# Very Large Space Optics for an Investigation of the Extreme Universe

Presented by Jim Adams
## for the Super EUSO Collaboration*

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Auger main anisotropy result
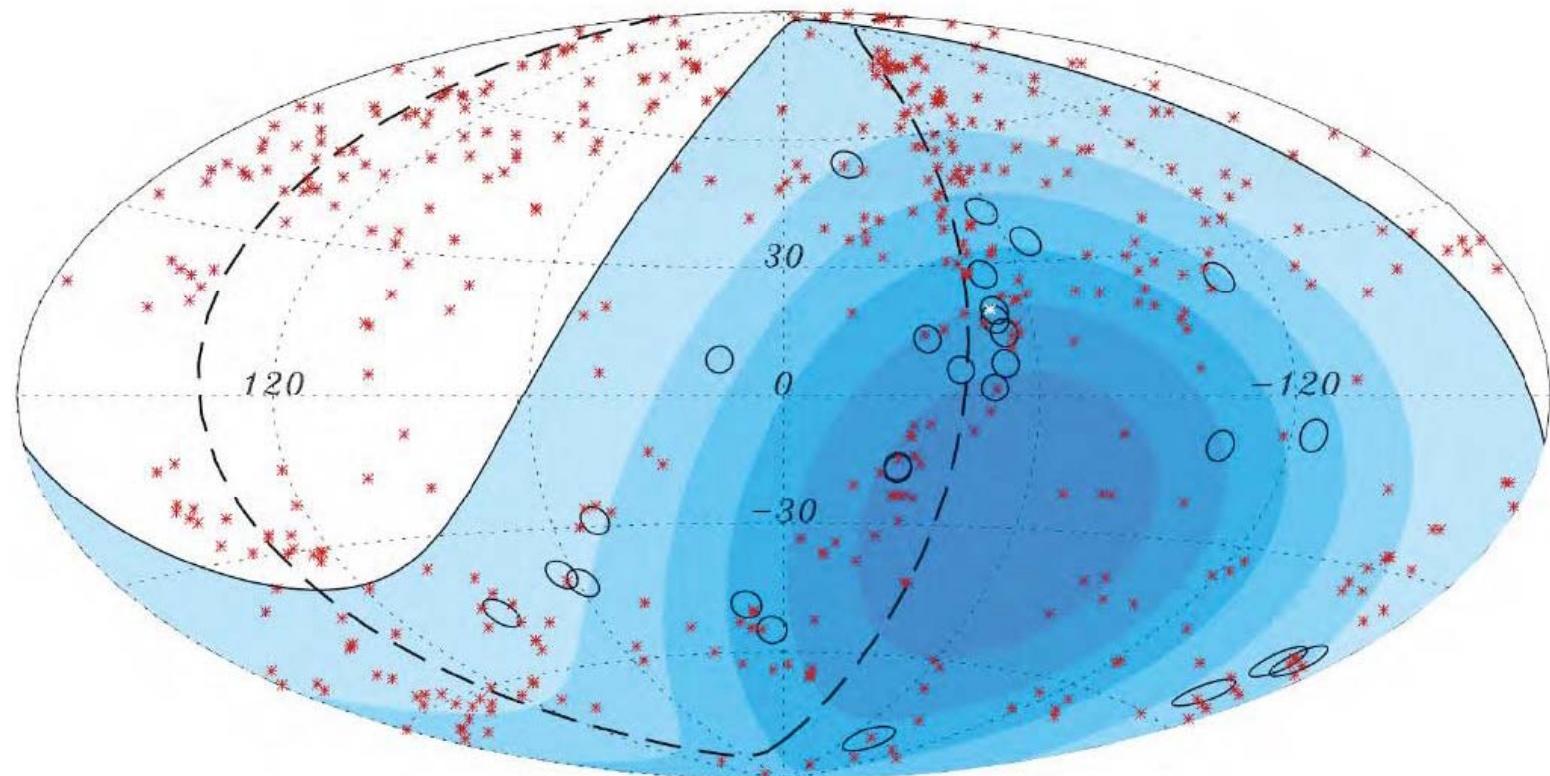
O (cosmic rays); X (active galactic nuclei); blue shading (exposure)

Event Arrival Direction Reconstruction

0.2°
0.2°
ν

2°
2°
proton
$(E = 10^{20}\ eV)$

Neutrino error box is limited only by the EUSO angular resolution while the proton error box is dominated by the intergalactic magnetic field.

$<B> = 1\ nGauss$

$<d> = 30\ Mpc$

ISS

EUSO FOV
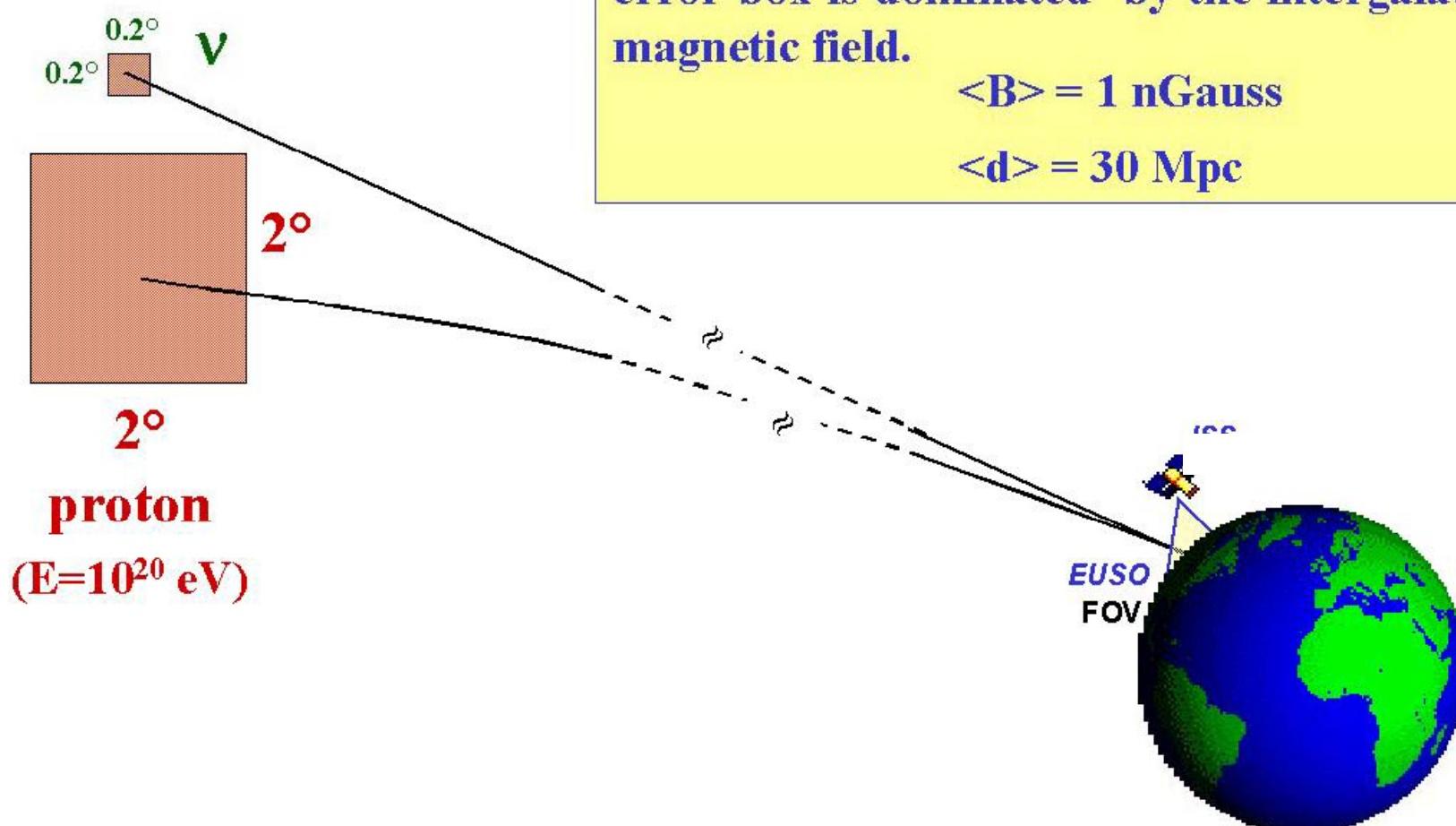
Extreme Energy Cosmic Rays (EECRs)

