MSL RAD Measurements of the Neutron Spectrum in Transit to Mars and on the Martian surface

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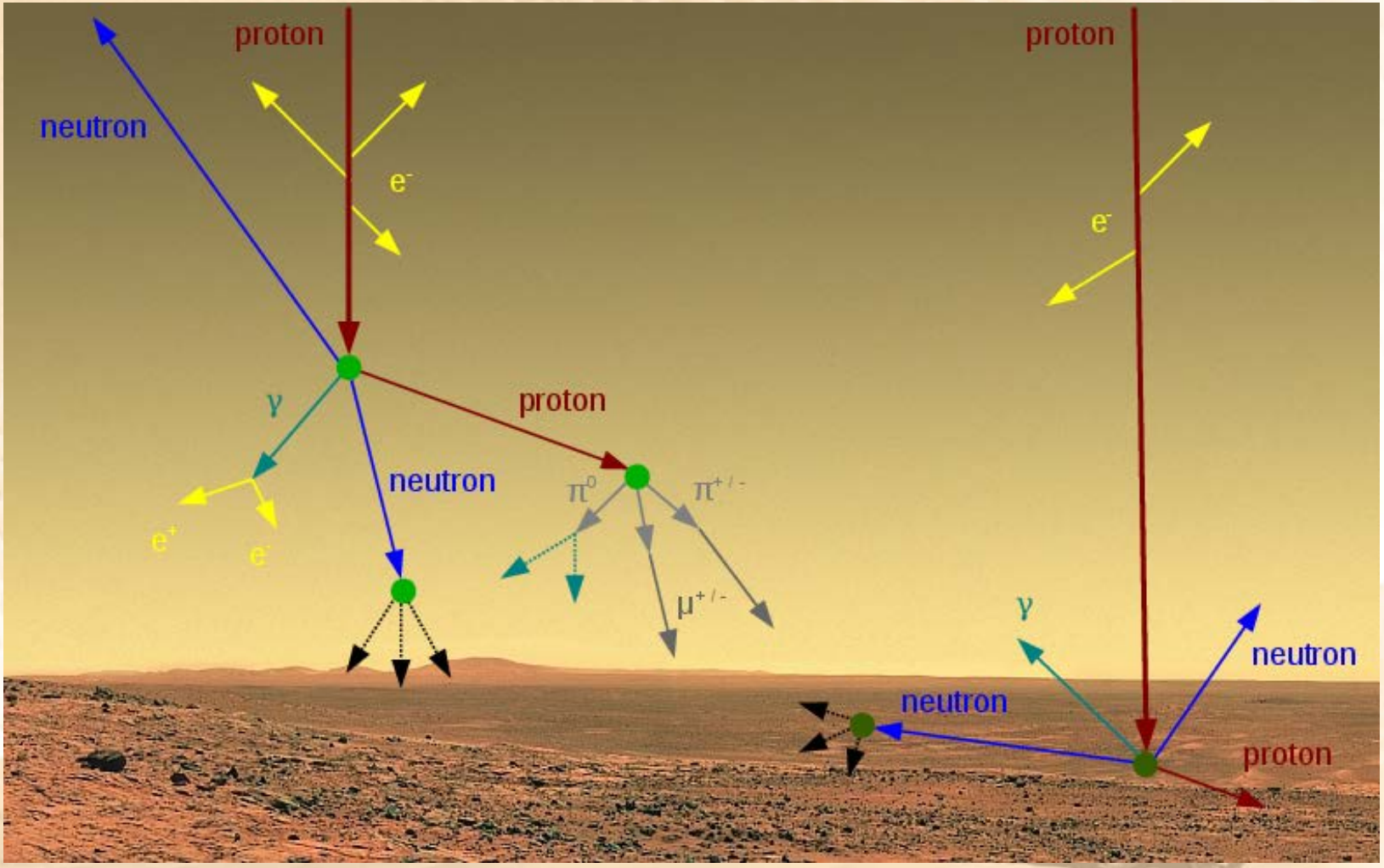
WRMISS

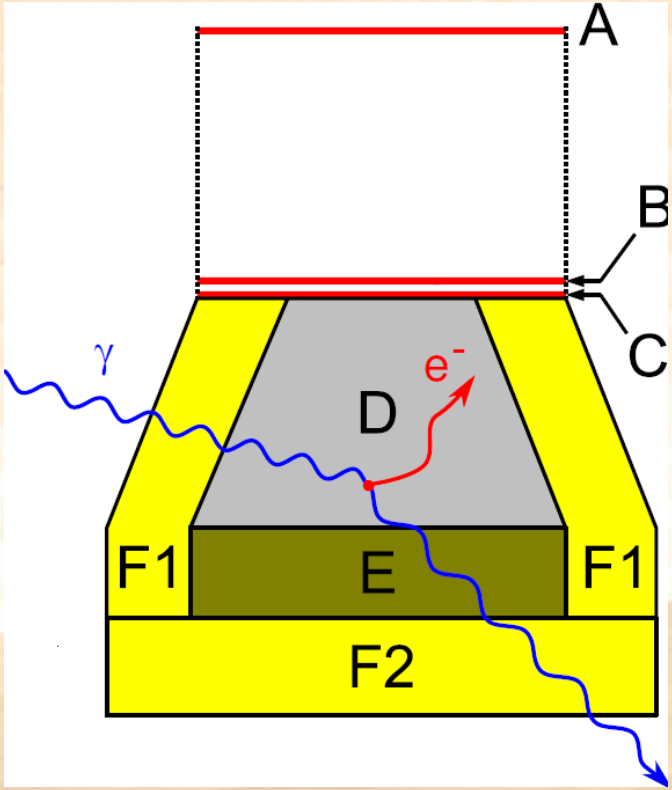
September 8-11, 2015

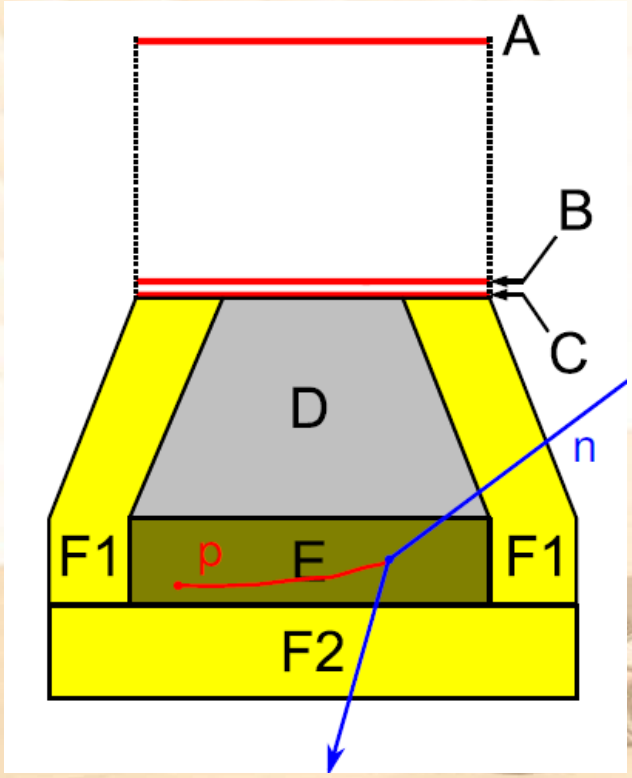
The Martian radiation environment



Measuring neutral particles

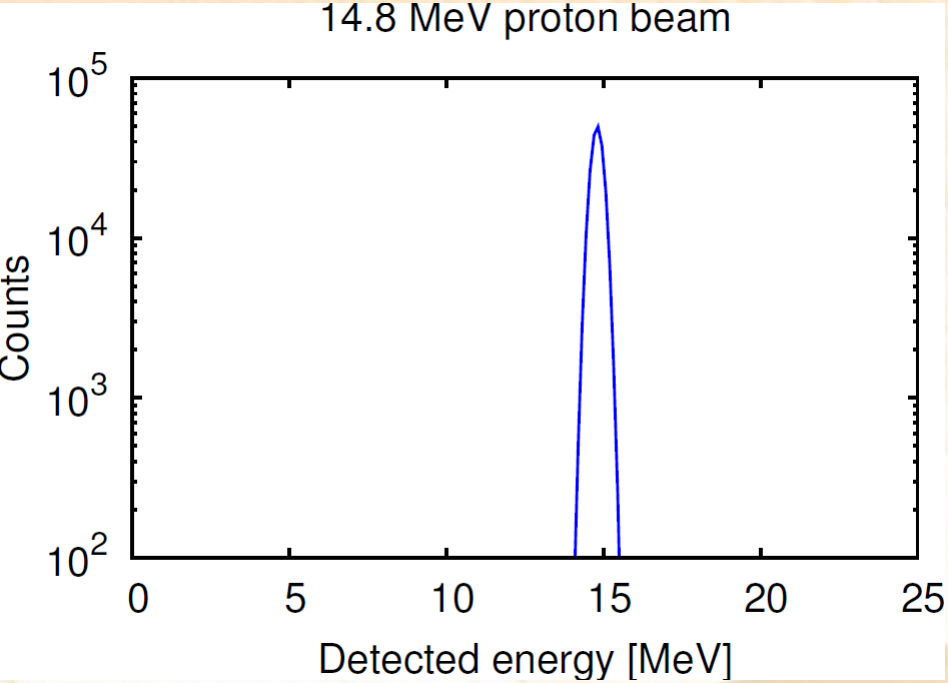
- Neutral particles can only be measured „indirectly“
- Neutral particles create signal in D/E but do not trigger the surrounding AC (F1/F2 and C)

