ASTROPARTICLE PHYSICS WITH ARGO-YBJ

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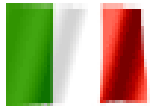
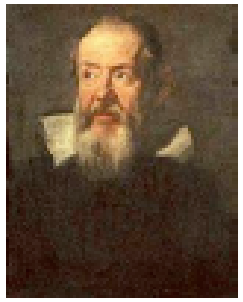
on behalf of the ARGO-YBJ Collaboration

The ARGO-YBJ experiment

Collaboration Institutes:

- ✓ **Chinese Academy of Science (CAS)**
- ✓ **Istituto Nazionale di Fisica Nucleare (INFN)**





INFN and Dpt. di Fisica Università, Lecce
INFN and Dpt. di Fisica Universita', Napoli
INFN and Dpt. di Fisica Universita', Pavia
INFN and Dpt di Fisica Università "Roma Tre", Roma
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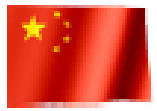
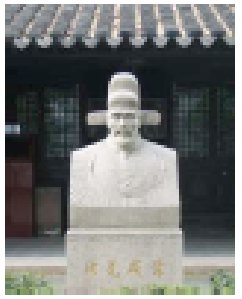
INAF/IFSI and INFN, Torino
INAF/IASF, Palermo and INFN, Catania





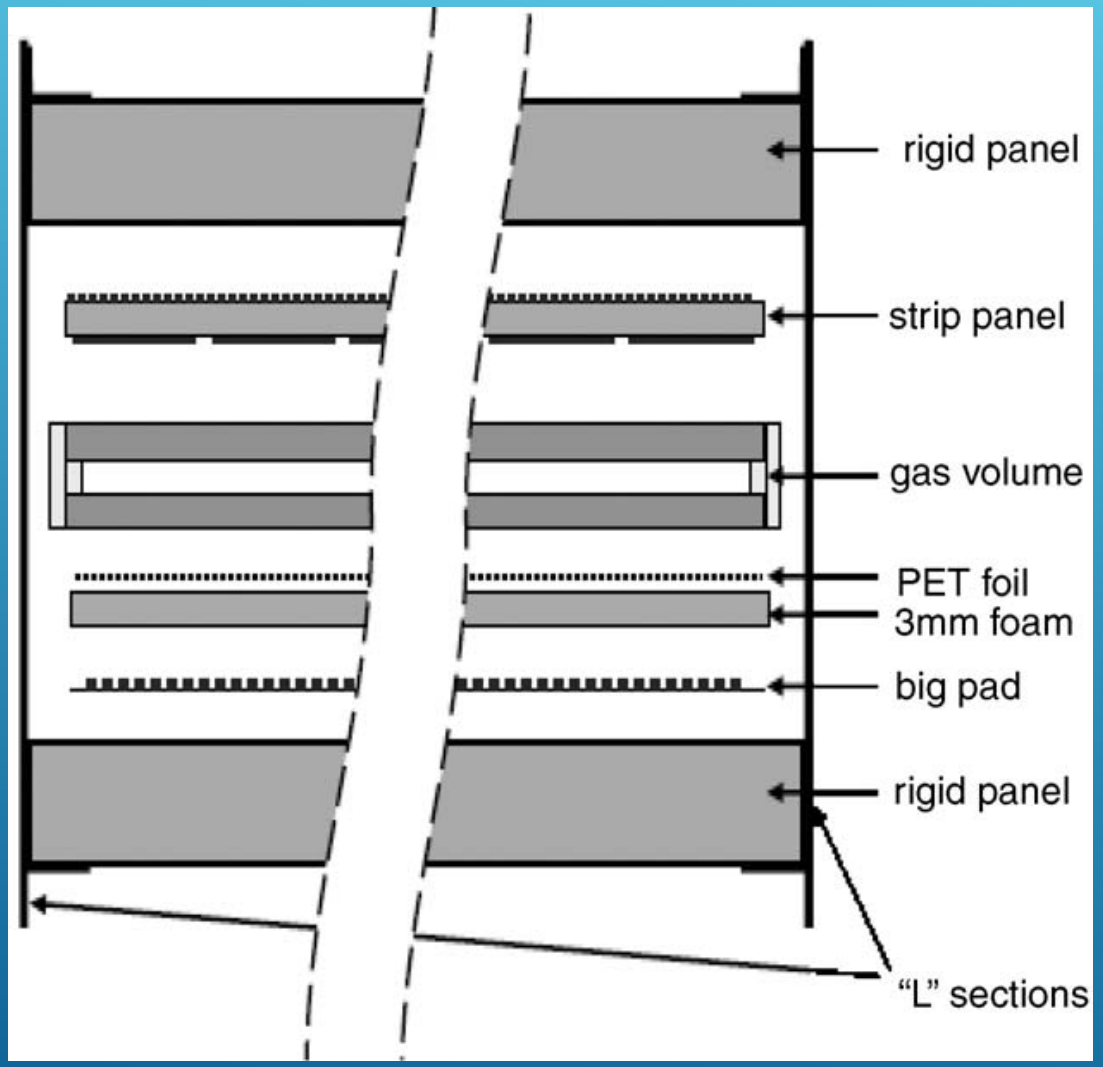
IHEP, Beijing
Shandong University, Jinan
South West Jiaotong University, Chengdu
Tibet University, Lhasa
Yunnan University, Kunming
Hebei Normal University, Shijiazhuang

Nucl.Instrum.Meth.A562:92-96,2006
Nucl.Instrum.Meth.A608:246-250,2009

OUTLINE

- The ARGO-YBJ detector: experimental set-up and performance
- γ-ray astronomy: γ-ray galactic sources and AGN flares
- Cosmic Rays: spectrum and anisotropy
- Summary

