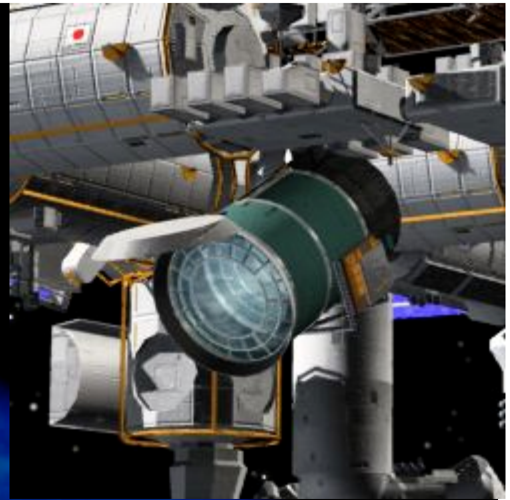
The Extreme Universe Space Observatory on board ISS



JEM-EUSO:Current status and perspectives

Philippe Gorodetzky

APC-Paris 7 — CNRS/Univ

for the JEM-EUSO Collaboration

Irfu seminaire, Saclay, 8 mars 2010

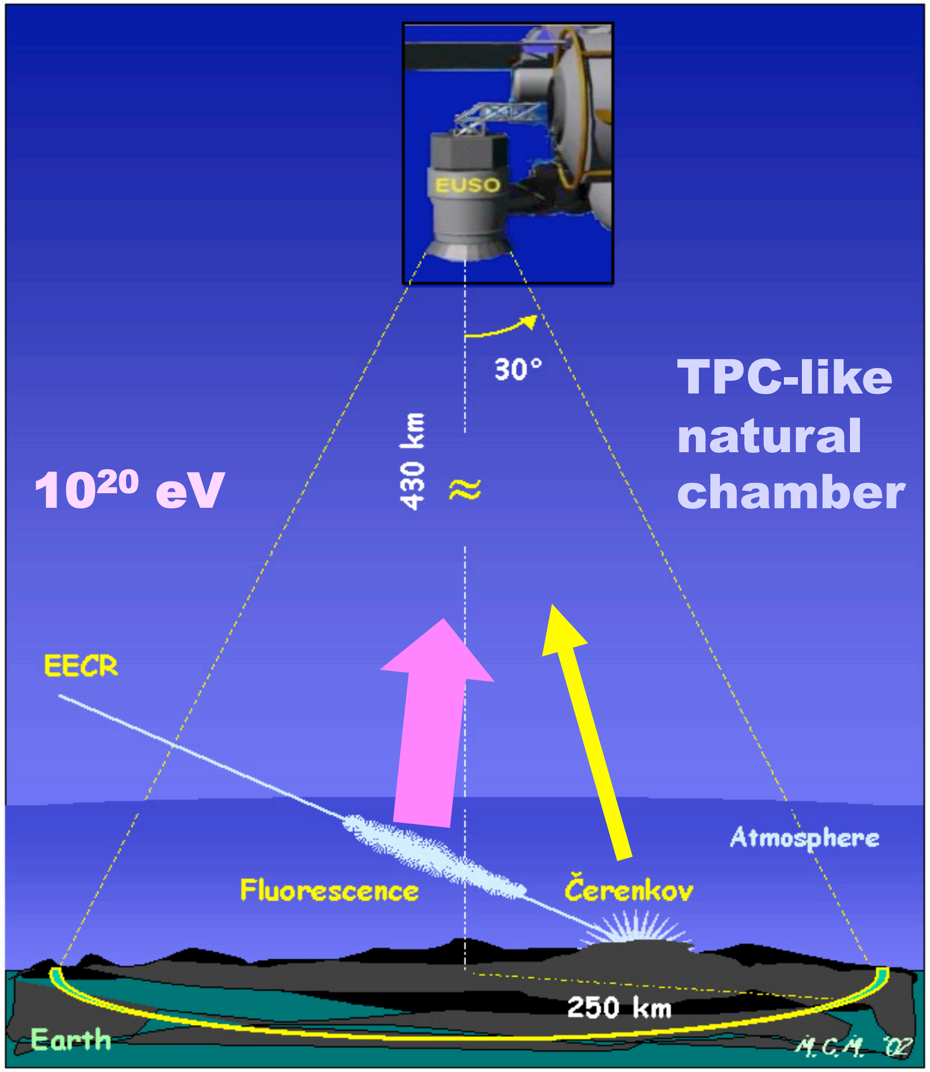
JEM-EUSO Collaboration

10 countries, 56 institutions, 156 members

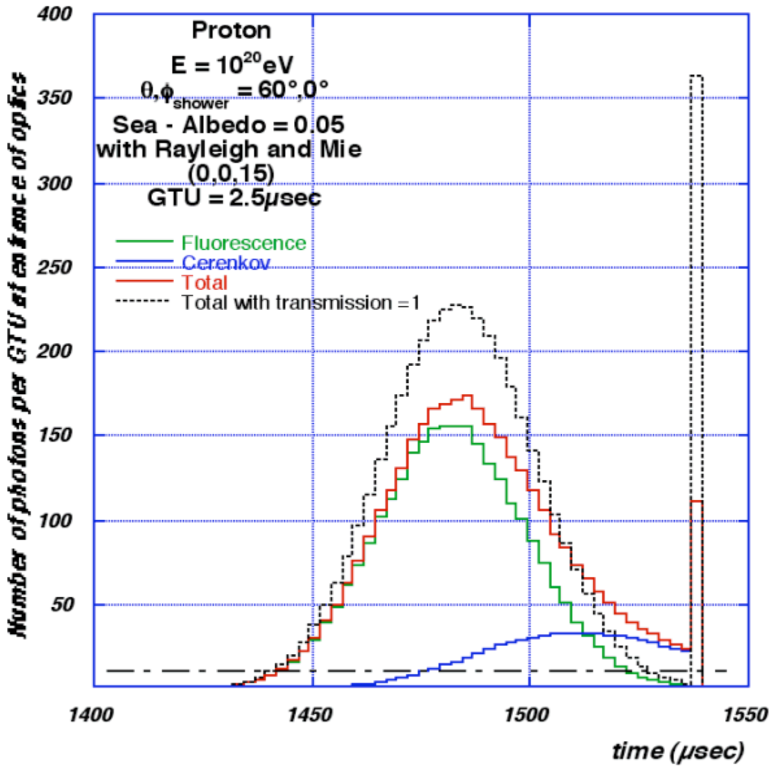
- Japan : T. Ebisuzaki, Y. Uehara, H. Ohmori, Y. Kawasaki, M. Sato, Y. Takizawa, K. Katahira, S. Wada, K. Kawai, H. Mase (*RIKEN*), F. Kajino, M. Sakata, H. Sato, Y. Yamamoto, T. Yamamoto, N. Ebizuka, (*Konan Univ.*), M. Nagano, Y. Miyazaki (*Fukui Inst. Tech.*), N. Sakaki, T. Shibata (*Aoyama Gakuin Univ.*), N. Inoue (*Saitama Univ.*), Y. Uchihori (*NIRS*), K. Nomoto (*Univ. of Tokyo*), Y. Takahashi (*Tohoku Univ.*), M. Takeda (*ICRR, Univ. Tokyo*), Y. Arai, Y. Kurihara, H.M. Shimizu, J. Fujimoto (*KEK*), S. Yoshida, K. Mase (*Chiba Univ.*), K. Asano, S. Inoue, Y. Mizumoto, J. Watanabe, T. Kajino (*NAOJ),* H. Ikeda, M. Suzuki, T. Yano (*ISAS, JAXA*), T.Murakami, D. Yonetoku (*Kanazawa Univ.*), T. Sugiyama *(Nagoya*), Y. Ito (*STEL, Nagoya Univ.*), S. Nagataki (*YITP, Kyoto Univ.*), A. Saito(*Kyoto Univ.*), S. Abe, M. Nagata (*Kobe Univ.*), T. Tajima (*KPSI, JAEA*)、M. Chikawa (*Kinki Univ*.), and M. Tajima (*Hiroshima Univ*.)
- USA : J. H. Adams Jr., S. Mitchell, M.J. Christl, J. Watts Jr., A. English, R. Young (*NASA/ MSFC*) , Y. Takahashi, D. Gregory, M. Bonamente, P. Readon, V. Connaughton, K. Pitalo, J. Hadaway, J. Geary, R. Lindquist, P. Readon (*Univ. Alabama in Huntsville*), H. Crawford, C. Pennypacker (*LBL, UC Berkeley*), K. Arisaka, D. Cline, J. Kolonko, V. Andreev (*UCLA*), T. Weiler, S. Csorna (*Vanderbilt Univ*.),
- France : D. Allard, J-N. Capdevielle, J. Dolbeau, F. Dorigo, P. Gorodetzky, C. Olivetto, E. Parizot, T. Patzak, D. Semikoz (*APC,CNRS*), A. Cordier, S. Dagoret, B. Kegl, K. Louedec, D. Monnier, M. Urban *(LAL, CNRS)*
- Germany: M. Teshima, T. Schweizer (*Max Planck Munich*), A. Santangelo, E.Kendziorra, F.Fenu (*Univ. Tuebingen*), P. Biermann (*MPI Bonn*), K. Mannheim (*Wuerzburg*), J. Wilms (*Univ. Erlangen*)
- Italy : S. Bottai. P. Spillantini, A. Zuccaro (*Firenze*), A. Anzalone, O. Catalano, M.C. Maccarone, P. Scarsi, B. Sacco (*IAS-PA/INAF*), G. D'Ali Saiti (*U. Palermo*), B. Alpat, R. Battiston, B. Bertutti, E. Fiandrini, P. Zuccon (*Perugia*), M. Casolino, M.P. De Pascale, A. Morselli, P. Picozza, R. Sparvoli (*INFN and Univ. Rome "Tor Vergata"*), P. Vallania (*INAF-IFSI Torino*), P. Galleotti, C. Vigorito, M. Bertaina (*Univ. Torino*), A. Gregorio (*Trieste*)
- Mexico: G. Medina-Tanco, J.C. D'Olivo, J.F.Valdes (*Mexico UNAM*), H. Salazar, O. Martines (*BUAP*), L. Villasenor (*UMSNH*)
- Republic of Korea : S. Nam, I. H. Park, J. Yang (*Ehwa W. Univ*.)
- Russia: Garipov G.K., Khrenov, B.A., Klimov P.A. Panasyuk M.I., Yashin I.V. (*SINP MSU*), D. Naumov, Tkachev. L (*Dubna JINR*)
- Switzerland : A. Maurissen, V. Mitev (*Neuchatel, Switzerland*) :
- Spain: D.Rodriguez-Frias, L.Peral, J.Gutierrez, R.Gomez-Herrero (*Univ. Alcala*)

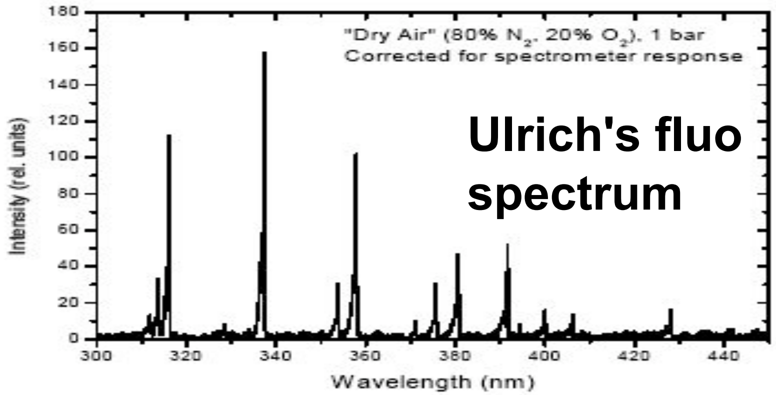
Principle of EUSO

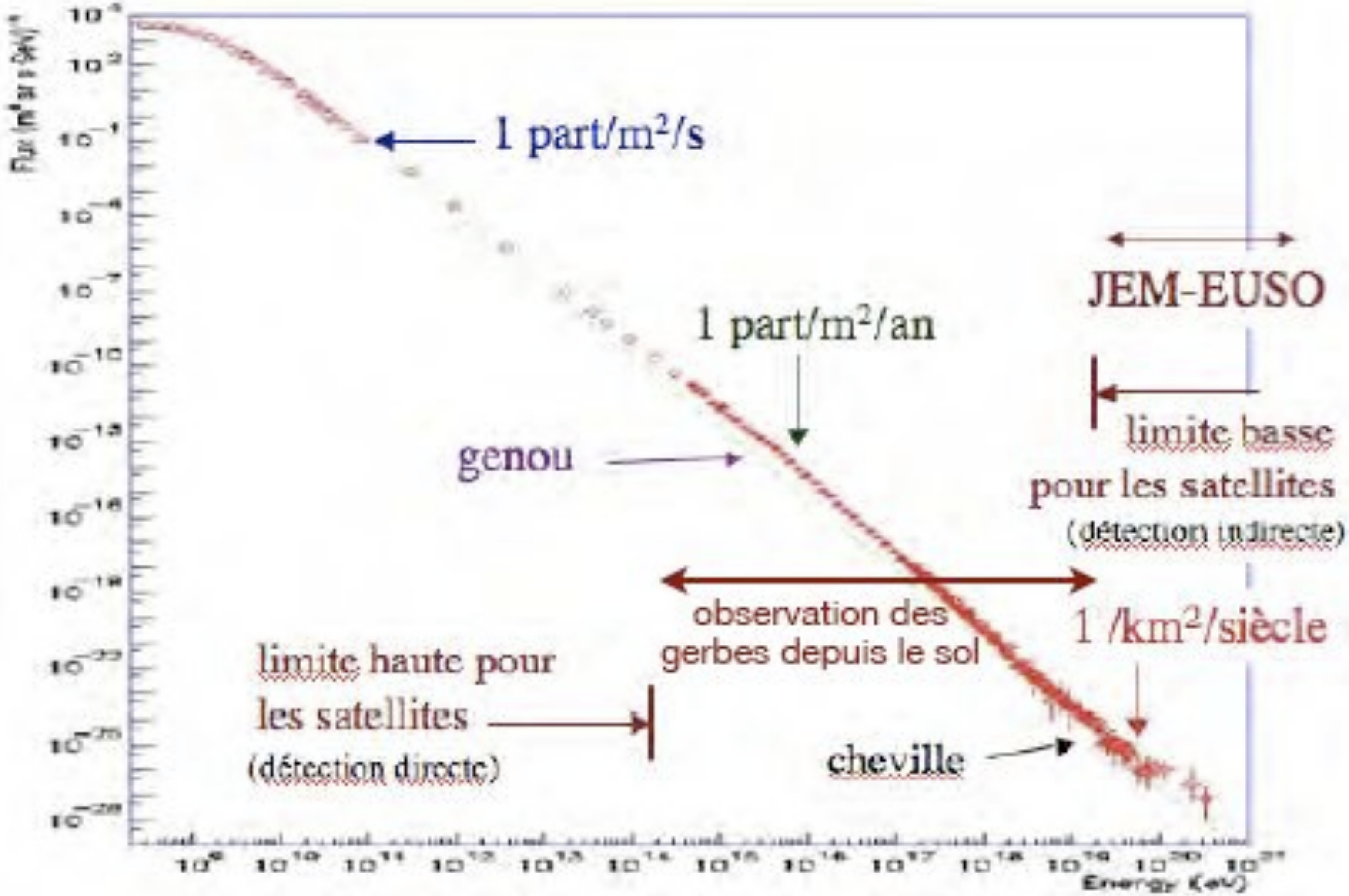
- first *remote-sensing* from space, opening a new window for the highest energy regime



ALL SKY SURVEY





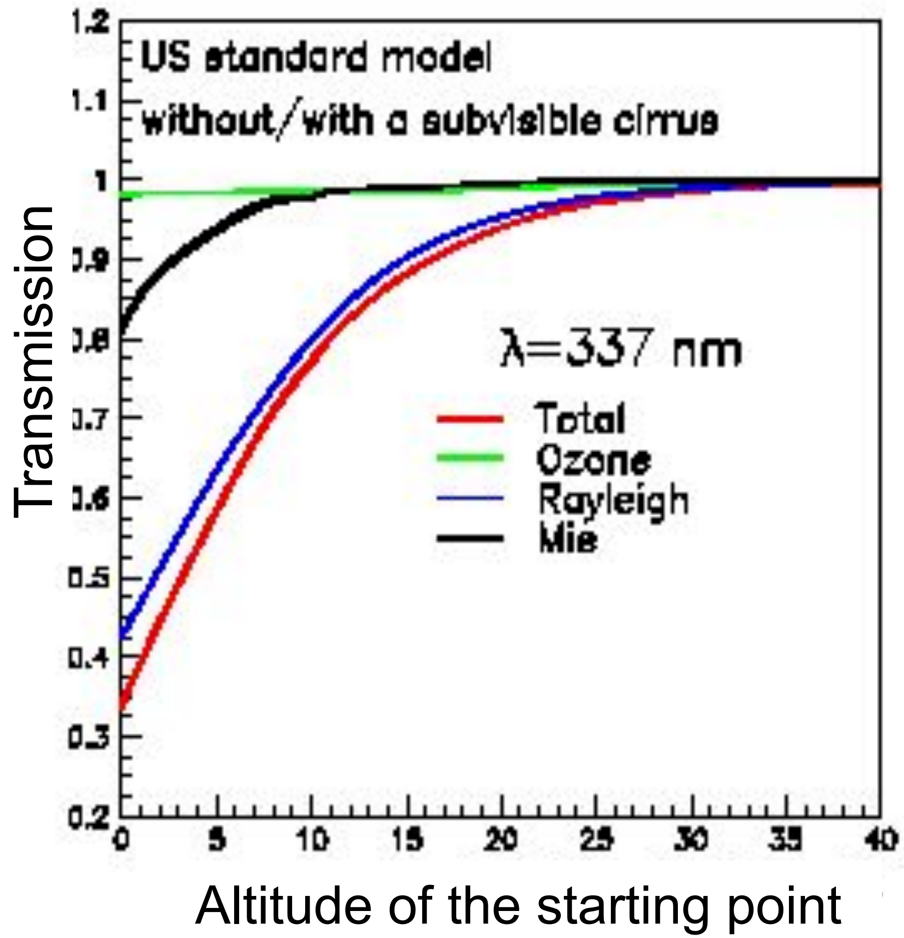


1 part/m²/s
JEM-EUSO
1 part/m²/an
limite basse
pour les satellites
(détection indirecte)
genou
observation des
gerbes depuis le sol
1 /km²/siècle
limite haute pour
les satellites
(détection directe)
cheville
Energy (eV)

Earth Atmosphere as a Detector

Looking Down from Space is **much better** than looking up from the ground; also duty cycle 20-25% instead of 13%.

- Smaller Mie Scattering
  - ~20%
- Low Cloud (2~3km) in night
  - Most of the showers reaches the maximum above the cloud
- Smaller Absorption (loss)
  - ~ 0.3, and uncertainty < 0.05
  - Large absorption/uncertainty (loss) X 10 ~100 for ground fluorescent observatory
- Well determined Distance to a Shower
  - Observation altitude : ~400km
  - Shower altitude : ~10km



From EUSO to JEM-EUSO

EUSO @ ESA selection 2000 -

- Europe：Phase-A Completed
  - »By July 2004
- Japan：JAXA and RIKEN funded concept studies 1998-06
- USA： End-to-End MIDEX $36M

Collaboration:（9 nations）

Italy, France, Switzerland
Germany, (Portugal), (Spain)
Japan, USA, (Brazil),
Russia, Korea, Mexico

↓

ESA/ESTEC meeting, October 2005,
Plan changed due to large stopping factors:
(i) USA changed the ISS plan and the usage of STS,
(ii) Budgetary troubles at D/S of ESA for Columbus EUSO

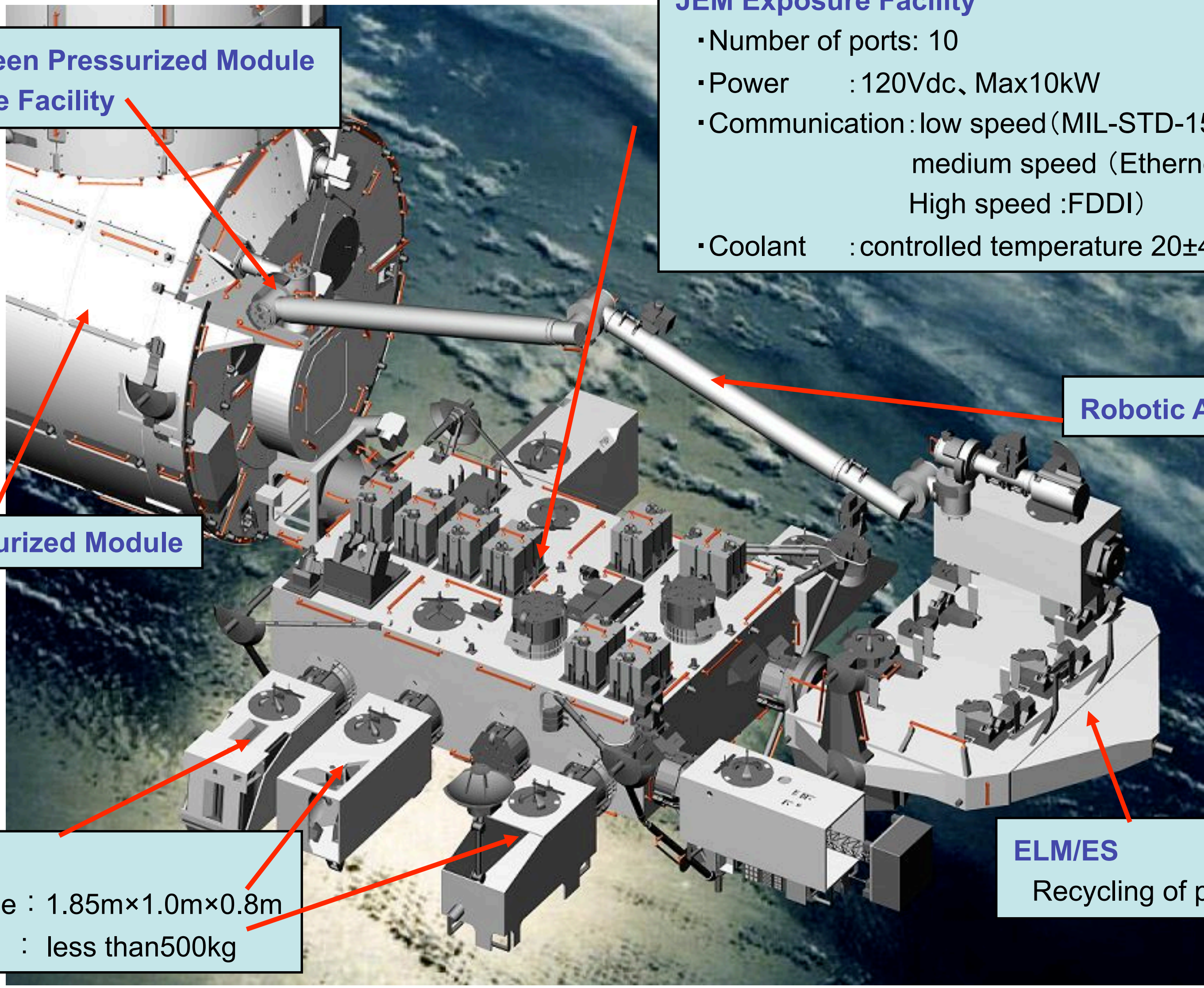
ESA D/HME and NASDA worked together to use (JEM EF) and HTV/H2B for EUSO (Phase-A extension 2004).

