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Experimental Study for Energetic Ion Confinement in CHS

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Outline of Talk

1) Motive

2) Experiments :

   a) Characteristics of co-going and trapped beam ion losses from CHS plasmas

      First orbit loss, MHD-induced loss

   b) Confinement of perp. injected-NB ions

      Comparison between standard & inward shifted configuration

3) Summary

Motive

Energetic ions, especially alpha particles are main heating source in nuclear fusion plasmas

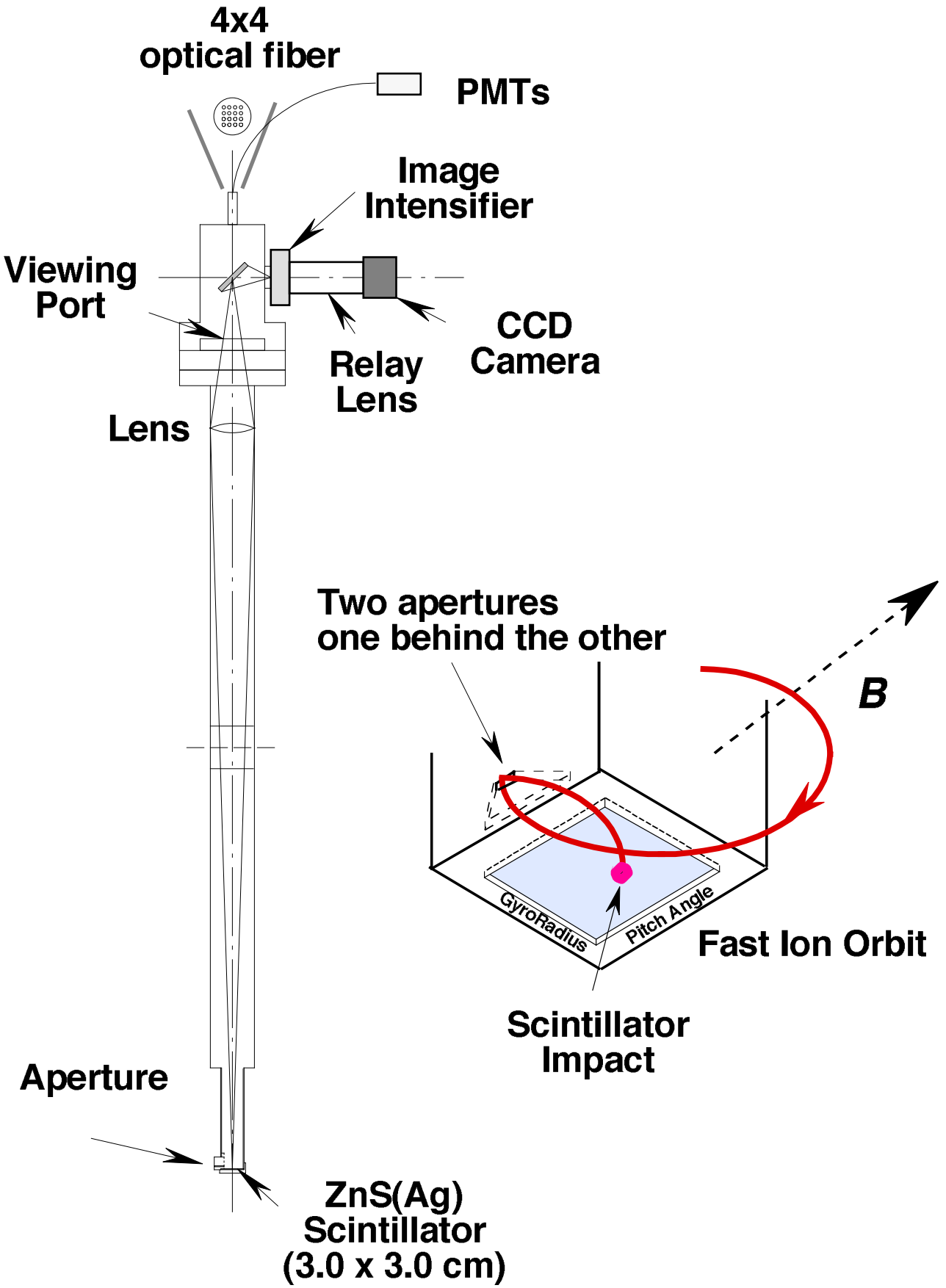
CHS

Non-axisymmetric magnetic field configuration
Enhanced toroidicity due to its low aspect ratio (*R/a*=5)

Loss cone region of energetic particle is thought to be large

Understanding behavior of energetic ions in low aspect ratio helical system CHS

Escaping fast ion probe



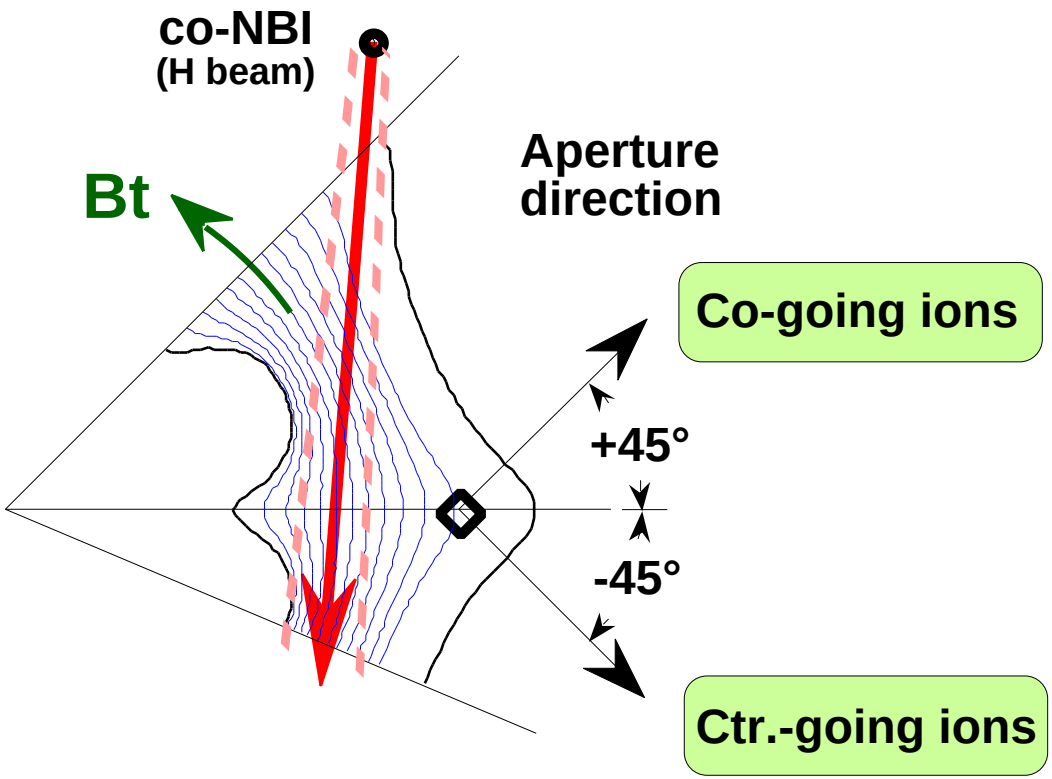
Fast ion loss via classical process

Our interest :

