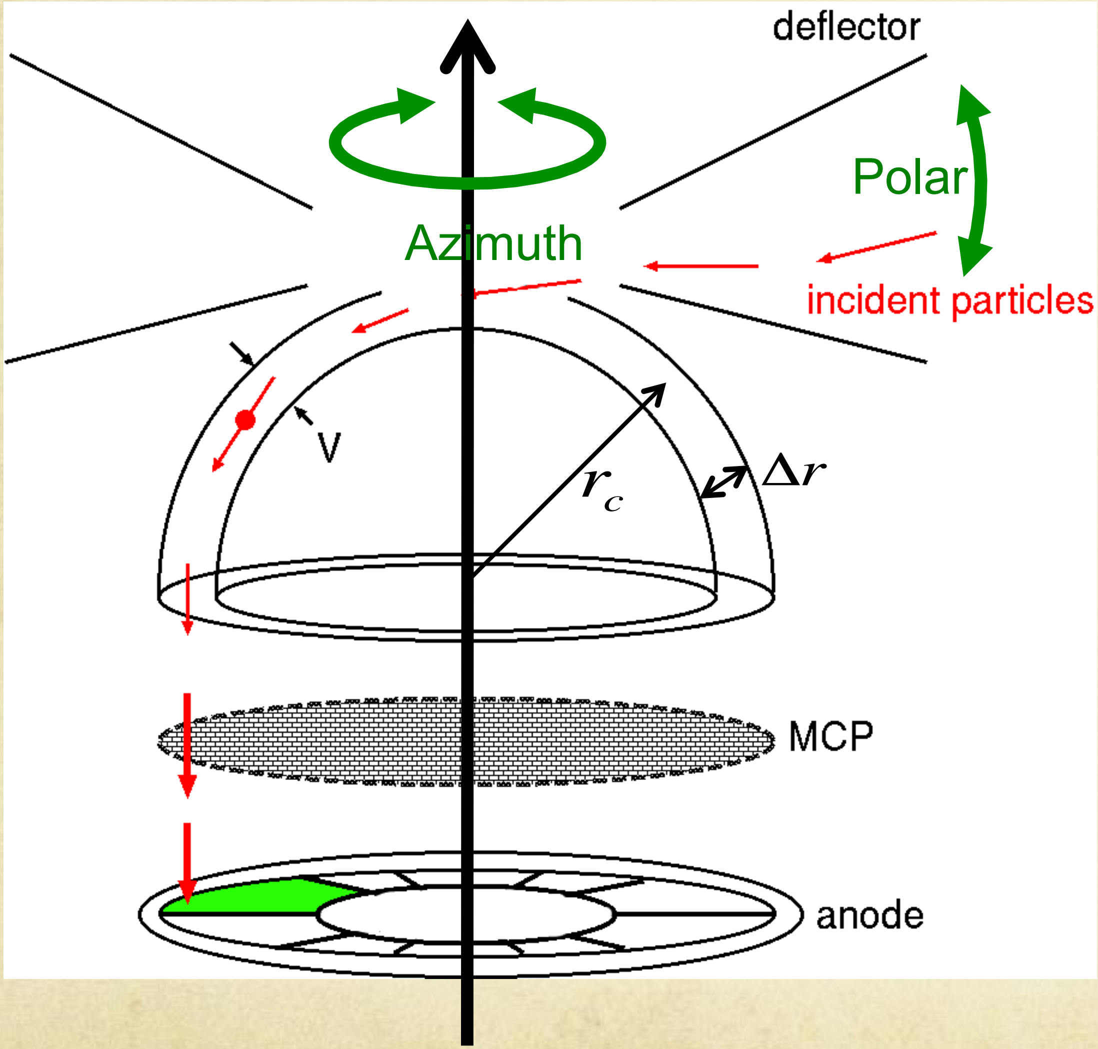
STP seminar 2010/7/7

Development of an Electron Low Energy Spectrometer for SCOPE

Yuu Tominaga

Dept. of Earth and Planetary Science, Tokyo Univ.

The low energy particle experiment



10 eV ～ 20 keV

$$E = q\frac{V}{2}\frac{r_c}{\Delta r}$$

V : voltage of the sensor

E : energy of the detected particles

We can measure C(E) ・・The number of particles detected within a sampling time

Field of view・・polar , azimuth

Calculate distribution functions and velocity moments (n,V,T) of plasma using C(E)

$$F(\vec{v}) = \frac{m}{v^2}\frac{C(E)}{\varepsilon g E \Delta t} \quad \ldots(1)$$

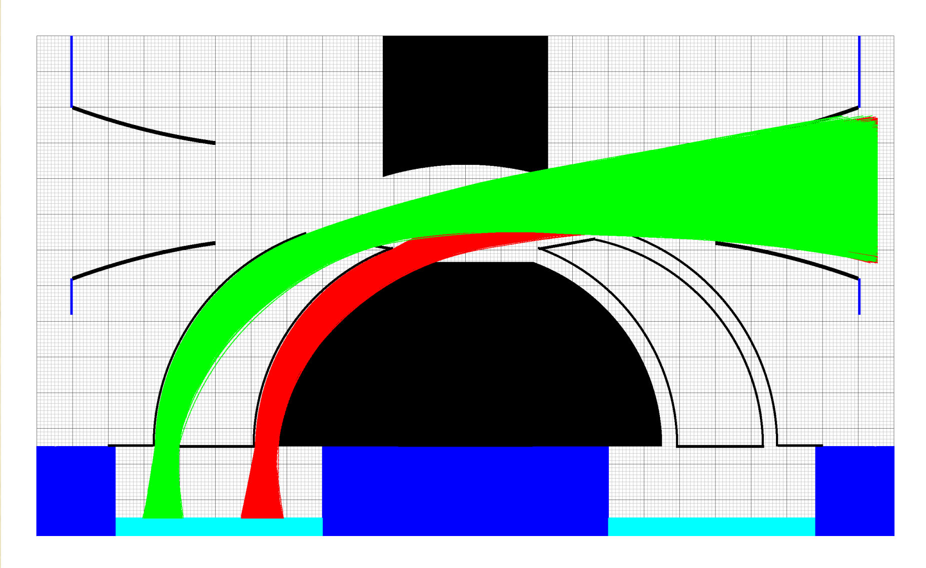
ε・・detection efficiency
g・・geometric factor
Δt・・sampling time
m・・mass of electrons

