Development of 3D tomography using IRVBs in LHD

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Outline

- Introduction

- Voxels and IRVB channels
- IRVB signal and geometry matrix calculation

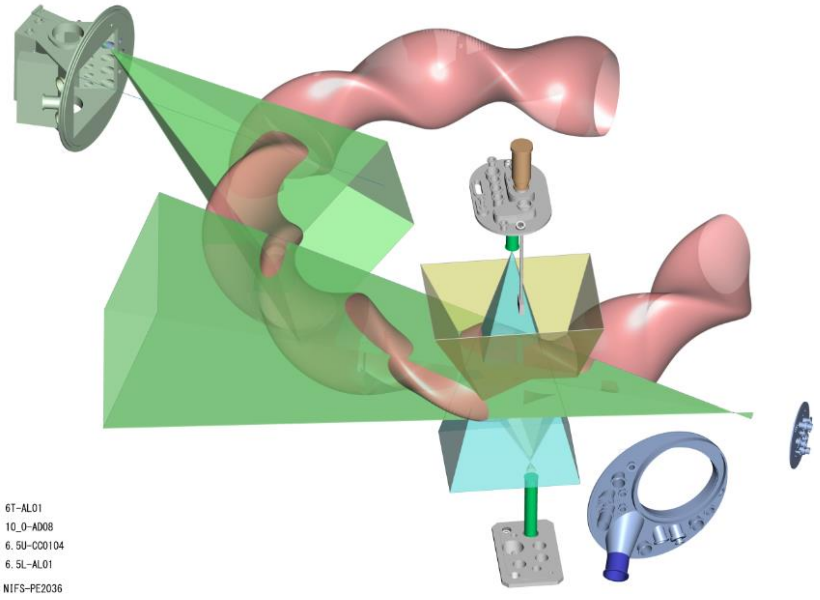
- Tomography
    - Issue for tomography
    - Inverse calculation
    - Assumption for 3D tomography

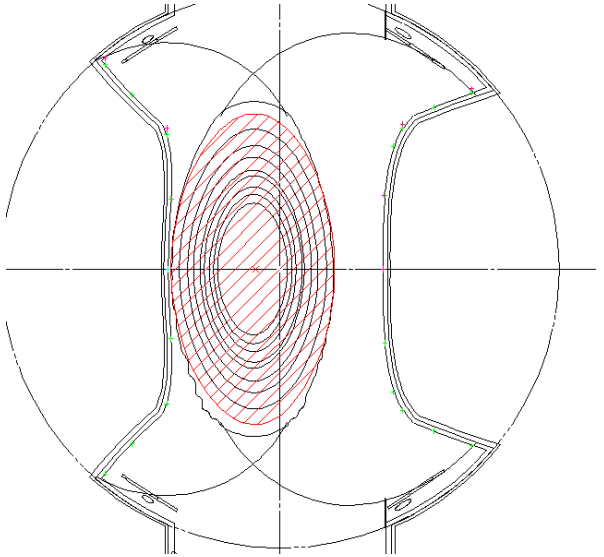
- Optimization of fields of view

- Summary

Introduction

Radiation loss: One of the major channels of energy loss from a fusion plasma





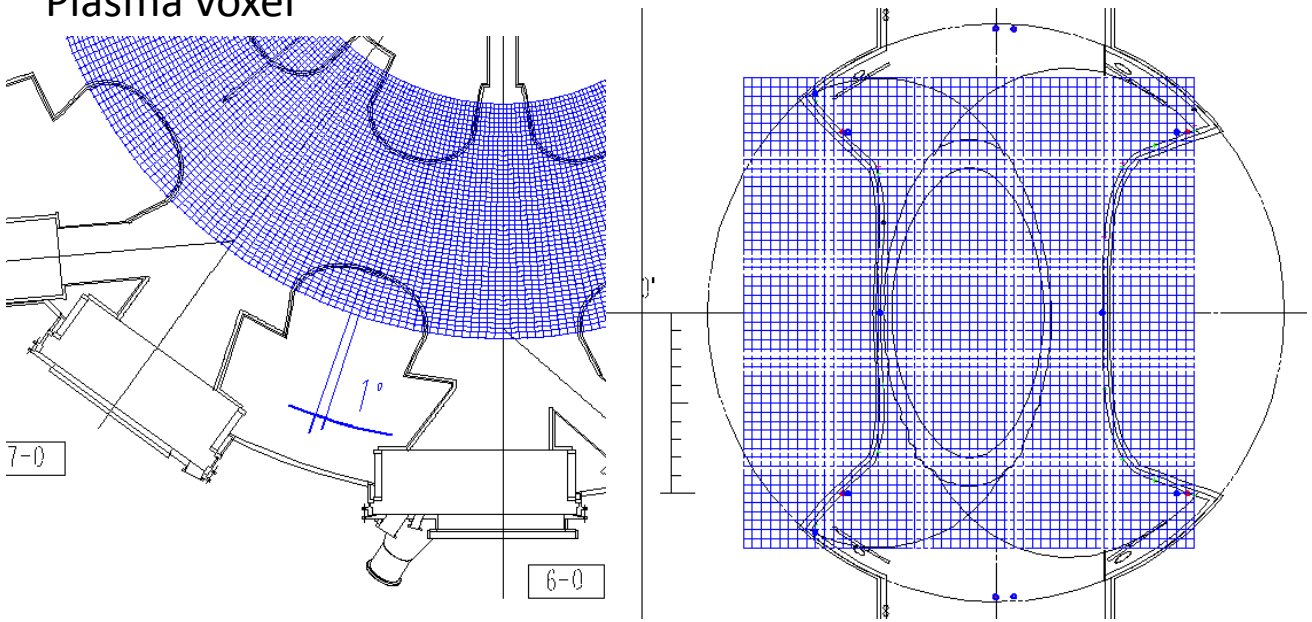
Radiation region has 3D structure

- 3D measurement for radiation distribution is required for understanding power balance in a fusion plasma

Reconstruct 3D radiation distribution from IRVBs data(cone-beam field of view) with 3D tomography

Plasma voxels and IRVB channels

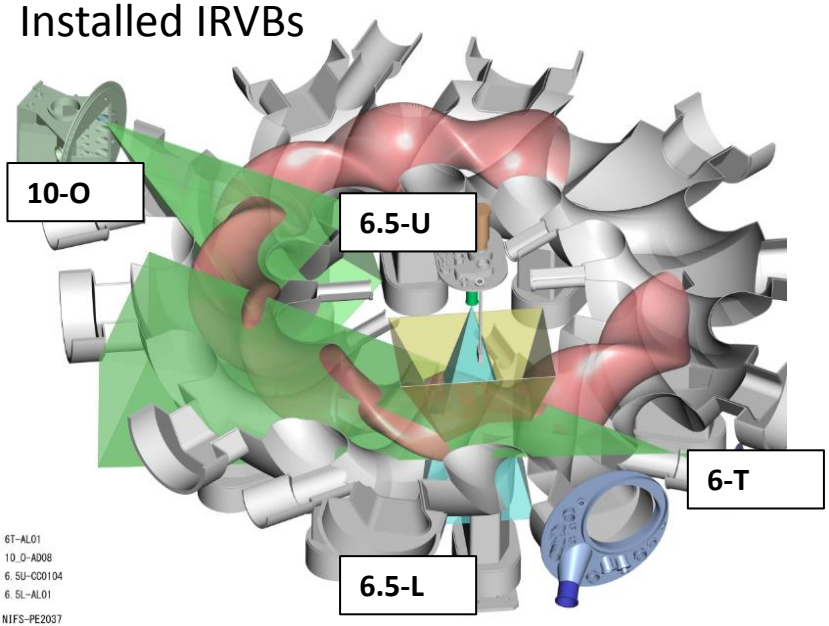
Plasma voxel



Horizontal: 5cm
50 divisions
(2.5m<R<5.0m)
Vertical : 5cm
52 divisions
(-1.3m<Z<1.3m)
Toroidal :1 degree
(360 divisions)

