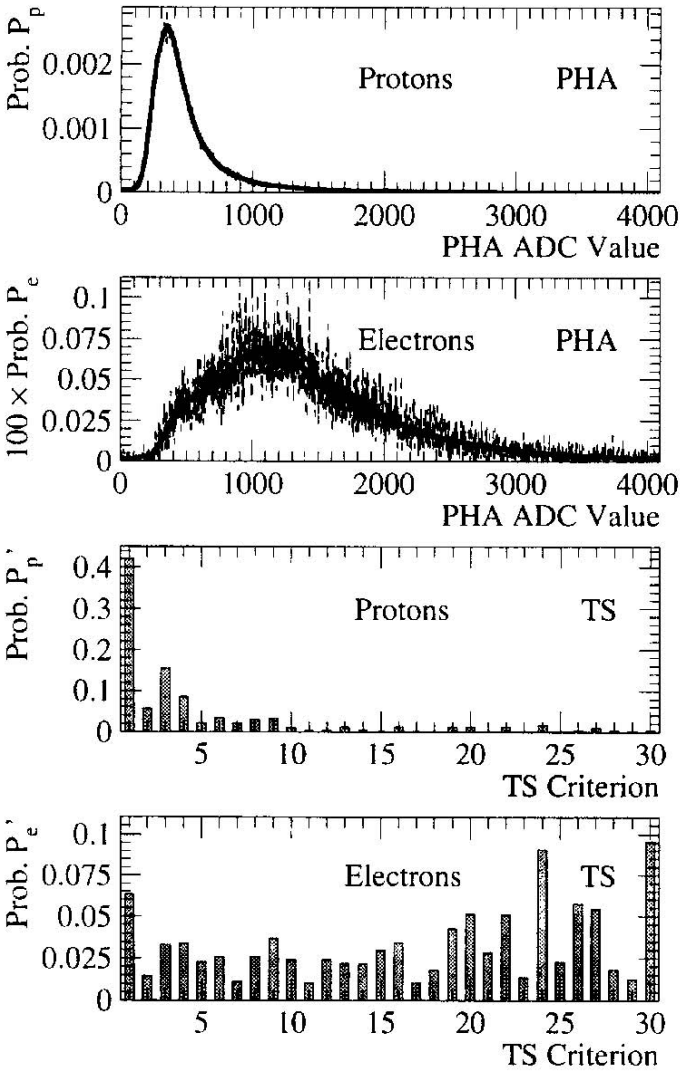
Two kind of signals recorded:

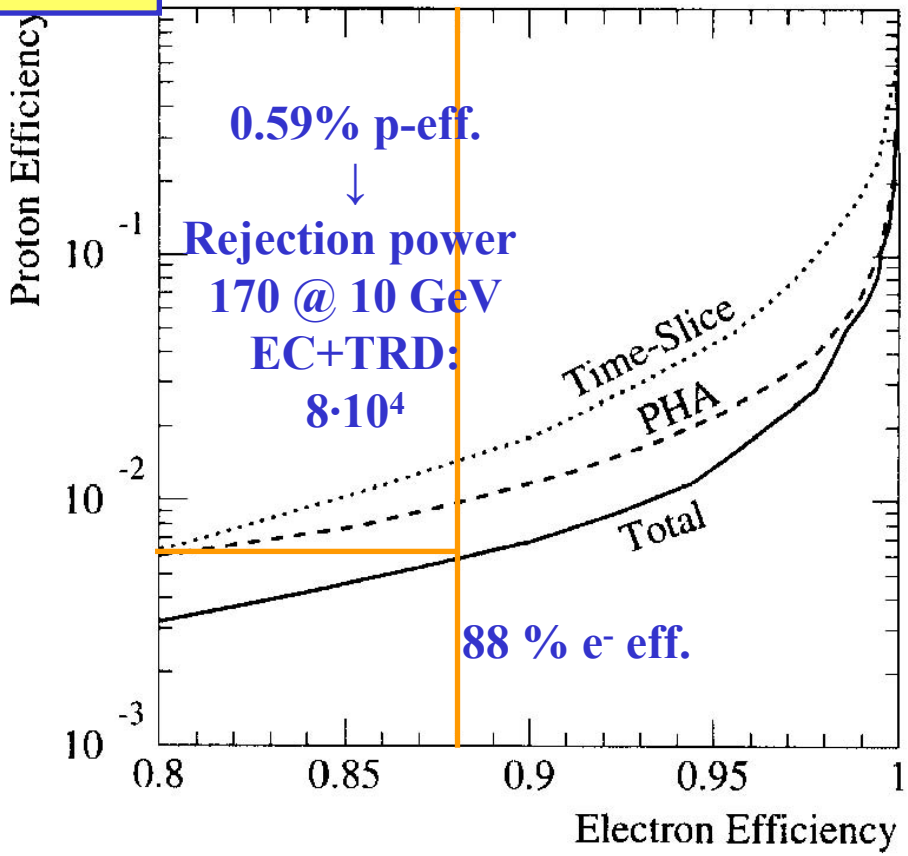
1. **<u>PHA method:</u> total charge induced on cathode planes eventwise**;
   planes closer to anode wires are subdivided into a total of 56 strips,
   each strip signal → charge sensitive/shaping amplifier → peak detector → 12bit ADC

2. **<u>Time slice method</u>: time structure of current pulses on anode wires** for all MWPCs
   anode wires combined into 96 wire groups (8-10 wires → 1 group);
   Signal from each group → Amplifier → 3 ‖ discriminators (different thresholds)
   → output polled every 25 ns
   System ~ flash ADC with coarse (2 bit) amplitude resolution

HEAT- TRD Performance

10 GeV p & e^- in single MWPC

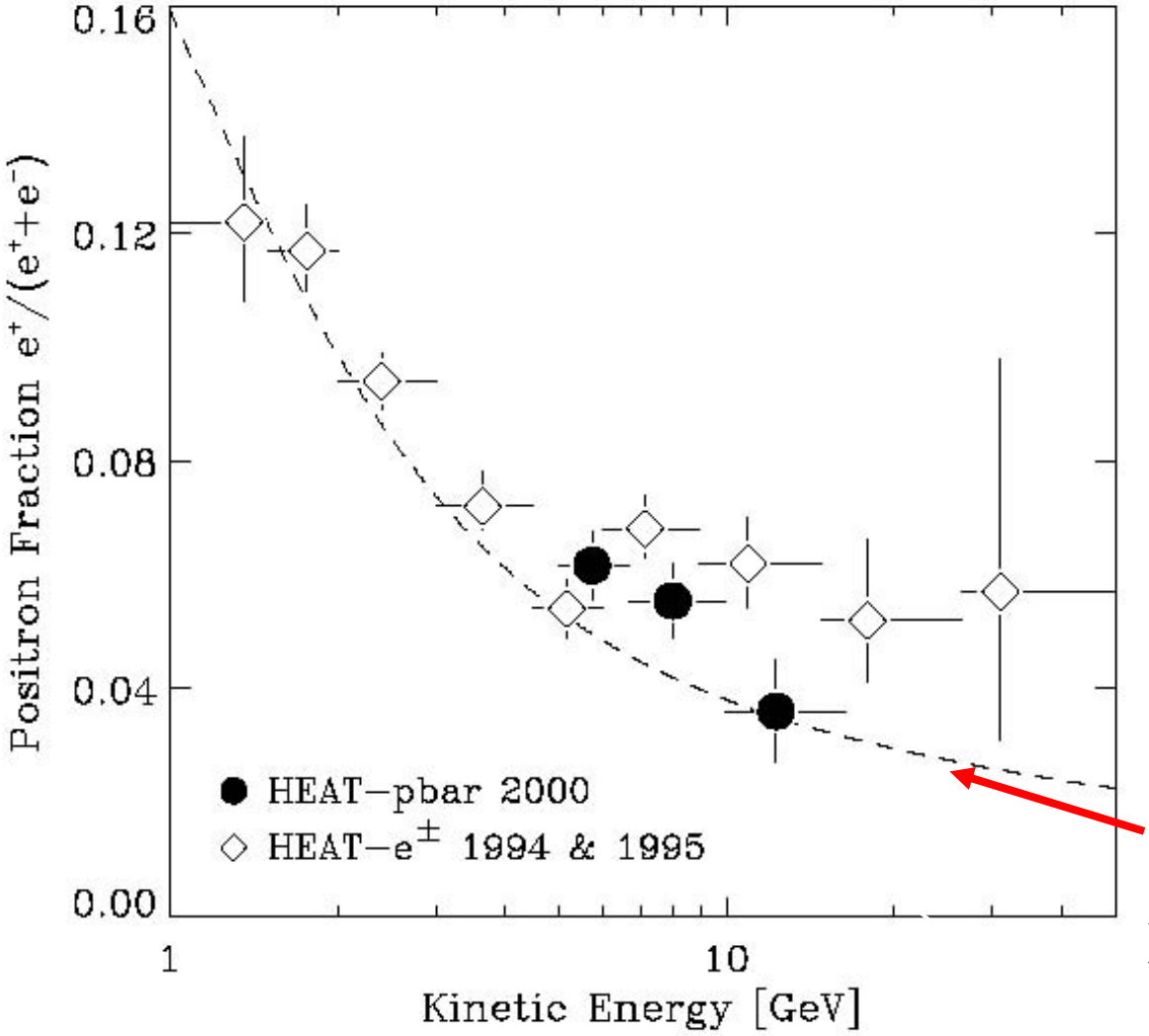




$$L_e/L_p = \prod_{i=1}^{6} (P_e(x_i)/P_p(x_i))$$

$$(L_e/L_p)_{\text{Total}} = (L_e/L_p)_{\text{PHA}} \times (L_e/L_p)_{\text{TS}}$$

HEAT- $e^+/(e^+ + e^-)$-Fraction



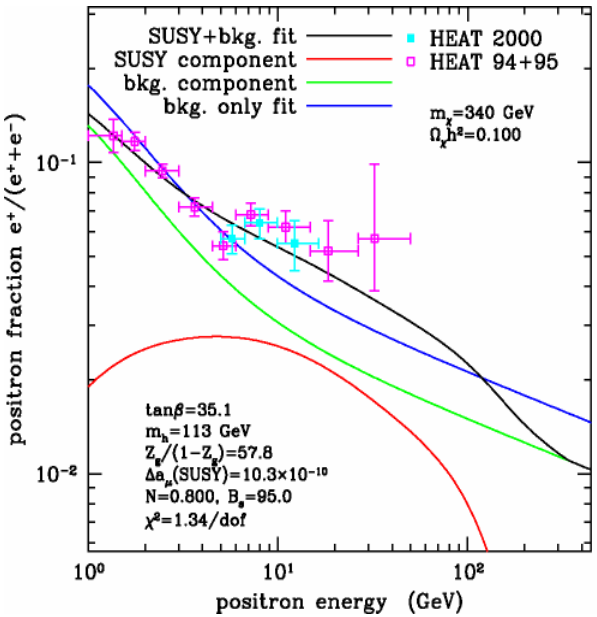
- Heat-$e^\pm$
  May1994, New Mexico,
  (4 GV cutoff), Solar min

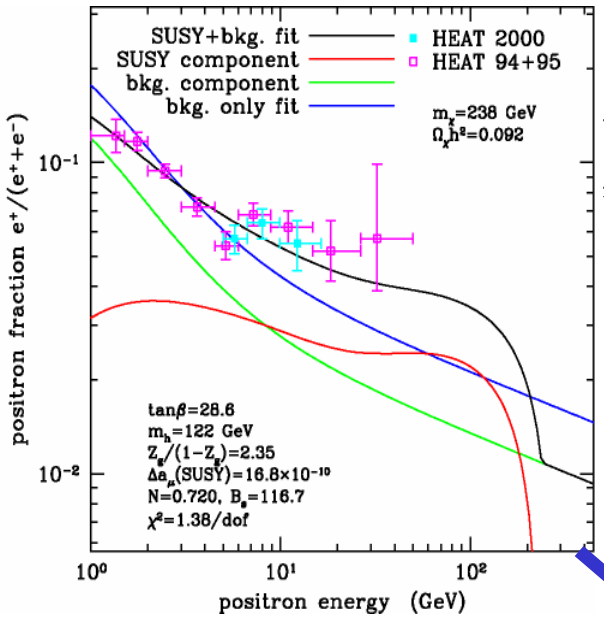
  August 1995, Manitoba,
  (<1GV cutoff), Solar min

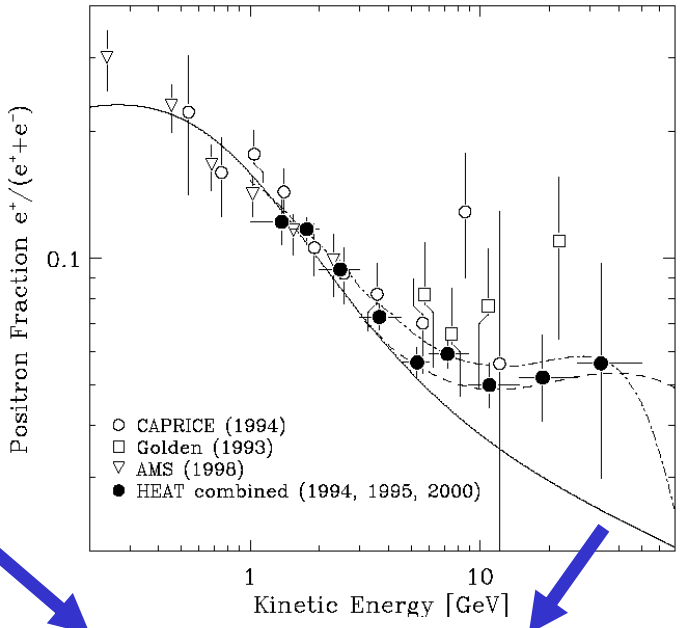
- Heat –pbar
  June 2000, New Mexico,
  (4GV cutoff), Solar max

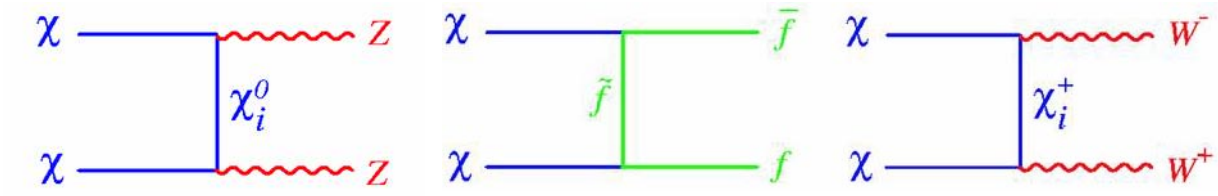
Moskalenko & Strong,
ApJ **493,** 694 (98), Positron fraction based on purely secondary e^+ & e^- production in a diffusive model for galactic CR-propagation

$e^+/(e^+ + e^-)$–Fraction: e^+ from Annihilating Galactic Halo WIMPs?









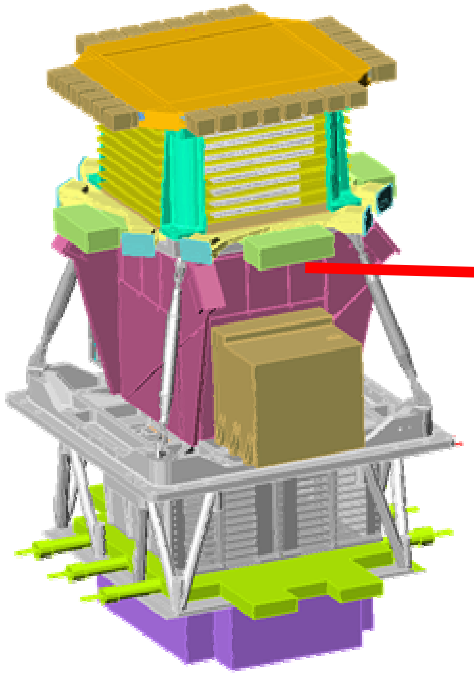
SUSY DM Hint?

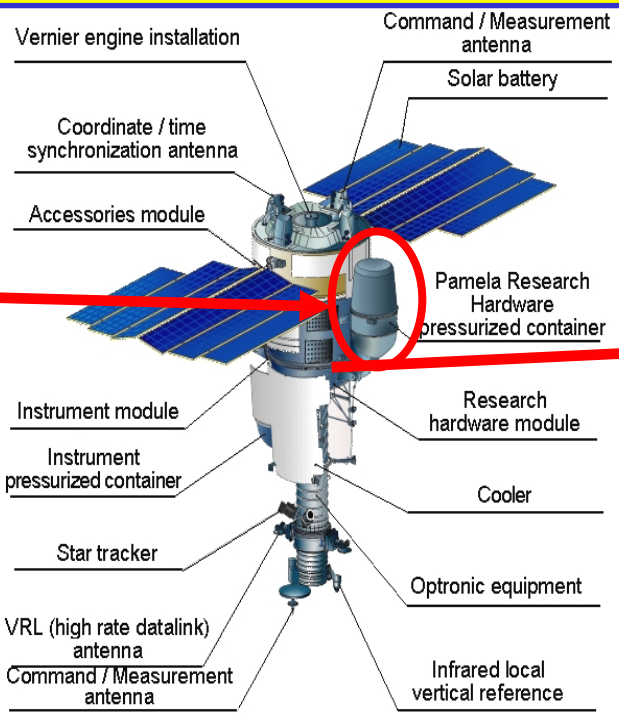
e^+-Spectroscopy:

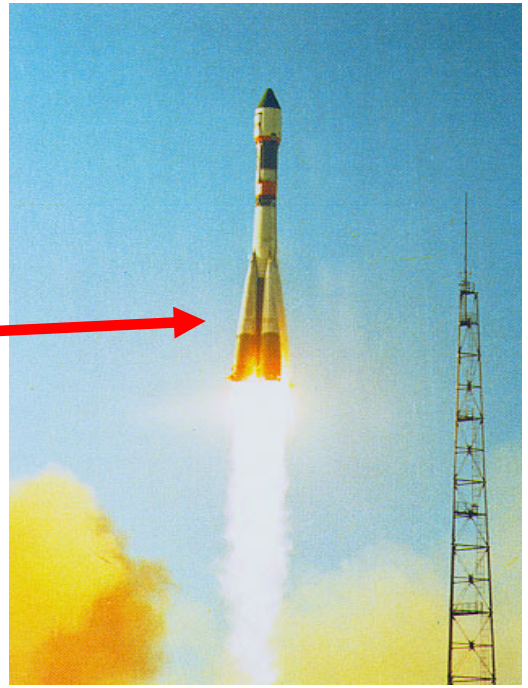
Precision measurements at higher energies needed !

Baltz/Edsjö, Phys. Rev. D **59** (1999);
Baltz, Edsjö, Freese & Gondolo, Phys. Rev. D **65** (2002);

Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics







PAMELA

Weight: 470 kg
Power: 380 W
GF: 20.5 cm² sr
Dimensions: 120x70x70 cm³

Satellite Resurs

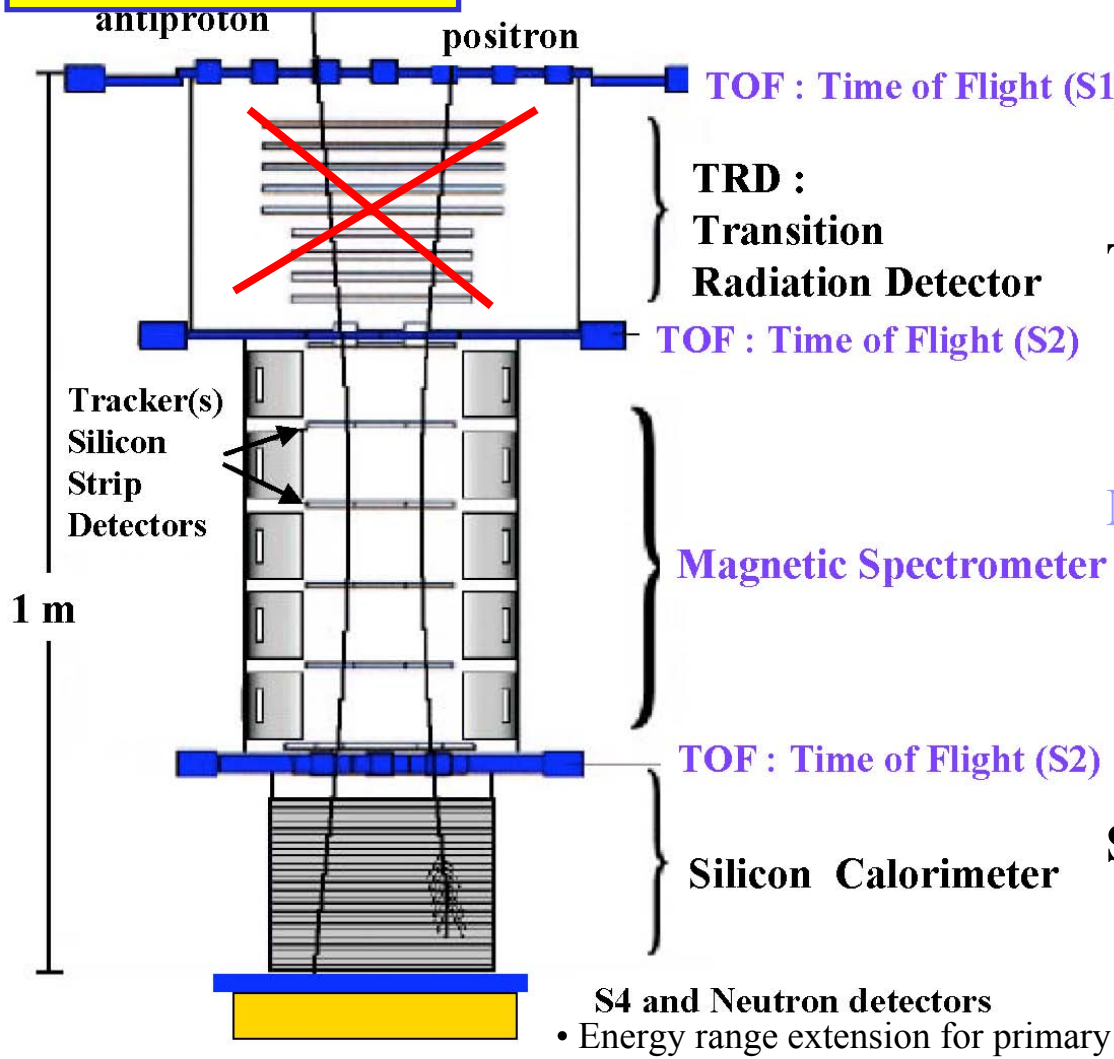
Weight: 10 t
Orbit: Elliptic (300 – 600 km)
Inclination 70.4°

Soyuz Launcher

Baikonur
Launch: End 2005

Measurements of (3 years Mission): $\mathbf{e^-}$ (50 MeV – 3 TeV), $\mathbf{e^+}$ (50 MeV – 270 GeV), **p** (80 MeV – 700 GeV), $\overline{\mathbf{p}}$ (80 MeV – 190 GeV), **Nuclei** < 200 GeV/n (Z<6)

PAMELA



- Energy range extension for primary p or e^- up to 10 TeV
- Plastic scintillator as trigger
- 36 ^{3}He counters in a polyethylen moderator

TOF System

- Level 1 trigger, Albedo discrimination
- dE/dx → Z of particle
- Particle identification (up to 1 GeV/c)
- Plastic scintillators + PMTs
- Time resolution 110 ps

Threshold TRD

- e^+/p-discrimination (E>1GeV/c @ 10^2)
- 9 carbon fiber radiator planes + straw tubes (4 mm ø, Xe/CO_2 80/20)

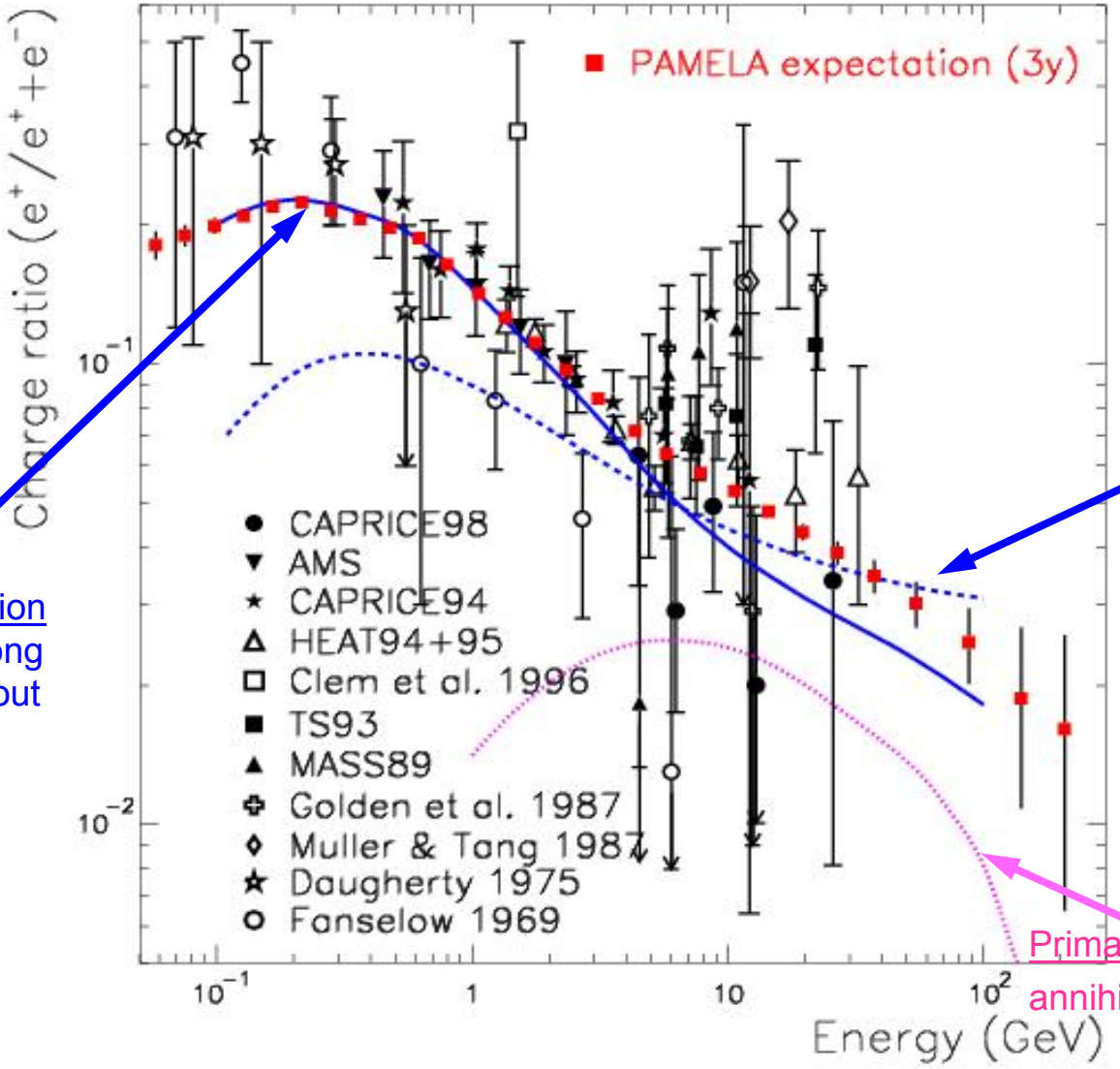
Magnet + Si Tracker + ACC

- Permanent Magnet B=0.4 T
- 6 planes double sided Si strips 300 µm thick, Spatial resolution ~ 3 µm
- Plastic scintillators + PMTs
- Defines tracker acceptance

Si-W Imaging Calorimeter

- reconstructs EM shower profiles
- Si-X / W / Si-Y structure
- 22 W planes, 16.3 X_0, $\Delta E/E < 5\%$ (20 – 200 GeV $e^{\pm}$), rejection power @ 10^4-10^5

PAMELA- $e^+/(e^+ + e^-)$-Fraction



Secondary production
'Moskalenko + Strong model' (1998) without reacceleration

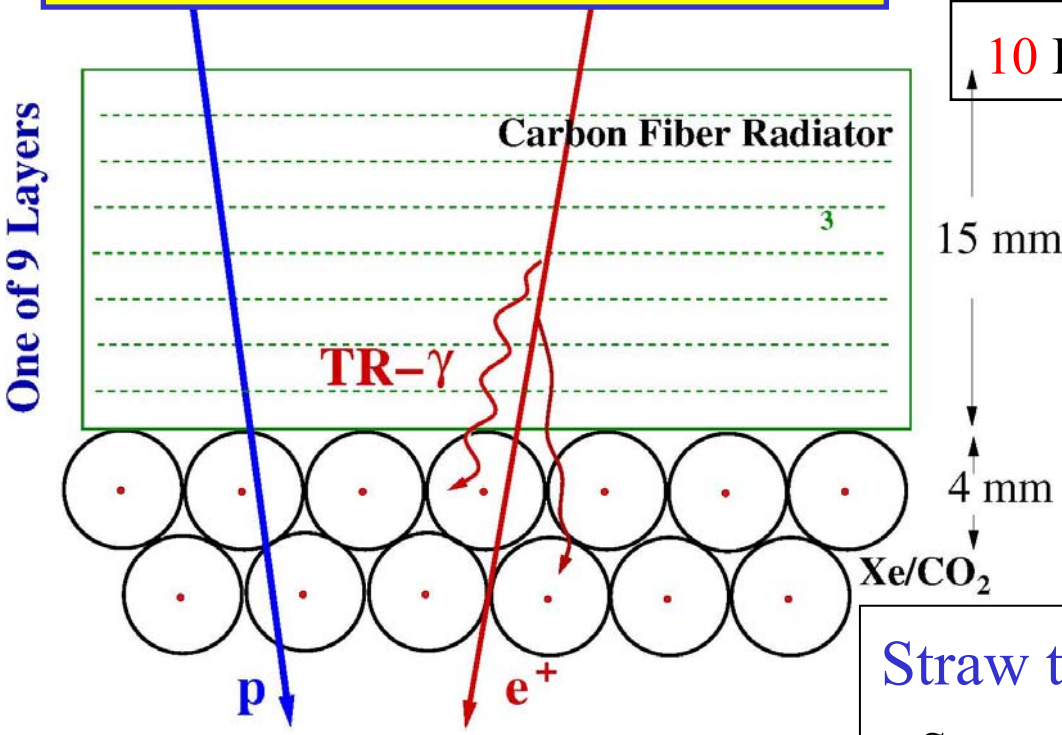
Secondary production
'Leaky box model' (Protheroe 1982)

Primary production from $\chi\chi$ annihilation (m(χ) = 336 GeV)

Space Qualified TRD

F. Cafagna

10 Layers of radiators + straws (1024)



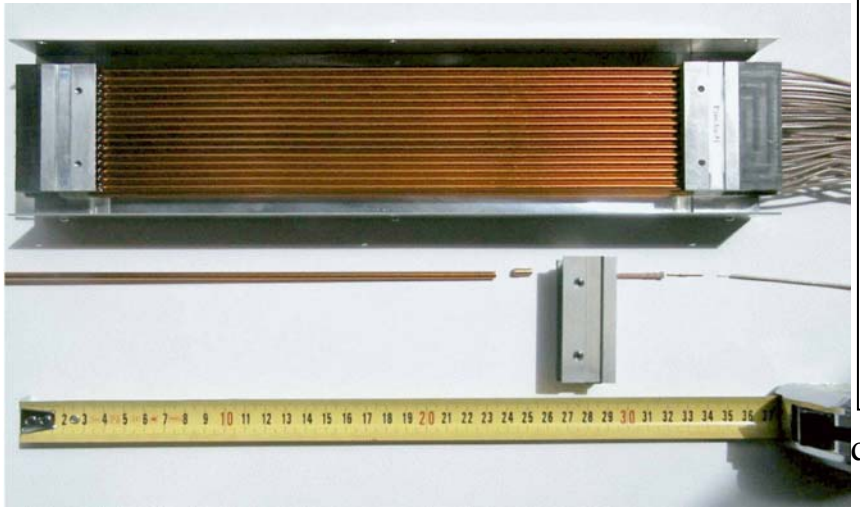
Radiator:

Carbon fibers

Effective fiber diameter: 7 μm

Radiator thickness: 1.5 cm

Density: 60 g/l



Straw tube proportional counter:

- Straw tube: 30 μm copperized Kapton foil, 4mm Ø, 28 cm length
- Wire: tungsten anode wire, 25 μm Ø, tension ≈ 60 g
- Gas mixture: Xe / CO_2 (80% / 20%), 1500 l
- Operating HV ~ 1400 V → Gasgain of ~ 10^4

Space Qualified TRD

SPS, July 2000

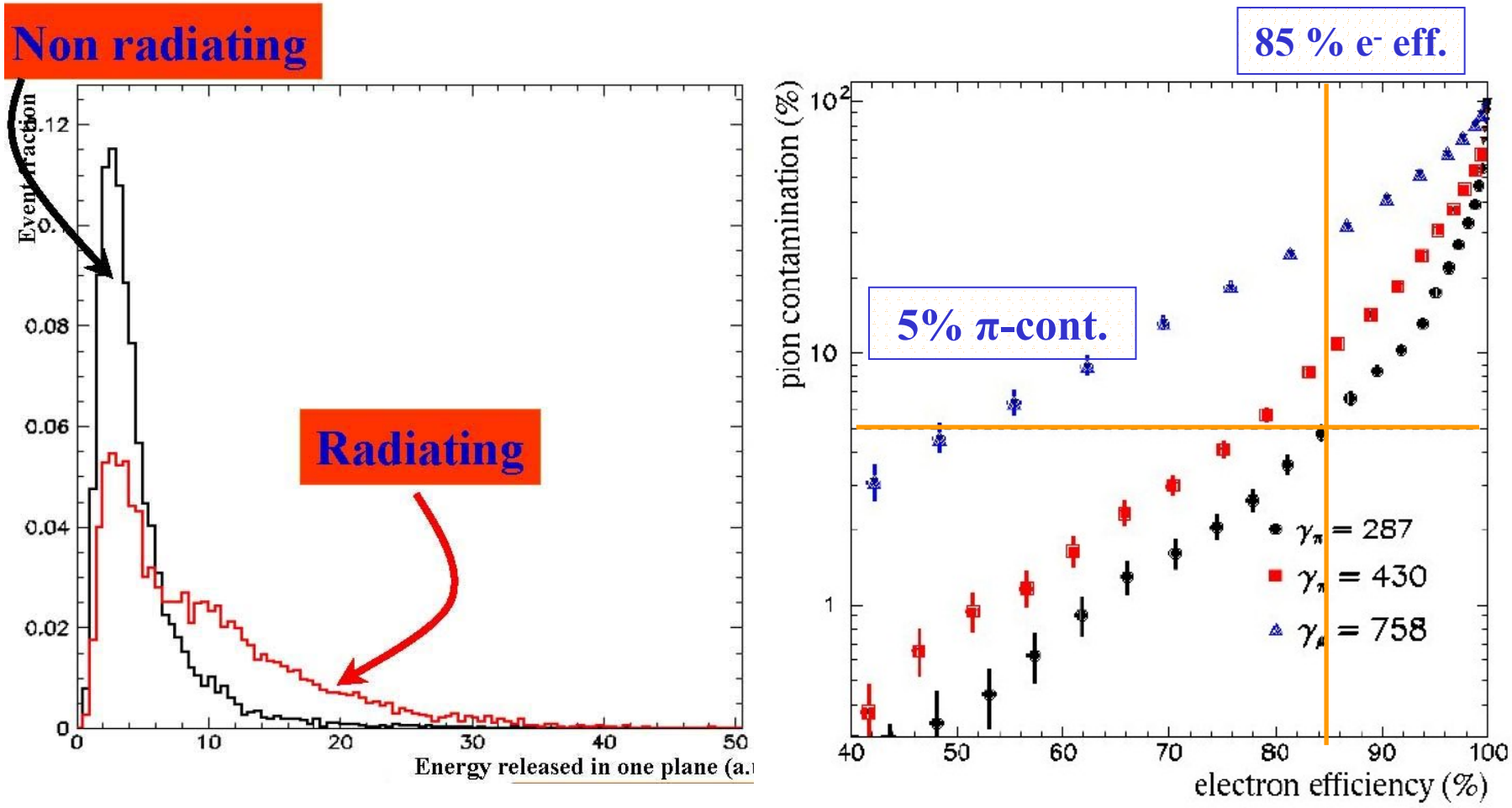
TRD Performance

Beamtests at CERN PS and SPS facilities

Particles: π, μ, e

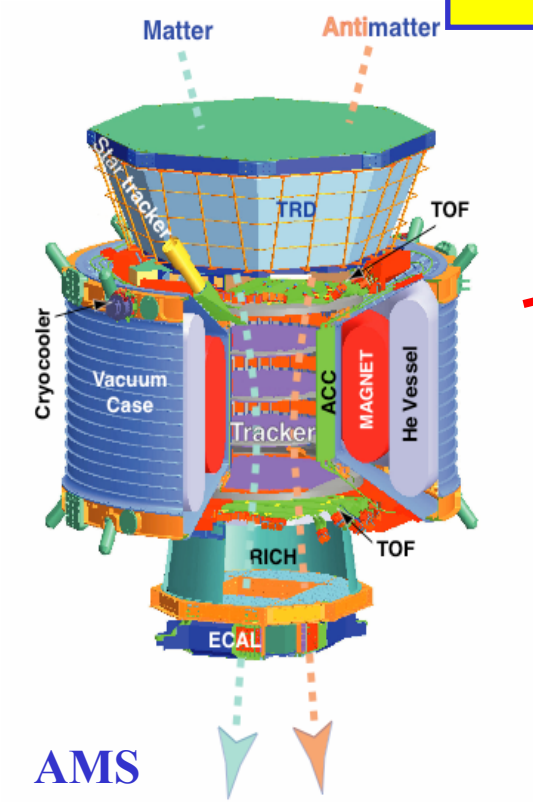
Momentum Range: 2 – 5 GeV/c (PS), 40 - 80 GeV/c (SPS)

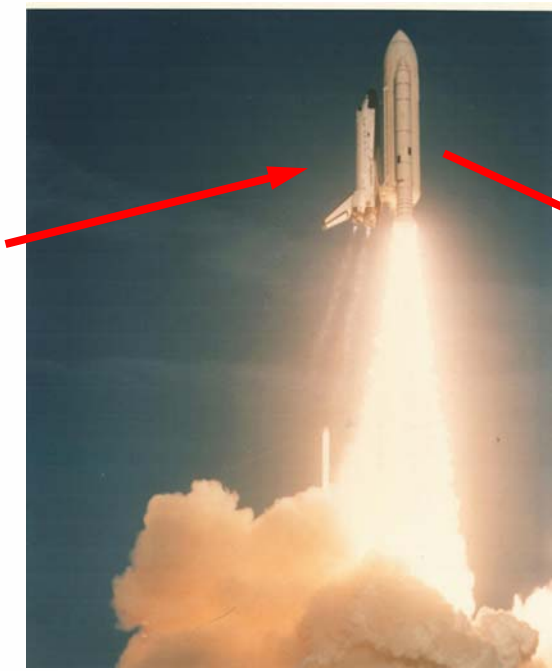
Space Qualified TRD Performance

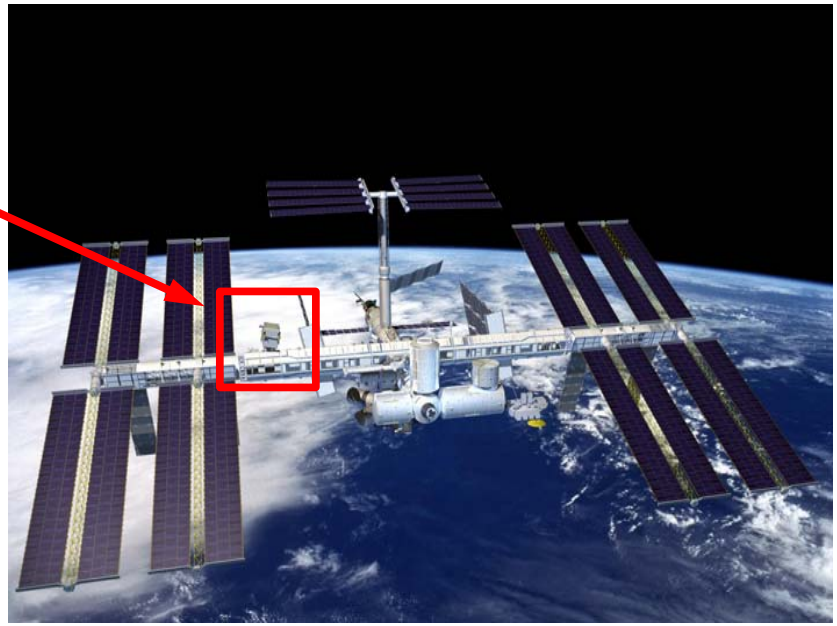


Rejection factor of 20 for non-radiating particles @ ~90 % e- efficiency

Alpha Magnetic Spectrometer AMS







AMS

Weight: 6700 kg
Power: 2500 W
GF: 0.5 m² sr
Dimensions: 3.5x2.3x2.3 m³
Mission: > 3 years

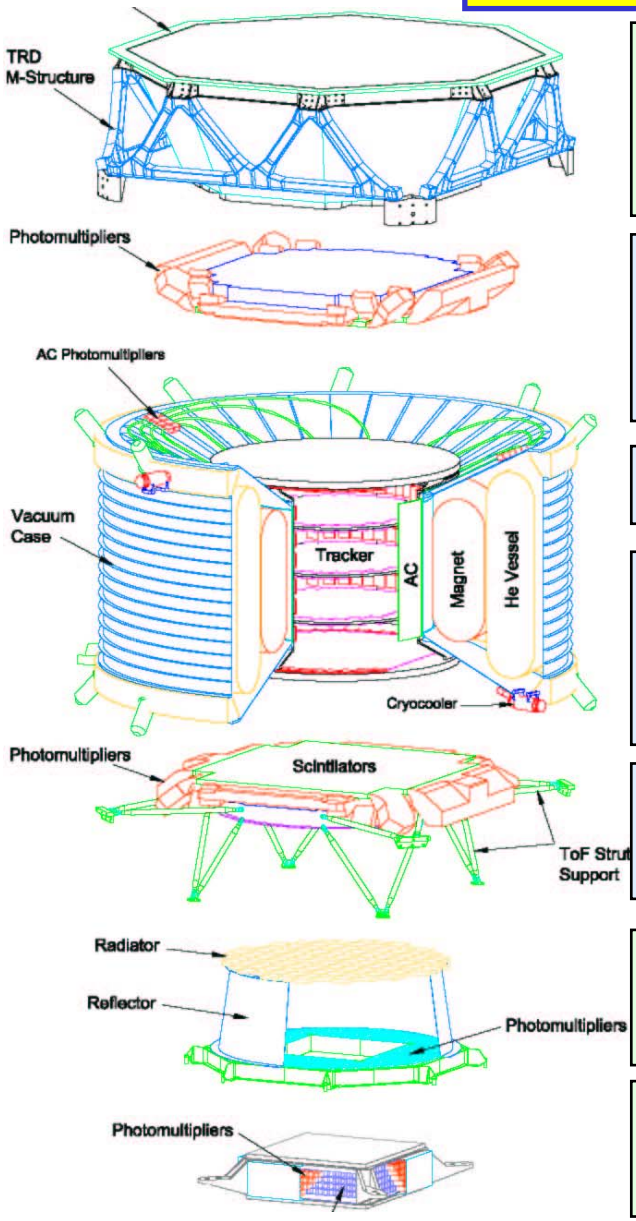
Space Shuttle

Acceleration: 3 (6) g
Launch: March 2008

International Space Station ISS

Weight: 420 t, Dimensions: 108 x 80 m²
Orbit: Elliptic (400 km)
Inclination 51.57°, 15.62 revolutions/d
Temperature Variations: -150 ÷ +30 °C
Deposition Limits: $<10^{-14}$ g/s/cm²

AMS-02 – A TeV Particle Spectrometer



TRD Particle ID & 3D tracking,
20 layers fleece + Xe/CO_2, 5248 channels 6mm straws
p^+ rej. $>10^2$ 1-300 GeV 0.5m^2sr

TOF 1,2 Trigger, $\sigma_{t:}$ = 120ps: β dE/dX: Z;
Anticoincidence (Veto) counter,
Fine Mesh PMTs + plastic scintillators

Superconducting Magnet, B=0.9 T, BL^2 = 0.8 Tm^2

Silicon strip tracker ($2 \cdot 10^5$ Ch) with internal laser alignment, 6 m^2 in 3 double+2 single xy layers,
1σ charge separation up to 1TV, dE/dX: Z

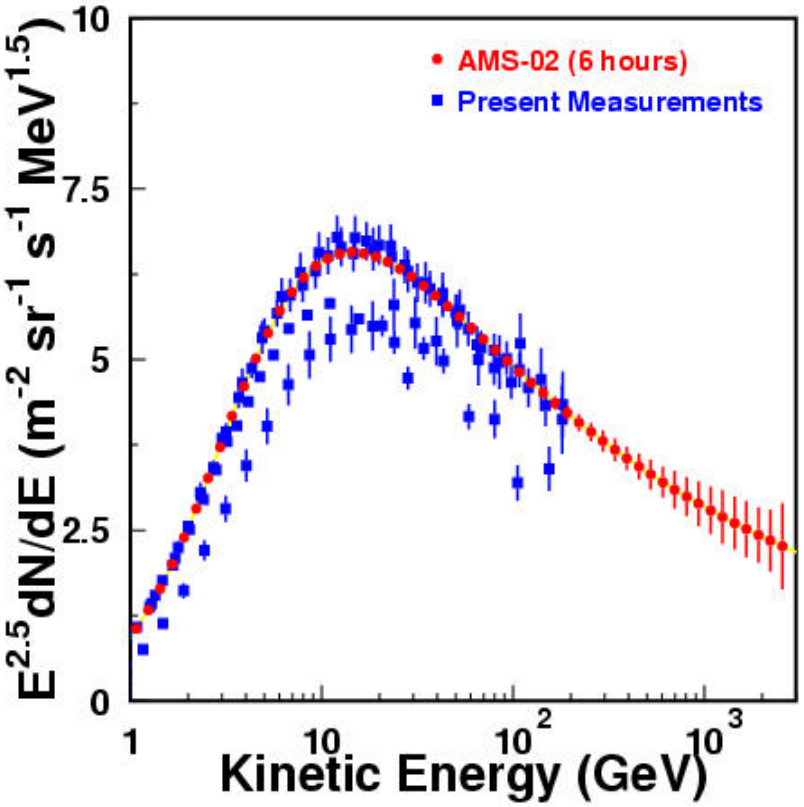
TOF 3,4 Trigger , 1.3 m distance to TOF 1,2
$p^+/e^+ > 3\sigma$ below 2 GeV

RICH Aerogel / NaF Radiator for A≤27 and Z ≤ 28
separation > 3σ from 1-12 GeV

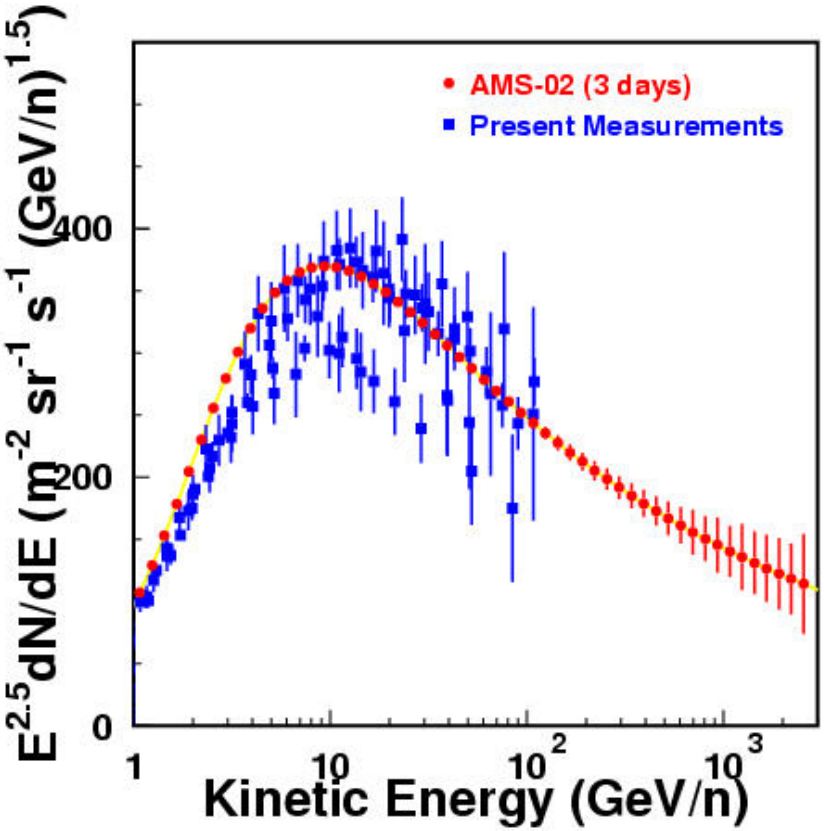
ECAL 3D sampling lead/scint.- fibre, with p-E matching + shower shape: **h rej. $>10^4$ 1-300 GeV 0.05m^2sr**

AMS-02-Physics Expectations: p, He Energy Spectra

p



He



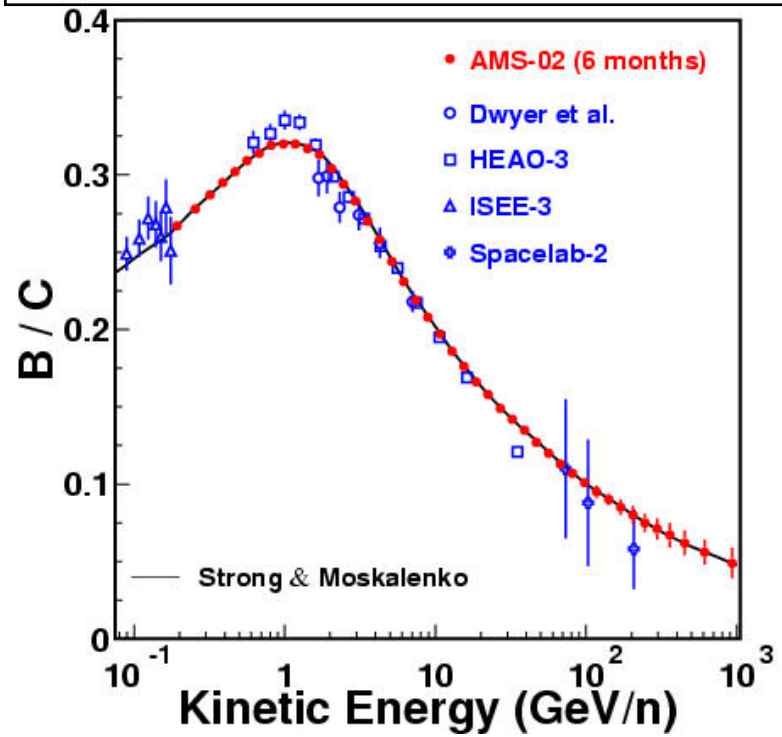
Protons and Helium: **The most abundant elements**

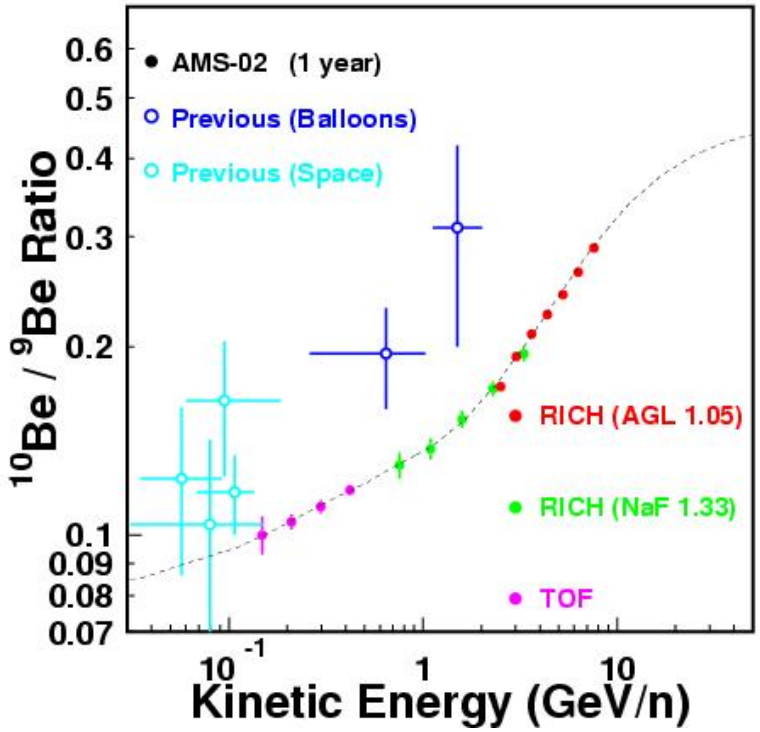
Spectral index: Origin and acceleration, differences between both species

Used to determine the expected fluxes of $\bar{p}$ and e^+, atmospheric neutrinos, etc…

AMS-02-Physics Expectations: Hadrons Z > 2

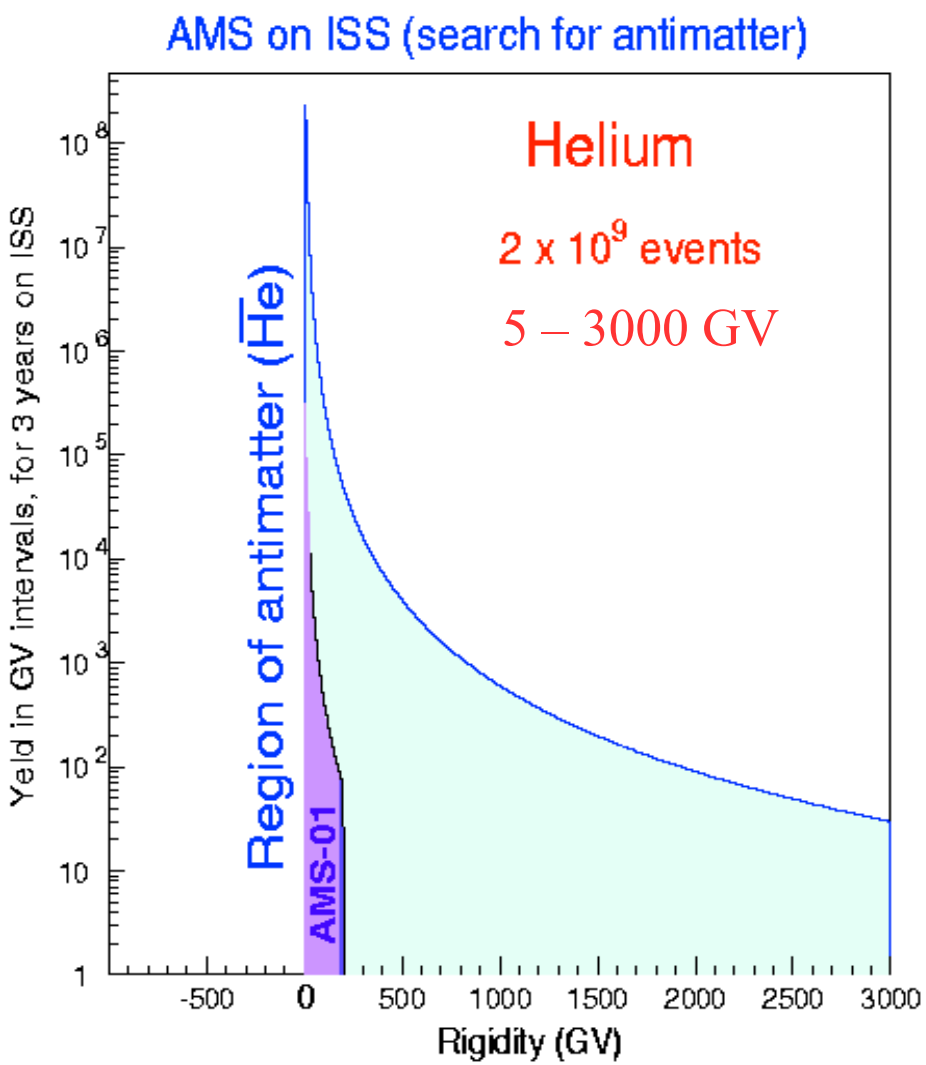
In addition to the information provided by primary CR such as C, N and O, secondary CR (produced by spallation) are used to estimate the amount of matter traversed by the CR (confinement volume and time)

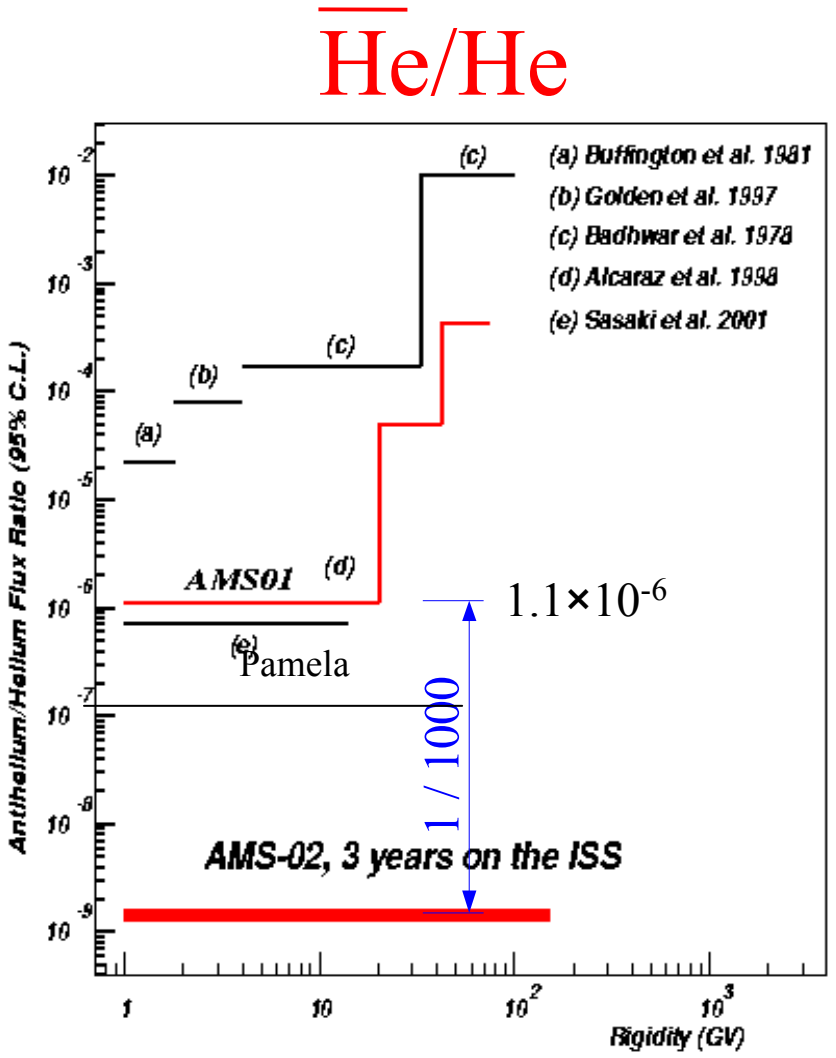




Radiactive Isotopes:
Provide information about the confinement time of CR in the Galaxy, → $t_{1/2\ Be} = 1.5 \cdot 10^6$ years

AMS-02-Physics Expectations. Direct Search for Anti-Helium

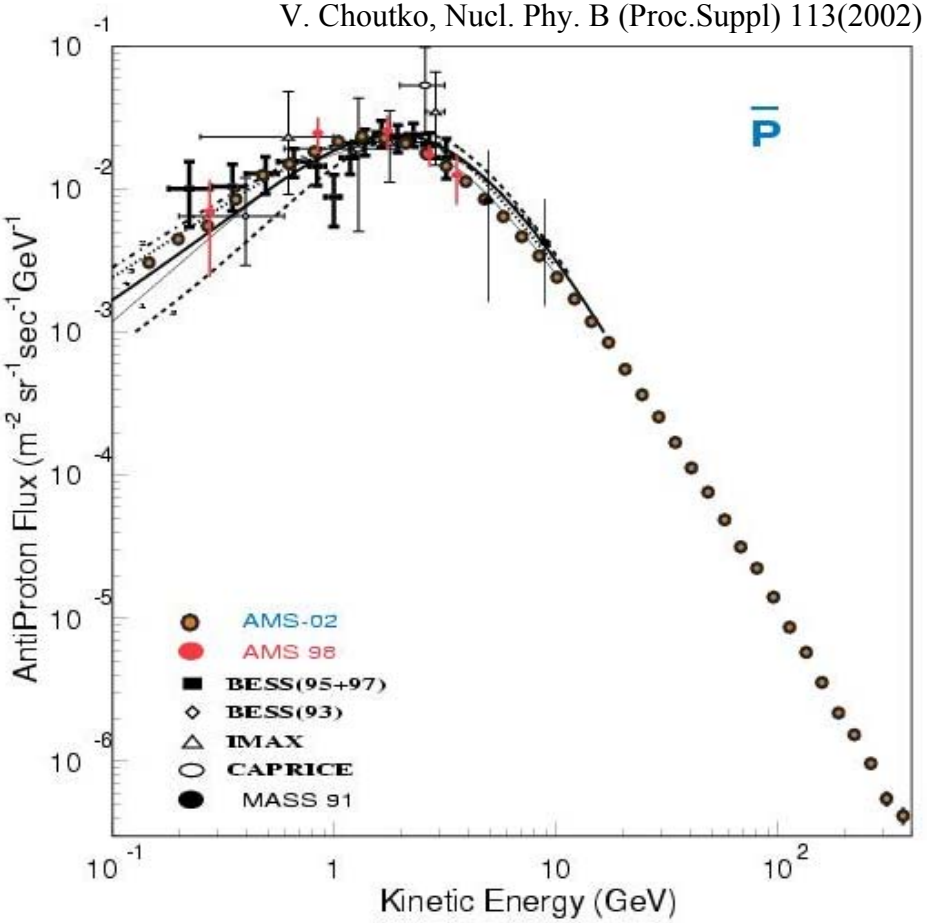




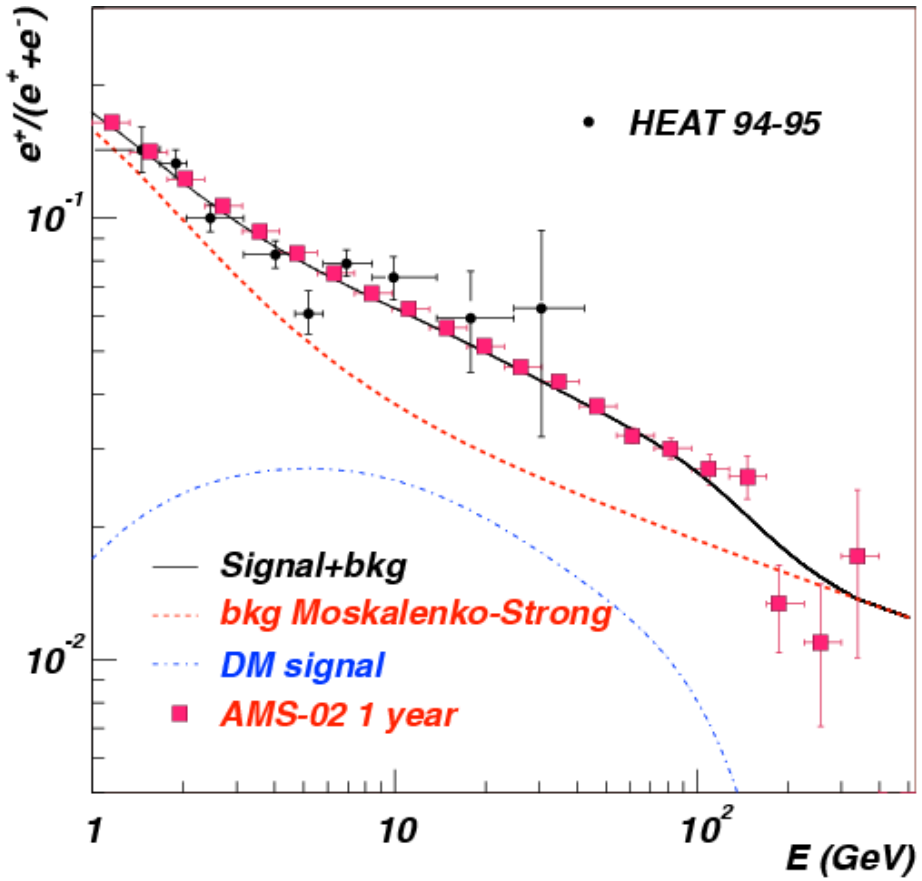
AMS-02-Physics Expectations: Indirect Dark Matter Search

