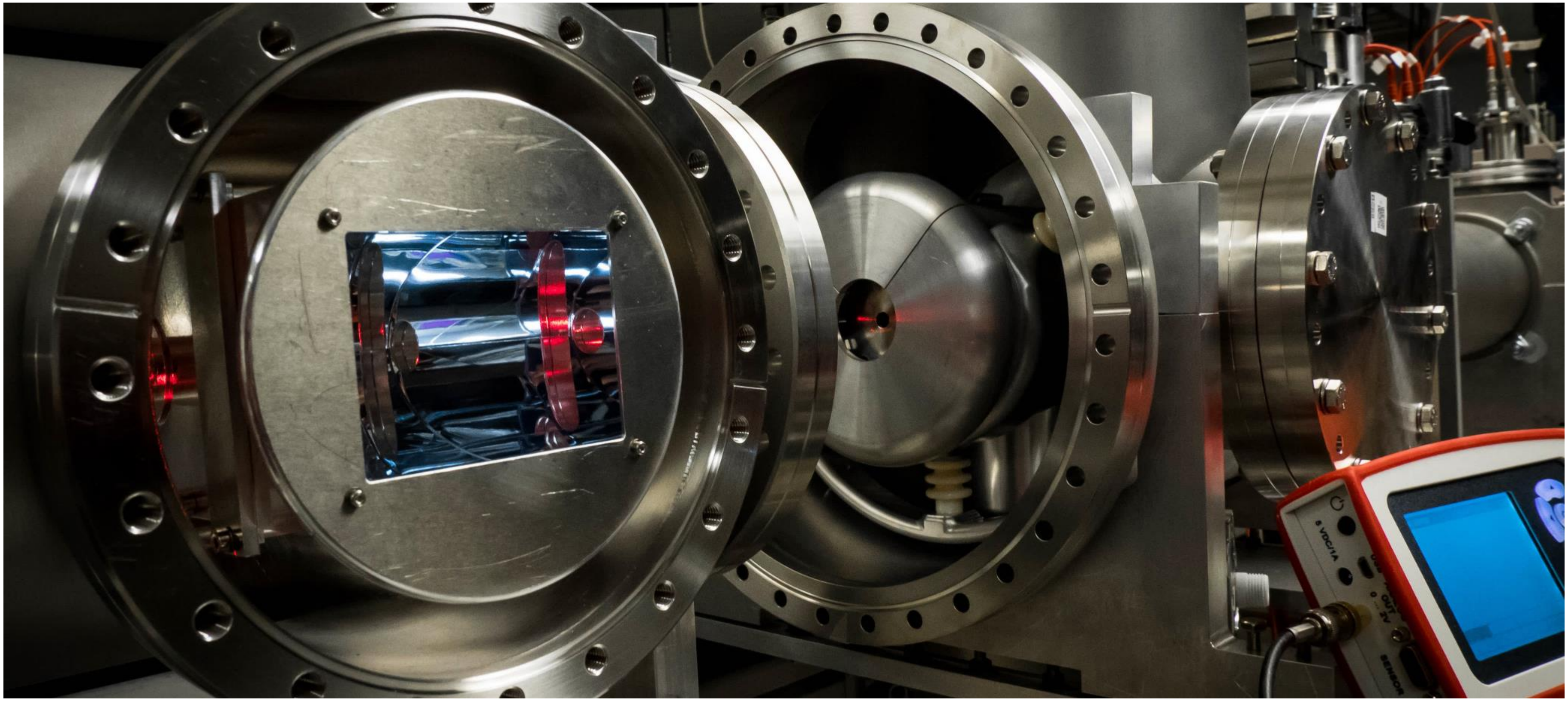
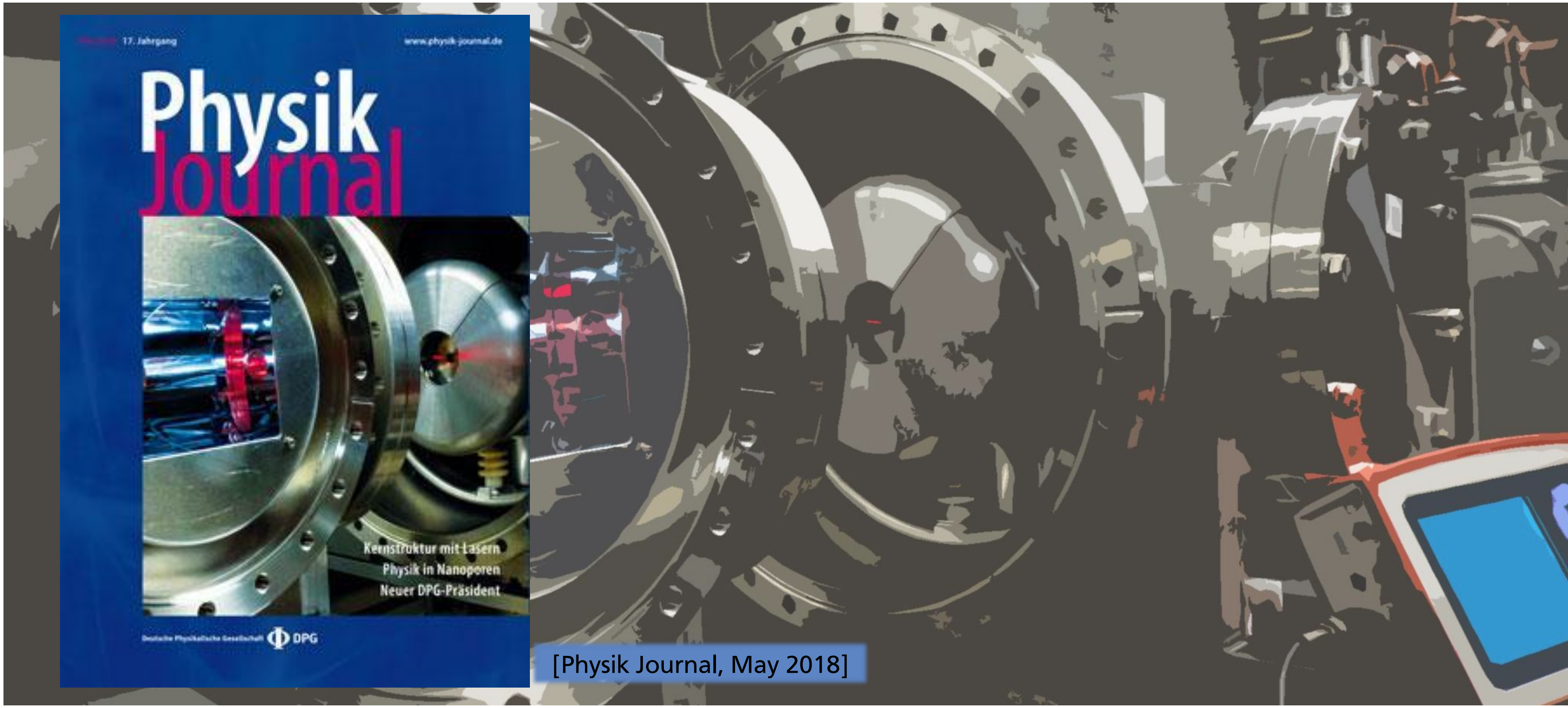
Fluorescence Detection for Laser Spectroscopy

