PAMELA PROTON SPECTRA VS. NM COUNT RATES (2006-2014)

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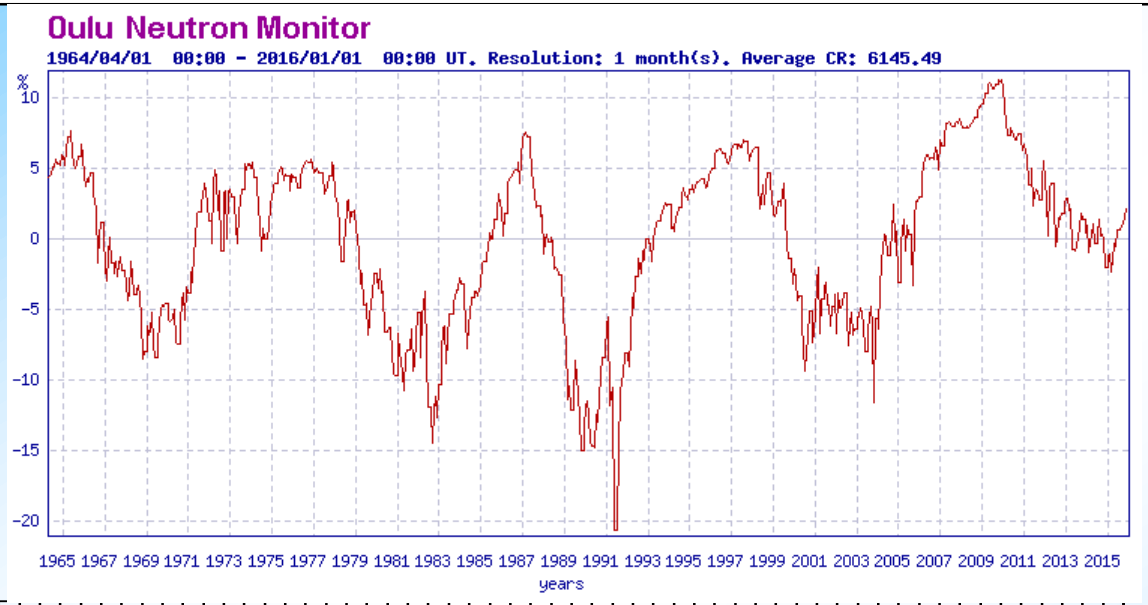
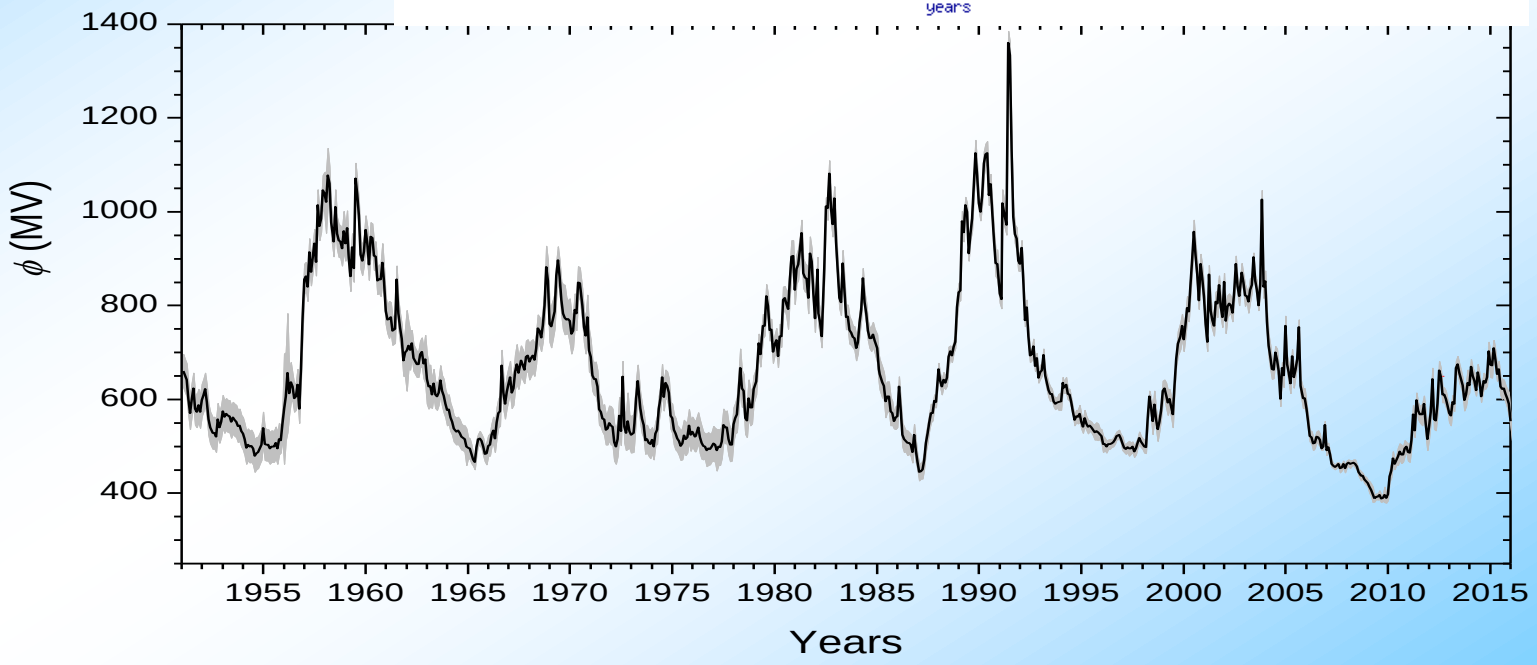
NM data vs. GCR modulation



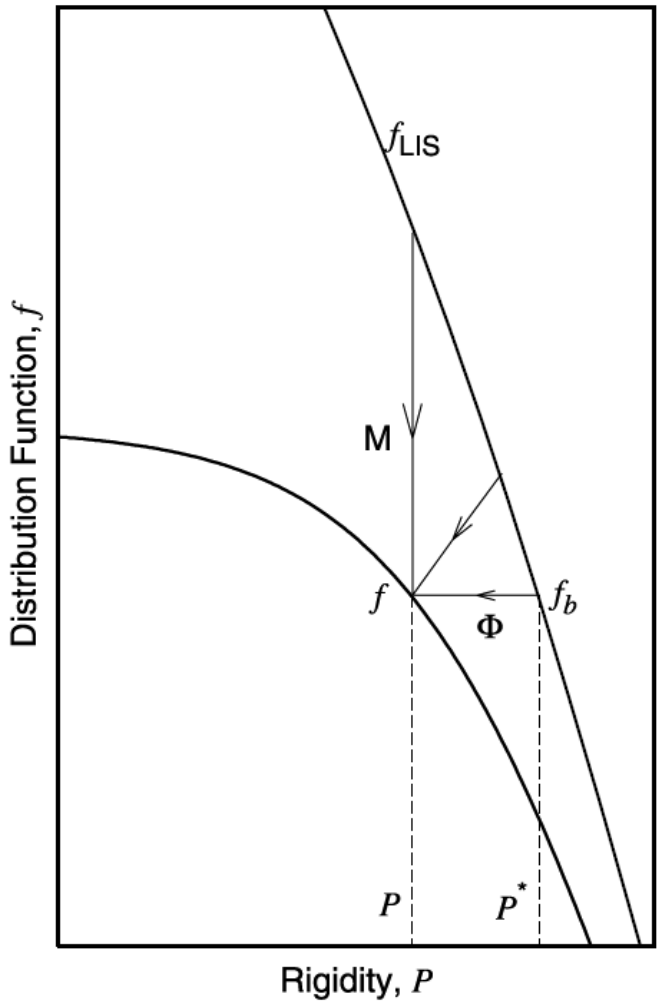


Force-field approximation

Under some (over)simplifying assumptions,

$$\frac{\partial f}{\partial r} + \frac{VP}{3\kappa} \cdot \frac{\partial f}{\partial P} = 0$$

