ELM rotation measurement via the NSTX FIReTIP system*

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Abstract

The high time resolution of the Far Infrared Tangential Interferometer/Polarimeter (FIReTIP) allows measurement of the critical parameters of the small Edge Localized Modes (ELMs), also known as a type V ELM, on the National Spherical Tokamak Experiment (NSTX) including the speed of rotation and size of each ELM structure. Understanding of ELMs is extremely important since the operation mode of future fusion devices such as ITER is likely an ELM free high confinement mode (*H*-mode). An extensive analysis of the type V ELM data demonstrates a strong relationship between the rotation speed and interval of the ELM. This paper includes the upgrade process of the multi-channel FIReTIP system and implications of the ELM physics by its rotation measurements.

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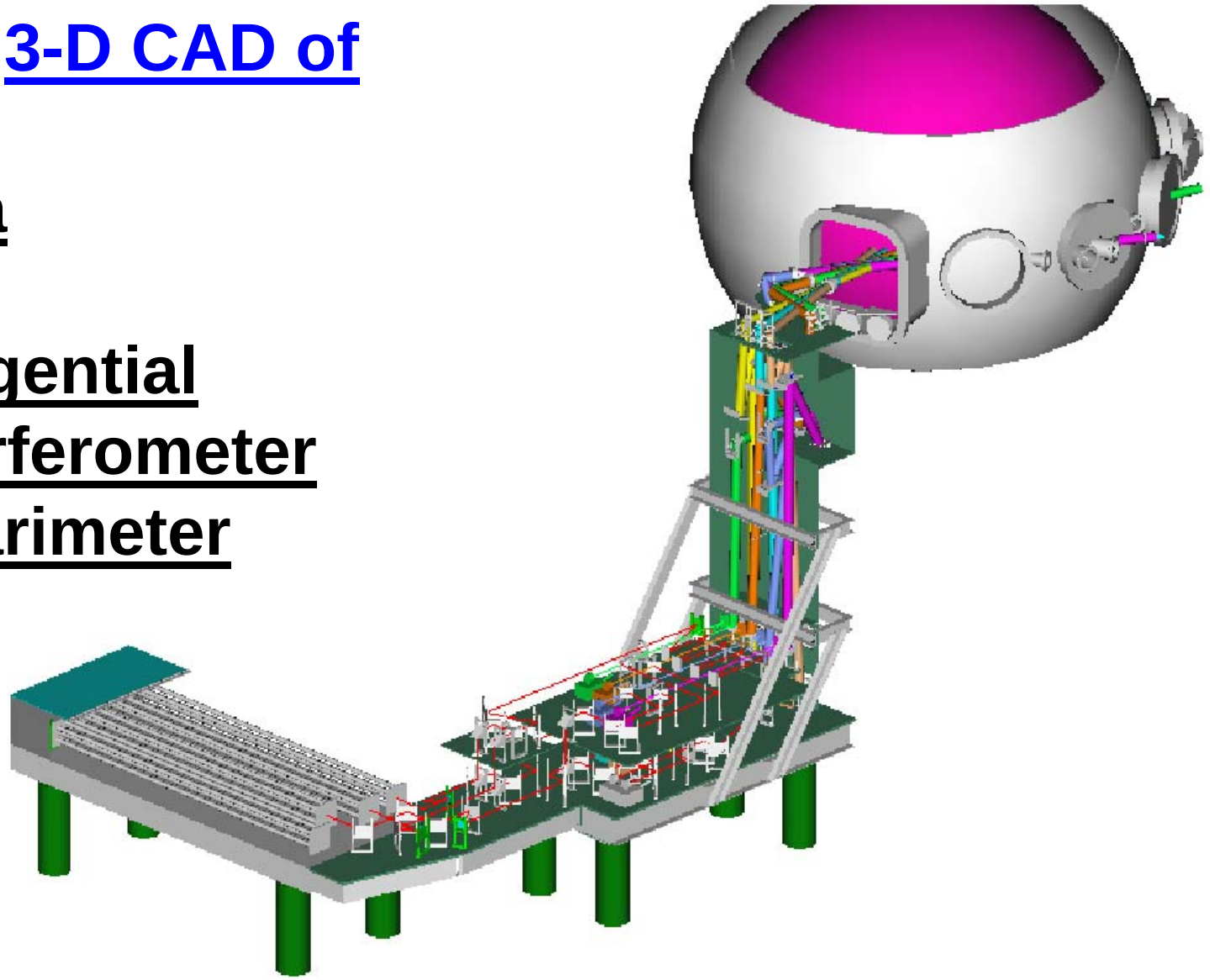
3-D CAD of

