Application of Thomson scattering system toward direct measurement of meniscus shape of the negative ion beam

Junichi Hiratsuka, Kentaro Tomita[1], Mieko Kashiwagi, Atsushi Kojima, Glynnis Mae Q. Saquilayan, Takashi Kaihori, Masahiro Ichikawa, Hiroyuki Tobari, and Kazuhiro Watanabe

National Institutes for Quantum and Radiological Science and Technology (QST), [1]Hokkaido University *e-mail: hiratsuka.junichi@qst.go.jp*

Summary

- **Thomson scattering with excellent spatial resolution was applied to negative ion source for the first time.**
- **Optical system was designed to meet the measurement in the ion source.**
- **Feasibility of direct measurement of extraction region with Thomson scattering was confirmed with < 0.5 mm spatial resolution at $n_e = 3\times10^{16}$ m^{-3}, which contributes to precise prediction of negative ion trajectory and design of negative ion accelerator.**

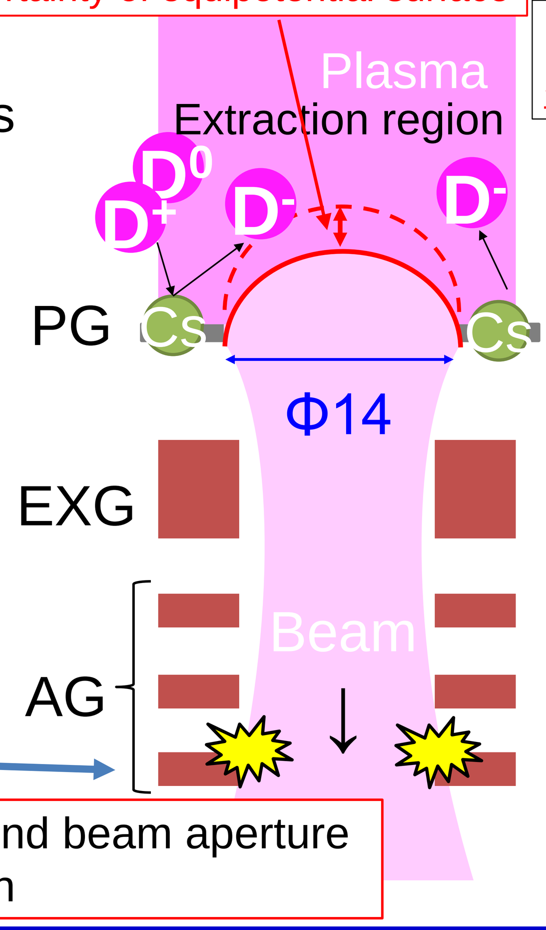
Introduction

Target of Long pulse acceleration

- For JT-60SA: 500keV, 130A/m^2, 100s
- For ITER: 1MeV, 200A/m^2, 3600s

Issue: unclear physics of extraction region of negative ions

Conventional simulation of negative ion trajectory and heat load **has not been consistent with experimental result.**



Precise prediction of negative ion trajectory
← Understanding potential profile of extraction region

- Different mechanism from positive ion source due to surface production of negative ion

⇒ Direct measurement can solve the essential issue of negative ion sources.

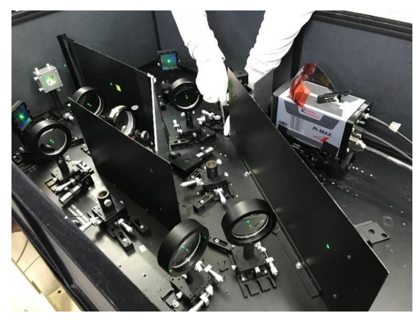
<Challenging Requirements>

- High spatial resolution
→Density profile within 14mm aperture
- Non-disturbance, but direct measurement
→Langmuir probe is unavailable due to high electric field and disturbance of plasma

Direct measurement of extraction region by applying Thomson scattering

Excellent spatial resolution, High sensitivity

- Developed for diagnostics of micro-structure of industrial plasmas
- High spatial resolution (~20μm)
- Non-disturbance measurement



