Indirect Dark Matter Search in Space with antimatter experiments

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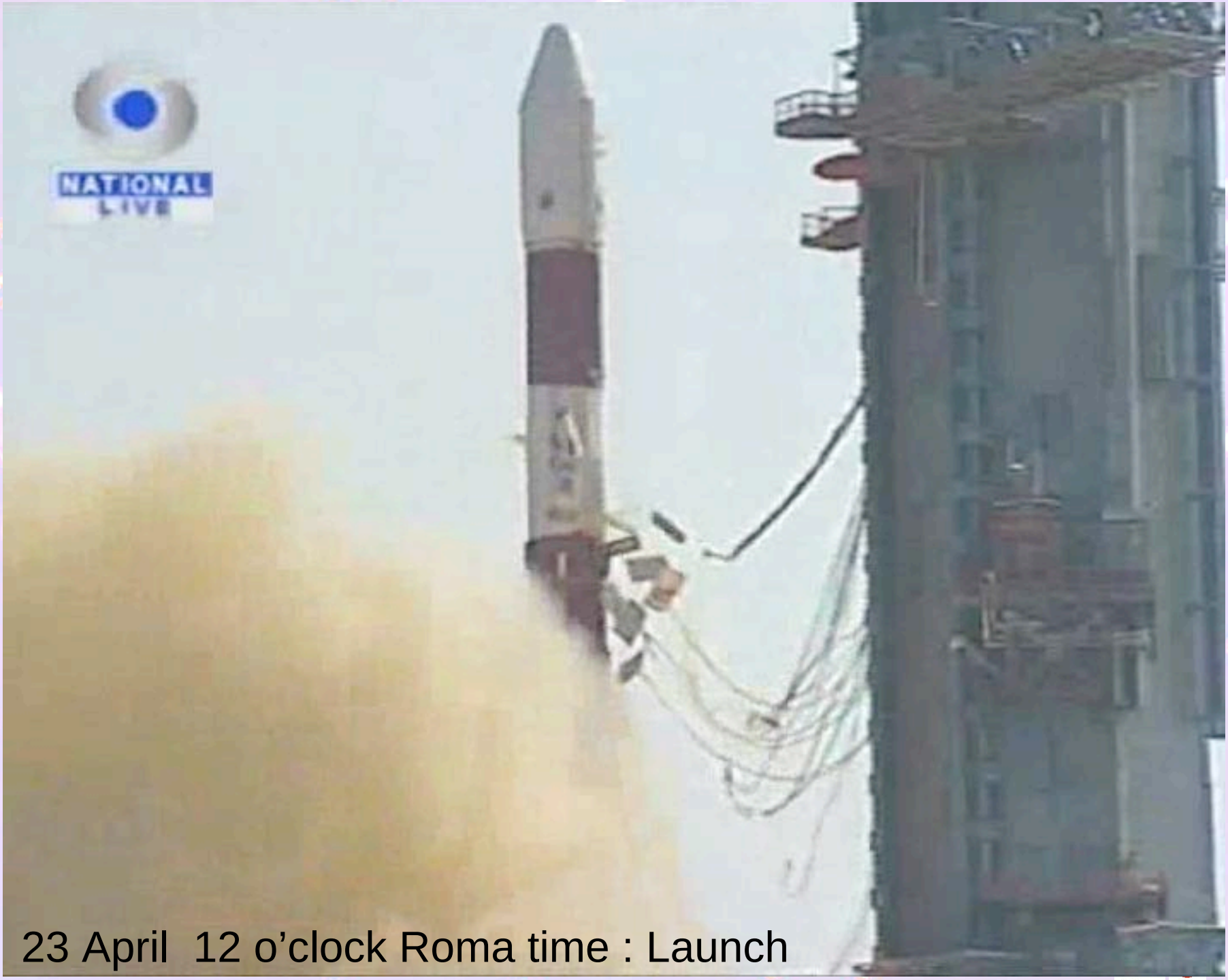
(

agile

Astro-rivelatore Gamma
a Immagini Leggero
asi
agenzia spaziale italiana
INAF
INFN
Alenia
telespazio



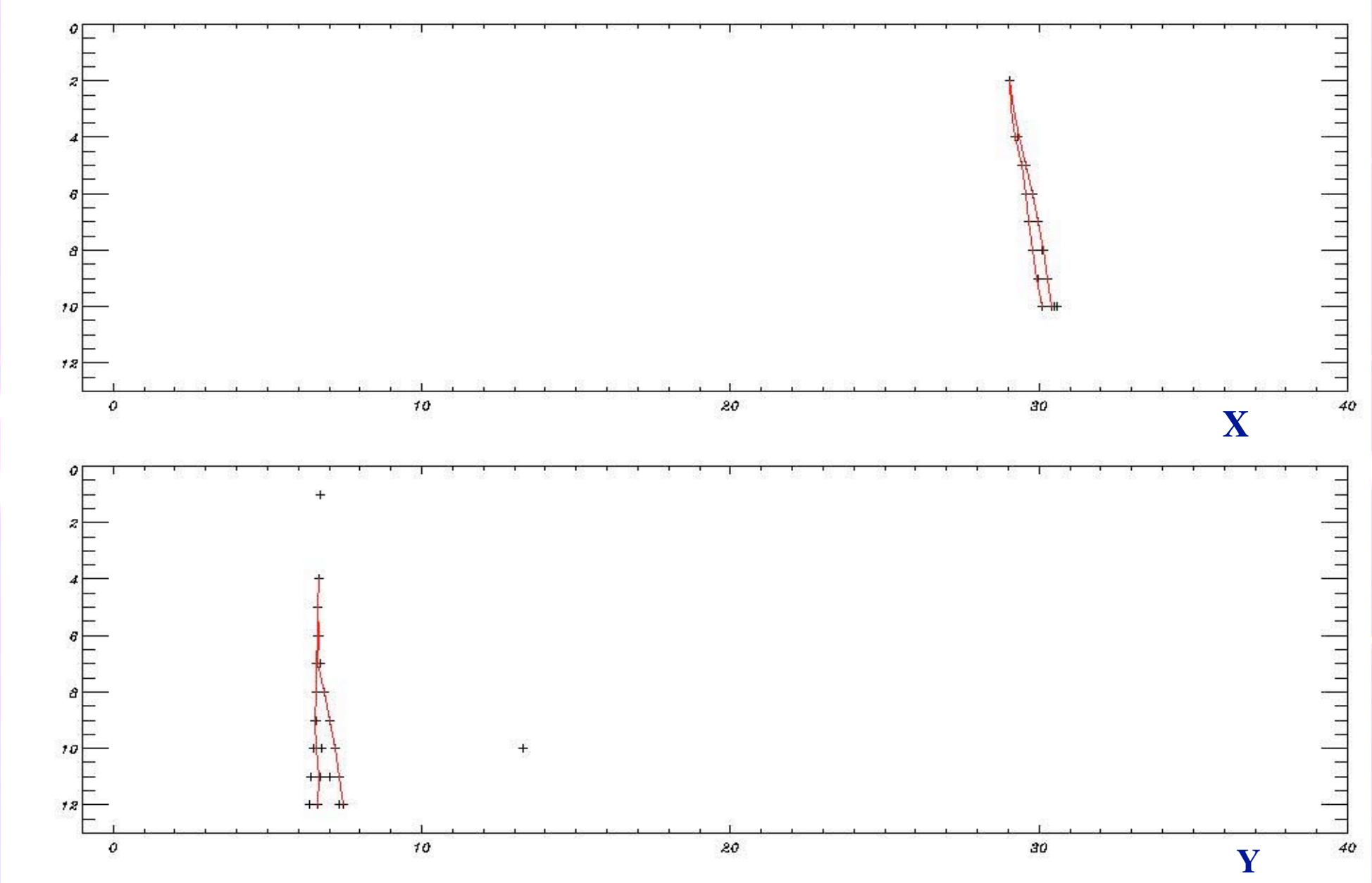
23 April 12 o’clock Roma time : Launch

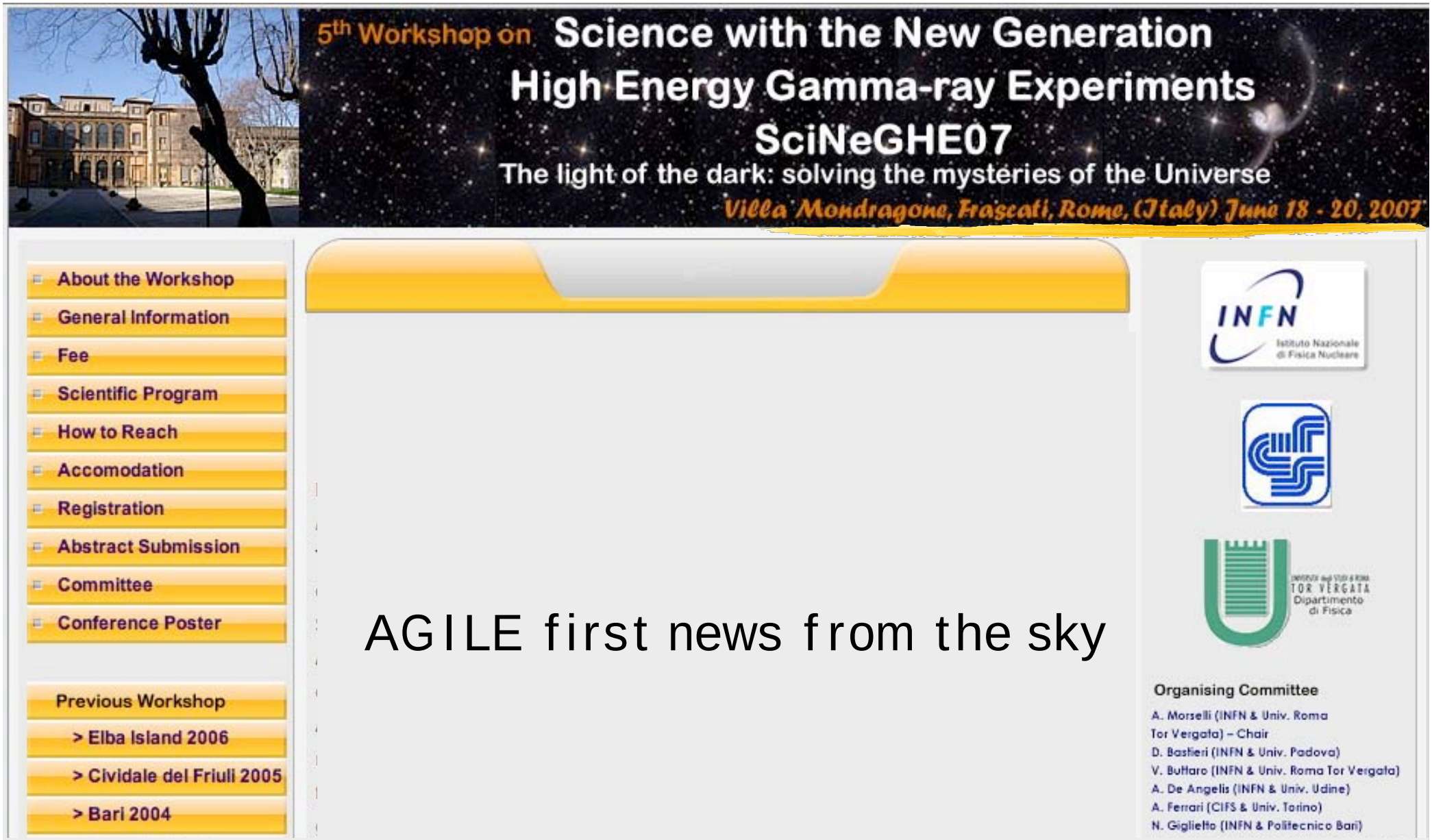
17 April 2007
closing the payload
AGILE mounted on the PSLV rocket, inside the Vehicle Assembly Building of Sriharikota

22 April
The rocket PSLV ready for the launch

NATIONAL
LIVE

8 May 2007 first photon received from AGILE in orbit





AGILE first news from the sky

www.roma2.infn.it/SciNeGHE07/

)

Dark Matter really exist ?

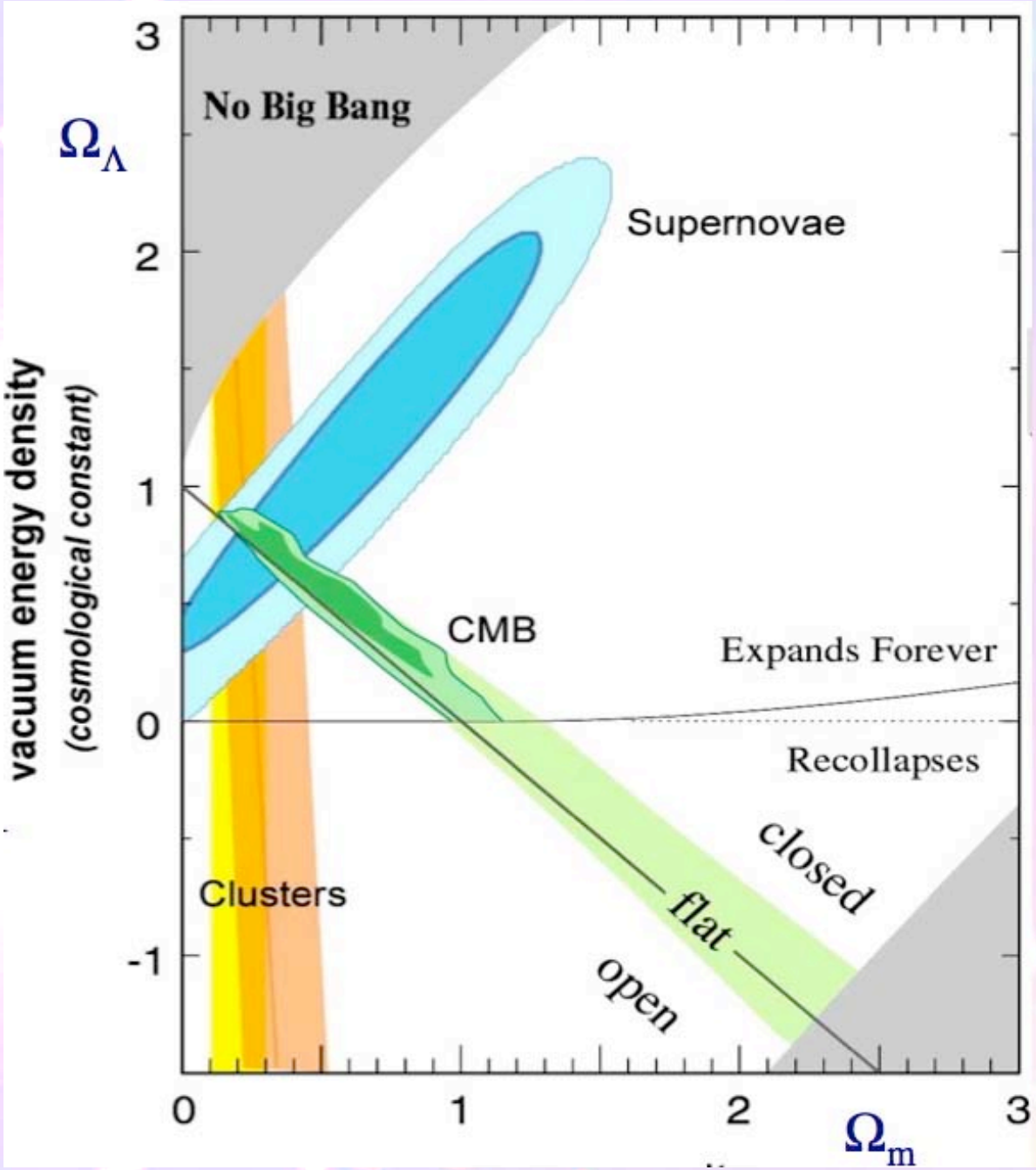
"Concordance model"

$\Omega = \Omega_M + \Omega_\Lambda = 1.02 \pm 0.02$

$\Omega_\Lambda \sim 0.73$

$$\Omega_M \sim 0.27 \begin{cases} \Omega_{CDM} \sim 0.23 \\ \Omega_b \sim 0.04 \\ \Omega_{HDM,\nu} < 0.01 \end{cases}$$

$\Omega_{CDM} \sim 6\ \Omega_b$



Dark Matter really exist ?

astro:ph/0608407

color image from the Magellan images of the merging cluster 1E0657−5 58

Chandra image of the cluster

200 kpc

Due to the collision of two clusters, the dissipationless stellar component and the fluid-likeX-ray emitting plasma are spatially segregated

Neutralino WIMPs

Assume χ present in the galactic halo

- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through $p + p \rightarrow \bar{p} + X$)
- So, any extra contribution from exotic sources ($\chi\,\chi$ annihilation) is an interesting signature
- ie: $\chi\,\chi \rightarrow \bar{p} + X$
- Produced from (e. g.) $\chi\,\chi \rightarrow q$ / g / gauge boson / Higgs boson and subsequent decay and/ or hadronisation.

Propagation Equation for Cosmic Rays in the Milky Way

$$\frac{\partial \psi(\mathbf{r},p,t)}{\partial t} = q(\mathbf{r},p) + \nabla\cdot(D_{xx}\nabla\psi - \mathbf{V}\psi) + \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{1}{p^2}\psi - \frac{\partial}{\partial p}\left[\dot{p}\psi - \frac{p}{3}(\nabla\cdot\mathbf{V})\psi\right] - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

convection velocity field that corresponds to galactic wind and it has a cylindrical symmetry, as the geometry of the galaxy. It's z-component is the only one different from zero and increases linearly with the distance from the galactic plane

diffusion coefficient in the impulse space, quasi-linear MHD: $D_{pp}(D_{xx}, v_A)$

loss term: fragmentation

loss term: radioactive decay

diffusion coefficient is function of rigidity

$$D_{xx} = \beta D_0(\rho/\rho_0)^\delta$$

primary spectra injection index

$$dq(p)/dp \propto p^{-\gamma}$$

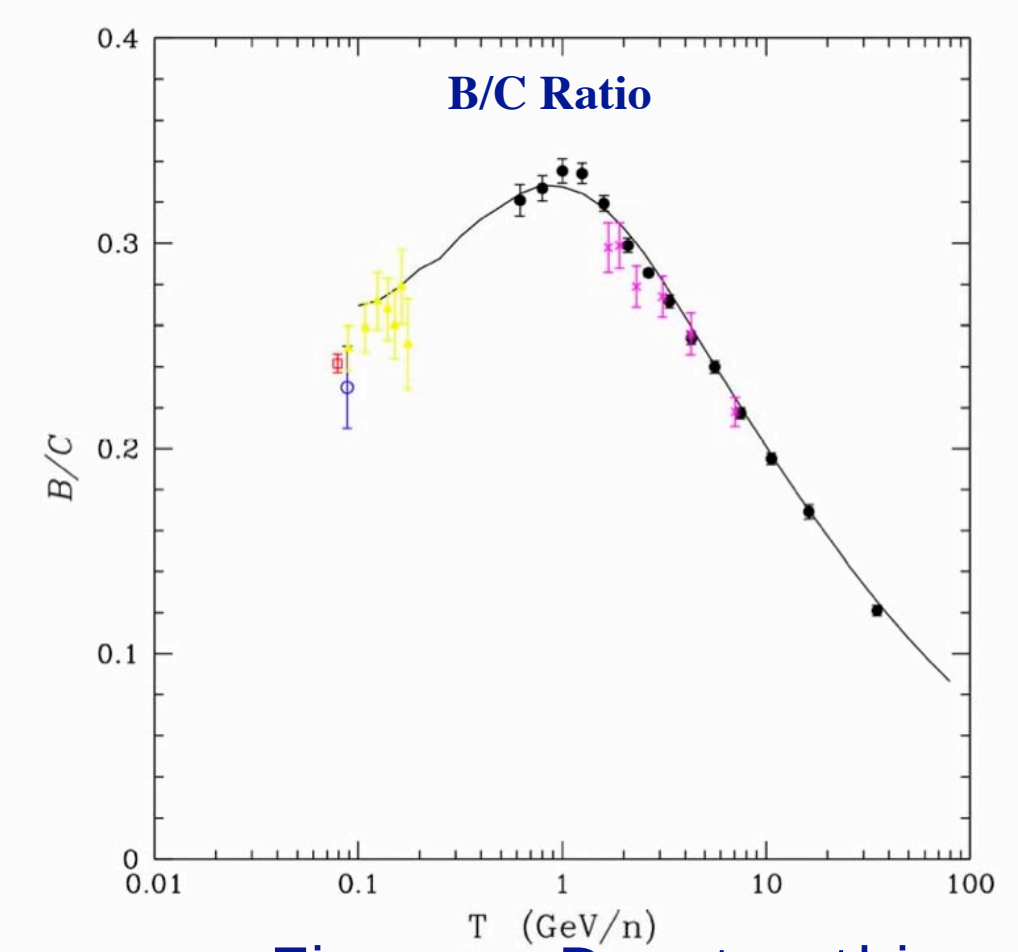
semi-analitical solution: Maurin et al, astro-ph/0101231

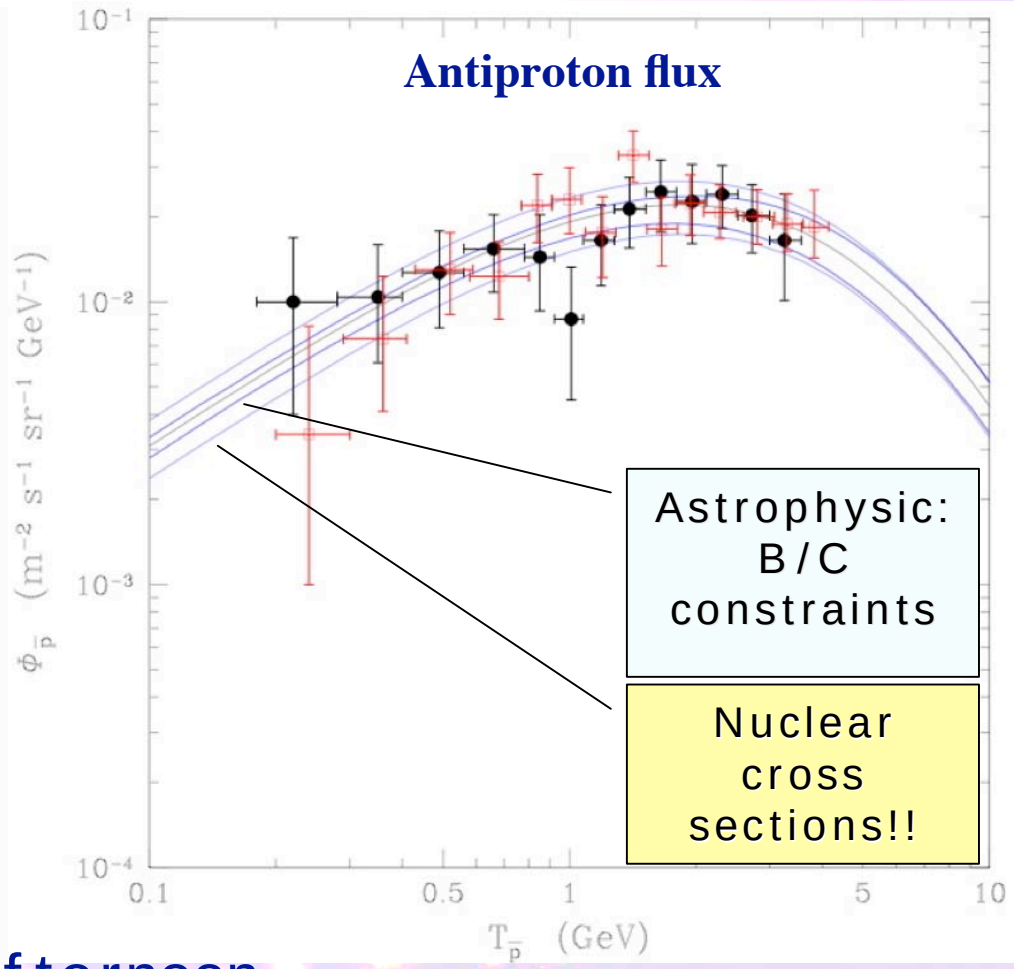
implemented in Galprop (Strong & Moskalenko, available on the Web)

Secondaries / primaries
i.e. Boron/ Carbon to constrain propagation parameters

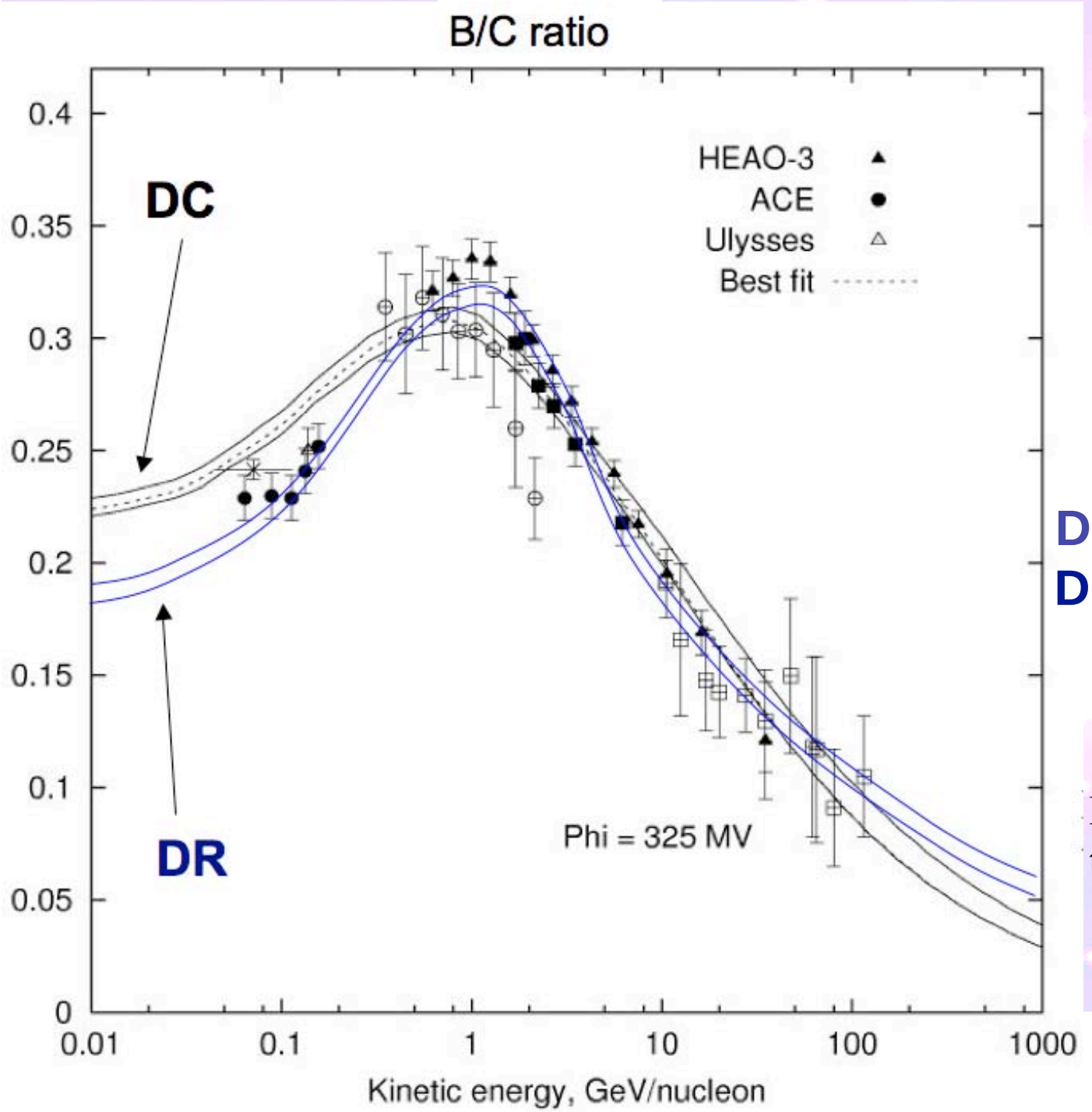
D. Maurin, F. Donato R. Taillet and P.Salati ApJ, 555, 585, 2001 [astro-ph/0101231]

