Development of the Atomic Beam System for the Laser Isotope Separation of ^{48}Ca

Tasuku HIRAIWA[1], Yusuke KAWASHIMA[1], Ren YUHAKU[1], Junya NAKAJIMA[1], Masashi TOZAWA[1], Hideaki NIKI[1,3], Saori UMEHARA[2], Sei YOSHIDA[3], Shigeki TOKITA[4], Noriaki MIYANAGA[5], Izumi OGAWA[1]

([1]Dept. of Engineering, Univ. of Fukui, [2]RCNP, Osaka Univ., [3]Fac. of Sci., Osaka Univ., [4]ICR, Kyoto Univ., [5]Inst. for Laser Tech.)

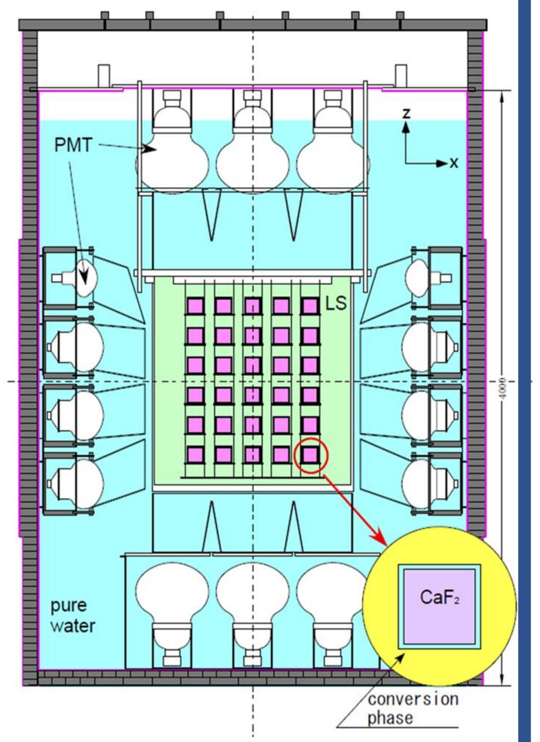
Double beta decay study of ^{48}Ca

Candles

A 350 kg CaF2 scintillator is being used to search for double beta decay of 48Ca.

^{48}Ca
- Highest Q-value(4.27MeV)
- Low natural abundance (0.187%)

Potential to increase sensitivity 500-fold by enriching ^{48}Ca.

