Laser Ion Sources Workshop, 25 Oct. 2016
at UPMC - Campus des Cordeliers, Paris

Latest developments on the narrow bandwidth laser systems for high resolution resonance ionization spectroscopy

Hideki Tomita[1,2]

[1] Nagoya University, Japan

[2] Nishina Center, RIKEN, Japan

Contents

- Overview of injection locked Ti:Sa laser
- Development of “blue” grating Ti:Sa laser to investigate highly efficient ionization scheme
- High resolution resonance ionization spectroscopy of Zr
- Status of PALIS, RIKEN and developments for high resolution resonance ionization spectroscopy
- Conclusion and future work

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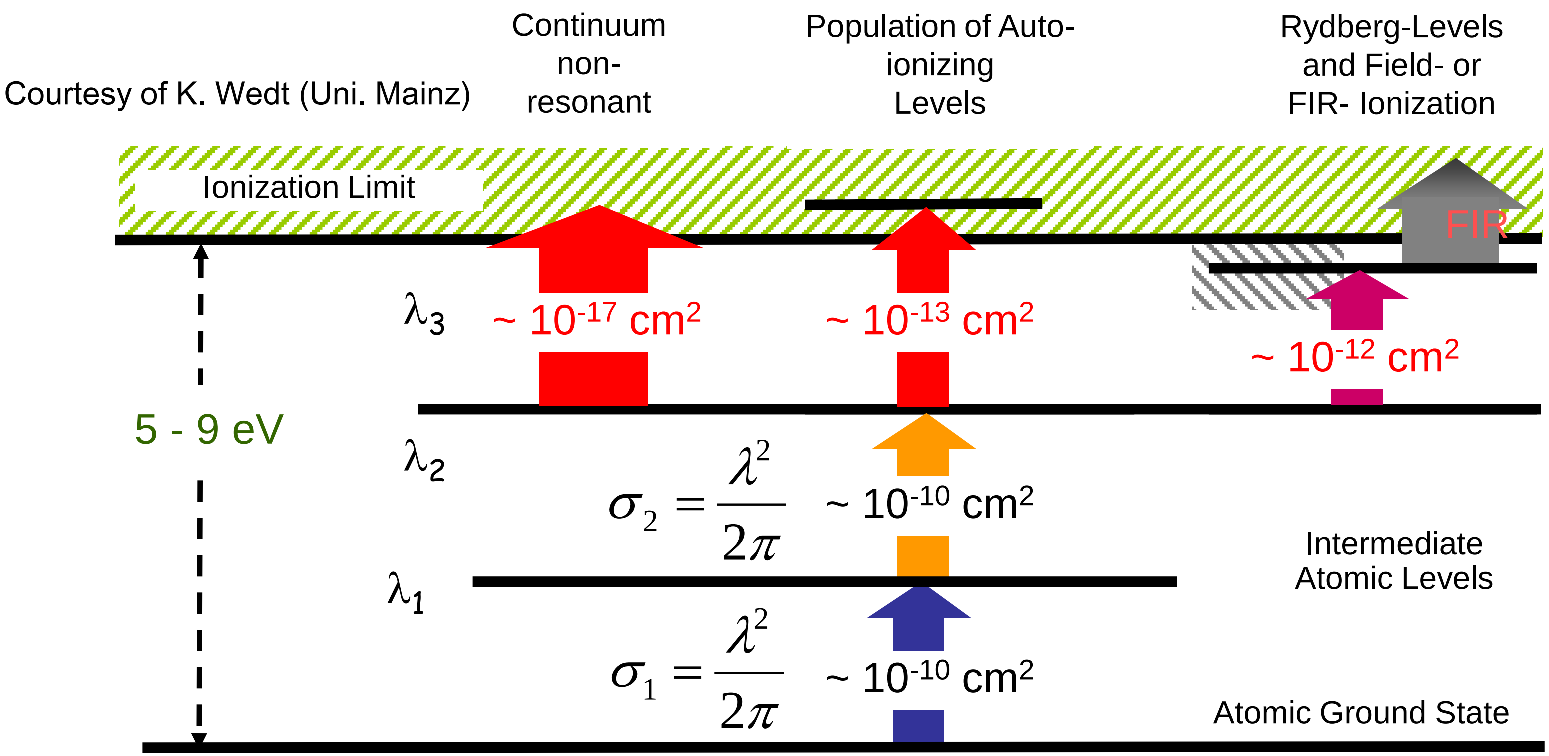
Element/Isotope/Isomer selective Resonance Excitation/Ionization



Broadband Pulsed lasers (Δν ~ 5 GHz)

➡ High element selectivity

i.e. Simple chemical sample preparation

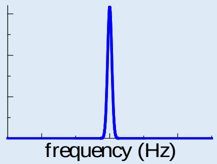
Narrowband pulsed lasers (Δν ~ 20 MHz)

➡ High isotope/isomer selectivity

\+ High Resolution - Resonance Ionization Spectroscopy (HR - RIS)

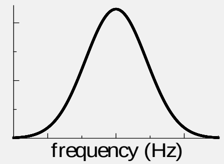
Principle of Injection Locked Ti:Sa Laser

Master Laser
- CW laser
- Narrow band
- Low power

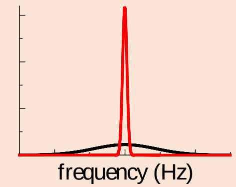


+

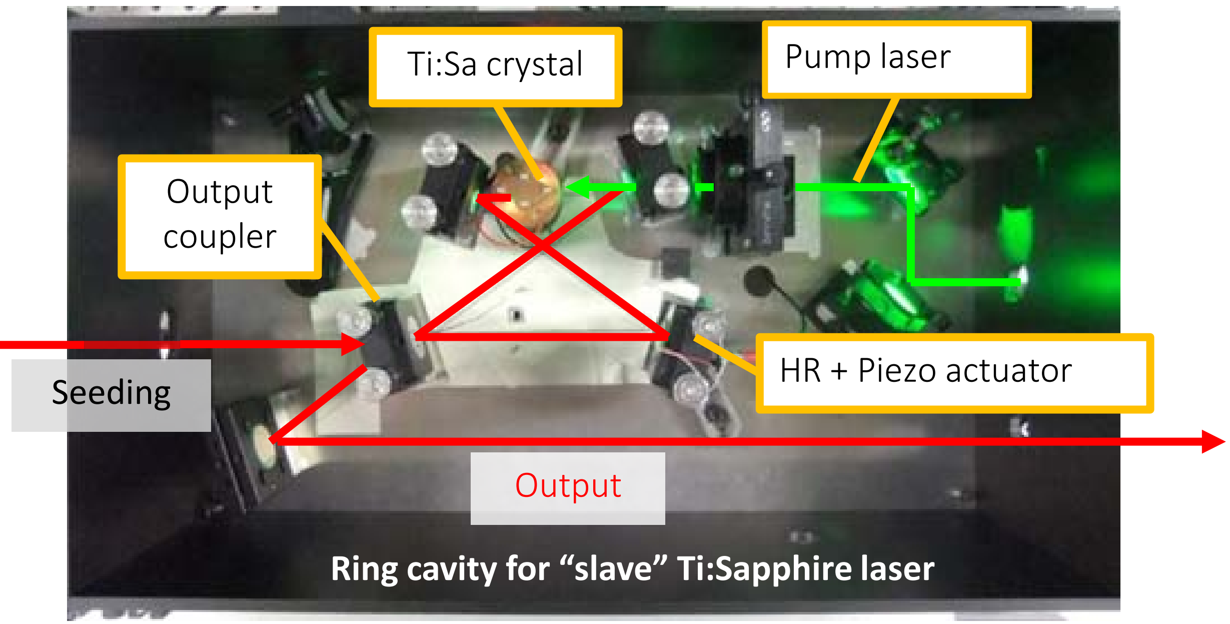
Slave Laser
- Pulsed laser
- Broad band
- High power



Seeded Laser
- Pulsed laser
- Narrowband
- High power



External Cavity Diode Laser as "master" laser

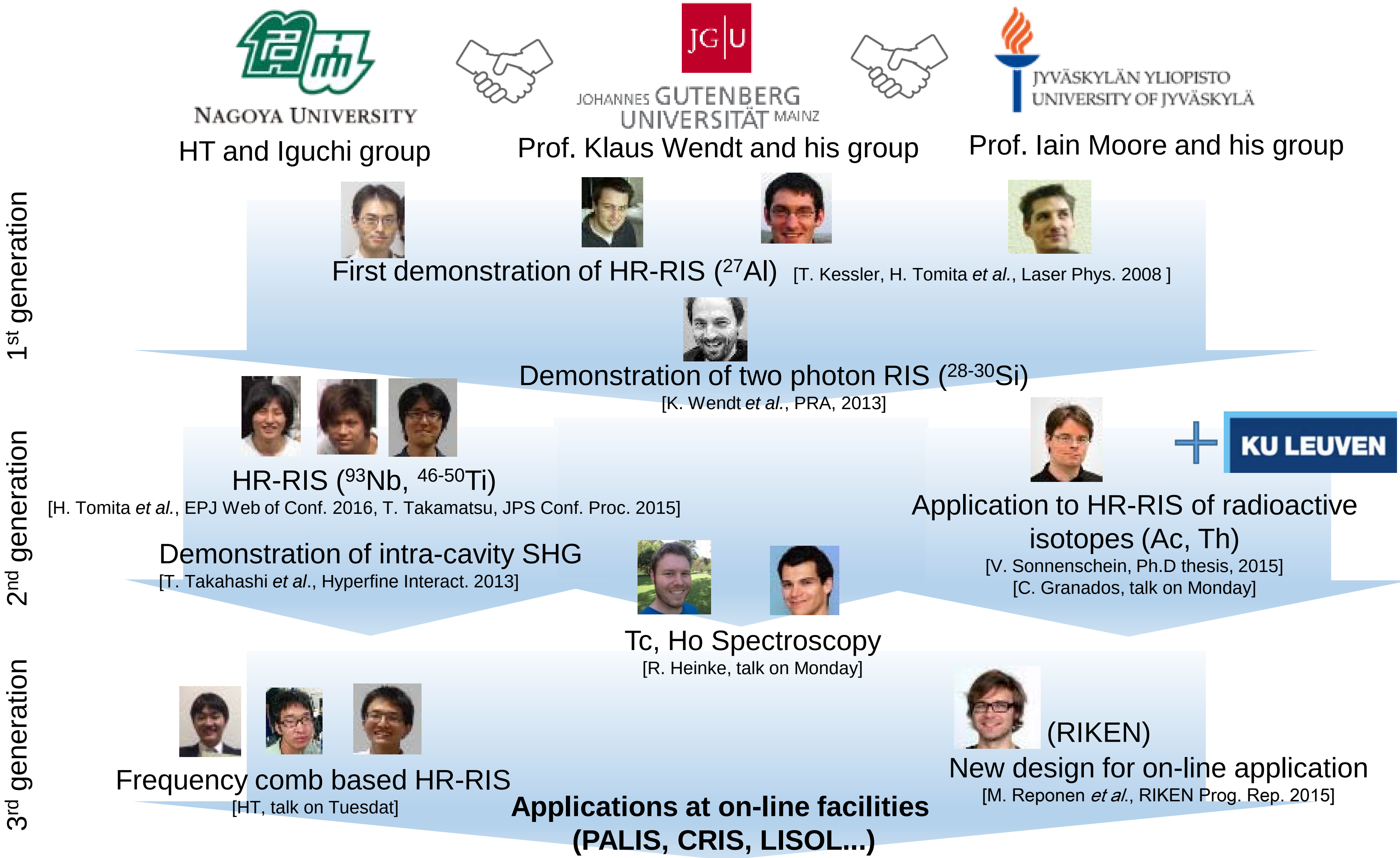


Ring cavity for "slave" Ti:Sapphire laser

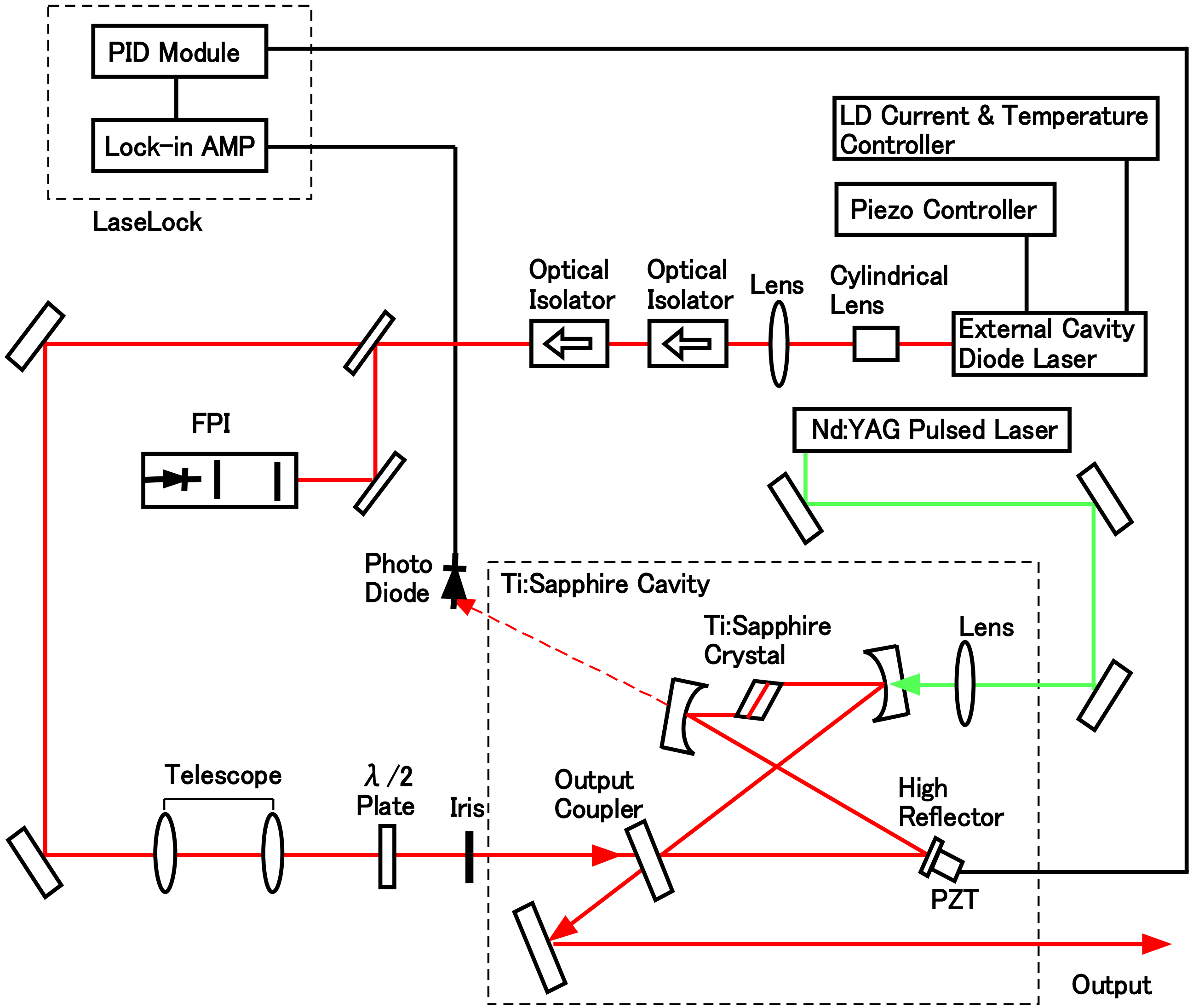
- Band width: ~20 MHz (Narrow-band)
- Output power: ~2 W @ rep. rate of up to 10 kHz
- Frequency doubling & tripling available

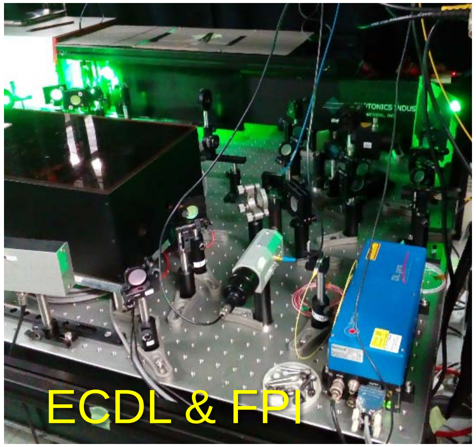
T. Kessler, H. Tomita *et al.*, Laser Phys. **18**, 842, (2008).

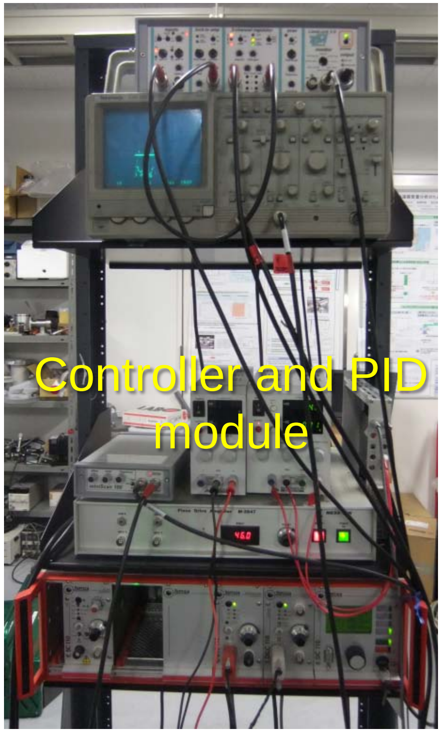
Development History of Injection Locked Ti:Sapphire Laser



