MEGA: Medium Energy Gamma-Ray Astronomy

Development of a prototype detector; concept for a balloon experiment and a small space mission

Gottfried Kanbach, MPE Garching, Germany

the MEGA Collaboration (Institutions, ca. 2003):

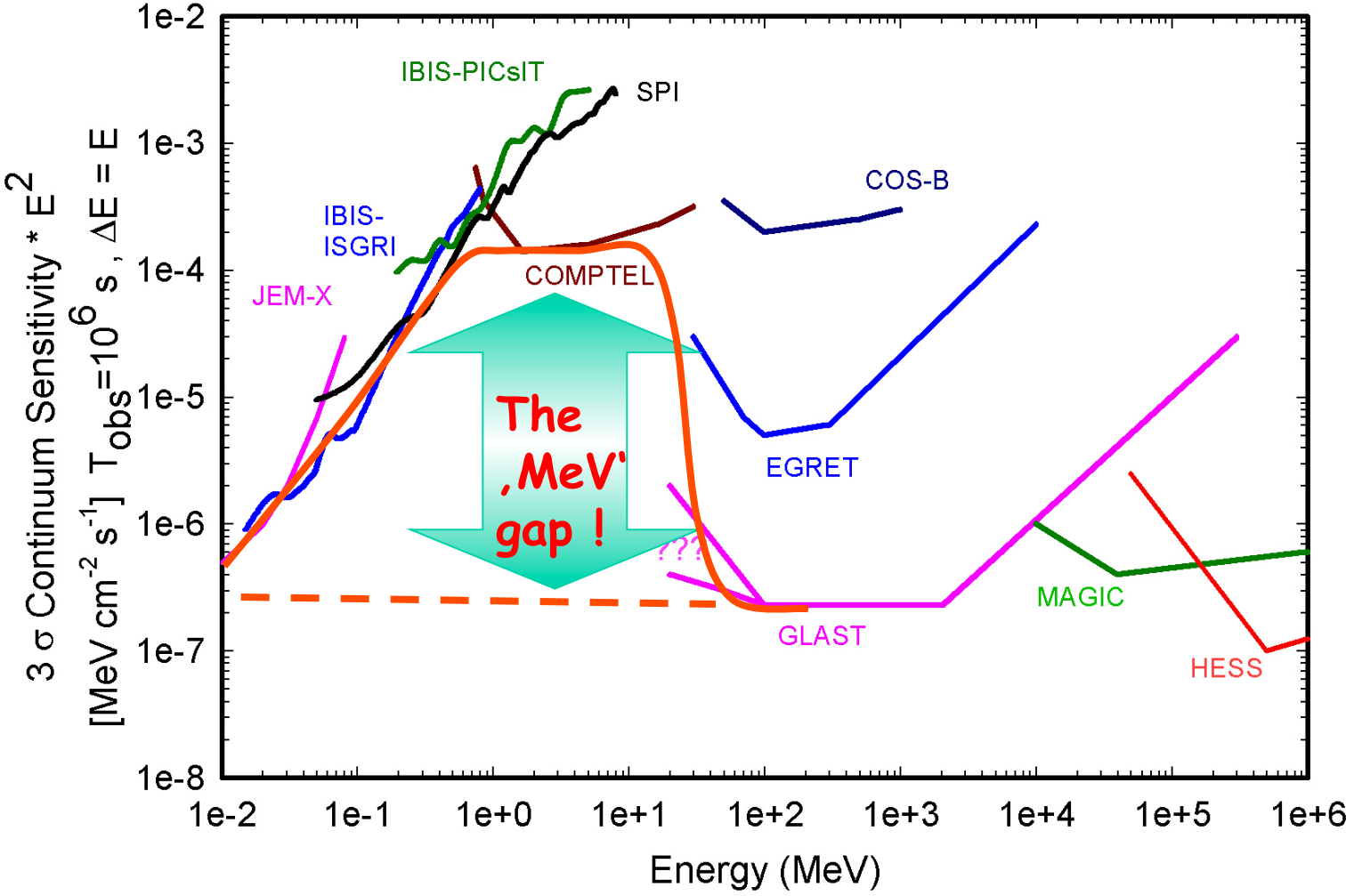
Europe:

MPE, Garching,D, GACE, Valencia, E, IASF, Bologna, I , CESR, Toulouse, F

U.S.A.:

UNH, GSFC, NRL, Columbia U., U of Alabama, IGPP-UCR, LANL, Clemson U.

Situation of multi-λ High-Energy astronomy: Severe sensitivity deficit at MeV energies



MEGA Goals:
Imaging, Timing, Spectroscopy, Polarimetry

- Mapping the Sky:
  - deep, continuous, survey from ~0.3-100 MeV
  - Diffuse and localized sources
- Discovery of transient and variable sources
  - fast: GRBs, transients, SGRs, Novae
    - solar flares, pulsars (periodic)
  - slow: AGN, SNe
- Broadband spectra:
  - SED characteristic for particles, fields & geometry
- Narrowband spectra:
  - Cosmic radioactivity with short and long half-lives
  - Nuclear resonance absorption
- Polarization: Pulsars, GRBs, AGN

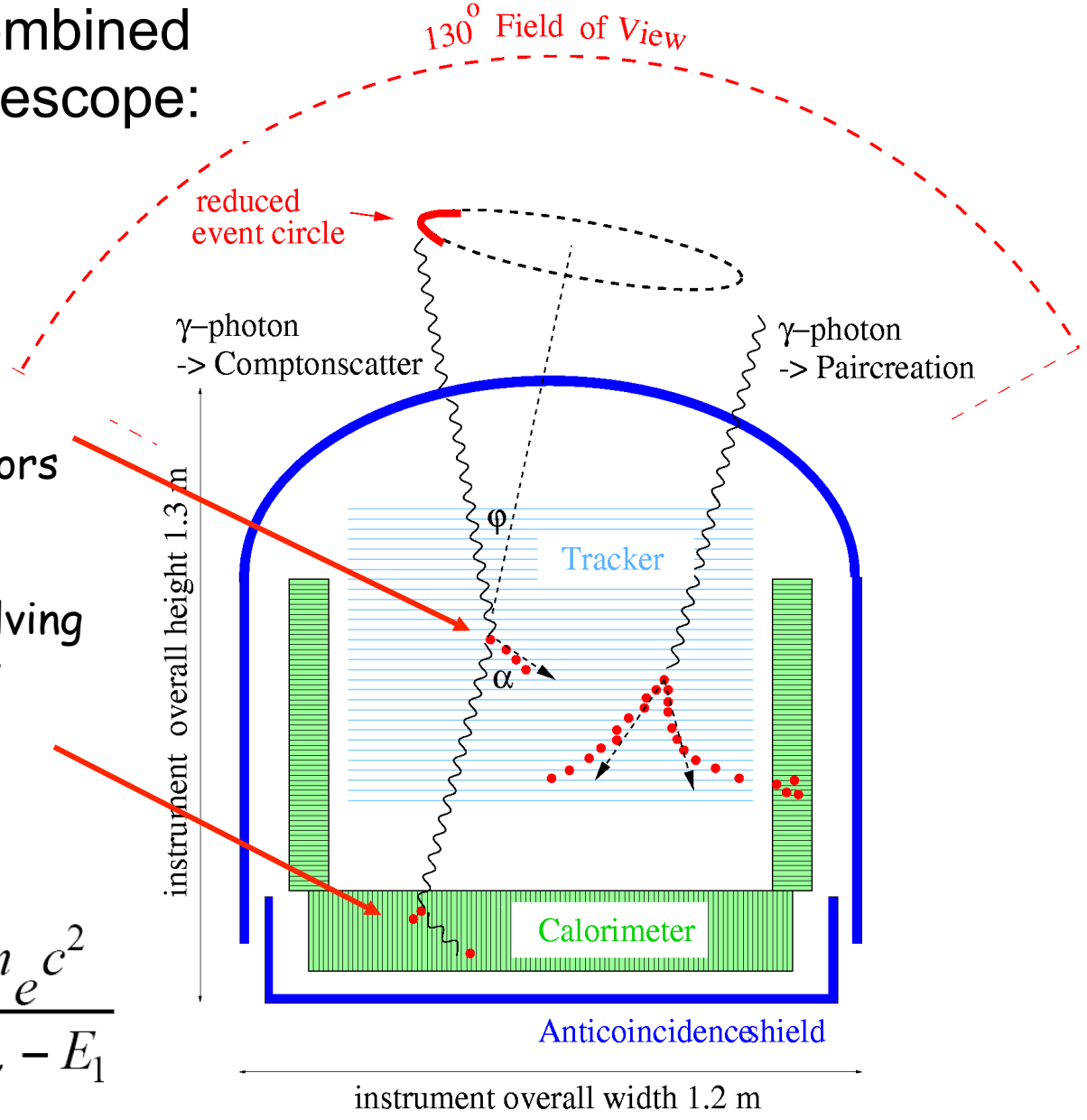
Concept for a combined Compton/Pair telescope:

Tracker: double sided Si strip detectors

Calorimeter: 2(3)D resolving voxel array

Compton Scattering:

$$\cos\varphi = 1 + \frac{m_e c^2}{E_\gamma} - \frac{m_e c^2}{E_\gamma - E_1}$$



Project Development Plan

1. Telescope Design and Simulation (1996-...)
2. Detector Development; build a Prototype (1999-2002)
3. Test the prototype with lab sources 0.5 – 4.4 MeV
4. Beam Calibration (April/May 2003) 0.7-50 MeV

5. Balloon Flight (2004-2005)

6. Update Simulations and Background Modelling
7. Study advanced detector designs
8. Be prepared to propose a MEGA space mission

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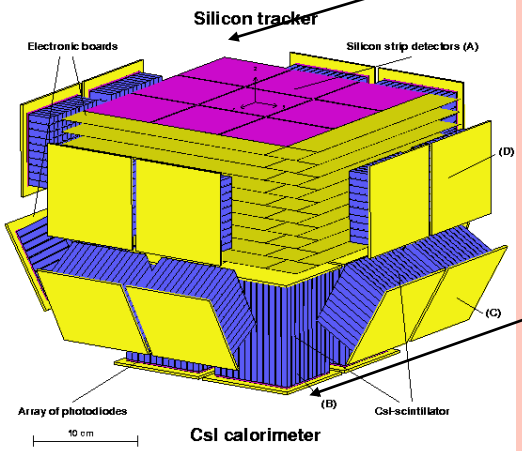
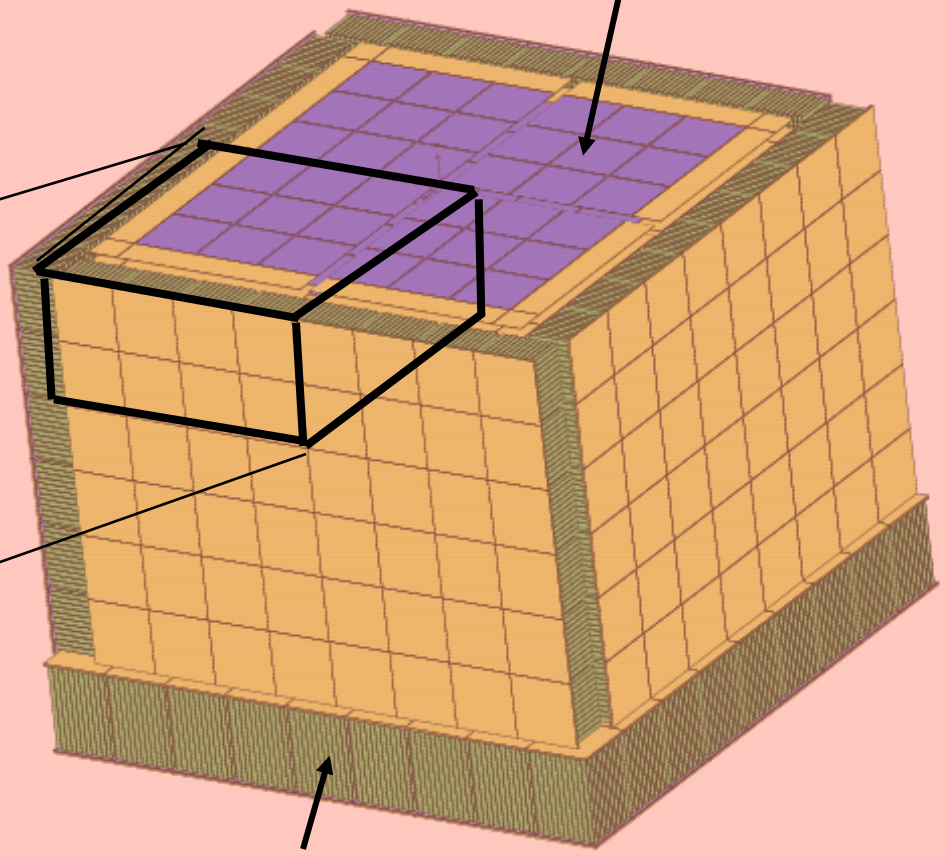
Prototype and Full-size Instrument



