

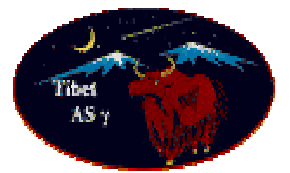
# Tibet実験の現状と将来

瀧田正人 ICRR

(For Tibet AS collaboration)

CRC宇宙線将来計画シンポジウム

@ICRR 07/01/2005



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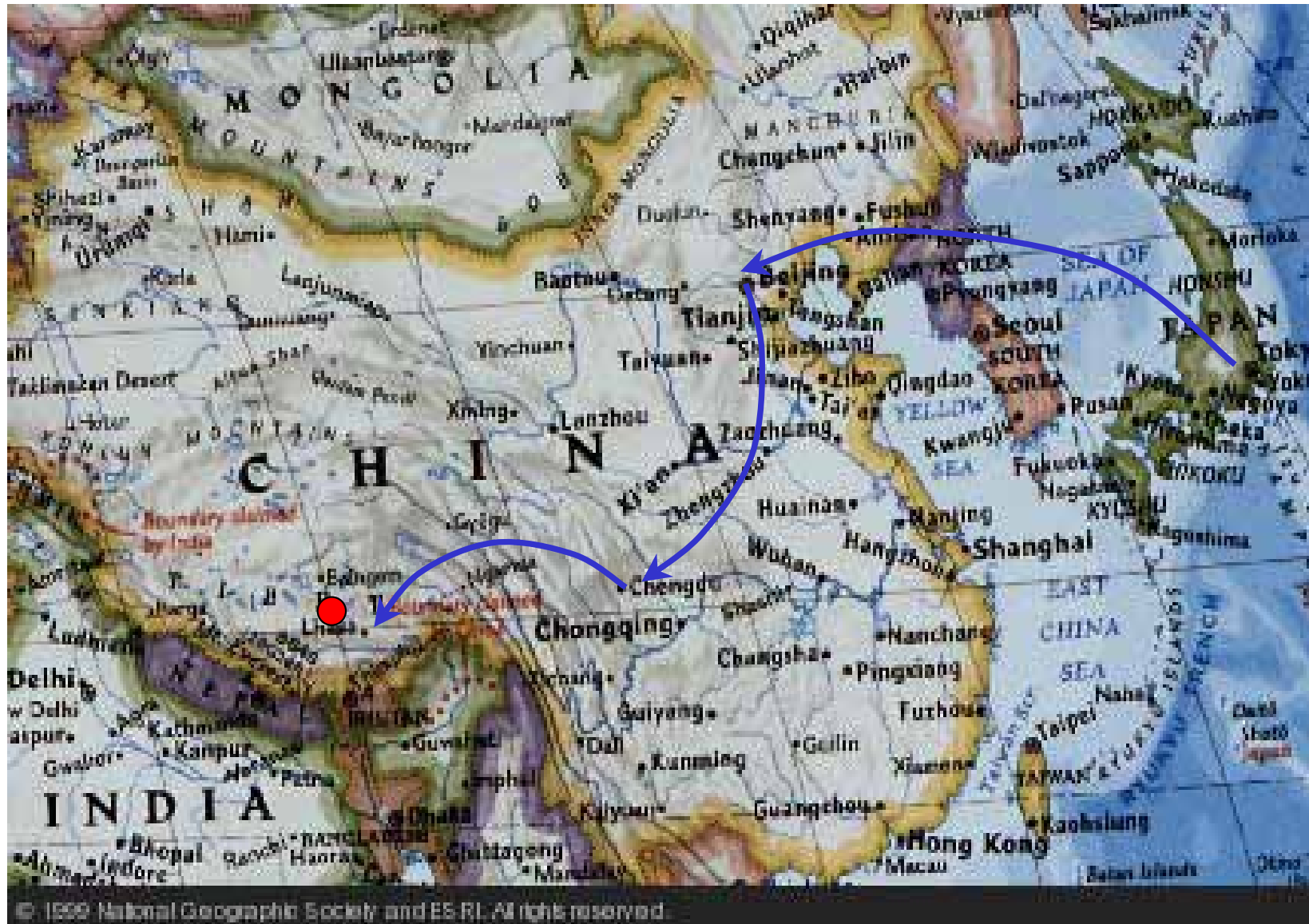
15 National Institute for Informatics, Tokyo 101-8430, Japan

16 Tokyo Metropolitan College of Aeronautical Engineering, Tokyo 116-0003, Japan

17 Shonan Institute of Technology, Fujisawa 251-8511, Japan

18 Department of Physics, Shinshu University, Matsumoto 390-8621, Japan

# Our site : Tibet



**Yangbajing , Tibet, China**

**90° 53E, 30° 11N, 4,300 m a.s.l. (606g/cm<sup>2</sup>)**

# Photo Gallery

## ポタラ宮殿

チベット仏教の聖地



## 納木湖

(ナムツォ)

チベット最大級の湖  
琵琶湖の3倍！！

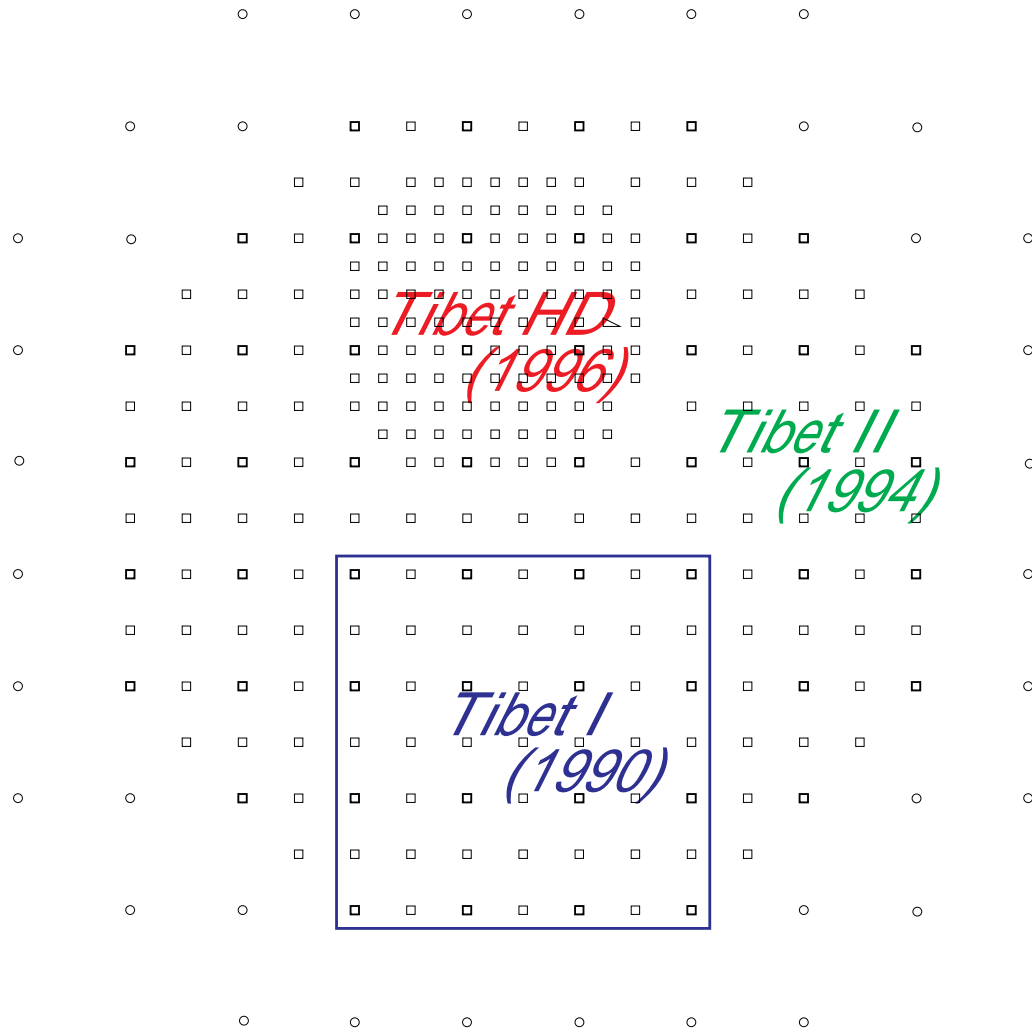
# 研究目的

大気チェレンコフ望遠鏡と相補的な  
広視野(約2sr)連続観測高エネルギー宇宙線望遠鏡

3 ~ 100TeVの高エネルギーガンマ線放射天体の  
探索、 $10^{14} \sim 10^{17}$ eVの一次宇宙線の観測から、  
宇宙線の起源、加速機構の研究を行う。

太陽活動期における“太陽の影”  
(太陽による宇宙線の遮蔽効果)を観測し、  
太陽近傍および惑星間磁場の大局的構造を知る。

# Tibet-I to Tibet-II/HD



Number of detector

I : 45

II : 185

HD: 109

Mode Energy

I : 10 TeV

II : 10 TeV

HD: 3 TeV

Area

I : 7,650 m<sup>2</sup>

II : 37,000 m<sup>2</sup>

HD: 5,200 m<sup>2</sup>

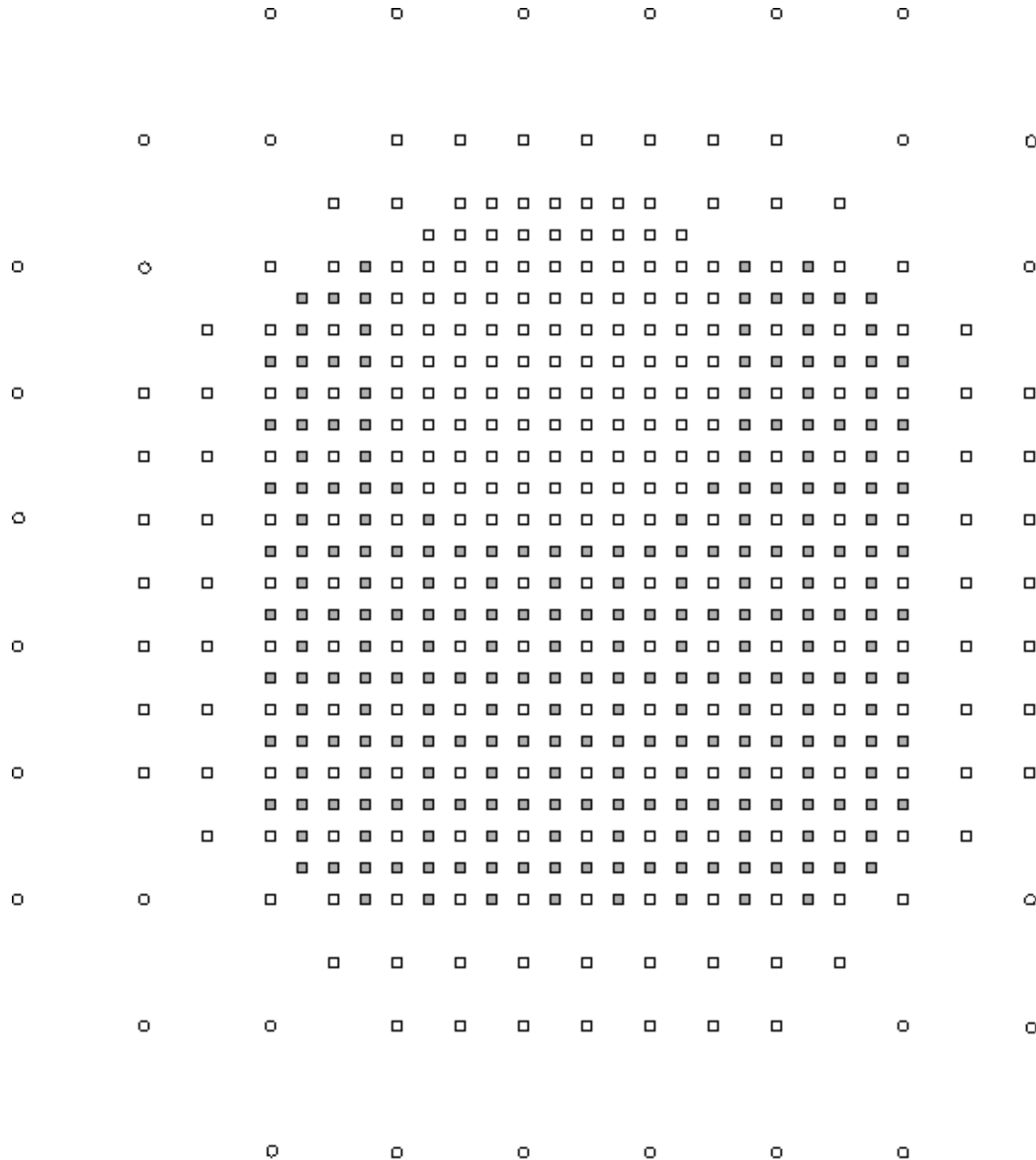


# Tibet III (22000m<sup>2</sup>)



Yangbajing (4300a.s.l.=606g/cm<sup>2</sup>), Tibet, China

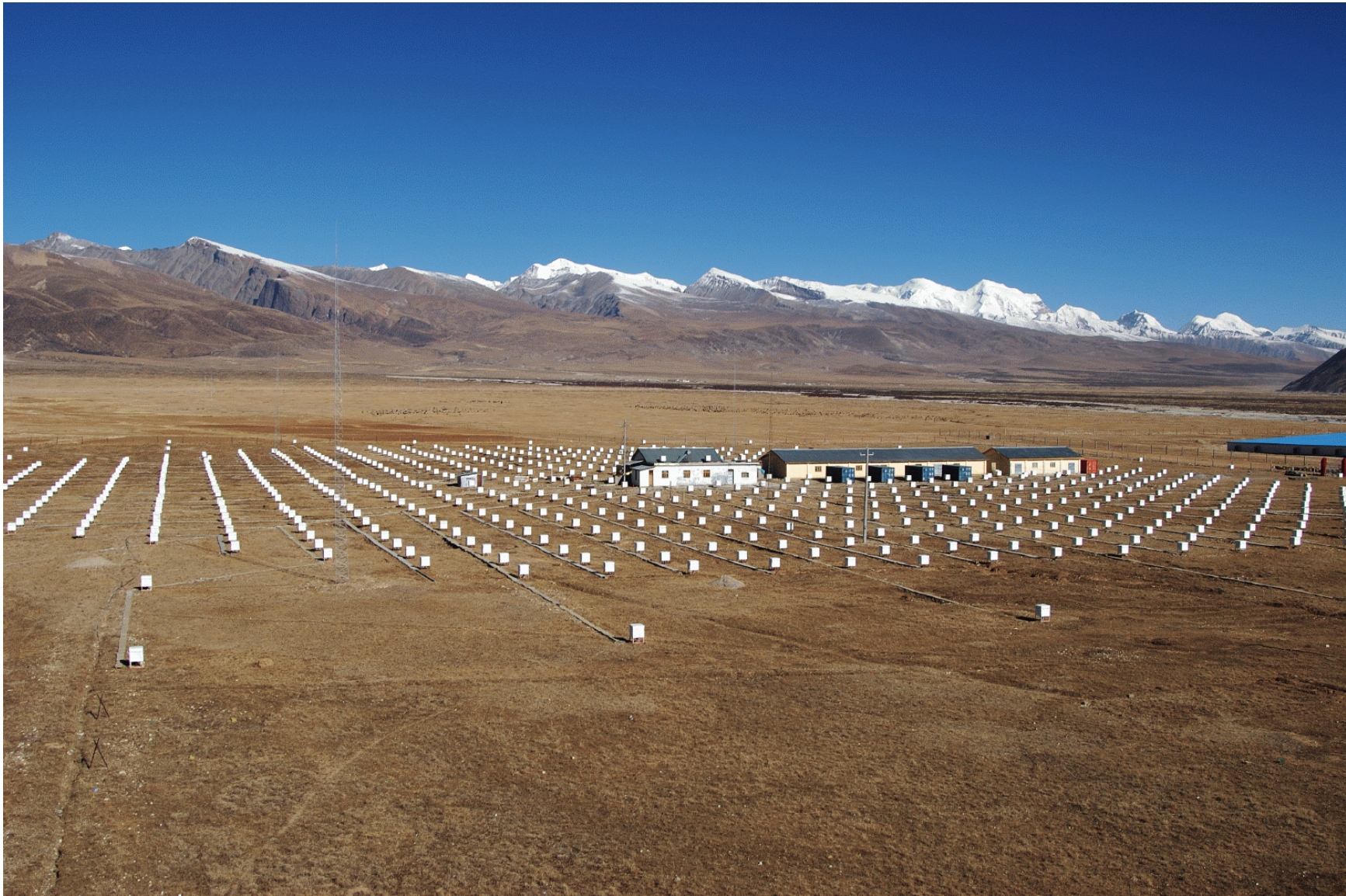
# Tibet III (22000m<sup>2</sup>)



- Total 545 detectors
- Mode Energy
  - ~ 3 TeV
- Angular Resolution
  - ~ 0.9 deg@3TeV
- Trigger Rate
  - ~680 Hz
- Data size
  - ~20GB/day
- Operation**
  - 1999 October-**
  - 2002 September**

