PHANGS

Photons at the Next Generation Synchrotron Facilities: from Production to Delivery

ICTP, Trieste, Italy / 4 – 5 December 2017

MAX IV Accelerators Status

Pedro F. Tavares on behalf of the MAX IV Accelerator Division

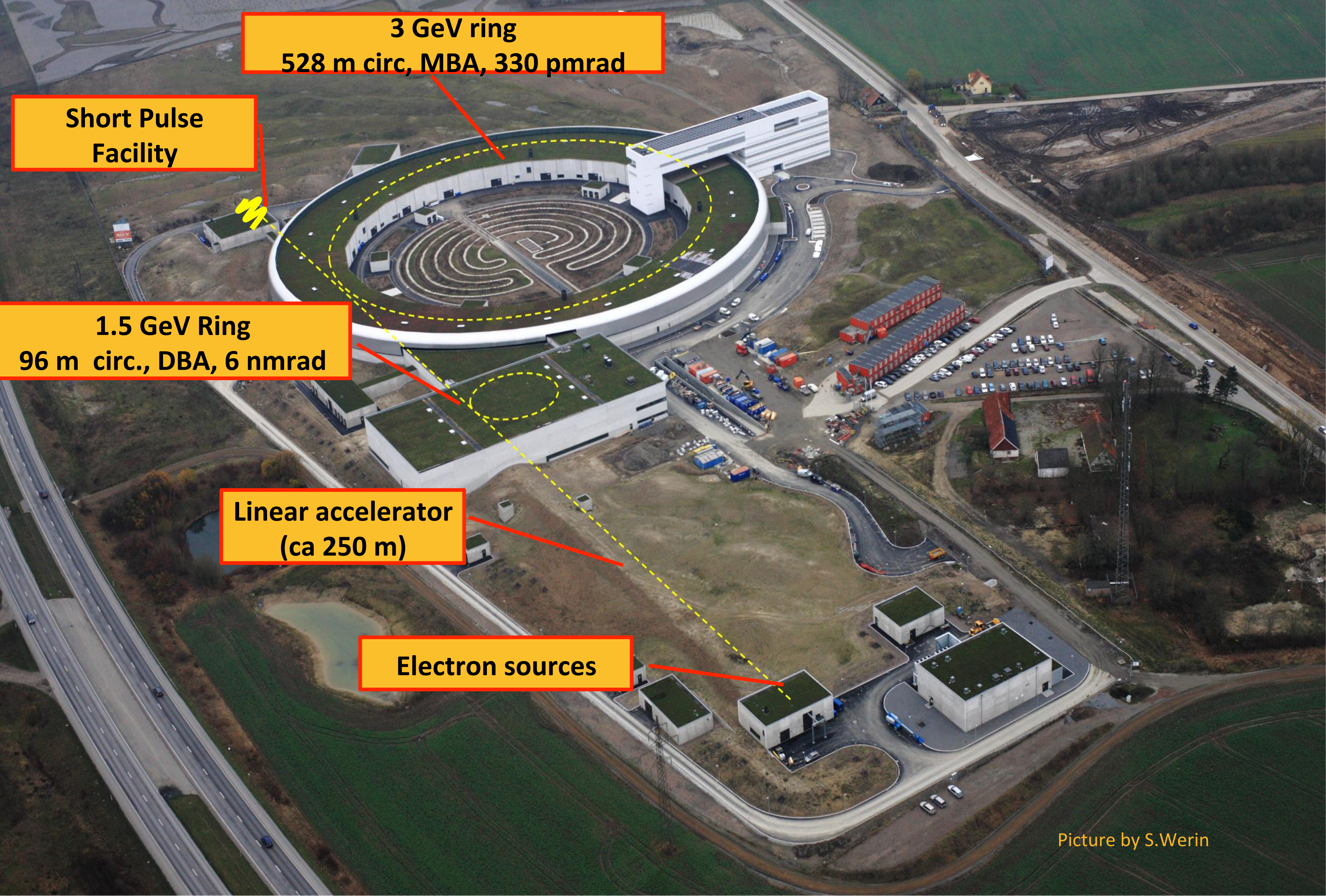
2017 Phangs Workshop

MAX IV

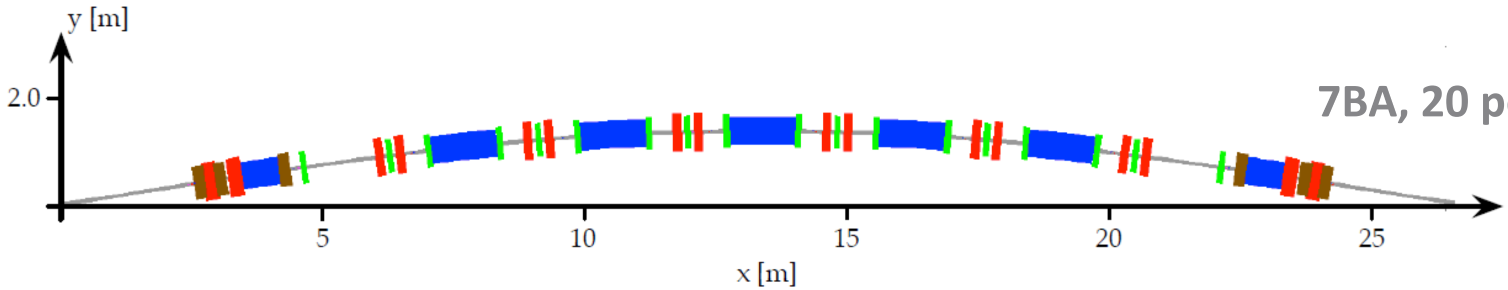
Outlook

- The MAX IV Facility
- The MAX IV 3 GeV Ring
  - Main Parameters & Technological choices
  - Status: achieved performance highlights
    - Lattice Corretion: linear, coupling and non-linear
    - Orbit stability: long and short term
    - Bunch-By-Bunch Feedback and HCs
    - Top-up injection
    - Multipole Injection Kicker
- First user operations statistics
- Future Perspectives

