Electron cooling at COSY - status and perspectives

Sept. 19, 2017 | COOL 17 | V. Kamerdzhiev on behalf of the COSY team
IKP-4, Forschungszentrum Jülich

The team

A. Halama, V. Kamerdzhiev with a lot of support from the COSY team (IKP)

M. Bryzgunov, V. Parkhomchuk, D. Skorobogatov, D. Senkov, V. Reva (BINP)

I. Meshkov (JINR)

T. Katayama (Nihon University)

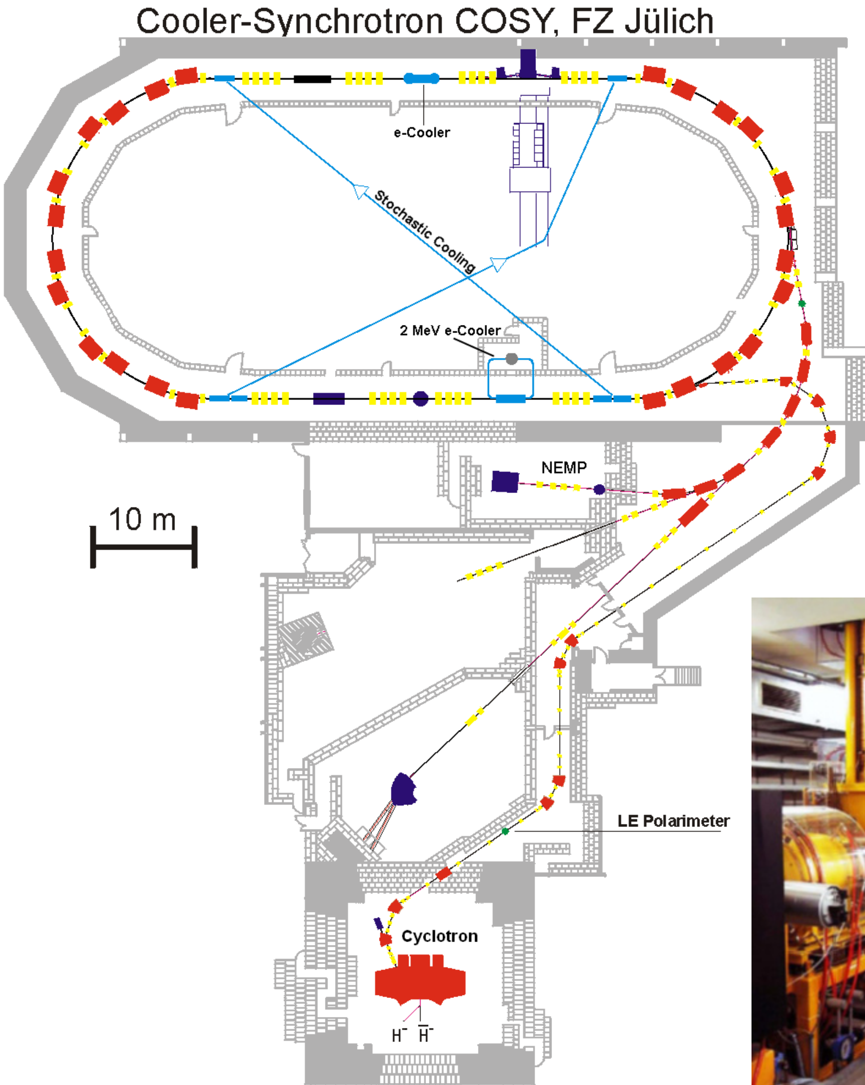
COSY beam

B. Lorentz, R. Stassen, R. Gebel, D. Prasuhn, (IKP)

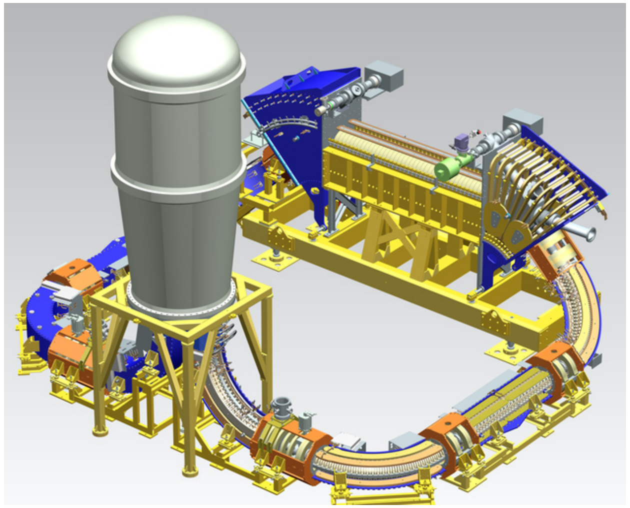
Thanks for providing the cluster jet target

A. Khoukaz, D. Schröer, C. Fritzsch (Münster University)

COSY facility



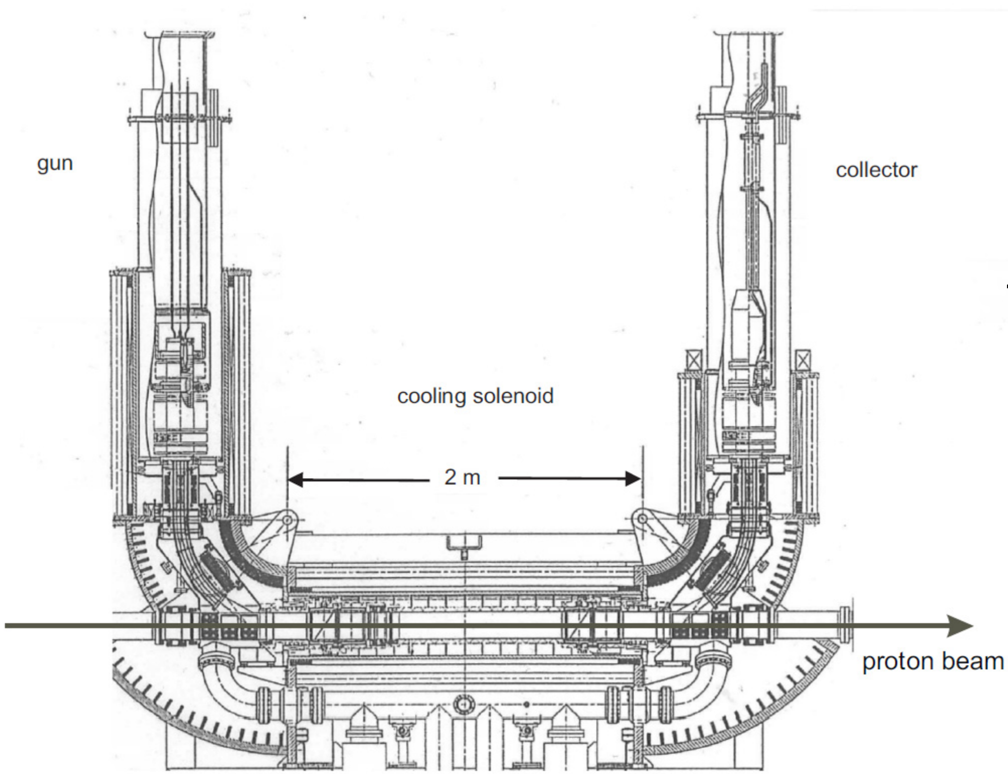
- 184 m circumference
- p, $^2H^+$ polarized and unpolarized
- electron & stochasic cooling
- exp. with circulating or extracted beams
- slow extraction
- BB RF system
- Palarimeters
- RF dipole & solenoid
- Wien filters
- Precision spin manipulation



Mitglied der Helmholtz-Gemeinschaft

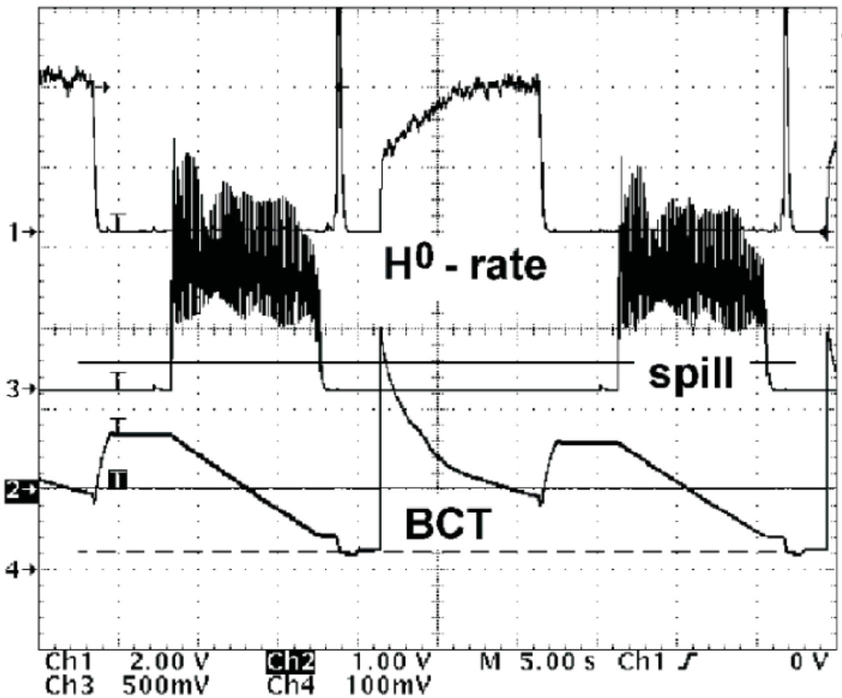
Low energy e cooling at COSY

- improve the quality of the beams extracted to fixed-target experiments
- enable transverse stacking of polarized beams to be used with targets in the ring
- improve the beam lifetime for internal experiments.



100 kV electron cooler

Pre-cooling prior to acceleration and extraction

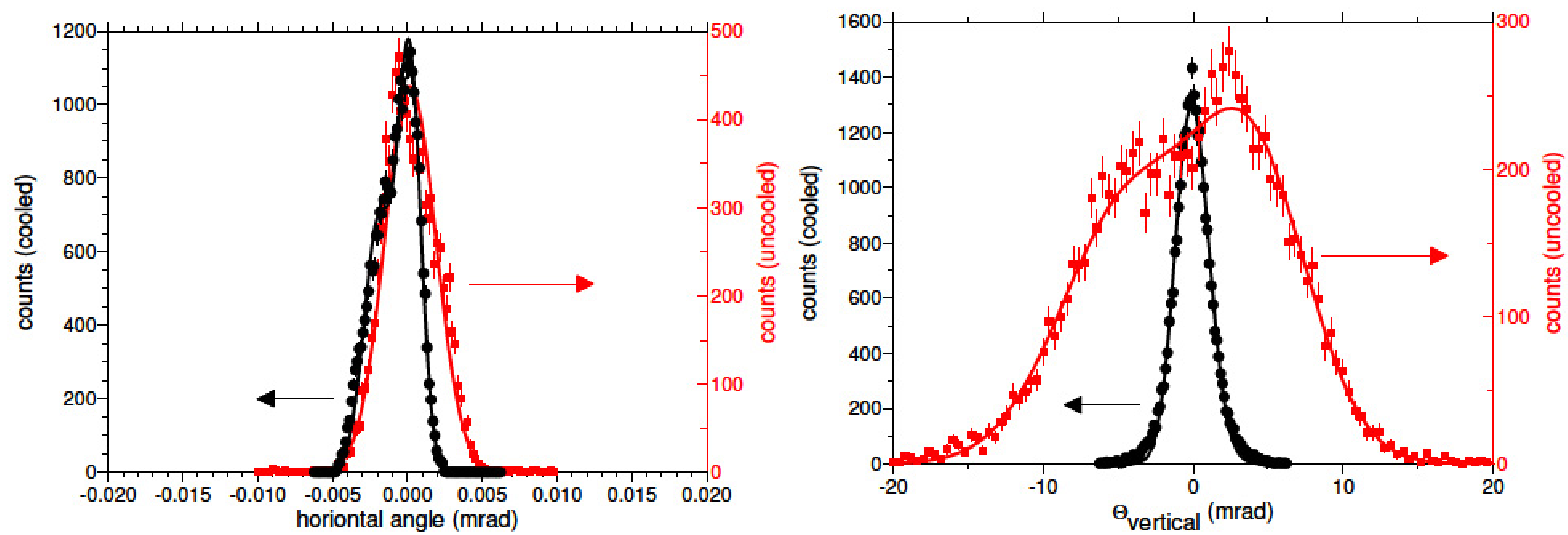


	Without electron cooling	With electron cooling
Stored Beam Intensity	$4 \cdot 10^{10}$	$1 \cdot 10^{10}$
Shortest extraction time	10 s	10 s
Shortest cycle time	20 s	30 s
Extraction efficiency	75 %	80 %
Intensity in the spill	$3.0 \cdot 10^{9}$ p/s	$8.0 \cdot 10^{8}$ p/s
Cycle averaged beam intensity	$1.5 \cdot 10^{9}$ p/s	$2.7 \cdot 10^{8}$ p/s
Halo ratio for a 3 mm veto hole	$2.5 \cdot 10^{-2}$	$4.0 \cdot 10^{-4}$

