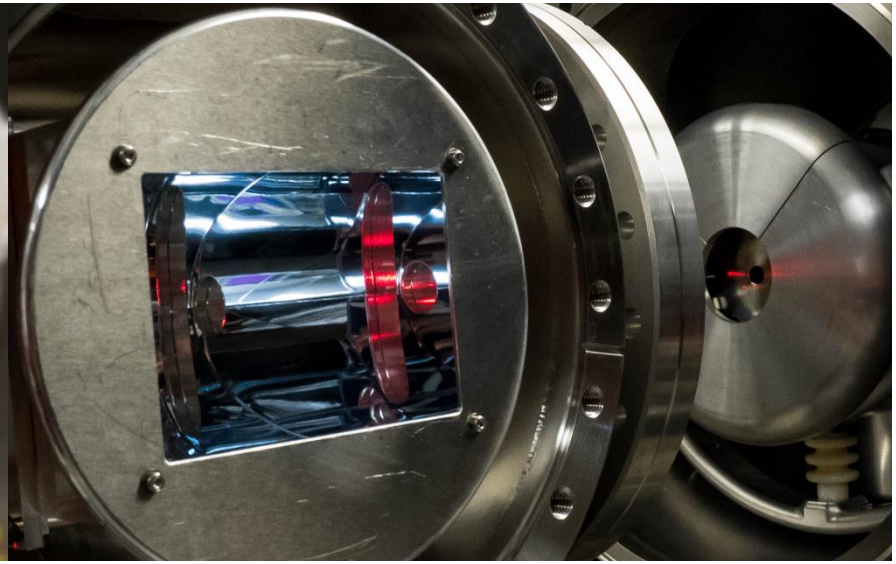
Nuclear Charge Radii of Boron Isotopes

TECHNISCHE UNIVERSITÄT DARMSTADT

Bernhard Maaß, Peter Müller, Jason Clark, Christian Gorges, Simon Kaufmann, Jan Krause, Kristian König, Jörg Krämer, Rodney Orford, Rodolfo Sánchez, Guy Savard, Felix Sommer and Wilfried Nörtershäuser



Argonne NATIONAL LABORATORY

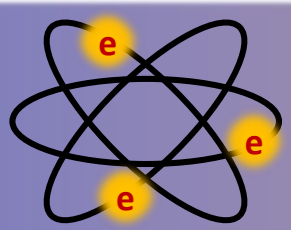
LASER SpHERe

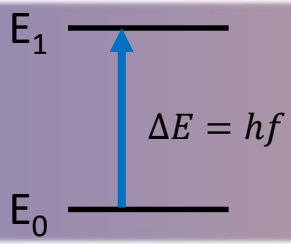
SFB 1245

BOR8

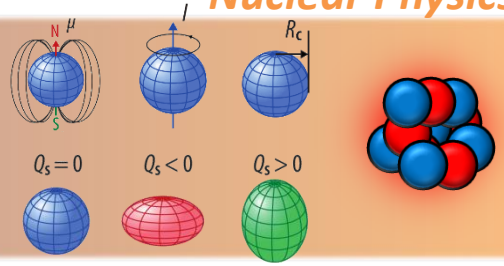
Nuclear Structure with Lasers

Atomic Physics





Nuclear Physics



Nuclear Structure with Lasers

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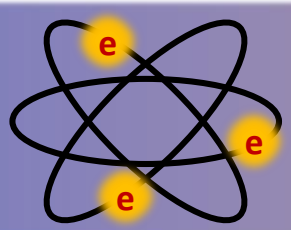
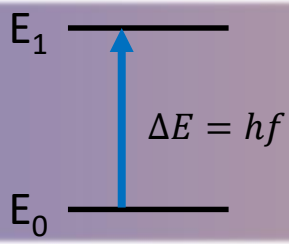
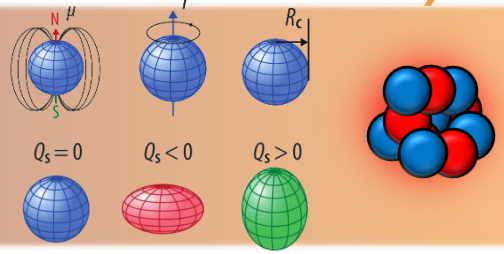
Atomic Physics *Nuclear Physics*





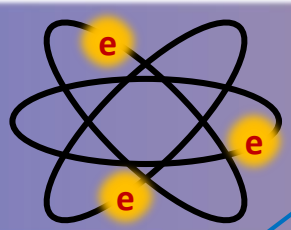
nuclear properties **shift and split** atomic energy levels

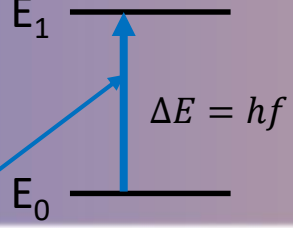


Nuclear Structure with Lasers

TECHNISCHE UNIVERSITÄT DARMSTADT

Atomic Physics ***Nuclear Physics***





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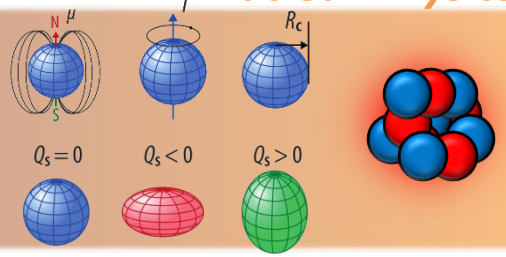
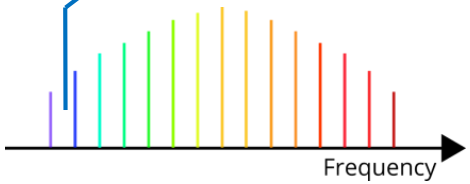
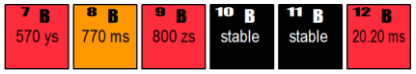




Measure transition with high accuracy

$$\delta\nu_{IS} = \delta\nu_{NMS} + \delta\nu_{SMS} + \delta\nu_{FS}$$

$$\delta\nu_{FS} = F_{el}\,\delta\langle r_c^2\rangle$$



„Subtract“ all exact atomic knowledge

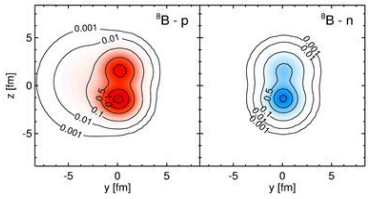
$\delta\langle r_c^2\rangle$ = …

I = …

Q = …

μ = …

Residuals: Nuclear properties – model-independent



FMD Model calculation (T. Neff, GSI)

Benchmark nuclear model calculations

Boron-8 in the SFB

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SFB 1245

Laser System
Comb-stabilized 250nm generation

TRIGA @ ANL
Our collinear Beamline at Argonne National Laboratory

Stable Boron 10/11
Laser Spectroscopy and NCR

BOR8
Measurement of the Nuclear Charge Radius via Laser Spectroscopy

Online Setup
Bunching, Cooling and Transporting the online Beam

Boron-8 Production
at the ATLAS LN2 ^{3}He target

Molecular Breakup
efforts at ANL and GSI

Boron-8 in the SFB

TECHNISCHE UNIVERSITÄT DARMSTADT

SFB 1245

Fe, Ca at NSCL
Laser Spectroscopy and NCR
SFB – A03

Laser System
Comb-stabilized 250nm generation

TRIGA @ ANL
Our collinear Beamline at Argonne National Laboratory

Palladium at CARIBU
Laser Spectroscopy and NCR / SFB – A03

Atomic $5e^-$ - Theory
Isotope shift calculations

Stable Boron 10/11
Laser Spectroscopy and NCR

BOR8
Measurement of the Nuclear Charge Radius via Laser Spectroscopy

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Abs. Charge Radii of Boron
e- scattering
S-DALINAC

