Simulating the detector response of MAVEN's Solar Energetic Particle (SEP) instrument with Geant4

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Mars Atmosphere and Volatile Evolution Mission

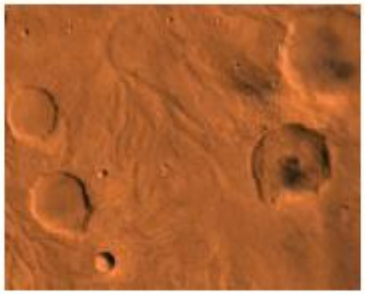
* Many slides previously shown in presentations by:
  - Bruce Jakosky, Principal Investigator, LASP, University of Colorado, Boulder
  - Davin Larson, SEP Instrument Lead, SSL, University of California, Berkeley
  - Robert Lillis, SEP Scientist, SSL, University of California, Berkeley

1. Mars Atmosphere and Volatile EvolutioN (MAVEN) Mission

2. Solar Energetic Particle (SEP) Instrument

3. Geant4 Simulations for SEP

What Will MAVEN Do? (1 of 2)

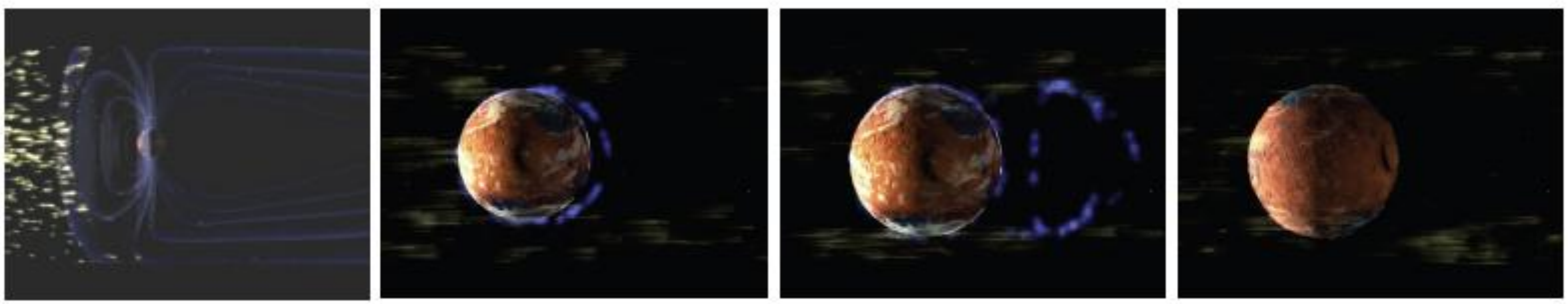


Ancient Valleys

Mars' atmosphere is cold and dry today, but there was once liquid water flowing over the surface.

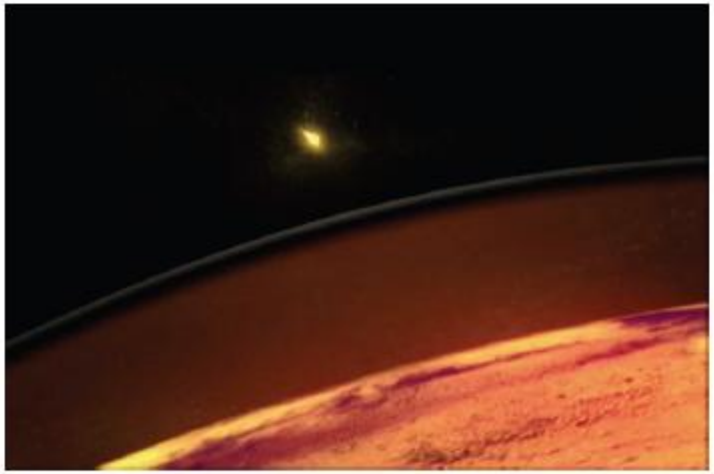
Where did the water and early atmosphere go?

- *H_2O and CO_2 can go into the crust or be lost to space.*
- *MAVEN will focus on volatile loss to space.*



Turn-off of the Martian magnetic field allowed turn-on of solar-wind stripping of the atmosphere ~ 3.7 billion years ago; combined with solar-EUV-driven loss, resulted in the present thin, cold atmosphere.

What Will MAVEN Do? (2 of 2)

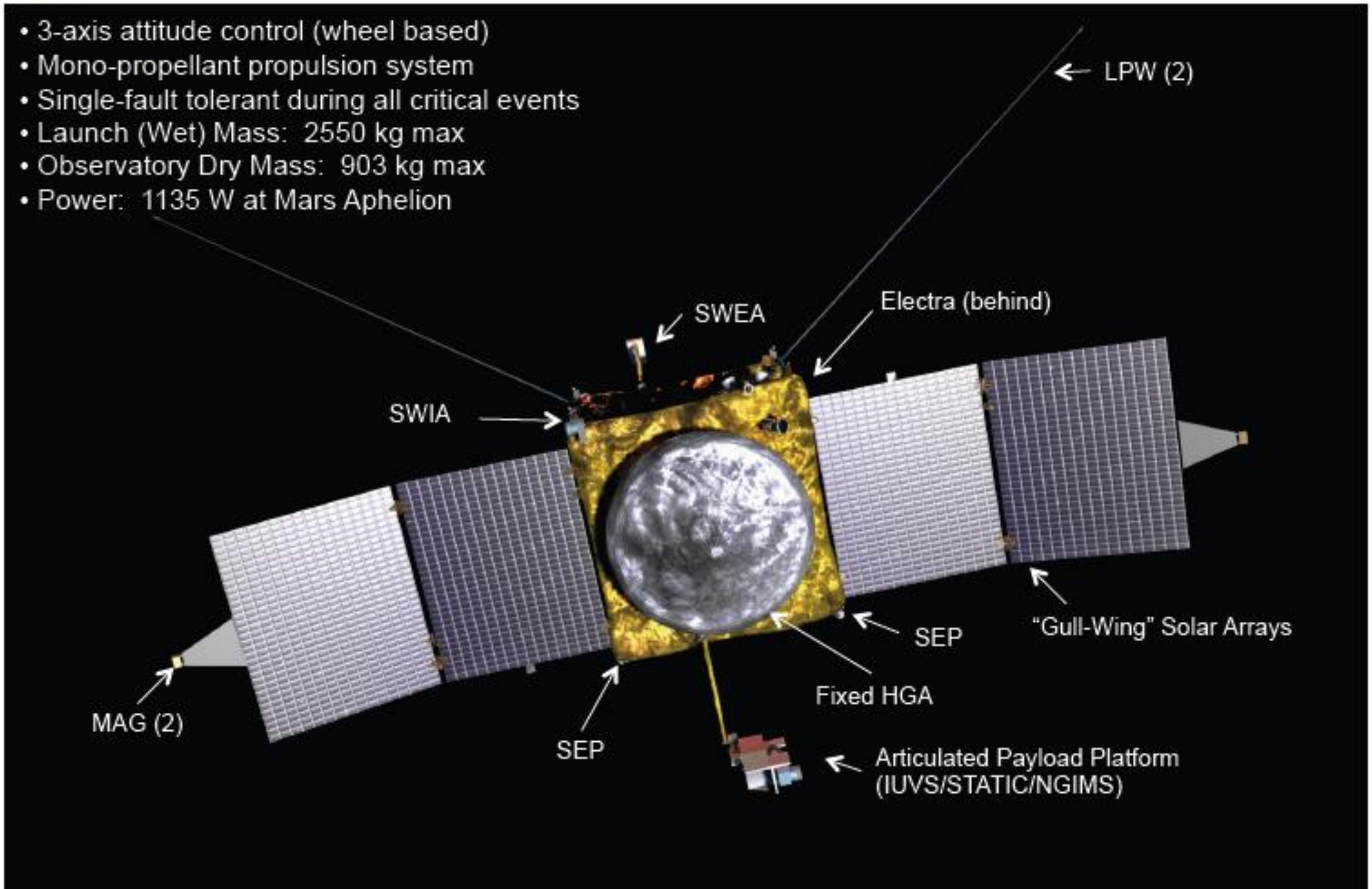


- Determine the structure and composition of the Martian upper atmosphere today
- Determine rates of loss of gas to space today
- Measure properties and processes that will allow us to determine the integrated loss to space through time

MAVEN will answer questions about the history of Martian volatiles and atmosphere and help us to understand the nature of planetary habitability.