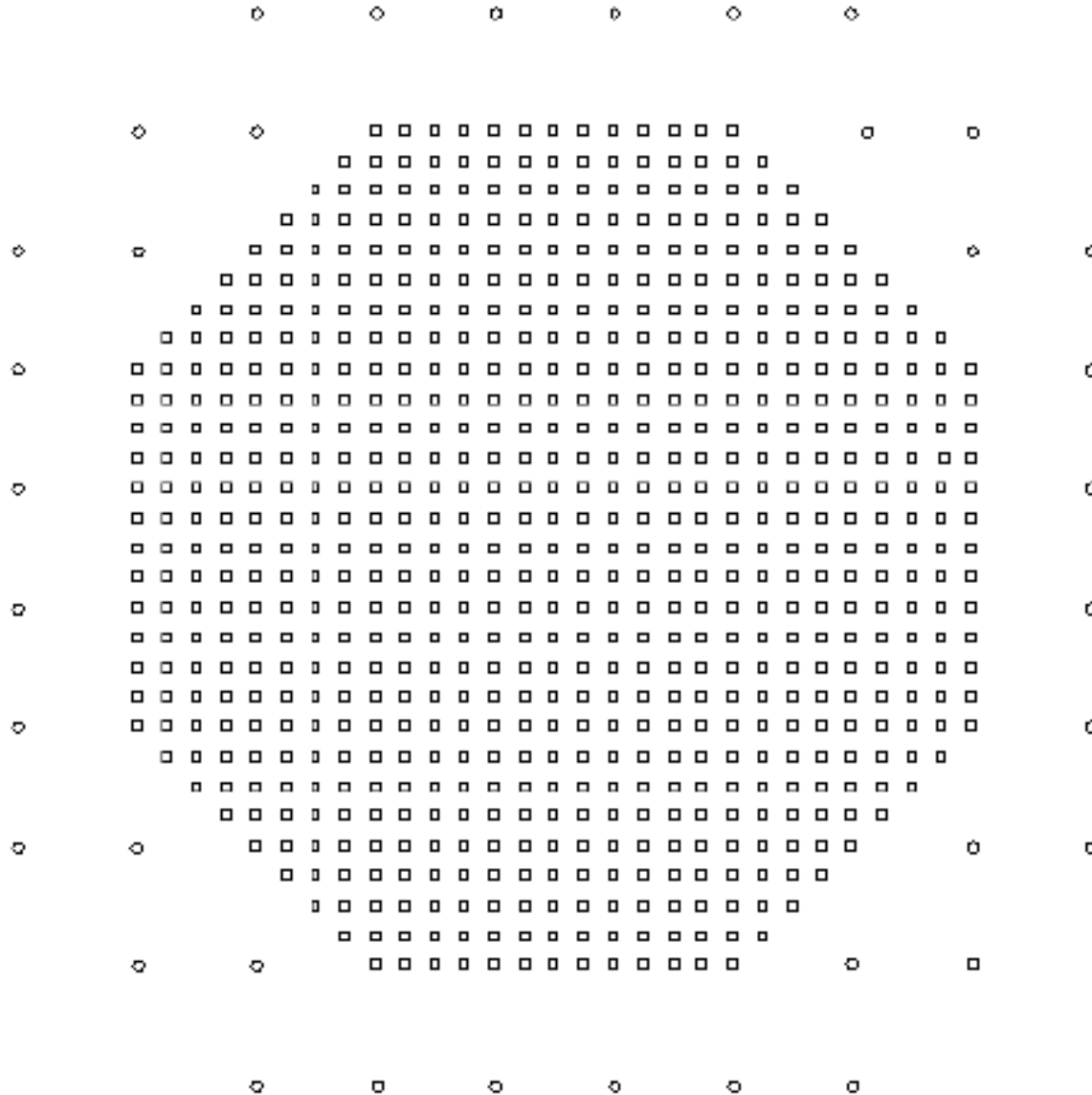


# Tibet III (37000m<sup>2</sup>)



Yangbajing (4300a.s.l.=606g/cm<sup>2</sup>), Tibet, China

# Tibet-III (37000m<sup>2</sup>)



Total 733 detectors

Mode Energy

~3 TeV

Angular Resolution

~0.9 deg @3TeV

Trigger Rate

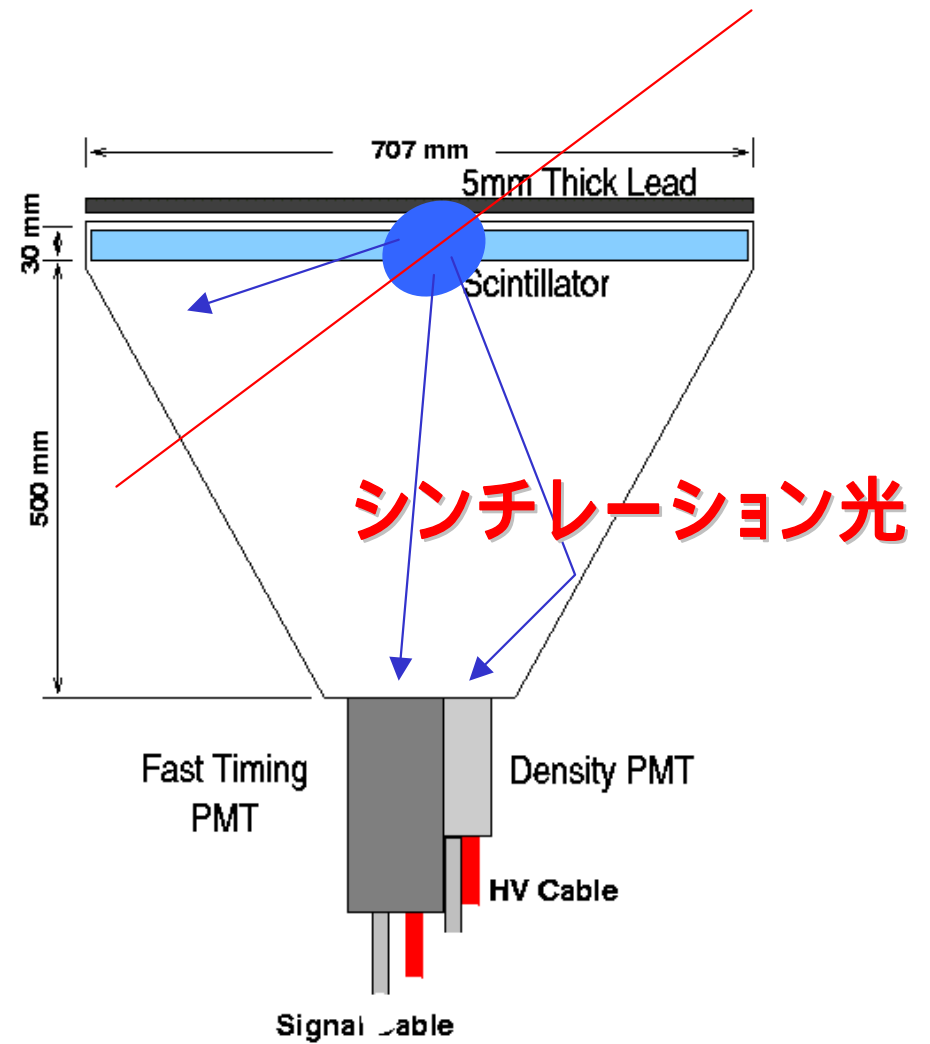
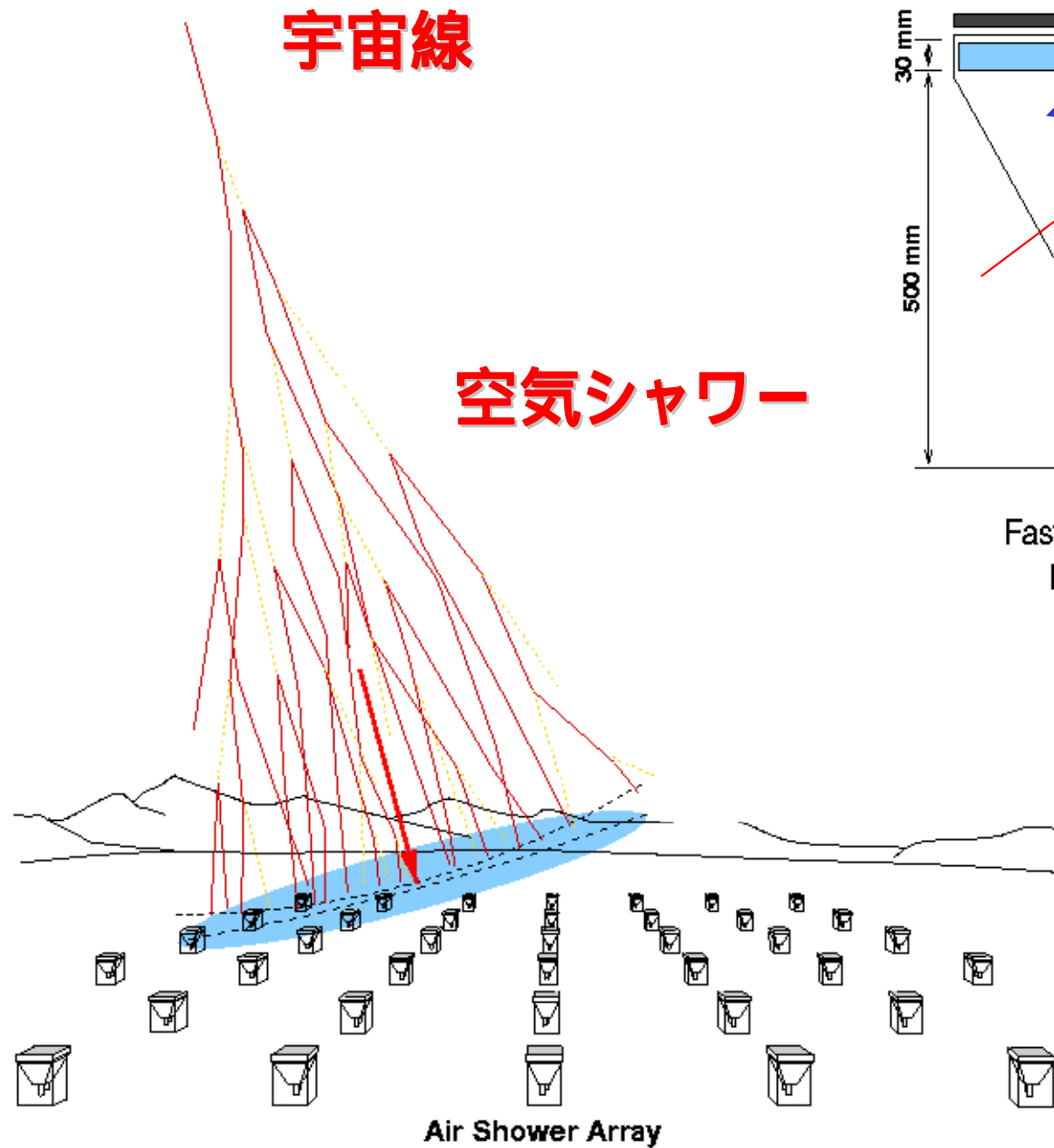
~1500 Hz

**Operation**

**November 2002 ~**

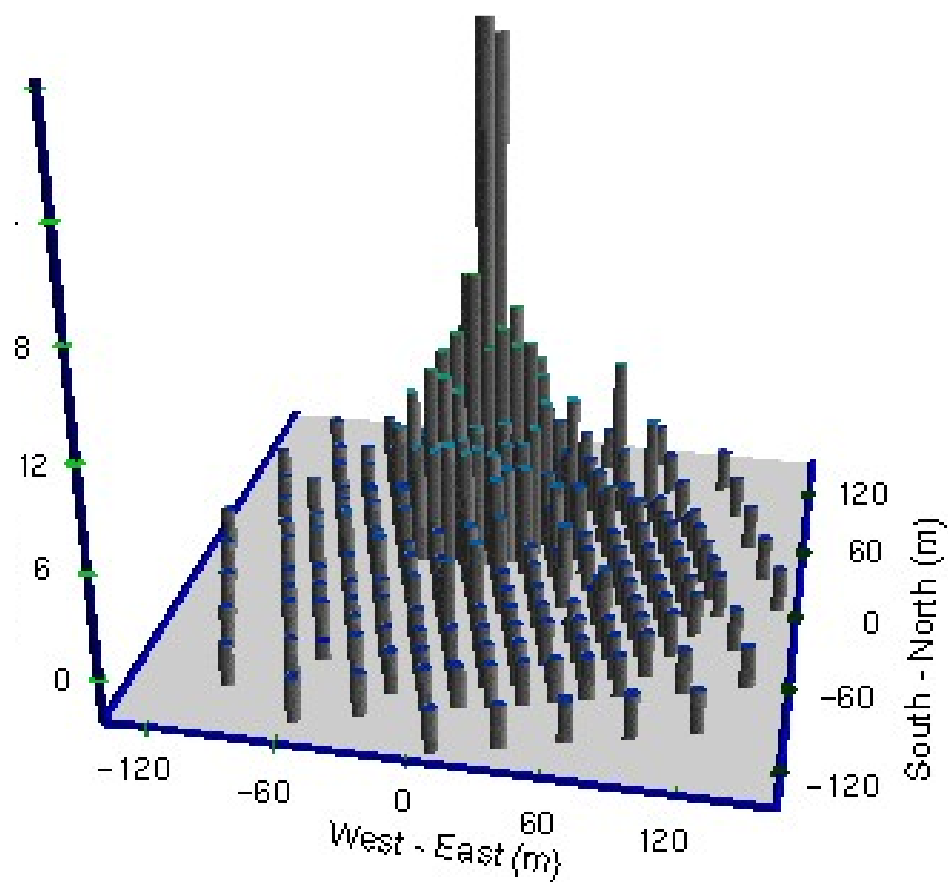


# 検出方法

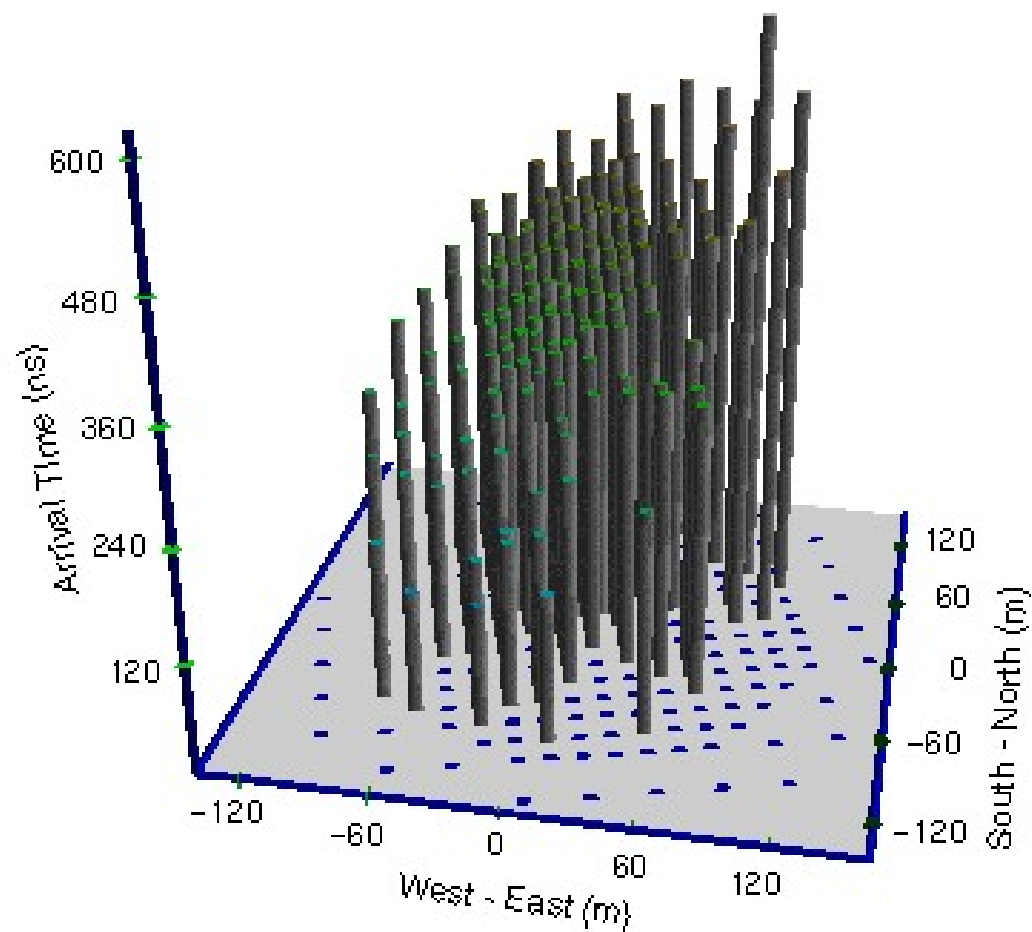


# イベントマップ

粒子数分布



到来時間分布



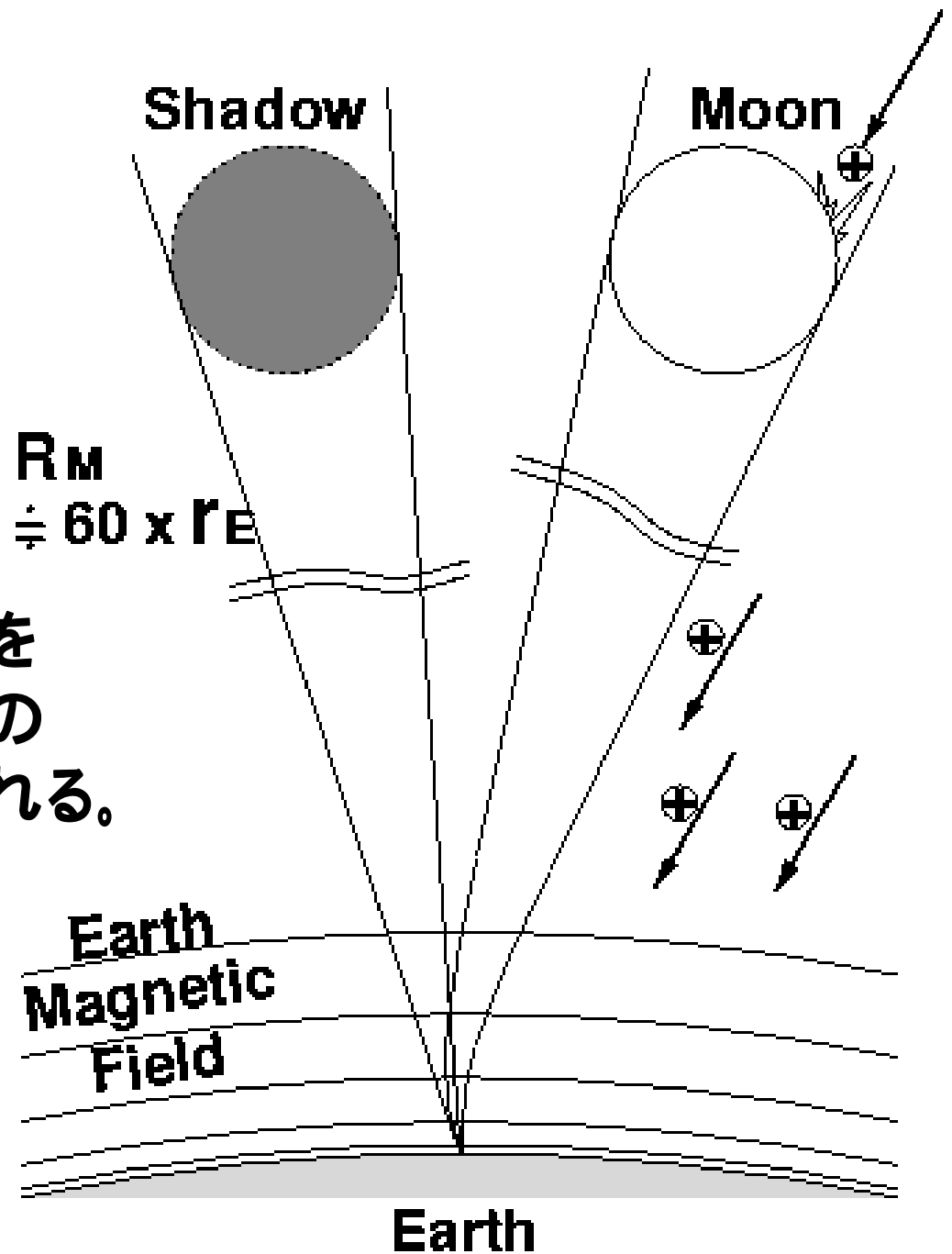


# 性能評価 月の影

地球に到来する宇宙線は月によって遮蔽されるため、ある程度の角度分解能を備えた装置で観測するとその方向に“へこみ”がみられる。

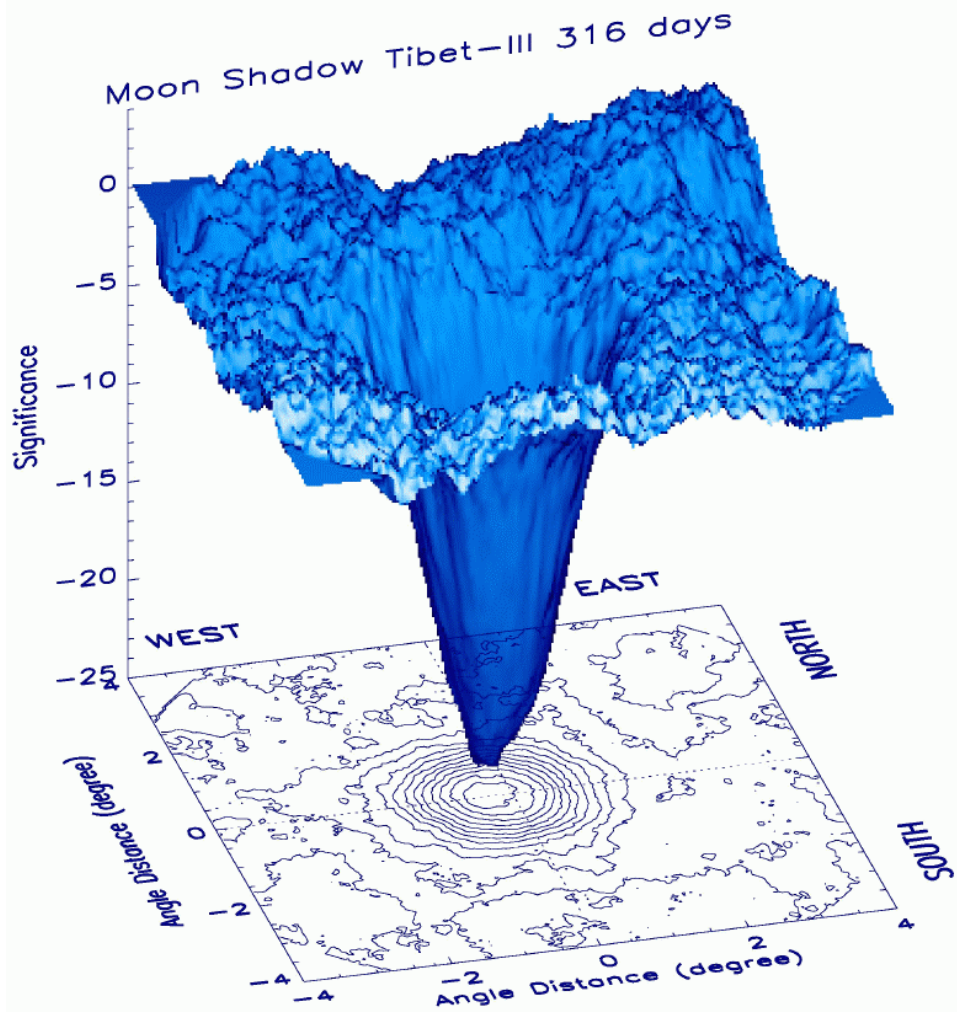
ほとんどの宇宙線は陽子などの荷電粒子のため、地磁気の影響を受け曲がるため“へこみ”は実際の月の方向からは“ずれ”で観測される。