Experimental setup of injection locked Ti:Sapphire laser

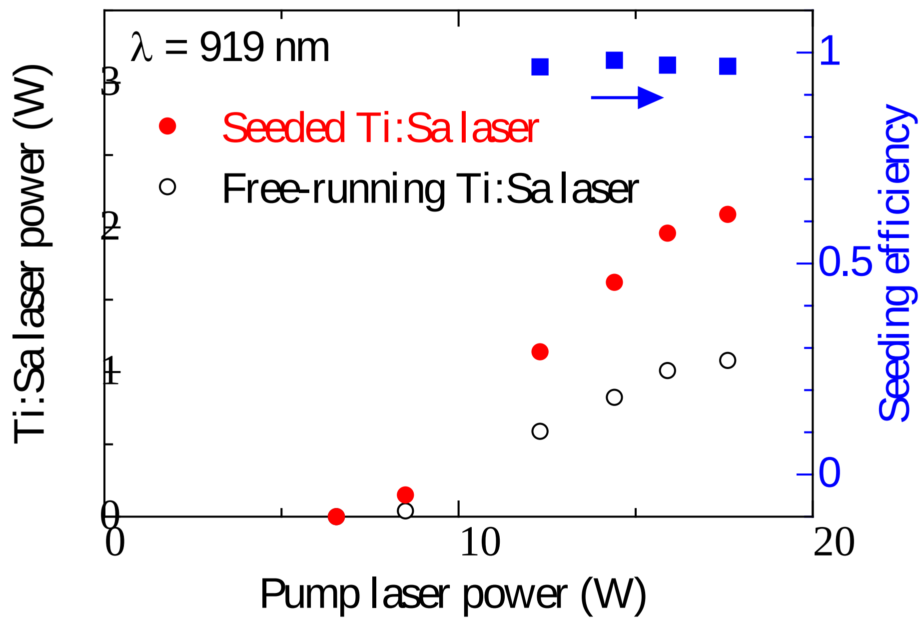




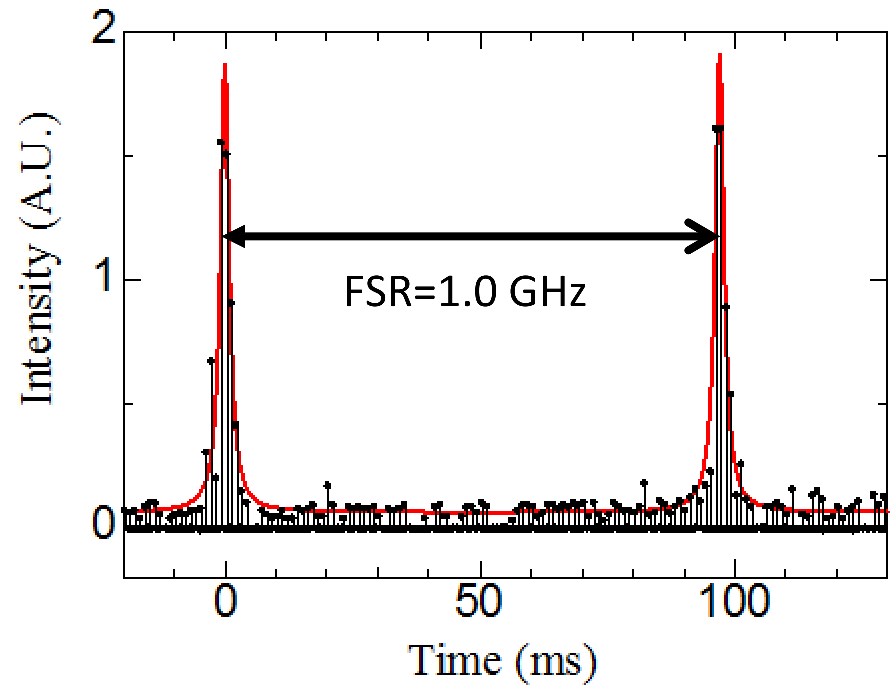


NAGOYA UNIVERSITY

Specifications



Output ~ 2.0 W

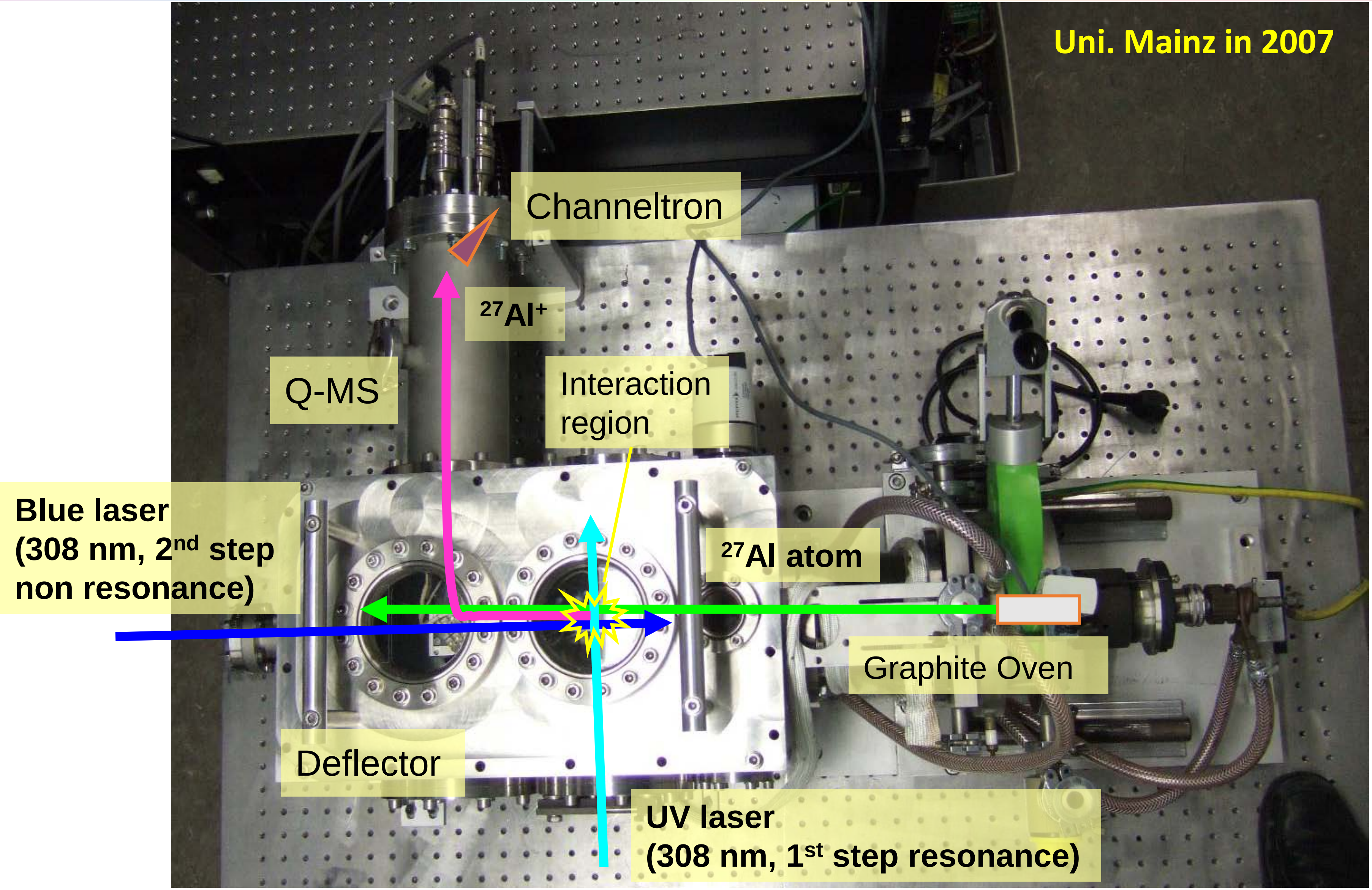


Spectrum of injection seeded Ti:Sa laser measured by Fabry-Perot Interferometer (FSR = 1 GHz)

Band width of ~20 MHz

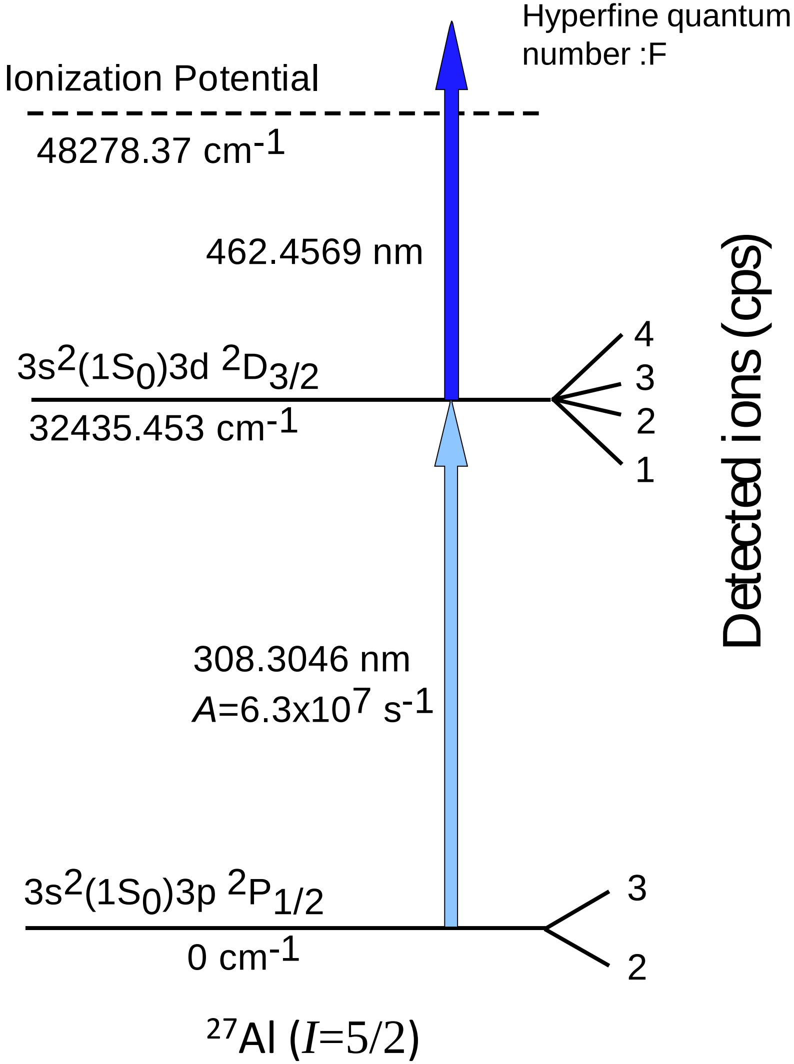
Laser source for isotope/isomer-selective resonant excitation/ionization

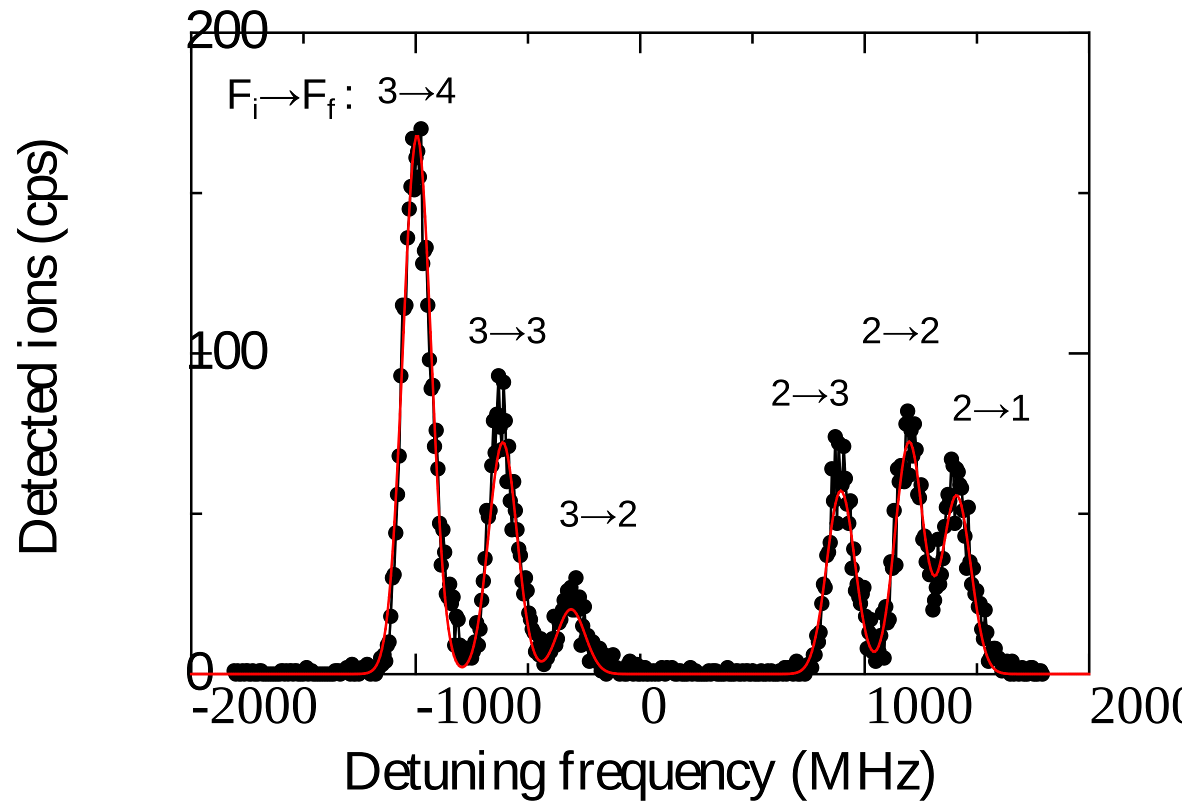
Experimental setup for HR-RIS on stable ^{27}Al



First demonstration of HR-RIS on stable ^{27}Al in 2007

Collaboration with
Uni. Mainz & JYFL



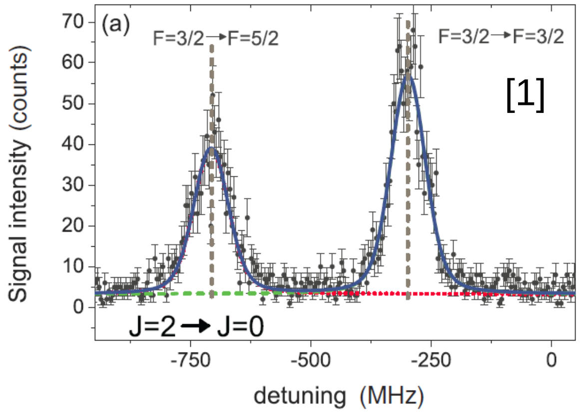


Line-width of 150 MHz [1]

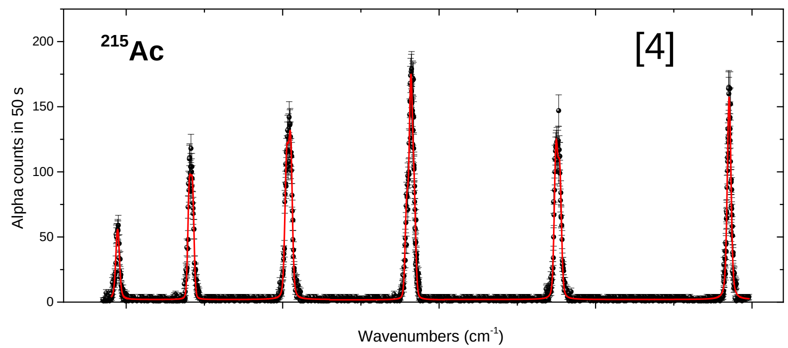
[1] T. Kessler, H. Tomita *et al*. Laser Physics, **18**, p.842–849 (2008).

Applications of the injection locked Ti:Sa laser

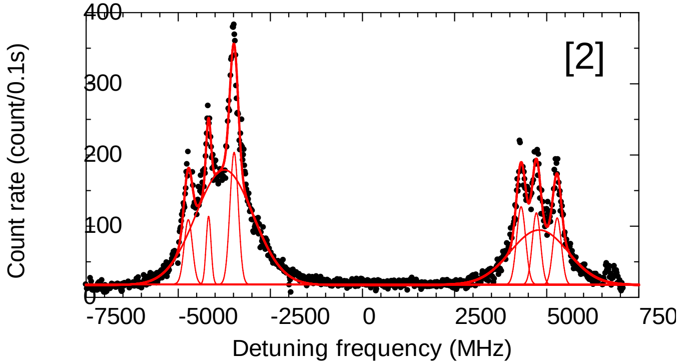
Si



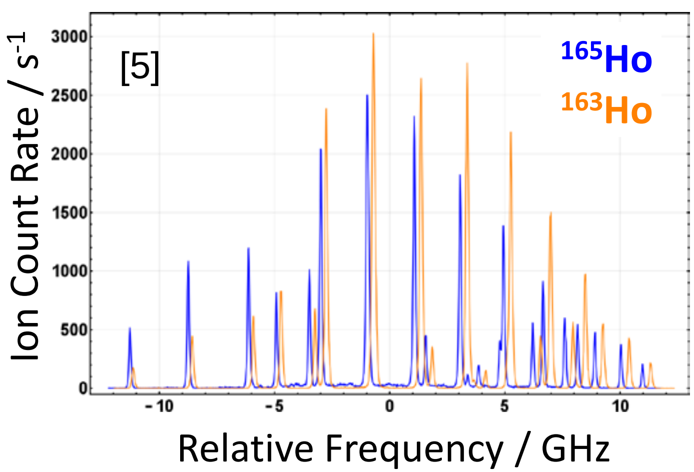
Ac



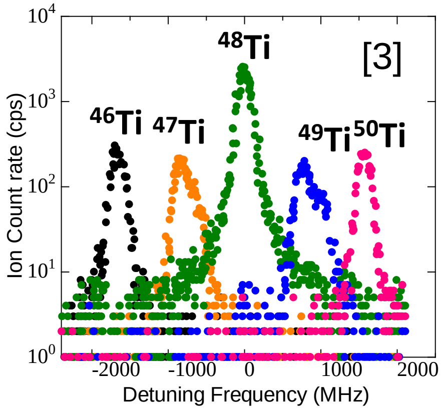
Nb



Ho



Ti



and Tc [6], Th [7]

[1] K. Wendt *et al*., Phys. Rev. A **88**, 052510, (2013).
[2] H. Tomita *et al*., EPJ Web of Conf. **106**, 05002, (2016).
[3] T. Takamatsu *et al*., JPS Conf. Proc. **6**, 030142, (2015).
[4] R. Ferrer *et al*., to be published.
[5] R. Heinke *et al*, to be submitted.
[6] T. Kron *et al*., to be submitted.
[7] V. Sonnenschein, Ph.D thesis, (2015).

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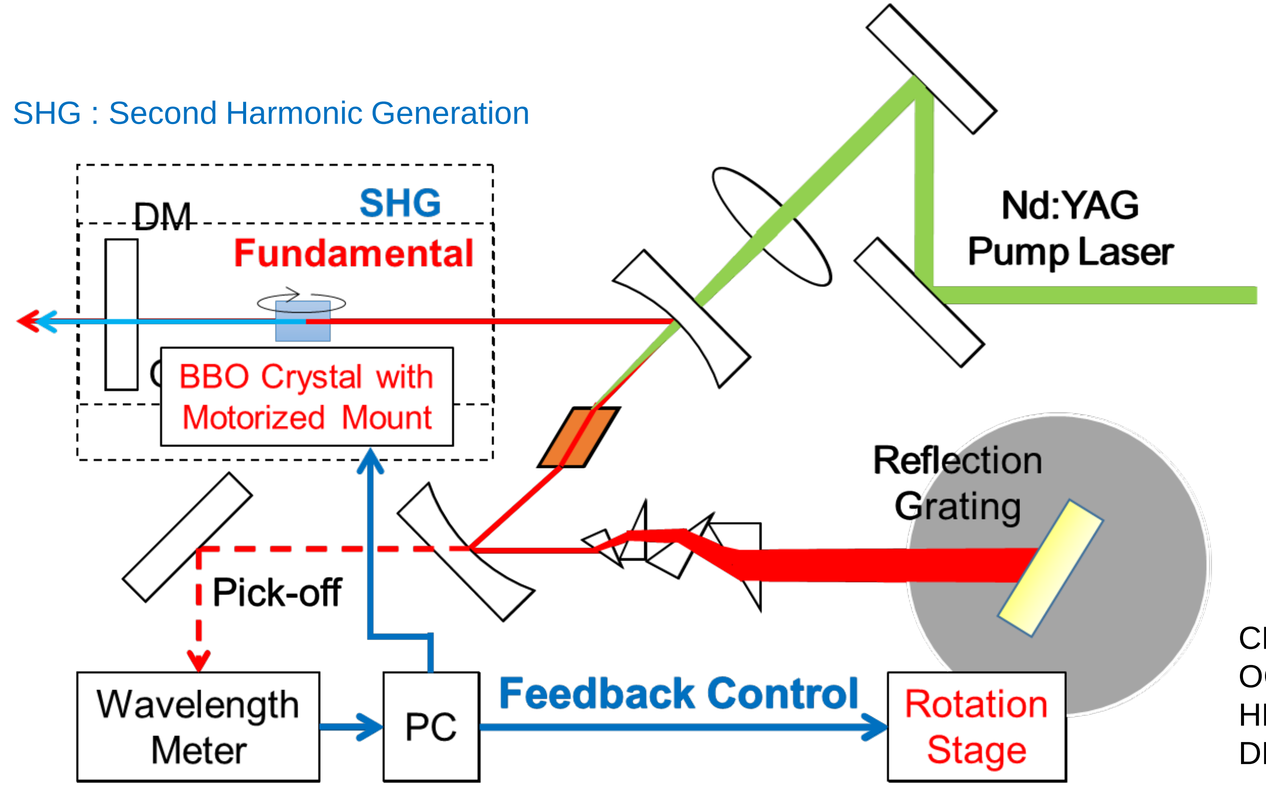
Auto-tuning Operation of Grating Ti:Sa Laser (fundamental & intracavity-SHG)

Toward HR-RIS, highly efficient ionization scheme should be developed.



Collaboration with K. Wendt (Uni. Mainz) and T. Sakamoto (Kogakuin Univ.)