Total number of plasma voxel
:936,000

Installed IRVBs



Detector channels

10-O:	768(32x24)
6-T:	768(32x24)
6.5-L:	560(28x20)
6.5-U:	432(24x18)

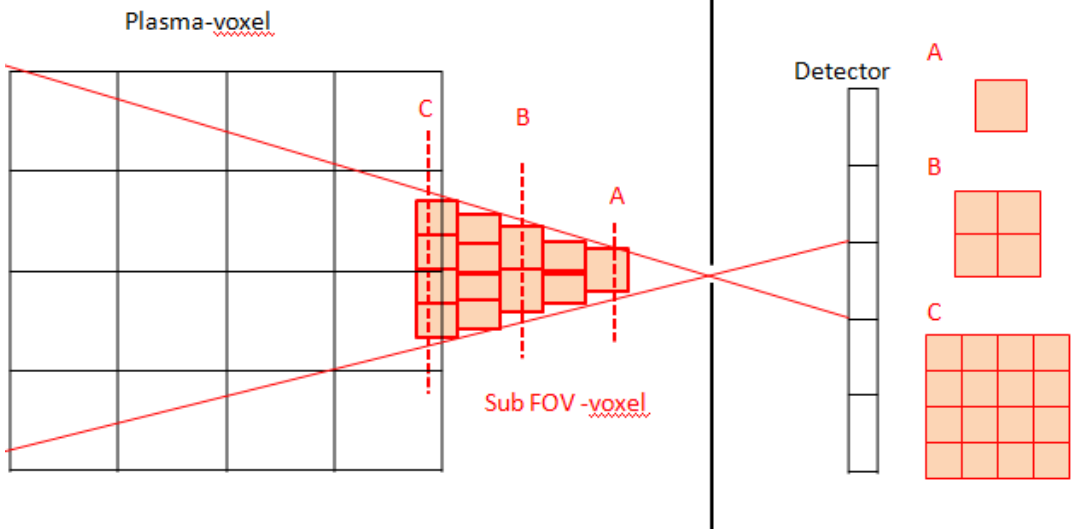
Total number of IRVB channels
:2,528ch

IRVB signal and geometry matrix calculation

Absorbed power at each detector channel

$$P_{rad,j} = \sum_{k=1} h_{j,k} S_k$$

$P_{rad,j}$:Absorbed power on each detector
$h_{j,k}$:The geometry matrix as a projection matrix
S_k :The radiation intensity from the plasma-voxel
j :Index of detector channel
K :index of plasma-voxel



Geometry matrix (projection matrix)

$$h_{j,k} = \sum_{i=1} \frac{V_{i,j,k}\Omega_{i,j,k}}{4\pi}$$

$h_{j,k}$: The geometry matrix as a projection matrix
$V_{i,j,k}$: Volume of FOV(field of view) sub-voxel
$\Omega_{i,j,k}$: solid angle of the detector with respect to the sub FOV sub-volume
k : Index of plasma-voxel
i : Index of FOV sub-volume
j : Index of detector channel

Issues for Tomography

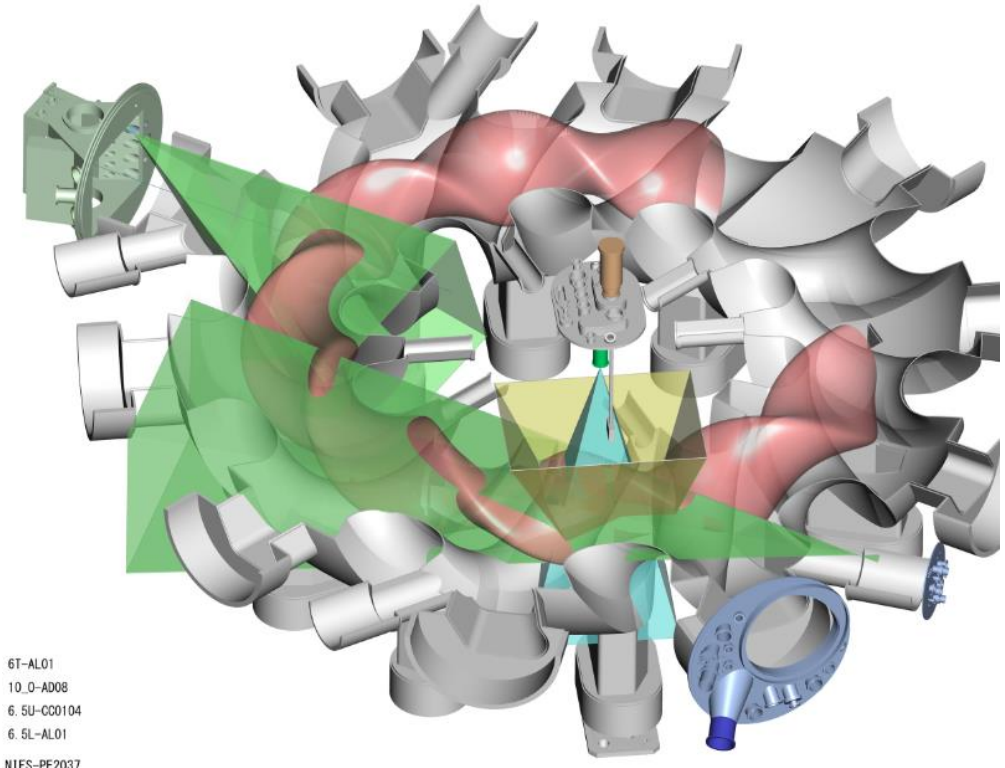
CT for medical → Tomography is applied in multi slices using measurement data from all directions.

In this study

- Installation location and direction for diagnostic instrument are restricted by port location and LHD wall.

→LHD plasma can't be seen from all direction.

→3D tomography (not multi slices) is necessary.



Tomography (Inverse calculation)

$$P_{rad,j} = \sum_{k=1} h_{j,k} S_k$$

Measured (IRVB)

Calculated (result)

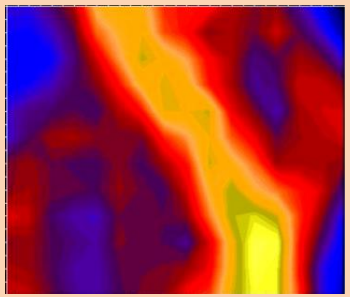
Geometry matrix

$P_{rad,j}$:Absorbed power on each detector
$h_{j,k}$:The geometry matrix as a projection matrix
S_k :The radiation intensity from the plasma-voxel
j :Index of detector channel
K :index of plasma-voxel

Measured

$P_{rad,j}(2{,}528ch)$

IRVBs signal



Tomography

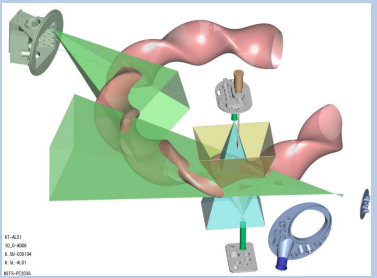
$h_{j,k}$

Geometry matric with cone beam

Required

$S_k\,(936{,}000)$

3D radiation distribution



Assumption for 3D tomography(1)