MAVEN
CU/LASP • GSFC • UCB/SSL • LM • JPL

The MAVEN Spacecraft

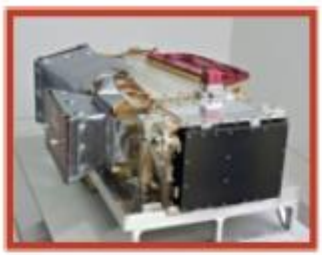


The MAVEN Science Instruments

Mass Spectrometry Instrument

Neutral Gas and Ion Mass Spectrometer; Paul Mahaffy, GSFC

Remote-Sensing Package



Imaging Ultraviolet Spectrometer; Nick Schneider, LASP

Particles and Fields Package

Solar Energetic Particles; Davin Larson, SSL

SupraThermal and Thermal Ion Composition; Jim McFadden, SSL

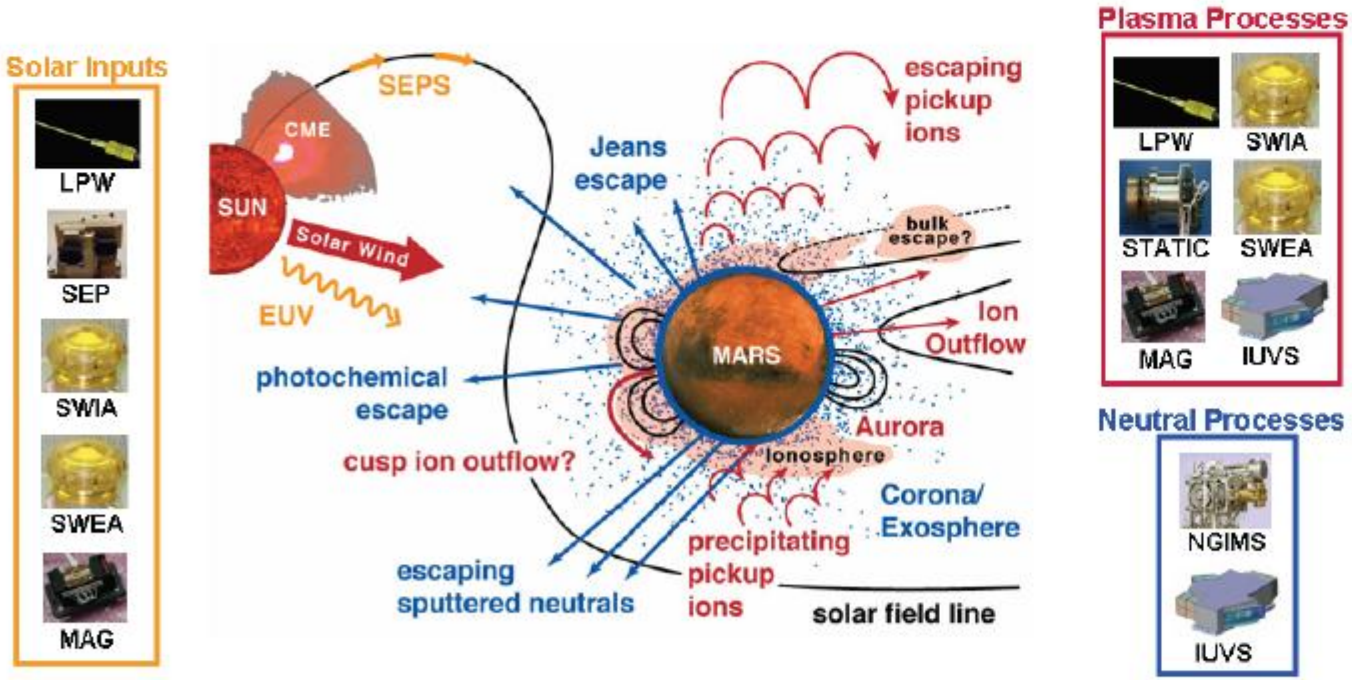
Solar Wind Electron Analyzer; David Mitchell, SSL

Solar Wind Ion Analyzer; Jasper Halekas, SSL

Langmuir Probe and Waves; Bob Ergun, LASP

Magnetometer; Jack Connerney, GSFC

MAVEN Will Measure the Drivers, Reservoirs, and Escape Rates

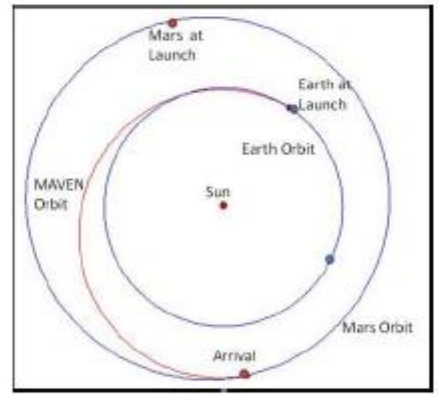


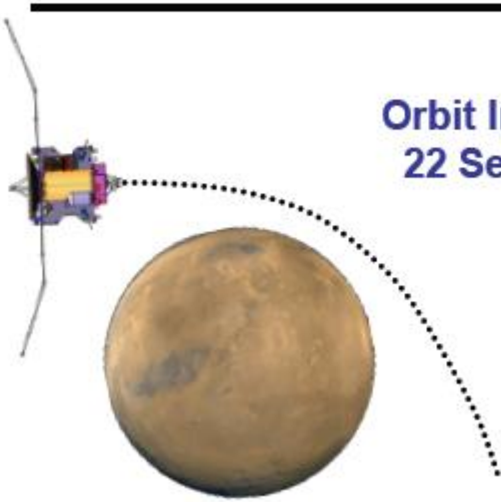
- MAVEN will determine the present state of the upper atmosphere and today's rates of loss to space.
- Measurements will allow determination of the net integrated loss to space through time.