- Energies extending to at least 50 Joules/particle
- Fluxes of 1 particle/(km^2*century)
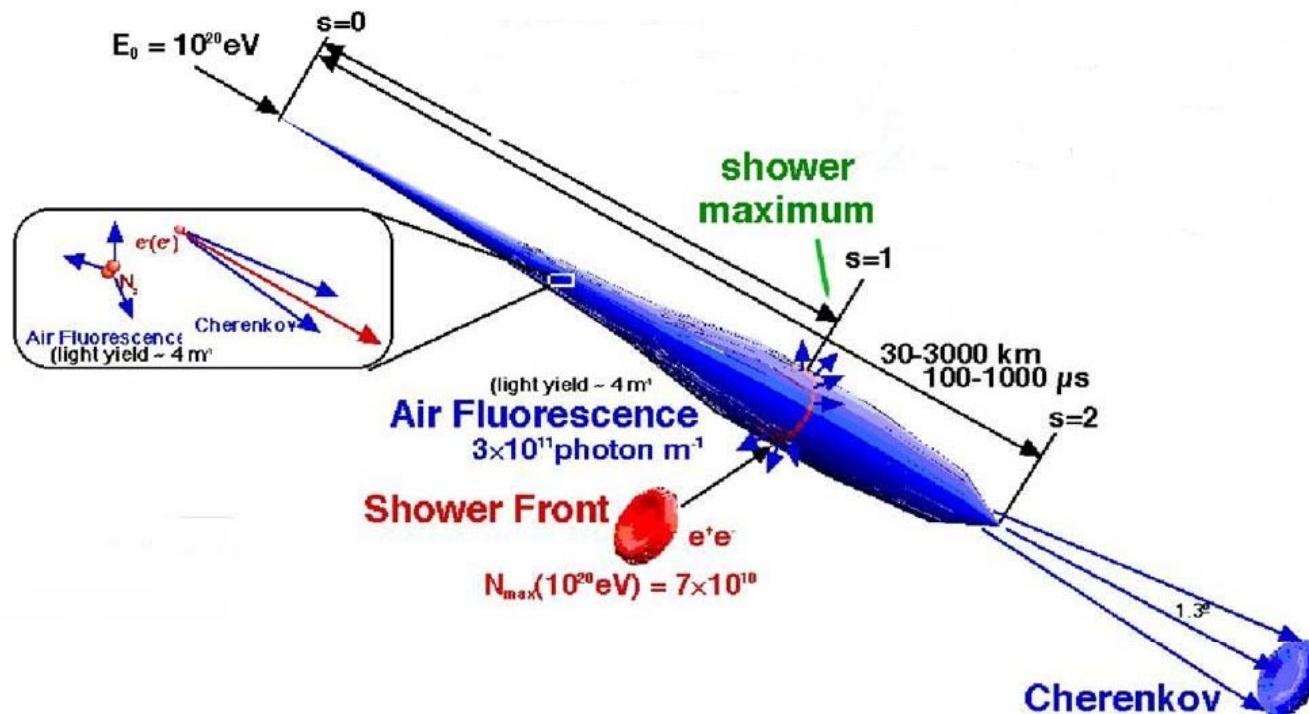
# Shower Time Profile
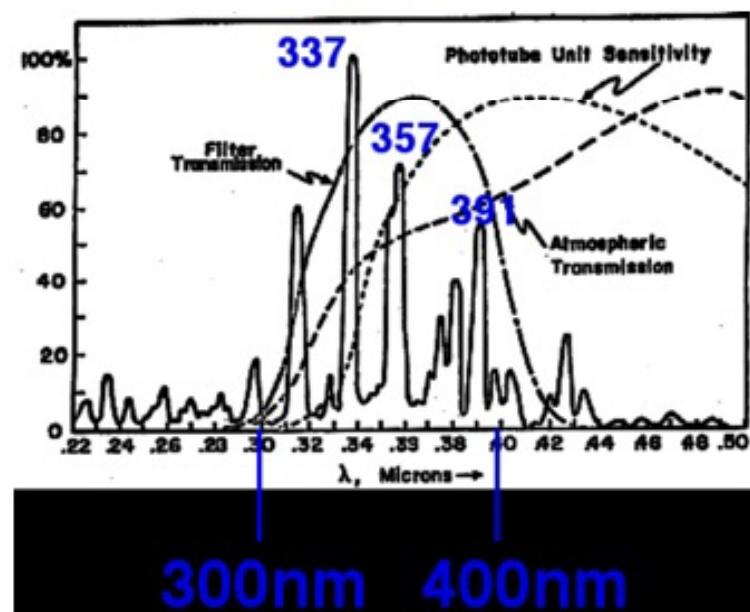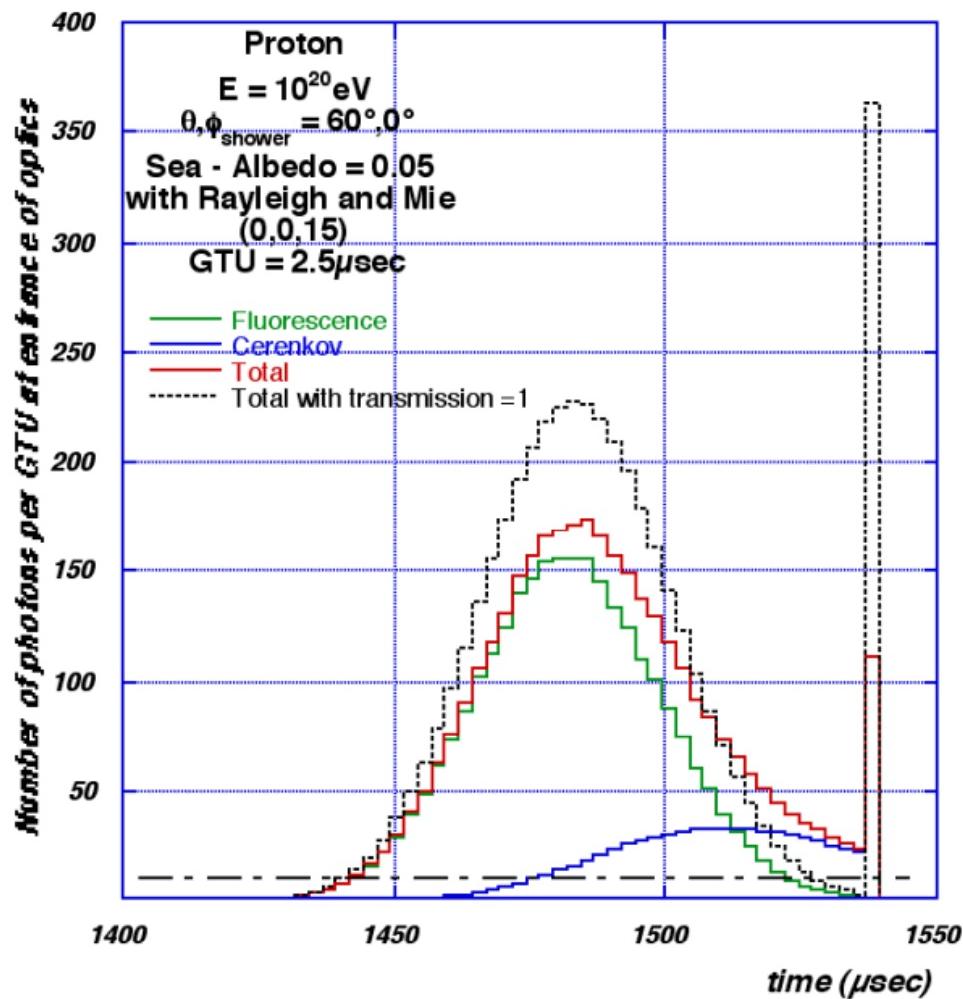
Hybrid Ground-based Array
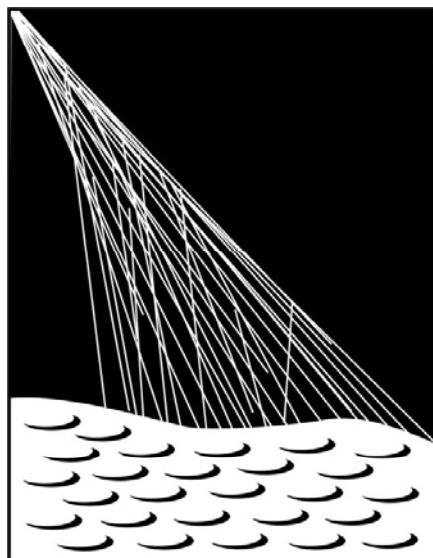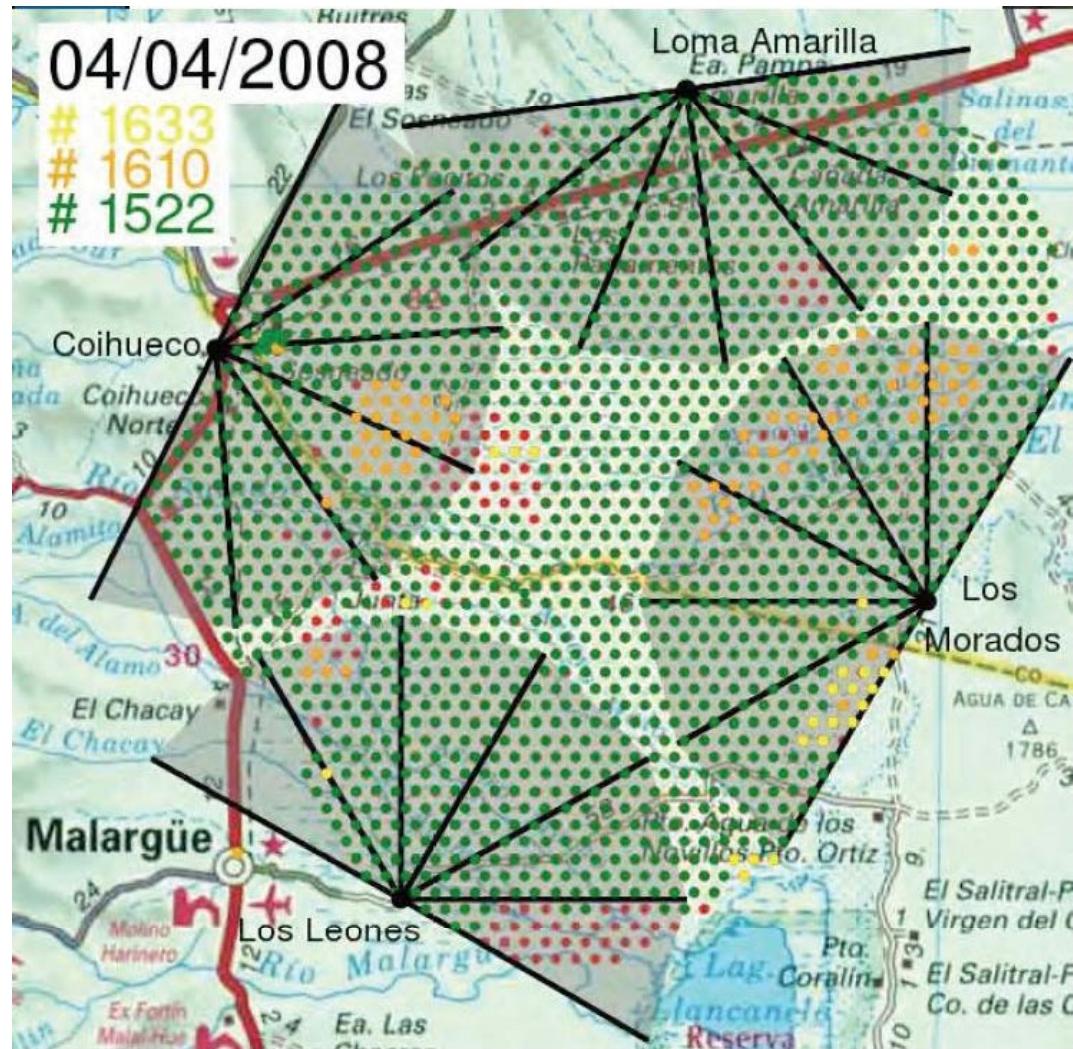
Fluorescence Detector