→ ESA bankrupt announces Cosmic Vision

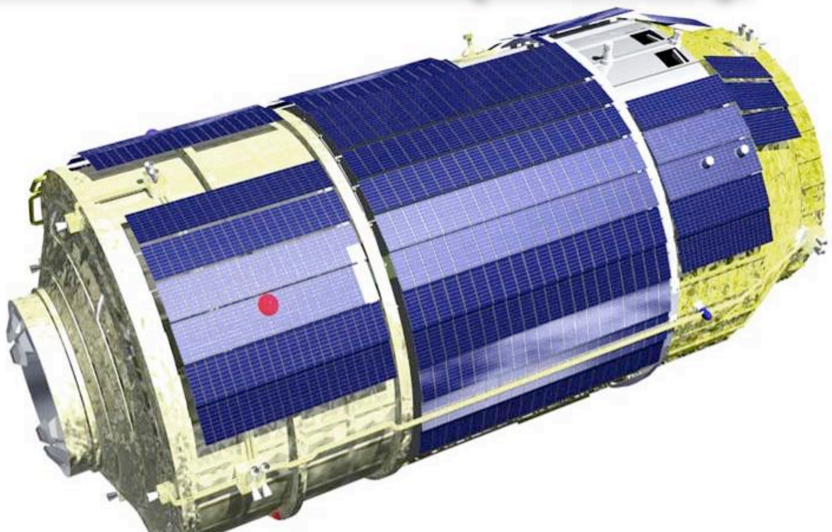
Japan and USA and a part of Europe made JEM-EUSO Working Group. It was authorized by JAXA/ISAS;

Europe re-organized, and Russia/Korea/Mexico joined.

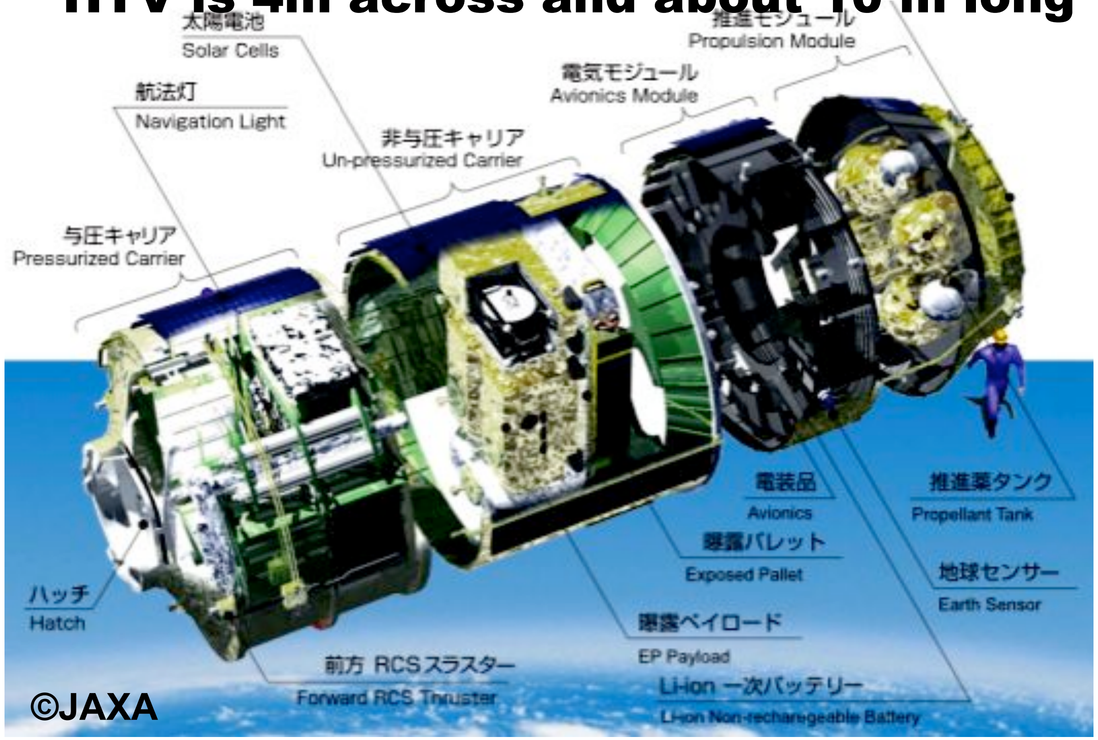
Outline of JEM Exposure Facility



H-II Transfer Vehicle (HTV)



HTV is 4m across and about 10 m long



Important calendar (forthcoming)

- August 2010
  - Selection for the Later Phases
- Year 2010-2014
  - Production, Assembly & Verification
- Expected launch by HIIB-HTV in 2015

Science Objectives

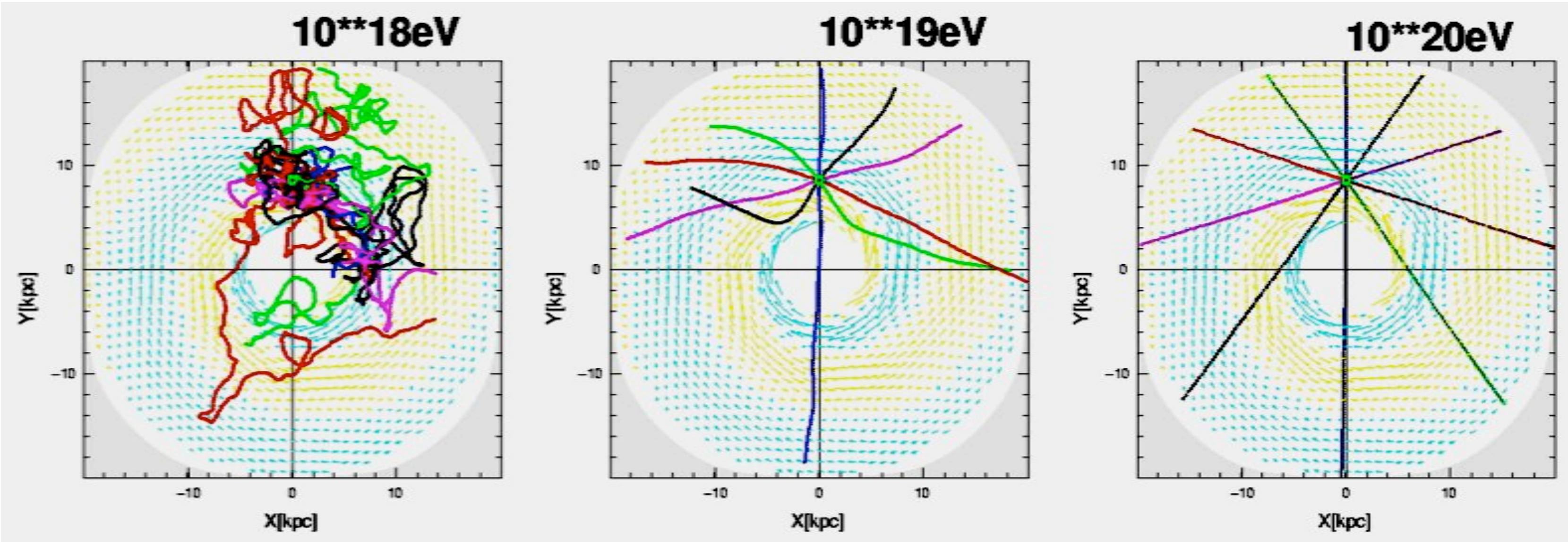
Fundamental Objective:

Extreme energy astronomy by particle channel

Exploratory Objectives

- Detection of extreme energy neutrinos to examine extra dimensions in super-gravity/string theory
- Examination of quantum gravity, dark matter and quantum limit at super-LHC energies to $m > 300$ TeV/c^2
- Global observations of night-glows, plasma discharges and lightings

$E > 10^{20}$ eV particles are not tilted by Galactic Mag Field

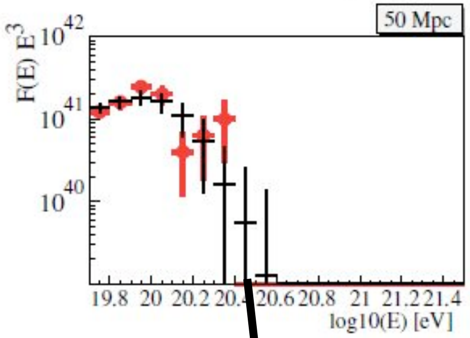


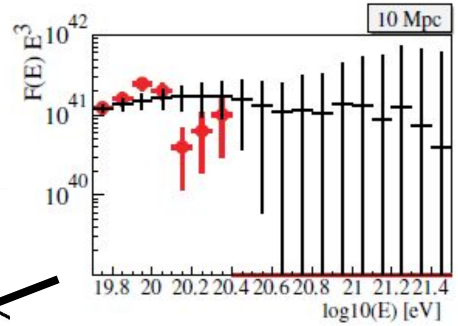
well done **al dente** **not cooked**

Specify origins by the arrival direction:

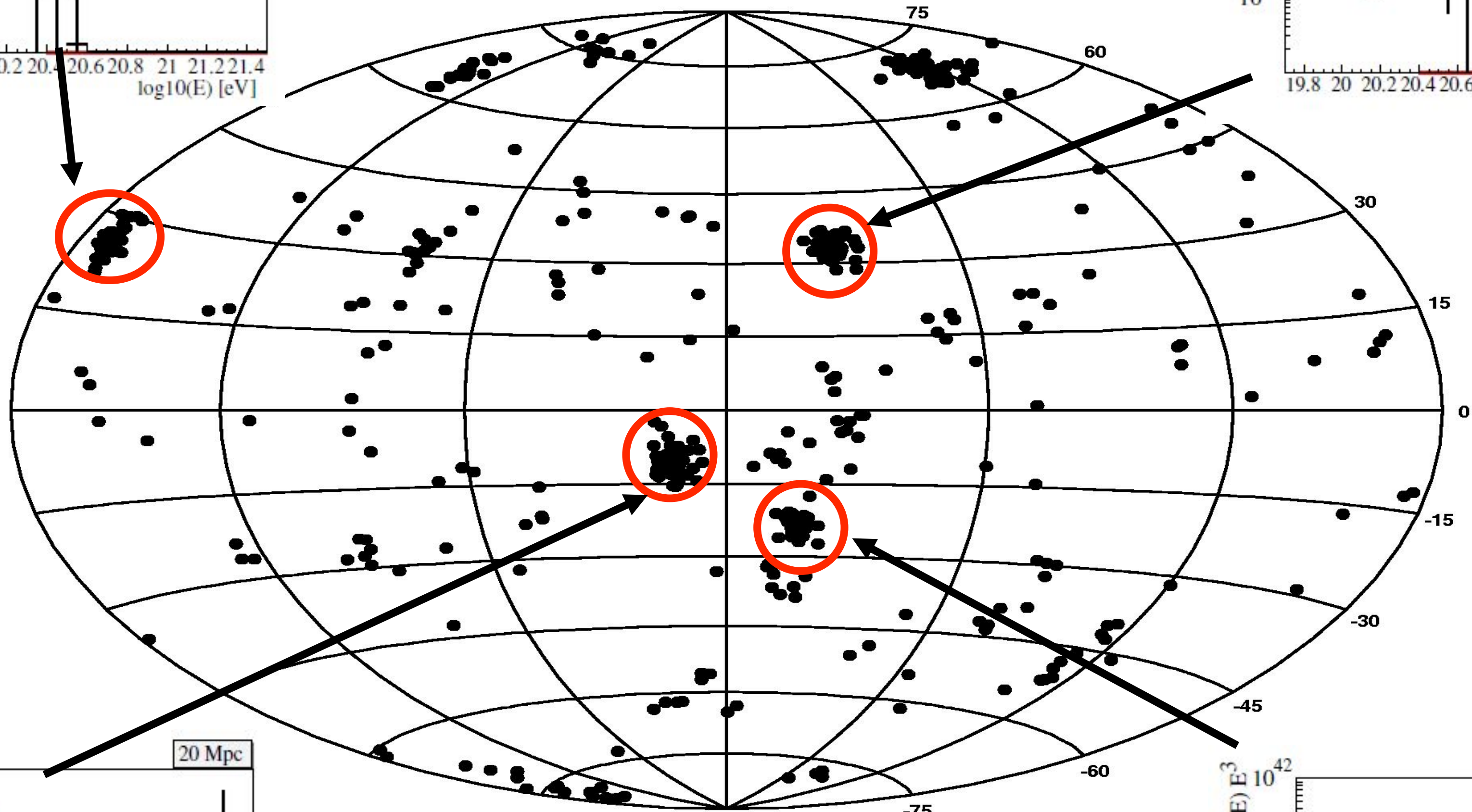
Particle Astronomy

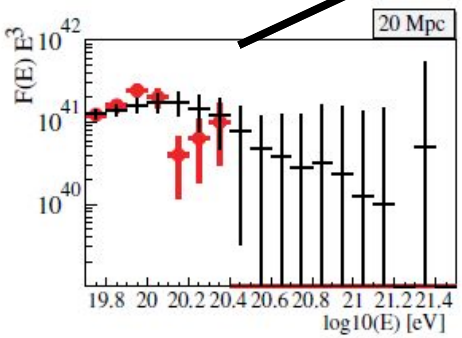
Particle Astronomy Simulation

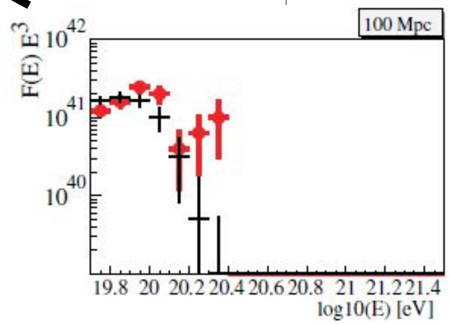




If we get >1,000 events,





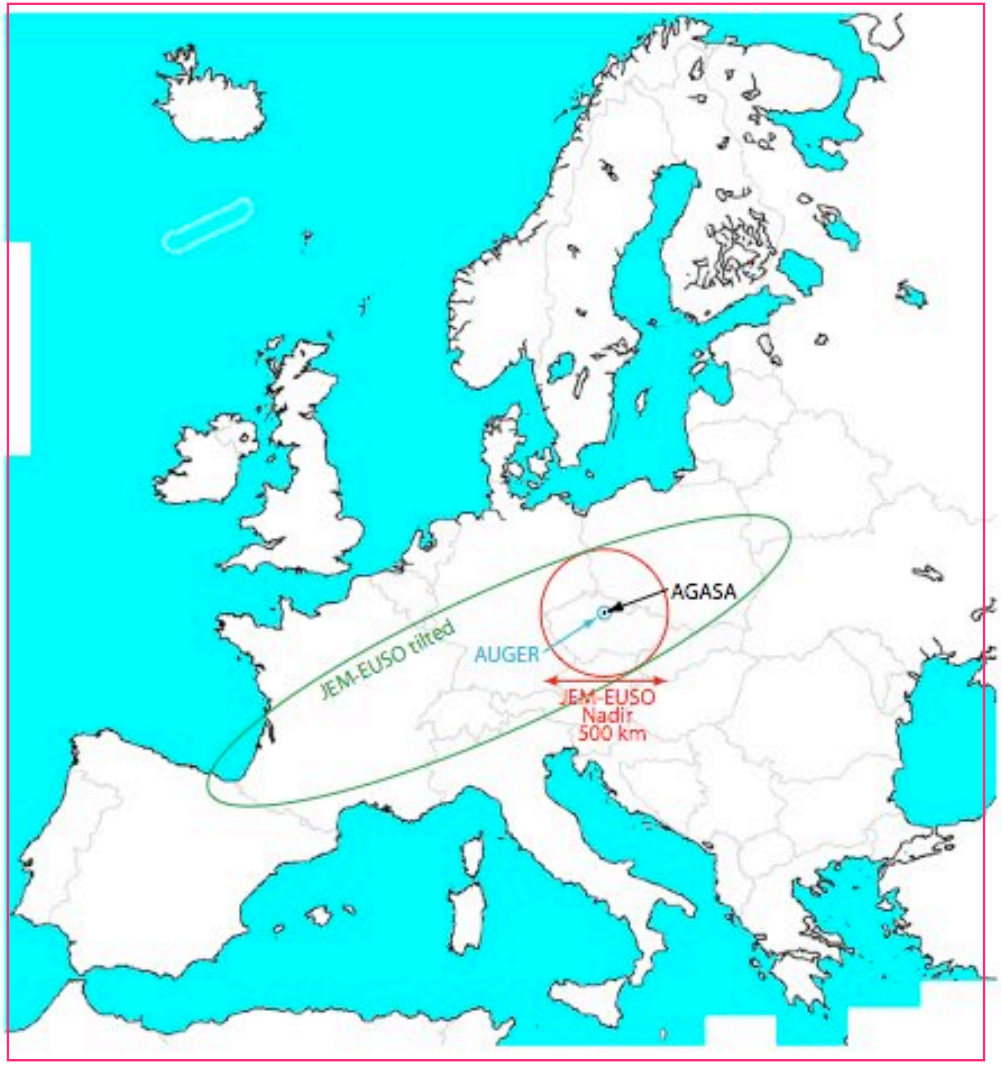


- 1,000 events : $E>7\times10^{19}$eV
- Several dozen clusters are expected
- All sky coverage

AGASA and AUGER have directions

JEM-EUSO FoV

EUSO ~ 1000 x AGASA ~ 30 x Auger
EUSO (Instantaneous) ~ 5000 x AGASA
(nadir mode) ~ 150 x Auger



Euso nadir: 2 years
Euso tilted: 3 years

JEM-EUSO, HTV, Kibo

Science Objectives

Fundamental Objective:

Extreme energy astronomy by particle channel

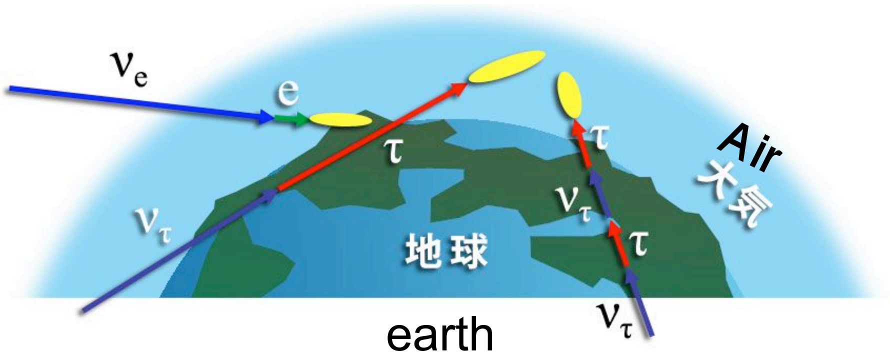
Exploratory Objectives

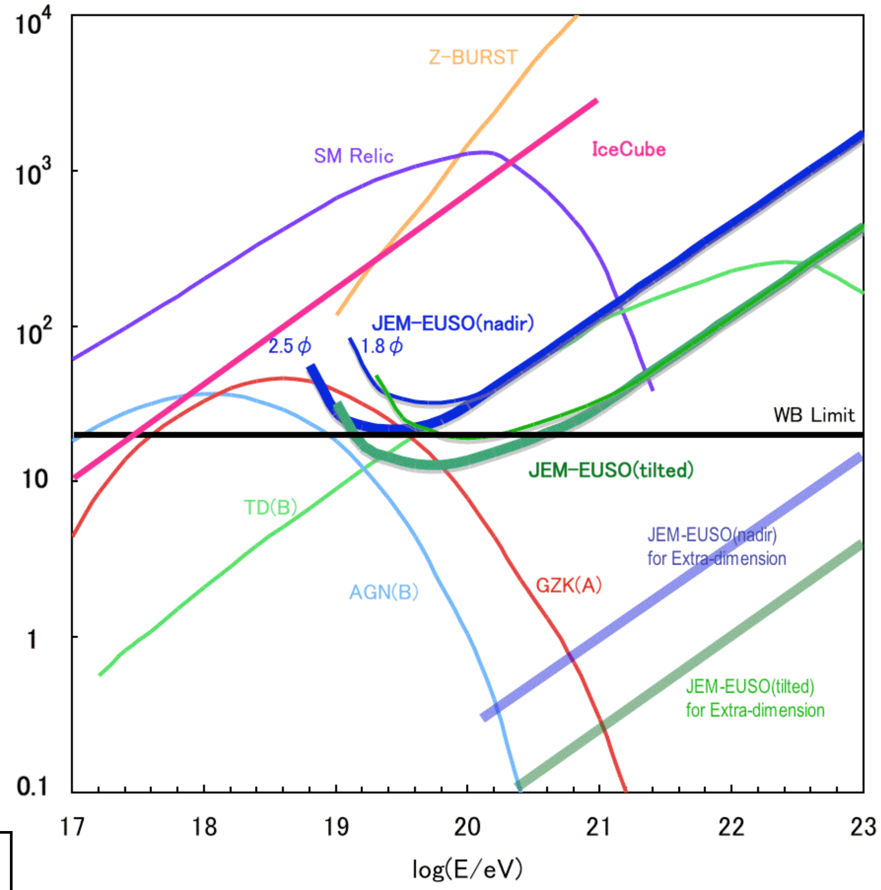
- Detection of extreme energy neutrinos to examine extra dimensions in super-gravity/string theory
- Examination of quantum gravity, dark matter and quantum limit at super-LHC energies to $m > 300$ TeV/c^2
- Global observations of night-glows, plasma discharges and lightings