$j=P^2 f \rightarrow j/P^2(T,1\mathrm{AU}) = j/P^2(T+\Phi,\mathrm{LIS})$



Analytical solution in the form of characteristic curves can be obtained

$$j_{1\mathrm{AU}}(T) = j_{LIM}(T+\Phi)\frac{T(T+2T_o)}{(T+\Phi)(T+\Phi+2T_o)}$$

$$\Phi = \frac{V(R-1)}{3\kappa_o}$$

is the modulation strength (in MV)

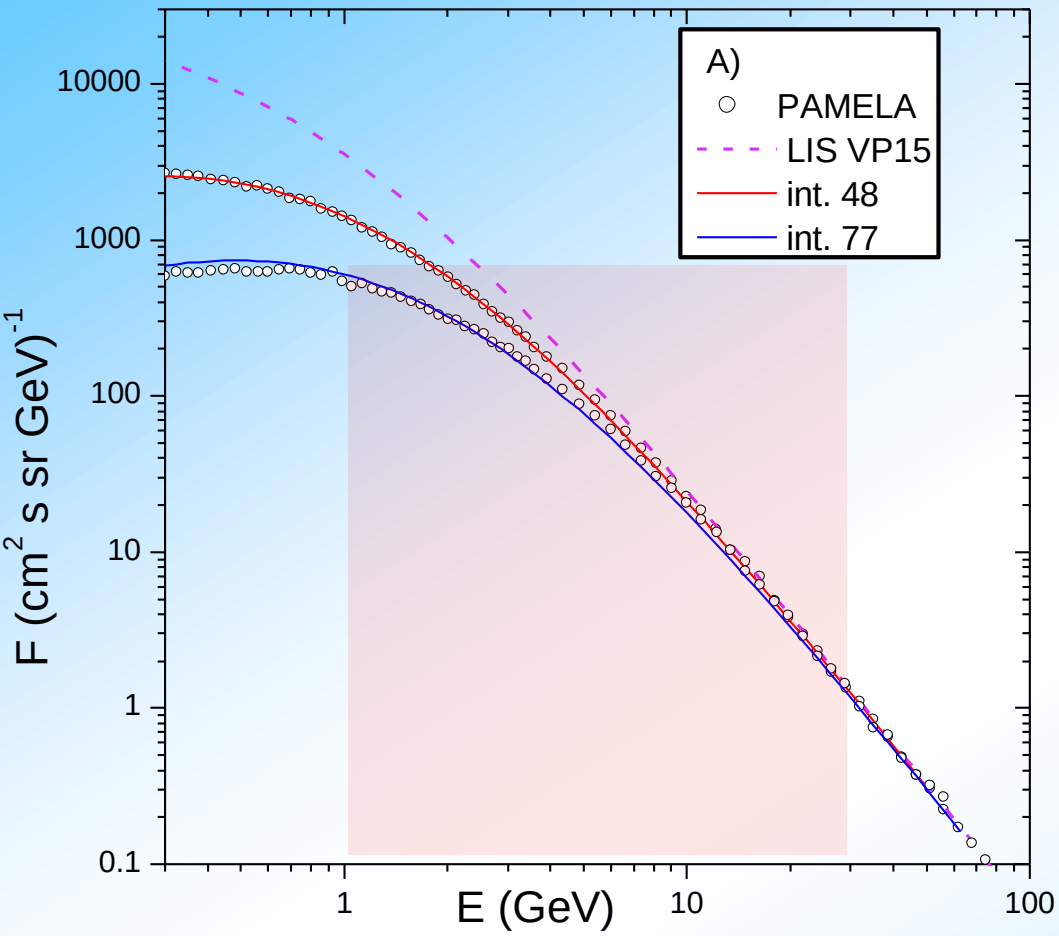
variable parameter

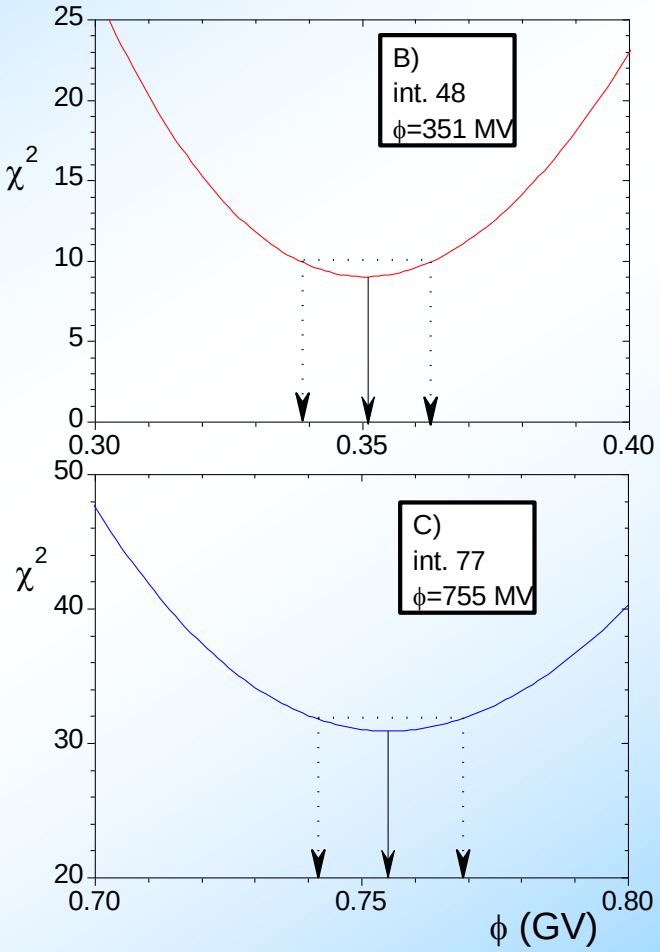
and

Vos & Potgieter, 2015

$$J_{\mathrm{LIS}} = 2.7 \cdot 10^3 \frac{T^{1.12}}{\beta^2}\left(\frac{T+0.67}{1.67}\right)^{-3.93}$$