The MAX IV Accelerators



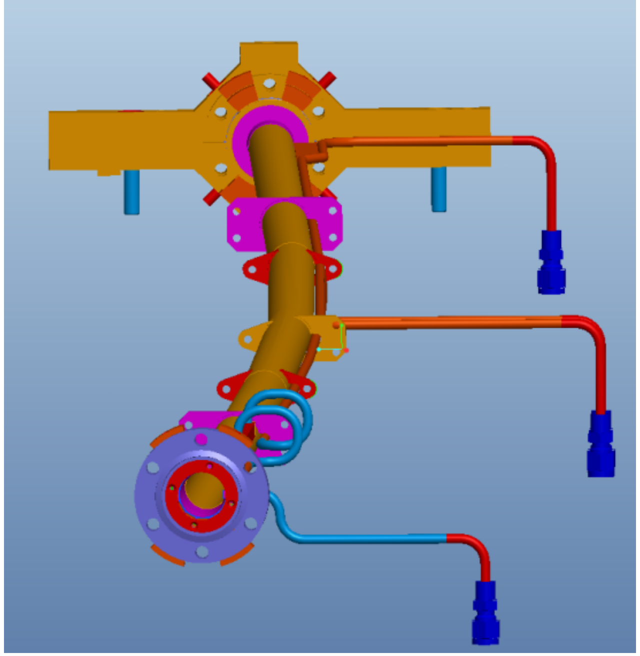
MAX IV 3 GeV ring: 528 m, 330 pmrad



7BA, 20 periods

100 MHz RF
Pasive HC

Circular, copper NEG-coated chambers



Compact Magnets

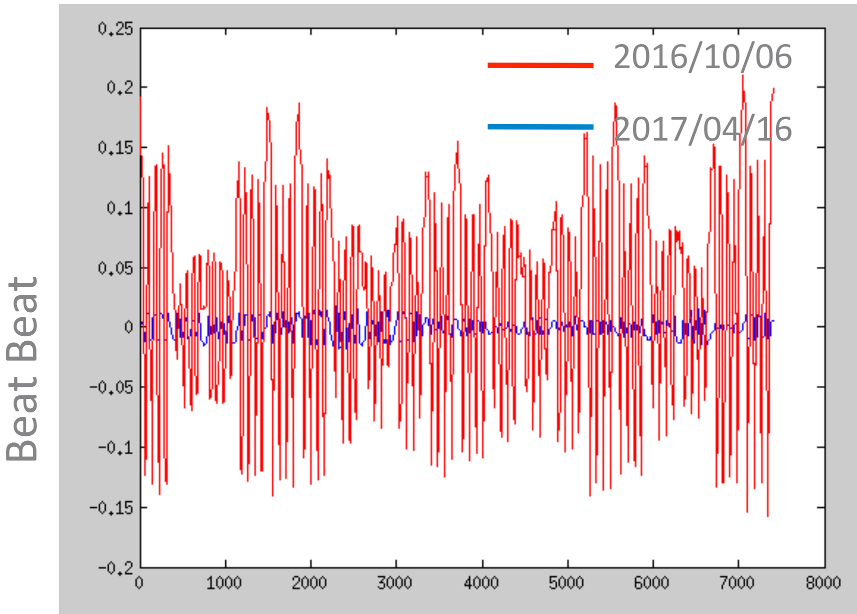
MAX IV

3 GeV Ring – achieved performance

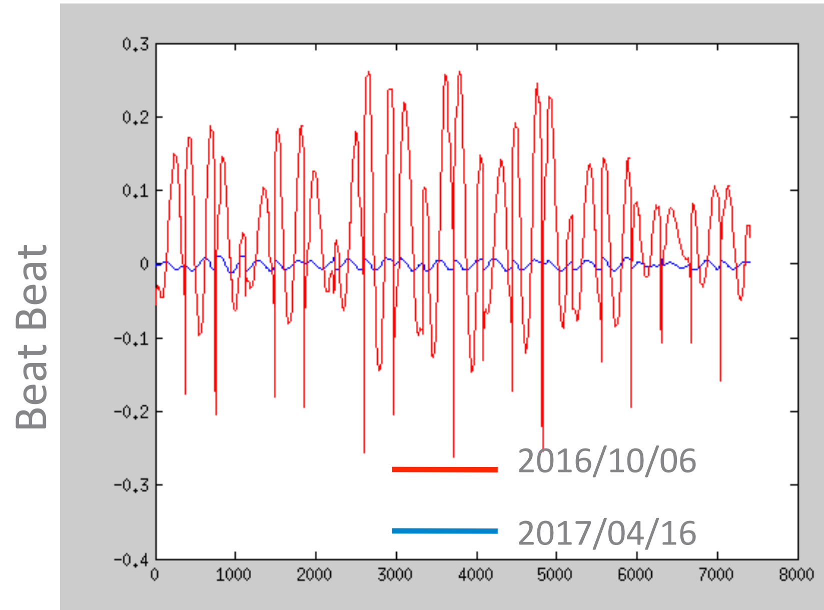
- ~ 200 mA stored current – multi-bunch
- ~ 9 mA stored current – single-bunch
- > 6 A.h lifetime.current product
- $\gtrsim$ 90% injection efficiency
- Emittances: ε_x=339.4 ± 30 pm rad; ε_y =6.5 ± 0.1 pm rad (down to 3 pm rad observed)
- RMS orbit stability (up to 100 Hz) better than 1.3/5.5 % of beam size (H/V).
- Beta beats < ± 2 %, Residual Vertical Dispersion < 0. 6 mm RMS
- Bunch-by-Bunch feedback operational. Longitudinal kicker cavity
- Multipole Injection Kicker under commissioning

