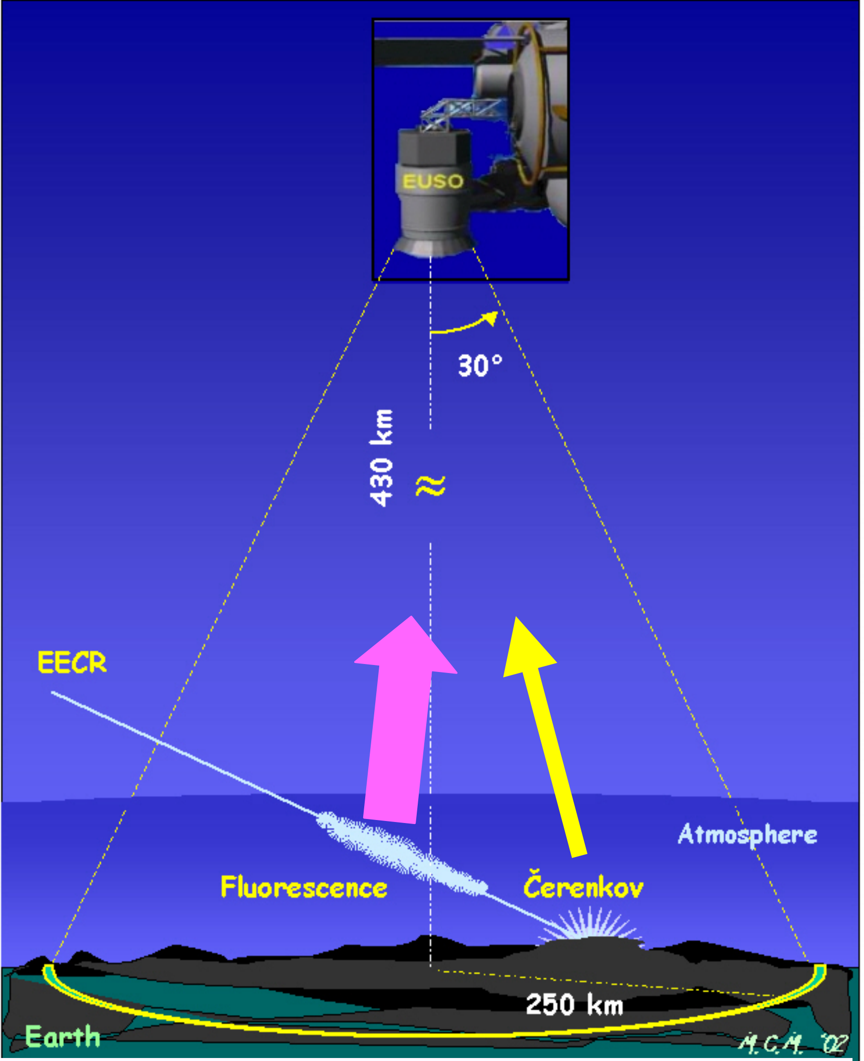
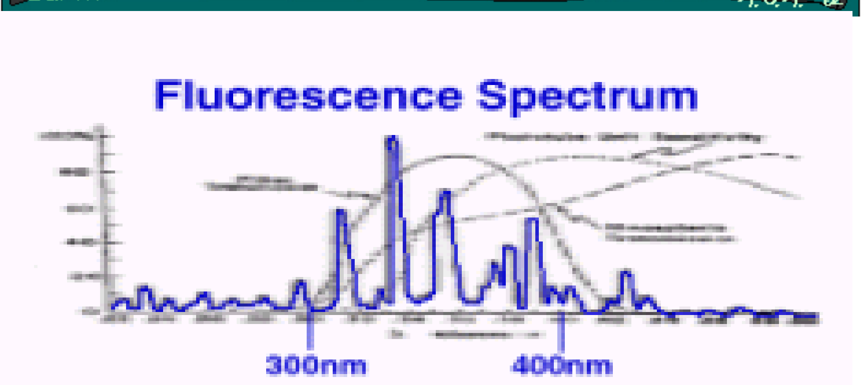
EUSO（Extreme Universe Space Observatory）

戎崎俊一
理化学研究所
EUSO-Japan

EUSOの観測方法

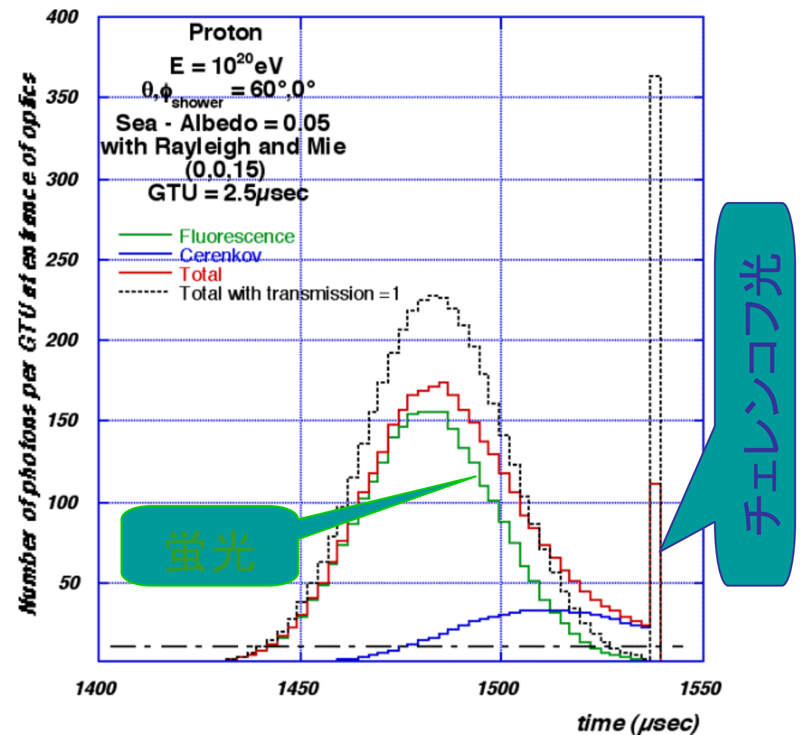




宇宙線が大気中に飛び込んで来て、空気シャワーをつくり、シャワー中の電子が窒素や窒素イオンを励起して蛍光を発する。

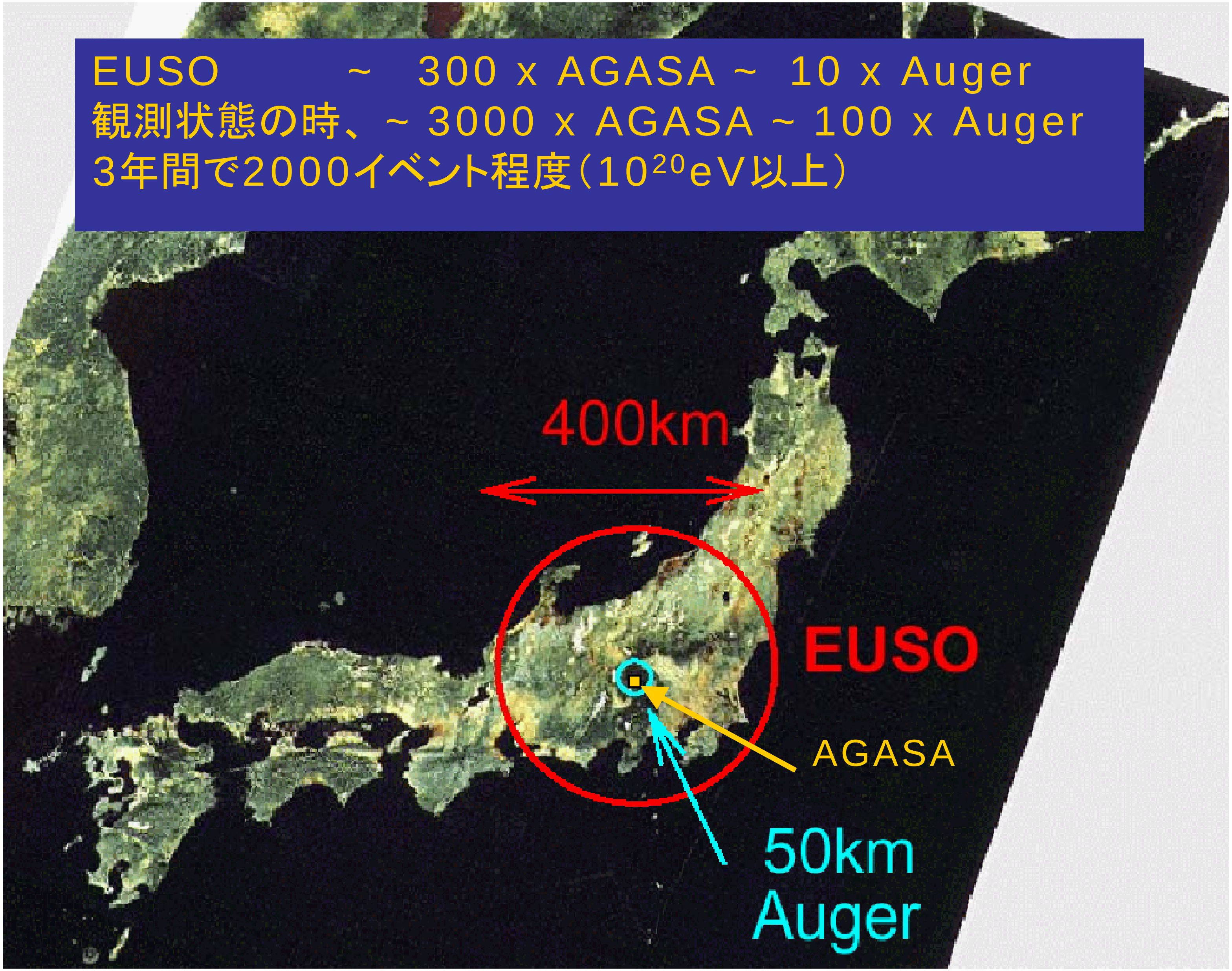
この蛍光を口径2.5mの望遠鏡で観測する。

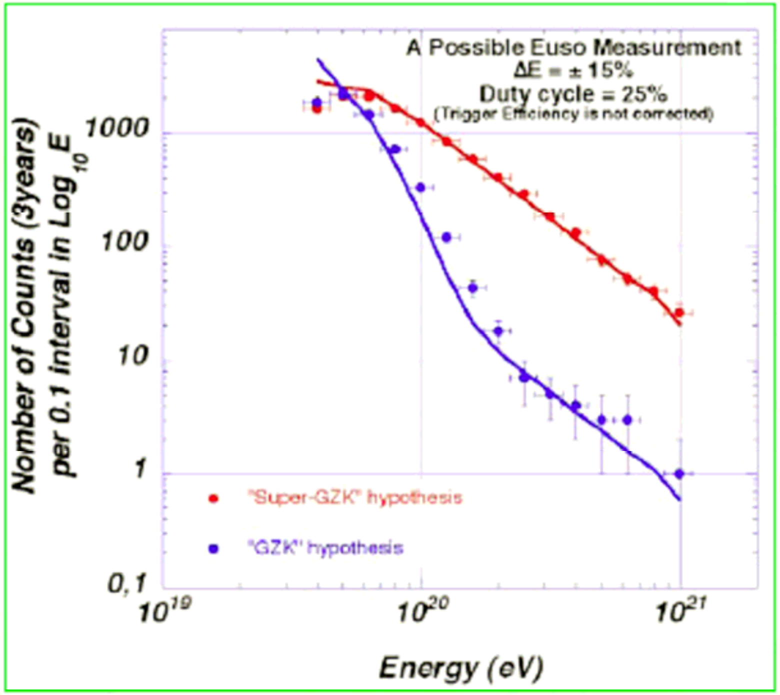
空気シャワーにそって発せられたチェレンコフ光の地上や海上での反射光を観測する。



EUSOの視野

EUSO ~ 300 x AGASA ~ 10 x Auger
観測状態の時、~ 3000 x AGASA ~ 100 x Auger
3年間で2000イベント程度（10^{20}eV以上）