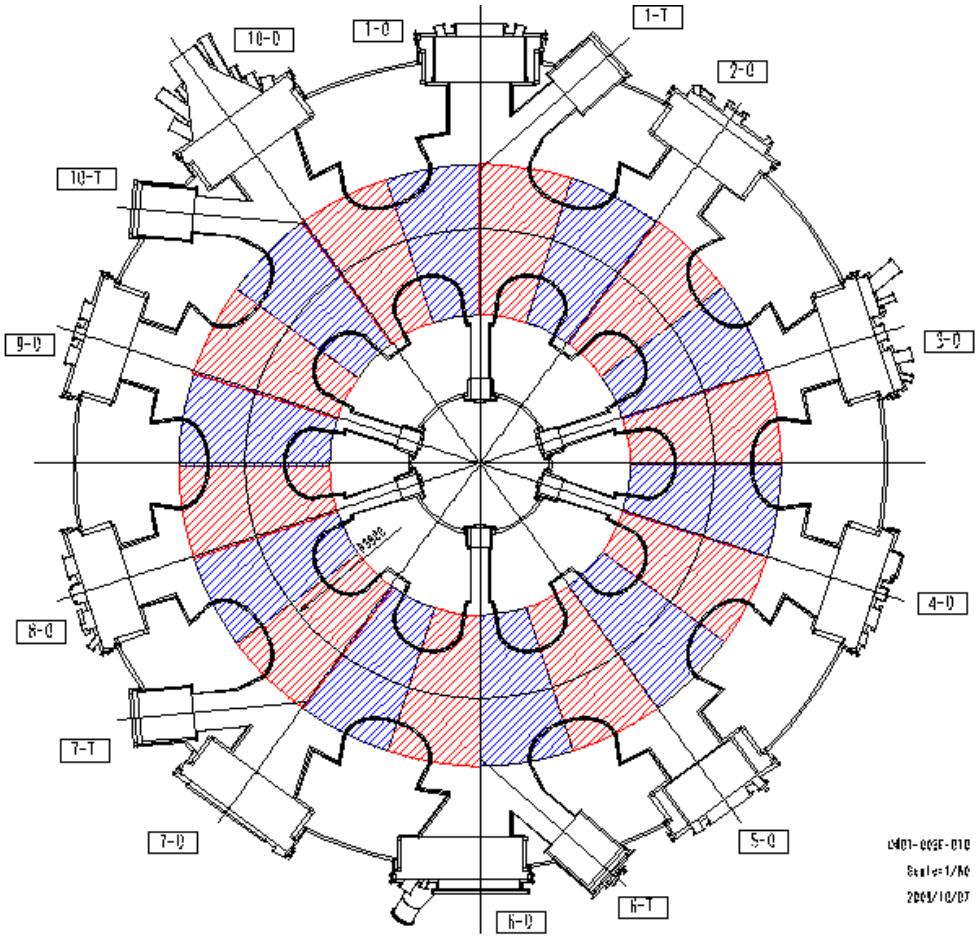
The tomography technique requires information from all plasma voxels.

→ Each plasma voxel should be seen by at least one IRVB.

Number of IRVBs is just 4.

→Fields of view of IRVBs can't be cover all plasma.

→ Assumption of helical symmetry is employed.



$S(R, \phi, Z) = S(R, \pi/5 - \phi, -Z)$

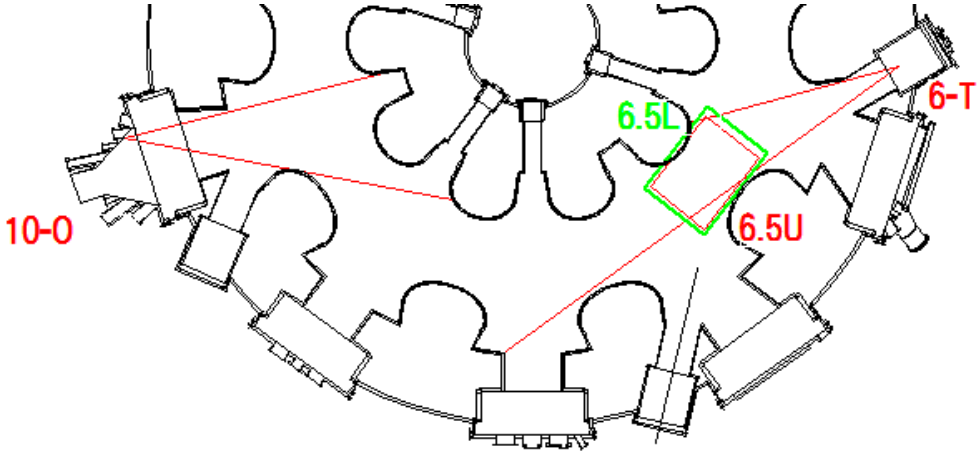
Helical symmetry

・The plasma repeats itself every 18 degree toroidally.

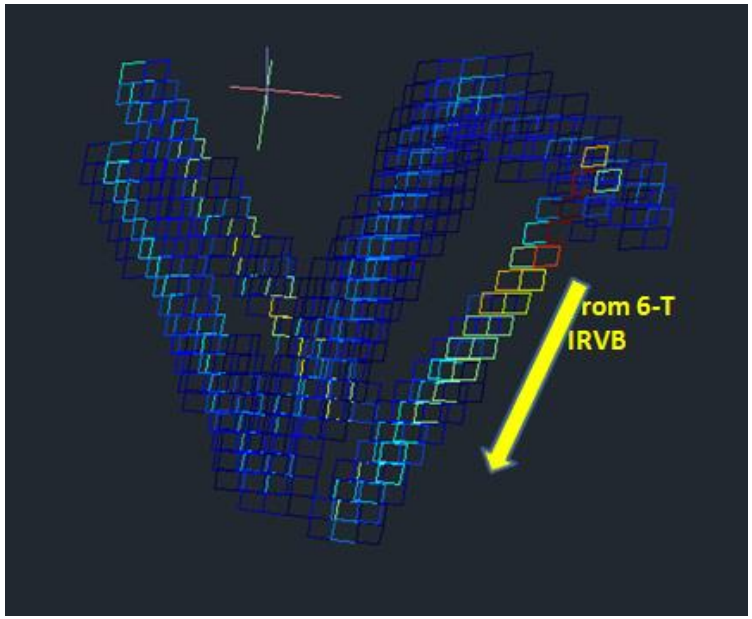
Total number of plasma voxel

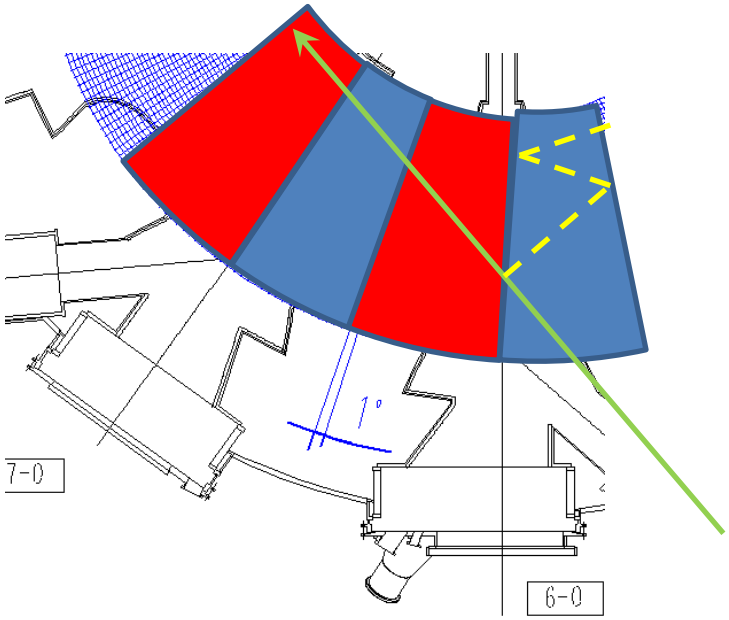
:936,000 → <u>46,800</u>

Assumption for 3D tomography(2)



- Field of view is turned by boundary of each half field period due to helical symmetry.





