PEBS: Positron Electron Balloon Spectrometer

- Physics Goals
- Detector Design
- Current Status

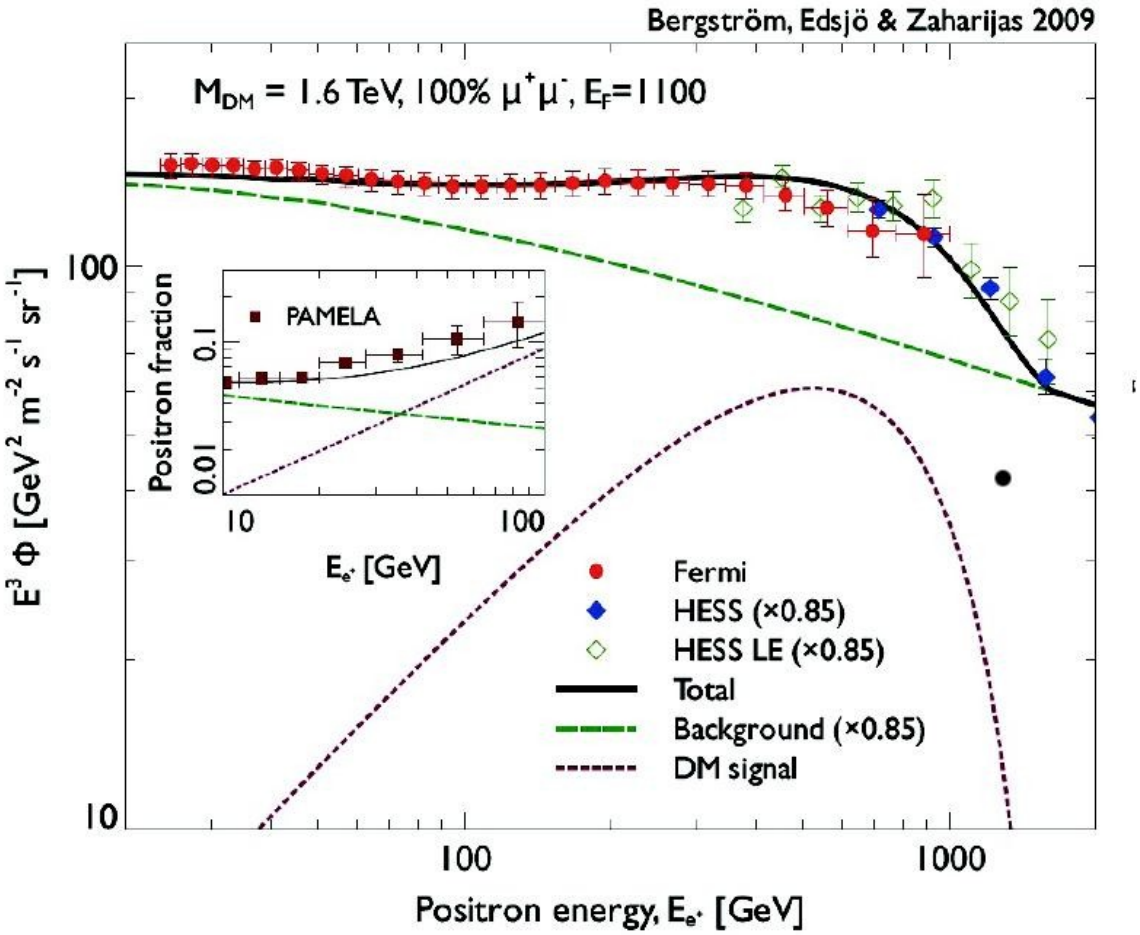
e^+

RWTH Aachen, Germany
EPFL Lausanne, Switzerland
ETHZ Zürich, Switzerland
Ohio State University
University Chicago

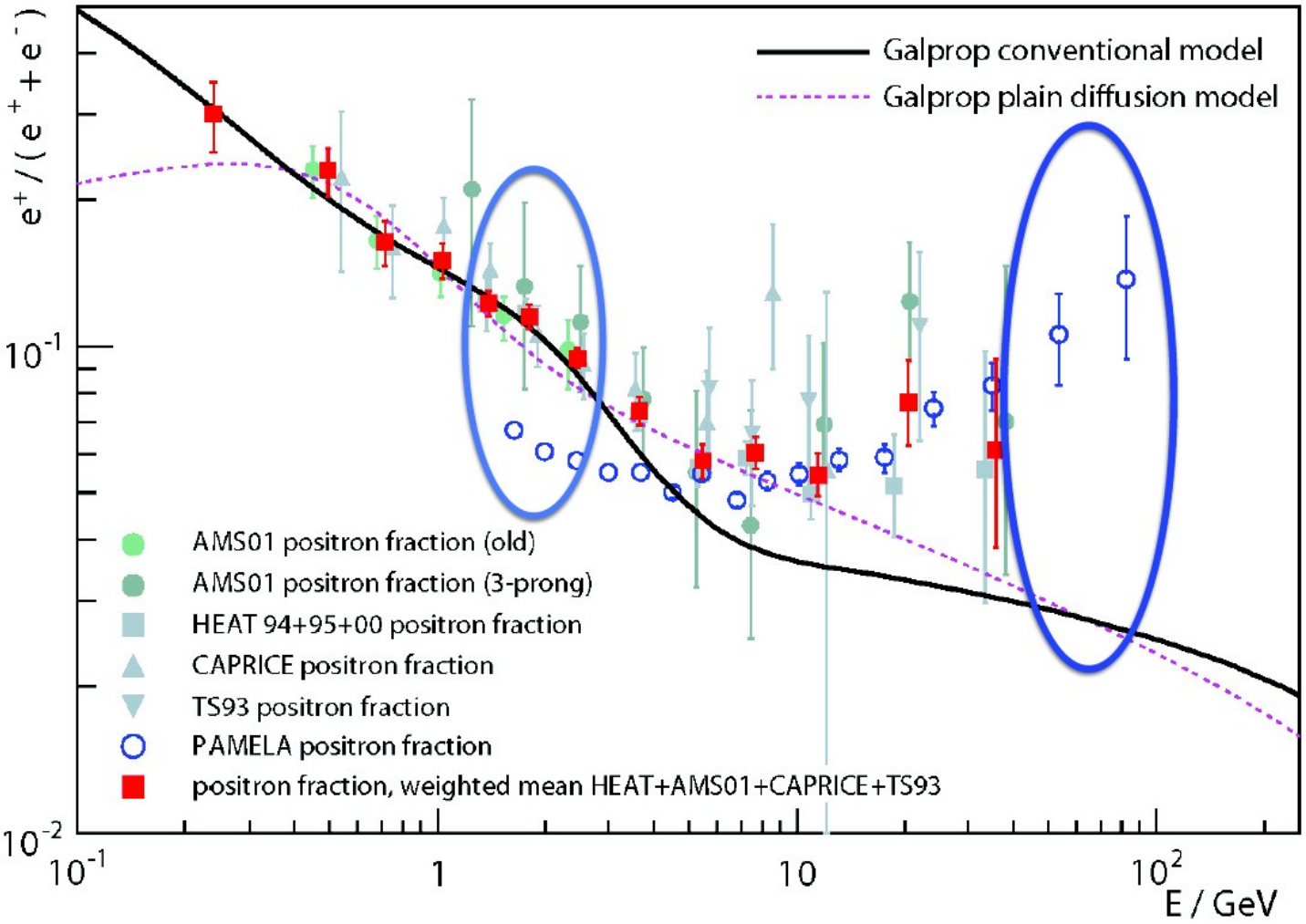
Cosmic ray backgrounds in dark matter searches
25 January 2010, AlbaNova, Stockholm

Fabien Zehr
EPFL, Lausanne, Switzerland

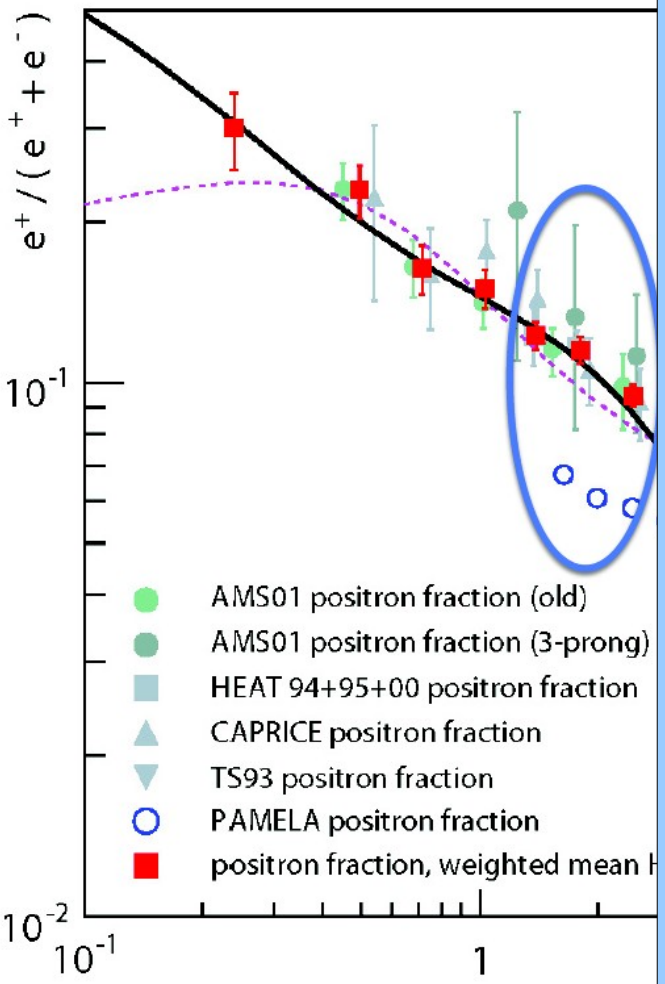
Interesting feature seen in electron+positron spectrum...



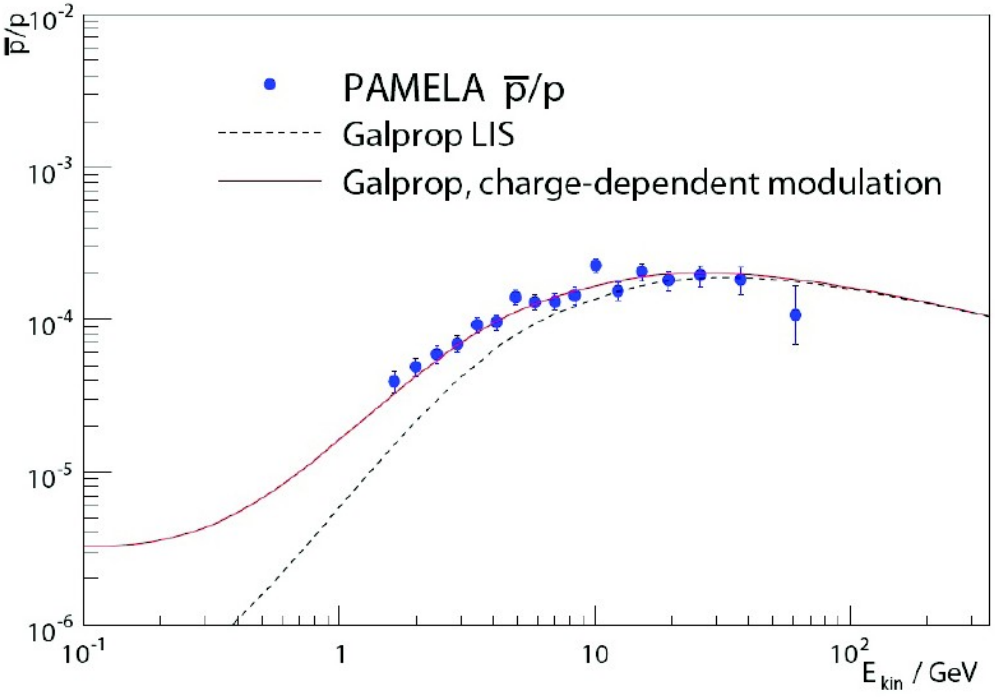
... and in positron fraction $\frac{e^+}{e^+ + e^-}$



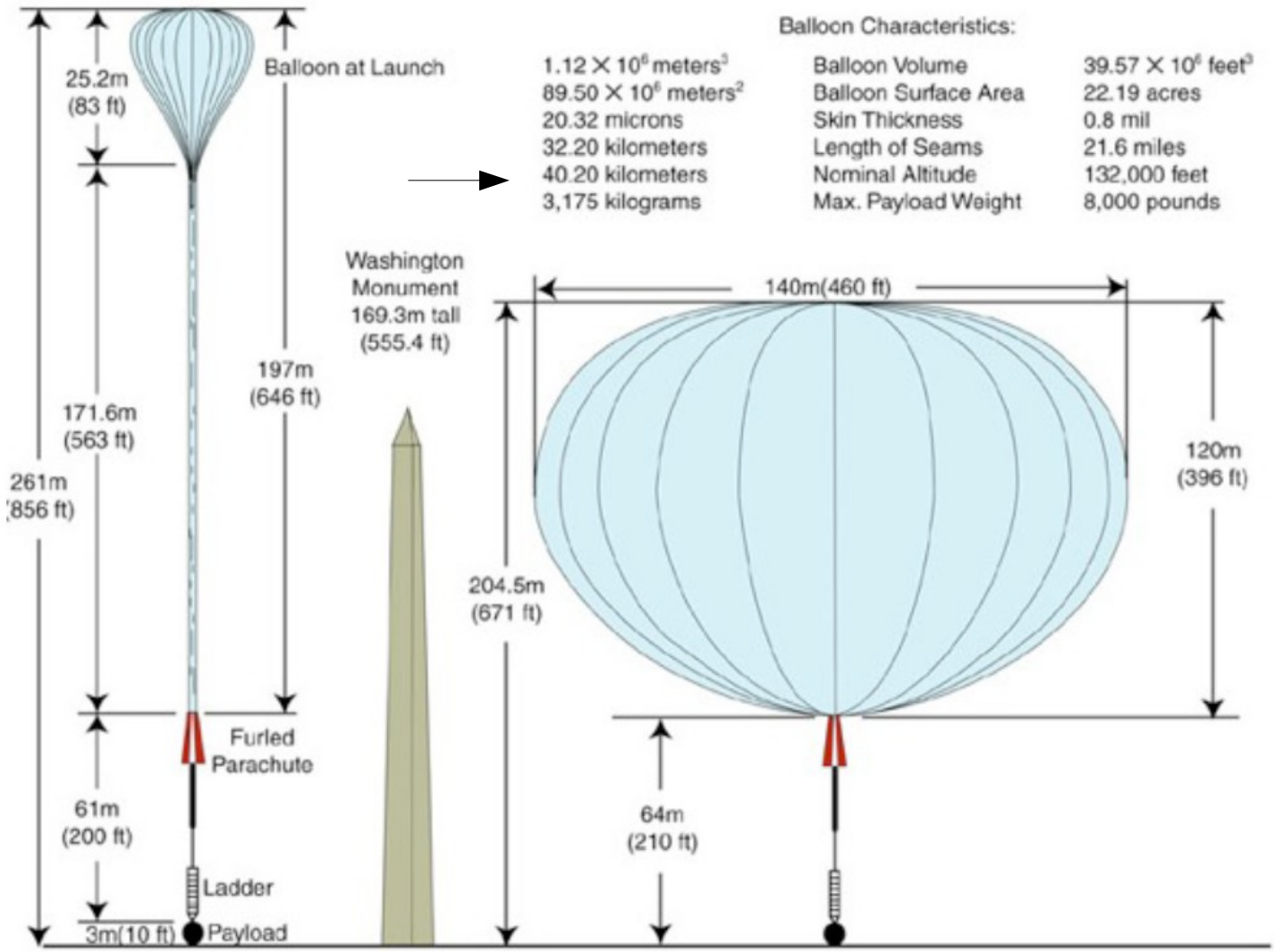
... and in positron fraction $\frac{e^+}{e^+ + e^-}$



Not seen in antiproton fraction $\frac{\bar{p}}{\bar{p}+p}$

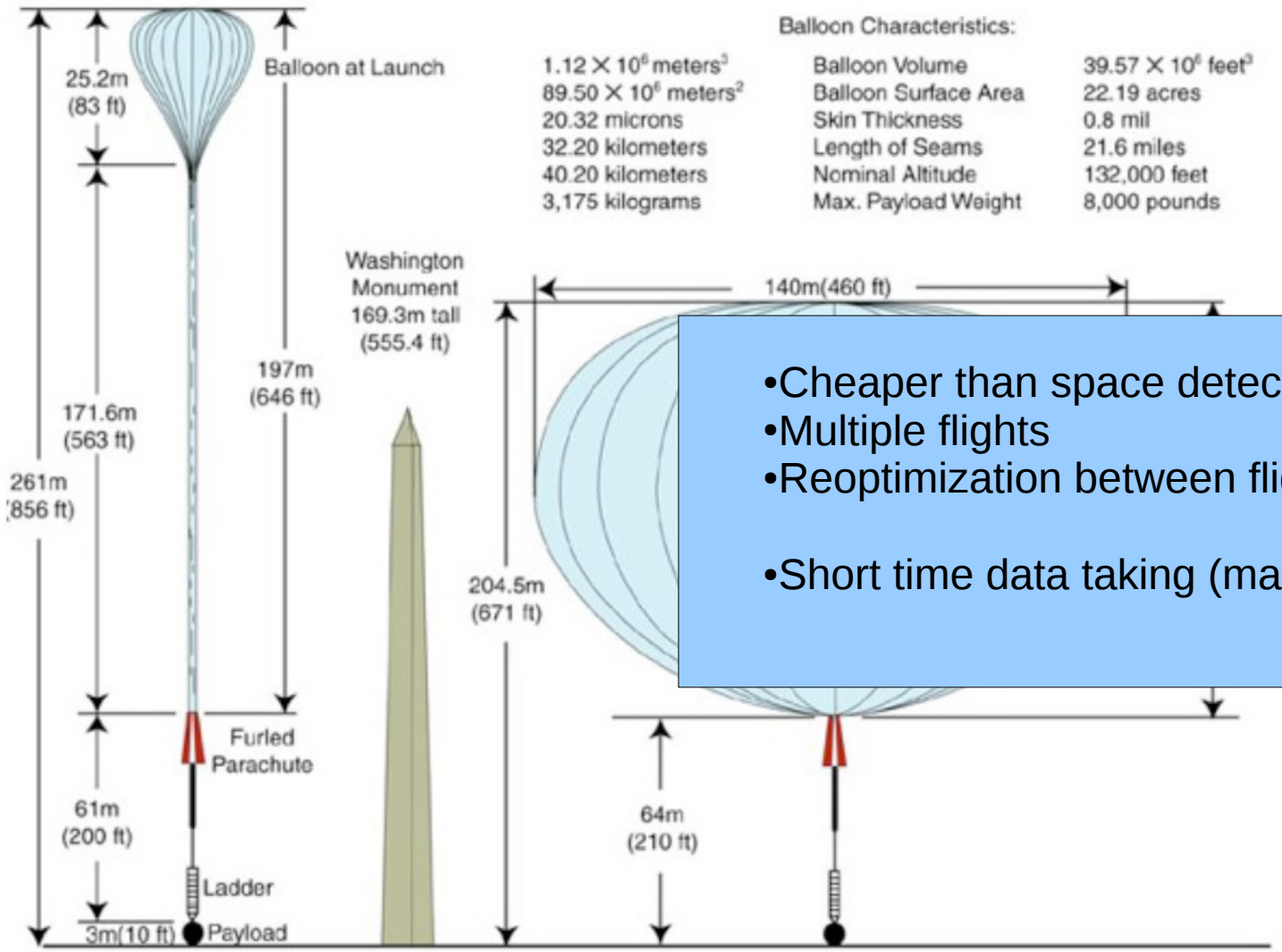


PEBS: Balloon-borne experiment



Weight ~2000 kg

PEBS: Balloon-borne experiment



- Cheaper than space detectors
- Multiple flights
- Reoptimization between flights

- Short time data taking (max 40 days)

PEBS Goals

PEBS I

North pole: 5 days flights in Summer 2012/2013

•Electron + positron up to ~1 TeV
•Positron fraction up to ~30 GeV

PEBS II

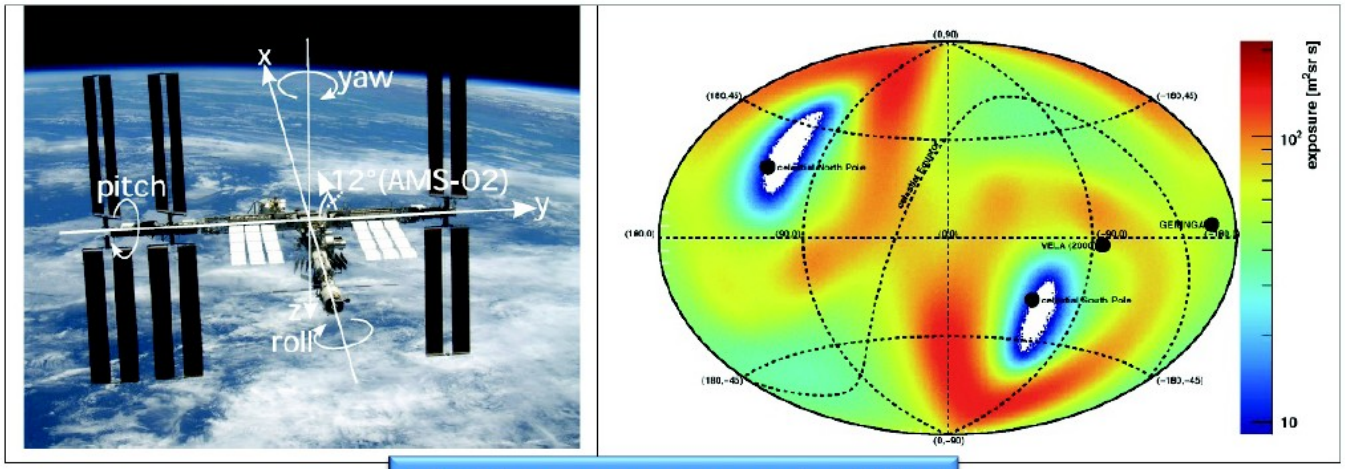
South pole: 40 days flights in Winter 2014/2015

•Positron fraction up to 1.8 TeV

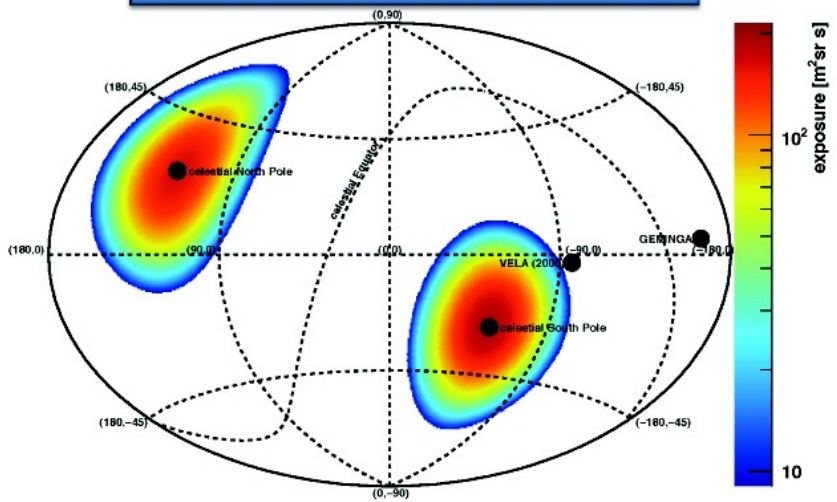
Challenges:

•Proton rejection (at 100 GeV p/e = 10^4, at 1TeV 10^5)
•Charge separation requires very strong magnetic fields.

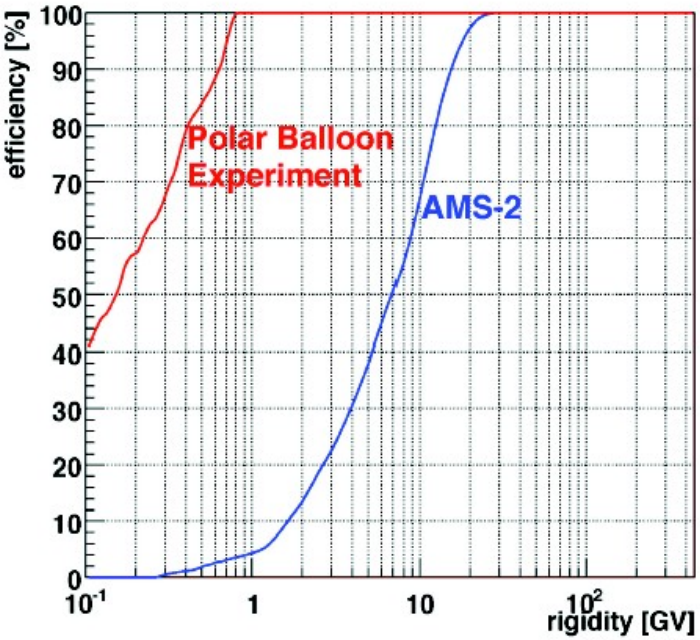
Why at the poles ?
I) Full sky coverage in conjunction with AMS-2

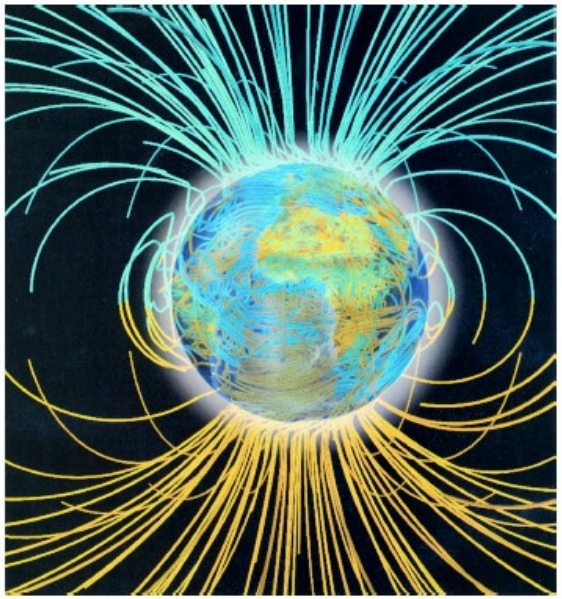


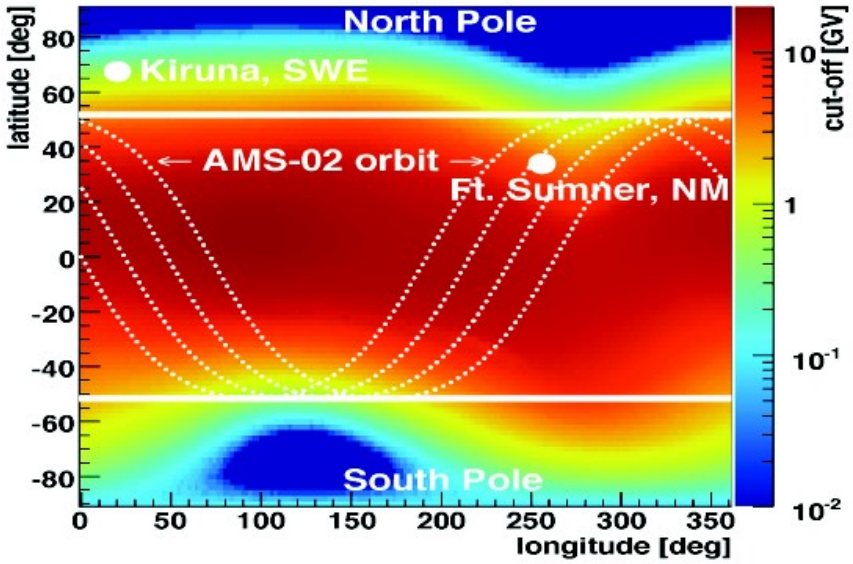
PEBS Skycoverage compared to AMS-2



Why at the poles ?
II) Geomagnetic Cutoff







AMS-2 Low Energy Threshold: ~2GeV

PEBS-1 Experiment

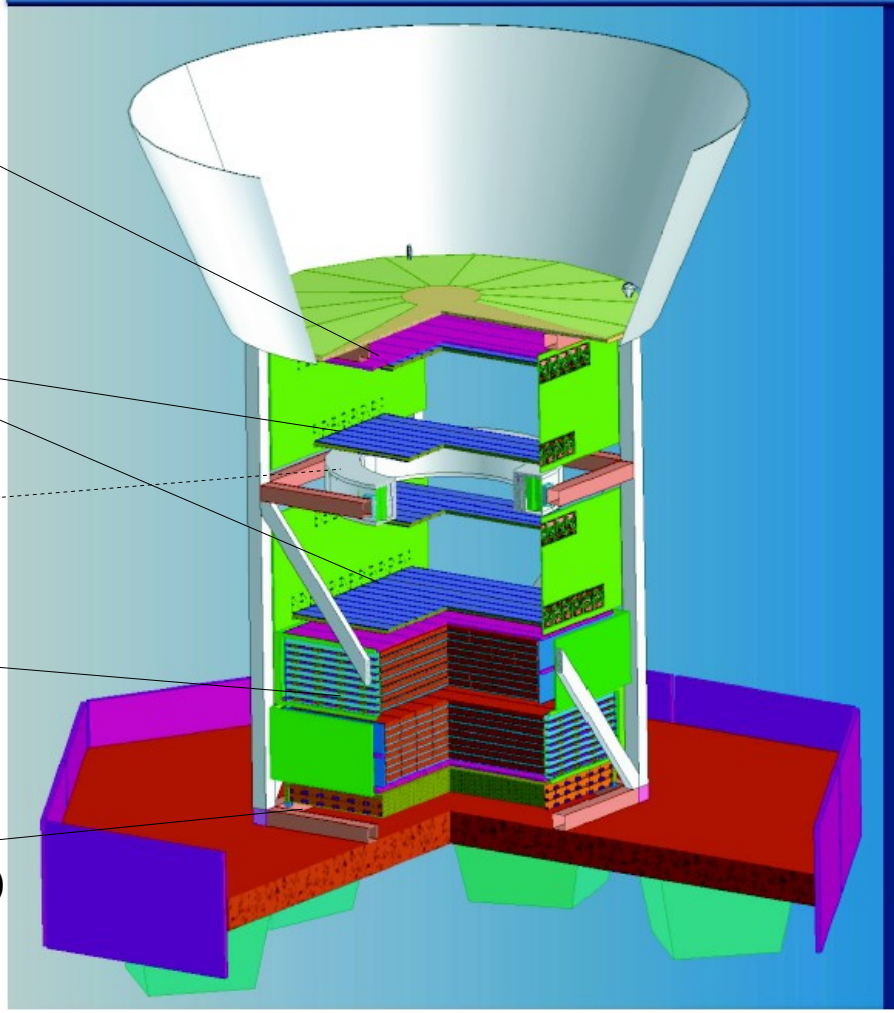
Time of flight detector (TOF)