850019_Longitudinal_Profile

$X_{max} = 761.9 +- 3.538$
$N_{max} = 3.9e+10 +- 4.4e+08$
$X_0 = 0 +- 0$
$\chi^2/dof\ 358 / 270$
$E_{em} = 4.9e+19$

E = 4.9 10^{19} eV
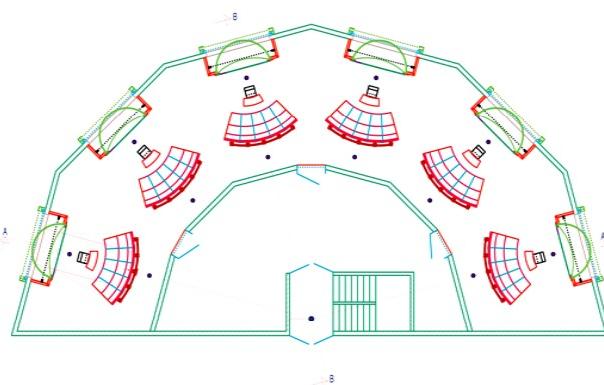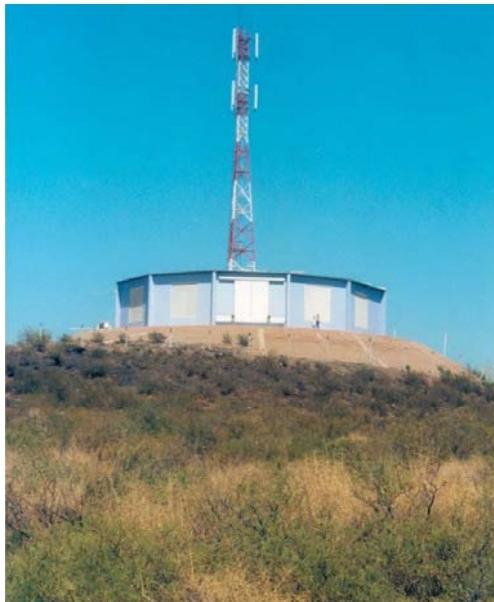
Independent analyses of stereo events