Issue		very low density
Original $n_e = 10^{23}$ m^{-3}	➡	Extraction region $n_e = 10^{16}$ m^{-3}

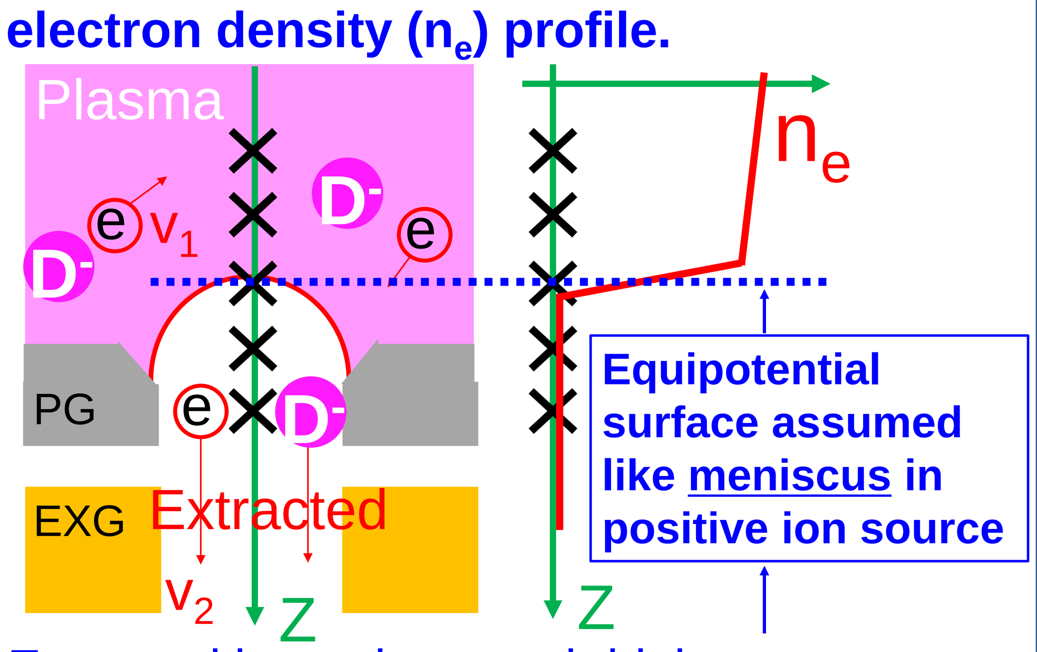
Application of Thomson scattering with high spatial resolution developed in Hokkaido-University

K. Tomita, et. al., nature scientific reports, 7 12328(2017)

Design of the Thomson scattering measurement

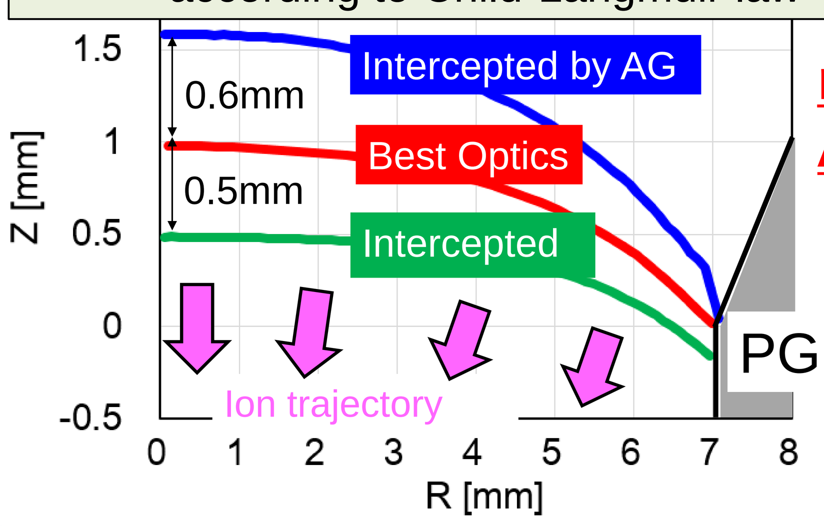
Idea to investigate extraction region

Try to detect **equipotential surface of beam extraction** from measurement of **electron density (n_e) profile.**



