# Beam emission measurement of hydrogen discharge with carbon pellet injection in LHD


Katsunori Ikeda

*National Institute for Fusion Science, Japan*

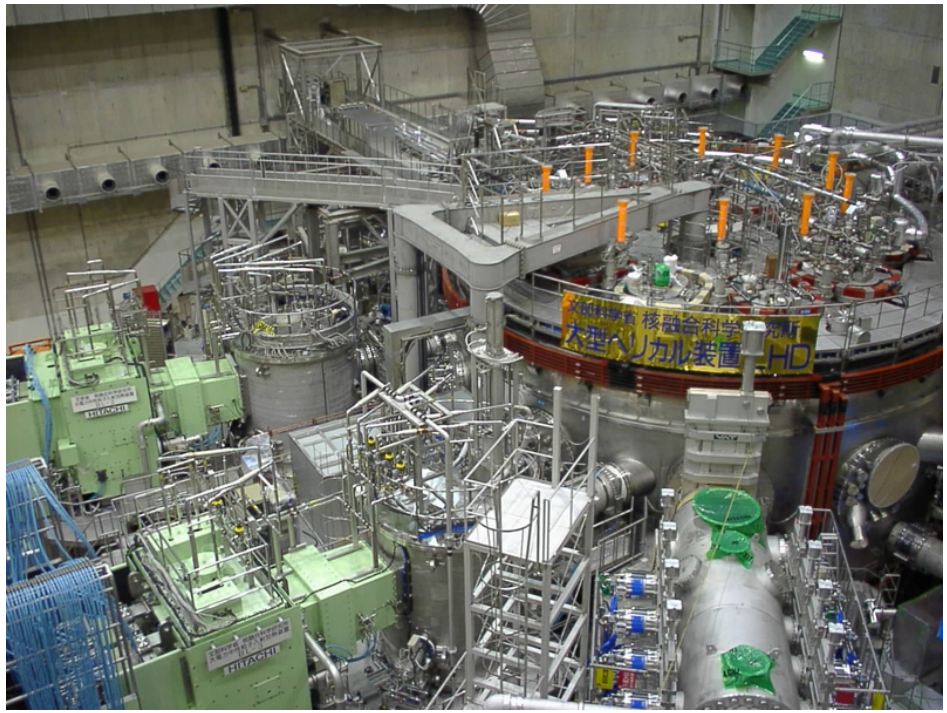
Supported by M. Osakabe, A. Whiteford, K. Nagaoka, M. Yoshinuma, K. Ida, O. Kaneko, D. Kato, H. Nakano, S. Morita, Y. Takeiri, K. Tsumori, and LHD experiment group

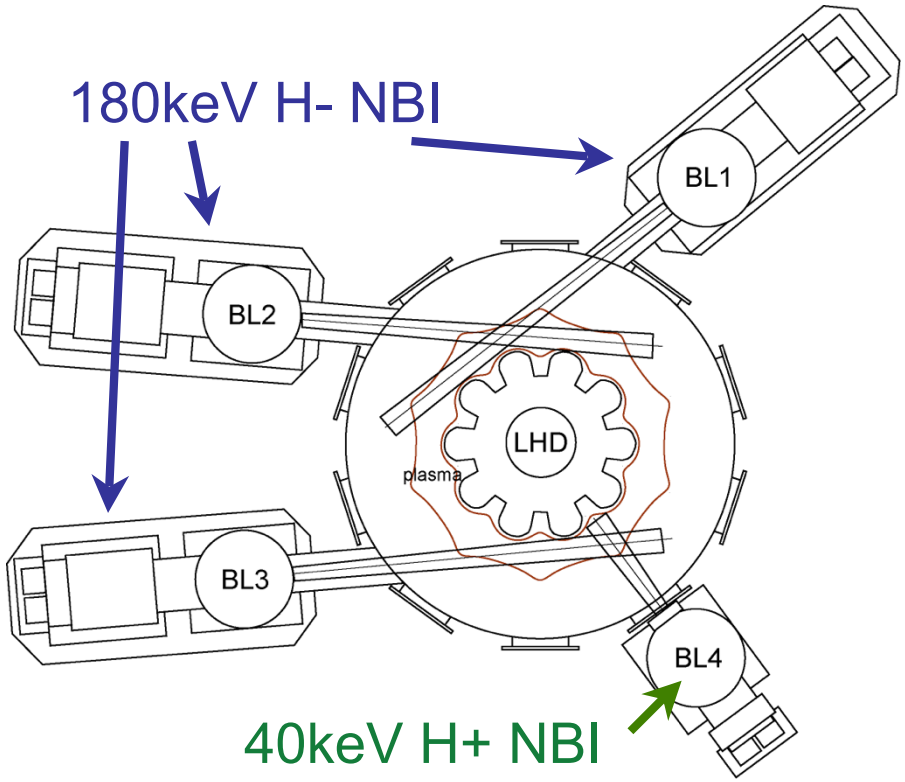
# Outline

- Introduction of LHD and beam emission diagnostic system for beam attenuation
- Producing high Ti plasma using carbon pellet injection
- Result of beam emission measurement
- Estimation of beam deposition in hydrogen plasma mixed carbon using ADAS data.
- Discussing beam heating and carbon fraction

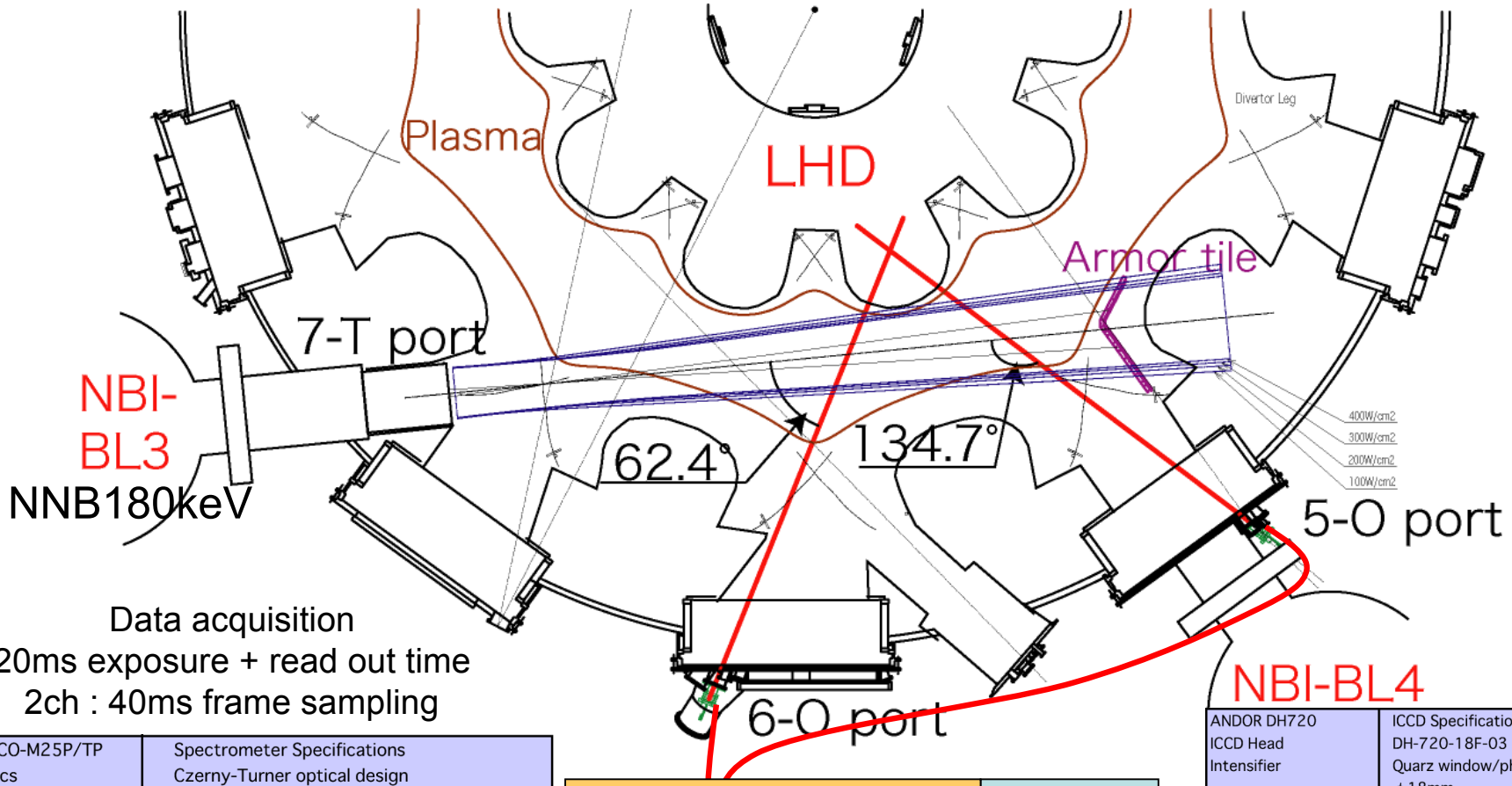
# Large Helical Device

- Machine Size : Height 9.1m, Diameter 13.5m
- Plasma size : R=3.5~4.0m r=0.6~1m(ellipse) Volume=30m$^3$ Bax<3T
- Three NNBI systems and a PNBI system are used (H beam).
- NNBI:180keV&5MWx3(tangential) PNBI: 40keV&6MW(perpendicular)
  (16MW beam now) (7MW beam now)





