



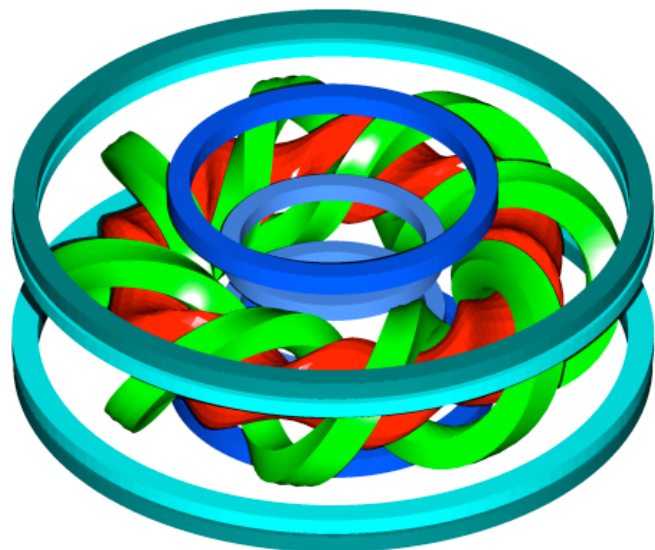
第7回若手科学者によるプラズマ研究会  
平成16年3月17日-19日 日本原子力研究所那珂研究所

# CHSにおいて観測される 高速イオン損失

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# コンパクトヘリカルシステム (CHS)



## ○装置

- ・  $m=8/l=2$  の低  $A_p$  ( $\sim 5$ ) ヘリカルプラズマ
- ・  $R=1\text{m}/a=0.2/B_t=2\text{T}$

## ○加熱

- ・ NBI  $\times 2$   $P_{nb}=1.5\text{MW}$
- ・ ECRH  $\times 2$   $P_{ec}=0.3\text{MW}$

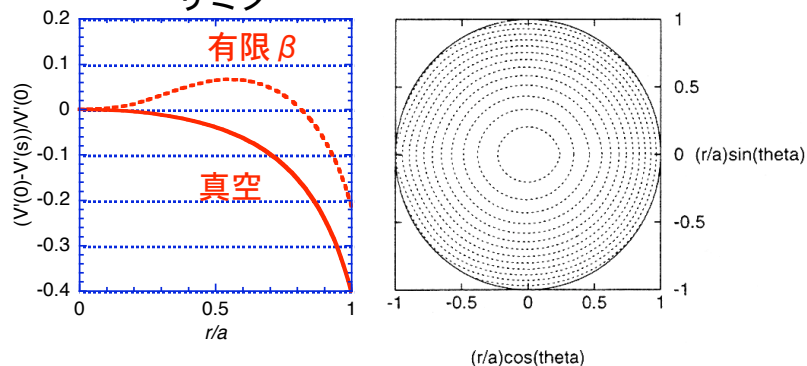
## ○パラメータ

- ・  $\langle \beta \rangle = 2.1\%$
- ・  $T_e(0) = \sim 4\text{ keV} / T_i(0) = \sim 1\text{ keV}$

## 磁場配位の特徴

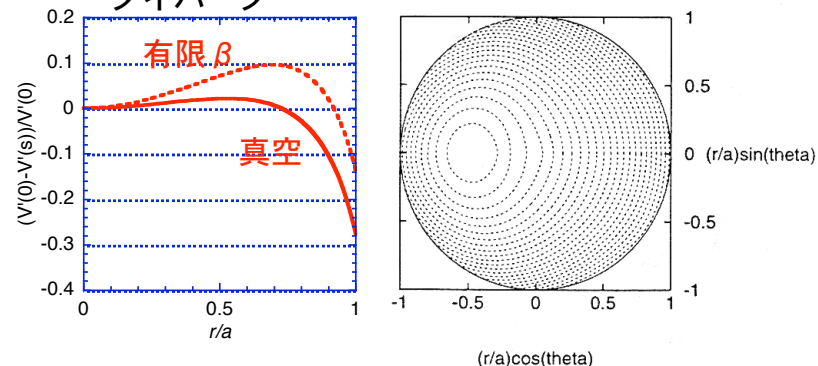
### 内寄せ

- ・ 真空にて全域磁気丘
- ・ Mod- $B_{\min}$  等高線が磁気面に沿う
- ・ リミター



### 外寄せ

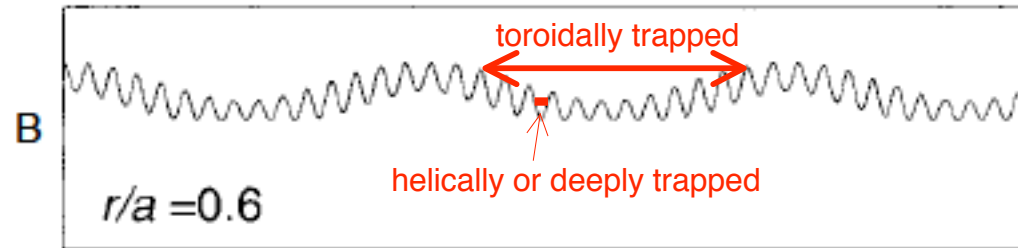
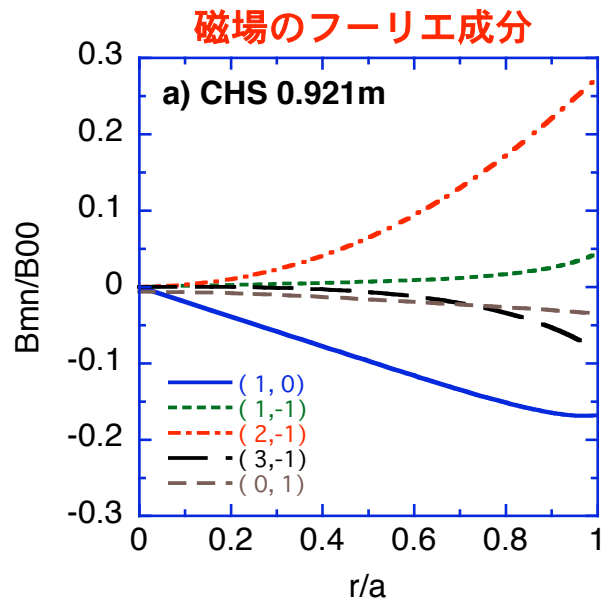
- ・ 真空にて中心部は磁気井戸、周辺部は丘
- ・ Mod- $B_{\min}$  等高線が磁気面からずれる
- ・ ダイバータ