NCSM/CEFT
Calculations for the Boron Isotopic Chain
SFB - A02

Halo EFT
Calculations for $^{7}Be/^{8}B$
SFB - A05

Boron-8 Production
at the ATLAS LN2 ^{3}He target

Molecular Breakup
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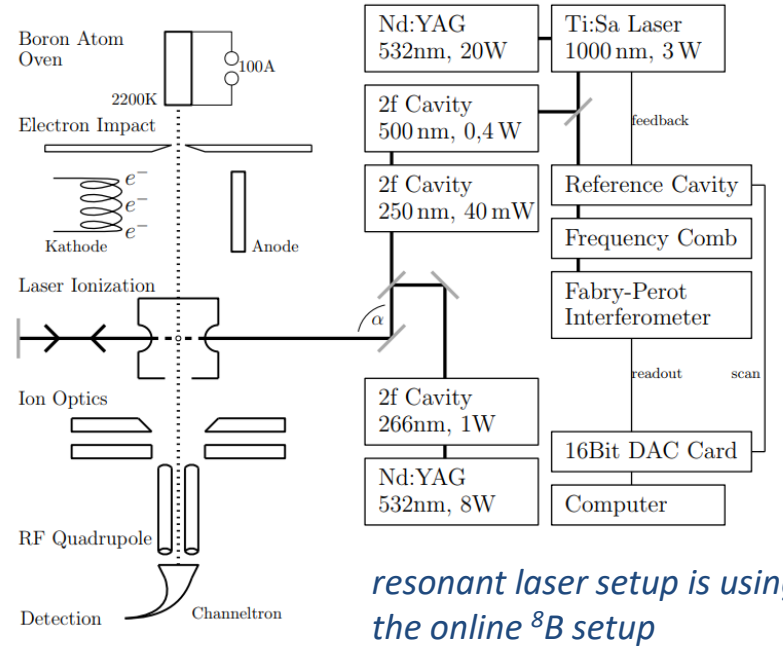
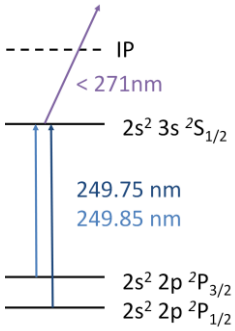
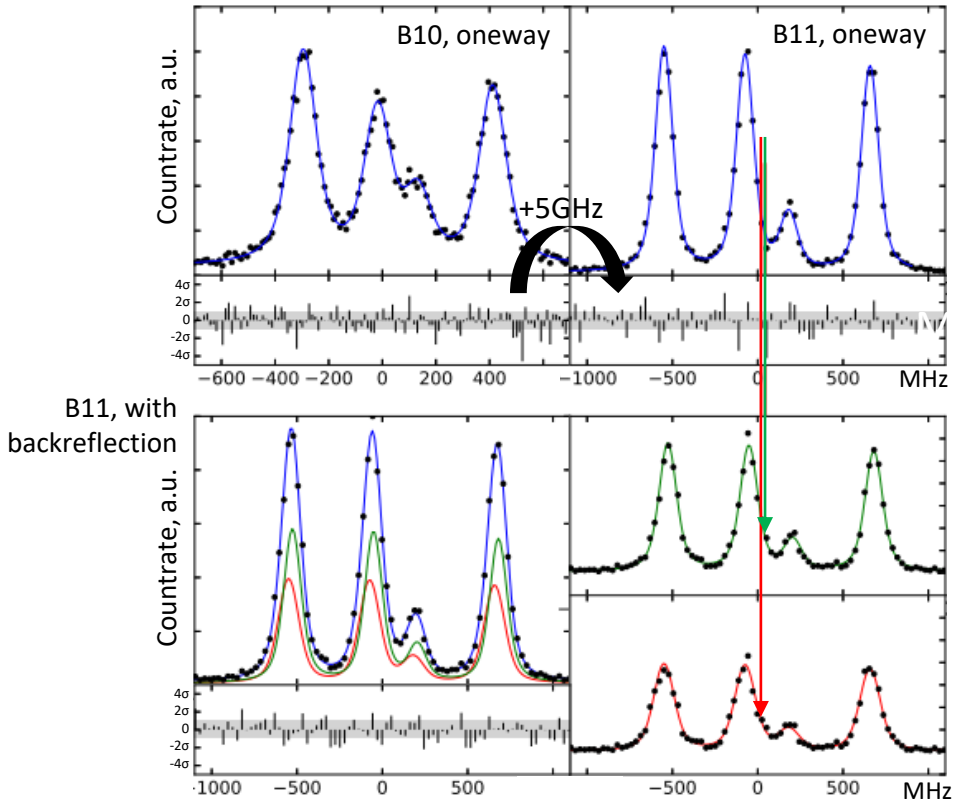
Boron 10 and 11 - Experiment



resonant laser setup is using the online ^{8}B setup components





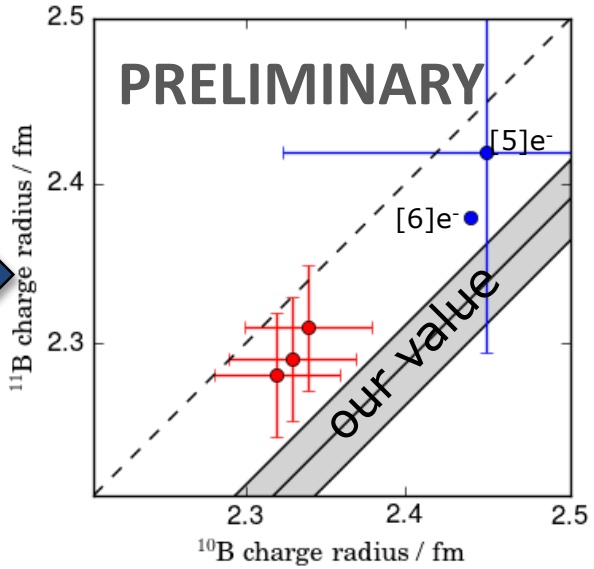
→ Scan the laser frequency over ^{10}B, ^{11}B resonance
→ Extract difference: isotope shift
→ repeat at different angles

Boron 10 and 11 - Results

	Value / MHz		Reference
Isotope Shift	−5250	(360)	[1]
	−4110	(360)	[2]
	−5220	(150)	[3]
	−5030.8	(5.3)	this work, exp.[a]
	−5031.8	(1.9)	this work, exp.[b]
Mass Shift	−5023.05	(0.10)	this work, theo.
Field Shift	16.89	(0.10)/fm^2	this work, theo. [4]
Field Shift	8.8	(2.0)	this work, combined

[a] Simple Difference between centroid frequencies
[b] Removed correlated errors

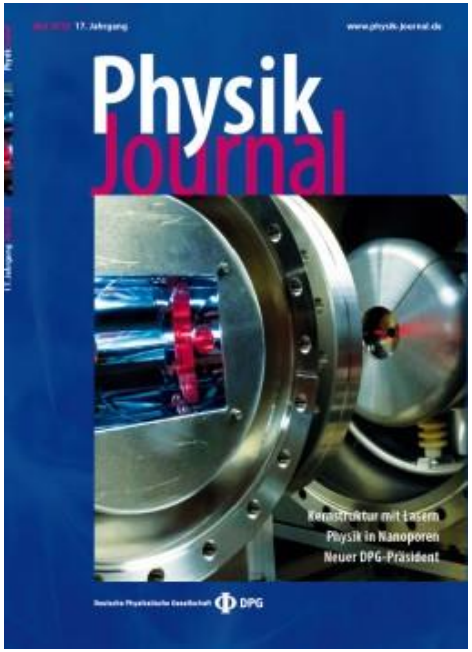
d<r^2>



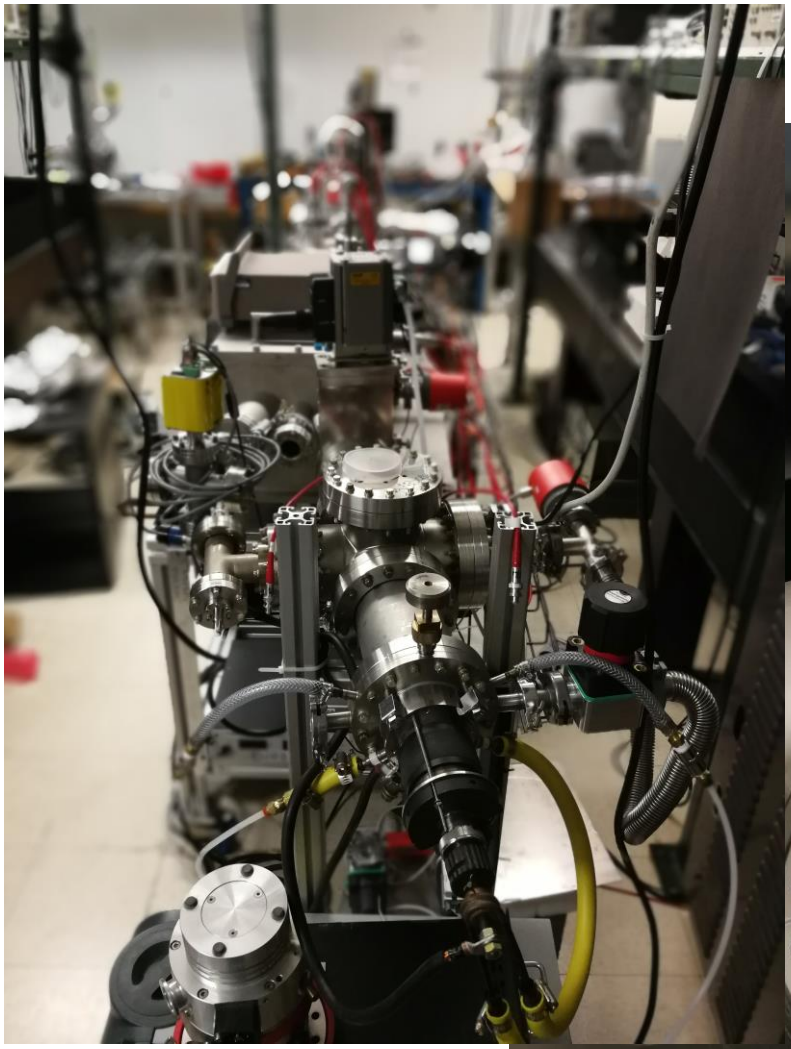
[1] S. Mrozowski, Z. Physik **112** (1939)
[2] E.W. Burke, Phys, Rev. **99**, 1839 (1955)
[3] S.G. Johansson, U. Litzn, J. Kasten, M. Kock, Astrophys. J. **403**, L25 (1993)
[4] M. Puchalski, J. Komasa, K. Pachucki, Phys. Rev. A. **92**, 062501 (2015) and priv. comm.
[5] T. Stovall, J. Goldemberg, D.B. Isabelle, Nucl. Phys. **86**, 225-240 (1966)
[6] A. Chichoki, J. Dubach, R.S. Hicks et al., Phys. Rev. **C51**, 2406-2426 (1995)

→ additional data points: theory calculations (R. Roth, B. Wiringa (ANL))
→ **Publication is in progress**
→ „fix“ the value with new experimental result from e- scattering from ^{11}B
→ online ^{8}B measurement will give a value for stable Boron as well.

