Monte Carlo simulation on background noise for ERG/MEP-e

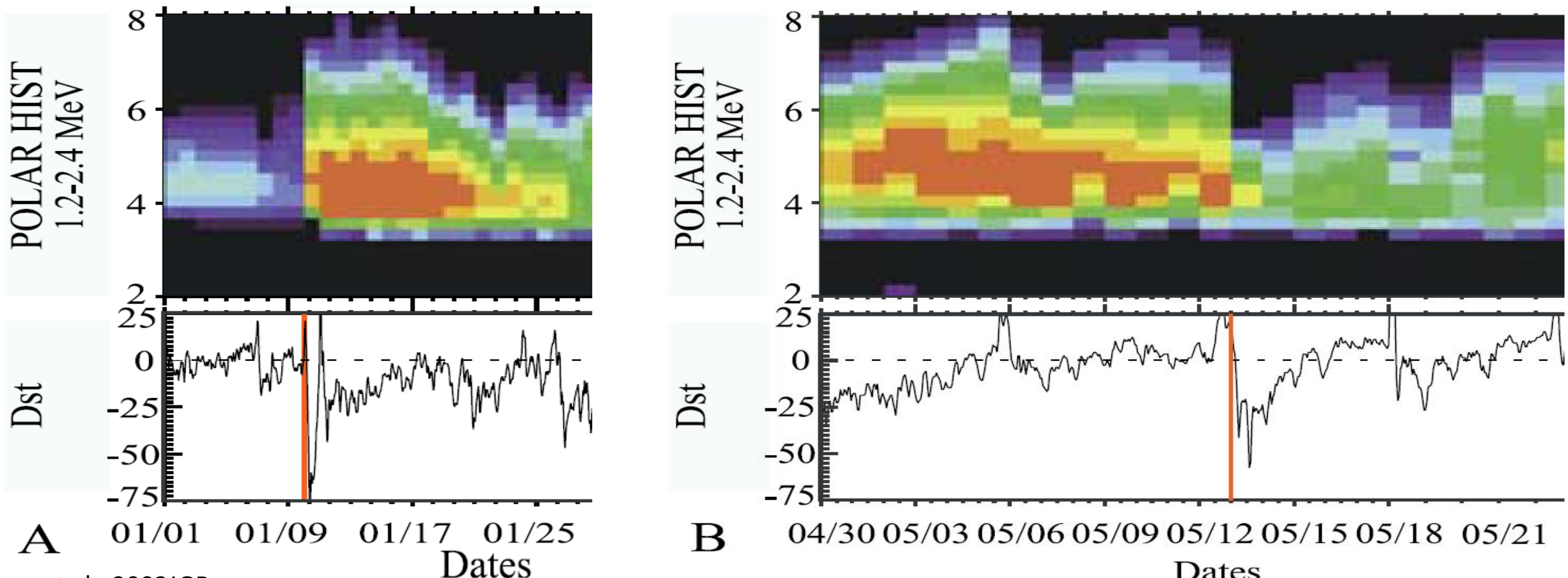
笠原 慧

God does play dice?

- M-C simulation handles stochastic phenomena by using dices (random numbers)
- M-C method suits for simulations of particle-matter interaction
  - because one doesn’t need to solve countless numbers of equation of motion
- Interaction simulations are based on physics models derived theoretically as well as experimentally
  - Models provide probability distribution about interactions

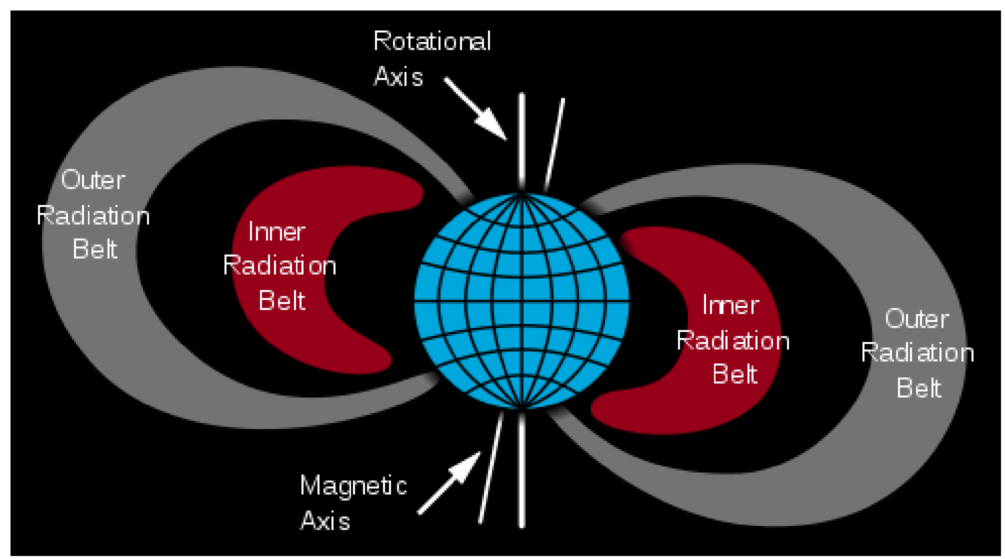
For what?

Radiation belt dynamics

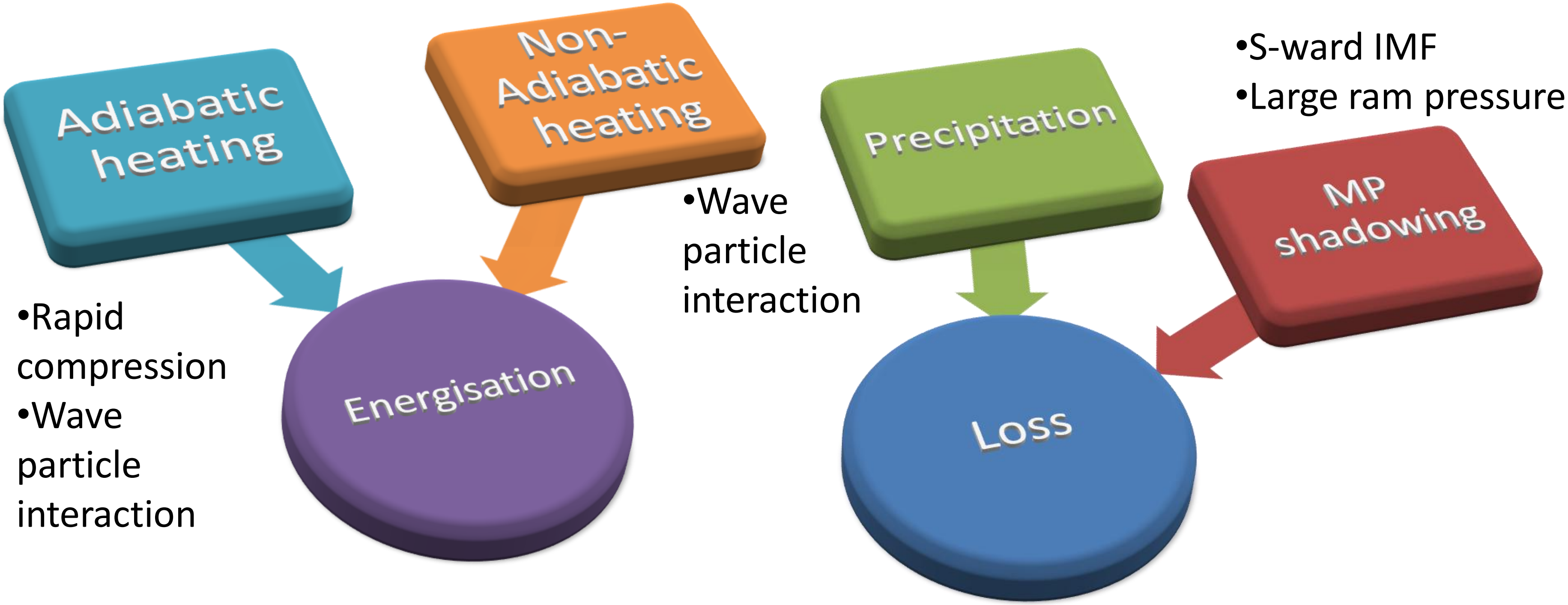


Reeves et al., 2003JGR

- The electron radiation belt is highly variable
- Energisation and loss occur simultaneously

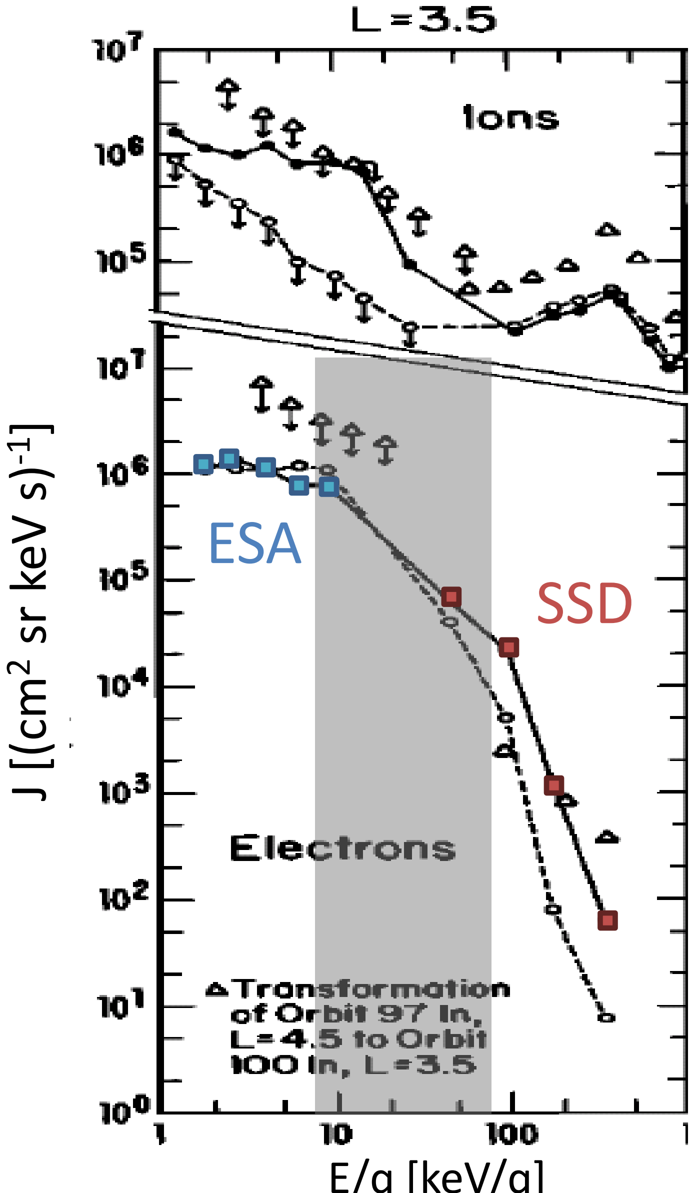


Possible causes of the variability



- Variation of relativistic electrons would be governed by a combination of several processes
  - How significant is each process?
- ERG will provide clues for this issue
  - Medium-energy (tens of keV) electron measurement is one of the key observations