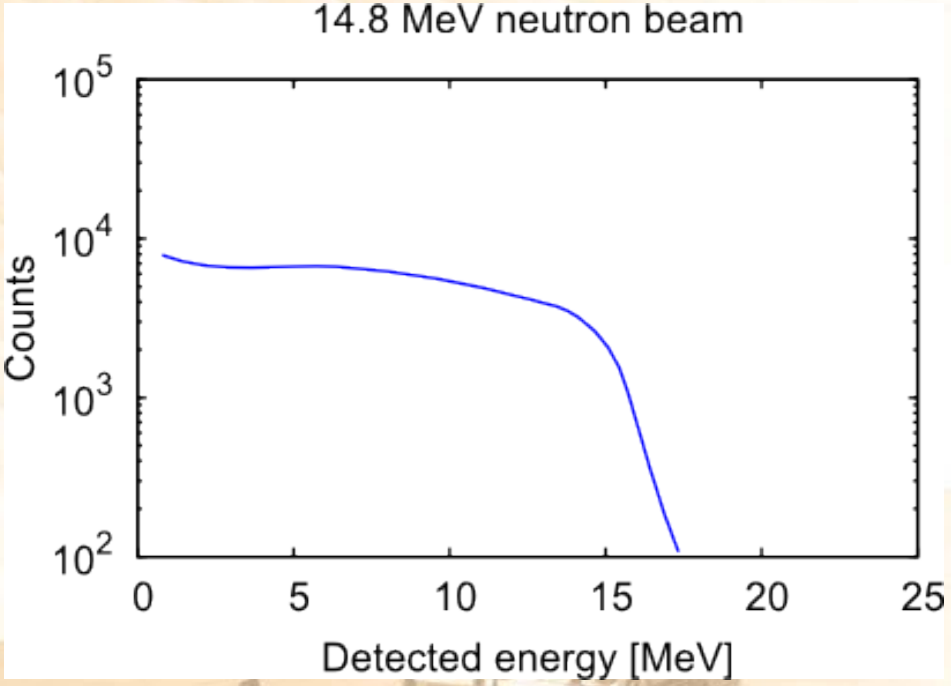




Measuring neutral particles

- Stopping charged particles deposit their complete energy
- Neutral particles deposit only a random fraction of their energy

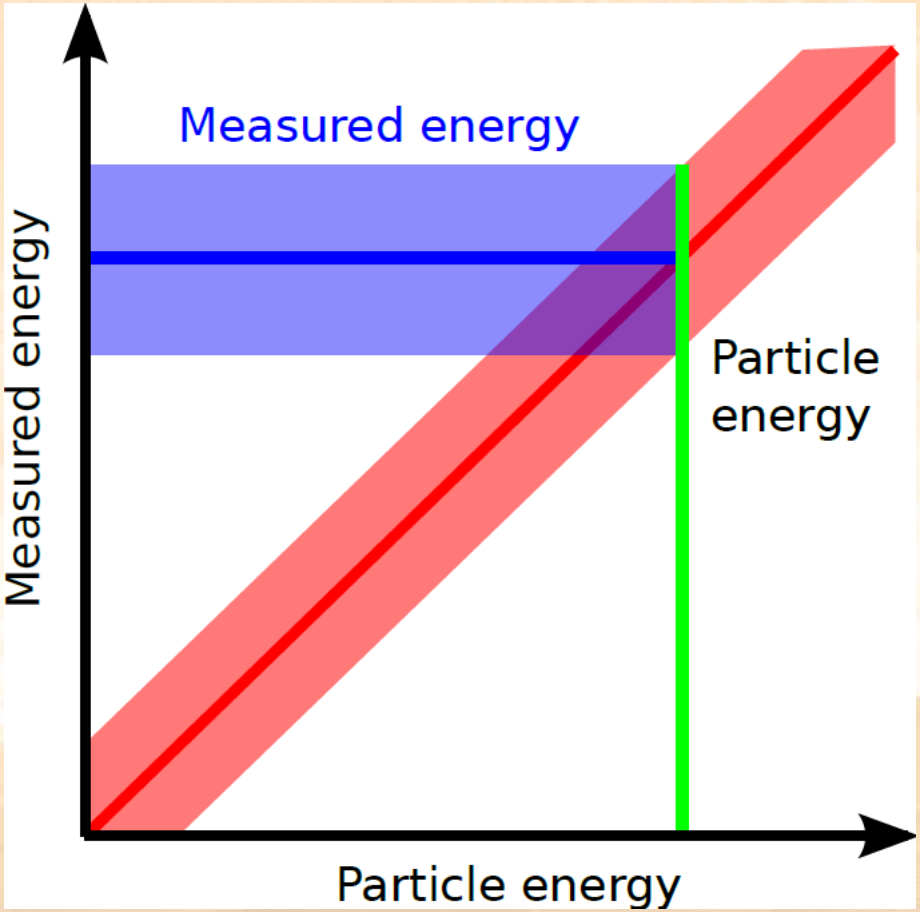




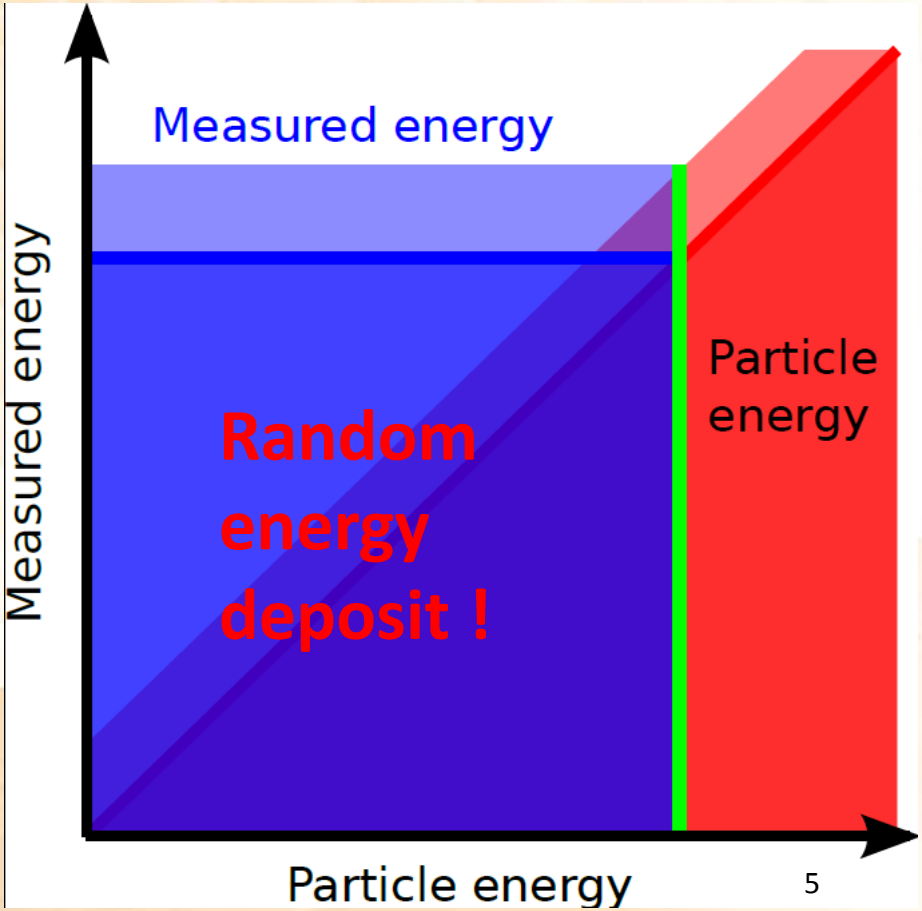
How can we obtain the real neutron energy from a measurement?

Instrument description via a Detector Response Function (DRF)

Charged particles



Neutral particles



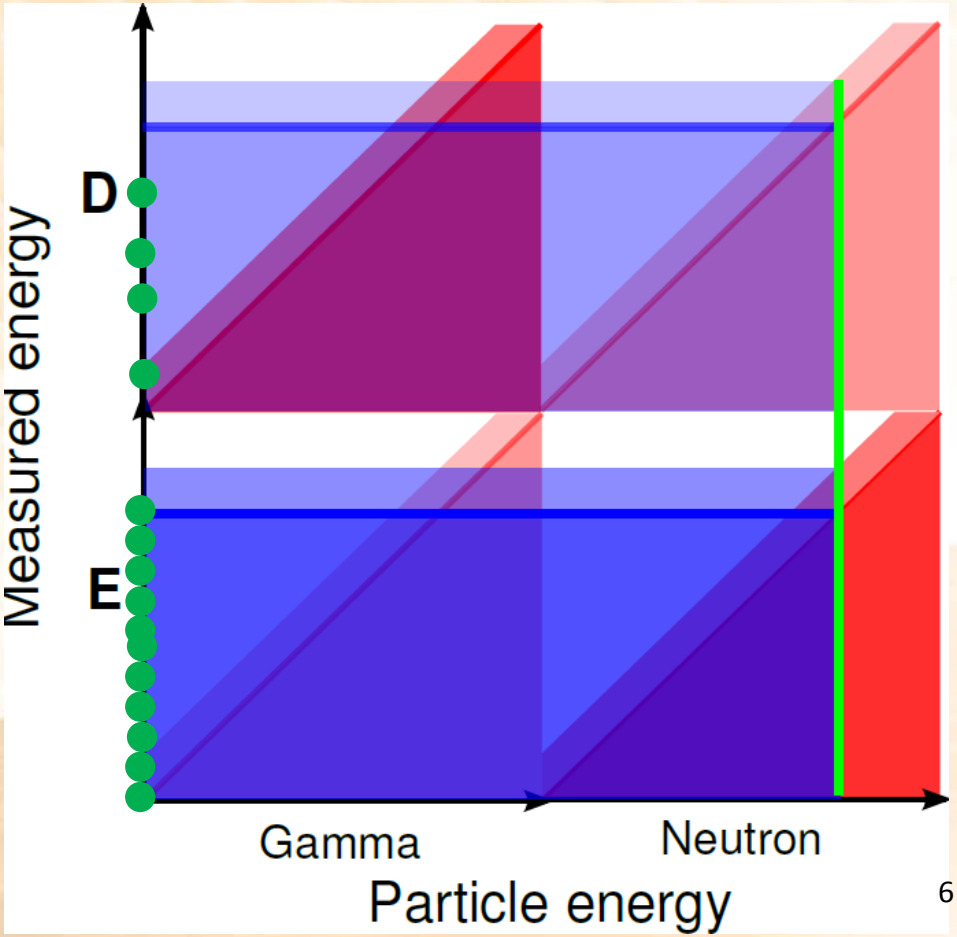
Instrument description via a Detector Response Function (DRF)

RAD measures gammas and neutrons in D and E

- Neutrons can be detected in E – but also in D
- Gammas can be detected in D – but also in E