Energy		SuperGZK	GZK	S.GZK	GZK
Log(E(eV))	eV×10^{19}	differential	differential	integral	integral
19.7	5.0	1900	1787,7	7832	3434,9
19.8	6.3	1763	1006,5	5932	1647,2
19.9	7.9	1293	414,0	4169	640,7
20.0	10	942	142,5	2876	226,7
20.1	12	640	42	1934	84,2
20.2	15	433	16,2	1294	42,2
20.3	20	293	9,0	861	26
20.4	25	200	6,0	568	17
20.5	31	135	4,0	368	11
20.6	39	87	2,7	233	7,0
20.7	50	60	1,8	155	4,3
20.8	63	40	1,2	85	2,5
20.9	79	29	0,8	45	1,3
21	100	16	0,5	16	0,5

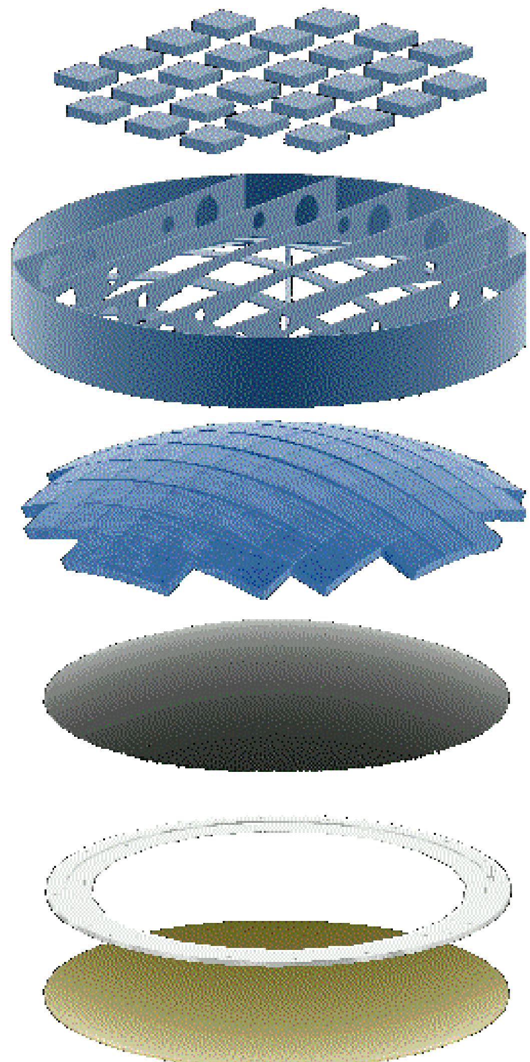
The EUSO scientific objective:

~1000 events/year in SuperGZK mode
>70 events/year in GZK-suppressed mode

EUSO expected statistics beyond GZK cut-off value will allow:

- GZK recovery and Compact source study – GZK-suppressed mode
- Detailed Spectrum study/Compact sources spectra – Super-GZK mode

EUSO望遠鏡の
構造と各国の責任分担



Electronics
single photon counting, fast
10 ns, track time sampling
(Gate time unit) 2.5 msec

Focal Surface Support Structure

→ **Europe**

Focal Surface
Focal surface, single photon counting, high pixelization,
$2*10^5$ pixels

→ **Japan**

Fresnel Lens 2

Entrance pupil

Fresnel Lens 1
Double sided,
2.5 m diameter

→ **USA**

宇宙ステーションに取り付けられる予定のEUSO望遠鏡

直径2.5mのEUSO望遠鏡は2010頃に欧州宇宙機構（ESA）の責任で国際宇宙ステーション欧州所有のコロンバスの外部観測パレットに装着される予定である

Phase-A Ext. 最終報告（2004．7）

- **EUSOのPhase-B進行が内定**
- Phase-B（当面の間）はESA－MSM（宇宙ステーション担当部署）が責任を持つ
  - もともとD-MSM部とD-SCI部の共同ベンチャー
- Augerの結果がどうあろうと、EUSOの価値は変わらない
  - 設計変更は基本的にはない
- 打ち上げ機会として日本のHTVの可能性を提案
- イタリア宇宙機関は約40Meuroの支払いの約束を行う

Nation	Direct Costs (M€)	Indirect Costs (M€)	Funding Agencies	Status
Italy	40	16	ASI, INFN, University	Submitted to ASI
France	10	8	CNES, IN2P3, University	Submitted to CNES (negotiable -8/10-M€ only technical staff
Germany	4.8	6	DLR, MPI, University	Letter of intent by Director of MPI
Portugal	4	2.6	GRICES, LIP	Mission approved end-to-end, with allocation to be reconfirmed on yearly basis.
Switzerland	5	2.4	Prodex Observatoire de Neuchatel	Negotiation with PRODEX under way ; Funding could increase to (15 – 17) M€
Japan	16	12	JAXA, RIKEN, Ministry of Education and Science	Phase A/B financed by RIKEN. Proposal being prepared for Phase C/D
USA	36M$ - 30M€	-	NASA	Mission approved end-to-end
Spain	3.8	TBD	Ministry of Science & Technology Programa Nacional de Investigation Espacial	Letter of Intent from Manager of Spanish National Space Programme.
Brazil	3	TBD	AEB	Letter of Intent from President of AEB

The additional 16.00 M€ required to cover the estimated deficit will be recovered by possible savings or by transferring to the available indirect costs.

ReFoundation会議

- イタリア宇宙機関：ASI
  - 40MEの支出が不可能
- ヨーロッパグループの一部
  - ESA：Cosmic Visonで独立衛星として提案
  - 打ち上げは2015年以降（早くて）
- 日本・米国
  - JEM/EF設置で再検討
  - 米国はMIDEX提案へ出しなおし

JEM/EFへ装着可能か？

- EUSO現状
  - 全重量1826kg :2500kg(#2#9#10)
  - 消費電力: 3kW

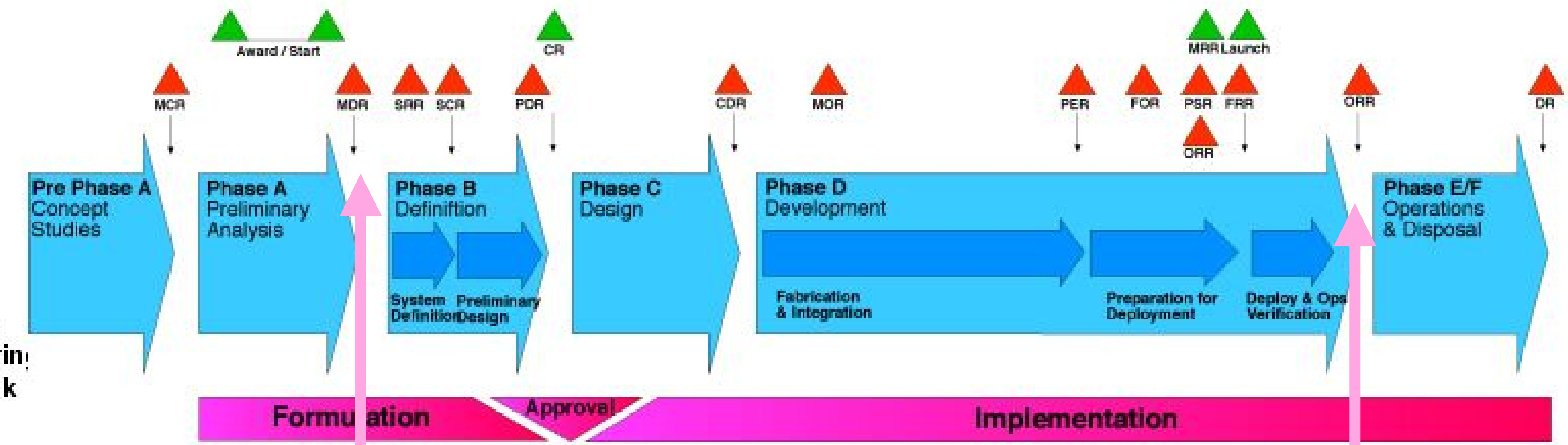
    1141W (稼動中) OK

    517W(非稼動中) OK

    263W(サバイバル) 0.1kW
  - 熱制御: 1141W: 3kW

Traditional Project Lifecycle

Systems Engineering Handbook SP-6105



NASA Project Lifecycle NPG-7120

Here we are Nov 2005

Here we like to go 2012+

Pre Phase A
- Define the Mission
- Study Multiple Approaches

Phase A
.Define Top Level Requirements
- Choose a single Approach

Phase B
- Complete the Requirements
- Complete Block Diagrams
- Allocation of Functions & Resources
- Definition of Interfaces
- Preliminary design

Phase C
- Complete the detailed system design,
- Drawings complete
- PDL complete

Phase D
- Build, integrate, verify, launch the system, and prepare for operations

Phase E/F
- Operate the system and dispose of it properly

JEM/EUSOへの拡張

- 敷居エネルギーを下げる: $E_{th} \sim 10^{19}$ eV
  1. 口径(2.5m→3.5m) x2 reduction.
  2. 新レンズ材(CYTOP)と新設計 x1.5 reduction.
  3. 高感度検出器(SiPMT) x3 reduction.
  4. 高効率トリガ(LBL)x2 reduction.
  5. 斜め向きモード x5 exposure E $\geq 10^{20}$ eV
- JEM/EUSO (normal + tilt-stage1) :
  - 1800 AGASA/yr = 90 Auger/yr
- Super-EUSO II brings to 5000 AGASA = 214 Auger/yr

JEM/EUSO の特徴

宇宙線物理への最初のチャレンジ

- **瞬間的有効体積 : $6 \times 10^5 km^2 sr$**
- Duty cycle ~20%
- 大気モニタ= AS + EUSO
- 観測エネルギー範囲 : $E > 5 \times 10^{19}$eV. ($E_{th} \rightarrow 10^{19}$ eVの可能性)
- ~ 10^3 events/year expected according to AGASA ;
- ~ 10^2 events/year expected if GZK is present.
- 全天に対して一様な露出
- ニュートリノにたいして10^{13} トンのターゲット質量
  - ニュートリノ天文学の開始
  - 新物理
- 大気科学 :
  - 雷放電、上向きシャワー（Tauニュートリノか弱相互作用粒子）、流星

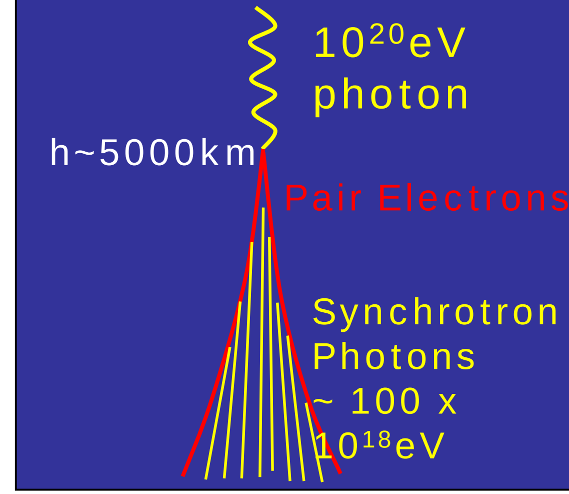
ROADMAP Comparison of expected Exposures for various Experiments.