Comparison of parameters of the extracted beam with and without electron cooling, 1571 MeV/c

Electron Cooling and Slow Extraction , D.Prasuhn, H. Stockhorst, H. J. Stein, R. Maier, A. Magiera , H. Machner, P. v. Rossen, IKP annual report 2001

Pre-cooling prior to acceleration and extraction

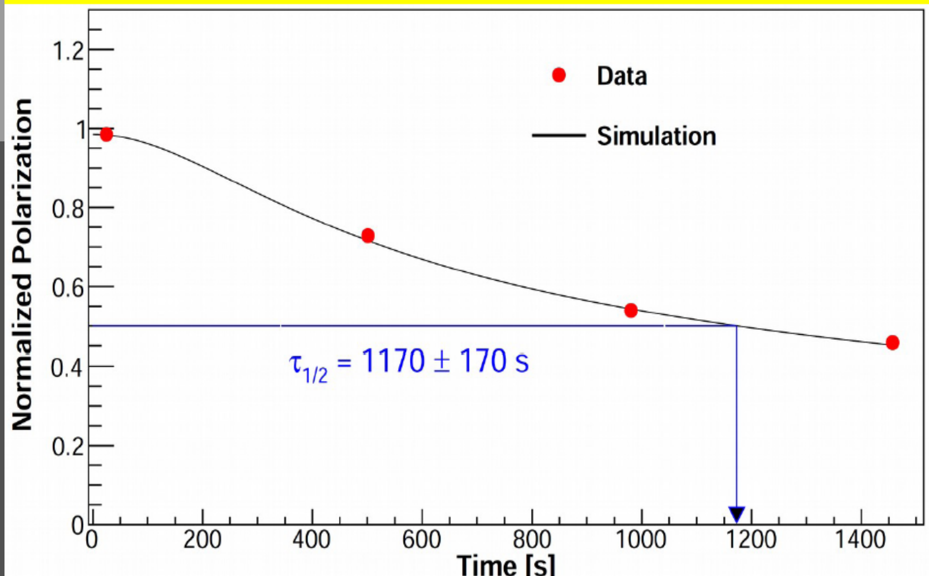


Transvers angular distributions of the uncooled beam (red squares, 800 MeV/c) and the cooled proton beam (black circles, 1440 MeV/c). Left: the horizontal distribution. Right: the vertical distribution. The solid curves denote Gaussian fits. The uncooled beam is fitted by two Gaussians with widths $y' = 4.48$ mrad and $y' = 3.78$ mrad. The cooled beam has $y' = 1.2$ mrad

Effect of Electron Beam Cooling on Transversal and Longitudinal Emittance of an External Proton Beam, K. Kilian, H. Machner, A. Magiera, D. Prasuhn, P. von Rossen, R. Siudak, H. J. Stein, H. Stockhorst, submitted to NIMA

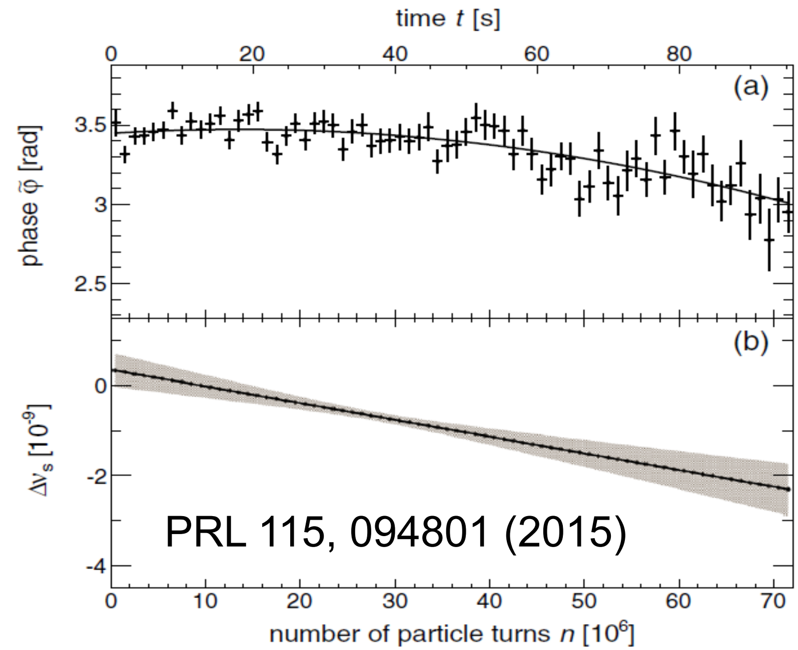
High precision spin manipulations

Record Spin Coherence Time for EDM Searches



IKP Annual Report 2015, Juel-4393

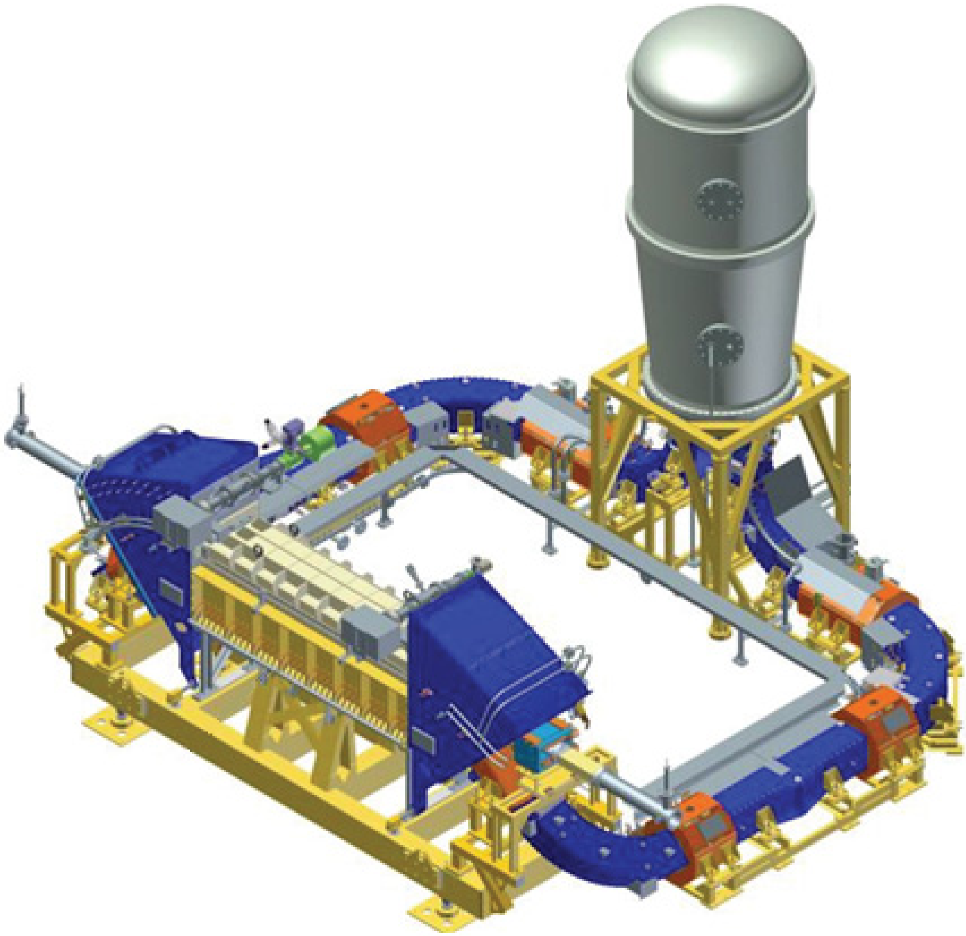
High precision spin tune measurement

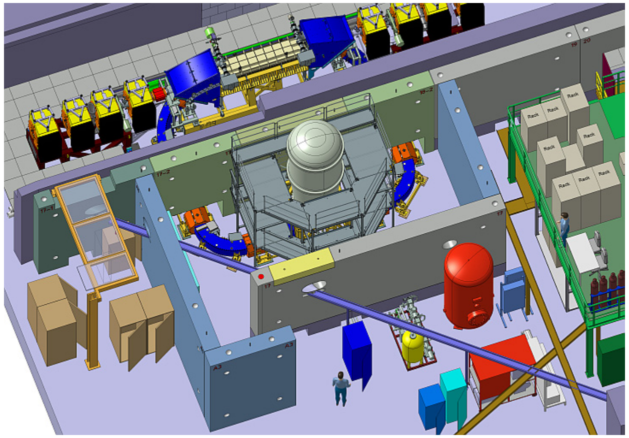


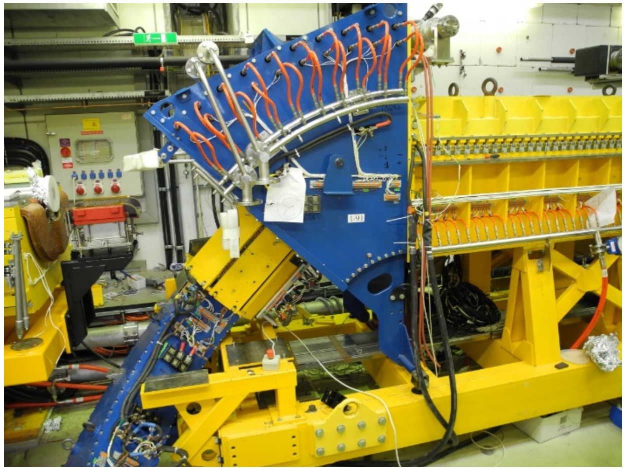
~10^9 Deuterons at 970 MeV/c.
pre-cooled with the 100 keV e-cooler
all sextupoles were adjusted to minimize
horizontal and vertical chromaticity

Phase of asymmetry with fixed ν_s meaured in a 100 s machine cycle. EDDA detector and a sophisticated read-out system used
Phys. Rev. STAB 17 052803 (2014)