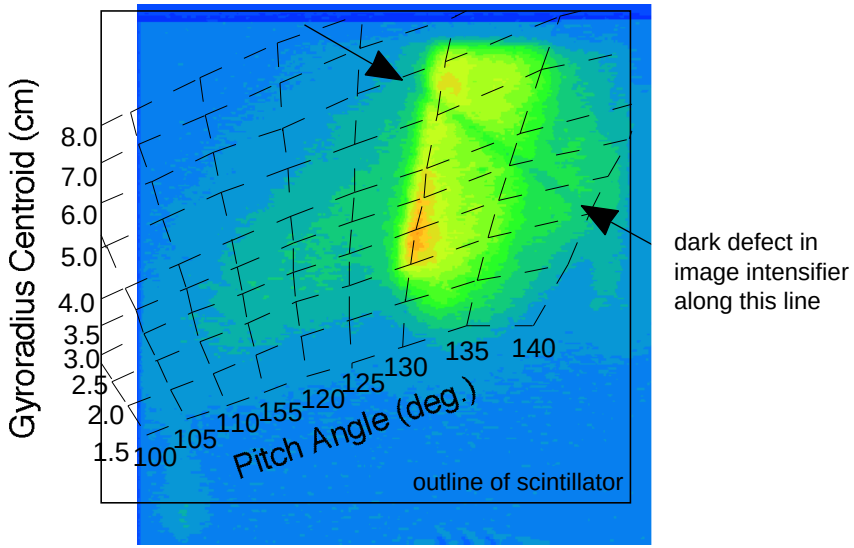
Behavior of coinjected-NB fast ions

Experimental set-up

as seen from the top



Typical 2-D image of scintillation light in aperture angle of +45 degrees



Orbits of escaping fast ion reaching the probe

Aperture : +45 deg.

Energy : 36 keV, H

Pitch angle at probe : 132 deg.

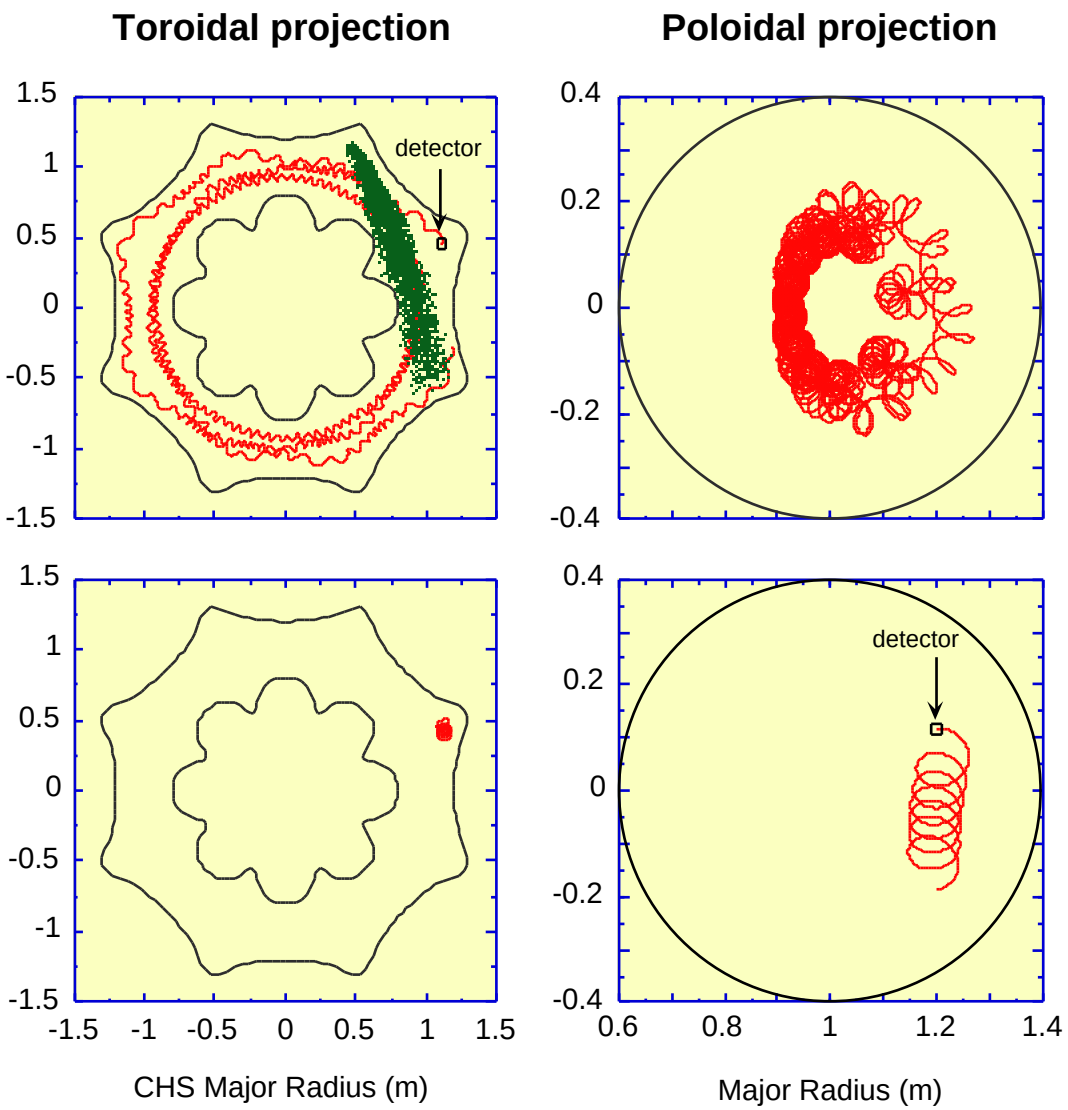
Co.-going barely passing orbit

Aperture : -45 deg.