# Optical Configuration for Beam Emission Diagnostic




Data acquisition
20ms exposure + read out time
2ch : 40ms frame sampling

| JASCO-M25P/TP | Spectrometer Specifications |
|---|---|
| Optics | Czerny-Turner optical design |
| (polychromator) | with troidal mirror for aberration correcting |
| Focal length | 25cm |
| Grating | 1800 grooves/mm (52mmx52mm effective) |
| | 500nm braze |
| Spectral range | 0-1200 nm(mechanical) |
| | Lower cut filter L-37 |
| Reciprocal dispersion | 1.8nm/mm |
| optical resolution | 0.1nm(spectrometer) |
| | 0.05nm/pixel |

**Spectrometer**

Total Spec. of SP System
Dispersion : 36.5pm/pixel
resolution : 0.21nm

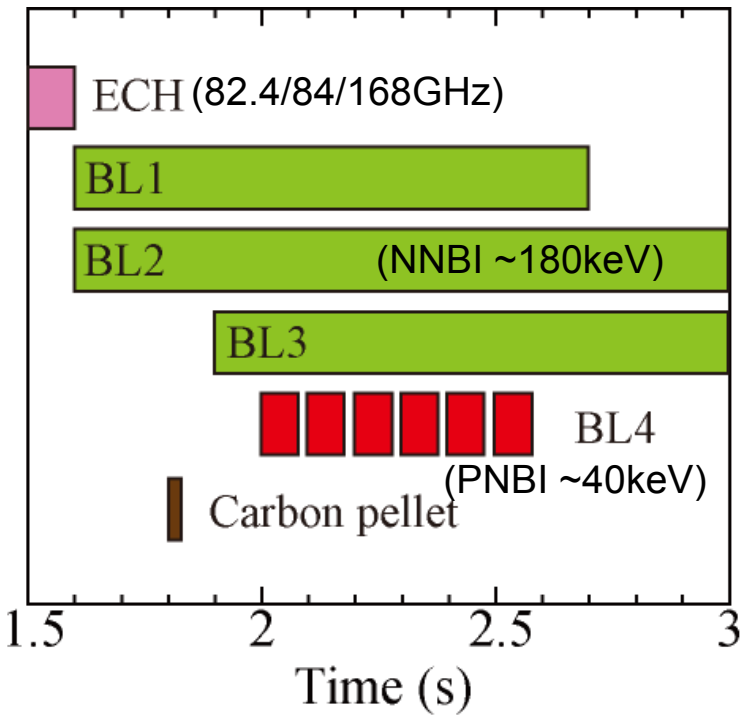
**ICCD**

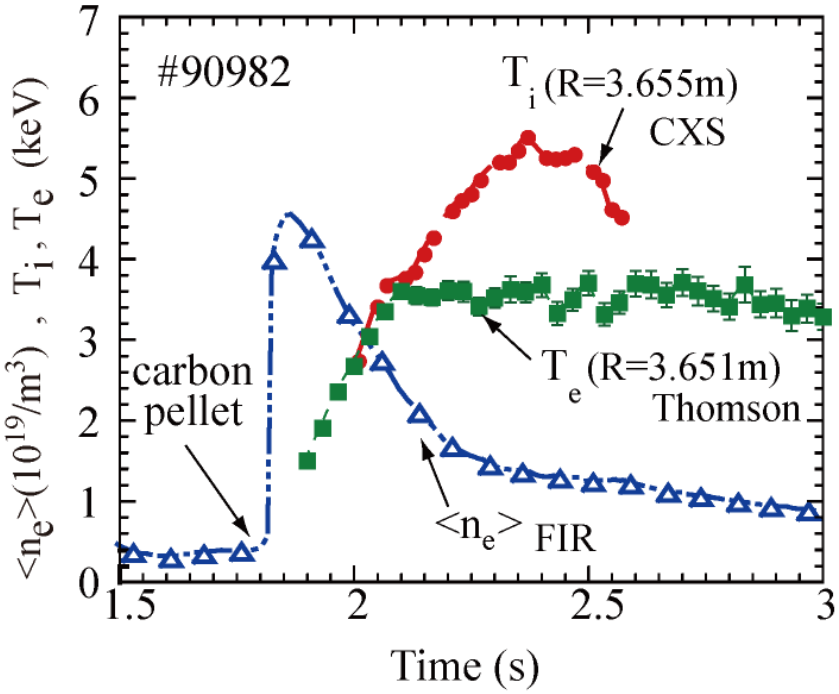
**PC**

| ANDOR DH720 | ICCD Specifications |
|---|---|
| ICCD Head | DH-720-18F-03 |
| Intensifier | Quarz window/photo cathode W |
| | $\phi$18mm |
| | phosphor P43 |
| CCD(E2V30-11) pixels | 1024X256 pixels [eff. pixel size 26$\mu$m2] |
| | 690x256(effective) |
| Spectral range | 180~850 nm |
| Peak QE | 19.77% |
| Max ICCD gain | 783 count per photoelectron |
| Dark current | 0.19electrons/pixel/sec @-36℃ with WC |
| min. spatial resolution | FWHM 35.43$\mu$m |
| A/D resolution | 16-bit |
| Read out speed | 1,2,16,32 $\mu$sec per pixel |

# Waveform of Carbon pellet discharge

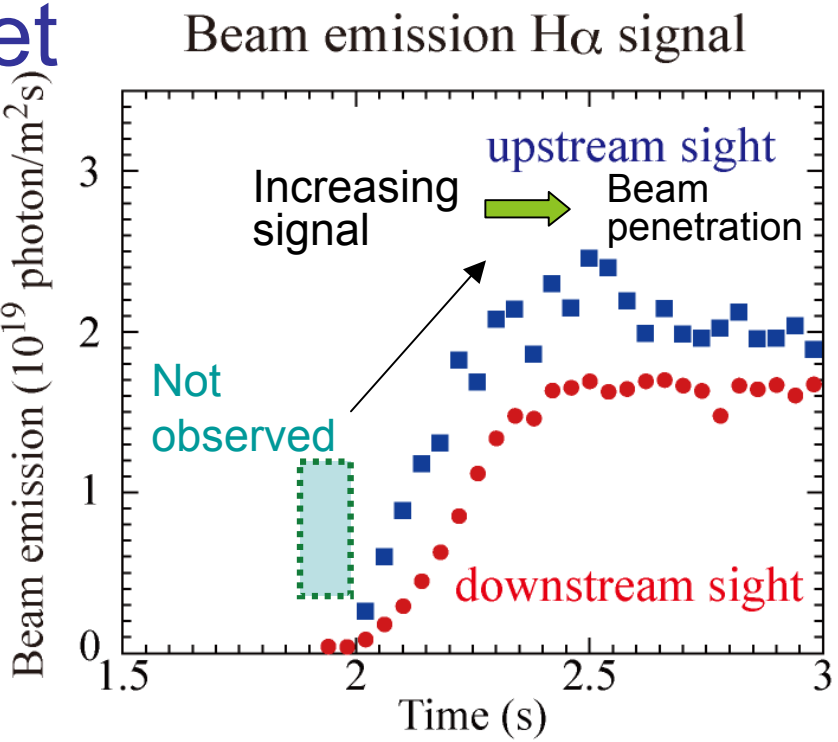
- Initial plasma is started by ECH.
- Low density plasma build up by two NB heatings. (<ne>~0.4x10$^{19}$m$^3$)
- Small carbon pellet ($\phi$=1.4mm) is injected at 1.8s, <ne> increase to 4.5x10$^{19}$m$^3$.
- Additional high energy NB heating at 1.9s. (Beam attenuation measurement)
- Additional low energy & high current NB heating at 1.9s (for CXRS measurement)
- Improving Ti to 5.6keV