Fit of the data

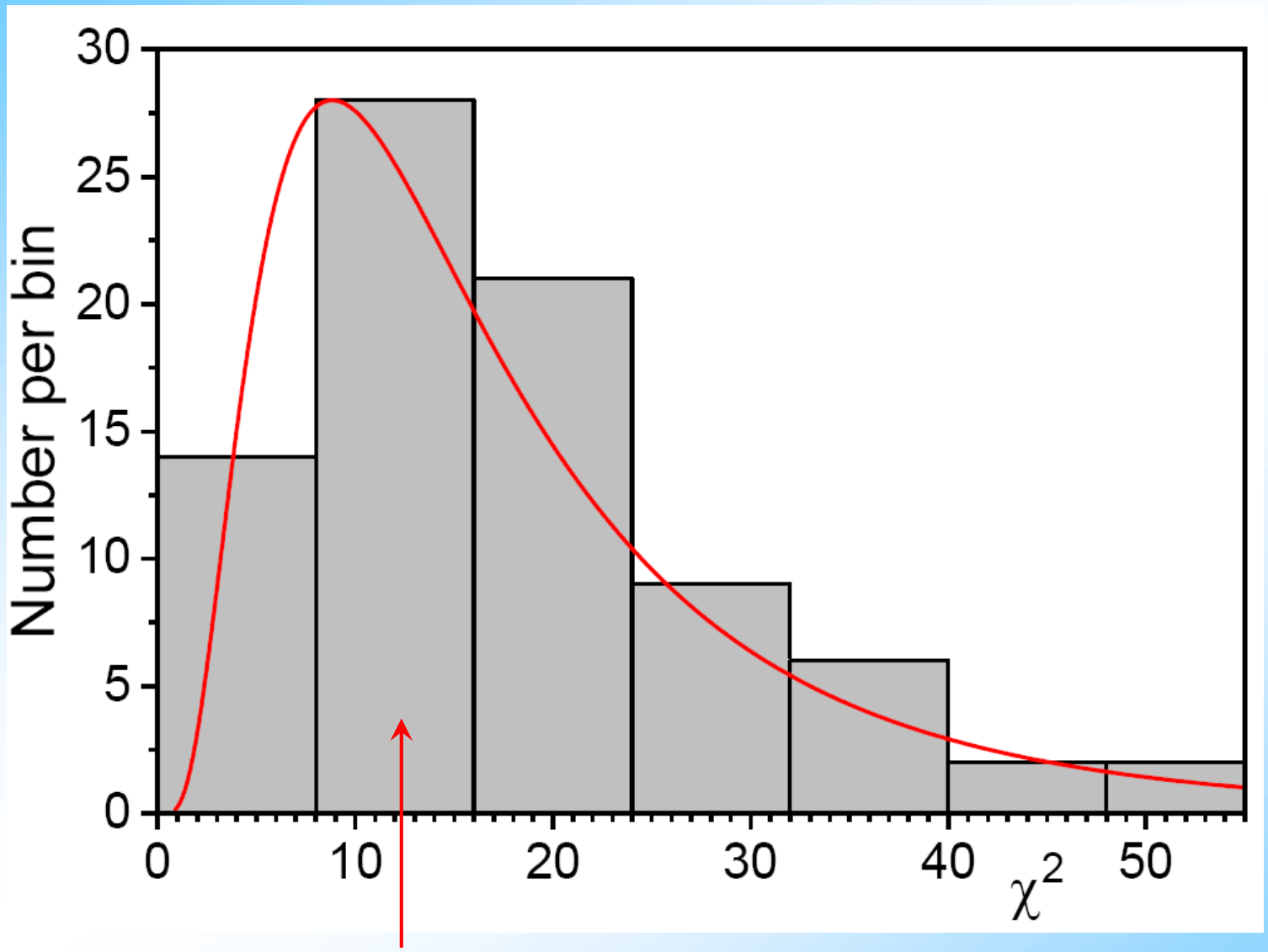




$$\chi^2 = \sum_j \left(\frac{J_{\mathrm{mod}}(T_j) - J_{\mathrm{meas}}(T_j)}{\sigma_j} \right)^2$$

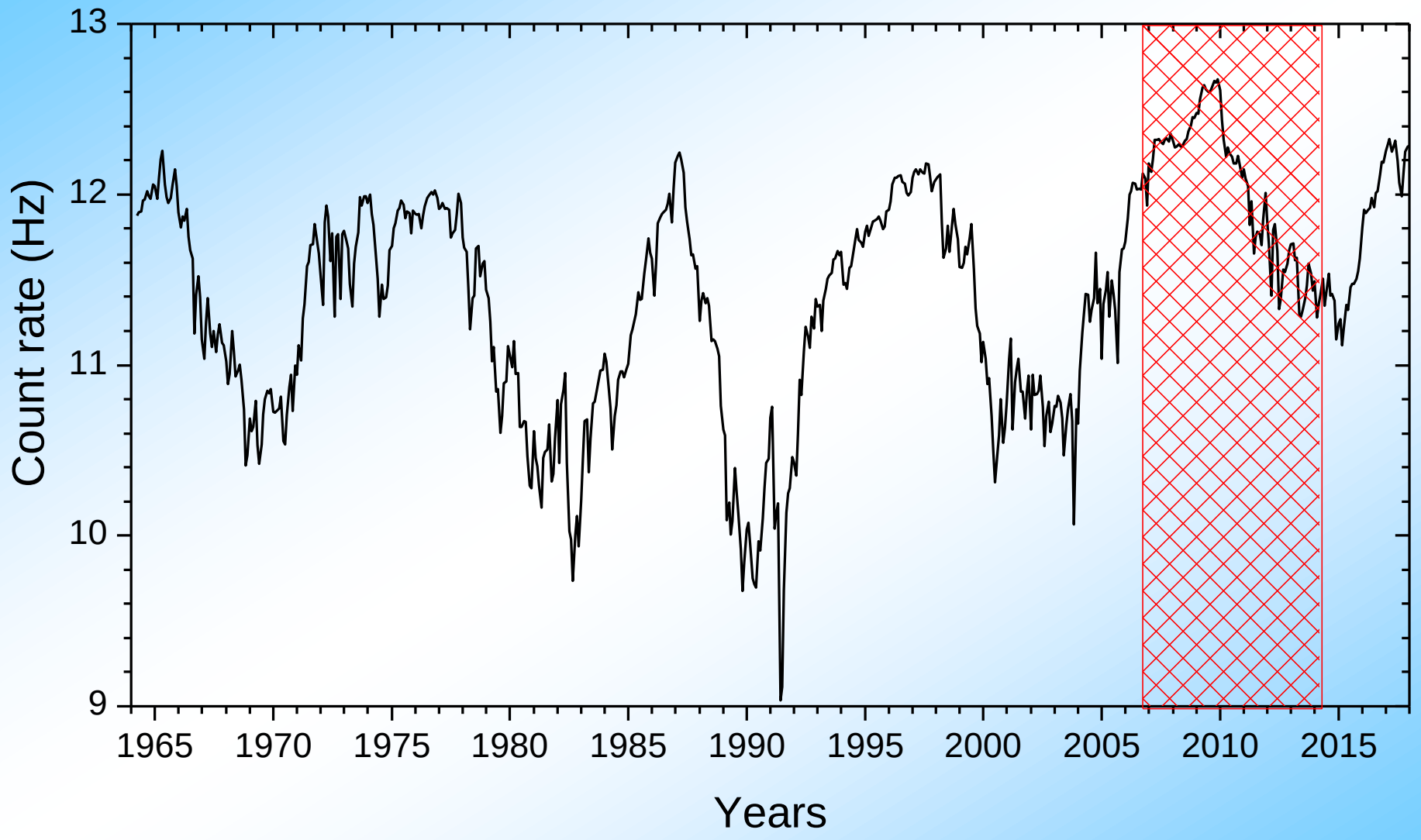
Fit by χ^2 in the range 1–30 GeV (n=42), which is the effective range of NM response.