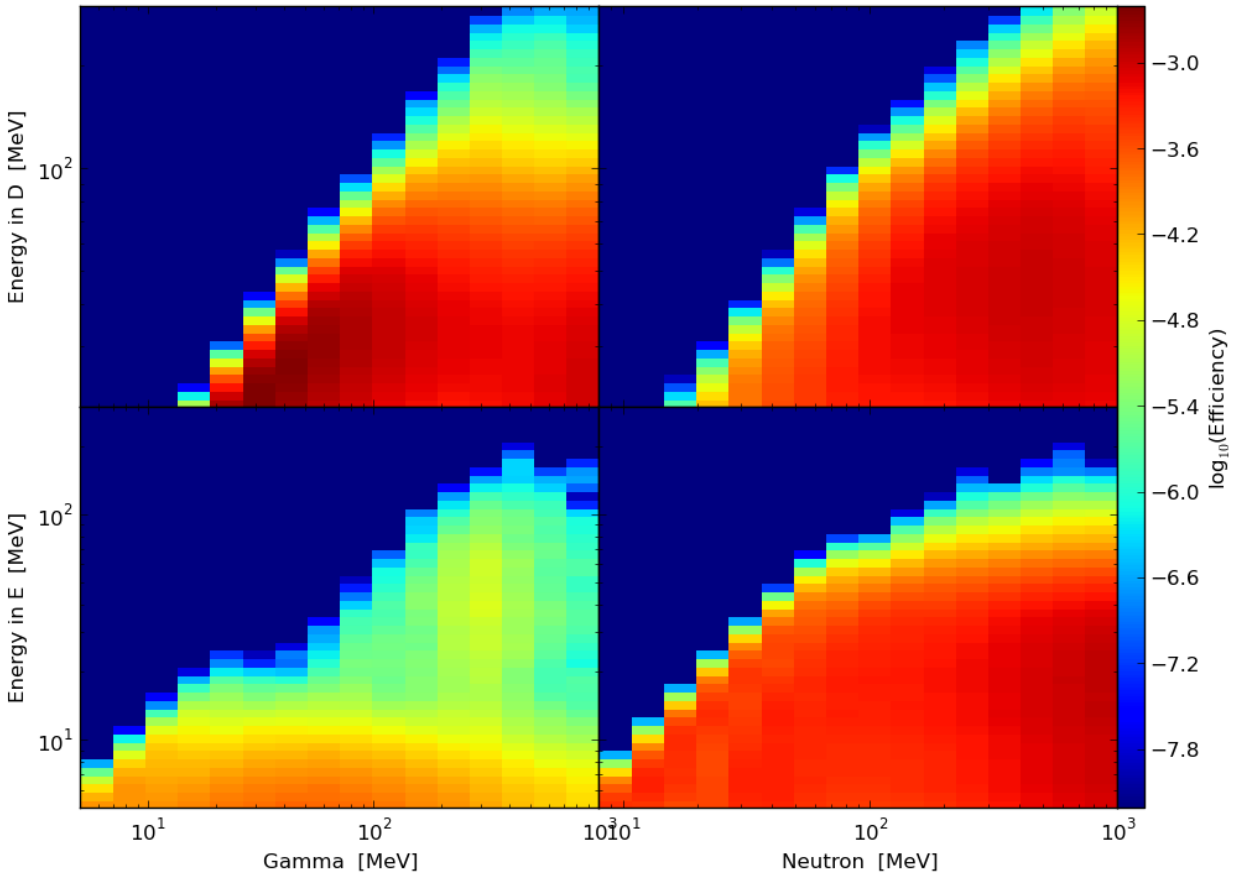
Example:

- A Neutron has a high likelihood to create a signal in E, and a low likelihood to create a signal in D.
- The energy deposit is randomly distributed



Instrument description via a Detector Response Function (DRF)

The DRF has been obtained via GEANT4



Mathematical background

Measurement = DRF * input spectrum

$$\vec{z} = \mathbf{A} \cdot \vec{f}$$

Example:

Measured low-energy neutrons

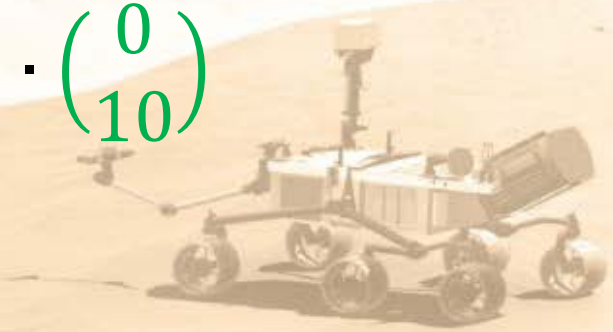
Measured high-energy neutrons

$$\begin{pmatrix} 10 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 & 0.5 \\ 0 & 0.5 \end{pmatrix} \cdot \begin{pmatrix} 10 \\ 0 \end{pmatrix}$$

Incoming low-energy neutrons

Incoming high-energy neutrons

$$\begin{pmatrix} 5 \\ 5 \end{pmatrix} = \begin{pmatrix} 1 & 0.5 \\ 0 & 0.5 \end{pmatrix} \cdot \begin{pmatrix} 0 \\ 10 \end{pmatrix}$$



Mathematical background

Measurement = DRF * input spectrum

$$\vec{z} = \mathbf{A} \cdot \vec{f}$$

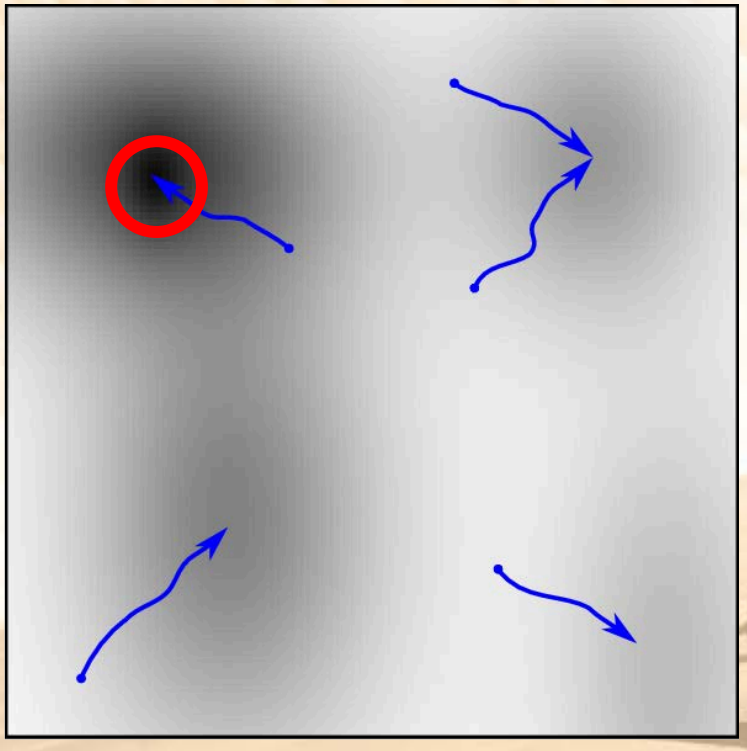
f can not be obtained directly, and a straightforward inversion (A^{-1}) results in unphysical results.

→ Formulate as a *maximum likelihood* problem with constraints:

$$\min \sum \left(\frac{\sum_i a_{ij} f_j - z_i}{\sigma_i^2} \right), \qquad \text{with } f_i > 0$$

Finding the (*global*) minimum

- The **L-BFGS-B** (Brodyden-Fletcher-Goldfarb-Shanno) algorithm finds a *local* minimum for a given initial guess

