ESR test beamtime
4-6 July 2016
Report:
laser cooling & spectroscopy

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GSI Helmholtzzentrum Darmstadt

SPARC laser cooling people:

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([a]auch Uni Mainz, [b]auch TU-Darmstadt, [c] auch HI Jena)

Michael Bussmann, Markus Löser, Ulrich Schramm, Mathias Siebold

Tobias Beck, Gerhard Birkl, Daniel Kiefer, Sebastian Klammes, Benjamin Rein, Sascha Tichelmann, Thomas Walther

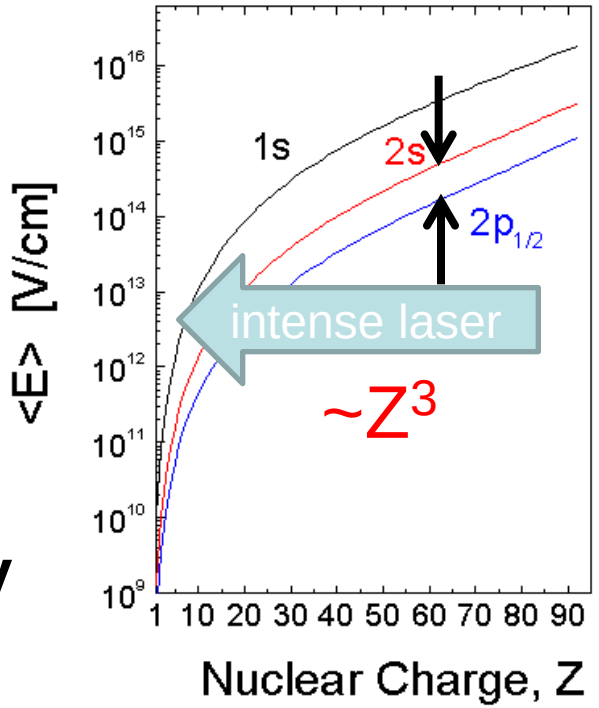
Bang Hai, Zhongkui Huang, Xinwen Ma, Lijun Mao, Jiancheng Yang, Youjing Yuan, Hanbing Wang, Weiqiang Wen, Dacheng Zhang

Axel Buß, Christian Egelkamp, Volker Hannen, Christian Weinheimer, Daniel Winzen

typical		special
light ions	→	heavy ions
low charge states	→	high charge states
low energies	→	high energies

Study simple (few electron) systems to compare theory & experiments.

Tests of QED in extreme electromagnetic fields.
New access to fundamental constants and to nuclear ground state properties.



$E_B \sim 10^5$ eV
$Z\alpha \sim 1$

$E_B \sim 10$ eV
$Z\alpha \sim 10^{-2}$

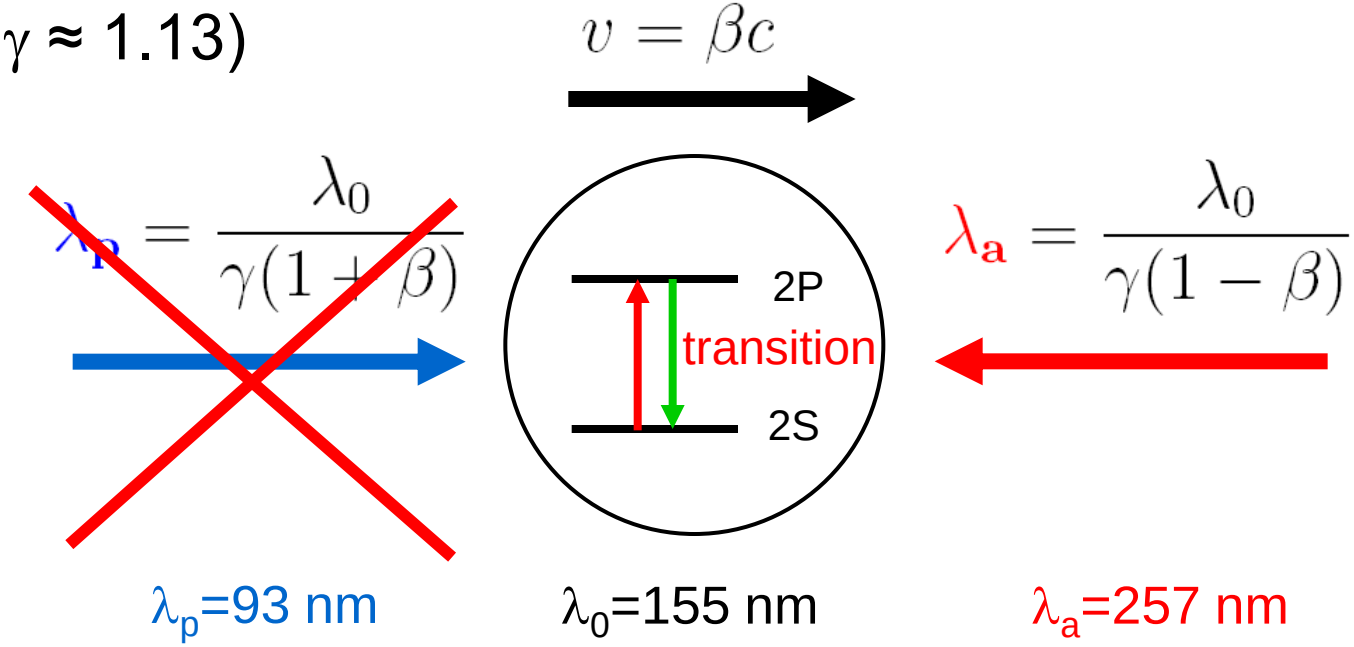
laser spectroscopy & laser cooling

The principle: laser cooling of stored relativistic ions

ESR example:

C^{3+} ion energy ≈ 122 MeV/u

(β ≈ 0.47, γ ≈ 1.13)



The ion absorbs many directional momenta from the photons and decays each time with a random recoil, averaging out to zero.

In our case, the cooling laser force is counteracted by the restoring force of the `*bucket´* when **the ion beam is bunched**.

used laser systems:

cw Ar^+ laser (514 nm) +
1 frequency doubling stage (257 nm)

2004-2006

tuneable cw ECDL (1028 nm) +
fiber amplifier +
2 frequency doubling stages (514 and 257 nm)

TU-Darmstadt

pulsed laser system (1028 nm) +
2 frequency doubling stages (514 and 257 nm)

HZDR Dresden

TU-Darmstadt

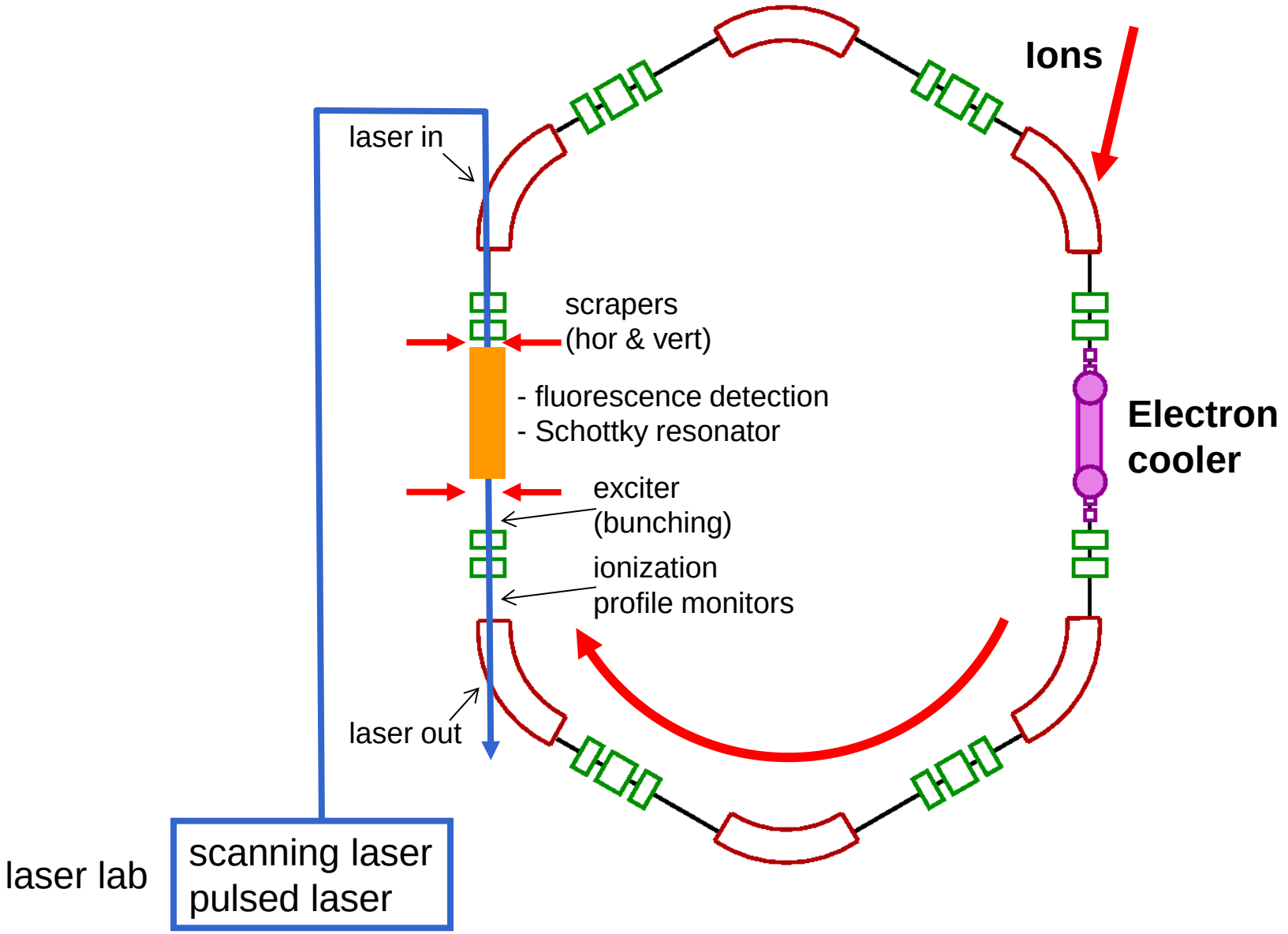
2012-2016

laser beam stabilization system (50 – 100 m length)

See the poster of Hanbing Wang (IMP)

→ test beamtime in April 2016 at CSRe in Lanzhou, China
→ test beamtime at GSI in July 2016 at ESR

