

Tibet AS+MD+YAC :
(チベットAS γ 実験の次期計画)

「100TeV領域(10-1000TeV)ガンマ線天文学の開拓
とKneeエネルギー領域宇宙線化学組成の研究」

AS=Air Shower array

MD=Muon Detector array

YAC=Yangbajing Air shower Core detector

講演者&日本側プロジェクトリーダー
東京大学宇宙線研究所 瀧田 正人

for the Tibet AS γ Collaboration

@CRCタウンミーティング (東京工業大学)

2012年1月22日(日)



日本側ホスト: ICRR

中国側ホスト: IHEP

The Tibet ASy Collaboration



M.Amenomori(1), X.J.Bi(2), D.Chen(3), S.W.Cui(4), Danzengluobu(5), L.K.Ding(2), X.H.Ding(5), C.Fan(2,6), C.F.Feng(6), Zhaoyang Feng(2), Z.Y.Feng(7), X.Y.Gao(8), Q.X.Geng(8), Q.B.Gou(2), H.W.Guo(5), H.H.He(2), M.He(6), K.Hibino(9), N.Hotta(10), Haibing Hu(5), H.B.Hu(2), J.Huang(2), Q.Huang(7), H.Y.Jia(7), L.Jiang(2,8), F.Kajino(11), K.Kasahara(12), Y.Katayose(13), C.Kato(14), K.Kawata(3), Labaciren(5), G.M.Le(15), A.F.Li(6), H.C.Li(2,4), J.Y.Li(6), C.Liu(2), Y.-Q.Lou(16), H.Lu(2), X.R.Meng(5), K.Mizutani(12, 17), J.Mu(8), K.Munakata(14), H.Nanjo(1), M.Nishizawa(18), M.Ohnishi(3), I.Ohta(19), S.Ozawa(12), T.Saito(20), T.Y.Saito(21), M.Sakata(11), T.K.Sako(13), M.Shibata(13), A.Shiomi(22), T.Shirai(9), H.Sugimoto(23), M.Takita(3), Y.H.Tan(2), N.Tateyama(9), S.Torii(12), H.Tsuchiya(24), S.Udo(9), B.Wang(2), H.Wang(2), Y.Wang(2), Y.G.Wang(6), H.R.Wu(2), L.Xue(6), Y.Yamamoto(11), C.T.Yan(25), X.C.Yang(8), S.Yasue(26), Z.H.Ye(27), G.C.Yu(7), A.F.Yuan(5), T.Yuda(9), H.M.Zhang(2), J.L.Zhang(2), N.J.Zhang(6), X.Y.Zhang(6), Y.Zhang(2), Yi Zhang(2), Ying Zhang(2,7), Zhaxisangzhu(5) and X.X.Zhou(7)

(1)Department of Physics, Hirosaki University, Japan.

(2)Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, China.

(3)Institute for Cosmic Ray Research, University of Tokyo, Japan.

(4)Department of Physics, Hebei Normal University, China.

(5)Department of Mathematics and Physics, Tibet University, China.

(6)Department of Physics, Shandong University, China.

(7)Institute of Modern Physics, SouthWest Jiaotong University, China.

(8)Department of Physics, Yunnan University, China.

(9)Faculty of Engineering, Kanagawa University, Japan.

(10)Faculty of Education, Utsunomiya University, Japan.

(11)Department of Physics, Konan University, Japan.

(12)Research Institute for Science and Engineering, Waseda University, Japan.

(13)Faculty of Engineering, Yokohama National University, Japan.

(14)Department of Physics, Shinshu University, Japan.

(15)National Center for Space Weather,

China Meteorological Administration, China.

(16)Physics Department and Tsinghua Center for Astrophysics, Tsinghua University, China.

(17)Saitama University, Japan.

(18)National Institute of Informatics, Japan.

(19)Sakushin Gakuin University, Japan.

(20)Tokyo Metropolitan College of Industrial Technology, Japan.

(21)Max-Planck-Institut für Physik, Deutschland.

(22)College of Industrial Technology, Nihon University, Japan.

(23)Shonan Institute of Technology, Japan.

(24)RIKEN, Japan.

(25)Institute of Disaster Prevention Science and Technology, China.

(26)School of General Education, Shinshu University, Japan.

(27)Center of Space Science and Application Research, Chinese Academy of Sciences, China.

羊八井 宇宙線観測所

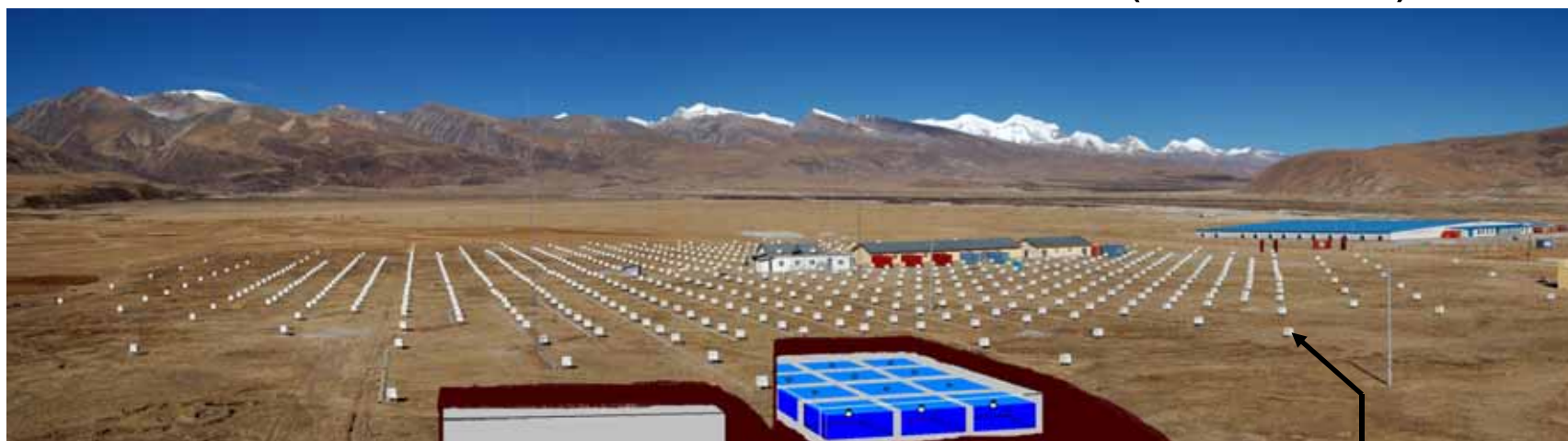
Tibet AS_γ実験(日中共同実験)
ARGO (中伊共同実験)
太陽中性子望遠鏡(名大-中国)
太陽中性子モニター(理研-中国)



中国 チベット自治区 羊八井(ヤンパーチン)

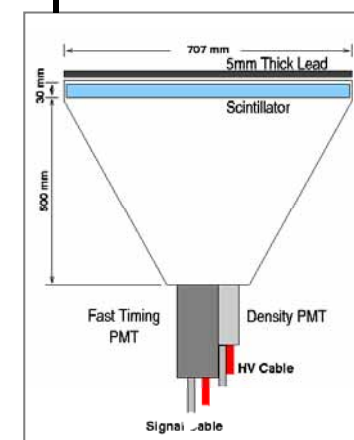
90° 522E, 30° 102N, 標高4,300 m (606g/cm²)

チベット空気シャワー観測装置 (Tibet AS)



水チェレンコフミュオン観測装置(イメージ)

- 中国チベット (90.522°E, 30.102°N) 標高4300 m
- シンチレーション検出器数 0.5 m² x 789
- 空気シャワー有効面積 ~37,000 m² → 83,000 m²
- 最頻エネルギー ~3 TeV
- 角度分解能 ~0.2 @100 TeV
- エネルギー分解能 ~40% @100TeV
- 視野 ~2 sr



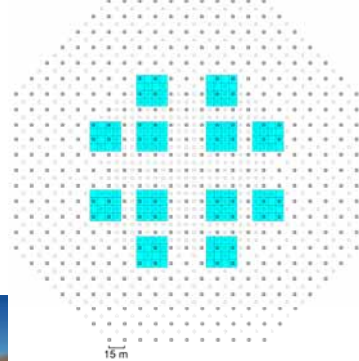
→ 空気シャワー中の電磁成分($e^{+/-}$, γ)を主に観測し
一次宇宙線エネルギー、方向、空気シャワーのコア位置などを測定

Tibet AS (~8.3万m²)

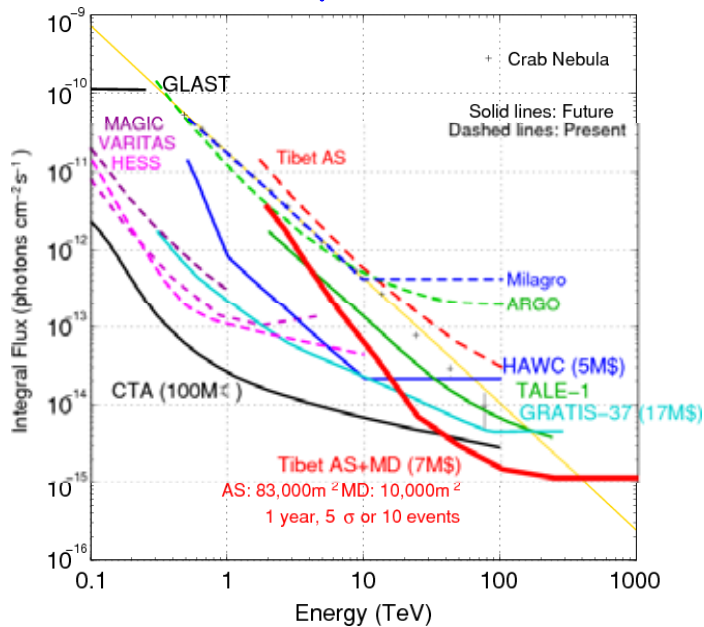
+MD (384ch, ~10⁴m²)

100TeV領域 $\gamma \rightarrow$

宇宙線起源と加速



Tibet AS + MDの γ 点源に対する感度



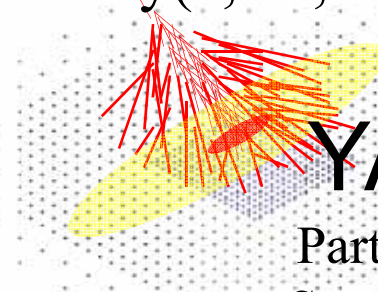
Tibet AS+YAC (0.2~5千m²)

Cosmic ray (P, He, Fe...)

Knee of p, He, Fe

-> 加速限界のZ依存性

-> SNR加速の証拠



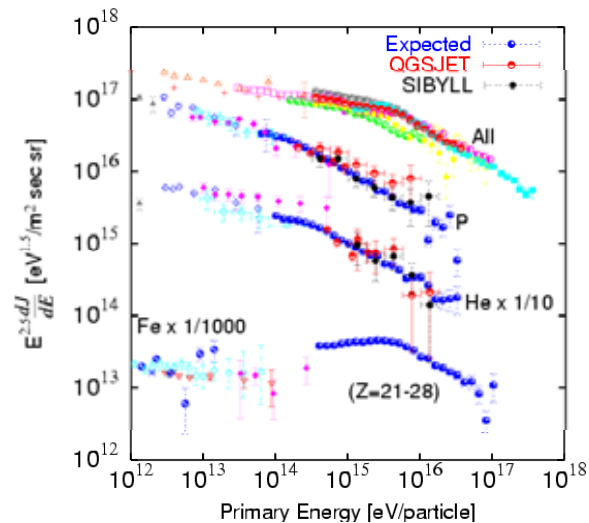
YAC

Particle density & spread

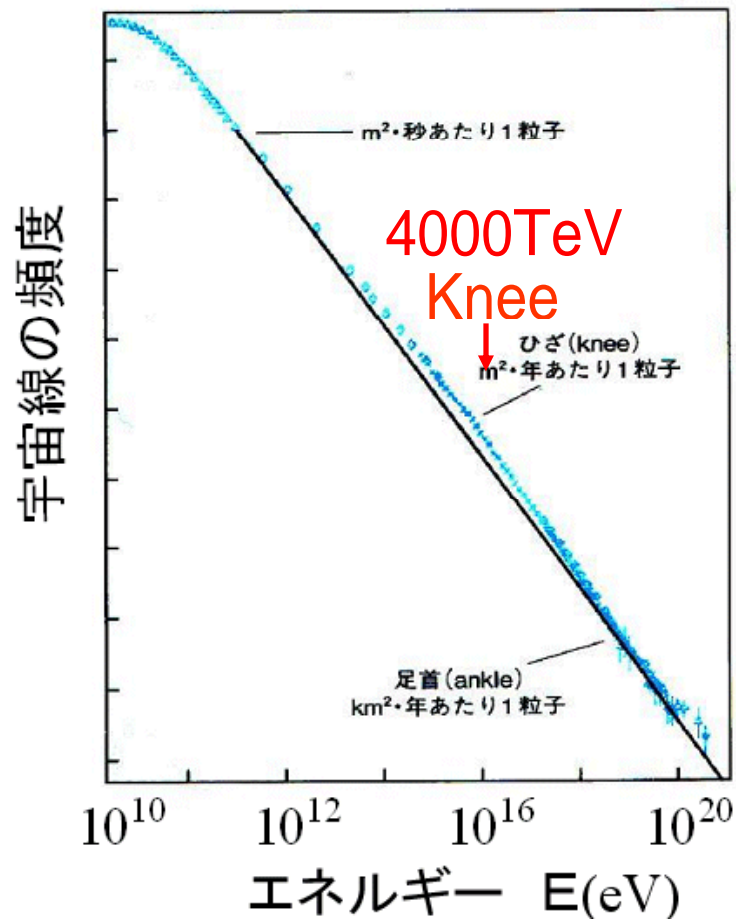
Separation of particles

Tibet AS: Energy and direction of air shower

青が期待値



イントロダクション



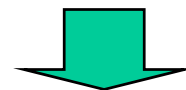
宇宙線の起源の候補:

Kneeエネルギー以上: 系外天体
AGN, GRB...

Kneeエネルギー以下: 系内天体
SNR, PWN, XRB...

かに星雲までの距離 2 kpc

1000TeV 陽子のラーモア半径 0.3 pc



超高エネルギーガンマ線の観測

宇宙線と星間物質の相互作用による $\pi^0 \rightarrow 2\gamma$

SNRによる原子核宇宙線の衝撃波加速

→宇宙線を100 ~ 10000TeV程度まで加速可能

→冪約-2のハードなガンマ線スペクトラム

→100TeV以上までガンマ線スペクトラムが延びる?