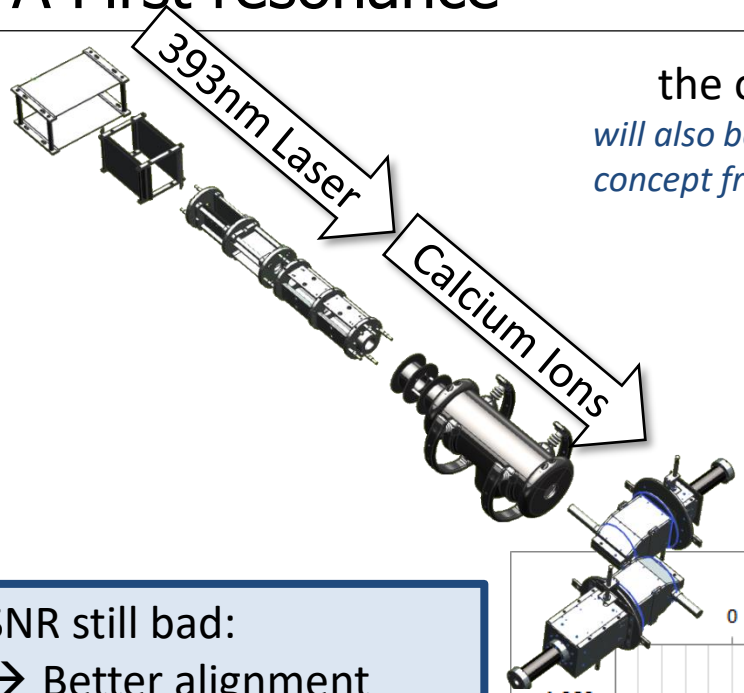
TRIGA Setup at Argonne



TRIGA Setup at Argonne



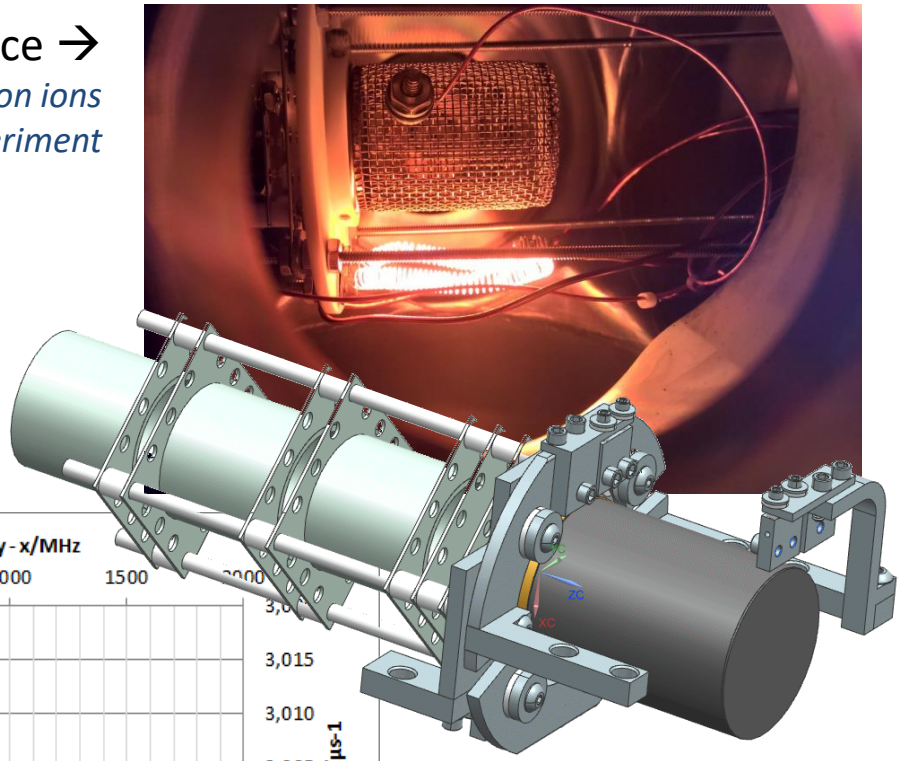
A First resonance



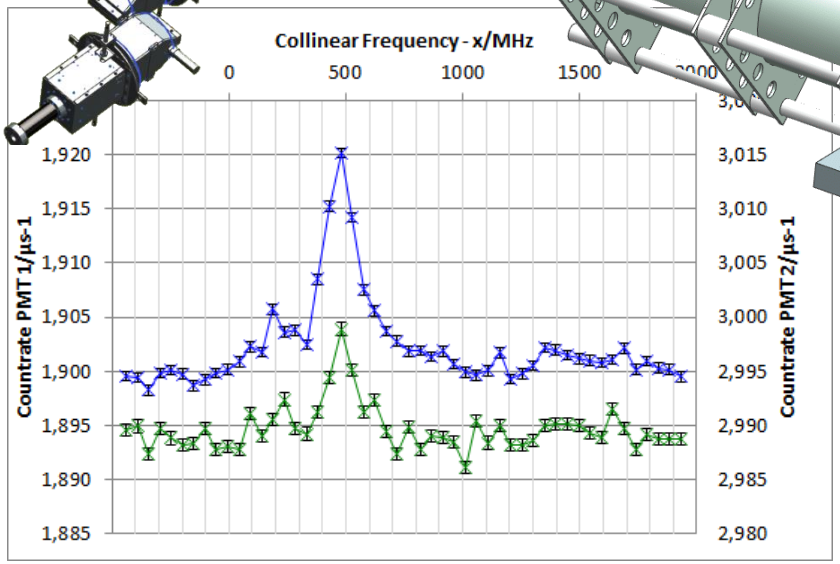
the offline source →

will also be used for boron ions

concept from ^{10,11}B experiment



planned source upgrade



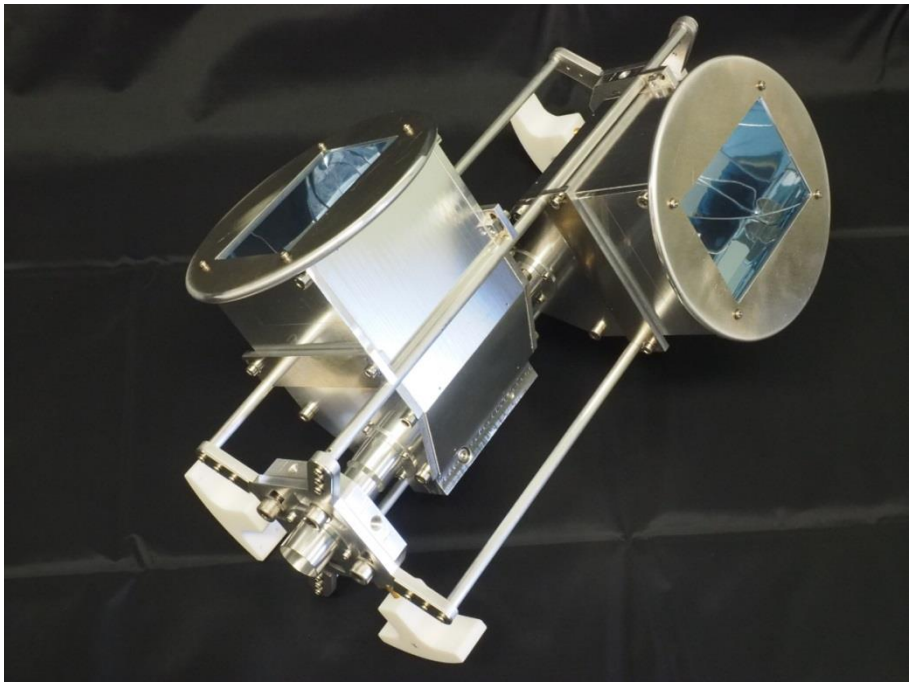
SNR still bad:

→ Better alignment (experience from ALIVE experiment)

→ Improvements in laser performane

→ Better ion beam quality

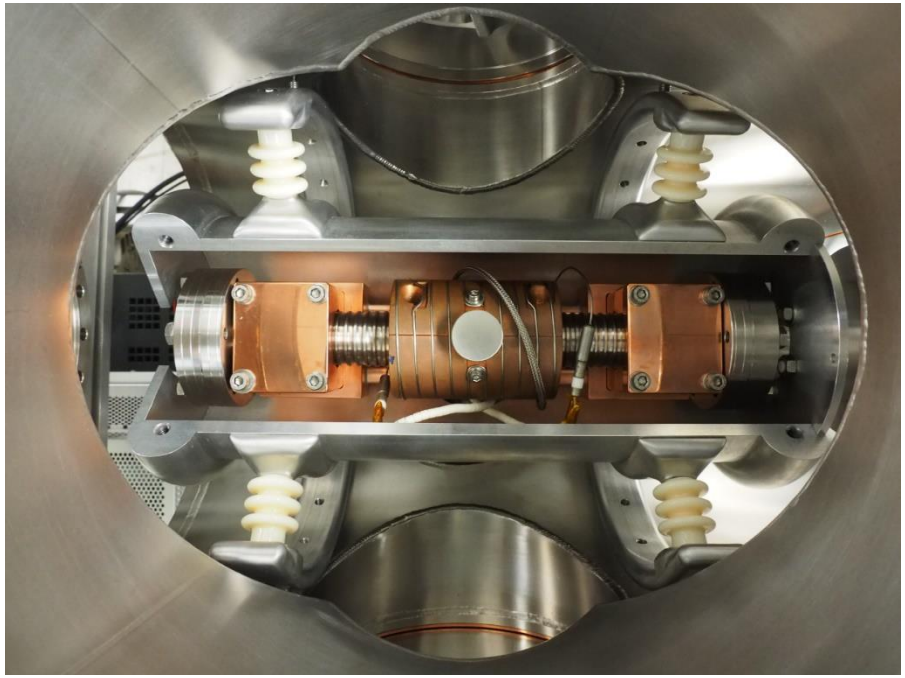
New components für the collinear Beamline



