A EUSO-like experiment as a precursor of a ultra-high energy neutrino Space Observatory

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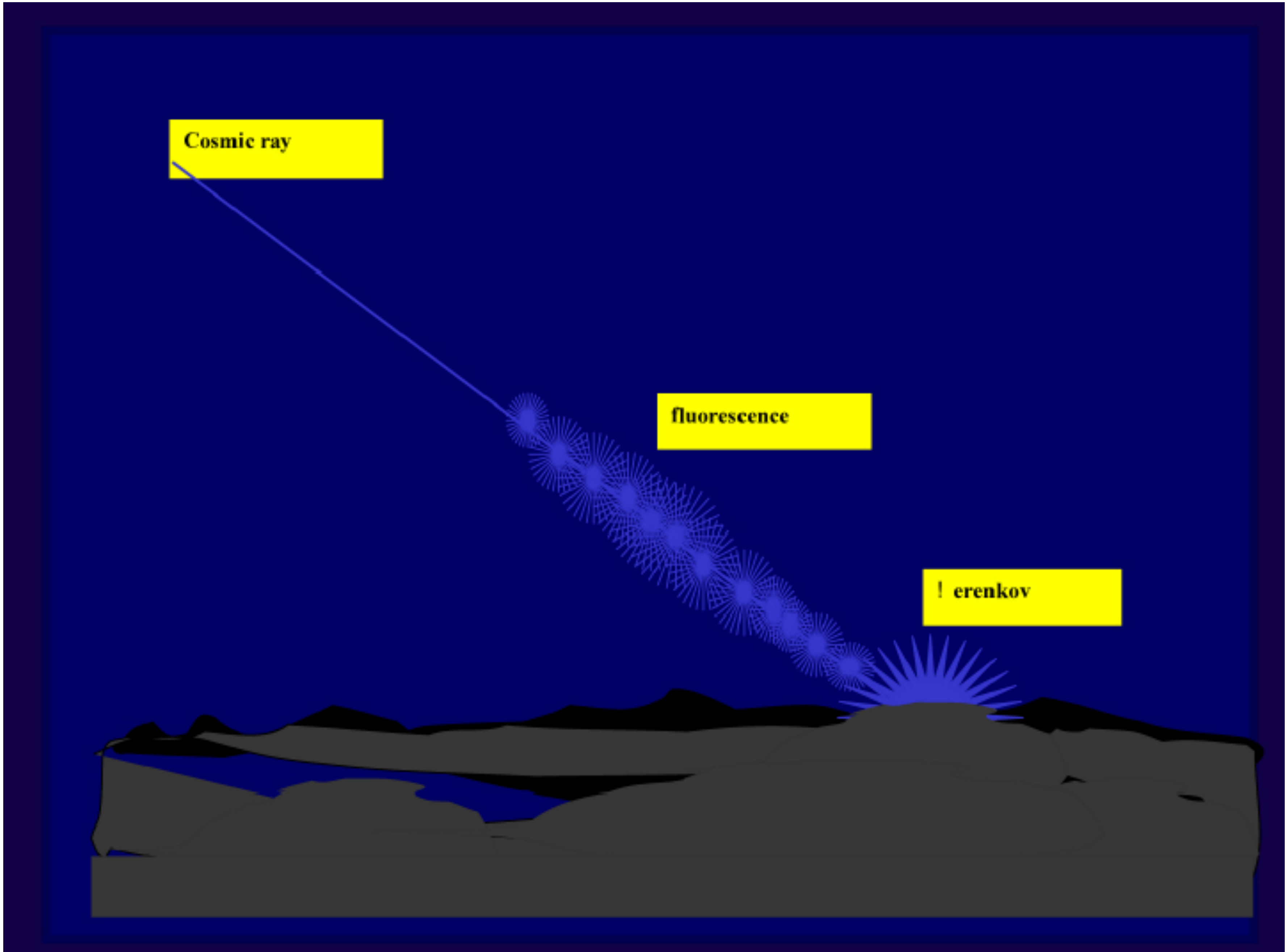
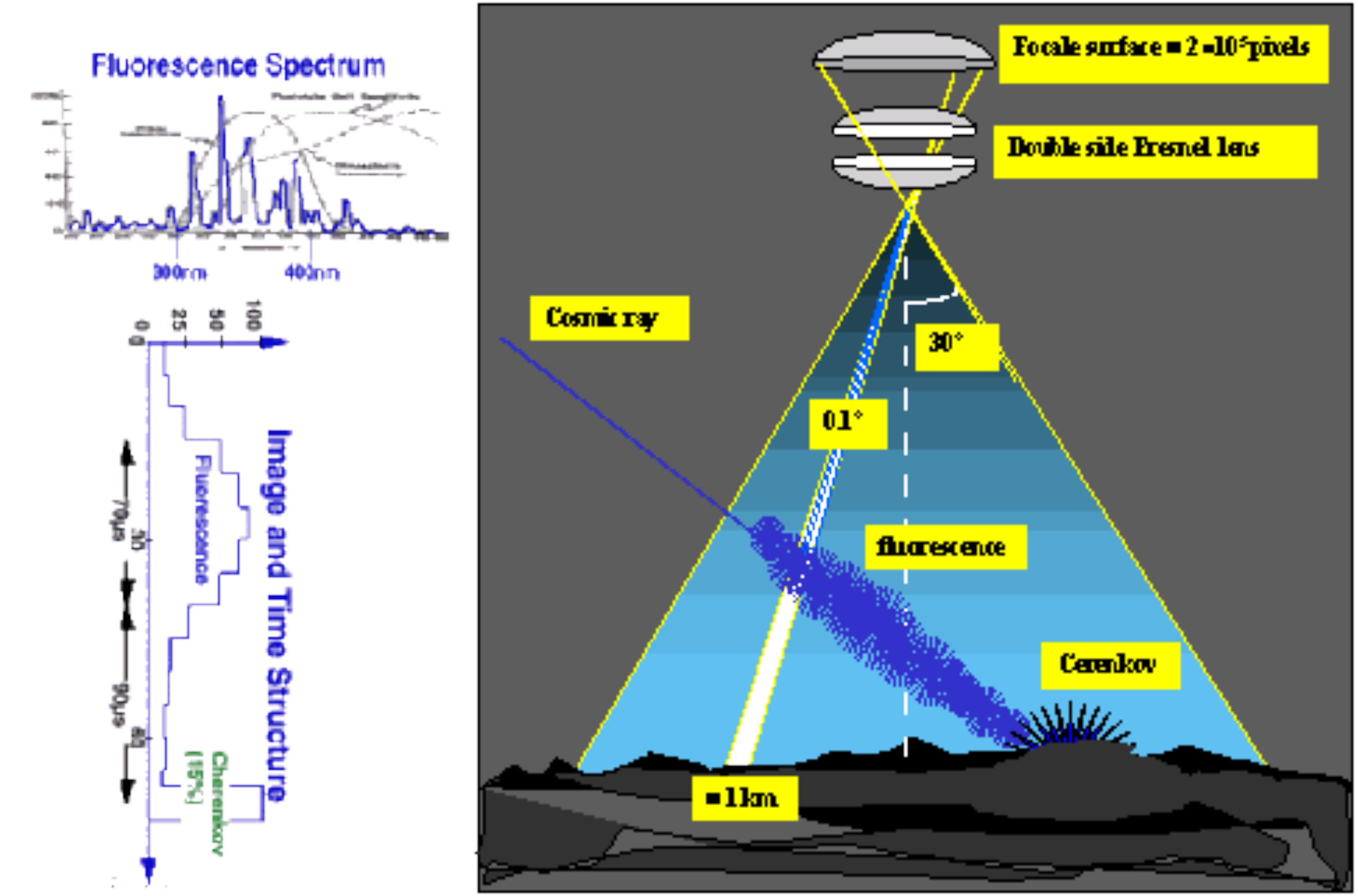
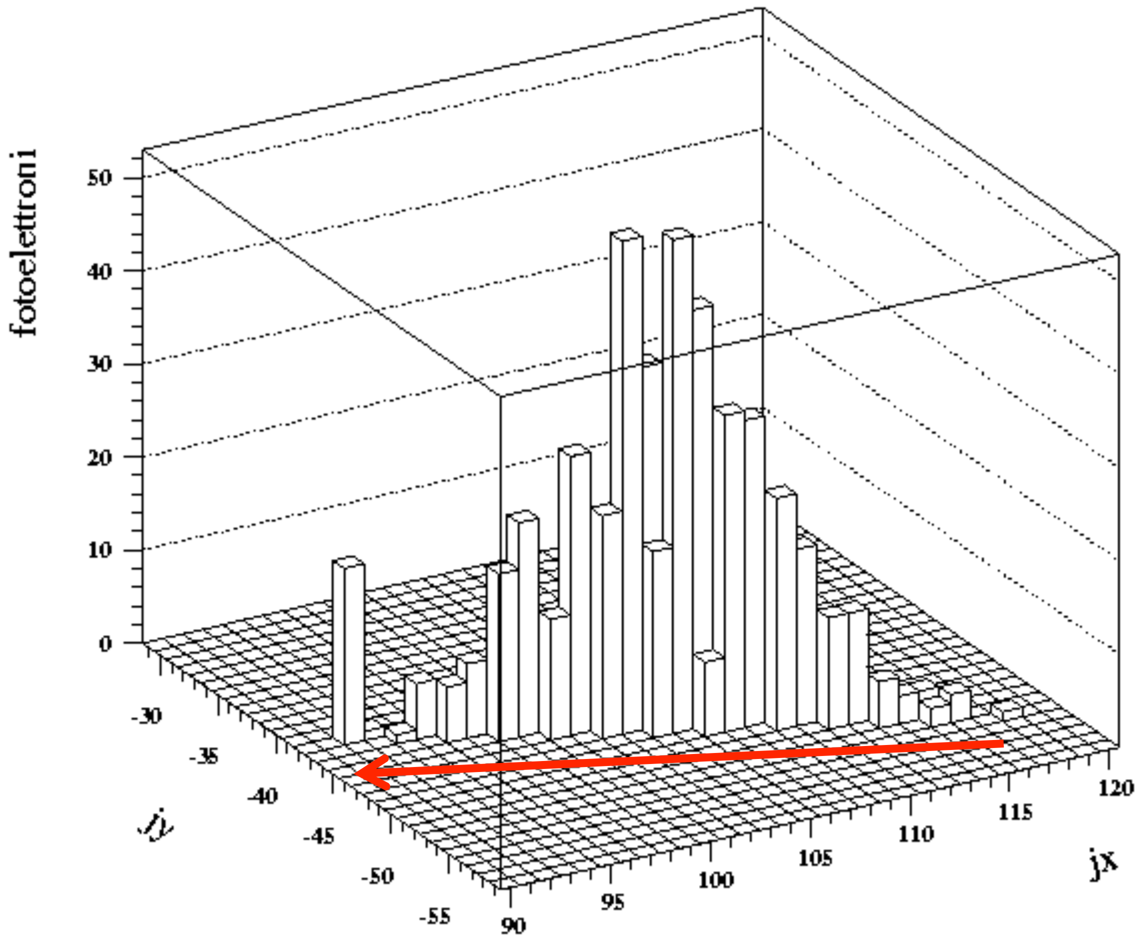