電子と星の光及び2.7Kによる逆コンプトン散乱

シンクロトロン冷却またはクライン-仁科効果

→超高エネルギー領域ではソフトなスペクトラム

→100TeV以上のガンマ線生成は困難

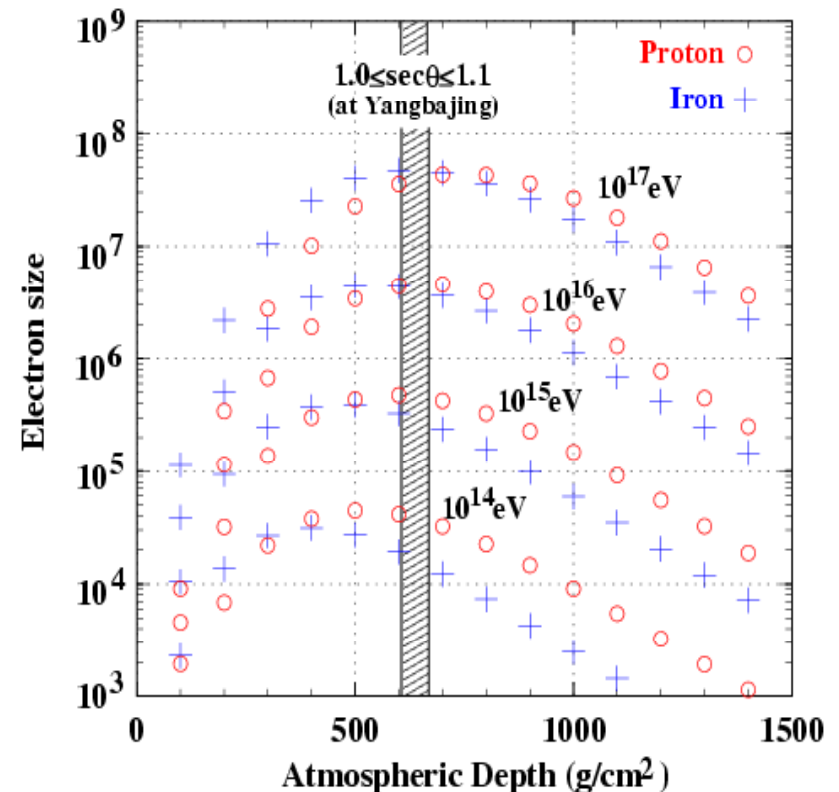
Why in Tibet?

1. 100TeV領域宇宙ガンマ線

- >大気中で減衰
- >Sea Levelに到達しない。

2. Knee領域宇宙線

- >エネルギー決定精度の原子核依存性が少ない。



次期計画概要:

1. Tibet Muon Detector ~ 10000m² の約1/3建設中、 残りは 4 億円
2. Tibet Air Shower Arrayの拡張 1.5億円
37000m²->83000m² (+292台)
Tibet AS + MD -> 100 TeV γ astronomy (point & diffuse sources, acceleration limits, origin of cosmic rays)
3. Yangbajing Air shower Core Detector phase II 現在建設中
Tibet AS+ YAC-II (160m²,100台) -> Proton & Helium knee
4. Yangbajing Air shower Core Detector phase IIIの建設 2.5億円
Tibet AS+ YAC-III(5000m²,400台) -> Fe knee

次期計画の年次計画： 合計6年間

1年目：MD1/3の建設と1/2YAC-IIIの建設

2年目：MD1/3の建設と1/2YAC-IIIの建設

3年目：Tibet AS拡張及び観測

4年目：観測

5年目：観測

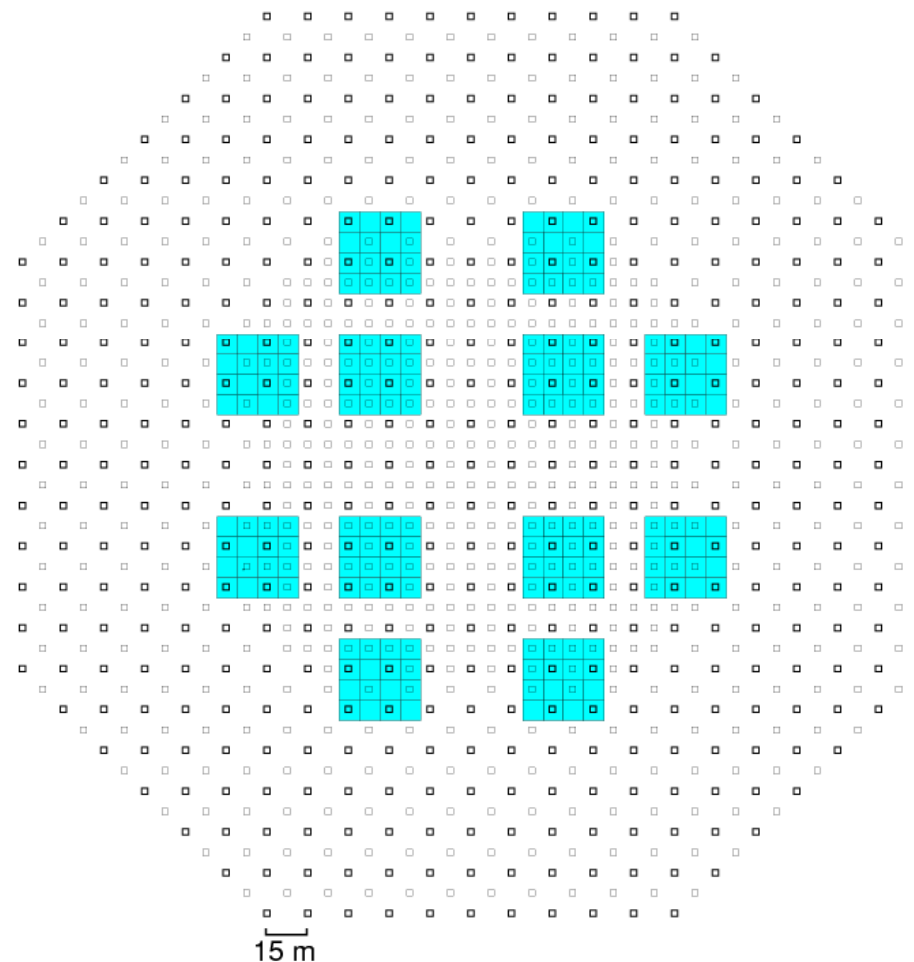
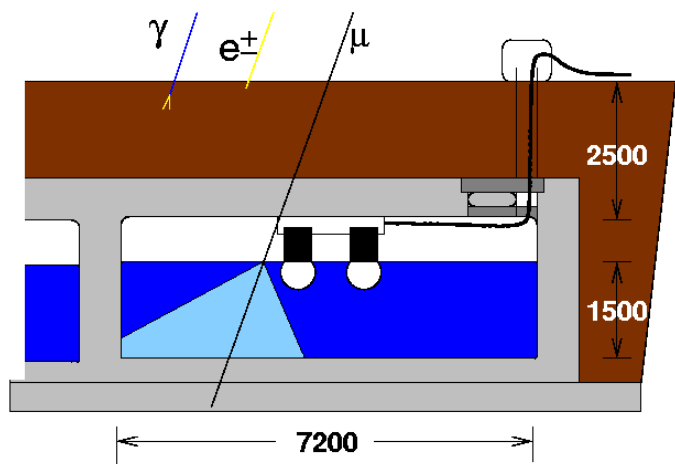
6年目：観測

チベット水チェレンコフミュオン観測装置 (Tibet MD)

地下 2.5m (物質厚 $\sim 515\text{g}/\text{cm}^2 \sim 19X_0$)
7.2m \times 7.2m \times 水深1.5m 水槽 192台
20" PMT 2本 (HAMAMATSU R3600)

水槽材質:
コンクリート
白色エポキシ樹脂塗装

合計 $\sim 10,000\text{m}^2$



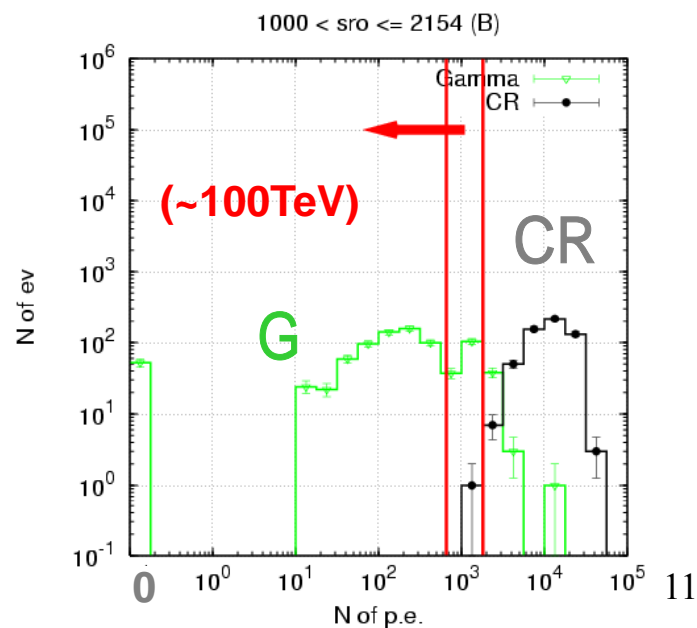
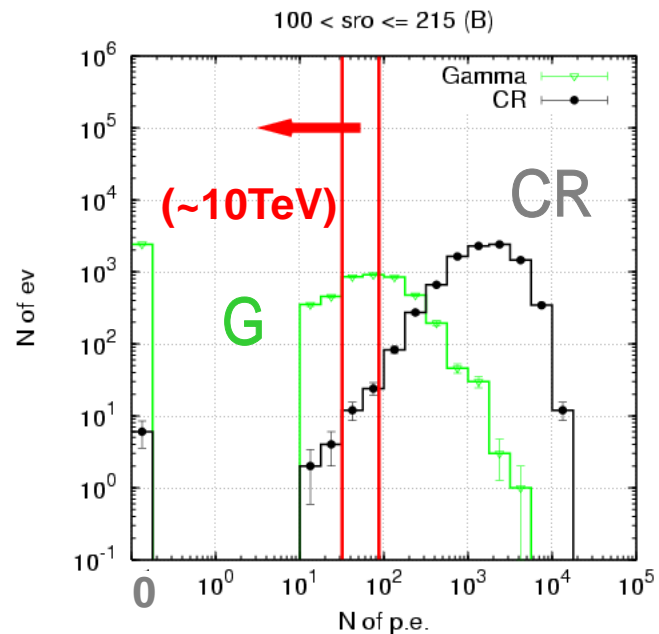
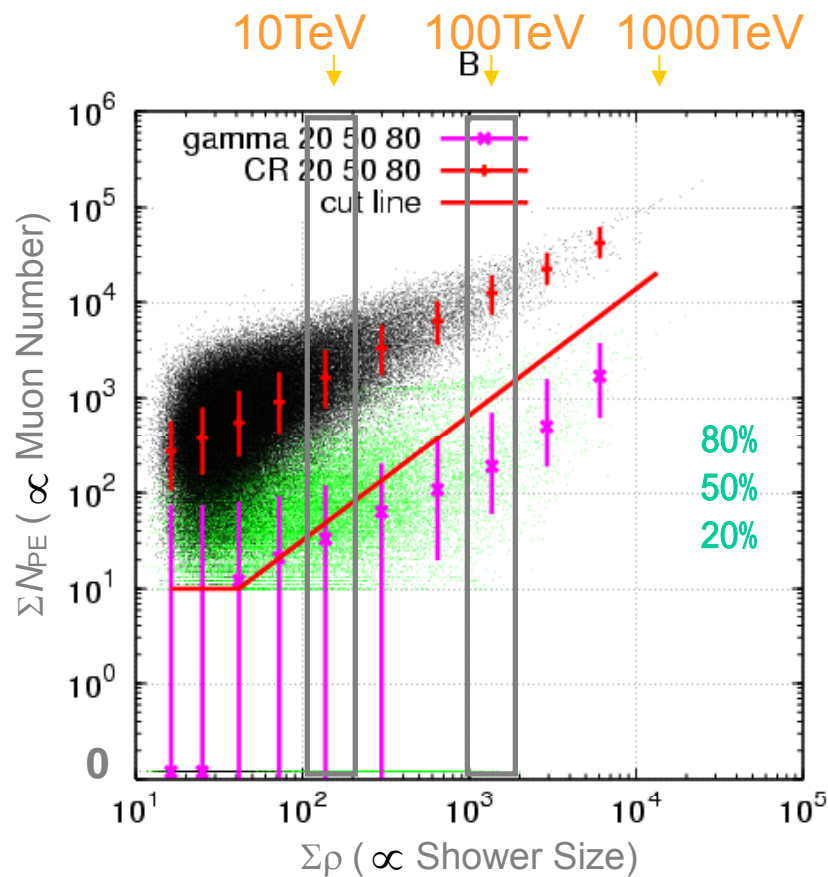
→空気シャワー中のミュオン数を測定し、ガンマ線 / 核子選別

ミューオン数 VS シャワーサイズ (シミュレーション)

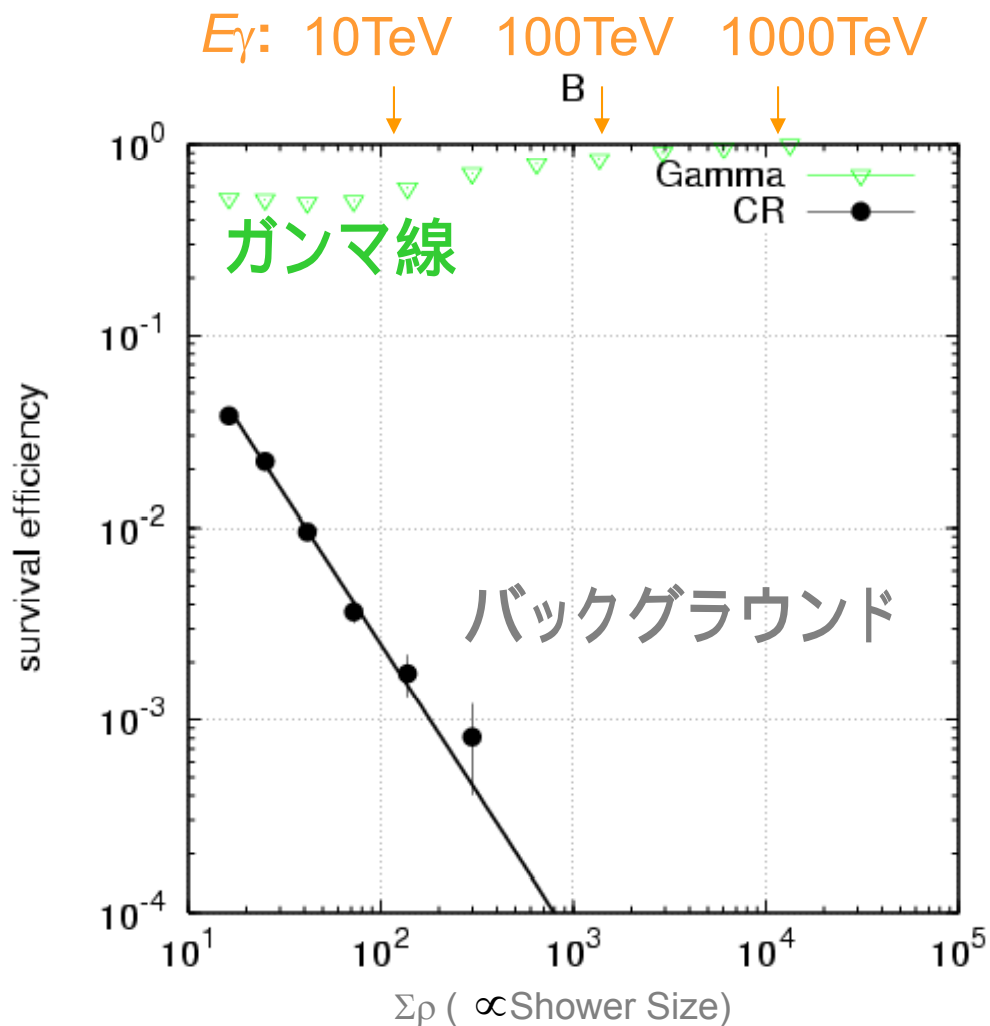
: シンチレータ検出器で観測した粒子密度の和
シャワーサイズ

N_{PE} : ミューオン検出器で観測した光電子数の和
ミューオン数

(MD検出器の閾値 $N_{PE} > 10$ 光電子)



カット後の生存率 (シミュレーション)



10TeV:

カット $\Sigma N_{PE} \approx 50$

バックグラウンド: ~99.8% 除去

ガンマ線: ~65% 生存

ガンマ線感度: ~10倍 感度UP!

