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Fast-ion D_α spectroscopy diagnostics in KSTAR

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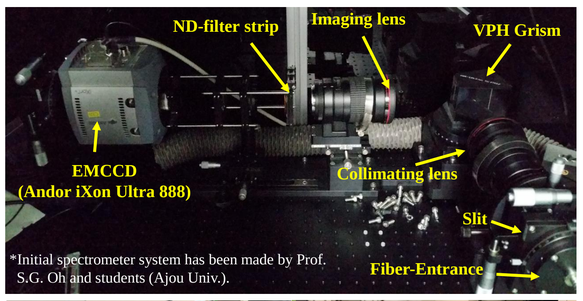
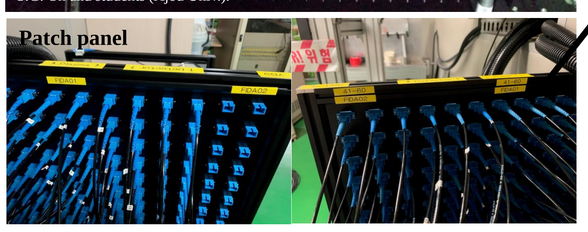
Introductions

- In KSTAR FIDA diagnostic system has been developed and the commissioning has been performed since 2018 KSTAR experimental campaign.
- It consists of the grism, two tele-lens sets, blocking strip and EMCCD. The temporal, spectral and spatial resolutions of the spectrometer are 20 msec, 0.0215 nm and 4-10 cm respectively.
- FIDASIM calculations has been commissioning with KSTAR spectrometer data to precisely evaluate FIDA signal.

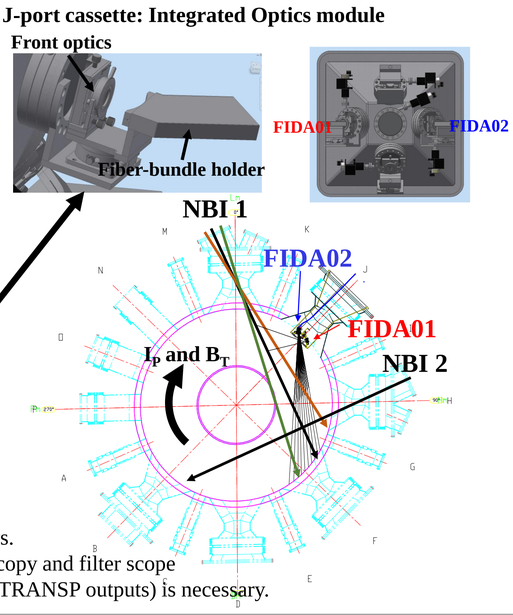
Experimental setup

FIDA spectrometer





J-port cassette: Integrated Optics module

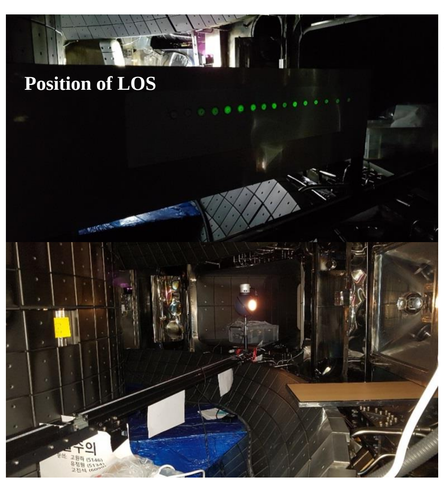


FIDA01	
CH	R [cm]
1	224.71
2	220.28
3	217.00
4	213.11
5	209.52
6	206.69
7	203.90
8	201.03
9	198.79
10	196.32
11	193.75
12	191.28
13	189.32
14	186.93
15	184.93
16	182.92

FIDA02	
CH	R [cm]
1	227.56
2	211.87
3	199.34
4	189.03
5	179.17
6	171.61
7	165.68
8	161.07
9	157.35
10	154.5

FIDA (D_α) system consists of two mid-plane *tangential* arrays.
J-port cassette: Integrated Optics module shared with visible spectroscopy and filter scope
Integrated FIDASIM modelling platform (handling the profile data + TRANSP outputs) is necessary.

