Ultra-Pure ^{163}Ho Samples for Neutrino Mass Measurements

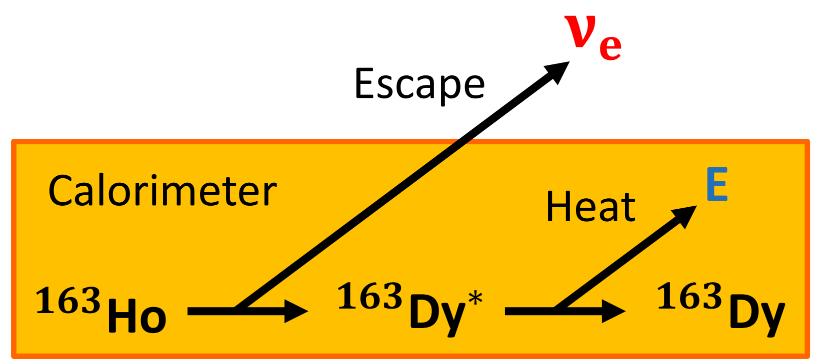
T. Kieck[1], H. Dorrer[1], Ch. E. Düllmann[1,2], K. Eberhardt[1], L. Gamer[3], L. Gastaldo[3], C. Hassel[3], U. Köster[4], B. Marsh[5], Ch. Mokry[1], S. Rothe[5], J. Runke[2], F. Schneider[1], T. Stora[5], A. Türler[6] and K. Wendt[1]
for the ECHo Collaboration

[1] Johannes Gutenberg University, Mainz, Germany
[2] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
[3] Heidelberg University, Heidelberg, Germany
[4] CERN, Geneva, Switzerland
[5] Institut Laue-Langevin, Grenoble, France
[6] Paul Scherrer Institute, Villigen and University of Bern, Bern, Switzerland

^{163}Holmium Electron Capture

$T_{1/2}$ = 4570 years

Q_{EC} = **2.833**$(30)_{stat}(15)_{sys}$ keV [1]

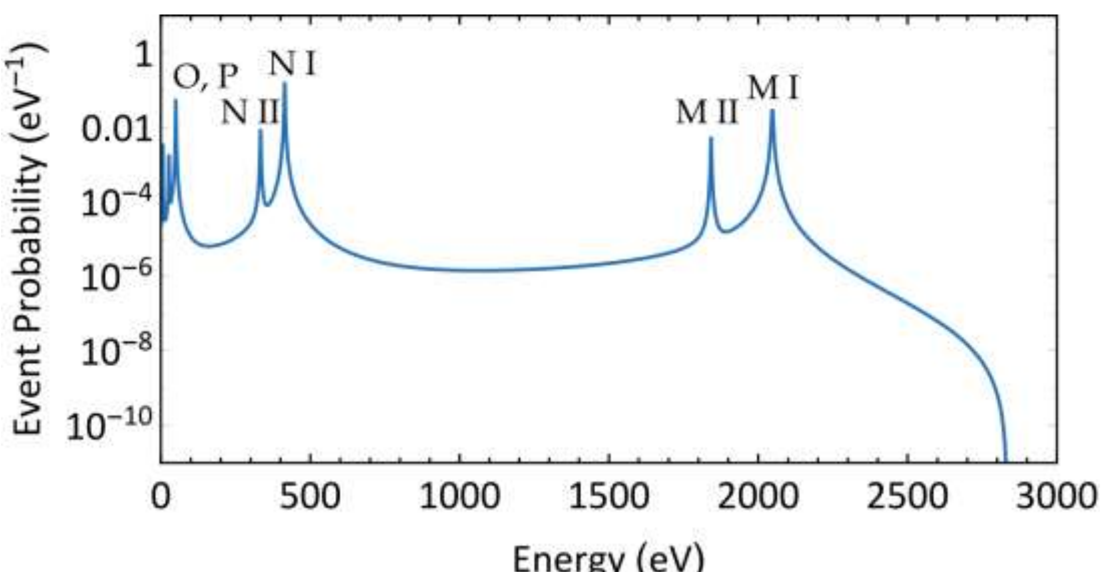


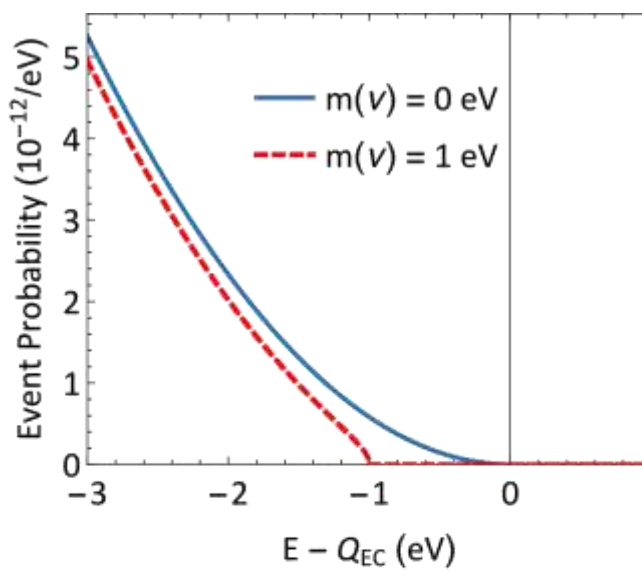
Atomic de-excitation:

- X-ray emission
- Auger electrons

} Calorimetric measurement

Non-zero neutrino mass affects de-excitation spectrum



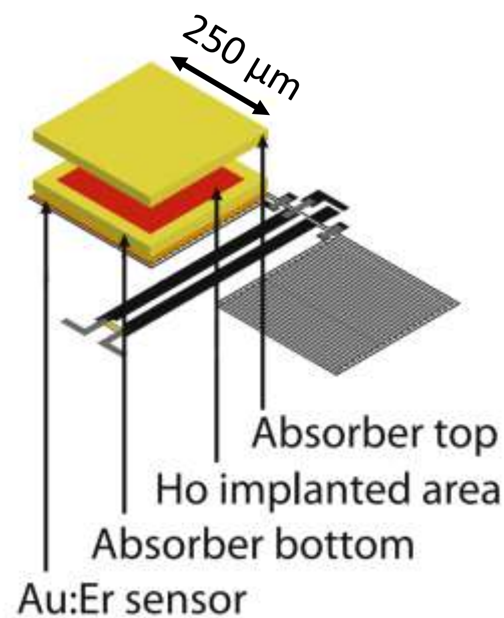


[1] S. Eliseev *et al.*,
Phys. Rev. Lett. **115**, 062501 (2015)