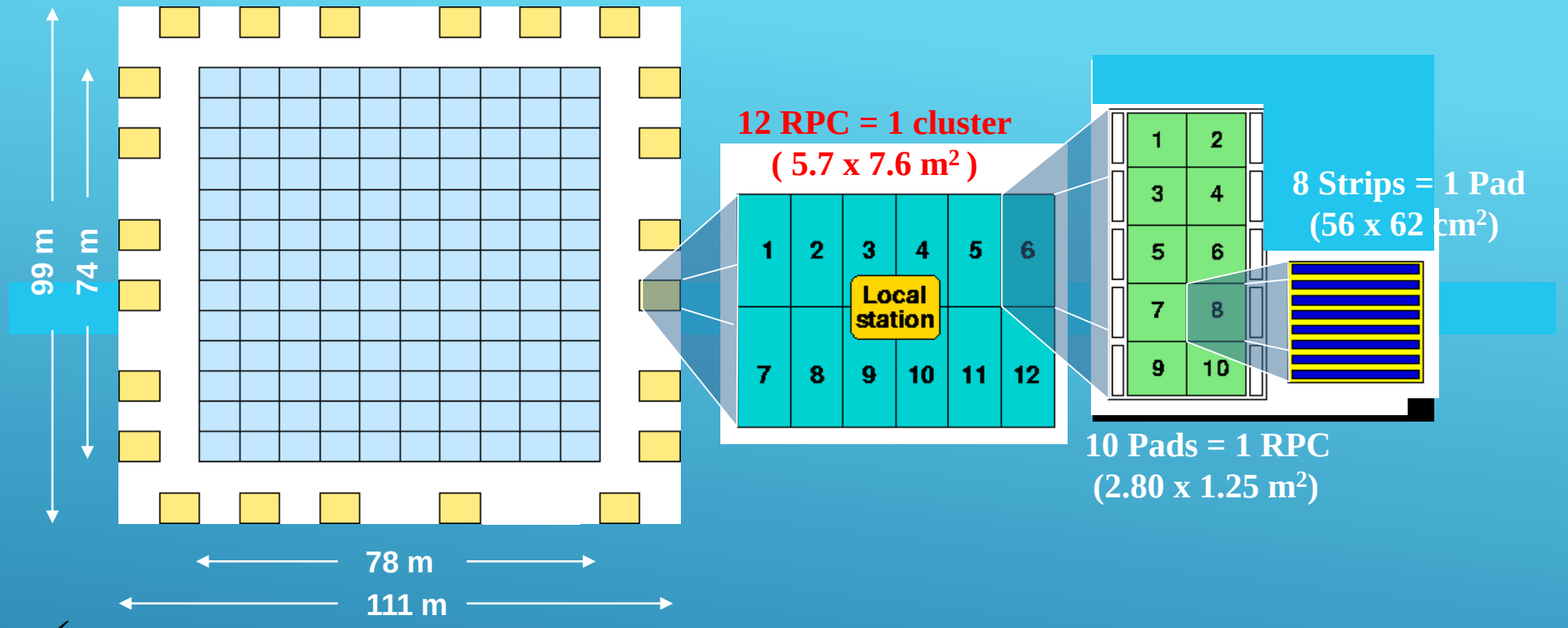
THE ARGO-YBJ RESISTIVE PLATE CHAMBERS



Gas mixture:
$C_2H_2F_4$/Ar/iC_4H_{10} = 75/15/10

Operated in streamer mode

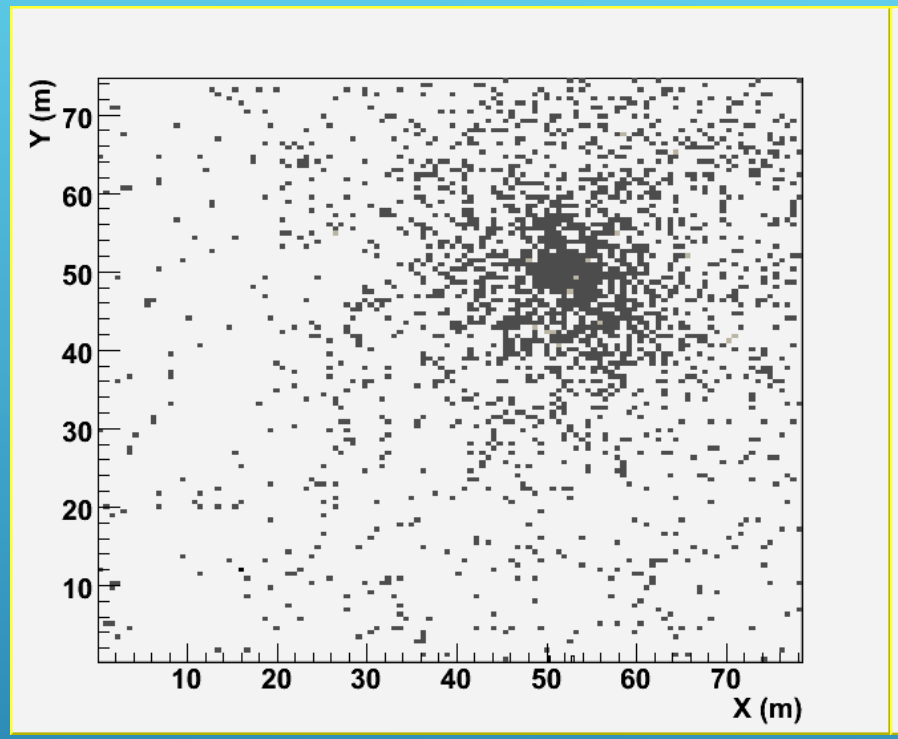
Time resolution ~ 1.5 ns

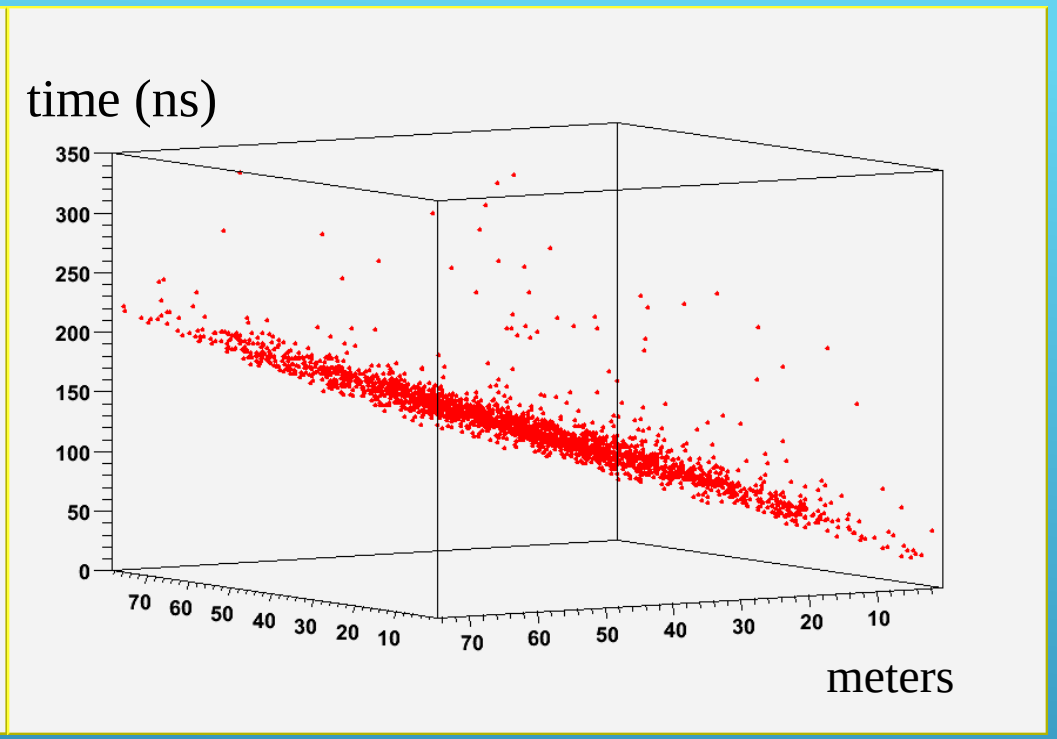


✓

Effective Area : central carpet ~ 5600 m²
sampling guard-ring ~ 1000 m²

- ✓ Data taking: November 2007 – February 2013 (5 X 10^{11} events)
- ✓ Trigger rate: 3.6 KHz
- ✓ Duty cycle: 86%
- ✓ Dead time: 4%
- ✓ Energy range: 300 GeV – few PeV