CM : Curved Mirror
OC : Output Coupler
HR : High Reflector
DM : Dichroic Mirror

For better usability:

- Wavelength meter readout was used for feedback control of the wavelength.
 (Computer contralled operation)

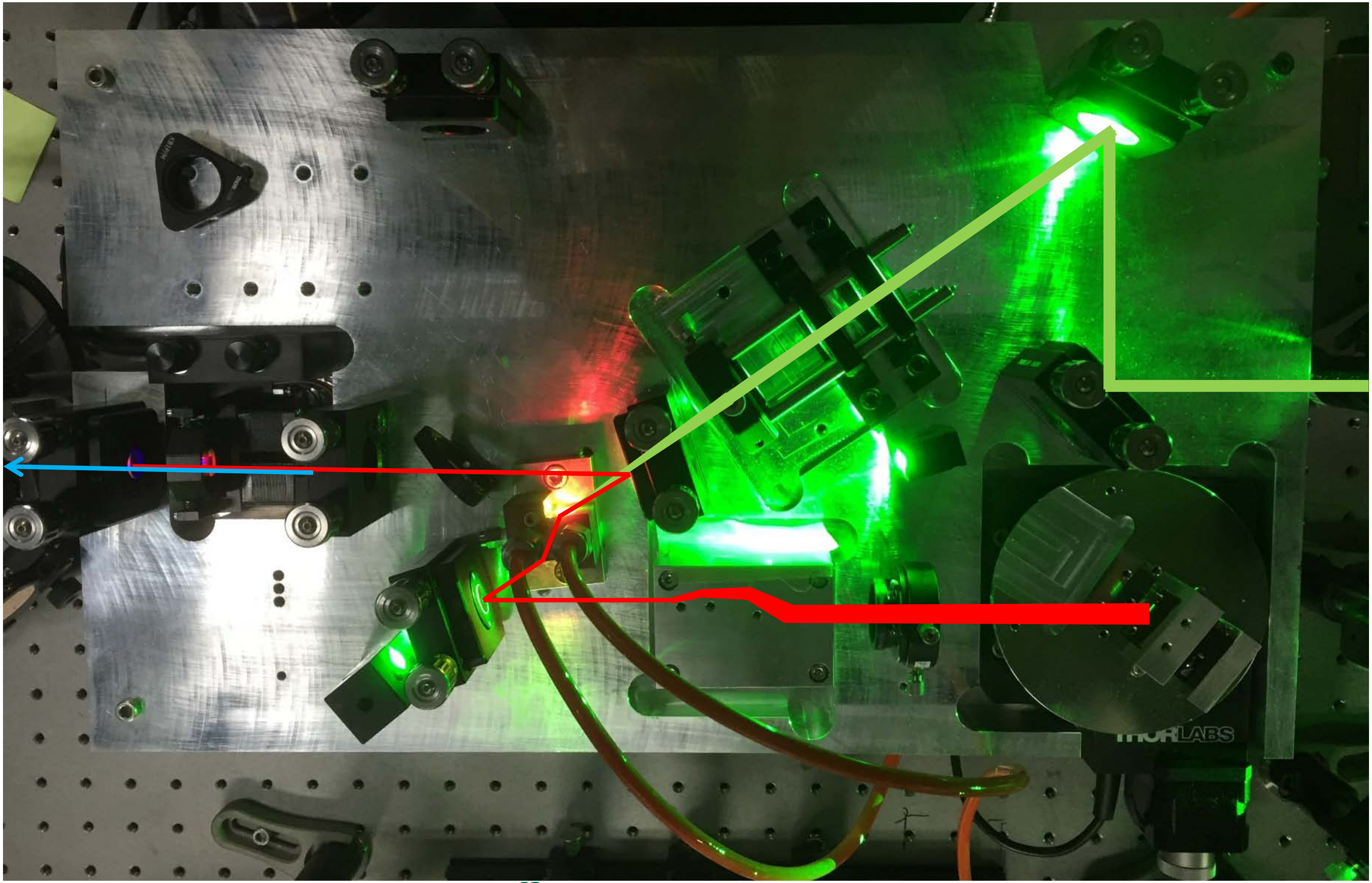
For scanning in blue region:

- Intracavity-SHG option was installed.
 (Phase matching requires constant tracking of the vertical BBO angle.)

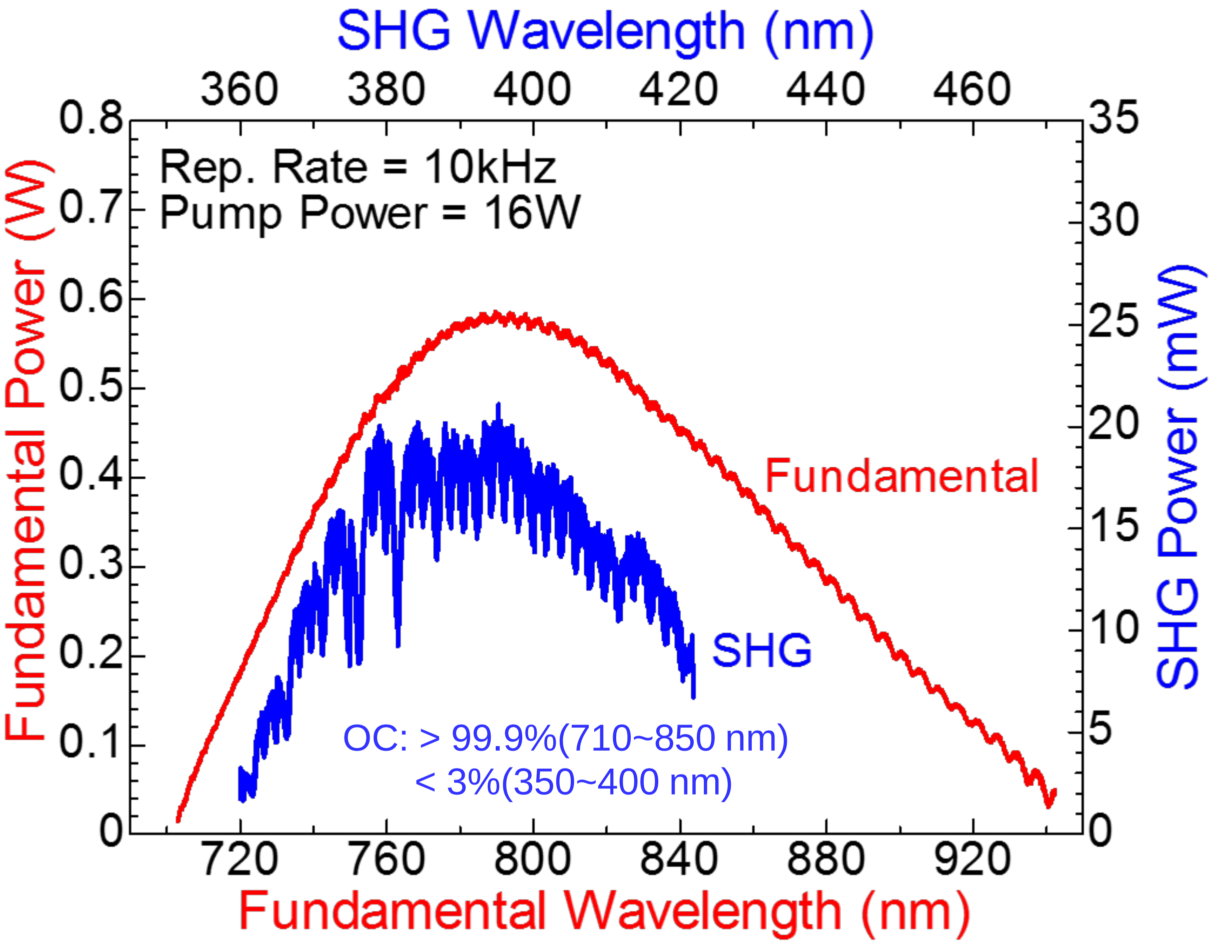
Grating Ti:Sa Laser with intracavity-SHG option

V. Degner, Master thesis, Uni. Mainz & Nagoya Univ. (2016)
D. Matsui, Master thesis, Nagoya Univ. (2016)

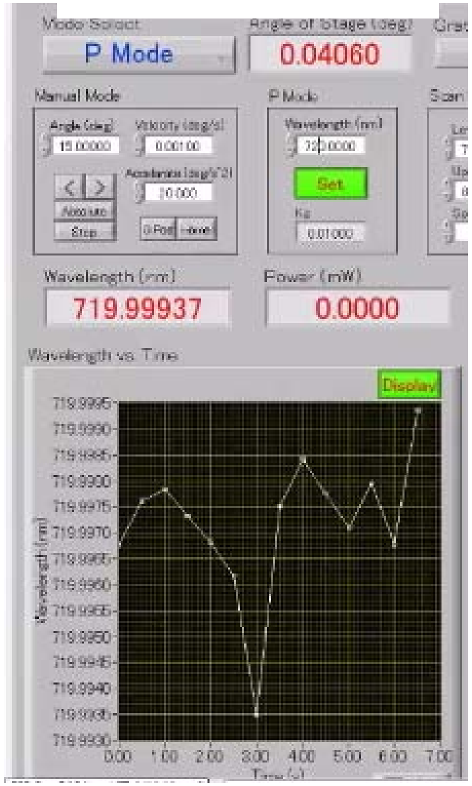
Grating Ti:Sa Laser with intracavity-SHG option



Scanning range of the grating Ti:Sa laser



λ-Scan

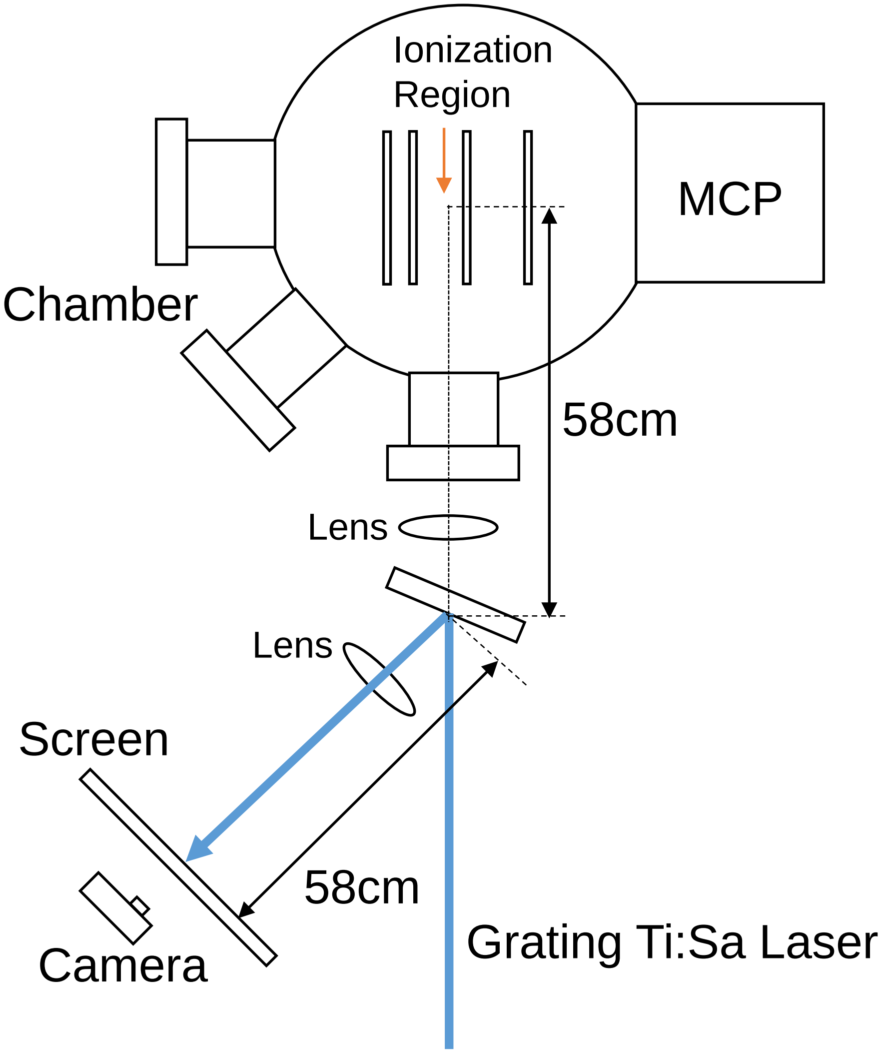


X10

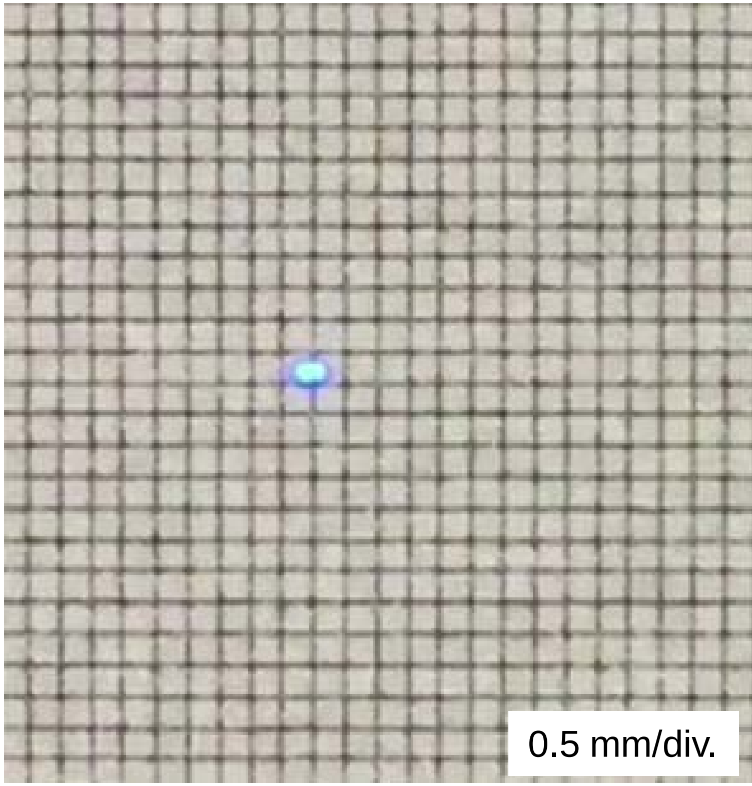
Auto-tuning of wavelength can be done within a few min.

Computer controlled feedback system provide scaning range in 710 ~ 940 nm (fundamental) and 360 ~ 420 nm (SHG).

Beam pointing stability



Beam pointing stability



Beam position shift < 0.5 mm @ 4 m

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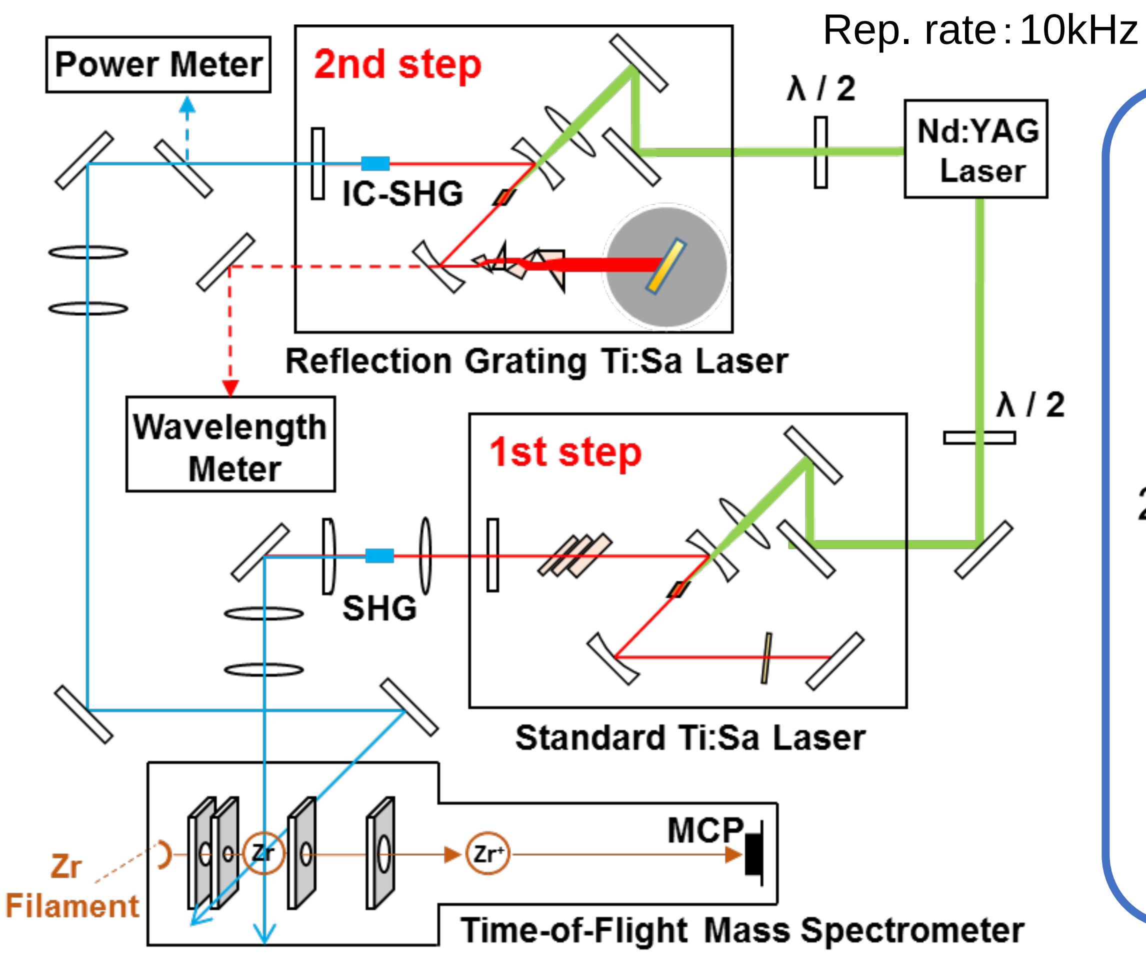
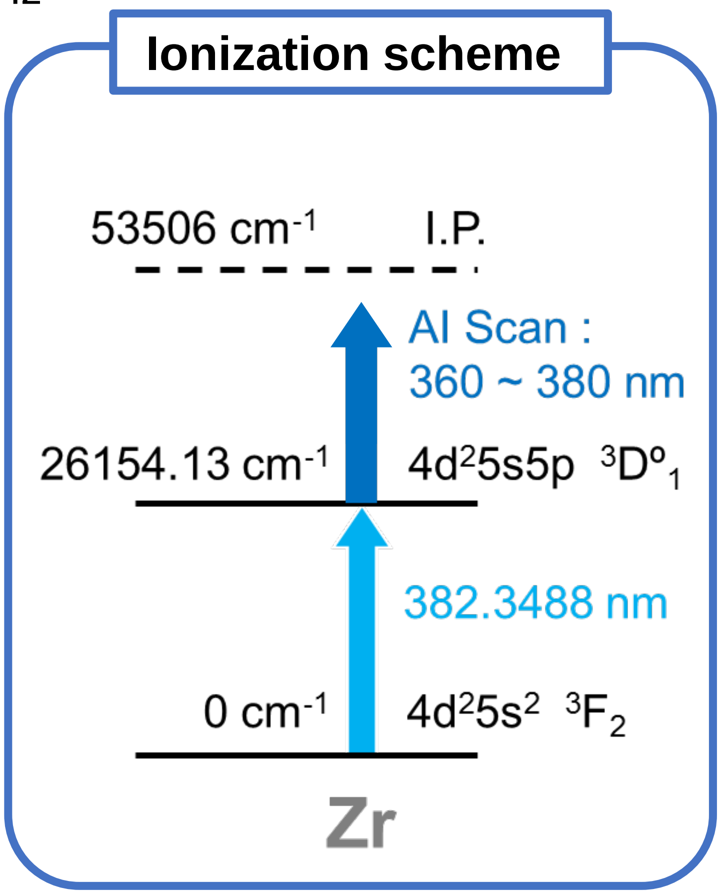
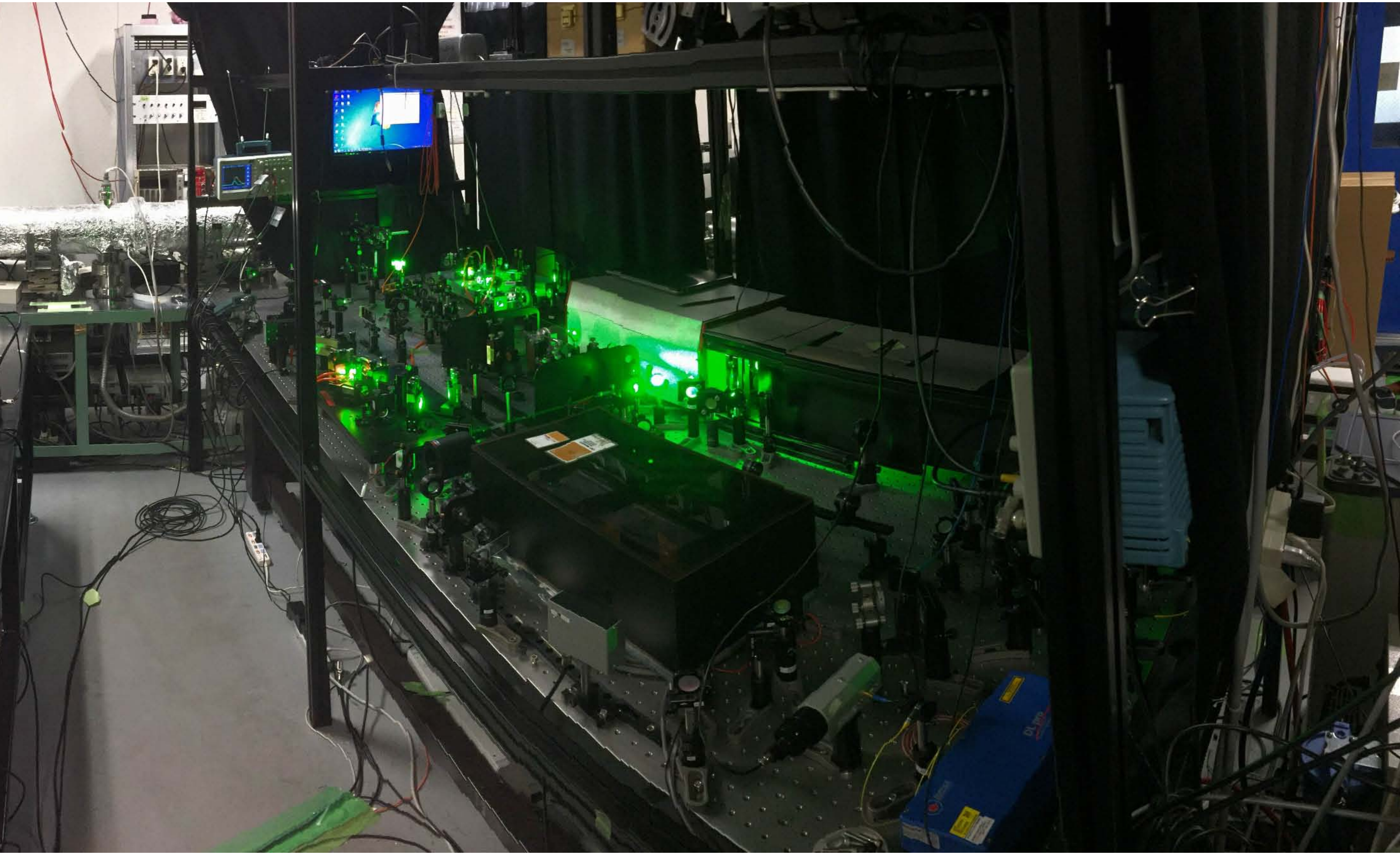
Experimental setup for Zr

