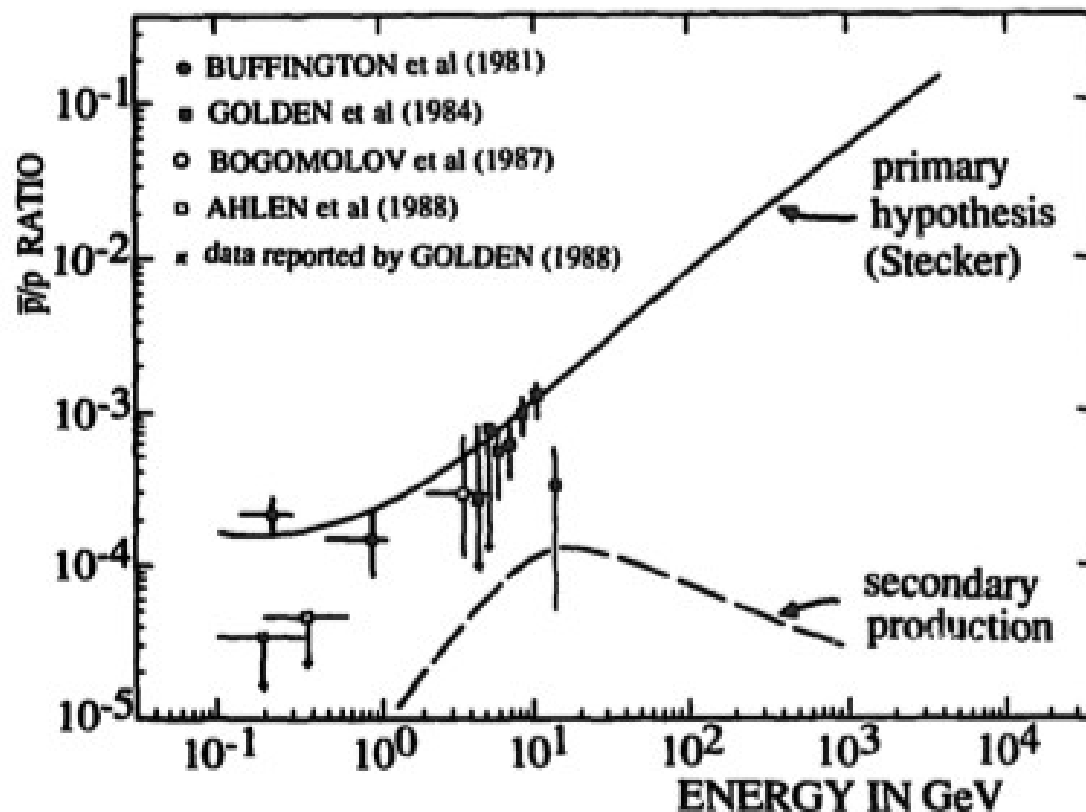


# ARTEMIS

Nuclear Physics B (Proc. Suppl.) 14B (1990) 223-236  
North-Holland

## CAN WE DETECT ANTIMATTER FROM OTHER GALAXIES BY THE USE OF THE EARTH'S MAGNETIC FIELD AND THE MOON AS AN ABSORBER?

M.Urban, P.Fleury and R.Lestienne, Ecole Polytechnique, 91128 Palaiseau, France.  
F.Plouin, Laboratoire National Saturne, C.E.N. Saclay, 91190 Gif-sur-Yvette, France.