100TeV:

カット $\Sigma N_{PE} \approx 1000$

バックグラウンド: ~99.99% 除去

ガンマ線: ~95% 生存

ガンマ線感度: バックグラウンドフリー!

1000TeV:

カット $\Sigma N_{PE} \approx 20000$

バックグラウンド: \gg ~99.99% 除去

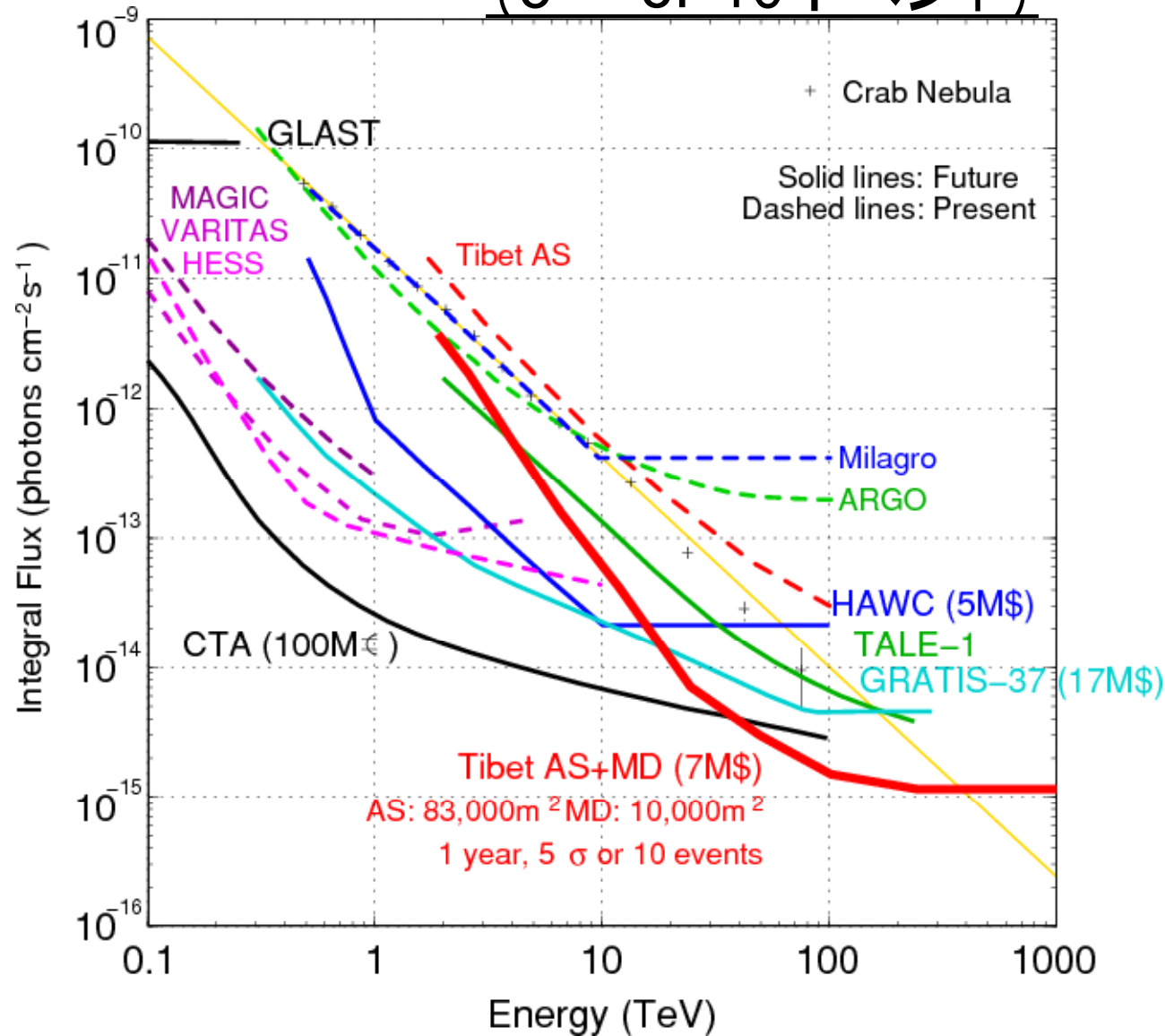
ガンマ線: ~99% 生存

ガンマ線感度: バックグラウンドフリー!

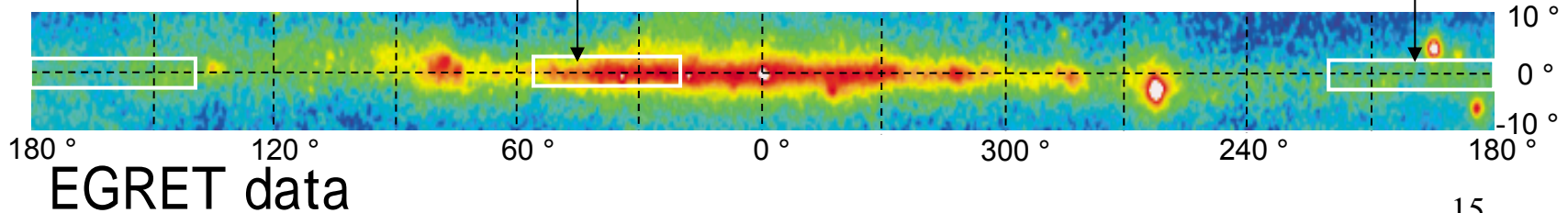
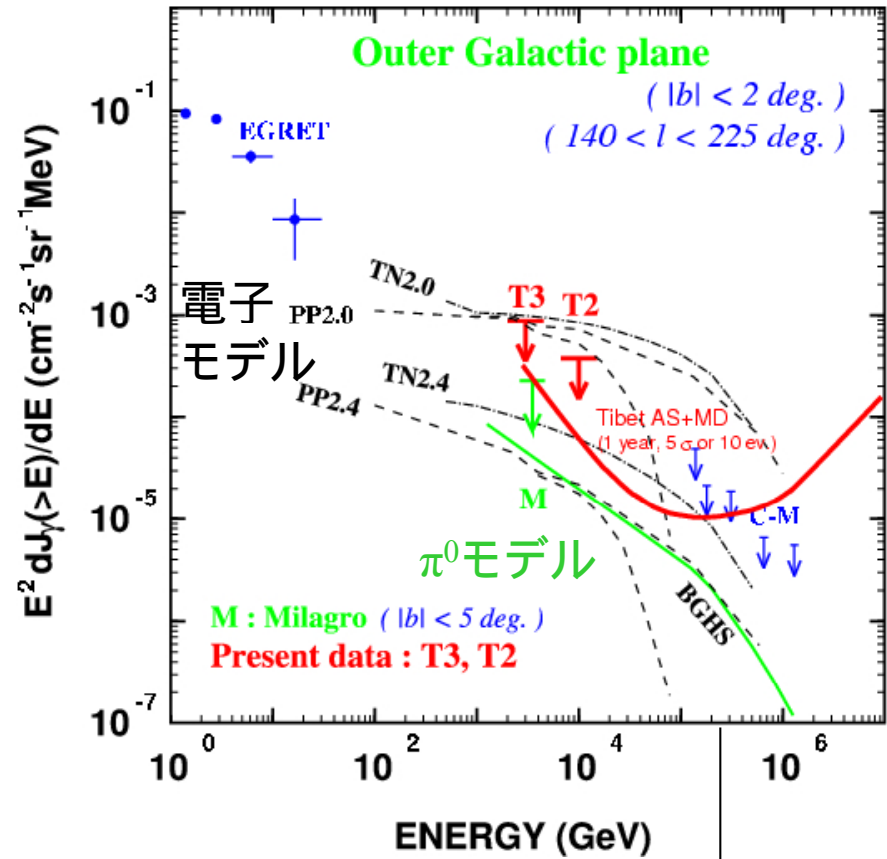
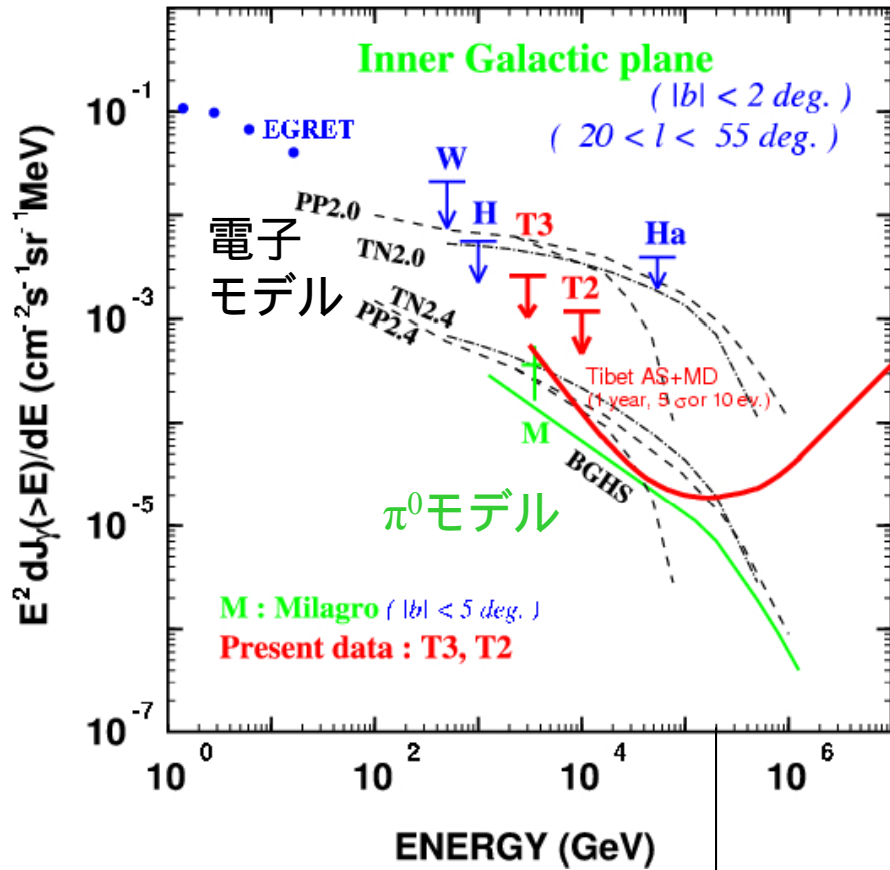
	Tibet AS+MD >~100 TeV	HESS >~TeV
Location	30N-90E	23S-16E
FOV	~2 sr	~0.02 sr
Duty cycle	~90%	~10%
θ Resolution	~0.2 °	~0.1 °
E Resolution	~40%	~20%
Background Rejection	~99.99%	~99%
S/N Ratio (RX J1713)	S/N = 80ev / 0.5ev (1yr in 0.6° radius, >100TeV)	S/N = 2500ev / 2000ev (50hrs in 0.6° radius, >1TeV)
	S/N = 200 / 5 (1yr in 0.6° radius, >40TeV)	S/N = 20 / 20 (50hrs in 0.6° radius, >40TeV)

Comparison with other experiments or future plans

(5 or 10 イベント)



銀河面からのDiffuseガンマ線



まとめ

チベットMD計画

~ 83000 m² チベット空気シャワー観測装置+

~ 10000 m² 水チェレンコフミュオン観測装置

→100TeV領域(10-1000TeV)ガンマ線の観測(宇宙線加速限界と拡散線)

シミュレーションによる予想感度

$F(>100(20)\text{TeV}) \sim 10^{-15} \text{ cm}^{-2} \text{ s}^{-1} \sim 10(5) \% \text{ Crabs}$

→従来より1桁以上ガンマ線に対する感度が改善

>10-20TeV で>HESS, >30-40TeVで>CTA

北天100TeV領域のガンマ線候補天体:

観測可能天体 : Diffuse γ from Milky way,

(1 year)