← Fluorescence Detection Region

Copy used at BECOLA-NSCL / A03

Resonantly emitted photons are emitted towards Photomultipiers

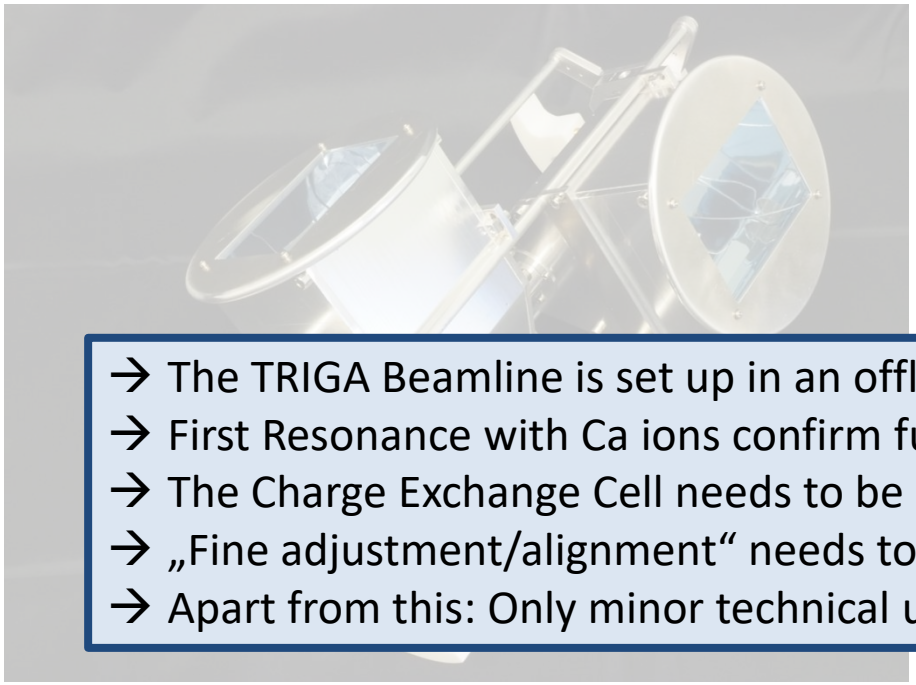


The ion beam is neutralized to generate an atom beam.

Charge Exchange Cell →

Also designed for the Pa-Measurement / A03

New components für the collinear Beamline

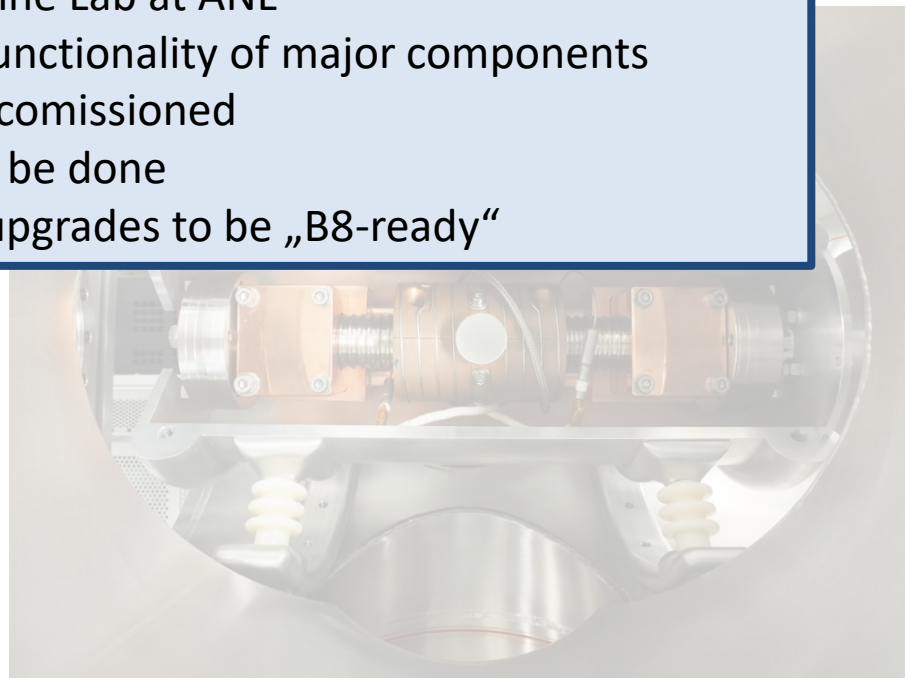


← Fluorescence Detection Region

Copy used at BECOLA-NSCL / A03

Resonantly emitted photons are emitted towards Photomultipiers

→ The TRIGA Beamline is set up in an offline Lab at ANL
→ First Resonance with Ca ions confirm functionality of major components
→ The Charge Exchange Cell needs to be comissioned
→ „Fine adjustment/alignment“ needs to be done
→ Apart from this: Only minor technical upgrades to be „B8-ready“



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Charge Exchange Cell →

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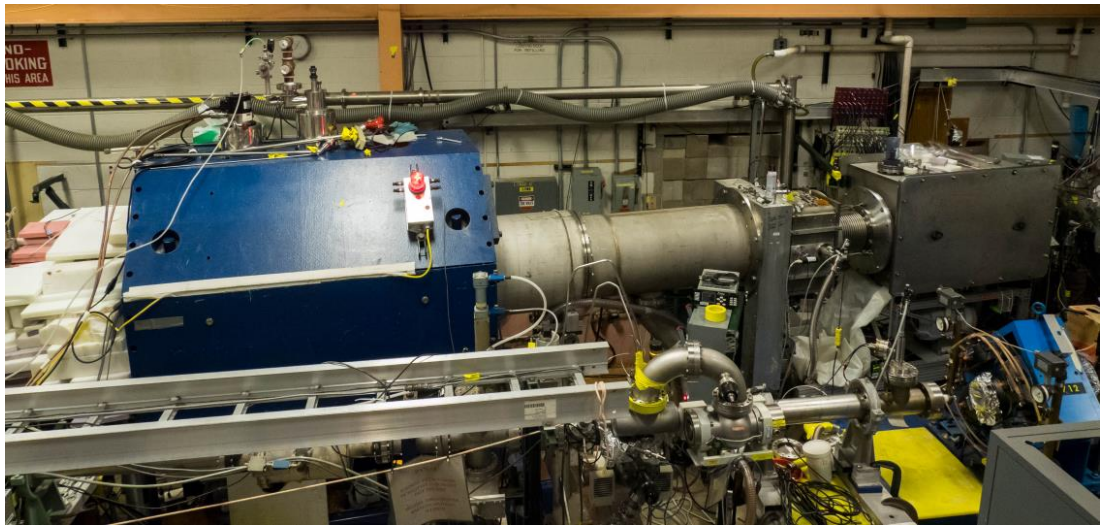
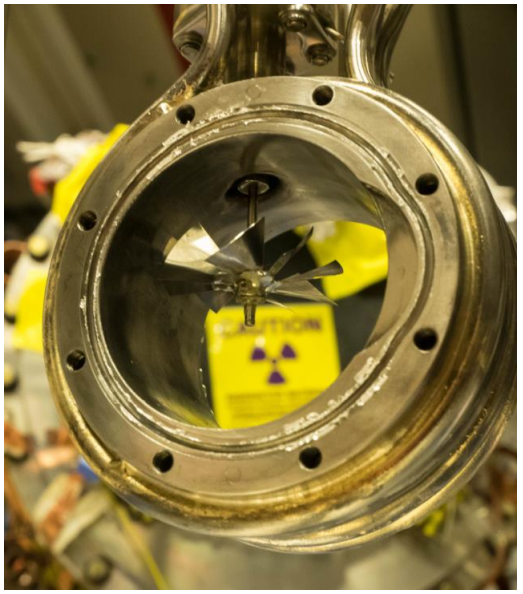
Boron 8 Production





In-flight production of boron-8 at ATLAS: 45MeV $^{6}Li(^{3}He,n)^{8}B$

focusing the reaction products into the gas catcher

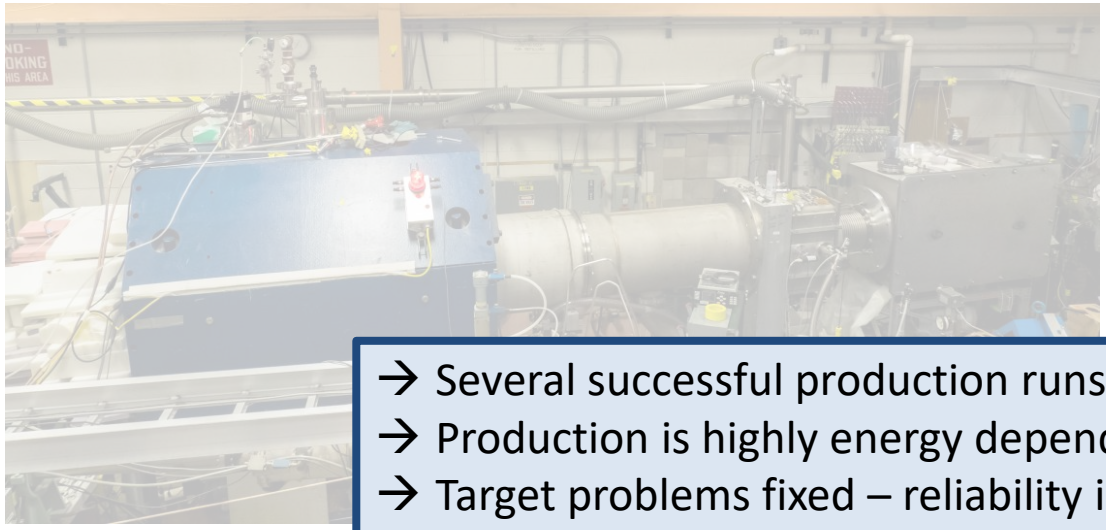
LN_2 cooled ^{3}He target → solenoid → He gas catcher → RFQ Cooler/Buncher → to experiment

stopping and thermalization of reaction products

cooling and extraction towards beamline

m>8 rates exceed proposal estimates…

Boron 8 Production



- → Several successful production runs since 2017
- → Production is highly energy dependent
- → Target problems fixed – reliability increased
- → Transport ^{8}B molecules, not „pure“ ^{8}B
- → High rates throughout all runs

