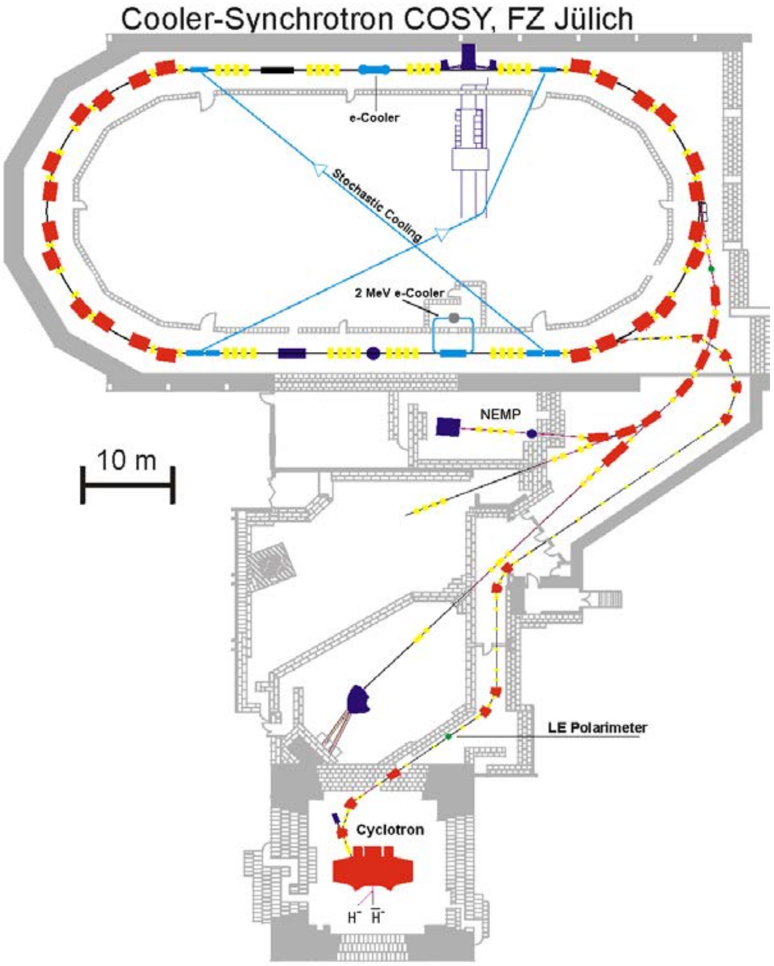
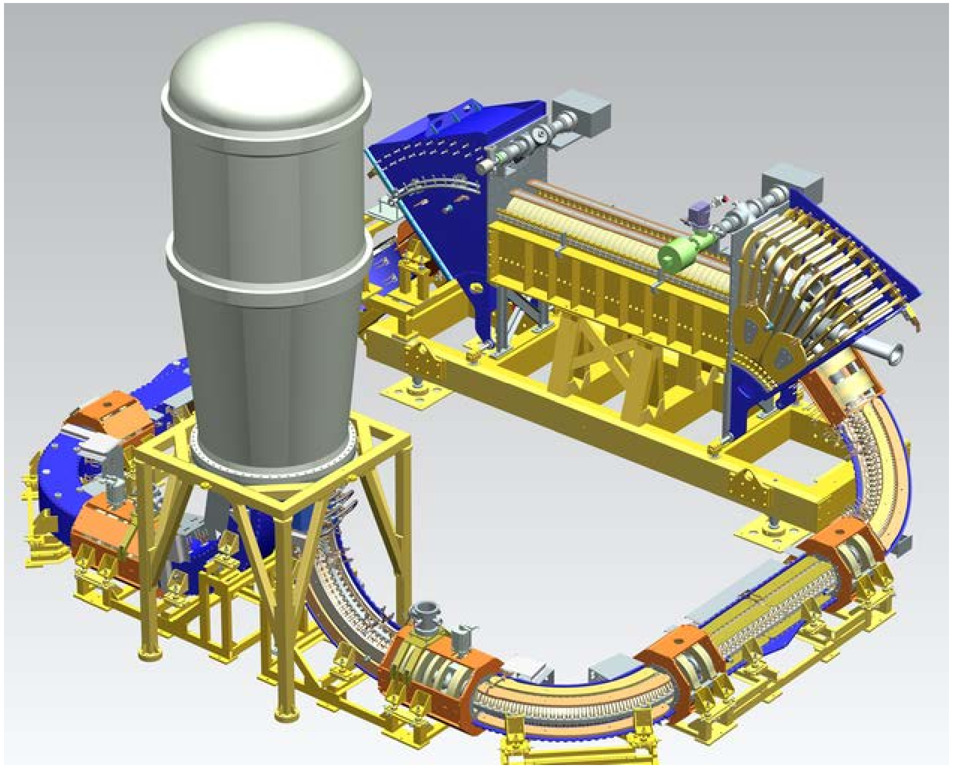
Performance of the 2 MeV Electron Cooler at COSY

