Space Science & Technology
Rutherford Appleton Laboratory

Imperial College London

Modelling of the Highly Miniaturised Radiation Monitor

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On behalf of the HMRM collaboration
(STFC Rutherford Appleton Laboratory & Imperial College London)

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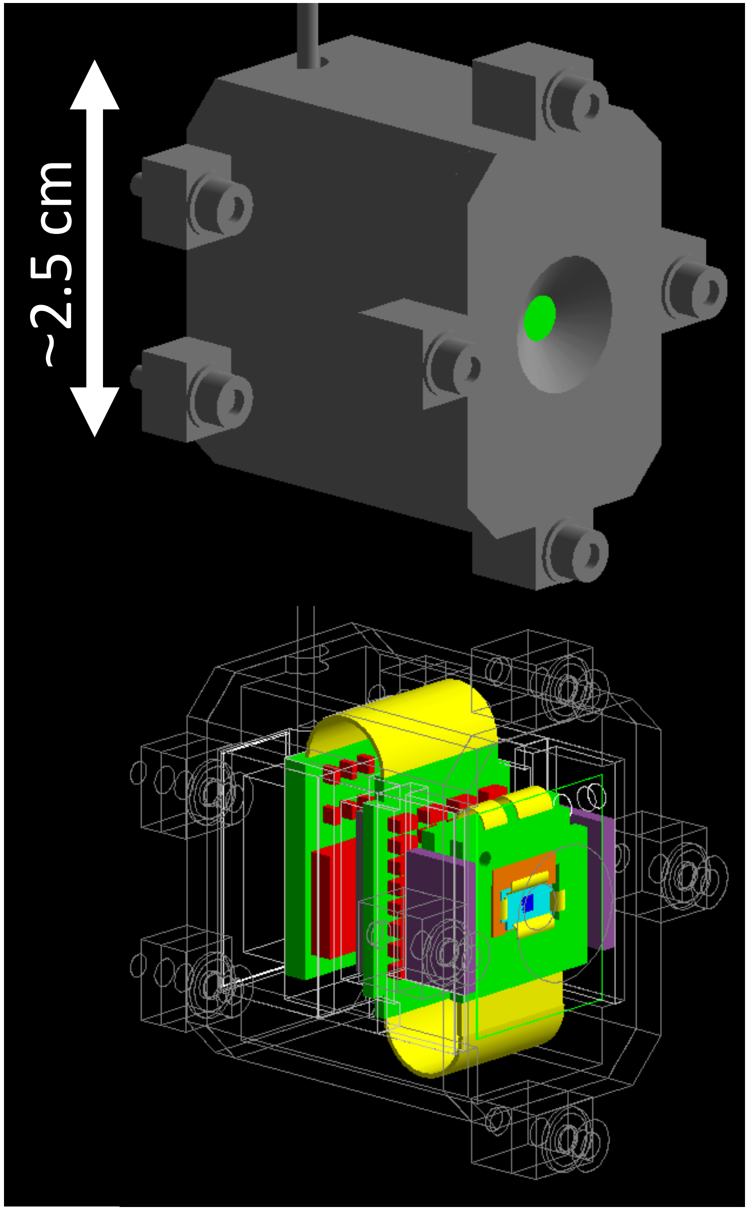
HMRM operation summary

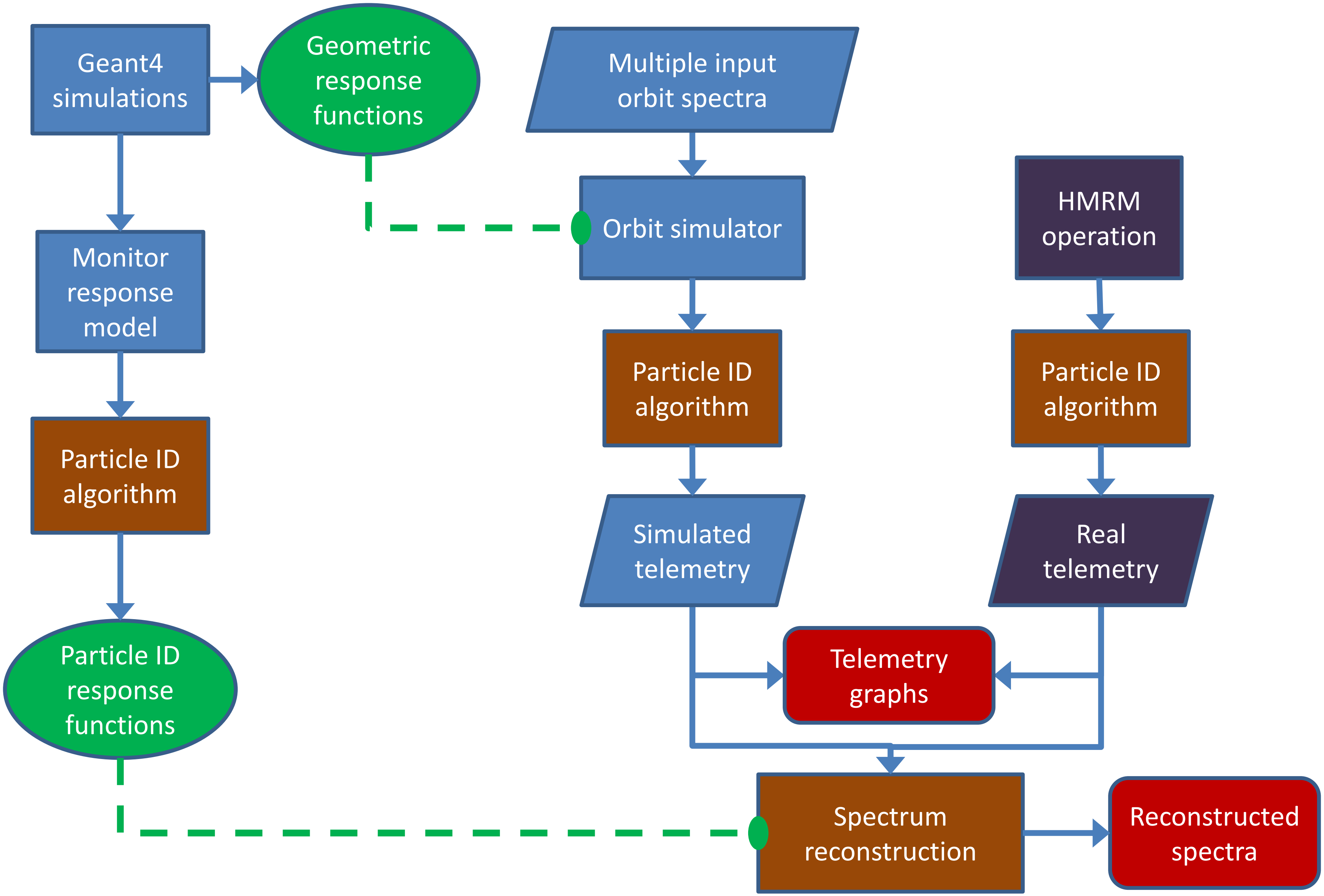
- Miniature monitor for energetic charged particles in a range of earth orbits
- Sensors read out at 10 kHz: up to 100 μs exposure time, divisible down to 3.125 μs
- FPGA executes particle ID algorithm on each read out
- Particle data output:
  - Count rate, dose rates
  - Identified particle rates