Exploratory objective 1:

ニュートリノ

Sensitivity for neutrino (preliminary: TBC)





100 times even rate in the case of extra dimension

Special trigger: 1 pixel with > 100 pe in < 10 ns

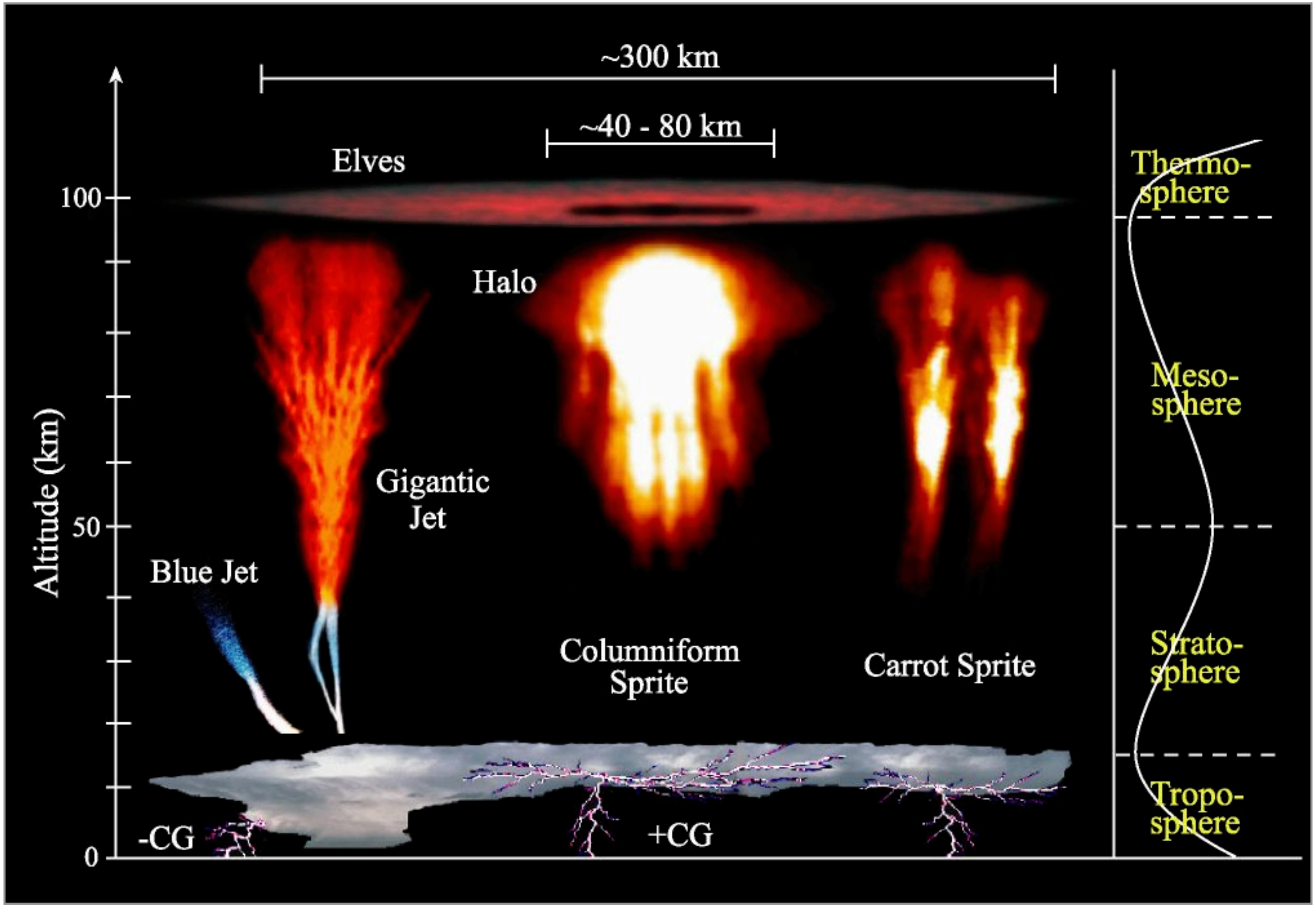
*Hundreds of neutrino events

大気圏

Exploratory objective 2:
Atmospheric Sciences

- Lightning, TLEs
  - Nadir Observation of Lightning and TLEs
  - Global Survey of TLEs
  - Correlation with CR
  - New adaptive data acquisition does not saturate ($photons_{AS} = 10^6\ photons_{shower}$)
- Night Glow, Plasma Bubbles
  - Global Imaging of O_2 Hertzburg I night glow
  - Formation Mechanism of Plasma Bubbles
  - Energy, Momentum, and Matter transfers in upper atmosphere
- Clouds
  - Global survey of cloud top hight
- Meteors: ablation studies (slow mode)

Luminescence phenomena associated with lightning



Exploratory objectives: meteors

τ ~ seconds

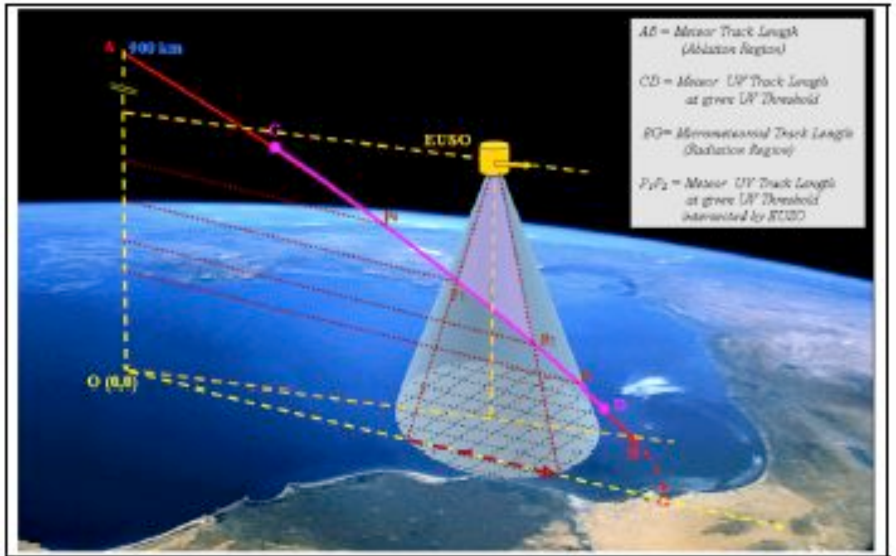


Figure 6.5.8-2 *The path of a meteor in the EUSO field-of-view*

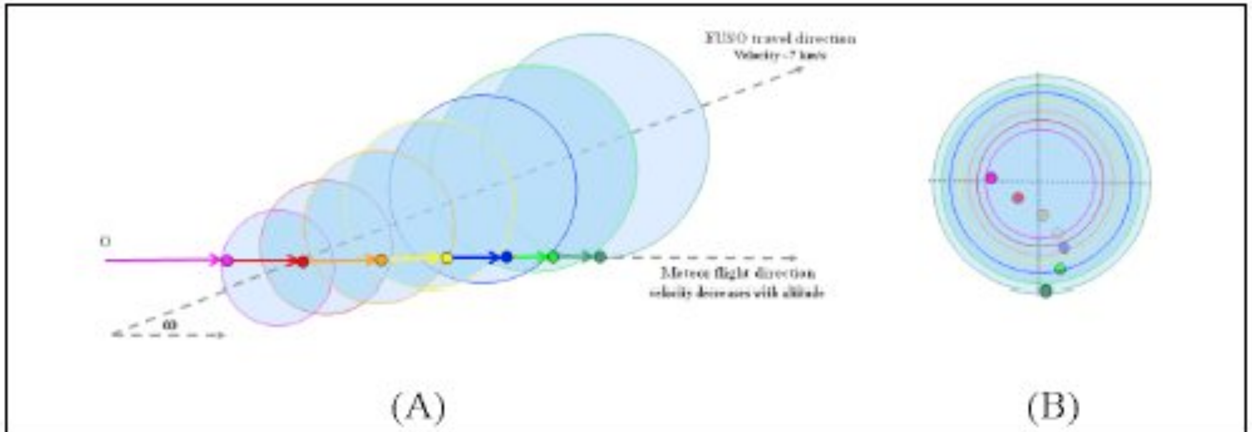
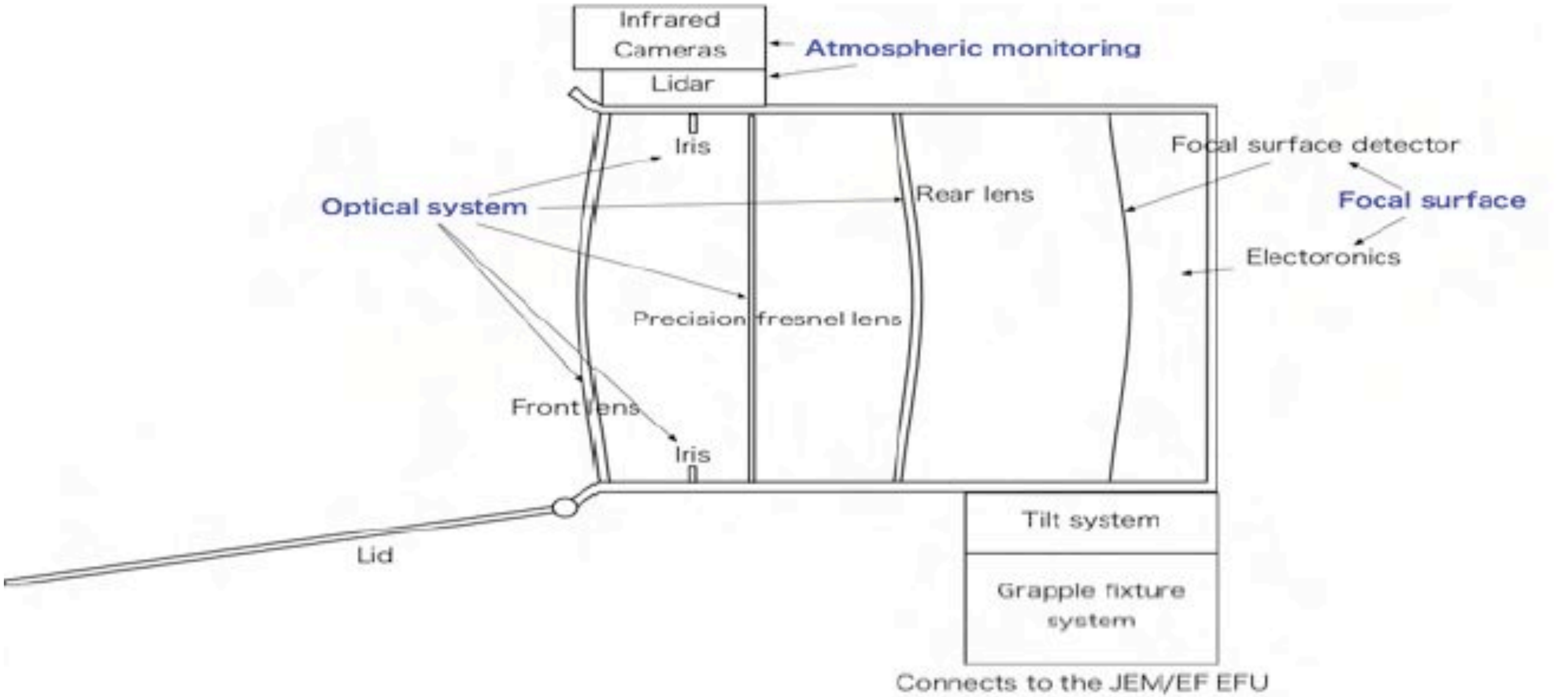
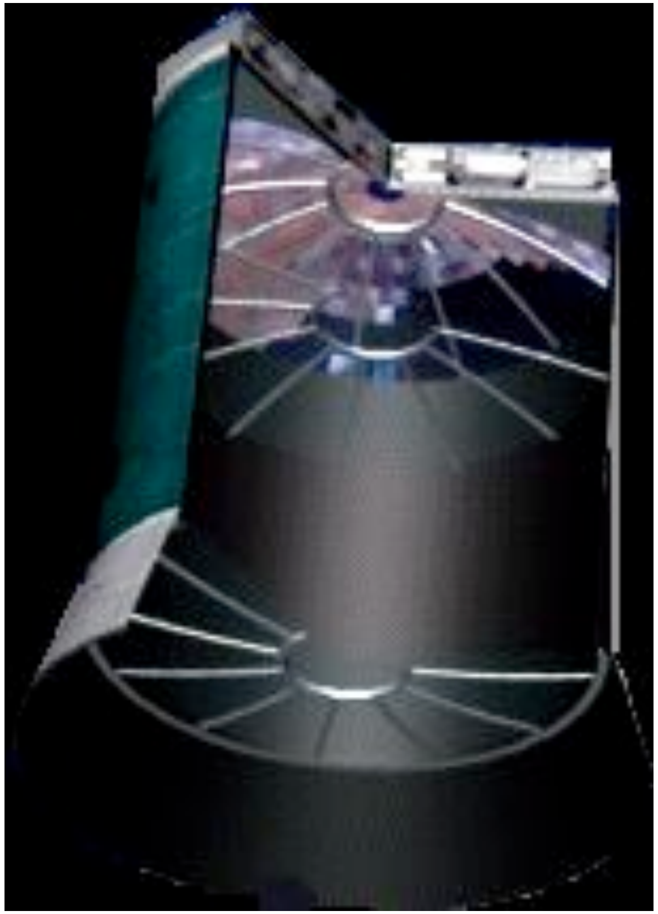


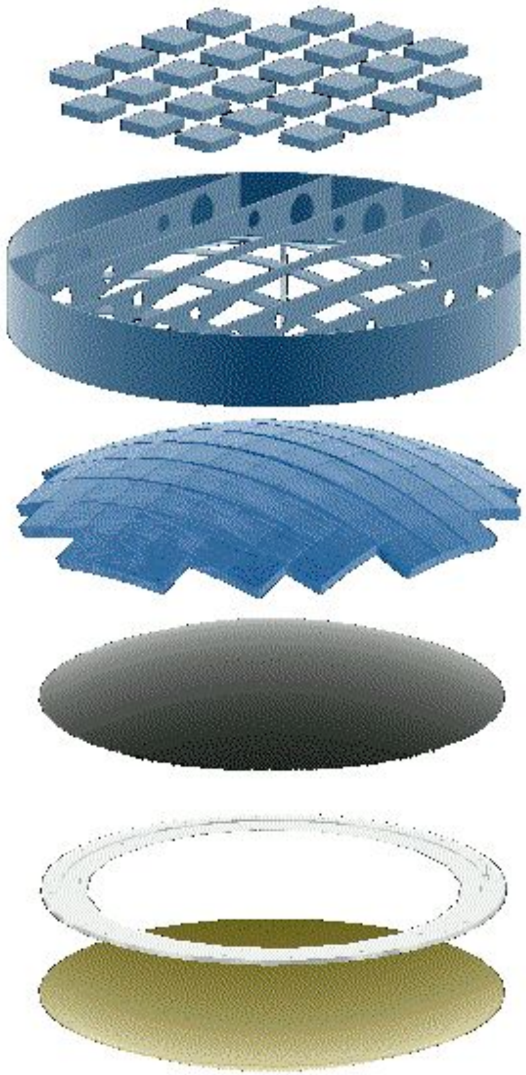
Figure 6.5.8-3 *EUSO meteor observation. (A) - Different frames are taken at constant time steps Δt and are represented by sections of the "cone" with different colors (first frame is pink, last is green). The sections move along the EUSO travel direction and are equally spaced because of the constant velocity (~7 km/s). The sections increase their diameter with time because they refer to progressively lower "cone"-meteor intersection altitude. Meteors velocities at each time are represented by colored vectors whose module decrease with time (altitude). The meteor "spots" moves with curved trajectories on the "observation cone" projection shown in the (B) panel.*



Infrared
Cameras
Atmospheric monitoring
Lidar
Iris
Focal surface detector
Optical system
Rear lens
Focal surface
Electoronics
Precision fresnel lens
Front lens
Iris
Tilt system
Lid
Grapple fixture
system
Connects to the JEM/EF EFU

JEM-EUSO Telescope Structure





Electronics : LAL + JAXA + Konan

Structure : Riken + Frascati

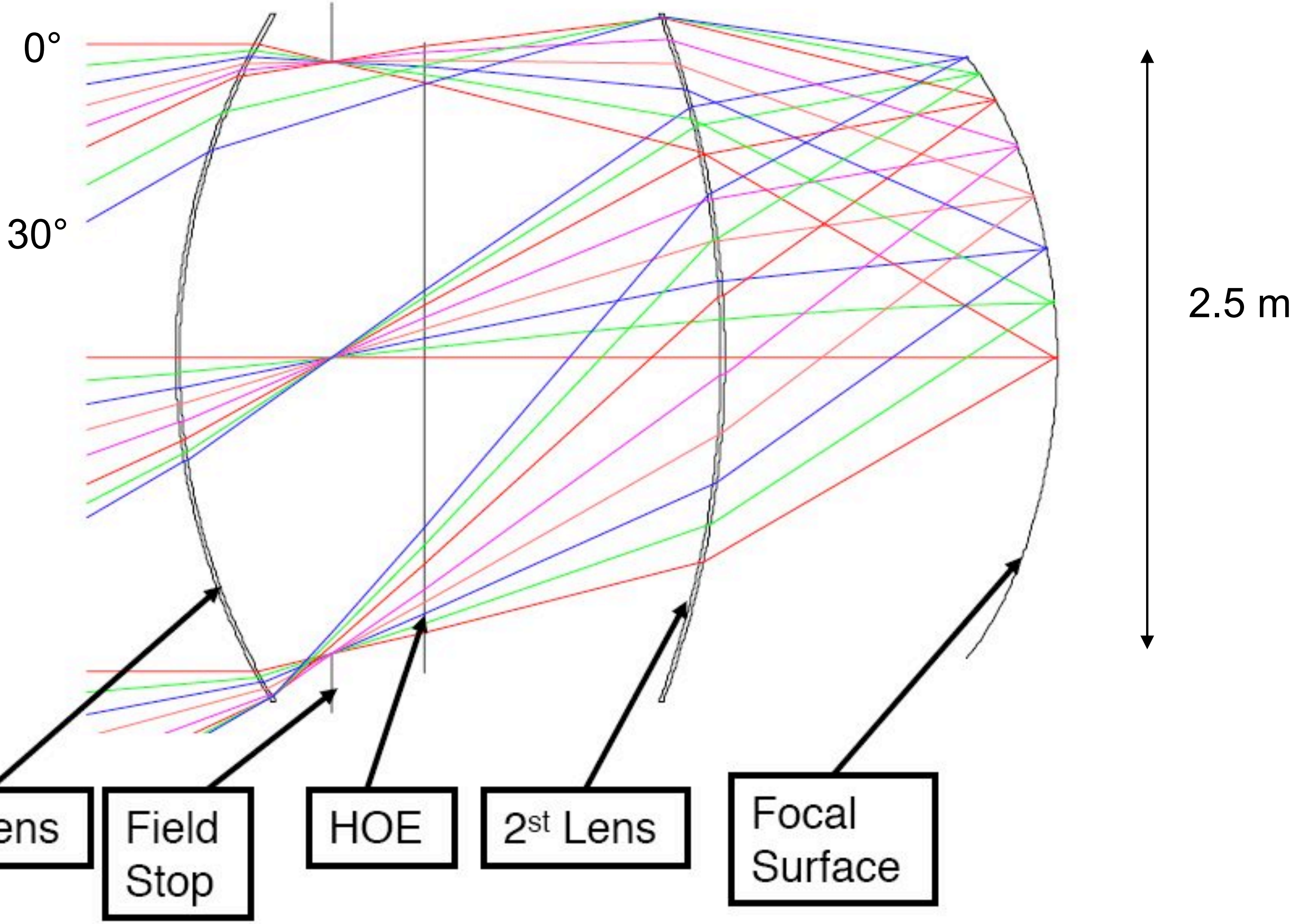
Focal Surface : Riken + (Munich?)