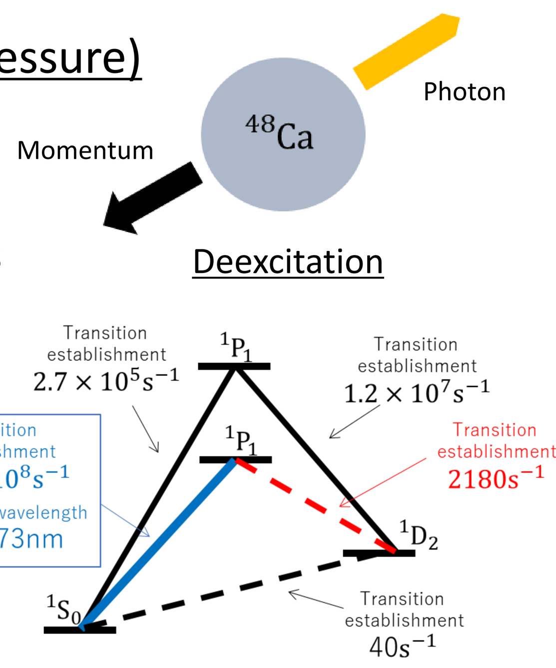


Deflection method

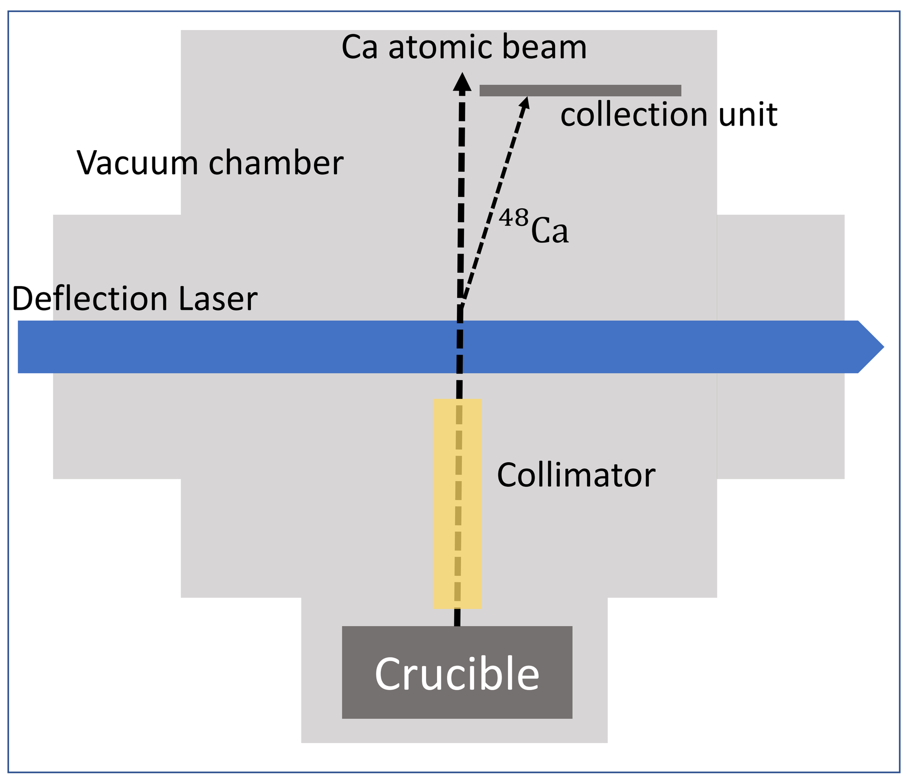
Using momentum transfer (radiation pressure) by laser photons.

Necessary to absorb and emit photons many times in a short period of time.

- High transition probability
- Low probability to other levels



For the mass production of ^{48}Ca

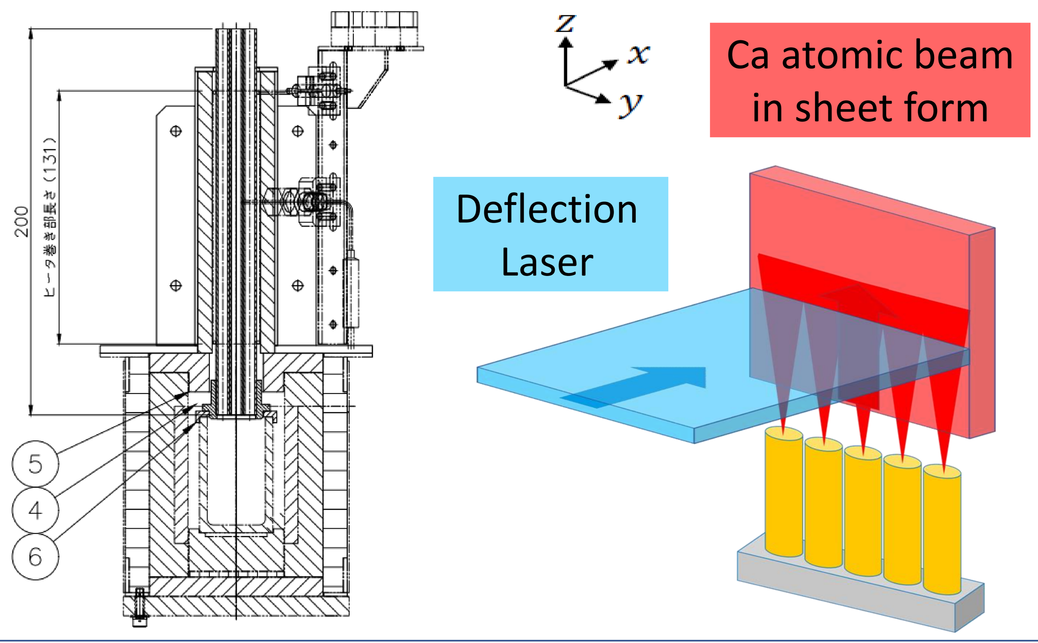


RCNP
- Development of collection system.