Sept. 28, 2015 | COOL'15 | Vsevolod Kamerdzhiev for COSY and BINP teams

Mitglied der Helmholtz-Gemeinschaft

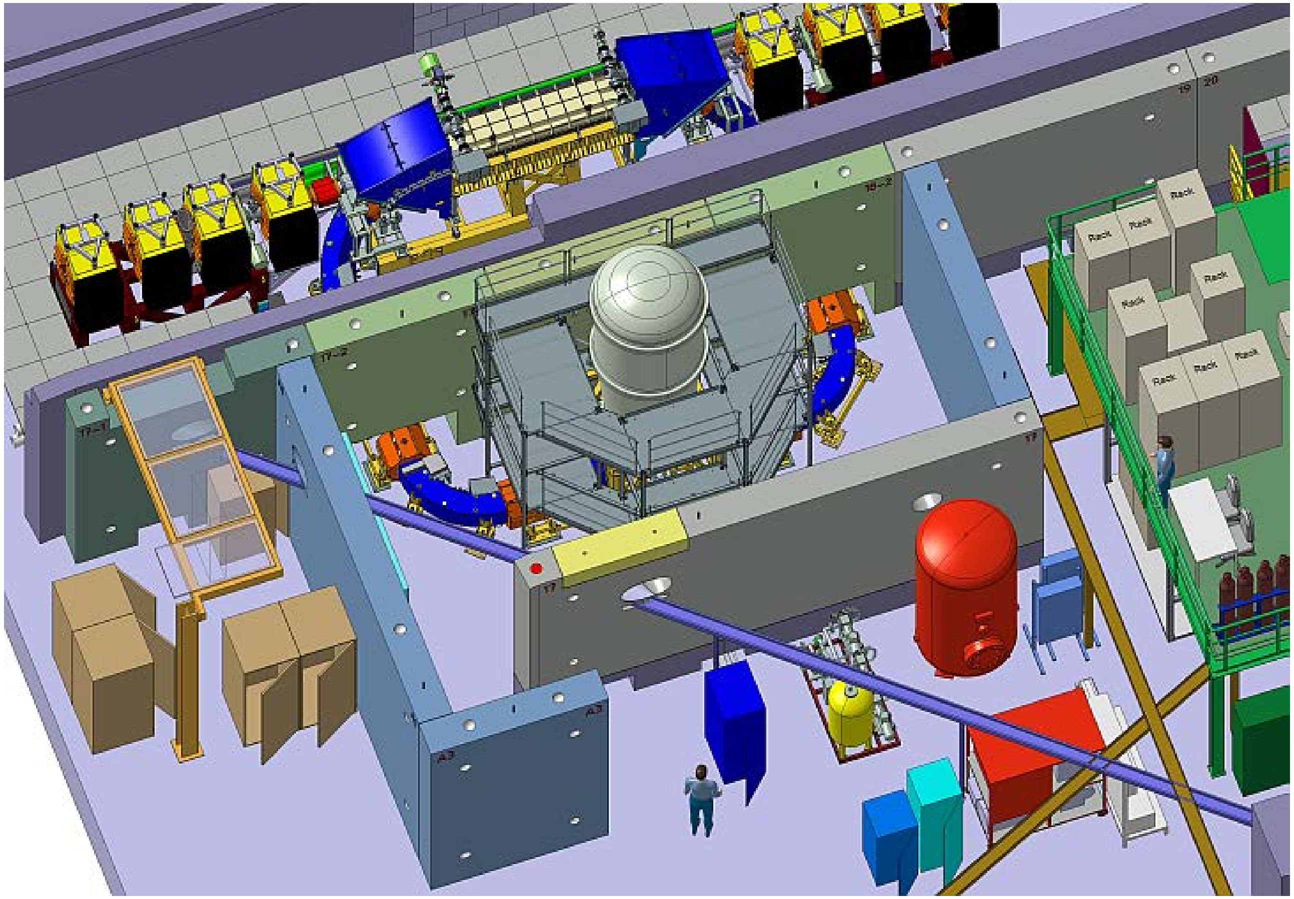
The 2 MeV electron cooler at COSY





Mitglied der Helmholtz-Gemeinschaft

Integration into COSY

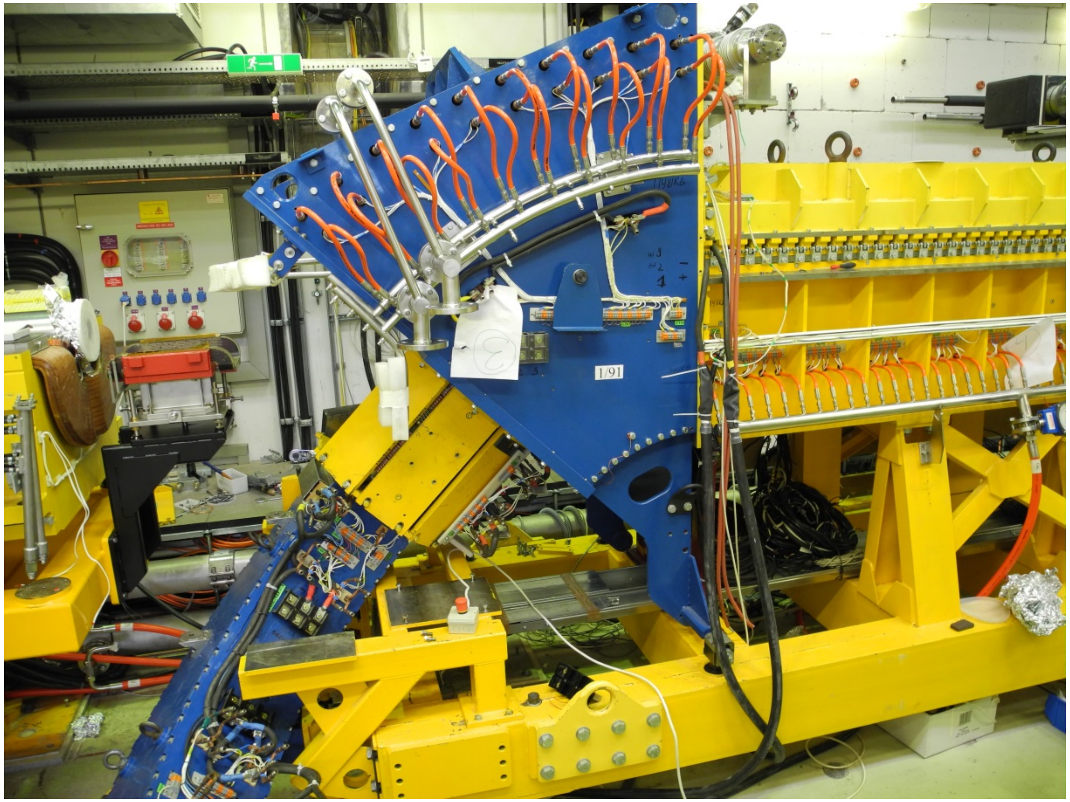


Mitglied der Helmholtz-Gemeinschaft

Installation into the COSY ring

Mitglied der Helmholtz-Gemeinschaft

Installation into the COSY ring



2 MeV e-cooler for COSY, project milestones

- 2003 first ideas and discussions
- 2004 development of prototype components started at BINP
- 2005 feasibility study
- **2005 dedicated working group on COSY 2 MeV cooler at COOL05 in Galena**
- 2005-2006 applications for funding
- 2006-2008 further reports completed (prototype of HV sections)
- **03.2009 allocation of funding**
- 07. 2009 signing the contract with BINP for the development and manufacturing of the 2 MeV cooler
- 12. 2009 CDR finished
- 2010-2012 Manufacturing at BINP
- 2012 initial commissioning with e-beam at BINP
- 12.2012 delivery to Jülich
- 04.2013 installation in COSY
- **10.2013 first beam cooling**

Mitglied der Helmholtz-Gemeinschaft

Design parameters of the 2 MeV e-cooler

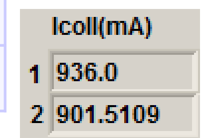
Energy range:	0.025 - 2 MeV
High voltage stability	$< 10^{-4}$
Electron current	up to 3 A
Electron beam diameter	10 - 30 mm
Cooling section length	2.7 m
Toroid radius	1 m
Magnetic field	
(cooling section solenoid)	0.5 - 2 kG
Vacuum at cooler	10^{-9} - 10^{-10} mbar

Designed and built at BINP, Novosibirsk

Current status

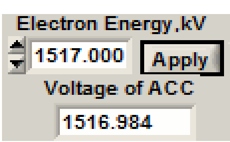
Electron cooling of proton beam

Proton energy, MeV	Electron energy, MeV	Max. electron current, A
200	0.109	0.5
353	0.192	0.5
580	0.316	0.3
1670	**0.908**	**0.9**



Electron current and energy demonstrated so far

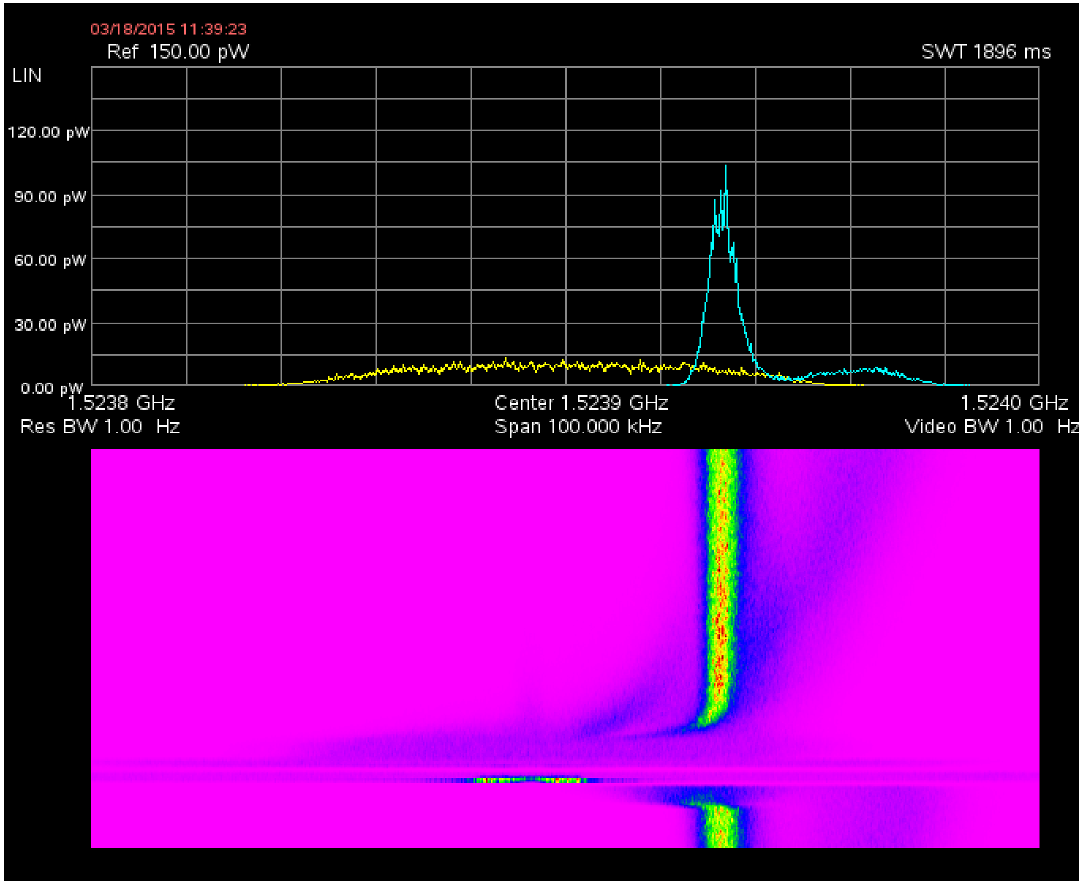
Electron energy, MeV	Electron current, A
0.024	**1**
1.25	0.2
1.5	0.09



Vacuum in the cooler 3-5·10^{-10} mbar

Mitglied der Helmholtz-Gemeinschaft

Electron cooling of a dc proton beam



final $\Delta p/p = 5 \cdot 10^{-5}$

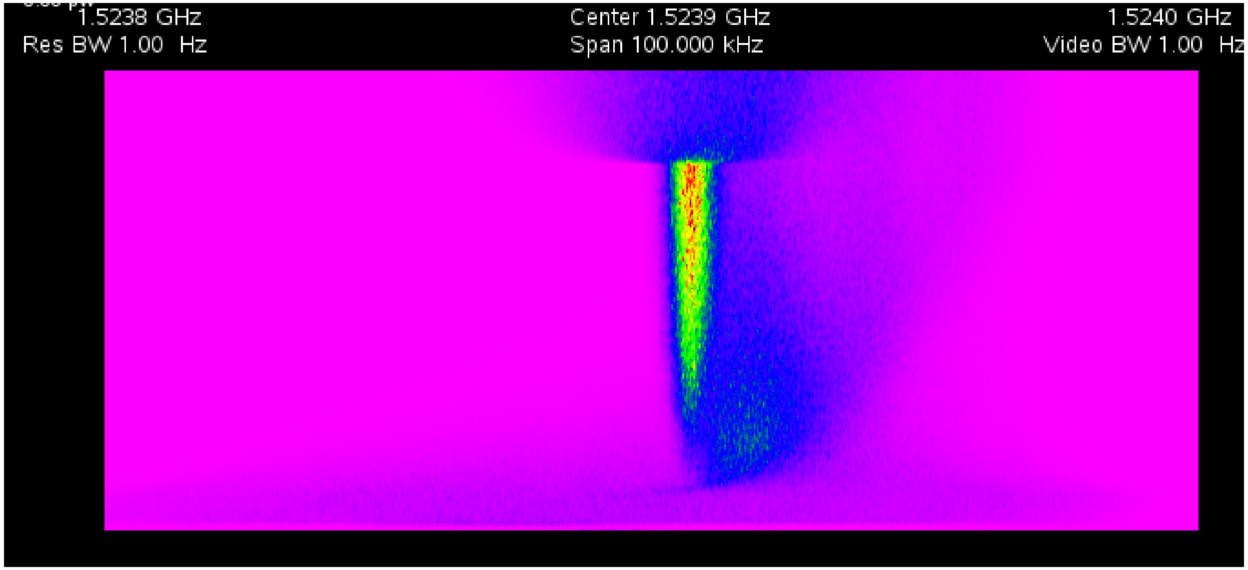
Time span of the color spectrogram 550 s

Vertical pickup of the SC system was used to measure the spectra

$5 \cdot 10^8$ protons, 1.66 GeV, electron current 0.8 A, 1.3 kG

Mitglied der Helmholtz-Gemeinschaft

E-cooling of a dc p beam, turning off EC

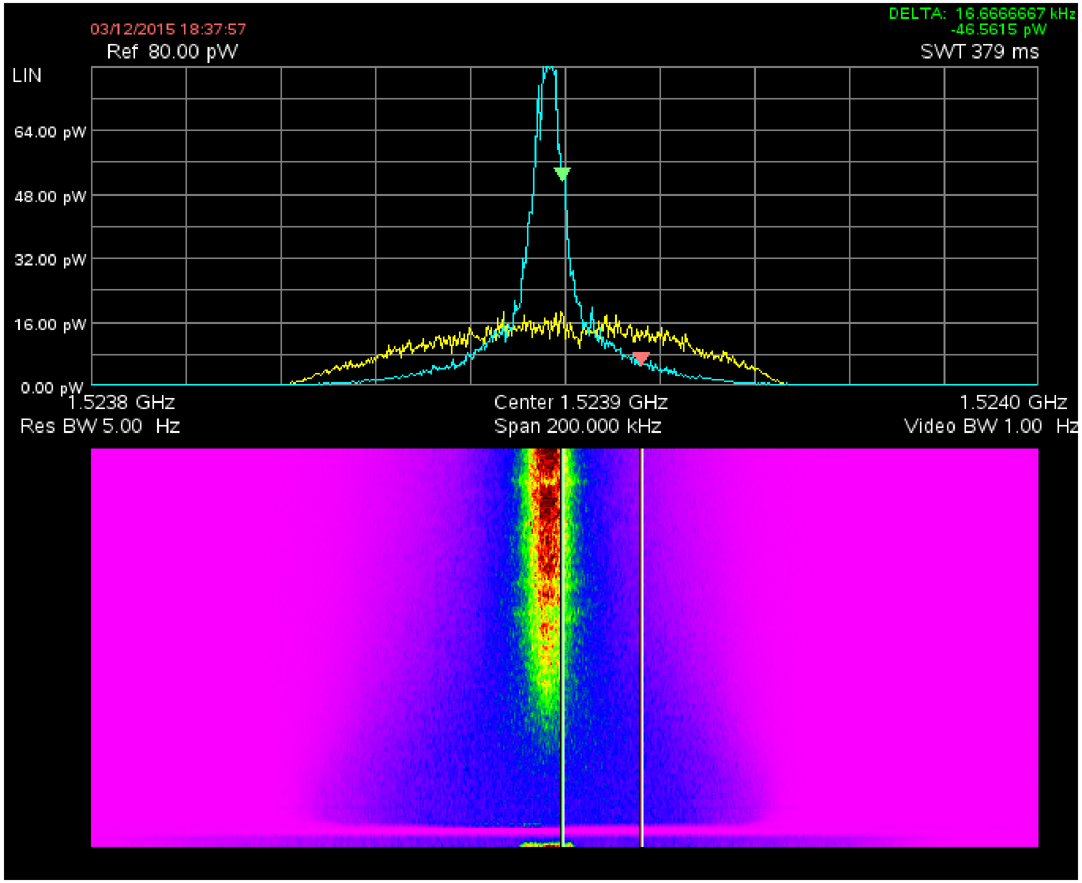


Time span of the color spectrogram 550 s

Longitudinal electron cooling process. e-beam turned off leading to fast Δp/p growth. $5 \cdot 10^8$ protons, 1.66 GeV, electron current 0.8 A