Crab, TeV J2032+4130,

MGRO J2019+37, MGRO J1908+06, MGRO J2031+41

HESS J1837-069, Mrk 421

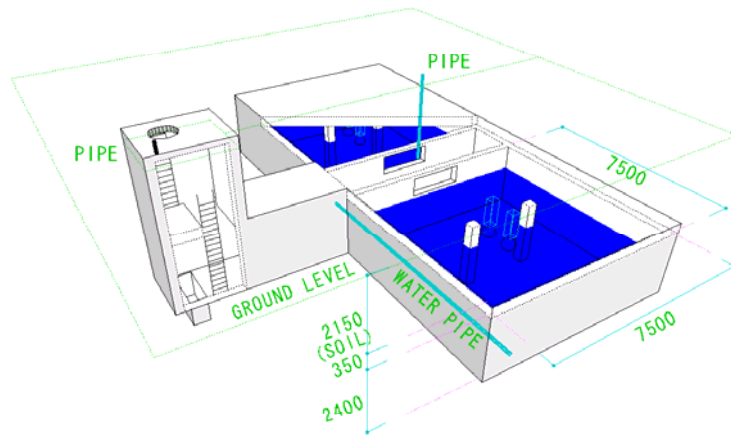
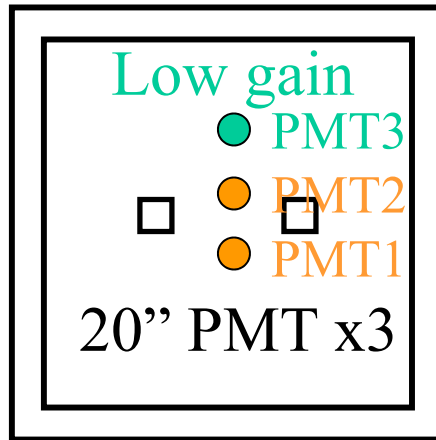
面白そう : Cas A, M87, HESS J1834-089, HESS J0632+058

(Several years)

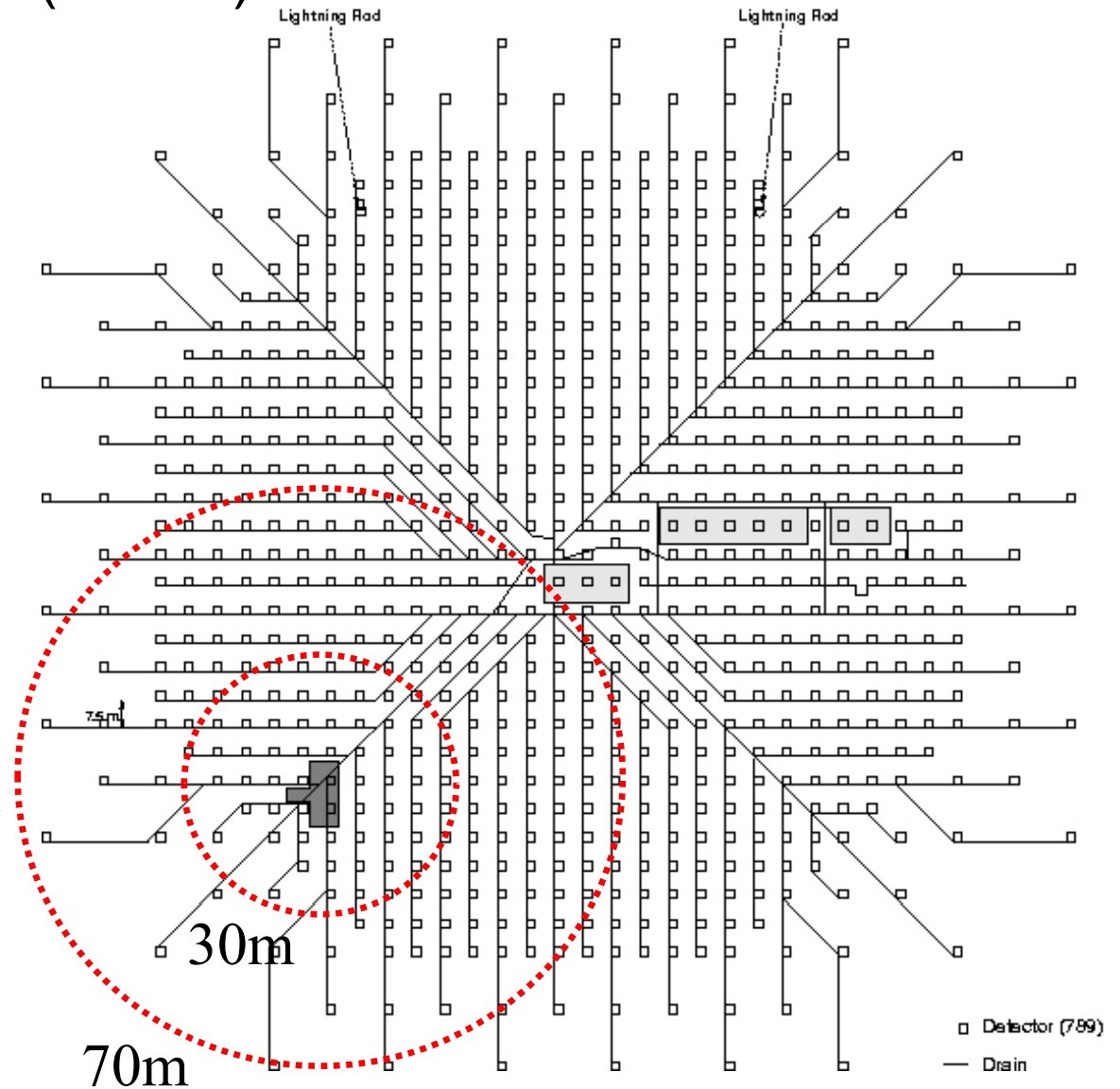
Mrk 501, LS I +61 303, IC443, Extragalactic Diffuse γ ???

予想未知天体数 : 数個-10個位!?

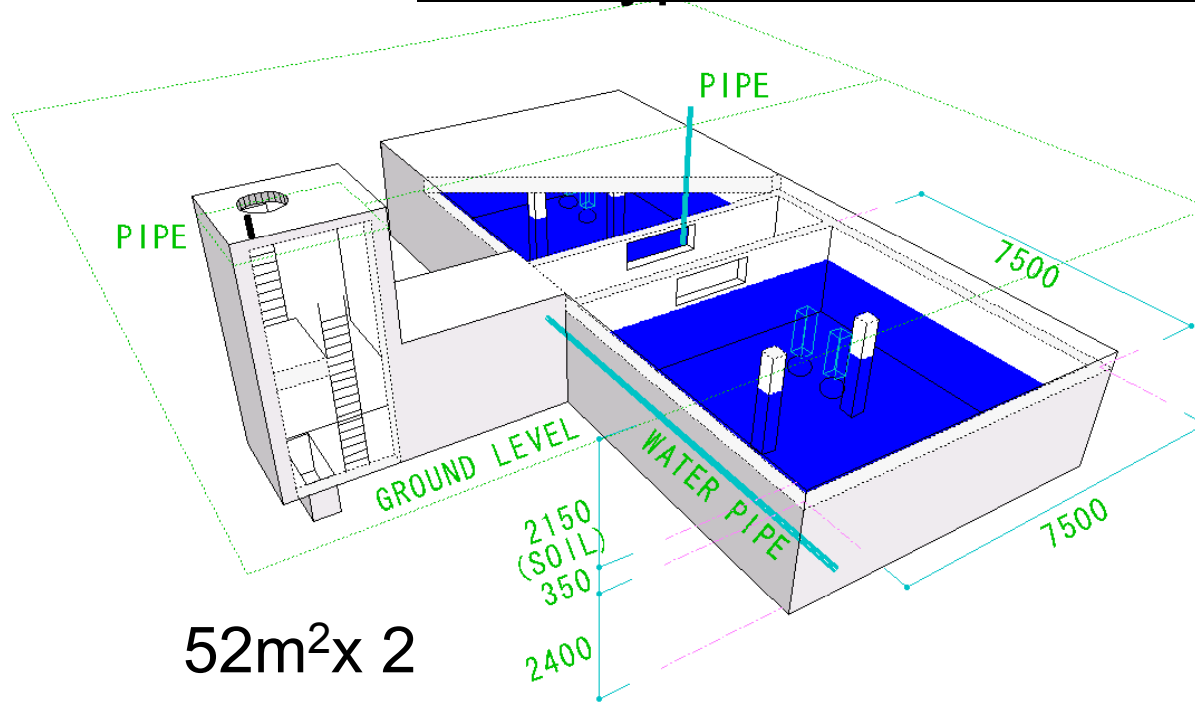
Proto-type Muon Detector (100m²)



50m² x 2 cells
1.5m depth water



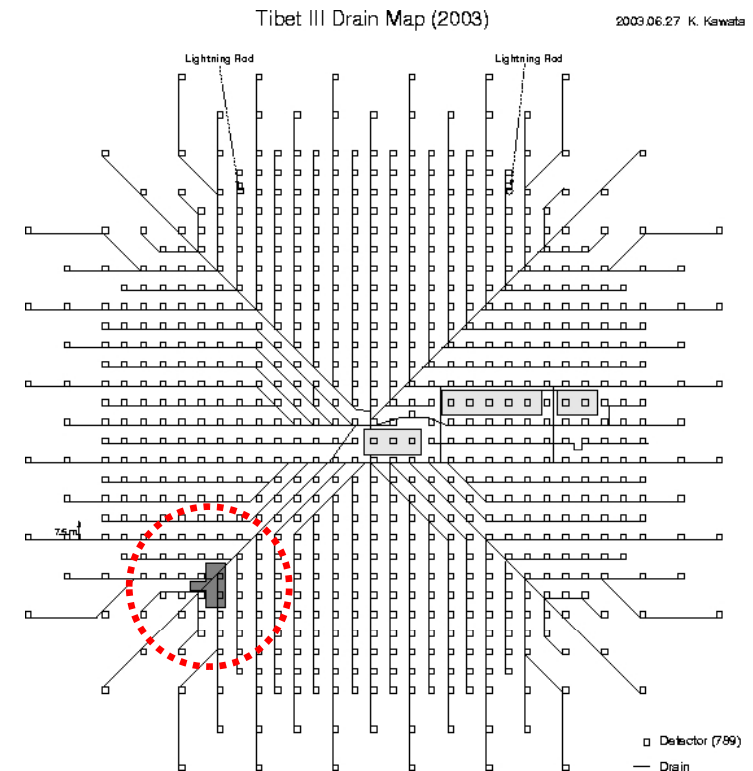
Prototype Muon Detector in Tibet



52m²x 2

- Construction feasibility in Tibet ?
- MC simulation OK?
- γ observation above multi 100 TeV

Construction from
Sep. 2007
Data taking from
Dec. 2007





16 November, 2007

Prototype Muon Detector



Prototype Muon Detector after backfilling

Inside of the Prototype MD

Clear underground water
from a nearby well

20" ϕ PMT x 3:
(Normal gain x 2, 1/100 gain x 1 for test)

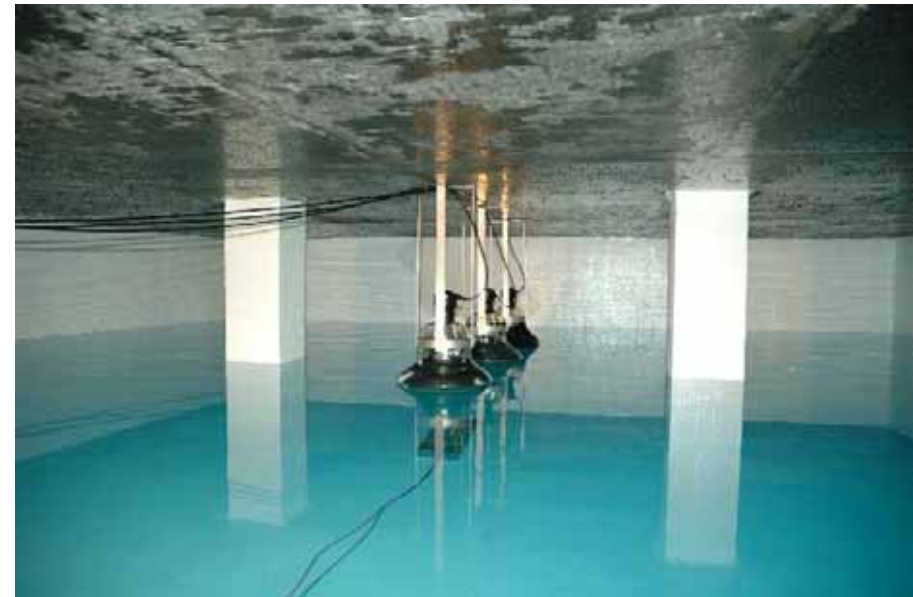
Water depth : 1.5 m



White paint



Pouring very clear well-water



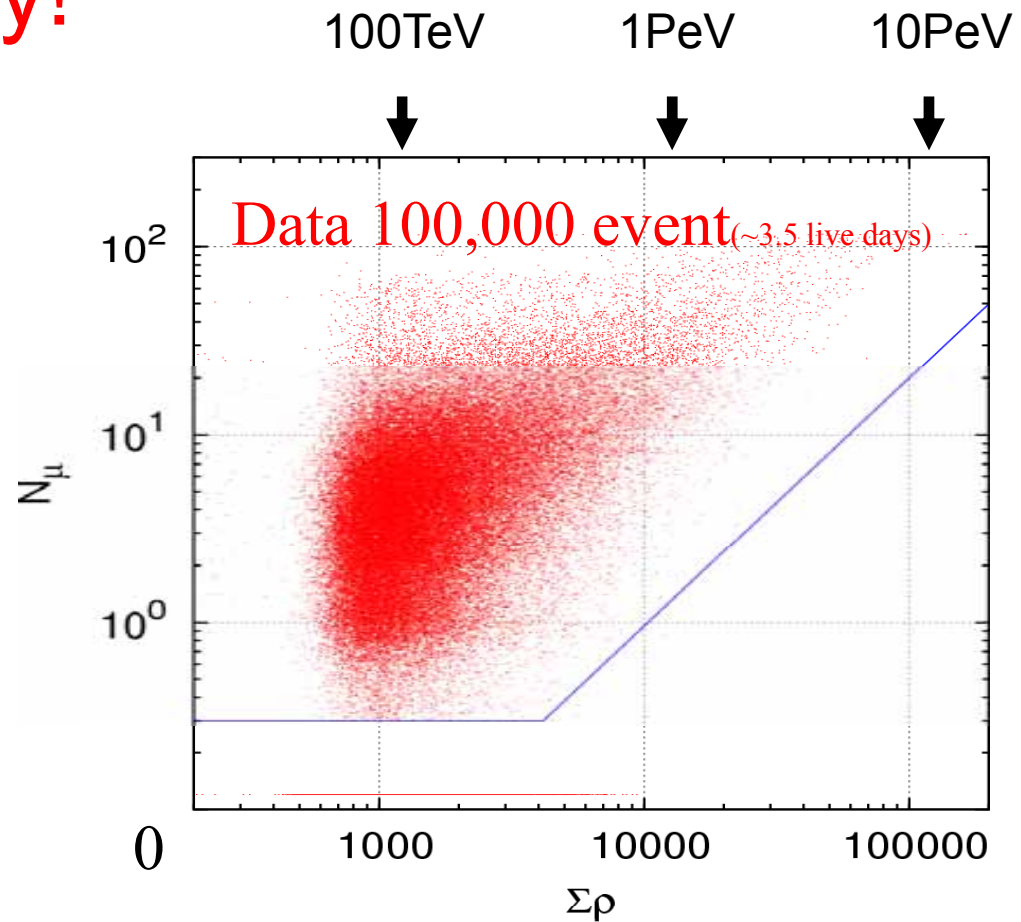
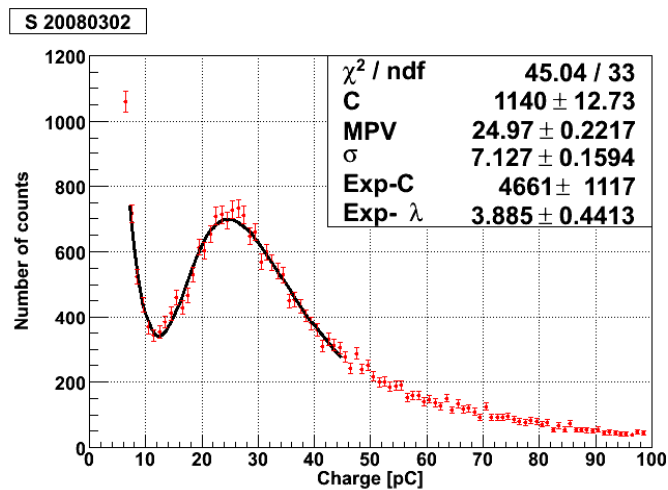
Filled up water 1.5 m in depth

Data Analysis

Air Shower Size v.s. N_μ
Low-energy events are cut ($E_{th} = \sim 50 \text{ TeV}$)

Very Preliminary!