ICR & ILT
- Development of laser systems with high power and stable oscillation.

Univ. of Fukui
- Development of an atomic beam system with a shape suitable for the deflection method.
- Development of control systems for all systems capable of stable production over long periods of time.

R&D of the atomic beam system



Development of an atomic beam system that maximizes production rate while maintaining high collection efficiency.

Using a collimated atomic beam in sheet form.

Multiple tubes arranged in a row as collimators.

Verify the collimating effect of a single tube as a first step.

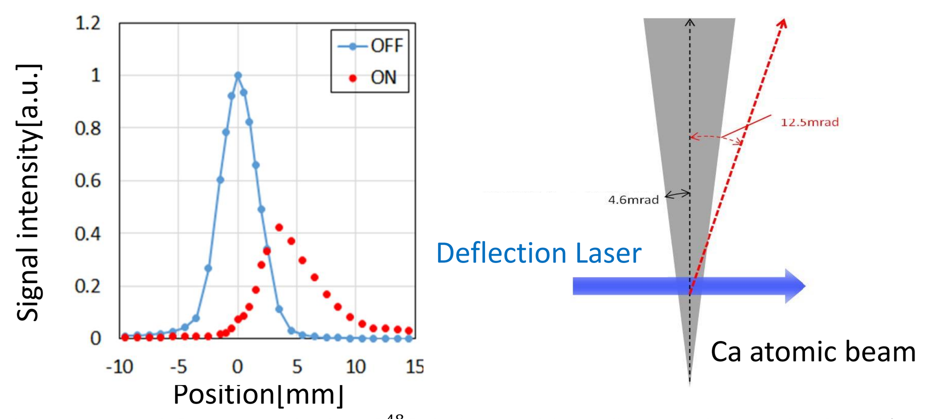
Previous research

The proof of principle of the deflection method has been completed.

^{40}Ca deflected by 12.5mrad

R&D for mass production of ^{48}Ca

- Aiming to produce several mol/yr. within a few years
- Goal : a few kmol/yr.



Kohei MATSUOKA, "Development research for mass production of ^{48}Ca by laser enrichment", Master thesis, Univ. of Fukui (2020)

Natural width

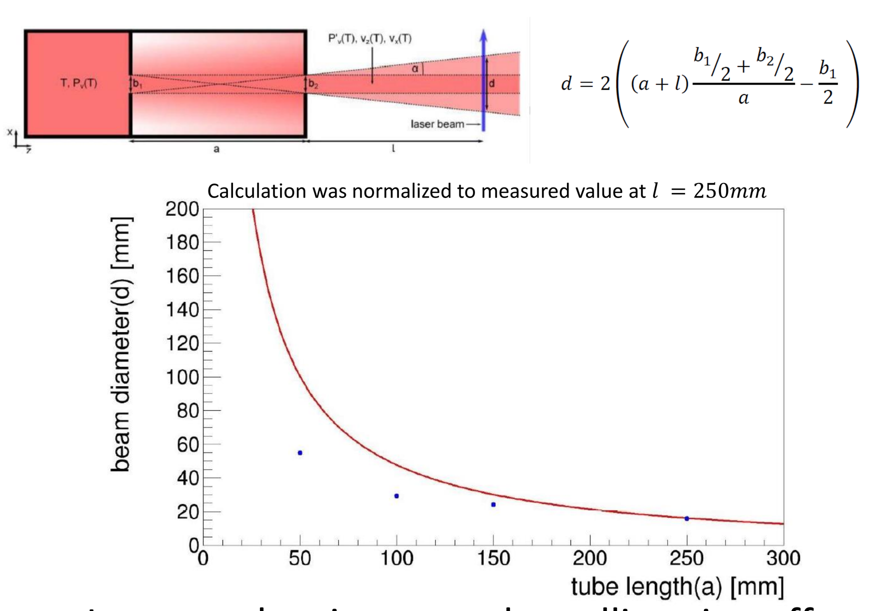
Transition	:	$^1P_1 - {}^1S_0$
Time constant	:	$\tau = 4.6\text{ns}$
Natural width	:	$\Delta\nu_{nat.} = \frac{1}{2\pi\tau}$
		$= 34\text{MHz(FWHM)}$

Suppress the FWHM of Doppler spread to about 34MHz of natural width of Ca.