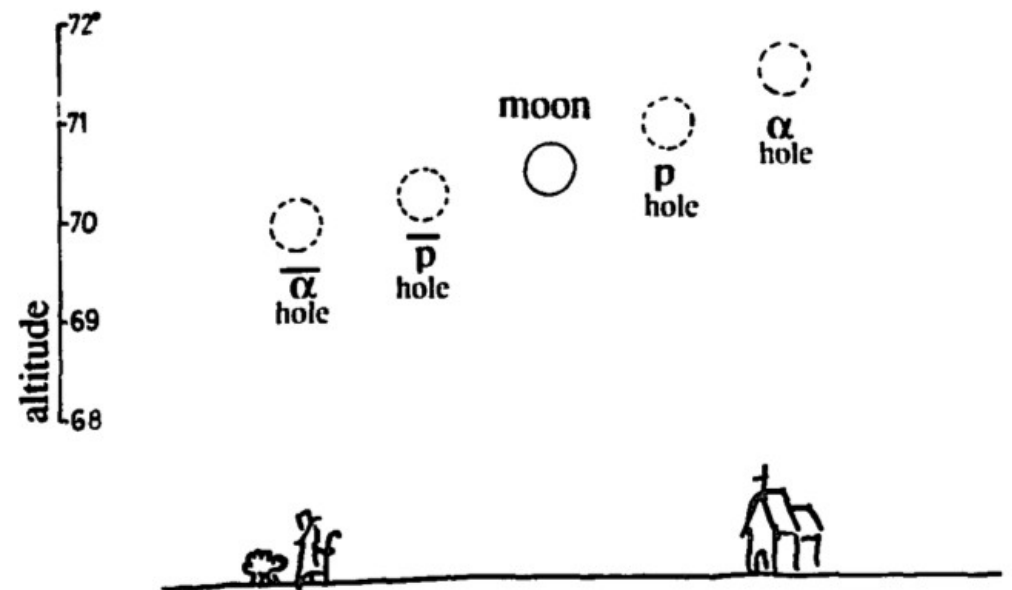
# Earth-Moon Ion Spectrometer



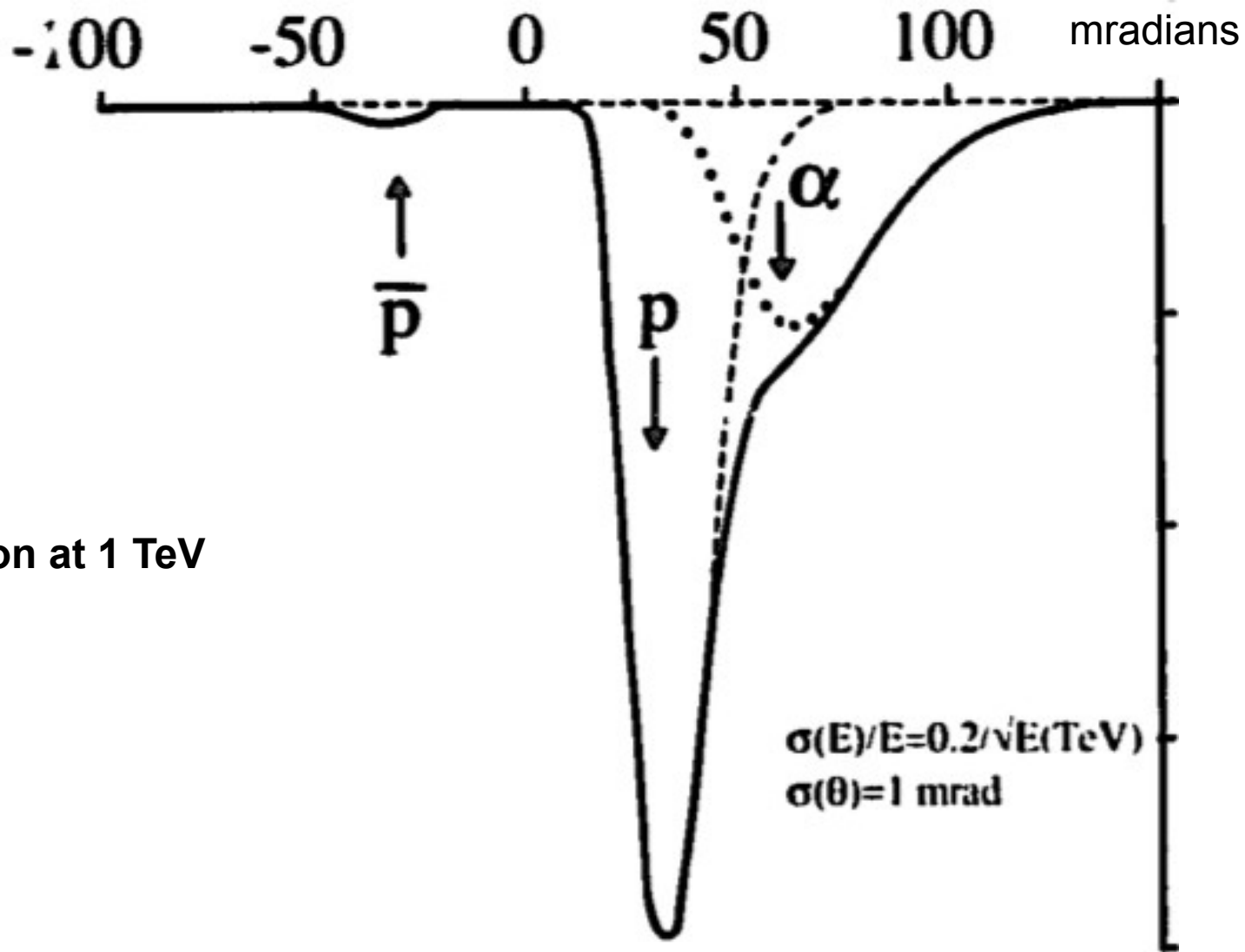
Marcel Urban

*"This was a Jules Verne experiment".*

$$Z = E \Delta\theta / \left[ 0.3 \int_{in}^{out} B dl \right]$$



# Shadowing Effect



Note: 2 degrees = 35 mradians

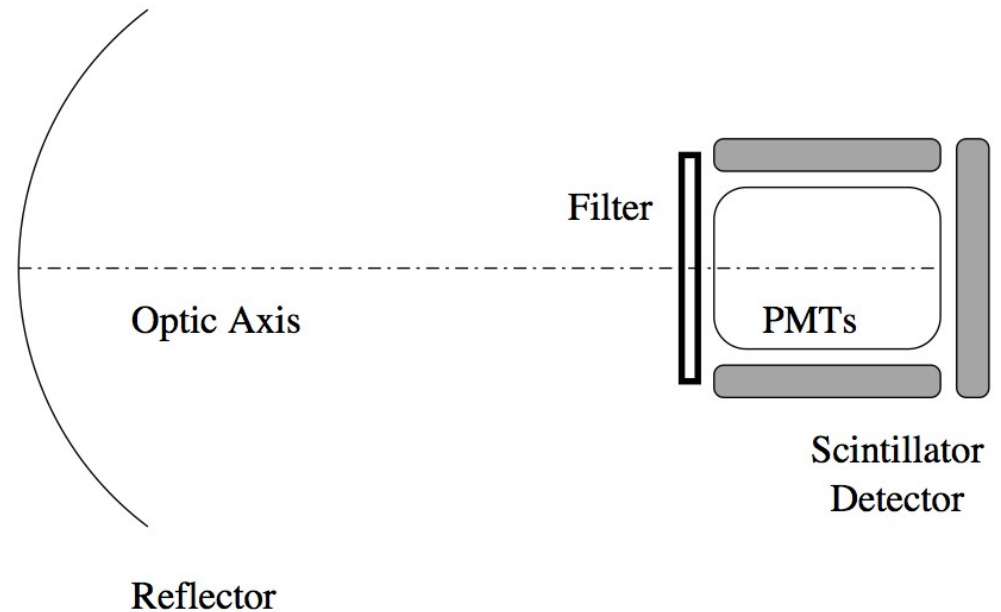
# Timeline

- 1980s Idea formed.
- 1989 First meeting between Marcel and Trevor in Tucson.  
***“I met that great guy and we had some refreshments in a bar.”***
- 1990 Initial paper published.
- 1991 UV Camera developed and deployed on Whipple 10m.
- 1991-93 Marcel and family in Tucson.
- 1992-95 Studies with UV camera (Moon shadow, muons and  $\gamma$ -rays).
- 1995 Development of an improved optical filter.
- 1996-97 Moon-shadow observations.
- 2000-01 Final results published.

*PhD Theses – Xavier Sarazin, Mark Chantell, Daniel Pomaredo, Jojo Boyle.*

# UV Camera

- Constructed at Ecole Polytechnique 1991
  - *camera could turn on an axis perpendicular to its focal plane.*
- Cost ~ \$300,000 USD.
- 112 PMTS
  - 109 in camera / 3 in scintillator.
- Hamamatsu R1802
  - 180 – 400 nm.
- Optical filter.



***“I was young and at that time I did not fully realise how nice it was of Trevor to allow me to change the camera with all the problems that could have occurred !”***

Prof. Marcel Urban

***“A big souvenir is when we had to interchange the PMTs in very cold, windy and snowy weather, that was tough.”***

Student Daniel Pomarede

# Muon and $\gamma$ -ray studies

## **Image Shapes of Showers in UV and Visible Cerenkov Light**

*Eric Pare et al., ICRC (1991).*

## **Absolute Calibration of an Atmospheric Cerenkov Telescope Using Muon Rings Images**

*Y. Jiang et al., ICRC (1993).*

## **Muon ring images with an atmospheric Cerenkov Telescope**

*G. Vacanti et al., Astroparticle Physics (1994).*

## **Observation of the Crab Nebula with an Ultraviolet Camera**

*X. Sarazin et al., Astroparticle Physics (1996).*

## **The use of an ultra-violet camera in the atmospheric Cherenkov technique**

*M. Urban et al., NIM A 368 593 (1996).*

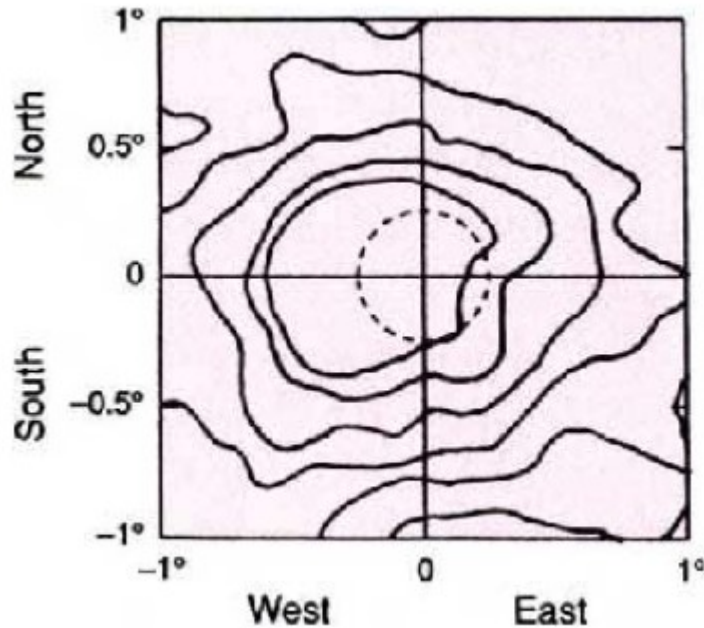
## **A hybrid version of the Whipple Observatory's Air Cerenkov Camera for use in Moonlight.**

*M. Chantell et al., Astroparticle Physics (1997).*

*“ my fondest memory of Trevor is when he gave me a hard kick in the ass at a time when I needed it. He helped instill in me a value for hard work and perseverance. I think that he had the rare ability to be no-nonsense and hold people accountable to a high standard in a way that made people take pride in their work and want to do their best.”* Mark Chantell