Scintillating Fiber Tracker

Permanent magnet

Transition radiation detector (TRD)

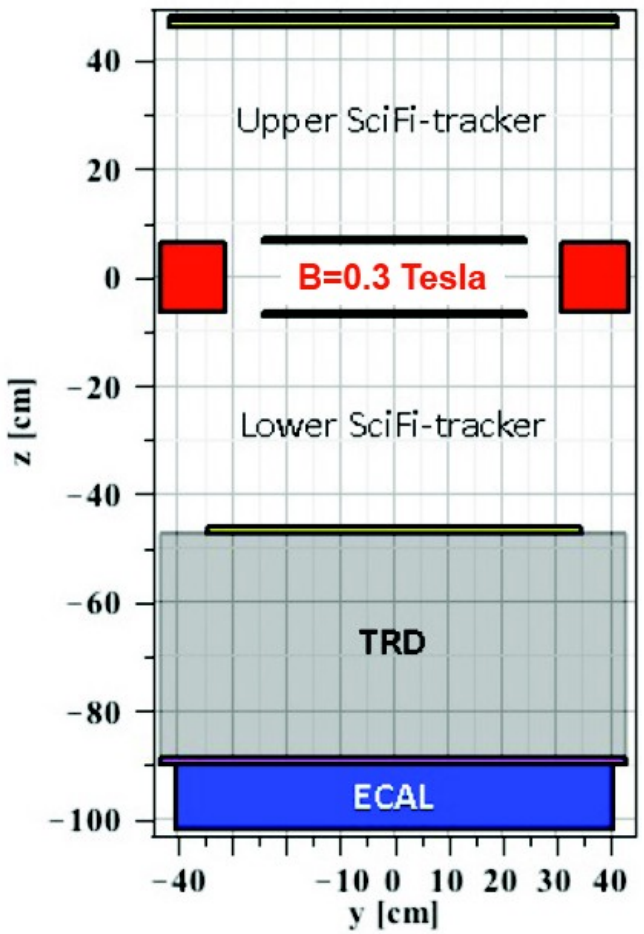
Electromagnetic Calorimeter (ECAL)



Summer 2012
Kiruna, Sweden➔Alaska

	e^-	P	e^+	$\bar{P}$, $\bar{D}$
TRD				
TOF				
Tracker				
ECAL				

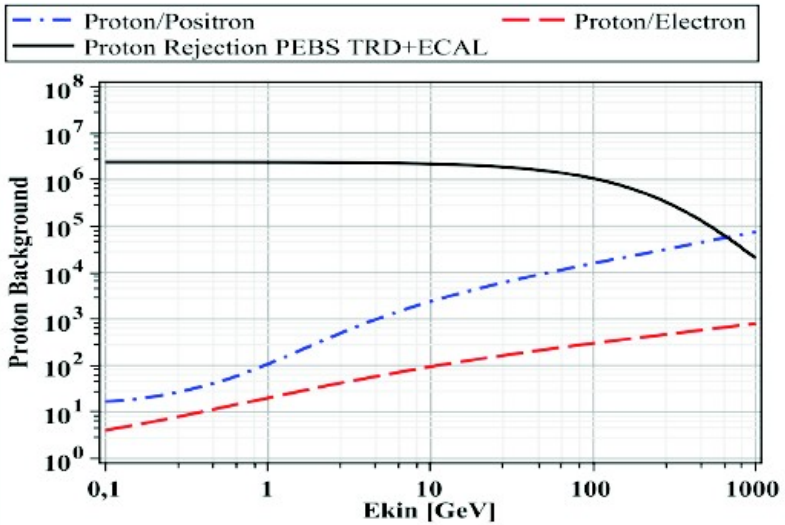
PEBS-1 Experiment



$$\frac{\sigma_p}{p} = 0.011 \cdot p \oplus 0.07$$

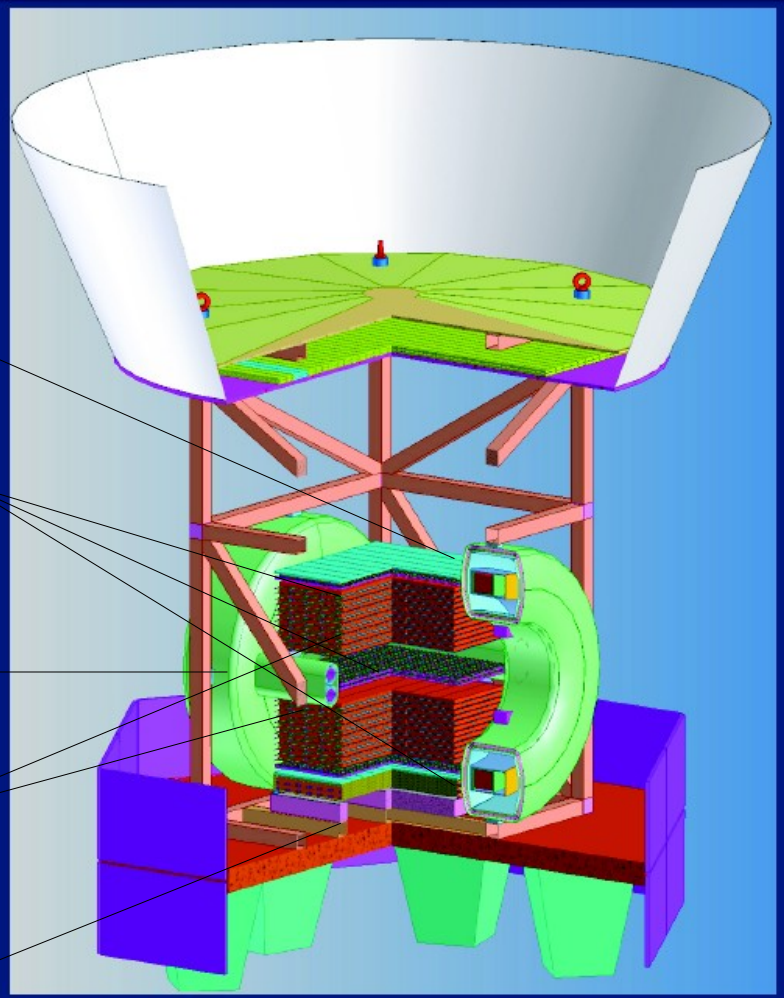
Acceptance:
Spectrometer: 1000 cm² sr
ECAL+TRD: 7500 cm² sr

Weight ~2000 kg Power Consumption ~900 W



ECAL proton rejection ~10^3
TRD proton rejection ~10^3

PEBS-2 Experiment



Time of flight detector (TOF)

Scintillating Fiber Tracker

Superconducting magnet

Transition radiation detector (TRD)

Electromagnetic Calorimeter (ECAL)

Antartica, 2014/2015

	e^-	P	e^+	$\bar{P}$, $\bar{D}$
TRD				
TOF				
Tracker				
ECAL				

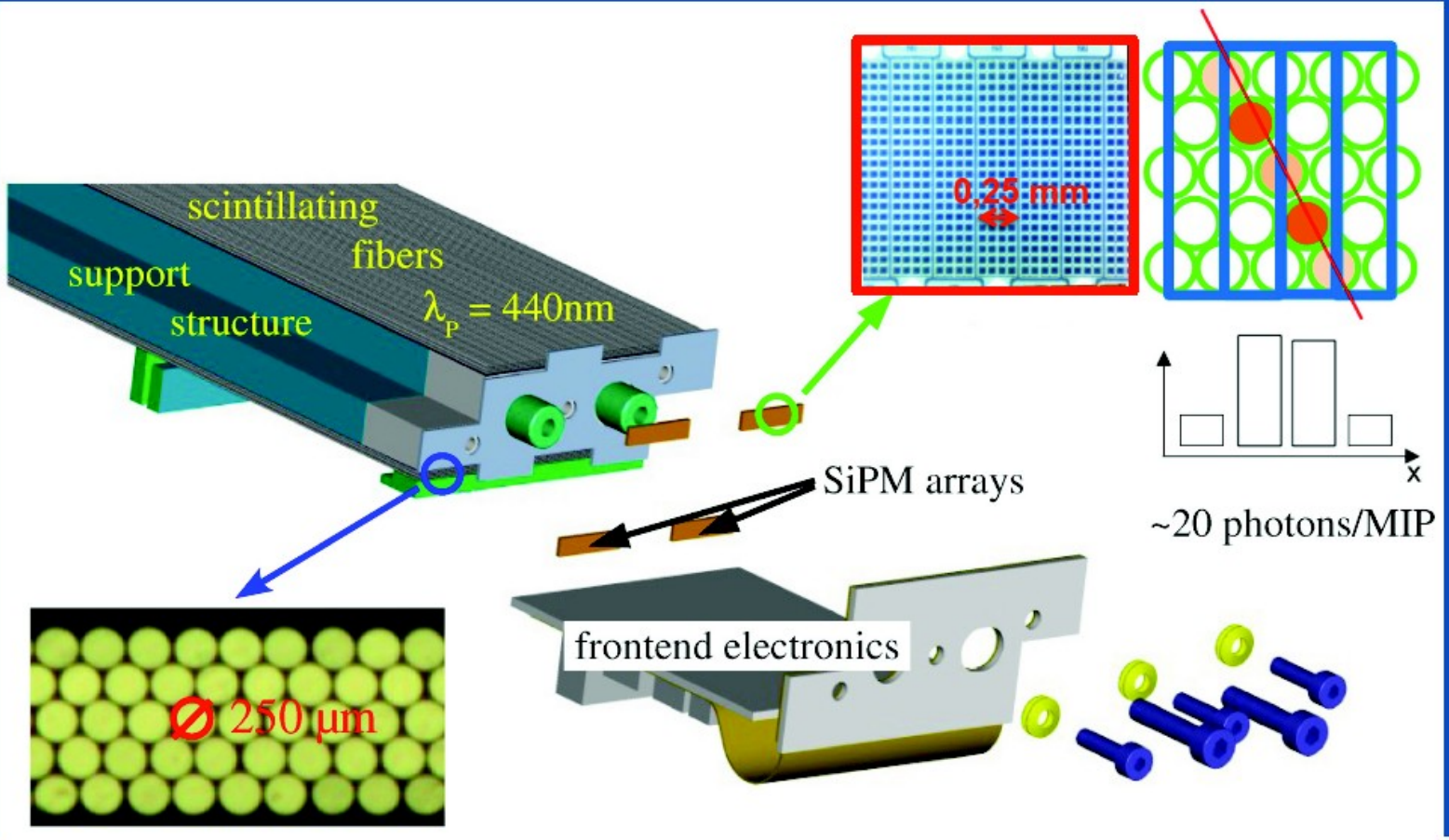
$$\frac{\sigma_p}{p} = 1.8 \cdot 10^{-4} \cdot p \oplus 0.008$$

20

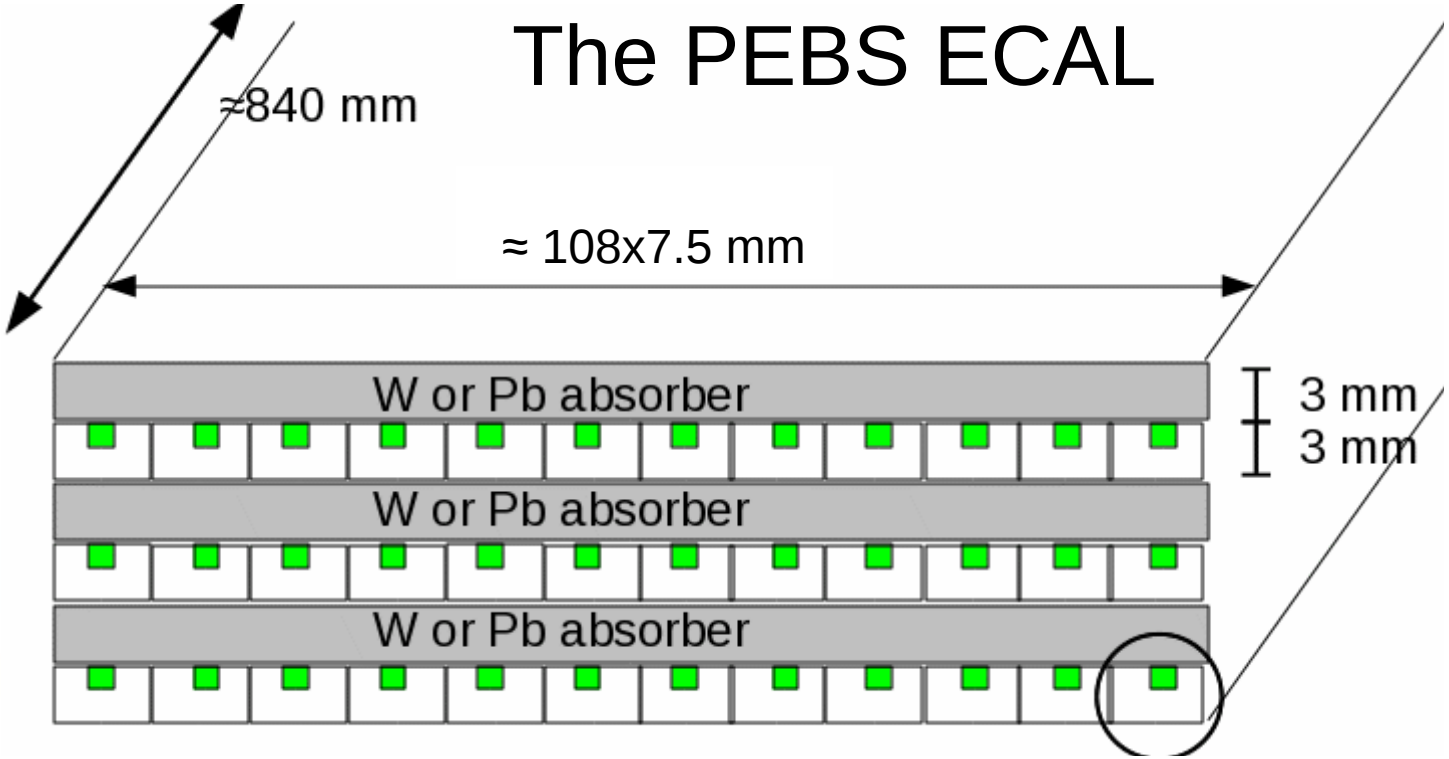
B = 2T

The PEBS ScFi Tracker

PEBS-1: 36 modules, l= 86cm, 80 km fibers, 576 MPPC arrays
PEBS-2: 60 modules, l=2000cm, 310 km fibers, 960 MPPC arrays