BERNHARD MAAß



Fluorescence Detection for Laser Spectroscopy

Bernhard Maaß



[Physik Journal, May 2018]

The publication

TECHNISCHE UNIVERSITÄT DARMSTADT

nature physics

LETTERS

https://doi.org/10.1038/s41567-019-0416-9

Proton superfluidity and charge radii in proton-rich calcium isotopes

A. J. Miller[1,2], K. Minamisono[1,2*], A. Klose[3], D. Garand[1], C. Kujawa[3], J. D. Lantis[1,4], Y. Liu[5], B. Maaß[6], P. F. Mantica[4,7], W. Nazarewicz[2,7], W. Nörtershäuser[6], S. V. Pineda[3], P.-G. Reinhard[8], D. M. Rossi[6], F. Sommer[6], C. Sumithrarachchi[1], A. Teigelhöfer[9] and J. Watkins[1]

One of the most important global properties of the atomic nucleus is its size. Experimentally determined nuclear charge radii carry unique information on the nuclear force and complex dynamics of protons and neutrons moving inside the nucleus. The intricate behaviour of charge radii along the chain of Ca isotopes, including the unexpectedly large charge radius of neu-

Recent advances in radioactive beam production and manipulation techniques, namely fast in-flight production and separation[15] followed by gas stopping[16], have made it possible to develop good-quality, high-rate beams of short-lived, proton-rich Ca isotopes, including ^{36}Ca with a half-life of $T_{1/2} = 102(2)$ ms (ref. [17]), which is sufficient for precise laser spectroscopy measurements. This pro-

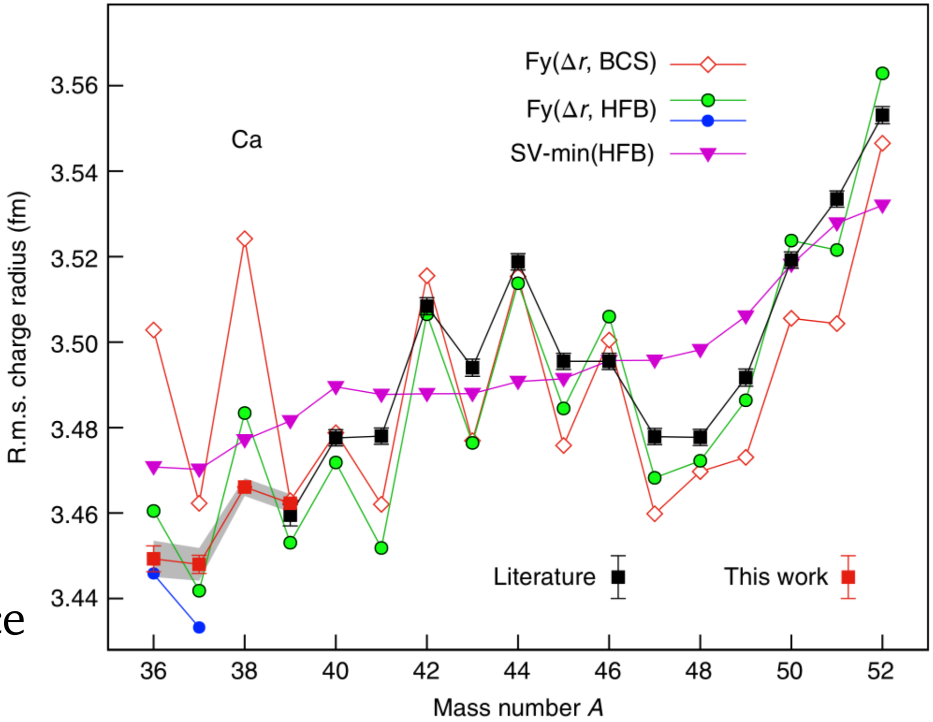
Received: 10 August 2018
Accepted: 17 December 2018
Published online: 11 February 2019

LASER SpHERe

Proton superfluidity and charge radii in proton-rich calcium isotopes

TECHNISCHE UNIVERSITÄT DARMSTADT

- Close to the continuum, *proton pairing* impacts the charge radius
- Continuum states have non-zero occupation probabilities
- Analog to Cooper pairs in metallic superconductors / superfluids
- New Fayans functionals that include more elaborate pairing terms reproduce the charge radii over 16 isotopes