E = 4.8 10^{19} eV

Fitted Electromagnetic Shower

Size vs Depth

E = 5.3 10^{19} eV
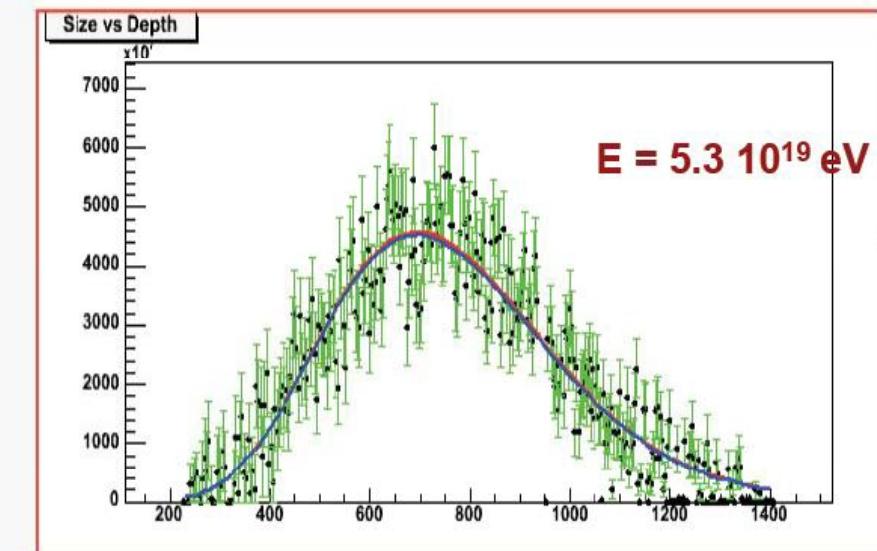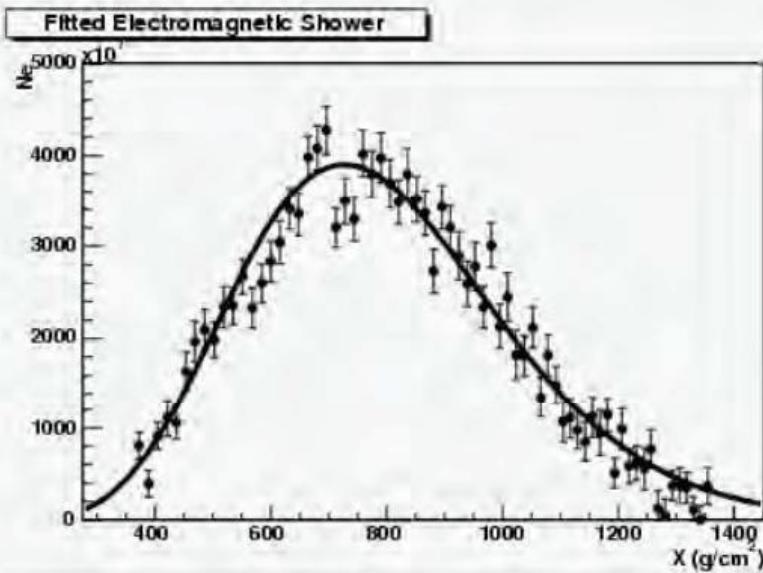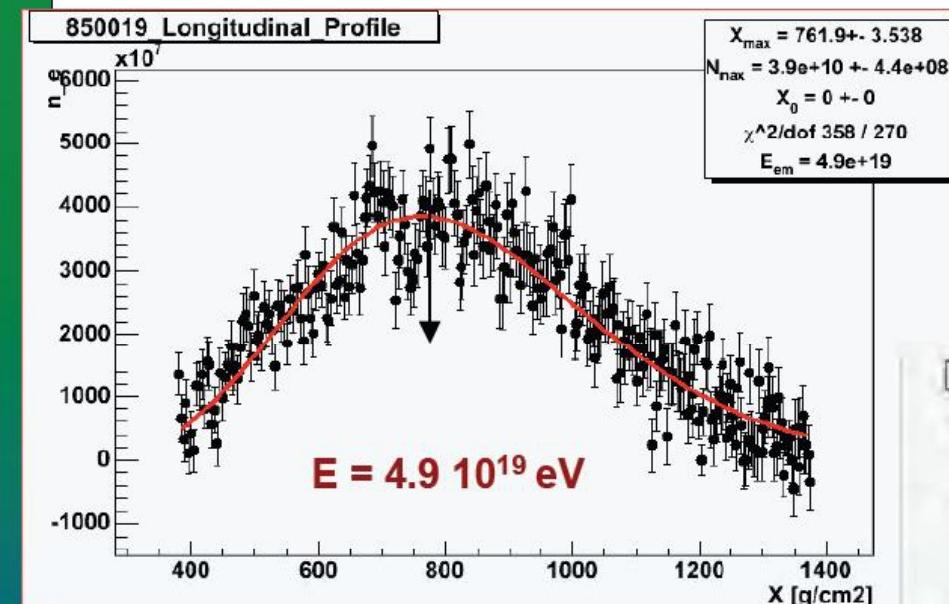
E_{em} calculated by fitting a GH profile and integrating

Super-EUSO

S-EUSO

25°

1000 km

EECR

Fluorescence   Čerenkov   Atmosphere

500 km

Earth   A.C.A. '02
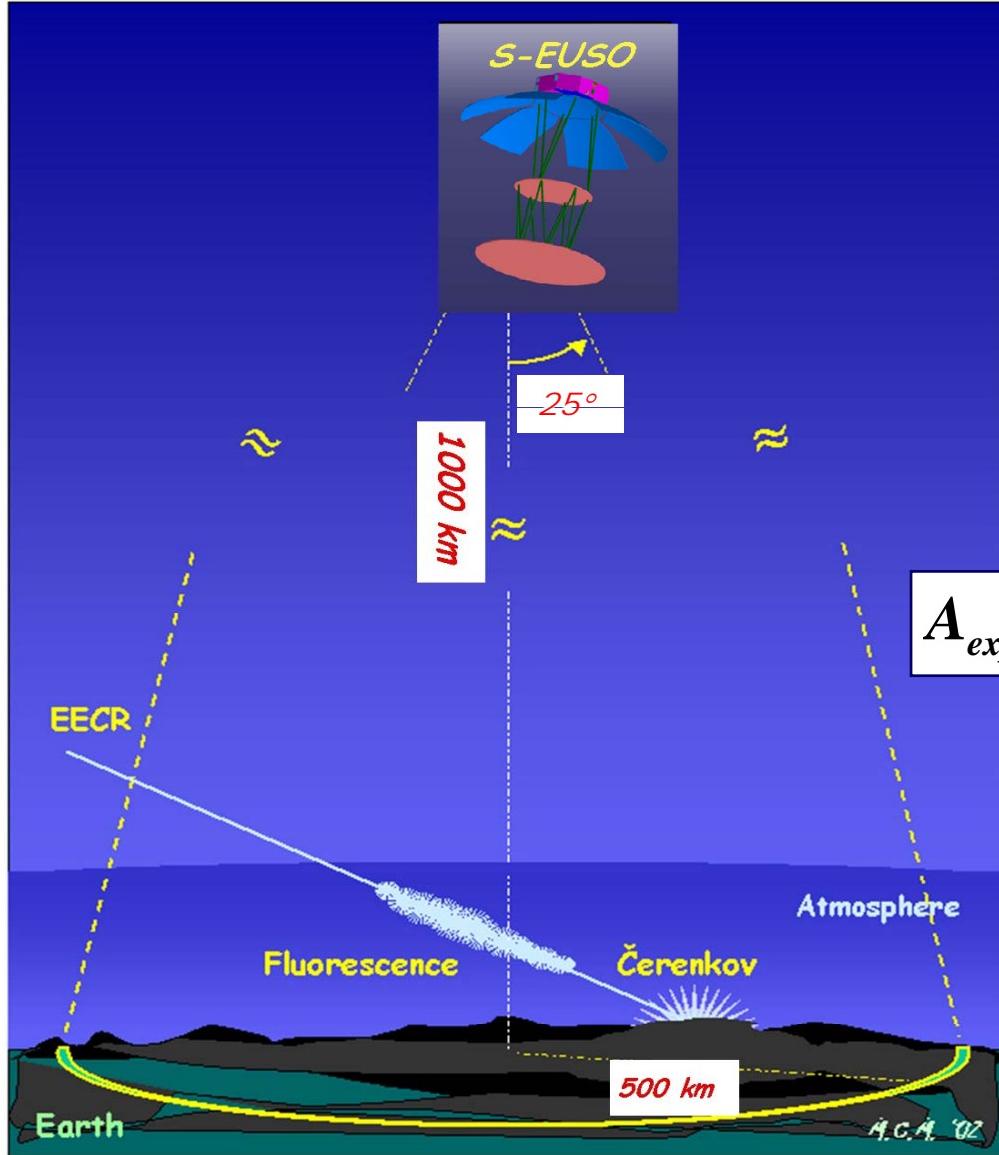
- **Free Flyer**
  - *Variable orbit 1000 km*
  - $A_{aper}^{inst} \approx 2.4 \times 10^6 \ km^2 \cdot sr$
  - $Life \approx 5 \ yr$
  - $\eta_{cycle} \approx 10 \div 20 \ \%$