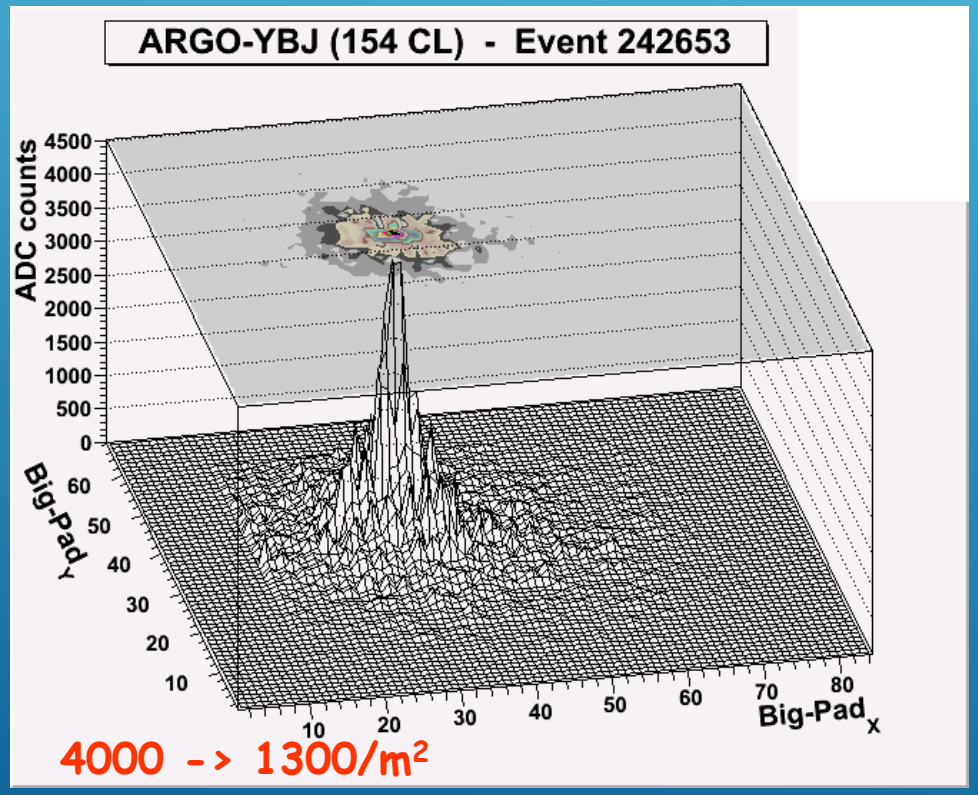


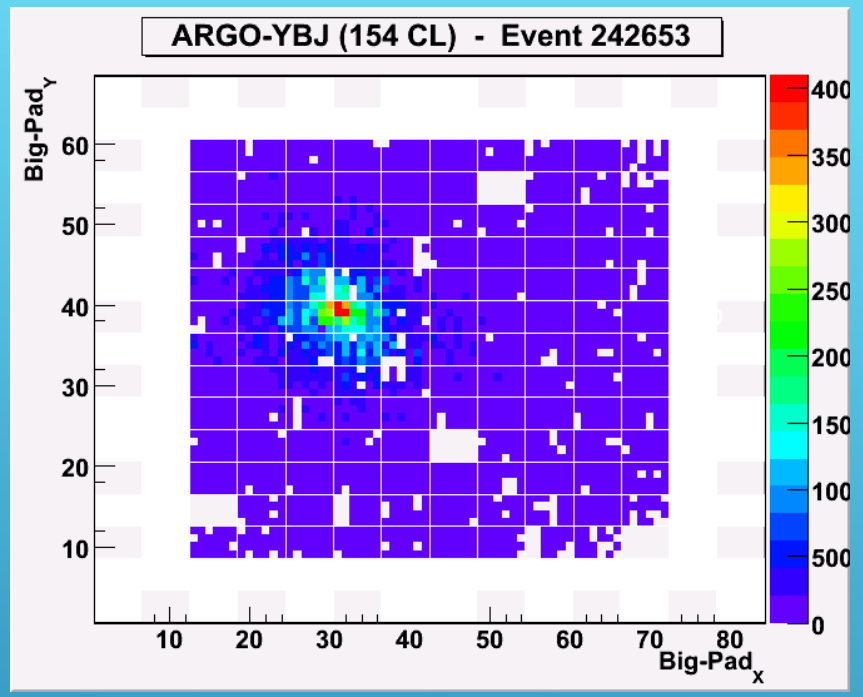
Fired pads on the carpet

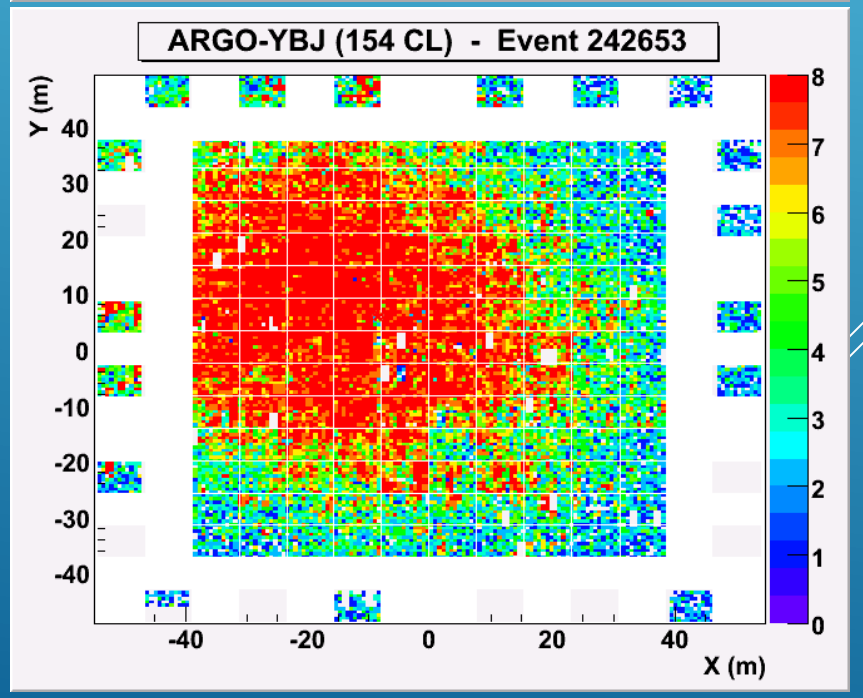
Arrival time vs position

SHOWER RECOSTRUCTION

A real event seen by ARGO-YBJ



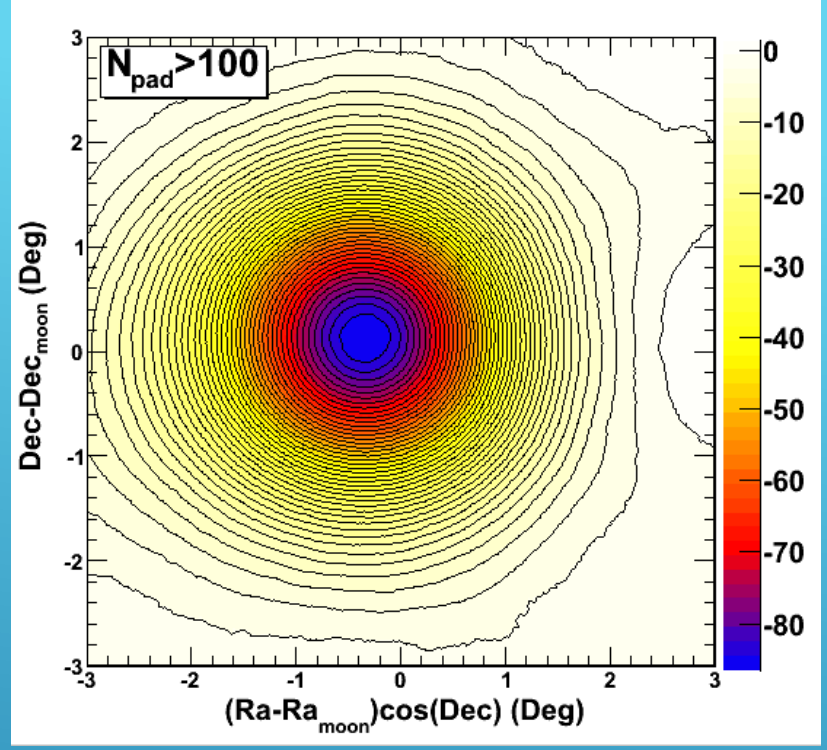


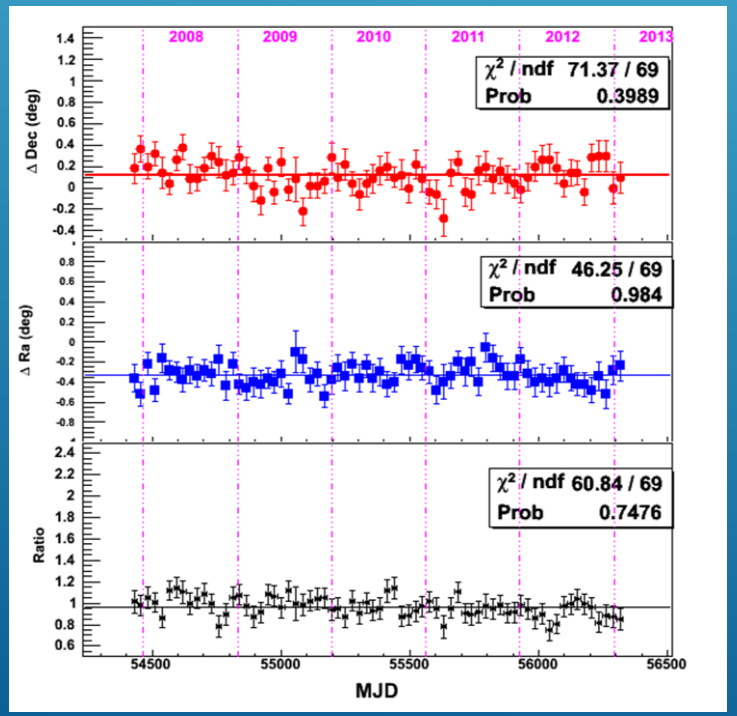


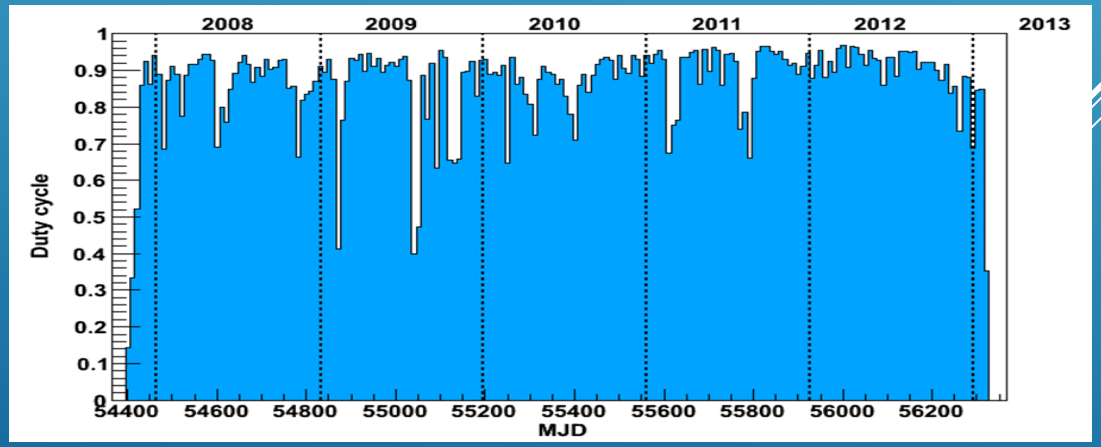
ARGO-YBJ

STABLE OPERATION IN 5 YRS

- duty cycle>85%
- event rate ±5%
- Moon shadow: 10 s.d. /month
-

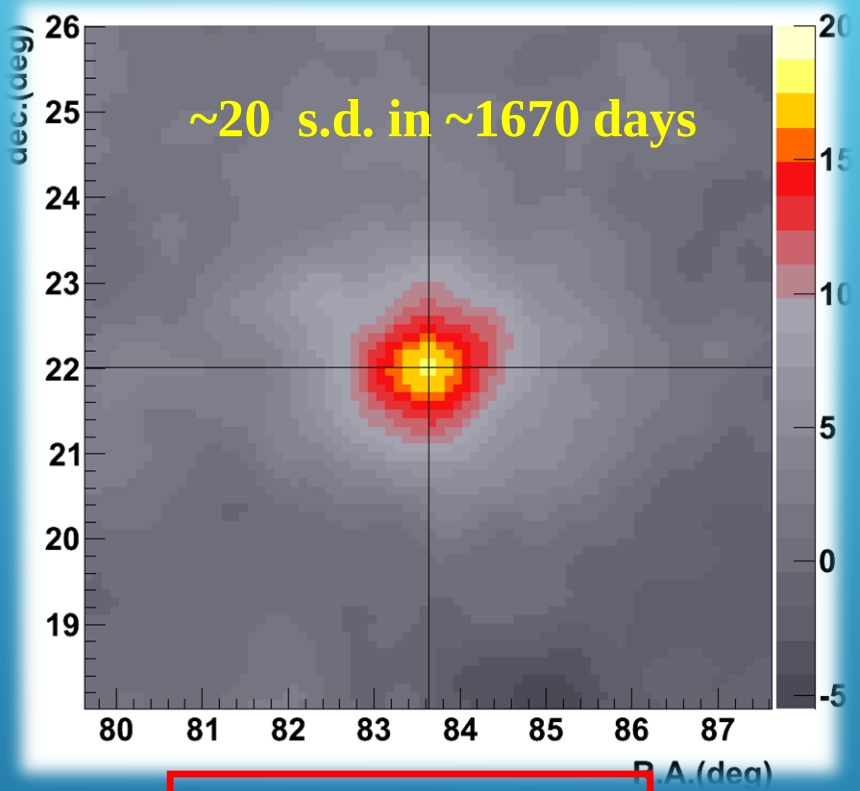




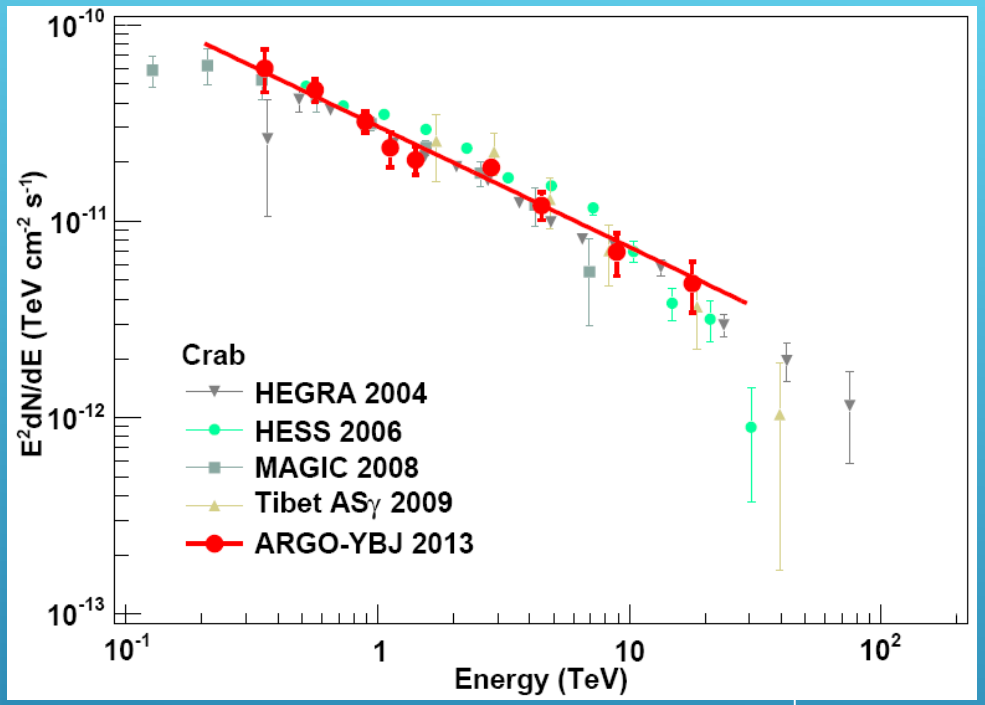


Crab Nebula (Standard candle)