10 layers of Si strip detectors
18 x 18 cm^2 , 0.5 mm thick

30 layers of Si strip detectors
36 x 36 cm^2 , 0.5 mm thick



10 cm

CsI Calorimeter

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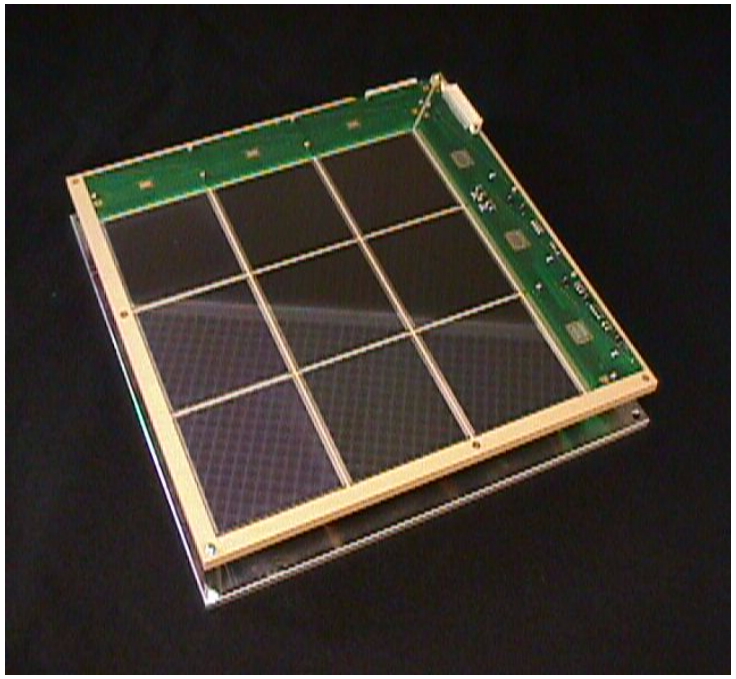
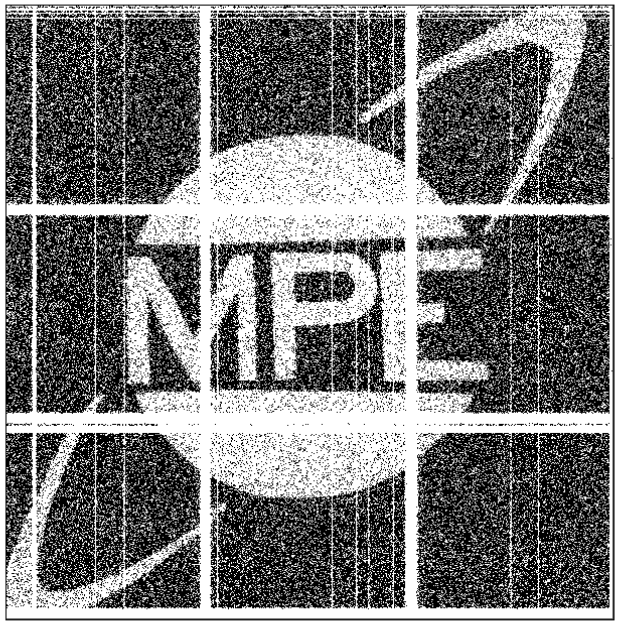
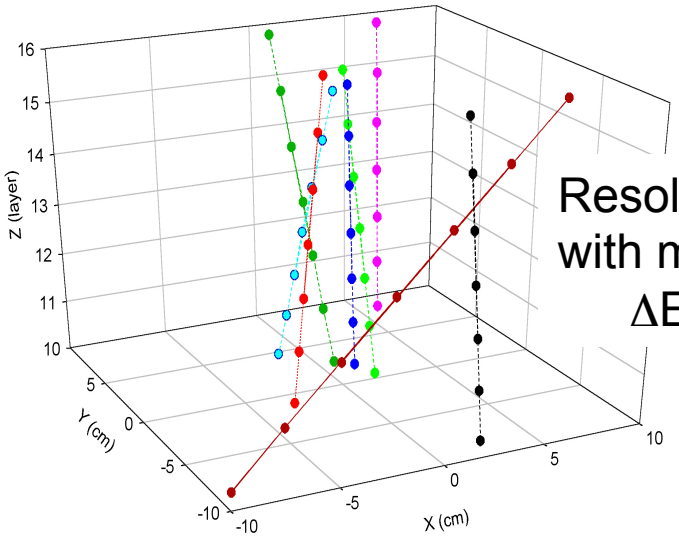
Tracker: 3x3 wafers DSSDs mounted on grid structure





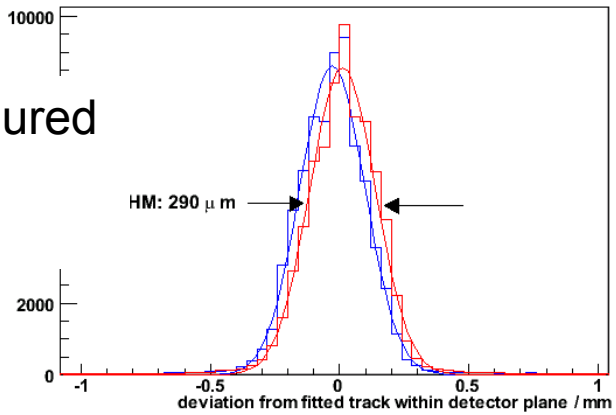
Muon tracks



Shadow of 6mm Pb mask irradiated with ^{57}Co

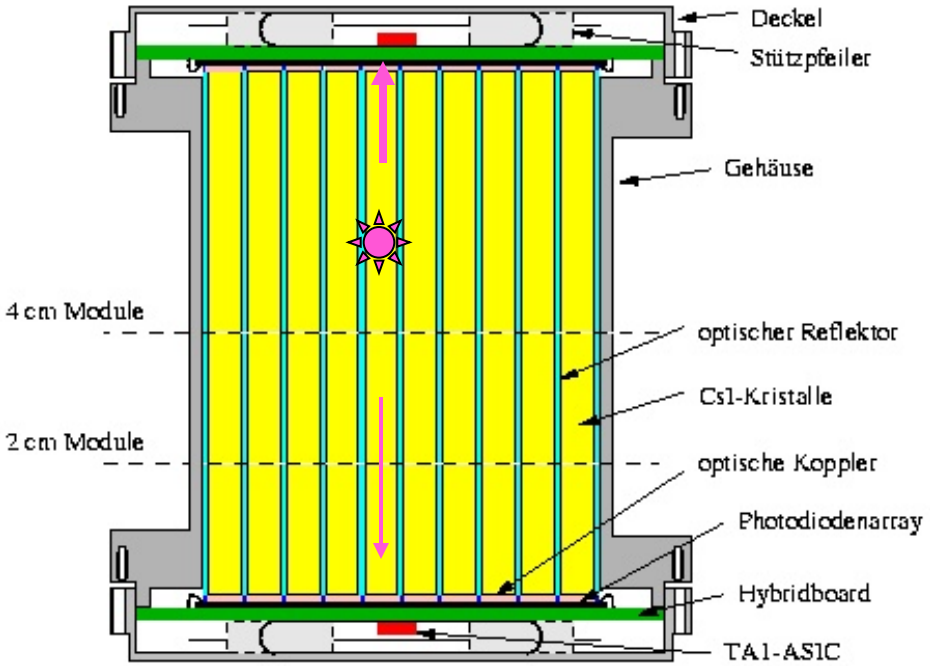
Resolution of tracker measured with muons: 290μm

ΔE_{FWHM}: ~ 15 keV



Calorimeter Modules

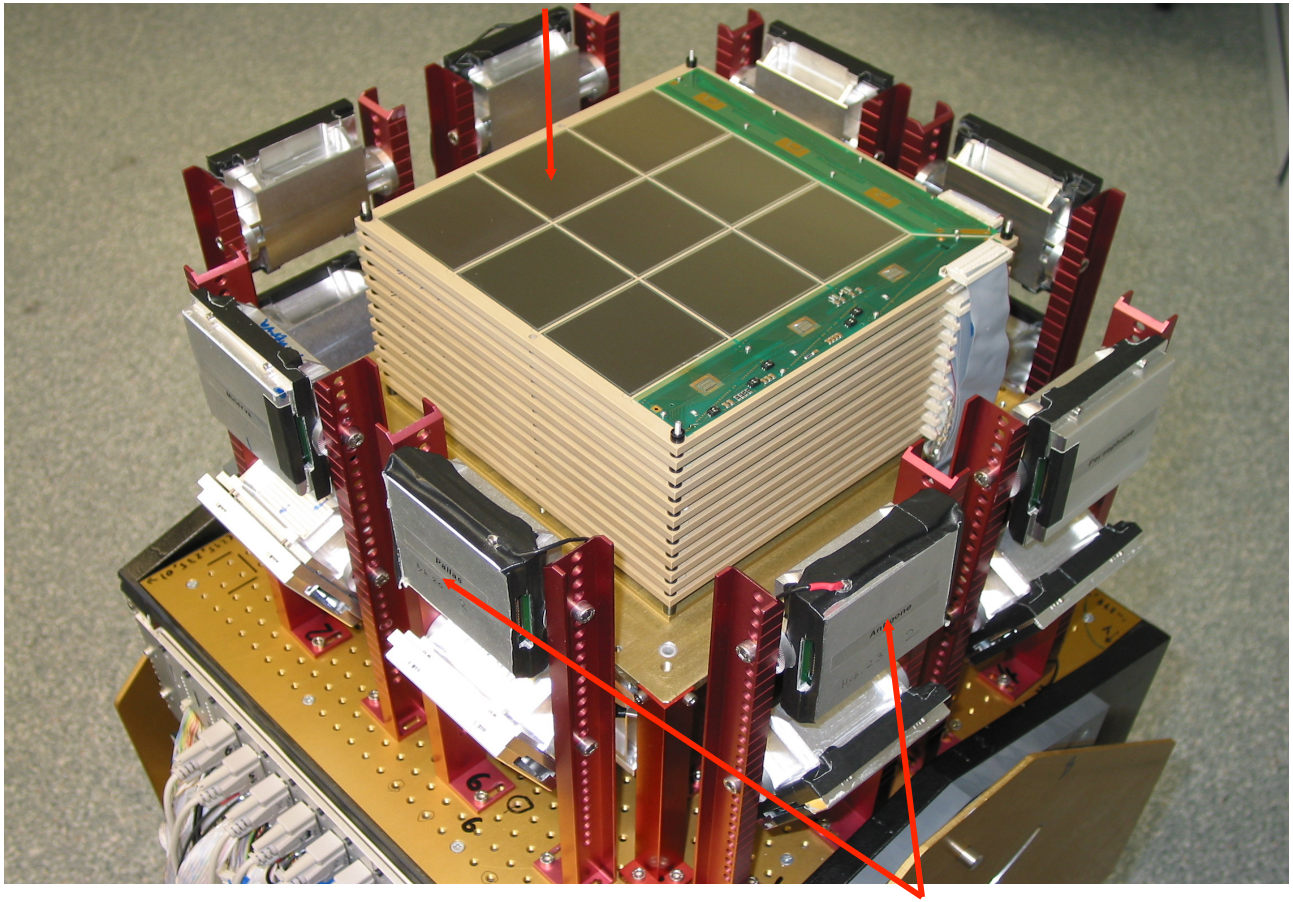
- 120 CsI crystal bars 0.5x 0.5x [2, 4 , 8] cm^3 / module
- Monolithic 10 x 12 PIN Diode Array with 5x5 mm^2 pixels (Hamamatsu)
- R/O electronics integrated on the backside of the Hybrids.
- Energy resolution @ 662 keV: ~ 10 % FWHM (3-D)
- Spatial resolution: x-y: pixel size; z:~1.5 cm



Prototype

Tracker:

11 layers with 3x3 DSSDs (ea. 6x6cm^2, 470μm pitch)
Total Si area ~ 4000 cm^2, ΔE_{FWHM}: > 15 keV @ 122 keV



A_{eff} estimate :

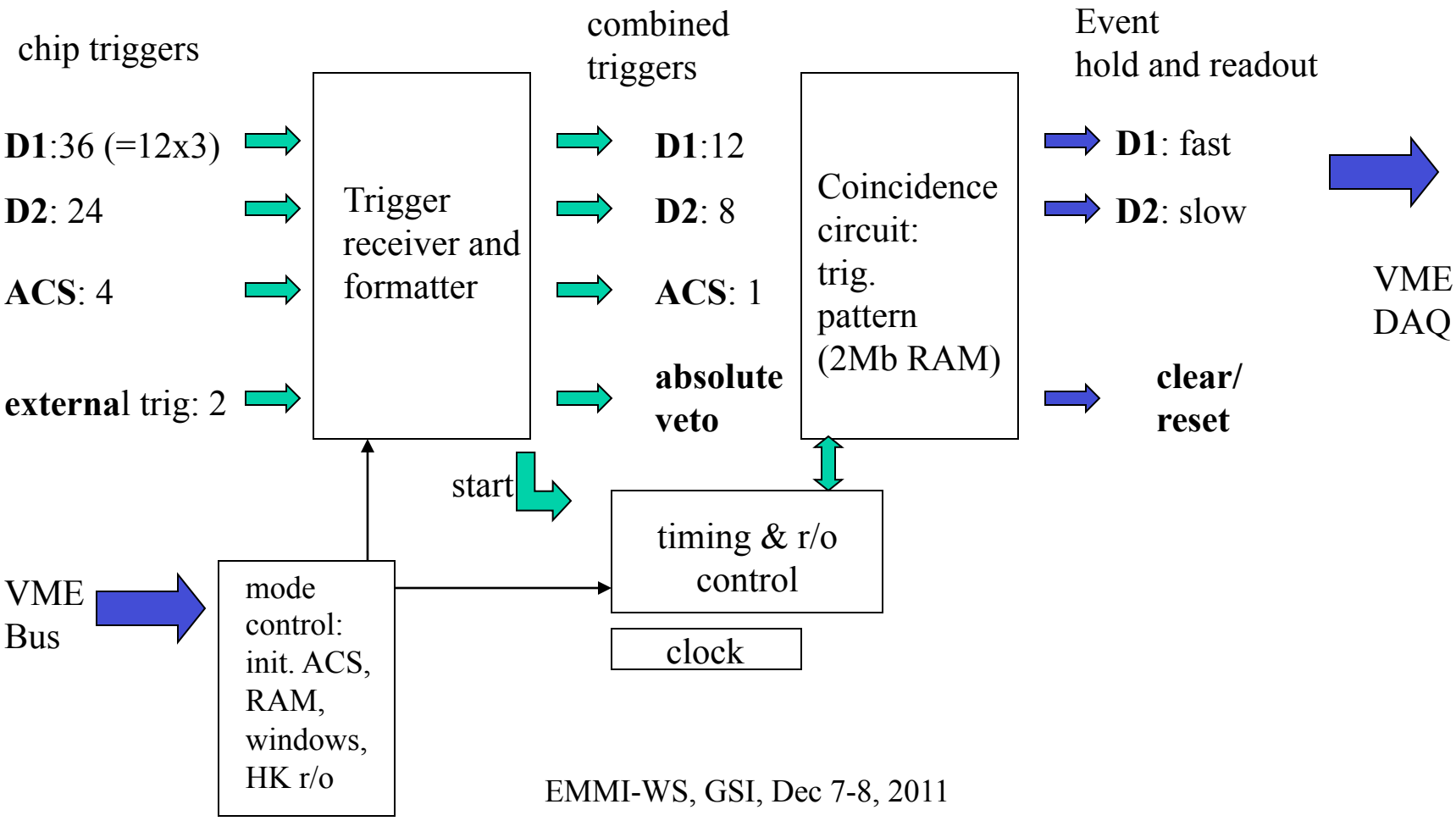
$A_{eff} = (1-e^{-\mu d}) A_{geom} \eta$
$= 16 \text{ cm}^2 \eta$
with $\eta = 0.4 \times 0.3$
$A_{eff} \sim 2 \text{ cm}^2$

Calorimeter: 20 modules of 120 CsI(Tl) bars each, 5x5x[20,40,80] mm^3
PIN diode readout (Hamamatsu), ΔE_{FWHM} : > 70 keV @ 662 keV
Ω fill factor lower hemisphere ~ 40%

Coincidence Electronics

Task: select valid events according to their trigger patterns / initiate configurations and readout