Cosmic ray
fluorescence
! erenkov

EUSO Approach



EUSO : Extreme Universe Space Observatory

Fig. 2.1 – Artist view of the ***EUSO*** concept. The shower development occurs in the atmosphere layers below 30-40 km a.s.l.; the isotopic fluorescence emission is proportional at any depth to the number of charged particles (mainly electrons) present in the shower front: $N_e \approx E_{eV} / (1.4x10^{9})$. The UV yield is ≈4 photons per meter of electron track, almost independent from air pressure and temperature.


fotoelettroni
50
40
30
20
10
0
-30
-35
-40
-45
-50
-55
jy
90
95
100
105
110
115
120
jx

The EUSO program

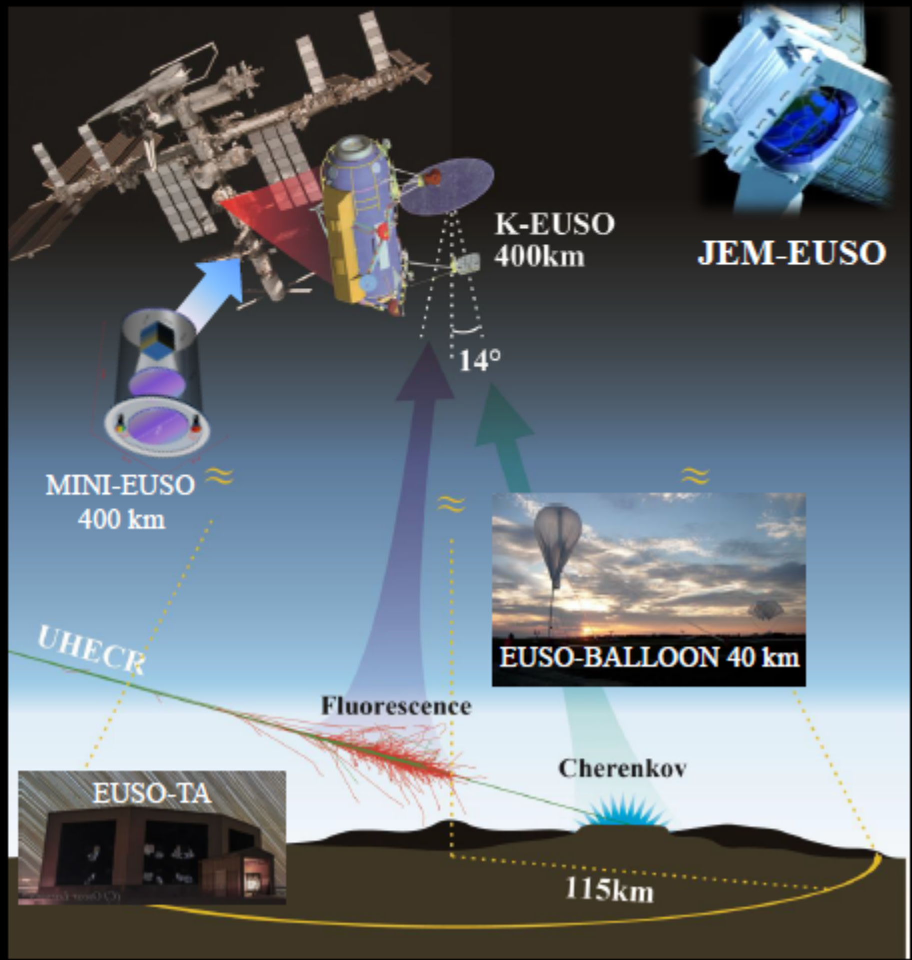
Ultra-High Energy cosmic rays from space

1. **EUSO-TA:** ***Ground detector installed in 2013 at Telescope Array site: currently operational***

2. **EUSO-BALLOON:** ***1st balloon flight from Timmins, CA (French Space Agency) Aug 2014; 2nd flight: 2016, NASA Ultra long duration flight: 2017***

3. **MINI-EUSO (2017):** ***Precursor from International Space Station (ISS: 30kg 2017). Approved by Italian and Russian Space agencies***

4. **K-EUSO (2019 JFY):** ***ISS Approved by Russian Space Agency***



JEM-EUSO collaboration 16 Countries, 93 Institutes, 351 people

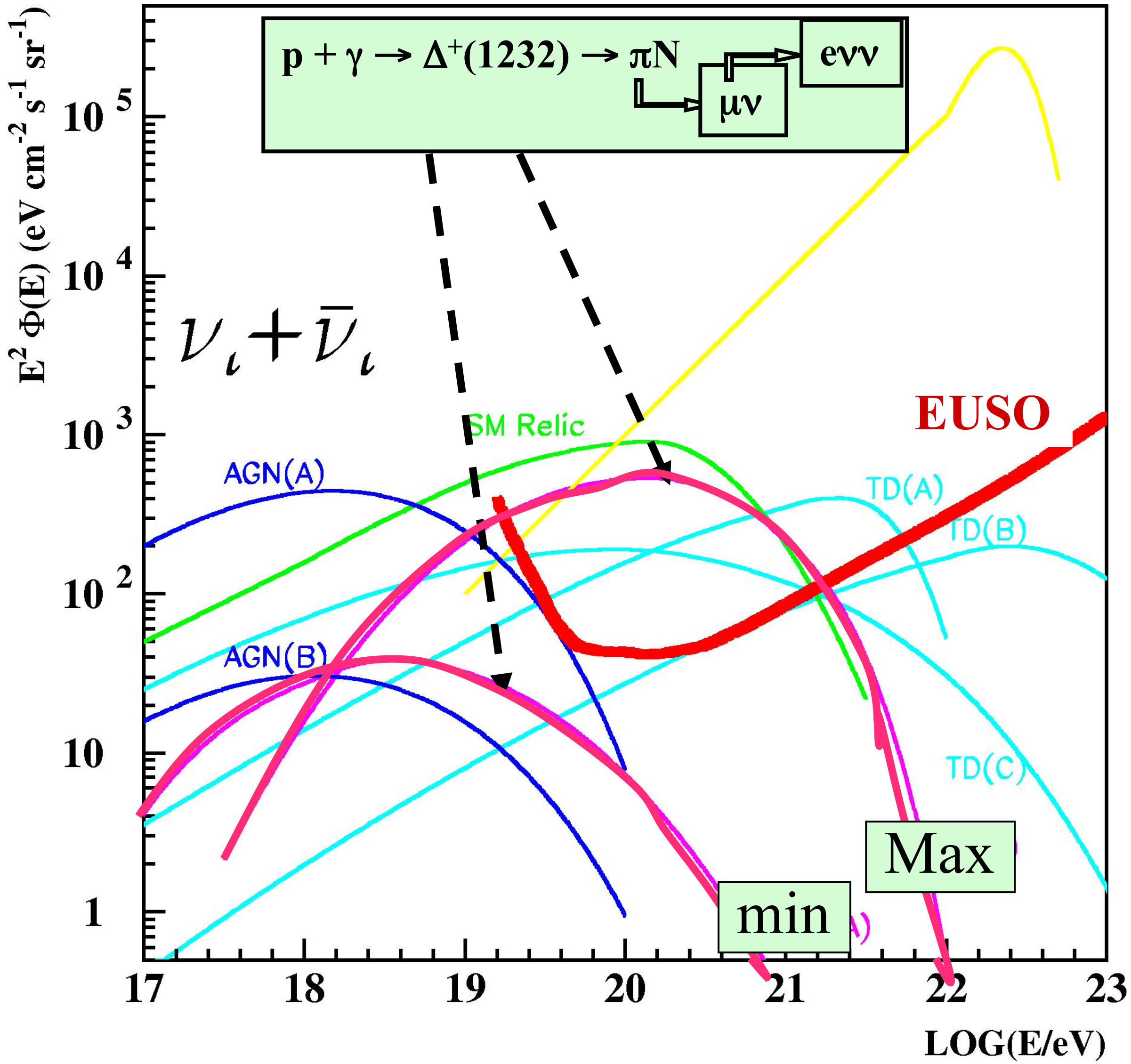
The most complete work was (@<2004)