Beta-beat correction

Horizontal

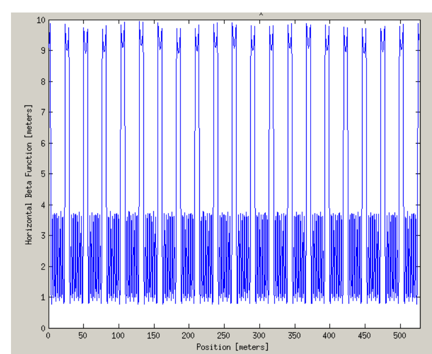


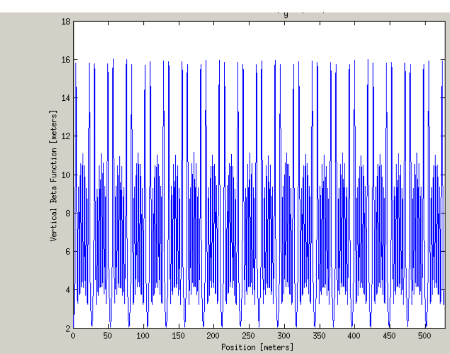
Vertical



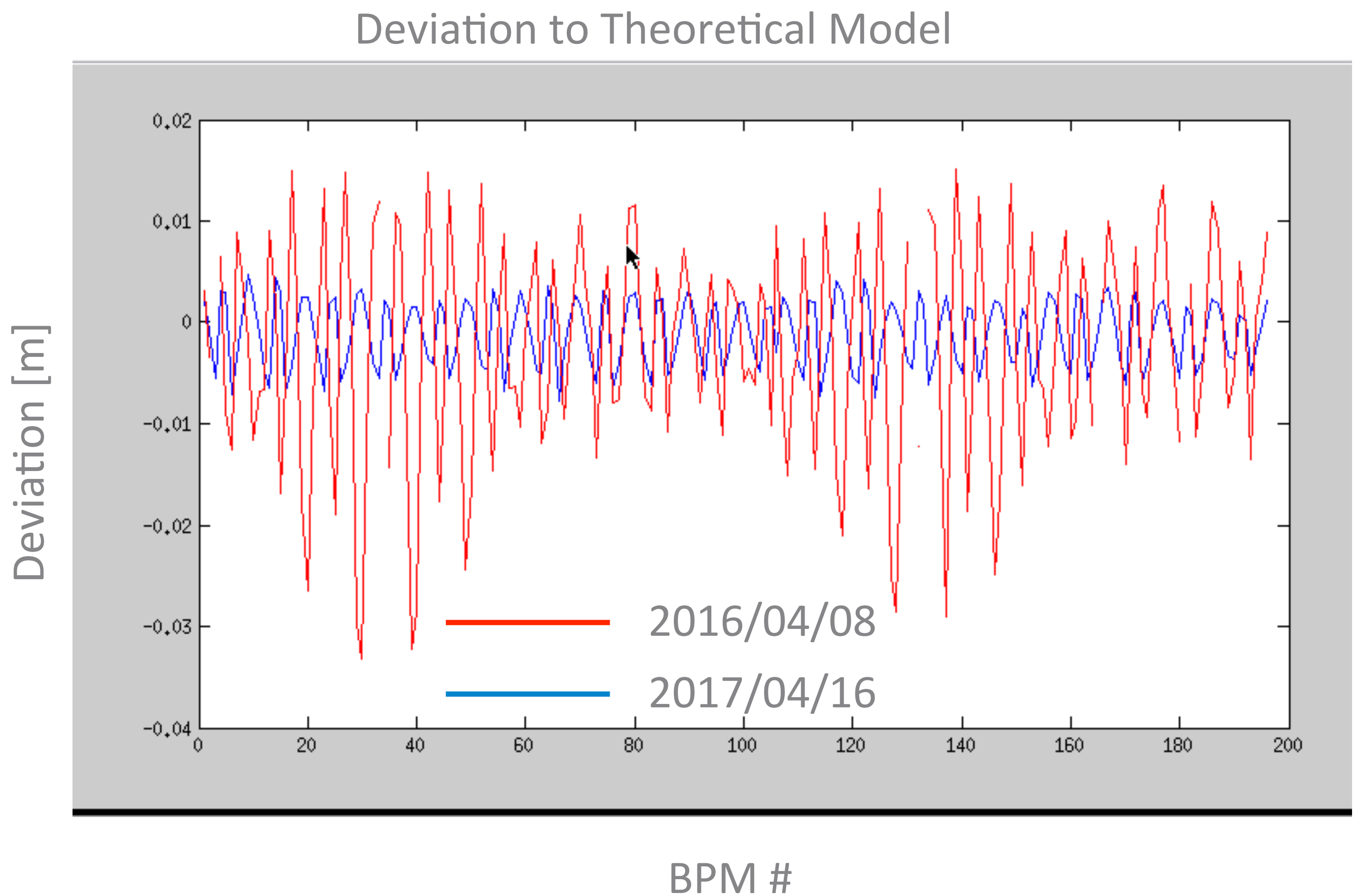
Beat beats reduced from ± 20/25 % to less than ± 2/1.5 %.