Optics : USA + Riken

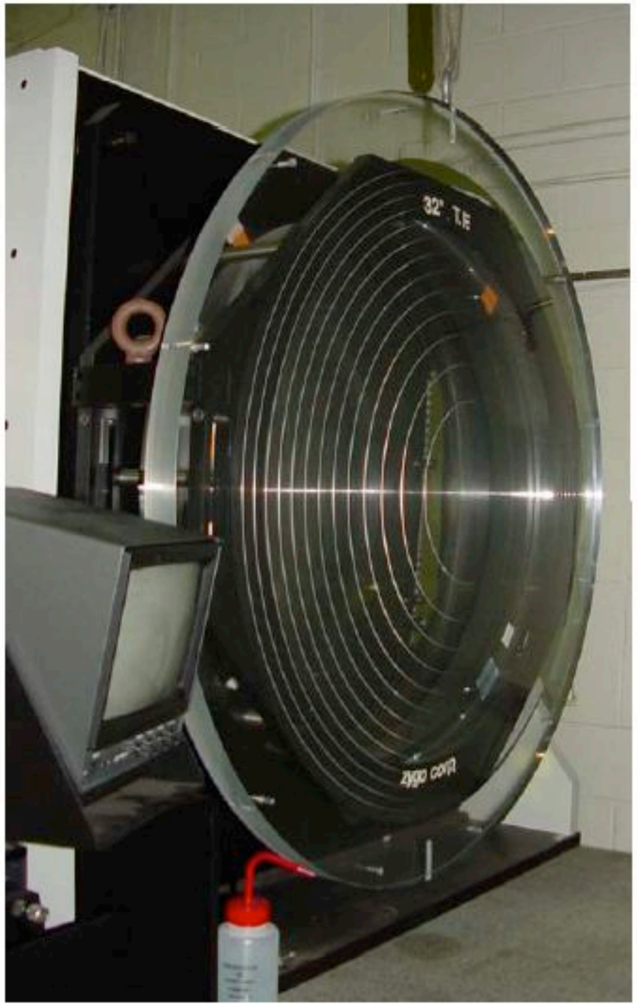
Simulation : Saitama U. + France + Tuebingen

Calibration : APC + Aoyama U.

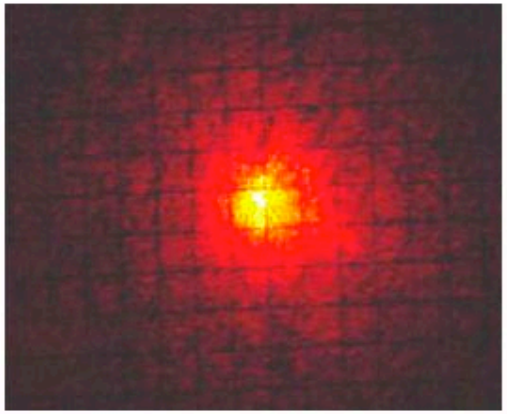
60° Design with CYTOP



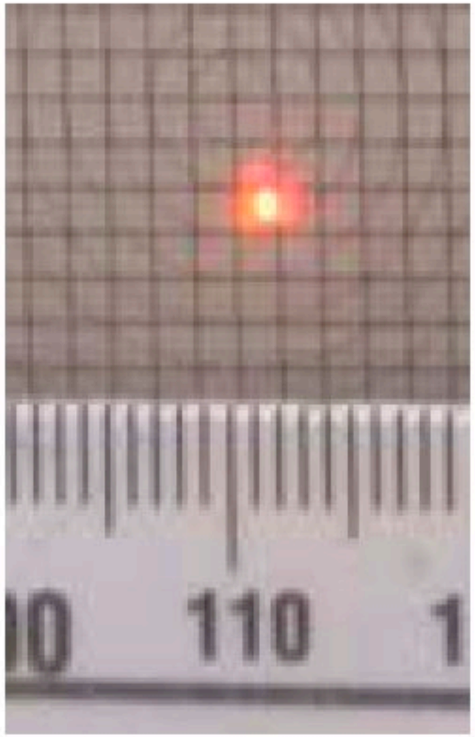
Diamond Turning and Polishing Fresnel Lenses



Phase A lens on 32 inch Zygo



Before
(PMMA)



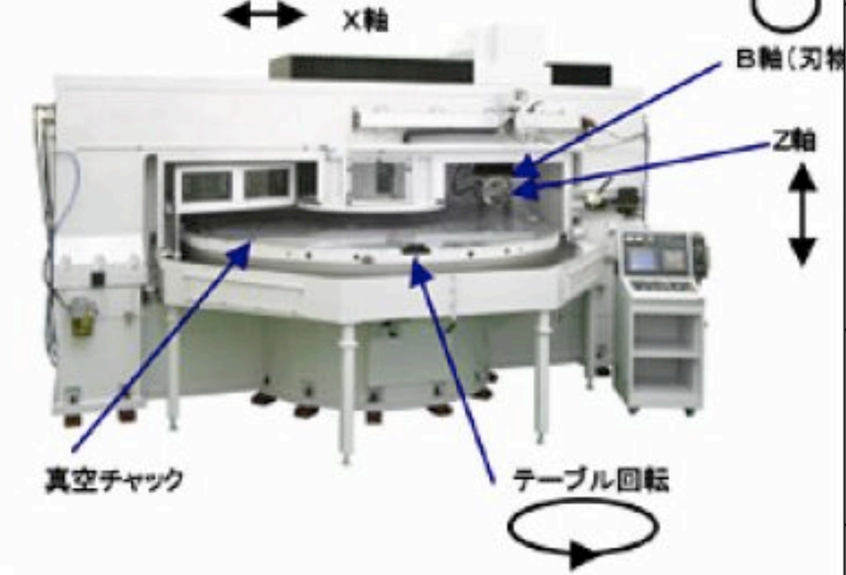
After
(CYTOP)

USA - JAPAN

instrument

2.UTD-3400
-Specifications-

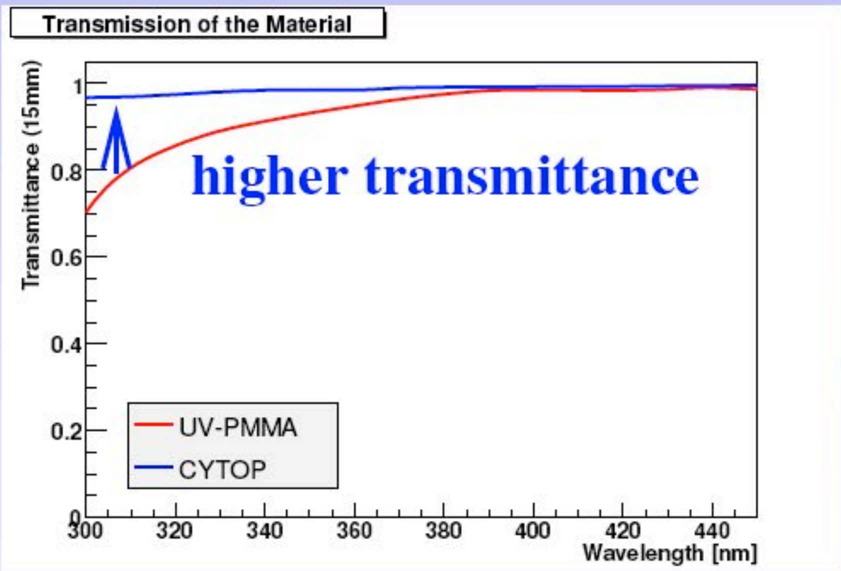
Toshiba lathe



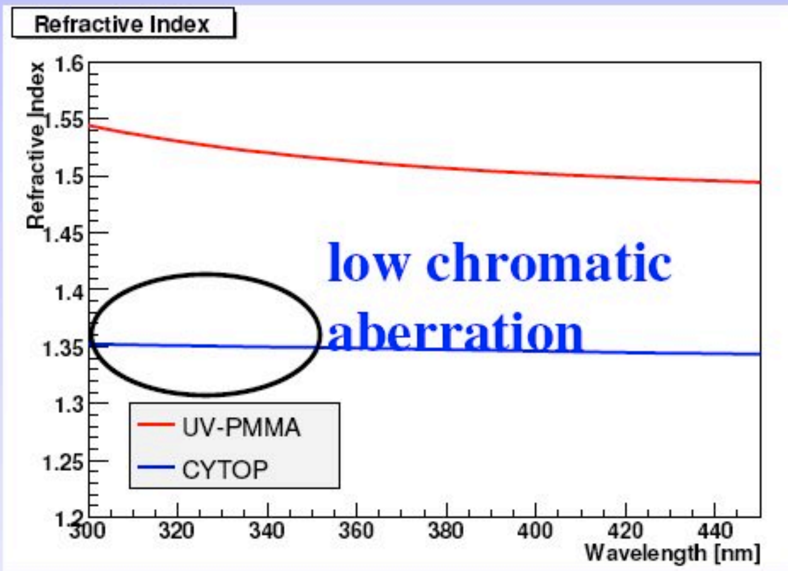
Major Specifications		
rotation Table	diameter (mm)	3400
	loadable mass(kg)	2000
	Rotation velocity (min^{-1})	10-80
	Largest prcessable diameter (mm)	3400
	oil sustained shaft	
Linear axis	Horizontal motion (X)(mm)	1850
	Vertical motion (Z) (mm)	240
	Super precision V-V roler guide	
Rotation axis	Angle range (B axis) (deg)	±360
	Air sustained shaft	
Least settable unit最小設定単位		X, Z: 0.01 μm, B: 0.00001 deg
mass (kg)		38000

UV PMMA vs. CYTOP

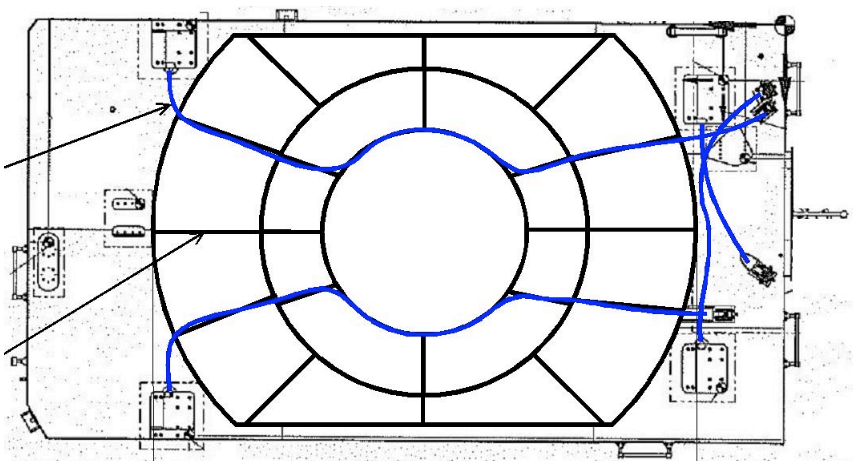
Transmission

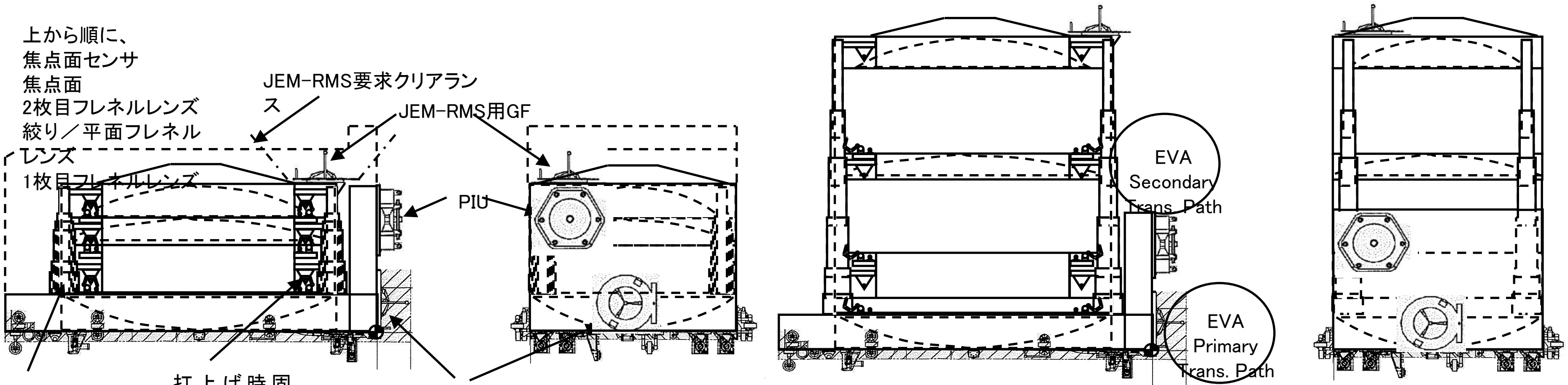


Refractive Index

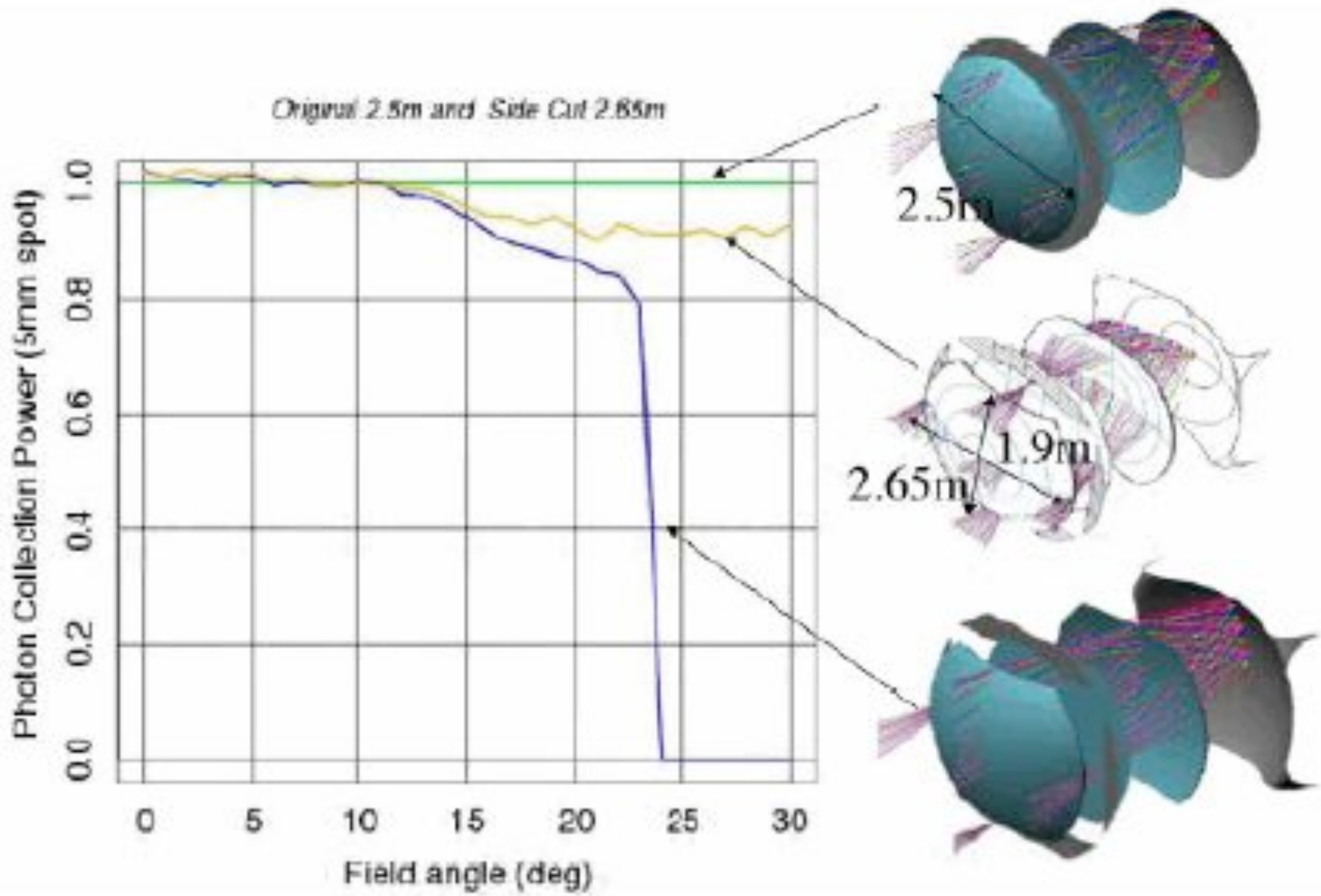


Accommodation to HTV：Case-C

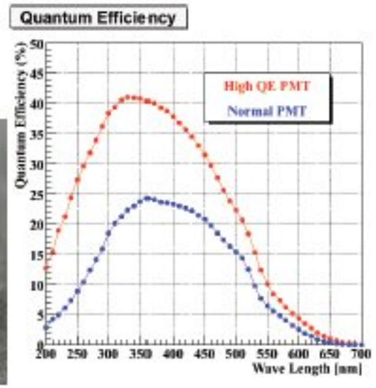


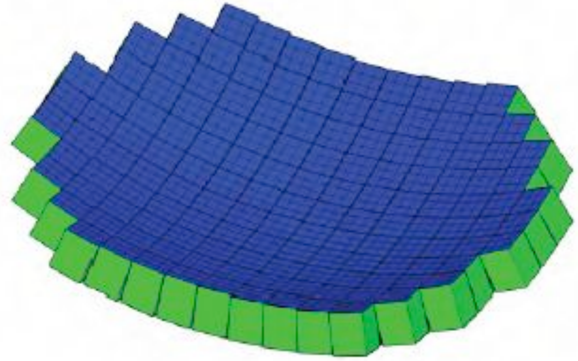


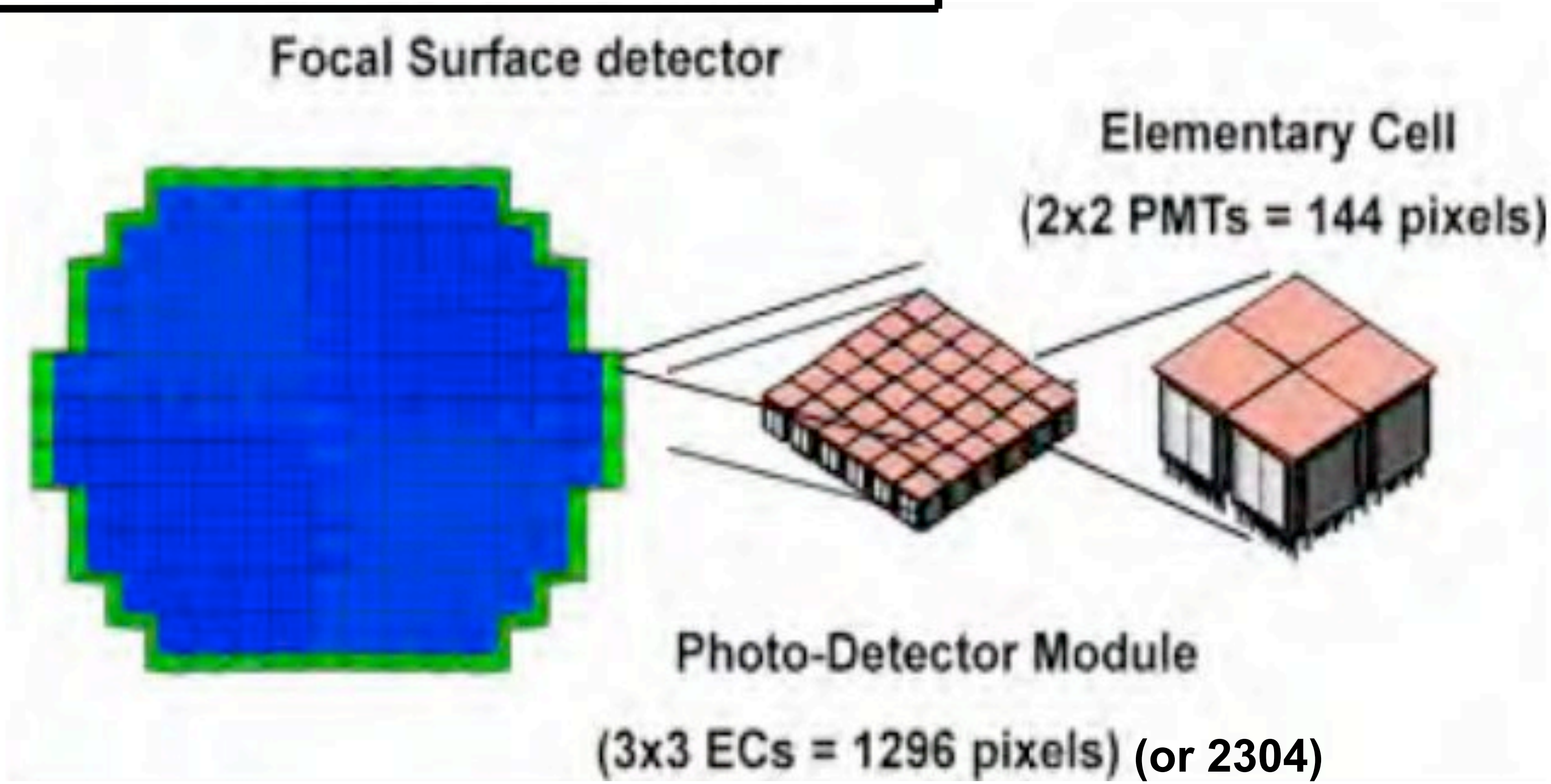
注）伸展機構の太さは強調して示してあり、EVA Secondary Trans. Pathとの干渉はないよう設計可能と考える。