F. Donato et.al, ApJ, 563, 172, 2001 [astro-ph/0103150]





Fiorenza Donato, this afternoon



Enveloping curves of all the good fits of the experimental B/C data

Dashed line: Best fit

DR: diffusion+ reacceleration

DC: diffusion+convection

In DC model problem with the ACE data at low energy

A.Lionetto, A.Morselli, V.Zdravkovic

JCAP09(2005)010 astro-ph/0502406

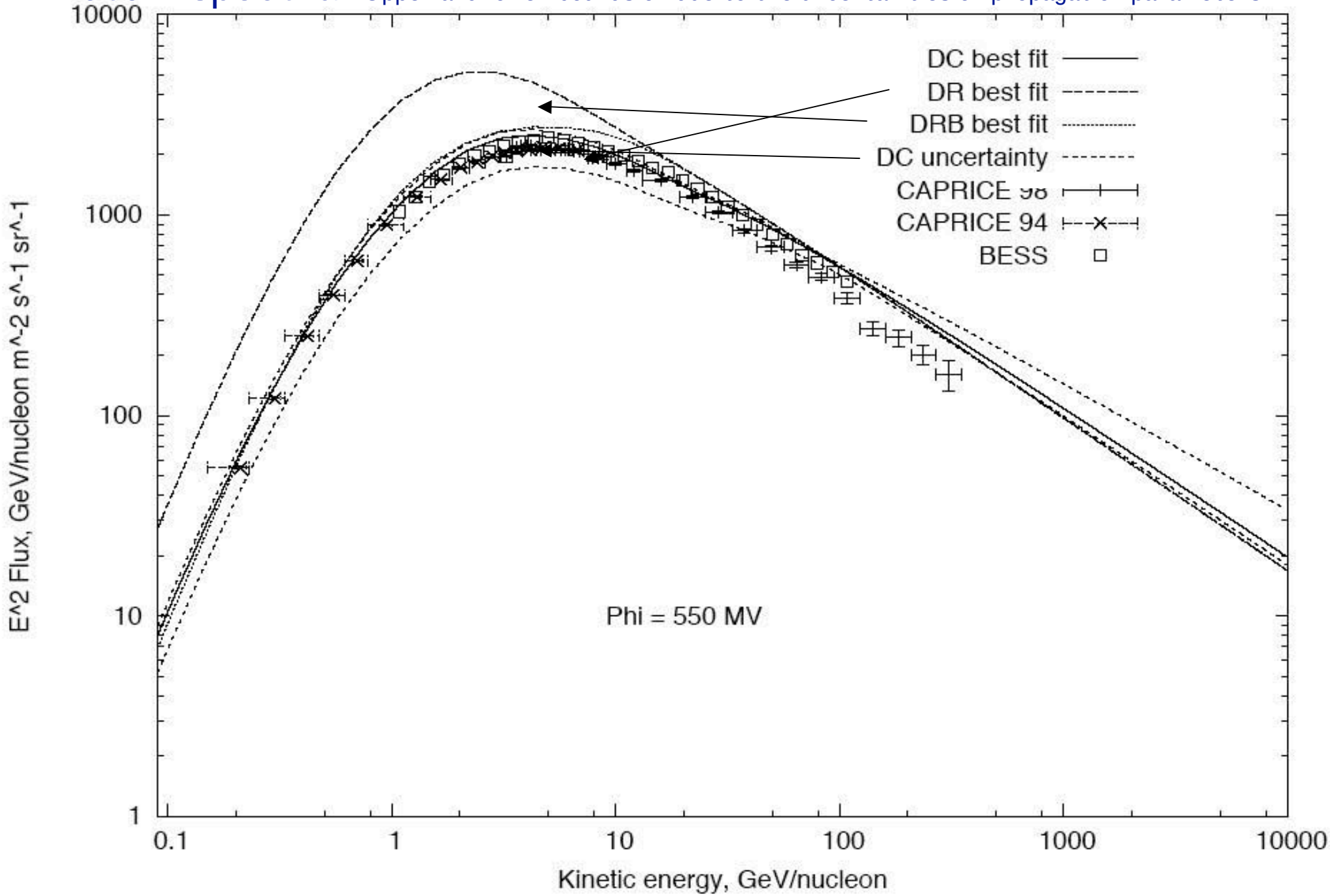
Allowed values for the propagation parameters for DR propagation

par./val.	halo size $z[kpc]$	diffusion constant $D_0[cm^2 s^{-1}]$	diff index δ	prim spec injection index γ	Alfven velocity $v_A[kms^{-1}]$
minimal	3.0	$5.2\ 10^{28}$	0.25	2.35	22
best fit	4.0	$5.8\ 10^{28}$	0.29	2.47	26
maximal	5.0	$6.7\ 10^{28}$	0.36	2.52	35

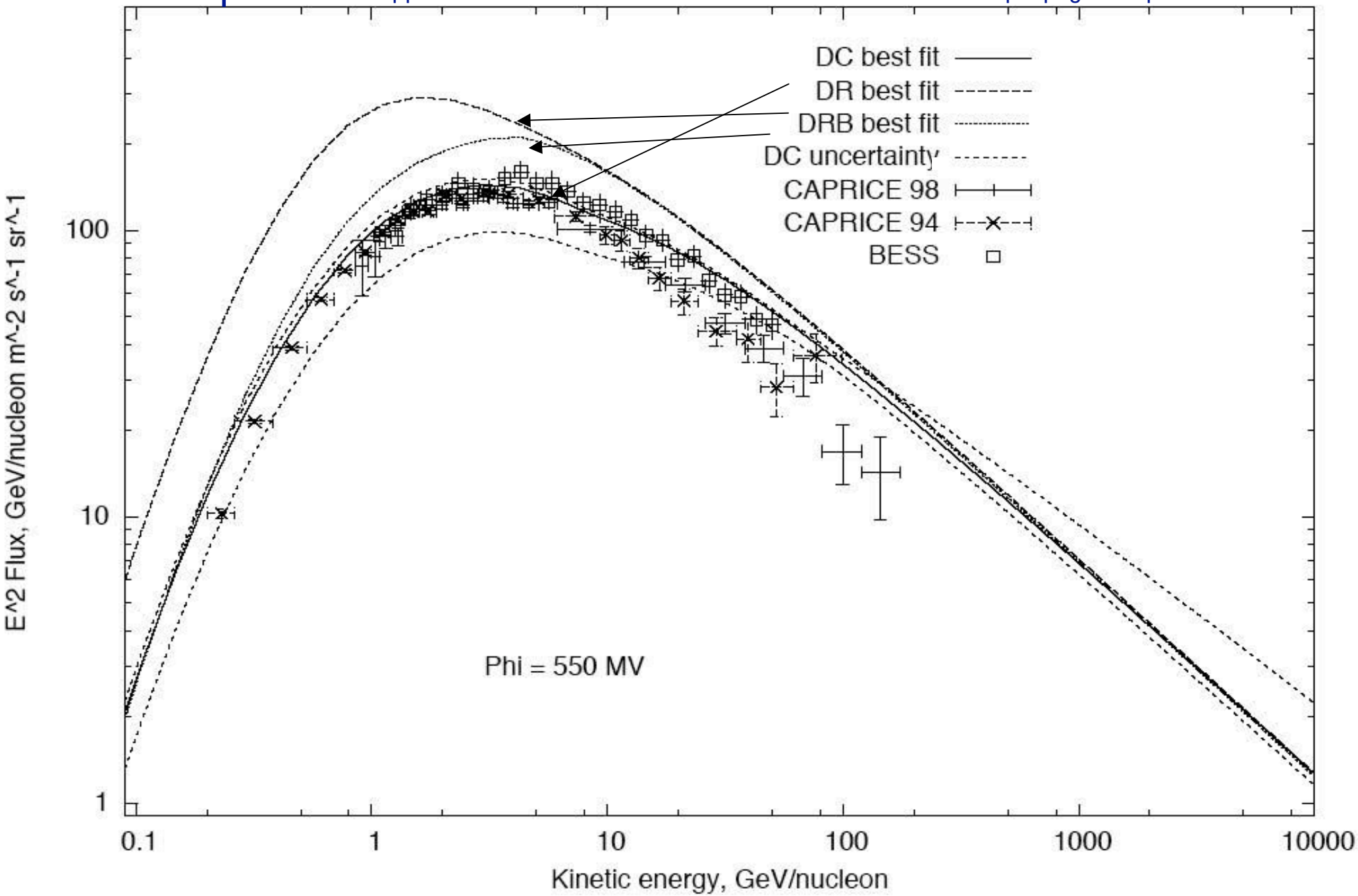
Allowed values for the propagation parameters for DC propagation

par./val.	halo size $z[kpc]$	diff constant $D_0[\frac{cm^2}{s}]$	diff index δ_2	V_c gradient $\frac{dV_C}{dz}[\frac{km}{skpc}]$	injection indexes γ_1	γ_2
minimal	3.0	$2.3\ 10^{28}$	0.48	5.0	2.42	2.14
best fit	4.0	$2.5\ 10^{28}$	0.55	6.0	2.48	2.20
maximal	5.0	$2.7\ 10^{28}$	0.62	7.0	2.50	2.22

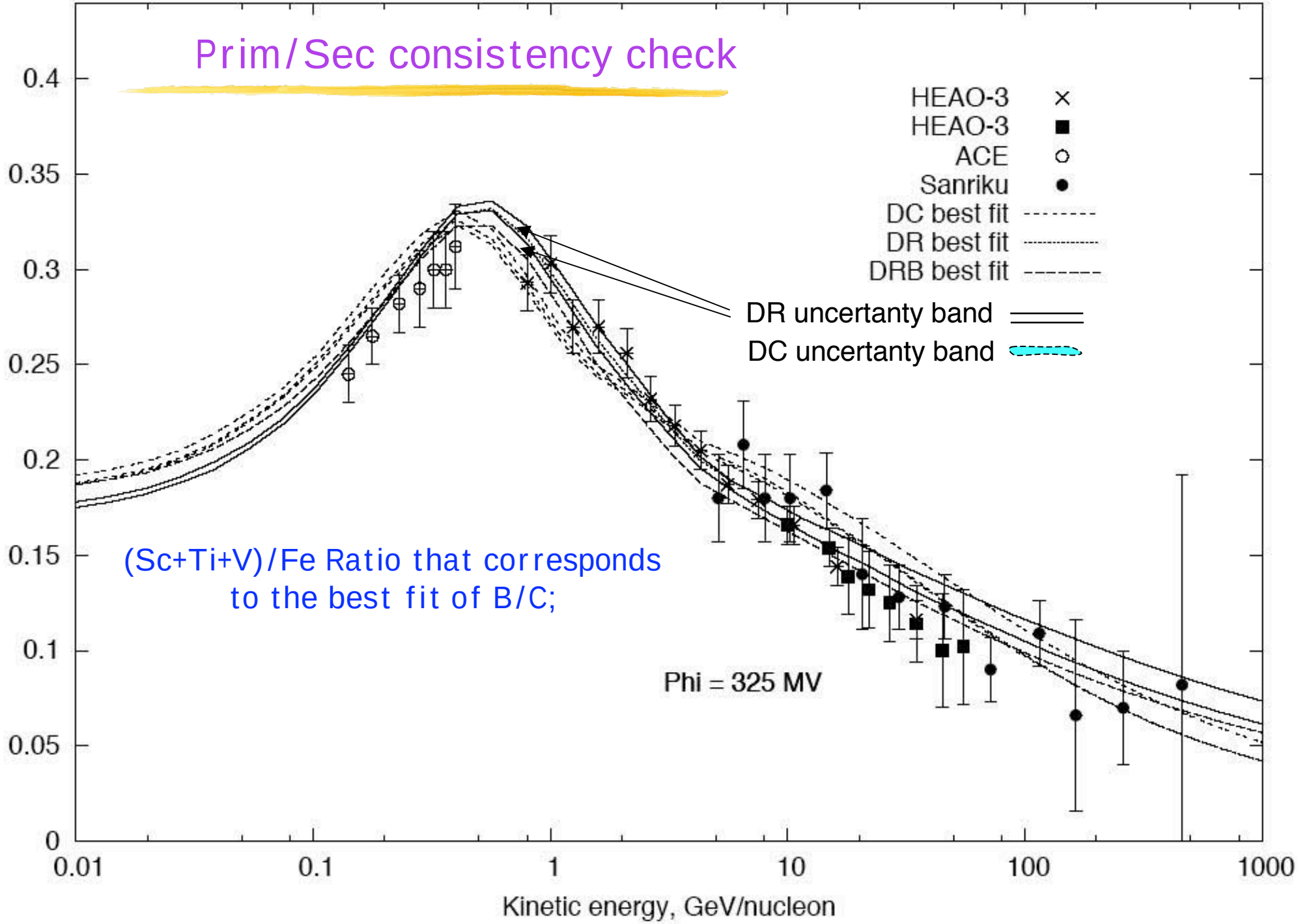
Proton spectra: Upper and lower bounds of due to the uncertainties of propagation parameters

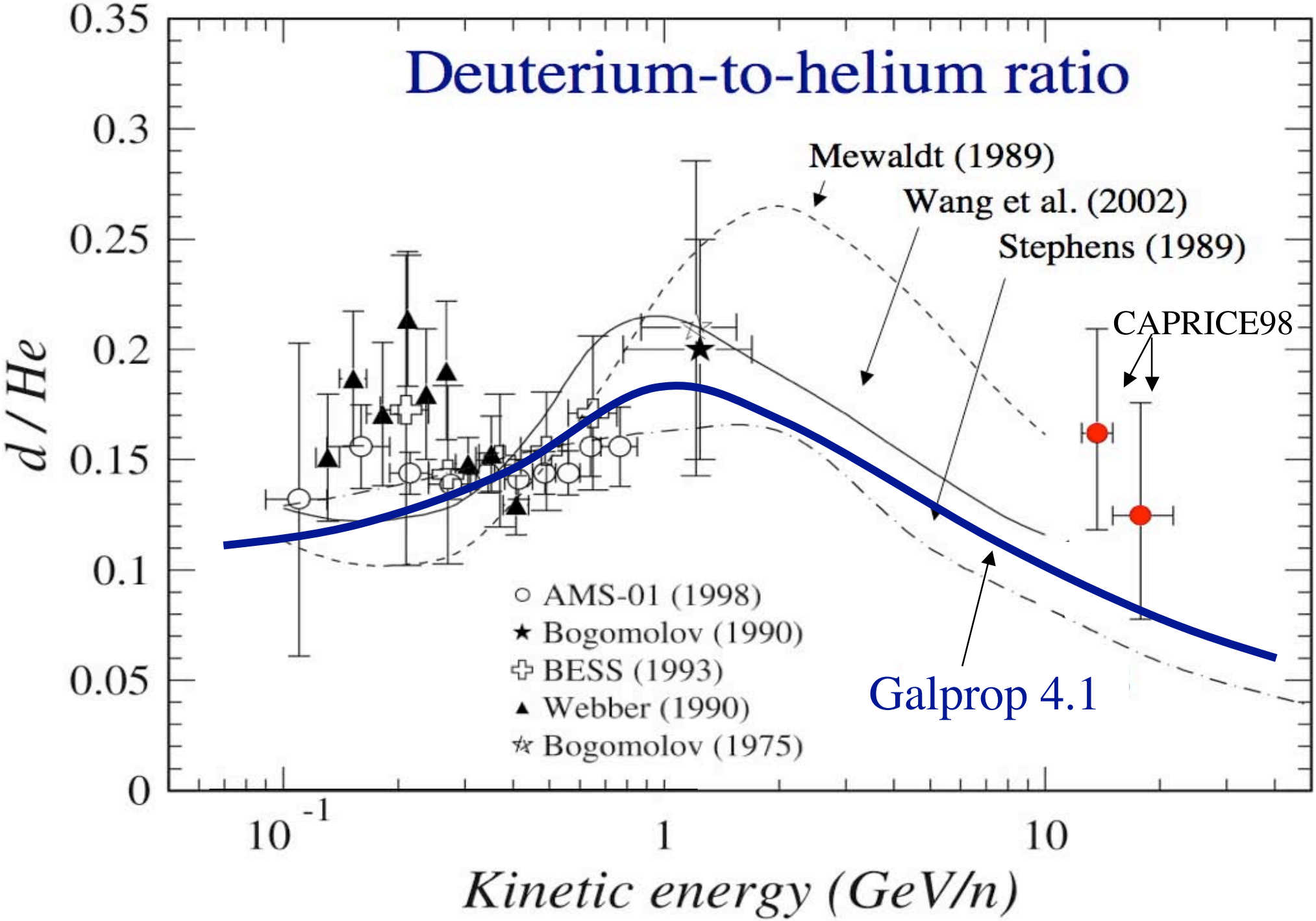


Helium spectra: Upper and lower bounds of due to the uncertainties of propagation parameters

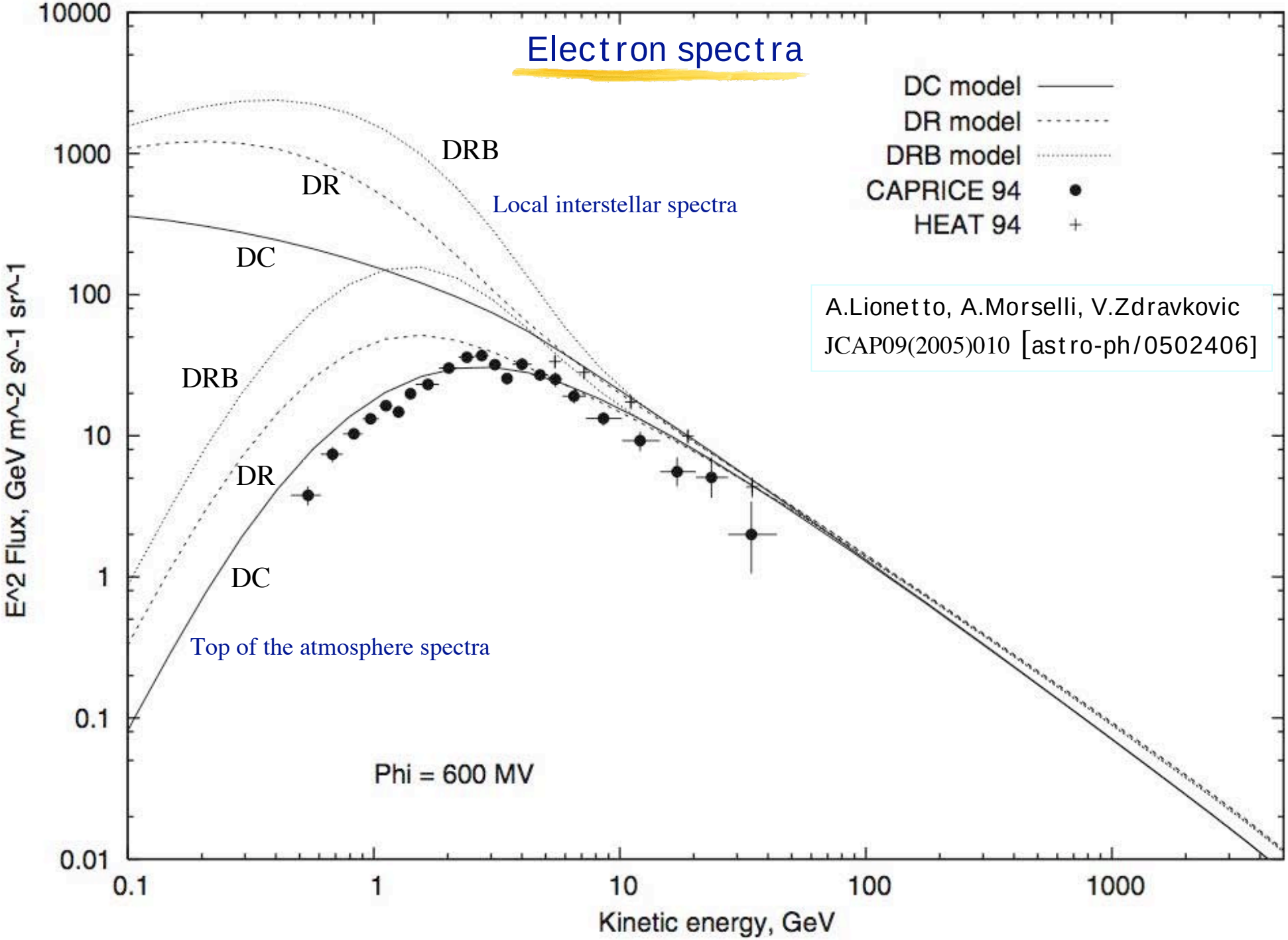


Prim/Sec consistency check



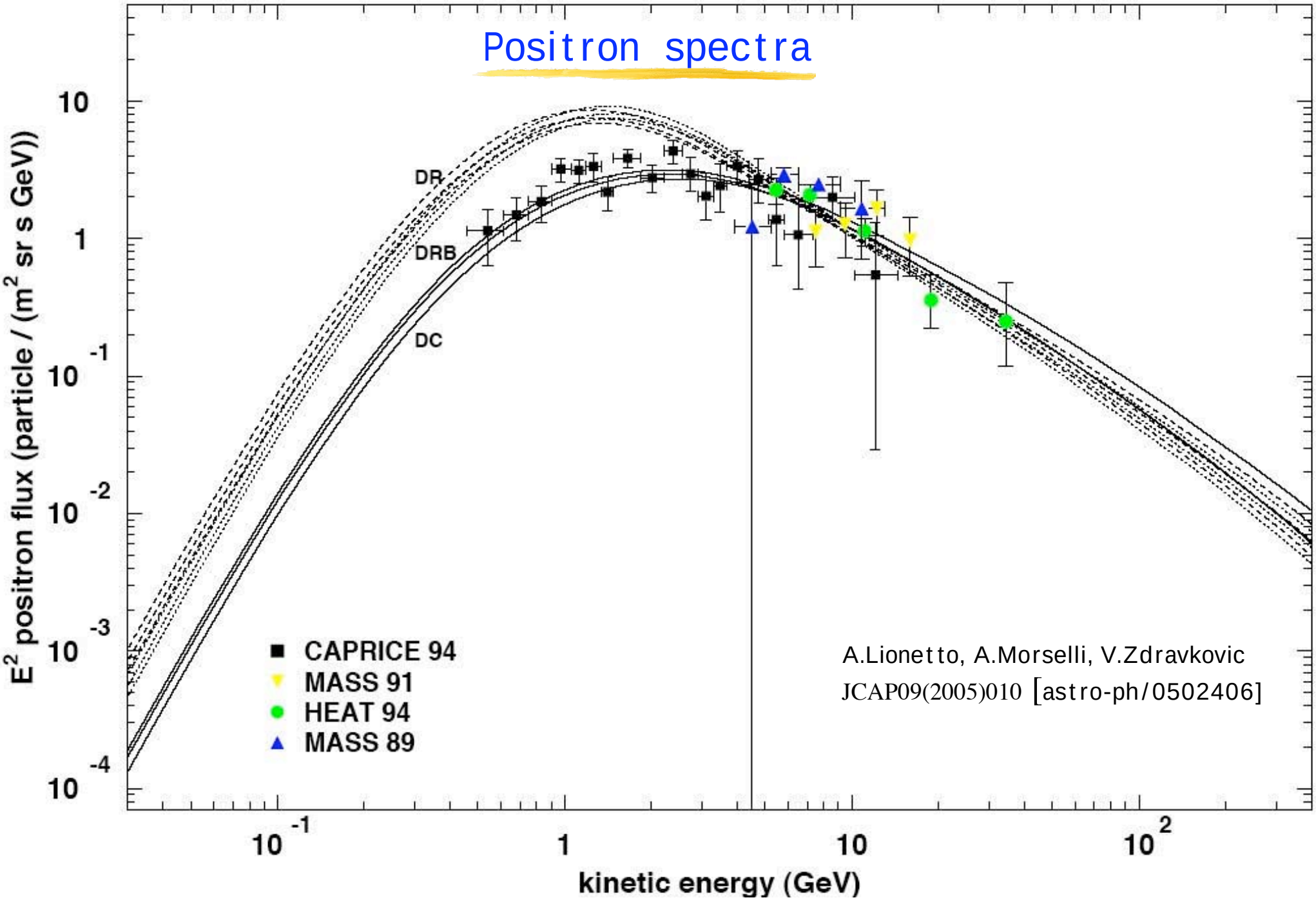

Deuterium-to-helium ratio
Mewaldt (1989)
Wang et al. (2002)
Stephens (1989)
CAPRICE98
Galprop 4.1
AMS-01 (1998)
Bogomolov (1990)
BESS (1993)
Webber (1990)
Bogomolov (1975)
d / He
Kinetic energy (GeV/n)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10 -1
1
10