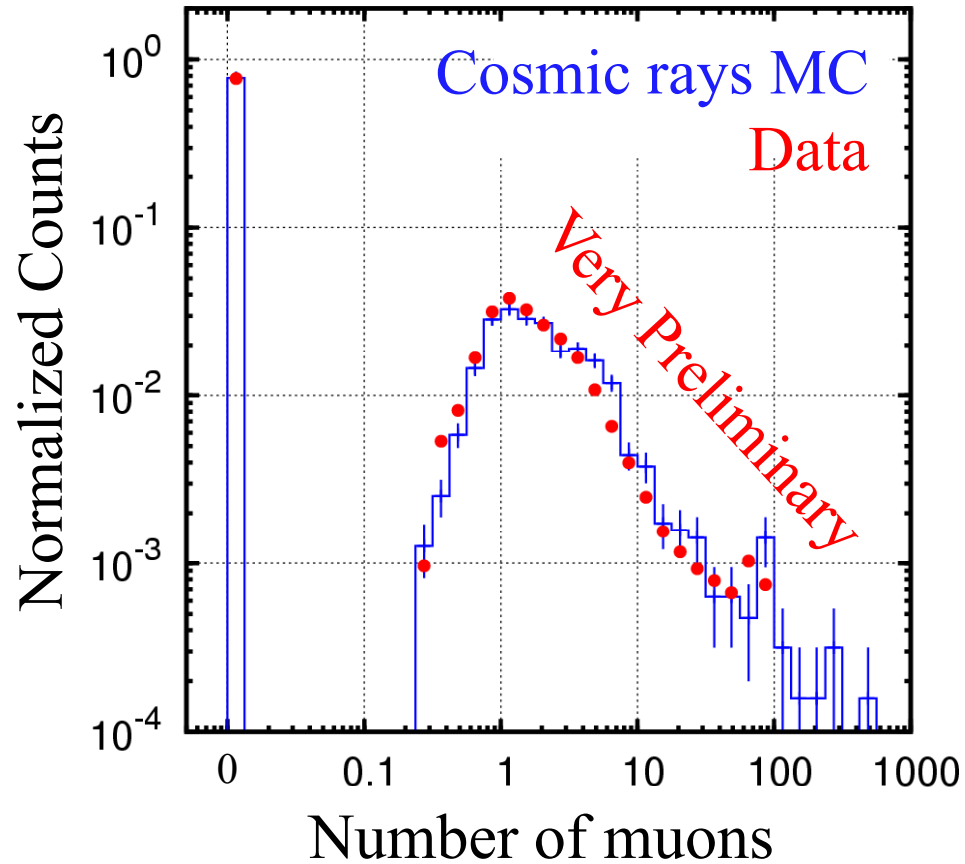
Single Muon Peak



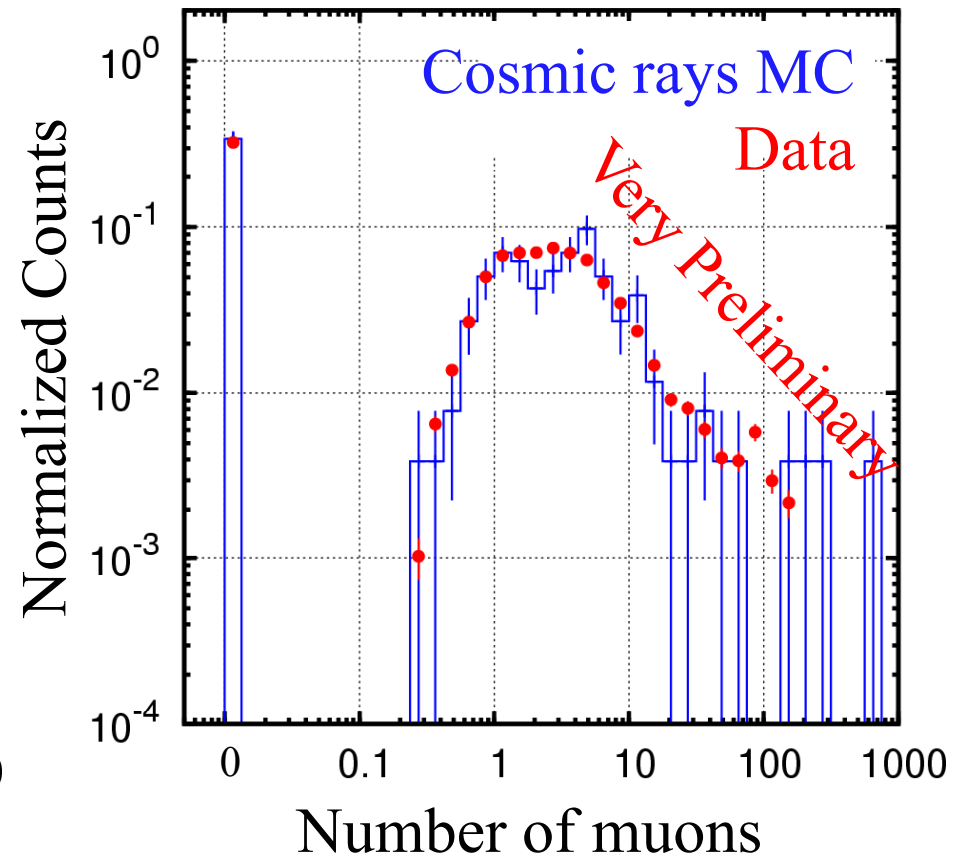
$\Sigma\rho (\propto \text{Air Shower Size})$

Number of muons

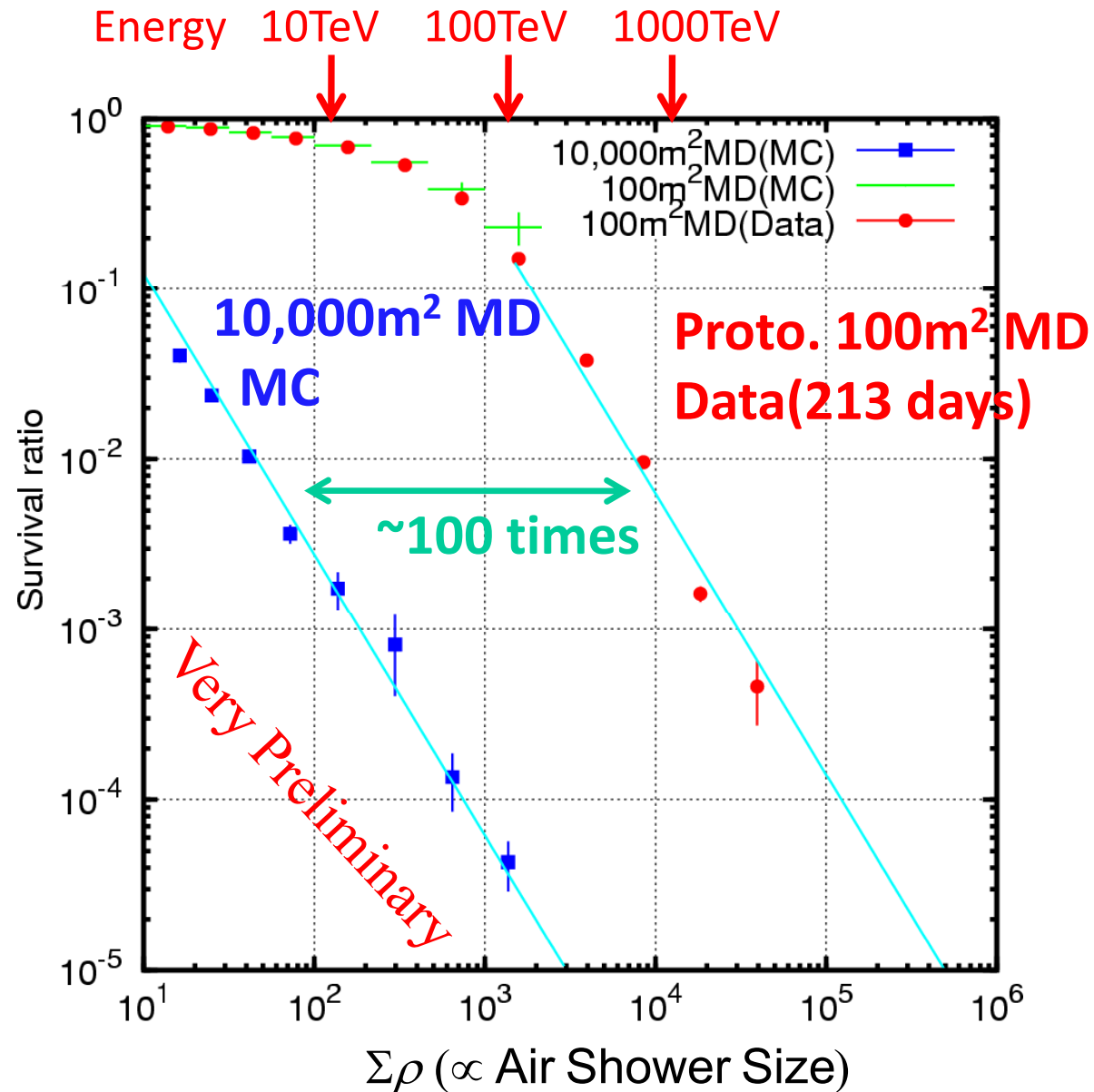
~10 TeV Air Showers



~100 TeV Air Showes

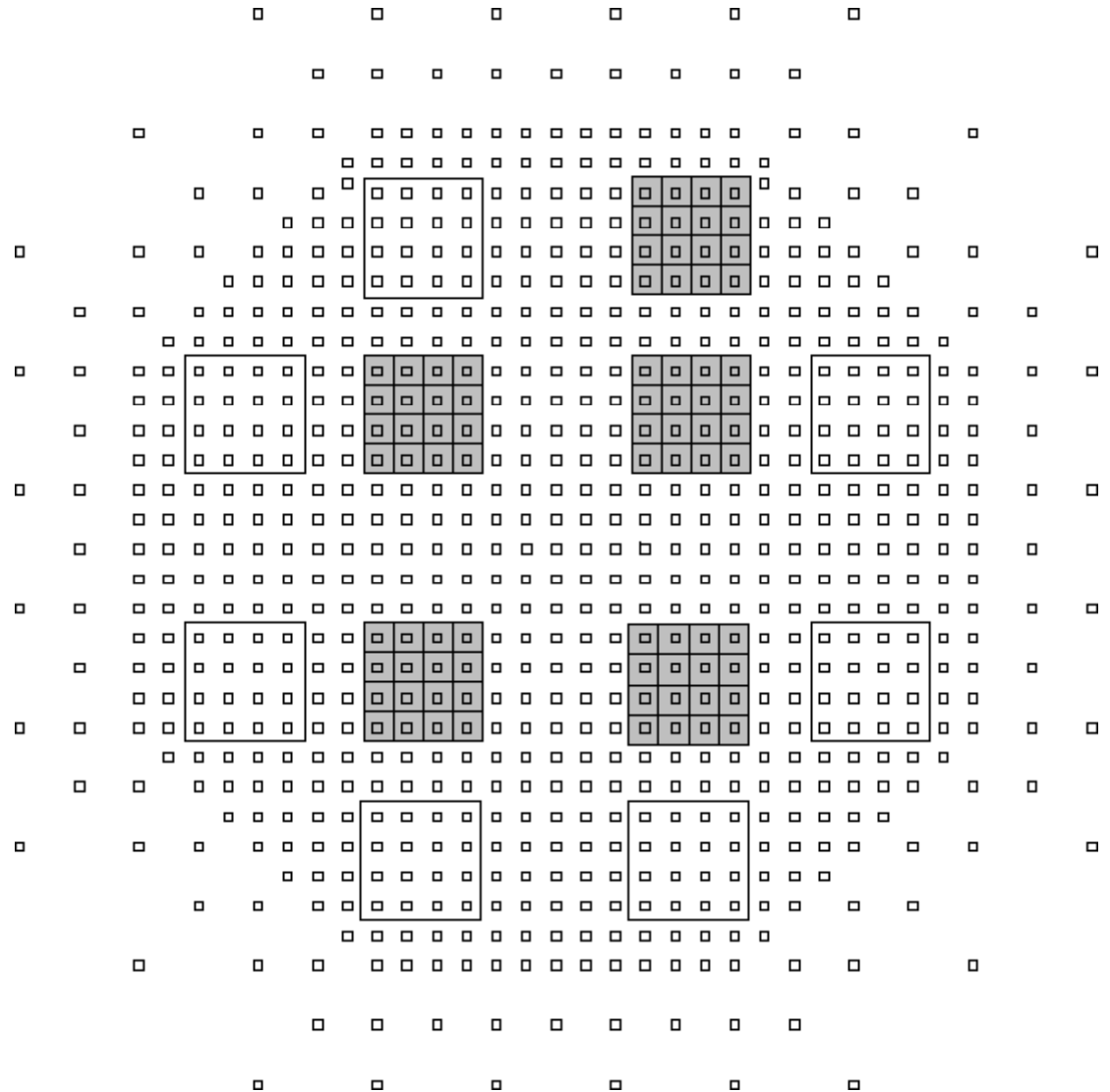


Cosmic Ray (Nucleus) Survival Ratio



Status of MD Construction

**~1/3 Full MD
under construction**





MD construction scene



Installing a 20 inch PMT in a MD cell.



