Neutron Monitor (NM) data to monitor GCR data

I. Monitoring the time variability of GCRs
II. From GCRs to neutron monitor count rates
III. Conclusions

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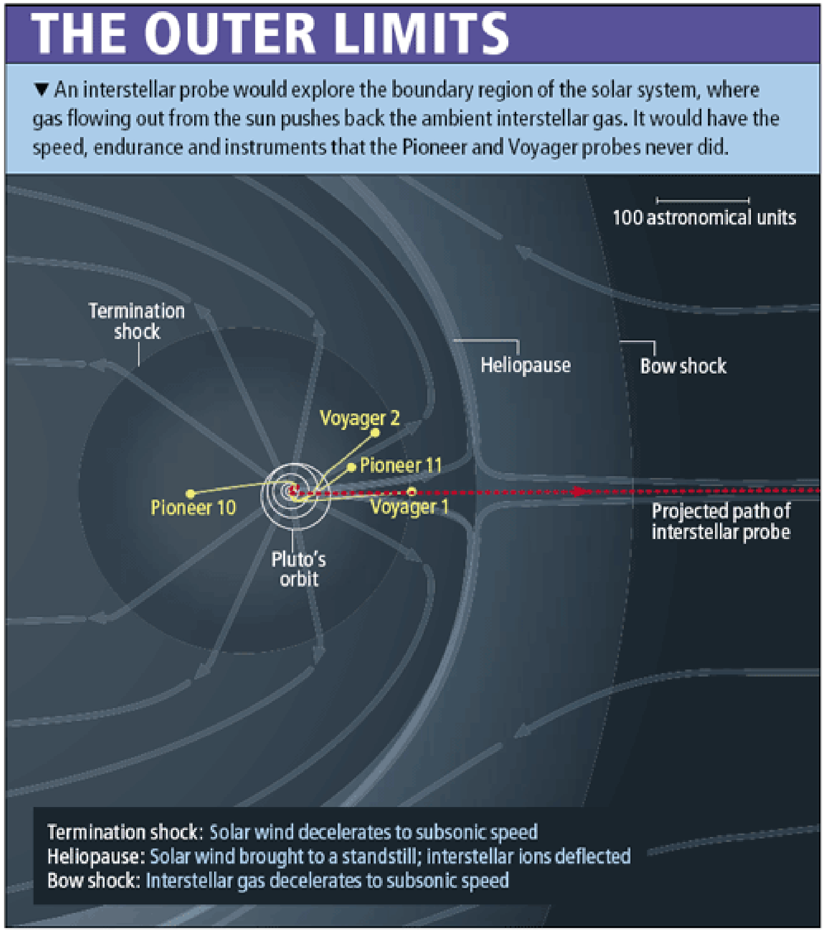
Nuclear physics for GCRs in the AMS-02 era
4/12/2012