Electron spectra



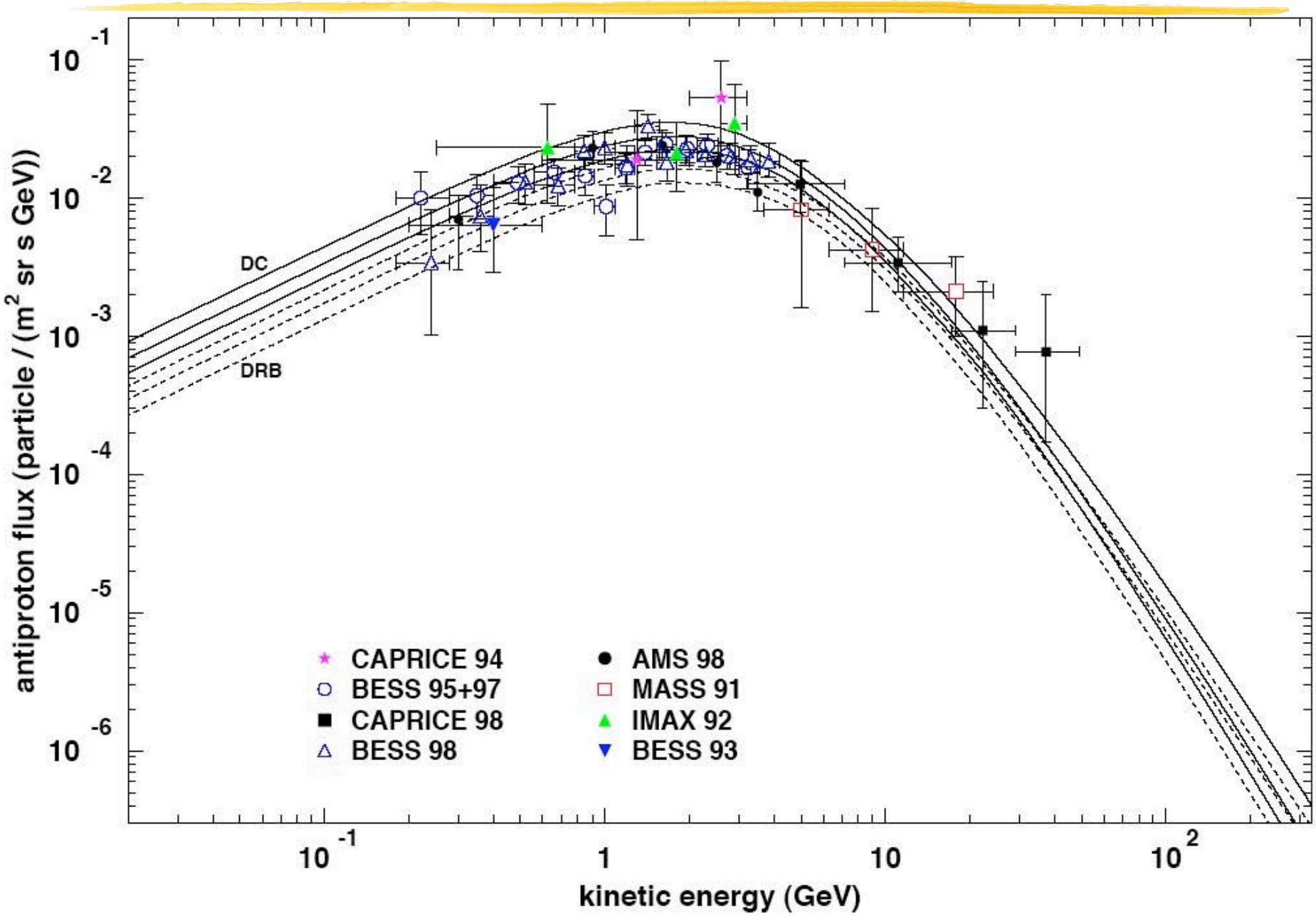
A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]

Positron spectra

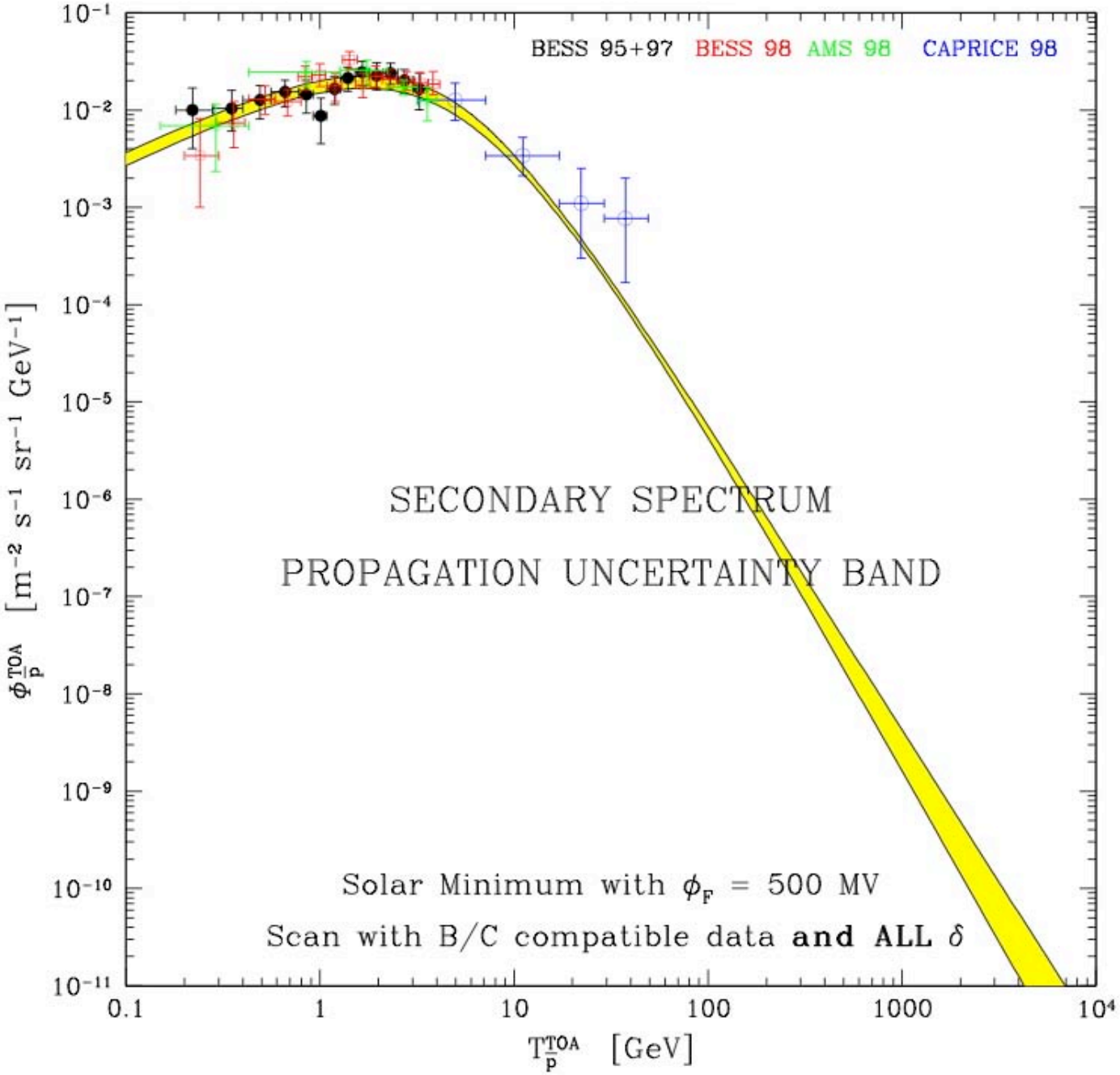


A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]

Antiproton spectra: Upper and lower bounds of due to the uncertainties of propagation parameters



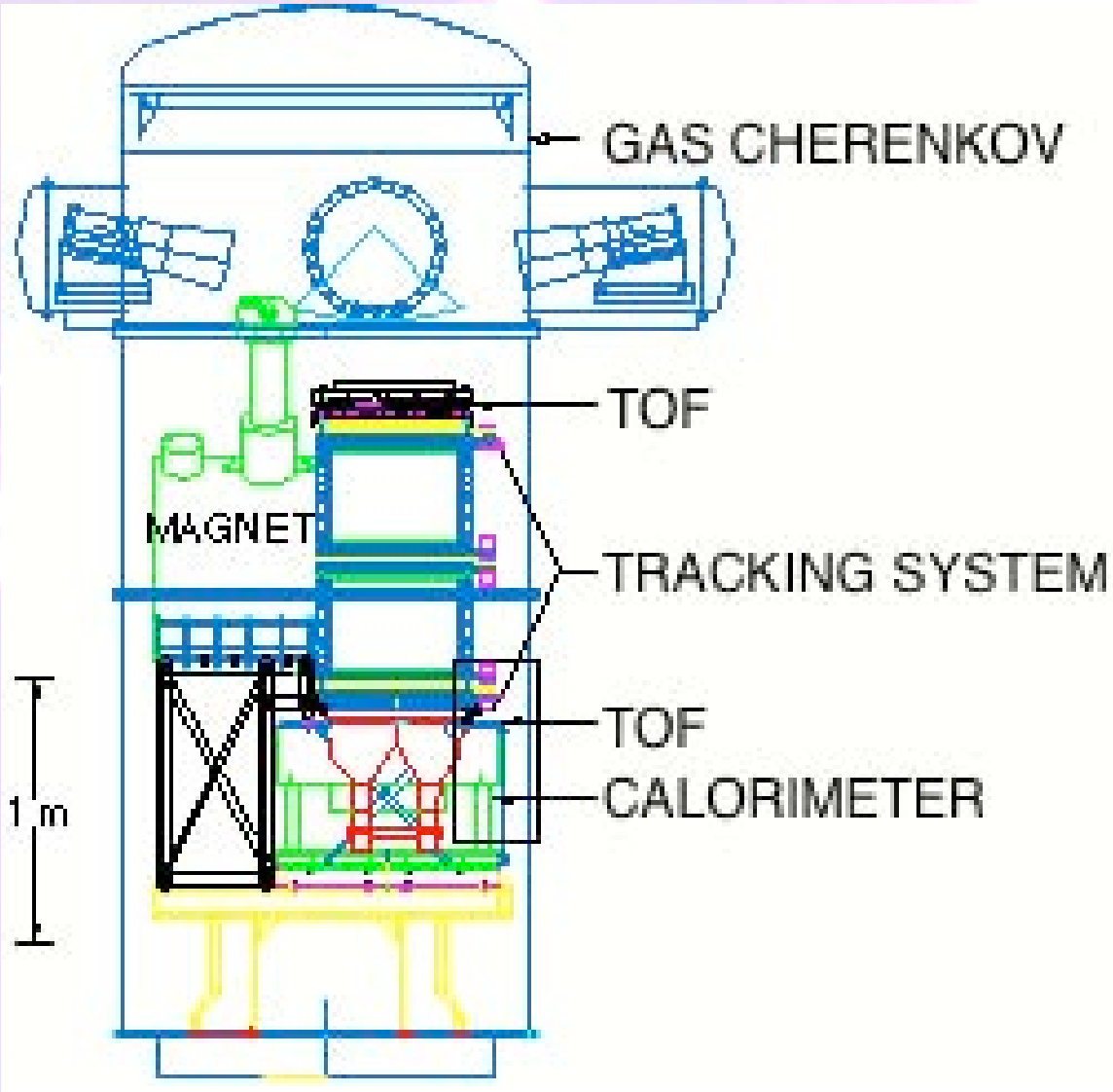
Antiproton spectra: Upper and lower bounds of due to the uncertainties of propagation parameters



Note: uncertainty will be reduced with the new PAMELA and AMS-02 B/C data

Torsten Bringmann,
Pierre Salati,
astro/ph 0612514

MASS Matter Antimatter Space Spectrometer (89&91)



MASS 89 flight

MASS 89 flight

MASS 89

PAMELA

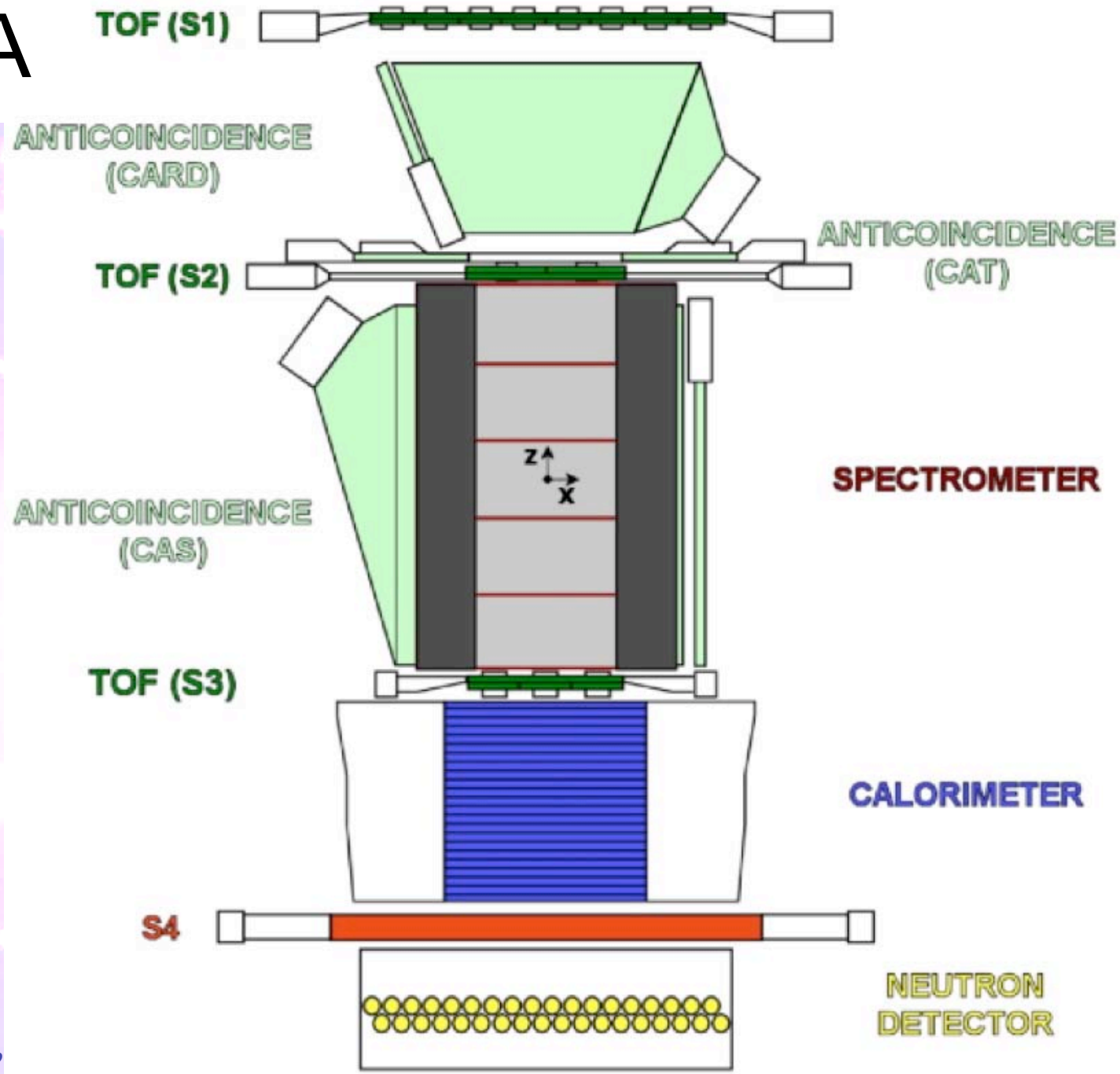
Payload for **A**ntimatter **M**atter **E**xploration and **L**ight Nuclei **A**strophysics

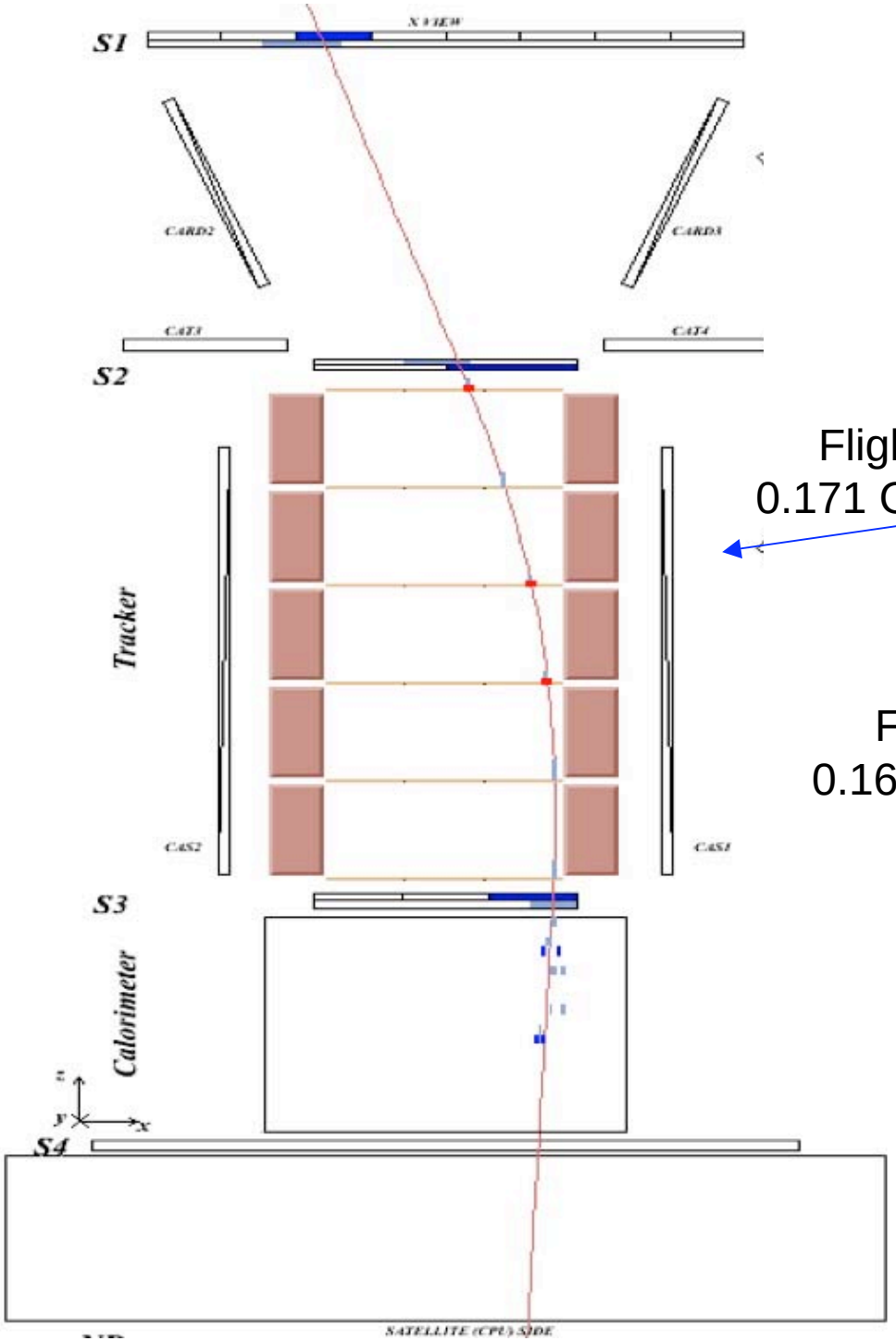
In orbit on June 15, 2006, on board of the DK1 satellite by a Soyuz rocket from the Bajkonour launch site.

First switch-on on June 21 2006

From July 11 Pamela is in continuous data taking mode

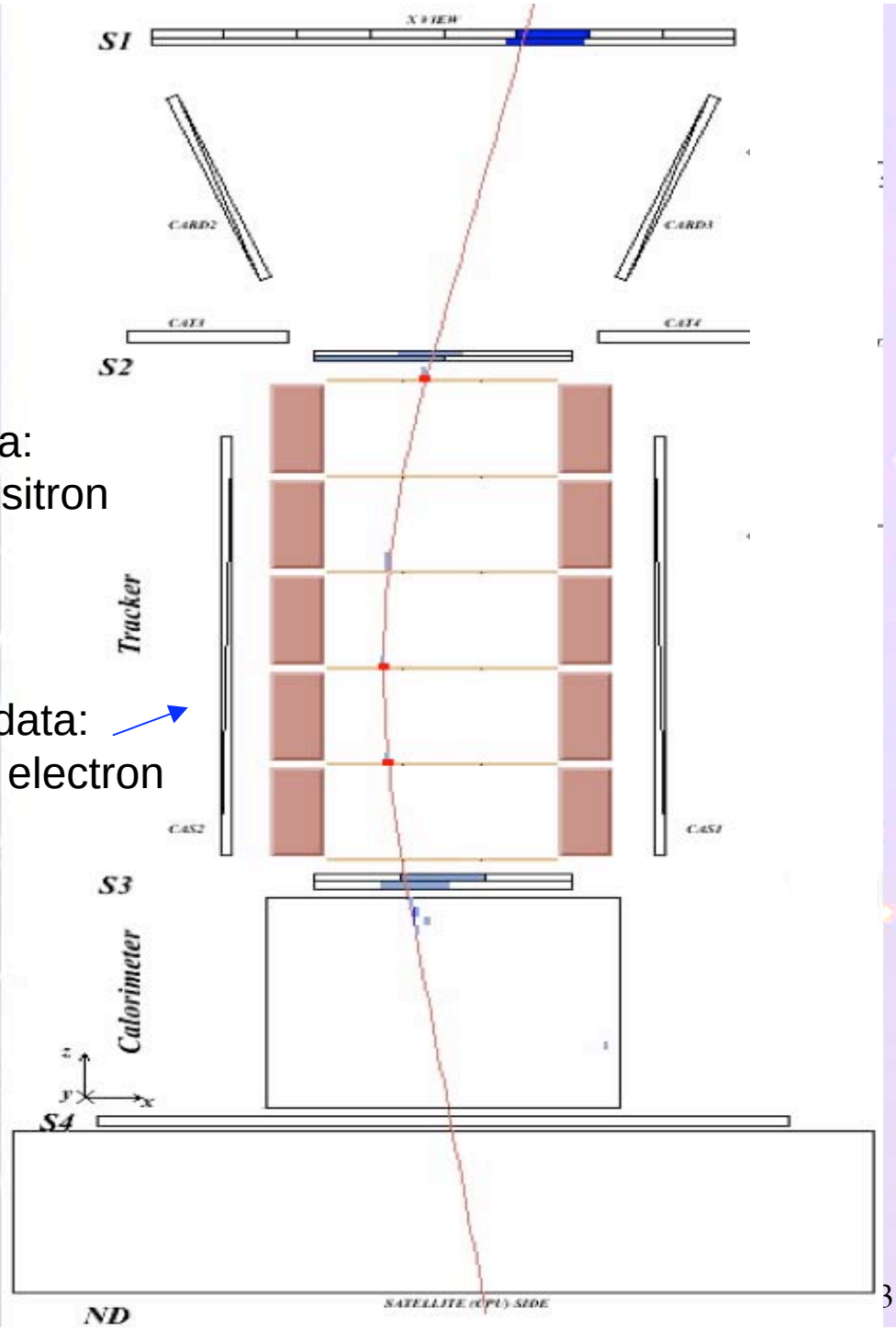
PAMELA


TOF (S1)
ANTICOINCIDENCE (CARD)
ANTICOINCIDENCE (CAT)
TOF (S2)
Z
X
SPECTROMETER
ANTICOINCIDENCE (CAS)
TOF (S3)
CALORIMETER
S4
NEUTRON DETECTOR



Flight data:
0.171 GV positron

Flight data:
0.169 GV electron



PAMELA scientific program

PAMELA is a magnetic spectrometer which will fly on a Russian satellite by Fall 2005. Its scientific scope is the measurement of the antiproton and positron spectra up to few hundred GeV, of the proton and electron spectra up to 700 GeV and that of light nuclei.