Implementation: FPGA Xilinx-Spartan



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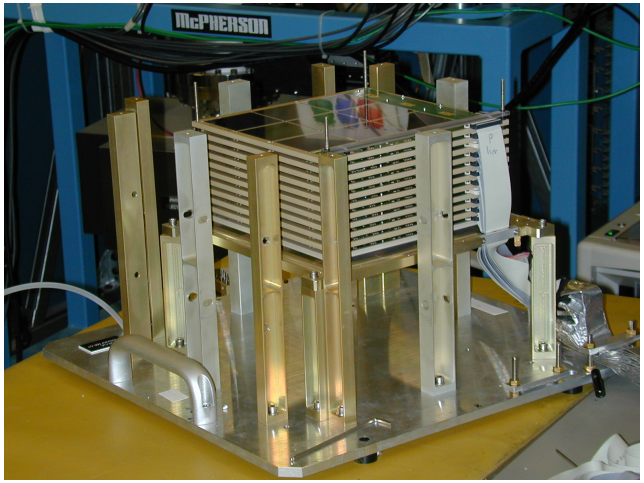
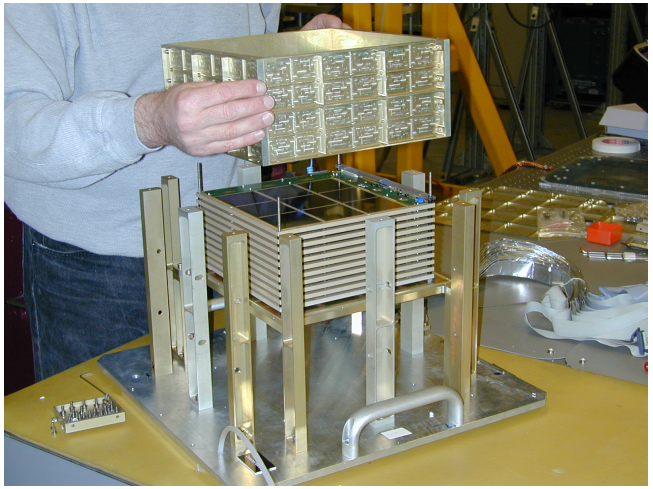
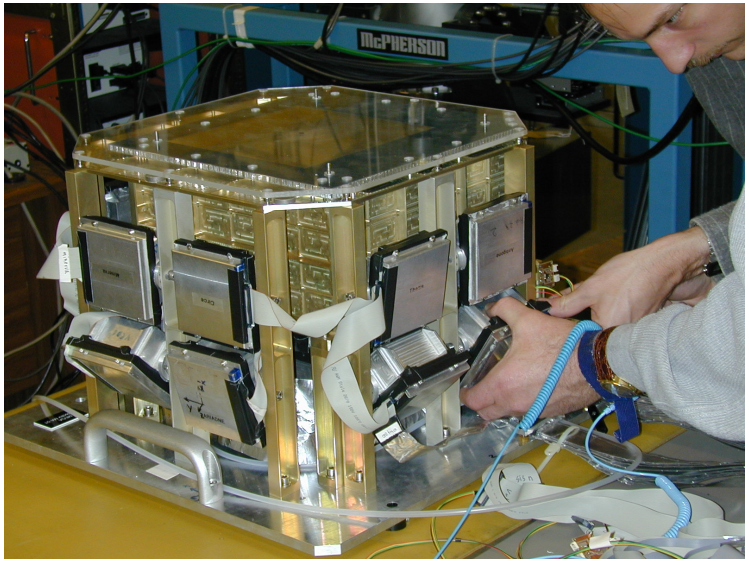
Assembly of the MEGA Prototype

Assembly of the Tracker





Assembly of Calorimeter Modules



The search for „hidden sources"

Five sources are hidden in the field of view of MEGA.

Their positions should be retrieved by the means of near-field image reconstruction.

Sources:

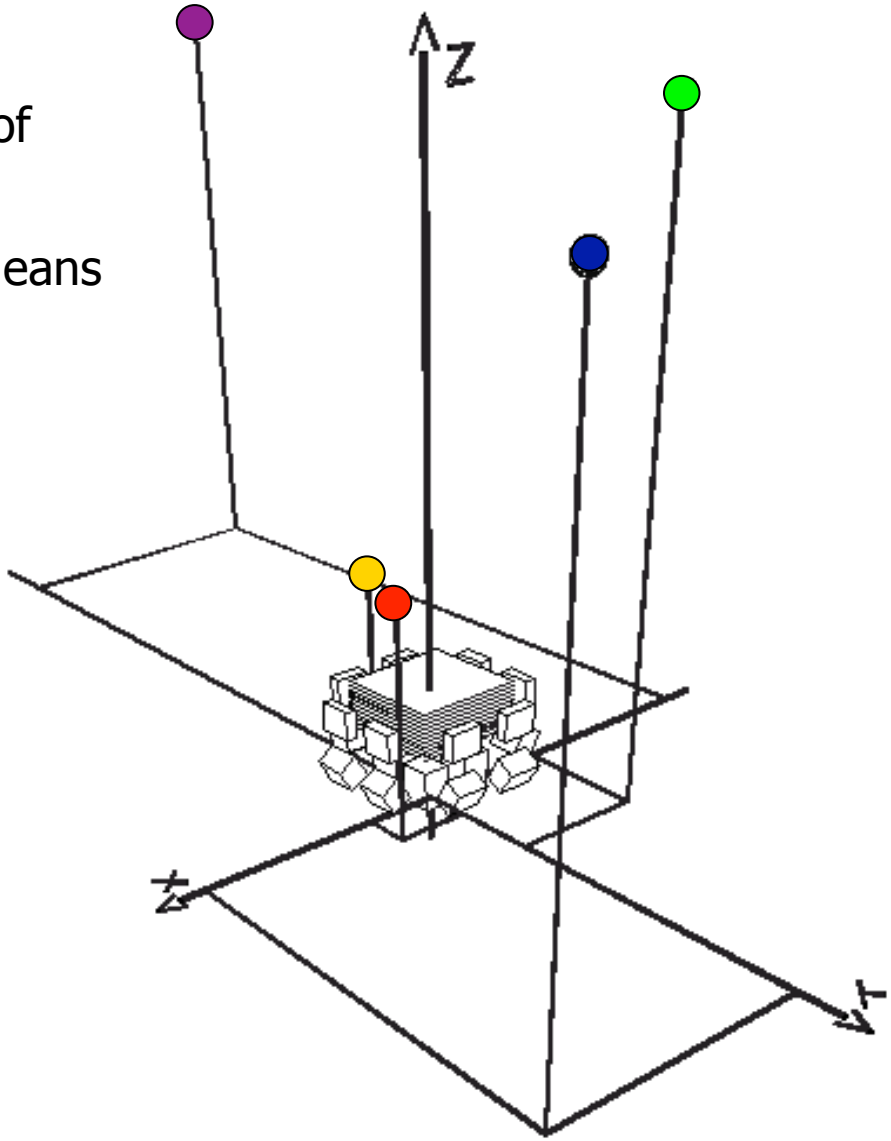
Co60: 2.0 MBq

Cs137: 4.0 MBq

Yt88: 70 kBq

Na22: 51 kBq

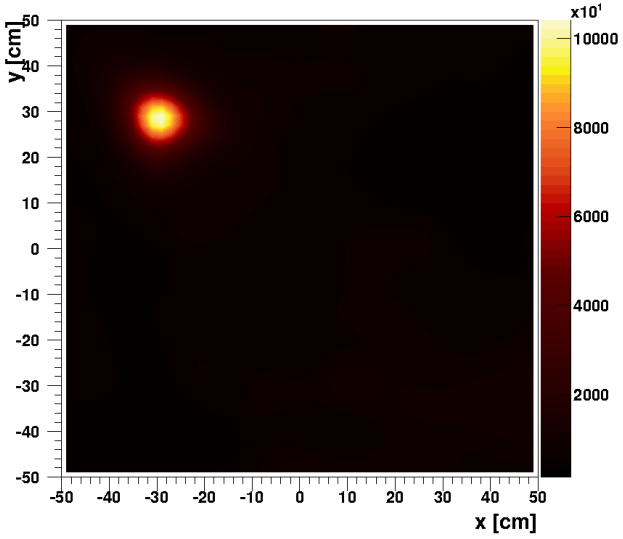
Na22: 1.9 MBq



Finding the hidden sources…

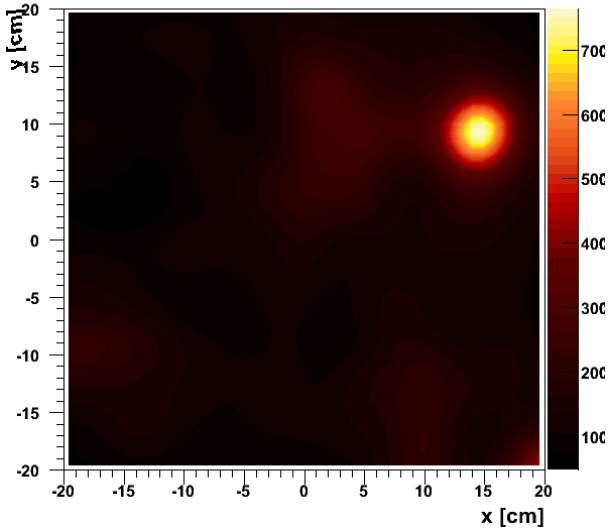
Cs137:

Energy: 620-700 keV, Events: 50000, Iterations: 20, reconstructed position: (-30, 29, 125) cm



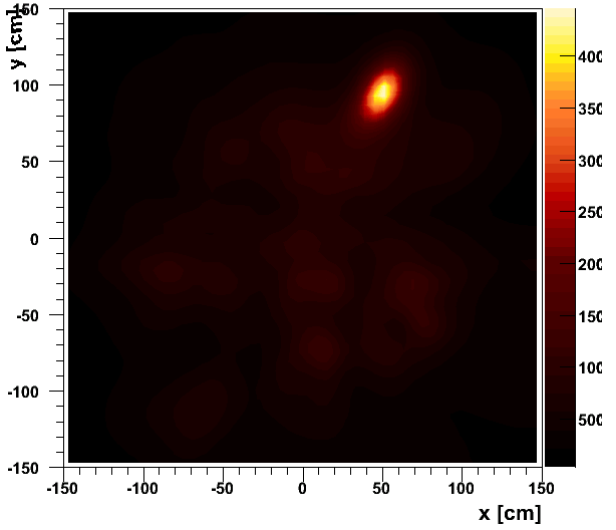
Y88:

Energy: 1.6-2.0 MeV, Events: 21000, Iterations: 20, reconstructed position: (15, 9, 51) cm



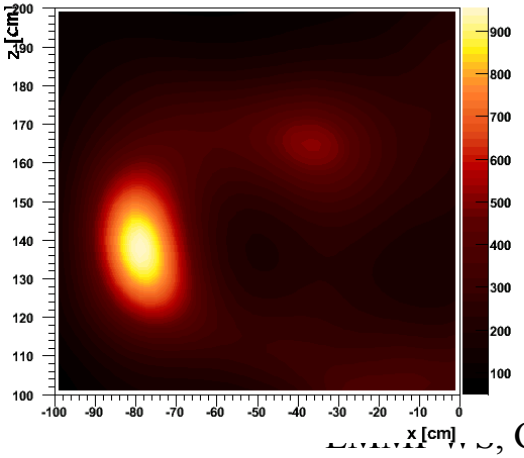
Co60:

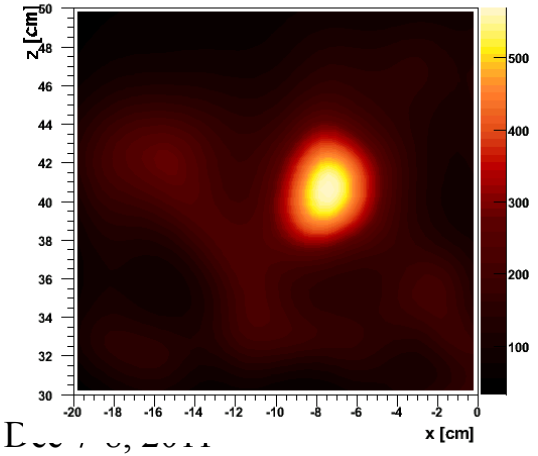
Energy: 1.1-1.4 MeV, Events: 40000, Iterations: 20, reconstructed position: (55, 95, 125) cm



Na22 strong:

Energy: 1.2-1.35 MeV, Events: 7200, Iterations: 20, reconstructed position: (-80, -170, 137) cm





Na22 weak:

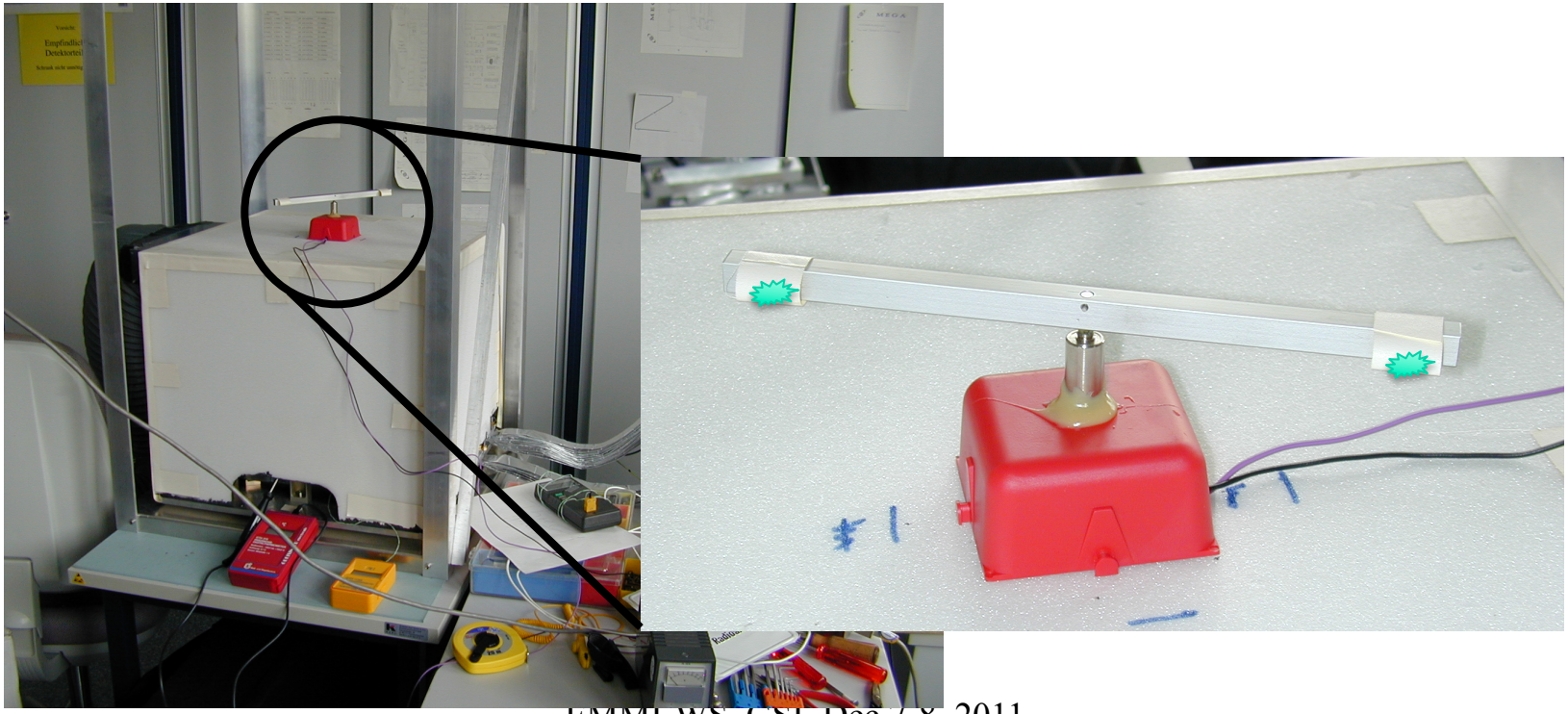
Energy: 1.2–1.35 MeV, Events: 8600, Iterations: 20, reconstructed position: (-7.5, -28.5, 40.5) cm

Extended source: setup

Measurement:

Two ^{88}Y sources are located on a rotating propeller and perform a circle with radius 7.5 cm

This is equivalent to a circle with 30° diameter at infinity.