Mitglied der Helmholtz-Gemeinschaft

RF & e-cooling

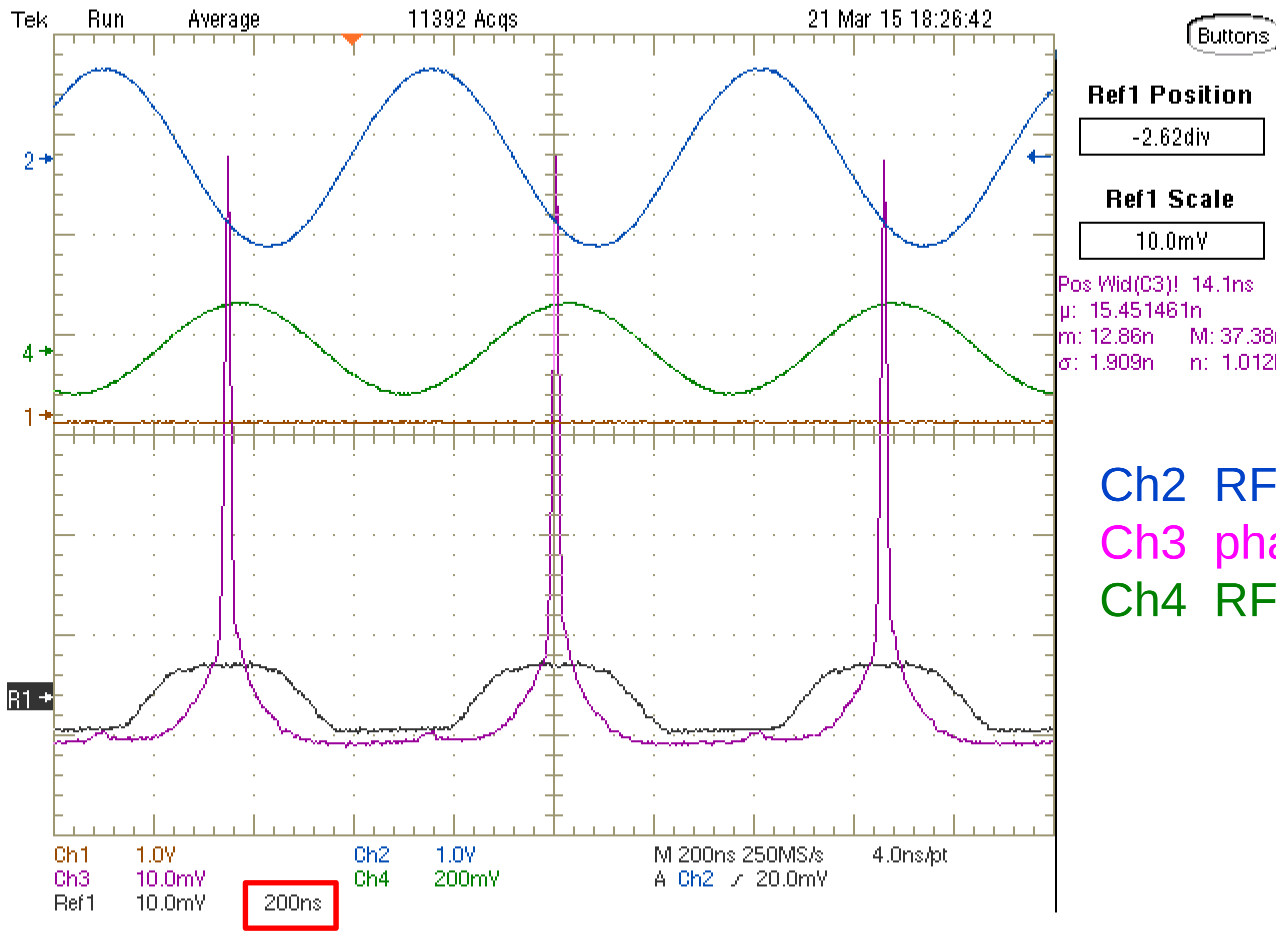


final $\Delta p/p = 10^{-4}$

RF on, e-cooling with 550 mA

Mitglied der Helmholtz-Gemeinschaft

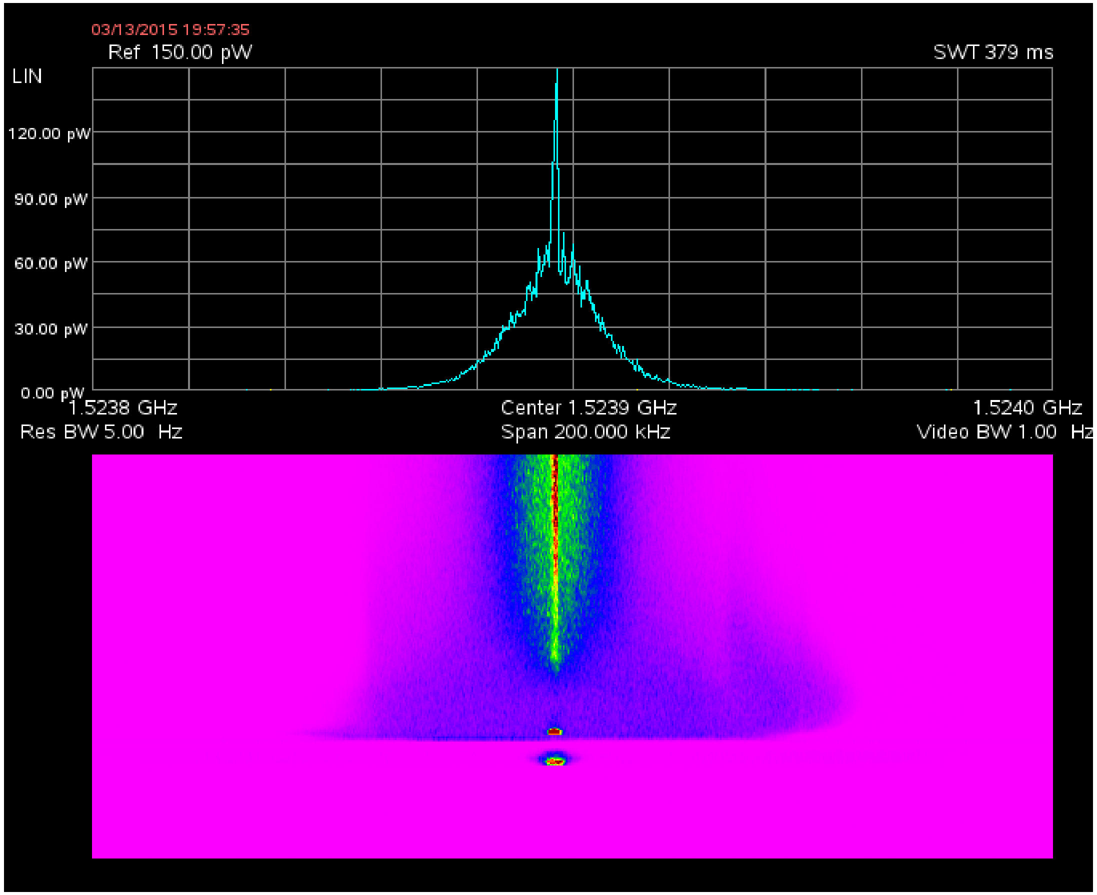
RF & e-cooling



Ch2 RF ref freq.
Ch3 phase probe
Ch4 RF gap voltage (1:1000)