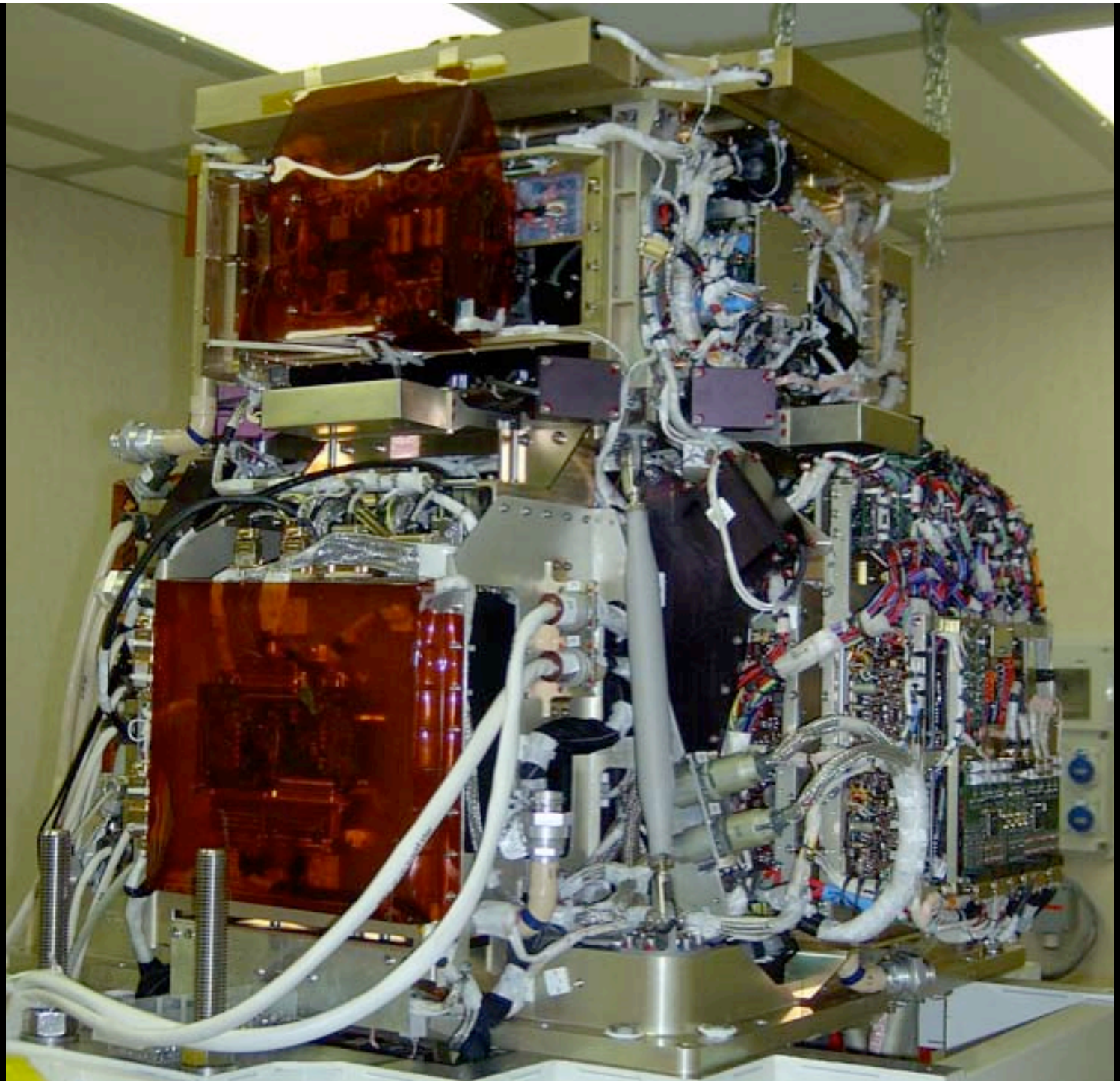
	energy range	particles/3 years
Antiproton flux	80 MeV - 190 GeV	$>3\ 10^{4}$
Positron flux	50 MeV – 270 GeV	$>3\ 10^{5}$
Electron flux	up to 400 GeV	$6\ 10^{6}$
Proton flux	up to 700 GeV	$3\ 10^{8}$
Electron/positron flux	up to 2 TeV	
Light Nuclei (up to Z=6)	up to 200 GeV/n	He/Be/C: $4\ 10^{7/4/5}$
AntiNuclei search	(sensitivity of $3\ 10^{-8}$ in $\overline{He}/He$)	

→ Unprecedented Statistics and new Energy Range in Cosmic Rays

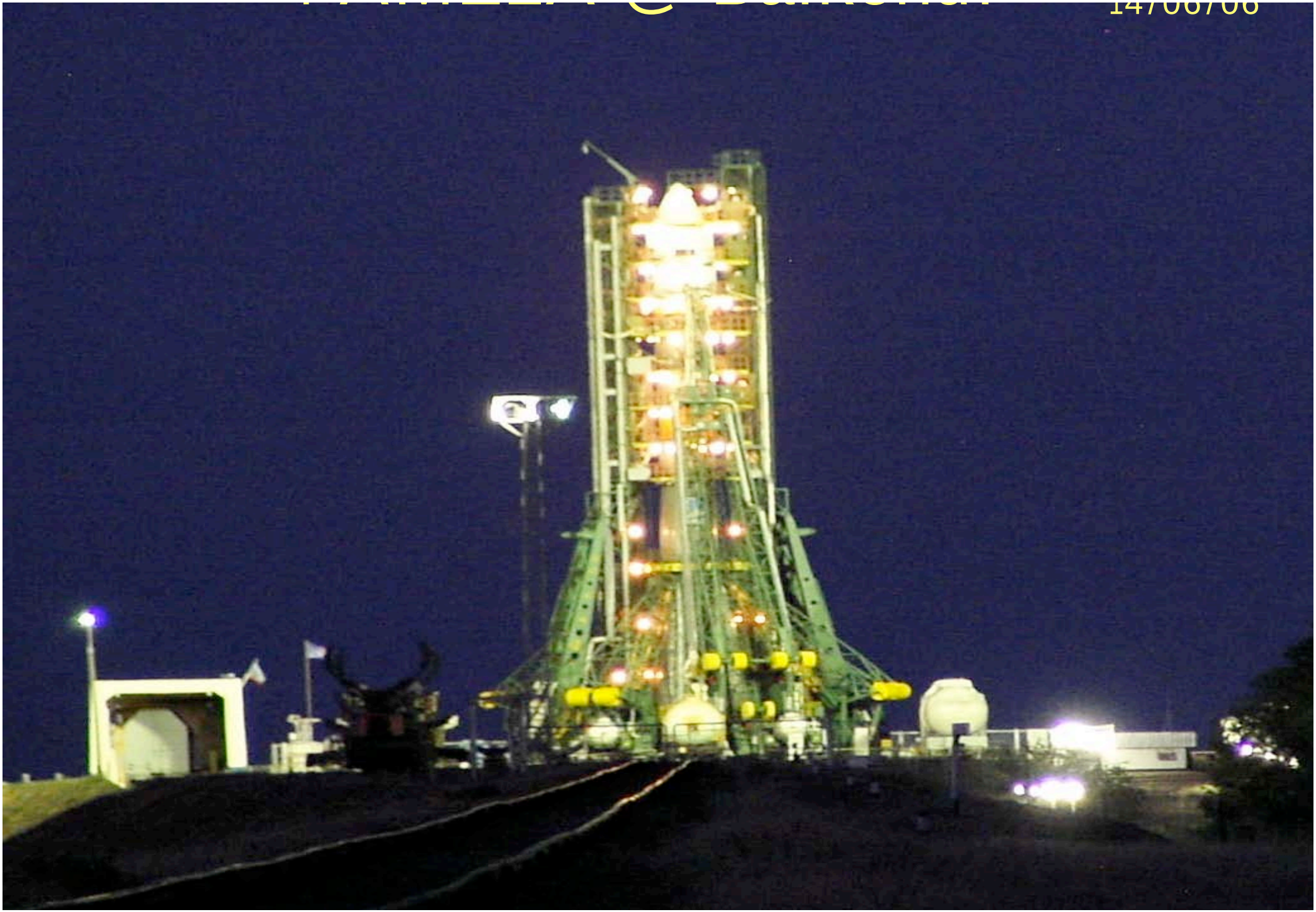
Actual limits: antip&positrons ≈ 40 GeV

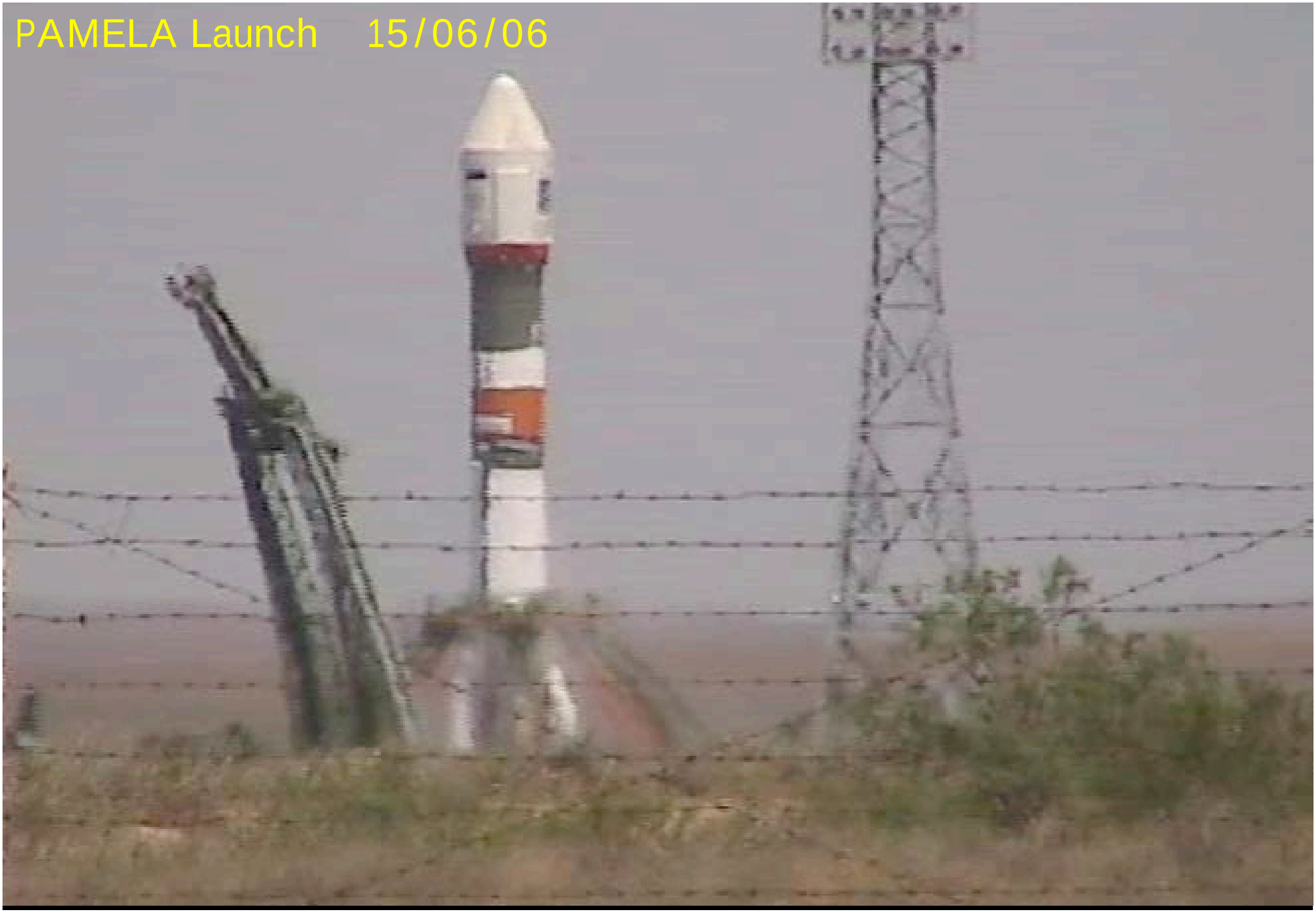
Pamela in Samara, Russia

4/09/05

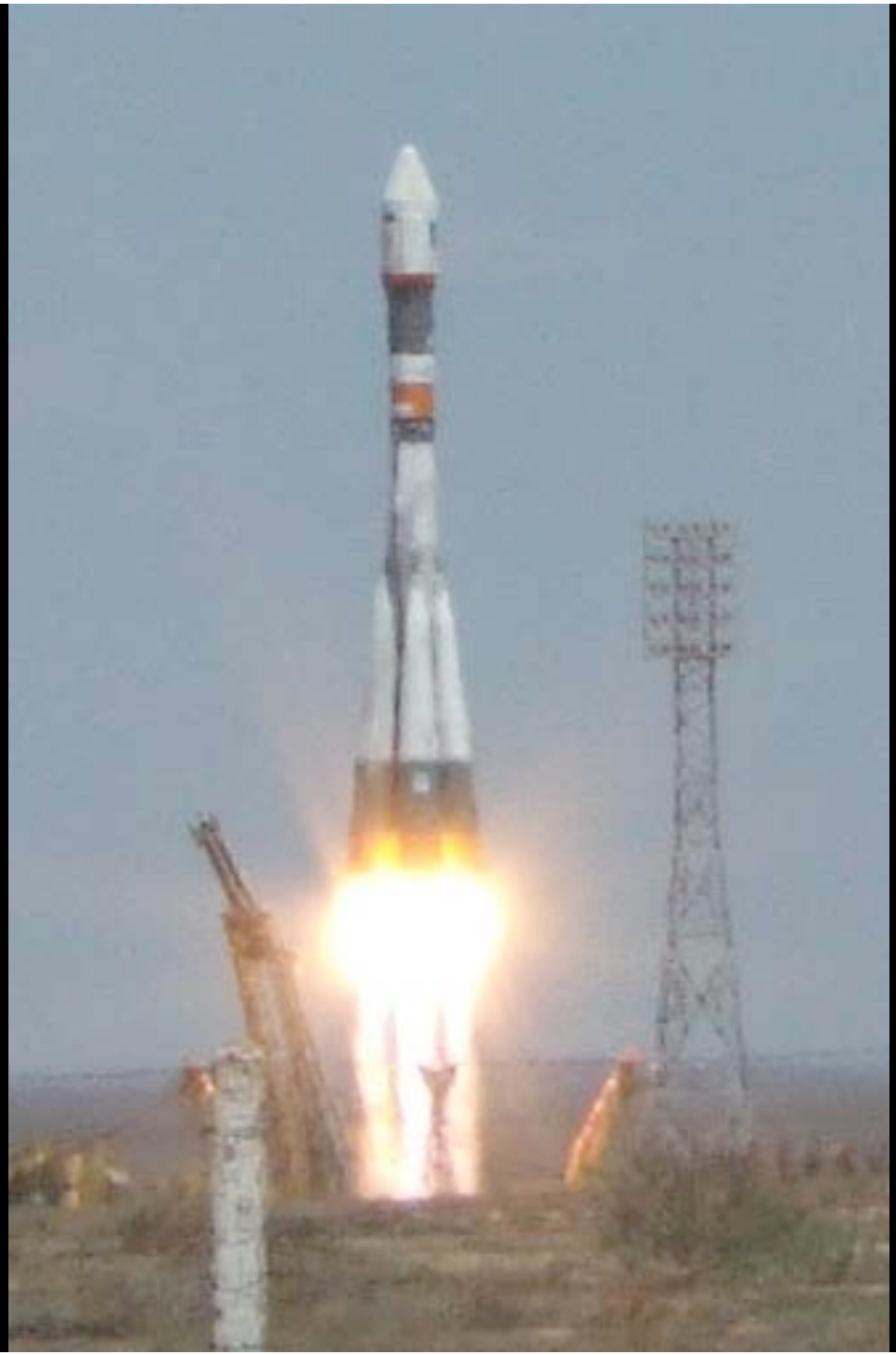


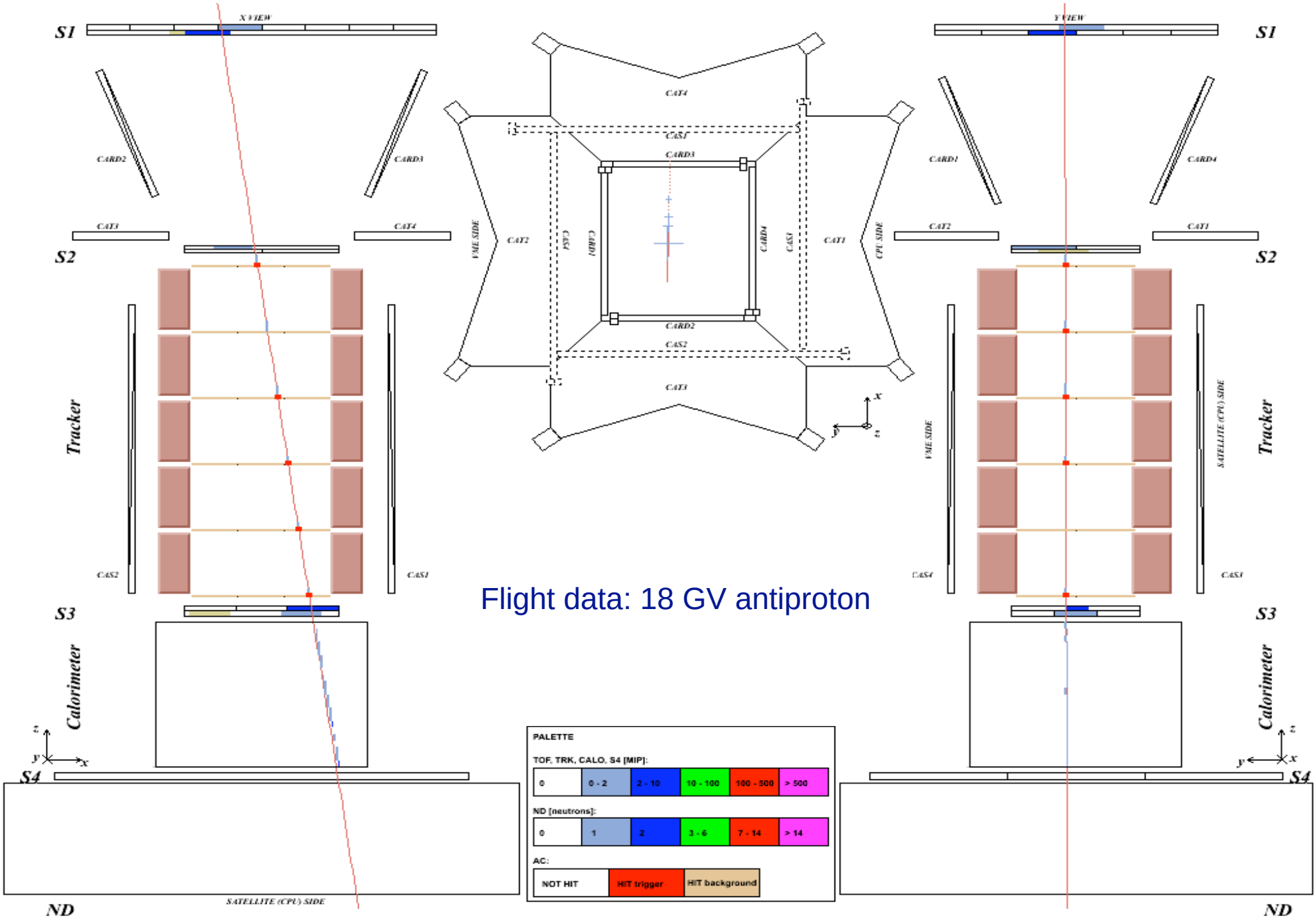
Transport from Progress building to Launch Pad 13-6-2006

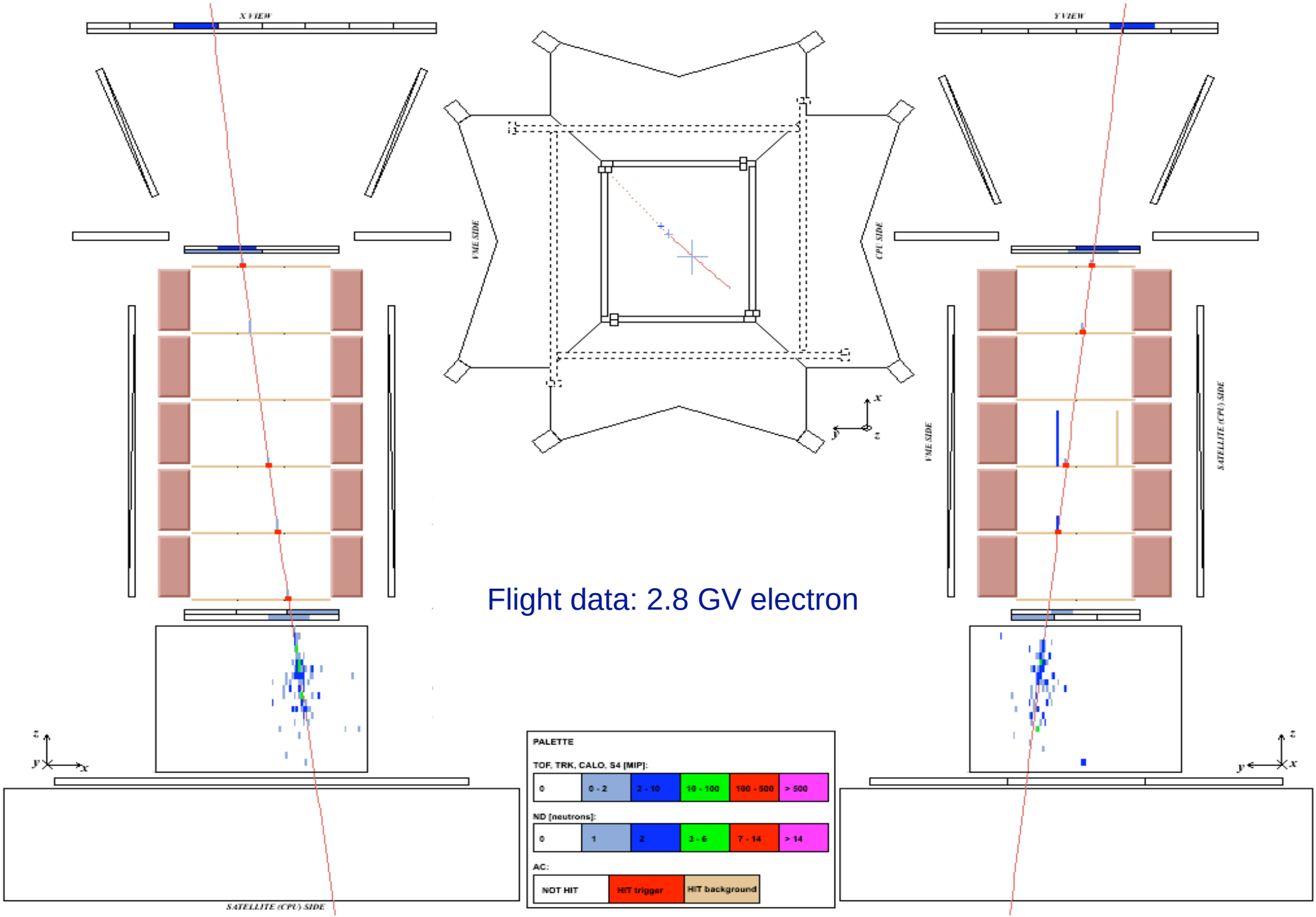



PAMELA Launch 15/06/06

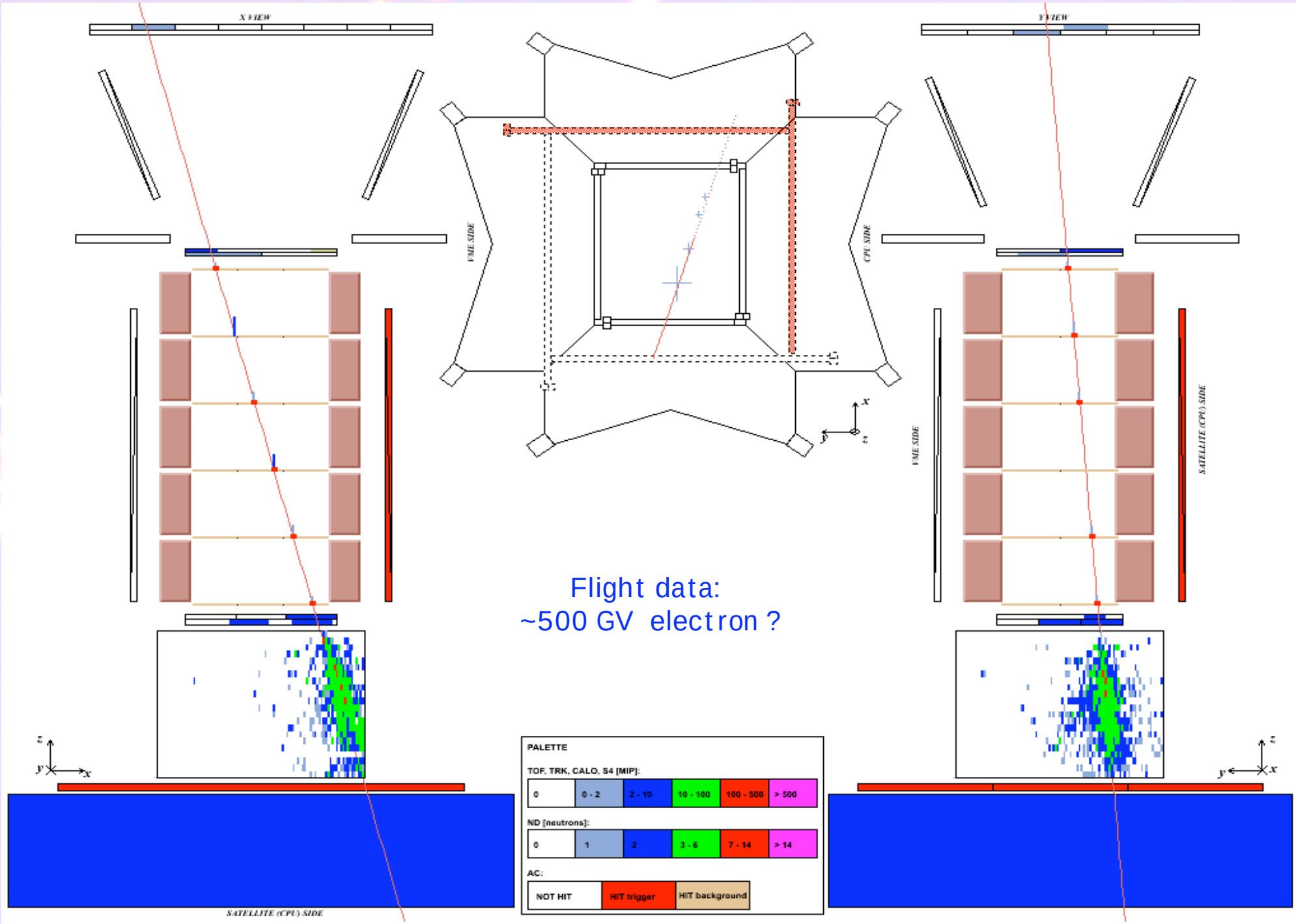
PAMELA Launch
15/06/06



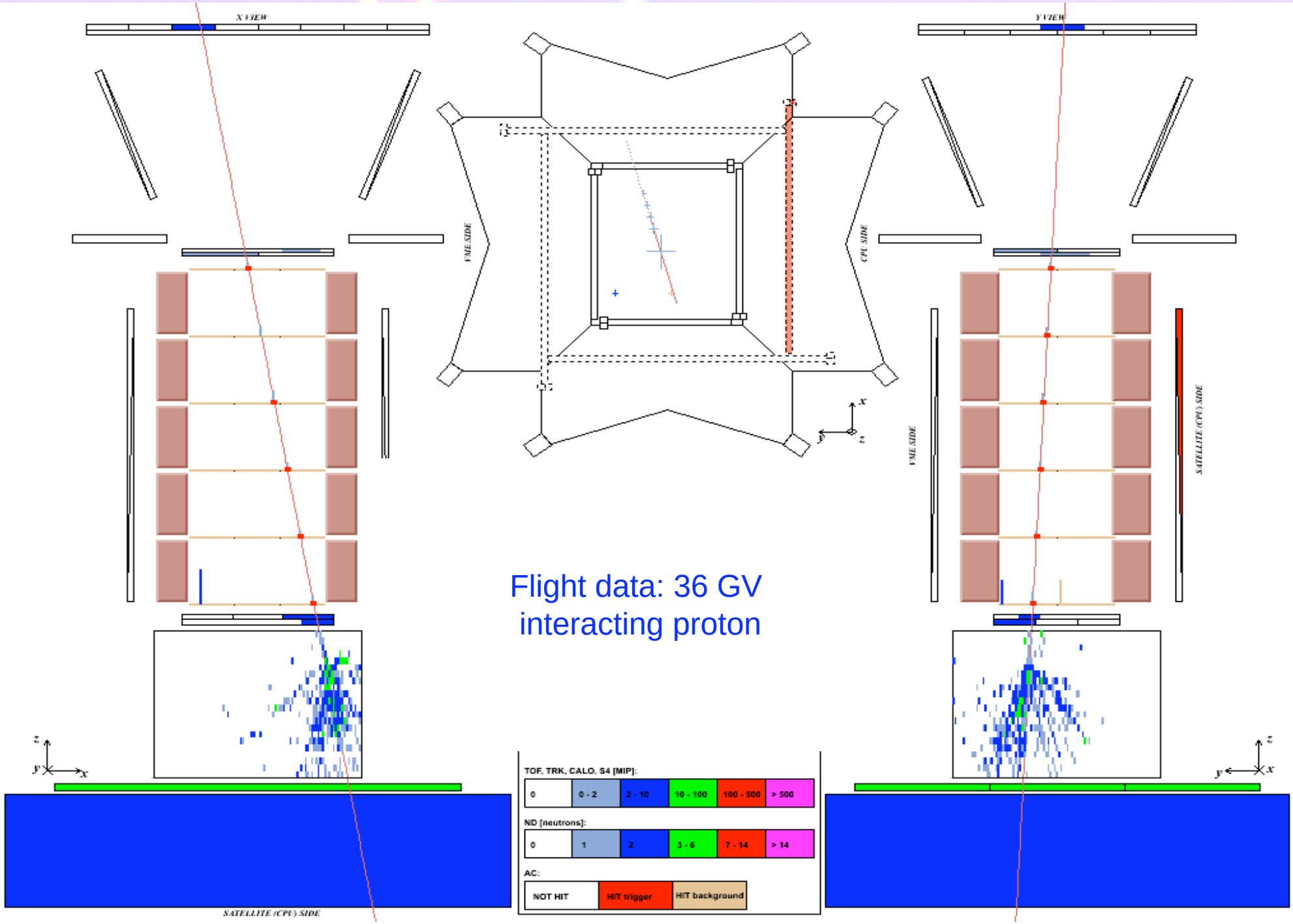

Flight data: 18 GV antiproton
S1
S2
S3
S4
ND
X VIEW
Y VIEW
Tracker
Calorimeter
CARD1
CARD2
CARD3
CARD4
CAT1
CAT2
CAT3
CAT4
CAS1
CAS2
CAS3
CAS4
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background