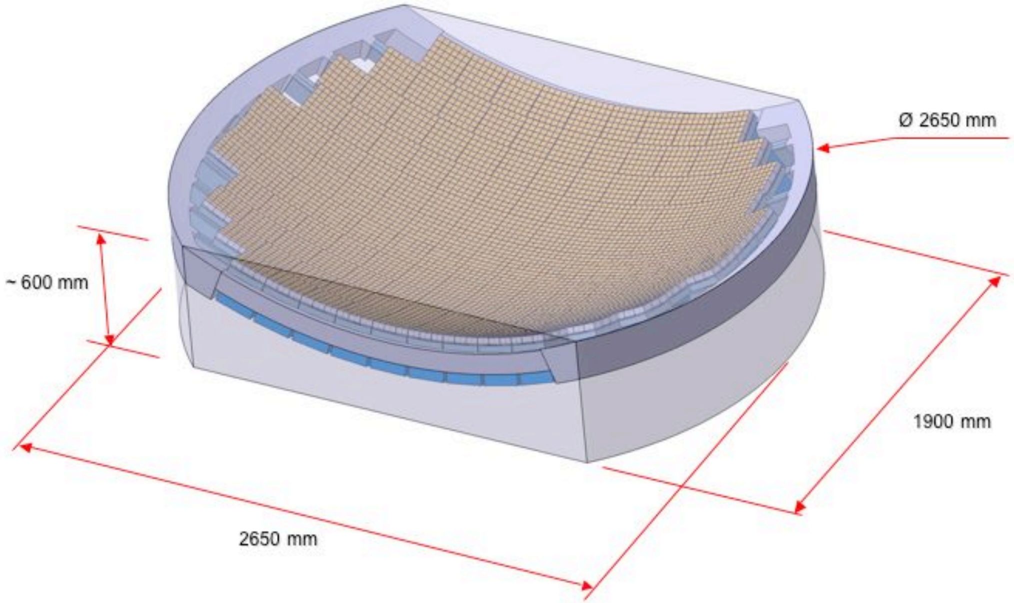


Original 2.5m and Side Cut 2.65m
Photon Collection Power (5mm spot)
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
20
25
30
Field angle (deg)
2.5m
1.9m
2.65m


Quantum Efficiency
Quantum Efficiency (%)
High QE PMT
Normal PMT
Wave Length [nm]




Focal Surface detector
Elementary Cell
(2x2 PMTs = 144 pixels)
Photo-Detector Module
(3x3 ECs = 1296 pixels) (or 2304)


Ø 2650 mm
~ 600 mm
1900 mm
2650 mm

Frascati

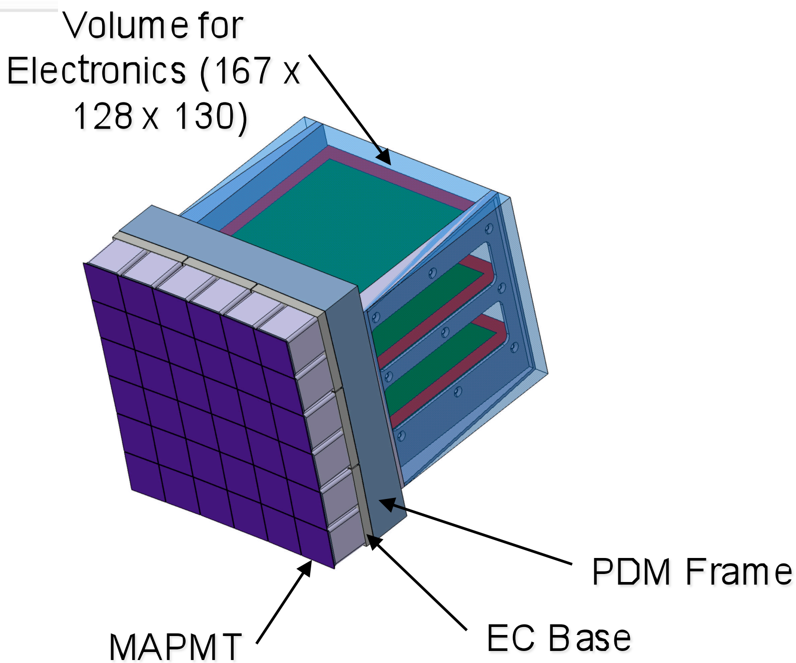
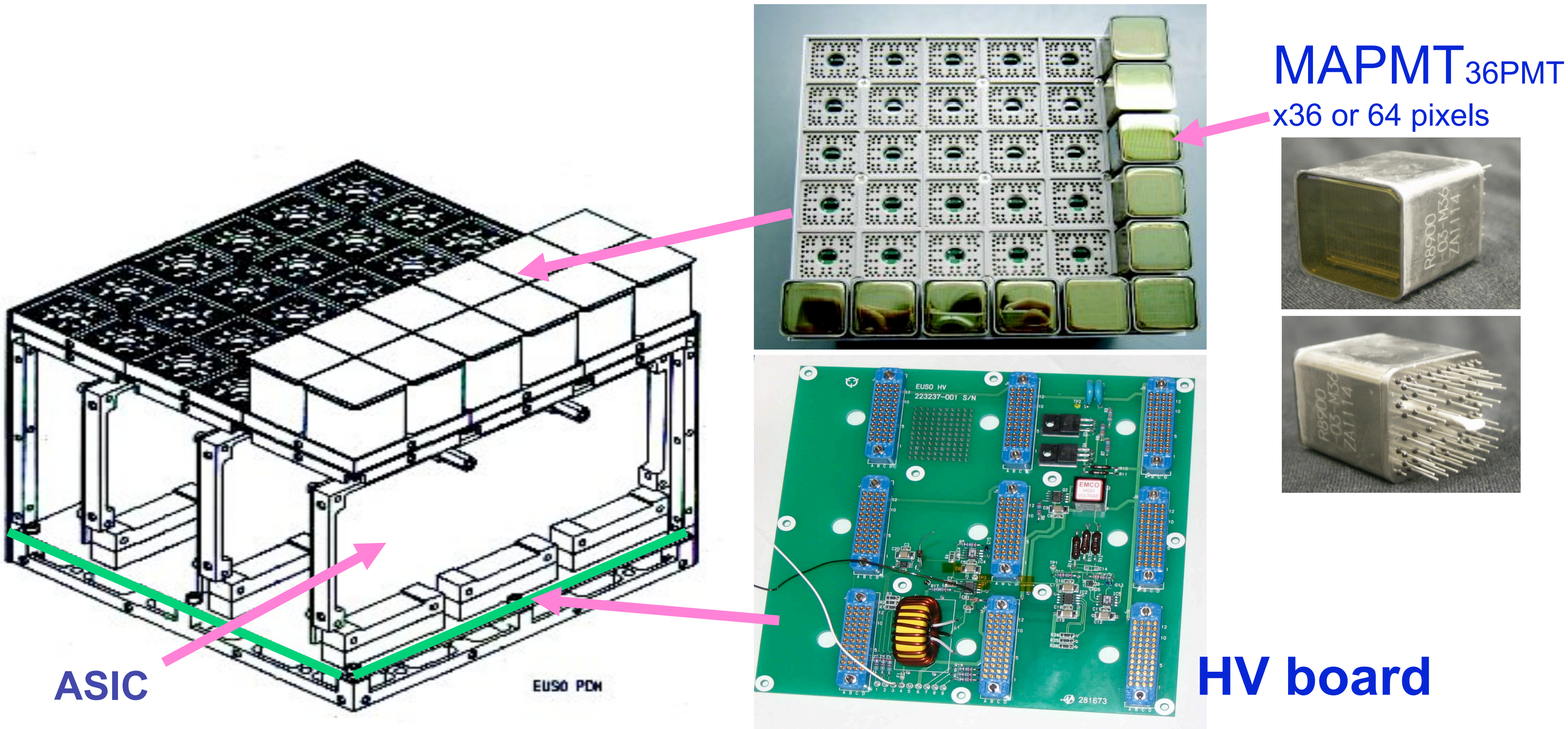

Volume for Electronics (167 x 128 x 130)
PDM Frame
EC Base
MAPMT

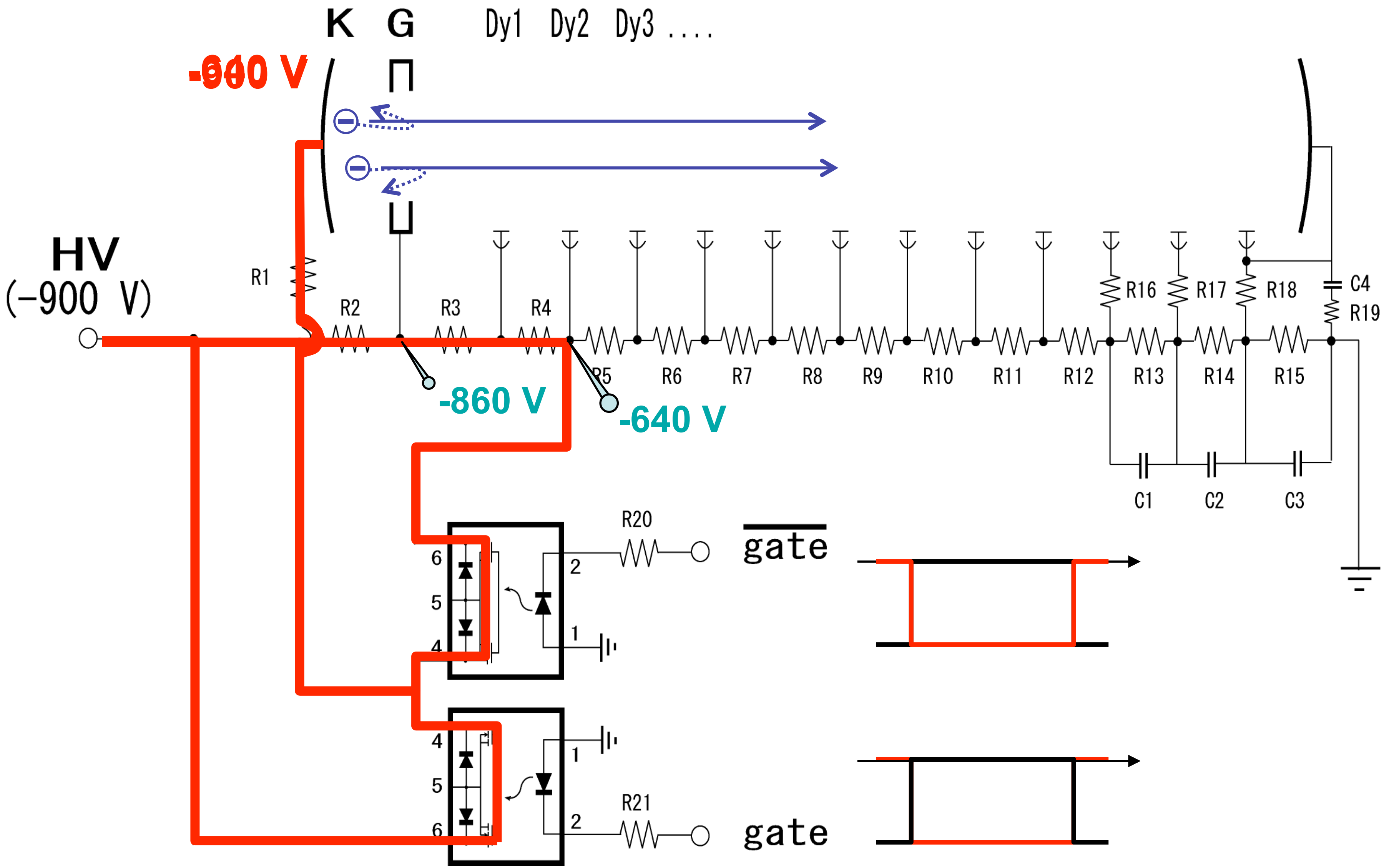
Photo Detector Module (PDM)



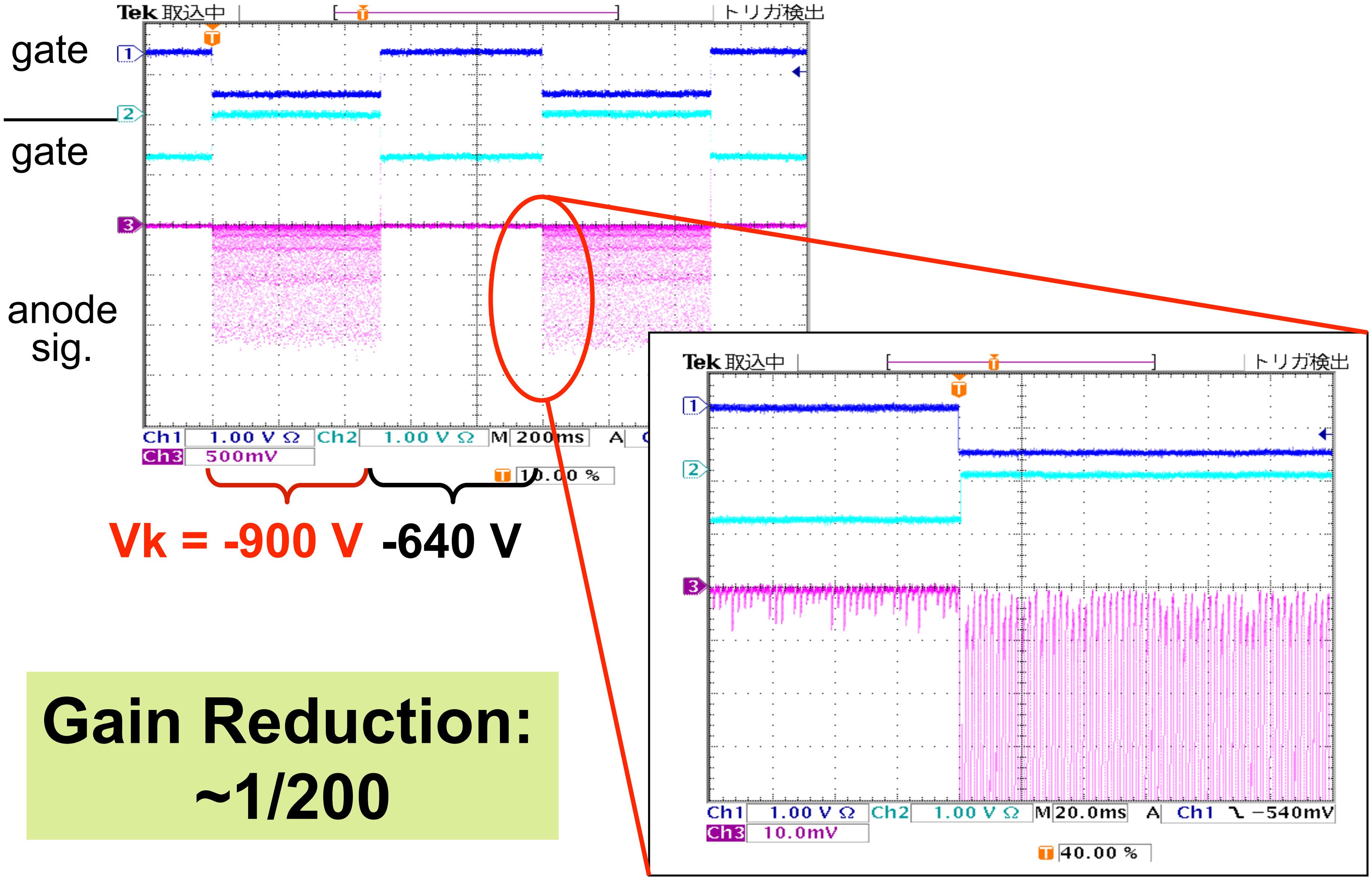
M36: PSF diameter = 6 mm

New M64: 3mm

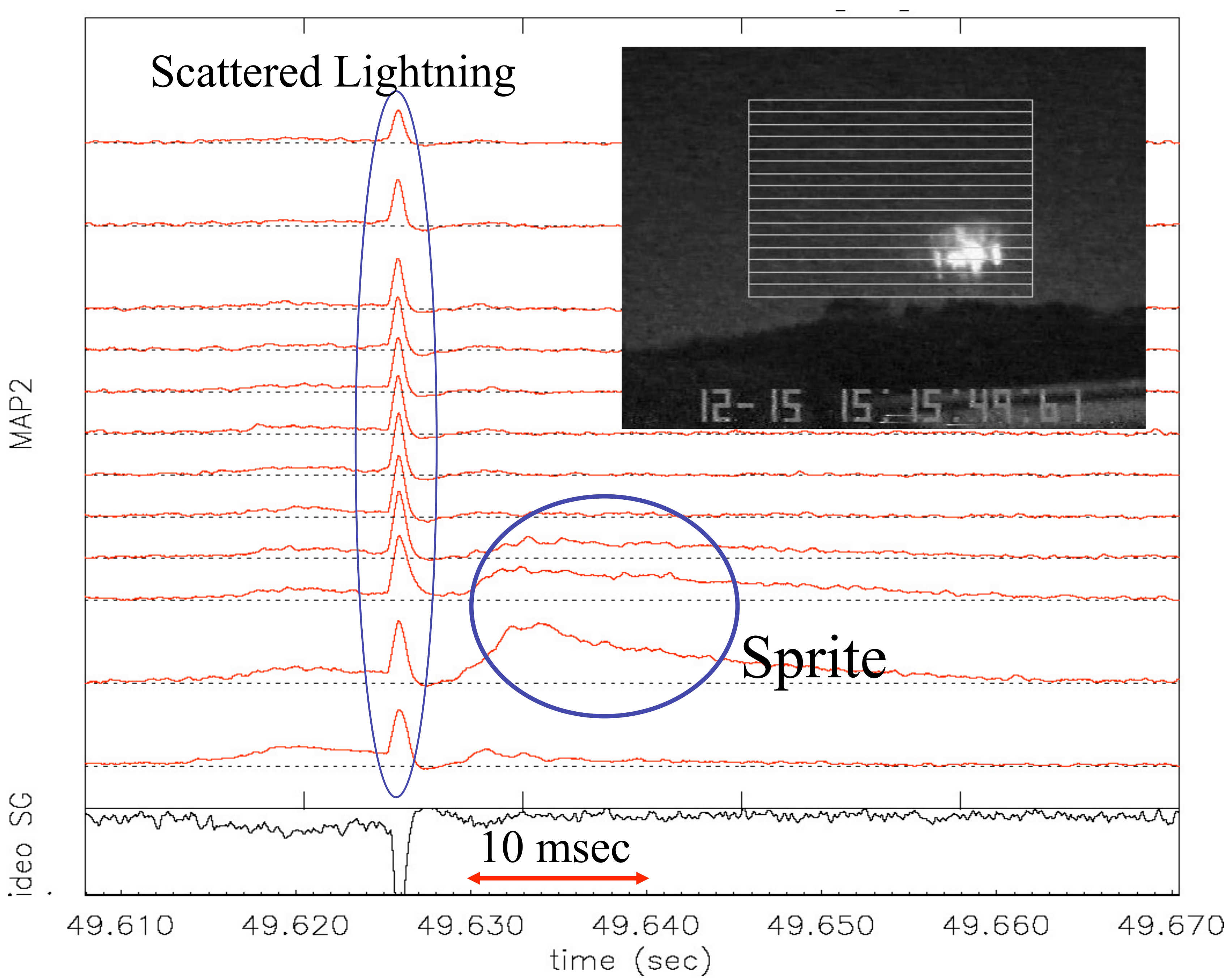
MAPMT Gain Control



MAPMT Gain Control



Gain Reduction: ~1/200


Scattered Lightning
12- 15 15:15:49:67
MAP2
Sprite
ideo SG
10 msec
49.610
49.620
49.630
49.640
49.650
49.660
49.670
time (sec)

Atmospheric Monitoring System

- **IR Camera**

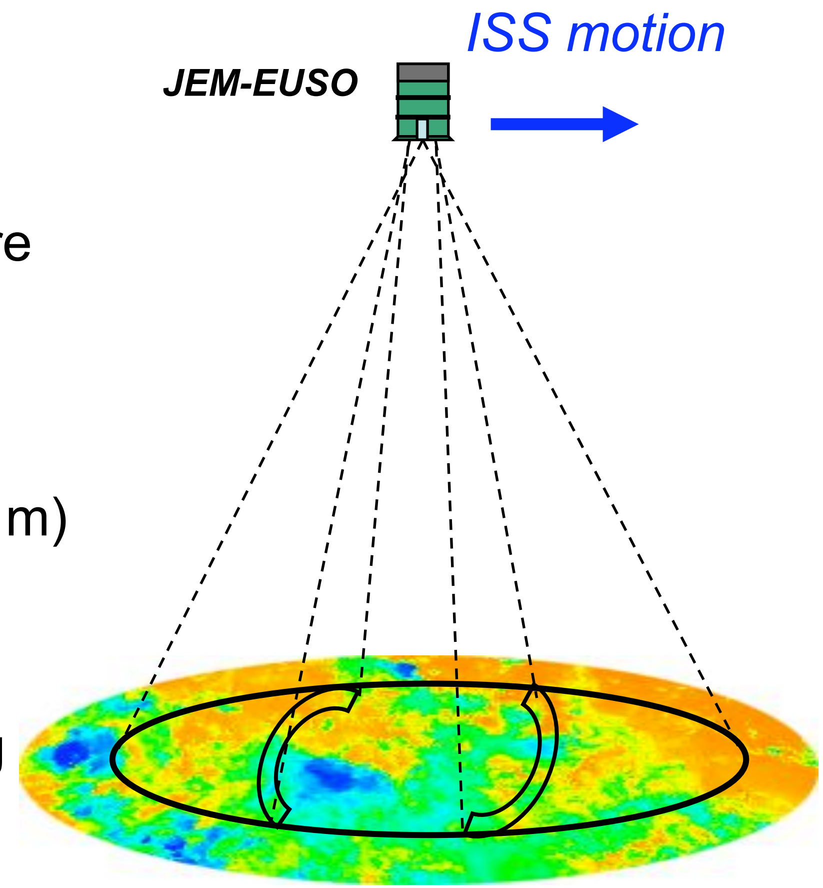
  Imaging observation of cloud temperature inside FOV of JEM-EUSO (200 m)

