Aditya Solar wind Particle Experiment (ASPEX)

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A revised and enhanced version of the original proposal named “Solar Wind and Thermal Ion Spectrometer (SWATIS)” submitted by Rajmal Jain

Genesis of the revised proposal

ADCOS queries to the earlier (SWATIS) proposal of 24-01-2014

- How to measure the anisotropy has to be worked out
- Spectral Index of [−6] has to be checked
- How to distinguish between Maxwellian and non-Maxwellian components in the velocity distributions of protons and ions?

Our Analysis of the issues

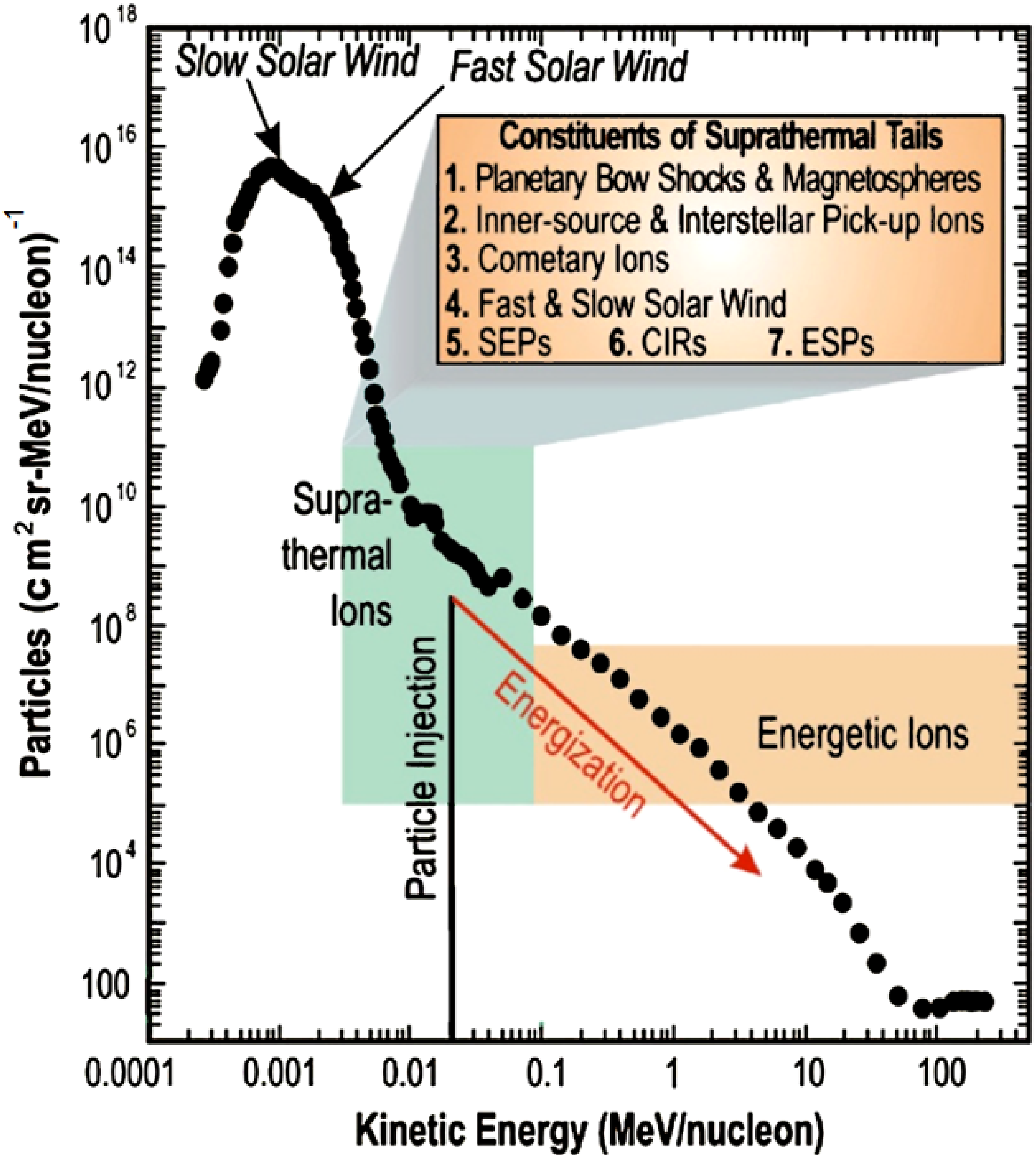
- Anisotropy alluded to in the original proposal was in error; the anisotropy relevant in the context of solar wind is thermal anisotropy, not spatial flux anisotropy
- The anisotropy is meaningful with reference to the local magnetic field.
- Distinction between Maxwellian and non-Maxwellian components may be made if the energy resolution and energy range are properly chosen
- However, species separation is necessary
- Moreover, species separation (He^{++}/H^{+}) is needed for addressing the anisotropy issue properly
- Thermal anisotropy as well as Helium abundance are affected by solar events and interplanetary processes

ASPEX : Science Objectives

- What is the thermal and spatial anisotropy in the distribution of particles in the direction of the Parker spiral vis-à-vis other directions at the L1 point?
- How different are the distributions of supra-thermal ions in normal solar wind as compared to that during SEP events?
- How strong is the correlation between various solar events and deviations from the average value of the He^{++}/H^{+} number density ratio at L1?

Solar Wind Energy Spectrum

- The energy distribution of solar wind particles can be approximated by a combination of multiple Maxwellian and power law distributions
- The (Maxwellian) temperature for solar wind particles streaming along the local magnetic field is different from the temperature for particle streaming perpendicular to the local magnetic field