Betatron Functions from LOCO fits– 2017/04/17



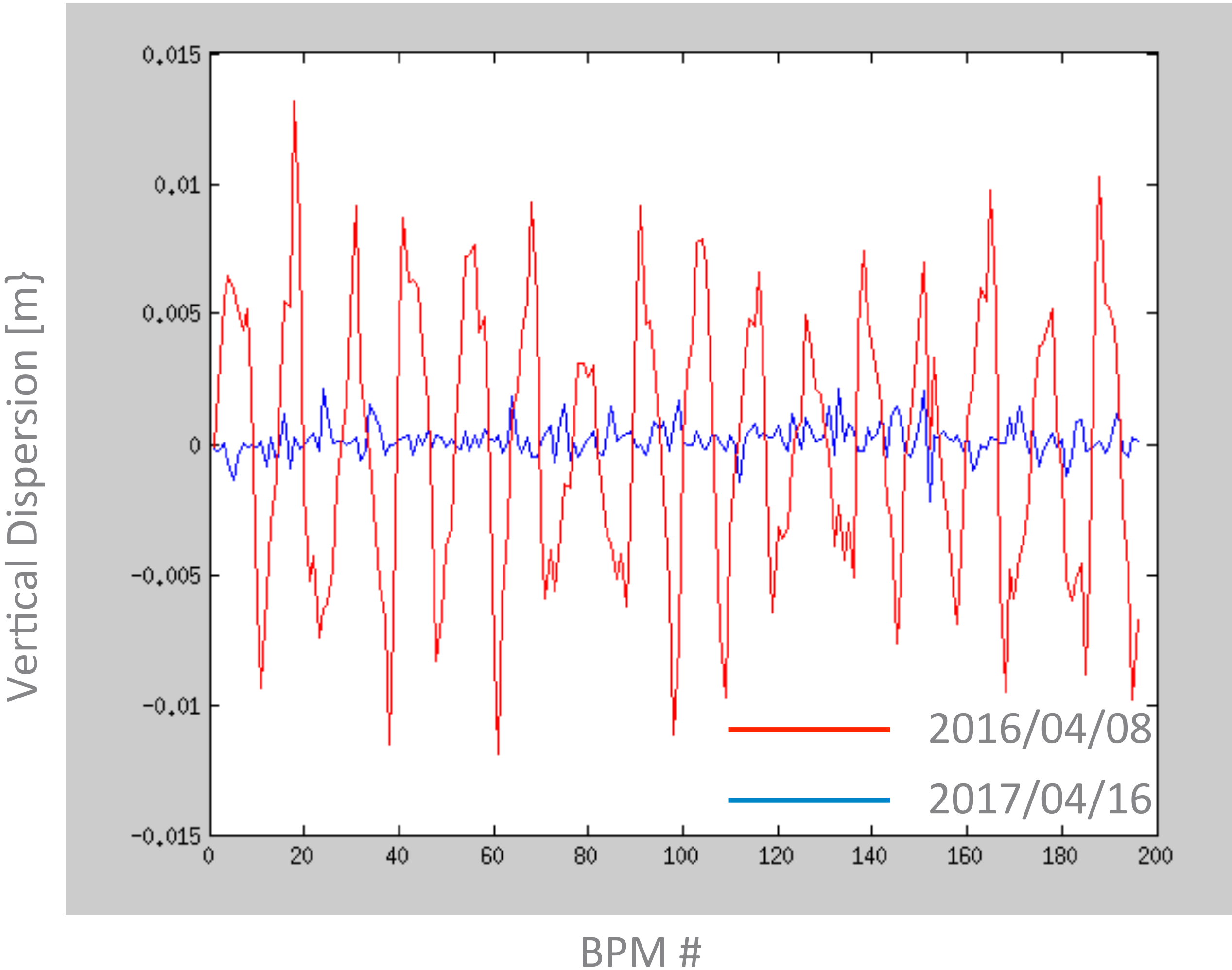


Correction of horizontal dispersion beating



RMs deviation to model reduced from 15 mm to 3.5 mm

Correction of residual vertical dispersion



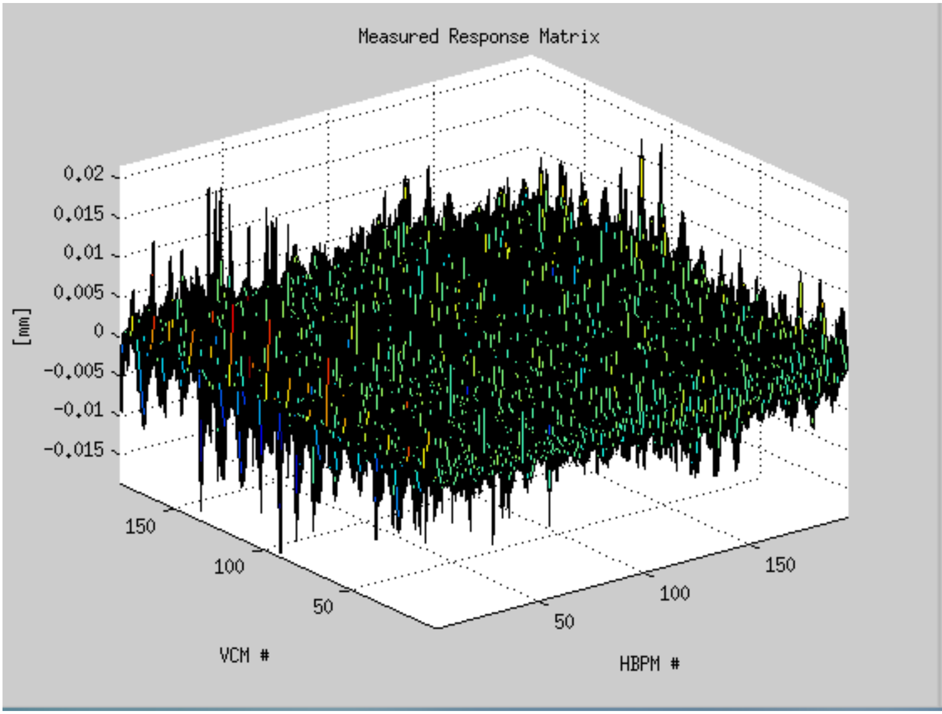
40 dispersive skews reducing the vertical dispersion. Maximum strength is roughly half of the available.

