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Use of Schottky analysis to specify various particle beam properties in different accelerator applications at COSY

ARIES Workshop 2018, CERN, Mai 14th- 16th 2018

Bernd Lorentz for IKP4, COSY, Forschungszentrum Jülich

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Use of schottky measurements at COSY

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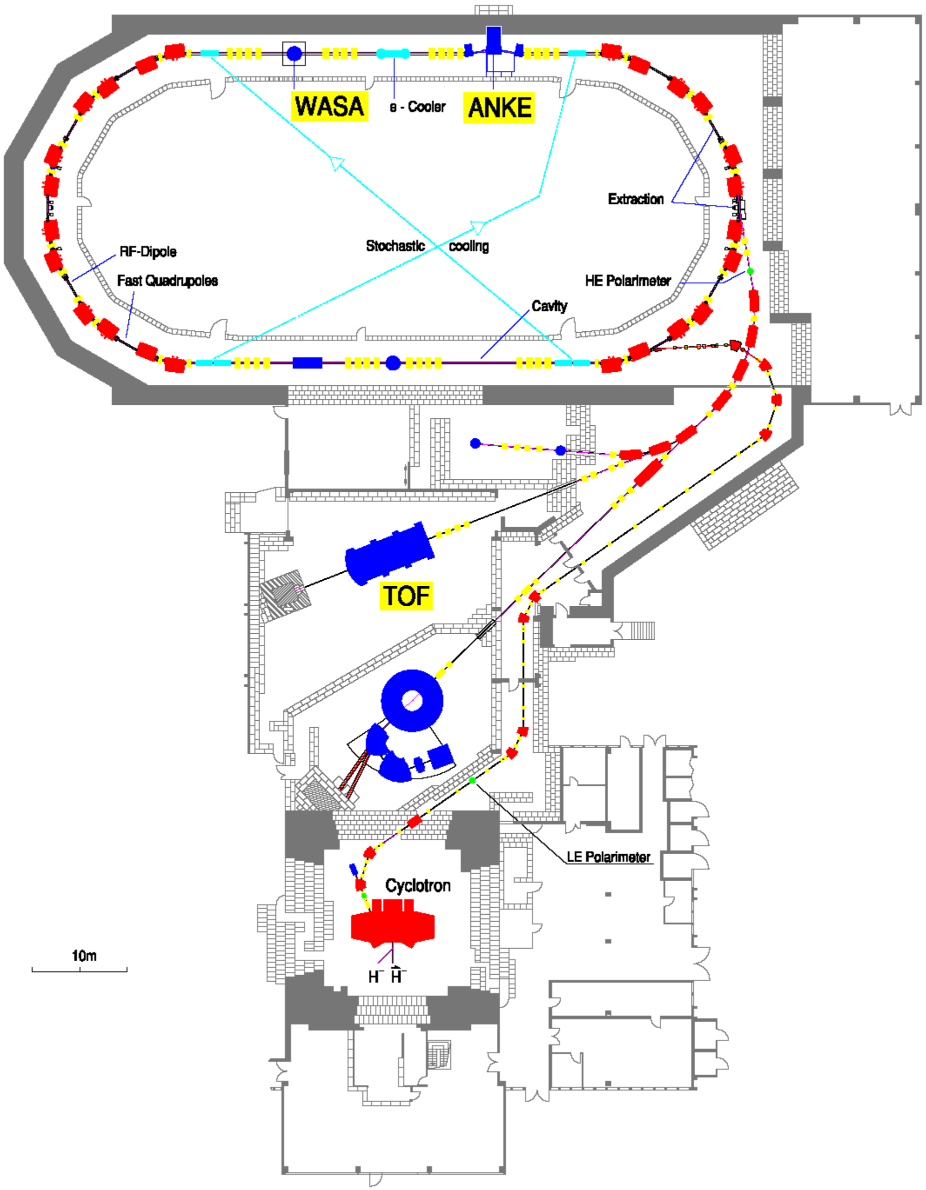
for IKP4, COSY, Forschungszentrum Jülich

Cooler Synchrotron (COSY)



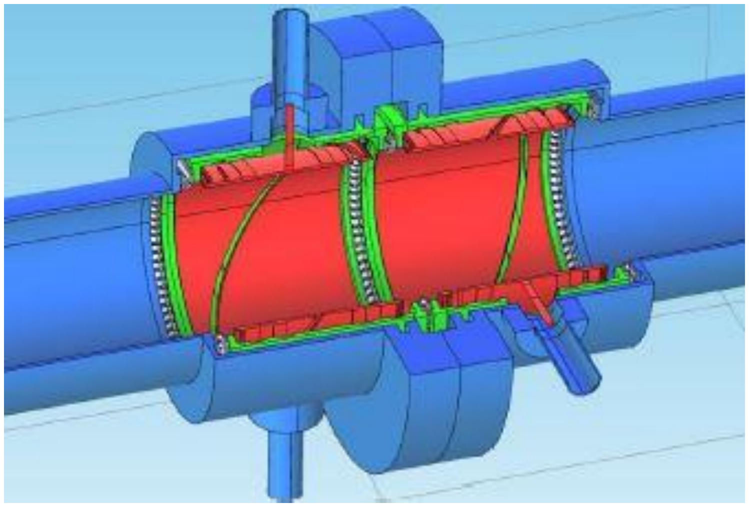
- **COSY**
- circumference 184 m
- (un)polarized protons / deuterons between 300/600 and 3700 MeV/c
- 4 internal and 3 external experimental areas
- 100 kV electron cooling for low momenta
- new 2MV electron cooling over full p-range
- Stochastic cooling at high momenta (β>0.8)

Outline

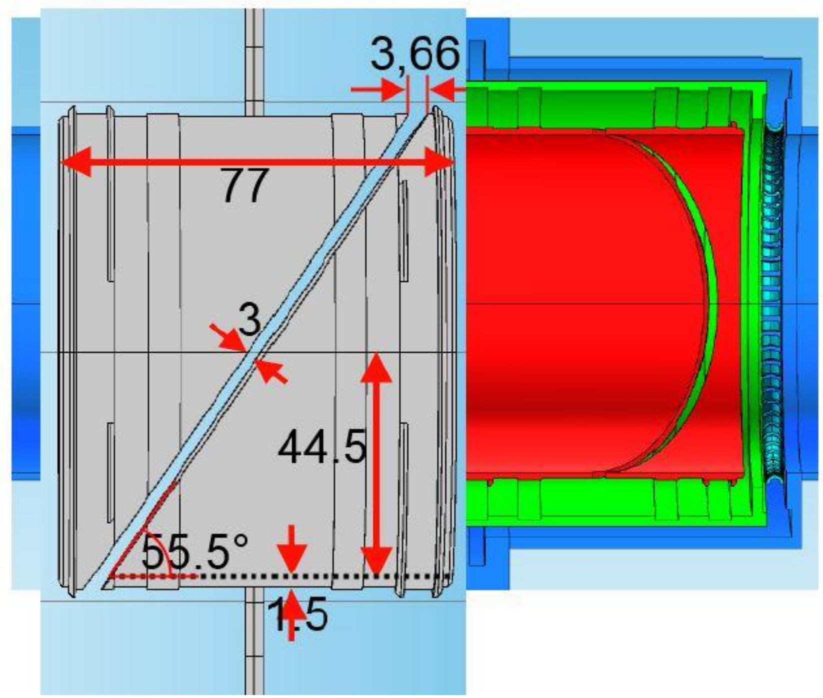
- Pickups
- Regular Use of Schottky Signals
- Dedicated Applications
  - Stochastic Extraction
  - Electron Cooling
  - Stochastic Cooling
  - Internal Target Experiments
  - Polarized beam

Pickups

1.) Standard beam position monitors: diagonally cut cylindrical electrodes



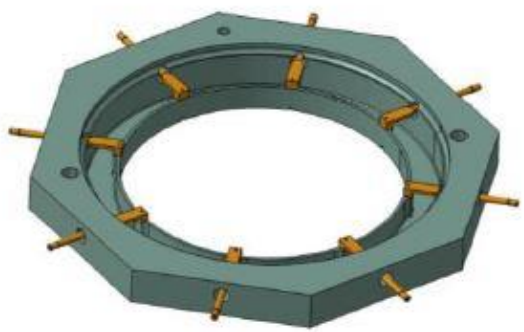
Sum Signal used for regular Longitudinal schottky measurements
Preamplified signal analyzed with R&S Spectrum Analyzer FSV
(Transverse signals available, usually too small in amplitude)