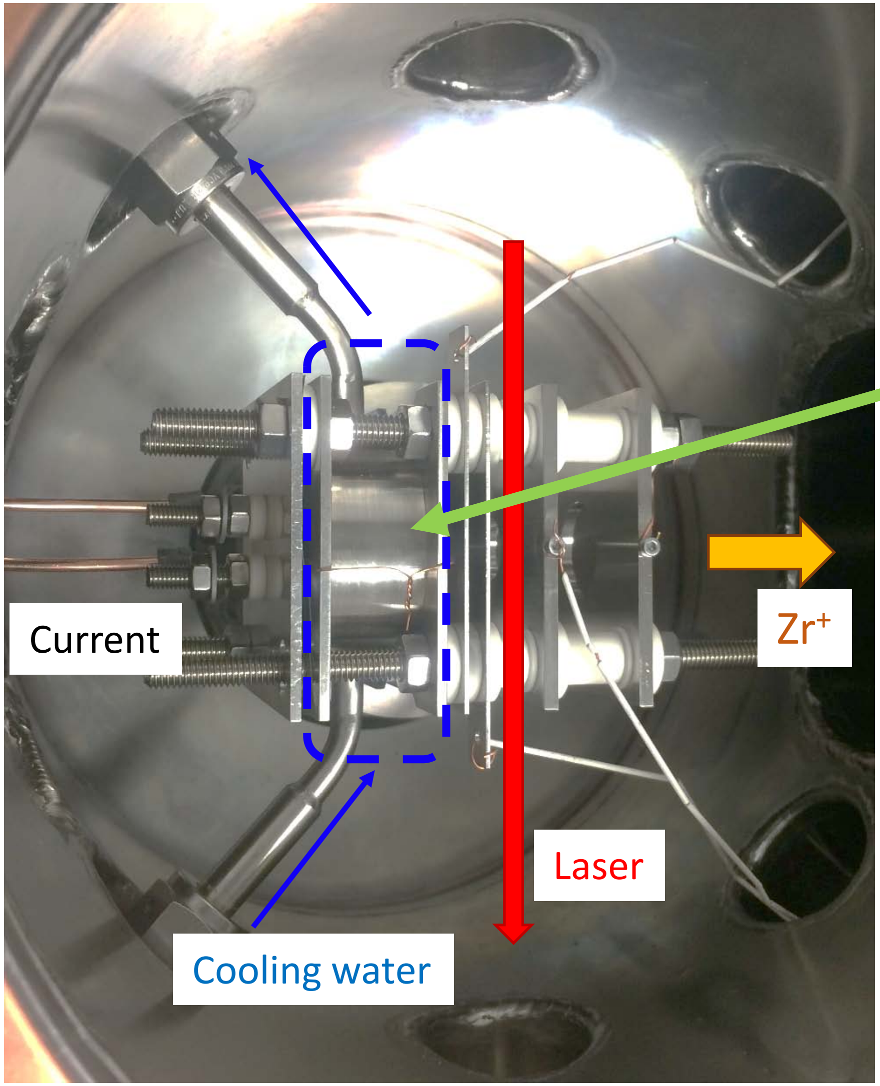


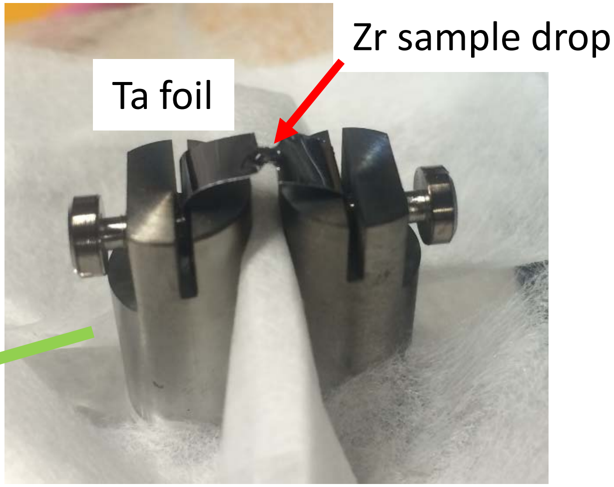


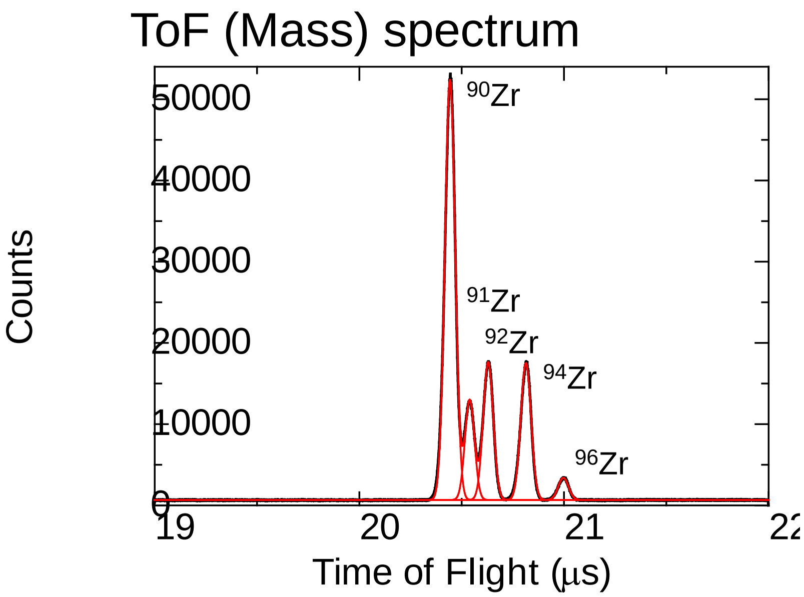
Laser laboratory at Nagoya Univ. (2016)



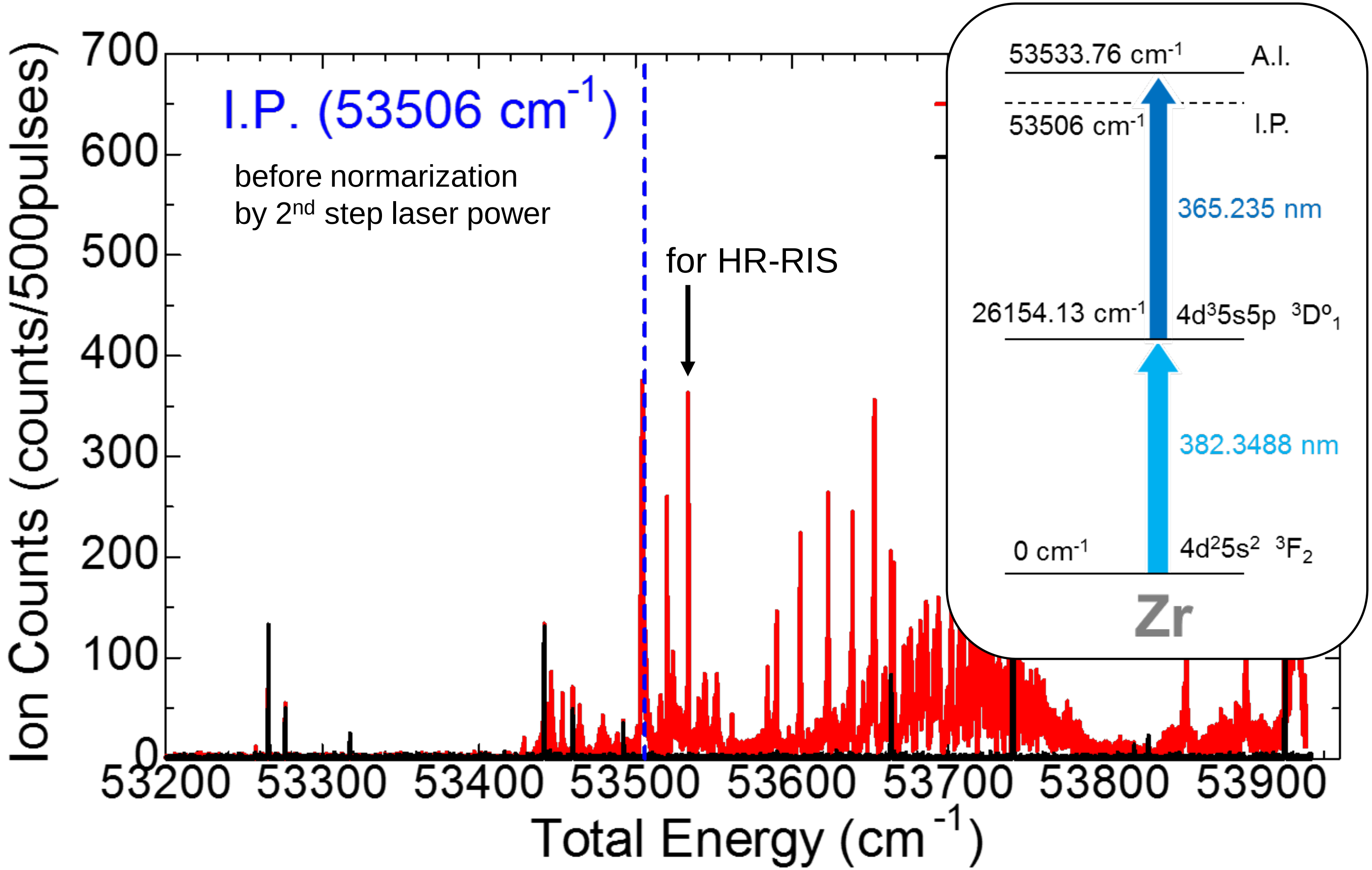
Atom source and ion optics in ToF-MS





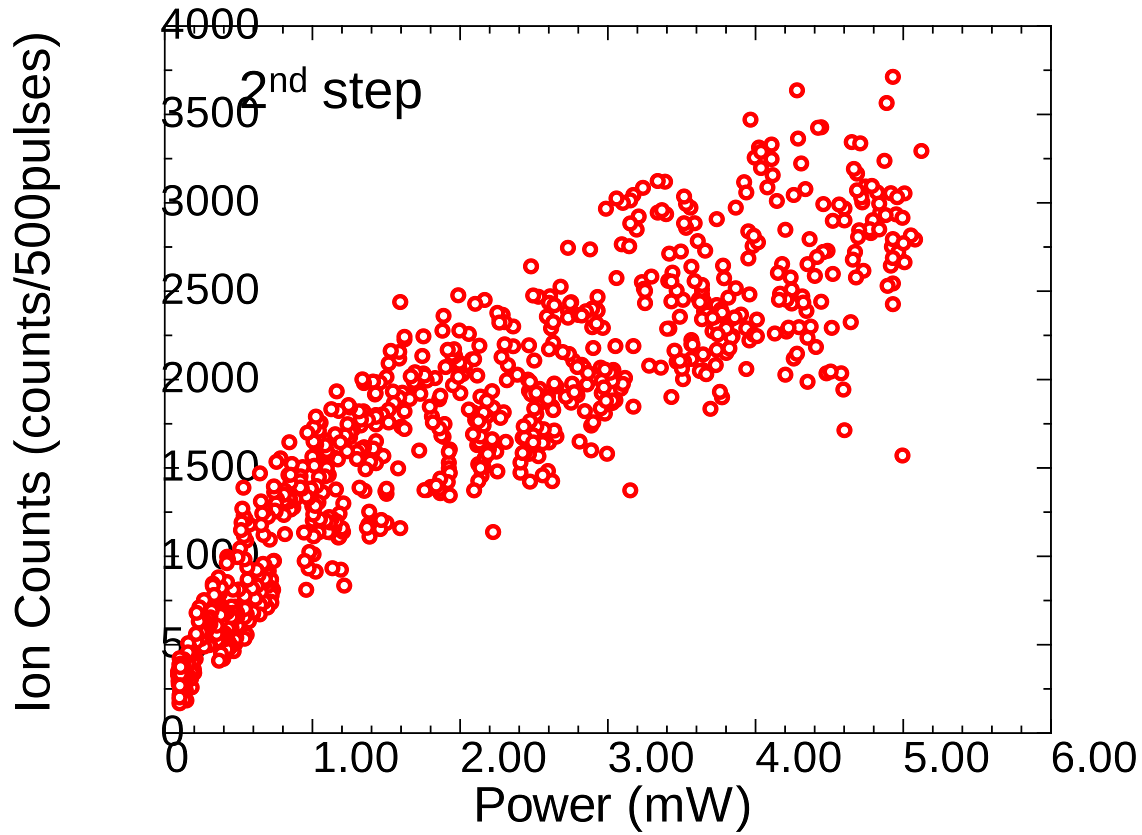


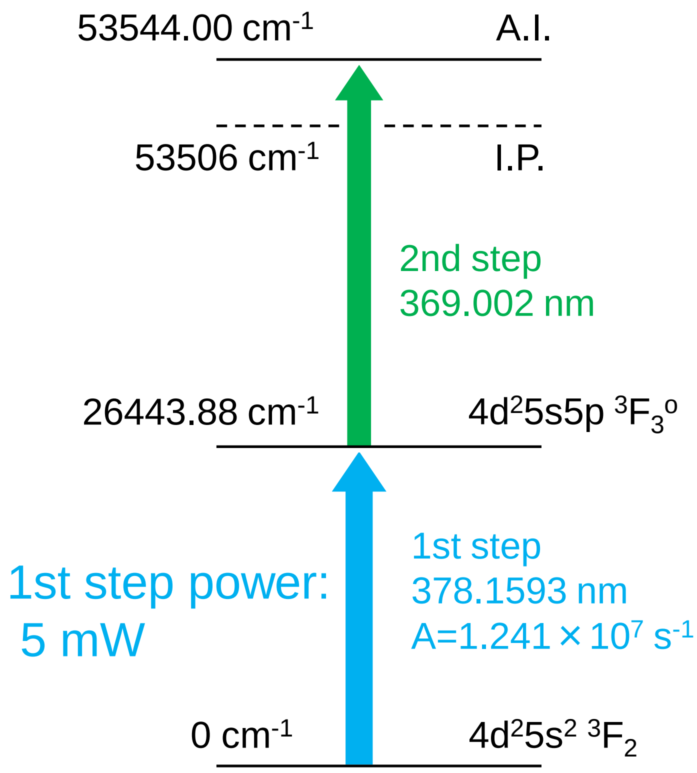
Wide range scanning around I.P.



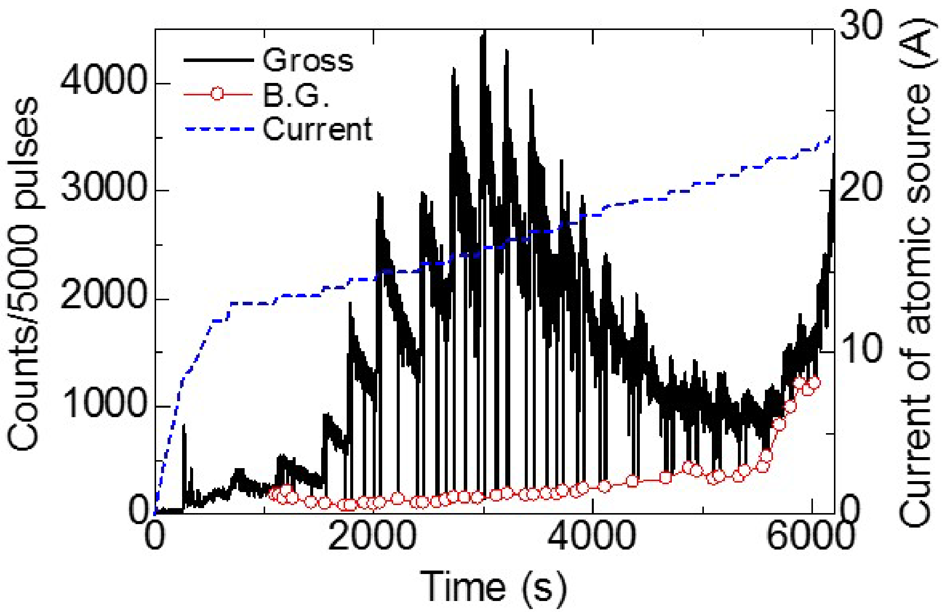
A.I. state at 53533.76 cm^{-1} was chosen for HR-RIS of Zr.

Saturation in 2nd step

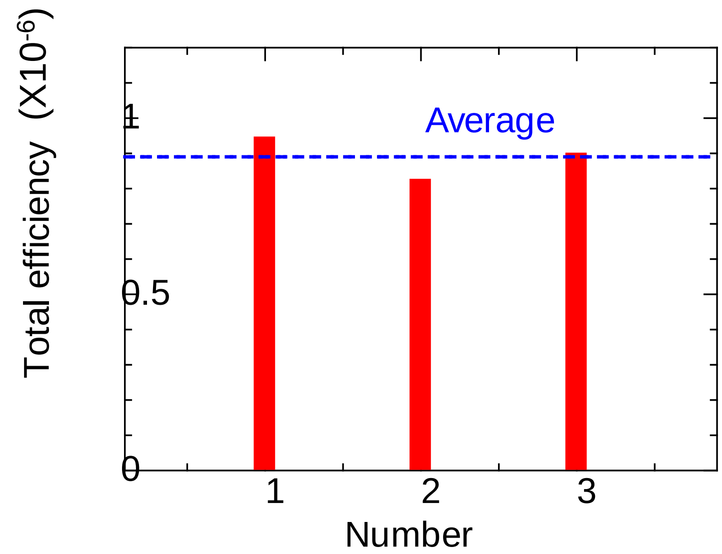




Evaluation of overall efficiency



Time trend of Zr ion signals



6.2×10^{6} ions

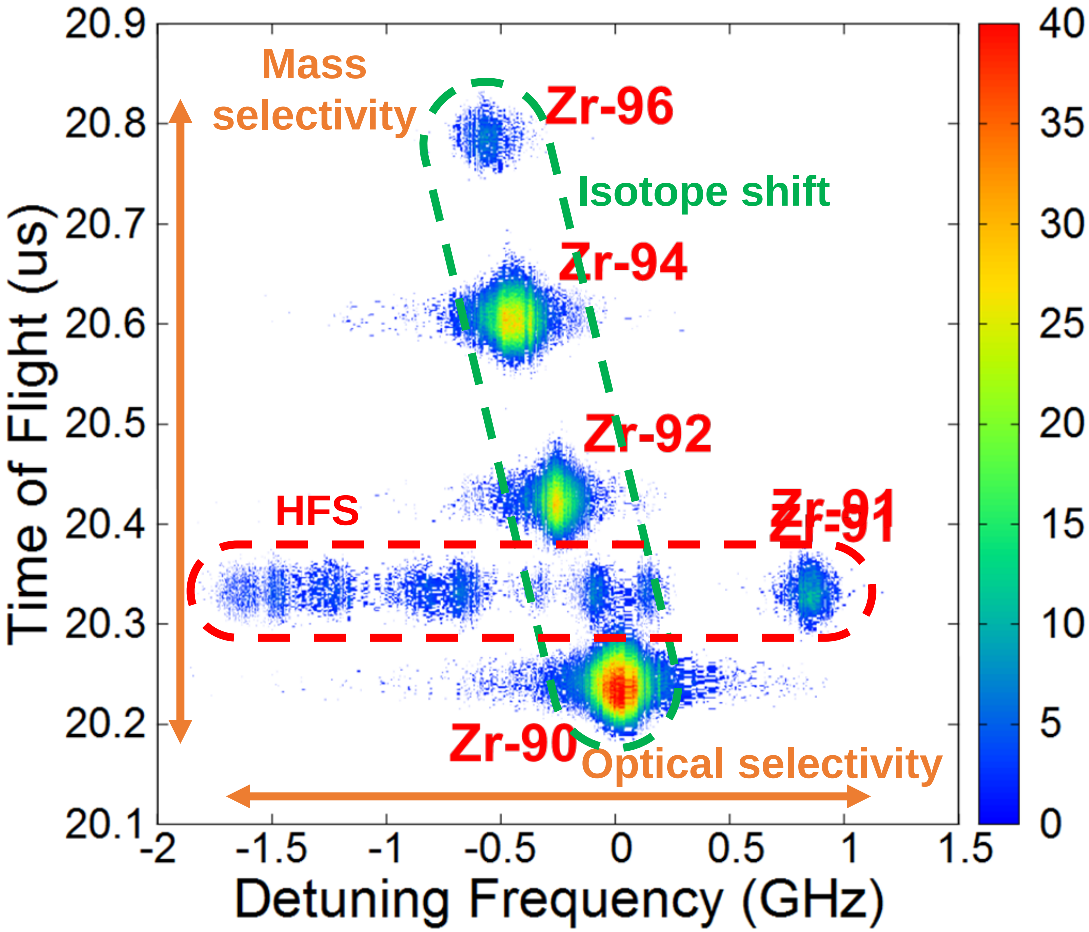
Overall efficiency $= \dfrac{\textit{Number of detected ions}}{\textit{Number of atoms in sample}}$