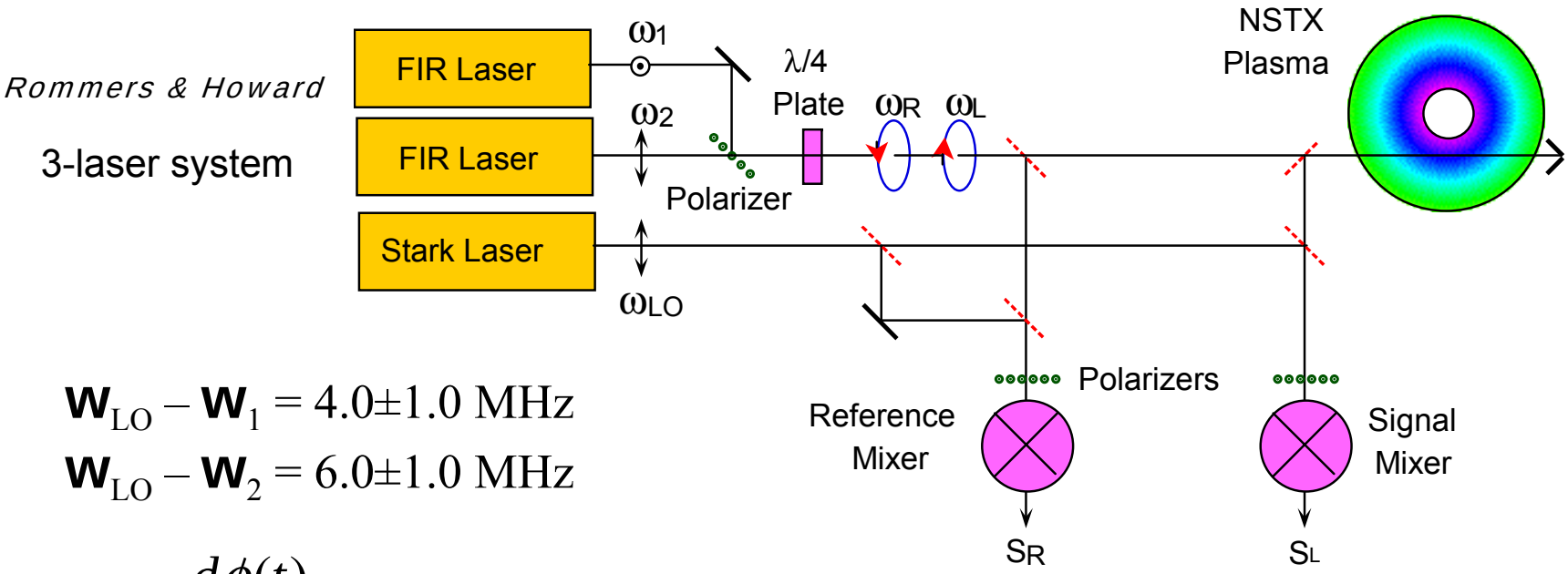
Far
Infra
Red
Tangential
Interferometer
Polarimeter



Principle of FIReTIP system on NSTX

$$\phi(x) = 2.8\times10^{-15}\,\lambda\int_{o}^{x} n(x')\,dx'$$

$$\Psi(x) = 2.6\times10^{-13}\,\lambda^{2}\int_{o}^{x} n(x')\,B_{T}(x')\,dx'$$



$$\mathbf{W}_{LO} - \mathbf{W}_{1} = 4.0\pm1.0\ \text{MHz}$$

$$\mathbf{W}_{LO} - \mathbf{W}_{2} = 6.0\pm1.0\ \text{MHz}$$

$$\frac{d\phi(t)}{dt} << \omega_{if}$$

[K.C. Lee *et.al.*, IEEE Trans. on Plasma **32**,1721(2004)]

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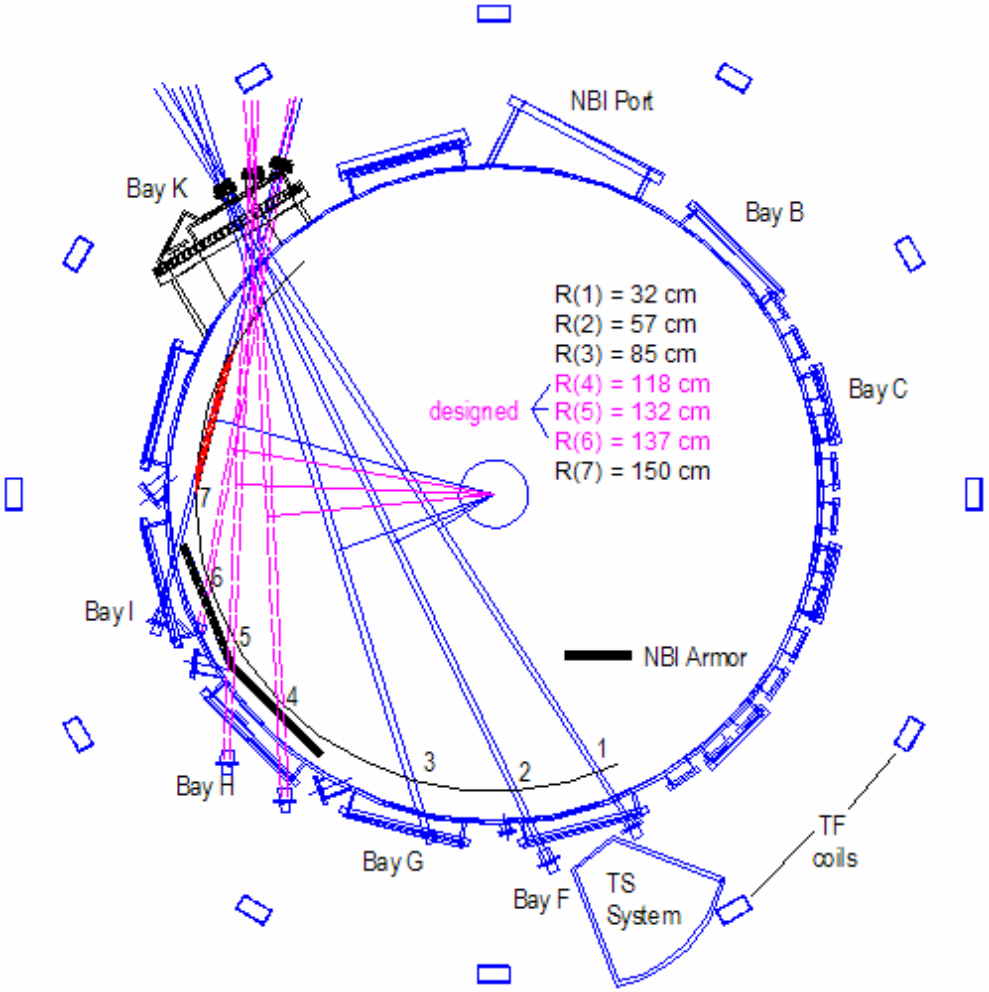
FIReTIP channels and upgrades