Solar cavity: a complex and varying environment

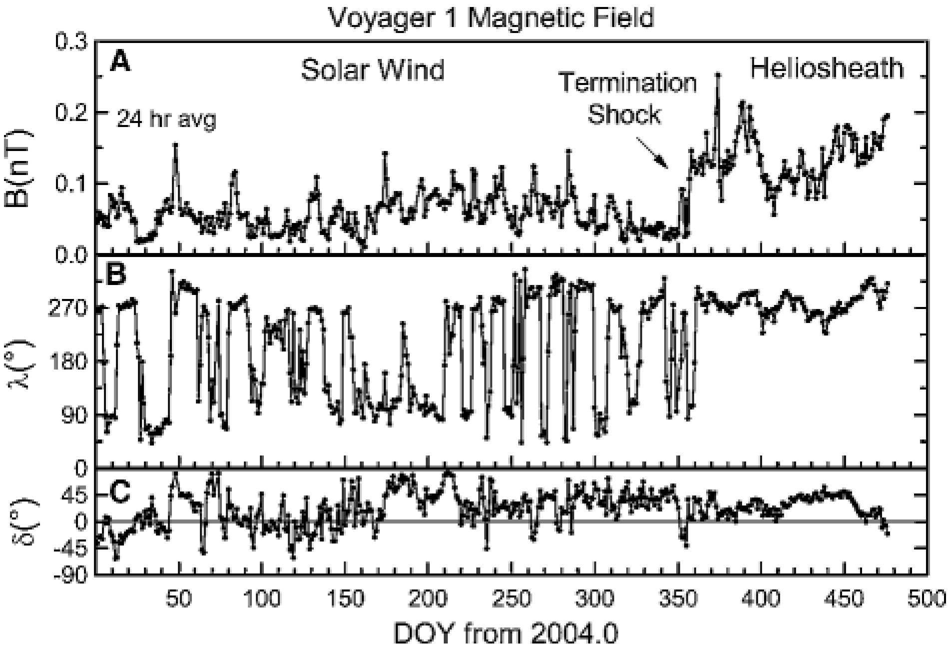


THE OUTER LIMITS

▼ An interstellar probe would explore the boundary region of the solar system, where gas flowing out from the sun pushes back the ambient interstellar gas. It would have the speed, endurance and instruments that the Pioneer and Voyager probes never did.

Termination shock: Solar wind decelerates to subsonic speed
Heliopause: Solar wind brought to a standstill; interstellar ions deflected
Bow shock: Interstellar gas decelerates to subsonic speed