Extracted beam has much higher v
→ **Rapid drop of n_e** will be observed at the surface ($n_1v_1/3 \sim n_2v_2$)

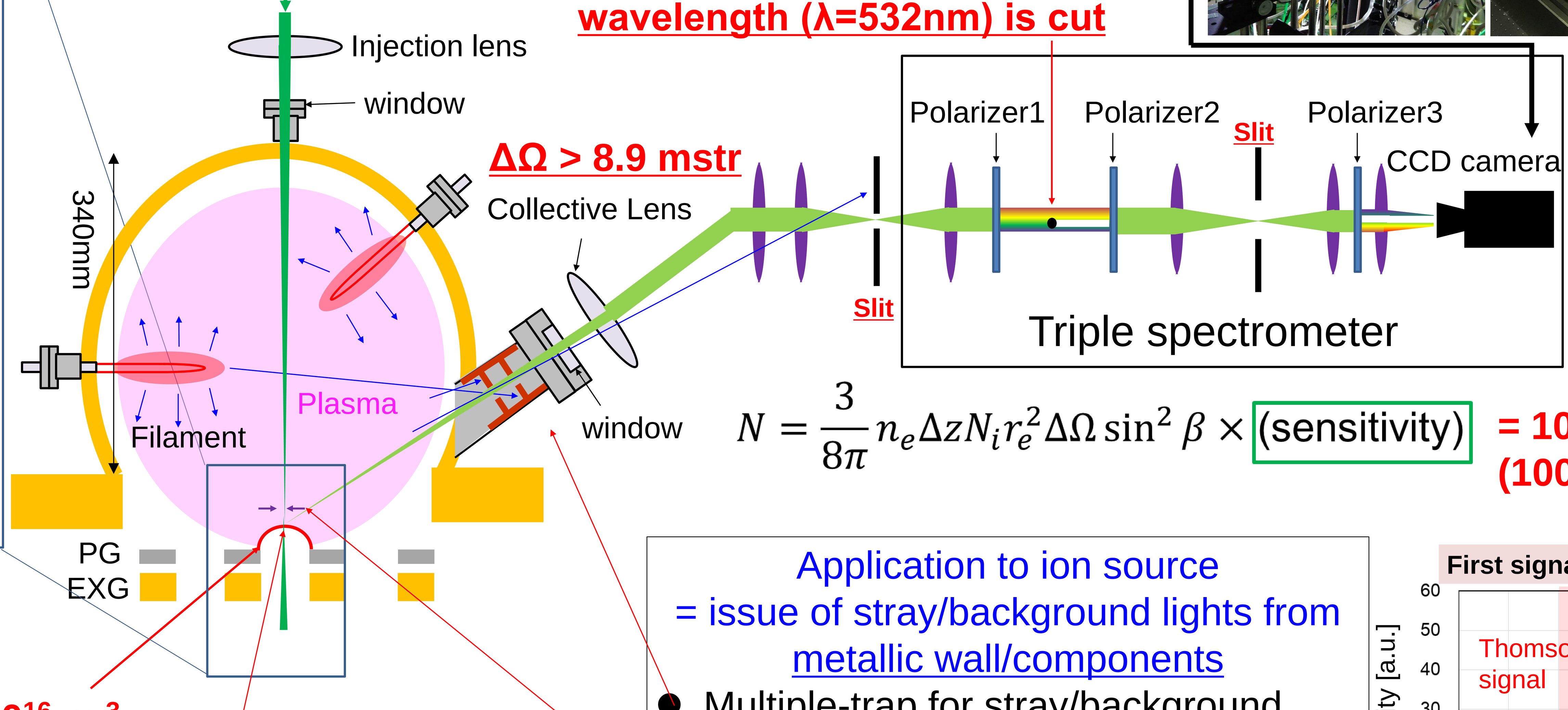
Prediction of Meniscus Shape with traditional beam simulation (BEAMORBT) according to Child-Langmuir law