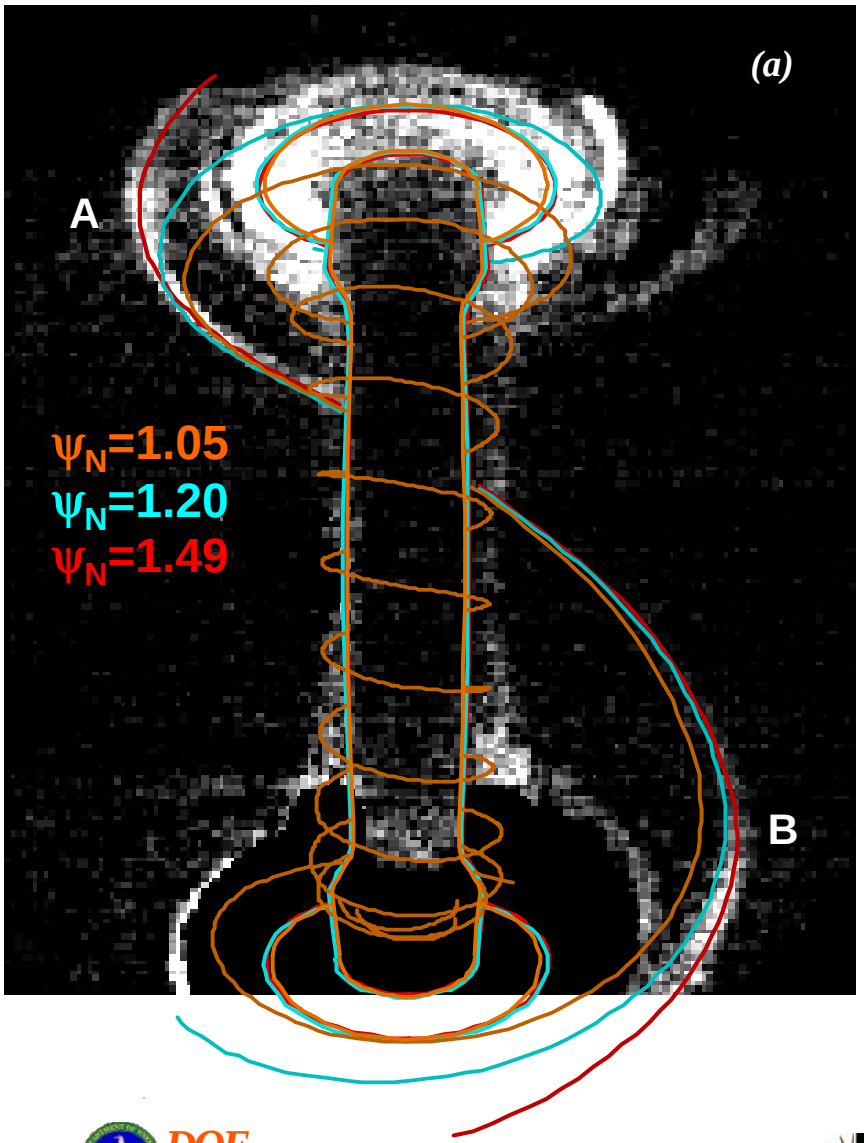


Recent upgrades

- Temporal Resolution : 500 kHz using PC based DAQ system (2004)
- Optical components of Ch4 & Ch5 are installed (2005)
- Test run of Ch5 & CH6 is in progress (2006)

Type V ELMs characteristics on NSTX

[Maingi, Bush *et al.* phys. of plasmas, 2006]



► visible camera picture with normalized poloidal flux values (#113024 @0.52sec, LSN)

► type V ELMs (small ELMs) : single or double filamentary helical formation aligned with magnetic field (A-B)

► large ELMs on NSTX deteriorate plasma properties (pulse length, confinement etc.)

