KNS spring meeting
Jeju, Korea, May 17–19, 2023
23S-281

Progress in development of soft X-ray two-filter diagnostic for electron temperature measurements in VEST

Myungwon Lee[1], Soobin Lim[2], Wonik Jung[2], Y. S. Hwang[2], *C. Sung[1]

[1]Department of Nuclear and Quantum Engineering, KAIST, Daejeon 34141, Republic of Korea
[2]Department of Energy Systems Engineering, Seoul National University, Seoul 08826, Republic of Korea

**Email: choongkisung@kaist.ac.kr*

KAIST Department of Nuclear and Quantum Engineering
NUCLEAR ENGINEERING 서울대학교 공과대학 원자핵공학과
국가과학난제도전융합연구개발사업 National Science Challenge Initiatives ST핵융합메타웨어연구단

Outline

Introduction

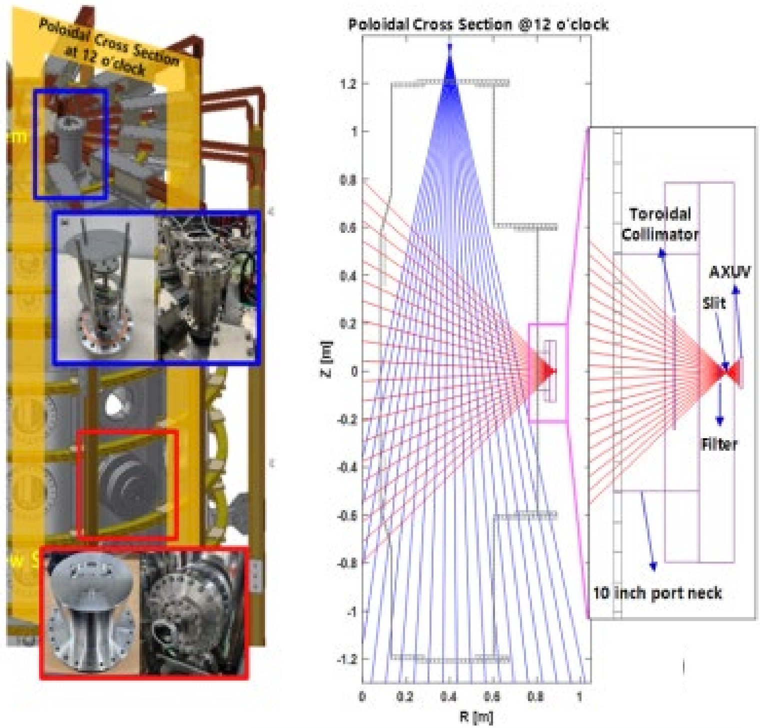
Design & Installation of the System

Initial Measurement Results

Summary & Future Work

Motivation for Development of the Two-filter Diagnostic on VEST

Current 40-channel SXR system on VEST in SNU



- **VEST specification**

Toroidal B Field	**0.05 – 0.19 T**
Major Radius	**0.45 m**
Minor Radius	**0.33 m**
Aspect Ratio	**>1.36**
Plasma Current	**<170 kA**

J. Jang et al., Rev Sci Instrum **93**, 093506 (2022)

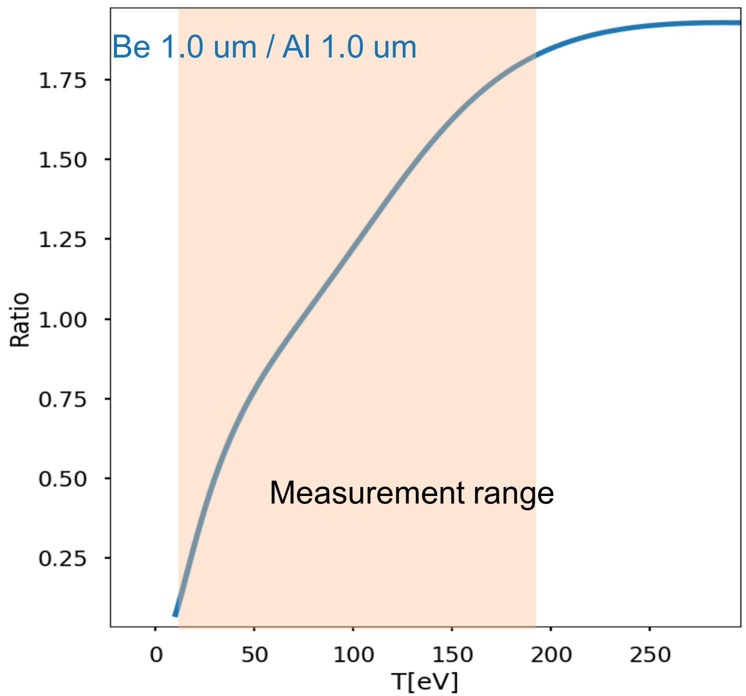
- 40-channel soft X-ray (SXR) system have been installed to study MHD mode on VEST (Versatile Experiment Spherical Torus) in SNU

- Measuring SXR power from plasma cannot give single plasma parameter

- However, using two-filter method, we can get **electron temperature (T_e)** from SXR data

Electron Temperature Estimation Using Two-filter Method

Temperature-ratio curve $R(T_e)$



- SXR power from bremsstrahlung depends on electron density (n_e), electron temperature (T_e), and effective ion charge (Z_{eff})

$$P_{rad} \sim {n_e}^2 \sqrt{T_e} Z_{eff}$$

- However, the SXR power through a filter with transmission $eff(E)$ only depends on photon energy

$$P_{rad}(T_e) = C \cdot \frac{1}{\sqrt{T_e}} \int e^{-\frac{E}{T_e}} eff(E) dE$$

Other parameters (n_e, Z_{eff}, etc.) become constant C

- By taking signal ratio, we can estimate T_e until temperature-ratio curve $R(T_e)$ is a monotonic function

$$R(T_e) = \frac{\int e^{-\frac{E}{T_e}} eff_1(E) dE}{\int e^{-\frac{E}{T_e}} eff_2(E) dE}$$