Calibration of each line of sight

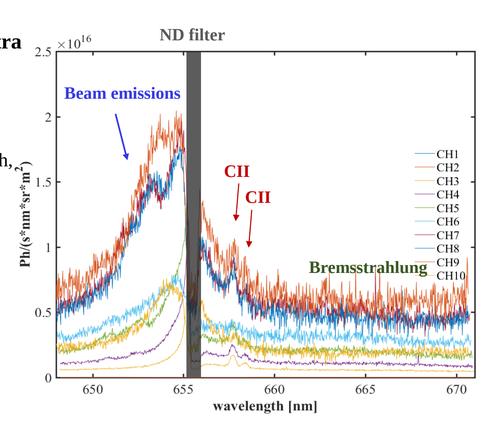


Absolute calibrations of raw spectra for comparisons of intensity

Conversion from digitized counts to photon radiance with,

$$L_\lambda \approx \frac{P}{A\cos\theta\,\Omega\Delta\lambda\Delta T} * F$$

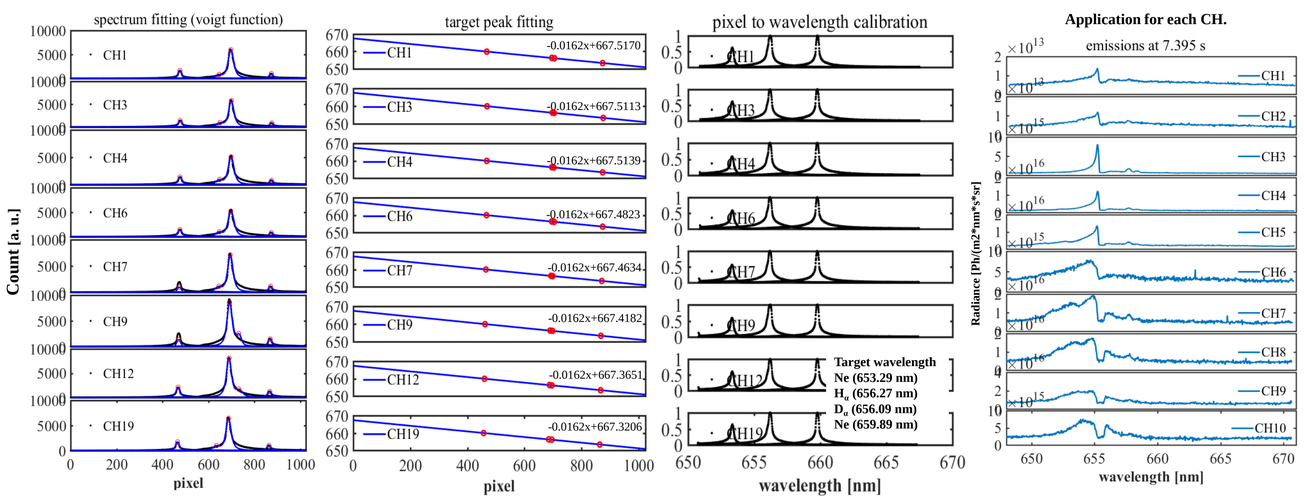
A, source area, P, digitized counts,
L_λ, spectral radiance,
θ, viewing angle, Ω, solid angle,
$\Delta\lambda$, wavelength bin,
ΔT, time bin, F, intensity cal. factor
$[\frac{Ph}{m^2 nm\ s\ sr}]$



FIDA measurement

Non-charge exchange component (OV, CII, OIV..) can be subtracted by beam modulations.

Wavelength calibrations



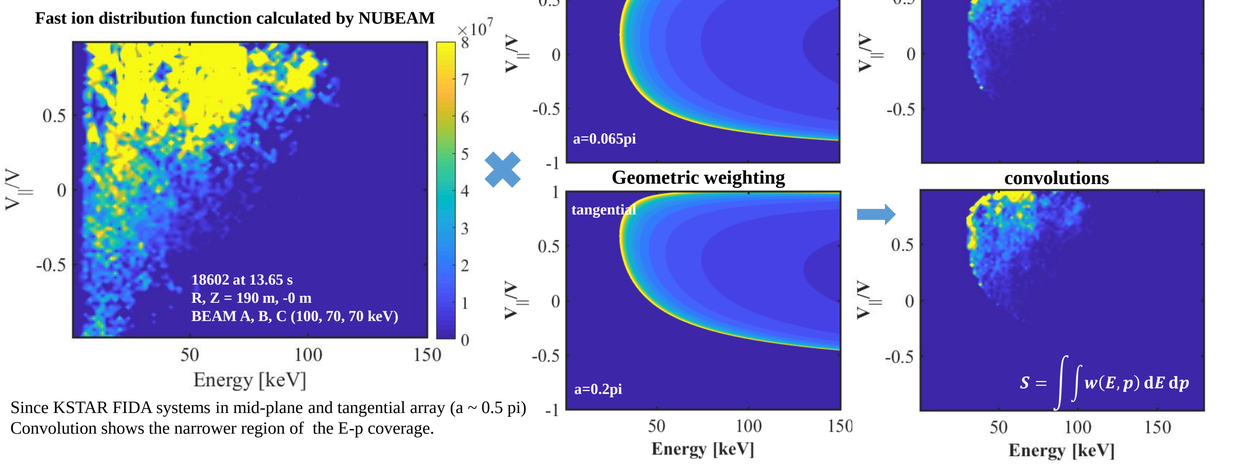
Predictions of E-p space sensitivity (weight function)