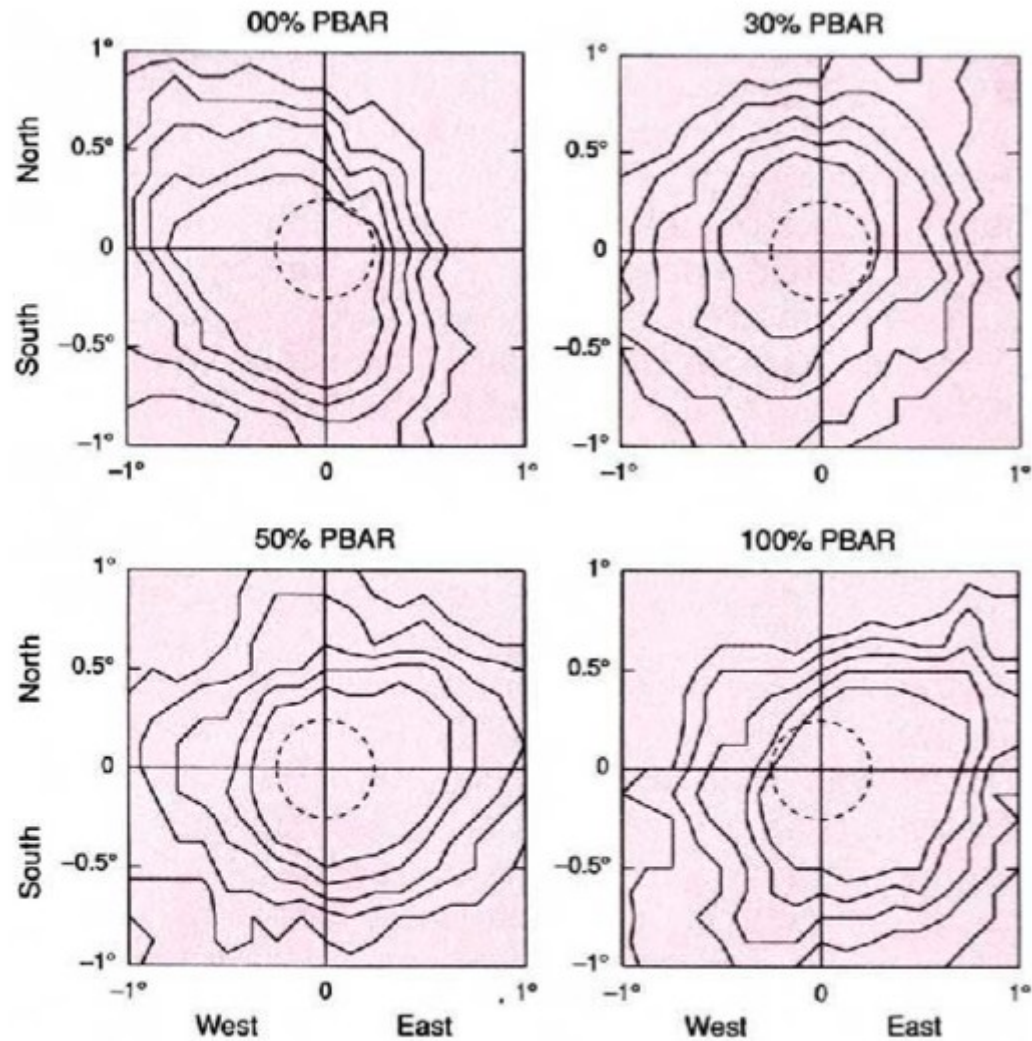
# Tibet Airshower Array

**Moon shadow  
ICRC 1993**



- **Threshold** 10 TeV
- **Significance**  $7.1\sigma$
- **Displacement**  $0.16^\circ$  West

**Chantell, Sarazin, Urban, and Weekes  
Nature 1994**



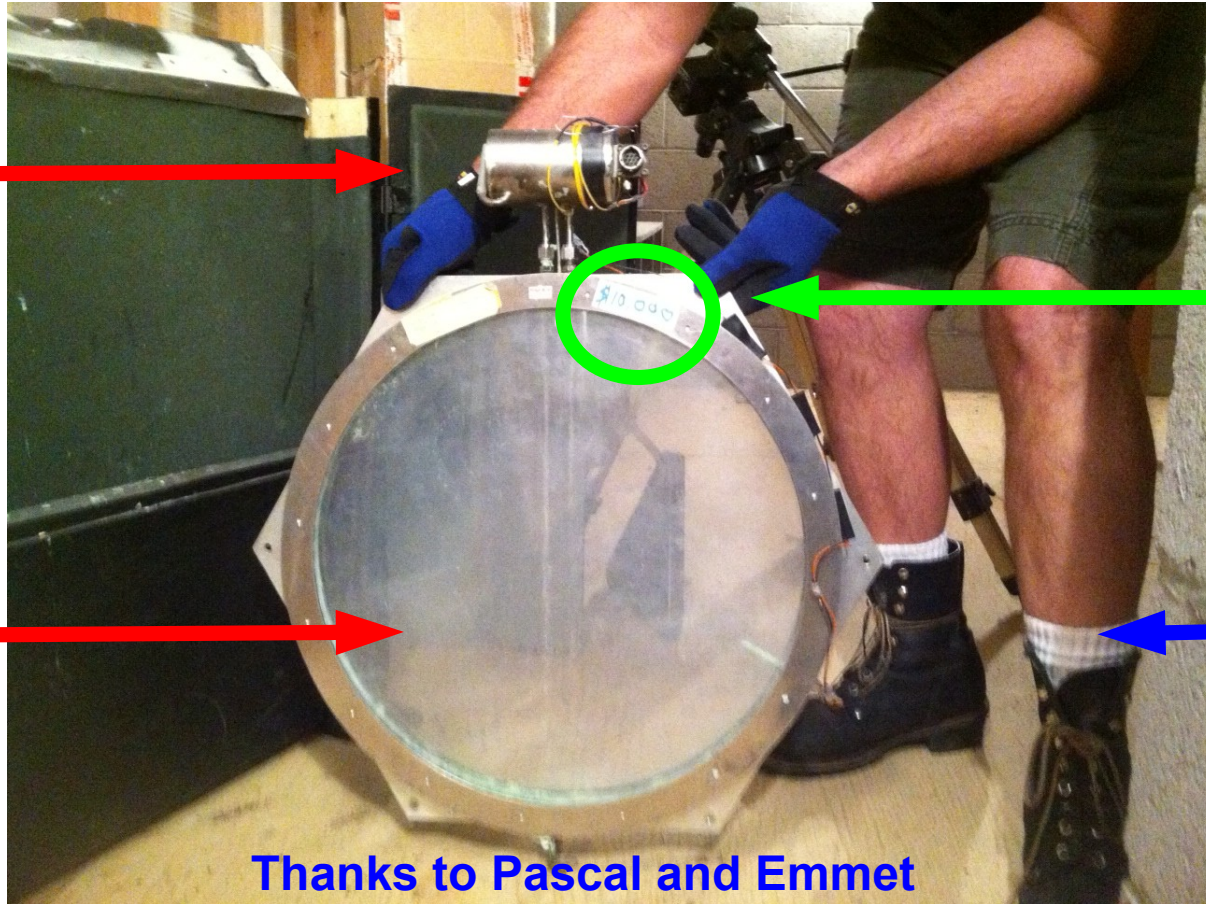
**Simulations show  $pbar/p < 30\%$**

# Optical Filter

Heater



Quartz window



\$10,000

whose legs ?

