Commissioning of the MAX IV Light Source

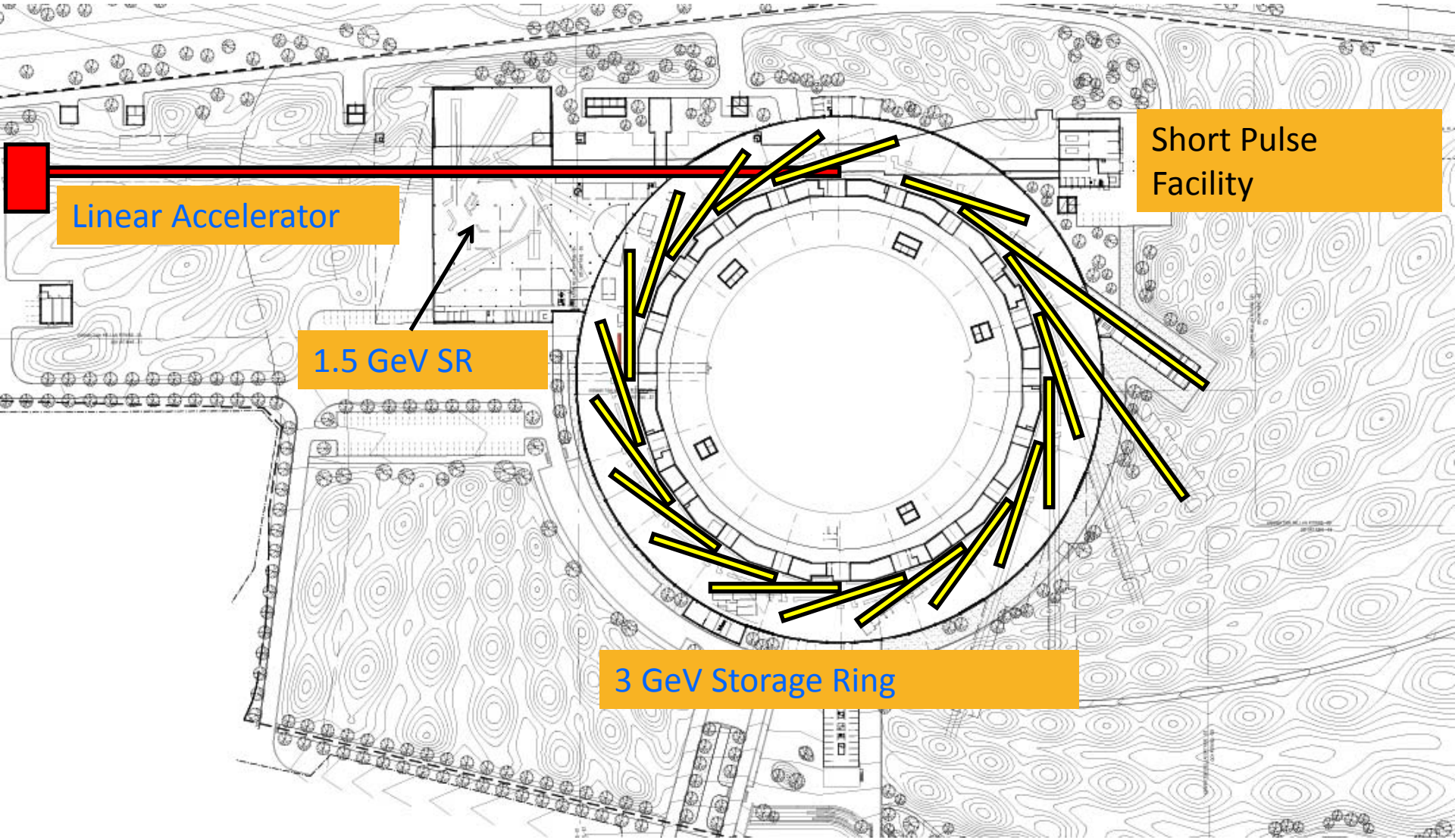
Pedro F. Tavares on behalf of the MAX IV team

NAPAC – Chicago, October 2016

Outline

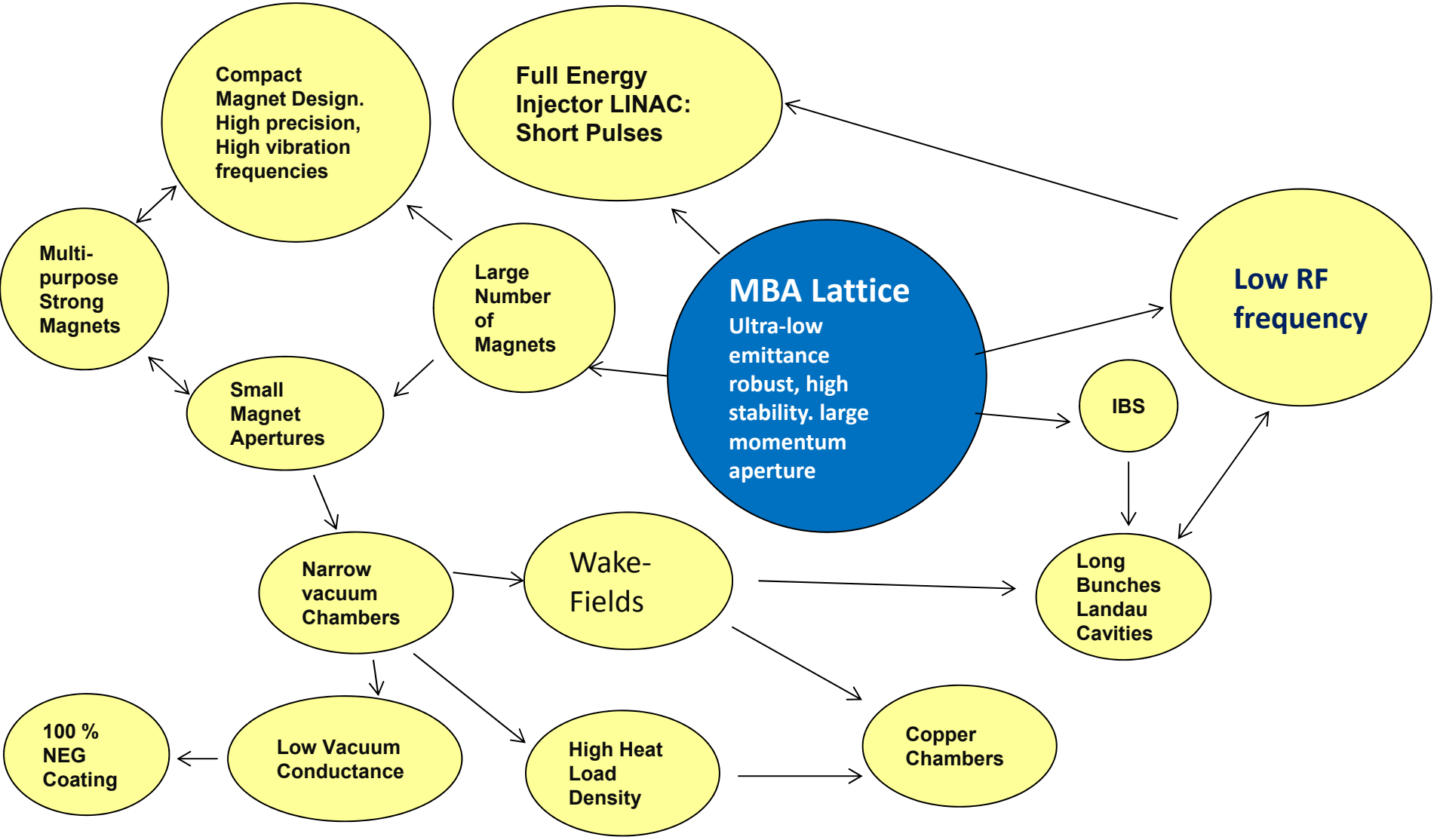
- The MAX IV Facility
- The MAX IV 3 GeV Ring
- Commissioning Highlights
- 1.5 GeV Ring Commissioning
- Next Steps
- Future Perspectives

MAX IV – an overview



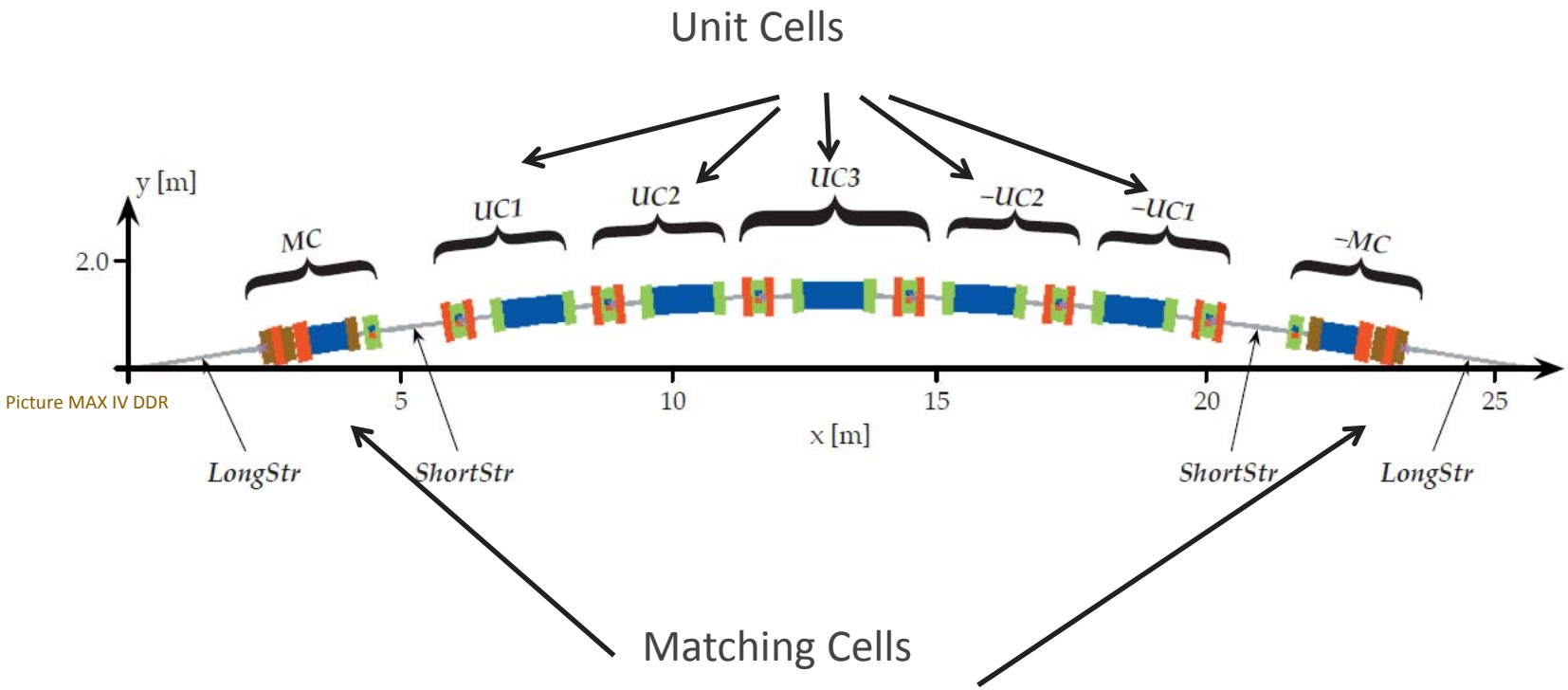
Energy	3	GeV
Current	500	mA
Emittance	0.2 - 0.33	nm rad
Circumference	528	m
# straight sections	20 × 5 m	

MAX IV - An integrated Solution



The MAX IV 3 GeV ring Lattice

7-bend achromat
20 periods



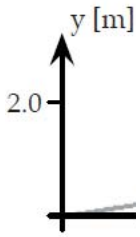
Picture MAX IV DDR

The MAX IV 3 GeV ring Lattice

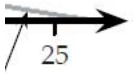
7-bend achromat

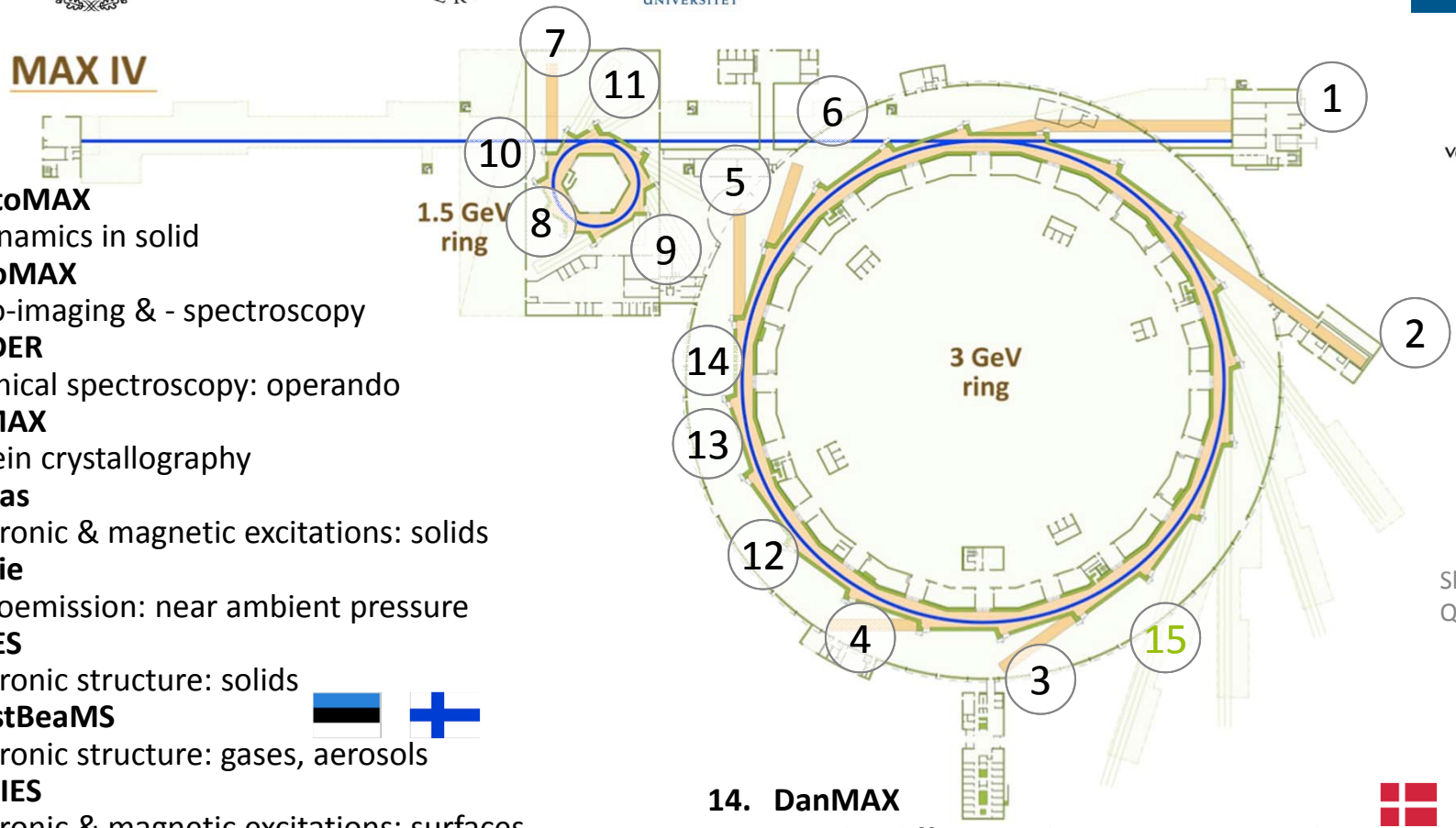
20 peri

Periodicity	20
Circumference	528 m
Horizontal tune ν_x	42.20
Vertical tune ν_y	16.28
Natural horizontal chromaticity ξ_x	−49.984
Natural vertical chromaticity ξ_y	−50.198
Momentum compaction (linear) α_c	3.06×10^{-4}
Horizontal damping partition J_x	1.8471
Bare lattice emittance ε_0	0.328 nm rad
Bare lattice energy loss per turn	363.8 keV
Bare lattice natural energy spread σ_δ	0.769×10^{-3}
Bare lattice horizontal damping time τ_x	15.725 ms
Bare lattice vertical damping time τ_y	29.047 ms
Bare lattice longitudinal damping time τ_E	25.194 ms
Horizontal beta function at center of LS β_x^* (bare lattice)	9.00 m
Vertical beta function at center of LS β_y^* (bare lattice)	2.00 m