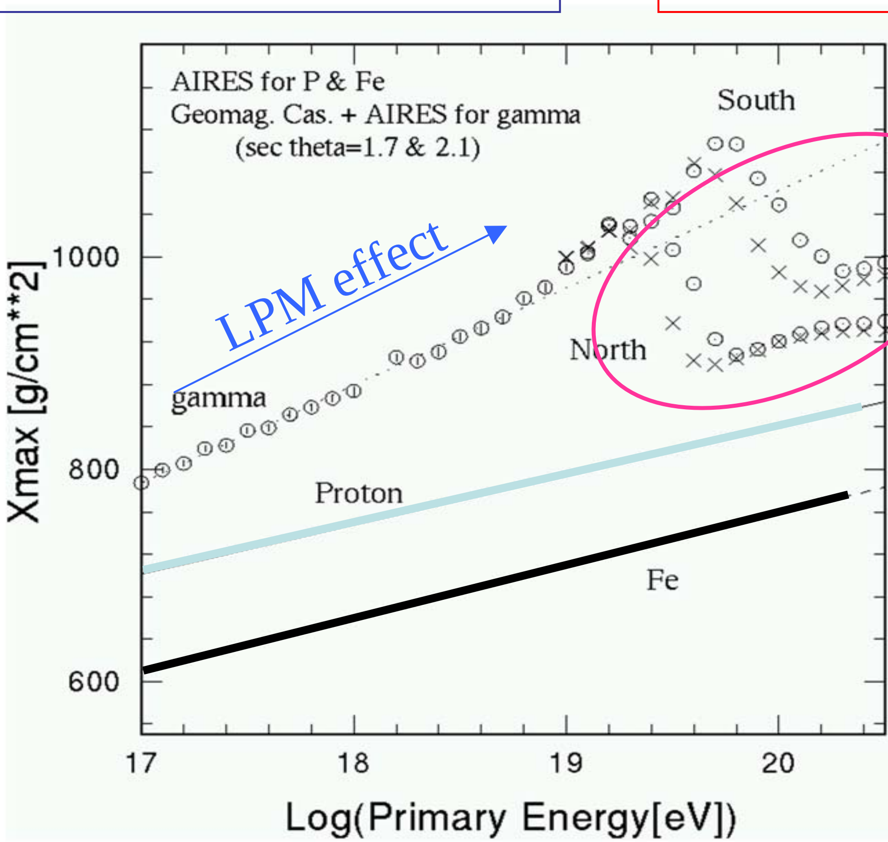
Experiment	Acceptance (Km^2 sr)	Assumed operational	Operation (N years)	Duty cycle(%)	Exposure (Km^2 sr year)	Units AGASA
AGASA	160	Completed	10.2	100	1.6×10^3	1
Auger South	7.000	2006-2015	10	100	7.0×10^4	45 (1ΣA)
Auger South + (Auger North) ---------------- Total Max	7.000 (7.000) ----------------	2006-2015 (2009-2015) ----------------	10 (7) --------------	100 (100) ----------	7.0×10^4 + (5.0×10^4) ---------------- (12.0×10^4)	44 + (31) ----------- (75)
EUSO EUSO tilt (Super-EUSO)	600.000 3,000,000 (3,750,000x2)	2012-2014 2014 - (2020s)	3 yrs 10 yrs (10 yrs)	20 20 (20)	3.6×10^5 6×10^6 (1.5×10^7)	234 [5.2ΣA] 3750 [85ΣA] (9400) [208ΣA]

粒子組成の識別による物理学

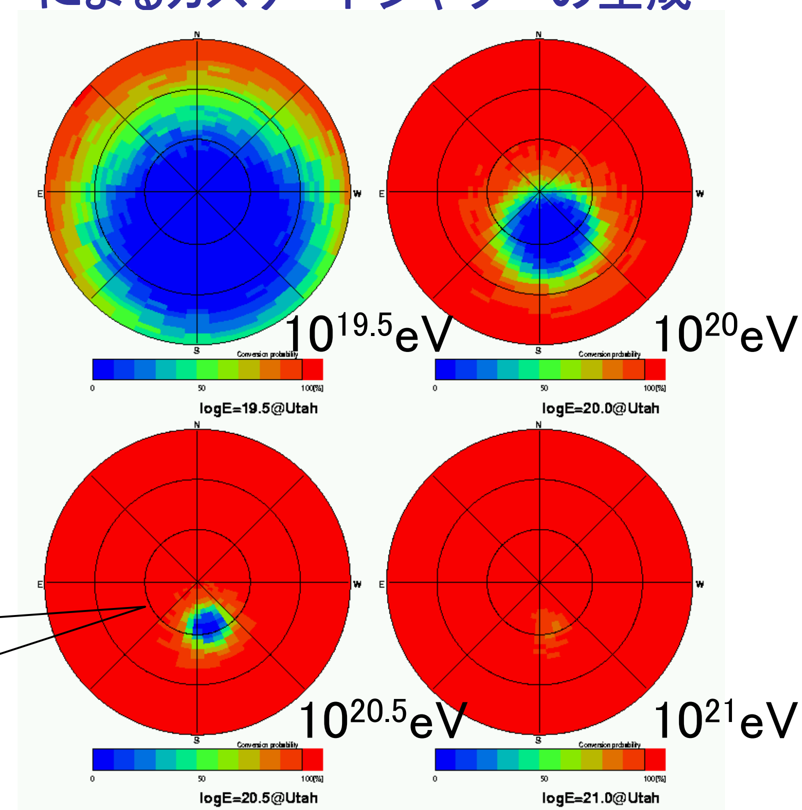
Xmax(シャワー発達の最大値の深さ)を利用すると粒子識別が可能

⇒ トップダウンシナリオ(宇宙創成初期にできた位相欠陥など)の検証が可能になる



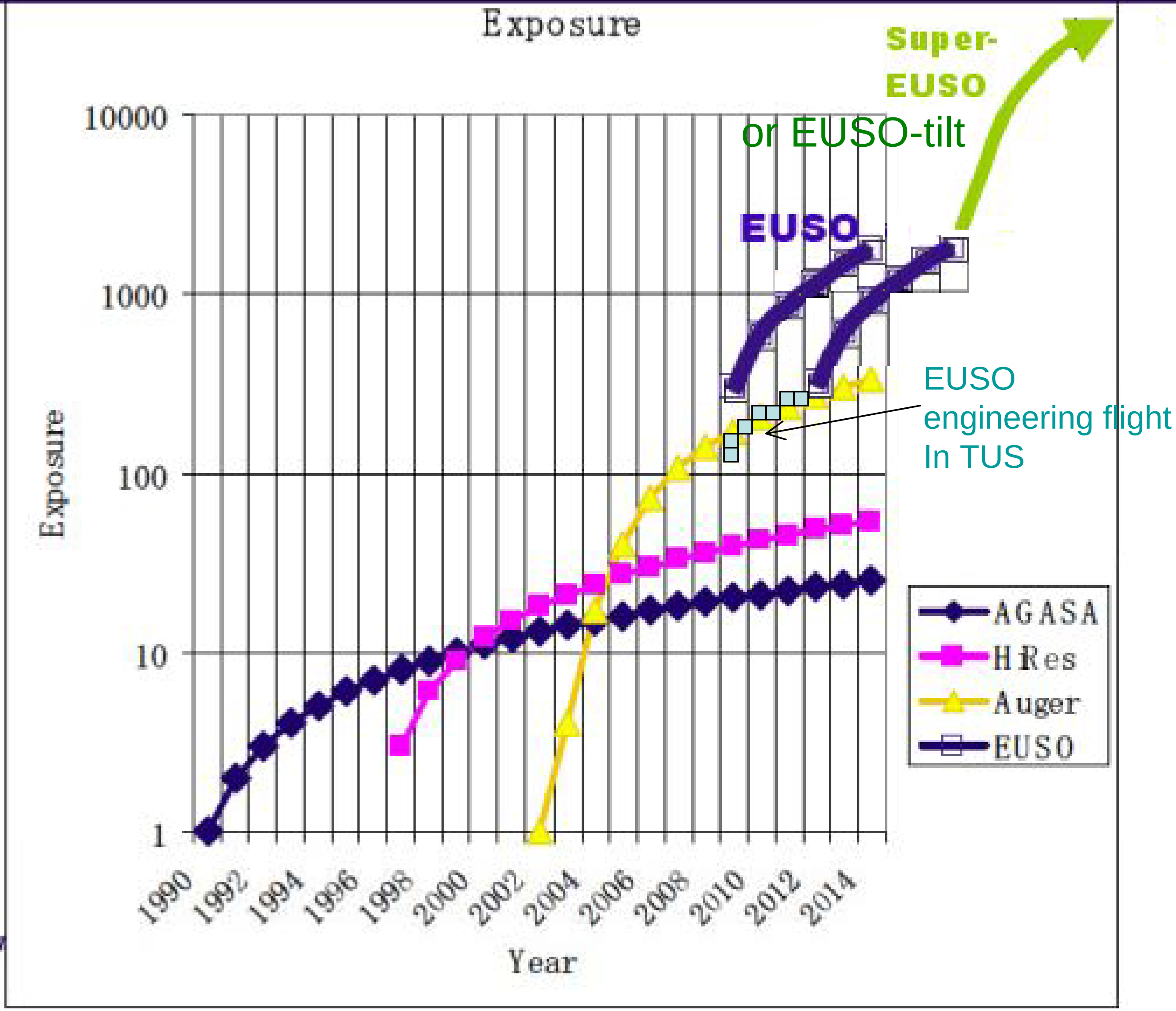


ガンマ線の地球磁場との相互作用によるカスケードシャワーの生成



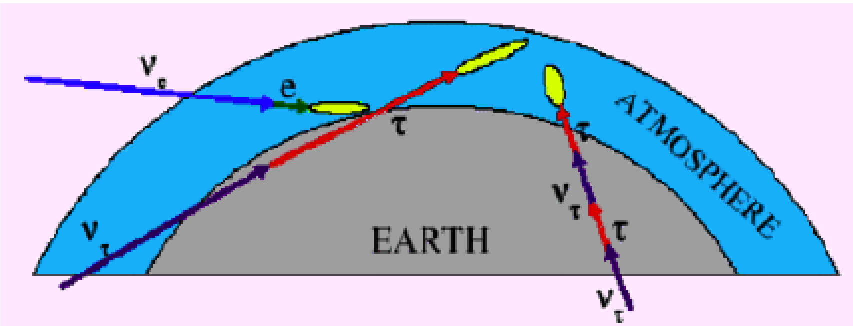
ガンマ線が極方向から入射したときの方が地球磁場による電子対創生をする確率は小さい

Exposure (AGASA unit)