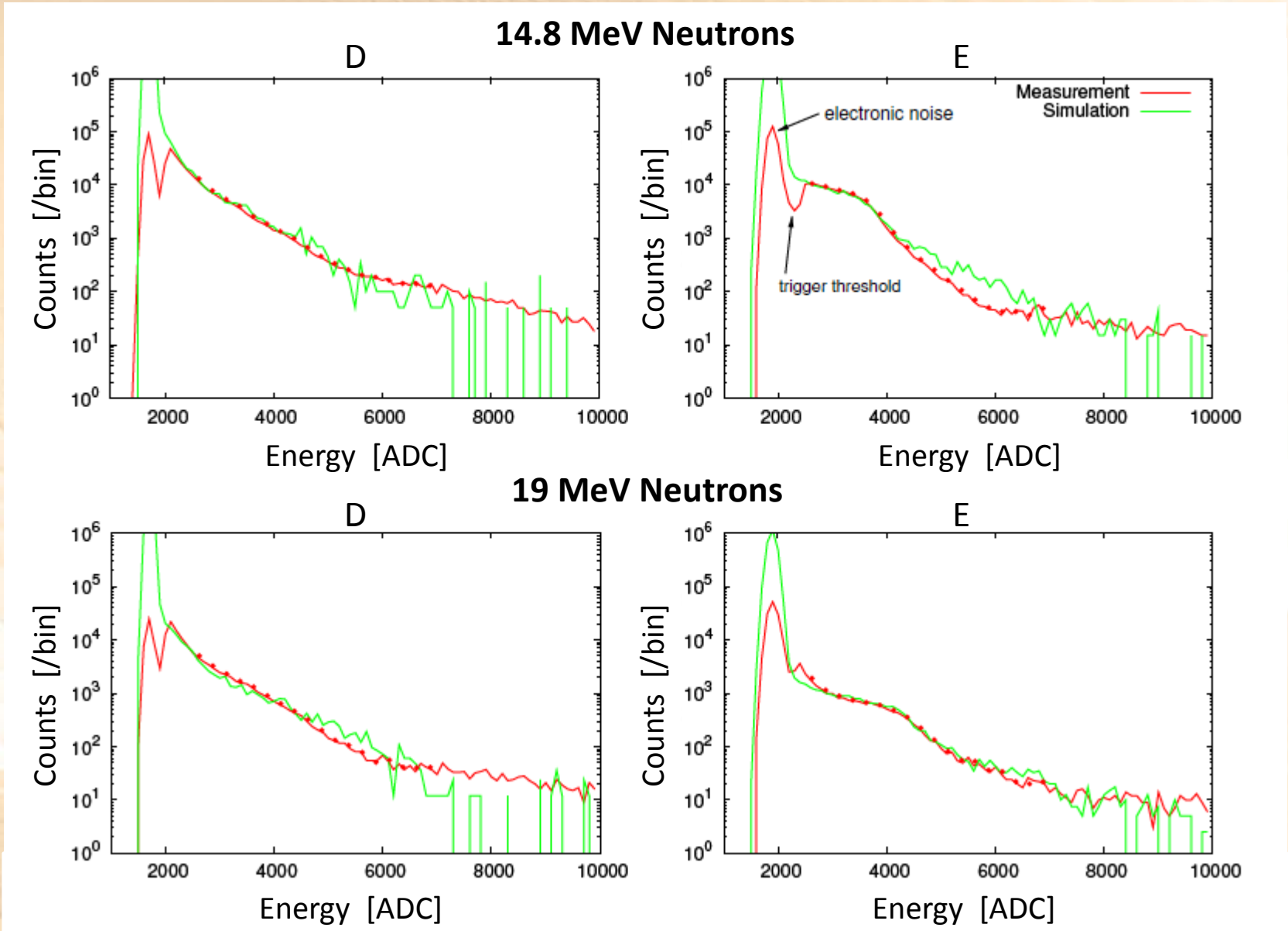


Finding the (*global*) minimum

- L-BFGS-B Brodyden-Fletcher-Goldfarb-Shanno algorithm finds a *local* minimum

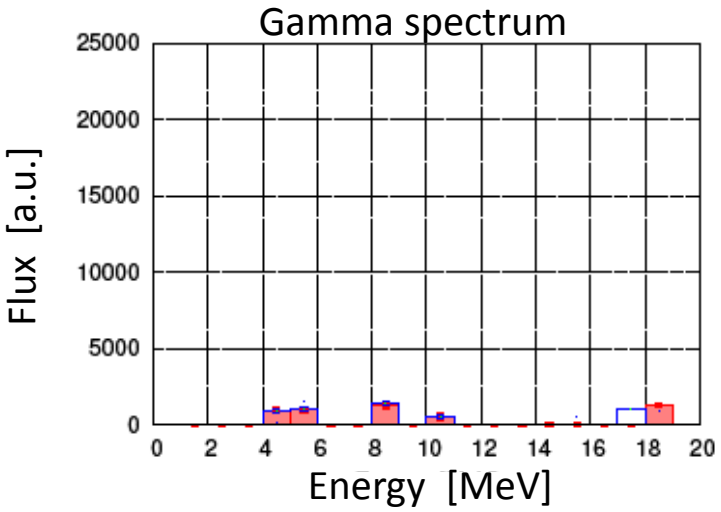
- Select *reasonable* initial guesses (E.g. power laws)
- Select the best result from all initial guesses
- Add some noise to the solution and try again
- Repeat untill the solution does not improve anymore

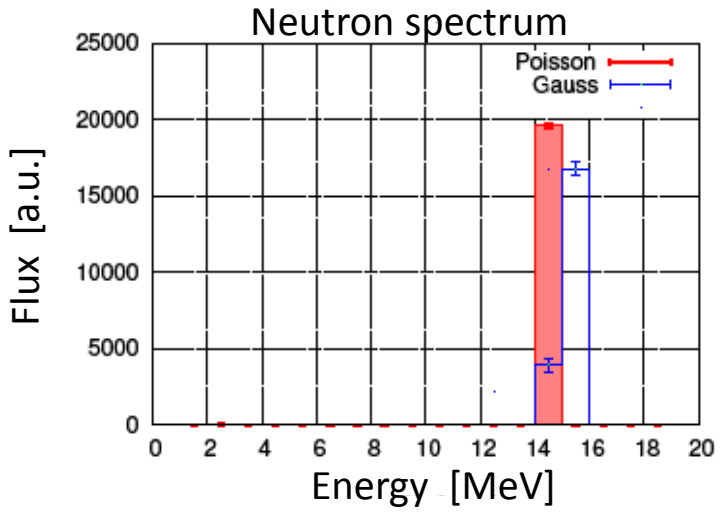
Verification with calibration measurements



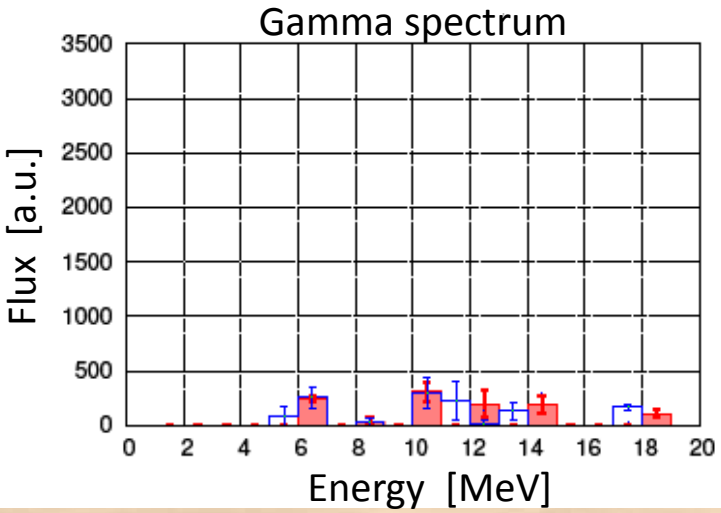
Verification with calibration measurements