Picture MAX IV DDR





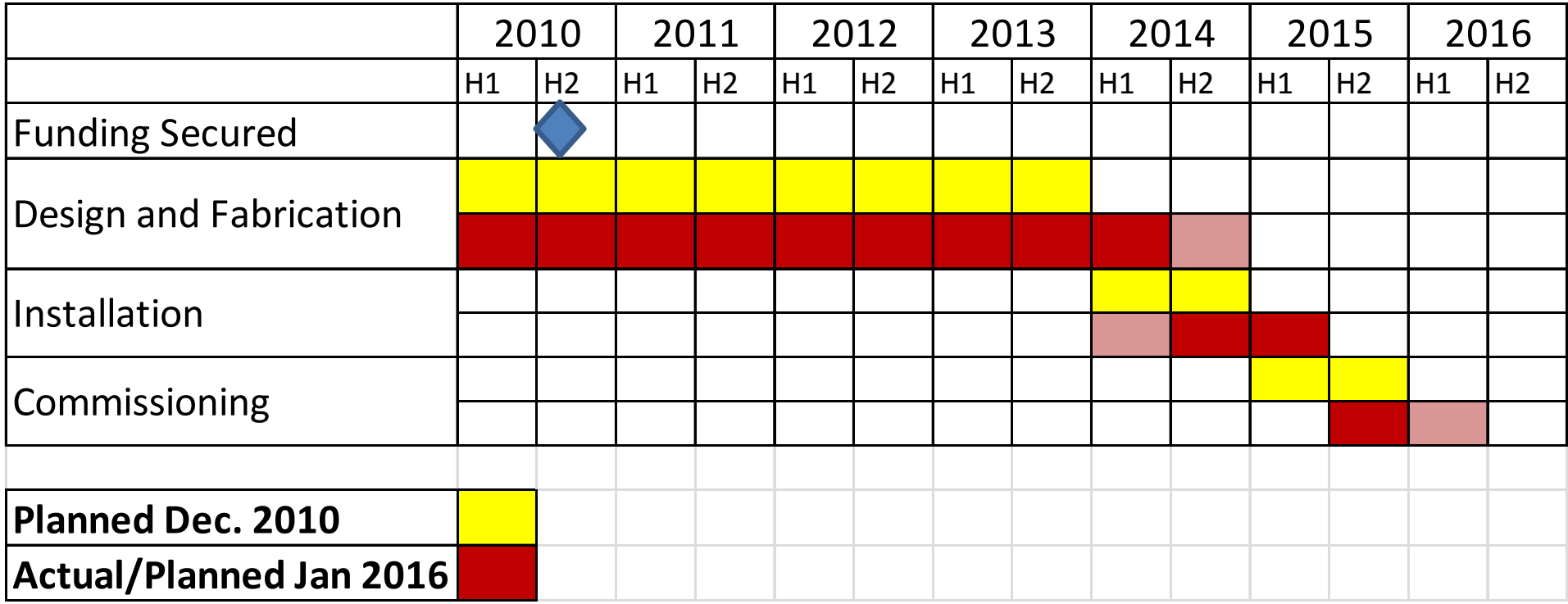
Vetenskapsrådet

1. **FemtoMAX**
   fs dynamics in solid
2. **NanoMAX**
   Nano-imaging & - spectroscopy
3. **BALDER**
   Chemical spectroscopy: operando
4. **BioMAX**
   Protein crystallography
5. **Veritas**
   Electronic & magnetic excitations: solids
6. **Hippie**
   Photoemission: near ambient pressure
7. **ARPES**
   Electronic structure: solids
8. **FinEstBeaMS**
   Electronic structure: gases, aerosols
9. **SPECIES**
   Electronic & magnetic excitations: surfaces
10. **Transfer_PEEM**
    Microscopy: surfaces
11. **Transfer_XPS**
    Electronic structure: surfaces & gases
12. **CoSAXS**
    Geometric structure & correlation: (bio) liquids
13. **SoftiMAX**
    Microscopy & method development

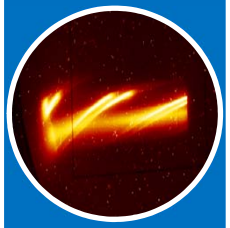
Slide by C. Quitmann

14. **DanMAX**
    Powder diffraction & imaging: materials science
15. **ForMAX**
    Wood & paper: structure & processing
16. **MicroMAX**
    Most relevant (difficult) protein structures
17. **DiffMAX**
    Crystal structure of bulk & surface
18. **iMAX**
    Imaging of engineering materials

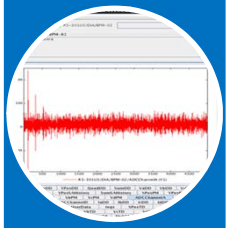
Project Timeline – MAX IV 3 GeV Ring



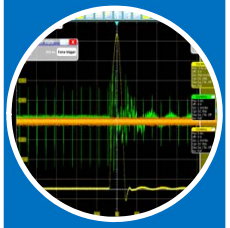
3 GeV Ring Commissioning Timeline



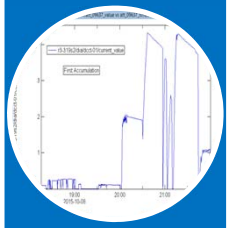
Beam in TR3
Aug 11
2015



First Turn
Aug 25
2015



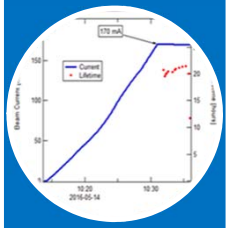
Stored Beam
0.1 mA
Sep 15
2015



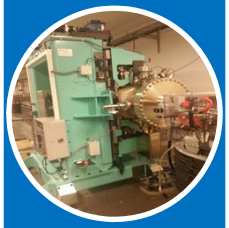
Stacking
4 mA
Oct 08
2015

First Light
Nov 2
2015

Feb&March
2016
First IVUs

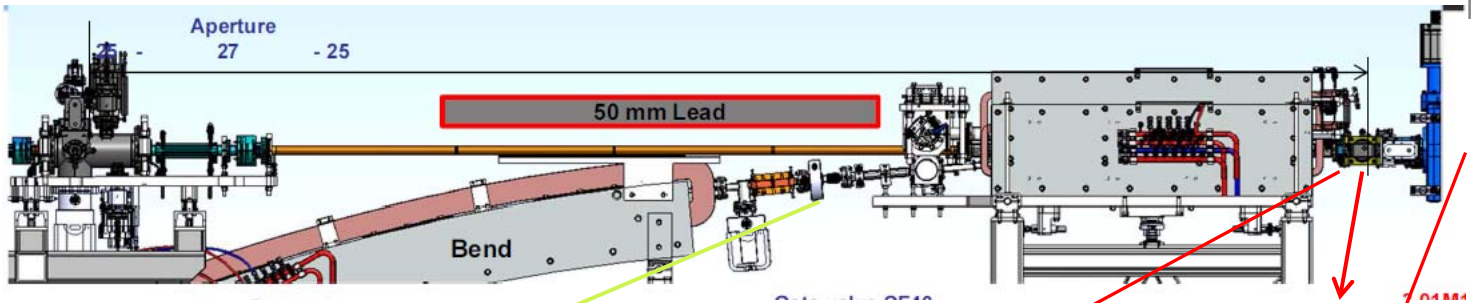


198 mA
July 9, 2016



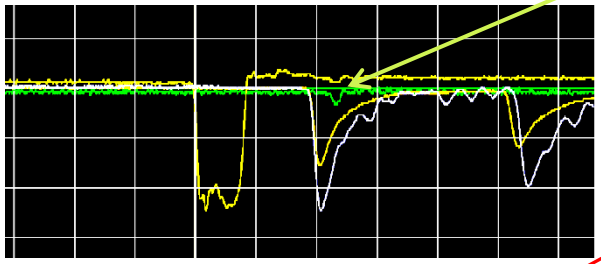
2 EPUs, 1
In/vacuum
Wiggler
September,
2016