2 MeV electron cooler







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

2 MeV e-cooler for COSY project milestones

Project lounched by Jürgen Dietrich

- 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**

Current status of the 2 MeV e-cooler at COSY

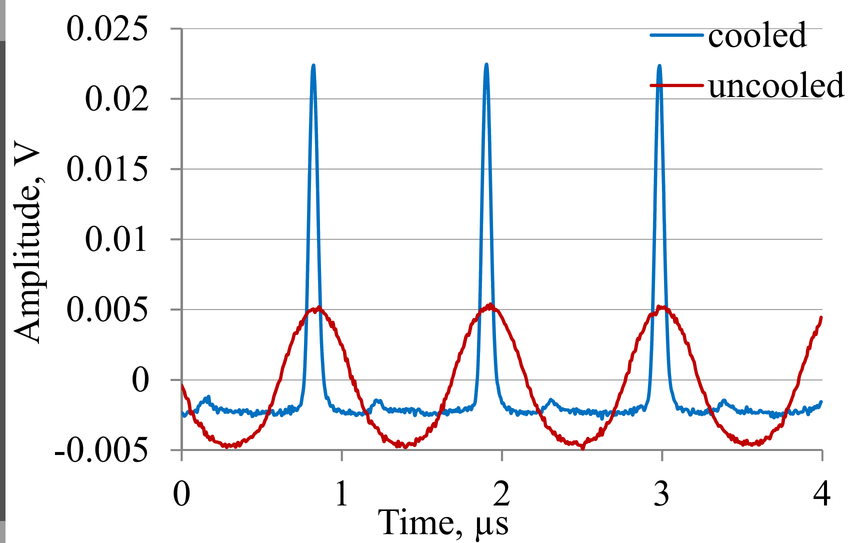
Electron cooling of the proton beam

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
2300	**1.25**	**0.5**

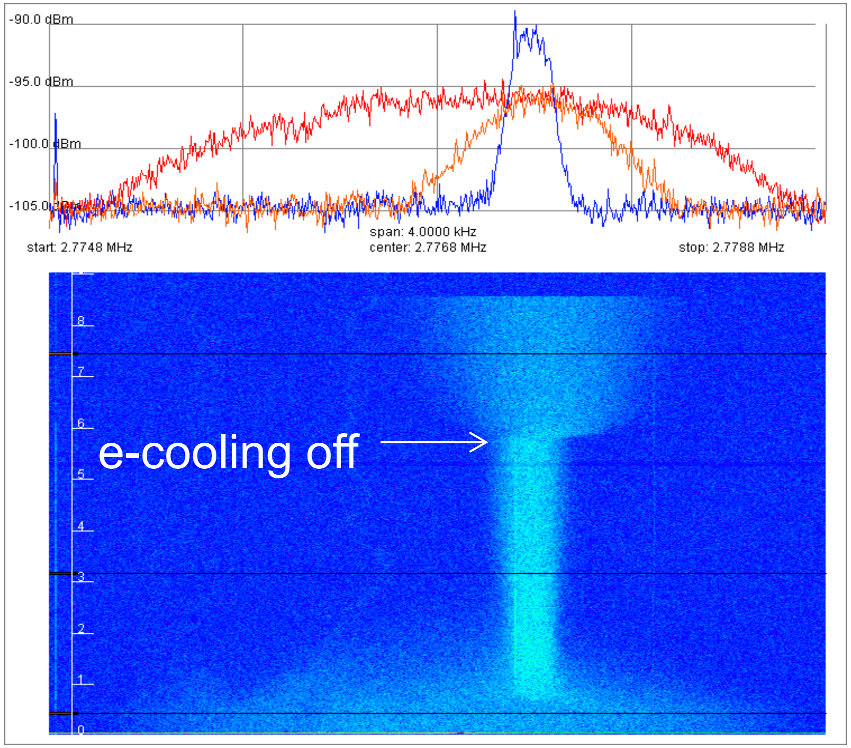
Maximum electron current and energy so far demonstrated