$$n = \iiint F(\vec{v})d\vec{v}$$

$$\vec{P} = \iiint m\vec{v}\vec{v}F(\vec{v})d\vec{v}$$

$$\cdots \quad \ldots(2)$$

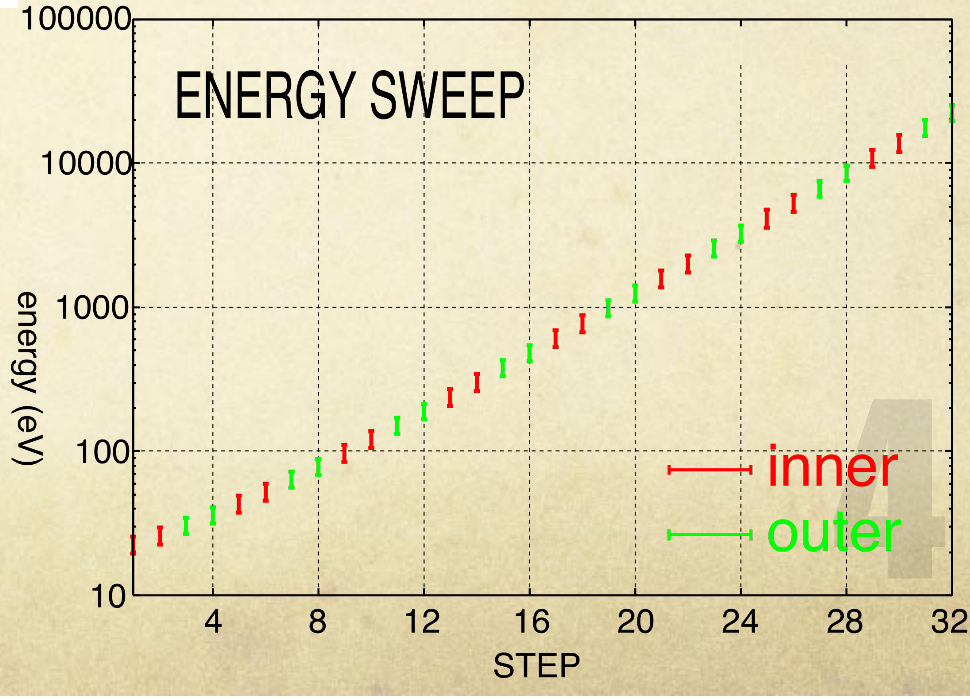
Design and characteristic of the analyzer



•Three nested hemispherical deflectors →measure two different energies simultaneously
•Small enough to set on the SCOPE spacecraft

measure 32 steps of energies from 10 eV to 22.5 keV

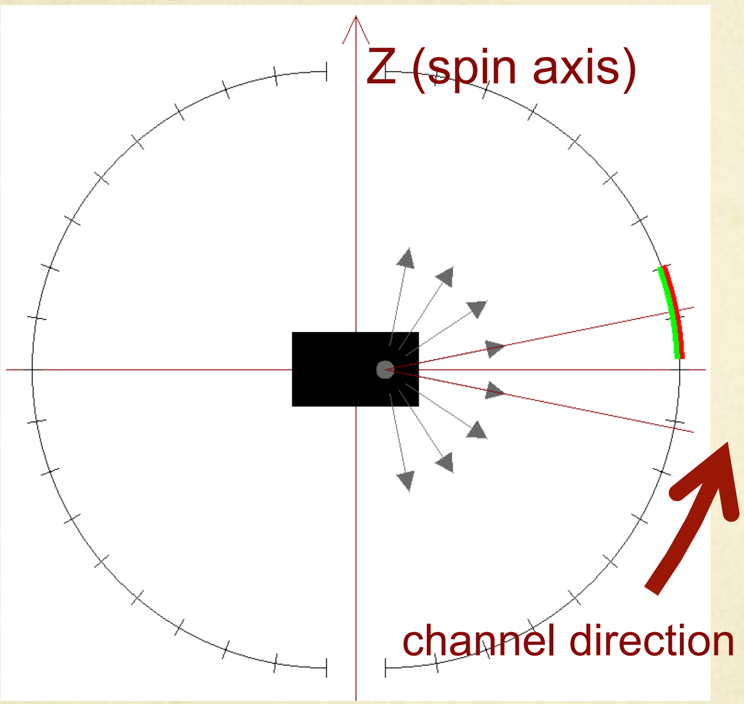
Δt(0.5 msec) × 16
= 8 msec



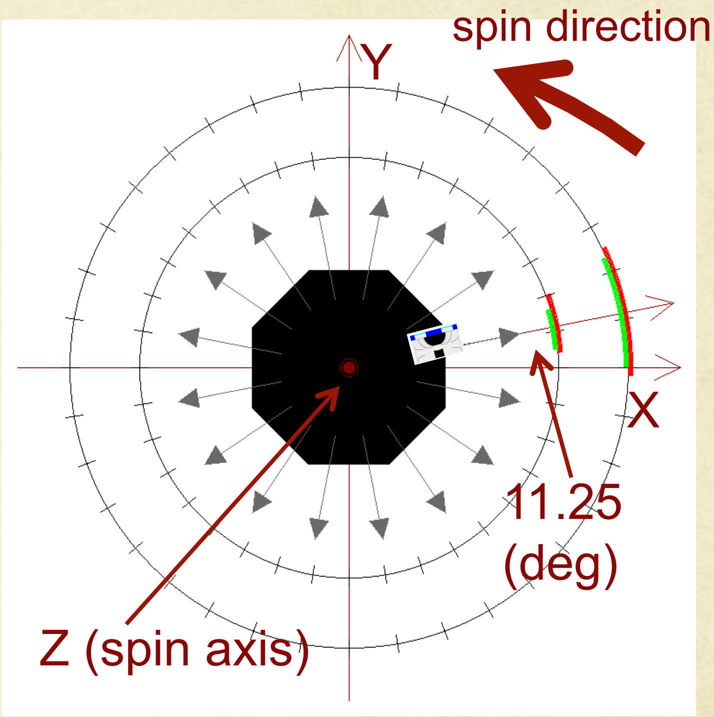
- 8 sets of sensors (16 sensors)

→ secure 4-pi str field of view simultaneously

- 8(spin) × 16(channel) = 128 windows



8 field of views along channel direction



16 field of views along spin direction

1.Introduction

characteristics	inner	outer
Geometrical factor (cm^-2 str^-1)	7.5*10^-3	1.0*10^-2
Energy resolution ΔE/E	0.23	0.17
Angular resolution Δα (deg)	16	11.5
sampling time (msec)	0.5	
time resolution (msec)	8	

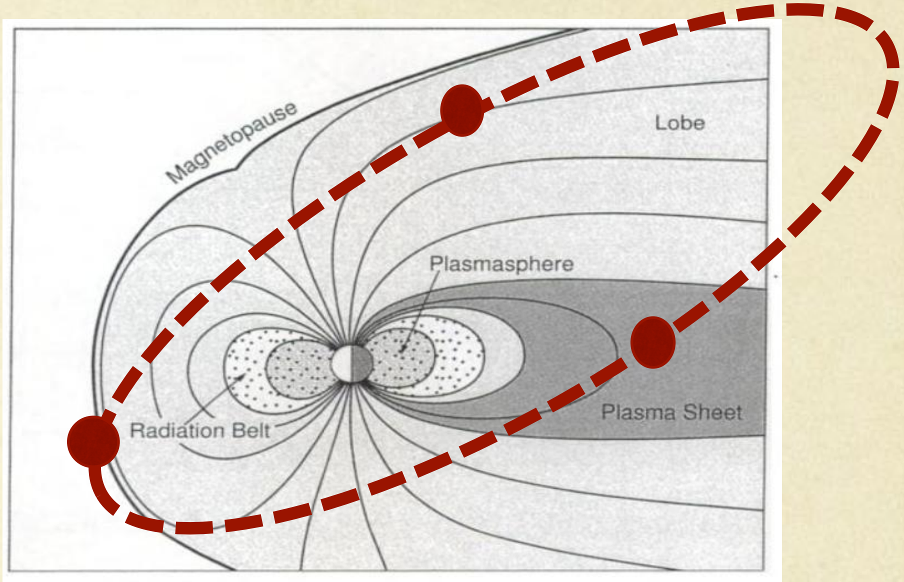
The purpose of this study is …

verify that these characteristics are appropriate for measuring and calculating velocity moments of plasma