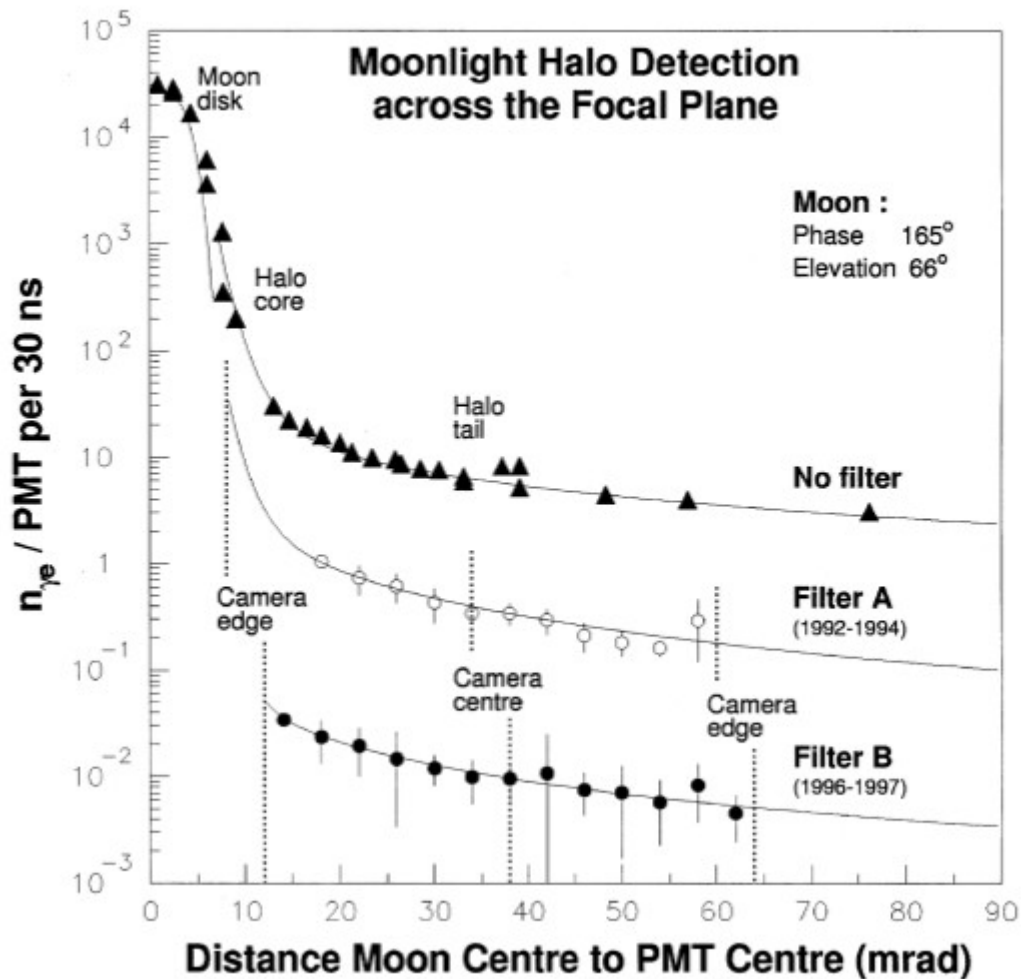
Thanks to Pascal and Emmet

**Development of Filter for Operation of Atmospheric Cerenkov Close to the Moon**  
*H. Badran, M. Urban, and T.C. Weekes, NIM A 1997.*

**A new optical Filter of the ARTEMIS Experiment**  
*Pomerade, Badran, Behr, Boyle, Brunetti, Fegan, Horan, Plouin, Urban, Weekes, NIM A 2000.*



# Optical Filter Overview



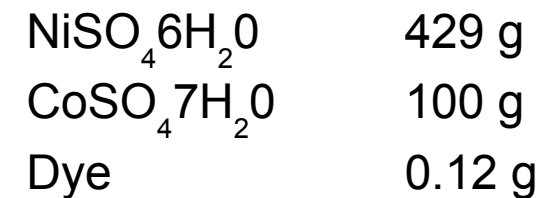
## Filter A 1992 – 1994



Outer 2 rows of camera switched off.

## Filter B 1996 – 1997

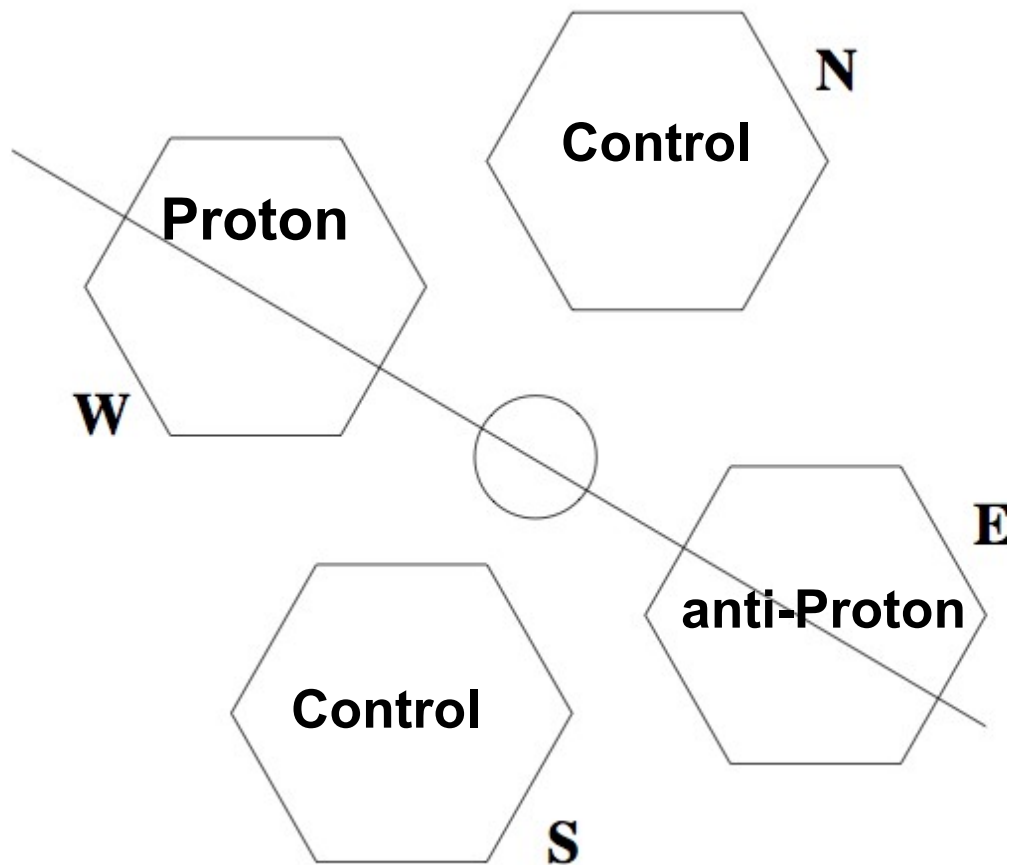
*2,7-dimethyl-3,6-diazacyclohepta-1,6-diene perchlorate*



Full camera used.

# Moon Shadow Observations

**Winter 1996 – 1997**  
262 hours in 50 nights



	<b>Hours</b>
ON Moon	115
OFF Moon	46
Calibration	101

	<b>#cycle</b>	<b>rate (Hz)</b>
On-Moon	86	3.0
A+	43	3.4
[15 hours on each position]		

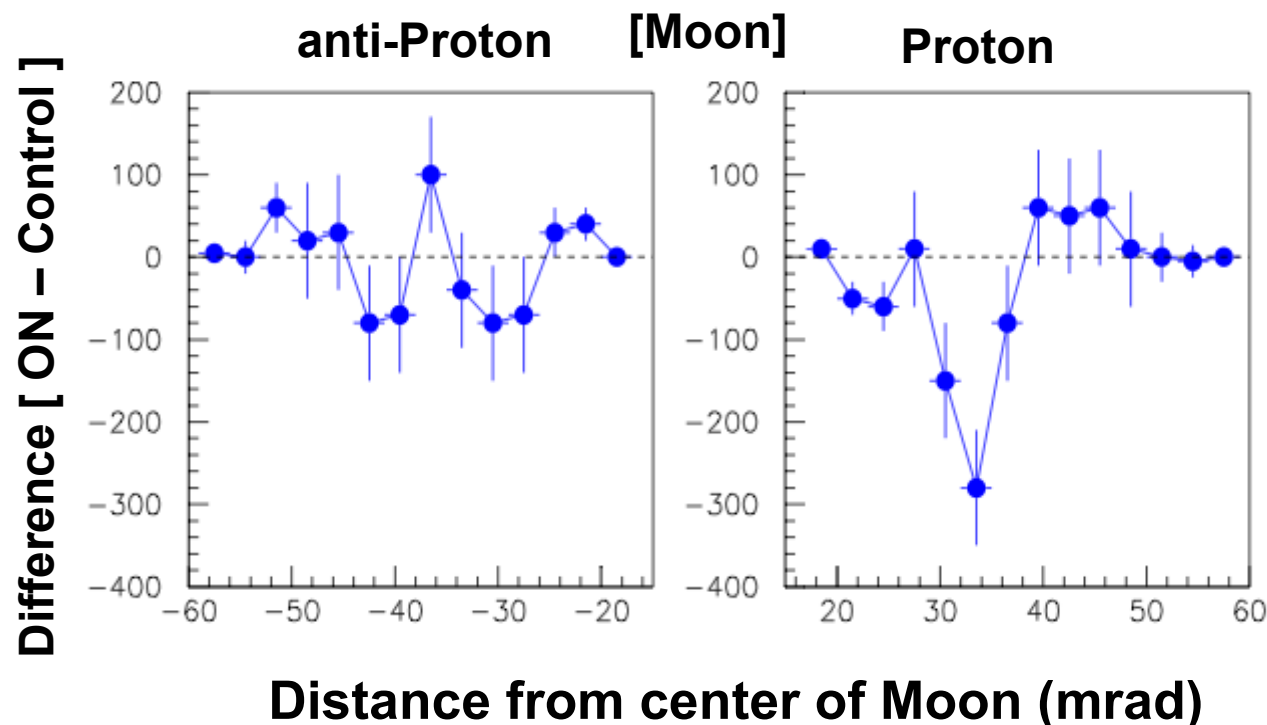
Center of camera 38 mrad from center of moon.