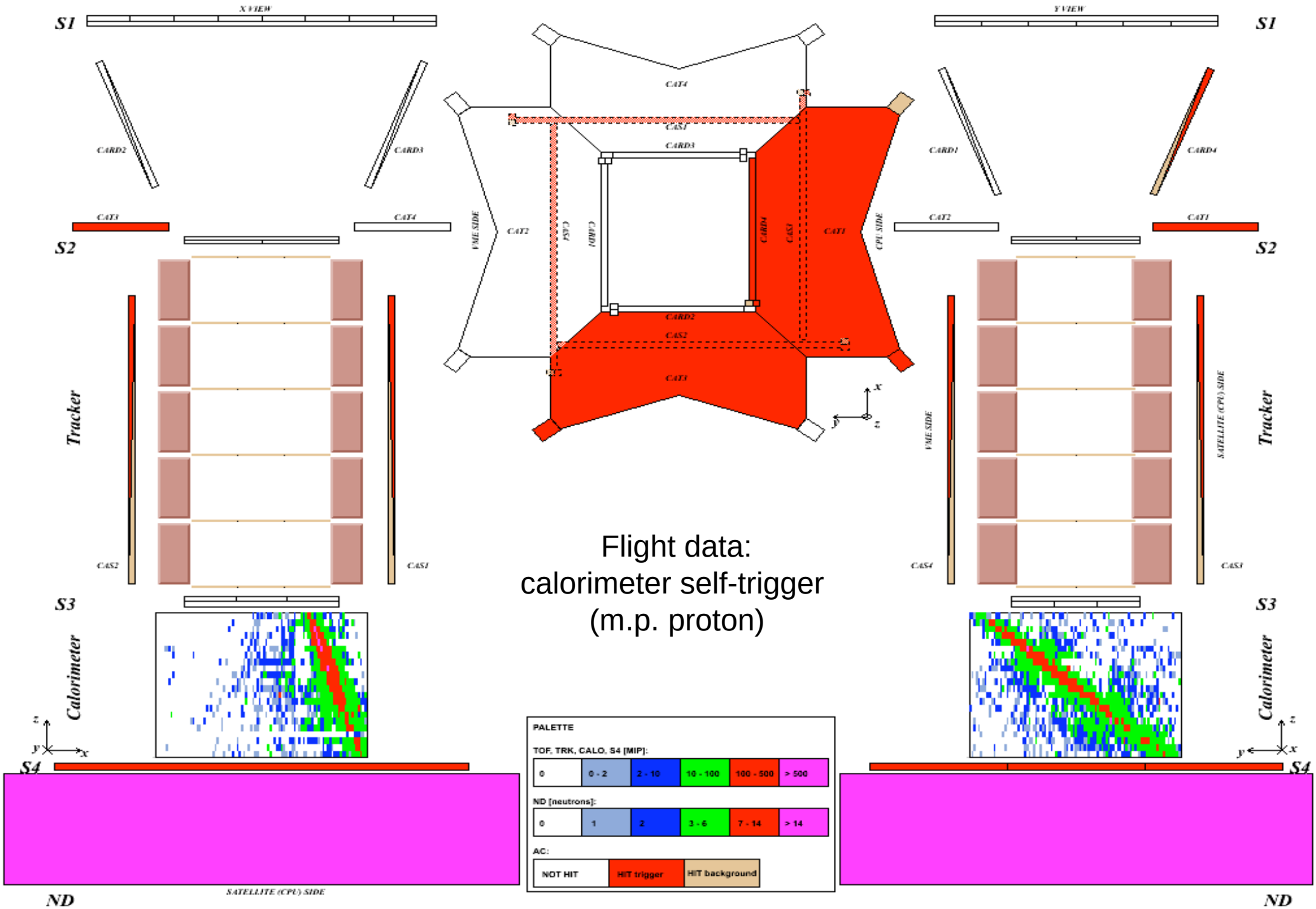
Flight data: 2.8 GV electron



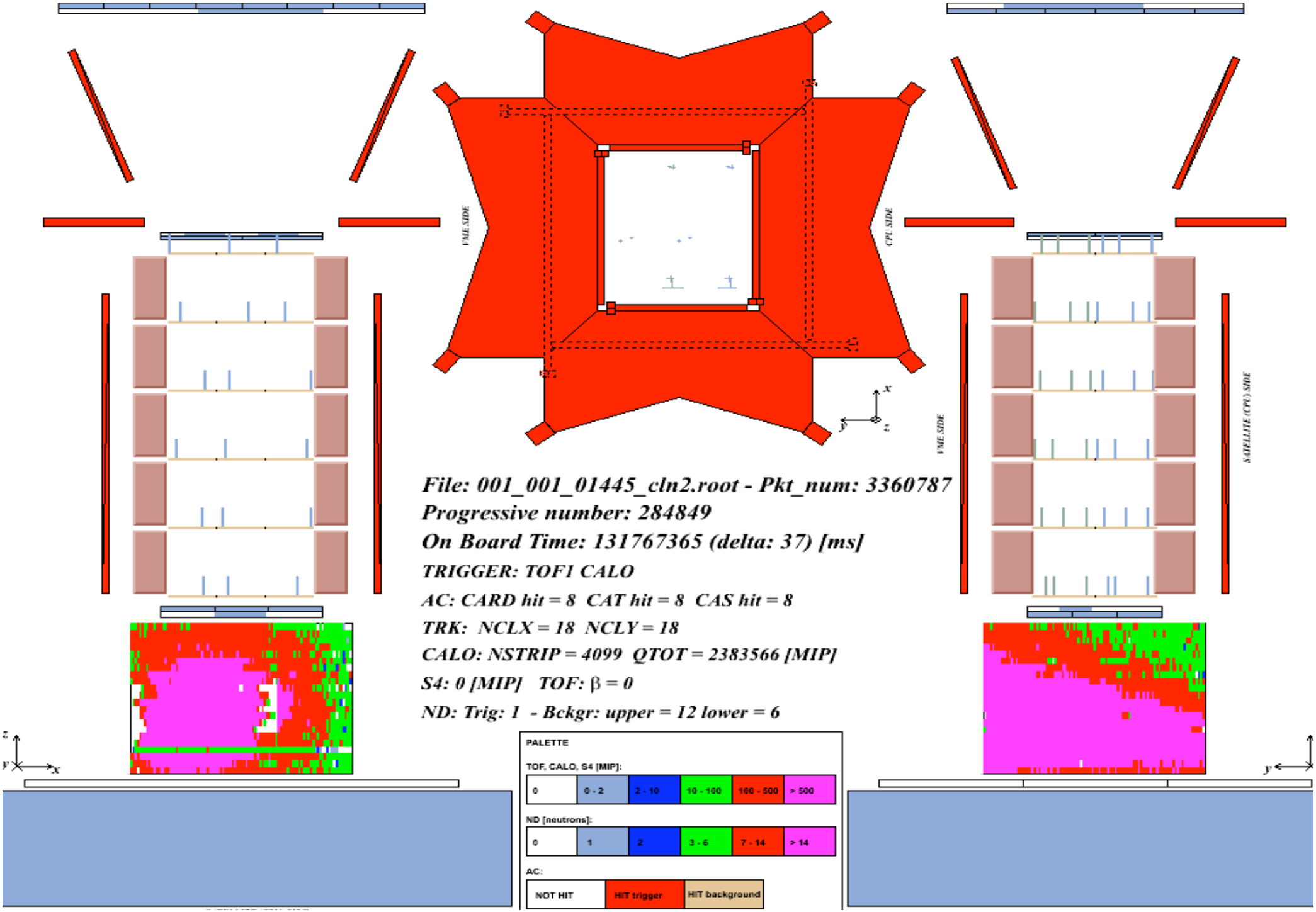
Flight data:
~500 GV electron ?

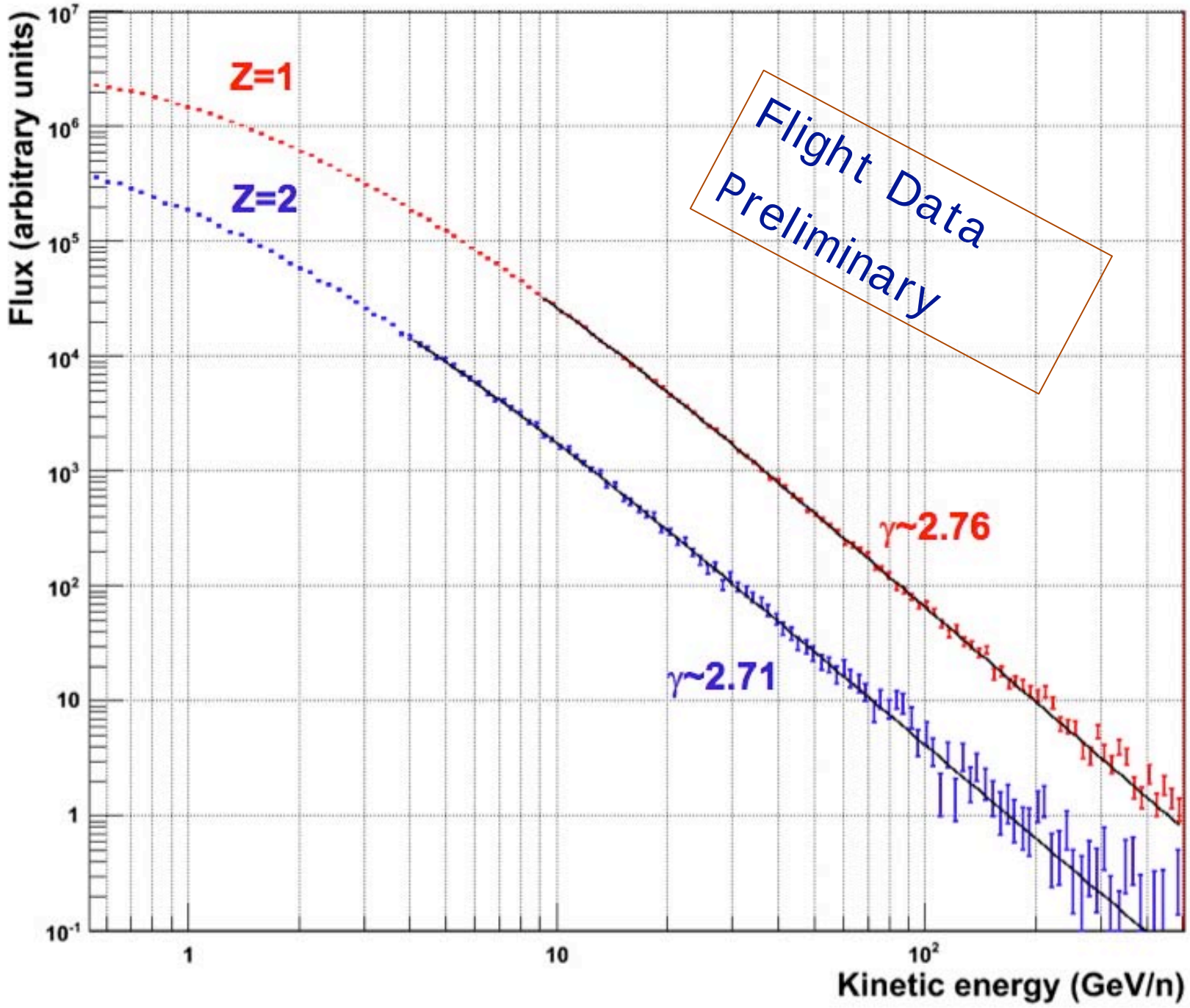


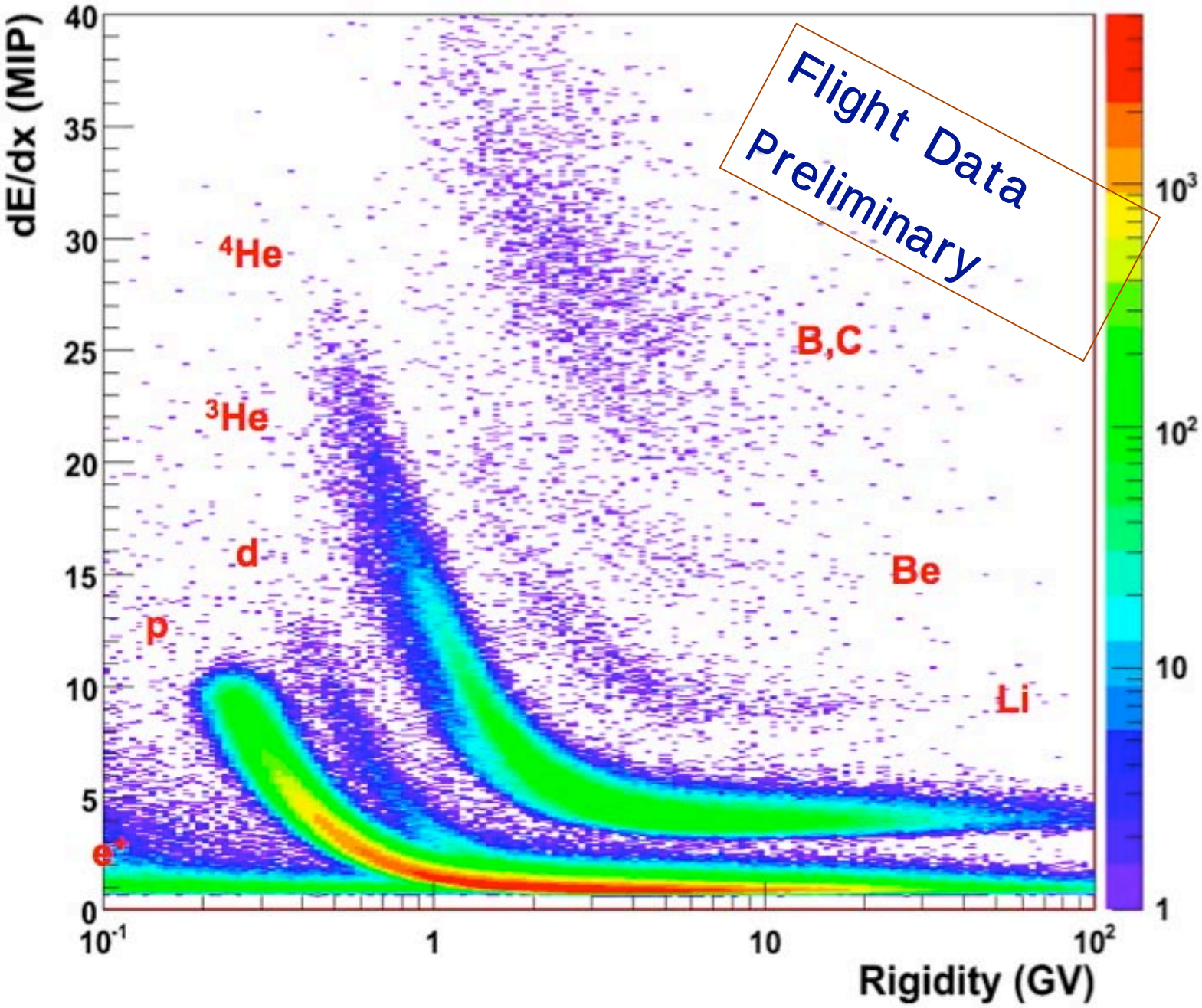
Flight data: 36 GV interacting proton



Flight data:
calorimeter self-trigger
(m.p. proton)


VME SIDE
CPU SIDE
VME SIDE
SATELLITE (CPU) SIDE
File: 001_001_01445_cln2.root - Pkt_num: 3360787
Progressive number: 284849
On Board Time: 131767365 (delta: 37) [ms]
TRIGGER: TOF1 CALO
AC: CARD hit = 8 CAT hit = 8 CAS hit = 8
TRK: NCLX = 18 NCLY = 18
CALO: NSTRIP = 4099 QTOT = 2383566 [MIP]
S4: 0 [MIP] TOF: β = 0
ND: Trig: 1 - Bckgr: upper = 12 lower = 6
PALETTE
TOF, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background


Flux (arbitrary units)
Z=1
Z=2
Flight Data
Preliminary
γ~2.76
γ~2.71
Kinetic energy (GeV/n)


Flight Data
Preliminary
dE/dx (MIP)
Rigidity (GV)
^{4}He
^{3}He
d
p
e$^+$
B,C
Be
Li
40
35
30
25
20
15
10
5
0
10^{-1}
1
10
10^2
10^3
10^2
10
1

PAMELA

Status @ April 2007

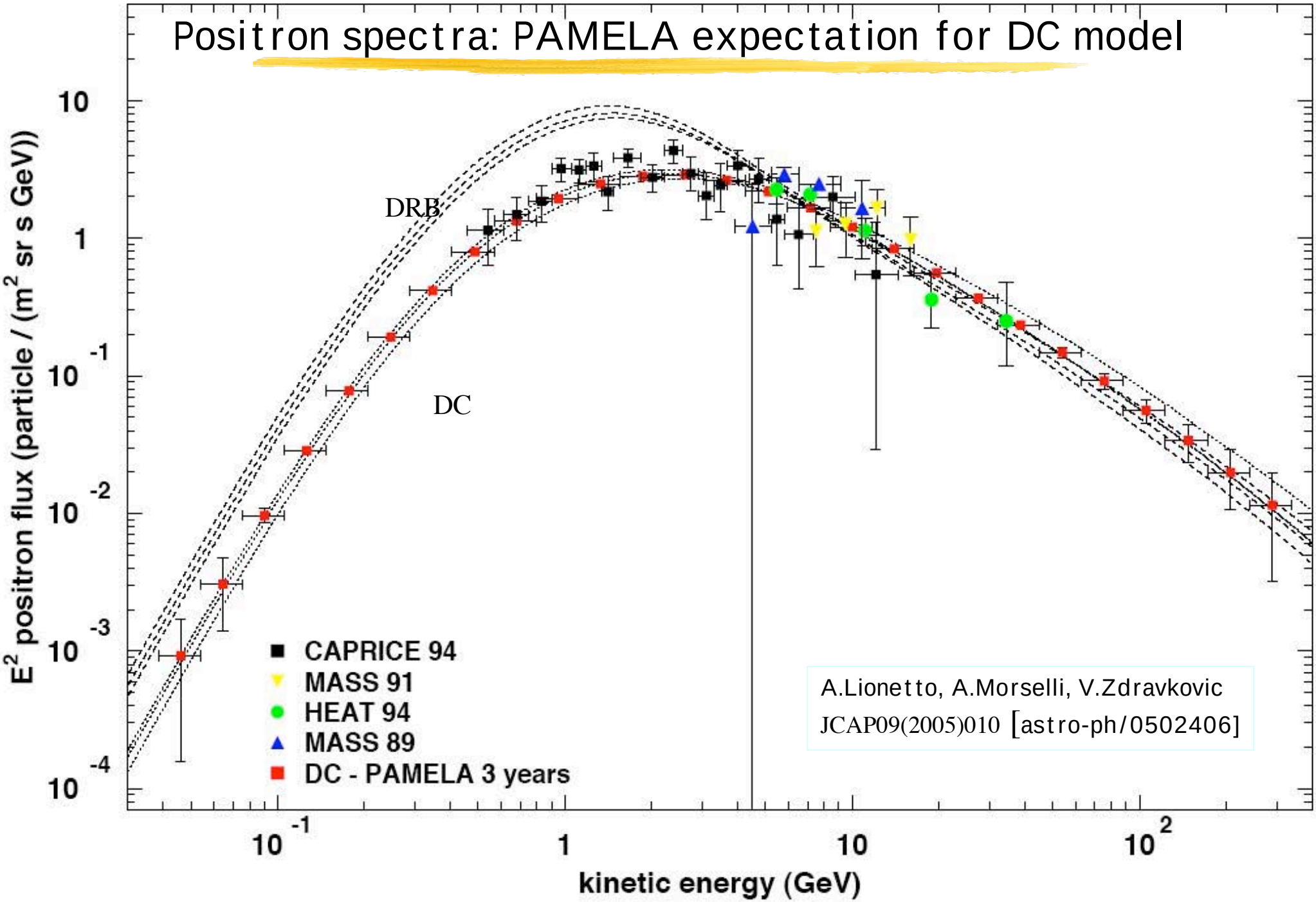
We have collected data for about 20 million seconds in full PAMELA configuration corresponding to ~220 days of continuous data taking.

- a first milestone: **SIX MONTHS OF DATA**

The amount of data collected is ~4TB, corresponding to more than 480 milion events.