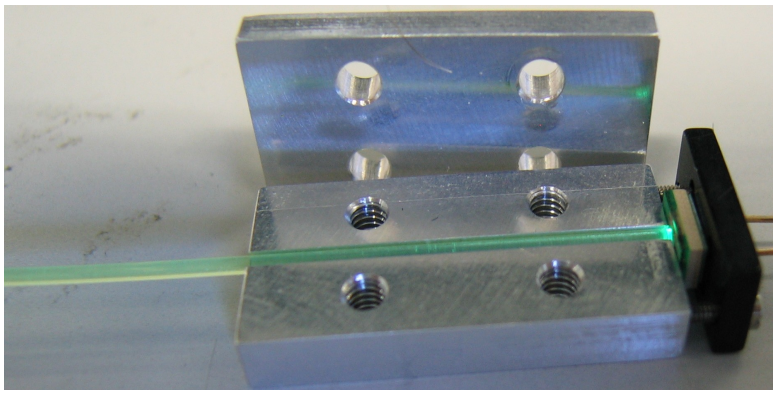


The PEBS ECAL

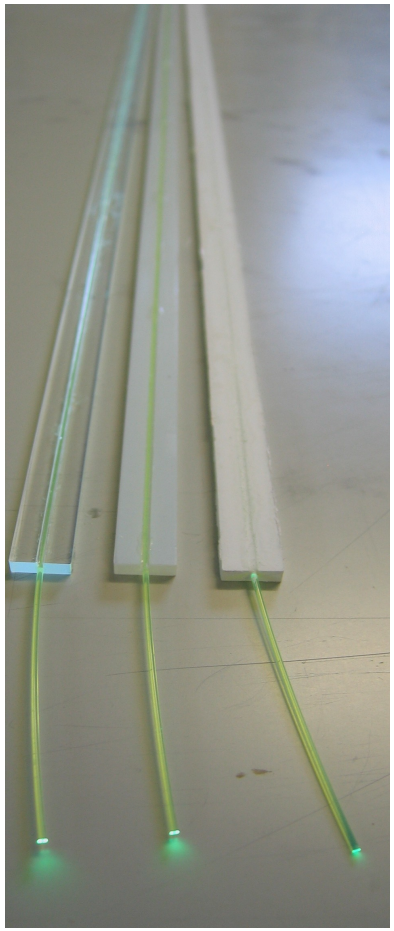


Superlayer

Total: 7 superlayers
≈16 X_0



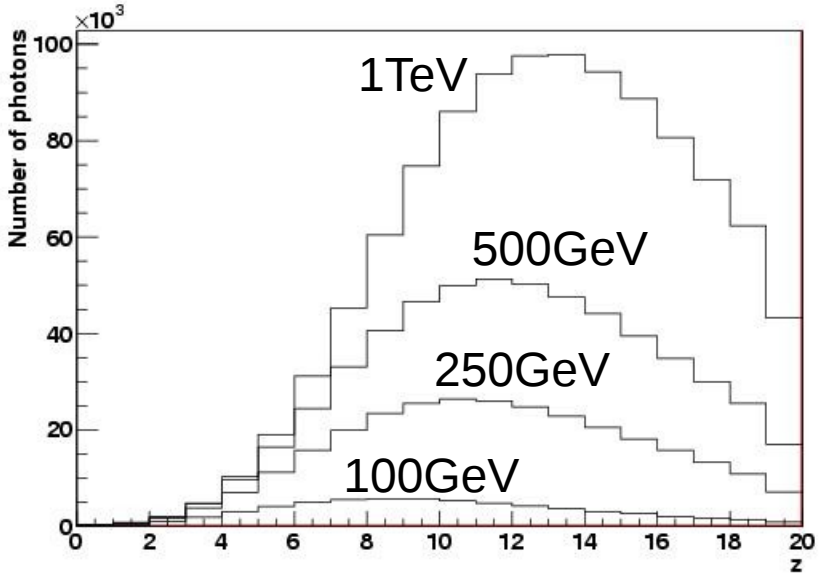
SiPM readout



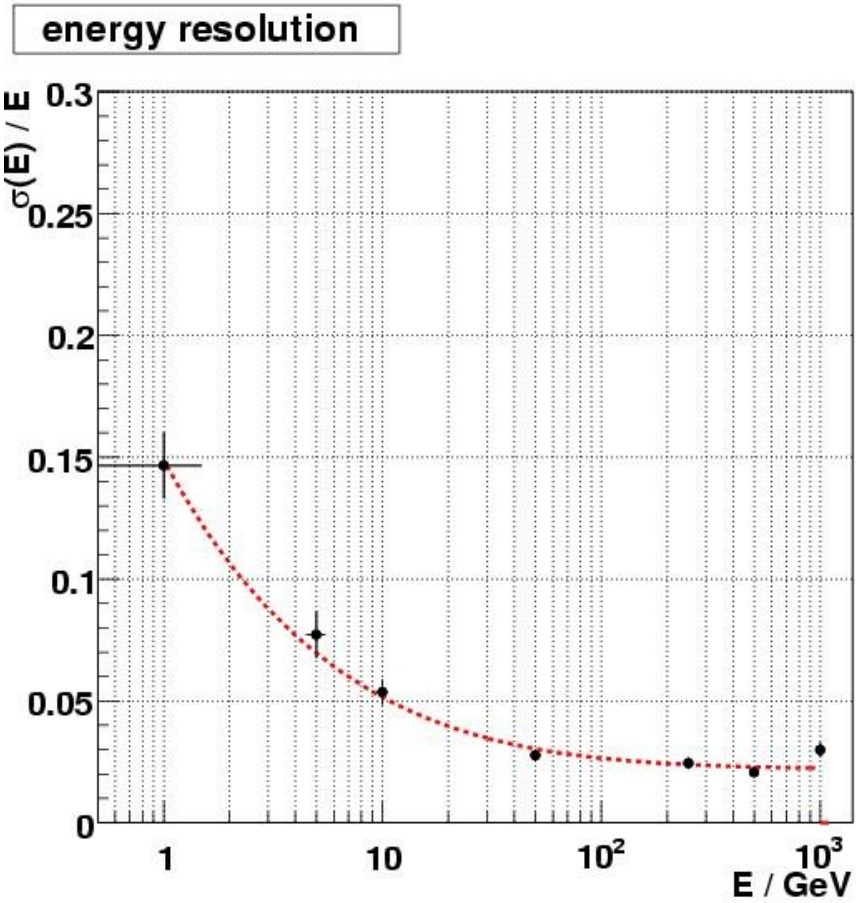
Scintillating bars with embedded fibres

ECAL Projected Performance

Good performance up to 1 TeV electrons

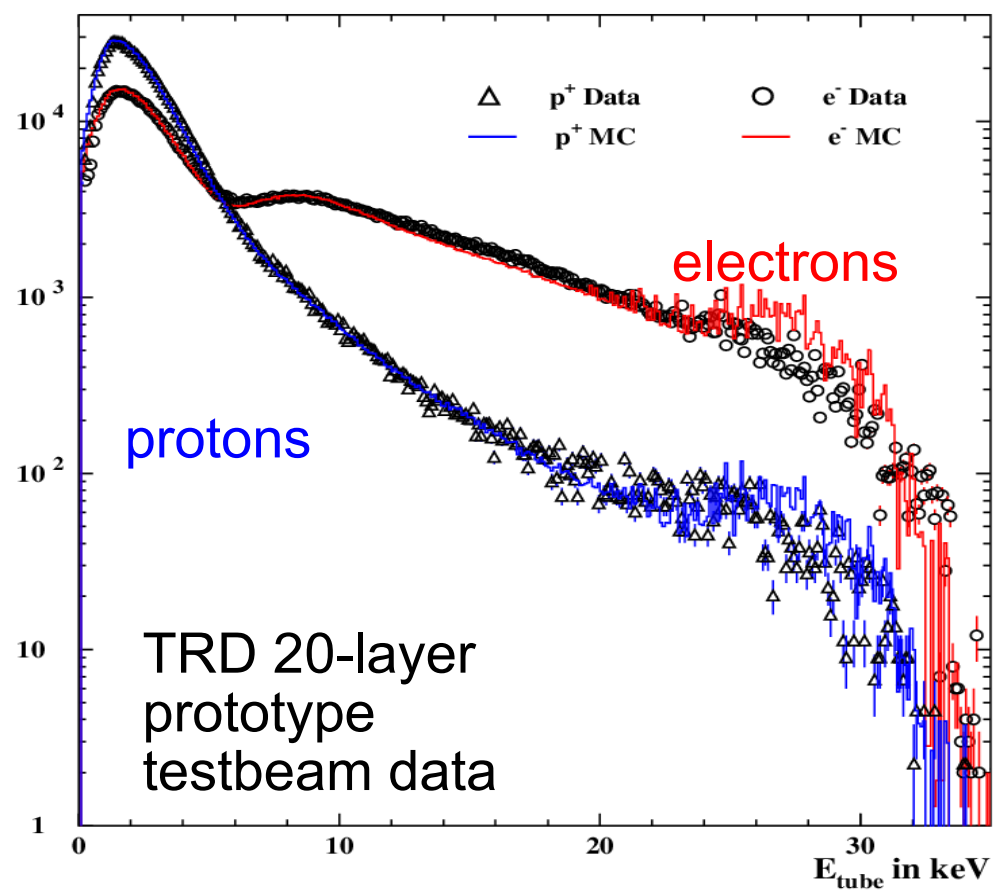


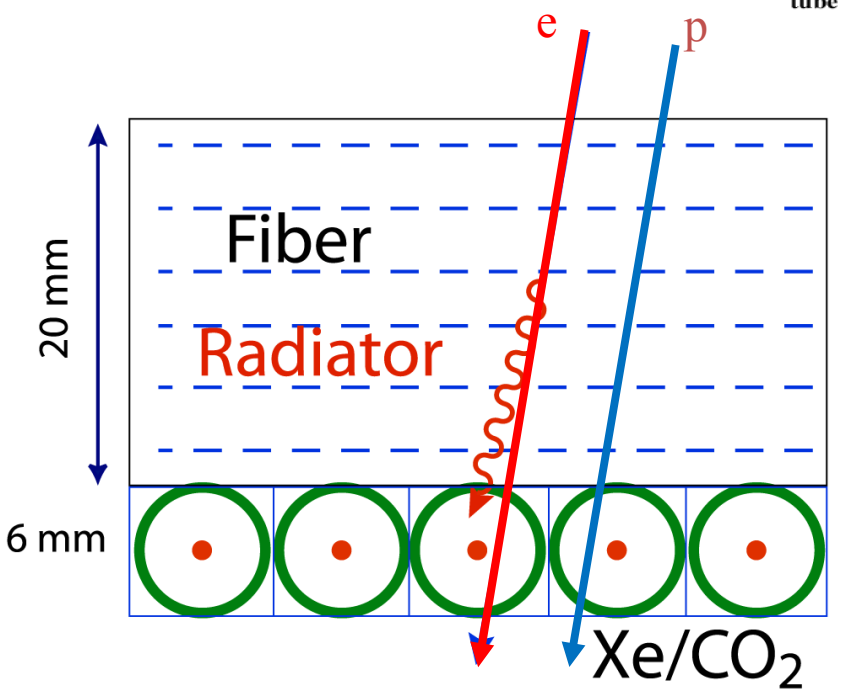
Shower contained within the ECAL



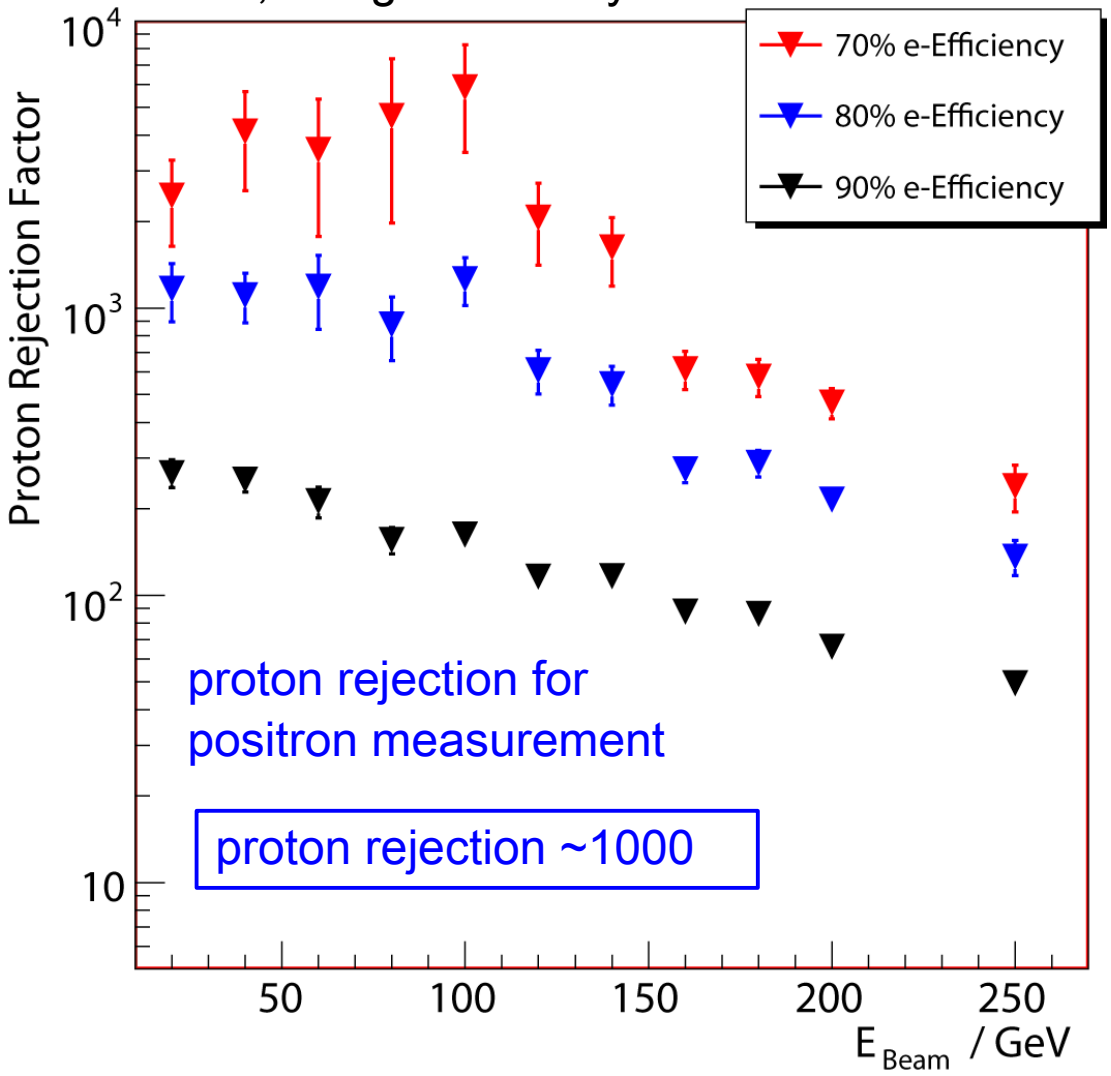
Good energy resolution

TRD Performance

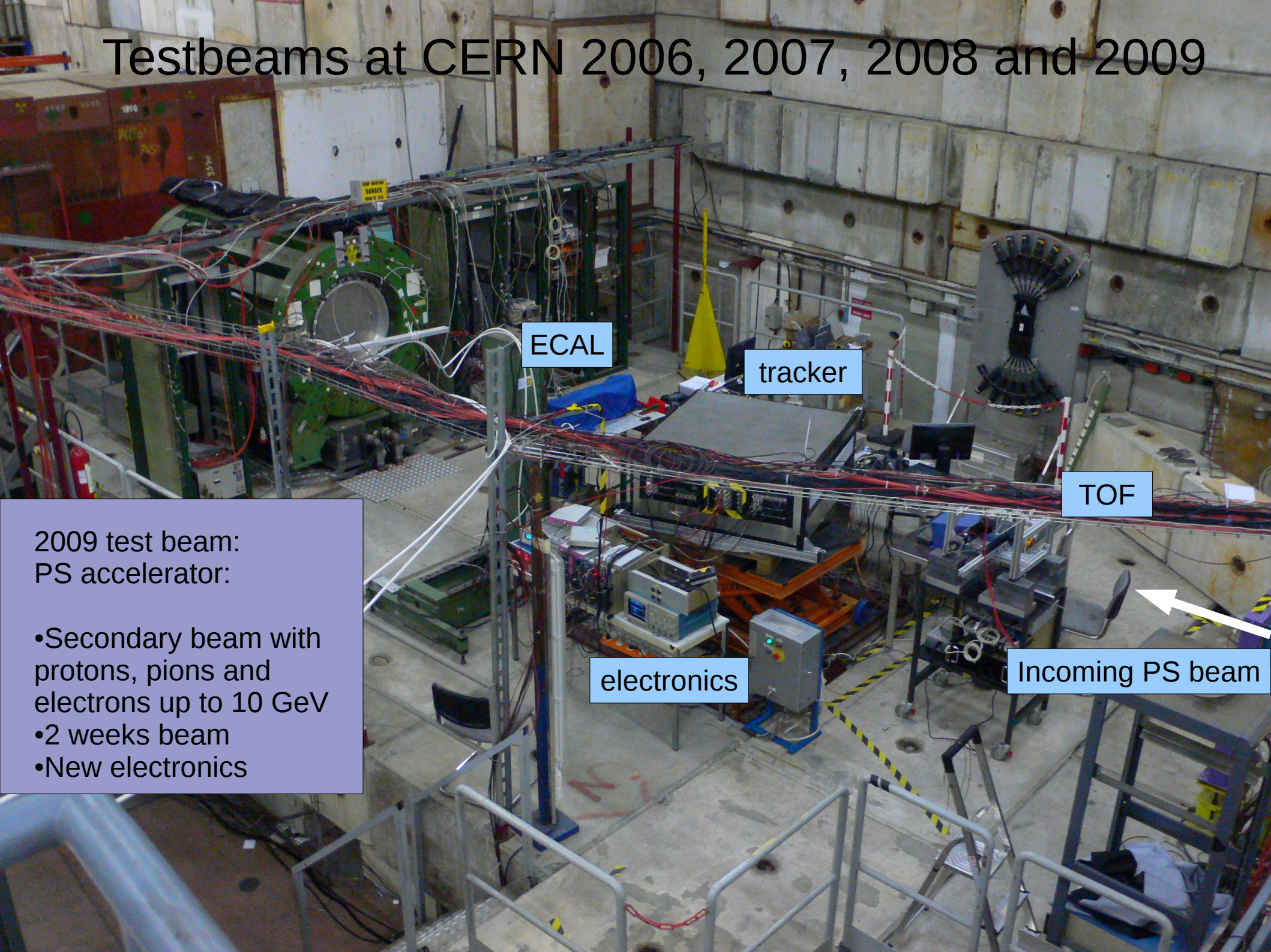




Analysis of TRD prototype testbeam data, using first 16 layers



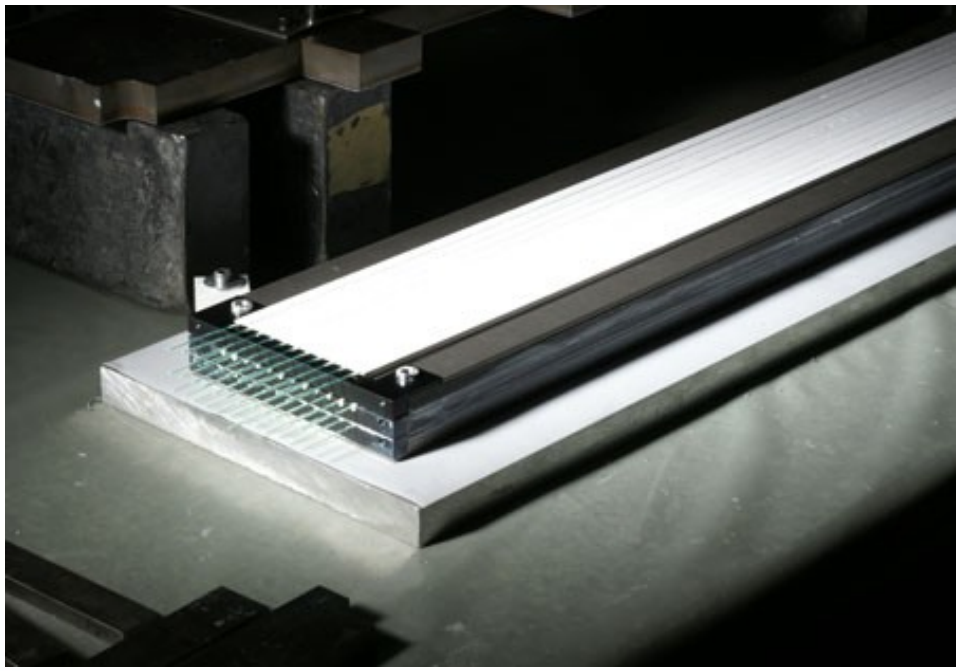
Testbeams at CERN 2006, 2007, 2008 and 2009

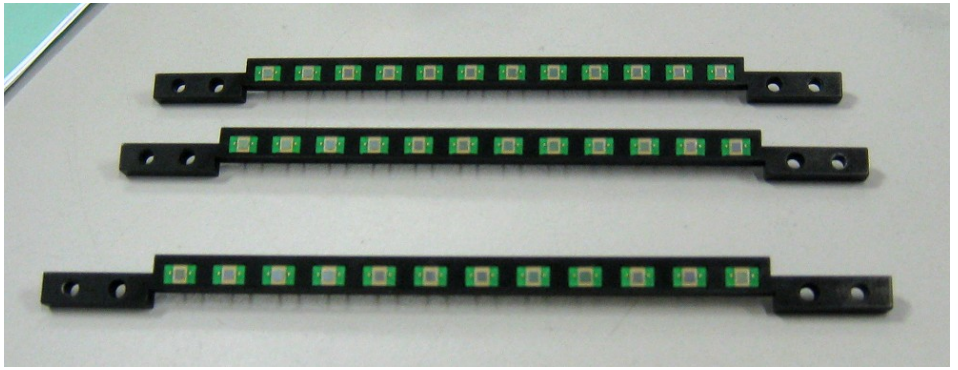


2009 test beam:
PS accelerator:

- Secondary beam with protons, pions and electrons up to 10 GeV
- 2 weeks beam
- New electronics

ECAL Prototype Results



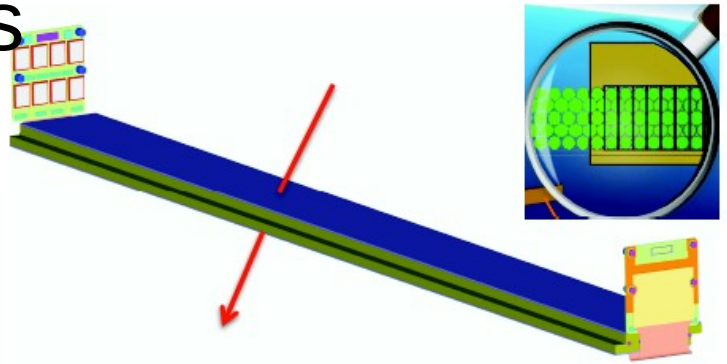


ECAL results coming soon...
Will be presented at

THE 12TH VIENNA CONFERENCE ON INSTRUMENTATION
FEB 15-20, 2010

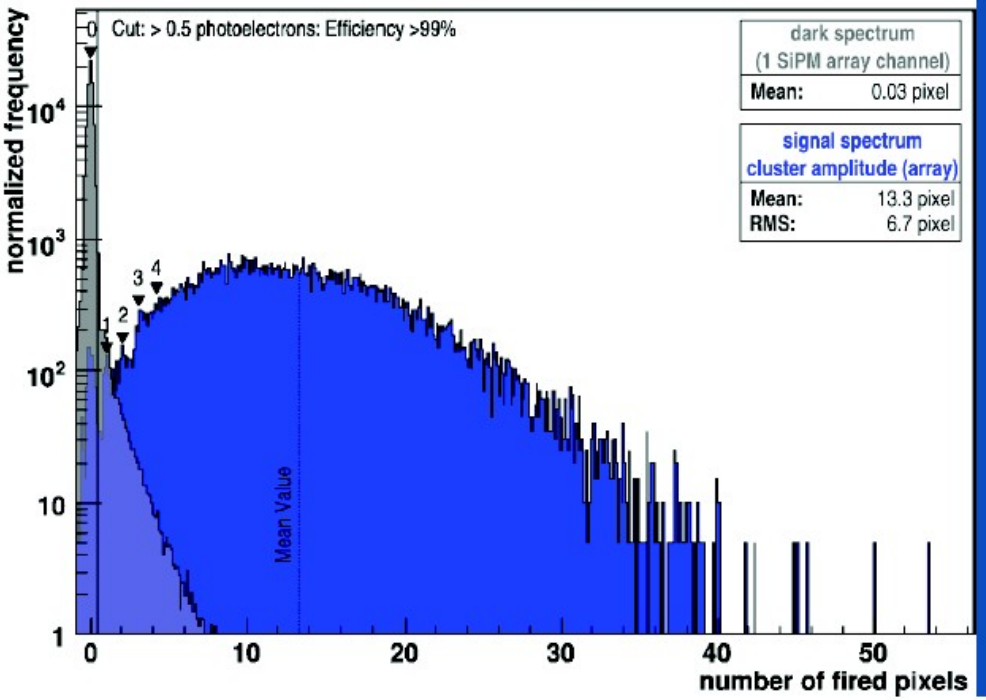
Next beamtime: September 2010
SPS secondary beam
protons, pions, electrons up to 450 GeV.

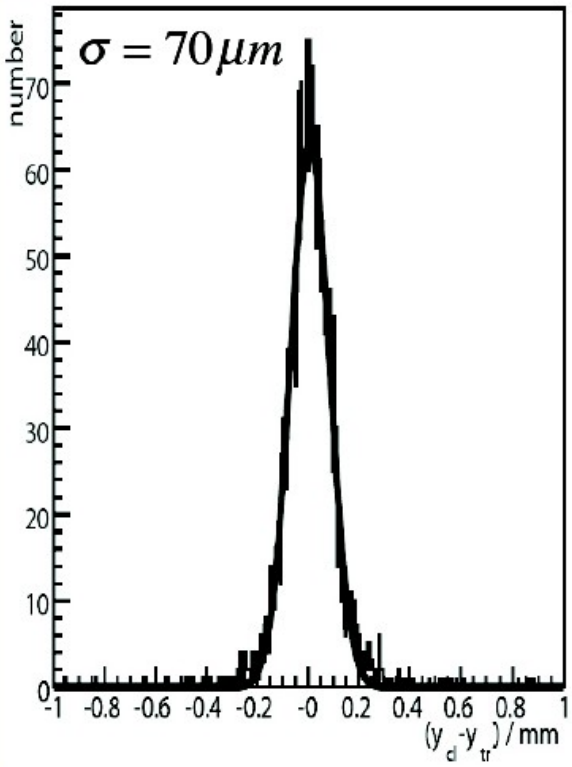
Tracker Prototype Results (2008)



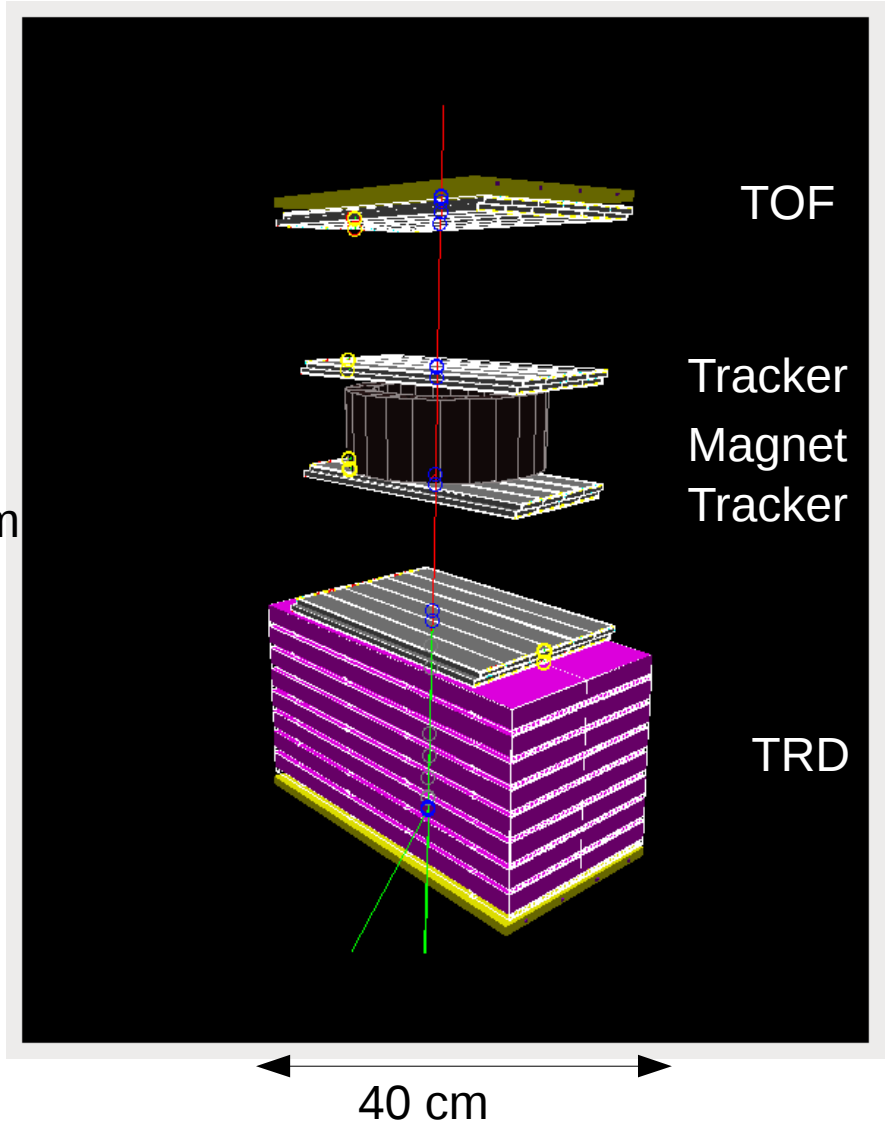
- MIP Signal 10 Photons
- Tracking Efficiency ≥ 99%
- Positionresolution 0.07 mm (2008)
  ➔ 0.05 mm (2009)

Signal Plot Hamamatsu MPPC 5883 + Kuraray Fiber
(central region => complete cluster amplitude contained)





PERDAix: Proton Electron Radiation Detector Aix-la-Chapelle **“Mini PEBS”**



Measure Proton and electron fluxes up to 5 GeV.

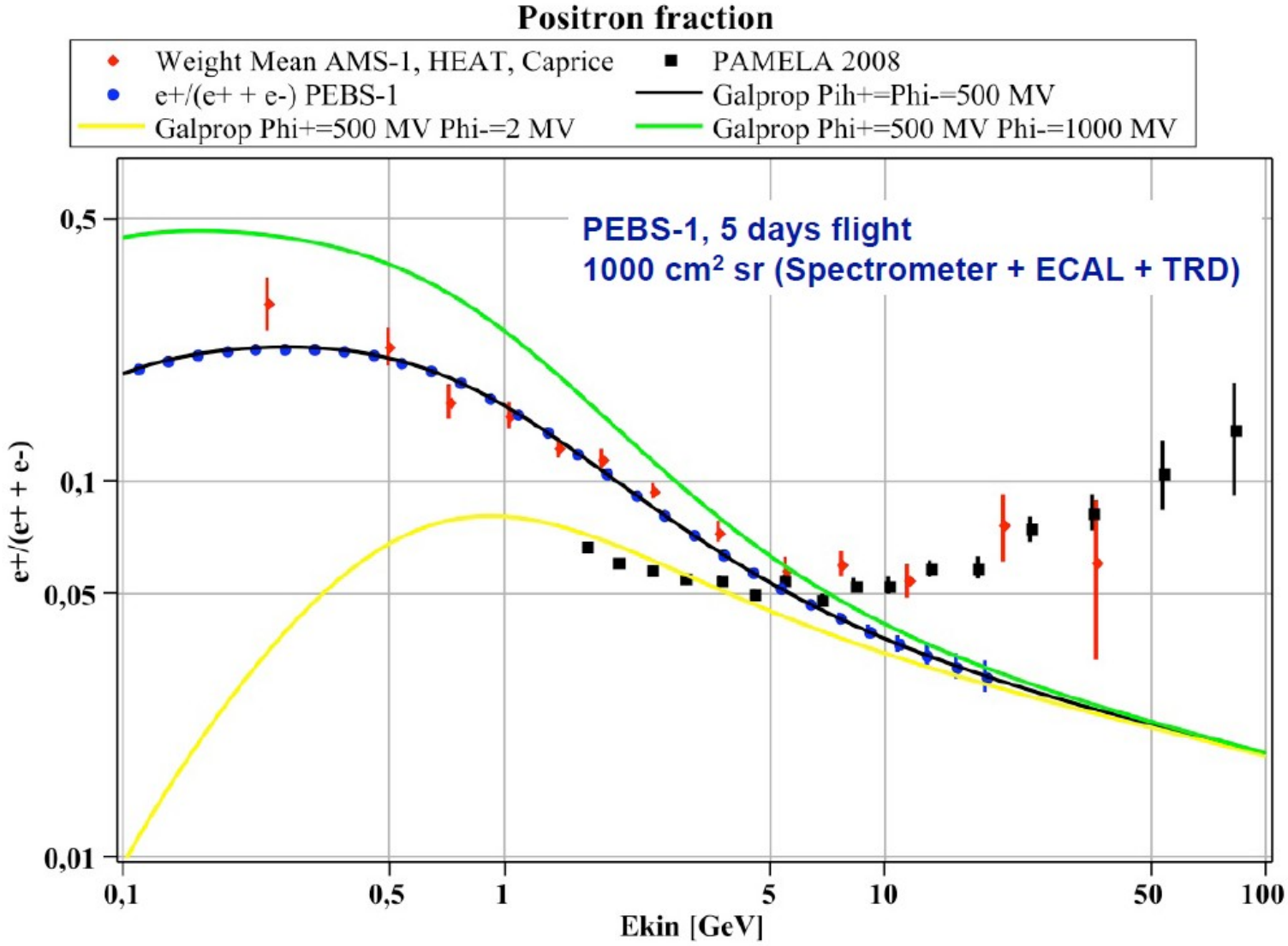
Two independent fittings of the solar modulation parameter Φ.

Simple experiment. Can be launched each year to monitor the solar constant over long periods.

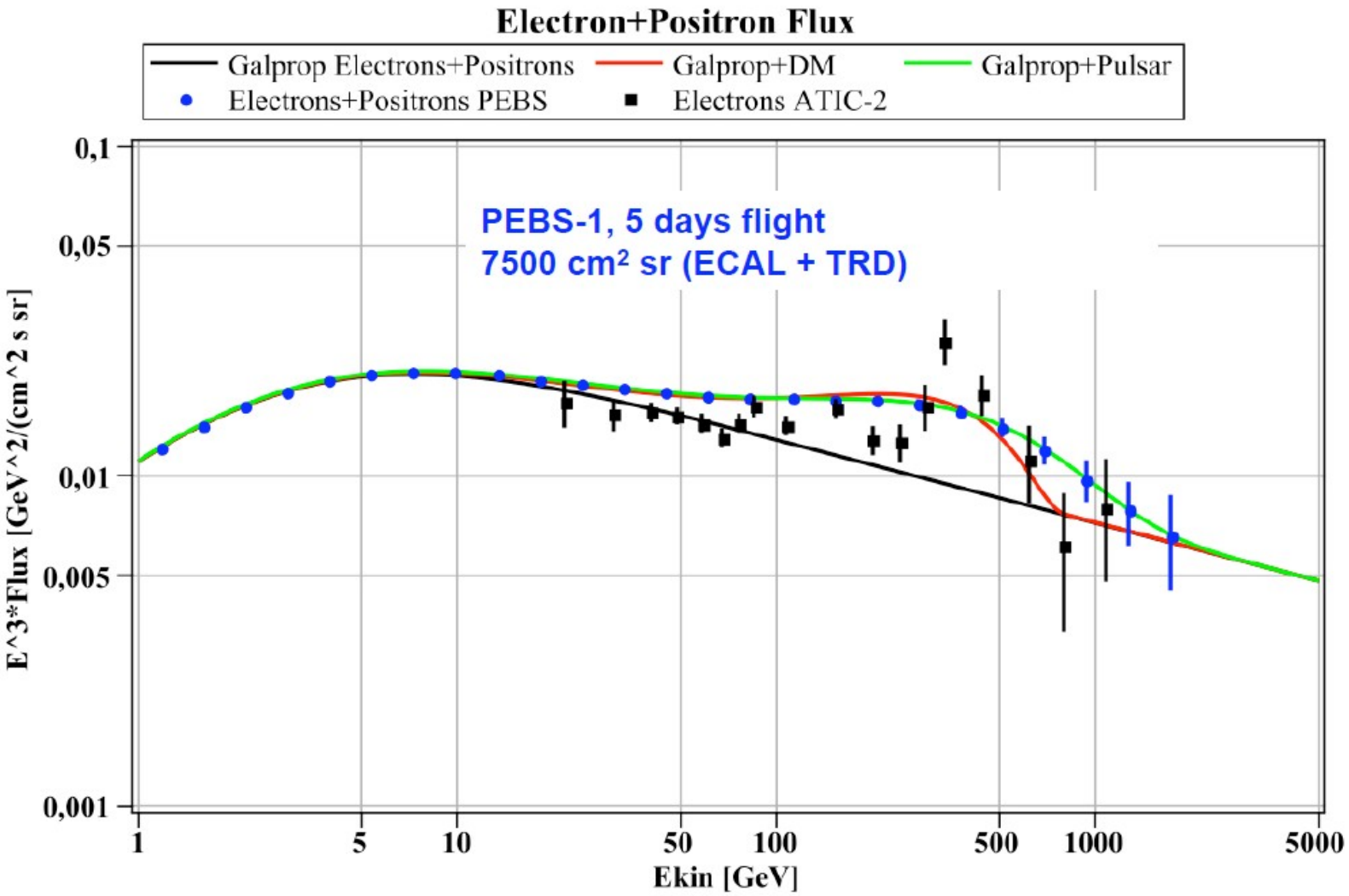
Gain experience for PEBS

First flight scheduled for autumn 2010, Kiruna, Sweden

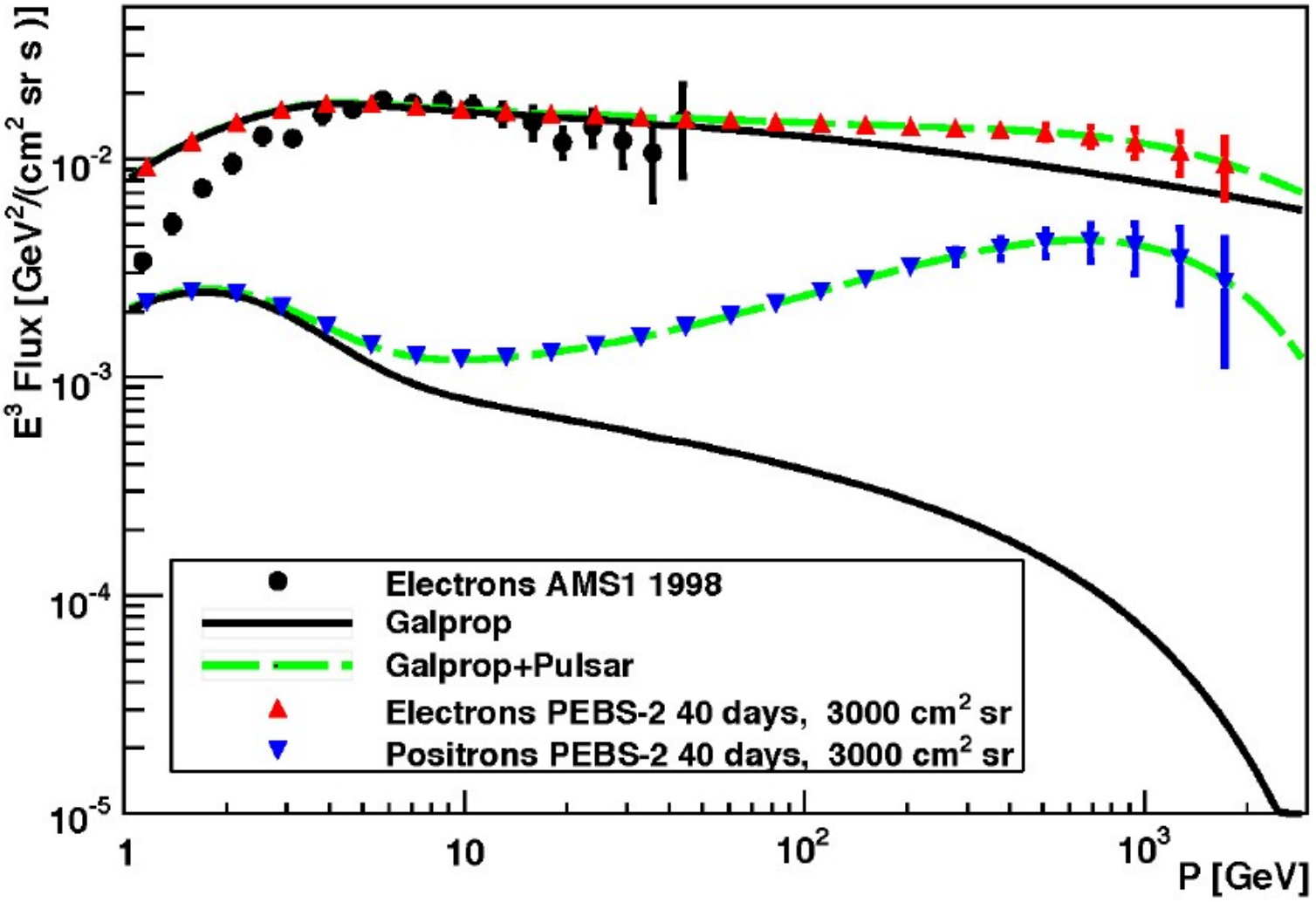
PEBS projected performance: PEBS I positron fraction



PEBS projected performance: PEBS I electron + positron flux



PEBS projected performance: PEBS II positron and electron fluxes



PEBS Summary

- A dedicated balloon experiment could provide a competitive measurement of the cosmic ray electron & positron flux.