# Results

## Search for shadowing of Primary Cosmic Radiation by the Moon at TeV energies.

*Pomarede, Boyle, Urban, Badran, Behr, Brunetti, Fegan, and Weekes, AstroPh 2001.*

- First time the hadron population of CRs has been studied with the Imaging technique.
- Proton shadow at  $3 - 4\sigma$  (stat),  $2 - 3\sigma$  (sys) [15 hours data].
- 1 % level on pbar-p (i.e.  $5\sigma$ )  $> 100$  hours.



# An important lesson from Trevor

1998 Final Analysis meeting  
- Ecole Polytechnique

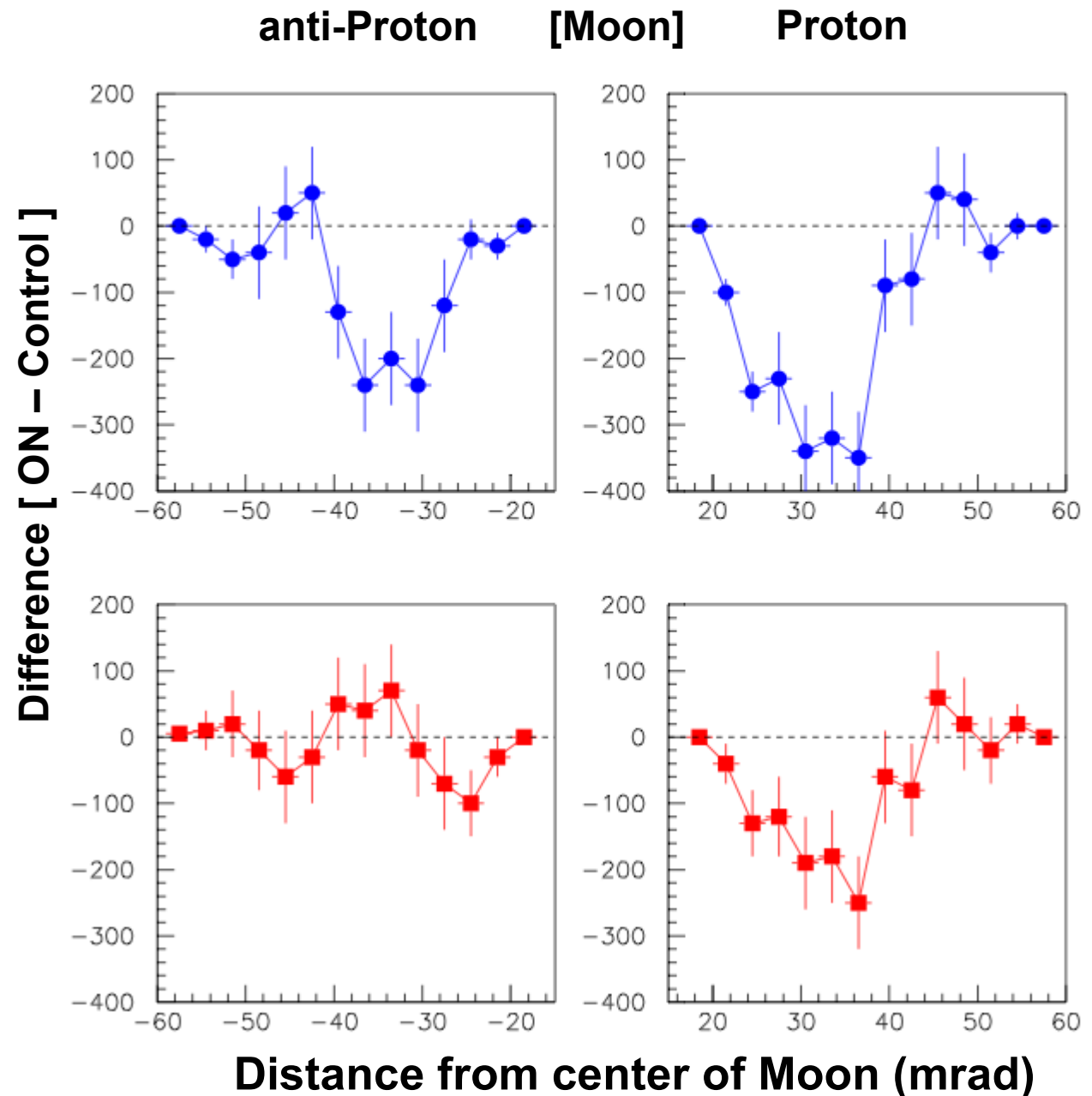
## Analysis A

*Nobel Prize?*

## Analysis B

*No Nobel Prize!*

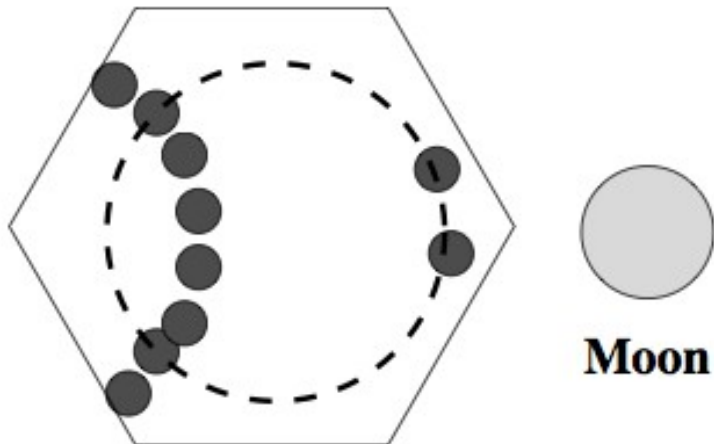
*Plotted using PAW for the  
elder iPad generation.*