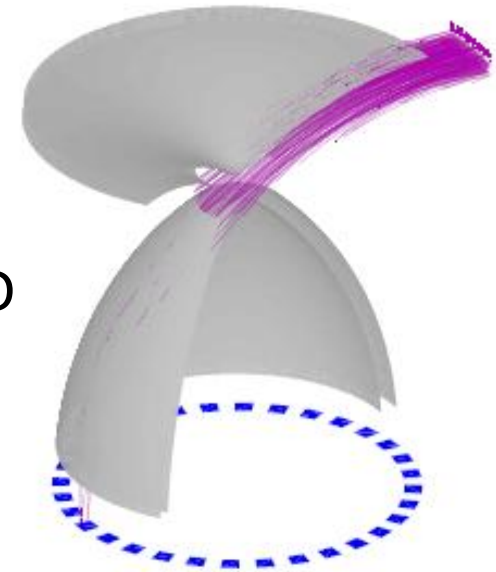
ERG/MEP-e



Lyons and Williams, 1980

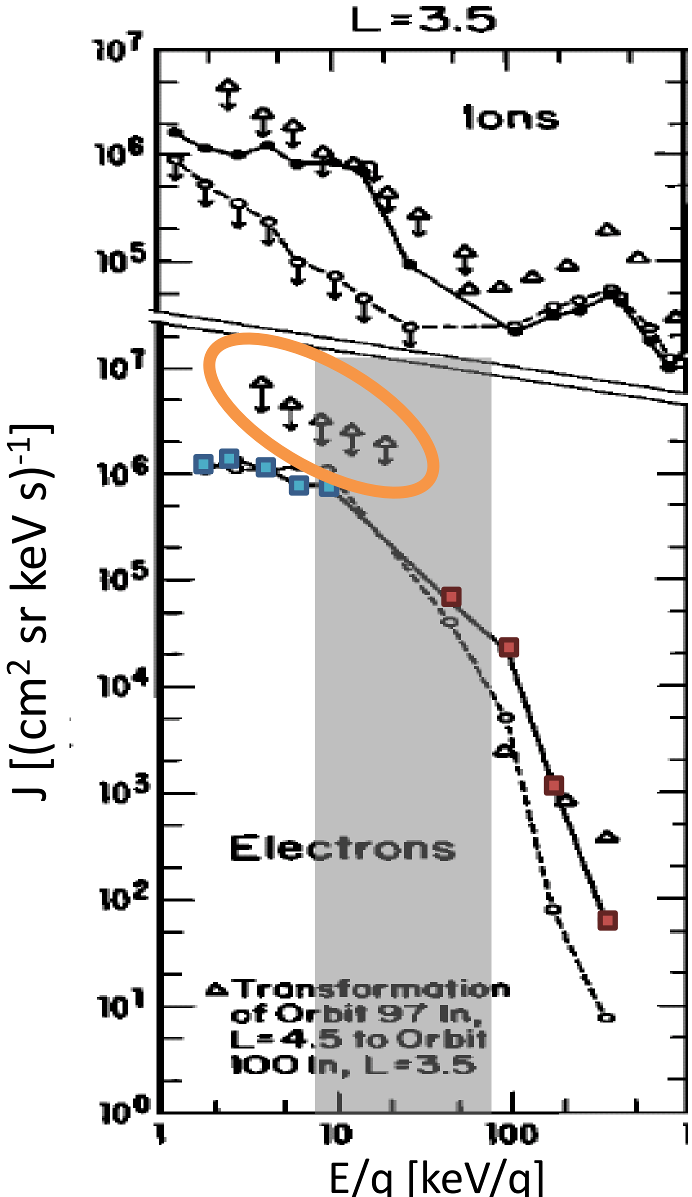
- Energy range : 8-80 keV
- FOV: 4π sr (in a half spin)
- Expected count rate: $10^{1\text{-}4}$ cps/sector

ESA+APD

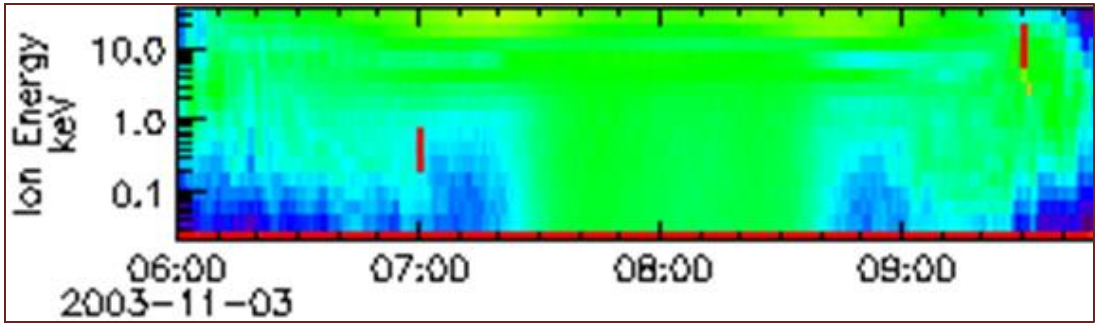


Kasahara et al., 2009

Example of background (BG) noise

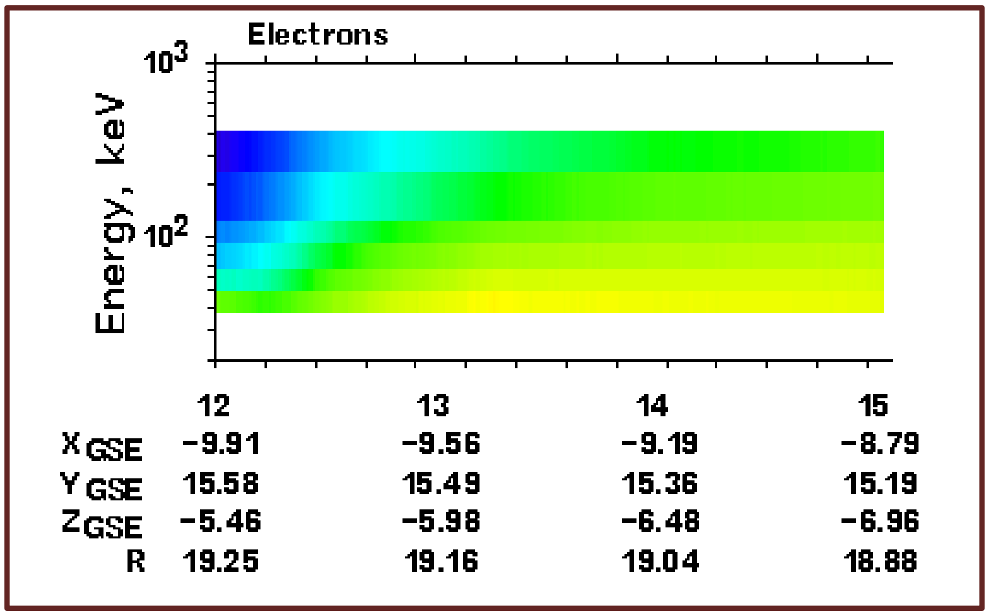


Lyons and Williams, 1980

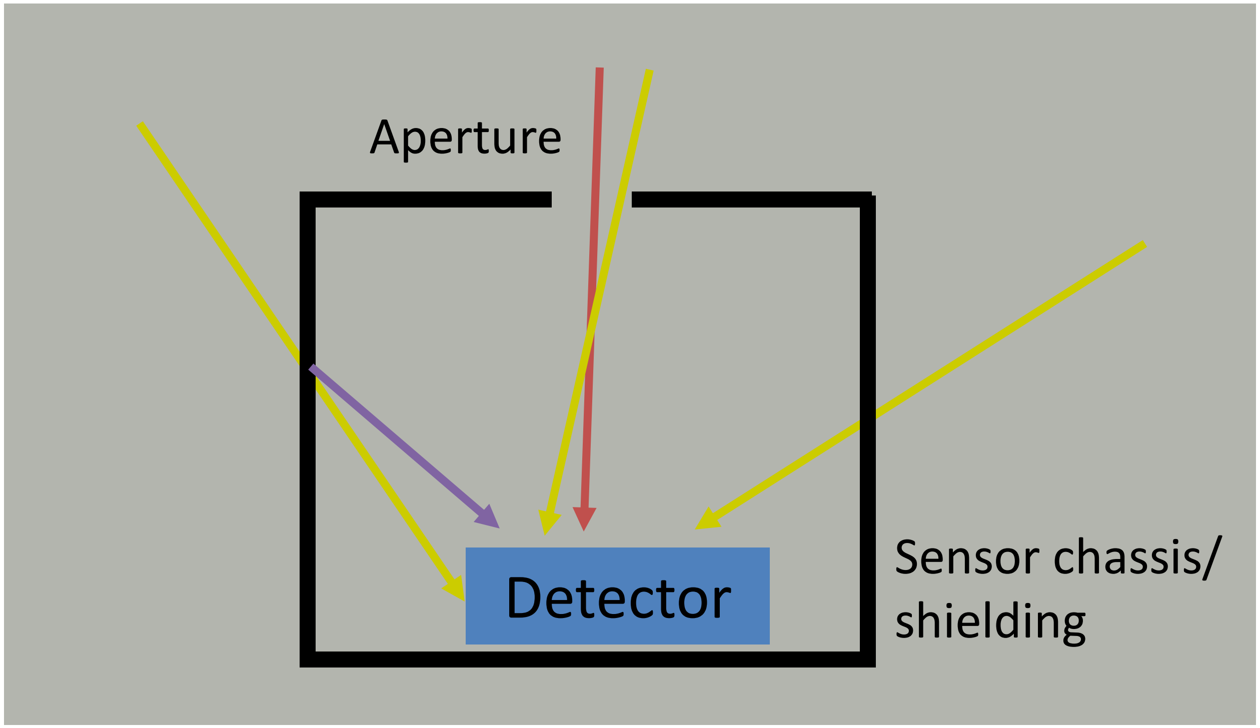


↑ Radiation belt electrons (observed by Cluster/CIS)

Solar energetic protons (seen by Cluster/RAPID) ↓



Cause of BG noise

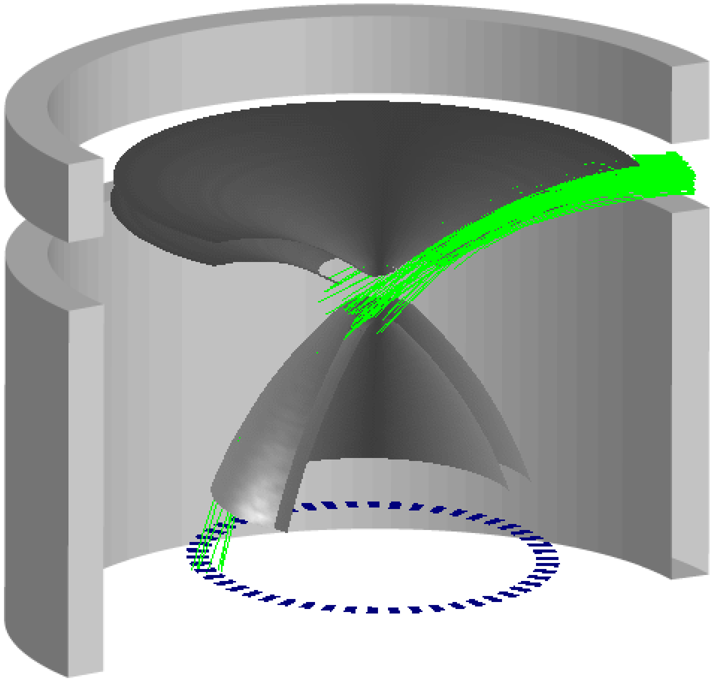


- Electrons (>100 keV)
  - Secondary γ-rays (Bremsstrahlung) (photoelectric effect)
  - Secondary electrons (ionisation) (Compton scattering)
- Protons (> 30 MeV)
  - Secondary electrons (ionisation)