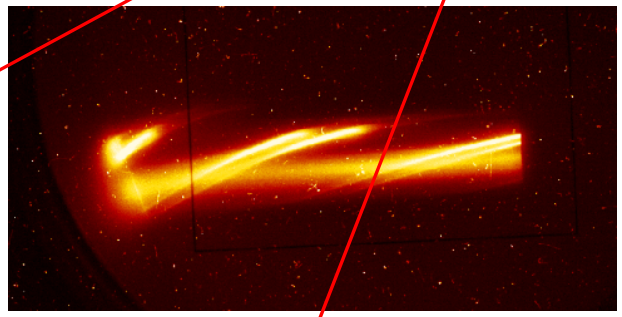
Early Commissioning Results

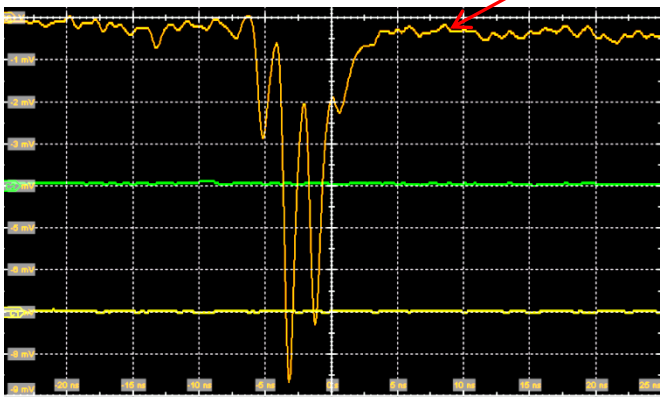


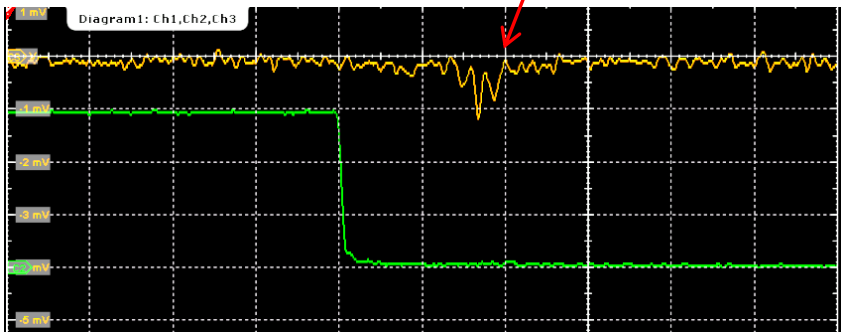
Picture J.Alhbäck

M1



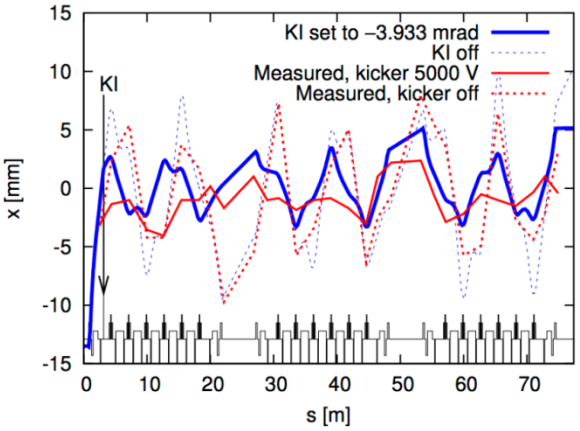




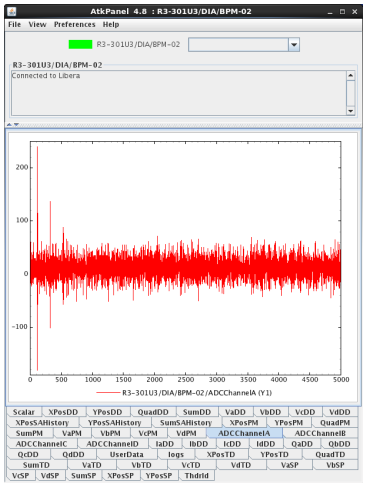


- Beam observed at the end of TR3 and into the ring. **2015/08/11**

Threading the beam – first turn – many turns



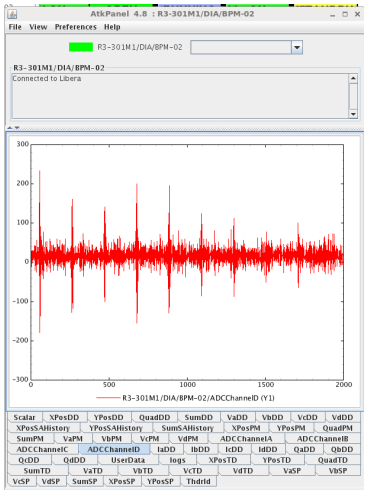
Picture S.Leemann



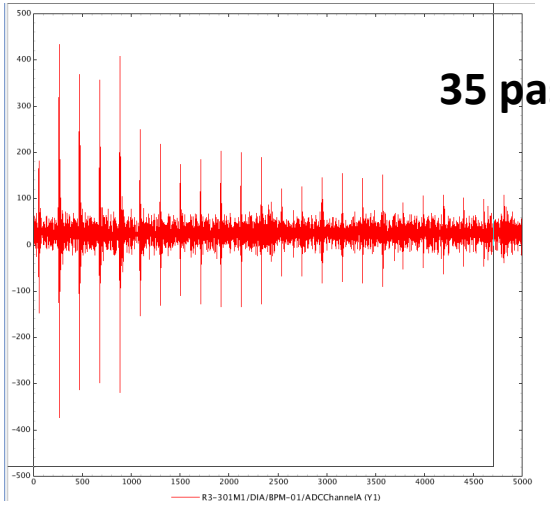
2015/08/25

3 passes

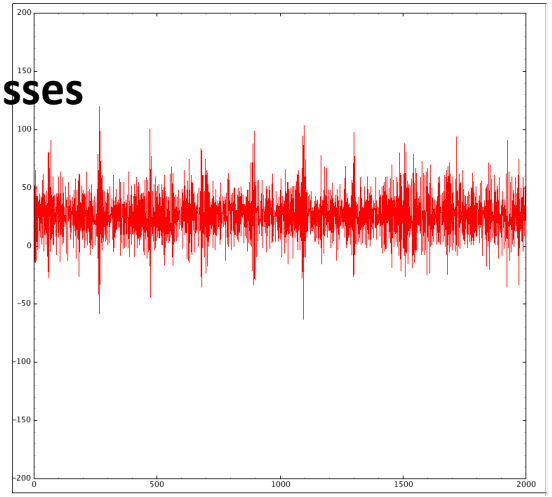
All correctors OFF



2015/08/26

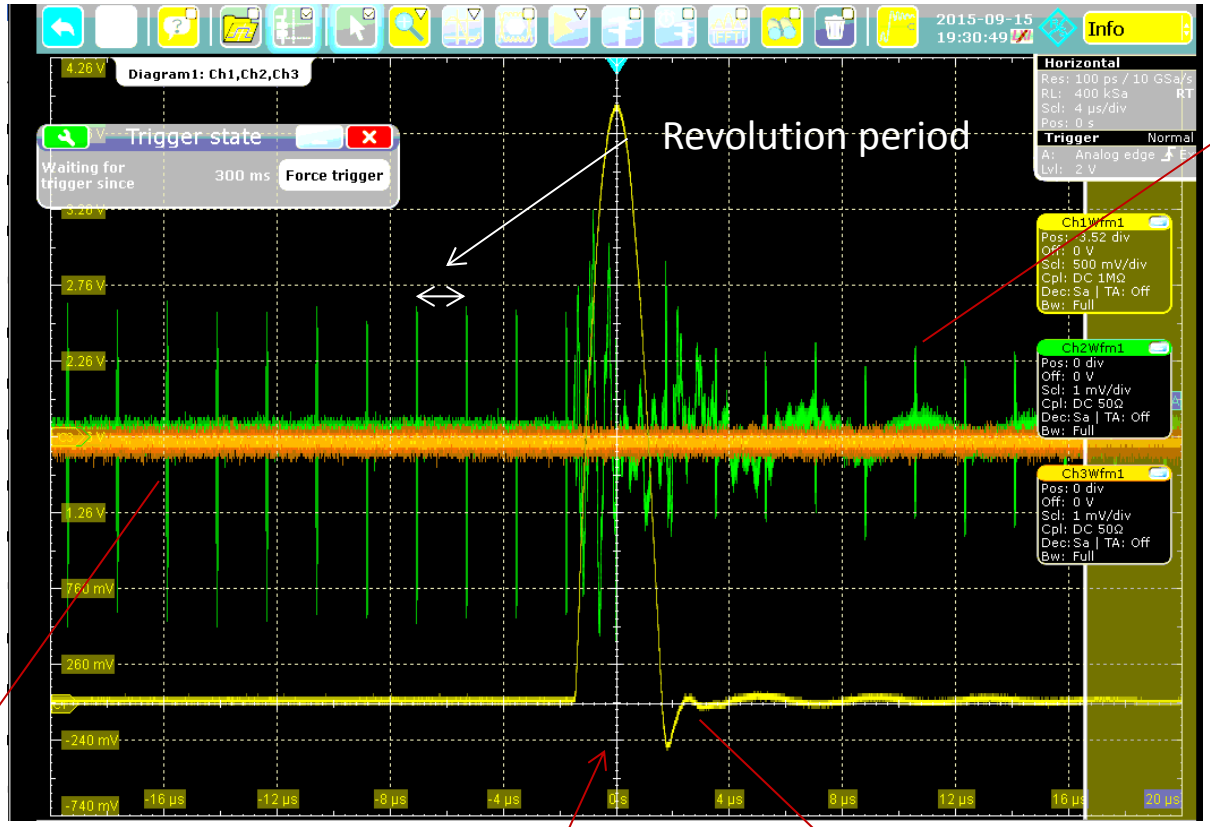


35 passes



2015/08/27

First Stored Beam



Revolution period

Injected beam

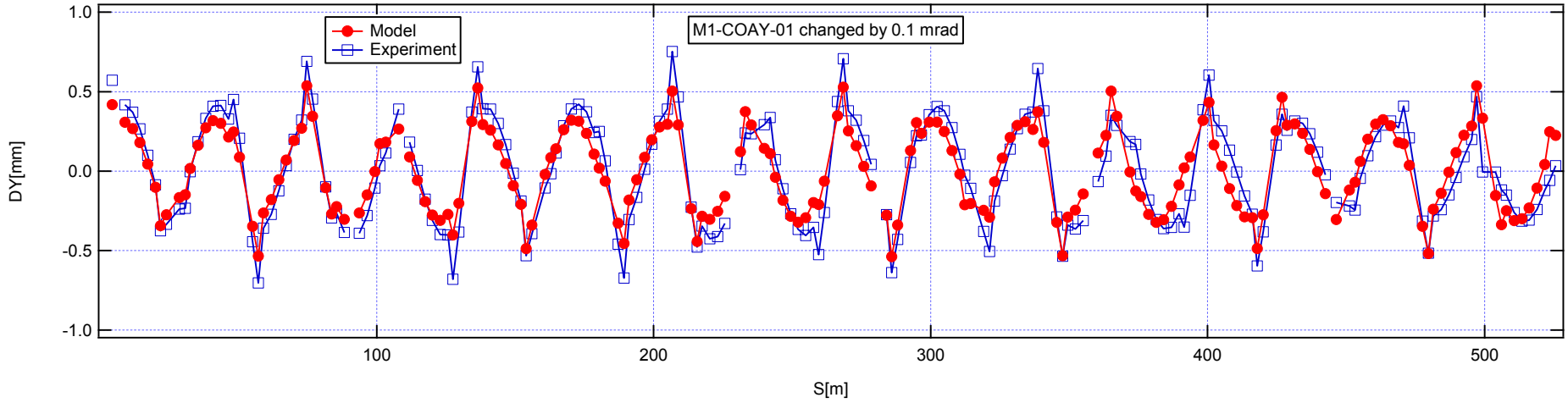
Stored beam 2 seconds after previous injection pulse