Weight function depends on,
Minimum energy $E = E_\lambda(1-p^2)$ and Gyro-angle weight $E = \frac{E_\lambda}{\left(\lambda_{||}p + \lambda_\perp\sqrt{1-p^2}\right)^2}$ [1]

Examples of weighting function for KSTAR

a, angle between b⊥1 and LOS at b ∥ , b⊥1 plane

Fast ion distribution function calculated by NUBEAM



Since KSTAR FIDA systems in mid-plane and tangential array (a ~ 0.5 pi)
Convolution shows the narrower region of the E-p coverage.

Modelling setup

FIDASIM [2] calculations

ⓐ **Preset**
Neutral beam geometry
Equilibrium
Plasma profiles

↓

TRANSP or NUBEAM (OMFIT [3])
Theoretical fast ion distribution functions
F (E, p)

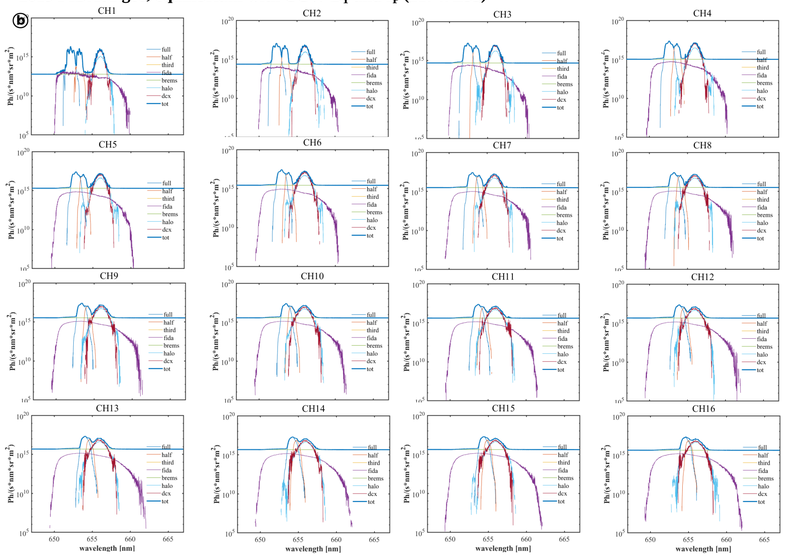
↓

FIDASIM with Preset
Models beam and halo neutrals, calculates VBE, cx probabilities, weight function, active FIDA radiance using sightline geometry

↓

FIDA and NPA

2019 FIDA01 geo, equilibrium with CCW B_T and I_p (21747Z35)

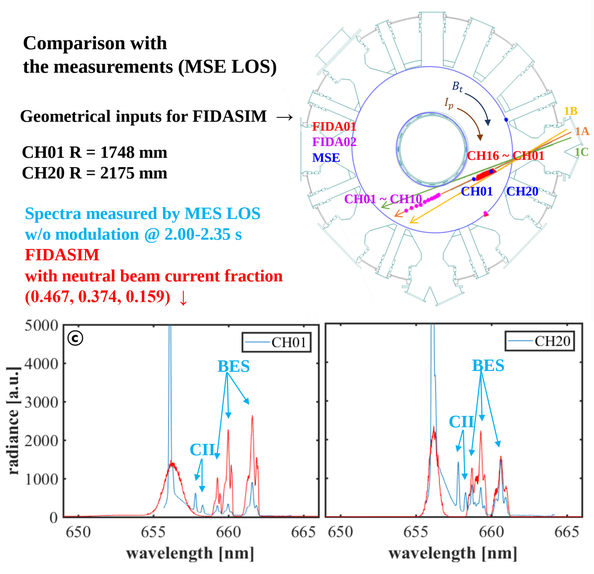


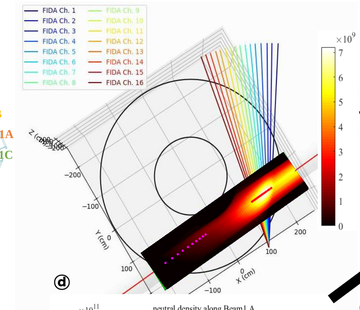
Comparison with the measurements (MSE LOS)