$$A_{exp} \approx (1.2 - 2.4) \times 10^6 \ km^2 \ sr \ yr$$

Tilted mode (? $A_{exp} \rightarrow 10^7 \ L$

Super EUSO Instrument Requirements

- Very large wide-angle telescope with high optical throughput and ~1 milliradian angular resolution
- High efficiency pixelated photo-detectors with single photon sensitivity
  - Photomultiplier tubes with ultra-bialkali photocathodes or
  - Silicon photomultipliers
- Optics Design Options
  - Reflective optics:
    - Schmidt or Maksutov optics
      - Convex focal surface
  - Refractive optics (the JEM-EUSO concept)
    - Very large and light-weight Fresnel lenses
    - Diffractive lens for chromatic correction
  - Antireflective coatings needed in either case

Photomultiplier Tubes

- Hamamatsu Ultra-Bialkali photocathodes
  - 40-45% Q.E. from 330-400 nm
  - Off the shelf (Hamamatsu)
  - Large inter-tube gaps on a convex surface
- Back-illuminated Silicon Photomultipliers
  - 90% Q.E. from 330-400 nm
  - Requires cooling
  - Developmental (Siemens)
  - Small inter-device gaps on a convex surface

Optics Design Concepts
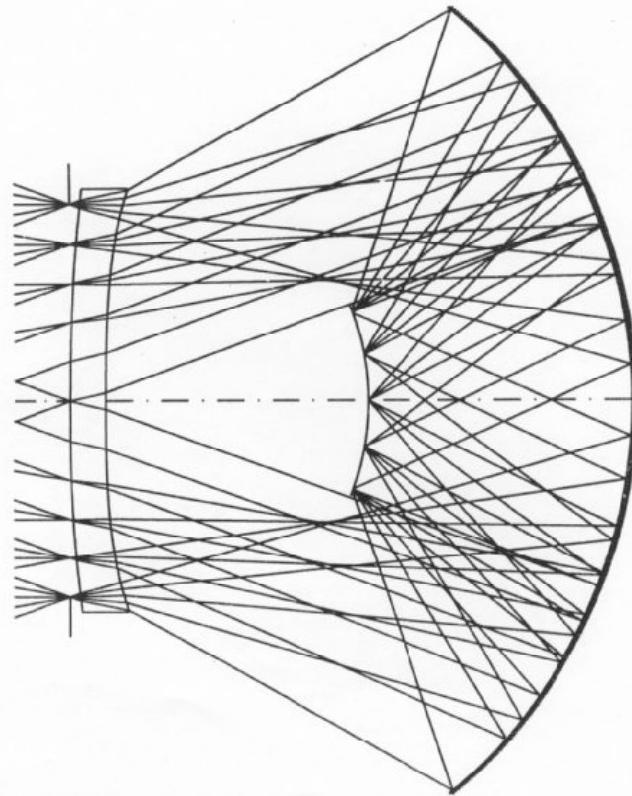
Maksutov optical design with an f/# of 0.66, CAO at UAH, Huntsville
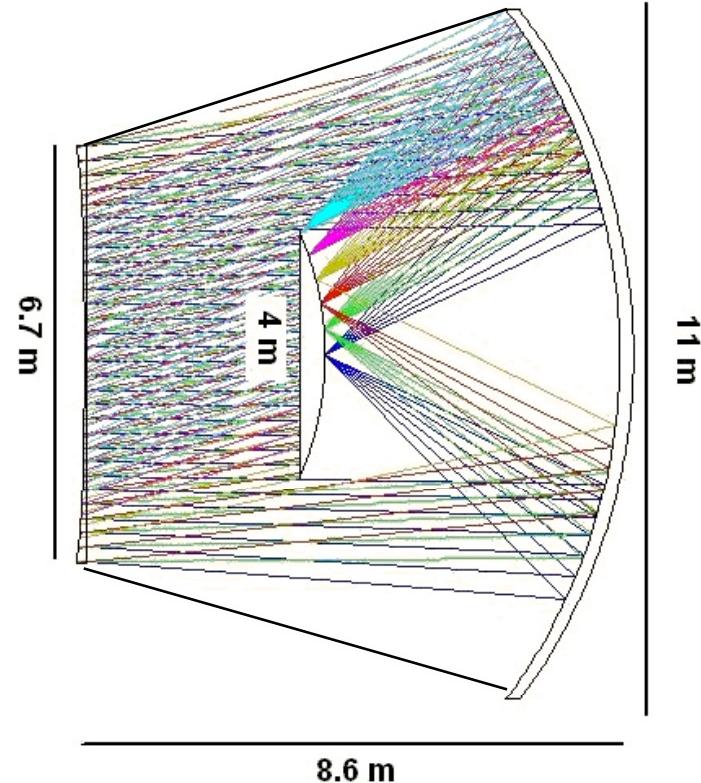
Schmidt design with an f/# of 0.7 and a 50° field of view, CNR- INOA, Firenze