$\bar{p}$ Flux with AMS (3 years)

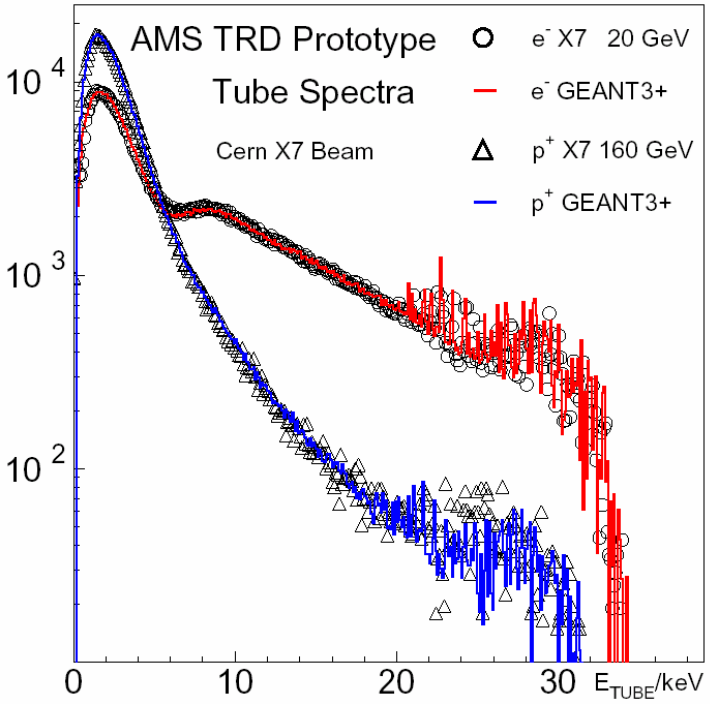
V. Choutko, Nucl. Phy. B (Proc.Suppl) 113(2002)

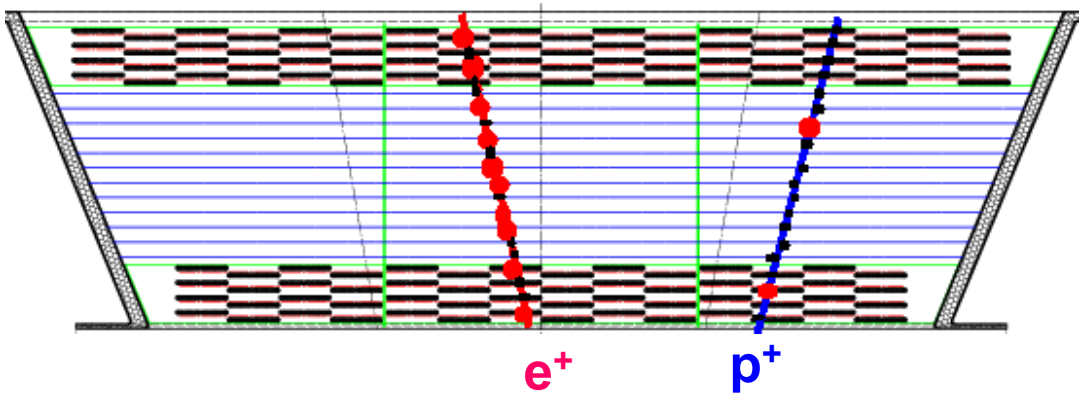


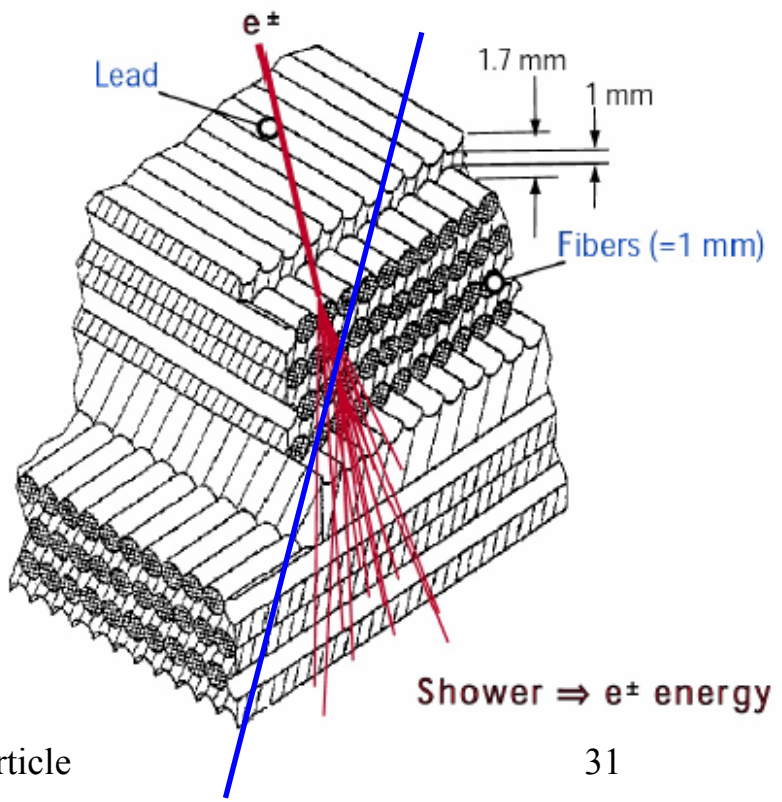
$\chi\chi \rightarrow e^+ + X$



AMS-02: p/e+-Separation







Proton Rejectionfactor

Elektron Efficiency jeweils ≈ 90%

TRD TR-Cluster: $10^2..10^3$

ECAL Shower-Shape: 10^3

ECAL+Tracker E / p: 10

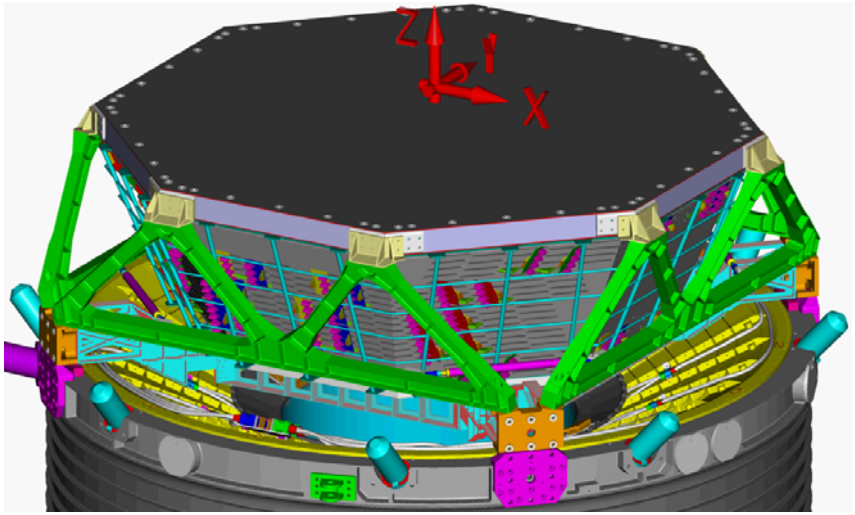
AMS-02 - TRD

p^+ rejection $>10^2$ 1-300 GeV 0.5m^2sr

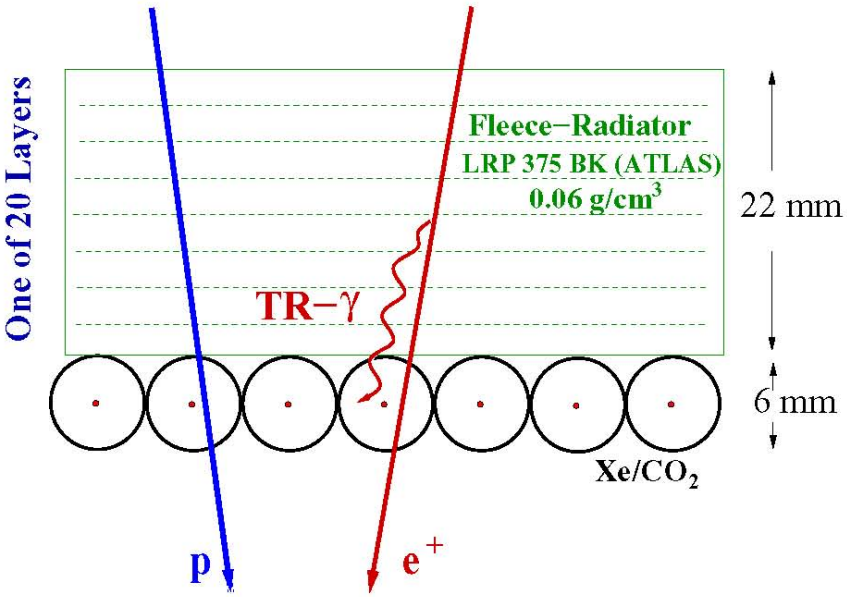
Choosen configuration for 60 cm height:

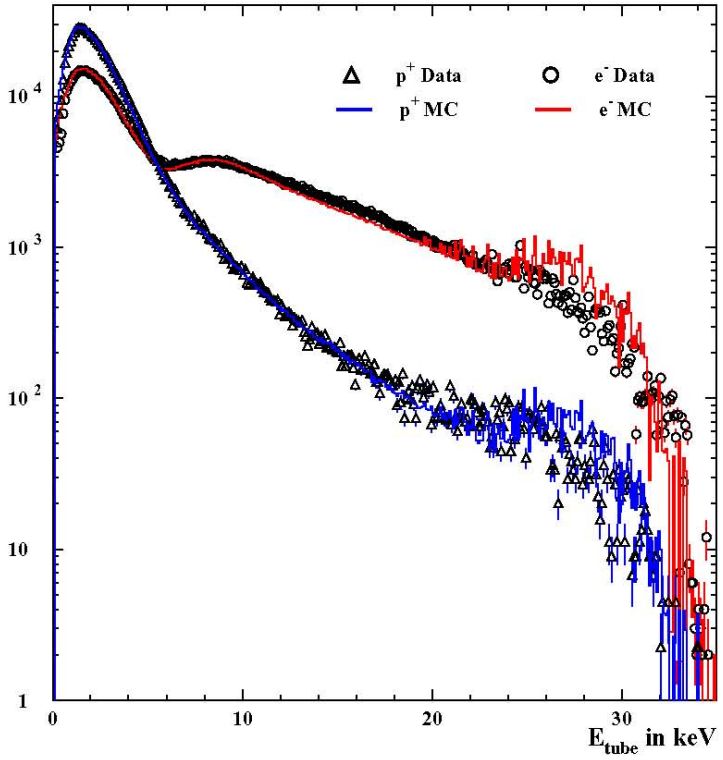
20 Layers each existing of:

- 22 mm fibre fleece
- Ø 6 mm straw tubes (Xe/CO_2 80%/20%)

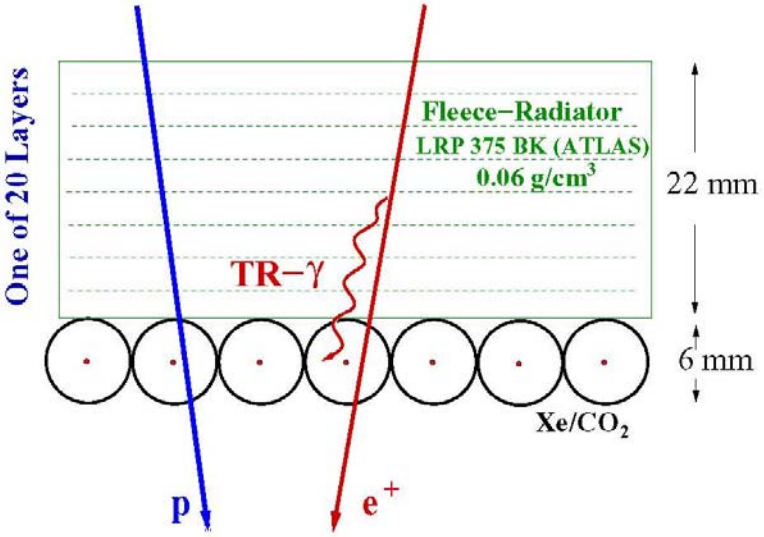


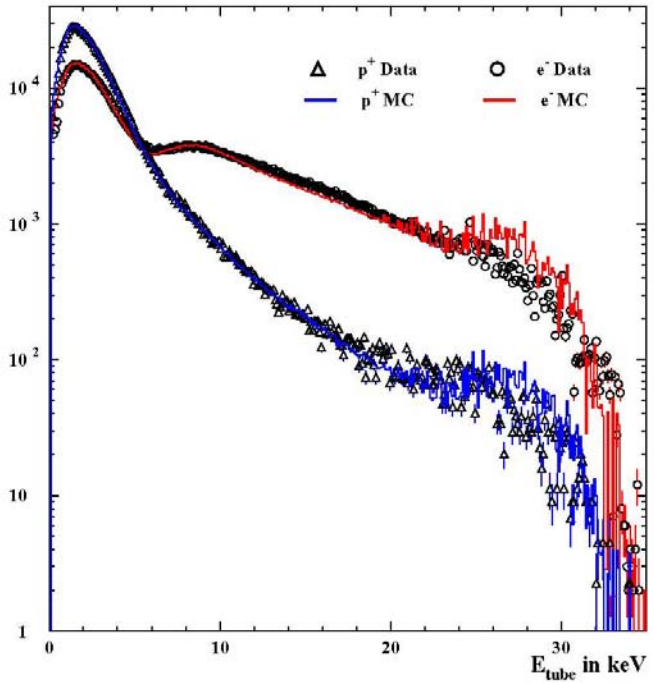
Radiator + Straws + Xe/CO_2	168 kg
Octagon + Support + Shielding	207 kg
Gas System	50 kg
Electronics	53 kg
TRD Total	478 kg

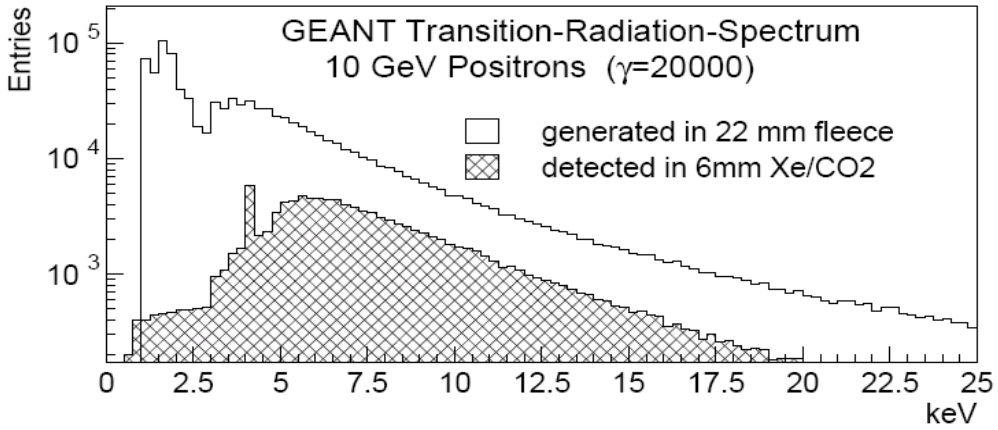


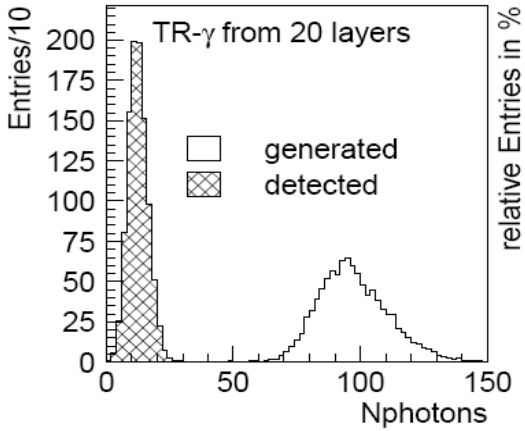


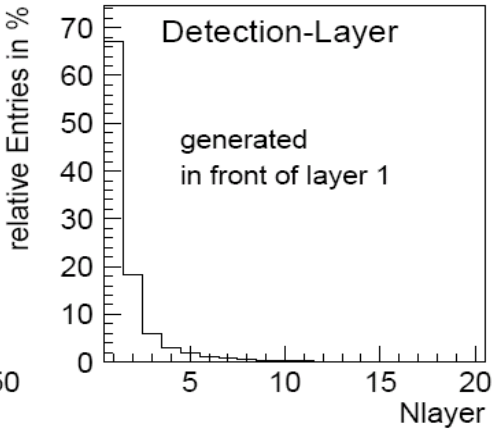
AMS-02 - TRD

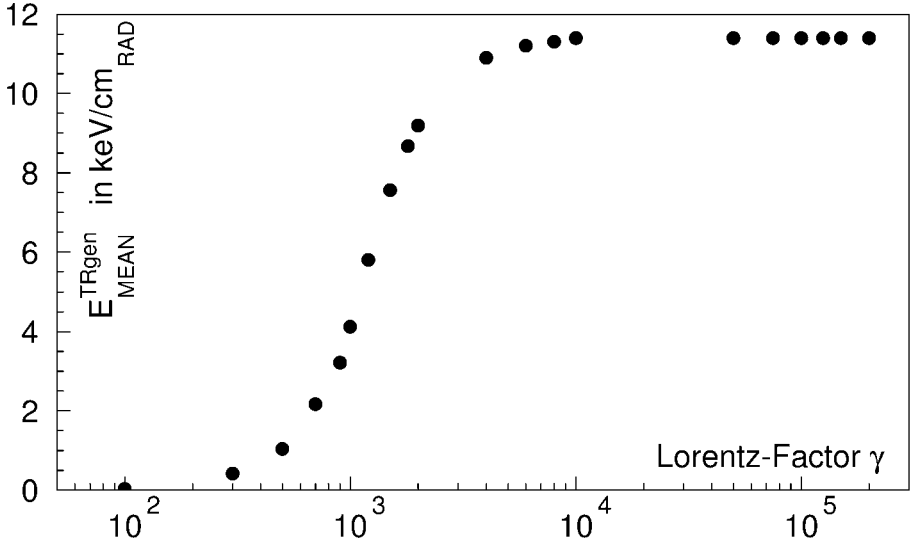

One of 20 Layers
Fleece−Radiator
LRP 375 BK (ATLAS)
0.06 g/cm3
22 mm
TR−γ
6 mm
Xe/CO2
p
e+


p+ Data
p+ MC
e- Data
e- MC
Etube in keV


GEANT Transition-Radiation-Spectrum
10 GeV Positrons (γ=20000)
generated in 22 mm fleece
detected in 6mm Xe/CO2
Entries
keV

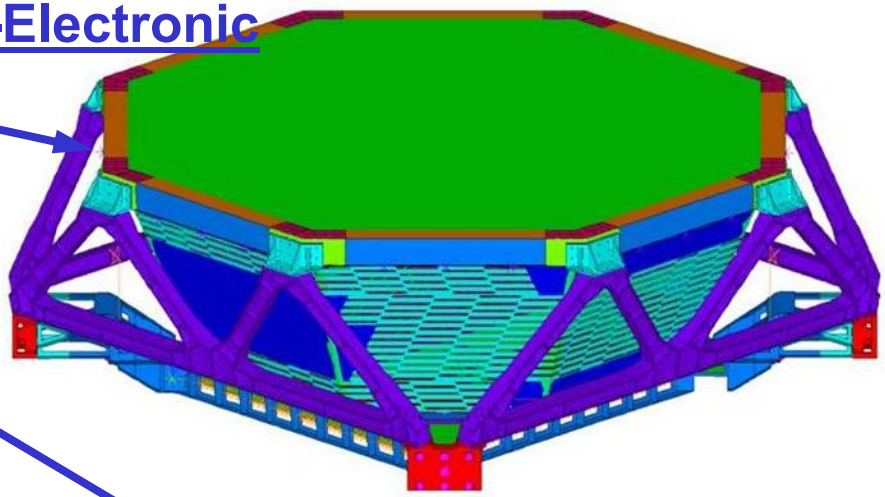

TR-γ from 20 layers
generated
detected
Entries/10
Nphotons


Detection-Layer
generated
in front of layer 1
relative Entries in %
Nlayer


E TRgen MEAN in keV/cm RAD
Lorentz-Factor γ

AMS-02 - TRD

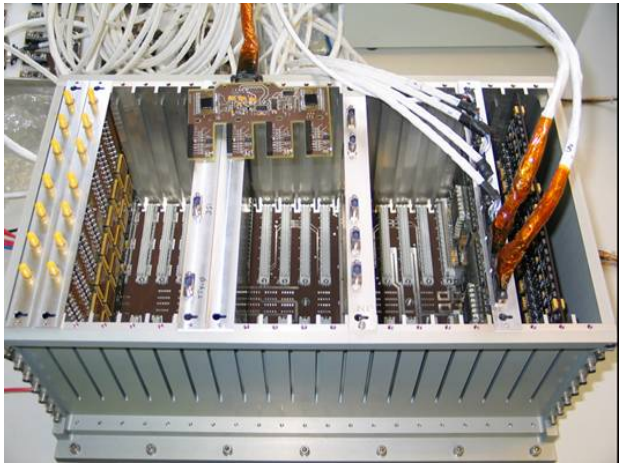
TRD Octagon/Straw tubes/Radiator/FE-Electronic
RWTH Aachen

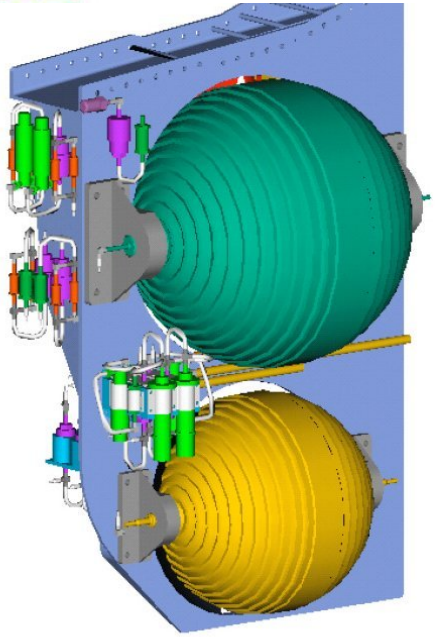


TRD Gas Supply/Circulation System
MIT – Design CERN & MIT - Construction

TRD Slow Control System
MIT & INFN Rome

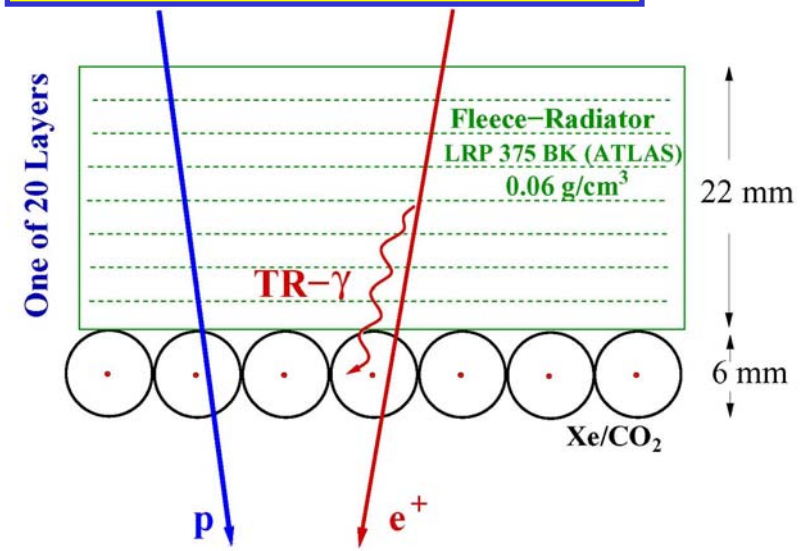
TRD DAQ
TH Karlsruhe





Box S mechanical design.

AMS-02 – TRD



Radiator LRP 375 BK:

Polyethylene/Polypropylene fibers

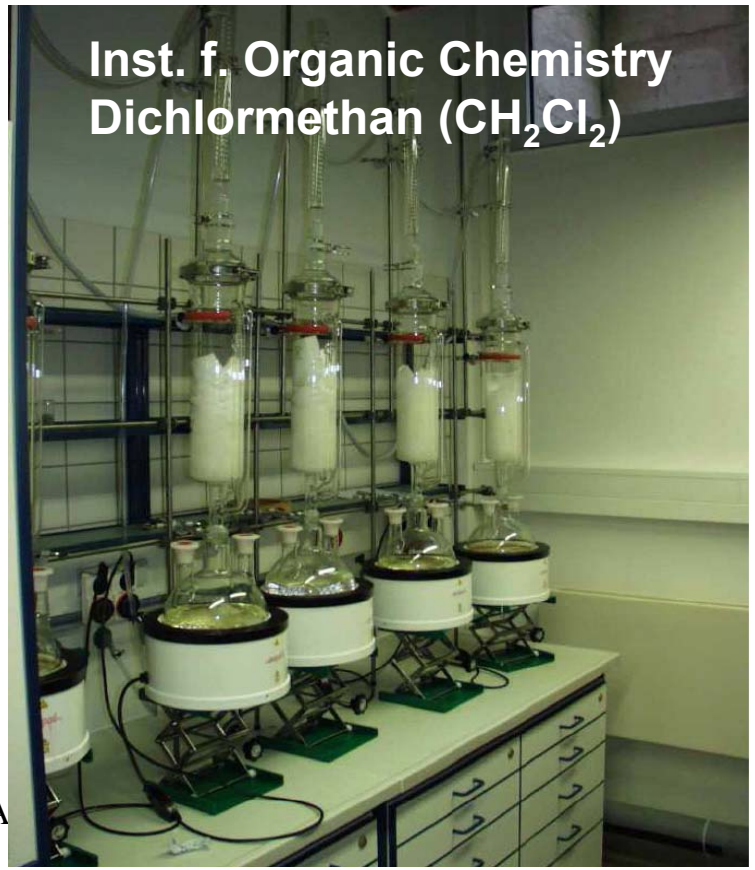
Effective fiber diameter: 10 μm

Radiator thickness: 22 mm

Density: 0.06 g/cm^3

Cleaning with Dichlormethane CH_2Cl_2

→ dM/dt ≈ 10^{-12} g/s/cm^2

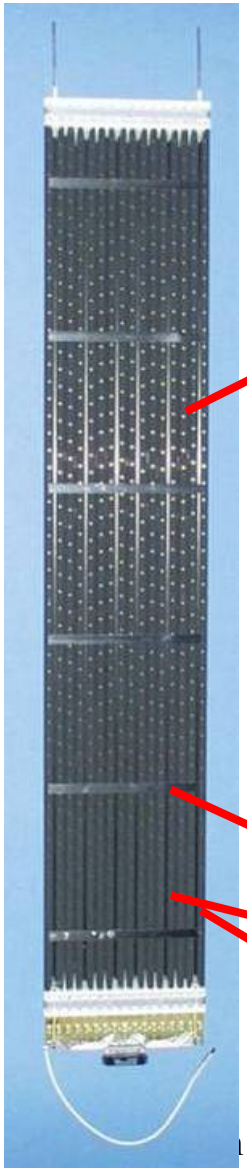


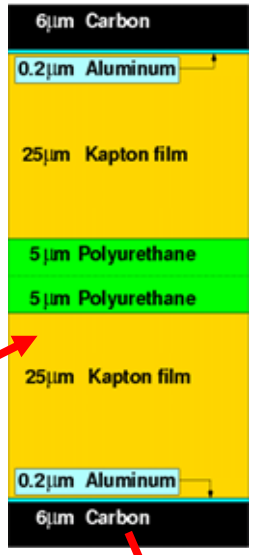
Os in A
hysics

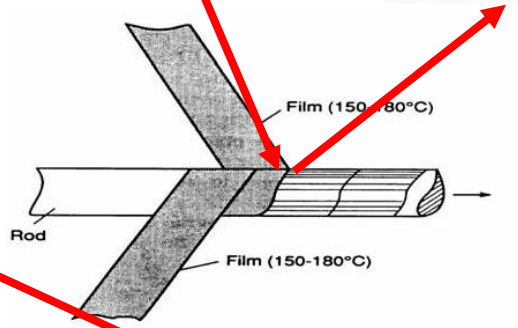
AMS-02 - TRD

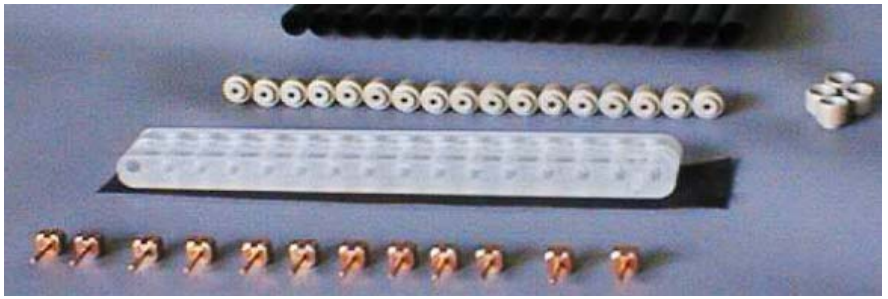
Straw tube proportional counter modules:

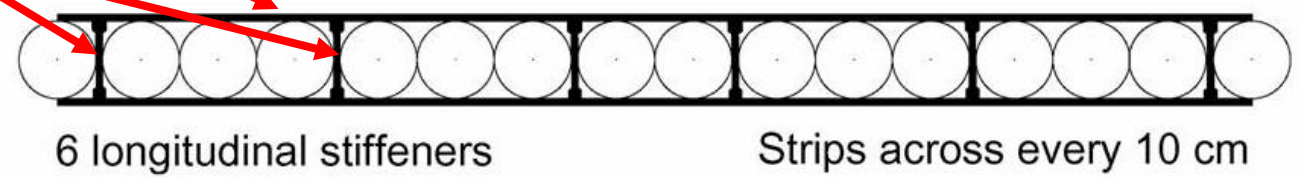
- Straw tubes: 72 μm multilayer aluminium kapton foil, Ø 6 mm , 0.8 ÷ 2.0 m length
- Wire: tungsten anode wire, 30 μm Ø, tension ≈ 100 g
- Gas mixture: Xe / CO_2 (80% / 20%)
- Operating HV ~ 1460 V → Gasgain of ~ 3000
- 1 Module → 16 Straws, 100 μm mechanical accuracy
- 328 Modules → 5248 Straws