"Ultra-High Energy Neutrino Fluxes and Their Constraints"

(Kalashek, Kuzmin, Semokov, Sigl)

[arXiv:hep-ph/0205050 v3 13 Dec 2002]

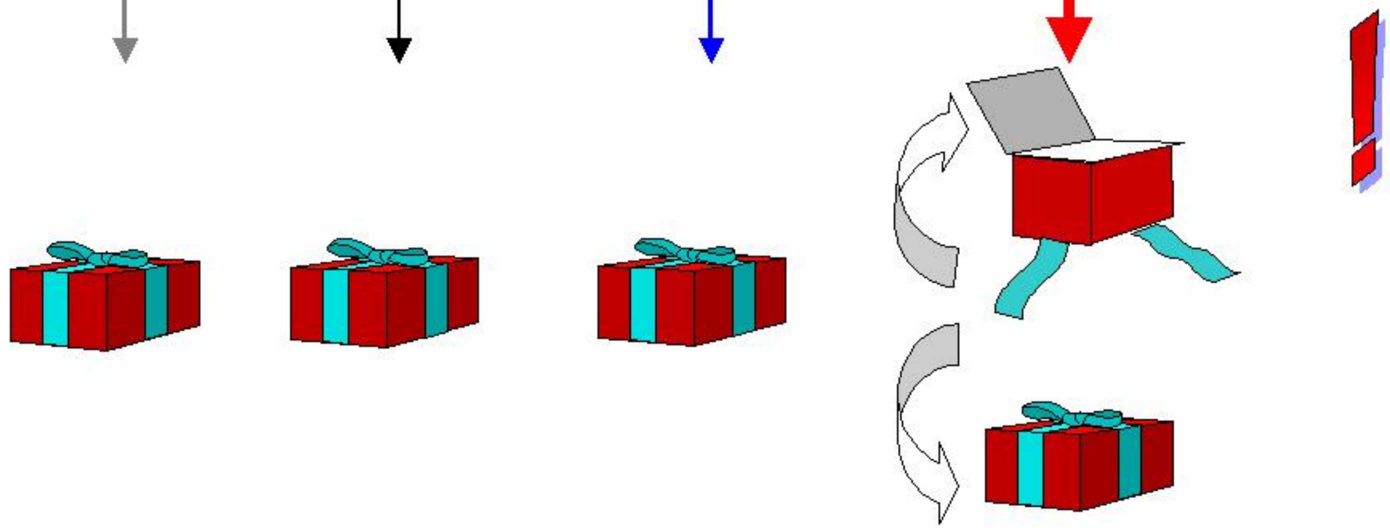
[Model consistent with gamma's and
UHECR data (Fly'sEye, Haverah Park, Yakytsk, AGASA)]



p + γ → Δ+(1232) → πN
μν
eνν
E2 Φ(E) (eV cm-2 s-1 sr-1)
10 5
10 4
10 3
10 2
10
1
ν + ν̄
SM Relic
AGN(A)
AGN(B)
TD(A)
TD(B)
TD(C)
EUSO
Max
min
17
18
19
20
21
22
23
LOG(E/eV)

	AGASA	HI-RES	AUGER	*EUSO*
EECR ($\geq 10^{20}$ eV) Events/year	1	10	10^2	10^3

ν



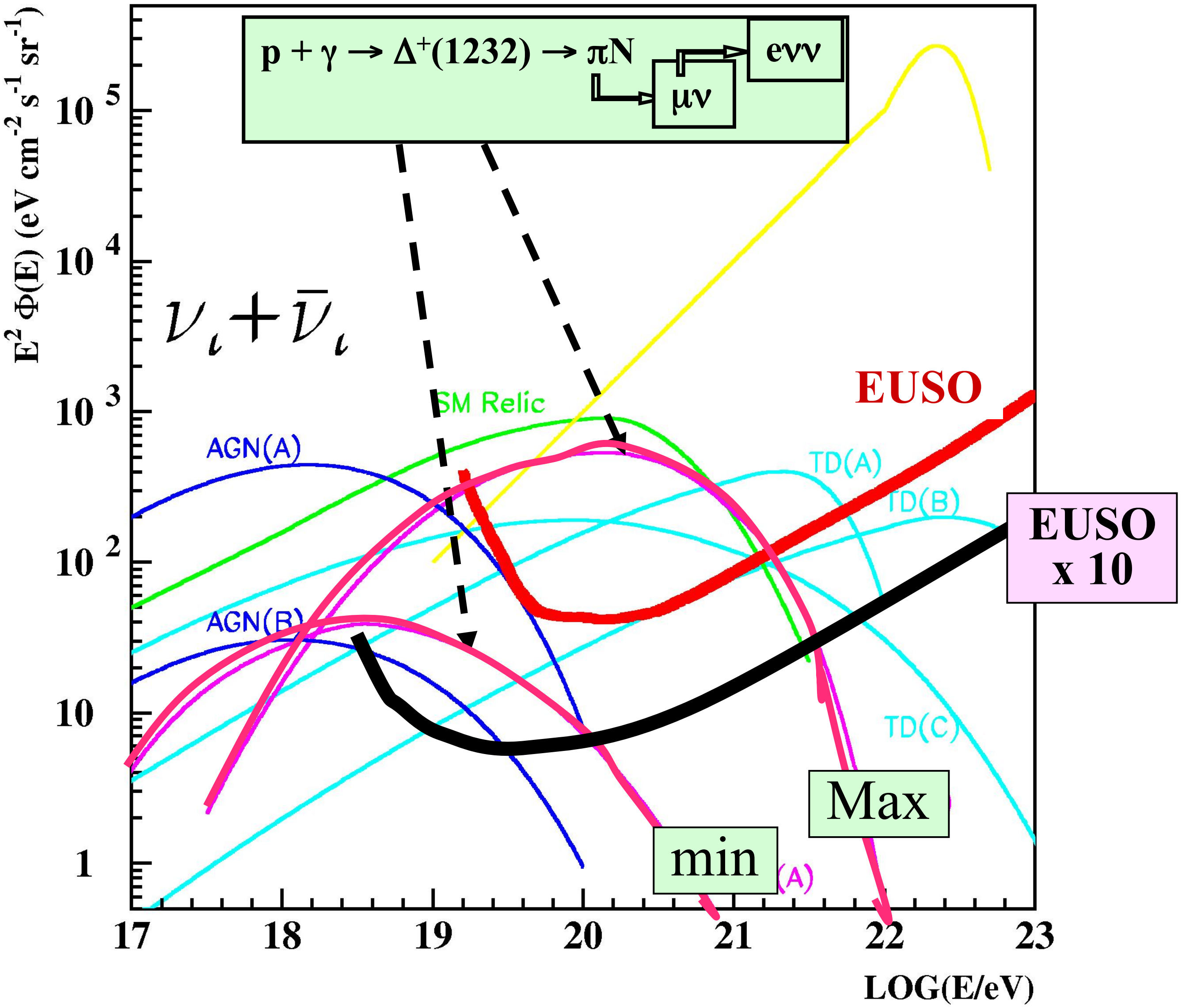
APS Neutrino Study:

Report of the Neutrino Astrophysics and Cosmology Working Group

(29 October 2004)

- We strongly recommend the development of experimental techniques that focus on the detection of astrophysical neutrinos, especially in the energy range above 10^{15} eV.

.... The technical goal of the next generation detector should be to increase the sensitivity **by factor of 10,** which may be adequate to measure the energy spectrum of the expected GZK (Greisen-Zatsepin-Kuzmin) neutrinos, produced by the interactions of ultra-high energy cosmic ray protons with the cosmic microwave background.



p + γ → Δ+(1232) → πN
μν
eνν
$\nu_\tau + \bar{\nu}_\tau$
E² Φ(E) (eV cm⁻² s⁻¹ sr⁻¹)
10 5
10 4
10 3
10 2
10
1
17
18
19
20
21
22
23
LOG(E/eV)
SM Relic
AGN(A)
AGN(B)
TD(A)
TD(B)
TD(C)
(A)
EUSO
EUSO x 10
Max
min

Is it possible to increase the number of detected neutrino events?