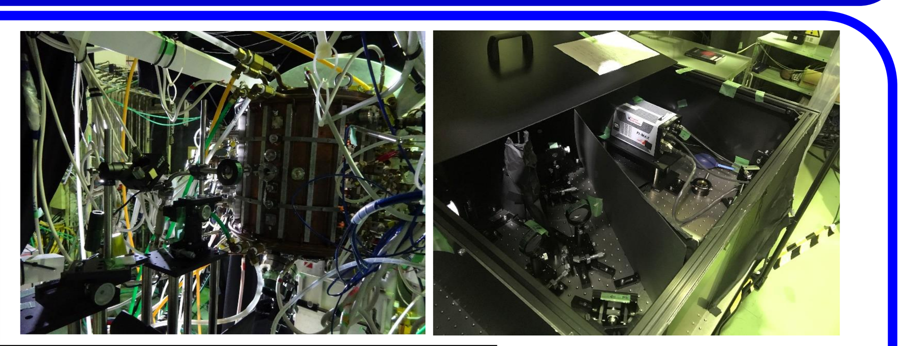


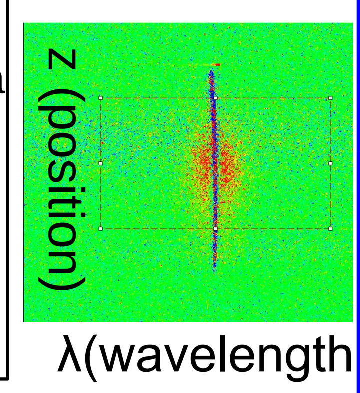
Laser: 300mJ, 532nm, 10Hz ($N_i = 8\times10^{17}$ photon)

Synchronization of laser and shutter

Mask → Main stray light of laser wavelength (λ=532nm) is cut







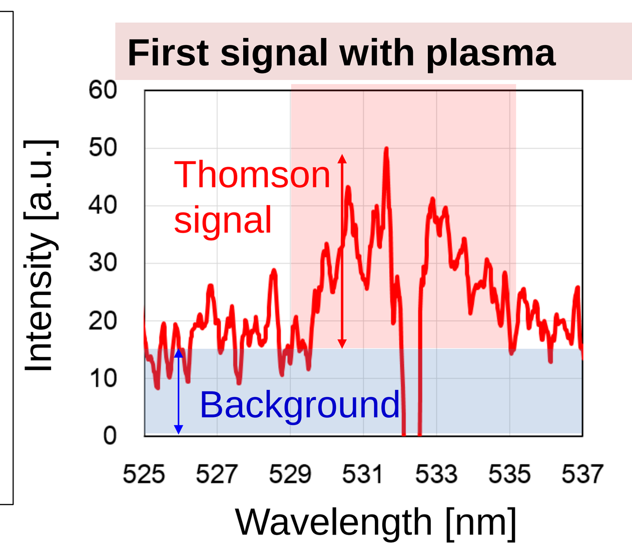
$$N = \frac{3}{8\pi} n_e \Delta z N_i r_e^2 \Delta\Omega \sin^2\beta \times (\text{sensitivity})$$ **= 1015 photon (10000 accum.)**

$n_e = 3\times10^{16}$ m^{-3}
$\Delta z < 0.5$mm

Thomson scattering signal = 9.6×10^5 photon (10000 accum.)