この“へこみ”と“ずれ”から装置の性能評価が可能になる。



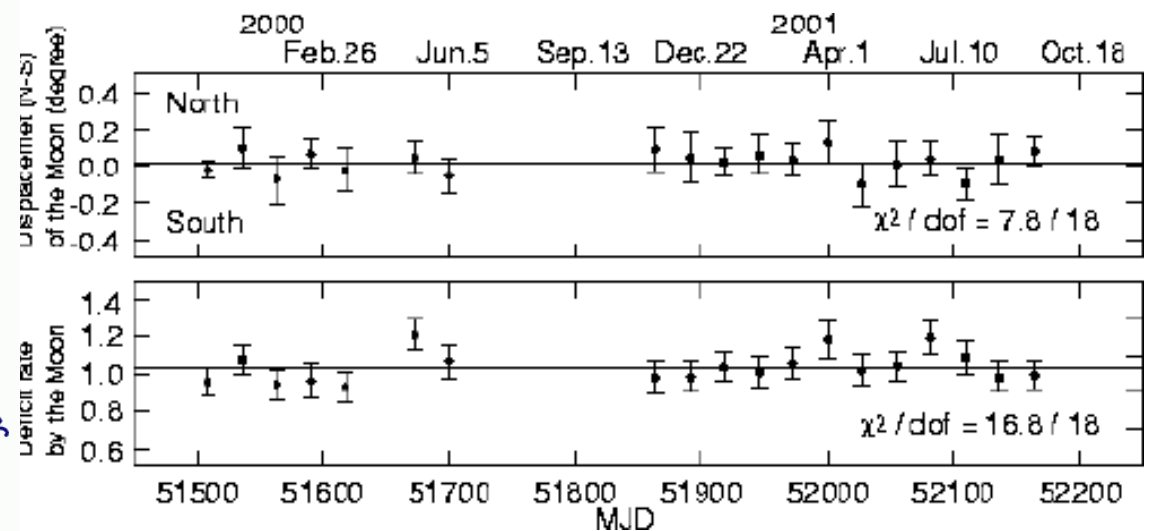
# How to point? (Air shower detector)

Moon's shadow in Cosmic Rays



North-South Displacement  
(geomagnetic field free):

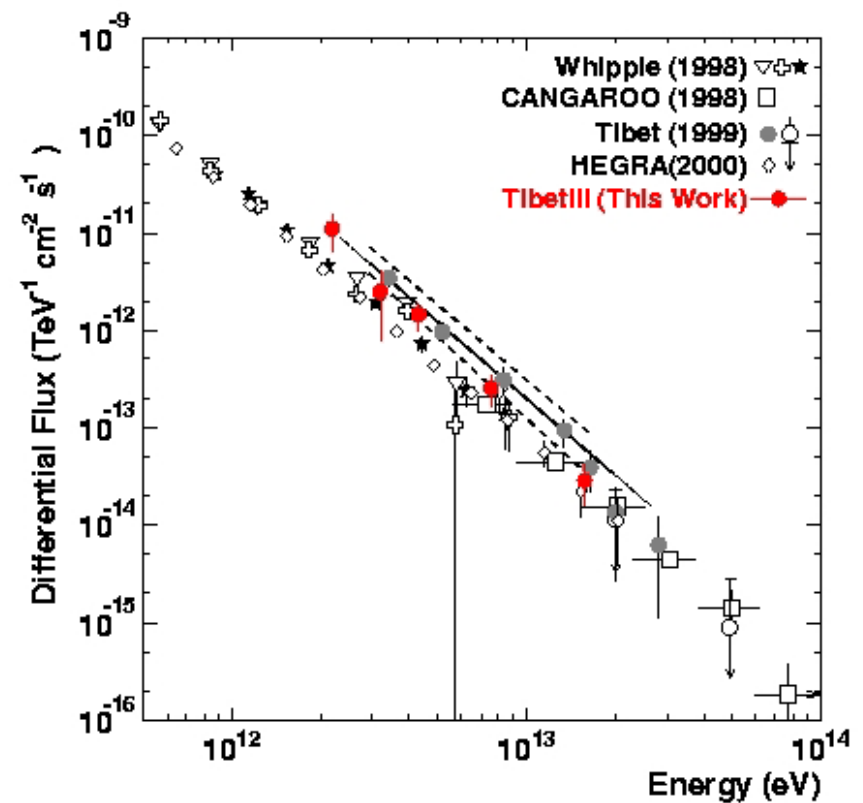
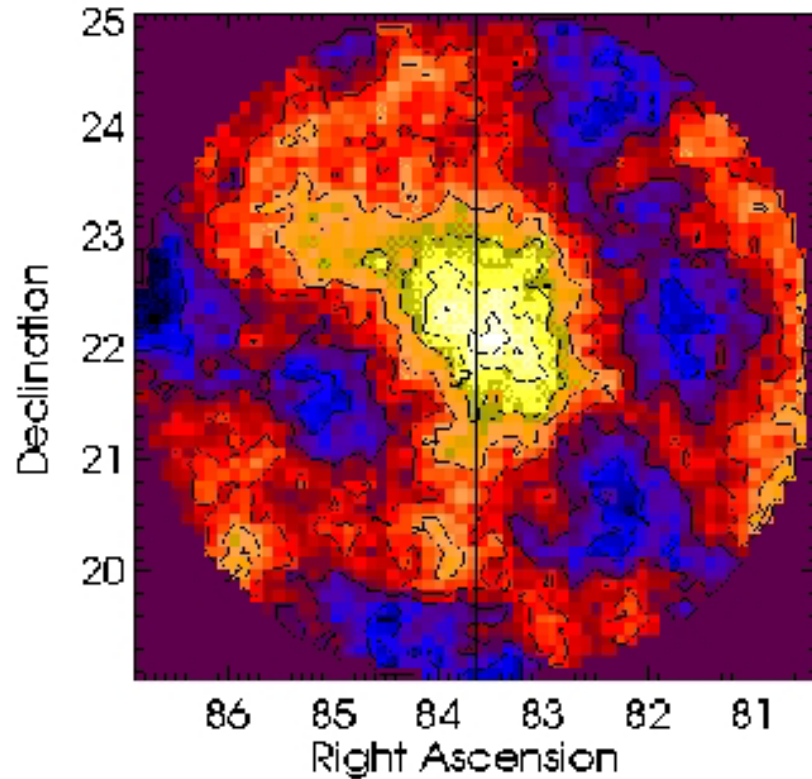
Pointing Accuracy  $< 0.02\text{deg}$   
(Tibet)



# $\gamma$ from Crab

$5.5\sigma$  Tibet-HD (5200m<sup>2</sup>)

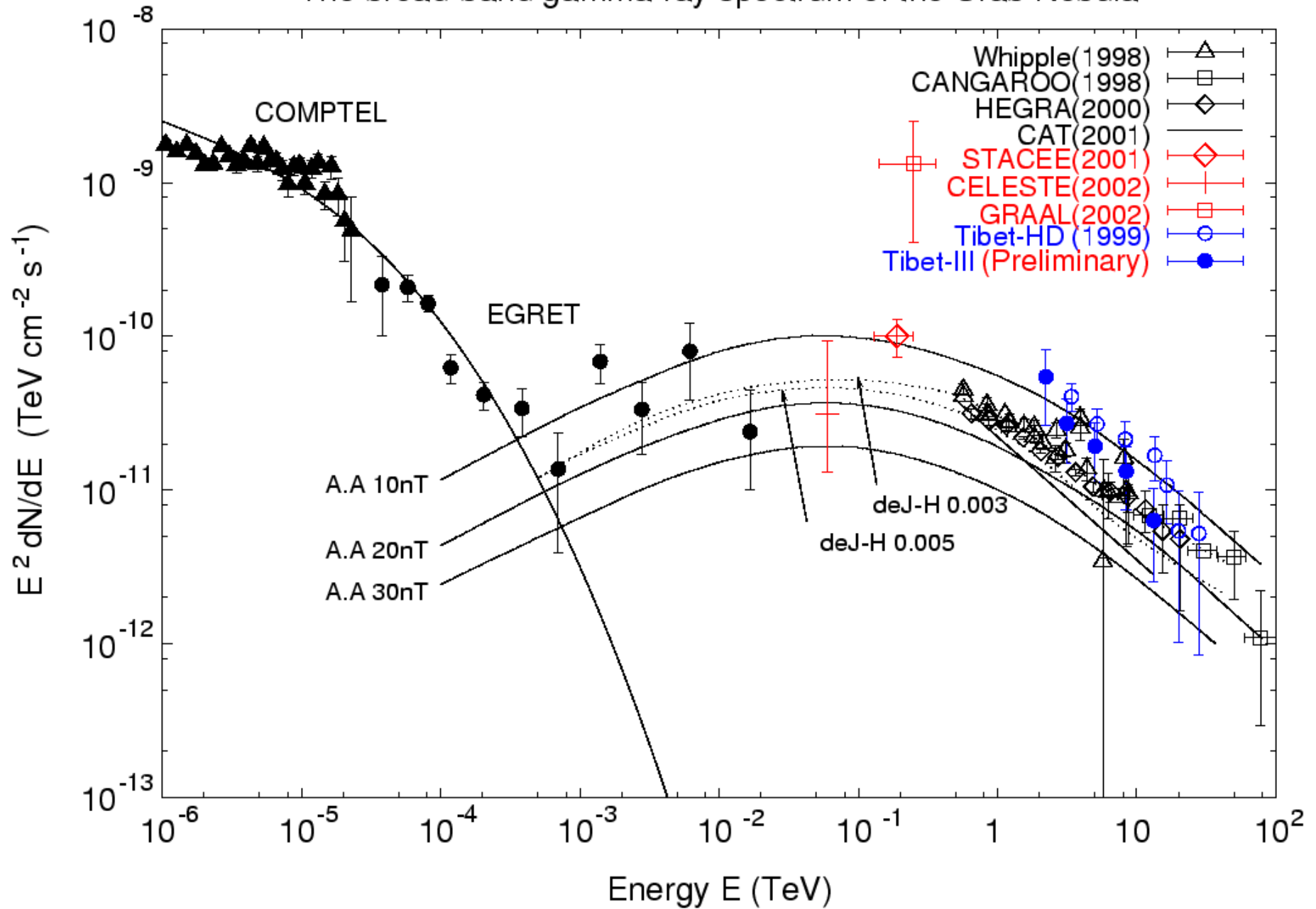
(1996 Nov-1999 May 502days)



ApJ 525, L93-L96, (1999)

# Crab $\gamma$ unpulsed

The broad-band gamma-ray spectrum of the Crab Nebula

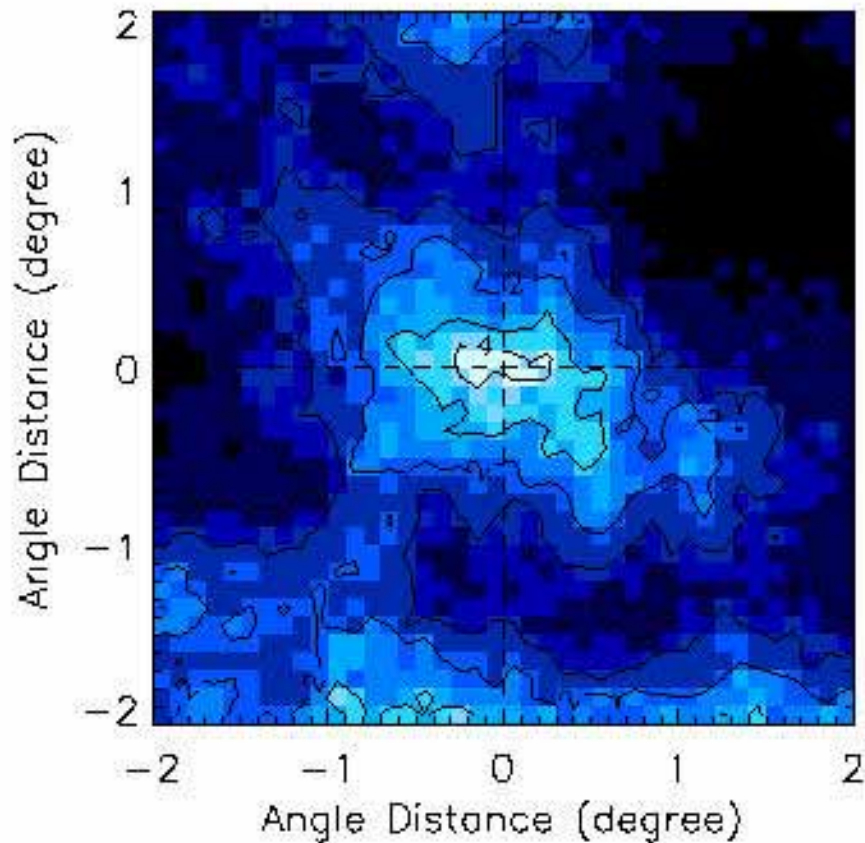




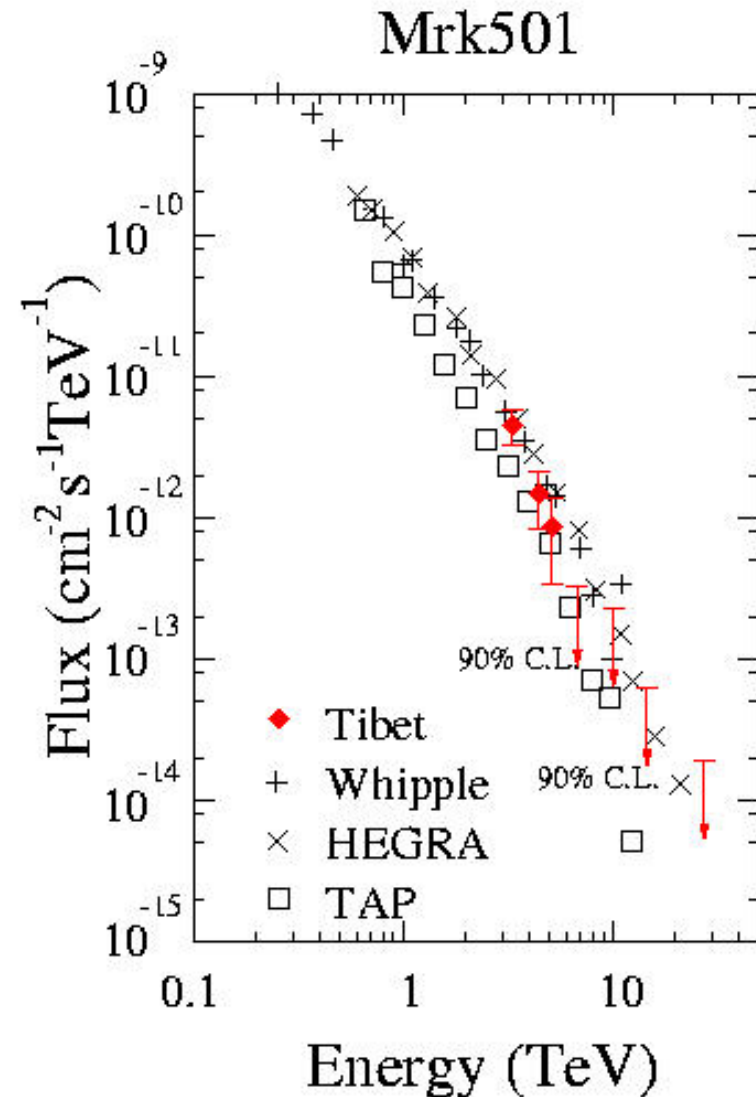
# Flare $\gamma$ from Mrk501 (1997)

3.7 $\sigma$ (Feb-Aug)~4.7 $\sigma$ (Apr-Jun)

Tibet-HD (5200m<sup>2</sup>)



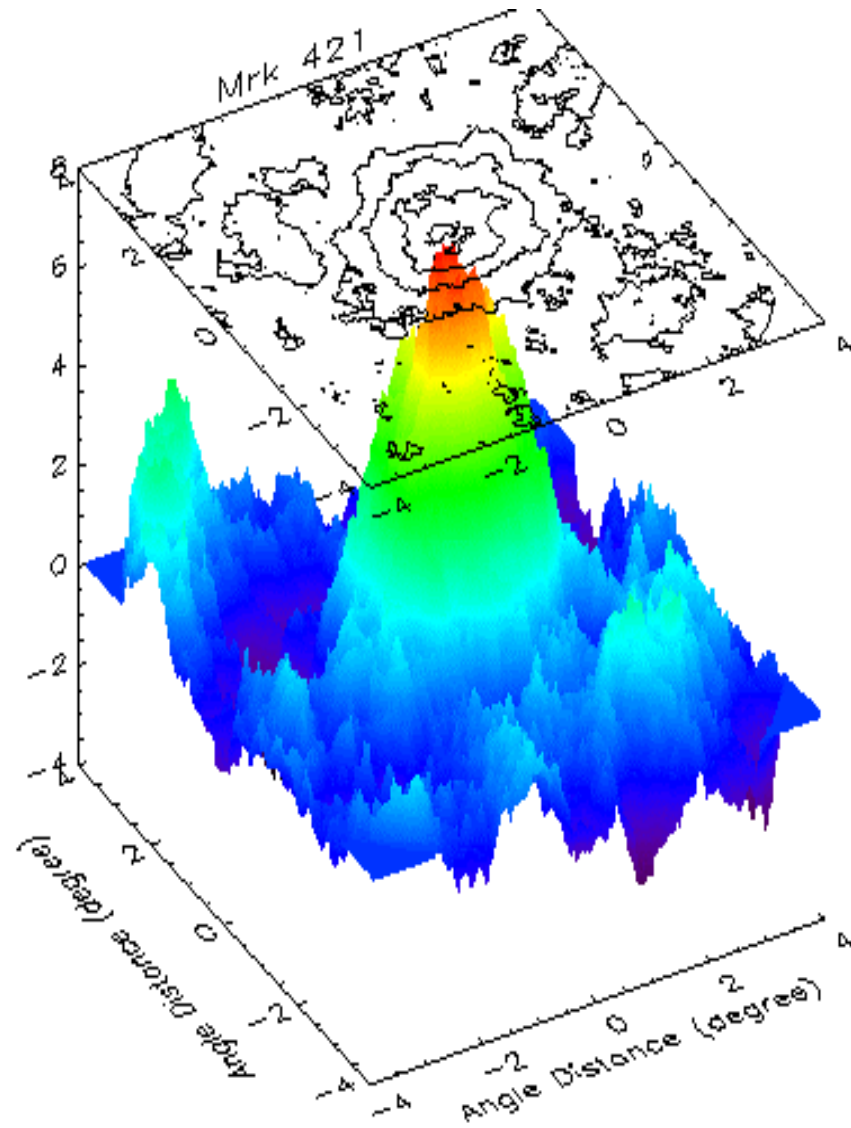
ApJ 532, 302-307, (2000)



