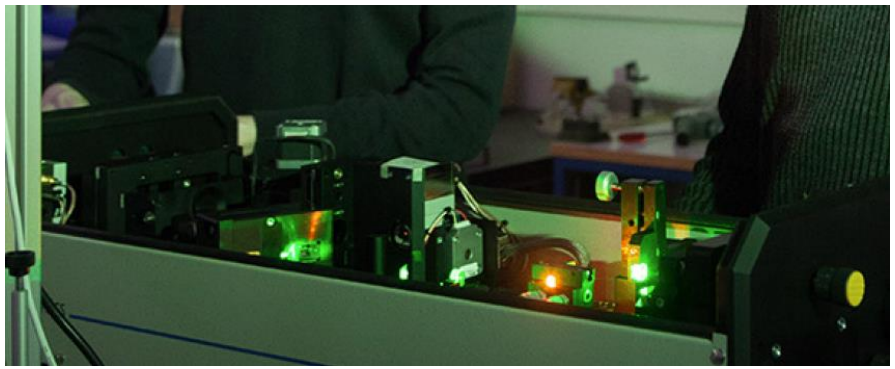
LASPEC in Phase-0: Towards a Nuclear Charge Radius Measurement of ^{8}B

Jörg Krämer
for the LaSpec and the Bor8 collaboration



Outline

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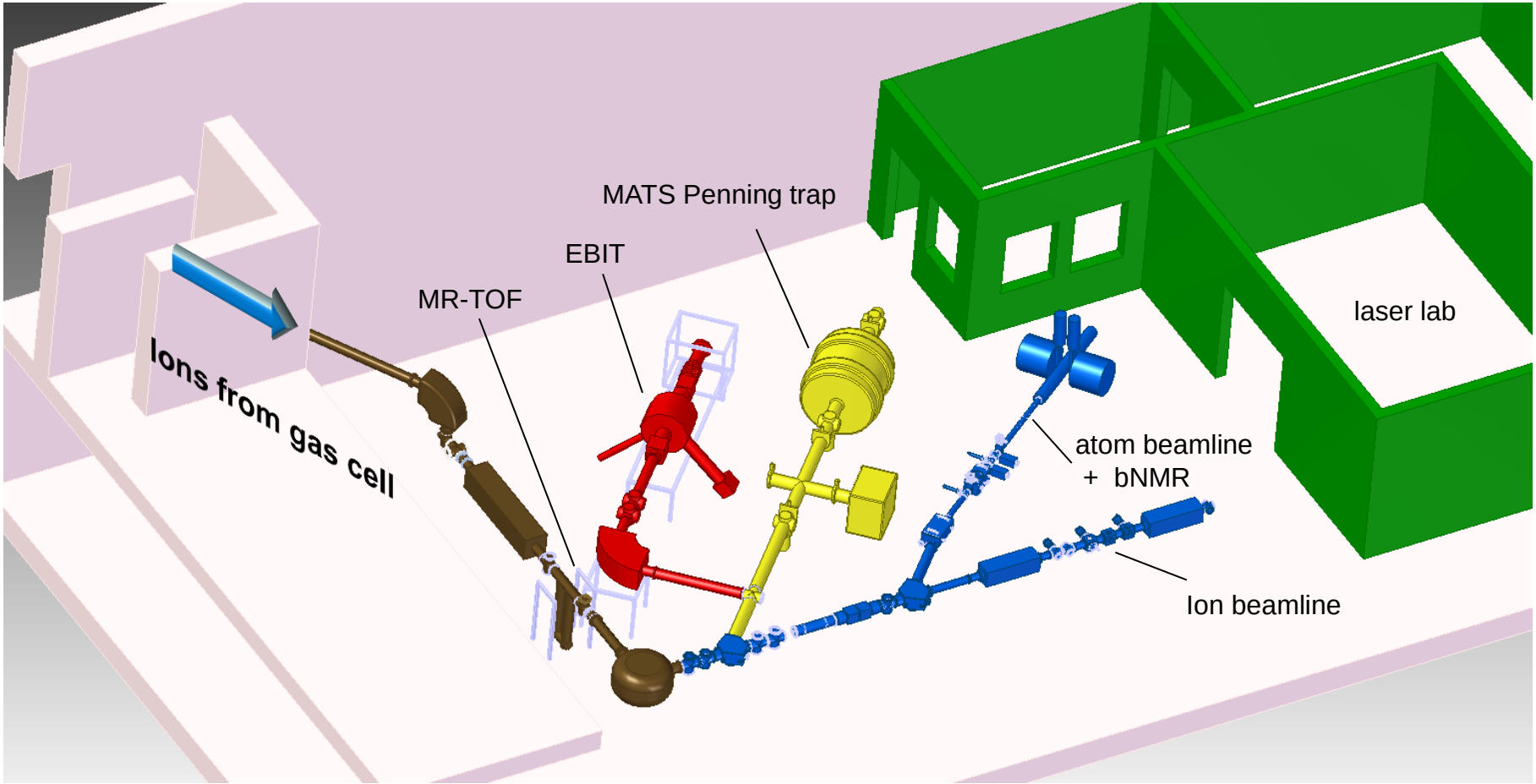
- LaSpec at FAIR
- TRIGALASER, the LaSpec atom beamline
- Bridging the gap: nuclear charge radius measurement of ^{8}B
- Preparatory studies: resonant laser ionization of ^{10,11}B
- And afterwards: collinear laser spectroscopy at CARIBU
- Summary

LaSpec – Current Layout



MATS & LaSpec TDR: D. Rodriguez, K.Blaum and W. Nörtershäuser, EPJ 183 (2010) 1-124

Nuclear Ground State Properties

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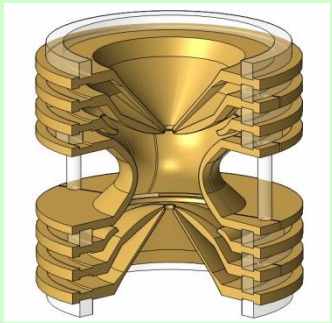
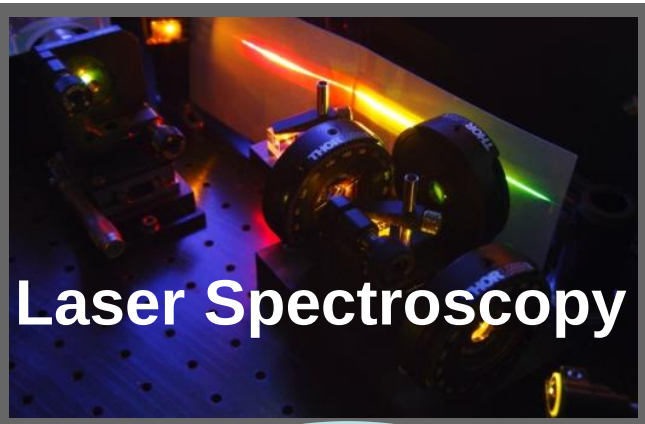
Mass Spectrometry