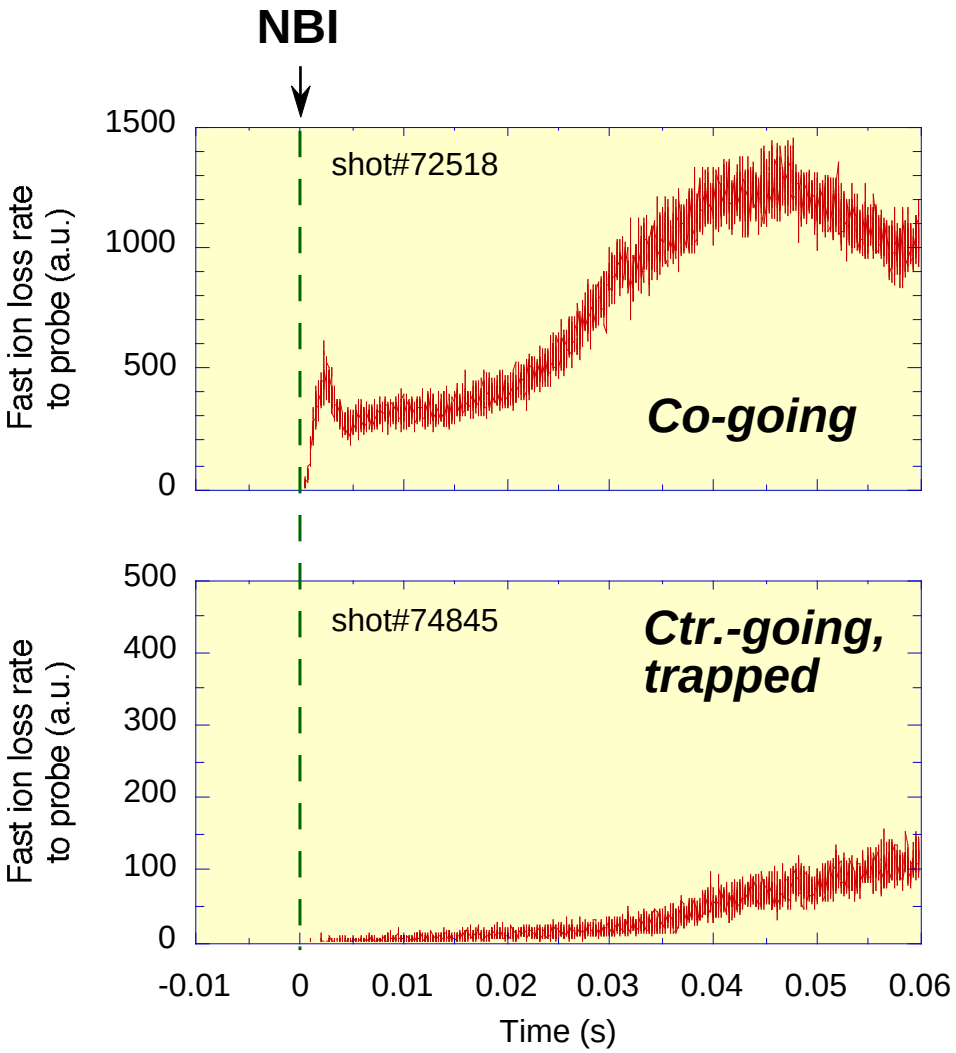
Energy : 36 keV, H

Pitch angle at probe : 81 deg.

Ctr.-going trapped orbit



Time traces of co-going and trapped fast ion loss rate



Time evolution of ctr.-going, trapped fast ions is quit different from that of co-going ions.

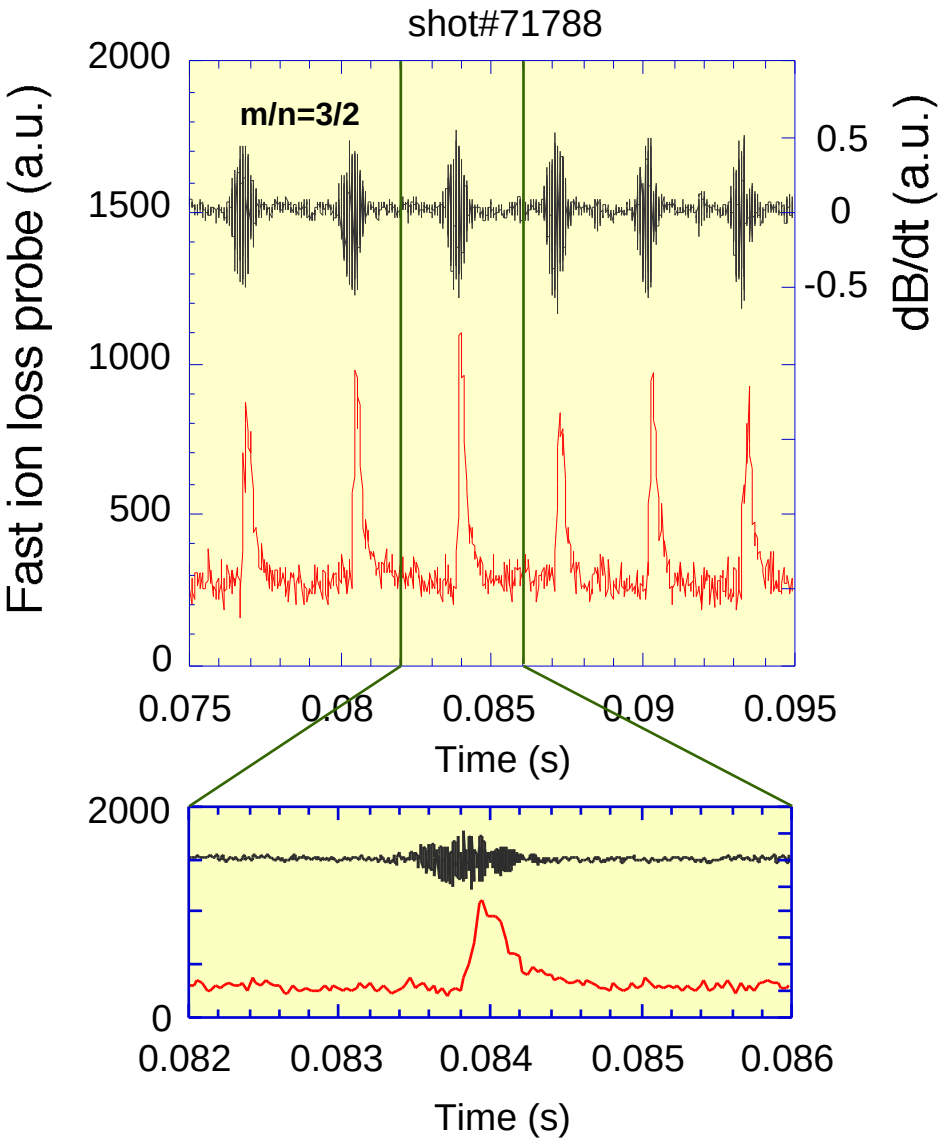
Losses of ctr.-going ions probably arises due to pitch angle scattering.

Features of enhanced beam ion losses while MHD activity occurs

In CHS, periodic recurrence of the fishbone type bursting mode have been observed in coinjected NBI plasmas.

Beam ion loss is enhanced during MHD activity.

