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Helium measurements using the pellet charge exchange in Large Helical Device

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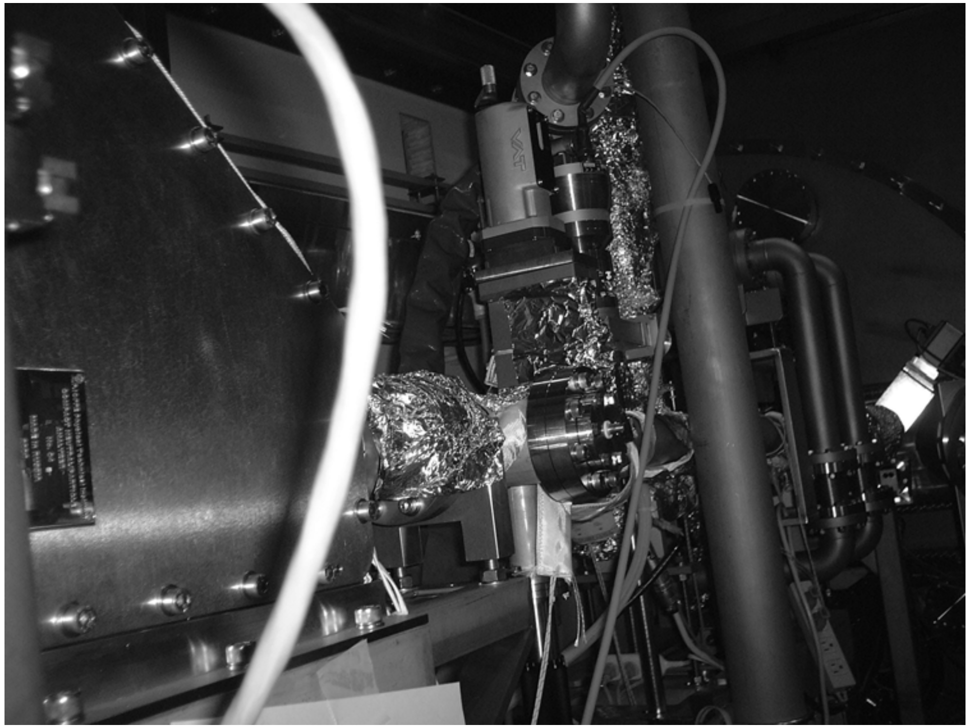

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Abstract

In Large Helical Device (LHD), it is possible to perform the simulation experiment of the α particle heating by using the ion cyclotron resonance heating (ICH) because high-energy particle generated by ICH is well confined in the plasma. The neutral particles (mainly hydrogen), which are generated by the charge exchange between the high-energy ion and the background neutrals, can be observed by using them. However a few neutral helium particles can be observed because α particle (or fully ionized helium) can emit only by double charge exchange process. Therefore we also introduce the pellet charge exchange system (PCX). The diagnostic pellet is injected to the plasma in order to obtain the charge exchange neutral particle, which is produced by the charge exchange reaction between the ablated pellet cloud and α particle or high-energetic particle. The helium distribution measurement in helium plasma is demonstrated.

Pellet Charge Exchange Measurement

●Direct measurement of energetic particles in plasma (proton, alpha etc.)

●Background neutral for charge exchange is required in passive measurement

Difficult to obtain central information due to low back ground neutral around the plasma center.

Double charge exchange is necessary to measure α-particle

Line integration

→Pellet Charge Exchange (PCX) by combination of TESPEL & CNPA

PCX has been tried in TFTR for α-particle measurement

New results can be obtained even in non-DT plasma device

→Diagnostic development

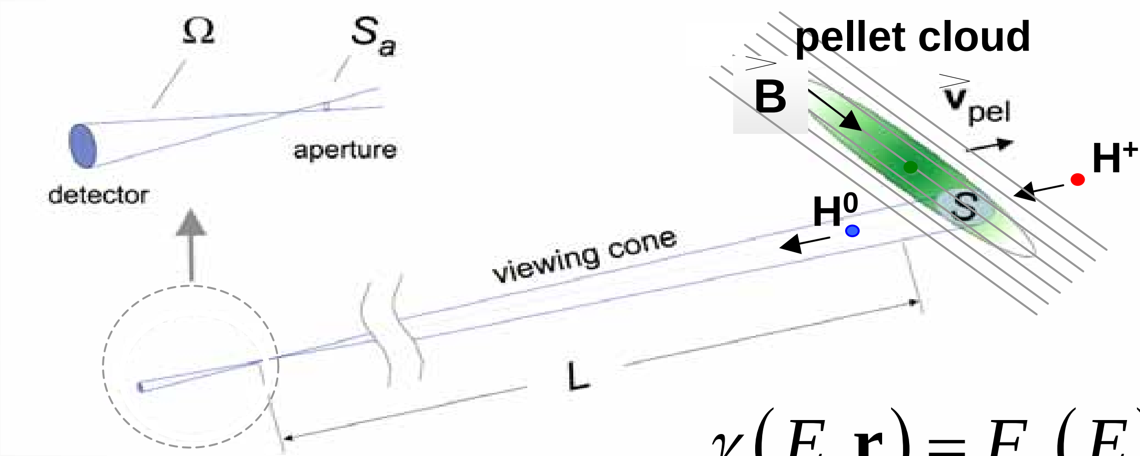
(1) Establishment of the PCX technique for proton (1/4 mass of α)

(2)Try helium ion measurement by using PCX

D) Pellet charge exchange (PCX) diagnostic

Localized active neutral particle analyzer (NPA) measurement can be obtained by PCX technique

Current pellet location: $\mathbf{r}(t)=\mathbf{r}_0+\mathbf{v}_{pel}t$



$$n_i \mathrm{v}_i f_i(E,\mathbf{r})\,dE$$

local flux of ions with energy E [$cm^{-2}s^{-1}$]

$$\gamma(E,\mathbf{r})=F_0(E)\,n_i(\mathbf{r})\,\mathrm{v}_i f_i(E,\mathbf{r})$$

local atomic emission [$erg^{-1}cm^{-2}s^{-1}$]
from the unit area of the cloud

Measured H^0 Flux [$erg^{-1}s^{-1}$]

$$\Gamma^{(PCX)}(E,\mathrm{r}(t))=\frac{S_aS}{4\pi L^2}\gamma(E,\mathrm{r})e^{-\tau(E,L)}$$

Attenuation Factor
(“optical thickness”)

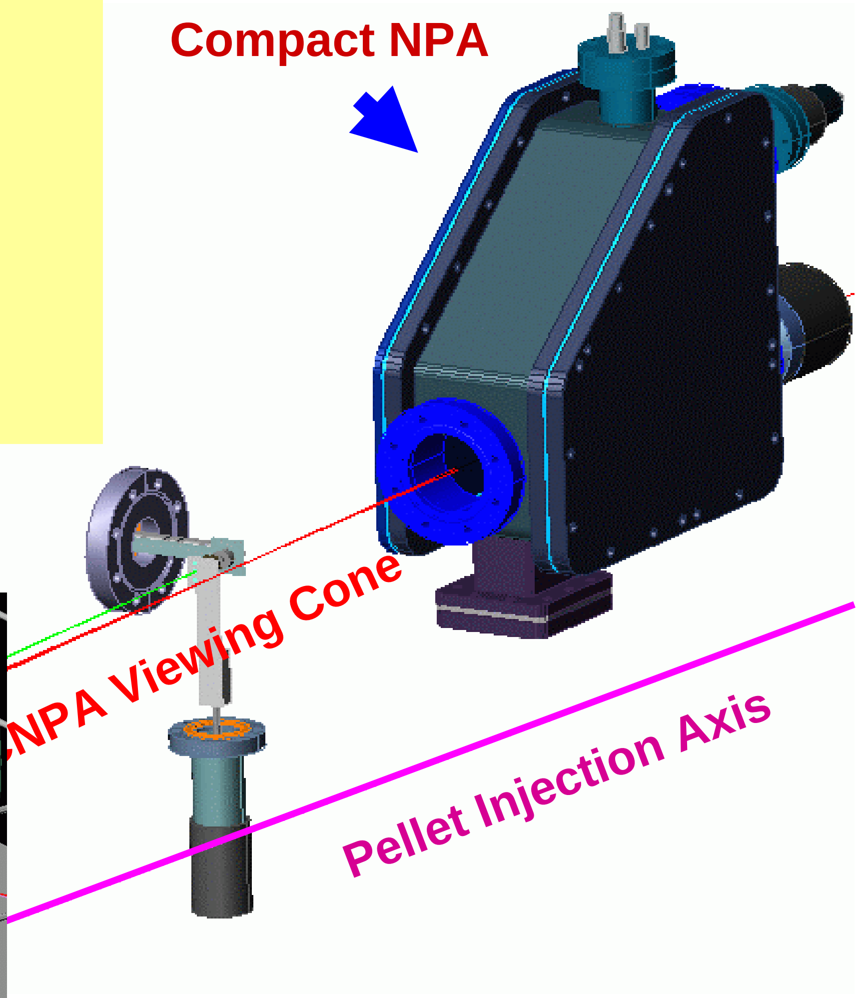
- Time-resolved particle energy spectra can be translated into the radially-resolved measurements along the pellet trajectory