Application to ion source
= issue of stray/background lights from metallic wall/components

- Multiple-trap for stray/background lights was introduced.
- Laser beam and slit size was reduced as small as possible (100um)



$n_e = 3\times10^{16}$ m^{-3}, Δz<0.5mm, error < 20% is expected with accumulation of shots. (Error is proportional to √N (Poisson distribution)), → **Applicable to meniscus measurement.**

Calibration for resolution and sensitivity check

Calibration with Raman Scattering with Nitrogen gas (200 Pa) for

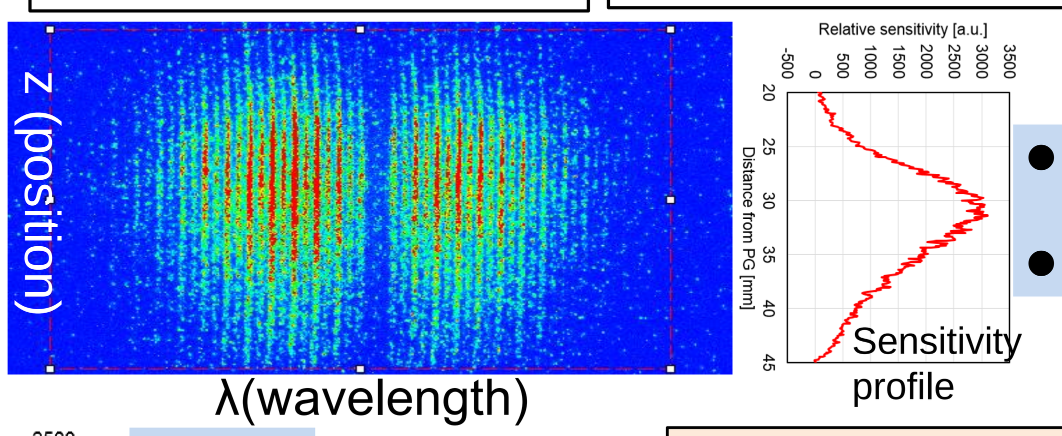
- **Absolute sensitivity**
- **Wavelength resolution**
- **Confirm cut width**

(Absolute sensitivity)

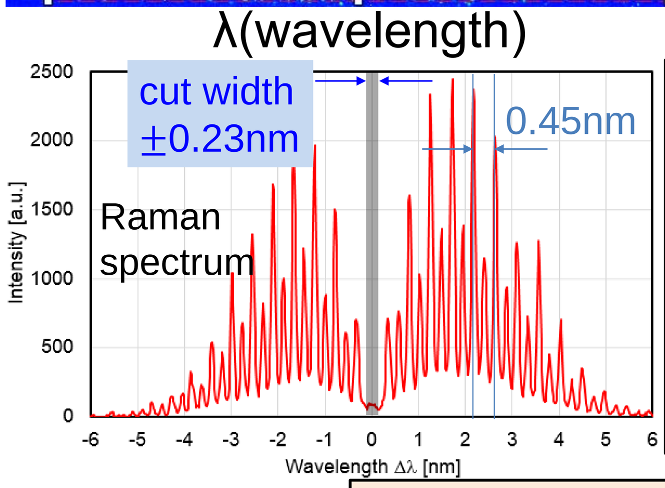
$$\text{Sensitivity} = \frac{\text{Raman signal}}{n(N_2)\times(\text{Raman cross section})}$$

$$n_e = \frac{\text{Thomson signal}}{\text{sensitivity}\times(\text{Thomson cross section})}$$