Tyvek sheet walls and two 20 inch PMTs

MD Summary

Prototype MD (52 m² x 2 cells)

– Successfully completed (2007)

Data vs MC in reasonable agreement

CR survival ratio: ~0.2 % @ ~1 PeV

-> Full (10⁴m²) MD @ ~10 TeV

-> Full (10⁴m²) MD MC: OK up to ~10 TeV

~1/3 Full MD under construction

Data-taking will start in 2012

YAC II

(Dense version) (建設中)

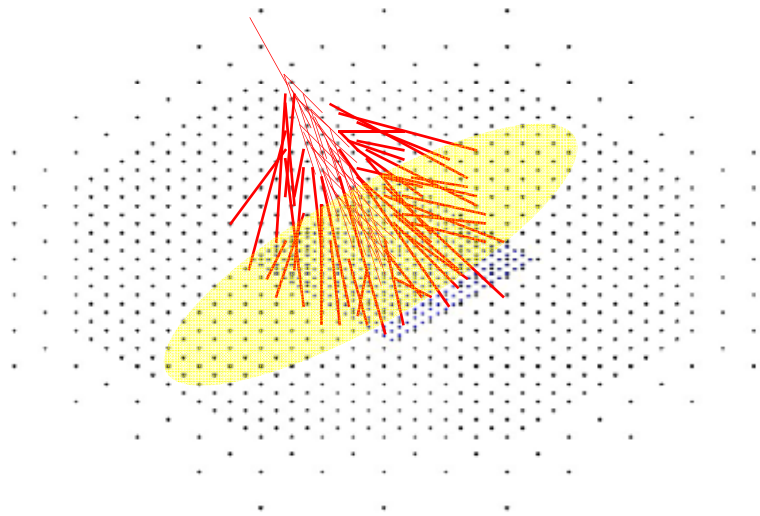
YAC II detector consists of 100 burst detectors with 1.5m spacing between detectors.

Total area of the array is 160 m² located near the center of Tibet III AS array.

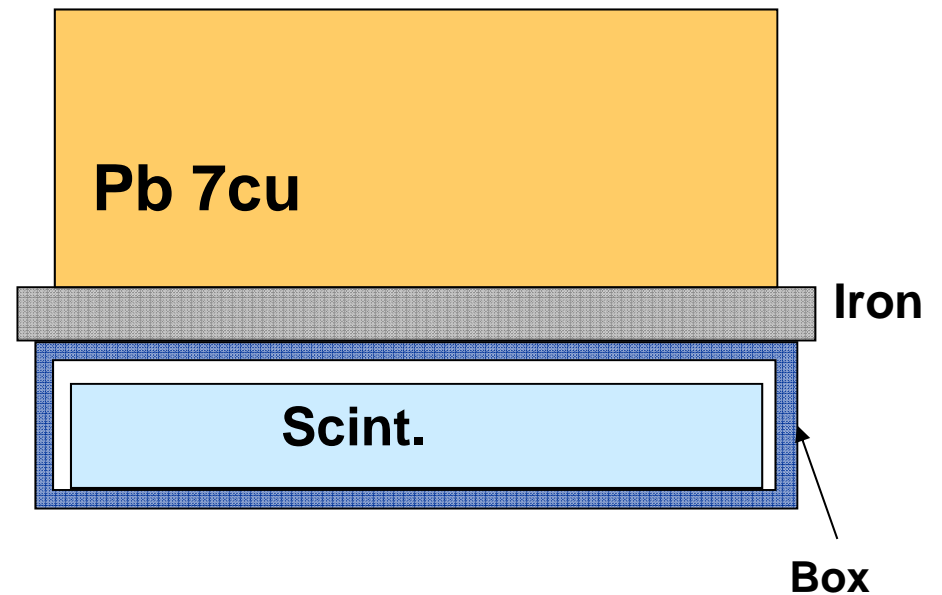
It is designed to measure proton and helium spectra in the knee region. Expected number of protons (>100TeV) and helium (>200TeV) using HD model are 2300 and 800 per one year, respectively.

Design of YAC-II

40cm x 50cm, 100 channels $S=160\text{m}^2$

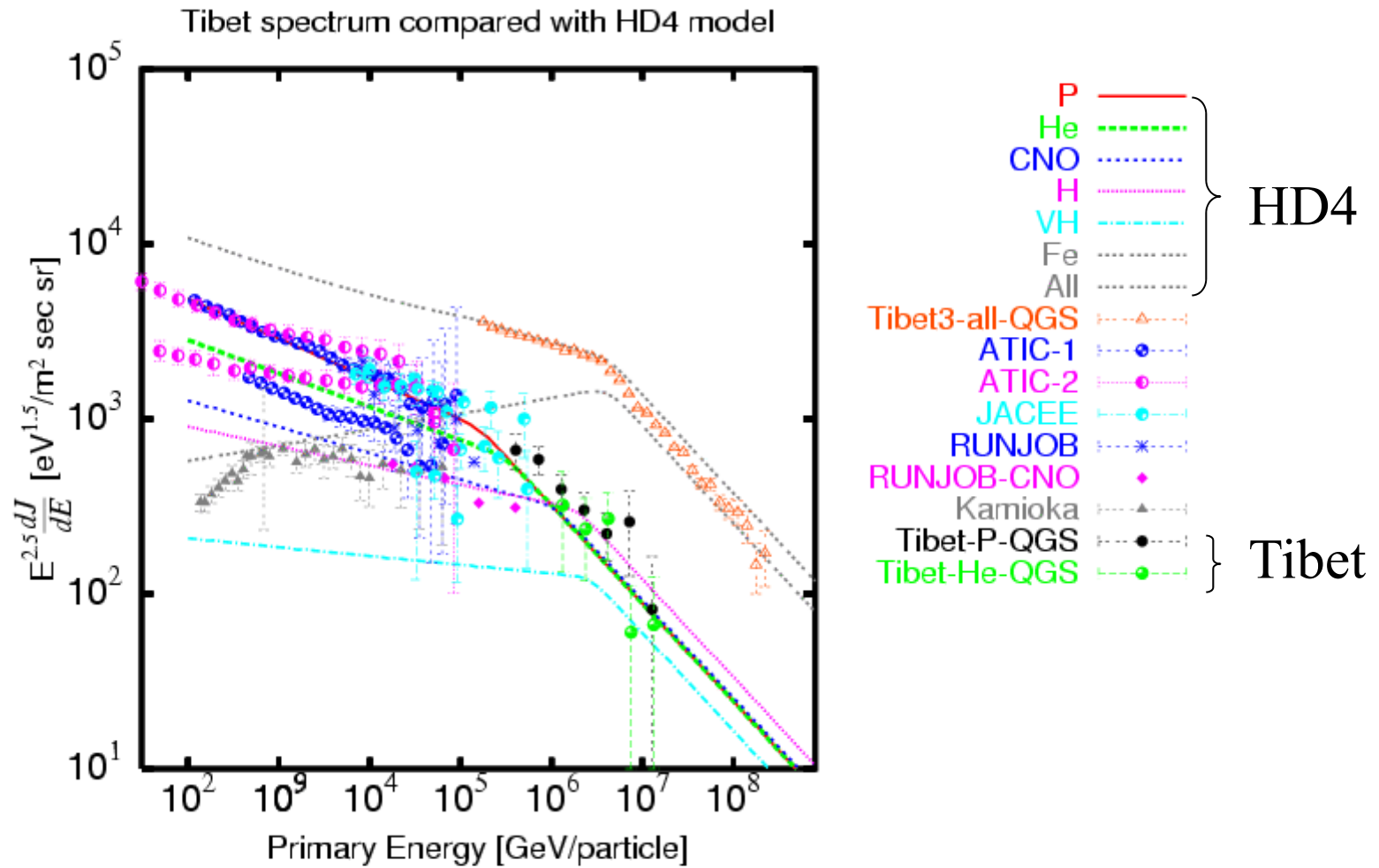


1.5m spacing 100ch
 $N_b > 100$ 電子数,
any 1 ($>30\text{GeV}$)

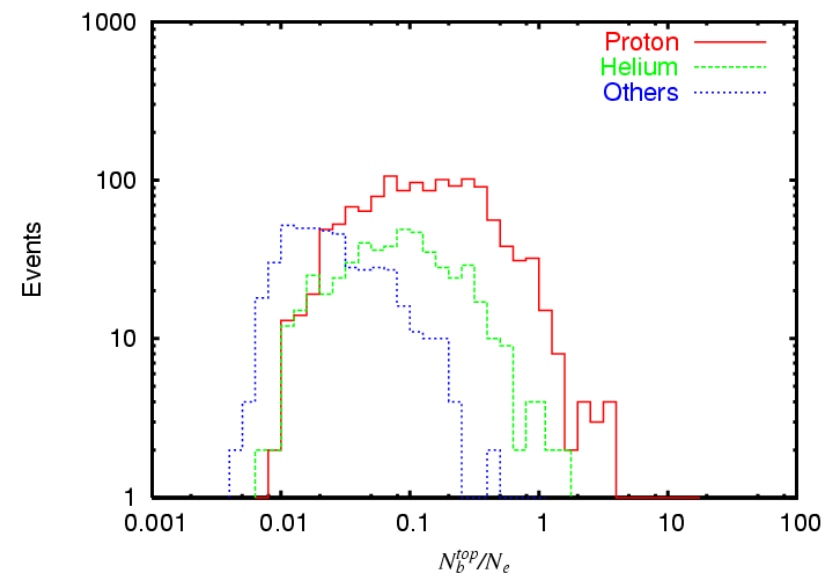
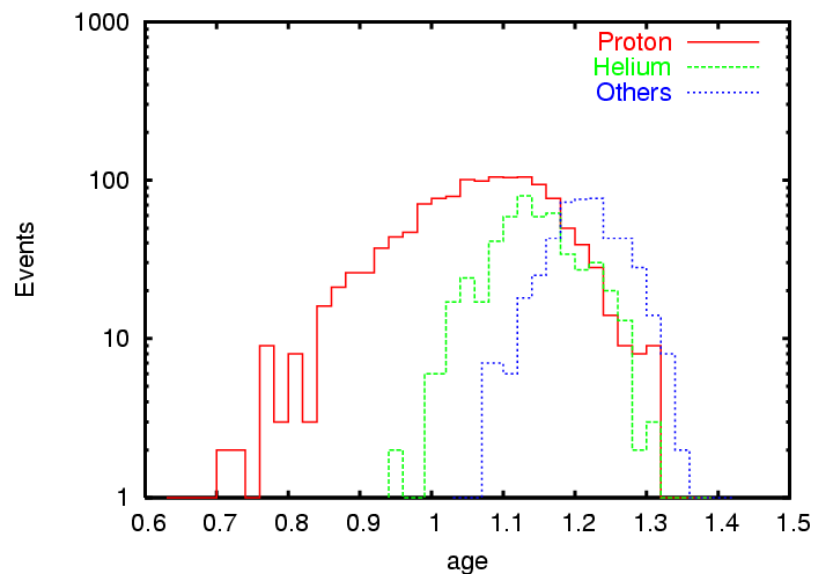
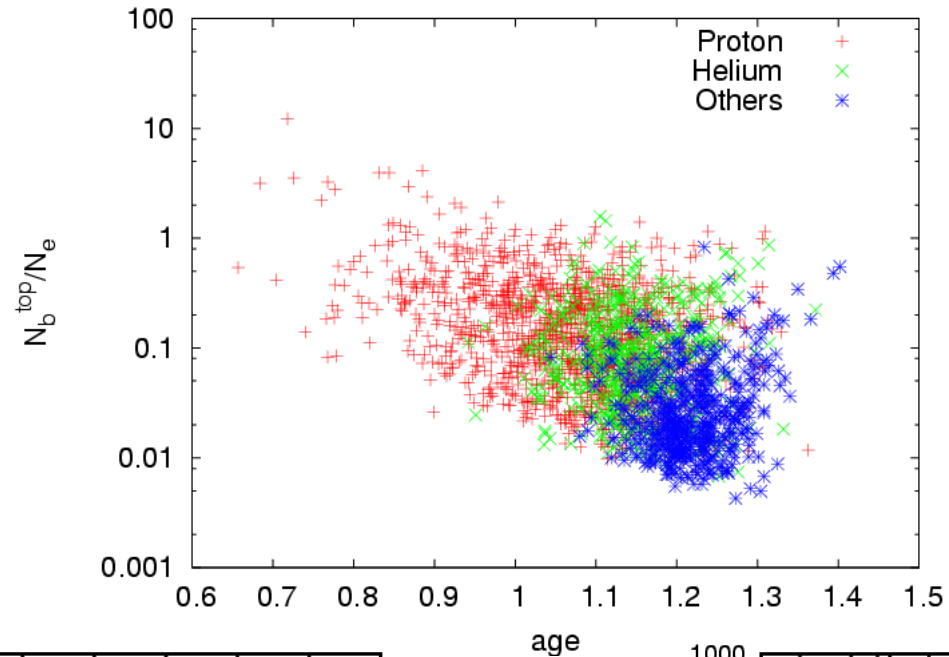