Mitglied der Helmholtz-Gemeinschaft

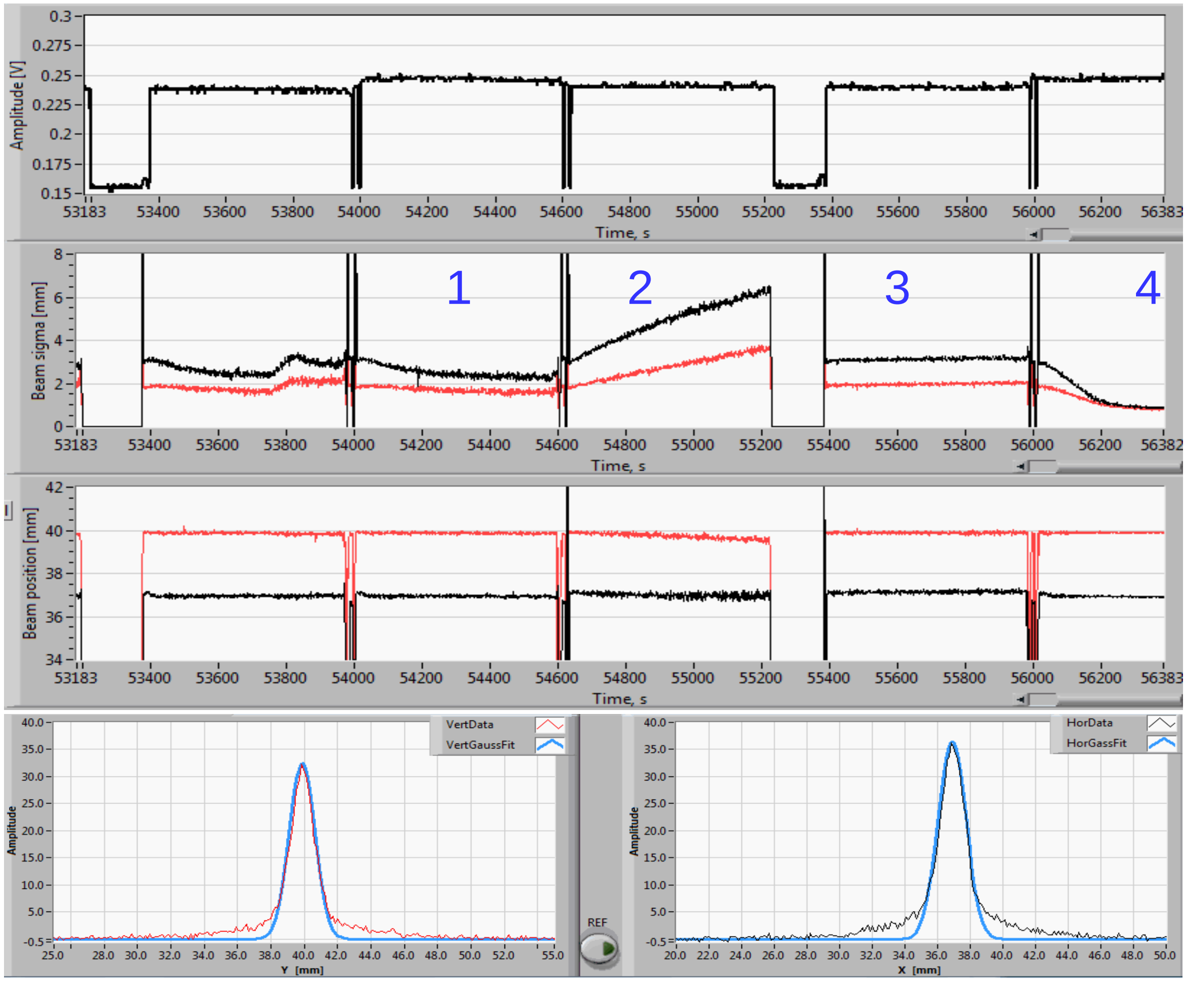
Barrier Bucket & e-cooling



Barrier bucket on (~200 V), e-cooling with 550 mA

Mitglied der Helmholtz-Gemeinschaft

Transverse e-cooling



$3.6 \cdot 10^8$ protons
1.66 GeV

$I_e = 0.8$ A
1.3 kG

1. Noise + EC
2. Noise only
3. Reference
4. EC

$\varepsilon_x = 1.1 \rightarrow 0.1$

ε_y: $=1.3 \rightarrow 0.2$

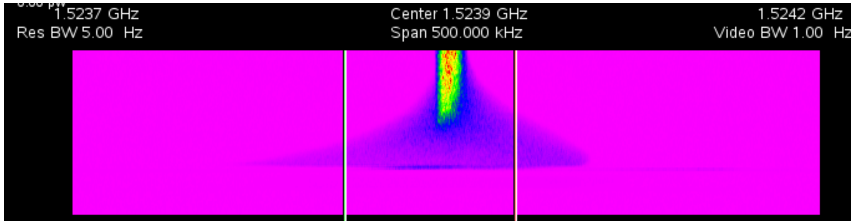
mm·mrad, normalized beam core

within 200s

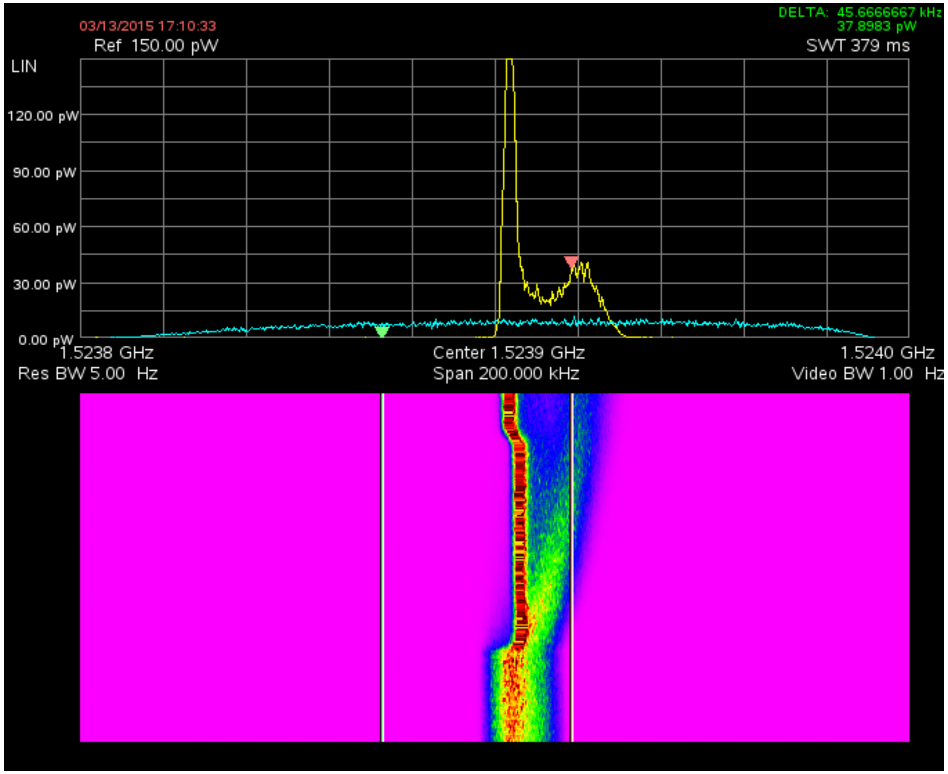
IPM screenshot

Mitglied der Helmholtz-Gemeinschaft

Electron and stochastic cooling



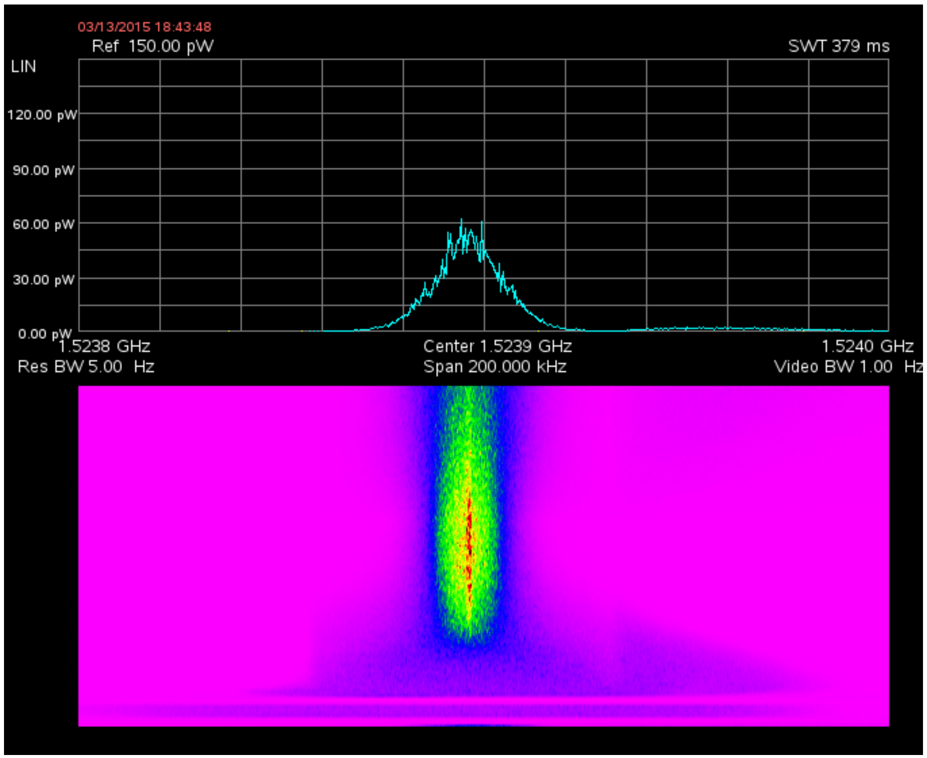
initial noise + e-cooling at 400 mA + stochastic cooling. Time span 220 s.



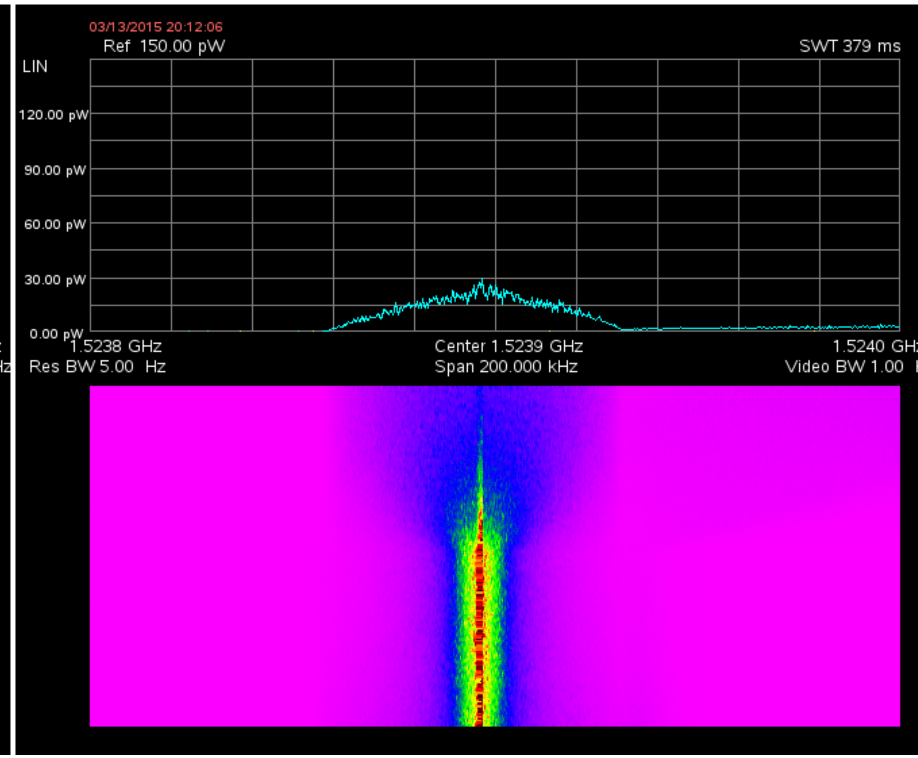
e+st. cooling. SC off, e-beam energy changed by +30 V (909.03 kV)