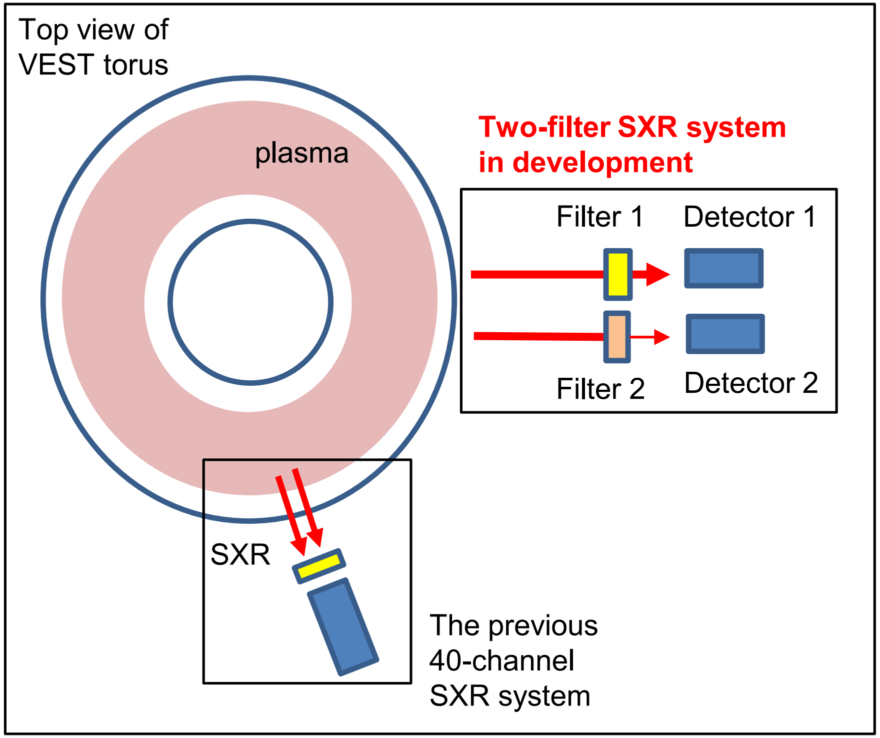
Filter #1 signal

Filter #2 signal

Constant C canceled out

Motivation for Development of the Two-filter Diagnostic on VEST

Schematic of the VEST SXR systems



- From signal ratio of SXR with two different filters, we can estimate T_e with high temporal resolution (~ MHz)

  - VEST Thomson scattering T_e: ~ 0.5 kHz

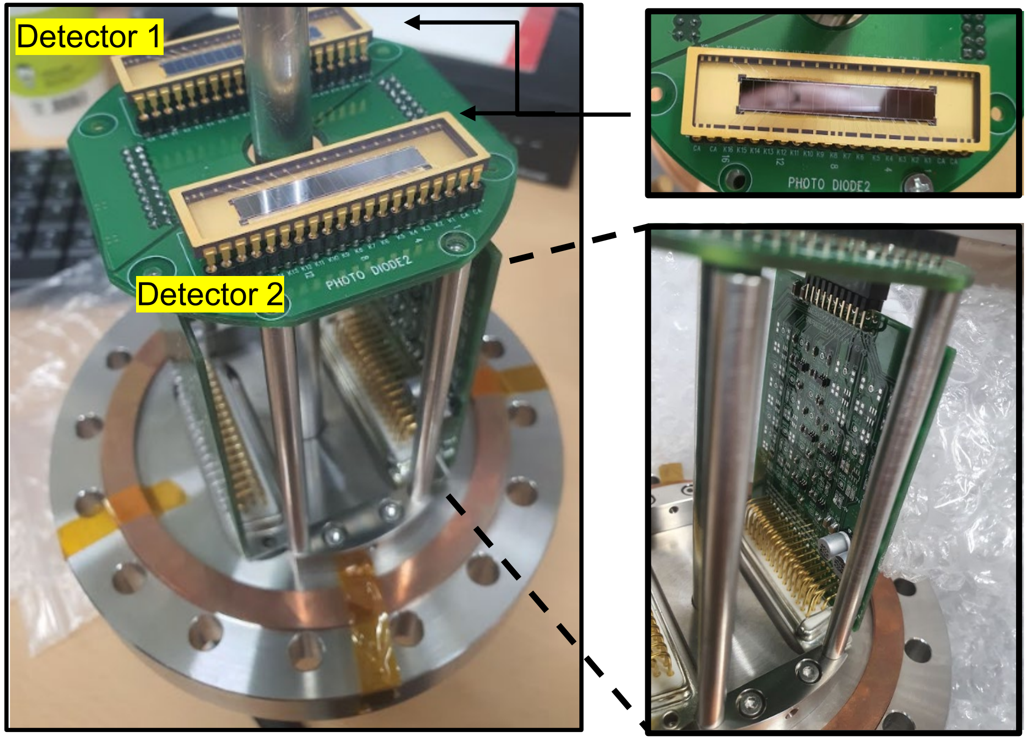
- 2D image of T_e evolution can be also obtained through tomography

- By combining the two SXR system at different toroidal location, we will study 3D mode structure in VEST

Design & Installation of the System

Sensor Array and Preamp Electronics for the SXR Pinhole Camera

16-channel AXUV photodiode

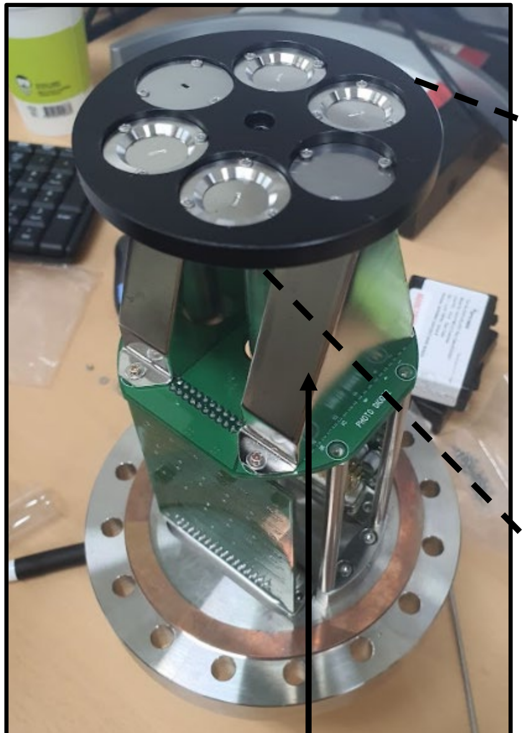


SXR camera for 6” vacuum port

16-channel transimpedance preamplifier (10^6 V/A)

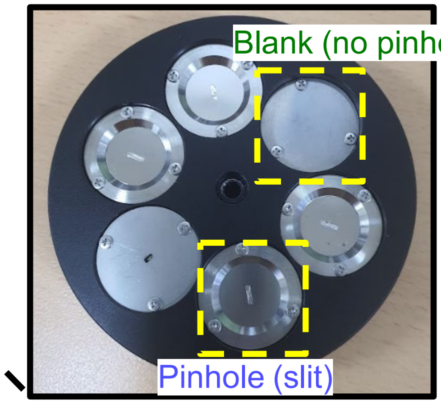
- Two 16-channel AXUV (absolute extreme UV) photodiode were used
- To minimize the noise, we installed multichannel preamp inside the SXR camera without cable connection