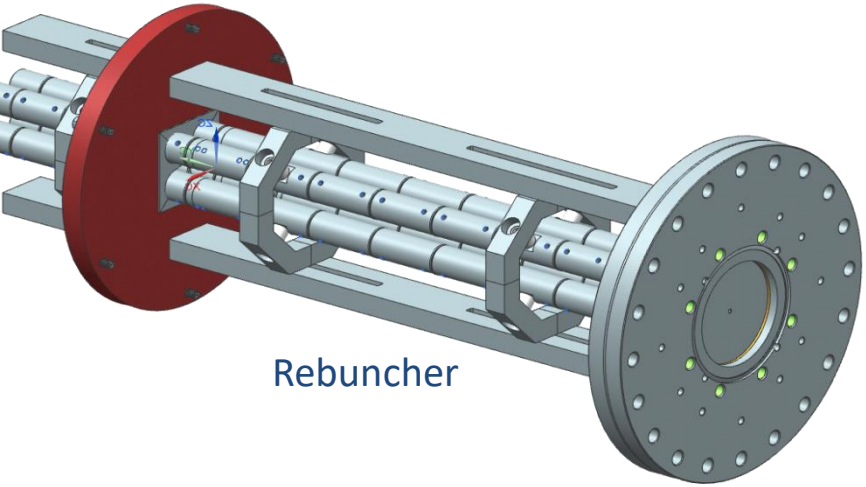
In-flight productio

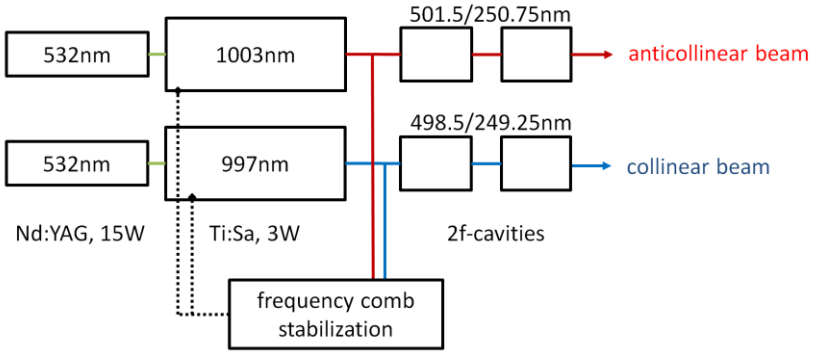
focusing the reaction products into the gas catcher

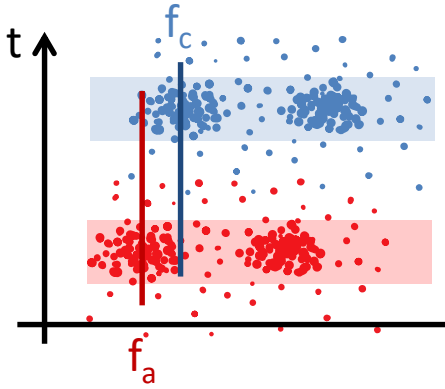
Argonne NATIONAL LABORATORY

LN_2 cooled ^{3}He target	→	solenoid	→	He gas catcher	→	RFQ Cooler/Buncher	→	to experiment
				stopping and thermalization of reaction products		cooling and extraction towards beamline		m>8 rates exceed proposal estimates…

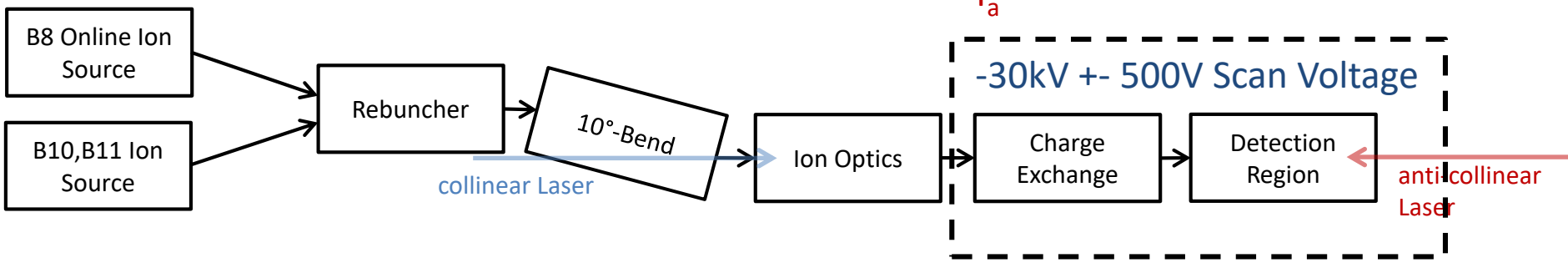
Boron 8 Online Setup



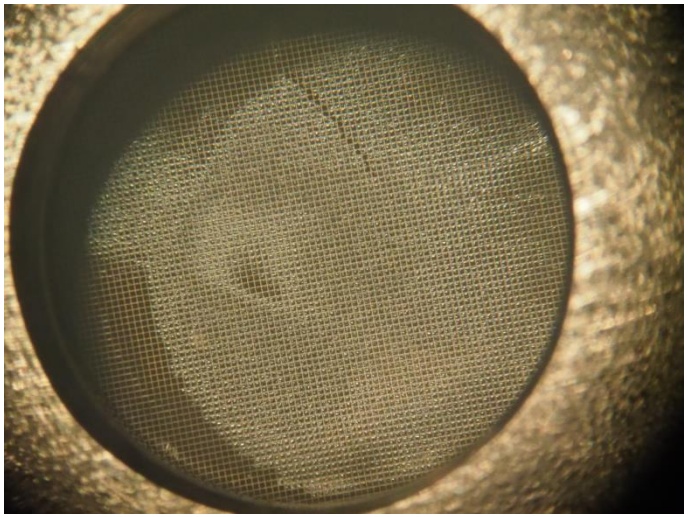




$$f_c \cdot f_a = f_0^2$$

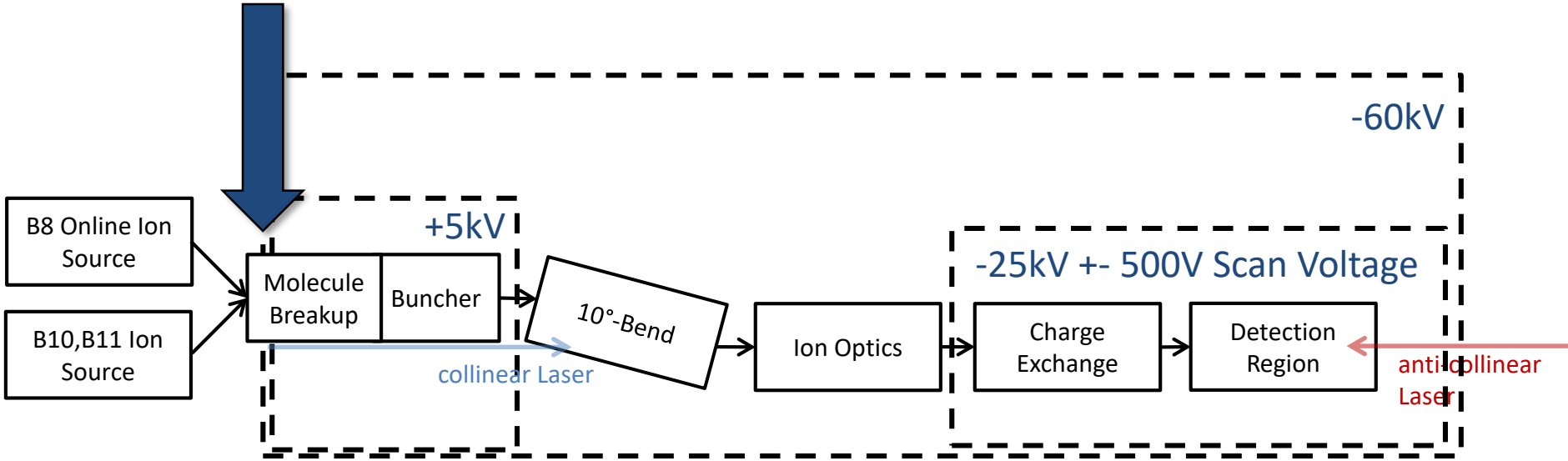


Boron 8 Molecular Breakup



← The molecular ions are shot with up to 60kV through a nm-thin carbon foil

Afterwards, they are captured in a „low pressure gas catcher“ and extracted into the laser beamline



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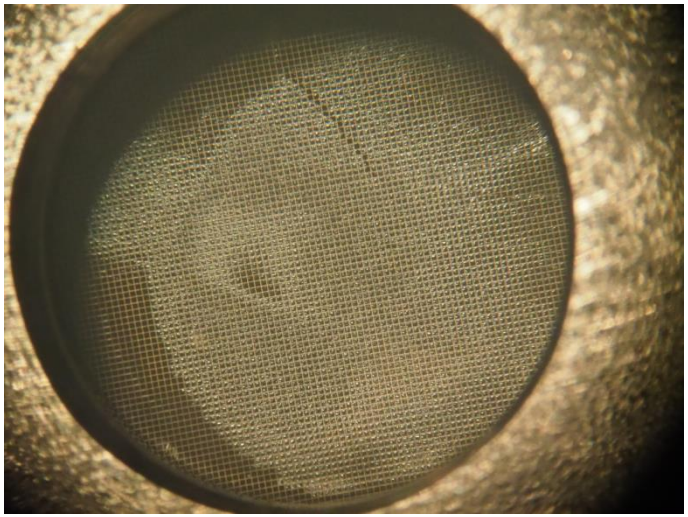