Distribution of χ^2_{min}

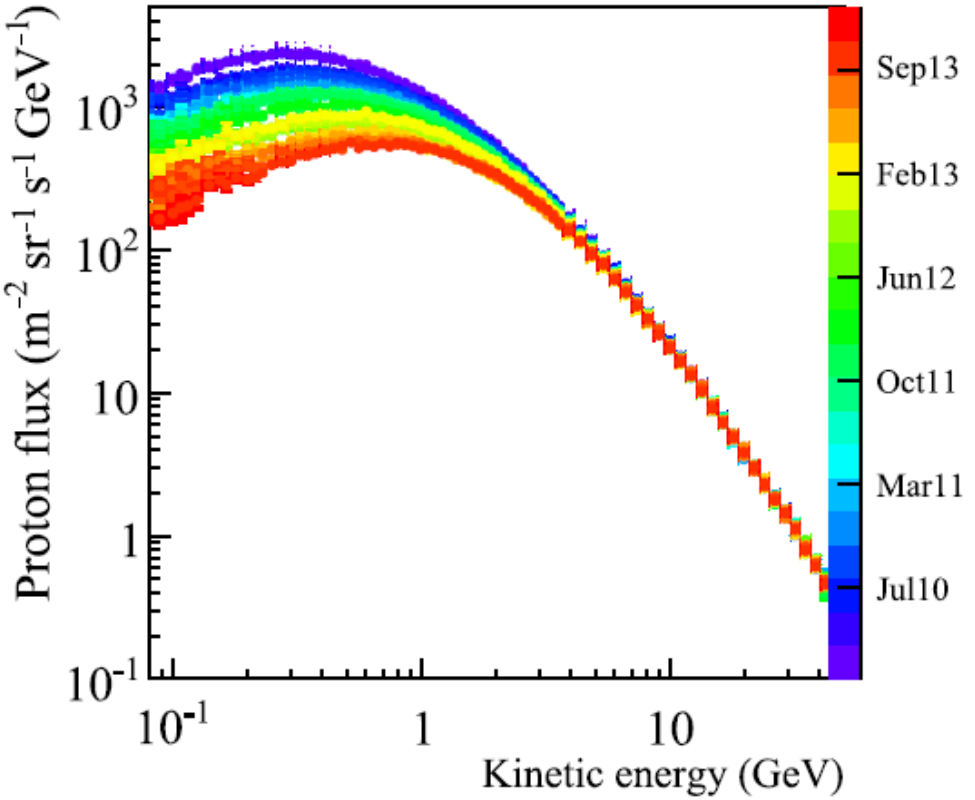


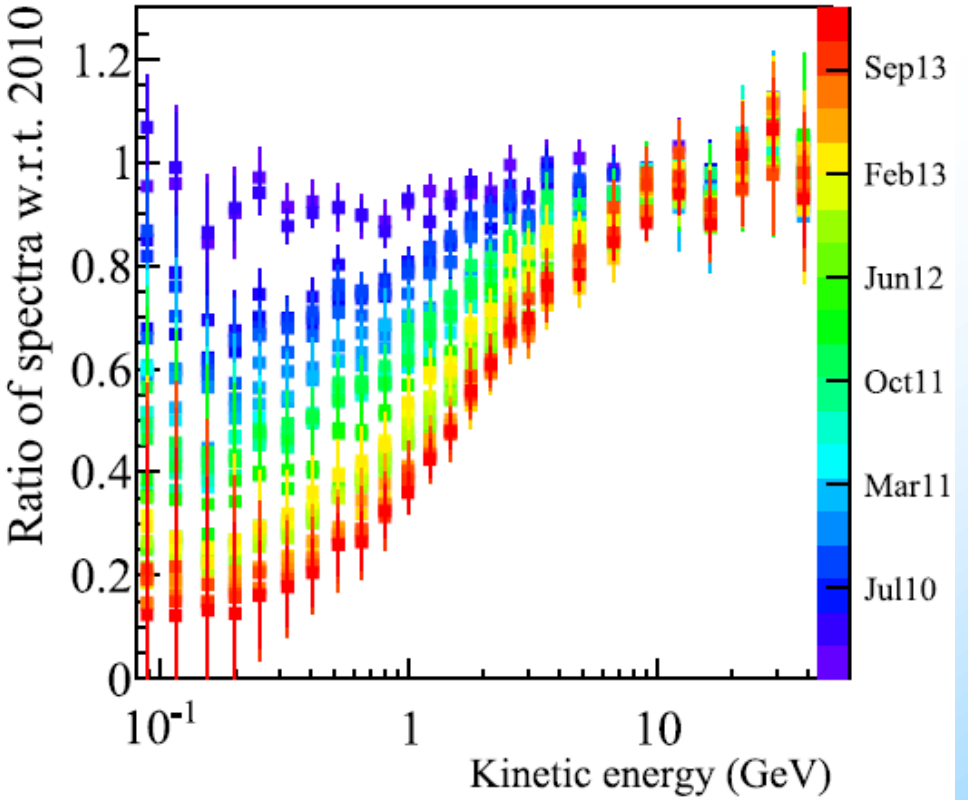
~ 0.3/DoF → too conservative errors?

New PAMELA data: 2006 – 2014



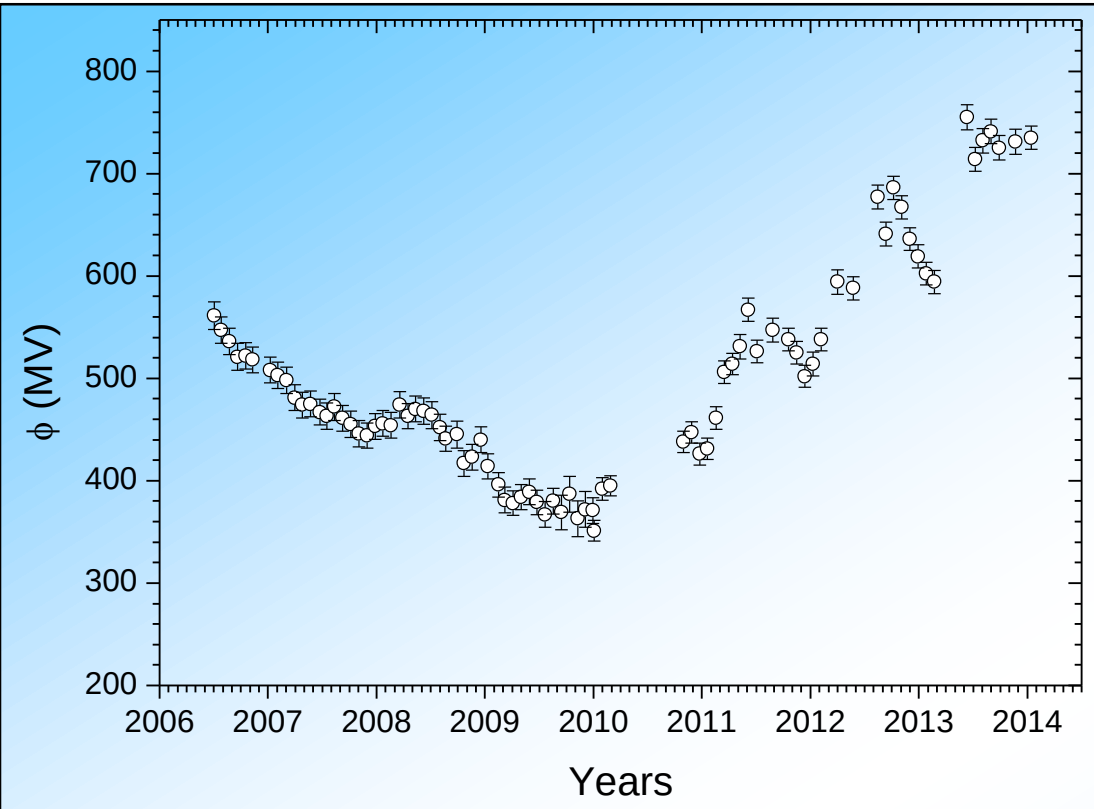
PAMELA data 2010–2014





Martucci et al., *Astrophys. J. Lett.*, 854, L2, 2018
Also at ASDC database *tools.asdc.asi.it/CosmicRays/*