nuclear binding energy

ground state properties of exotic nuclei

spectroscopic quadrupole moment

magnetic dipole moment

nuclear spin

nuclear charge radius

LaSpec Atom Beamline: the TRIGA-LASER Setup

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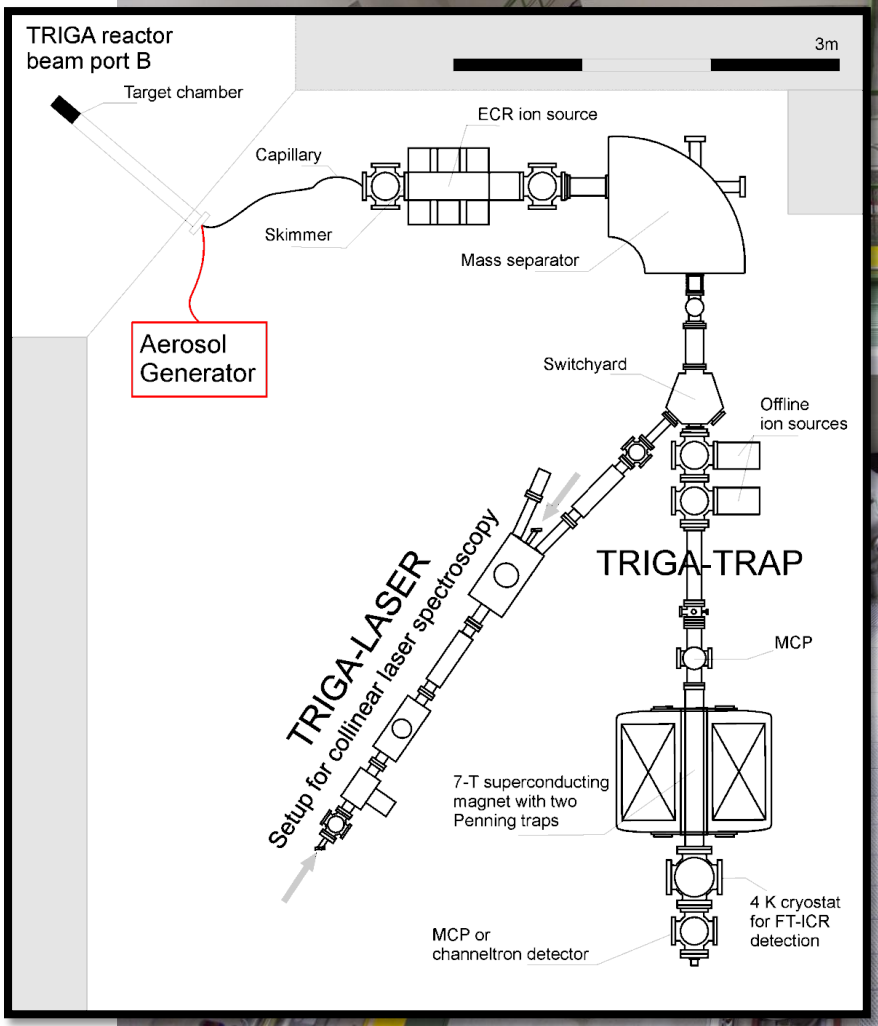

TRIGALASER: a Summary

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- LASPEC atom beamline: setup started in 2008[1]
- Offline commissioning with Rb- atoms and Ca- ions[2]
- Strong Python-based data acquisition (TILDA) and experiment control systems (TRITON) have been developed and are spread among other experiments (COLLAPS@CERN and ALIVE@TUD)
- 4 PHD theses (2 in progress) and 5 Diploma theses
- potential of TRIGALASER experiment has been exploited -> new challenges to bridge the gap to „FAIR Day 1 experiments“

[1]Ketelaer et al., Nucl. Instr. Meth. A 594 (2008) 162

[2]Gorges et al., J. Phys. B 48 (2015) 245008

Bridging the Gap: Beamline Exchange Program

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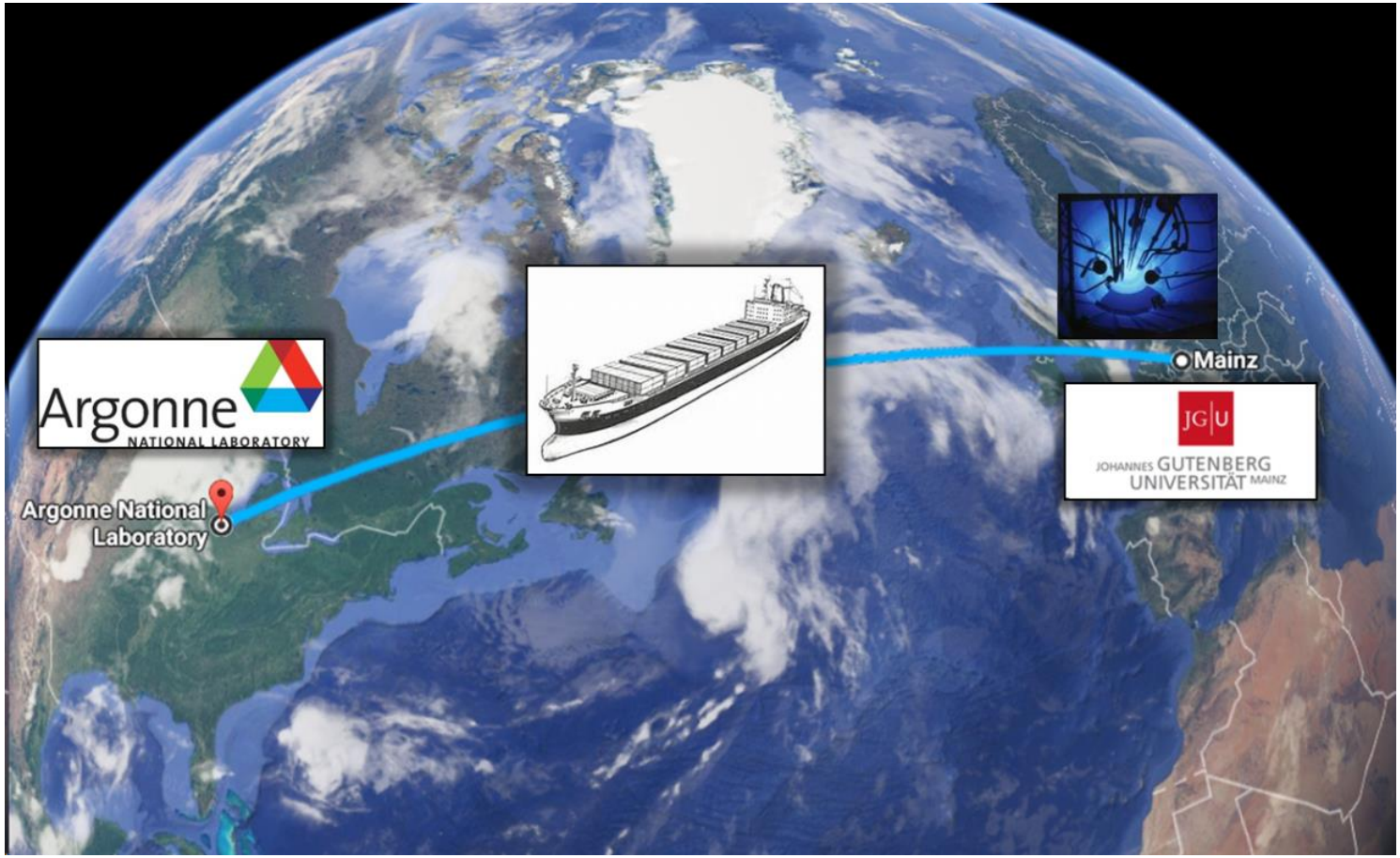

Nuclear Charge Radius of ^{8}B – a Proton Halo?