Locations/timings

- Inner and Outer radiation belts
  - electron (+ γ-rays), proton
- Substorm injections (around synchronous orb.)
  - electron ➔ γ-rays
- SEP events (even inside the M'sp)
  - proton

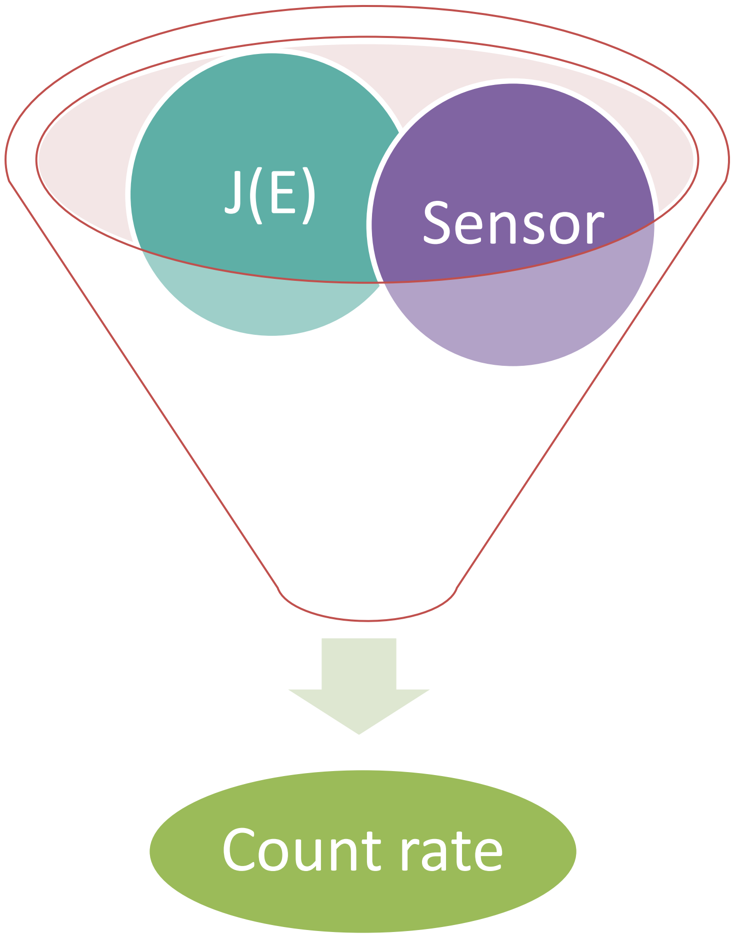
Countermeasures?



- Shielding
- Double Energy Analysis (x ~1/10)
- Thickness of shielding?
  - BG count rate should be quantified

BG estimation

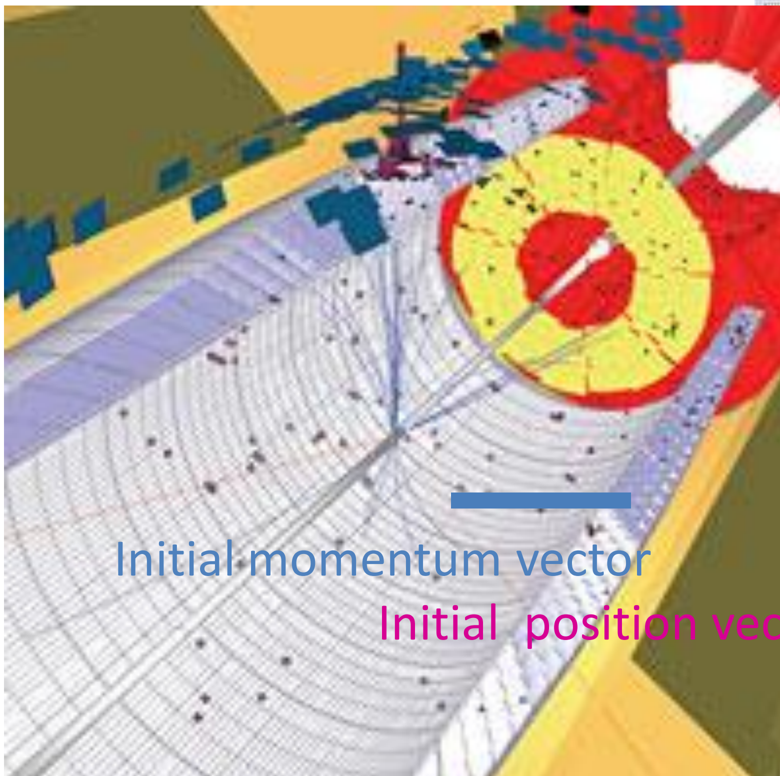
- Input: energy spectrum J(E) and a sensor structure
- Output: Count rate C_R
- How can J(E) be converted to C_R ?