PAMELA-based φ

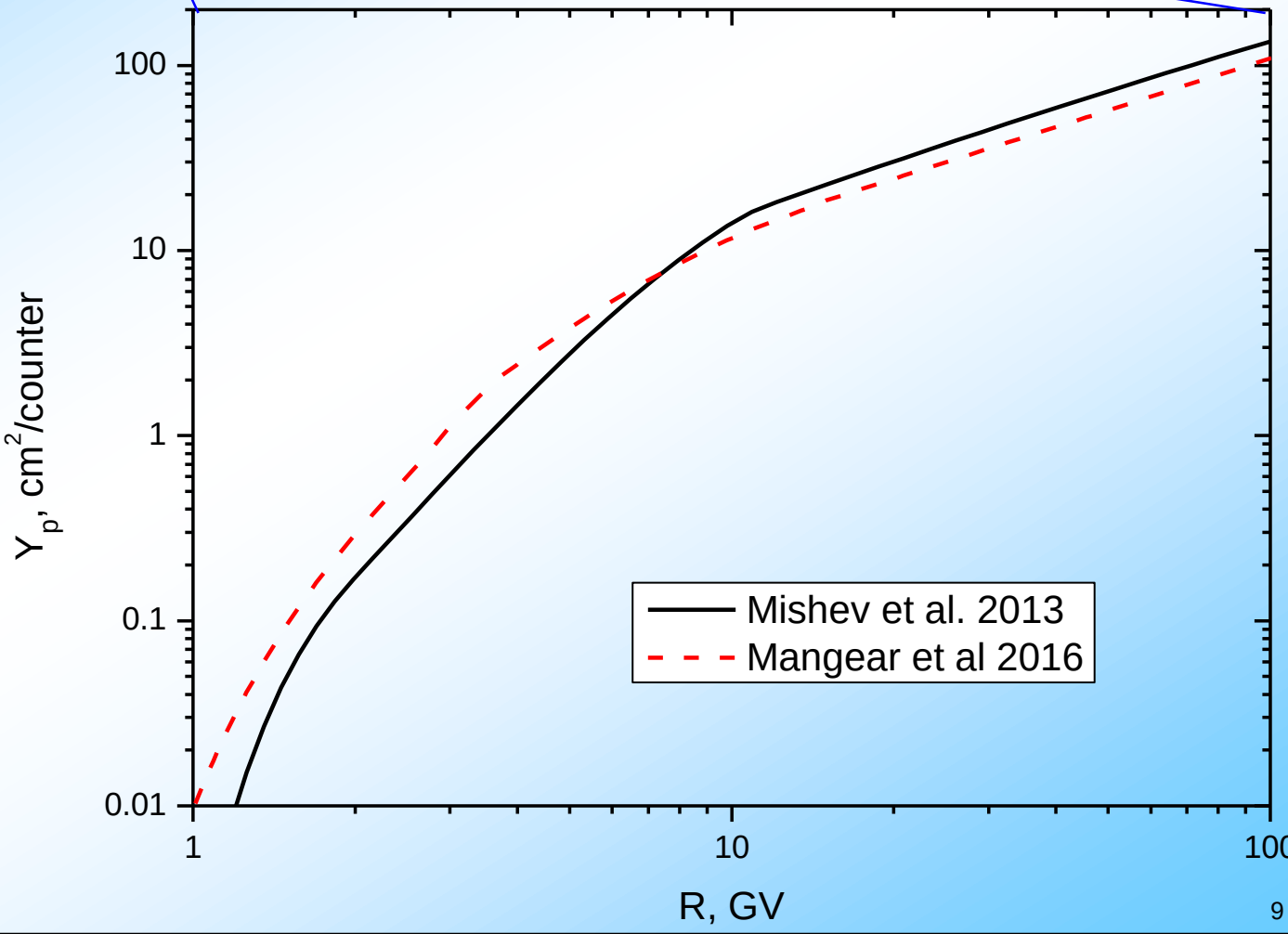


#	Start	End	ϕ (MV)	#	Start	End	ϕ (MV)
1	2006-07-07	2006-07-26	561±13.5	43	2009-09-15	2009-10-11	369±17
2	2006-07-27	2006-08-22	547±13	44	2009-10-12	2009-11-07	387±17.5
3	2006-08-24	2006-09-19	536±13	45	2009-11-08	2009-12-05	363±17.5
4	2006-09-20	2006-10-16	521±13	46	2009-12-06	2010-01-01	372±17.5
5	2006-10-17	2006-11-12	522±13	47	2010-01-02	2010-01-23	371±12.5
6	2006-11-13	2006-12-04	518±12.5	48	2010-01-03	2010-01-30	351±12
7	2007-01-11	2007-02-02	508±12.5	49	2010-01-30	2010-02-27	392±11
8	2007-02-03	2007-03-02	503±13	50	2010-02-27	2010-03-26	395±10
9	2007-03-03	2007-03-29	498±13	51	2010-10-30	2010-11-26	438±10.5
10	2007-03-30	2007-04-25	481±12.5	52	2010-11-26	2010-12-24	447±10.5
11	2007-04-26	2007-05-22	474±12.5	53	2010-12-24	2011-01-20	426±10.5
12	2007-05-23	2007-06-17	475±12.5	54	2011-01-20	2011-02-16	431±10.5
13	2007-06-27	2007-07-16	467±12.5	55	2011-02-16	2011-03-16	461±11
14	2007-07-17	2007-08-12	463±13	56	2011-03-16	2011-04-12	506±11
15	2007-08-13	2007-09-06	472±13	57	2011-04-12	2011-05-09	514±10.5
16	2007-09-09	2007-10-06	461±12.5	58	2011-05-09	2011-06-05	531±12
17	2007-10-07	2007-11-02	455±13	59	2011-06-05	2011-07-03	567±11.5
18	2007-11-03	2007-11-29	446±13	60	2011-07-03	2011-07-30	526±11
19	2007-11-30	2007-12-27	444±12.5	61	2011-08-26	2011-09-22	547±11.5
20	2007-12-28	2008-01-23	453±12.5	62	2011-10-19	2011-11-16	538±11
21	2008-01-24	2008-02-19	456±12.5	63	2011-11-16	2011-12-13	525±11
22	2008-02-20	2008-03-17	454±12.5	64	2011-12-13	2012-01-09	502±11
23	2008-03-19	2008-04-14	474±13	65	2012-01-09	2012-02-06	514±11.5
24	2008-04-15	2008-05-11	463±12.5	66	2012-02-06	2012-03-04	538±11
25	2008-05-12	2008-06-07	470±12.5	67	2012-03-31	2012-04-28	594±12
26	2008-06-08	2008-07-04	468±13	68	2012-05-25	2012-06-21	588±11.5
27	2008-07-05	2008-08-01	464±13	69	2012-08-15	2012-09-11	677±11.5
28	2008-08-02	2008-08-28	452±13	70	2012-09-11	2012-10-08	641±11.5
29	2008-08-29	2008-09-11	441±12.5	71	2012-10-08	2012-11-04	686±11.5
30	2008-10-01	2008-10-21	445±13	72	2012-11-04	2012-12-02	667±11.5
31	2008-10-22	2008-11-18	417±12.5	73	2012-12-02	2012-12-29	636±11
32	2008-11-19	2008-12-15	423±12.5	74	2012-12-29	2013-01-25	619±11.5
33	2008-12-20	2009-01-11	440±12.5	75	2013-01-25	2013-02-22	602±11
34	2009-01-12	2009-02-08	414±12.5	76	2013-02-22	2013-03-21	594±11.5
35	2009-02-21	2009-03-07	396±12	77	2013-06-11	2013-07-08	755±12.5
36	2009-03-08	2009-04-03	381±12.5	78	2013-07-08	2013-08-04	714±11.5
37	2009-04-04	2009-05-01	378±12	79	2013-08-04	2013-08-31	732±12
38	2009-05-02	2009-05-28	384±12.5	80	2013-08-31	2013-09-28	741±12
39	2009-05-29	2009-06-24	389±12.5	81	2013-09-28	2013-10-25	725±12
40	2009-06-25	2009-07-21	379±12	82	2013-11-21	2013-12-19	731±12
41	2009-07-22	2009-08-18	367±12.5	83	2014-01-15	2014-02-11	735±11.5
42	2009-08-19	2009-09-14	380±12.5				