Verification of the collimate effect

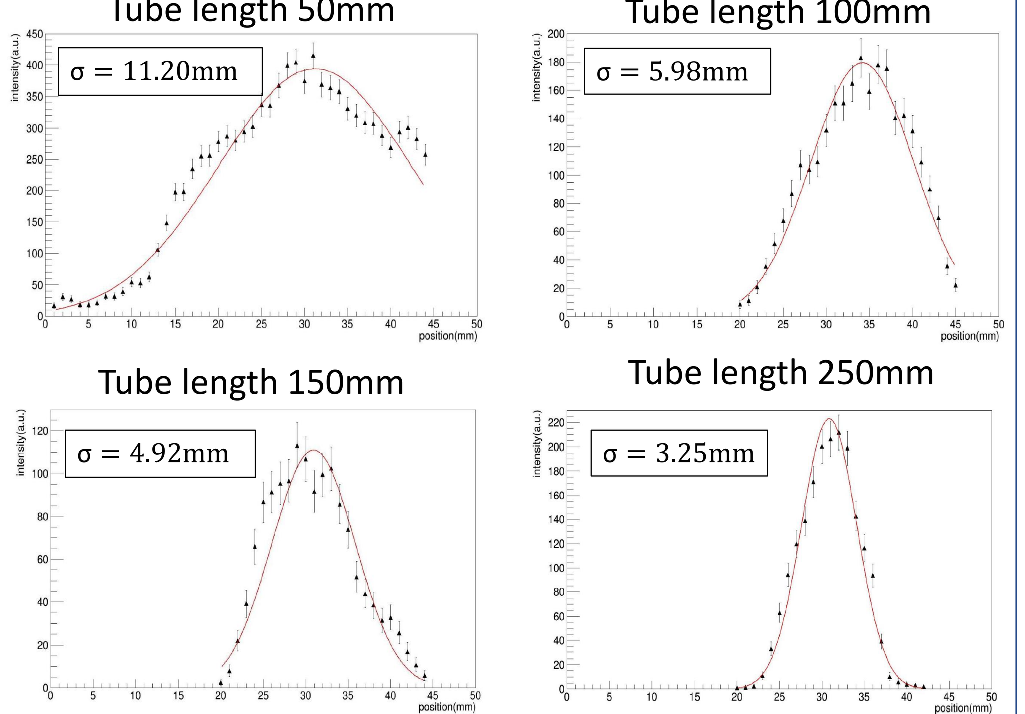
The length of the tube was varied to check the collimating effect.