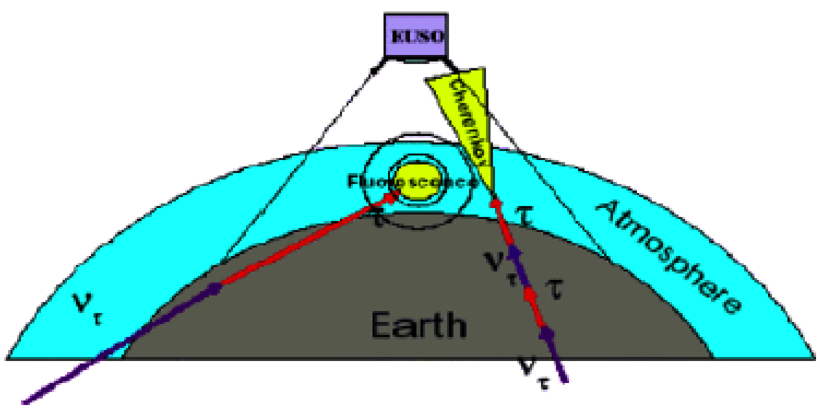


Andrea

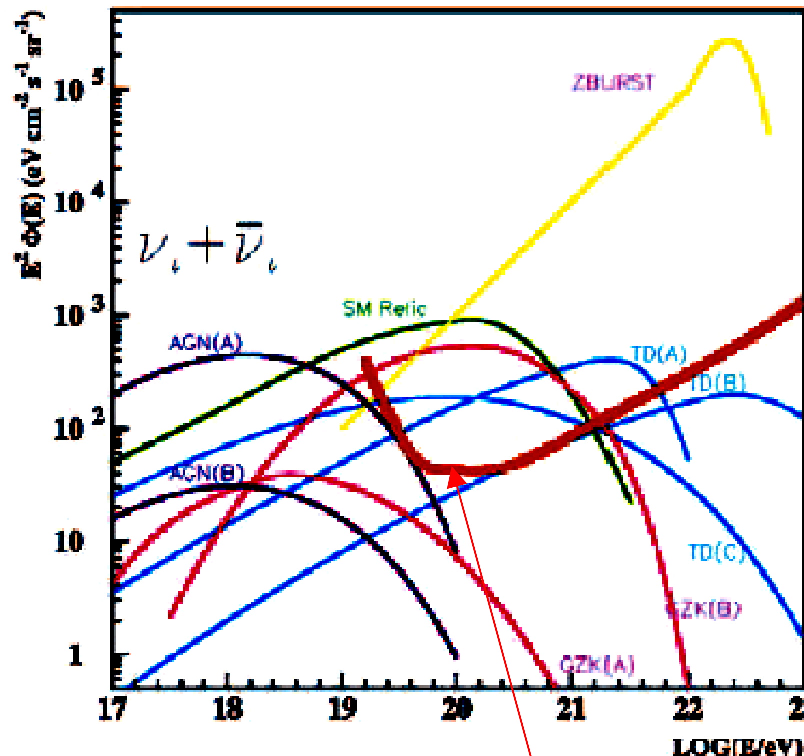
超高エネルギーニュートリノ天文学



ニュートリノの識別方法

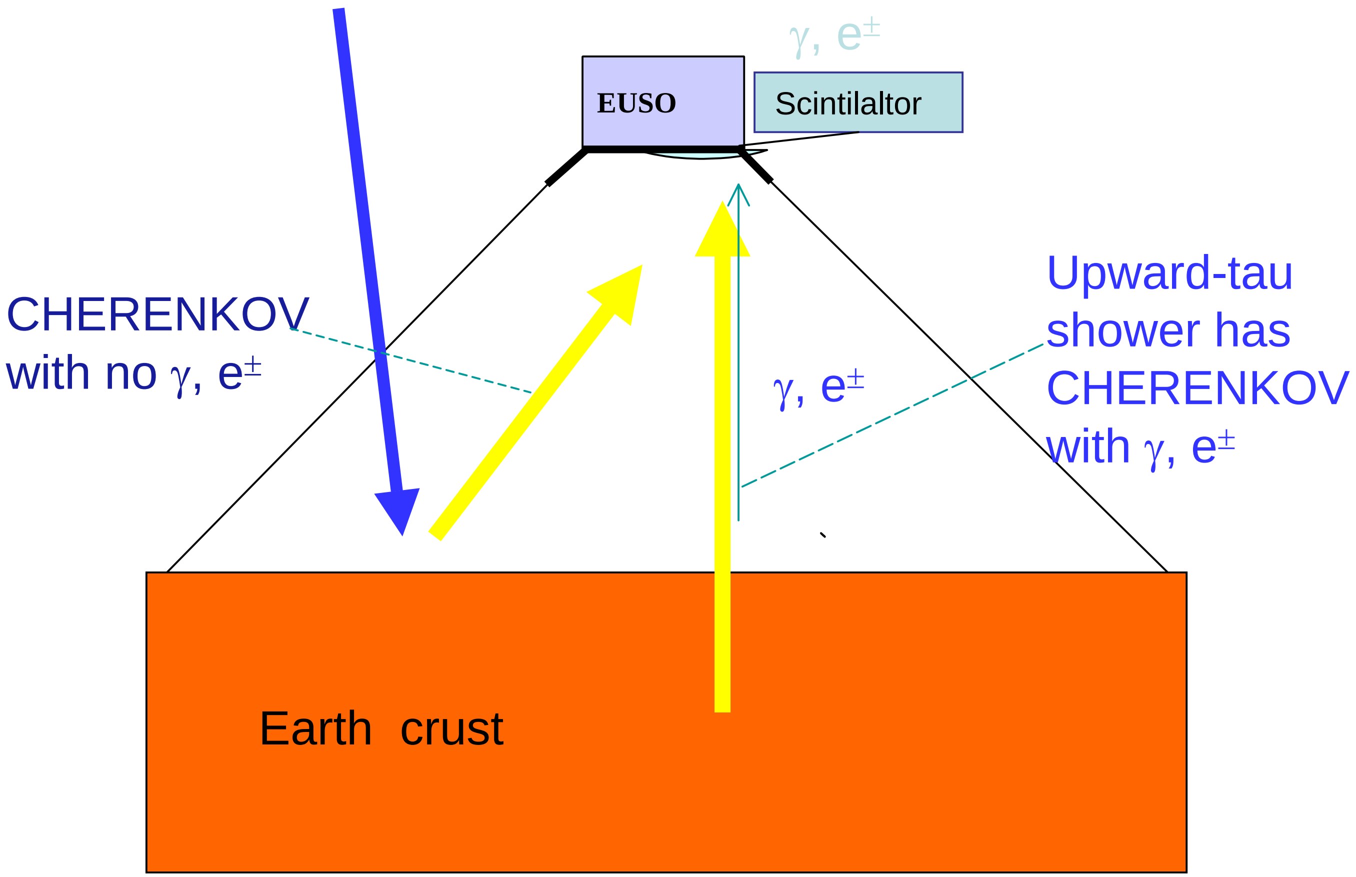


上方向ニュートリノの識別方法



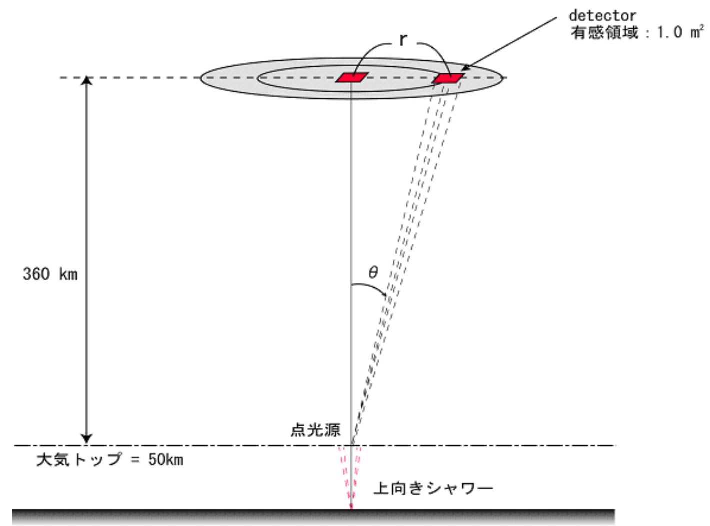
EUSOでエネルギー1桁あたり
1年に1イベント起こったときの
1フレーバーあたりの検出感度

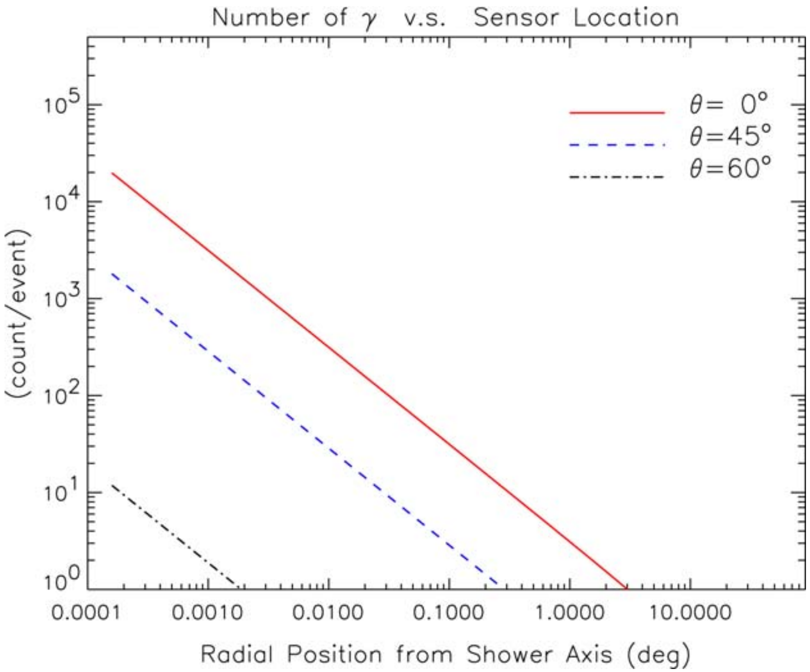
ガンマ線同時観測による上向きシャワーの検出



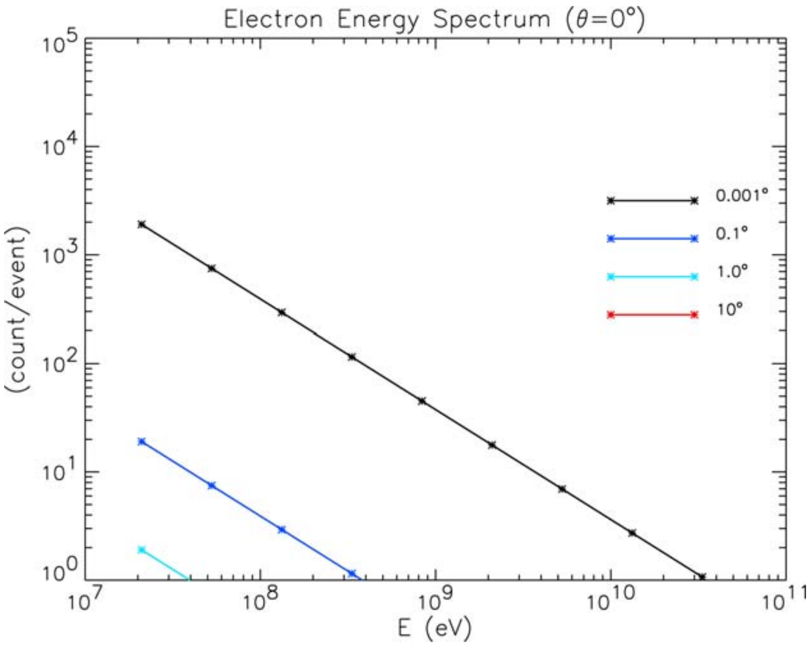
In case fluorescence is not detected for an AS event, the Cherenkov light reflected on ground-clouds can well mimic the neutrino direct Cherenkov signal. But,

SCINTILLATOR DISCRIMATES TRUE FROM FALSE. Binocular does not solve this.