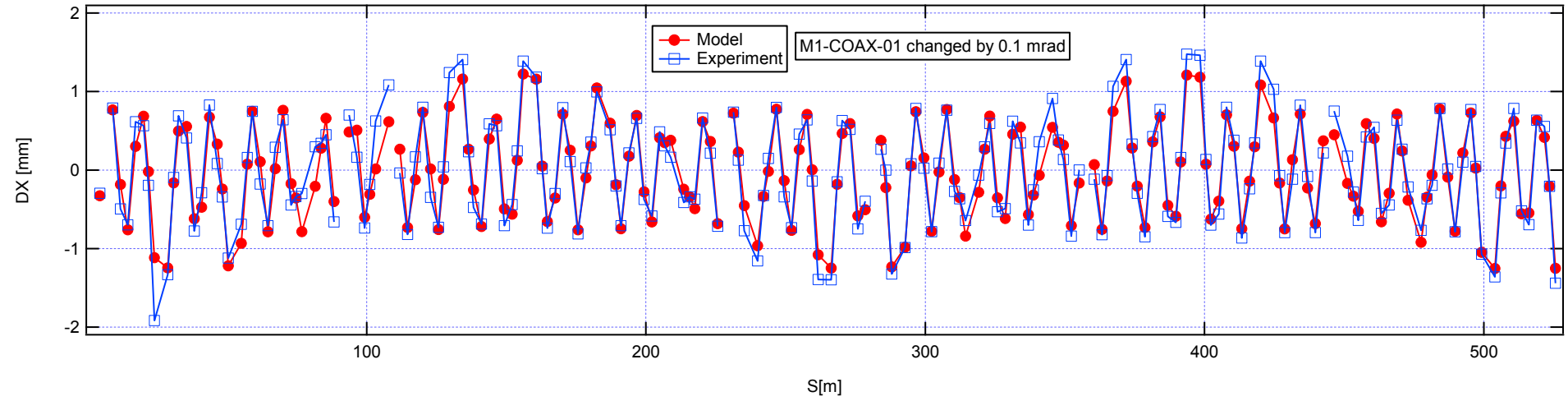
Injection

Kicker Current

2015/09/15

Linear Optics Characterization: Integer Tunes

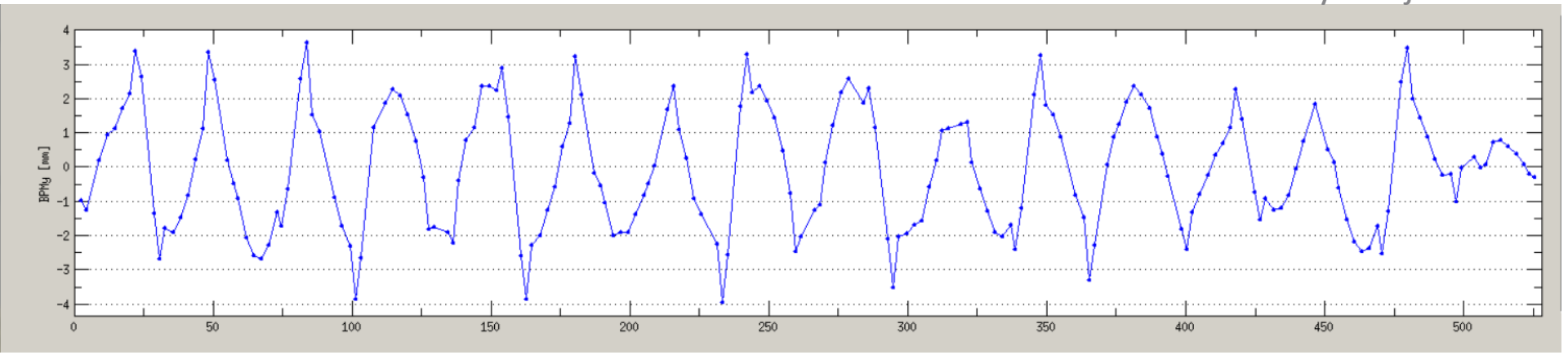


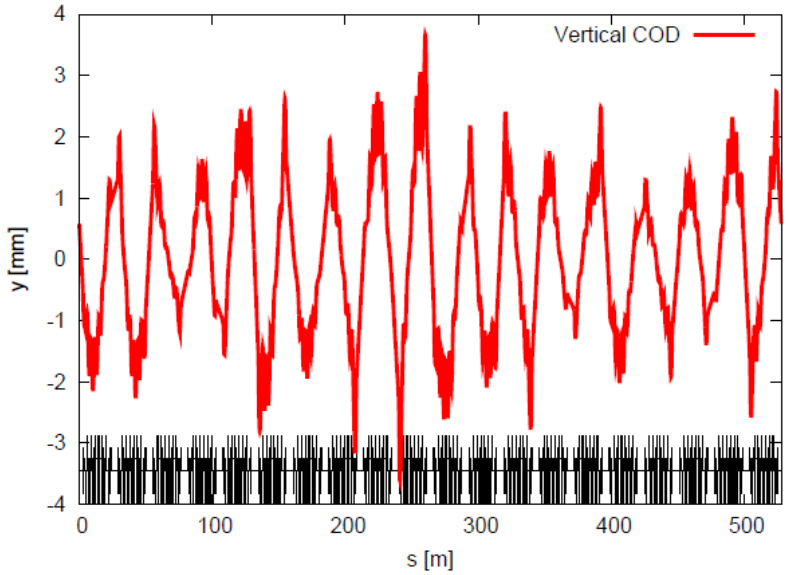


Fractional tunes: 0.2087/0.2676

Bare Vertical Orbit

Plot by M.Sjöström

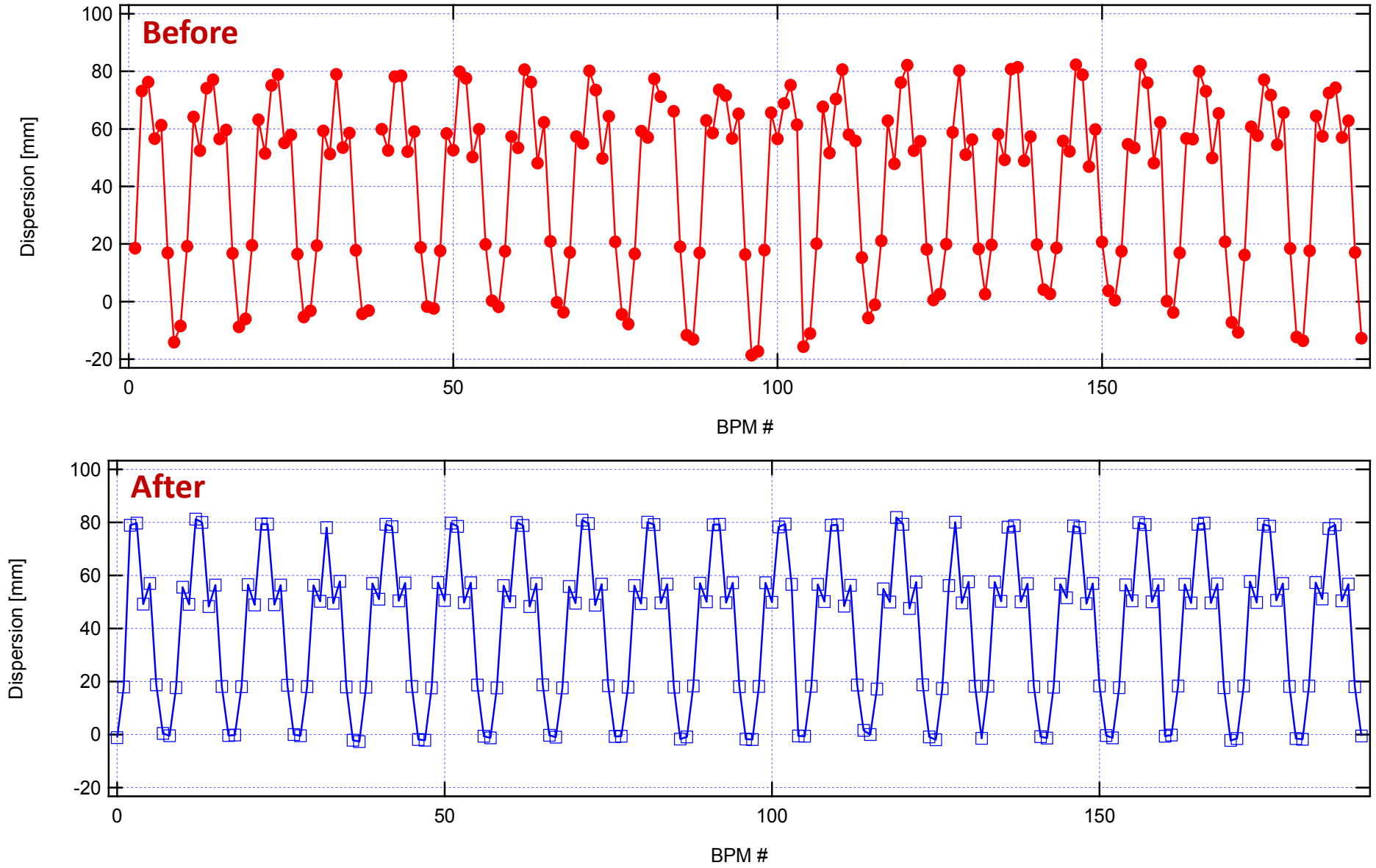




Example calculation for one random seed

MAX-lab Internal Note 201211071 by S.Leemann

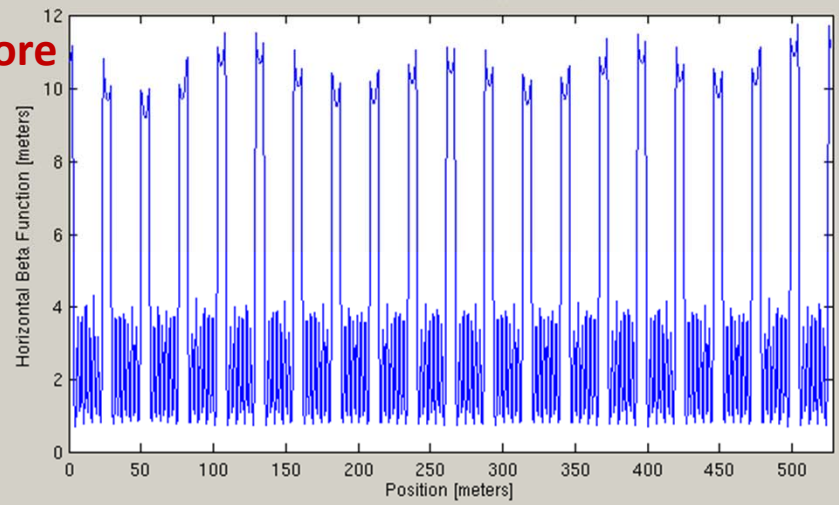
LOCO: reduction in dispersion beating

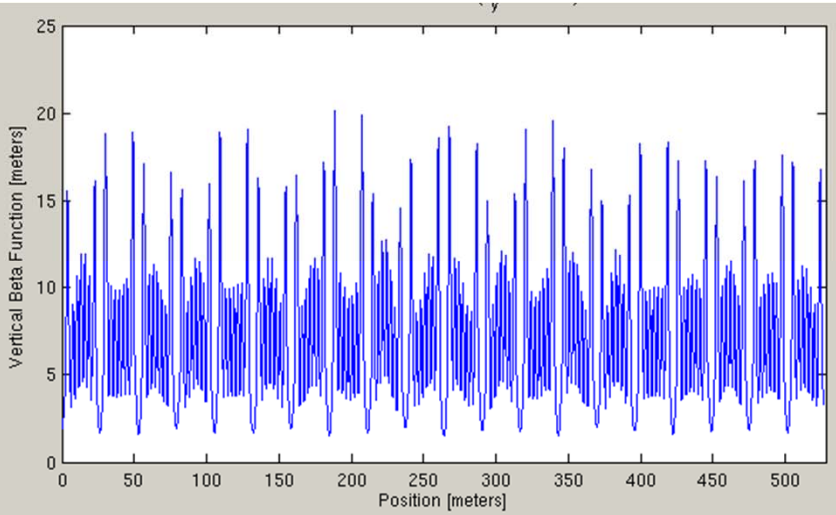


Optical Functions from LOCO

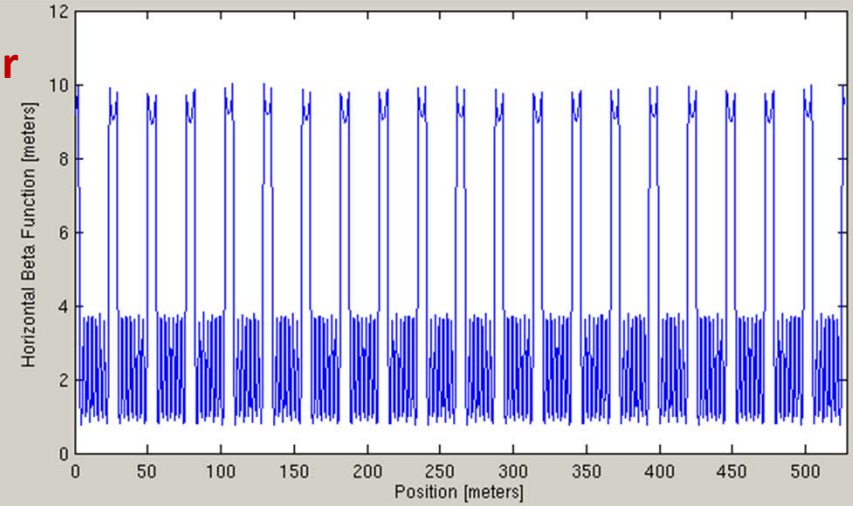
Plots by J.Sjögren

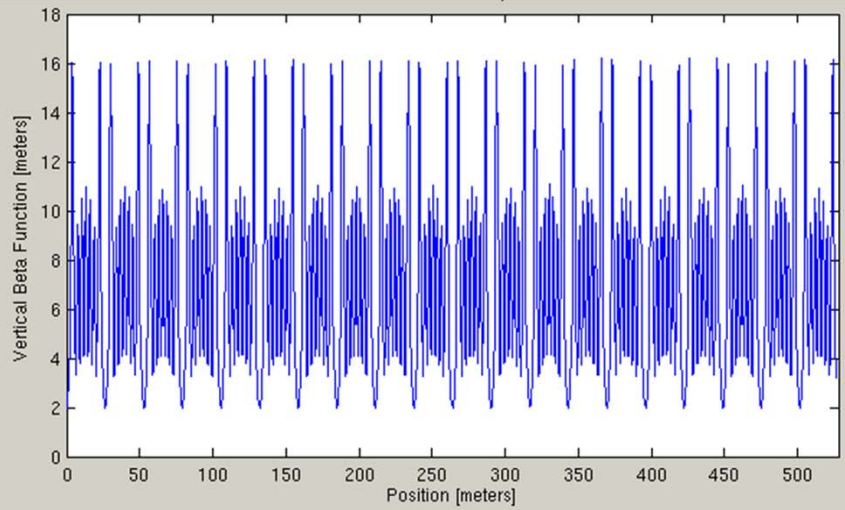
before





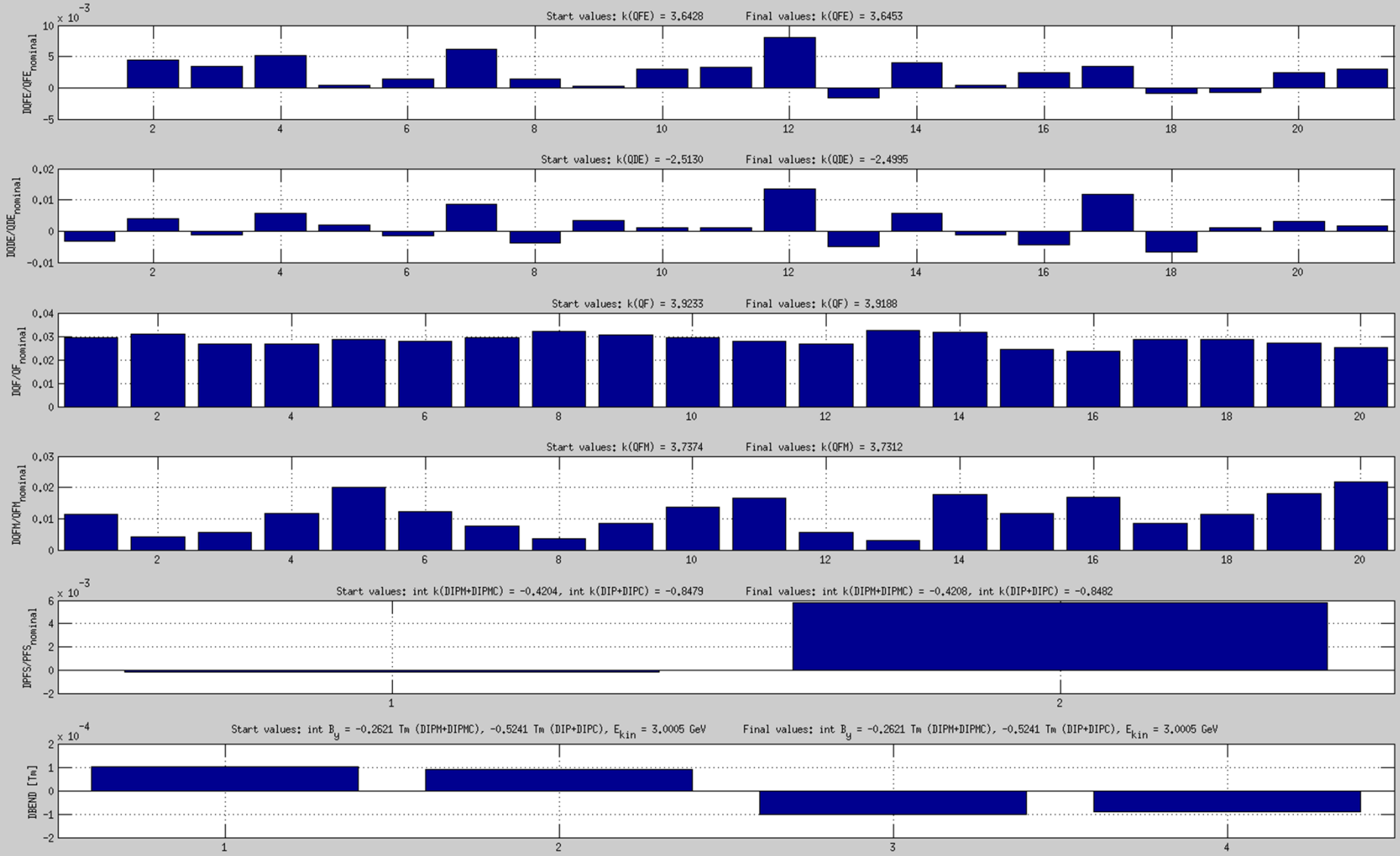
after





Changes Implemented by LOCO

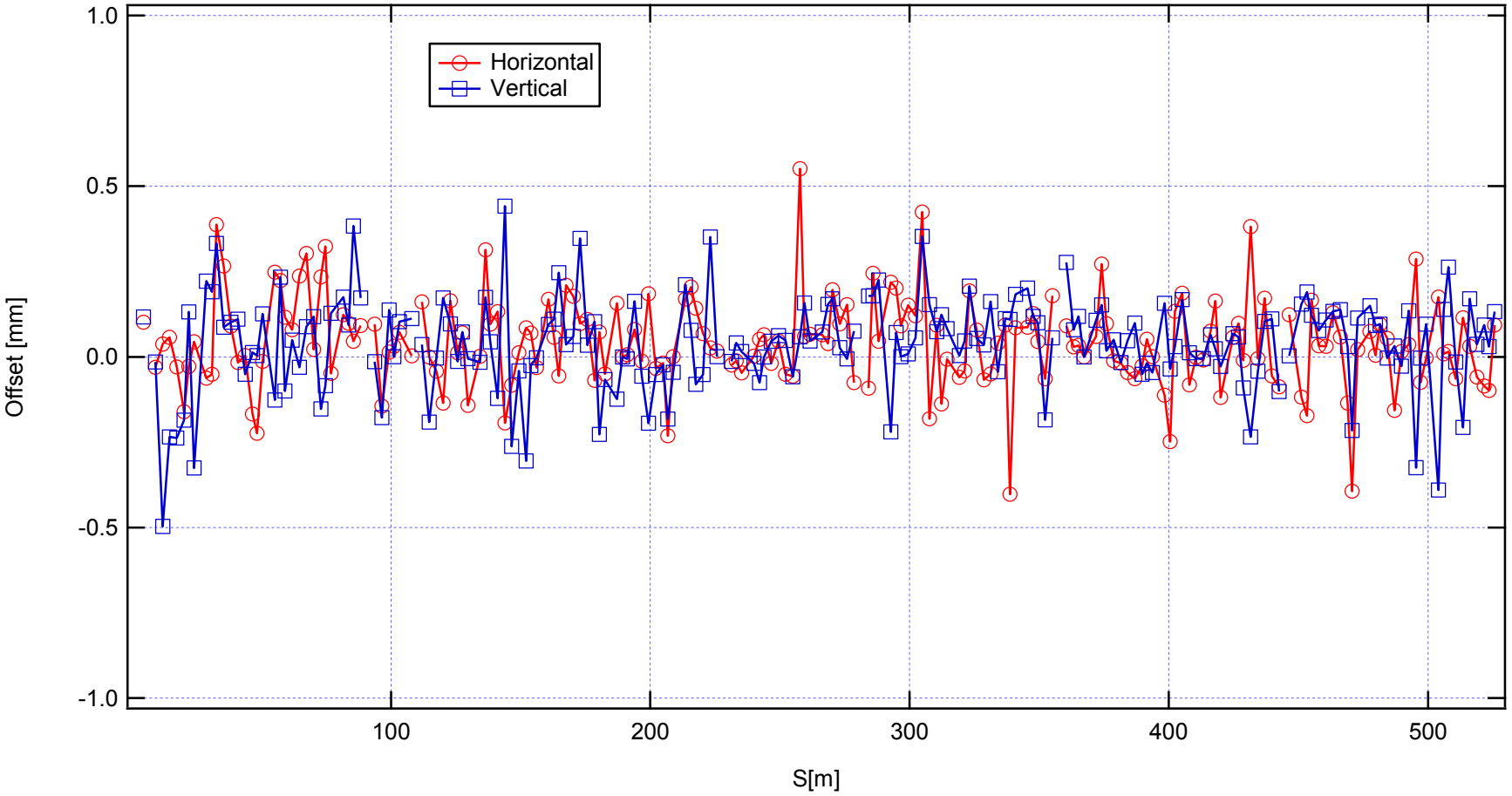