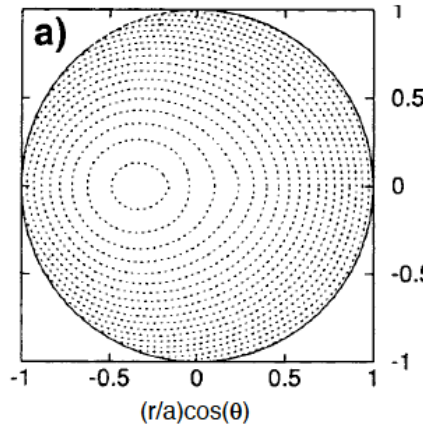
# CHSタイプの磁場配位にて高速イオン閉じ込めが何故問題となるのか？

CHSタイプの磁場配位は、磁場構造に対称性を欠いているが故、粒子軌道の問題は常に議論の対象となっている。



trapping/detrappingを繰り返す遷移粒子の存在

⇒ 径方向への拡散を助長



Mod- $B_{\min}$  等高線が  
磁気面から偏差

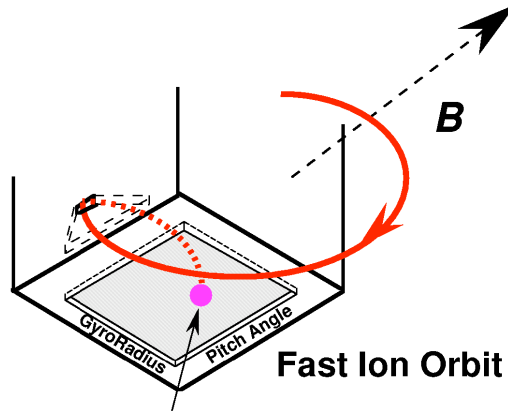


ヘリカル捕捉粒子の軌道  
が磁気面からずれる

⇒ ロスコーン

内寄せにすることで改善可能

# 実験における配置



- ・シンチレータに基づく高速イオンプローブを2台使用  
⇒ 損失高速イオンの空間分布を把握したい。
- ・損失高速イオンのピッチ角とエネルギーの同時測定が可能

Scintillator  
Impact

NB#1  
(Co-)

計測ビーム  
(from Perp.  
to Counter-)

NB#2  
(Co-)

## 1st probe(1997-)

detectes passing ions deviating largely from flux surfaces.

- ・ D.S.Darrow *et al.*, J. Plasma Fusion Res. SERIES1(1998)362.
- ・ M.Isobe *et al.*, Rev. Sci. Instrum. 70(1999)827.