- Also other isotopes, like $^{100-130}$Cd are reproduced with these novel pairing models

LASER SpHERe

Isotope Shift Measurements

- Measure the (relative) transition frequency along an isotopic chain

$$\Delta\nu_{\mathrm{IS}} = \delta\nu_{\mathrm{MS}} - K_{i,f}\left[r_{c,a}^2 - r_{c,b}^2\right]$$

- Calculate (or determine → King Plot) the atomic factors
- Extract the difference in nuclear charge radius

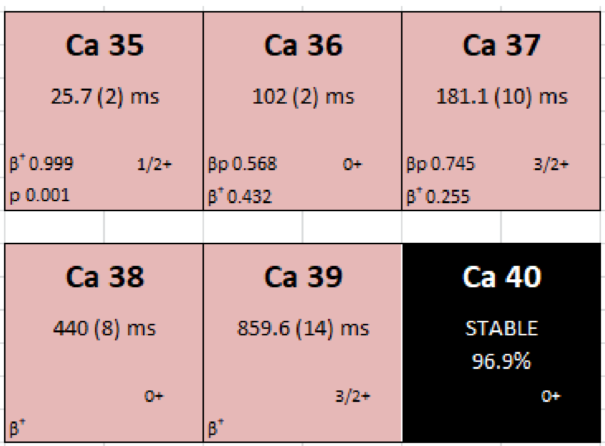


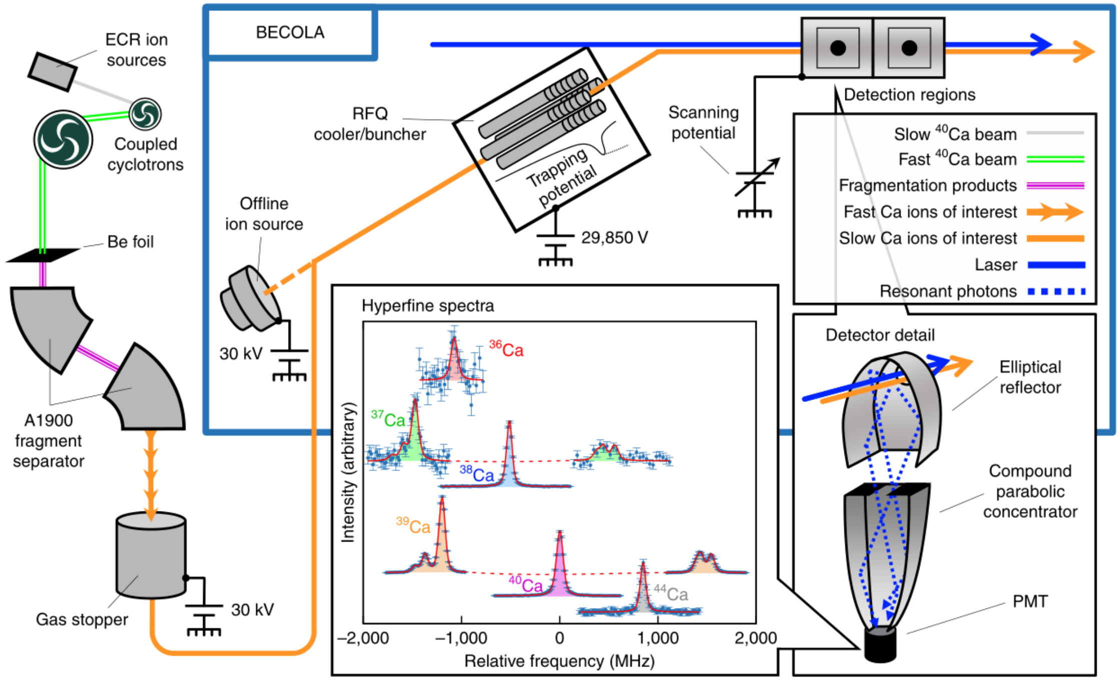
Table 1 | Isotope shifts and deduced differential mean-square charge radii