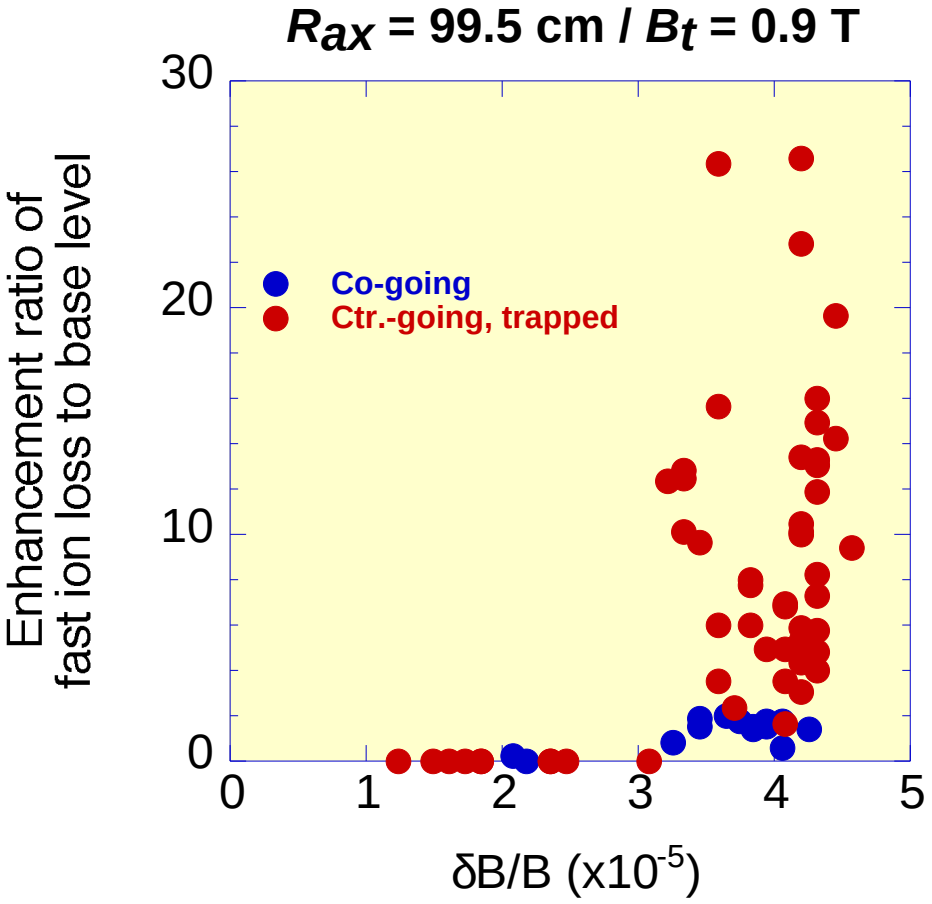
Expulsion of co-going fast ions of ~38 keV



Beam ion loss does not begin until Mirnov coil reaches a maximum.

Mode stabilization occurs after expulsion of fast ions ?

Loss of ctr.-going, trapped fast ions is more enhanced

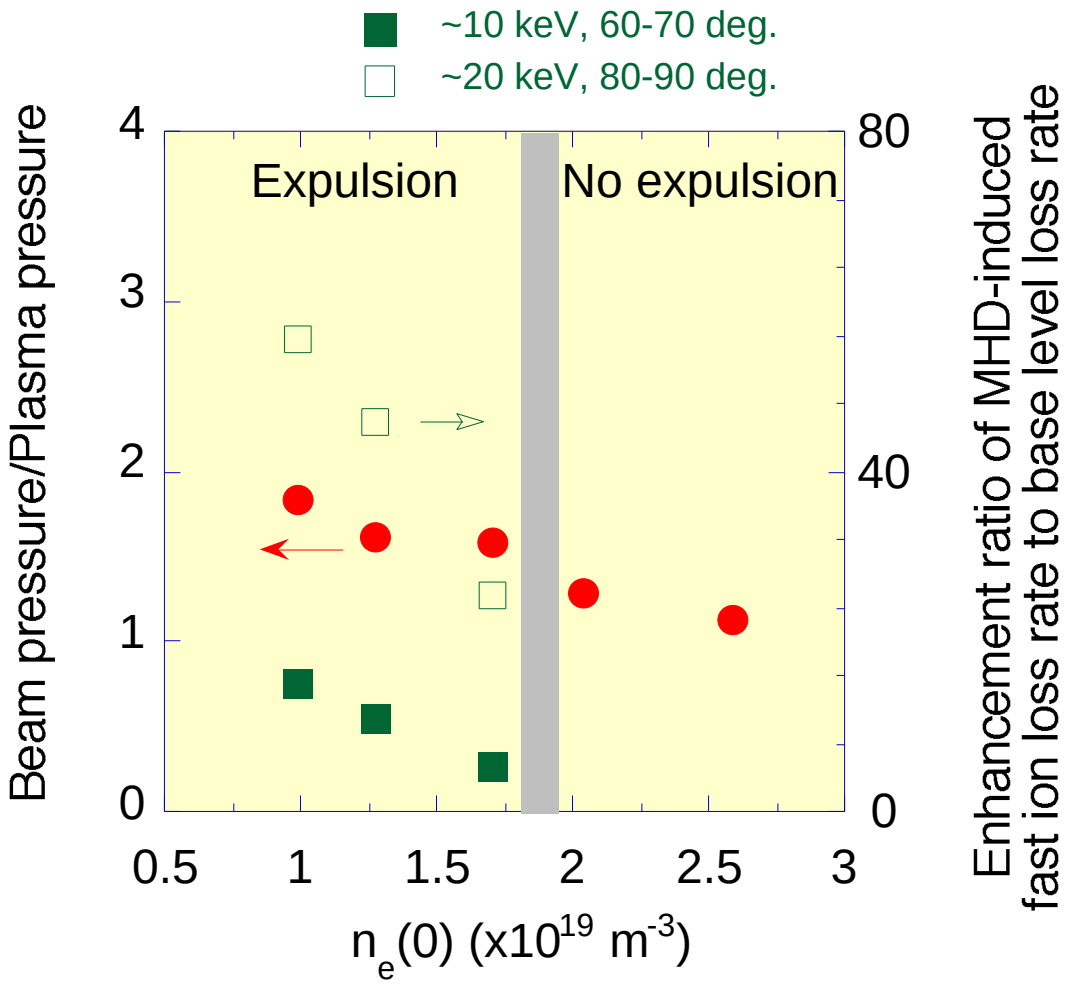


For ctr.-going, trapped ions, slowed down fast ions(~20 keV) are expelled.

There is a threshold in amplitude of fluctuation in expelling fast ions.

MHD-induced fast ion losses increase as n_e decreases

The repetitive nature of the instabilities and resulting expulsion of beam ions suggest that beam beta may play an important role in destabilizing of the instabilities.