Calculate f(v) and velocity moments

①: Assume velocity distribution function

- Maxwellian velocity distribution
- Density(n)
- Bulk velocity(Vb)
- Temperature (Te)



Wolfgang Baumijohann ,Basic Space Plasma Physics ,P6

Plasma sheet	Lobe	Solar wind
ne = 5.0e-01 (/cc)	ne = 5.0e-02 (/cc)	ne = 7.0 (/cc)
Te = 5.0e-01 (keV)	Te = 5.0e-02 (keV)	Te = 5.0e-02 (keV)
Vb = 100.0 (km/s)	Vb = 100.0(km/s)	Vb = 450.0 (km/s)

Table1:
Typical velocity moments of space plasma

②: Calculate C(E) and f(v)

$$f\left(v\right) = n\left(\frac{m_e}{2\pi k_B T_e}\right)^{\frac{3}{2}} \exp\left(-\frac{m\left(\vec{v} - \vec{v}_b\right)}{2 k_B T_e}\right) \quad \ldots(3)$$

Assumption
(Continuous function)

$$C\left(E\right) = \varepsilon g E \frac{v^2}{m} f\left(v\right)\Delta t \quad \ldots(4)$$

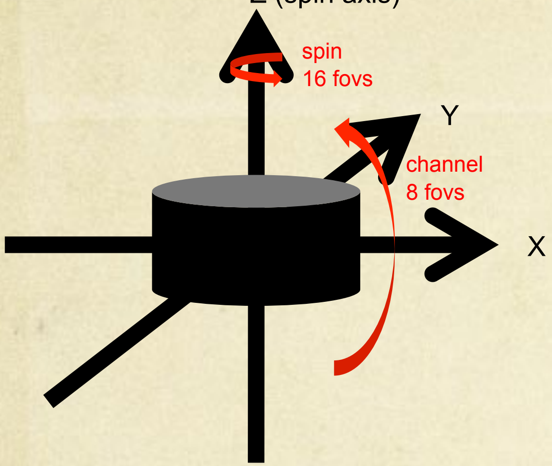
$$f\left(v\right) = \frac{m}{v^2}\frac{C\left(E\right)}{\varepsilon g E \Delta t} \quad \ldots(5)$$

Calculation
(Discrete functions)

ΔE
$\Delta\alpha$
g

•see whether 1 < C(E) < 500
•compare assumed f(v) and calculated f(v)

③: Calculate velocity moments



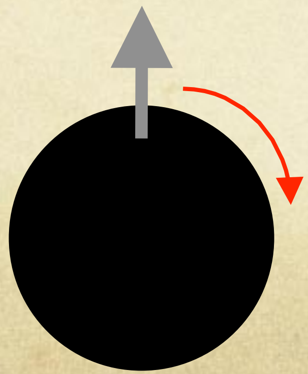
$$n = \sum\sum\sum \frac{C(E)}{g\varepsilon\Delta t}\frac{1}{v}\cos(\theta)\frac{\Delta E}{E}\Delta\theta\Delta\varphi \quad \ldots(6)$$

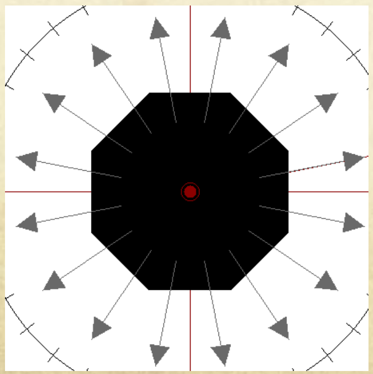
$$Vx, Vy, Vz$$

$$Tx, Ty, Tz$$

- Compare calculated (n,V,T) with assumed (n,V,T)
- Estimate the effect of Deviations of the detection efficiency(ε)

$$C(E) = g\varepsilon E f(E)\Delta t \propto \varepsilon$$





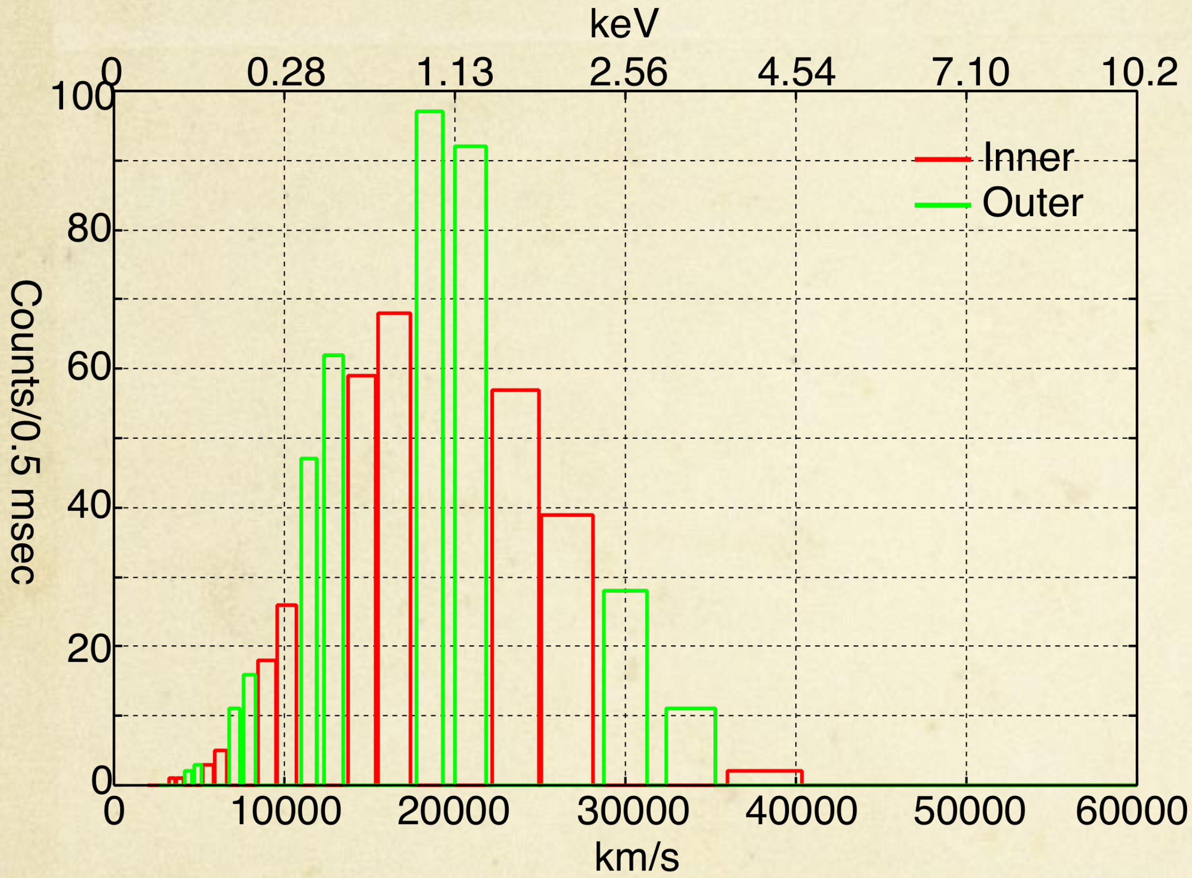
There is a small deviation of ε between 16 sensors.