From M. Teranishi

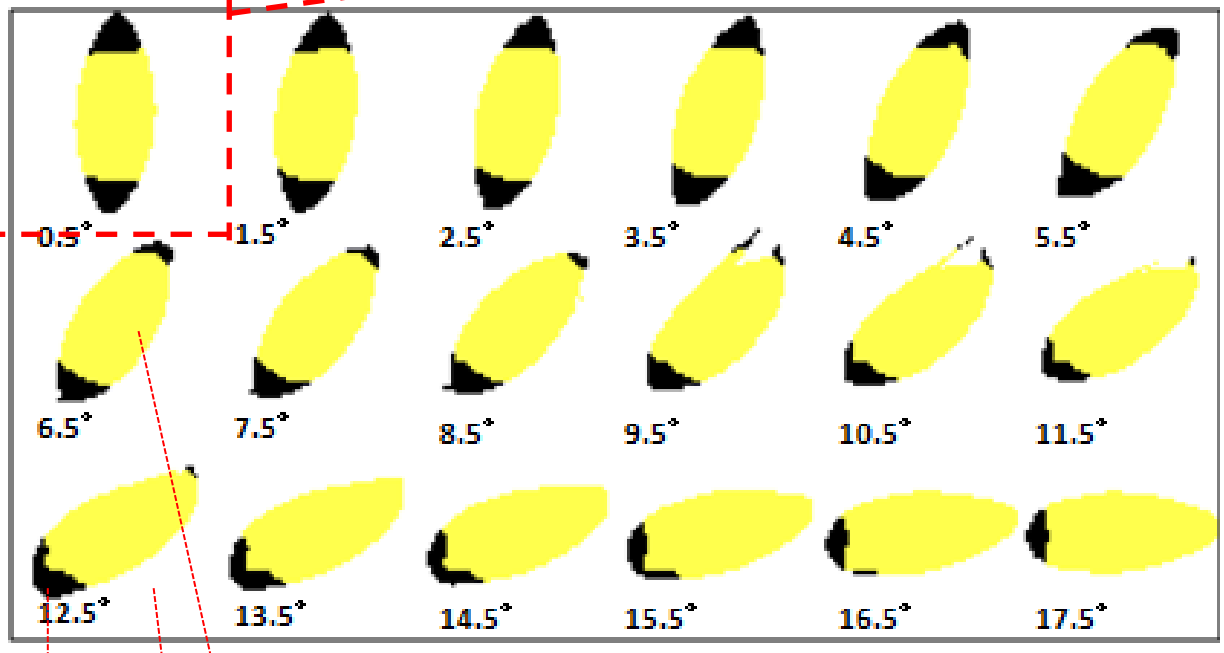
Optimization of fields of view (6T)

- **Field of view for each IRVB are moved to reduce total number of non-visible voxel.**

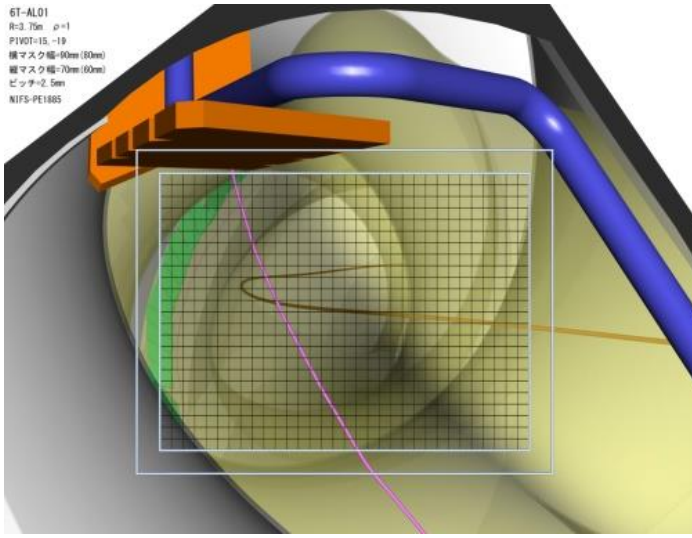
Fields of view for each IRVB

50(R)x52(Z)

6-T



6-T



Visible voxel in radiation region

Non-radiation region

Non-visible voxel in radiation region

Plasma voxel in radiation region (EMC-3)

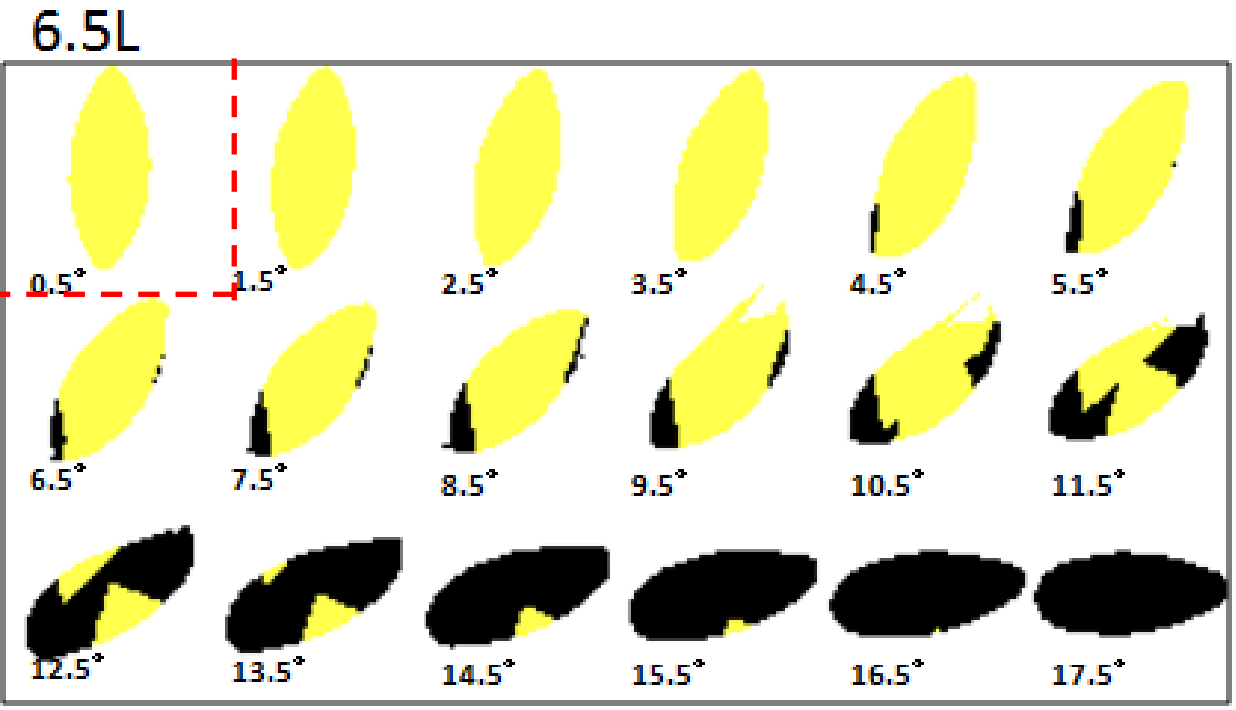
13,161/46,800

Total number of IRVB channels :2,528ch

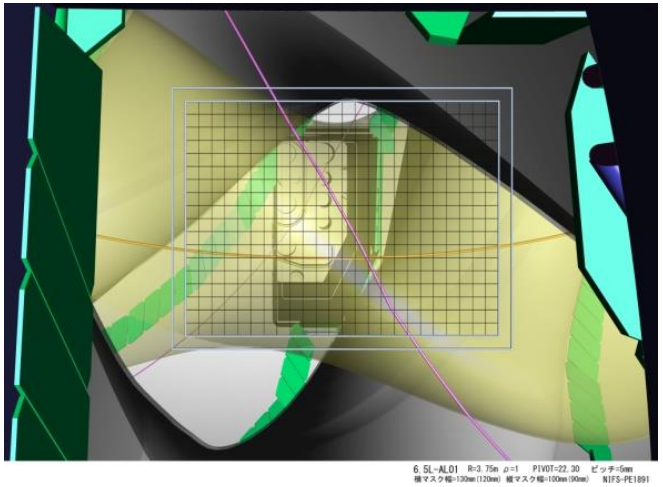
Optimization of fields of view (6.5-L)