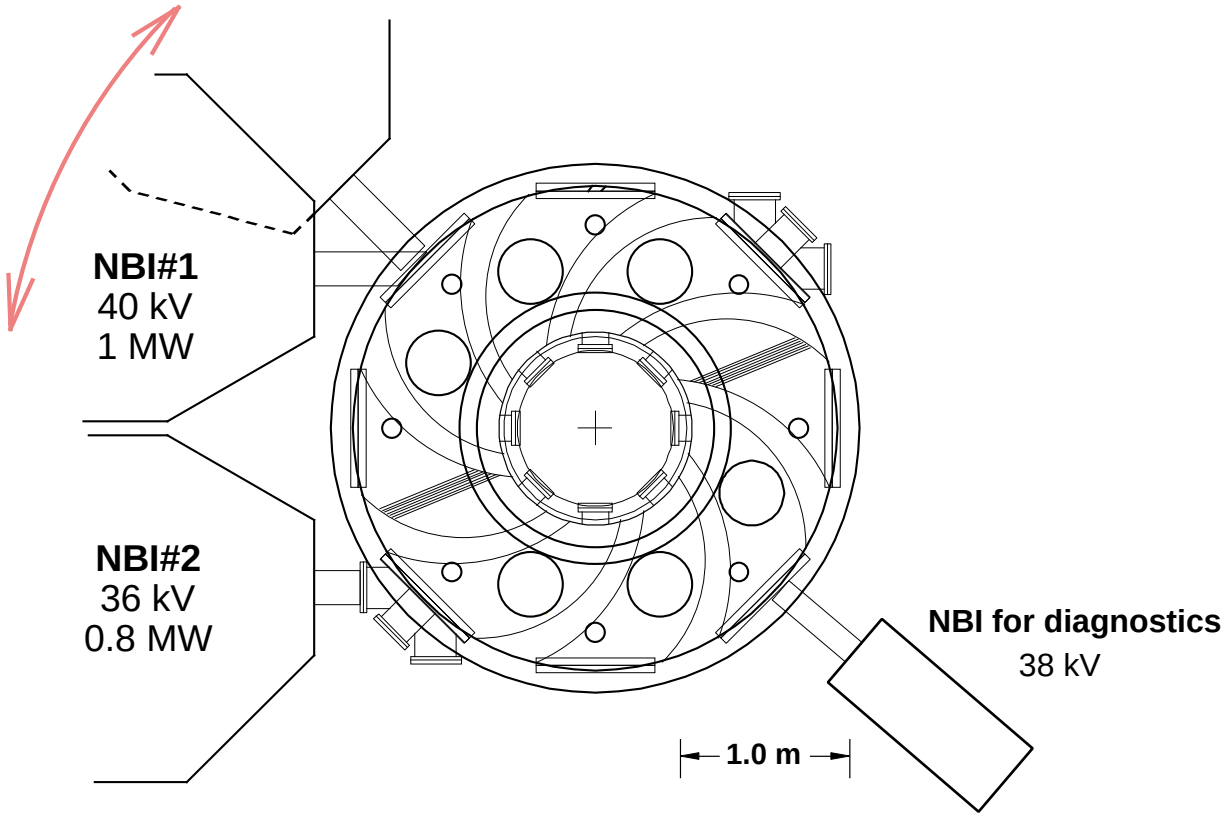
The ratio W_{beam}/W_{plasma} becomes high as n_e decreases. Beam ion loss is enhanced In low n_e plasmas.

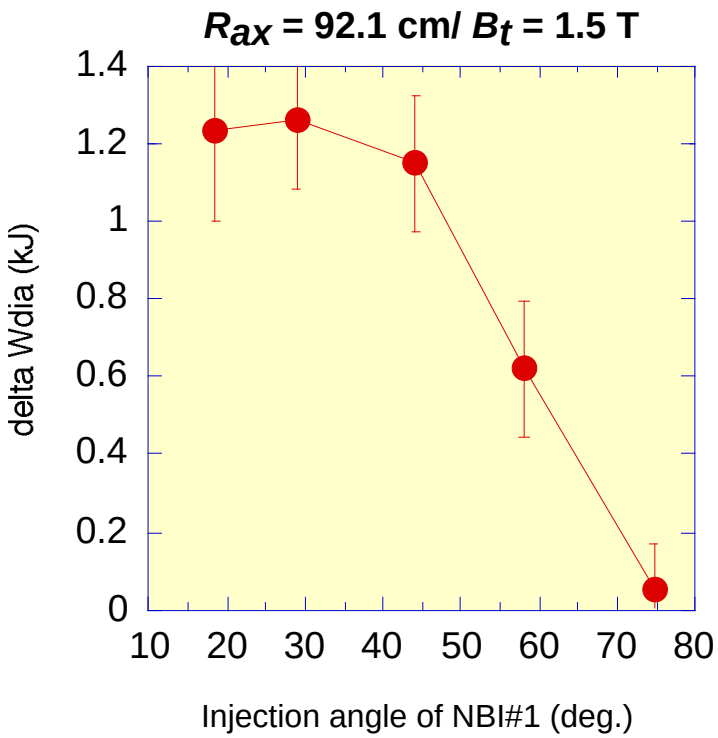
It seems that there exists causal relationship between W_{beam}/W_{plasma} and MHD-induced fast ion loss.

Experiment on confinement property of NB-injected energetic ions in CHS

NBI experiments with variable injection angle

S. Okamura et al., IAEA conf. Würzburg, 1992





poor heating efficiency of perp. NB injection in R_{ax} of 92.1 cm

Experimental methods :

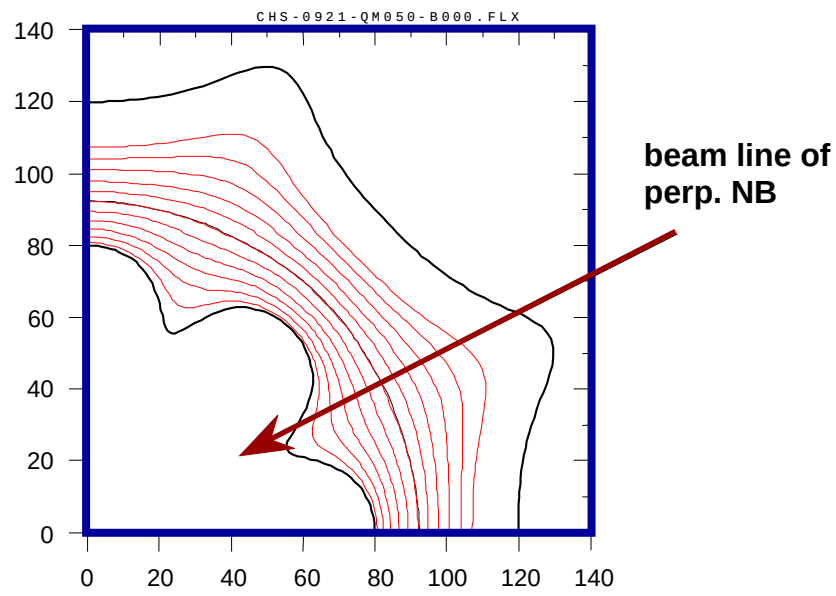
”Blip” perp. D^0 NB injection into D^+ plasmas

Neutrons(d-d) coming from beam-plasma reaction are measured after short pulse of NBI.