ApJ 798 (2015) 119

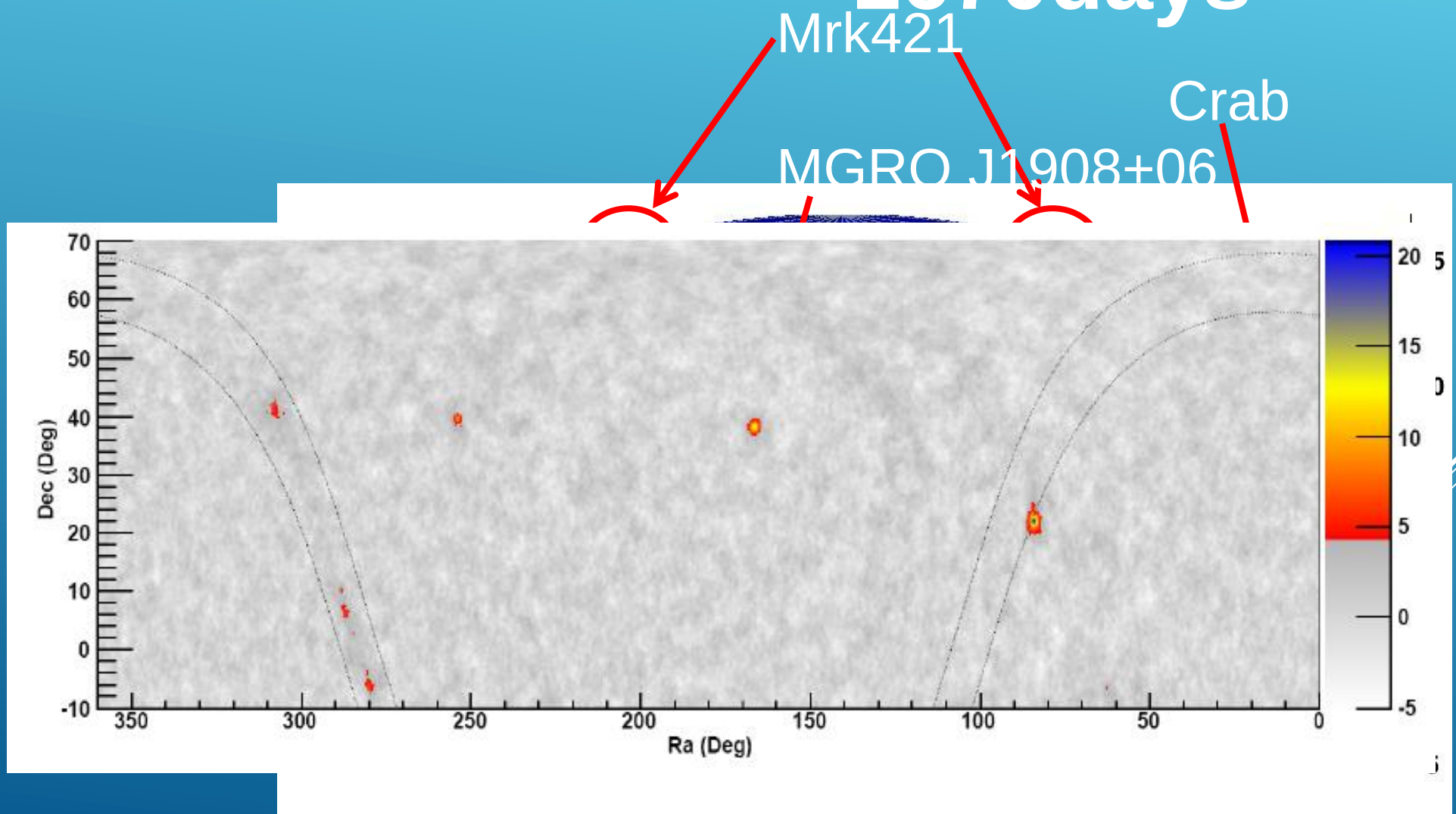


NO γ/h discrimination
~ 0.55 Crab/year



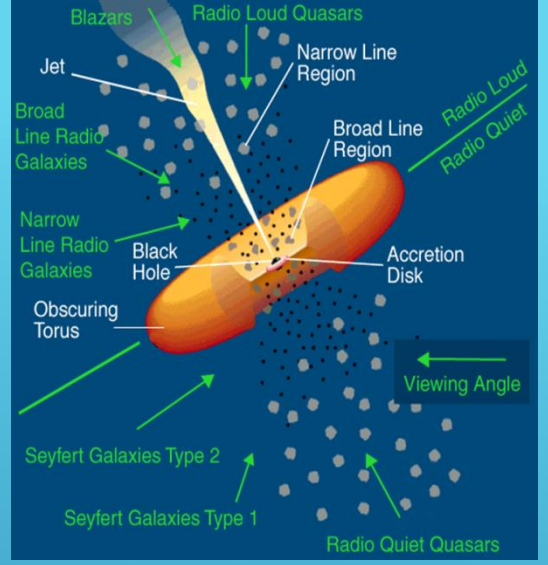
$$\frac{dN}{dE} = (3.00 \pm 0.18_{stat})(E/1\,\mathrm{TeV})^{(-2.62\pm0.06_{stat})} \times 10^{-11}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{TeV}^{-1}$$

ARGO全天扫描 1670days



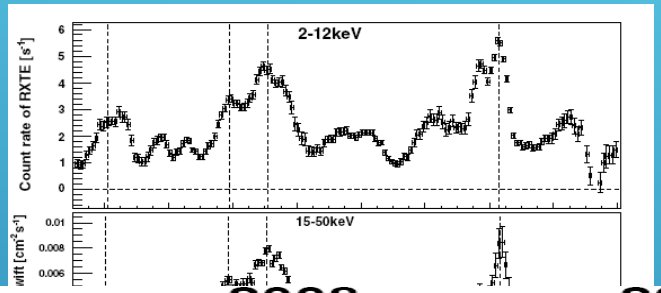
ARGO-YBJ GAMMA RAY SOURCES

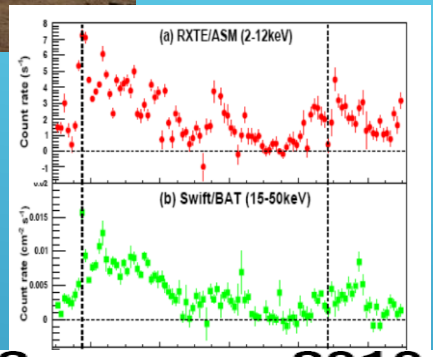
ARGO-YBJ Name	Ra (deg)	Dec (deg)	l (deg)	b (deg)	S (S.D.)	Associated TeV Source
ARGO J0409−0627	62.35	-6.45	198.51	-38.73	4.8	
ARGO J0535+2203	83.75	22.05	184.59	-5.67	20.8	Crab Nebula
ARGO J1105+3821	166.25	38.35	179.43	65.09	14.1	Mrk 421
ARGO J1654+3945	253.55	39.75	63.59	38.80	9.4	Mrk 501
ARGO J1839−0627	279.95	-6.45	25.87	-0.36	6.0	HESS J1841-055
ARGO J1907+0627	286.95	6.45	40.53	-0.68	5.3	HESS J1908+063
ARGO J1910+0720	287.65	7.35	41.65	-0.88	4.3	
ARGO J1912+1026	288.05	10.45	44.59	0.20	4.2	HESS J1912+101
ARGO J2021+4038	305.25	40.65	78.34	2.28	4.3	VER J2019+407
ARGO J2031+4157	307.95	41.95	80.58	1.38	6.1	MGRO J2031+41 TeV J2032+4130
ARGO J1841-0332	280.25	-3.55	28.58	0.70	4.2	