  } In monitor, in real-time

  - Spectrum reconstruction (in development) ground segment, offline



Modelling overview



Particle identification

1. Pixel signals summed to find total charge for each sensor

2. Event allocated to one of 32 channels via a lookup table. Some channels are of high purity

3. Table imposes coincidence, and anticoincidence constraints

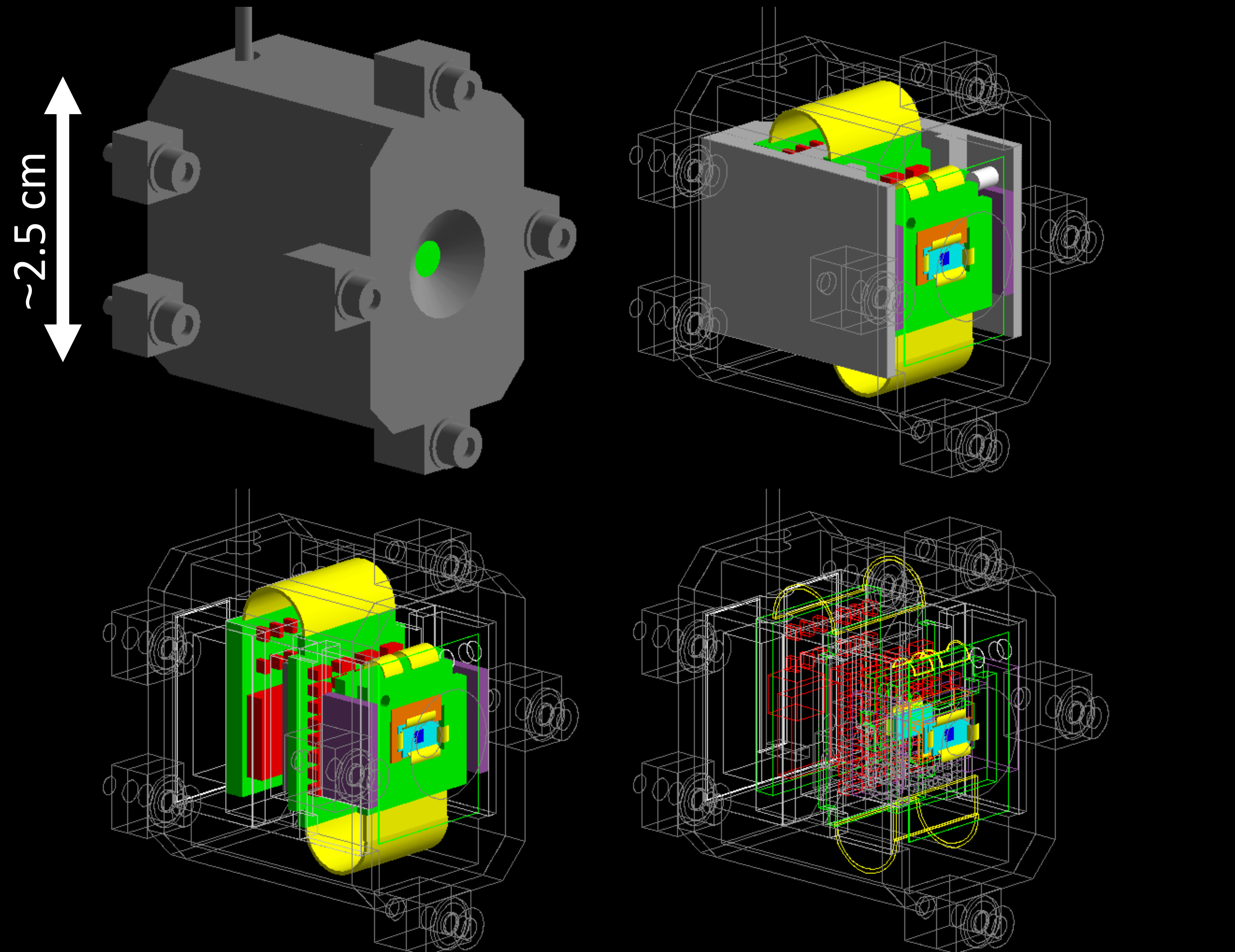
4. No-hit event counter informs integration time "shuttering"