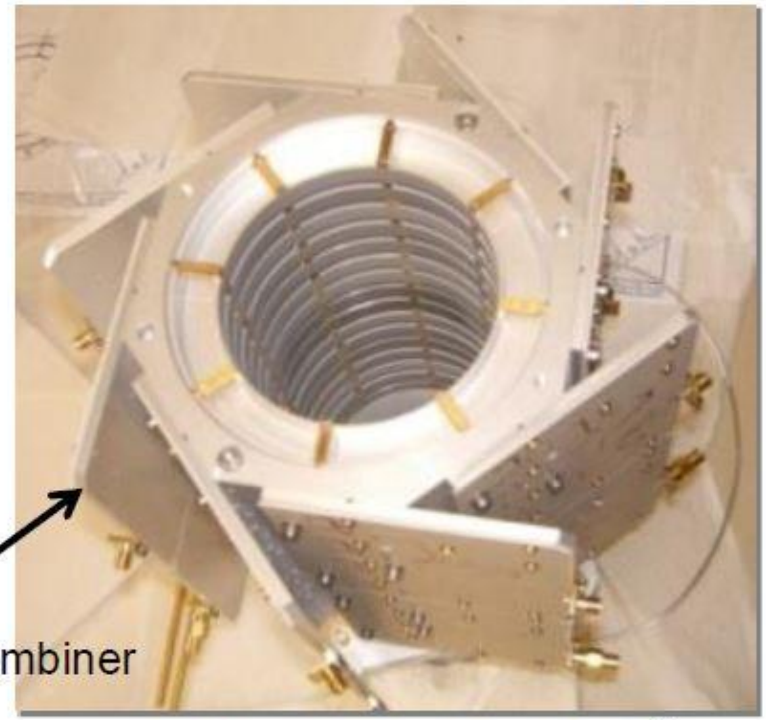
Pickups

2.) Stochastic Cooling Pickups (HESR design, installed and in operation at COSY)

Slot Coupler Cell (2 – 4) GHz:
Eight electrodes per ring



Pickup/Kicker ***Ring Slot Coupler***



16:1 Combiner

R. Stassen, L. Thorndahl *):

- High sensitivity
- Transverse and/or momentum cooling
- Compact design
- No movable parts
- Successfully tested with beam at COSY and Nuclotron (JINR)

*) R. Stassen et al., Proc. of IPAC12, New Orleans, Louisiana, USA

Pickups

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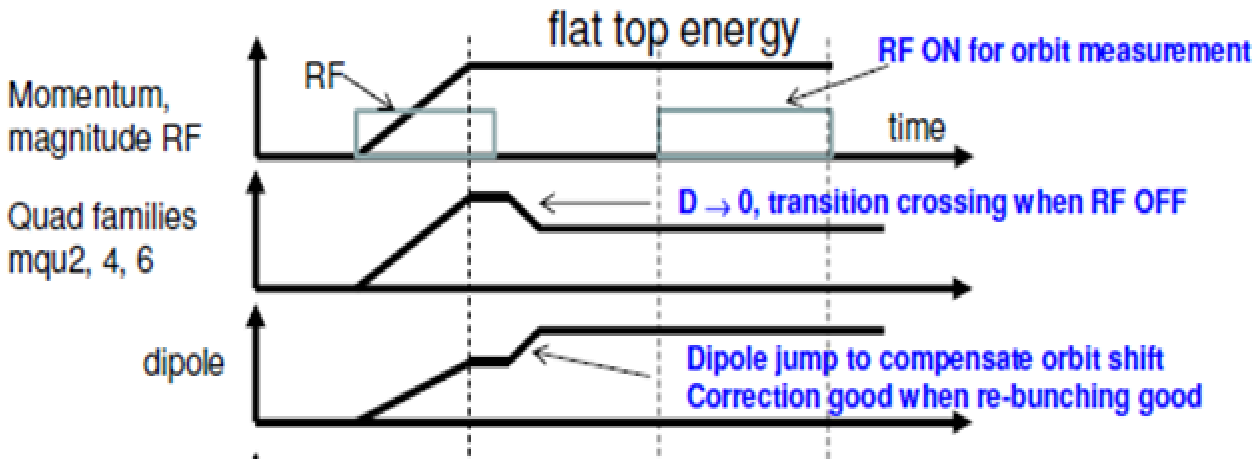
2.) Stochastic Cooling Pickups (HESR design, installed and in operation at COSY)

original

new

longitudinal and transverse schottky measurements, restricted to designed operation range of stochastic cooling system (β>0.8)
Signal Analysis R&S Spectrum Analyzer FSV

Regular Use of Schottky Signals
Standard Cosy acceleration and optics setup



Beam optics is changed during acceleration to avoid crossing of γt
For experiments (both internal and external) adjustment of optics at flat top
Crossing of gt after acceleration is practically always needed
Procedure:
- debunching of beam - optics change to required settings (with γt crossing, coasting beam) -rebunching

In principle rebunching without problems, only change is optics, i.e. quadrupole strength
However: quadrupole changes are large (e.g. 20 %), unavoidable transverse offsets of beam in quadrupoles lead to change of revolution frequency

$\Rightarrow$ Schottky signals used to correct orbit changes and match the cavity frequency
$\Rightarrow$ Enables rebunching without any beamloss

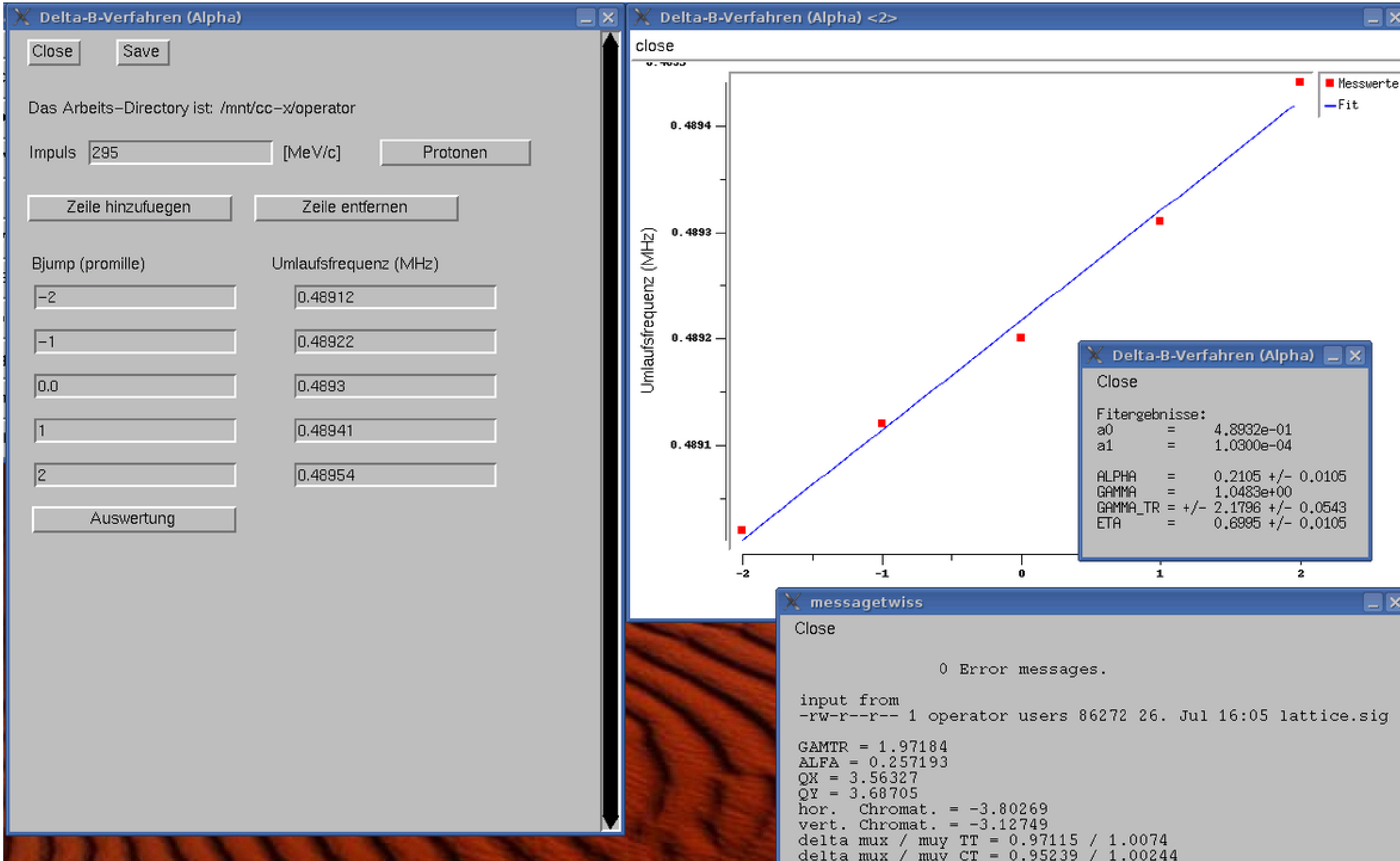
Regular Use of Schottky Signals

Standard Cosy Operation Modes:
Injection at 45 MeV for protons, 55 or 75 MeV for Deuterons from JULIC Zyklotron
stripping Injection over 20 ms, coasting beam
injection settings for Cosy Magnets vary
(dependend on final momentum for experiment)