Filter Wheel is Applied to the Pinhole Camera



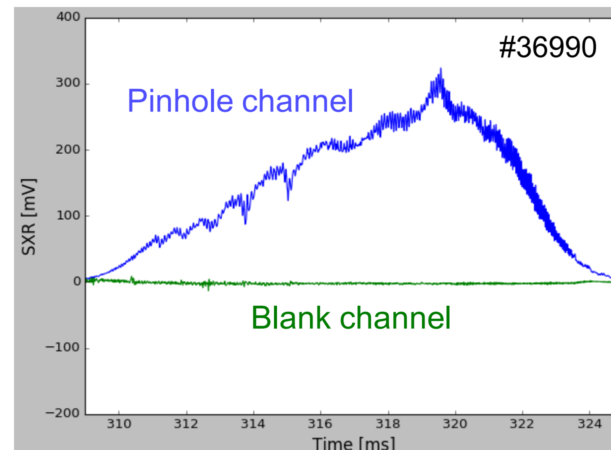
Light cover to prevent stray light

Filter wheel

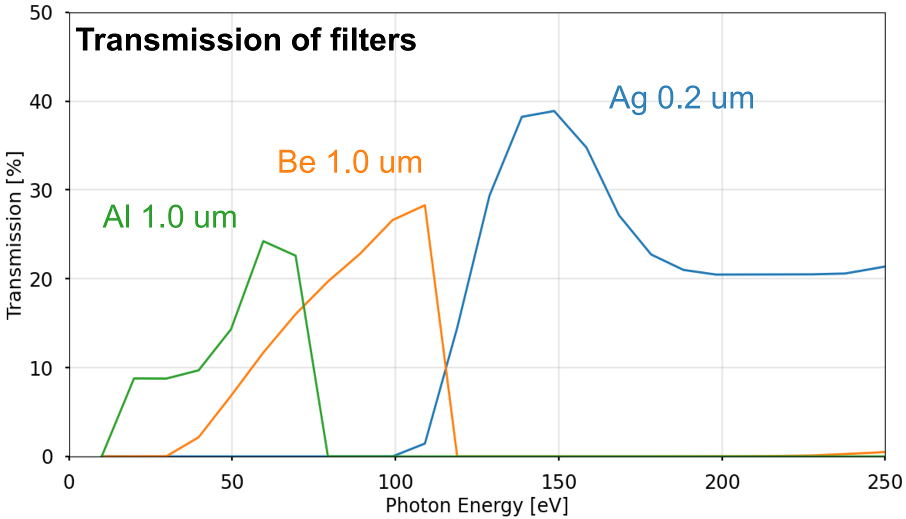


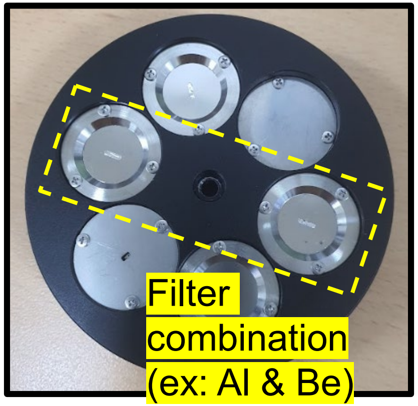
- We applied filter wheel that can load 6 different filters to test various parameters (filter material, thickness, pinhole size, and stray light)

- We loaded a blank channel and checked there was no stray light signal



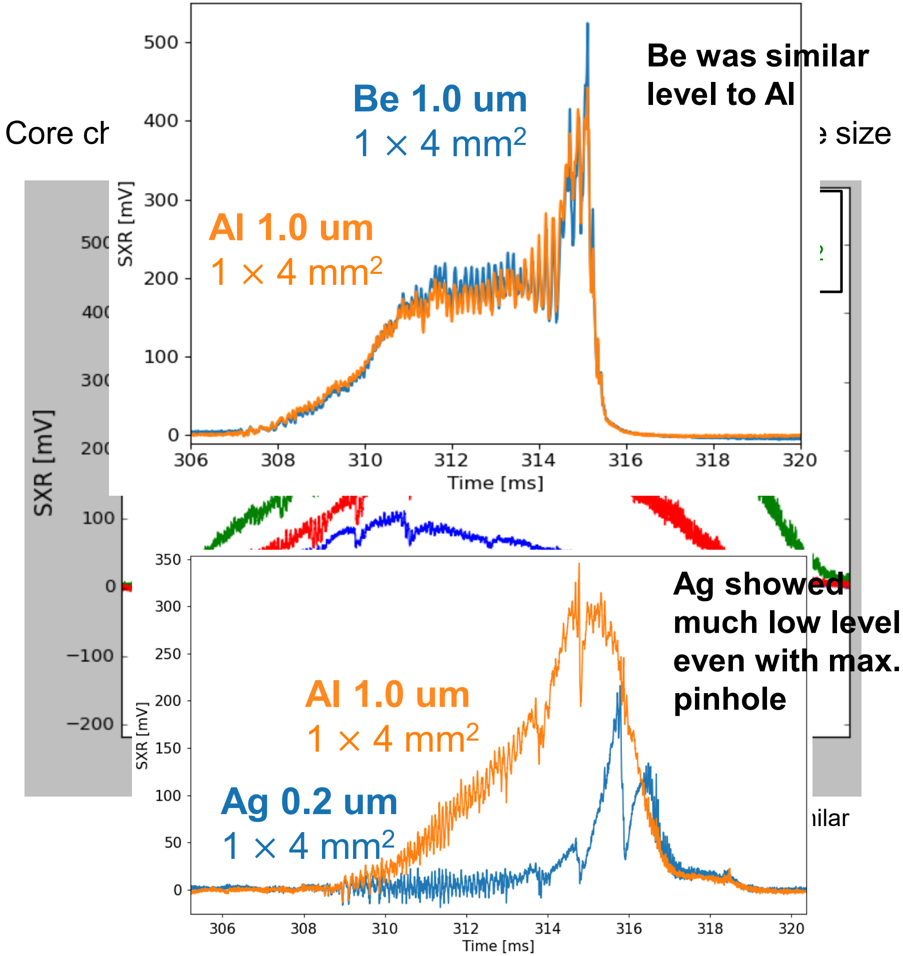
Selection of Filter Material





- We considered estimated VEST T_e (30 eV ~ 150 eV) to select filter materials
- Aluminum (Al) was selected to measure low energy photon (< 70 eV)
- Silver (Ag) was used to measure photon energy over 100 eV
- We also tested Beryllium (Be) which has transmission between Al and Ag (but it is a toxic and brittle material)

Selection of Filter thickness & Pinhole size



- We determined filter thickness and pinhole size considering our setup
  - Peak to peak range of the digitizer : 2 V
  - Possible thinnest filter thickness : 0.1 um
  - Maximum pinhole size : 1 × 4 mm^2