Plots by J.Sjögren



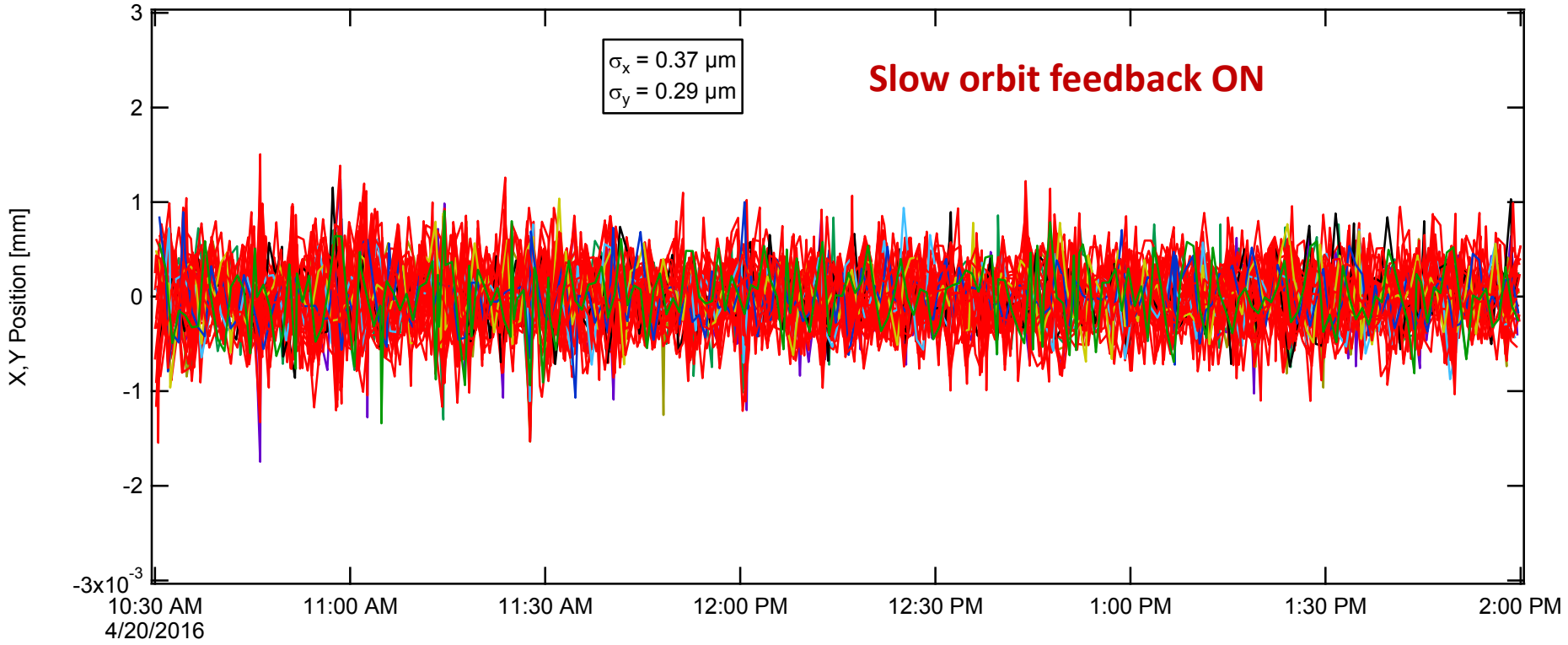
BPM Offsets

- Measured by BBC using trim coils in sextupole magnets

RMS: 144 µm H / 138 µm V

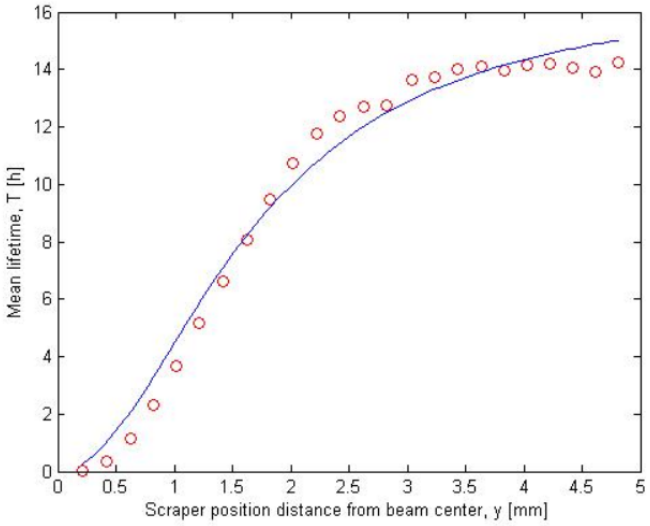


Orbit Stability



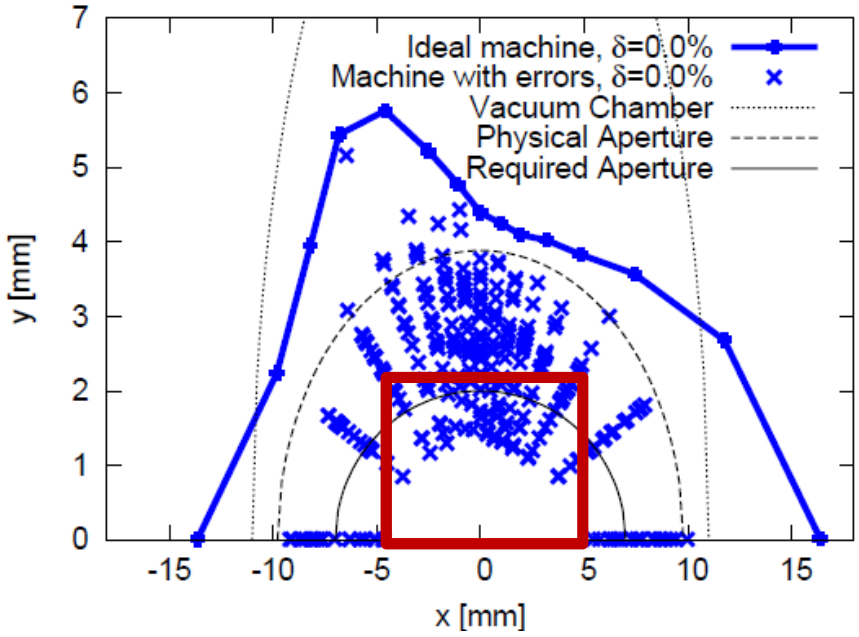
Horizontal & Vertical around ID straights

Aperture scans, scraper measurements



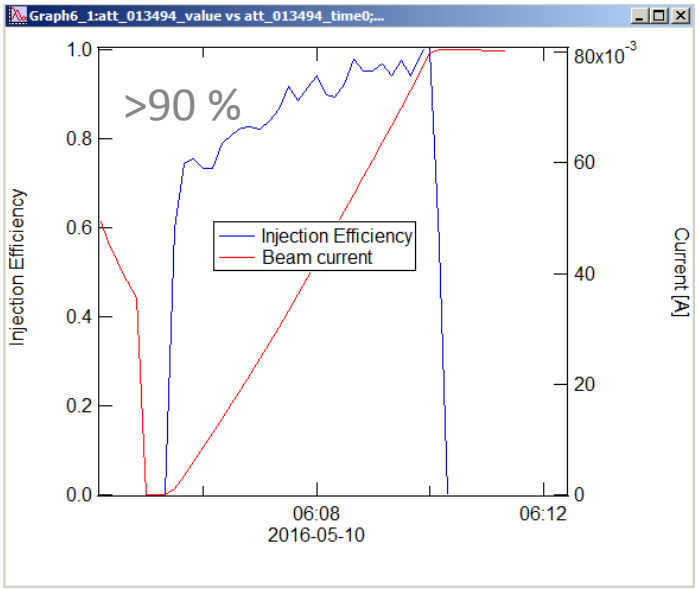
2016-02-03 measurement by J. Sundberg

Error model: uncorrected machine (before shunting/girder real.)

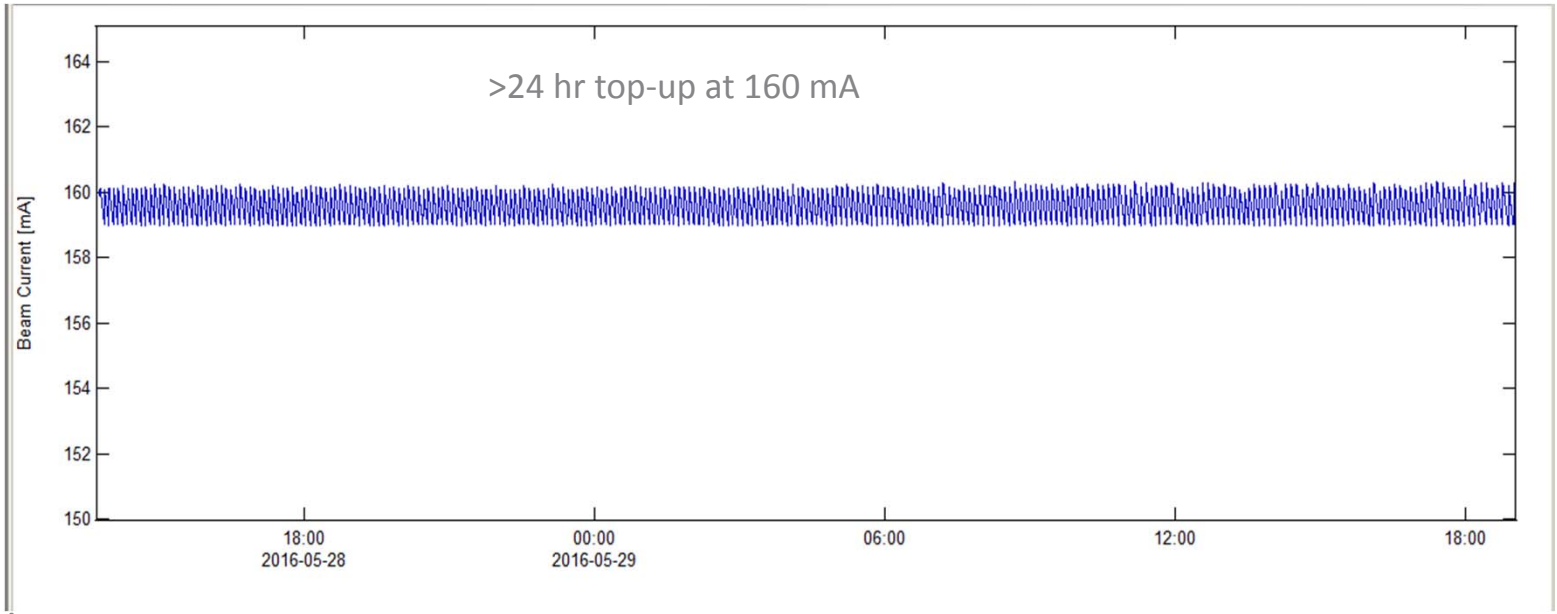


MAX-lab internal note 20121107
Simon Leemann

Injection Efficiency&Top-up (closed shutters)

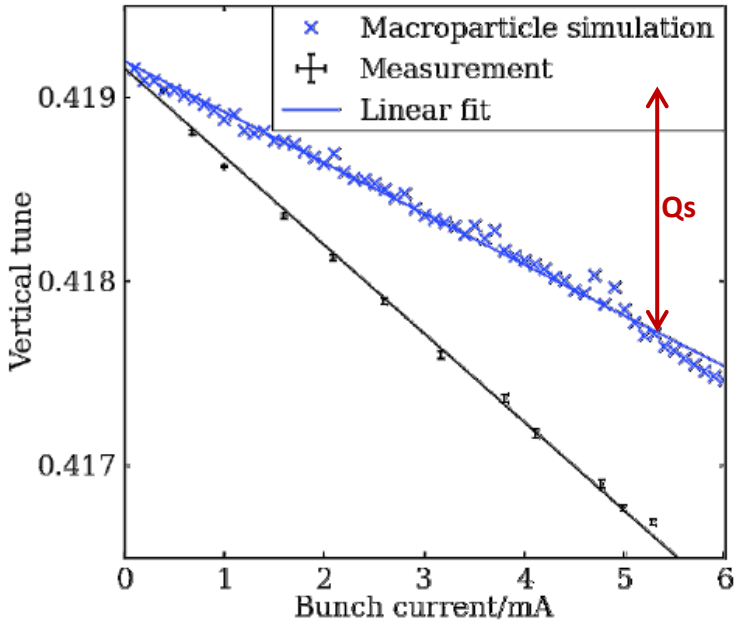


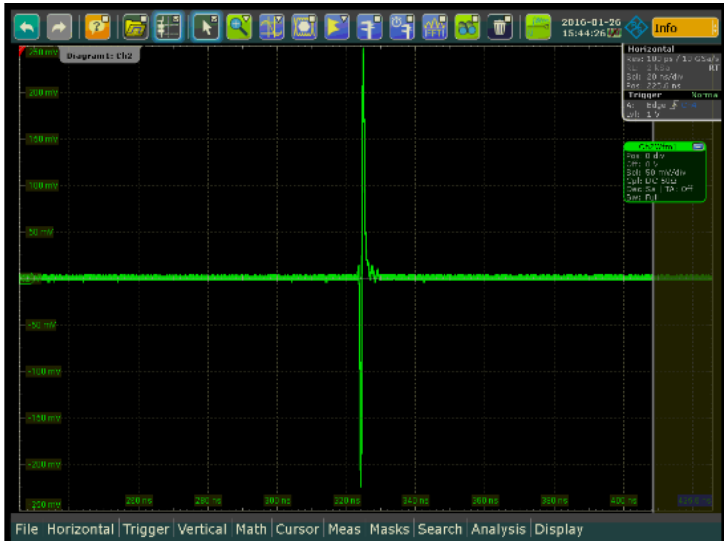
Injection with Single Dipole Kicker
NIM-A **693**, 117, 2012



