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Charge Exchange Neutral Particle Flux during Fueling Pellet Injection on Large Helical Device

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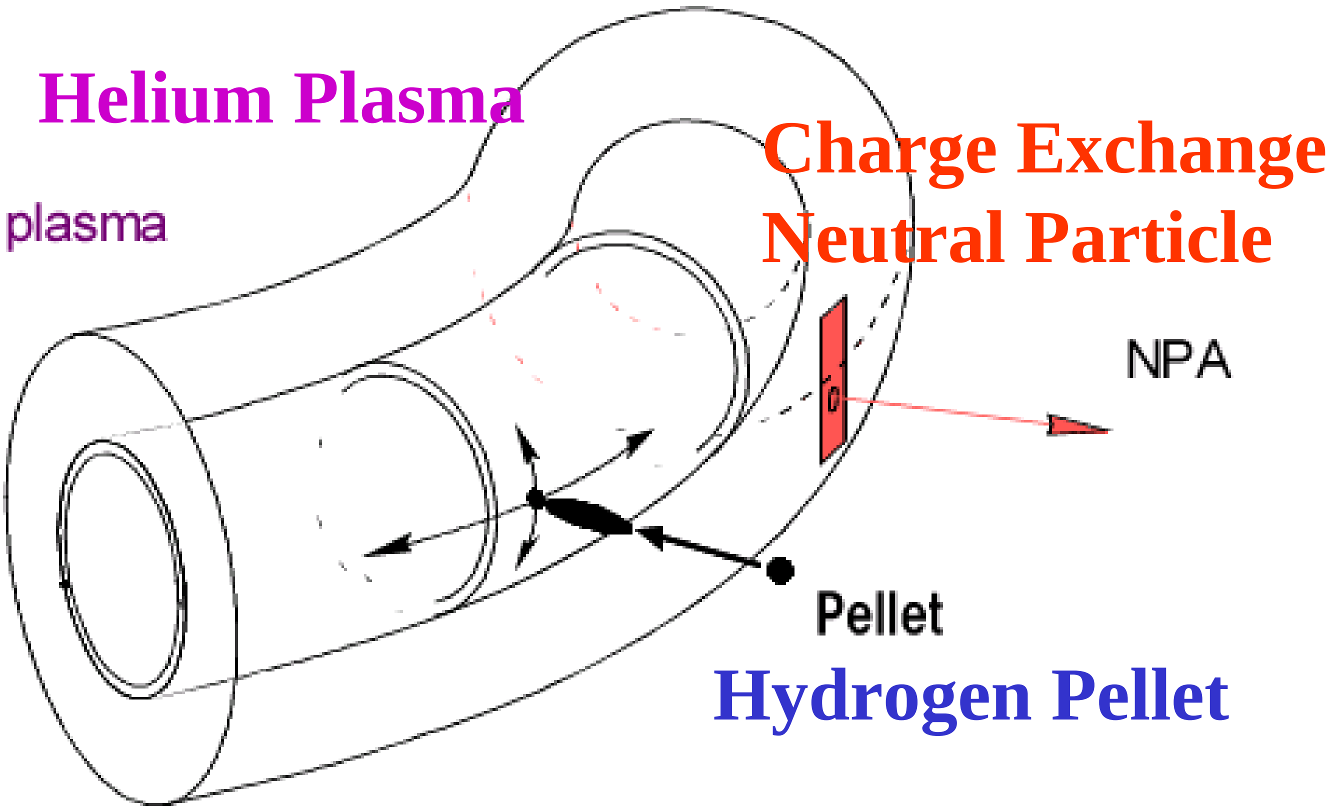
OUTLINE

- Principle
- TOF-NPA in LHD
- Experiments
- Analysis
- Summary

Arrangement



Hydrogen pellet injects to the **helium plasma**. **Charge exchange high energy neutral hydrogen** can be measured by the neutral particle analyzer (**NPA**).

Reaction

Pellet

$H^0 + e \rightarrow H^+ + 2e$

$H^0 + He^+ \rightarrow H^+ + e$ Ionization

$H^0 + He^{++} \rightarrow H^+ + e$

$H^0 + He^+ \rightarrow H^+ + He^0$ Charge Exchange

$H^0 + He^{++} \rightarrow H^+ + He^+$

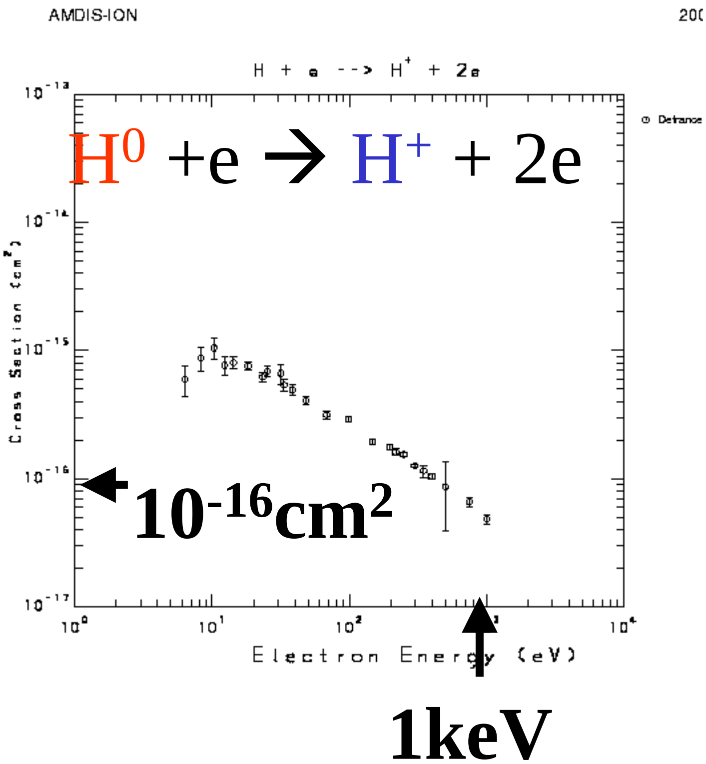
$H^+ + He^0 \rightarrow H^0 + He^+$ Charge Exchang