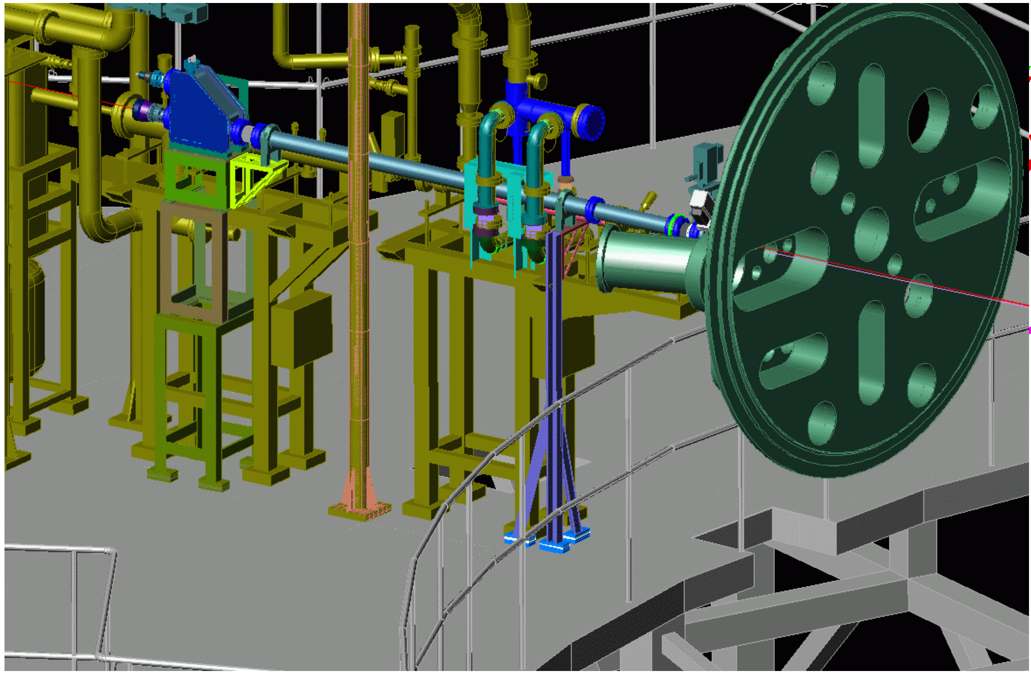
T. Ozaki, P. Goncharov

Experimental Apparatus

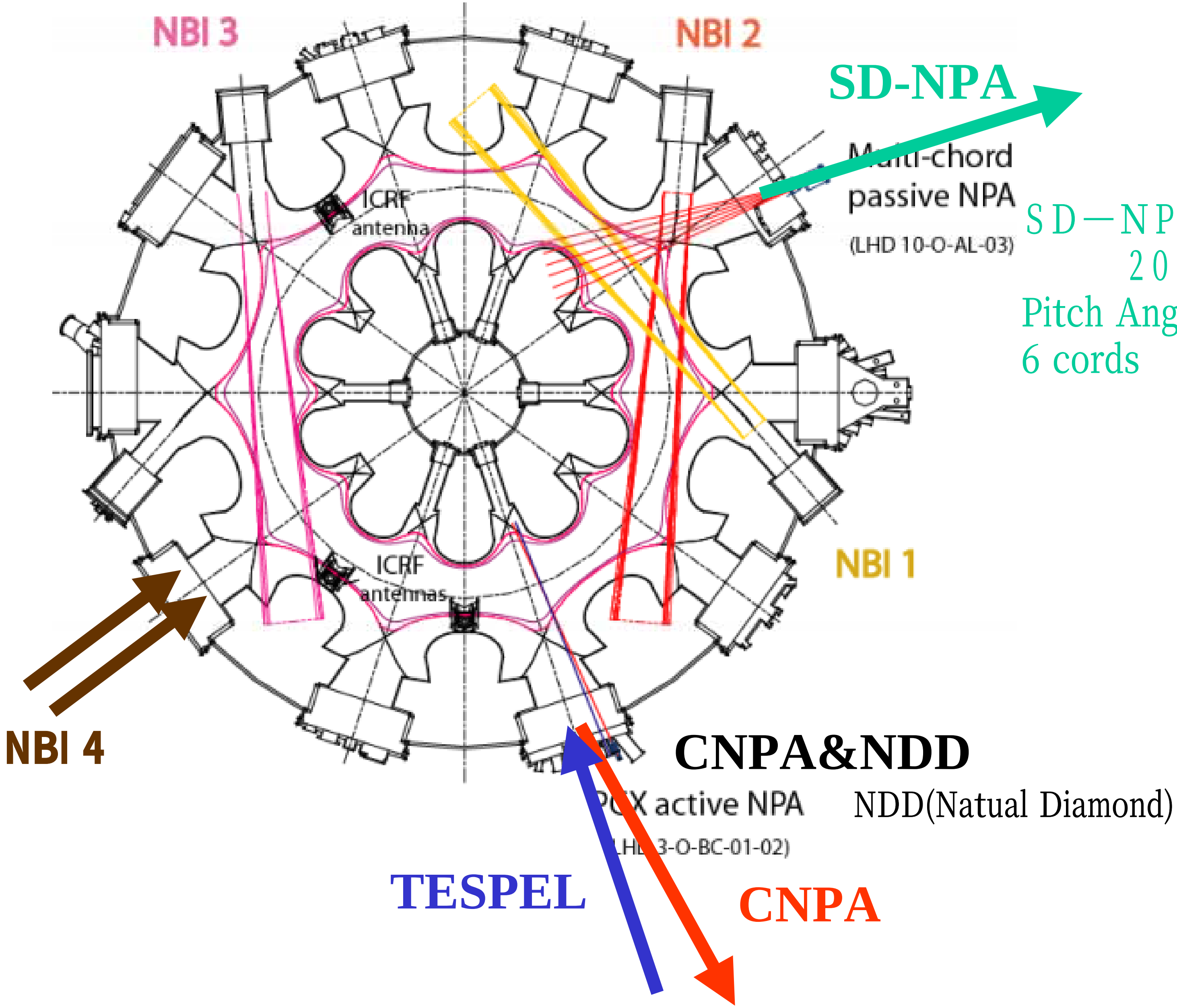
CNPA (Compact Neutral Particle Analyzer)

Channel	40
Energy resolution	Typically several %
Energy range	0.8～168 keV
Time resolution	100 μ s