- **Lidar: just a 355 nm laser**

  Ranging observation using UV laser (10 m)

- **JEM-EUSO "slow-data"**

  Continuous background photon counting with some selected PMTs (stereo)



- *Cloud amount, cloud top altitude*: (IR cam., Lidar, slow-data)
- *Airglow*: (slow-data)
- *Calibration of telescope*: (Lidar)

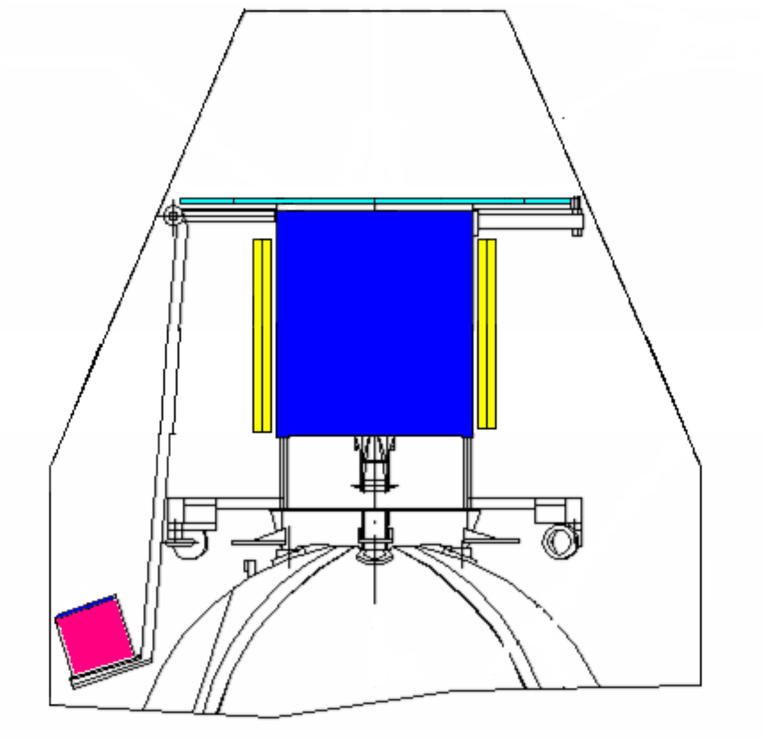
TUS : Path finder mission

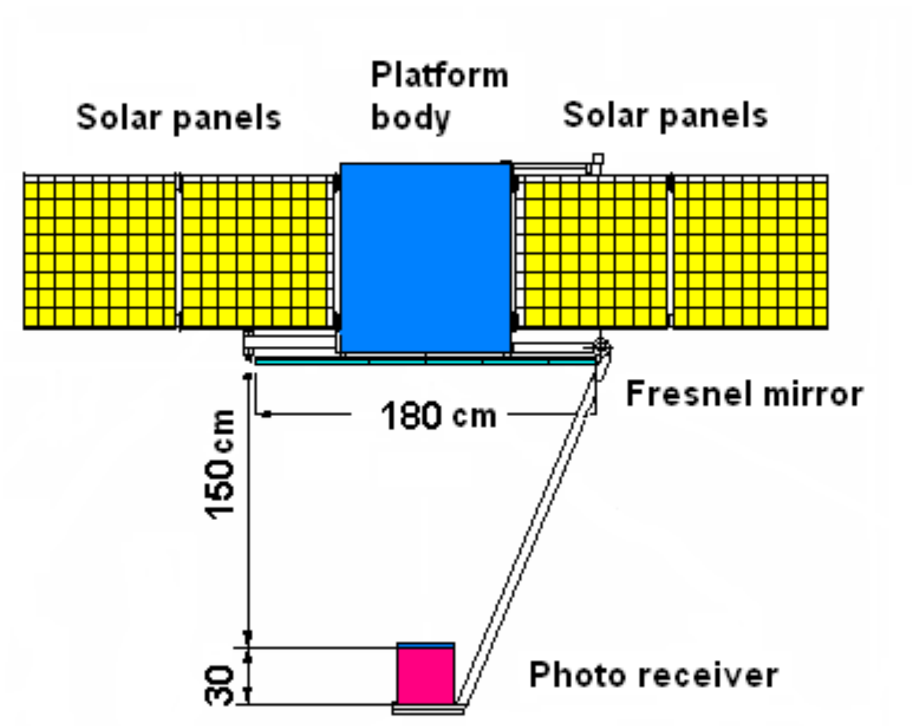
After Tatiana which measured the background from the stars reflected on earth, the TUS detector will be launched on a new platform separated from the main body of the “Foton” satellite (RosCosmos project, Samara enterprise, launching in 20010-2011).

Satellite limits for the scientific instrument are:

mass 60 kg, electric power 60 W, orientation to nadir ±3^o .

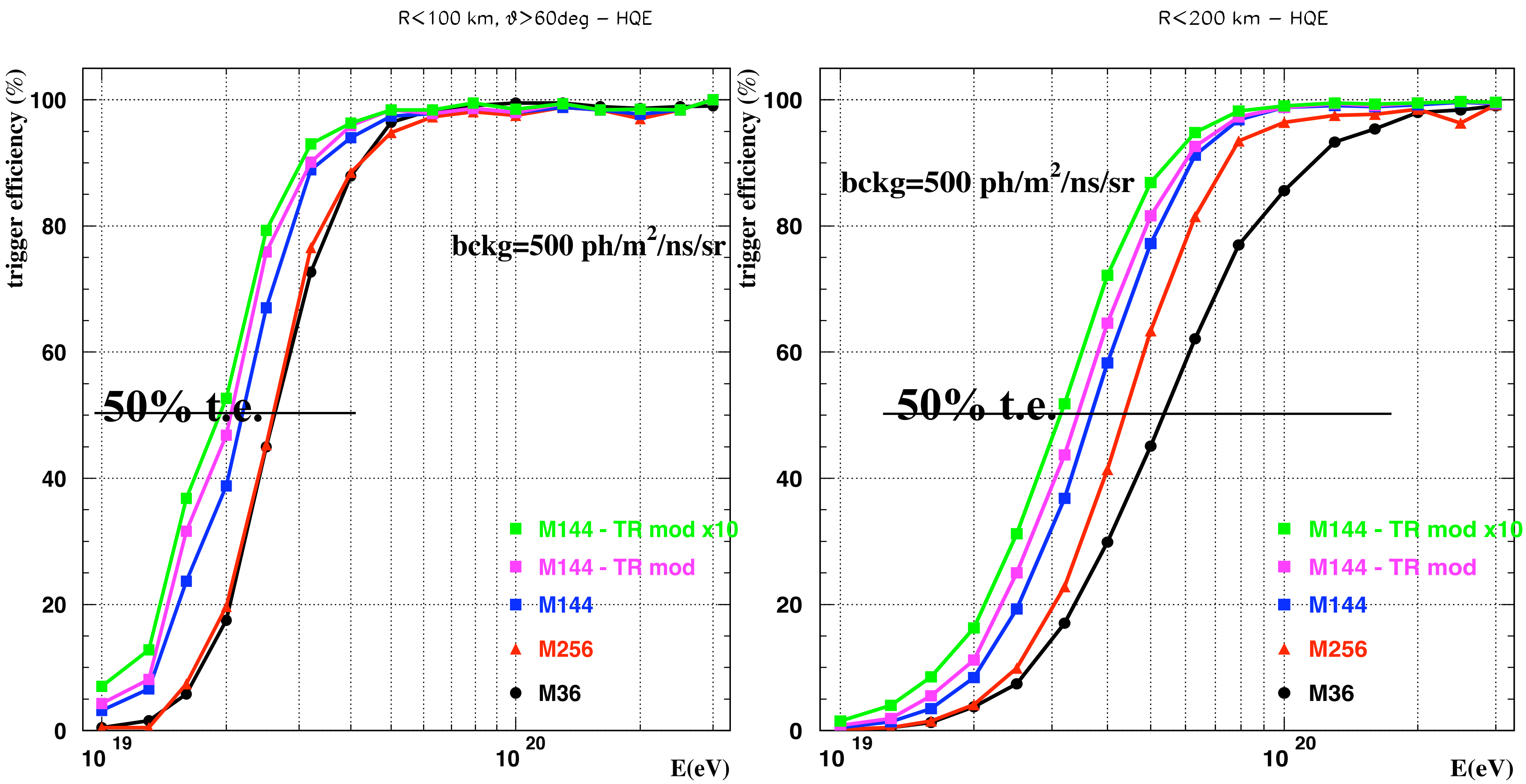
Preliminary TUS design: 1- in the transportation mode, 2 – in operation.



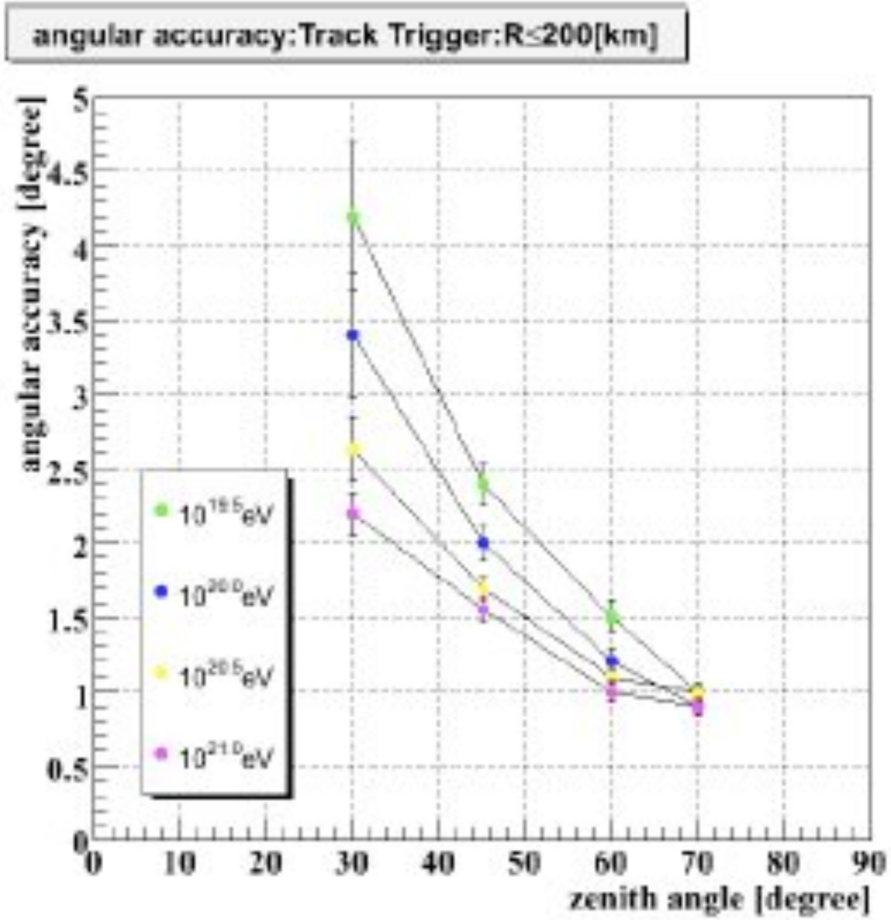


Mirror area 1.5 m^2 , pixels cover 4000 km^2 of the atmosphere (orbit height 400 km).

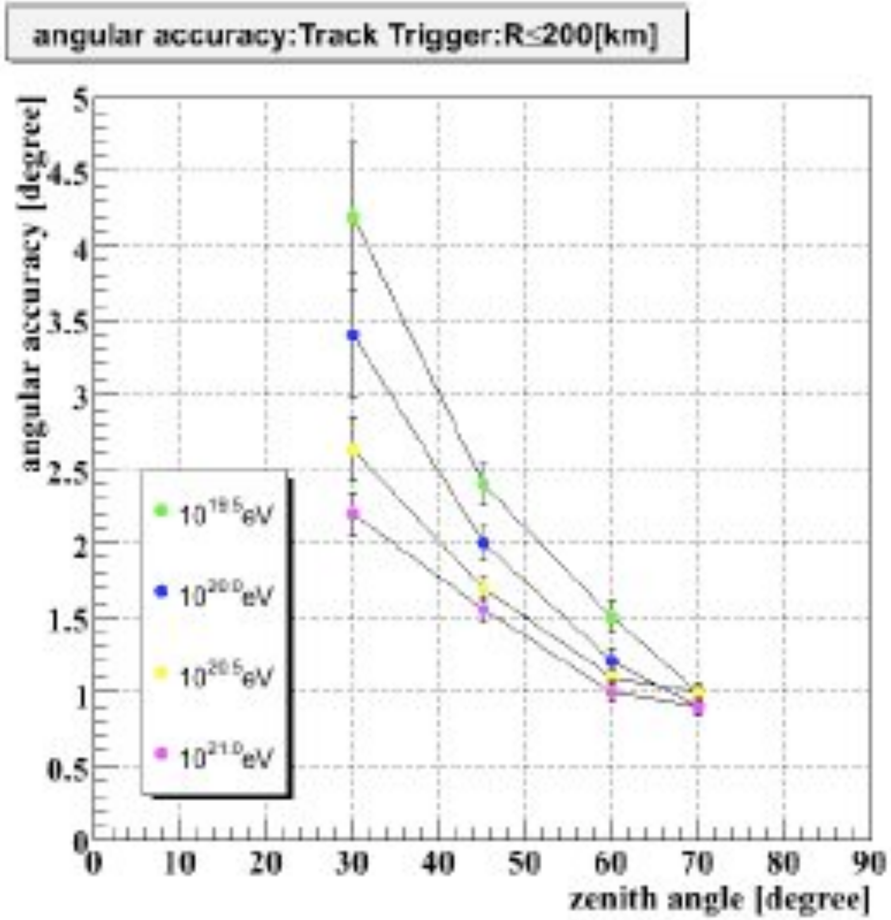
Trigger efficiency by simulation



θ

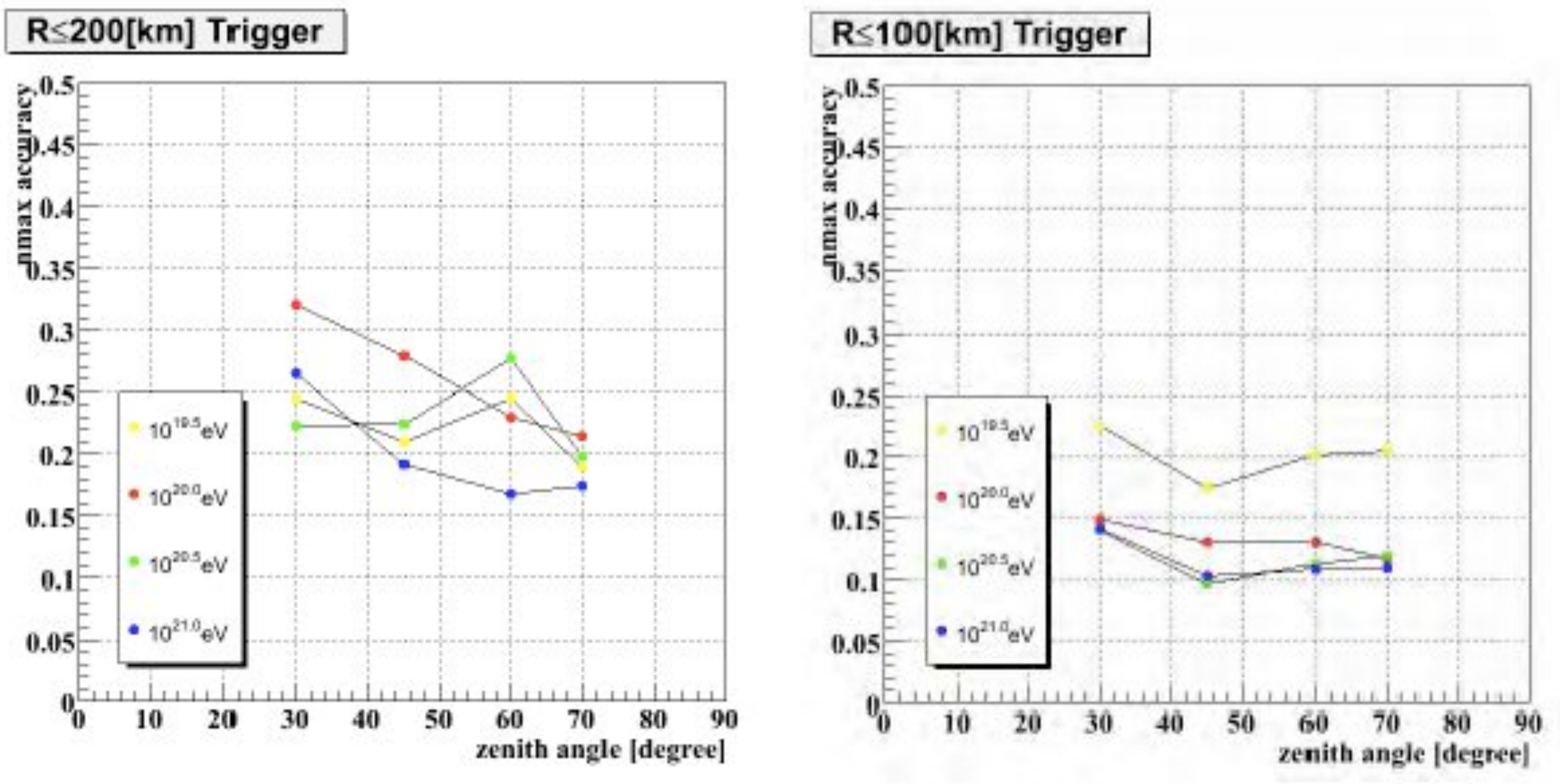


angular accuracy:Track Trigger:R≤200[km]
angular accuracy [degree]
zenith angle [degree]
10^19.5eV
10^20.0eV
10^20.5eV
10^21.0eV

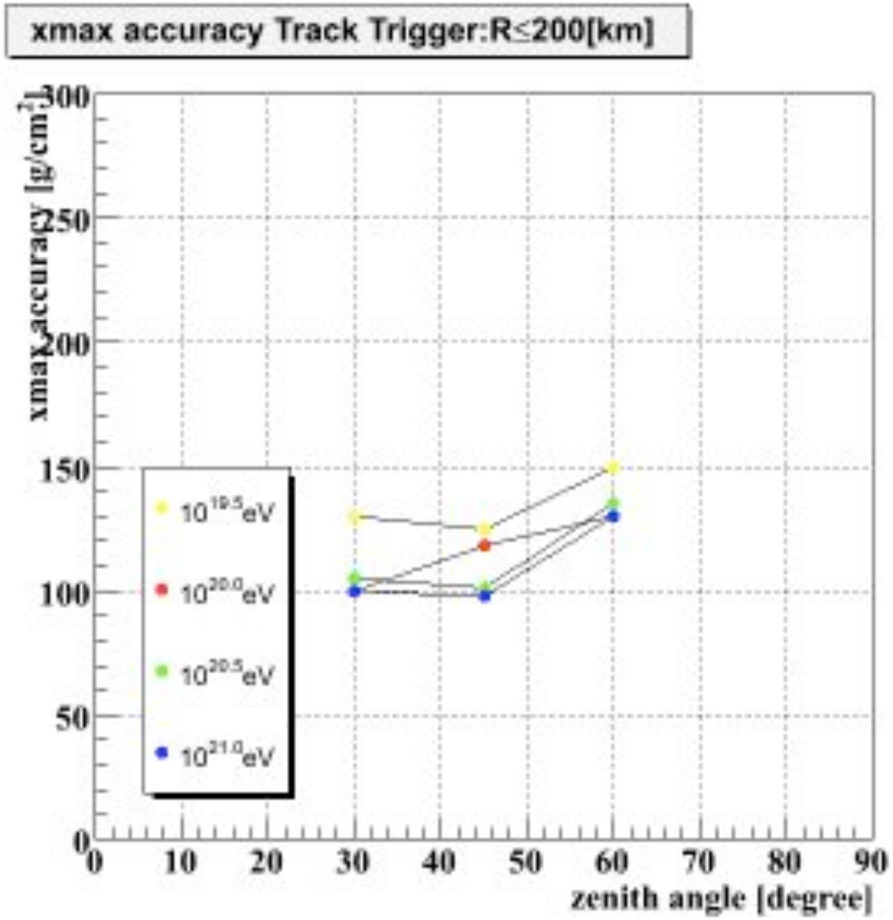


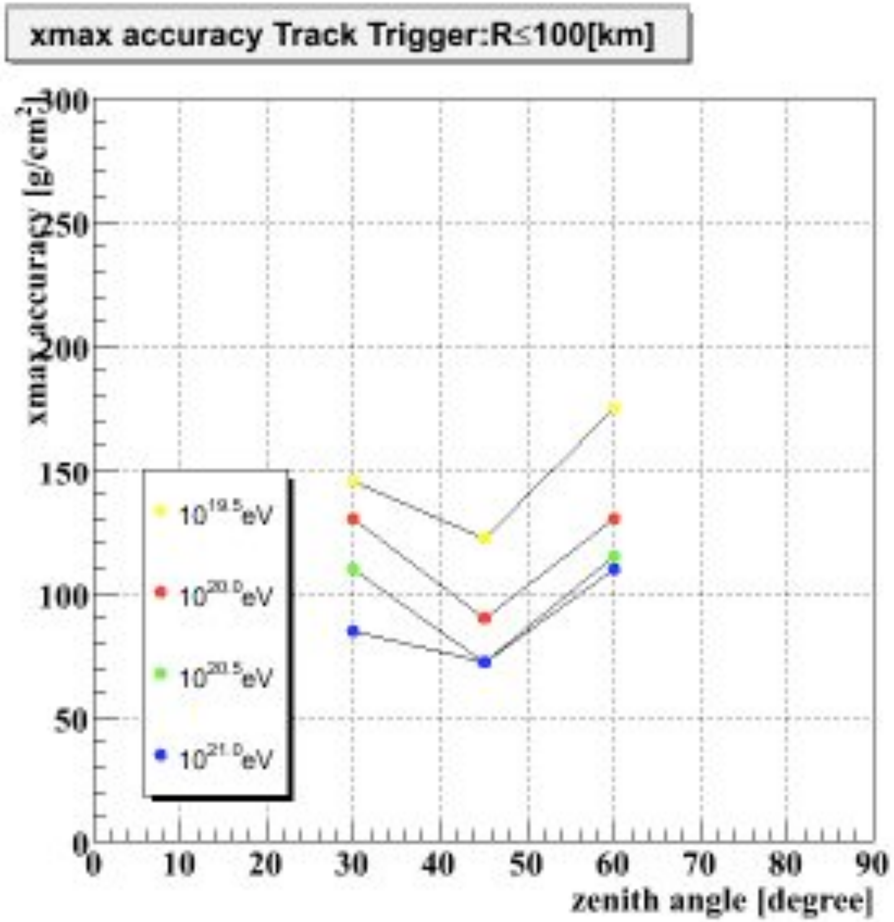
angular accuracy:Track Trigger:R≤200[km]
angular accuracy [degree]
zenith angle [degree]
10^19.5eV
10^20.0eV
10^20.5eV
10^21.0eV