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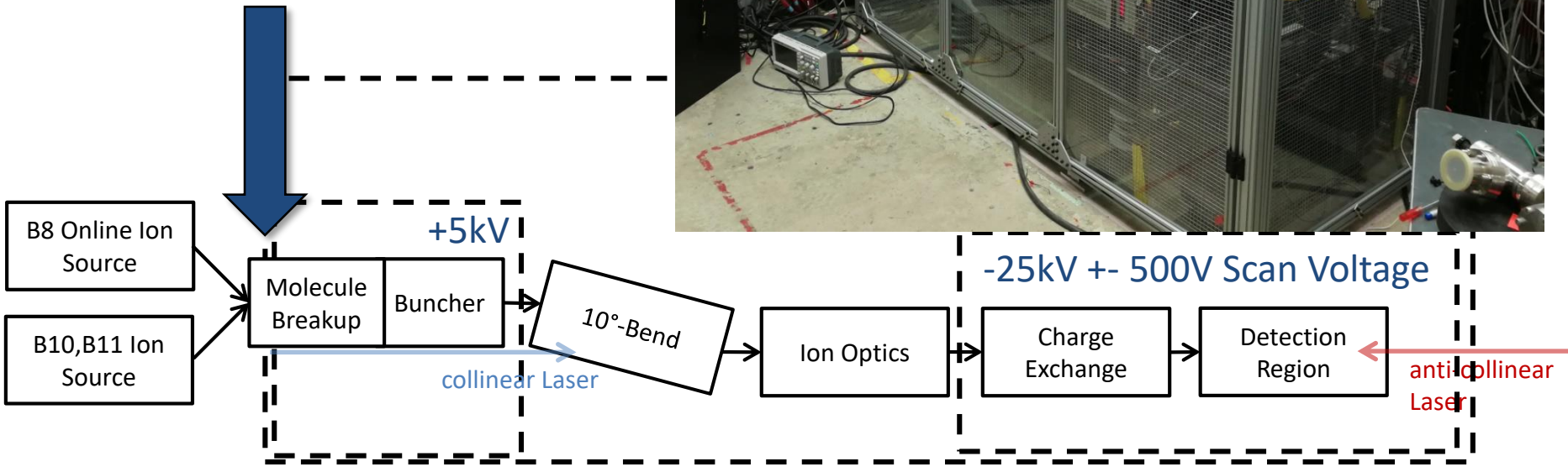
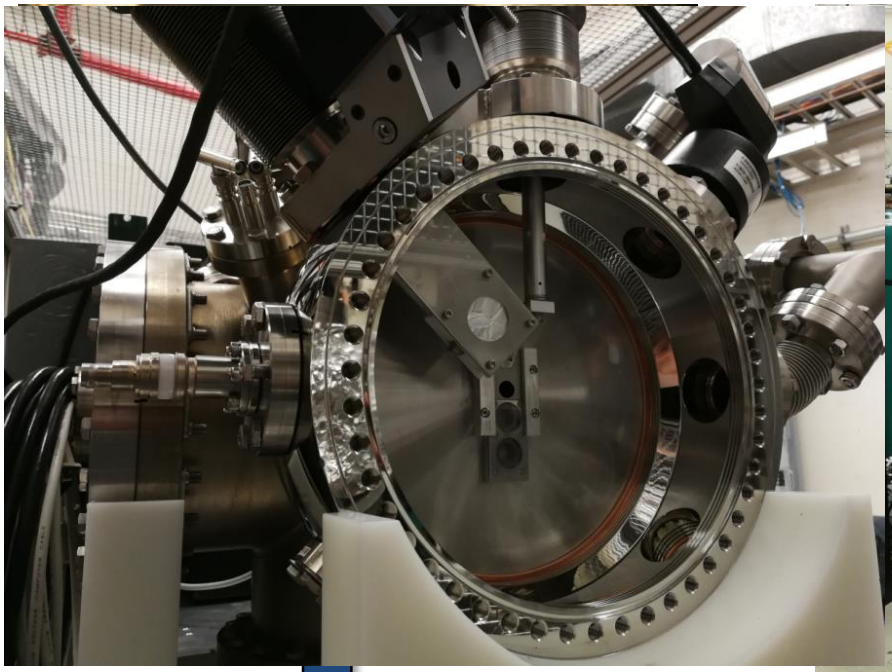
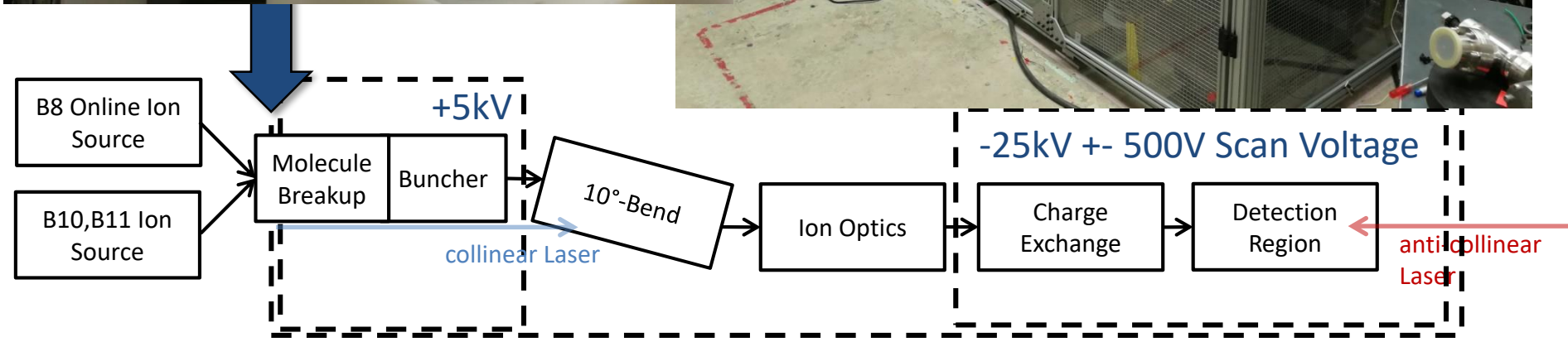
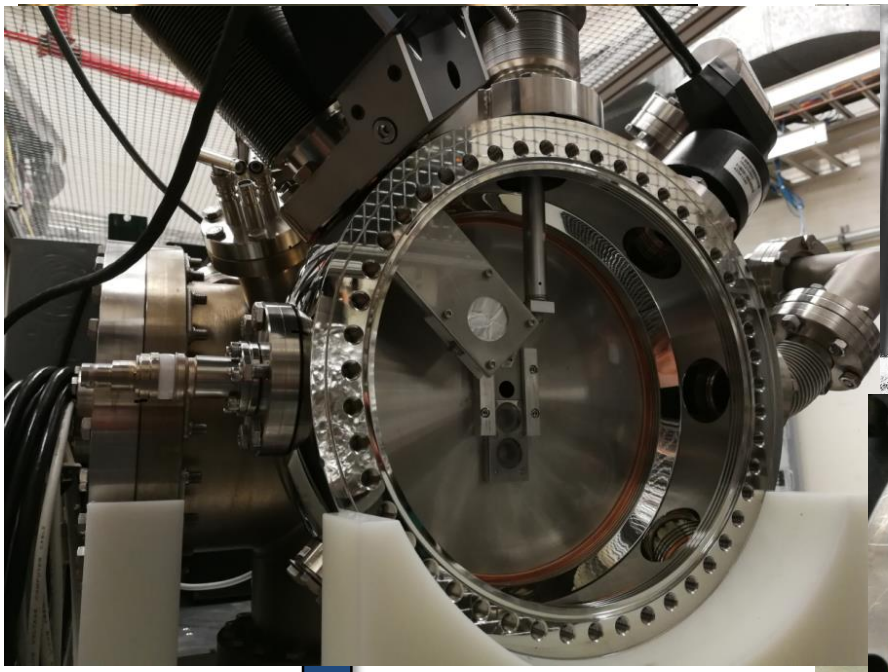