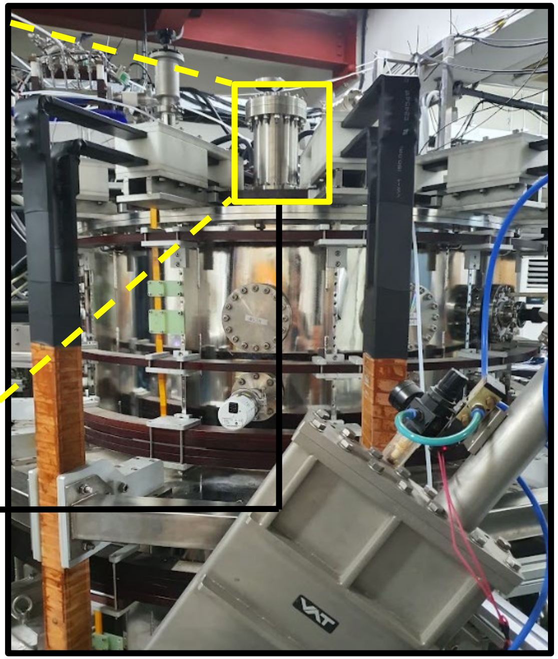
- After tests, we chose 1 × 4 mm^2 pinhole and 1.0 um thickness for Al and Be which showed hundreds of mV signal

- Ag was expected to show low signal for its high cutoff energy, so we chose 0.2 um (0.1 um was too fragile)

Installation of the Two-filter Camera on VEST

SXR camera with a stainless-steel shield

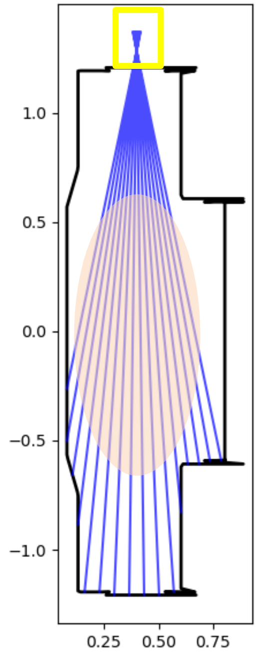
Camera installed on VEST top port



Power supply & DAQ system (~125 MS/s)

Signal lines are connected to DAQ system through D-sub cable

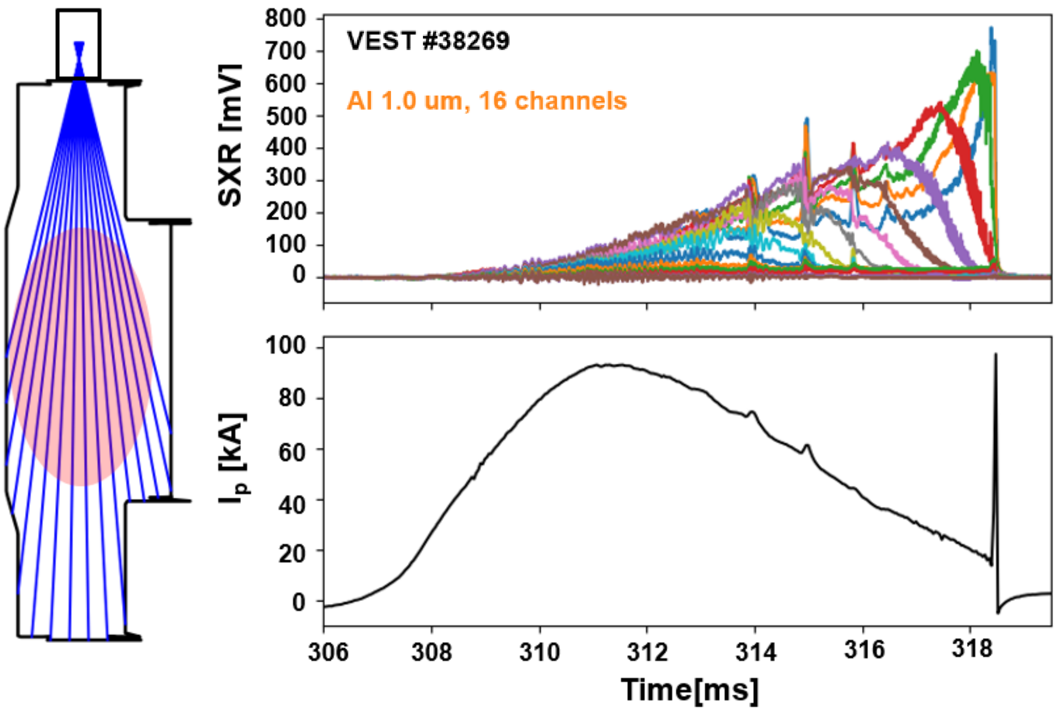
16 LOS in poloidal plane



- We installed the SXR camera on the VEST top port
- The 32-channel camera covers 16 lines-of-sight (LOS) in the VEST poloidal plane
- The amplified signal is transmitted to the DAQ system outside the VEST chamber

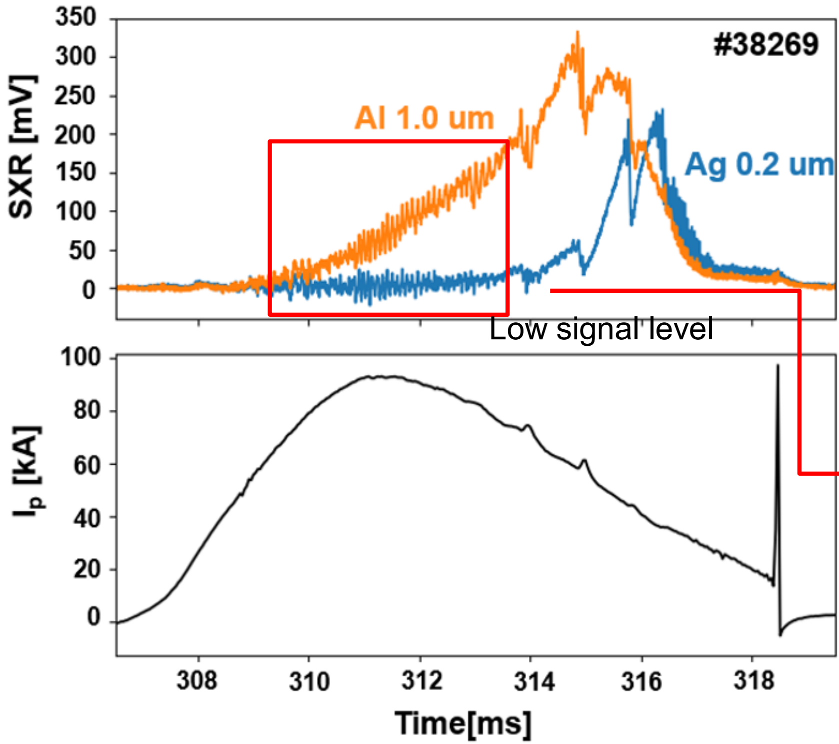
Initial measurement results

Measurement Result of Al Filter at VEST Ohmic Discharge

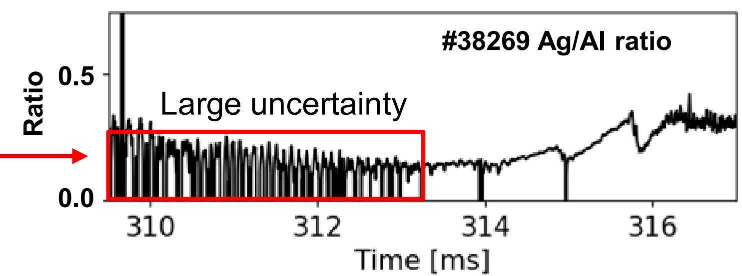


- We could measure all channels covering plasma core to edge
- Core channel showed higher signal level compared to edge, expected from higher n_e
- We set Al signal as the base for ratio comparison because its sufficient signal level