(Wavelength resolution)
Te = 0.3 eV
→ HWHM = 1.0 nm



- sensitivity = 0.11 (still enough)
- Δλ = 0.018 nm/pixel

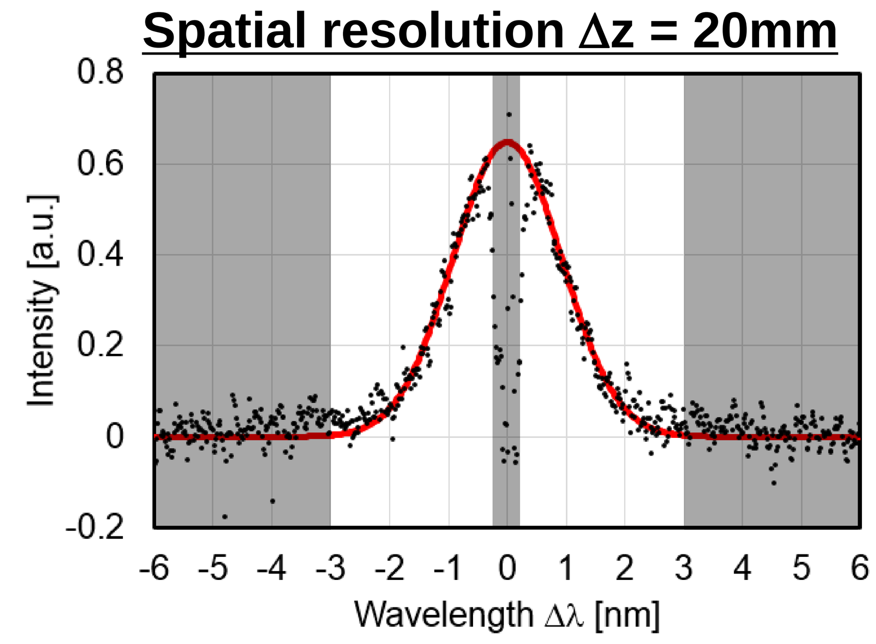


Enough sensitivity and wavelength resolutions for meniscus measurement have been obtained as designed.

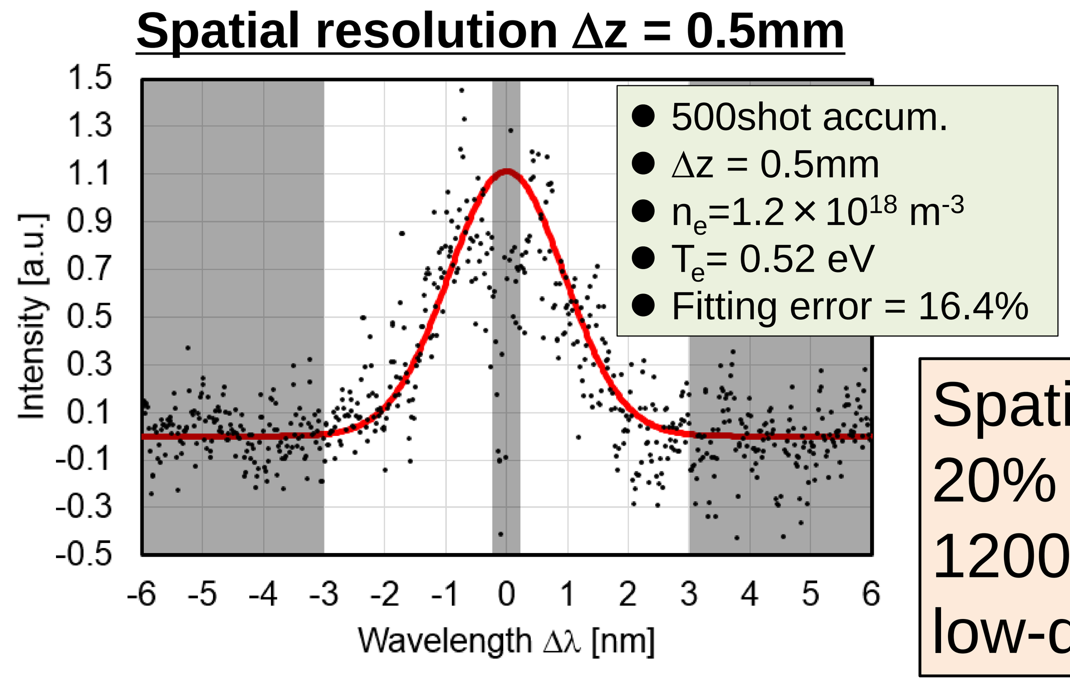
Small cut width enables meniscus measurement up to low temperature