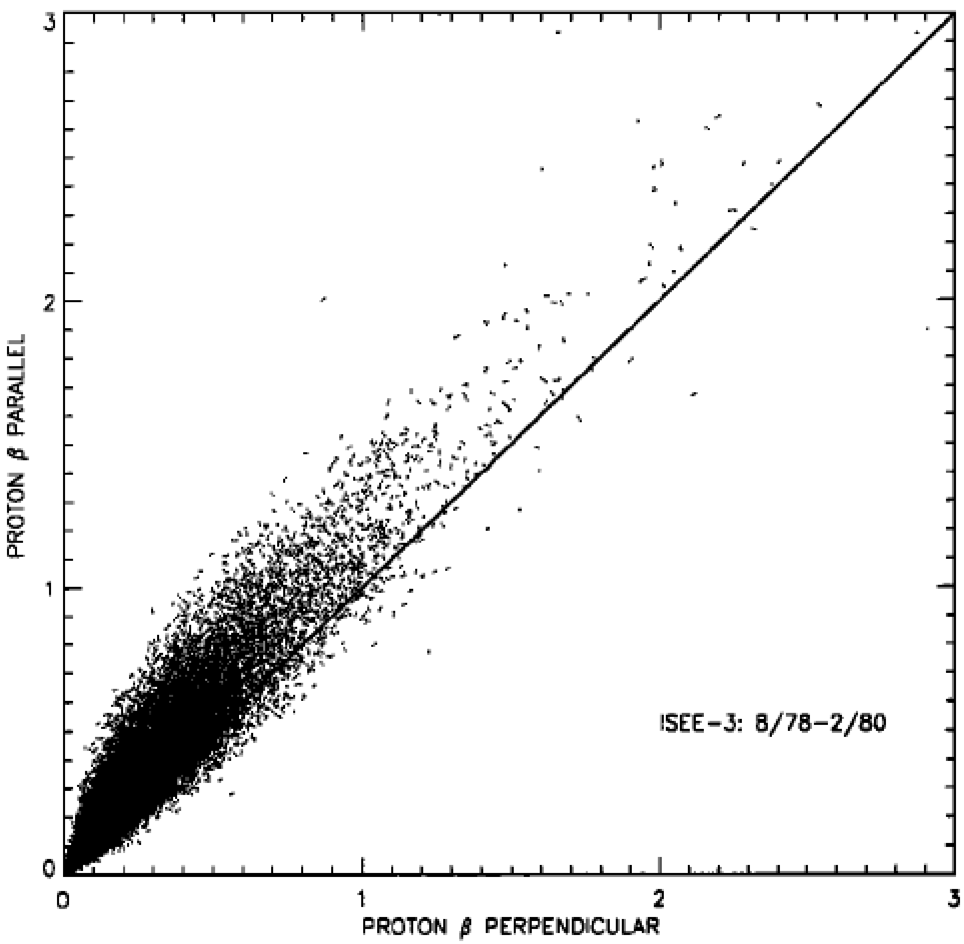
Solar Wind Thermal Anisotropy

Thermal Anisotropy

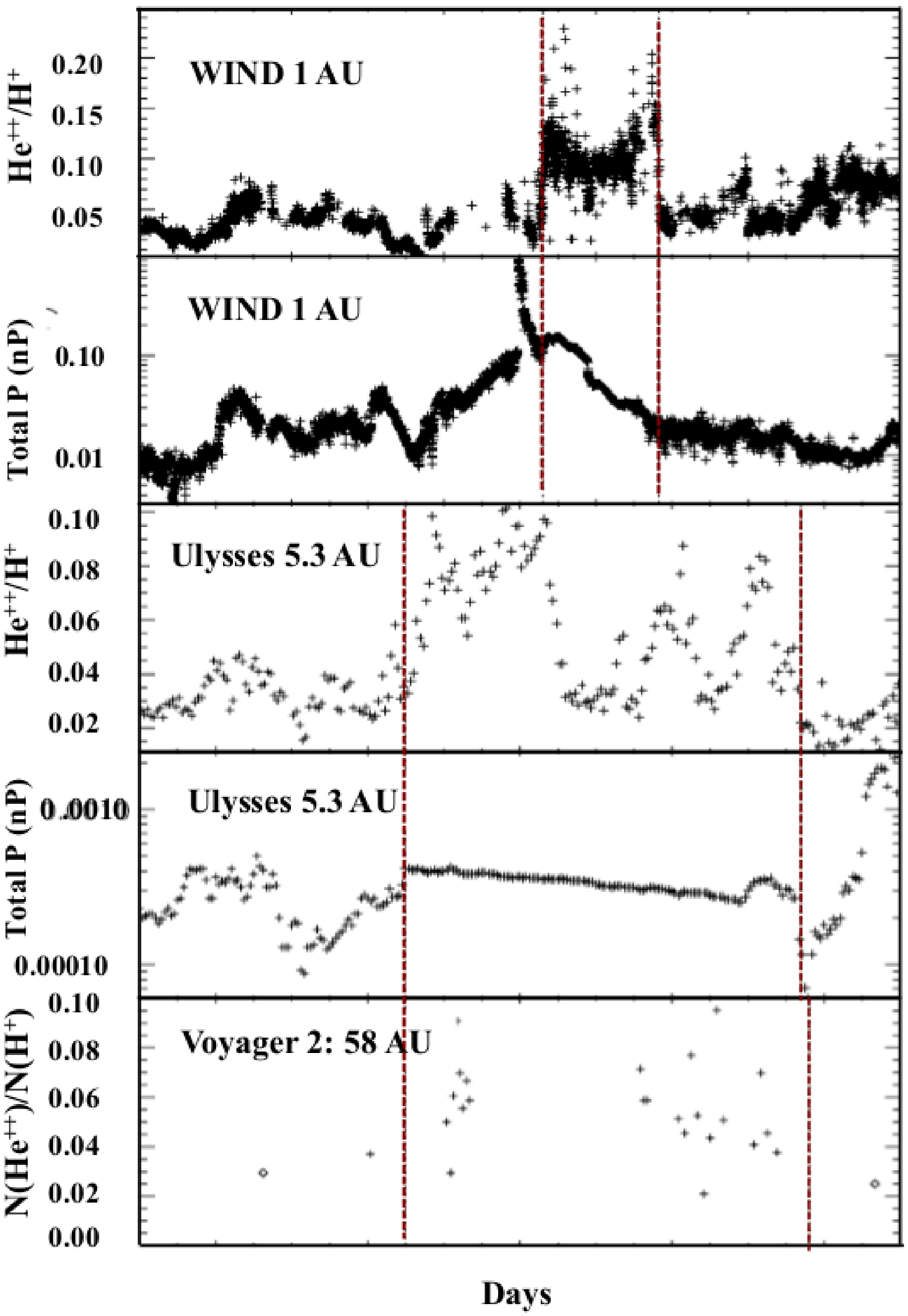
$$\beta = \frac{\textit{Kinetic Energy}}{\textit{Magnetic Energy}}$$

β perpendicular:
ratio for particles streaming perpendicular to the local magnetic field

β parallel:
ratio for particles streaming along the local magnetic field



Solar Wind Helium Abundance



Steiger and Richardson, 2006

- The He^{++}/H^{+} ratio can vary from a few % to even 35%. Possibly has a solar cycle dependence. (Steiger and Richardson, 2006)
- CME occurrence can be determined in situ by helium abundance enhancement (HAE)
  [$He^{++}/H^{+} > 0.08$] signals CME occurrence
  (Neugebauer and Goldstein, 1997).
- Other solar events and interplanetary activities also expected to influence the He^{++}/H^{+} ratio

ASPEX : Measurement Strategy

- Use HAE as the flag for unusual Solar activity or interplanetary events
- When flagged, search for thermal and spatial (flux) anisotropies from the energy-angle distributions of the two species separately.
- In the absence of a magnetic field probe, flux changes in different directions vis-à-vis the Parker spiral is the best alternative for addressing magnetic field dependent effects
- Concurrent species, direction, and energy resolving ability of the instrument are the key to such investigation

ASPEX delivers competing Science

- Addresses thermal and spatial anisotropy
- Addresses proton/alpha flux variation
- Wide energy coverage including the supra-thermal range
- Optimal match of Science goals with L1 location

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Comparison with SWATIS

- Angular distribution capability in one plane only (but the plane was undefined).
- No species separation.
- Only meant to measure energy (not velocity) dependent fluence.