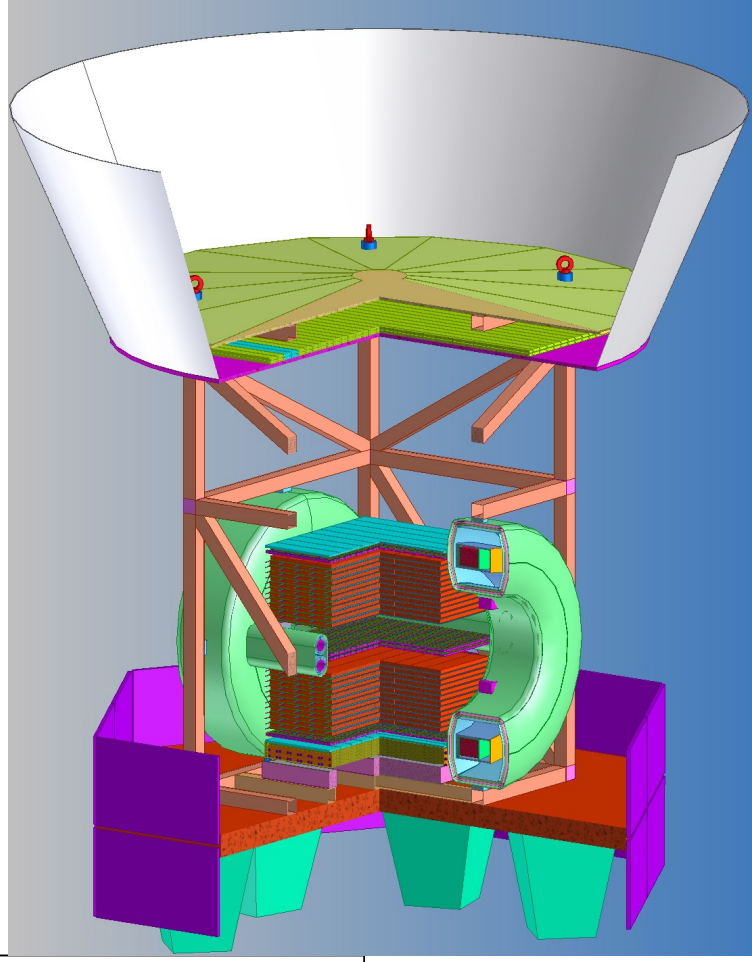
- A novel scintillating fiber tracker with SiPM readout allows the construction of large area, high resolution (0.05 mm), low power and low weight tracking detectors.

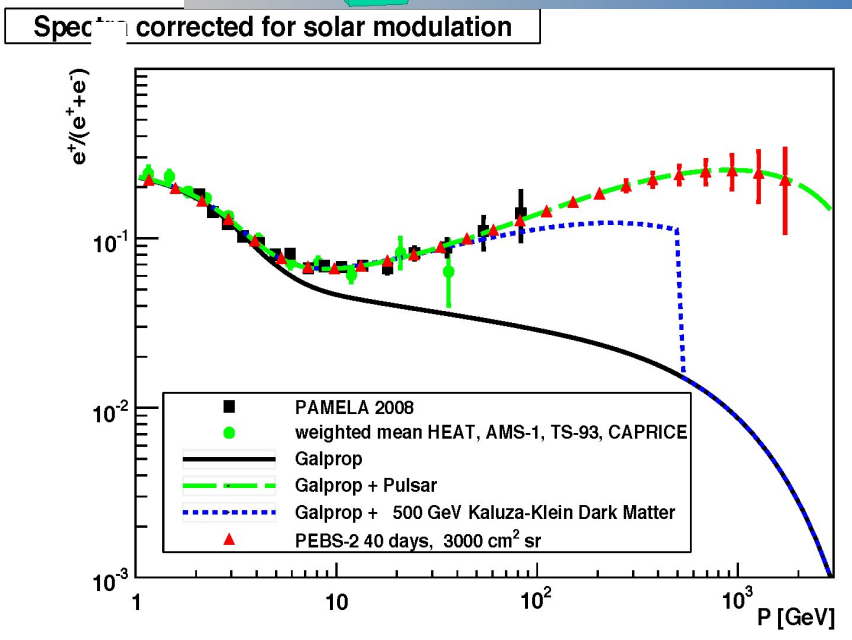
- The proton rejection of ~10^6 can be achieved by a combination of ToF, TRD, ECAL and Tracker.

- Key parameters:
  Acceptance: ~3000 cm2 sr
  Weight: ~2000 kg
  Power: ~900 Watt

- R&D Phase:
  2006 – 2009
  Construction Phase:
  2010 - 2012

First Flight: Summer 2012
from Kiruna, Sweden





Backup Transparencies

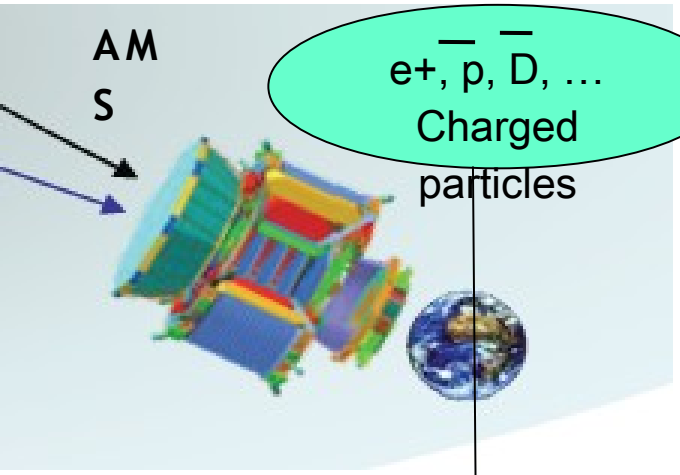


Proposal for PEBS-1 & PEBS-2 submitted to NASA in March 2009 by:

- **Prof. J. Beatty, Ohiho State University PEBS ToF, Gondula**
- **Prof. G. Dissertori, ETH Zuerich, Switzerland PEBS ECAL**
- **Prof. Dr. T. Nakada, EPF Lausanne, Switzerland PEBS ECAL**

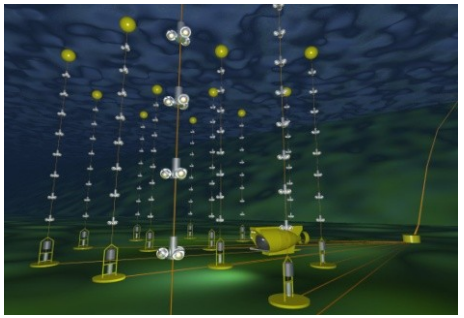
- **Prof. Dr. S. Schael, RWTH Aachen, Germany PEBS Magnet, TRD, Tracker**
- **Prof. Dr. S. Swordy, University Chicago, USA PEBS Trigger, DAQ, RICH**

Dark Matter Searches



e+, $\bar{p}$, $\bar{D}$, … Charged particles

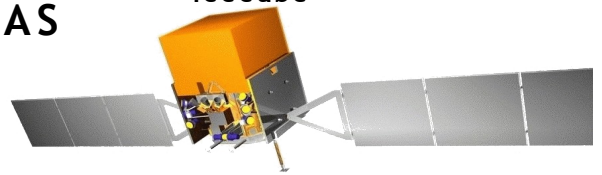
γ,ν



Antares, Km3, … Amanda, Icecube

CANGAROO, HESS, MAGIC, Veritas, …

GLAST

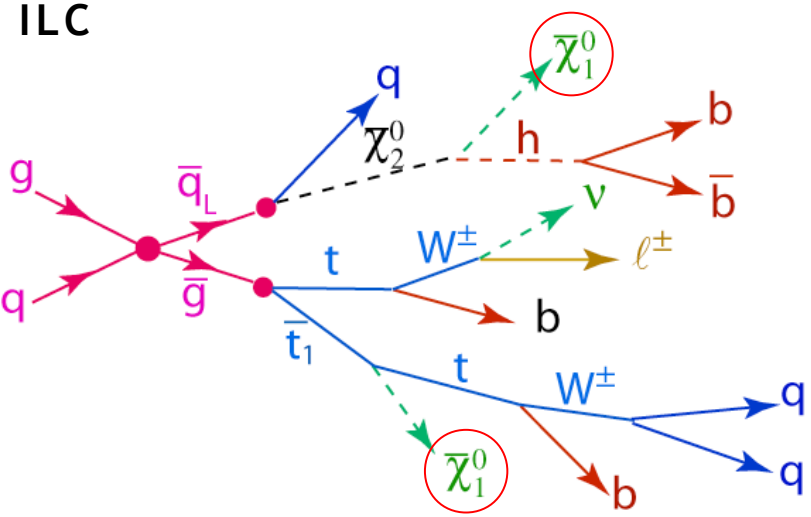


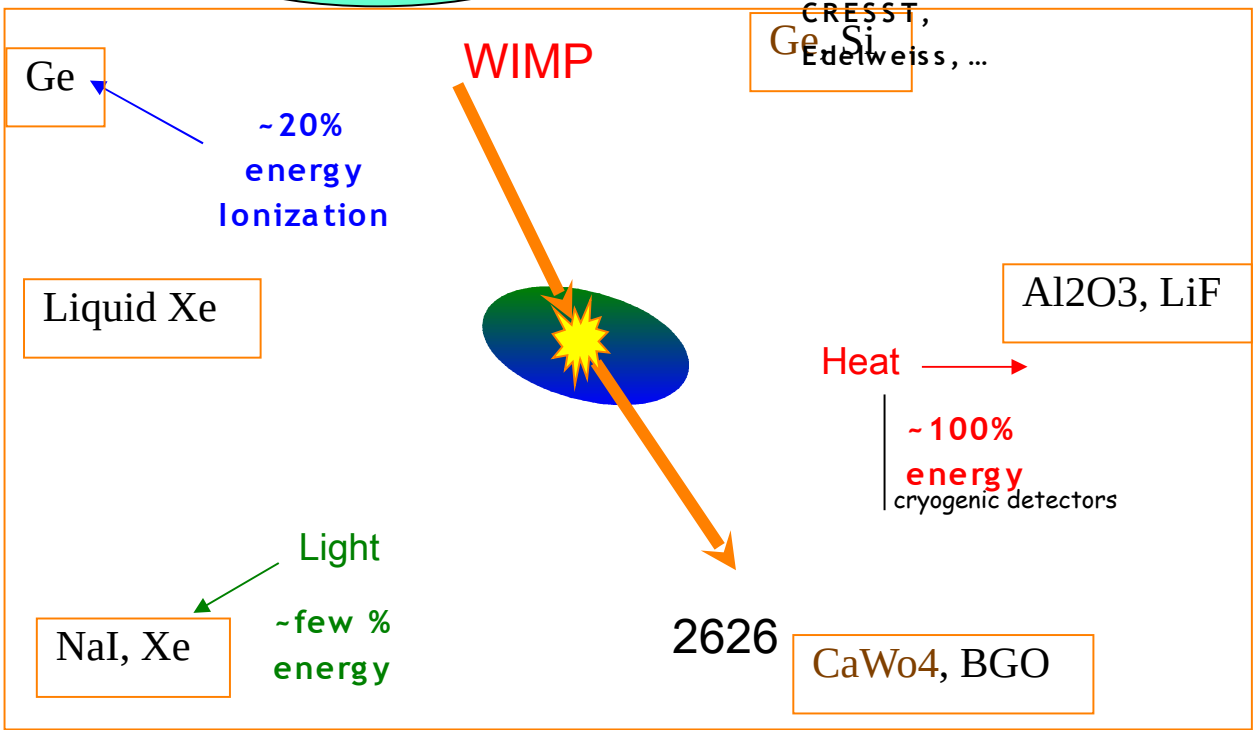
Colliders

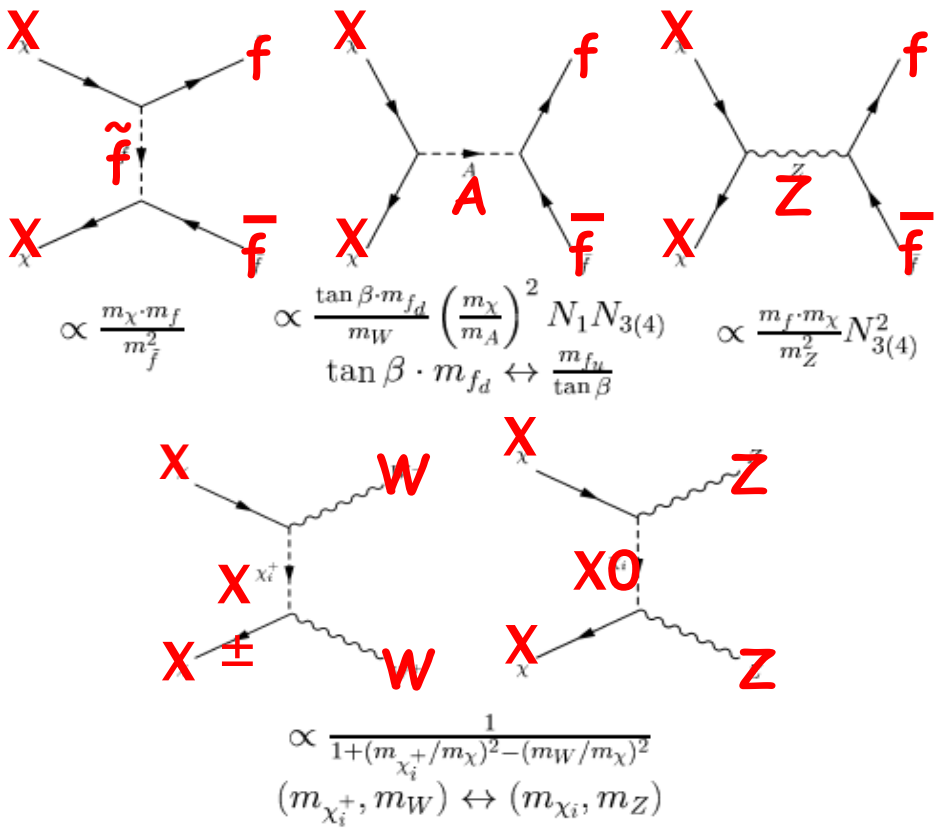
Direct detection

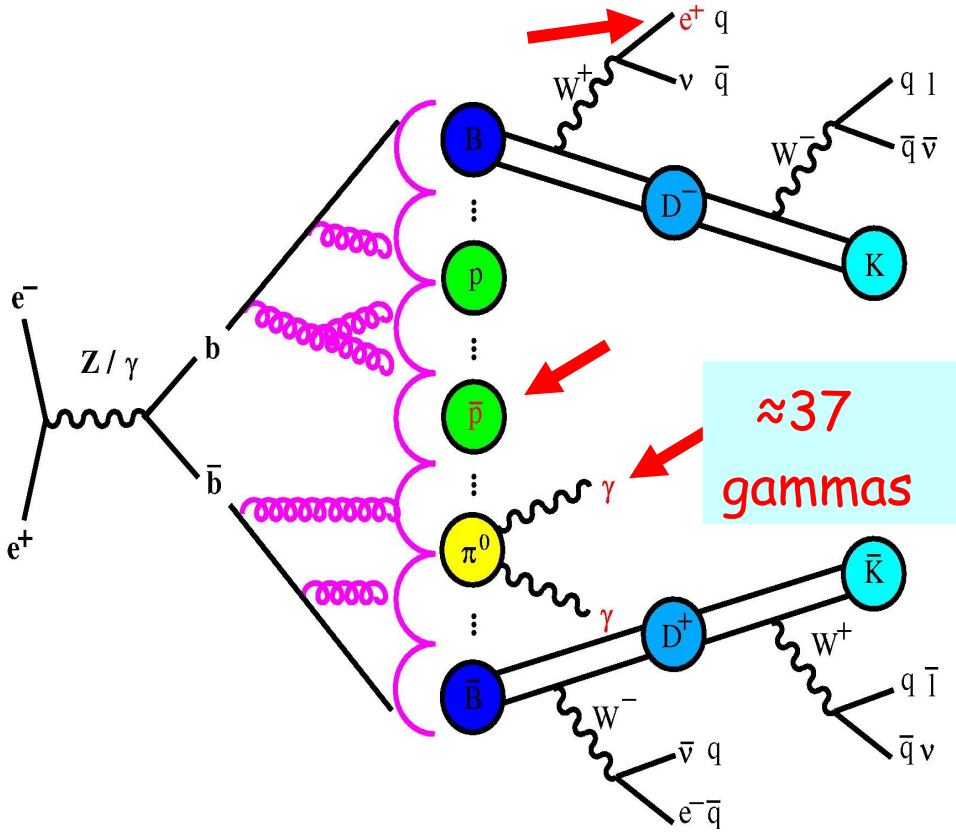
Dama, CDMS, GENIUS, CRESST, Edelweiss, …

FNAL, LHC, ILC









Dominant
X + X ➔ A ➔ b bbar quark pair

B-Fragmentation known!
Hence Spectra of Positrons, Gammas and Antiprotons known!

Galaxy = Super B-Fabrik with rate 1040 x B-Factory

Cosmic Ray Spectra

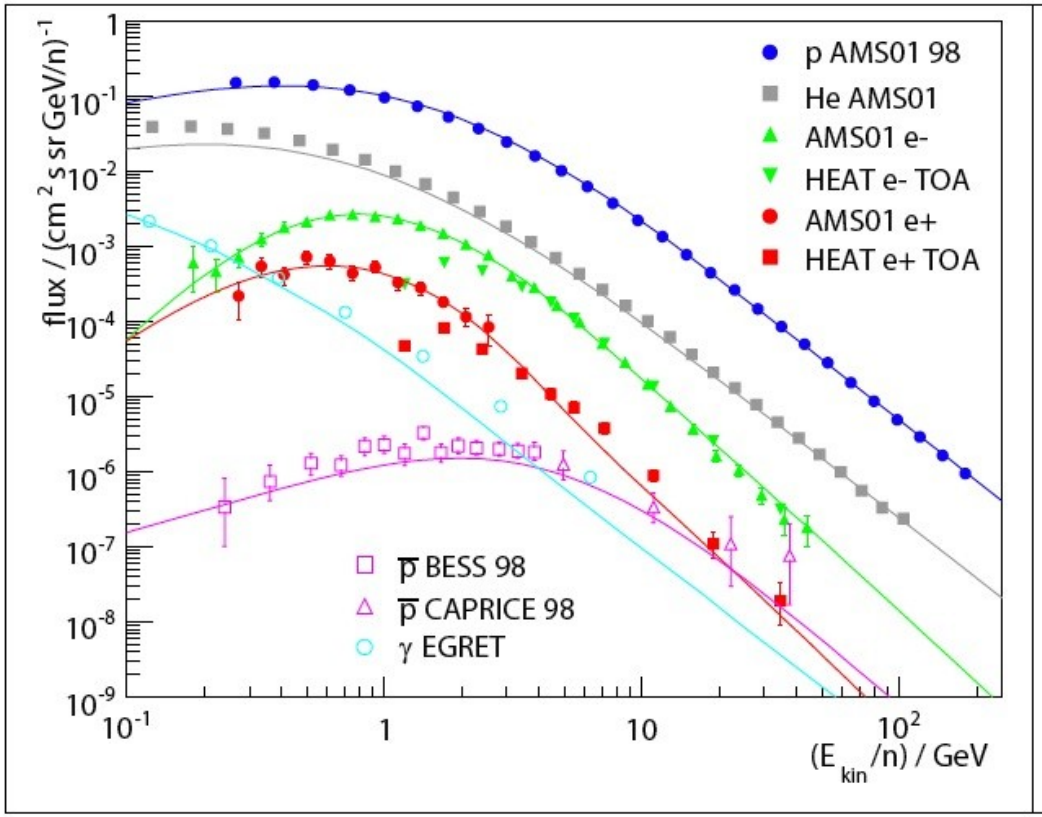
Proton Flux: $F_p : E^{-2.74}$

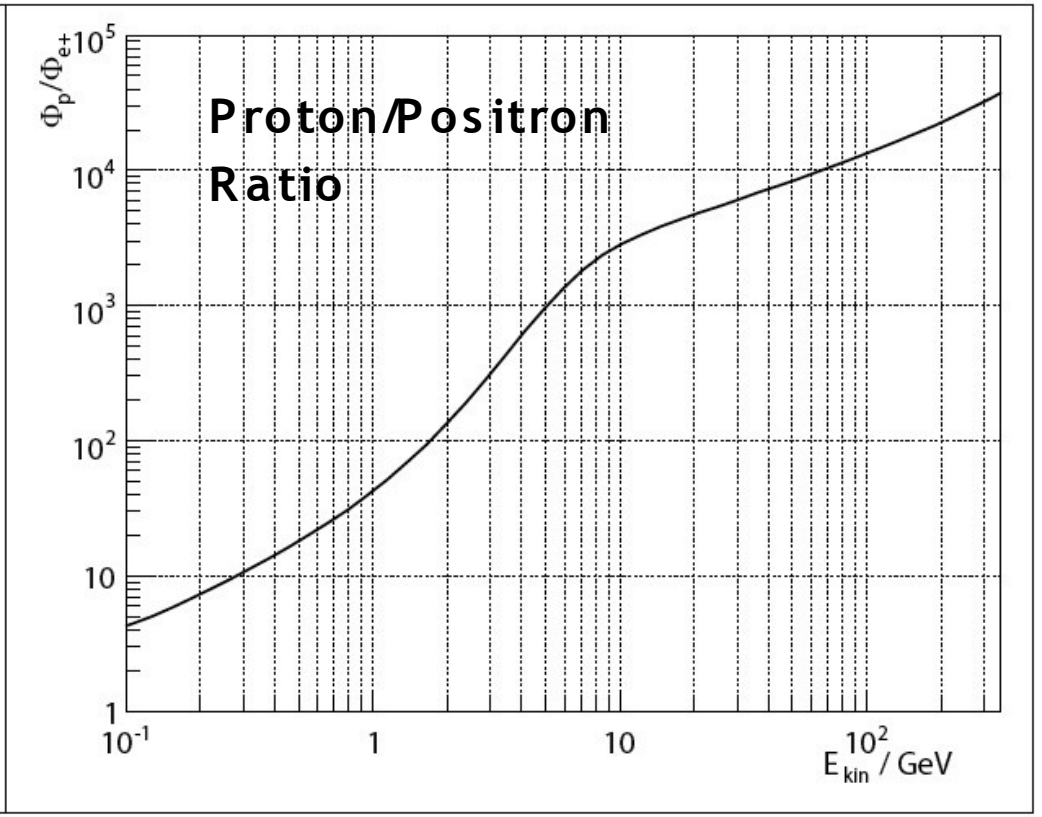
Ελεχτρον Φλυξ : $\Phi_{\varepsilon^-} : E^{-3.44}$

Ποσιτρον Φλυξ: $\Phi_{\varepsilon^+} : E^{-3.43}$

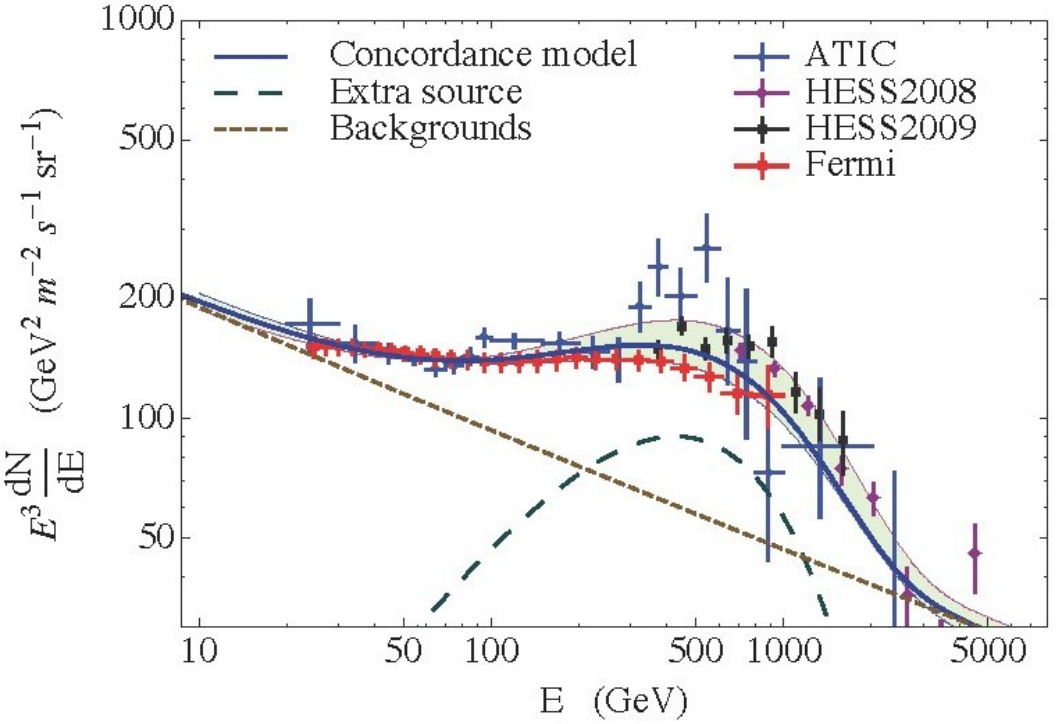
$\rho \quad 1 \ \kappa\pi\chi \ \frac{E}{1 \ T\varepsilon\varsigma}^{-1}$