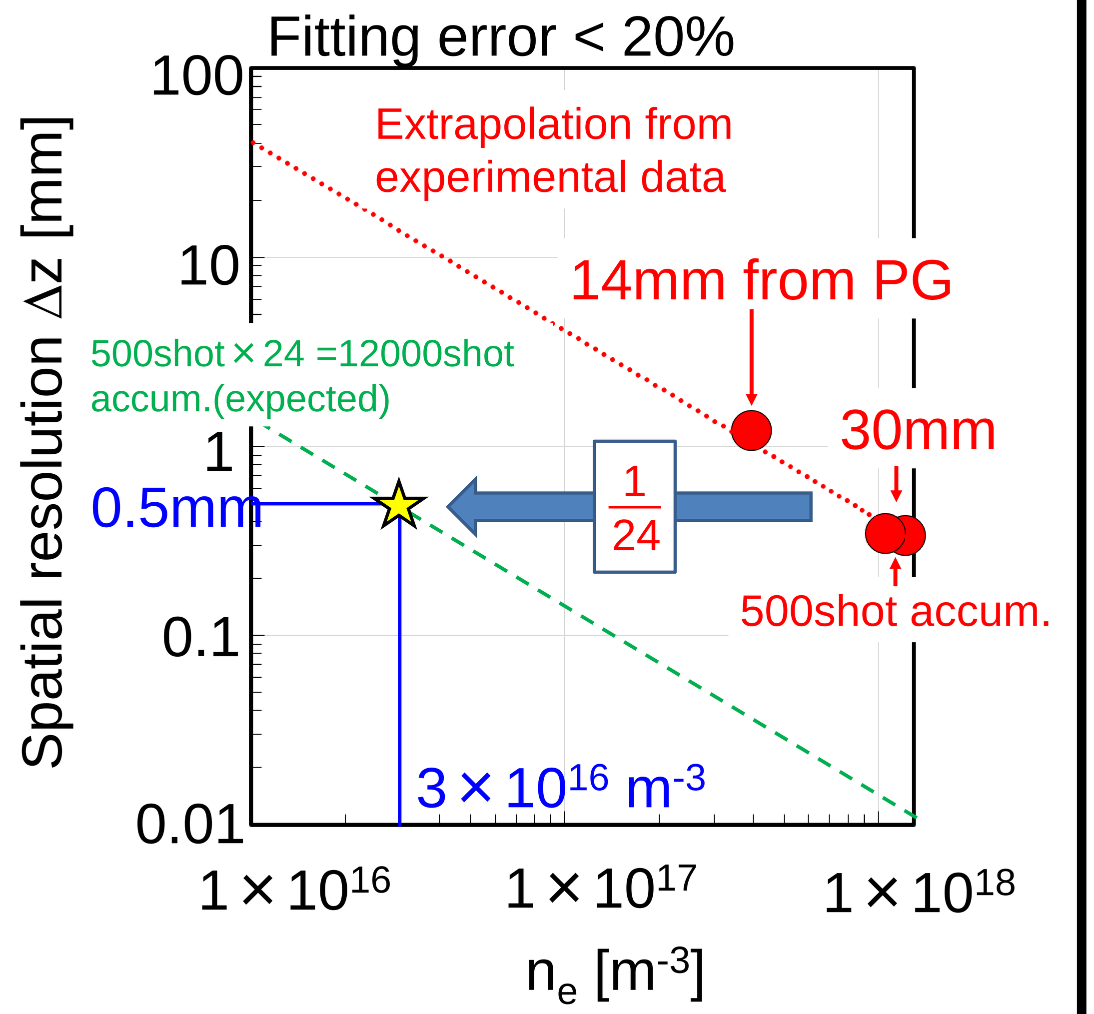
Application to measurement in negative ion source

Spatial resolution Δz = 20mm



Spatial resolution Δz = 0.5mm





Spatial resolution < 0.5mm with error < 20% is achievable by accumulation of > 12000 shots (1200s in total), even in such low-density region.