MAVEN Mission Architecture

20-Day Launch Period: November 18 – December 7, 2013

Ten Month Ballistic Cruise to Mars





Orbit Insertion: 22 Sept 2014

One Year of Science Operations

Solar Energetic Particle (SEP) Instrument

Measurements will help address important SEP-related questions

MAVEN
Mars Atmosphere and Volatile Evolution Mission
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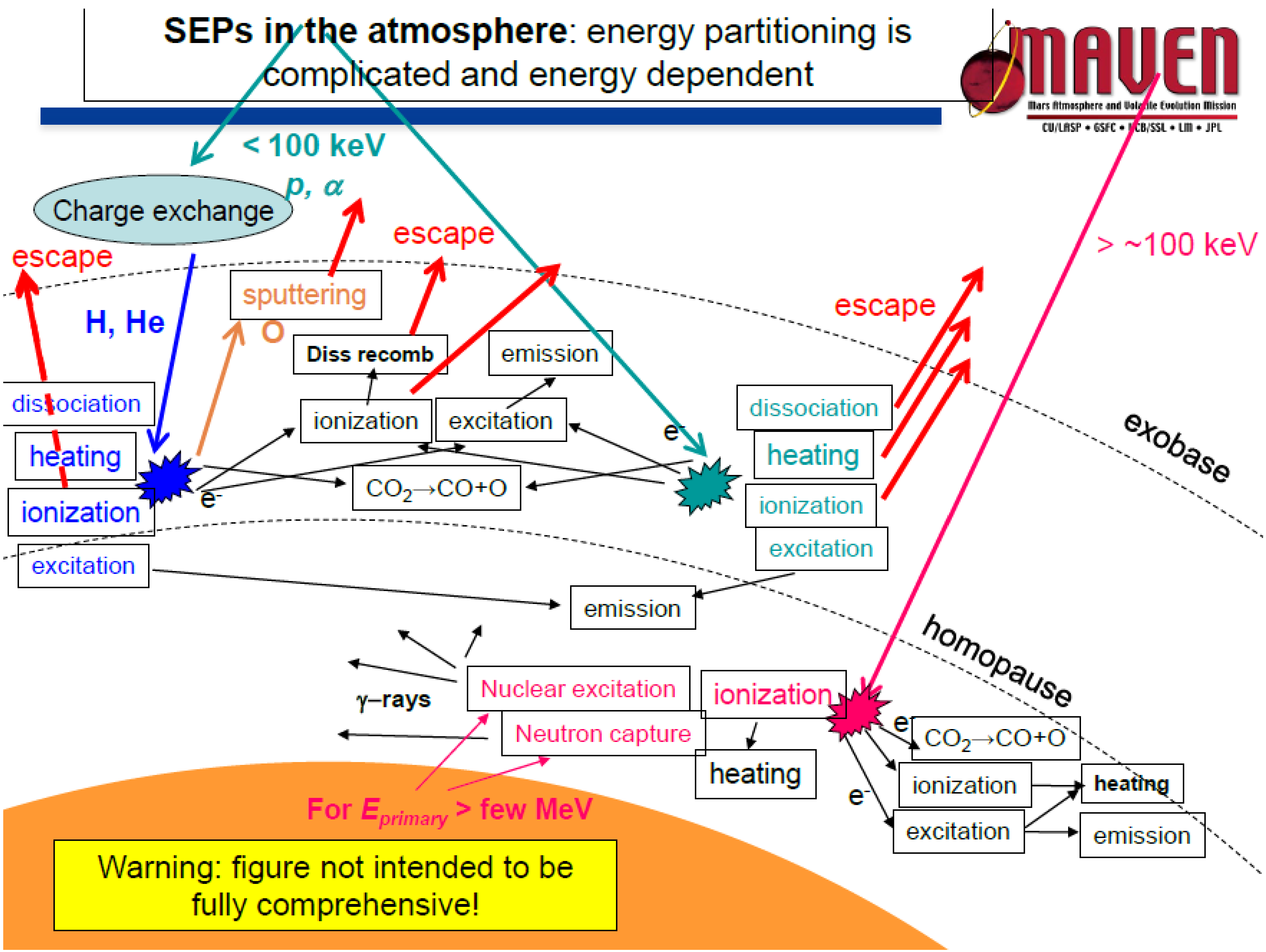
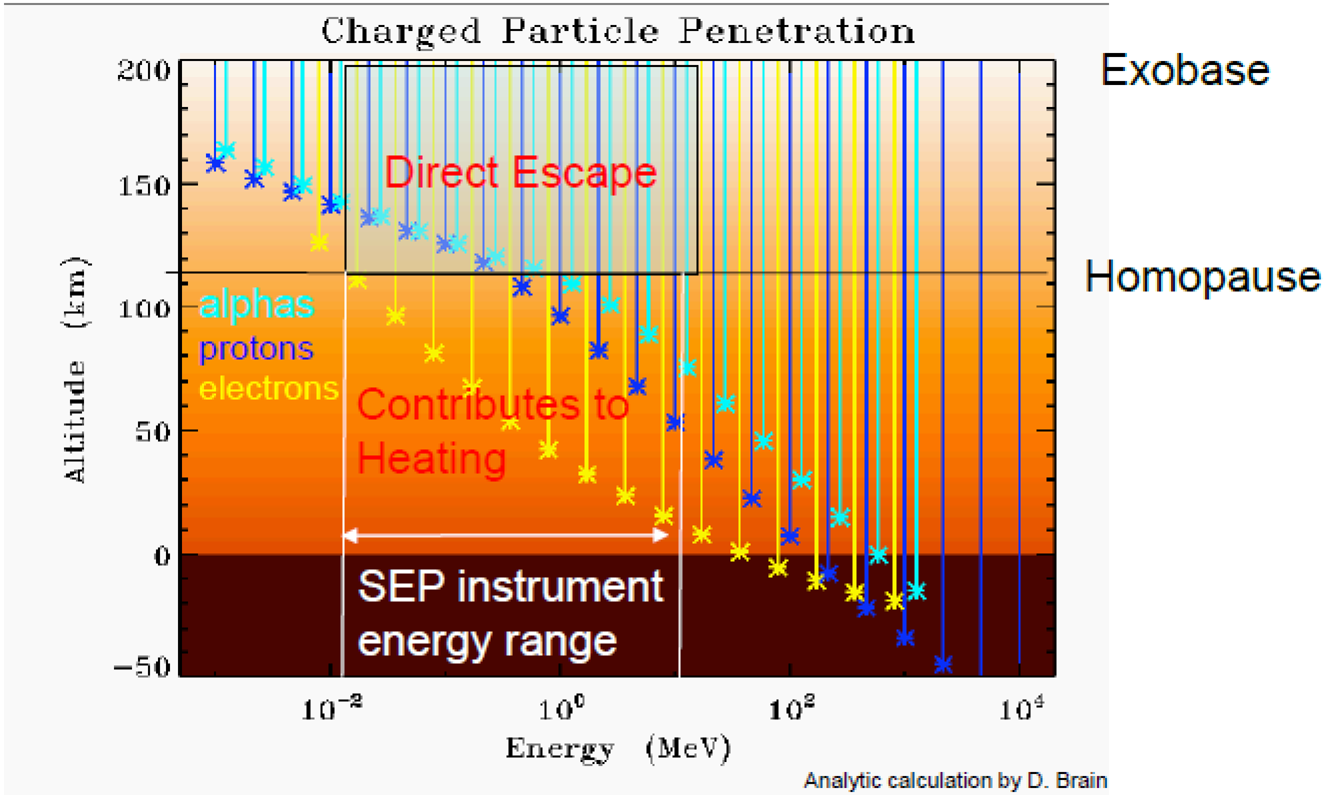
1) How & to what degree is the Mars atmosphere shielded
   - by the planetary-scale magnetosphere?
   - by the crustal magnetic fields?

2) What are the ways in which incident SEPs of various energies affect the atmosphere?
   - SEP spectrum degradation with altitude?
   - Sputtering by energetic neutrals created via charge exchange?
   - Bulk heating from SEP collisions with neutrals ?
   - SEP impact ionization → dissociative recombination → escape
   - Electronic excitation → auroral emission?
   - Molecular dissociation → effect on atmospheric chemistry?
   - Ionospheric currents?