$$d = 2\left((a+l)\frac{b_1/2 + b_2/2}{a} - \frac{b_1}{2}\right)$$

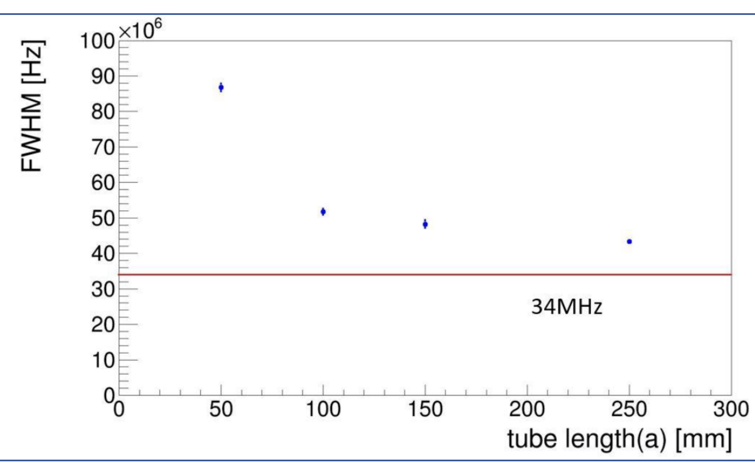


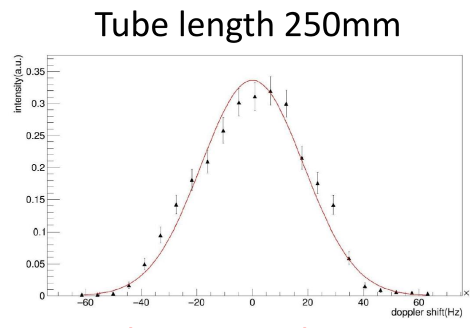
Longer tubes increase the collimating effect.

σ is the standard deviation when fitted assuming the spatial distribution is Gaussian.



Higher collimating effect than the geometrically calculated value could be obtained.





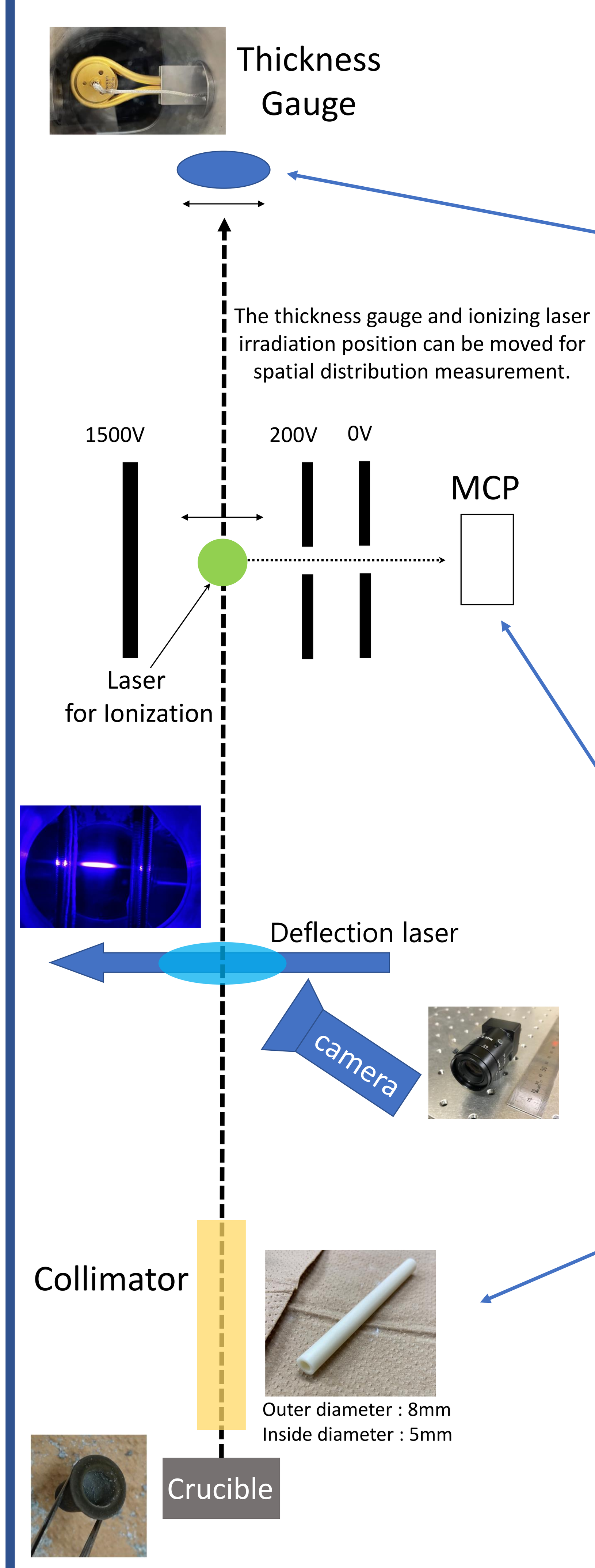
Estimated Doppler spread.