LUCY READING-IKKANDA



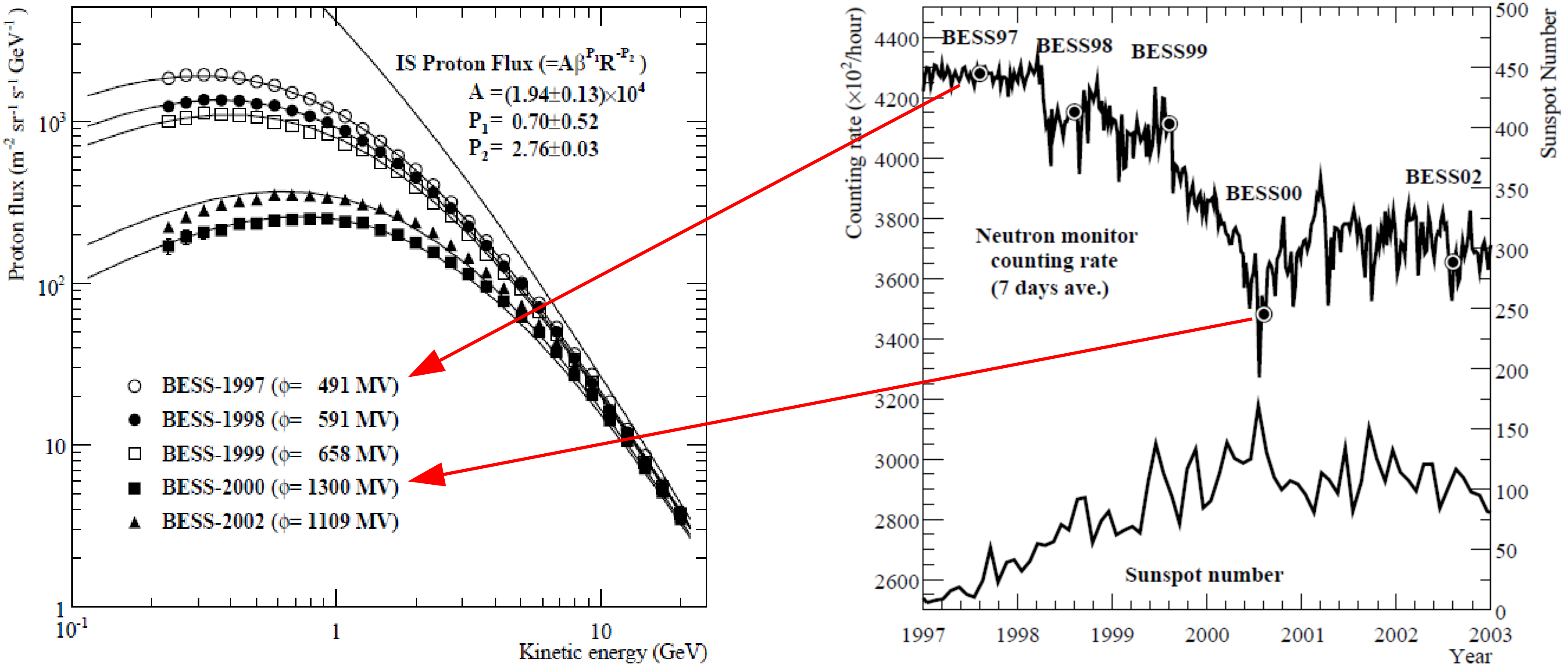
Voyager 1 Magnetic Field

→ In situ measurements scarce and difficult to connect easily to CR fluxes

Solar cavity: simple modulation models

Shikaze *et al.*, APh **28**, 154 (2007)

BESS (balloon-borne experiment)



→ Neutron monitors good proxy for Solar modulation
(but not the only ones, see next talks)

Questions in the AMS-02 context

- **From AMS-02 point of view:**

  → Can we predict AMS-02 flux time-variability from NMs?
  → What is the TOA flux variation range in a given period?
  → Should we exclude periods of intense activity ? Based on what criteria?

- **For the space weather community (over short and long periods):**

  → AMS-02 protons is another monitor of the Solar activity
  → NMs, ground μ studies, etc. may gain from monitoring p flux?

- **And more globally, in the context of Solar modulation:**

  → Access to IS spectra and fit of Solar modulation parameters
  → Study of charge dependence for Solar modulation

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The invention of NMs in the 50's (John A. Simpson)

Simpson, Space Sci. Rev. **93**, 11 (2000)