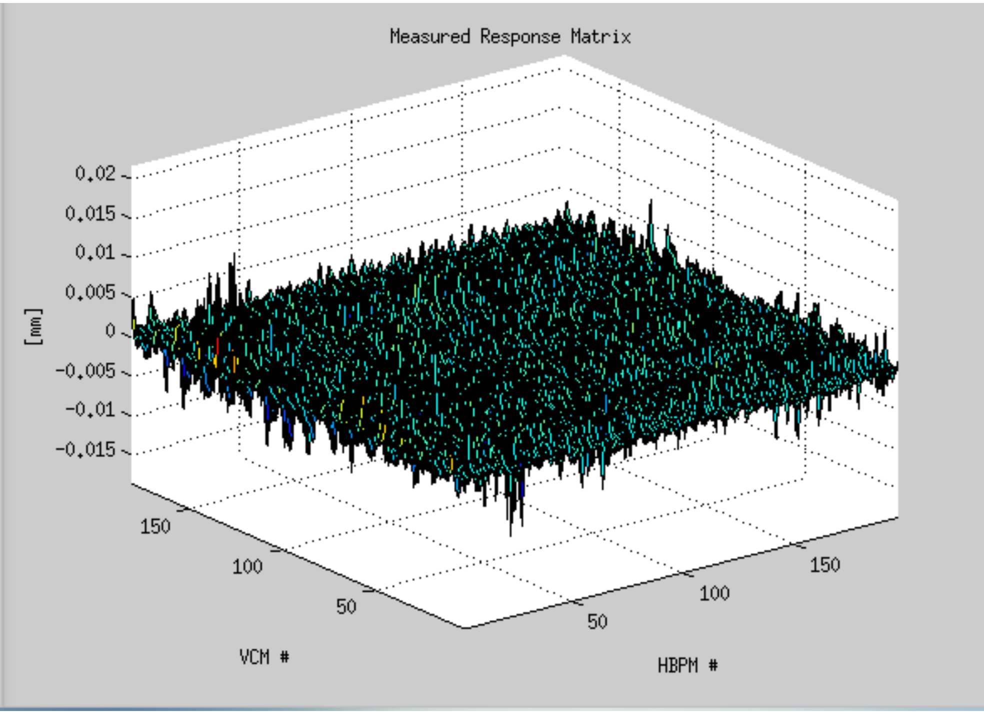
RMS reduced from 5 mm to 0.6 mm

MAX IV

Correction of betatron coupling

40 non-dispersive skews reducing the coupling. Maximum strength is roughly half of the available.



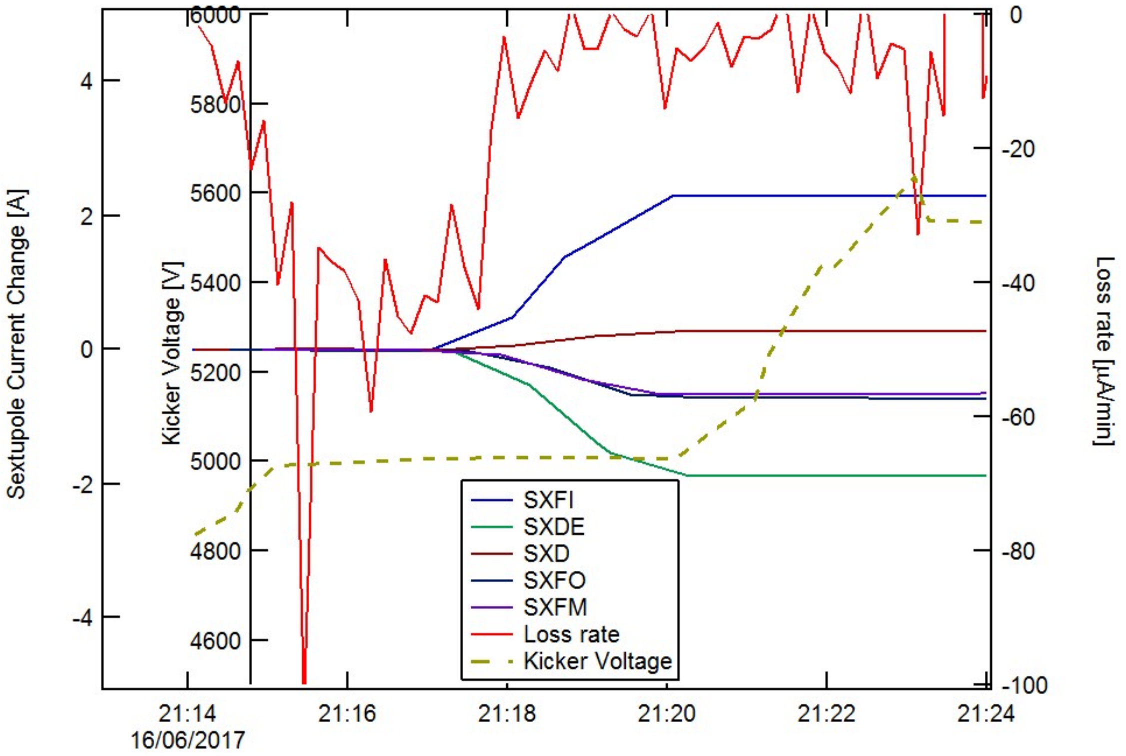


Slide by Å.Andersson

Non-linear Lattice Optimization

Thanks to Xiaobiao Huang for providing the RCDS code

RCDS (**Robust Conjugate Direction Search**) applied using all sextupole (5) and octpole families (3) as knobs and beam loss rate while kicking the beam as a proxy for dynamic aperture.