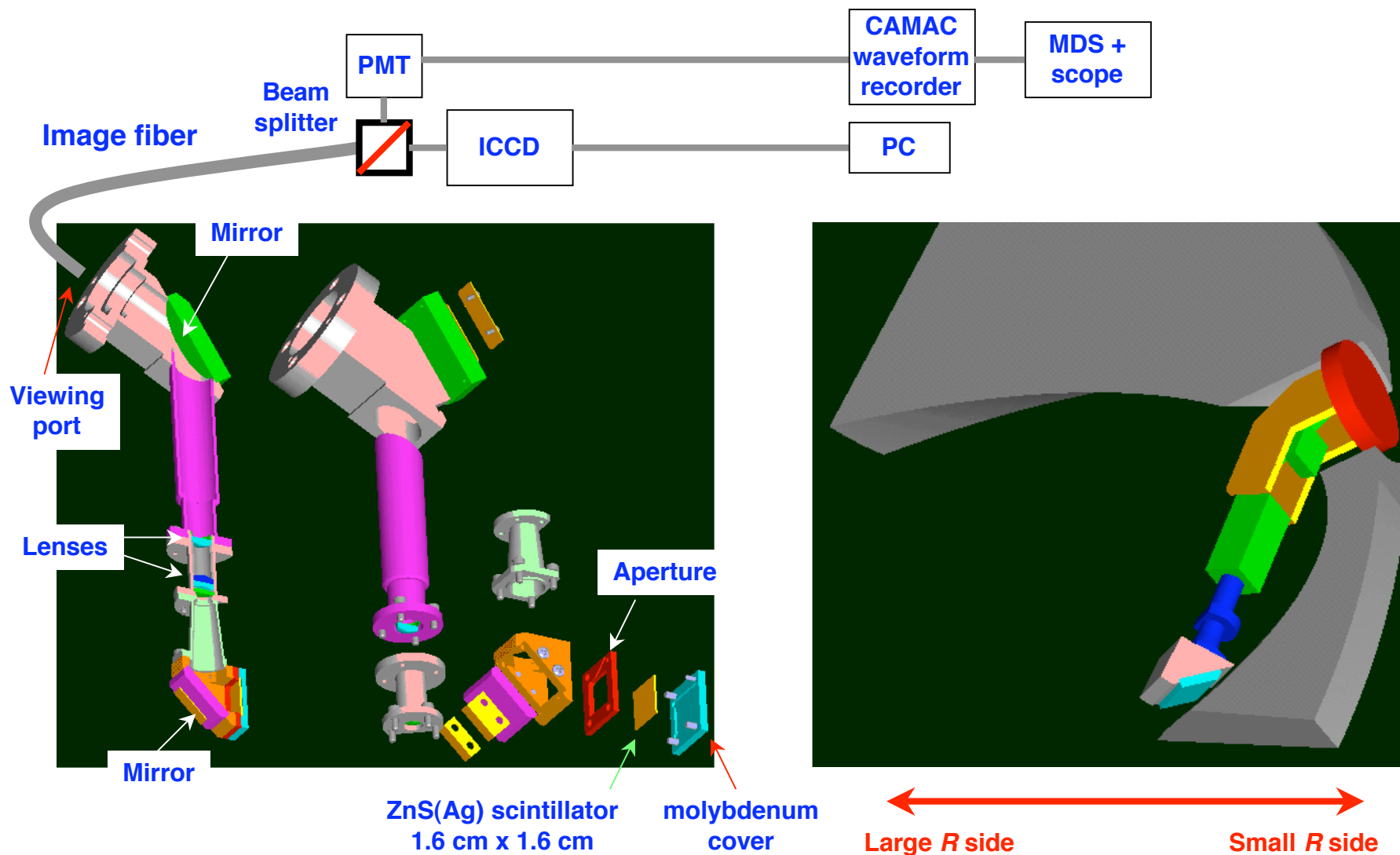
## New, 2nd probe

detectes unconfined helically trapped and counter-going barely passing fast ions.

- ・ M.Isobe *et al.*, Rev. Sci. Instrum. 74(2003)1739.