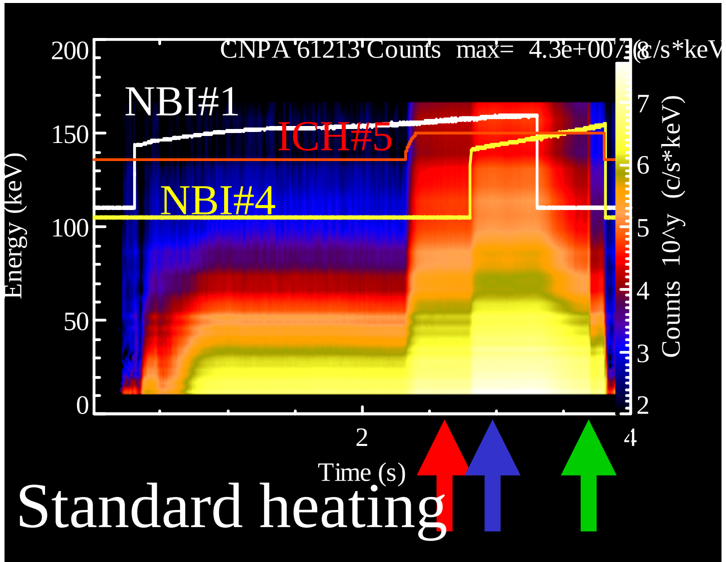




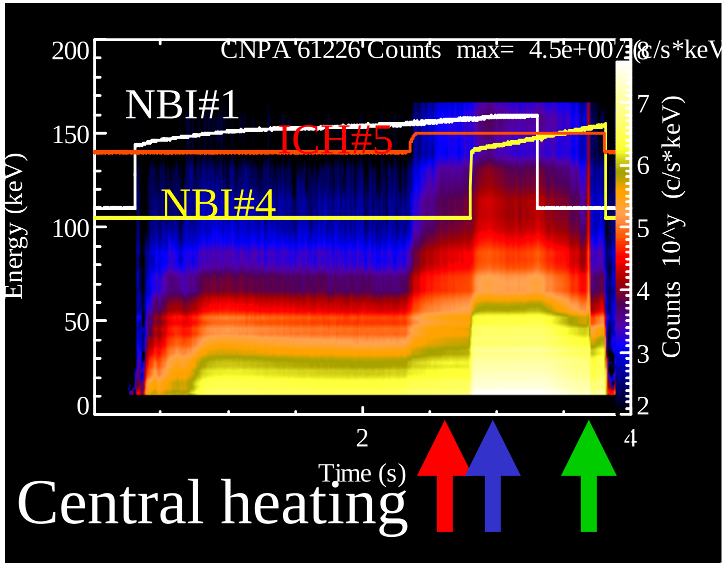
Experimental Setup

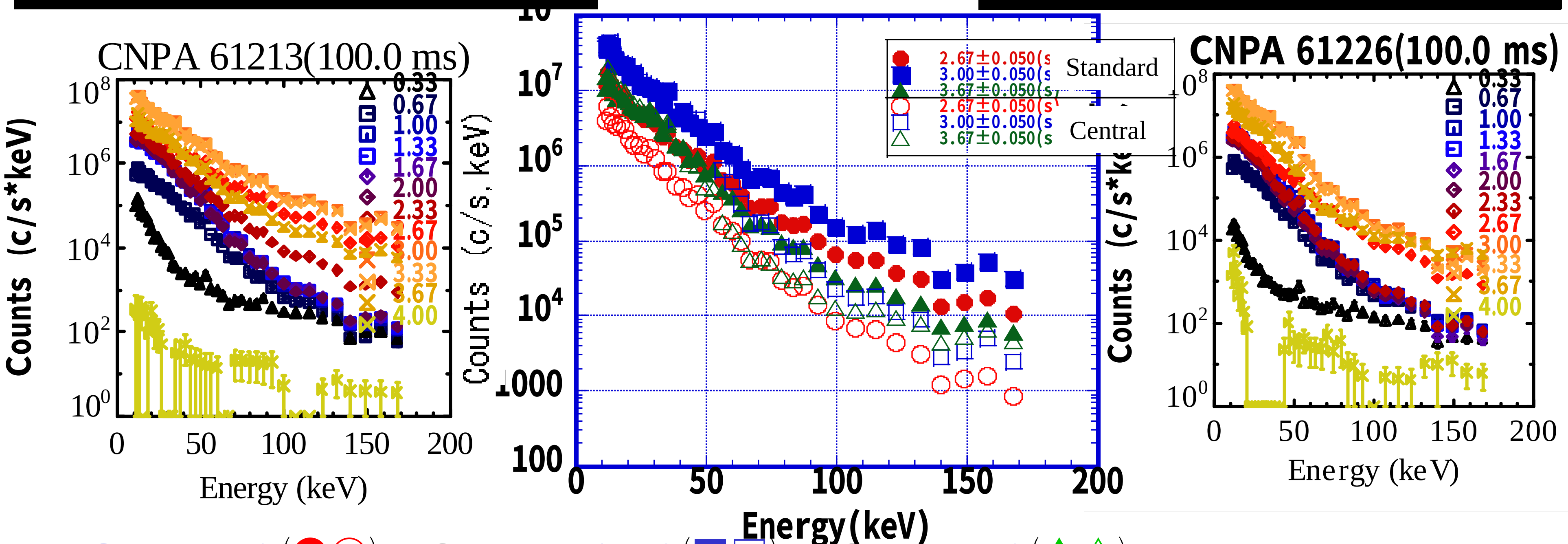


SD－NPA　25～400keV
2048 ch
Pitch Ang.　45～90deg
6 cords



Typical CNPA results in ICH plasma

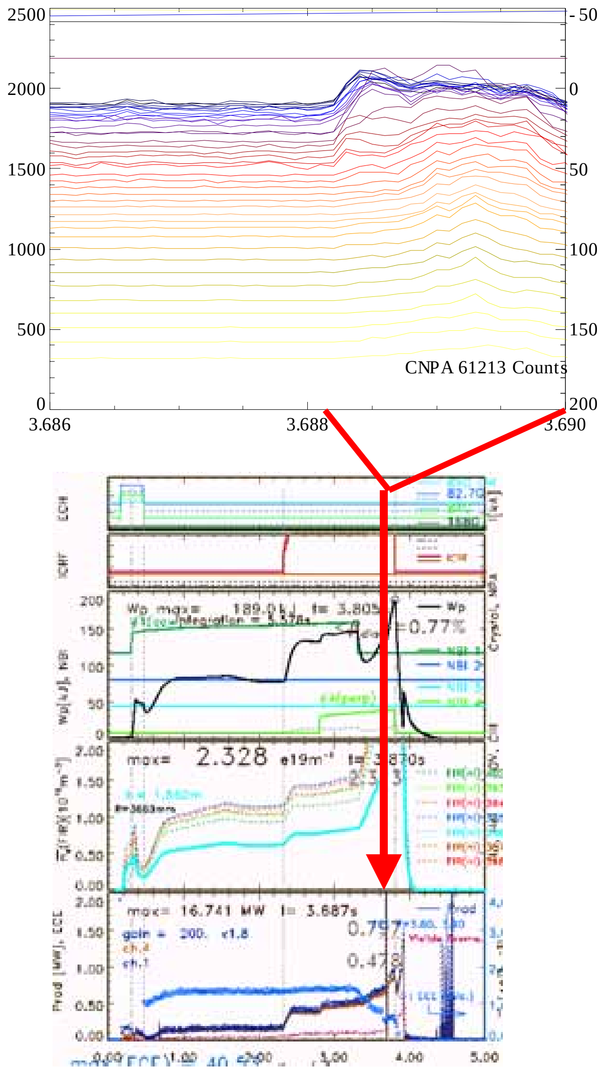




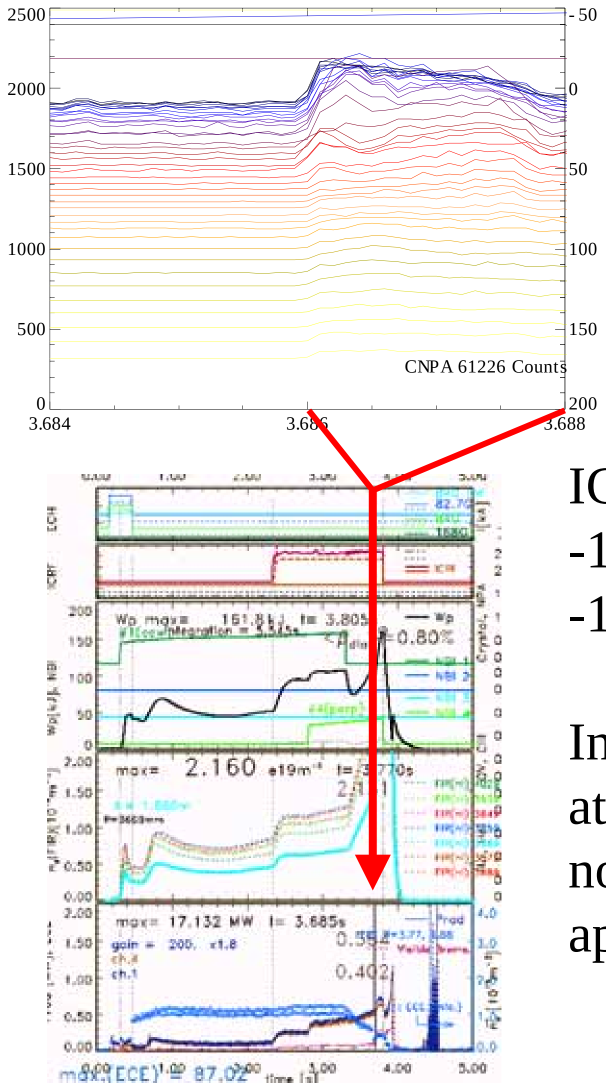
ICH+NBI#1 (●○)、ICH+NBI#1+#4 (■□)、ICH+NBI#4 (▲△)

Closed marks (●■▲) mean the standard heating, open marks (○□△) mean the central heating of ICH. The difference of both cases is remarkable in the ICH+NBI#1. Particles from NBI#4 is also obviously observed.