ECHo Detector Setup

Metallic Magnetic Calorimeters (MMCs)

- ^{163}Ho embedded in 250 × 250 × 10 µm^3 Au absorber
- 64 MMC pixels per detector chip

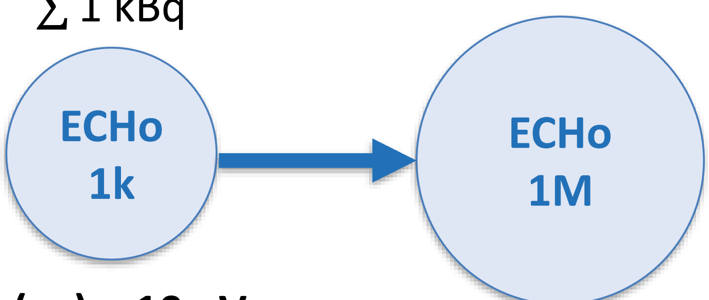


Present

100 MMCs
$\sum$ 1 kBq

Future

100 000 MMCs
$\sum$ 1 MBq



m(ν_e) < 10 eV

m(ν_e) < 1 eV

Source Requirements for sub-eV Sensitivity

Statistics

Total counts > 10^{14} → **Activity ≈ 1 MBq**

Background level

< 0.5 events/eV/day → **$^{166m}Ho/^{163}Ho < 10^{-9}$**
and no other radioactive contamination

Ultra-Pure + Efficient Production

Production of Pure ^{163}Ho

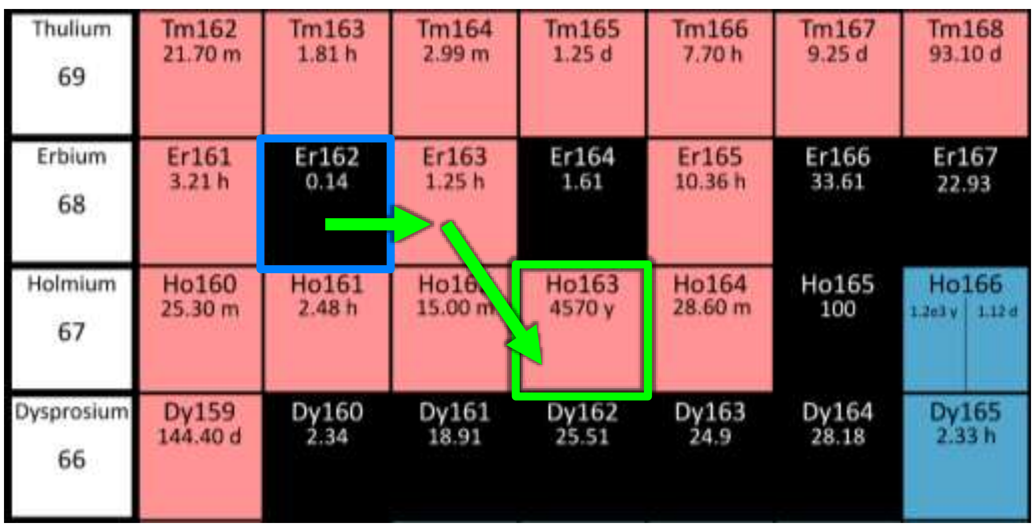
1. Chemical separation of Er from all lighter lanthanides
2. Neutron irradiation at ILL high flux reactor
3. Chemical separation of Ho from all heavier lanthanides
4. 163Ho Isotope Enrichment by Resonance Ionization Mass Separation
5. Ion Implantation into MMCs

Reactor-Based ^{163}Ho Production at ILL Grenoble

Neutron activation of enriched ^{162}Er sample at high flux reactor:

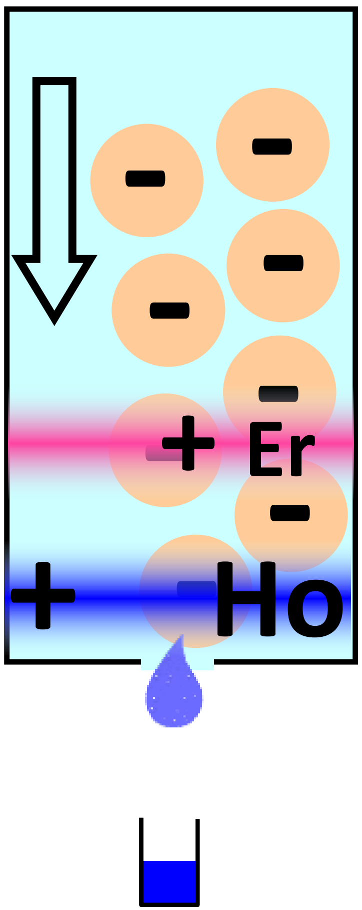
$$^{162}\text{Er} \xrightarrow{(n,\gamma)} {}^{163}\text{Er} \xrightarrow{(\epsilon)} {}^{163}\text{Ho} \;\; (+\, ^{166m}\text{Ho} + {}^{170,171}\text{Tm})$$

- Large cross-section + high flux ($\Phi_{th} = 1.3 \times 10^{15}\,\text{cm}^{-2}\,\text{s}^{-1}$) → high ^{163}Ho yield
- Production of 6 MBq ^{163}Ho completed ($\sim 10^{18}$ atoms, 1 mg)

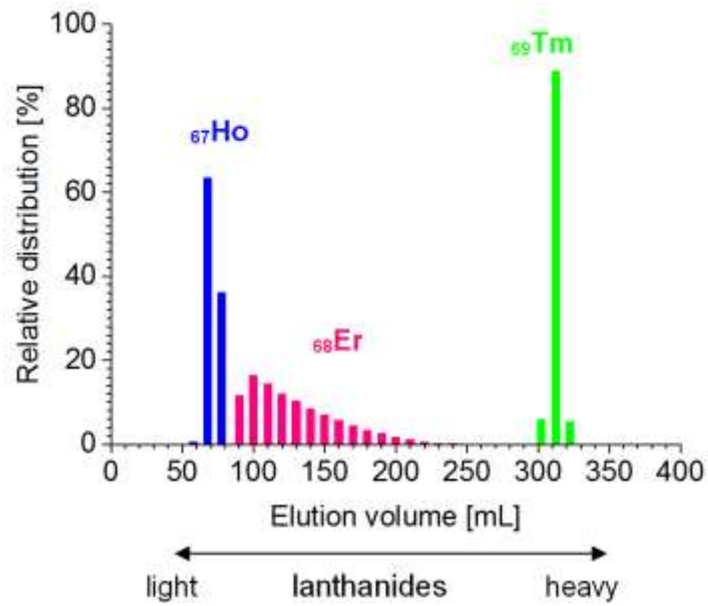


Chemical Separation of Holmium

High Performance Liquid Chromatography (HPLC)