# 大半径方向内側設置の 高速イオンプローブの分解図

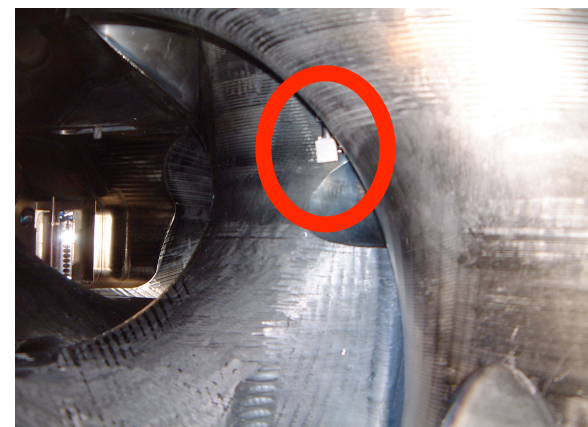


# 真空容器内における高速イオンプローブ

## 外側プローブ



## 内側プローブ



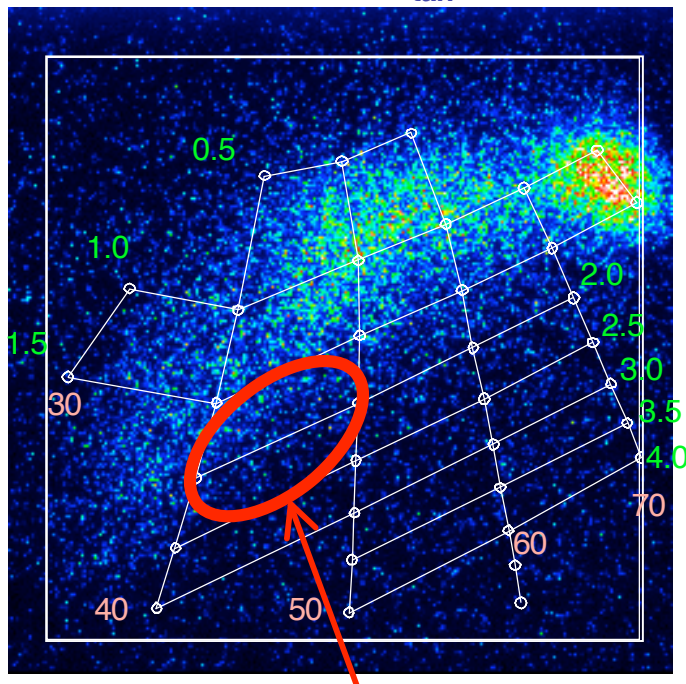


# NBを接線方向にco-入射した際に観測される内側への高速イオン損失

shot#104181

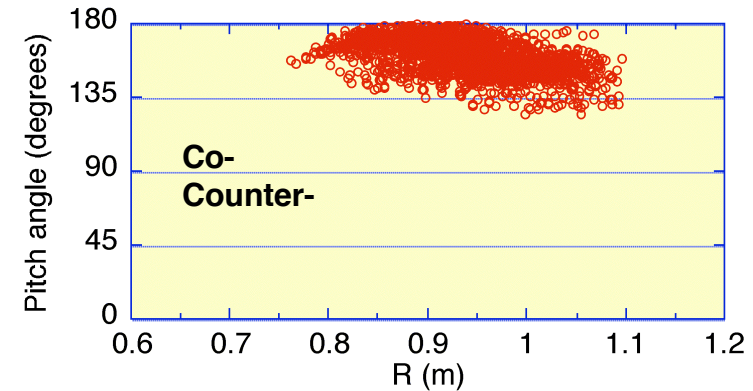
$R_{ax}/B_T=0.921\text{m}/1.76\text{T}$

NBI#1 (38keV),  $R_{tan}=0.87\text{m}$



Primary loss spot  
at DNB XP

電離位置での初期ピッチ角分布

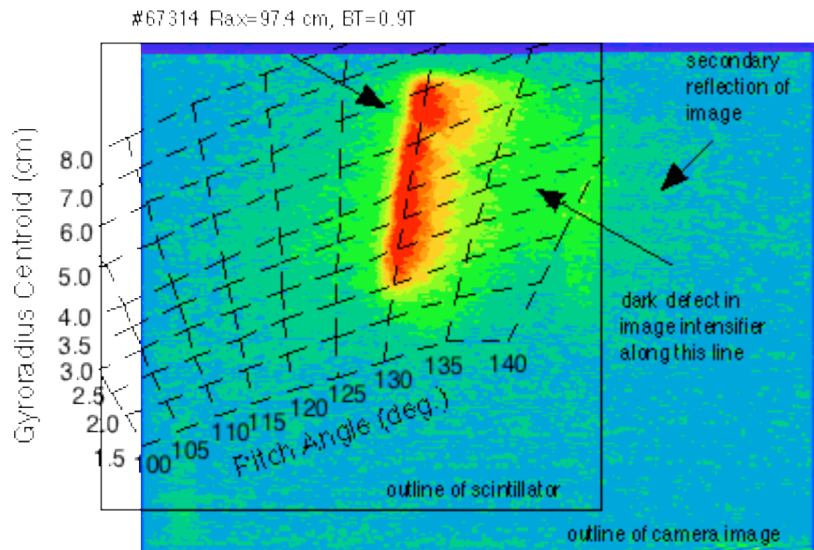
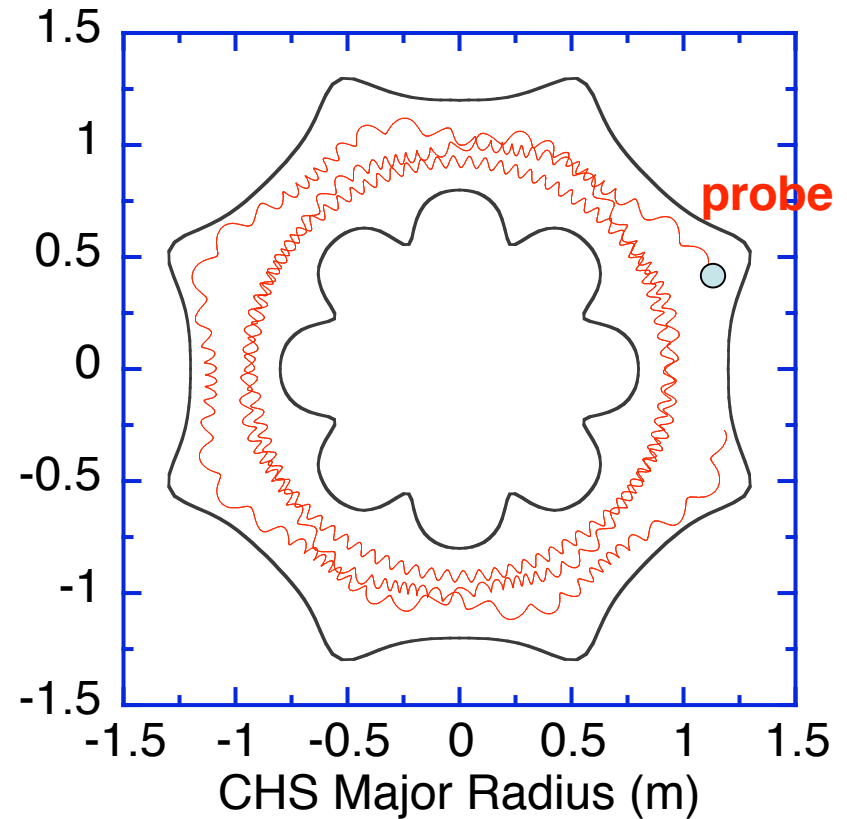
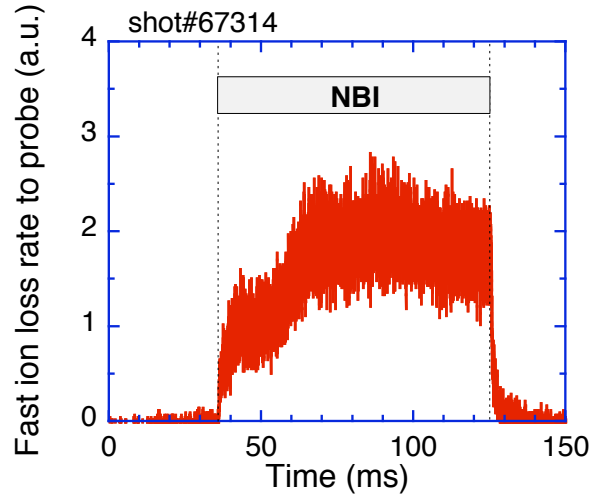


Observed bright spot must be due to  
1. partially thermalized  
2. pitch angle-scattered  
helically trapped escaping fast ions.

- Bright spot appears at pitch of  $\sim 80$  degrees and gyroradius centroid of  $\sim 1.0 - 1.5$  cm, corresponding to 10 - 25 keV H<sup>+</sup> ions.