Extended source

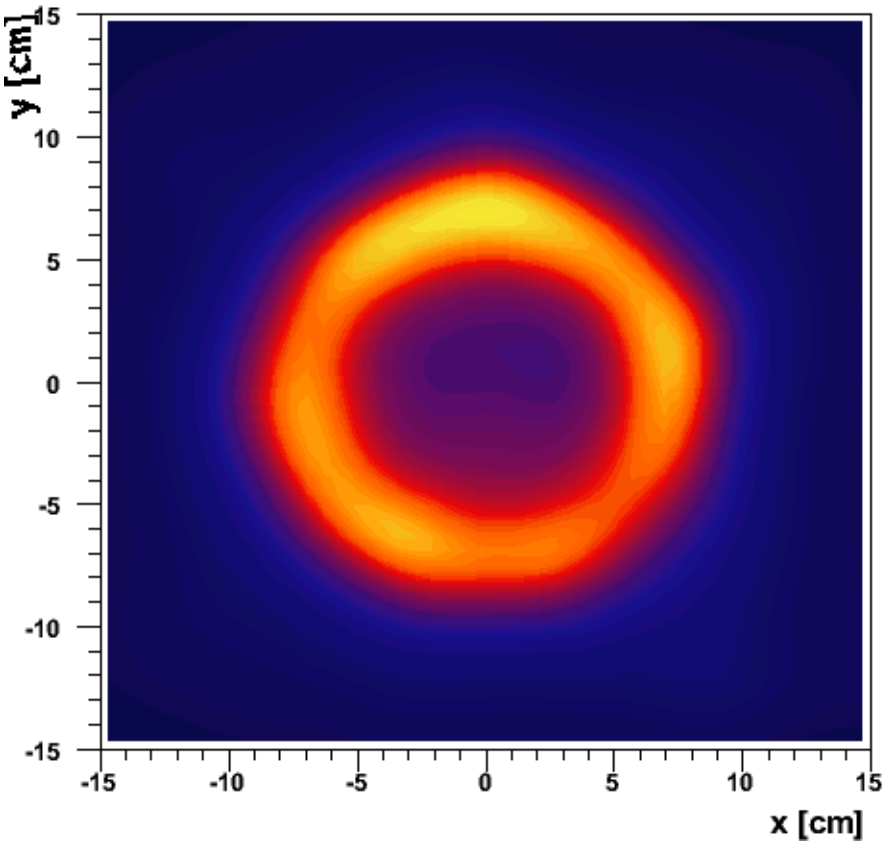


Image properties:

- Includes tracked and not tracked events, single and multiple Compton events
- Energy range: 0.8 to 1.0 MeV
- Number of events: ~138000
- First hints for a circular structure visible with ~5000 events
- Minor irregularities result from assuption that all detectors have same efficiency

.... „MEGA Supernova remnant“

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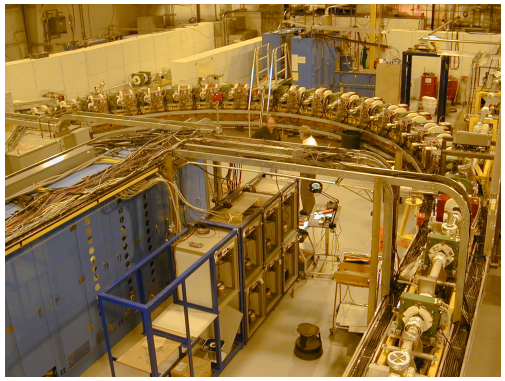
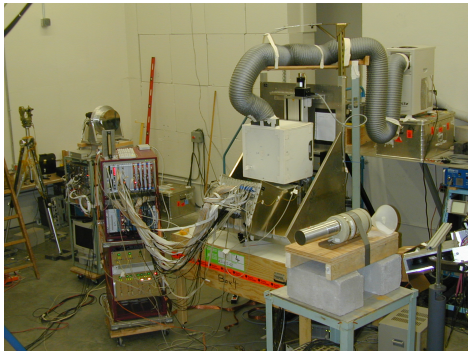
The Duke University High Intensity γ-ray Source (HIγS)



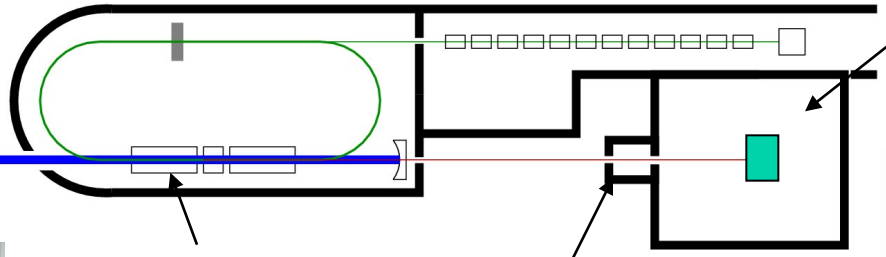


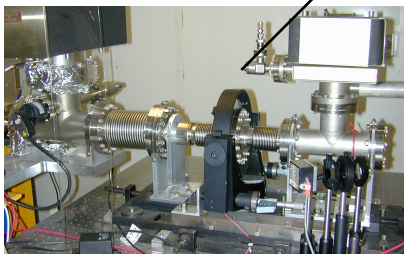
linac

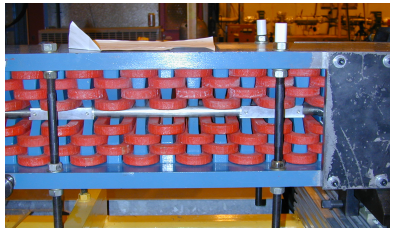
storage ring

γ-ray vault

free electron laser





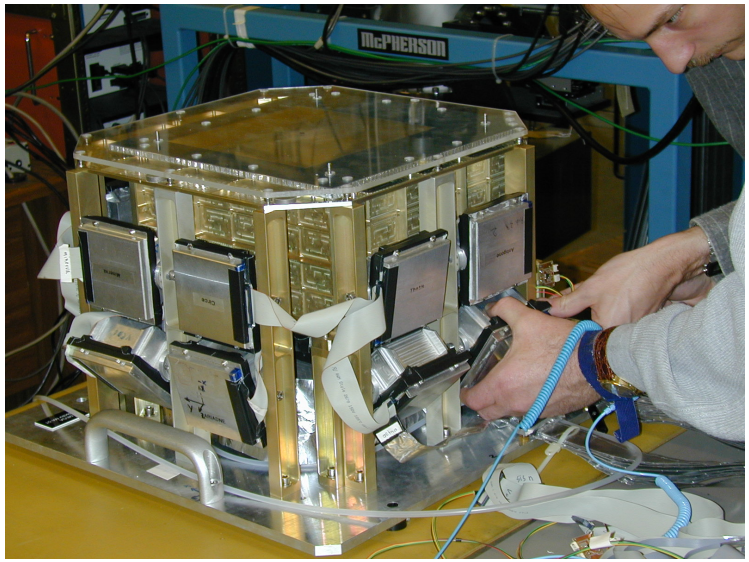


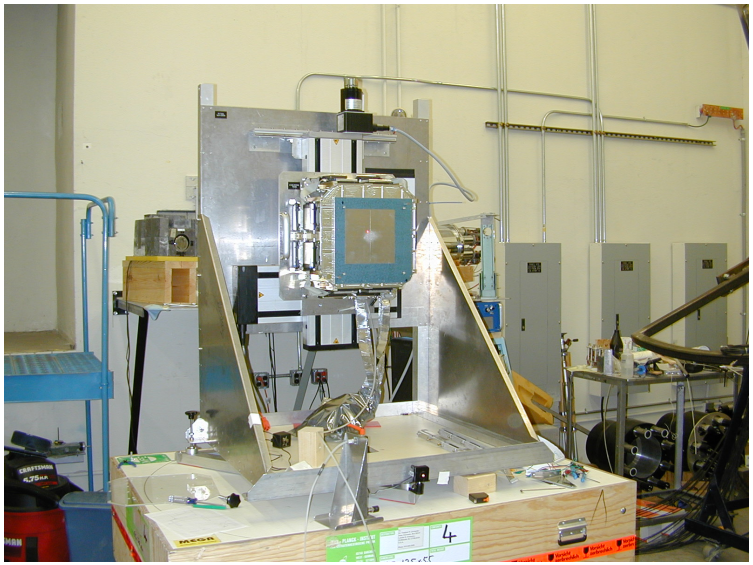
collimator hut

mirror

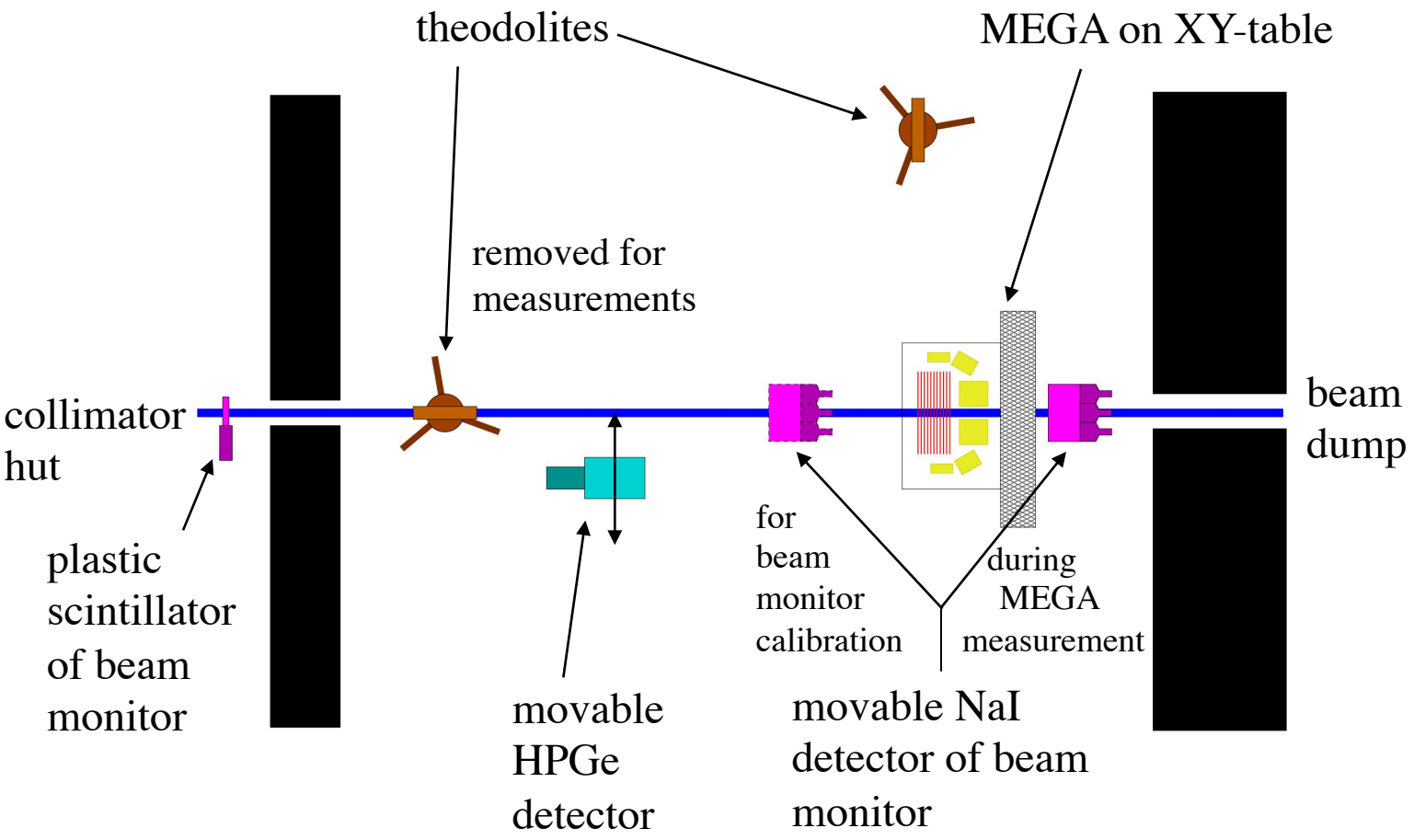
wiggler

...assembly, testing, and installation on the x-y table in the beam area





Setup in γ-ray Vault



DUKE Calibration: Measured Energies and Angles
Detected events (unit =10^3)

Energies [MeV]

Angles	0.7	2	5	8	10	12	17	25	37	50
0°	300	400	345	255	435	435	435	345	435	1095
30°	246		345		525	525	525	390	480	390
60°			480		525	705	570	570	570	570
80°						480		570	480	480
120°			120			165		165	120	165
180°			120		165	120			220	240
Σ	546	400	1410	255	1650	2430	1530	2040	2305	2940