SEPs in the atmosphere: energy partitioning is complicated and energy dependent

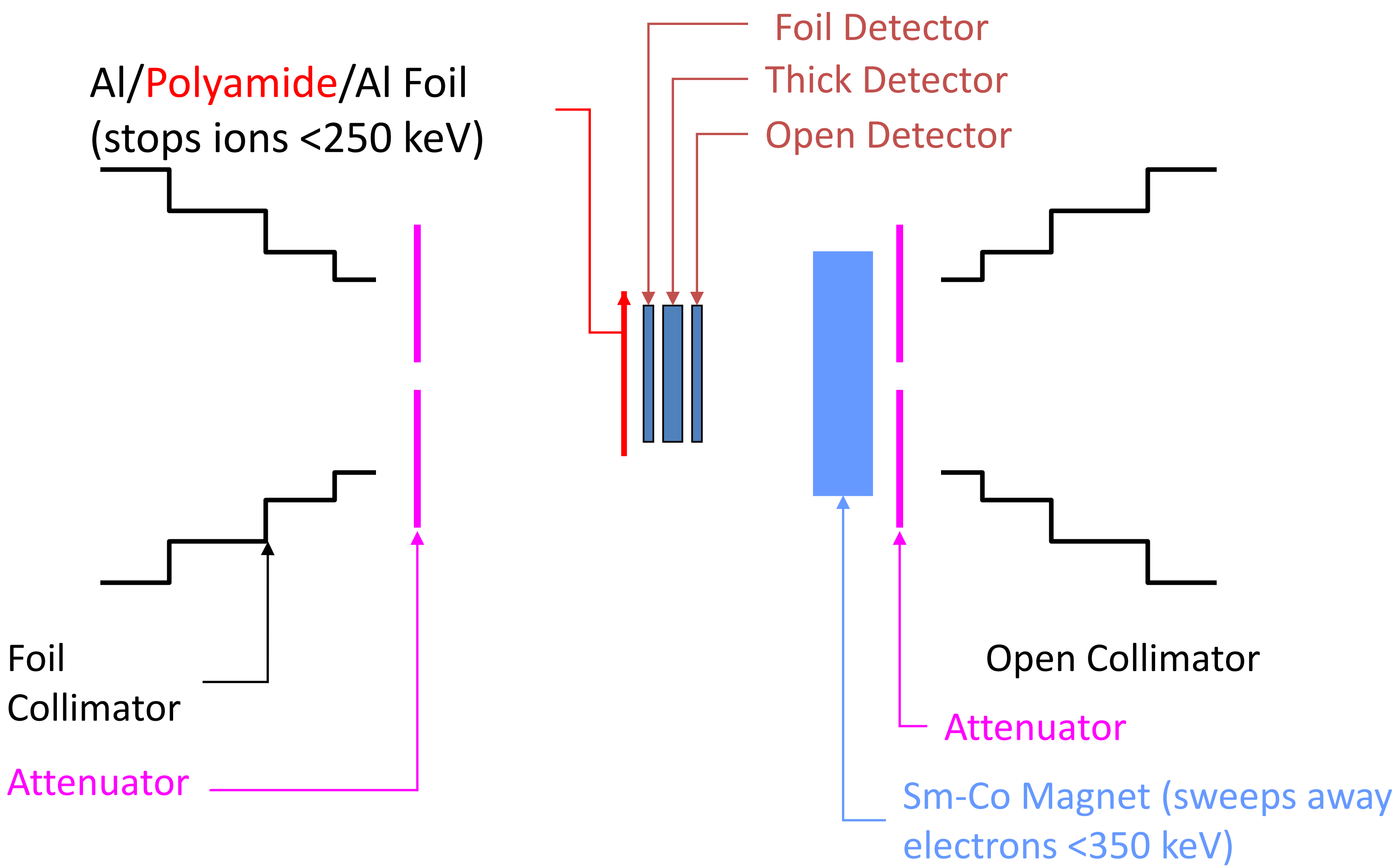


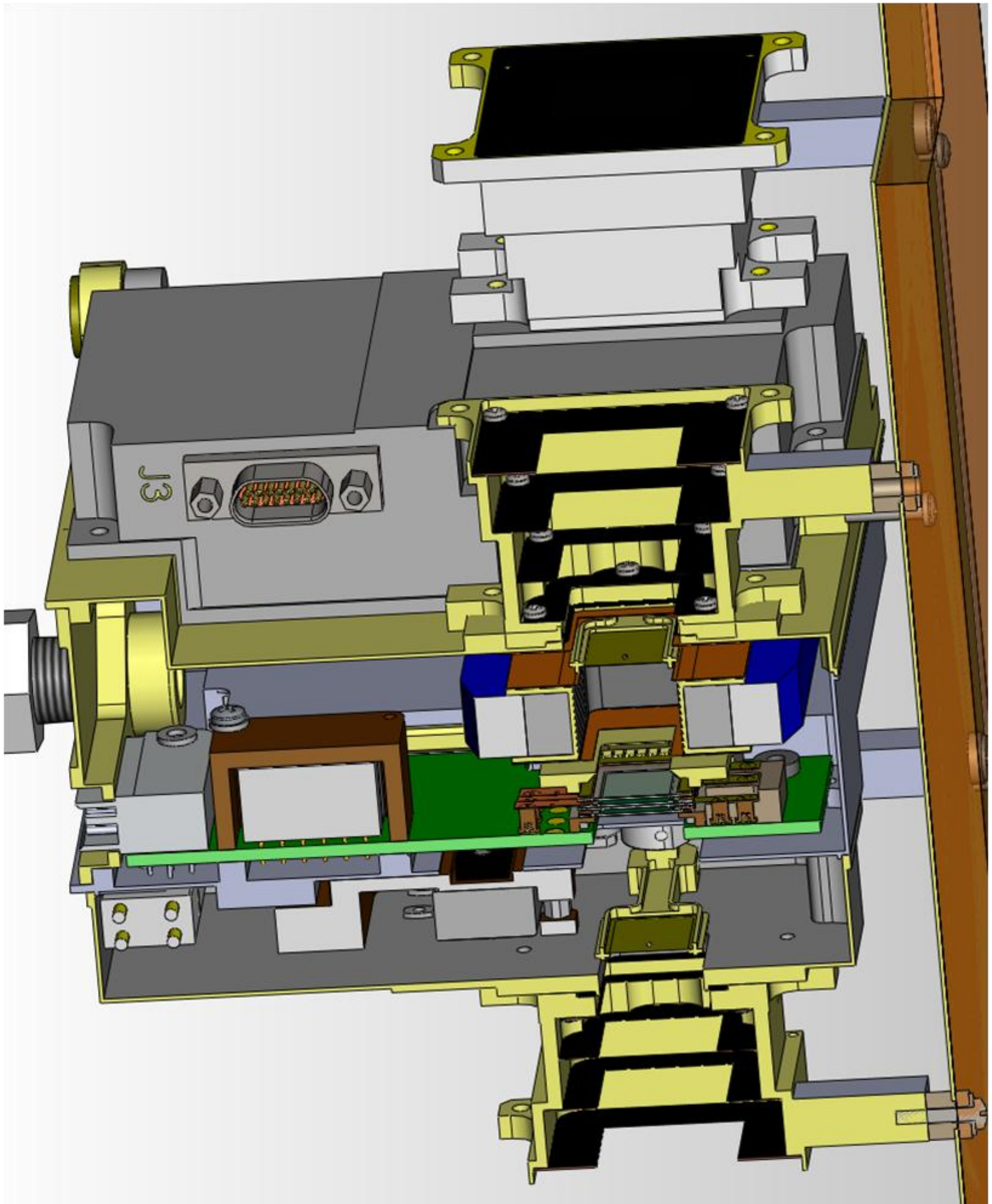
SEP instrument will measure particles that penetrate to altitudes important for escape processes.