Optics Throughput


Obscuration due to focal surface

+ Mirror reflectivity + transmission of Schmidt corrector reduce of ~ 0.9
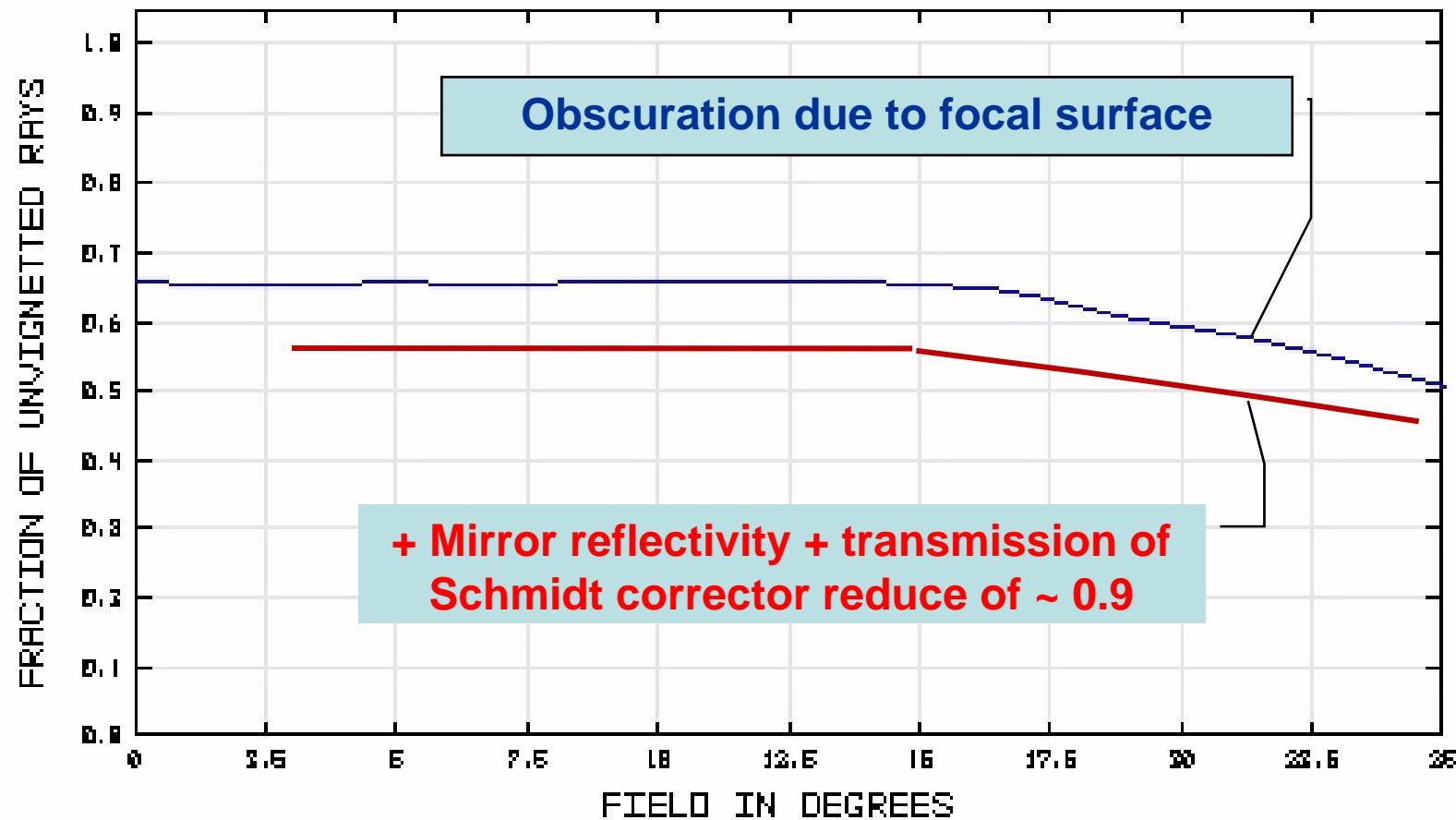
Filters not considered so far!!

Refractive Optics

Diffractive/Fresnel

Focal Surface

500.00 MM

Achromatic Fresnel- Diffractive, f/1.0   Scale: 0.05 AZ   28-Apr-04

Throughput is less than with reflective systems
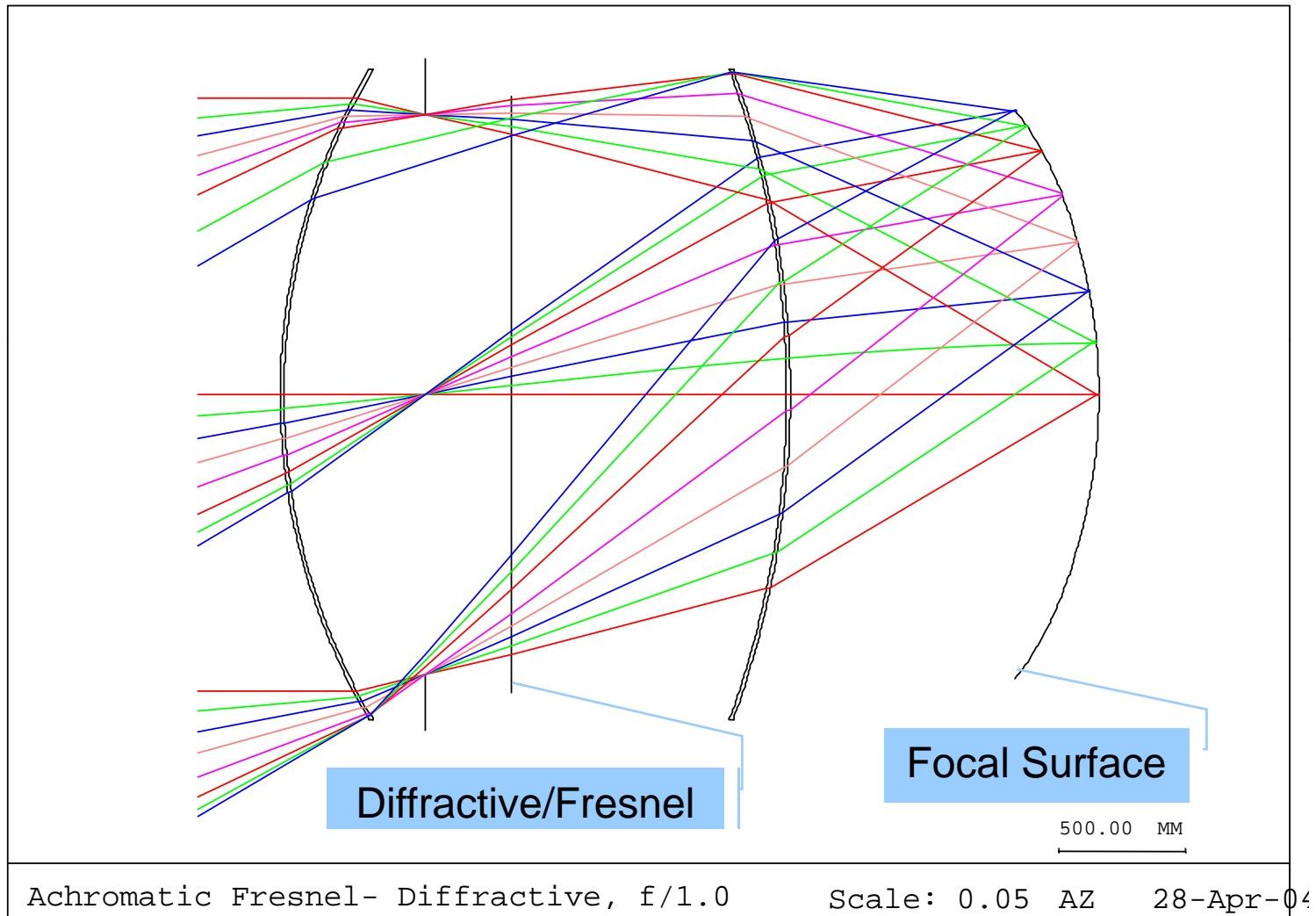
Shower Imaging and Reconstruction

Super-EUSO functions like a high-speed and wide angle video camera

• Frame rate: ~3 μsec/frame

• Pixel Size: 4×4 mm^2 on the focal surface or 1×1 km^2 on Earth

• Reconstruction in $1 \times 1 \times 1$ km^3 voxels

• Arrival direction reconstruction to $<0.2°$

• Energy reconstructed from fitted intensity at shower maximum

For those events with a detected Cherenkov reflection at a known altitude:

• Shower profile versus atmospheric depth will be reconstructed.