Collective Effects – Single Bunch

- No signs of TMCI up to 8.55 mA (nominal 2.8 mA/bunch).
- Significant bunch lengthening even without harmonic cavities





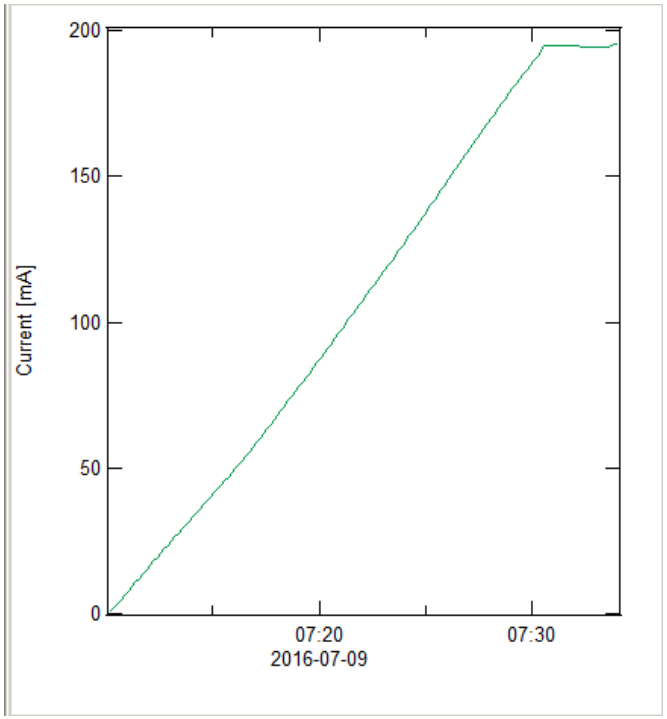
Data by J.Breunlin, Å.Andersson, G.Skripka, R.Nagaoka

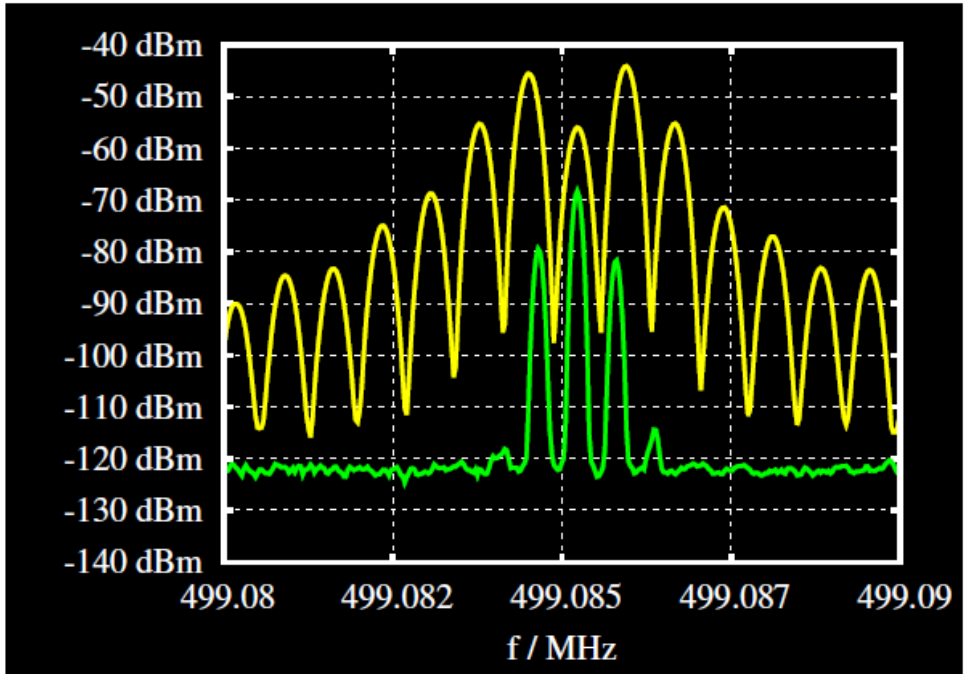
Details: see presentation by F.Cullinam Impedance Characterization and Collective Effects in the MAX IV 3 GeV Ring

Collective Effects - Multibunch

- Possible to store ~ 200 mA without feedback and without harmonic cavities. Predicted RW threshold was only ~ 40 mA !
- HOM driven longitudinal motion is evident at a few mA in uniform fill.
- Temperature tuning has proved effective in fighting longitudinal CBI.

Up to 198 mA in multibunch mode





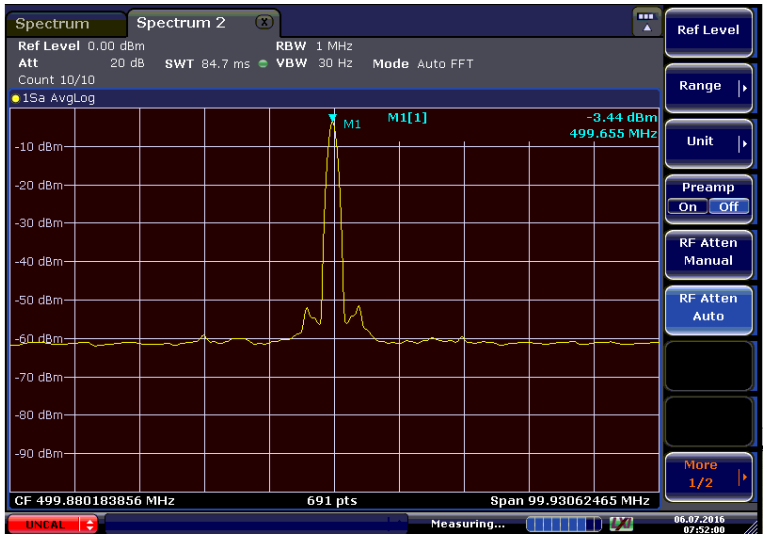
HC stabilization of CBMs at 120 mA

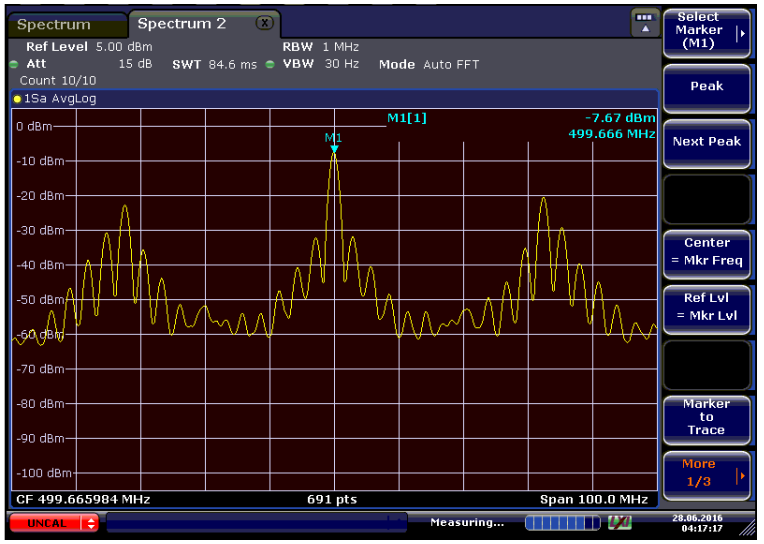
Bunch-By-Bunch feedback

Stable beam with **feedback on** at 90 mA

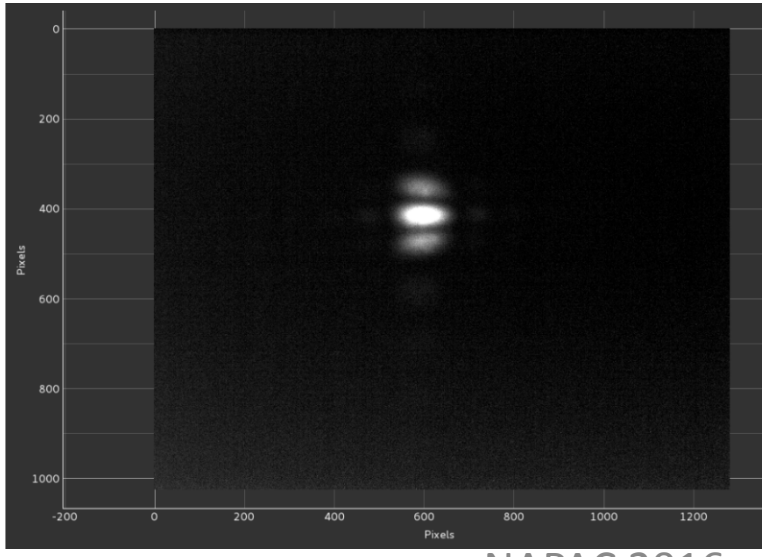
Unstable beam with **feedback off** at 100 mA

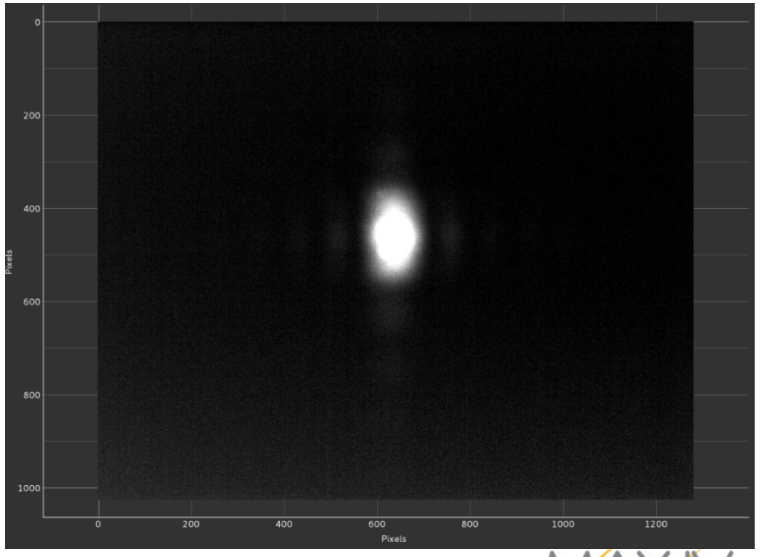
Longitudinal Spectrum





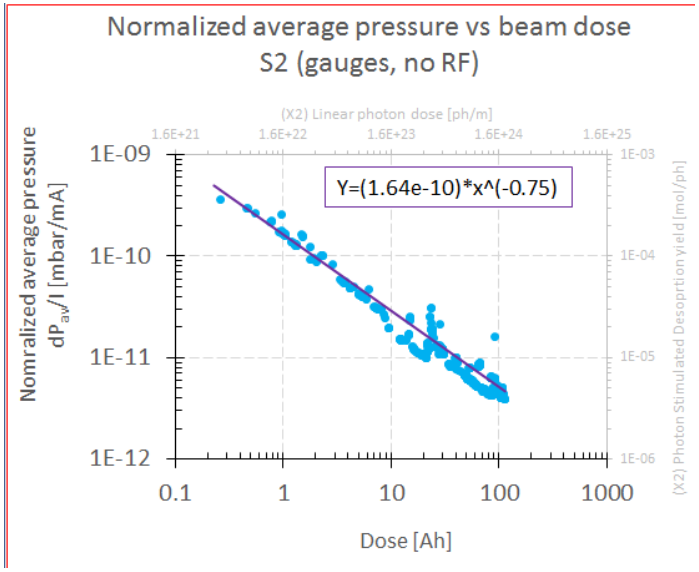
Transverse Profile



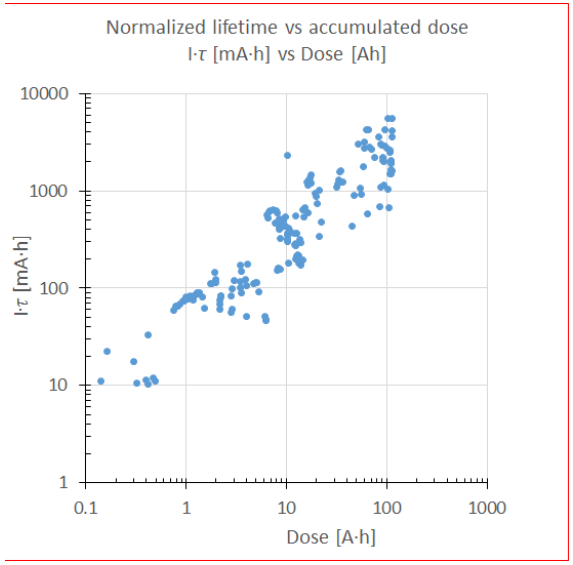


Vacuum System

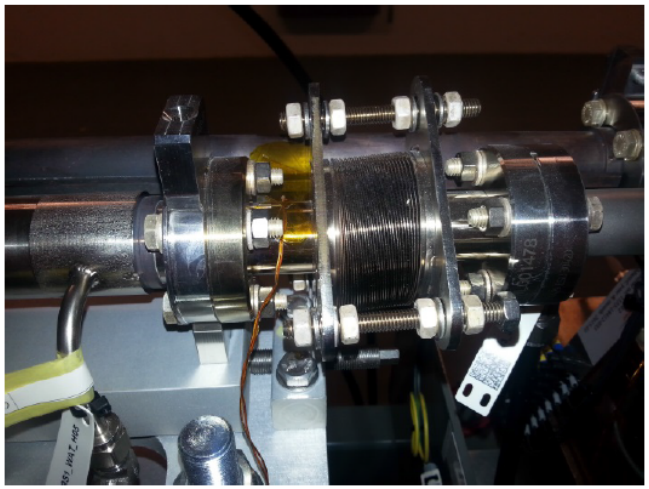
> 100 A.h Accumulated Dose



>6 A.h product lifetime*Current



Plots by M.Grabski



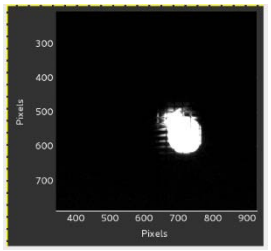
Chamber Heating downstream of absorber

Photo by M. Sjöström

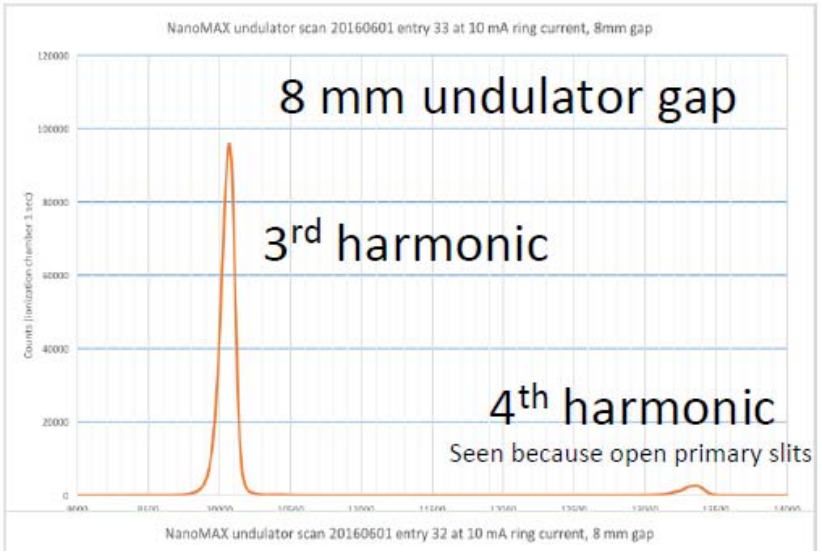
Insertion Devices 3 GeV ring

- 2 In vacuum undulators in spring 2016
- 1 in vacuum wiggler + 2 EPUs (Autumn 2016)