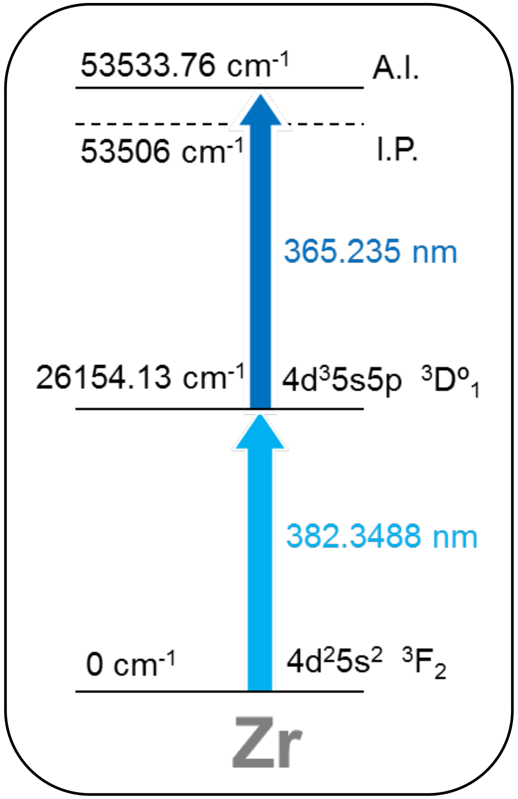
Zr standard solution（1 mg/L）
1 μL ＝ 6.6×10^{12} Zr atoms

$= (8.9 \pm 0.5) \times 10^{-7}$

Lower efficiency was due to lower spatial overlapping in perpendicular atom / laser beam geometry (loss $10^{-3} \sim 10^{-4}$)

HR-RIS of stable Zr isotopes



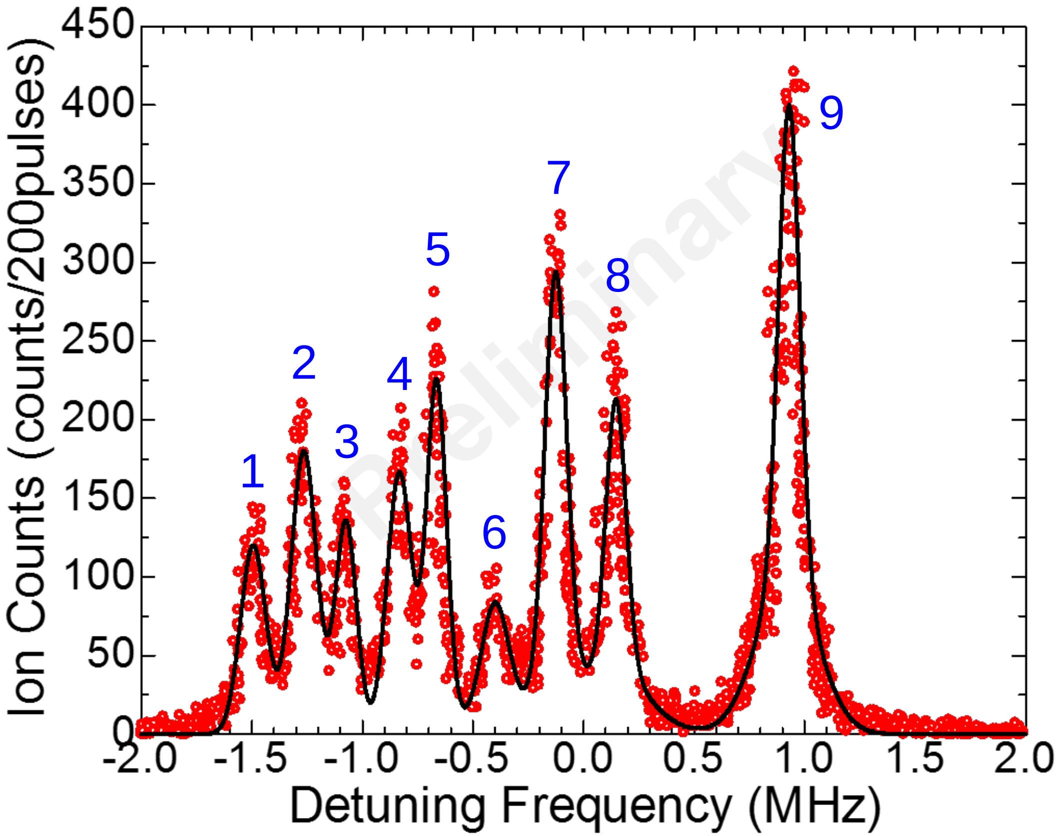


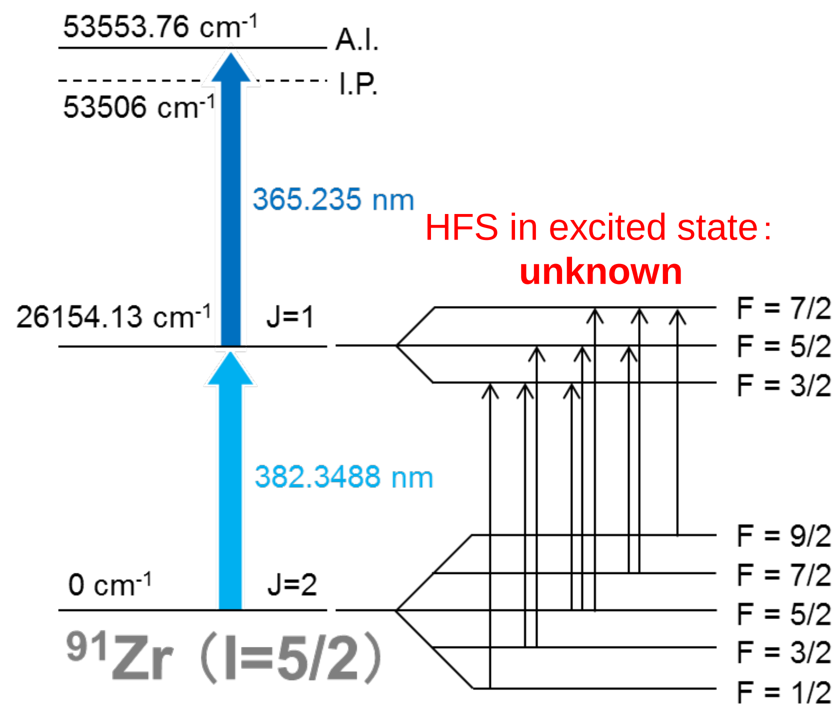
Rather large uncertainty was caused by uncalibrated frequency of the master laser in this experiment. (Typically calib. by FPI was used.)

Line width (MHz)

^{90}Zr	^{92}Zr	^{94}Zr	^{96}Zr
119	86	96	74
(Ave.) 94 ± 17 MHz			

High resolution spectrum of ^{91}Zr





9 peaks were clearly resolved with 100 MHz linewidth.

HFS in ground state (0 cm^{-1}) [5]

F	shift (MHz)
9/2	782.8
7/2	594.2
5/2	416.0
3/2	246.0
1/2	

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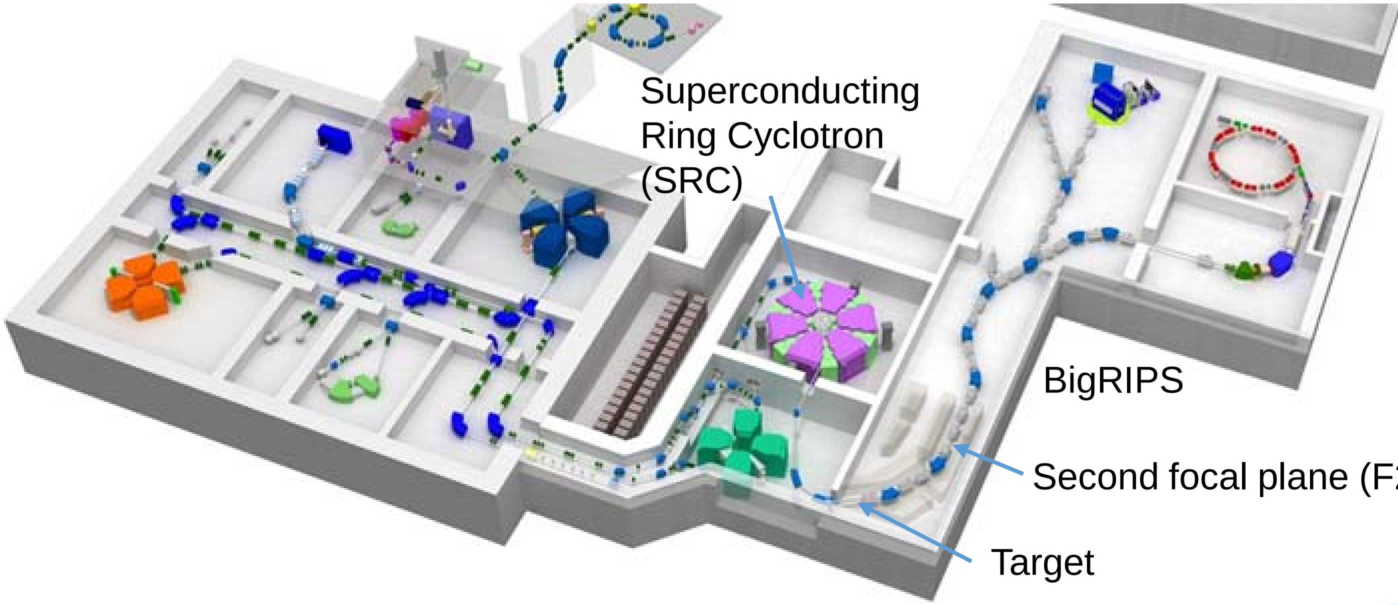
On-line Facility SLOWRI, RIKEN

RI Beam Factory (RIBF) at RIKEN, Japan



A universal Stopped and LOW-energy RI beam facility:

stopped and low energy pure RI-beams of all elements for comprehensive precision spectroscopy

- Measurements of nuclear charge radii and moments by laser spectroscopy (Collinear laser spectroscopy, Trapped ion laser spectroscopy etc.)
- High precision mass measurement (multi-reflection TOF-MS etc.)

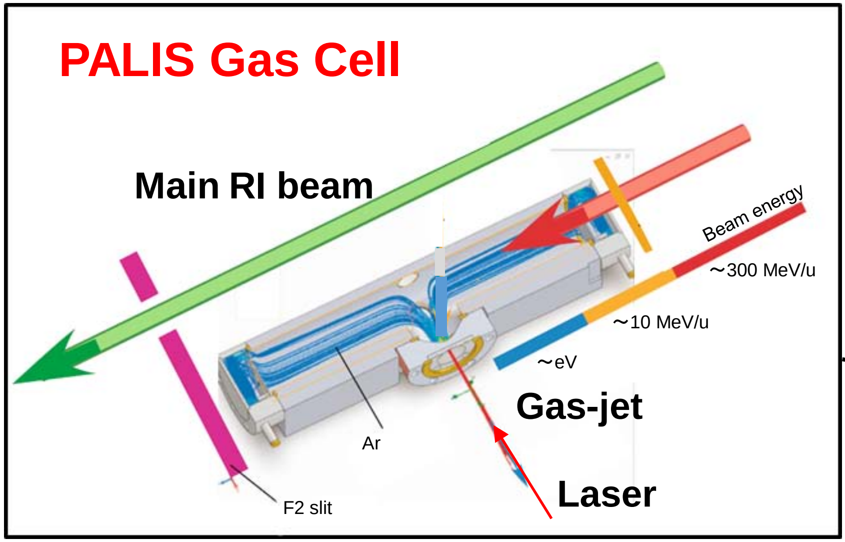
M. Wada *et al*. RIKEN Acc. Prog. Rep. **47** 203 (2013). M. Wada, Conference on Stopping and Manipulation of Ions, SMI-13 (2013).

PArasitic Laser Ion-Source: PALIS

Parasitic slow RI-beam production with gas catcher

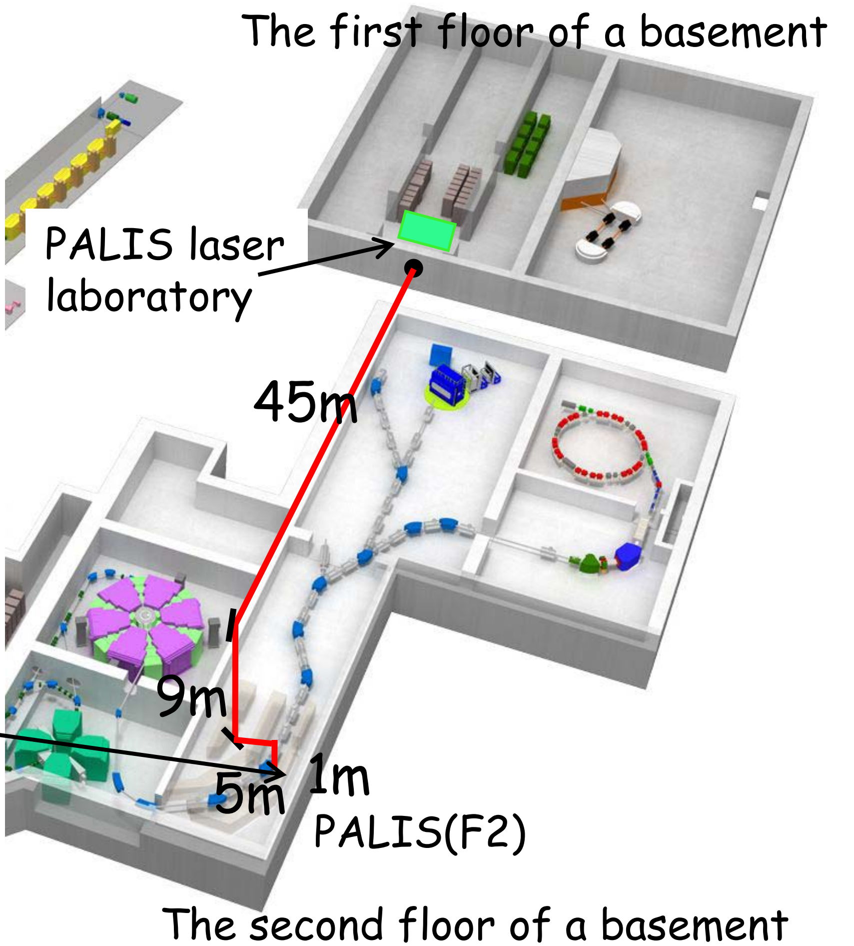
(1) Set a small gas catcher at beam line
(2) Stop & neutralize in Ar (1 bar)
(3) Extract by gas flow
(4) Re-ionize at exit and SPIG

Not universal, not very fast, but...
A/Z, Z, A separation



T. Sonoda *et al.*, Hyperfine Interact, **216**, 103 (2013).

Courtesy of Dr. Sonoda (RIKEN)



PALIS Collaboration

/RIKEN/
T. Sonoda, M. Wada, I. Katayama, T.M. Kojima, S. Arai, F. Arai, Y. Ito (SLOWRI)
T. Kubo, K. Yoshida, N. Inabe, K. Kusaka, Y. Yanagisawa, N. Fukuda, H. Takeda,
H. Suzuki, A. Deuk Soon, T. Sumikama, Y. Shimizu (BigRIPS)
M. Wakasugi (SCRIT)

/Japan Atomic Energy Agency/
H. Iimura

/Nagoya Univ. Iguchi group/
V. Sonnenschein , D. Matsui, T. Takamatsu, H. Tomita

/University of Jyvaskyla/
M. Reponen

/Energy Accelerator Research Organization(KEK)/
H. Miyatake, Y. Hirayama, Y. Watanabe, P. Schury

/Department of Physics, Sophia University/
K. Okada

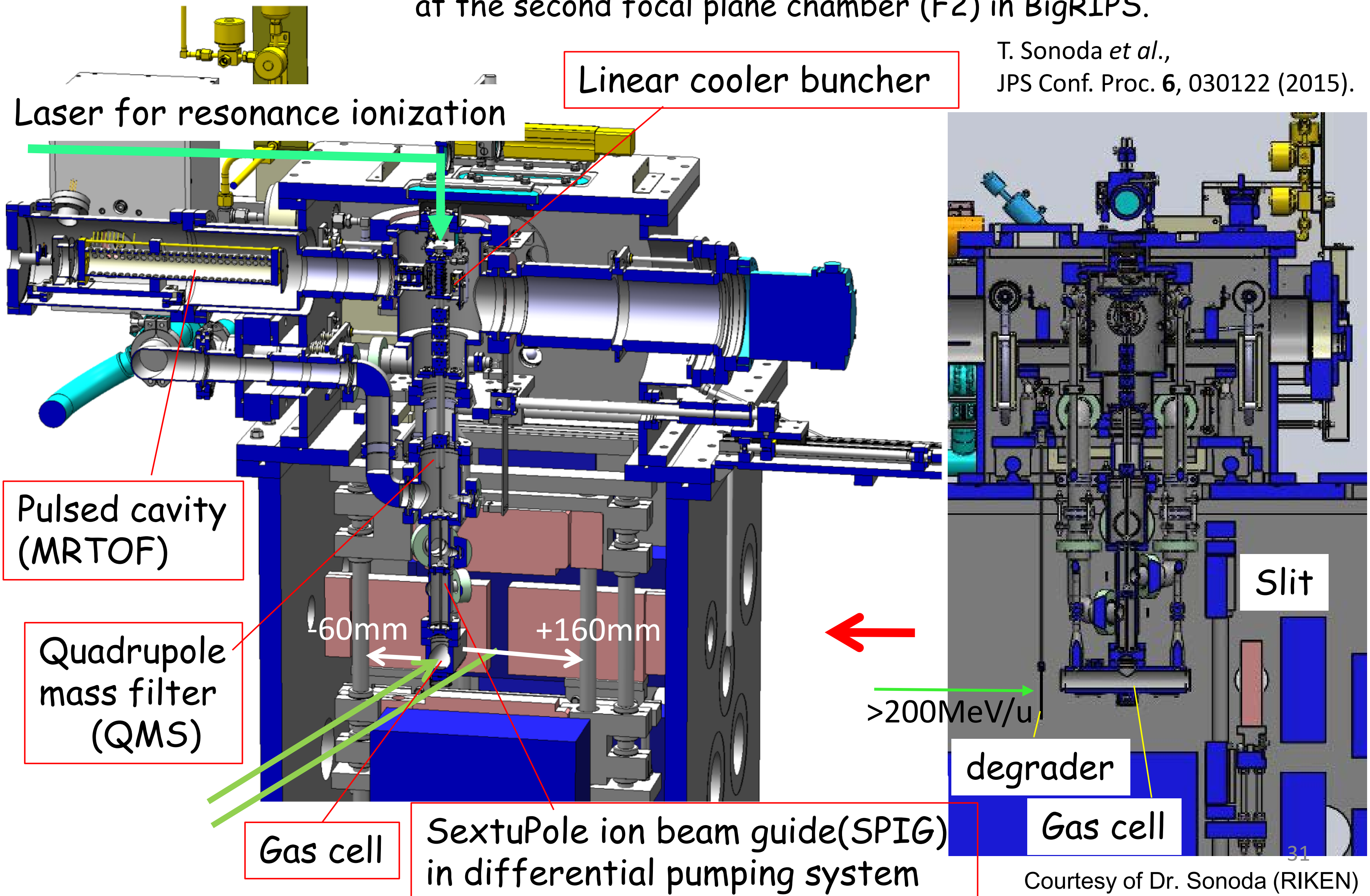
Support and discussion member
R. Ferrer , M. Huyse, Yu. Kudryavtsev, P. Van Duppen(K.U.Leuven)
K. Wendt (Mainz)

Courtesy of Dr. Sonoda (RIKEN)