- **Field of view for each IRVB are moved to reduce total number of non-visible voxel.**

Fields of view for 6.5-L IRVB



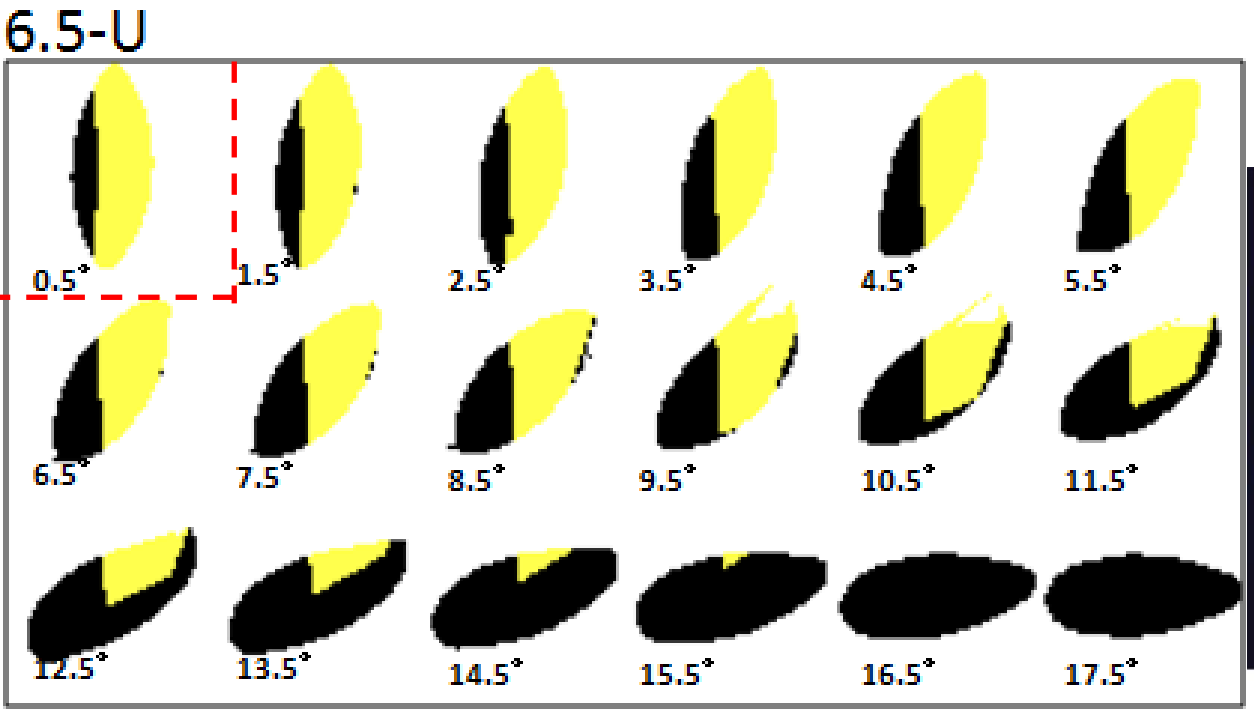
6.5-L

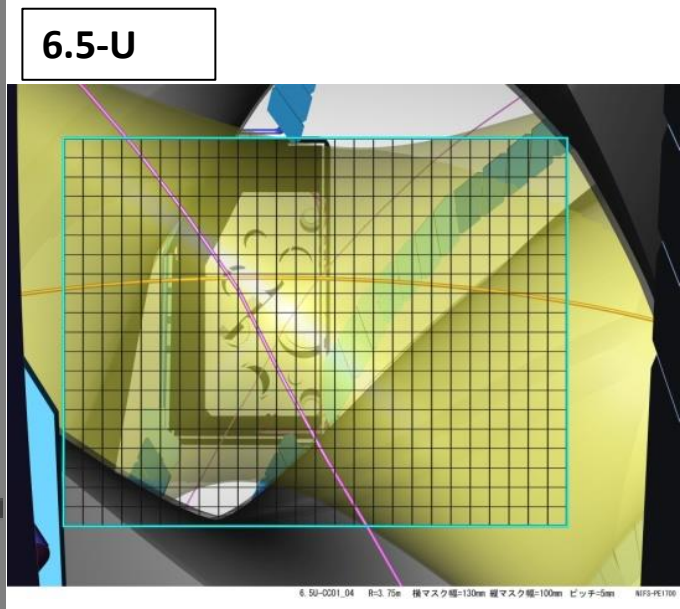


Optimization of fields of view (6.5-U)

- **Field of view for each IRVB are moved to reduce total number of non-visible voxel.**