5. Table chosen through:
   - Theory (similar to ΔE,E detectors[1] [2] [3])
   - Experiment
   - **Simulation**

Channel	Sensor 1		Sensor 2		Sensor 3		Sensor 4		ID
	L1	U1	L2	U2	L3	U3	L4	U4	
1	0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.2	No Hit
2	361.0	624.2	23.4	208.8	0.0	0.2	0.0	0.2	Proton 2.5 - 4.0 MeV
3	23.4	69.8	23.4	69.8	23.4	40.4	0.0	0.2	Proton 20 - 60 MeV
4	4.2	6.6	4.2	6.6	4.1	11.9	1.5	13.5	Proton 180 - 500 MeV
5	4.5	13.5	1.5	2.6	0.0	0.2	0.0	0.2	Electron > 0.1 MeV
6	1.5	2.6	1.5	2.6	2.6	4.5	0.0	0.2	Electron > 0.5 MeV
7	1.5	7.8	1.5	2.6	0.9	1.5	0.0	0.2	Electron > 1.0 MeV
8	13.5	23.4	0.0	0.2	0.0	0.2	0.0	0.2	Mixed
9	120.7	208.8	120.8	208.8	0.0	0.2	0.0	0.2	Mixed

Part of an example table (scaled units)

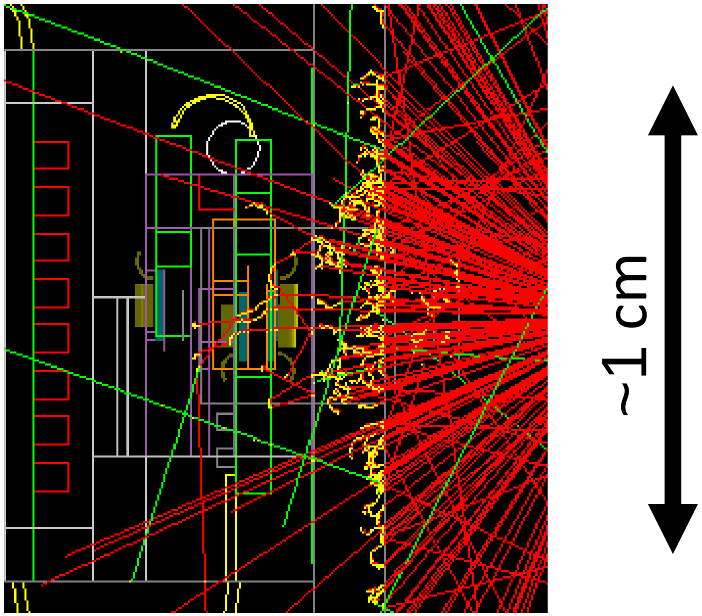
Geant4 simulation geometry



Geant4 simulation

- Highly accurate Monte Carlo, extra validation with data for
  - Energy losses in thin films[4] [5]
  - Backscattering angular distributions [6]
- More than 10^9 primaries simulated
- Electrons: 0.04 – 6 MeV
- Protons: 1 – 500 MeV
- Obtain sensor energy deposits as a function of incident particle species, energy, angle

HMRM sensor region



1 MeV electrons demonstrating front shielding and acceptance

Response functions (RFs)

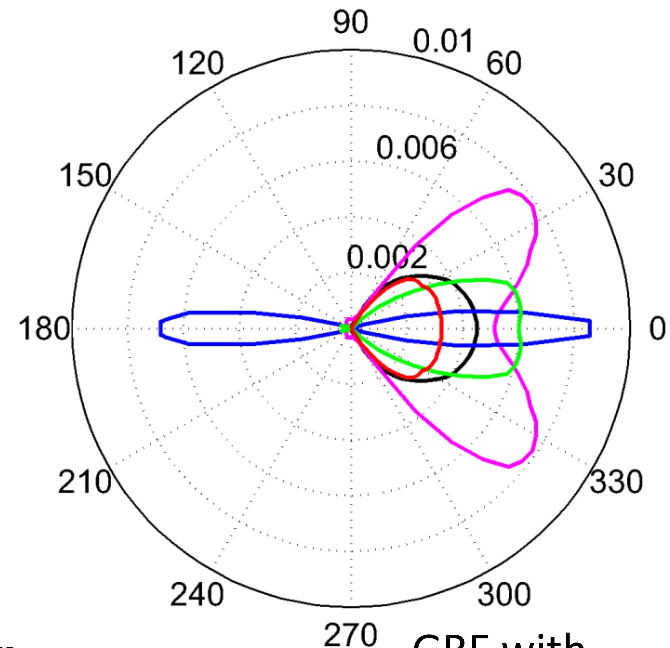
- Avoid the need for further Geant4 simulations
- Doubly differential in particle energy and solid angle, per unit incident particle fluence
- Geometric RF
  - Probability of a hit to each or any sensor
- Energy deposit RF
  - Energy deposit p.d.f for each sensor, per hit

Used in orbit simulator

- Particle ID RF
  - Probability of obtaining a count in each channel
  - Assuming a single hit (no pile up)

Used in spectrum reconstruction

Particle	Energy range / MeV	Sensor coincidence
Proton	1 – 10	1
	10 – 60	1 + 2 + 3
	60 – 500	1 + 2 + 3 + 4
Electron	0.04 – 0.3	1
	1 - 6	1 + 2