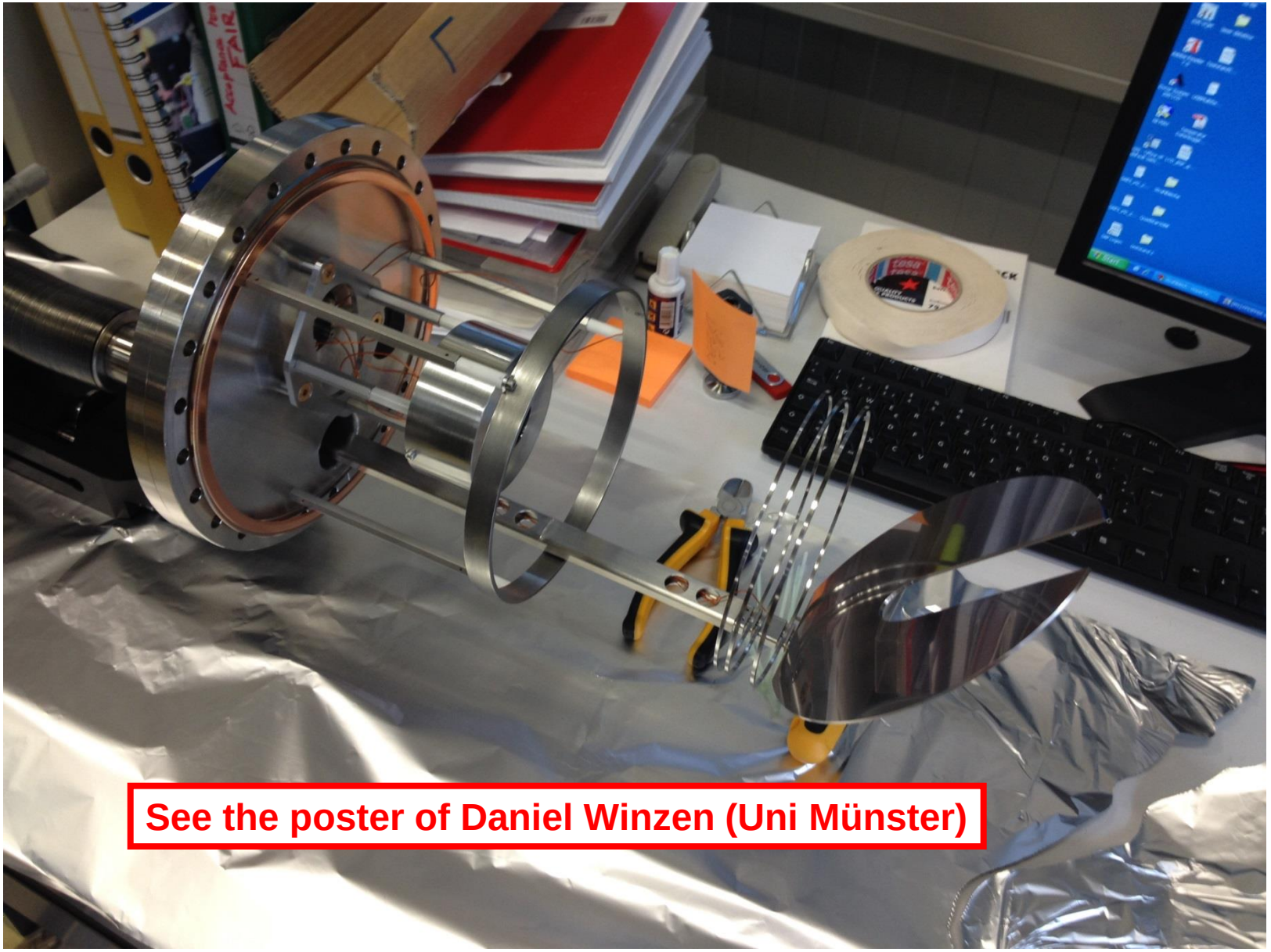
Experimental setup: ESR



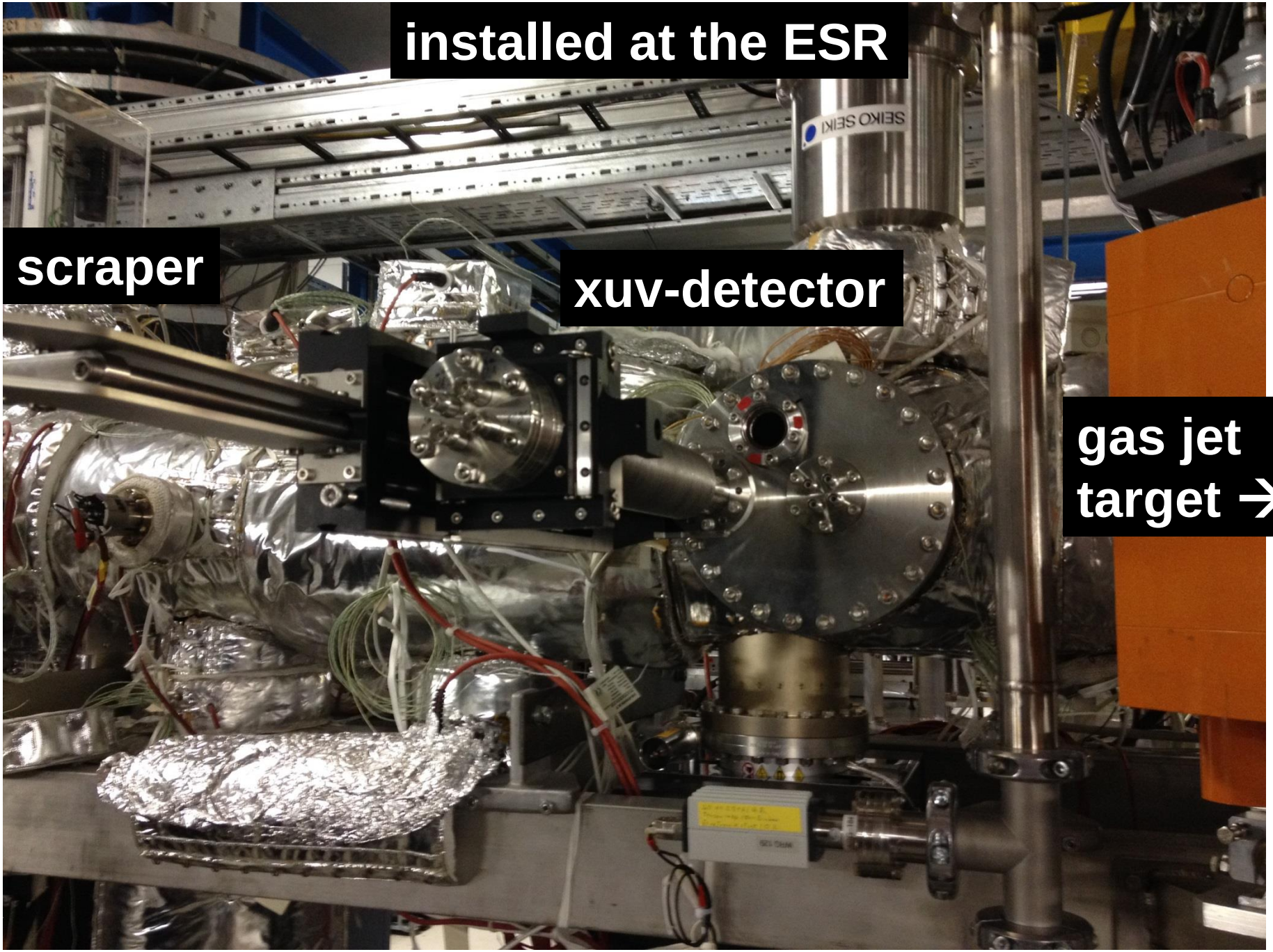
moveable CsI-cathode for XUV fluorescence detection

→ BMBF funding: group of Prof. Christian Weinheimer (Uni Münster)

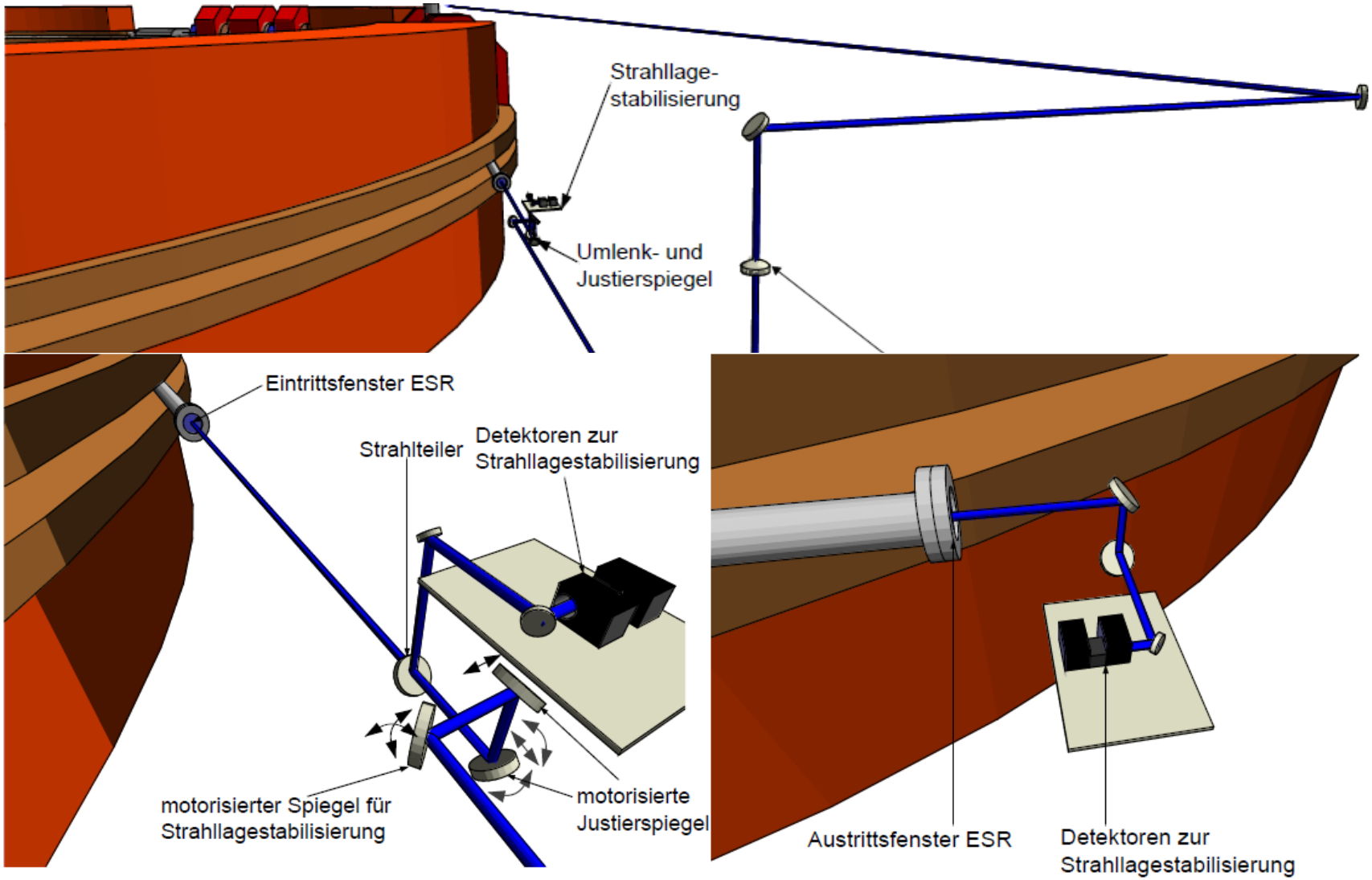
moveable CsI-cathode for XUV fluorescence detection



→ BMBF funding: group of Prof. Christian Weinheimer (Uni Münster)


installed at the ESR
scraper
xuv-detector
gas jet
target →

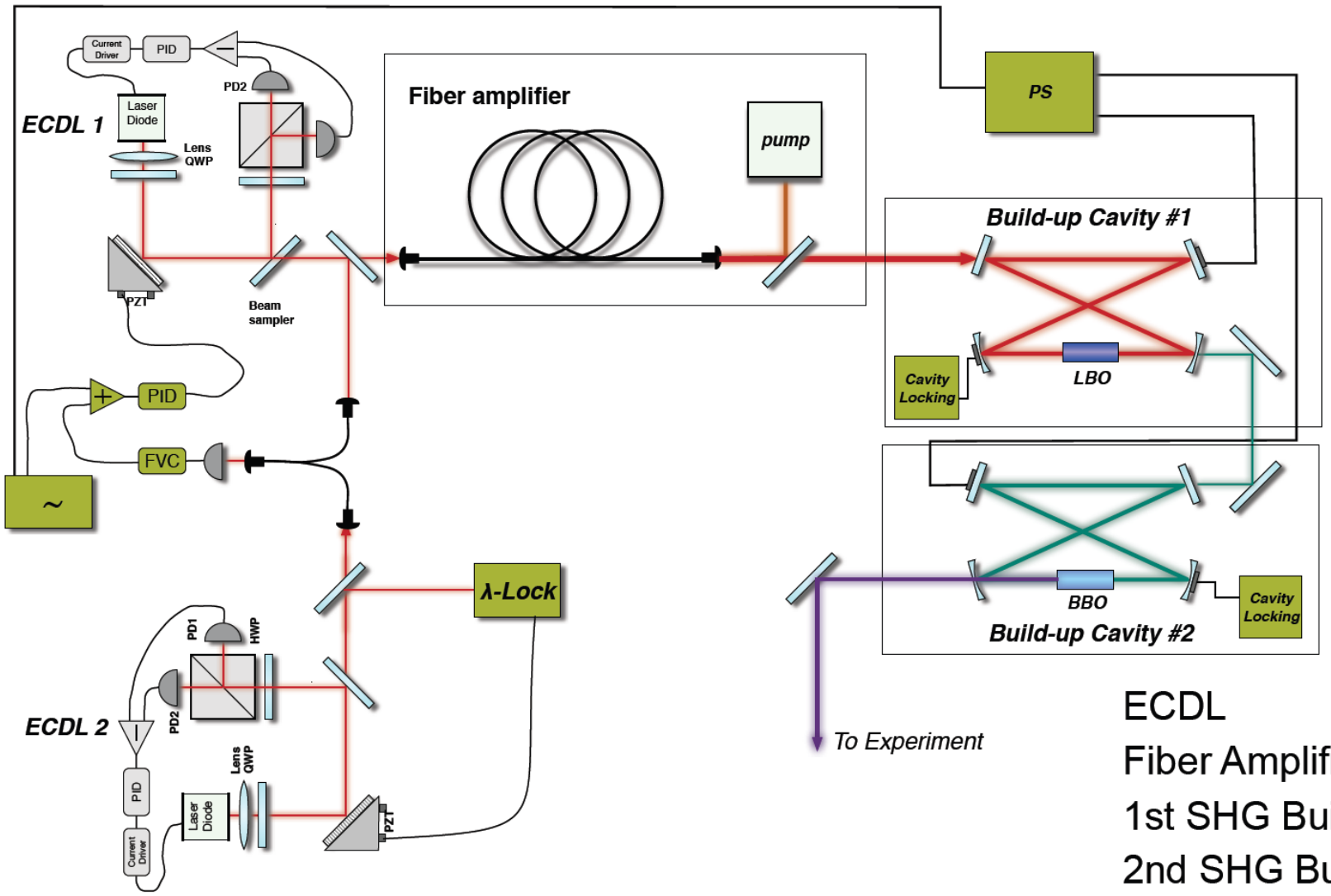
Laser beam transport and stabilization



→ BMBF Funding: group of Prof. Wilfried Nörtershäuser (TU-Darmstadt)
→ ARD funding: SIS100 project

ECDL scanning cw laser system

(20 GHz IR, 3 GHz needed)