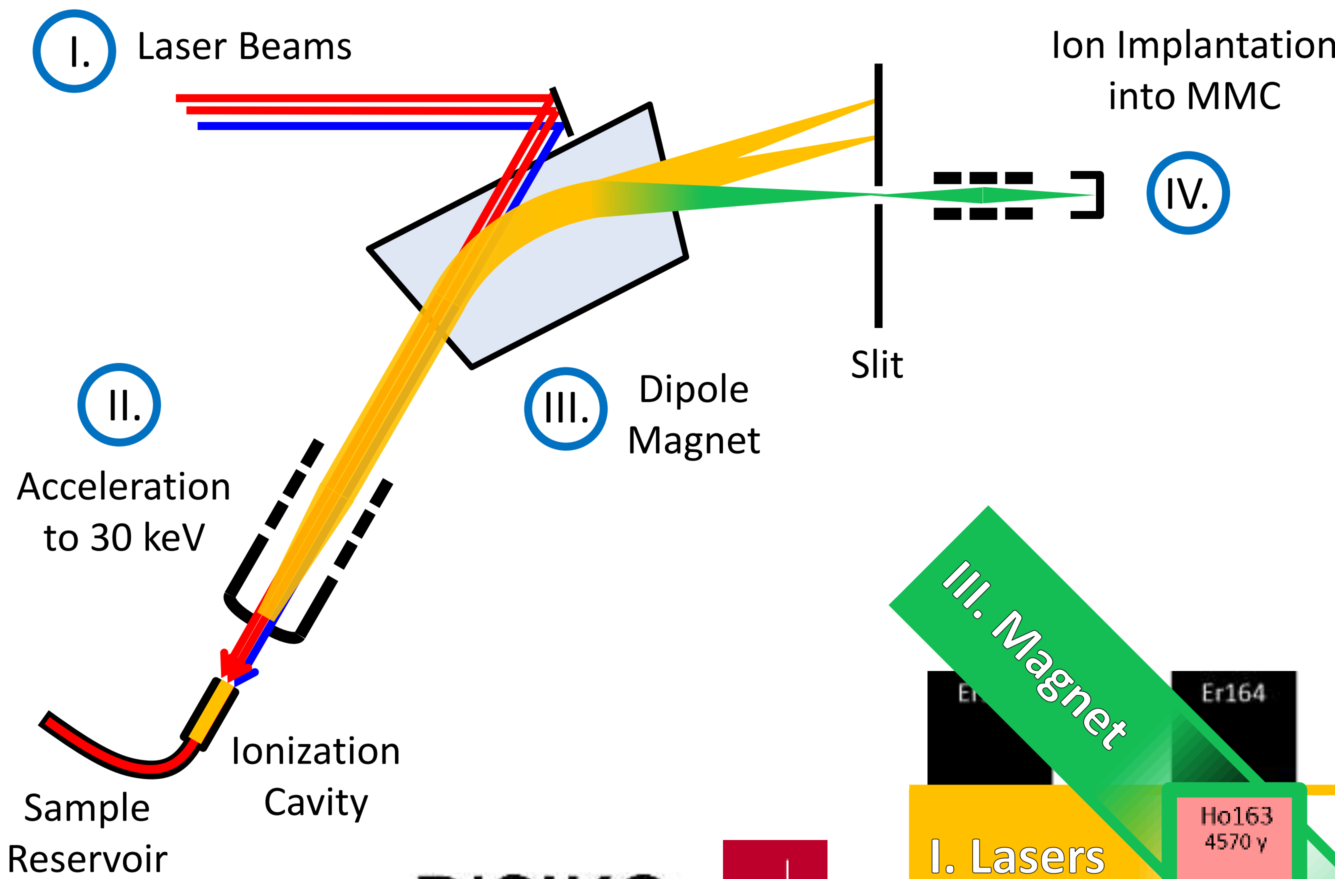
Dedicated System for Er / Ho Separation

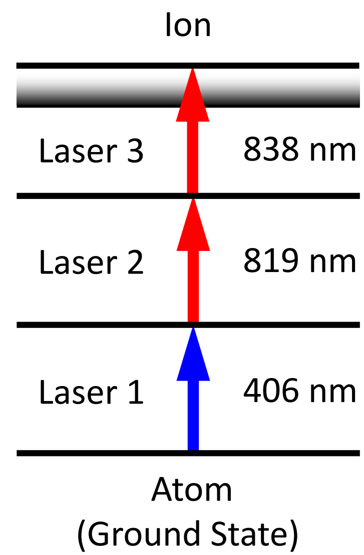


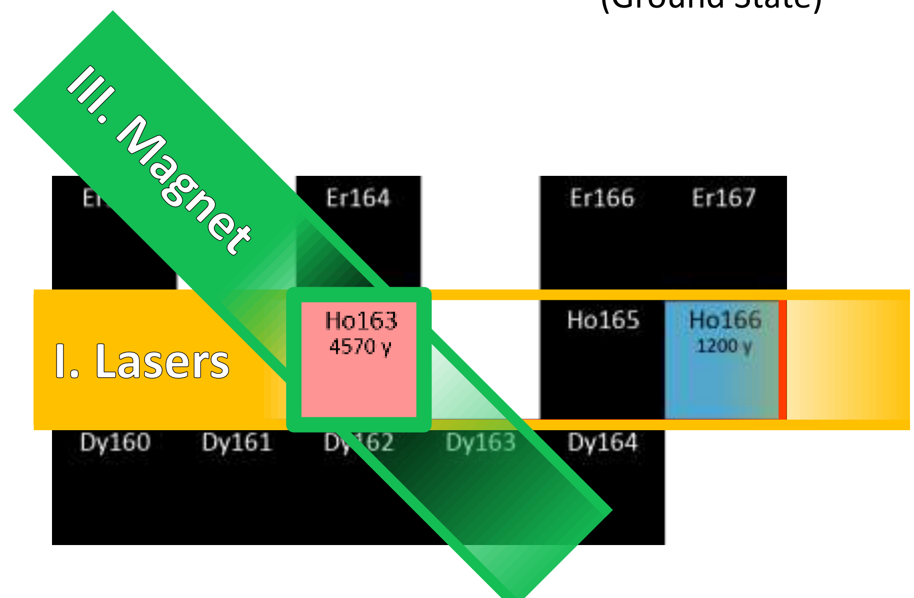
H. Dorrer *et al.*, submitted to Radiochim. Acta. (2017)