Overview of PALIS system

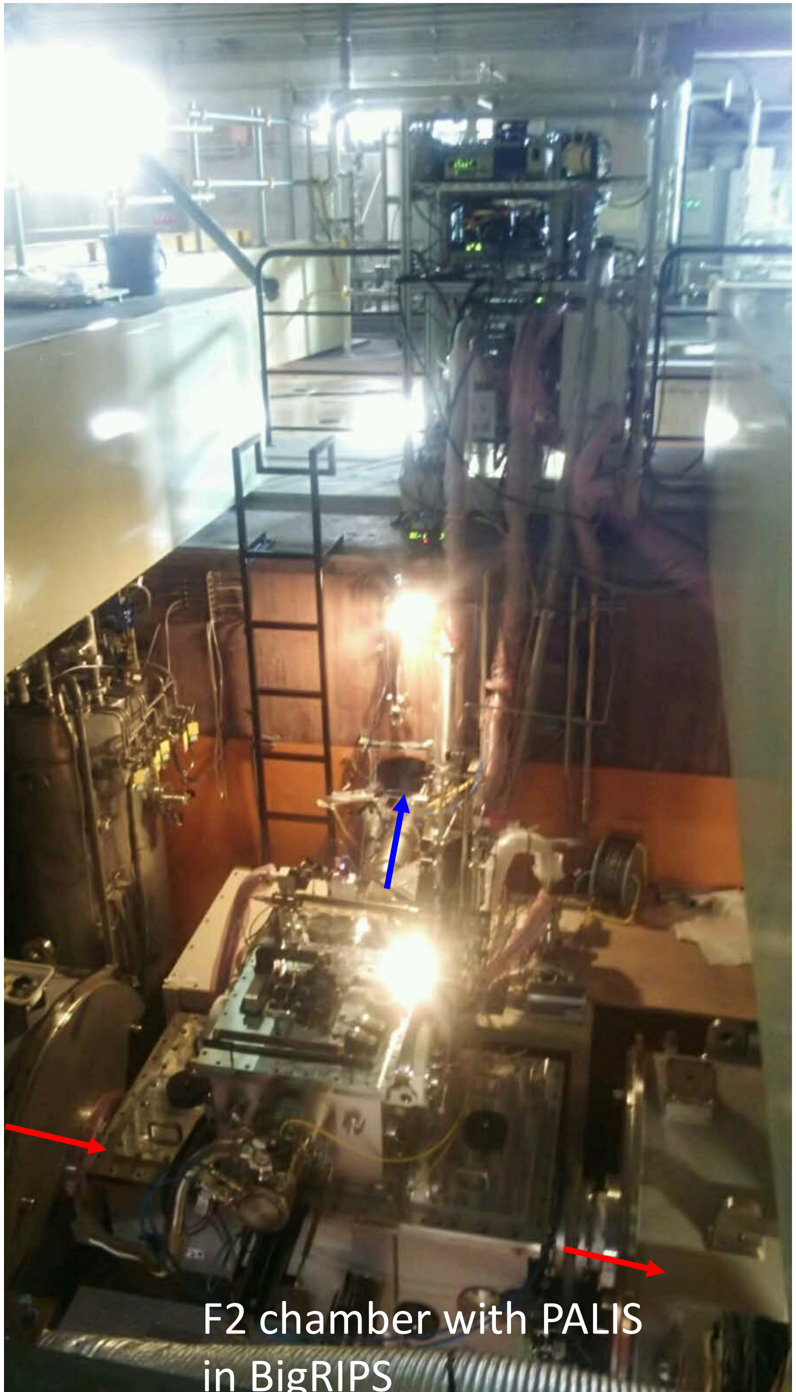
We constructed the Parasitic slow RI-beam production by Laser Ion Source(PALIS) at the second focal plane chamber (F2) in BigRIPS.

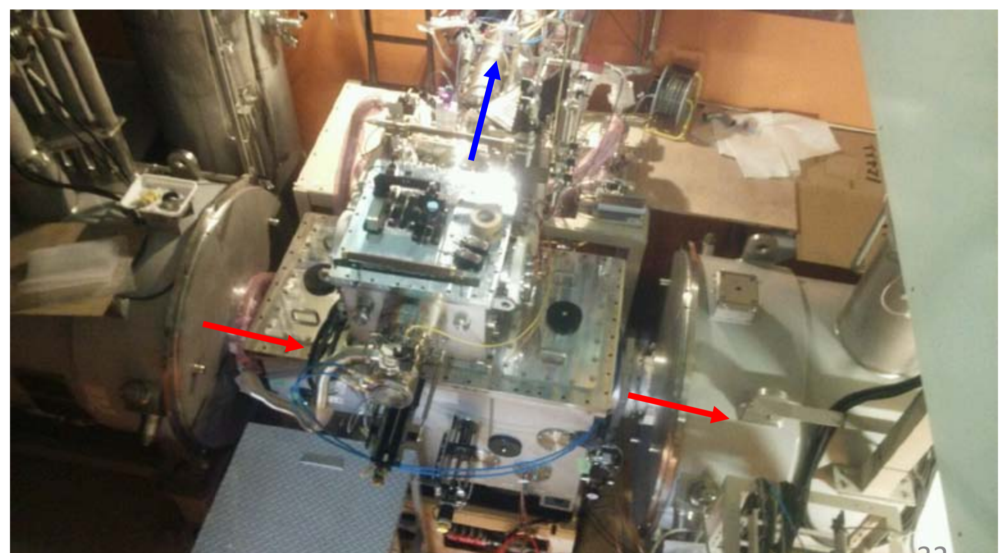
T. Sonoda *et al.*, JPS Conf. Proc. **6**, 030122 (2015).



Courtesy of Dr. Sonoda (RIKEN)

PALIS system is integrated with the F2 chamber's roof.

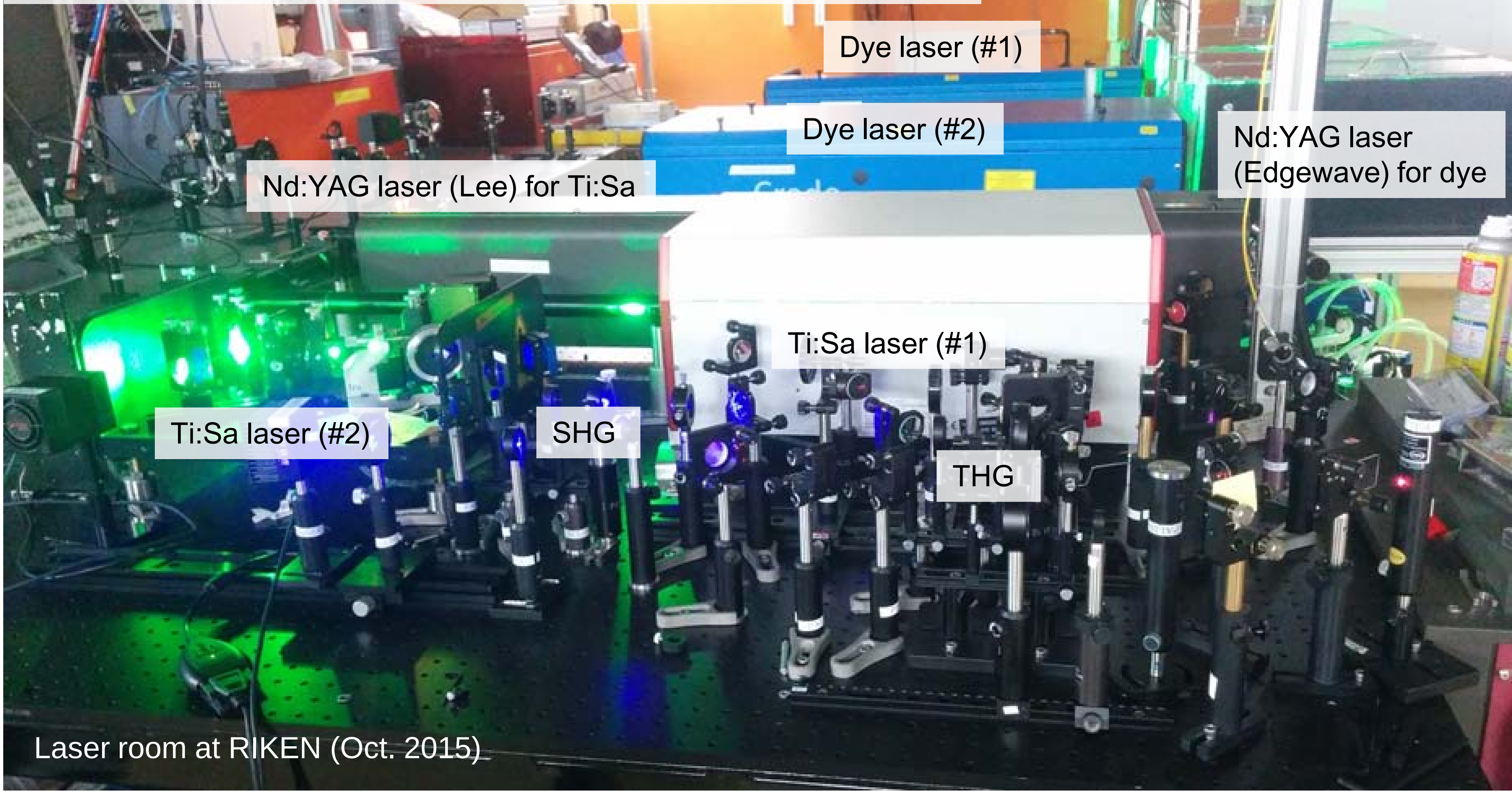




Courtesy of Dr. Sonoda (RIKEN)

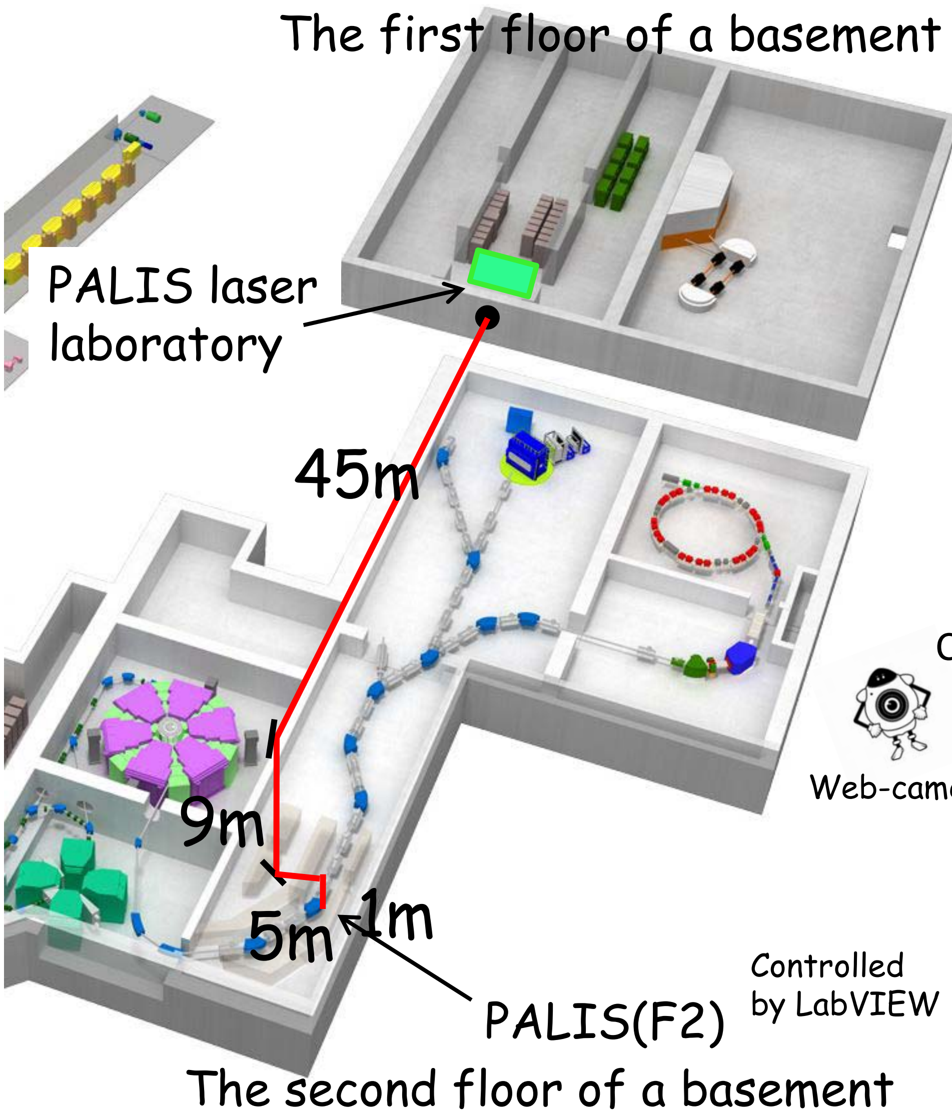
Ti:Sa and Dye Laser System for PALIS

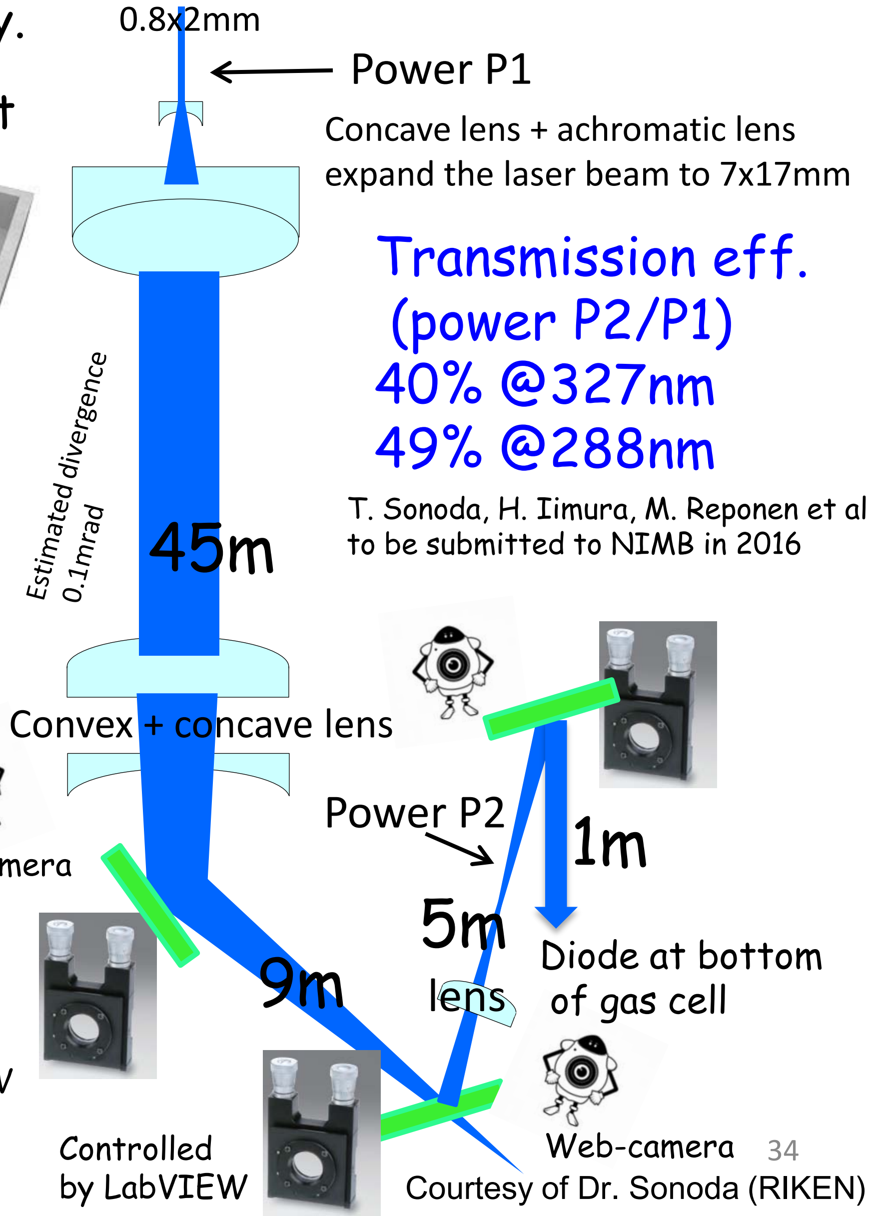
2 X dye laser (Credo)
2 X standard Ti:Sa laser (Mainz design)
1 X injection locked Ti:Sa laser (not in picture, under construction)



Long distance laser beam transport

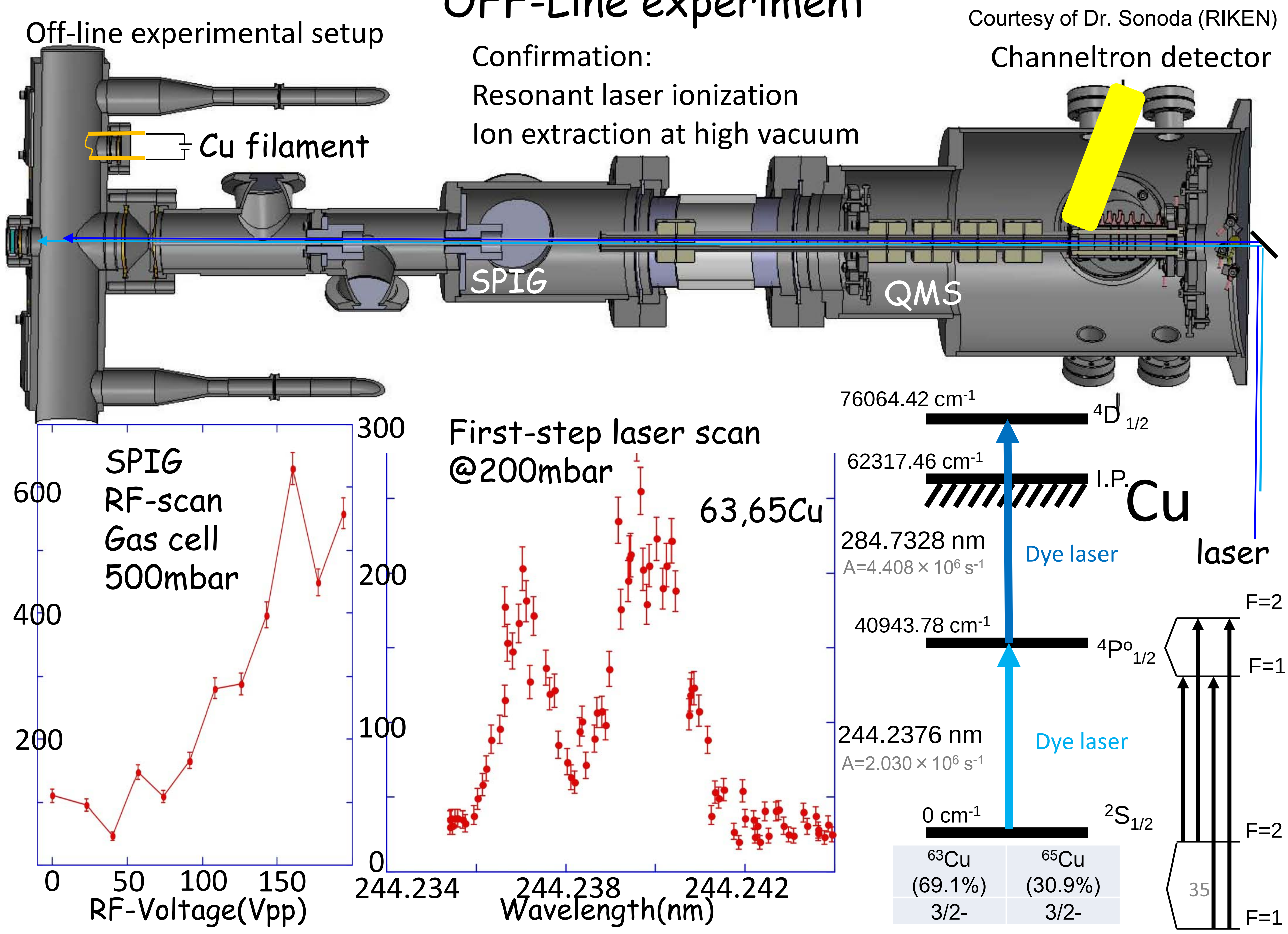
Since the radiation area is not accessible, the laser laboratory stays very far from the PALIS system. The laser beams must be sent for long distance(45+9+5+1=60m). All adjustments must be controlled remotely.