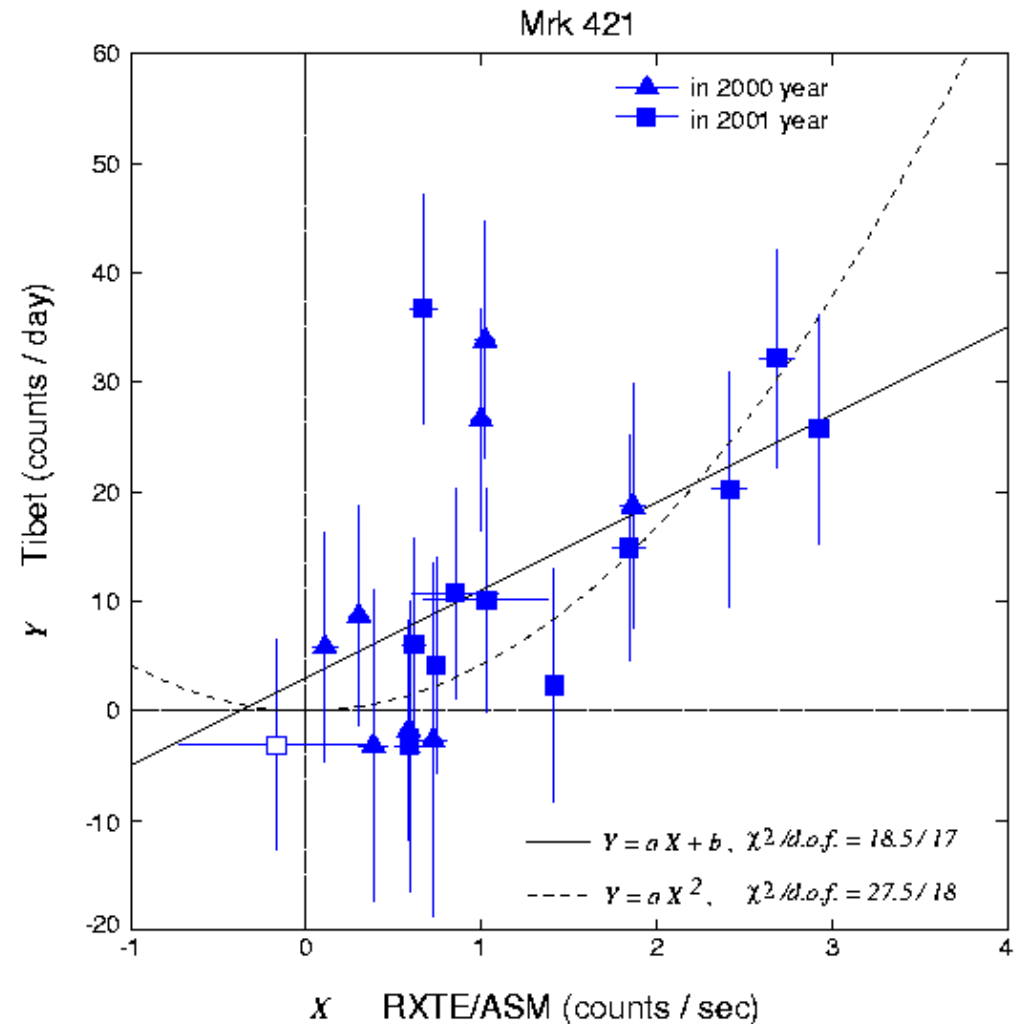
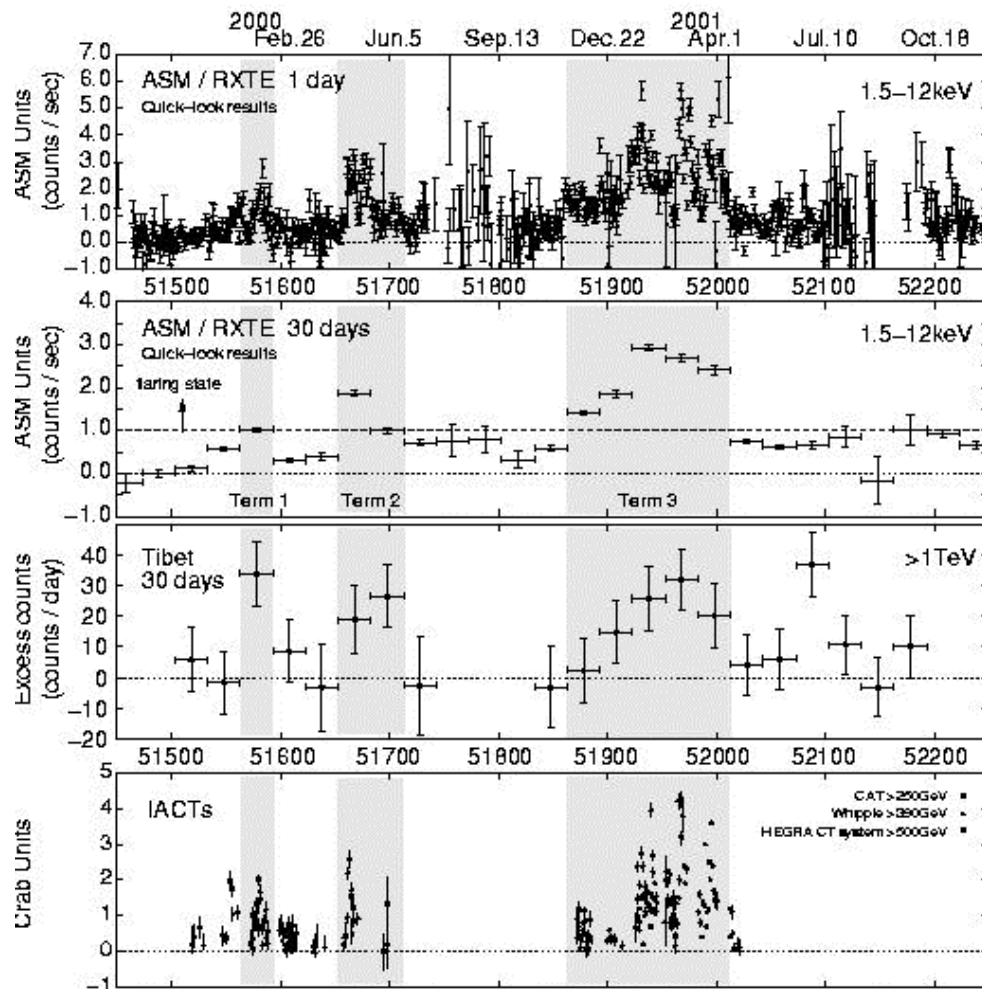
# Flare $\gamma$ from Mrk421 (2000-2001)

5.1 $\sigma$

Tibet-III (22000m<sup>2</sup>) 457days



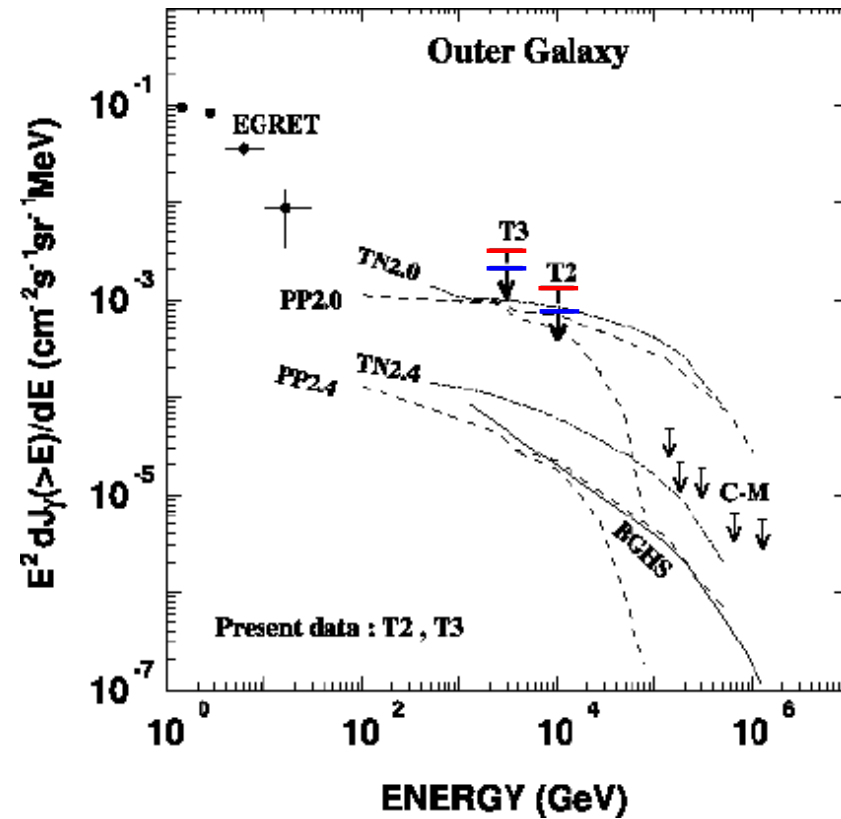
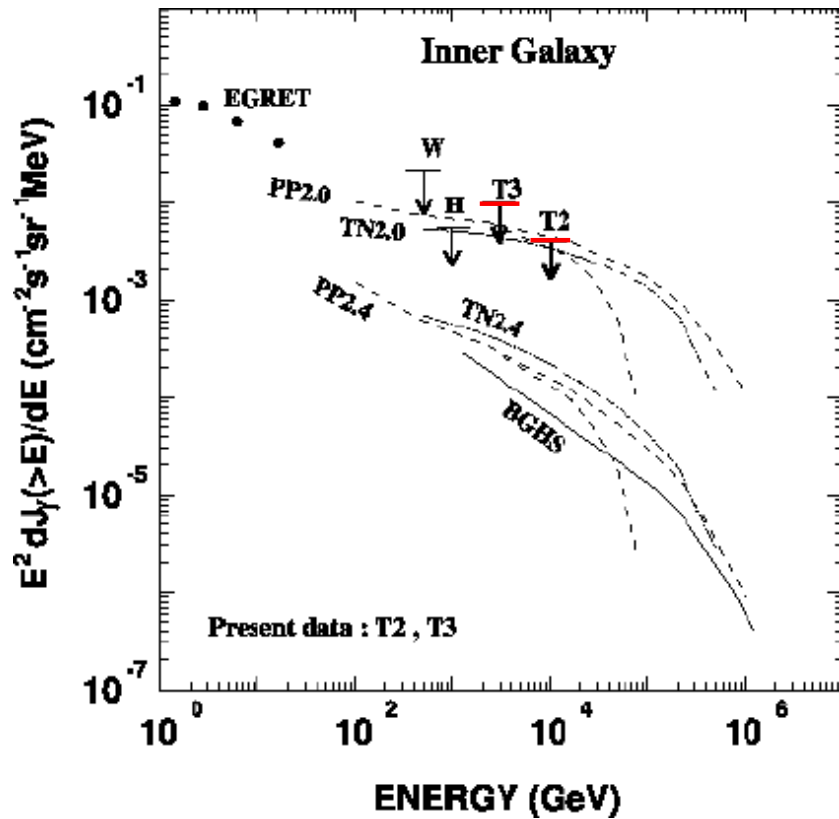
# Mrk421 X線データとTeV データの 長期相関



# Upper limits on galactic diffuse rays

Inner galaxy  
( $20 < l < 55 \text{deg}$ )

Outer galaxy  
( $140 < l < 225$ )



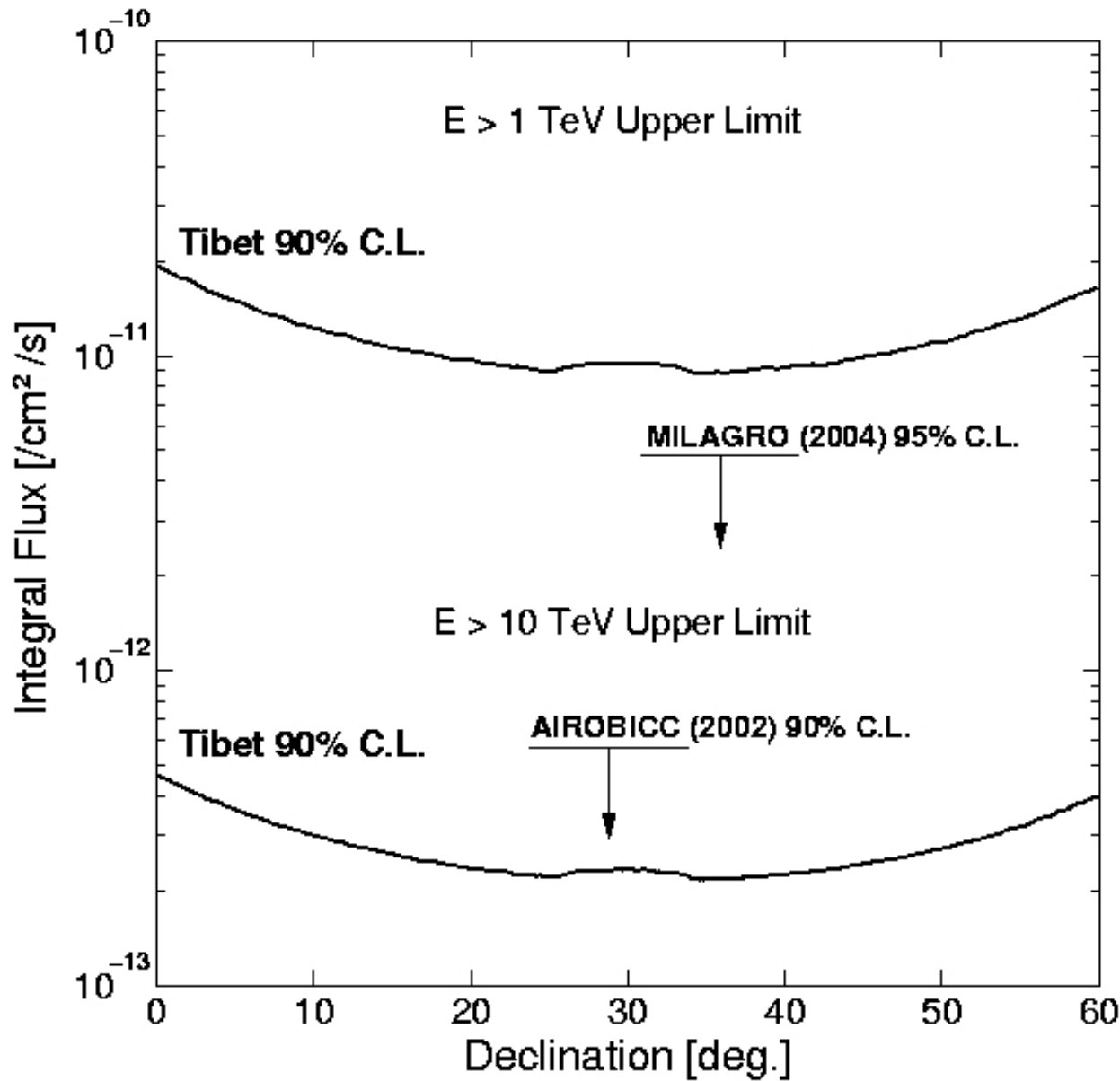
Red:99%CL, Blue:90%CL



# Northern Sky Survey

( $\gamma$  point source search)

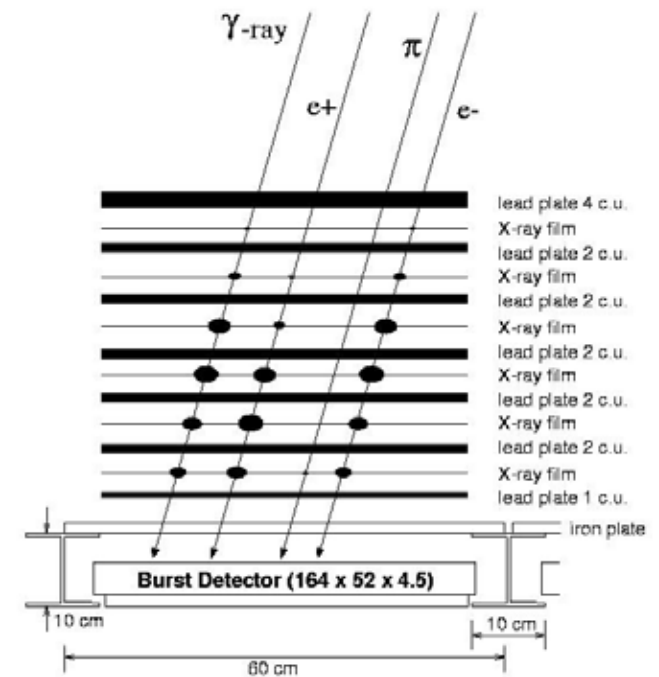
Tibet-HD (5200m<sup>2</sup>) 556 days +  
Tibet-III(22000m<sup>2</sup>) 457 days)



No significant  
new source!

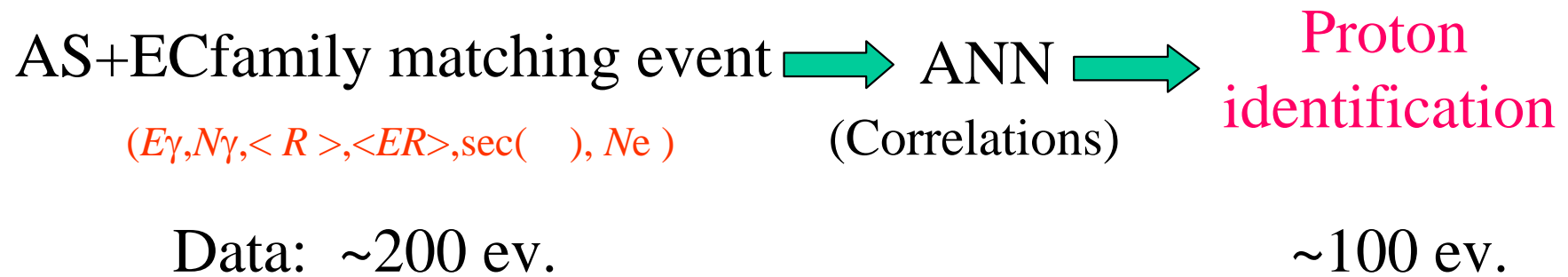
Will be  
submitted  
soon

# TIBET Hybrid Experiment



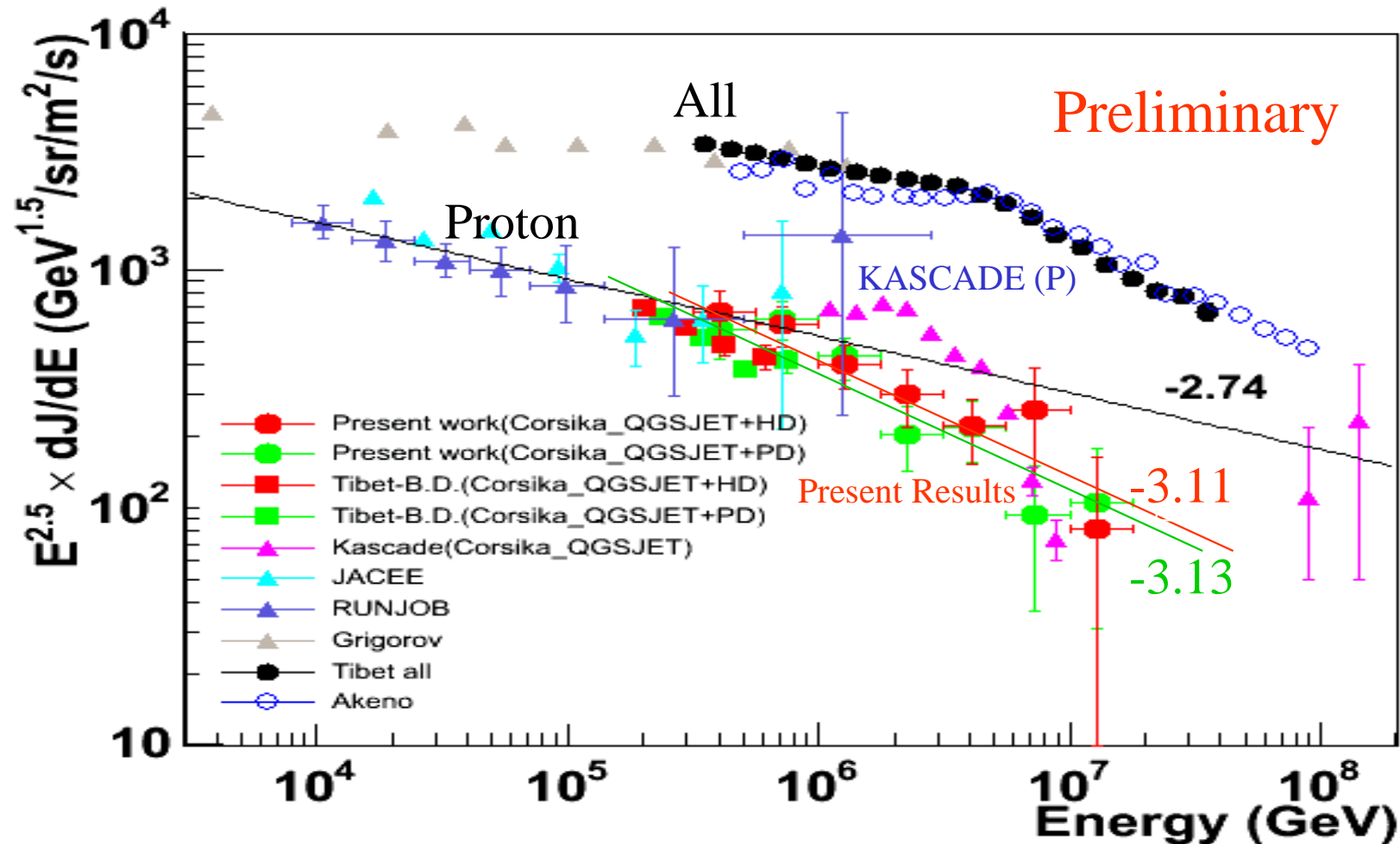
# How to obtain proton spectrum?