Purity:	Er/Ho	< 0.1
	$^{166m}Ho/^{163}Ho$	≈ 10^{-4}
	no other radioactive contamination visible in γ-spectrum	
Efficiency:	95 ± 1 %	

Resonance Ionization Mass Separation

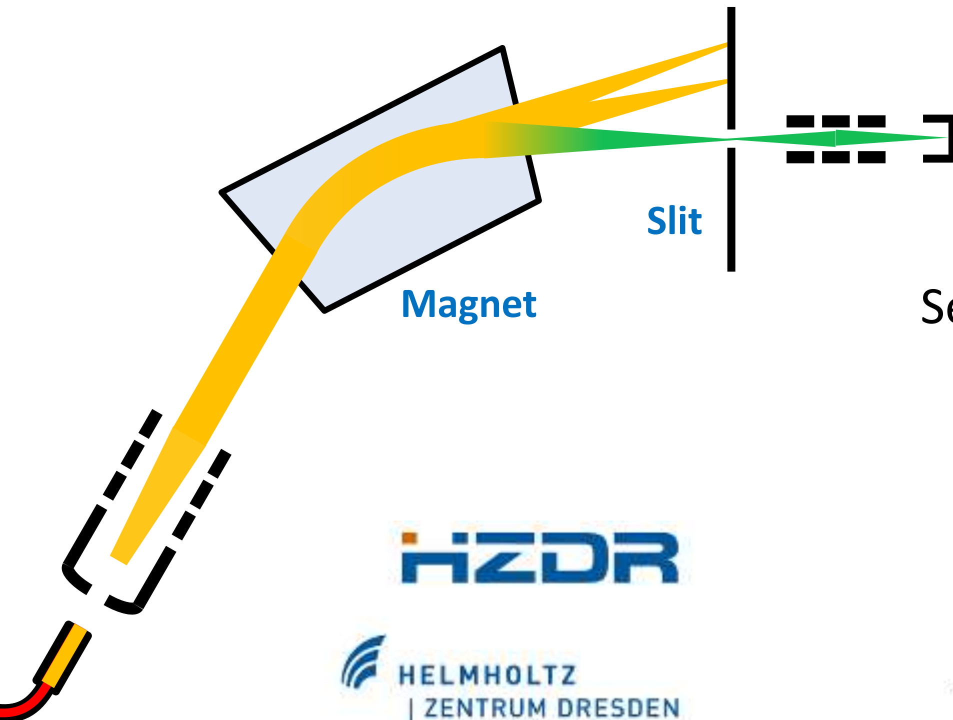






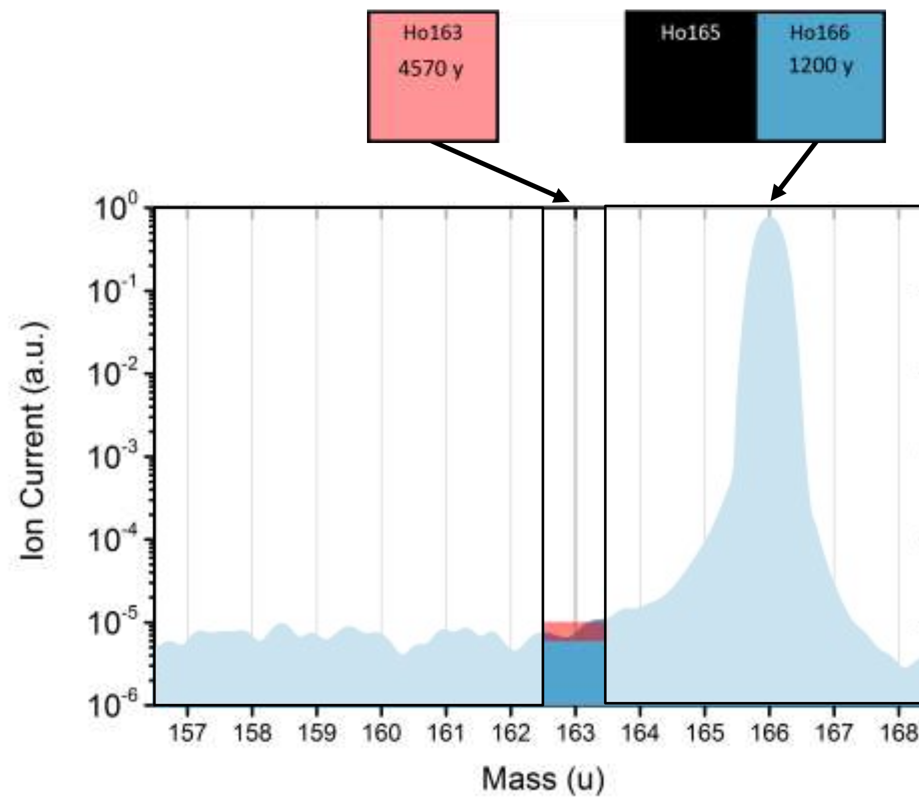
F. Schneider *et al.*,
NIM B **376**, 388 (2016)