Comparison with other missions

- ACE & WIND : At L1 but spinning platform
- STEREO : Not at L1 (one leading and one trailing the Earth in its orbit)
- SOHO : At L1 and three-axis stabilized but no multi-directional capability.

ASPEX : Instrument Capabilities

- Will measure particle flux along different directions:
  - Along the direction of the Parker spiral (and anti-Parker direction)
  - Along the sunward direction (and anti-sunward direction)
  - Normal to the ecliptic plane.
- Will cover the energy range 100 eV to 20 keV using two measurement techniques
- Will have alpha/proton separation over the entire energy range.
- Concurrent direction, energy and species resolving ability sets it apart from other existing spacecraft at L1.

The ASPEX Instrument

ASPEX

Solar Wind Ion Spectrometer (SWIS)

- 100 eV to 20 keV energy range using an Electrostatic Analyser
- Separation of proton, alpha and heavier ions by means of a magnetic analyzer and a position sensitive detector
- Angular distribution over complete azimuth in one plane and ±30 deg in an orthogonal plane.

Supra-thermal and Energetic Particle Spectrometer (STEPS)

- Covers the energy range 0.02 to 5 MeV using solid state detectors
- Multi-directional capability (4 orthogonal directions)
- A pair of detectors in each direction — one for protons and the other for heavier ions

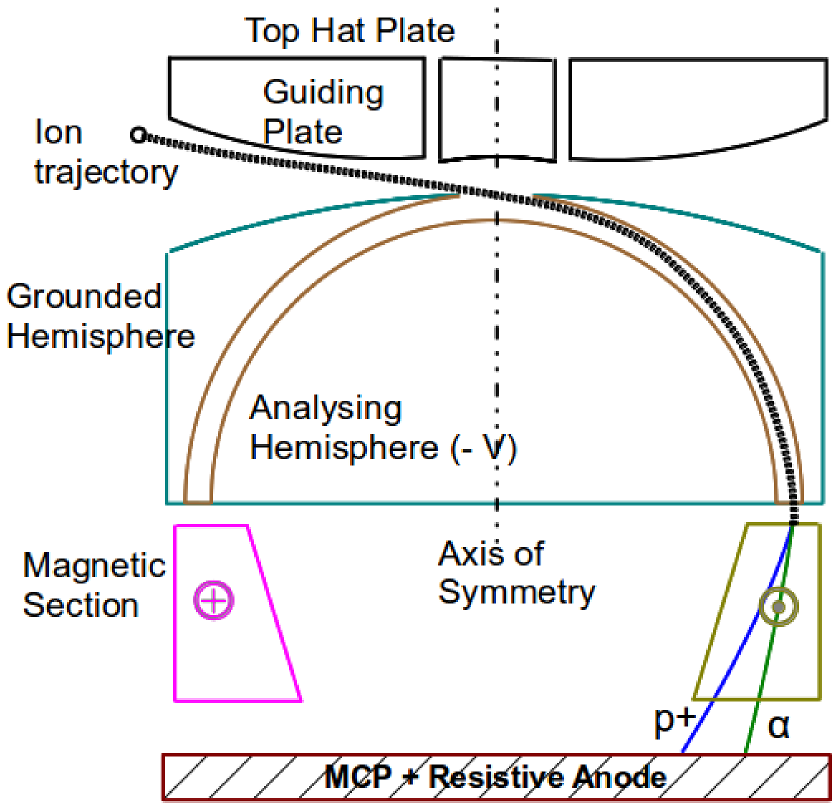
ASPEX : The SWIS Module

Observational requirements & implementation

Observational Requirement	Instrument Implementation
Acquiring the energy spectrum of solar wind particles over the energy range (*E*/*q*) of 100 eV to 20 keV	Electrostatic Energy Analyser (Top Hat Geometry)
Measuring the angular distributions of the particles in and across the ecliptic plane	Electrostatic Guiding plate and position sensitive detection
Measure energy spectrum of proton and alpha particle separately	Magnetic mass separation of energy analysed particles

SWIS Instrument Details

- Top Hat electrostatic energy analyser
- Followed by permanent magnet mass separator (radial dispersion)
- Finally, a position resolving planar detector (MCP + resistive anode)



Section View

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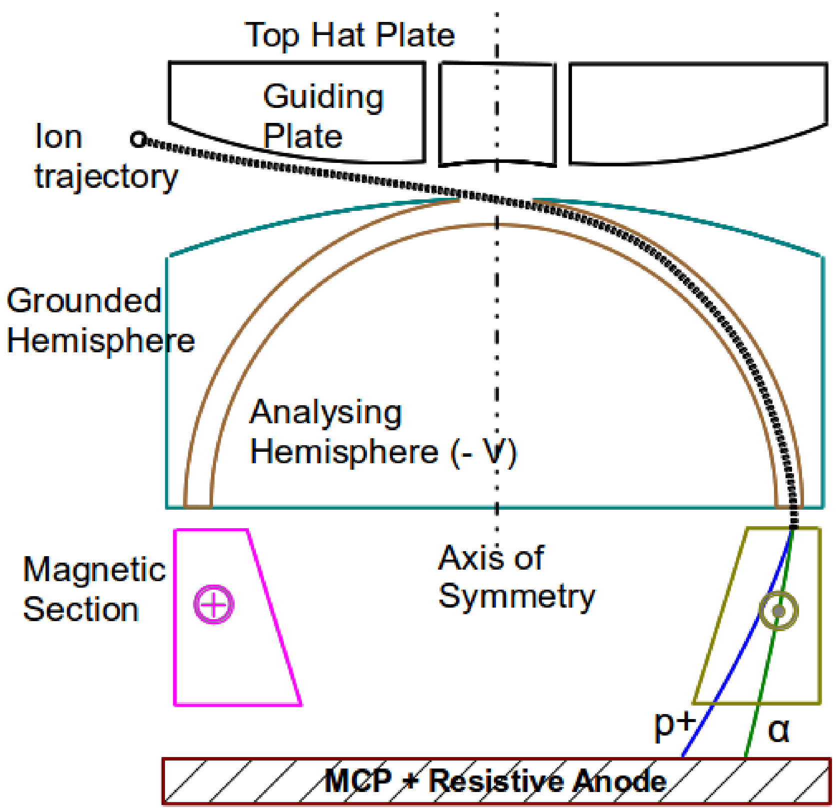
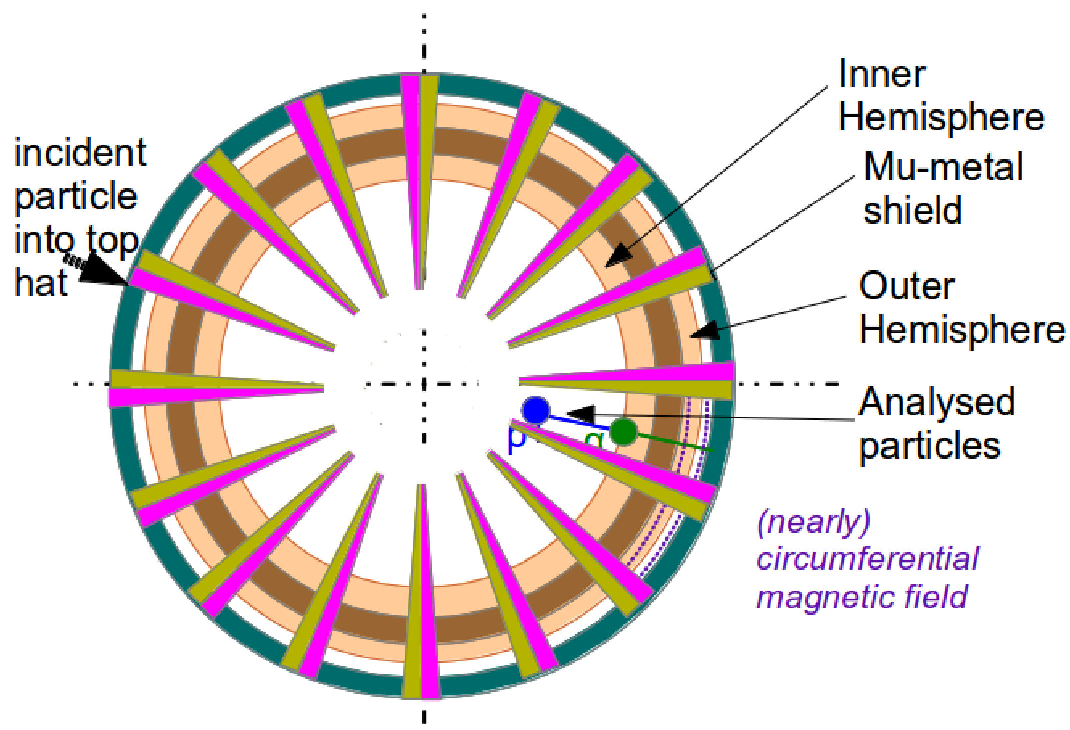