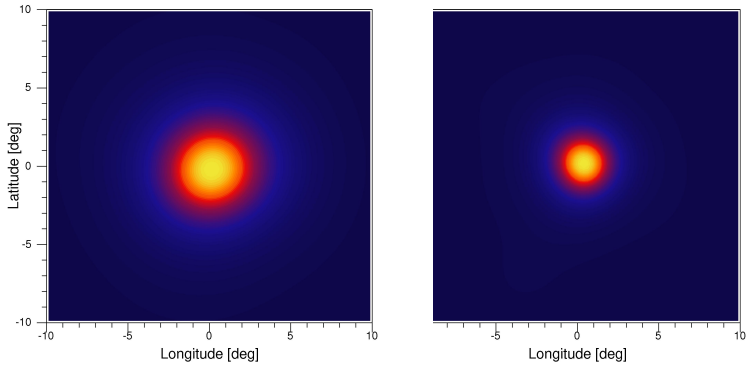
$\cdot 10^3$ events

IR-mirrors (1. week)
≈ 45 % beam time

UV-mirrors
≈ 70 - 80 % beam time

Total: 15.5 · 10^6 triggered events

Compton imaging at Duke energies



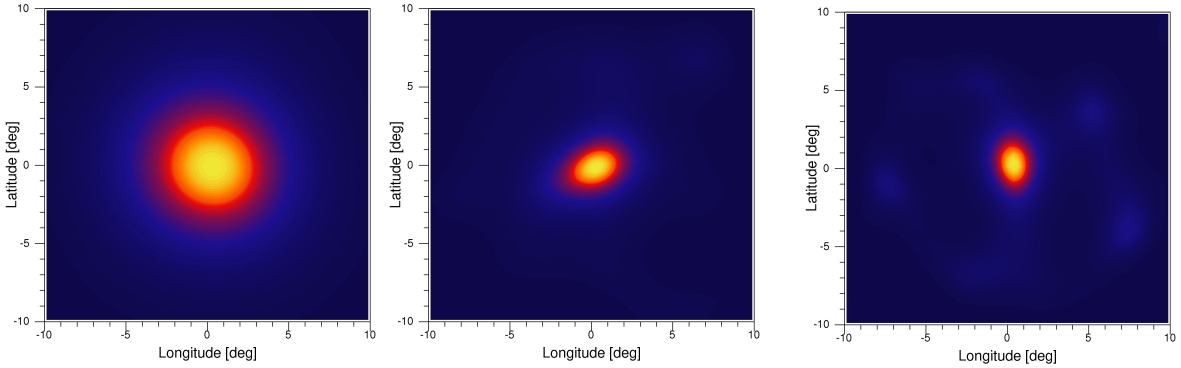
Compton without track

710 keV

2 MeV

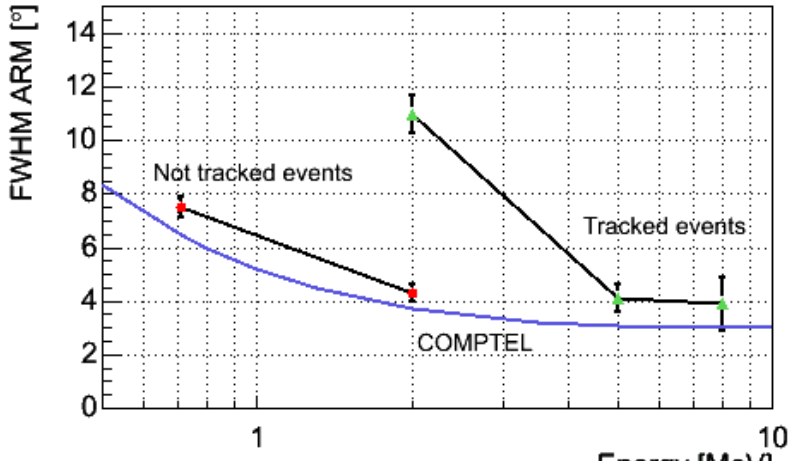
5 MeV

8 MeV

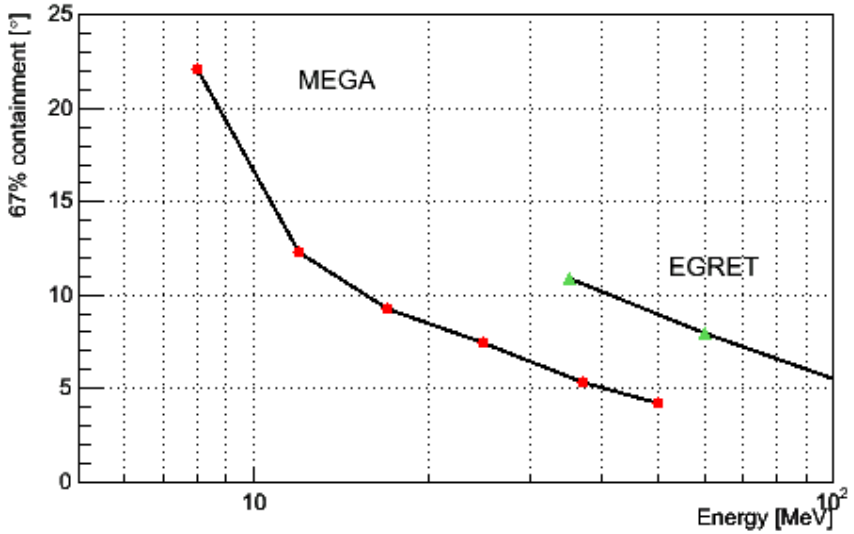


Compton with tracks

Angular resolution overview (Andreas Z.)

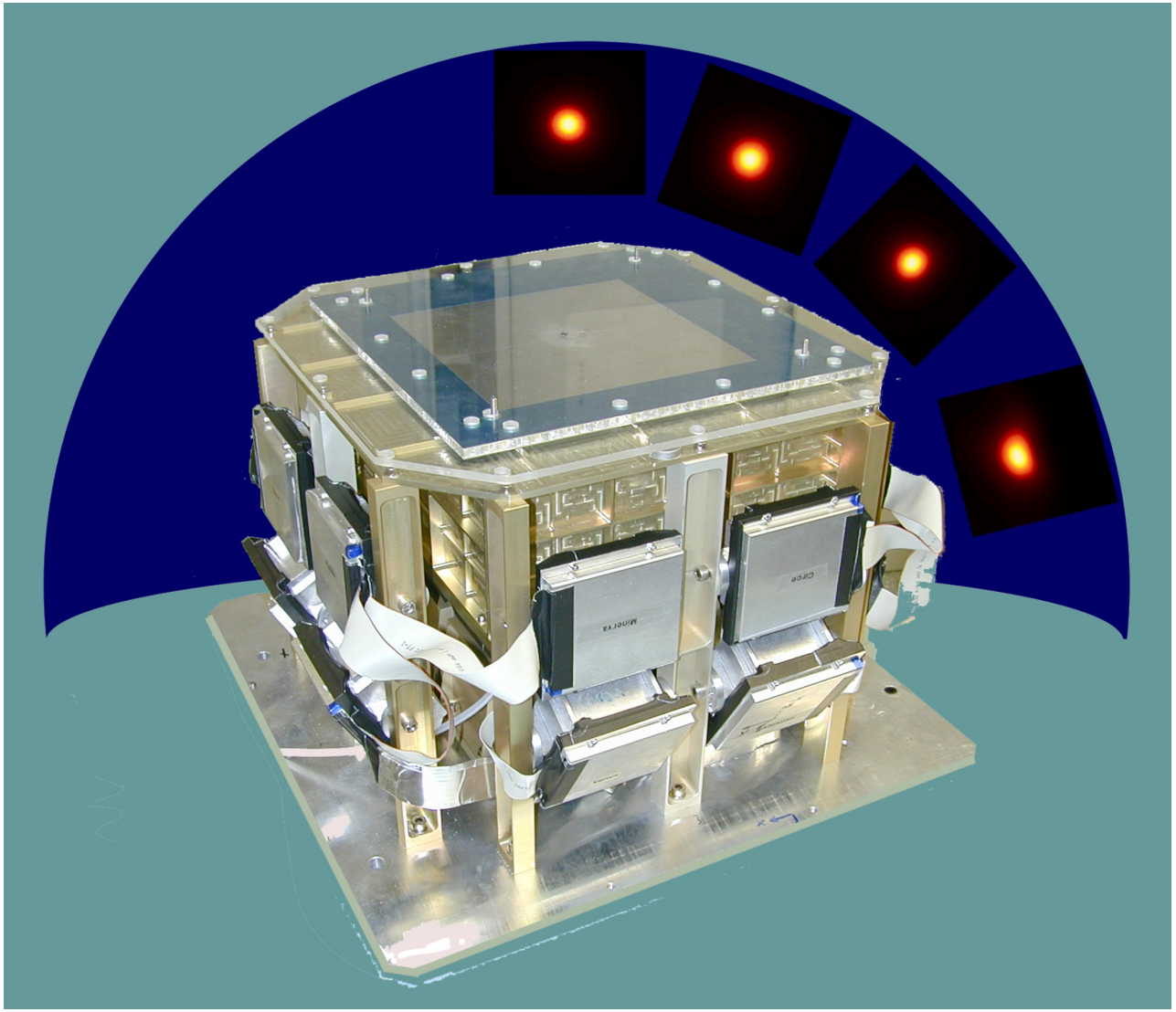


Compton

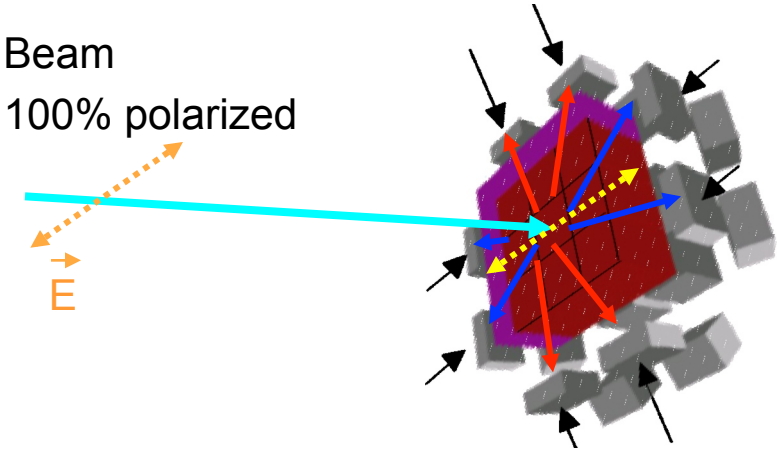


Pairs

MEGA Prototype field of view @ 50 MeV: imaging of calibration beams from 0° to ~80°

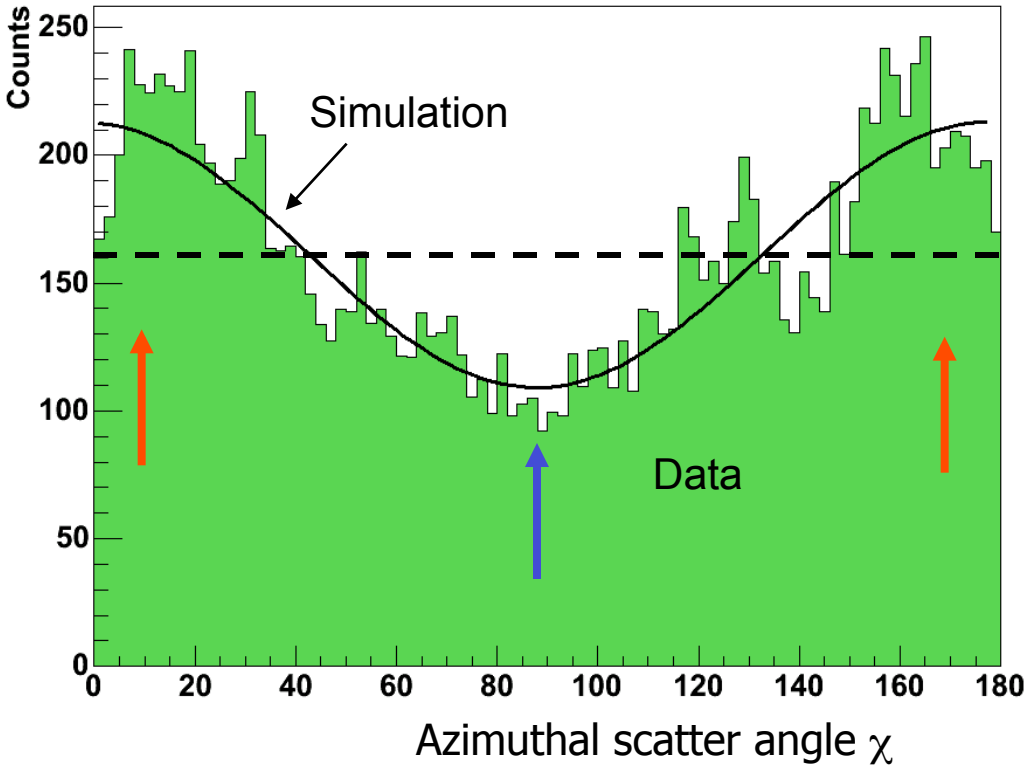


Polarization: Measurement & Simulation



$$\frac{\partial\sigma}{\partial\Omega} = \frac{r_e^2}{2}\left(\frac{E_g}{E_i}\right)^2\left(\frac{E_g}{E_i}+\frac{E_i}{E_g}-2\sin^2\varphi\cos^2\chi\right)$$

Azimuthal distribution: a*cos(2(χ+χ_0))+c



Calibration result:

E (MeV)	Modulation [%] meas.	sim.
0.7	17± 4	19± 1
2.0	13± 3	14± 1
5.0	6± 3	3± 2

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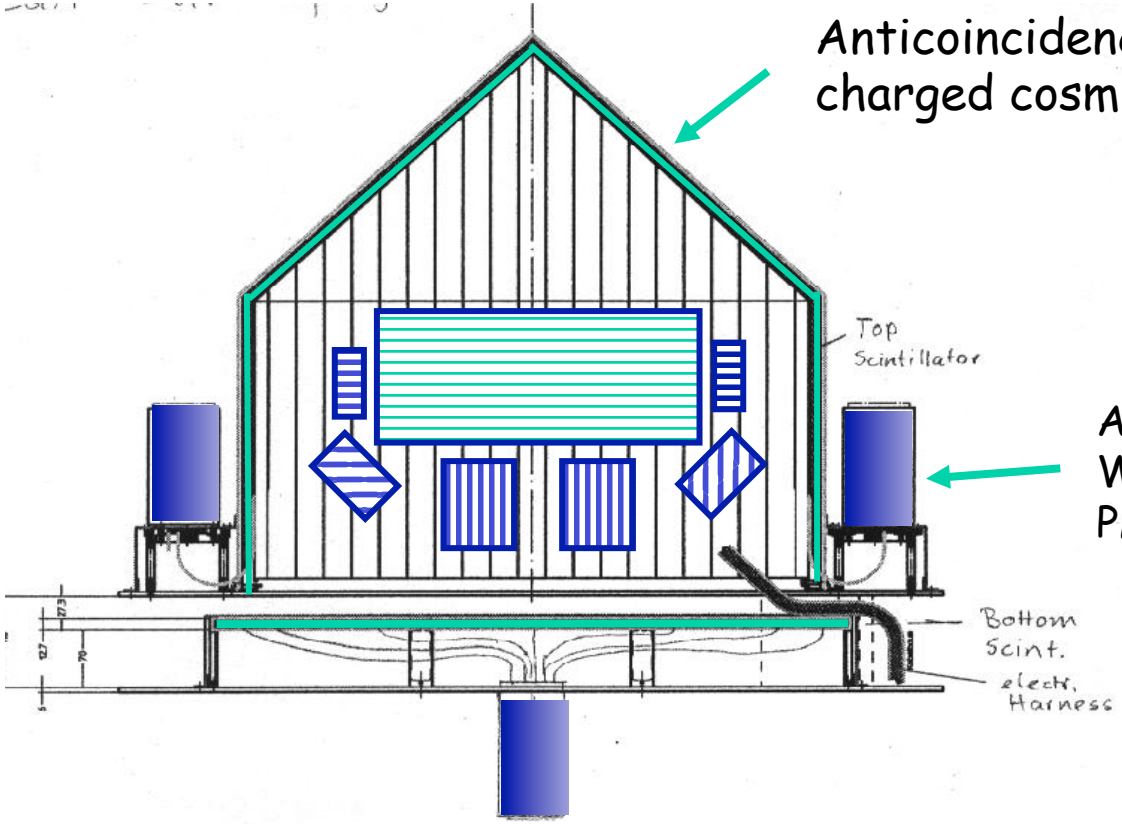
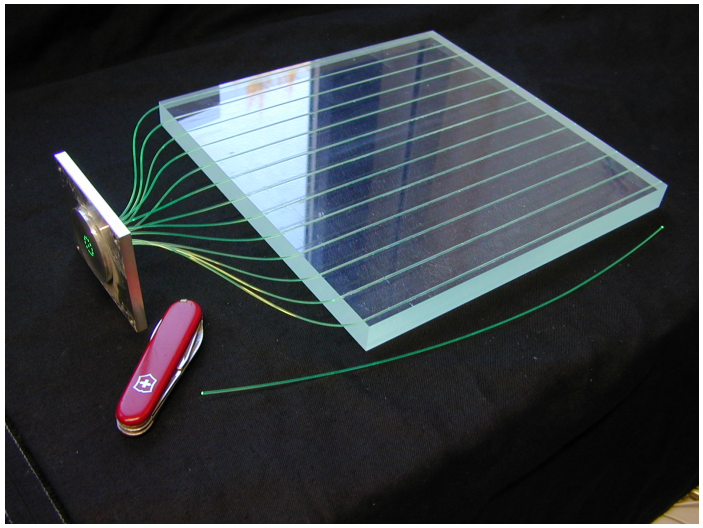
MEGABALL Detector Layout