Isotope Selectivity of Mass Separation



Purity Enhancement:
$^{166m}Ho/^{163}Ho \approx 10^{-5}$

Separation demonstrated on stable holmium

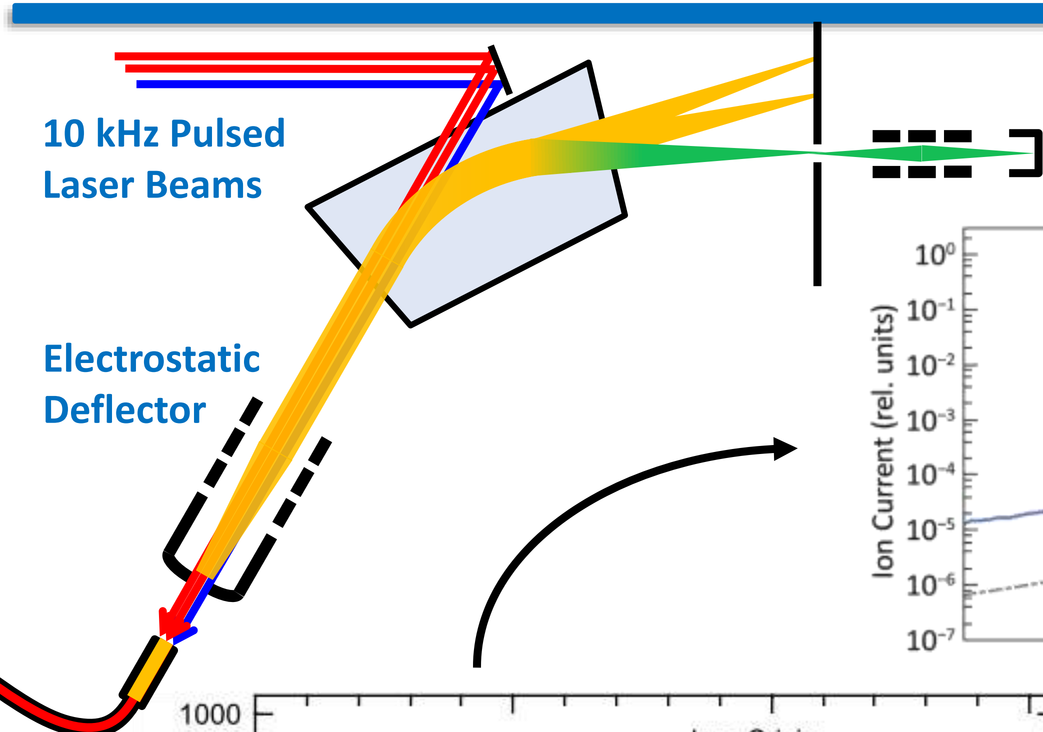


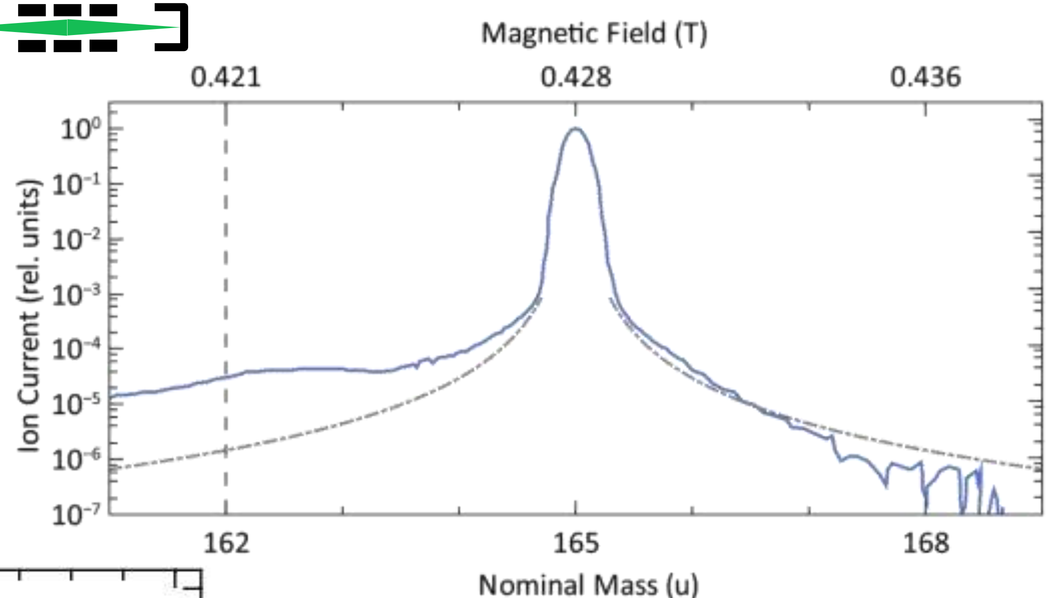
HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