↓

Calculation of velocity moments will be affected

Plasma sheet

- Counts



Sampling time : 0.5 msec

↓

Count rate < 100

33 eV ~ 4.5 keV

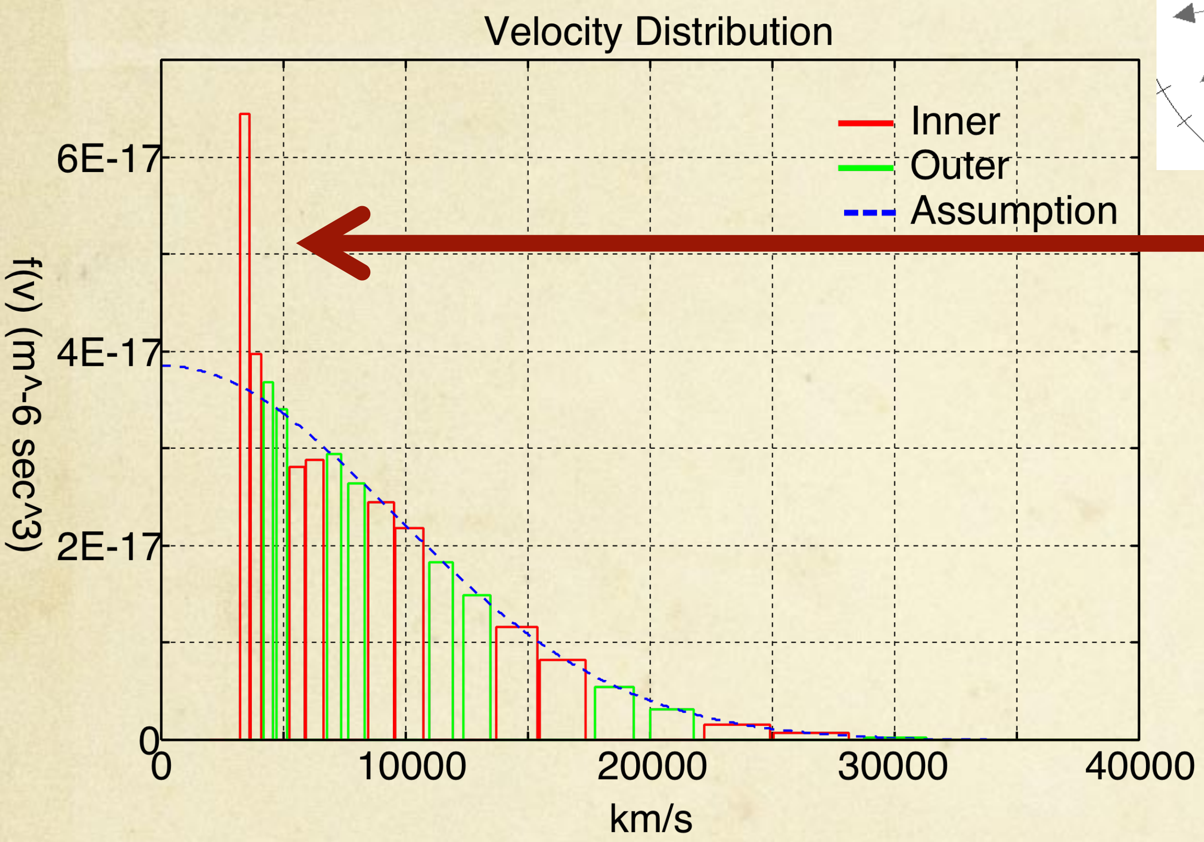
$$\underbrace{C(E)}_{\text{integer}} = \underbrace{\varepsilon g E \frac{v^2}{m} f(v) \Delta t}_{\text{real number}} \quad \ldots(4)$$

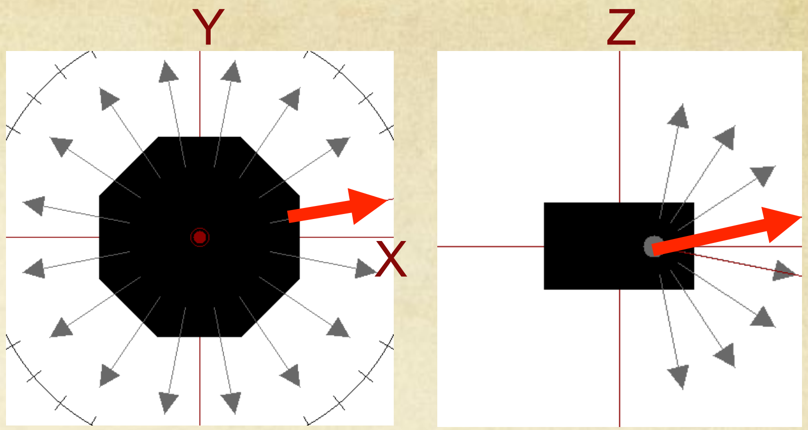
Errors of calculation

Counts are rounded off

→ΔC(E) = 1 (Casting error)

- Velocity distribution





deviations from assumption

:

because of casting errors ΔC(E)

$$F(\vec{v}) = \frac{m}{v^2}\frac{C(E)}{\varepsilon g E \Delta t} \propto v^{-4} \quad \text{...(7)}$$

ΔC(E) is dominant where v is relatively small

・Calculate velocity moments

Table2:
Calculation results

	Assumption	Calculation (ε = 0.6)	Calculation/ Assumption
ne (/cc)	0.5	4.137e-01	0.827
Te_x (keV)	0.5	4.994e-01	0.999
Te_y (keV)	0.5	4.991e-01	0.998
Te_z (keV)	0.5	5.092e-01	1.018
Vb_x (km/s)	100.0	9.689e+01	0.969
Vb_y (km/s)	0	-5.192e-03	
Vb_z (km/s)	0	-2.472e-10	

Errors of calculation

Te ･･ ~ 1 %

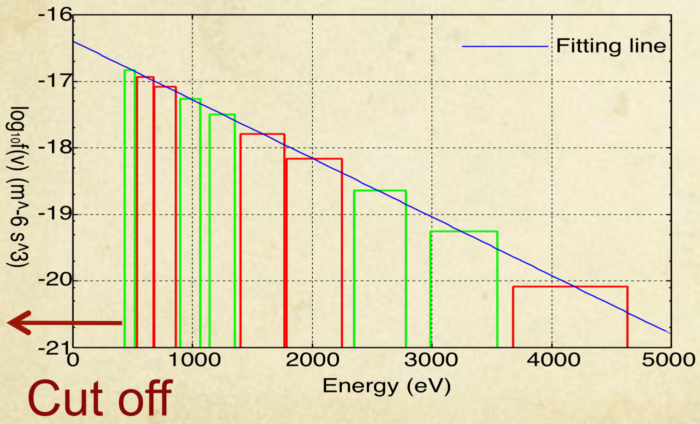
Vb ･･ ~ 3 %

ne ･･ ~ 20 %

- Casting errors
- Absence of data under 10 eV

・Density correction

•Cut off the counts of low energy
→ reject the effect of casting errors
•Fit a line to a set of (E,log10f(v)) and estimate f(v) of low energy → $f_e(v)$