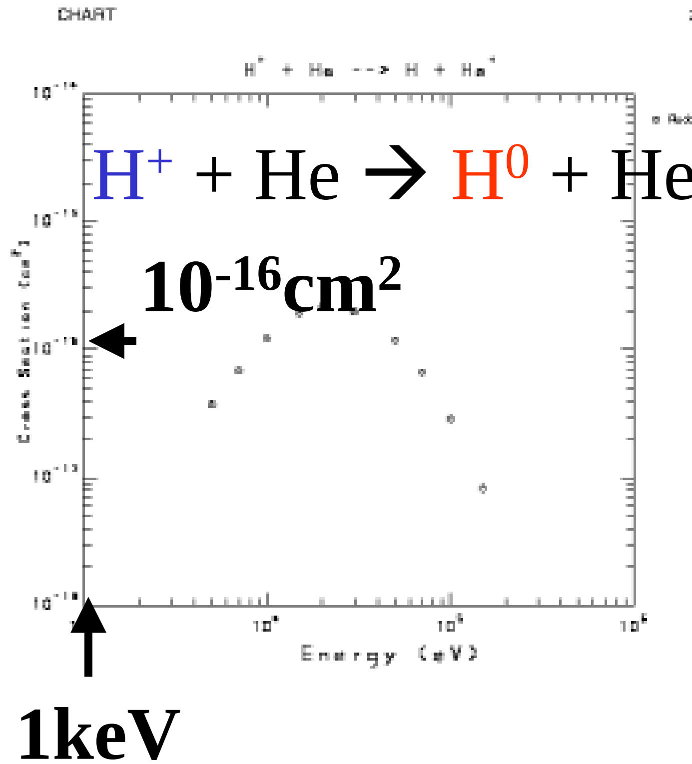
$H^+ + H^{bg} \rightarrow H^0 + H^+$

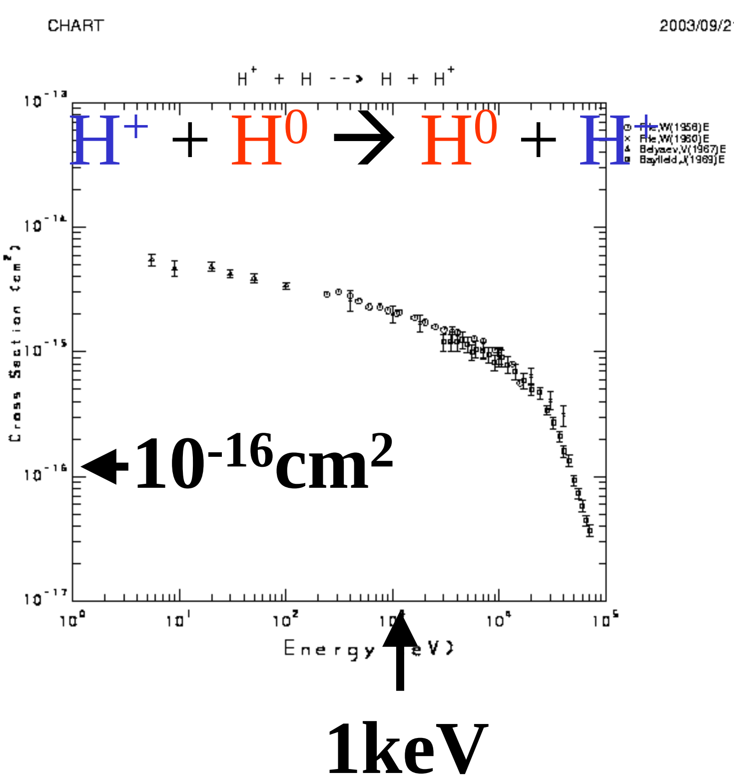
Analyzer

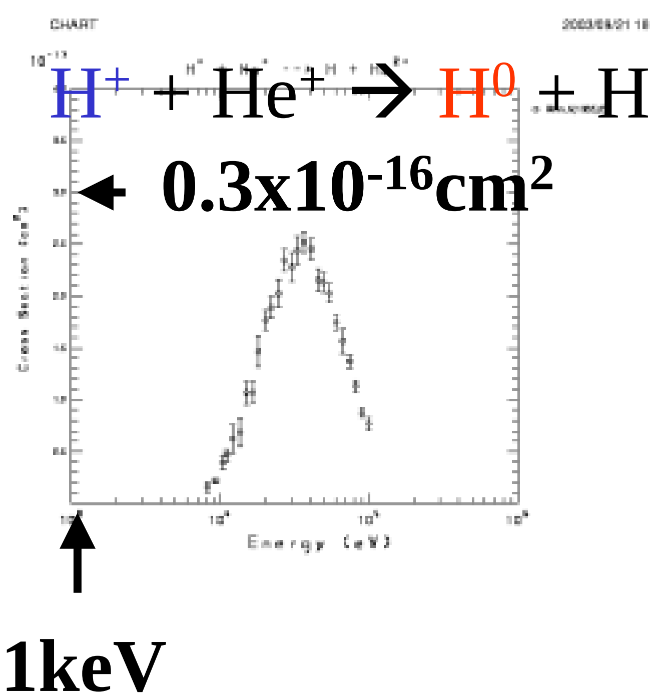
H^{bg} Background hydrogen neutral

Cross Section









Model Consideration

In Cylindrical Configuration;

(Time variation of H^+)

= Diffusion

+ Ionization(e,$He^{+,++}$)

+ CX($He^{+,++}$)

- CX(He^0,H^{bg})

$$\frac{\partial n_{H_+}}{\partial t} = -\frac{1}{r}\frac{\partial (r\Gamma_{H_+})}{\partial r}$$

$$+ I \cdot n_e \cdot n_{H_0} + I \cdot n_{He^+} \cdot n_{H_0} + I \cdot n_{He^{++}} \cdot n_{H_0}$$

$$+ C \cdot n_{He^{++}} \cdot n_{H_0} + C \cdot n_{He^+} \cdot n_{H_0}$$

$$- C \cdot n_{He^0} \cdot n_{H^+} - C \cdot n_{H^{bg}} \cdot n_{H^+}$$

Continue

Introduce to

D (Diffusion Coefficient)

V (Convection)

$$\Gamma = -D(r)\frac{\partial n}{\partial r} + V(r)n$$

To Simplification

D : Constant

V = 0

$$\frac{\partial n_{H_+}}{\partial t} = \frac{D}{r}\frac{\partial\left(r\frac{\partial n_{H_+}}{\partial r}\right)}{\partial r}$$

$$+ I \cdot n_e \cdot n_{H_0} + I \cdot n_{He^+} \cdot n_{H_0} + I \cdot n_{He^{++}} \cdot n_{H_0}$$

$$+ C \cdot n_{He^{++}} \cdot n_{H_0} + C \cdot n_{He^+} \cdot n_{H_0}$$

$$- C \cdot n_{He^0} \cdot n_{H^+} - C \cdot n_{H^{bg}} \cdot n_{H^+}$$

Continue2

Atomic process is faster than Diffusion.
For example;

$I = 10^{-8}\,\mathrm{cm}^{-3}/\mathrm{s},\ n_e, n_{H_+} = 1\times 10^{13}\,\mathrm{cm}^{-3}$

(Atomic Process)$\sim 10^{5}\, n_{H_+}$
(Diffusion)$\sim 10^{2}\, n_{H_+}$

→Atomic process should become equilibrium.

Introduce to

$$n_{H_+} = e^{-\alpha t} n(r)$$

Then

$$-\alpha \cdot e^{-\alpha t} n(r) = \frac{De^{-\alpha t}}{r} \frac{d(r\frac{dn(r)}{dr})}{dr}$$

$$= \frac{De^{-\alpha t}}{r}\{\frac{dn(r)}{dr} + r\frac{d^2 n(r)}{dr^2}\}$$

Continue3

$$\frac{d^2 n(r)}{dr^2} + \frac{1}{r}\frac{dn(r)}{dr} + \frac{\alpha}{D} n(r) = 0$$