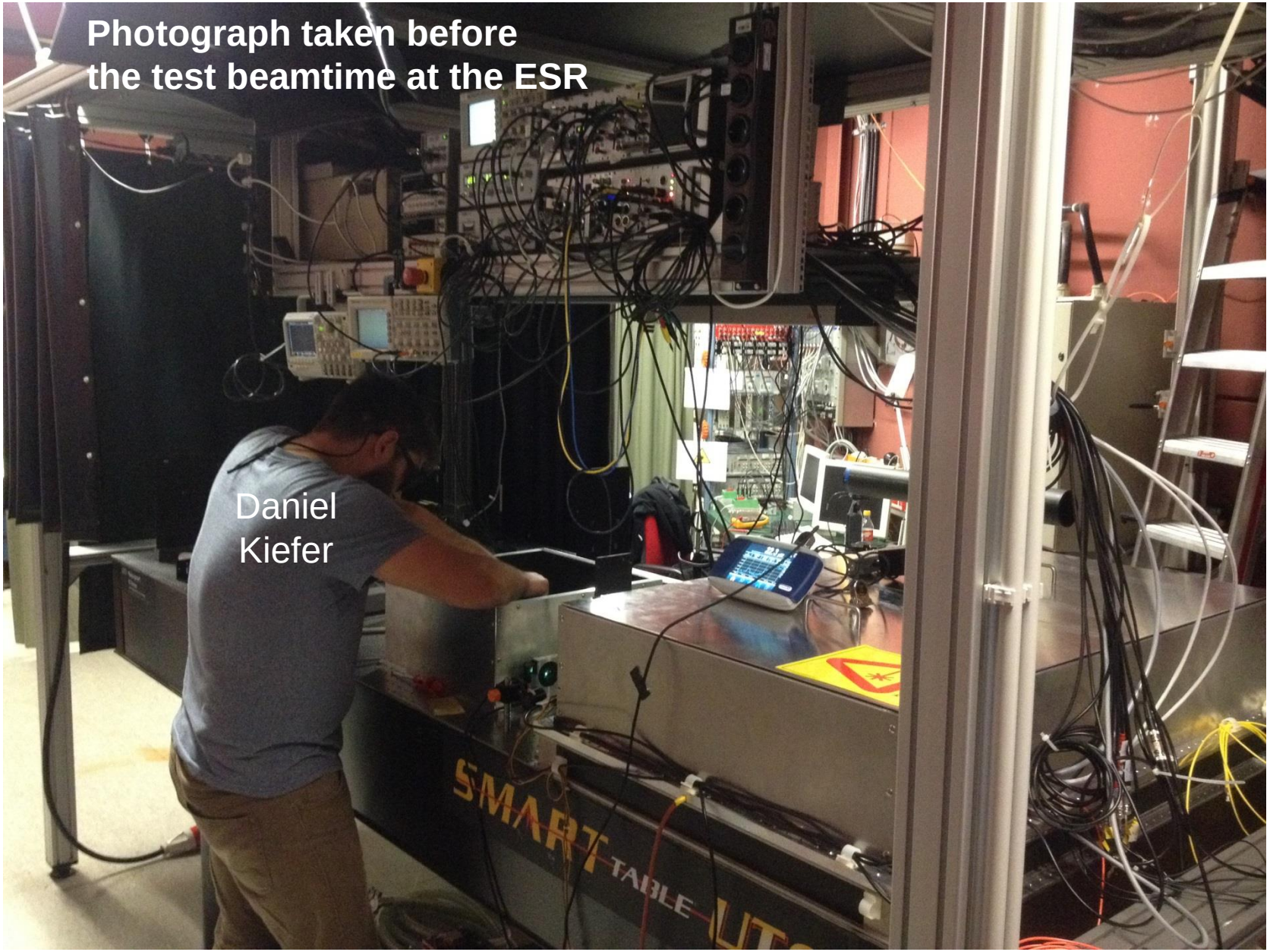
ECDL

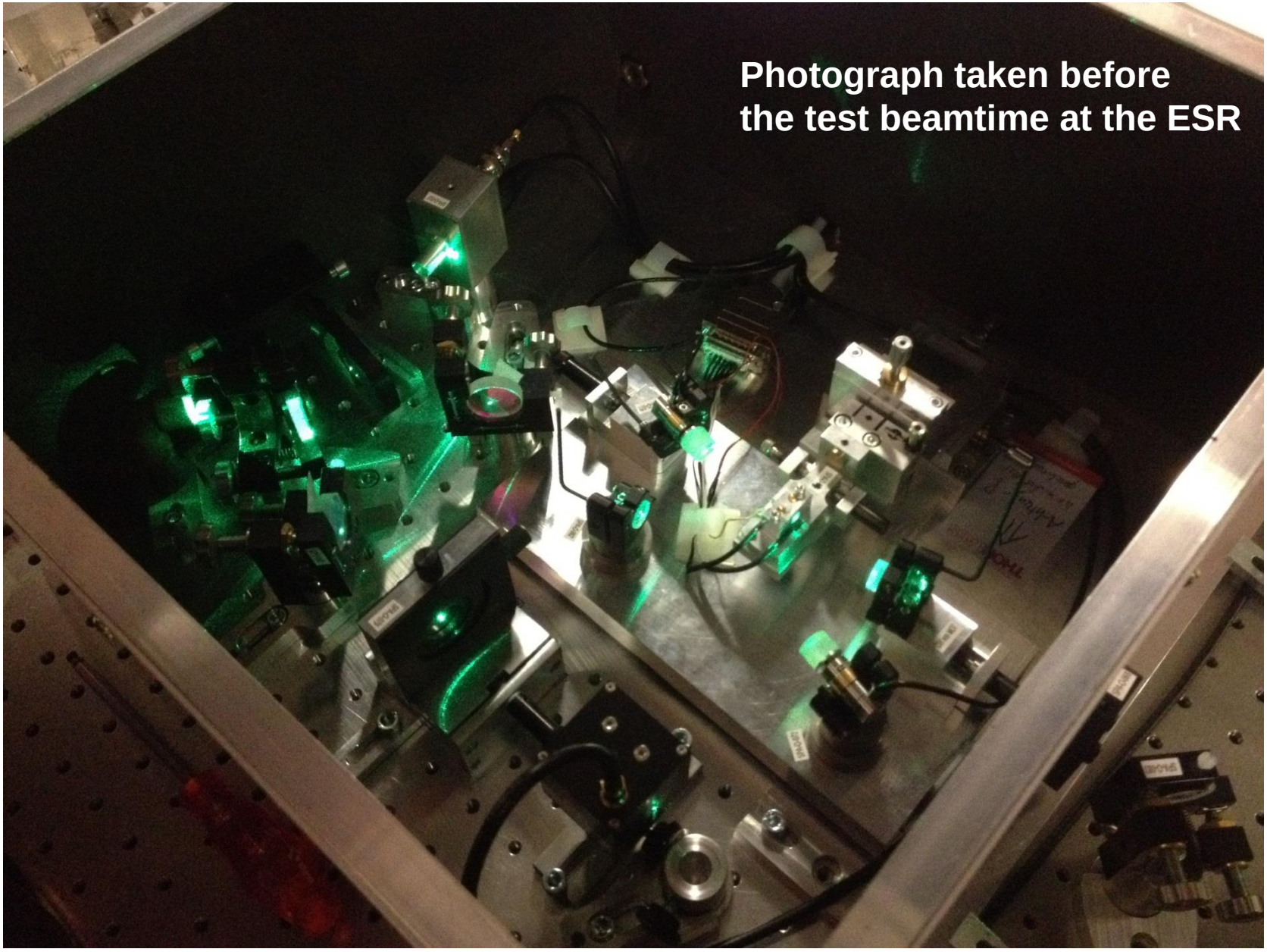
Fiber Amplifier

1st SHG Built-up Cavity

2nd SHG Built-up Cavity

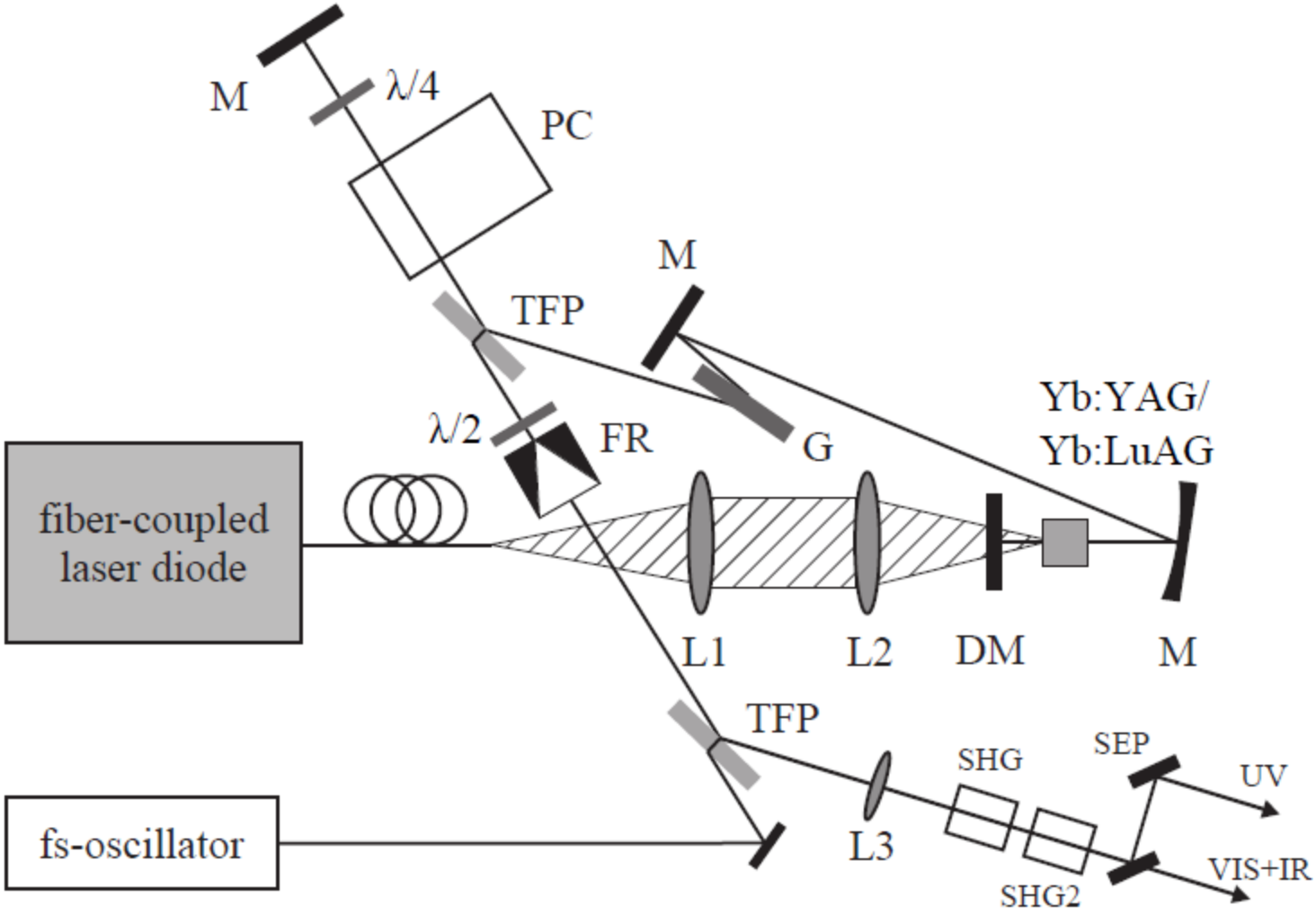
→BMBF funding: group of Prof. Thomas Walther (TU-Darmstadt)


Photograph taken before
the test beamtime at the ESR
Daniel
Kiefer
SMART TABLE

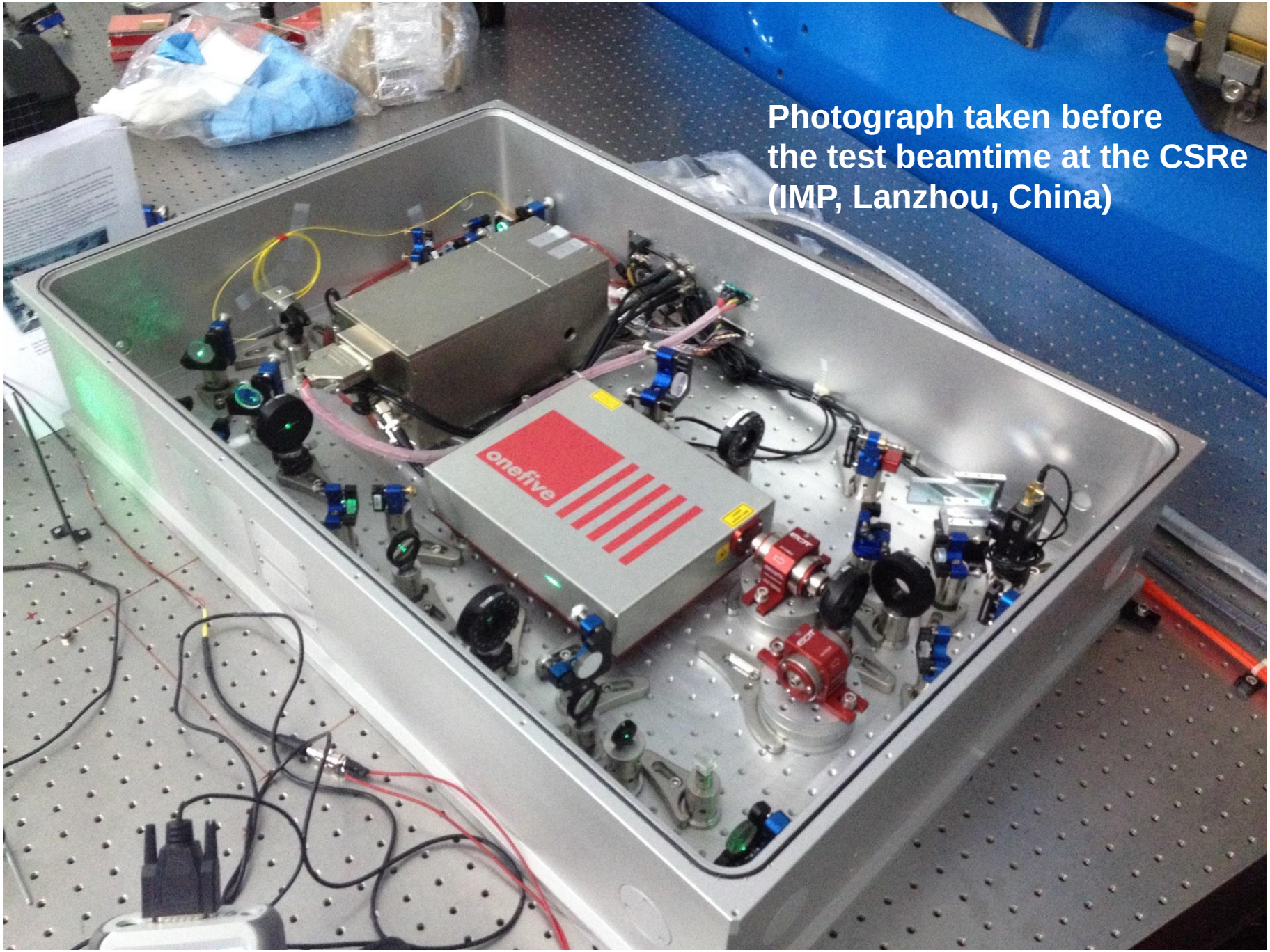

Photograph taken before
the test beamtime at the ESR

Pulsed laser system

frequency-selective intra-cavity grating



→ BMBF Funding: group of Prof. Ulrich Schramm (HZDR, TU-Dresden)