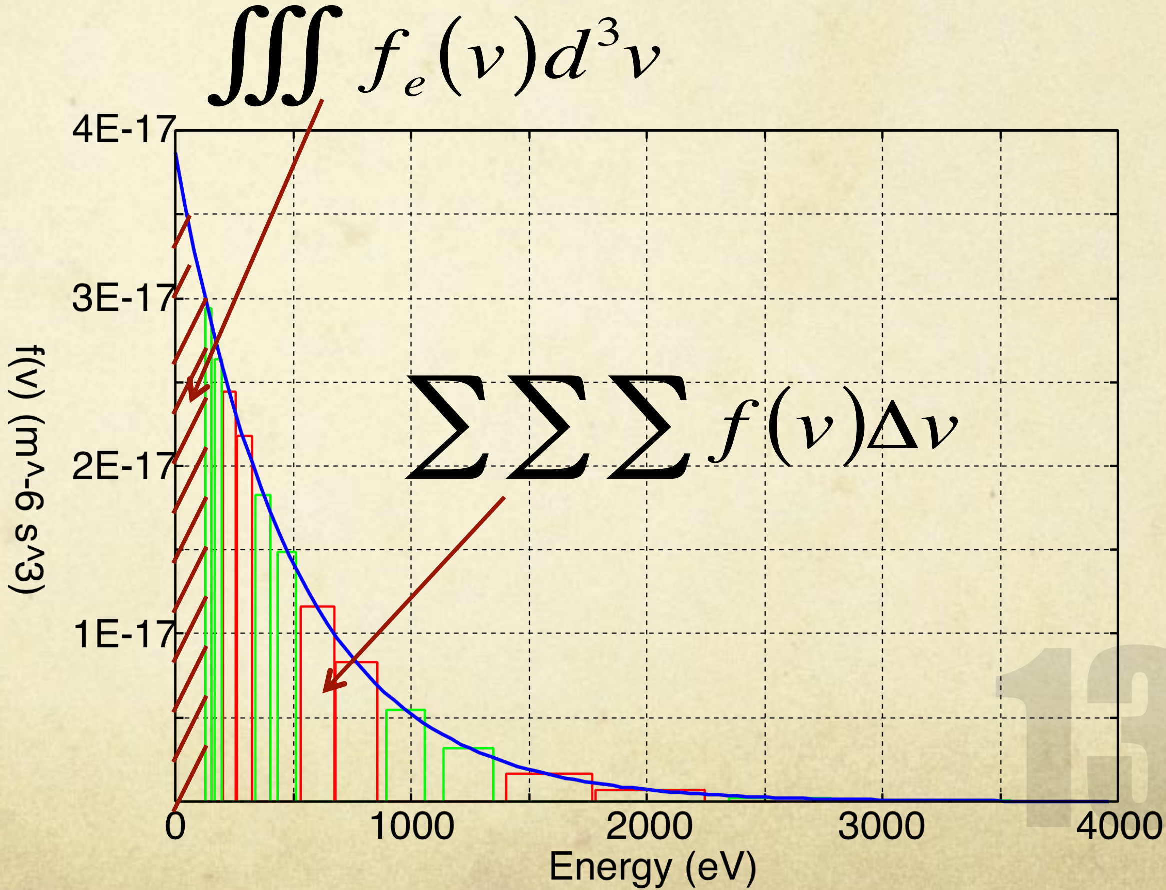
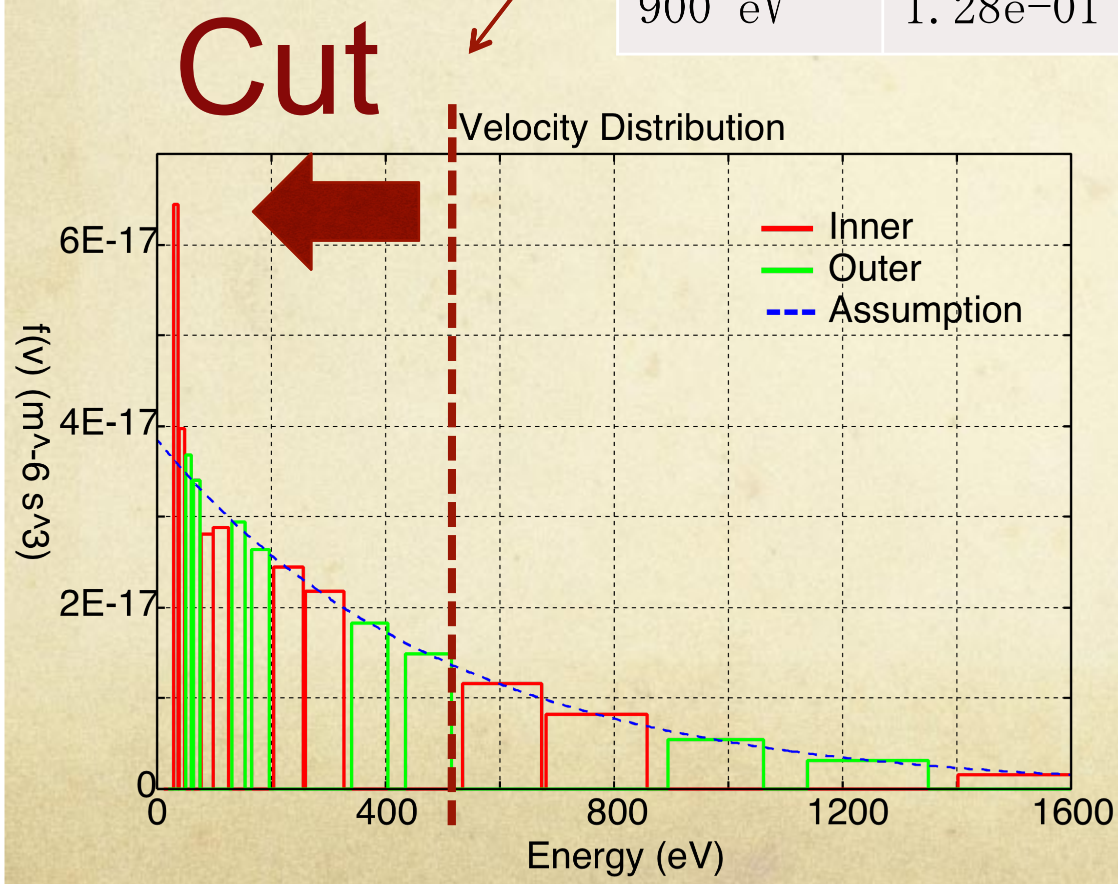


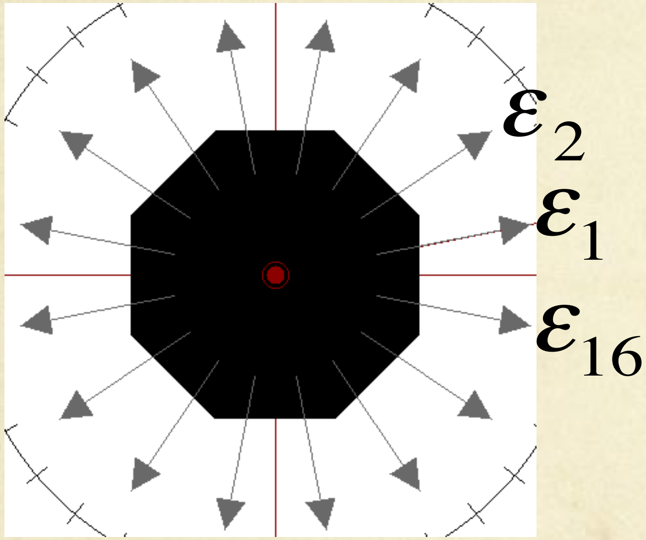
Table 3:
Calculation results

Cutting energy	Σf(v)Δv	∫f(v)dv	ne
300 eV	2.97e-01 /cc	1.60e-01 /cc	4.58e-01 /cc
500 eV	2.33e-01 /cc	2.60e-01 /cc	4.94e-01 /cc
700 eV	1.81e-01 /cc	3.19e-01 /cc	5.00e-01 /cc
900 eV	1.28e-01 /cc	3.78e-01 /cc	5.06e-01 /cc



We can calculate ne more precisely with density correction.