cf. true signal: $10^{1\text{-}4}$ cps/sector

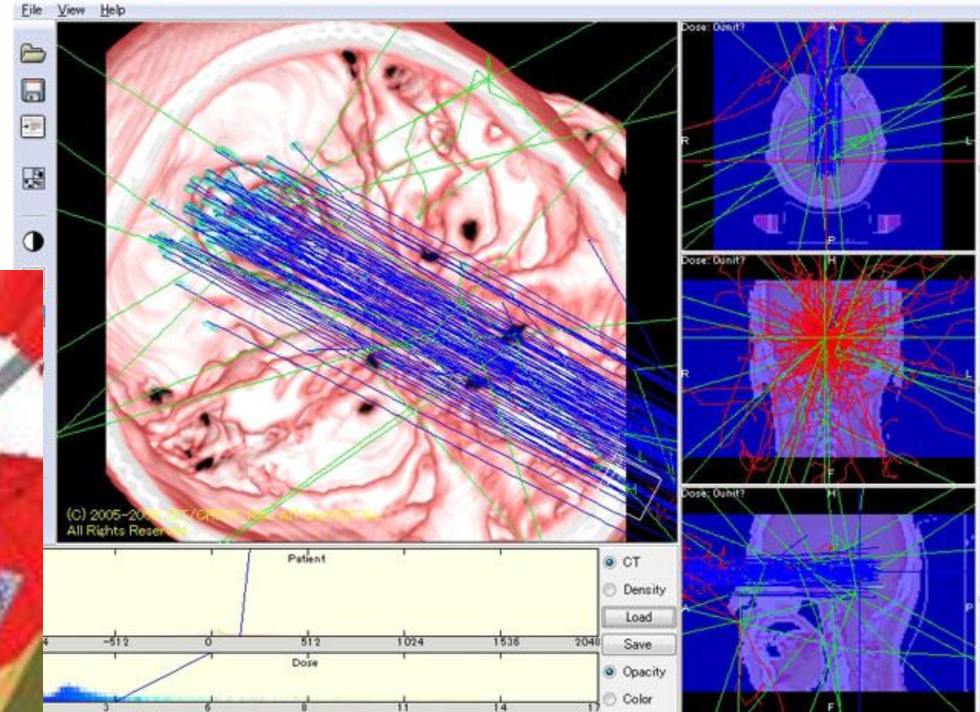
Method

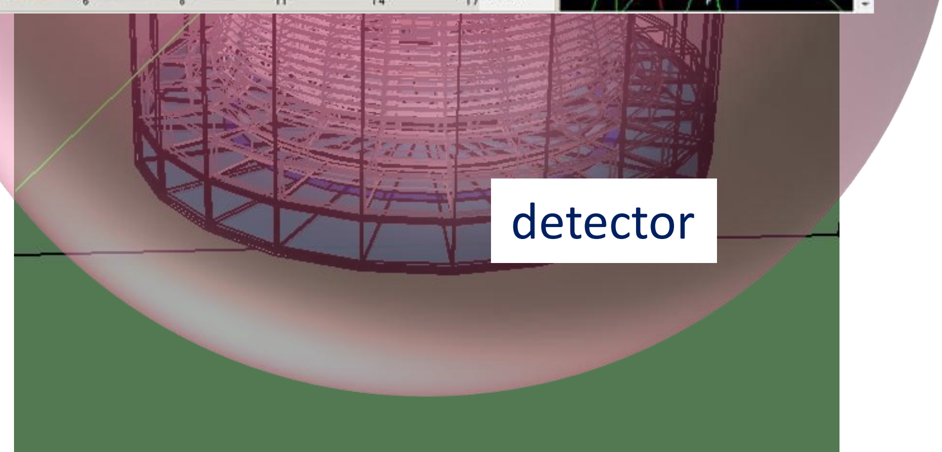
- Use Geant4
  - Monte Carlo method



Initial momentum vector

Initial position vector

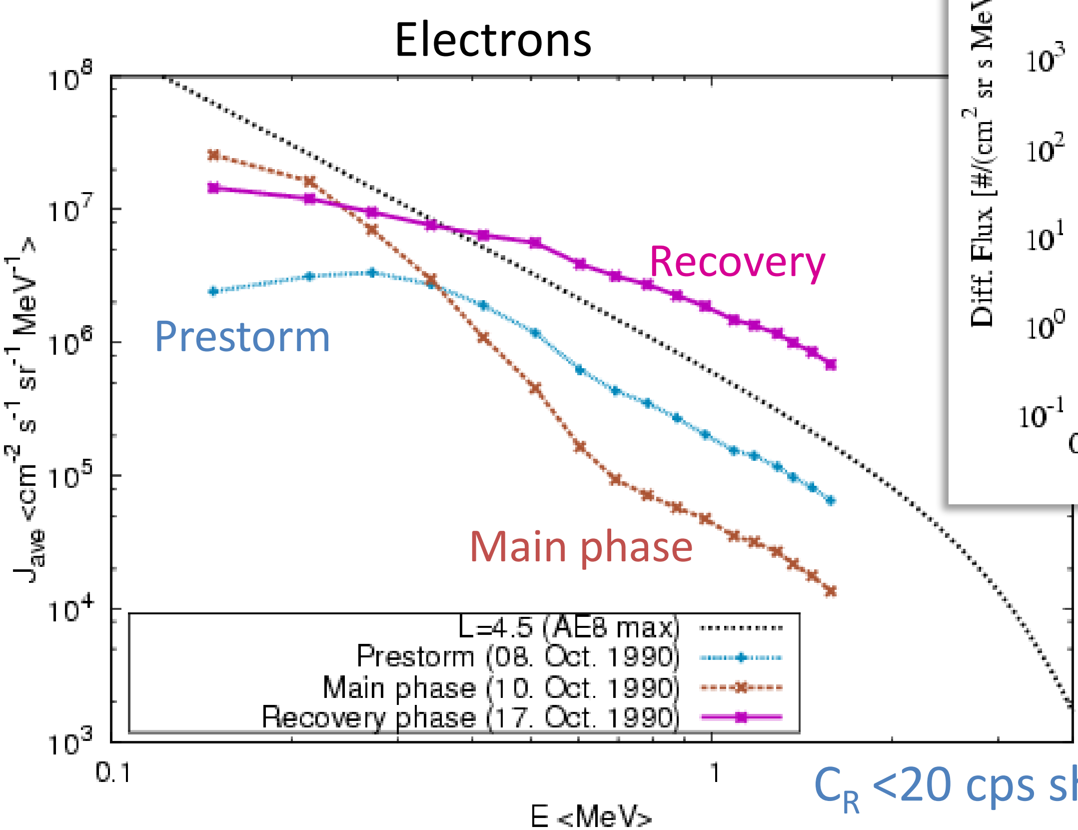


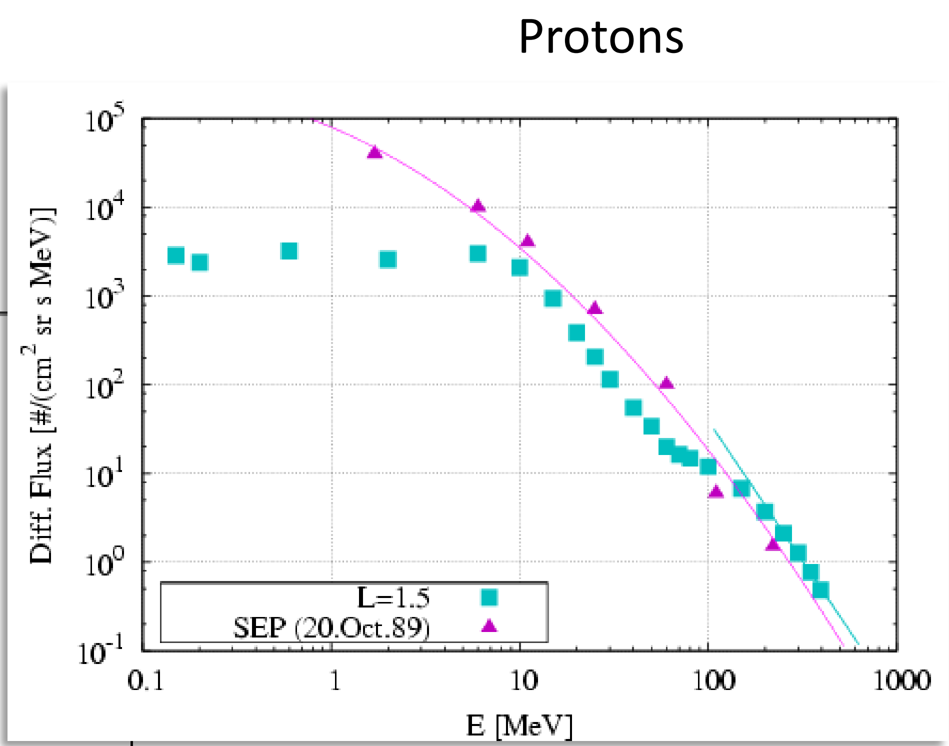


$$C_R = \int J(E)A(E)dE$$

Used spectrum J(E)

- Electron: AE8max (CRRES)
- Proton: AP8max, GOES



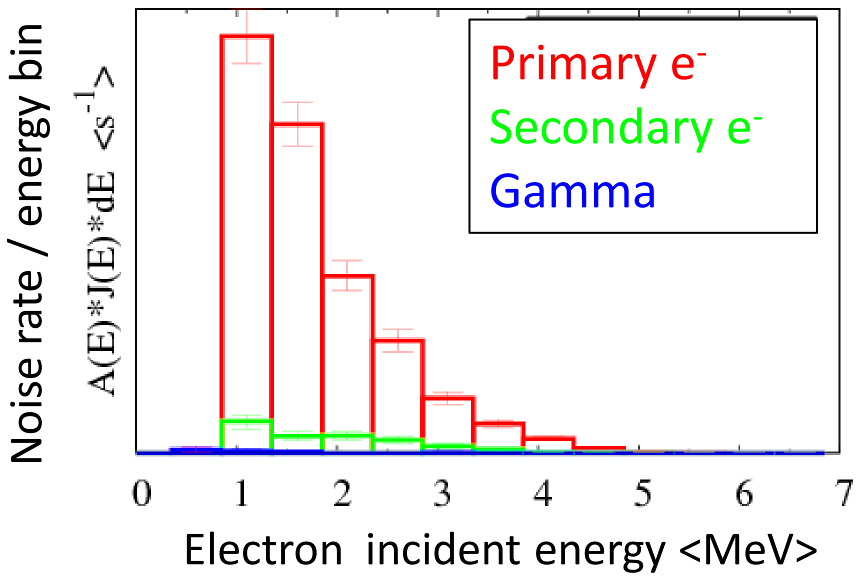


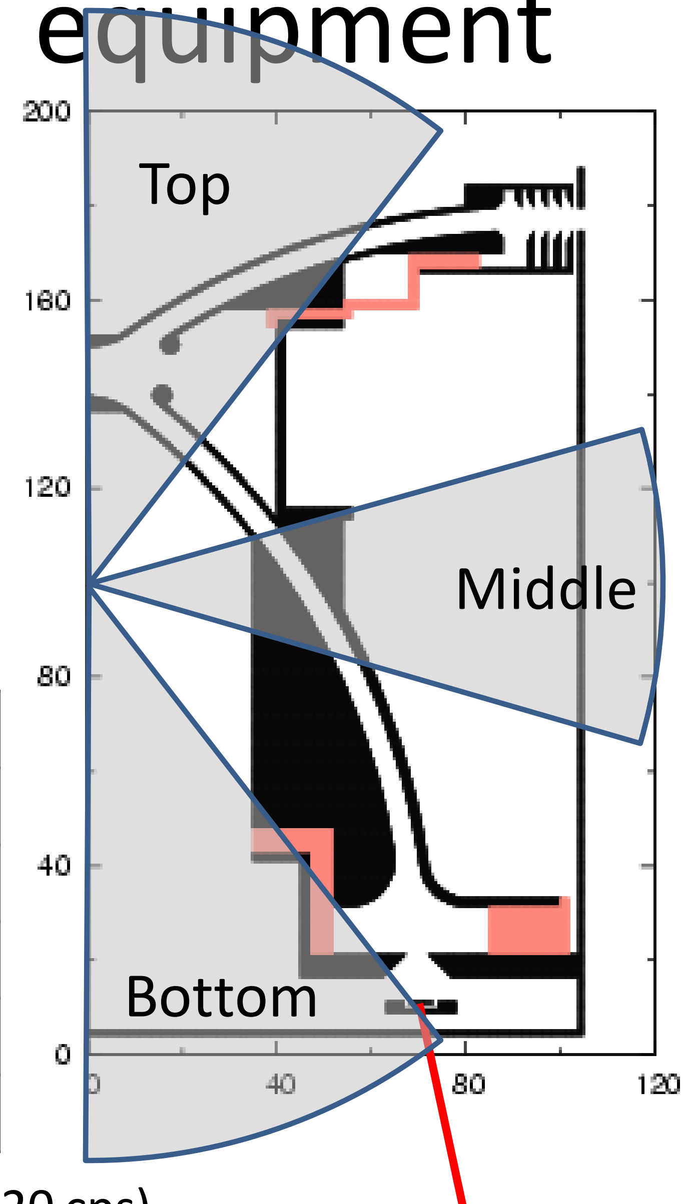
C_R <20 cps should be achieved with AE8max

Results and Discussions

- For Electrons
- For Protons

Result e1: minimum equipment

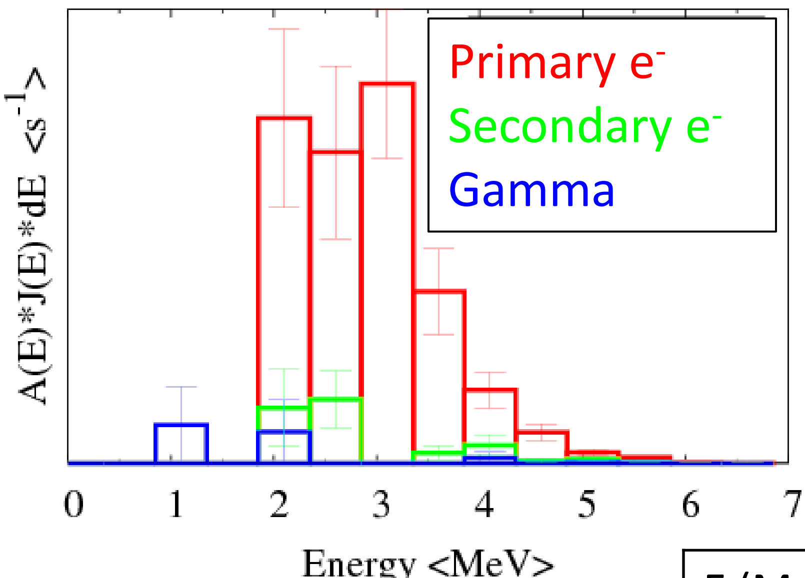




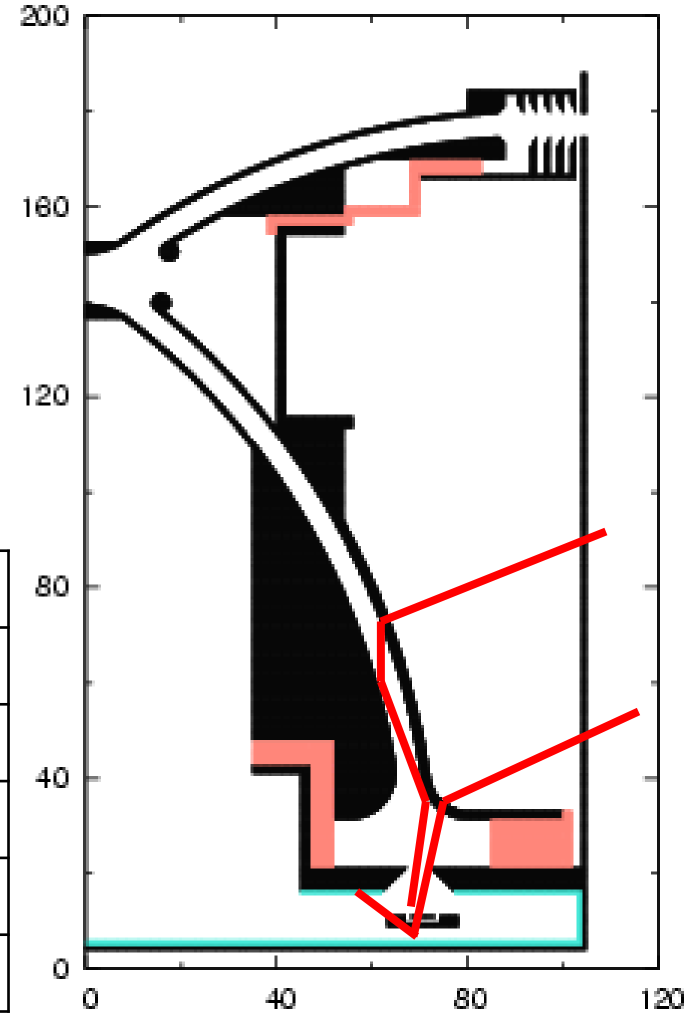
E (MeV)	1.1	3.1
top (%)	0	0
	0.4	0
middle	3	7
	46	44
bottom	51	49