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- weakly bound proton: **0.13MeV** separation energy
- large quadrupole moment: **Q(^{8}B)=49mb** mirror nucleus: Q(^{8}Li)=33mb
- break-up reaction on ^{8}B: longitudinal momentum distribution of ^{7}Be **much narrower** than expected
  -> wider spatial distribution of proton

A	$T_{1/2}$ (ms)	I^p
8	770	2+
10	stable	3+
11	stable	3/2-
12	20,4	1+
13	17,4	3/2-
14	13,8	2-
15	10,3	3/2-
17	5,1	(3/2-)

VOLUME 69, NUMBER 14 PHYSICAL REVIEW LETTERS 5 OCTOBER 1992

Proton Halo of ^{8}B Disclosed by Its Giant Quadrupole Moment

T. Minamisono,[1] T. Ohtsubo,[1] I. Minami,[1] S. Fukuda,[1] A. Kitagawa,[1],[a] M. Fukuda,[1] K. Matsuta,[1] Y. Nojiri,[1] S. Takeda,[2] H. Sagawa,[3] and H. Kitagawa[4]
[1]*Department of Physics, and Laboratory of Nuclear Studies, Faculty of Science, Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560, Japan*
[2]*Department of Chemistry, Faculty of Science, Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560, Japan*
[3]*Department of Physics, Faculty of Science, The University of Tokyo, 7-3-1 Hongou 7-3-1, Bunkyo, Tokyo 113, Japan*
[4]*Research Center for Nuclear Physics, Osaka University, 10-1 Mihogaoka, Ibaraki, Osaka 567, Japan*
(Received 29 May 1992)

The quadrupole mor
=68.3 ± 2.1 mb by us
Cohen-Kurath shell mo
protons in ^{8}B carry mor
ly well by the proton ha
evidence for the existen

PACS numbers: 21.10.Ky

Nuclear properties that deper
enhanced and clearly observed in
in those nuclei located near the
lines in the mass chart. One of
of those nuclei is the radius of t
bution. For example, from the n
tion cross sections by use of a hi

Z. Phys. A 350, 283–284 (1995)

Short note

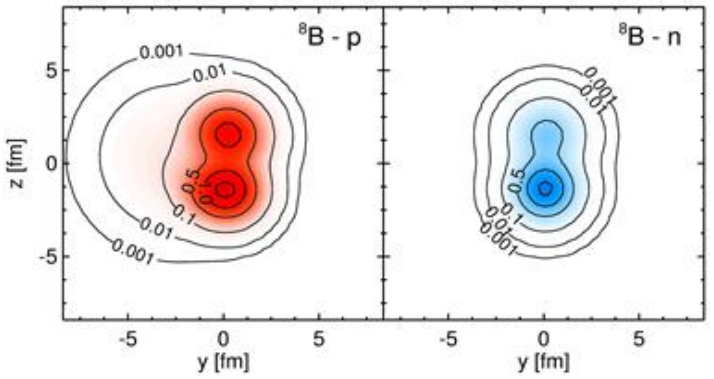
Observation of a proton halo in ^{8}B

W. Schwab[1], H. Geissel[1], H. Lenske[2], K.-H. Behr[1], A. Brünle[1], K. Burkard[1], H. Irnich[1], T. Kobayashi[3], G. Kraus[1], A. Magel[4], G. Münzenberg[1], F. Nickel[1], K. Riisager[5], C. Scheidenberger[1], B.M. Sherrill[6], T. Suzuki[1], B. Voss[1]
[1] Gesellschaft für Schwerionenforschung mbH, Planckstrasse 1, D-64291 Darmstadt, Germany
[2] Institut für Theoretische Physik, Universität Gießen, Heinrich-Buff-Ring 16, D-35392 Gießen, Germany
[3] RIKEN, 2-1 Hirosawa, Wako, Saitama 351-01, Japan
[4] II. Physikalisches Institut der Universität Gießen, Heinrich-Buff-Ring 16, D-35392 Gießen, Germany
[5] Institute of Physics and Astronomy, Arhus University, DK-8000 Aarhus C, Denmark
[6] Michigan State University, East Lansing, MI 48824, USA

ZEITSCHRIFT FÜR PHYSIK A

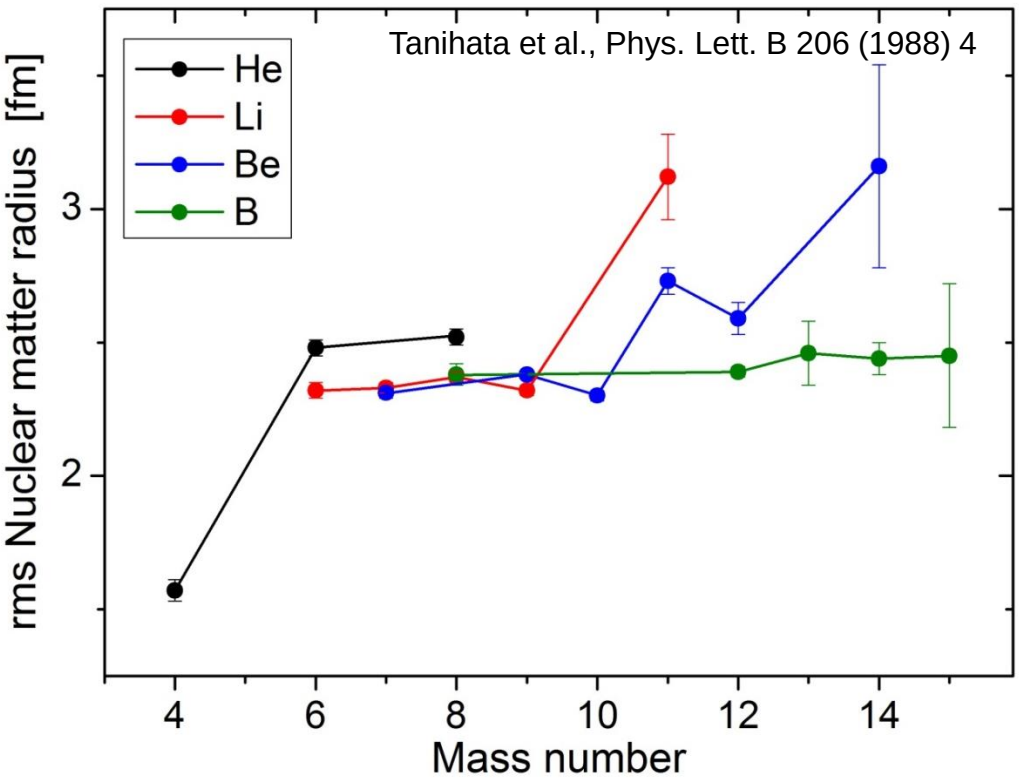
Received: 8 December 1994

Abstract. The longitudinal momentum distribution of ^{7}Be was measured after the break-up reaction of ^{8}B in C, Al, and Pb targets were used at the central and at the final focal plane for momentum and cross-section measurements, respectively. The fields of the first



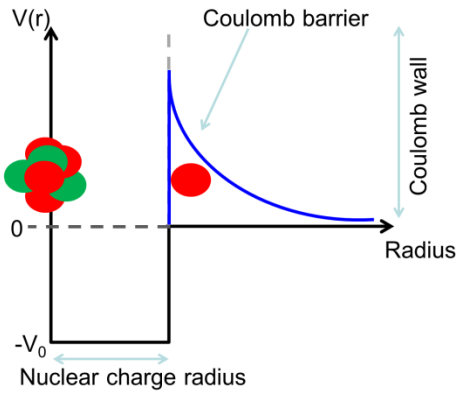
FMD calculations
T. Neff (GSI)

Nuclear Charge Radius of ^{8}B – a Proton Halo?