Electron energy, MeV	Electron current, A
0.024	1
1.25	**0.8**
1.5	0.1
1.57	

First electron cooling, 200 MeV protons



bunched

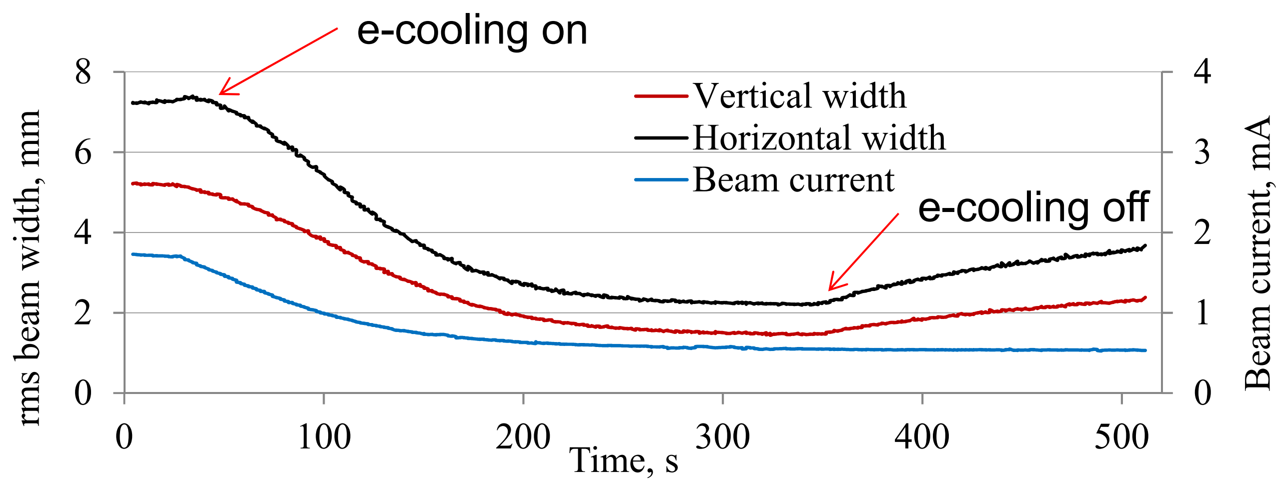


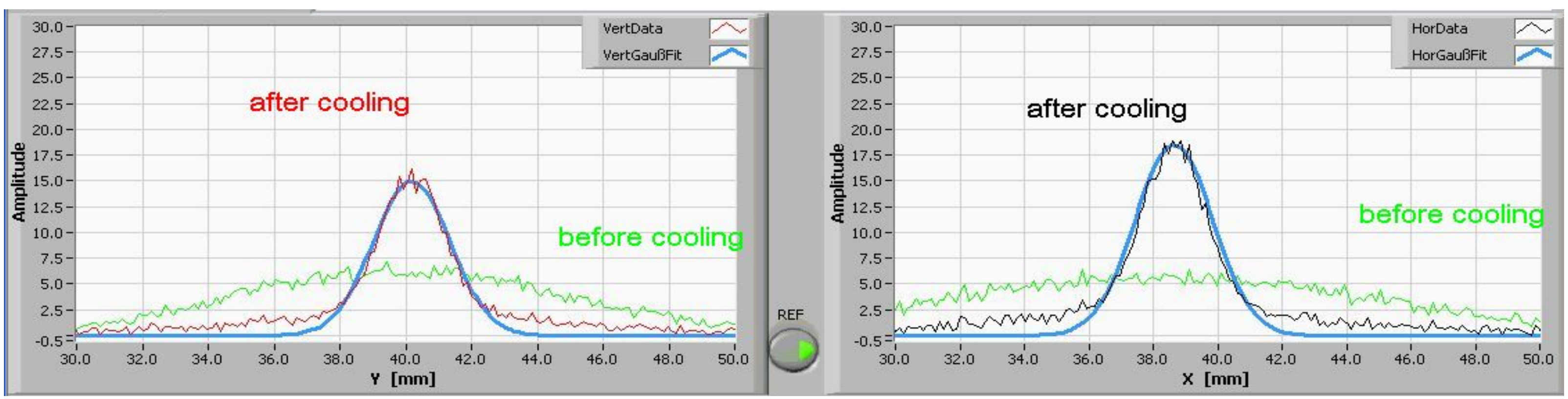
dc

electron energy 109 keV, electron current 0.2 A

N.Alinovsky et al., IPAC14

First electron cooling, 200 MeV protons, de

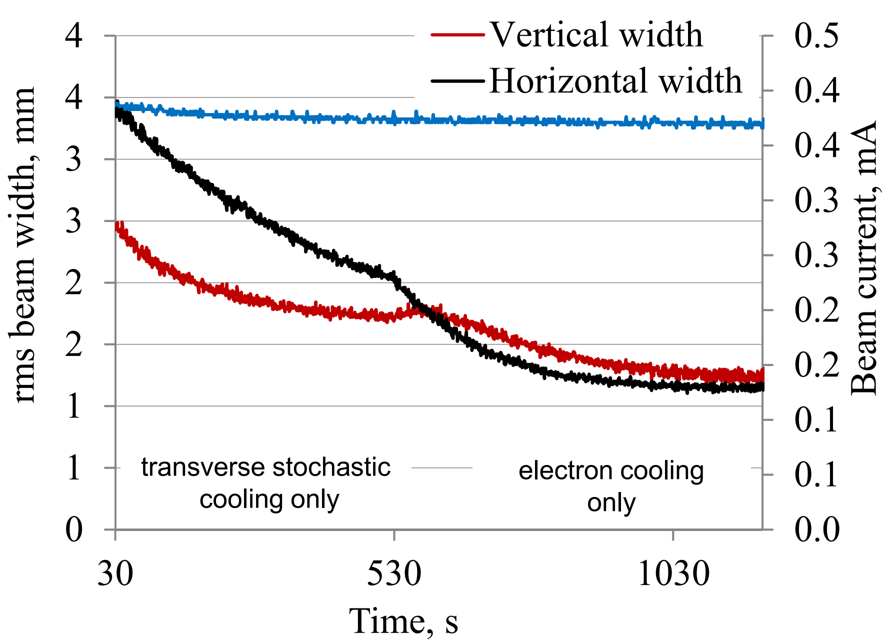


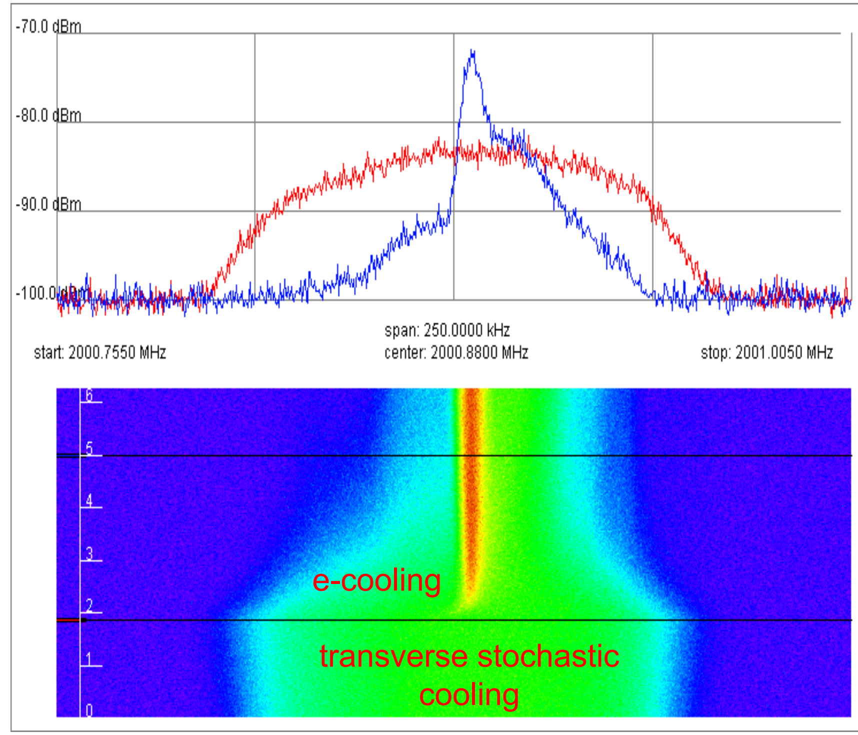


electron energy 109 keV, electron current 0.2 A

N.Alinovsky et al., IPAC14

First electron and stochastic cooling 1670 MeV protons, dc





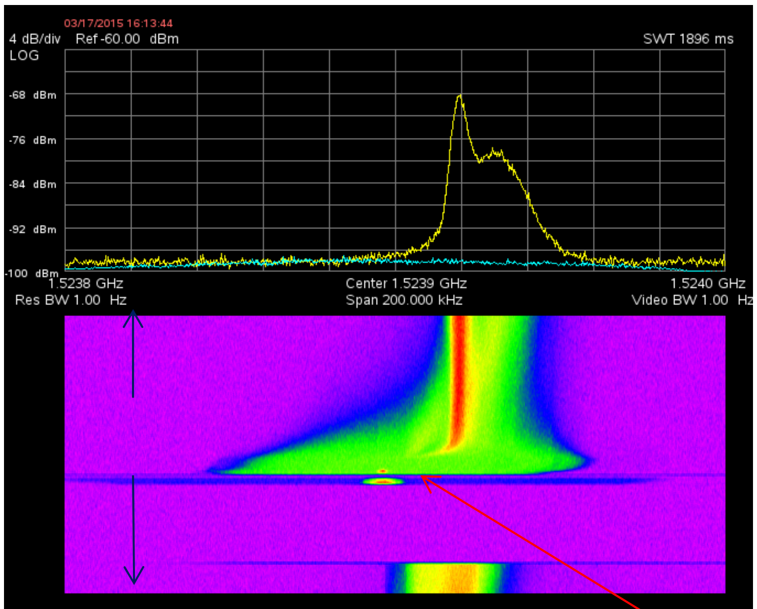
Transverse stochastic cooling was applied first. After turning off st. cooling e-cooling was applied

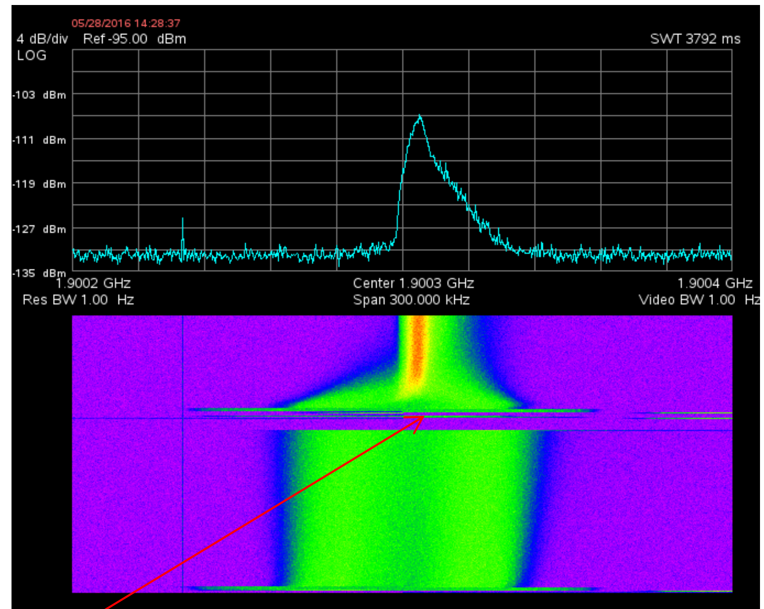
electron energy 908 keV, electron current 0.32 A

N.Alinovsky et al. IPAC14

Longitudinal electron cooling in 2015 & 2016

st. cooling pickup used to measure the Schottky spectra: COSY vs HESR designs





pickup: COSY design

2015

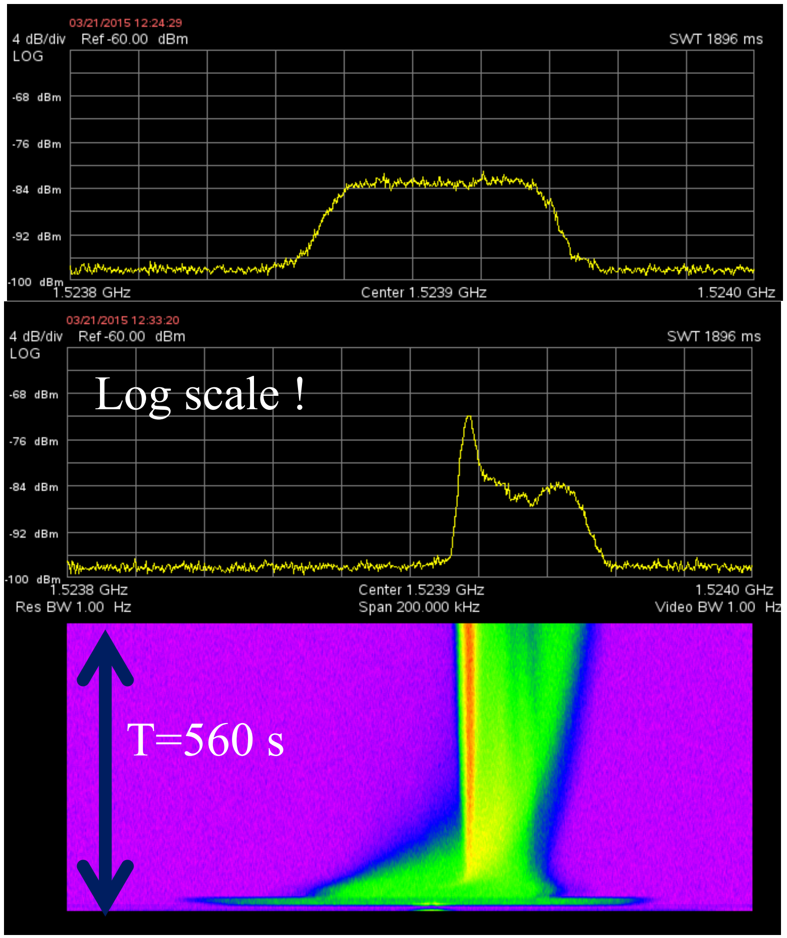
injection

2425 MeV/c

pickup: HESR design
(reduced length in use)

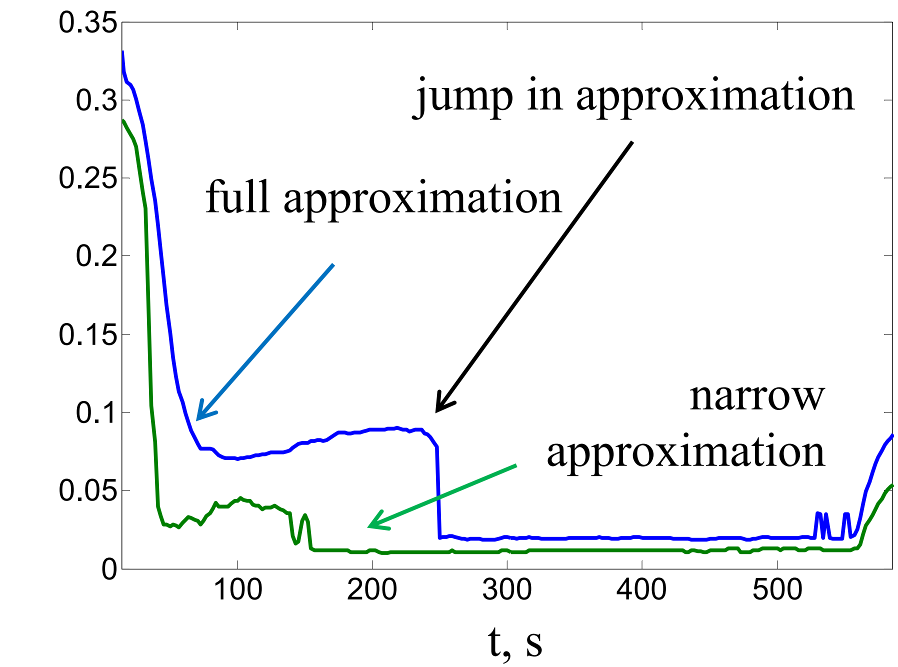
2016

Longitudinal cooling time



$N_p = 2.7 \cdot 10^8$, $J_e = 520$ mA, $E_e = 0.909$ MeV,
Exp. time is March 21, 2015 12:26, $\gamma_{tr} = 2.259$

Longitudinal cooling time can be approximated as 100 s or less



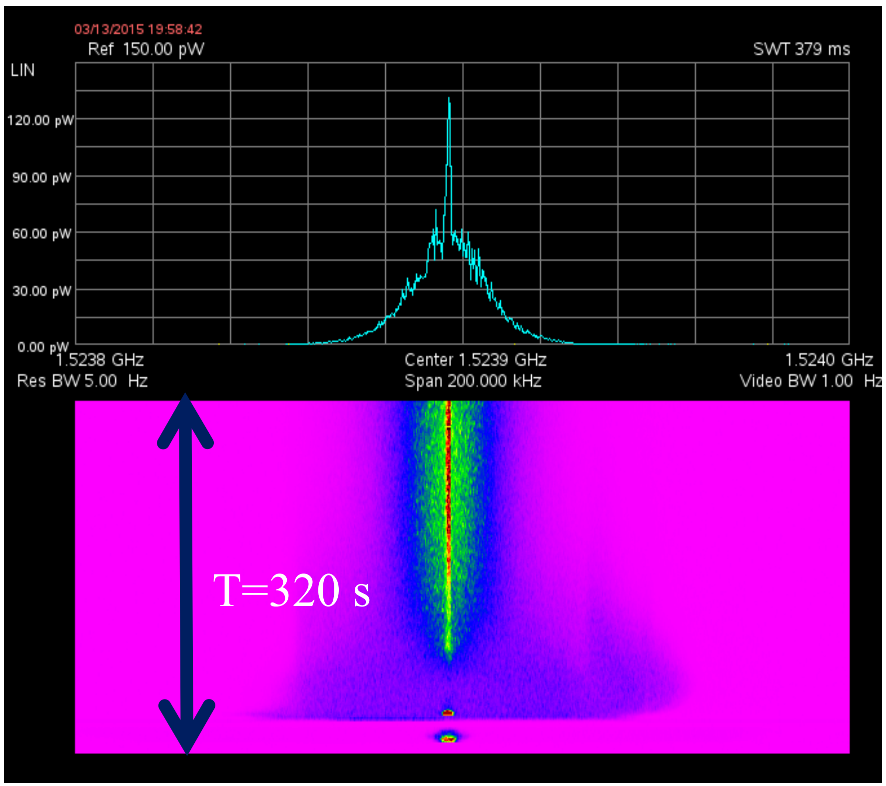
$$w = A \cdot \exp\left(-\left(p - p_0\right)/\sigma^2\right)$$

The narrow approximation takes into account only the peak of the distribution function (beam core), the full approximation takes into account the full shape.