1996-1999 DATA (699days)



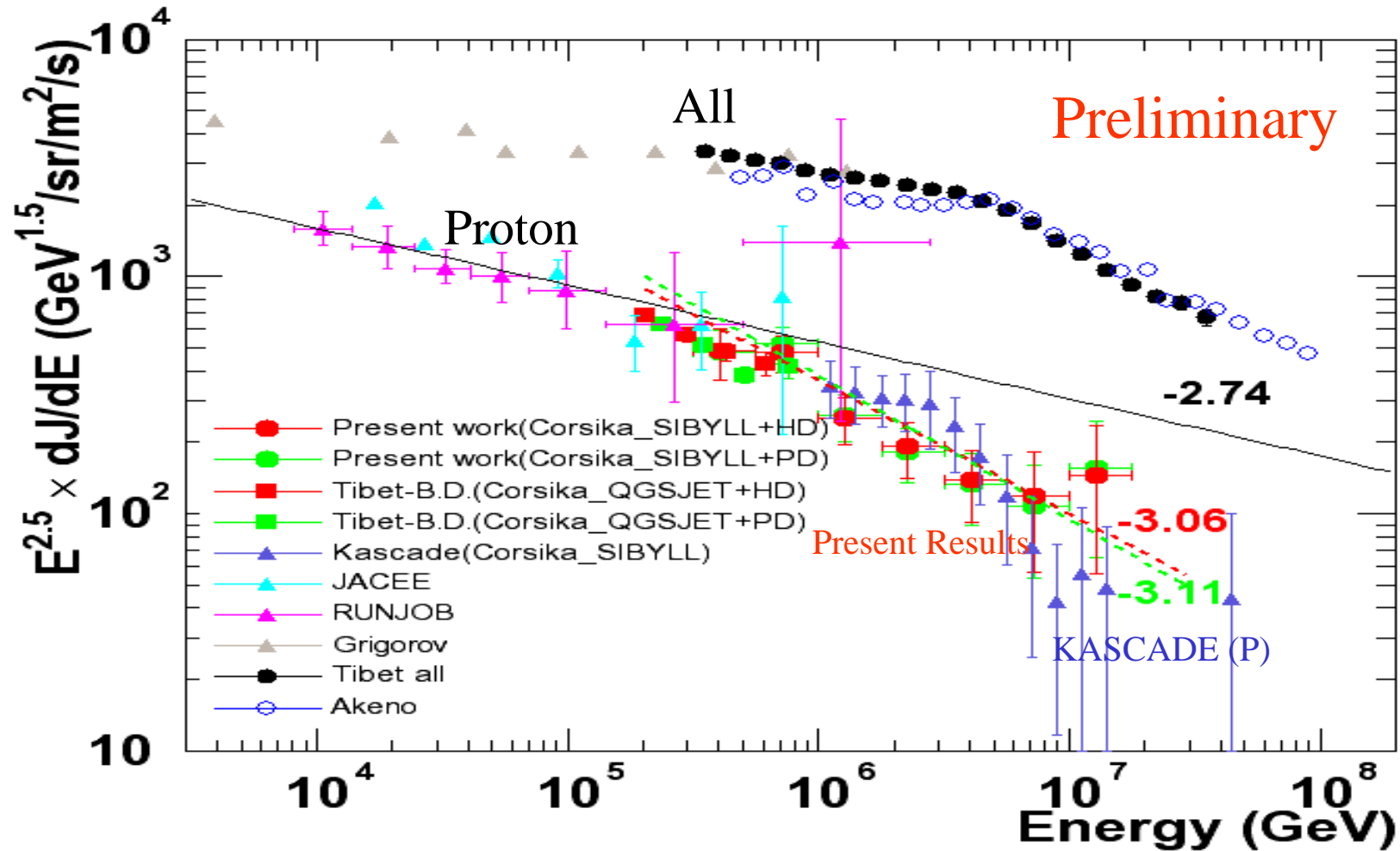
	EC( $\gamma$ family)	AS	BD
Location(x, y)			
Direction( $\quad, \phi$ )		x	
Time (t)	x		
Measurement Parameter	$E_\gamma, N_\gamma, \langle R \rangle, \langle ER \rangle, \text{sec}(\quad)$	$Ne \longrightarrow E0$	$N_b$

# Primary **proton** spectrum (analyses based on **Corsika\_QGSJET** )

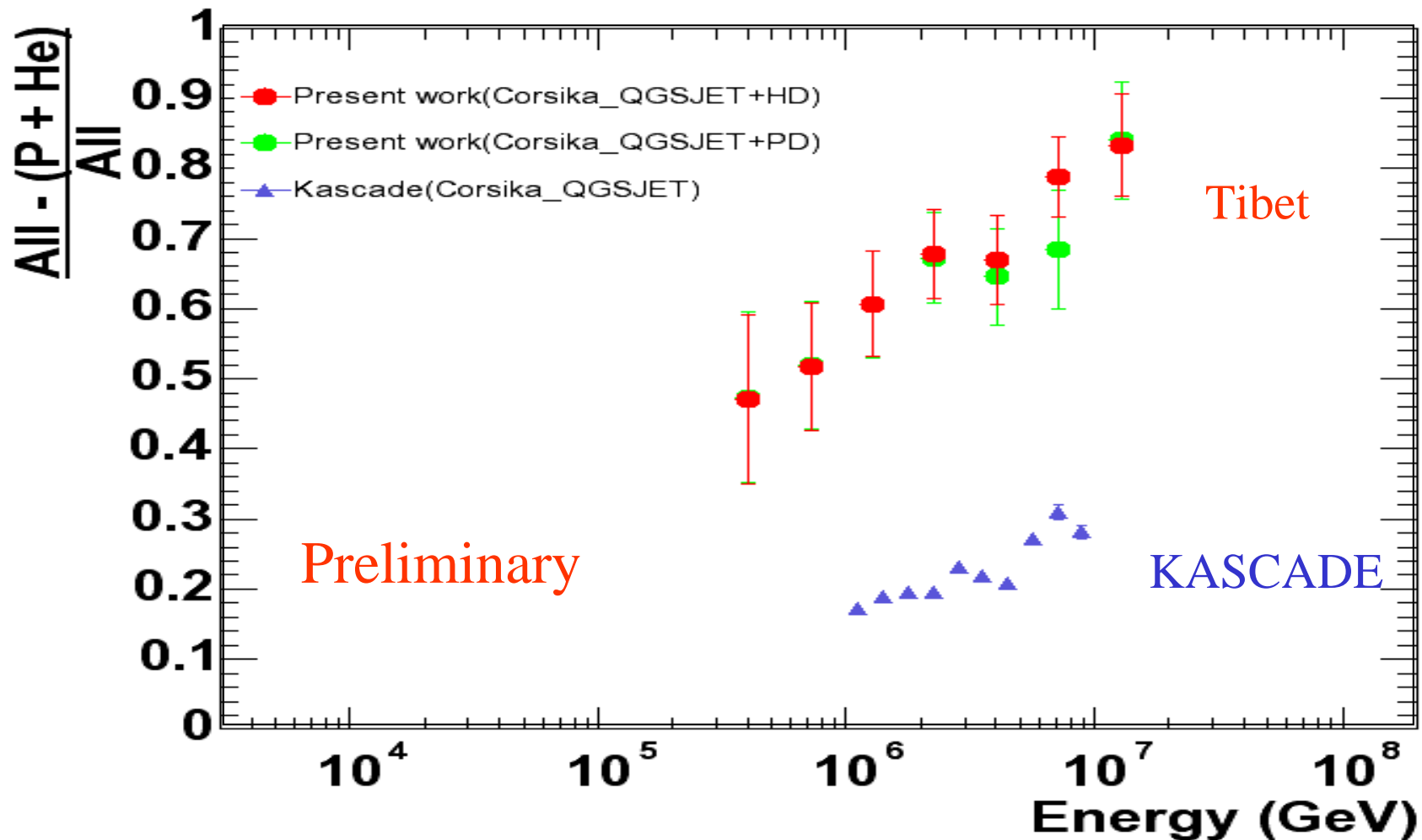




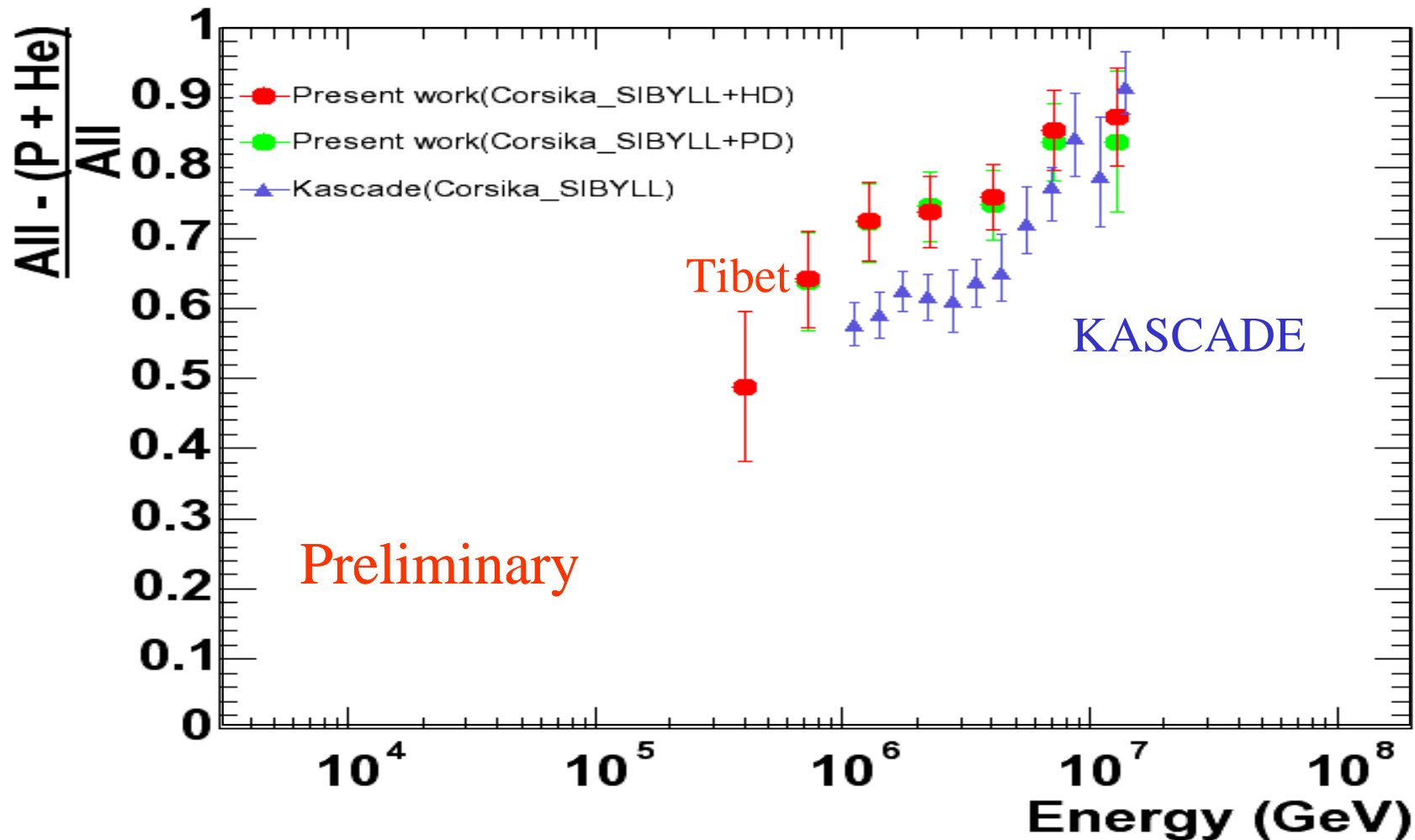
# Primary proton spectrum (analyses based on Corsika\_SIBYLL)



# Primary All - (P+He) component (analyses based on Corsika\_QGSJET )



# Primary All - (P+He) component (analyses based on Corsika\_SIBYLL)



# Summary (Draft in preparation)

( 1 ) Steepening of the proton energy spectrum in the knee region is observed.

**power index** =  $\sim -3.1 \pm \sim 0.15$  above 500TeV

*cf.* Gaisser line (-2.74)

$\left( \begin{array}{l} \text{Primary} \\ \text{Composition} \end{array} \& \begin{array}{l} \text{Interaction} \\ \text{Model} \end{array} \text{ dependence} \right) = 0.07 < \sigma_{\text{stat.}}$

( 2 ) Comparison with direct measurement suggests the break point of protons exists around **a few 100 TeV**.

The knee of all particle spectrum (3-5PeV) is

**NOT** composed of **P + He component**.



# The anisotropy at the solar time frame

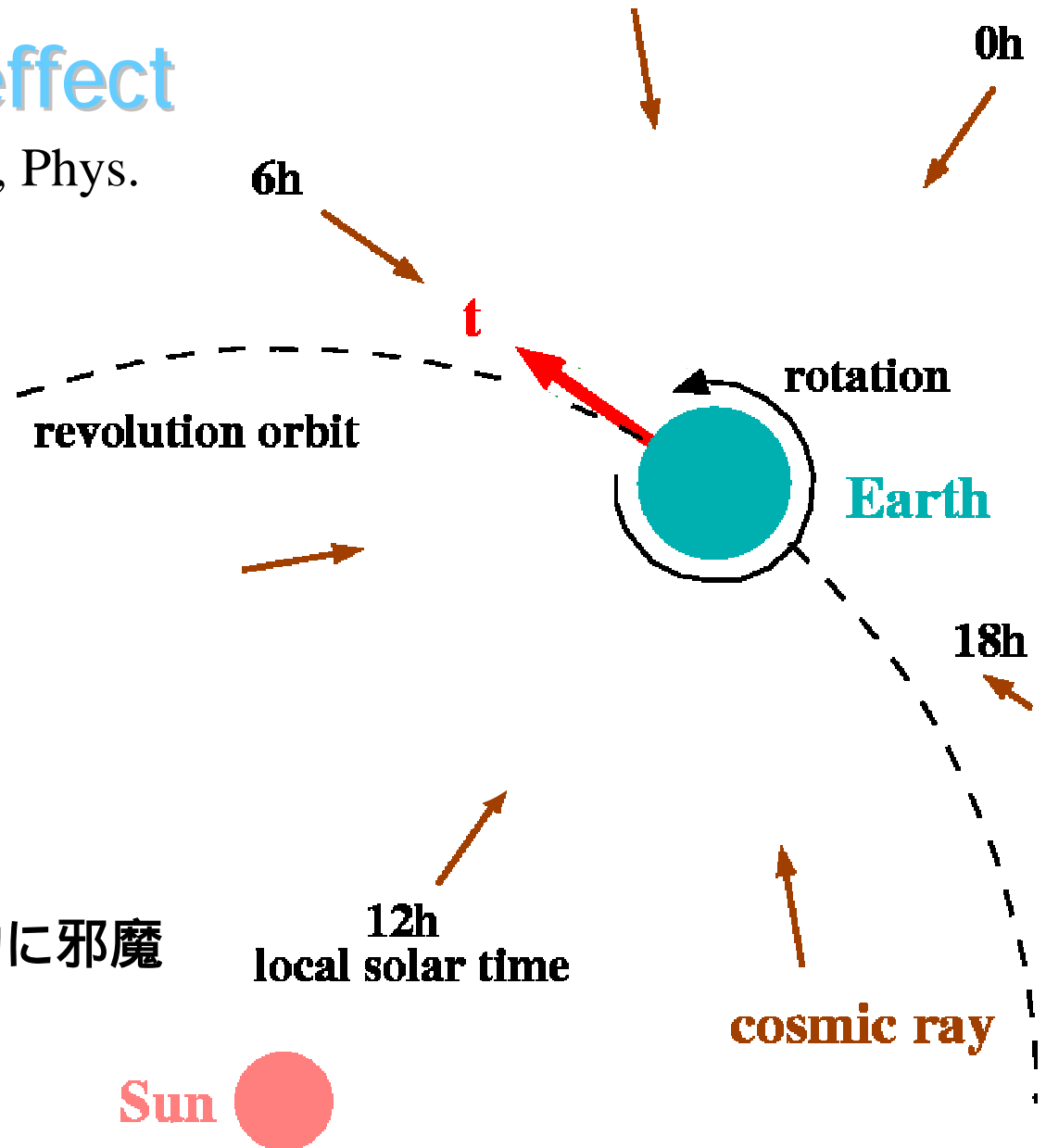
## • Compton - Getting effect

(Compton, A. H., Getting, I. A. 1935, Phys. Rev. Let. 47, 817-821)

地球の公転運動によって  
生じる見掛けの  
宇宙線強度異方性

$$CG(t) = (2 + \gamma) \frac{v}{c} \cos(t)$$
$$(2 + \gamma) \frac{v}{c} \approx 0.05\%$$

- エネルギーに依存しない
- TeV領域より下では太陽活動に邪魔されて観測できない？

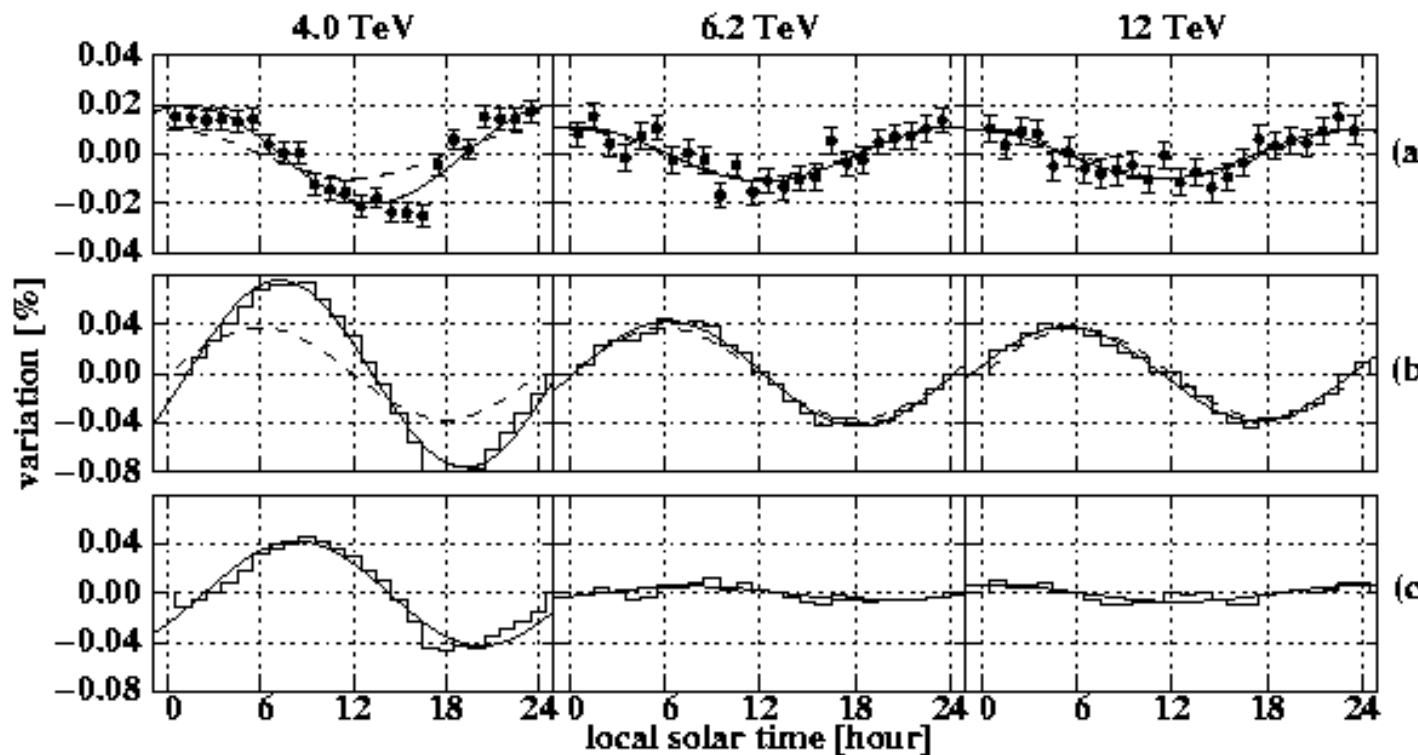


# CG effect (Nov1999 – Nov2003)

PRL 93,  
061101,(2004)

$\sim 3 \times 10^{10}$  EV in Total

Some other effects at low energies?