Section View



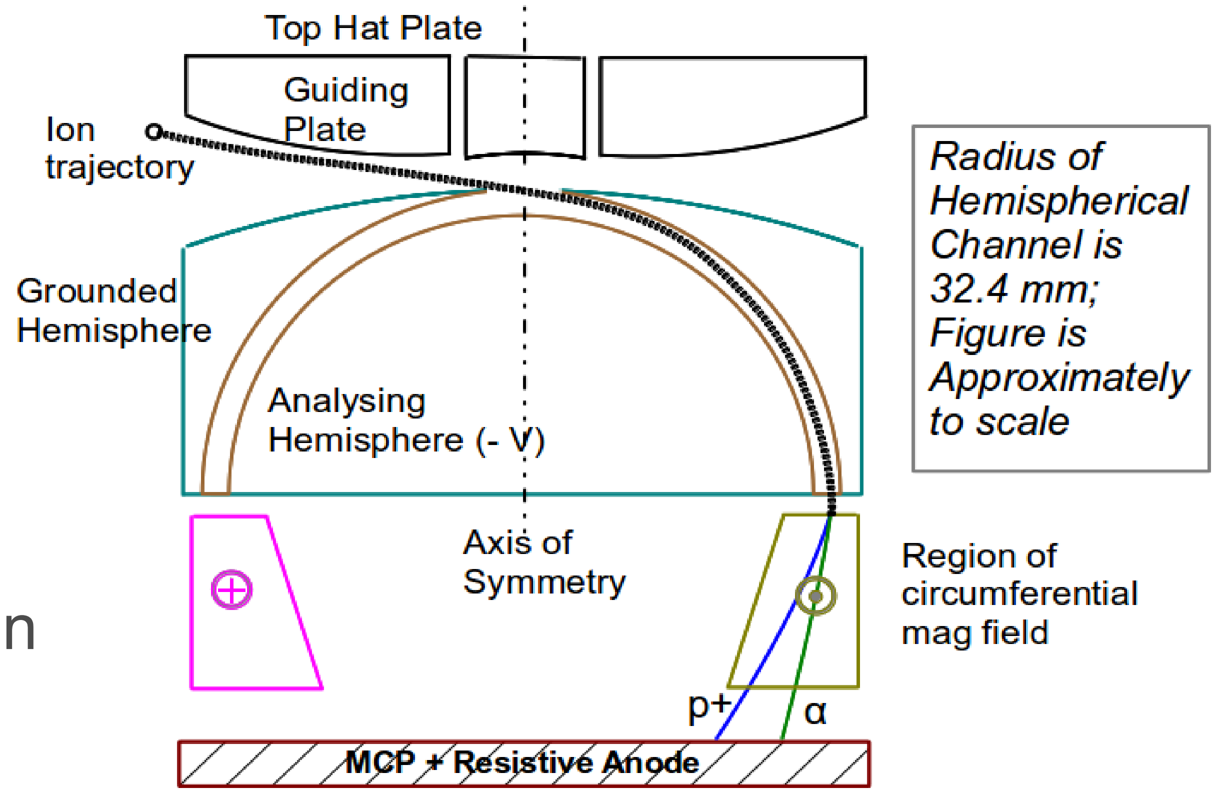
Bottom View (detector removed)

SWIS Design Elements

Element	*Description*	*Parameter values [Range]*	*Purpose*
Ion guide	opposed hemispherical plates	[-3500,3500] V voltage scan (energy dependent range)	to sweep the angle in the ecliptic plane
Energy Analyser	concentric hemispheres with gap	[-15,-3500] V voltage scan	to obtain the energy spectrum
Accelerating stage	planar grid	-2.5 kV for low energy ions, 0 for high energy ions	to accommodate a larger range of energies for mass analysis
Mass separator	permanent magnets arranged circumferentially	0.8 T each, 16 pieces	to separate p+,α, heavy ions
Detector	80 mm diameter microchannel plate with position sensitive anode	-2.5 kV bias, resisitive anode readout	to determine particle hit radial and angular coordinate

Magnetic mass analyzer

- Radial array of 16 permanent magnets
- Pole strength 0.5—0.8 T (Sm-Co or NdFeB)
- Approx trapezium section and short pole length
- Will need special fabrication