- Coulomb barrier suppresses large radius tail of wave function

-> effect on matter radius not resolved



- Nuclear charge radius might exhibit a kink at A=8

Isotope Shift – A Challenging Mass Region

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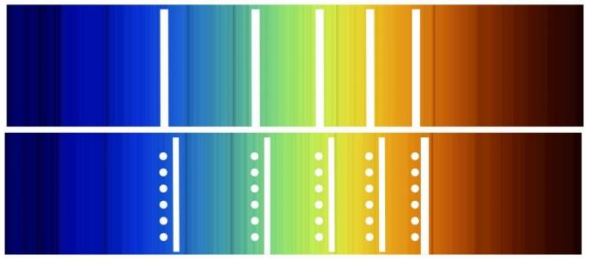
The energy levels are shifted in different isotopes

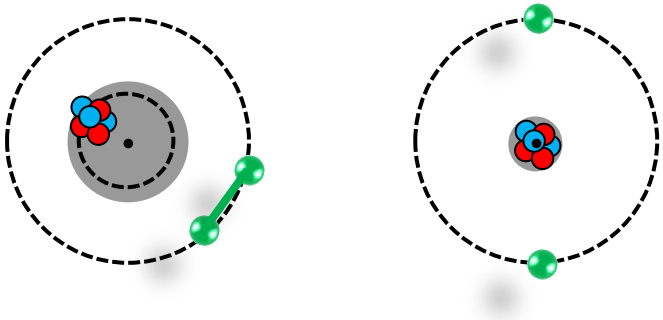
$$\delta\nu_{IS} = \delta\nu_{MS} + \delta\nu_{FS}$$
$$\| $$
$$F_{el}\delta\langle r_c{}^2\rangle$$



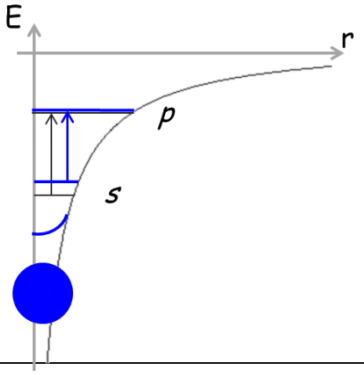
$\delta\nu_{MS} \approx 35$ GHz
$\delta\nu_{FS} \approx 10$ MHz/fm^2

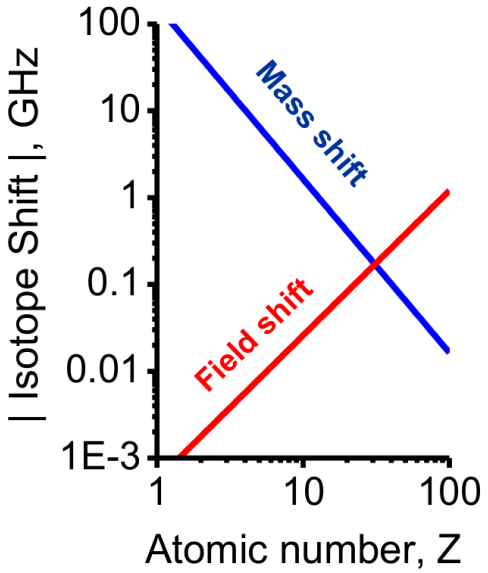
relativistic QED calculations:
up to 5e$^-$ system (Puchalski et al. Phys. Rev. A92, 062501 (2015))

mass shift: nuclear motion around center of mass



field shift: finite size of the nucleus





ATLAS @ ANL

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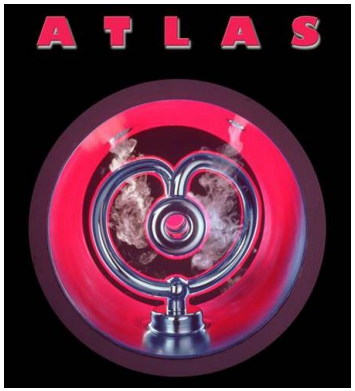
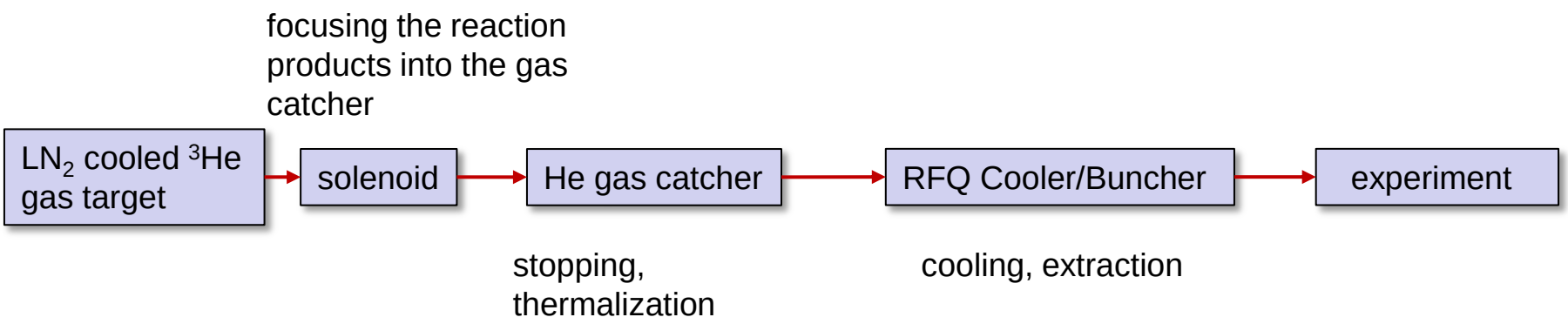


ATLAS

Argonne Tandem Linac Accelerator System

^{8}B Production

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



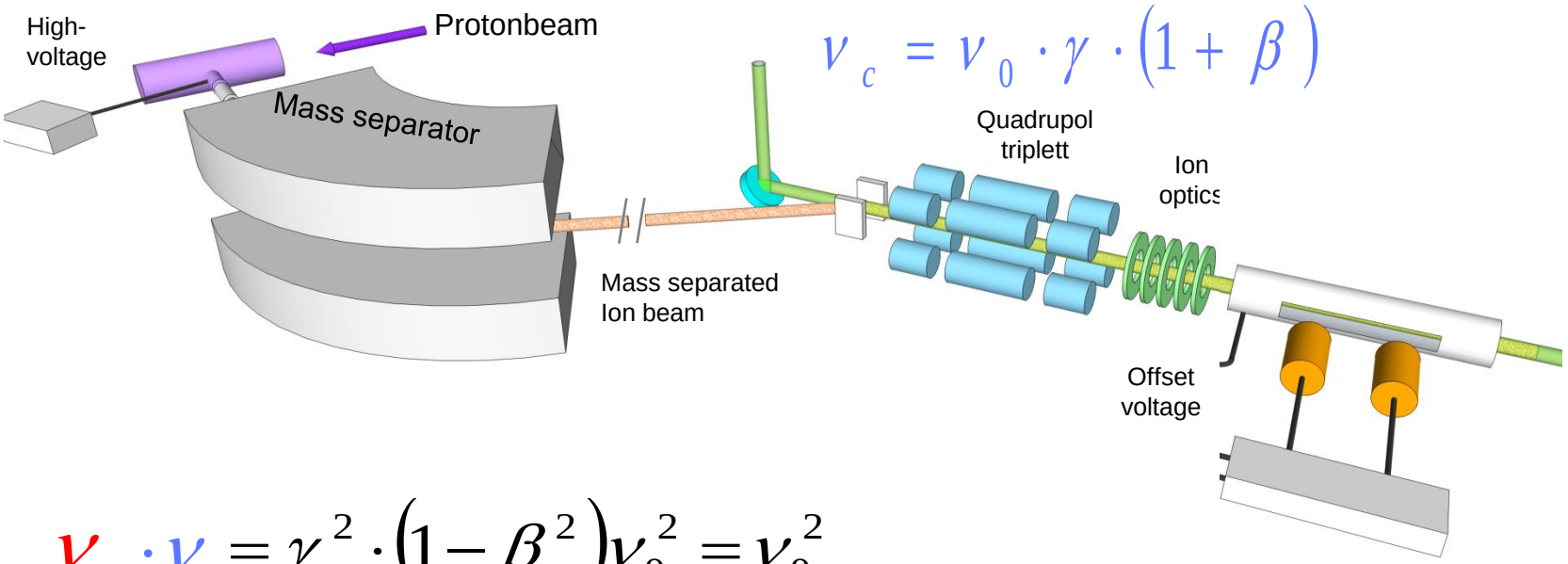
(rough) estimates:
20 ^{8}B / pnA
x 300 pnA (after intensity upgrade)
x 5 upgrades in gas catcher (purity, cooling)
= 30 000 ^{8}B/s produced