Photograph taken before
the test beamtime at the CSRe
(IMP, Lanzhou, China)
onefive

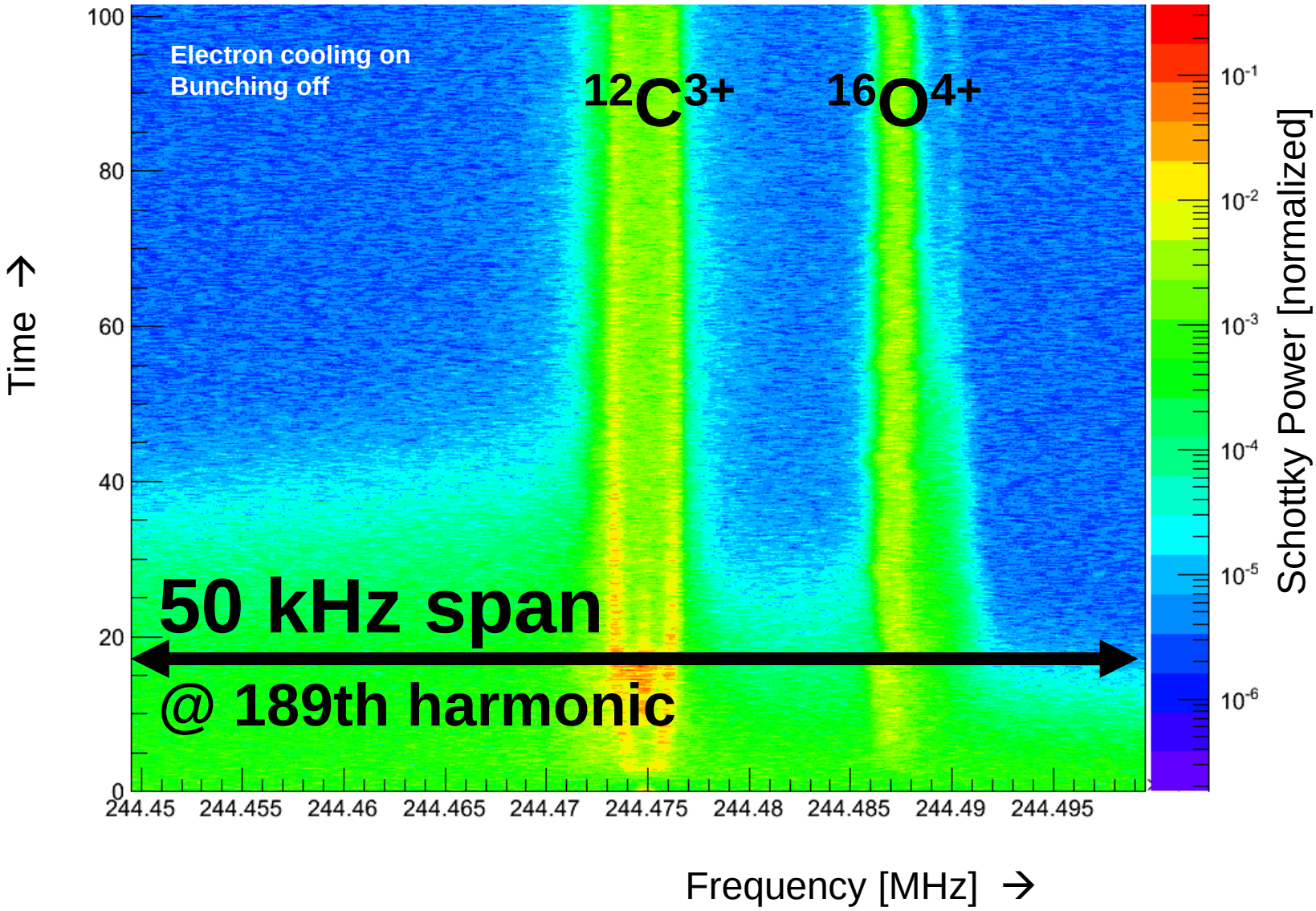
experimental results: laser cooling

- pulsed laser (TU-Dresden, HZDR)

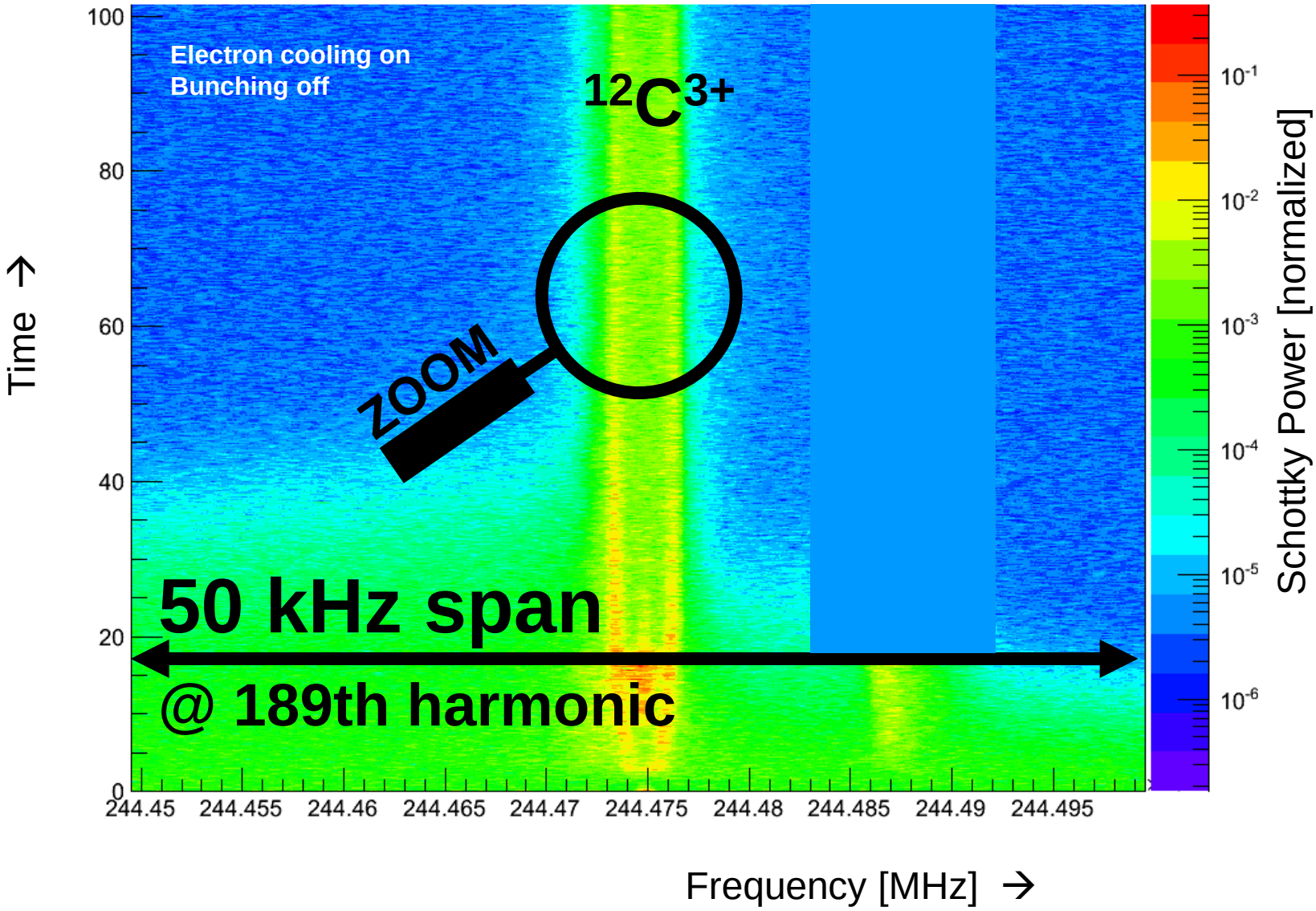
- scanning cw laser (TU-Darmstadt)

- xuv-detector (Uni Münster)

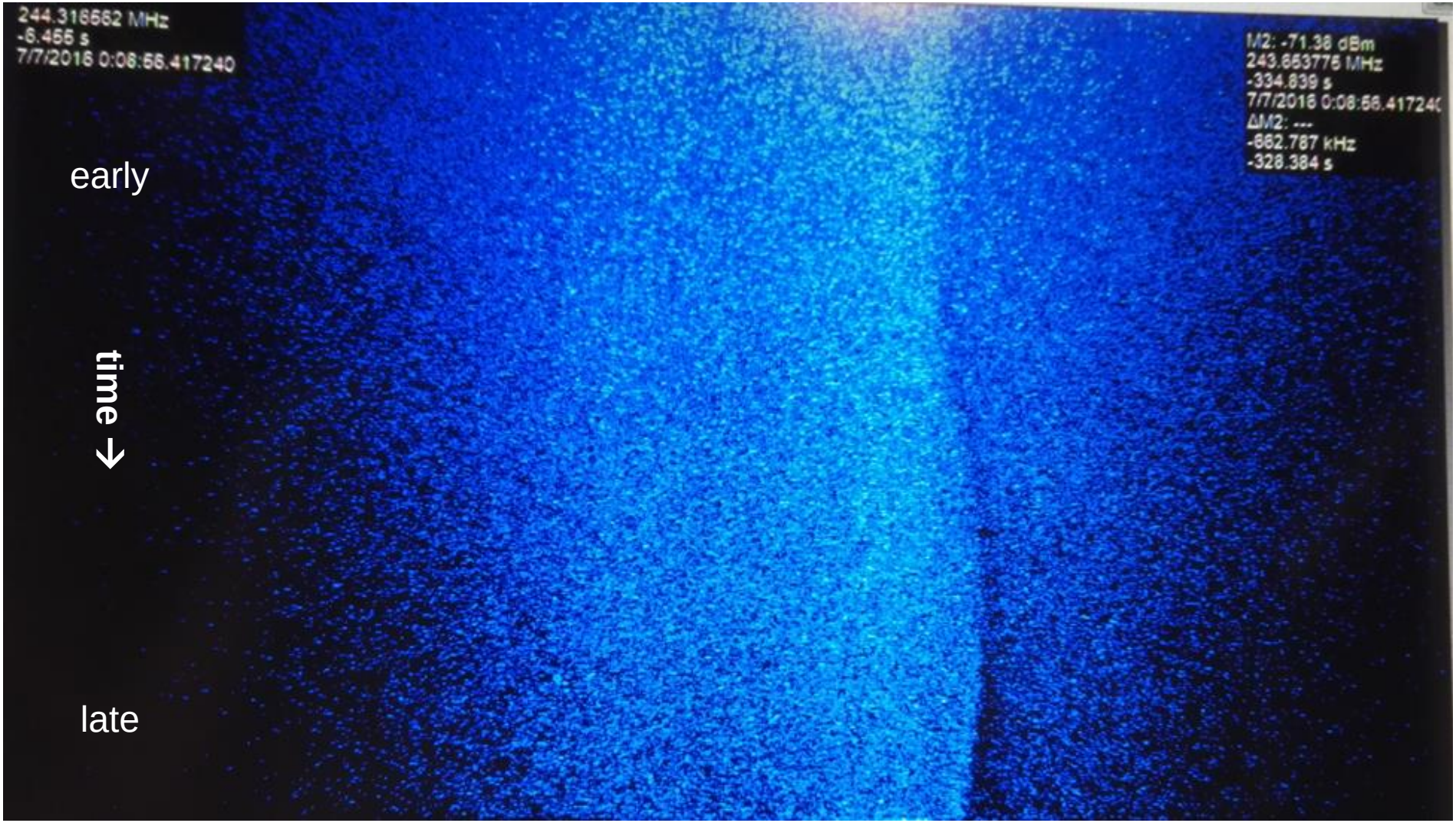
in 2012 two ion species : $^{12}C^{3+}$ (88%) & $^{16}O^{4+}$ (12%)



in 2016 one ion species : $^{12}C^{3+}$ (100%)



scanning (sine wave) of cw laser (TU-Darmstadt)