Difference of the resonance positions in PCX



Rax=3.6,Bt=-1.375T



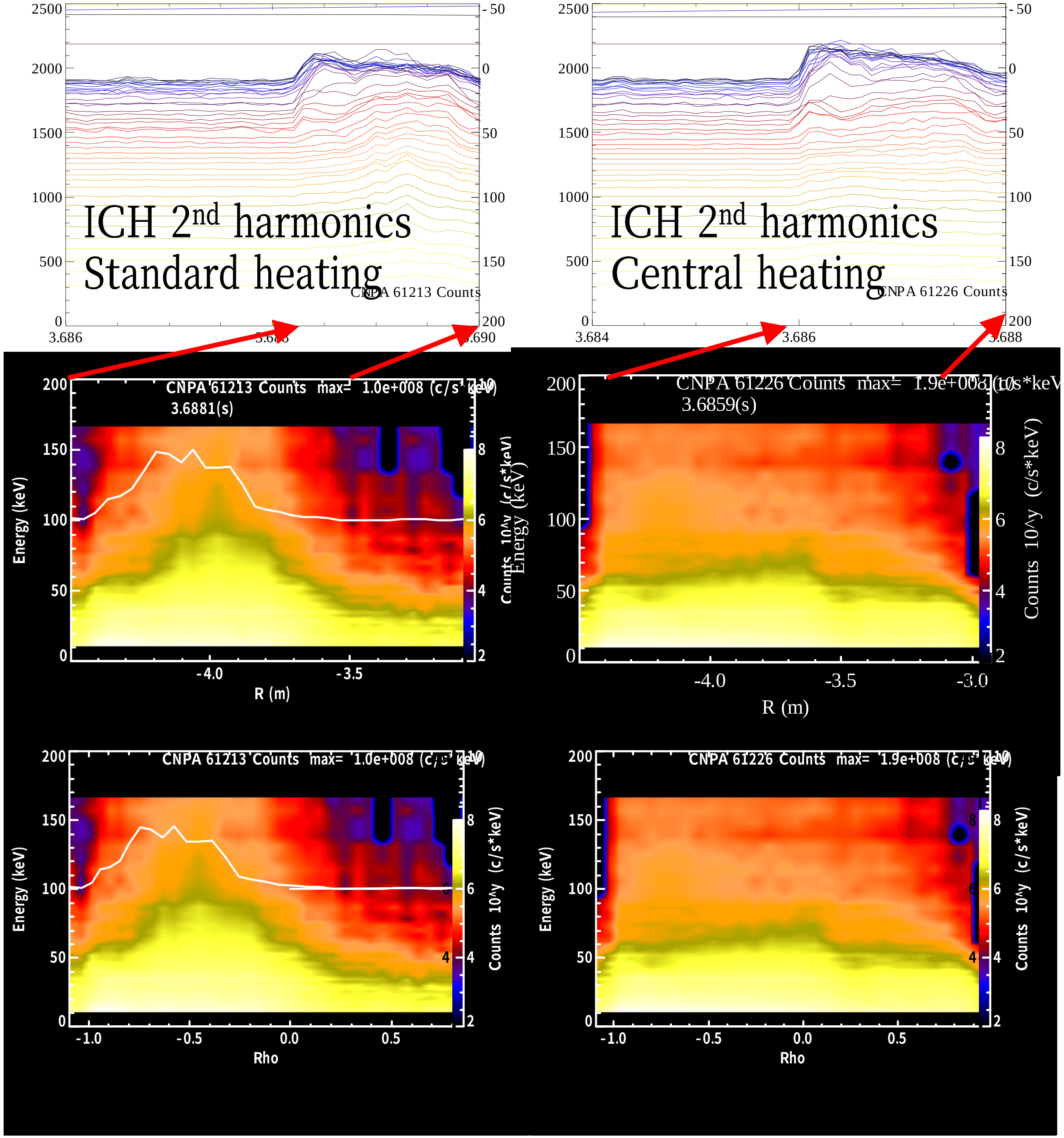
Rax=3.6,Bt=-1.25T

←Time trace of the charge exchange particle flux during TESPEL injection. Here the time means the pellet penetration depth. The pellet reaches ρ=0.1. Vertical axis shows the particle energy.

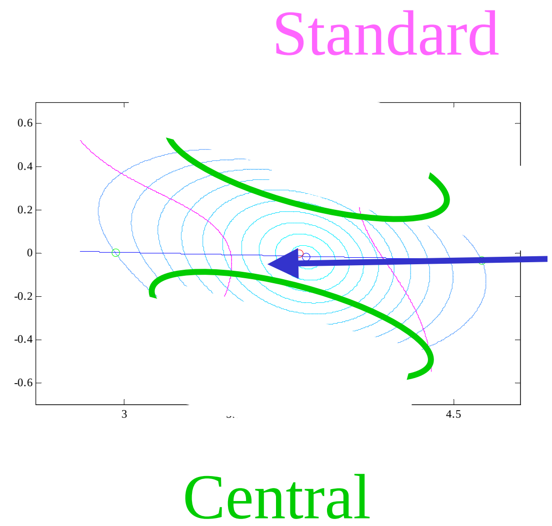
ICH 2nd harmonics
-1.375T Standard heating
-1.25T Central heating

In -1.375T, the flux increase at ρ =0.5. However in -1.25T, no enhancement of the flax appears.