+charge exchange and spectroscopic efficiency

Be12 run @ ISOLDE:
2000 ^{12}Be/s produced

→4 days of data taking

Combined Collinear and Anti-collinear Spectroscopy



$$\nu_c = \nu_0 \cdot \gamma \cdot (1 + \beta)$$

$$\nu_a \cdot \nu_c = \gamma^2 \cdot (1 - \beta^2)\nu_0^2 = \nu_0^2$$

cancel out ß (=voltage) dependency

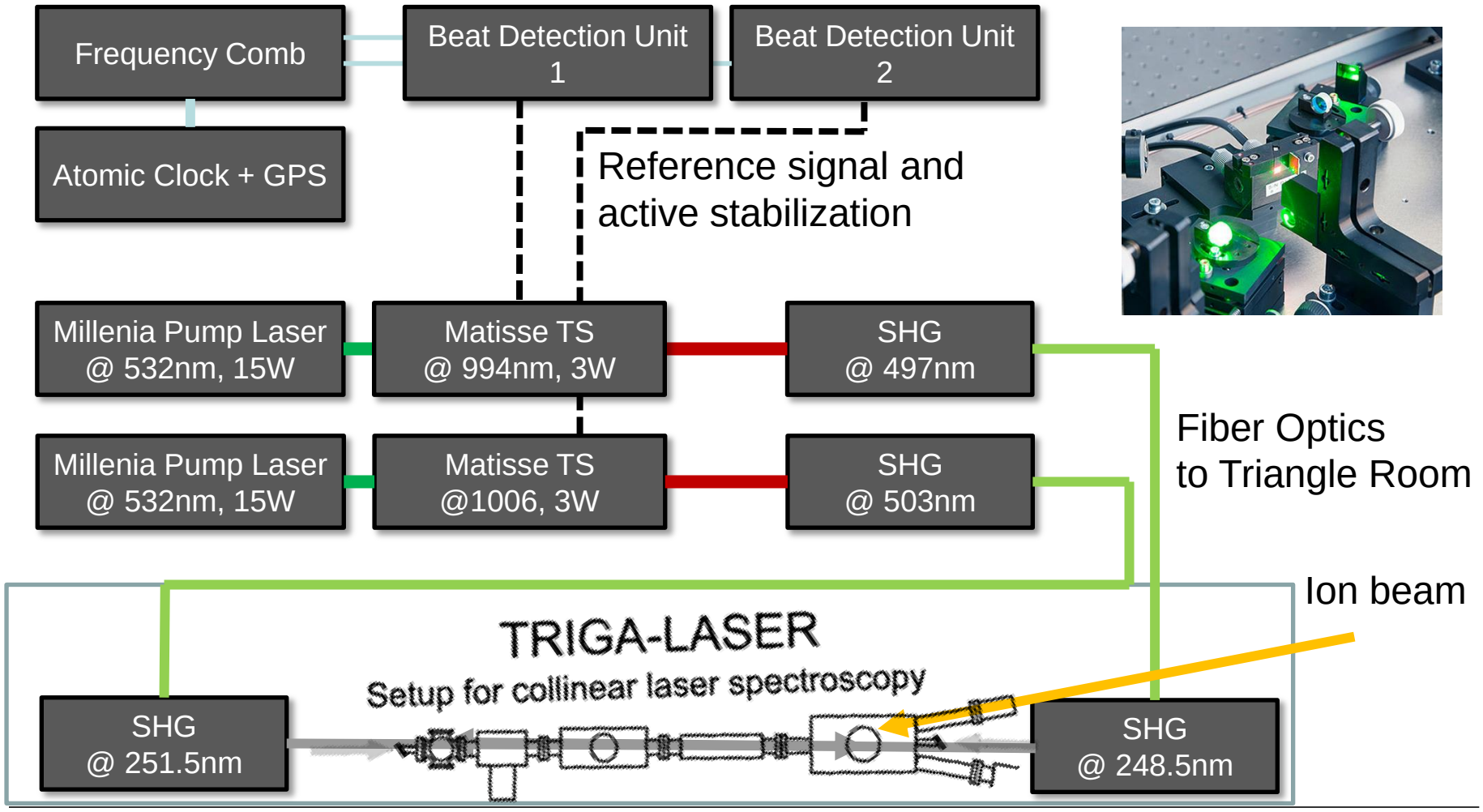
$$\nu_a = \nu_0 \cdot \gamma \cdot (1 - \beta)$$

Requirements:

- two independent laser systems
- **measure absolute frequencies**
- accuracy: $\Delta\nu/\nu < 10^{-9}$

A. Krieger et al, Phys. Rev. Lett. **108**, 142501 *(2012)*

Laser System



The BOR8 Timeline

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When	Where	What
Summer 2016	TU Darmstadt	• Offline measurement (Test of Theory)
Fall 2016	ANL	• Boron-8 production tests
Until Spring 2017	Uni Mainz	• pack and send LaSpec atom beamline to ANL
Spring 2017	ANL	• Setup beamline at ANL
Afterwards	ANL / TUD	• Setup laser system • Online runs (Testing and data taking)

Offline Studies: Resonant Ionization of ^{10,11}B

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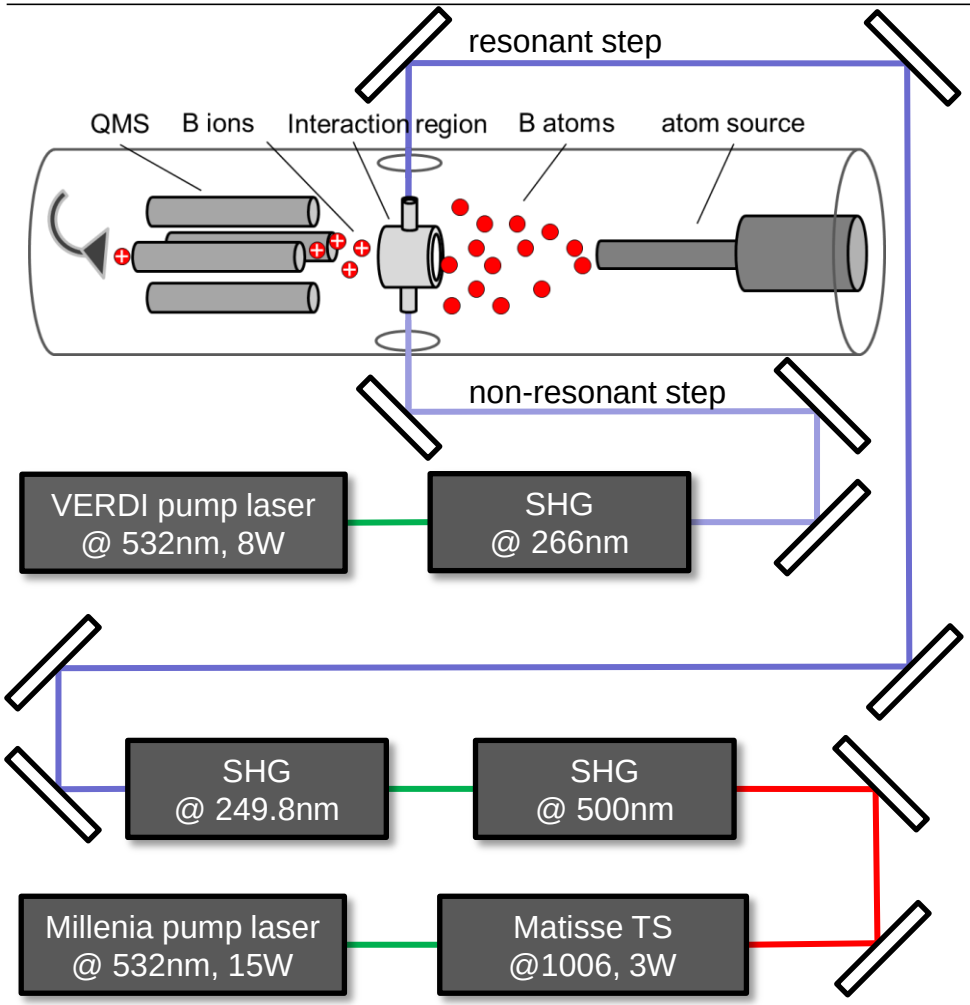
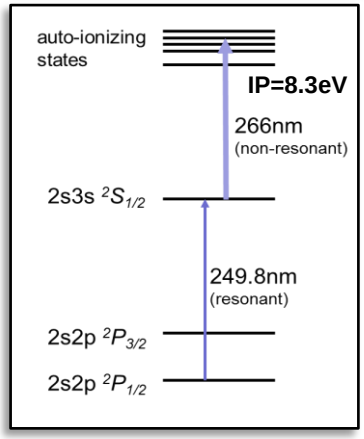
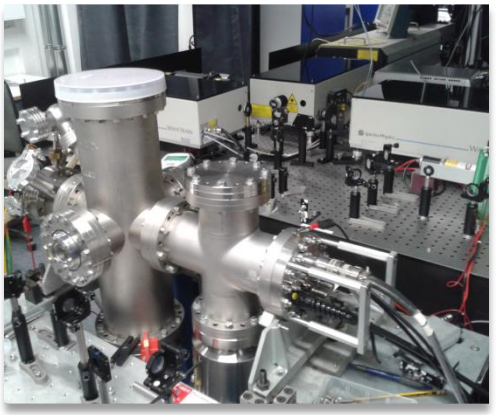