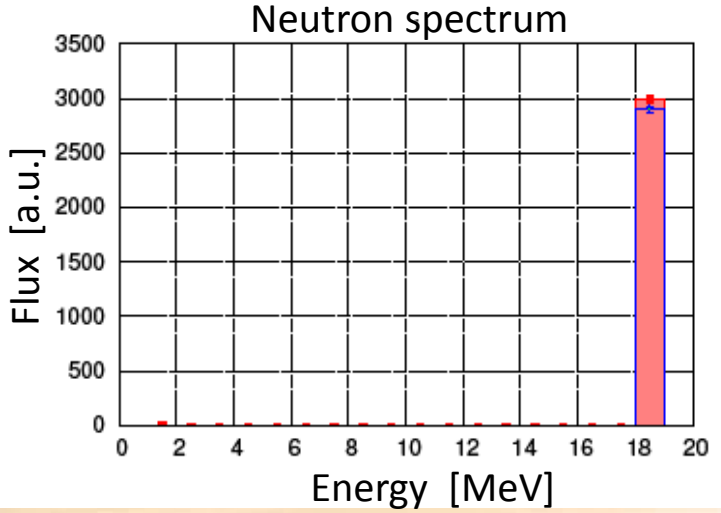
14.8 MeV Neutrons



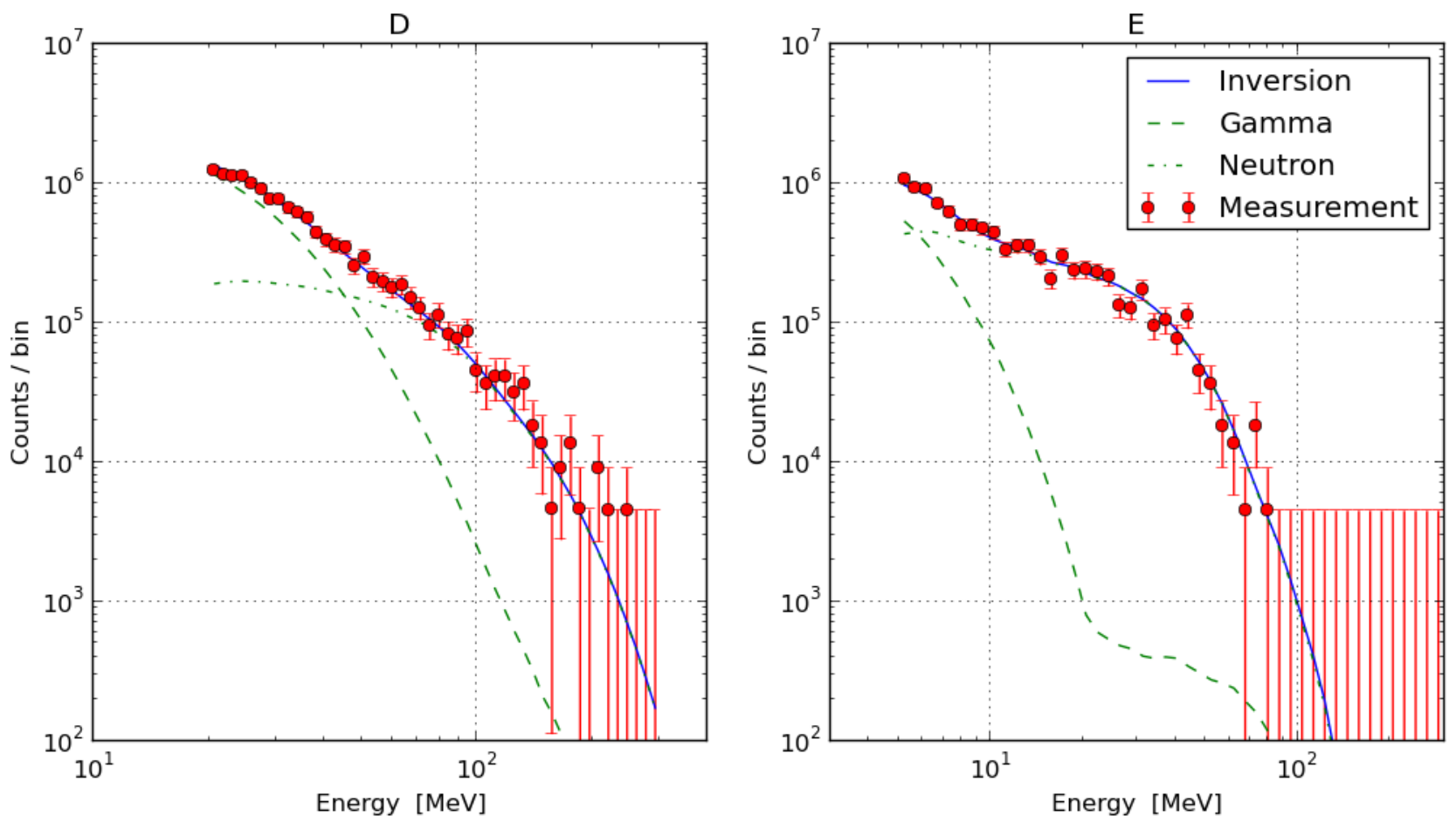


19 MeV Neutrons

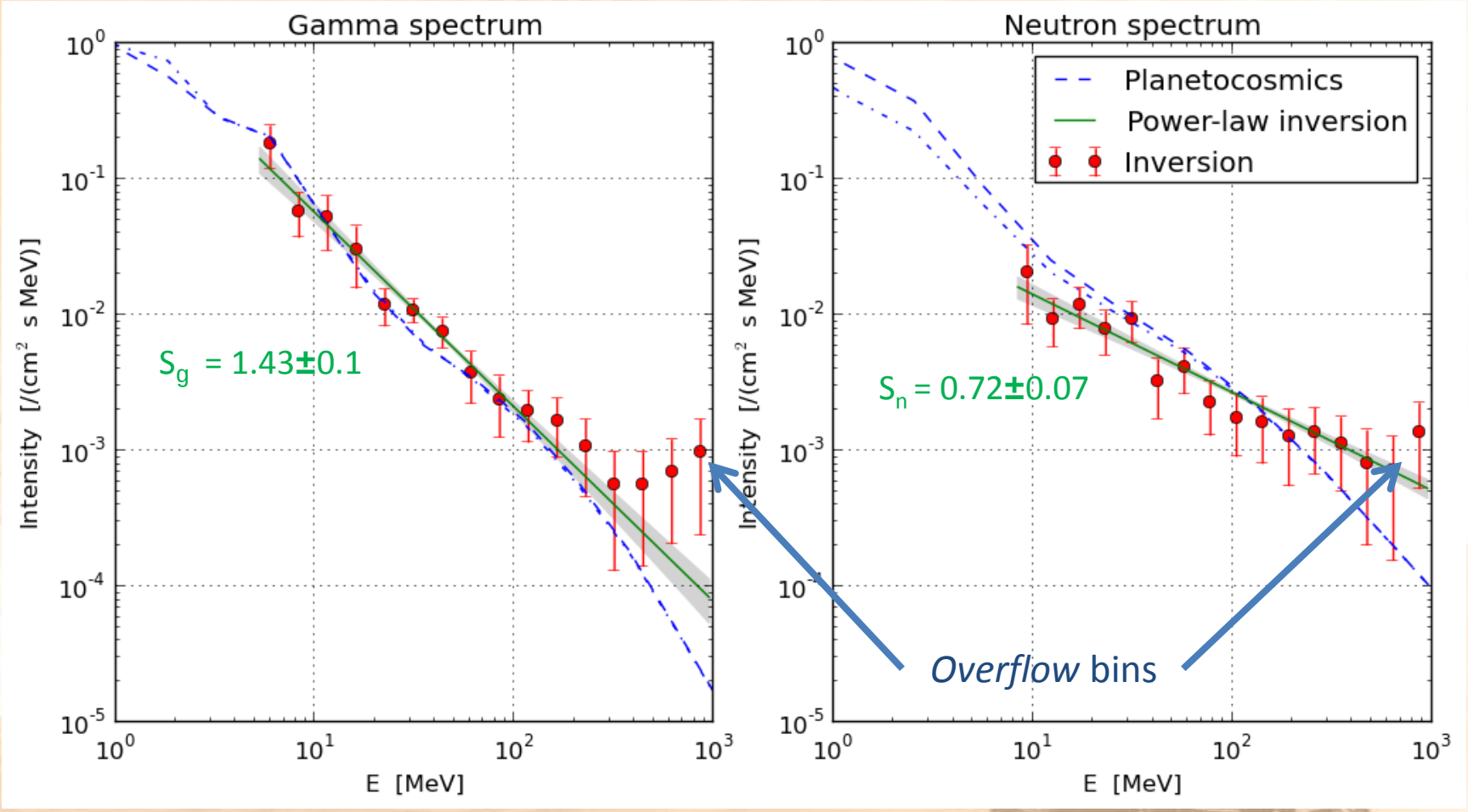




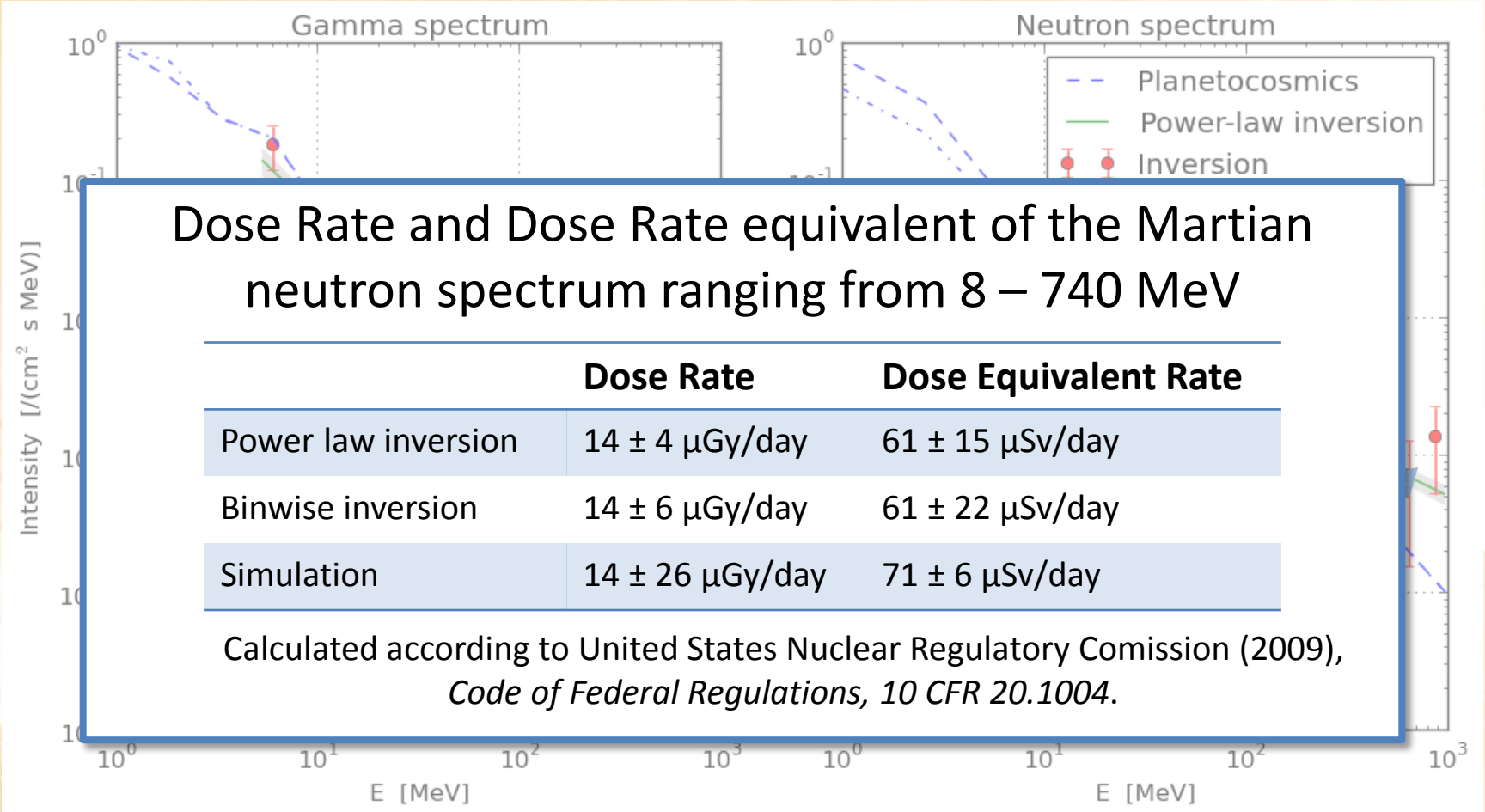
Neutral particle measurements (Sol 1-194) from the Martian surface



The Martian Gamma and Neutron spectra



The Martian Gamma and Neutron spectra

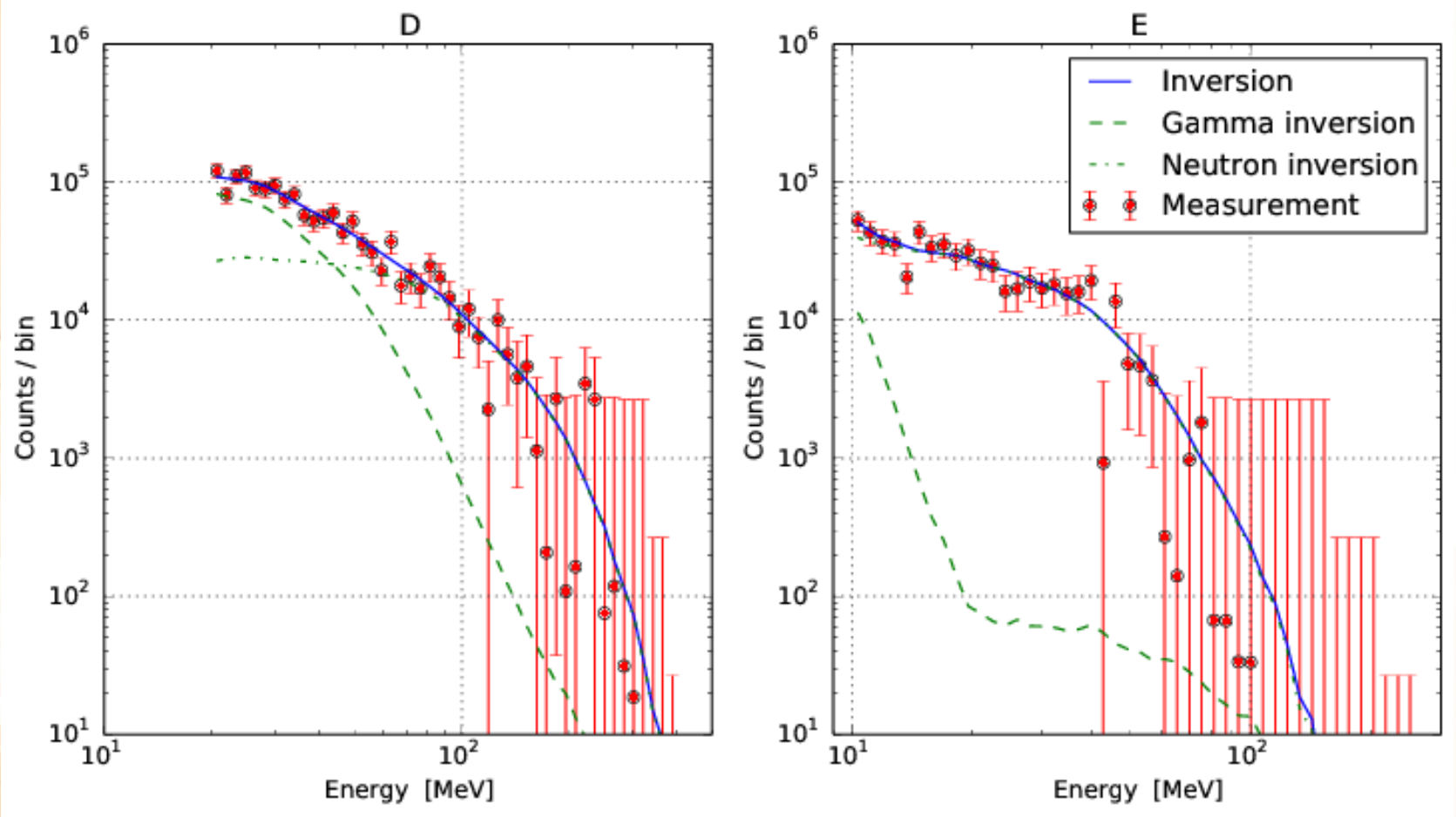


Dose Rate and Dose Rate equivalent of the Martian neutron spectrum ranging from 8 – 740 MeV