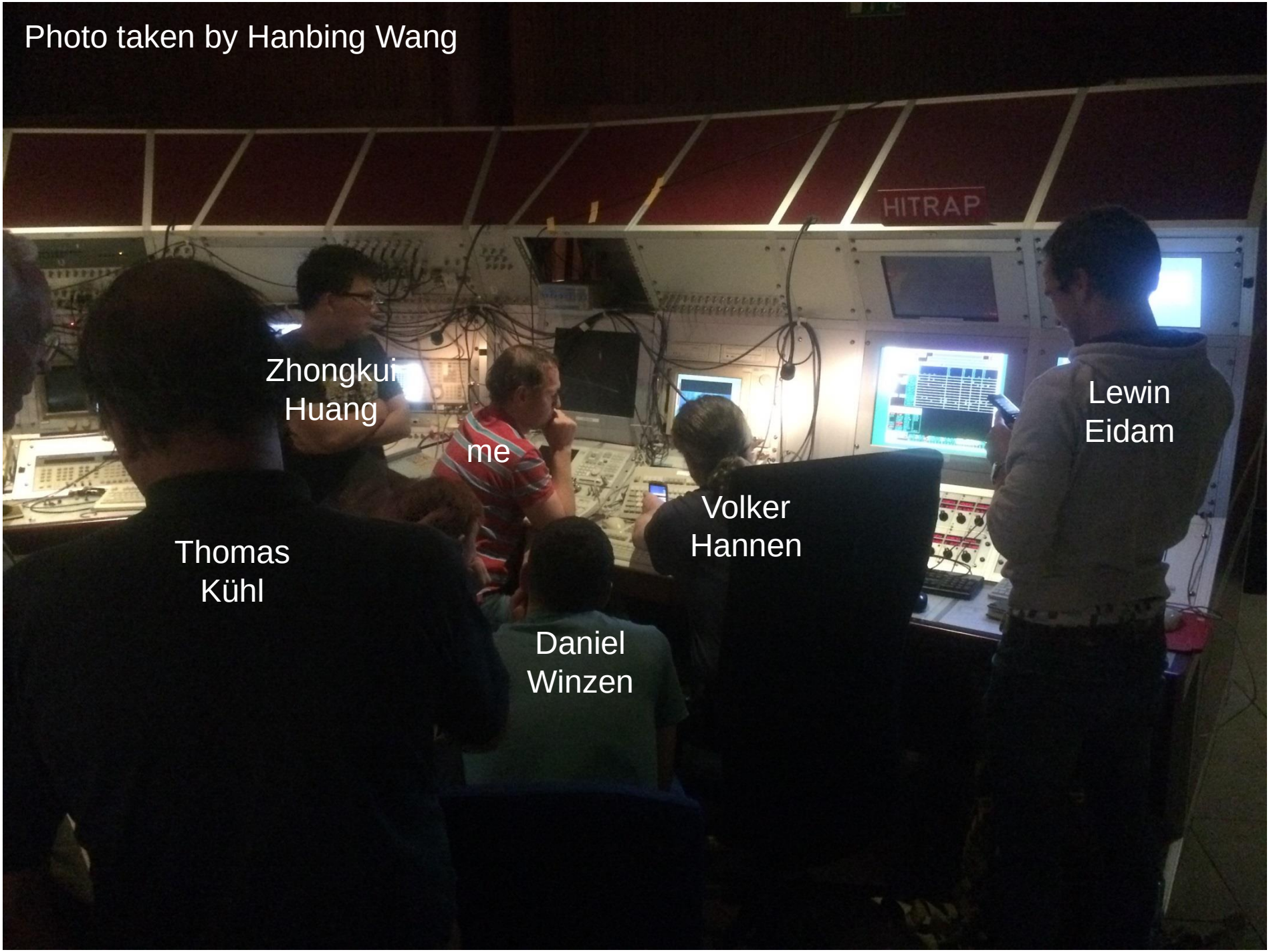
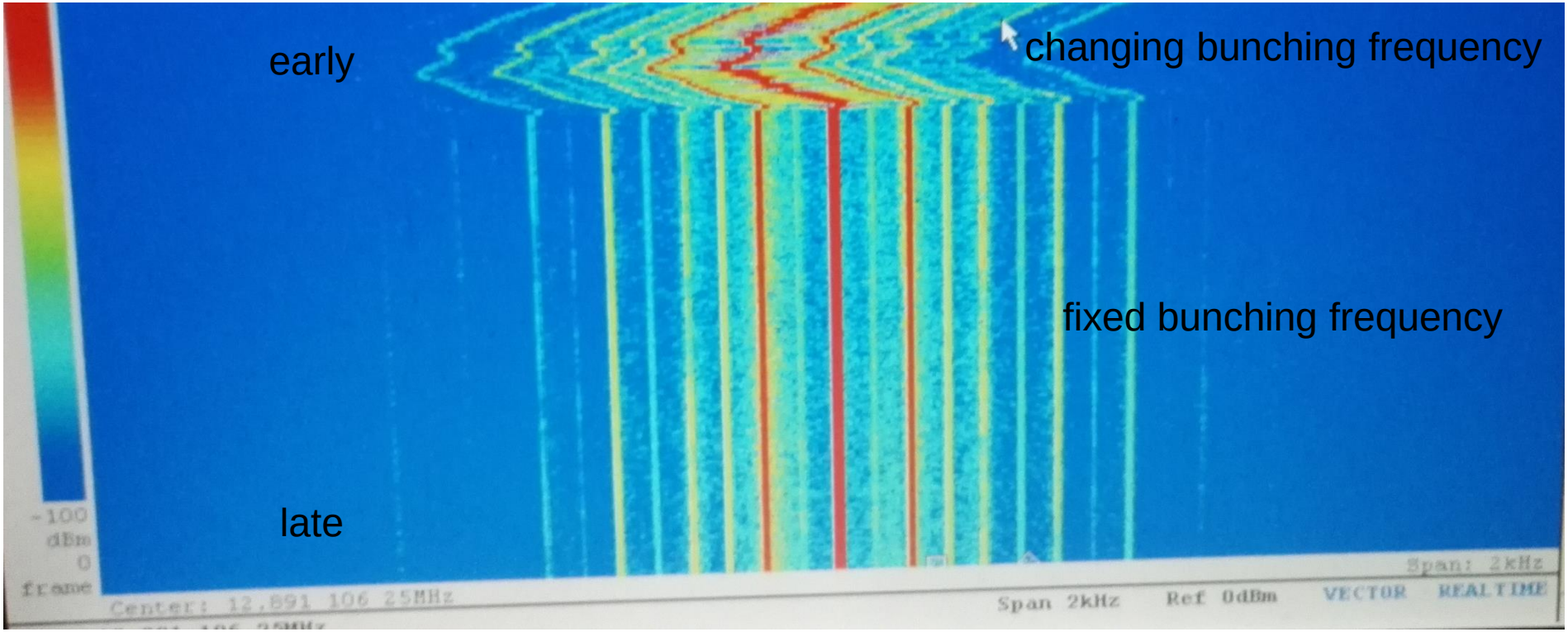


Photo taken by Hanbing Wang
HITRAP
Zhongkui
Huang
me
Lewin
Eidam
Volker
Hannen
Thomas
Kühl
Daniel
Winzen

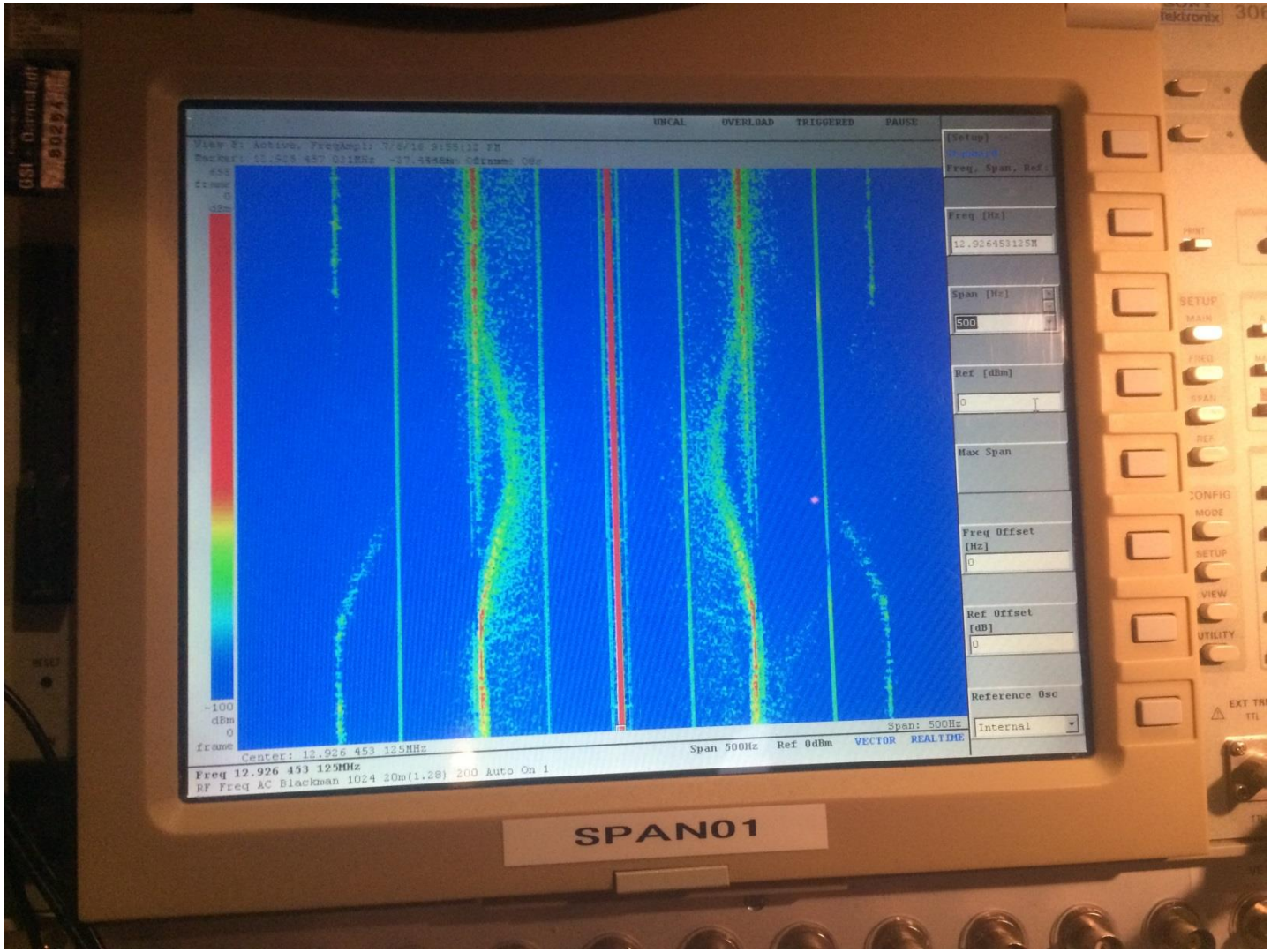
Axel
Buß

Schottky spectrum: bunching ON, fixed cw laser frequency

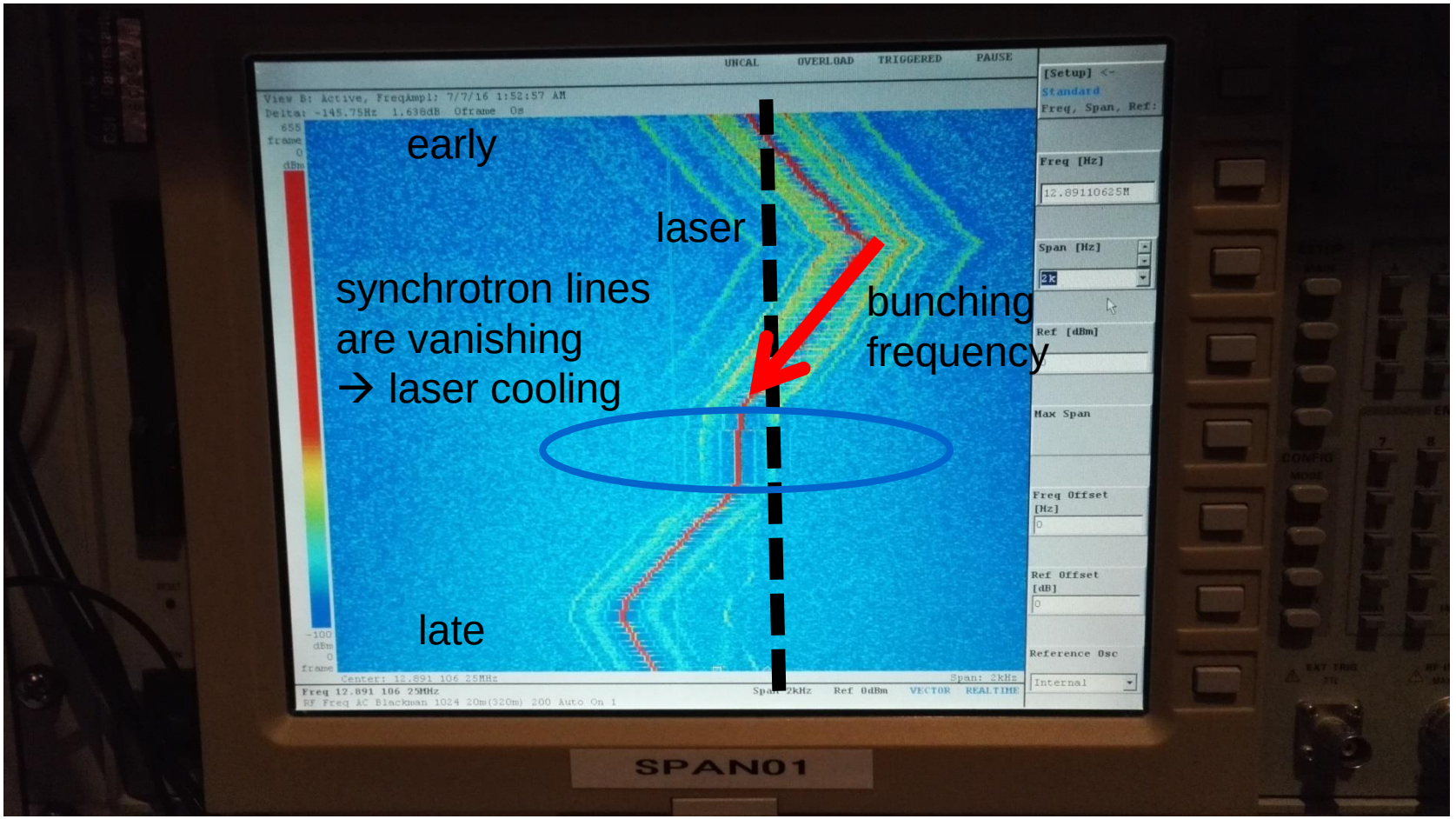


→ You can see the synchrotron lines, because the ion beam is bunched.
Unfortunately, there are also 50 Hz (and higher order) lines due to noise.