一次エネルギーが10^{19} eVのときの上向きシャワーによるγ線量

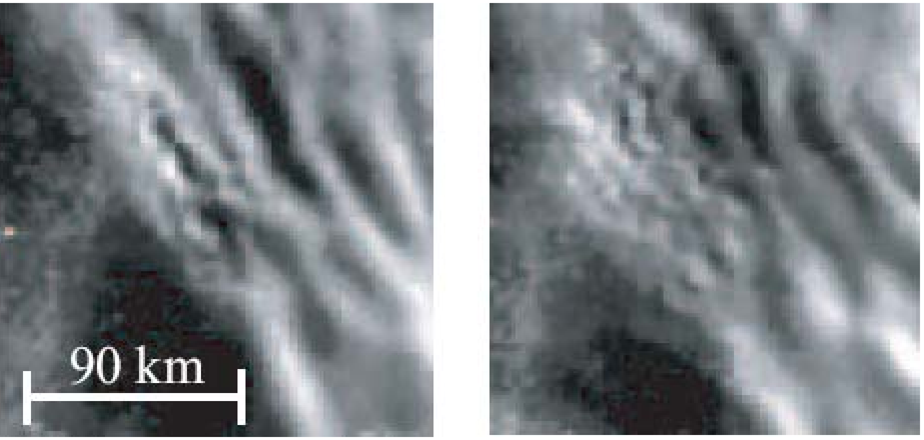


一次エネルギーが10^{19} eVのときの上向きシャワー（シャワー軸が0°）によるγ線のスペクトル

まとめ

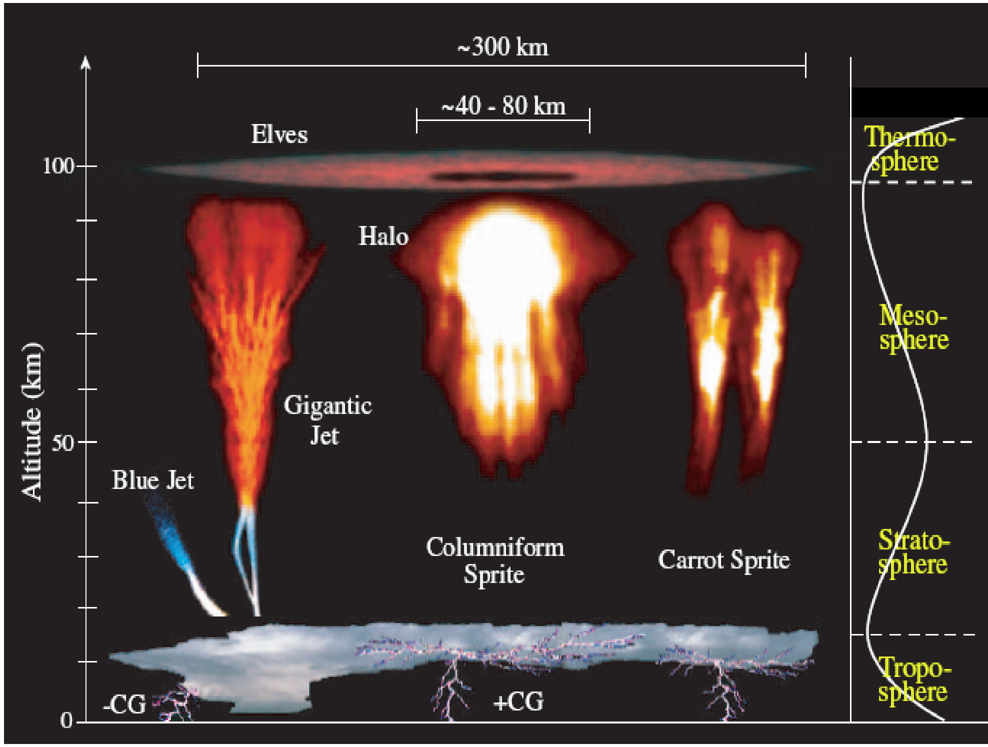
- JEM/EUSOとして再出発
  – 米国・ヨーロッパとの協力
  – ロシアのTUSで実証実験
- JEM第二期利用に向けての準備を開始
  – エネルギー閾値を下げる努力
  – ガンマ線検出器
- 地球観測の科学
  – 雷、夜光

大気発光現象の科学



地上から観測したOH 大気光の変化

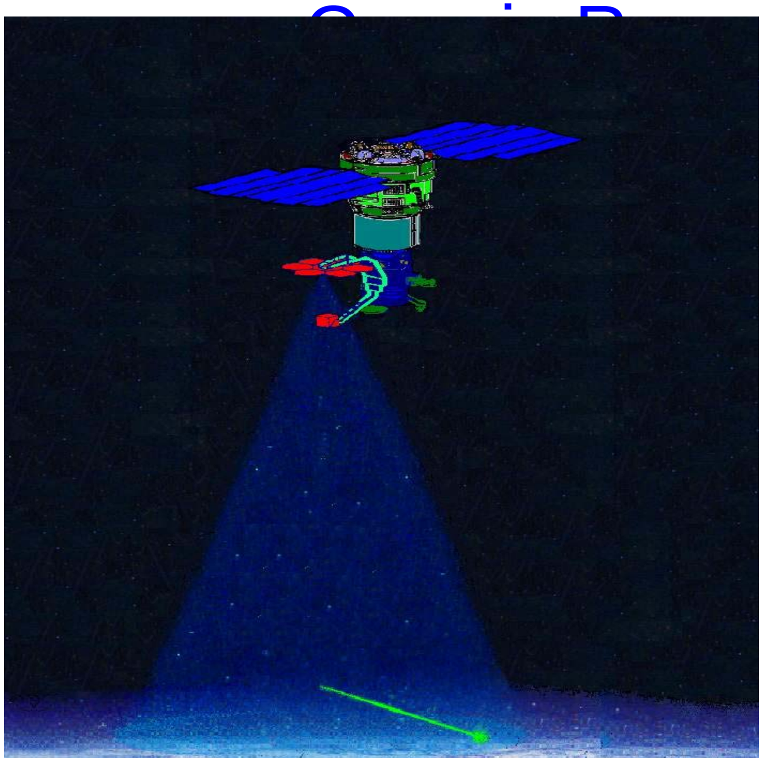
ハイビジョンカメラによる
2001 年のしし座流星群



雷放電に伴う成層圏・中間圏・下部
熱圏でのトランジェントな発光現象

What does it mean "TUS"?

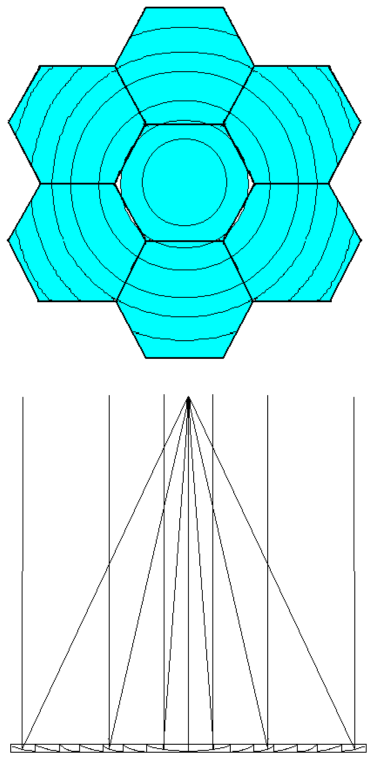
- Do not try to decode this your self:
  - Космические Лучи Сверх Высоких Энергий
  - of Ultra High Energies



Single eye option

Project Design. Optics

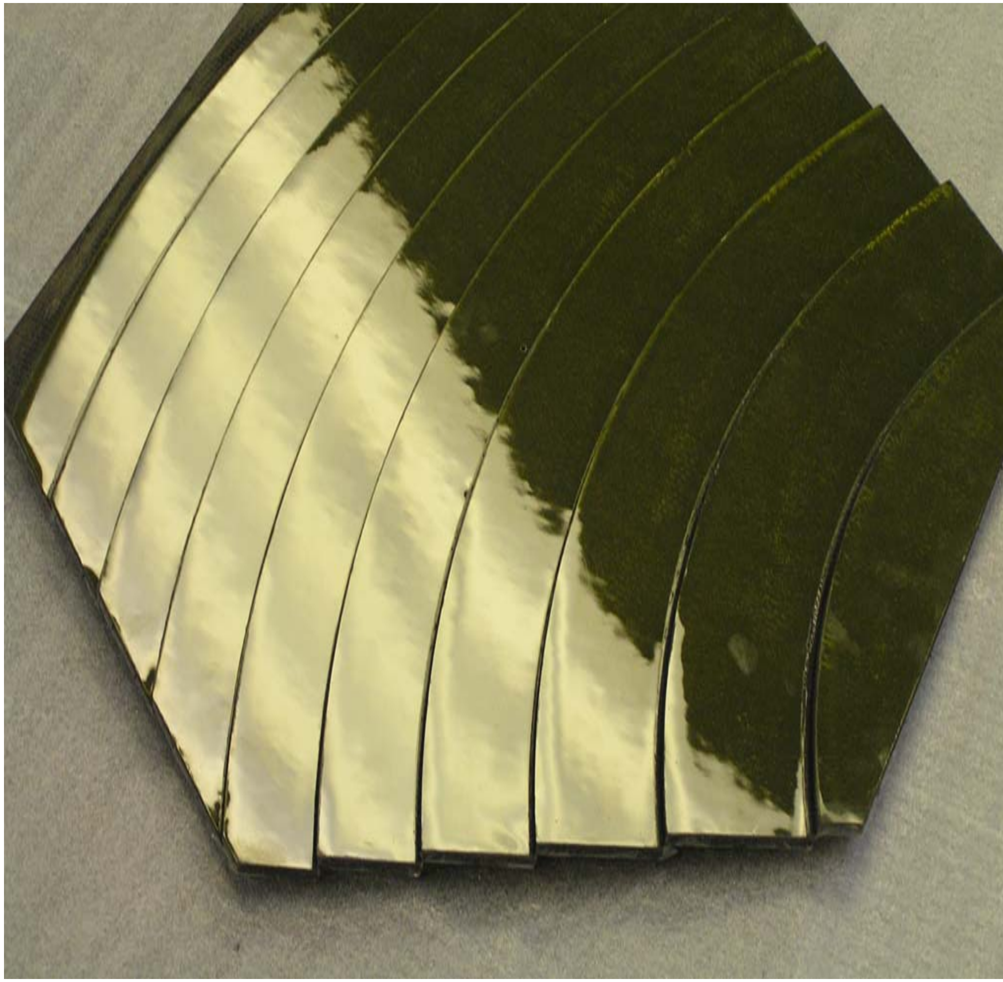
- Segmented Fresnel Mirror



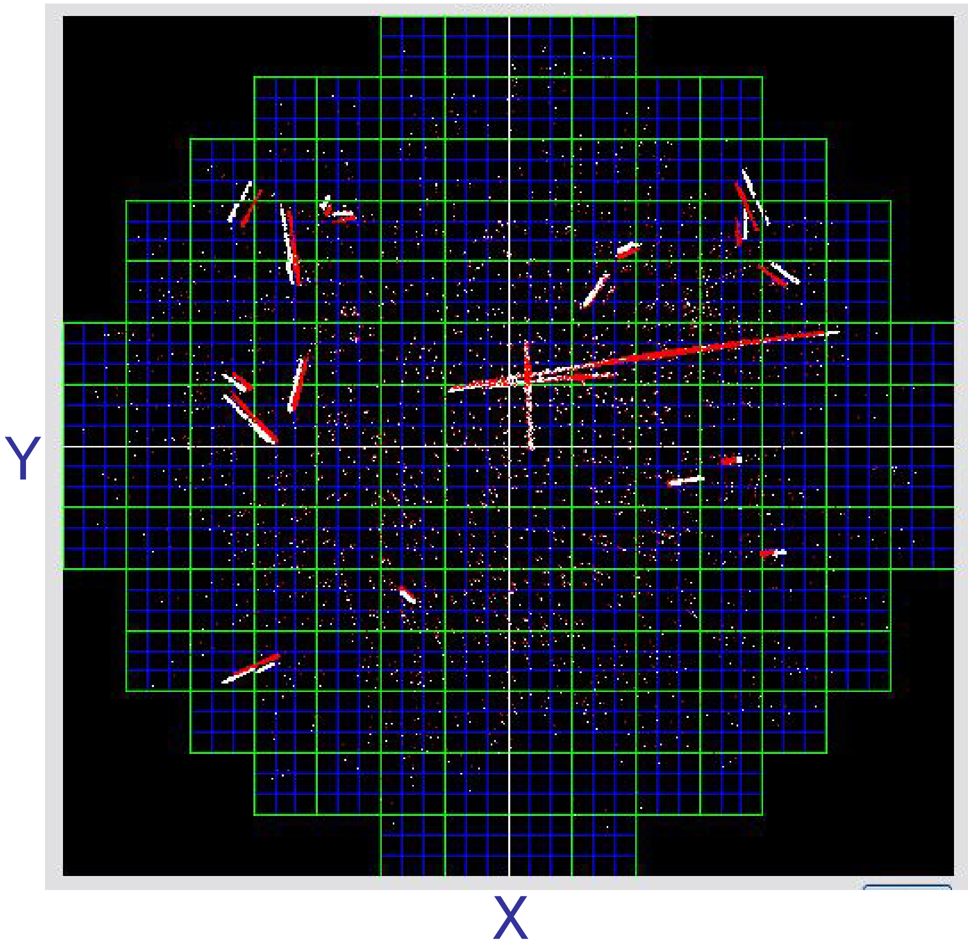
- The mirror- concentrator mass is less than 20 kg for the mirror area 1.4 m^2.
- Accuracy in mirror ring profiles ± 0.01 mm.
- Stability of the mirror construction in the temperature range from –80º to + 60º C.
- 10 parabolic rings with focal distance 1500 mm
- the mirror surface is protected by SiO2
- The mirror development mechanism makes the mirror plane with the angular accuracy less than 1 mrad.