isotope	%	I
^{10}B	19.9	3
^{11}B	80.1	3/2





setup at TU Darmstadt

Test of Theoretical Predictions

$$\delta\nu^{AA'} = \boldsymbol{M}\,\frac{A - A'}{AA'} + \boldsymbol{F} \times \delta\langle r_c{}^2\rangle$$

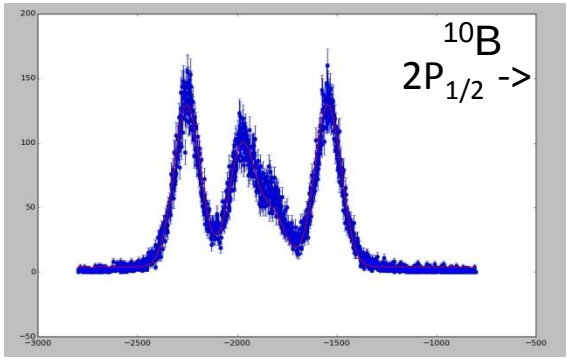
from theory (from elastic electron scattering)

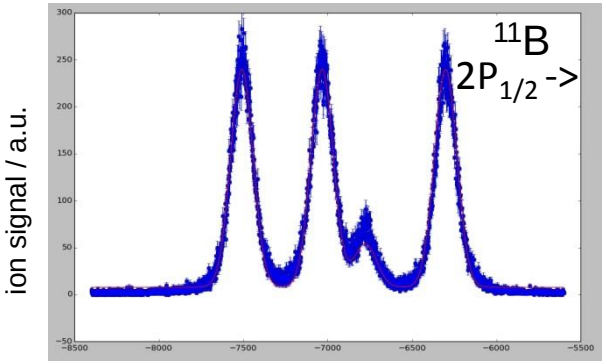
relativistic QED calculations:
up to 5e$^-$ system (Puchalski et al. Phys. Rev. A92, 062501 (2015))

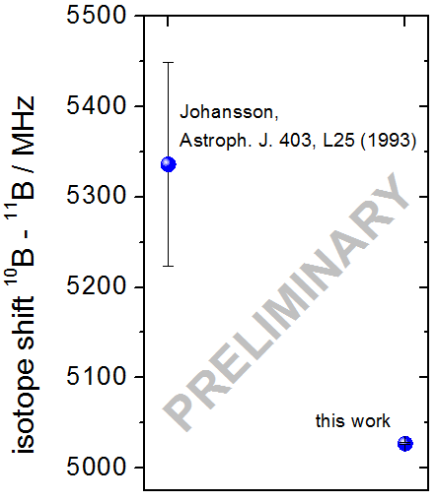
- Find the best optical transition (technical)
- Test bed for atomic theory: transition frequency, mass shift factor, field shift factor, hyperfine parameters A and B
- Comparison with elastic e$^-$ scattering data

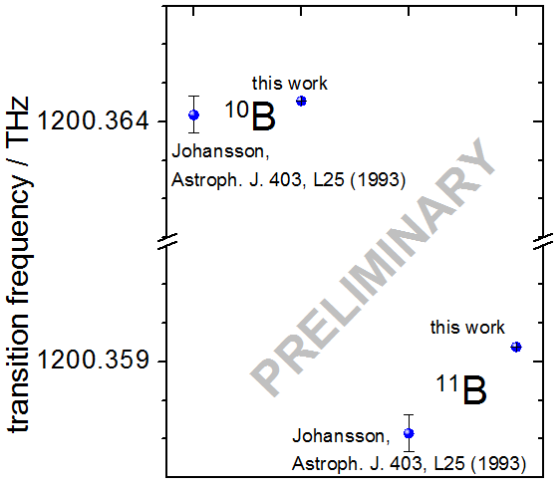
-> viability for extraction of the ^{8}B charge radius is tested

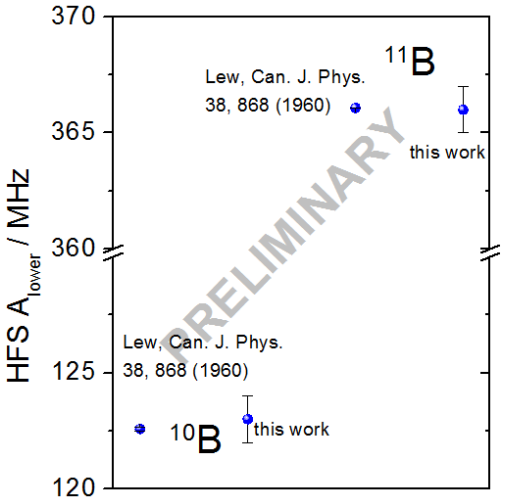
Preliminary Results











And after ^{8}B? CARIBU!