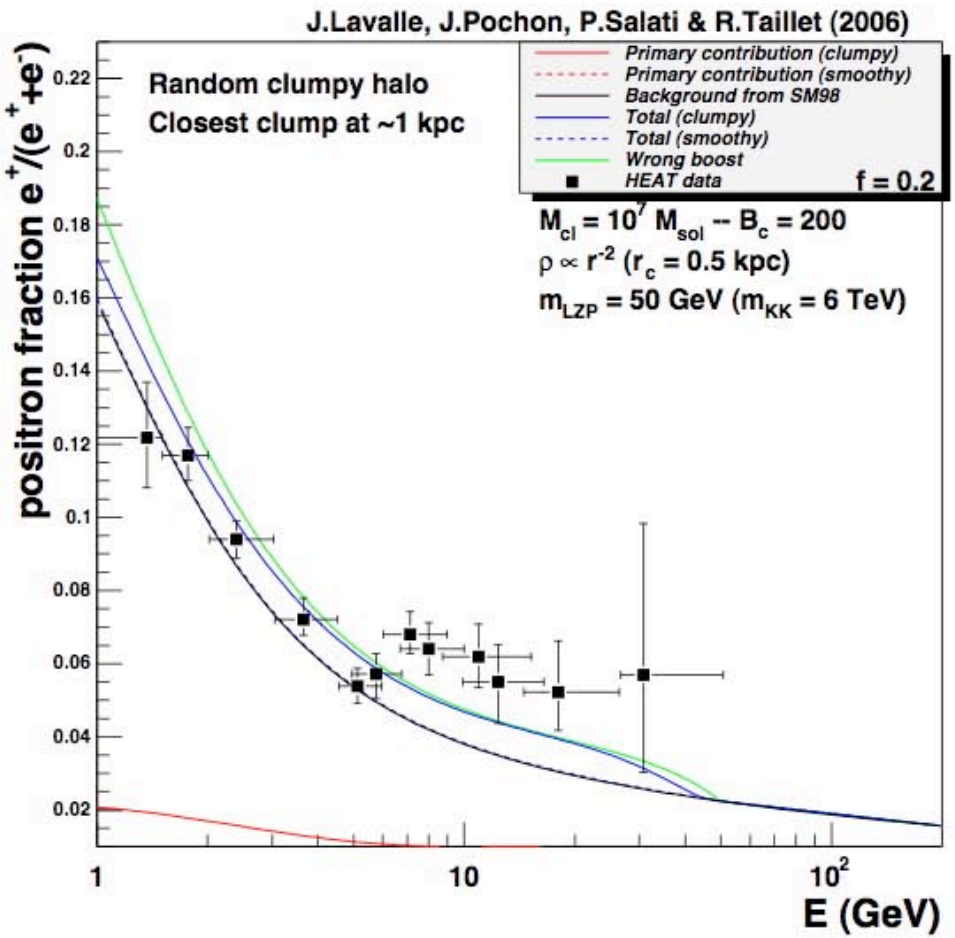
more news on PAMELA: Mark Pearce talk this afternoon

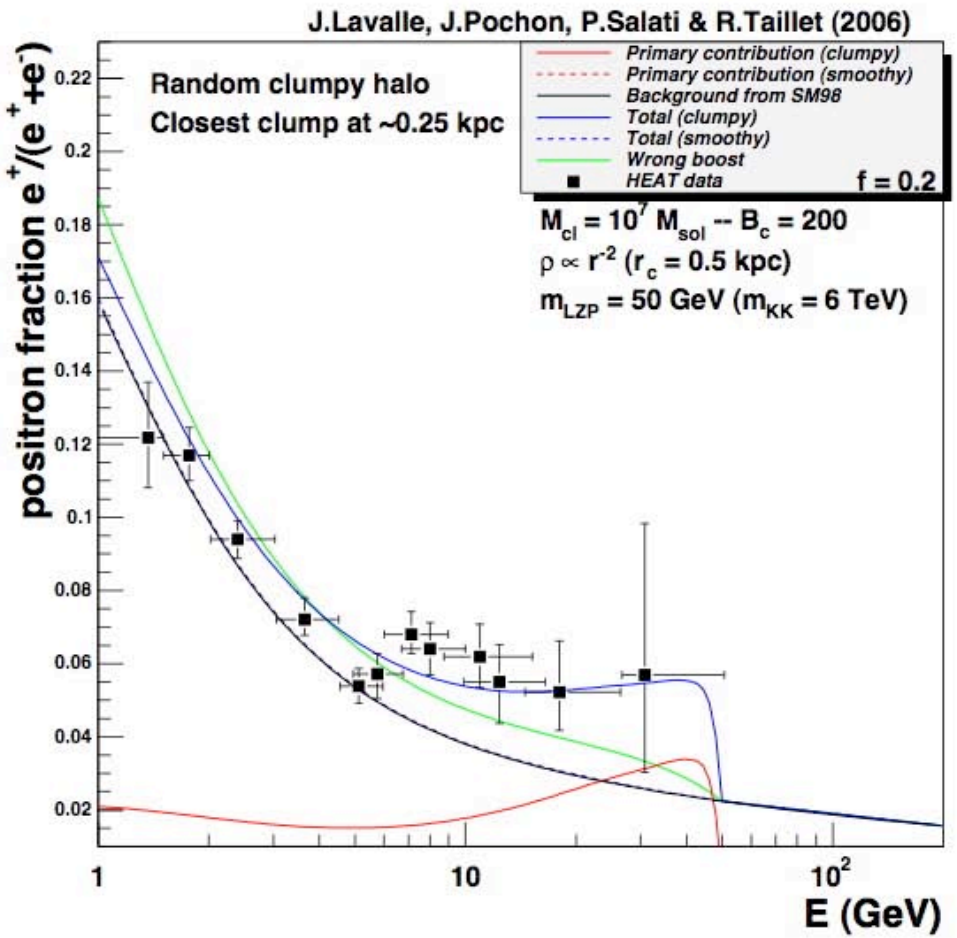
Positron spectra: PAMELA expectation for DC model



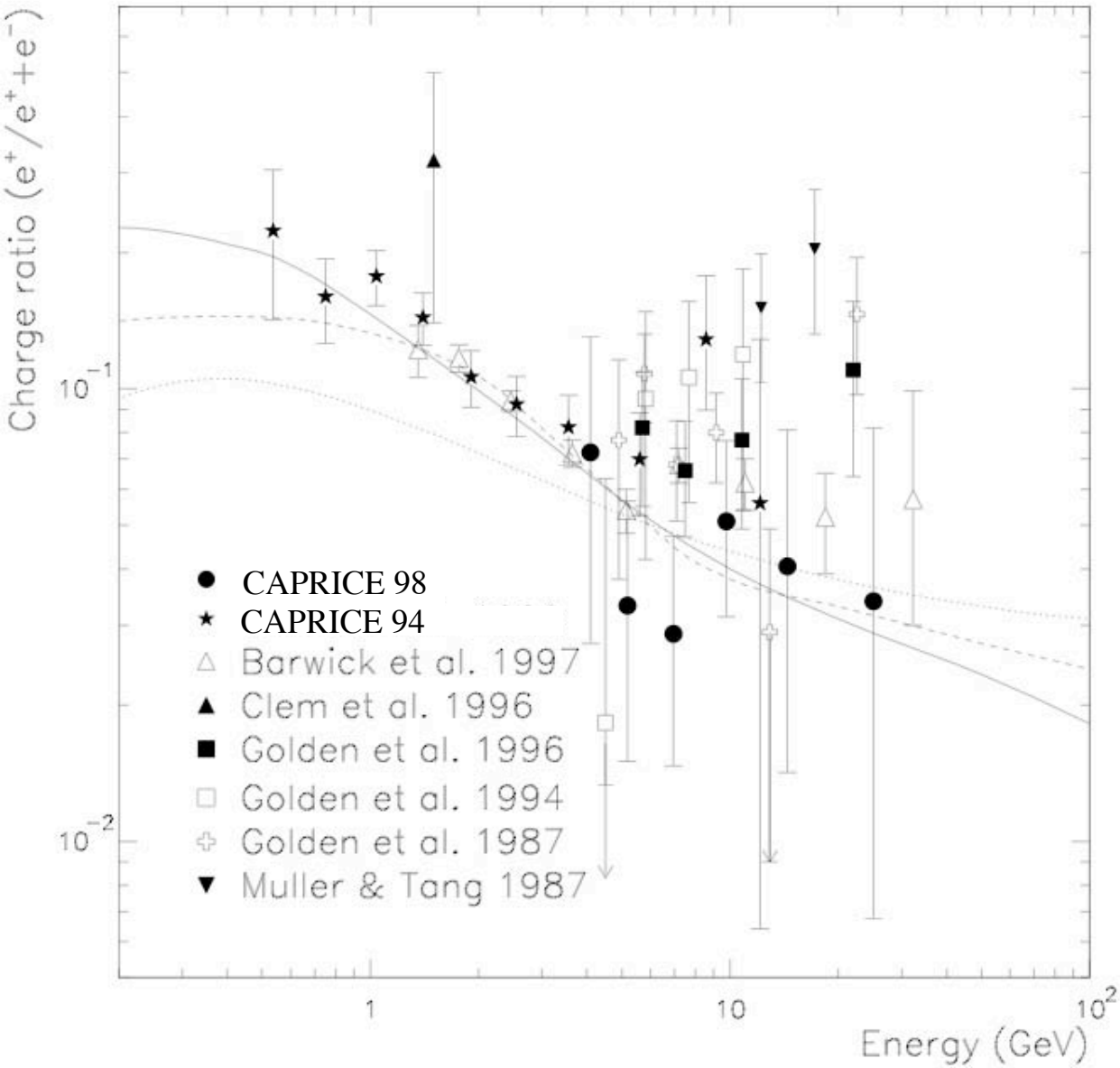
A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]

HEAT Data and positron excess

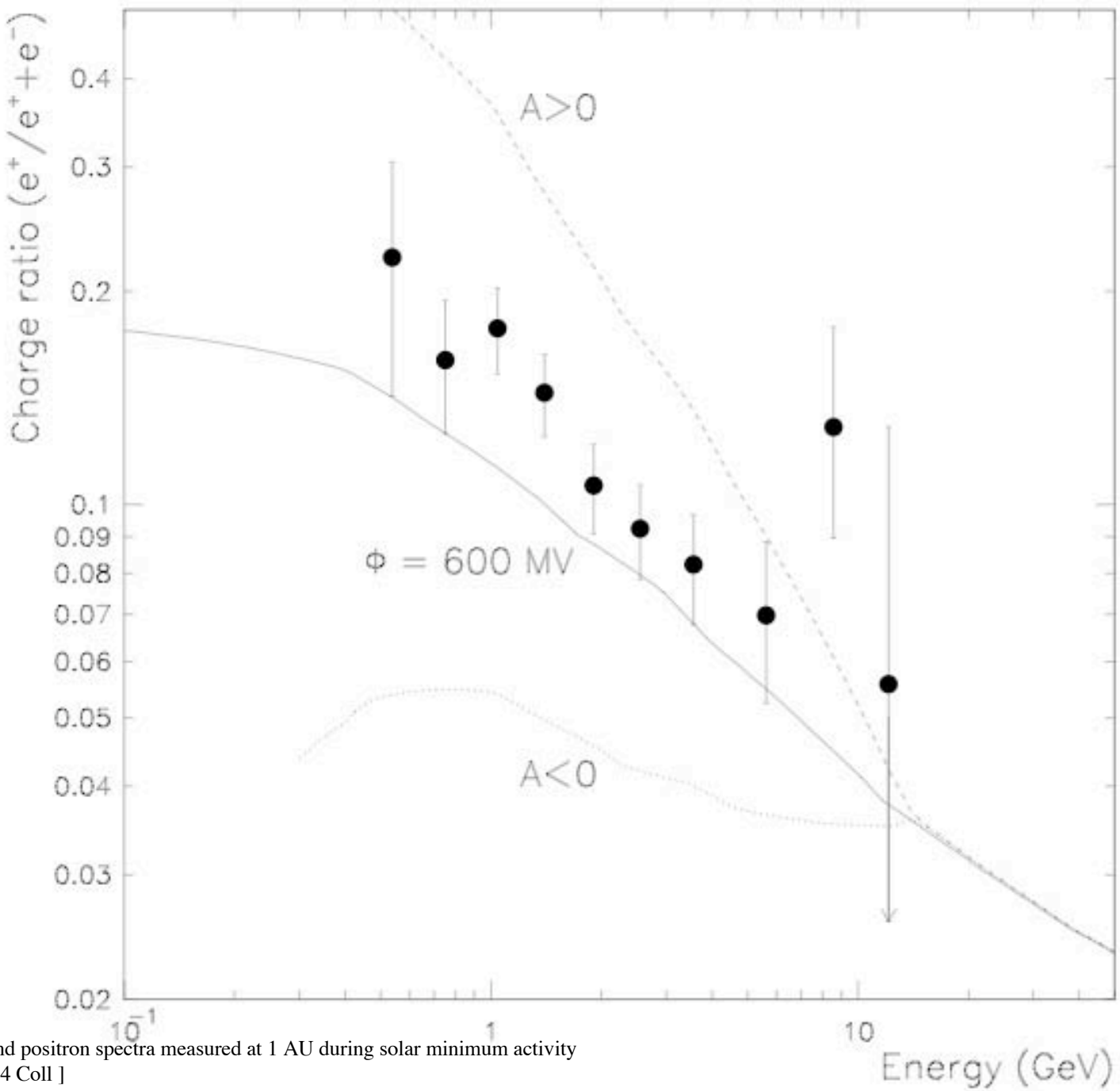




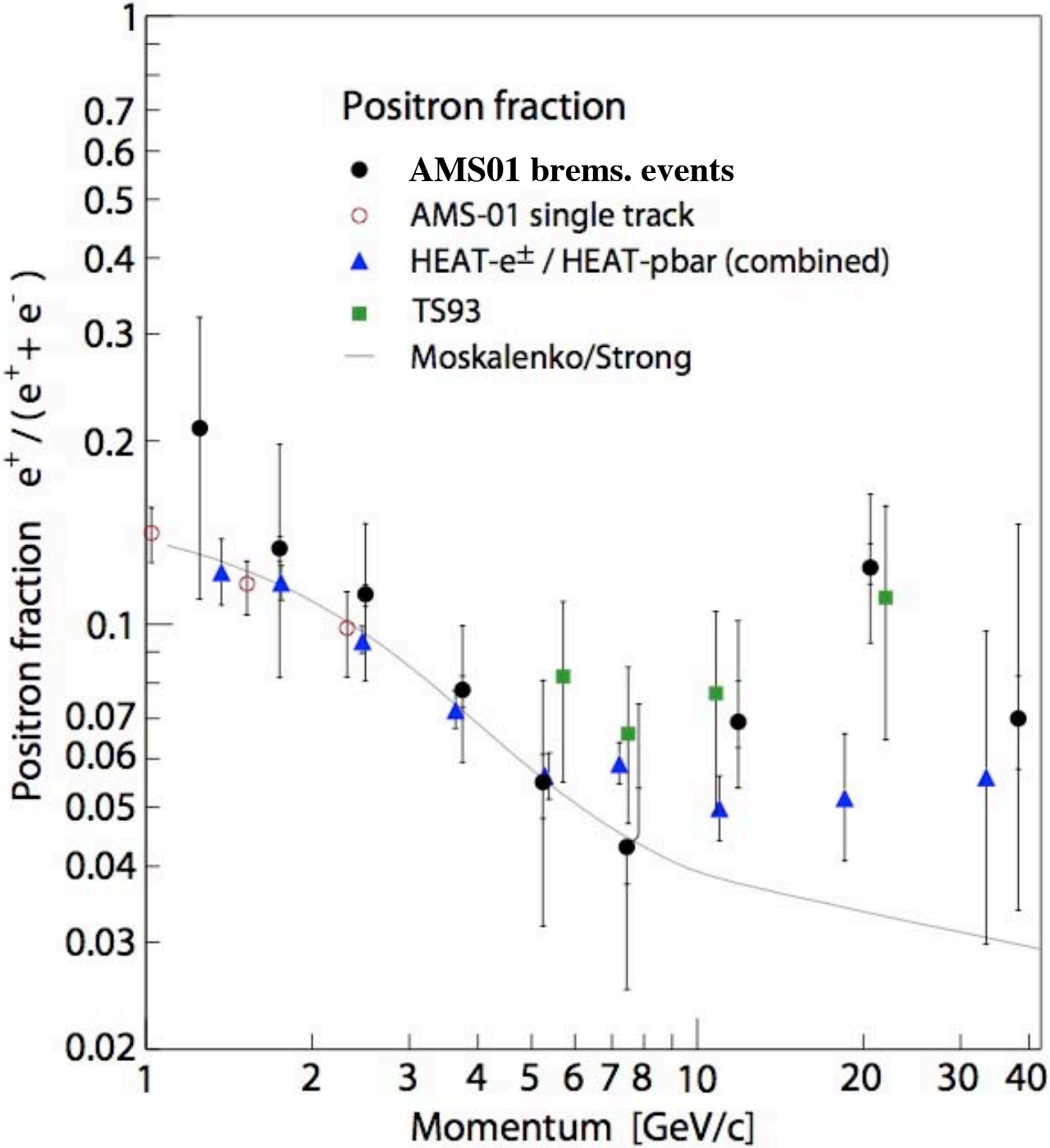
astro-ph/0603796



Measurements of Cosmic-Ray Electrons and Positrons by the WiZard/CAPRICE Collaboration
M.Boezio et al. [CAPRICE98 Collaboration]
Advances in Space Research 27: (4) 669-674 2001 XXVI International Cosmic Ray Conference, OG.1.1.16, Salt Lake City, 1999

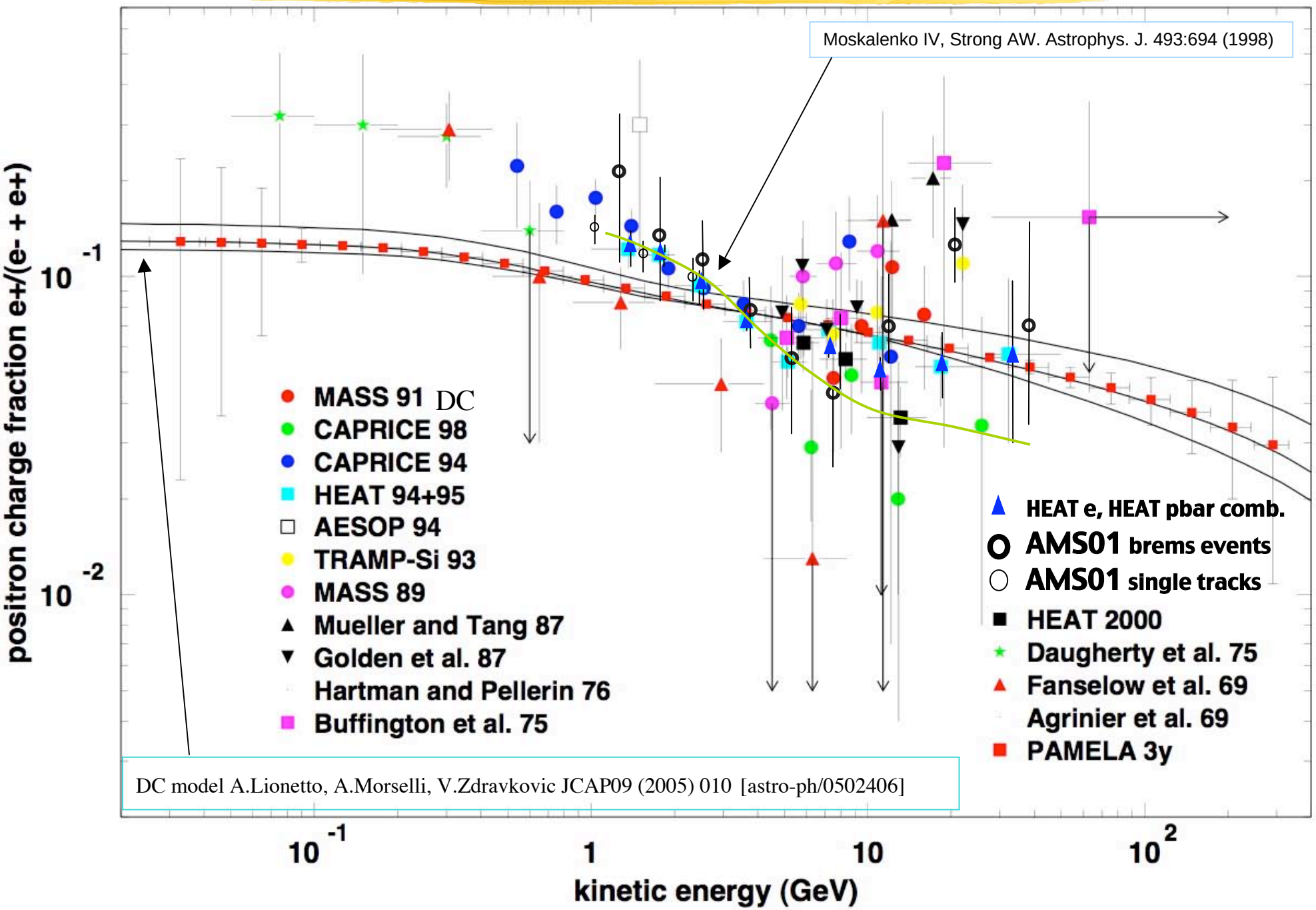


The cosmic ray electron and positron spectra measured at 1 AU during solar minimum activity
M.Boezio et al. [Caprice94 Coll]
The Astrophysical Journal, 532, 653, 2000



AMS 01
PhysLett B 646 2007 145-154
[astro-ph/0703154]

Positron ratio: Experimental situation and PAMELA expectation for DC model



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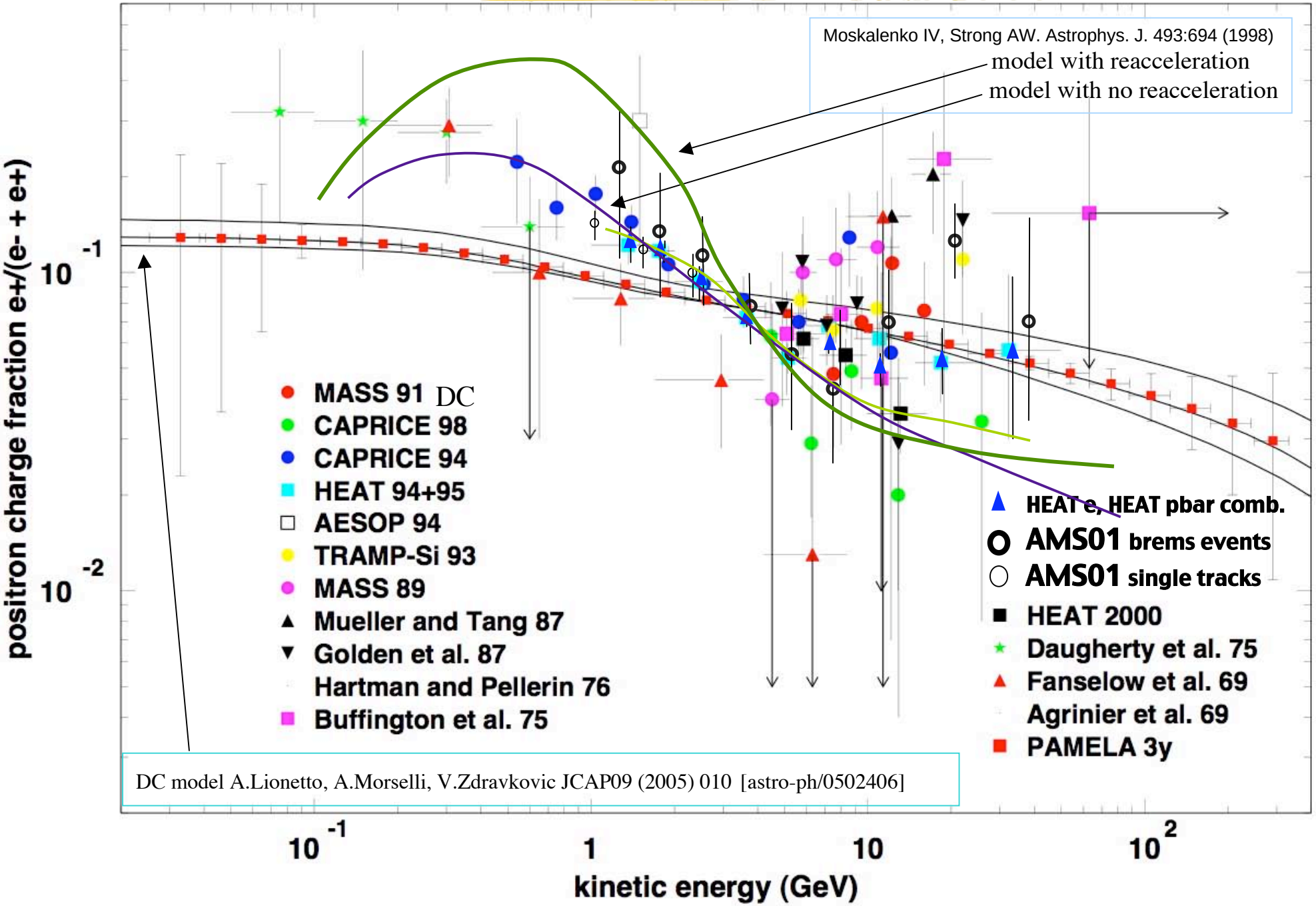

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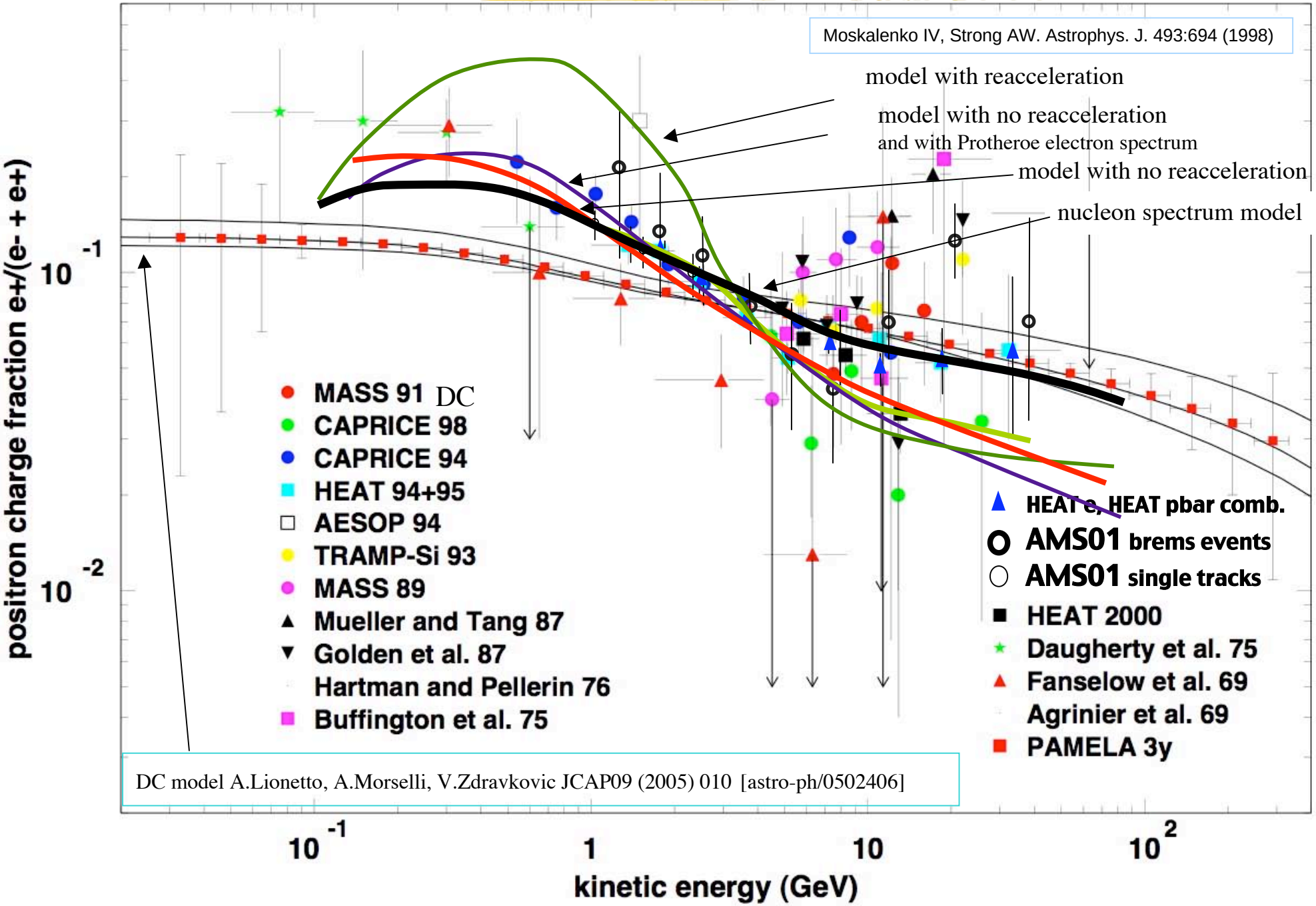