Ag Filter Signal Level Was Too Low for Getting Signal Ratio

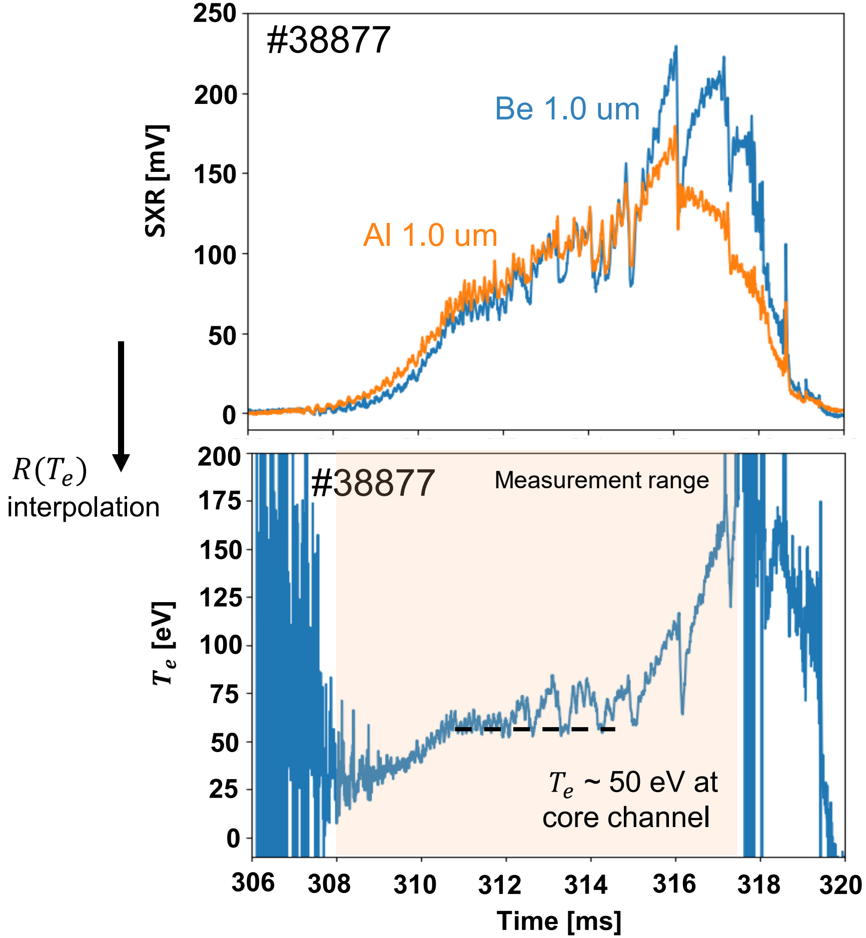


- During I_p ramp-up phase, Ag filter signal level was lower than fluctuation level (~14 mV)
- Because the Ag signal, T_e estimation was hard with Ag/Al filter combination



- Considering the Ag transmission (cutoff at 100 eV), number of photon over 100 eV was not much during ramp-up phase

T_e estimation Using Be / Al Combination Was Possible

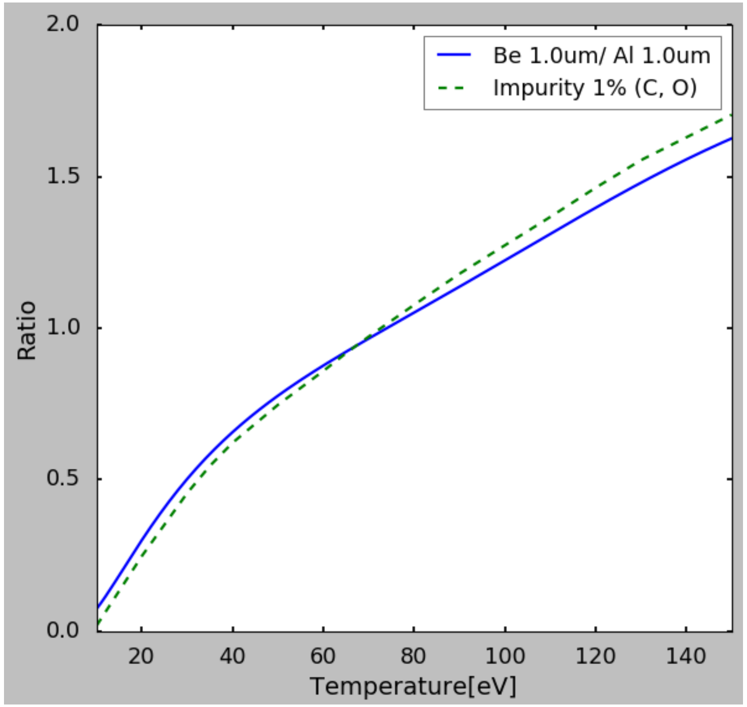


- We also tested Be/Al combination, and Be shows the similar signal level compared to Al
- Estimated T_e at core channel is ~ 50 eV after I_p ramp-up
- Estimated T_e showed a similar order with VEST Thomson measurements (30 eV ~ 150 eV)

Error Contribution of Impurity Line Emission

$$P_{rad}(T_e) = C \cdot \frac{1}{\sqrt{T_e}} \int e^{-\frac{E}{T_e}} eff(E)dE + \boxed{line\ emission}$$

Temperature-ratio curve with correction



- Two-filter method assumes bremsstrahlung continuum radiation, but impurity line emissions can be included in the measurements
- We estimate the dominant impurity radiation in VEST hydrogen plasma is carbon and oxygen
- Using FLYCHK* code, we simulated line emission within VEST operation condition (n_e ~ 10^{19} m^{-3}, 1% C, O concentration)
- The estimated error contribution is not so significant (~ 5%) at 30 eV ~ 120 eV

*Chung, H-K., et al., *High energy density physics* 1.1 (2005): 3-12.