A	$\delta\nu^{40,A}$ (MHz)	$\delta\langle r^2\rangle^{40,A}$ (fm²)	$T_{1/2}$ (ms)	T_b (ms)	Rate (s⁻¹)
36	−1,073.8 (60)(43)	−0.196 (21)(16)	102	180	50
37	−766.1 (47)(49)	−0.205 (15)(17)	181	330	960
38	−513.1 (3)(17)	−0.0797 (11)(63)	440	220	13,500
39	−230.5 (2)(18)	−0.1060 (7)(64)	859.6	30	60,000

The statistical and systematic errors are given in the first and second parentheses, respectively. The differential m.s. charge radius of ^{39}Ca relative to ^{40}Ca is consistent with the previous value[14] of −0.127(20) fm². The half-life ($T_{1/2}$), bunching period (T_b) and rates at the cooler/buncher for each isotope are also included.

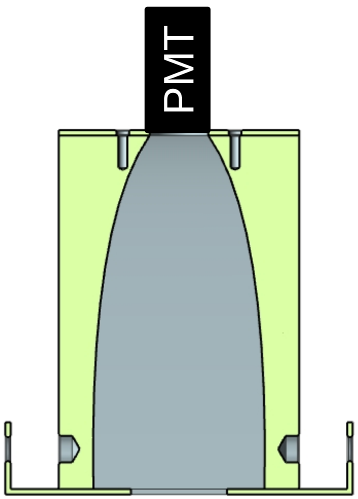
Fluorescence detection spectroscopy

- Production at NSCL, MSU
- Projectile fragmentation on Be foil
- Bunched beam
- Stabilized laser
- Doppler tuning

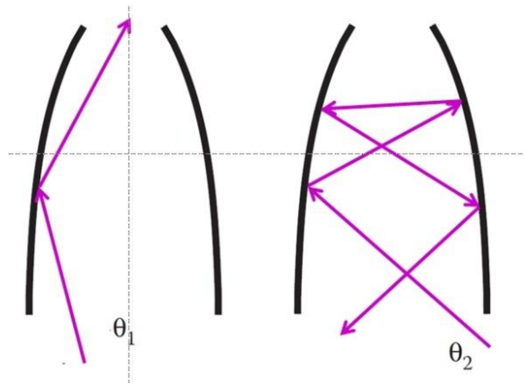


Light collection

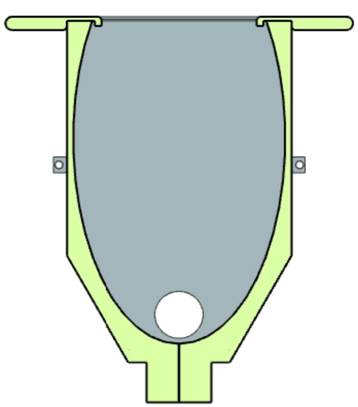
TECHNISCHE UNIVERSITÄT DARMSTADT

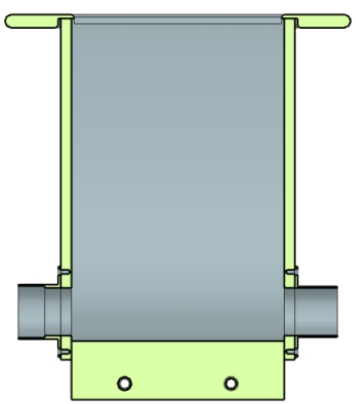


Compound parabolic concentrator (CPC)

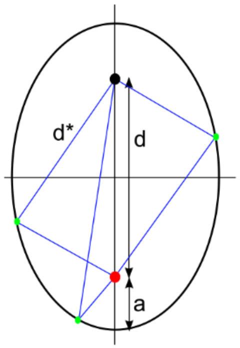


- Only light with angle <θ exits the concentrator
- θ can be choosen by design
- CPCs with 20° and 30° were built





Elliptical mirror (EM)



- light is emitted from one axis and is reflected to second axis.
- light that does not origin on beam axis „prefers“ higher exit angles
- reflection is not „disturbed“ in forward direction
- almost 4π-forwarding of photons.