Project Design. Optics

- A real sample of the mirror segment

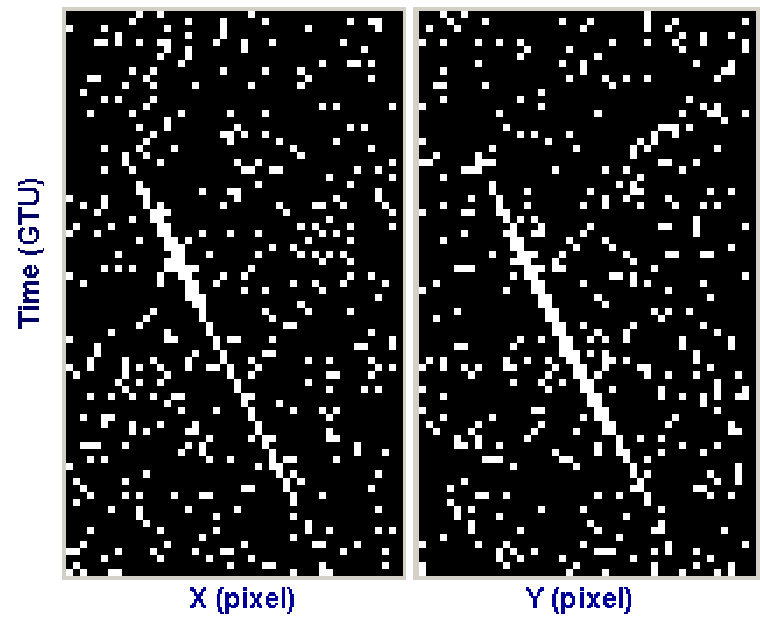


日本独自のEUSOシミュレーション 焦点面でのイメージ



10^{20}eV protonによるシャワー
20イベントの重ね書き

192k pixels



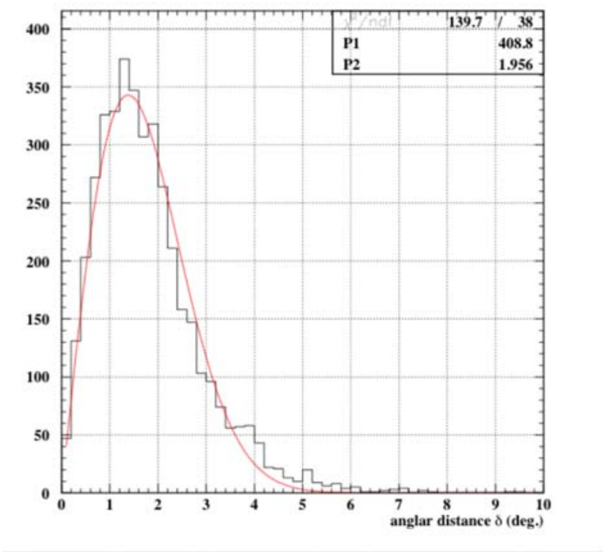
2.5μsごとの時間構造

赤：焦点面上でのシャワーイメージ
白：PDMを平面に展開したときのシャワーイメージ

日本版シミュレータでのEUSO性能

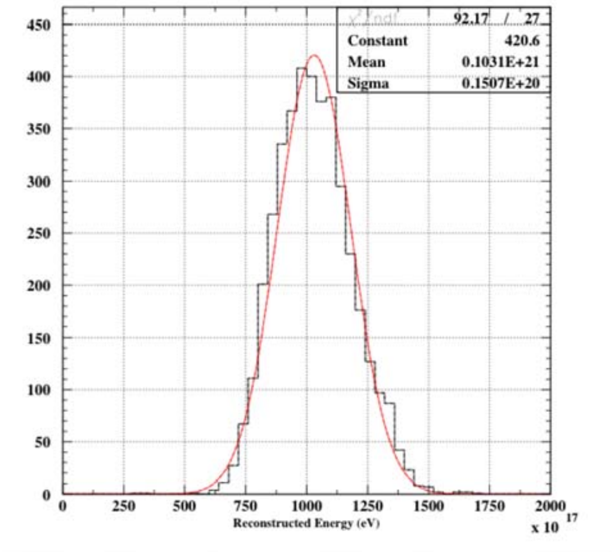
初期解析結果(10^{20}eV空気シャワー解析）

到来方向決定精度



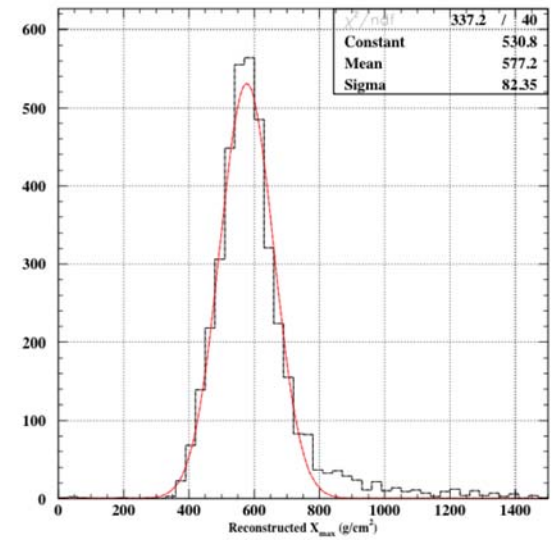
2.0度

エネルギー決定精度



15%

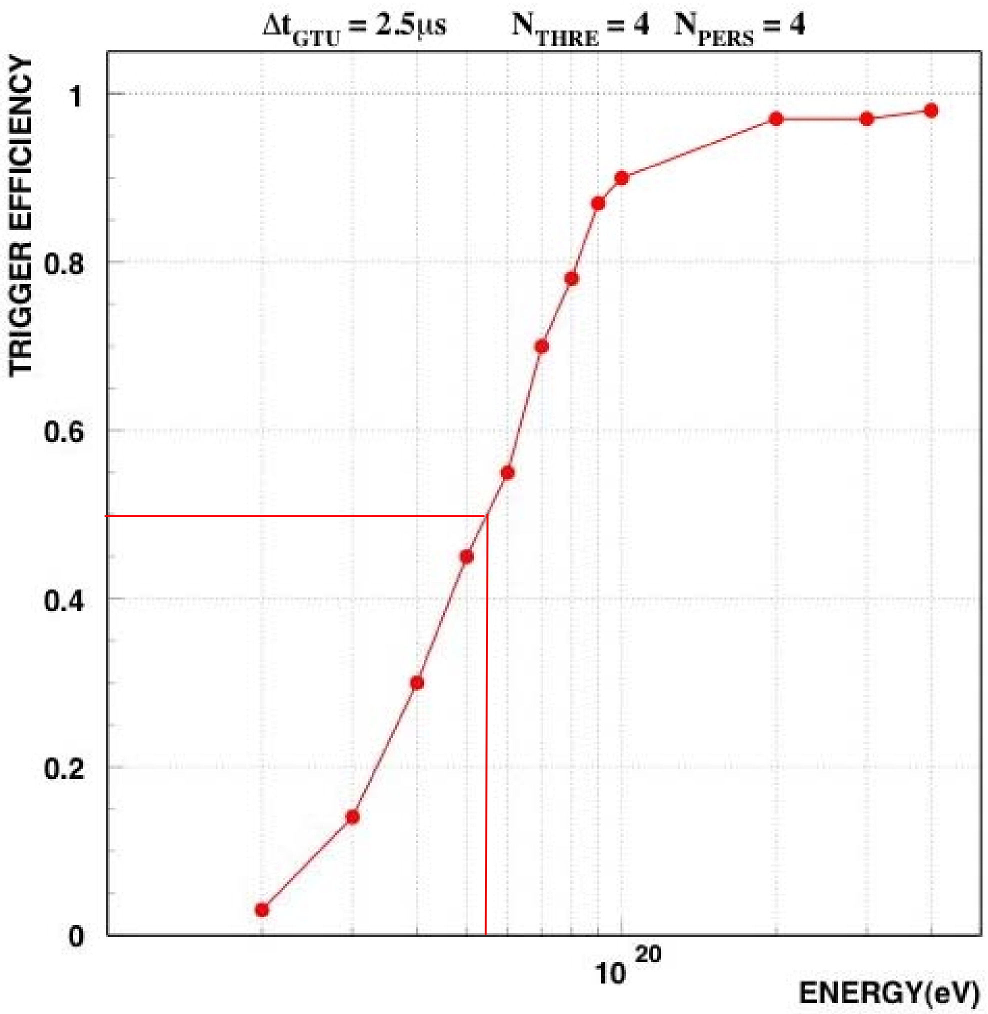
最大発達大気深さ決定精度



$82g/cm^2$

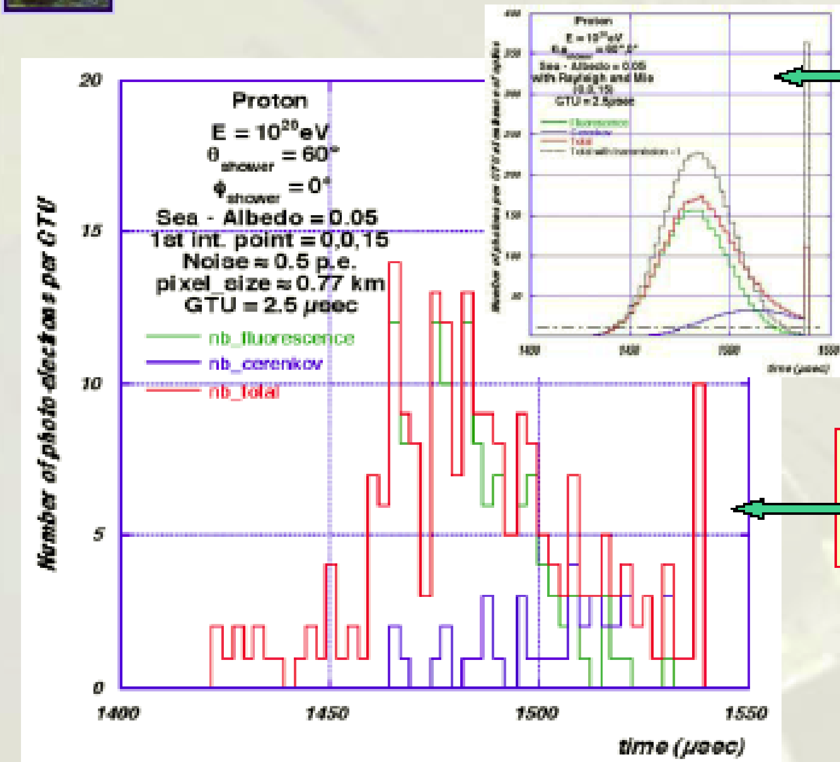
日本版シミュレータでのEUSO性能

初期解析結果(トリガ効率)