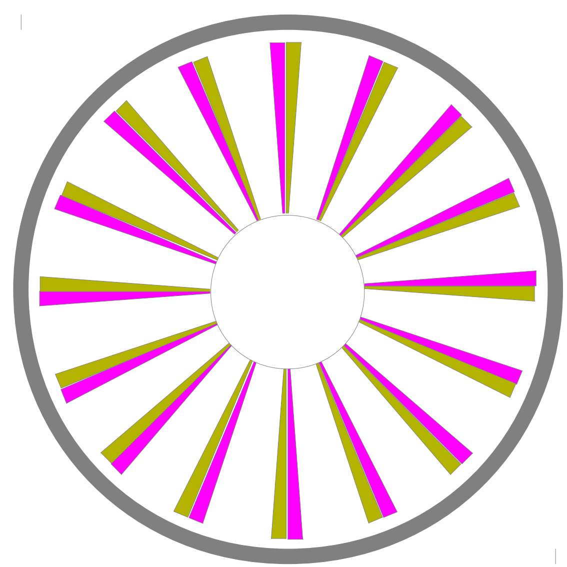


Radial deflection

$$r - r_0 = (1/8)^{1/2}\,(q/E)^{1/2}\,(q/m)^{1/2}\,BL^2$$

Angle of exit

$$\tan \psi = (qBL) / (2mE)^{1/2}$$



Cross-section Through Magnetic separator

Magnetic Analyzer Parameters

Dimension	*Value*	*Tolerance*	*Comments*
Length of Magnetic Field region	40 mm	1.0 mm	in axial direction
Pole Strength (B_r)	0.8 T		circumferential
Radial extent of Magnetic Field region	15--40 mm	1.0 mm	increases away from the equatorial plane of energy analyser
mu-metal shield	dia 130, 2 thk	1 mm	cylinder with end caps and annular slits
Leakage field	30 μT (= B_{earth})	7 cm from instrument axis	Dependant on exact shielding geometry (being worked out)

Basic Measurables using SWIS

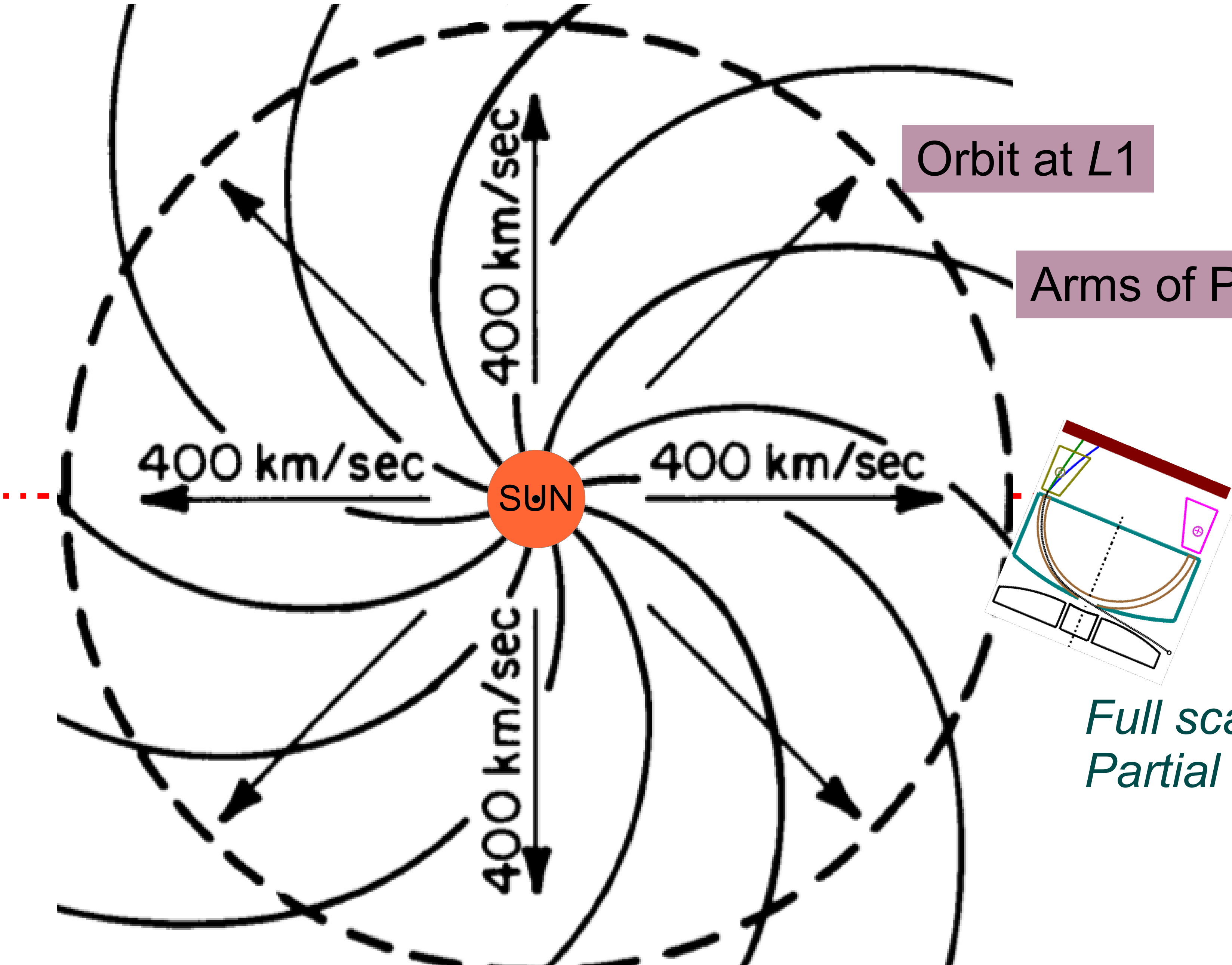
Measured Quantity	*Range*	*Accuracy*	*Related Instrument Parameter*
Energy	0.1–20 keV		Scanning of voltage on inner hemisphere
Angle of incidence	0–360° in zenith plane ±30 in ecliptic plane	22.5° 5°	Angular coordinate of particle hit on MCP/Anode Guiding plate Voltage
Species	1– ∞ a.m.u.	Three groups: p^+, α, heavier ions	Magnetic field and radial coordinate of particle hit ions

Operation of the instrument

- Scan over the 0.1–20 keV energy range in 100 variable steps [ΔE = 5–100 eV]
- Azimuth angular scan by sweeping the guiding plate voltage
- At fixed hemisphere voltage the guiding field will be scanned to admit particles with different angles of incidence
- Guiding field voltage will be the most cycled parameter