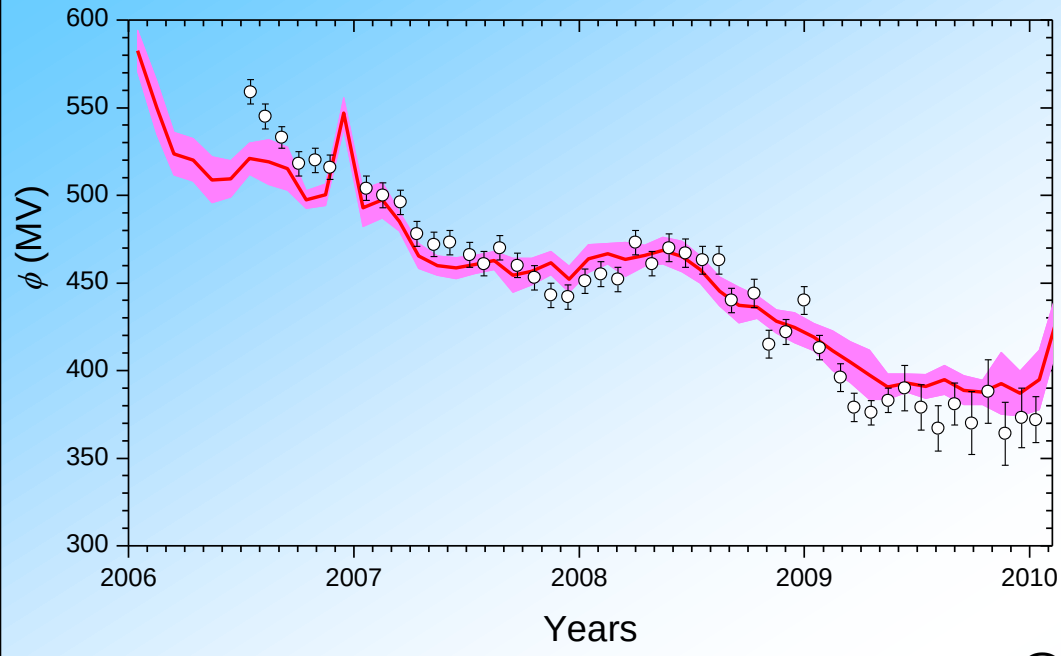
NM yield functions

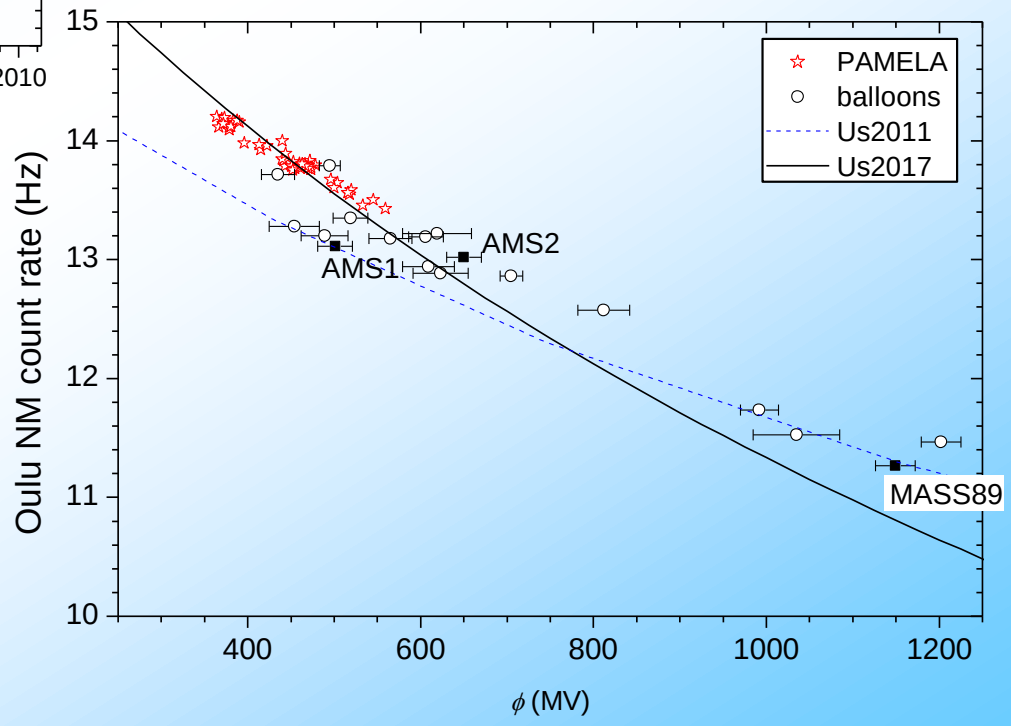
$$N(T,h) = \frac{1}{\kappa}\sum_i \int_{T_{c,i}}^{\infty} J_i(T,t)\cdot Y_i(T.h)\cdot dT,$$