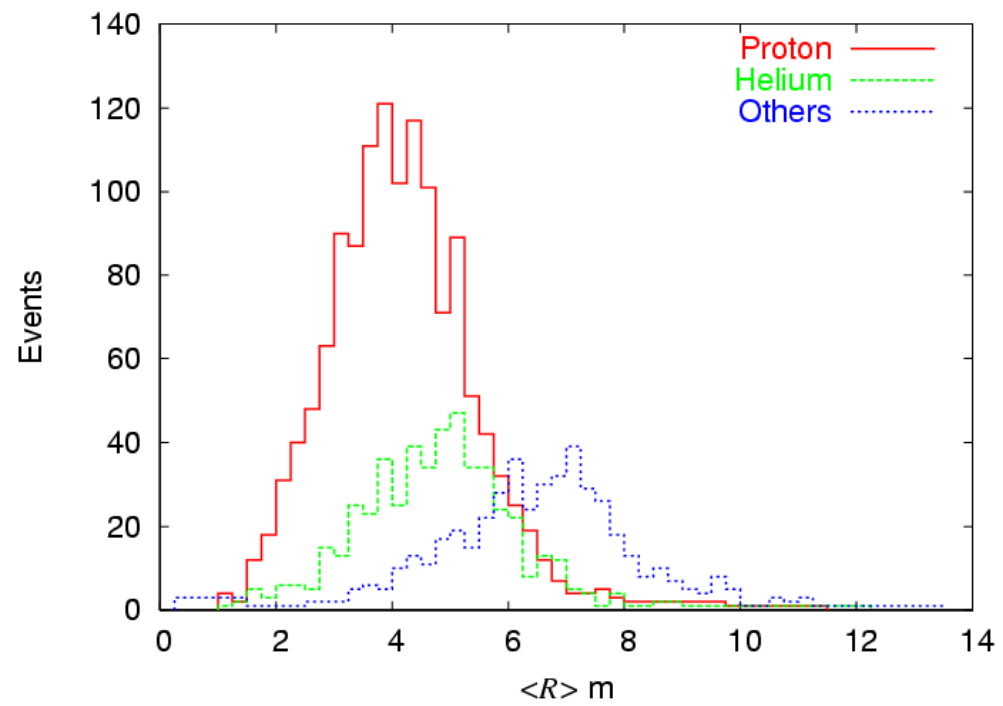
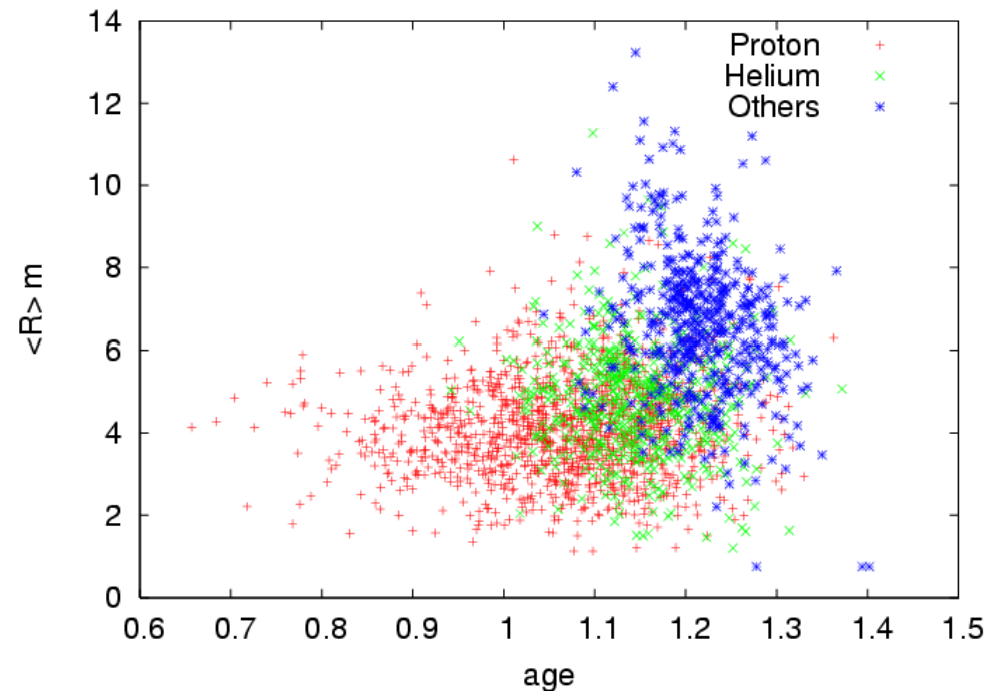
Wave length shifting fiber
+ 2 PMTs
(Low gain & High gain)
 $10^2 < N_b < 10^6$

Tibet All, P, He spectrum



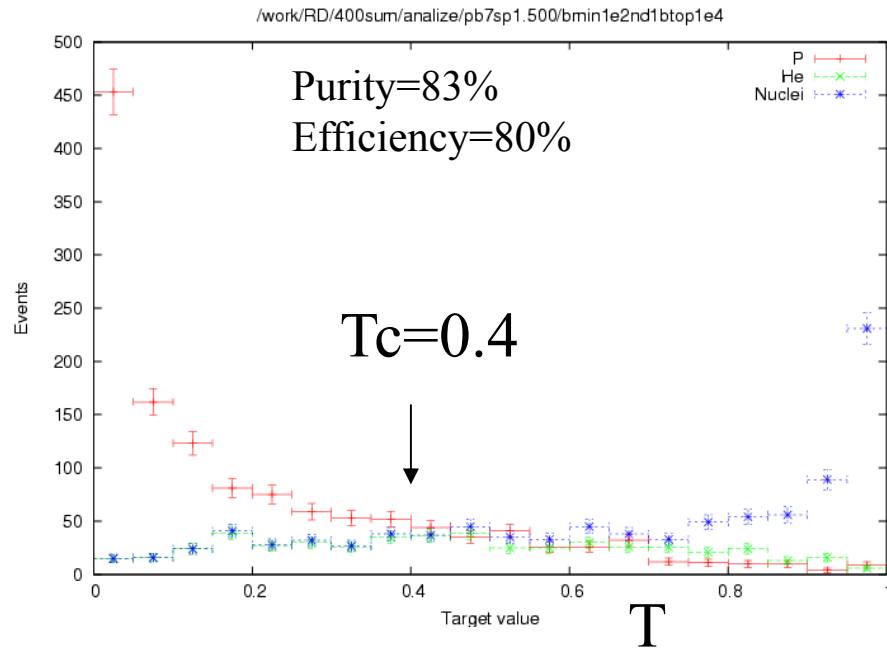
Features of YAC-II observables





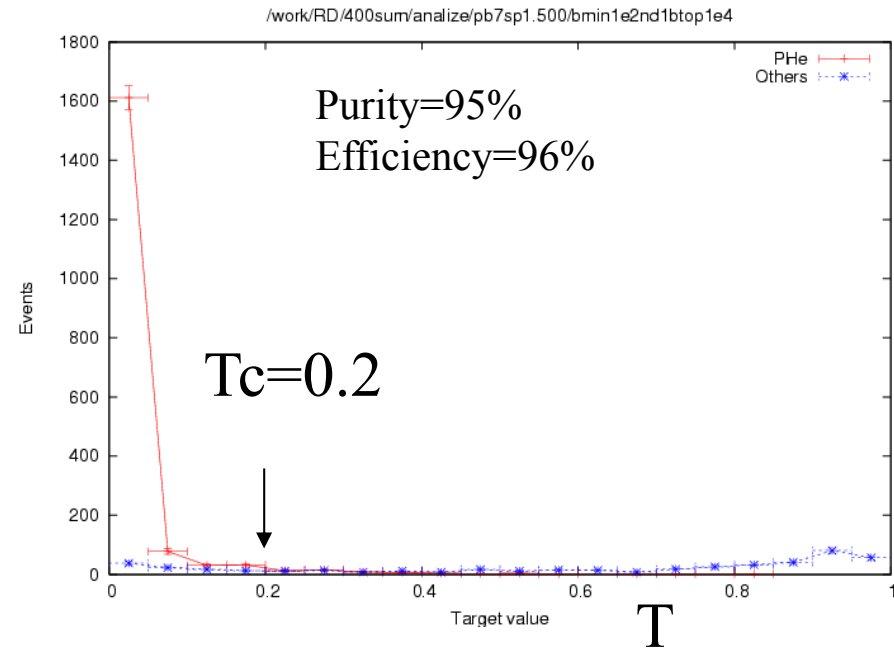
ANN output

Proton separation



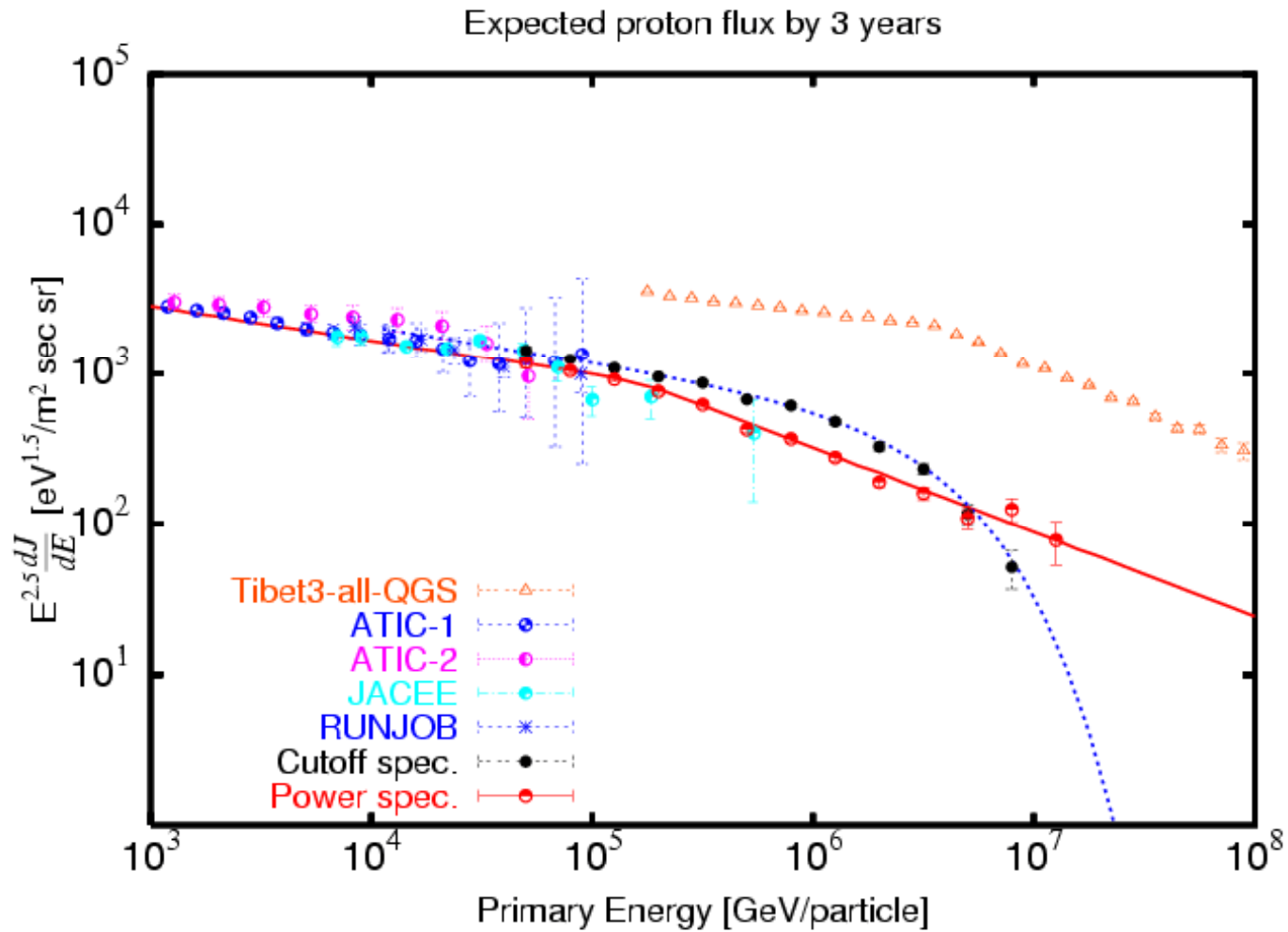
Contamination is exclusively by helium nuclei.
The fraction of helium events missidentified as protons is about 40% of helium events by $T_c=0.4$.

P+He separation

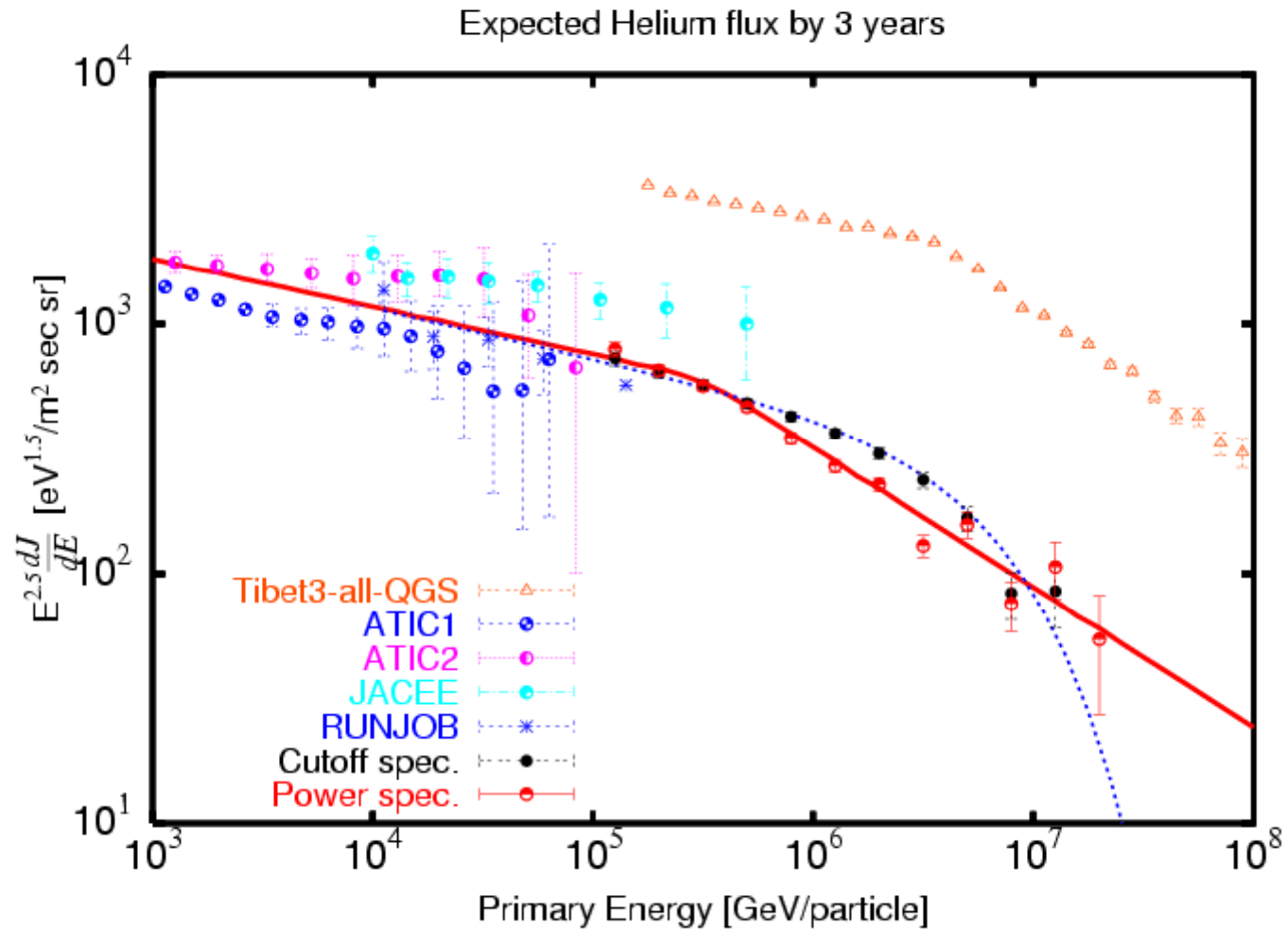


20% of heavier nuclei than helium contaminates to P+He region.