- Mass: ~2.5 kg
- 10^5 cps/sector in total
  - ~ 10^4 cps/sector with DEA (cf. It should be <20 cps)
- The penetration round the bottom part is significant ➔ bottom shield

Result e2: with bottom shielding

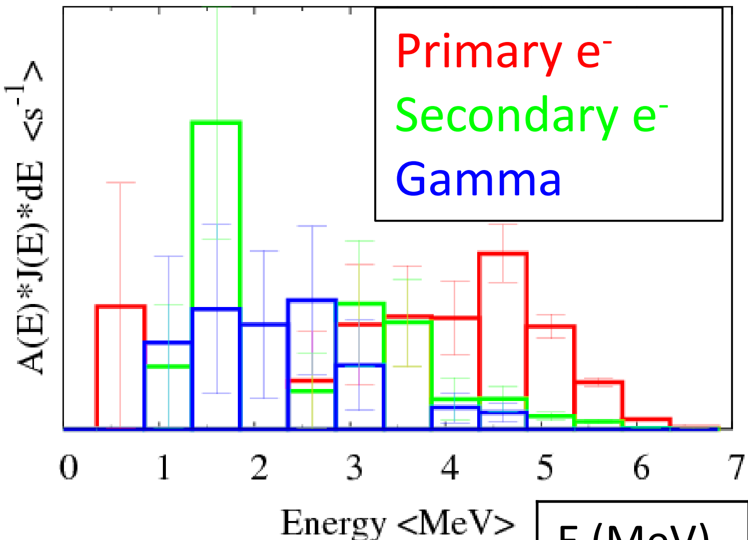


E (MeV)	2.1	3.1
top (%)	0	0
	13	11
middle	80	69
	7	19
bottom	0	0

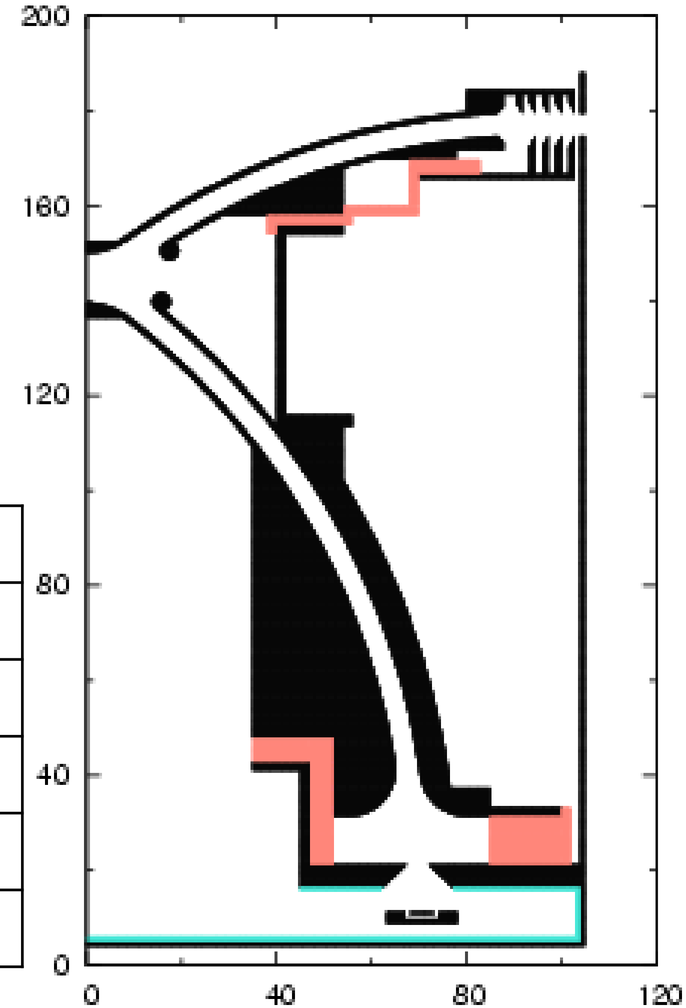


- Mass: ~3.5 kg
- ~2000 cps/sector in total
  - ~200 cps/sector with DEA (cf. It should be <20 cps)
- MeV e- from the middle part produce noise by penetration plus scattering ➔ thicker bending plate

Result e3: with a thick bending plate

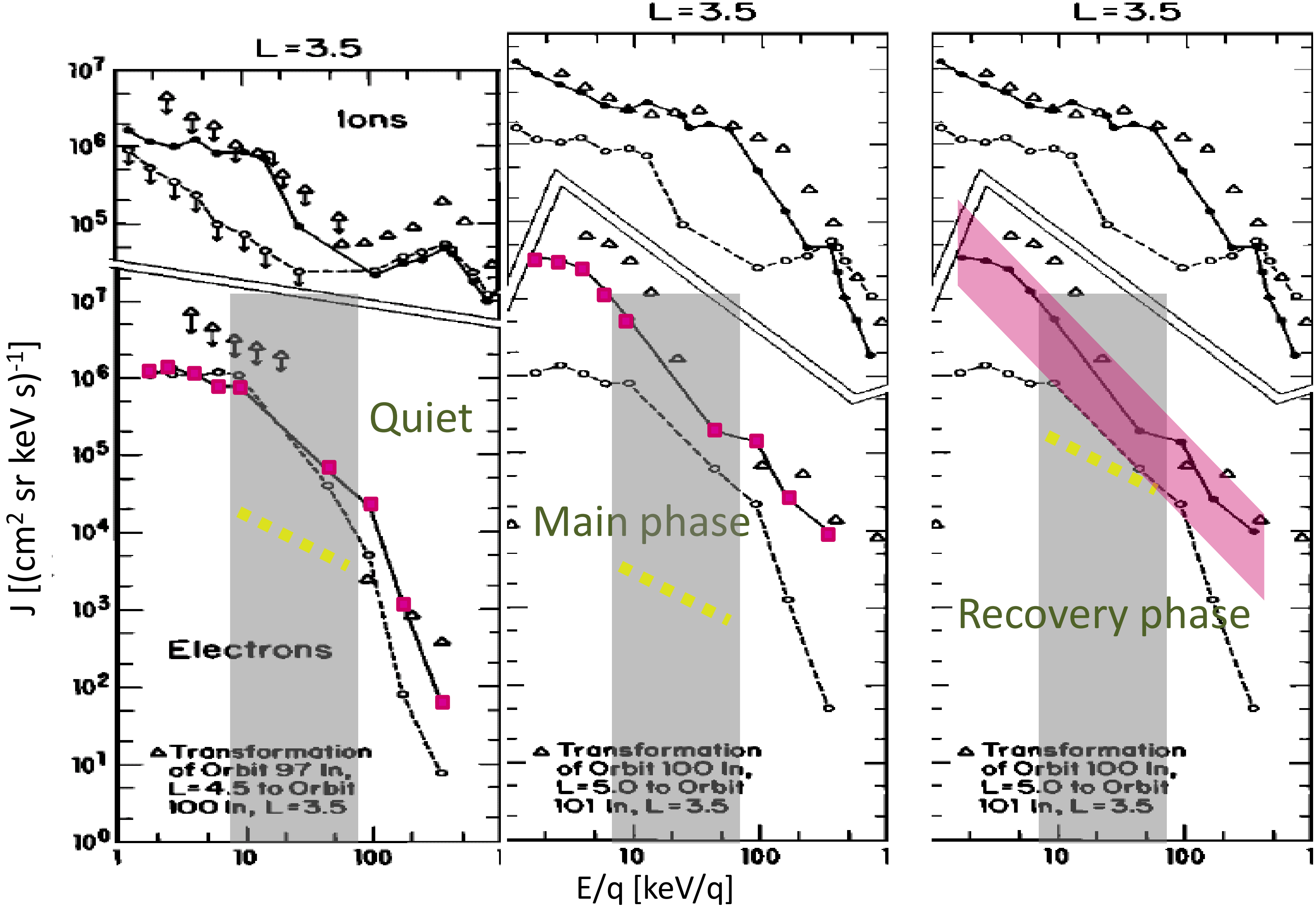


E (MeV)	1.6	1.6	4.6
top (%)	0	14	0
	0	28	8
middle	100	0	38
	0	14	14
bottom	0	43	41



- Mass: ~4.0 kg
- ~100 cps/sector in total
  - ~10 cps/sector with DEA (cf. It should be <20 cps)
- Electron (and gamma) noise is sufficiently attenuated

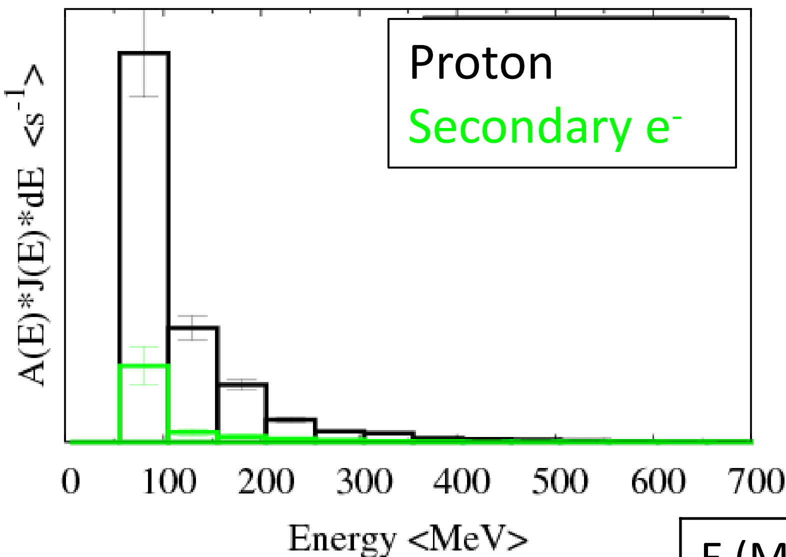
Discussion : relative fluxes of electrons