- Effect of the deviation of the detection effeciency



Given that each sensors has its own εi

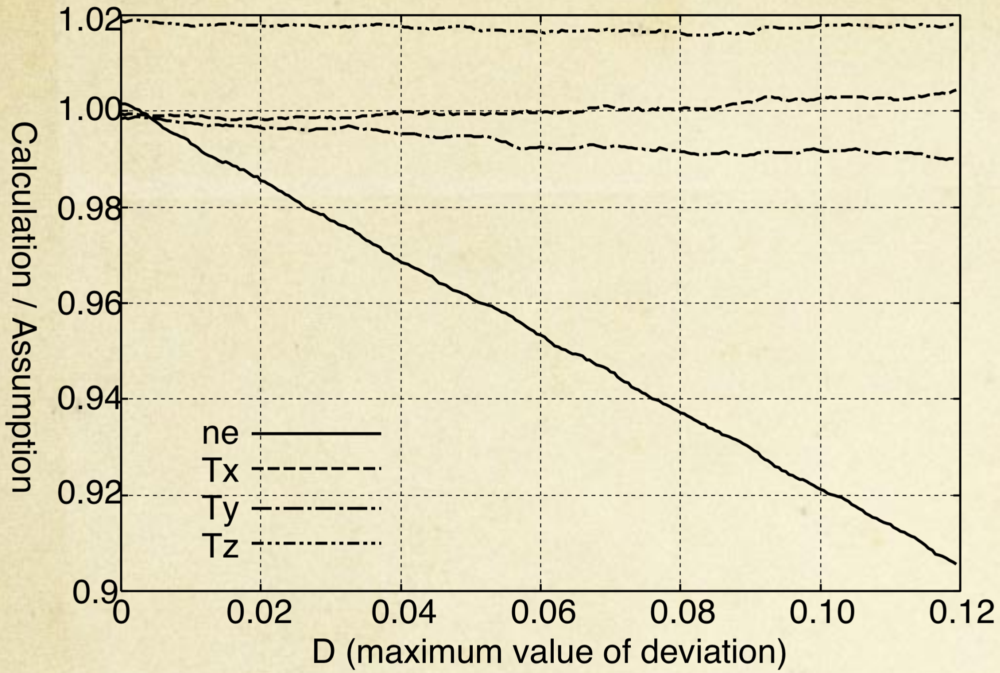
$$\varepsilon_i = 0.6 - D_i \quad \ldots(8)$$

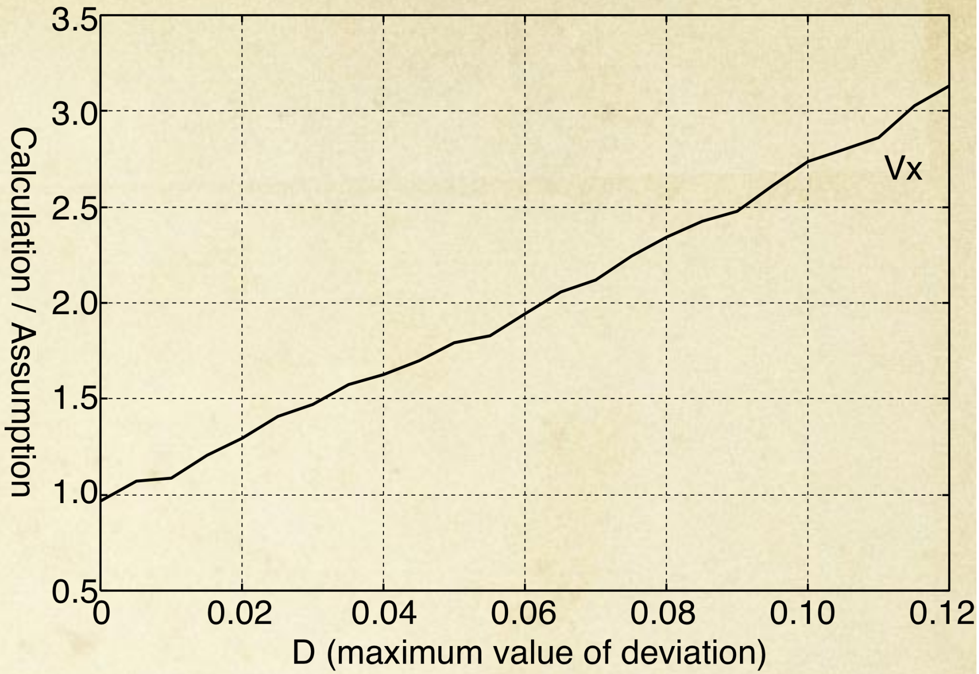
$$0 < D_i < D_{\max}$$

i = 1 ~ 16

Calculate velocity moments and see how the deviation affects

3. Results and Discussions



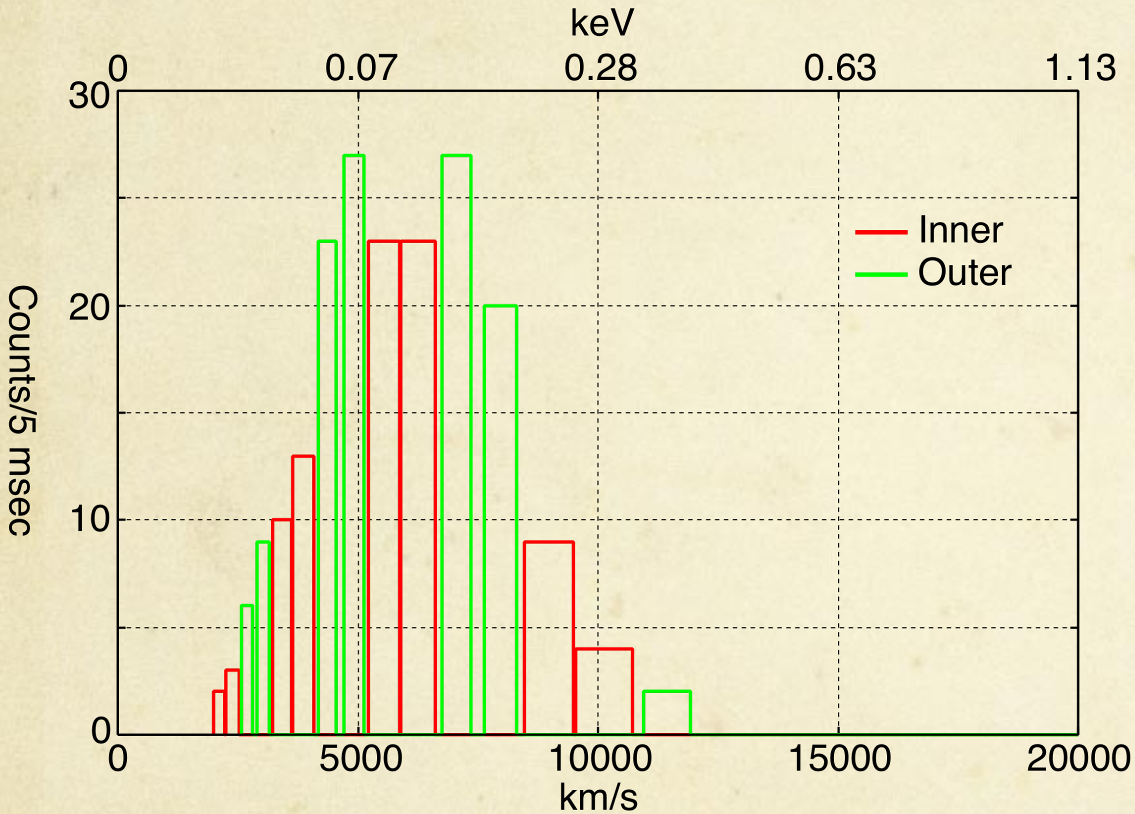


•ne,Te･･calc error will be under 5 % if the deviation of ε is under 10 %
•Vb･･calc error will be much greater than ne and Te

Severe calibration of ε is necessary for estimating the accurate value of Vb.