Expected proton spectrum (YAC-II)



Expected He Spectrum (YAC-II)



YAC III

(Wide version) 2.5億円

YAC III detector consists of 400 burst detectors with 3.75m spacing between detectors.

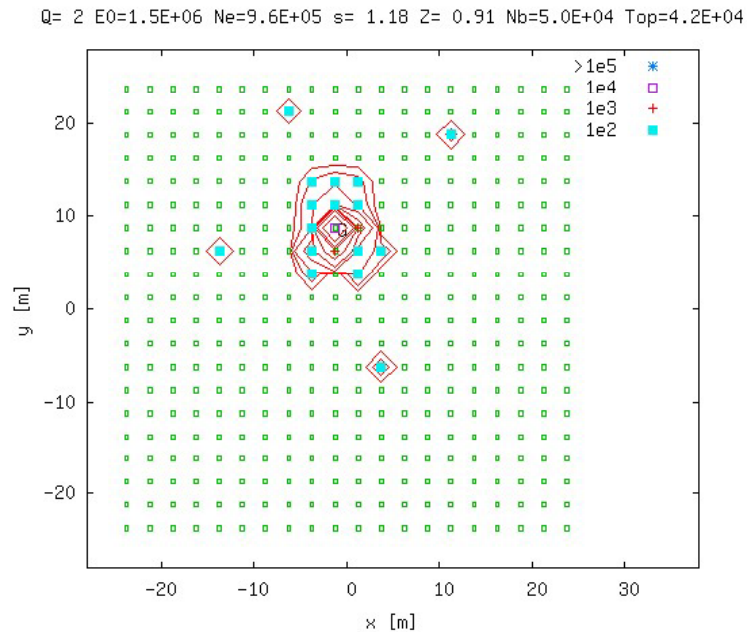
Total area of the array is 5000 m² located near the center of Tibet III AS array.

It is designed to measure iron group spectra in the knee region. Expected number of irons (>1000TeV) using HD model is 4400 per one year.

Design of YAC-III

40cm x 50cm, 20x20 channels

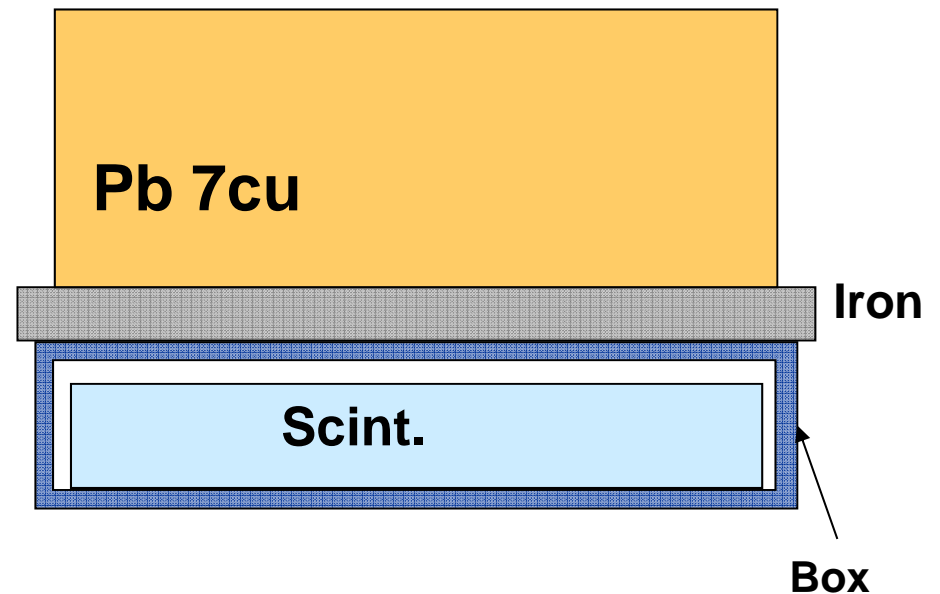
$$S=5000\text{m}^2$$



3.75m spacing 400ch

$N_b > 100$, any 5

(>30GeV)



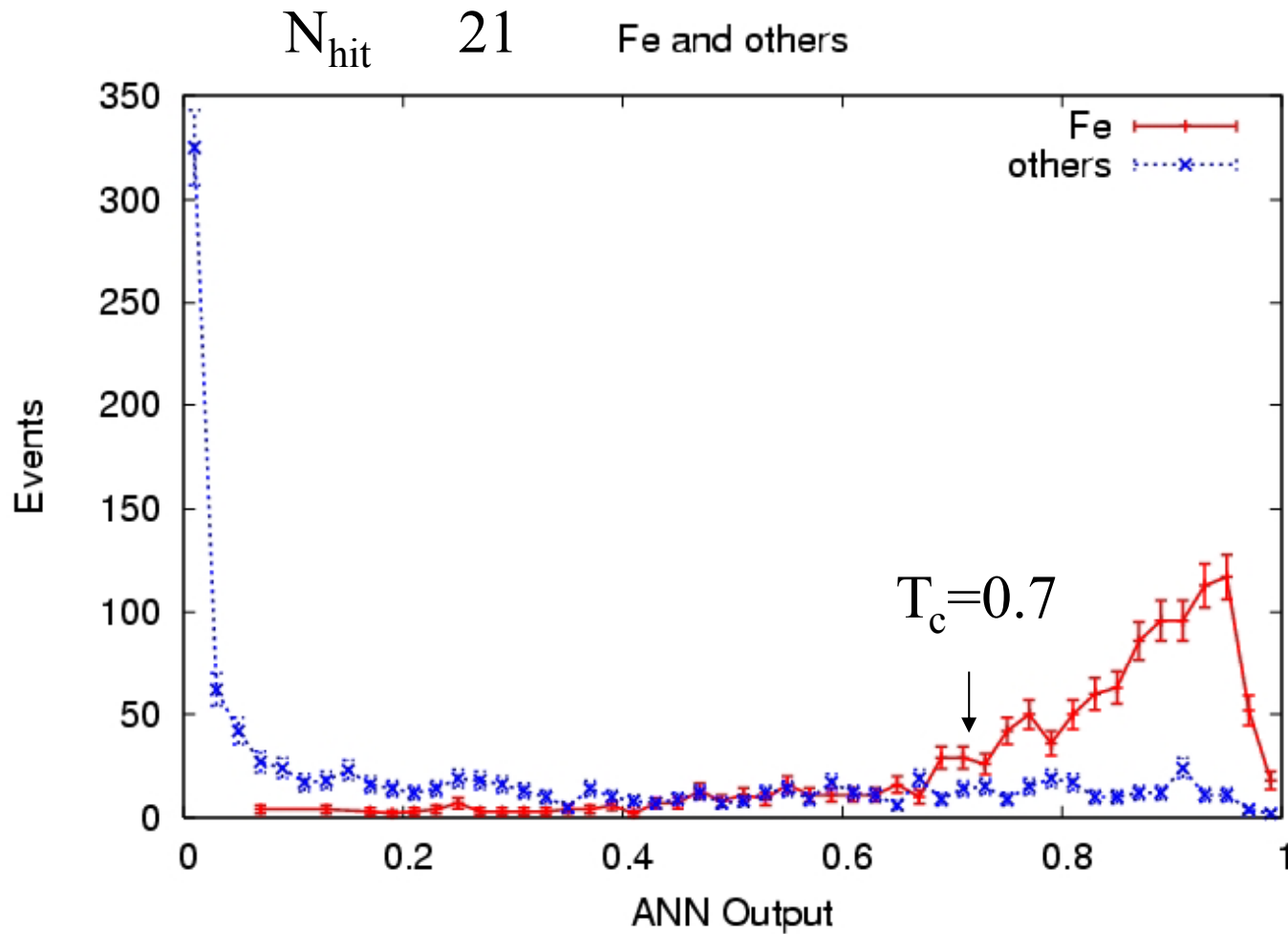
Wave length shifting fiber

+ 2 PMTs

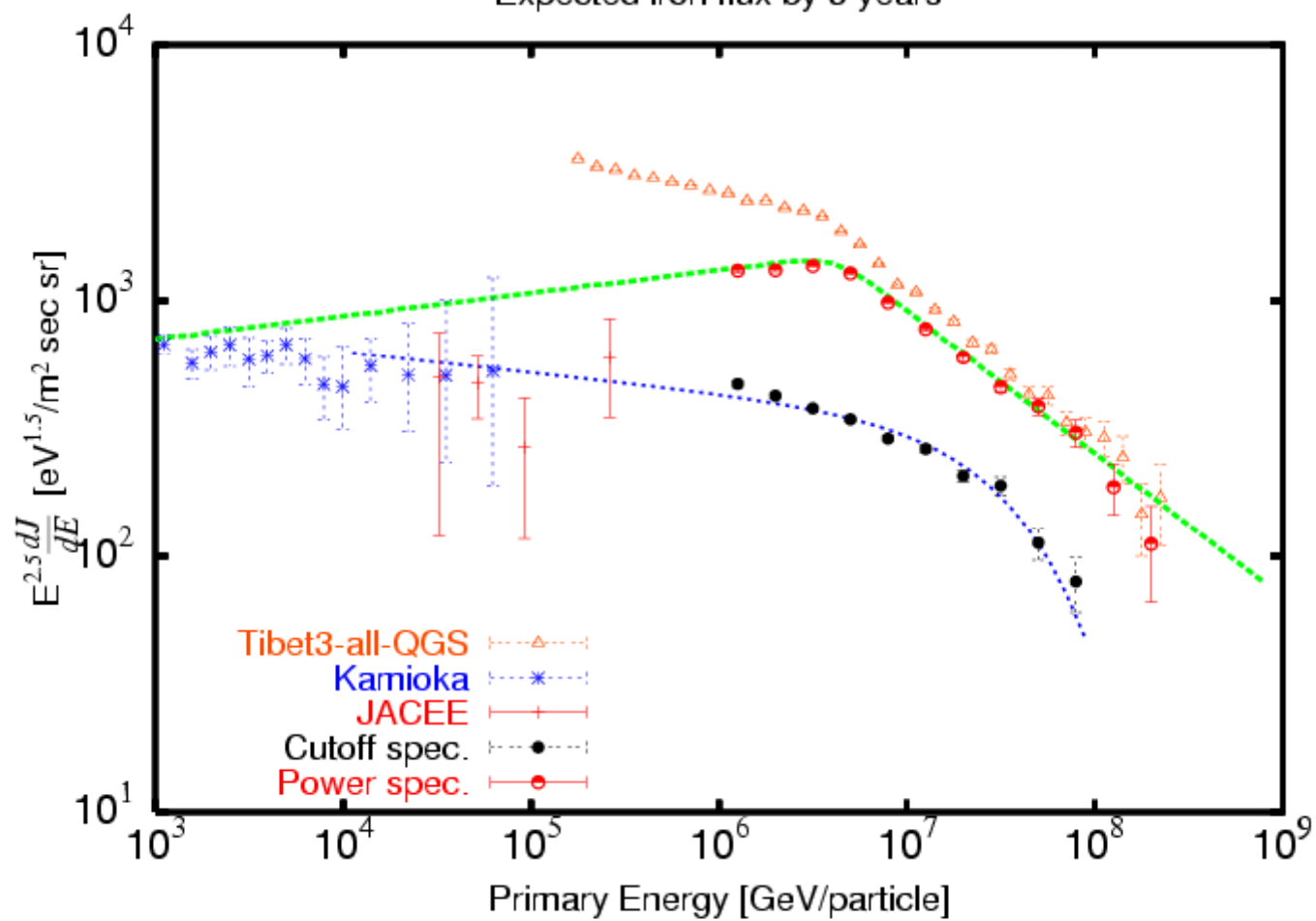
(Low gain & High gain)

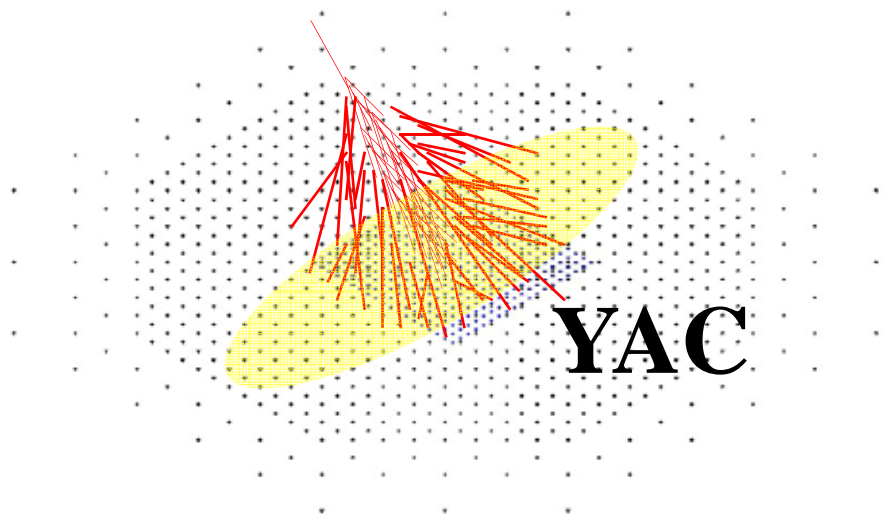
$$10^2 < N_b < 10^6$$

Separation of Fe by YAC III



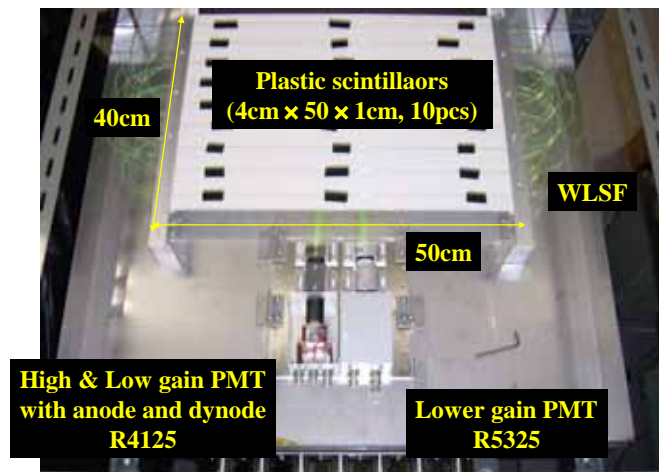
Expected iron flux by 3 years





Proto-type YAC Detector

Prototype of YAC
(Yangbajing Air shower Core detector)



YAC-II under construction



Data-taking will start 2012

- R&D DONE for MD&YAC
- ~1/3 MD under construction
YAC-II under construction
- We are ready for the rest of the plan, if funded.

End