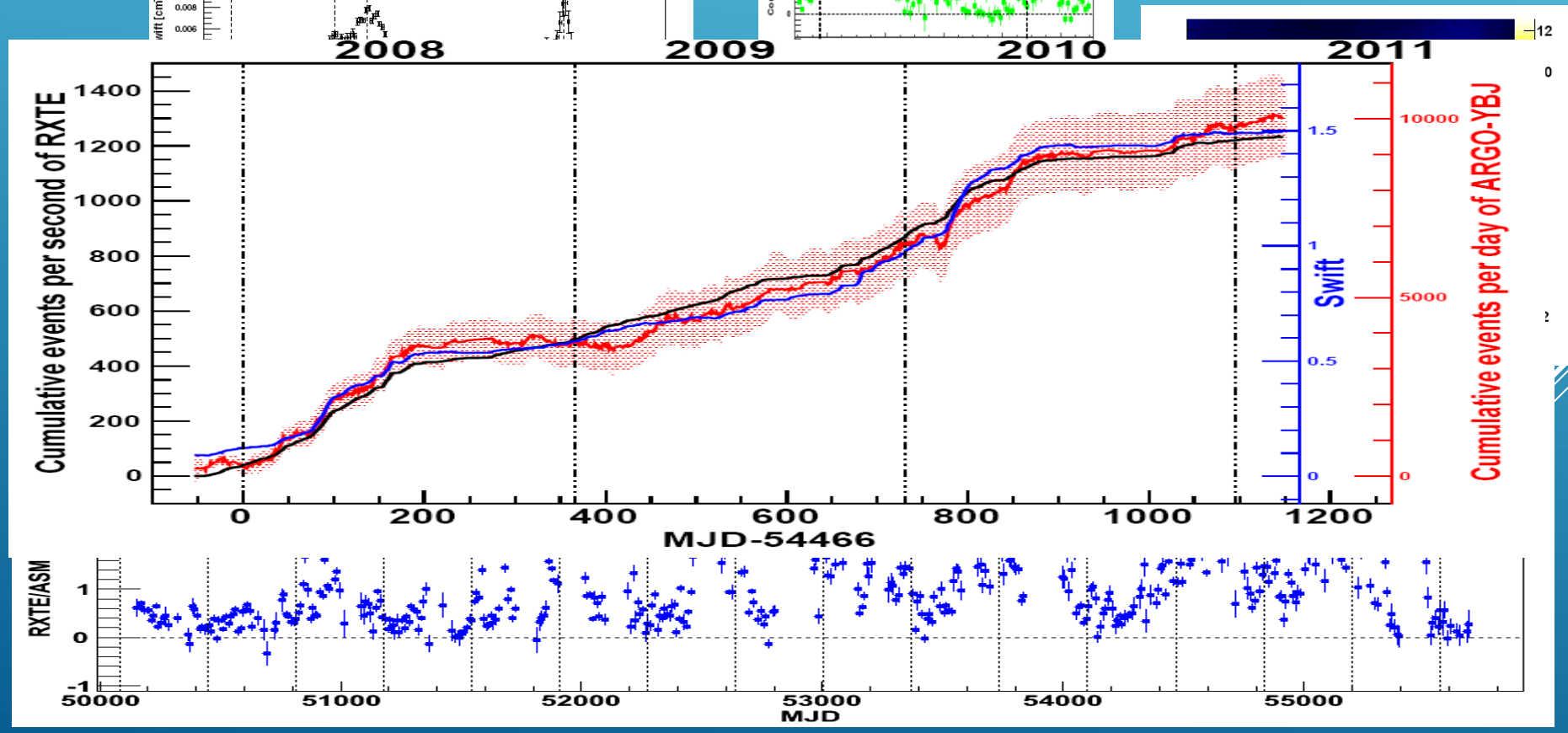


ApJ 734 (2011) 110

ApJ Supplement Series 222:6 (2016)