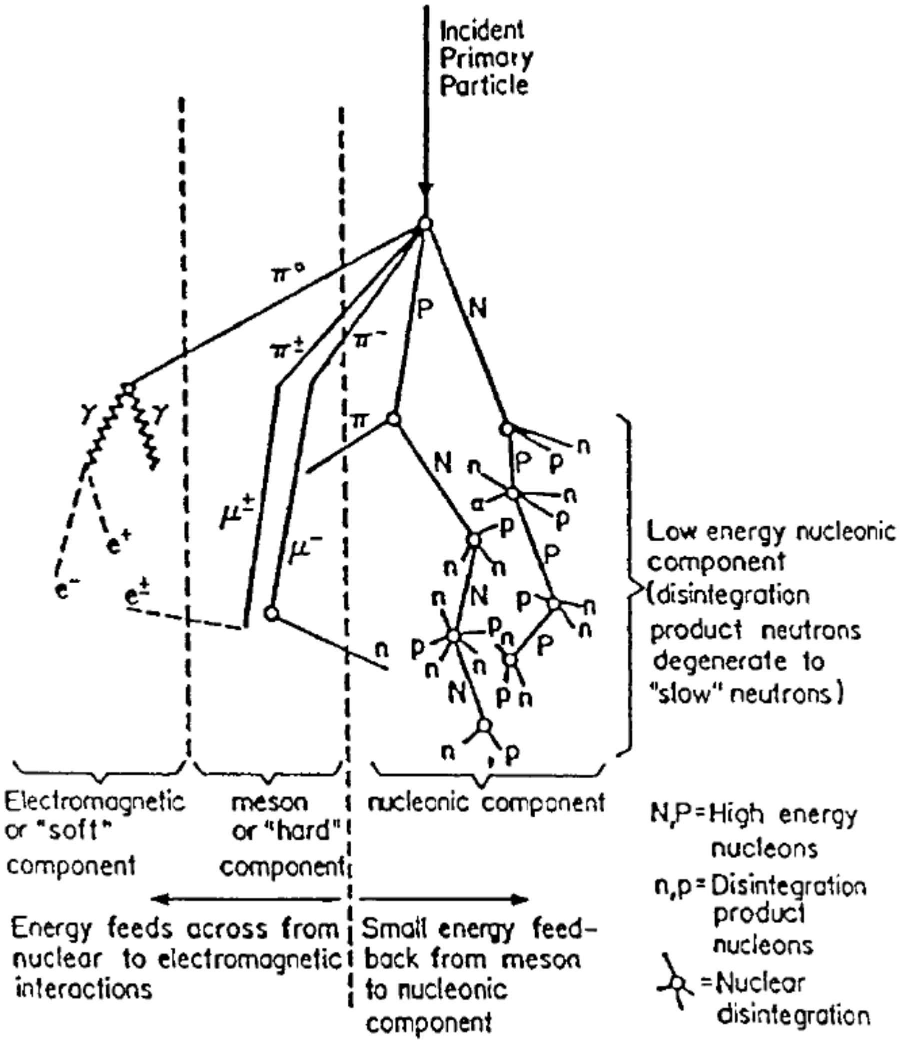
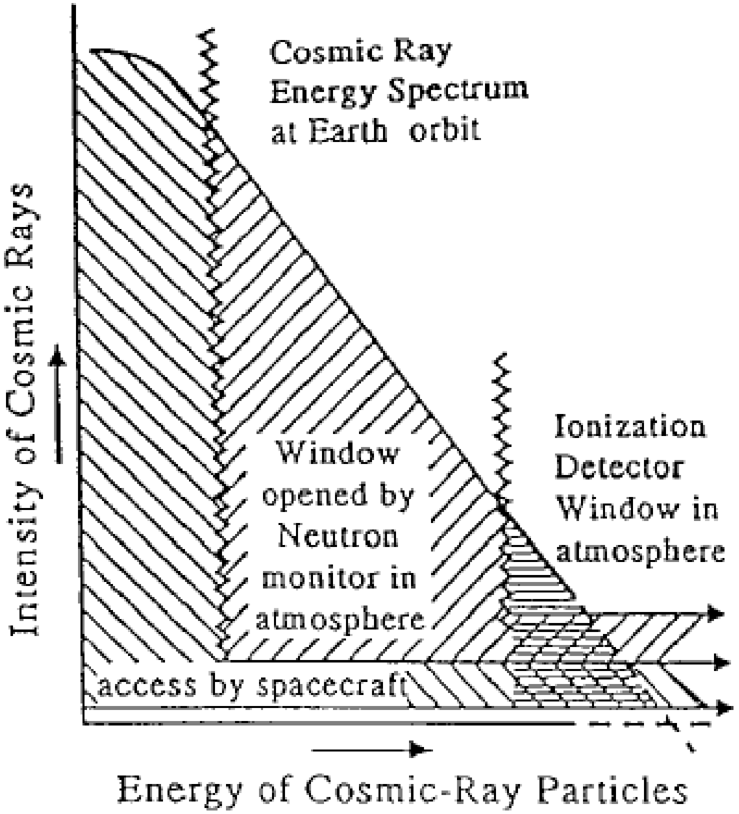
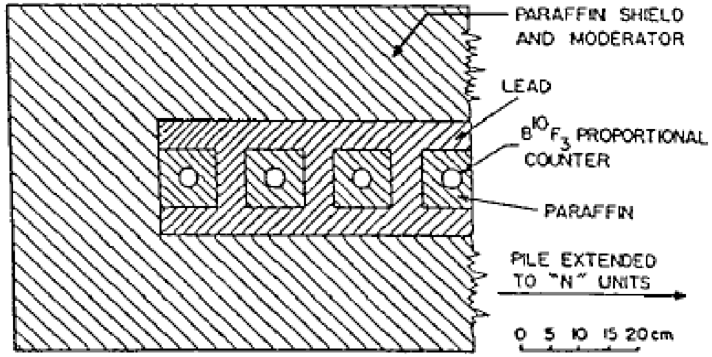


Figure 1. Schematic representation of the typical development of the secondary cosmic radiations within the atmosphere arising from an incident primary particle (Simpson *et al.*, 1953b).