The solution is Bessel function、

$$n(r) \propto J_0(\sqrt{\frac{\alpha}{D}} \cdot r)$$

Then if n(r)=0 at r=a,

$$D = \alpha(\frac{a}{2.4})^2$$

Continue4

Here,

$$n(r) \approx n(r, E)$$

Then the positions where $n(r,E) \sim 0$ differ by the energies,

$$a = a(E)$$

Energy ～ Position

$\rightarrow$ $D(r)$

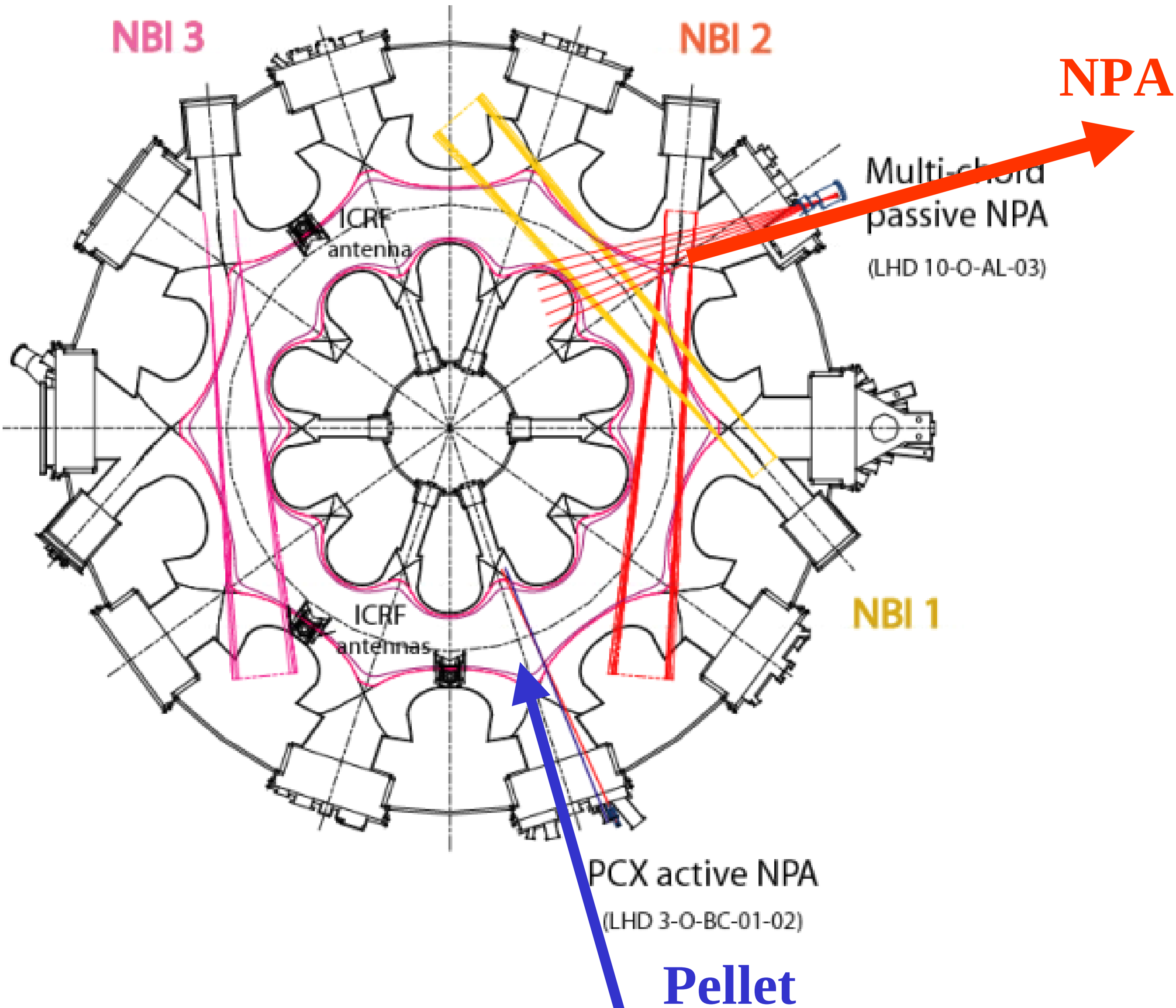
Low Energy Particle Flux

$\rightarrow$Peripheral Diffusion

High Energy Particle Flux

$\rightarrow$ Central Diffusion

Experimental Arrangements



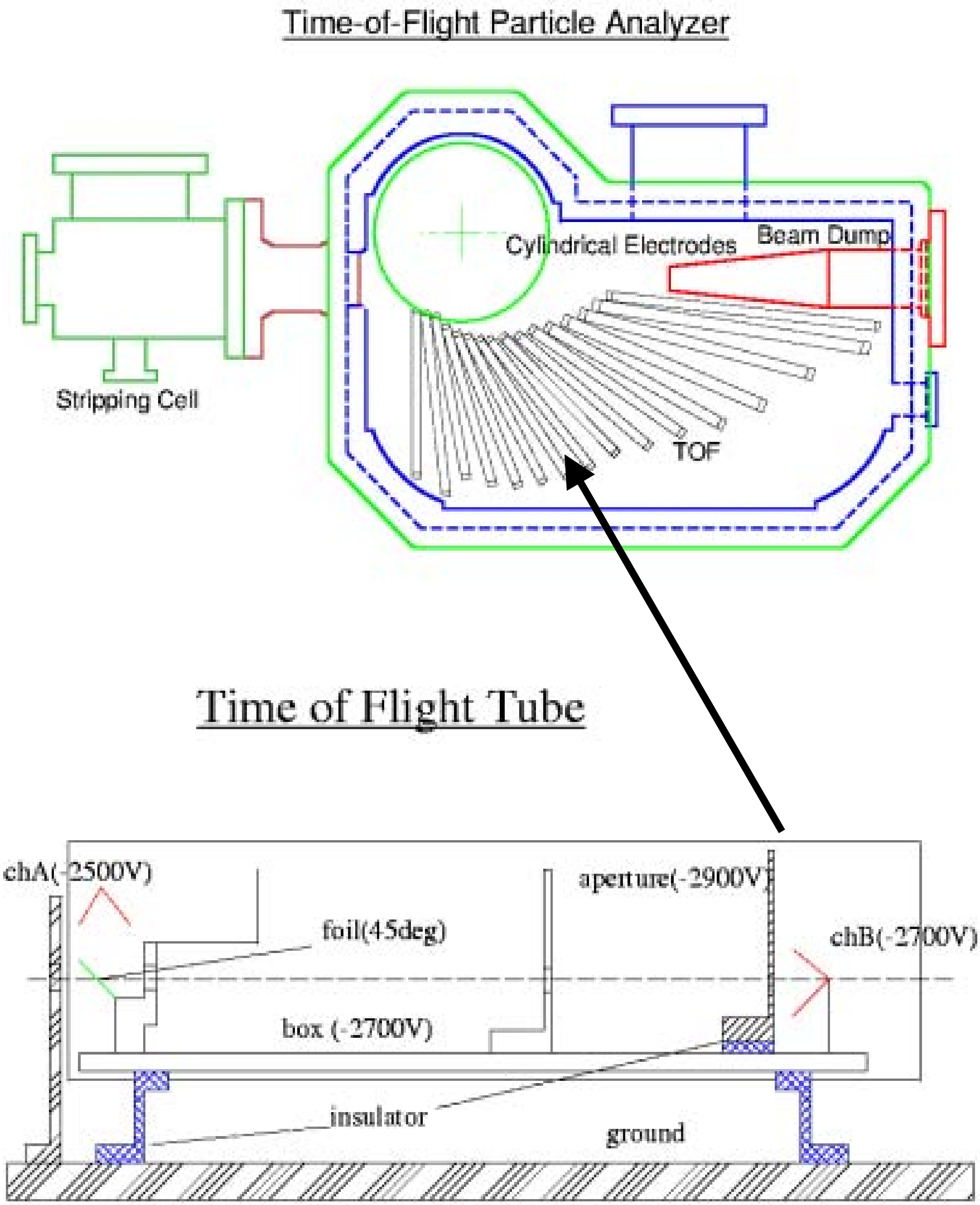
Measurements

Energy ０．７～２８keV(１６channels)

Position Pitch Angle of 77 degree

(on the magnetic axis)

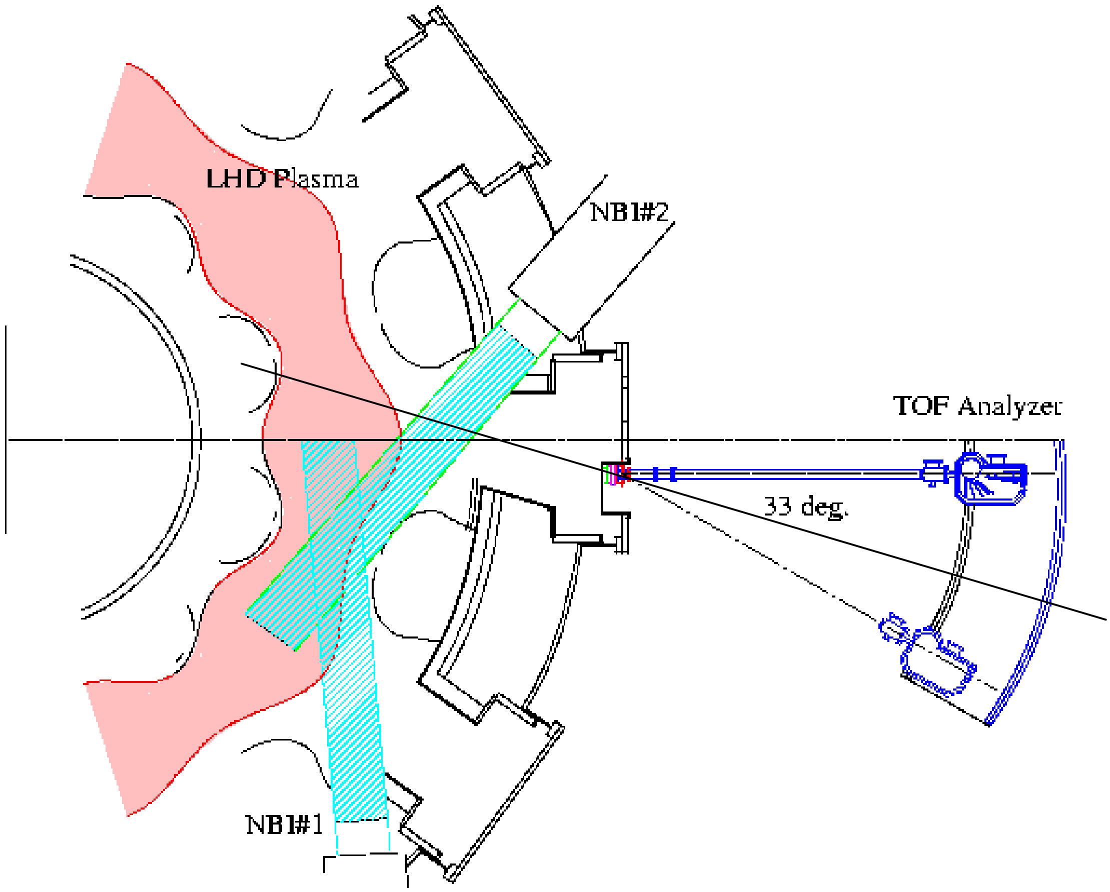
Time-of-Flight Neutral Particle Analyzer