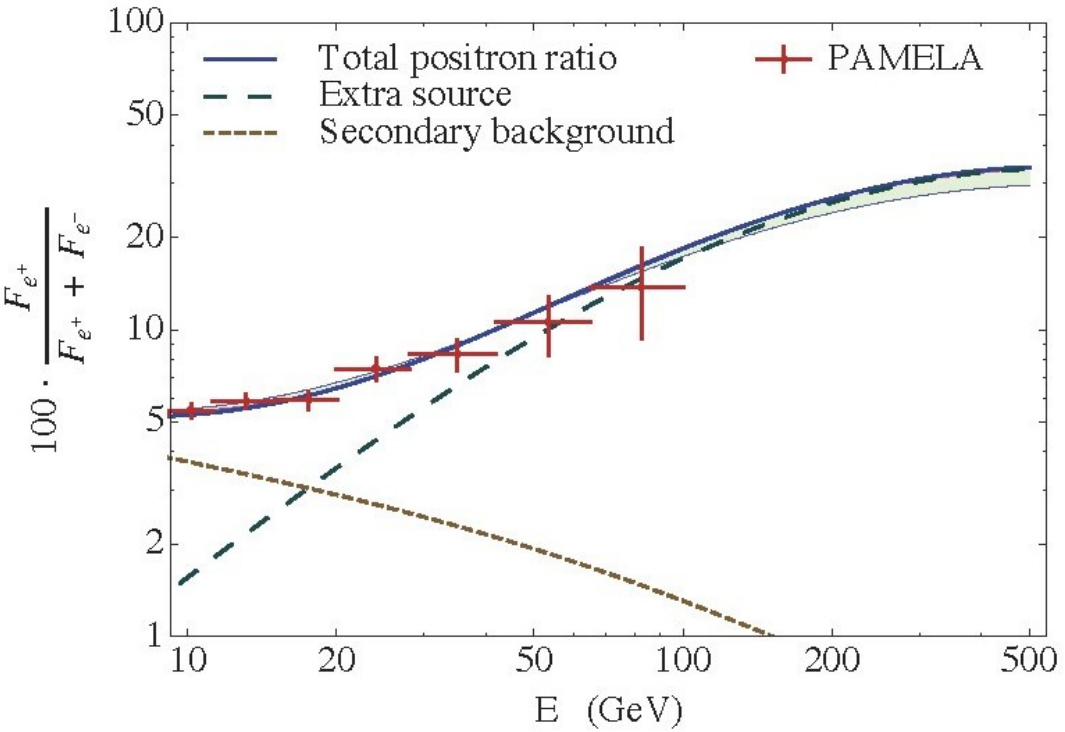
$\tau_{\rho\alpha\delta} \quad 2.1 \quad 10^5 \ \psi\rho \ \frac{E}{1 \ T\varepsilon\varsigma}^{-1}$



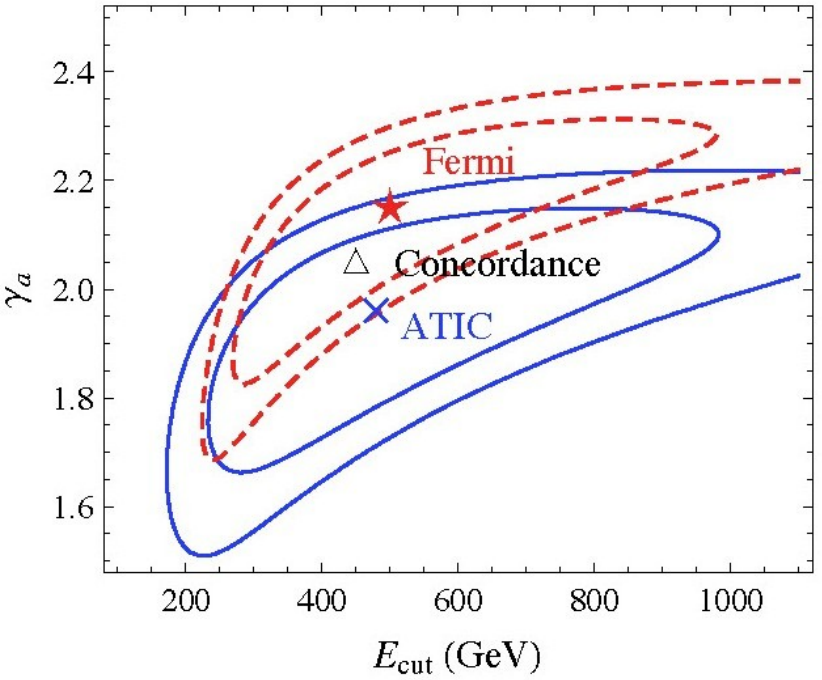


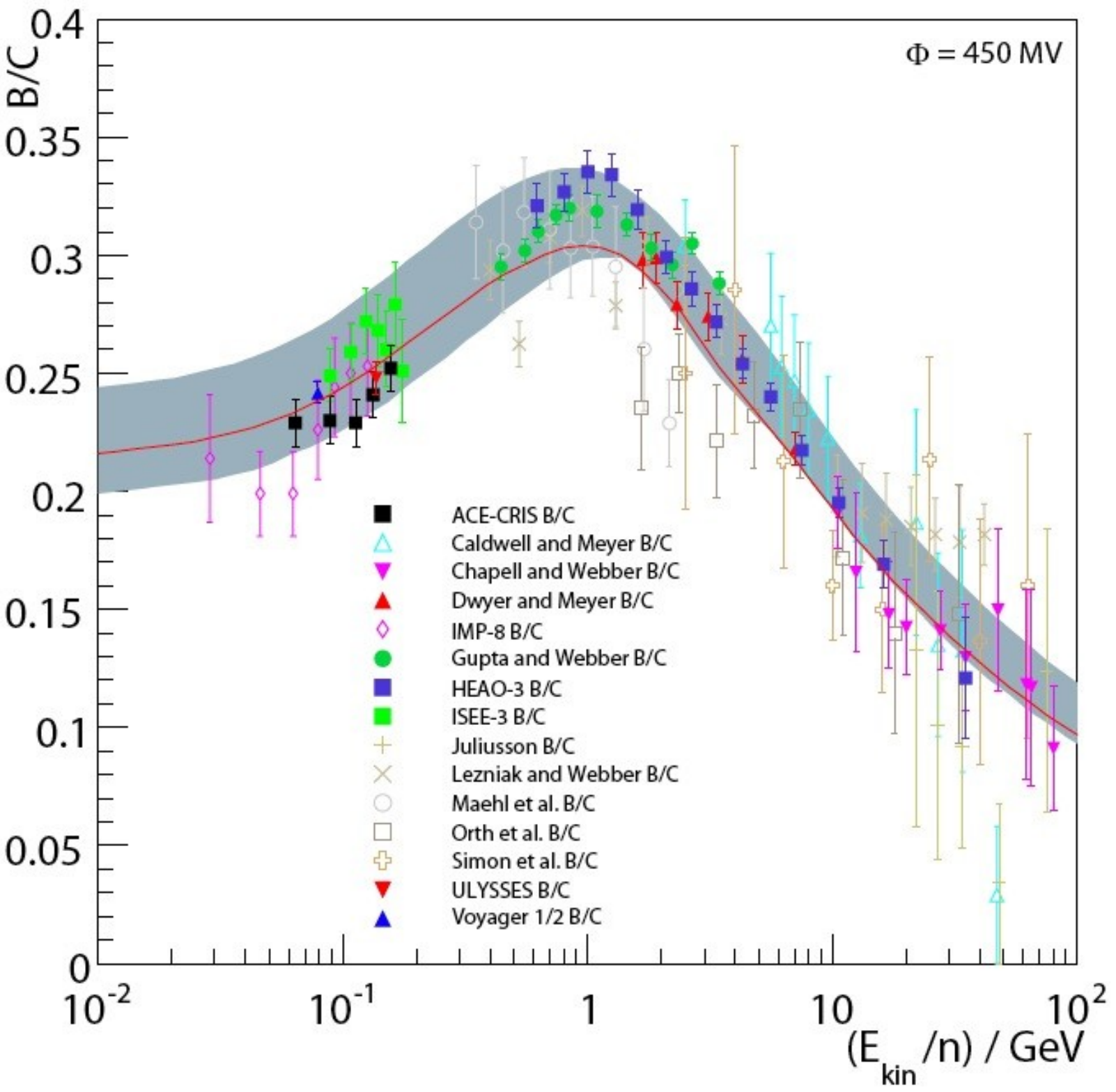
D. Malyshev, astro-ph.HE/0905.2611





$$F_a : E^{-\gamma_\alpha} \varepsilon^{-E/E_{\chi\upsilon\tau}}$$




Φ = 450 MV
B/C
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10^{-2}
10^{-1}
1
10
10^{2}
(E_{kin}/n) / GeV
ACE-CRIS B/C
Caldwell and Meyer B/C
Chapell and Webber B/C
Dwyer and Meyer B/C
IMP-8 B/C
Gupta and Webber B/C
HEAO-3 B/C
ISEE-3 B/C
Juliusson B/C
Lezniak and Webber B/C
Maehl et al. B/C
Orth et al. B/C
Simon et al. B/C
ULYSSES B/C
Voyager 1/2 B/C

Antarctic LDB Facilities (new)

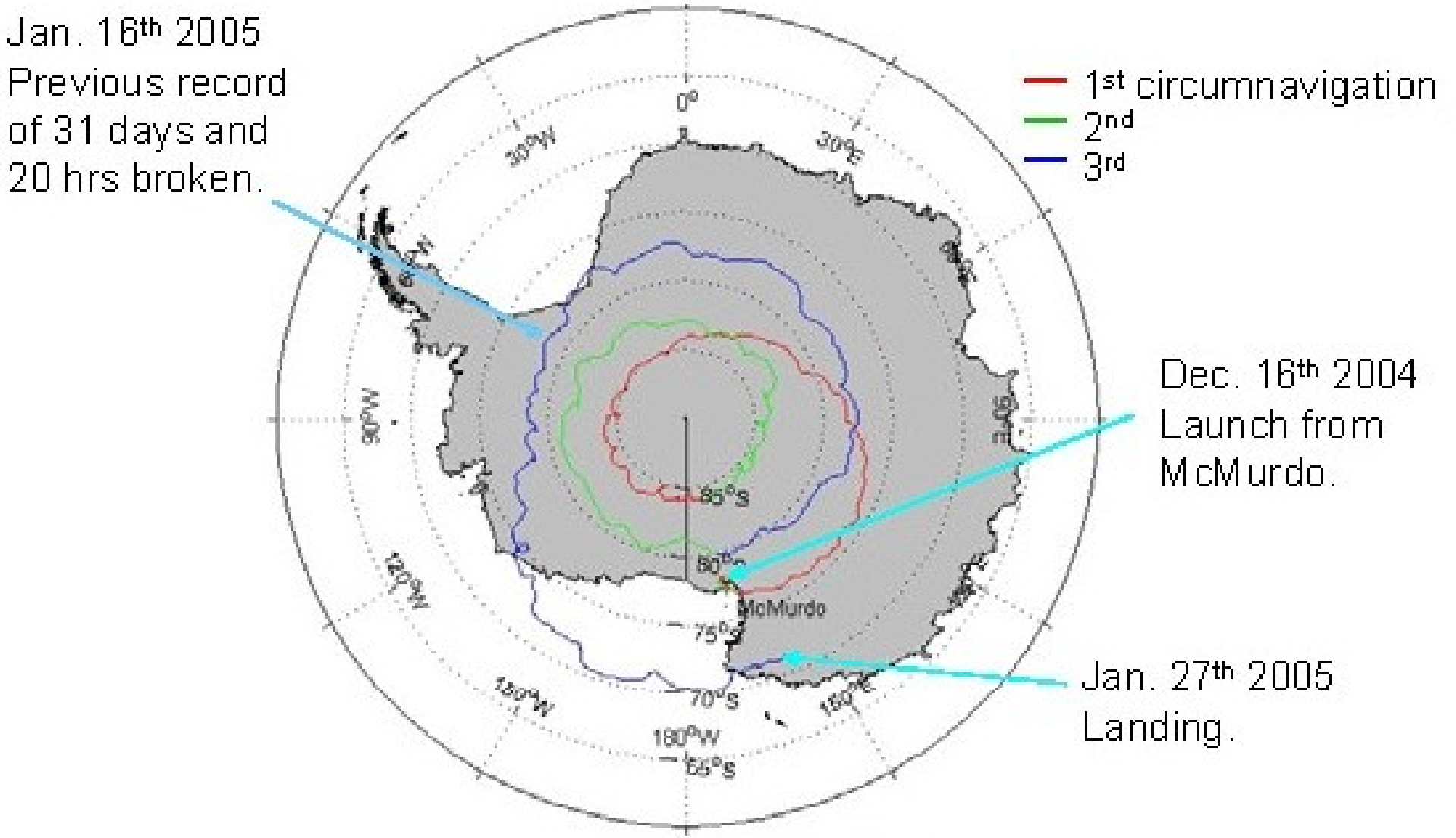


Figure 1. Balloon trajectory of the CREAM flight. CREAM broke both distance (~14,000 nautical miles) and duration (41 days 21 hrs 36 mins) records for a LDB flight.

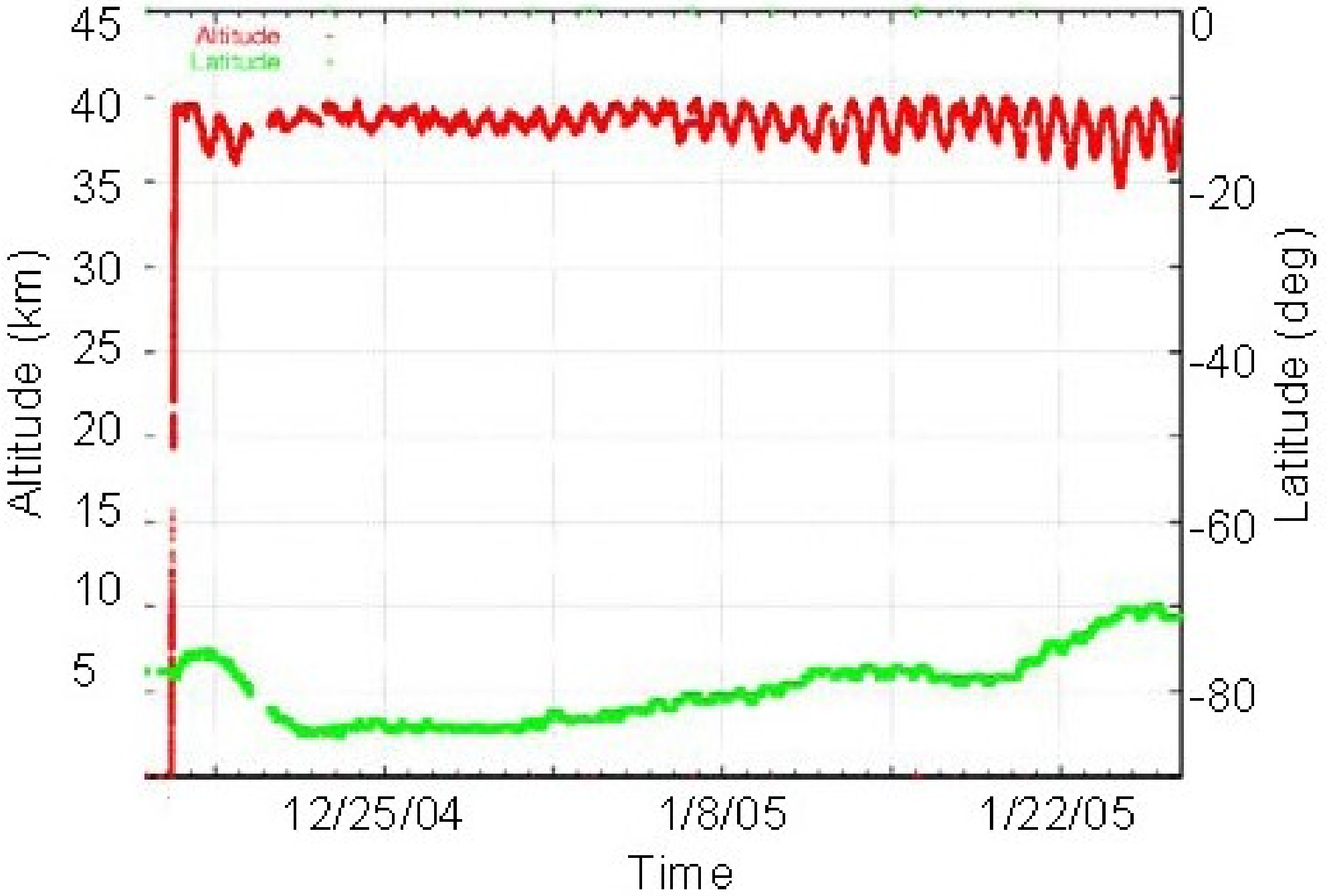
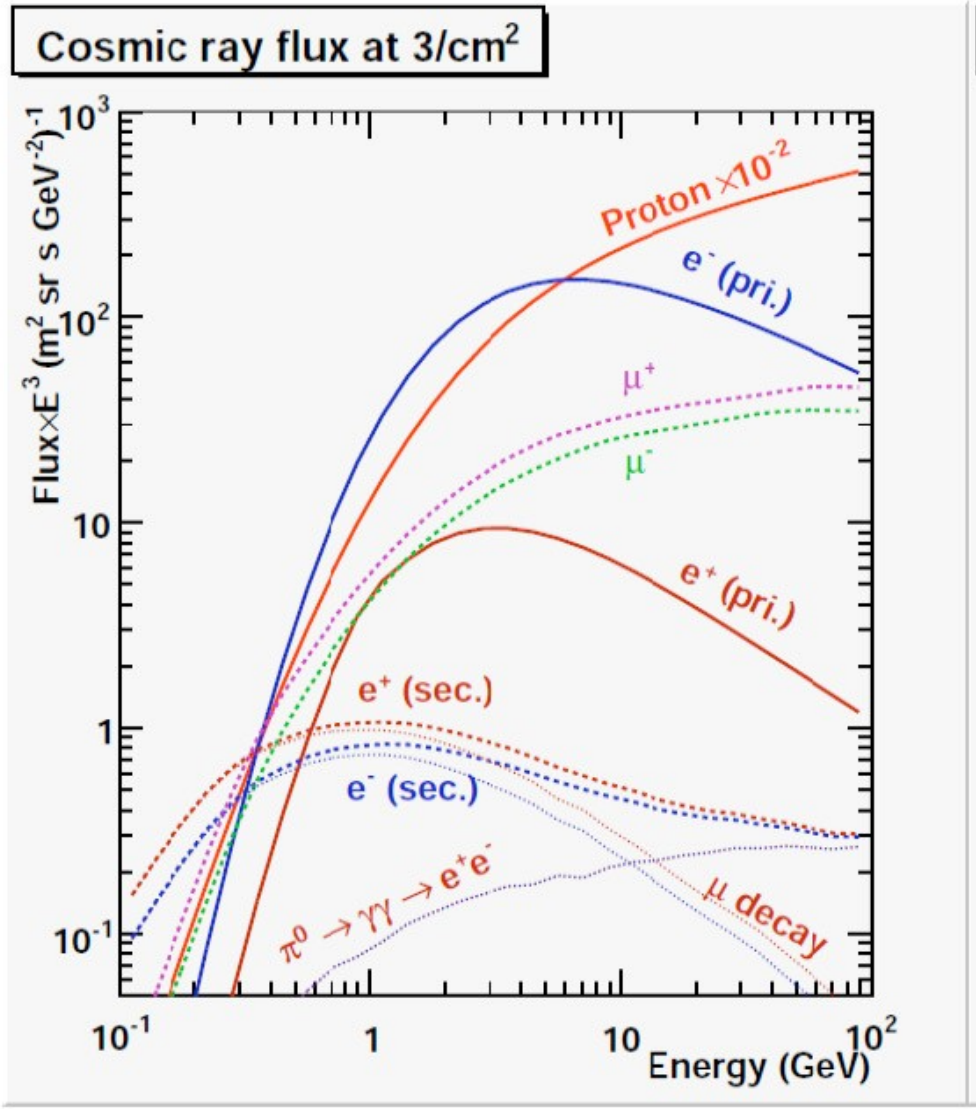
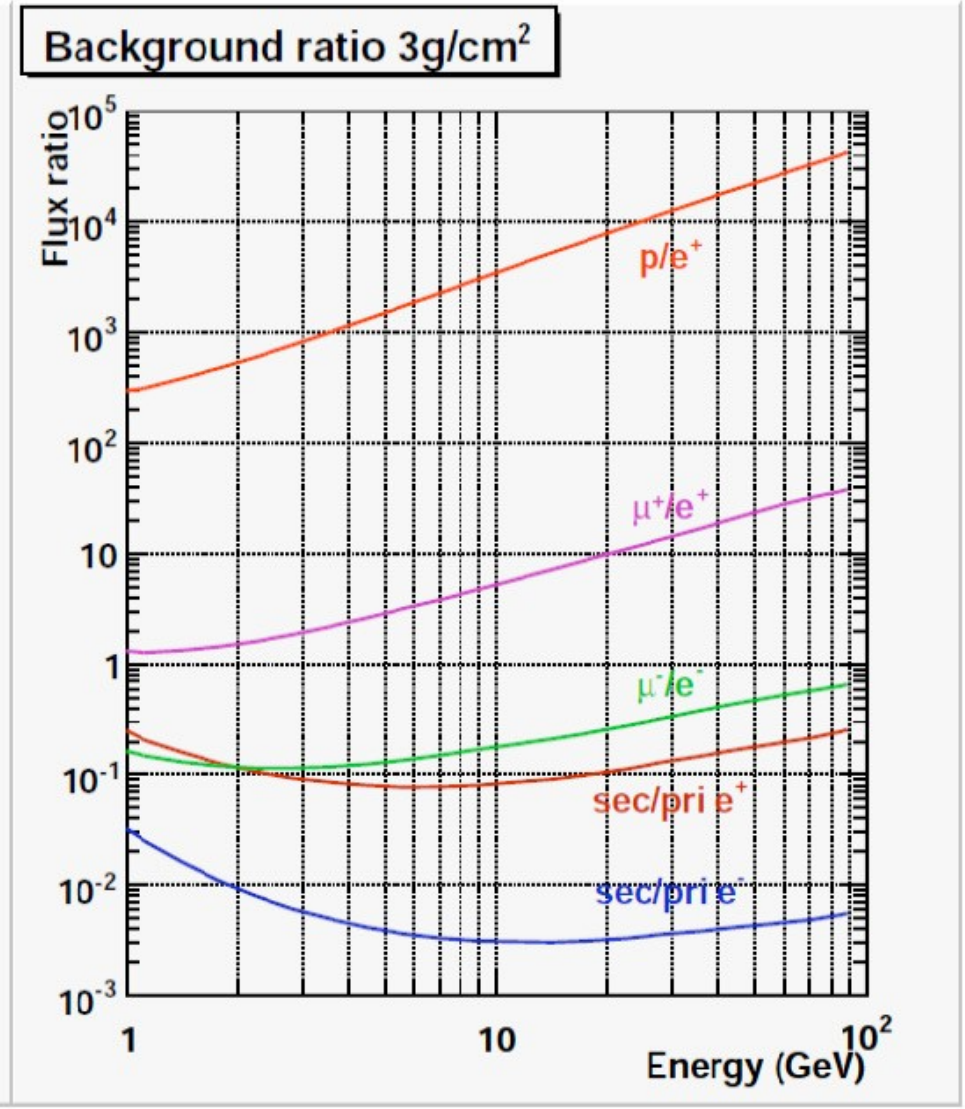
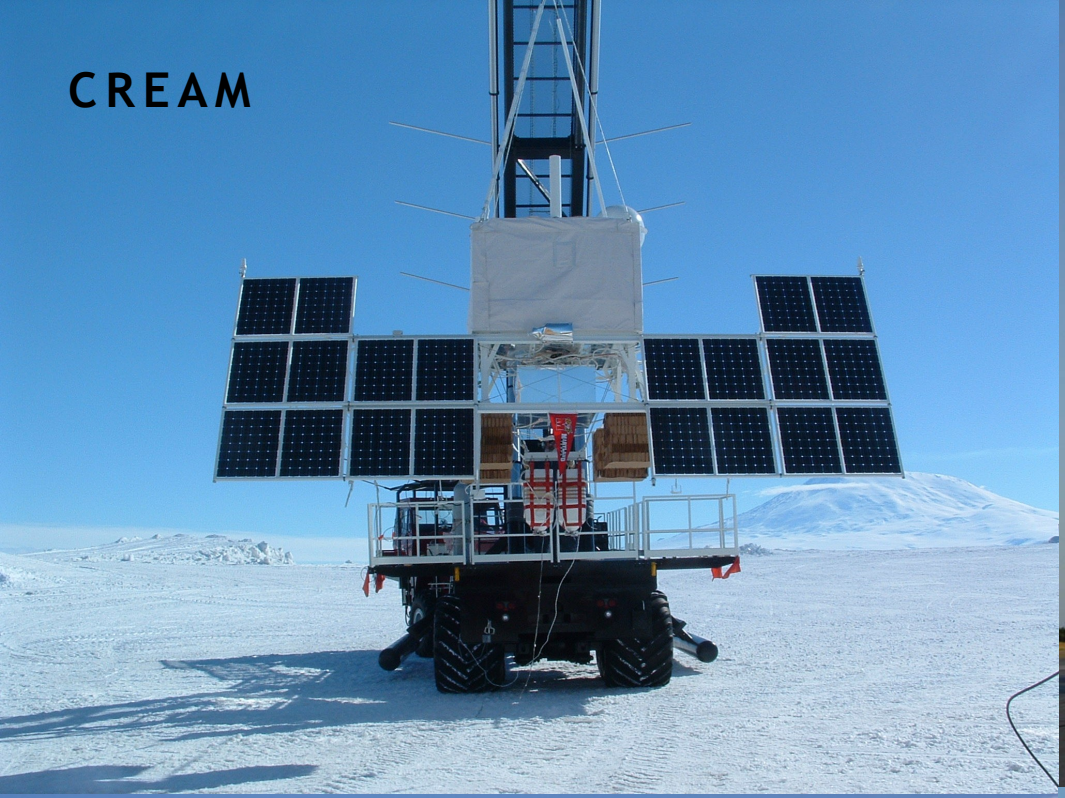


Figure 2. Altitude and latitude of the balloon.