Differential

Integral

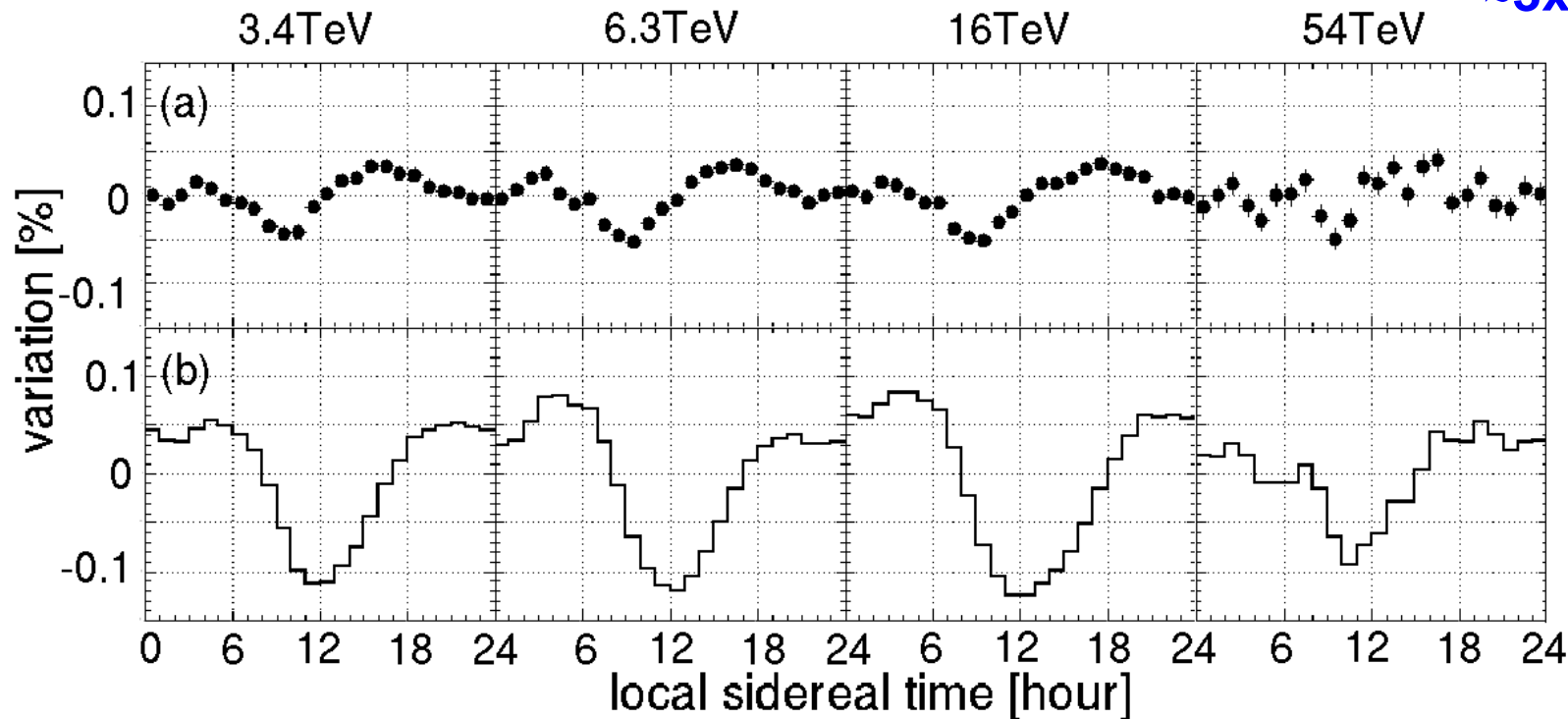
Data-CG

CG expected: ---

# Cosmic Ray Anisotropy at Sidereal Time (Draft in preparation)

1999Nov-2003Nov  
918 live days

$\sim 3 \times 10^{10}$  ev



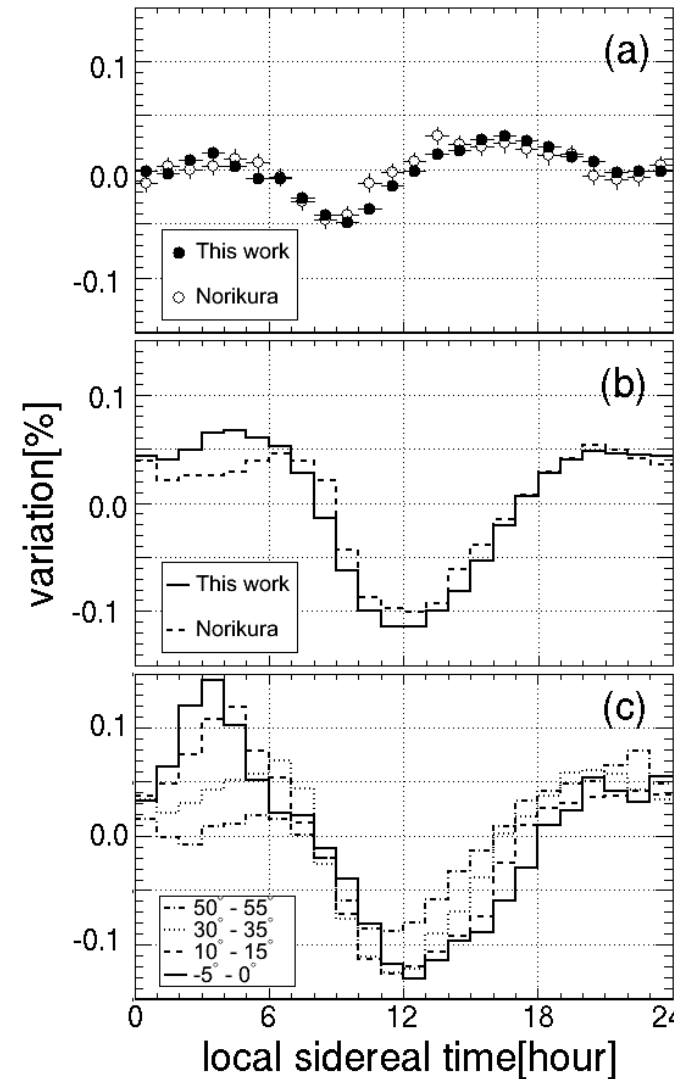
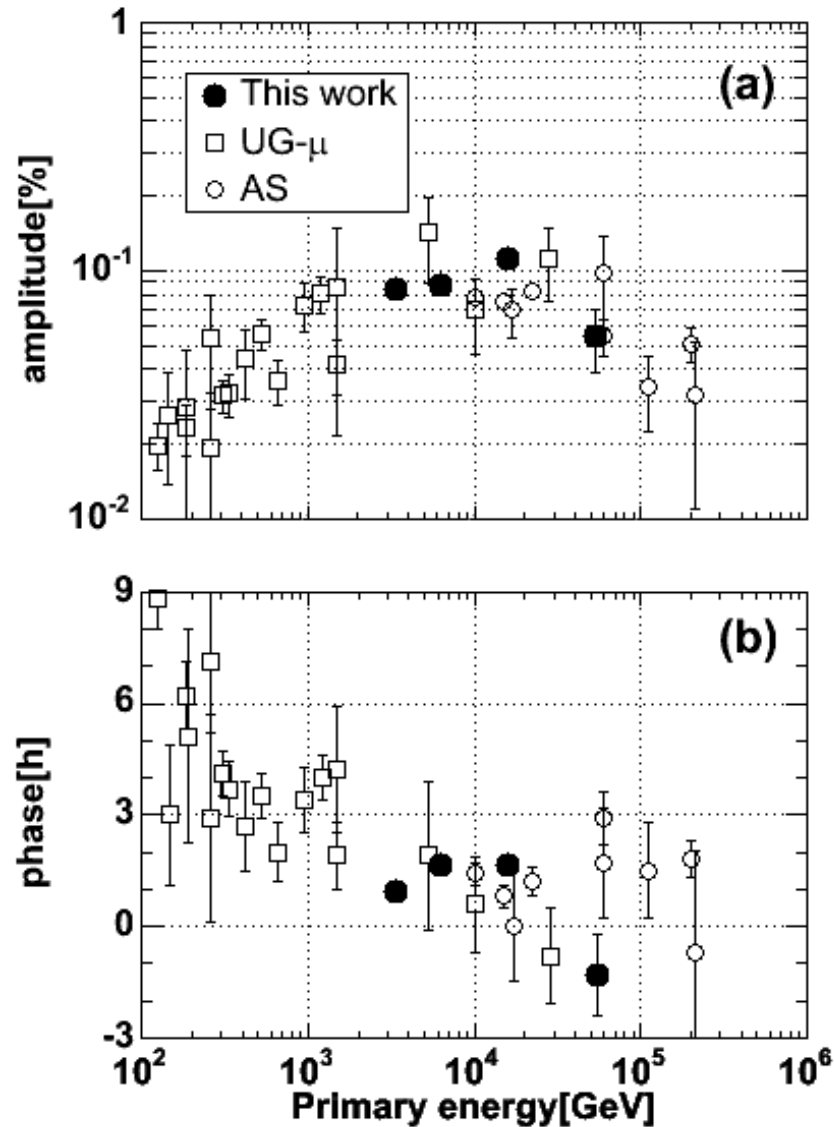
Differential

Integral=  
(Physical  
Quantity)

# Sidereal Time Anisotropy

Fourier First Harmonics  
F

Declination Dependence of  
Amplitude



All  
Dec

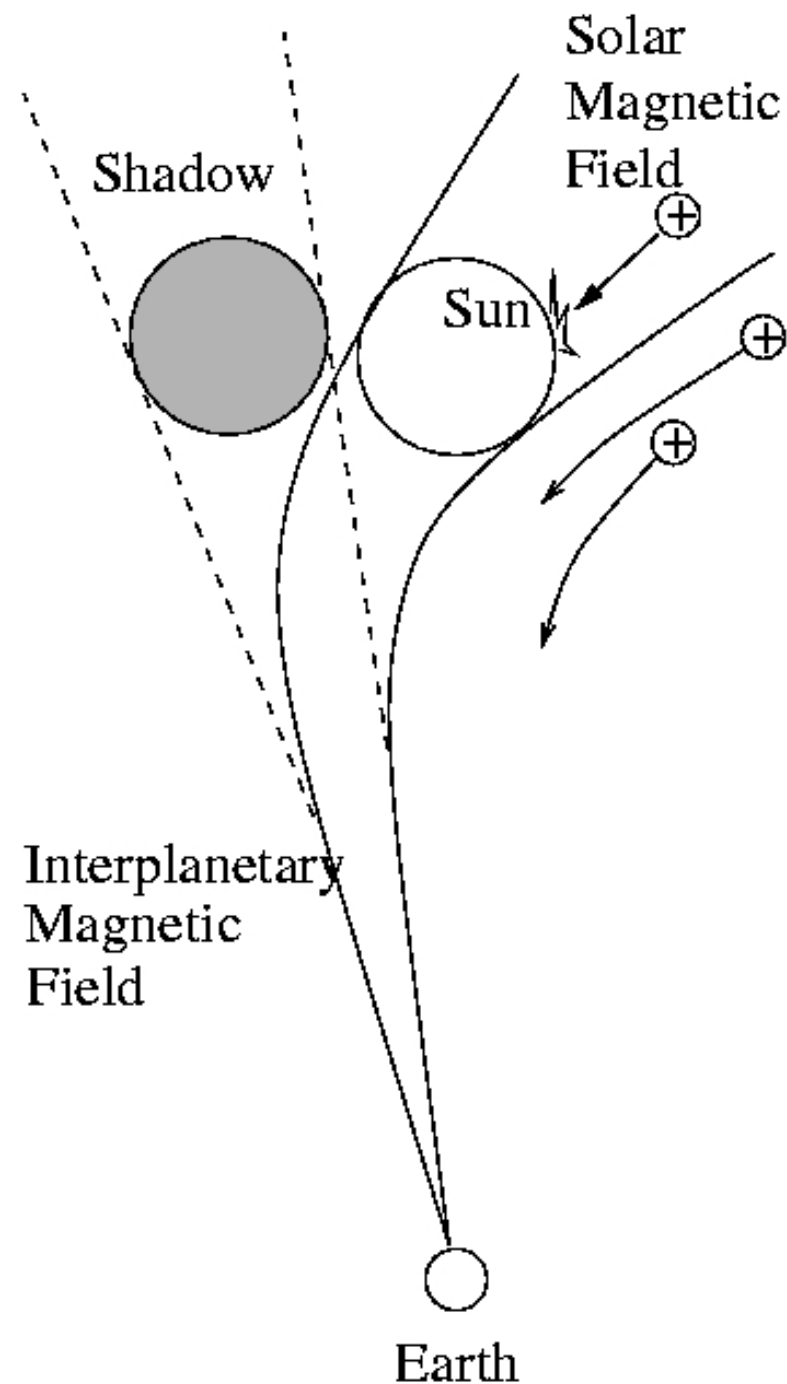
Dec  
Dep



# 惑星間磁場 太陽の影

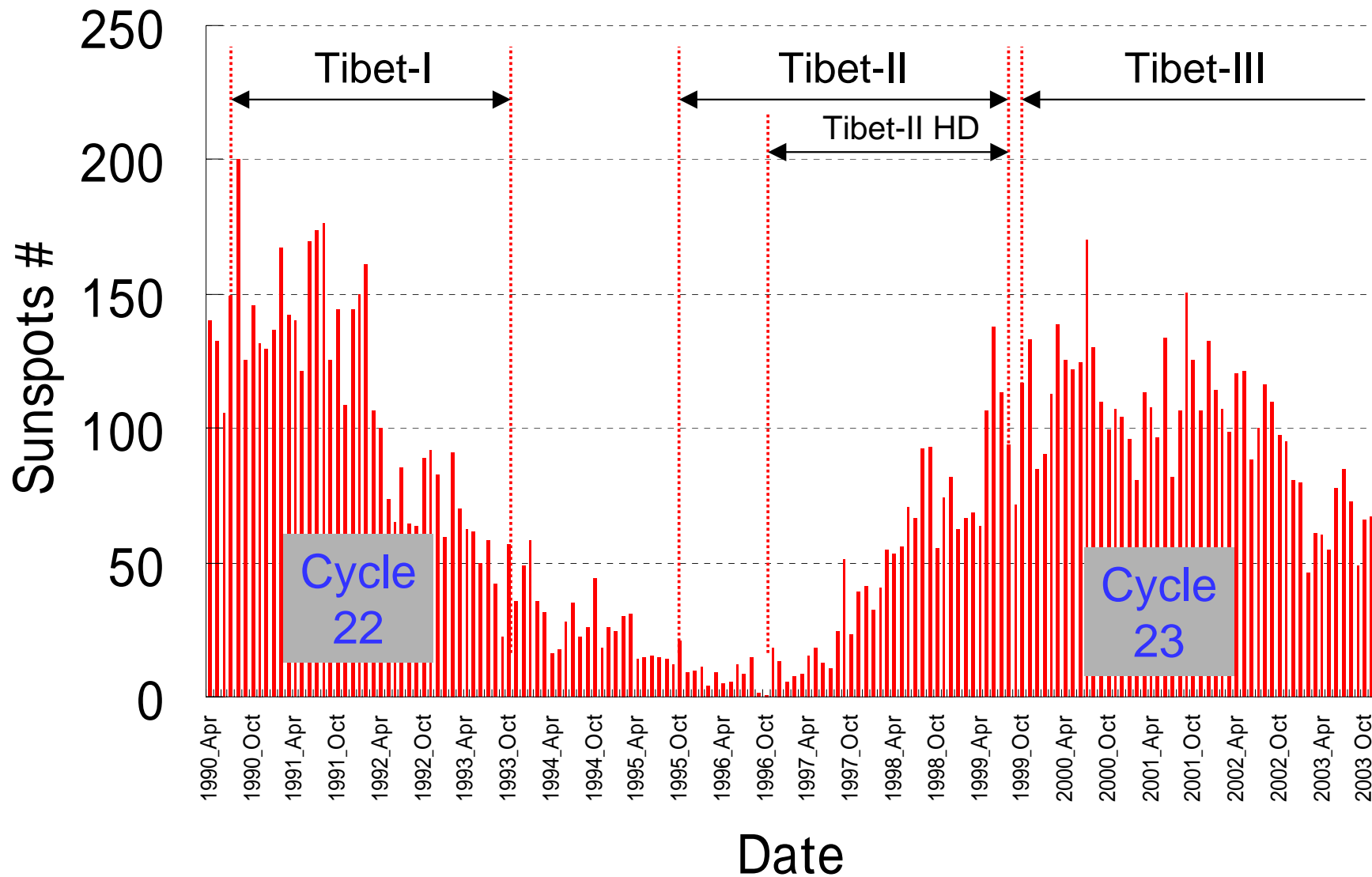
宇宙線は太陽によって遮蔽される。  
正電荷をもった宇宙線は  
太陽磁場、惑星間磁場によって  
曲げられ、観測される“へこみ”は  
磁場の変動によって“移動”する。

太陽活動は11年周期で極大期を迎え、  
磁場の変動も活発になる。  
この“へこみ”の“移動”を観測すること  
によって、**太陽磁気圏の大局的磁場構造**  
を知ることができる。

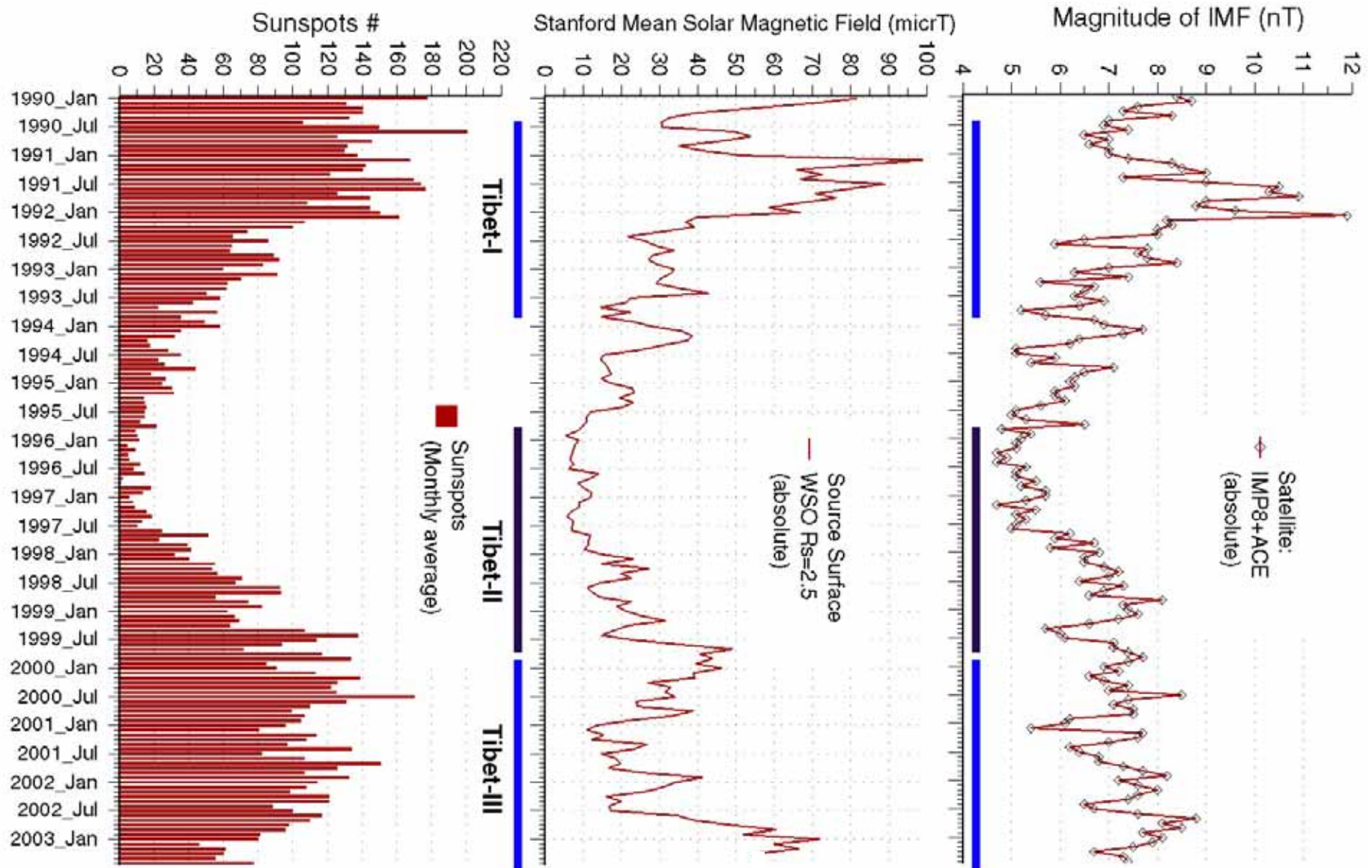


# Solar Activity – Sunspots (Monthly)

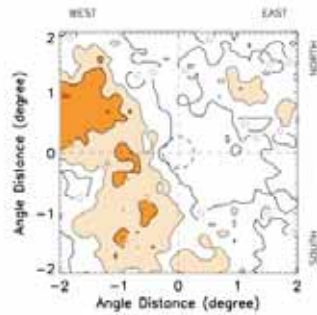
Monthly Sunspots 1990-2003



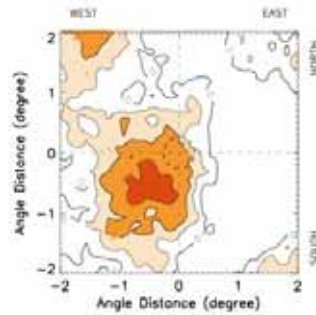
# Solar Activity: Sunspot #, SMSMF, IMF



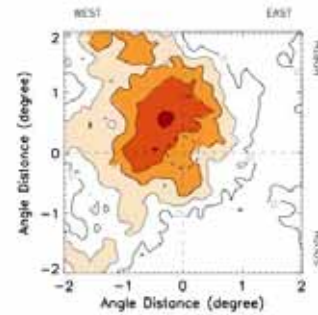
# Yearly variation of Sun s shadow (10TeV)