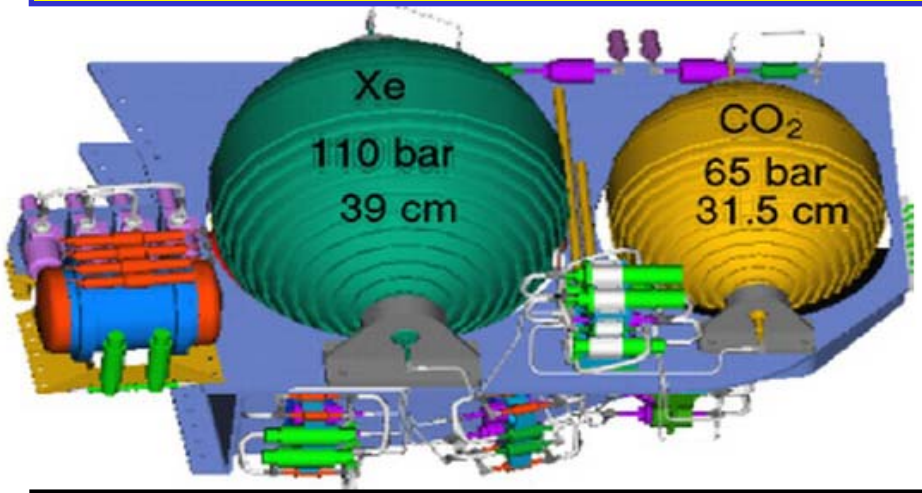






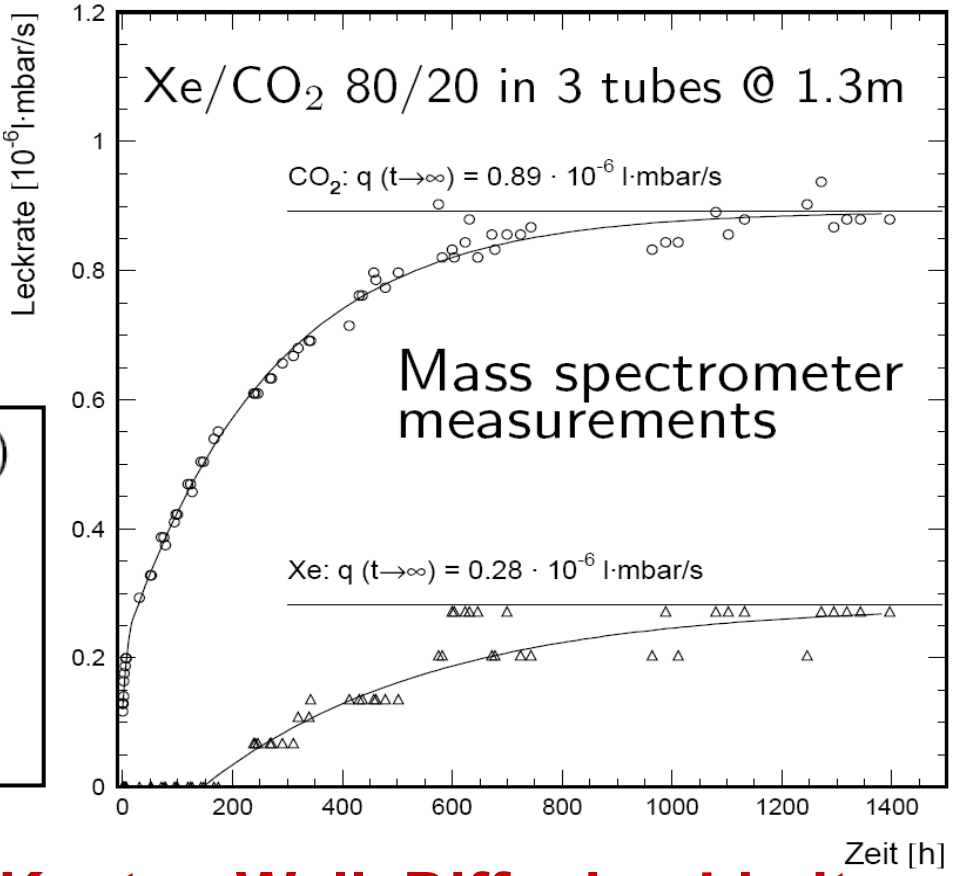


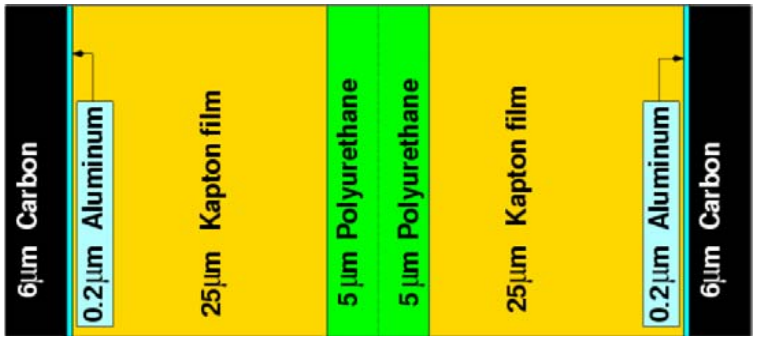
AMS-02 – TRD: Gas-System & Single Straw Gastightness



TRD 230 l in 41 loops (500 m_{CH})
Xe 49.5 kg (9340 l @ 1 bar)
CO_2 4.5 kg (2530 l @ 1 bar)

CO_2 Safety-Factor SF=1 for 10^8s
$25.3 \cdot 10^{-5}$ l mbar/s/m_{CH} @ 1 bar



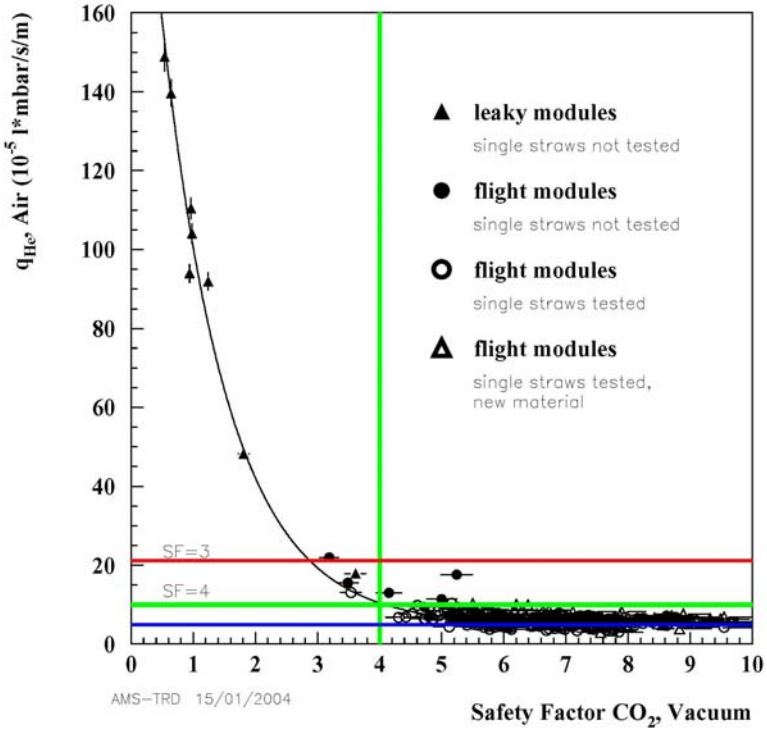


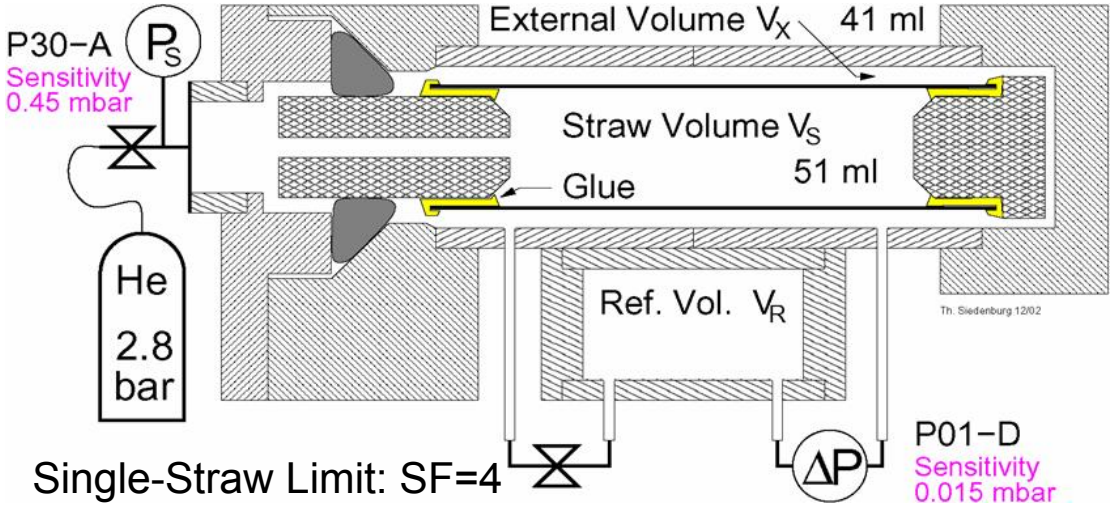
Kapton Wall Diffusion Limit

Xe $0.12 \cdot 10^{-5}$ l mbar/s/m_{CH} → SF = 183

CO_2 $0.37 \cdot 10^{-5}$ l mbar/s/m_{CH} → SF = 16

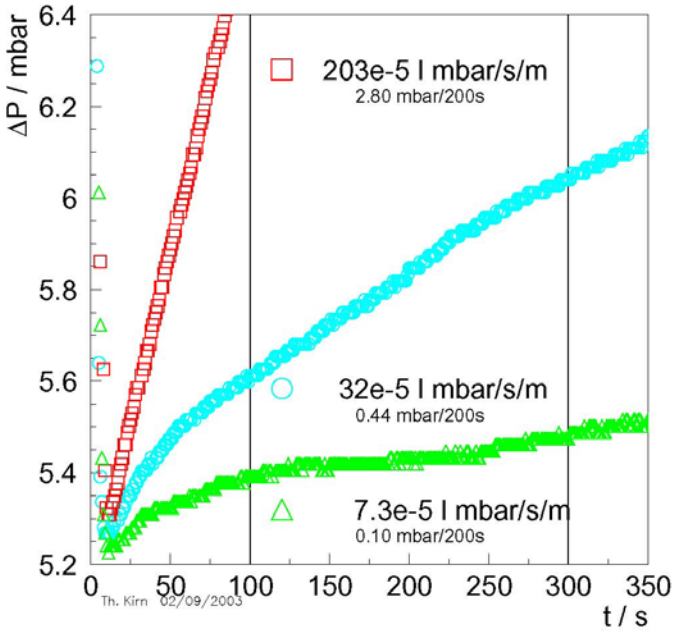
AMS-02 – TRD: Single Straw Test

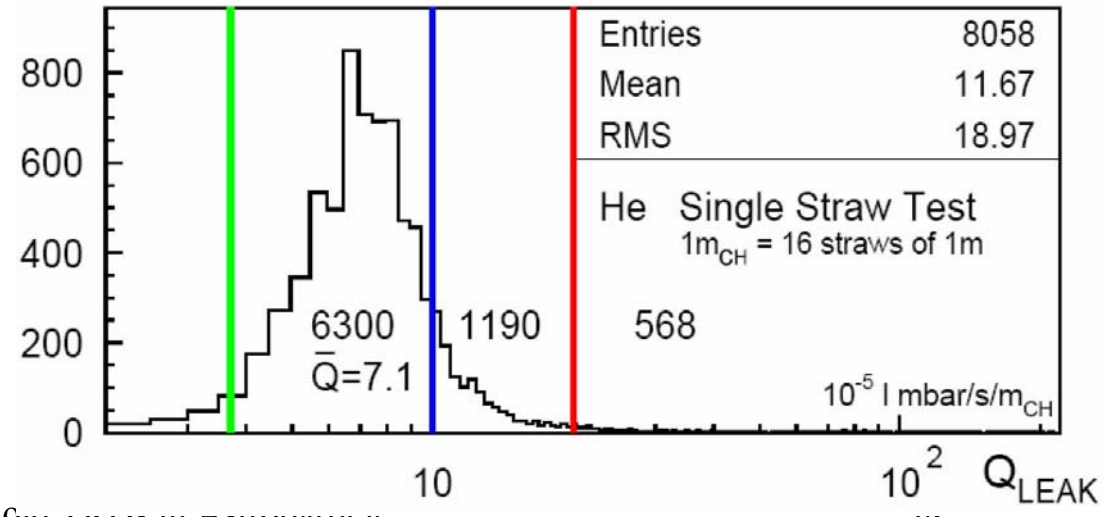




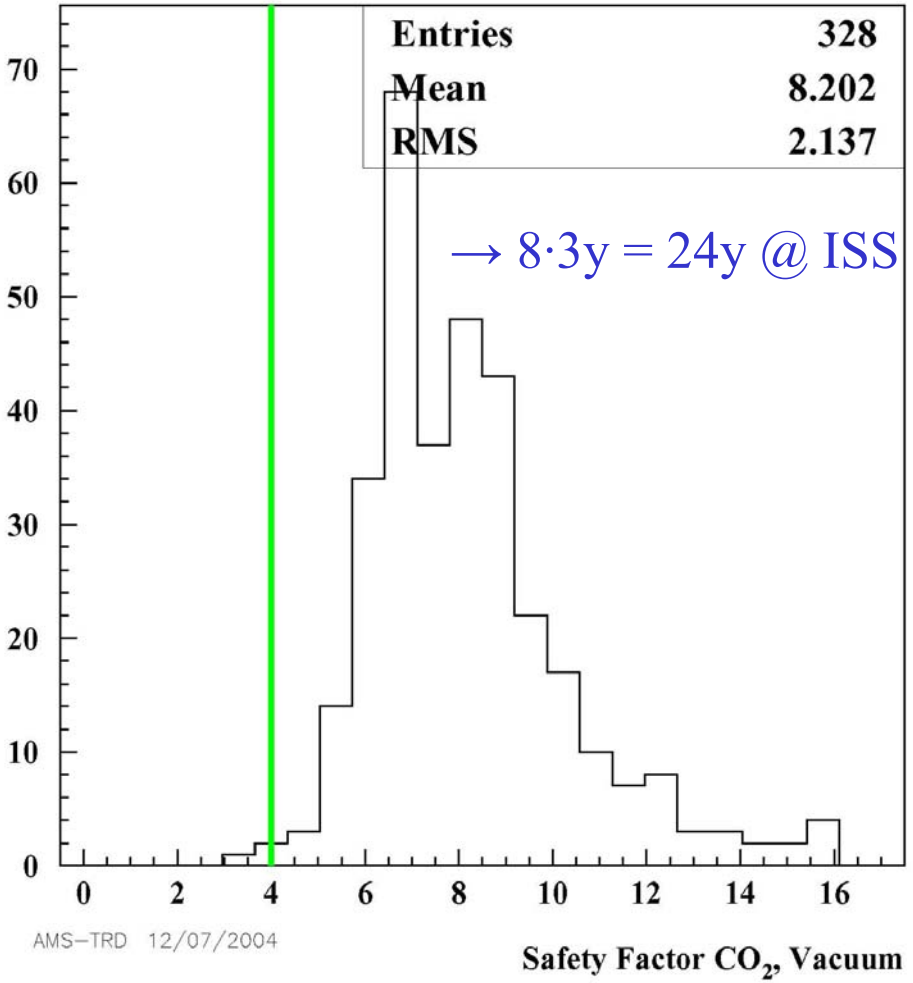
Single-Straw Limit: SF=4

He $q_{PV} < 1 \cdot 10^{-5}$ l mbar/s/m



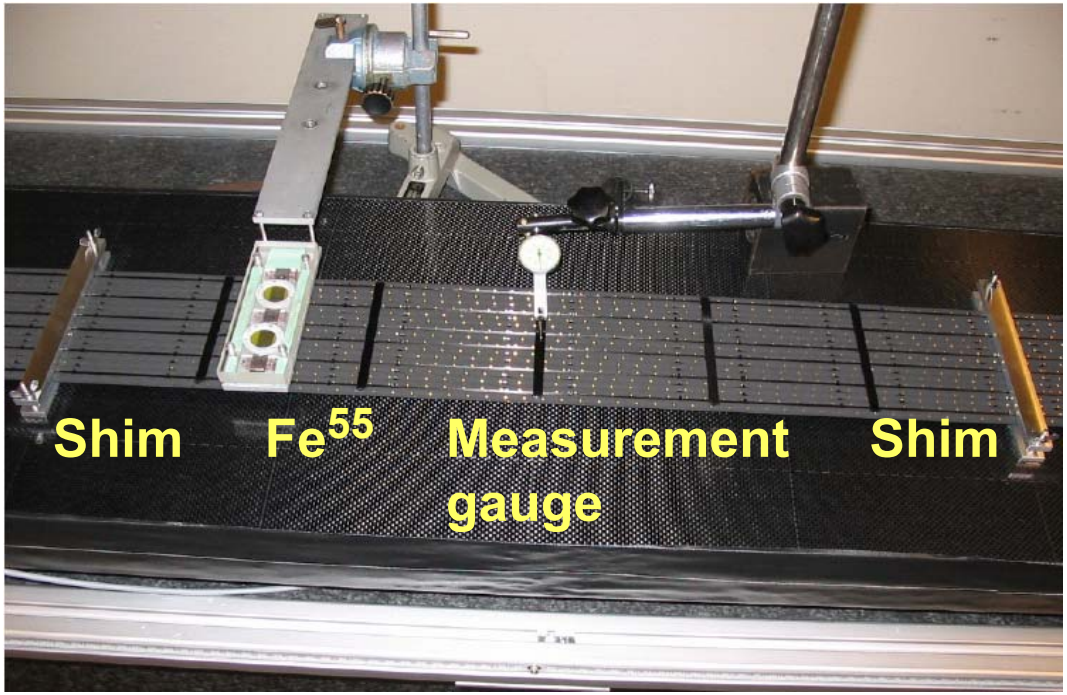


AMS-02 – TRD: Flight Module Gastightness

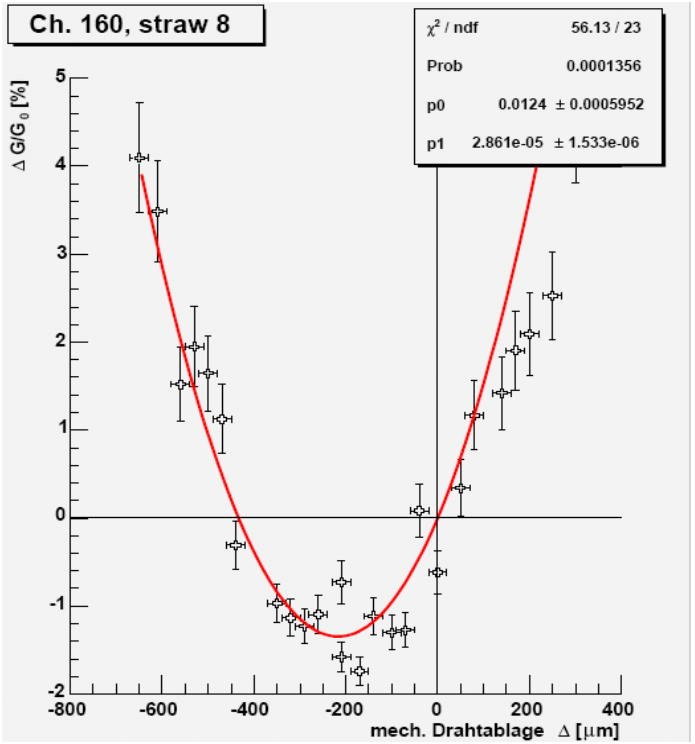


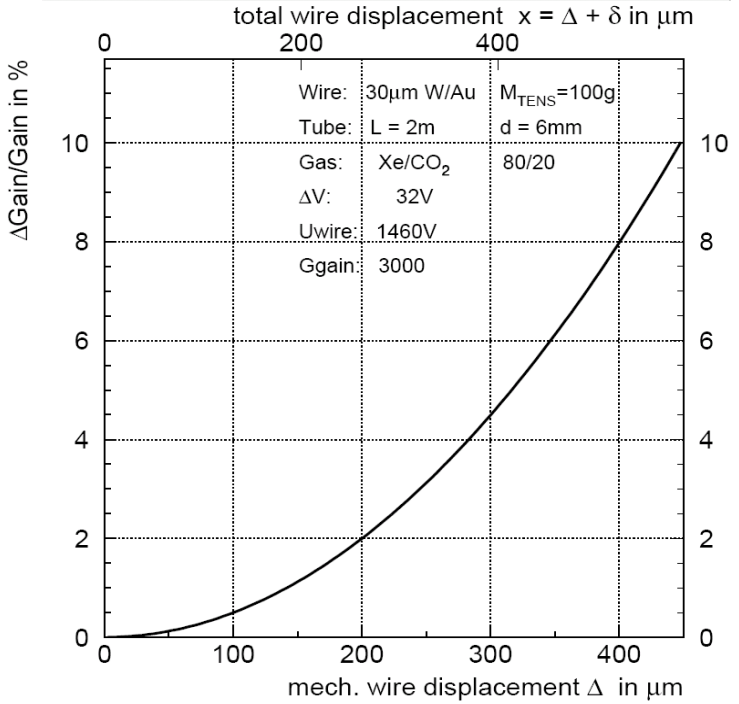
CO_2 Leaktest in Vacuum	Straws @ 1bar:	$1.85 \cdot 10^{-5}$ l mbar/s/m_{CH} ≡ SF 13.7
$1m_{CH}$ = 16 straws of 1m [+2 endpcs]	Typ. Module [1.5m] :	$3.1 \cdot 10^{-5}$ l mbar/s/m_{CH} ≡ SF 8.2

AMS-02 – TRD: Fe^{55} - Gasgain

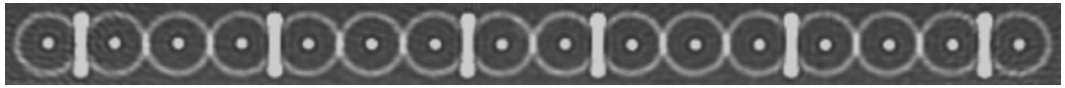


Controlled Modul-Shimming

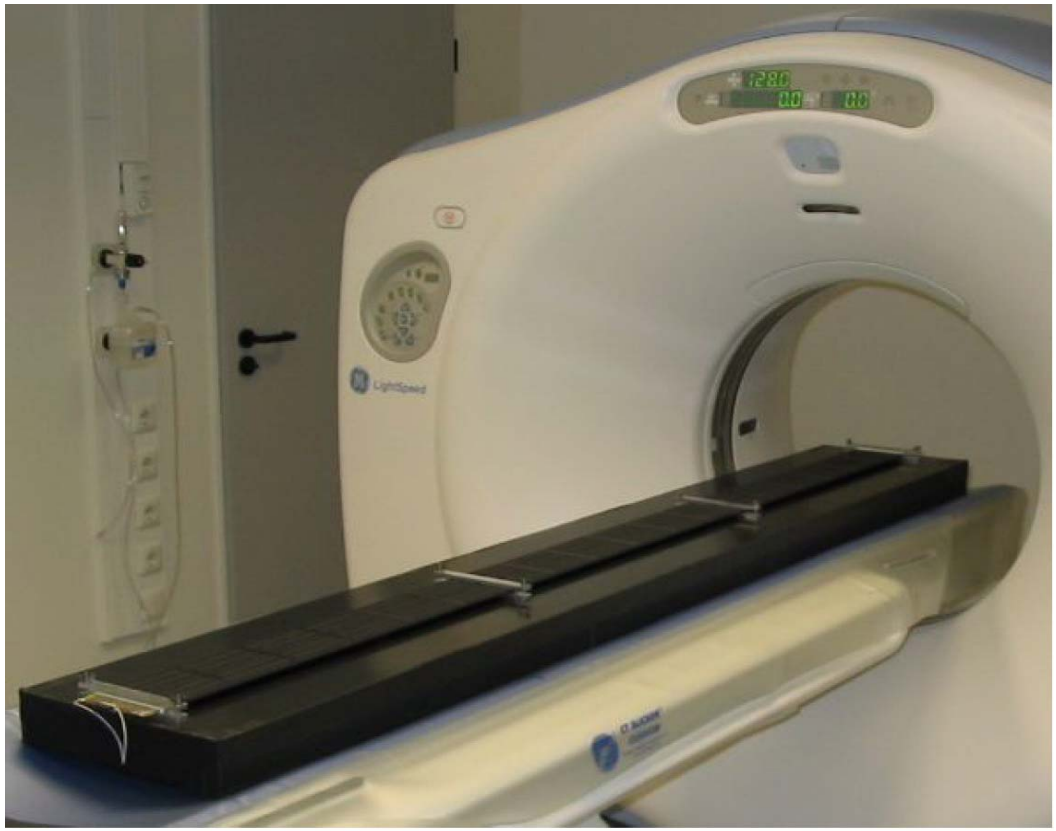




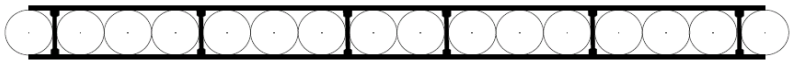
AMS-02 – TRD: Computer Tomography X-Ray

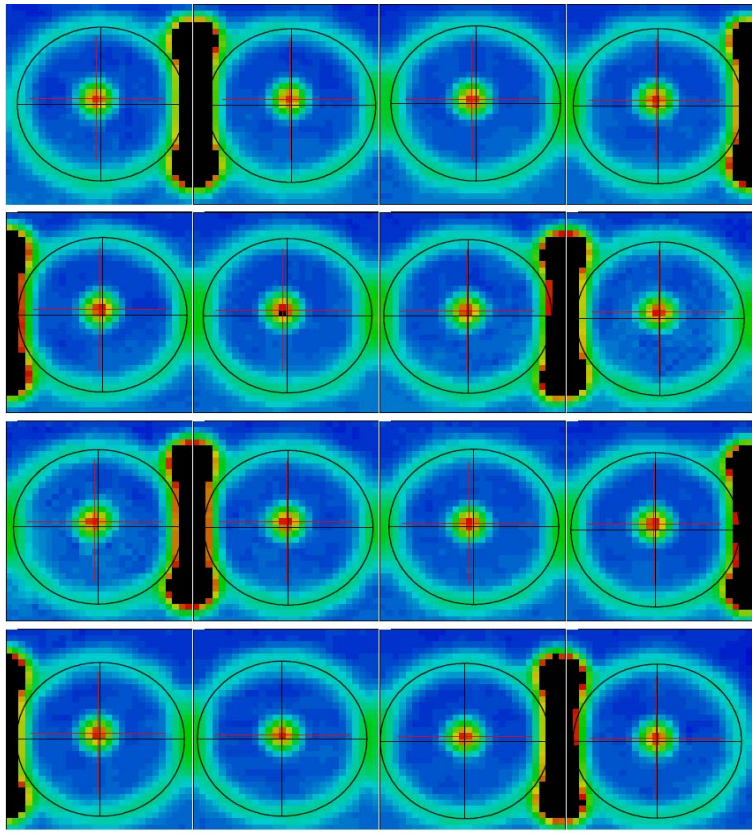


Dicom Image File



Luisenhospital Aachen (GE 16-Channel CT)

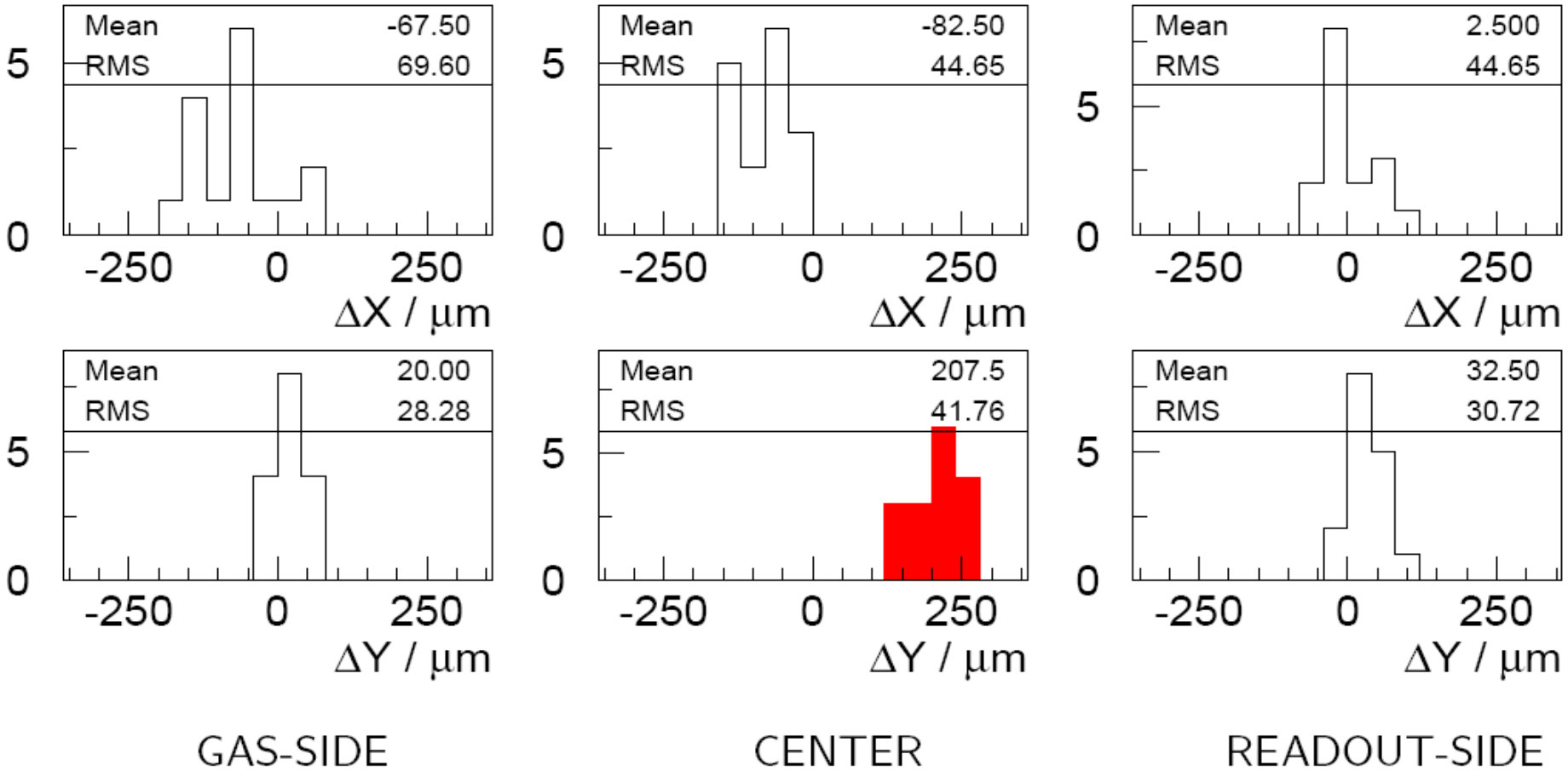




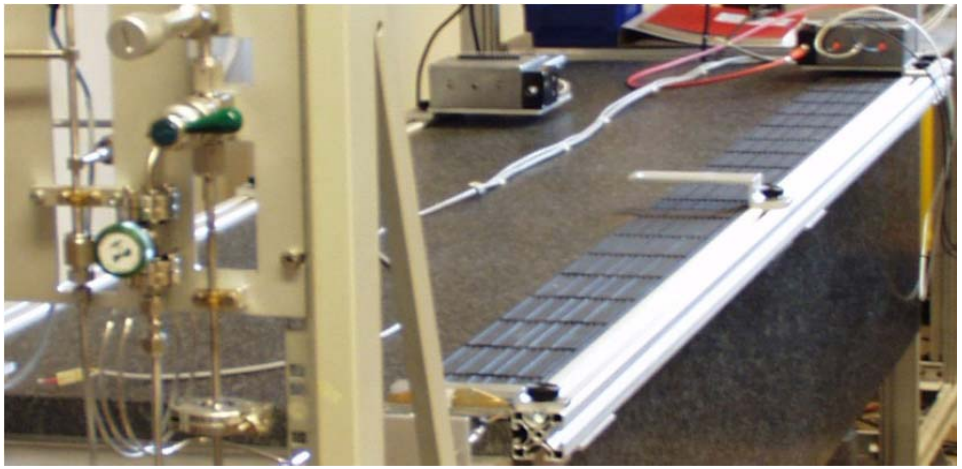
Wire- and Tube-xy-Fit ($\sigma \approx 10 \mu$m)