► type V ELMs rotate in toroidal and poloidal directions

Motivation of Type V ELM study on NSTX

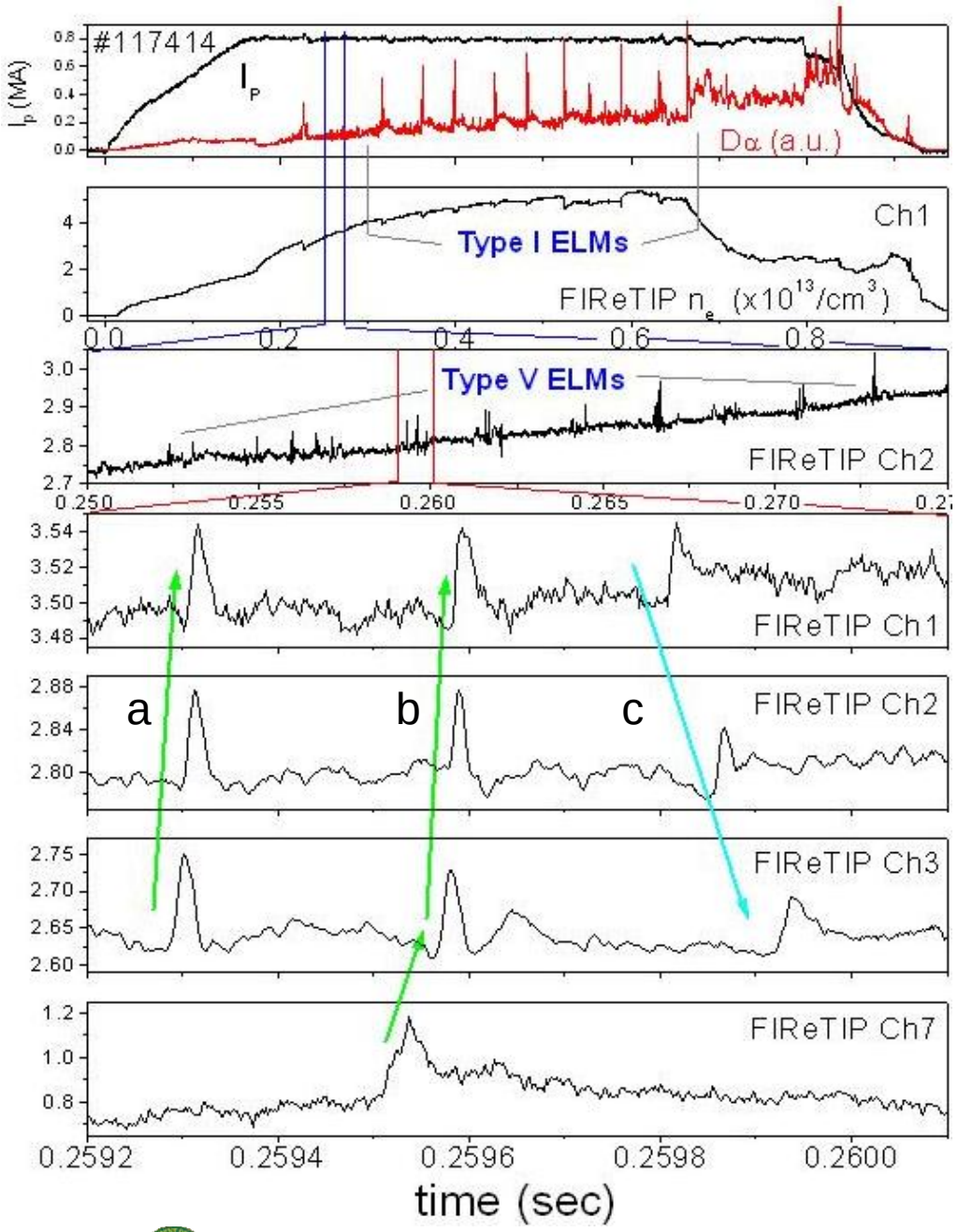
why Type V ELMs?

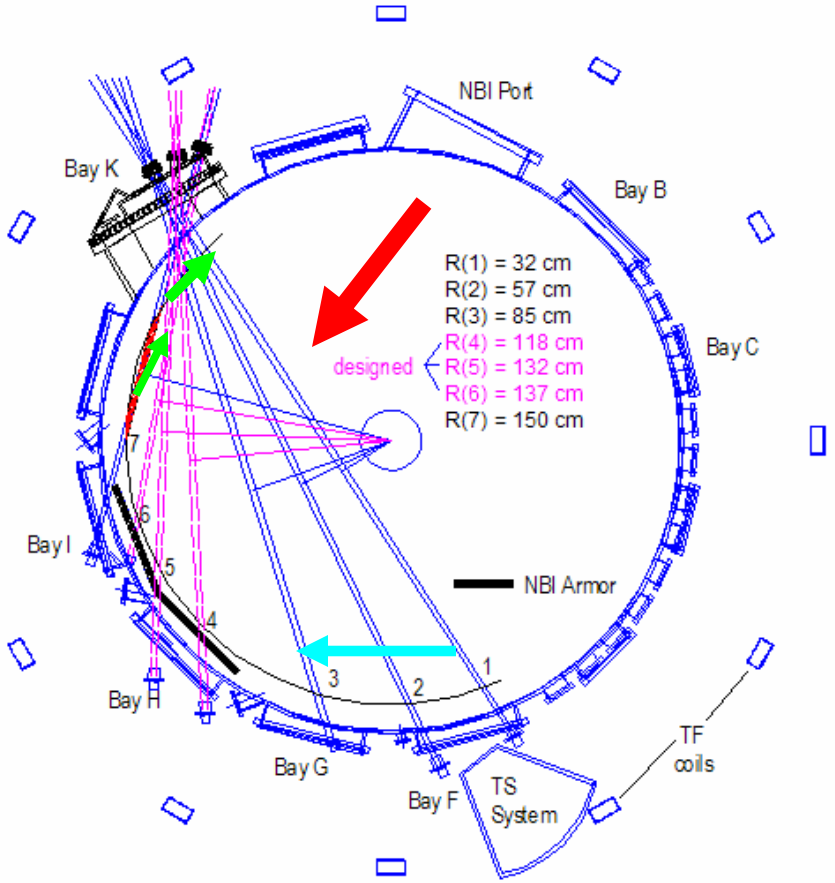
- similarities with other Types of ELMs : diverter signature
- basic difference in number of filaments (toroidal mode number) Type V (n=2,3,4) < Type III <Type I (n= 12~16)

=> toroidaly localized Type V ELMs provide opportunity of ELM mechanism study (Rotation & toroidal asymmetry)

- small ELM regime enables long pulse operation with good performance on NSTX.