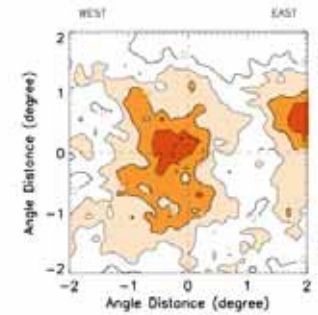
1990 (Tibet-I)



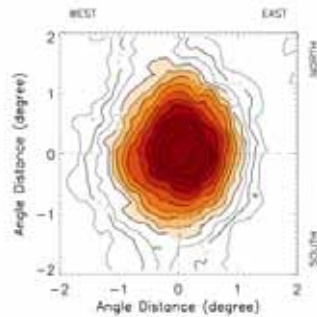
1991 (Tibet-I)



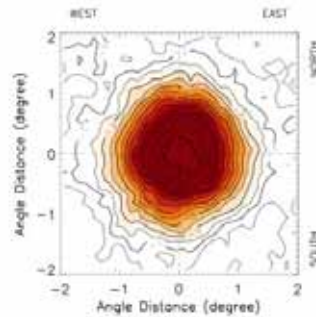
1992 (Tibet-I)



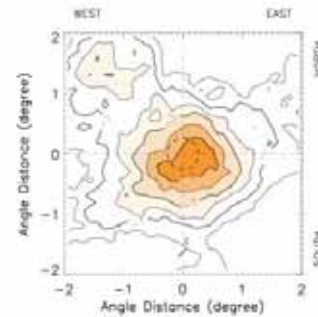
1993 (Tibet-I)



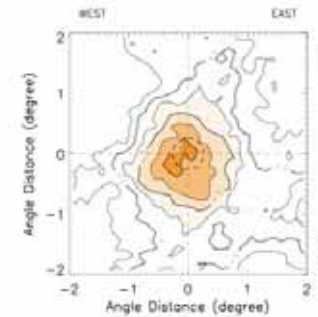
1996 (Tibet-II)



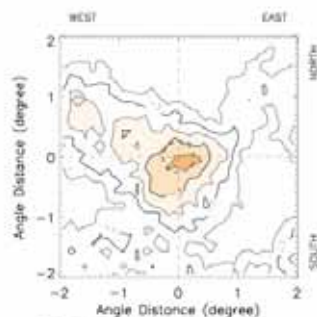
1997 (Tibet-II)



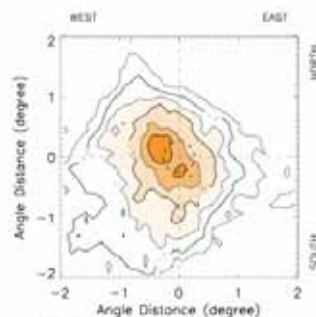
1998 (Tibet-II)



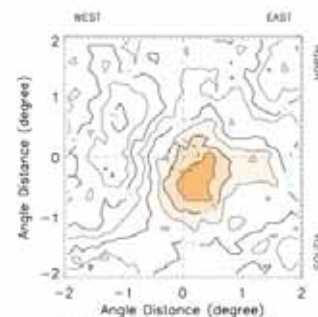
1999 (Tibet-II)



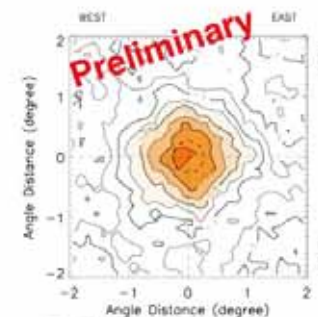
2000 (Tibet-III)



2001 (Tibet-III)



2002 (Tibet-III)



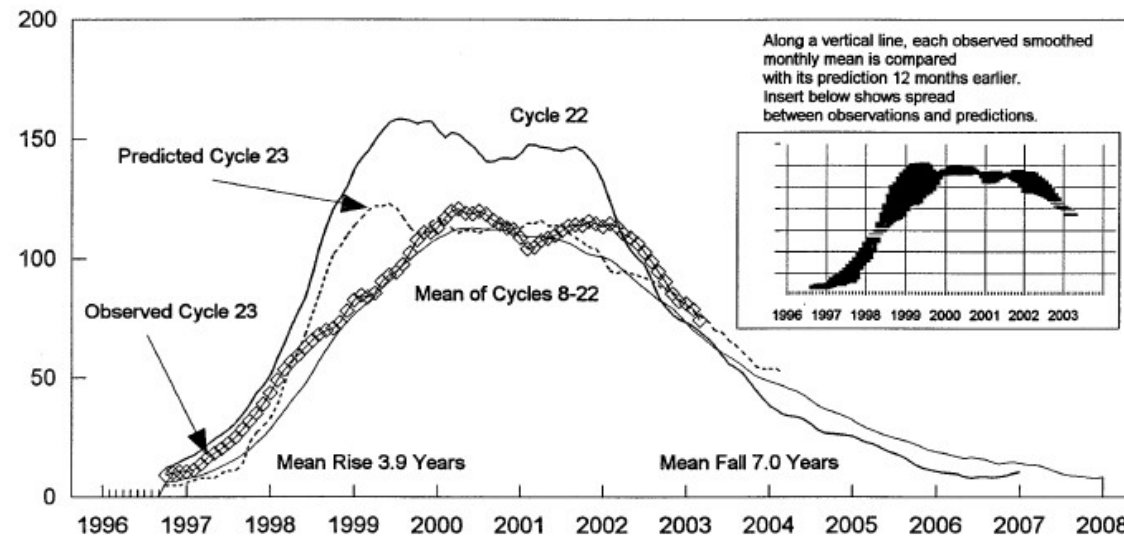
2003 (Tibet-III)



# Cycle23 Smoothed Sunspot #

Cycle 23 Smoothed Sunspot Numbers: Observed and Predicted

25  
Sep 03



Smoothed Sunspot Numbers (Observed and Predicted) for Parts of Solar Cycles 22 and 23

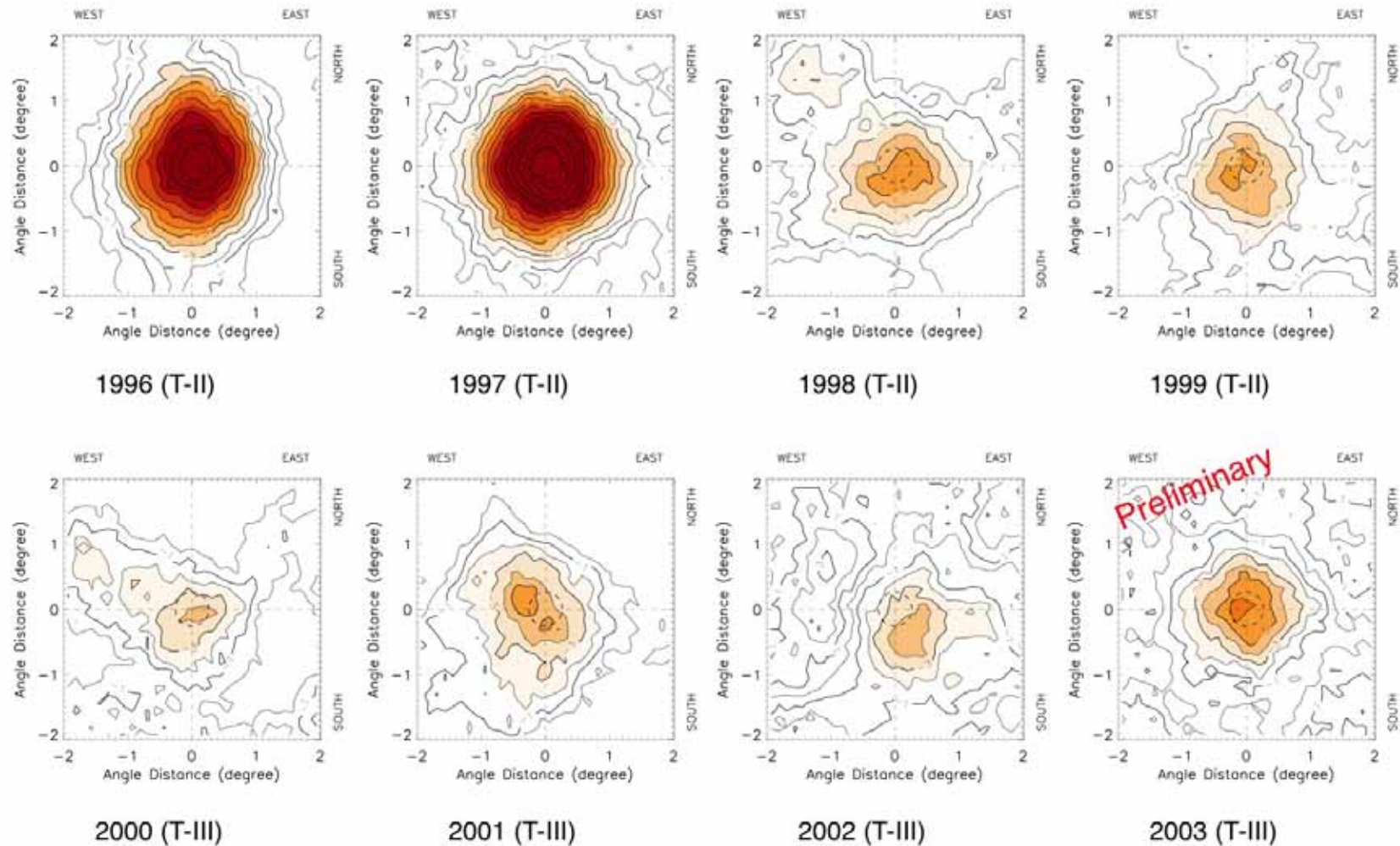
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1994	37	35	34	34	33	31	29	27	27	27	26	26	31
1995	24	23	22	21	19	18	17	15	13	12	11	11	17
1996	10	10	10	9	8*	9	8	8	8	9**	10	10	8
1997	11	11	14	17	18	20	23	25	28	32	35	39	23
1998	44	49	53	57	59	63	65	68	69	71	73	78	62
1999	83	85	84	85	90	93	94	98	102	108	111	111	95
2000	113	117	120	120.8+	119	119	120	119	116	115	113	112	107
2001	109	104	105	108	109	110	112	114	114	114	115	115	111
2002	114	115	113	111	109	106	103	99	95	91	85	82	102
2003	81	79	74	72	69	66	64	62	60	58	57	54	66
				(3)	(5)	(7)	(8)	(10)	(12)	(14)	(16)	(18)	(8)
2004	53	52	51	50	49	47	45	42	41	40	38	37	45
	(19)	(20)	(20)	(21)	(21)	(21)	(21)	(22)	(23)	(24)	(24)	(24)	(22)

  Solar Cycle 22    
   Solar Cycle 23    
   Min, Max, and Predictions  
 \* May 1996 marks Cycle 22's mathematical minimum.    \*\* October 1996 marks the consensus minimum NGDC is now using.  
 + April 2000 marks Cycle 23 maximum.

cf. Solar Geophysical Data

# Yearly variation of Sun's shadow (10TeV)

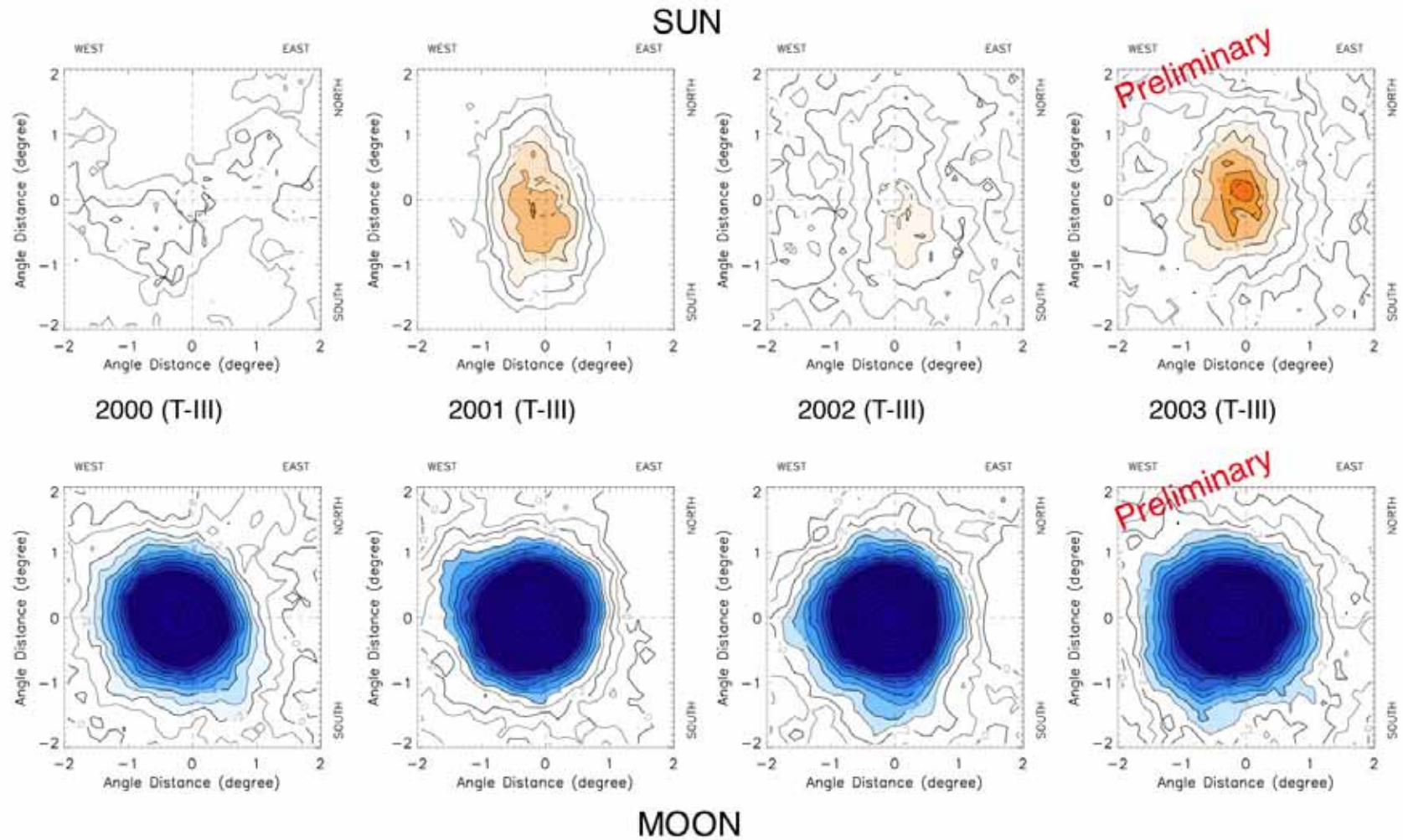
SUN's shadow by Tibet-II,III Array (10TeV: Equivalent Tibet-II)



Sub-Array (Equivalent Tibet-II) analysis for Tibet-III

# Sun's and Moon's shadows by Tibet-III (3TeV)

SUN and MOON's shadow by Tibet-III Array (3TeV: Full array)