σ_d = 18.4MHz

FWHM = 43.4MHz

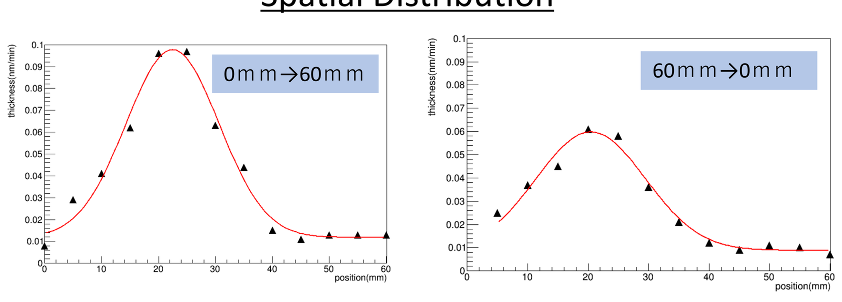
The Doppler spread is measured to be comparable to the natural width.

Monitoring system



σ is the standard deviation when fitted assuming the spatial distribution is Gaussian.

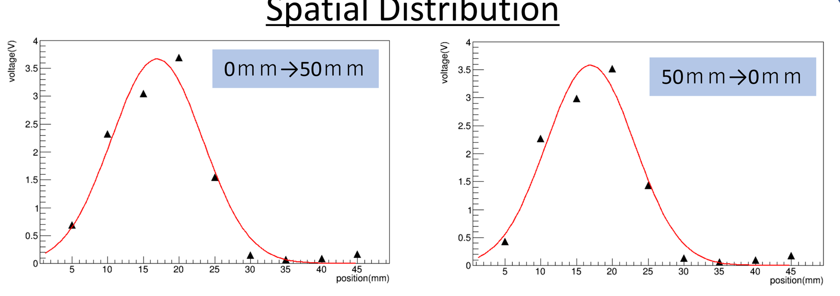
Thickness Gauge



σ = 8mm	σ = 9mm
σ※ = 5mm	σ※ = 5mm

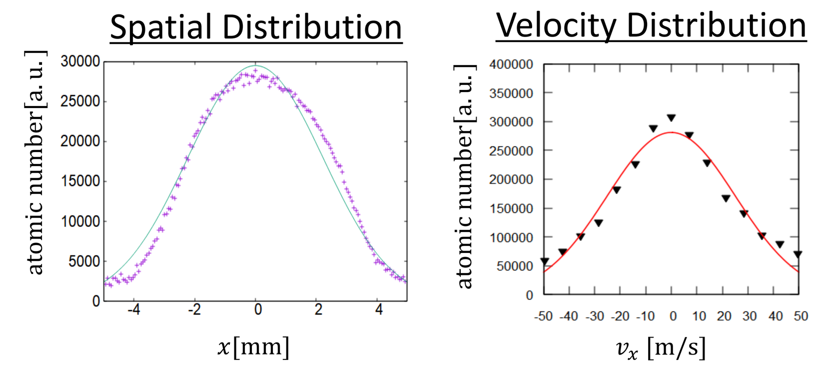
Accuracy is not good because of the BG.

TOF



σ = 6.422mm σ = 6.202mm

Fluorescence measurement



x : Position coordinates perpendicular to the atomic beam

σ = 2.24mm

σ※ = 19.1mm

σ_{v_x} = 25.1m/s (Measured value)

σ_{v_x} = 9.2m/s (Calculated value)

Further studies are needed.

※σ for measurements using fluorescence and thickness gauges are converted to TOF position

Conclusion

- Higher collimating effect than the geometrically calculated value could be obtained.
- The Doppler spread is measured to be comparable to the natural width.

- TOF measurements provide high accuracy.
  - → Use TOF measurement for accurate spatial distribution measurement after deflection.
- Thickness gauges are easy to measure, but BG has a large influence.
  - → Can be used for simple measurement of atomic beam quantity.
- Fluorescence measurement needs further studies.
  - → Consider whether the analysis method is valid.
  - → Spatial distribution before deflection is easily measured by fluorescence measurement.

The next step is to generate a sheet atomic beam using a collimator with three tubes in a row with a large-volume crucible.