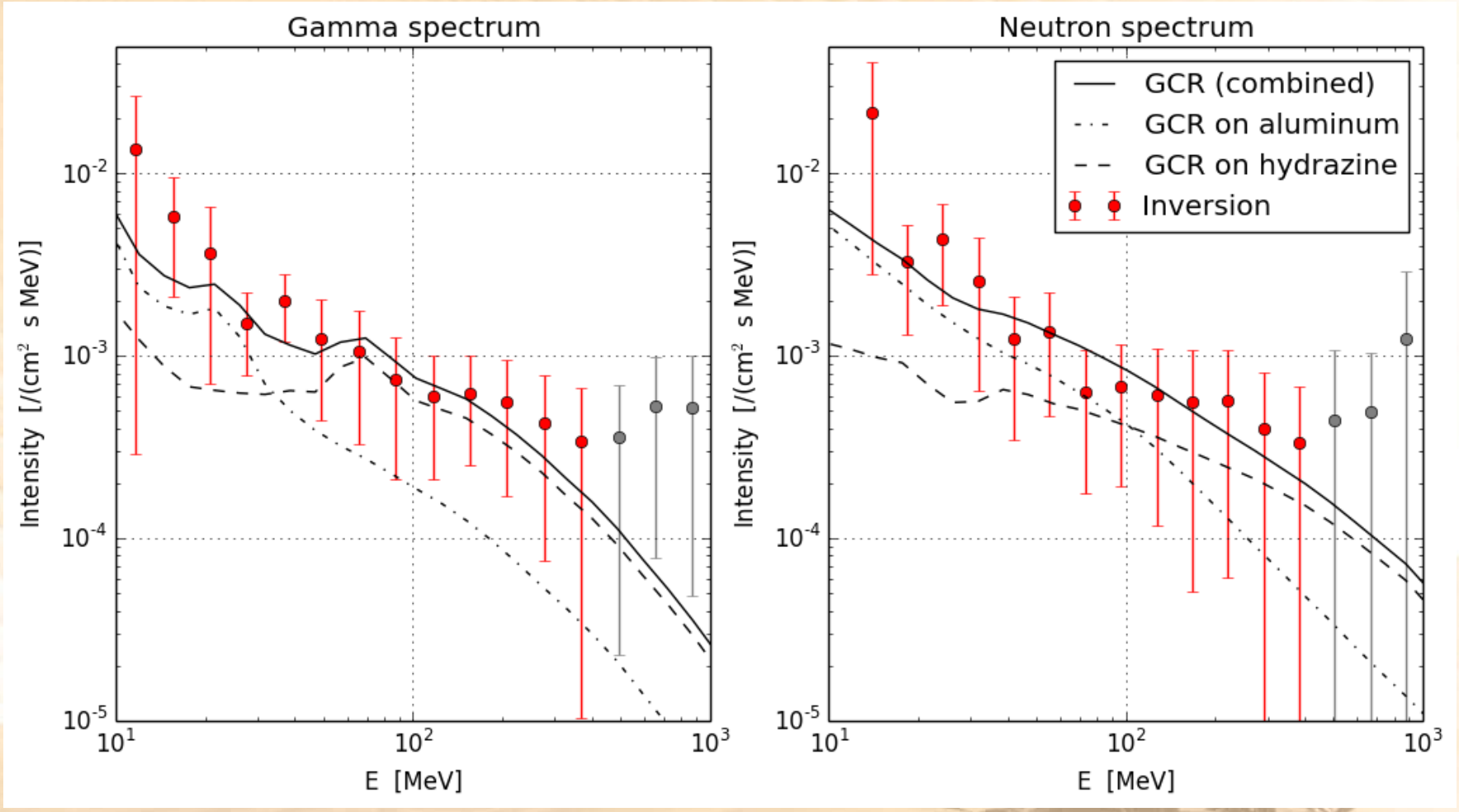
	Dose Rate	**Dose Equivalent Rate**
Power law inversion	14 ± 4 µGy/day	61 ± 15 µSv/day
Binwise inversion	14 ± 6 µGy/day	61 ± 22 µSv/day
Simulation	14 ± 26 µGy/day	71 ± 6 µSv/day

Calculated according to United States Nuclear Regulatory Comission (2009), *Code of Federal Regulations, 10 CFR 20.1004*.

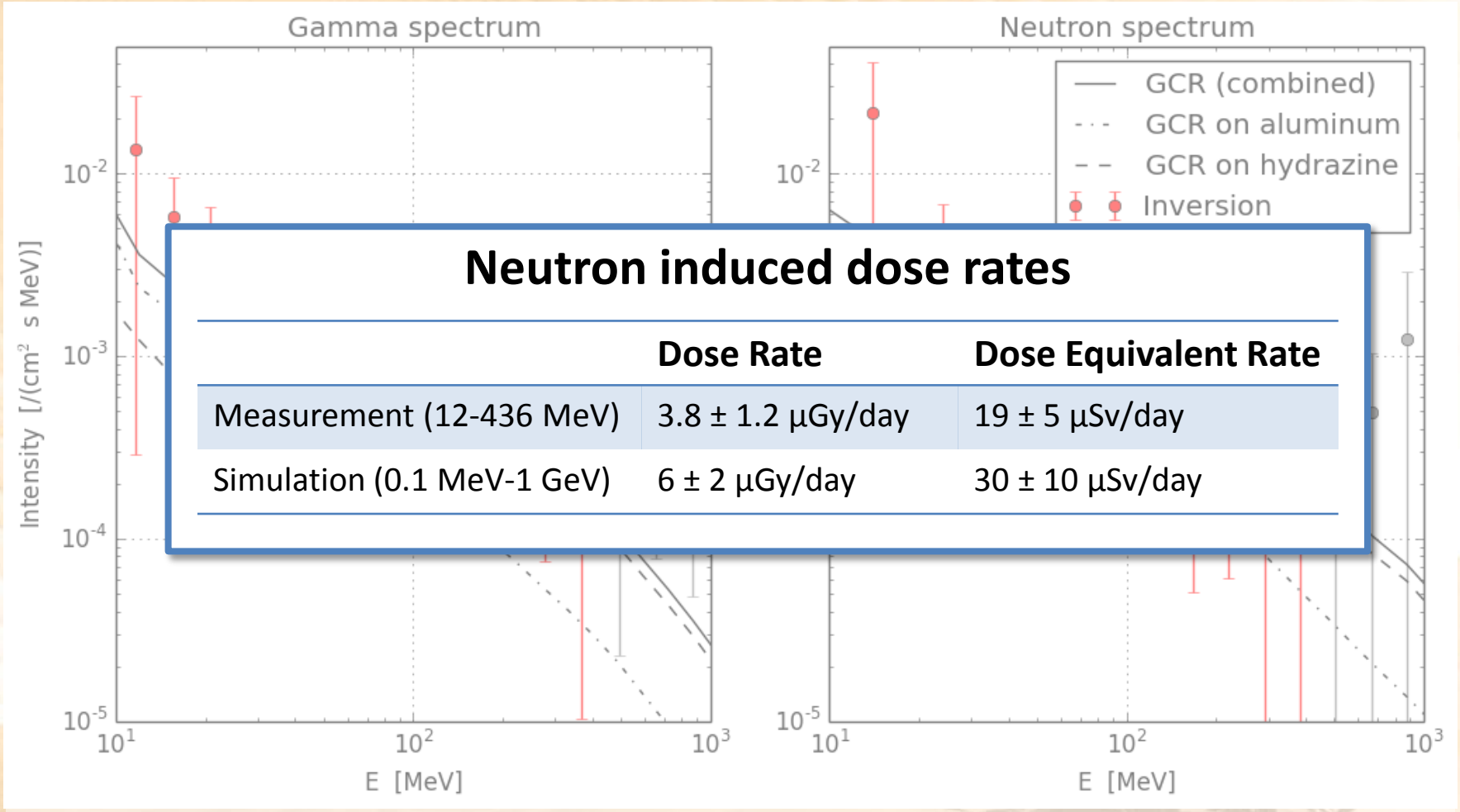
Neutral particle measurements during cruise phase



Gamma and Neutron spectra from cruise phase



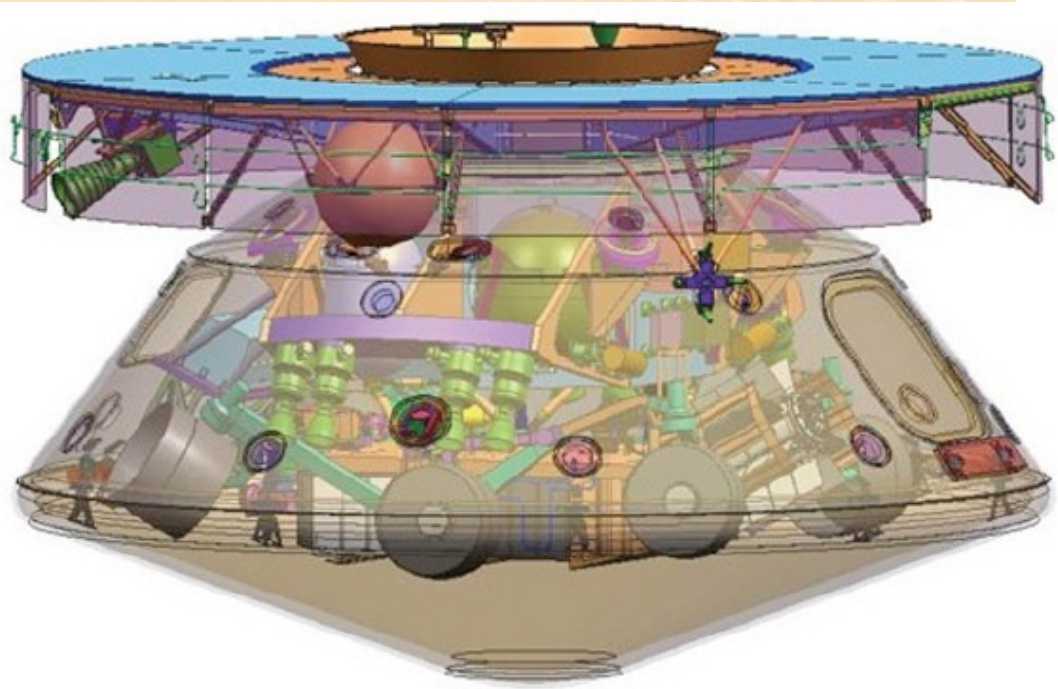
Gamma and Neutron spectra from cruise phase