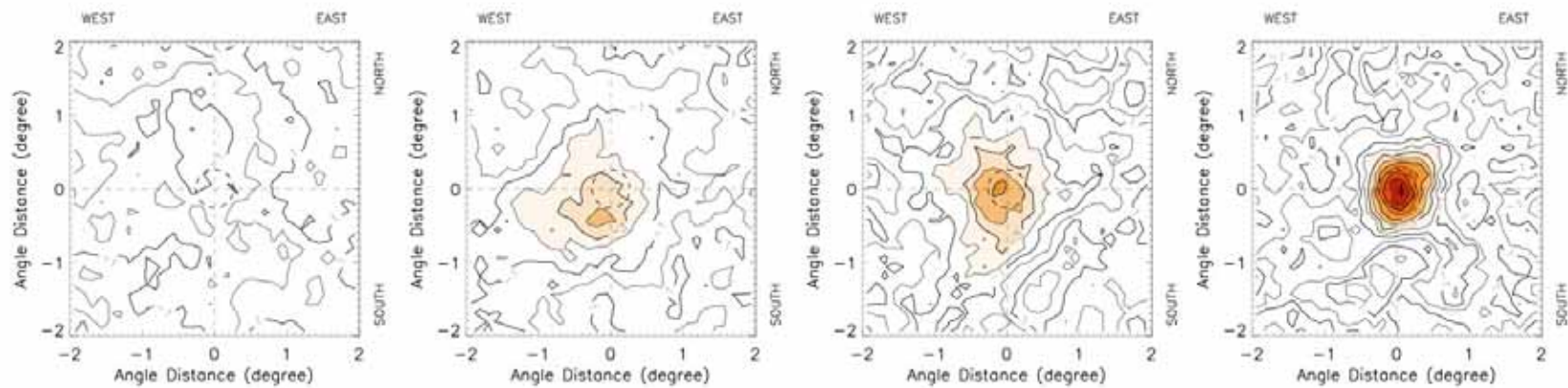
Full set analysis : 3TeV



# Energy Dependence of SUN and MOON's shadow by Tibet-III Array (Full array)

Preliminary

SUN

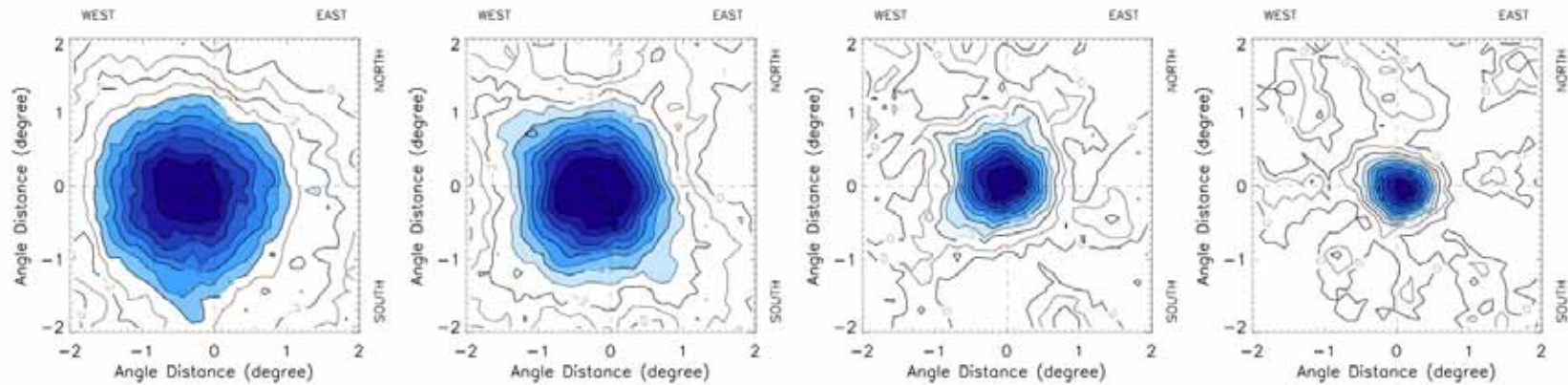


2 TeV

5 TeV

15 TeV

50 TeV



MOON

# Relation between Sun's Shadow and Solar Activity

## Normalized Significance of Sun's Shadow

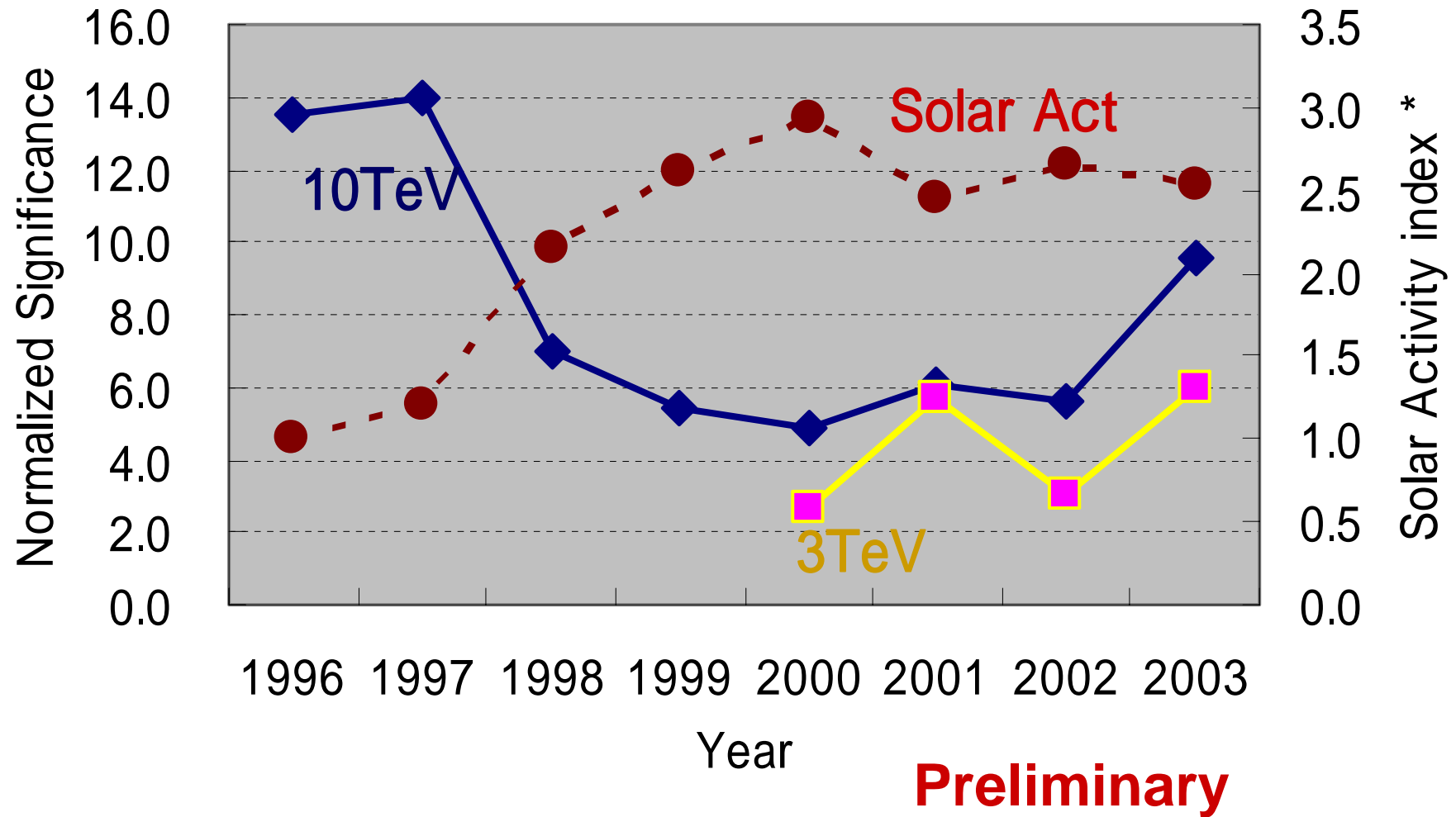
		1996	1997	1998	1999	2000	2001	2002	2003	
SUN	Defisit( )	13	16	6	6	4	6	5	7	(5.0E+06)
	10TeV Event #	4.6E+06	6.6E+06	3.7E+06	6.1E+06	3.4E+06	4.9E+06	4.0E+06	2.7E+06	
	Norm( )	13.5	14.0	7.0	5.4	4.8	6.1	5.6	9.6	
	Defisit( )					2	6	3	7	(1.5E+07)
	3TeV Event #					7.7E+06	1.6E+07	1.4E+07	1.9E+07	
	Norm( )					2.7	5.7	3.0	5.9	

## Solar Activity Index (Preliminary)

	1996	1997	1998	1999	2000	2001	2002	2003	
sqrt(Sunspot #)	2.8	4.7	8.5	9.9	11.4	10.6	10.5	8.0	Apr. – Sep. 6 months Average
Source Surface MF ( μ T)	9.0	7.8	18.0	27.1	29.0	19.3	24.1	29.3	
IMF at Earth's orbit (nT)	5.0	5.4	7.0	6.4	7.4	6.8	7.4	7.3	
Solar Activity index	1.0	1.2	2.2	2.6	2.9	2.4	2.6	2.5	

Index = Average( Norm(sqrt(sunspot#), Nrom(Source Surface), Norm(IMF) )  
normalize to the value of 1996

# Solar Activity vs. Normalized Sun's Shadow Significance





# Physics with Tibet-III (37000m<sup>2</sup>)

- Primary : All particle  $10^{16}$ - $10^{17}$  eV  
(consistency with UHECR)  
Modulation
- : Unknown DC & AC sources  
( $\sim 0.5$  crab/yr@5 for DC)  
Crab multi-10 TeV (IC or  $\theta^0$ )  
Single Counter Trigger mode  
(sub100GeV GRB with GLAST)
- Long-term AGN Observation
- Sun : Solar Cycle 23, 24!?
- Etc...

# What's After Tibet-III

Tibet-III Grants in Aid for Scientific Research:  
Until March 2005

## Next Plan

Higher Density in Tibet-III

Upgrade of Burst Detectors

Cherenkov Detectors?

# 1. Sub-TeV空気シャワー観測装置

TeV領域(100 GeV – 10 TeV)の宇宙放射線の広視野(約2Sr)連続観測

( Whipple 望遠鏡程度の感度 or 約0.1Crab/yr程度@ $5\sigma$  )

これまでの広視野地上観測と飛行体による観測の観測エネルギーギャップを埋める実験

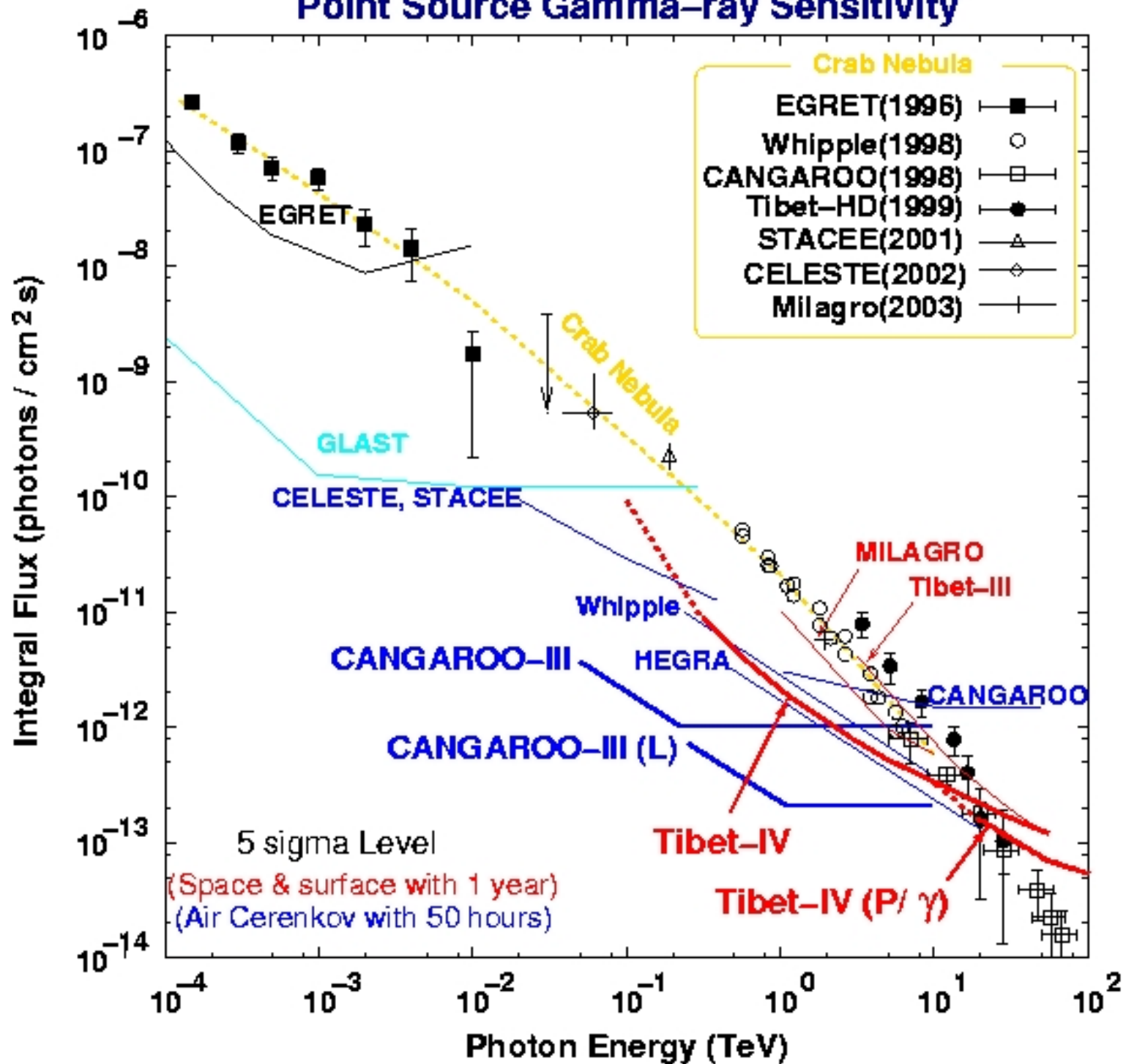
# Sub-TeV空気シャワー観測装置の概要

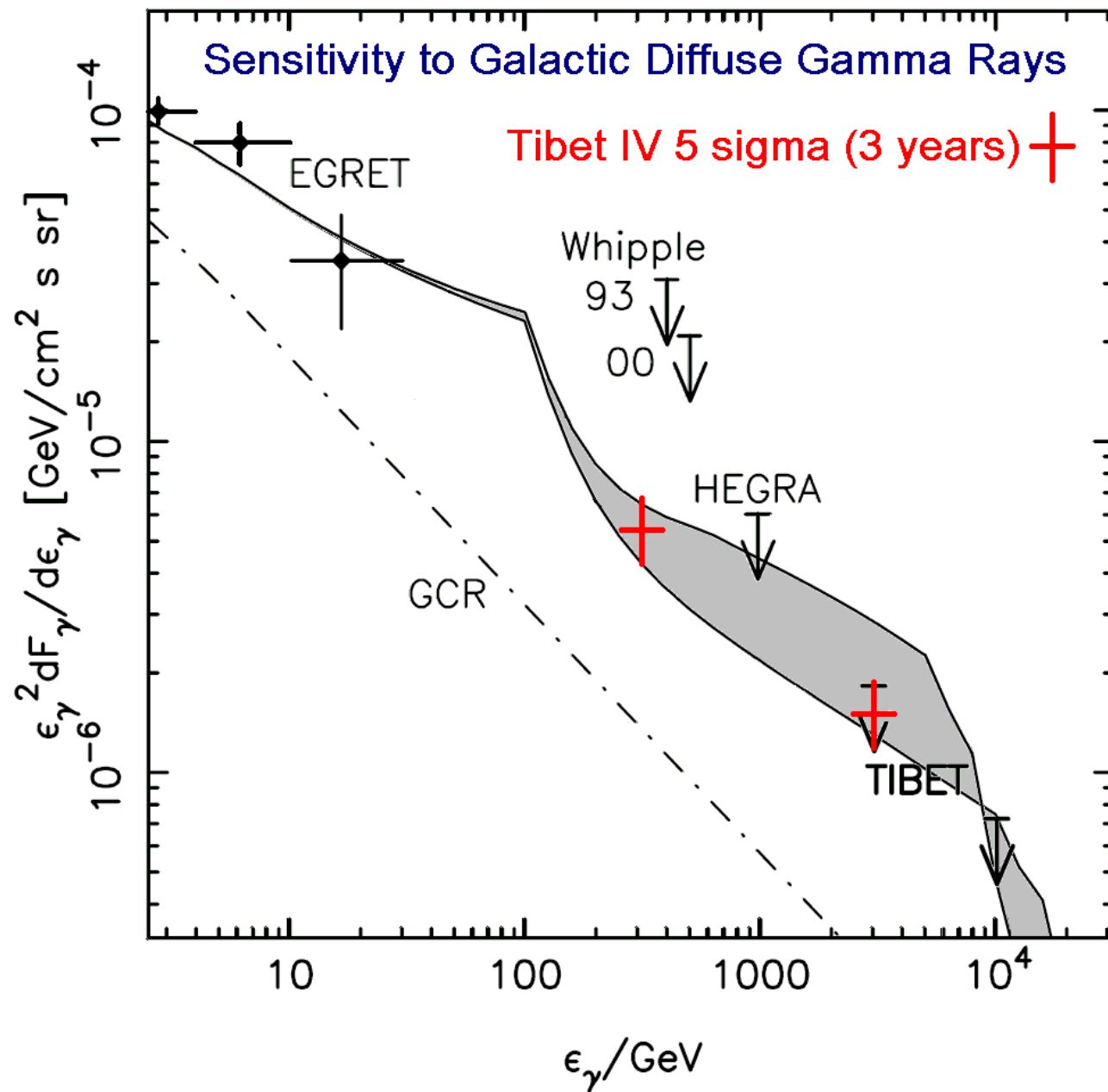
- 大型 ( $4\text{m}^2$ 程度) のプラスチックシンチレータ  
ー検出器
- Tibet-IIIの中央付近に $3.75\text{m}$ の間隔で697台  
設置し、全面積は約 $9200\text{m}^2$
- 全面積に対する光有感面積の割合  
約30% -> Tibet-IIIの約30倍

- TeV領域のシャワーの到来方向を約1度の精度で決定
- 約2strの広視野で未知の定常的又は時間変動するガンマ線放射天体の北天探索
- ガンマ線バーストや活動銀河核等の他波長同時観測
- 銀河面からの超新星起源拡散ガンマ線
- 銀河ハローからのダークマター起源拡散ガンマ線
- 銀河宇宙線異方性



# Point Source Gamma-ray Sensitivity





Solid line: Berezhko&Voelk ApJ 611, 12-19, (2004)  
 Upper  $B=10 \mu\text{G}$ , Lower  $B=30 \mu\text{G}$

## 2. 空気シャワーコア観測装置

- 空気シャワーコア観測装置（有効面積約  $3000\text{m}^2$ ）を現在稼働中のTibet-III中央付近に設置し連動実験

- 1,000 TeV以上の鉄等成分：

数万事例 / 3yr

鉄等の重粒子成分に関する観測データはない（全粒子Knee=鉄等Kneeの検証）

- 200 TeV以上の陽子・ヘリウム成分：

従来の統計 x10倍以上 /3yr

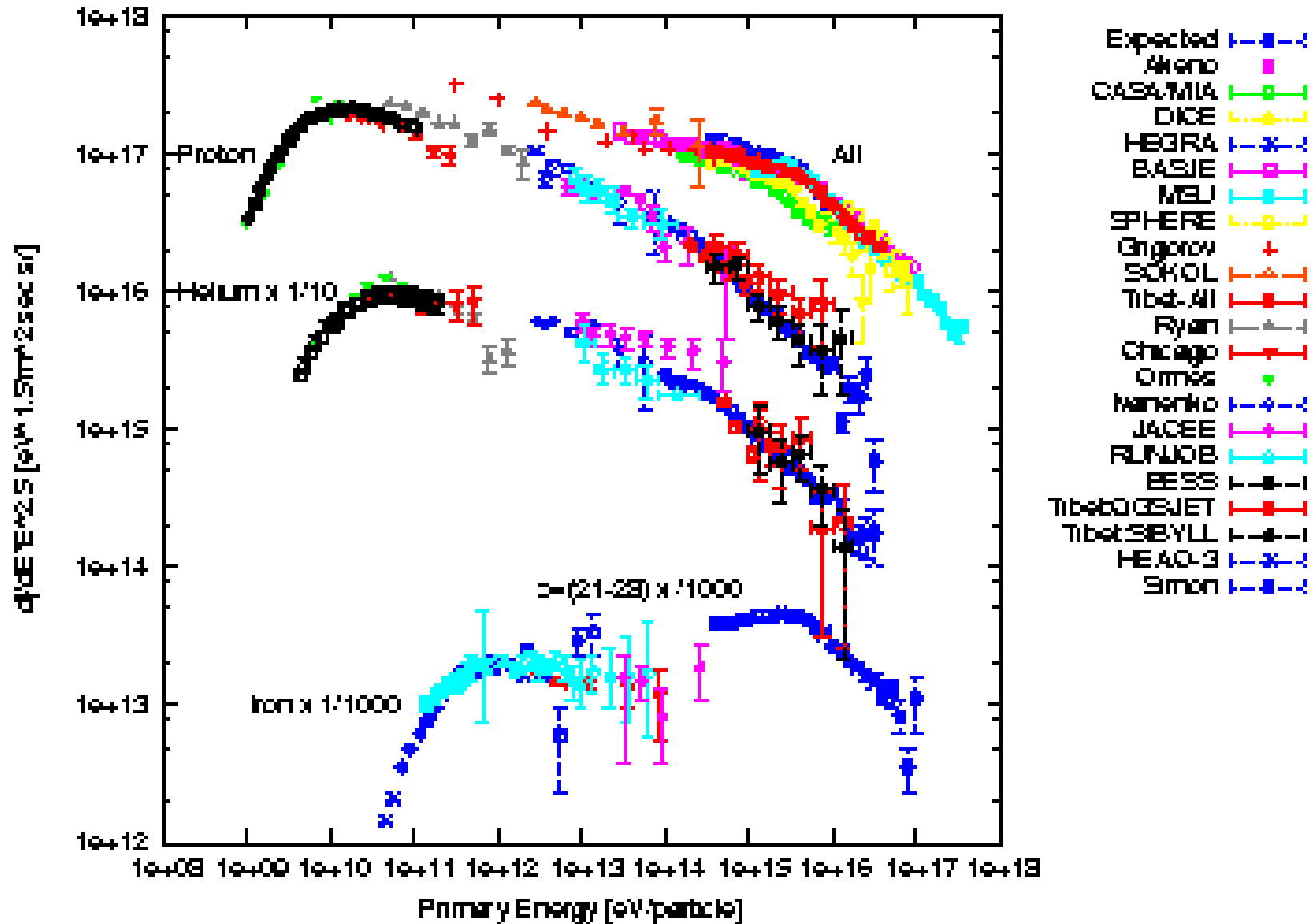
# 空気シャワーコア観測装置の概要

- ・ 40cm × 50cm × 1cmのプラスチックシンチレーター上に3.5cm(7r.l.)の鉛板を載せたバースト検出器

Tibet-IIIアレイの中心に3.75m間隔で格子状に213台配置(総面積約3000m<sup>2</sup>)

- ・ 高エネルギー電磁成分 (> GeV) が鉛中で作るカスケードシャワーのサイズ(バーストサイズ)を測定(空気シャワー軸付近のエネルギー流を測定) -> 鉄等成分のANNによる選別

# New Core Detector Sensitivity (3 yr)





- sub-TeV空気シャワー観測装置及び  
R&D 及び建設 2年 観測3年以上
- 空気シャワーコア観測装置  
R&D 及び建設 3年 観測3年程度
- 現チベット実験の構成機関を主たる構成機関とする予定。
- 予想予算：約5億円 + 維持費

できるだけ早期に実現したい！