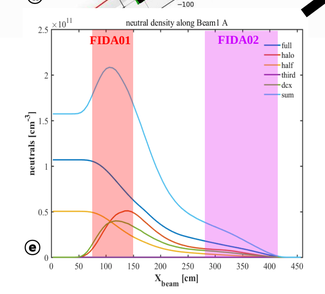
Geometrical inputs for FIDASIM →

CH01 R = 1748 mm
CH20 R = 2175 mm

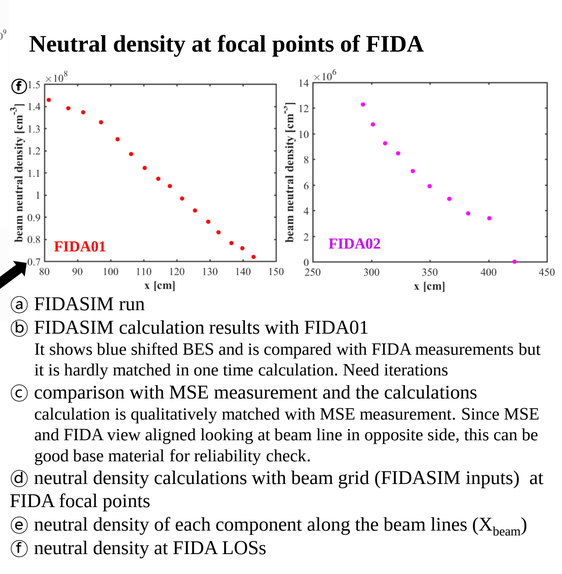
Spectra measured by MES LOS w/o modulation @ 2.00-2.35 s
FIDASIM with neutral beam current fraction (0.467, 0.374, 0.159) ↓