Cosmic-ray flux at 3g/cm^2 (40km)






CREAM

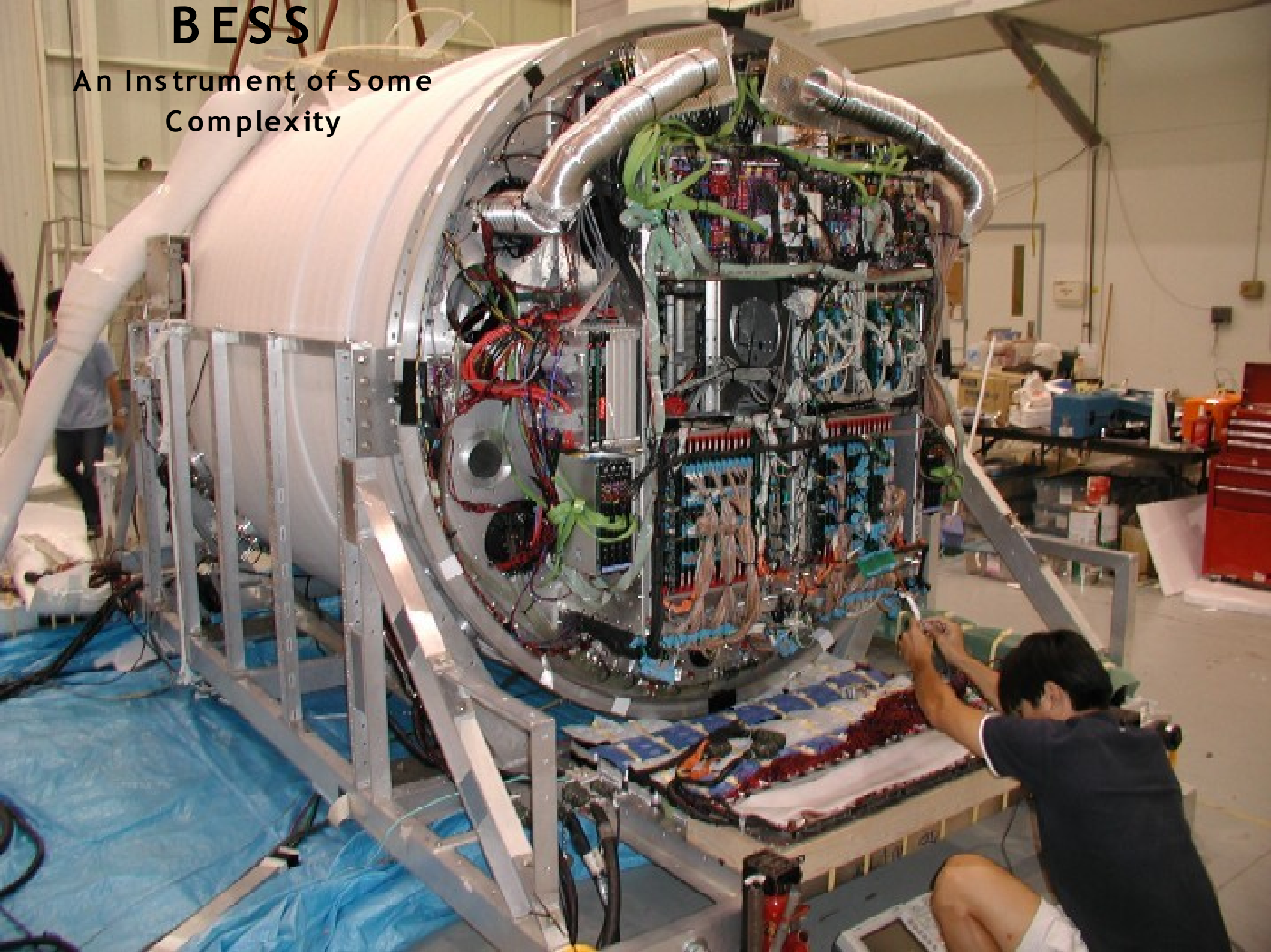

BESS


TRACER

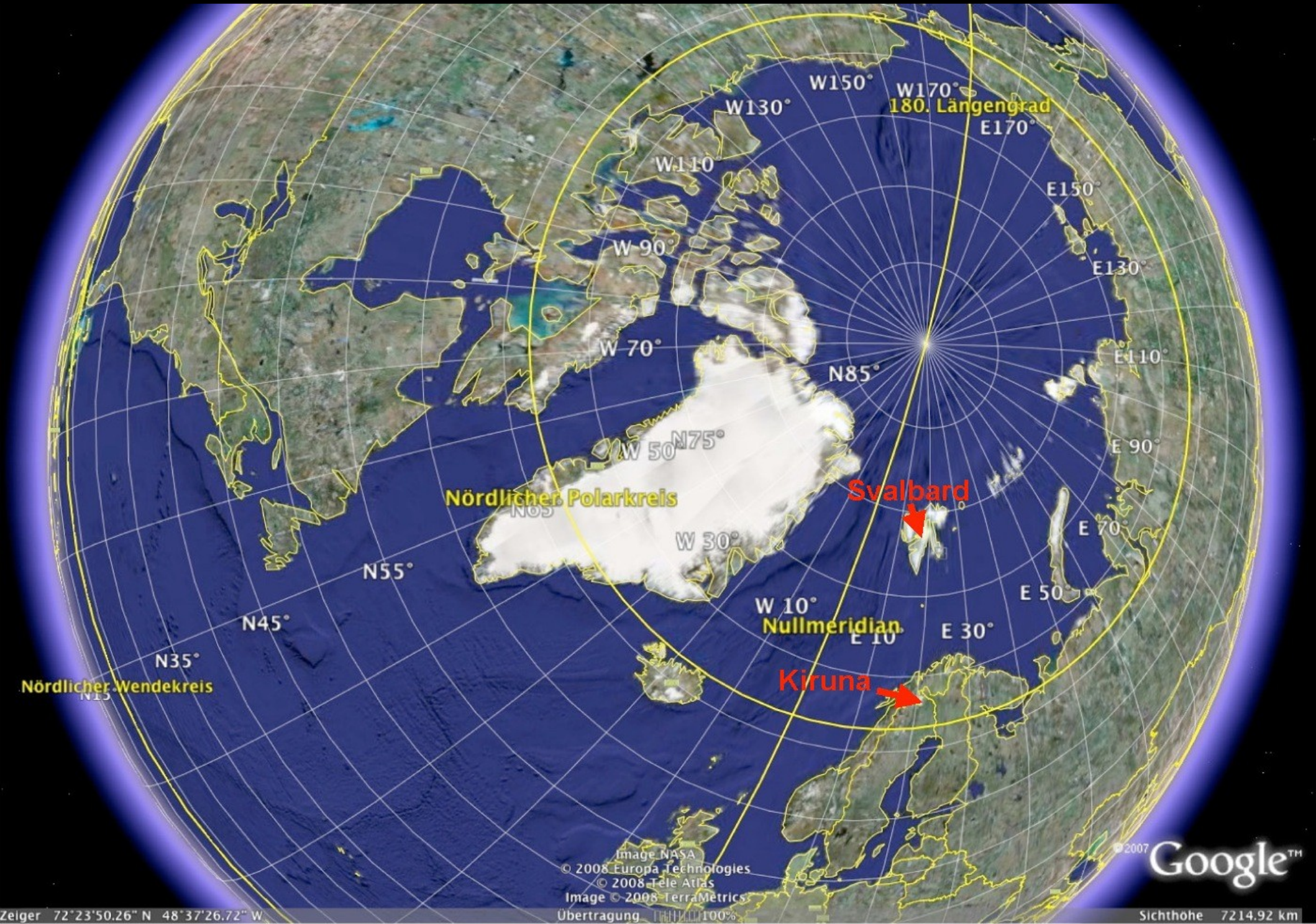

TIGER

BESS

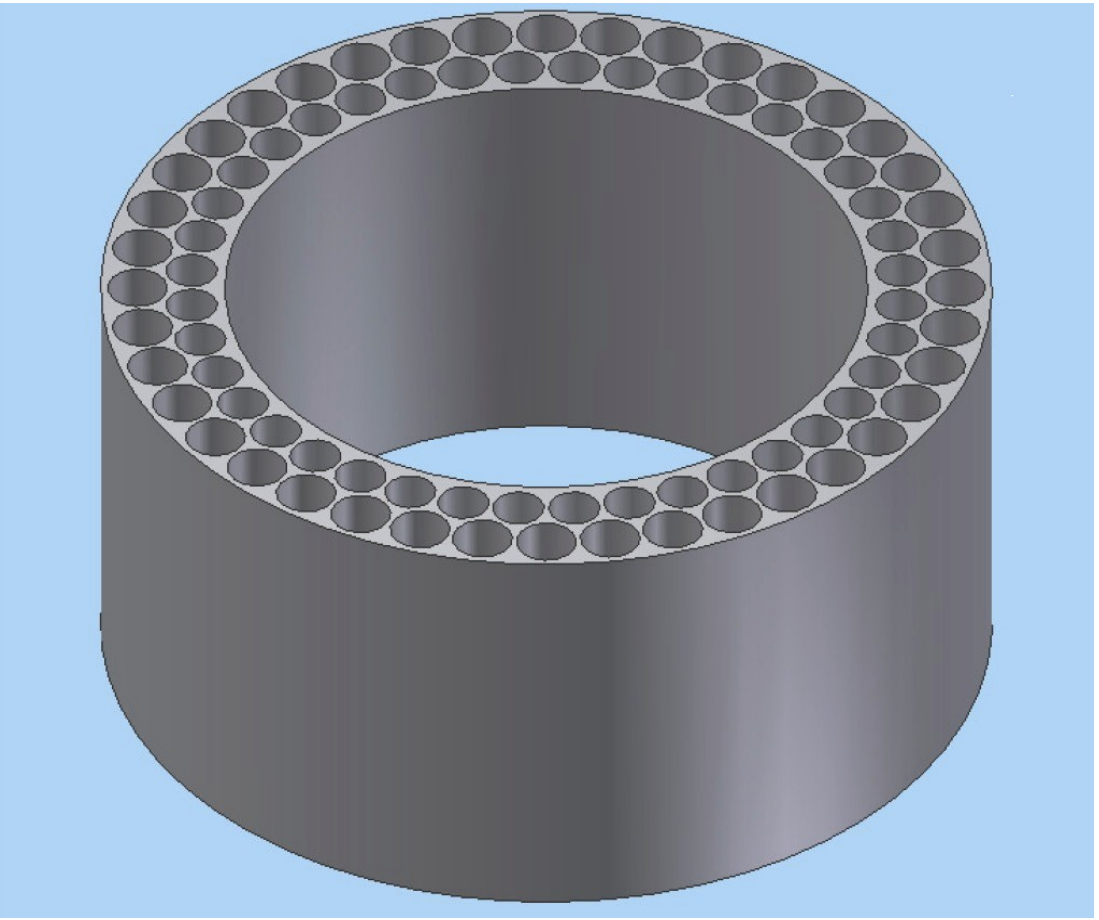
An Instrument of Some Complexity

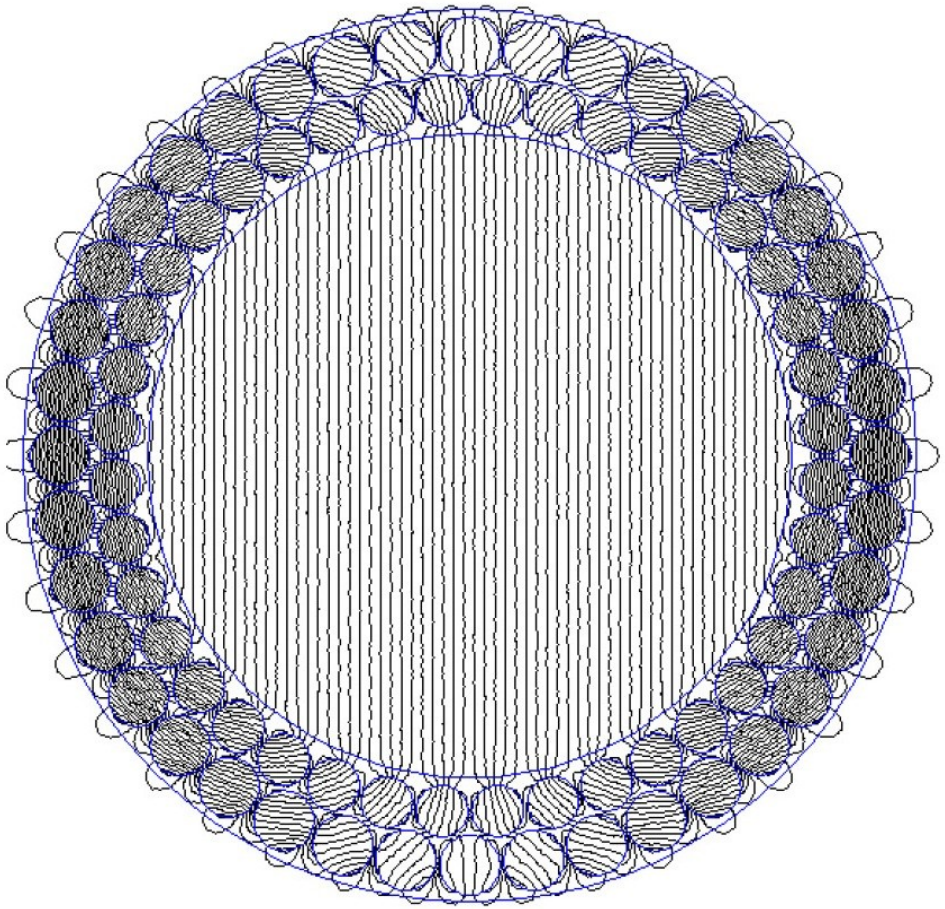


Launch Sides



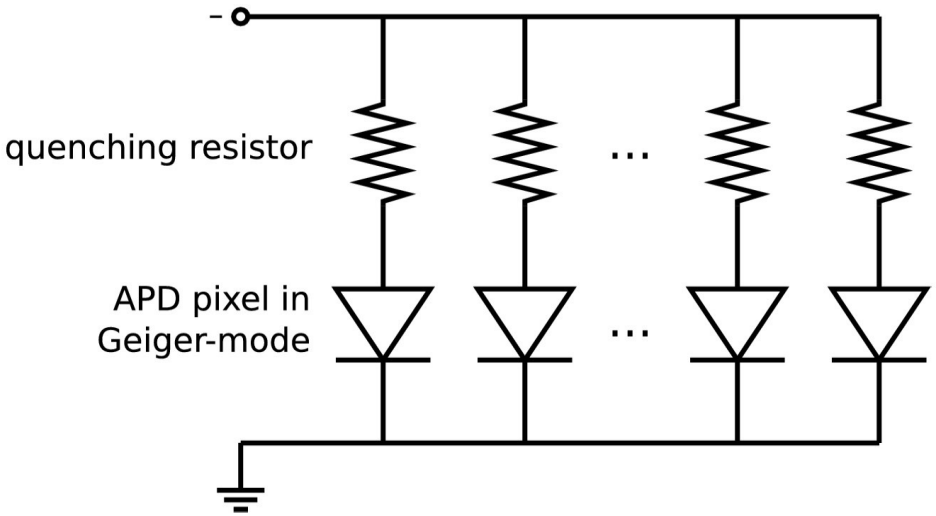
PEBS-1 Permanent Magnet



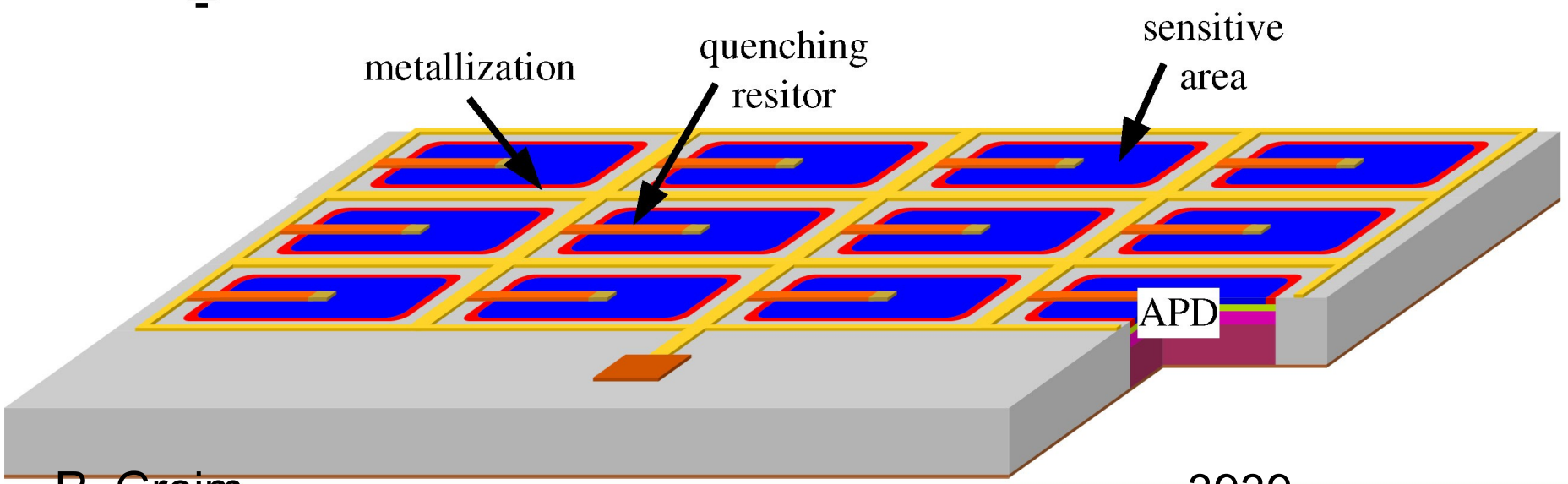


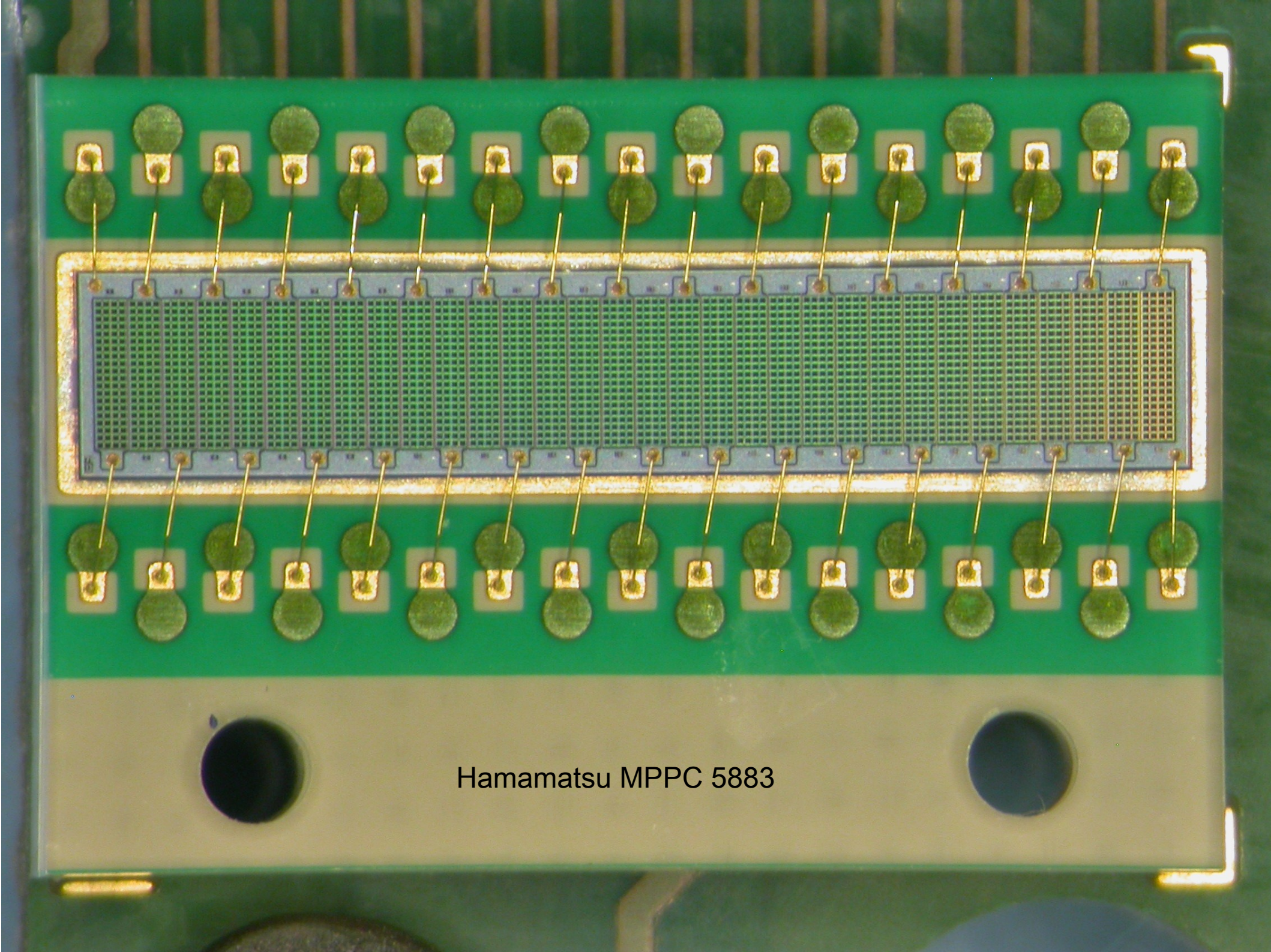
Weight 250 kg, B-Field 0.3 Tesla,
rInner=0.31 m, rOuter = 0.43 m, Height = 12.5 cm

Silicon Photomultipliers
(Geiger-mode APD)



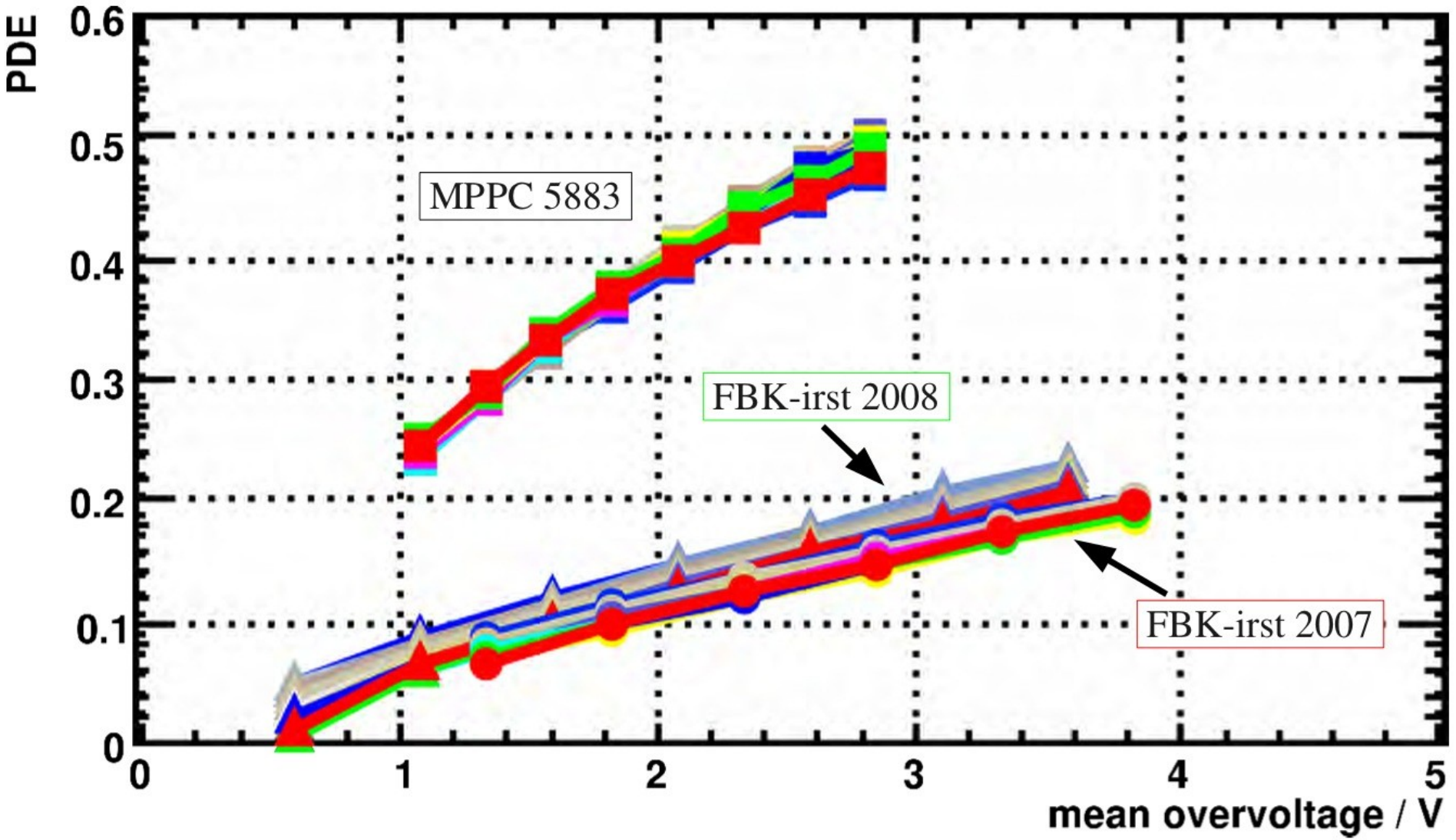
- avalanche photo diodes (APD) operated in Geiger mode
- internal gain ~10^6, compact in dimension, insensitive to magnetic fields, low bias voltage (<100 V)
- noise is an issue