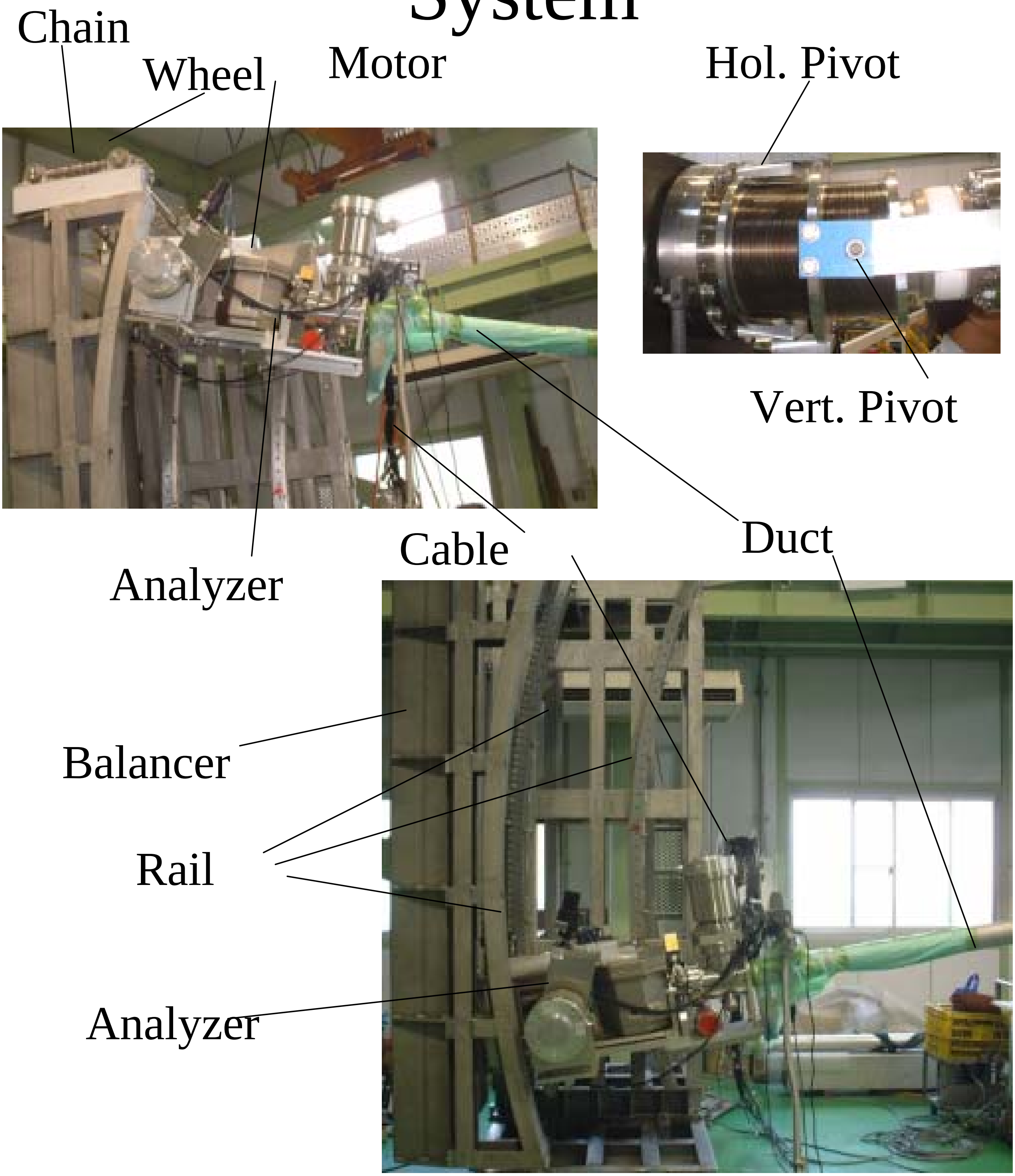
Spec. of the TOF analyzer

weight/size______ 350 kg, 71×42×31 cm
minimum detectable energy__0.5 keV
maximum detectable energy__370 keV
channel number__________ 16
Emax/Emin____________25
Energy resolution______typically 7%
Mass rejection_________1/1000
particle species_______ H, D, He3, He4
horizontal scan angle____34 degree
(pitch angle at the magnetic axis 35 - 103 deg.)
vertical scanning angle 27 degree