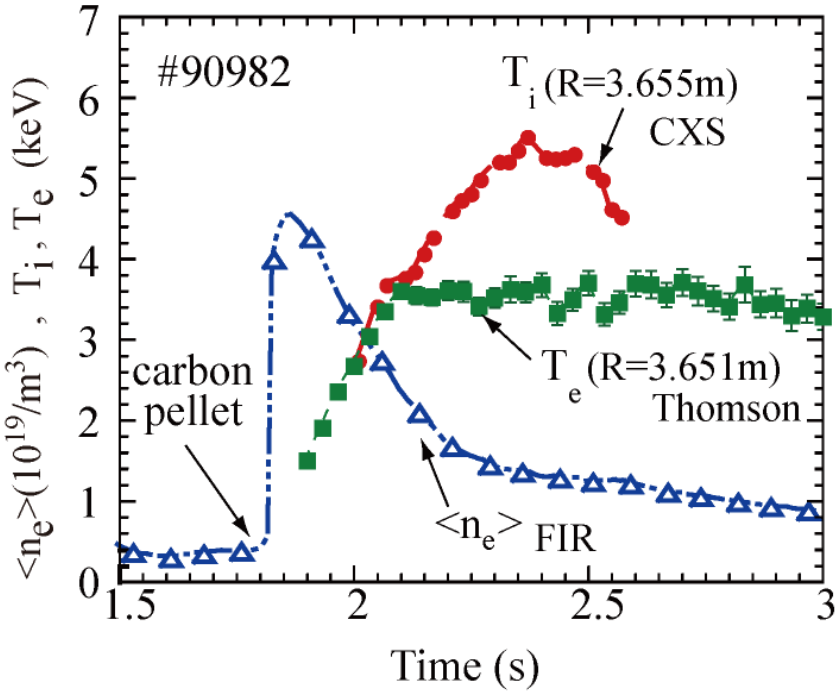


# Waveform of Carbon pellet discharge

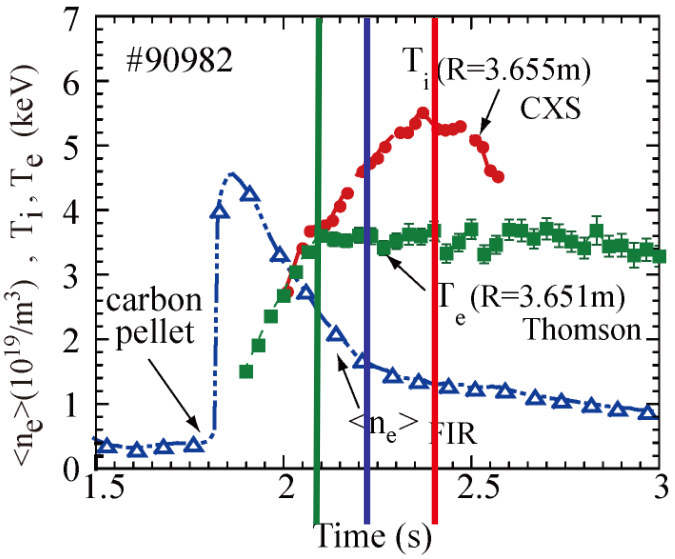
- Initial plasma is started by ECH.
- Low density plasma build up by two NB heatings. (<ne>~0.4x10$^{19}$m$^3$)
- Small carbon pellet ($\phi$=1.4mm) is injected at 1.8s, <ne> increase to 4.5x10$^{19}$m$^3$.
- Additional high energy NB heating at 1.9s. (Beam attenuation measurement)
- Additional low energy & high current NB heating at 1.9s (for CXRS measurement)
- Improving Ti to 5.6keV
- No beam emission due to strong beam attenuation before t=2.0s
- Increasing B.E signal as decreasing $n_e$



# Density and temperature profile during increasing Ti

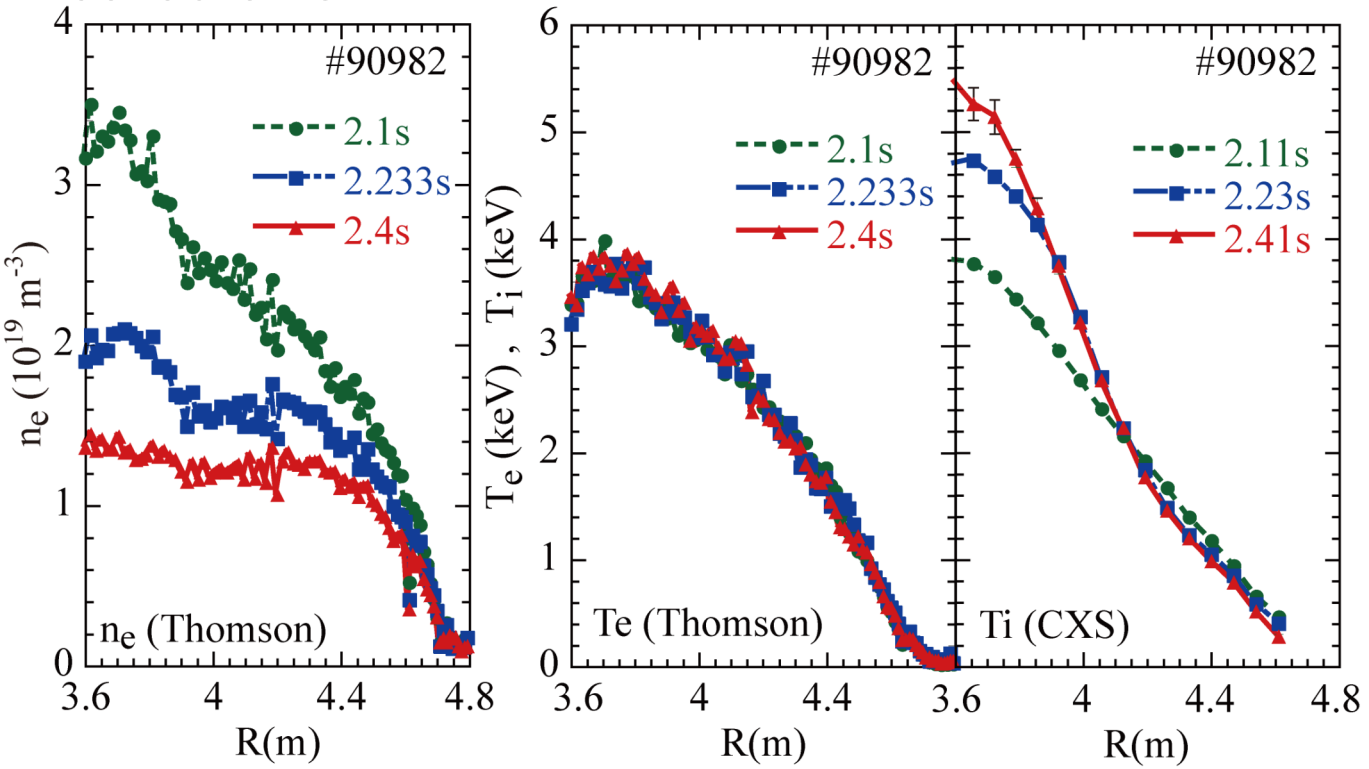
- Peak density profile was produced by carbon pellet injection.
- Density profile formed flat
- Center ion temperature increased
- These profiles are used for a beam attenuation calculation.