E


R≤200[km] Trigger
Xmax accuracy
zenith angle [degree]
10^19.5eV
10^20.0eV
10^20.5eV
10^21.0eV
R≤100[km] Trigger
Xmax accuracy
zenith angle [degree]
10^19.5eV
10^20.0eV
10^20.5eV
10^21.0eV

X_{max}


xmax accuracy Track Trigger:R≤200[km]
xmax accuracy [g/cm²]
zenith angle [degree]
10^19.5 eV
10^20.0 eV
10^20.5 eV
10^21.0 eV

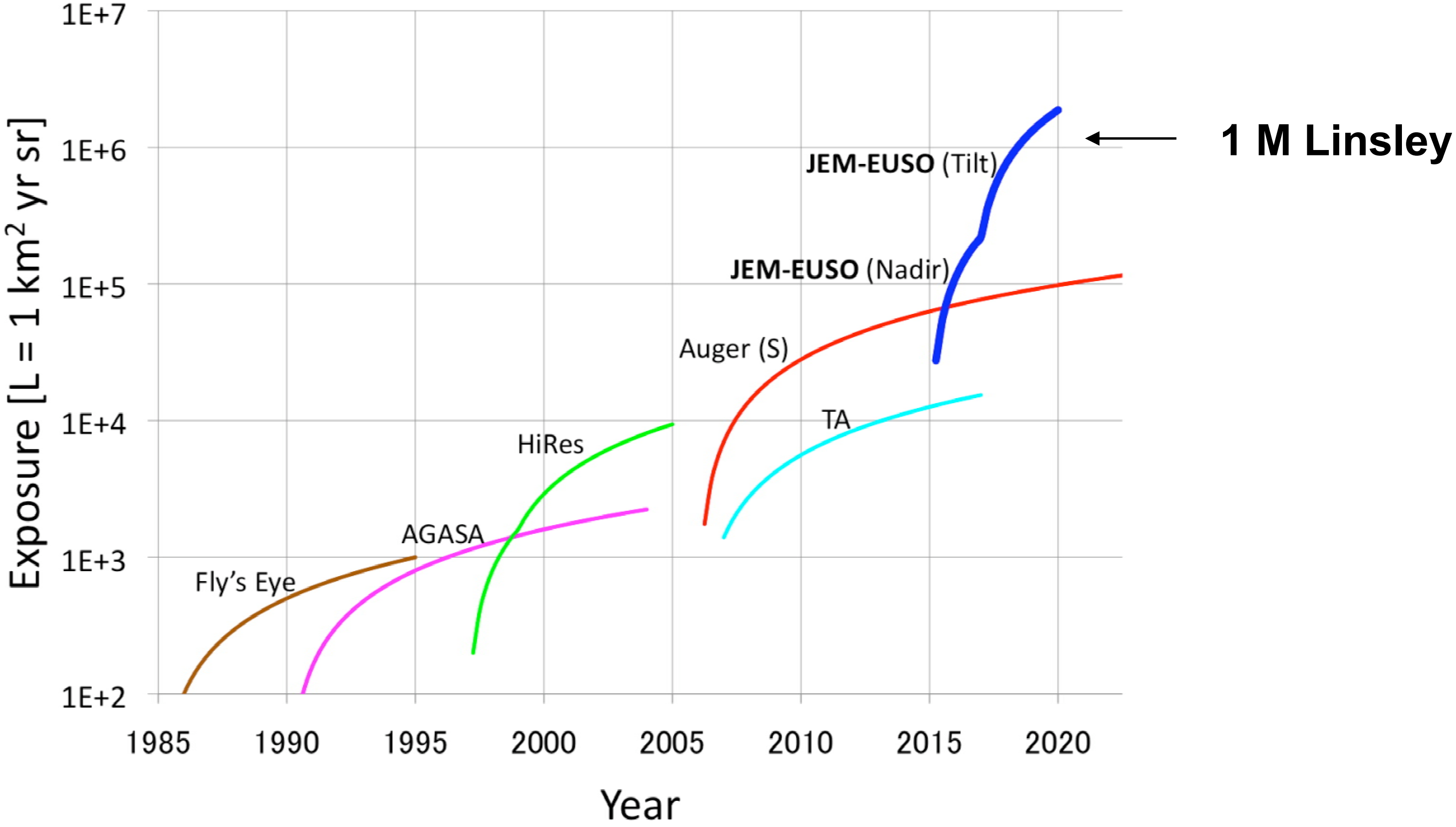

xmax accuracy Track Trigger:R≤100[km]
xmax accuracy [g/cm²]
zenith angle [degree]
10^19.5 eV
10^20.0 eV
10^20.5 eV
10^21.0 eV

Success Criteria

- **Full Success：**
  Number of Events >1000
  （above 7×10^{19} eV）
- **Minimum Success：**
  Number of Events > 500 ← Critical number to clarify the origin of EECRS
- **Extra Success**
  Achieve one or all of three exploratory objectives

- Arrival direction
  - < 2 degrees
- Energy resolution
  - < 30%
- Hadron/Photon/neutrino：
  - $\Delta X_{max} < 120$ g / cm^2

Exposure



1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
Exposure [L = 1 km² yr sr]
1985
1990
1995
2000
2005
2010
2015
2020
Year
Fly's Eye
AGASA
HiRes
Auger (S)
TA
JEM-EUSO (Nadir)
JEM-EUSO (Tilt)
1 M Linsley

FRANCE

1) Calibration (APC)
   A. *Before flight*
      - PMTs (10000)
      - PDMs (we make the apparatus and ship it to the assembly line)

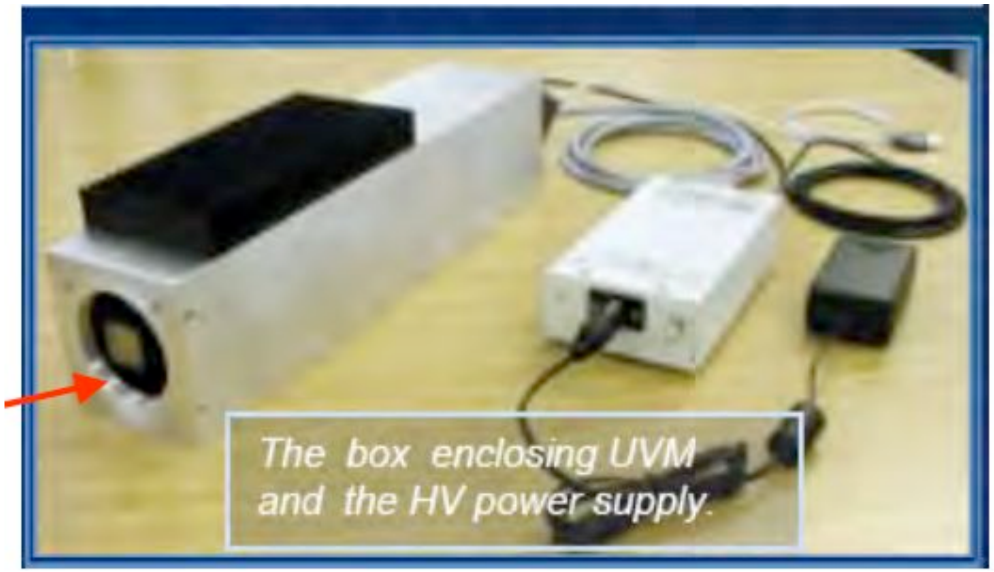
   B. *In flight*
      - Focal Surface
      - Lenses

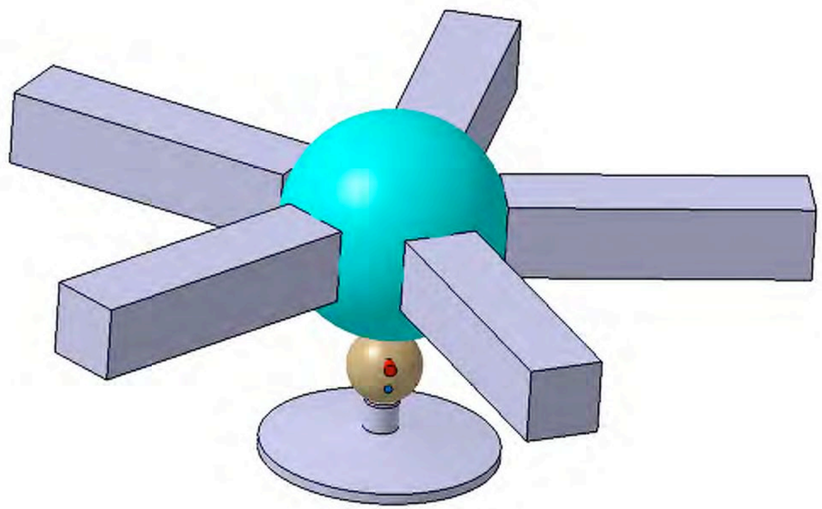
2) Fluorescence yield of individual lines (APC + LAL)

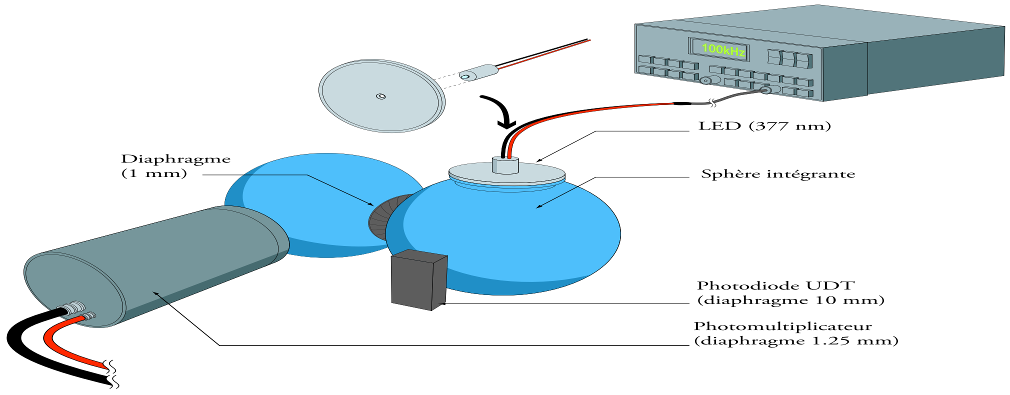
3) Front End Electronics: Maroc (pe counting) + KI (integrating) (LAL)

4) High Voltage for PMTs (APC - Lodz)

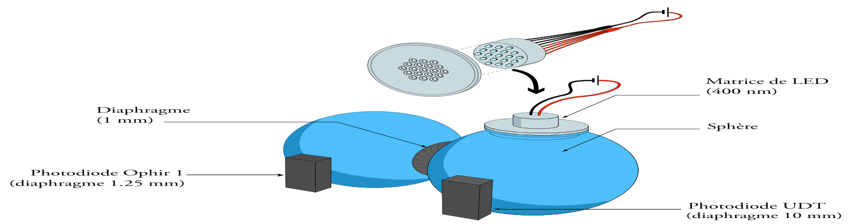
Calibration of 10000 PMTs (Paris)





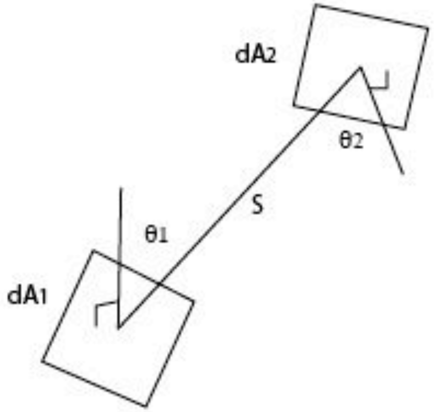


Brevet France N° 06/09088 :
« Méthode pour déterminer l'efficacité d'un appareil optique et dispositif pour réaliser une telle méthode »



Pour Ioannis: le miracle de la sphère intégrante

Considérons l'échange de radiation entre deux élements différentiels de surfaces diffuisantes (lambertiennes):

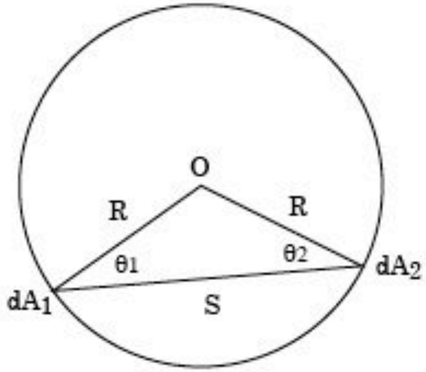


La fraction d'énergie quittant dA_1 et arrivant en dA_2 est le "facteur d'échange" $dF_{d_1 d_2}$

$$dF_{d1-d2} = \frac{\cos\theta_1 \cos\theta_2}{\pi S^2} dA_1$$

où θ_1 et θ_2 sont les angles de S par rapport aux normales.

Prenons maintenant 2 éléments différentiels dA_1 et dA_2 sur la surface interne diffusante d'une sphèreintégrante:



Comme $S = 2R\cos\theta_1 = 2R\cos\theta_2$

$$dF_{d1-d2} = \frac{dA_1}{4\pi R^2}$$

Ce résultat est important car il est indépendant de l'angle de vue et de la distance entre les deux aires élémentaires. La fraction de flux recue par dA_2 est la même pour n'importe quel point rayonnant à la surface de la sphère.

Si nous intégrons:

$$dF_{d1-d2} = \frac{1}{4\pi R^2} \int dA_2 = \frac{A_2}{4\pi R^2}$$

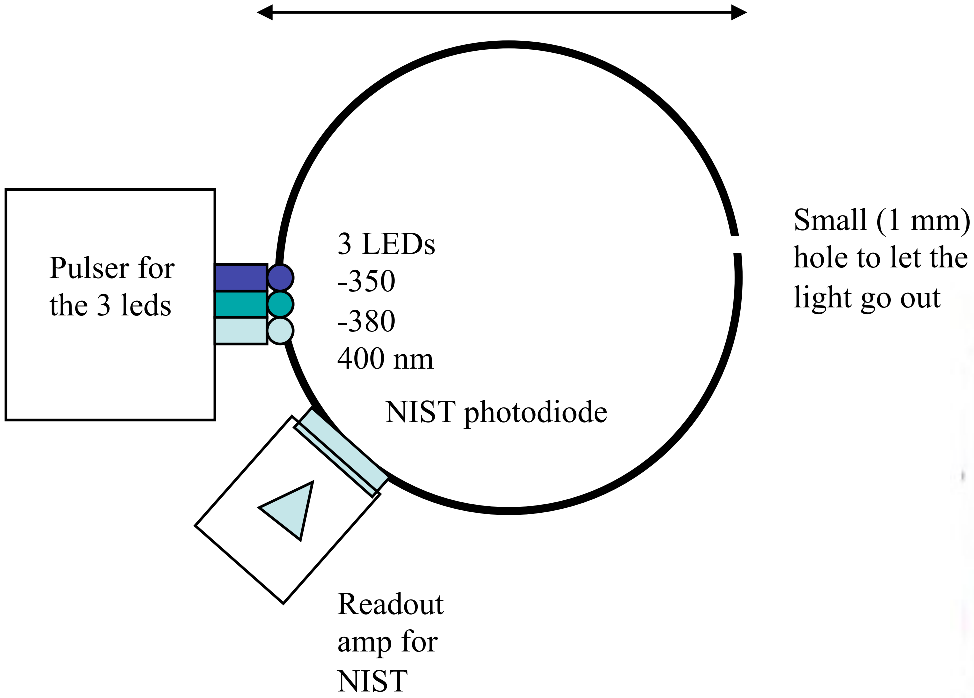
Comme ce résultat est aussi indépendant de dA_1:

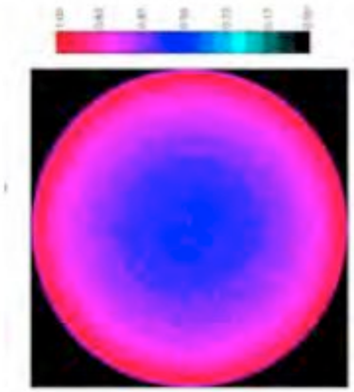
$$F_{1-2} = \frac{A_2}{4\pi R^2} = \frac{A_2}{A_1}$$

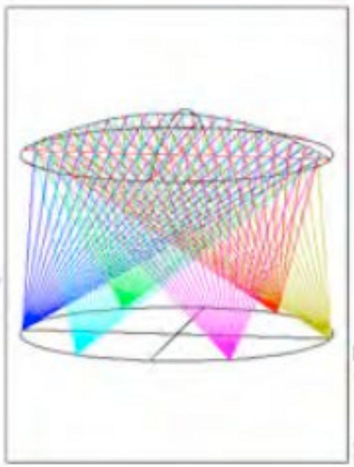
où A_2 est la surface de toute la sphère. La fraction du flux radiant reçu par A_2 est la fraction de la surface qu'elle représente sur la sphère.

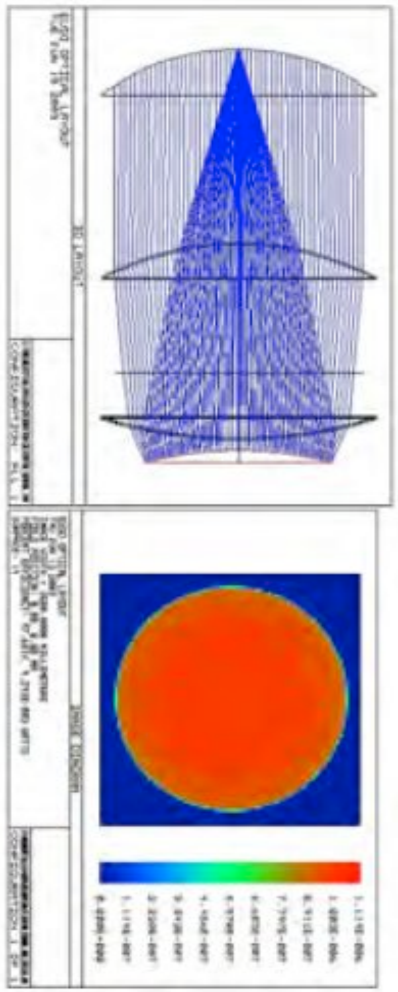
http://www.labsphere.com/data/userFiles/A%20Guide%20to%20Integrating%20Sphere%20Theory&Apps.pdf

On board calibration (APC)





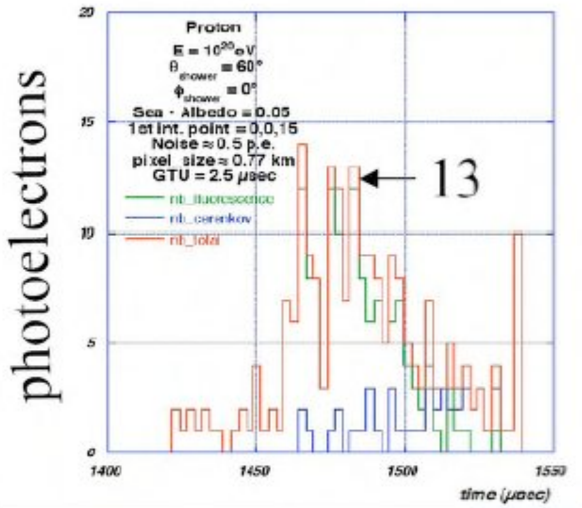




Space qualification!