Instrument Orientation

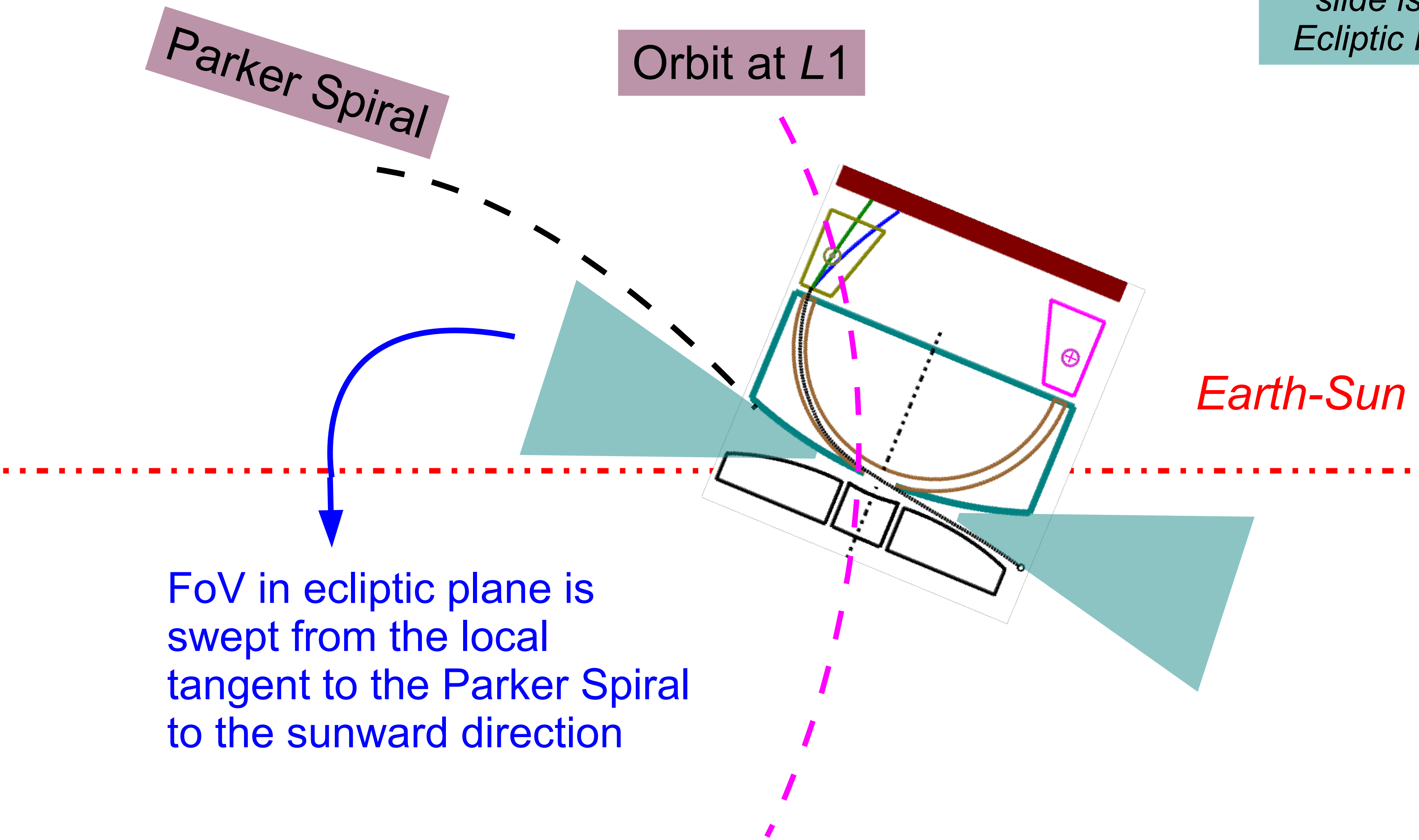
Plane of this slide is the Ecliptic Plane



Full scan of elevation
Partial scan of ecliptic

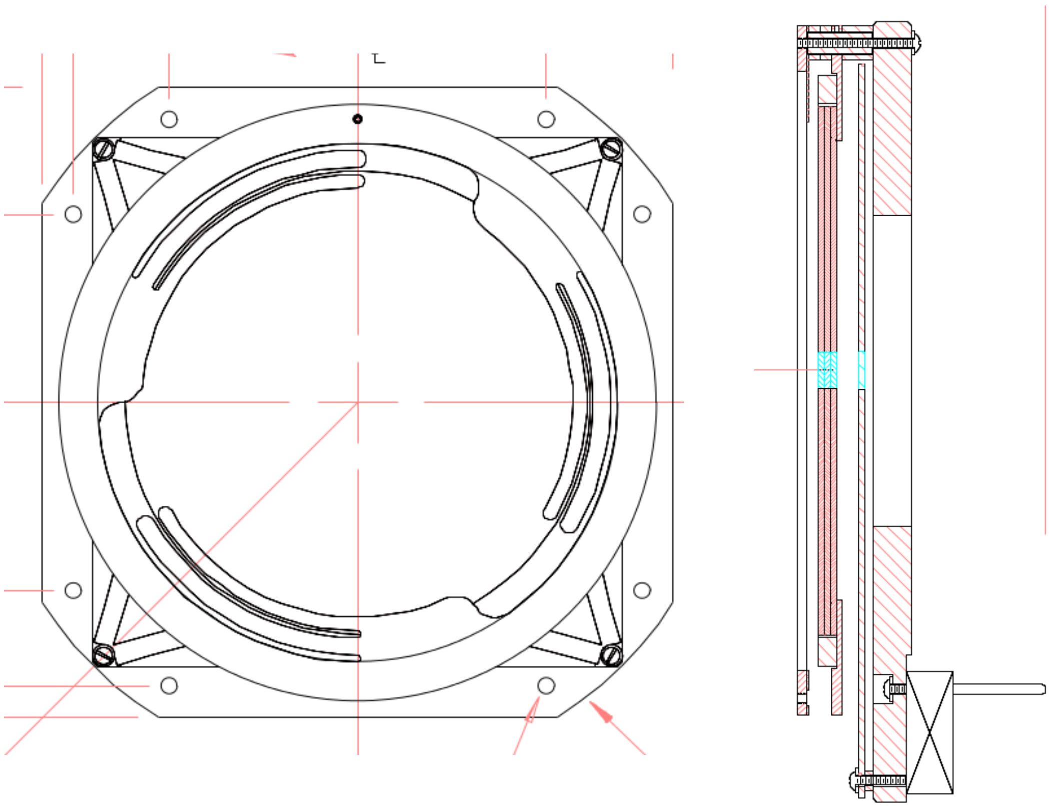
Instrument Orientation

Plane of this slide is the Ecliptic Plane



Detector and readout

- Primary detector is a 80 mm dia microchannel plate pair
- Anode is a resistive sheet (*Quantar Inc.*)
- Secondary electron shower on Anode is read off 4 electrodes simultaneously, giving a charge division
- Charge division pattern is analysed to get the centroid (position) of the shower