GRF with angle / deg

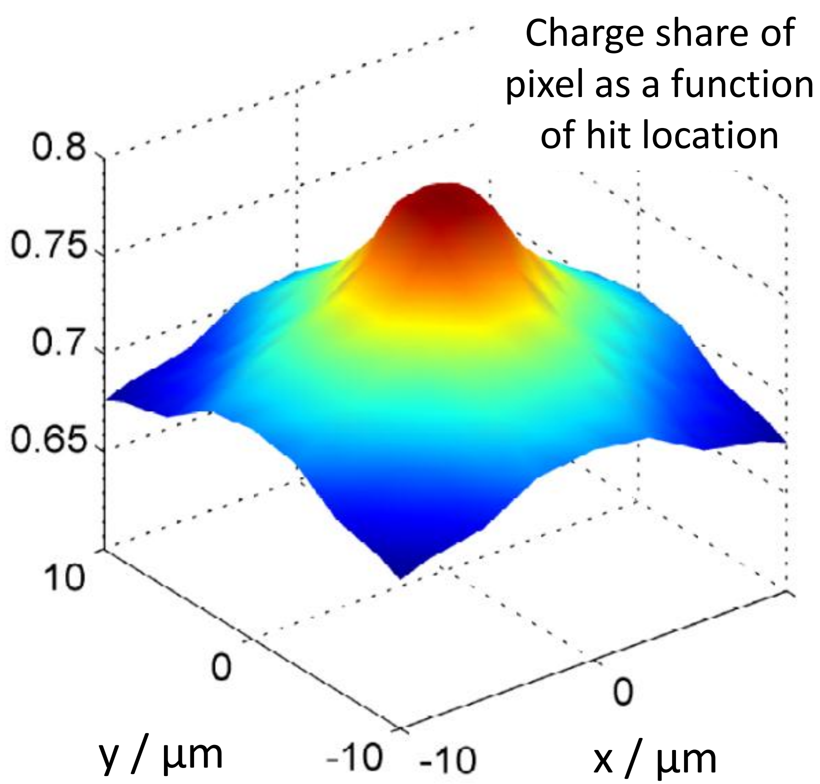
Monitor response model

Convert Geant4 energy deposits into realistic signal by introducing:

1. **Pixellation effects**: lateral charge diffusion equation
2. **Noise**: simple Gaussian model
3. **Analogue to digital conversion:** 7 programmable comparator levels

Diffusion and noise model parameters fitted via experiment

Proposed 2D charge diffusion model result using arbitrary parameters



Orbit simulator

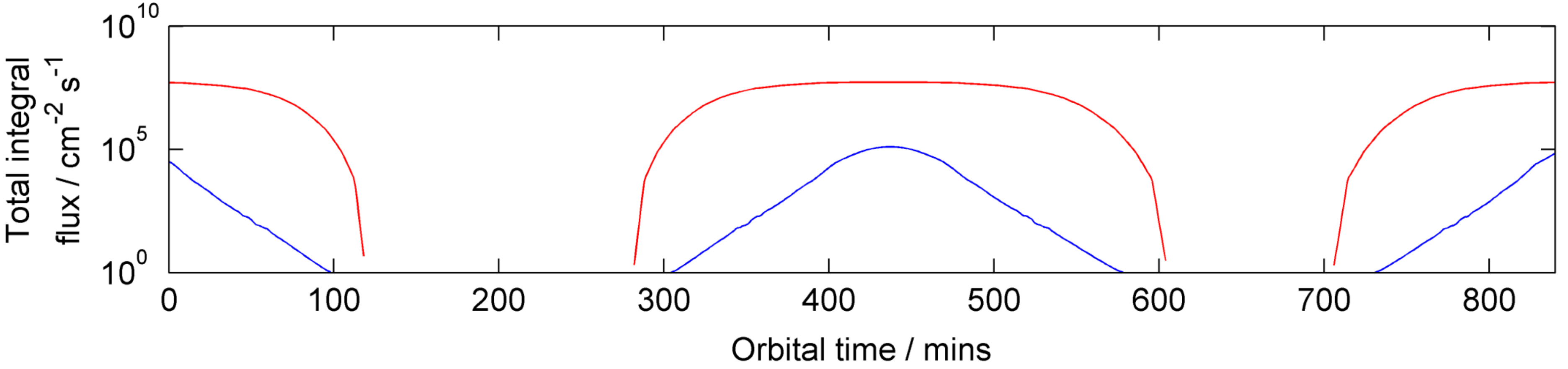
- Introduce:
  - Time-dependence (transient spectra, relative motion, pile up effects, exposure “shuttering”)
  - Multiple simultaneous species and spectral components (trapped particles, GCR, SEP etc) compatible with SPENVIS[7] output files

- At each point in time:

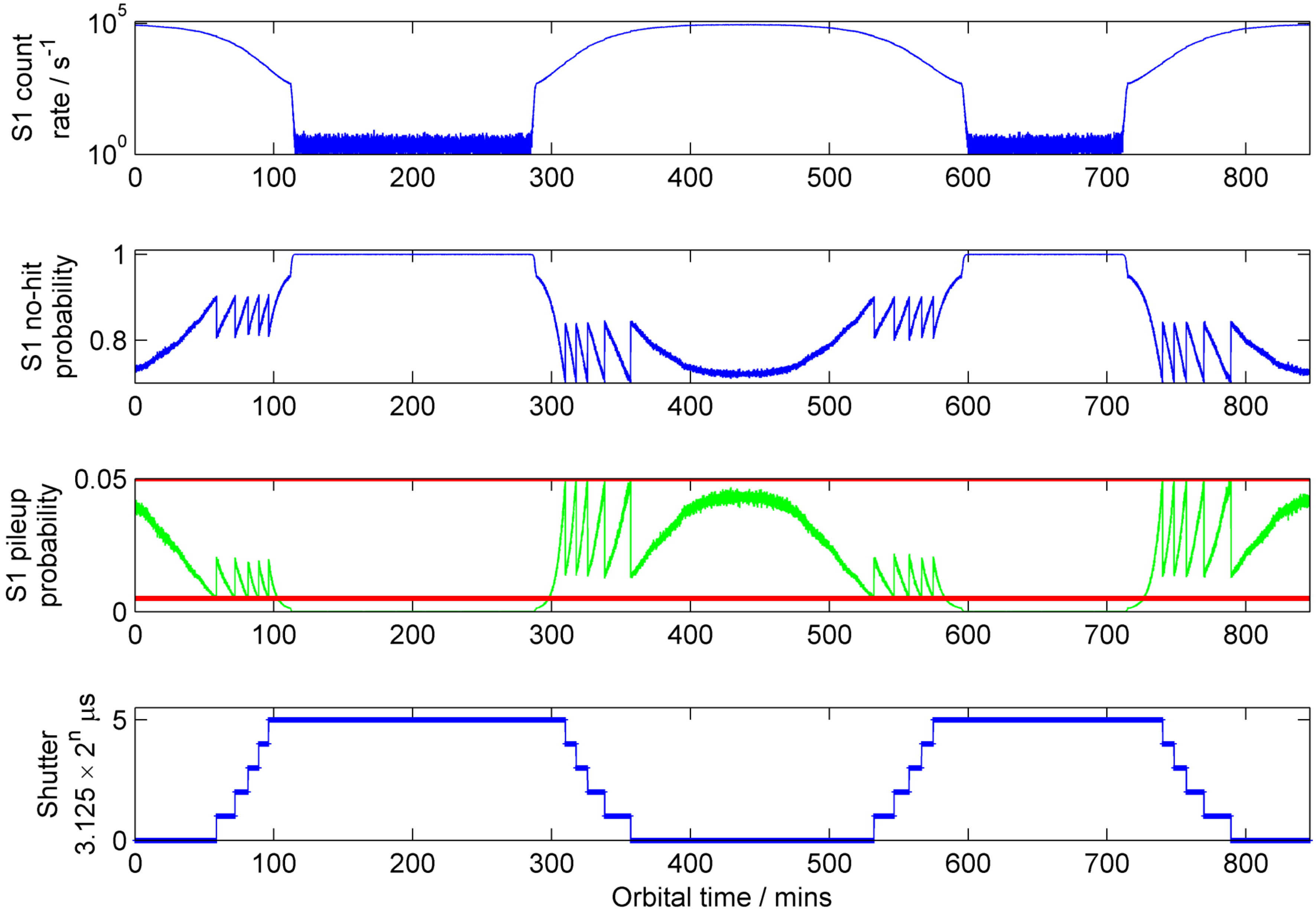
1. Fold response functions with instantaneous incident spectra
2. Monte Carlo sample the resulting distributions
3. Apply monitor response model
4. Execute HMRM algorithm

Orbit simulator: example results

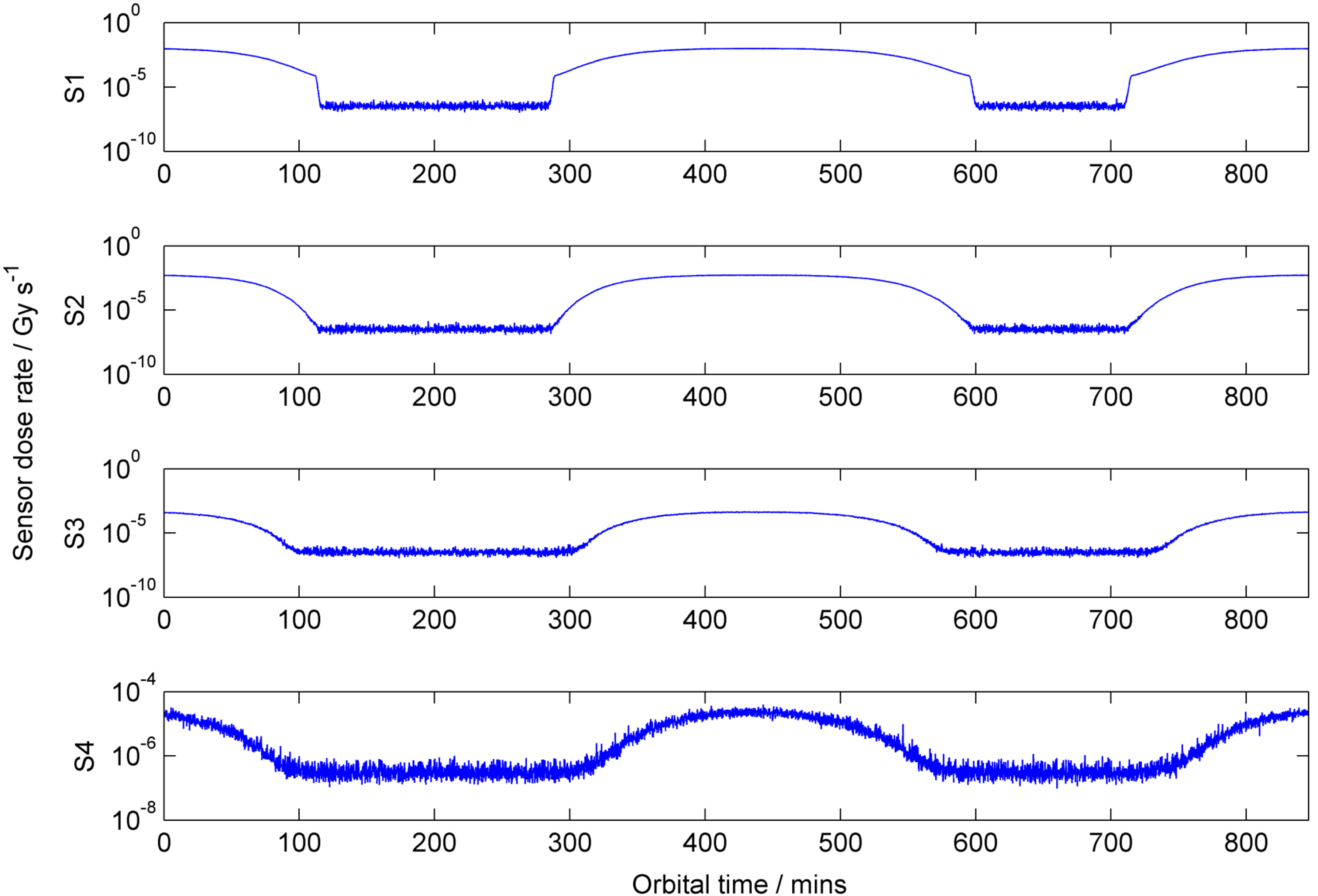
- Example orbit: 23,222 km MEO at 56^{o} inc. (840 min period)
- Assume isotropic fluence, using omnidirectional AP-8 and AE-8 model spectra
- Total integral flux for **protons** and **electrons** shown below (simulator uses full energy spectra).