AMS-02 – TRD: Computer Tomography X-Ray

Controlled Shimming of +200μm y-direction in middle of module

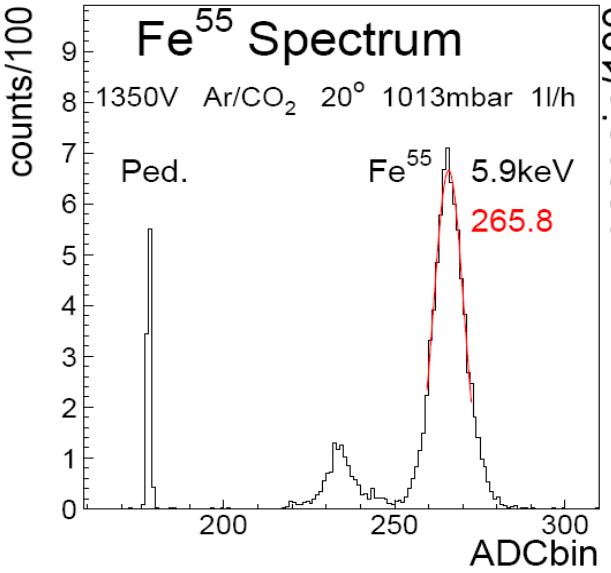


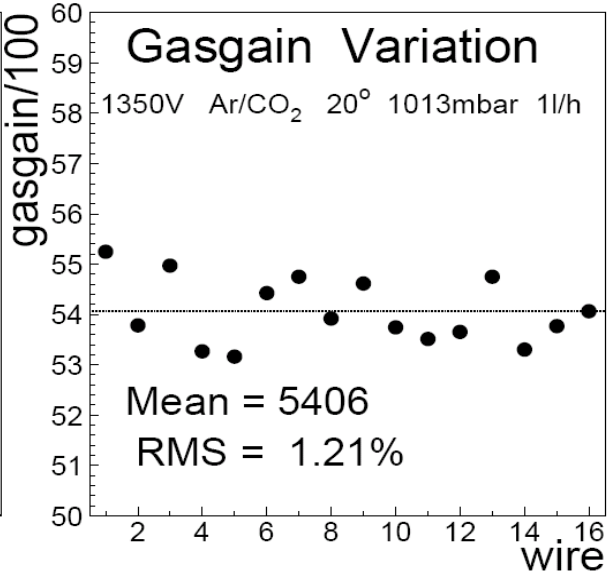
AMS-02 – TRD: Fe^{55} - Gasgain Flight Modules



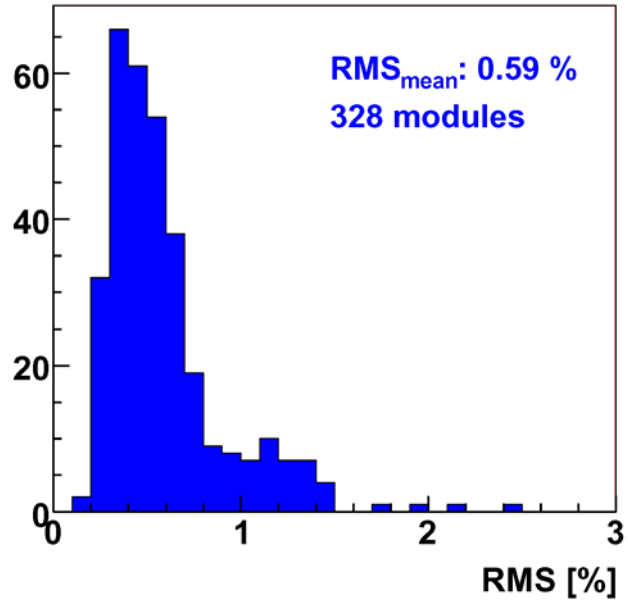
Ch160 on Nomex Shim 0.6mm Gain 6098 RMS 150

0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9m	Straw
3.2	1.5	4.2	1.8	5.7	7.1	5.2	4.2	0.2	-0.9	1
0.1	-0.1	0.2	1.0	4.1	3.8	2.9	1.8	-1.2	-2.4	2
-2.0	-0.7	0.2	0.5	0.1	3.2	4.2	-0.6	-2.9	-3.8	3
-2.6	-1.3	-2.1	0.4	0.6	2.5	2.8	-0.6	-2.8	-4.6	4
-2.9	-3.3	-1.4	-1.1	0.8	3.2	1.7	0.7	-3.0	-3.7	5
-3.7	-1.4	-4.0	-1.2	-0.9	1.4	2.8	-0.6	-1.9	-4.7	6
-1.9	-2.6	-1.1	-2.1	0.7	2.7	1.9	0.6	-2.9	-3.0	7
-2.4	-0.5	-1.0	0.8	1.1	2.3	2.1	-0.6	-2.0	-3.6	8
0.6	-1.0	1.0	0.4	5.8	5.6	1.6	2.8	-1.1	-1.1	9
-0.1	-1.2	0.3	0.5	2.8	3.6	0.9	0.8	-1.4	-2.7	10
-2.1	-0.6	-1.4	-1.0	0.4	1.6	2.1	-1.7	-3.6	-4.4	11
-2.3	-1.7	-0.5	-1.5	1.3	2.0	-0.1	-0.3	-4.8	-5.0	12
-2.1	-0.3	-0.6	0.7	2.2	1.9	3.4	0.4	-3.1	-5.1	13
-0.7	-1.4	0.8	-1.1	1.9	4.2	1.7	0.5	-3.0	-3.1	14
-1.6	-0.1	-2.1	1.8	2.6	2.2	2.7	1.0	-0.7	-2.9	15
-1.9	1.3	-0.7	2.4	1.6	3.1	4.5	1.6	-0.6	-4.2	16

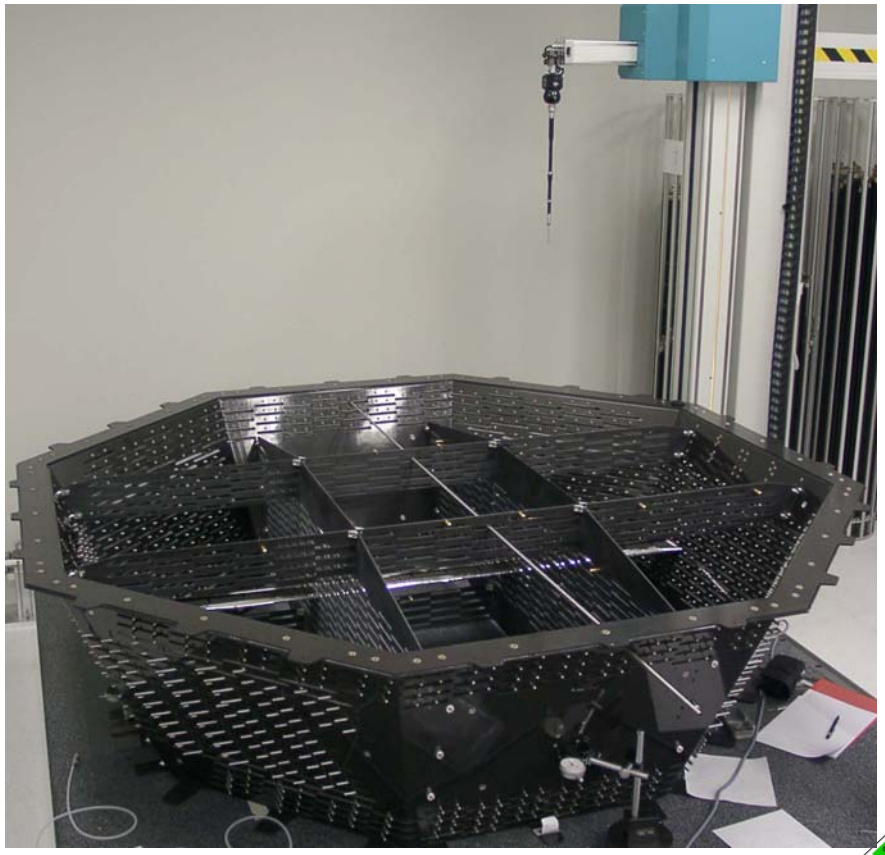


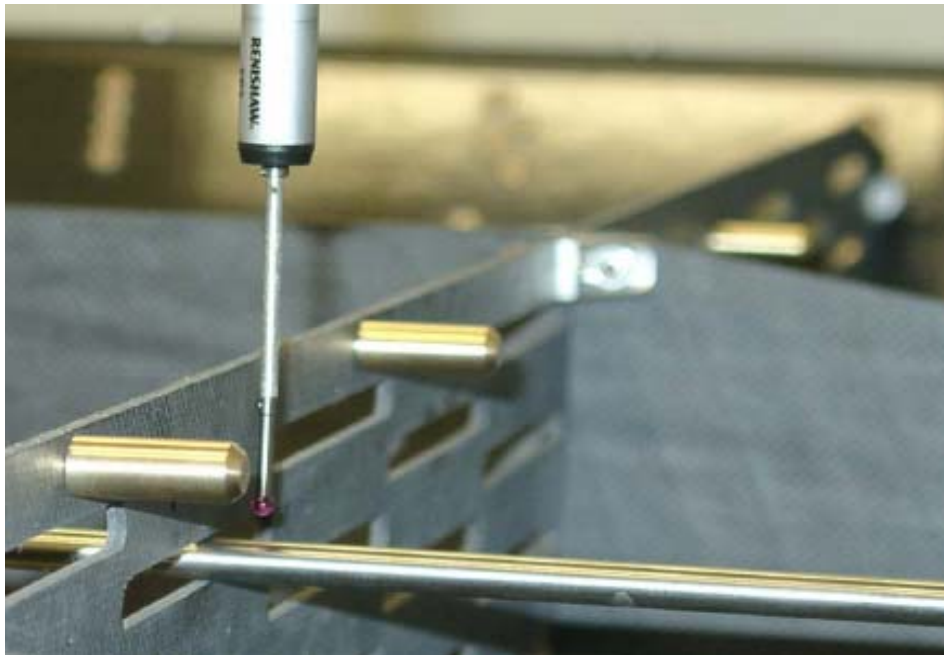


RMS gasgain



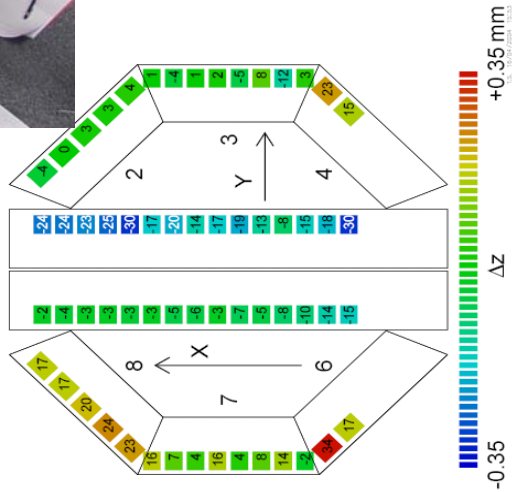
AMS-02 – TRD: Octagon Structure: 3D-Measurement

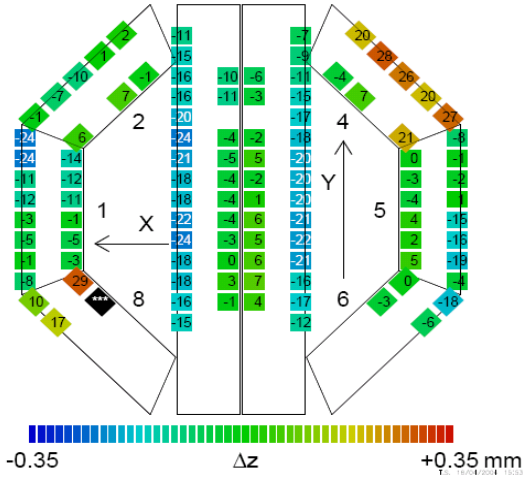




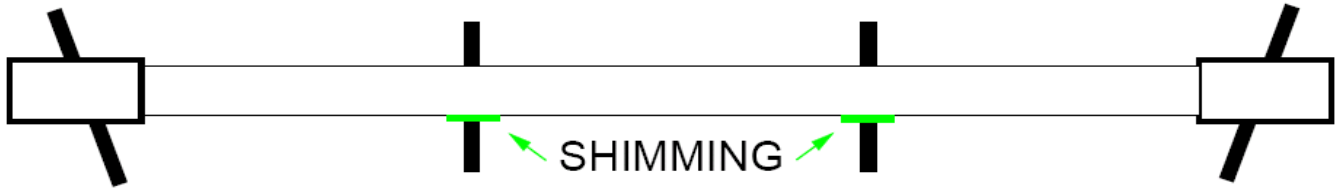
Upper and lower 4 layers ∥ B

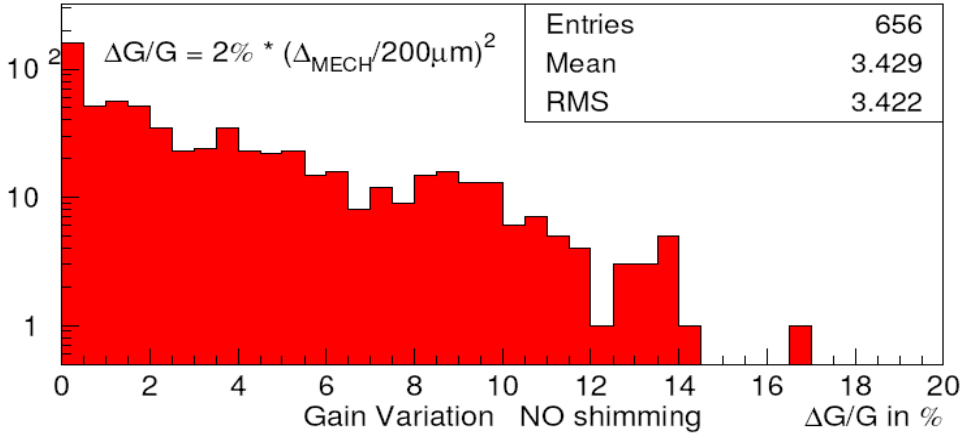
Middle 12 layers ⊥ B

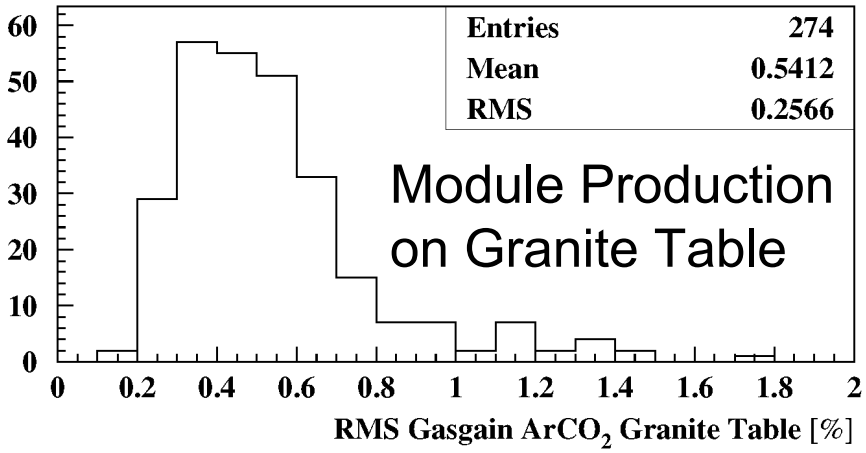


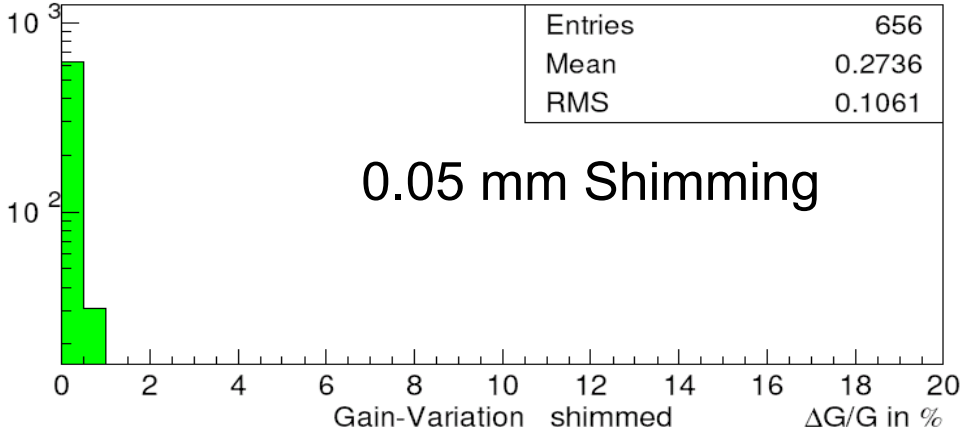


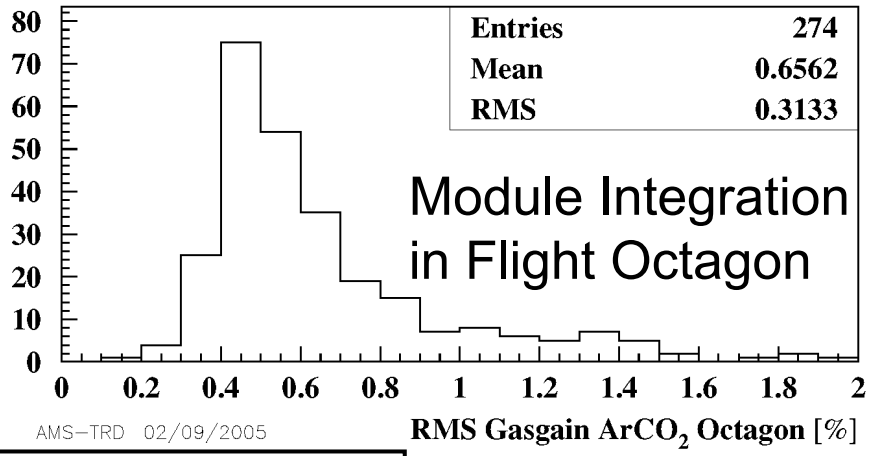
AMS-02 – TRD: Flight Modules Gasgain Homogenity





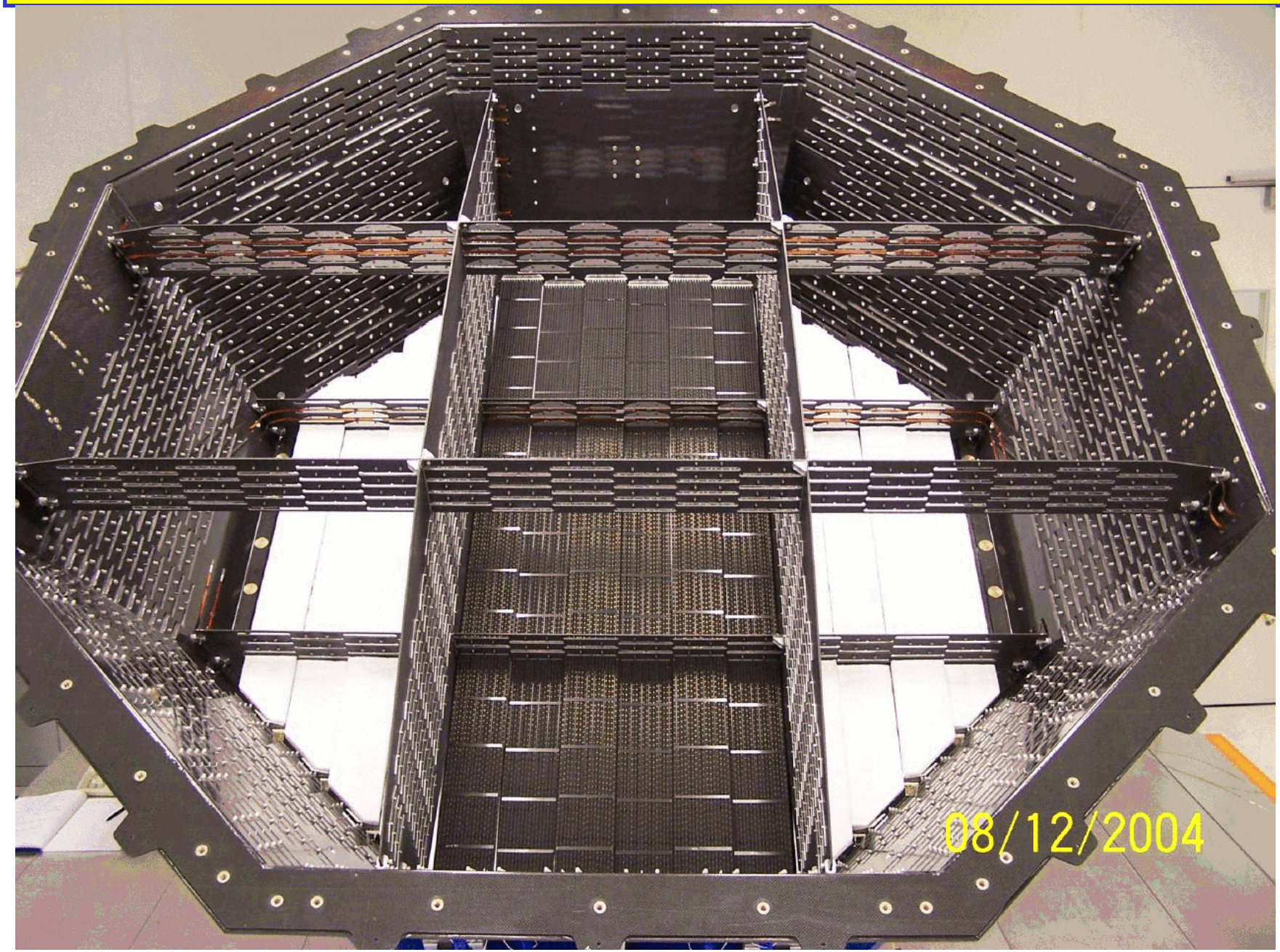




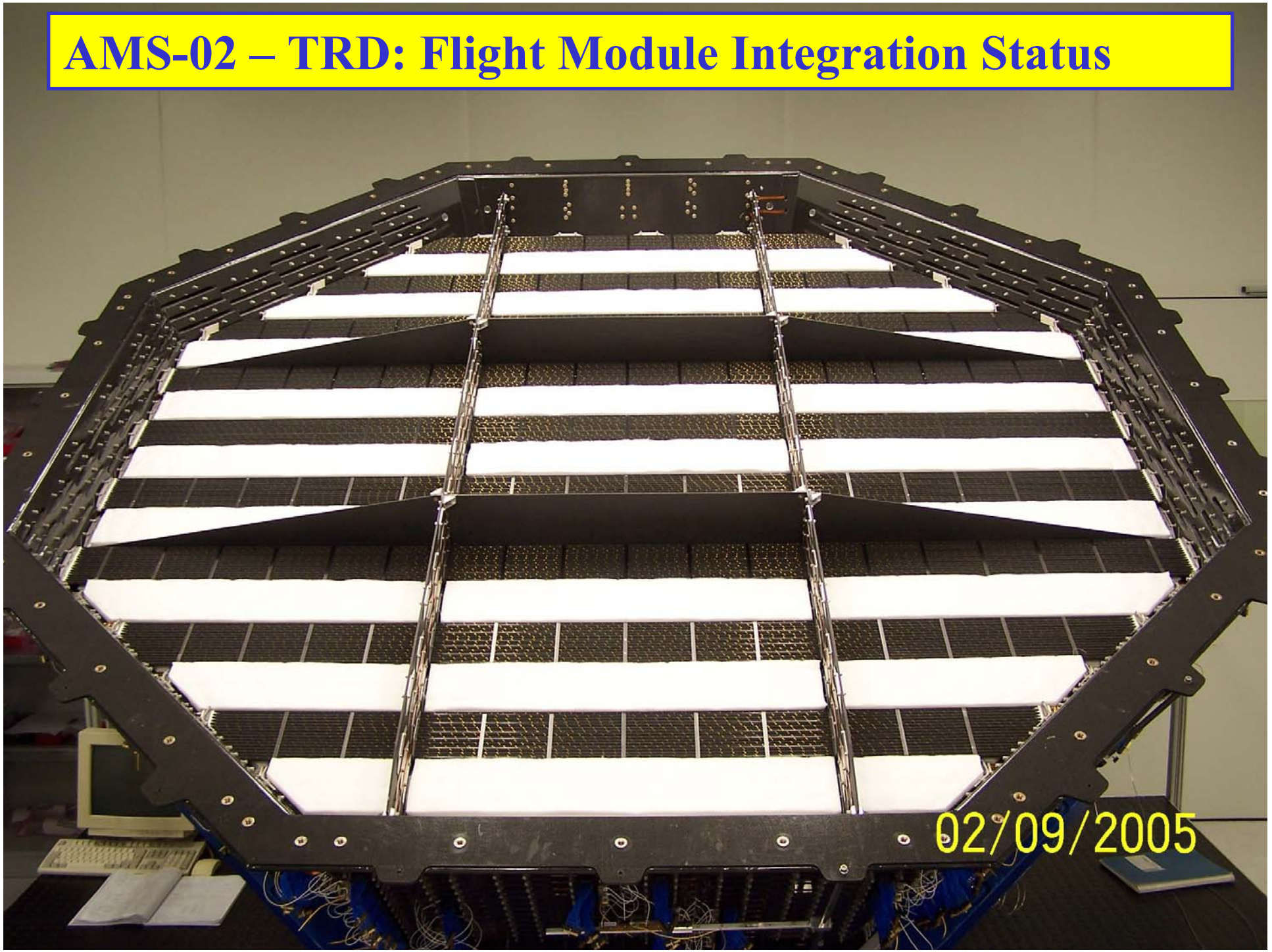


$$Grms^2_{OCT} = Grms^2_{GRT} + Grms^2_{SHM}$$

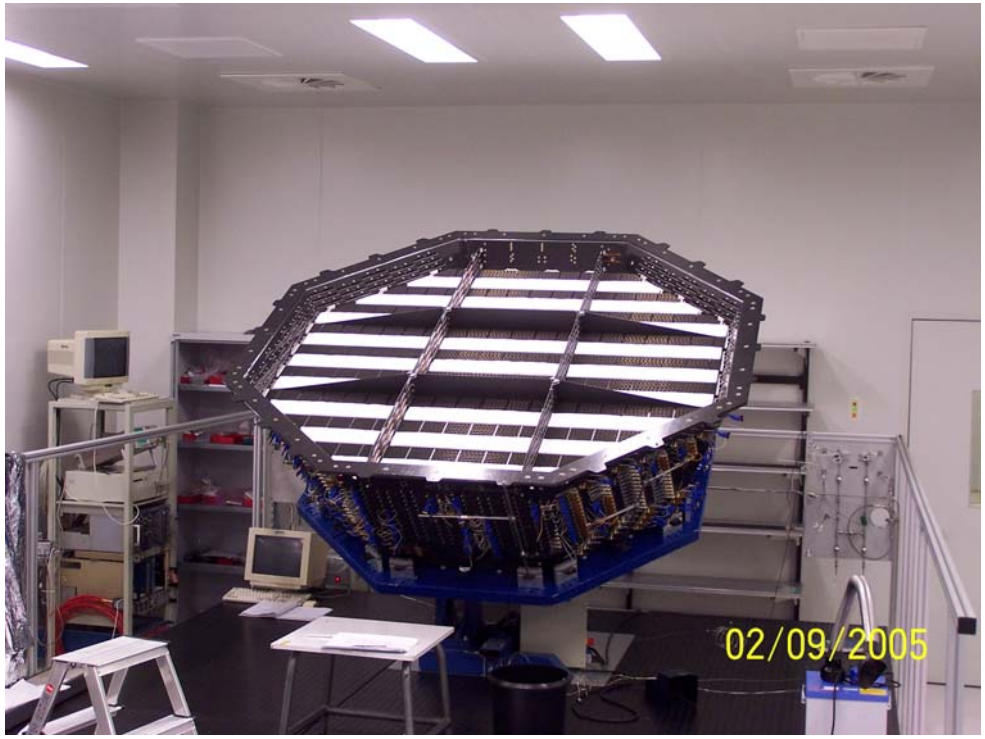
AMS-02 – TRD: Flight Module Integration Status

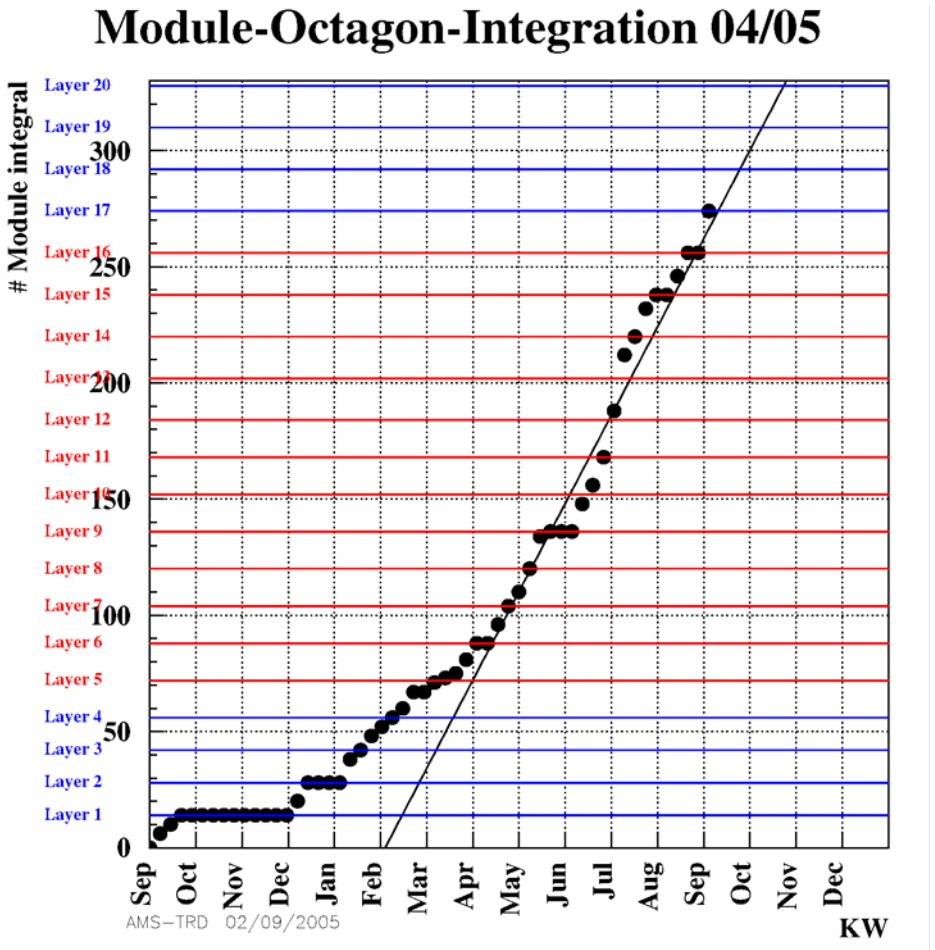


AMS-02 – TRD: Flight Module Integration Status

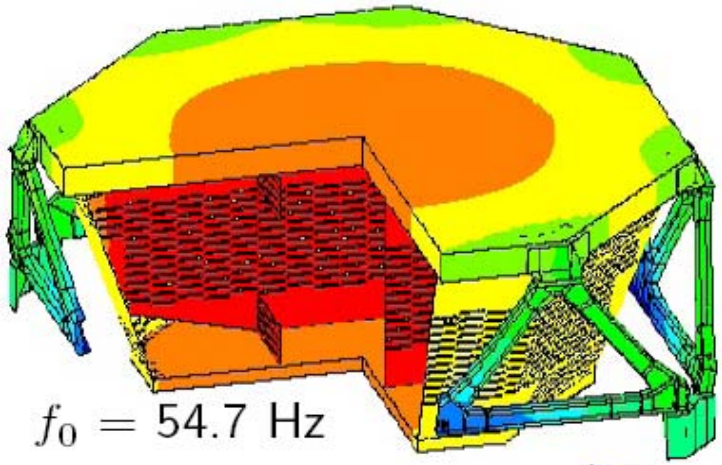


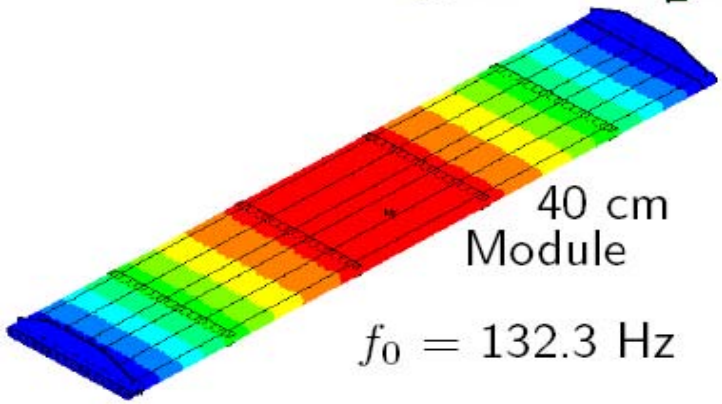
AMS-02 – TRD: Flight Module Integration Status