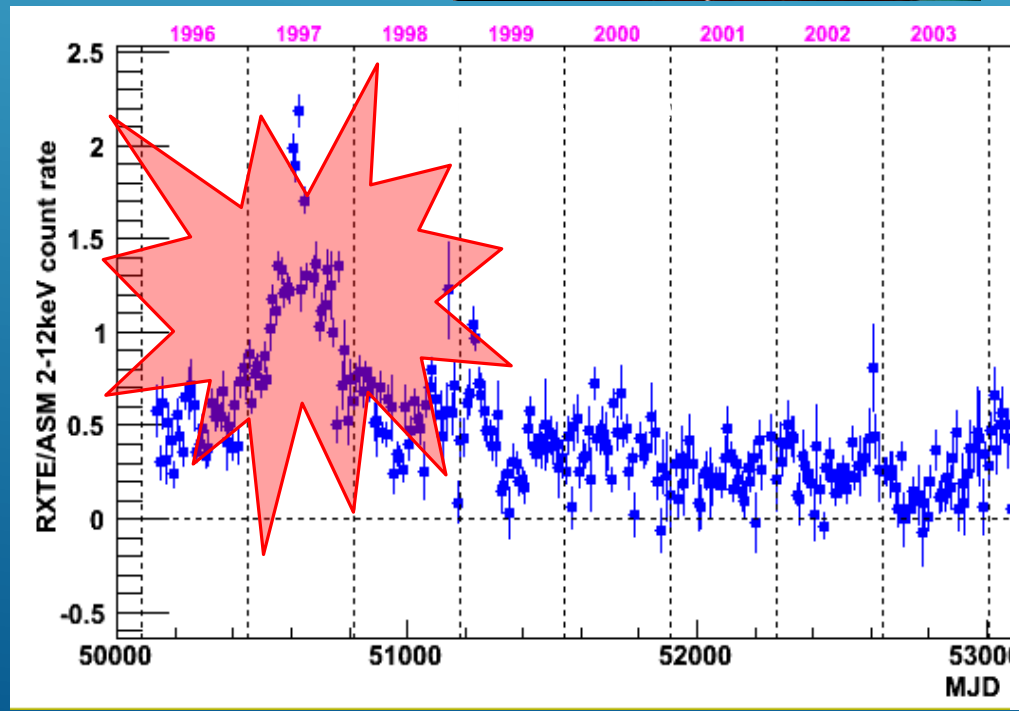


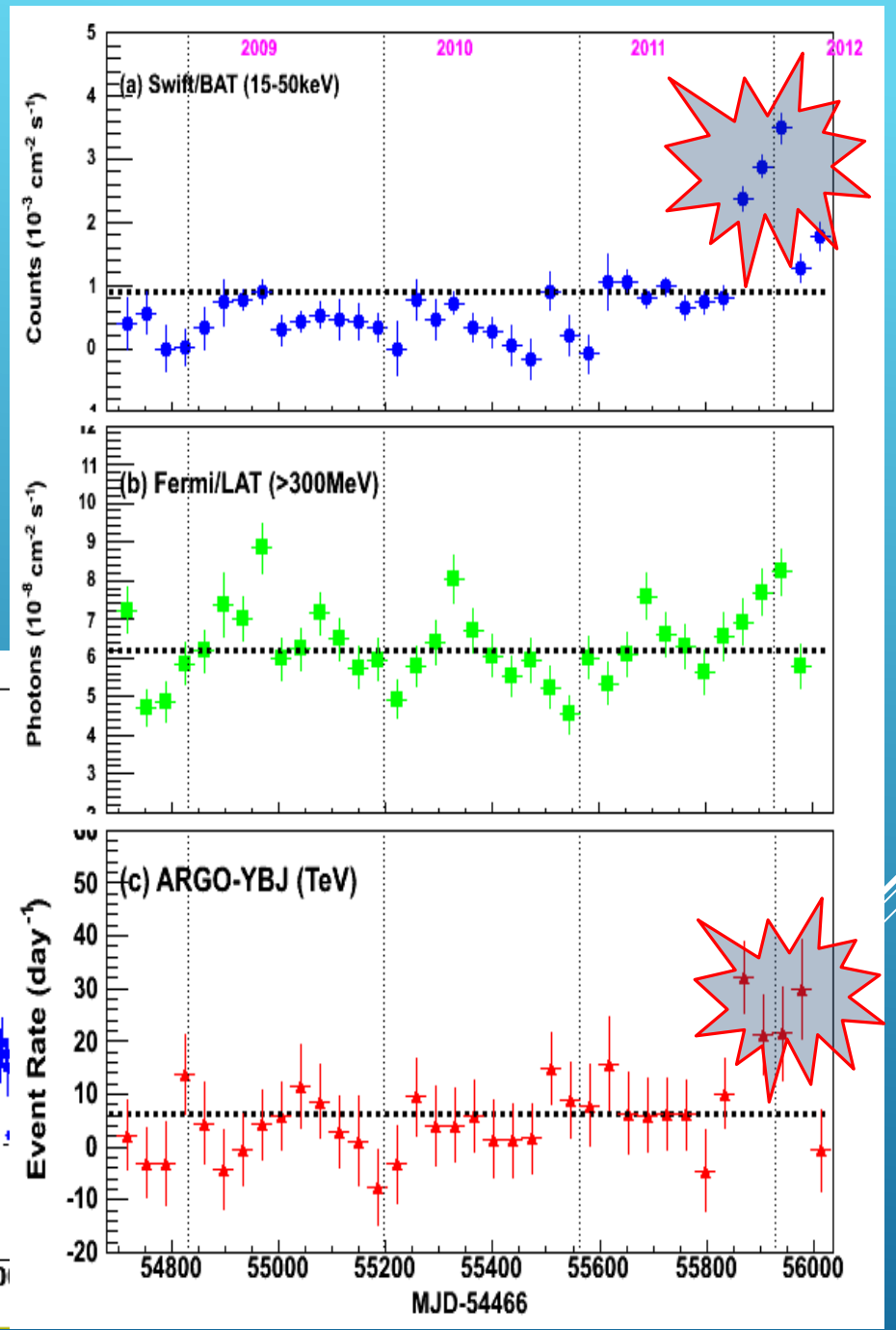




AGN : TRANSIENTS MRK501

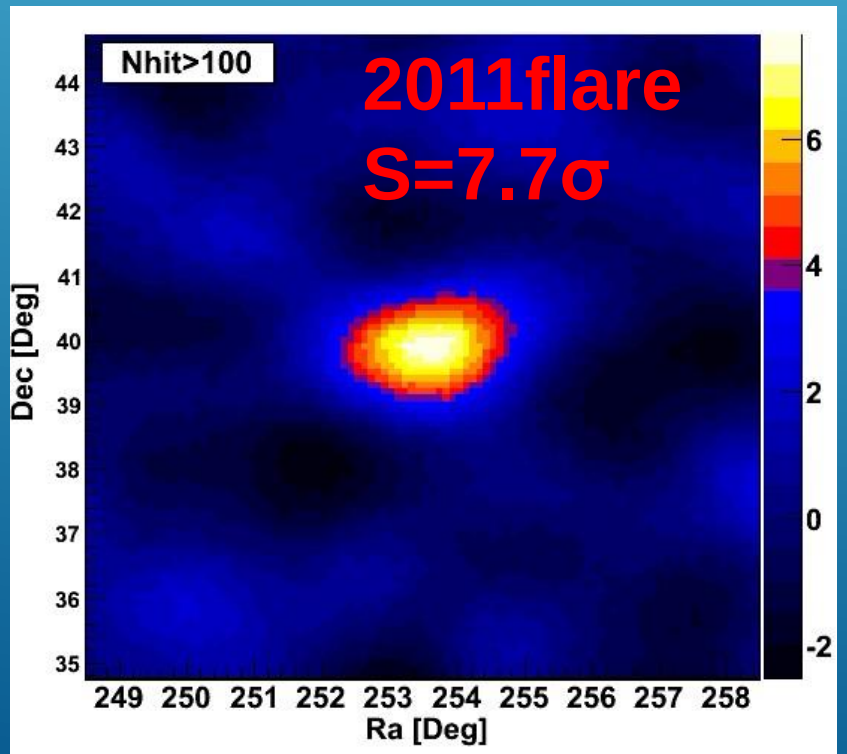
ApJ 758 (2012) 2

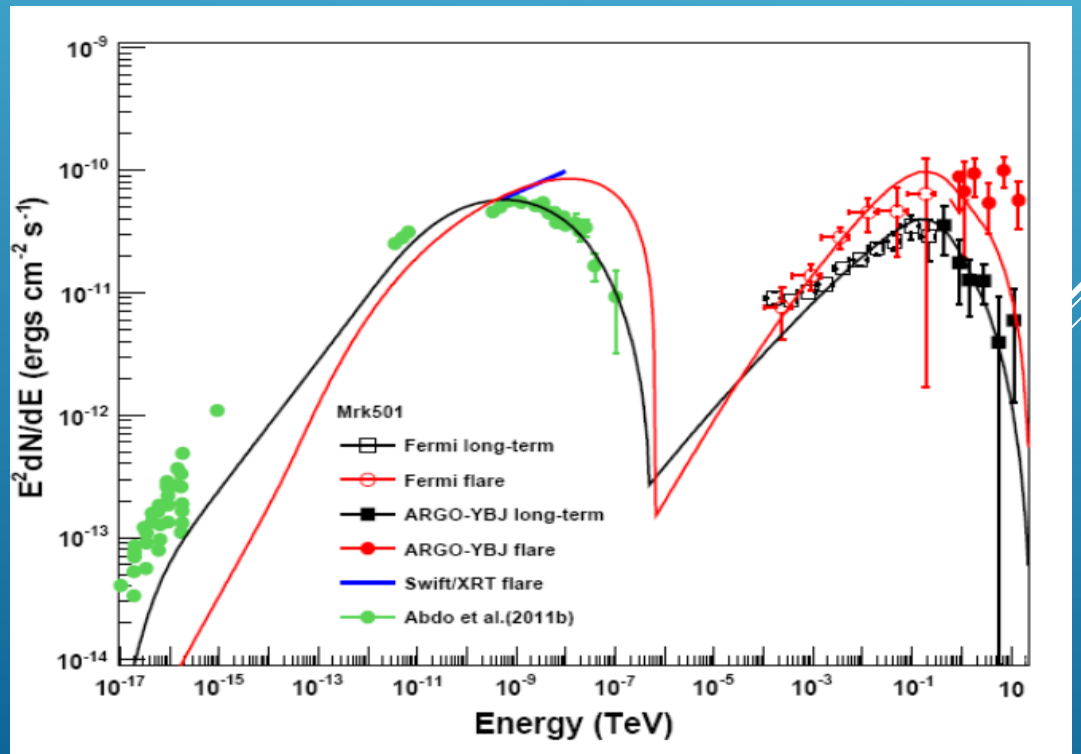




SED ANALYSIS FOR RADIATION MECHANISM

- For steady states, the SSC model is favored.
- **During flares, the spectrum is hardened. Simple SSC model is not favored**
- **Evolution is well observed**





COSMIC RAY PHYSICS

- Light component (p+He) energy spectrum
- CR anisotropy in the few TeV region
- Compton Getting effect
- Mass composition studies
- Antiproton to proton ratio
- Hadronic interaction studies
- Horizontal air showers
- Geomagnetic effects
- Atmospheric effects
- Sun shadow and solar activity

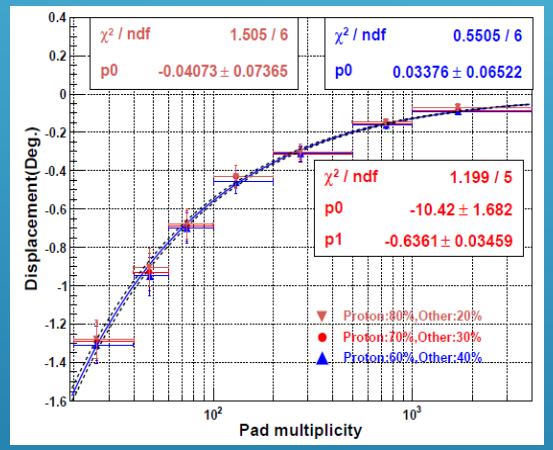
ENERGY SCALE: MOON SHADOW DISPLACEMENT

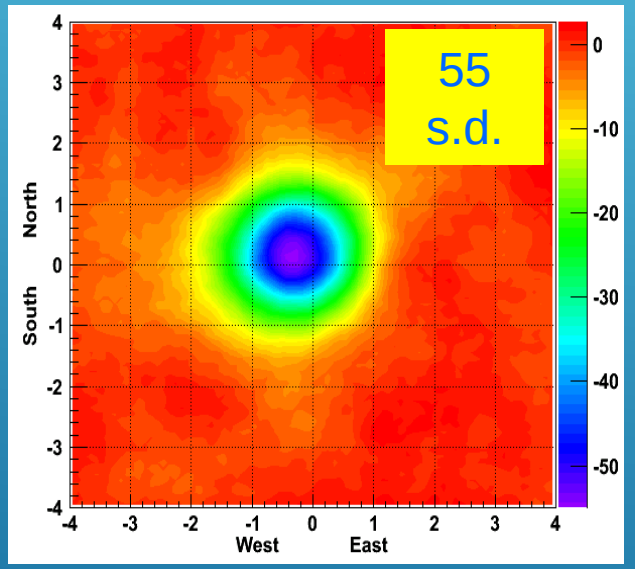
$$N \approx 21 \cdot (E_{TeV}/Z)^{1.5}$$

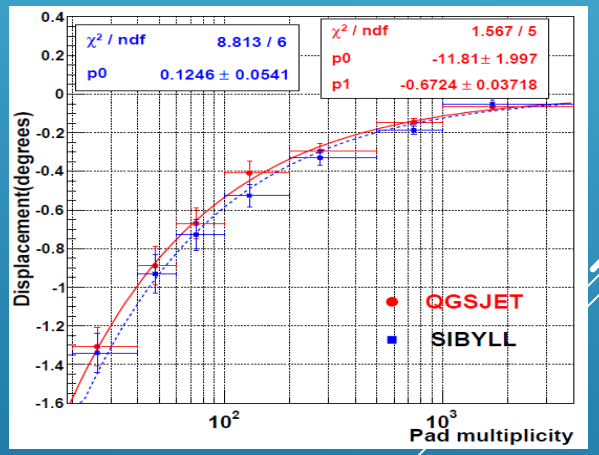
1 – 30 (TeV/Z)

Two systematic uncertainties may affect the Multiplicity-Energy relation:

- the assumed primary CR chemical composition (7%)
- the uncertainties of different hadronic models (6%)



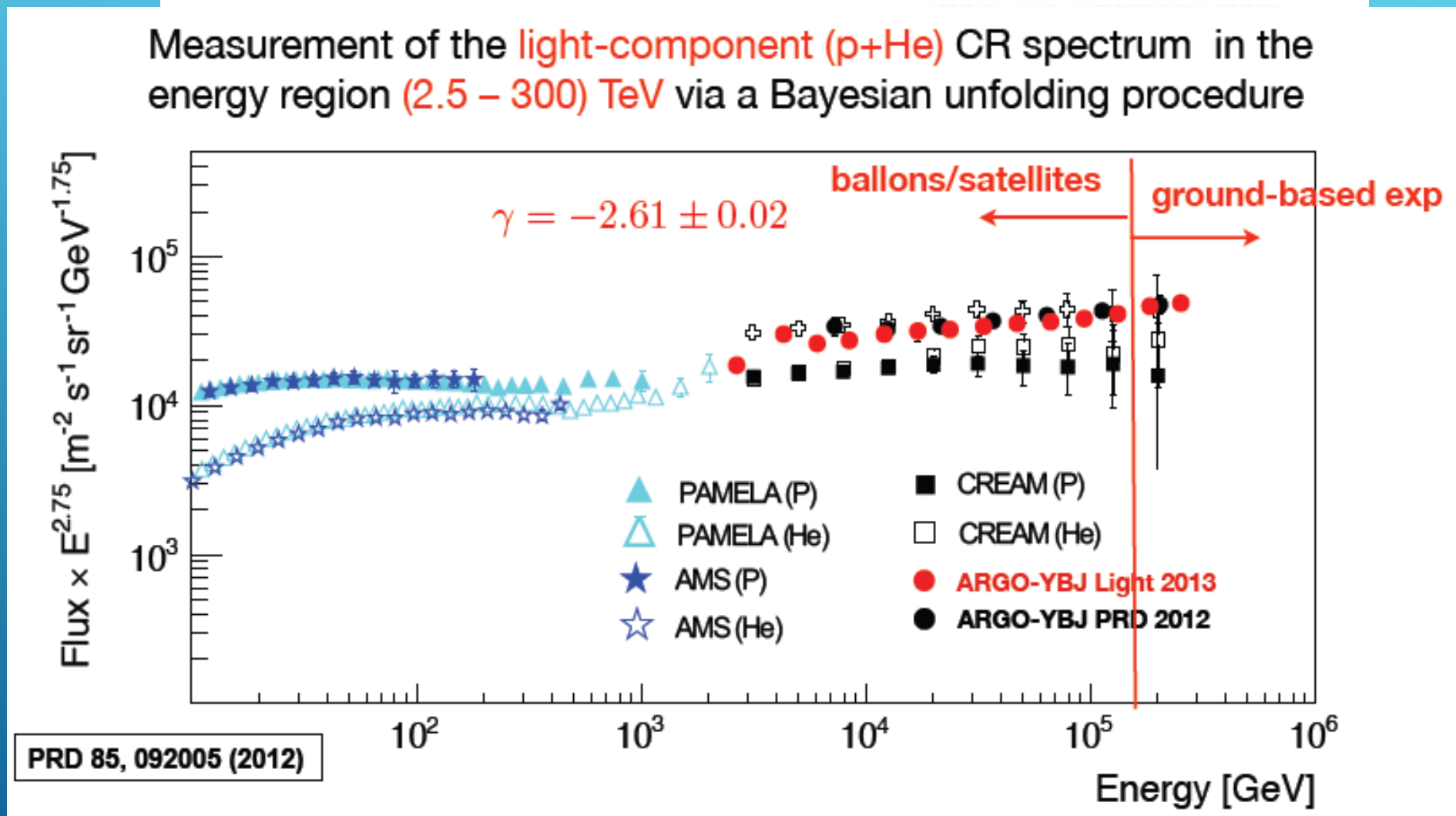




The energy scale error is estimated to be less than 13% in the energy range 1 – 30 (TeV/Z).