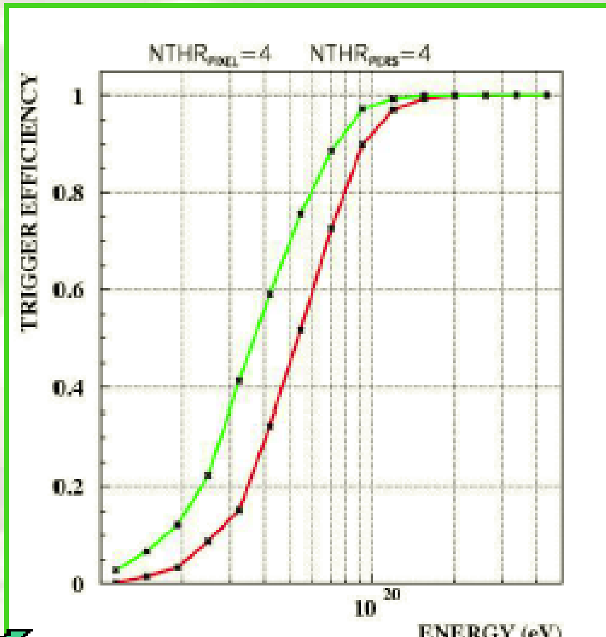
5.5×10^{19}eVで50%

The Detector Performances

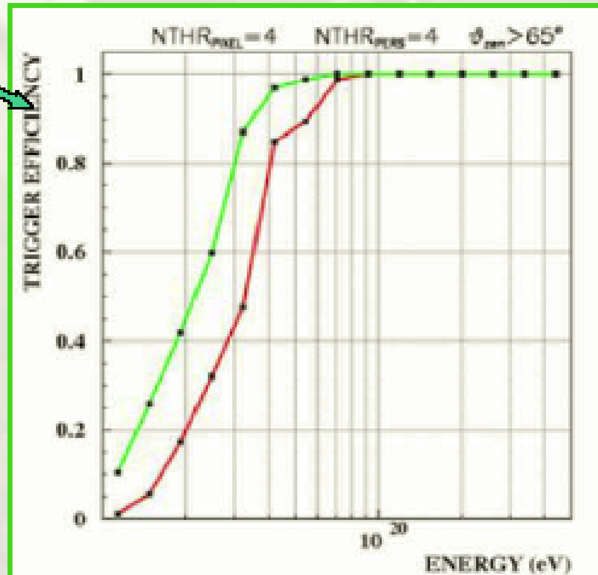


The incoming light

The detected signal



The trigger efficiency



According to very recent data (May '04):

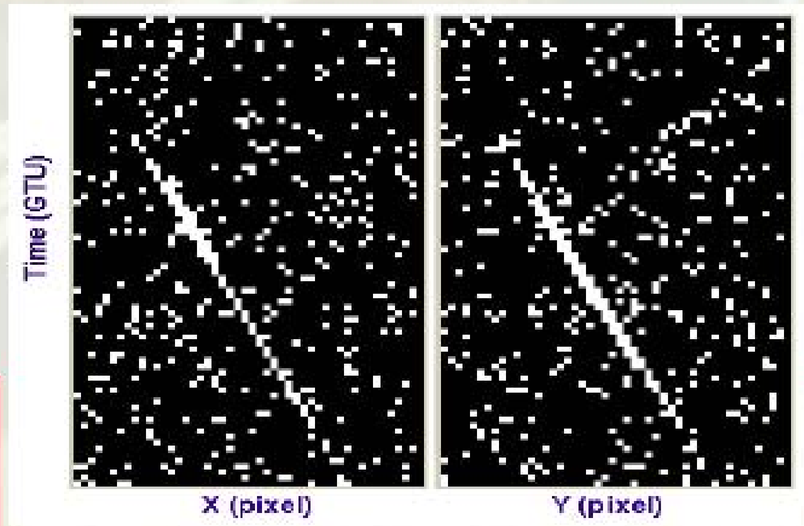
PD efficiency improved .16/.12=1,33

OM efficiency loss 0.73/0.83=0,88

EUSO Light collection eff. 1,33×0,88=1,17 with respect to quoted values

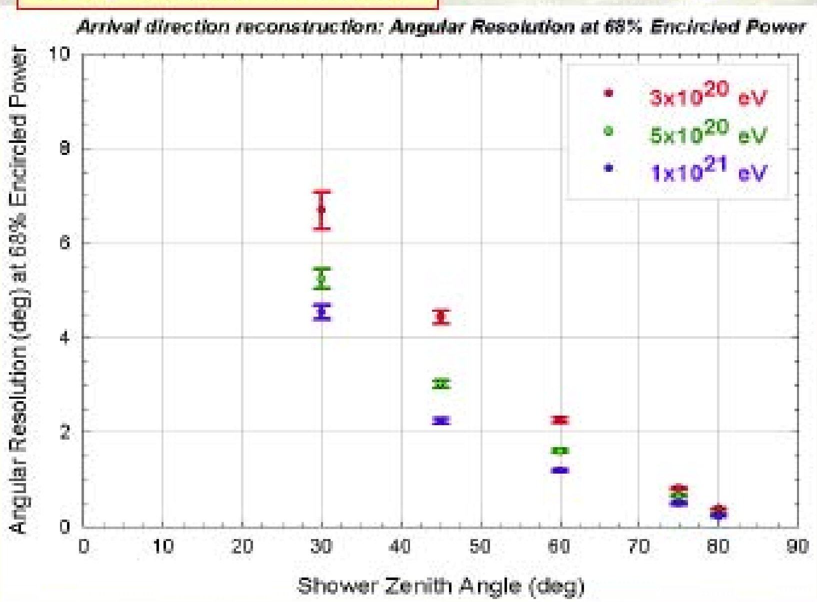
EUSO angular resolution

M.C. Maccarone, 2003

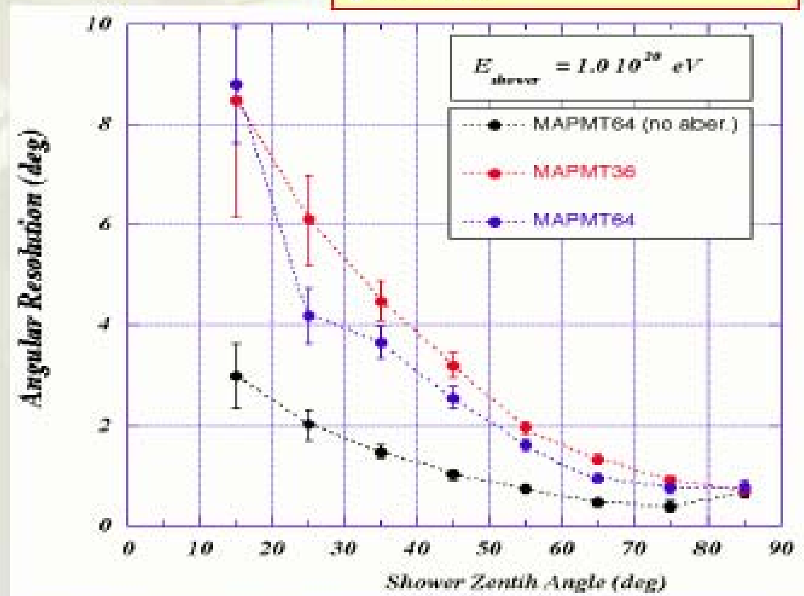


J. Dolbeau, 2003

At high energy, without Cerenkov footprint information



At 10^{20} eV, using the Cerenkov footprint position

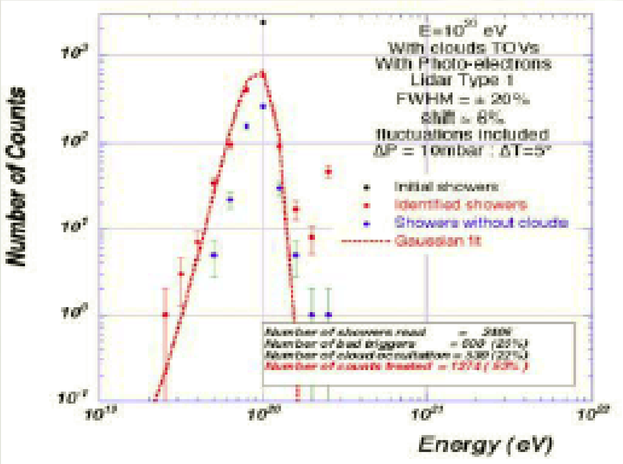


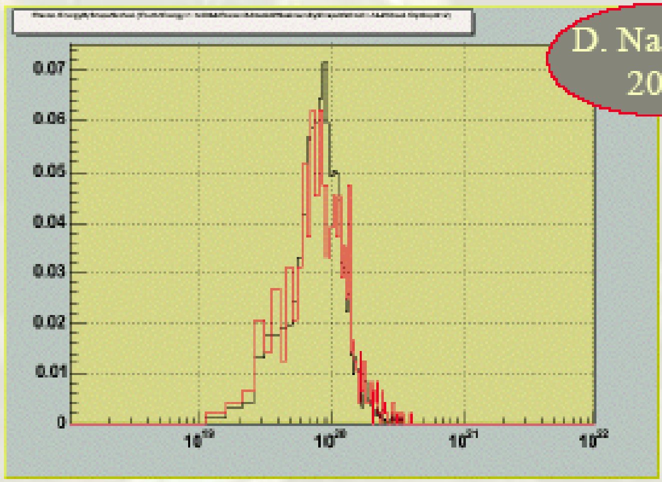
Energy resolution (clouds included)

The energy of 10^{20} eV events, in a random cloudy atmosphere, can be retrieved,…

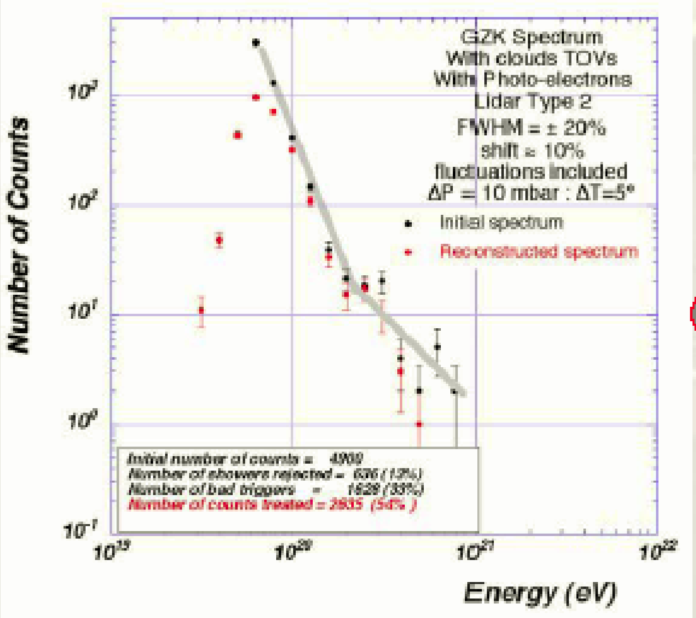
Using the ASD info, with 17% (RMS) resolution