Mitglied der Helmholtz-Gemeinschaft

BB, e + st. cooling and pellet target



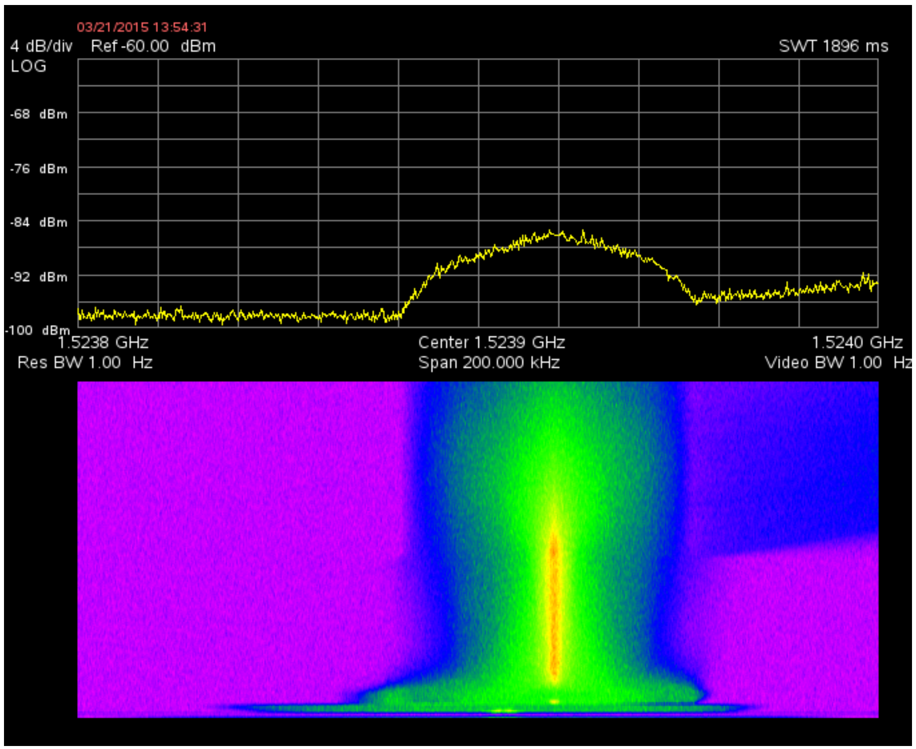
Barrier bucket + e & st. cooling + target (after cooling finished)

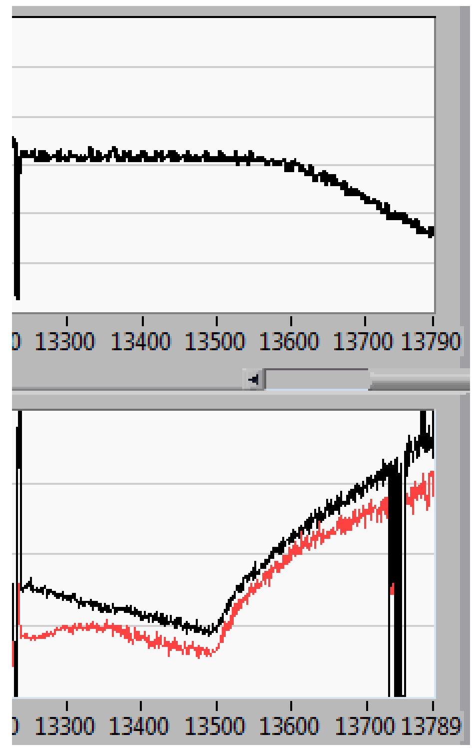


e-cooled beam + BB on + target, then EC off.

Mitglied der Helmholtz-Gemeinschaft

BB, e + st. cooling and pellet target





Beam current

hor. width
vert. width

e-current 0.8 A, barrier bucket.   Need higher BB voltage?

Mitglied der Helmholtz-Gemeinschaft

Summary of the March 2015 beam time

- Due to hardware issues (EC & COSY) there was not enough time to go for higher energy and different magnetic field
- Better e-beam diagnostics and correction schemes allowed for faster cooling
  - $\Delta p/p$ = 5e-5 in less than 100 s
  - $\varepsilon_x = 1.1 \rightarrow 0.1$, ε_y: $=1.3 \rightarrow 0.2$ mm·mrad, within 200s (beam core)
- EC works well together with stochastic cooling, RF, BB
- Application of simultaneous stochastic and EC aided by the barrier bucket system to suppress $\Delta p/p$ and emittance growth due to a pellet target operation
  - Longitudinal losses observed, $\Delta p/p$ = const.
  - Transverse: the cooling at current settings was not powerful enough to prevent emittance growth
- Successful compensation of emittance growth due to “virtual target” (noise excitation) using EC

Mitglied der Helmholtz-Gemeinschaft

Lessons learned

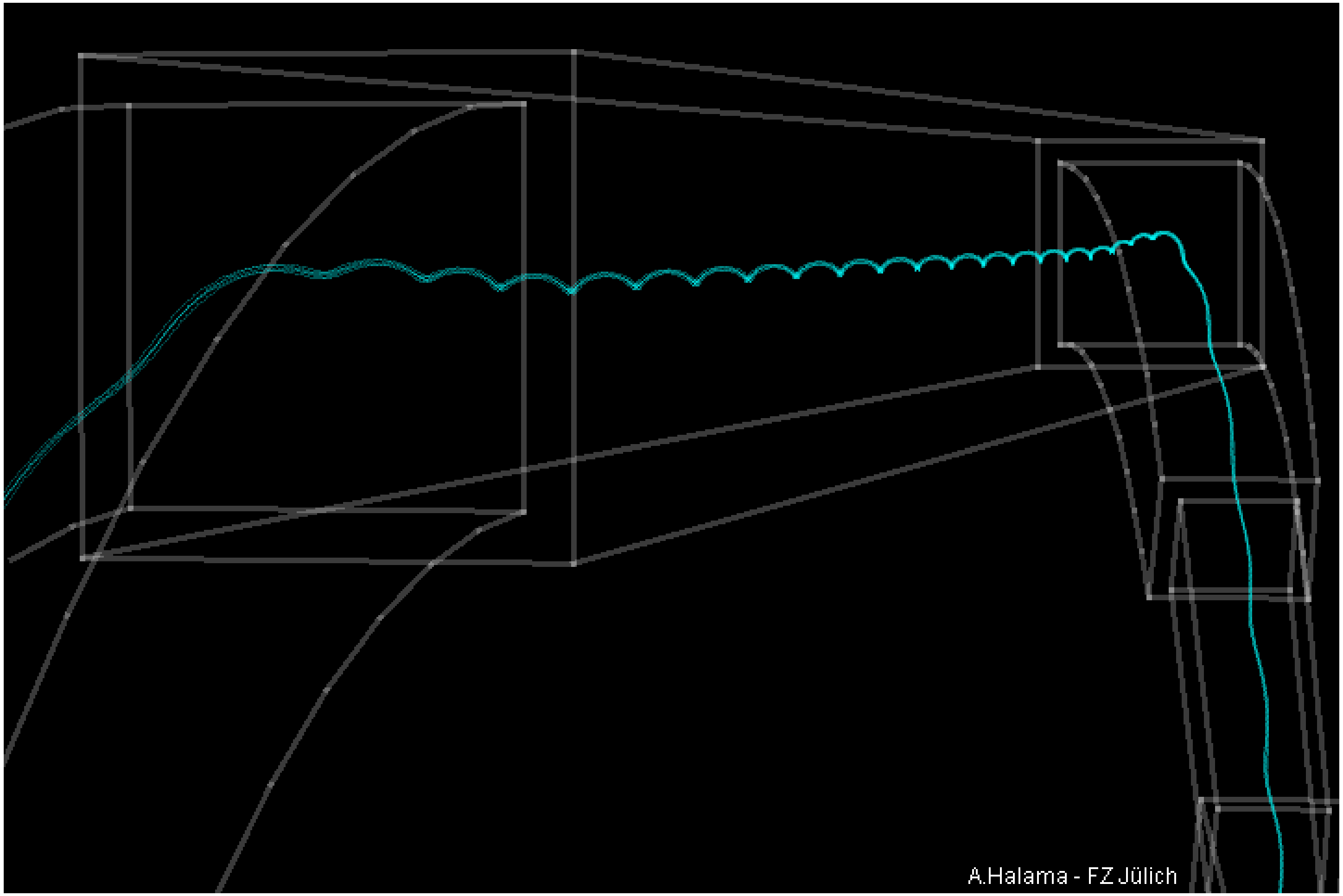
- Parameter space is too large to tune manually, need model-based setup
  - Change of energy, magnetic field, e-orbit, e-current results in significant retuning
- A detailed 3D model of the magnetic system (as is) is a must
  - Systematic studies of cooling time vs energy and magnetic field
- E-beam instrumentation is crucial for understanding e-beam quality and thus cooling process
  - BPMs
  - Sector e-gun
  - Adjustable e-beam profile
- Automated measurement and correction of the e-beam Larmor oscillations significantly shortened setup time and improved cooling performance