Hamamatsu MPPC 5883

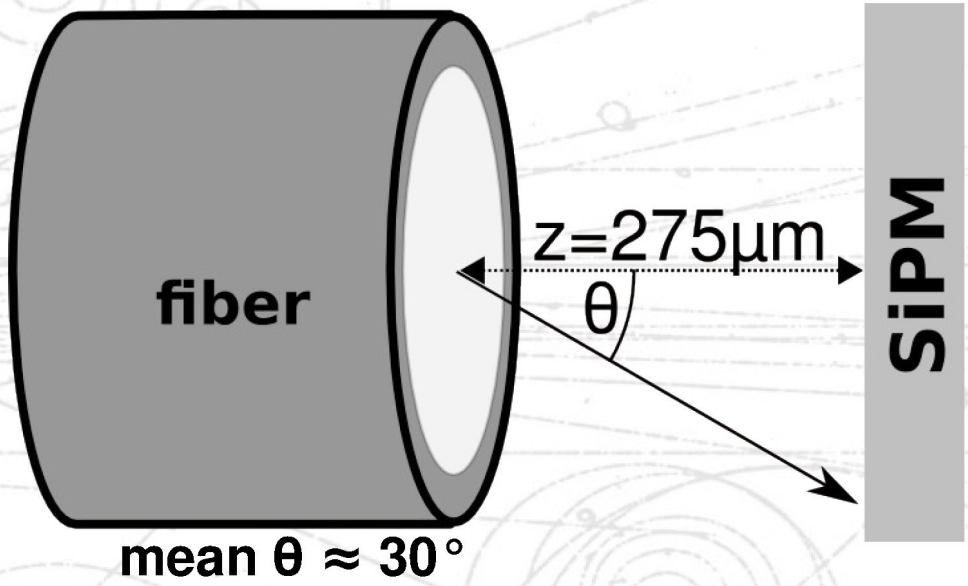
Photon detection efficiency

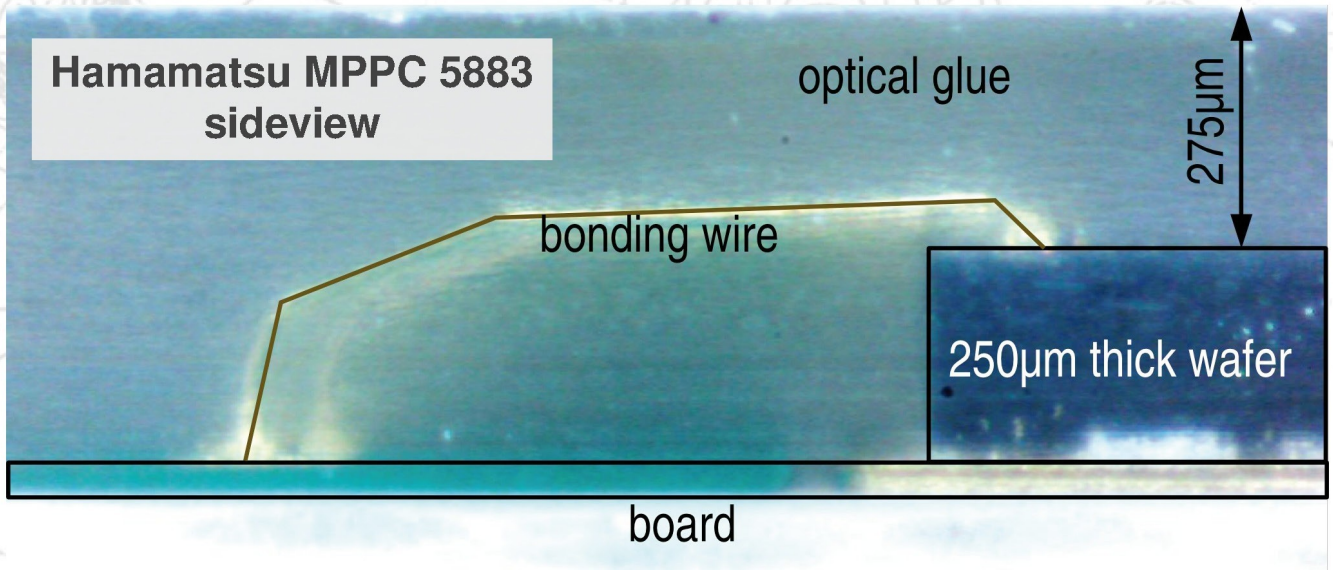
@ 440nm



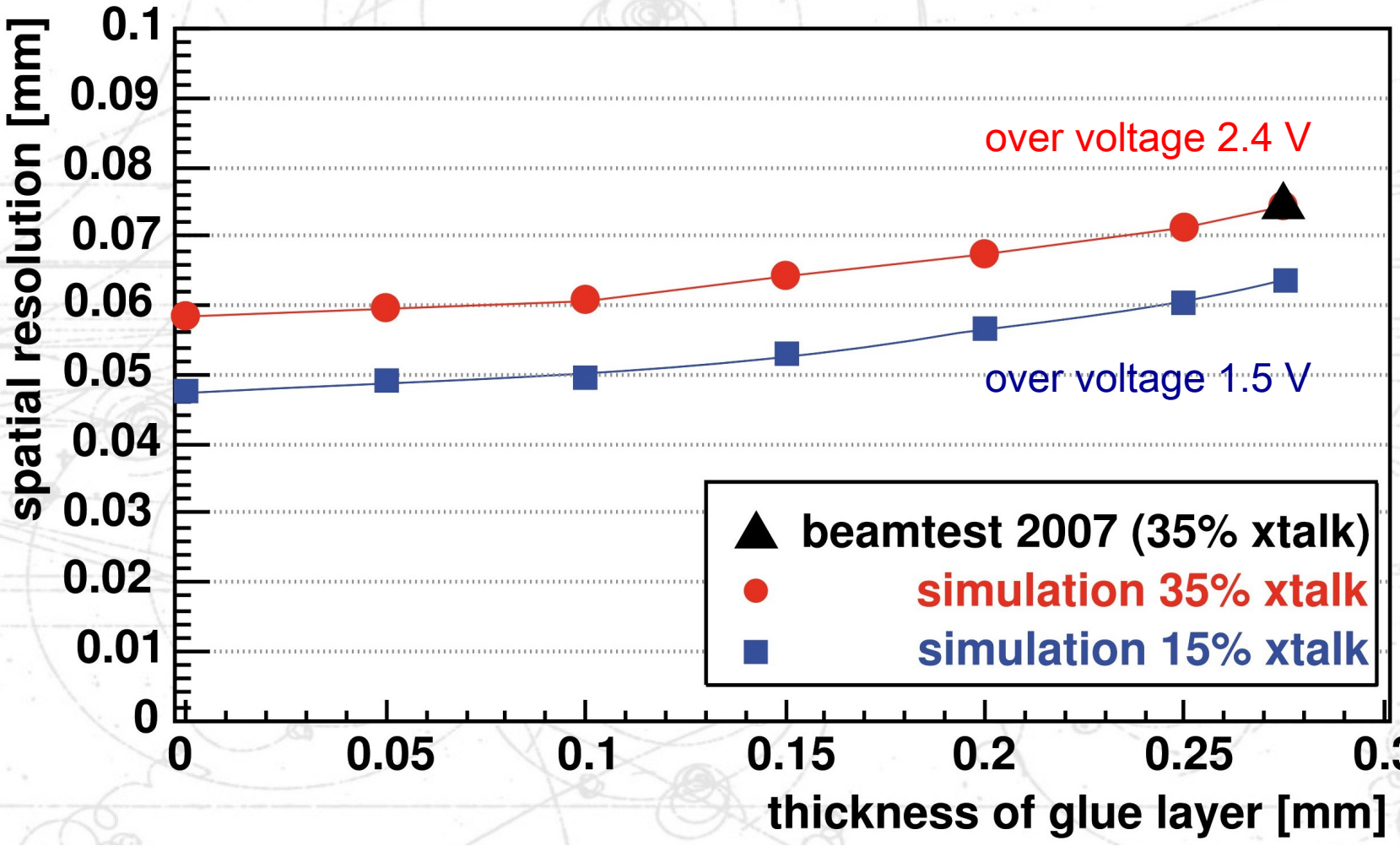
Optical Glue On MPPC 5883

- *optical glue layer on top of Hamamatsu MPPC 5883 defines fiber-SiPM-gap*

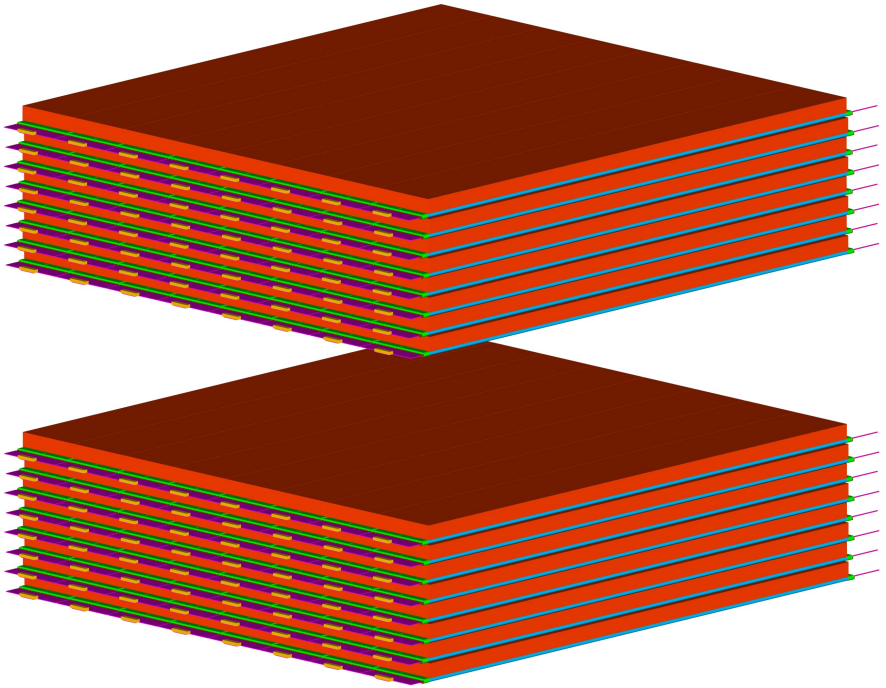


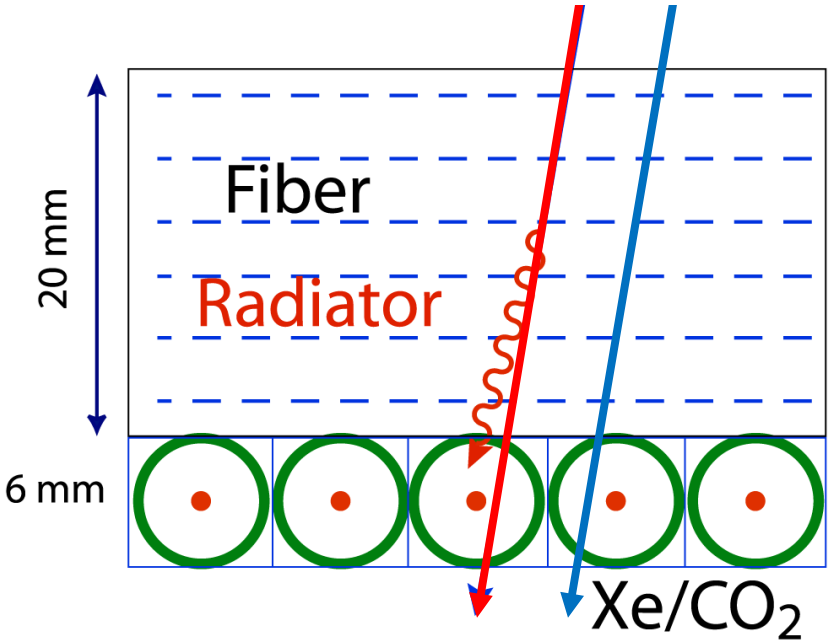


Expected Resolution



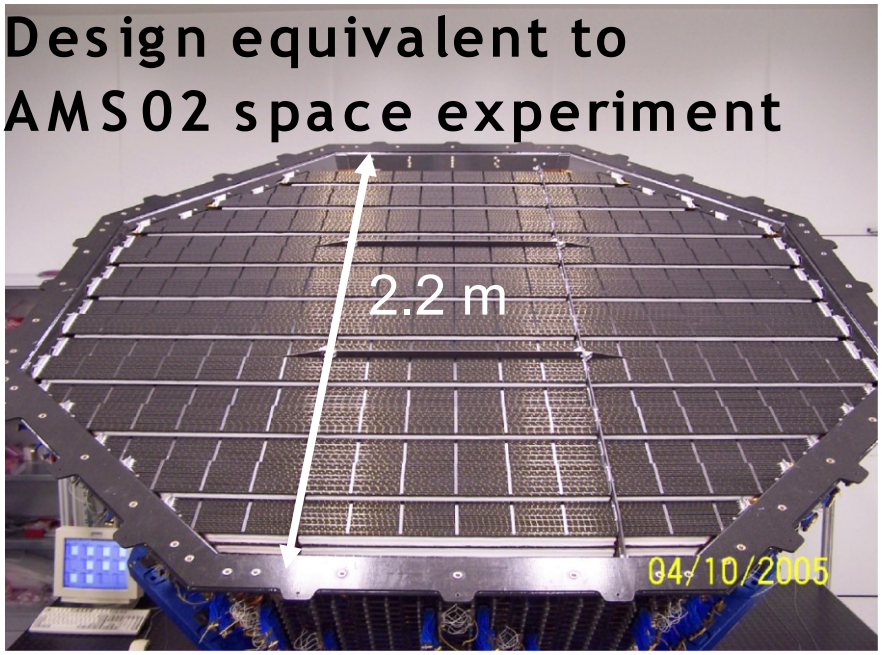
TRD design





2 x 8 layers of fleece radiator,
TR x-ray photons absorbed by Xe/CO2 mixture (80:20), in 6mm straw tubes with 30 µm tungsten wire

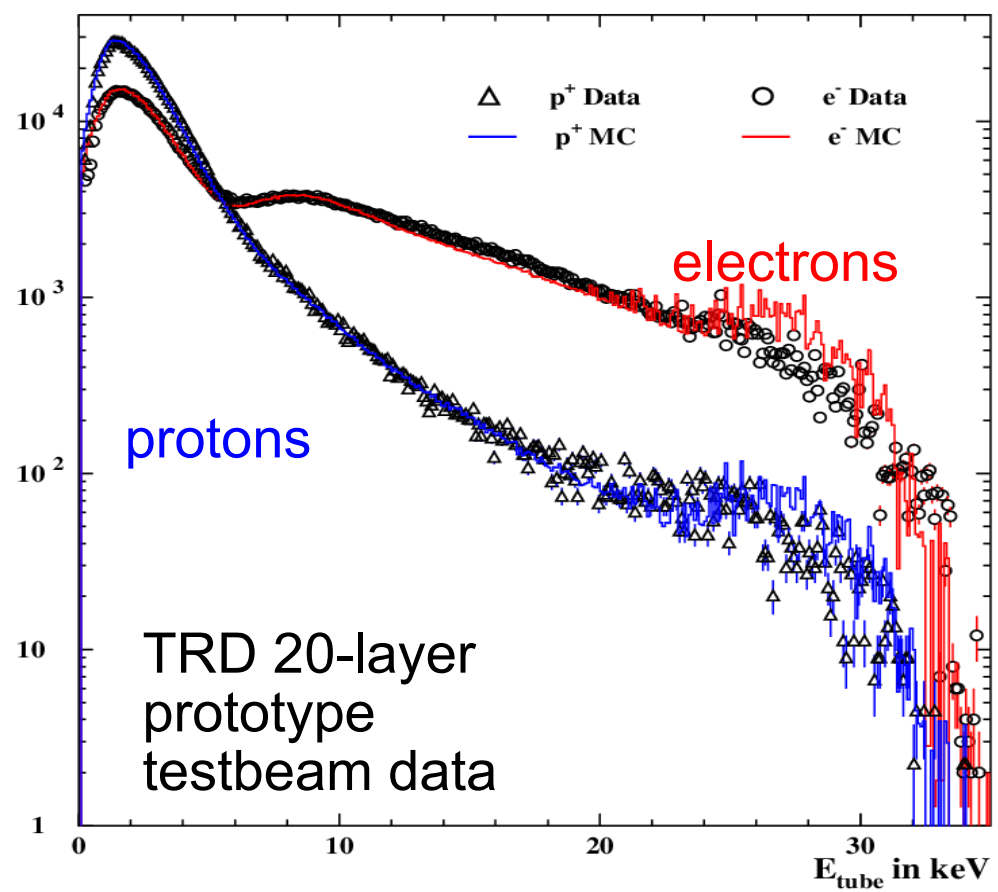
Design equivalent to AMS02 space experiment