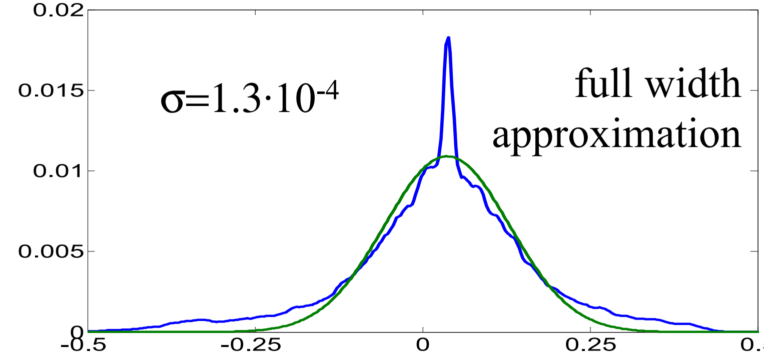
march 2015

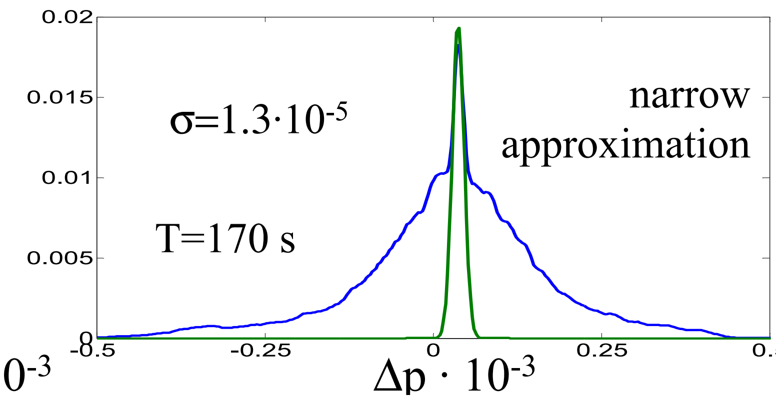
Example of the longitudinal cooling with barrier bucket

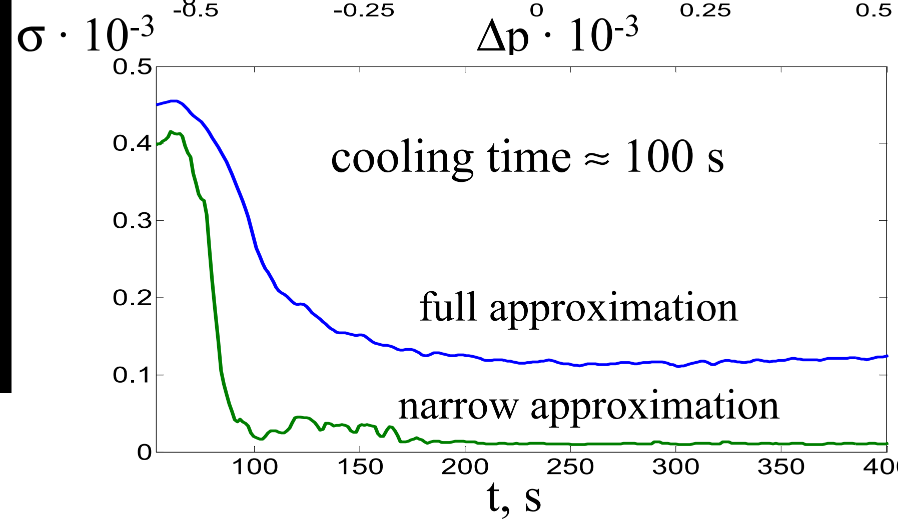
$N_p = 7.8 \cdot 10^8$, $J_e = 0.55$ A, $E_e = 0.909$ MeV
$\gamma_{tr} = 2.259$