ELM rotation measurement by FIReTIP





ELMs rotate clockwise : opposite to plasma rotation

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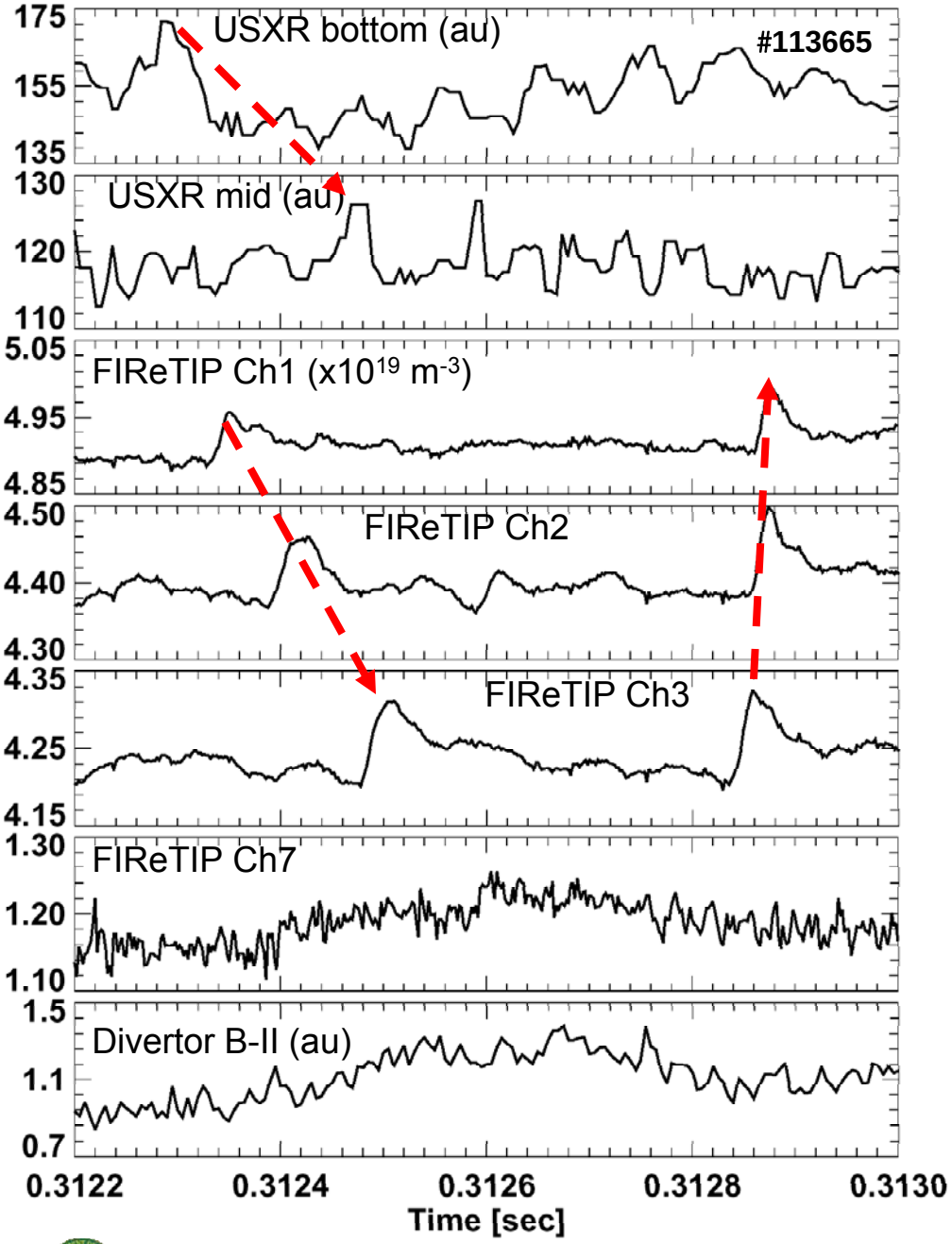
ELMs rotation measurement by FIReTIP

- From #117414 measurement
  - Third peak (c) is analyzed to be same filament of first peak (a)
  - Second peak is shown on edge channel (Rt=150 cm => out side of separatrix, Rs=~146 cm)
  - Second peak filament is in SOL and occurred where Te < 200 eV (from comparing USXR emission)
- From #113665 measurement
  - Peaks were not detected on edge channel =>radial extend of filament had not drifted Rt=150 cm
  - First peak (Ch1 -> Ch2 -> Ch3) indicates velocities of -5 and -7 km/sec
  - Speed calculation from channel spacings at Rt = ~140 cm



From #113665 continue

- USXR measured same peak moving upward in poloidal direction (toroidal location of USXR port is near CH3 of FIReTIP)
- Second peak (Ch3 -> Ch2 -> Ch1) indicates velocities of -8 and -10 km/sec
- Probably same filament generates both peaks
- Lower divertor B-II line emission indicate relation with FIReTIP CH7