This provides information of confinement property of NB-injected fast ions.

Experiments are carried out in standard(R_{ax} of 92.1 cm) & inward-shifted(87.7 cm) configuration.

Top view of CHS plasma & beam line



NB condition ;

D beam
beam energy E_b : 38 keV
pulse width : 2 ms

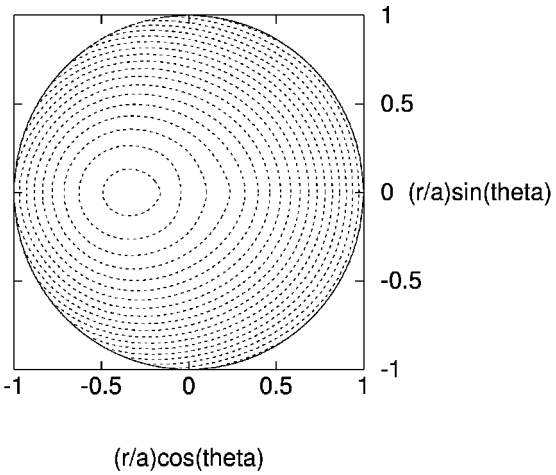
Detector ;

Plastic scintillation neutron detector (10 kHz)

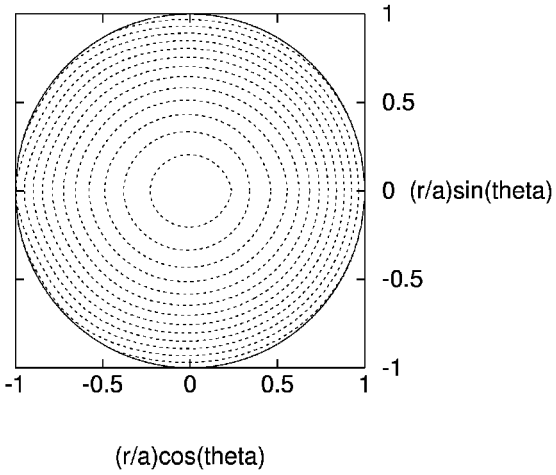
Mod B-min contour plot & confinement domain of perp. injected-NB ions

standard & inward shifted configuration

Standard
R_{ax}=92.1 cm

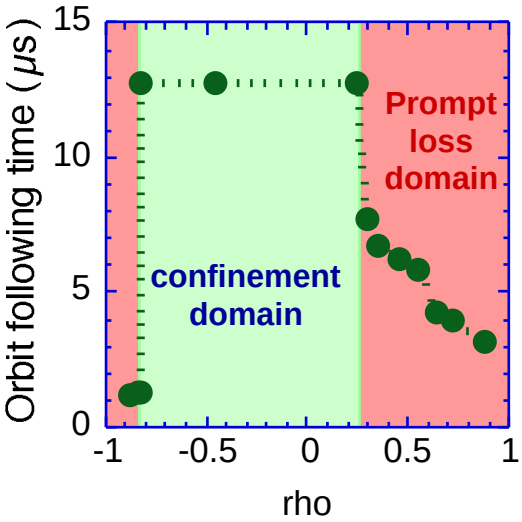


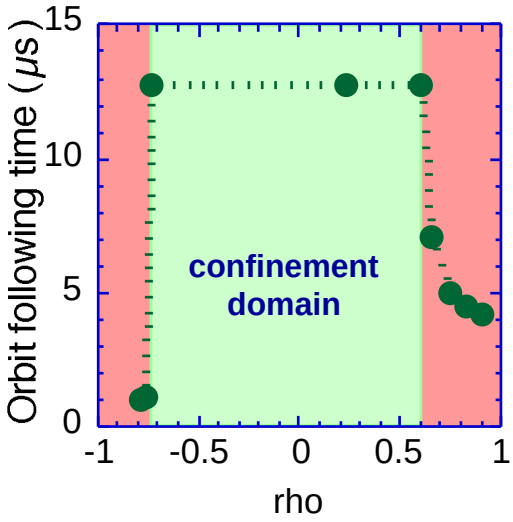
Inward shifted
R_{ax}=87.7 cm



Confinement domain of perp. injected NB ions along the beam line

D+, 38 keV





Standard

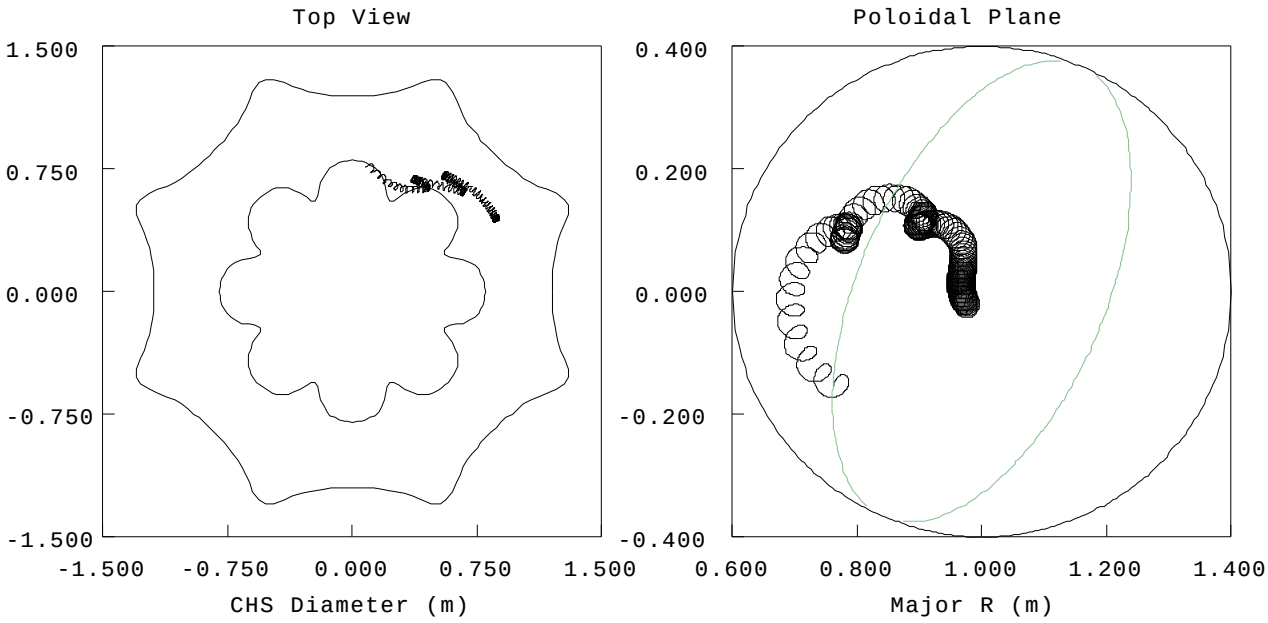
D+ 38 keV

start point : rho = +0.30

FAST ION HITS !! 9668

B0(T) = 1.760
Rax(m)= 0.921

CHS LORENTZ ORBIT



STEP(s) = 0.8000D-09
R0 (m) = 0.9756
VX0(m/s)= -0.1700D+07
ENERGY(eV)= 0.3794D+05
PITCH(deg)= 88.041
Er (V/m) = 0.0000D+00