Peak

$n_e$

Flat

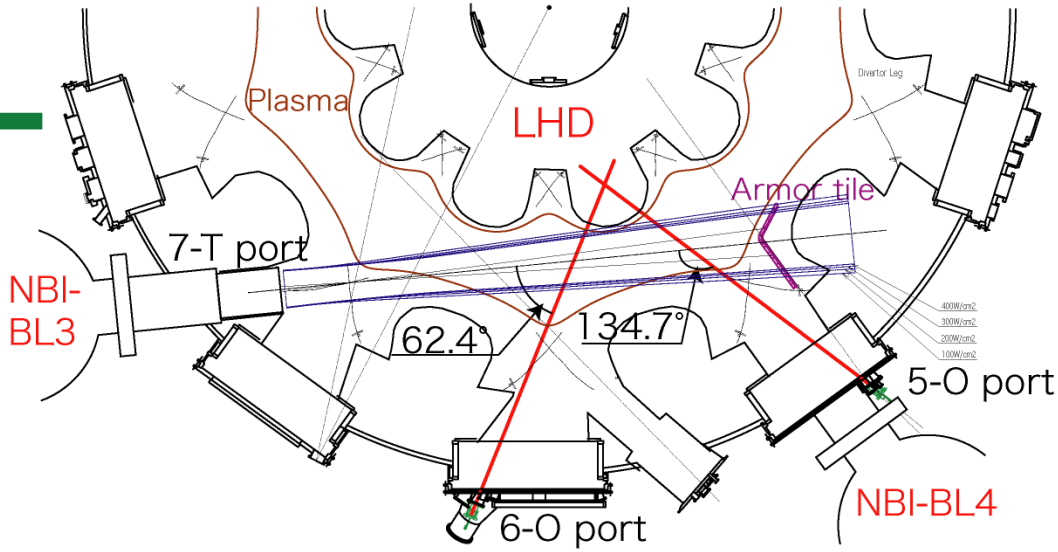


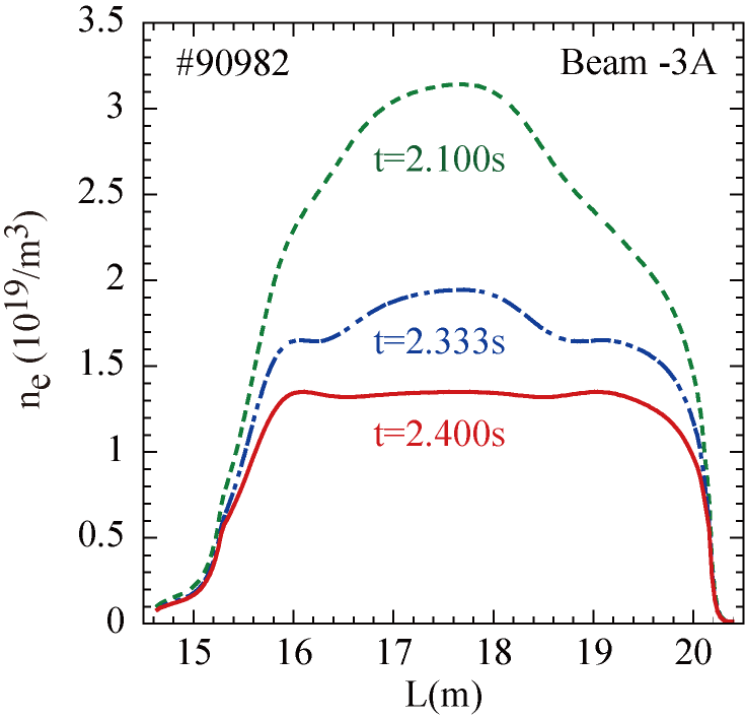

Peaking at center

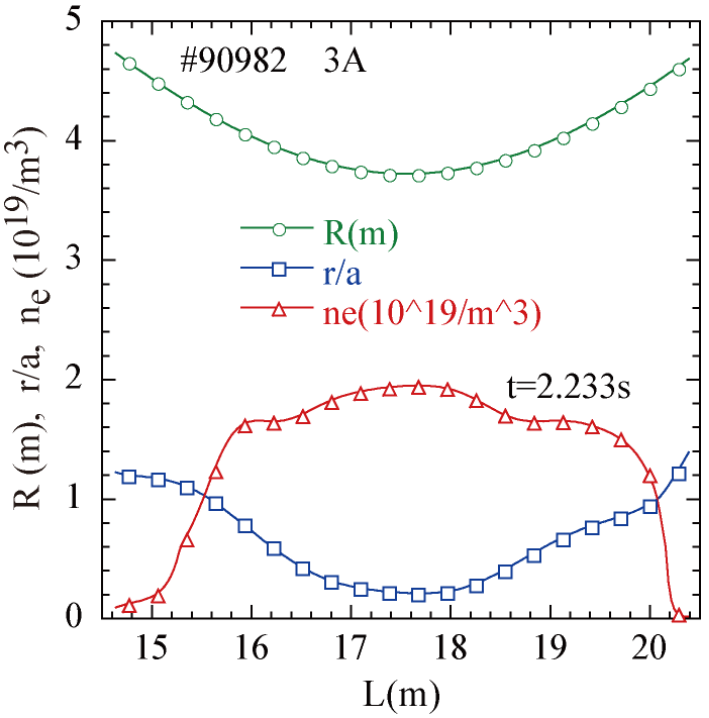
$T_i$

# Electron density along the beam injection axis

- Neutral beam path through the plasma 4~5m long.
- Closest position is about 17.5m downstream from ion source.
- Beam attenuation is estimated by local parameters along the beam injection axis.



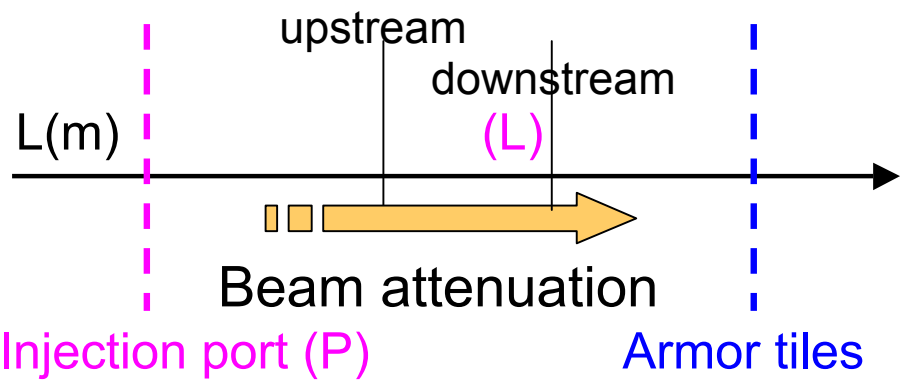
# Estimation of beam emission intensity used ADAS data

Attenuation factor

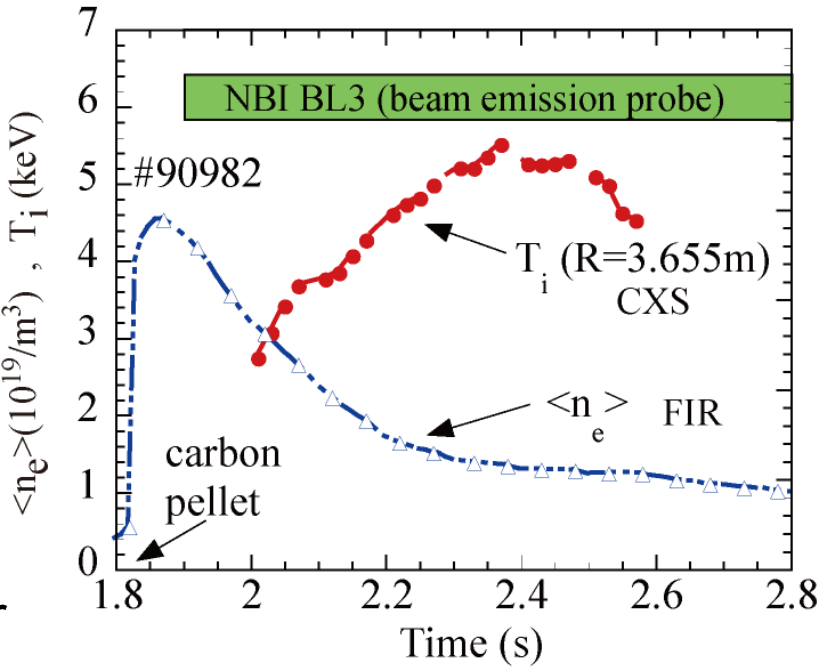
$$\frac{n_{beam}(L)}{n_{beam}(P)} = \exp\left(-\int_P^L n_e(l) S_{cr}(l) \sqrt{\frac{m}{2E}}\, dl\right)$$

ADAS data base

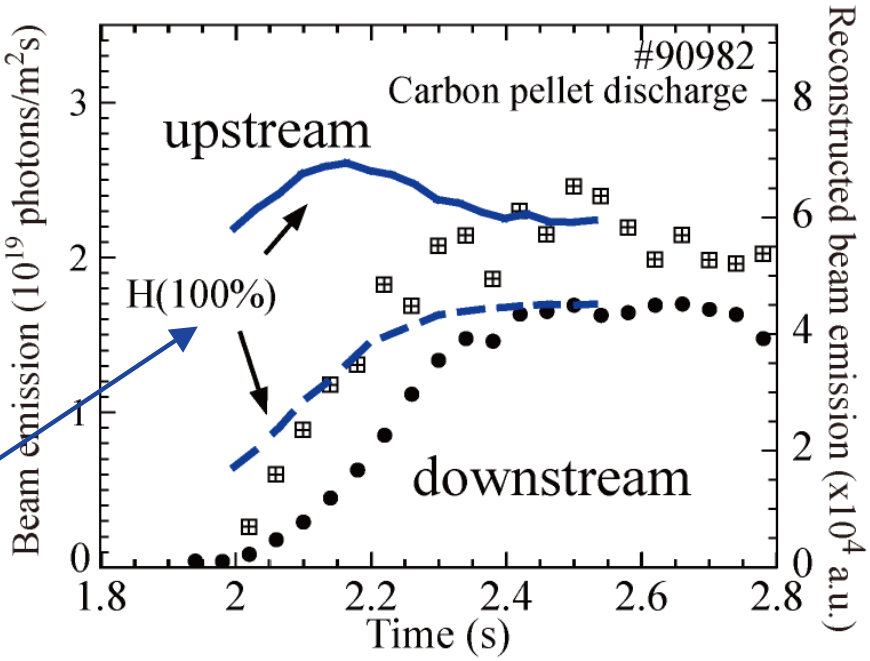
Local parameter $n_e, T_e, T_i$ → $S_{cr}$, $E_{beam}$ → Attenuation factor $n_{beam}(L)/n_{beam}(P)$