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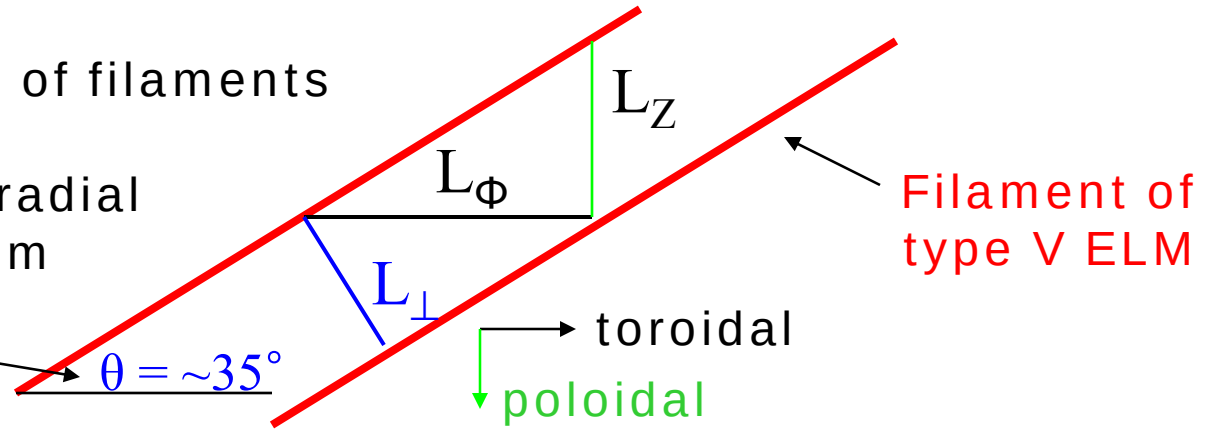
ELMs measurement by FIReTIP (#113665)

Characteristic size of filaments

ribbon shape with radial dimension of few cm



Channel Number	Peak Time (msec)	Width (msec)	v_ϕ (km/sec)	L_ϕ (m)	$L_\perp$ (m)	L_Z (m)
1 (far)	312.346	0.039	---	0.18	0.10	0.12
2 (far)	312.425	0.039	-5.5	0.18	0.10	0.12
3 (far)	312.508	0.037	-6.3	0.20	0.11	0.14
3 (near)	312.861	0.039	-7.3	0.25	0.14	0.17
2 (near)	312.874	0.032	-9.8	0.28	0.16	0.20
1 (near)	312.874	0.028	---	0.25	0.14	0.15

- ELMs accelerate at near FIReTIP port, decelerate at far from FIReTIP port

- Absolute value and direction of ELM rotation measured by FIReTIP are comparable to the Edge Rotation Diagnostics (ERD) on NSTX, [Biewer et al., RSI, '04]
(ERD showed toroidal and poloidal velocities : -5 ~ -15 km/sec <= ExB)

- Measured rotations are in opposite direction to plasma current and opposite to neutral beam momentum input direction.
(CHERS: ~10-20 km/sec from carbon at top of H-mode pedestal)

Measurement of ELM characteristics on NSTX

- Type V ELMs on NSTX : 60% had single filament and 40% had double filament perturbation <= survey of 50 Type V ELMs
- Toroidal mode number of Type V ELMs : n=3 or n=4
- Large Type I ELMs measured by FIReTIP had at least four separate filament perturbations => toroidal mode number: $12<n<16$
- Comparable data from other diagnostics:

• Magnetic coils : toroidal propagation : -6~ -10 km/sec

• Gas Puff Image (GPI) : poloidally–elongated structure (10~15 cm), radial propagation speed : less than 1 km/sec