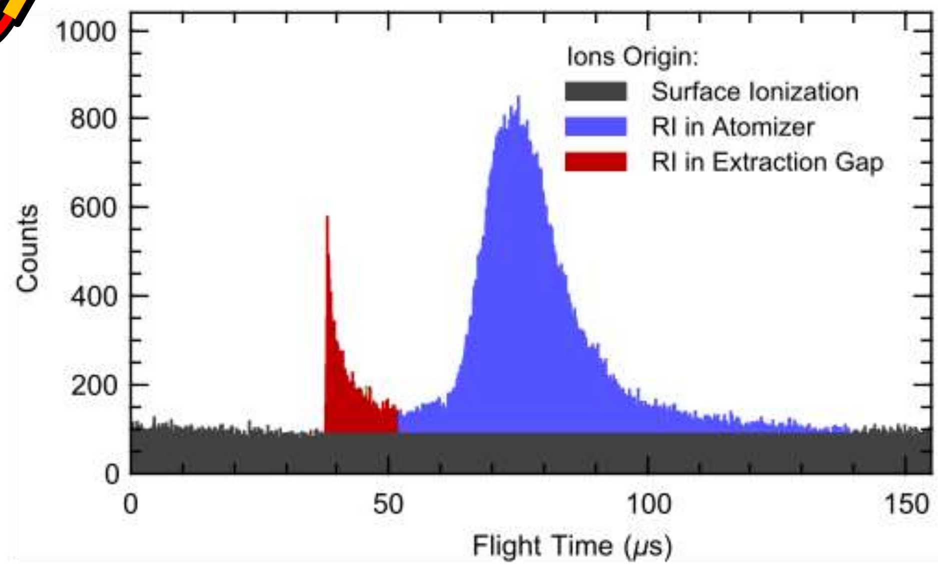
Next Step

AMS measurements @ DREAMS facility to confirm purity

Ion Beam Gating





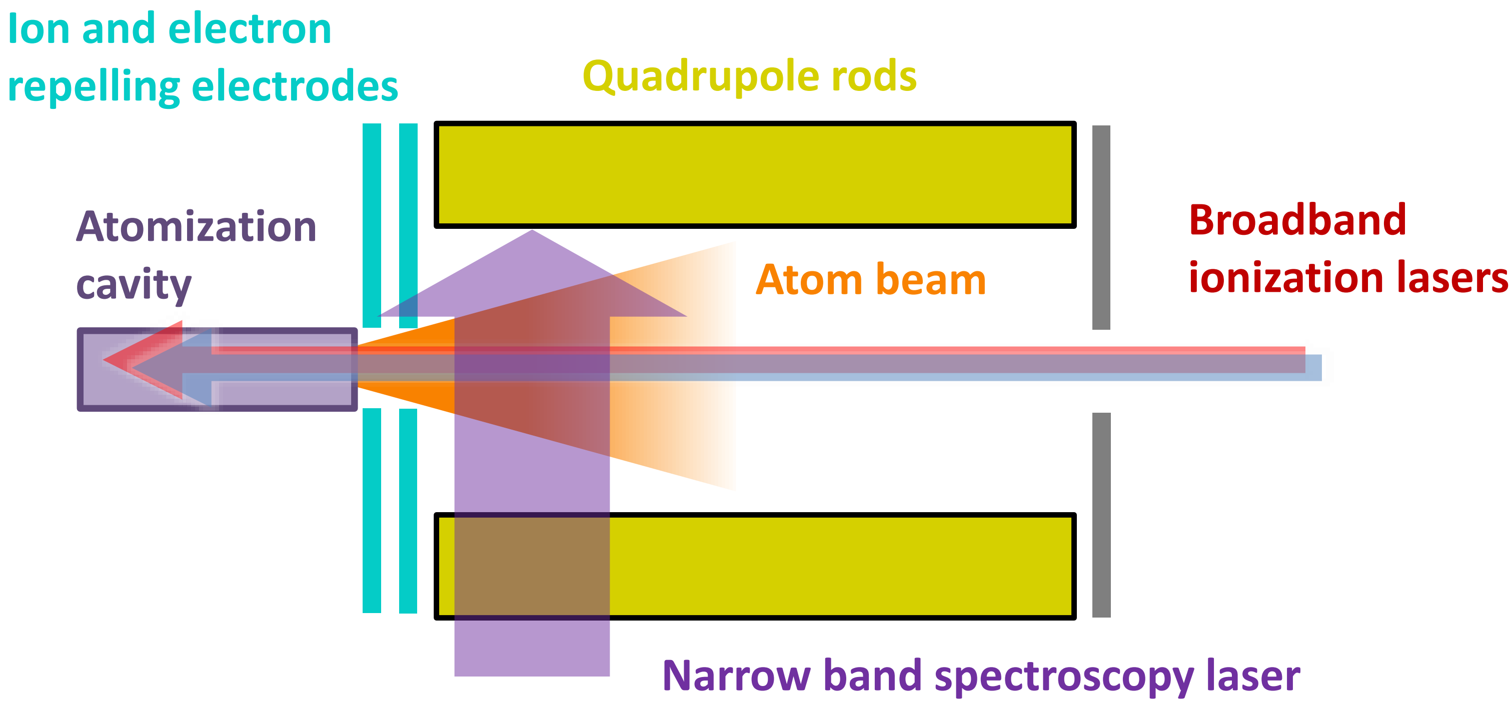


Expected
Purity Enhancement:
$^{166m}Ho/^{163}Ho > 10^{-1}$

F. Schneider,
PhD Thesis 2016

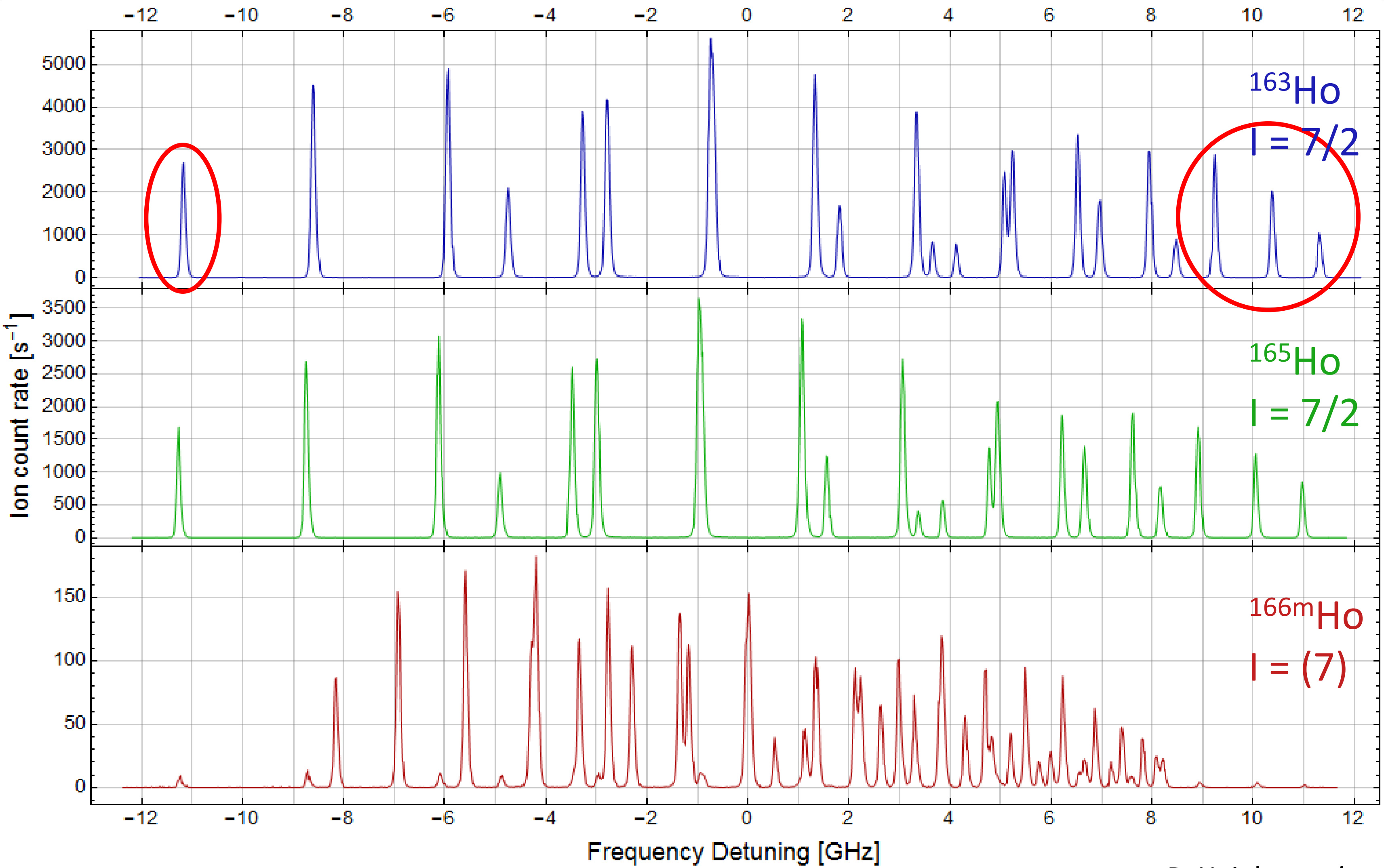
Hot Cavity High Resolution Spectroscopy

Perpendicular Irradiated Laser Ion Source PI-LIST @ RISIKO



- Strong suppression of background
- Radial confinement by RF field
- Drastic reduction of Doppler broadening (typically 1 – 3 GHz in-source) down to < 100 MHz