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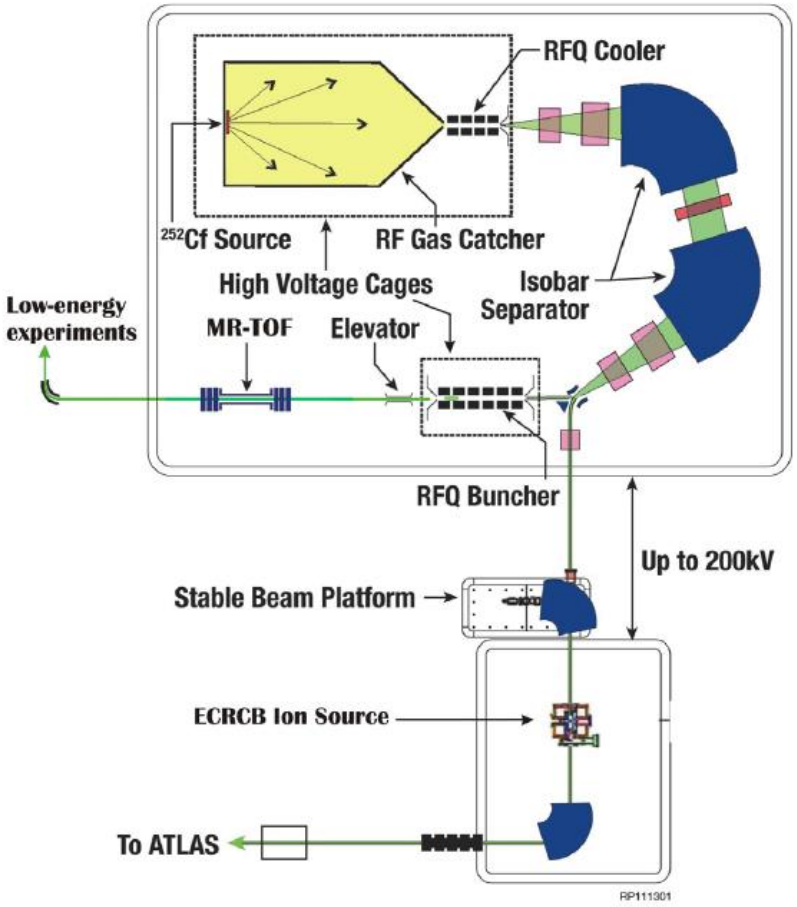
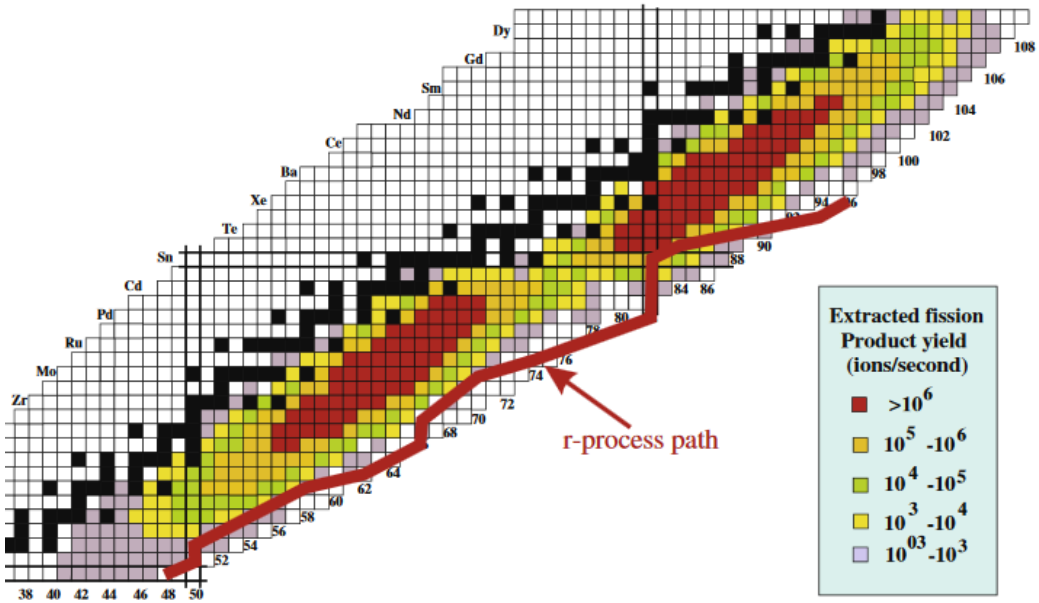


Californium Rare Isotope Breeder Upgrade

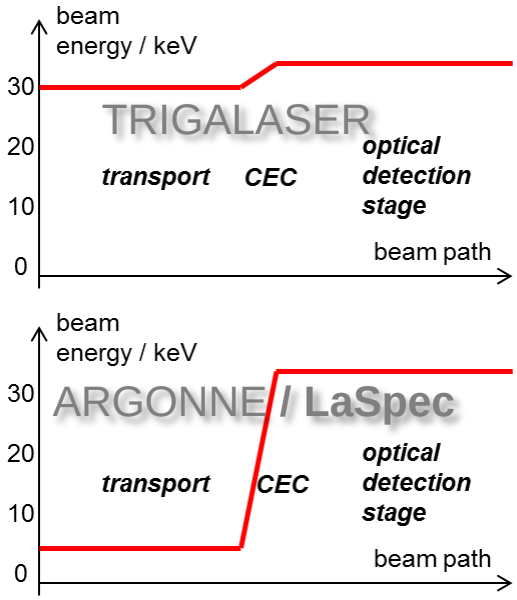
- 1 Ci ^{252}Cf spontaneous fission source
- 10^{9} fissions/s
- extraction time 20-30ms



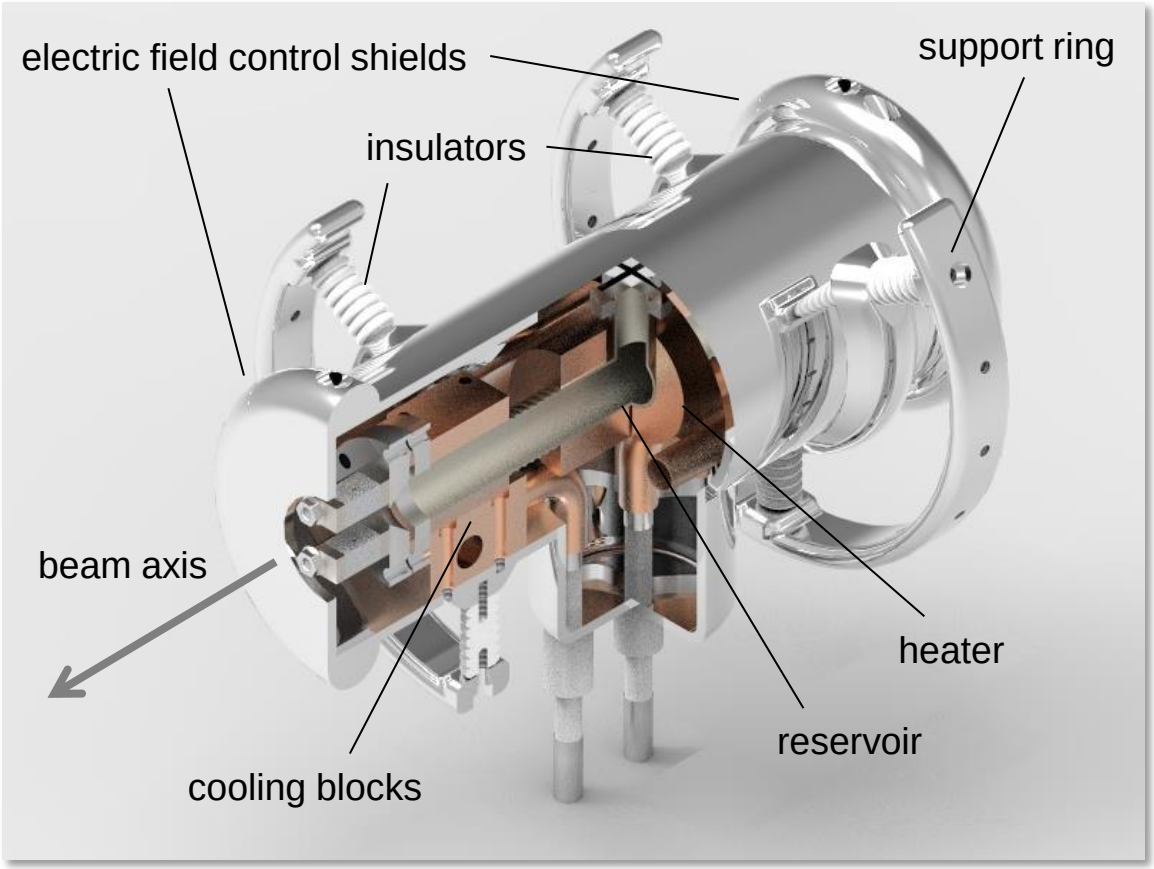
G.Savard et al. Nucl. Instr. Meth. ***B*** *(2016), http://dx.doi.org/10.1016/j.nimb.2016.02.050*