Mitglied der Helmholtz-Gemeinschaft

JÜLICH
FORSCHUNGSZENTRUM

Model development

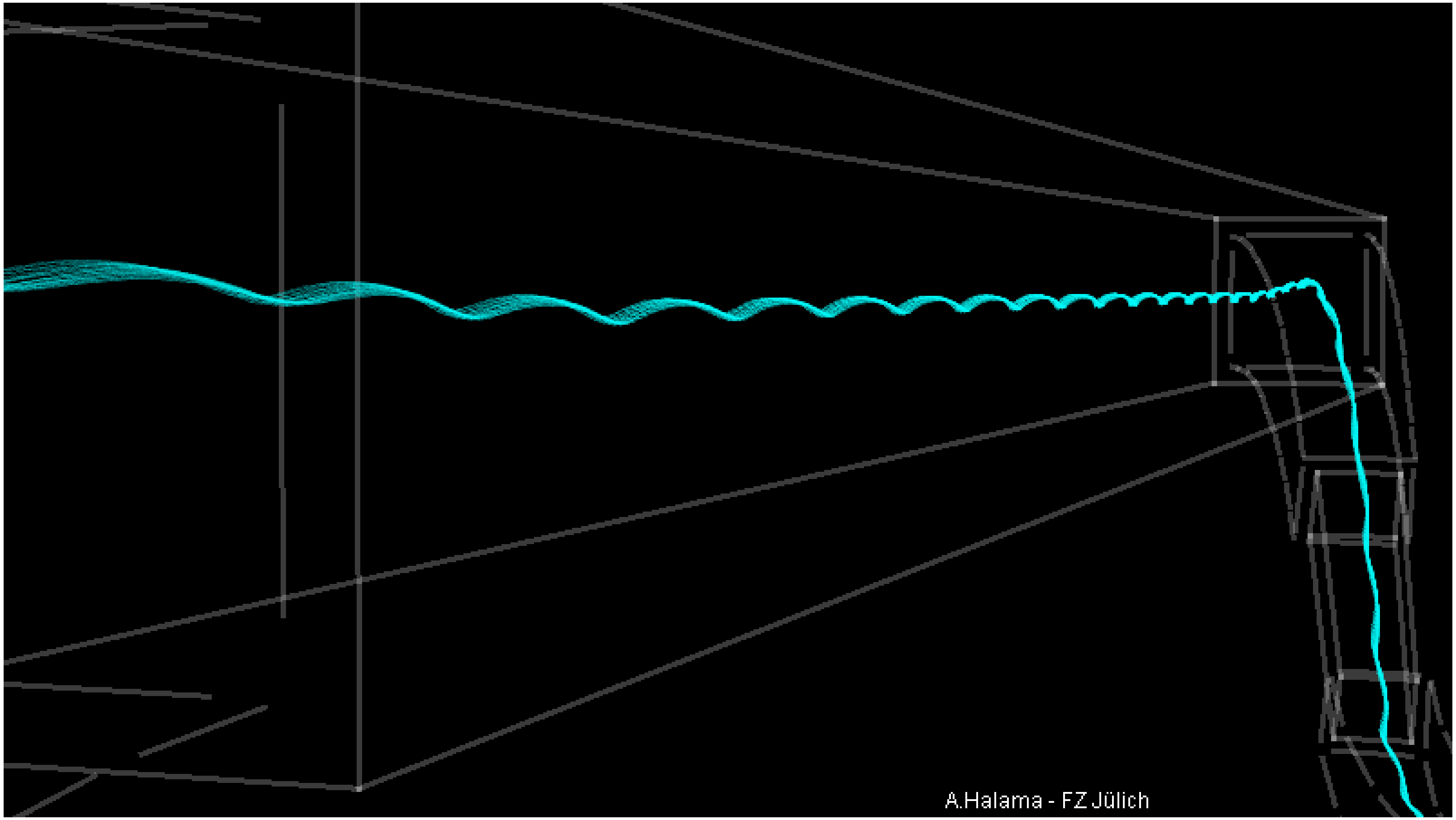
UNDER CONSTRUCTION



EDIP

Mitglied der Helmholtz-Gemeinschaft

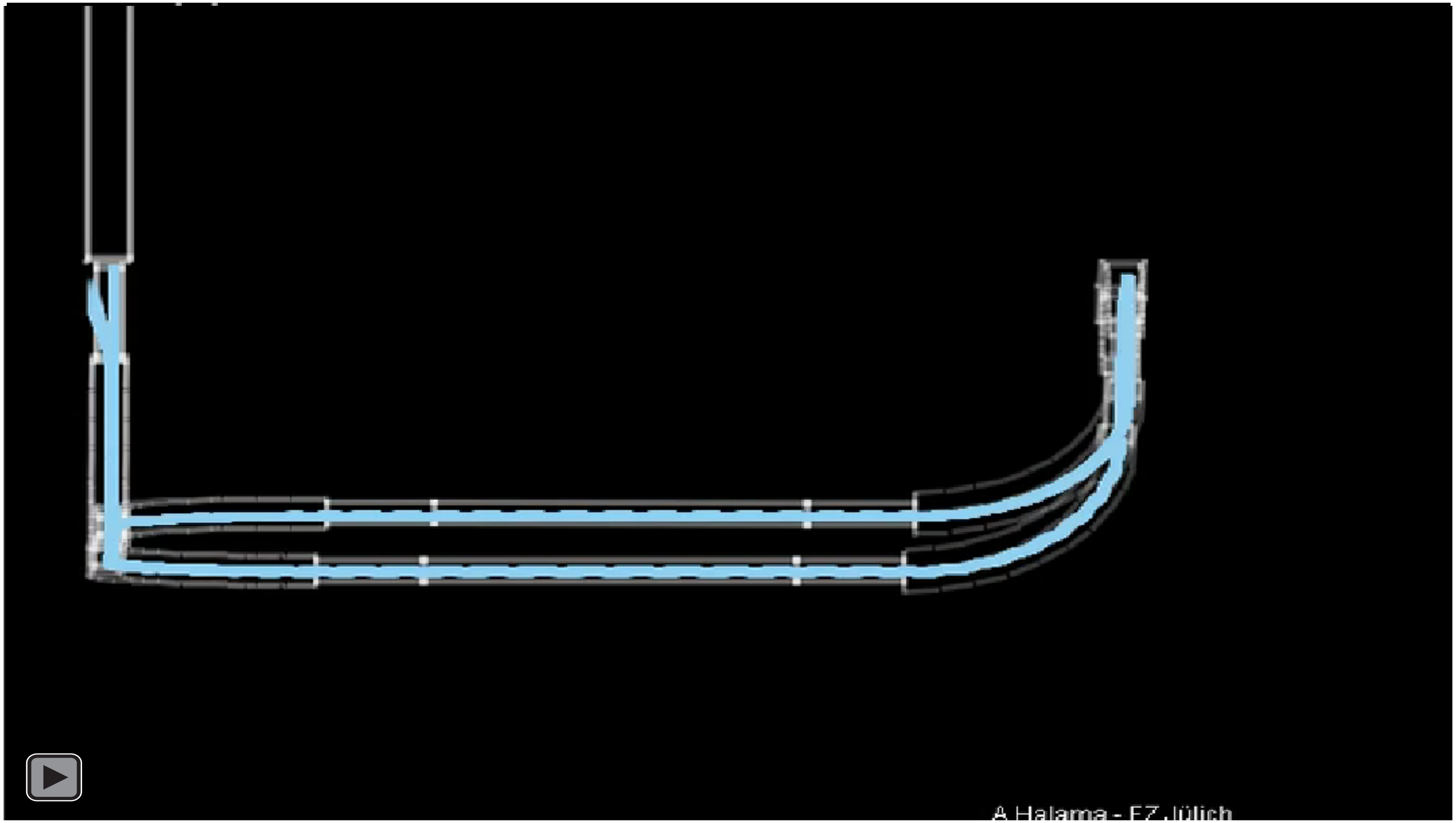
Model of the e-cooler



EDIP

Mitglied der Helmholtz-Gemeinschaft

Model of the e-cooler



Mitglied der Helmholtz-Gemeinschaft

Summary

- The 2 MeV electron cooler at COSY is a unique device as it combines high energy and high magnetic field
- Low intensity 1.6 GeV proton beam was cooled within:
  - 100 s longitudinally
  - 200 s transverse
- Need to establish model-based automated e-beam setup procedures (work in progress) to carry out systematic studies on cooling time vs energy and vs B under reproducible conditions

even shorter cooling time?

Mitglied der Helmholtz-Gemeinschaft

Thank you

Mitglied der Helmholtz-Gemeinschaft

Backup slides

Mitglied der Helmholtz-Gemeinschaft

Plans / work in progress

Proton + electron beams are required:

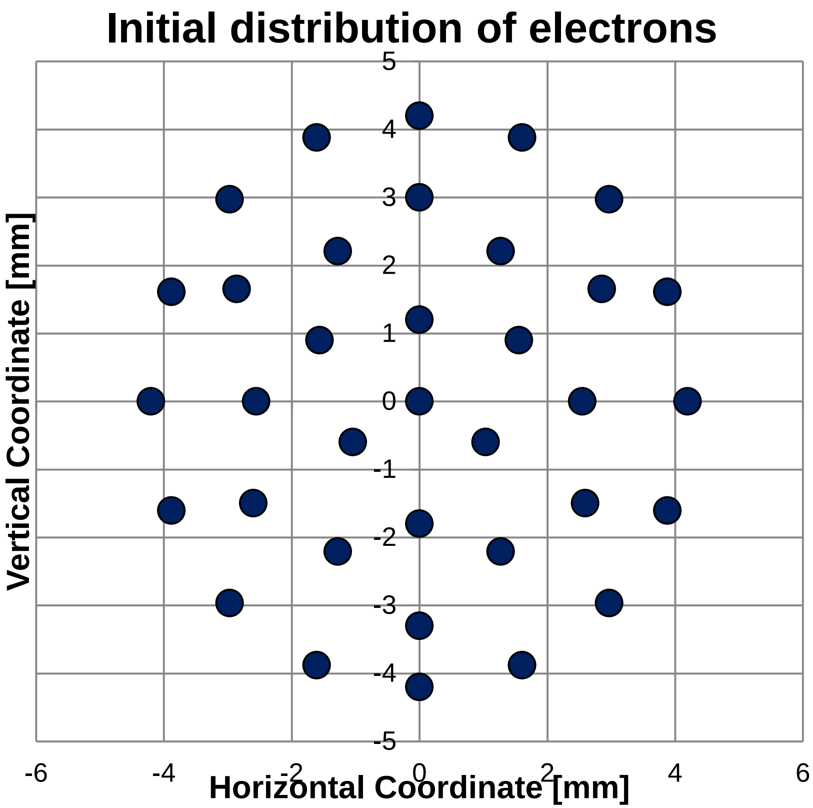
- Acquire experimental data on how the cooling rate scales with energy and compare with simulation results
- Investigate cooling performance in presence of internal cluster target
- Study/optimize interaction of the accelerator and the cooler
- Study intensity/impedance effects
- Explore simultaneous electron and 3D stochastic cooling in more detail
- Incorporate the cooler into the COSY model and perform beam tests

Electron beam only is required:

- Implement model-based techniques for setting up the cooler
- Commission “virtual operator” software
- Continue HV conditioning
- Further improve straightness of the magnetic field in the cooling section

Mitglied der Helmholtz-Gemeinschaft

Simulations



Magnetic fields used in the simulation shown on slide 20
IST_COOL, SETTING: 53.04 A
IST_TOROID, SETTING: 146.88 A
IST_LONGITUDINAL, SETTING: 56.01 A
IST_STRAIGHT, SETTING: 56.01 A
IST_BENDING, SETTING: 21.33 A

EDIP 5.5 A and 6.0 A

Matching coils for the simulation shown on slide 21
5.11, 1.91, 4.05, 1.67, 5.27, 2.19, 6.00
Arbitrary numbers for demonstration purposes

Model and simulations by Arthur Halama

Mitglied der Helmholtz-Gemeinschaft

Mitglied der Helmholtz-Gemeinschaft

Beam instrumentation

As electron cooling is inherently a 3D process, longitudinal and transverse proton beam diagnostics is essential for understanding the cooling dynamics