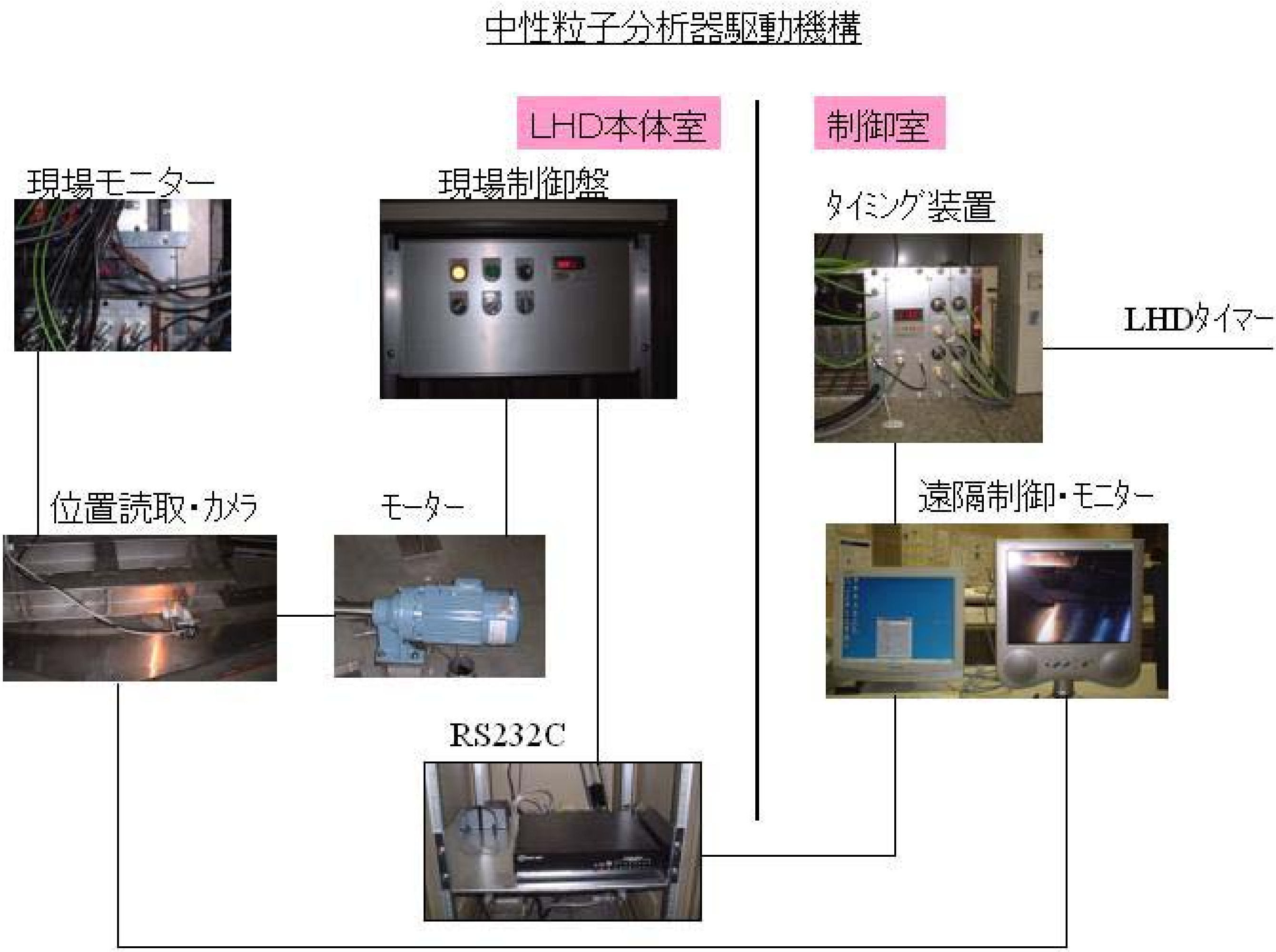
Neutral Particle Analyzer



Vertical Scanning System

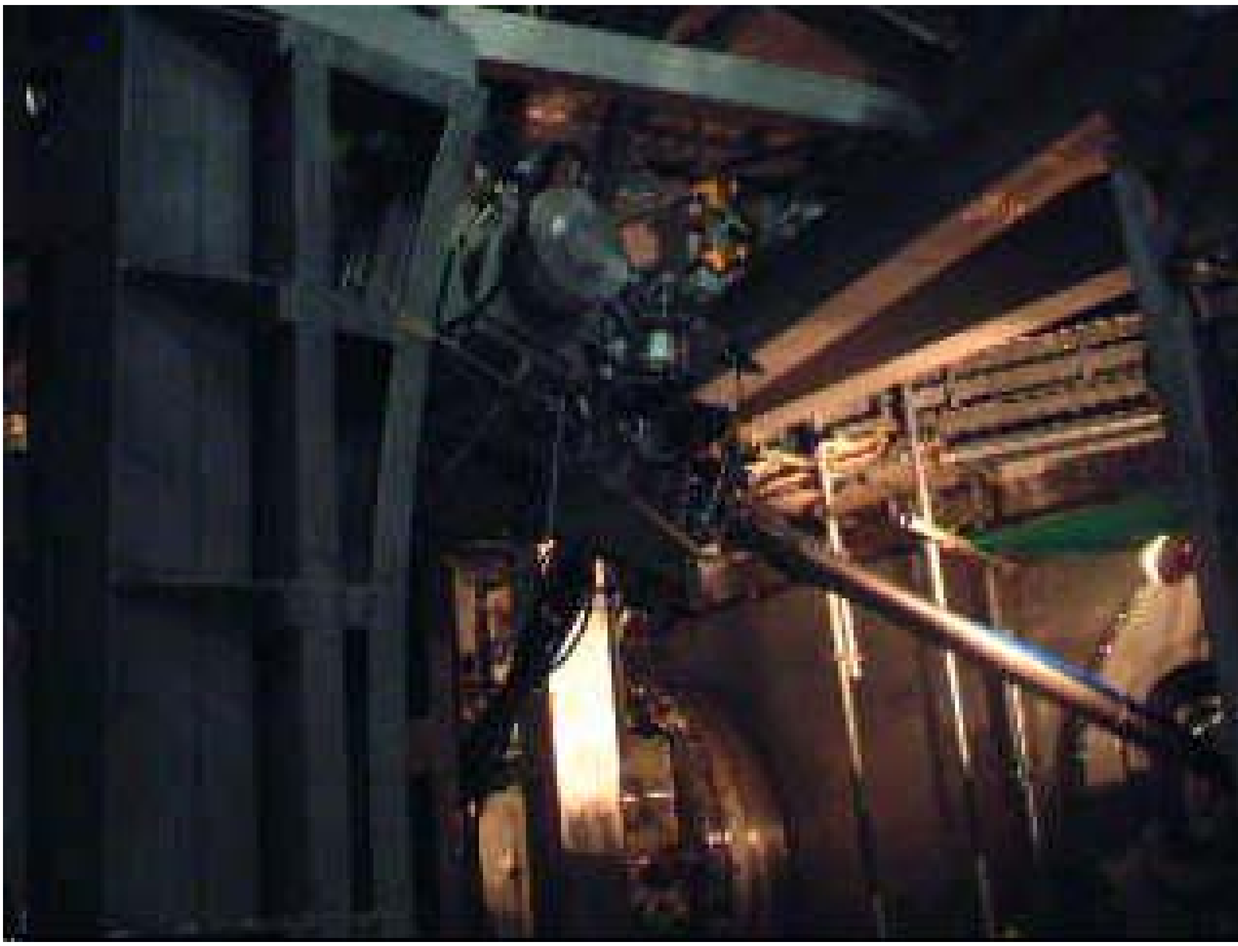


Remote Control

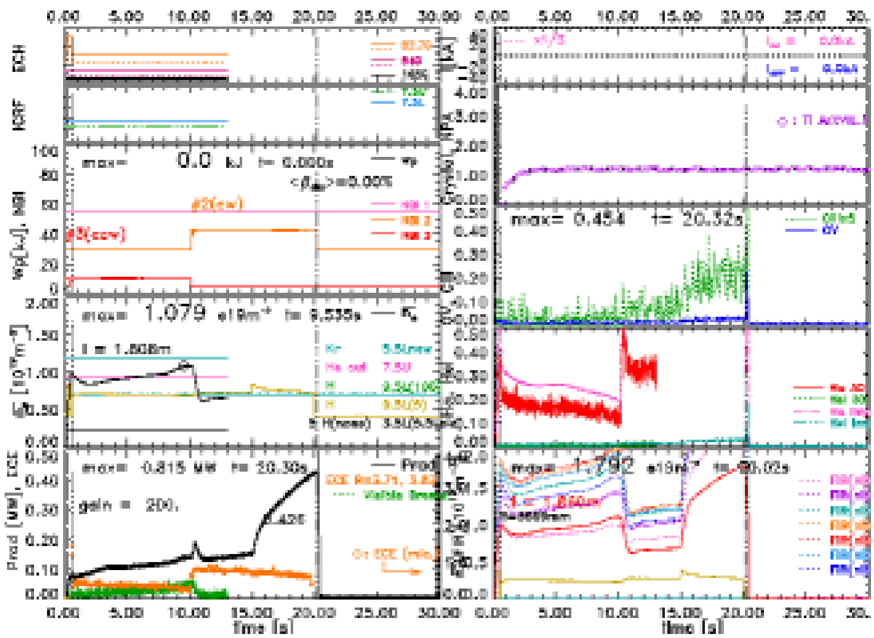


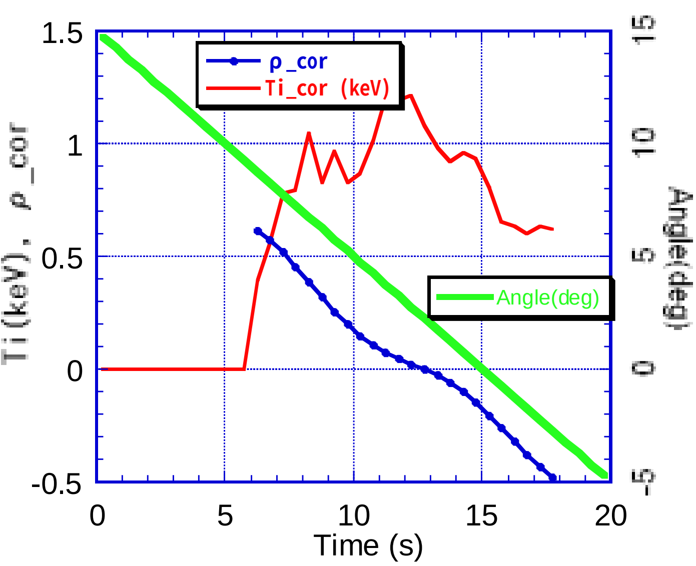
Horizontal Scan
0.17 deg./sec
Vertical Scan
1 deg./sec

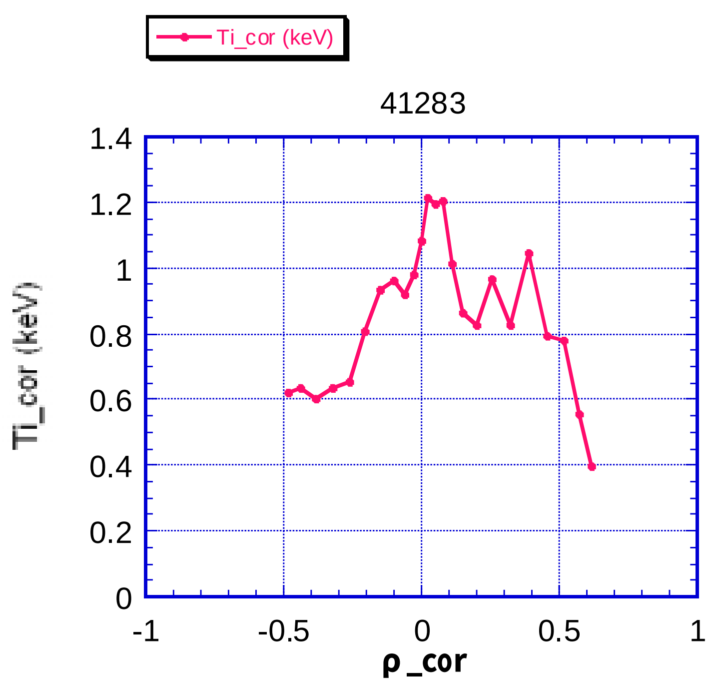
Vertical Scan System



Ti(r)