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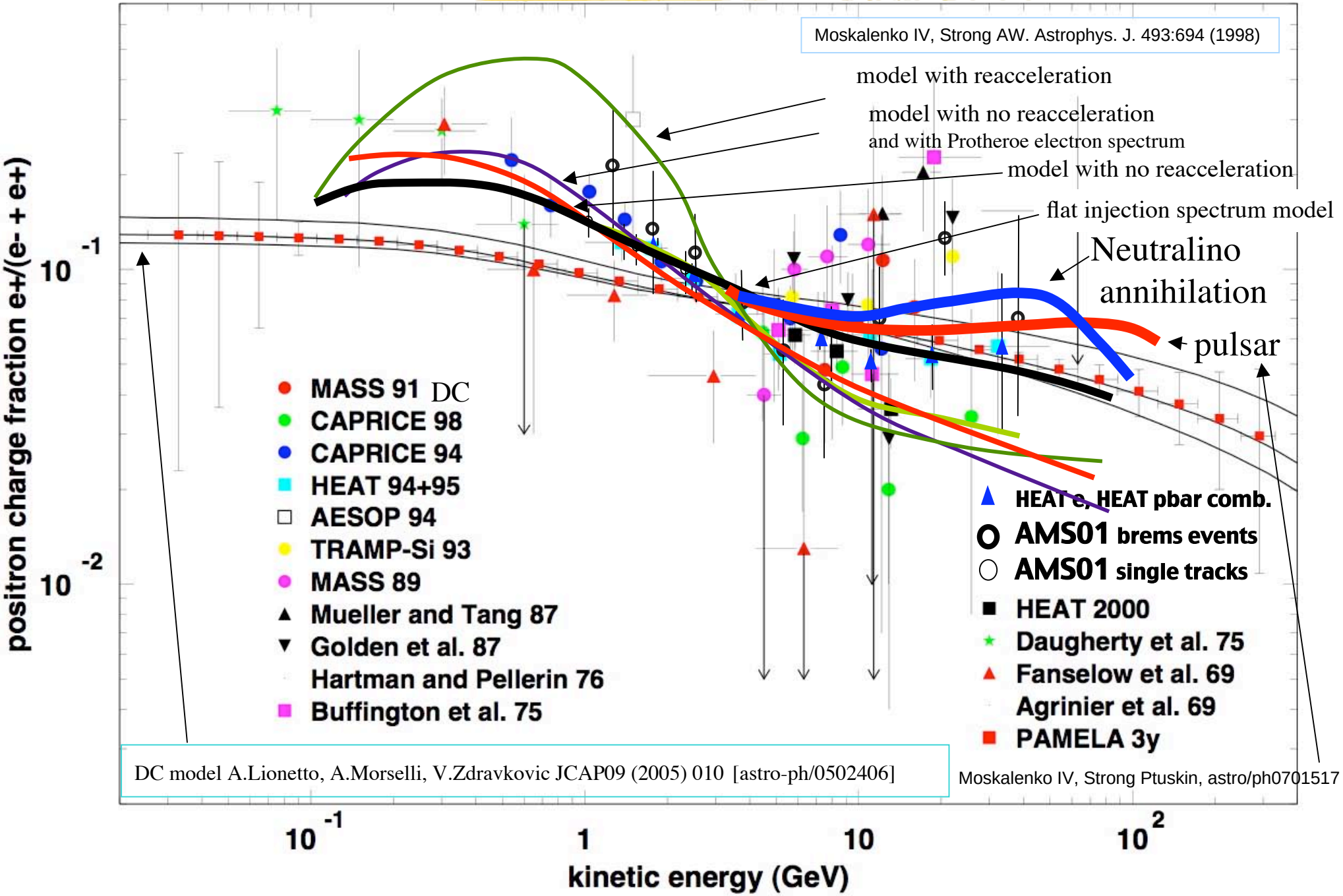
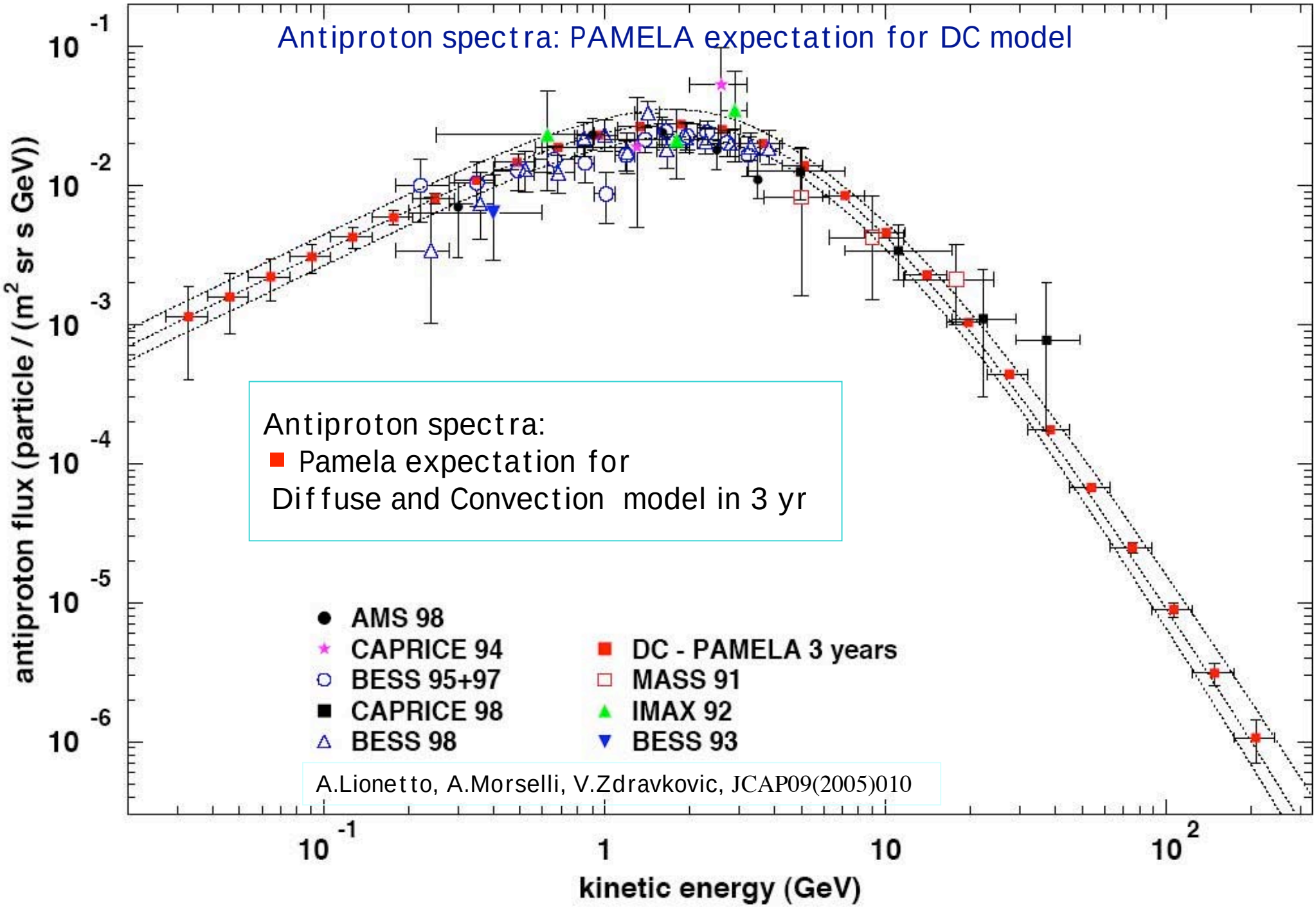



Antiproton spectra: PAMELA expectation for DC model
Antiproton spectra:
Pamela expectation for
Diffuse and Convection model in 3 yr
AMS 98
CAPRICE 94
BESS 95+97
CAPRICE 98
BESS 98
DC - PAMELA 3 years
MASS 91
IMAX 92
BESS 93
A.Lionetto, A.Morselli, V.Zdravkovic, JCAP09(2005)010
antiproton flux (particle / (m2 sr s GeV))
kinetic energy (GeV)

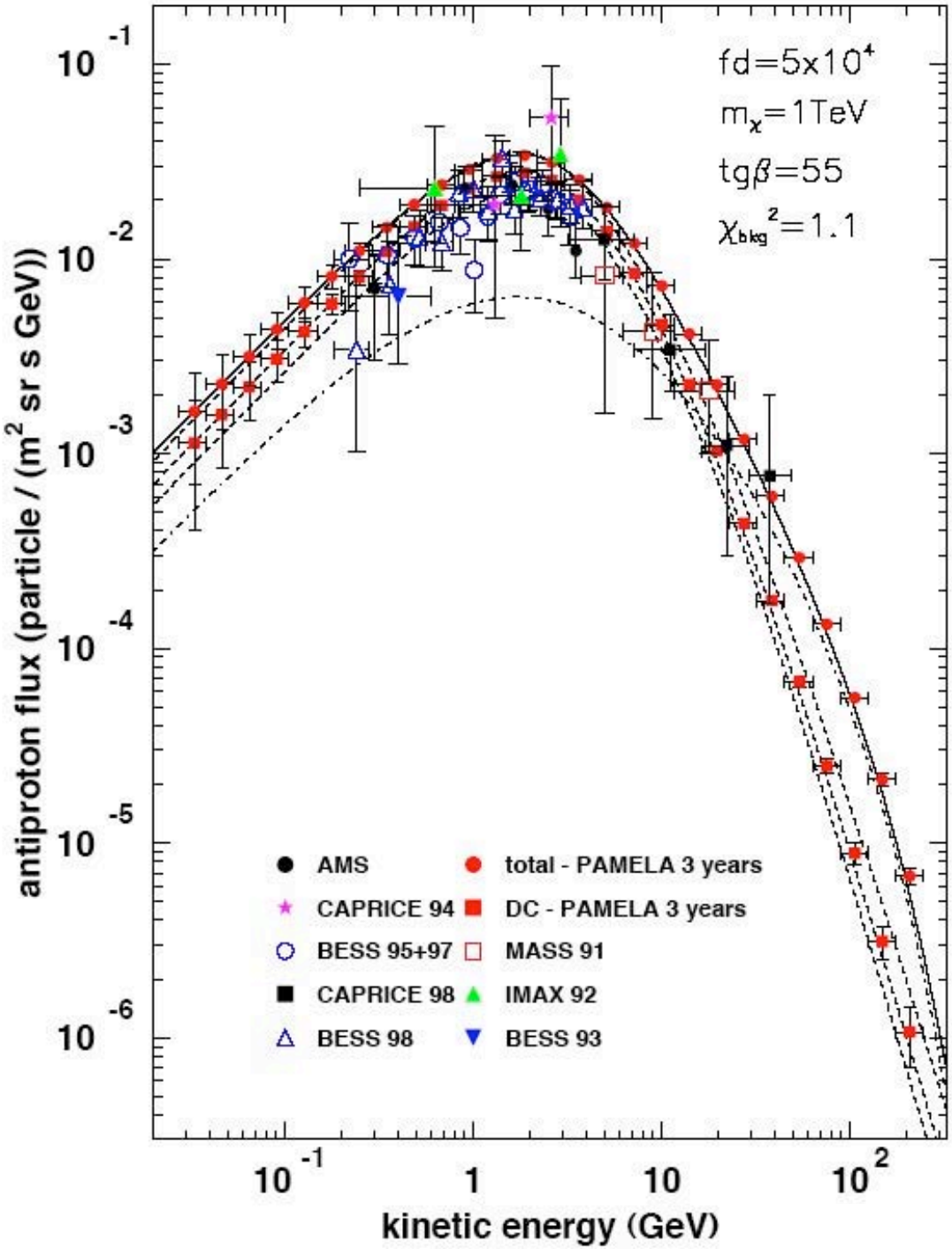
PAMELA:

Cosmic-Ray Antiparticle Measurements: Antiprotons

an example in mSUGRA

fd: Clumpiness factors needed to disentangle a neutralino induced component in the antiproton flux

f = the dark matter fraction concentrated in clumps
d = the overdensity due to a clump with respect to the local halo density



A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]

PAMELA:

Cosmic-Ray Antiparticle Measurements: Antiprotons

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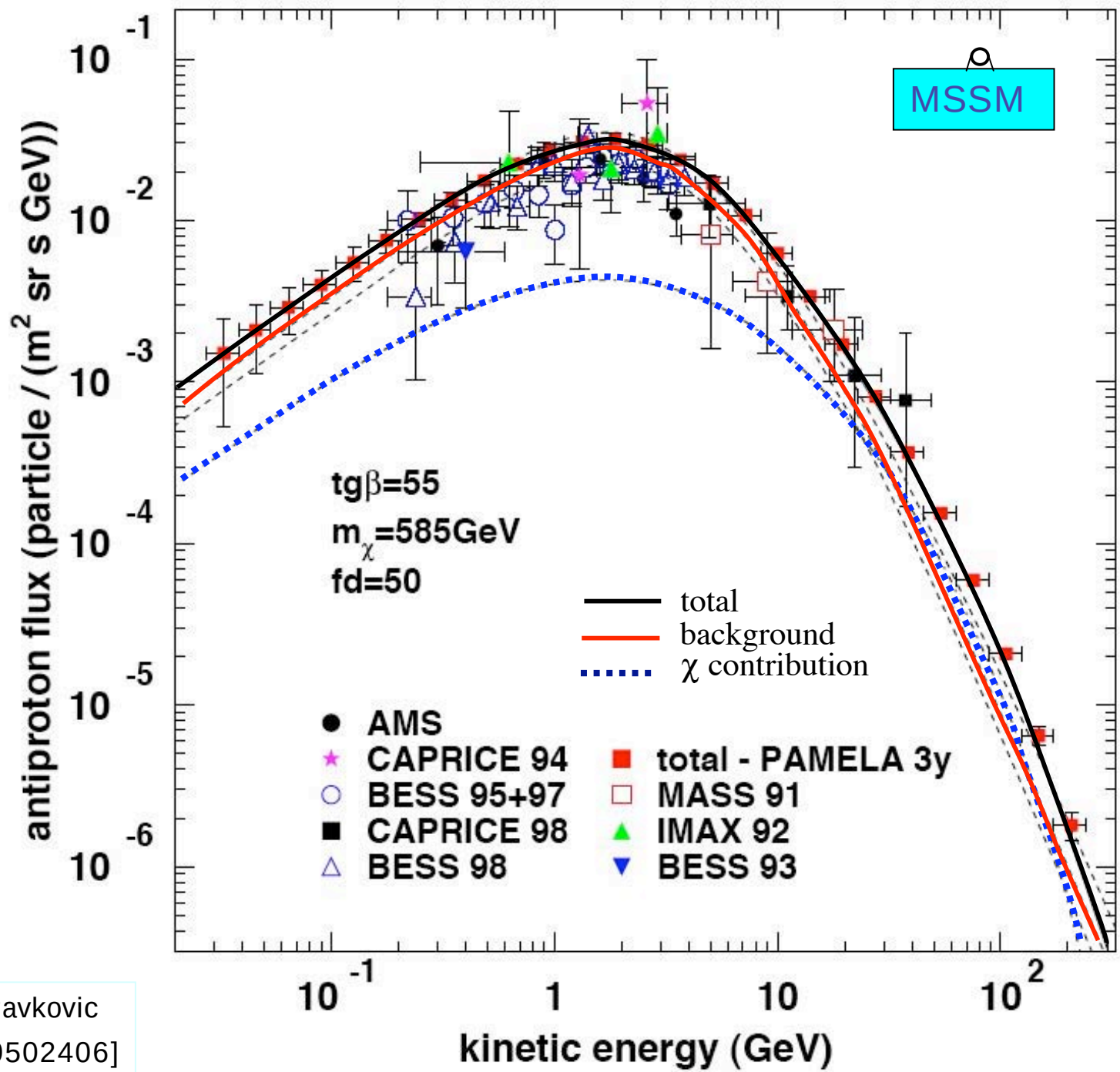
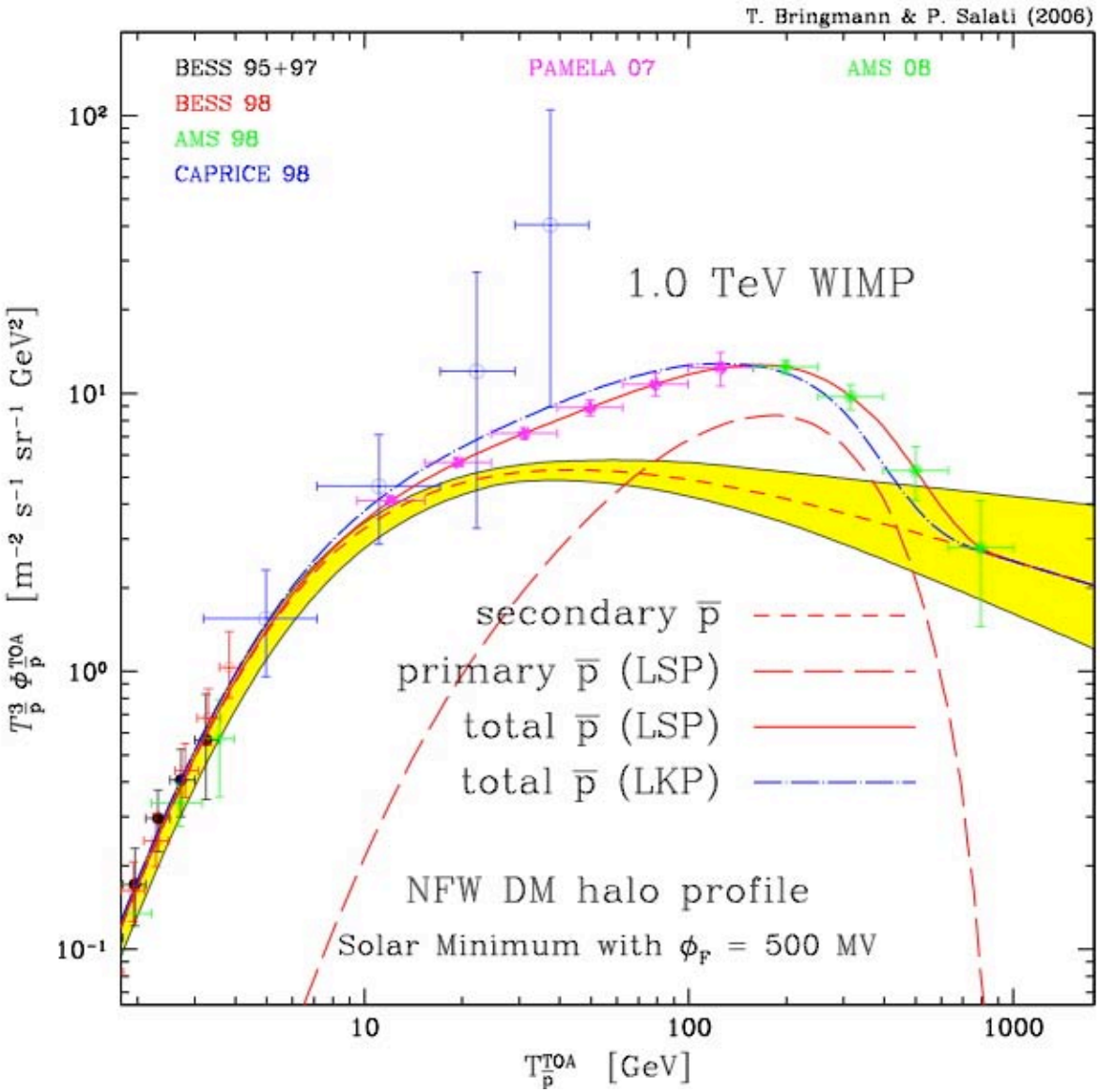


A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]

Antiproton spectra

Torsten Bringmann,
Pierre Salati,
astro/ph 0612514



DM model	m	$\langle\sigma_{\rm ann}v\rangle$	$t\bar{t}$	$b\bar{b}$	$c\bar{c}$	$s\bar{s}$	$u\bar{u}$	$d\bar{d}$	ZZ	W^+W^-	HH	gg	Boost factor
LSP1.0	1.0	0.46	-	-	-	-	-	-	-	100	-	-	330
LKP1.0	1.0	1.60	10.9	0.7	11.1	0.7	11.1	0.7	0.5	1.0	0.5	0.5	270

Supersymmetry introduces free parameters:

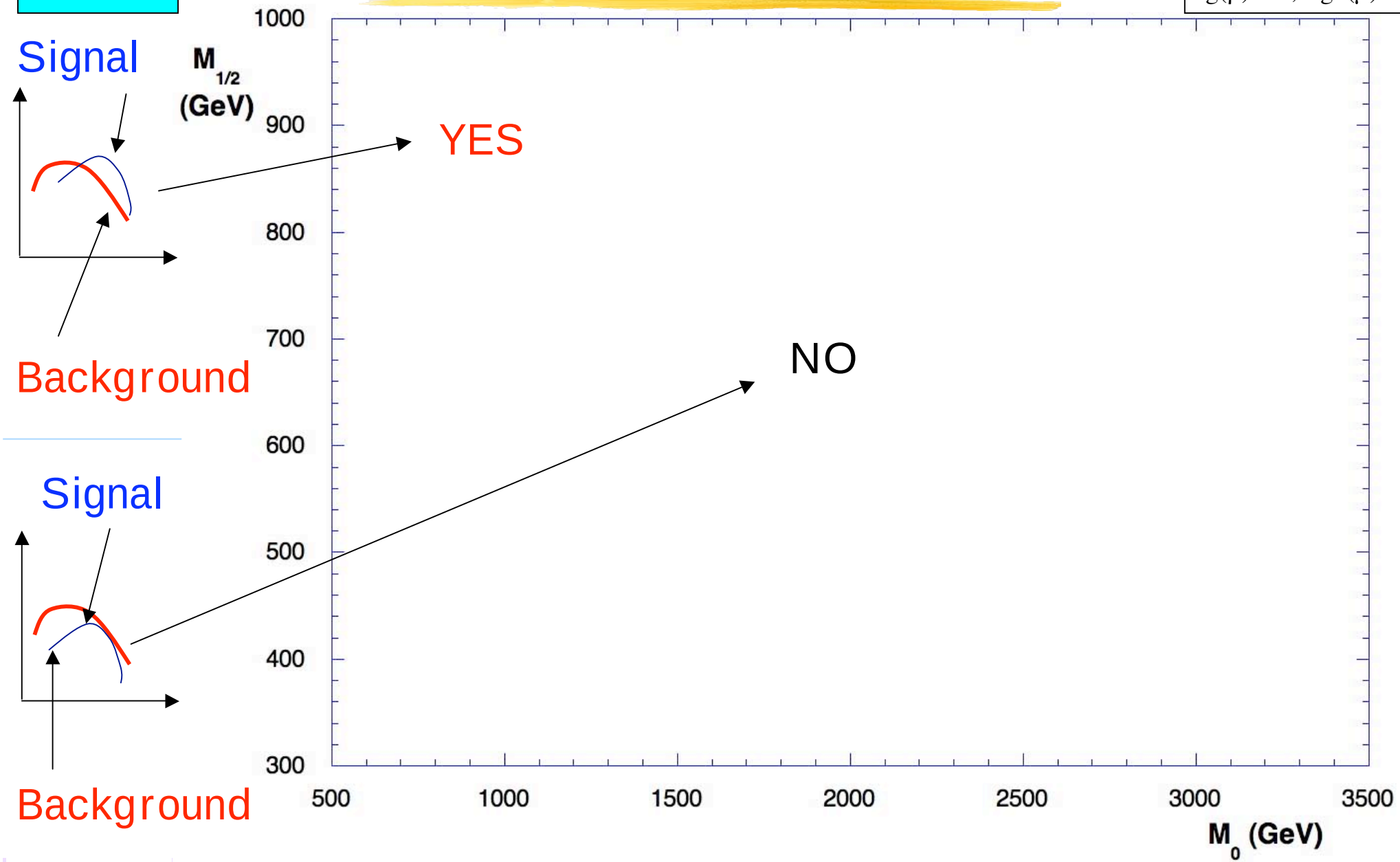
In the MSSM, with Grand Unification assumptions, the masses and couplings of the SUSY particles as well as their production cross sections, are entirely described once 5 parameters are fixed:

- $M_{1/2}$ the common mass of supersymmetric partners of gauge fields (gauginos)
- m_0 the common mass for scalar fermions at the GUT scale
- μ the higgs mixing parameters that appears in the neutralino and chargino mass matrices
- A is the proportionality factor between the supersymmetry breaking trilinear couplings and theYukawa couplings
- tang $\beta = v_2 / v_1 = \langle H_2 \rangle / \langle H_1 \rangle$ the ratio between the two vacuum expectation values of the Higgs fields

mSUGRA

Signal and Background are separated ?

tg(β)=55, sign(μ)=+1



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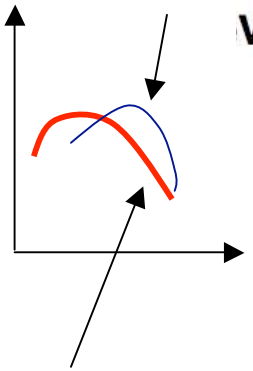
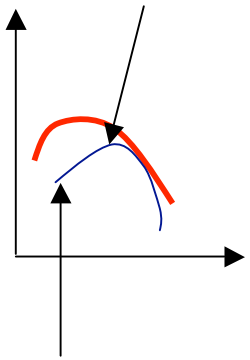
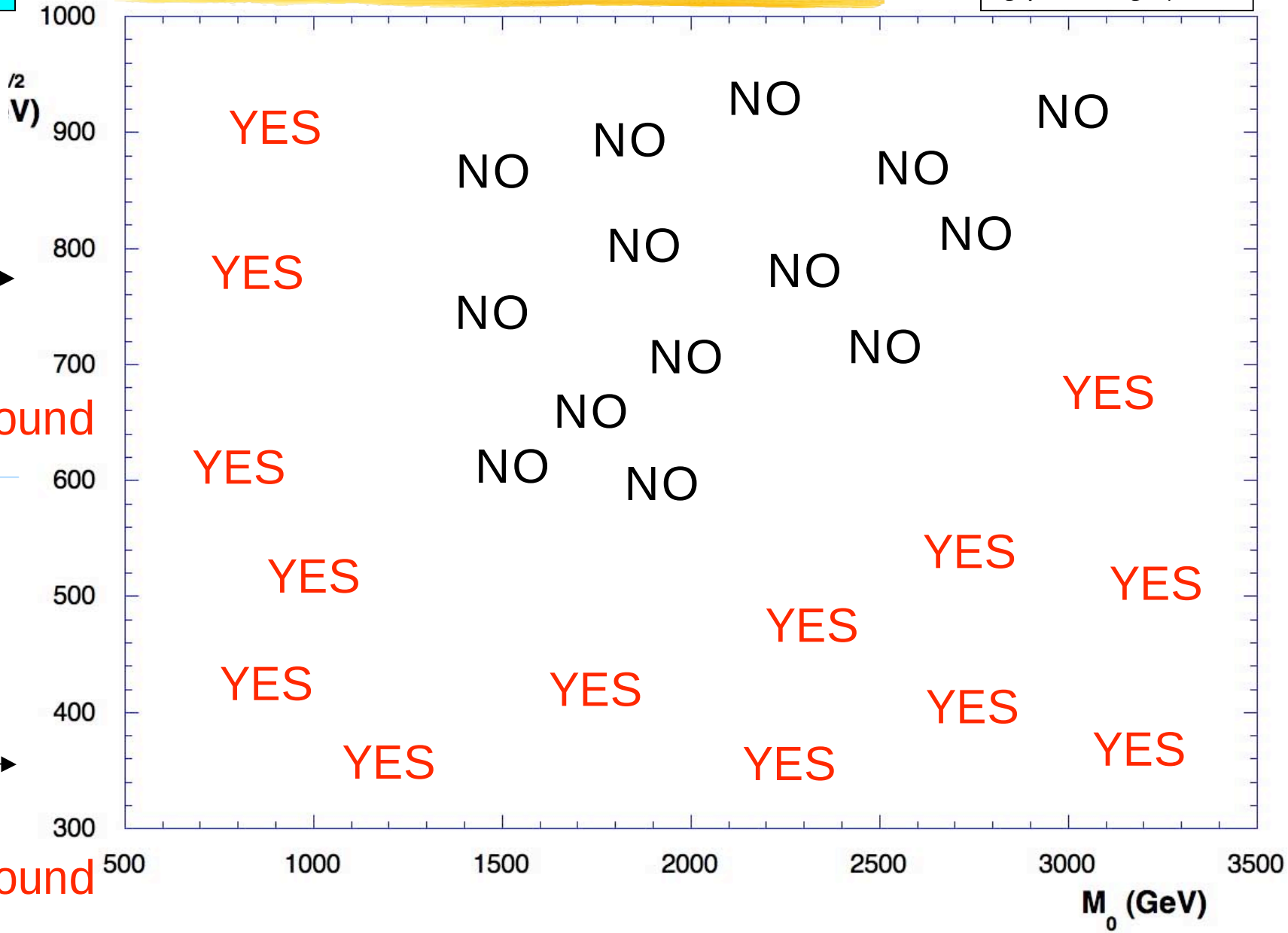