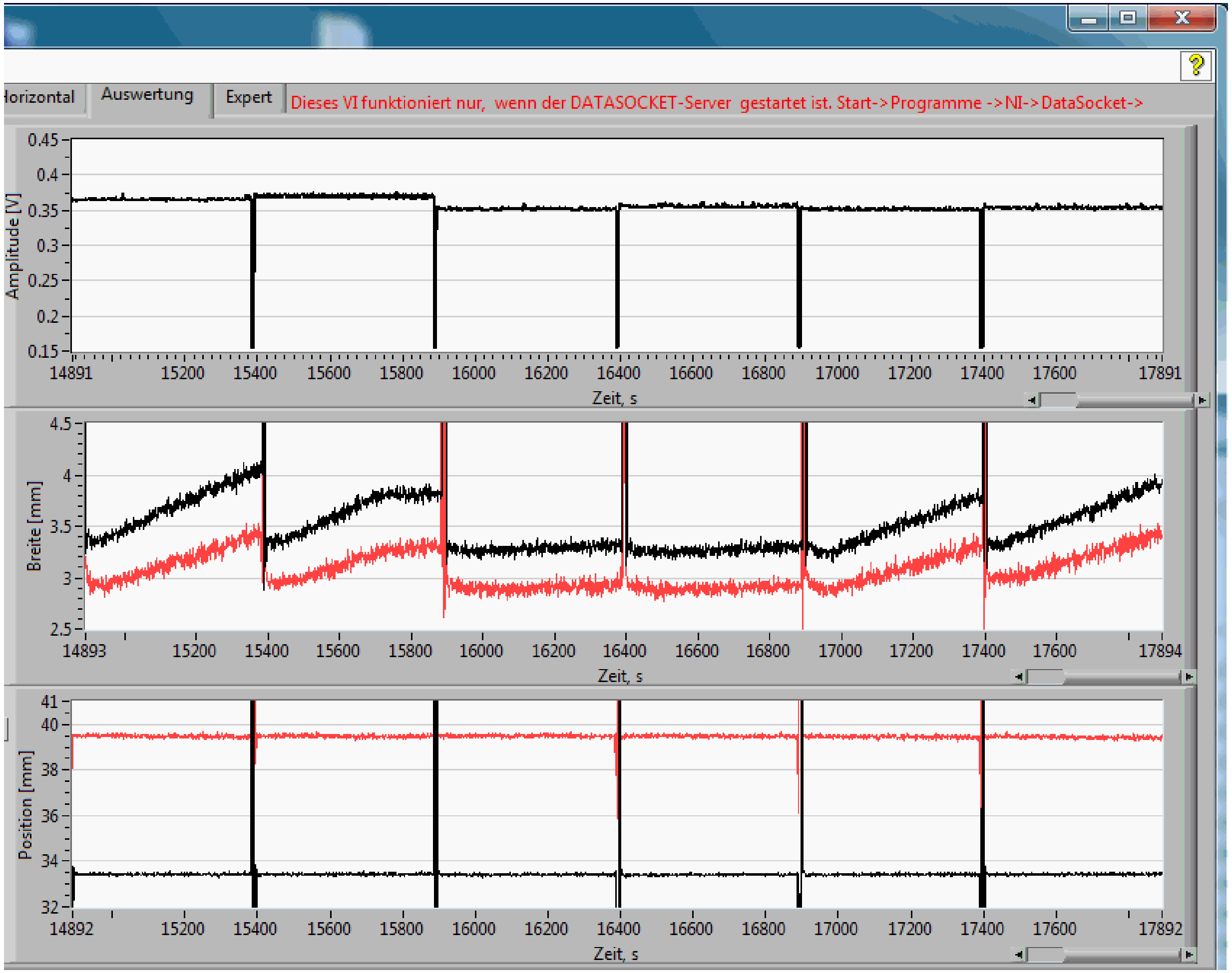
At COSY non-destructive beam instrumentation is readily available

- Stochastic cooling pickups (medium and high energy)
- Standard BPM pickups (any energy)
- Bunch length / phase monitor
- Ionization beam profile monitor (H+V)
- H^0 diagnostics (count rate)

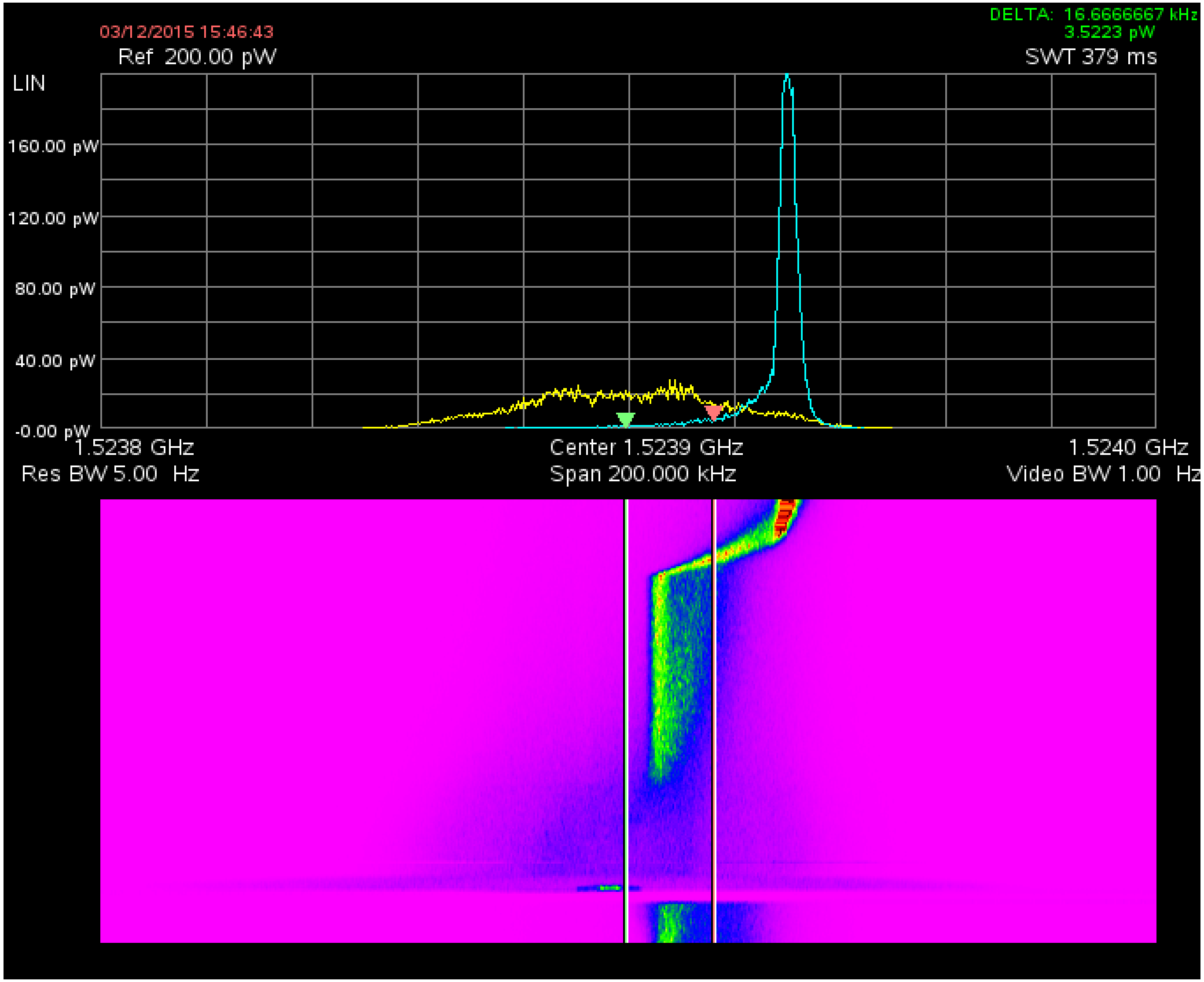
The e-cooler is equipped

- 12 BPMs
- Sector e-gun, helps making galloping effects visible
- Option to vary e-beam profiles