(EUSO-like from ISS)

-Decrease the energy threshold (5×10^{19}eV → 10^{18}eV)

by improving the sensor efficiency (0.20 → 0.50) x 1.5

by improving the light collection (pupil ∅ 2m → 6m) x 9

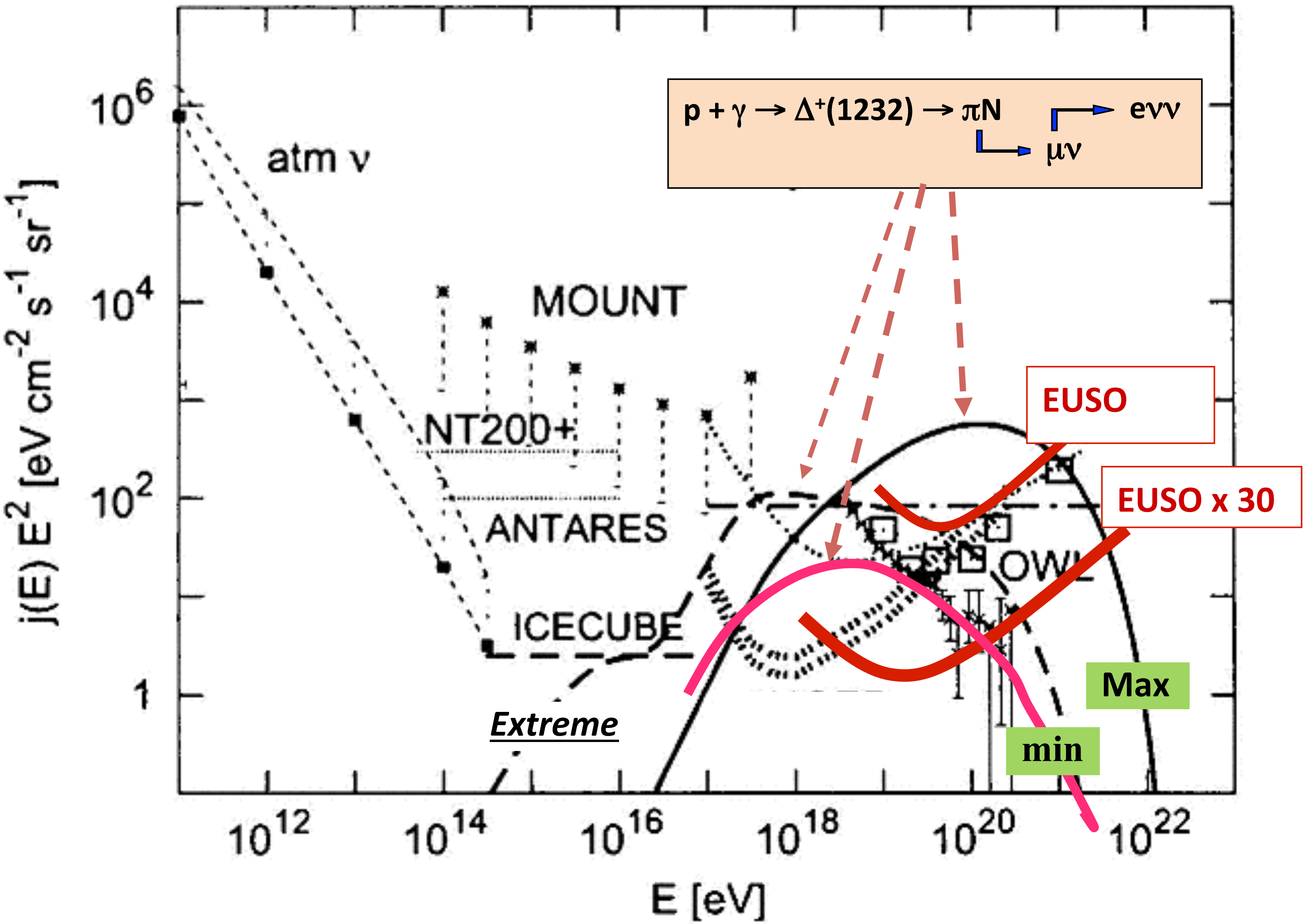
(what implies reflective systems and modularity)

-Increase the target volume

-by increasing the FOV (60° → 140.8°) (x 90)

but limited to ≅90º by attenuation by air and by distance x 3

....


p + γ → Δ⁺(1232) → πN
eνν
μν
atm ν
MOUNT
NT200+
ANTARES
ICECUBE
OWL
Extreme
EUSO
EUSO x 30
Max
min
j(E) E² [eV cm⁻² s⁻¹ sr⁻¹]
E [eV]

	One optical system (EUSO like)		Multi-mirror		
H (km)	400		400		
Total FoV (o)	60		90		
Radius on ground (km)	235		400		
Area on ground ($10^3 km^2$)	173		503		
Target volume (km^3)	1730		5030		
Pixel on ground (km * km)	0.8 x 0.8		0.8x0.8		
number of pixels) (.8x.8 km2)	270k		786k		
Pupil diameter (m)	2.0	2.0	4.0	6.0	10.0
Photo detection efficiency	20%	50%	50%	50%	50%
E threshold (EeV)	50	30	8	3	1.2
Proton events/year,					
GKZ + uniform source distrib.	1200	4000	35k	300k	2000k
with E_p >100 EeV)	100	100	290	290	290
Neutrino events per year (≈ min)	**0.2**	**0.4**	**1.5**	**4.5**	**10**
Neutrino events per year (≈ Max)	**4**	**6**	**12**	**14**	**18**

After 2004: new data:

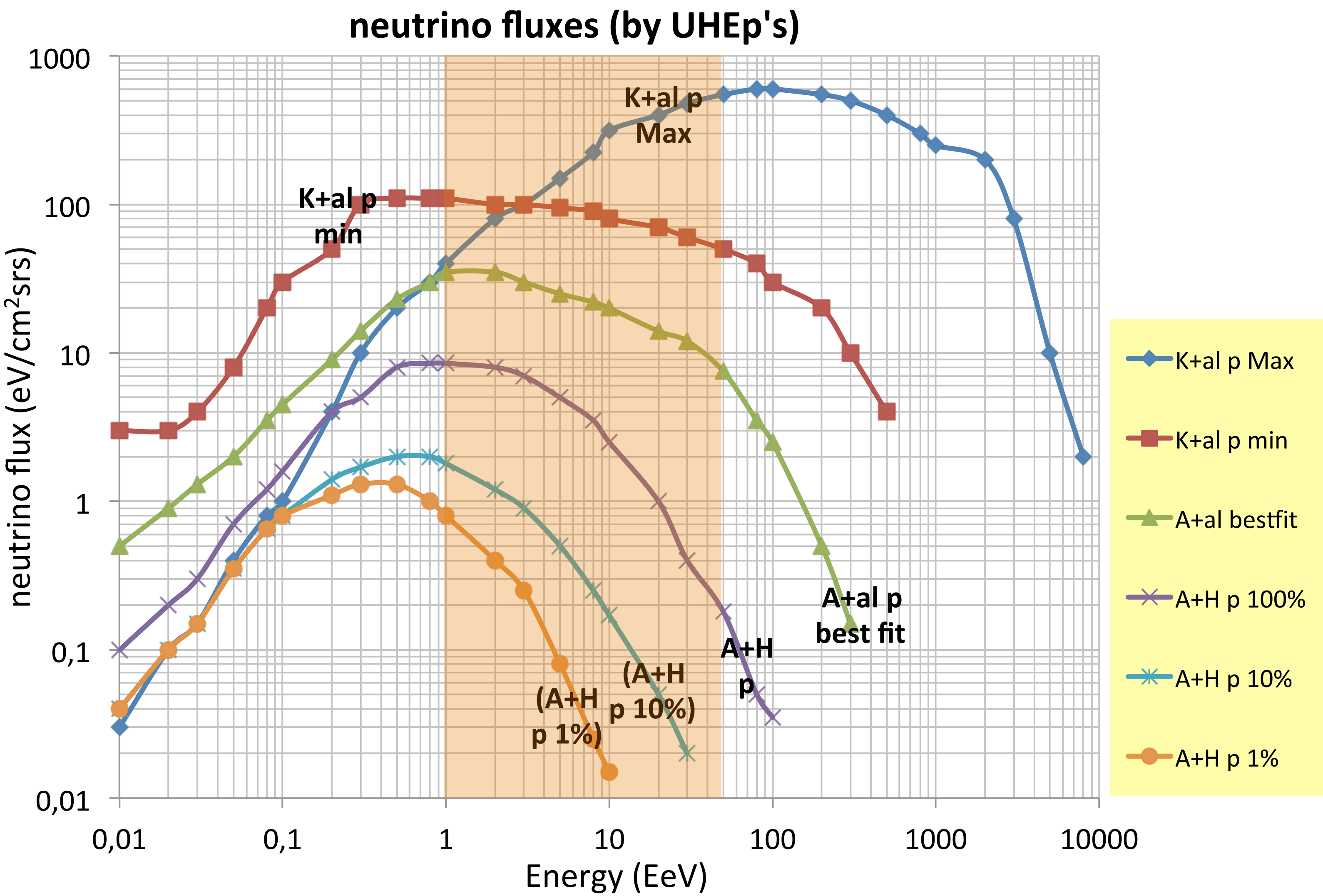
- GZK confirmed + (?) primary UHECR heavier than p (?)
- Fermi-LAT