Beam emission signal is not consistent used a pure hydrogen model

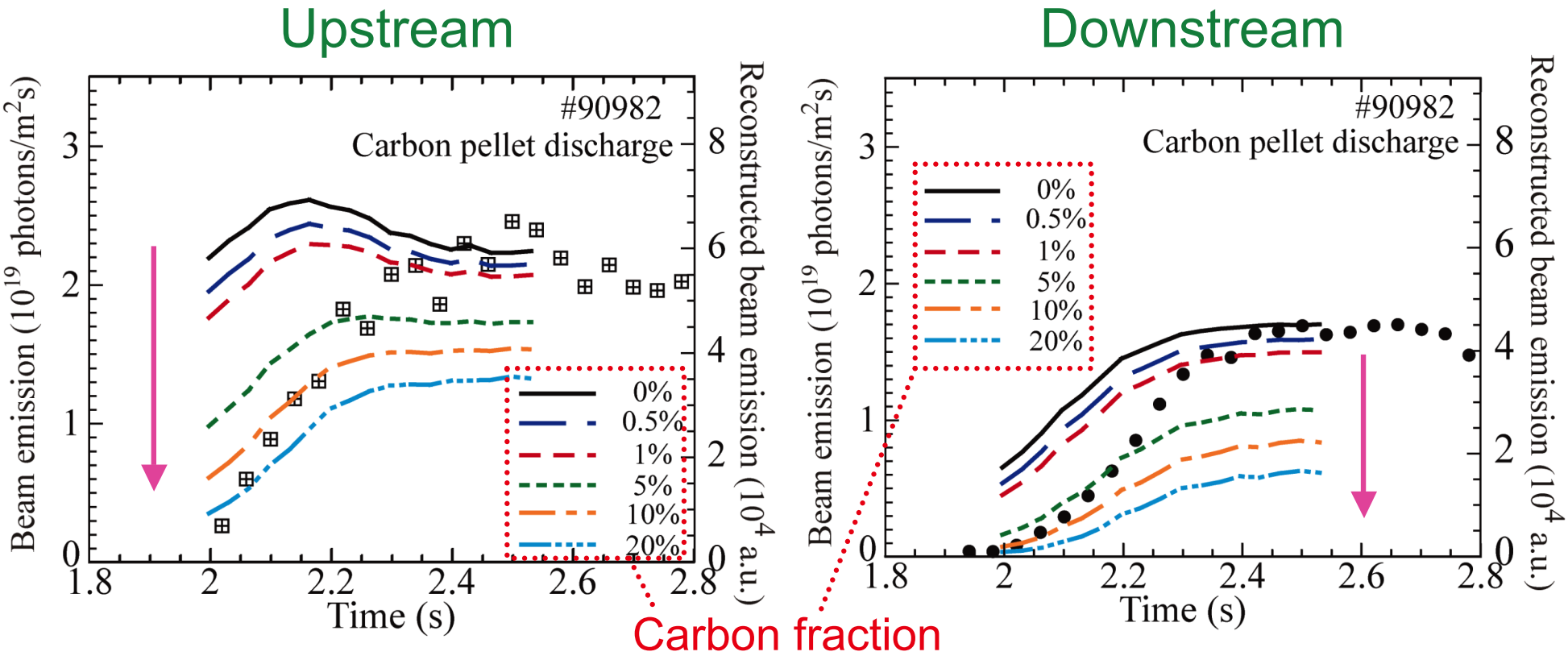



Beam emission



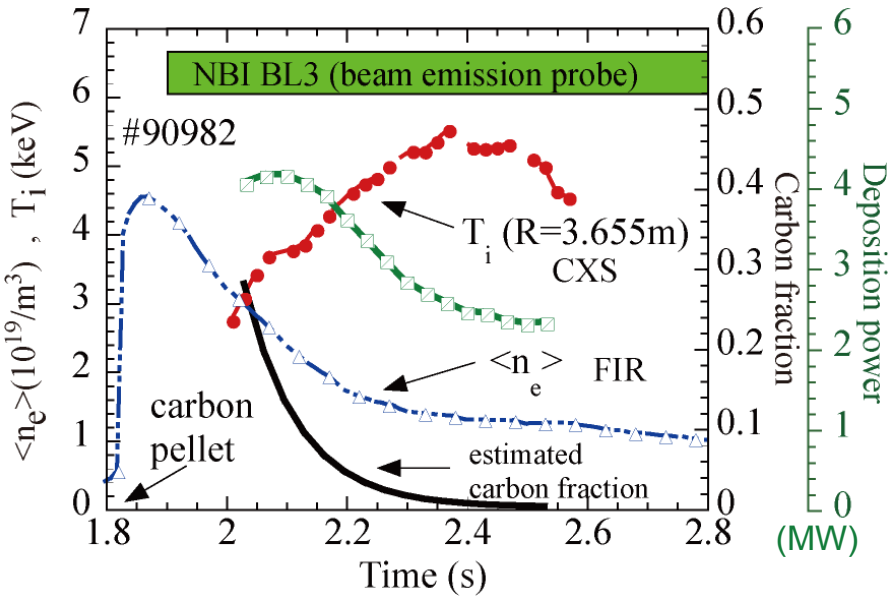
# Estimation beam emission intensity ( Mixing H and C target plasma model)

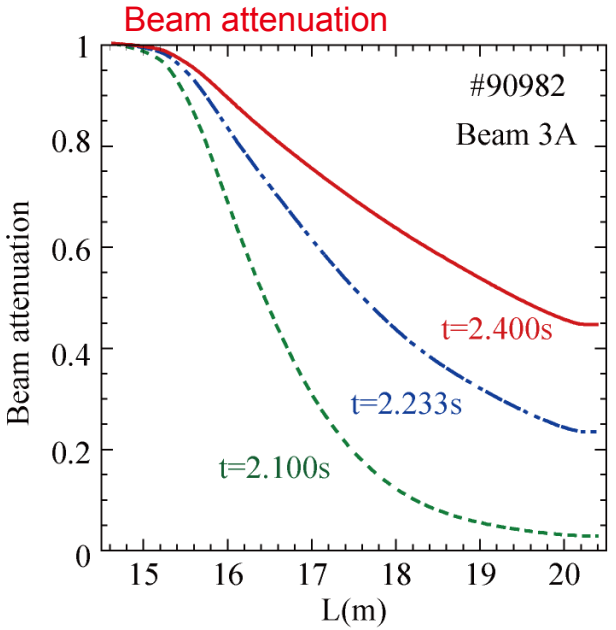
- Beam emission intensity decreases as increasing carbon fraction.
- Carbon is effective to increase beam attenuation.




- It is reasonable to assume that changing the carbon fraction

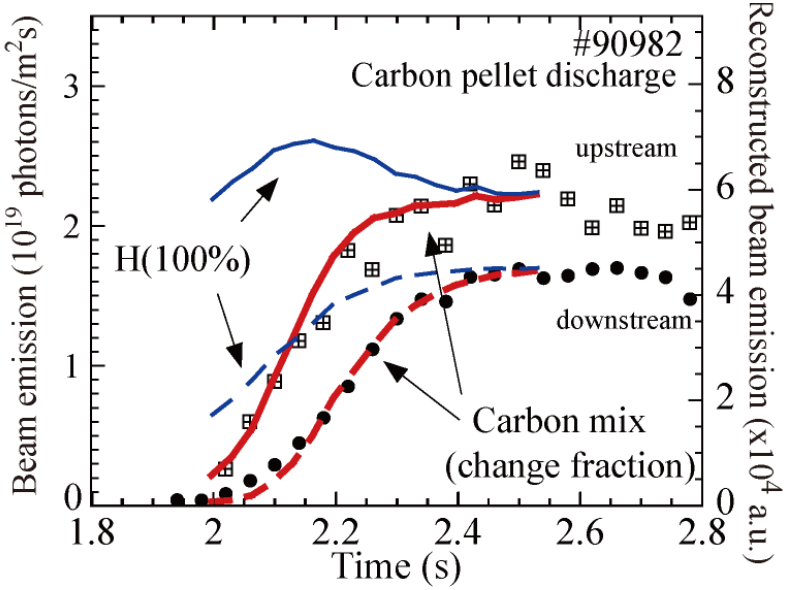
# Beam attenuation along the beam injection axis

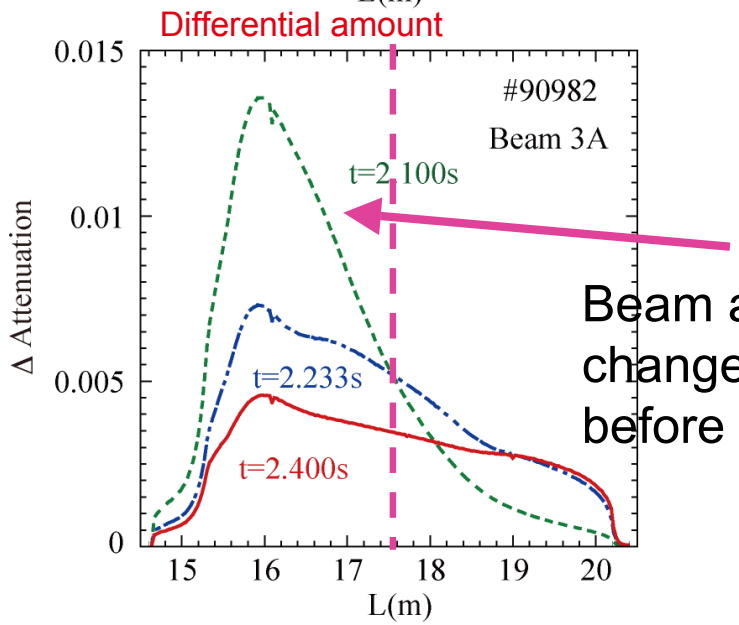



| Carbon fraction | Beam deposition |
|---|---|
| 0.5% | 56% |
| 3.1% | 76% |
| 13.4% | 97% |