G.Savard et al. Nucl. Instr. Meth. ***B 266*** *(2008), 4086-4091*

New Charge Exchange Cell

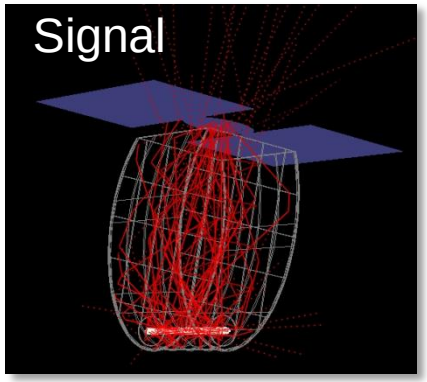


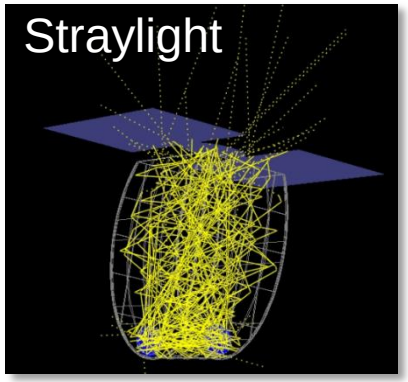
- post acceleration to 30keV
- high-temperature operation (450°C) for Mg charge exchange

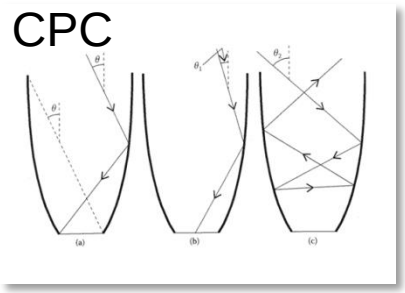


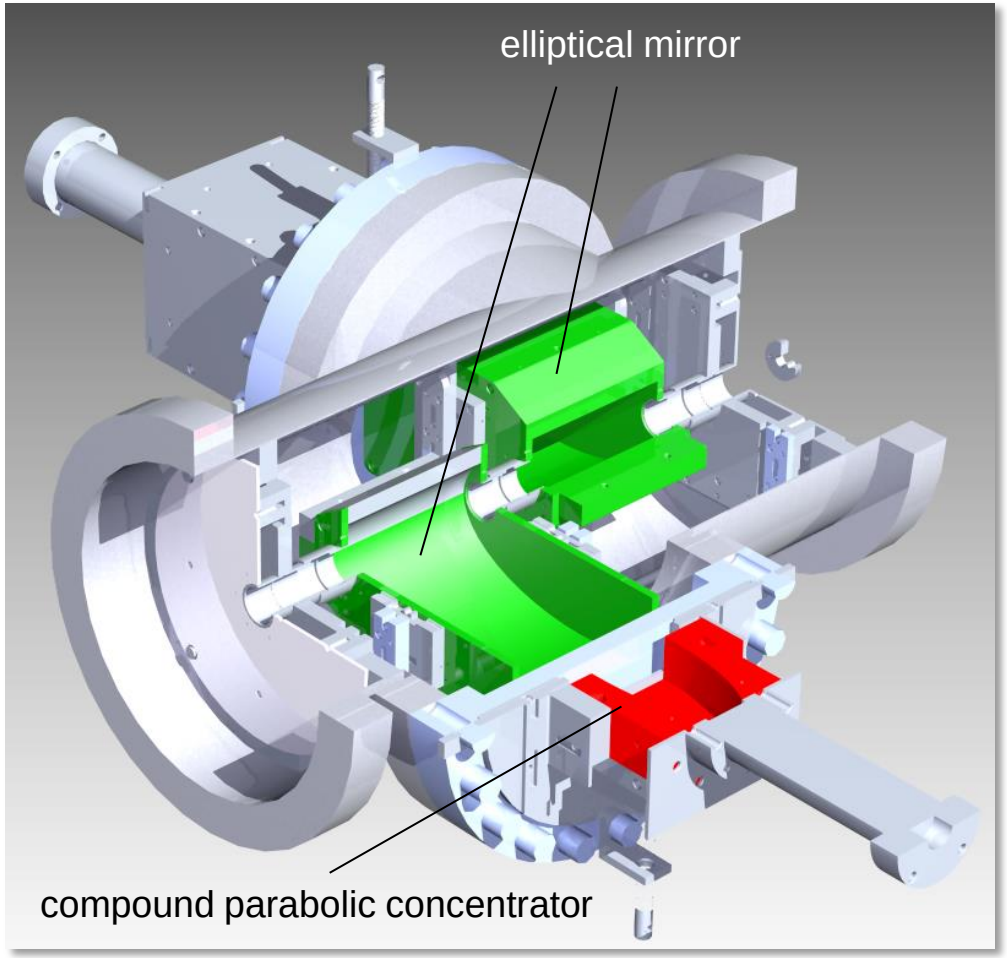
New Optical Detection Unit

- Elliptical collection mirror
- comp. parabolic concentrator (CPC)
- can be floated to 30kV for ion spectroscopy









Laser Spectroscopy of Refractory Elements

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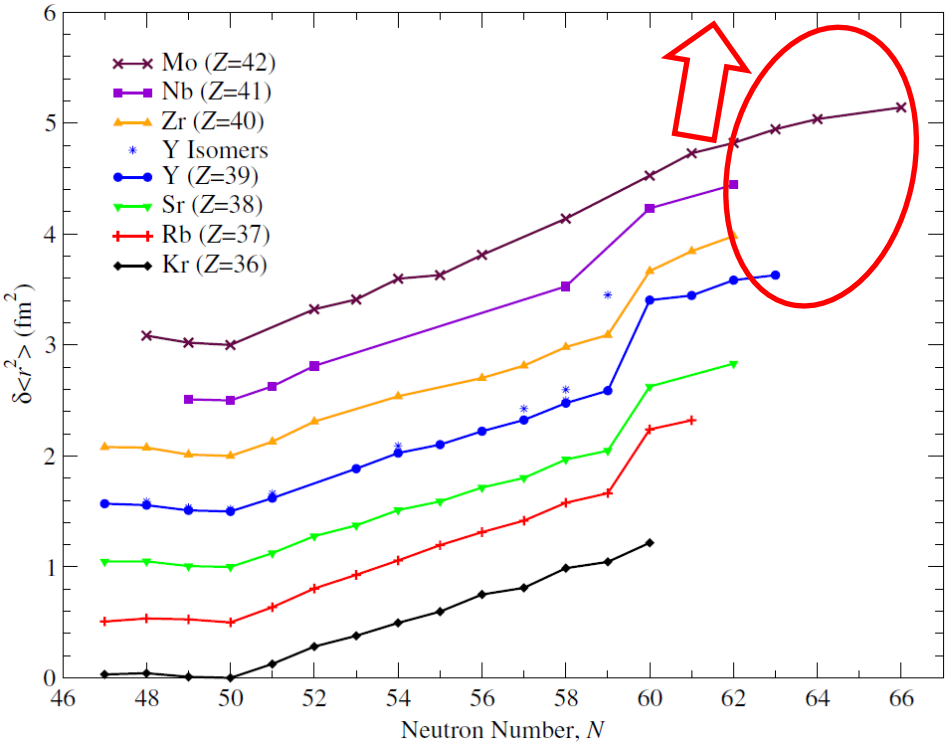
- Install LaSpec atom beamline at CARIBU after ^{8}B experiment
- Detection limit with fluorescence detection: 10^4 ions/s

→ study region beyond the sudden deformation at N=60 and Z>38

- extend the region of known nuclear charge radii and moments by 1-2 isotopes per isotopic chain



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

Summary

TECHNISCHE UNIVERSITÄT DARMSTADT

- LaSpec will allow measurements of nuclear ground state properties: spins, moment, (changes in) charge radii
- LaSpec atom beamline already exists at TRIGA Mainz and will be moved to ANL beginning of next year
- Charge radius measurements of ^{8}B planned, prestudies ongoing at TU Darmstadt
- Before moving in to the LEB hall: LaSpec atom beamline will be operated at CARIBU – FAIR Phase-0

Acknowledgements

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Guy Savard
Kevin Siegl

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Wilfried Nörtershäuser
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Christian Gorges
Simon Kaufmann
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