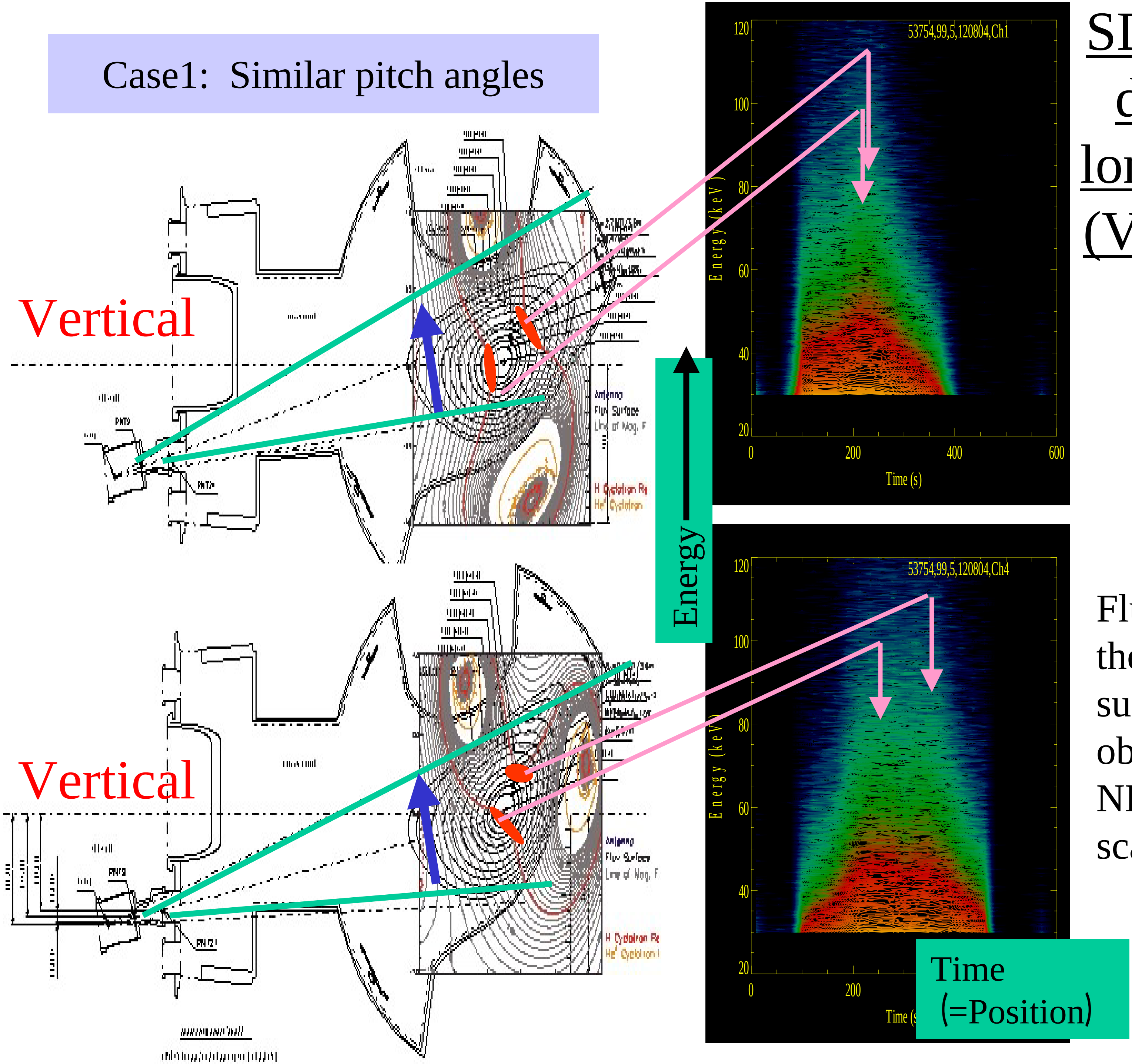
Difference of the resonance positions in PCX(cont.)



In the standard heating, the flux increases at ρ =0.5. In the central heating, the flux increase can not be found because the the pellet trajectory is not cross the resonance surface.



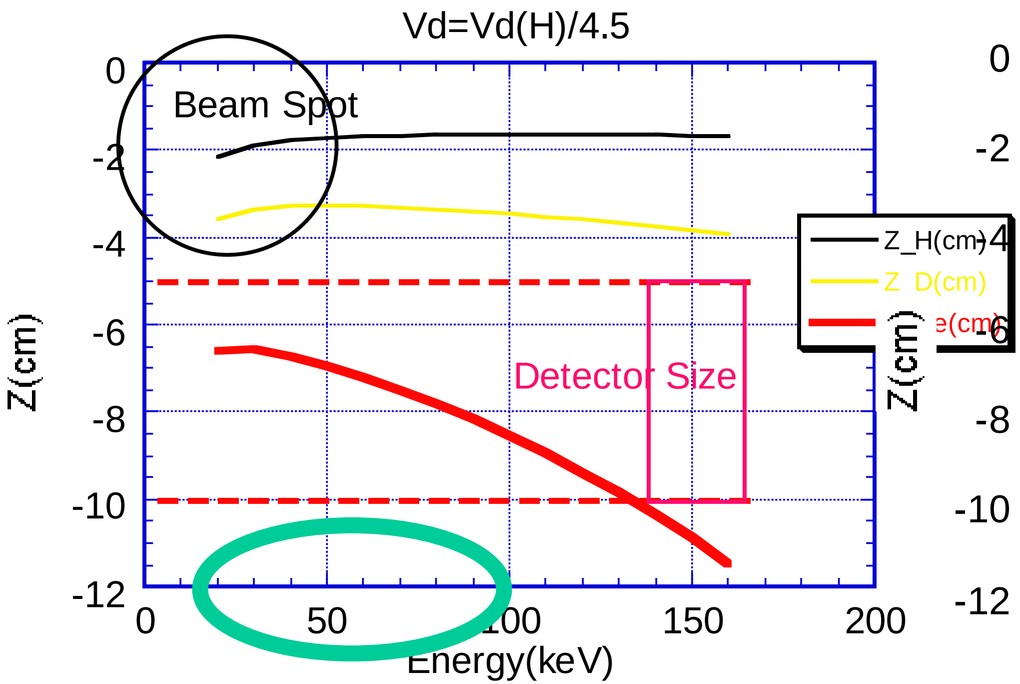
Case1: Similar pitch angles

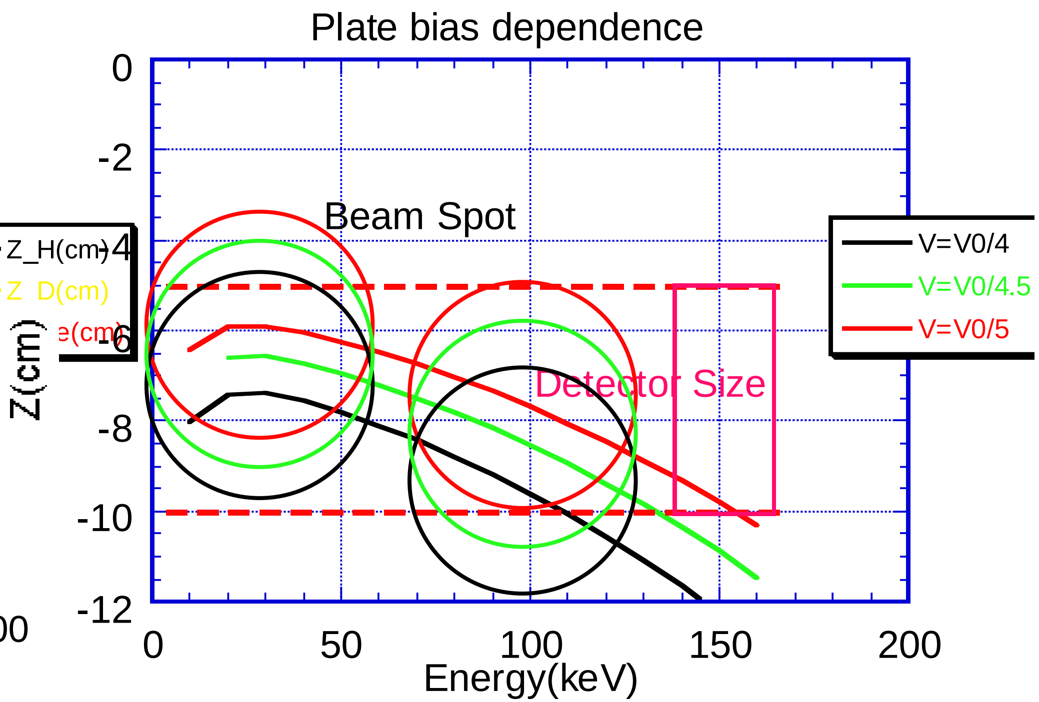


SD-NPA scan during ICH long discharge (Vertical sight lines)