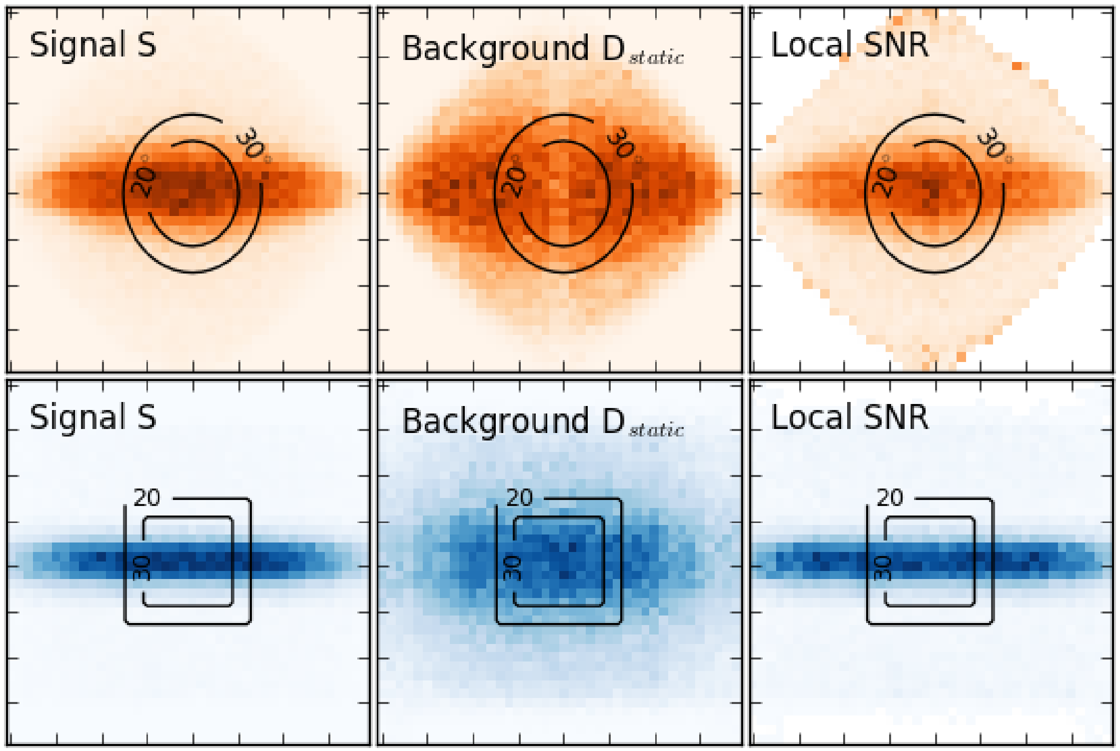
LASER SpHERe

Background light suppression

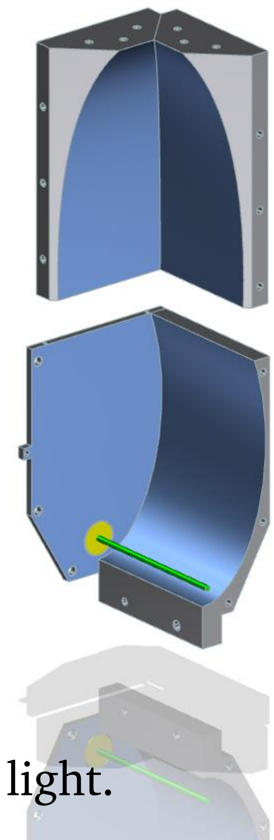
Histograms: Output of elliptical mirror
Contour: Acceptance of CPCs