The invention of NMs in the 50's (John A. Simpson)

Simpson, Space Sci. Rev. **93**, 11 (2000)





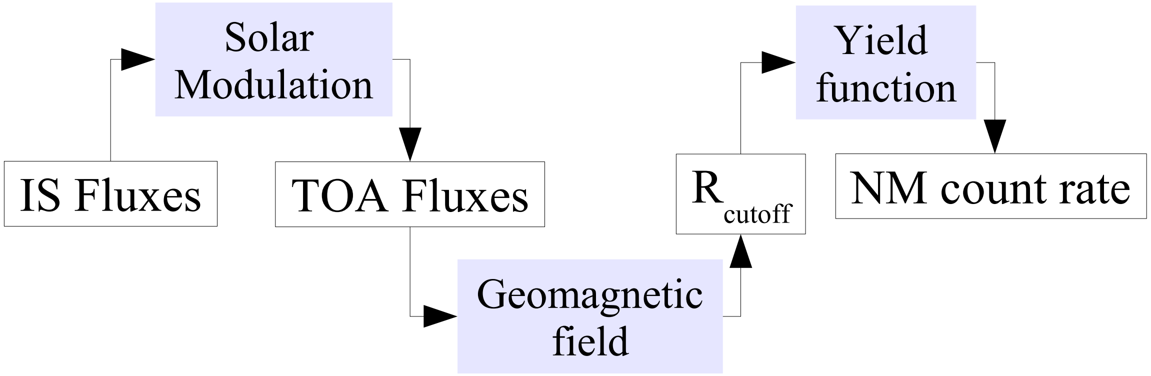
$$^{10}\mathrm{B} + \mathrm{n} \to {}^{11}\mathrm{B}^* \to {}^{7}\mathrm{Li} + {}^{4}\mathrm{He}^{++} + \mathrm{Q}\,.$$

$$^{3}\mathrm{He}_{2} \;+\; \mathrm{n} \;\to\; {}^{3}\mathrm{H}_{1} \;+\; \mathrm{proton}$$

Izmiran NMs (Russia)

→ NMs come cheap, immune to low energy SCRs,
active since the 50's (more in next talks)

From IS fluxes to NM count rates: Yield function



IS Fluxes

Solar Modulation

TOA Fluxes

Geomagnetic field

R_{cutoff}

Yield function

NM count rate

$$N(P_c,z,t)=\int_{P_c}^{\infty}\underbrace{\sum_i S_i(P,z)\cdot J_i(P,t)\cdot dP}_{W_T(P,z,t)} \qquad (1)$$

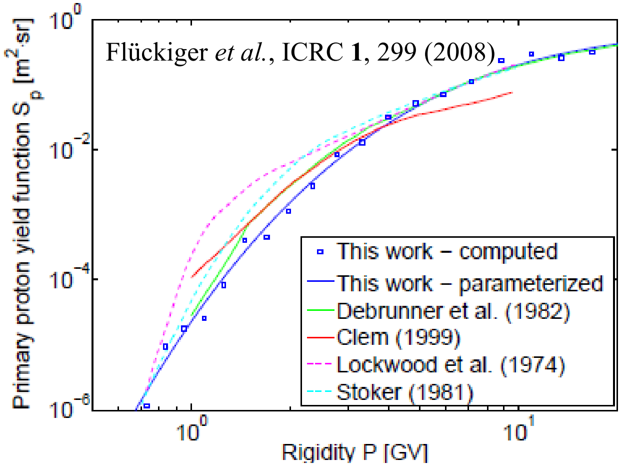
i	primary particle type (proton or α);
P	primary particle rigidity;
P_c	effective vertical cutoff rigidity;
z	atmospheric depth over the NM;
J_i	primary particle rigidity spectrum;
W_T	total differential response function.

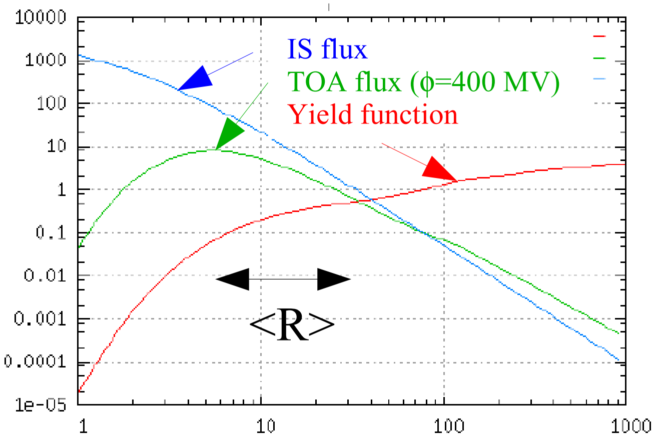
→ **Yield function**: MC (see next talk) or parametric