Decreasing deposition power




Beam absorption changes substantially before the closest point

Changing carbon fraction → Beam emission intensities fit well

# Summary

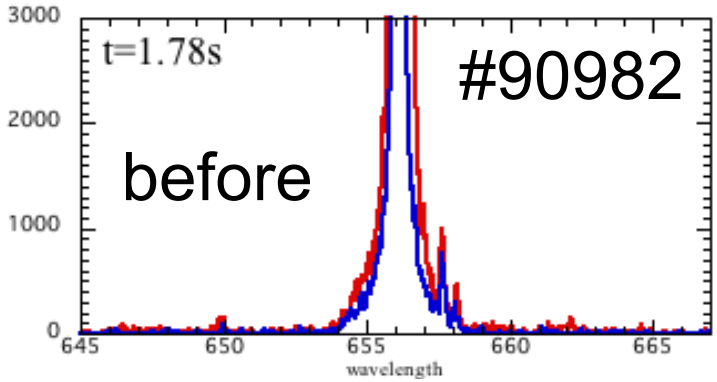
- Ion temperature has been improved 5.6keV by C pellet discharge in LHD.
- Strong beam attenuation was observed by beam emission measurement.
- Reconstruction beam emission intensity estimated by ADAS data with H & C plasma model is well fit to the observed behavior.
- Beam emission measurement with ADAS analysis is a good utility to know NBI beam attenuation directly. It will be able to apply for future high energy NBI.