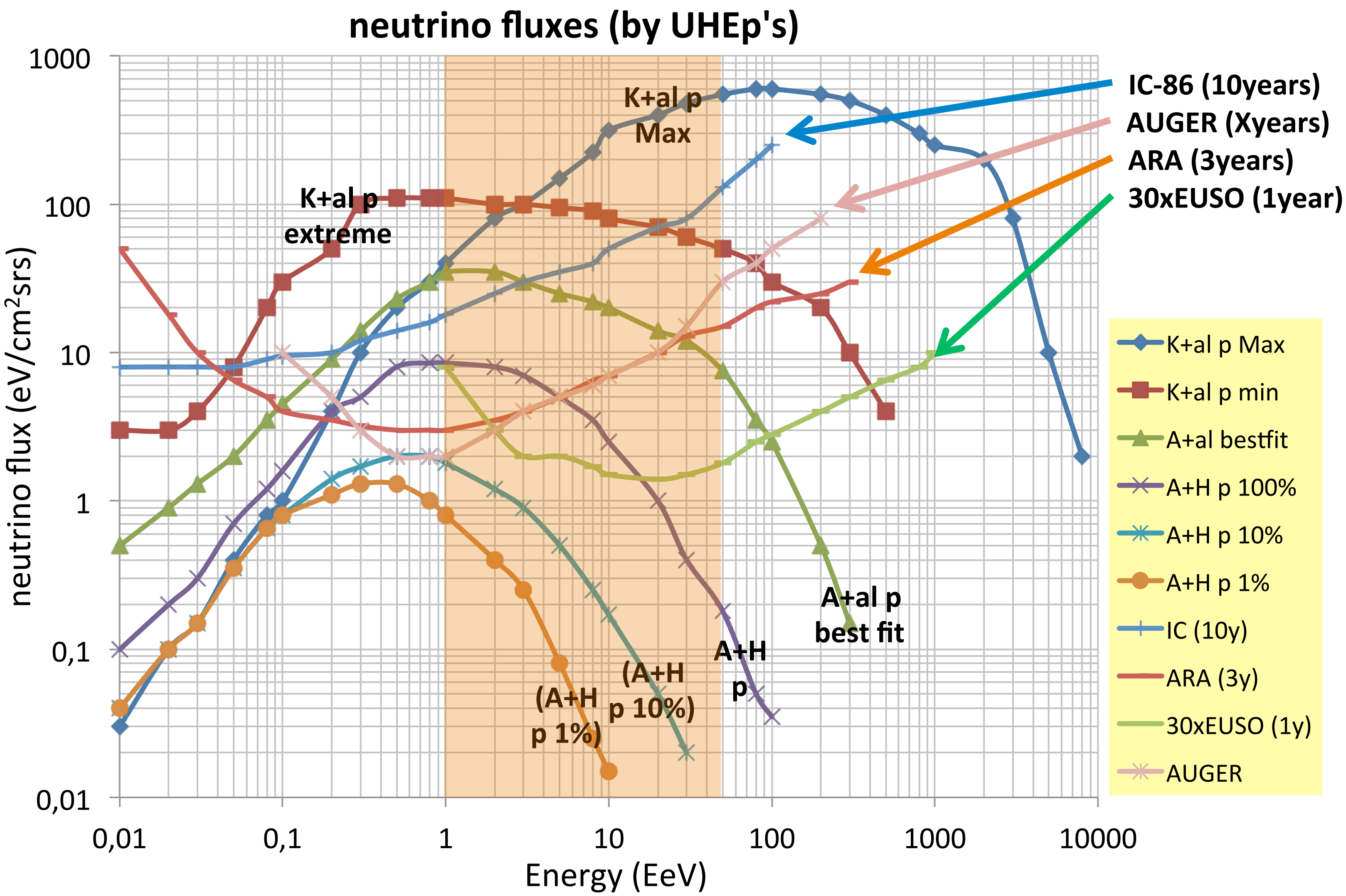
Ahlers et al. bestfit, consistent with HiRes spectrum and Fermi-LAT diffuse gamma's

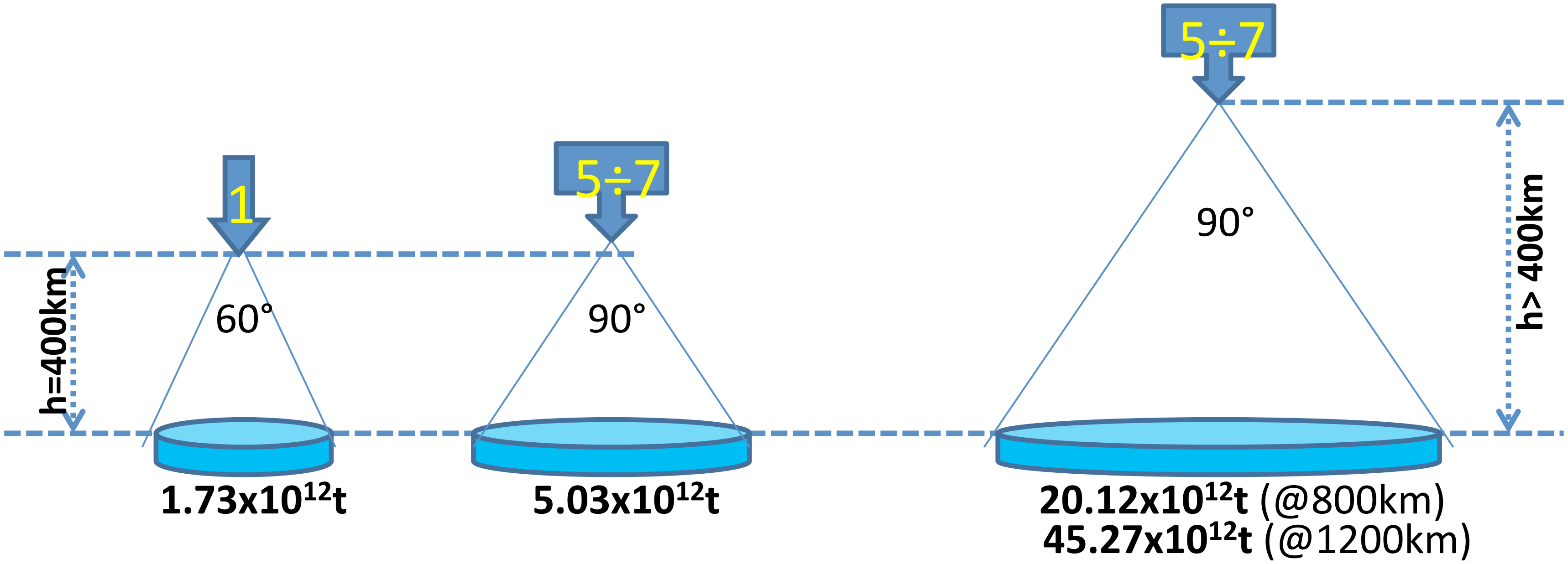
<u>'GZK neutrinos after Fermi-LAT diffuse photon flux measurement'</u>
M.Ahlers et al., Astropart. Phys. 34, 106 (2010)

Ahlers and Halsen updates of lower limits (normalization to Auger data)