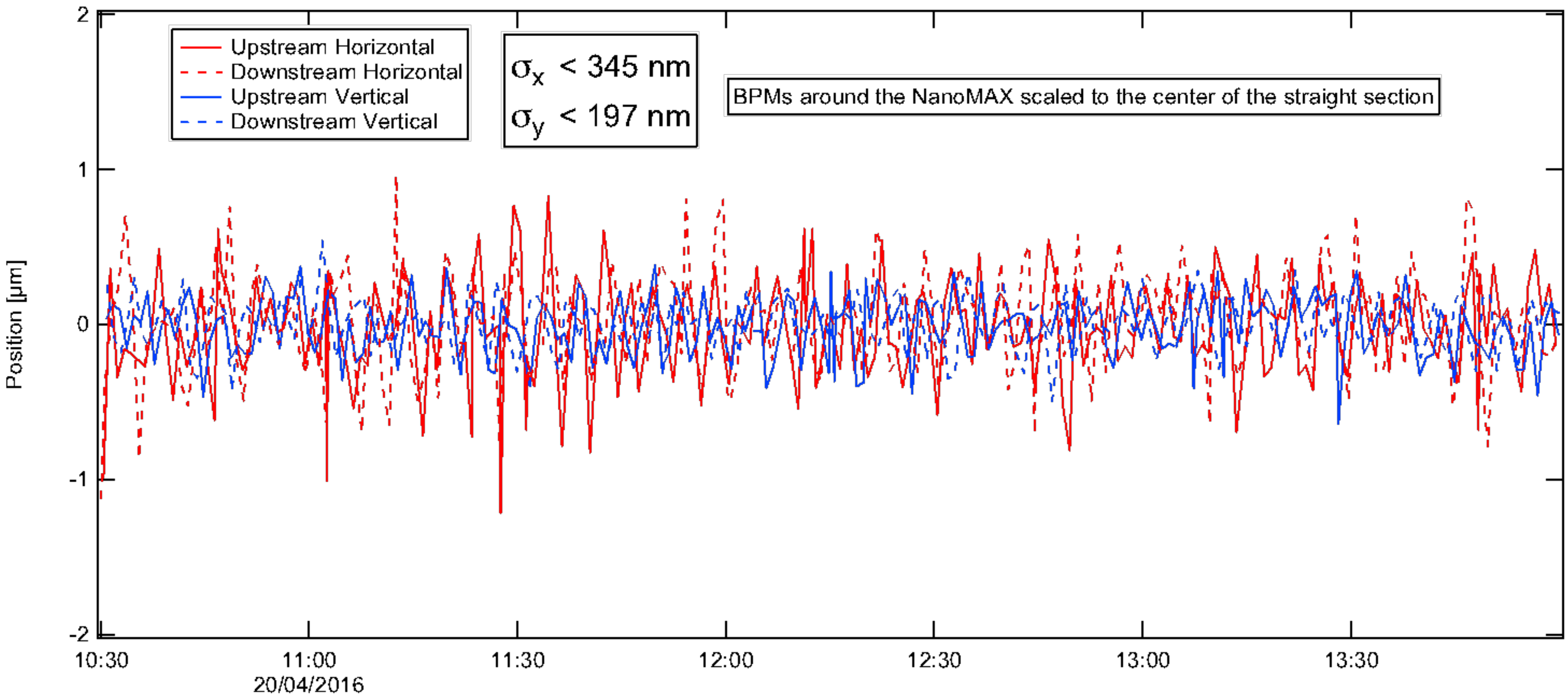


Data by M.Sjöström and D.K.Olsson

Orbit Stability – Long Term

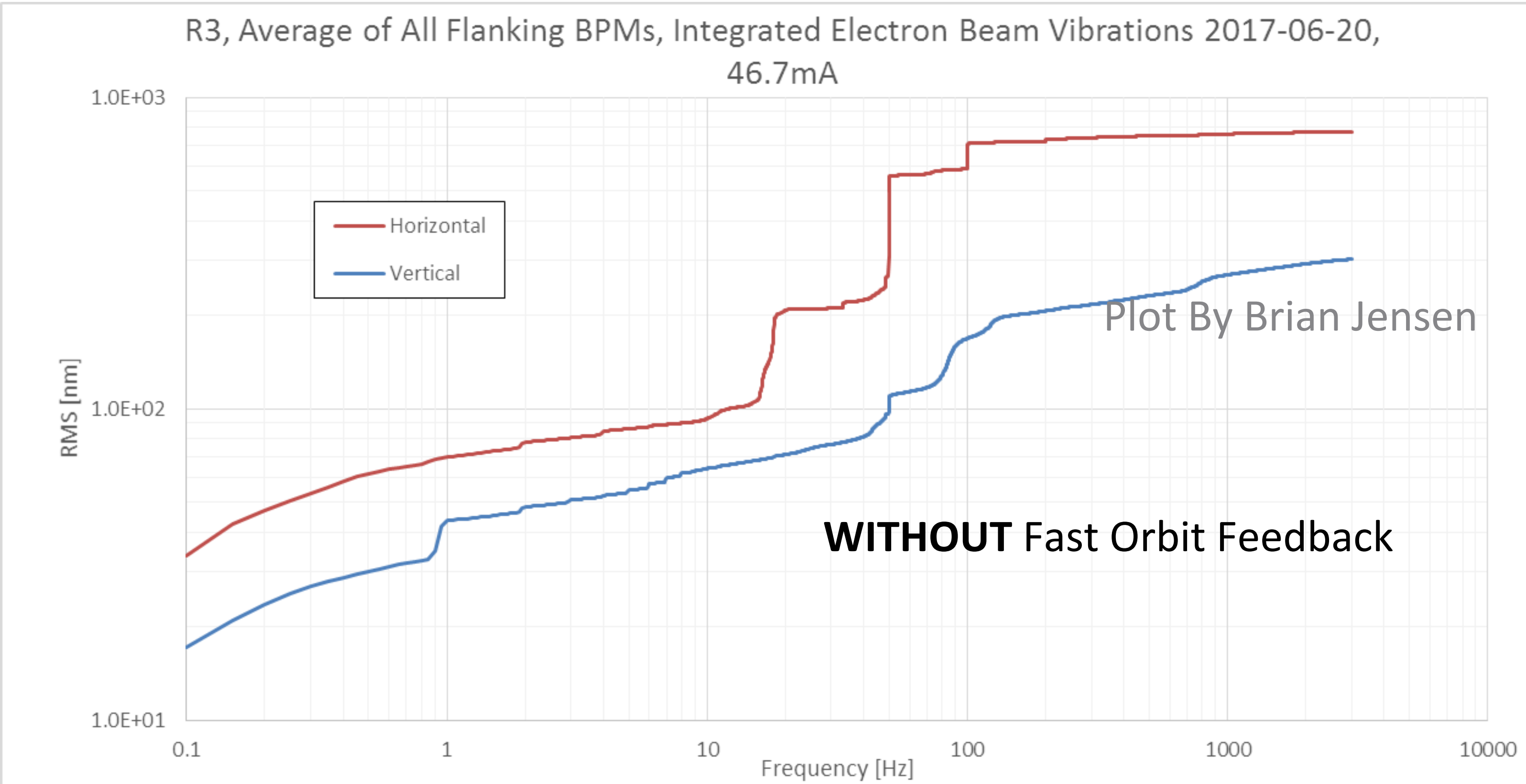
RMS beam sizes at source points
- Horizontal: 47 µm
- Vertical: 2 µm

Stability goals (RMS)
- Horizontal: < 4.7 µm
- Vertical: < 0.2 µm



Slow Orbit feedback ON

Orbit Stability – Short Term