AMS-02 – TRD: Space Qualification: Structural Verification

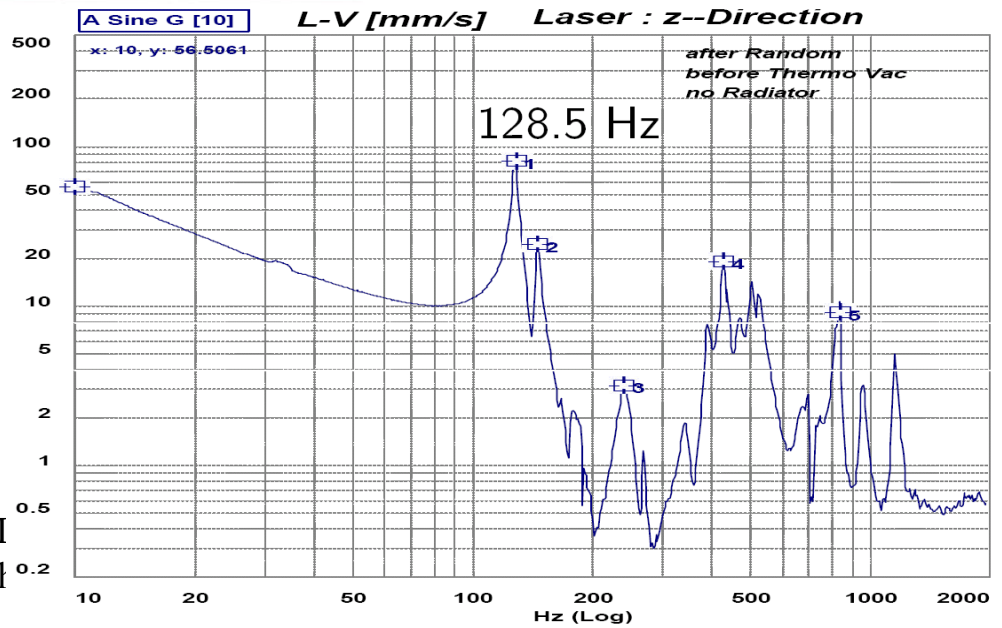




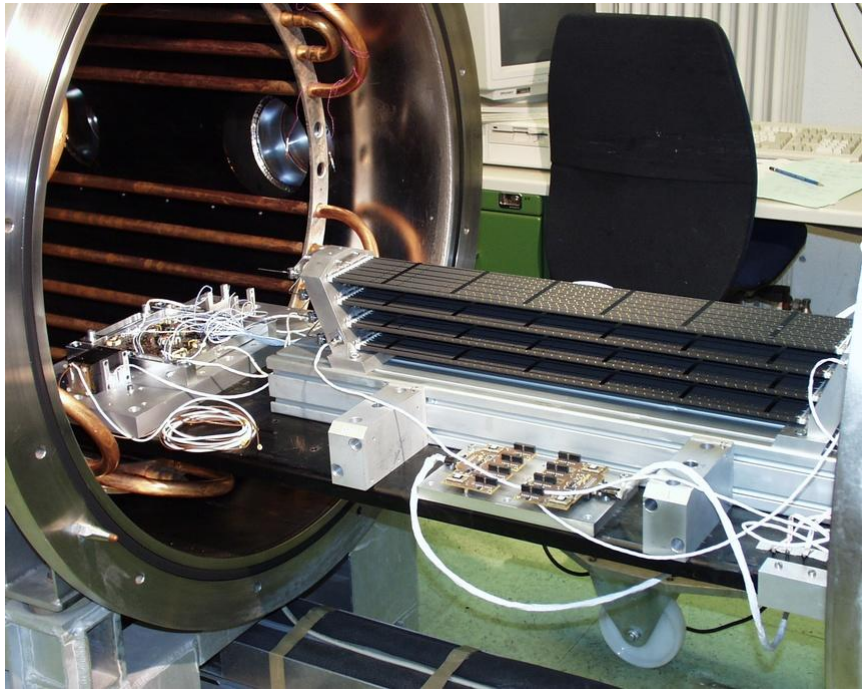
FEC coupled load modal analysis

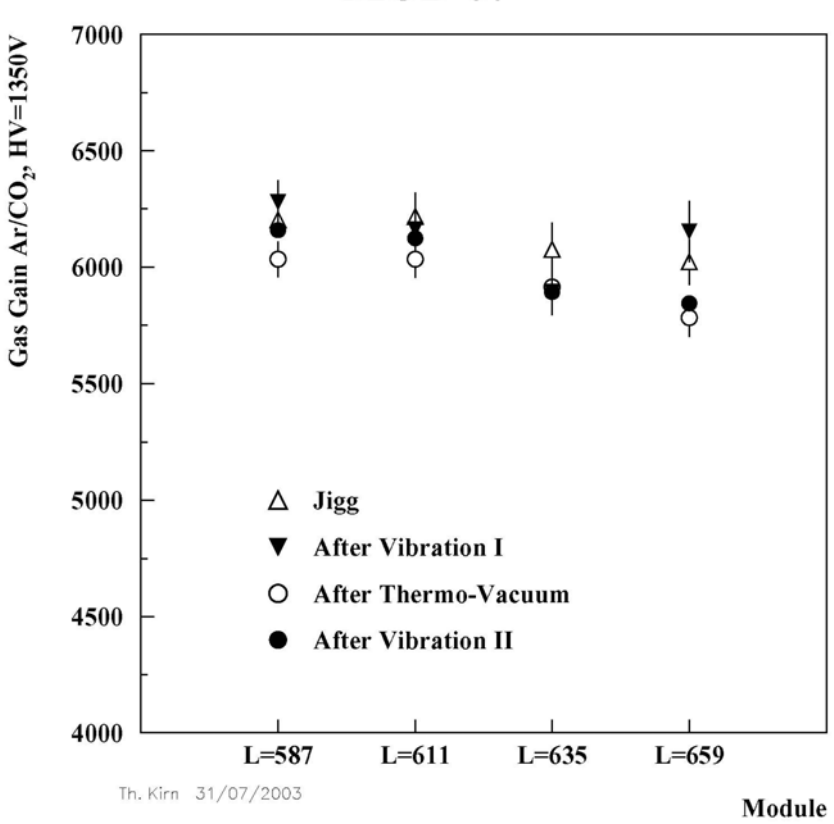
Parameters from static measurements
Verify with component vibration tests

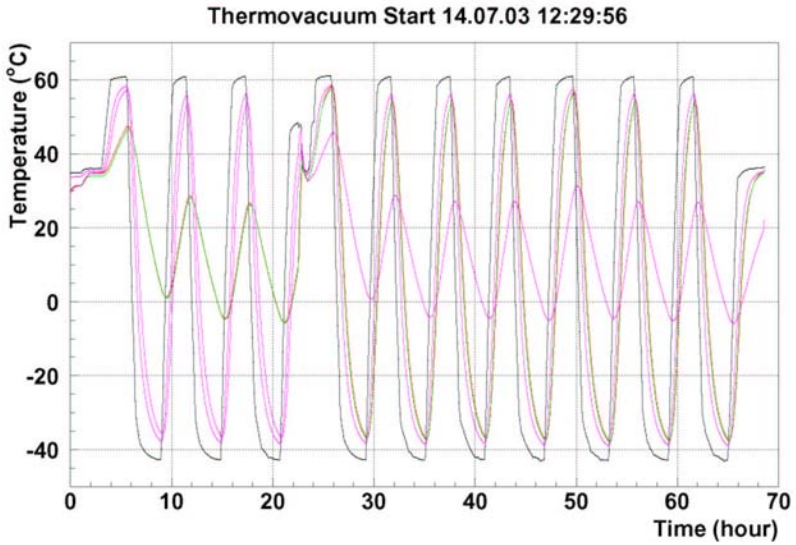
Vibration-Test-Cycle:
- Sine Sweep 0.5g (10-2000Hz)
- Random Spectrum $a_{RMS} = 6.8$g
- Sine Sweep 0.5g (10-2000Hz)



AMS-02 – TRD: Space Qualification: Thermo-Vacuumtest







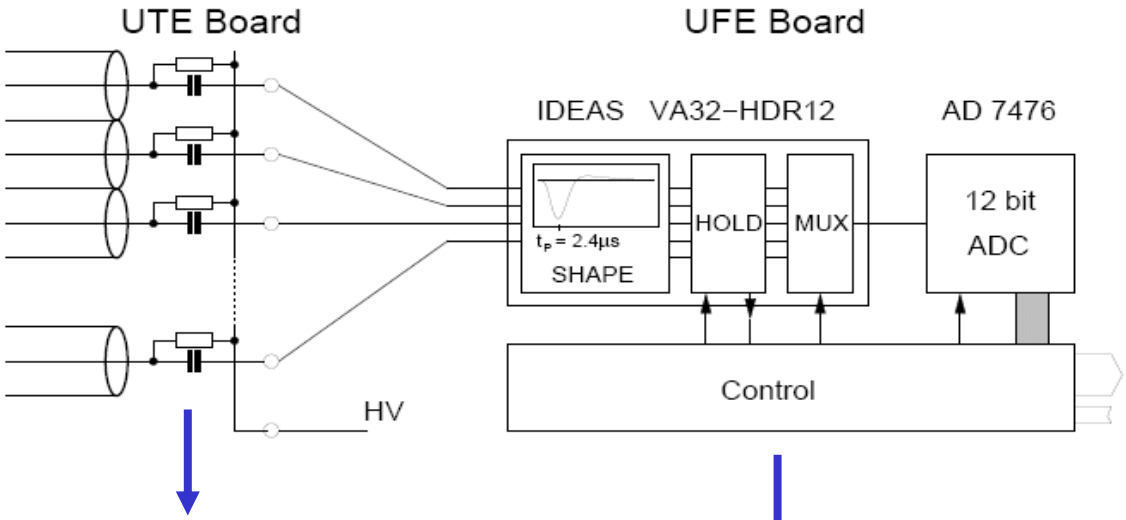
No significant changes in:

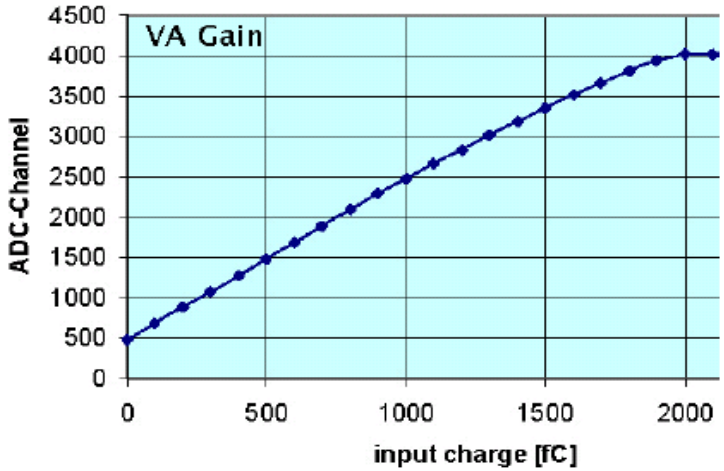
- Gasgain
- Gastightness

→ Straw Modules space qualified

AMS-02 – TRD: Front End Electronic

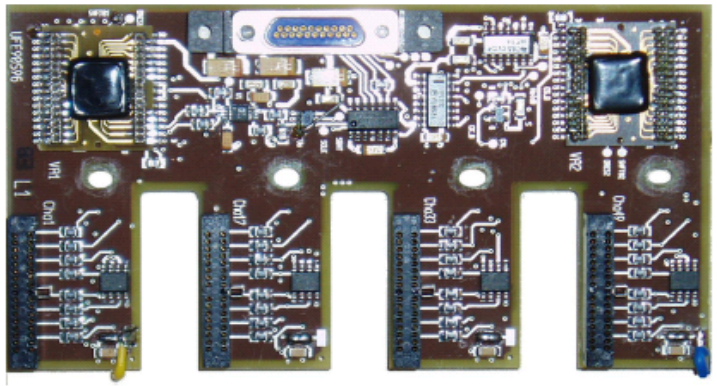
VA-Chip Multiplexed Pulsheight Readout





Tube-End Board

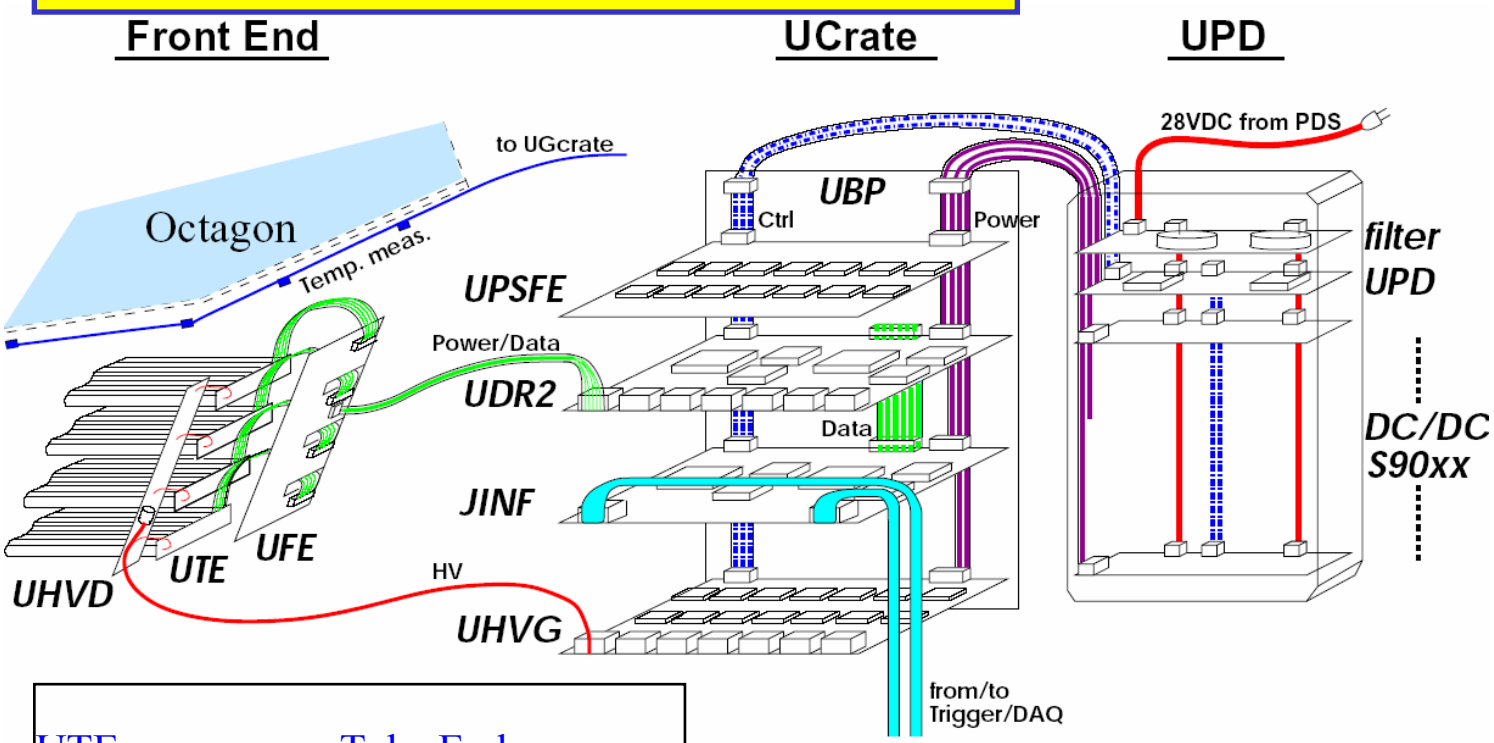
Front-End Board



Power: 20W/5248 Channels

MIP MOP (G=3000)	30 fC 60 bins
MIP S/N	> 60/2
Range	60 MIPs

AMS-02 – TRD: FE & DAQ



UTE	Tube End
UHVD	High Voltage Distributor
UFE	Front End
UPSFE	Power Supply for Front End
UDR2	Data Reduction '
UHVD	High Voltage Generator
JINF	**J-Crate Interface**

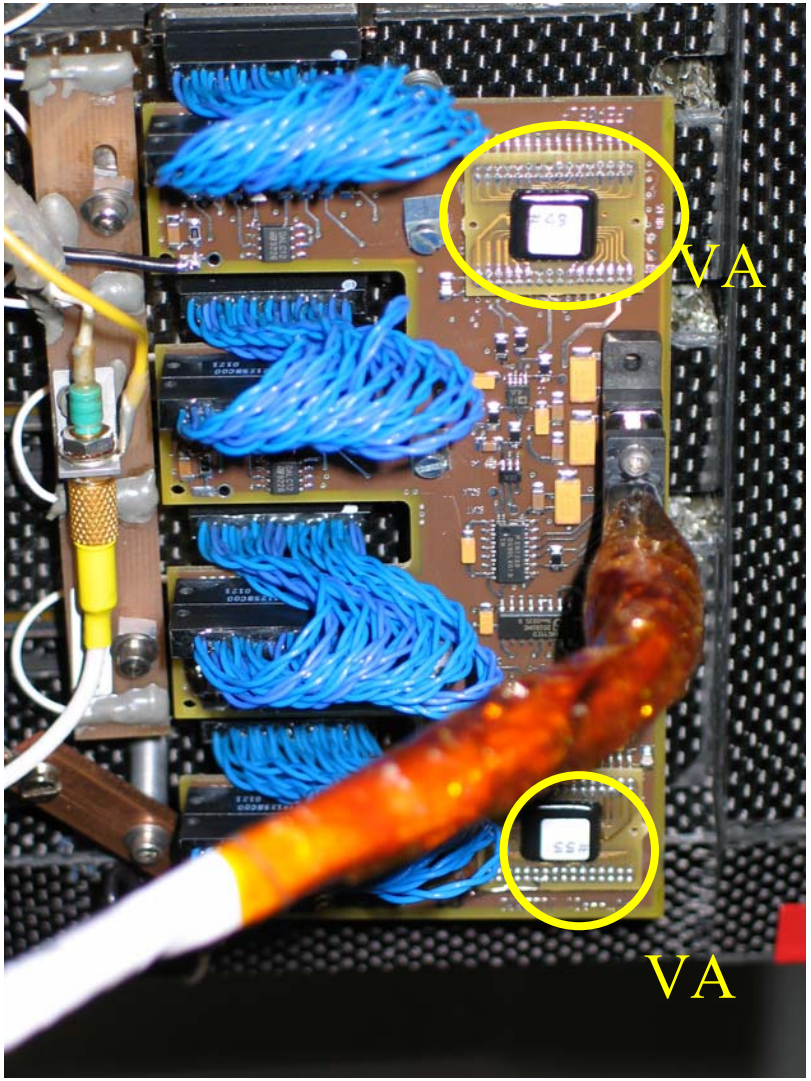
Space requirements issued by NASA :

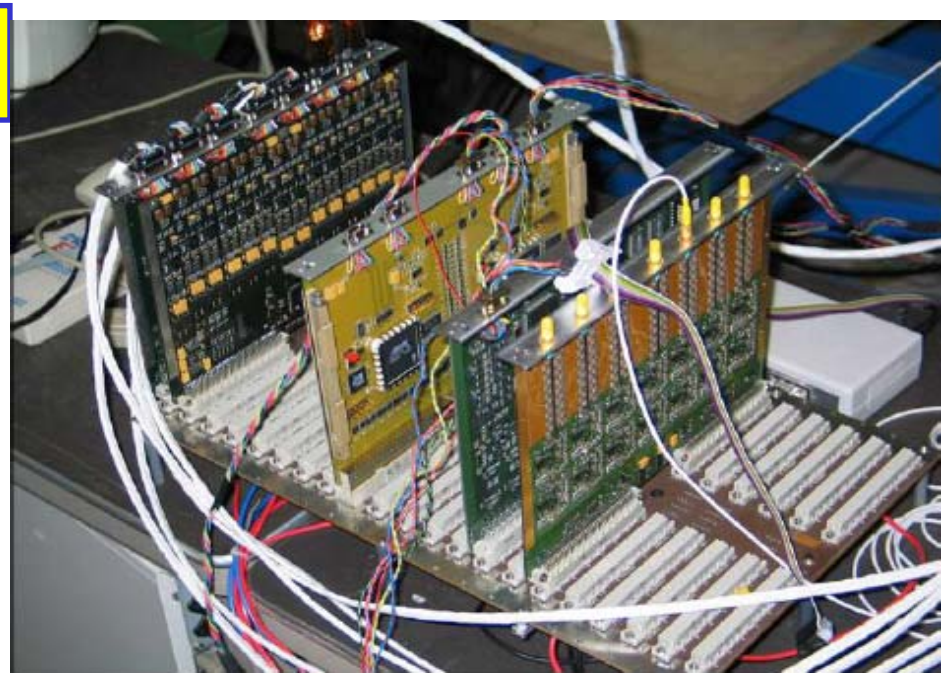
Electromagnetic Interference
Electromagnetic Compatibility
Mechanical Vibration
Thermal Vacuum Test