# NBを接線方向にco-入射した際に観測される外側への高速イオン損失

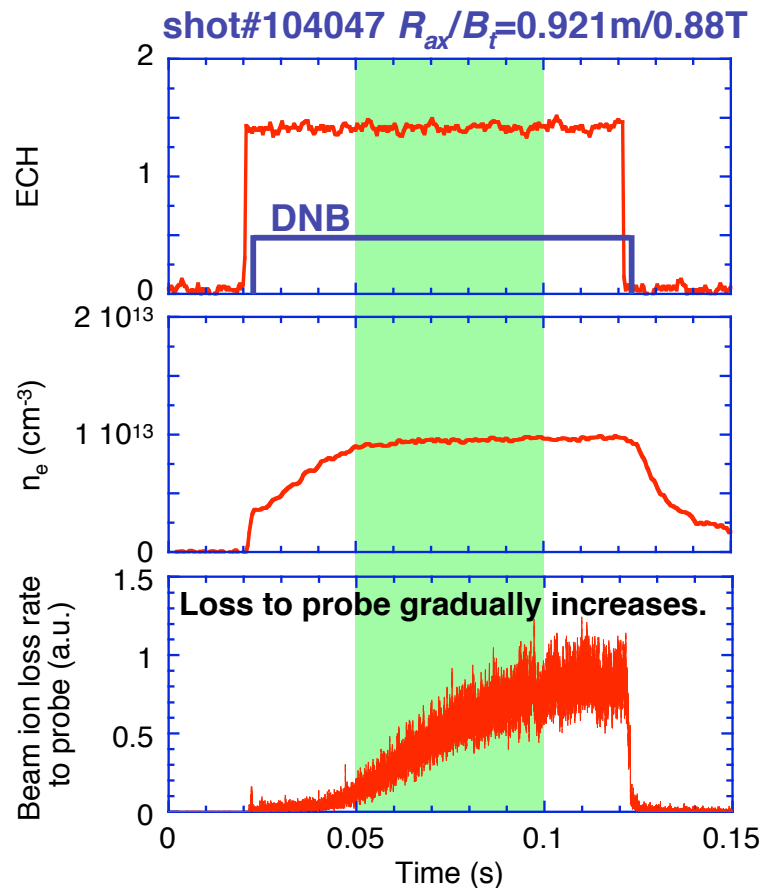


**Barely passing beam ion deviating significantly from magnetic flux surfaces are detected.**

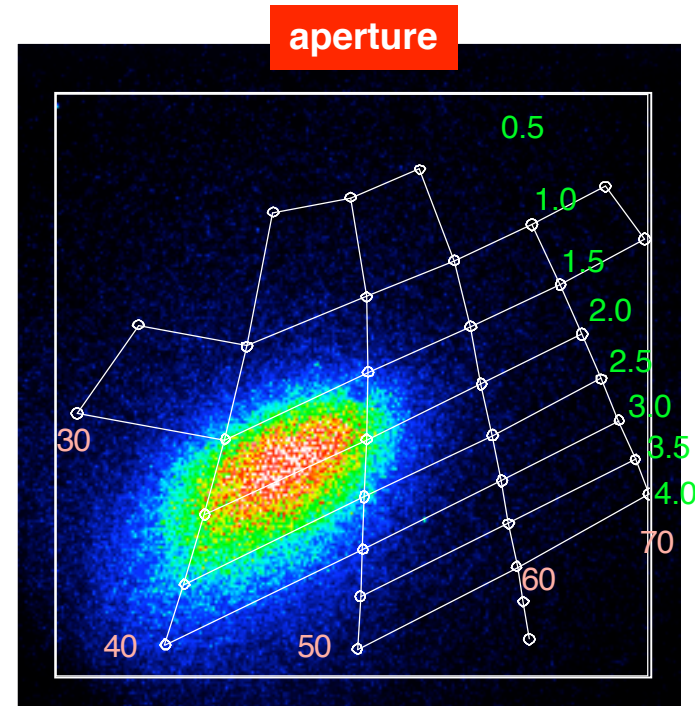
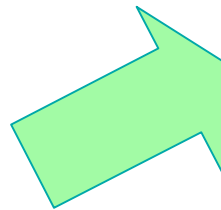


# 計測ビームを接線方向にcounter-入射した際の内側への高速イオン損失

- **DNB is counter-injected** into ECRH target plasma.
- **No significant effect of DNB on global parameters** such as  $n_e$  and  $T_e$ .
- **Localized bright spot** appears on the scintillator screen during DNB injection.
- **No signals are seen in ECRH plasmas** without DNB.



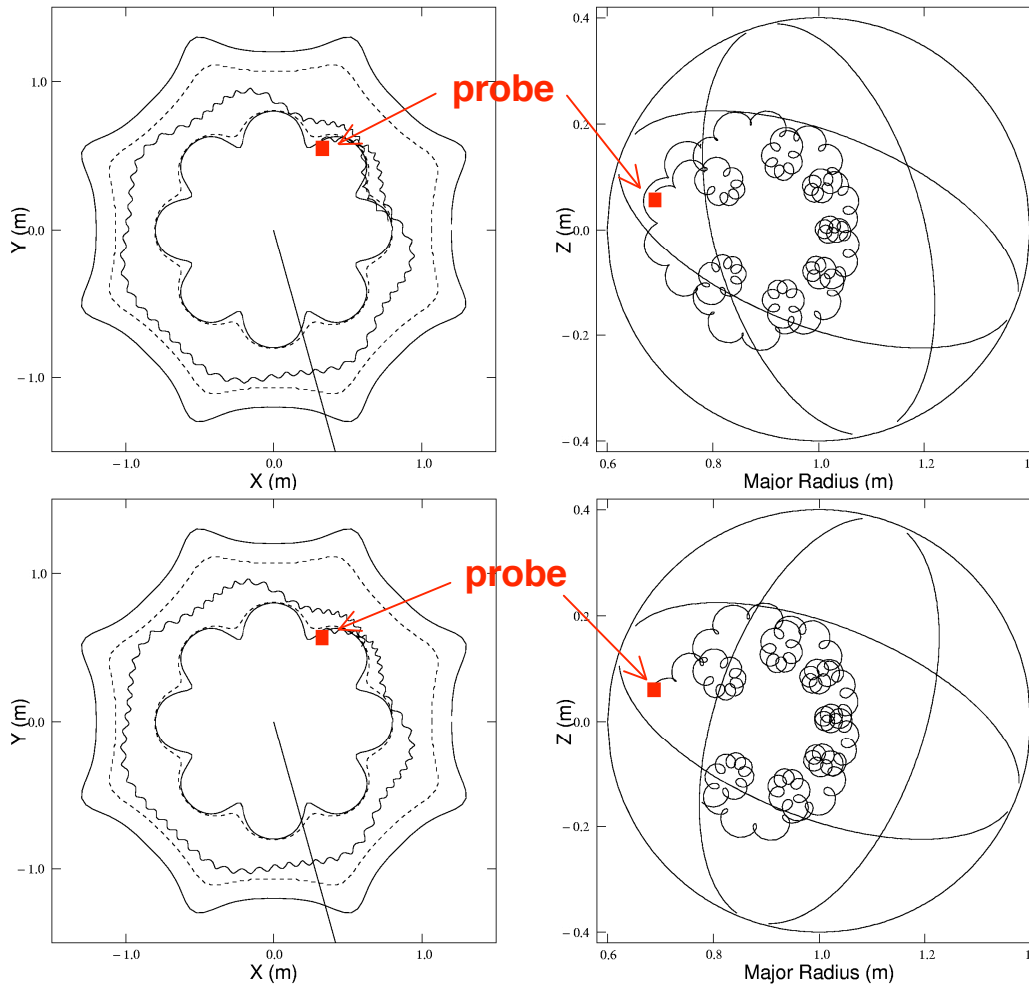
DNB  
 $R_{tan} = 0.67\text{m}$   
 $E_b = 27\text{-}28\text{kV}$   
 IBI = 1.56 T  
 at probe



- Peak loss is at  $\sim 1.6 - 2.3$  cm gyroradius, corresponding to energy of 10 - 15 keV.
- Gradually increasing loss suggests that the bright spot is due to slowed down, pitch angle-scattered ions?