Time Variation

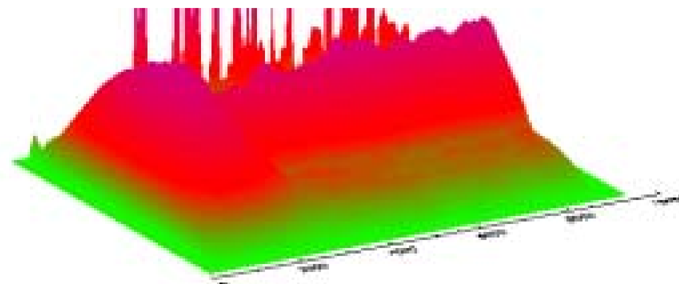
Profile

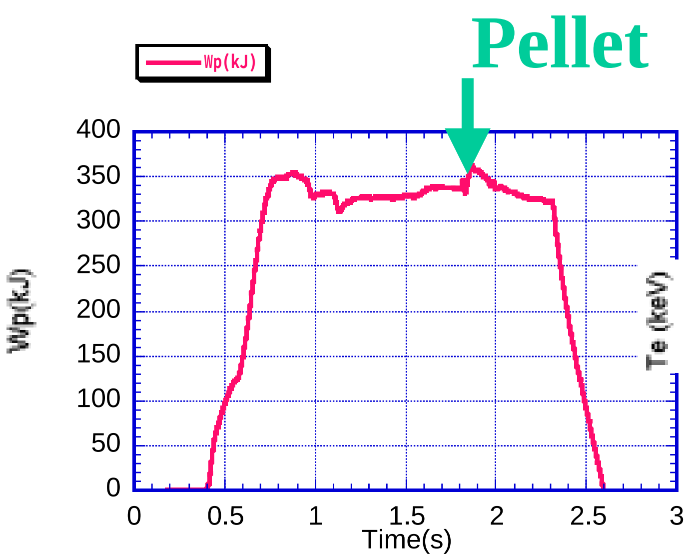
Plasma (Fuel Pellet)