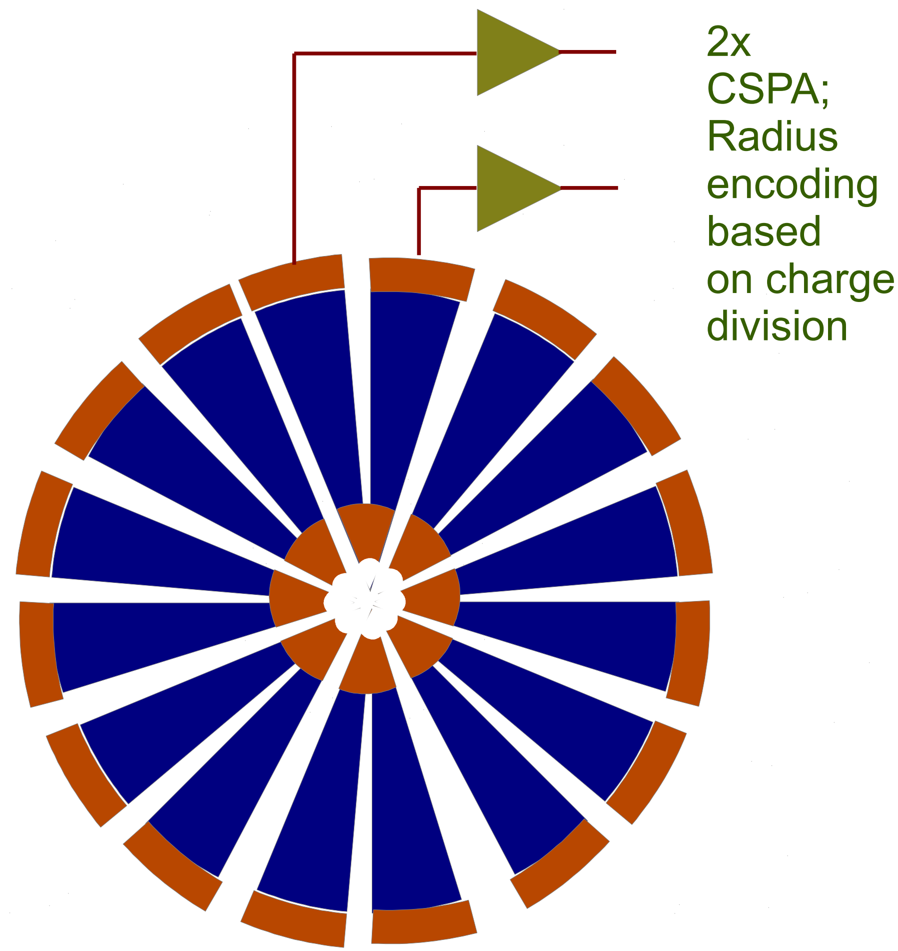
$$x = (Q_1 + Q_2 + Q_3 - Q_4) / (Q_1 + Q_2 + Q_3 + Q_4)$$
$$y = (Q_1 - Q_2 - Q_3 + Q_4) / (Q_1 + Q_2 + Q_3 + Q_4)$$

Data readout/binning

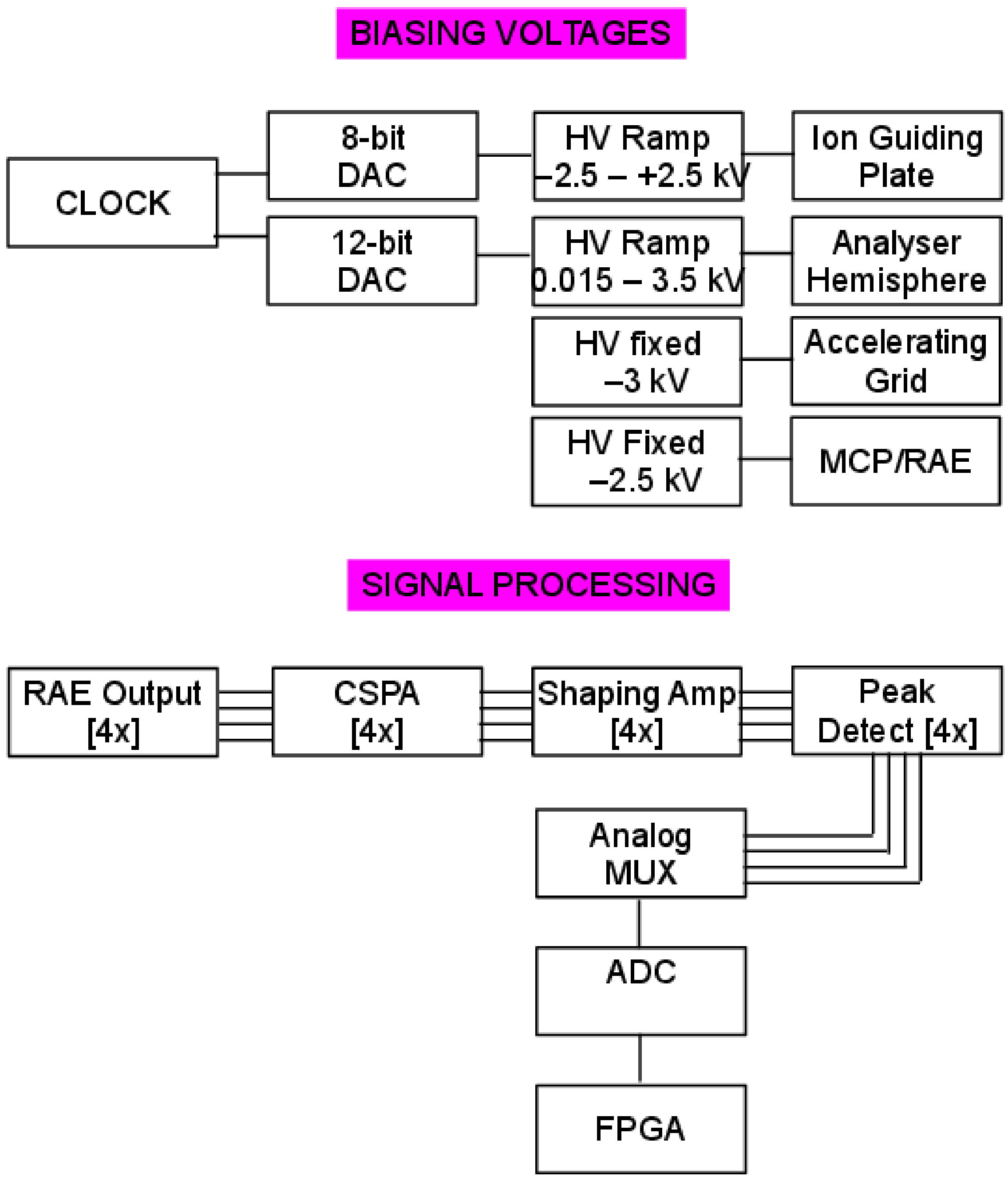
- 4 charge values are recorded for each ion detected.
- Position (x,y) is derived and binned in a 100*100 array
- Polar coordinates are better (needs a different anode readout)
- Histogramming is advanatageous when count rates are low, list-mode storage of (x,y) values is advantageous