Summary

A soft X-ray two-filter diagnostic was developed for VEST T_e measurements

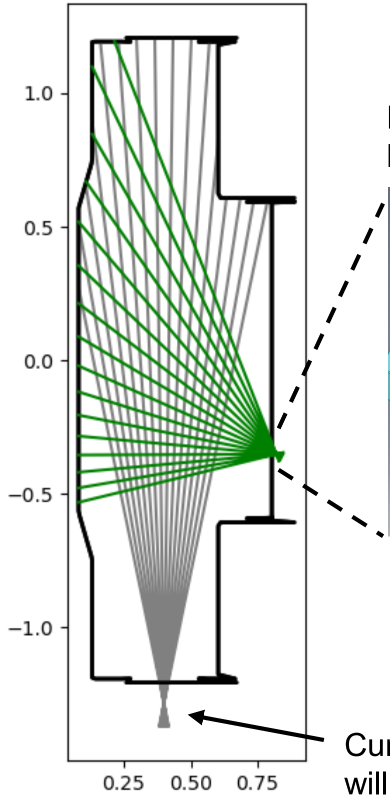
- To apply two-filter method, we tested various parameters such as pinhole size, filter material, thickness, and stray light

Initial measurement shows that the estimated T_e was in the similar order of Thomson

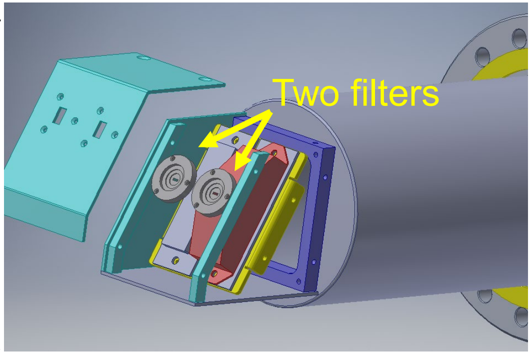
- Measurement with Be/Al filters showed that T_e was ~50 eV at plasma core channels
- Effect of impurity line emission was simulated, and it gave estimation error of ~5 %
- Estimated T_e with error contribution was still consistent with Thomson measurements

Future Work

Another camera will be added for tomographic reconstruction



Design of the mid-port camera, which has a tilted view



Current top port camera (32 channels) will be moved to bottom port

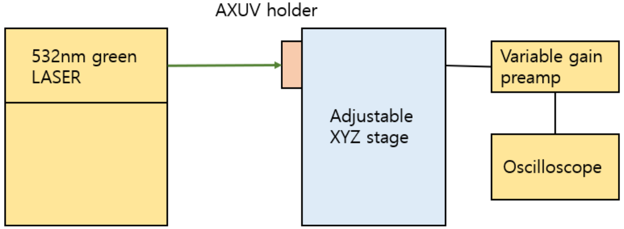
- The signal is a sum of SXR from a sight line, and the estimated T_e is not a local value
- We plan to install another camera at the VEST mid-port for tomography
- With tomography, we will study local and 2D T_e evolution in various scenarios

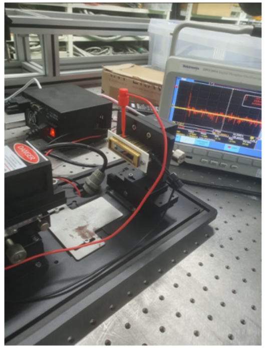
Thank you!

Backup

Relative calibration of AXUV channels

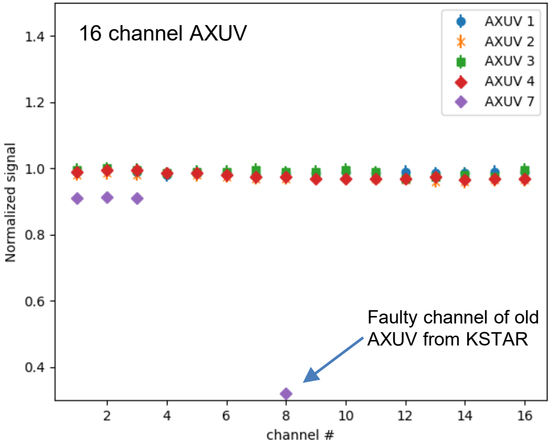
Objective: Check the sensitivity of each channels and sensors for multi-channel tomography application

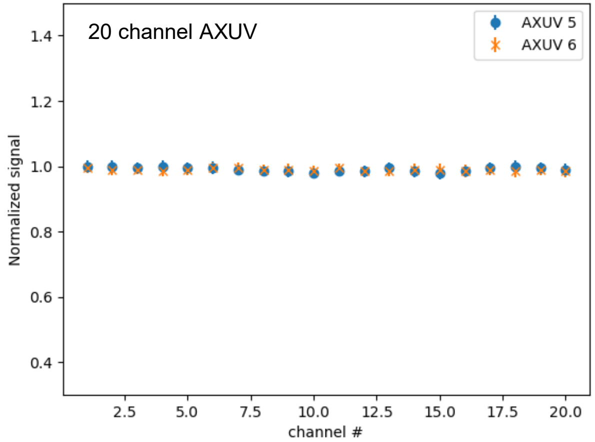




- Sensitivity of each channel was measured using a laser source in KFE
- Each channels were measured 3 times to get standard deviation (~0.02)

* Signal normalized by maximum value in the figure (data/ max(data))