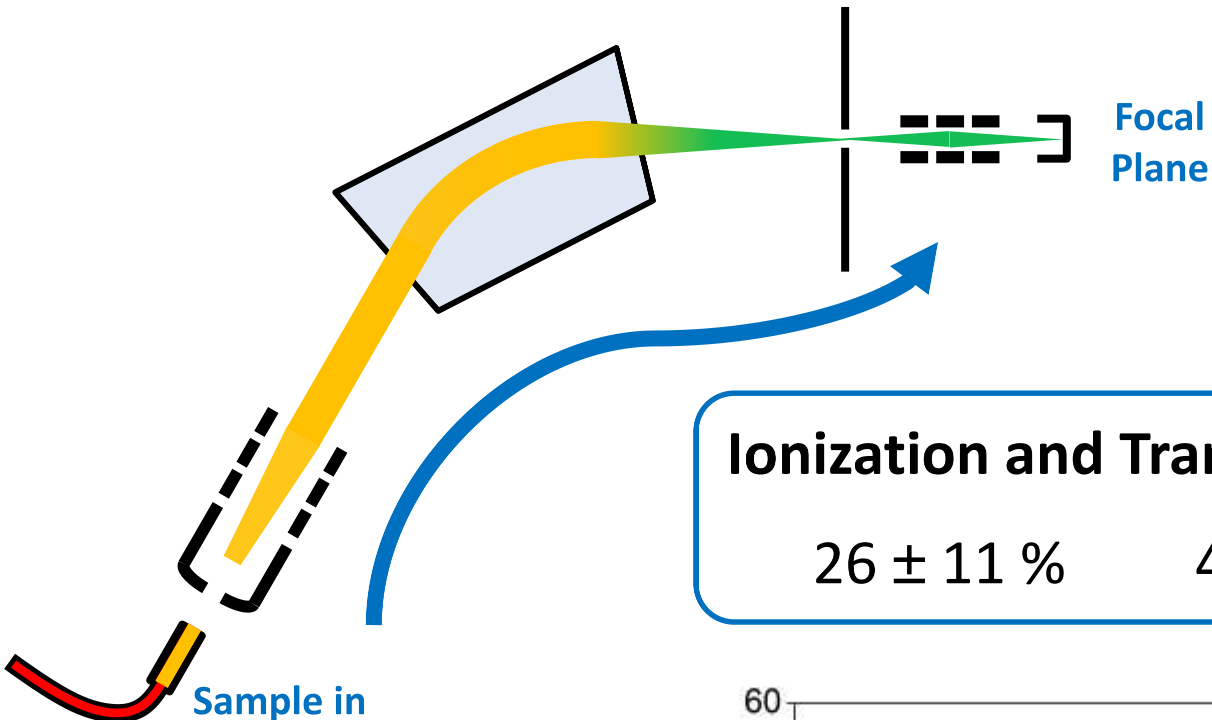
HFS Selective Ionization of ^{163}Ho



Isotope selective ionization possible to enhance source purity

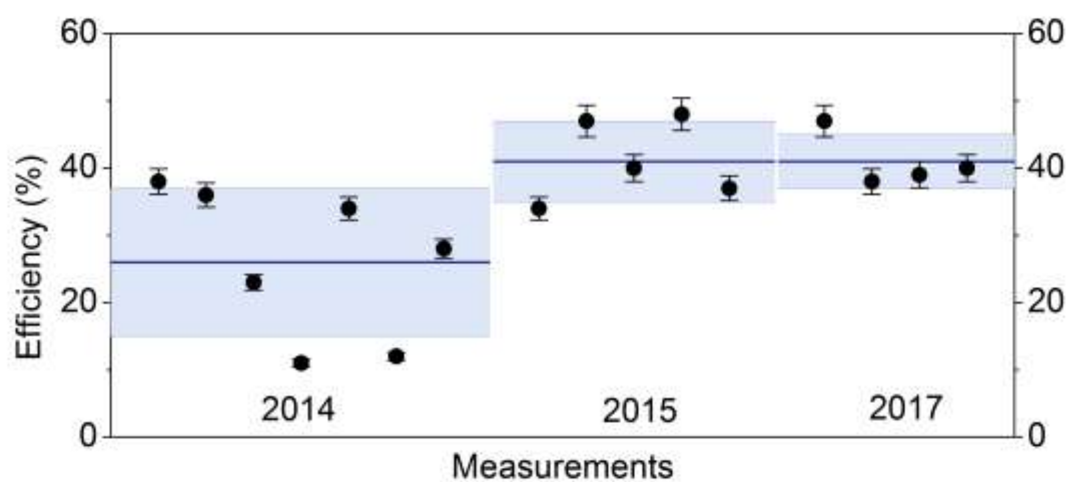
R. Heinke *et al.*,
to be published (2017)

Efficiency of Isotope Separation



Ionization and Transmission Efficiency:

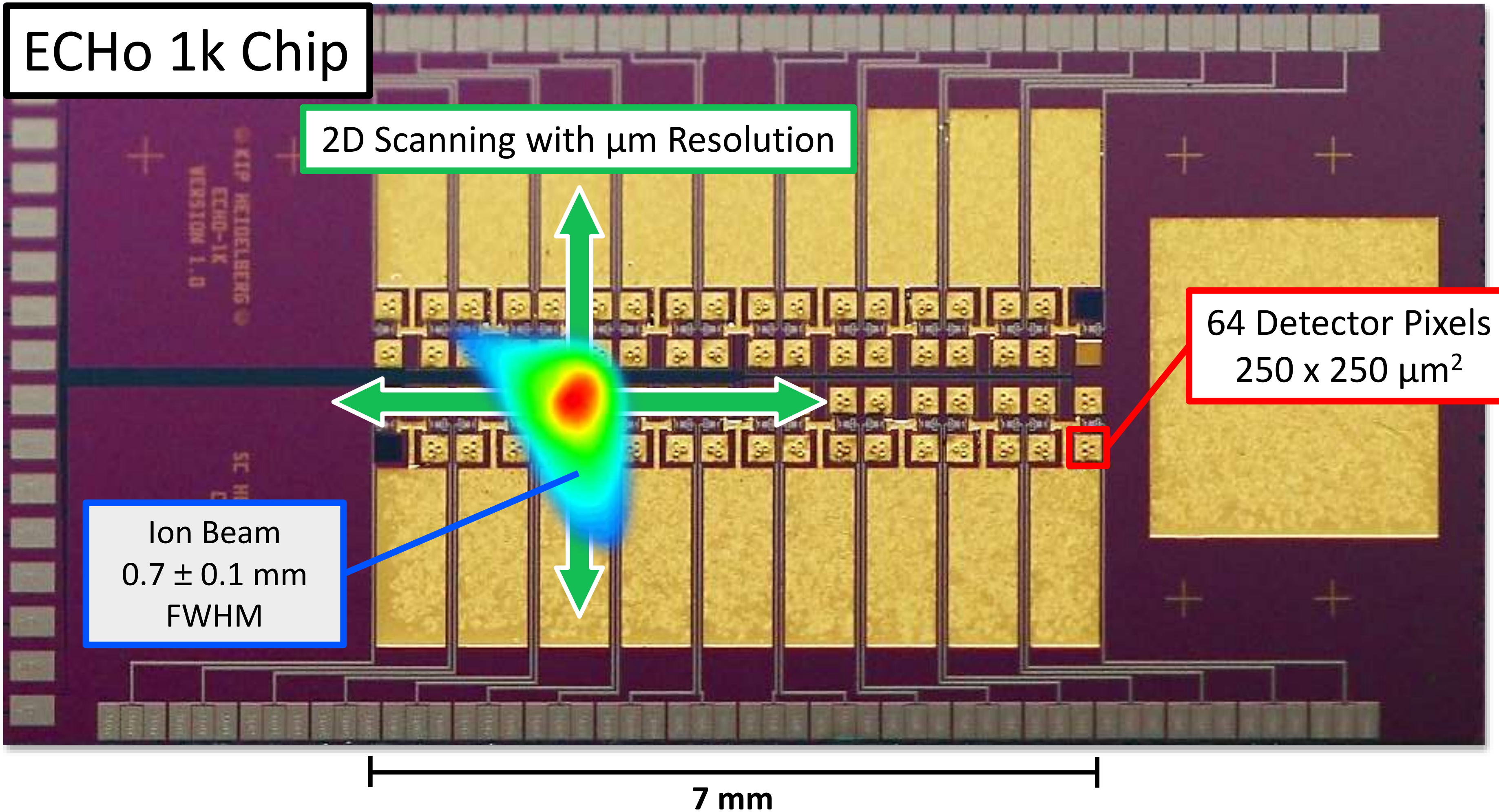
26 ± 11 % 41 ± 6 % **41 ± 4 %**



F. Schneider *et al.*,
NIM B **376**, 388 (2016)

T. Kieck *et al.*,
to be published (2017)

Direct Ion Implantation @ RISIKO



Geometric Efficiency: 25 ± 5 %

T. Kieck *et al.*,
to be published (2017)

Status of ^{163}Ho Production for sub-eV Sensitivity

		Radiochemical Purity		^{163}Ho Efficiency
		^{166m}Ho/^{163}Ho	^{170,171}Tm	
1.	Production	10^{-4}	6 GBq	
2.	Chemical Separation	-	not measurable	95 ± 1 %
3.	Isotope Separation	10^{-5}		41 ± 4 %
4.	Ion Beam Gating	10^{-1}		~ 99 %
5.	(HFS Selection	< 10^{-4}		~ 1 %)
6.	Ion Implantation	-		25 ± 5 %
	Total	**10^{-10}**	(ECHo limit = 10^{-9})	**10 ± 2 %**

→ Already meeting future phase purity requirements

→ Source production almost finished for large scale experiment
(0.6 of 1 MBq implantation dose)

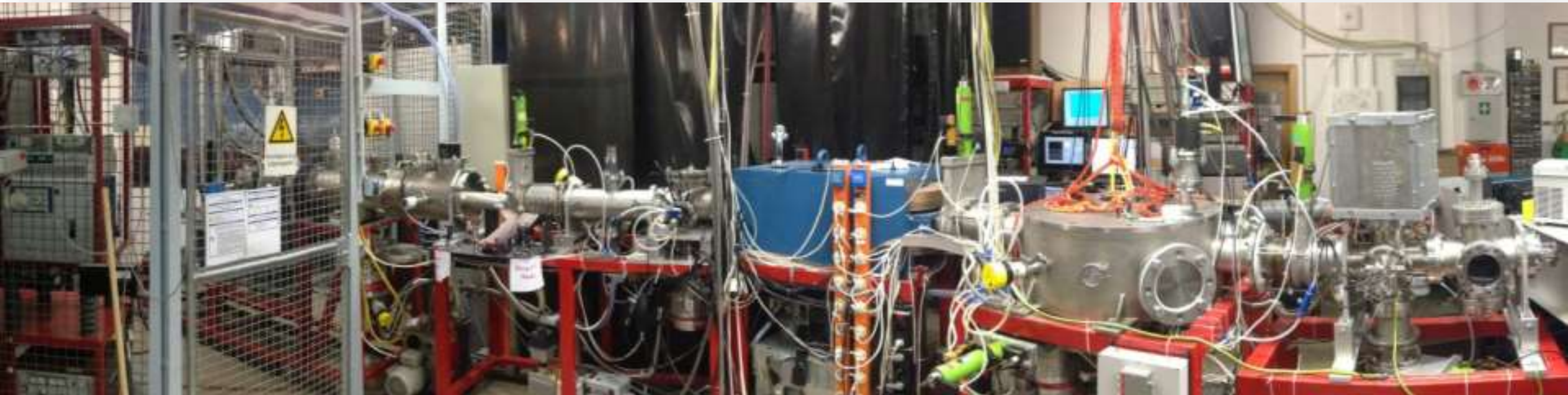
Conclusion and Outlook

- Large amount of ^{163}Ho produced and purified
- Implantation into detectors established with 10 % efficiency

→ Source production almost finished for future large scale experiment

- Purification process already meeting future phase requirements
- More than 200 MMCs successfully implanted

- Further improvements of purity possible with isotope selective ionization
- AMS measurement to confirm ^{166m}Ho suppression



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