<u>'Minimal Cosmogenic Neutrinos'</u> arXiv:1208.4181v1, 21 Aug 2012

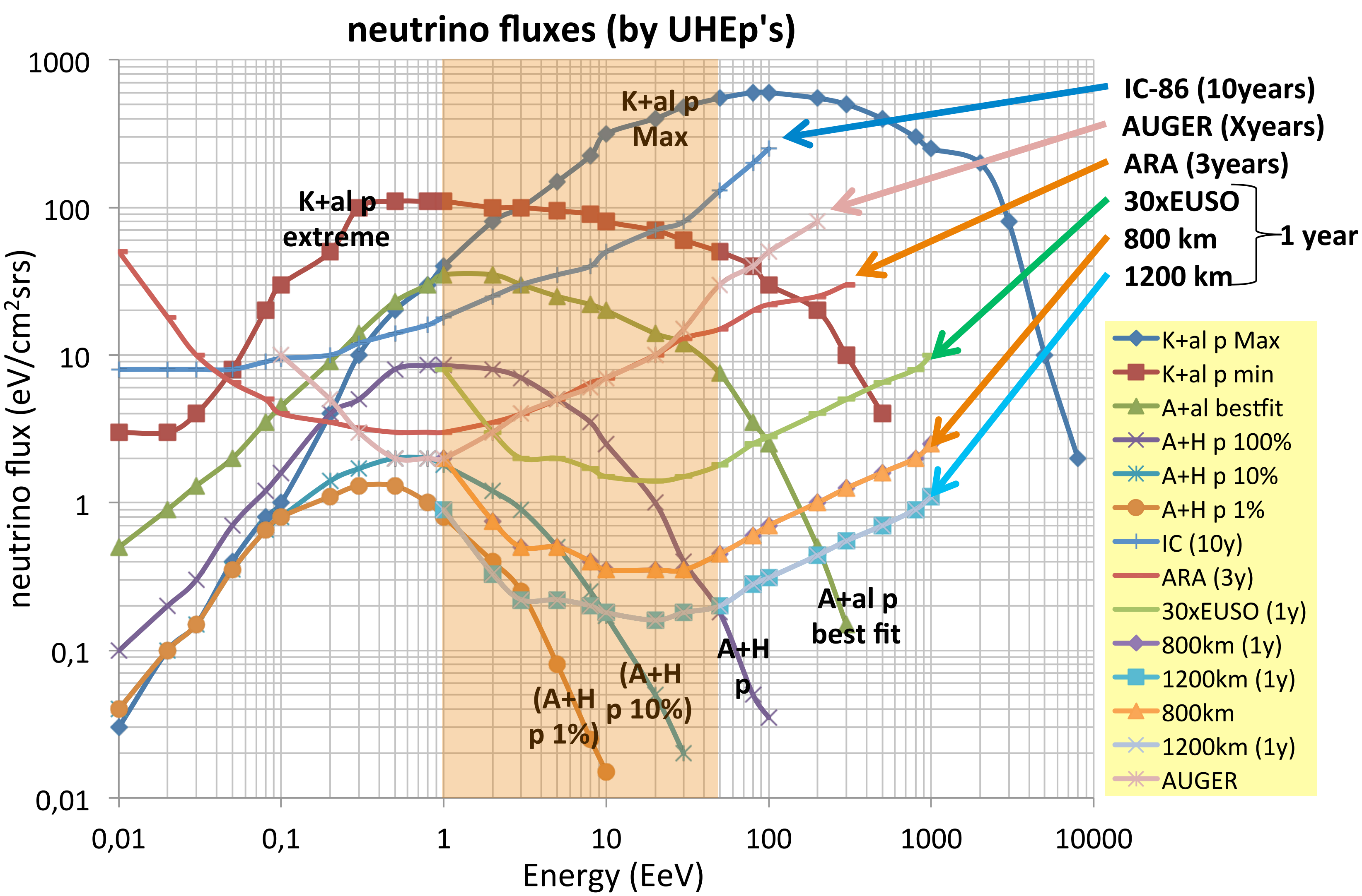

neutrino fluxes (by UHEp's)
1000
100
10
1
0,1
0,01
neutrino flux (eV/cm2srs)
0,01
0,1
1
10
100
1000
10000
Energy (EeV)
K+al p Max
K+al p min
A+al p best fit
A+H p
(A+H p 10%)
(A+H p 1%)
K+al p Max
K+al p min
A+al bestfit
A+H p 100%
A+H p 10%
A+H p 1%


neutrino fluxes (by UHEp's)
neutrino flux (eV/cm²srs)
1000
100
10
1
0,1
0,01
0,01
0,1
1
10
100
1000
10000
Energy (EeV)
K+al p Max
K+al p extreme
A+al p best fit
A+H p
(A+H p 10%)
(A+H p 1%)
IC-86 (10years)
AUGER (Xyears)
ARA (3years)
30xEUSO (1year)
K+al p Max
K+al p min
A+al bestfit
A+H p 100%
A+H p 10%
A+H p 1%
IC (10y)
ARA (3y)
30xEUSO (1y)
AUGER

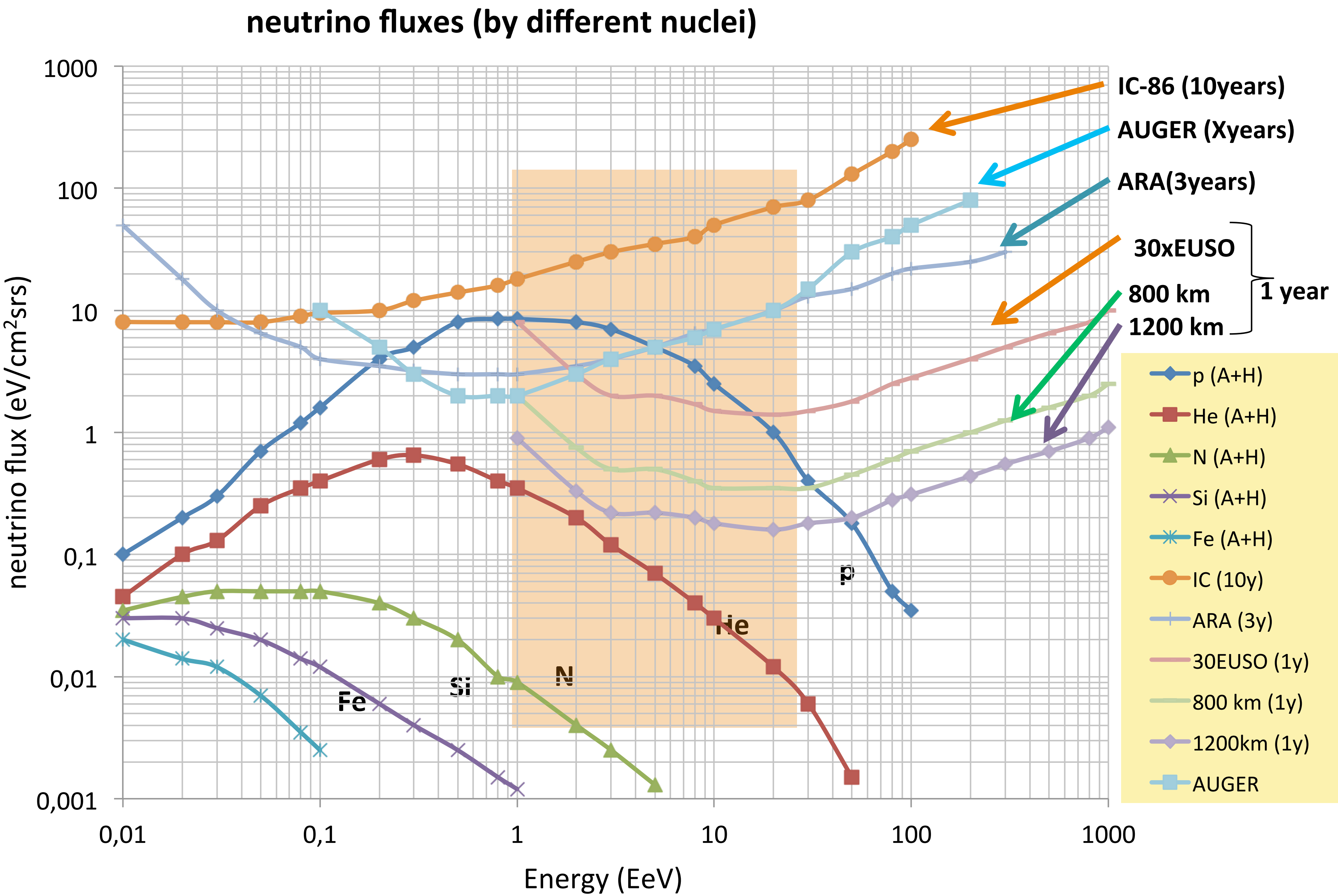


Increase FOV
Increase pupil (decrease threshold)

Increase target
Increase pupil (for maintain threshold)



neutrino fluxes (by UHEp's)
neutrino flux (eV/cm²srs)
Energy (EeV)
1000
100
10
1
0,1
0,01
0,01
0,1
1
10
100
1000
10000
K+al p Max
K+al p extreme
A+al p best fit
A+H p
(A+H p 10%)
(A+H p 1%)
IC-86 (10years)
AUGER (Xyears)
ARA (3years)
30xEUSO
800 km
1200 km
1 year
K+al p Max
K+al p min
A+al bestfit
A+H p 100%
A+H p 10%
A+H p 1%
IC (10y)
ARA (3y)
30xEUSO (1y)
800km (1y)
1200km (1y)
800km
1200km (1y)
AUGER



neutrino fluxes (by different nuclei)
neutrino flux (eV/cm²srs)
Energy (EeV)
1000
100
10
1
0,1
0,01
0,001
0,01
0,1
1
10
100
1000
IC-86 (10years)
AUGER (Xyears)
ARA(3years)
30xEUSO
800 km
1200 km
1 year
Fe
Si
N
He
p
p (A+H)
He (A+H)
N (A+H)
Si (A+H)
Fe (A+H)
IC (10y)
ARA (3y)
30EUSO (1y)
800 km (1y)
1200km (1y)
AUGER