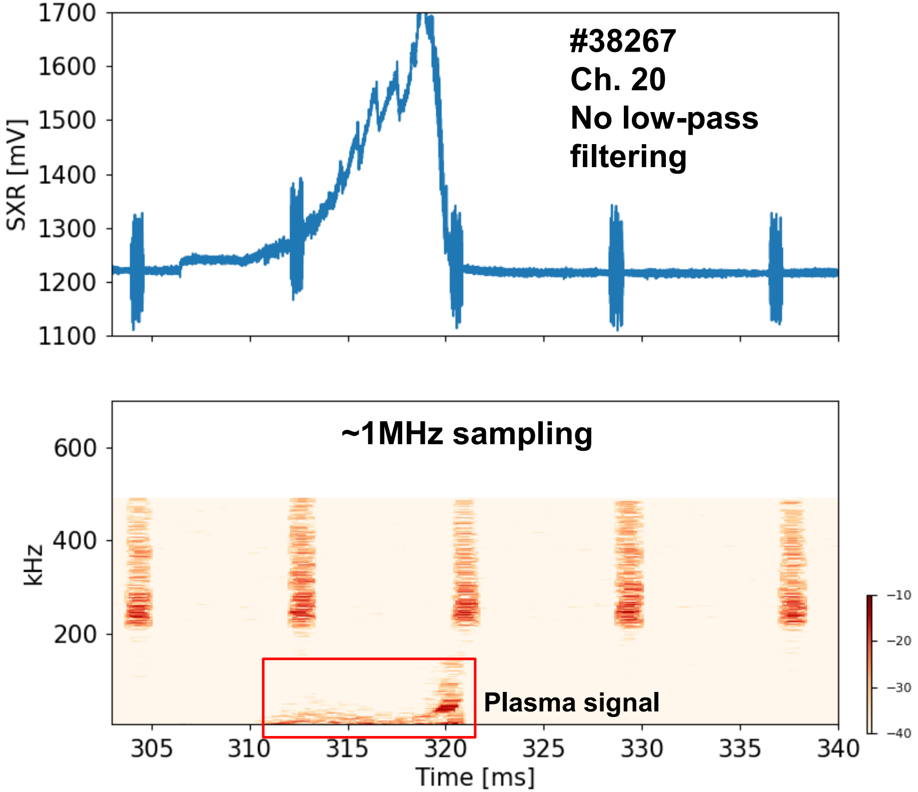


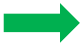
Label	Manufactured in	Channel	Used at	Channel mean [V]	Channel range (max-min) [V]
AUXV 1	2021/08/23	16	Not used	2.01	0.03
AUXV 2	2021/08/23	16	Not used	1.98	0.05
AUXV 3	2021/08/23	16	VEST (diode 1)	2.01	0.06
AUXV 4	2021/08/23	16	VEST (diode 2)	1.99	0.06
AUXV 5	2021/12/16	20	VEST (upper)	1.95	0.04
AUXV 6	2021/12/16	20	VEST (mid)	1.94	0.03
AUXV 7	Not sure	16	KSTAR	x	x

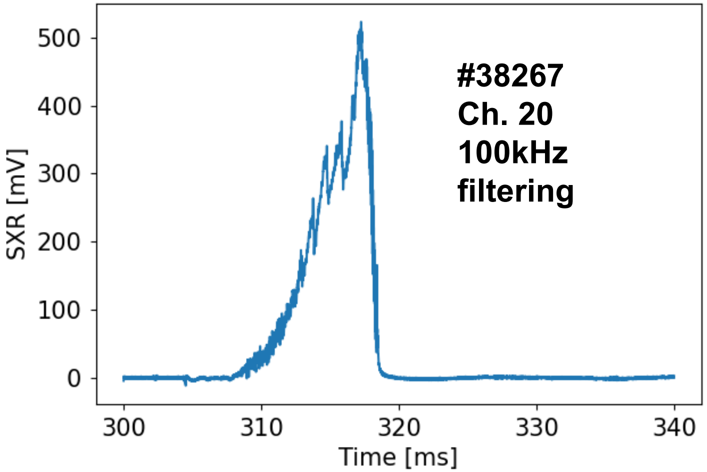
- All AXUVs were manufactured in the similar period, except old one from KSTAR
- AXUV 1,2 will be used for the new system at 4 o'clock lower midplane

- Difference was small (max. ~3.5 %) between channels and array units
- We can use the sensitivity information to tomography in future work

High frequency noise can be removed by filtering

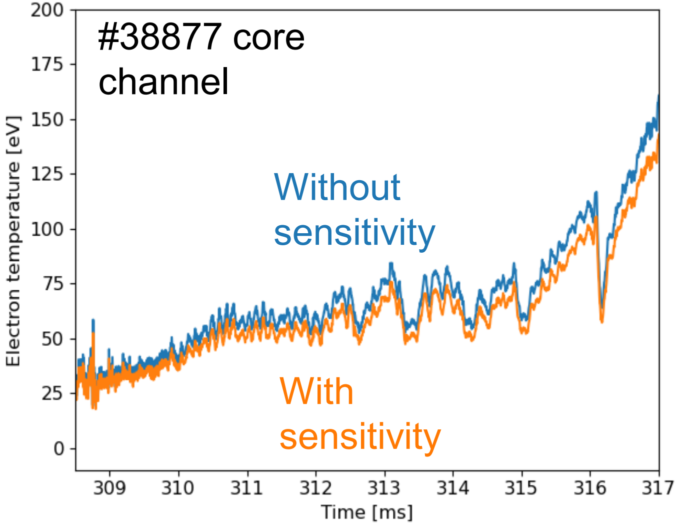


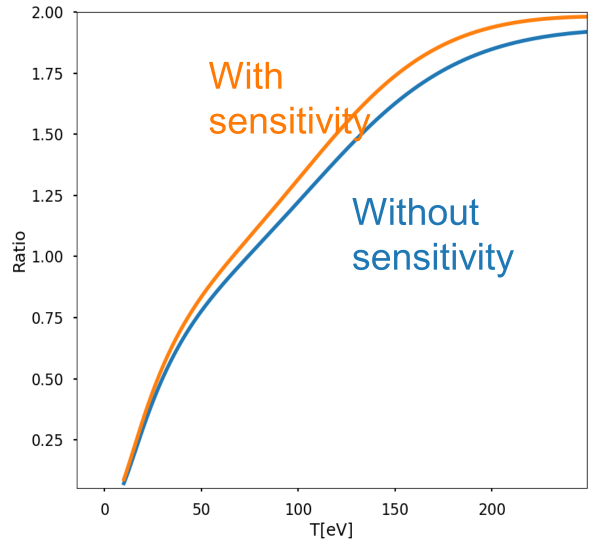


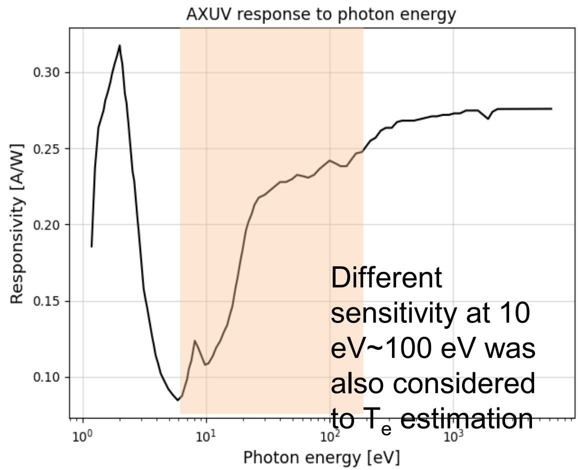


- High frequency noise over 200kHz is present
- Because the plasma spectrum is around tens of kHz, postprocessing using LPF can further reduce the high frequency noise