Biomax undulator

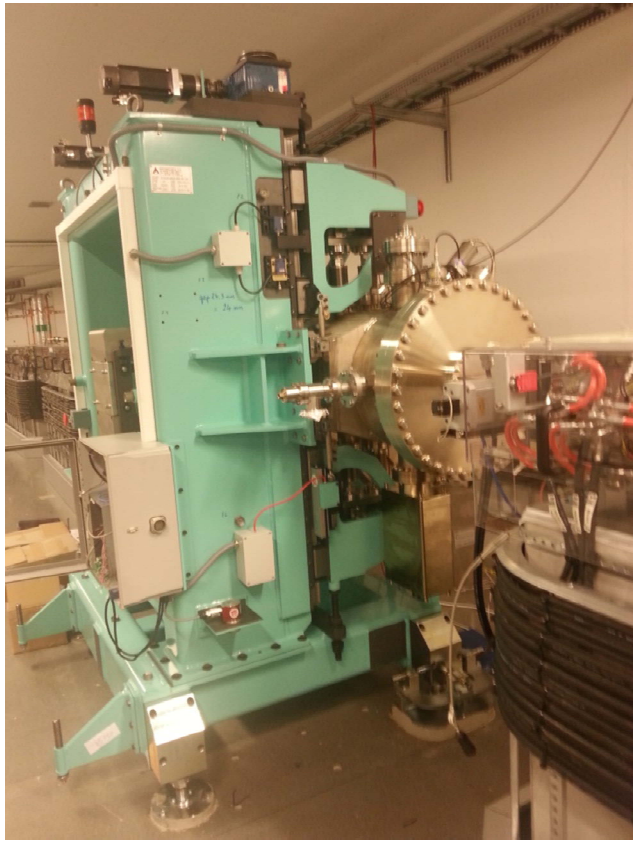


First light from in Biomax
2016/04/29 0.5 mA, 14 mm gap

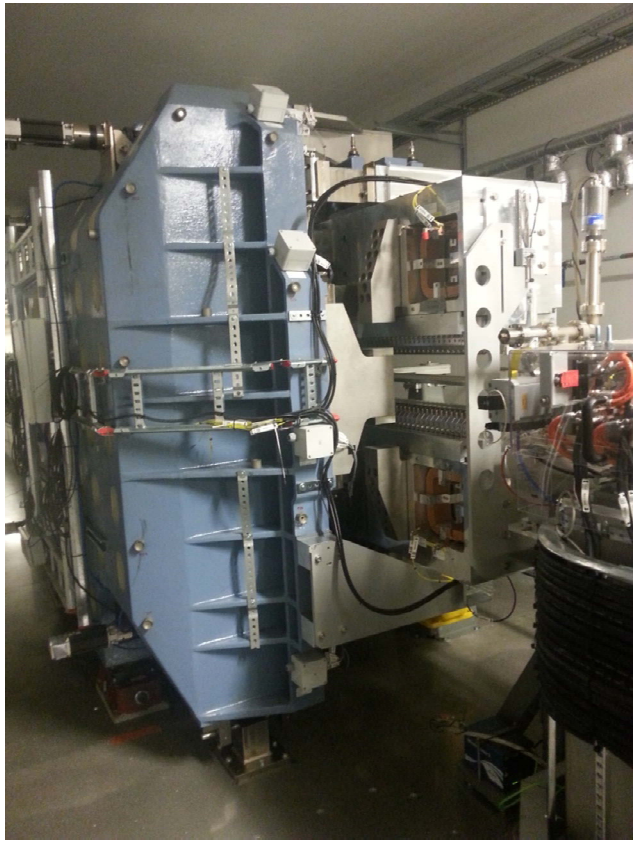


First spectrum in NanoMAX
Plot by Ulf Johansson

Insertion Devices in the 3 GeV Ring



Balder In-vacuuum wiggler

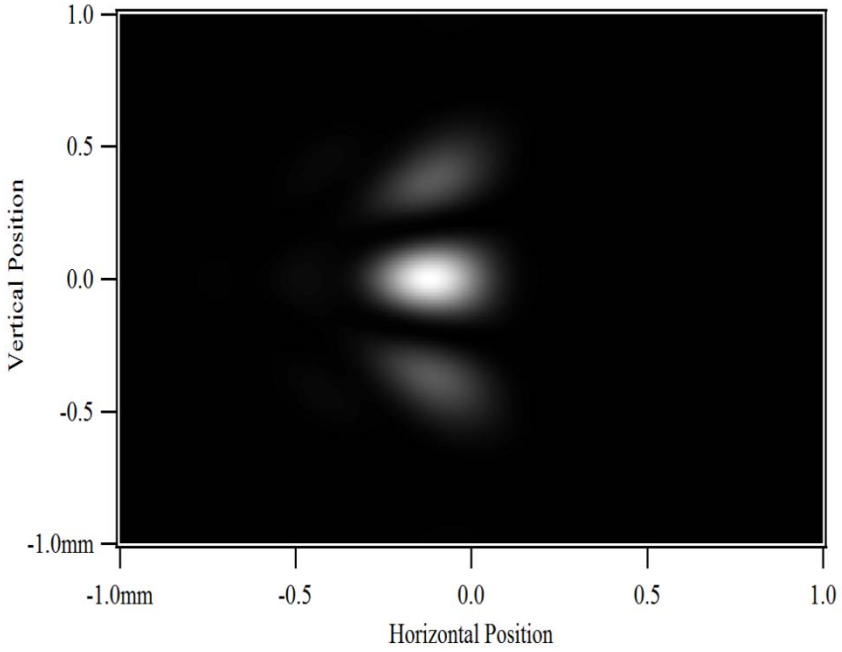


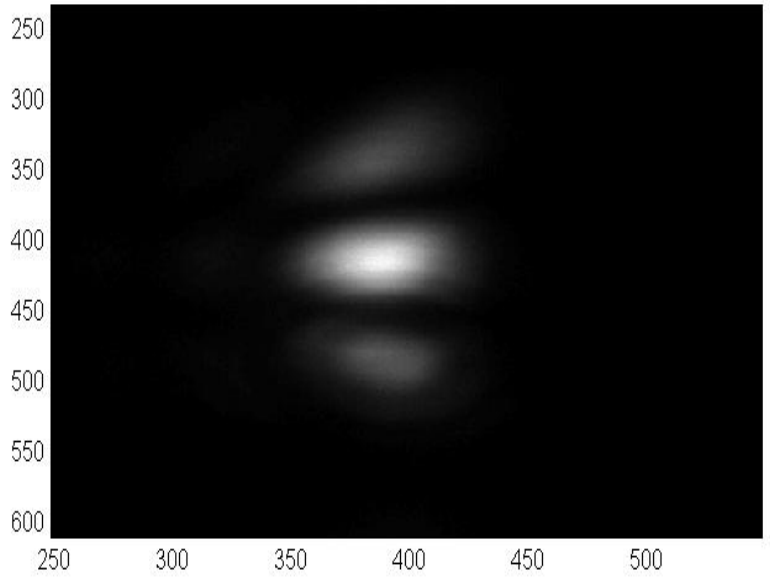
Hippier EPU

Veritas EPU chamber

Emittance Measurement

Slide by J.Breulin

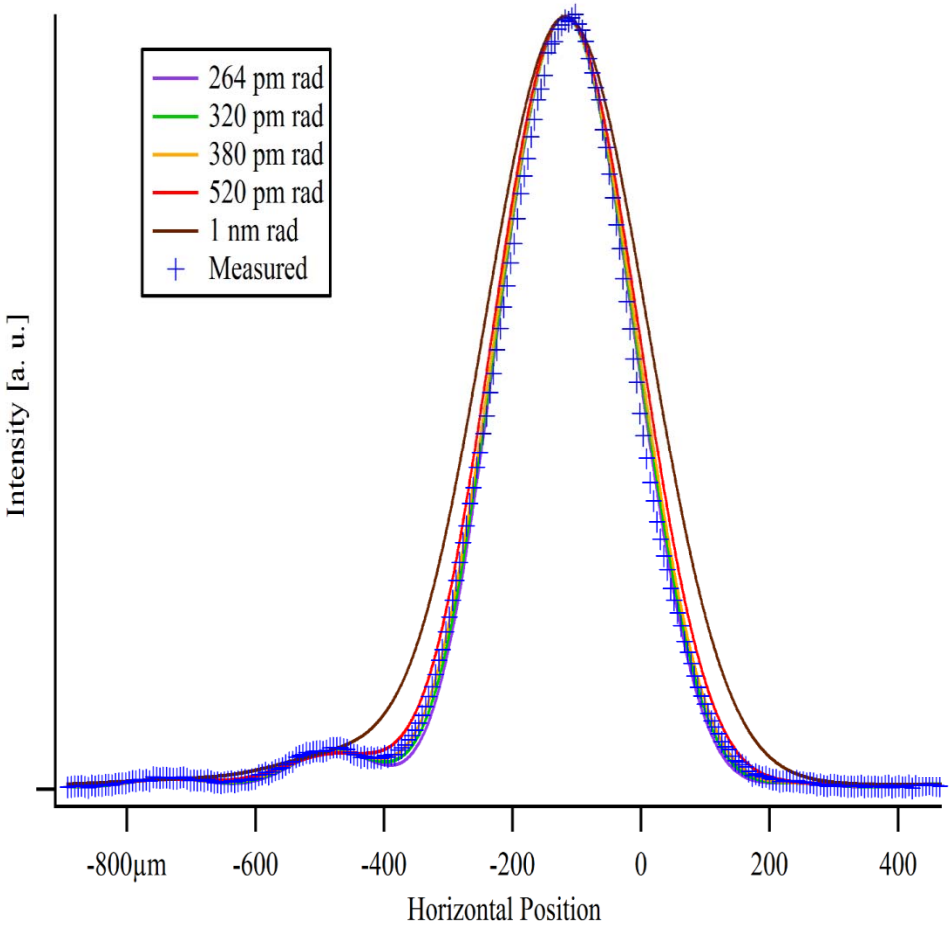


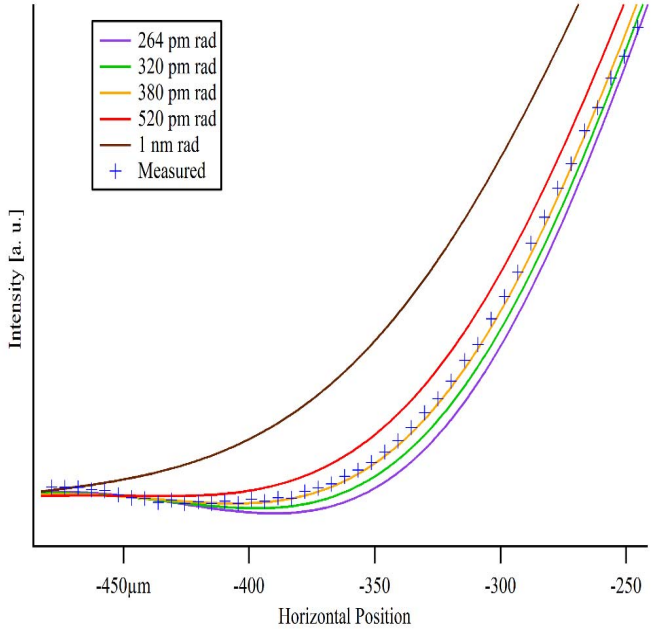


Sigma polarized SR, 632.8 nm, SRW calculation (left) and measured image (right). The simulation is done for ε_x = 320 pm rad, β_x = 1.5 m.
Both figures show a 2 x 2 mm^2 area of the image plane.
The fringe pattern is too weak to be visible.

Optical magnification of m=-2.28 is taken into account in the SRW model
Horizontal opening angle: 6 mrad
Vertical opening angle: 8 mrad
Exposure time: 2.9 ms

Slide by J.Breulin



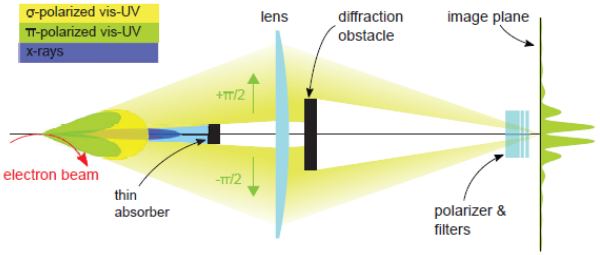


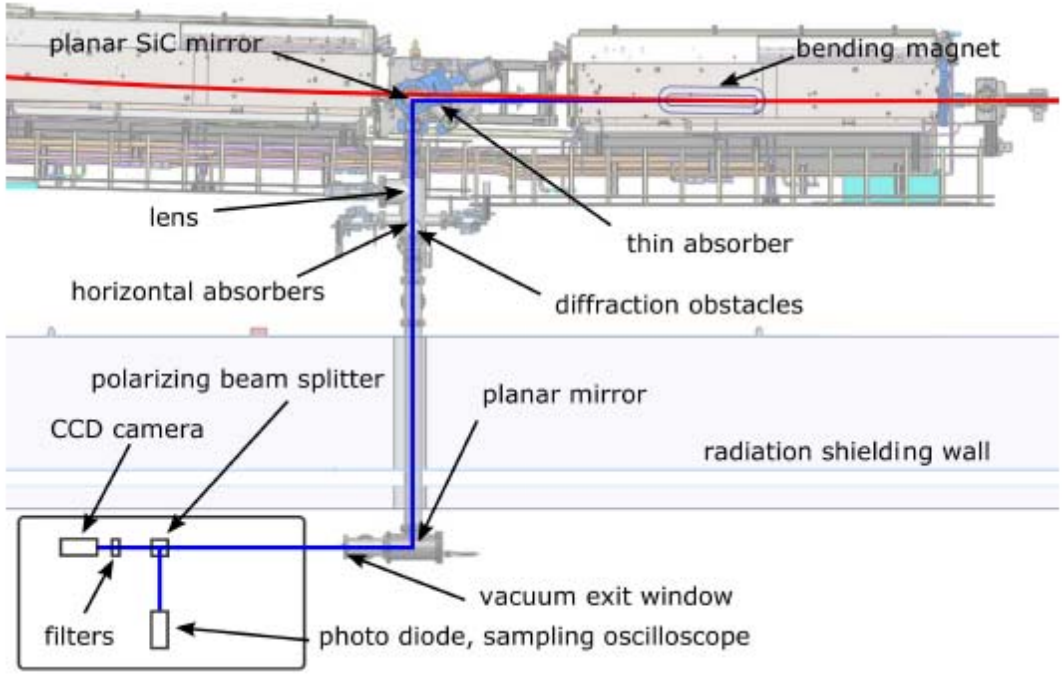
Horizontal intensity profile of imaged sigma polarized SR. Due to the reduced horizontal opening angle the fringe pattern is not as pronounced as it could be, but easier to understand and to calculate.