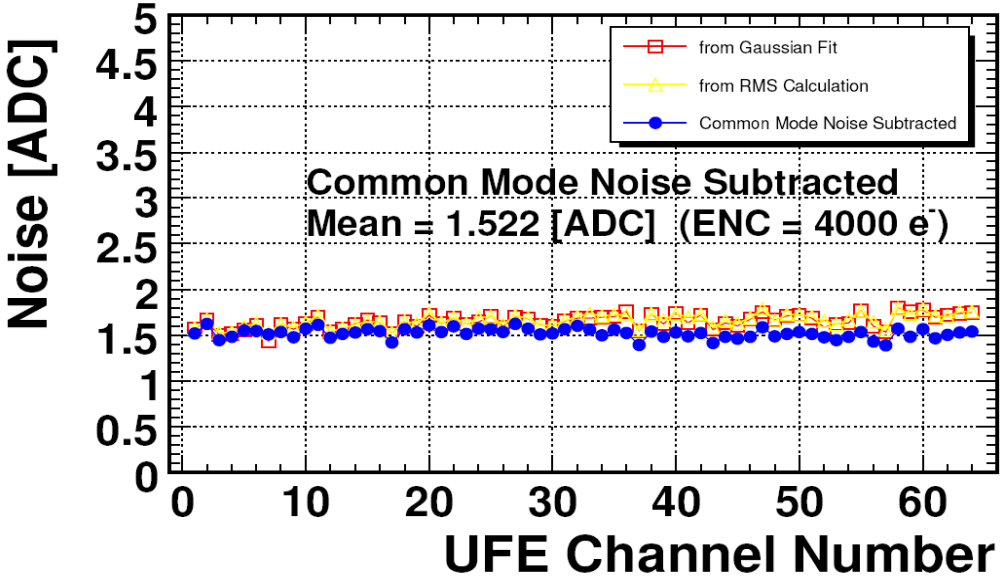
TRD Power Consumption

UFE(20 W) + Ucrate(41W) + UPD(36W) ≈ 100W

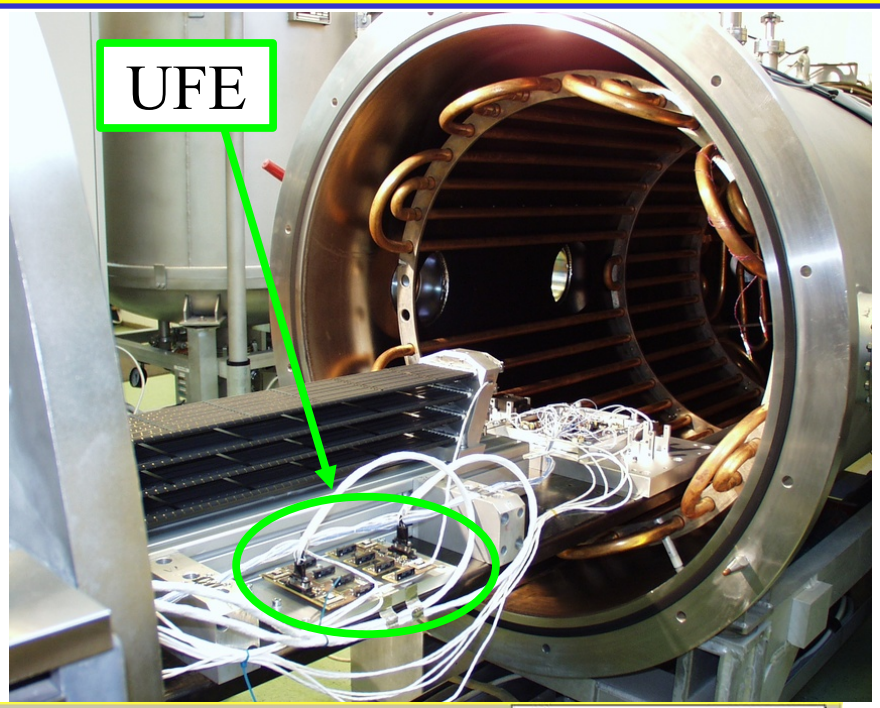
AMS-02 – TRD: FE & DAQ

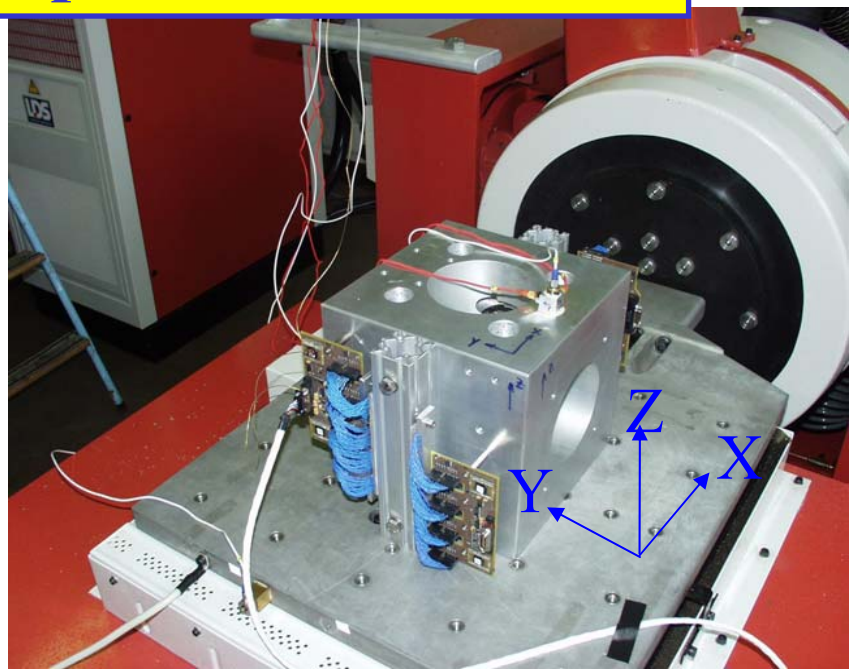


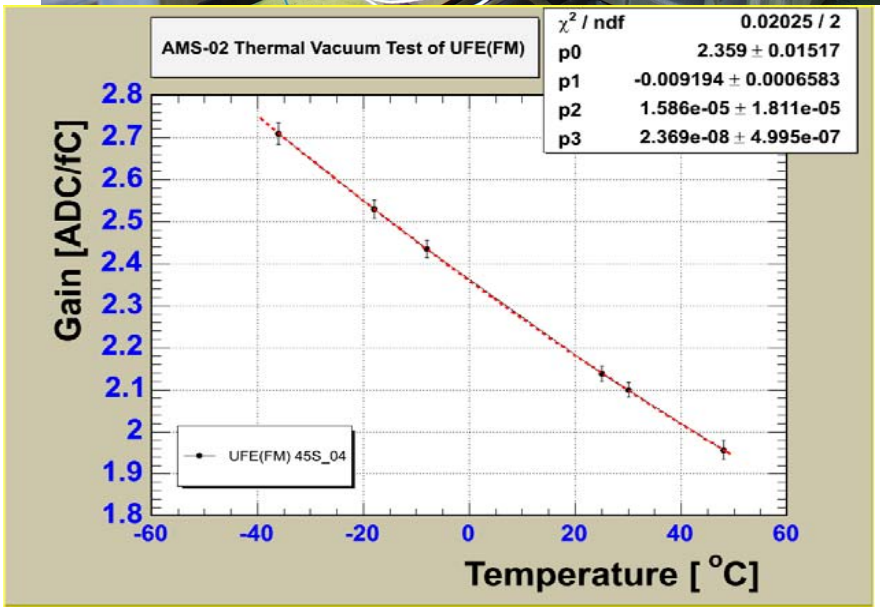


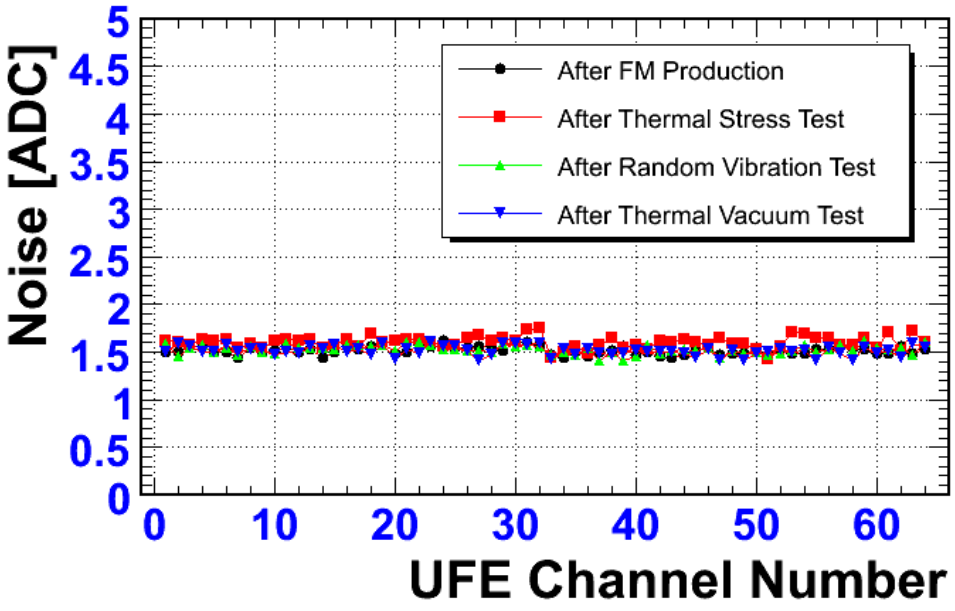


AMS-02 – TRD: FE & DAQ: Space Qualification

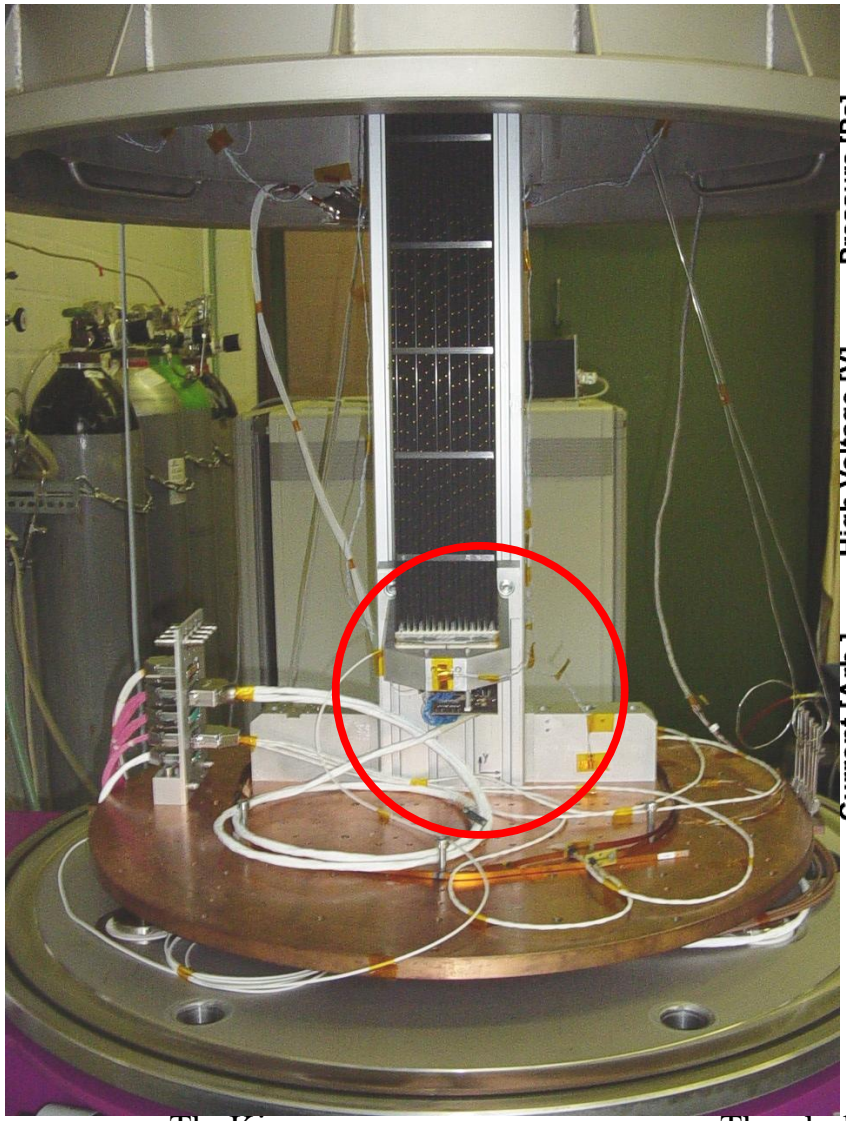


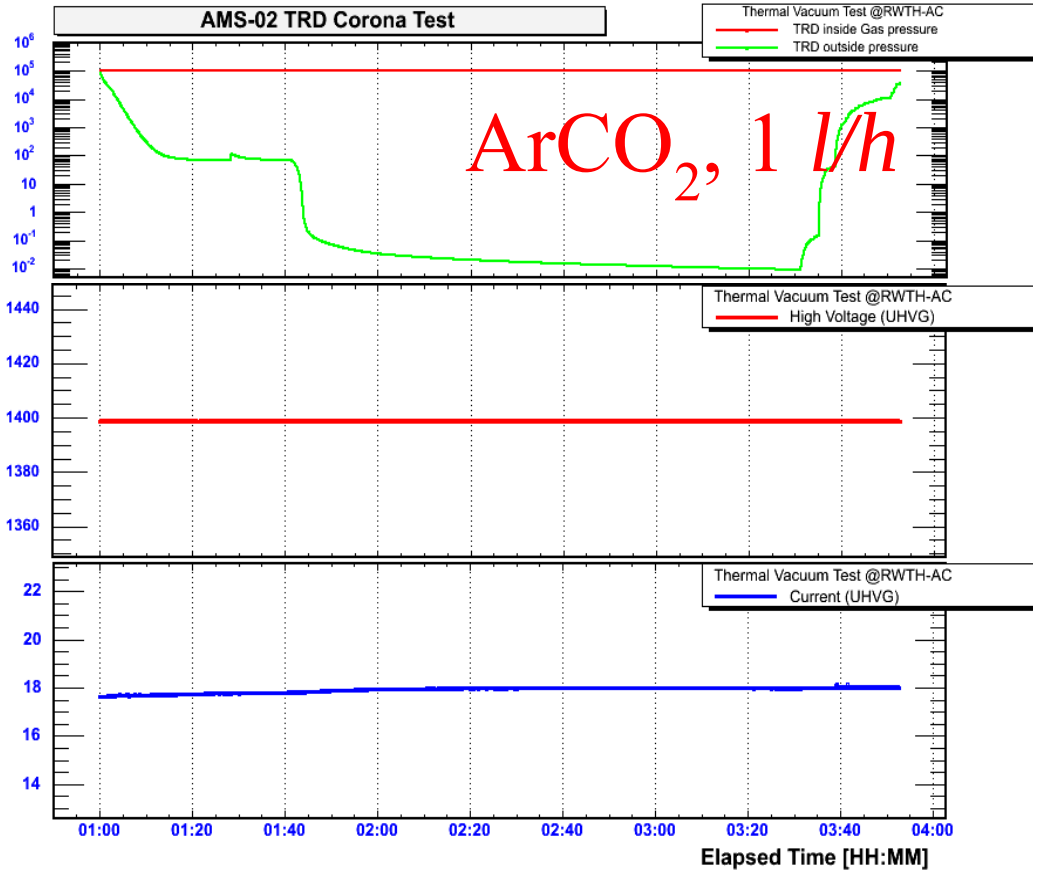






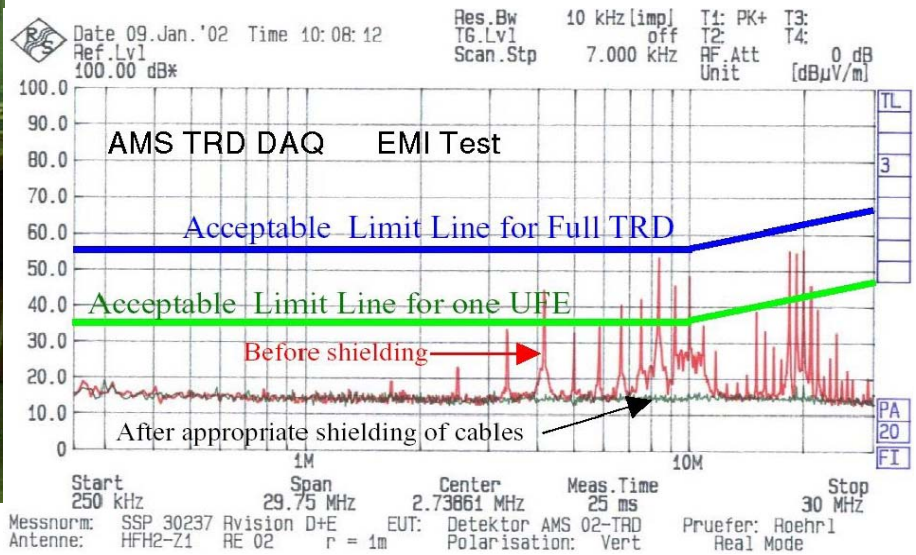
AMS-02 – TRD: FE & DAQ: Local Discharge (Corona) Test





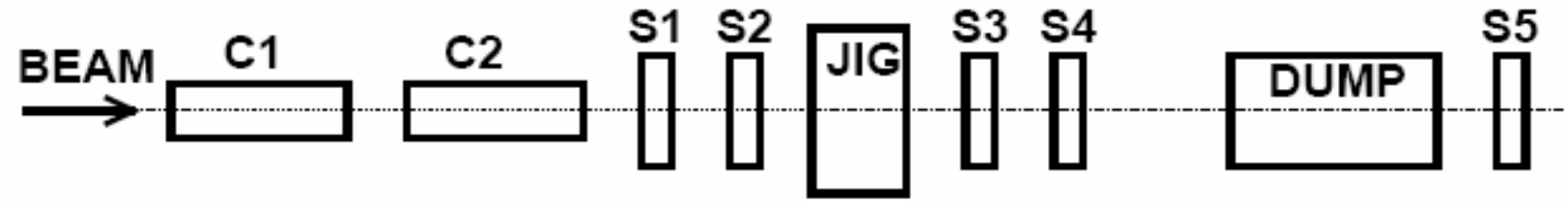
AMS-02 – TRD: FE & DAQ EMI-Test

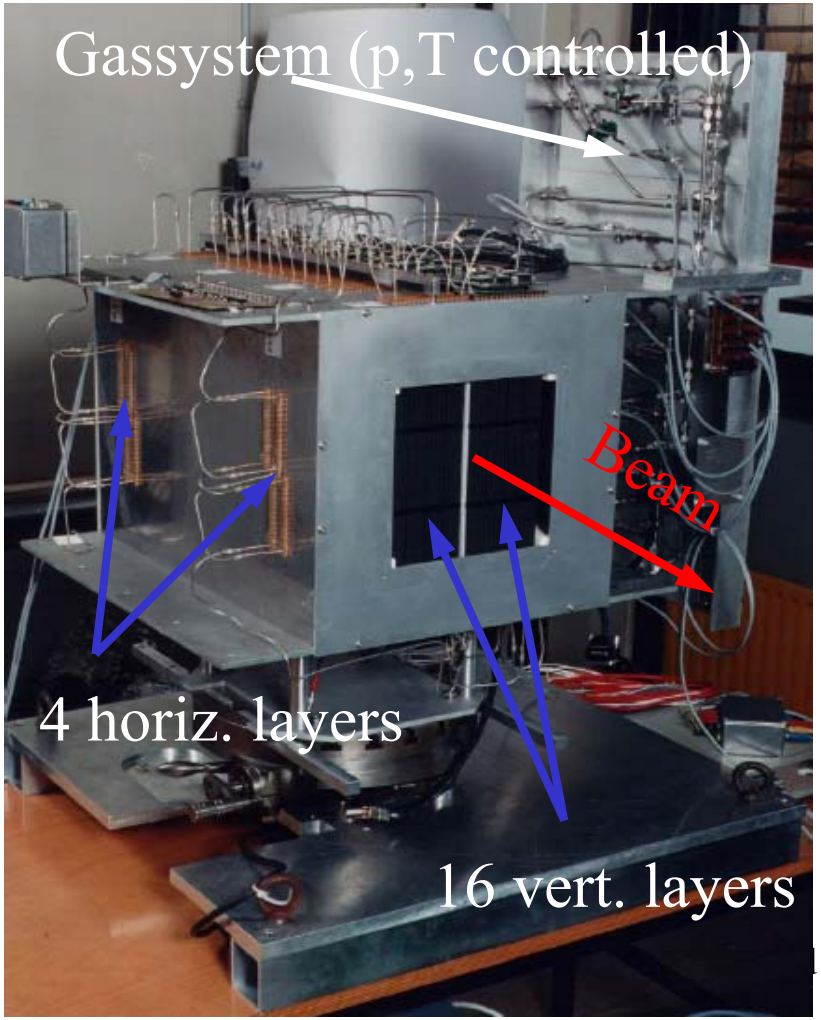
EMI Test @KMW Co. Munchen



Wave : Horizontal / Vertical Polar.
Frequency range : 10 kHz ~ 1 GHz
Electric Field : 5 ~ 100 [V/ m]

AMS-02 – TRD: Performance, 20 Layer Prototype





Beamtest @ CERN 2000

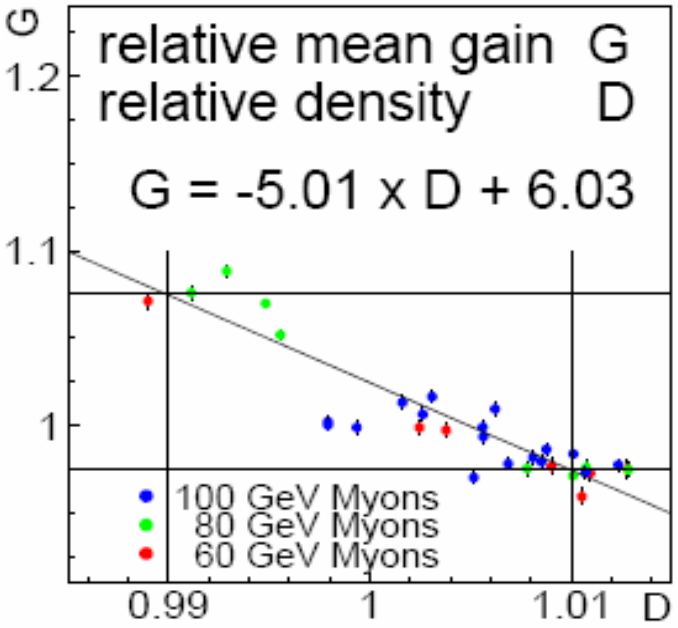
PS (T9) & SPS (X7, H6):

Recorded events: $3 \cdot 10^6$

Particles: e^-, μ^-, π^+ 10 - 100 GeV

Protons 10 - 250 GeV

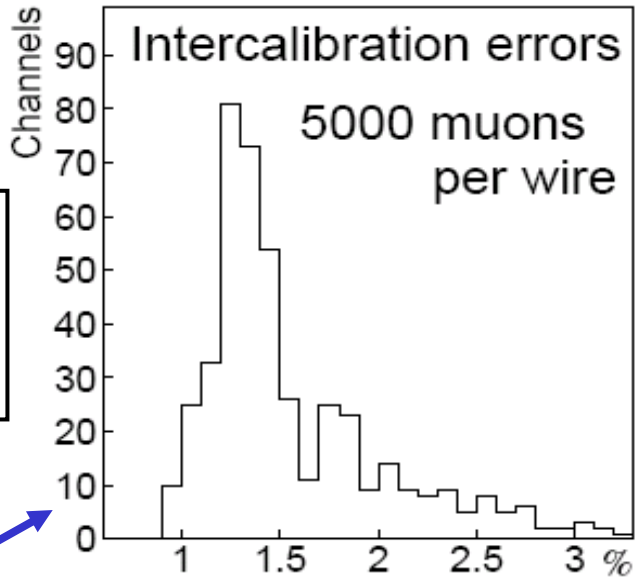
AMS-02 – TRD: Performance, 20 Layer Prototype

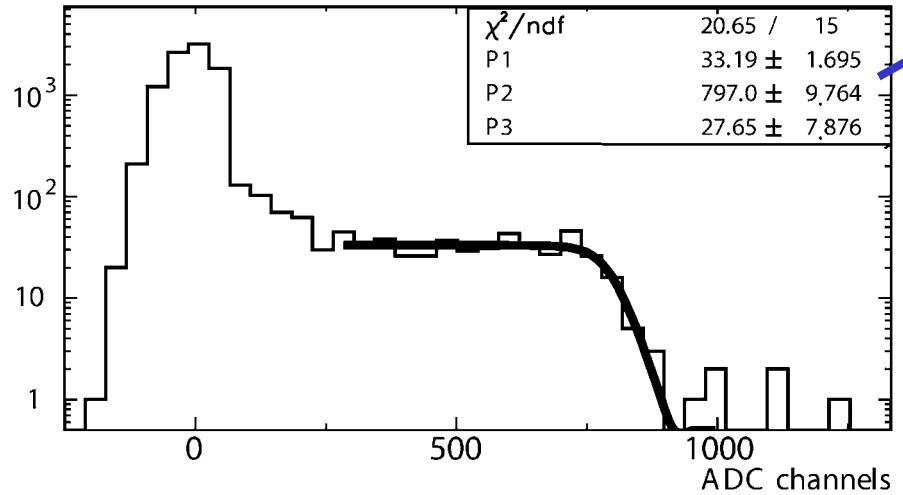


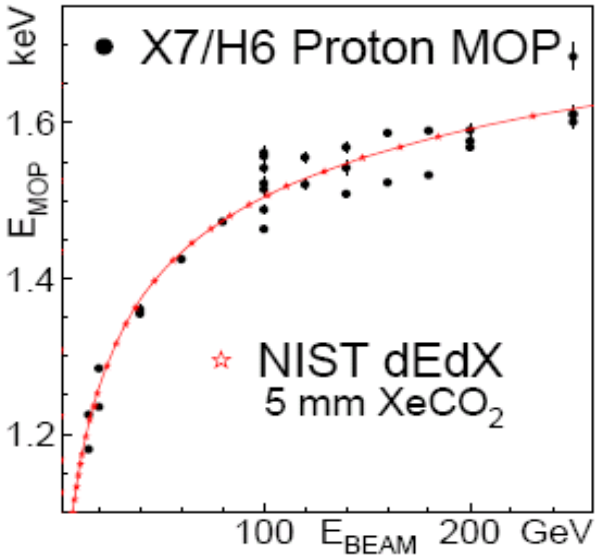
Tube Intercalibration

Gasgain-Density-Corr.

Fe^{55} Energy Calibration





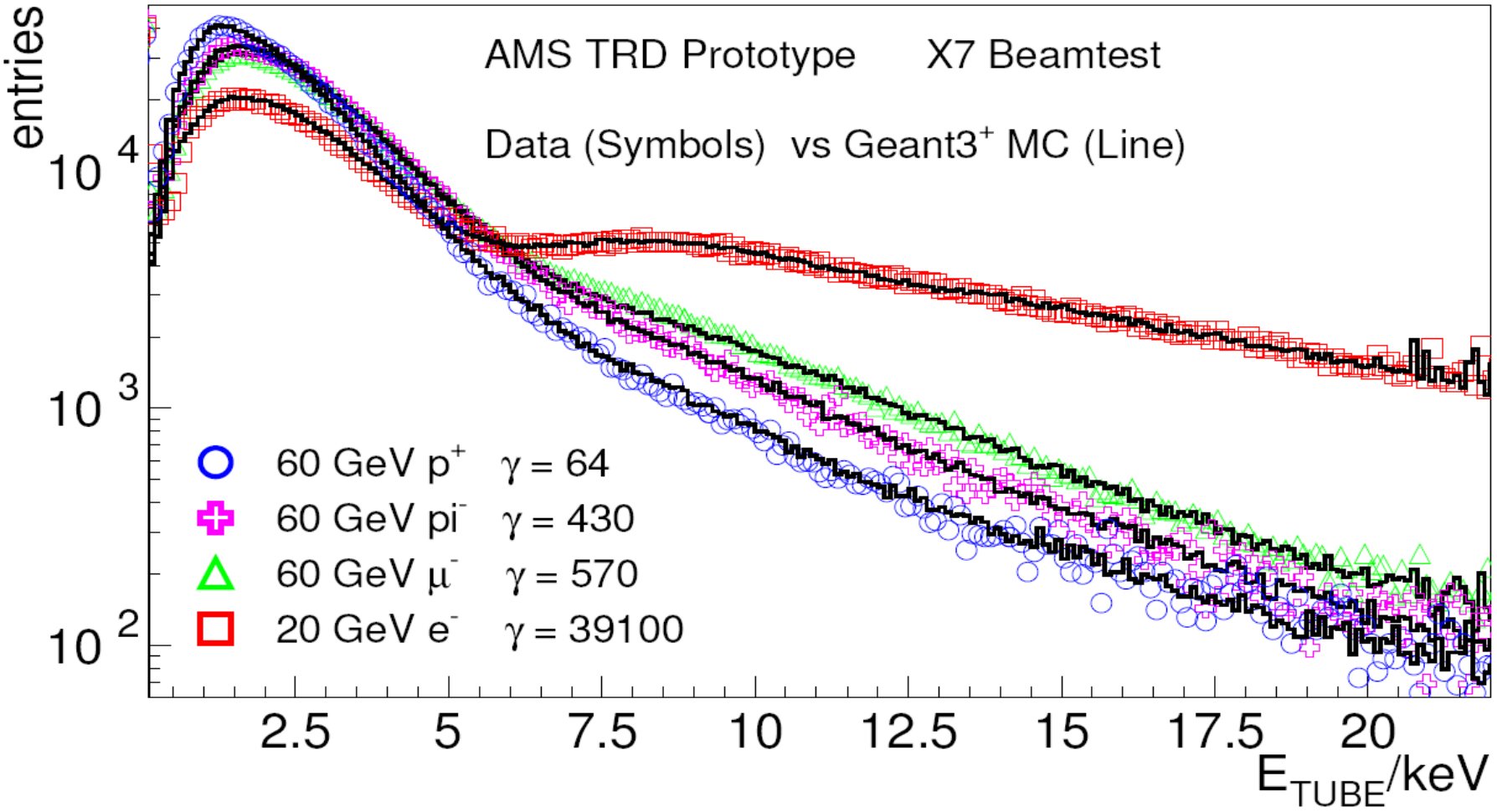


AMS-02 – TRD: TRD Spectra with Geant 3$^+$ MC

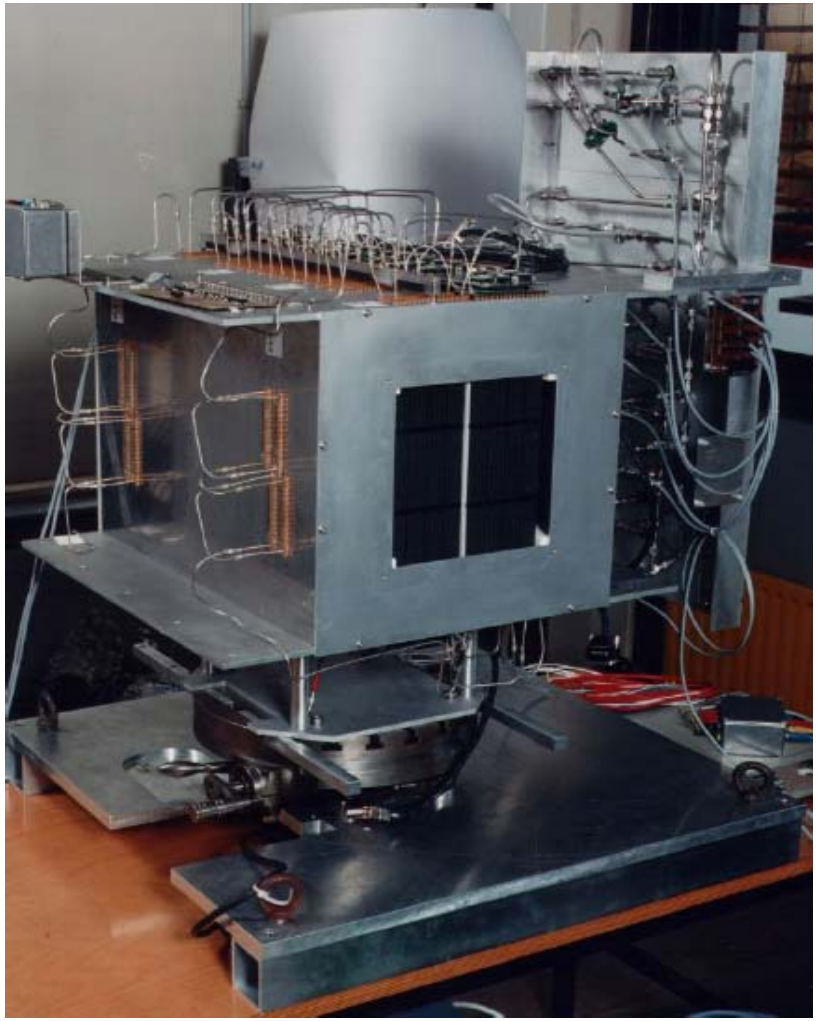
dE/dX in thin gas-layers V. Ermilova, NIM A **145** (1977) 555

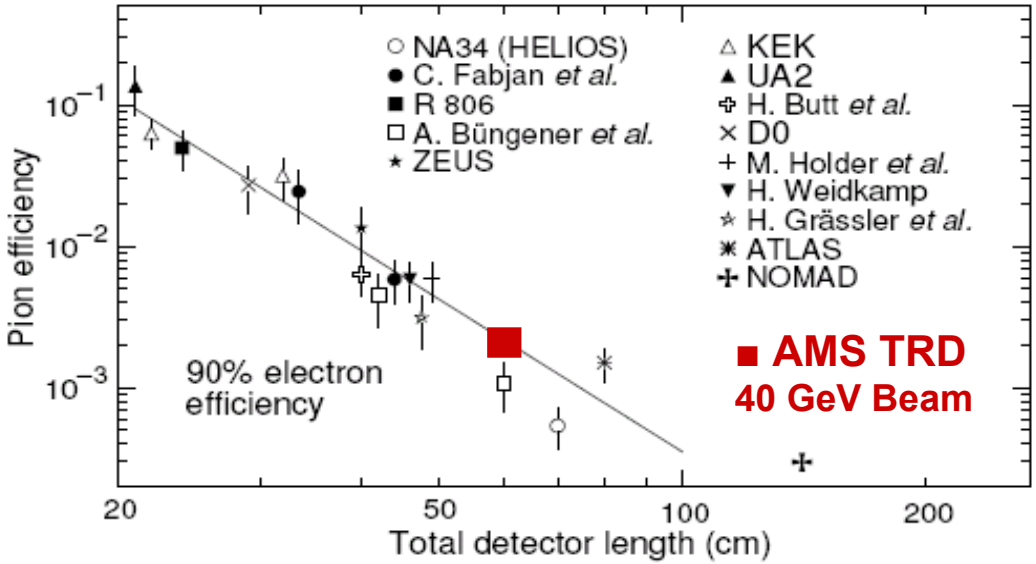
TR gener. and absorp. M. Cherry, Phys.Rev.Lett. D **10** (1974) 3594

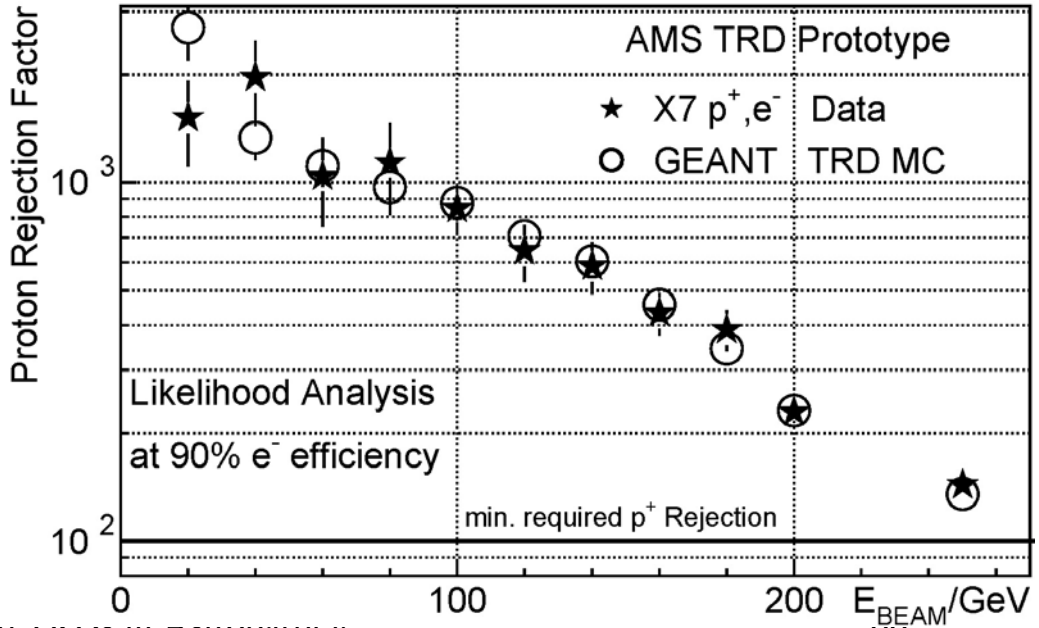
Implement. V. Saveliev (HERA-B) G.M. Garibian, NIM A **125** (1975) 133



AMS-02 – TRD: Performance, 20 Layer Prototype







AMS-02 – TRD: Longterm Test

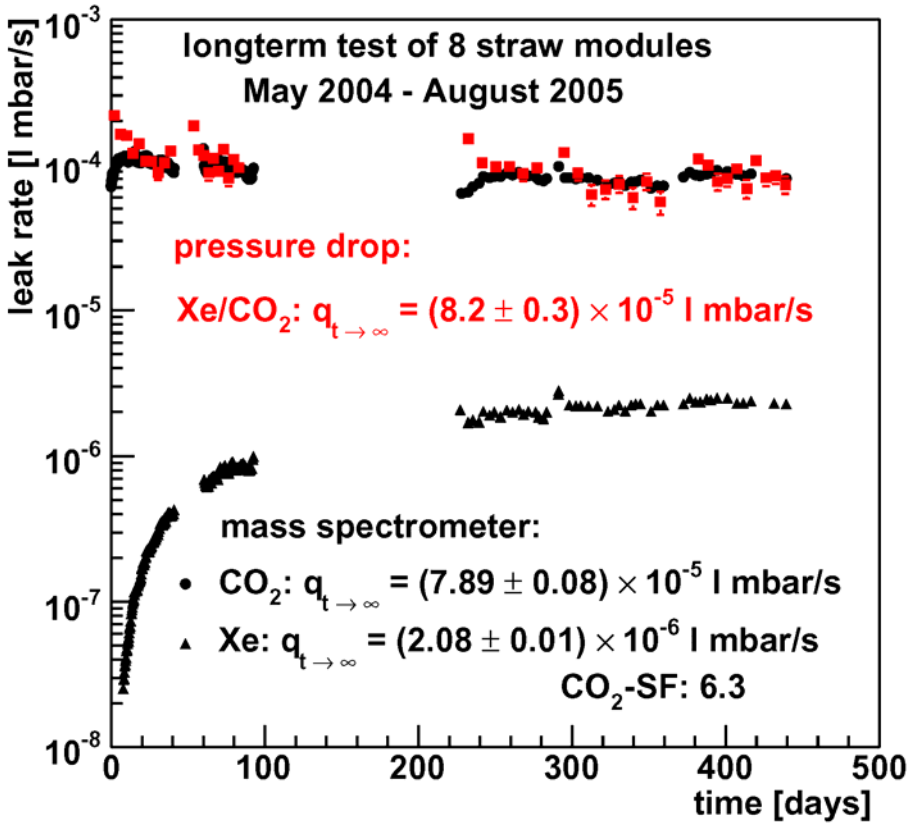
1 Gasgroup → 8 Modules

Fe^{55} – Monitoring

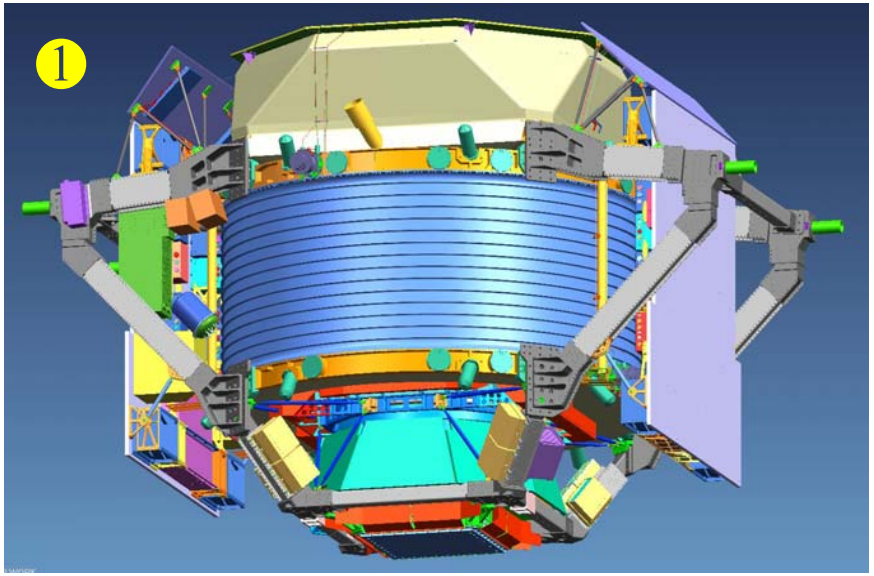
Pressure-Drop Measurements

Mass-Spectrometer Measurements

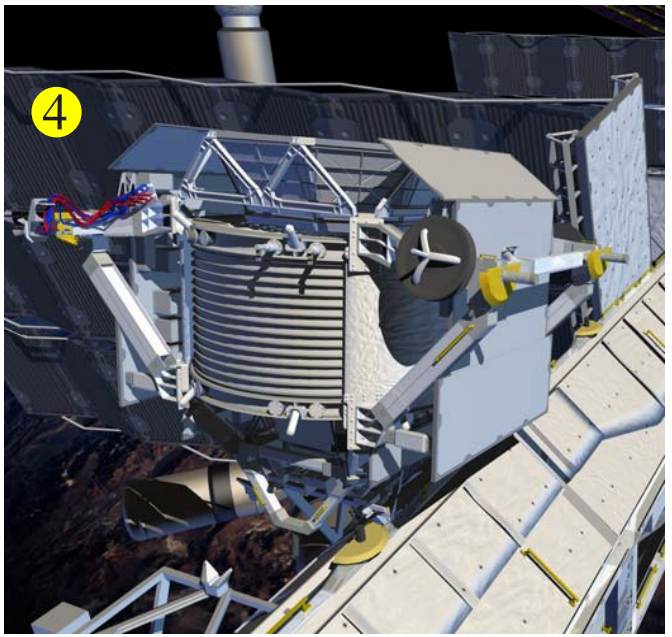
Stable Operation for 1 year



AMS-02: Launch Schedule

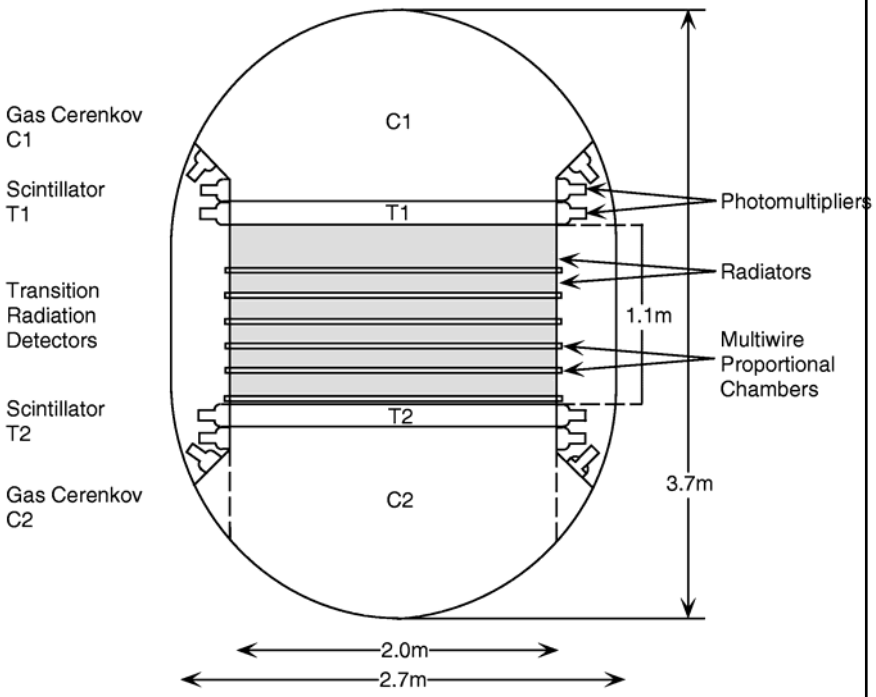


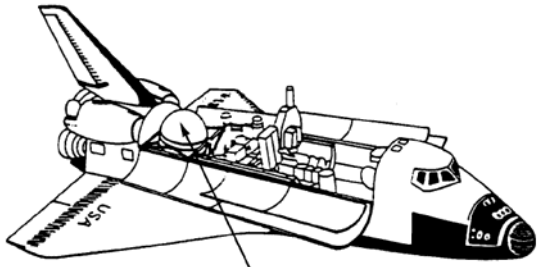
1. AMS Assembly @ CERN (2006)
2. AMS Space Test @ ESTEC (2007)
3. Launch @ NASA/KSC (2008)
4. Installation On-board ISS (2008)