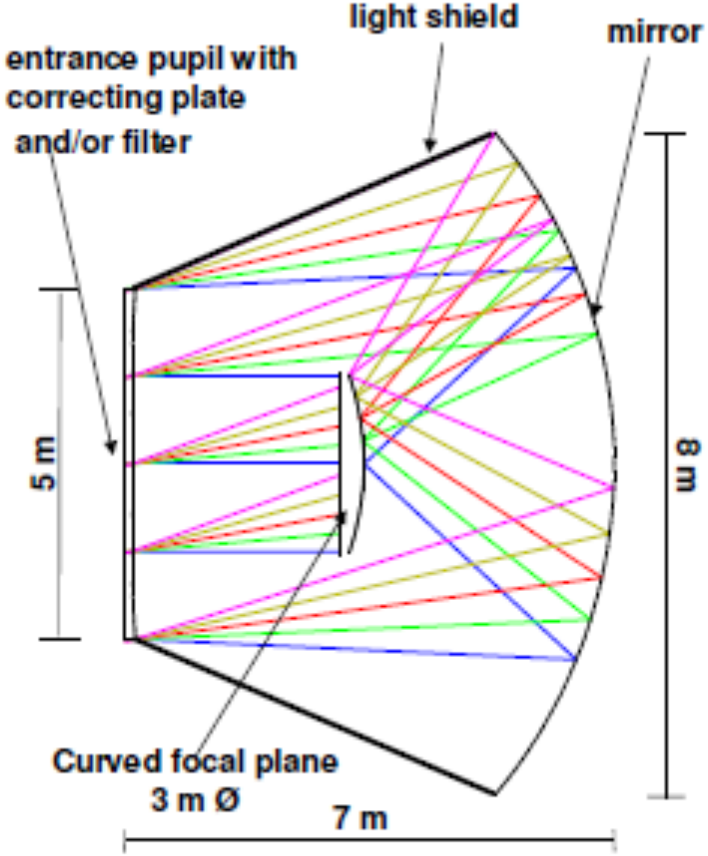
	One optical system (EUSO like)	Multi-System (≅3 systems FoV≈20°) Multi-mirror				
H (km)	400		400		800	1200
Total FoV (°)	60		90		90	90
Radius on ground (km)	235		400		≅ 800	≅ 1200
Area on ground ($10^3 km^2$)	173		503		≅ 2000	≅ 4500
Target volume (w.e. km^3)	1730		5030		≅ 20000	≅ 45000
Pixel on ground (km x km)	0.8 x 0.8		0.8x0.8		0.8x0.8	0.8x0.8
number of pixels) (.8x.8 km^2)	270k		786k		≅ 3000k	≅ 7000k
Pupil diameter (m)	2.0	4.0	6.0	10.0	12	18
Photo detection efficiency	50%	50%	50%	50%	50%	50%
E threshold (EeV)	30	8	3	1.2	3	3
Proton events/year,						
GKZ + uniform source distrib.	4000	35k	300k	2000k	1200K	2700k
with E_p >100 EeV)	100	290	290	290	1180	2600
Neutrino events per year (≈ min)	**0.4**	**1.5**	**4.5**	**10**	**18**	**40**
Neutrino events per year (≈ Max)	**6**	**12**	**14**	**18**	**56**	**126**
Neutrino events per year (bestfit)	**0.05**	**0.3**	**1**	**2.5**	**4**	**9**
Neutrino events per year (px100%)	**0.002**	**0.035**	**0.15**	**0.5**	**0.6**	**1.3**
Neutrino events per year (px10%)	**-**	**0.0025**	**0.015**	**0.08**	**0.06**	**0.13**
Neutrino events per year (px1%)	**-**	**0.0002**	**0.003**	**0.025**	**0.012**	**0.027**

from ISS

A proposed 5 m EPD mirror system

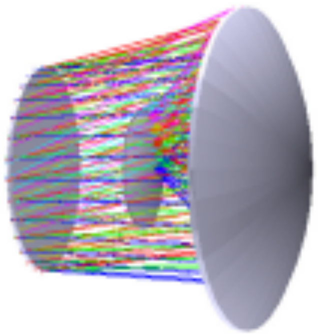
Design of a mirror optics, based on the Schmidt camera principle

This is the only design allowing wide FOV, up to ≈ 50°, with just 2 optical elements



FEATURES

- Mirror is larger than EPD (depending on FOV)
- Light shield is necessary for stray light reduction
- The correcting plate greatly improves performances
- F/# investigated as low as 0.6
- Detector diameter smaller than any other proposed solution
- Weight saving solution (both for optics and detector)
- Obscuration acceptable for FOV up to 25°
- Vignetting almost constant for all FOV
- Low sensitivity to misalignment (except decenter)
- Optical system design scalable to any dimension



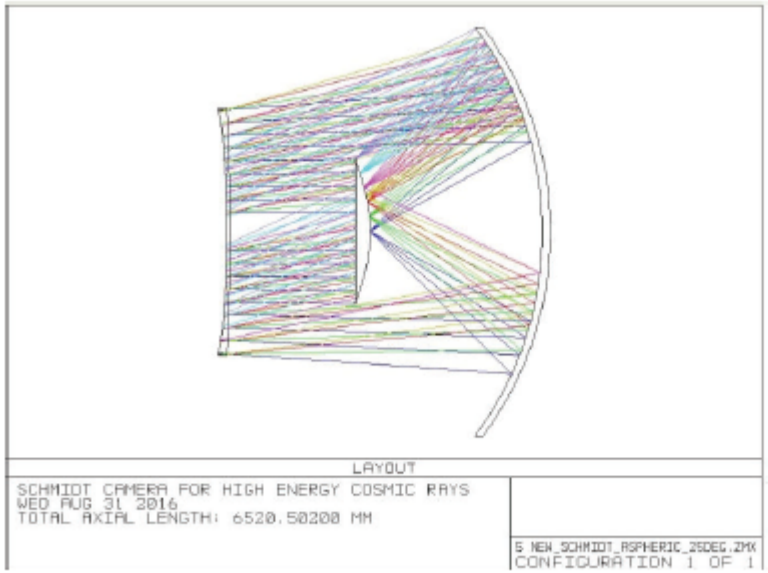


Figure 1 - System layout

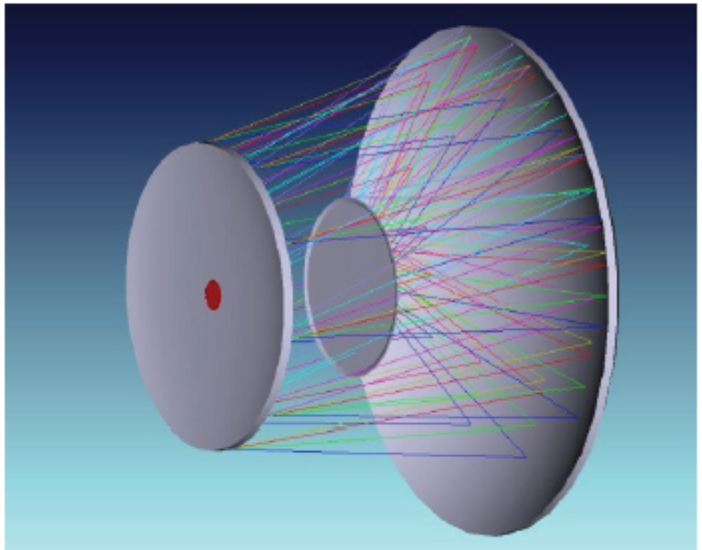
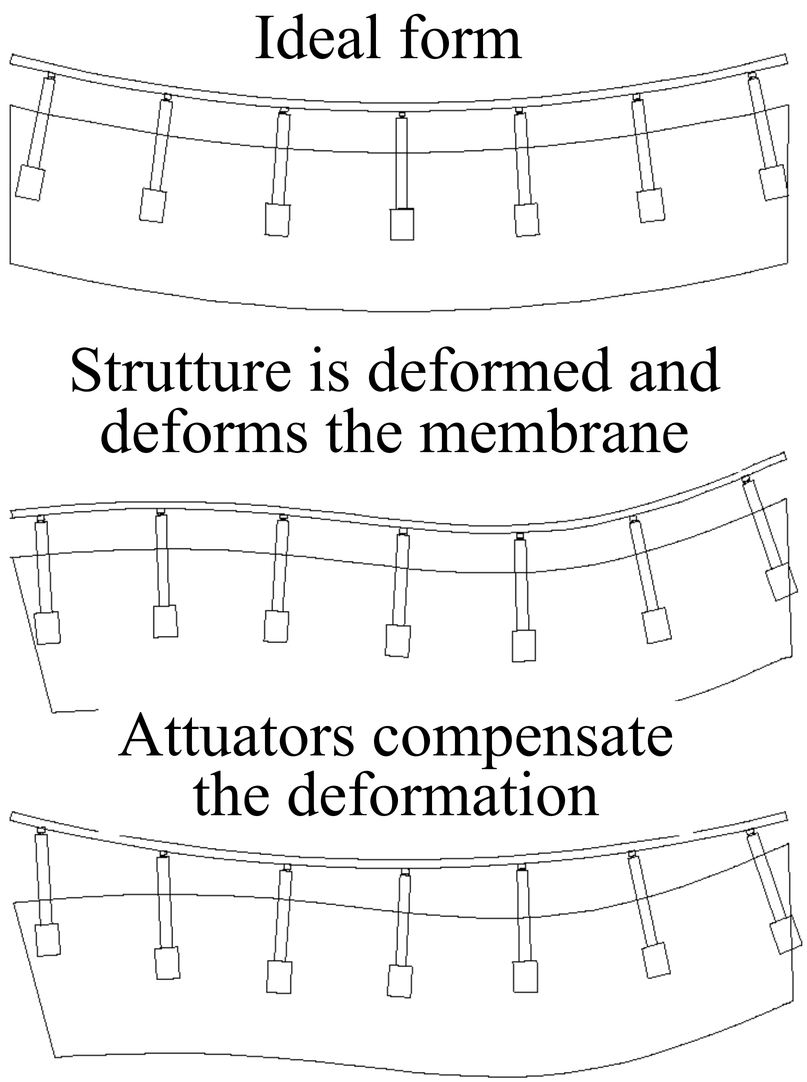