In self-diagnosis way, with 27% (RMS) resolution

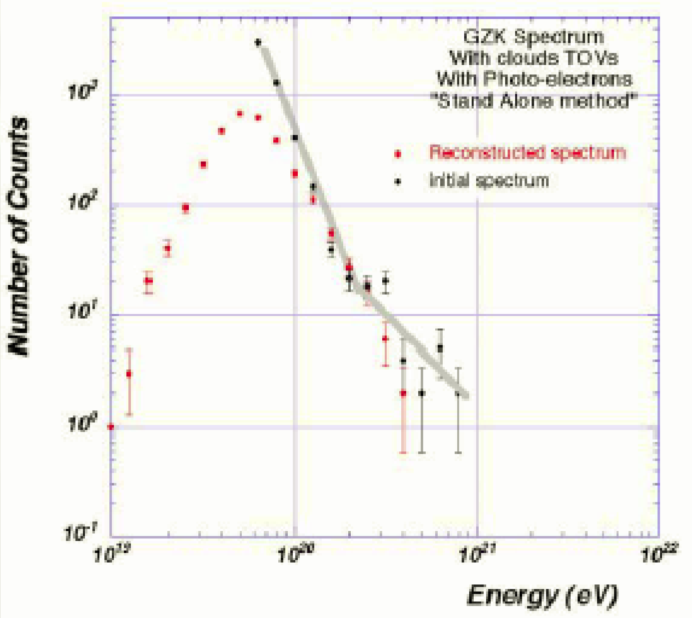




D. Naumov, 2004

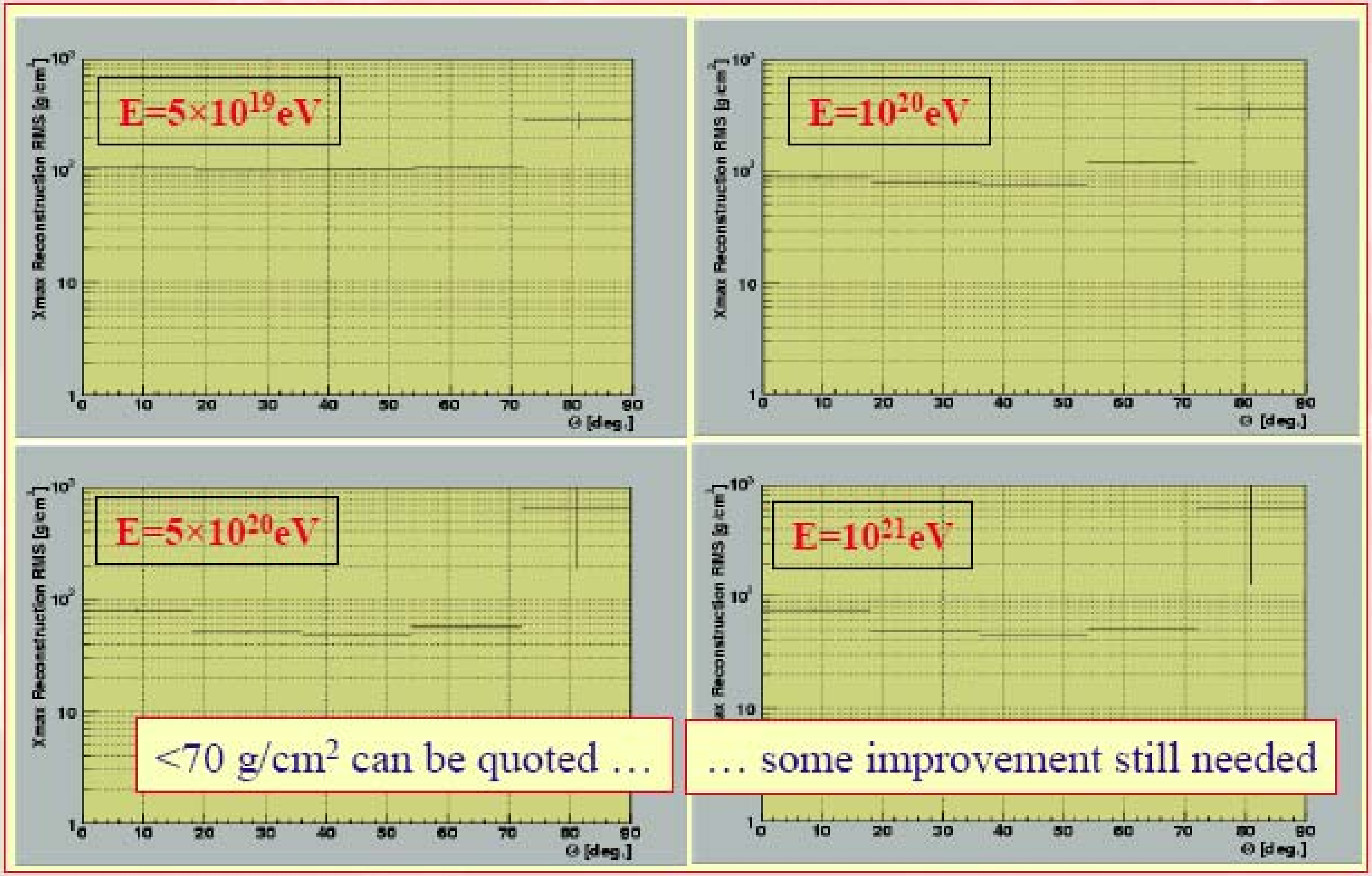


E. Plagnol, 2004



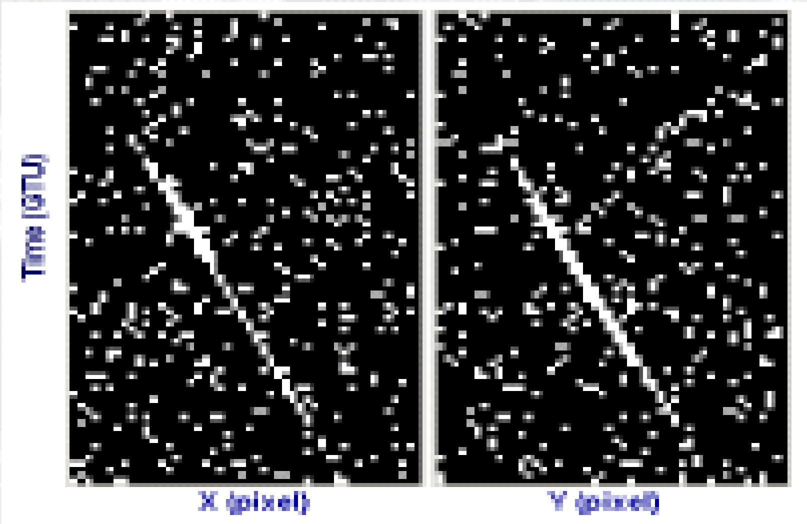
X_{max} resolution

Scientific requirement is 35 g/cm2 to perform primary separation(heavy.vs.light)
Actual result when cloud altitude is assumed or no cloud is present



EUSO angular resolution

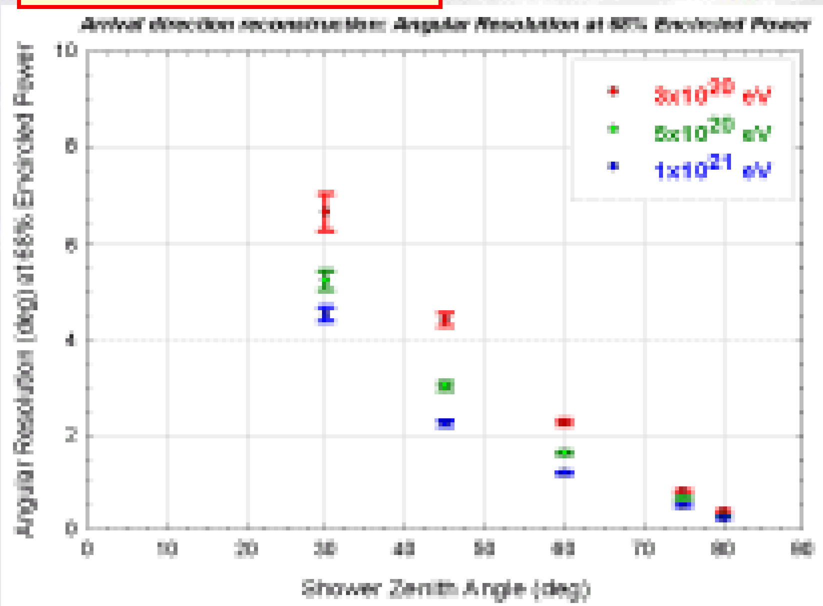
M.C. Maccarone, 2003

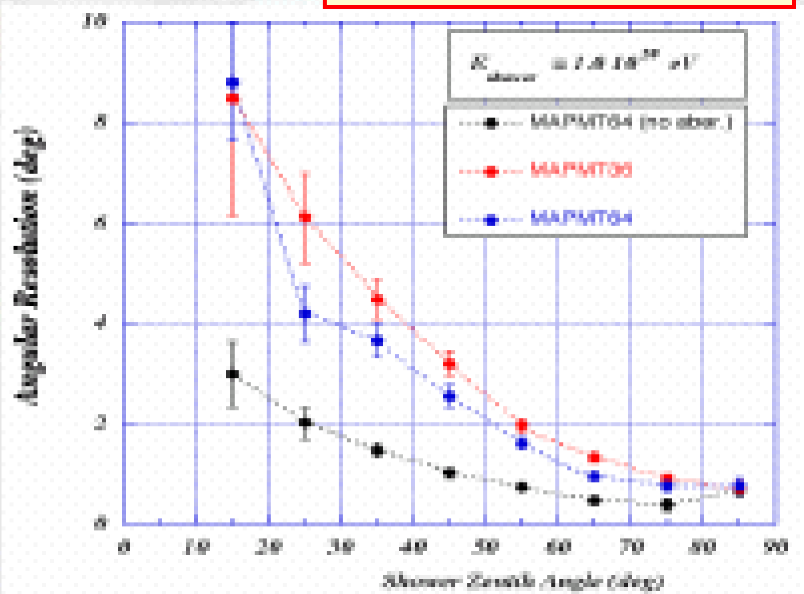


J. Dolbeau, 2003

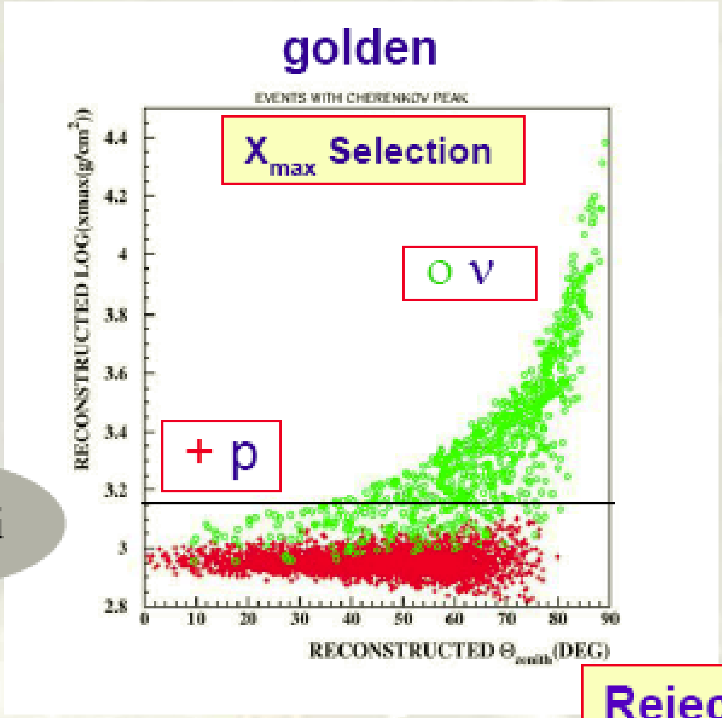
At high energy, without Cerenkov footprint information

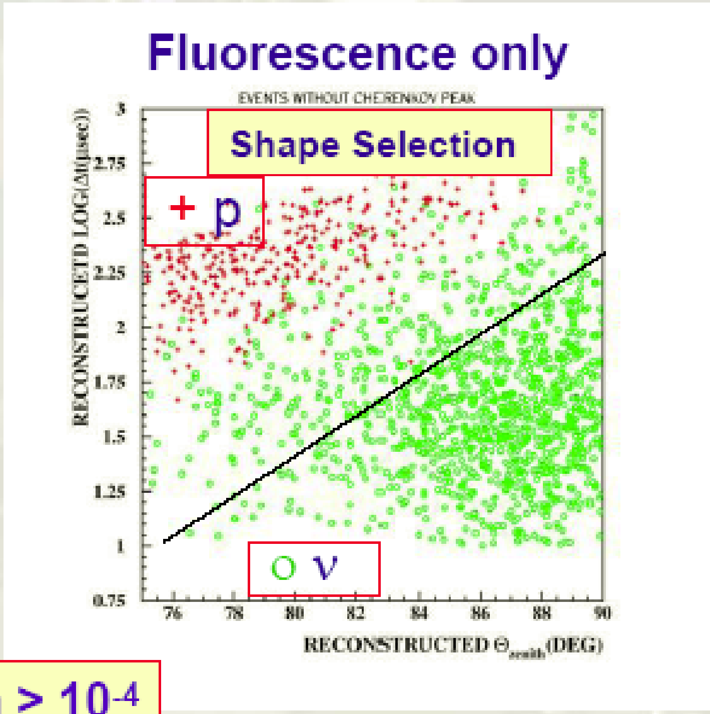
At 10^{20} eV, using the Cerenkov footprint position





Downward neutrino acceptance for EUSO





S. Bottai

Rejection > 10^{-4}

- ✓ $2 * 10^{18}$ g is the total target mass under the FOV
- ✓ reduction due to trigger efficiency is calculated by full simulation. Clouds distribution is considered
- ✓ reduction due to selection efficiency needed for 10^{-4} proton rejection has been calculated from full simulation
- ✓ results show a sensitivity around 10 times AUGER for neutrino in the10^{20}eV energy region