Precision TRDs

Cosmic Ray Nucleus Experiment





University of Chicago
Cosmic Ray Nuclei Detector

Dimensions: Ø 2.7 m
height: 3.7 m
Mass: 2420 kg
Average Power: 330 W @ 28 V dc
Geometry Factor: 5 m^2 sr
Data Rate: 102 Kbit/s
Average Event Rate: 70 Hz

2 Scintillation counters T1 & T2
→ Trigger, Z, up-down by time of flight
2 integrating gas Cherenkov counters C1 & C2
→ Energy Measurement (40 – 120 GeV/amu)
6 Layer TRD Radiator + MWPC
→ Energy > 400 GeV/amu
→ Hodoscope for trajectory information

Space Shuttle Challenger Flight
July 29th 1985, Duration 8 days
Orbit inclination 49.5°
Altitude: ~ 310 km

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CRN TRD Radiator: 6 Modules

Radiator composition and fiber batting materials

Radiator composition	Composition	Effective thickness [g/cm^2]
Radiator 1 [a]	15.2 cm fiber batting #1	~ 0.6
	6.7 cm fiber batting #2	~ 0.3
Radiators 2–6	5.0 cm fiber batting #1	~ 0.2
	6.7 cm fiber batting #2	~ 0.3

Fiber batting materials	Batting #1	Batting #2
Supplier	Hercules Inc.	3M Company
Material Type	Herculon 101	Thinsulate M400
Composition	Olefin fibers	Polyolefin fibers
Fiber Diameter [μm]	17	2–5 (average 4.5)
Fiber density [g/cm^3]	0.9	0.9
Batting Density [mg/cm^3]	40	45

[a] Radiator 1 is the most upstream radiator.

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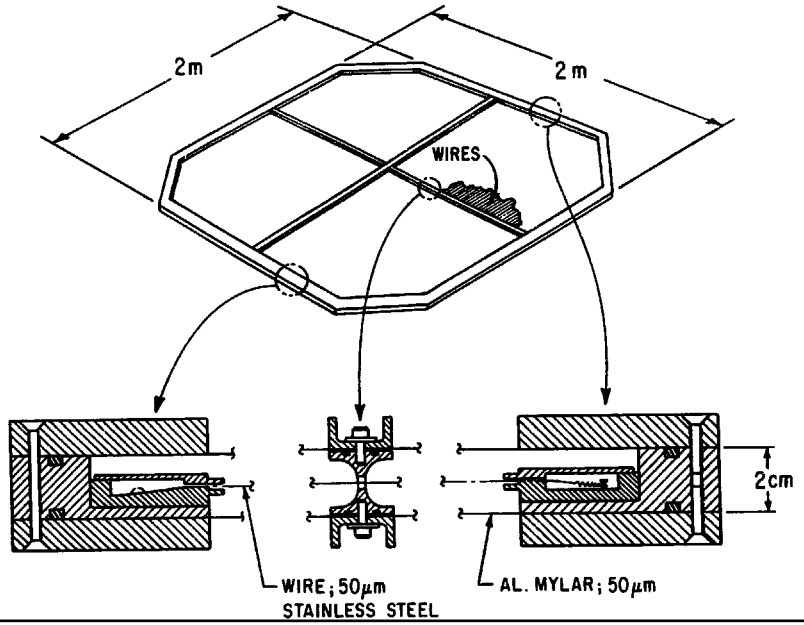
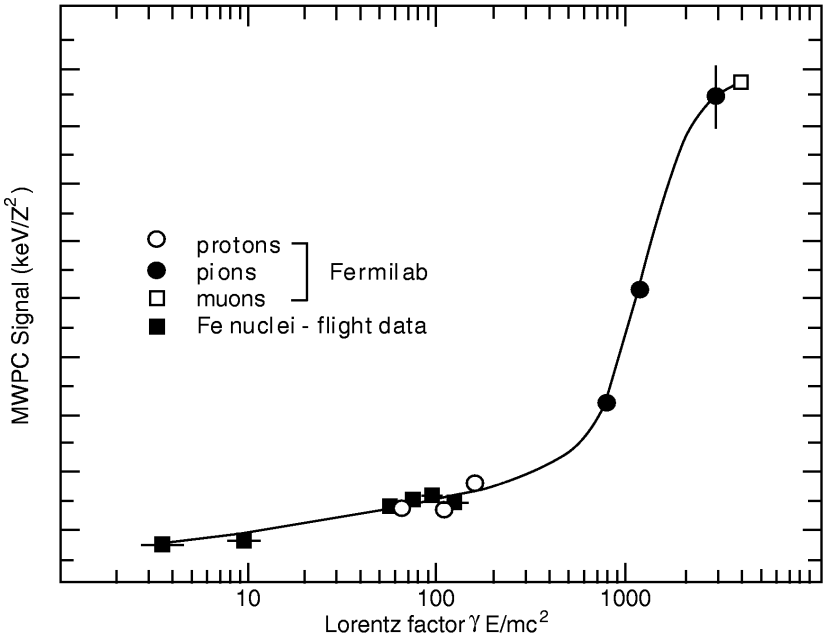
→ X-Rays 2-15 keV

CRN TRD MWPC





MWPC:

1 Wire → Ø 50 μm stainless steel, Length: 2m

1 MWPC → 200 Wires

→ Thickness: 2cm

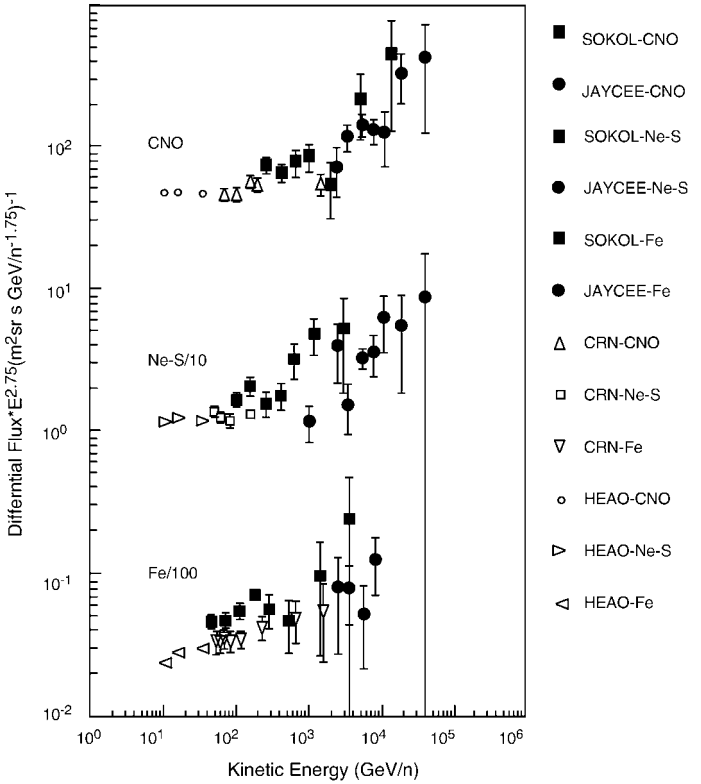
→ Gas: Xe/He/CH_4 @ 1bar

(25%/60%/15%)

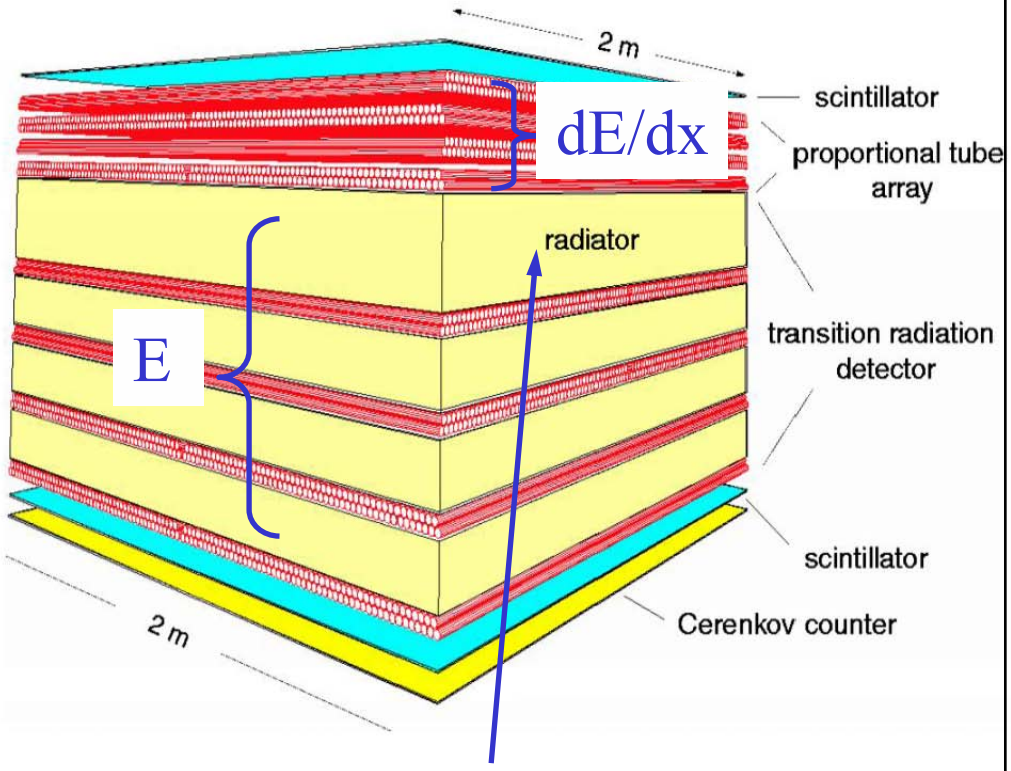
→ HV: 1300 V → Gasgain: 20

→ Fe-nuclei → Signal < 1pC

6 MWPC → 1200 Wires



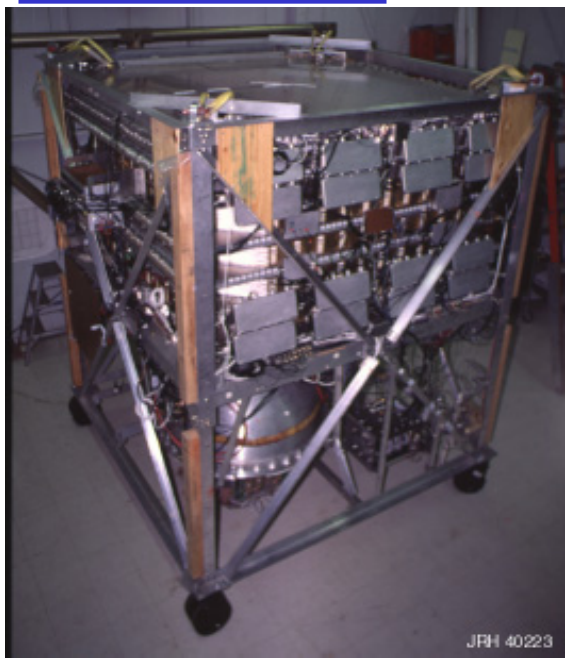
Transition Radiation Array for Cosmic Energy Radiation

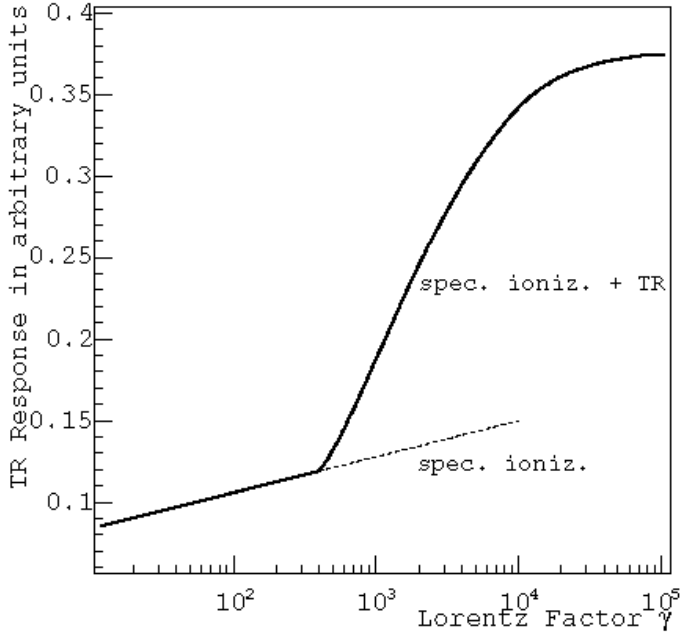


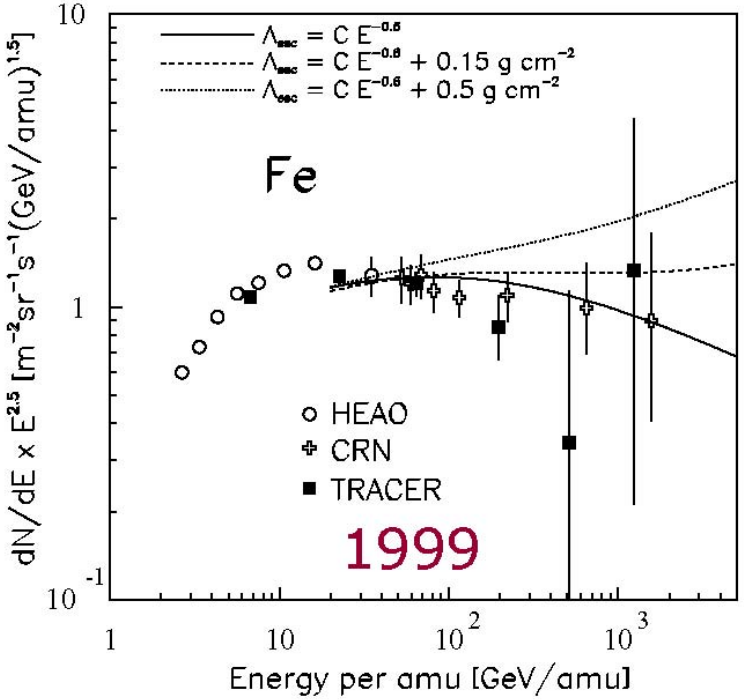
CRN Radiator

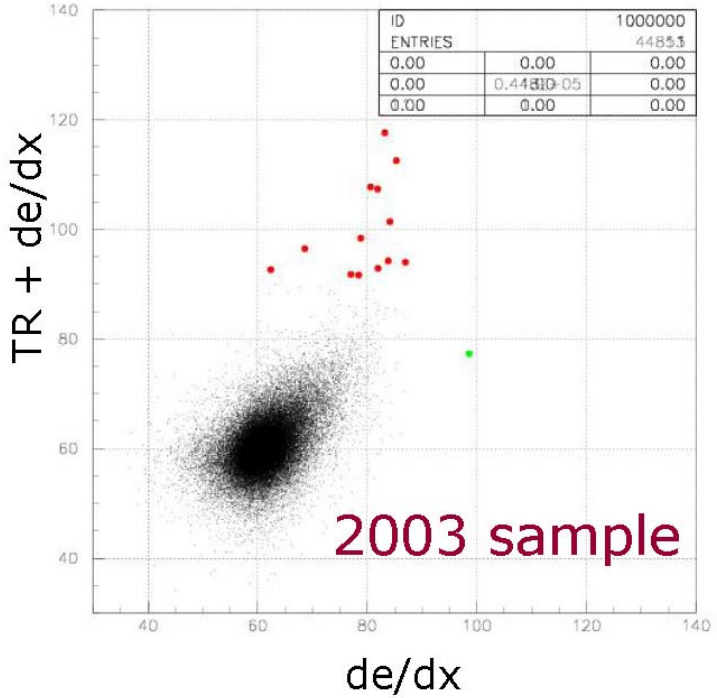
- Detector Dimensions:
  ~ 2.0m x 2.0m x 1.5m
- Geometric Factor ~ 5m^2 sr
- Scintillation Counter
  → Z measurement of
- 1600 Proportional tubes
(Ø 2cm, L=200 cm) filled with Xe/CH_4:
8 Layers straws
  → dE/dx of incoming CR particle
4 Layer Radiator + double layer straws
  → Energy measurement of elements
    O – Fe (0.5 GeV/n to 10 TeV/n)
- Cerenkov Counter rejects low energy particles
- 1-day flight Antarctica 1999
- 10-day LDB flight Antarctica 03

TRACER


JRH 40223


TR Response in arbitrary units
0.4
0.35
0.3
0.25
0.2
0.15
0.1
spec. ioniz. + TR
spec. ioniz.
10^2
10^3
10^4
10^5
Lorentz Factor γ

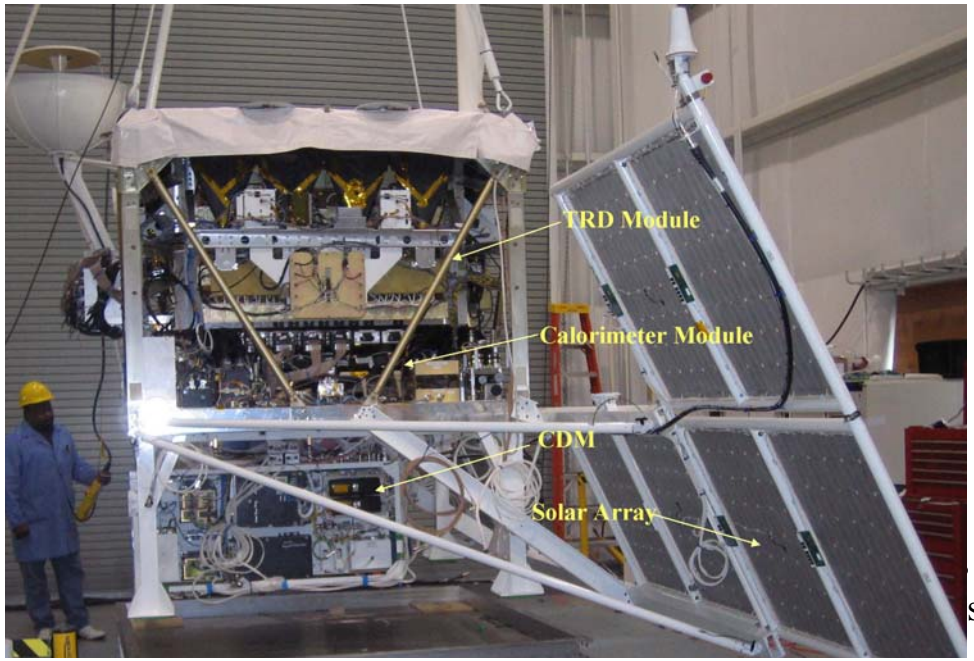

$\Lambda_{esc} = C\,E^{-0.6}$
$\Lambda_{esc} = C\,E^{-0.6} + 0.15\ g\ cm^{-2}$
$\Lambda_{esc} = C\,E^{-0.6} + 0.5\ g\ cm^{-2}$
Fe
HEAO
CRN
TRACER
1999
$dN/dE \times E^{2.5}\ [m^{-2}sr^{-1}s^{-1}(GeV/amu)^{1.5}]$
10
1
10^{-1}
1
10
10^2
10^3
Energy per amu [GeV/amu]


ID
ENTRIES
1000000
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
TR + de/dx
de/dx
2003 sample

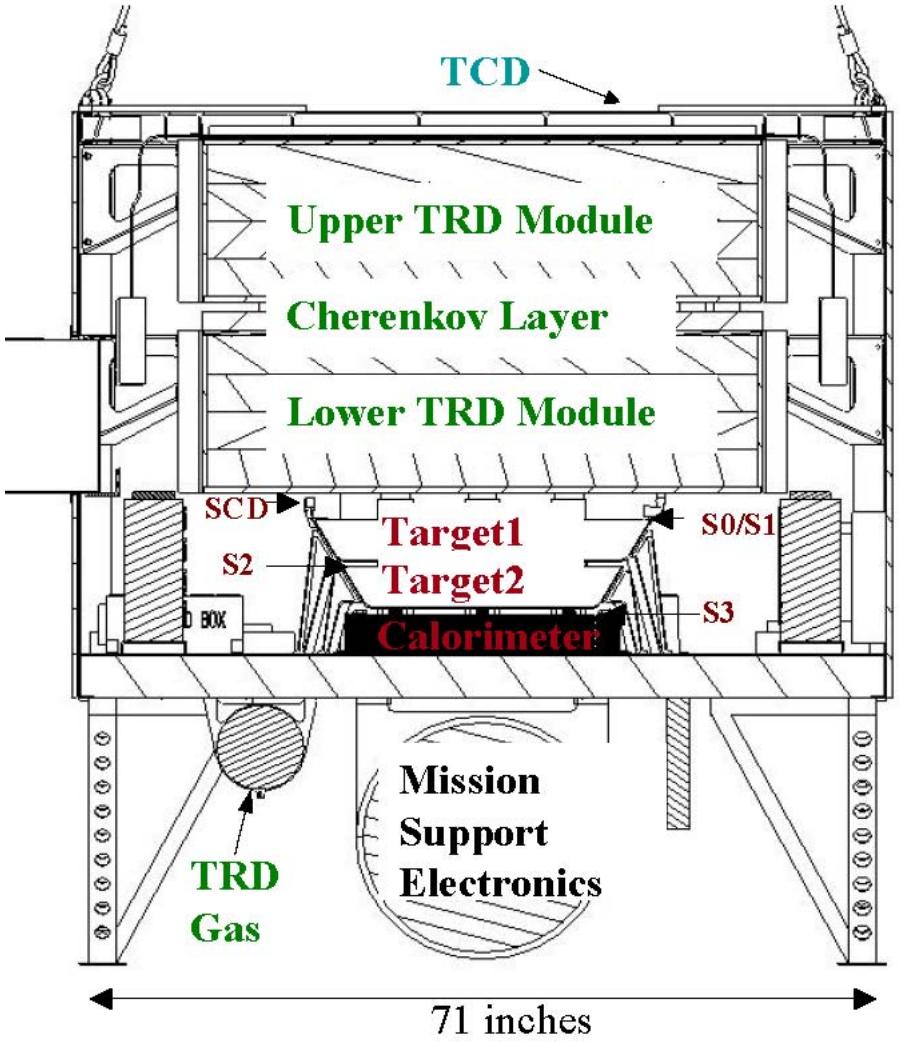
Cosmic Ray Energetics And Mass

- Measurement of individual energy spectra and element composition of CR ($1 = Z \geq 26$) from 1 TeV – 1000 TeV
- Search of cutoff in p-spectrum ~ 100 TeV
- Test of propagation models:
  Measurement of B/C up to 500 GeV/n

Balloon flight: 41d 21h 31 min
December 15th 2004 – January 27th 2005

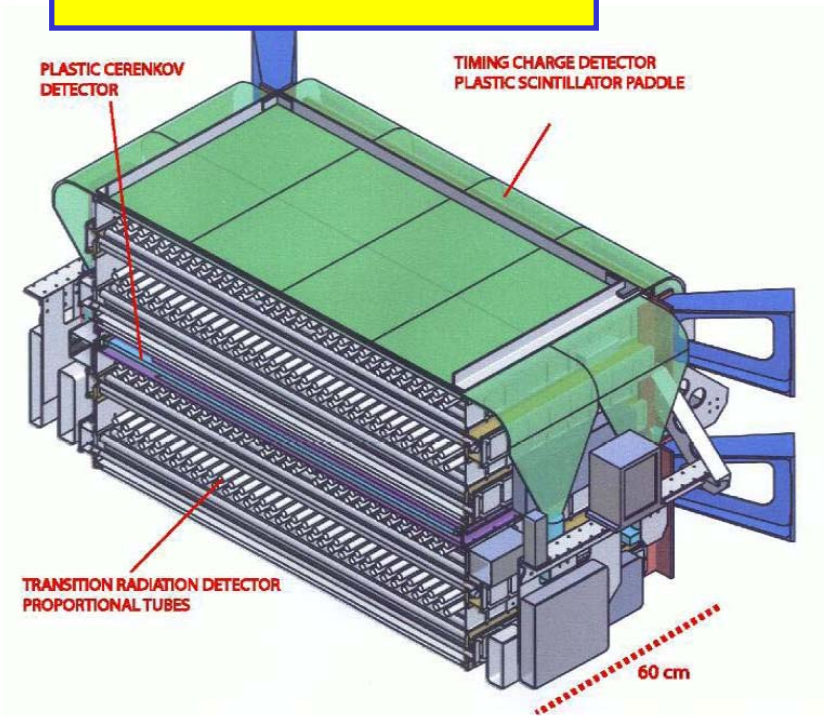


CREAM



- Three Complementary Z-Measurements
  - Timing Based Charge Detector
  - Pixelated Silicon Detector
  - Scintillating Fiber Hodoscope
- Two Complementary E-Measurements
  - Transition Radiation Detector
    Xe/CH_4 (95%/5%) mix
    (velocity for $Z \geq 3$)
  - Tungsten SCN Calorimeter
    (energy for $Z \geq 1$)
- Acceptance
  - 0.3 m^2 sr for Z=1 & 2
  - 1.3 m^2 sr for $Z \geq 3$

CREAM TRD



- 2 Sections (35 cm) of 4 Layers → 8 Layers
- Active area 120·120 cm^2
- Polystyrene foam radiator
  (mechanical support for tubes)

- 512 Proportional tubes, 16 Layers
  Aluminized Mylar (100 μm),
  Length: 1.2m, Ø 2cm
  Xe/CH4 (95%/5%) @ 1bar

- Measurement of γ and trajectory
- Sensitivity range $10^3 < \gamma < 10^5$

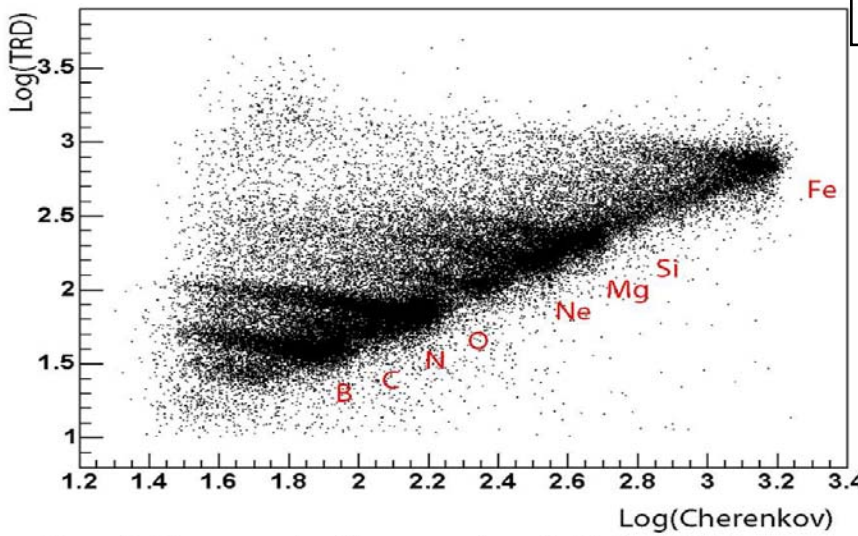
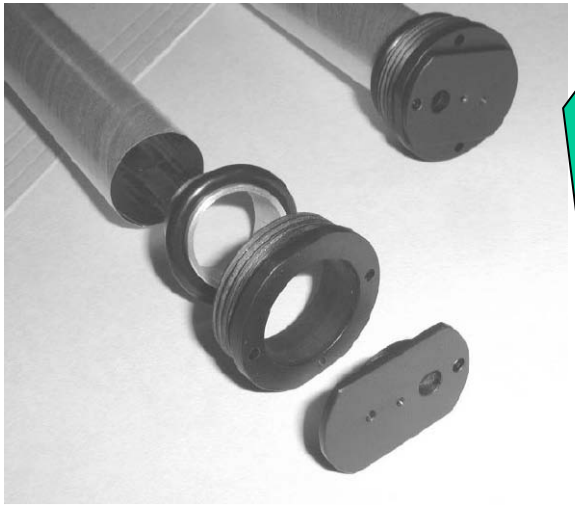


Figure 3: Measurements of the energy deposited in the TRD tubes versus the normalized Cherenkov light signal during the flight (~1 day).



Conclusions

- TRDs have been used in underground, balloon and space experiments
  → Measurements of cosmic ray e^-, e^+ and highly relativistic nuclei
- Threshold TRDs excellent devices for Dark Matter Susy searches
  - Advantage of low mass to area ratio
  - Space qualified TRD designs like AMS-02 or PAMELA
  - Long flight duration in space > 3 years possible
- Precision TRDs excellent devices for measuring high energy CR-nuclei up to the energy of the knee → no saturation before $\gamma \sim 10^5$