Fields of view for 6.5-U IRVB

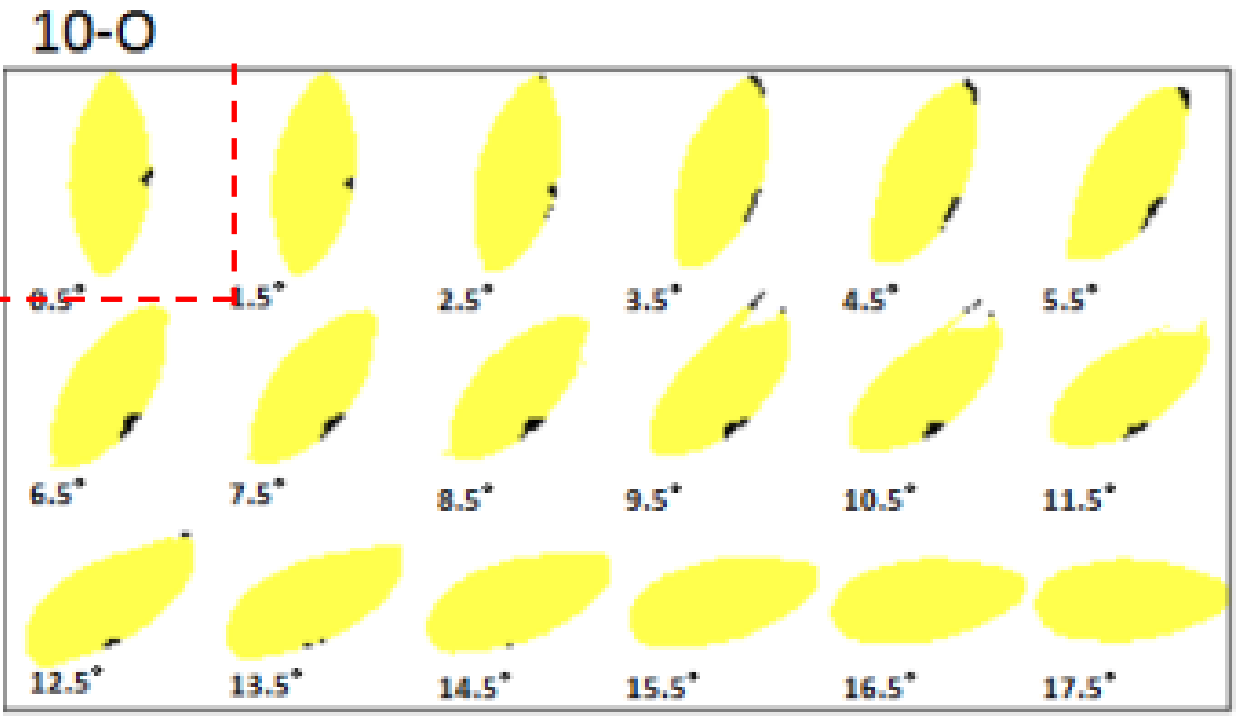




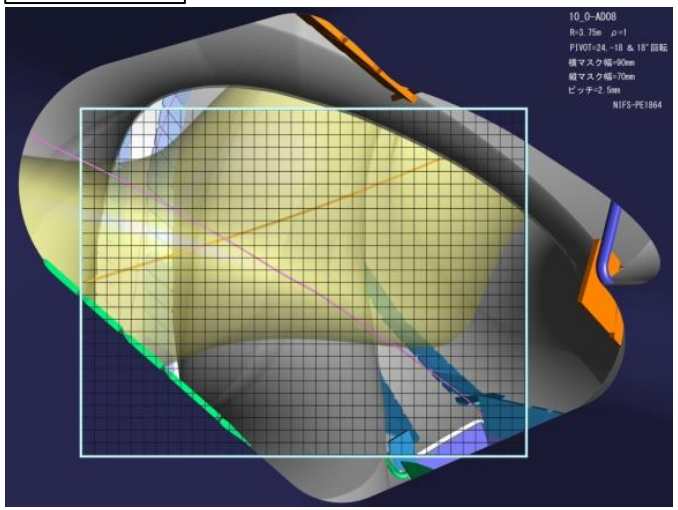
Optimization of fields of view (10-O)

- **Field of view for each IRVB are moved to reduce total number of non-visible voxel.**

Fields of view for 10-O IRVB

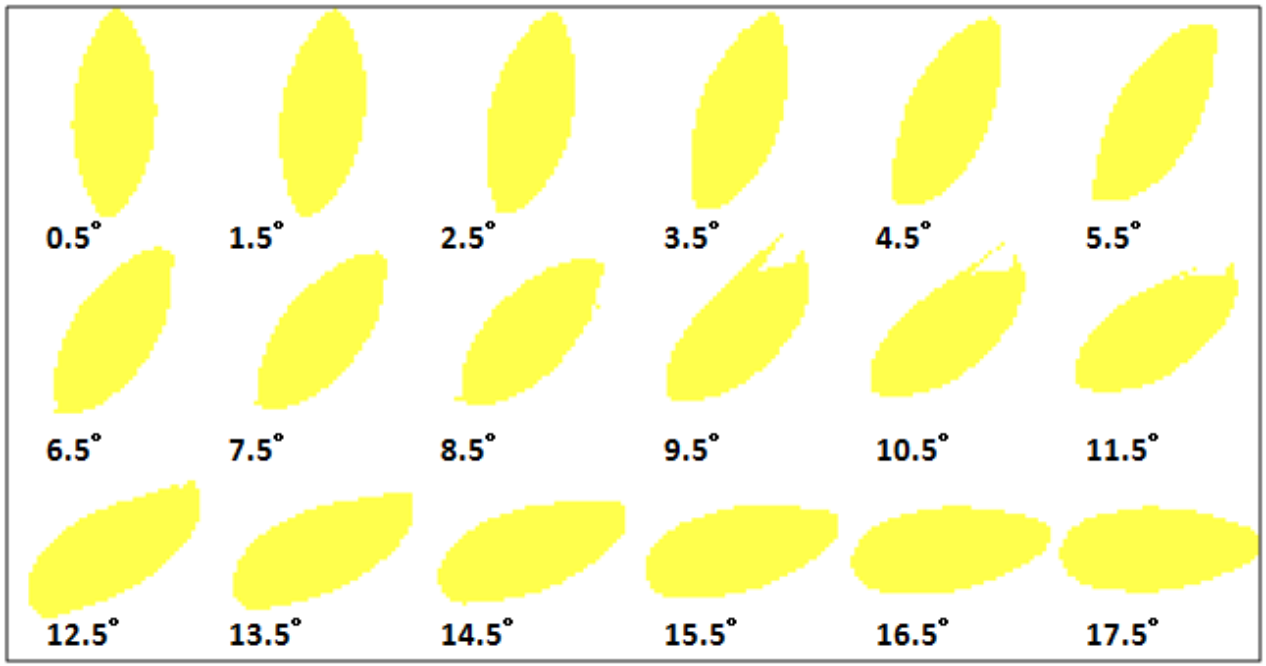


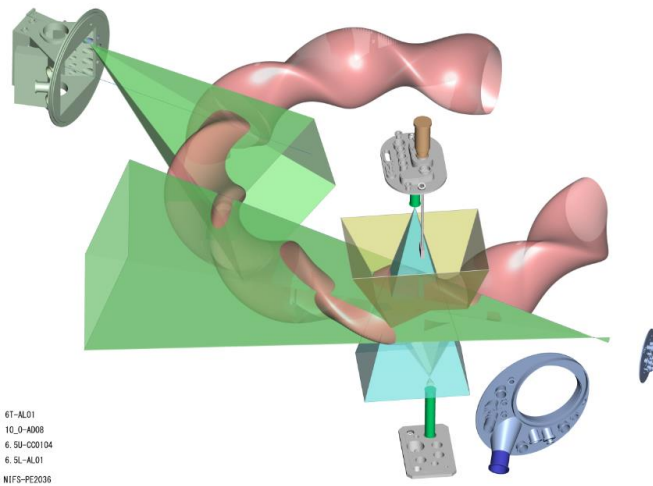
10-O



Optimization of fields of view (combined)

Combined field of view





Plasma voxel in radiation region (EMC-3)

13,161/46,800

Total number of IRVB channels

:2,528ch

- All plasma voxel are viewed by combined IRVB field of view

Summary

For radiation measurement in LHD

- Reconstruction of 3D radiation profile from 4 IRVBs data is necessary.

For 3D Tomography

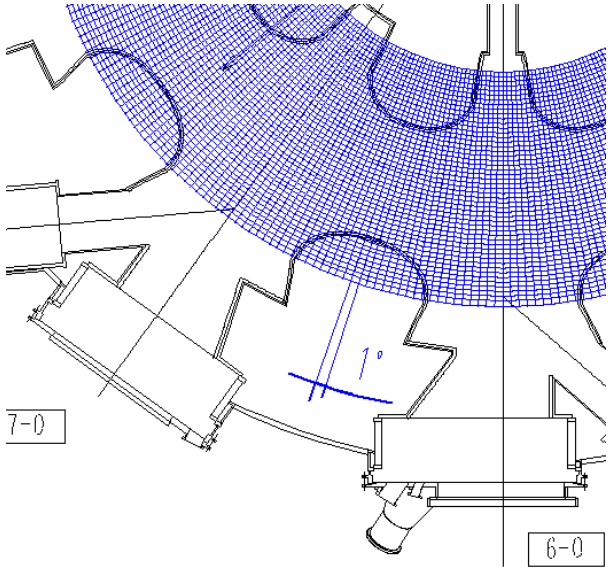
- Assumption of helical symmetry is employed to complement field of view.
- Field of view are adjusted to eliminate non-visible voxels.