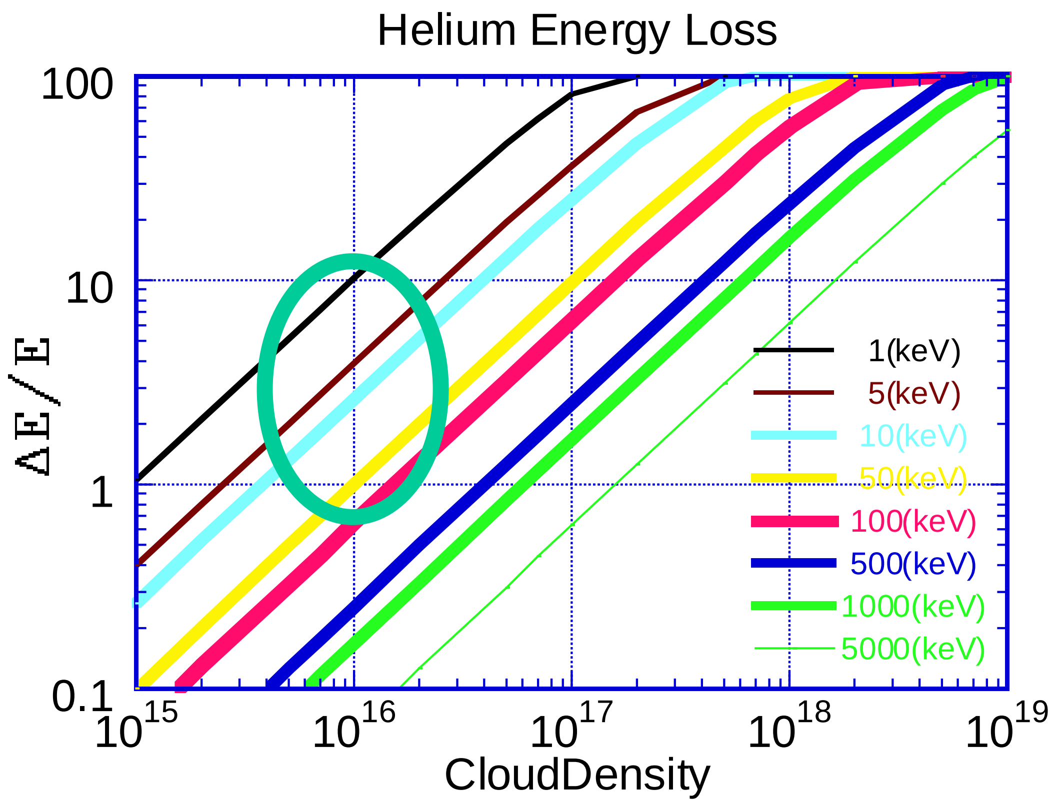
Flux increase at the resonance surface can be observed in SD-NPA vertical scan.

Spot on Detector





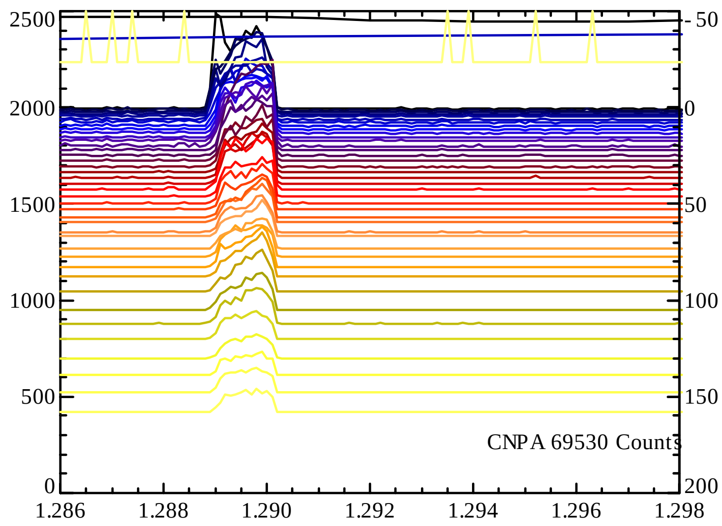
Energy loss in Cloud



$$\frac{\Delta E}{E_0} = 1 - \frac{\left(E_0^{0.6} - 0.6 \cdot Z_{Li} \cdot 0.96 \cdot 10^{-16} \cdot S_n\right)^{\frac{1}{0.6}}}{E_0}$$

(by Sergeev)

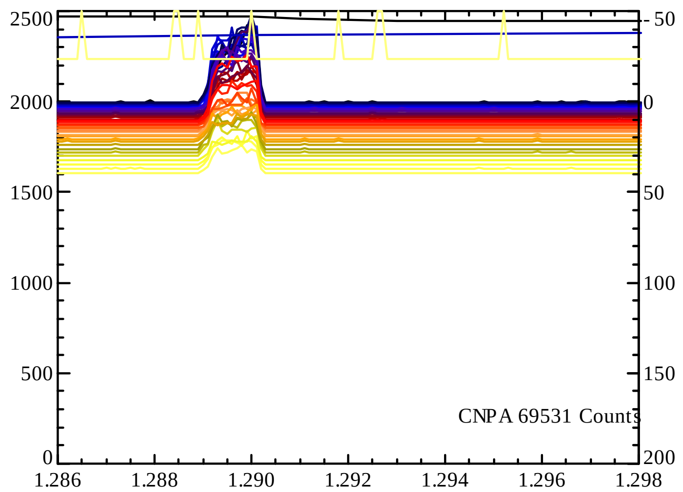
Helium profile (NBI)



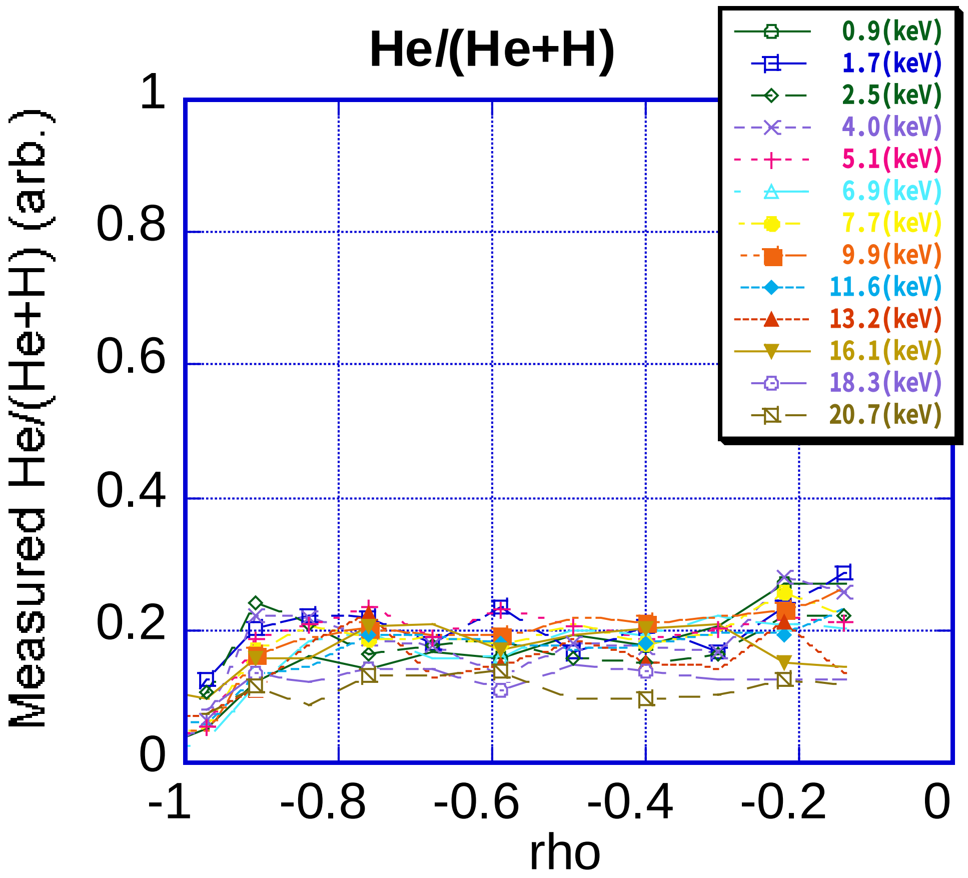
Hydrogen

TESPEL is injected to the helium plasma during NBI#2 phase. Helium ion profile can be obtained by PCX. TESPEL reaches ρ=0.2 in NBI plasma.