Anode Readout Alternative

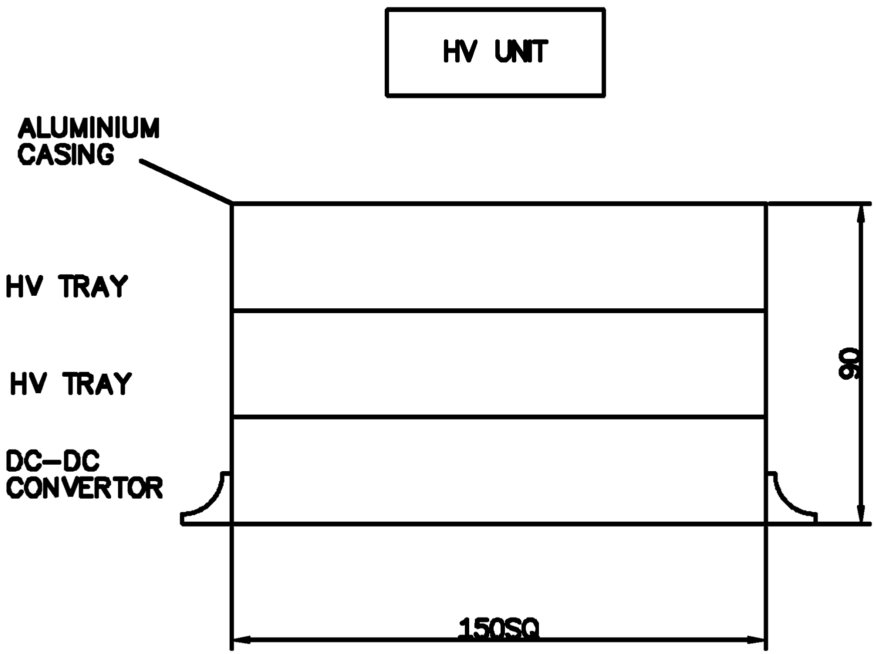
- 16 angular sectors
- Adjacent sectors shorted near centre
- Charge deposition on a sector-pair read out by one CSPA pair and radial position derived based on charge division
- The typical charge per shower 100 fC, and is amplified using a charge-sensitive preamplifier (such as Amptek 121) followed by a shaping amplifier and peak-detection.
- Total 8 readout pairs (16 CSPAs)
- Sector number and radius are stored

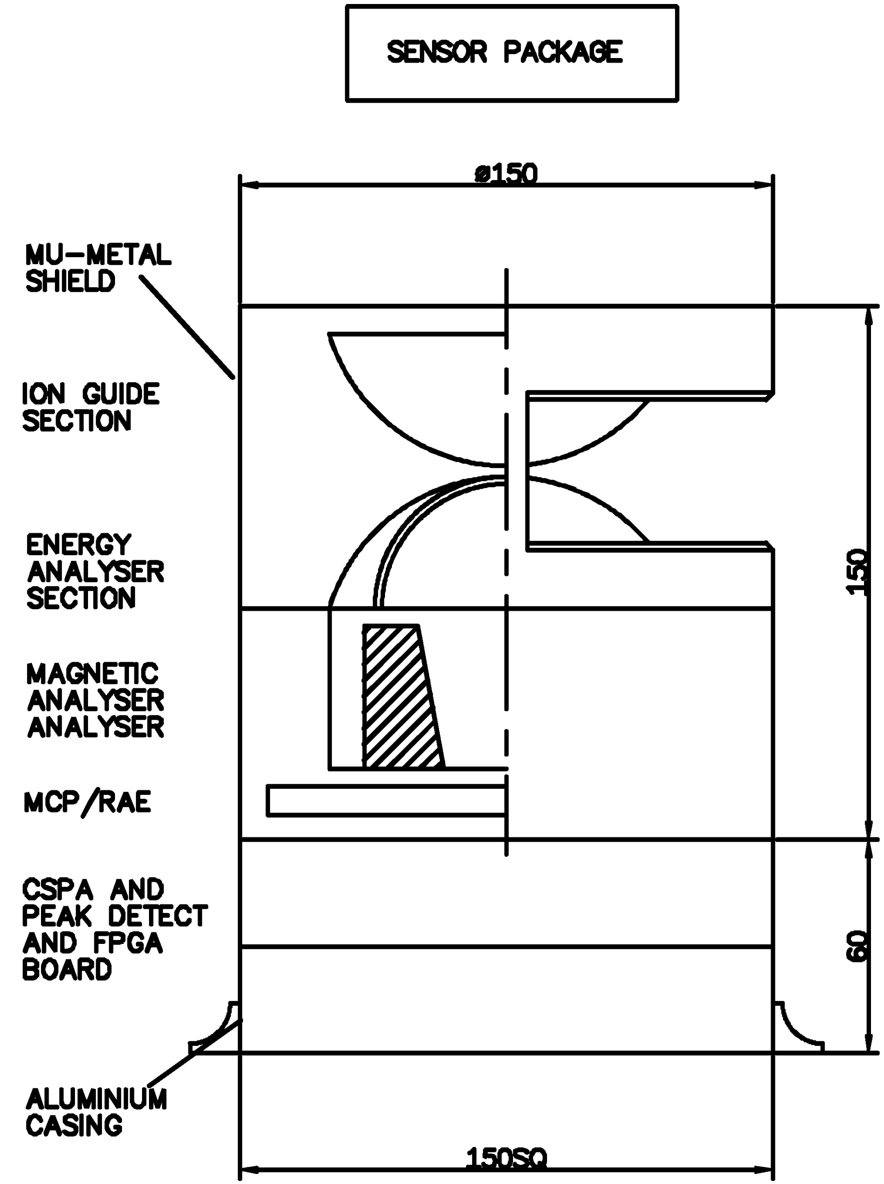


SWIS Electronics Block Diagram



SWIS Package/ Dimensions





SWIS Masses

Analysing and guiding hemispheres	150 g	Aluminium Alloy
Magnets	320 g	16 pieces, Sm-Co
Soft iron Yoke	290 g	2 nos, inner and outer rings
Mu-metal shield	770 g	Cylinder and end caps
Detector	70 g	Including resitive anode
Fasteners, posts etc.	100 g	
Total	1800 g	Excluding electronics

Total Resources

Sensor package	Weight	Weight 1800 gm (Likely to reduce with better magnetic shield design)
	Size	Size 150 dia × 150 ht with a base of 150 × 150 × 60 [ht] mm^3
Processing electronics package (including HV)	Weight	3700 gm (Likely to reduce significantly if potting issues are resolved)
	Size	150 × 150 × 90 [ht]
Total weight and raw power		**5500 gm and ~15 W**
Data rate		20 kB/histogram or $10 kBs^{-1}$ (~ 1 GB/day)

New Elements

Magnet Array

- High field permanent magnets, which can withstand high temperatures.
- Sm-Co magnets which have a space heritage and are available in the desired strengths
- Consultations with ISRO engineers are needed
- The magnets are needed in the form of trapezoidal cross section and small dipole length
- These special shapes will have to manufactured. One vendor has already been identified for this
- Effects of leak fields to be estimated

Detector Readout

- Microchannel plate position readout (preferably in polar coordinates).
- Of these the resistive anode scheme has been chosen on grounds of compactness of the readout unit and simplicity of the electronics.
- Various anode patterns are being considered
- The typical charge per shower 100 fC, and is amplified using a charge-sensitive preamplifier (such as Amptek 121) followed by a shaping amplifier and peak-detection.

Proof of Concept

Construction

- Top Hat Elements : fabrication nearly complete
- NdFeB bar magnets ordered, array and shield assembly being designed
- Imaging MCP (delay-line based, not RAE) and readout software available
- Vacuum system for testing is at hand
- Segmented RAE fabrication under discussion with RRCAT, Indore

Testing

- Initial testing using Penning ion source (up to 5 keV) at PRL
  - One will be borrowed for a short time
  - Another is indented
- For higher energies, testing will be done at IUAC, Delhi
- Expect proof of concept demonstration by Sep 2014

  (using commercial standard electronics and detector)