Figure 2 - 3D rendering of the telescope layout

Active thin mirror concept

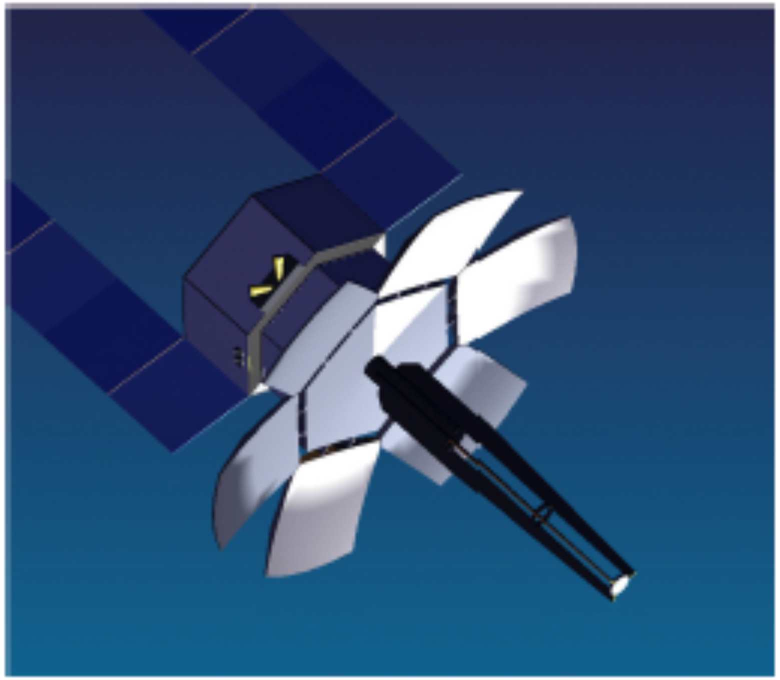


The optical surface is coupled to a structure of light rigid supports by a matrix of actuators, adjusted on the measurements of the wave front

INO

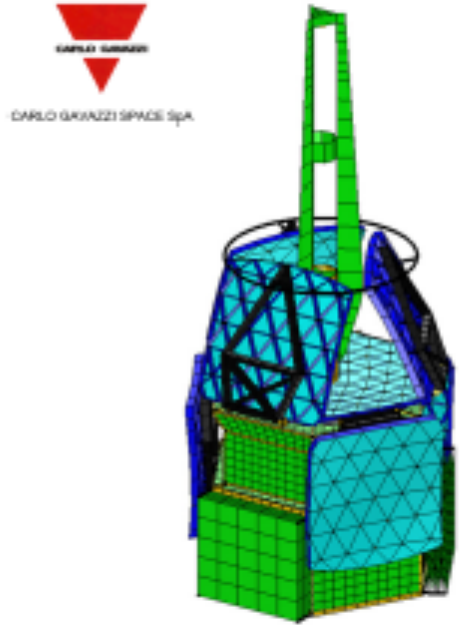
Mirror deployment technologies

A 4 m ∅ deployable mirror for LIDAR application has been developed on a ESA contract (ITT AO/1-4629/NL/CP Ref. 2053, Advanced Lidar Concept, ALC)



Satellite concept after deployment

Diffraction limited 4 m ∅ telescope !



Stowed configuration
for launch

Courtesy of Carlo Gavazzi Space SpA

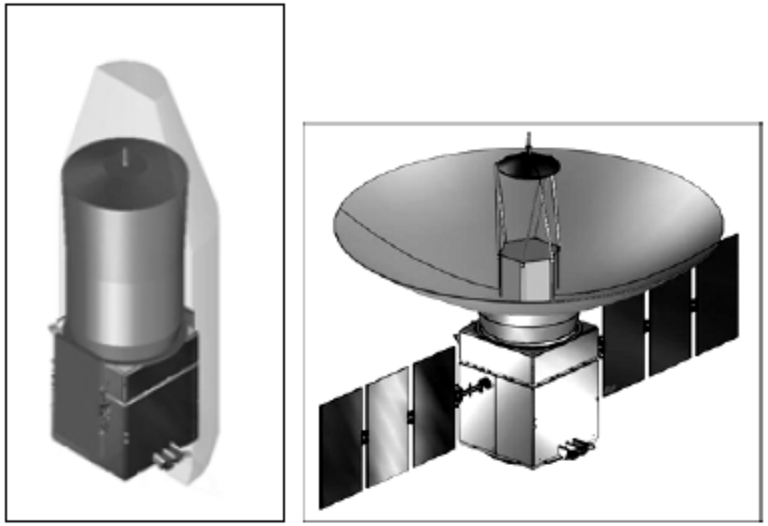


Fig. 1. Stowed and deployed unfurlable reflector aboard a mini satellite on a small launcher

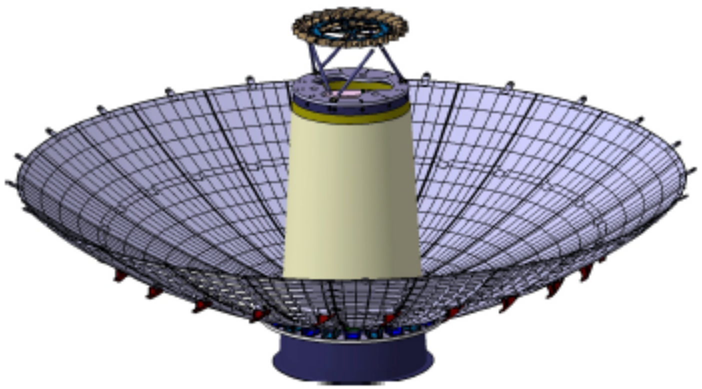


Fig. 2. LURA deployed configuration

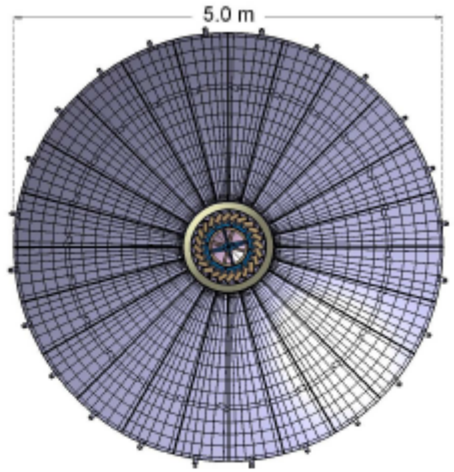


Fig. 4. LURA - Deployed envelope

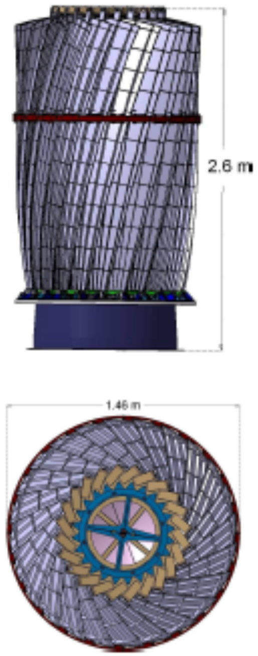


Fig. 5. LURA -Stowed envelope

Fig. 9. Radioastron reflector by Lavochkin

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Conclusions

- ✓ **A mirror system is a consistent solution for EUSO**
- ✓ **Construction technology is already demonstrated**
  - ⇨ ESA considers LATT technology as TRL 5 (ready for mission)
  - ⇨ Areal Density < 17 Kg/m^2 (still to be optimized)
  - ⇨ Power consumption 58 mW per actuator (to be space qualified)
- ✓ **The system can be scaled up, to get:**
  - ⇨ higher signal ⇒ lower threshold energy
  - ⇨ higher orbit ⇒ increased observed area
- ✓ **Items still to be better taken into account:**
  - ⇨ stray light and its influence on SNR
  - ⇨ impact of the atmospheric drag

A higher orbit with a much larger diameter may be a better option
Deployable mirrors have virtually no limit in size!

(just in costs)