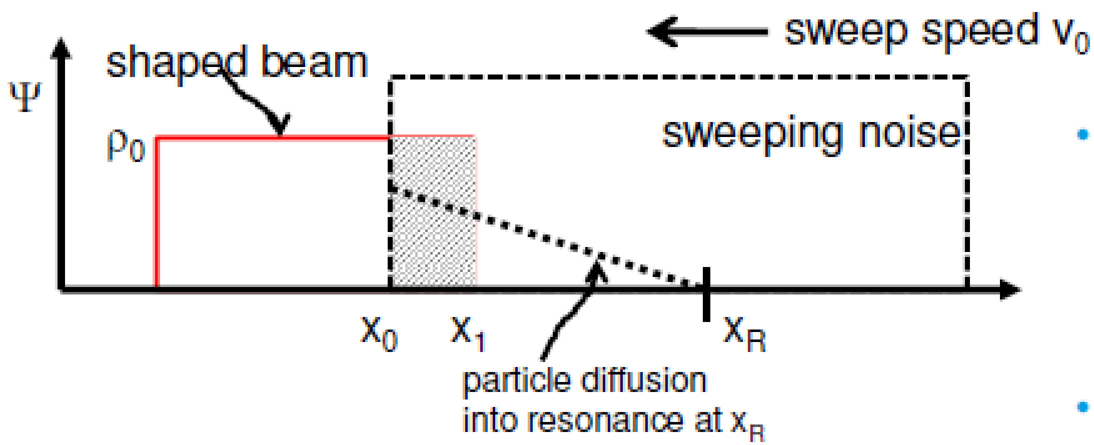
=> revolution frequency varys:
schottky signals of injected coasting beam are used for matching of
cavity frequency

Measurements of momentum compaction factor

Change of main dipole bending field B by ΔB/B is equivalent to change of momentum by Δp/p



Stochastic Extraction



- Band-limited white noise permanently covering the resonance is swept over the beam with speed v_0.
- Diffusion equation with diffusion coefficient D

In the vicinity of the resonance:

$$\Psi_0(x) \approx -\frac{v_0 \cdot \rho_0}{D}(x - x_R) \qquad \Rightarrow \quad \Psi_0(x_R) = 0$$

- The number of particles that are extracted per sec is given by

$$\Phi_{ex}(t) = \Phi(x_R, t) = -D \cdot \frac{\partial}{\partial x} \Psi(x_R, t)$$ and yields the **constant flux** $\Phi_{ex}(t) = \Phi_0$

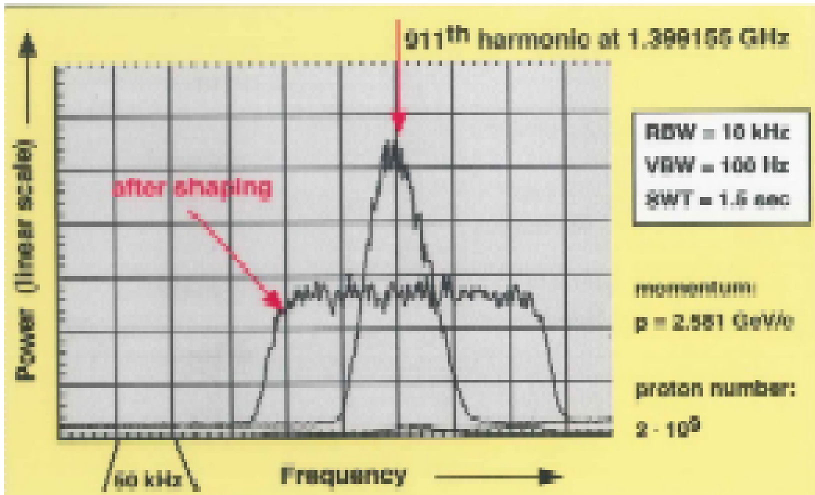
W. Hardt, “Remarks on Stochastic Extraction”, PS/DL/Note 78-5

Stochastic Extraction

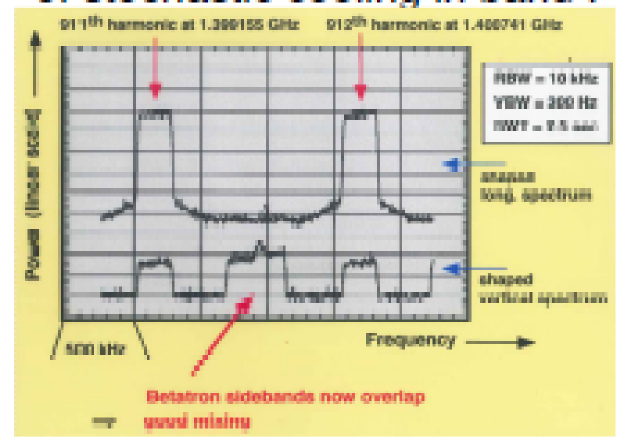
- ***Step 1:***
  - Beam Momentum Distribution Shaping
    - *Gaussian beam → Uniform beam distribution*

- ***Step 2:***
  - Uniform noise is applied **that always covers the resonance.**
  - The carrier frequency is slowly moved towards the shaped beam distribution.
    - *Particles diffuse into the resonance and are extracted.*