6.7 m

4 m

11 m

8.6 m
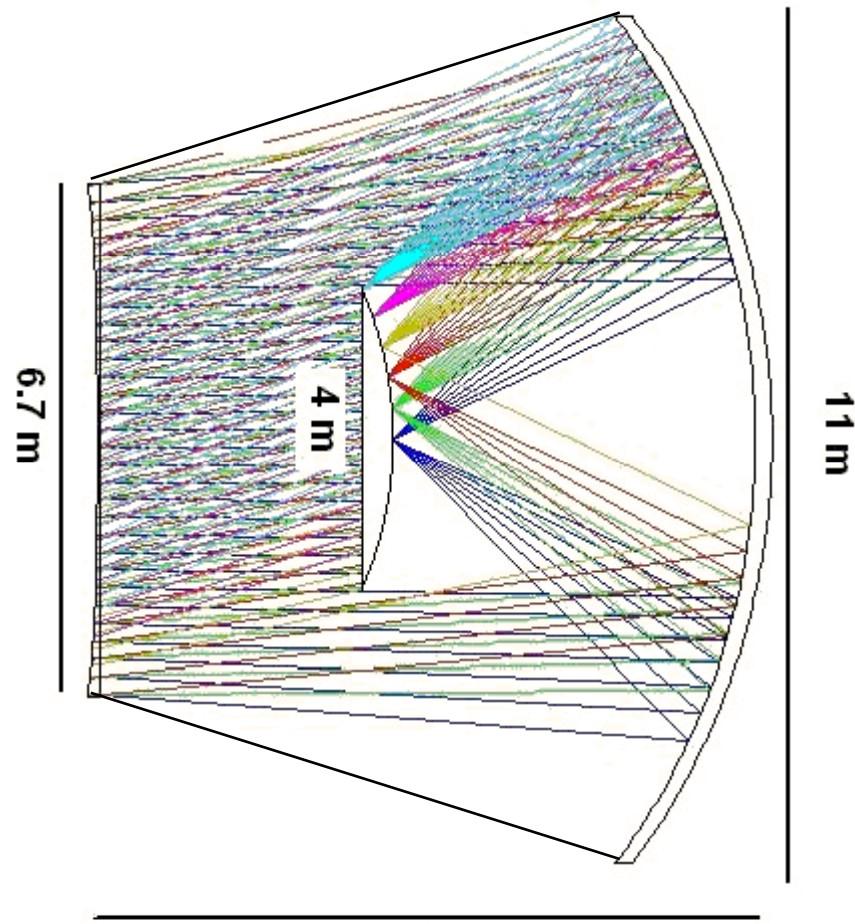
Optics Manufacturing Requirements

- ## Surface Roughness

  - 20 nm RMS on refractive elements

  - 5 nm RMS on reflective elements

- ## Tilt errors

  - <0.5 milliradian

- ## Anti-reflective Coatings on refractive elements

 - >90% transmission in the 330-400 nm band

Super EUSO Spacecraft Concepts
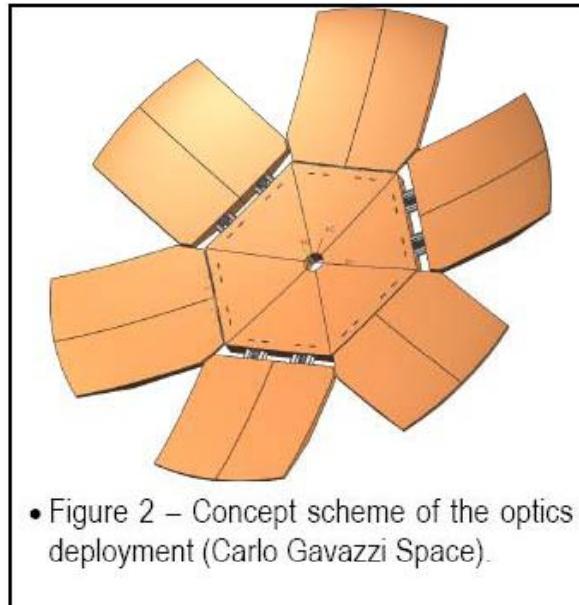
- Figure 2 – Concept scheme of the optics deployment (Carlo Gavazzi Space).
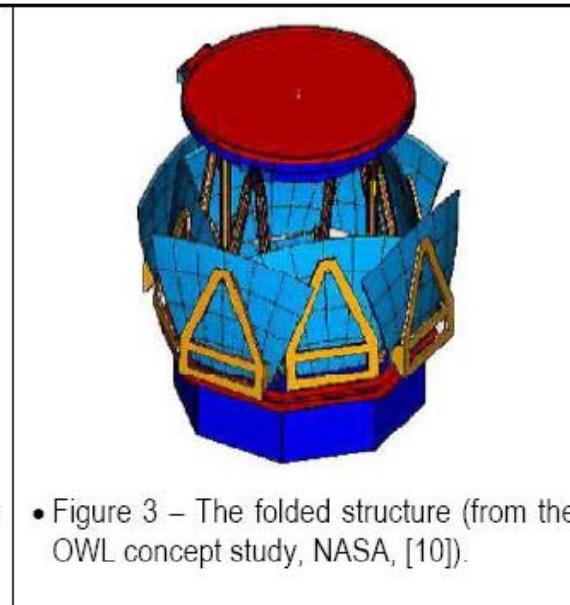
- Figure 3 – The folded structure (from the OWL concept study, NASA, [10]).
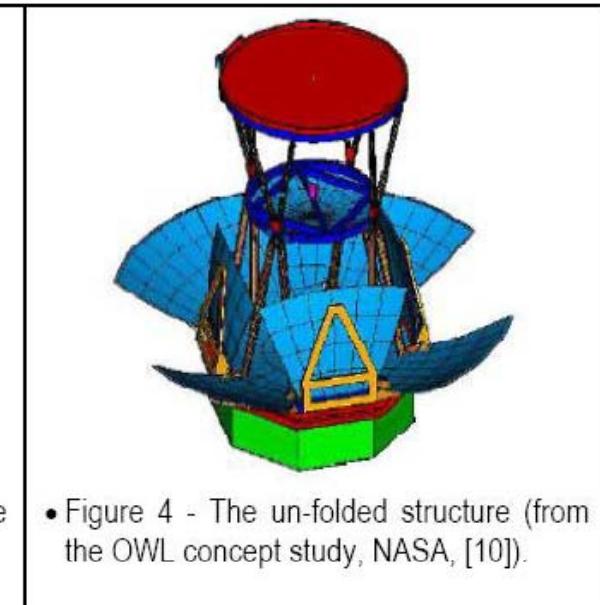
- Figure 4 - The un-folded structure (from the OWL concept study, NASA, [10]).

These folding concepts were developed to fit Super-EUSO into an existing faring.