Clem & Dormann, Space Sci. Rev. **93**, 335 (2000)
Nagashima *et al.*, Nuovo Cim. **12**, 113 (1989)
Flückiger *et al.*, ICRC **1**, 299 (2008)

$$S_i(P,z)=\sum_j\iint A_j(E,\theta)\cdot\Phi_{ij}(P,z,E,\theta)\cdot dE\cdot d\Omega$$

j	secondary particle type (n, p, $\mu^{\pm}$, $\pi^{\pm}$);
A_j	effective area (efficiency × geom. area);
Φ_{ij}	differential flux of secondary particles per primary;
E	secondary particle energy;
θ, dΩ	secondary particle angle of incidence and solid angle.





→ NMs at different altitude (depth) and position (Rc) sample slightly different <R>

From NM count rates to ϕ, and fluence

- **Use previous ingredients**

Usoskin *et al.*, Solar Physics **207**, 389 (2002)
Usoskin *et al.*, J. Geophys. Res. **110**, A12108 (2005)
Usoskin *et al.*, J. Geophys. Res. **116**, A02104 (2011)

- **Source of uncertainties**

→ IS flux (form not known)
→ Yield function
→ Absolute normalisation of NMs

- **Comparison to fluence**

→ 80000 launches (Lebedev institute)

→ Reconstruction method fairly successful

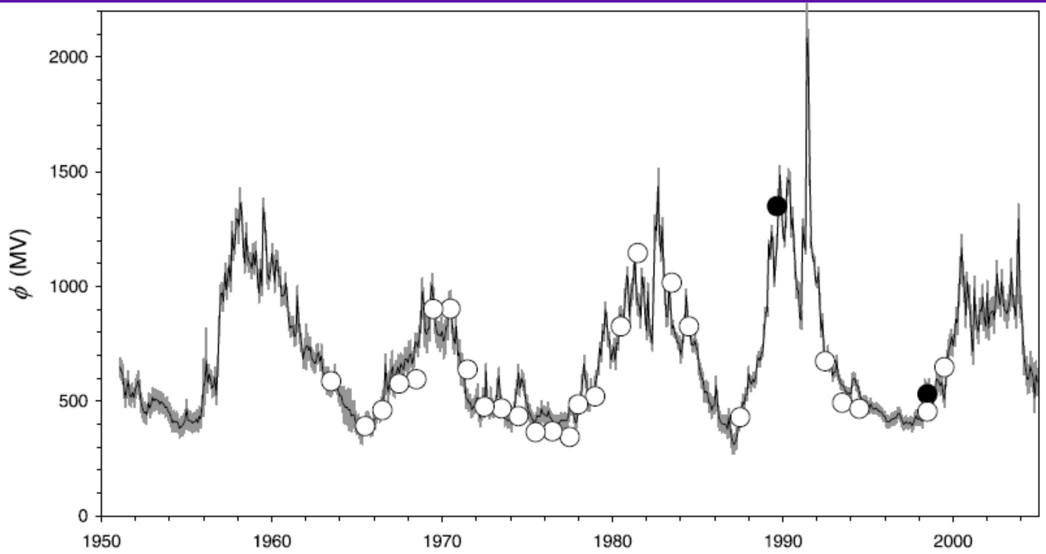


Figure 7. The reconstructed modulation parameter ϕ (solid line) together with 68% confidence intervals (grey shading). Two large black dots denote the reference periods (see text). Open dots correspond to some fragmentary estimates of the cosmic ray spectrum from balloon or space-borne experiments.