# 計測ビーム入射時に観測される 損失高速イオンの軌道



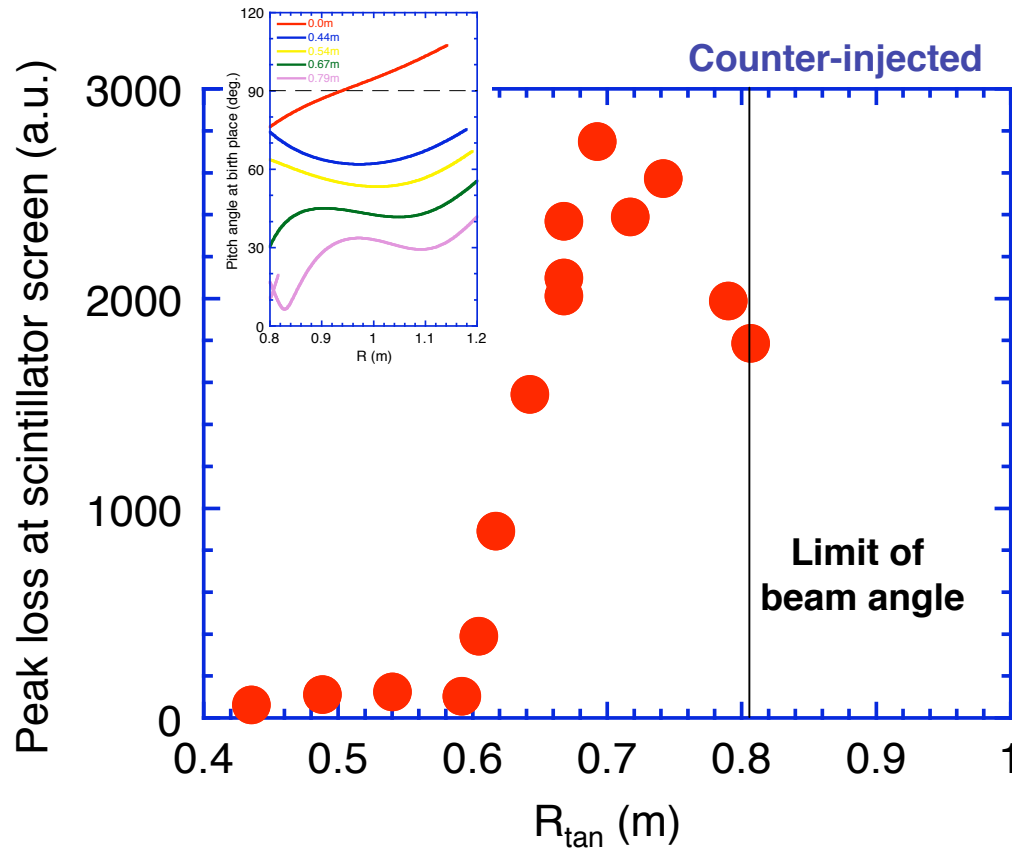
Pitch angle at probe  
~41 degrees

Pitch angle at probe  
~45 degrees

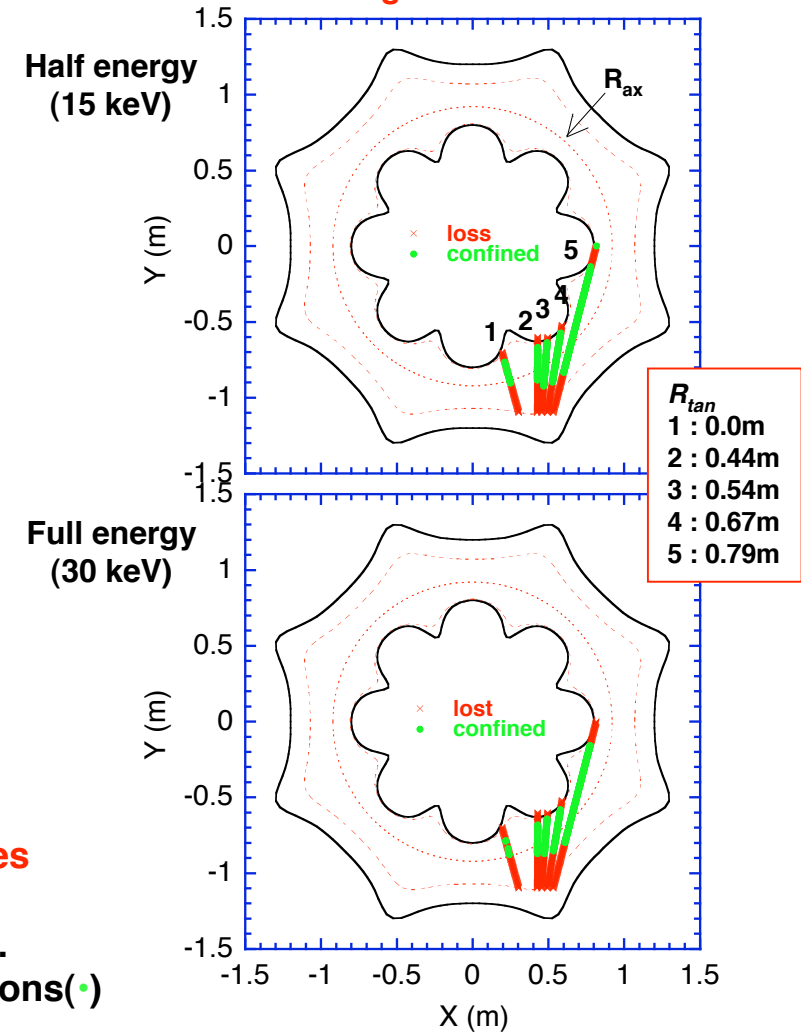
**Barely counter-going transit fast ion**