Longitudinal Beam Shaping

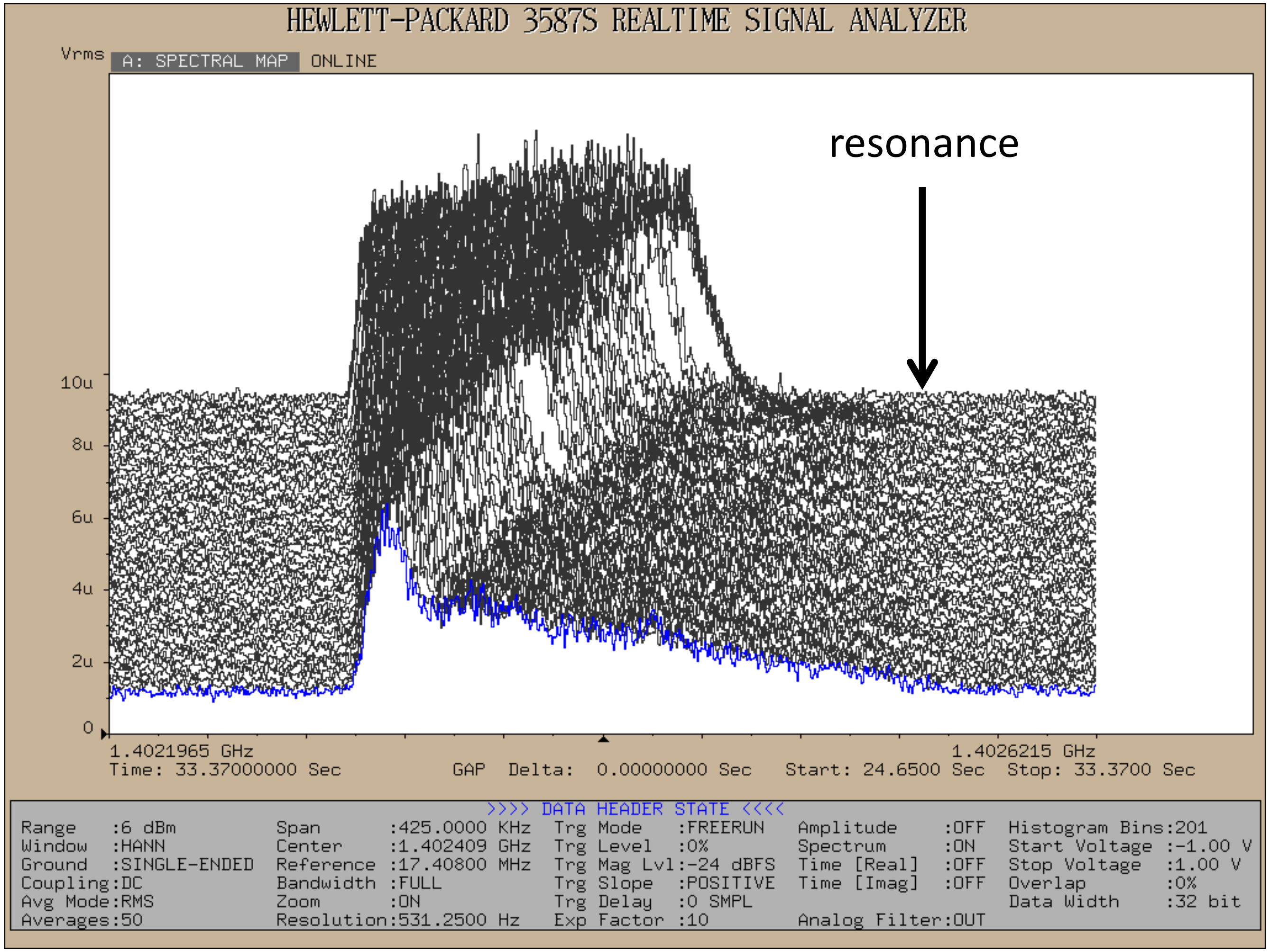


observed with PU
of stochastic cooling in band I



- Rectangular shaped noise with width W = 1 kHz applied to the 4th revolution harmonic
- Longitudinal momentum distribution rectangular ⇒ transverse sidebands rectangular
- Shaping time 1 s
- Width of 4th harmonic without noise 340 Hz
- The resulting width of the revolution harmonic 911 agrees with $W = 911 \cdot \frac{1kHz}{4} = 228\,Hz$
- Necessary voltage: U_{rms} = 77 V, noise power into 50 Ω: 120 W, spectral noise density: S = 120 mW/Hz

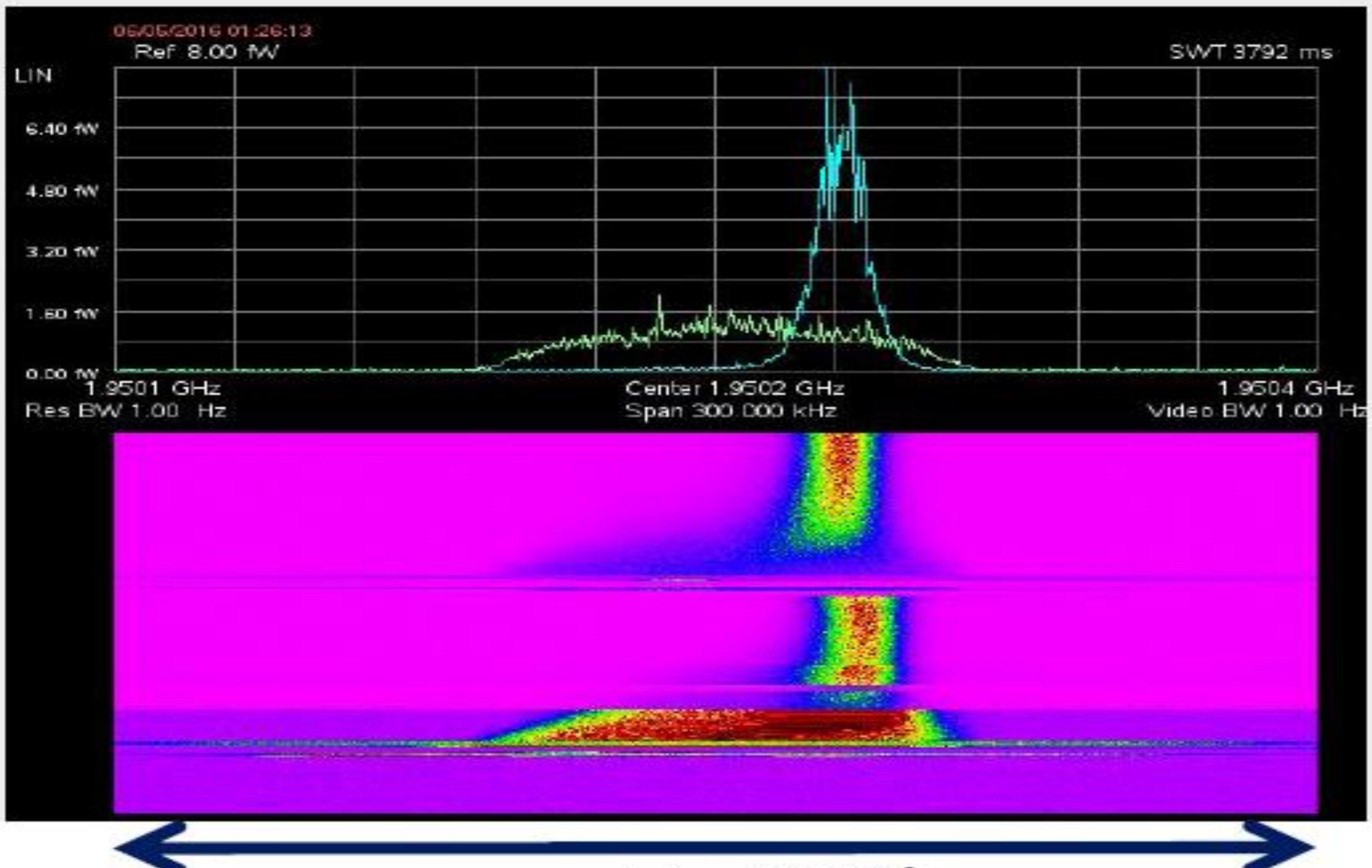
Stochastic Extraction



Electron Cooling

Schottky measurements are used to match the electron energy (HV) to energy of stored beam

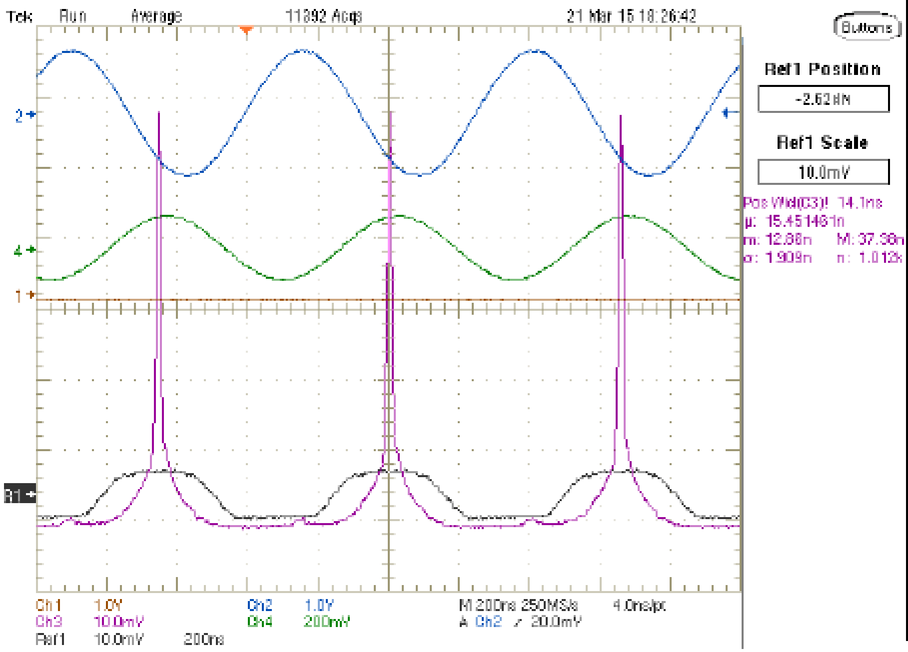
Longitudinal e-cooling at Ee = 1.257 MeV