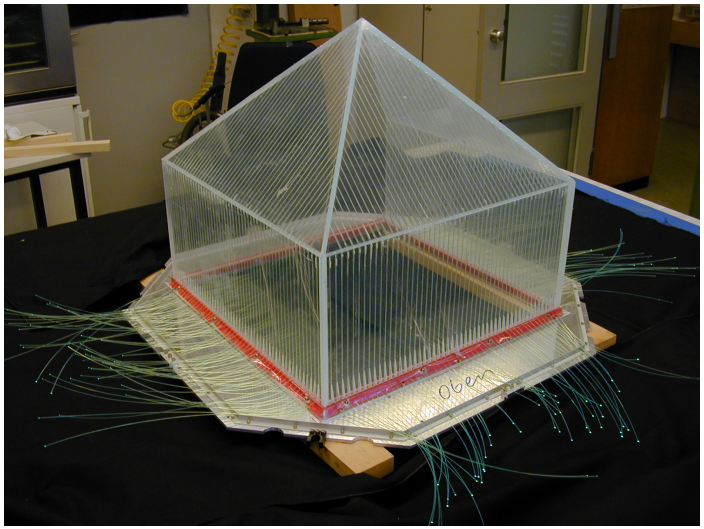


Anticoincidence Shield to veto charged cosmic ray particles

ACS readout:
WLS fibres collected at PMTs

MEGABALL ACS Development

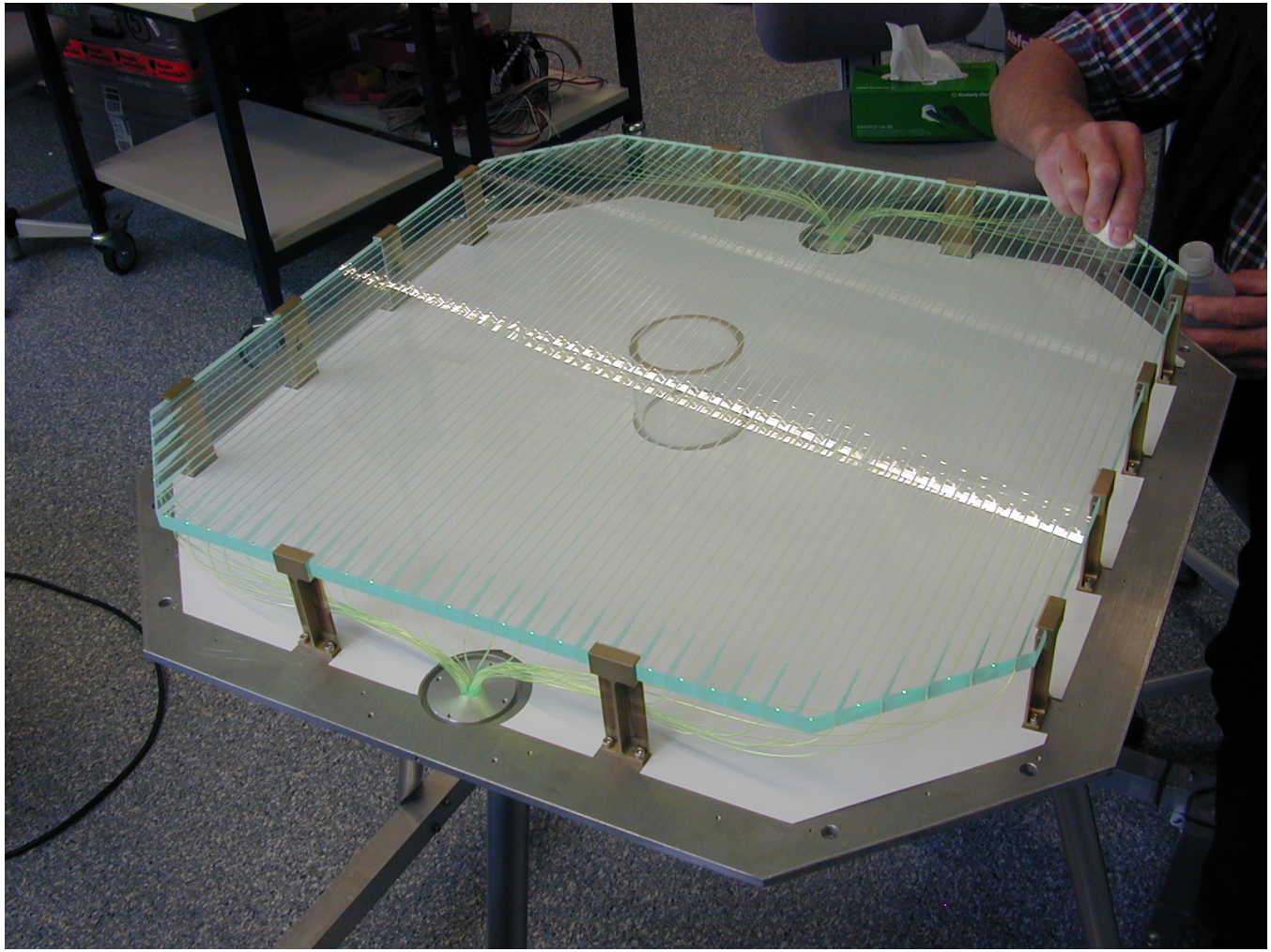




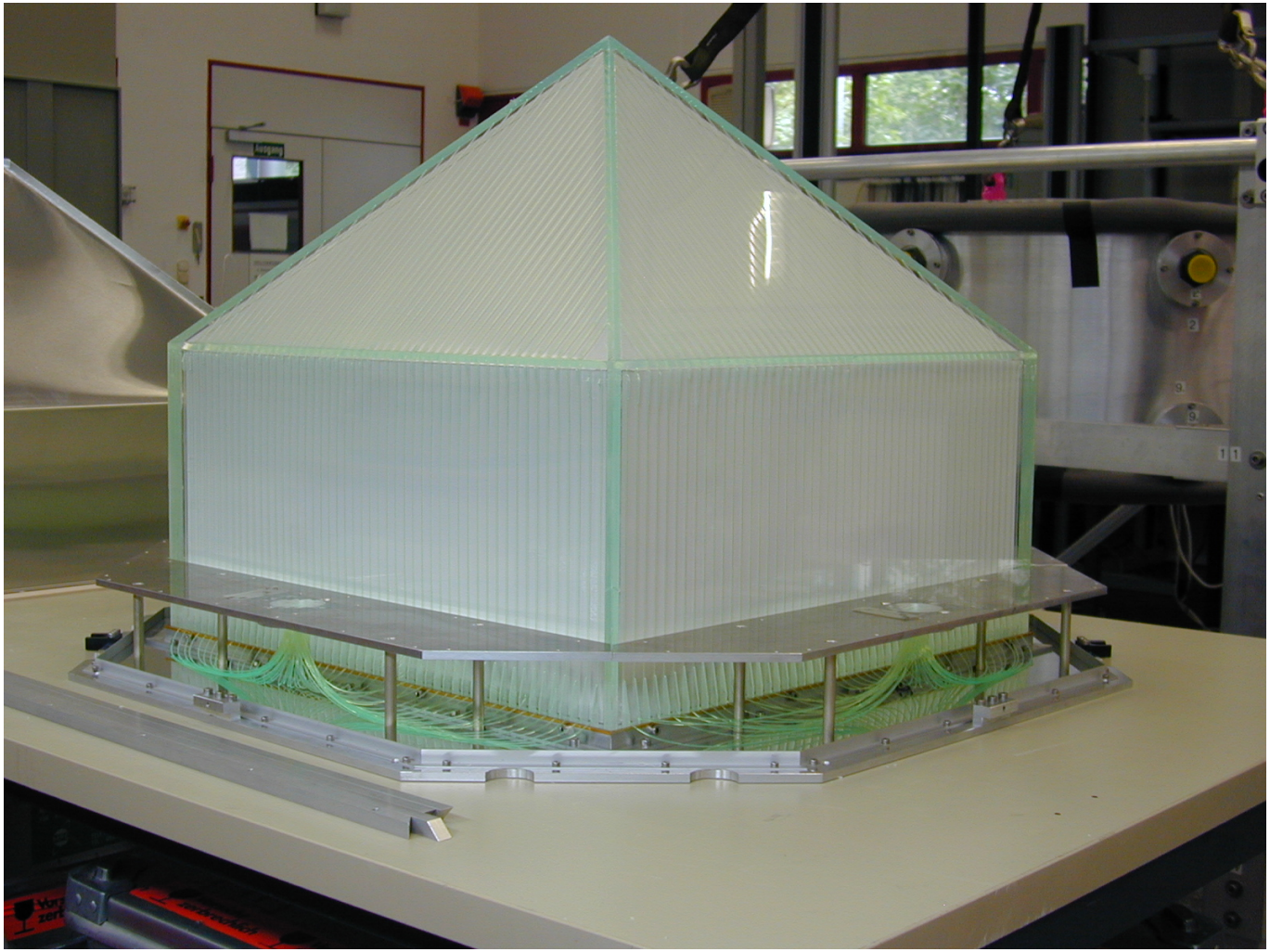
Material:
Plastic Scintillator BC-412 (equiv. to NE-110), 0.5 inch
Readout:
Wavelength Shifting fibers BCF-91A in grooves with 10mm pitch

Detectors:
EGRET ACS flight spare PMT units

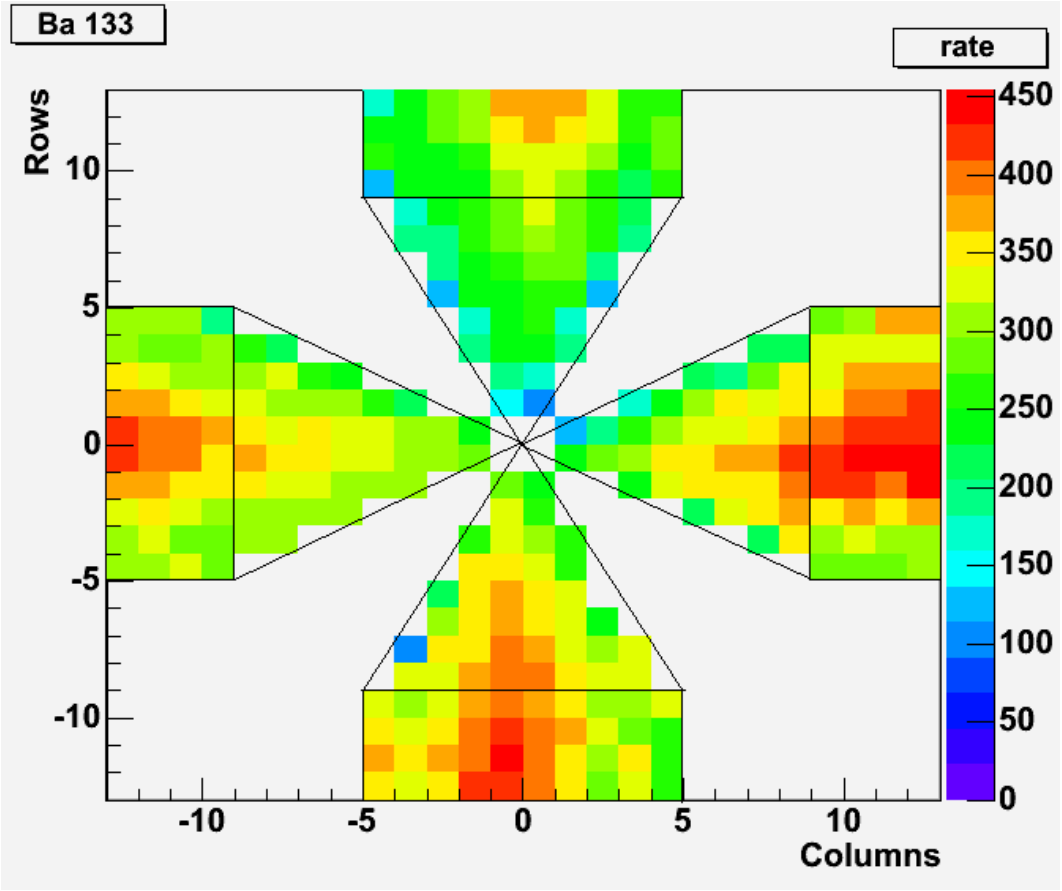
Lower ACS Plate of the MEGA Balloon Experiment:

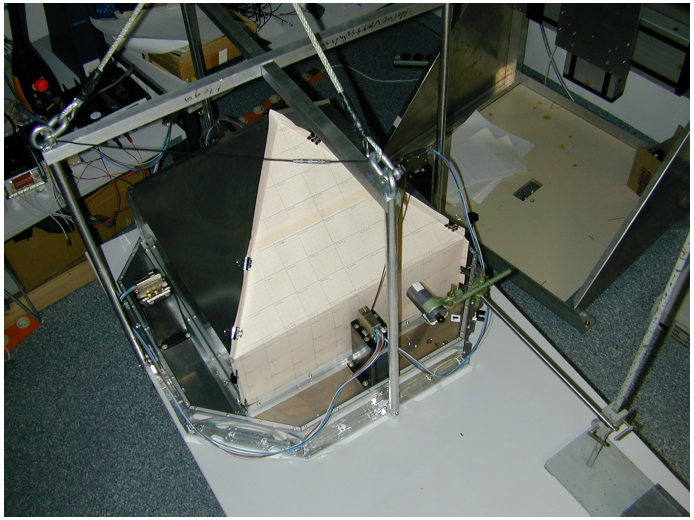


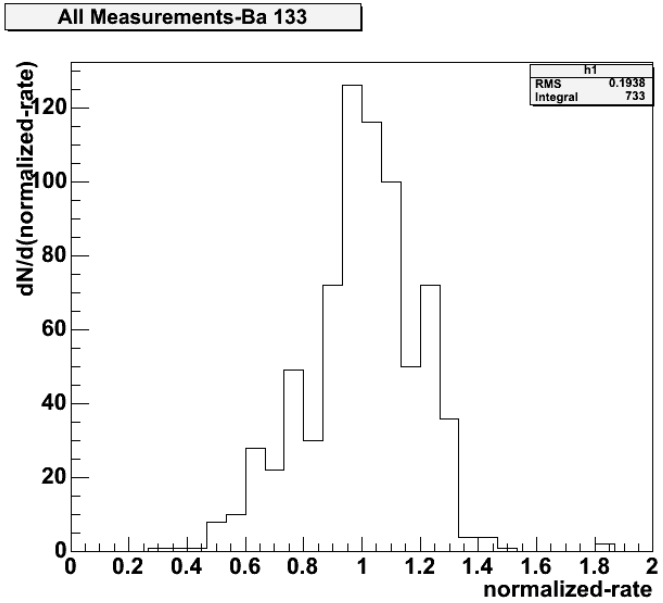
Upper ACS Dome of the MEGA Balloon Experiment:



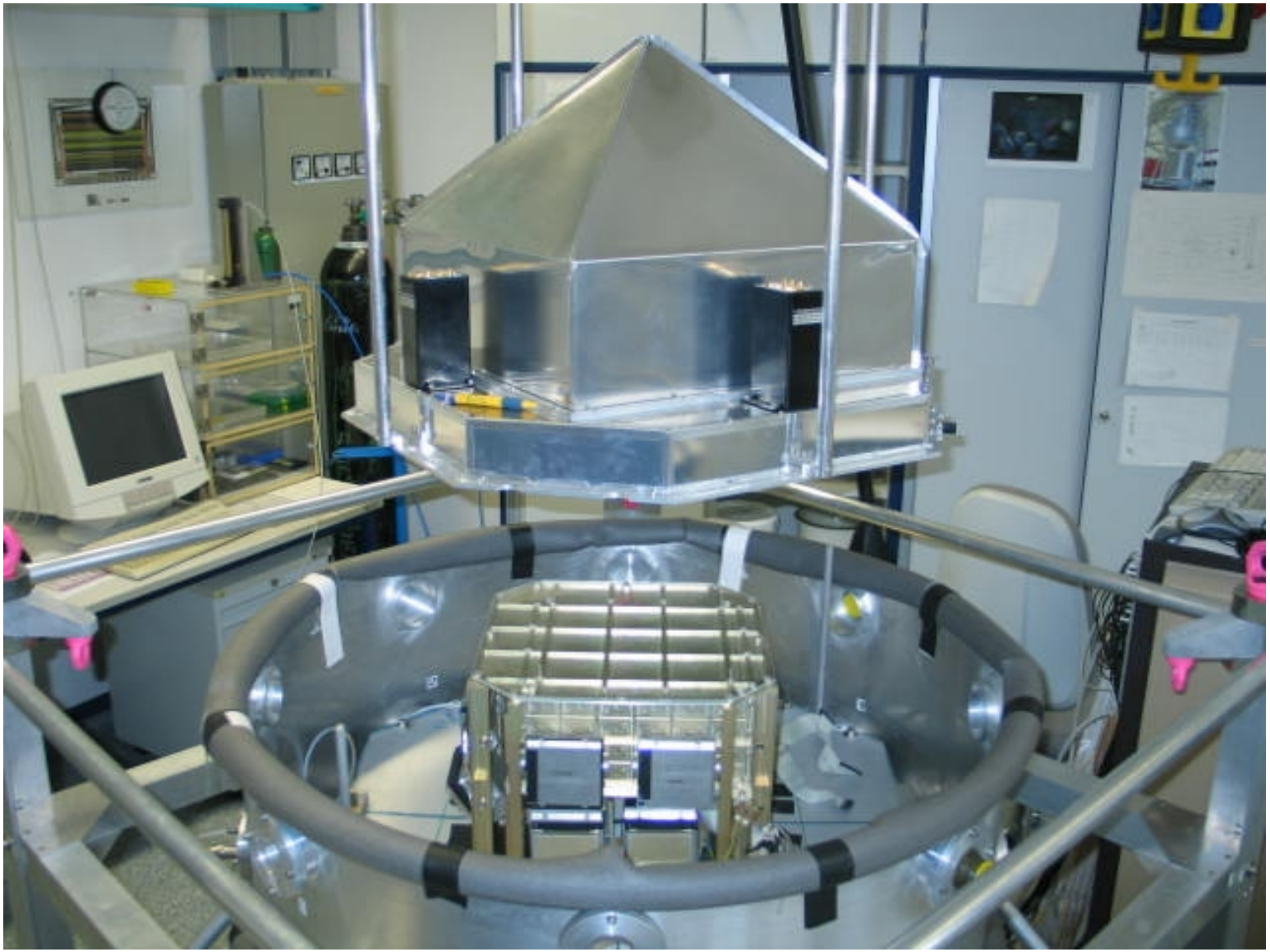
ACS Uniformity (M. Ajello)





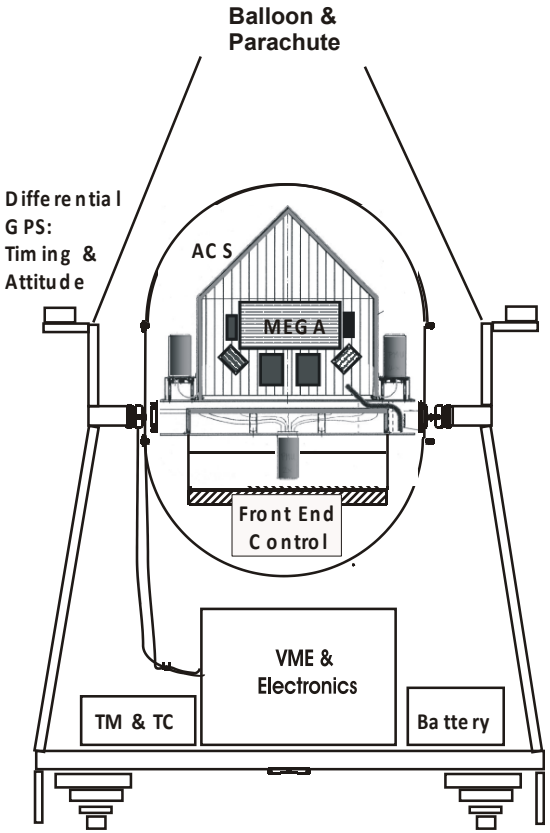


MEGABALL: Detector Platform & ACS



The MEGABALL* Balloon Flight

(NSBF, Ft. Sumner, NM, Spring 2004 ?)



Pressure vessel for the MEGA Prototype, ACS & FEC

VME DAQ

Batteries & Telemetry,

Total weight of payload ~ 400 kg
No active attitude control
Attitude measured with a differential GPS

Project Development Plan

1. Telescope Design and Simulation (1996-...)
2. Detector Development; build a Prototype (1999-2002)
3. Test the prototype with lab sources 0.5 – 4.4 MeV
4. Beam Calibration (April/May 2003) 0.7-50 MeV
5. Preparing a Balloon Flight (2004-2005)

On October 30, 2003 the MPE directorate decided to cancel further work on the MEGA project!

Gamma-ray astronomy was no longer considered to be part of MPE's science program

Proposing for a German Small Satellite Mission 2000

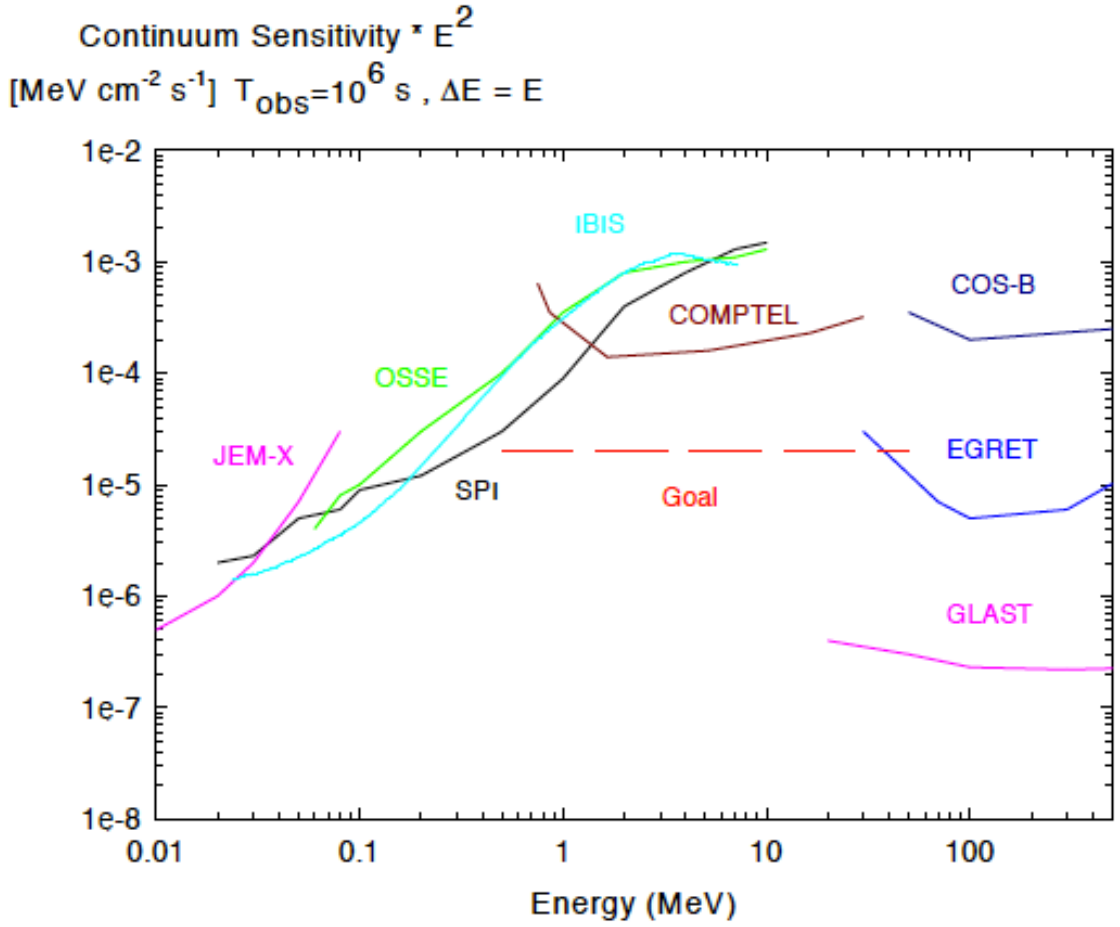
MEGA

A Telescope for Medium Energy Gamma-Ray Astronomy

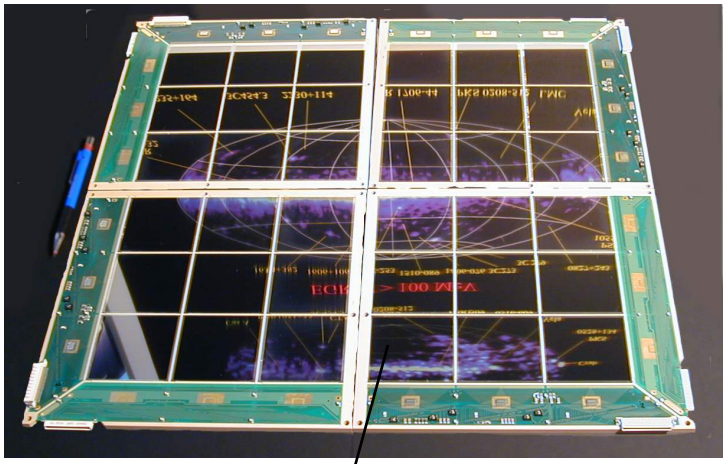
Proposal for a DLR Kleinmission
'Extraterrestrische Grundlagenforschung'

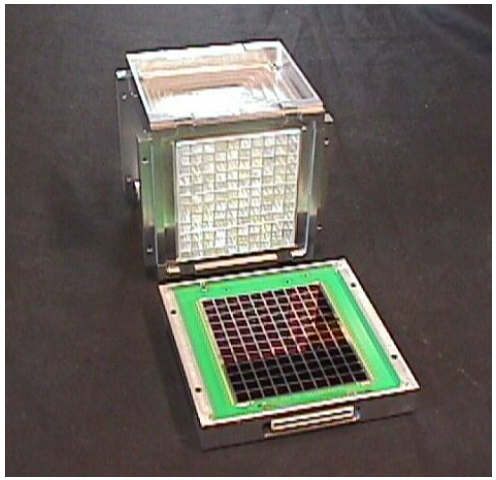
August, 2000

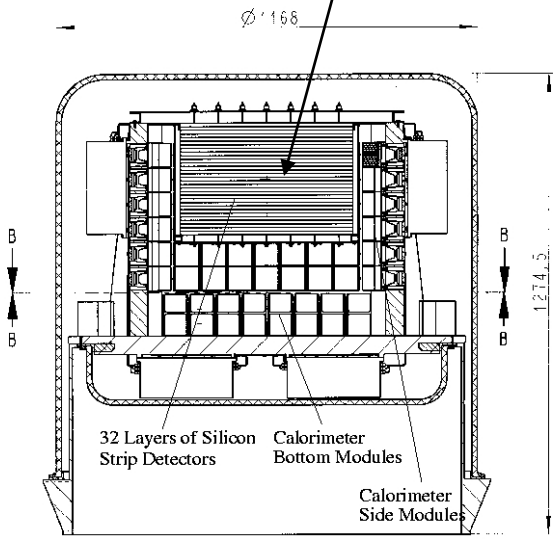
Proposing for a German Small Satellite Mission 2000