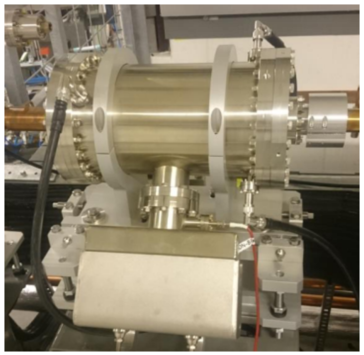
Integrated up to 100 Hz

- Horizontal RMS < 710 nm ~ 1.3 % of RMS beam size at BPM position
- Vertical RMS < 170 nm ~ 5.5 % of RMS beam size at BPM Position

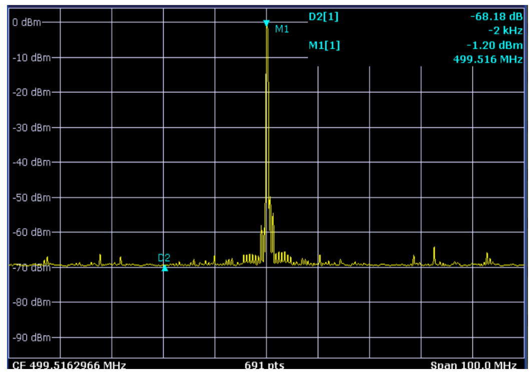
Collective Effects –BbB Feedback and HCs

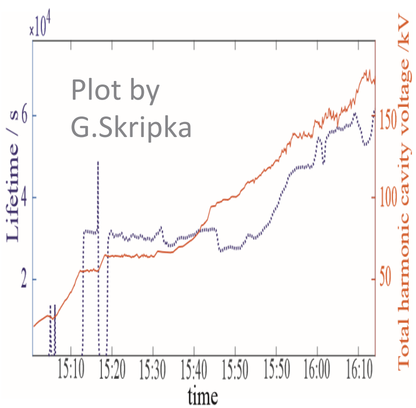
Longitudinal Plane (HCs tuned out)