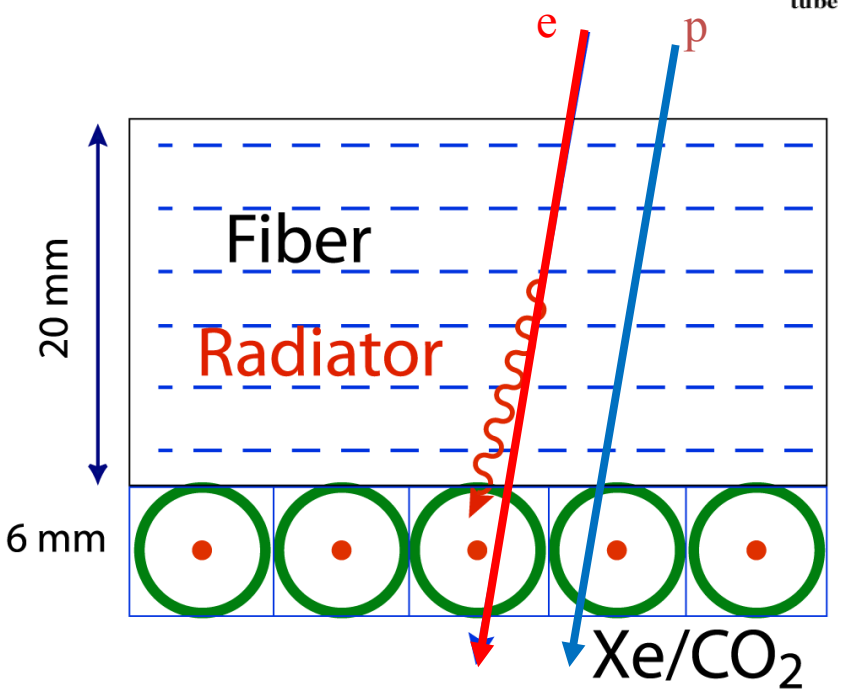


AMS02 TRD octagon integrated at RWTH Aachen

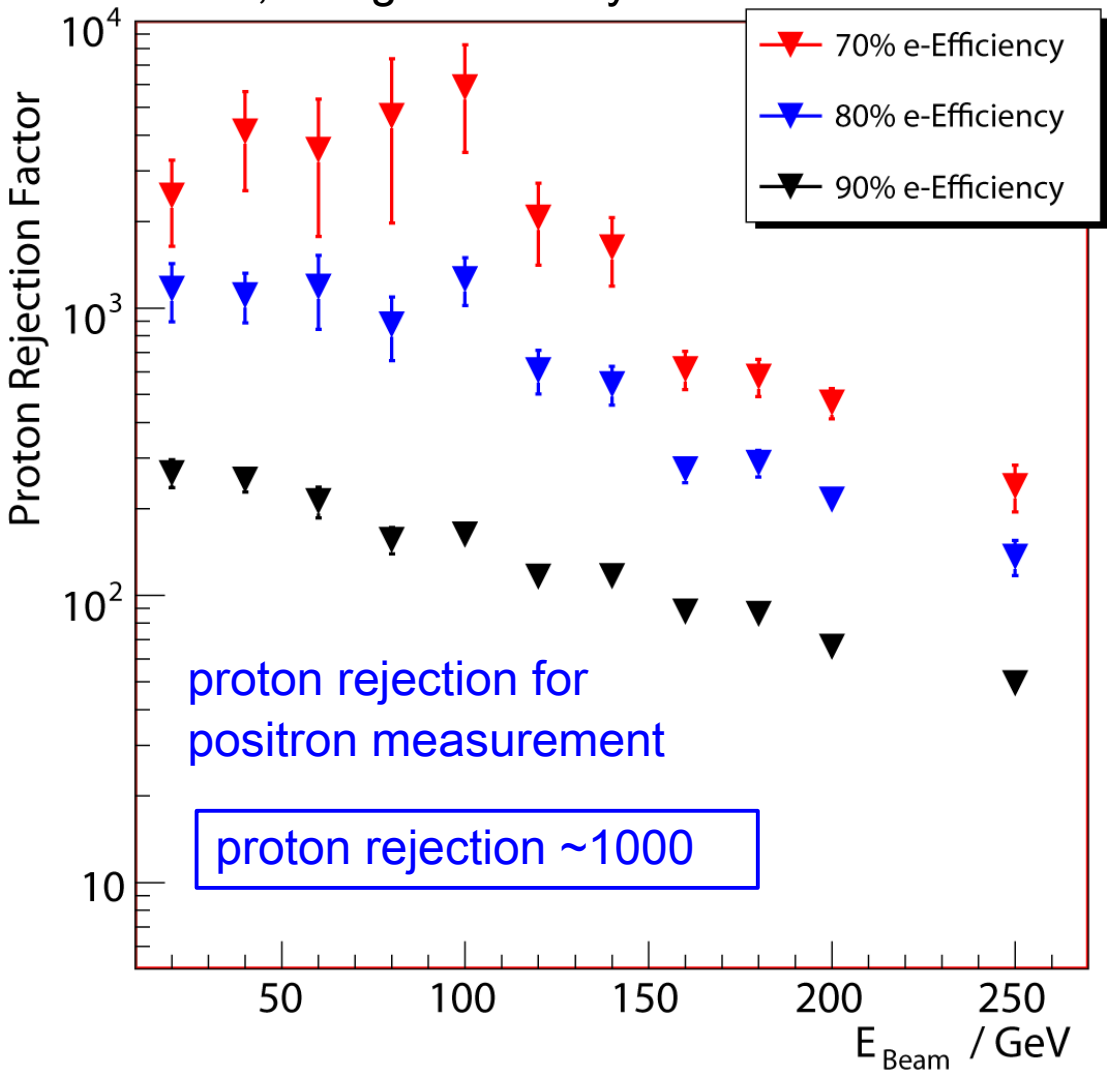
workshop

TRD Performance



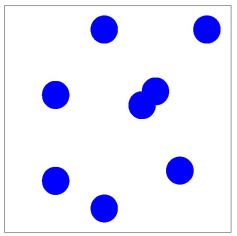


Analysis of TRD prototype testbeam data, using first 16 layers

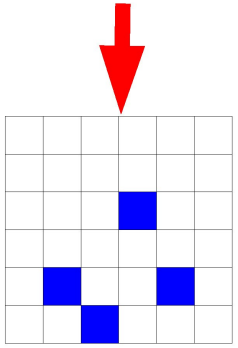


ECAL dynamic range

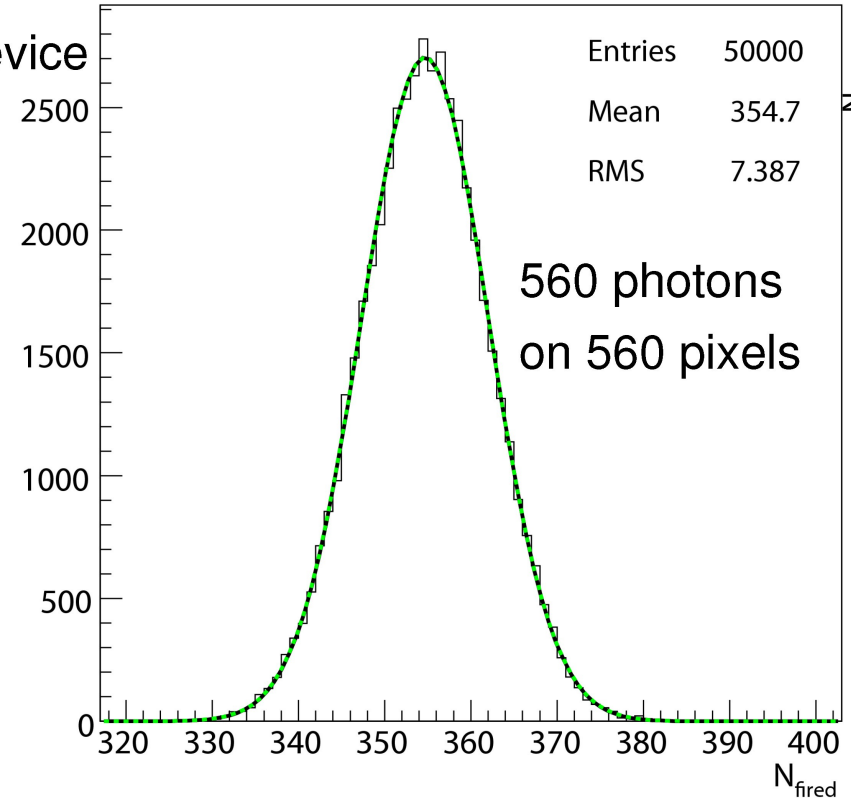
SiPM is pixellated device

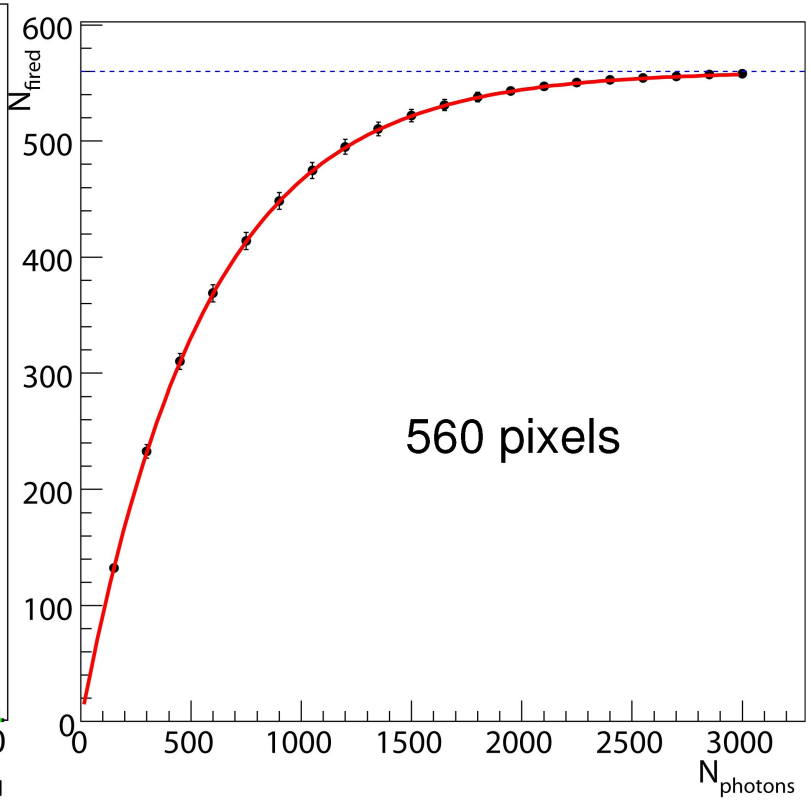


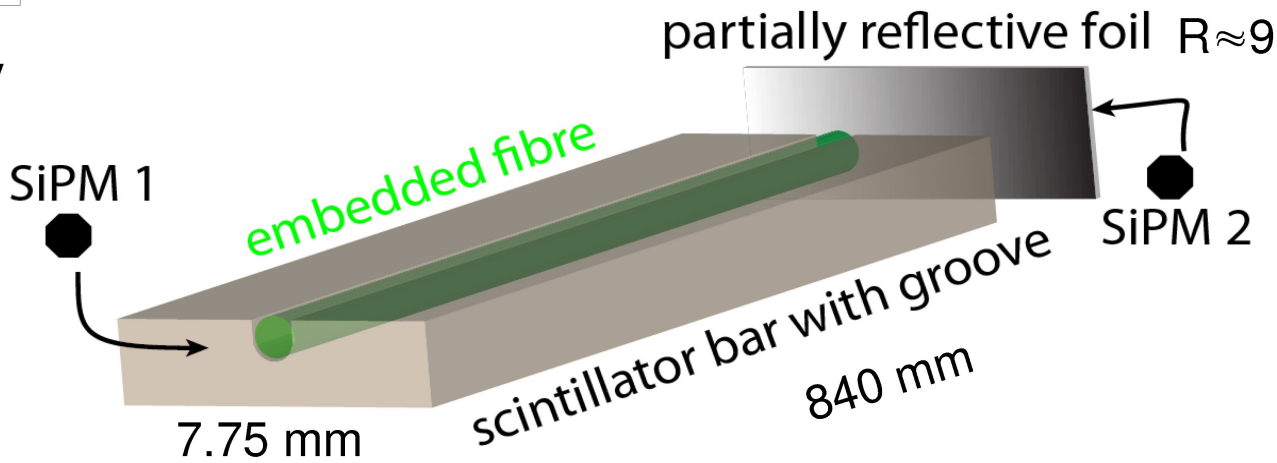
photons at fibre end



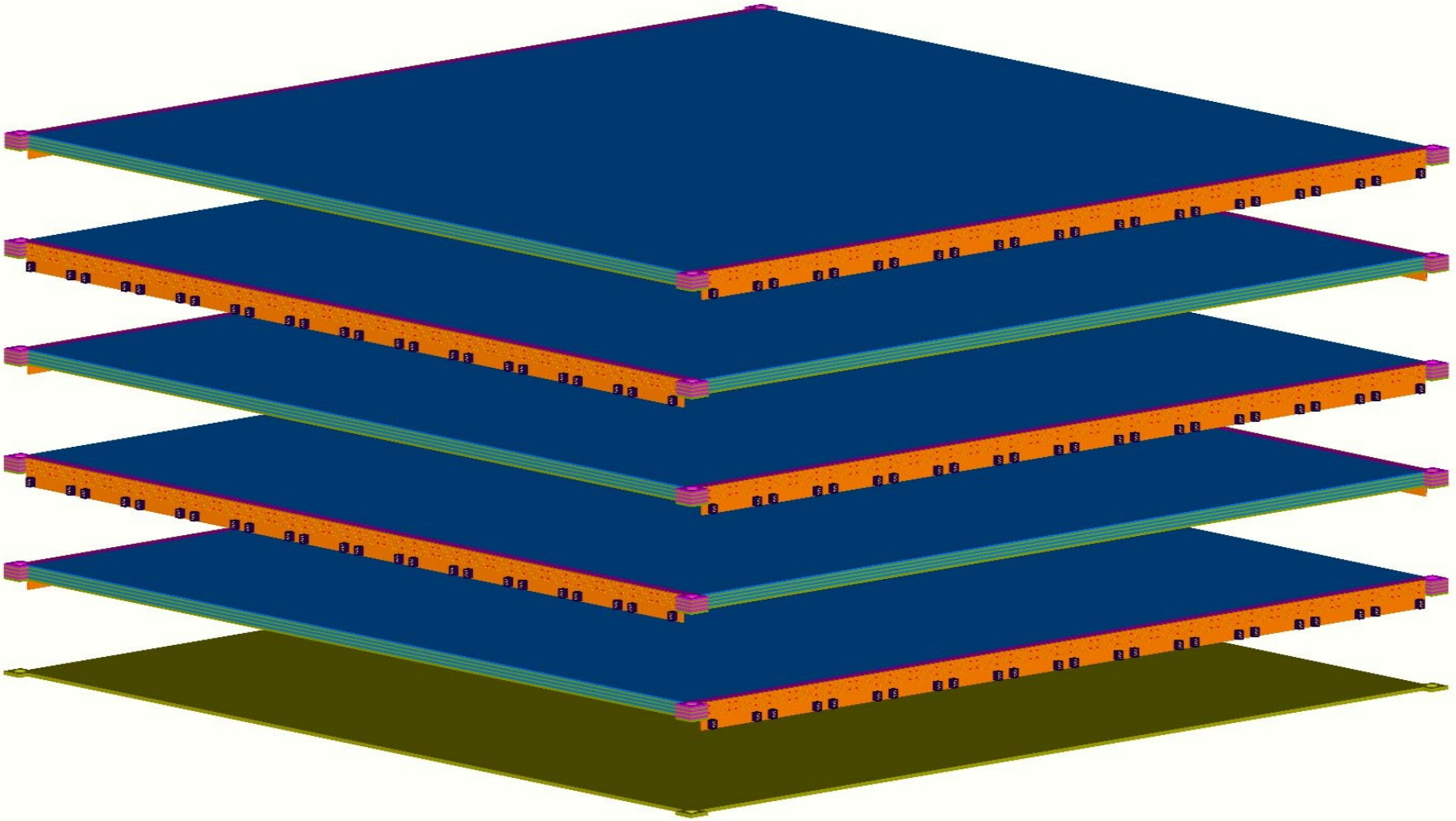
pixel array



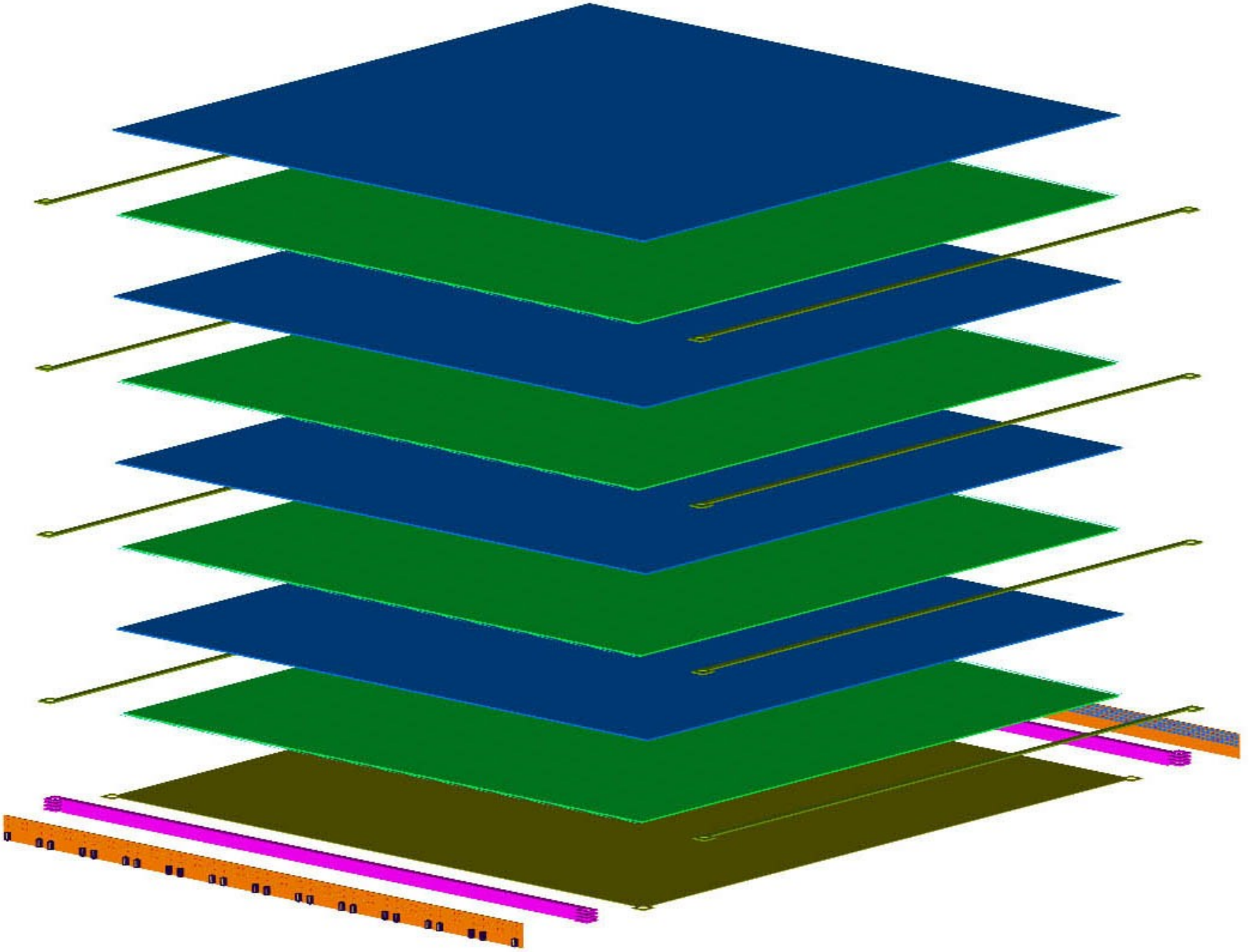




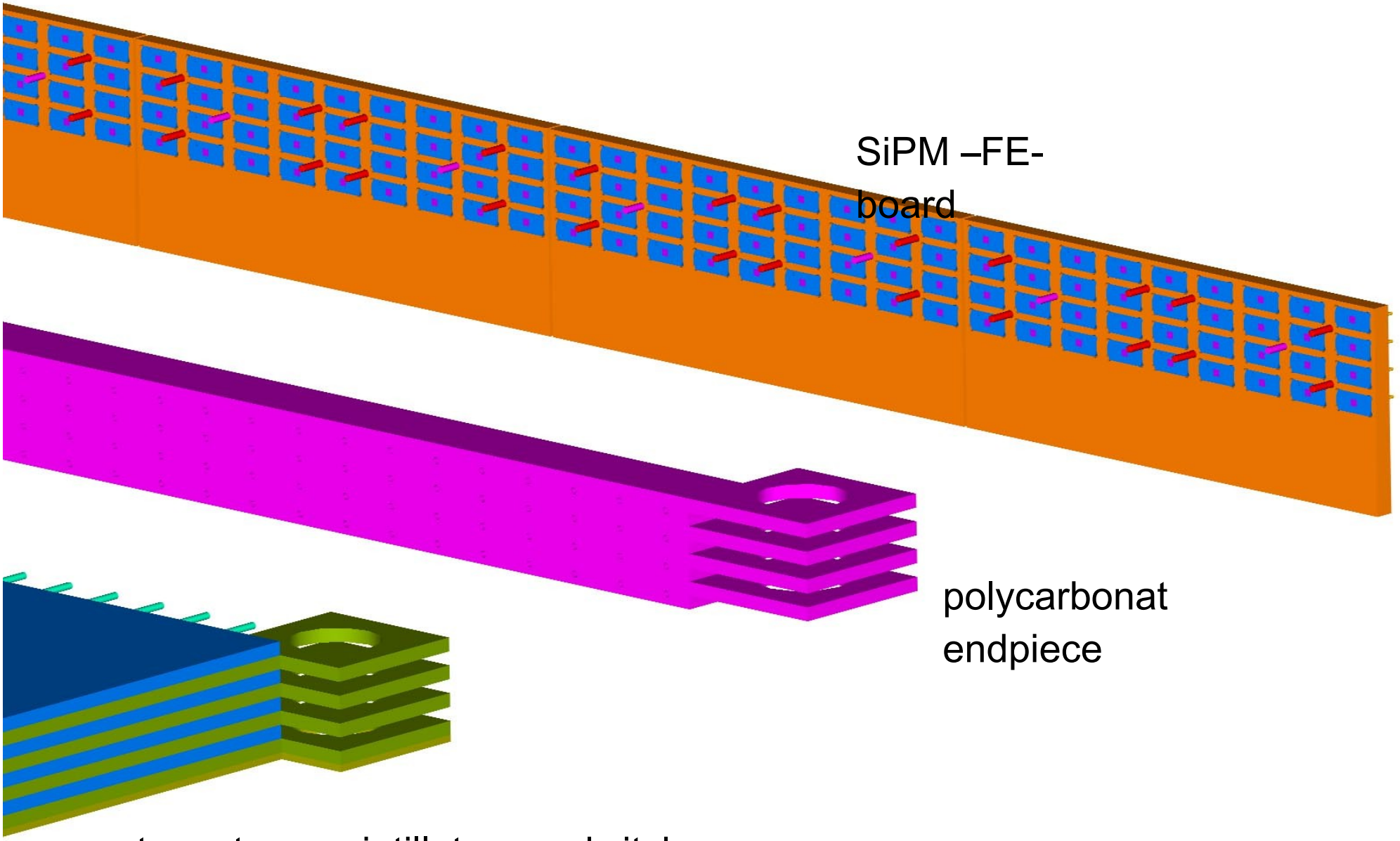
building up the the ECAL out of 5 super layers
with a 5mm Ti support plate below

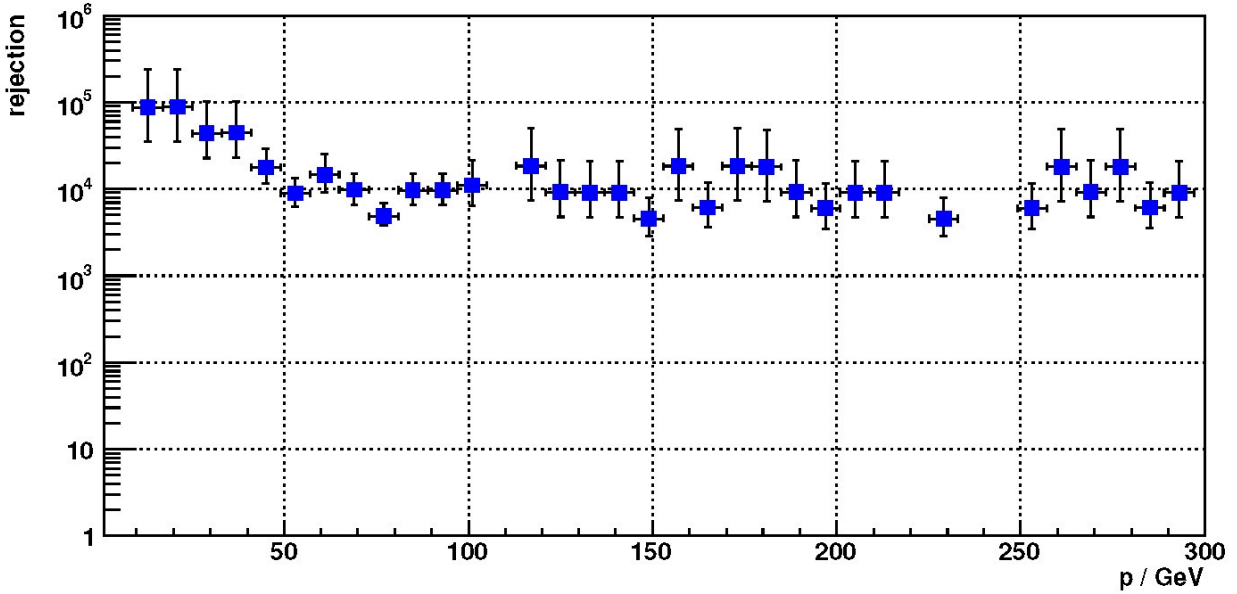


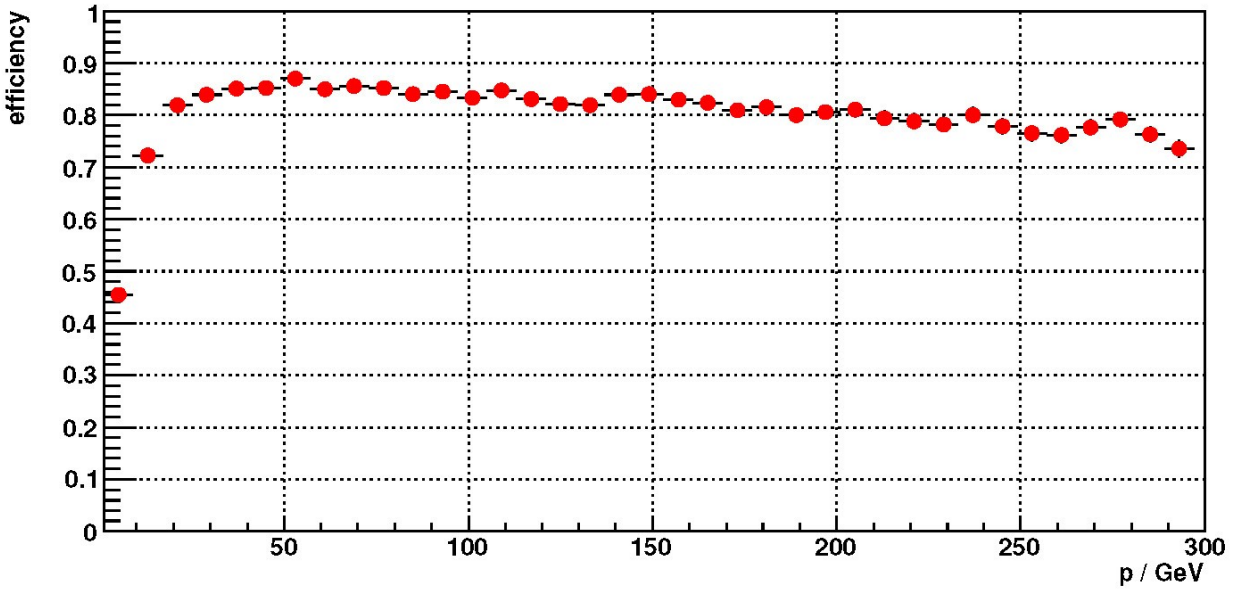
complete super layer explodet view



zoom on the other corner

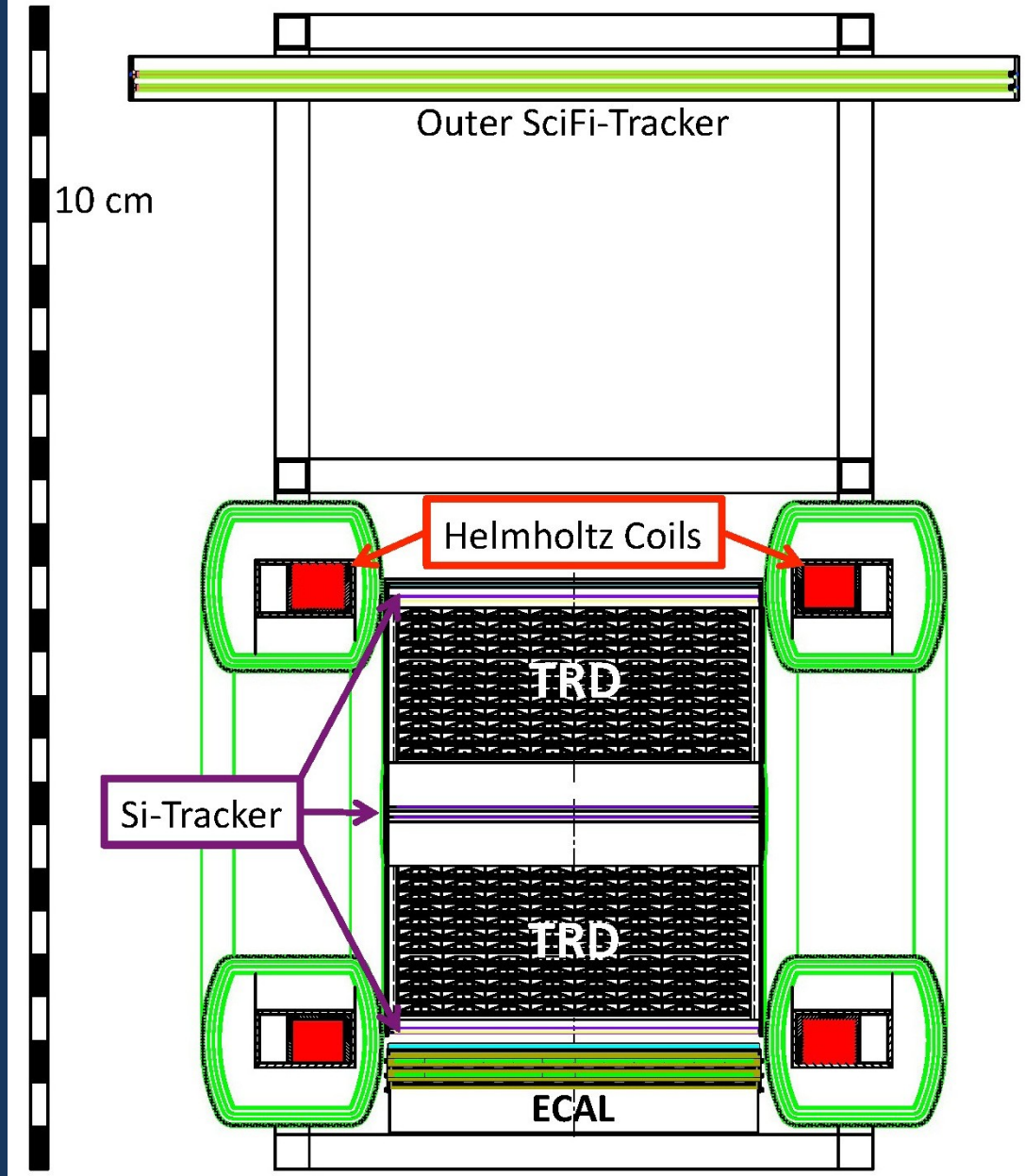



rejection
10^6
10^5
10^4
10^3
10^2
10
1
50
100
150
200
250
300
p / GeV

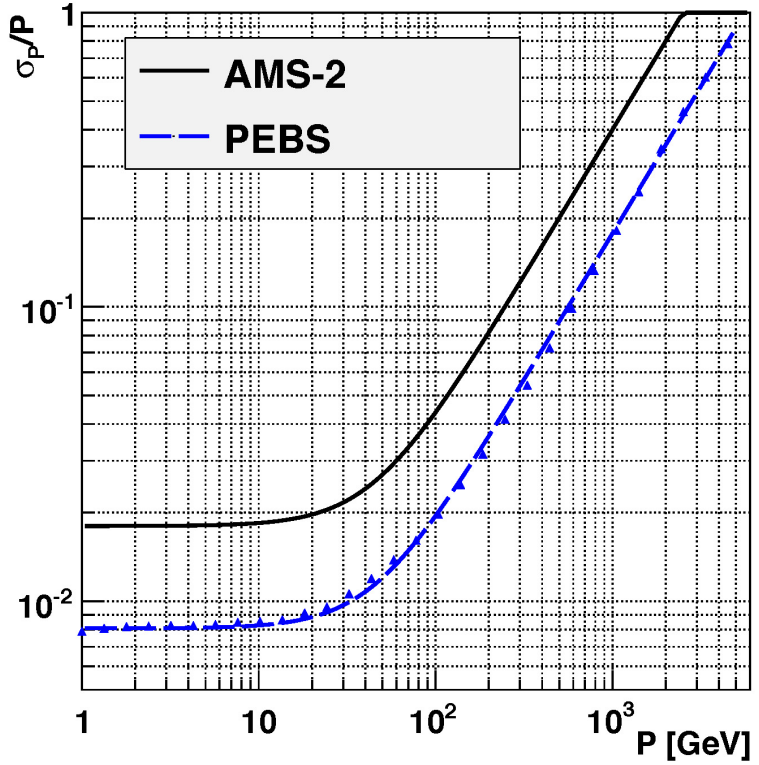

efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
p / GeV

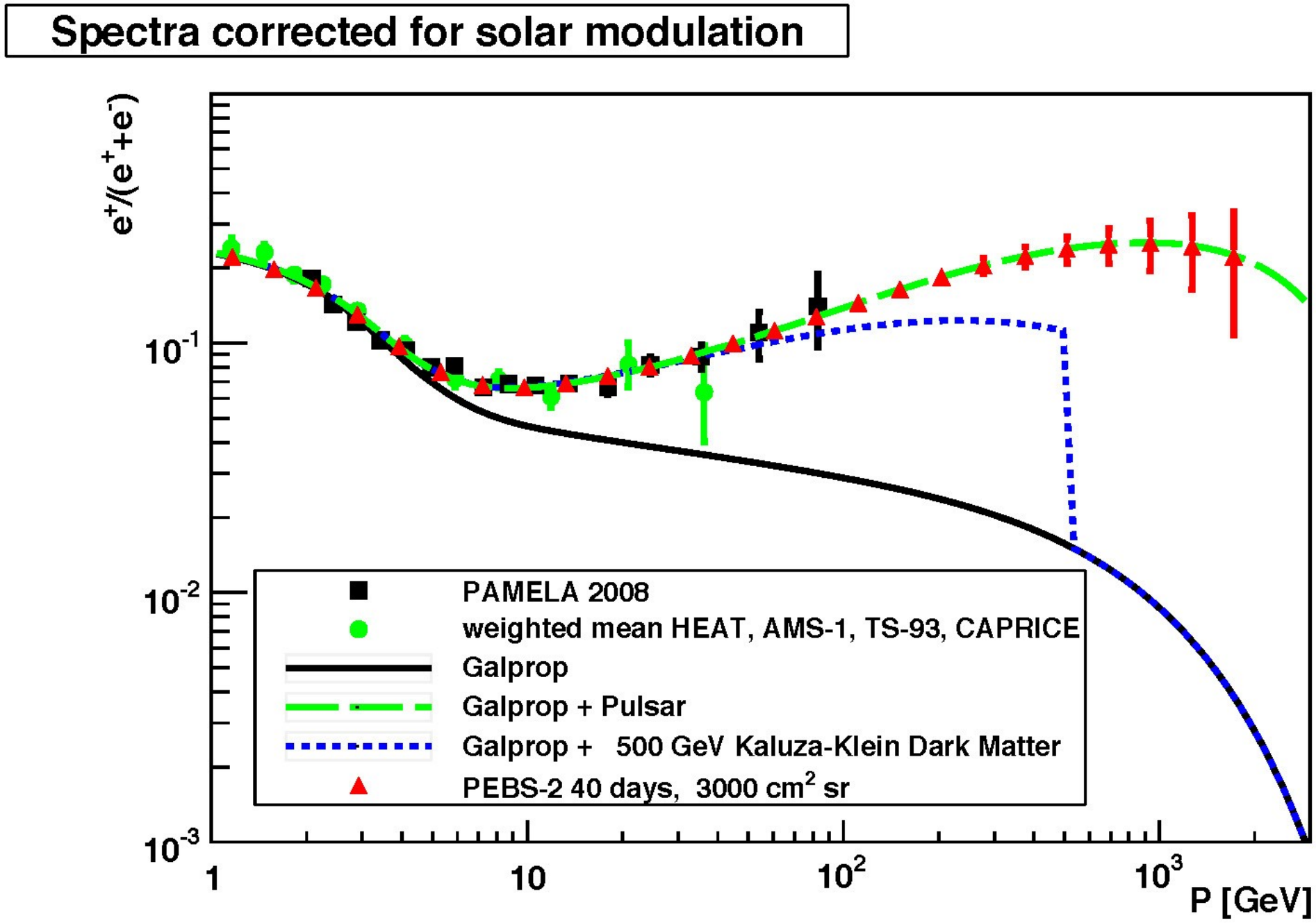
25/01/10

PEBS-2 Experime



$$\frac{\sigma_p}{p} = 1.8\ 10^{-4}\ p \quad 0.008$$

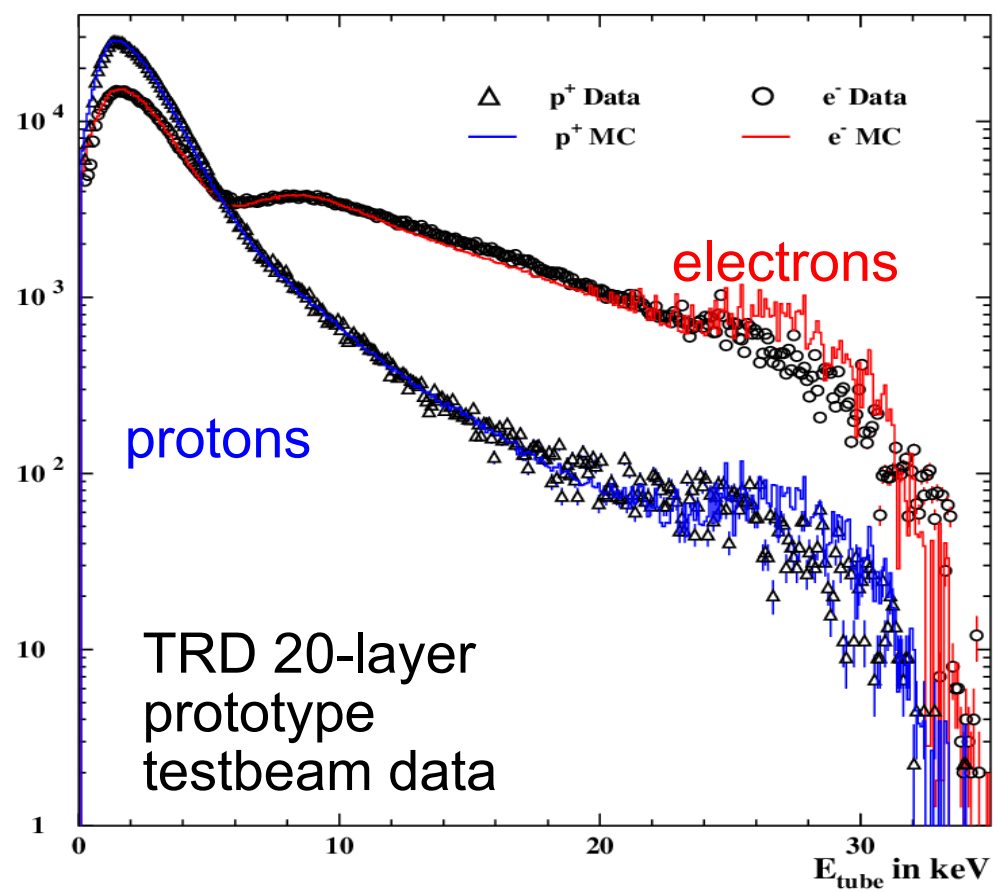


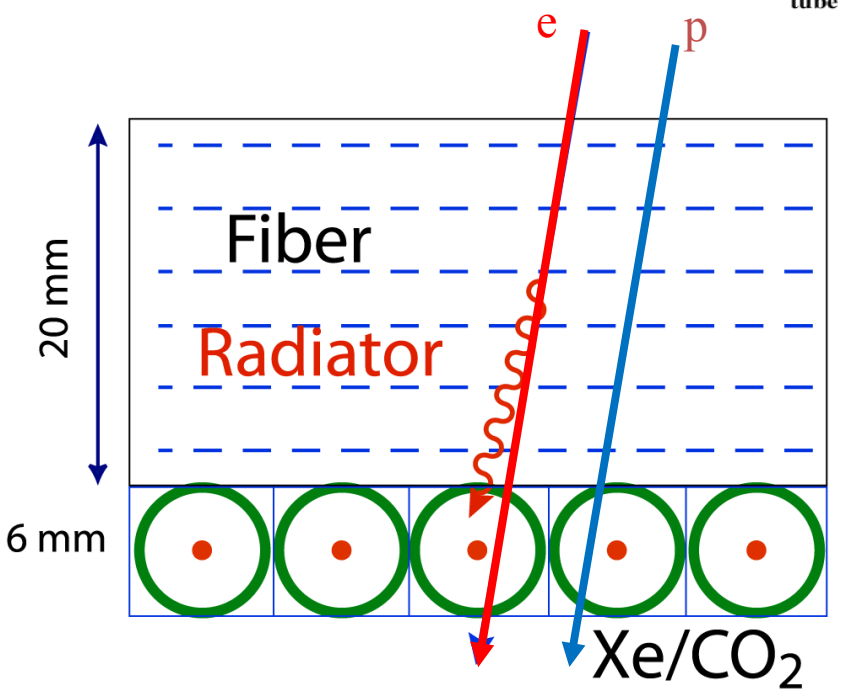

Spectra corrected for solar modulation
e+/(e++e-)
10-1
10-2
10-3
1
10
102
103
P [GeV]
PAMELA 2008
weighted mean HEAT, AMS-1, TS-93, CAPRICE
Galprop
Galprop + Pulsar
Galprop + 500 GeV Kaluza-Klein Dark Matter
PEBS-2 40 days, 3000 cm2 sr

Cosmic Ray Experiments

	Acceptance [cm2 sr]	Duration [days]	Electron Identification
PAMELA	20	1000	Spectrometer + ECAL
AMS-2:	850	1000	Spectrometer + ECAL + TRD
PEBS-1	1000	10	Spectrometer + ECAL + TRD
ATIC-2:	1500	20	ECAL
PEBS-2	3000	40	Spectrometer + ECAL + TRD
PEBS-1	7500	10	ECAL + TRD
FERMI	25000	2000	ECAL

TRD Performance





Analysis of TRD prototype testbeam data, using first 16 layers