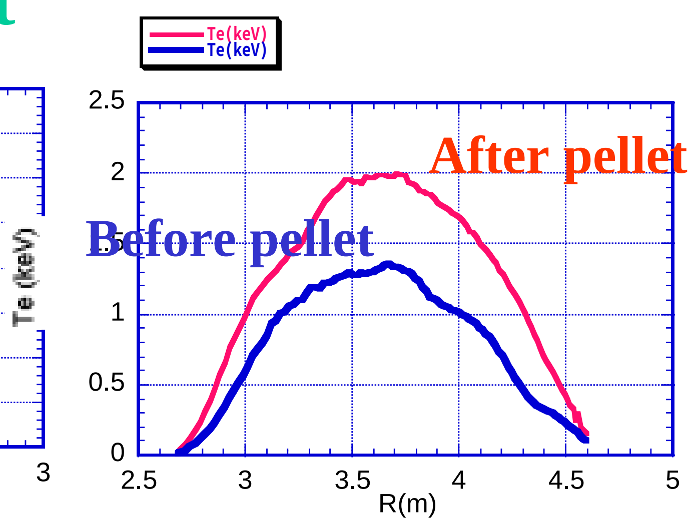
Helium Plasma

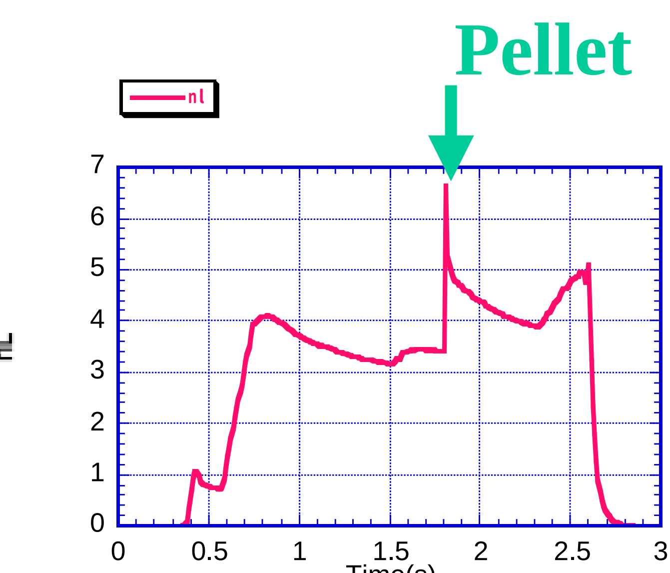
NBI(H) heated Plasma

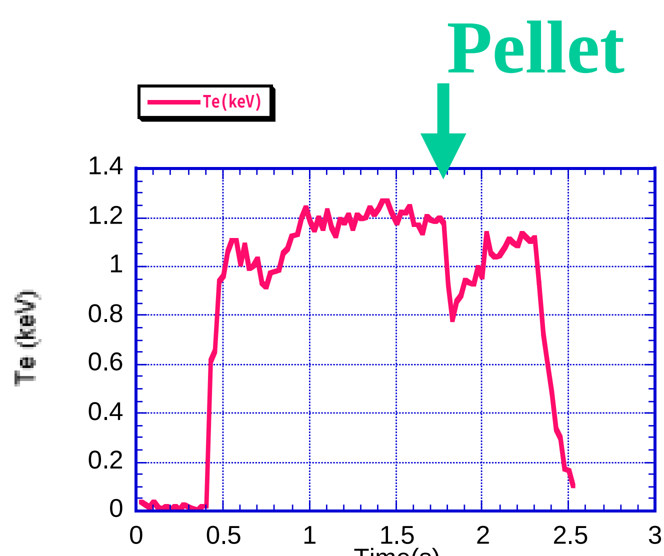
Hydrogen pellet at 1.8s



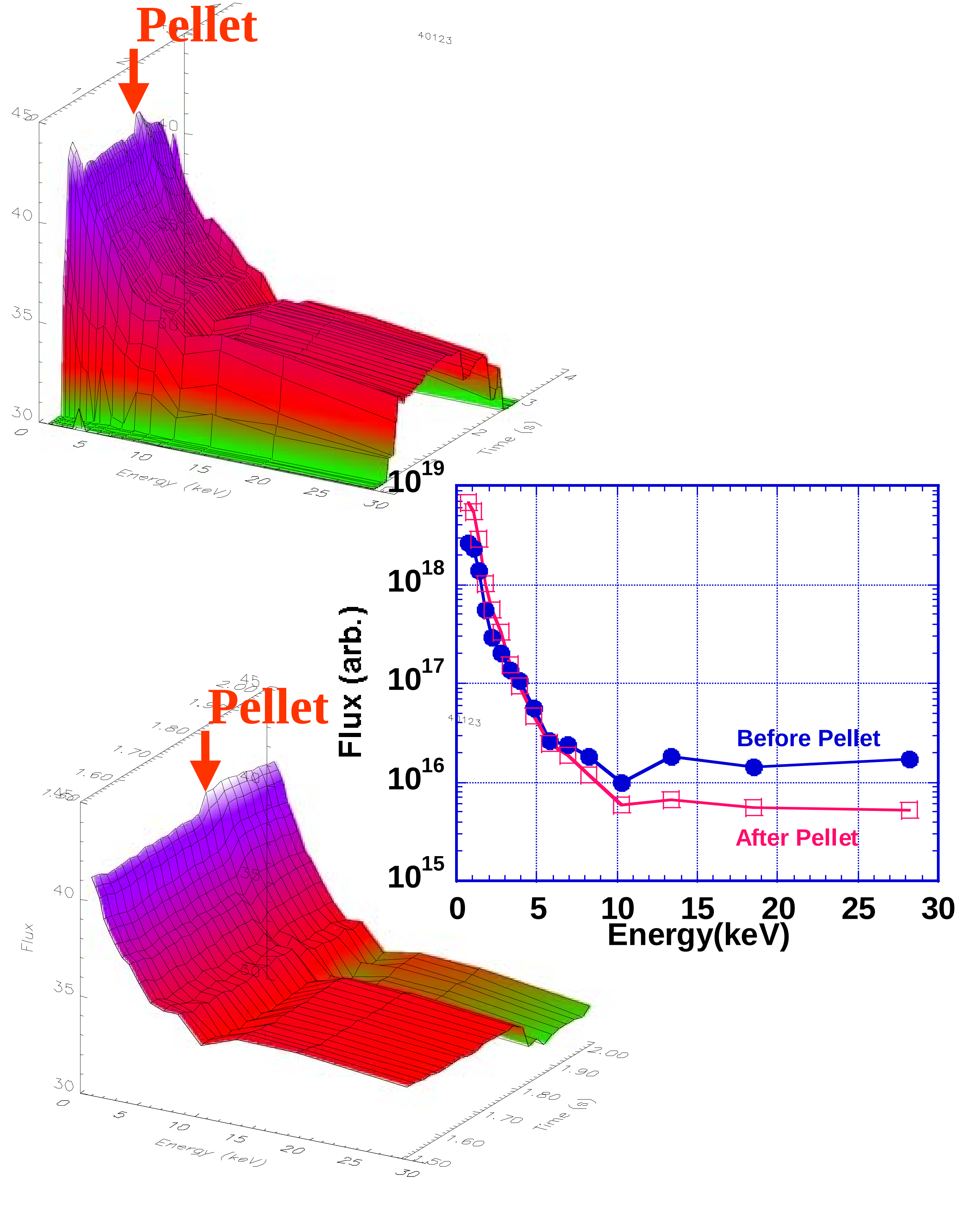






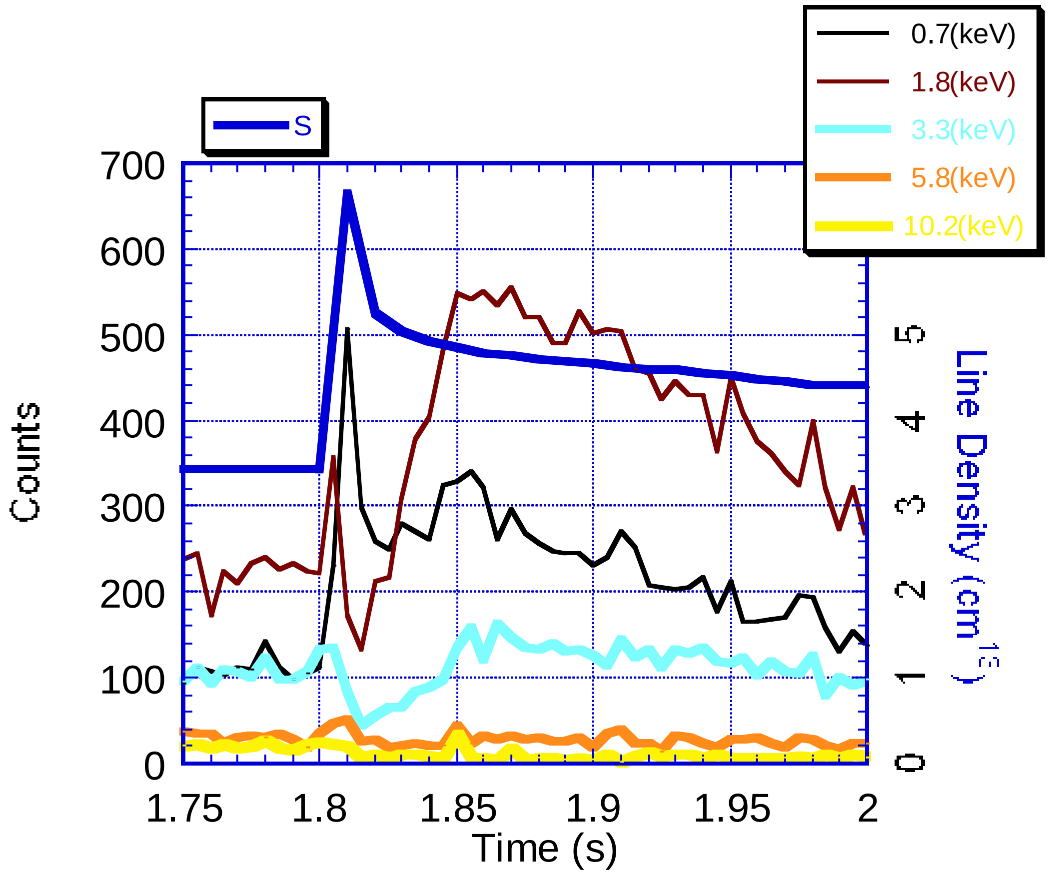


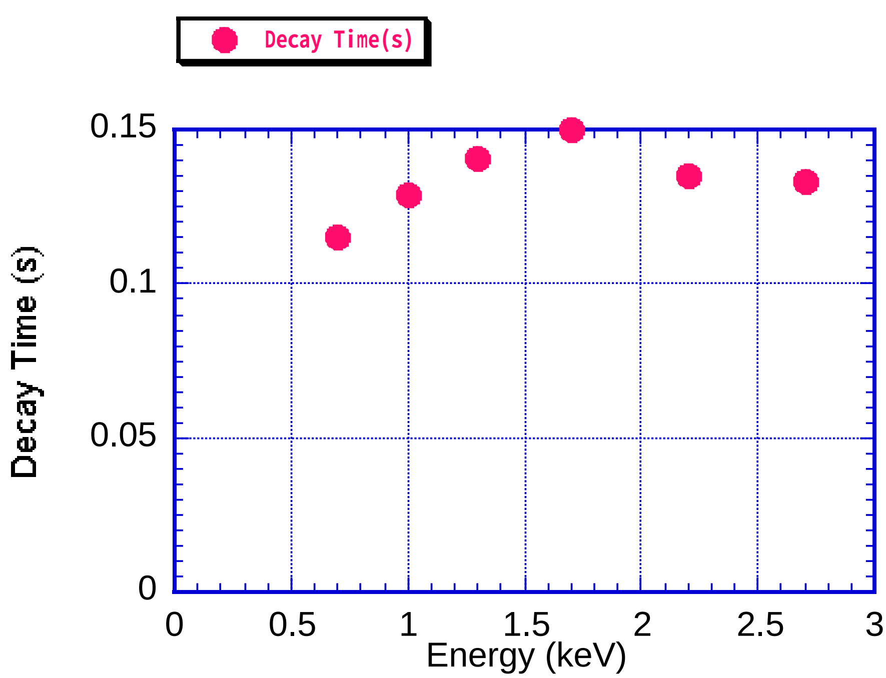
NPA Results



Pellet
40123
Energy (keV)
Time (s)
Pellet
40123
Flux
Energy (keV)
Time (s)
Flux (arb.)
Energy(keV)
Before Pellet
After Pellet
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
0
5
10
15
20
25
30

NPA Results (cont.)





Spatial Information

Background neutral distribution
by Aurora code

Helium plasma

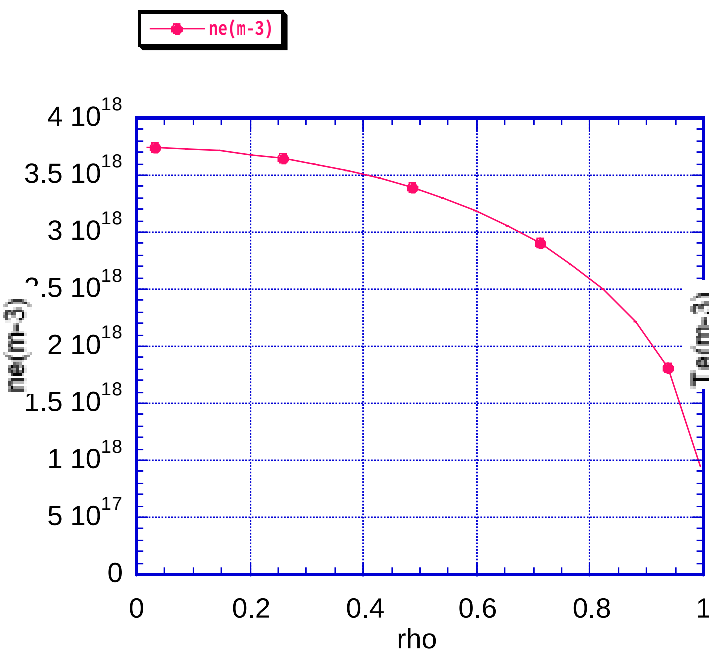
→Actually helium-hydrogen mixed plasma (NBI, wall)

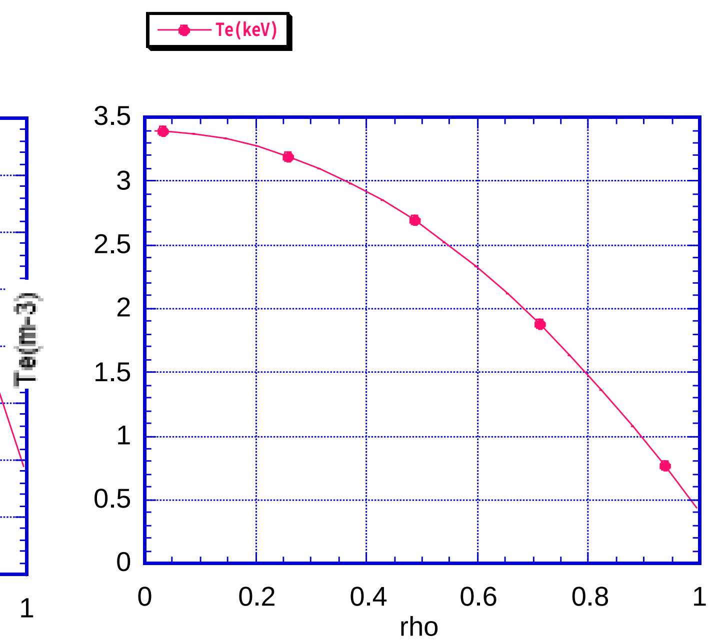
In calculation, the background neutral distribution is obtained in hydrogen plasma.