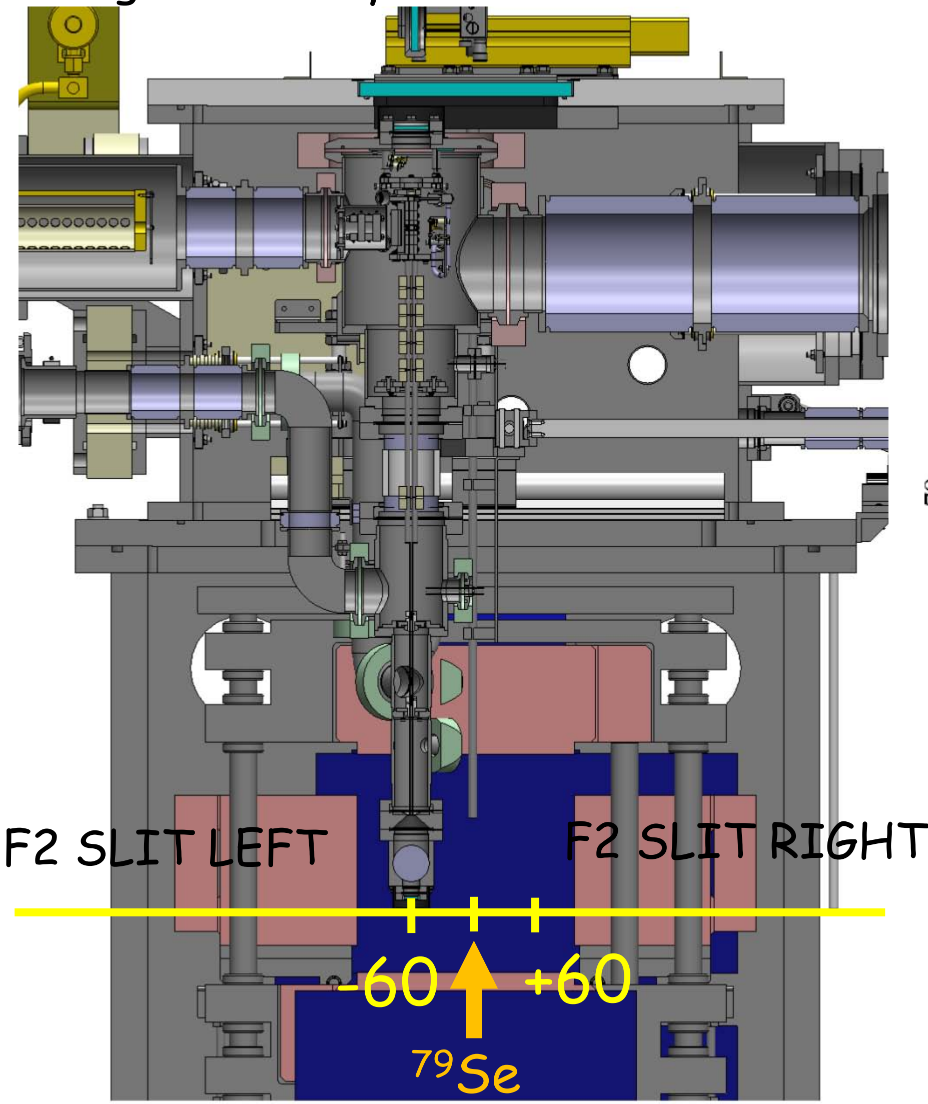
Courtesy of Dr. Sonoda (RIKEN)

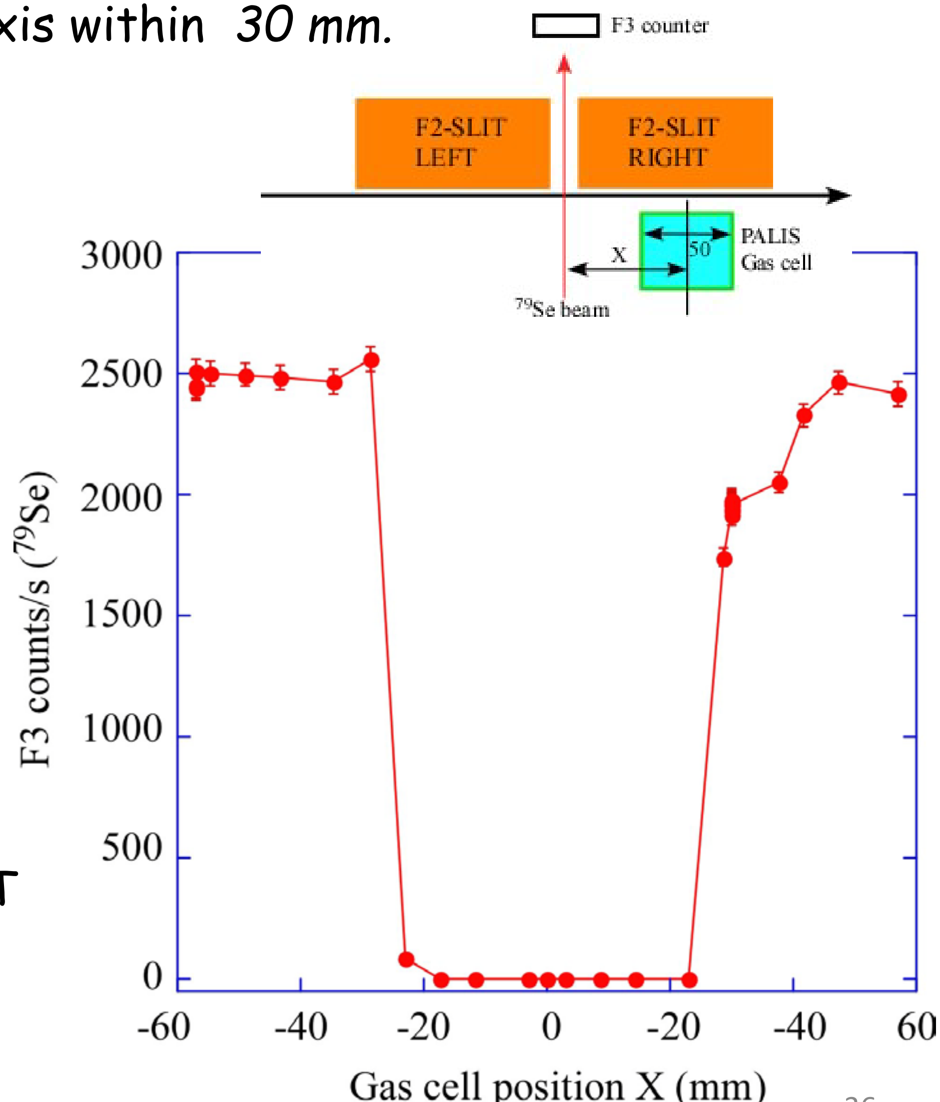
OFF-Line experiment



ON-Line experiment

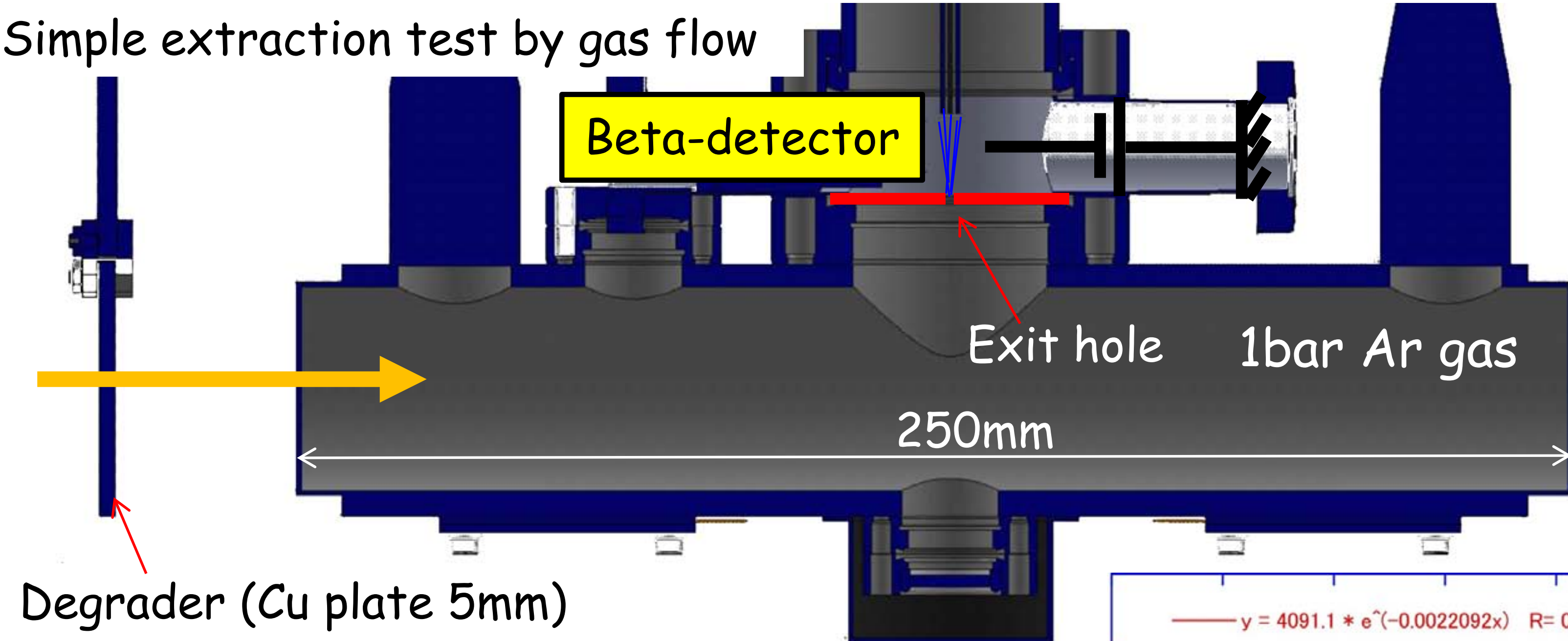
The first on-line commissioning study (12h) was performed at 2015 October.
Main aim was to confirm the feasibility of the parasitic experiment.
We demonstrated that there is no interruption on the main beam passage, unless the gas cell stays in the beam central axis within *30 mm.*





Courtesy of Dr. Sonoda (RIKEN)

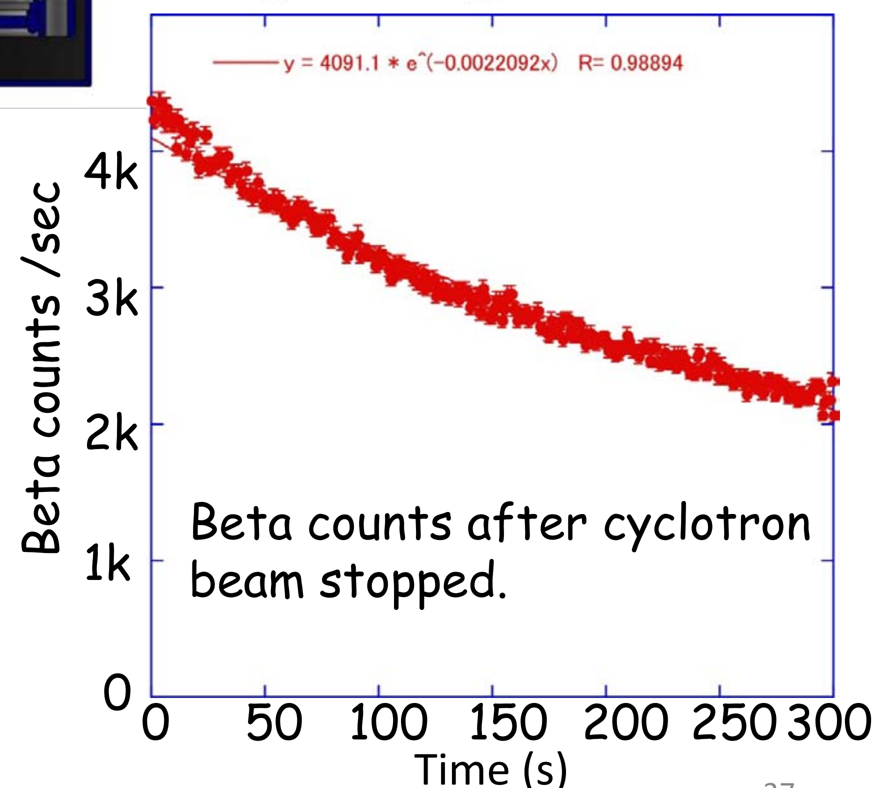
Simple extraction test by gas flow



In-flight fission
Primary beam ^{238}U + Be target
Implanted isotopes to the gas cell:

^{66}Cu(5.12m)~645kcps (yield from LISE)
^{68}Cu(3.75m)~645kcps (yield from LISE)
^{69}Cu(2.85m)~520kcps (yield from LISE)

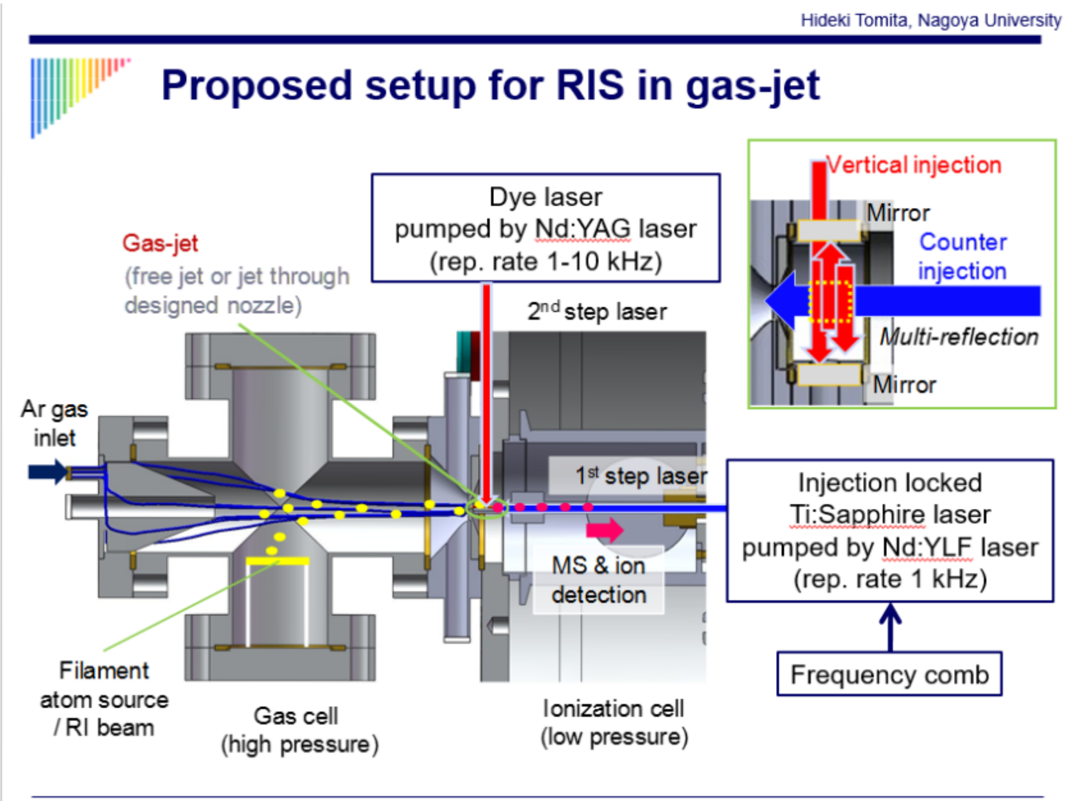
Beam ON (300s) -> Beam OFF ->
Wait(100s) -> Measure.(300s)



Extraction efficiency (extracted RIs/implanted RIs) was evaluated from the decay carve as approximately 10%.

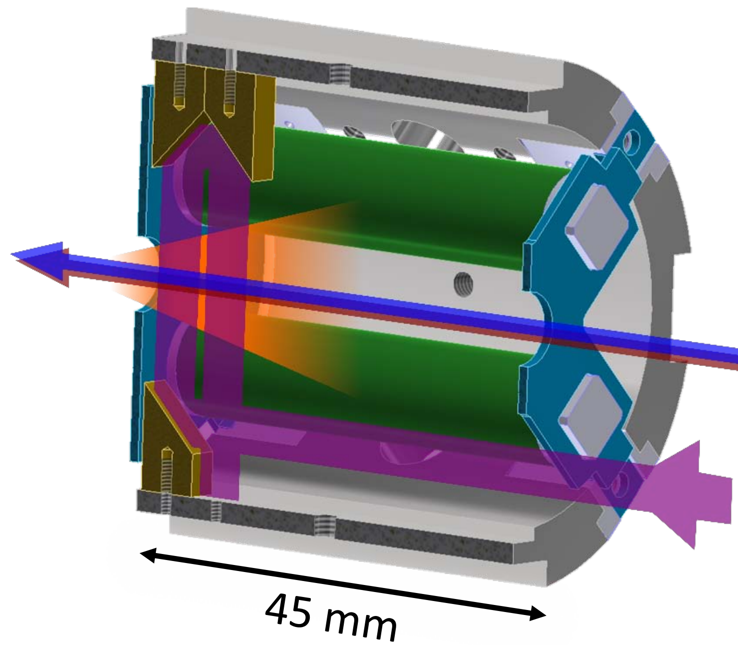
Courtesy of Dr. Sonoda (RIKEN)

Perpendicular atom / laser beam geometry



Slide from EMIS2012 Post workshop, RIKEN, 11th Dec. 2012

PI-LIST Experimental Setup:
Perpendicular atom / laser beam geometry



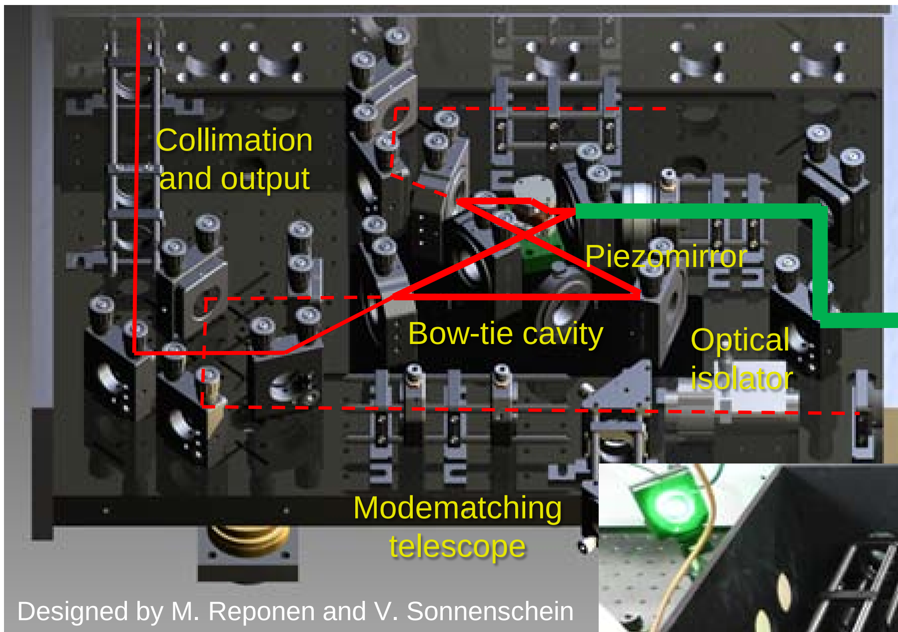
Courtesy of R. Heinke (Uni Mainz)

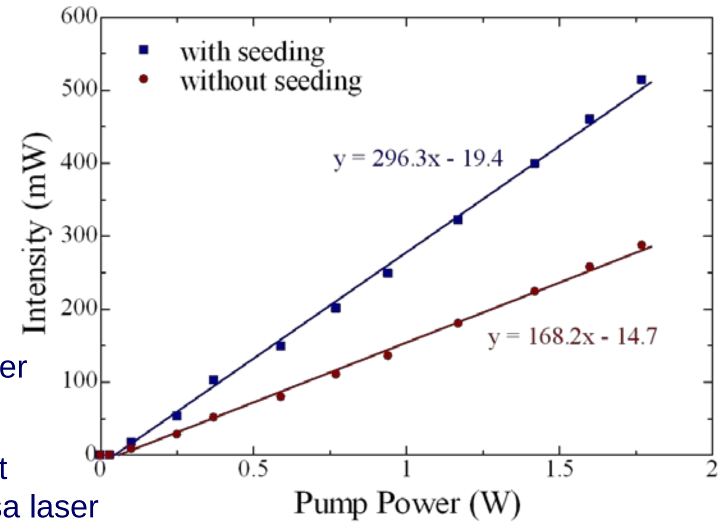
This geometry is prefer to install in PALIS for in-gas-jet spectroscopy to achieve highest resolution.
(Proposal for future upgrade)

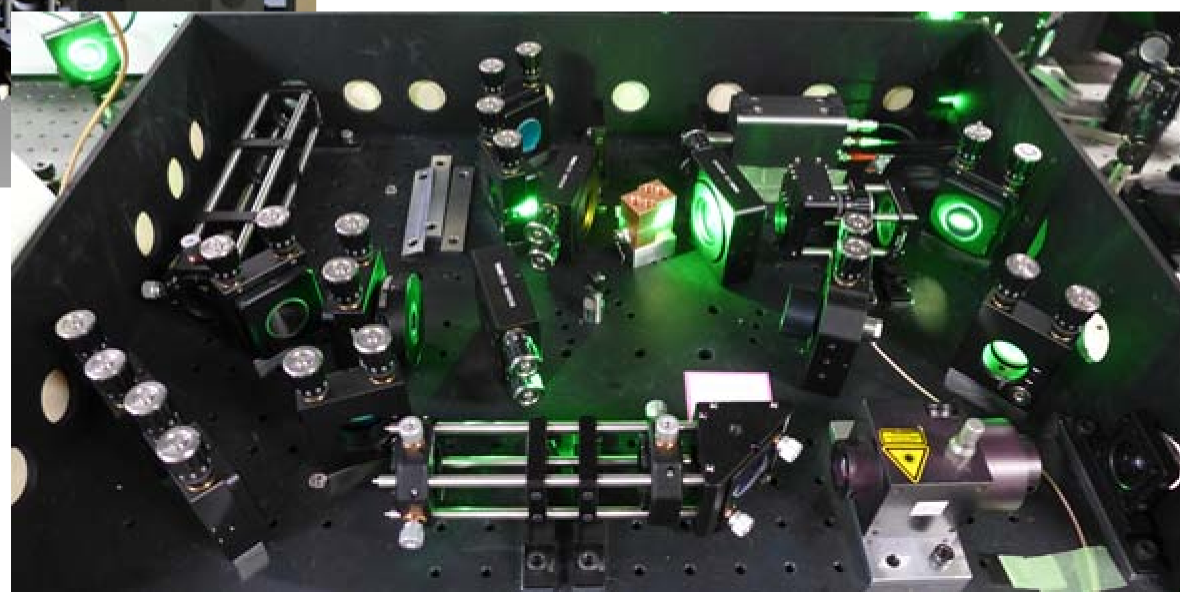
New Design of Injection Locked Ti:Sa Laser (3rd Generation)

Collaboration with Dr. M. Reponen at RIKEN *et al*.