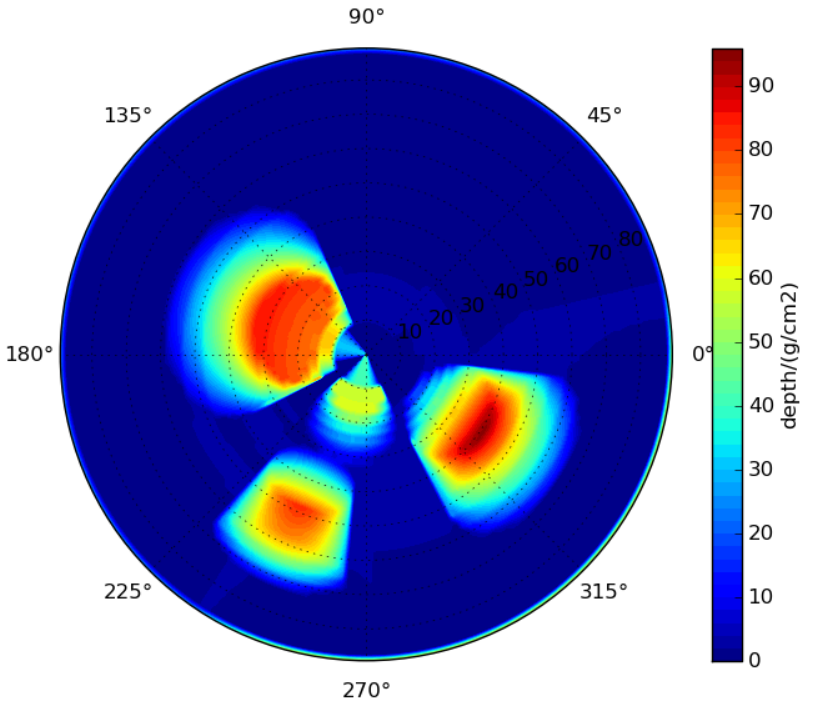


Neutron induced dose rates

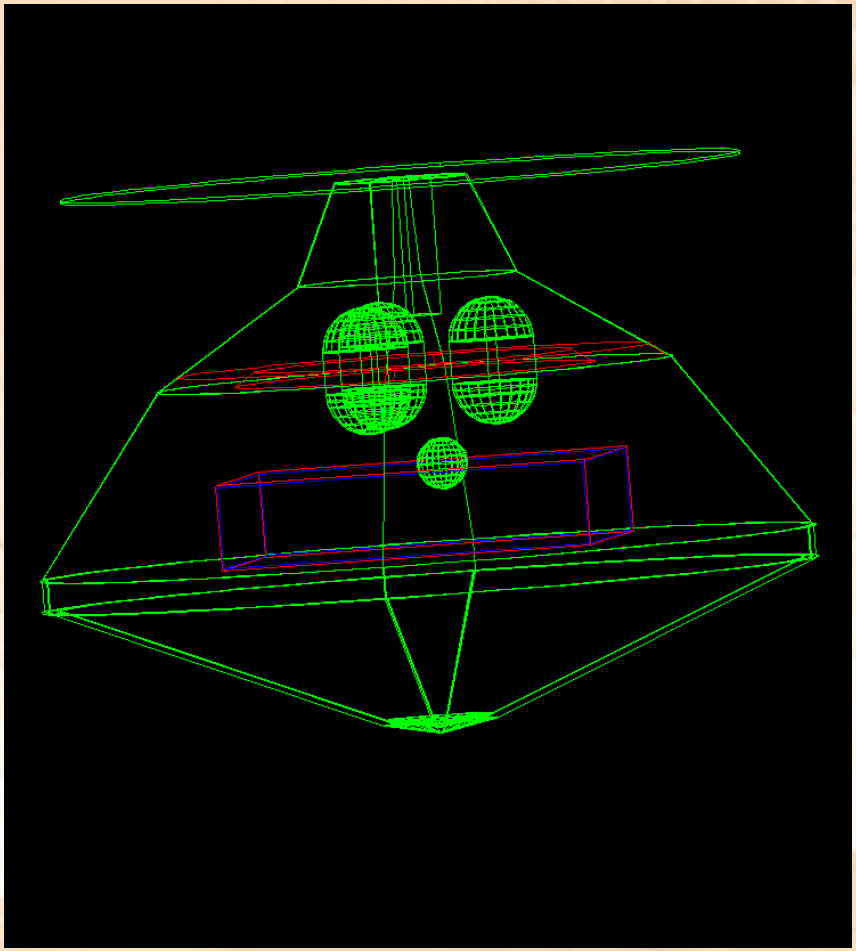
	Dose Rate	Dose Equivalent Rate
Measurement (12-436 MeV)	3.8 ± 1.2 µGy/day	19 ± 5 µSv/day
Simulation (0.1 MeV-1 GeV)	6 ± 2 µGy/day	30 ± 10 µSv/day

The MSL spacecraft





Modelling the MSL spacecraft



- Geometry, mass and composition, all based on information from Wikipedia and JPL websites
- Shielding, made to fit given shielding distribution.

Furure Work

- Apply the inversion to onboard neutral particle histograms *(ongoing)*
- Simulate neutron production onboard the MSL spacecraft *(ongoing)*
- Investigate temporal variations of the neutron flux on the Martian surface *(ongoing)*
- Inversion procedure will be applied to ISSRAD *(**NIISS** - Neutron Inversion for ISS)*

Thank you for your attention!

Inversion procedure:

Köhler, J., et al., 2011, *Inversion of neutron/gamma spectra from scintillator measurements*, NIM-B

Surface measurement:

Köhler, J., et al., 2014, *Measurements of the neutron spectrum on the Martian surface with MSL/RAD*, Journal of Geophysical Research

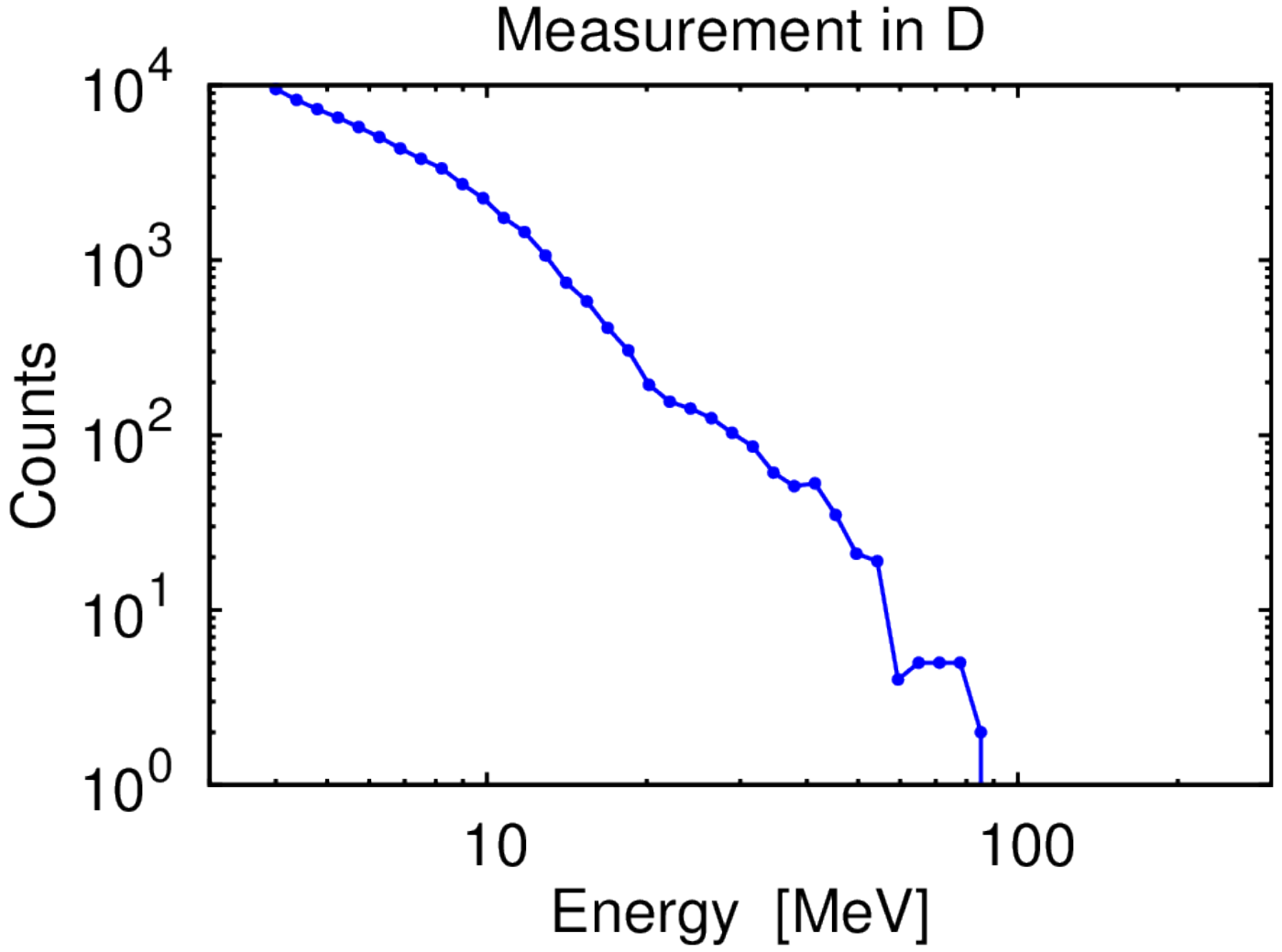
Cruise measurement:

Köhler, J. et al., 2015, *Measurements of the neutron spectrum in transit to Mars on the Mars Science Laboratory*, Life sciences and space research

Information on error estimation:

Ask me for my backup slides

How to determine the error bars



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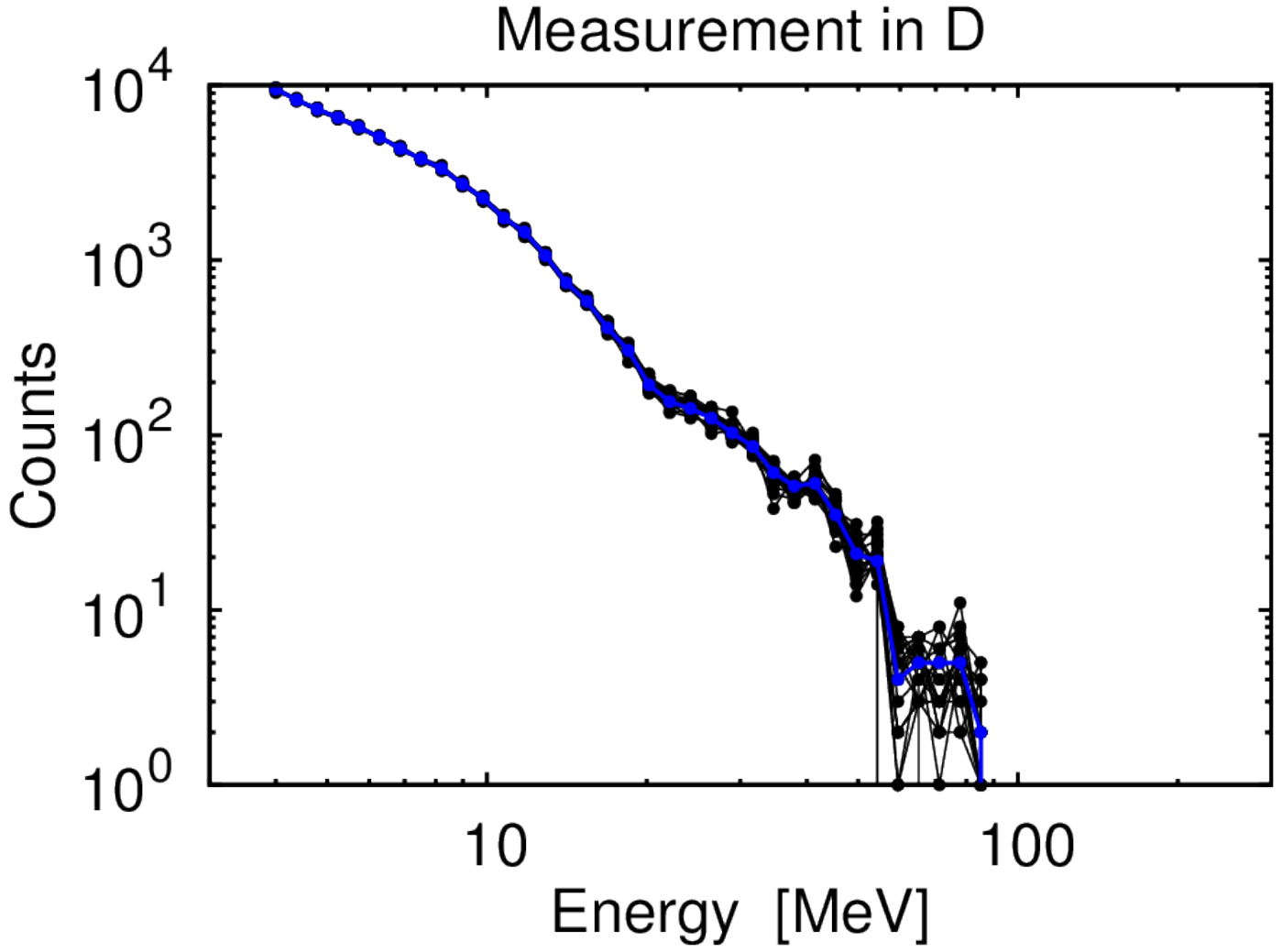

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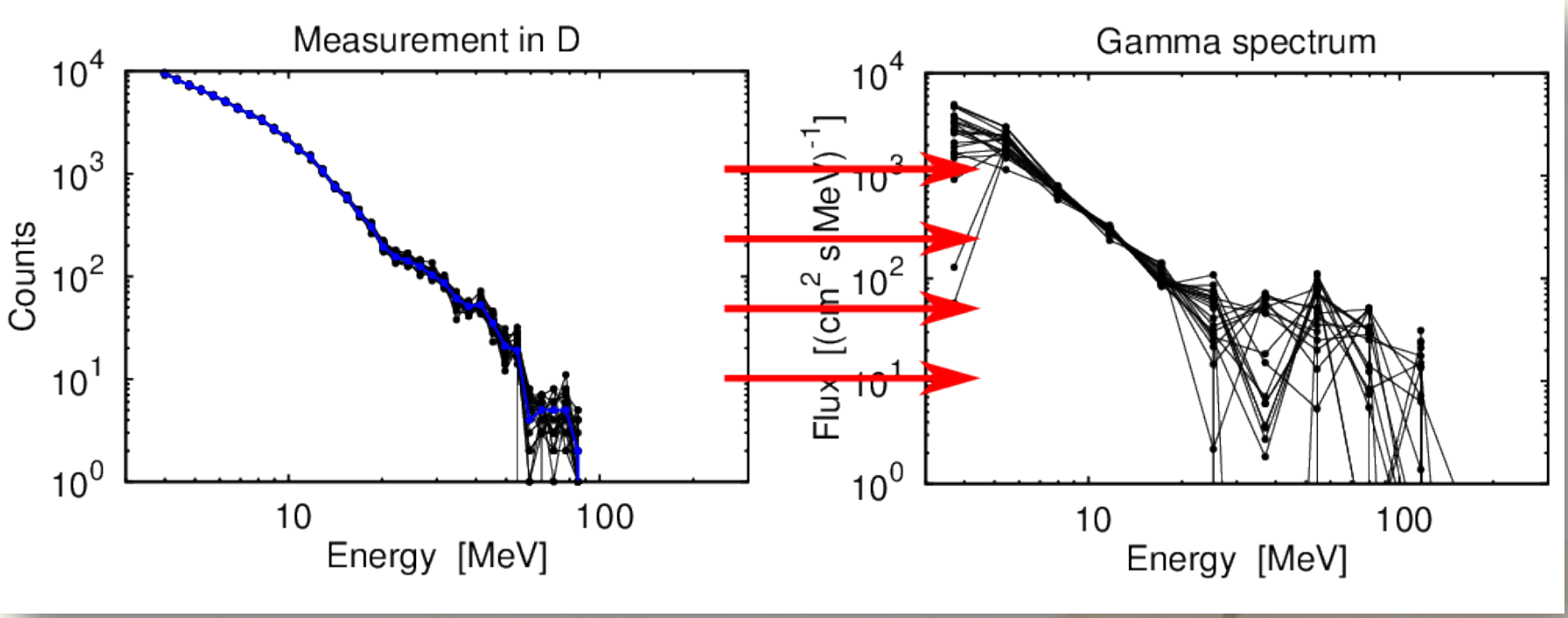

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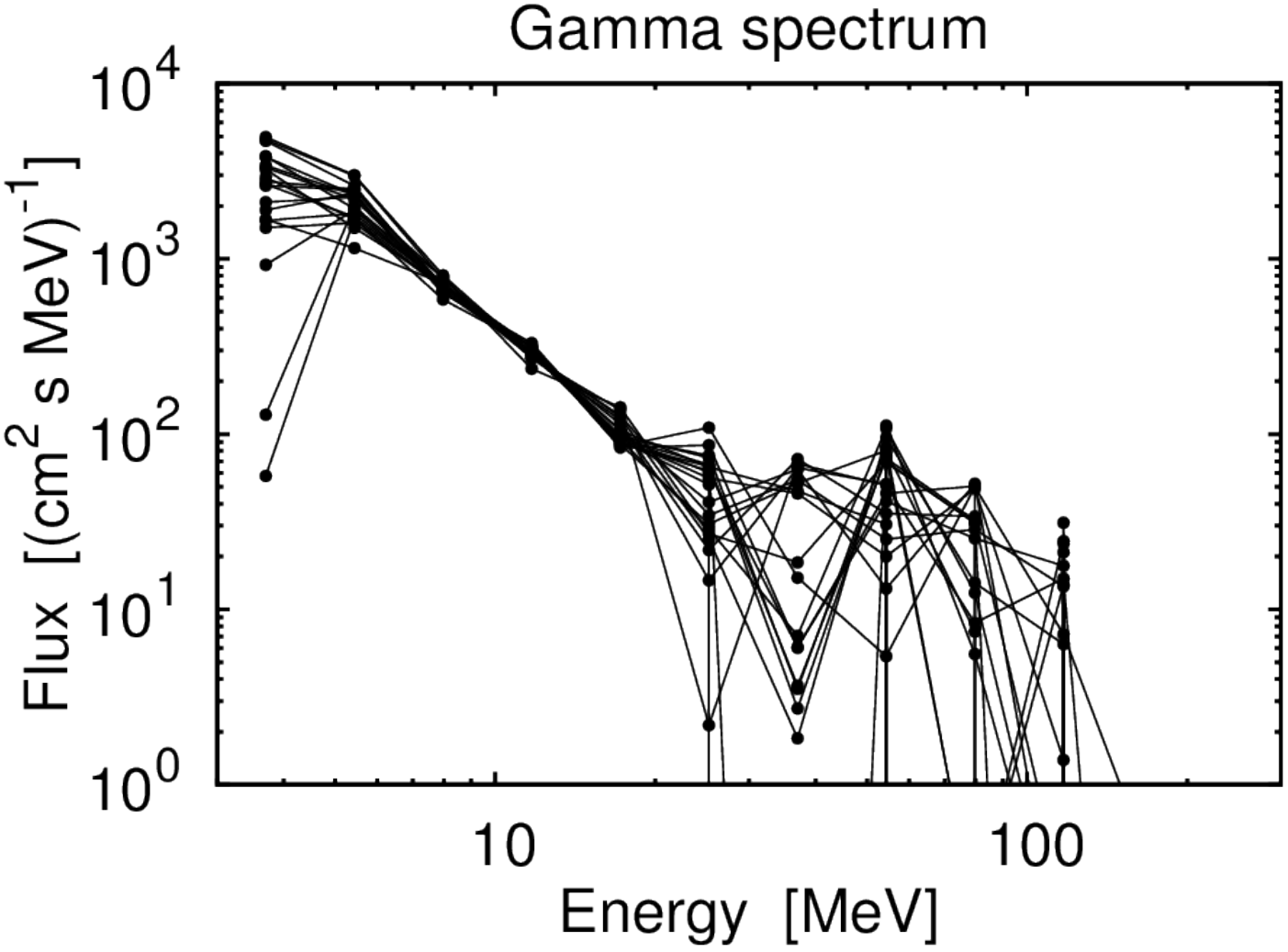

How to determine the error bars