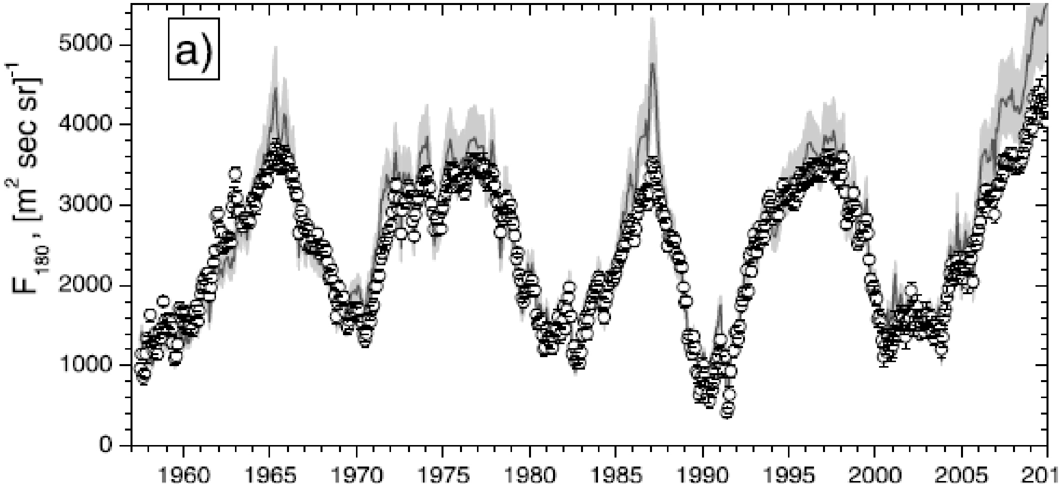
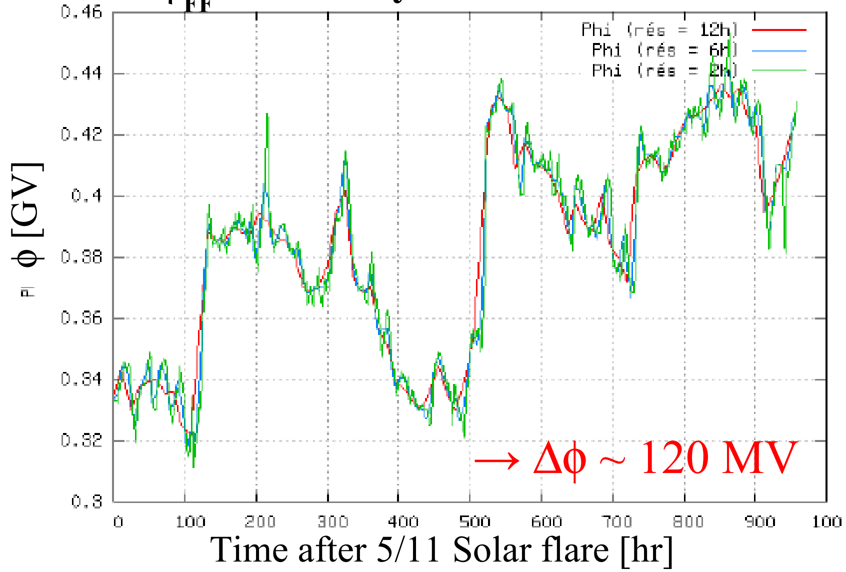


Figure 3. (a) Time profile of the cosmic ray flux (>180 MeV/nuc) F_{180} as measured at balloons (open dots with error bars) and computed from NM-data (solid curve with grey shading denoting 1σ uncer-

From NM count rates to fluxes: AMS-02 period

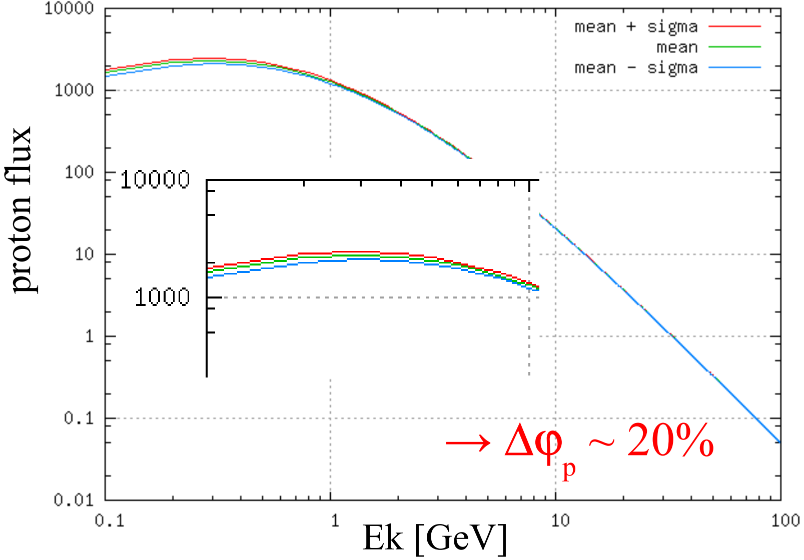
[similar analysis performed on AMS-02 periods (using NMDB)]