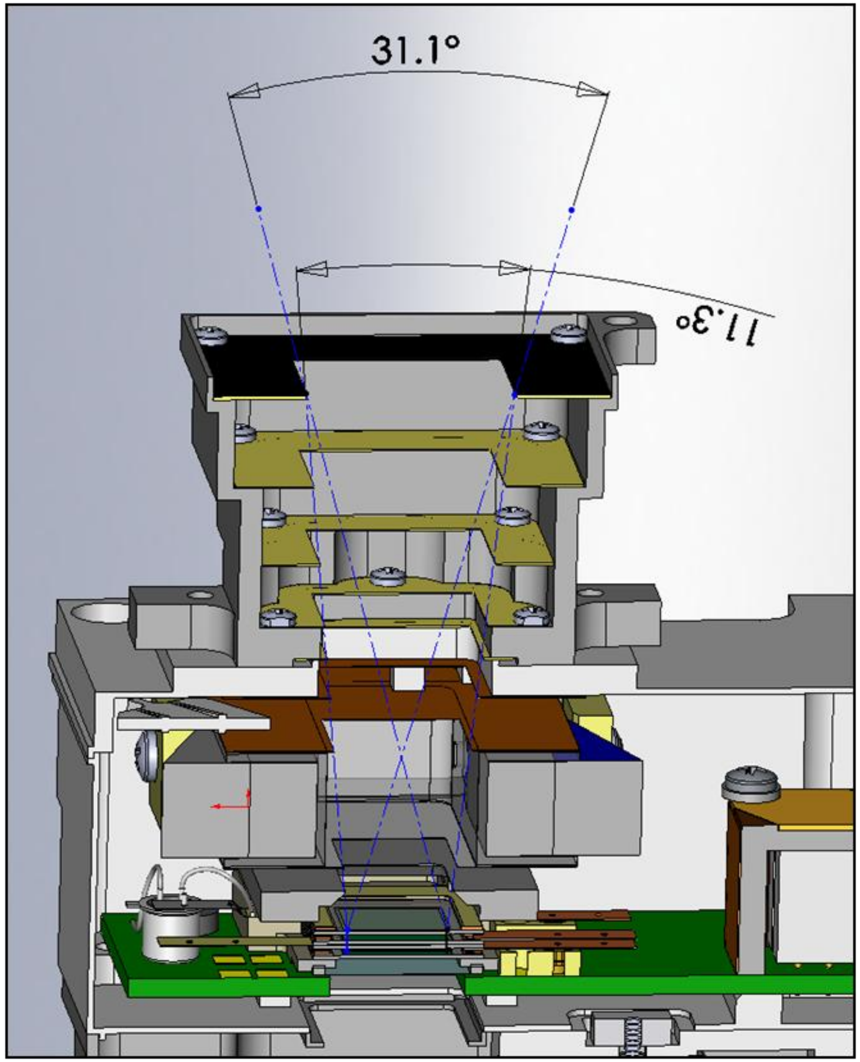


- The bulk of SEP event total energy is generally below 50 keV, deposited mostly between 100 km and 130 km [LeBlanc et al., 2002], though events widely vary.
- We will measure particles that penetrate to 50 km-150 km, providing important constraints on modeling of atmosphere/ionosphere dynamics.

Basic design of SEP instrument



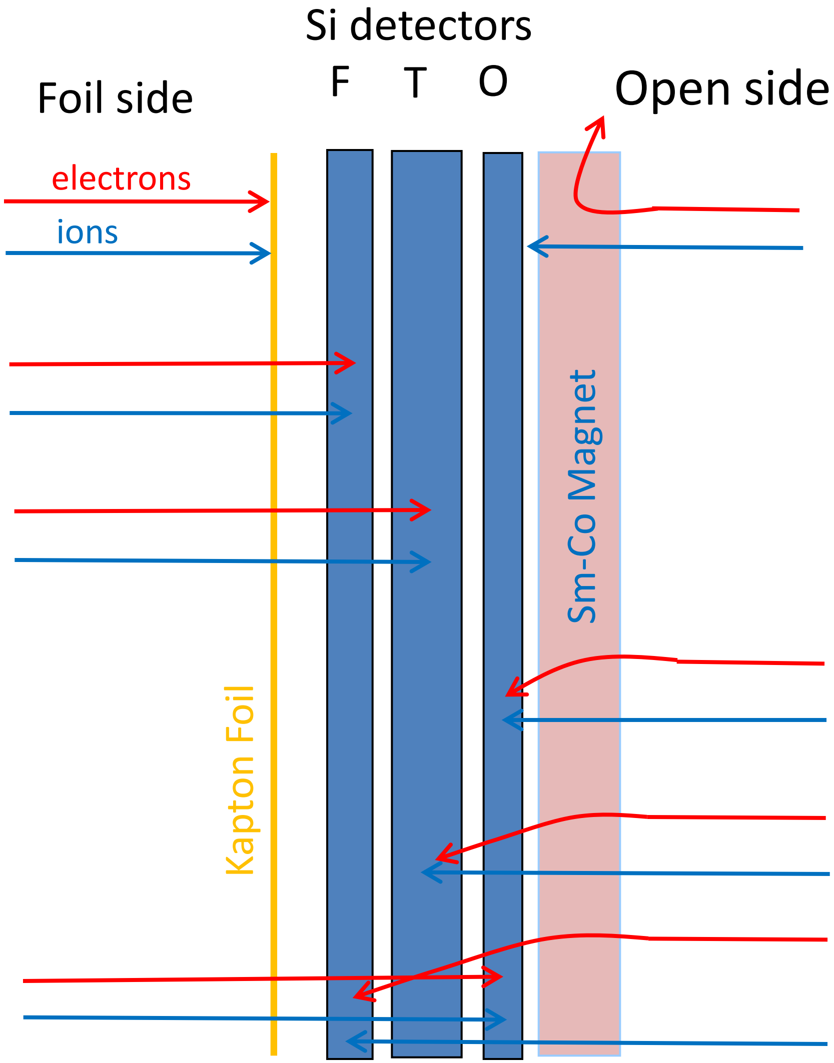

J3


31.1°
11.3°

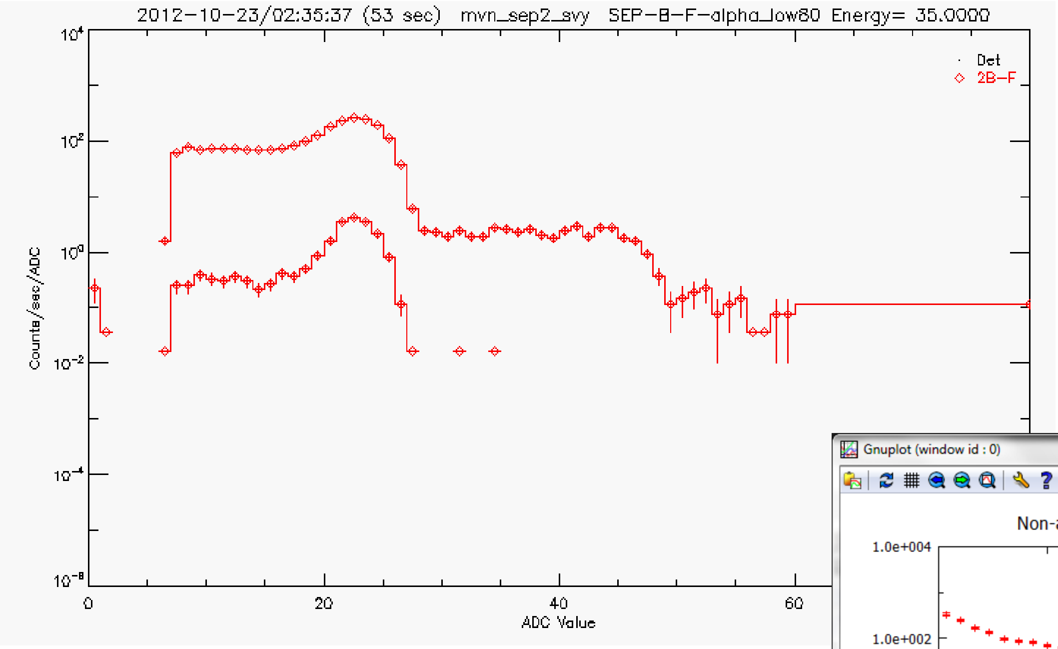
Basic separation strategy: 3 detectors, 2 filters