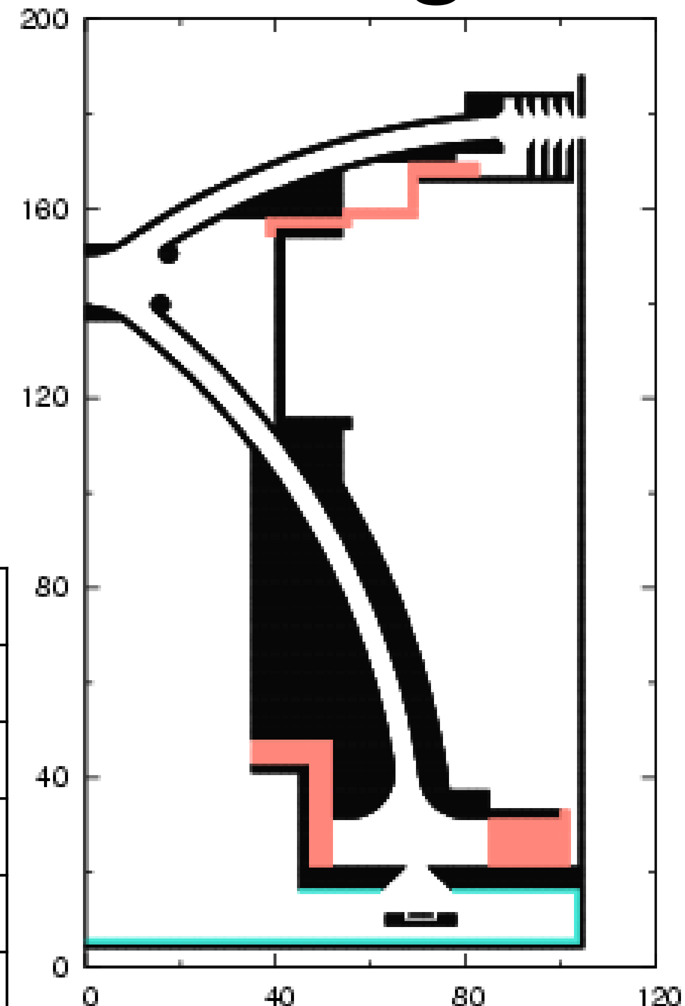
Results and Discussions

- For Electrons
- For Protons

Result p: no further shielding

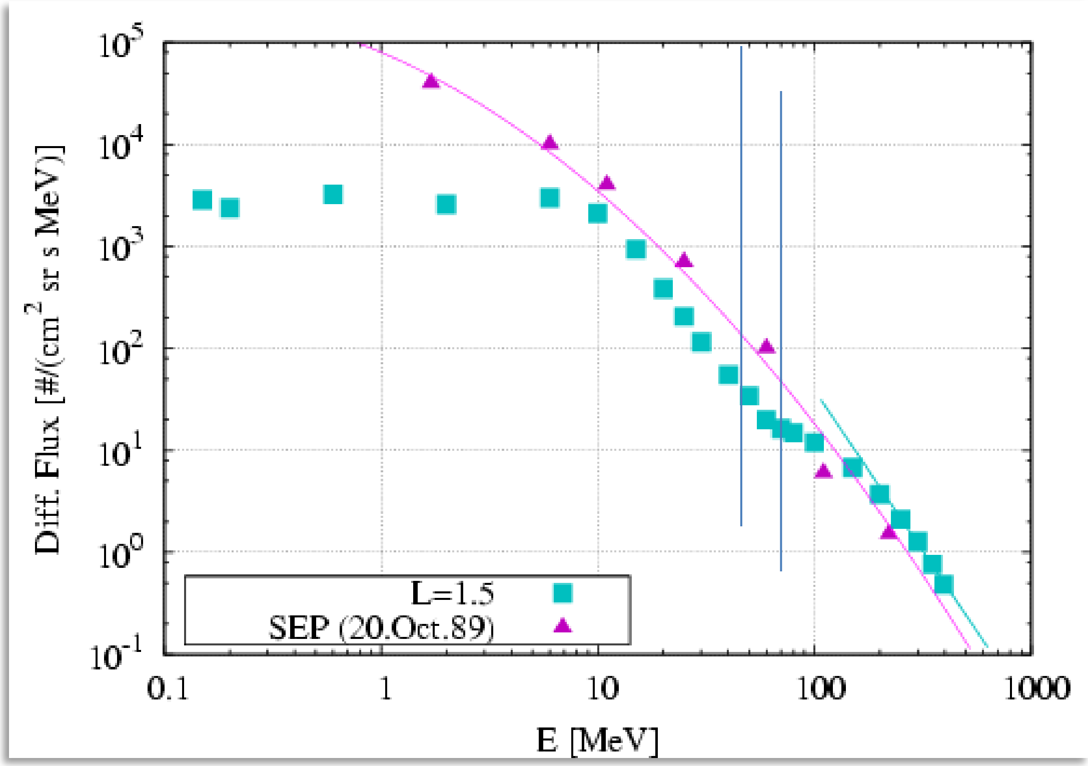


E (MeV)	80	130
top (%)	0	6
	17	12
middle	21	19
	31	28
bottom	32	34



- 4000 cps/sector in total
- ~ 400 cps/sector with DEA
- Proton noise cannot be sufficiently attenuated
  - But the saturation can be avoided ➔possibly subtracted

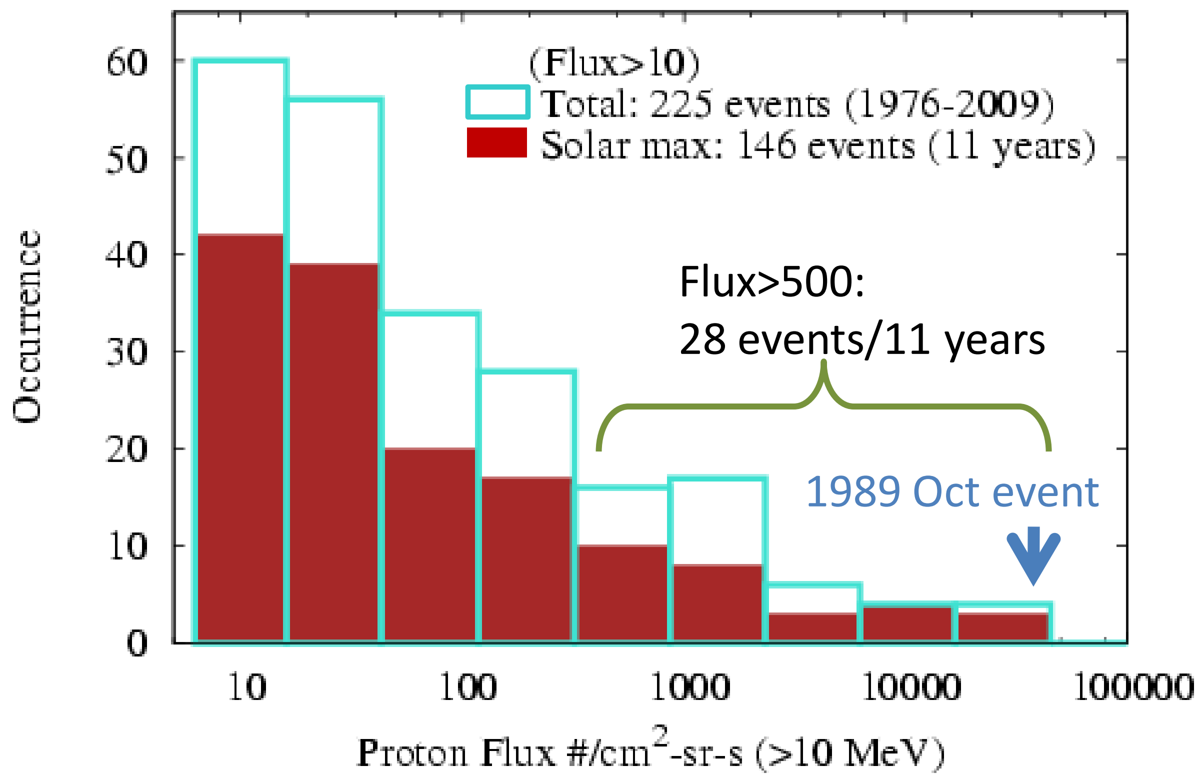
Discussion: thicker shielding effective?



- Al 8 mm (default) ➔ E_min~45 MeV
- Al 20 mm (Mass + 4 kg)➔ E_min~70 MeV
- Shielding does not help much

Discussion: frequency of SEP events

- Significant SEP contamination: < 3 events/yr
  - ~ 20% of SEP events
- Intense SEP events are associated with CME
  - ➔Most CIR storms are not affected



Summary

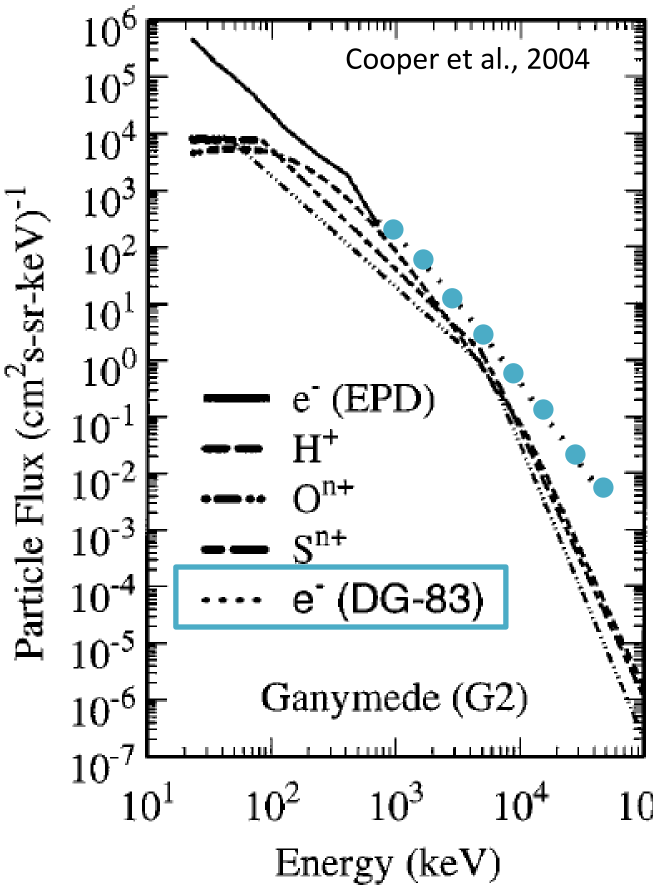
- BG by electrons would be sufficiently attenuated for most events
  - Main phase data are promising
  - Some contamination are possible in recovery phases and quiet times depending on the MEP-HEP flux ratio
- BG by the inner RB protons cannot be avoided
  - But possibly subtracted with careful analysis
- BG by protons of SEP events can be attenuated for most events
  - even for CME-driven cases, expected occurrence of severe contamination is only ~20 %

The method developed here can be applied to other situations (cf., appendix)

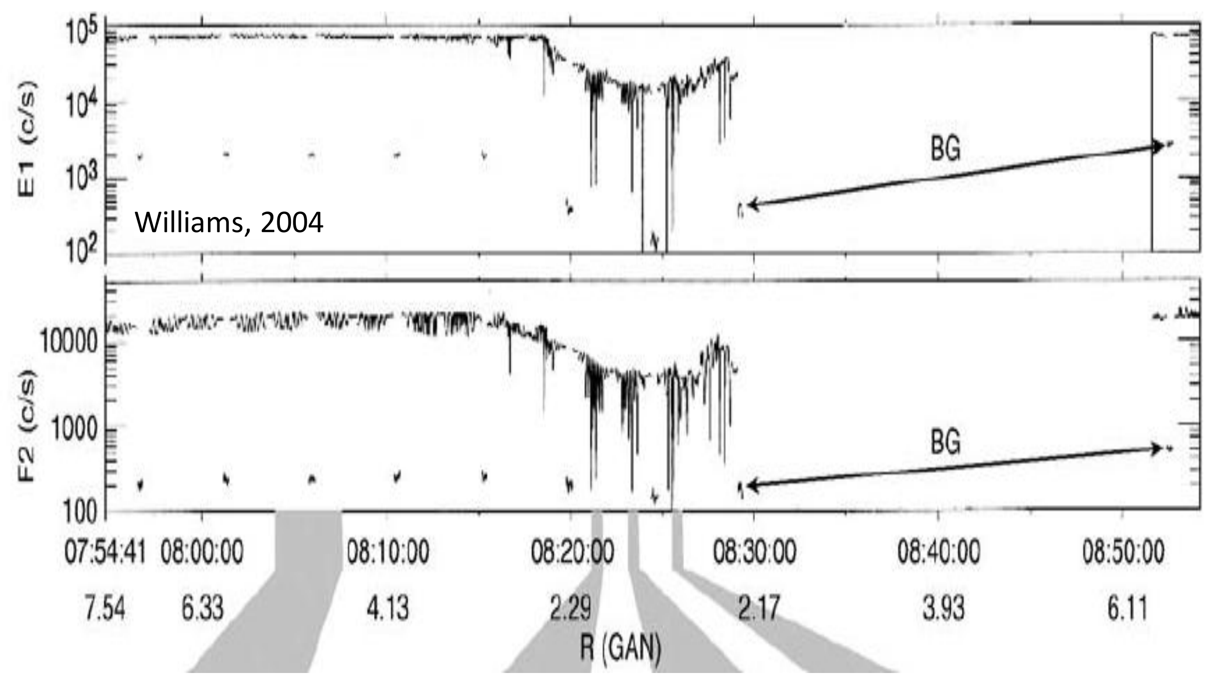
Future work

- More detailed simulation with electronics
- Test of simulation results with beam experiments