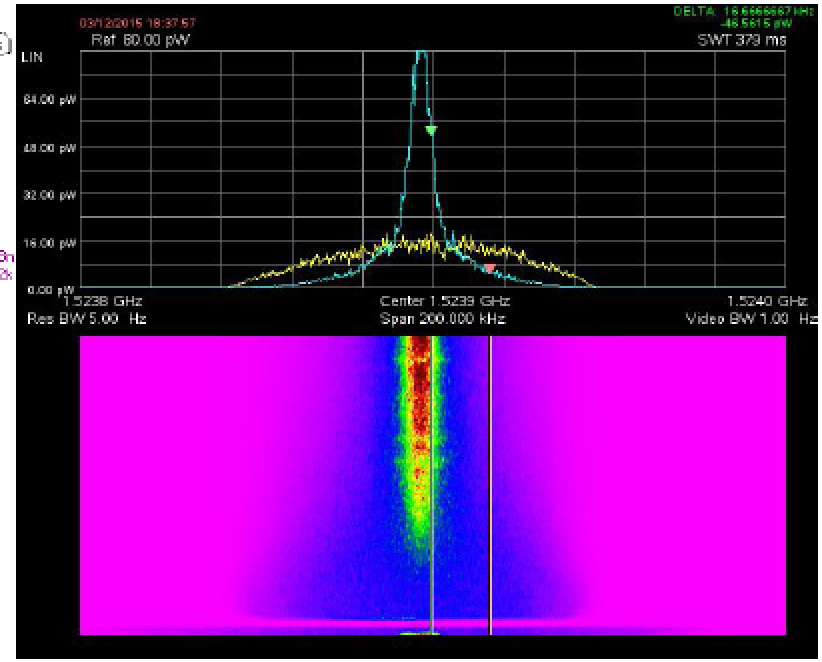
$\Delta p/p = 2.5\ 10^{-3}$

Electron Cooling

E-cooling of bunched beam



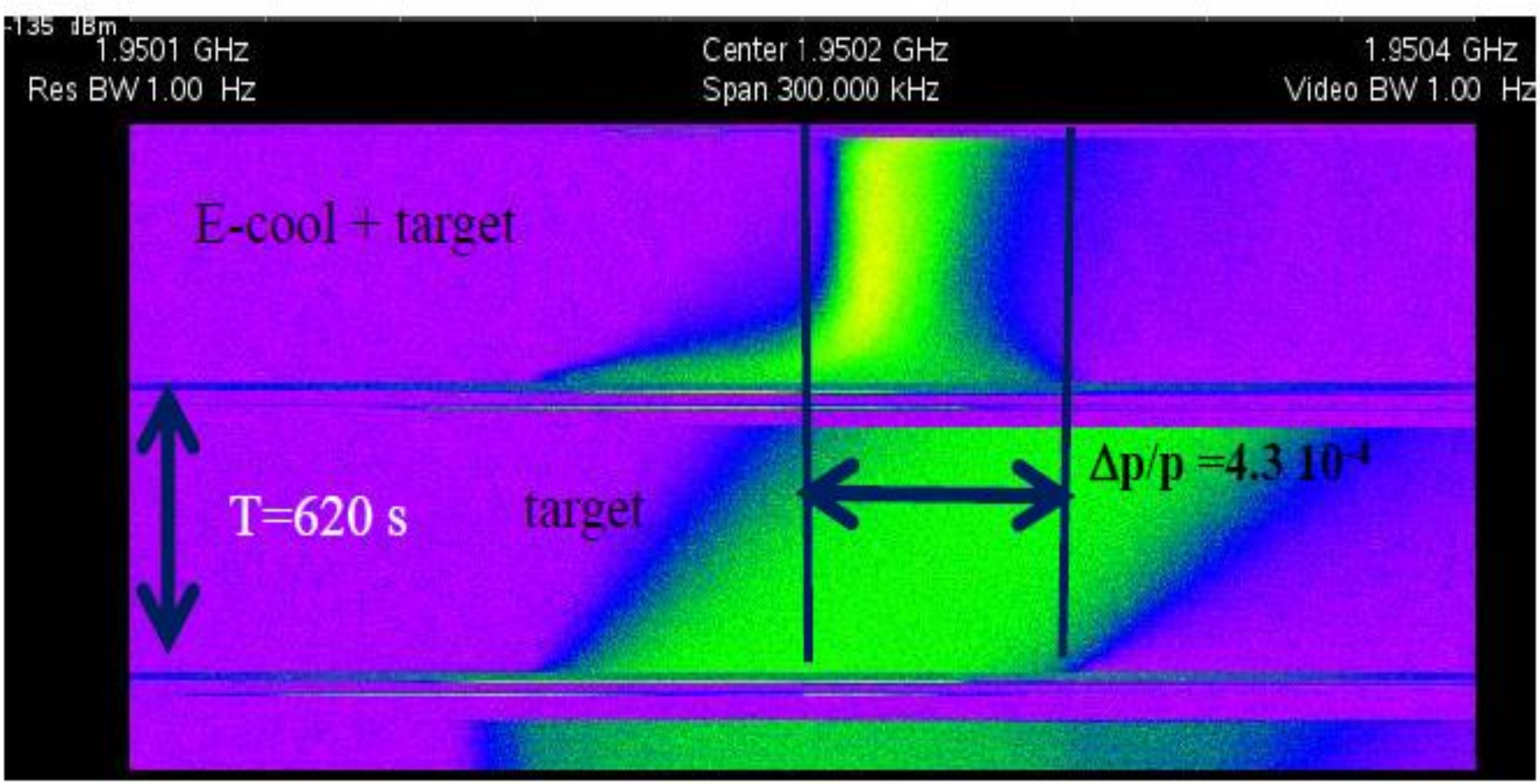
RF of 1st harmonic
and phase probe signal of p-beam