Lobe

- Counts



Sampling time : 0.5 msec

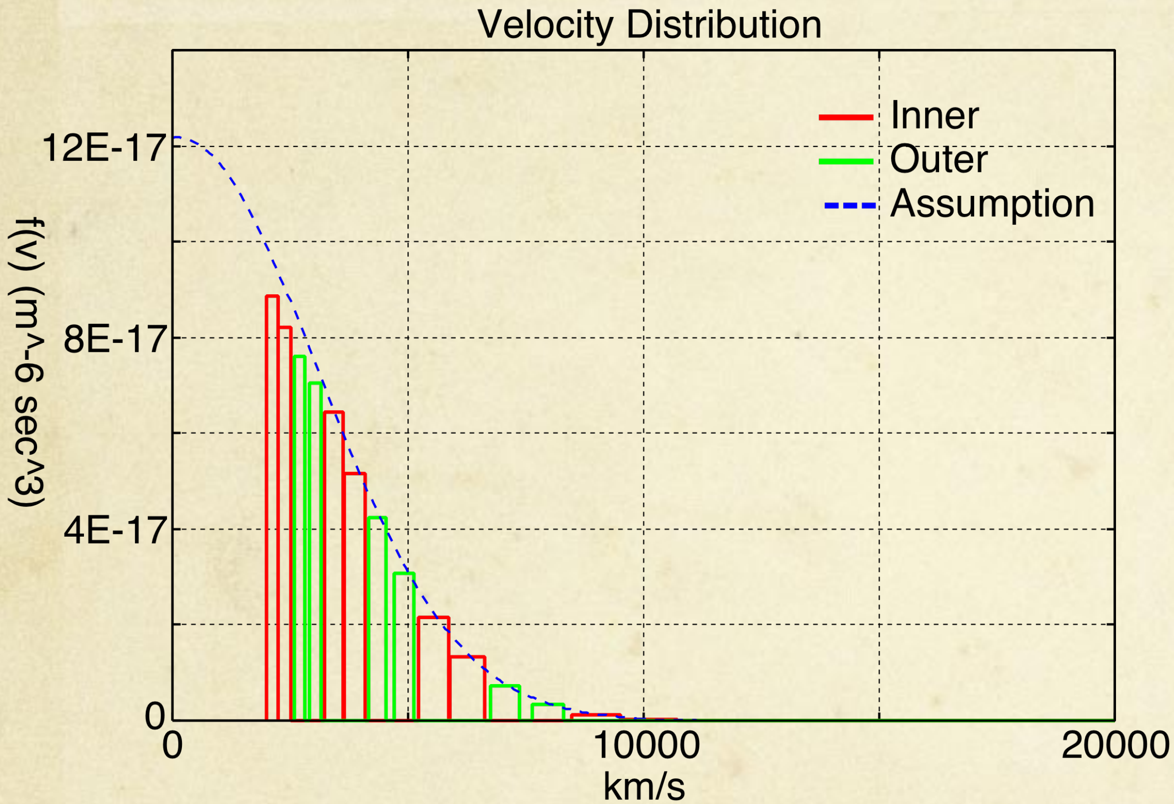
↓

Count rate < 3

・・Too small !!

Sampling time should be 5 msec

・Velocity distribution



deviations from assumption at small velocities are smaller than that of plasma sheet

↑

Δt is 10 times larger
→The effect of ΔC will be 1/10

$$F(\vec{v}) = \frac{m}{v^2}\frac{C(E)}{\varepsilon g E \Delta t} \quad \ldots(9)$$

・Calculate velocity moments

Table 4:
Calculation results

	Assumption	Calculation (ε = 0. 6)	Calculation/ Assumption
ne (/cc)	0. 05	3. 868e-02	0. 774
Te_x (keV)	0. 05	5. 320e-02	1. 064
Te_y (keV)	0. 05	5. 304e-02	1. 061
Te_z (keV)	0. 05	5. 410e-02	1. 082
Vb_x (km/s)	100. 0	1. 037e+05	1. 037
Vb_y (km/s)	0	-5. 556e-03	
Vb_z (km/s)	0	3. 767e-10	