# Loss rate to small $R$ side probe depends on DNB injection angle



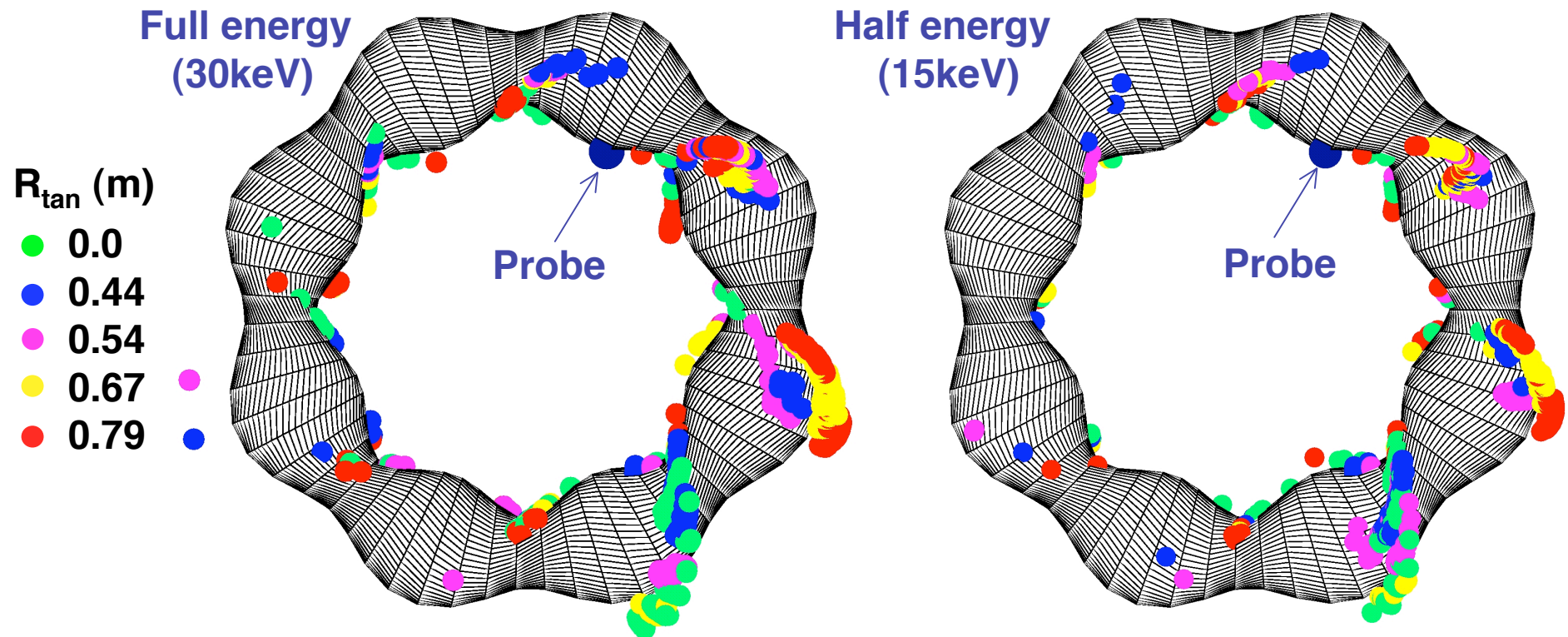
Calculated confinement/prompt loss domain along the beam line



- Pitch angle of escaping ions is always around 40 - 50 degrees at probe position irrespective of  $R_{tan}$ .
- Beam ion loss intensity rapidly increases from  $R_{tan}$  of  $\sim 0.6$ m.
- The calculation indicates that initial orbit of confined beam ions(•) is transit.

# 真空容器壁上における 即発損失高速イオンの空間分布

- Collisionless beam ion orbits including finite Larmor radius are followed.
- Beam ions (200-500 particles) are launched along the center of beam line.

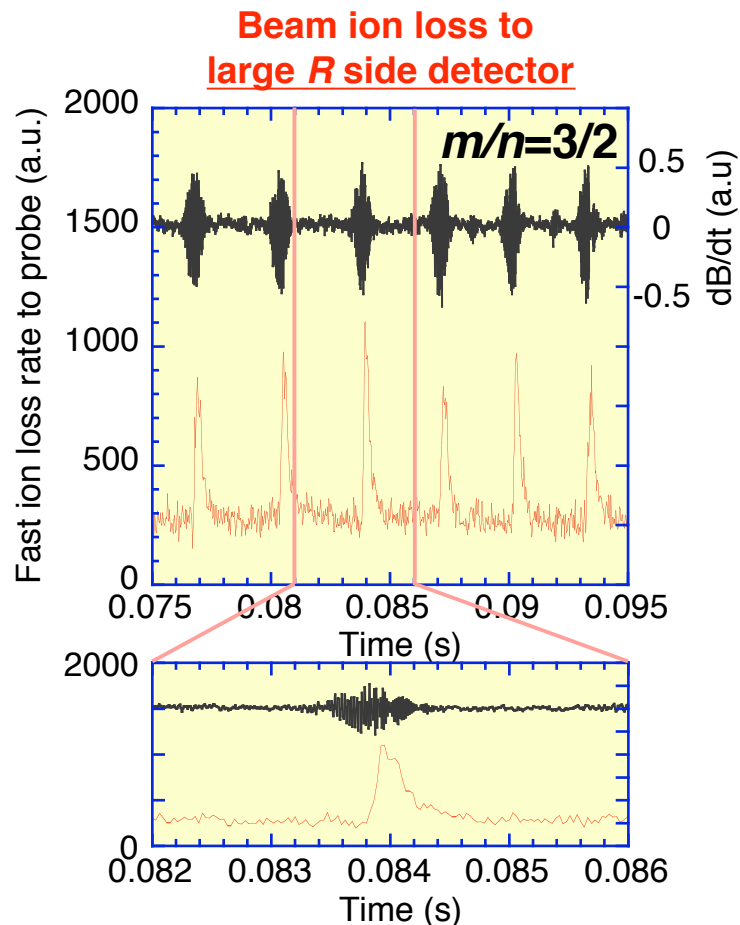


First orbit loss ions reaching the probe directly have not been found yet.