Schottky
RF on, e-cooling with 0.55 A

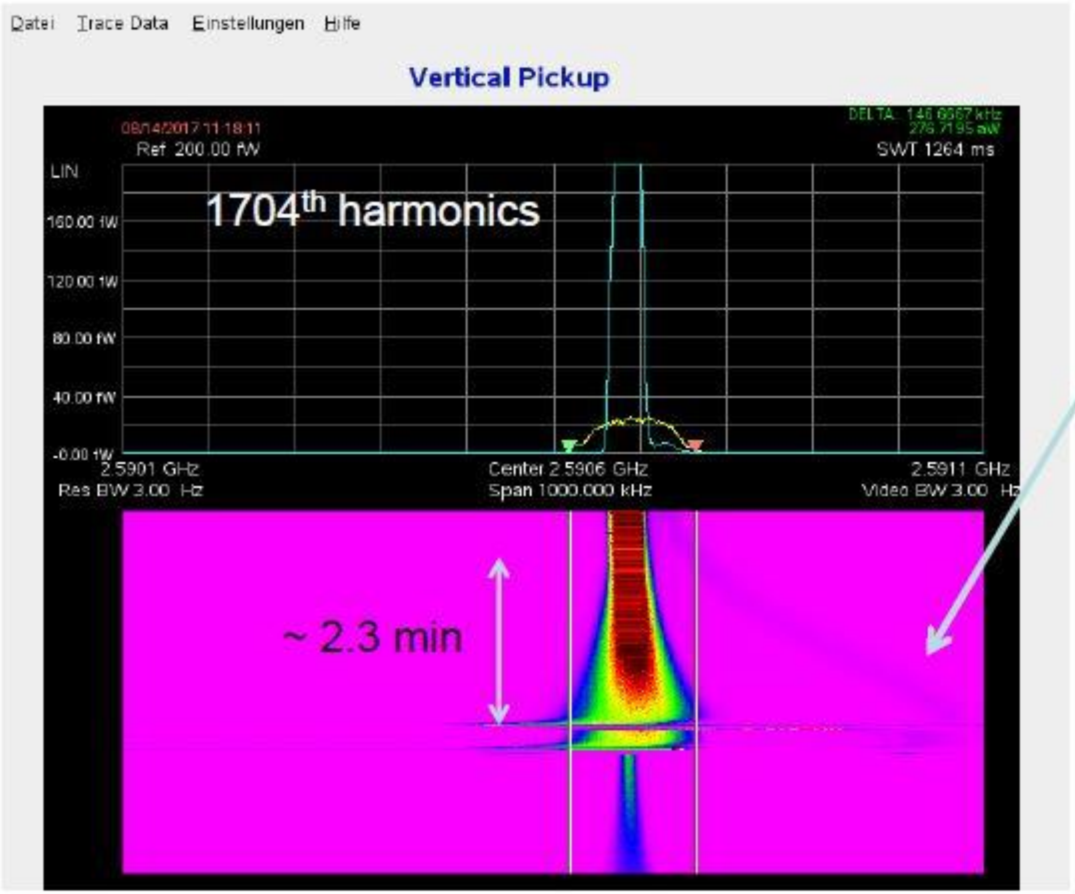
Electron Cooling

e-cooling at Ee = 1.257 MeV with target



Stochastic Cooling

Longitudinal cooling 7E9 particles

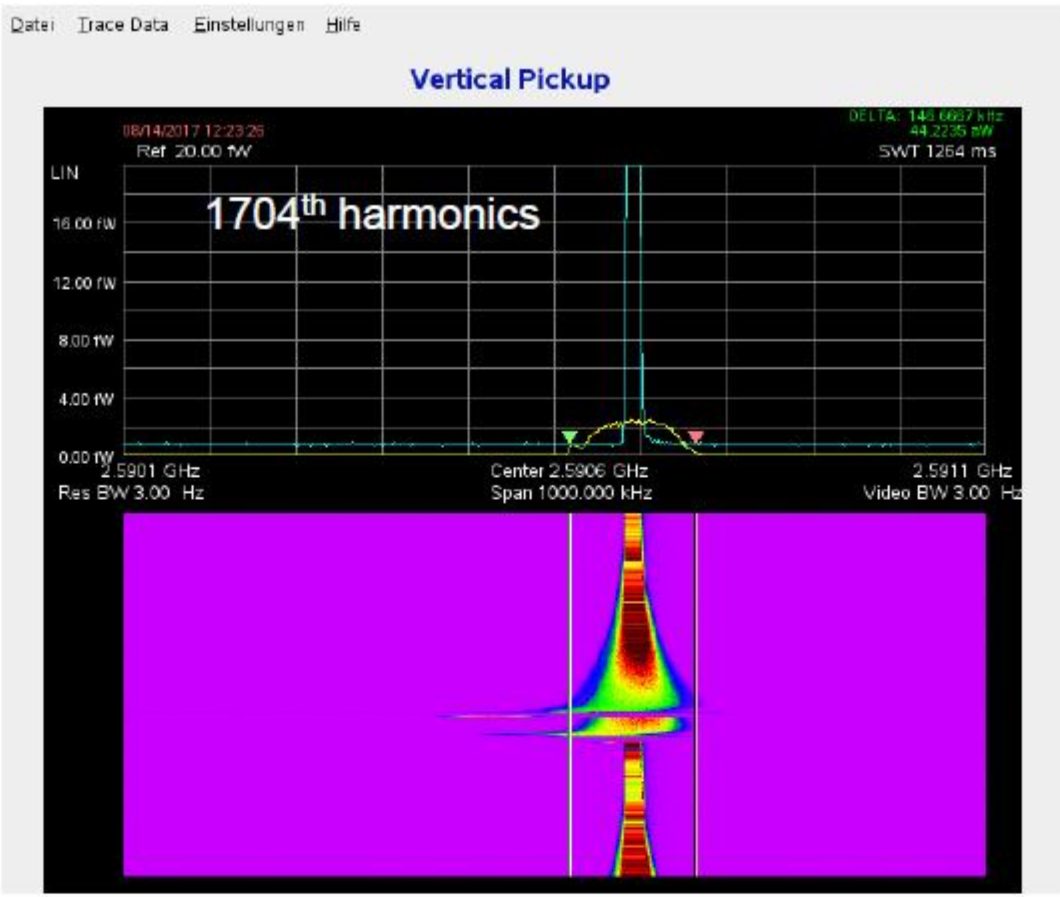


Even particles shifted to lower energies during re-bunching were captured by the filter cooling.

Fastest stochastic cooling ever seen at COSY

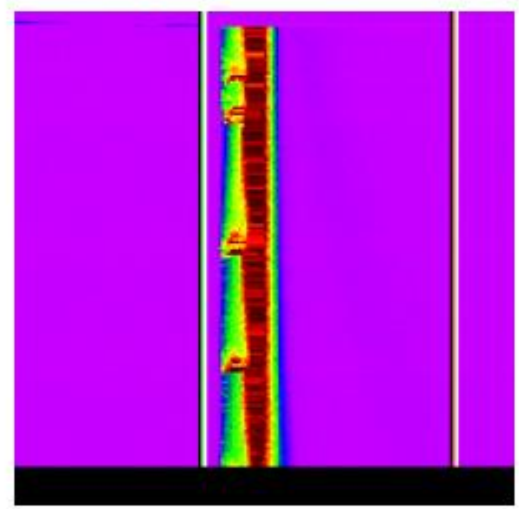
Stochastic Cooling

Longitudinal cooling 2E8 particles



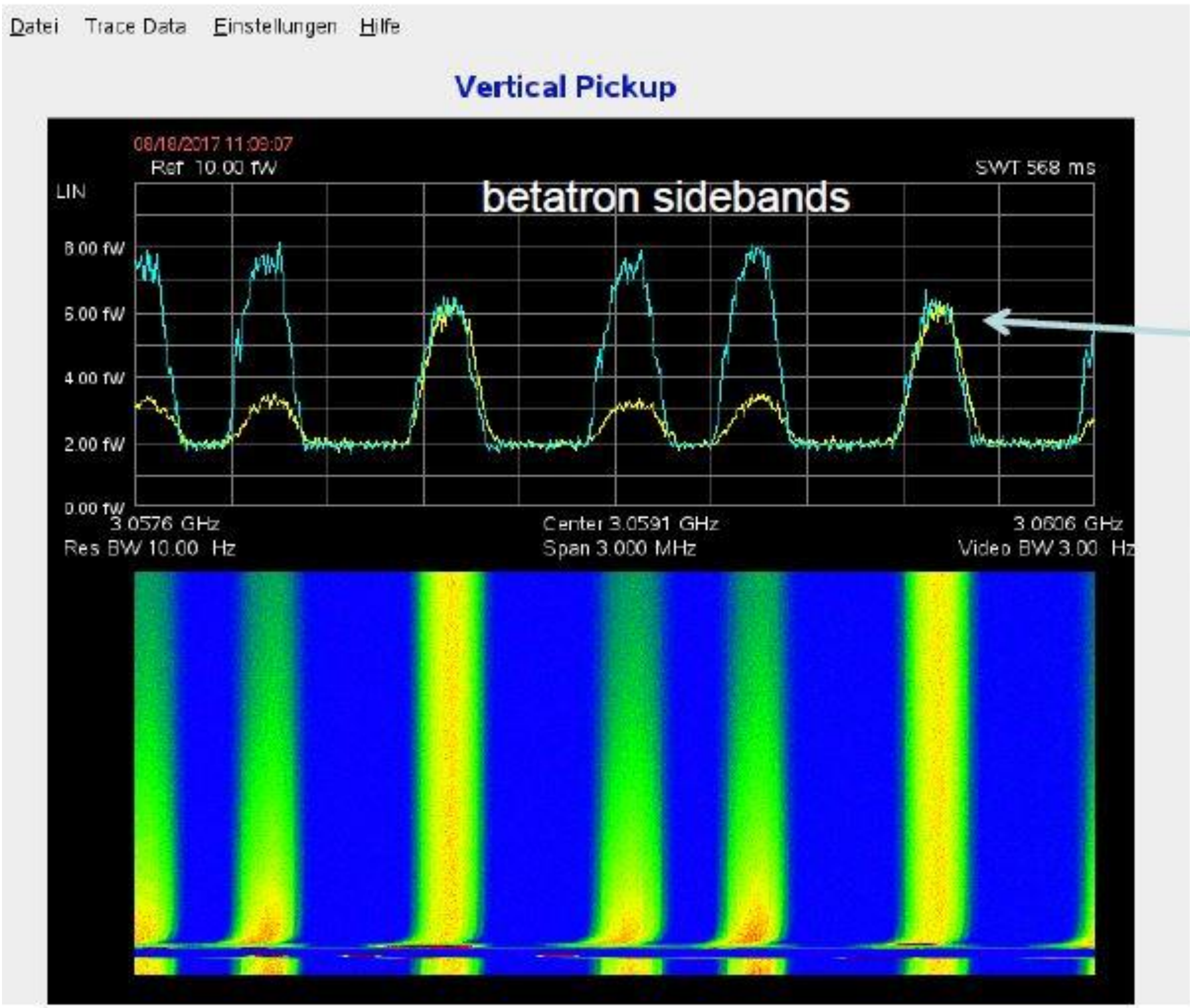
Slightly faster cooling and smaller equilibrium
Constant gain!

Instabilities visible, but no beam loss.