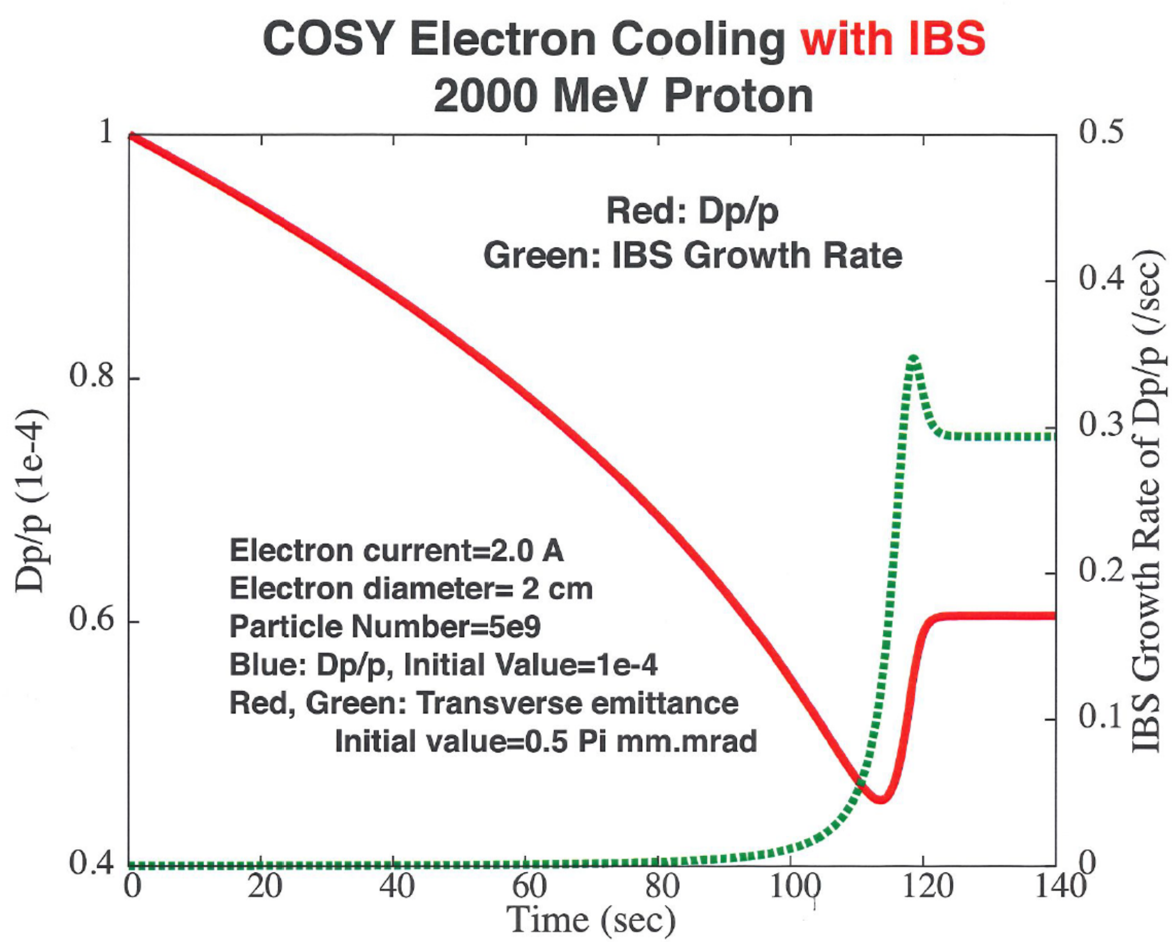
Experiment time is March 13, 2015 19:53



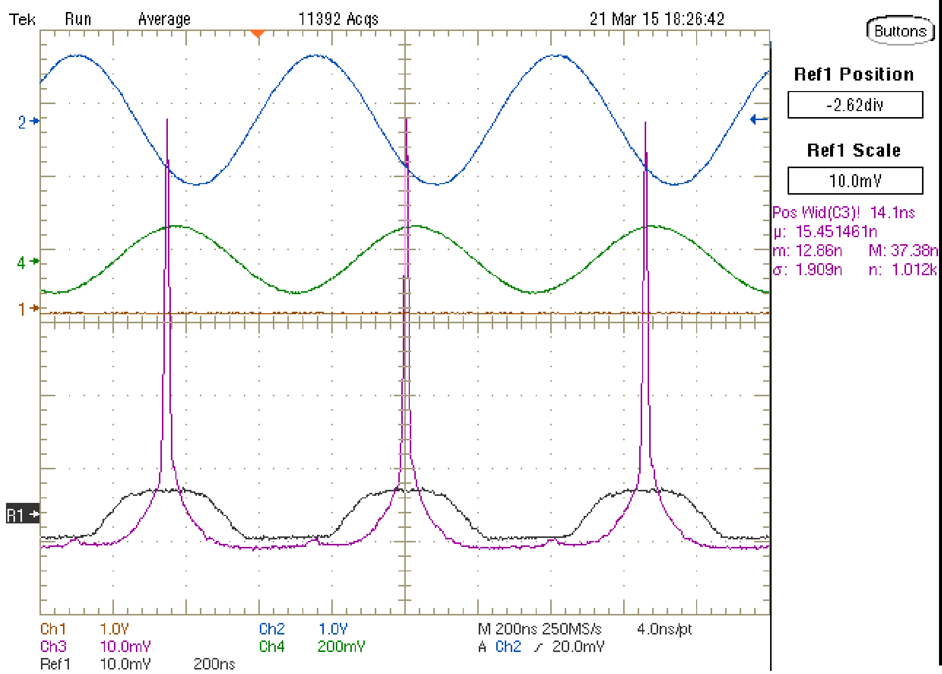




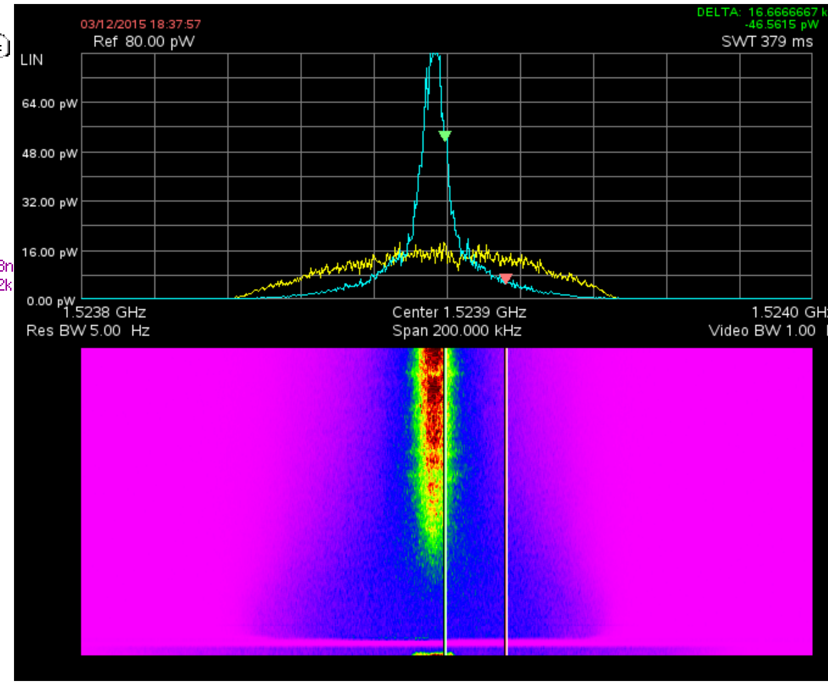
Simulations by T.Katayama



E-cooling of bunched p-beam



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

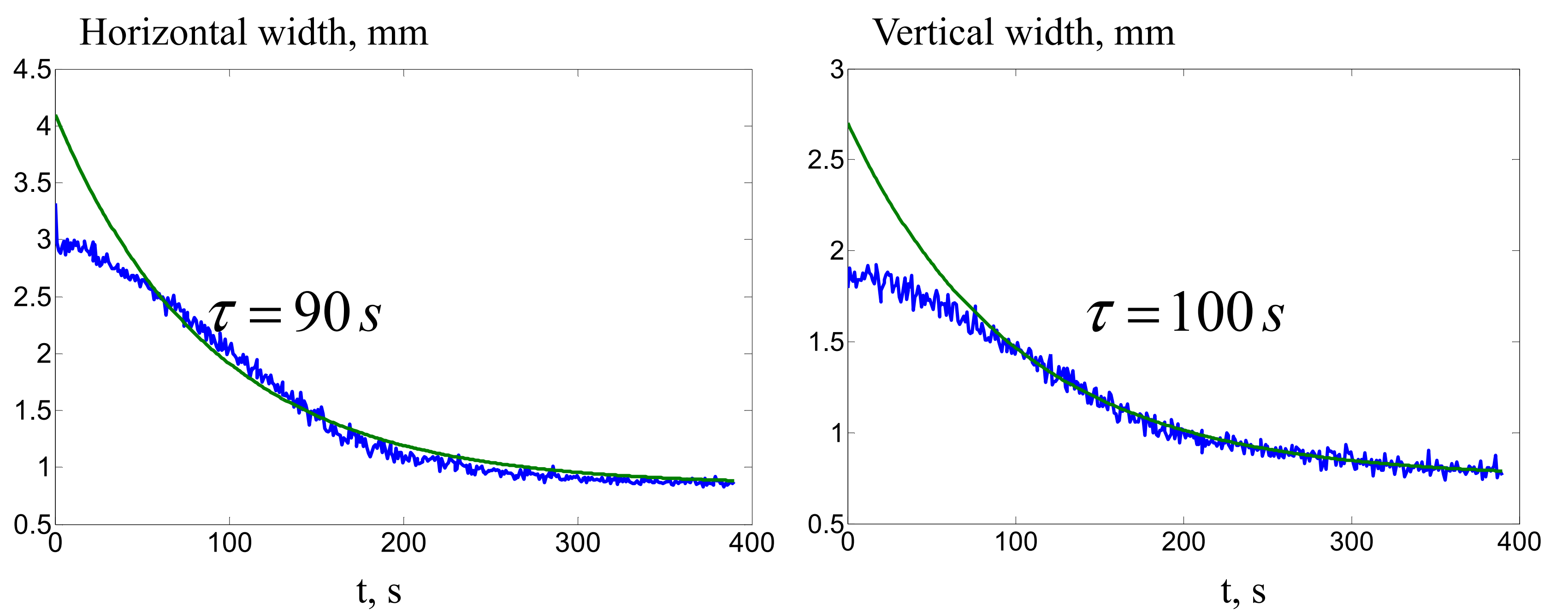


RF on, e-cooling with 0.55 A

march 2015

Transverse electron cooling 2015

$N_p = 3 \cdot 10^8$, $I_e = 0.8$ A, $E_e = 0.909$ MeV,

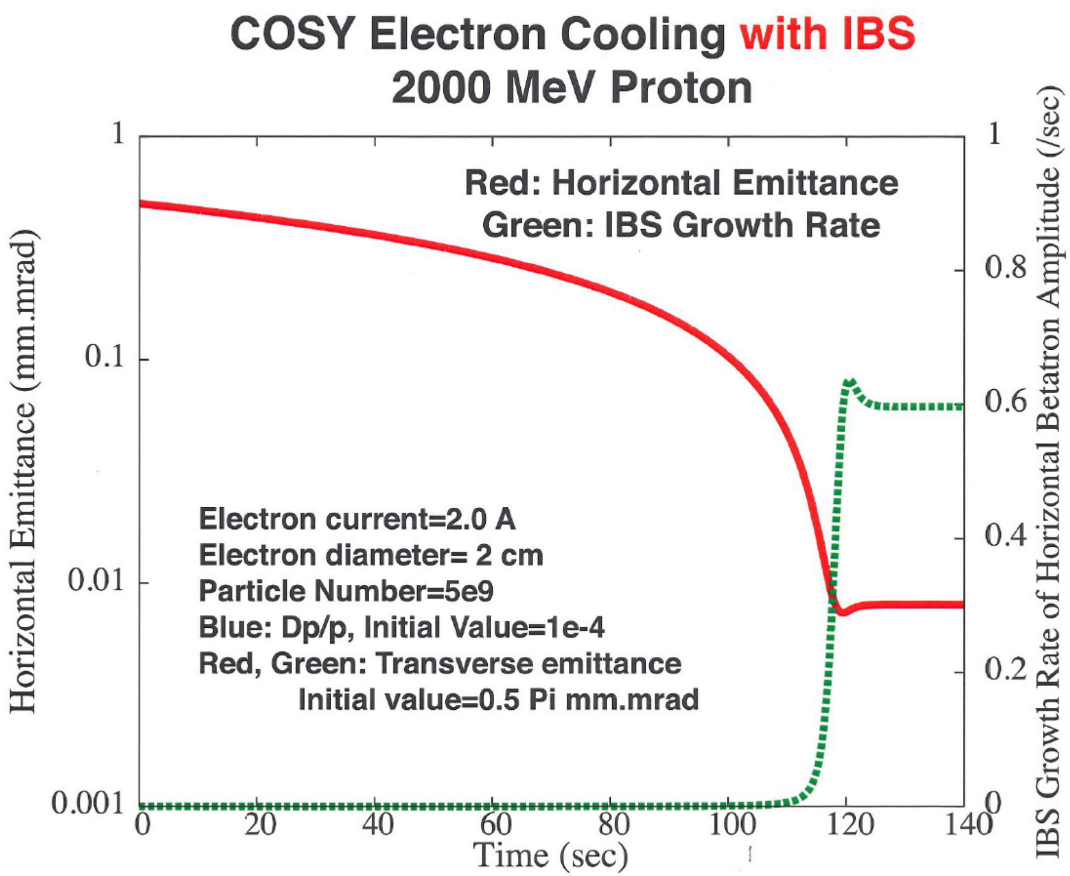


Fitting equation: $w = (w_0 - w_\infty) \cdot \exp(-t/\tau) + w_\infty$ $\quad w_0$ is the size of the proton beam at t=0

w is the value of the horizontal or vertical width $\quad w_\infty$ is the size at $t \to \infty$

march 2015

Simulations by T.Katayama



Transverse electron cooling 2016

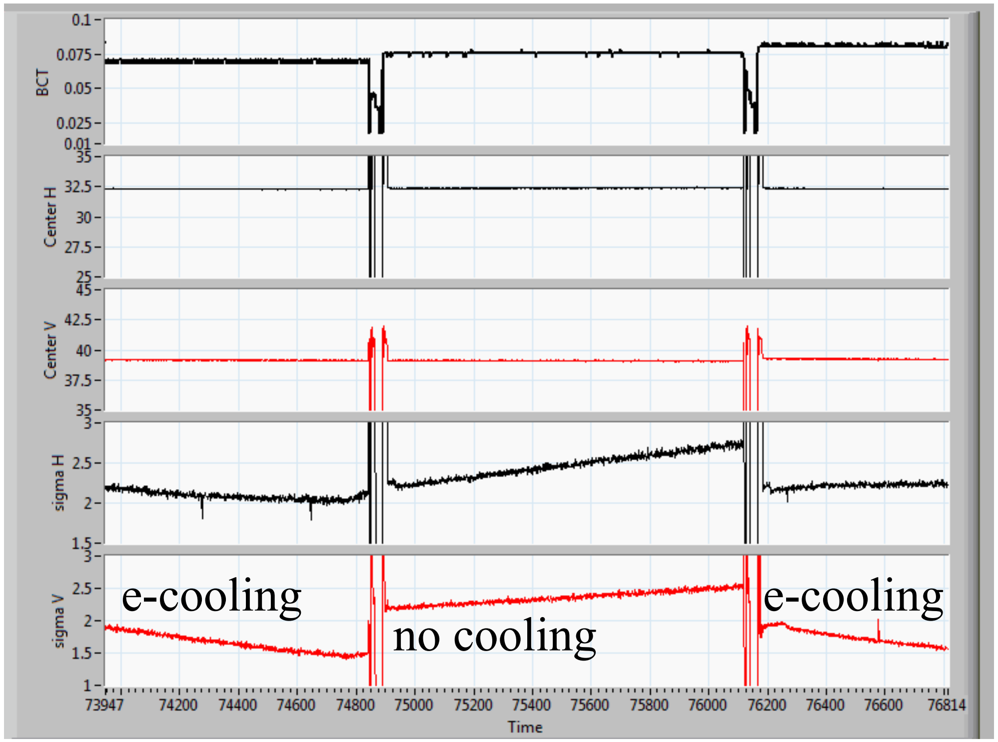
Beam intensity

Horizontal position

Vertical position

Horizontal width

Vertical width

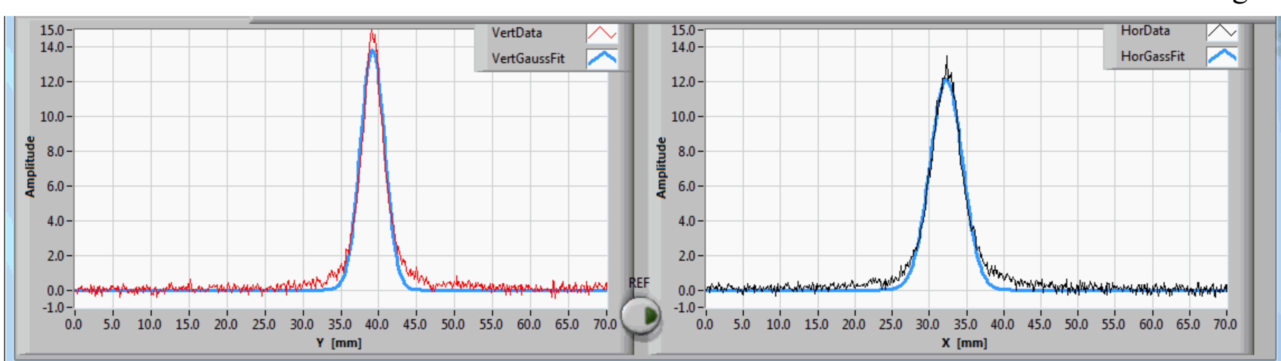


Orbit and tune settings are essential for the cooling operation

e-cooling suppresses unidentified growth of the transverse emittance

electron energy 0.909 MeV
machine cycle 640 s

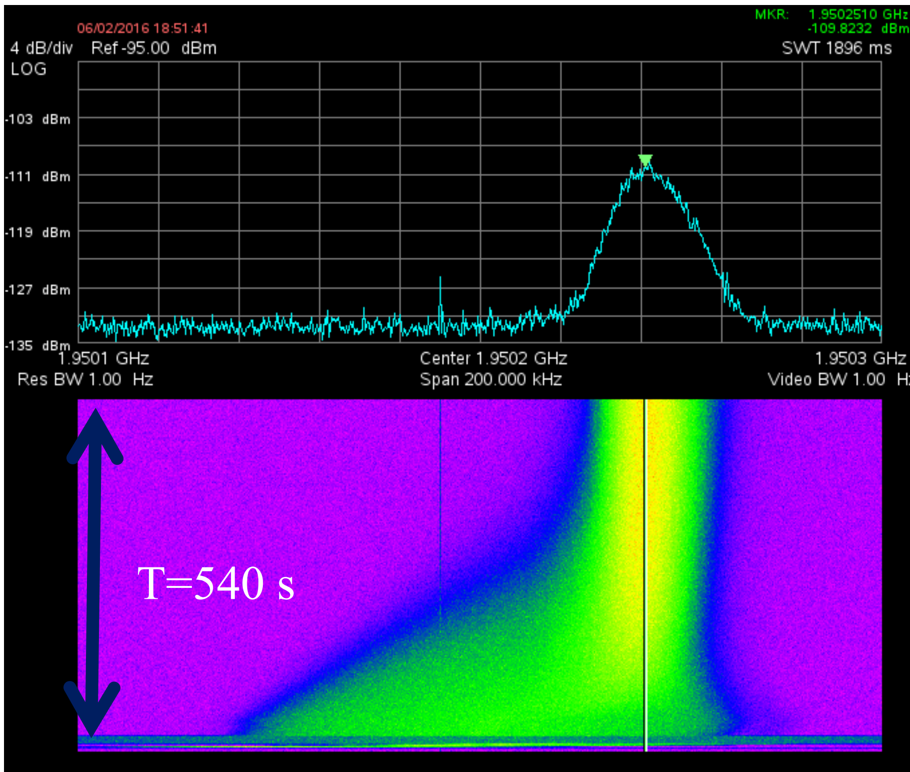
Transverse cooling with electron beam $I_e = 0.51$ A, $U_{an} = 3$ kV, $U_{gr} = 0.8$ kV, May 29, 2016