$J_{LIS,\alpha}$=0.3 $J_{LIS,p}$

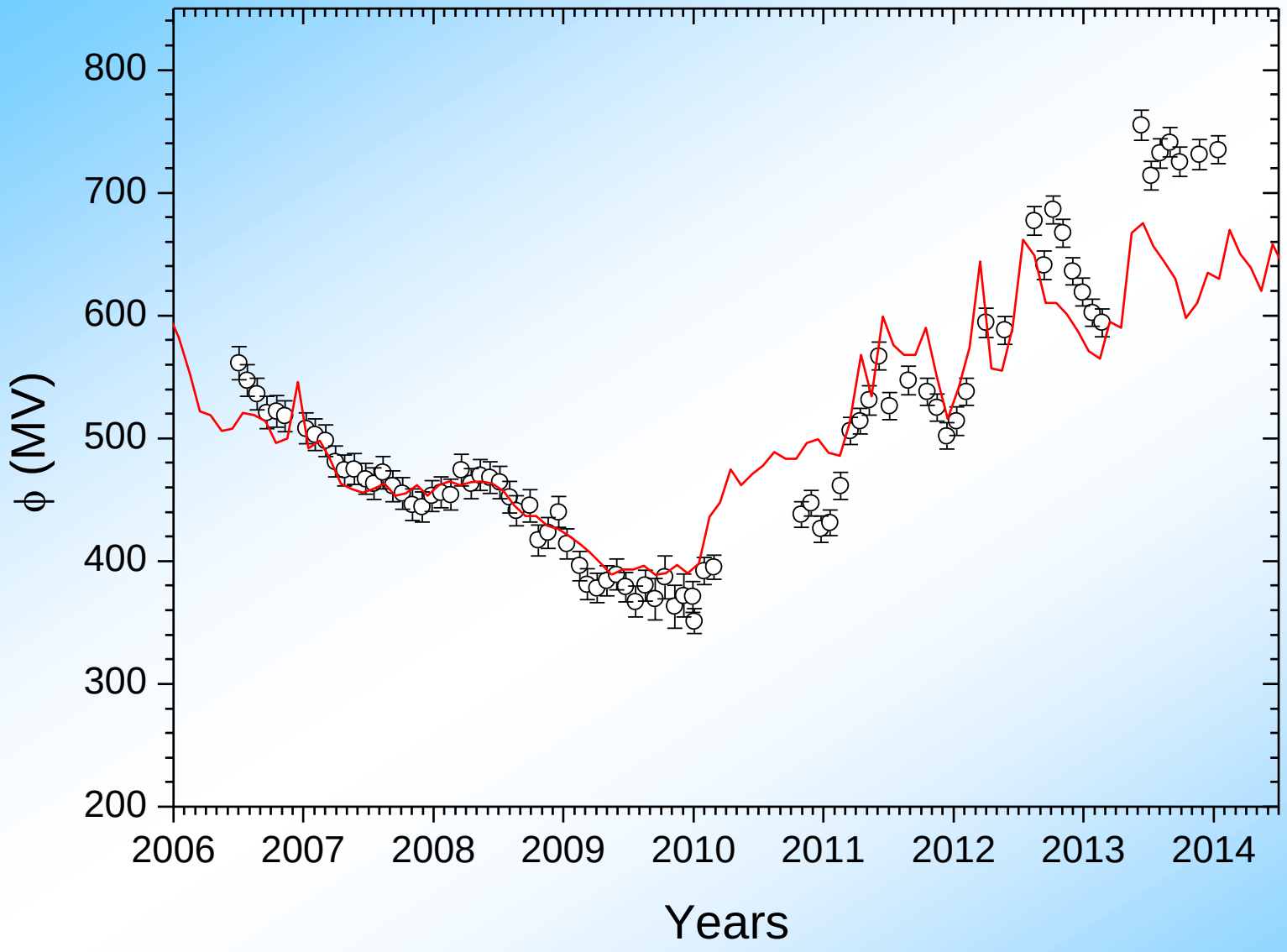


PAMELA 2006–2009: Good agreement?