For reliable, easy and stable operation, ...



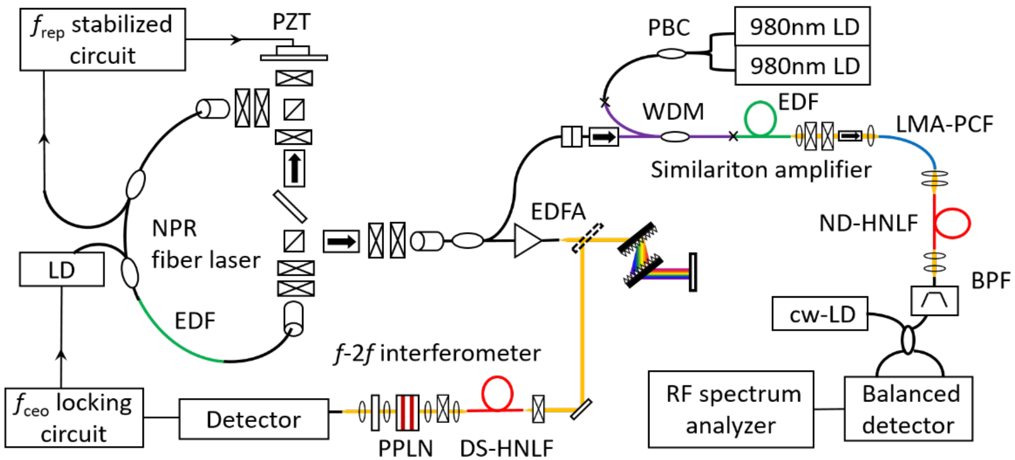




- Output power <500 mW @1 kHz
- 88 % seed efficiency @ 1 kHz
- Lasing threshold ~ 65 mW

Optical frequency comb (OFC) based high resolution RIS

For high accuracy in HR-RIS, we plan to use optical frequency comb (OFC) as a frequency reference of the injection locked Ti:Sapphire laser.

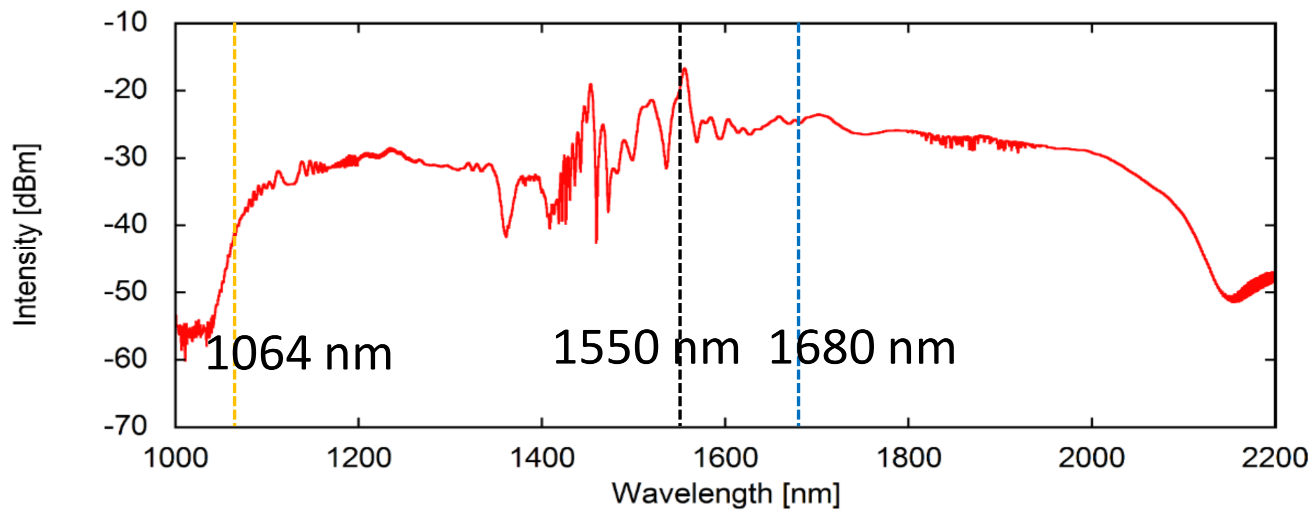


Collaboration with N. Nishizawa (Nagoya Uni.)

Details will be presented in Advanced Solid State Lasers 2016 on 1st Nov. 2016 by N. Nishizawa.

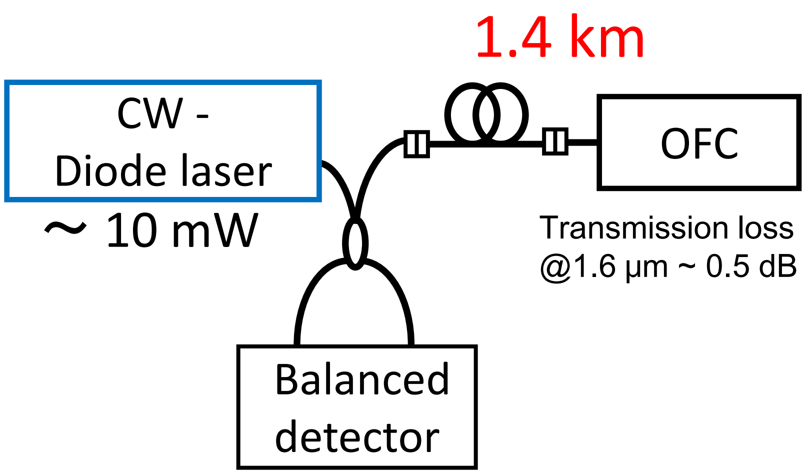
1.0-2.1 um octave spanning, coherent supercontinuum comb was developed based on Er-doped ultrashort pulse fiber laser.

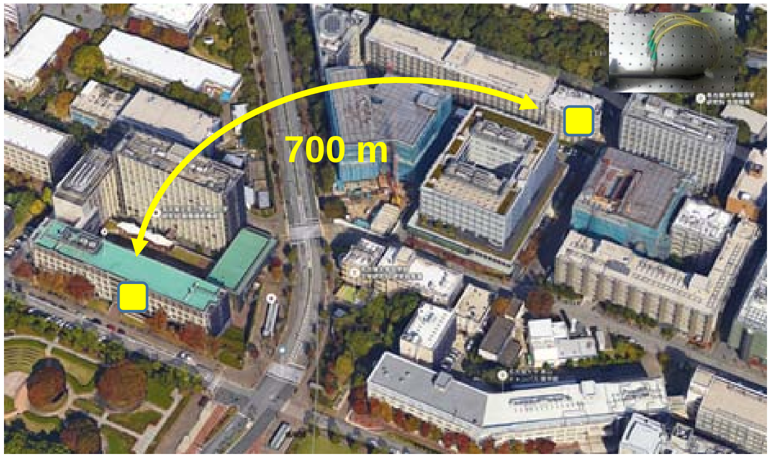
- Lower transmission loss in telecommunication optical fiber ~ 0.5 dB@1.6 μm
- SHG of the OFC is matched to tuning range of Ti:Sa laser.



Long distance transmission of OFC

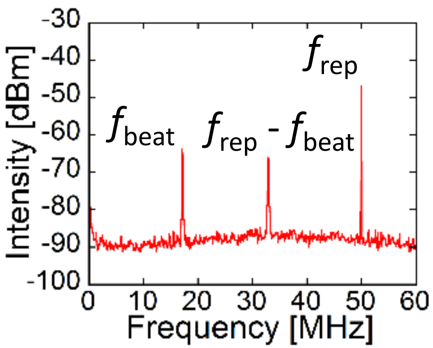
Direct transmission of optical frequency comb in 1.4 km optical fiber was investigated.



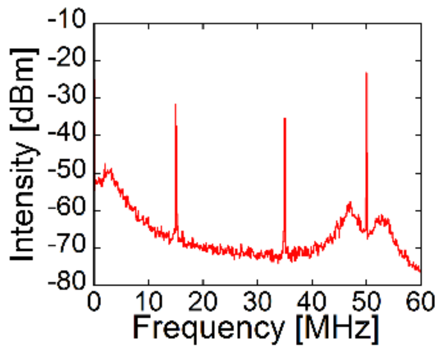


Silica glass single-mode optical fibers (9/125 μm, cutoff 1260 nm) 654.8 m in total (no joint)

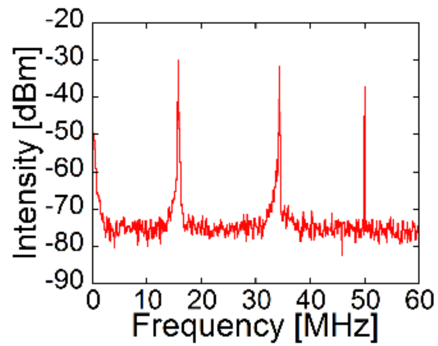
1064 nm



1550 nm

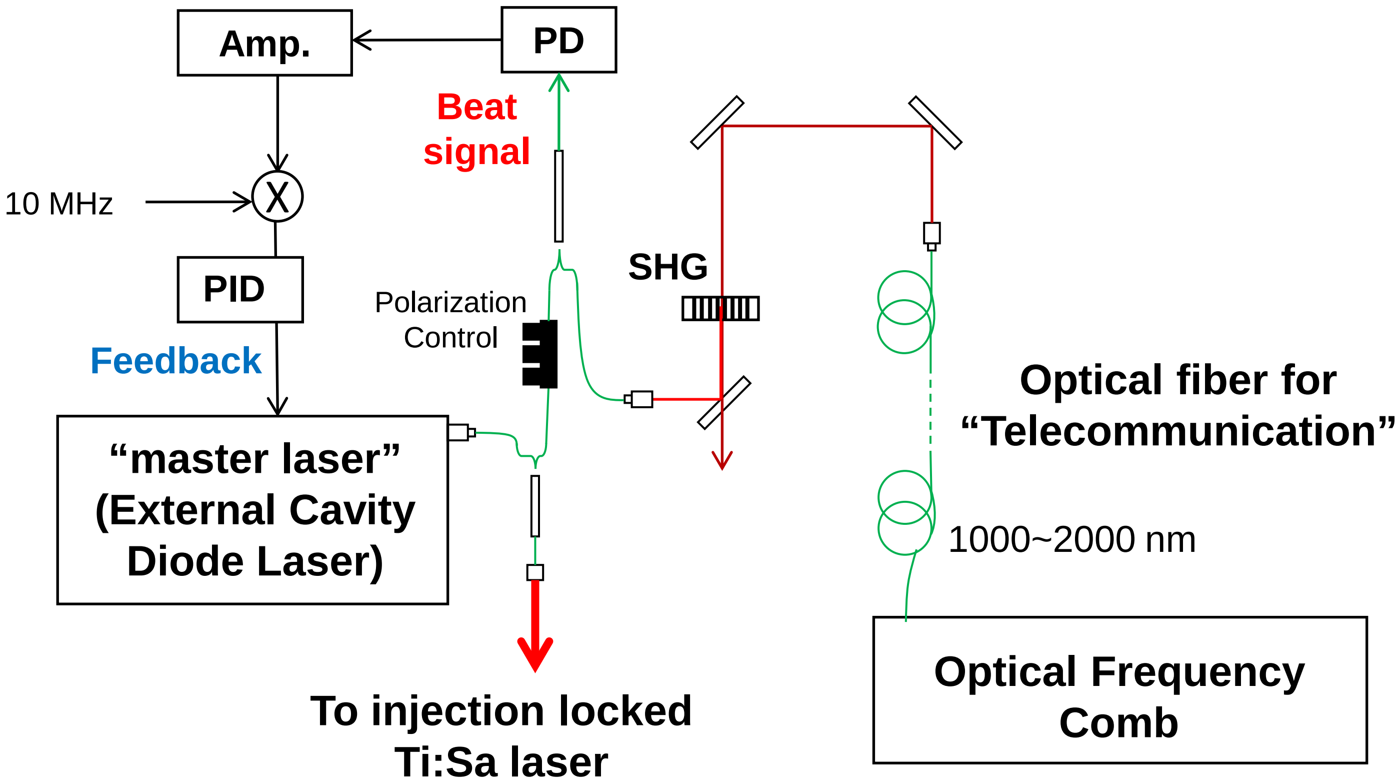


1680 nm



High S/N ratio beat signals were obtained even after long distance transmission of OFC.

Frequency Stabilization of "master laser" using Optical Frequency Comb



- Comb can be distributed to each laser room in the on-line facility via telecommunication optical fiber.
- Master laser (670-950 nm) can be stabilized by SHG of comb (500-1000 nm).

➡ Cover full spectrum range of Ti:Sa laser

Conclusion and future work

- Injection locked Ti:Sa laser is successfully in use in Nagoya and RIKEN.

- Auto-tuning operation of grating Ti:Sa laser with intracavity SHG option was developed.

→ Intracavity SHG provides wide range, mode-hope-free scanning in blue region.

- High resolution RIS of stable Zr was demonstrated.

→ Scheme via Al for HR-RIS was developed by the "blue" grating Ti:Sa laser.

→ HFS of ^{91}Zr was clearly resolved with 100 MHz linewidth.

- On-line commissioning machine study of PALIS run in Oct. 2015.

→ No disturbances to the main experiment

→ RI (^{58}Cu) was successfully extracted by gas flow.

→ Further developments for HR-RIS are ongoing.

Acknowledgments

Collaborators

Nagoya Univ.	V. Sonnenschein,D. Matsui, A. Nakamura, R. Ohtake, V. Degner, R. Terabayashi, K. Saito, T. Iguchi and members of Iguchi group T. Niinomi, N. Nishizawa and members of Nishizawa group
Univ. Mainz	P. Naubereit, K. Wendt and members of LARISSA group
RIKEN	M. Reponen, T. Sonoda, M. Wada (KEK), I. Katayama, T.M. Kojima, and RIKEN BigRIPS team
Kogakuin Univ.	M. Morita, T. Sakamoto
JAEA	H. Iimura
Univ. Jyvaskyla	I. Moore and members of Prof. Moore group

and all PALIS collaborators

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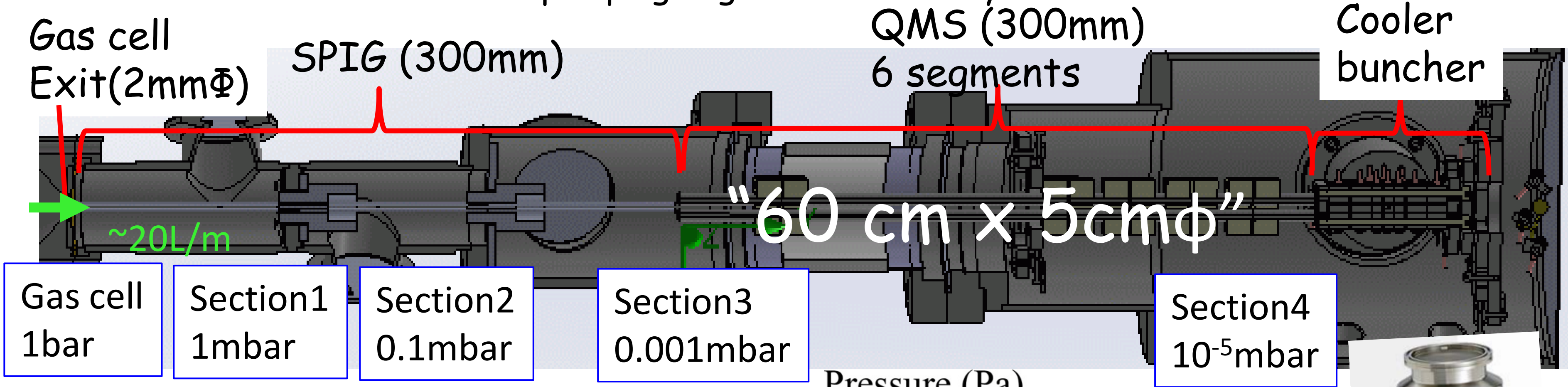
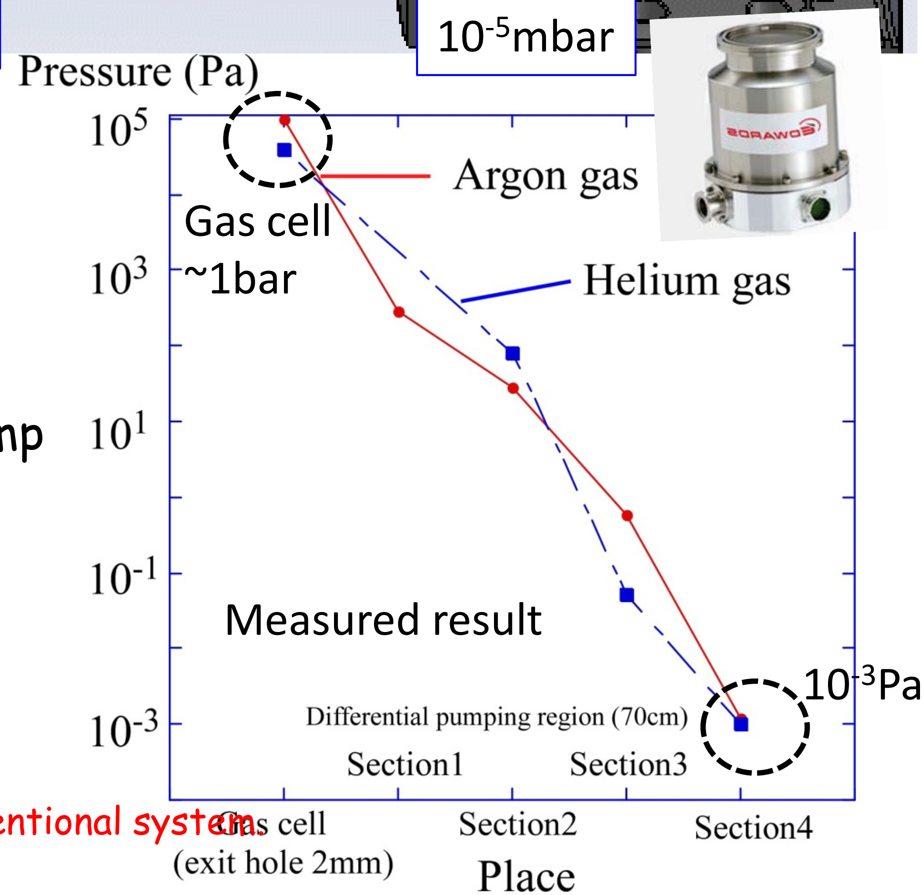
Thank you for your kind attention.

We developed a unique implementation of the differential pumping method in combination with SPIG. The pumping region is divided by several small sections.





Canned-motor, air cooled and multistage root DRY pump (100kg)
5000 L/m
Unozawa Co. Ltd.
(KTS300)

DRY pump
2880 L/m

Edwards
(EPX180L)

Turbo pump
300 L/s

Edwards
(STP300)

Geometry is drastically miniaturized compared to conventional system.

T. Sonoda , M. Wada et al. NIMB 295(2013)1.

Courtesy of Dr. Sonoda (RIKEN)