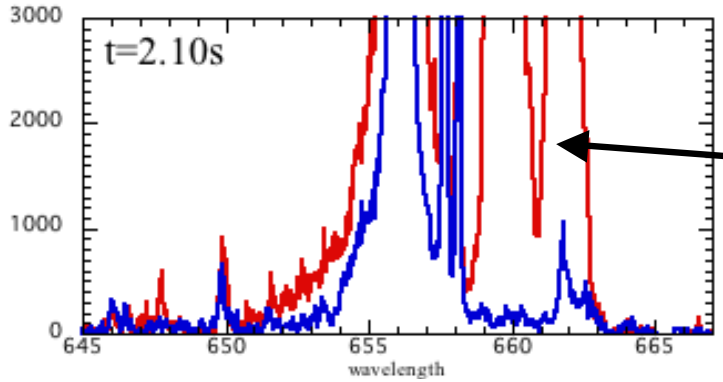
# Beam Emission Spectrum

upstream
downstream

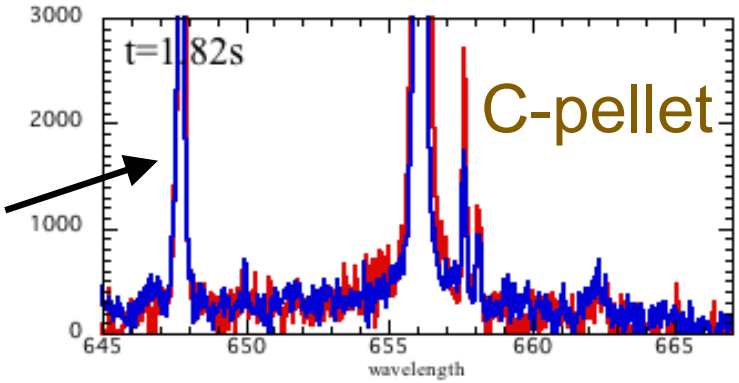
Hα

Beam heating

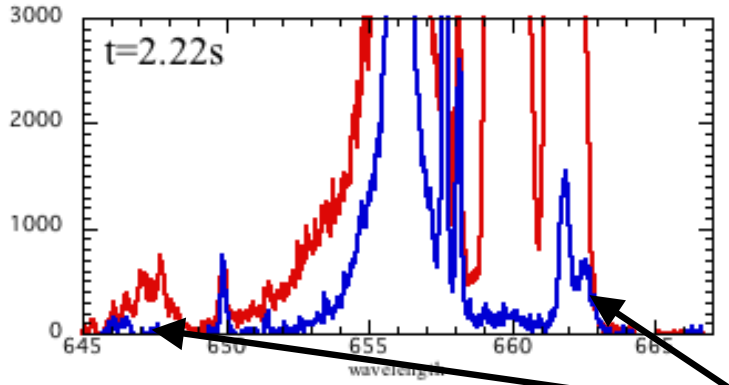


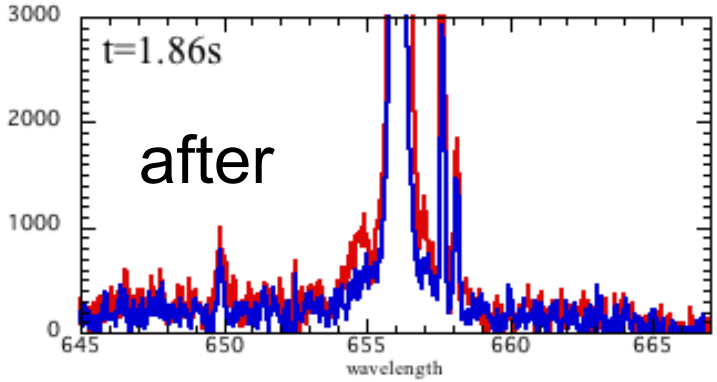

BL4
PNBI

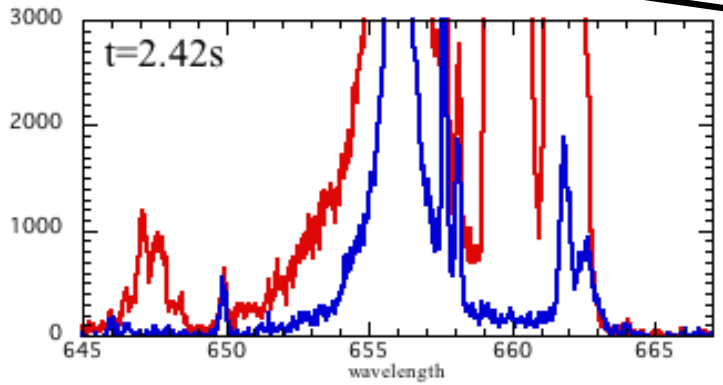



Unknown
spectrum

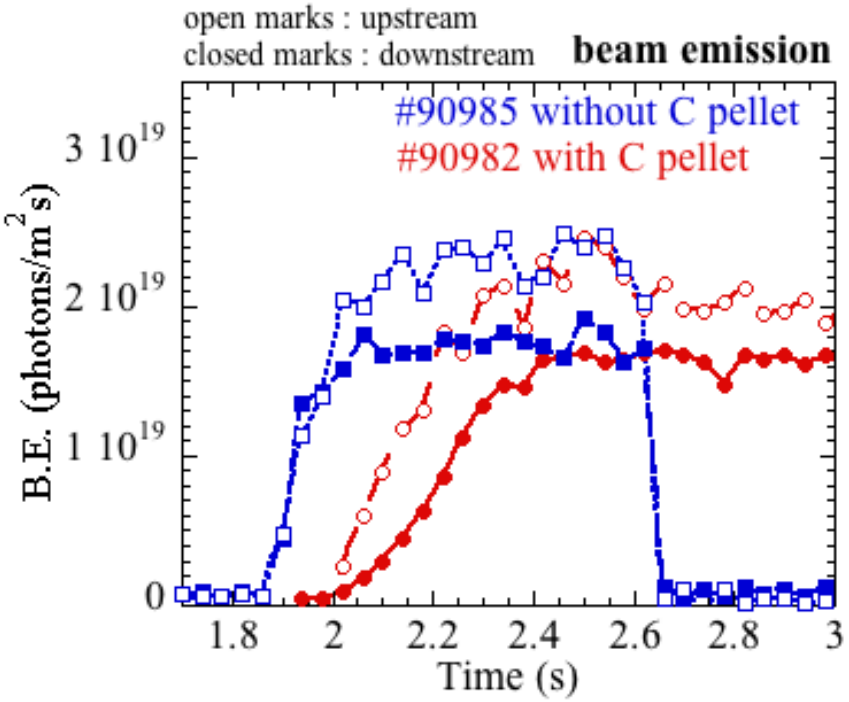


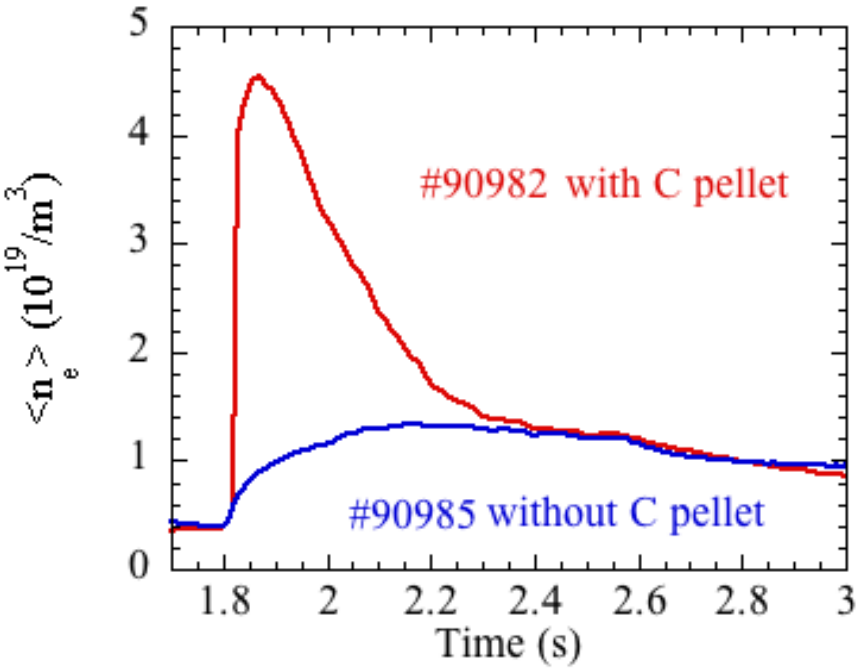

BL3
NNBI



# Hydrogen discharge vs carbon pellet discharge



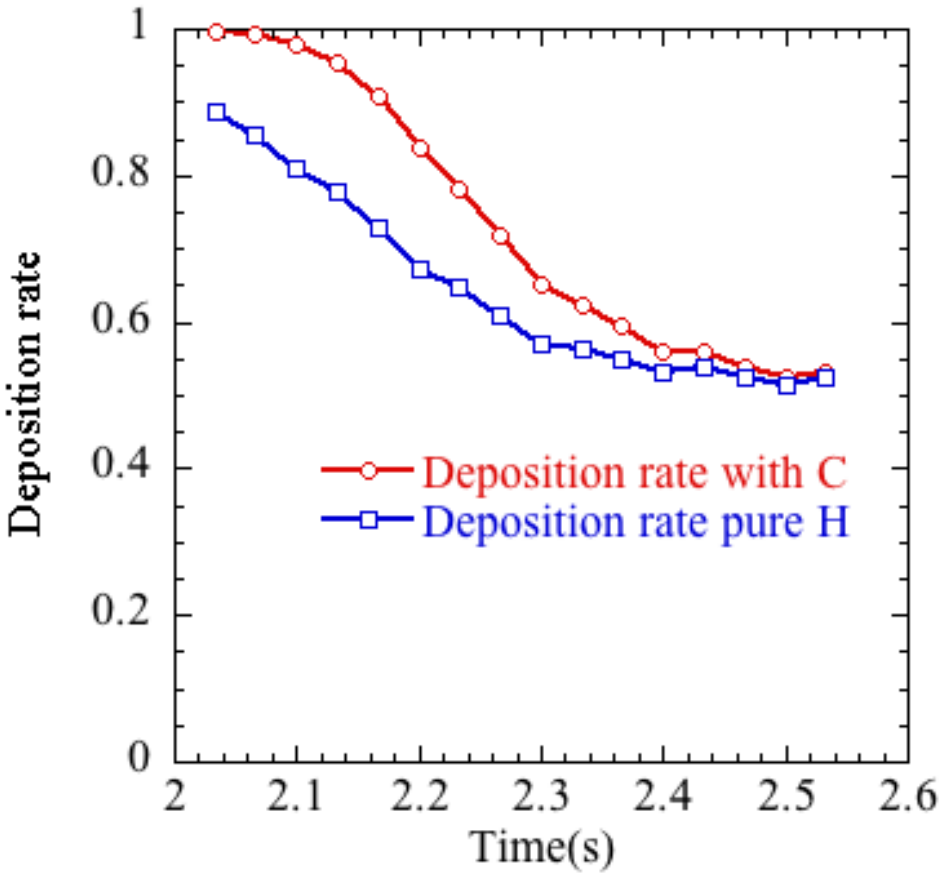



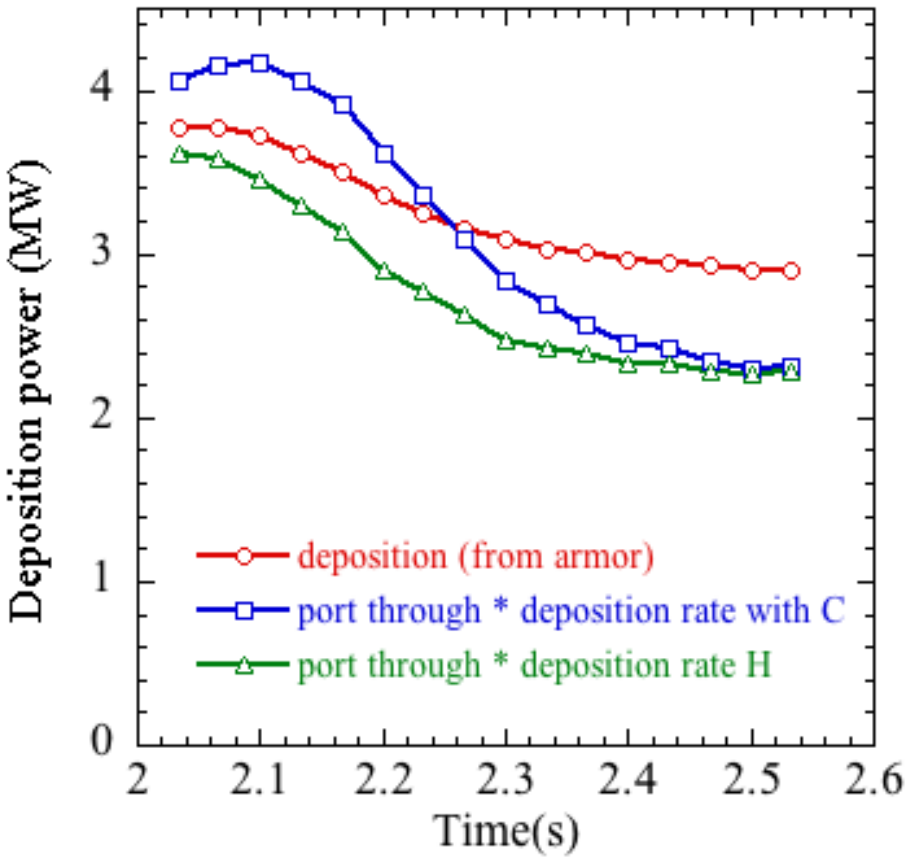

Carbon fraction is almost equal after 2.4s

# Beam deposition

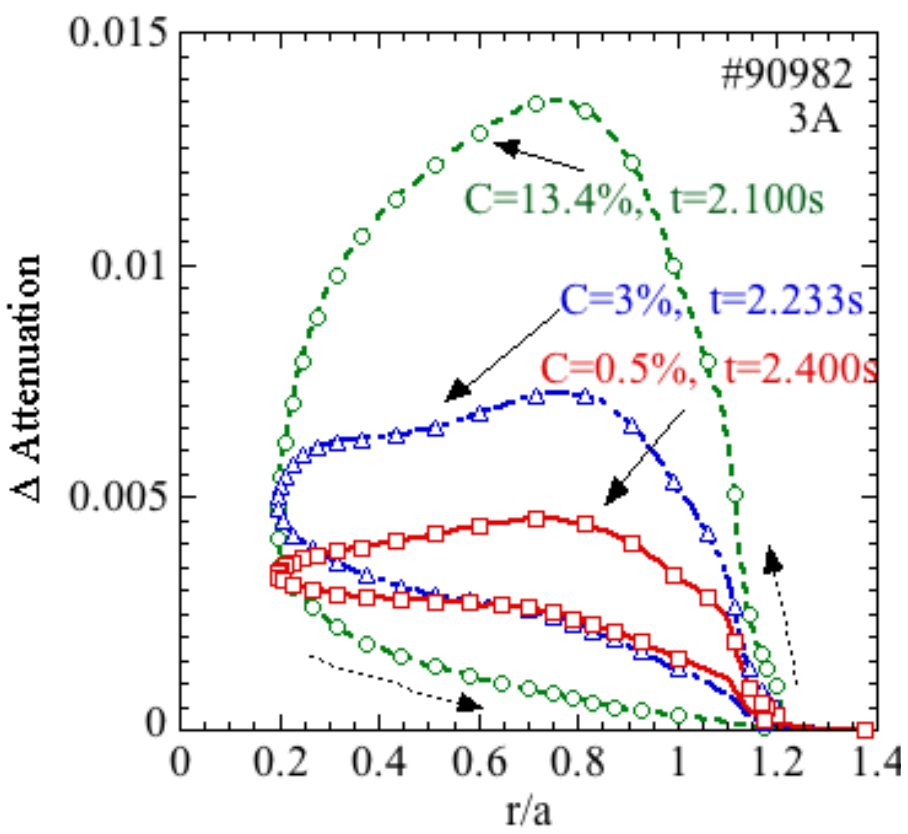
Deposition rate
- Hydrogen + Carbon
- Hydrogen