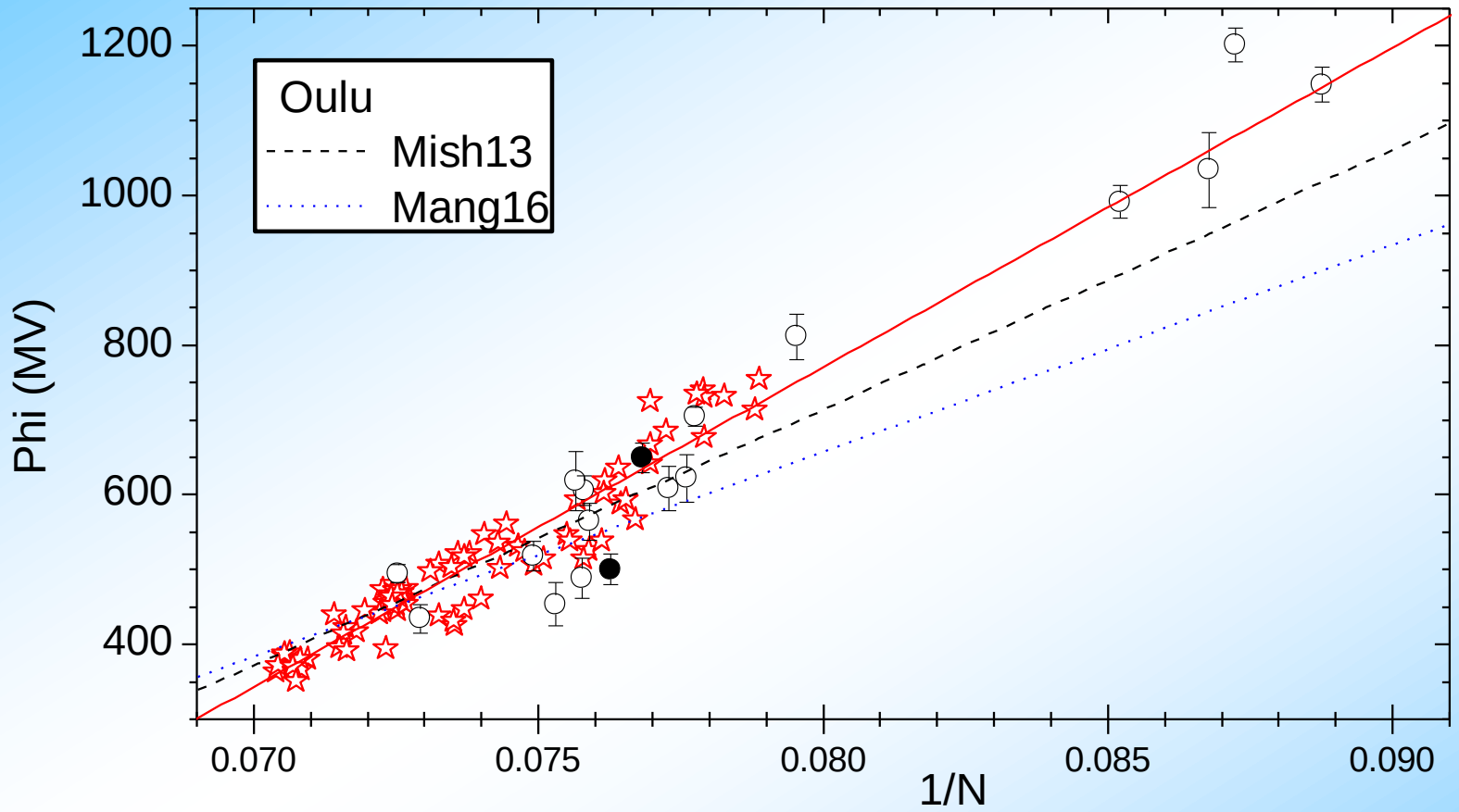




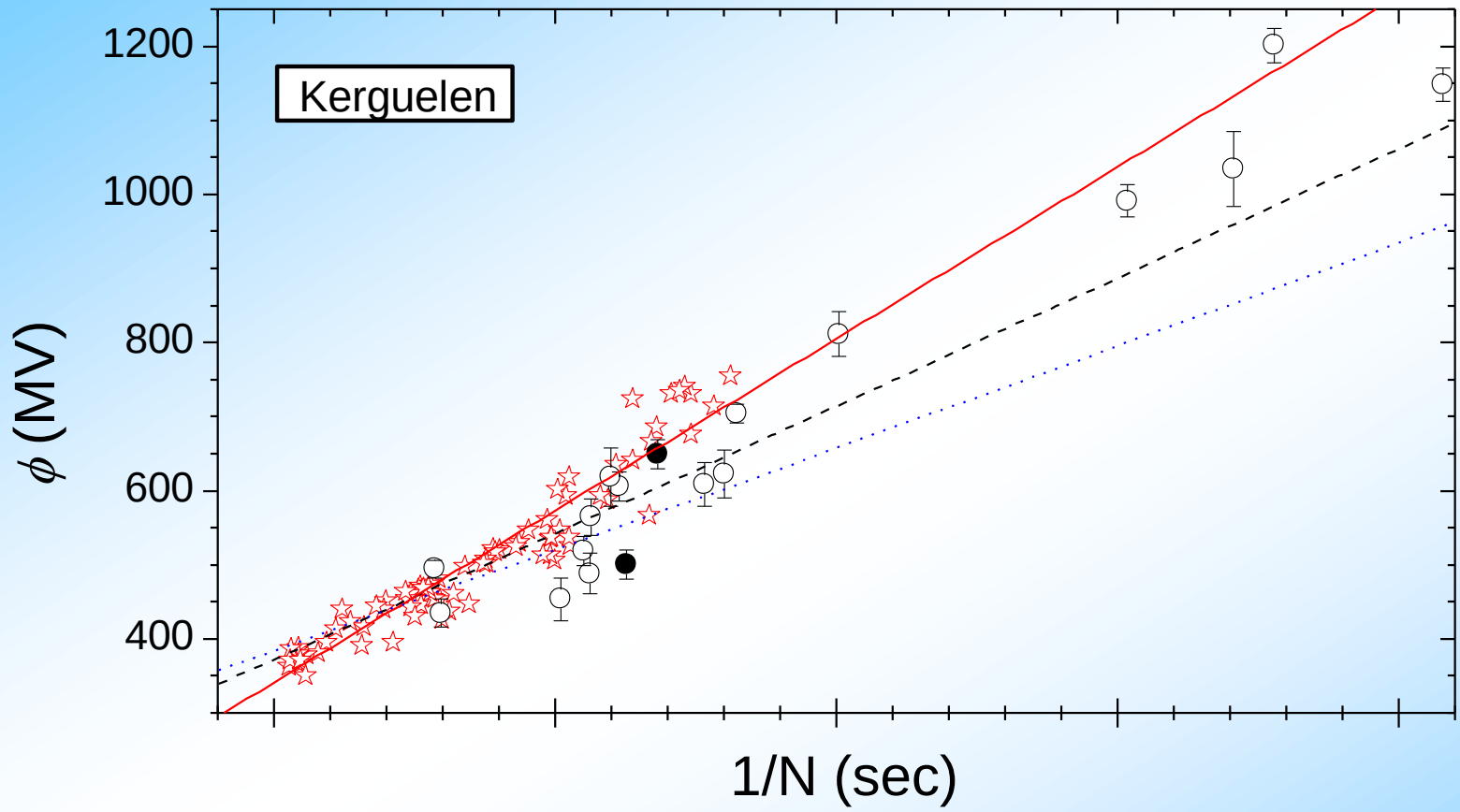
Comparison with NM



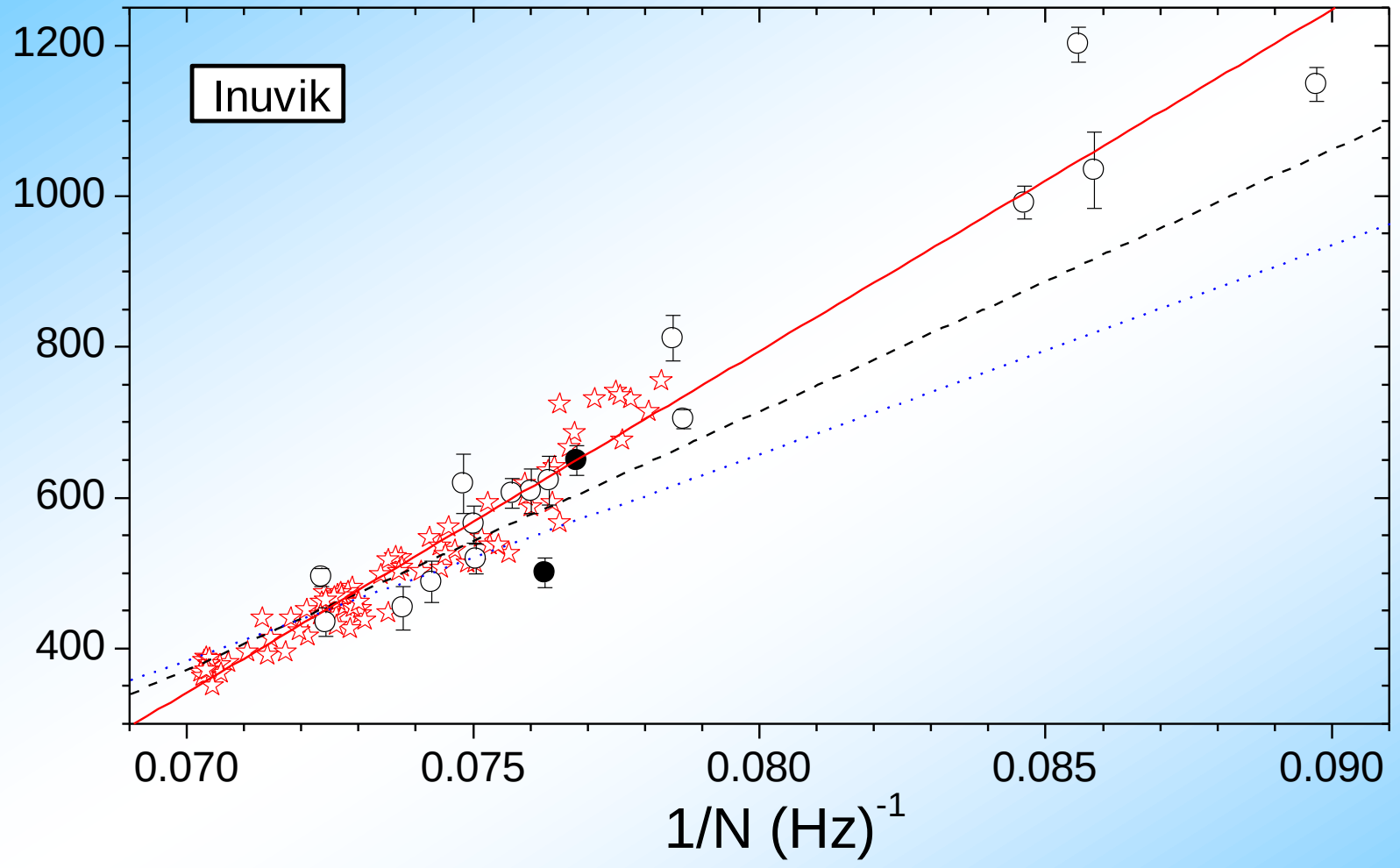
PAMELA vs. Oulu NM



PAMELA vs. Kerguelen NM



PAMELA vs. Inuvik NM



Discrepancy

- There is a discrepancy (small, <100 MV, but systematic) between the energy spectra of GCR protons measured in space and those reconstructed from ground-based NM data.

- Both used yield-function models disagree with the data, but the results based on Mi13 lie closer to the experimental data than those based on Ma16.

REASON?

1) Possible degradation of the PAMELA sensitivity with time, thus overestimated modulation potential during the late years: BUT the spectral shape is not distorted, and the discrepancy is consistent with independent balloon-borne data → **unlikely**

2) Incorrect yield function of NM: overestimate of the low-energy part or underestimate of the high-energy tail

3) Alphas do not behave as we expect.

We cannot distingusih now → more data needed (AMS?)

Summary

- GCR **proton spectra** measured by PAMELA **are well parameterized by the force-field model** in the range 350–750 MV for the LIS by Vos & Potgeiter (2015).
- The obtained φ-values are **in agreement with** those calculated from **NM data** (Usoskin et al., 2017) for **low solar activity** 2006–2012, but **diverge during the maximum** of solar cycle 24 around 2013–2014.
- The empirical relation between the modulation potential and the (inverted) NM count rate is steeper than the modelled one. The discrepancy is small (<~10%) but systematic. Results based on the **NM yield function by Mishev** et al. (2013) **lie closer** to the data points than those based on the results by Mangeard et al. (2016).
- **The reason for the discrepancy is unclear.** We speculate that a likely reason is a possible underestimate of the NM yield function in the high energy range. More investigation is needed with the use of an independent dataset → GCR spectra measured by the AMS experiment.


THANK YOU !