Energy ranges for counted events

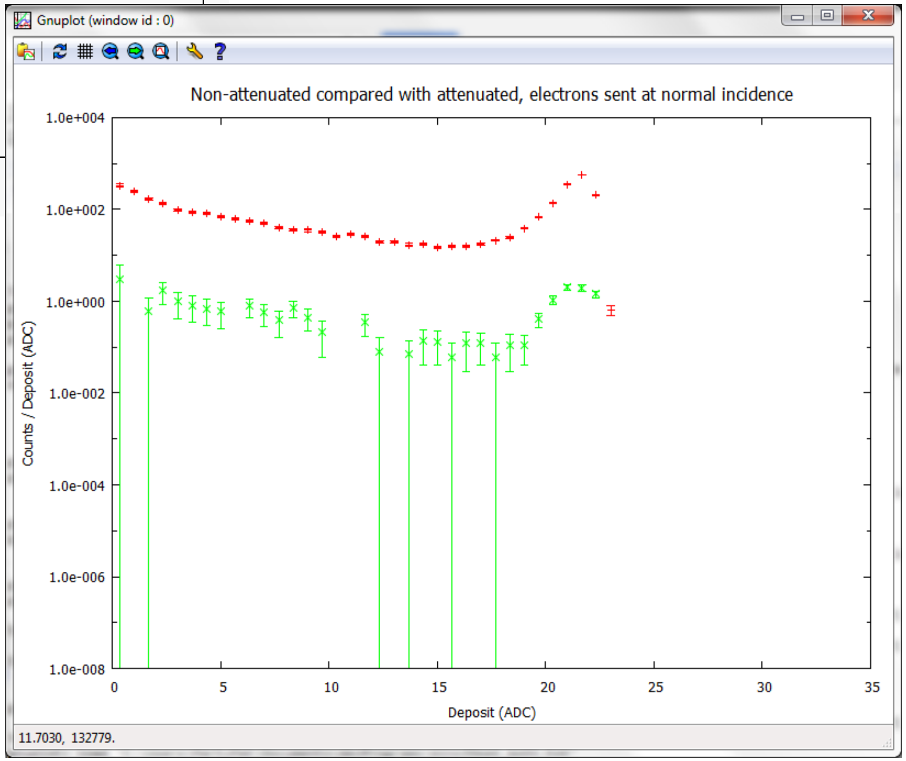
	Electrons		Ions	
keV	Foil side	Open side	Foil side	Open side
No count	<20	<350	<250	<15
F	20-700	X	250-6000	X
FT	350-1300	X	6000-11,000	X
O	X	350-700	X	15-6000
OT	X	350-1300	X	6000-11,000
FTO	300-2000		>11,000	



GAINING THE TRUST OF AN INSTRUMENT LEAD

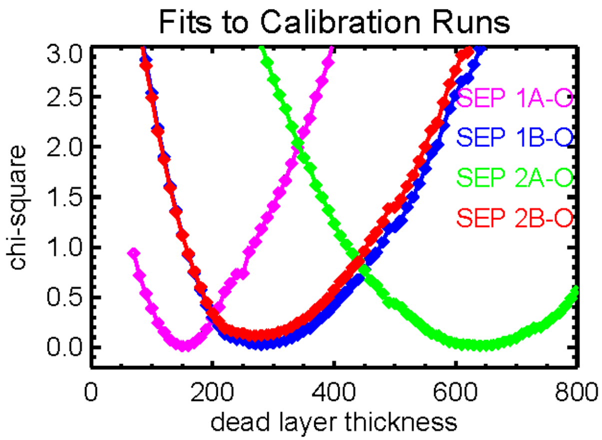


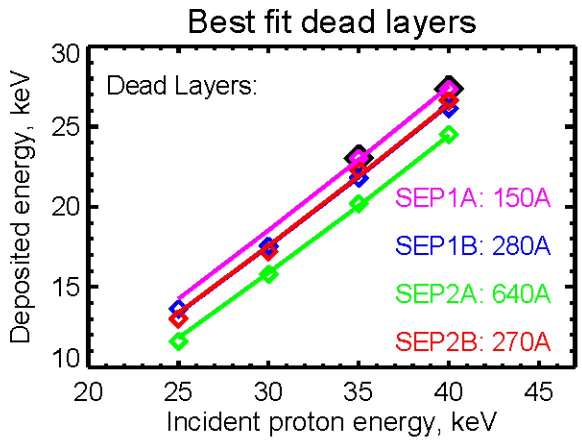
Experimental results, electron gun



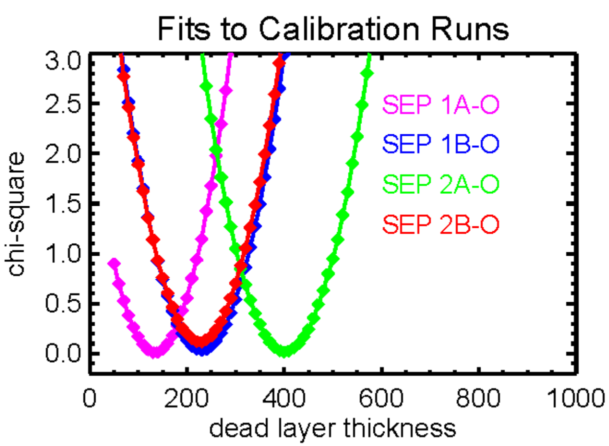
Simulation results, Geant4

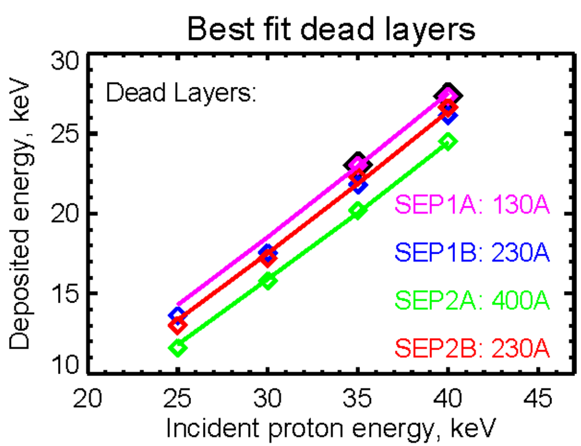
DETERMINING THICKNESS OF DETECTOR "DEAD" LAYERS





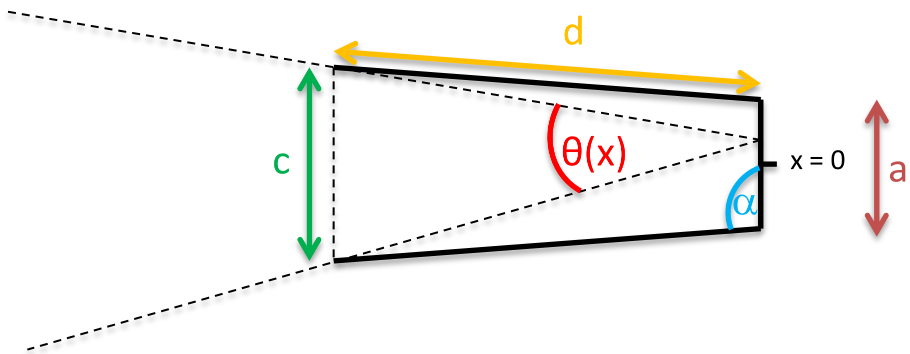
Oops! Misplaced volume.