# Fishbone type mode enhances beam ion loss to large $R$ side

- In CHS, periodic recurrence of the fishbone(FB) type bursting mode have been observed in co-injected NBI plasmas at  $B_t$  of 0.95T.
- Beam ion loss to large  $R$  side are periodically enhanced while MHD activities occur and coincides with the timing of fluctuation.



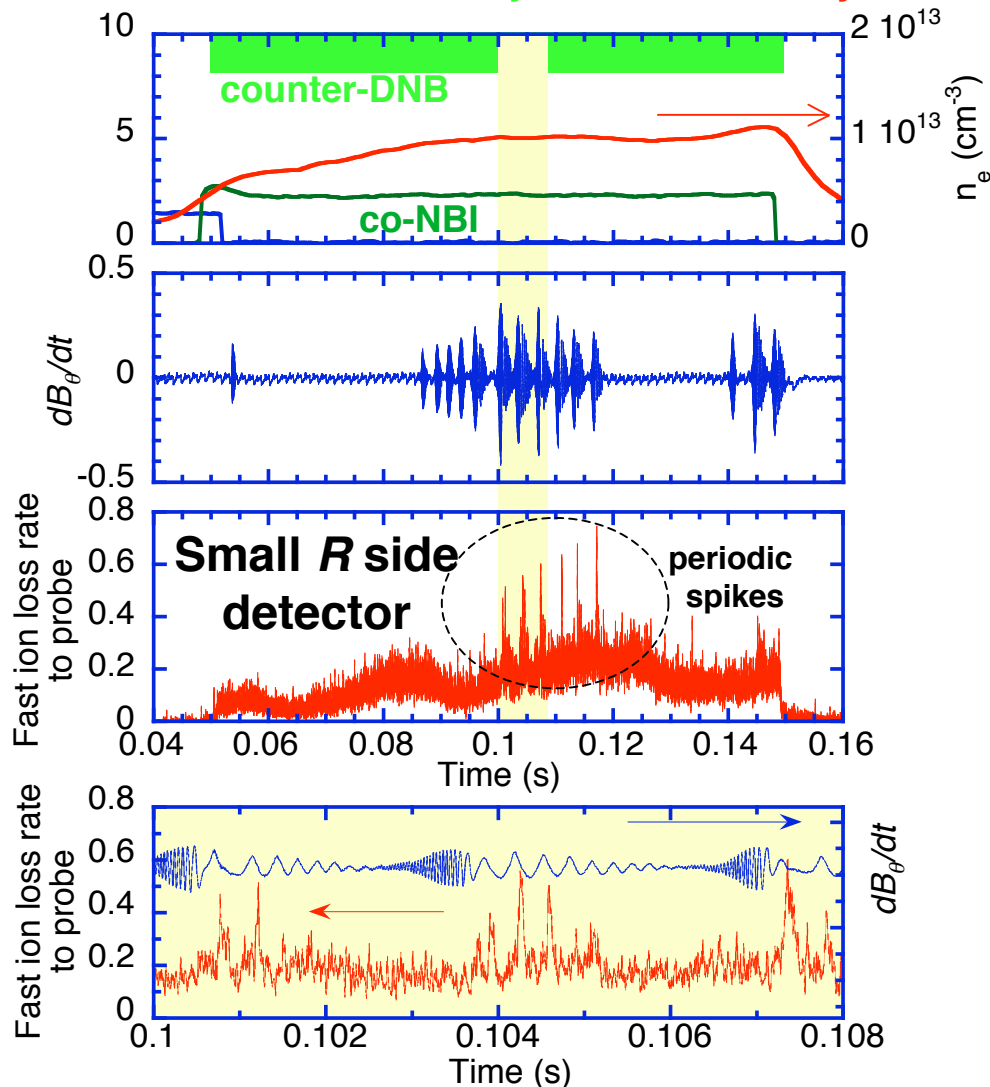
- Freq. of the mode is  $\sim 50$ kHz.
- Barely passing beam ions are expelled to large  $R$  side and their energy is near  $E_b(\sim 38$ keV).
- Enhanced loss of helically trapped ions due to FB mode has never seen at small  $R$  side.
- Beam ion loss to large  $R$  side does not begin until Mirnov coil reaches a maximum.

- K.Toi *et al.*, Nuclear Fusion **39**(1999)1929.
- M.Isobe *et al.*, 26th EPS Conf. on Contr. Fusion and Plasma Physics, Maastricht, ECA Vol.**23J**(1999)21-24.
- T.Kondo, M.Isobe *et al.*, Nuclear Fusion **40**(2000)1575.



# Low freq. mode ( $\sim 5\text{kHz}$ ) enhances loss of counter-going beam ions to small $R$ side

- In order to look into interaction between MHD mode and counter-going beam ions, **DNB is counter-injected into co-injected NBI plasmas.**



- Bursting MHD activities are excited by co-injected heating NB.
- First, high freq. mode ( $\sim 30\text{-}40\text{kHz}$ ) appears and then switches to low freq. mode ( $\sim 3\text{-}5\text{kHz}$ ).
- Barely counter-passing fast ions are lost in the timing of low freq. mode and their energy is about 10-15keV.
- Expulsion of fast ions to small  $R$  side due to high freq. mode is not seen.
- Large  $R$  side probe does not detect periodic loss during low freq. mode.



## ま と め

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- ・ CHSでは、損失高速イオンの空間分布を把握する目的で、最近2機目の高速イオンプローブを大半径方向内側に設置した。
- ・ 内側プローブの観測結果は、ビームのco-入射、counter-入射のいずれの場合も、無衝突軌道では説明できない。観測結果が衝突リップル輸送のみで説明できるのか否かを現在コード計算にて確認中。
- ・ FBタイプのMHD振動により高速イオンは外側にのみ排出される様子。内側プローブでは排出は確認できない。
- ・ 低周波振動（ $\sim 5\text{kHz}$ ）の発生に伴い内側への高速イオン損失がある。この時外側には無い模様。