Schottky spectrum: bunching ON, fixed bunching frequency
→ scanning cw laser (sine wave)



Schottky spectrum: pulsed laser ON, laser frequency fixed, bunching ON,
→ scanning bunching frequency



→ Important result: the pulsed laser acts on the ions!

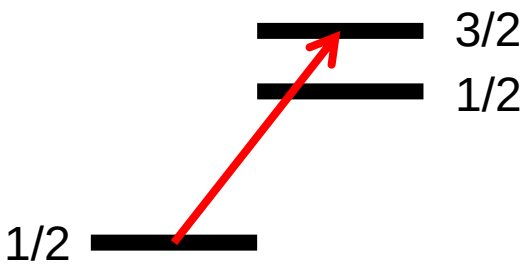
experimental results: laser spectroscopy

- xuv detector (Uni Münster)

- HV divider (TU-Darmstadt) + DMM

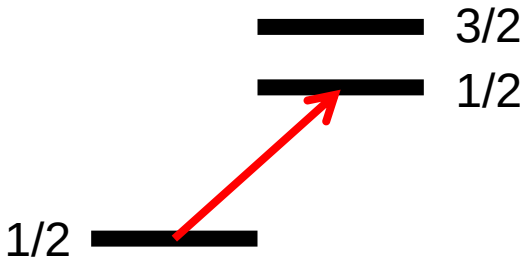
- scanning cw laser systems (TU-Darmstadt)

- pulsed laser system (TU-Dresden, HZDR)



$2s_{1/2} \rightarrow 2p_{3/2}$
laser wavelength = 257,17 nm
transition wavelength = 154,82 nm
calc. HV = 67221,0 V

154,8216
154,8202
154,8203 nm
154,8202
154,8127



$2s_{1/2} \rightarrow 2p_{1/2}$
laser wavelength = 257,17 nm
transition wavelength = 155,07 nm
calc. HV = 66770,9 V

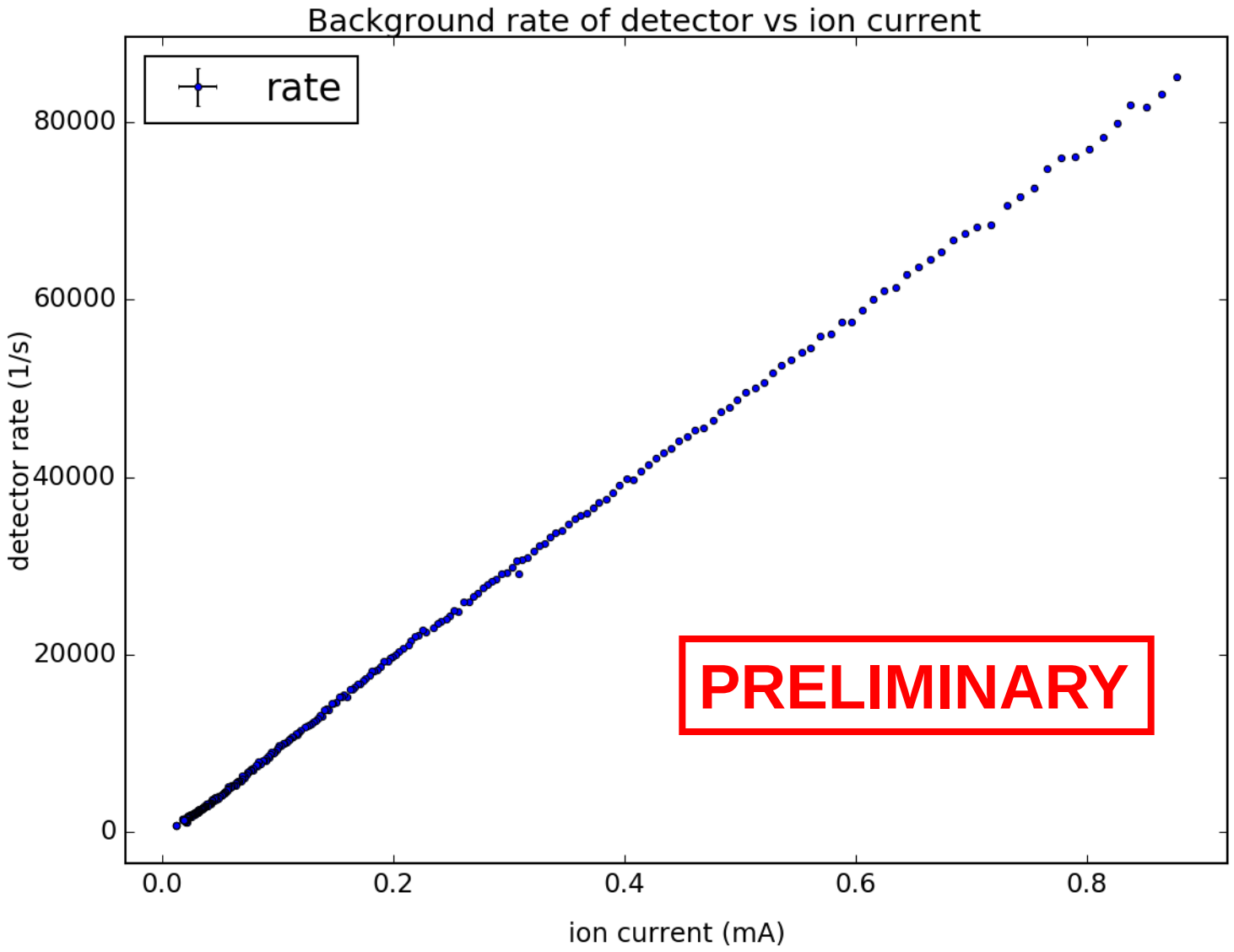
155,0798
155,0774
155,0777 nm
155,0774
155,0705

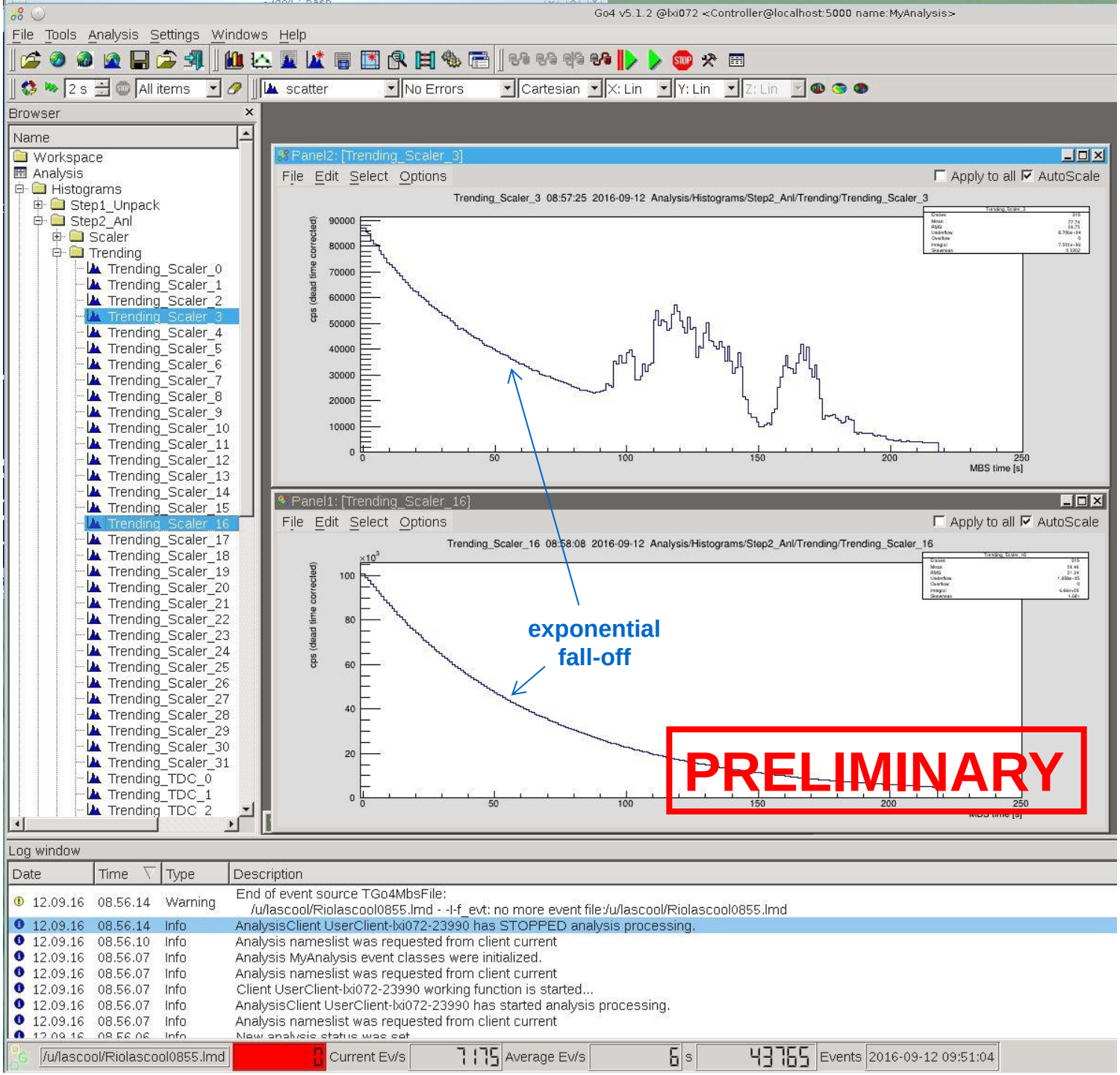
Hyperfine Interactions (2005) 162:181–188
U. Schramm, M. Bussmann, D. Habs et al.

	$\lambda(2S_{1/2} - 2P_{1/2})$ [nm]	$\lambda(2S_{1/2} - 2P_{3/2})$ [nm]
Kim *et al.* 1991 [20]	155.060	154.804
Johnson *et al.* 1996 [11]	155.078	154.819
Tupitsyn and Shabaev 2003, private communication [2004]	155.0739(26)	154.8173(53)
This work	155.0705(39)(3)	154.8127(39)(2)
Edlen *et al.* 1983 [21]	155.077	154.820


DANGER
HIGH VOLTAGE
Sombrero
high-voltage divider
TU-Darmstadt (10000:1)
installled at the ESR
electron cooler