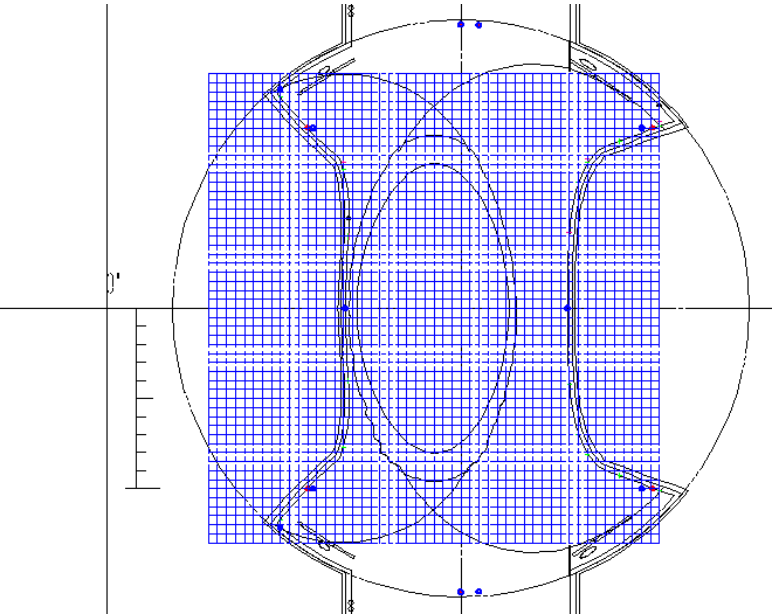
Future plan

- Tomography schemes will be applied.
  - Hopfield
  - SVD
- Number of IRVB channels will be increased to about 5000.

Plasma voxel

Plasma voxel





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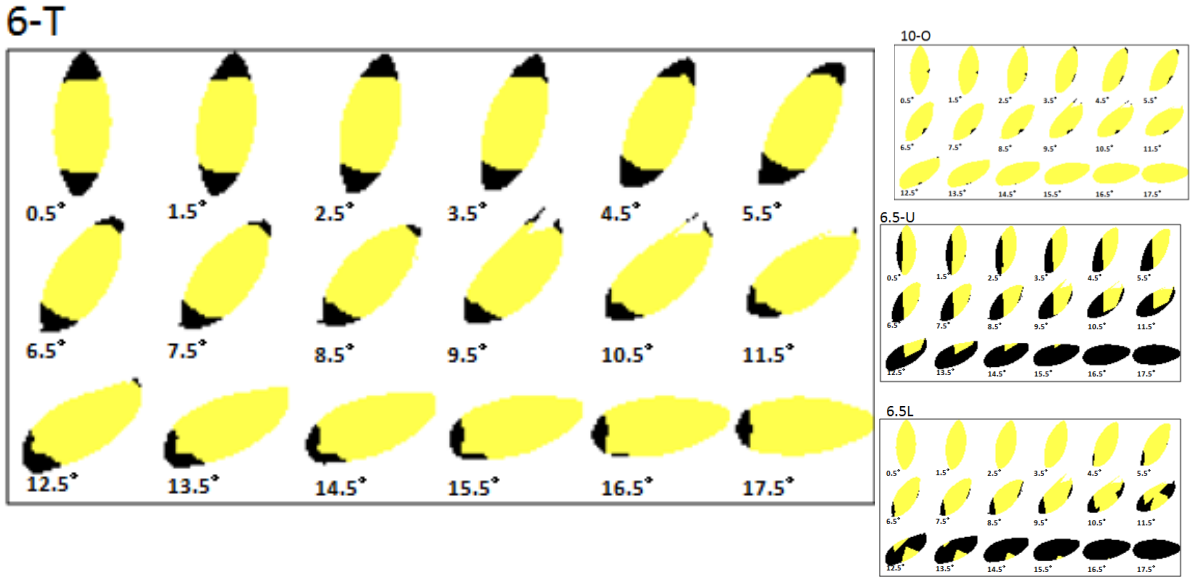
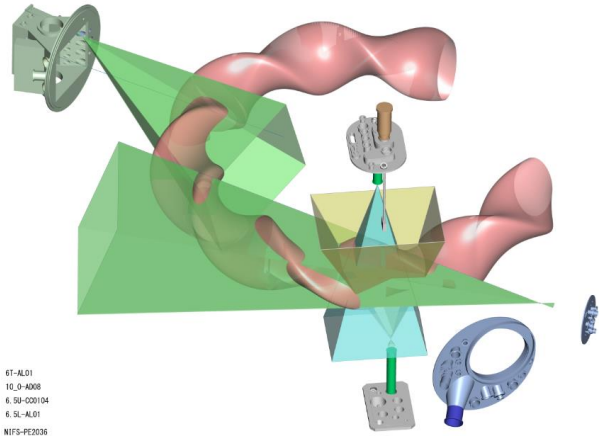
Optimization of fields of view

Fields of view for each IRVB





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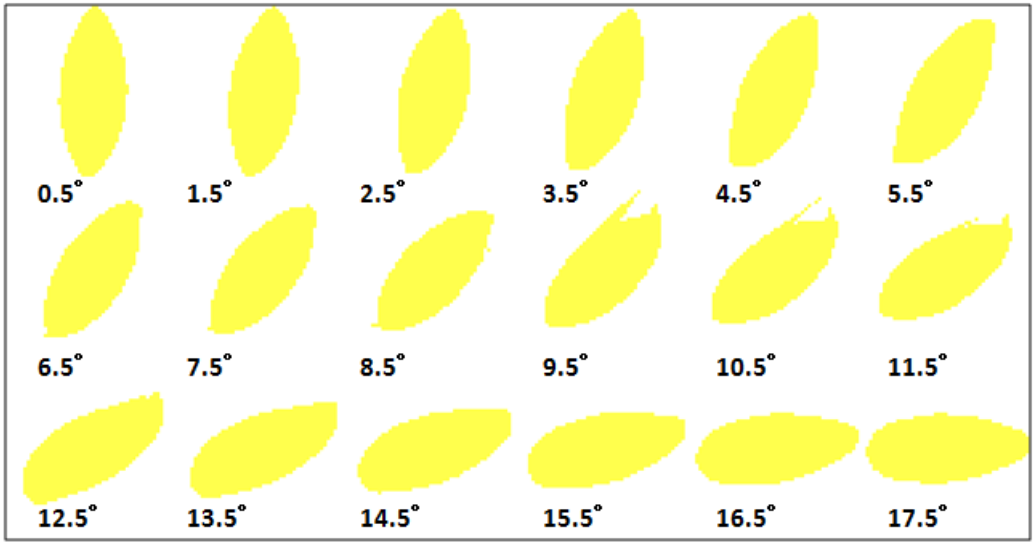
Combined field of view