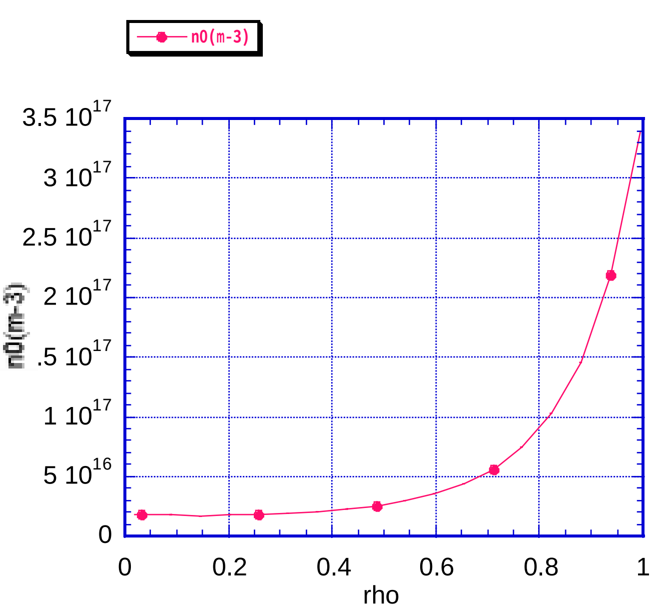
The neutral particle generation profile with each energy can be calculated from the plasma temperature and density profiles considering the attenuation.

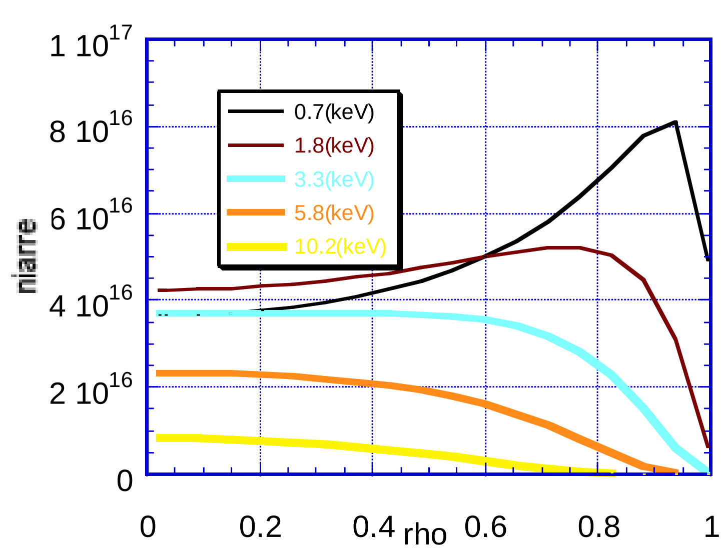
→Generation Position

Flux Contribution

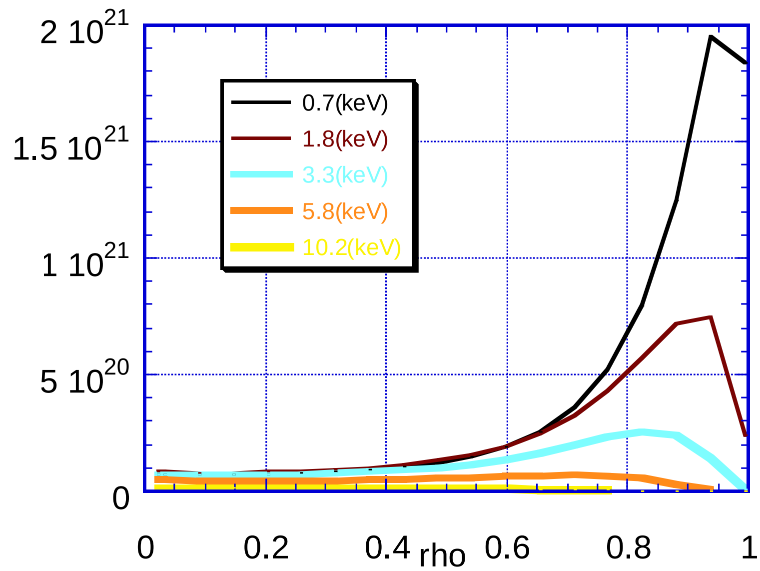


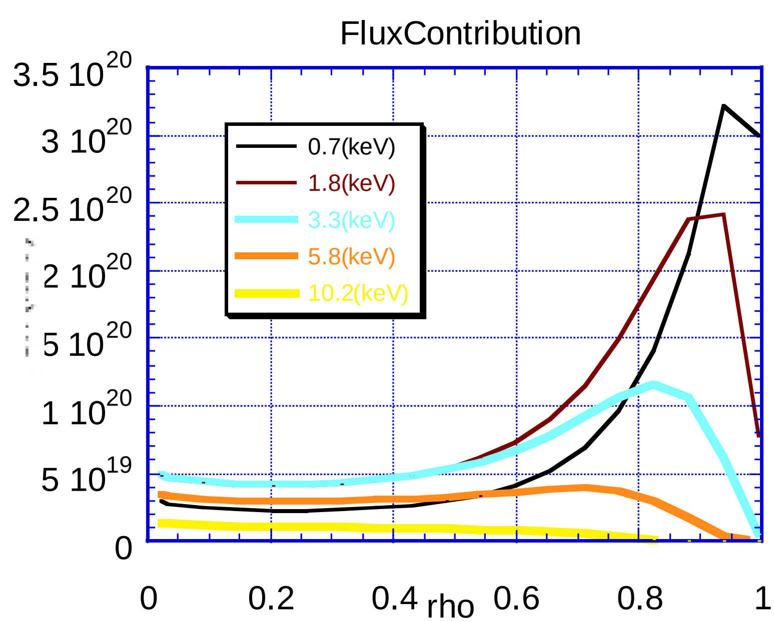






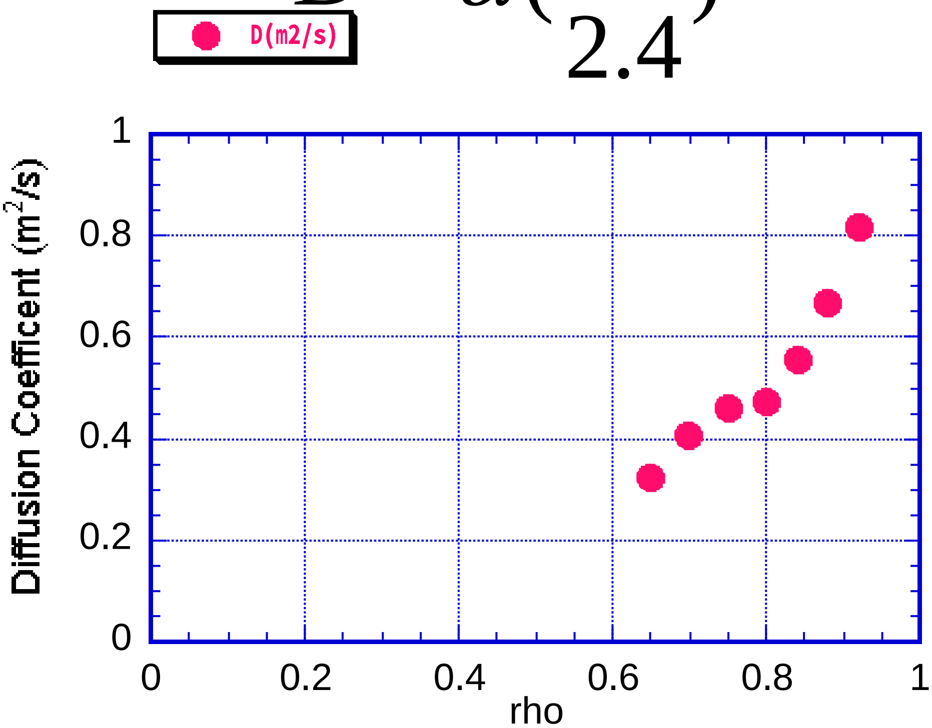
Flux Contribution 2





Analysis

$$D = \alpha\left(\frac{a}{2.4}\right)^2$$



Diffusion is larger at the outer radius.

The decay of the line density is similar to that of the neutral flux at 3.3keV. The emission region of the particle is broad in the plasma.

SUMMARY

- The charge exchange neutral particle flux is measured after the hydrogen pellet.
- The measurement has been done by the TOF-NPA settled 4m far from the pellet injector.
- The decay of neutral flux means the diffusion. The energy indicates the position in the plasma.
- The diffusion coefficient is 0.8 m^2/s near the plasma edge.
- The central diffusion coefficient maybe obtained by the diagnostic pellet instead of the fuel pellet.

Future Plan

Hydrogen Pellet for fueling

Large amounts→ Large Density Increase

→Low Flux of High Energy Particle from Plasma Center

→Lack of diffusion information at the center

➔Small size Diagnostic pellet (TESPEL)