angular

spatial

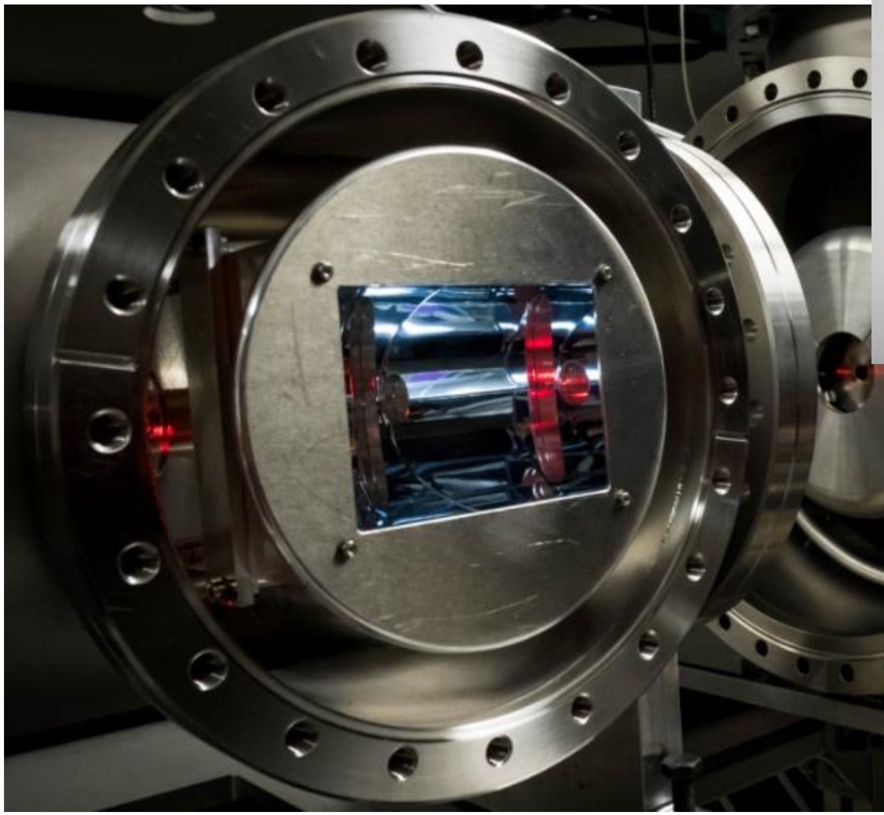
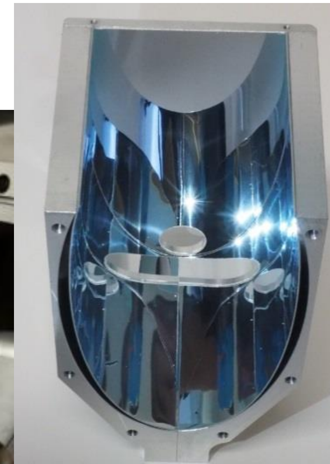
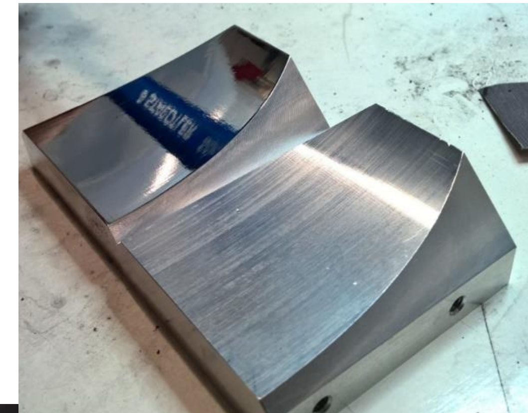
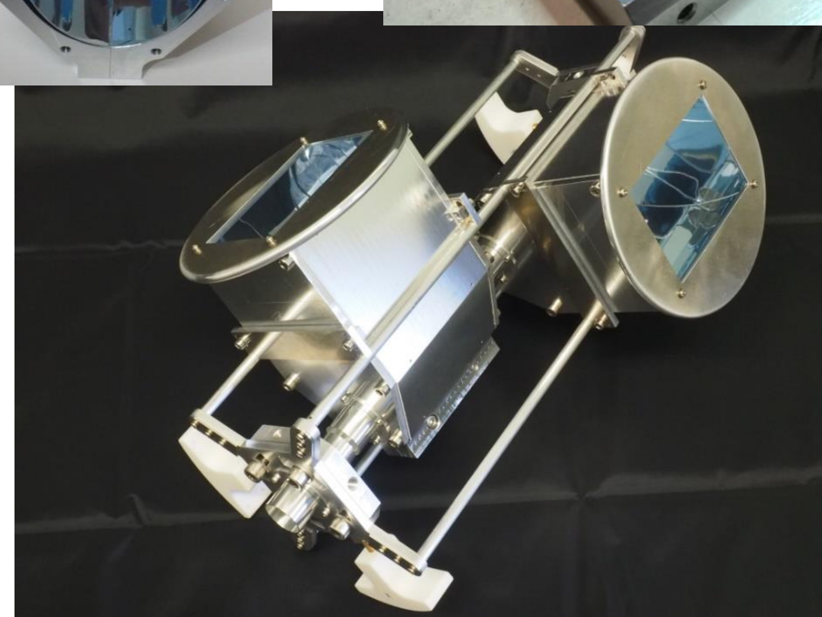