Appendix: Energy spectrum at Ganymede

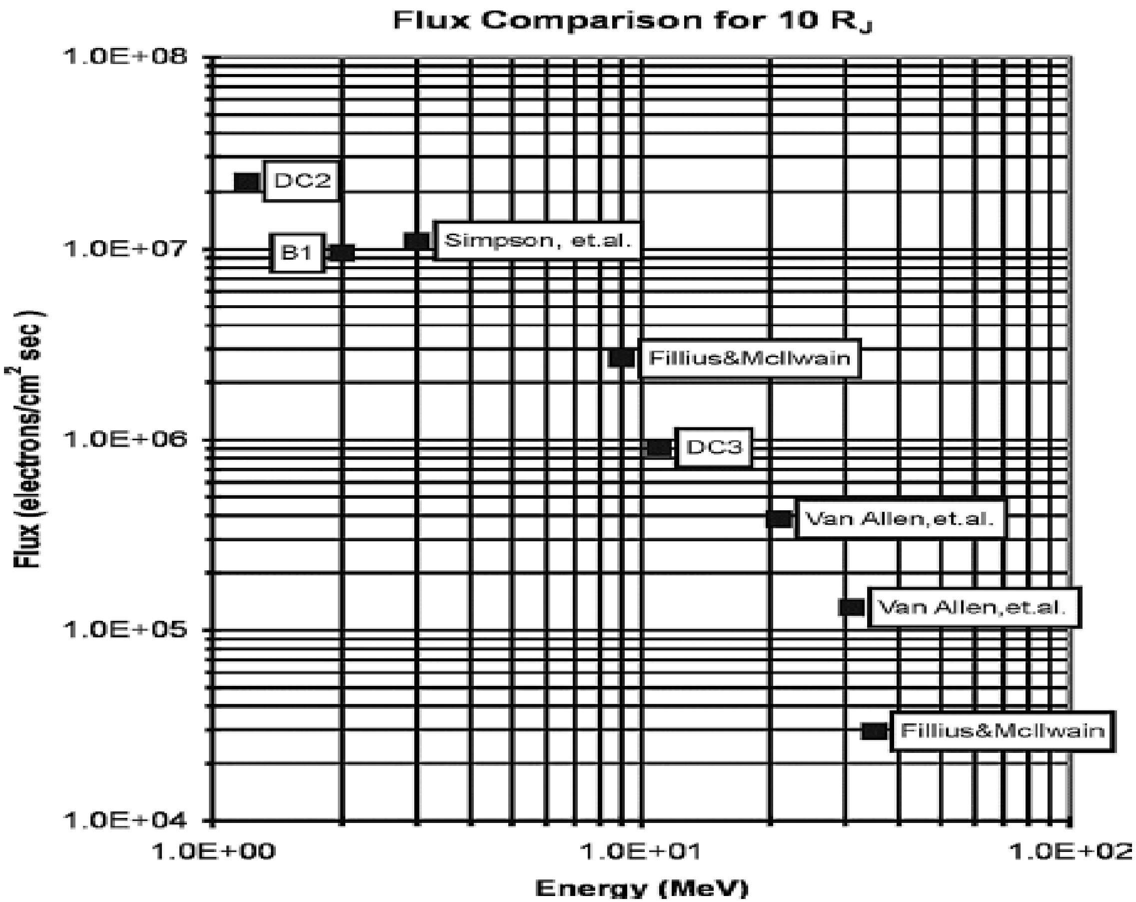


- Electron background is most severe
- Flux depletion in the Ganymede's magnetosphere
  - by a factor of 3-10



Appendix: Flux at 10 Rj

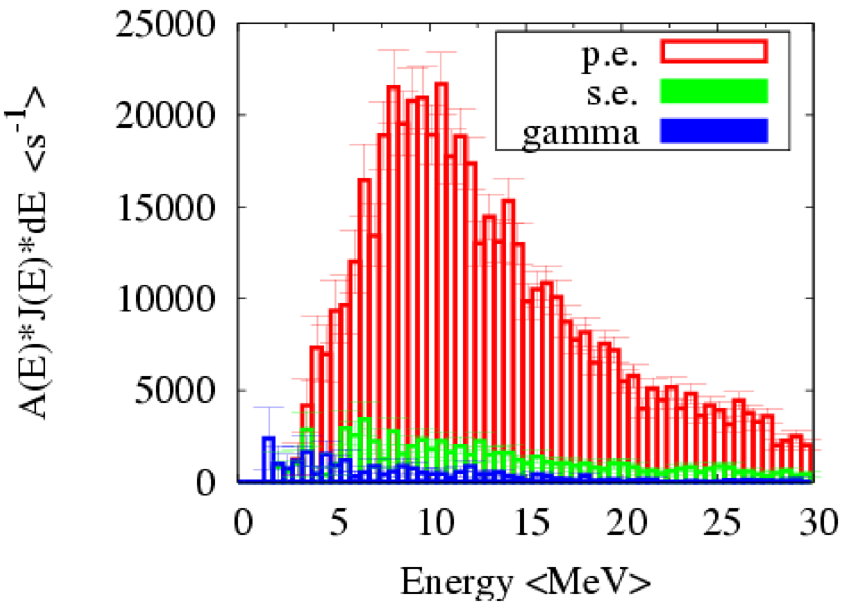
- We assume sharp cutoff at 30 MeV



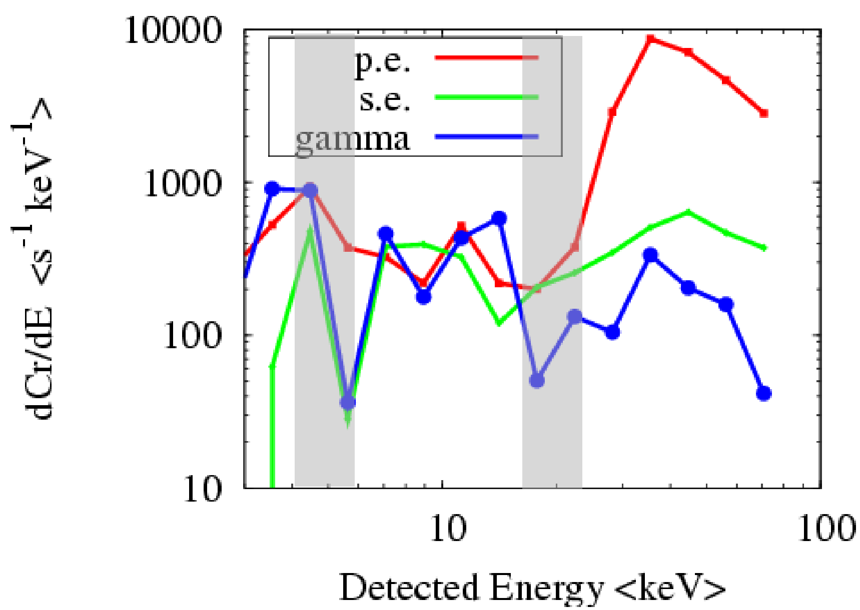
Sorensen et al., 2005)