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13,161/46,800

Total number of IRVB channels :2,528ch

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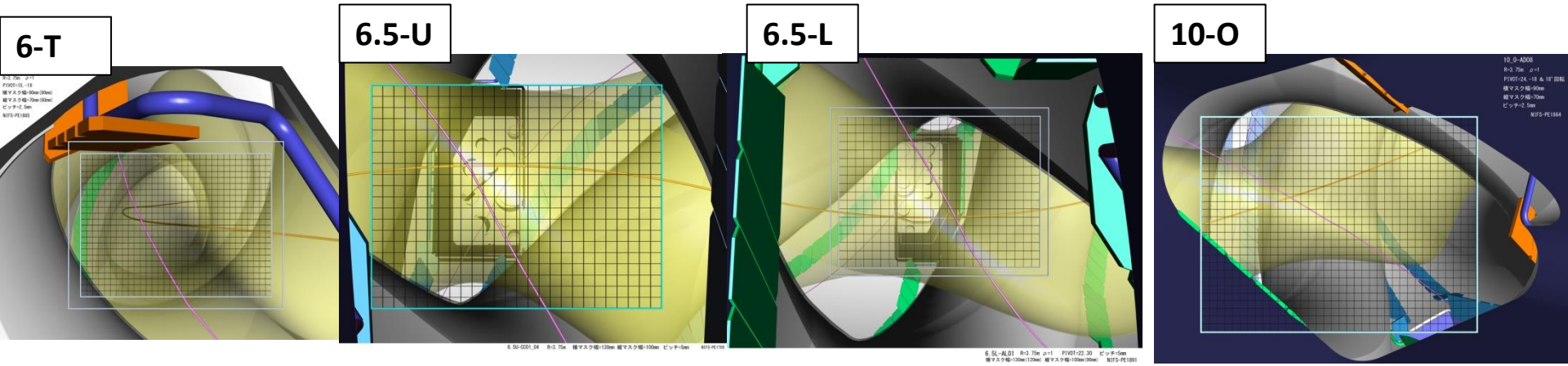
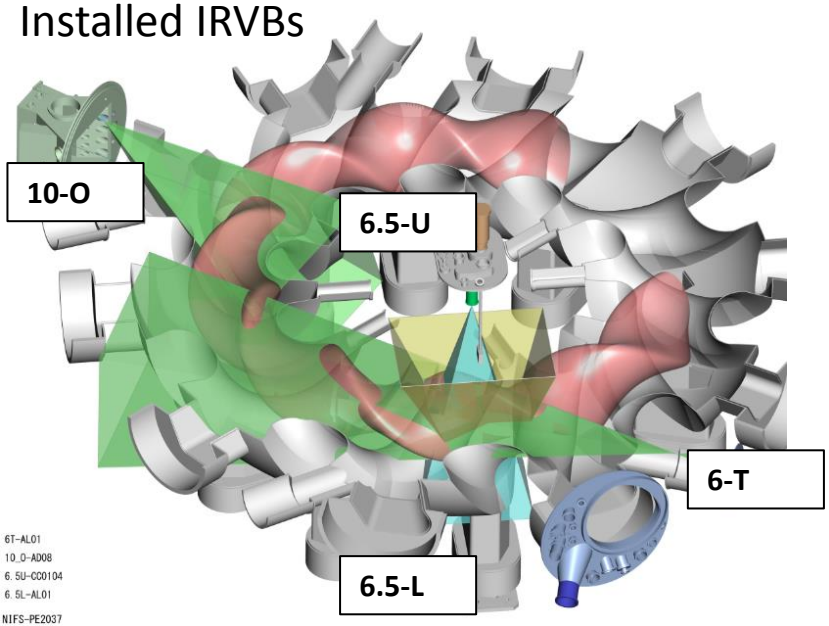
IRVB channels



Installed IRVBs



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Total number of IRVB channels
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Tomography (Inverse calculation)

$$P_{rad,j} = \sum_{k=1} h_{j,k} S_k$$

Measured (IRVB)

Calculated (result)

Geometry matrix

Issues on Tomography

CT for medical → Tomography is applied on multi slices
from measurement data from all directions.

In this study

- Installation location and direction are restricted
by port location for diagnostic instrument and LHD wall.

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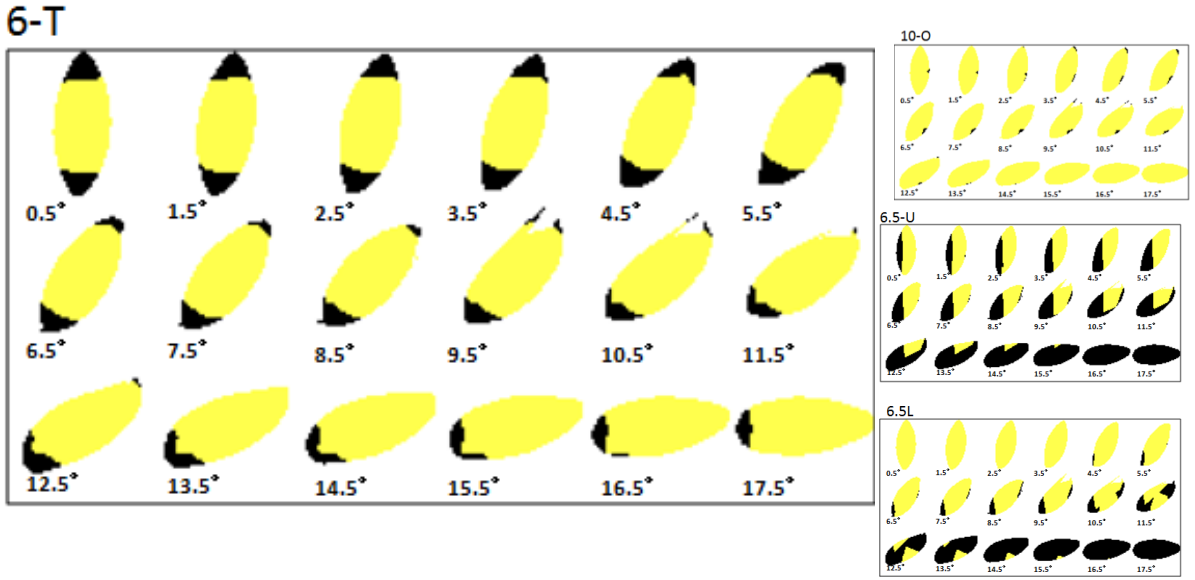
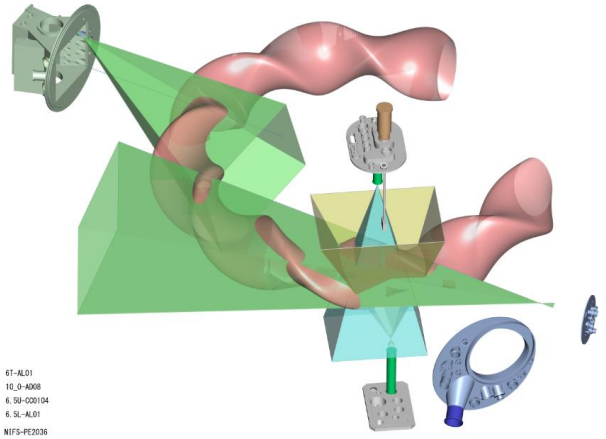
Optimization of fields of view

Fields of view for each IRVB





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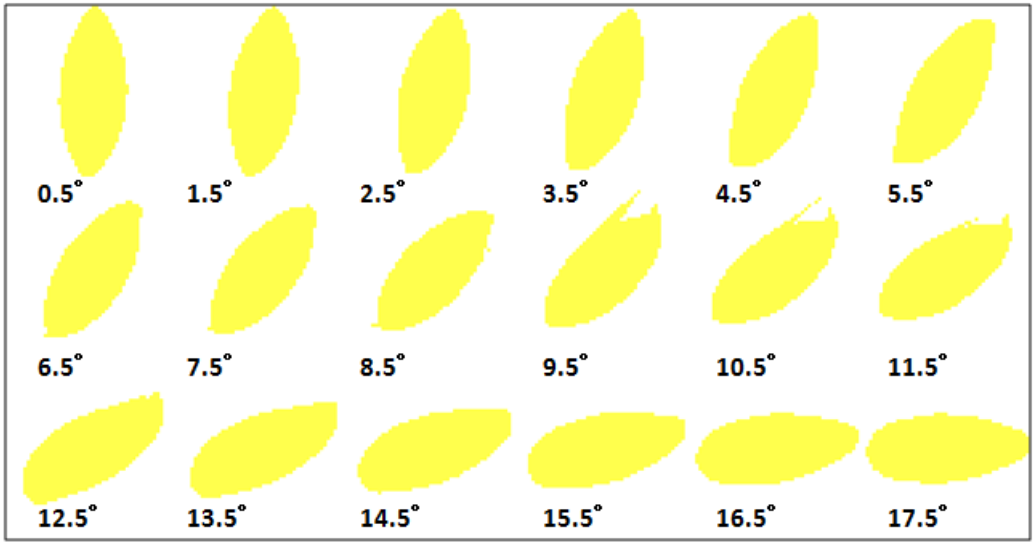
Combined field of view



Plasma voxel in radiation region (EMC-3)

13,161/46,800

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