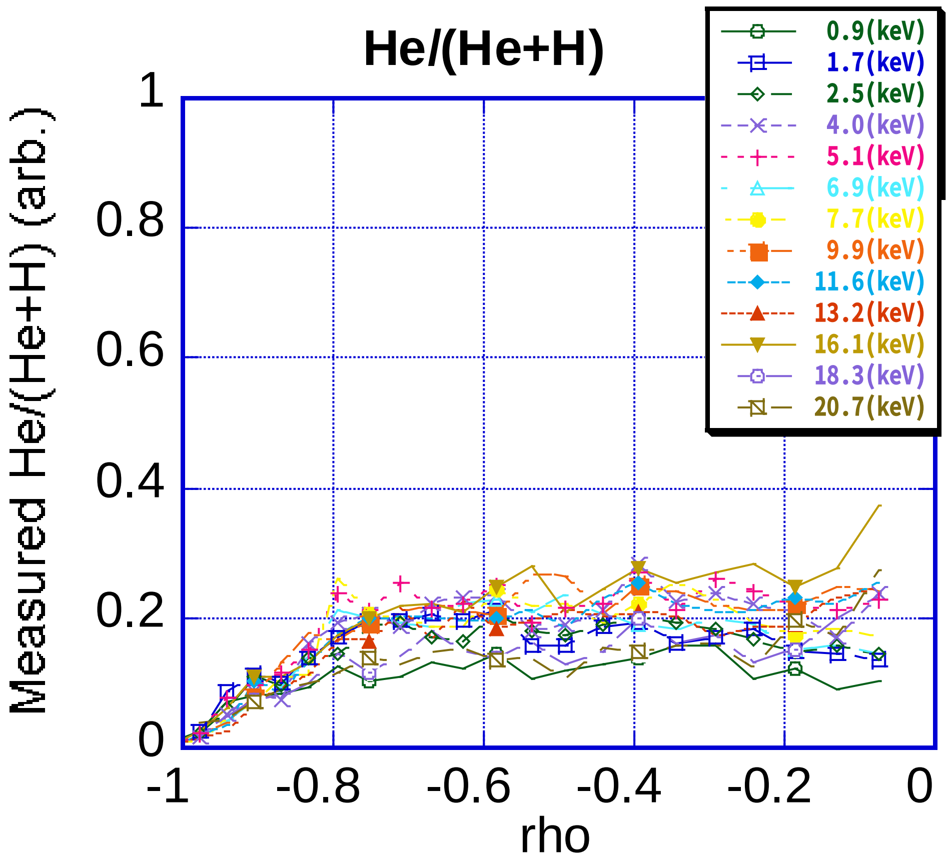
Hydrogen is aloso observed at ρ>1. Low helium/hydrogen ratio is observed in the peripheral region due to the hydrogen flow from the wall.



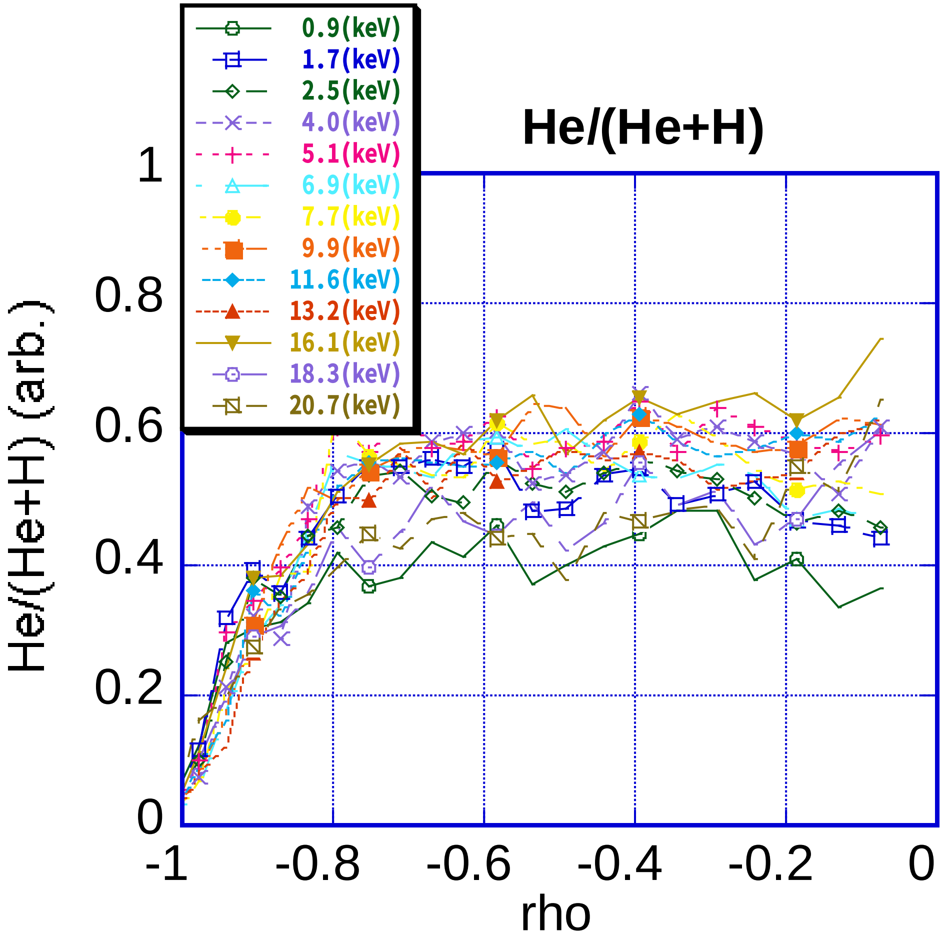
Helium



Helium Ratio (ICH)



Ratio in the detector



Ration in the plasma

Neutralization factor in the pellet cloud

Polystyrene

$$F_0(E)=\frac{n_0(x)}{n_1(0)}=\frac{n_0(x)}{n_0(x)+n_1(x)}\approx\frac{1}{1+\sigma_{0\to1}/\sigma_{1\to0}}$$

50% H^0 , 25% C^{1+} , 25% C^{2+}

Neutralization ($\sigma_{1\text{-}0}$)

$$H^+ + H^0 \to H^0 + H^+$$

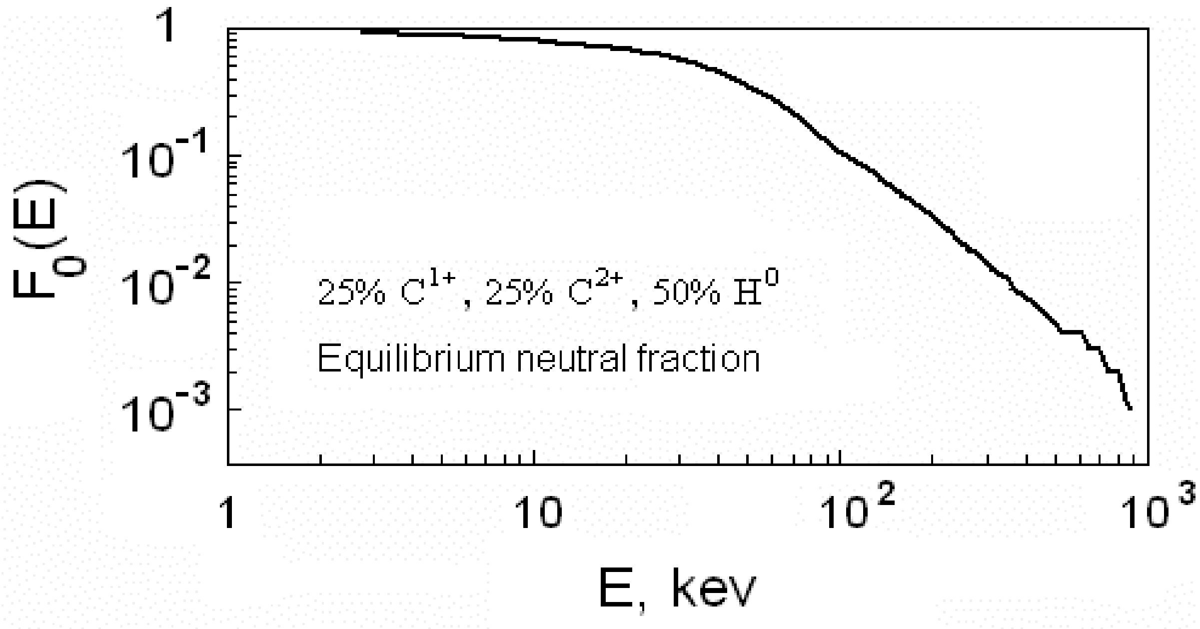
$$H^+ + C^{1+} \to H^0 + C^{2+}$$

$$H^+ + C^{2+} \to H^0 + C^{3+}$$

Ionization ($\sigma_{0\text{-}1}$)