Appendix: Jupiter case

Incident electron's energy
vs.
count rate /energy bin /all sectors

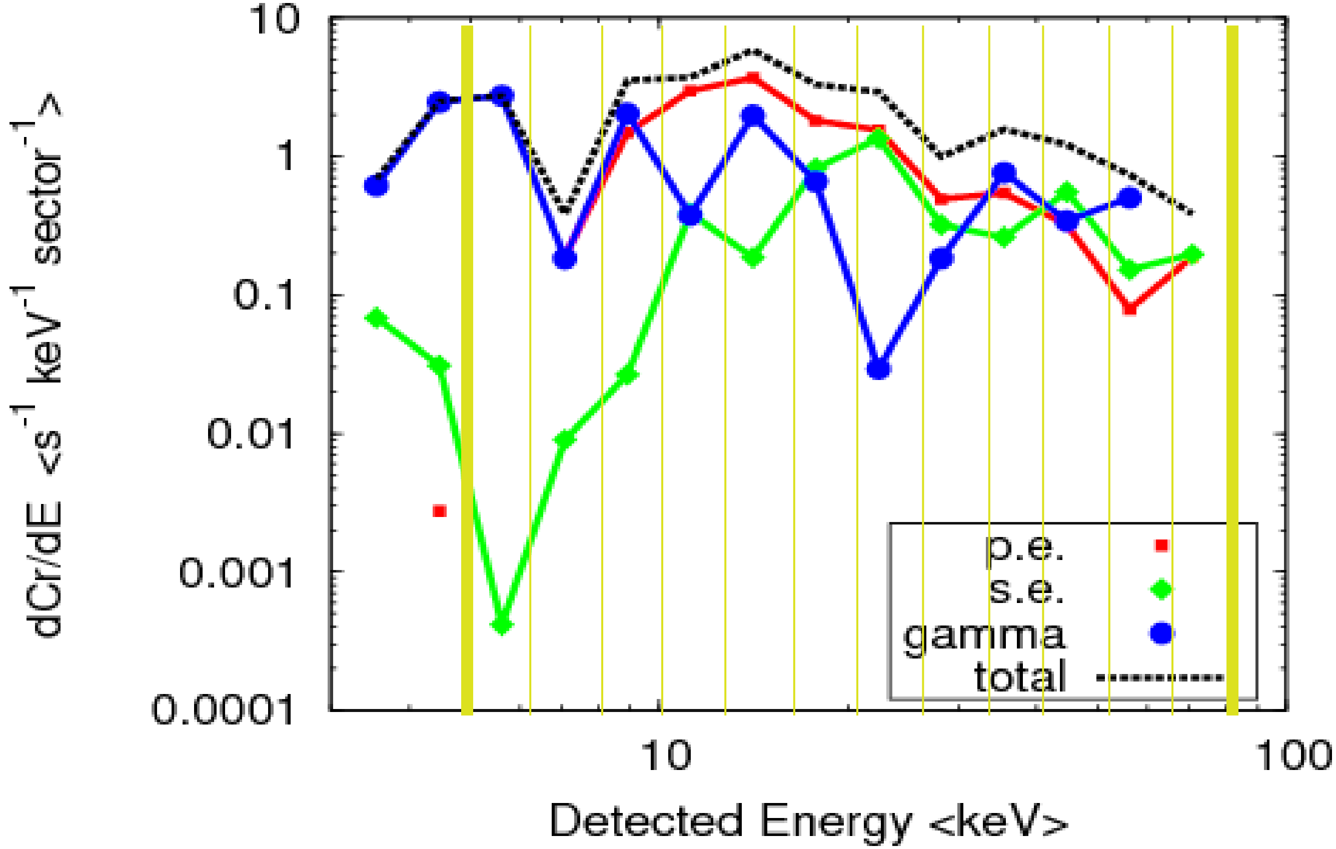


Detected energy
vs.
count rate /energy /all sectors



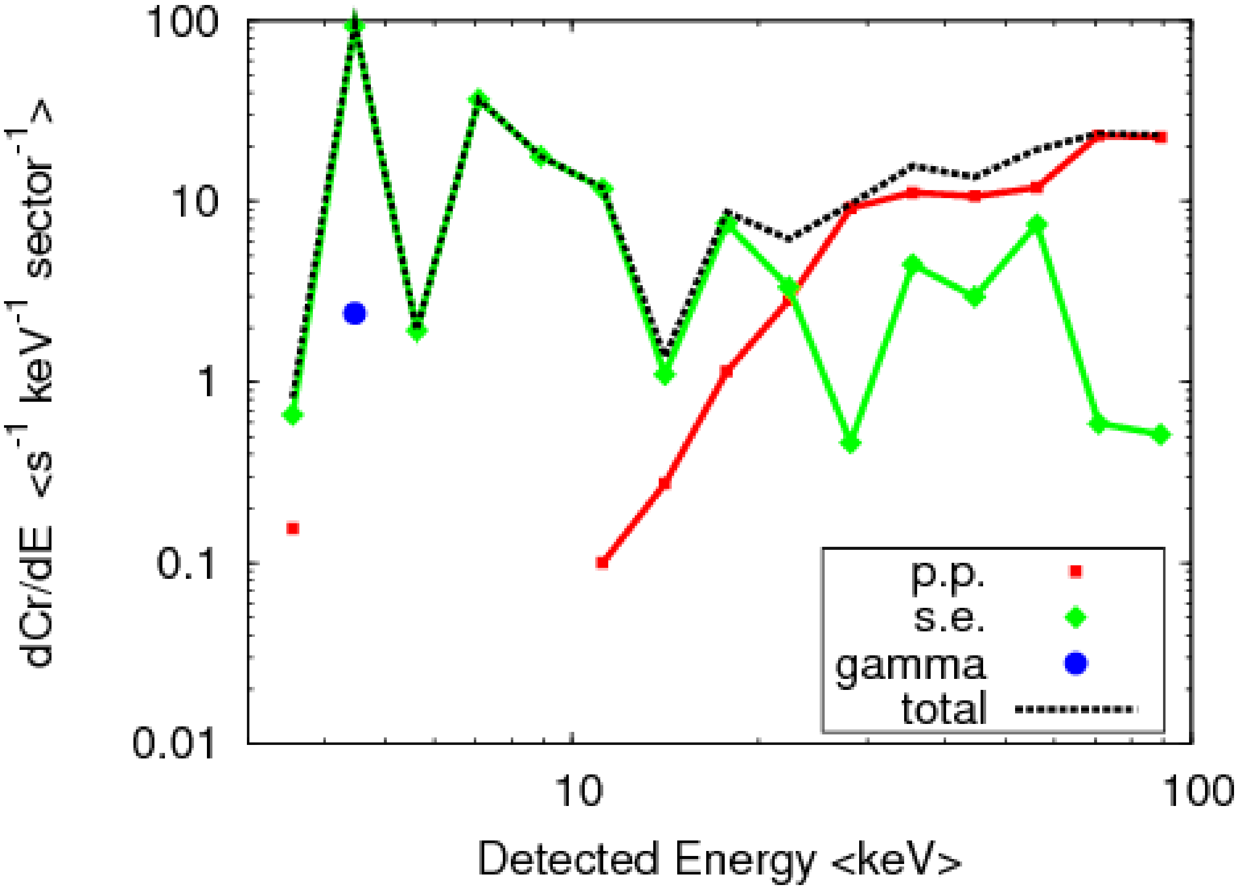
- Peak of the detected energy spectrum is at 35 keV
  - much lower count rates at < 35 keV
- For 1/16 azimuthal sector,
  - 20-30 cps for eV range and 50 cps for 20 keV incidence at Ganymede's orbit
  - 10-20 cps within the Ganymede's magnetosphere and in the outer magnetosphere

Appendix: The DEA method



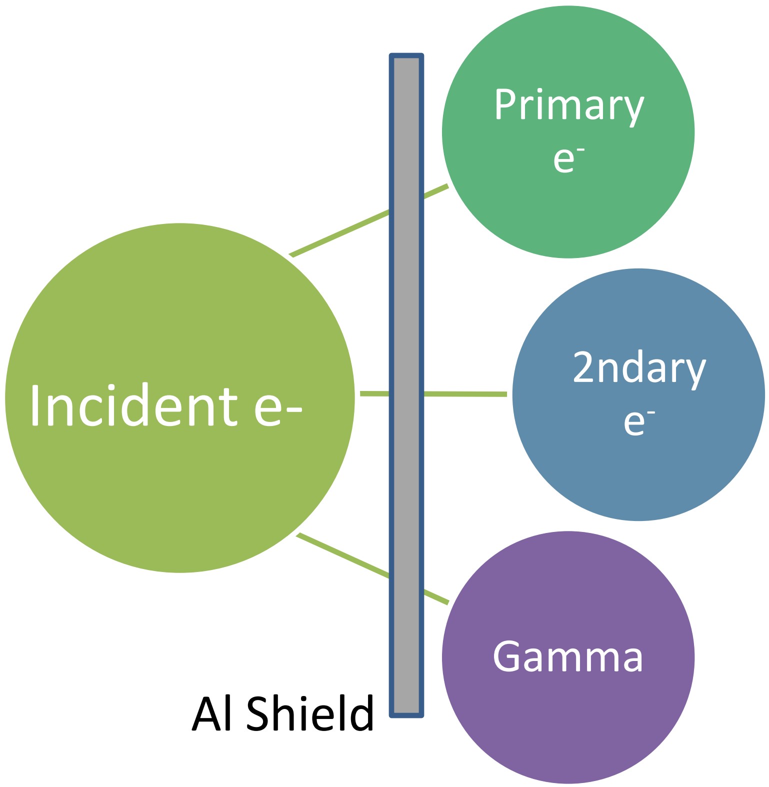
- ~100 cps in total
- 10 keV: 3 cps/keV x 5 keV =15 cps
- 30 keV: 2 cps/keV x 10 keV =20 cps
- 80 keV: 0.5 cps/keV x 20 keV = 10 cps

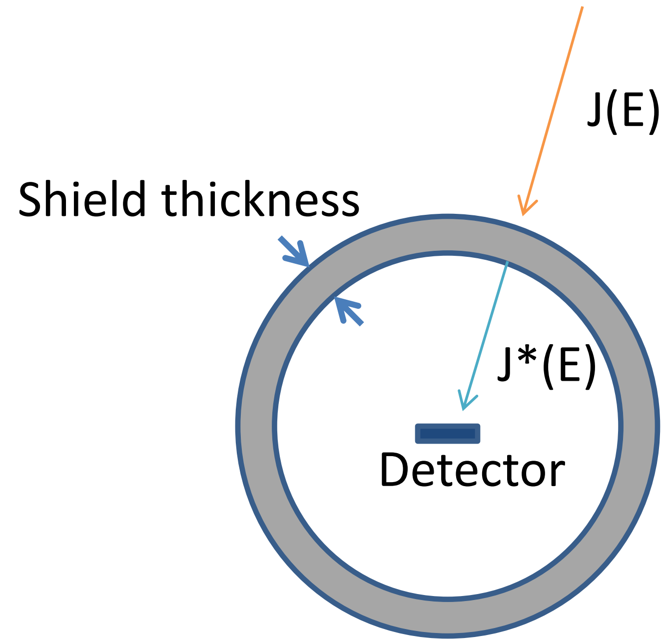
Appendix: Proton noise



- Greater than the electron case by one order of magnitude

Previous study

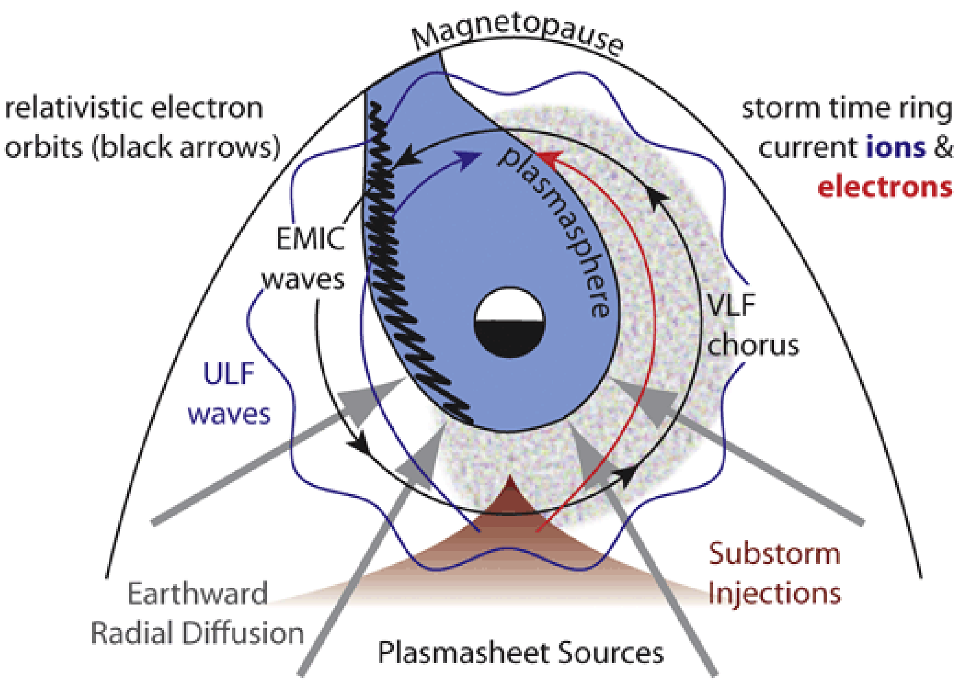




$$C_R = \int \mathbf{J}^*(\mathbf{E}) \bullet d\mathbf{S} dE d\Omega$$

- Simple analysis → 10 mm (Al) required
  - Mass: > 3 kg (cf. 3.5 kg allocated to the sensor)
- Real structure simulations enable more quantitative/realistic discussion
- More detailed analysis would reduce shielding mass

ERG observation



[*Reeves et al.*, 2007]

- Relativistic electrons can be generated by whistler chorus
- Whistler chorus is likely to be generated by medium-energy electrons (1-100 keV)
- Key observation: 3D distribution function and energy density of medium-energy e-