# Muon + moon noise

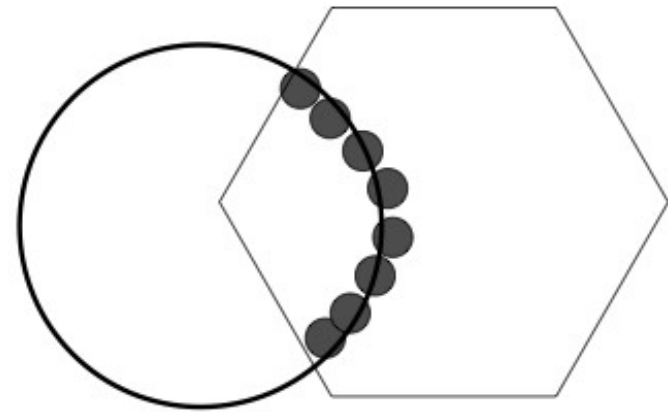
## Image cleaning 101

Analysis A



**Non**

Analysis B



**Oui**

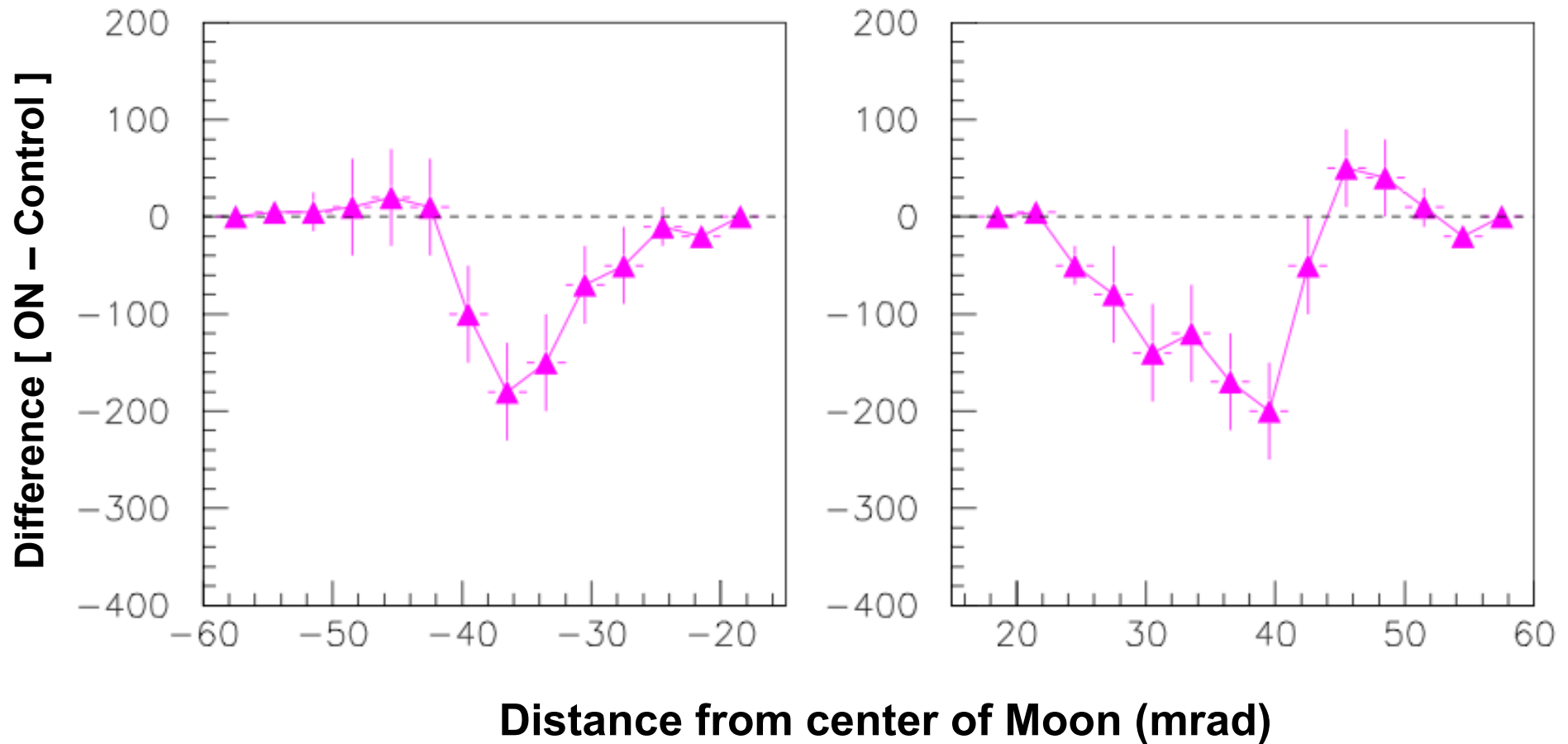
**4,000 in nearly a million events.**

# Misidentified muons

*... or evidence of primary antimatter ?*

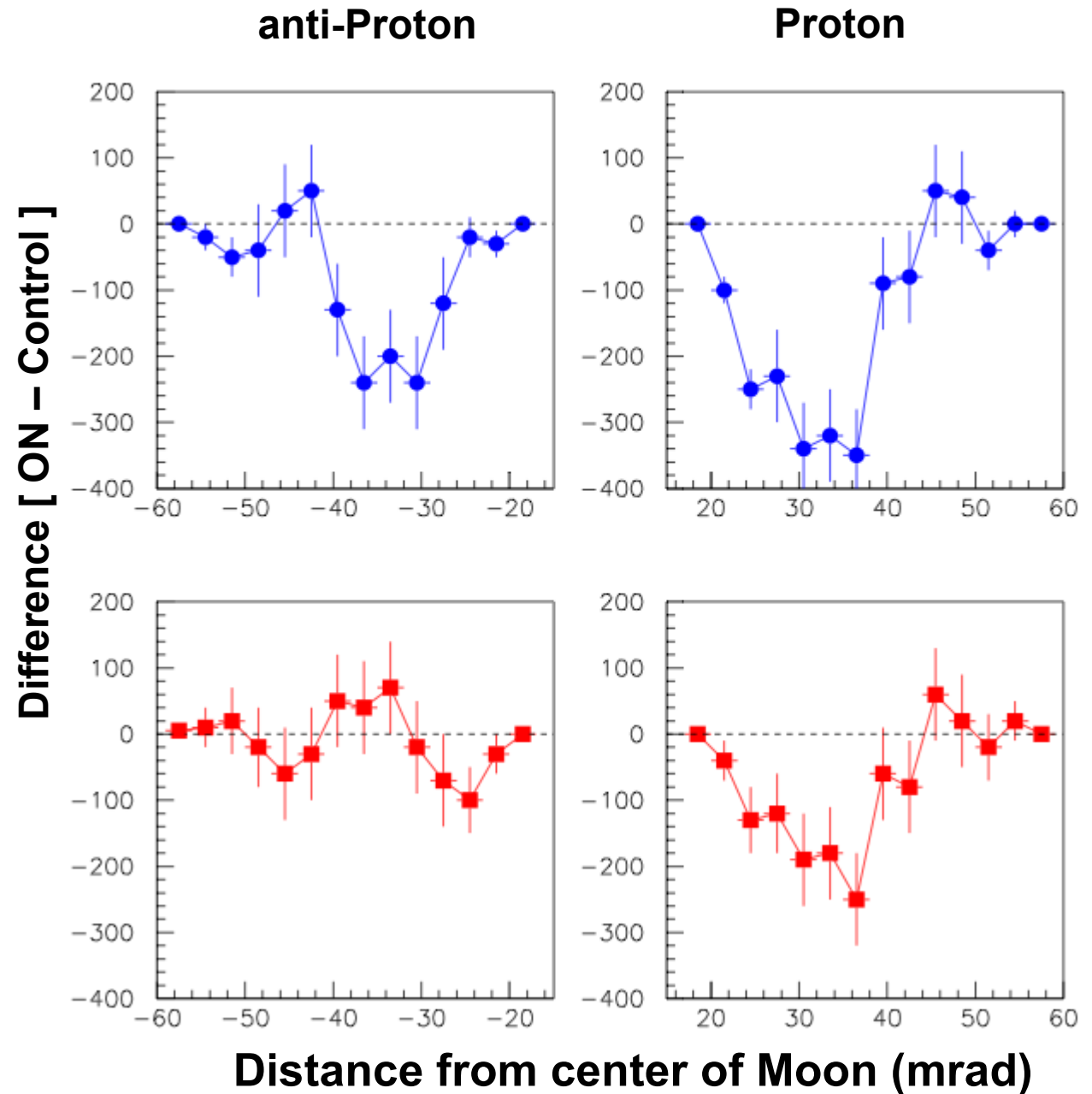
**anti-Proton**

**Proton**



# Now you see it

Analysis A

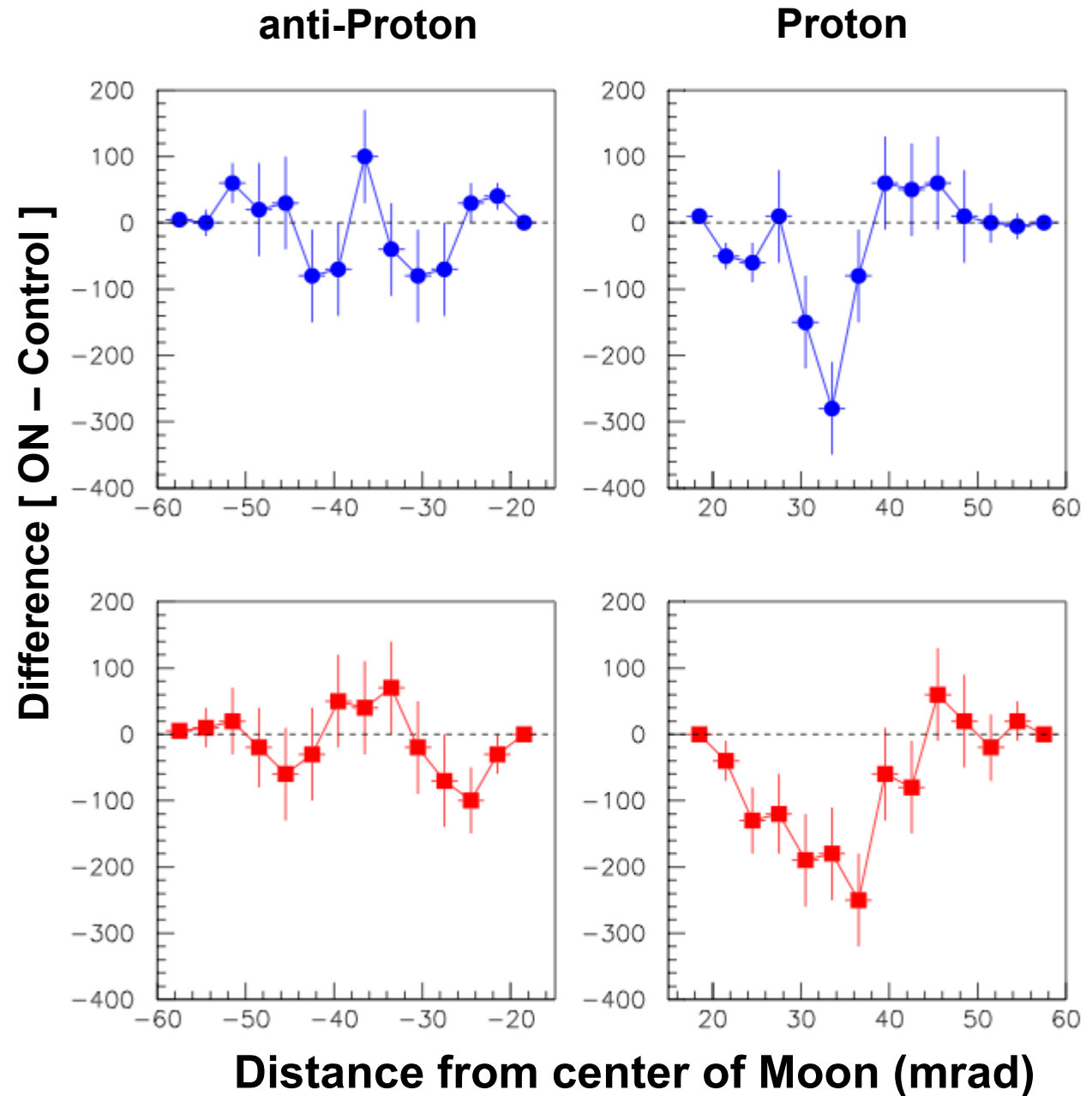


Analysis B