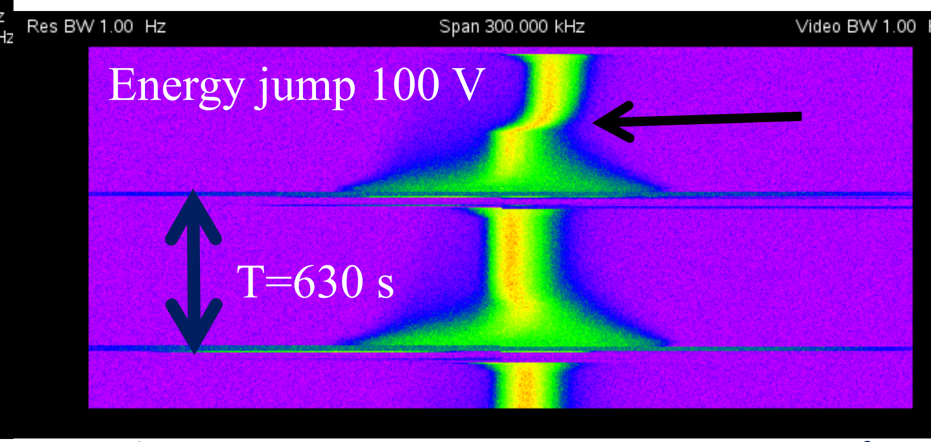


First longitudinal e-cooling at E_e = 1.257 MeV

JÜLICH
FORSCHUNGSZENTRUM

Spectra measured with the newly installed HESR st. cooling pickup





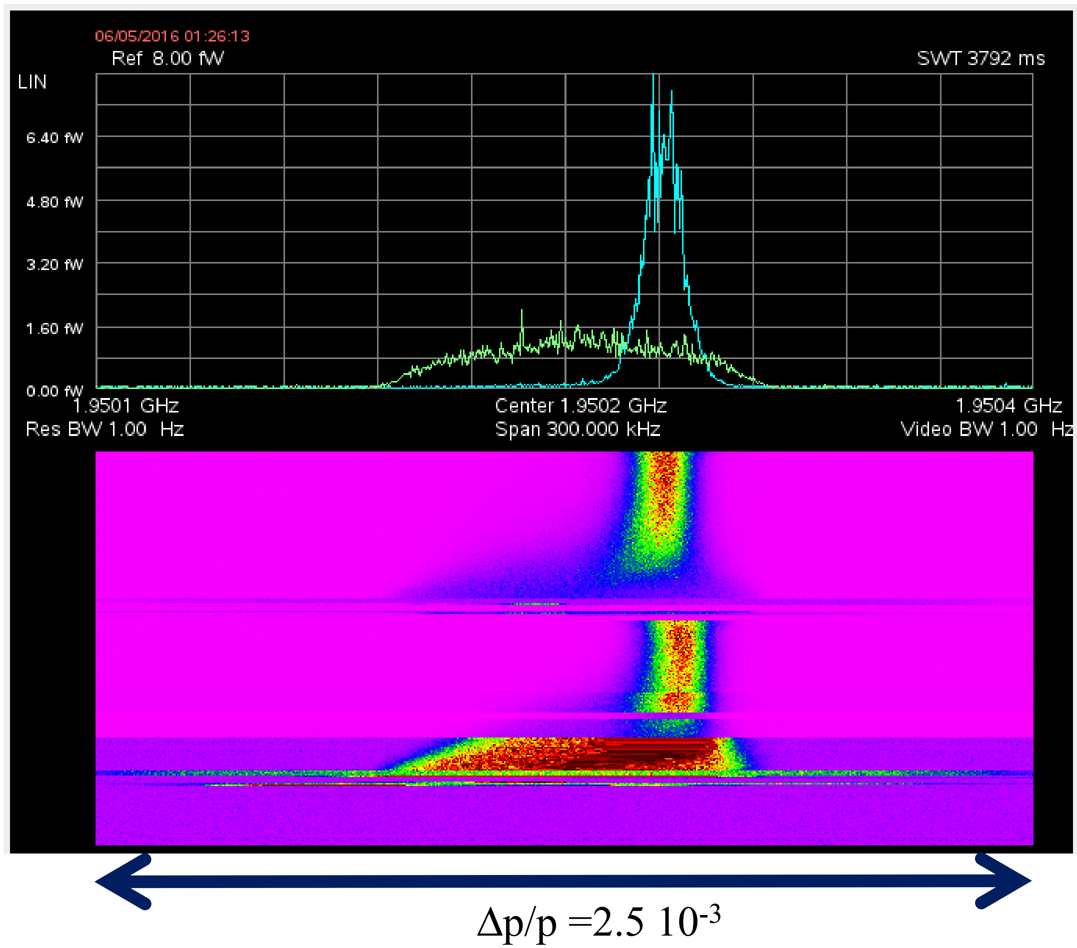
$\Delta p/p = 1.7 \; 10^{-3}$

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

e-cooling after tuning process
cooling time can be estimated as 100-150 s

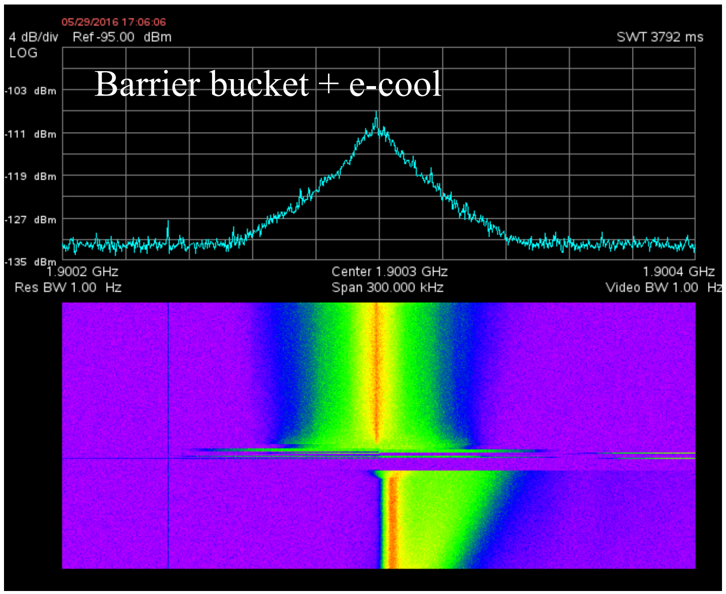
May 2016

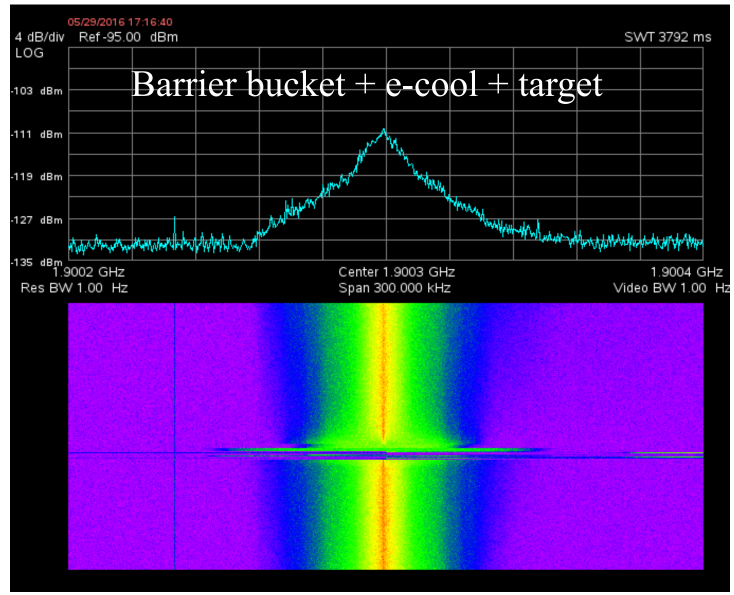
Longitudinal e-cooling at E_e = 1.257 MeV

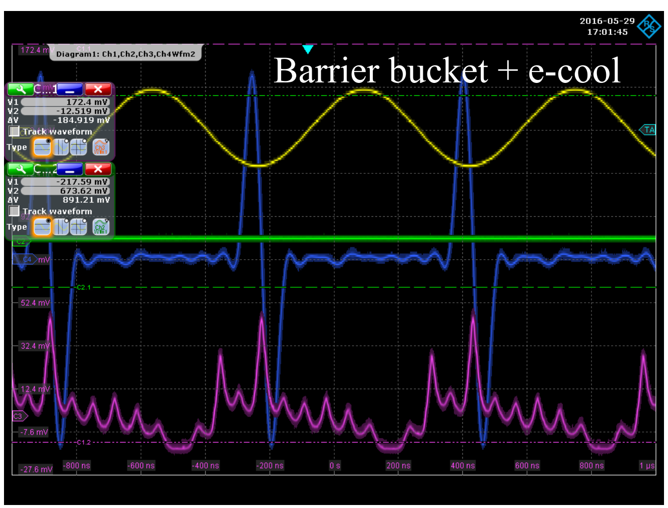


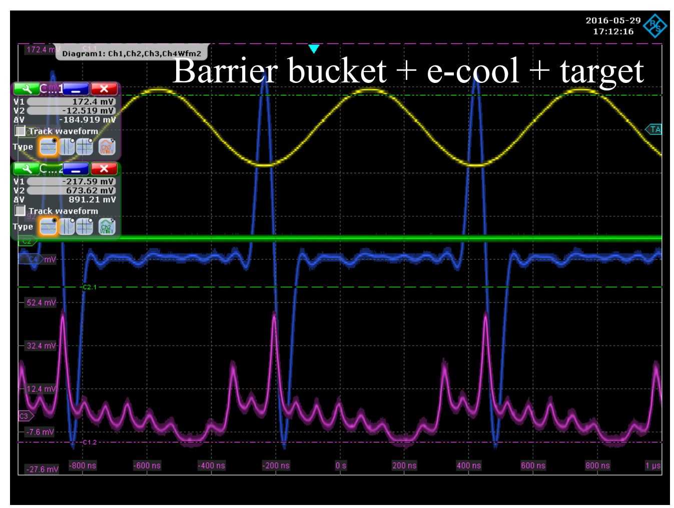
Linear scale

E-cooling at E_e = 0.909 MeV with cluster target and barrier bucket system turned on