Measurement of density on Type V ELMs

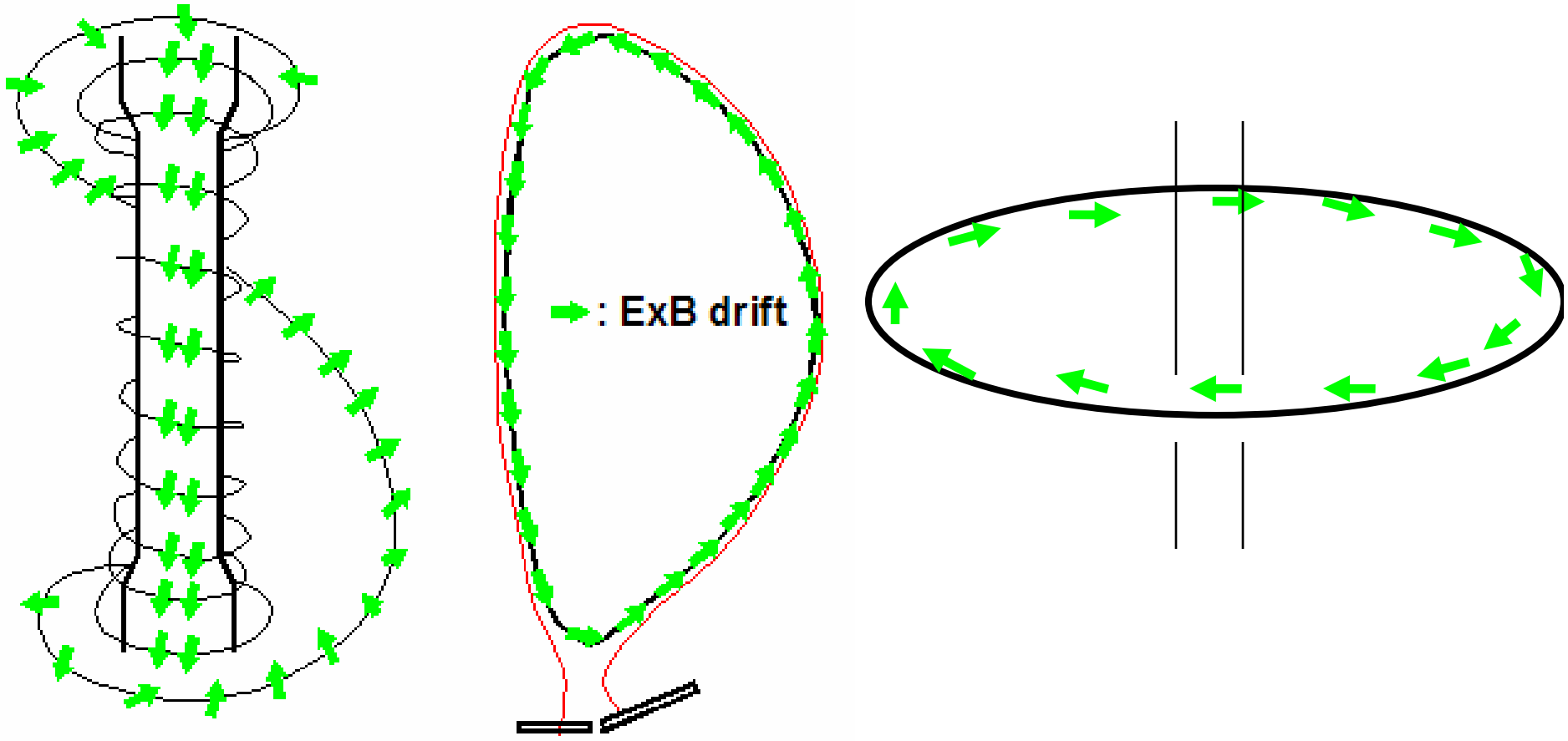
- Calculated from the channel of most perpendicular to flux surfaces: Ch1
- Background density perturbation in line integrated FIReTIP data :

  $\delta n_{eb} \sim 1.4 – 2.0\ \%$

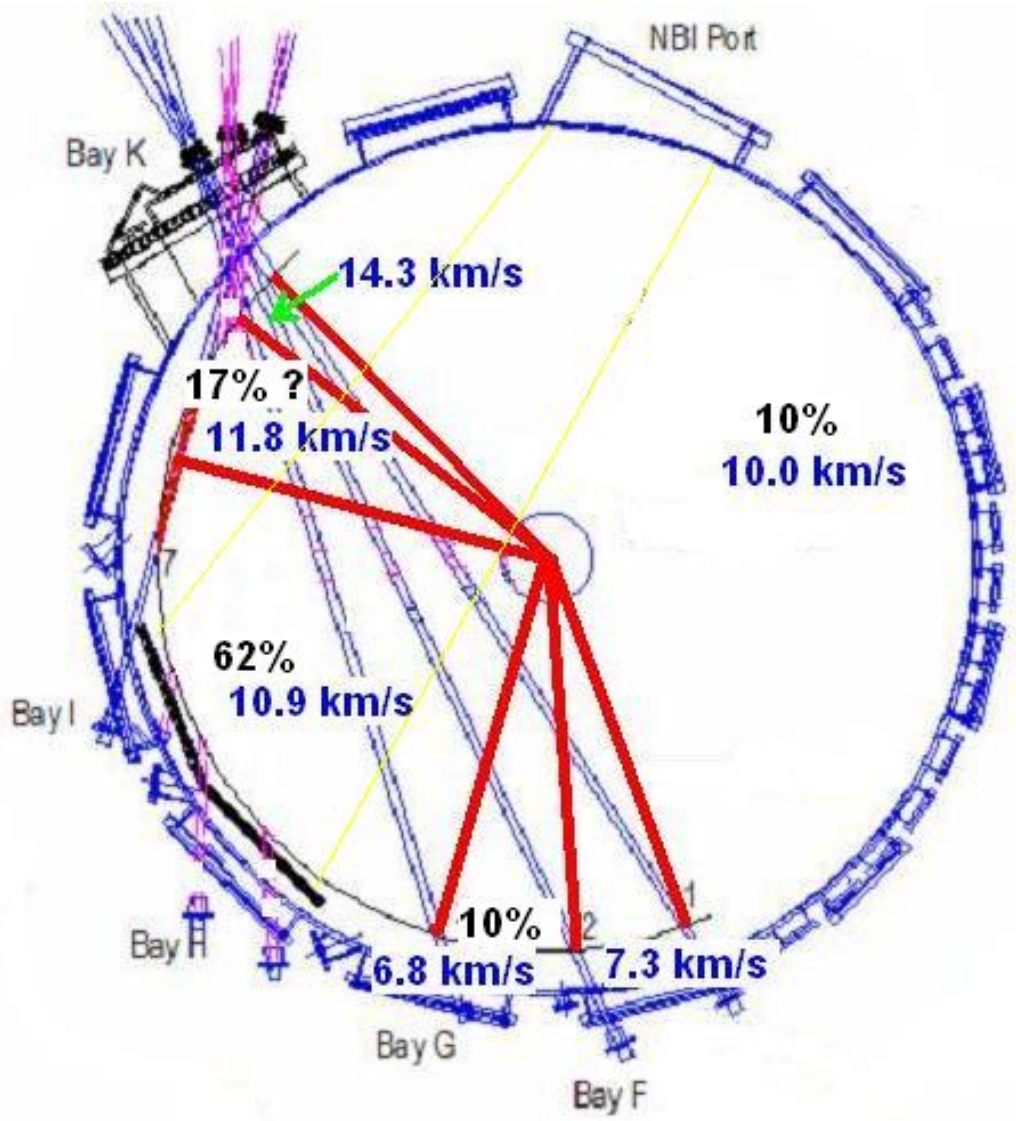
- δn_{ef}(in filament)/$\overline{n}_e$: ~140 -200 % (FIReTIP Ch1 beam path length ~ 3m)
- Density of filament is approximately 400 – 700 % higher than background density since boundary density is smaller than line averaged value