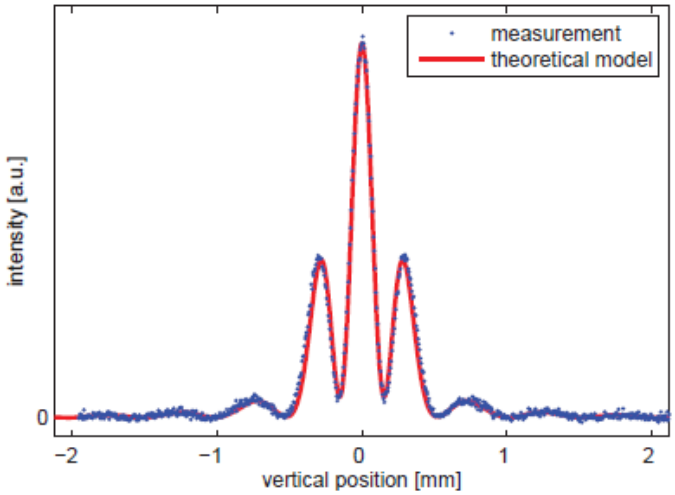
Present setup is limited by optical aberations (from misalignments) and surface quality from optical components (some are inherited from MAX II, MAX III). Steady improvements during the next weeks are planned. Camera linearity might also be an issue!

Challenges on the SRW model side are to include for example: variation of dipole field, variation of beta_x, variation of vertical opening angle, along the observed electron beam path.

Vertical Emittance Measurement







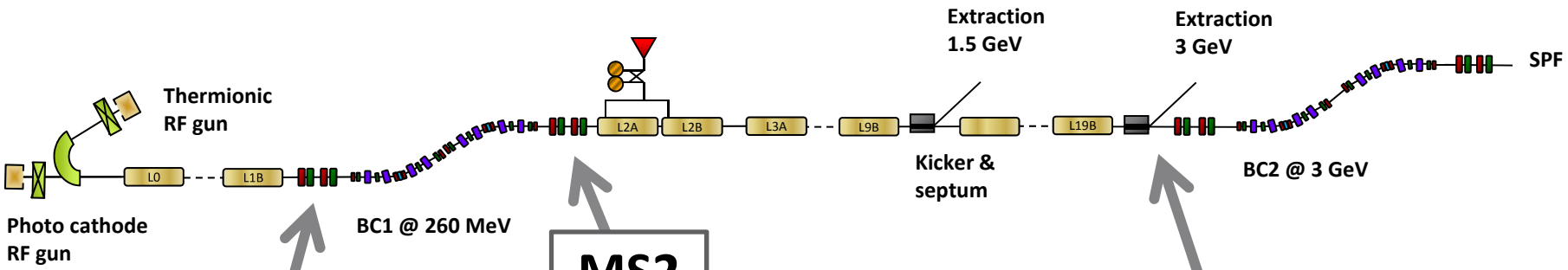
ε_y=6.94 ± 0.9 pm.rad

Figure 5: Vertical profile of imaged σ-polarized SR with 5 mm diffraction obstacle at 488 nm wavelength. Measurement (blue dots) and SRW calculation (red lines).

Figs by J.Breunlin and Å.Andersson

MAX IV

Beam parameters Thermionic Gun



MS1

Energy	270 MeV
Energy spread	0.5 % (fwhm)
Norm emittance x	5.5 mm mrad
Charge	~ 280 pC

MS2

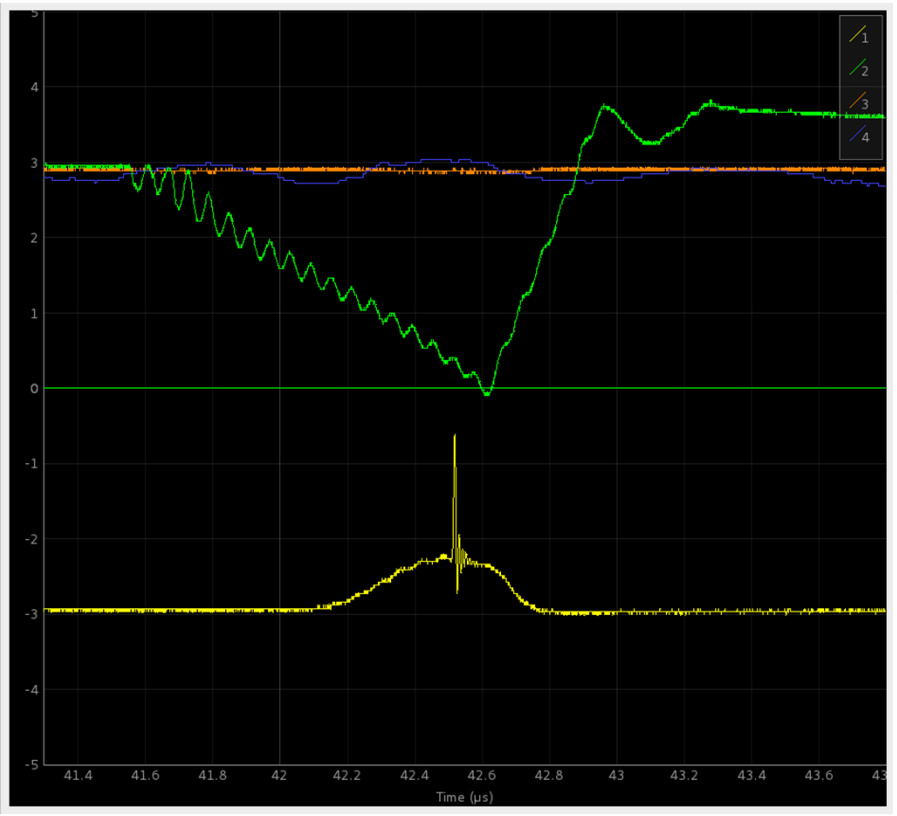
Energy	270 MeV
Energy spread	0.5 % (fwhm)
Norm emittance x	12 mm mrad
Norm emittance y	4.7 mm mrad
Charge	~ 280 pC

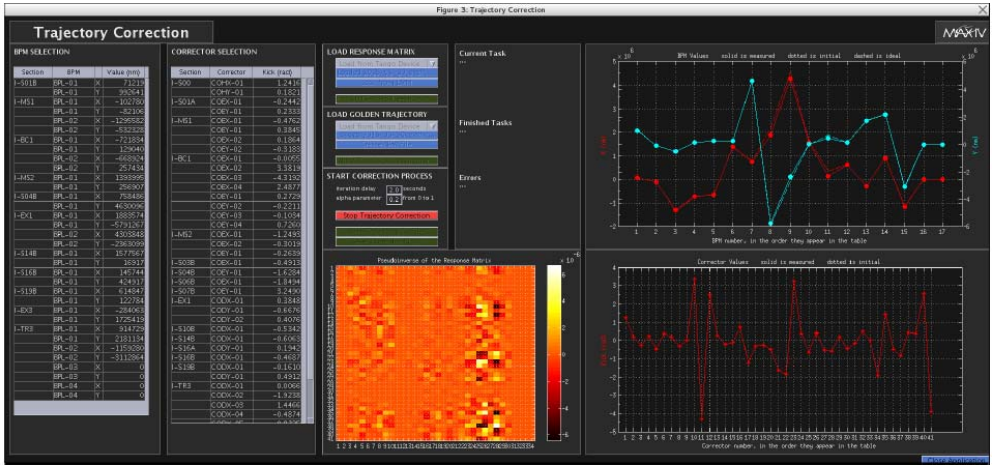
MS3/TR3

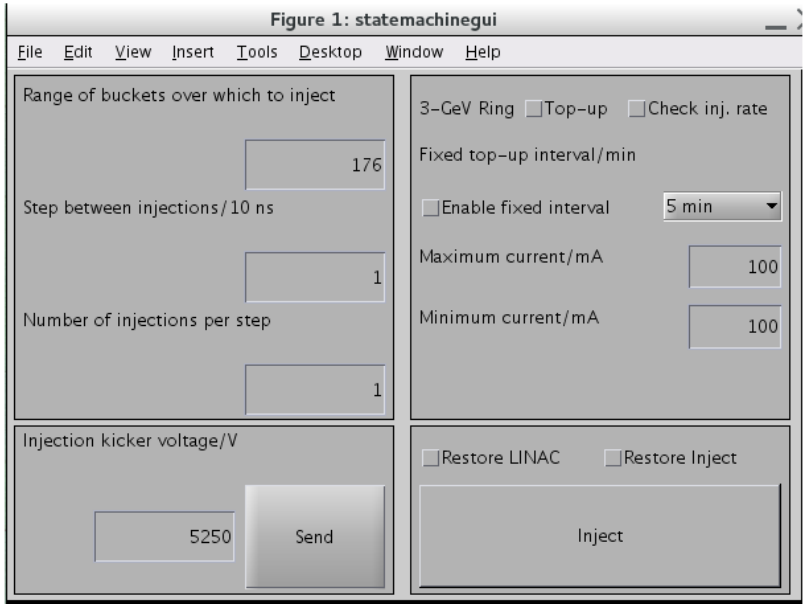
Energy	3 GeV
Energy spread	0.6 % (fwhm)
Norm emittance x	15 mm mrad
Charge	~ 220 pC

Slide by S.Thorin

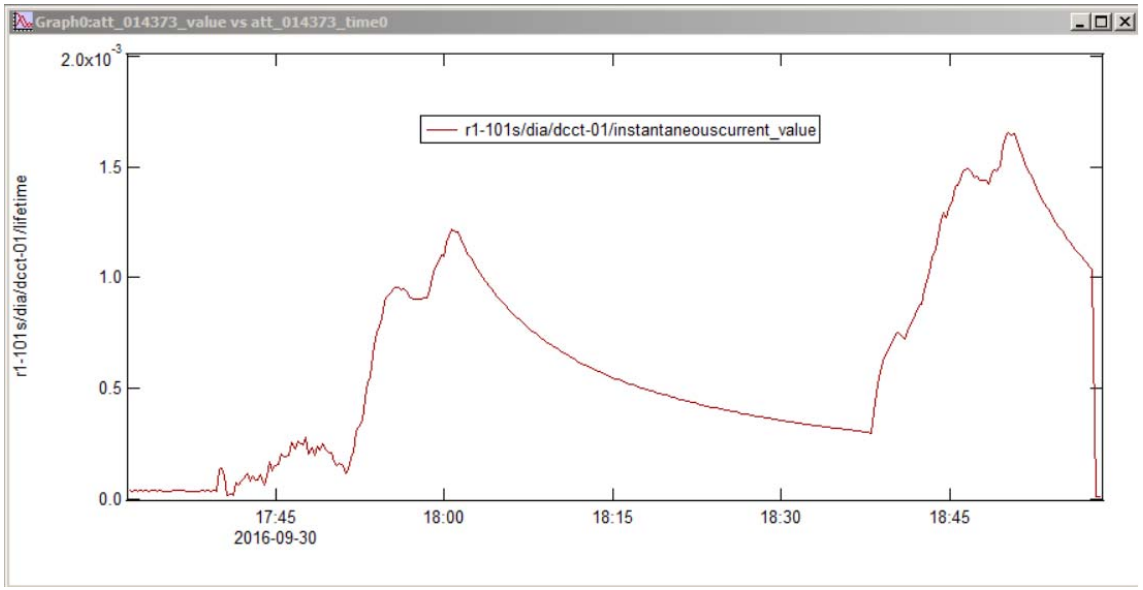
LINAC Mode Switching and Feedback



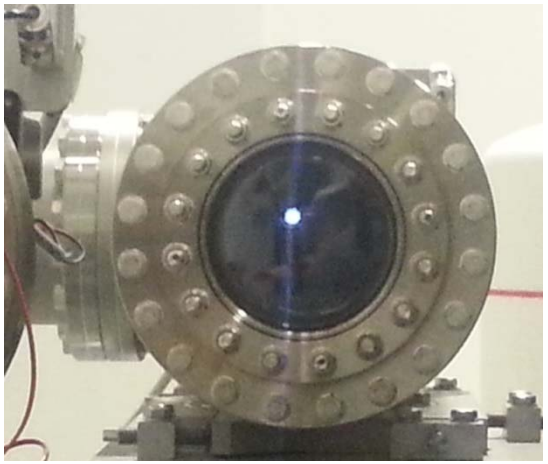




1.5 GeV Ring: Start of Commissioning



Beam capture, stacking and first light:
September 30th , 2016



Main Problems/Difficulties

- RF Cavity Conditioning
- Diagnostic System Commissioning
  - BPMs
- Kicker Magnet PS failure
- Gun Klystron Failures
- Long Radiation Surveys
- Cooling System Failures
- Heating of chambers (in photon beam pipe)

Next Steps

- 3 GeV Ring
  - Further conditioning of RF cavities
  - Further linear optics trimming/Non-linear optics trimming
  - Collective Effects studies (Harmonic cavity tuning)
  - Fast Orbit feedback
  - Multipole Kicker (SOLEIL&BESSY collaboration)
- 1.5 GeV ring
  - Optics trimming
  - Higher current
- *November 2016: Commissioning users (3 GeV ring)*
- *Spring 2017: First open call users (3 GeV ring)*
- *Spring 2017: First Ids in the 1.5 GeV ring*
- *May-June 2017: LINAC RF upgrade*

Conclusions

- Progress with the MAX IV 3 GeV ring commissioning gives us increased confidence that the MBA concept is sound.
- Much remains to be done to reach the final design specifications, but nothing indicates there is any fundamental obstacle ahead.

Thank You !