Errors of calculation

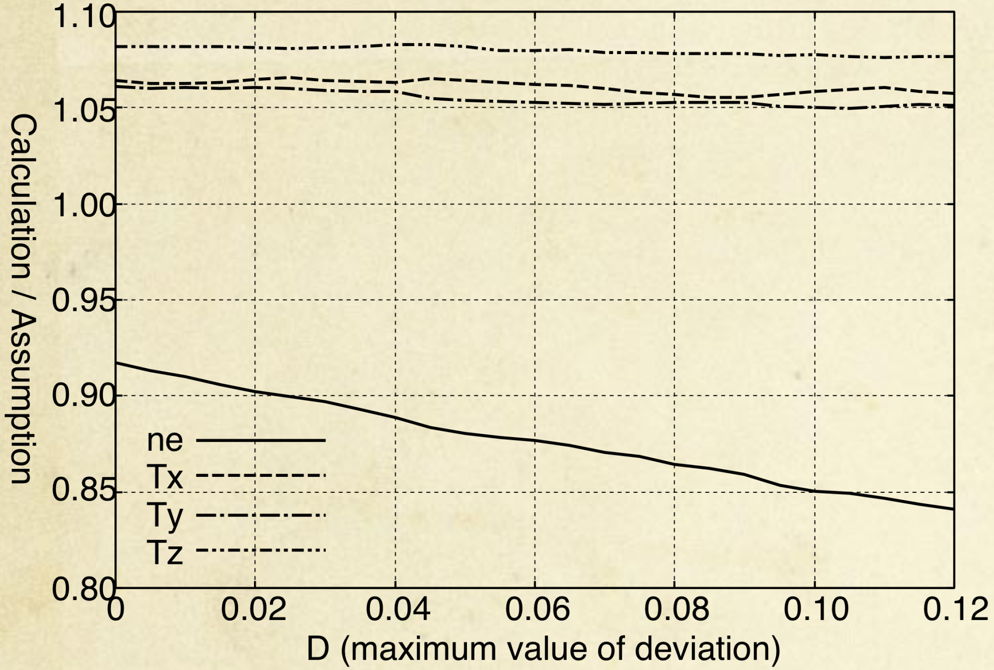
Te ･･ ~ 6 %

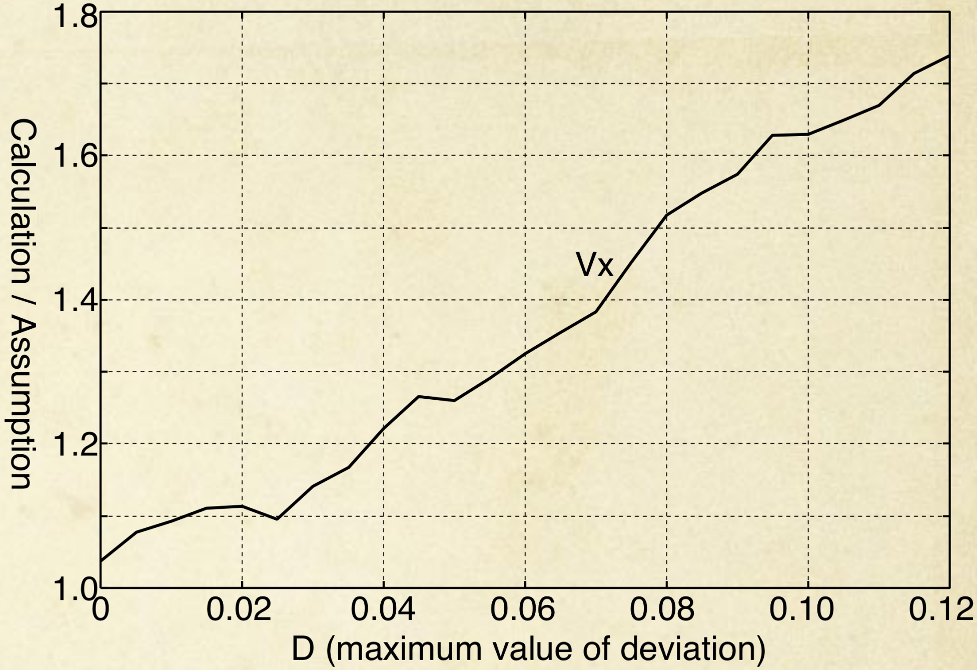
Vb ･･ ~ 3 %

ne ･･ ~ 25 %

- Casting errors
- Absence of data under 10 eV

・Effect of the deviation of the detection effeciency εi





•Te・・calc error will be over 5 % if the deviation of ε is under 20 %

•ne・・calc error will be under 10 % if the deviation of ε is under 5 %

•Vb・・calc error will be much greater than ne and Te

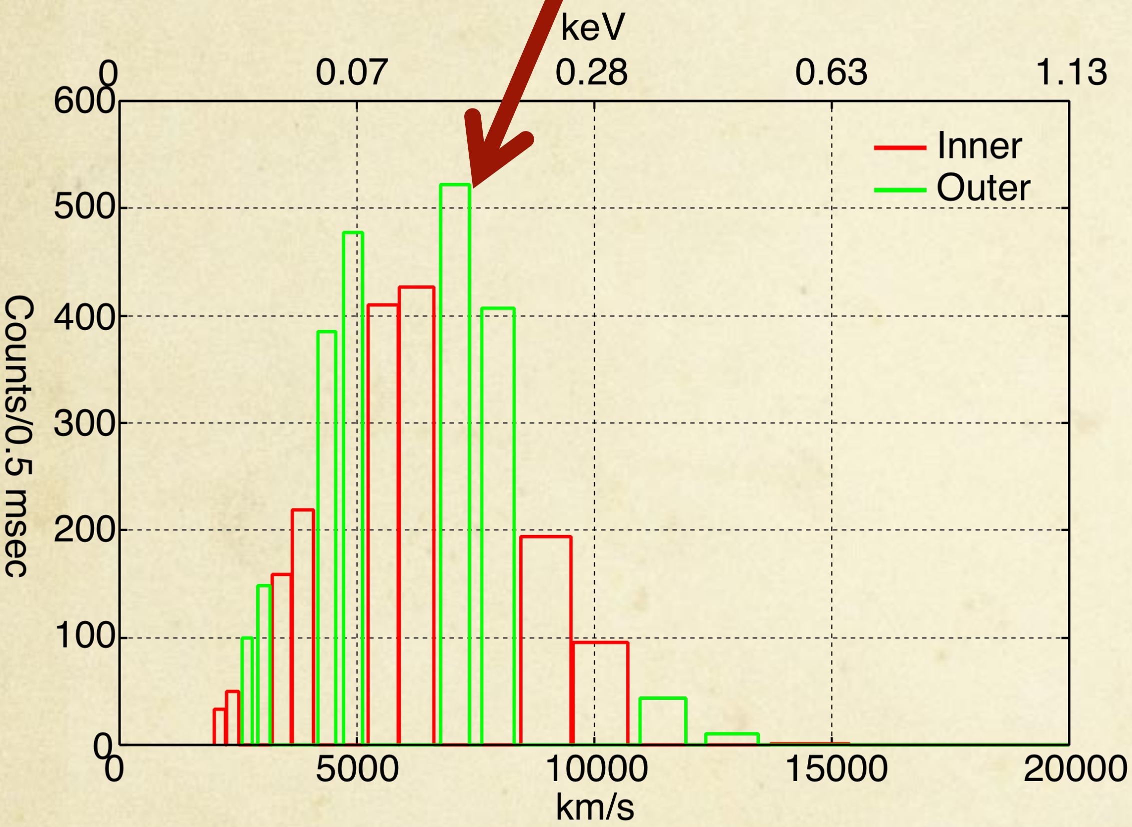
(Density correction :
Cut off C(E) lower than 30 eV)

Solar Wind

C(E) > 500

・・Saturation

・Counts



Sampling time : 0.5 msec

・・Cannot calculate (n,V,T)

Another observation mode is necessary

:

•g-factors should be 1/100 smaller

→g ~ 1.0E-4 cm^-2 str^-1

•sampling time should be 10 times greater

→Δt = 5 msec

Count rate will be 1/10

Conclusion

	Plasma sheet	Lobe
ne (calc/assumption)	0.82	0.77
Vb (calc/assumption)	0.96	1.03
Te (calc/assumption)	0.99	1.06
*ne (calc/assumption)	0.95	0.87
*Vb (calc/assumption)	2.0	1.5
*Te (calc/assumption)	1.02	1.08

Table 5:
Calculation results

sampling time : 0.5 msec (plasma sheet) , 5 msec (lobe)
* : Given that the deviations of ε are 10 %

- The precision of calculating Vb and Te is < 10 %.
(We can calculate ne if we cut off C(E) of low energies.)
- The deviations of ε severely affect calculations of Vb.
- Another observation mode is necessary for measuring solar wind regions.

Future works

- Solar wind observation mode
- Spacecraft potential correction

- Calculate velocity moments from f(v) which is calculated by numerical simulations.

:

References

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•Mukai, T., Machida, S., Saito, Y., Hirakawa, M., Terasawa, T., Kaya, N., Obara, T., Ejiri, M., and Nishida, A.: 1994, The Low-Energy Particle (LEP) Experiment Onboard the Geotail Satellite, *J. Geomag. Geoelect.* ***46, 669.***

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GEOTAIL LEPとの時間分解能の比較

GEOTAIL LEP・・ 12 sec
SCOPE・・ 8 msec

$$2 \times 16 \times 40 = 1280$$

2エネルギー同時測定

スピンによらないサンプリング

サンプリングタイム
20 msec・・GEOTAIL
0.5 msec・・SCOPE