ARES V Option

- Launch Super EUSO as a rigid unit
  - Spherical mirror constructed from regular hexagonal zones
  - Segmented corrector plate in the style of a lighthouse lens
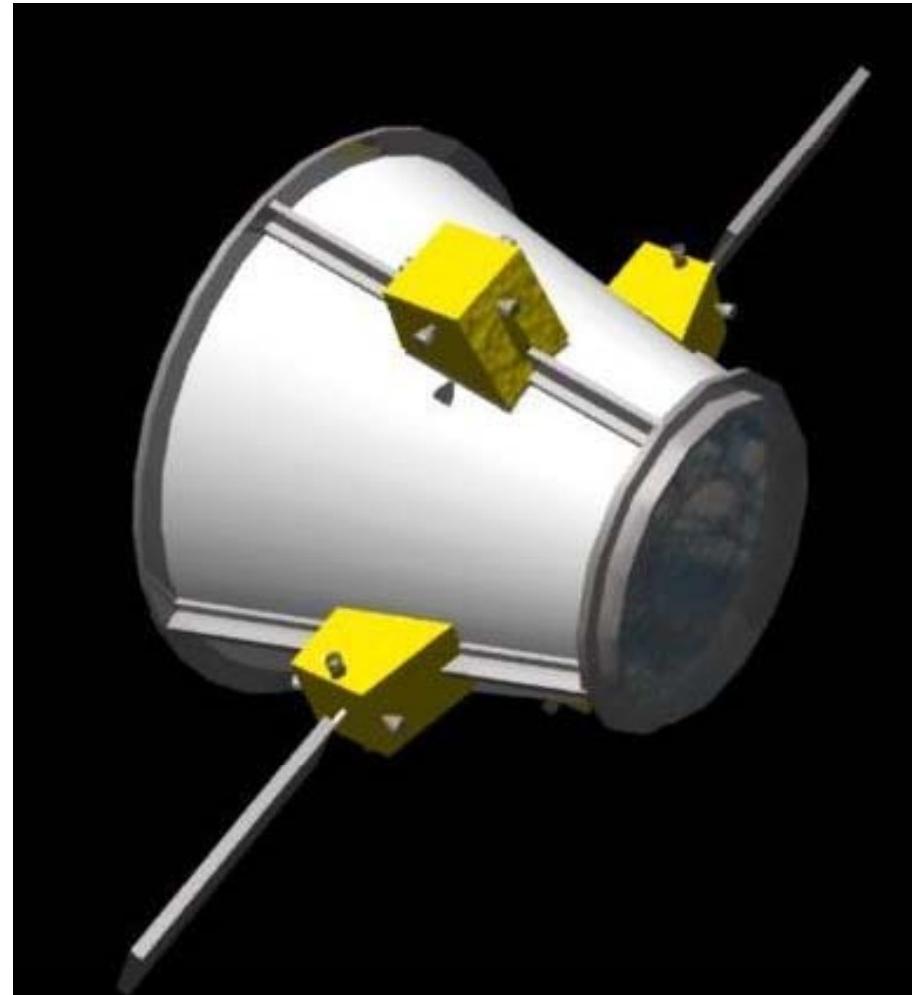
Notional Design
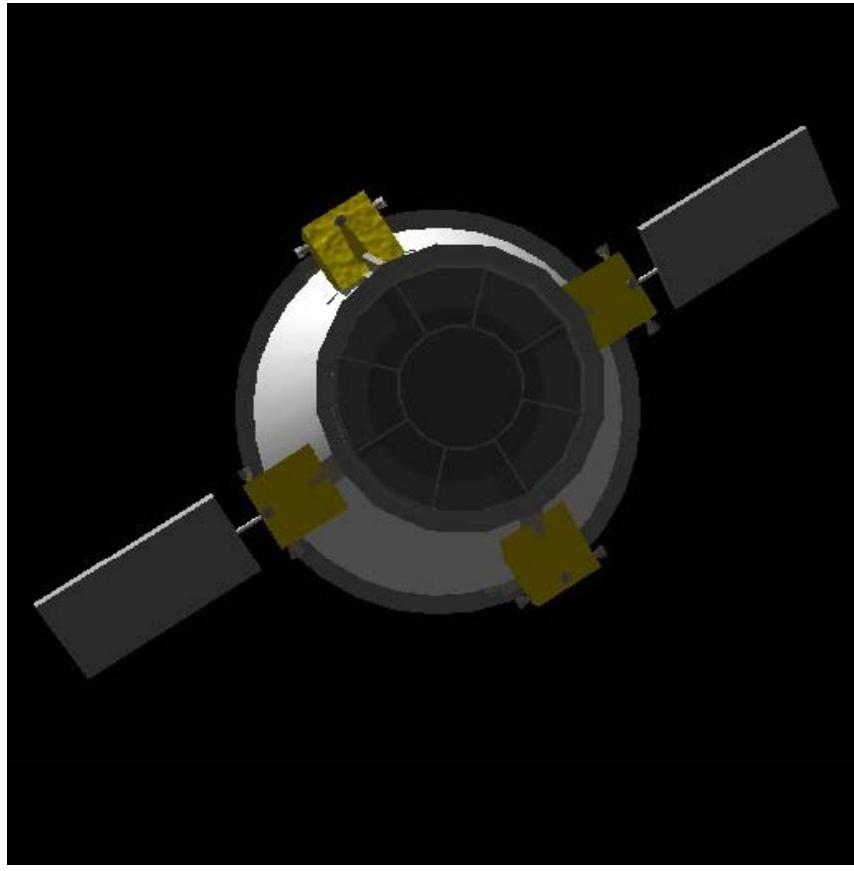
Segmented Corrector Plate
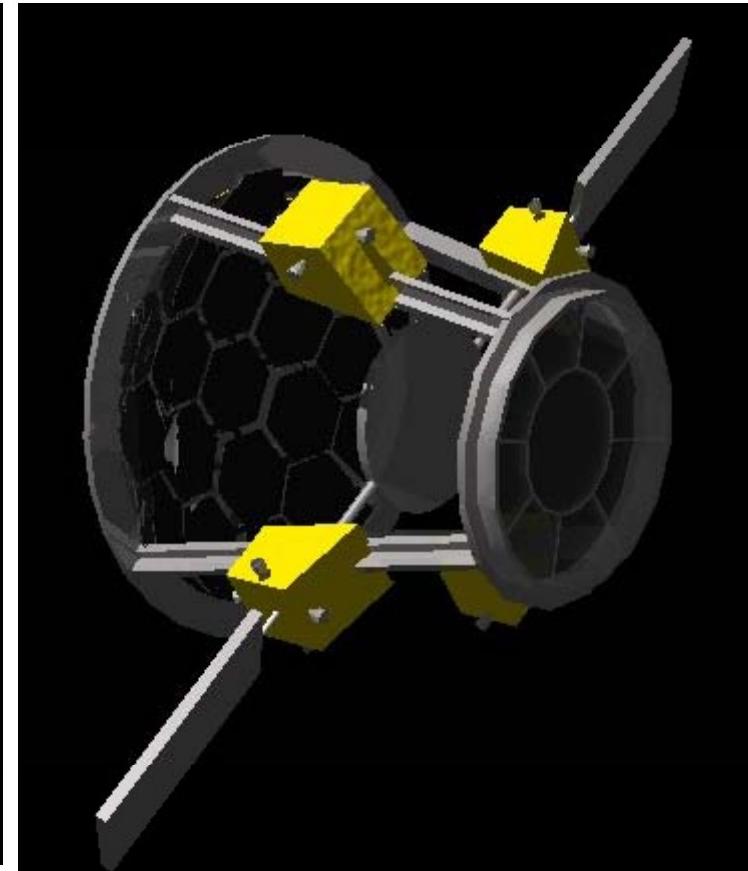
Mirror constructed from
hexagonal spherical segments

Summary

- Super EUSO is needed to find out how the most energetic cosmic accelerators work and what they are accelerating?

- The Super-EUSO instrument must be a very large high-speed and wide-angle video camera in space.

- We are open to suggestions for improvements in design and also concepts for manufacturing such an instrument.

The End