Stochastic Cooling

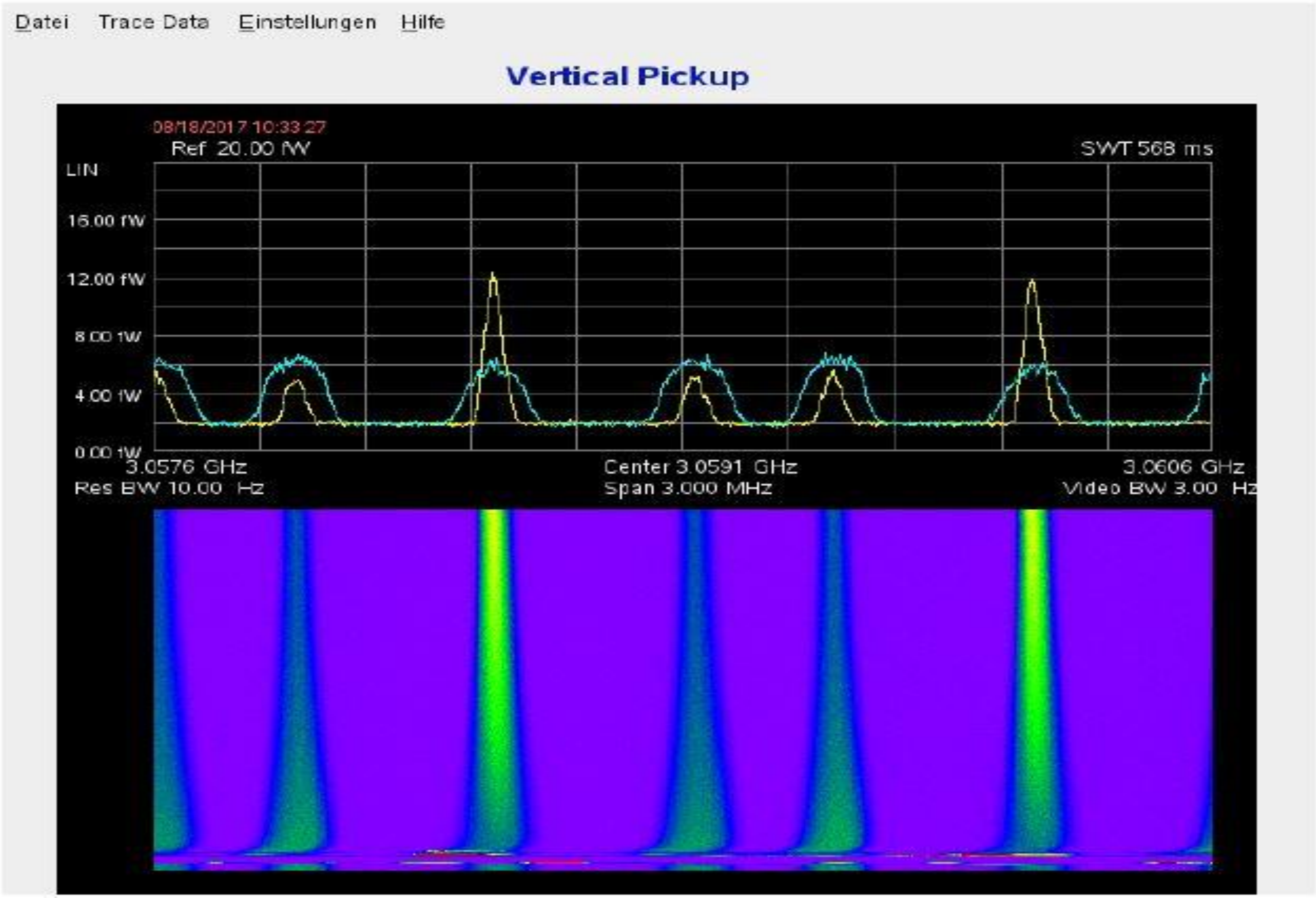
Vertical cooling 7E9 particles



Even after beam centering, longitudinal parts visible (due to limited isolation in hybrid), but this does not influence the transvers cooling

Stochastic Cooling

2d cooling (long. + vertical) of 5E9 particles

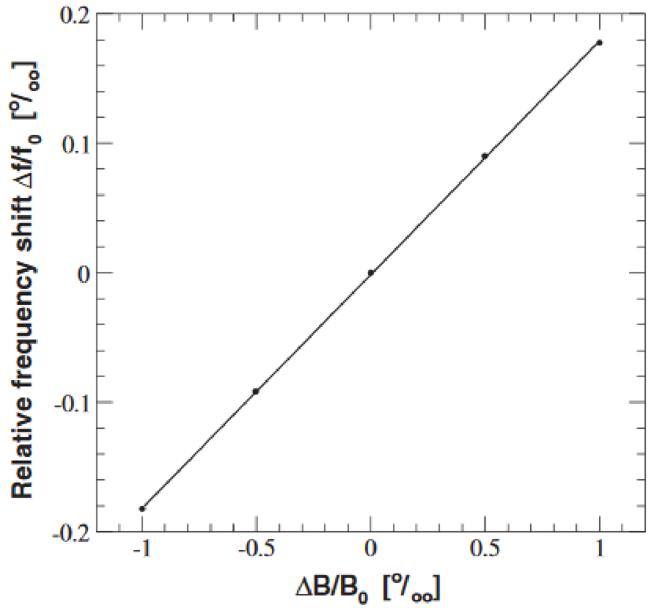


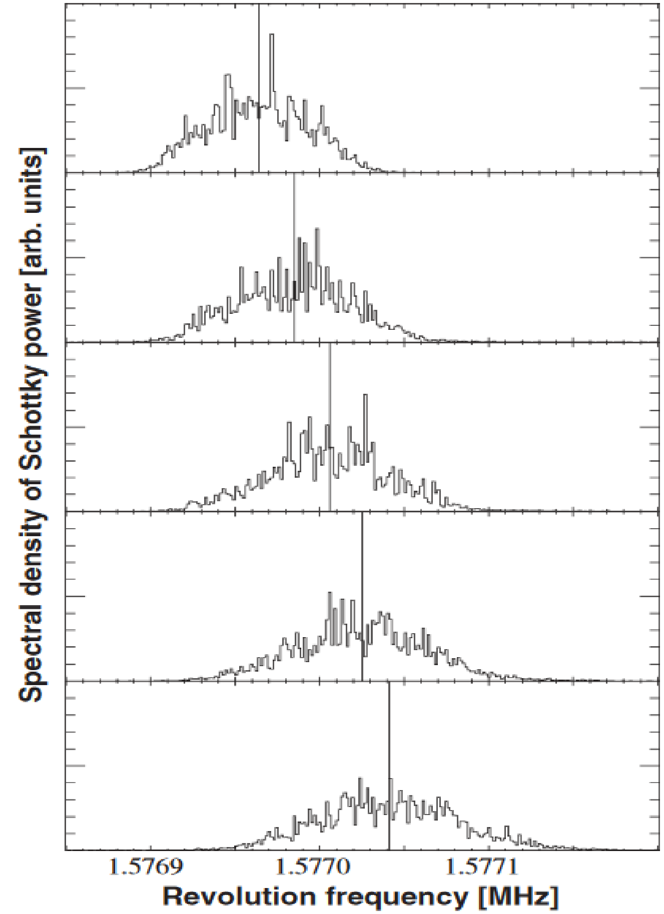
Internal Target Experiments

target density determination
via energy loss

$$n_T = \left(\frac{1+\gamma}{\gamma}\right)\frac{1}{\eta}\frac{1}{(dE/dx)m}\frac{T_0}{f_0^2}\frac{df}{dt}.$$