Static Background: yellow disc
Signal: green cylinder



→ Suppression of „static“ BG such as scattered laser light or ambient light.

The detection system at MSU

Performance (for ^8B?)

- Spectroscopy with **30-50 ions per second**!
- ~500 ions per photon

	λ	A_{21}	Rel.
Ca	393nm	$1.47*10^8$	1
B	250nm	$8.4*10^7$	0.15

What does that mean for ^8B?

Spectroscopic efficiency: $B_{12} \sim A_{21}\lambda^3$

Hyperfine structure: 4 peaks (/4)

Collinear/Anticolllinear (/2)

PMT Sensitivity (/2)

Surface Reflectivity at 250nm (/?)

– *under investigation*

~ **3-5k ions per second**

What do we have?

10-15k, but

without molecular breakup (/2-3)

without charge exchange (/2-3)

…

Thank you…

TECHNISCHE UNIVERSITÄT DARMSTADT

A. J. Miller [1,2]
K. Minamisono [1,2]
A. Klose [3]
D. Garand [1]
C. Kujawa [3]
J. D. Lantis [1,4]
Y. Liu [5]
B. Maaß [6]
P. F. Mantica [4,7]
W. Nazarewicz [2,7]
W. Nörtershäuser [6]
S. V. Pineda [3]
P.-G. Reinhard [8]
D. M. Rossi [6]
F. Sommer [6]
C. Sumithrarachchi [1]
A. Teigelhöfer [9]
J. Watkins [1]

Development of the FDR
M. Hammen
K. König
J. Krämer
J. Willmann

1 National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI, USA.
2 Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA.
3 Department of Chemistry, Augustana University, Sioux Falls, SD, USA.
4 Department of Chemistry, Michigan State University, East Lansing, MI, USA.
5 Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA.
6 Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany.
7 Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI, USA.
8 Institut für Theoretische Physik, Universität Erlangen, Erlangen, Germany.
9 TRIUMF, Vancouver, British Columbia, Canada.

This work is supported by the U.S. DOE, Office of Science, Office of Nuclear Physics, under contract DE-AC02-06CH1135, and by the Deutsche Forschungsgemeinschaft through Grant SFB 1245

DFG Deutsche Forschungsgemeinschaft

U.S. Department of Energy | Office of Science

HGS-HIRe for FAIR – Helmholtz Graduate School for Hadron and Ion Research

SFB 1245