Phys.Rev.D84:022003,2011

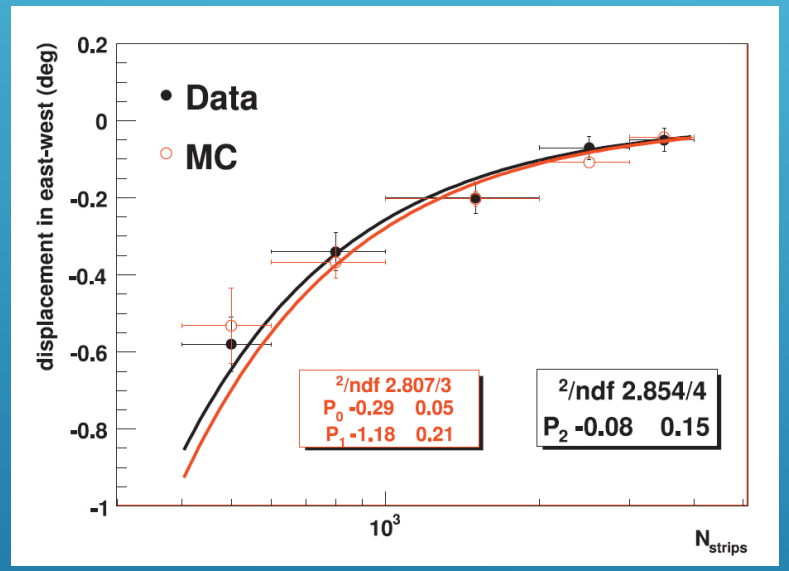
CR ENERGY SPECTRUM BY ARGO-YBJ:

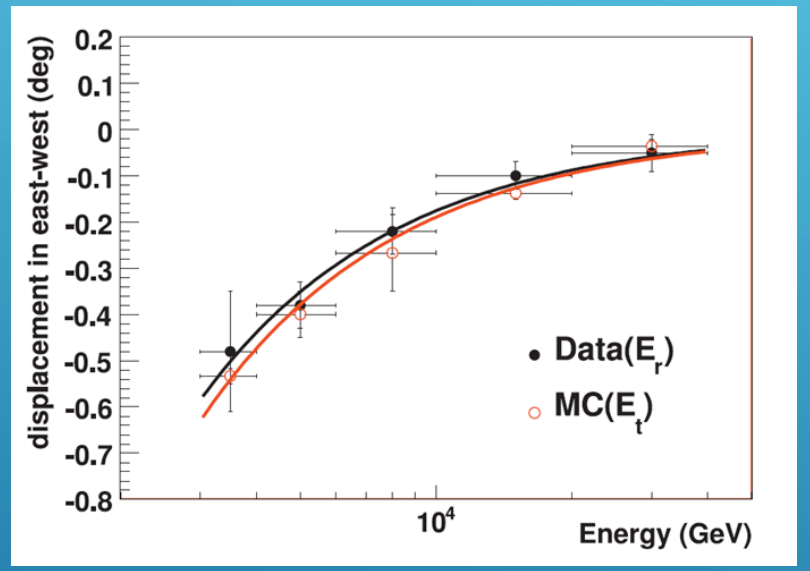


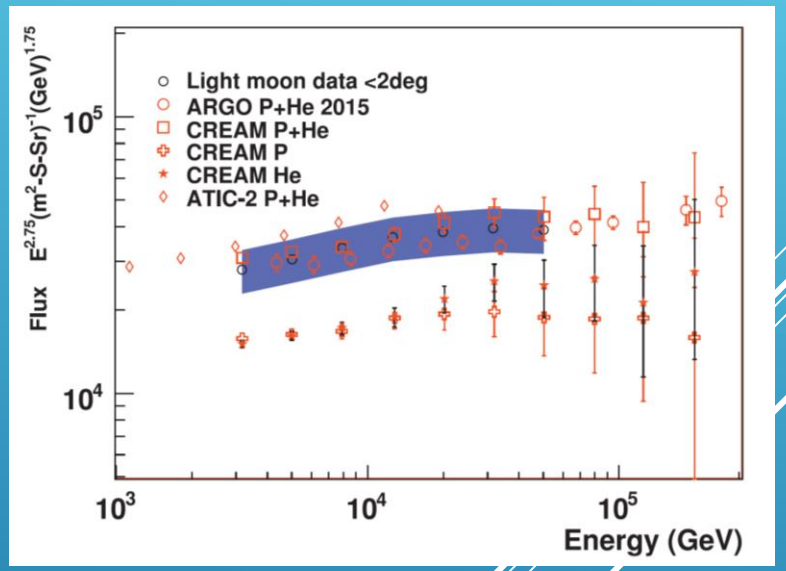
PRD.85,092005 (2012)

ABSOLUTE ENERGY-SCALE CALIBRATION WITH THE MOON SHADOW

Astroparticle Physics 90 (2017) 20-27







Data selection: $N_{strip} > 400$, $\theta < 35°$,
reconstructed shower cores inside an area of 62 x 62 m^2 around the center

These results are compatible with the previous results obtained using the unfolding technique

Medium Scale Anisotropy

Data: November 8, 2007 - May 20, 2012

$\approx 3.70 \times 10^{11}$ events

dec. region $\delta \sim -20^\circ \div 80^\circ$

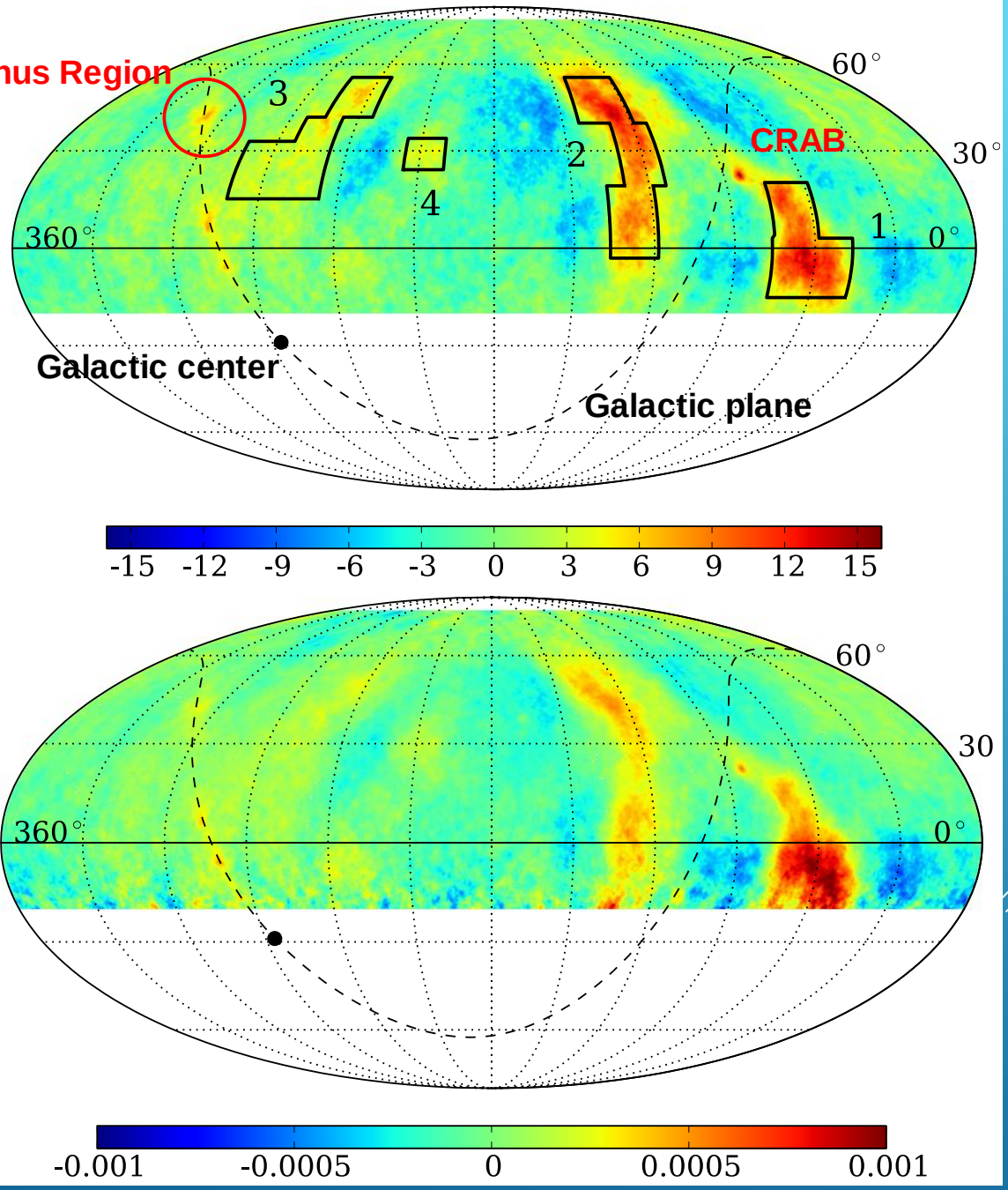
Map smoothed with the detected PSF for CRs

Proton median energy ≈ 1 TeV

CRs excess ≈ 0.1 %
with signifincance up to 15 s.d.