η (α) determination: change of main
Bending field B and measure schottky





Achieved accuracy for target thickness approx. 5 %

Internal Target Experiments

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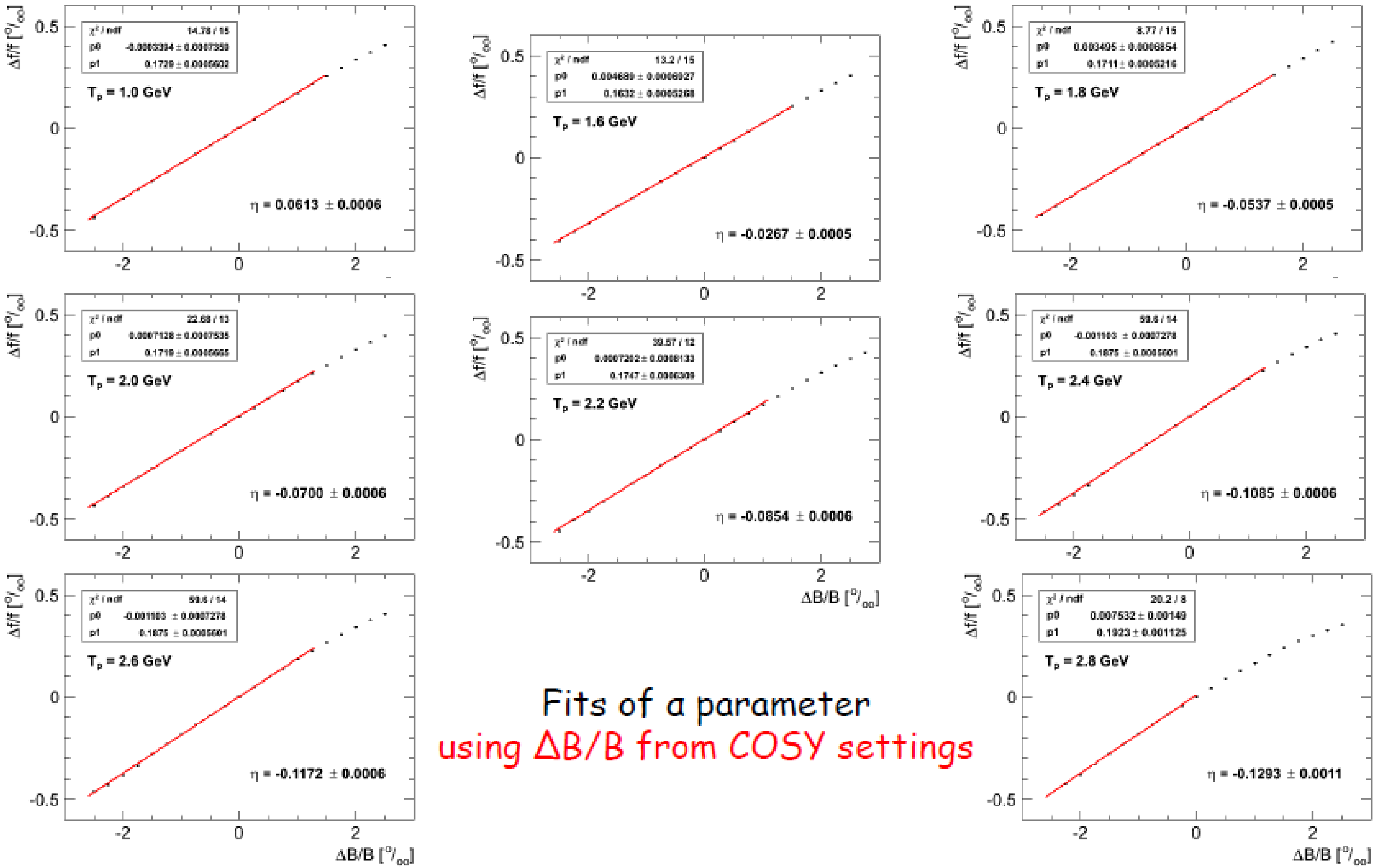
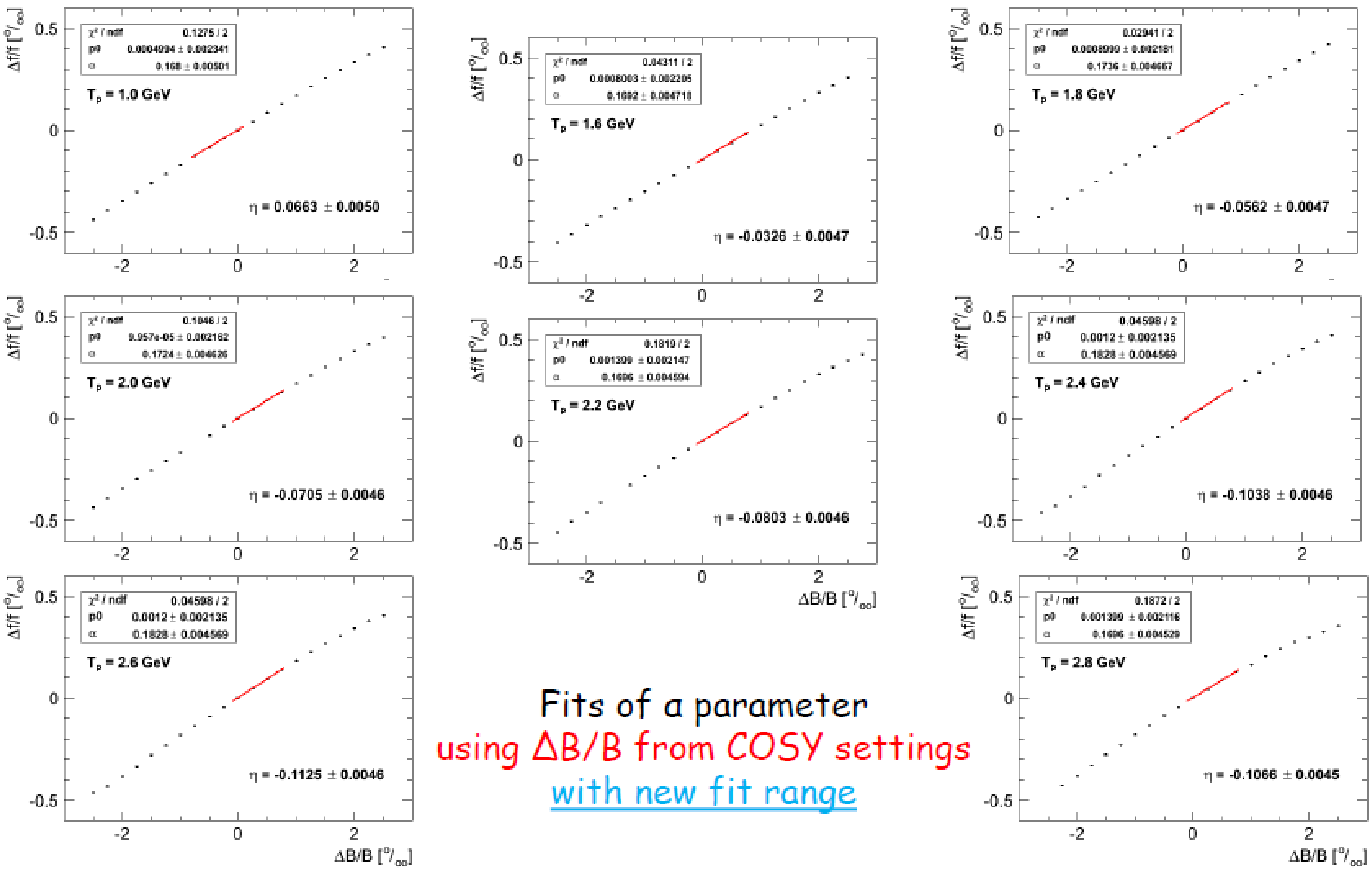
A lot more of this ...



Fits of a parameter
using ΔB/B from COSY settings

Internal Target Experiments

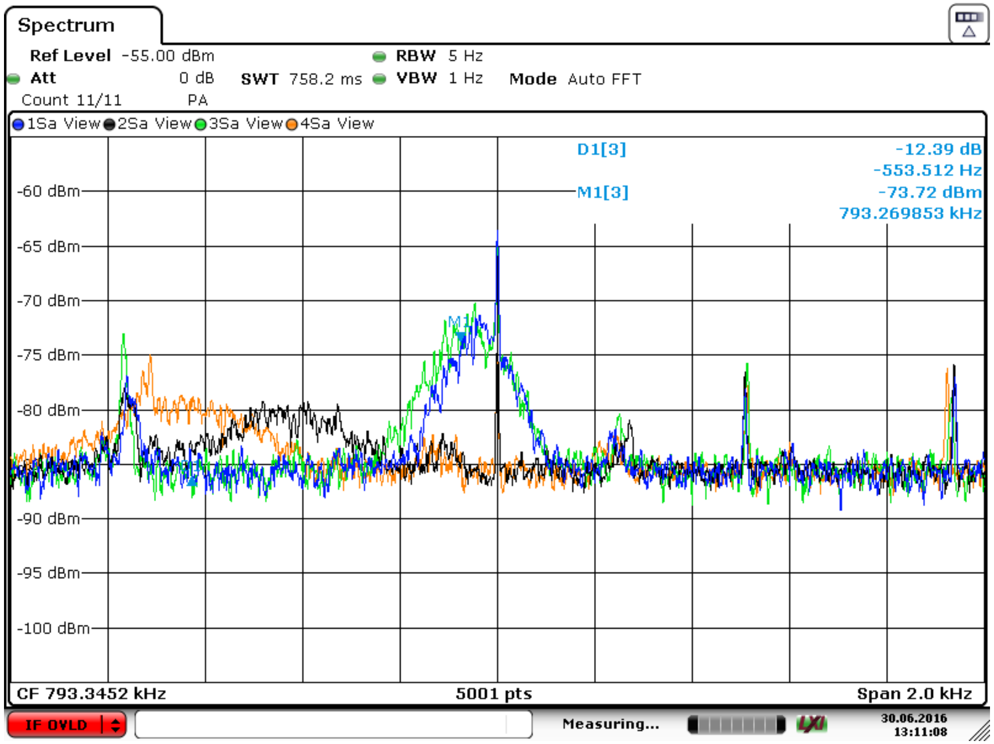
A lot more of this …solution to nonlinear behaviour…



Fits of a parameter
using ΔB/B from COSY settings
with new fit range

Internal Target Experiments

Target density via schottky, polarized target tests



blue/green: after acceleration
black: 1 hydrogen hfs state after 3 min
Orange 2 hydrogen hfs states after 3 min

Summary

Schottky measurement are essential tool used at COSY in regular accelerator operation and for specific applications.

- **stochastic extraction**
- **electron cooling**
- **stochastic cooling**
- **internal target operation**

Special thanks to
R. Stassen and stochastic cooling team
V. Kamerdzhiev and electron cooling + beam instrumentation team

Thank You