- **ϕ_{FF} variability in Forbush decrease**



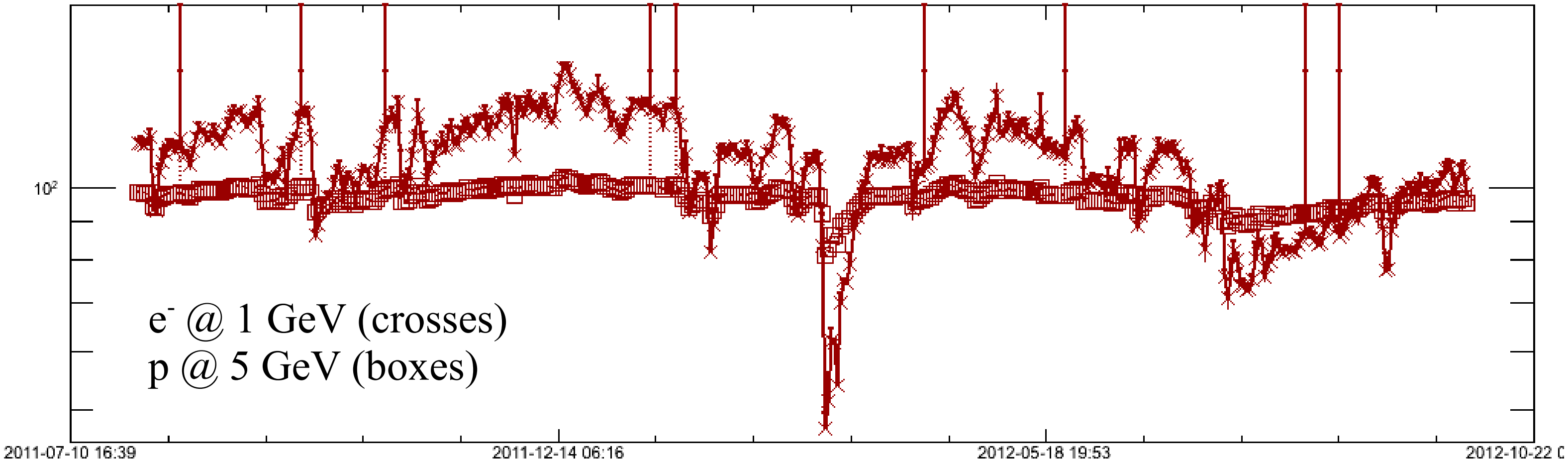
→ Δφ ~ 120 MV

- **1 day 'envelope' for proton flux**



→ $\Delta\varphi_p$ ~ 20%

- **1 day average proton and e^- flux variability**



e^- @ 1 GeV (crosses)
p @ 5 GeV (boxes)

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Conclusions

- **From AMS-02 point of view:**
  - Can we predict AMS-02 fluxes time-variability from NMs?
    → At first order, we should be able to do that
  - What is the TOA flux variation range in a given period?
    → Depends on the Solar activity, but we can calculate it
  - Should we exclude periods of intense activity ? Based on what criteria?
    → Needs to be explored...

- **For the space weather community (over short and long periods):**

  → AMS-02 will be another useful tool to monitor Solar activity and impact on IS flux

- **And more globally, in the context of Solar modulation:**
  - Access to IS spectra and fit of Solar modulation parameters
  - Study of charge dependence for Solar modulation

  } Can be answered only with AMS-02 data

→ But need to improve Yield functions, better understanding of NMs relative normalisation, better Solar modulation models... and the use of AMS-02 data!