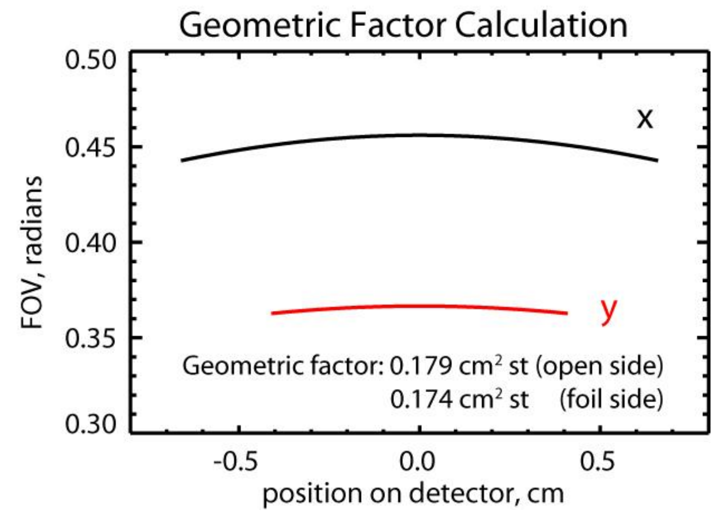




OK, much better! ☺

GEOMETRIC FACTOR CALCULATED GEOMETRICALLY





- Rectangular field of view: consider x,y separately
- Determine opening angles θ(x),ϕ(y) as a function of position on the detector.
- Integrate across the detector in x and y.
- Geometric factors:
  - 0.179 cm^2 st (open side)
  - 0.174 cm^2 st (foil side)
- GEANT4 simulations on following slide.

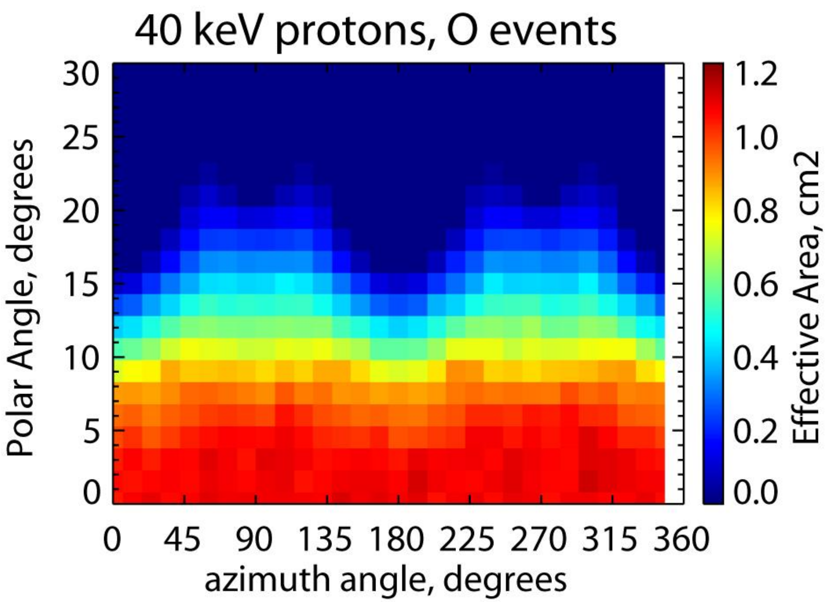
$$p_1^2 = d^2 + \left(\frac{a}{2} + x\right)^2 - 2d\left(\frac{a}{2} + x\right)\cos\alpha$$

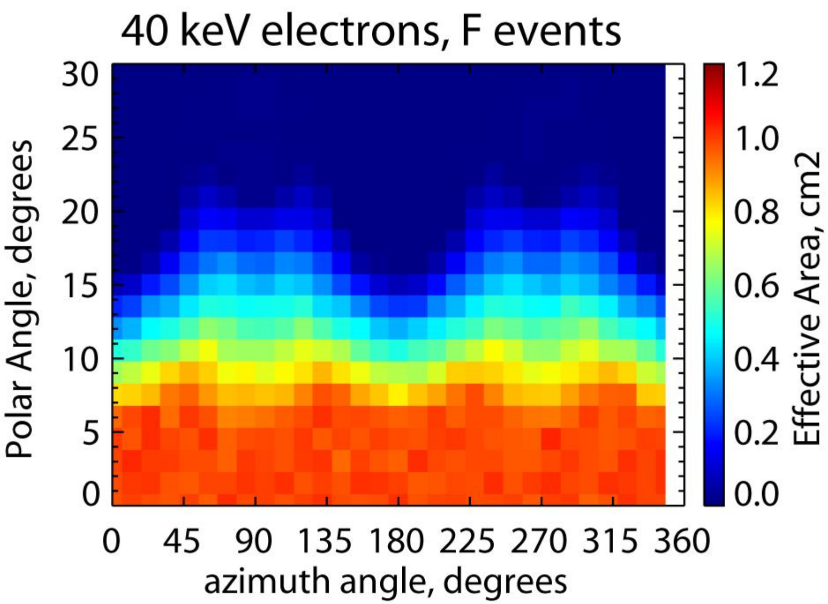
$$p_2^2 = d^2 + \left(\frac{a}{2} - x\right)^2 - 2d\left(\frac{a}{2} - x\right)\cos\alpha$$