# Now you don't

## Analysis A

*Corrected for  
misidentified muons*

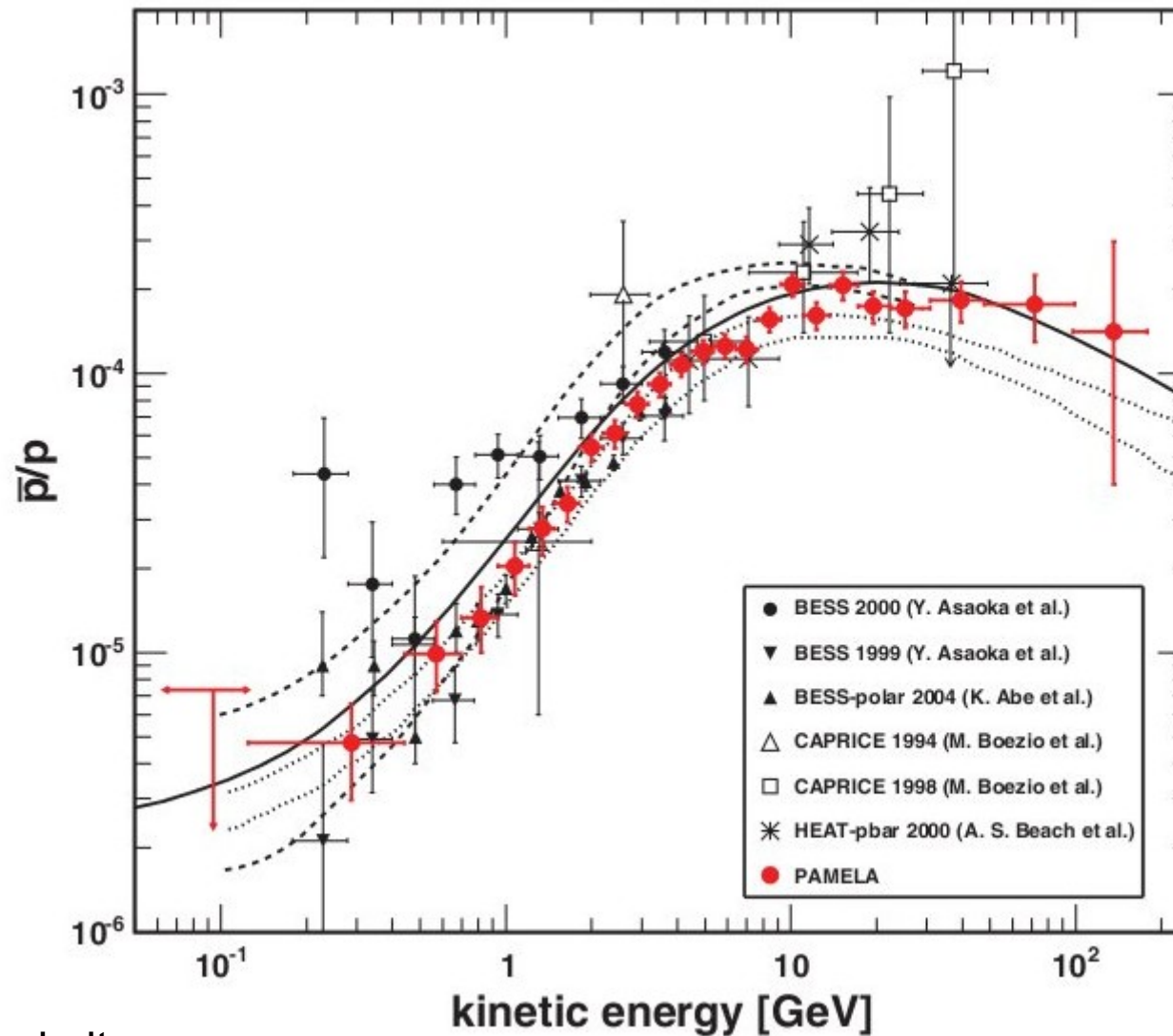


## Analysis B



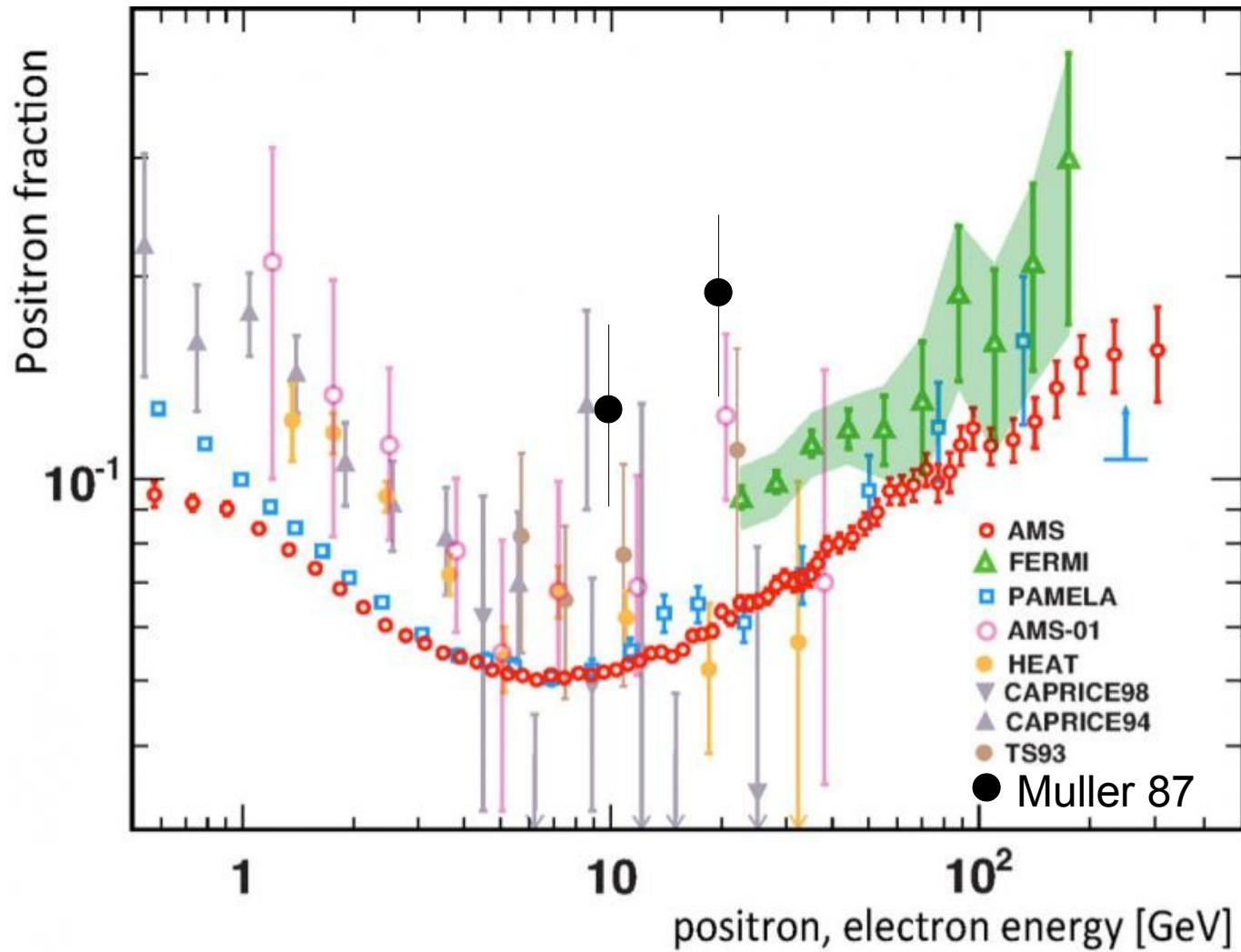
# pbar-p 2013

Consistent with secondary production of antiprotons.



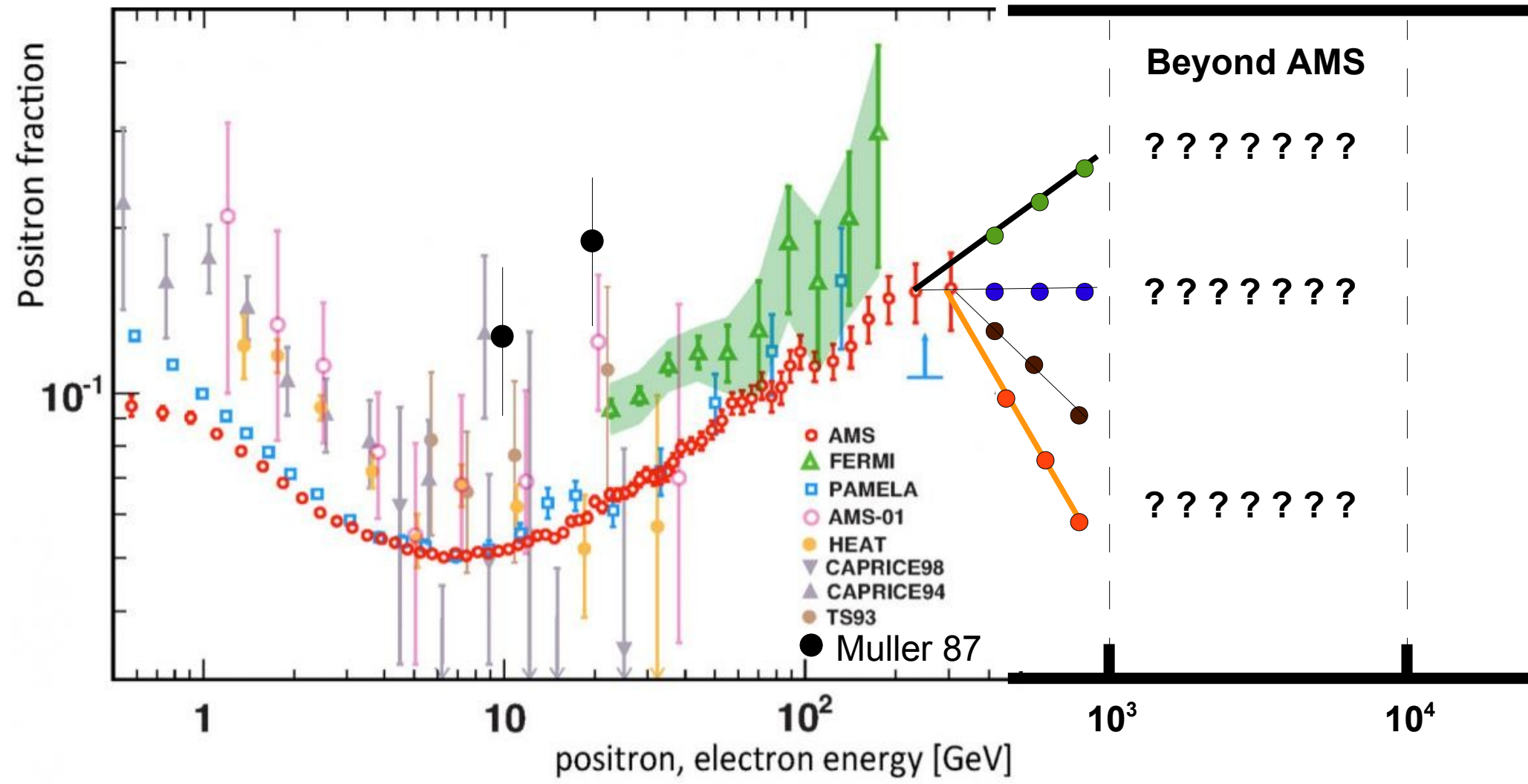
Source: PAMELA website.

# Positron Fraction 2013



Source: AMS website.

# Positron Fraction 2013



[Magic Telescope using ARTEMIS ideas - P. Colin et al. ICRC 2009.]

Source: AMS website.

# Go raibh maith agat a chara



*“What I am thankful for is that Trevor trusted young, inexperienced people like me to operate a telescope which was so important to him, so intimately connected to his career (and life probably too). Thanks to his trust, young PhDs could gain experience, operating the telescope and conducting their research by themselves.”*  
Daniel Pomarede



Thank you  
شكرا  
Trevor