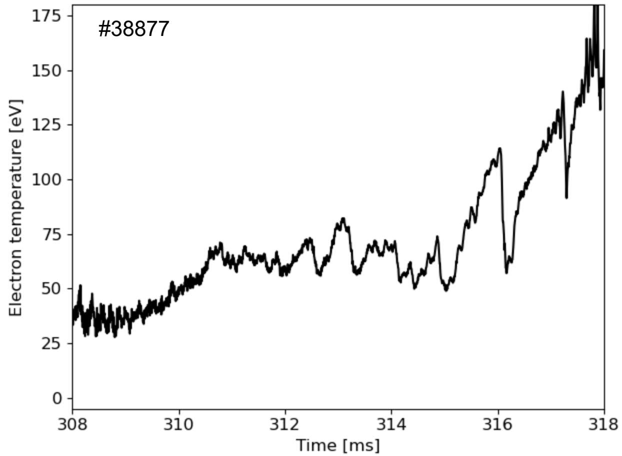
Consideration of AXUV sensitivity by photon energy

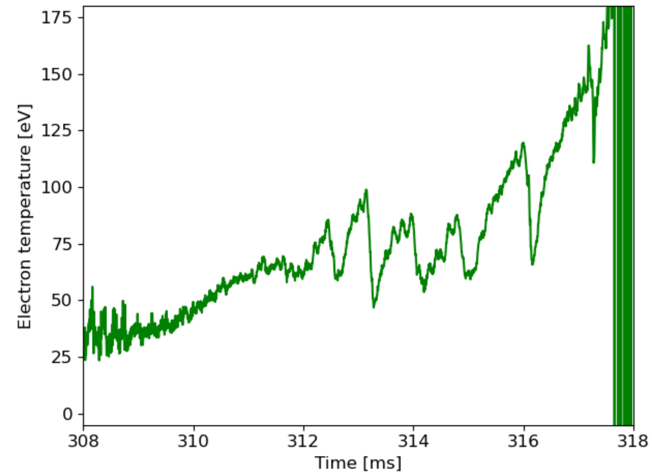


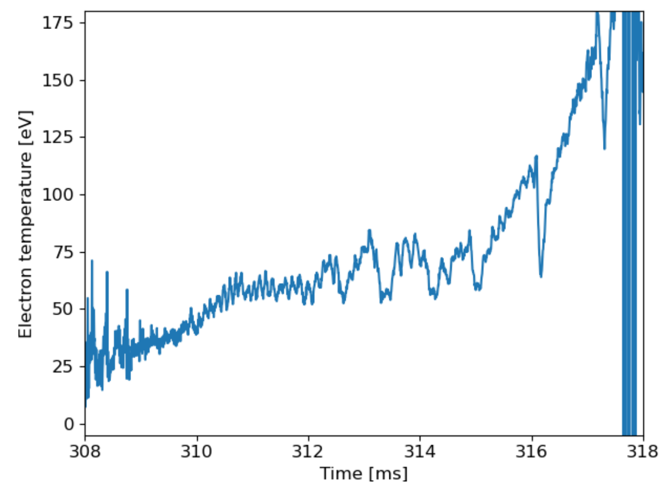


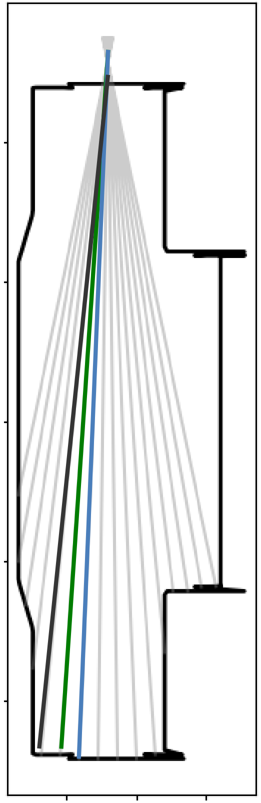


- Consideration of AXUV sensitivity alters temperature-ratio curve
- After correction, the estimated electron temperature is lowered

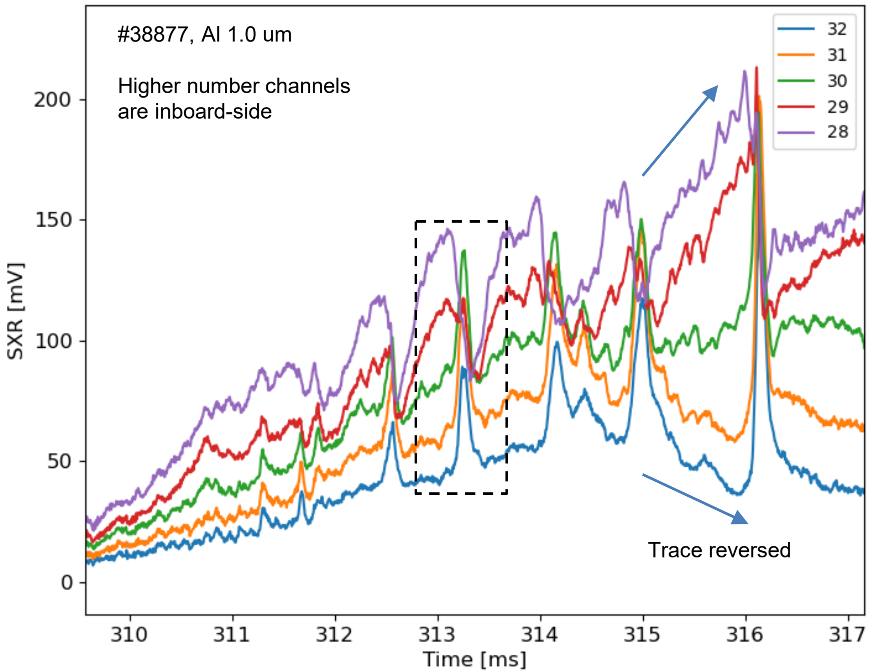

#38877
Electron temperature [eV]
Time [ms]
0
25
50
75
100
125
150
175
308
310
312
314
316
318

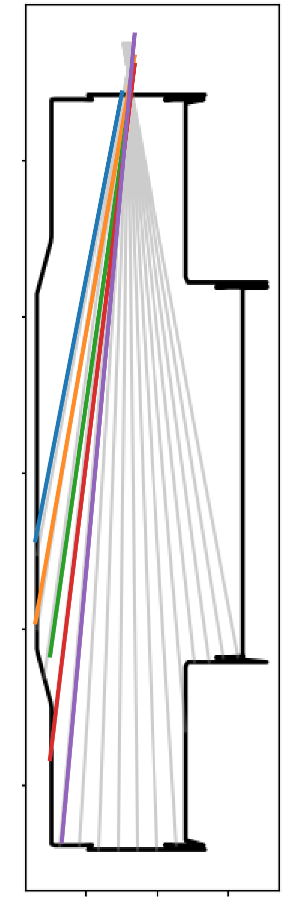

Electron temperature [eV]
Time [ms]
0
25
50
75
100
125
150
175
308
310
312
314
316
318


Electron temperature [eV]
Time [ms]
0
25
50
75
100
125
150
175
308
310
312
314
316
318



Local structure at IRE burst





- It seems that some event at core results in a burst at edge channels
- we need to do further measurement afterward to see the local T_e evolution