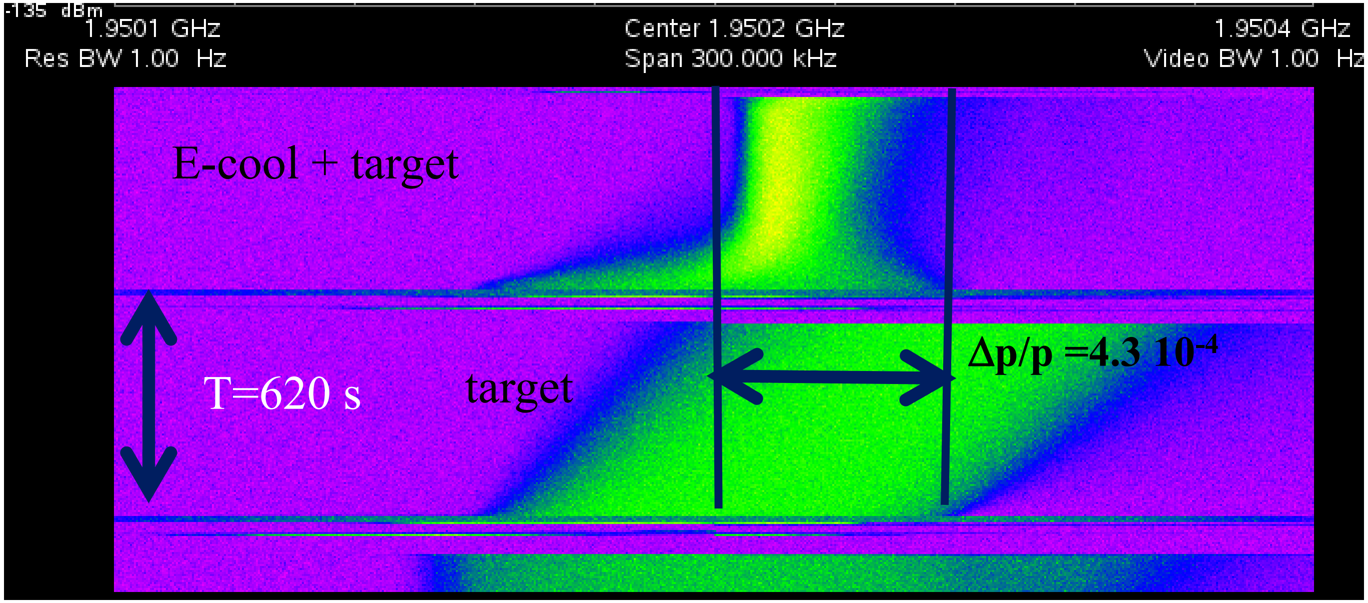




target density
$n_a = 2 \cdot 10^{14}$ cm^{-2}
(May 29, 2016),
$E_e = 908.75$ kV,
$N_p = 2 \cdot 10^{9}$

Experiments with the cluster jet target at E_e = 1.257 MeV

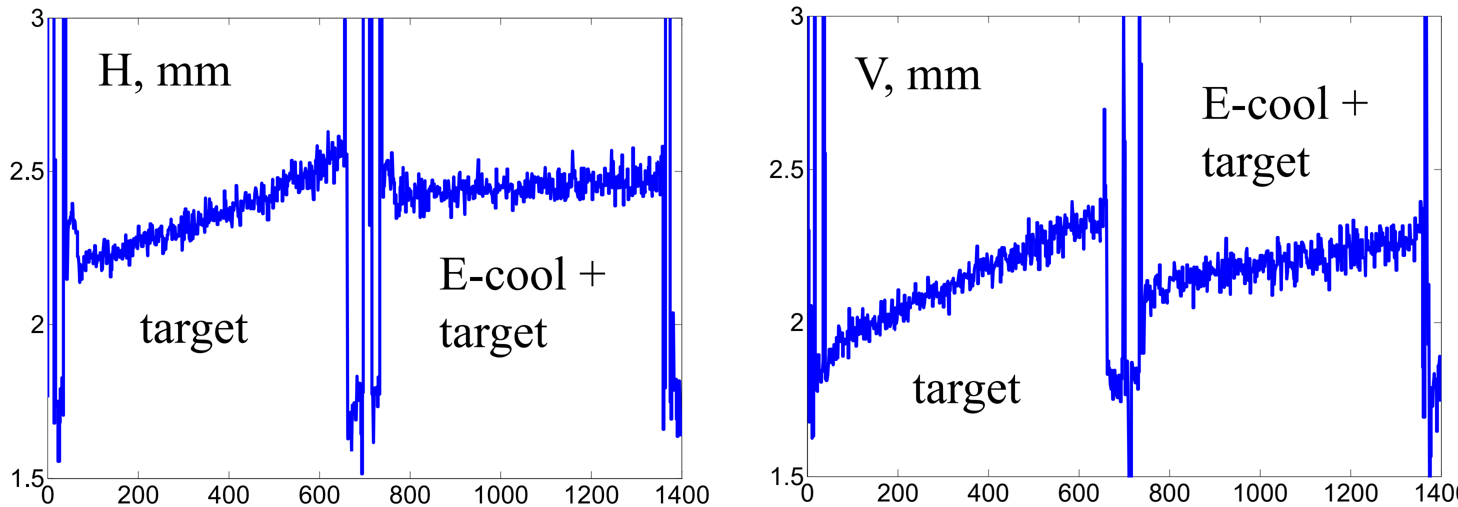
Electron cooling suppressed the longitudinal effect of the target with density $n_a = 2 \cdot 10^{14}$ cm^{-2} without the help of the RF system, June 5, 2016.



Electron energy 1.257 MeV, I_e = 0.5 A

Experiments with the cluster jet target at E_e = 1.257 MeV, transverse case

Electron cooling practically suppressed longitudinal and transverse growth induced by the target but a more careful tuning of the storage ring and e-cooler is necessary.



Electron energy 1.257 MeV, I_e = 0.5 A

June 2016

Problems encountered

- Suffered a significant setback - a failure of the cascade transformer PS, that provides primary power to all 33 HV sections and the HV terminal, disabled the 2 MeV cooler early in the March 2017 beam time (fixed)
- Different DAQs, not all channels could be recorded
- Lack of automatic tune scanning procedure
- Sensitivity to beam alignment
- Long setup times for the 2 MeV cooler, coupled parameters
- Occasional interlock trips

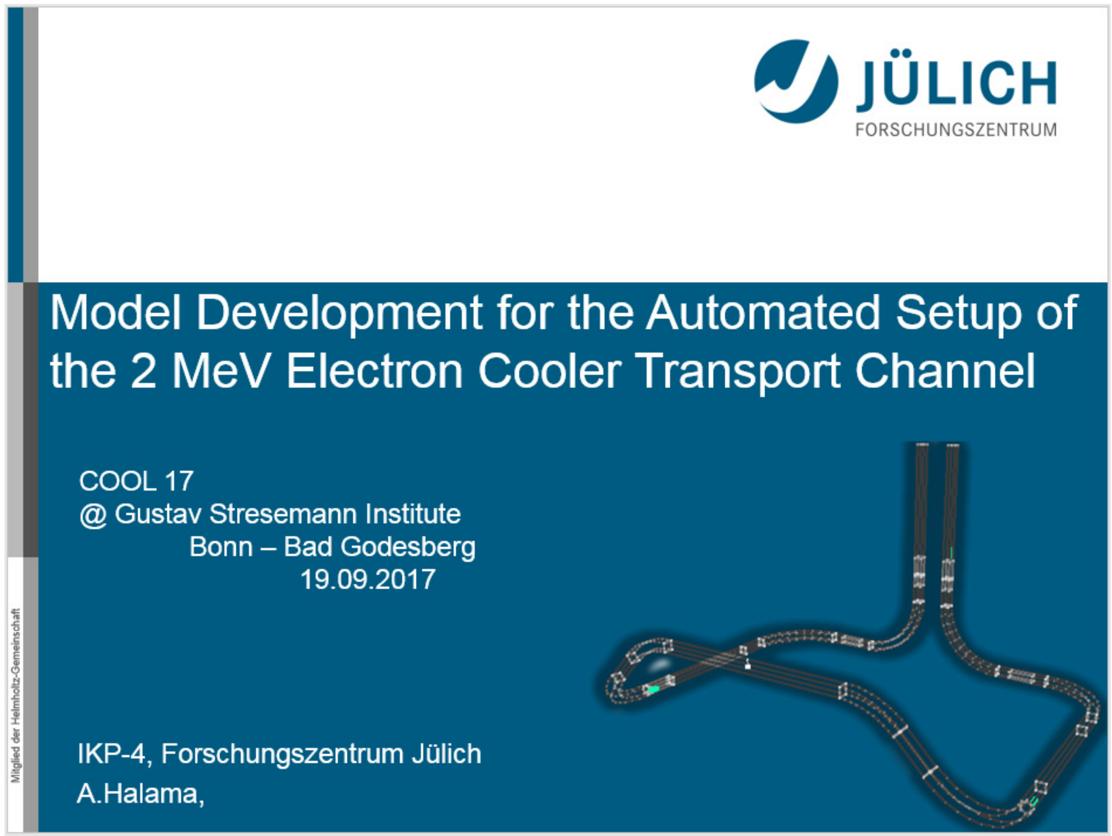
Prerequisites for the upcoming beam studies

- Implementation of an EPICS IOC in the cooler control system
- Commission the fast tune meter for dc and bunched beams
- Prepare SW to perform automated tune scans (in progress)
- Commission new BPM electronics (done)
  - Closed orbit (done)
  - Turn-by-turn measurements (done)
  - Tune measurements for bunched beam (in progress)
- Finalize cooler simulation and toolset (in progress)

Beam request submitted to CBAC

- 2 weeks dedicated to the beam dynamics experiments with electron cooling and internal cluster jet target. Feb 2018
  - Cooling rates vs beam energy
  - PANDA target + e-cooling, compensation of mean energy loss by the barrier bucket RF system and suppression of the dP/P and transverse beam size growth by means of electron cooling (also in combination with stochastic cooling)
  - Effects of electron cooling on the tales of the beam distribution
  - Cooling performance, beam lifetime and luminosity evolution vs electron beam profile with and without target
  - Study cooling performance vs magnetic field in the cooling solenoid
  - Tune scans with e-cooled beam
- Additional 3 days of beam time in 2017 are requested to optimize the COSY model to increase beam intensity and to look into the beam dynamics with the e-cooler magnets operating at high fields.

More details on the 2 MeV cooler in the talk by A. Halama today



Summary

- Since the initial commissioning of the 2 MeV electron cooler at COSY in 2013 electron cooling of unpolarized proton beam in the energy range of 0.2 - 2.3 GeV was demonstrated
- Combined electron and stochastic beam cooling was performed at 1.66 GeV
- Electron cooling compensated the longitudinal effects of the cluster jet target on the proton beam at 2.3 GeV
- Further experiments included e-cooling of deuteron beams, e-cooling into the barrier bucket, and e-cooling of bunched beams.
- An adjustment and analysis toolset is used to assist the operator in achieving the required parameters of the magnetic system
- A software aiming at the automated adjustment of the cooler, based on an advanced physical model, is in the final stage of development
- Upgrades of the COSY BI and controls systems completed / in progress

Thank you