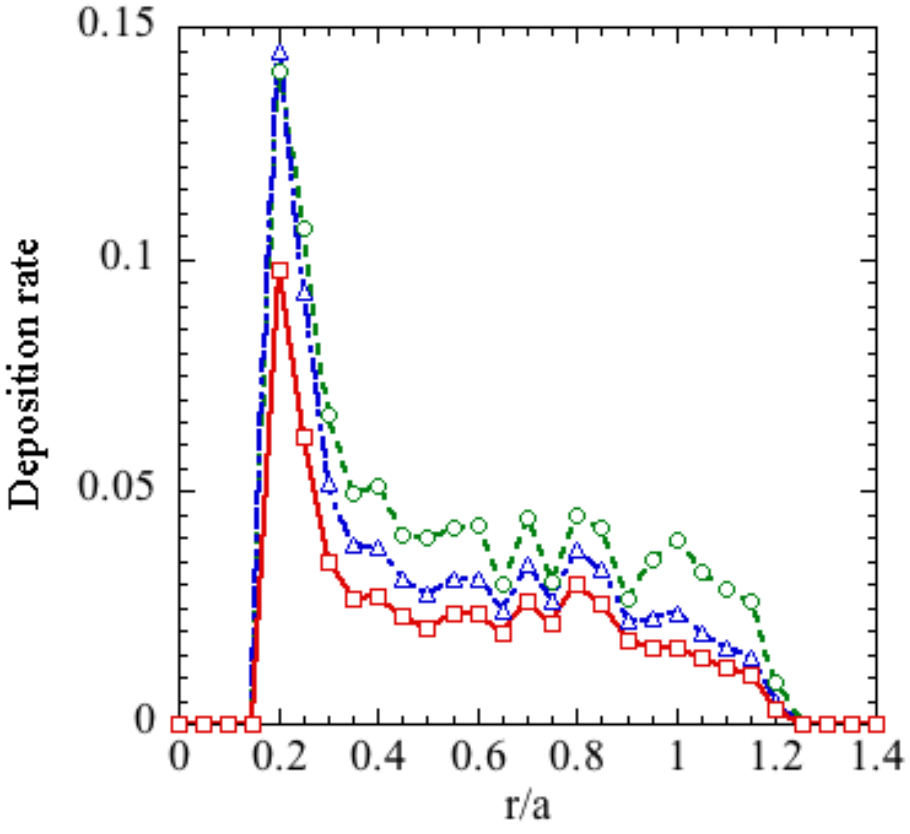
Deposition Power
- Armor tile estimation
- Hydrogen + Carbon
- Hydrogen



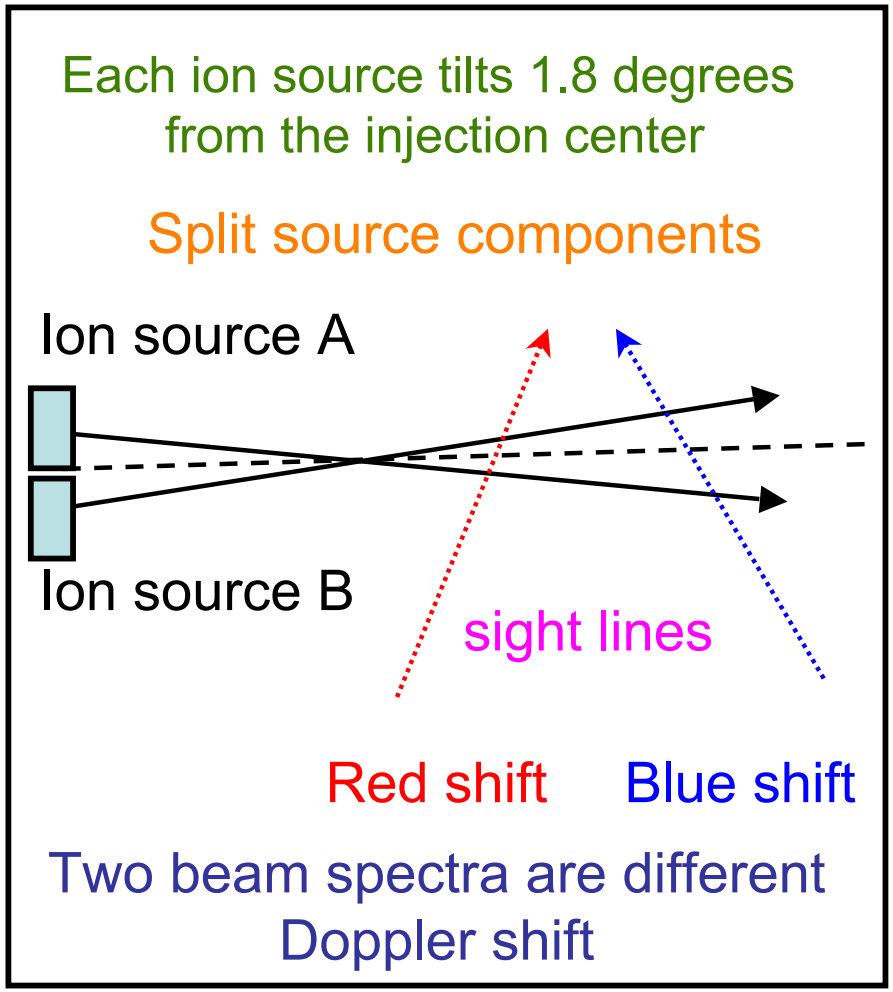



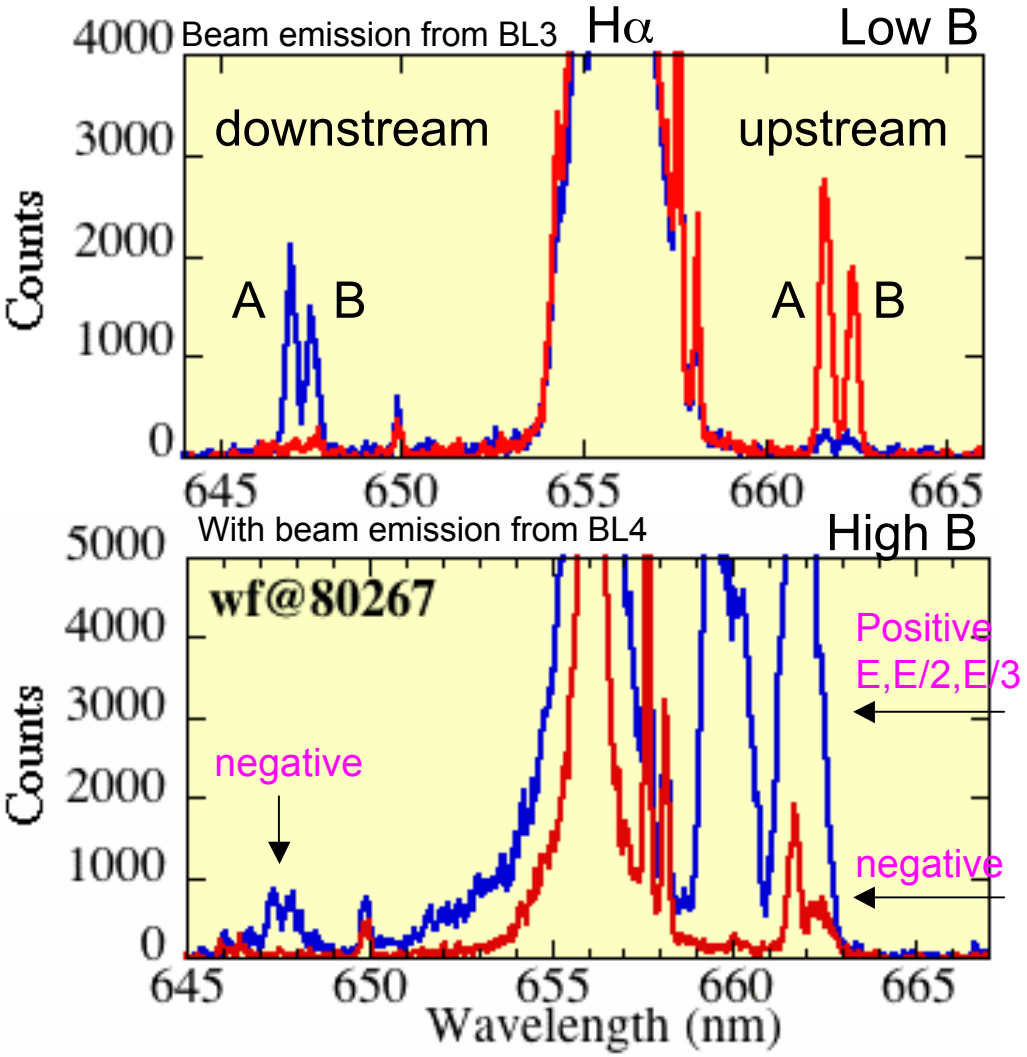
# Deposition profile



# Beam Emission Spectrum




The beam emission spectrum is able to separate from the background Hα emission with the wavelength of 656.3nm by the Doppler effect.