Front-end ASIC (LAL)

- Shower measurement: single electron mode. Best results: photon counting (existed in "old" MAROC chip at LAL)



- Most other measurements involve more light: counting saturates. Pulse charge integration (existed in "old" japanese chip)

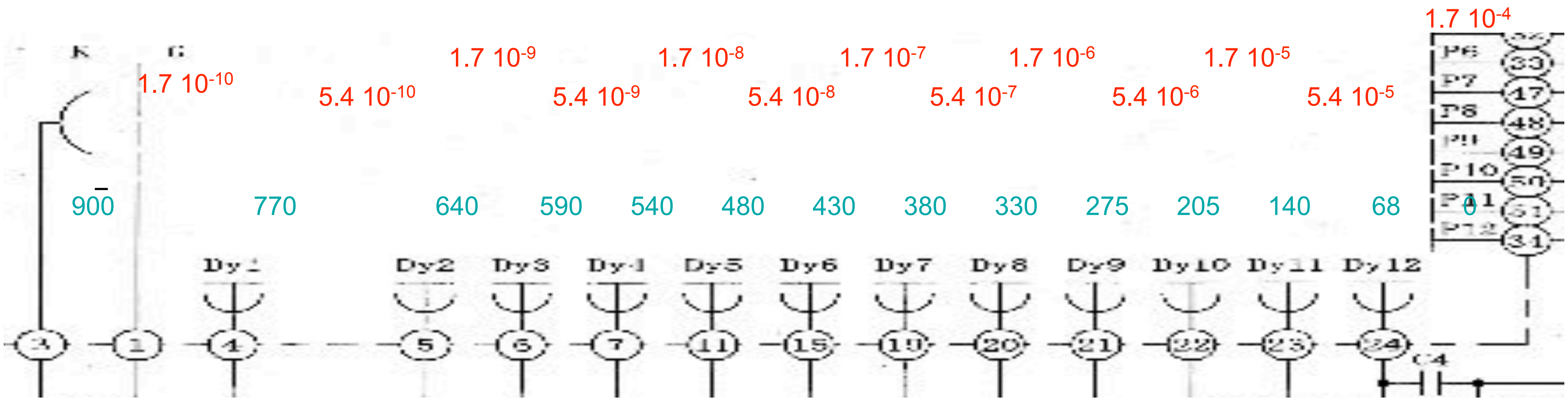
- Best of both worlds: the two circuits on the same ASIC at LAL

- Power reduced to 0.5 mW / pixel (175 W total)

- Proto vient de partir en fonderie

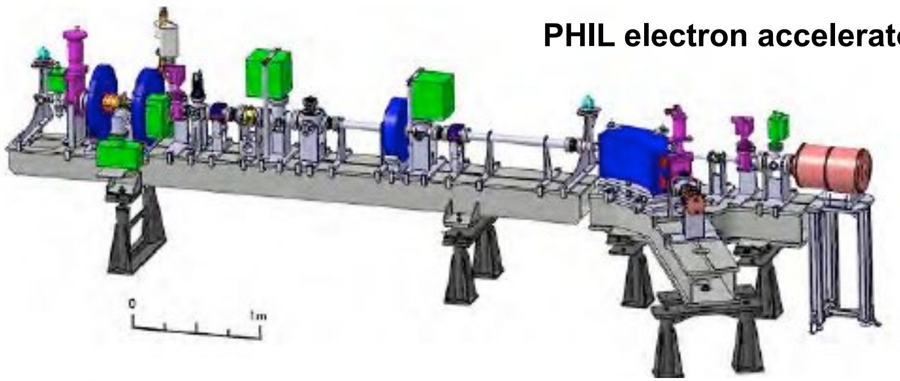
High Voltage Power Supplies

Possible solution : For a PDM (36 PMT) dynodes currents in A and voltages in V. Bkg here is per GTU (2.5 μs) = 0.75 10^6 / (pixel • sec.) **There are 137 PDM, so if one fails we lose less than 1% of the focal surfac**



Lodz + Warsaw

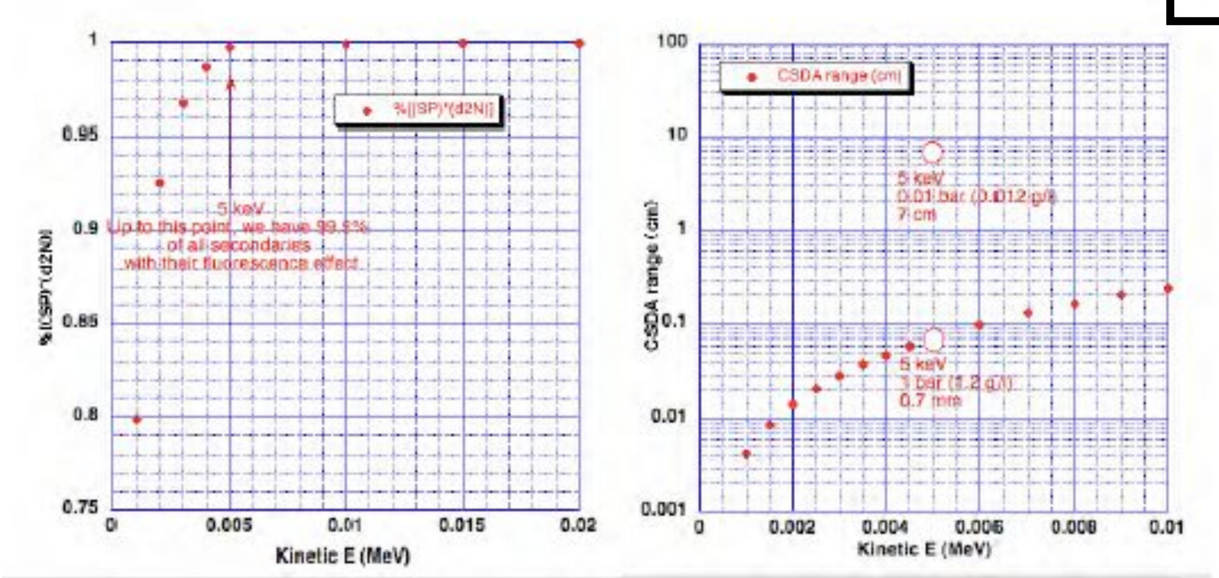
PHIL electron accelerator



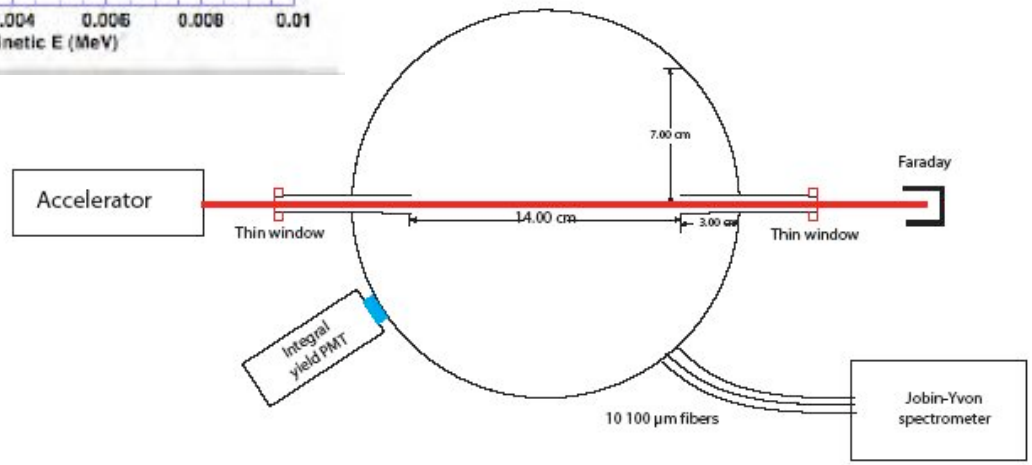
Fluorescence yield measurement

(APC & LAL & Madrid)

Goal: 5% precision



Measurement at atmospheric pressure only with a 5% precision: *"Absolute measurement of the nitrogen fluorescence yield in air between 300 and 430 nm"*
G. Lefeuvre et al. NIM A 578 (2007)78



Simulateur optique de gerbes

Un PDM (36 PMT de 64 pix) = 2304 pixels au pas de 2.88 mm est illuminé par 2304 fibres. A l’autre extrémité, 2304 LEDs (378 nm) sont commandées par 2304 LED drivers, au rythme de EUSO: 1 GTU = 2.5 µs.

Permet de simuler des gerbes, du bruit de fond, des évènements très lumineux, etc.

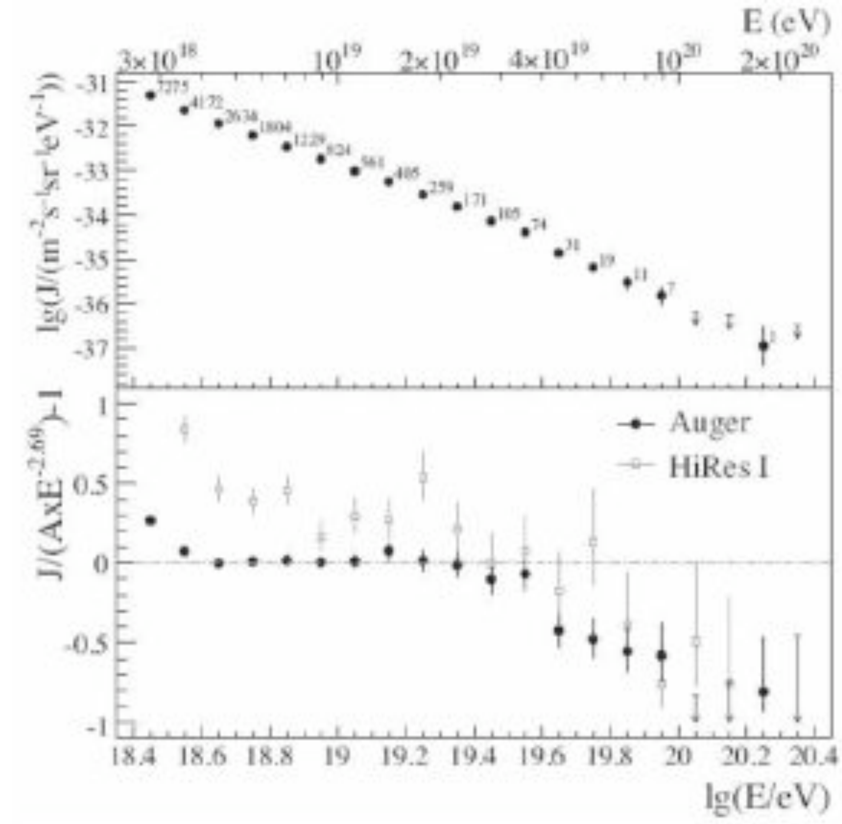
Test en vraie grandeur des performances du télescope.

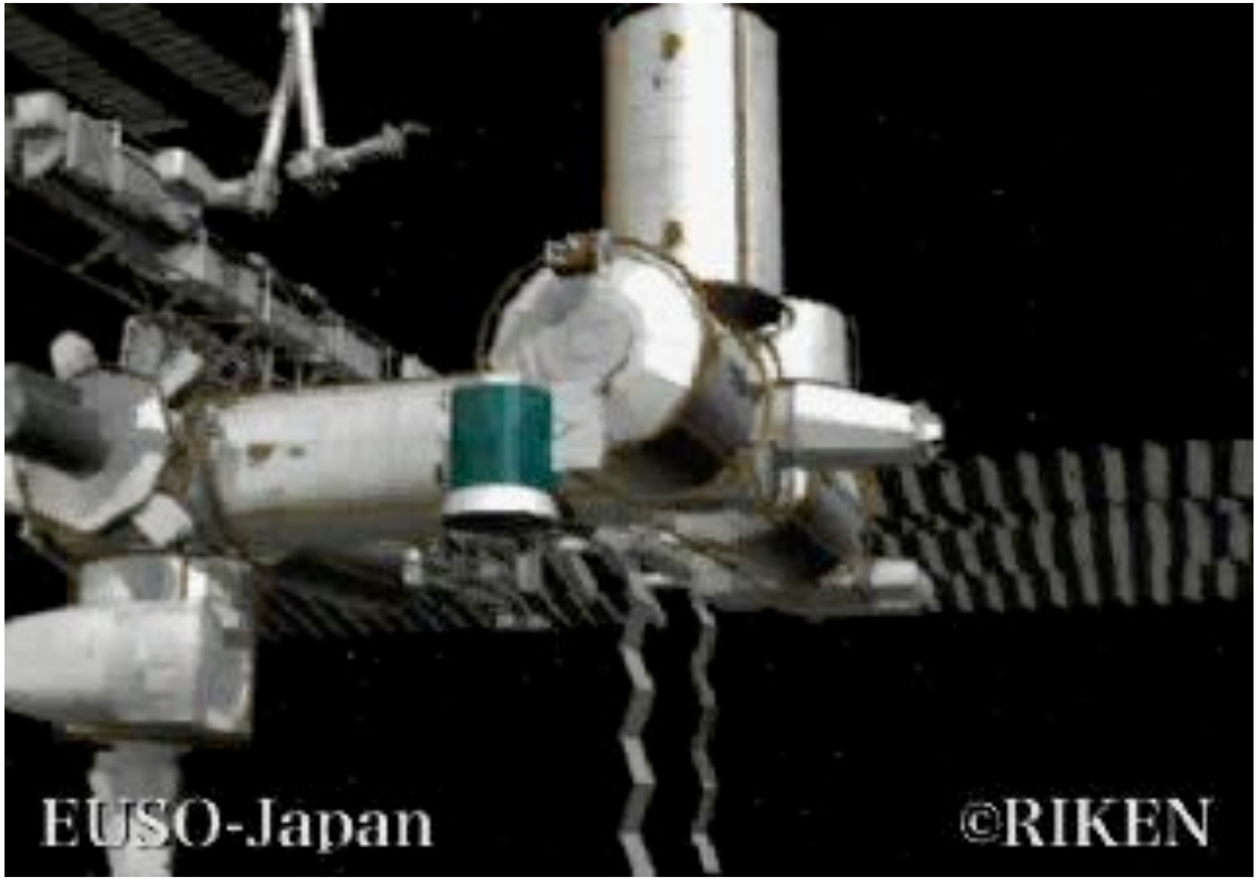
Summary

- EUSO completed Phase-A from 2000 to 2004 in the ESA program and NASA MIDEX program
- JEM-EUSO has been selected by JAXA as a mission candidate for the second-phase utilization of JEM/EF on ISS for launch in 2015 for 5-yrs (or longer) exposure.
- Phase-A Study under JAXA finished April 2010
- JEM-EUSO has exposure (with tilt) > 10^6 km^2 sr yr
  - First Observatory of EECR from space

Expected Number of Events
5 years

	>7x10[19] eV	>1x10[20]eV
2.6 m dia. side cut Case-C	2170	530
Advanced Design (more smaller pixels) Case-D	3820	769

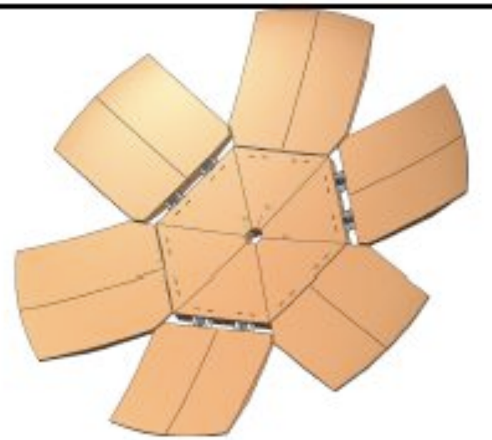



EUSO-Japan
©RIKEN

ESA-EUSO, the shuttle and Columbus

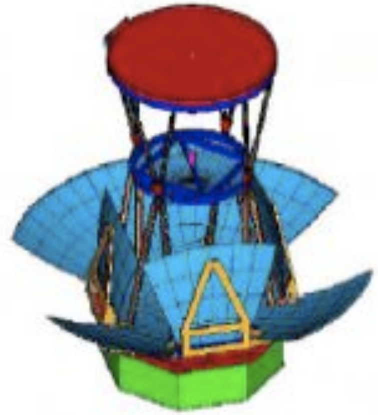
ESA's Cosmic Vision: S-EUSO

2020 - 2025



• 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]).

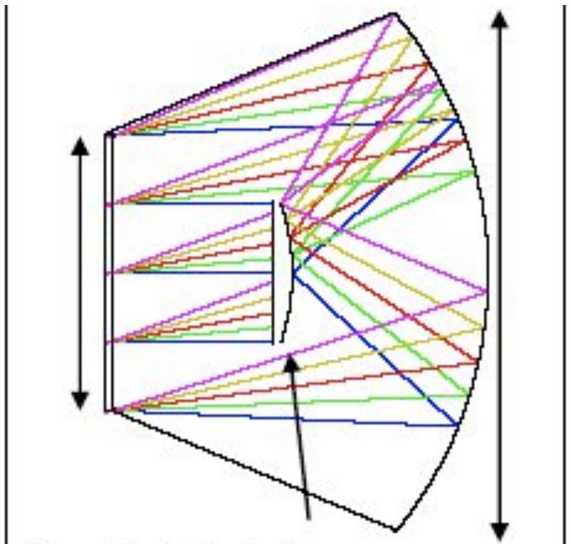
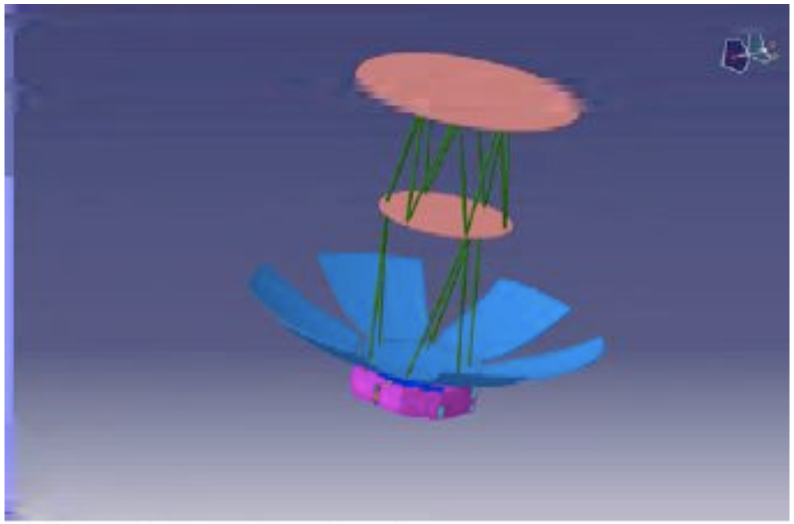
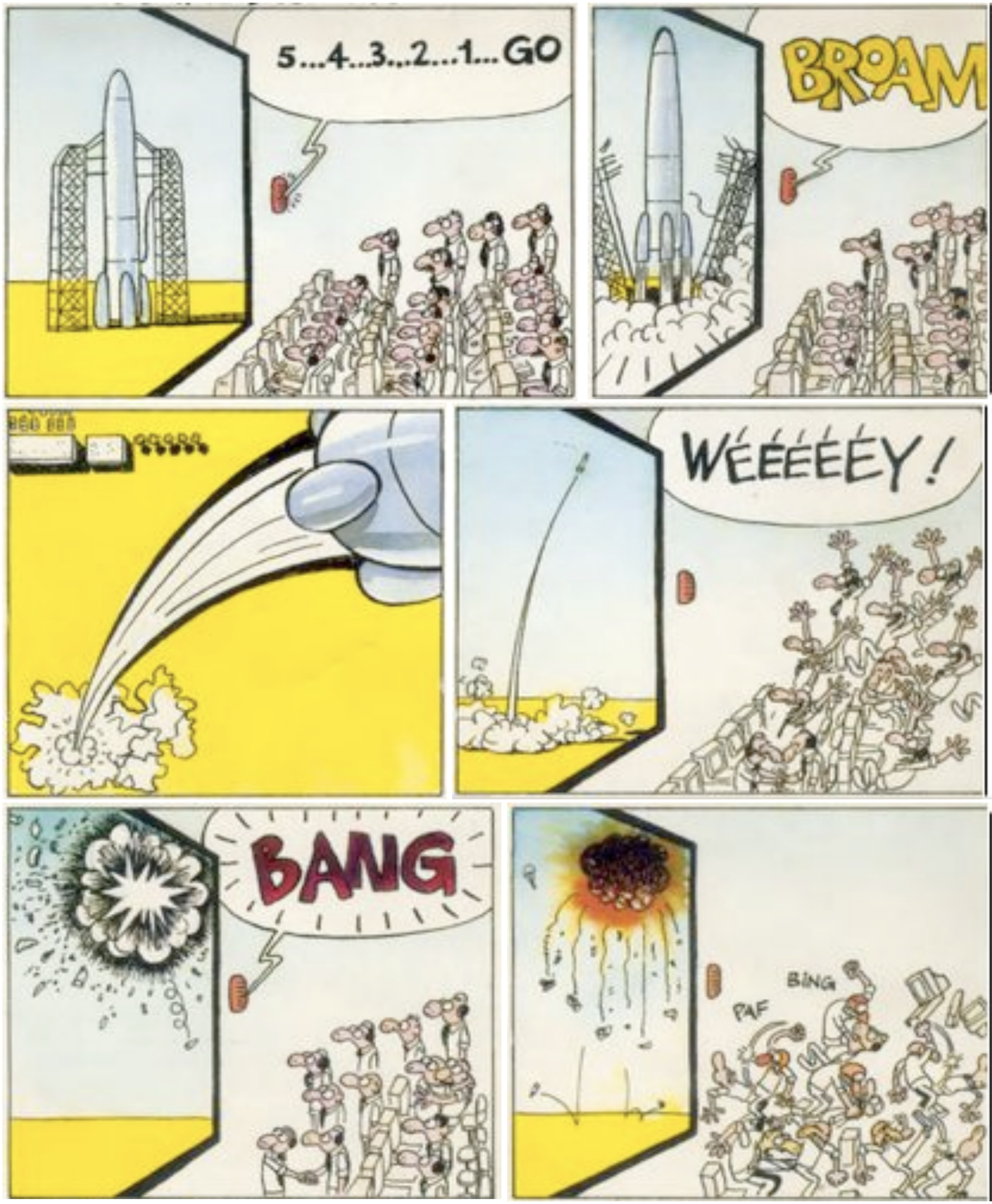


Figure 1 – Optical scheme.



• Figure 11 – In-flight configuration.


5...4...3...2...1...GO
BROAM
WÉÉÉÉÉY!
BANG
PAF
BING