Discussion on Type V ELMs rotation

- Direction of Type V ELMs rotation : possibly related with ExB drift at the boundary induced by radial electric field



Toroidal asymmetry of Type V ELMs



(1) start points of Type V ELMs are concentrated in front of NBI Armor

(2) rotation speed of Type V ELMs is high at Bay-K and low at Bay-G

- **based on 52 cases including most of Type V ELMs in a whole shot**
- **velocity calculated at R=145 cm**
- **CH7 (Rt=150) data included**
- **radial location : inside or outside of separatrix?**
- **ELM rotation <= ExB drift?**

Discussion: toroidal asymmetry of Type V ELMs

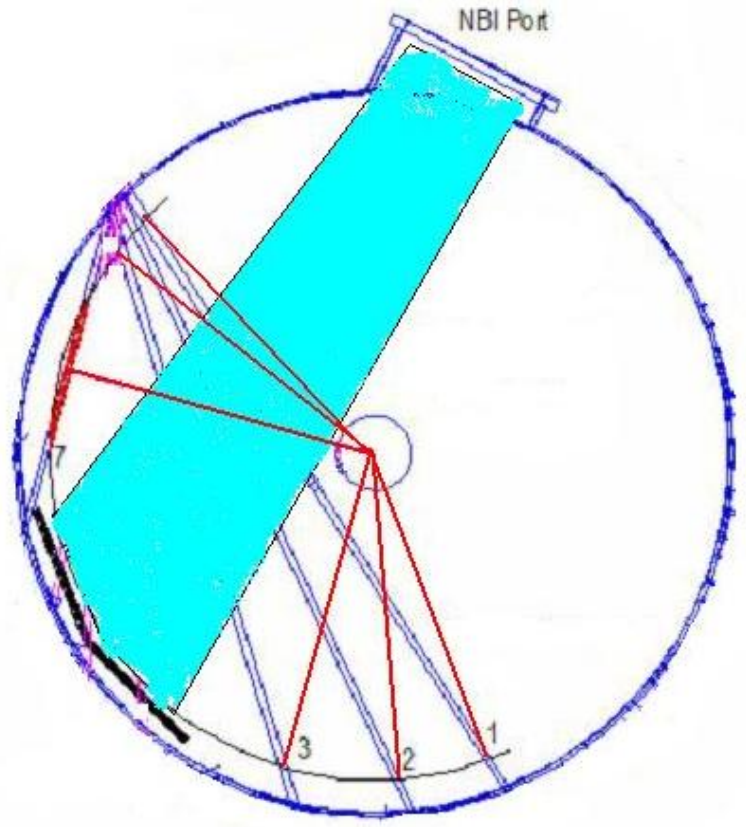
- possible interpretation of toroidal asymmetry of Type V ELMs
  - asymmetric momentum transfer at the boundary?
  - charge exchange neutral distribution
  - trapped particles
  - high collisionality at boundary
  - toroidal velocity shear and viscosity
- Weakening ExB drift by the drag

  of locally enhanced toroidal rotation

  around NBI armor?

  (where the ELMs start?)
- Gyrocenter shift theory [K.C. Lee,PoP2006];

  peak of ExB flow at inside saparatrix



Impacts of additional FIReTIP channels on NSTX ELMs measurement

- Ch4 (Rt=118 cm) and Ch5 (Rt=132 cm) on Bay-H
- Increase of toroidal coverage of FIReTIP measurement
- Accuracy enhancement of ELM rotation => determine acceleration or deceleration of Type V ELM propagation
- Study of radial location and propagation of ELMs : inside or outside of separatrix, rotation speed profile in radial direction
- Measurement of toroidal mode number of ELMs

Summary

- **ELMs measurement by FIReTIP**
  - **Toroidal rotation in opposite to plasma rotation**
  - **Rotation speed is -7 to -14 km/sec**
  - **Ribbon shaped filament has width of 8 to 16 cm in perpendicular to magnetic field**
  - **60% of Type V ELMs : single filament , 40% of Type V ELMs : double filament**
  - **δn_{ef}(in filament)/ n_e : ~140 -200 %**
- **Toroidal asymmetry of Type V ELM**
  - **rotation speed and starting location**
    - **Possibly related with asymmetry of boundary plasma rotation**
    - **ELM rotation related with ExB drift**
- **FIReTIP system upgrade**
  - **Ch4 and Ch5 (Rt=118cm,132 cm) will be installed**