T_ANGLE =26.900
VY0(m/s)= -0.8625D+06
H(1) or D(2)= 2.000

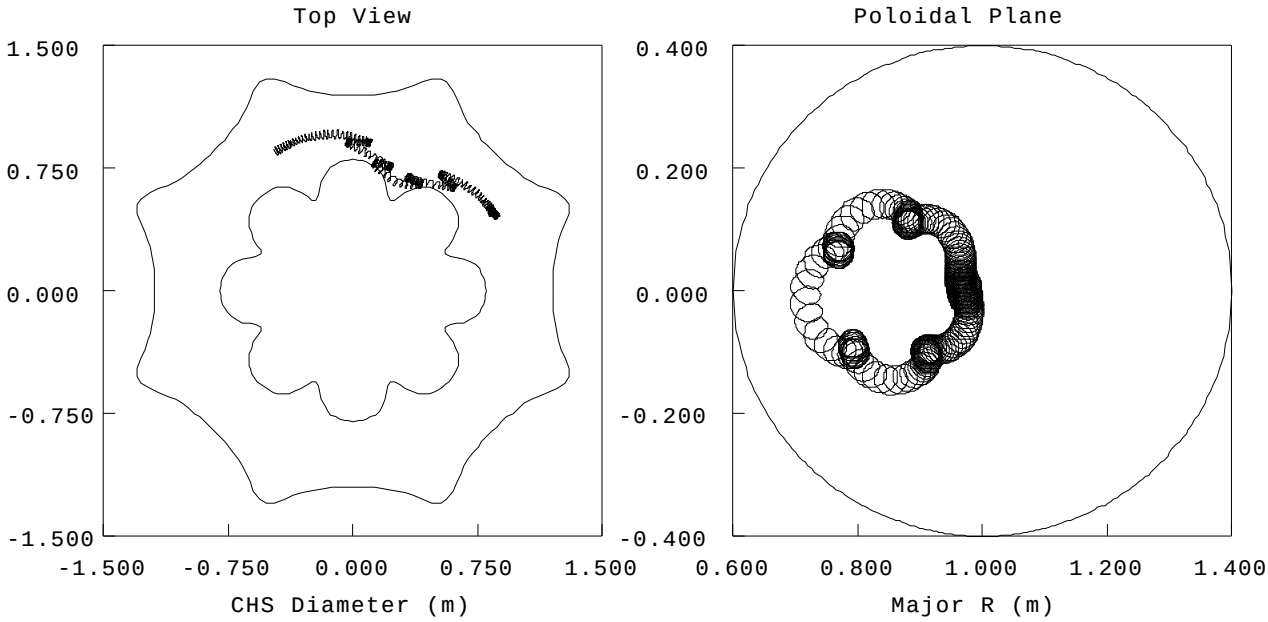
Z0 (m) = 0.000
VZ0(m/s)= 0.0000D+00

Inward shifted

start point : rho = +0.61

B0(T) = 1.620
Rax(m)= 0.877

CHS LORENTZ ORBIT



STEP(s) = 0.8000D-09
R0 (m) = 0.9756
VX0(m/s)= -0.1700D+07
ENERGY(eV)= 0.3794D+05
PITCH(deg)= 88.042
Er (V/m) = 0.0000D+00