Prephase-A Study: Instrument

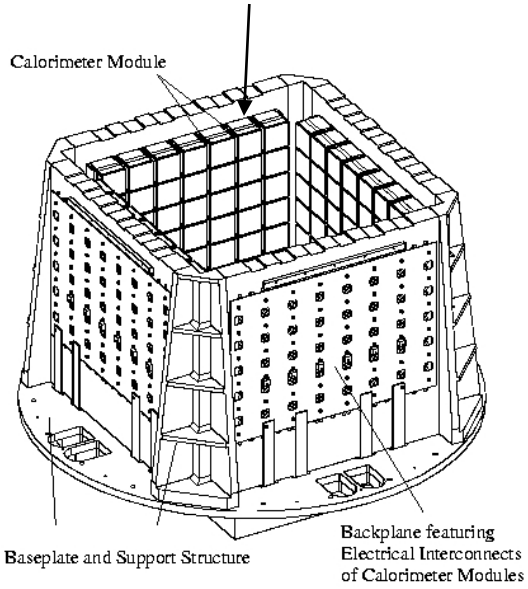




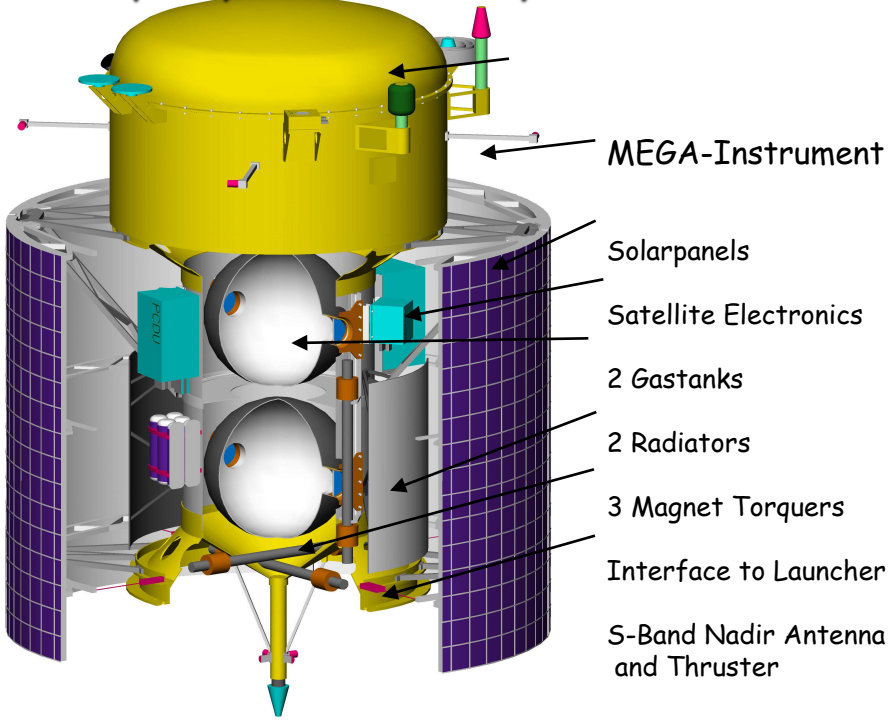


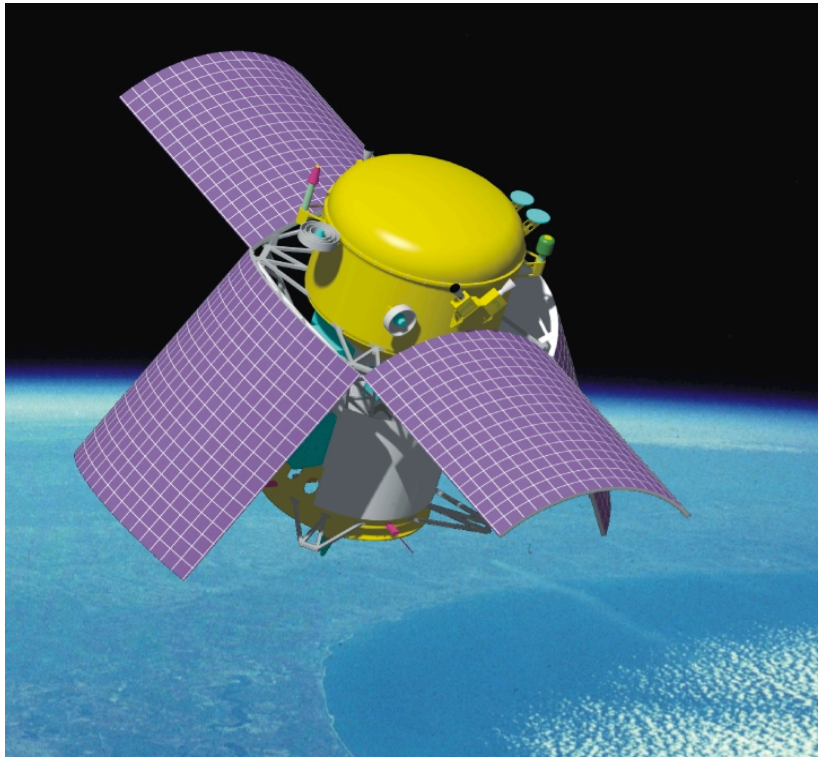
Technical data of the Instrument

Mass:	650 kg
Power:	214 W
Channels:	134120



pre phase-A study of the Satellite





Technical Data of the Satellite

Mass:	950 kg
Diameter:	200 cm
Length:	235 cm
Power:	350 W
Telemetry:	online, max. 150 kbit/s (TDRSS - DAS)

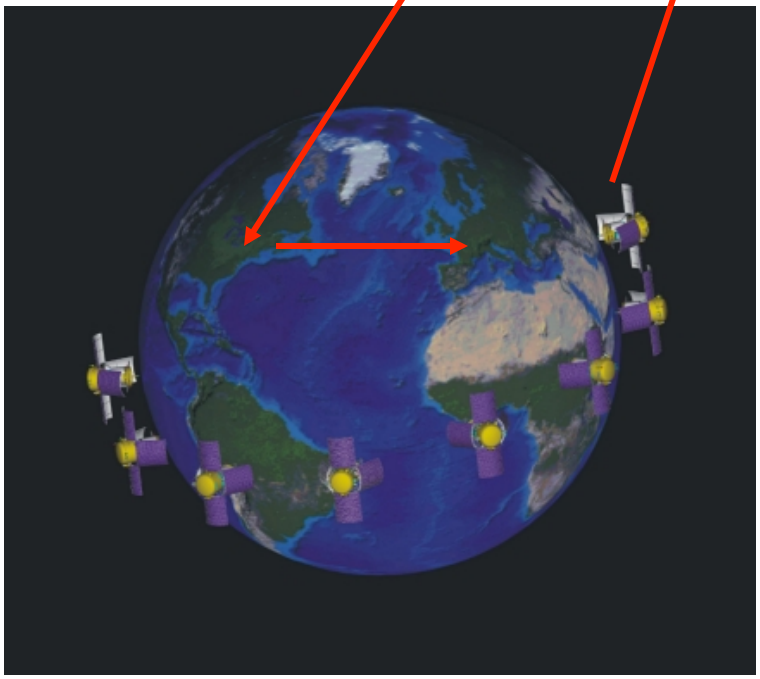
Orbit and Mission

Altitude:	550 km, circ.
Mission Time:	3 - 5 years
Inclination:	0° (<28.5°)
Attitude:	Zenith-Scan
Position:	GPS, Starsensors

MEGA Mission:

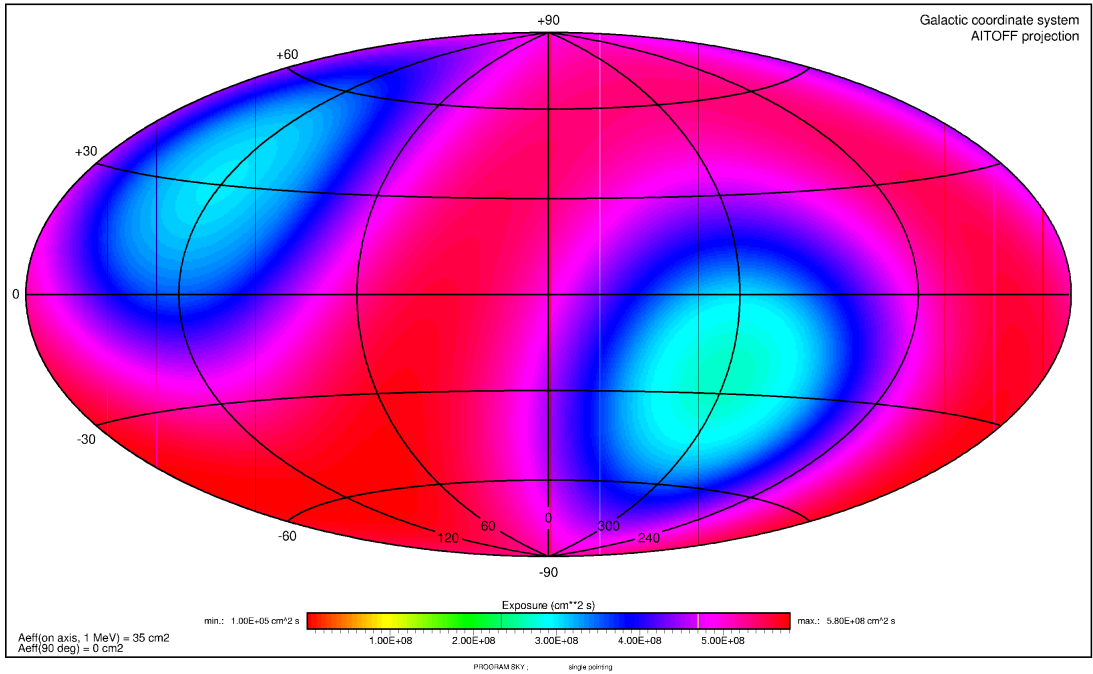
All Sky `Real-Time` Monitor

To TDRSS-DAS
Real Time Telemetry



Exposure Map
2 years Mission

MEGA Viewing Plan: 11238 orbits (2 y), i=28.5 deg, 500km

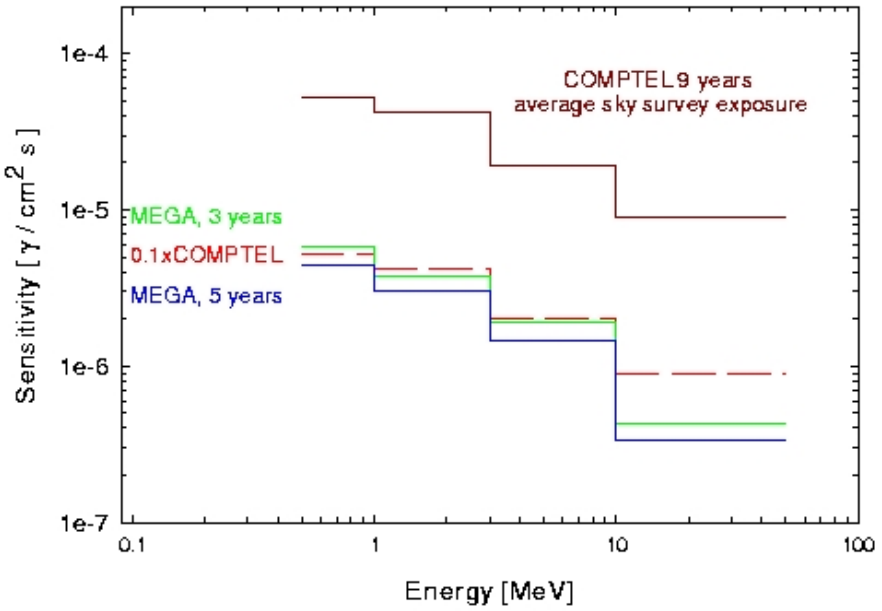


- Transient sources are detected in real time
- Prompt follow-up observations
- Homogeneous exposure with slight tilting of attitude

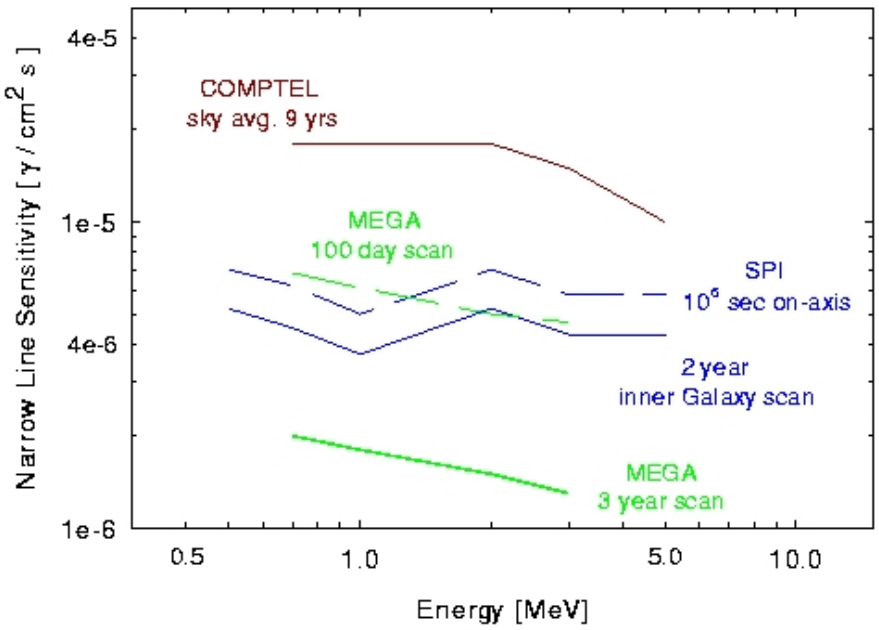
MEGA Sensitivity

GEANT Simulations incl. Orbital Background

Continuum



Narrow Lines



Angular Resolution 2.4° FWHM @ 2 MeV / Source Location: < 2 arcmin

Energy resolution 3% FWHM @ 2 MeV

Polarization 10% (Crab in 100 h or typical GRB in 100 sec)

Expectations for a MEGA Satellite in a ~3 year lifetime

Source	MEGA	COMPTEL
Pulsars	10	3
Binary Systems Binary Novae Micro-Blazars, Jet Sources	5 5 5	1 (Cyg X-1) 1 (N Per 91) 1?
Unidentified EGRET Sources	100	4
Radiogalaxies / Seyfert Galaxies	10 - 15	1 (OSSE: 4 / 25)
Blazars	100	10
Novae (^{7}Be, ^{22}Na, e^{+} e^{-} Ann.) Supernovae Ia (^{56}Ni , ^{56}Co, ^{57}Co)	5 / year 2-3 / year	0 1(+1987a, SMM)
young SNR (^{44}Ti)	5 ?	1(+ 1?)
Gamma Ray Bursts	~0.5 / day	39 (total)
Solar Flares: continuum and lines	depends on cycle	27

Outcome of the DLR Kleinsatelliten AO in 2001:

MEGA was in second place with high scientific credentials (after the astrometry mission DIVA, which turned out to be underfinanced and was later cancelled)

After the 2003 decision to terminate MEGA activities at MPE, the gamma-ray group resumed thinking about an advanced low- to medium energy telescope. The outcome of these studies is known as
„GRIPS" (Gamma-Ray Imaging, Polarimetry, Spectroscopy)

→ presentation by Jochen Greiner

END