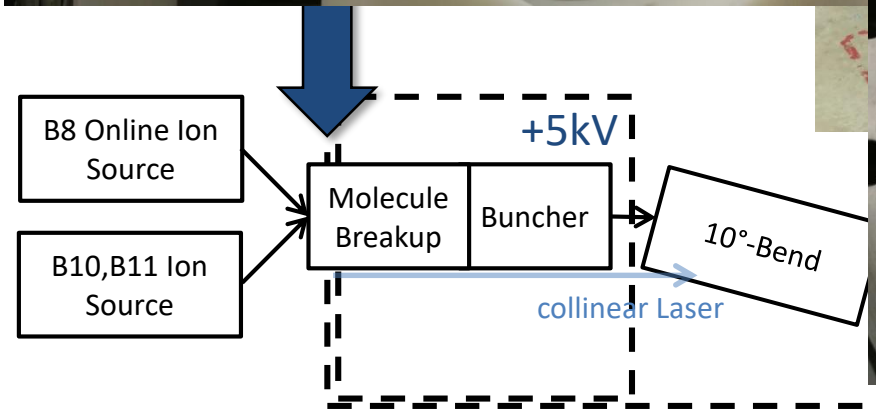
Boron 8 Molecular Breakup



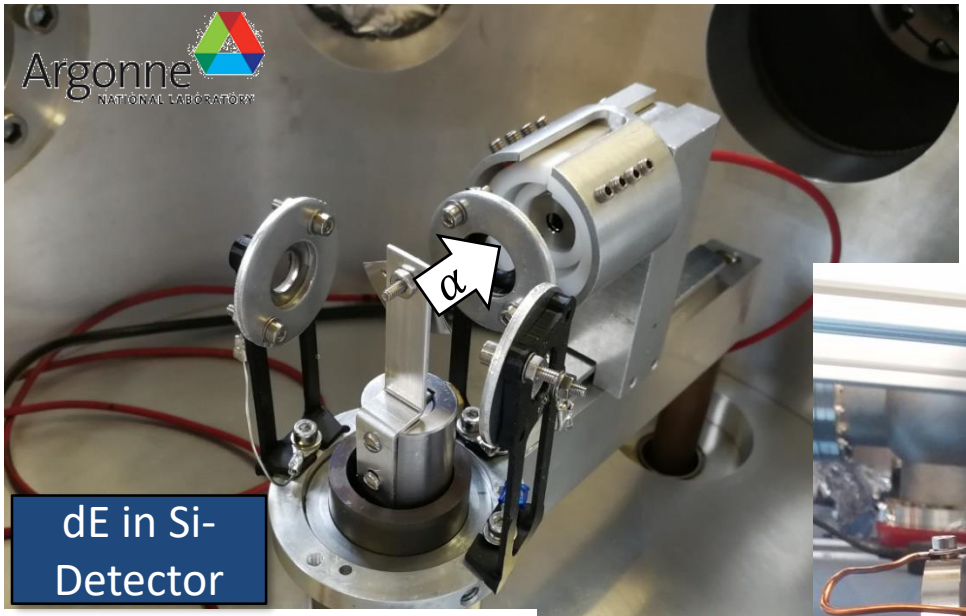


Boron 8 Molecular Breakup

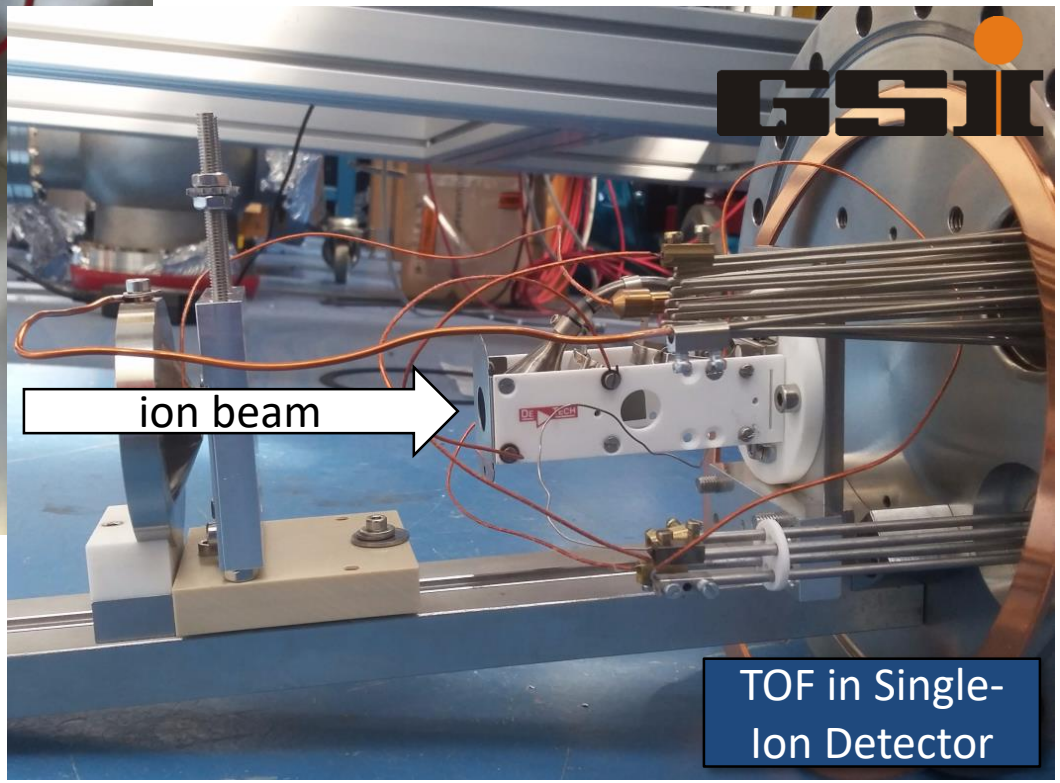


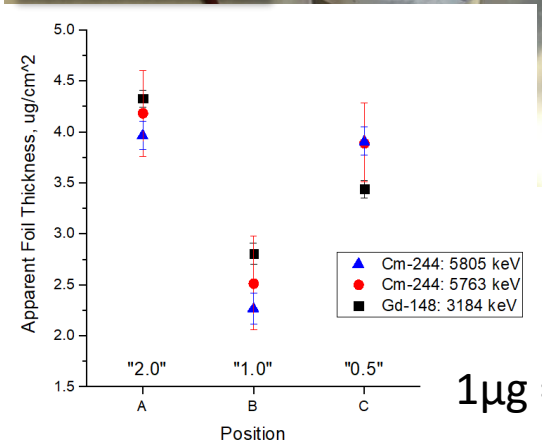


Foil characterization



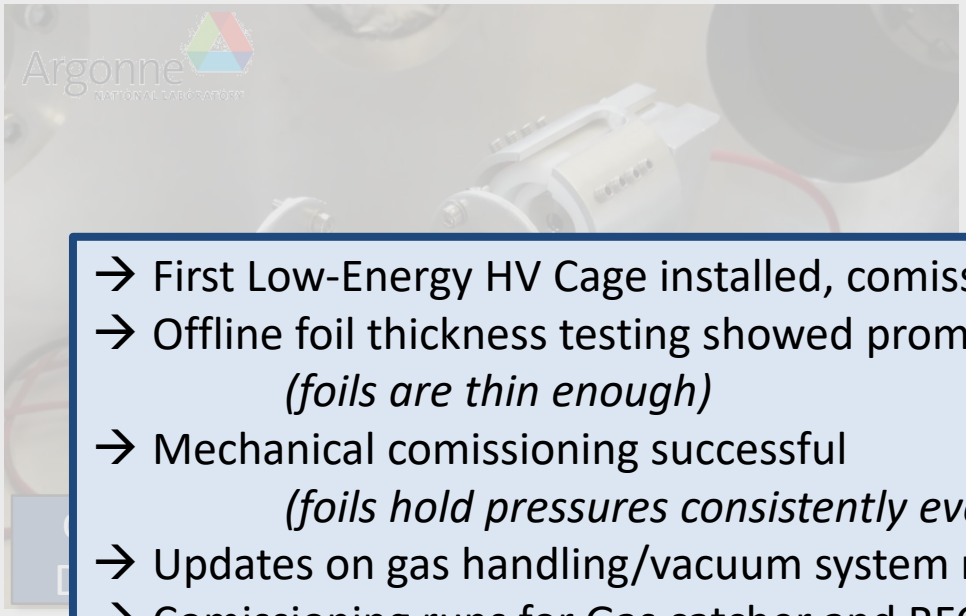
Foil Testing at Argonne and at GSI





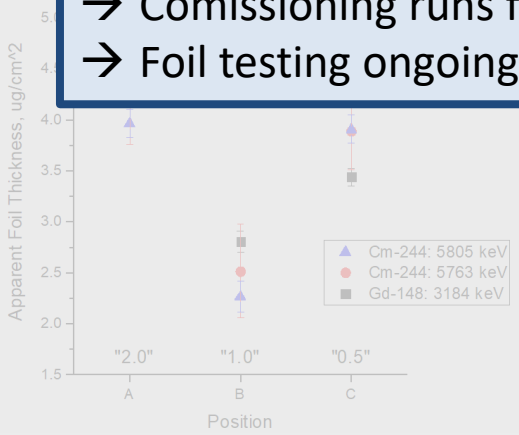
1µg = 4nm

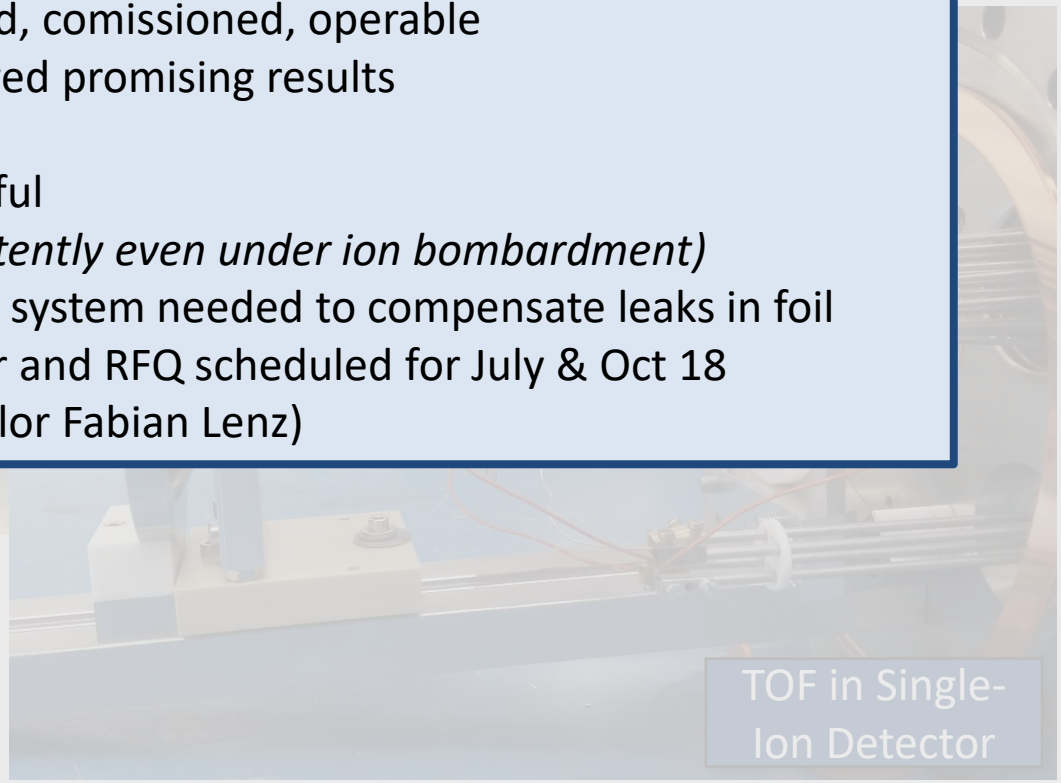
Foil characterization



Foil Testing at Argonne and at GSI

- → First Low-Energy HV Cage installed, comissioned, operable
- → Offline foil thickness testing showed promising results
  (foils are thin enough)
- → Mechanical comissioning successful
  (foils hold pressures consistently even under ion bombardment)
- → Updates on gas handling/vacuum system needed to compensate leaks in foil
- → Comissioning runs for Gas catcher and RFQ scheduled for July & Oct 18
- → Foil testing ongoing at GSI (Bachelor Fabian Lenz)