Background

Signal



Background



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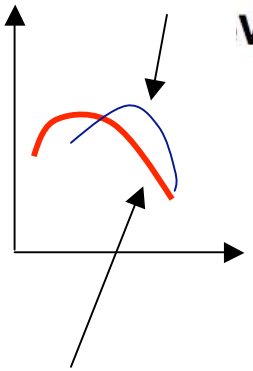

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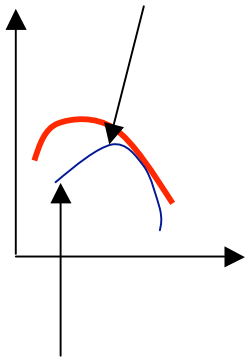

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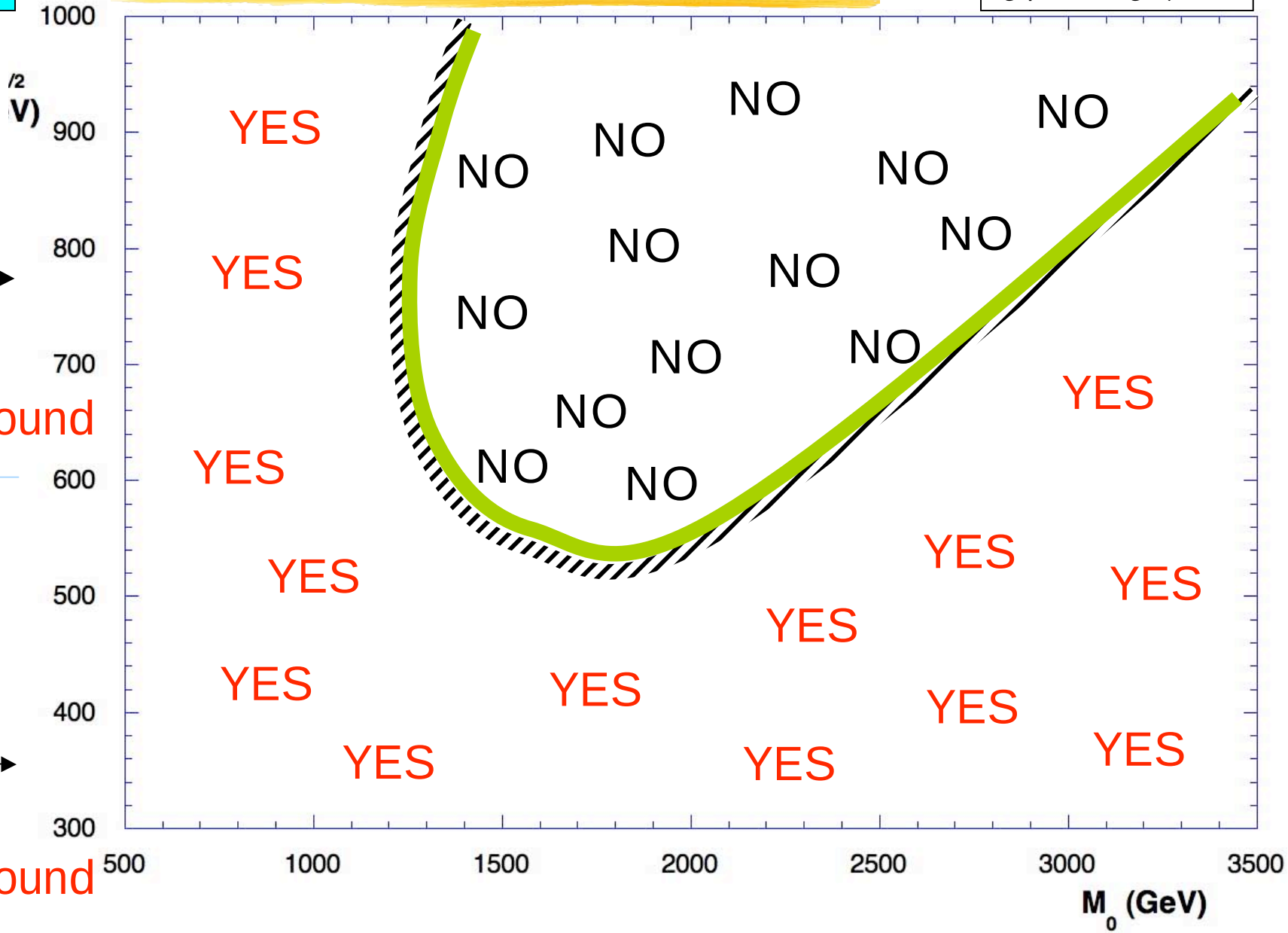
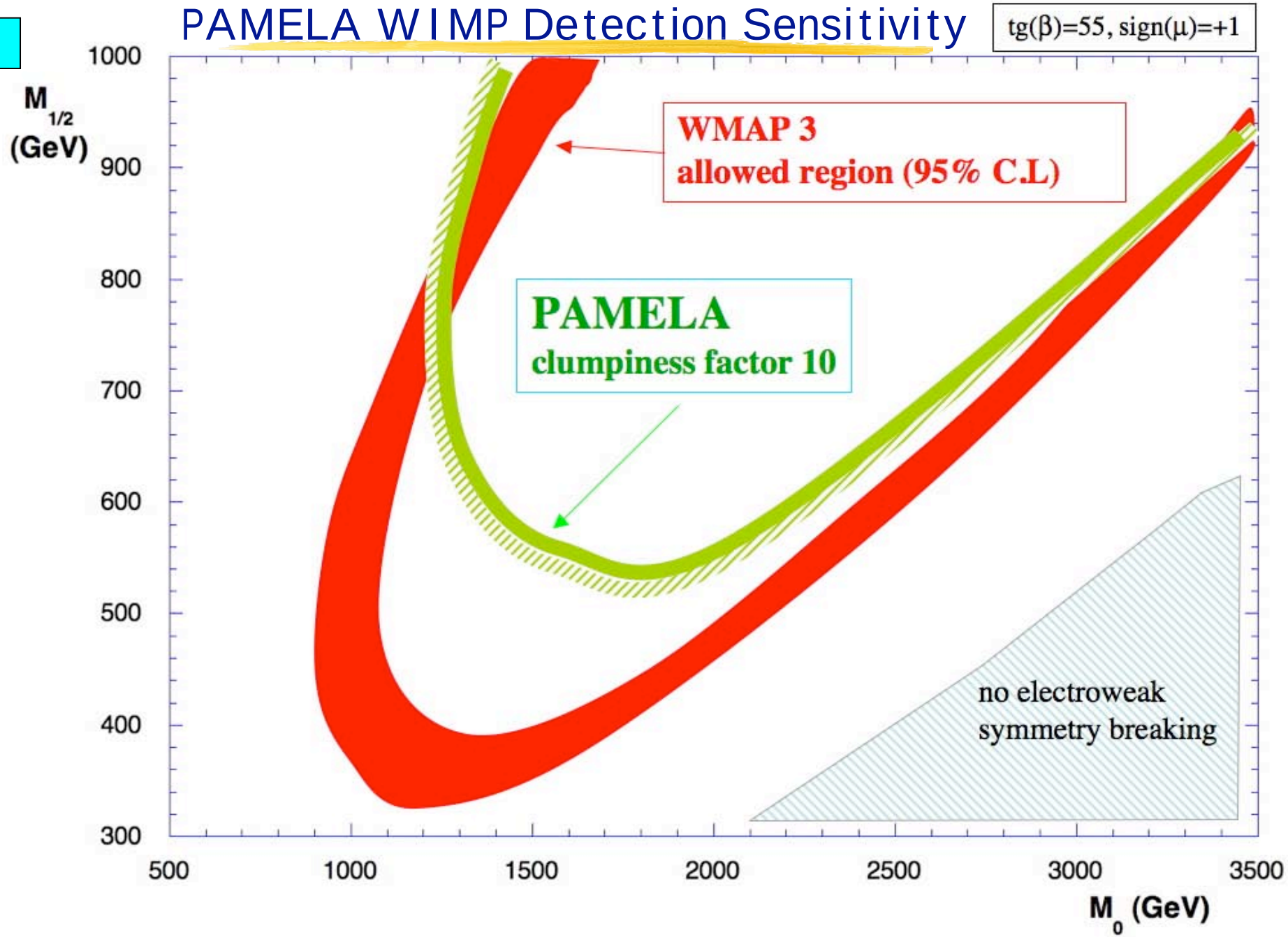
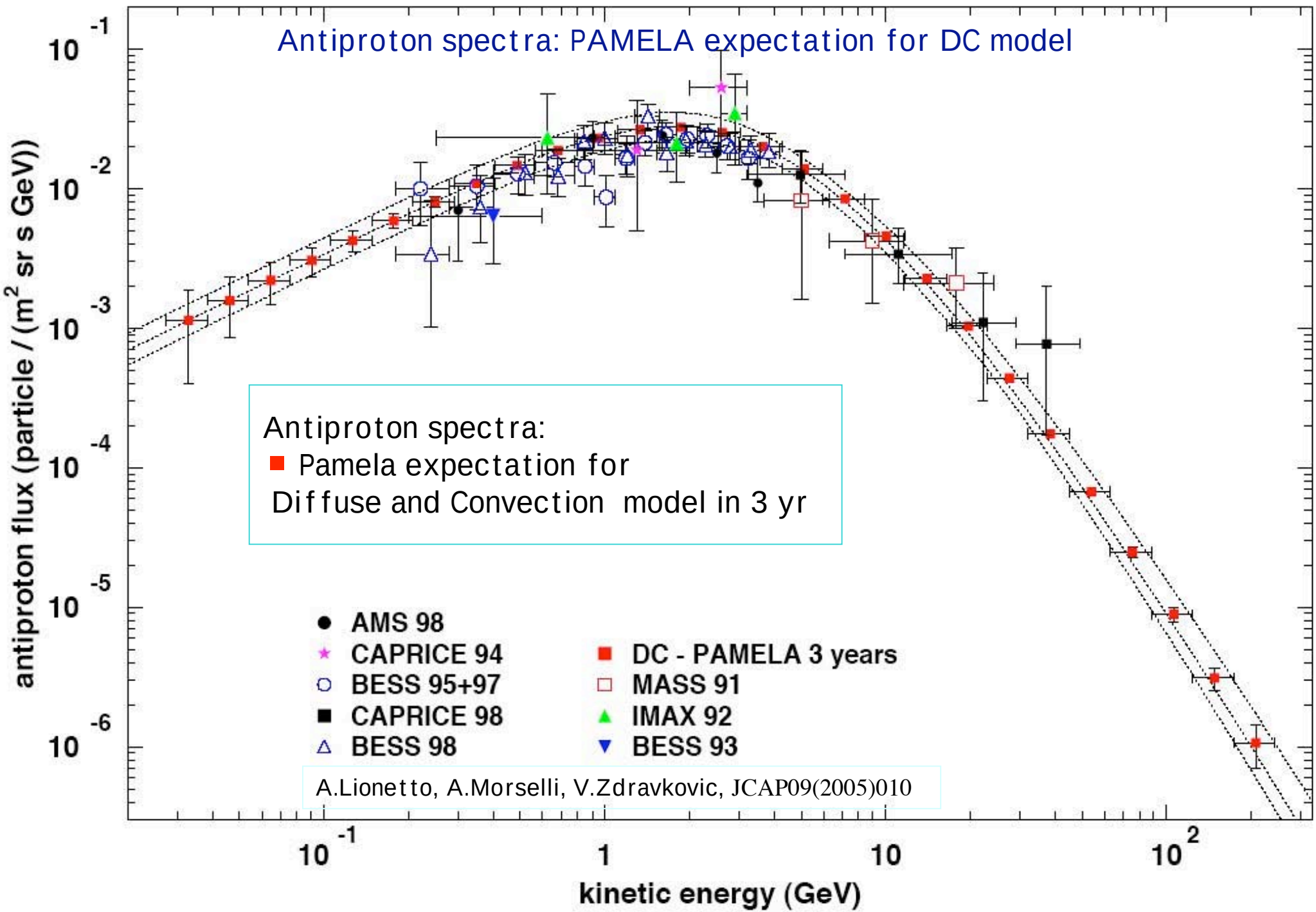


mSUGRA

PAMELA WIMP Detection Sensitivity

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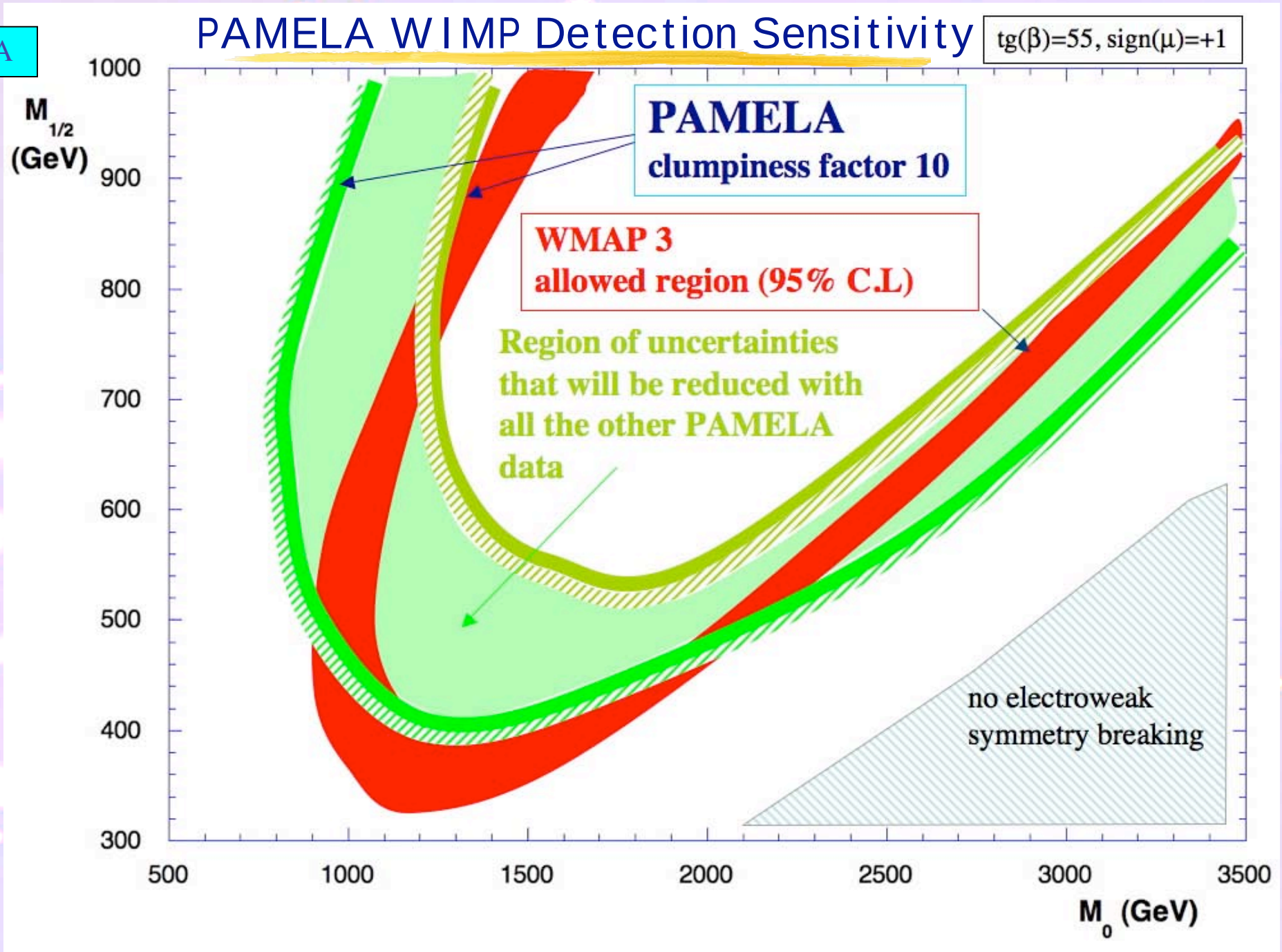
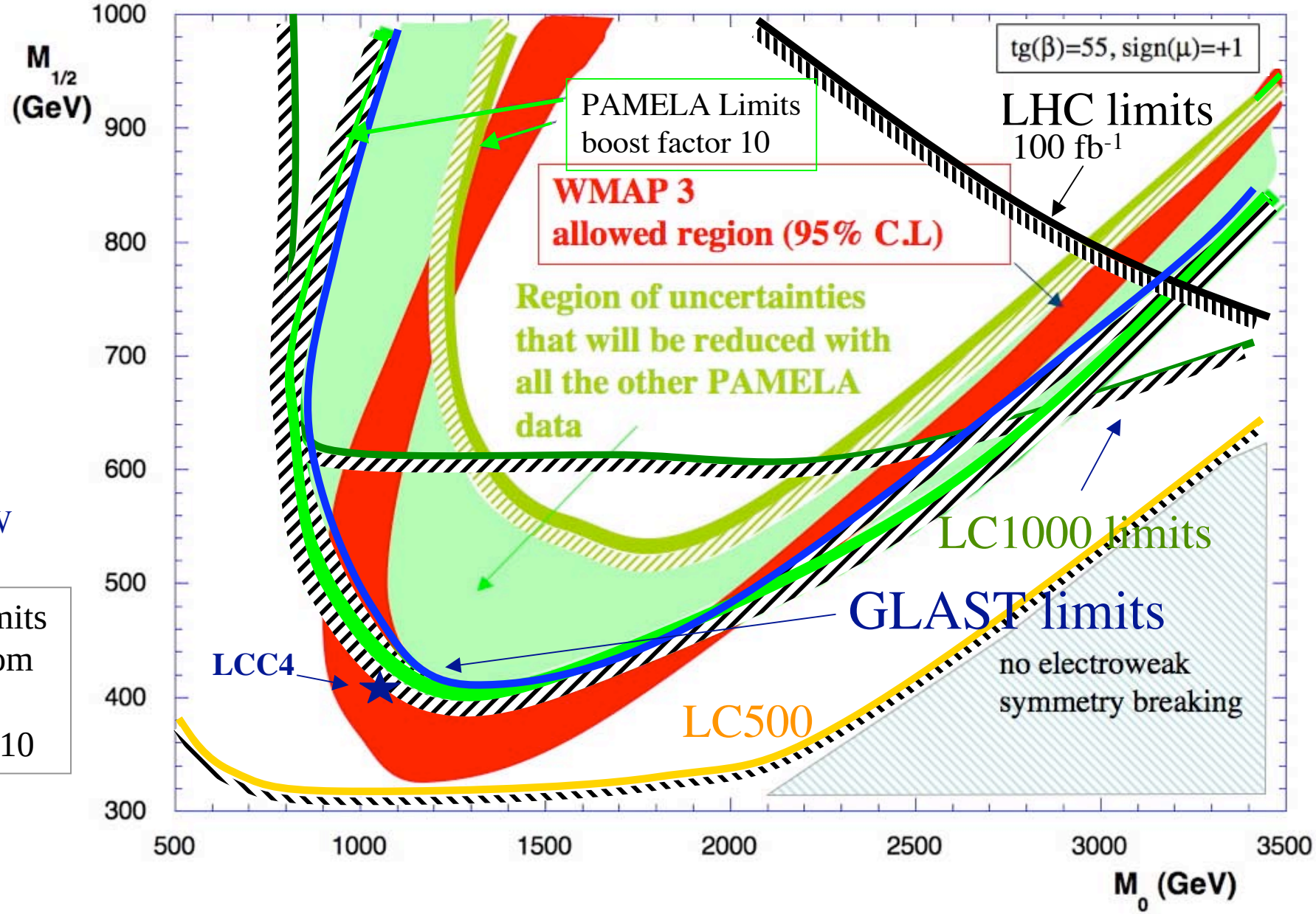


mSUGRA

GLAST, PAMELA, LHC, LC Sensitivities to Dark Matter Search

Sensitivity plot for 5 years observation of mSUGRA for GLAST for tg(b)=55 and for other experiments. GLAST 3σ sensitivity is shown at the blue line and below for truncated NFW halo profile

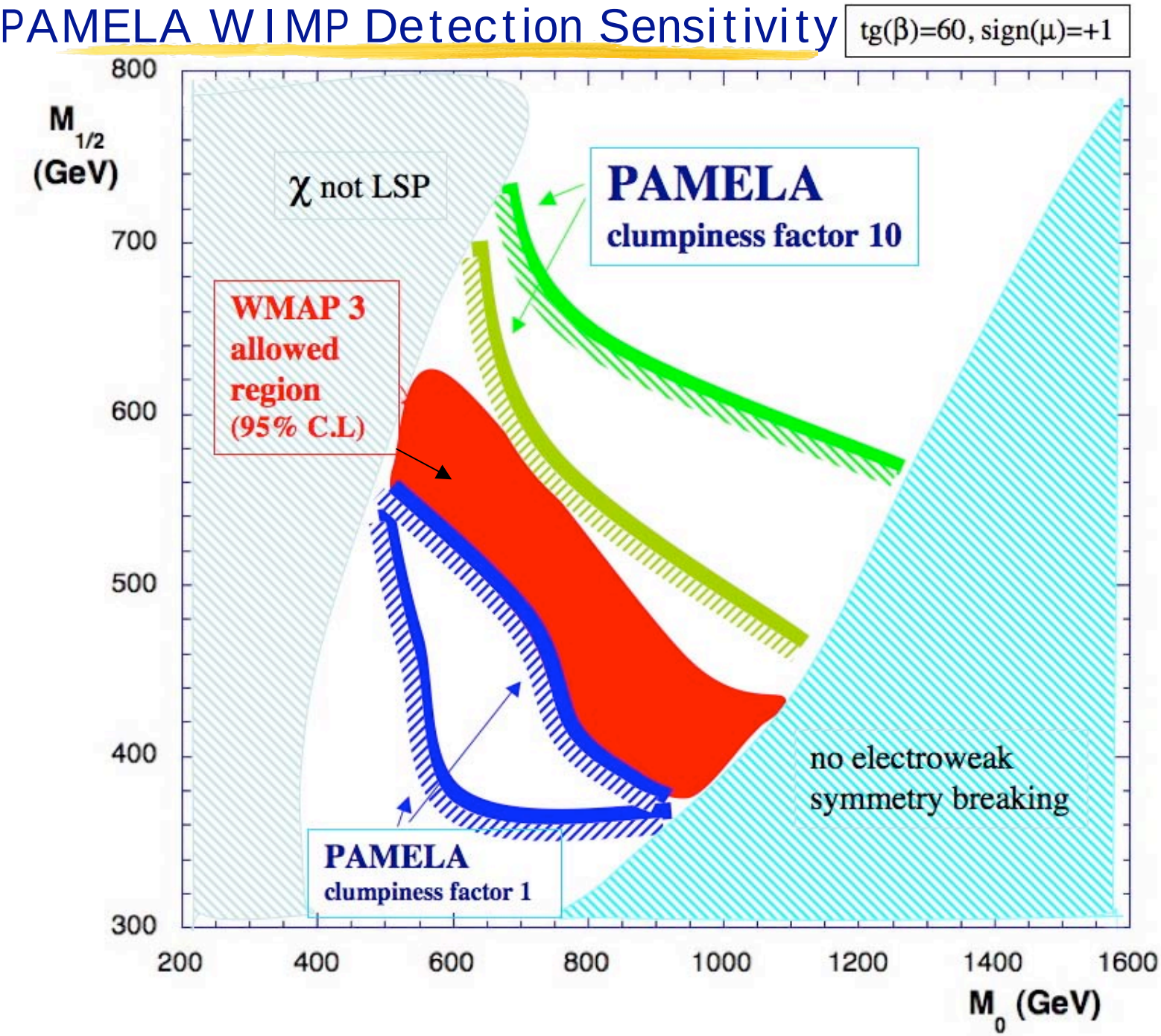
accelerator limits @ 100 fb^{-1} from H.Baer et al., hep-ph/0405210



mSUGRA

PAMELA WIMP Detection Sensitivity

larger values of tg(B) gives larger signals both in antiprotons and gammas



Conclusion

- from 15 June 2006 PAMELA is in the sky !

- Will give strong constraints on propagation parameters.

- Discovery Potential for Supersymmetry

- End 2007 : GLAST will be launched from Kennedy Space Flight Center

- Complementary Discovery Potential for Supersymmetry

- Both searches complementary to LHC and Direct Search

Roma International Conferenze on Astro-Particle physics

RICAP'07

University "La Sapienza and INFN

Roma, Italy

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Physicists by these institutions are deeply involved in major experiments on Astro-Particle physics, (AGILE, AMS, ANTARES, ARGO, Auger, GLAST, NEMO, PAMELA, ...) and in deep and fruitful theoretical speculations.

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