$$H^0 + C^{1+} \to H^+ + C^0$$

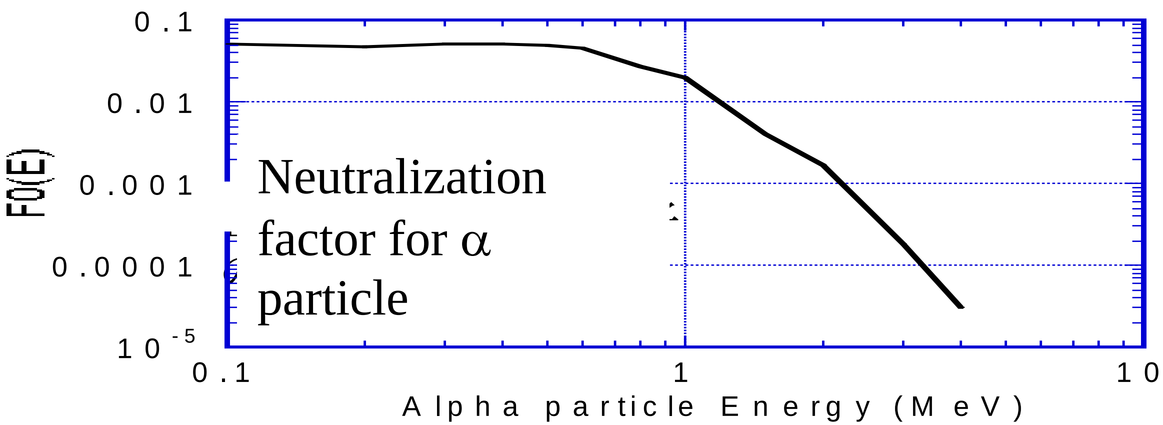
$$H^0 + C^{2+} \to H^+ + C^{1+}$$



Then neutralized particle from the pellet cloud

$$\frac{dn_0}{dx}=\left(n_1(x)\sigma_{1\to0}-n_0(x)\sigma_{0\to1}\right)n_c(x)$$

$$\frac{dn_1}{dx}=\left(n_0(x)\sigma_{0\to1}-n_1(x)\sigma_{1\to0}\right)n_c(x)$$



Effect of the scattered hydrogen in the detector

$$\frac{He(r)}{He(r)+H(r)} \rightarrow \frac{h(r)}{h(r)+H(r)} \approx a$$ (should be 0 but 0.1)

(in Hydrogen plasma)

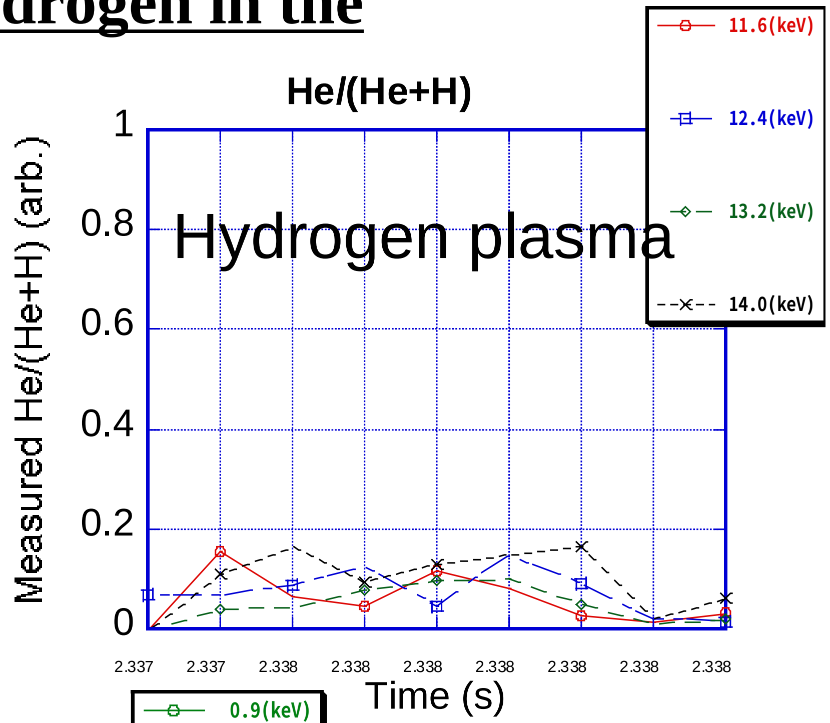
$$\therefore h(r) = \frac{a}{1-a} H(r)$$

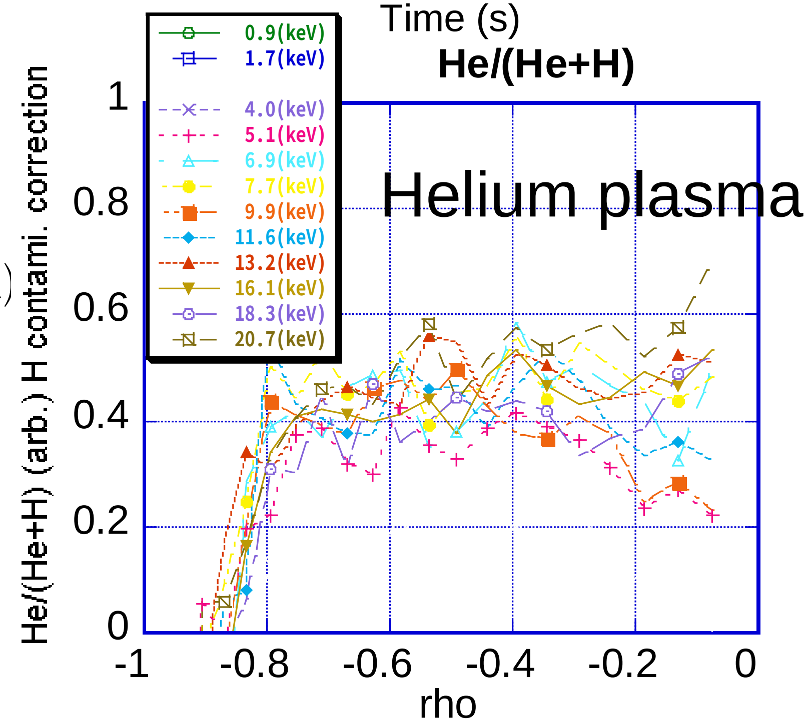
$$f(r) = \frac{He(r)+h(r)}{He(r)+h(r)+H(r)} = \frac{(1-a)He(r)+aH(r)}{(1-a)He(r)+H(r)}$$

$$R = \frac{He(r)/b}{He(r)/b+H(r)} \rightarrow He(r) = \frac{bRH(r)}{1-R}$$

$$\therefore R = \frac{f-a}{(1-a)b-a-(1-a)bf(r)+f(r)}$$

h(r):contribution from hydrogen scattering
a: contribution from hydrogen scattering in experiment (=0.1)
b:Neutralization factor difference in pellet cloud
between He/H (=0.2)





Summary

- The preliminary demonstration of the alpha particle diagnostics using PCX and SD-NPA has been done.

- The high-energy particle flux enhancement around the resonance surface of ICH can be observed in the standard heating mode of ICH 2^{nd} harmonics.

- The helium profile measurement has been tried by using PCX.