Timetable

A1, position #13	Charge radius of ^{8}B							
Tasks	16/1	16/2	17/1	17/2	18/1	18/2	19/1	19/2
Laser system development (TU Da)								
Beamline Setup (ANL)								
Control system and DAQ (TU Da)								
Laser installation at ANL, ^{10,11}B off-line								
^{8}B spectroscopy at ANL								
Data Analysis and publication								

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completed

CEC and Alignment (Fall 2018)

completed

Laser system can be sent and set up at ANL within 4 months.

^{10,11}B Offline results at TUD

Molecule Breakup: Tests in July and Oct. 18
+ Online setup (Rebuncher, HV platform)

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„Best Case“ for 2018

→ Working molecule breakup system this year
→ Beamline (CEC) almost ^{8}B-ready (will need adjustments to online beam still!)
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→ Preparing for sending the Laser

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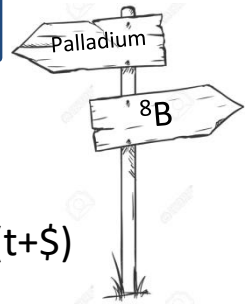

Possible Showstoppers:

- CEC doesn‘t work – need mechanical reworking (concept is working and tested)
- Molecule Breakup doesn‘t work – Big parameter room for improvement, but expensive (t+$)

(conceptional tests ongoing at ANL and GSI)

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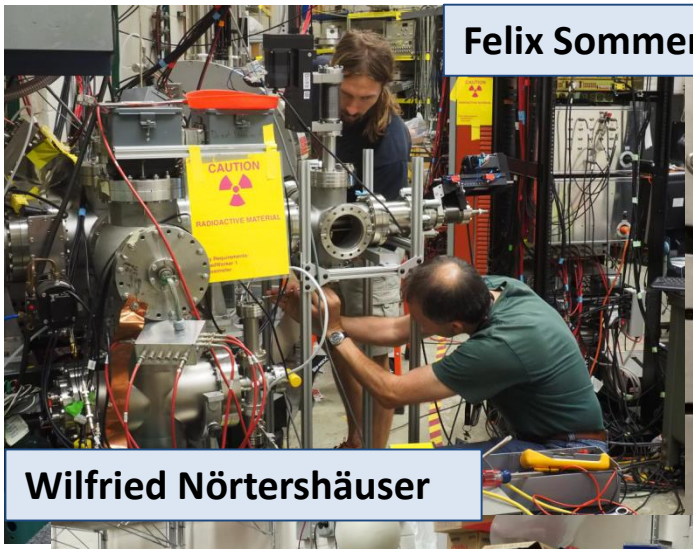
Support at Argonne



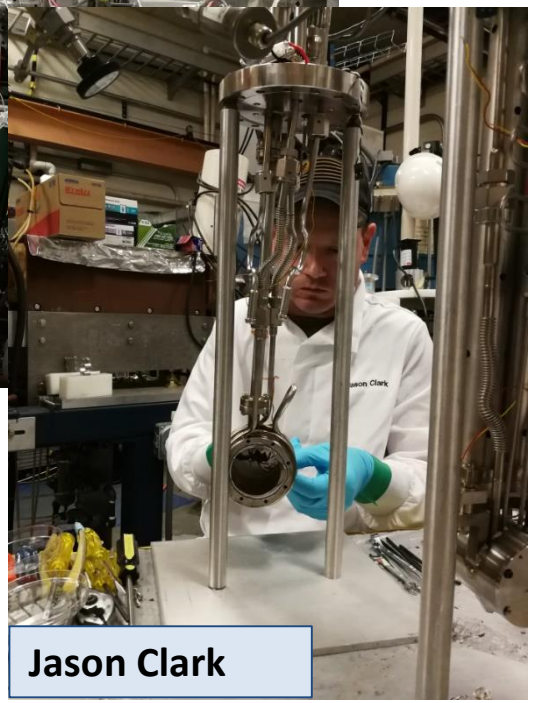
Felix Sommer

Wilfried Nörtershäuser

Guy Savard

Peter Müller

The team at Argonne



Jason Clark

Thank you for your attention

The LaserSpHERe Group in collaboration with the ANL Physics Division

Bernhard Maaß, Jan Krause, Peter Müller, Wilfried Nörtershäuser, Kevin Bailey, Michael Bishof, Mary Burkey, Jason Clark, Matthew Dietrich, Felix Sommer, Christian Gorges, Simon Kaufmann, Kristian König, Jörg Krämer, Thomas O'Connor, Rodney Orford, Tim Ratajczyk, Rodolfo Sánchez, Guy Savard

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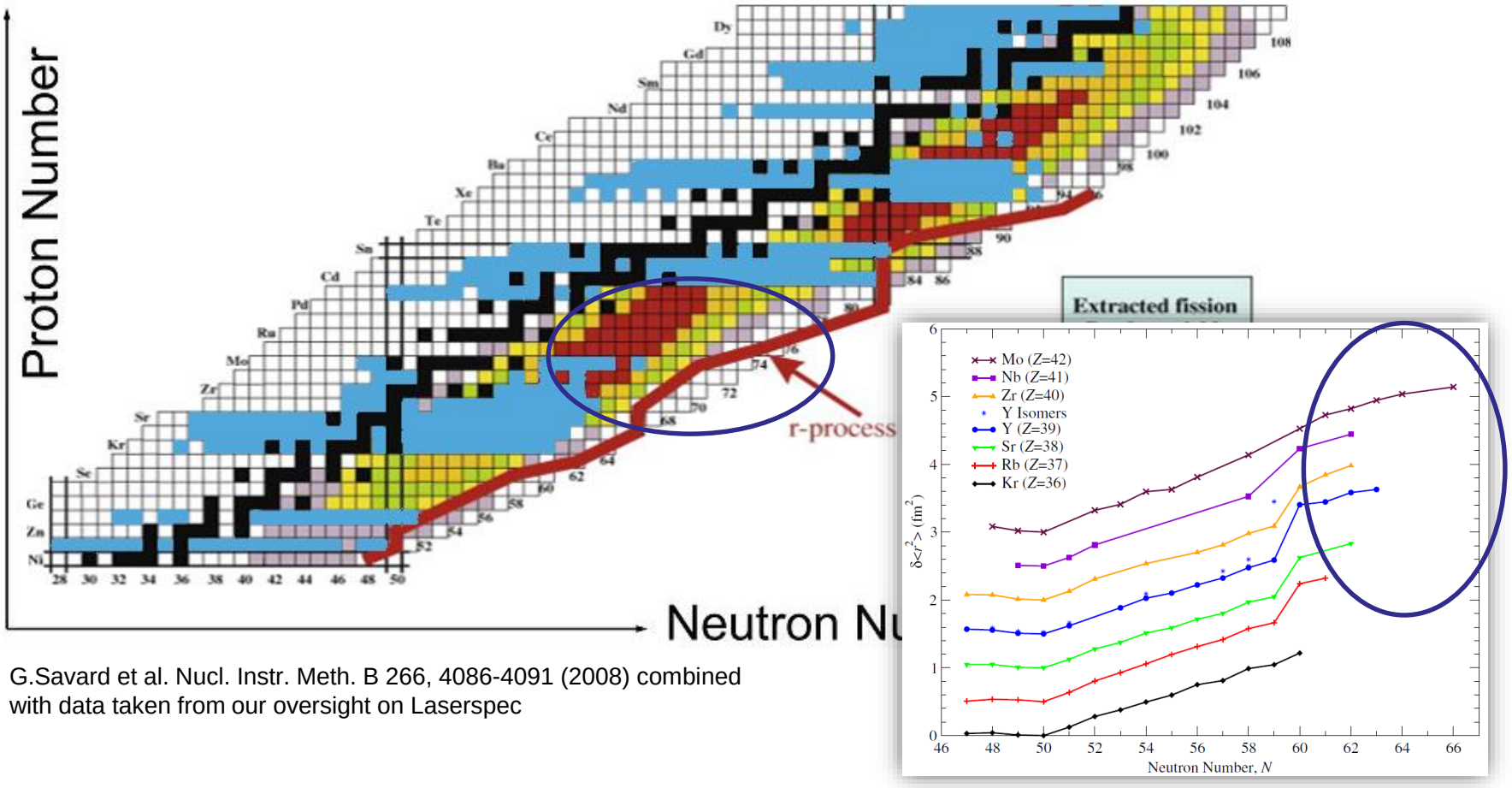
Palladium at CARIBU



G.Savard et al. Nucl. Instr. Meth. B 266, 4086-4091 (2008) combined with data taken from our oversight on Laserspec

B. Cheal and K. Flanagan, J.Phys. **G 37** (2010)113101