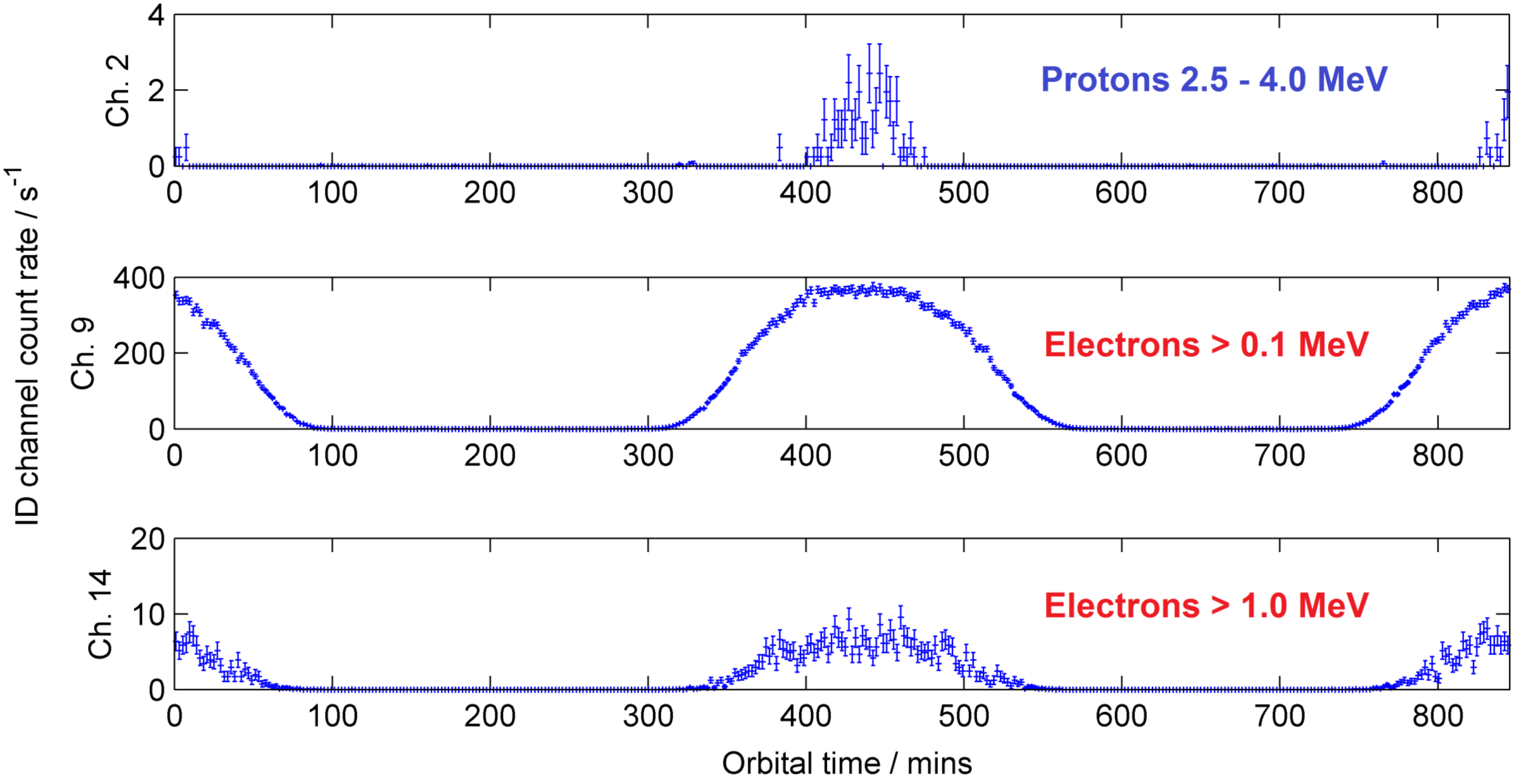
Orbit simulator: example results



Orbit simulator: example results

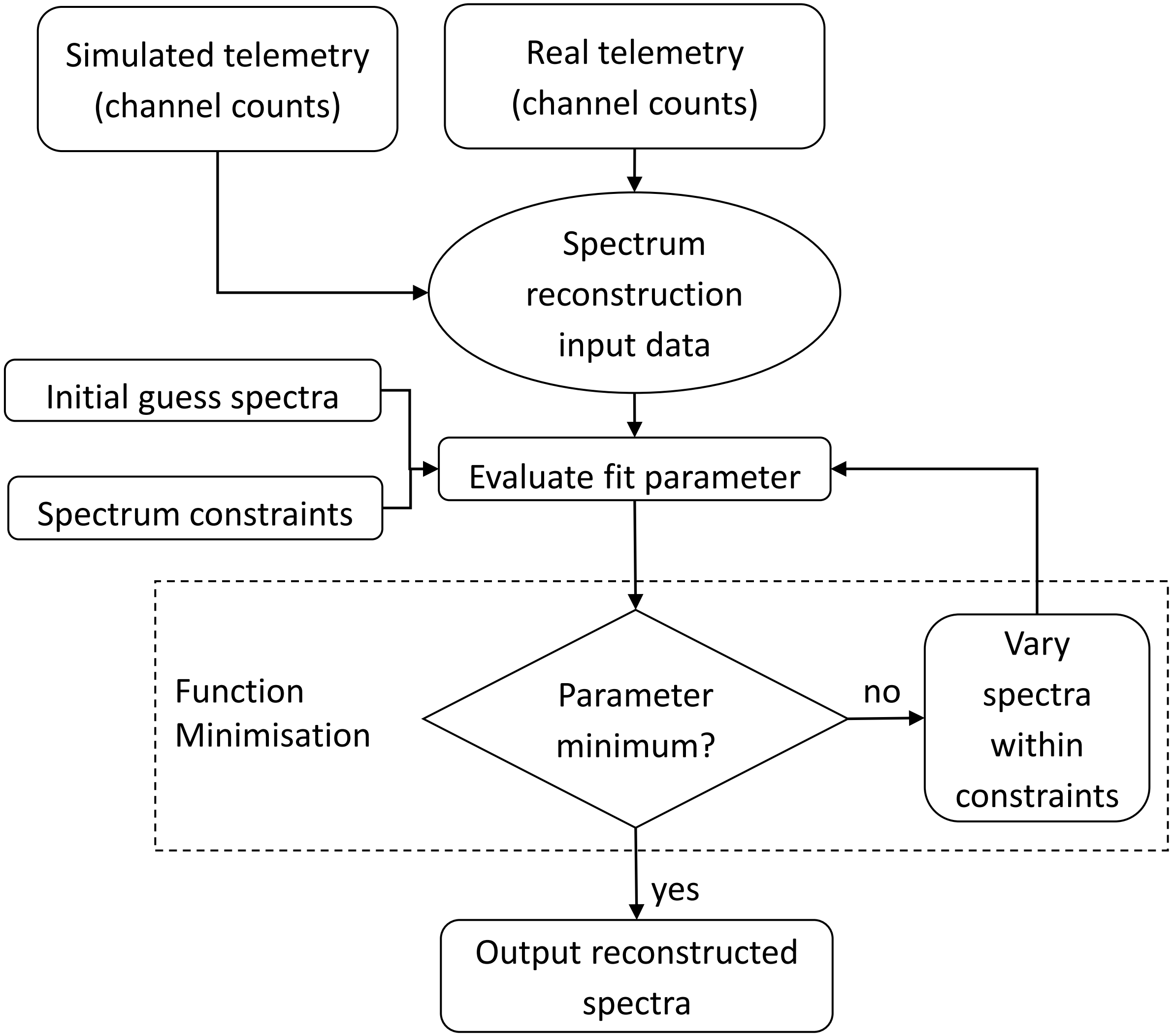


Orbit simulator: example results



Spectrum reconstruction development

- Simplistic matrix method rejected
  - $n = Ms$; $s = M^{-1}n$
  - Intolerant of fluctuations
  - Requires a large number of channels, resulting in small counts