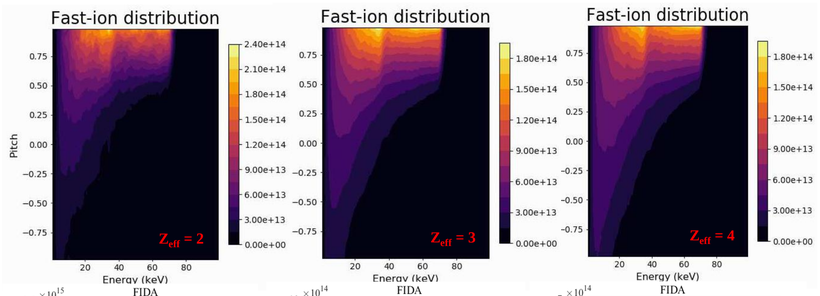


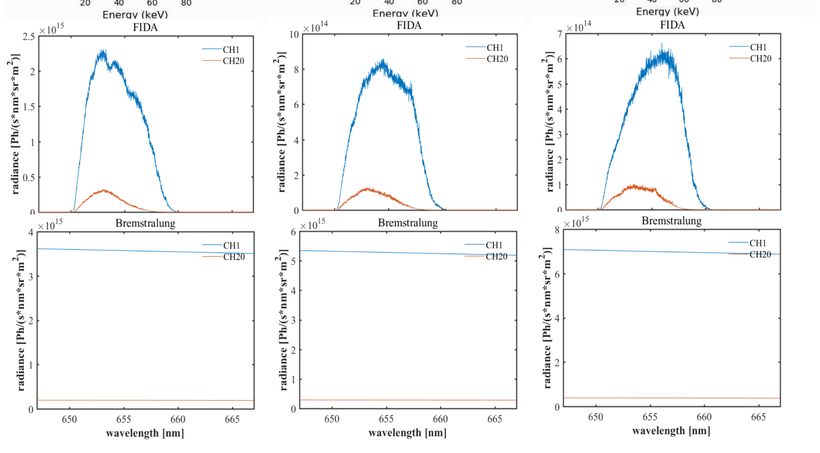
Neutral density at focal points of FIDA

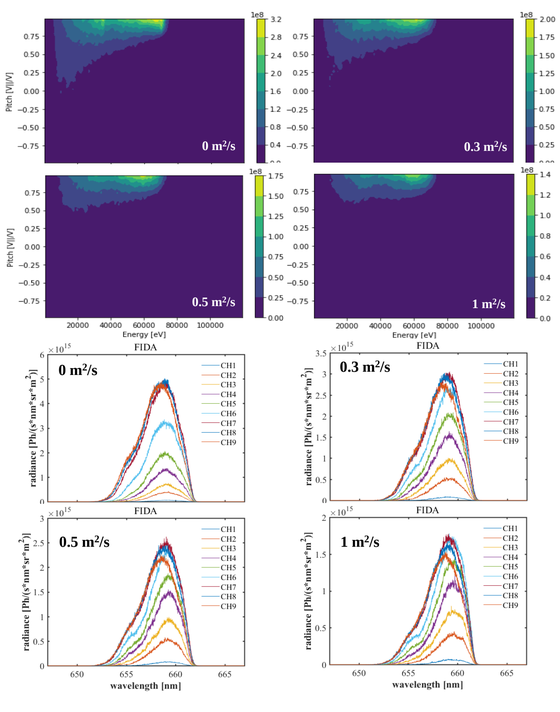


ⓐ FIDASIM run
ⓑ FIDASIM calculation results with FIDA01
It shows blue shifted BES and is compared with FIDA measurements but it is hardly matched in one time calculation. Need iterations
ⓒ comparison with MSE measurement and the calculations
calculation is qualitatively matched with MSE measurement. Since MSE and FIDA view aligned looking at beam line in opposite side, this can be good base material for reliability check.
ⓓ neutral density calculations with beam grid (FIDASIM inputs) at FIDA focal points
ⓔ neutral density of each component along the beam lines (X_{beam})
ⓕ neutral density at FIDA LOSs

Sensitivity study with Z_{eff} and D_f

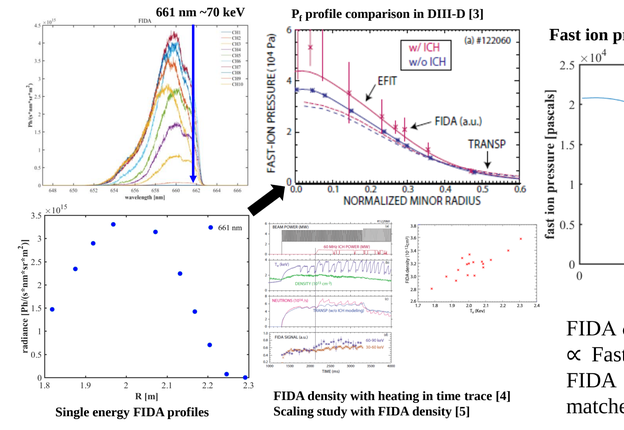






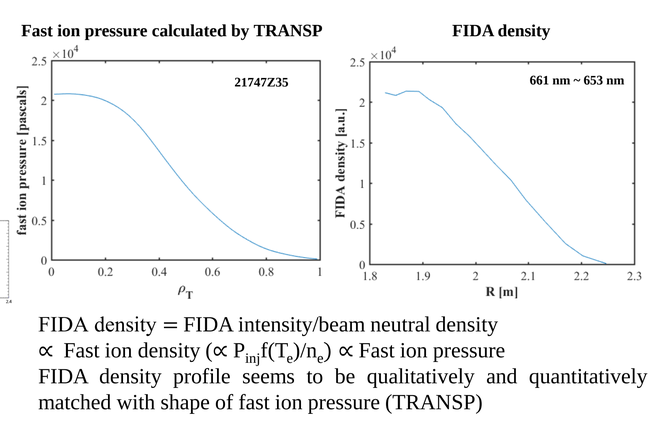
For the sensitivity study, effective Z, profile shape of Z_{eff}, fast ion diffusivity and current fraction are scanned. Especially large values of Z_{eff} enhances bremsstrahlung emissions signal to noise ratio is gone bad. Bremsstrahlung, one order larger than FIDA intensity ($\propto n_e^2$)

Comparison with physical parameters



Single energy FIDA profiles

FIDA density with heating in time trace [4]
Scaling study with FIDA density [5]



FIDA density = FIDA intensity/beam neutral density
$\propto$ Fast ion density ($\propto P_{inj} f(T_e)/n_e$) $\propto$ Fast ion pressure
FIDA density profile seems to be qualitatively and quantitatively matched with shape of fast ion pressure (TRANSP)

Summary

1. Spectroscopic measurements in beam into gas and plasma discharges will be performed for the reference spectra.
2. Additional FIDA array (FIDA02) will be introduced in 2019 campaign to span the detectable fast-ion phase-space.
3. FIDASIM iteration is necessary with newly acquitted data.
4. To expand FIDA operational range of fast-ion phase-space, optical alignment is under discussion.
5. To understand fast ion physics, various operation scenarios and relevant MHD instabilities will be investigated.

Acknowledgments

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