$$\theta(x) = \cos^{-1}\left(\frac{p_1^2 + p_2^2 - c^2}{2p_1p_2}\right)$$

$$GF = \int_{-b/2}^{b/2}\int_{-a/2}^{a/2}\theta(x)\phi(y)\,dx\,dy$$

GEOMETRIC FACTOR CALCULATED WITH GEANT4 SIMULATIONS





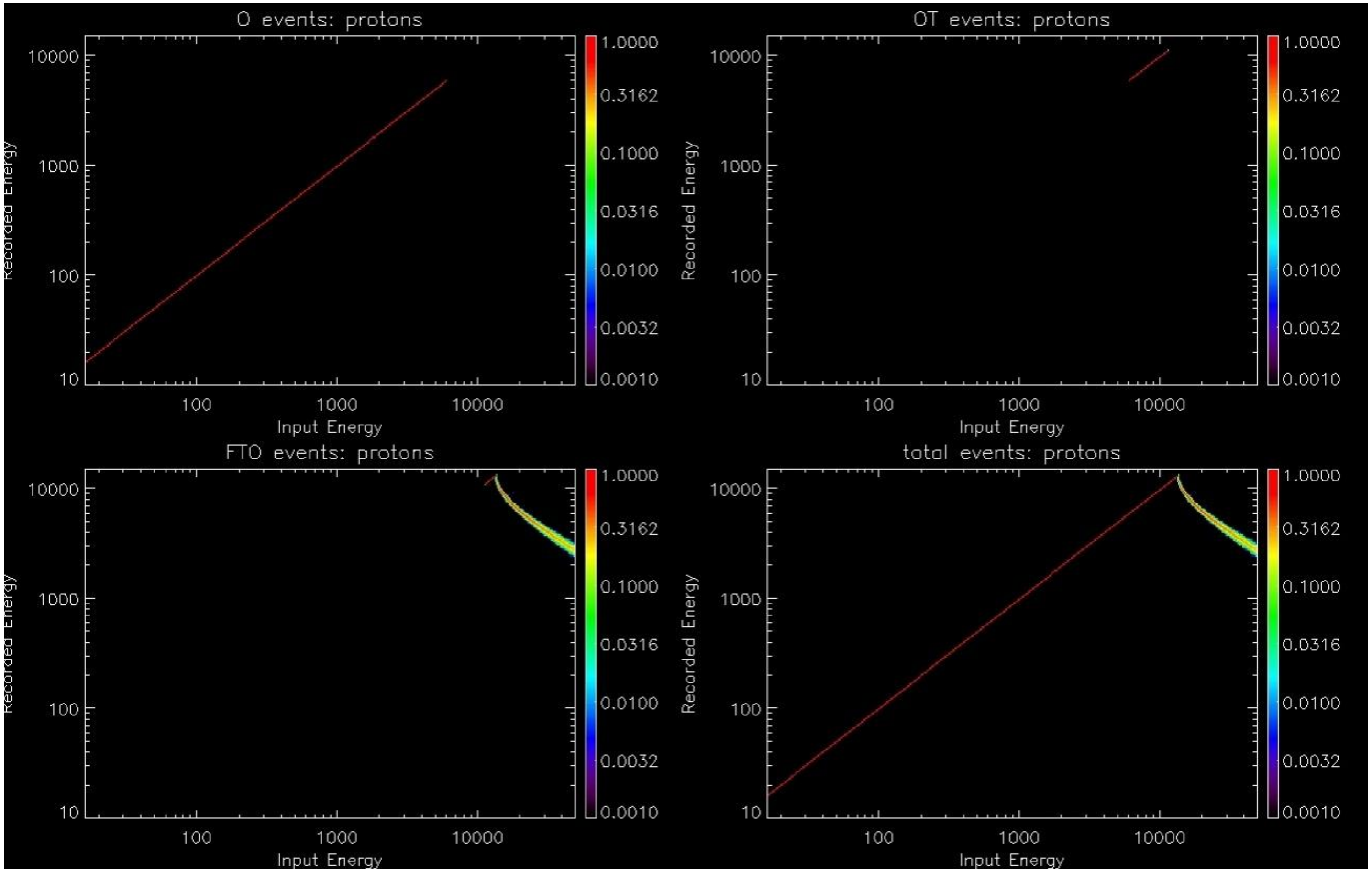
- 40 keV electrons. Foil side.
- Beam Area : 7.07 cm²
- # particles per angle: 20,000
- *GF* = 0.1689 ±.0025 cm^2 sr
- 1.47% error from counting statistics
- 2.87% lower than simple geometric value of 0.174 cm^2 sr (see previous slide)

- 40 keV protons. Open side.
- Beam Area : 7.07 cm²
- # particles per angle: 20,000
- *GF* = 0.1769 ±.0027 cm^2 st
- 1.54% error from counting statistics
- 1.17 % lower than simple geometric value of 0.179 cm^2 sr (see previous slide).

$$GF = \frac{A_{beam}}{N_{incident}} \int_0^{2\pi} d\phi \int_0^{\pi/2} N_{\mathrm{det}ected}(\phi,\theta) \sin\theta d\theta$$

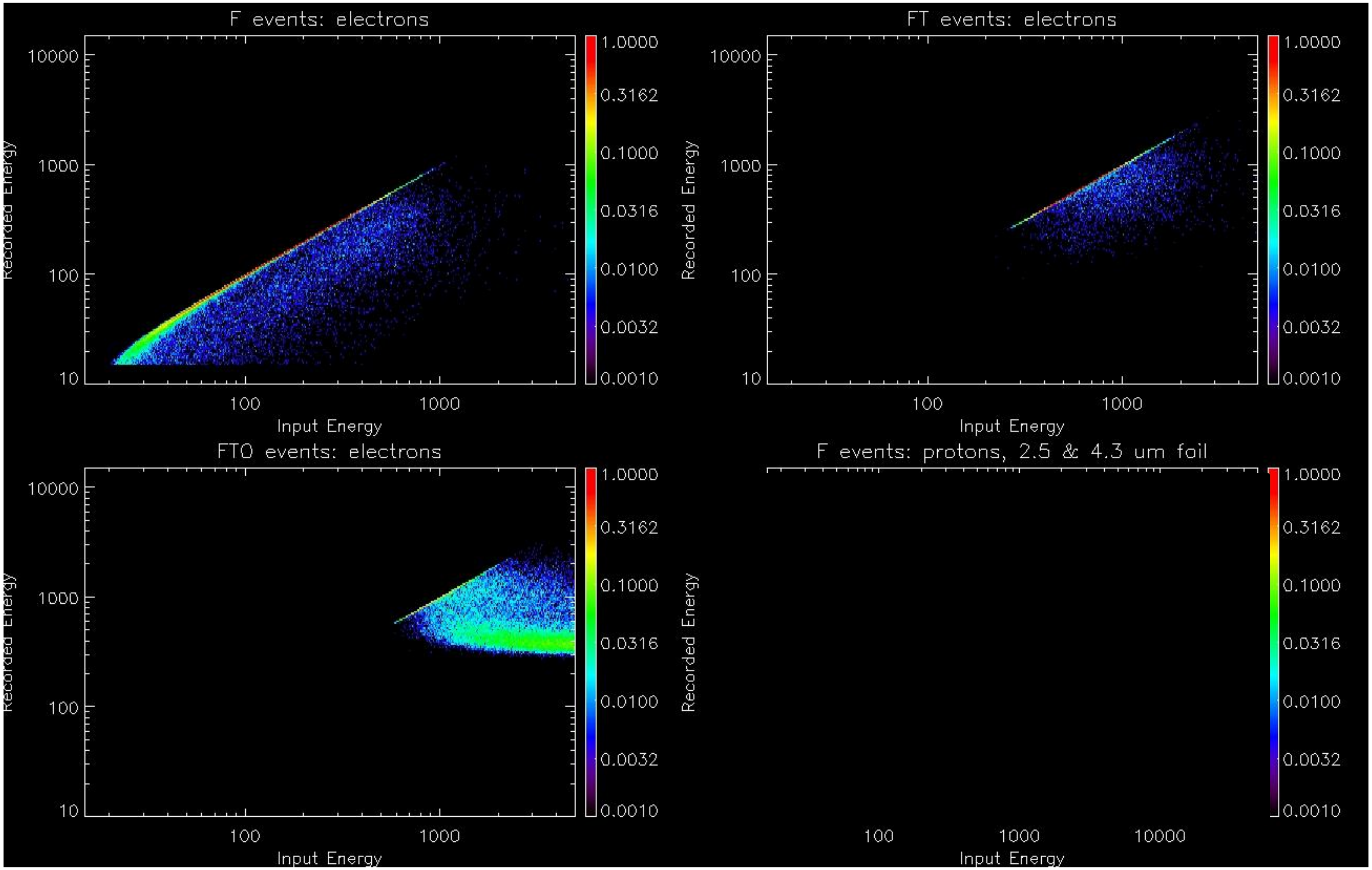
Ion response matrices

- Since ions deposit most of their energy at the very end of their trajectory, proton response matrix for O, OT and FTO events is quite clean.



Electron response matrices

- Electrons deposit their energy over a much longer distance than ions. Response matrices are much less diagonal.



SUMMARY

SEP tasks already completed with Geant4:

- Calculation of width of "dead" layer coating on detectors
- Calculation of low-energy (25 keV) geometric factor
- Minimum energy for Oxygen ions (O^+) to reach detector

SEP tasks yet to be completed (ongoing) with Geant4:

- Response matrices of detectors
- ???