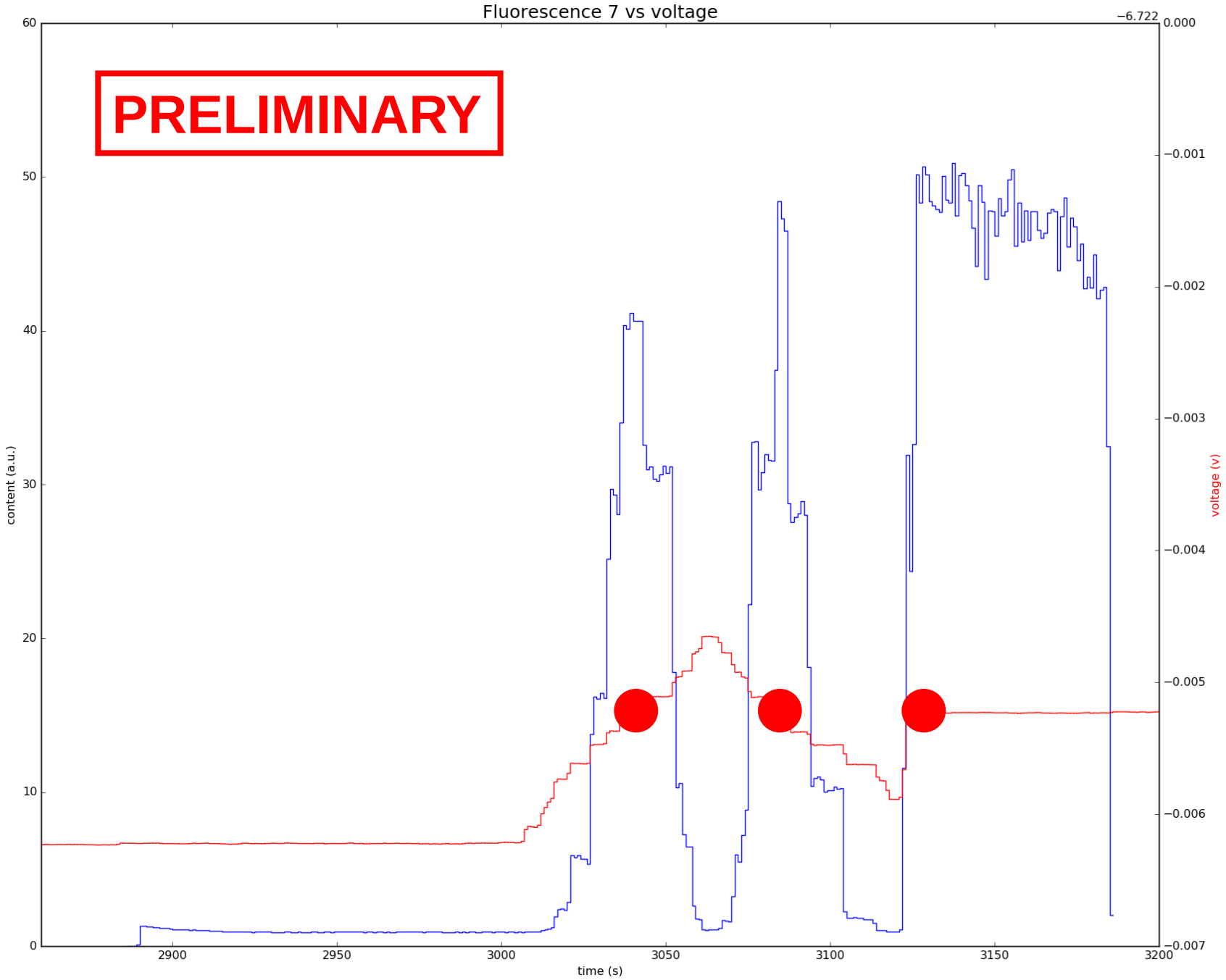
See the poster of Daniel Winzen (Uni Münster)





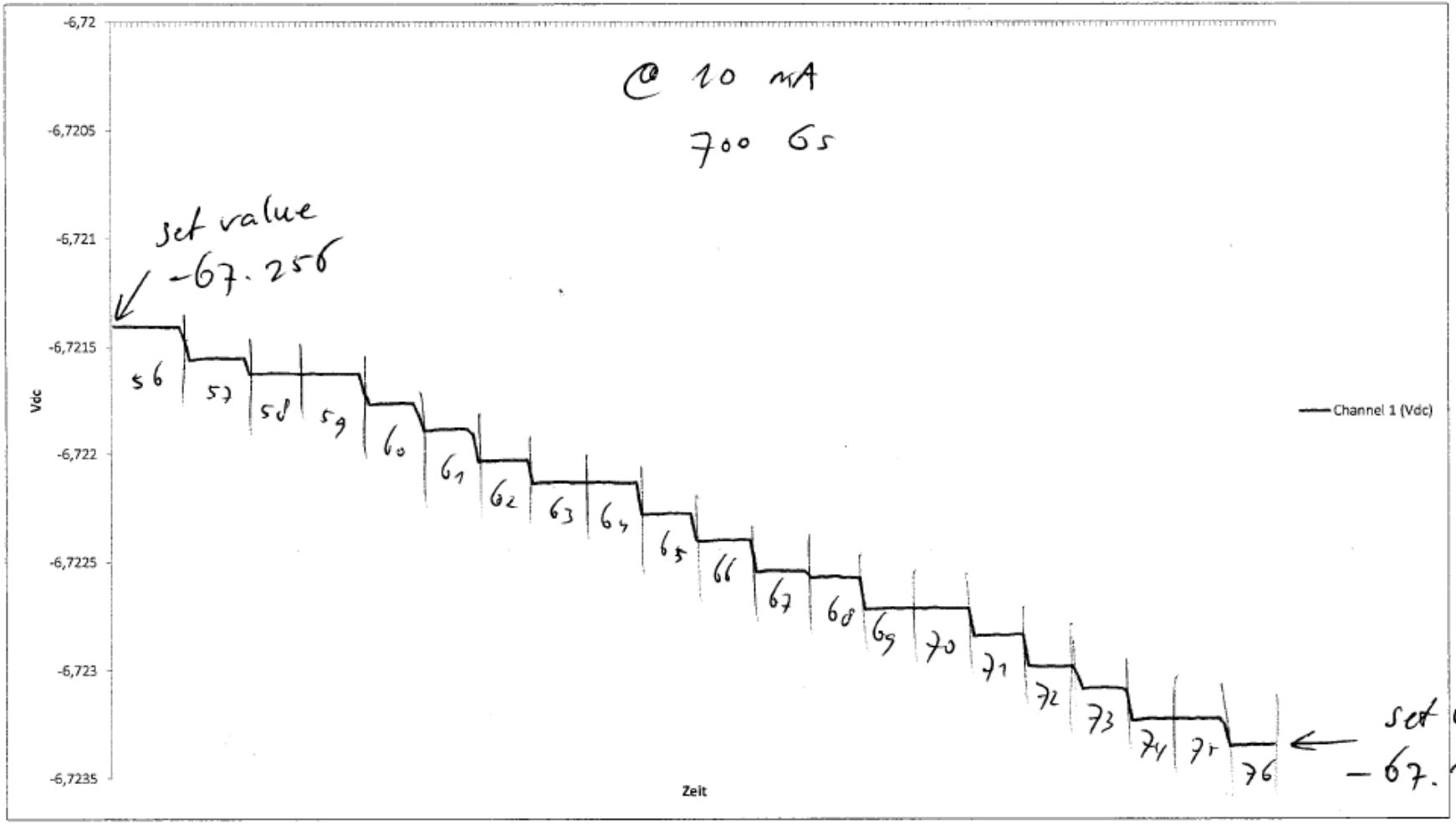
fluorescence vs time

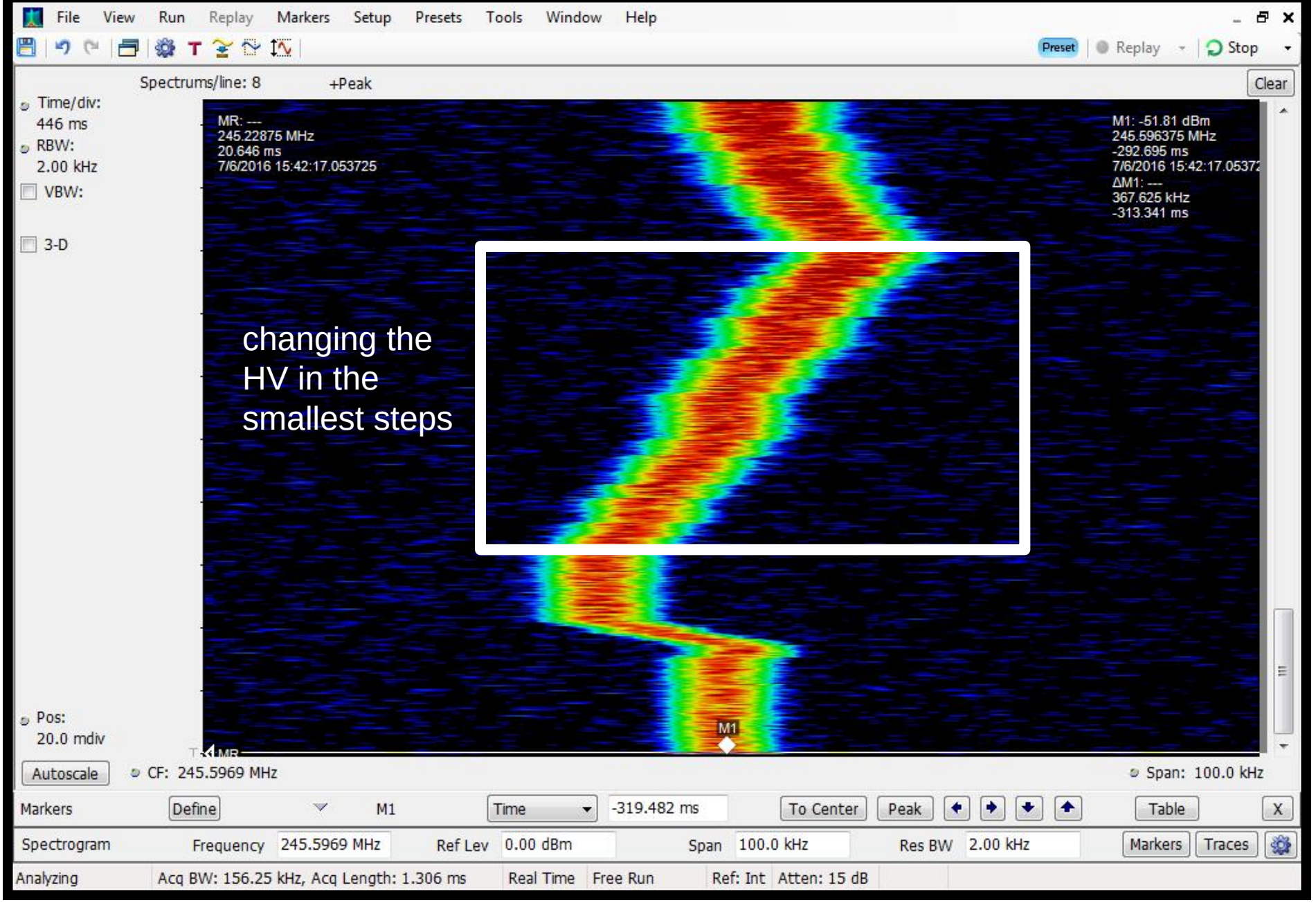
(DC-Trafo) ion current vs time


Fluorescence 7 vs voltage
PRELIMINARY
content (a.u.)
time (s)
voltage (v)
−6.722
0
10
20
30
40
50
60
2900
2950
3000
3050
3100
3150
3200
0.000
−0.001
−0.002
−0.003
−0.004
−0.005
−0.006
−0.007

16/7/2015 18:11

Change of HV set ?

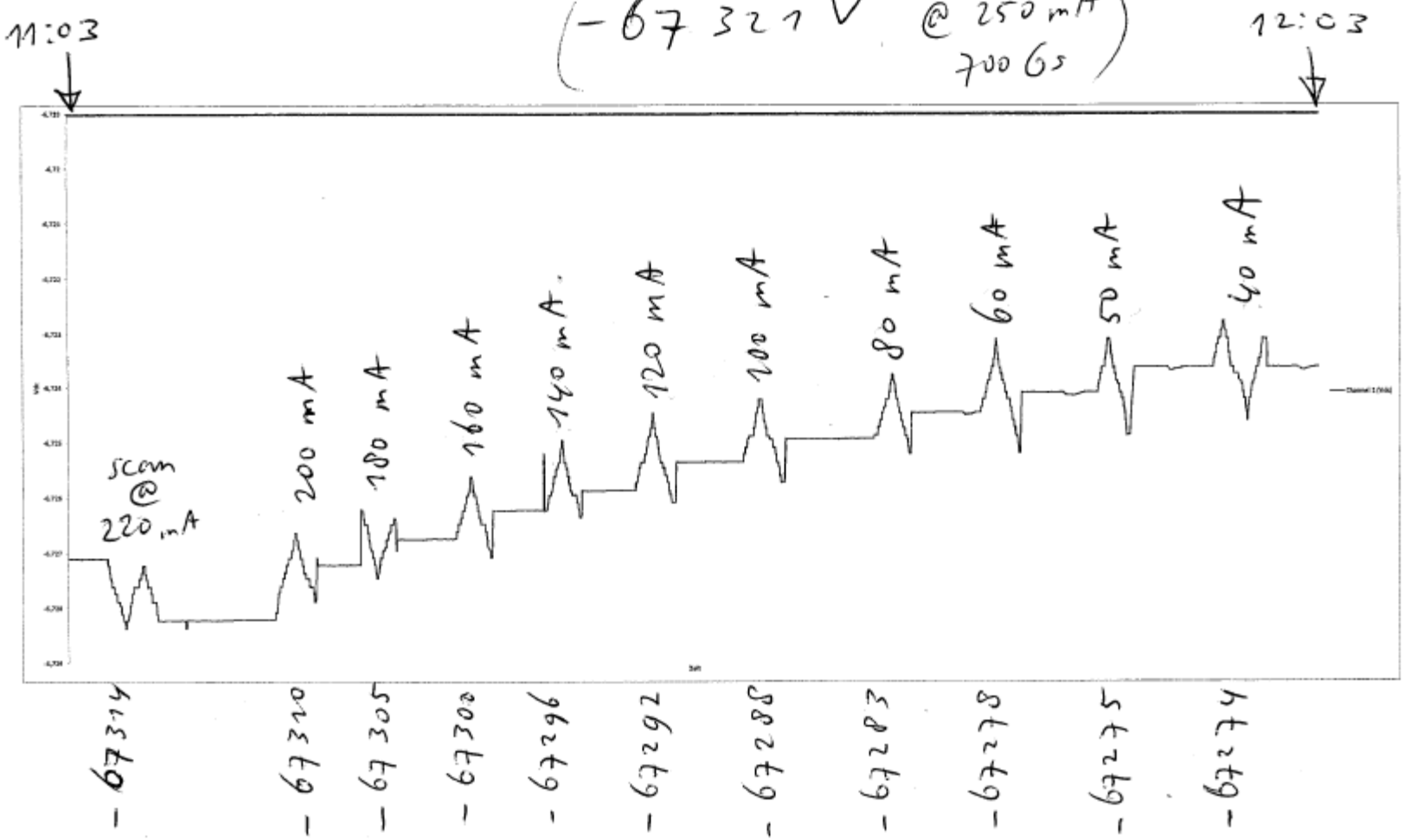



File View Run Replay Markers Setup Presets Tools Window Help
Preset Replay Stop
Spectrums/line: 8 +Peak
Clear
Time/div:
446 ms
RBW:
2.00 kHz
VBW:
3-D
MR: ---
245.22875 MHz
20.646 ms
7/6/2016 15:42:17.053725
M1: -51.81 dBm
245.596375 MHz
-292.695 ms
7/6/2016 15:42:17.05372
ΔM1: ---
367.625 kHz
-313.341 ms
changing the HV in the smallest steps
M1
Pos:
20.0 mdiv
Autoscale
CF: 245.5969 MHz
Span: 100.0 kHz
Markers Define M1 Time -319.482 ms To Center Peak Table X
Spectrogram Frequency 245.5969 MHz Ref Lev 0.00 dBm Span 100.0 kHz Res BW 2.00 kHz Markers Traces
Analyzing Acq BW: 156.25 kHz, Acq Length: 1.306 ms Real Time Free Run Ref: Int Atten: 15 dB