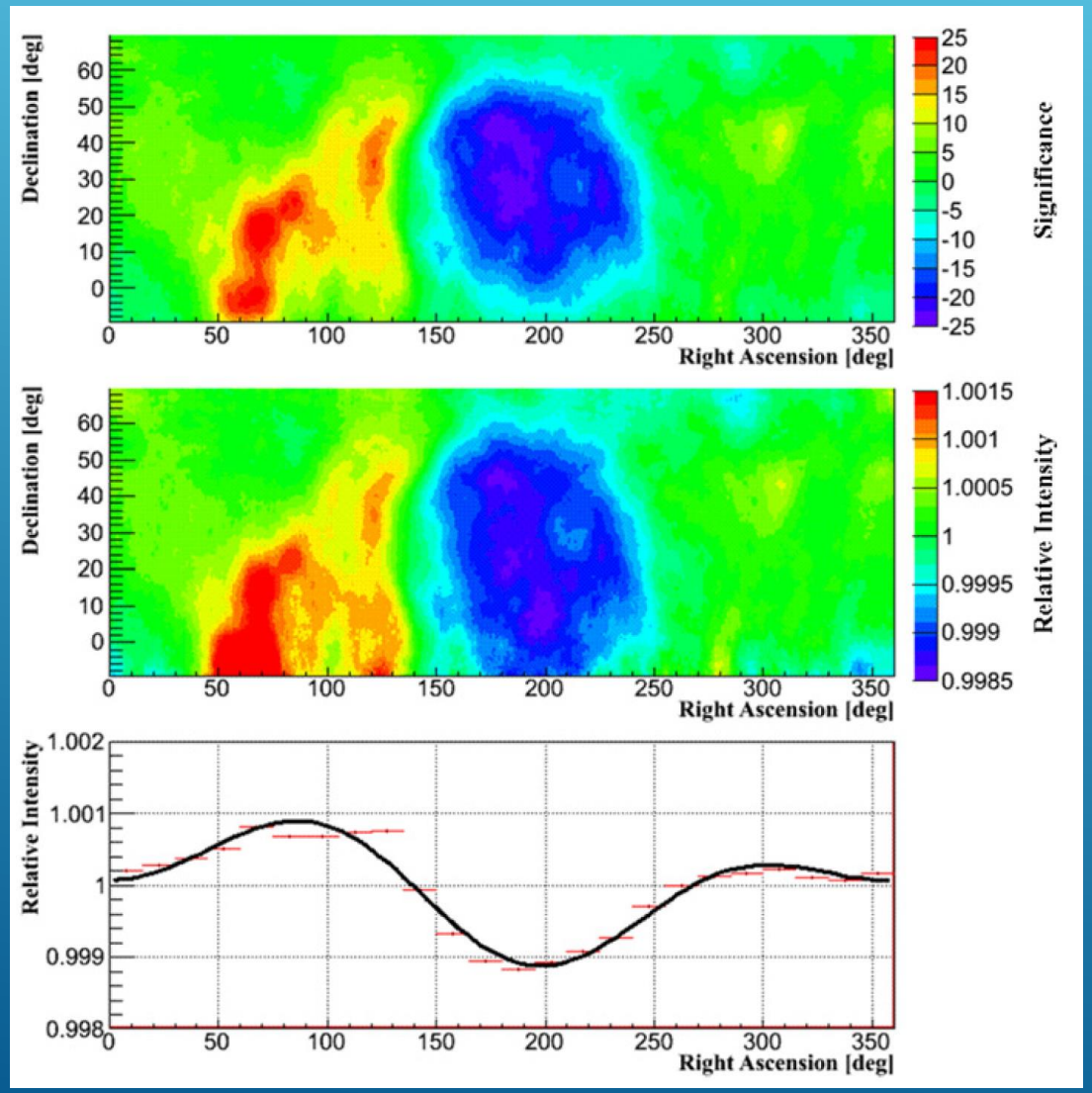
Strip-multiplicity interval	number of events	E_p^{50} [TeV]
25 – 40	1.1409×10^{11} (38%)	0.66
40 – 100	1.4317×10^{11} (48%)	1.4
100 – 250	3.088×10^{10} (10%)	3.5
250 – 630	8.86×10^{9} (3%)	7.3
more than 630	3.52×10^{9} (1%)	20

TABLE I: Multiplicity intervals used in the analysis. The central columns report the number of events collected. The right column shows the corresponding isotropic CR proton median energy.



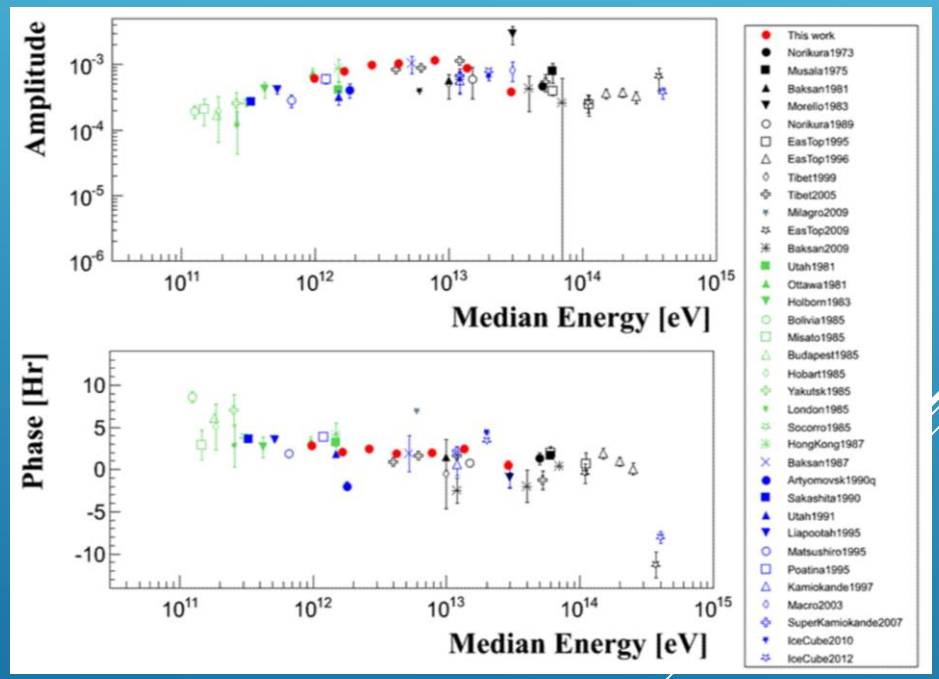
COSMIC-RAY ANISOTROPY DURING THE SOLAR MINIMUM BETWEEN CYCLES 23 AND 24

ApJ 809:90 (2015)



Detailed study on the data collected during the solar minimum in 2008-2009

Data selection: $N_{pads} > 40$, $\theta < 45°$



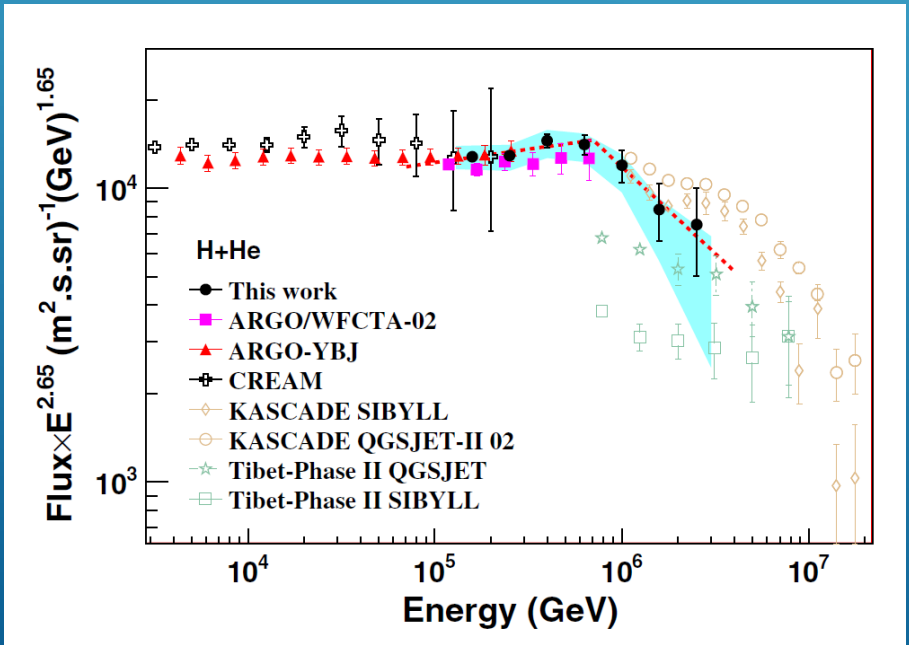
First-harmonic parameters in agreement with the results of other experiments

KNEE OF THE H + HE SPECTRUM BELOW 1 PEV WITH A HYBRID MEASUREMENT

Phys. Rev. D 92, 092005 (2015)

ARGO-YBJ in coincidence with the Cherenkov telescope WFCT-02

Coincidence within an 8-μs time window using the GPS event time stamps of the two detectors
Data collected between December 2010 and February 2012
Event selection for ARGO-YBJ: well reconstructed shower-core position, shower direction within 6° from the telescope axis, more than 6 fired pixels in the telescope PMT matrix, more than 1000 fired pads in the ARGO-YBJ central carpet; coincident events for H+He selection: number of charged particles in the shower core and shape of the Cherenkov-light image.



A steepening of the light-component energy spectrum is observed, starting at about 700 TeV
This is compatible with the results previously obtained by Tibet ASγ, CASA-MIA and MACRO
This result strongly encourages further investigation in future experiments (e.g. LHAASO), in order to improve our understanding of proton acceleration by SNRs up to energies approaching 1 PeV

SUMMARY

- ARGO-YBJ has operated very stably for over 5 years, until February 2013, the overall significance on the standard candle Crab-Nebula having reached 20 s.d.
- 6 VHE gamma-ray sources were observed in the all-sky survey at a level of 0.25 crab unit. Both spatially extended and temporally flaring sources were investigated in very significant ways that deepen the knowledge about the radiation mechanism of the sources.
- The energy spectrum of CR proton and Helium were well measured at energies above 10 TeV up to about 3 PeV with all the systematic issues under control. Light-component knee observed @ 700 TeV
- The anisotropy of CR arrival directions was investigated at both large and medium spatial scales, with significant features found
- Future dedicated experiments (such as LHAASO) will hopefully deepen the investigations started by ARGO-YBJ around the knee.