Broken power amplifier exciting the beam

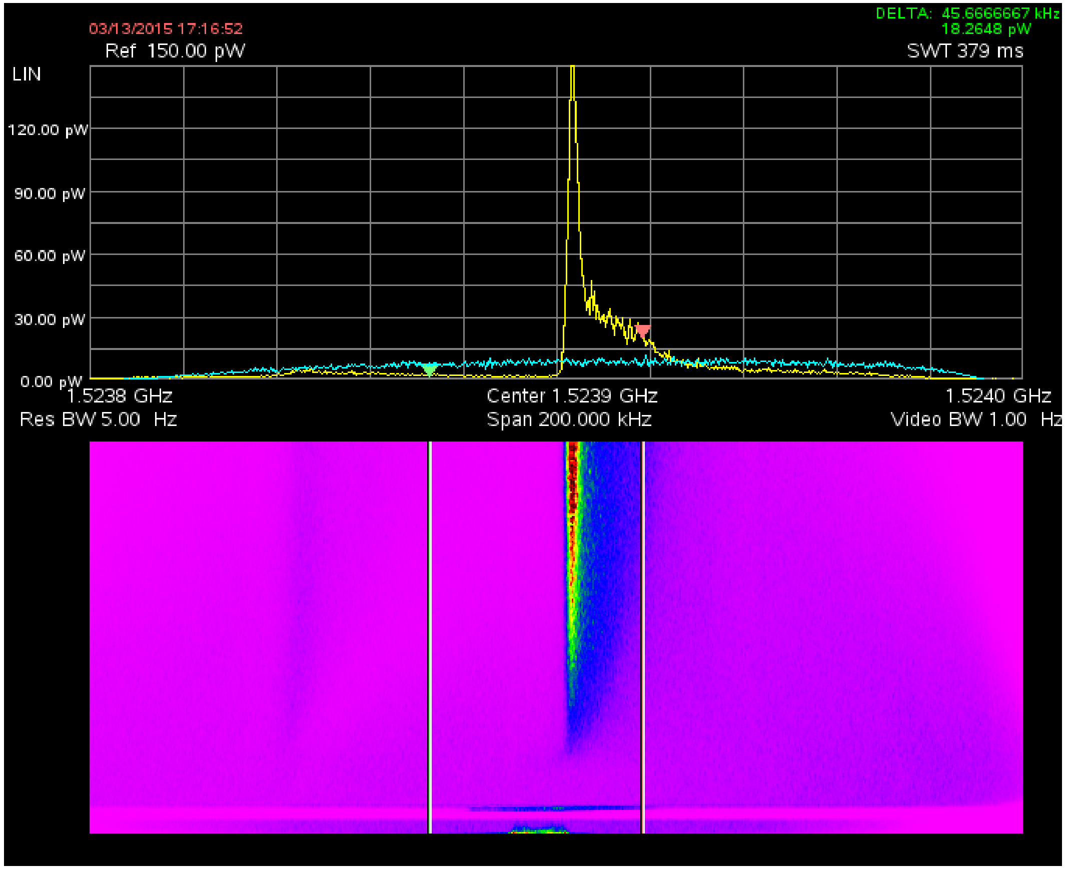


Mitglied der Helmholtz-Gemeinschaft



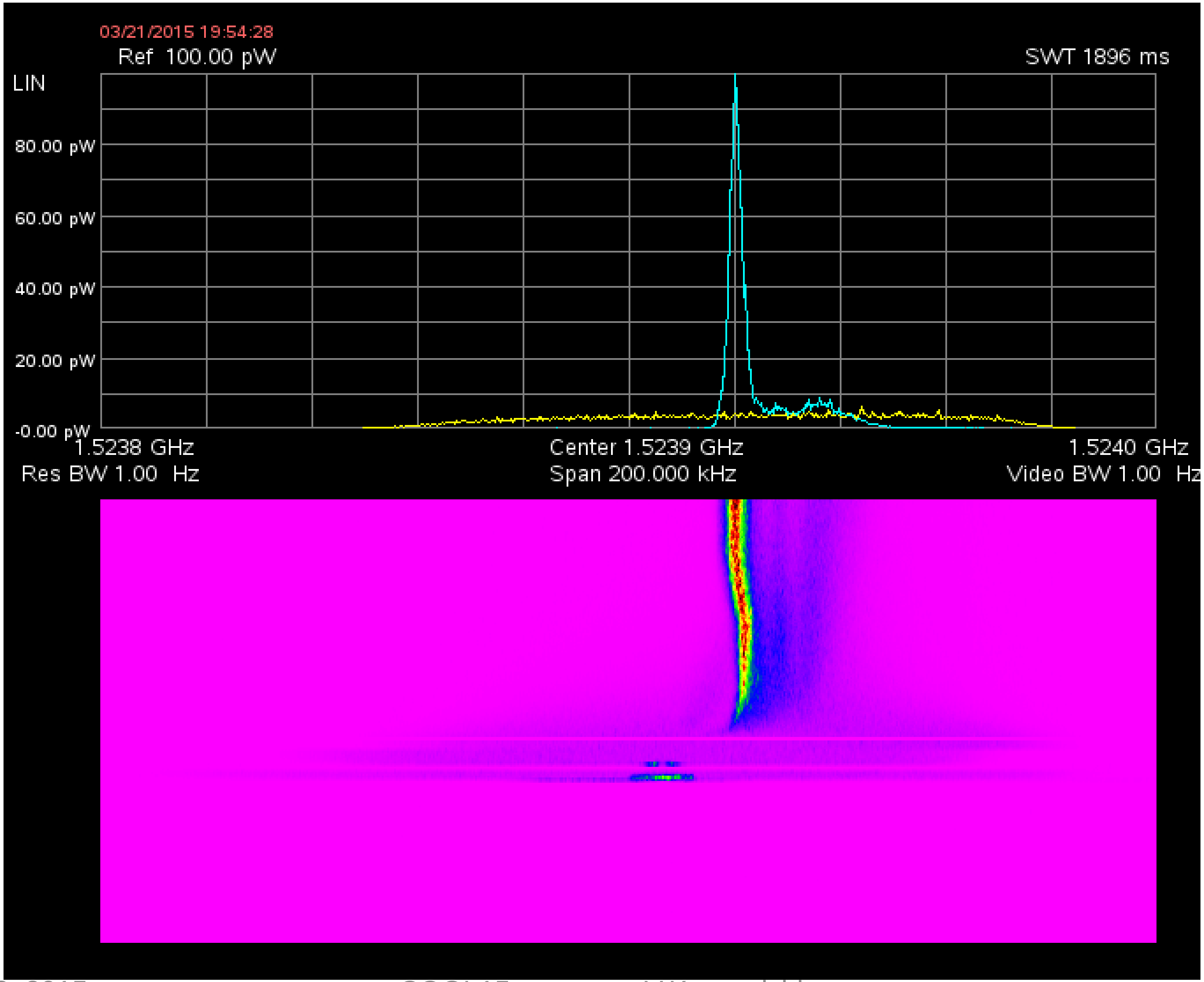
Mitglied der Helmholtz-Gemeinschaft

Experimental results, dc beam & e-cooling

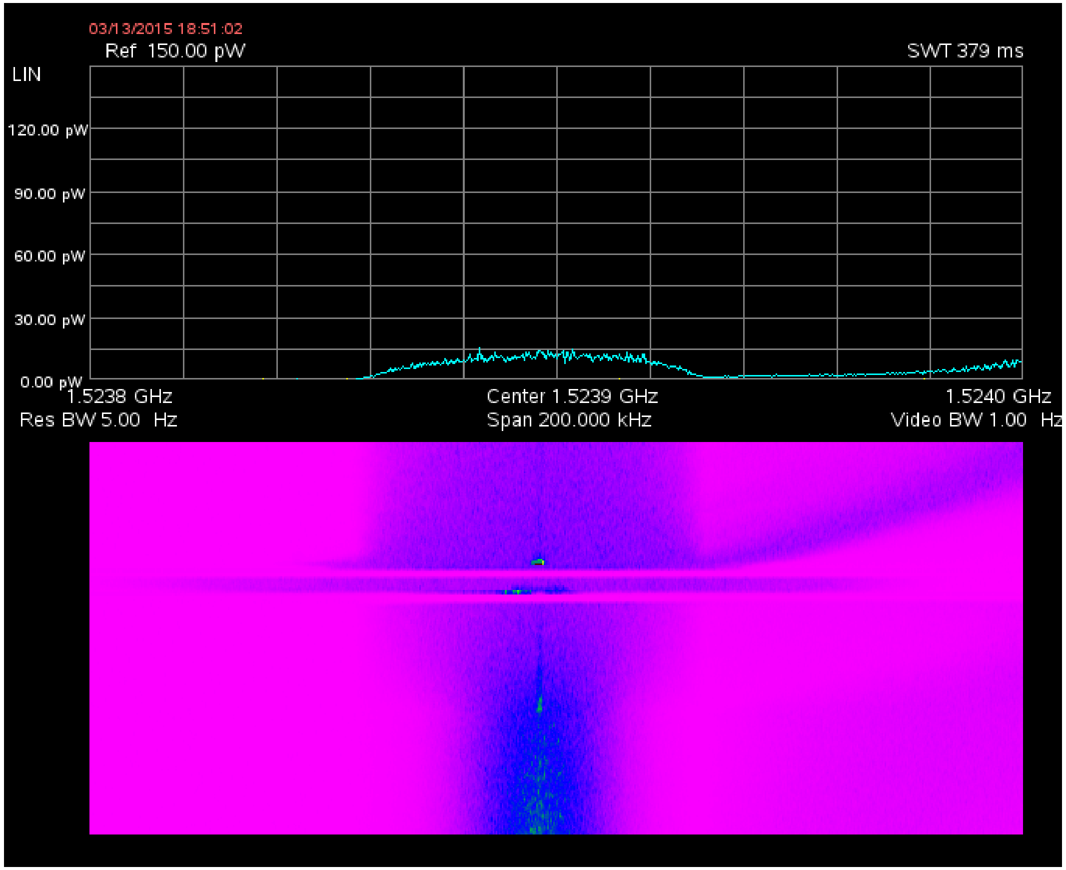


initial noise + electron cooling at 400 mA @ 909.03 kV

Mitglied der Helmholtz-Gemeinschaft

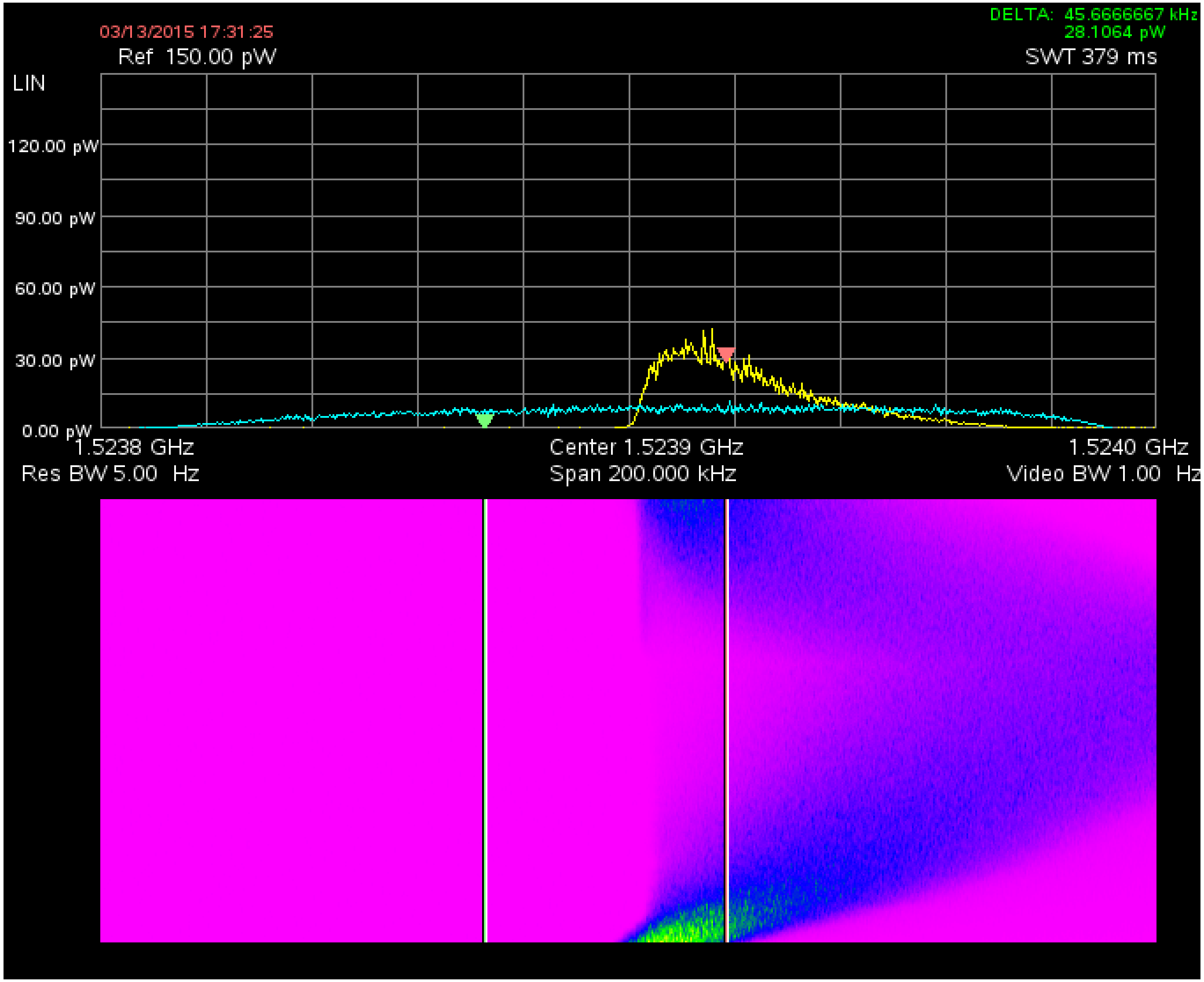


Mitglied der Helmholtz-Gemeinschaft



no cooling, BB on, target on, particles escaping from the BB are clearly seen

Mitglied der Helmholtz-Gemeinschaft



e+st cooling on, then pellet target (WASA) on, later target off, the beam is cooled again by st. cooling

Mitglied der Helmholtz-Gemeinschaft