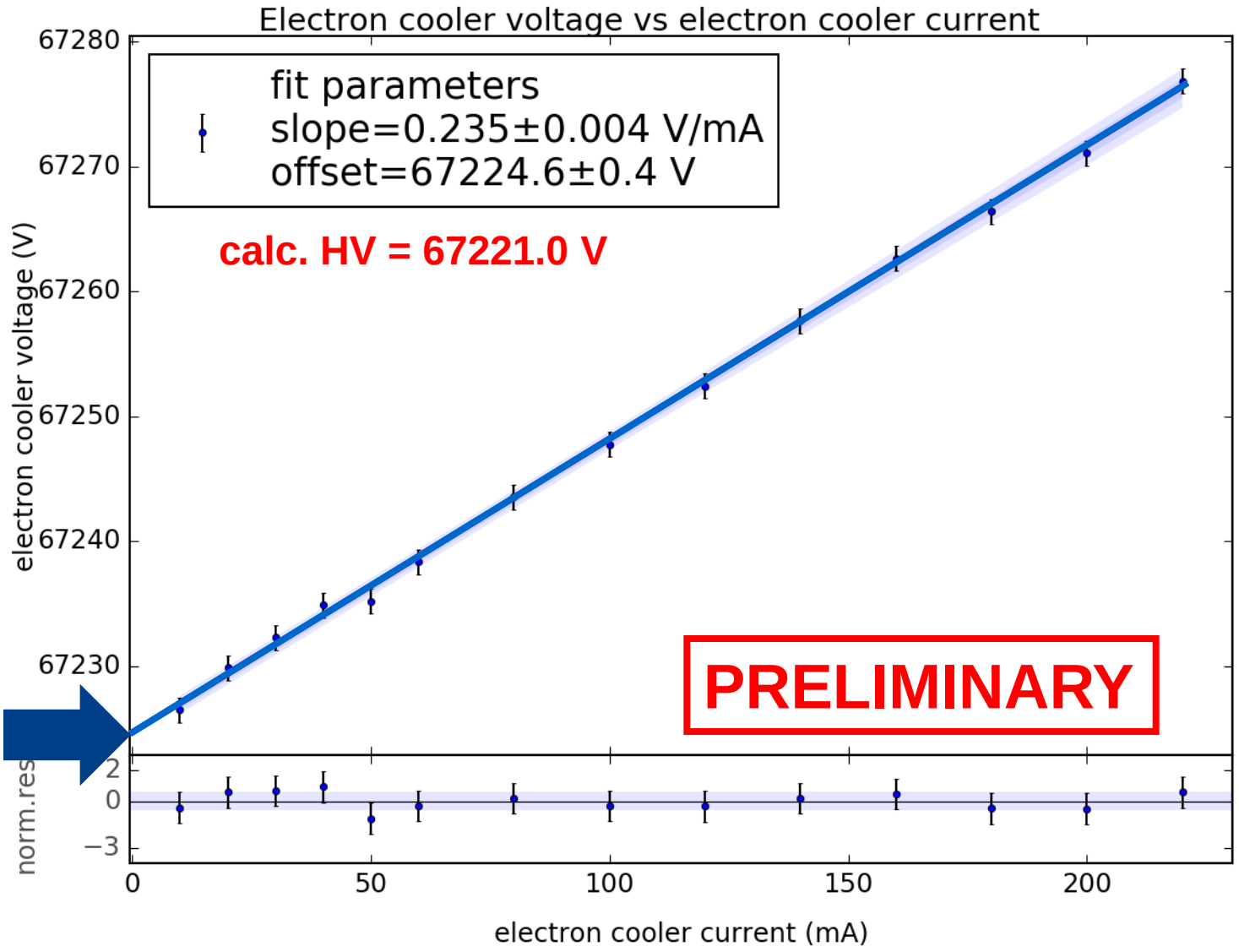
06/07/2016

transition measurement
$2S_{1/2} - 2P_{3/2}$

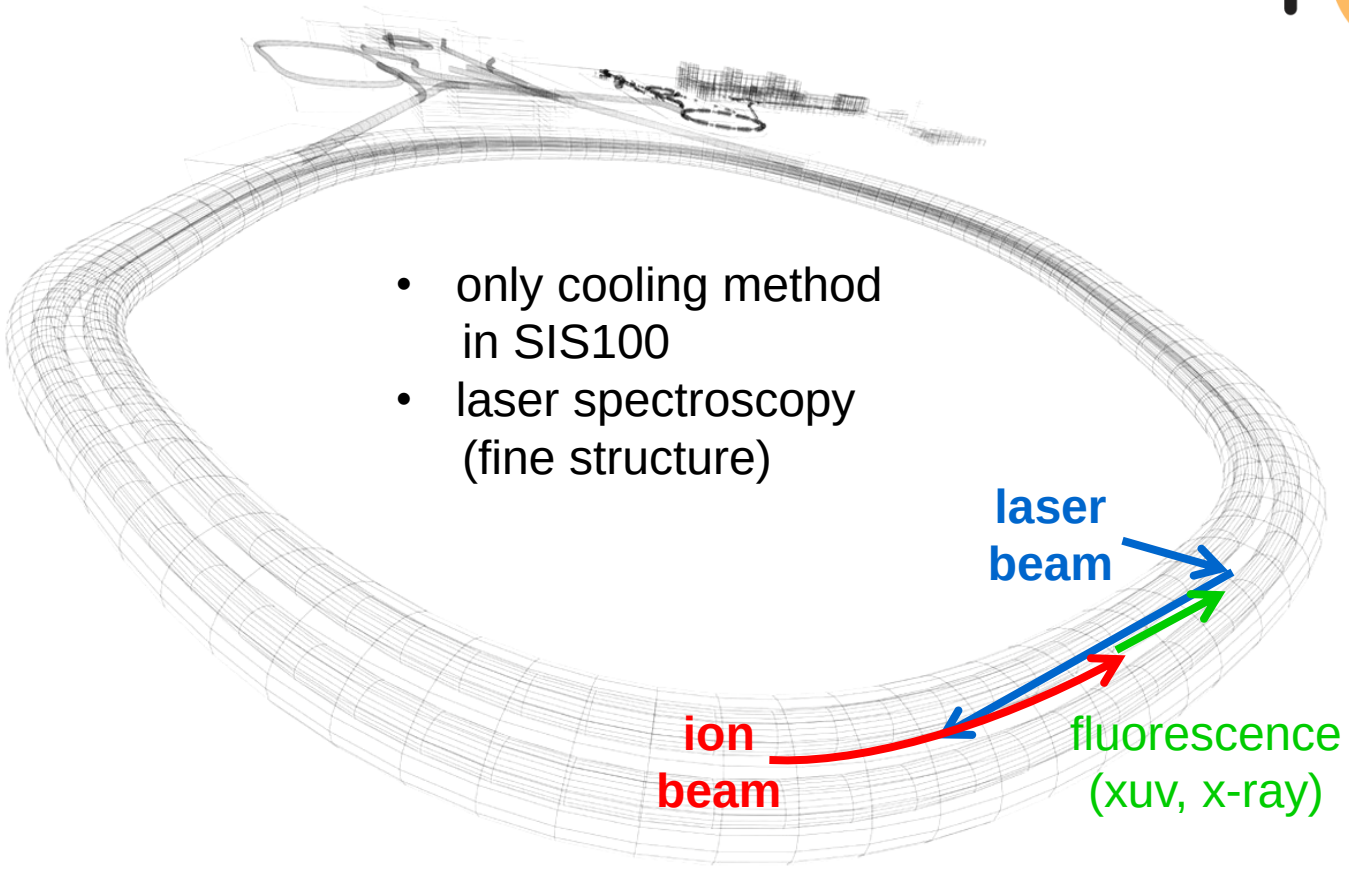
(-67321 V @ 250 mA
700 Gs)



Measurement of the $2s_{1/2} \rightarrow 2p_{3/2}$ fine structure transition

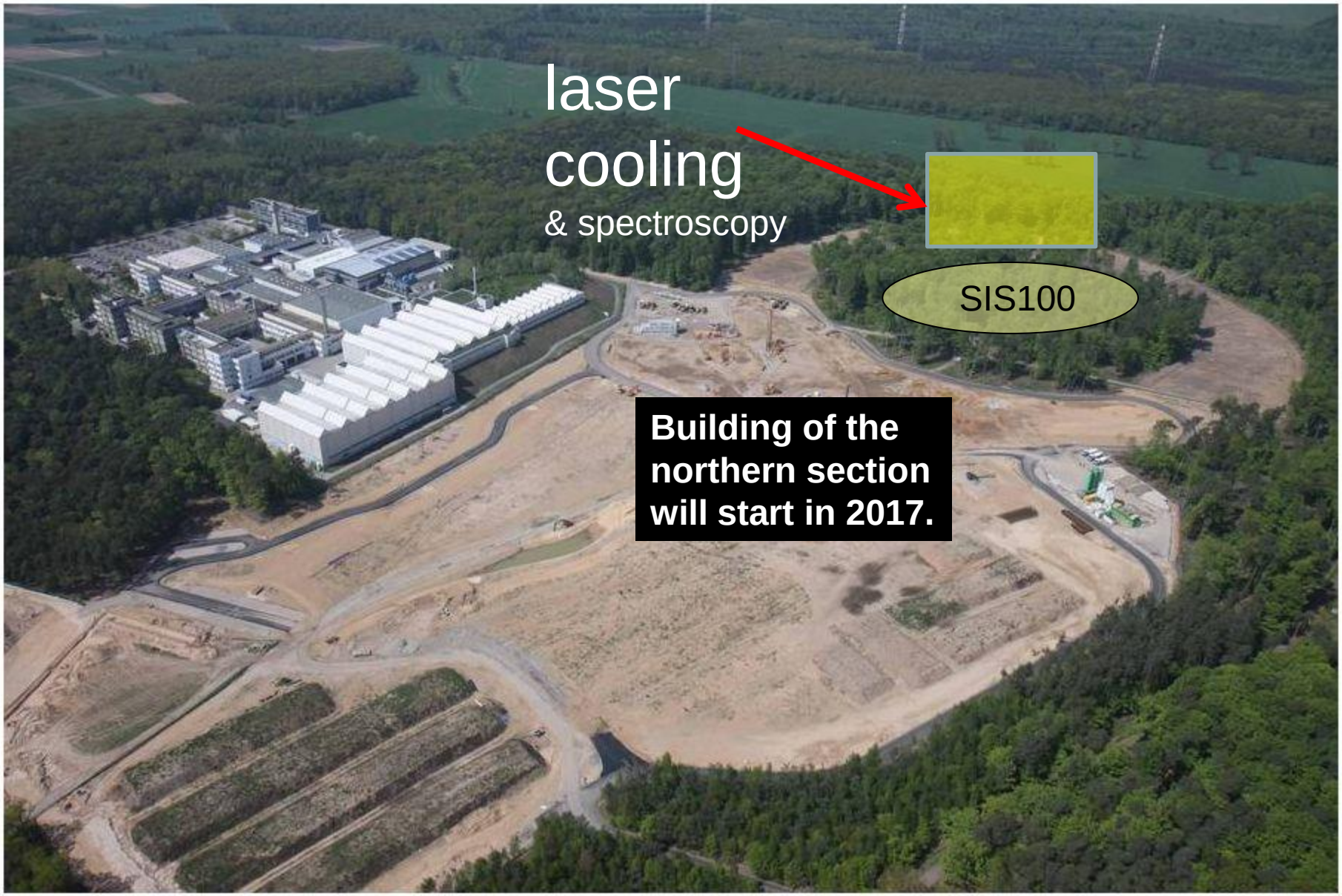


executive summary



- laser-cooled relativistic heavy ion beams
- Z_{ion}= 10 – 60 (3 – 19 electrons)
- γ up to 13 (huge Doppler-shift)

- extraction of very cold and very short ultra-relativistic ion bunches



Photograph of the FAIR building site


Thank you for your attention ☺