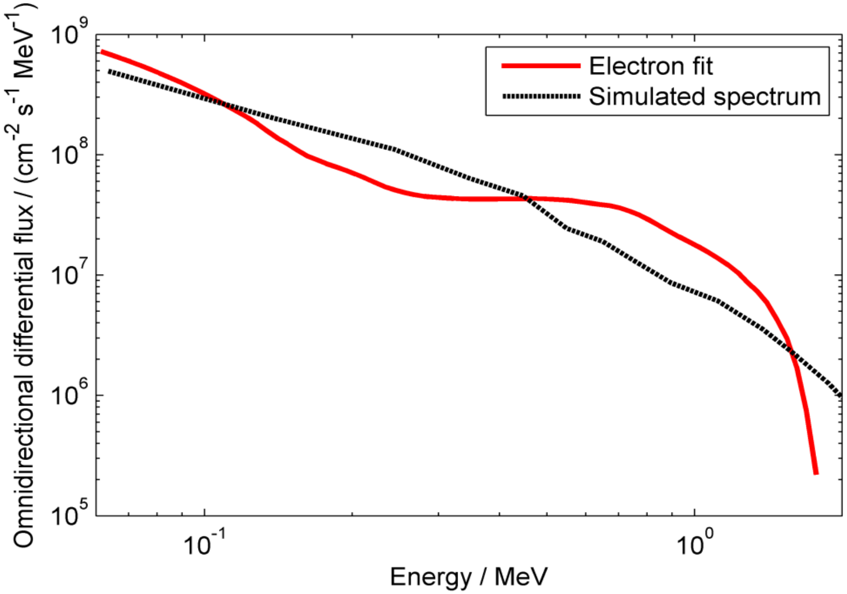


- Proposed method: Iterative fitting with Likelihood or Least Squares parameter

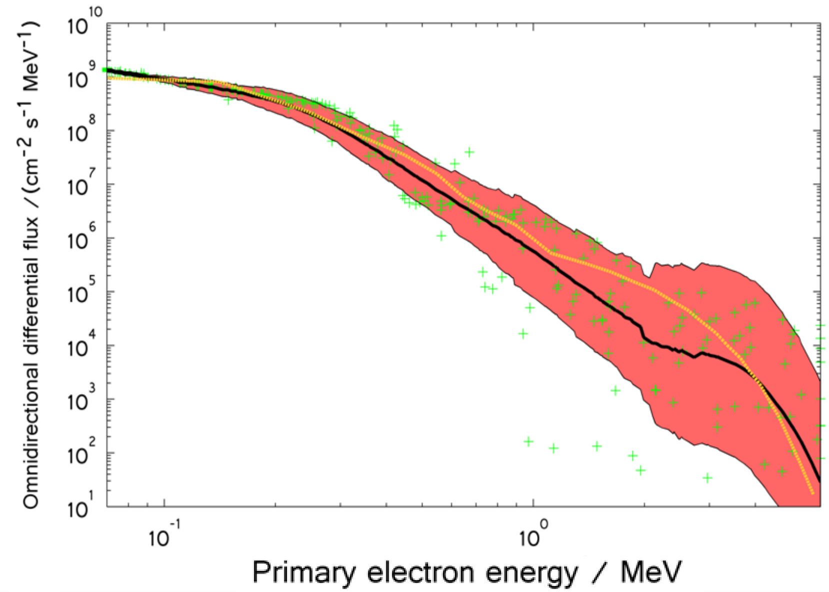
- Electron and proton spectra are simultaneously fitted (combined hypothesis)

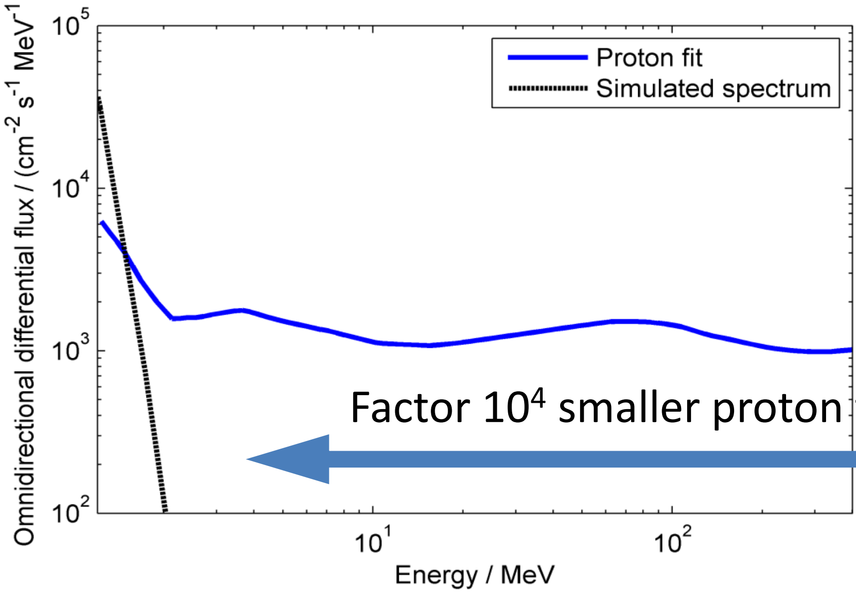
Spectrum reconstruction: initial tests

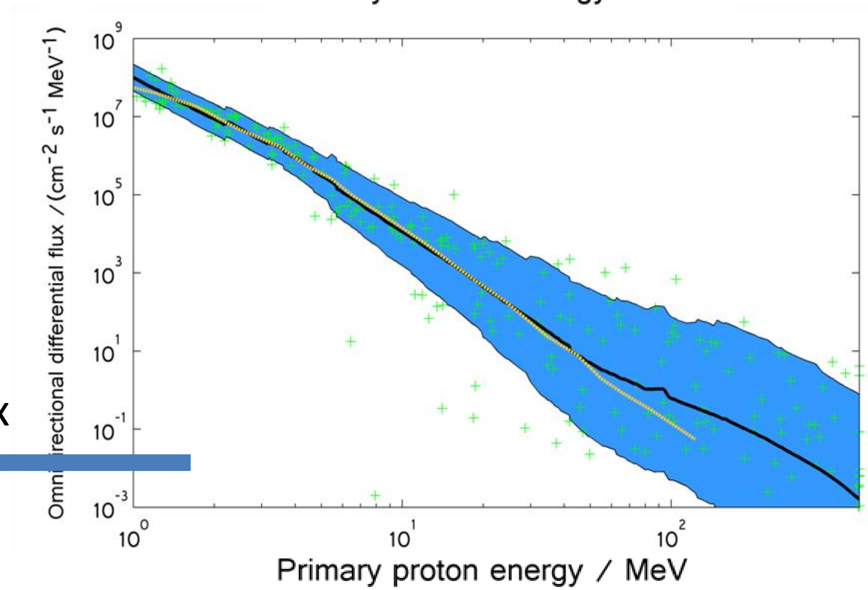
60 minutes in 23,222 km, 56° inc. MEO



10 seconds in 10,000 km, 0° inc. MEO







Factor 10^4 smaller proton flux

HMRM collaboration

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