T_ANGLE =26.900
VY0(m/s)= -0.8625D+06
H(1) or D(2)= 2.000

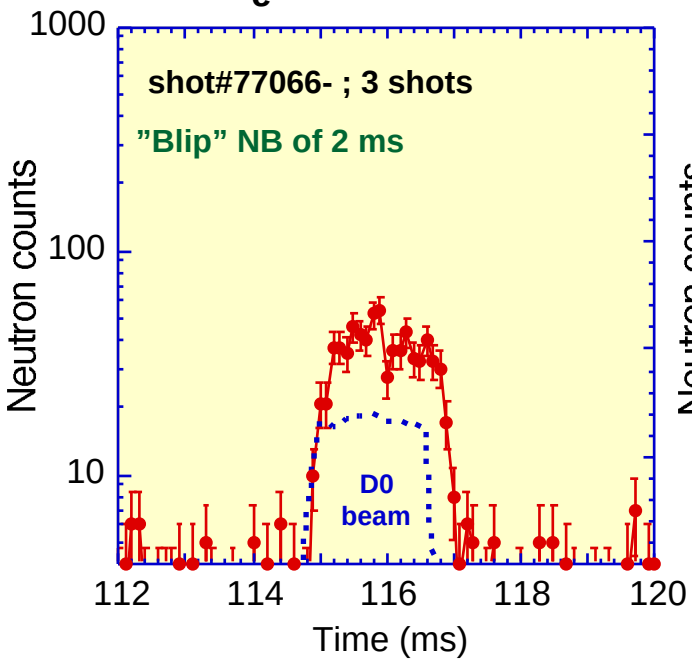
Z0 (m) = 0.000
VZ0(m/s)= 0.0000D+00

Time traces of neutron emission rate time trace & n_e dependence

Standard

R_{ax} = 92.1 cm, B_t = 1.76 T

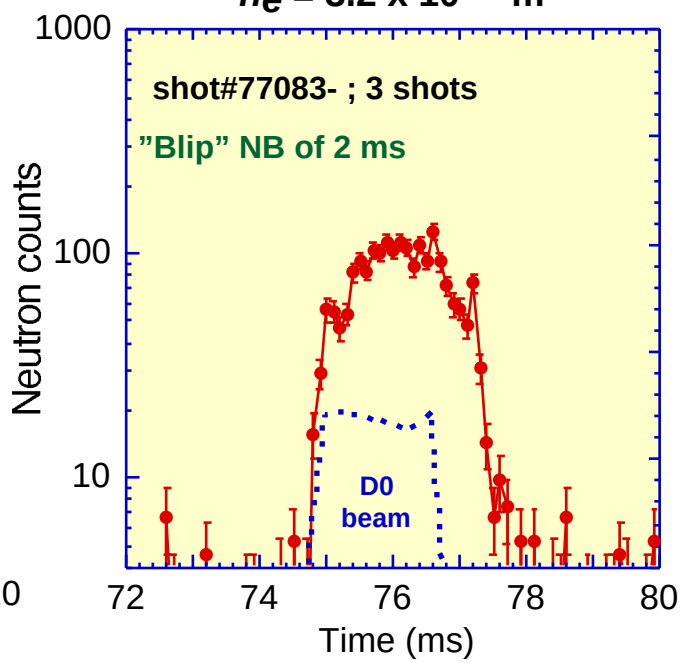
n_e = 3.3 x 10^{19} m^{-3}



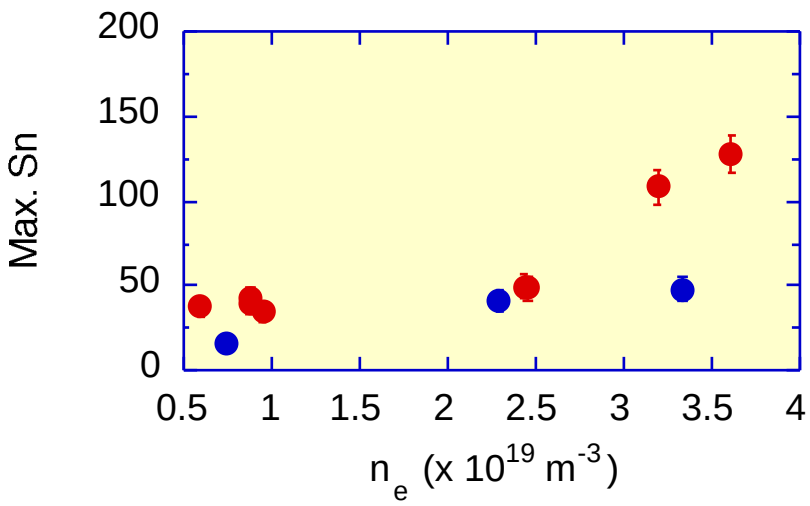
Inward shifted

R_{ax} = 87.7 cm, B_t = 1.62 T

n_e = 3.2 x 10^{19} m^{-3}

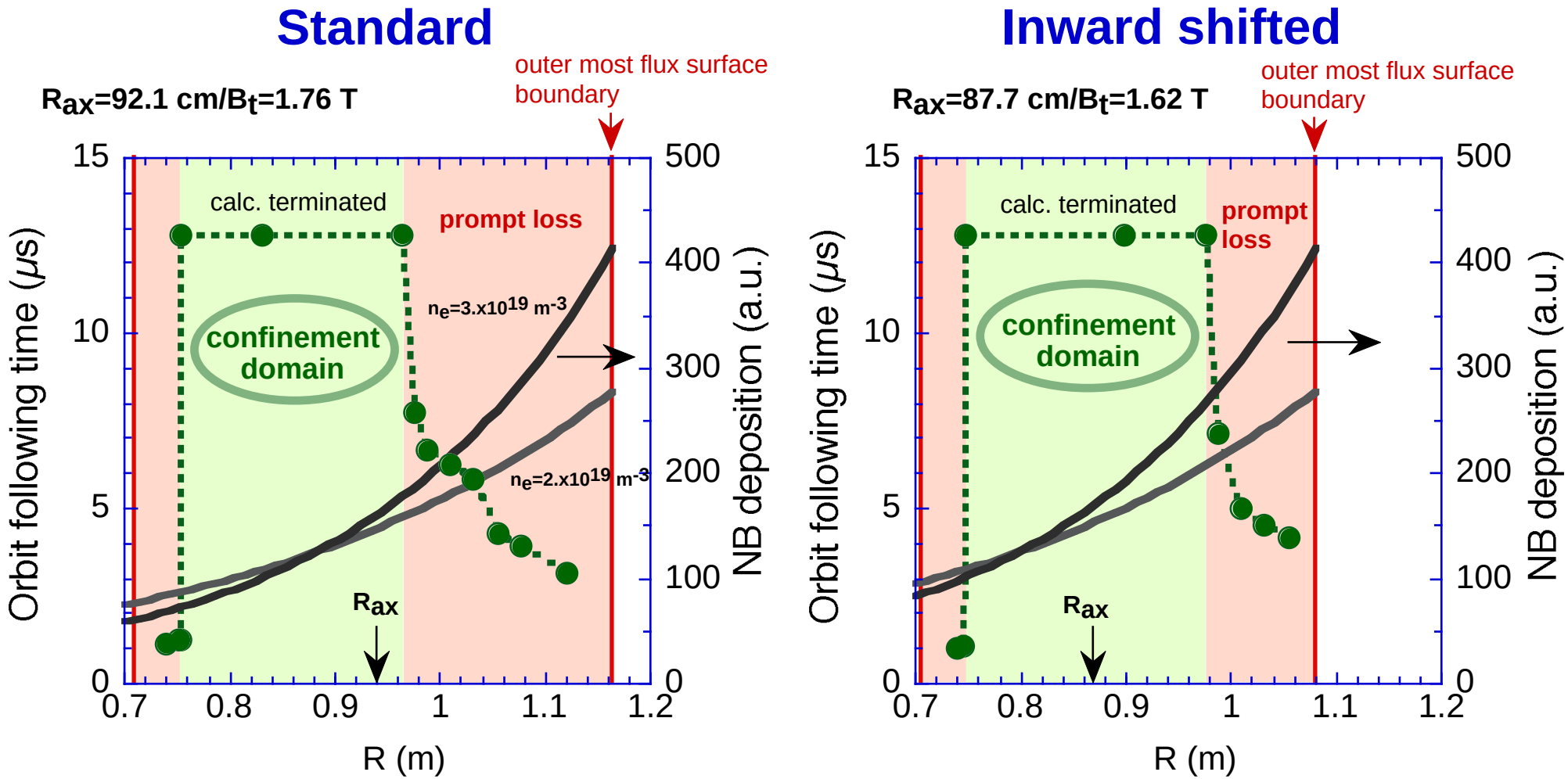


Higher neutron yield in the inward shifted plasma



In the inward shifted plasma,
the neutron emission rate is more enhanced as n_e increses.

Confinement domain and perp. injected-NB deposition in standard & inward shifted plasmas



In the inward shifted plasma, beam deposition in the confinment domain is larger than that in the plasma with standard configuration.

Beam deposition in the inward shifted plasma is more increased as n_e increses.

Summary

Beam ion loss has been measured with a scintillator-based escaping fast ion probe on CHS.

Barely passing, transition and trapped fast ion can be detected. Loss signals are reasonably explained by classical model.

MHD-induced fast ion losses are clearly observed. Initial analysis suggests that there is causal relationship between W_{beam} and MHD-induced fast ion loss.

Experiment on confinement of perp. injected-NB ions was carried out in standard(R_{ax} of 92.1 cm) & inward shifted(R_{ax} of 87.7 cm) configuration.

Neutron emission rate S_n in R_{ax} of 87.7 cm is higher than that in R_{ax} of 92.1 cm. This suggests larger beam deposition and/or better beam confinement in R_{ax} of 87.7 cm.

The slightly longer neutron decay time after NB turn-off in R_{ax} of 87.7 cm is supposed to be due to better beam confinement compared with that in R_{ax} of 92.1 cm.