Longitudinal Kicker Cavity

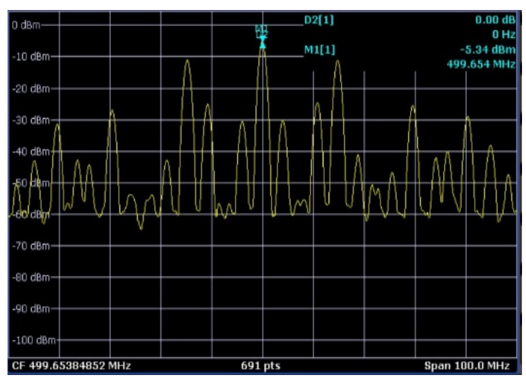


BbB Feedback ON



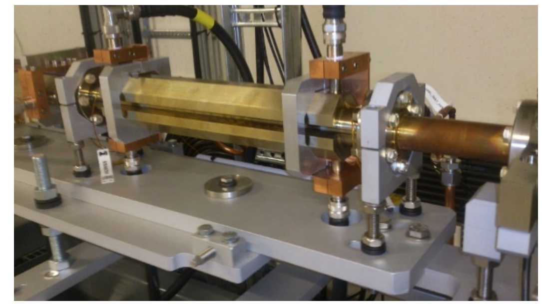


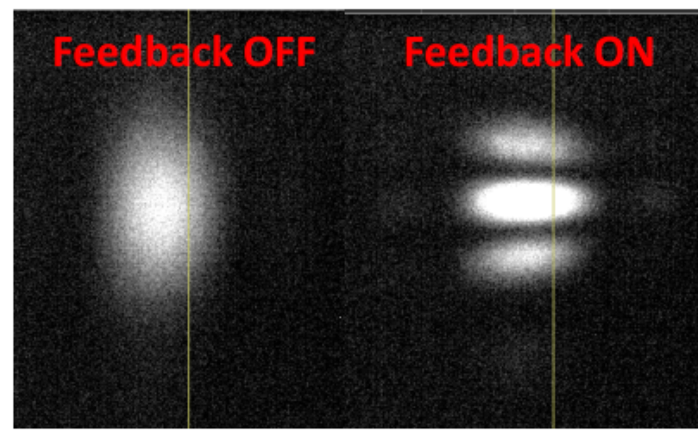
BbB Feedback OFF



Transverse Plane

Striplines





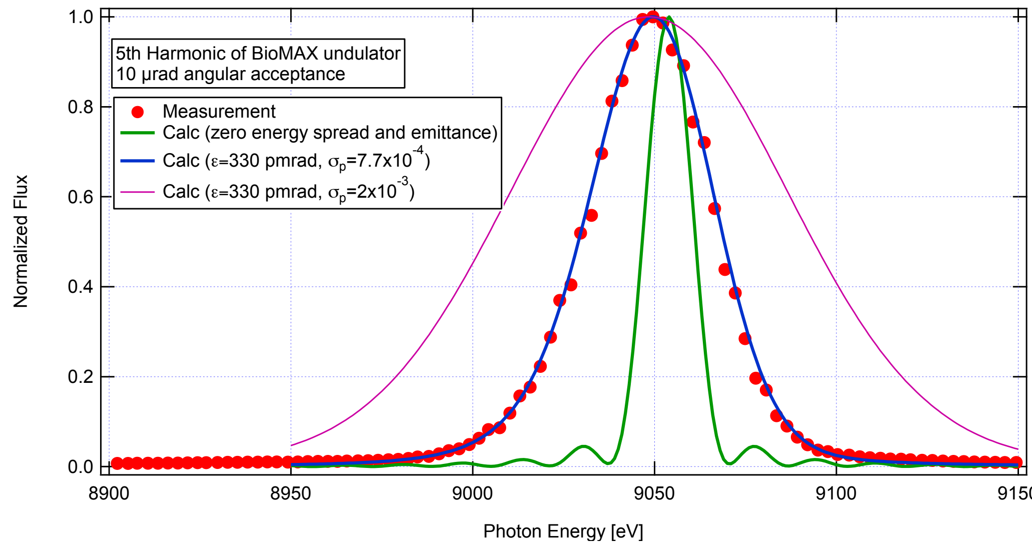
Pictures D.Olsson and
F.Cullinan

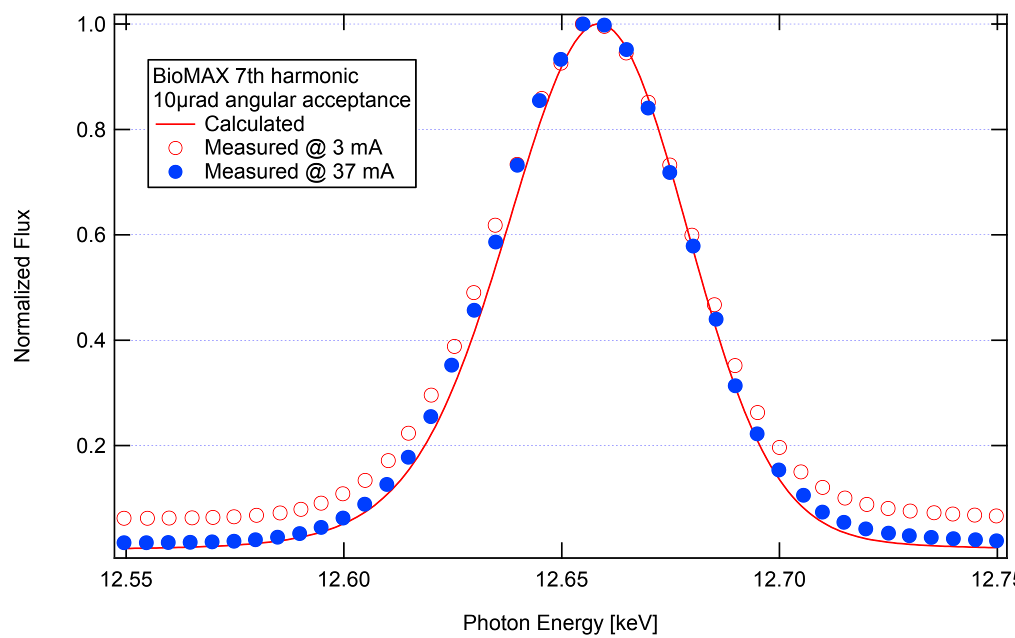
Insertion Devices

Data by T. Ursby and D.Olsson

- 2 In-vacuum undulators
- 1 In-vacuum wiggler
- 2 EPUs

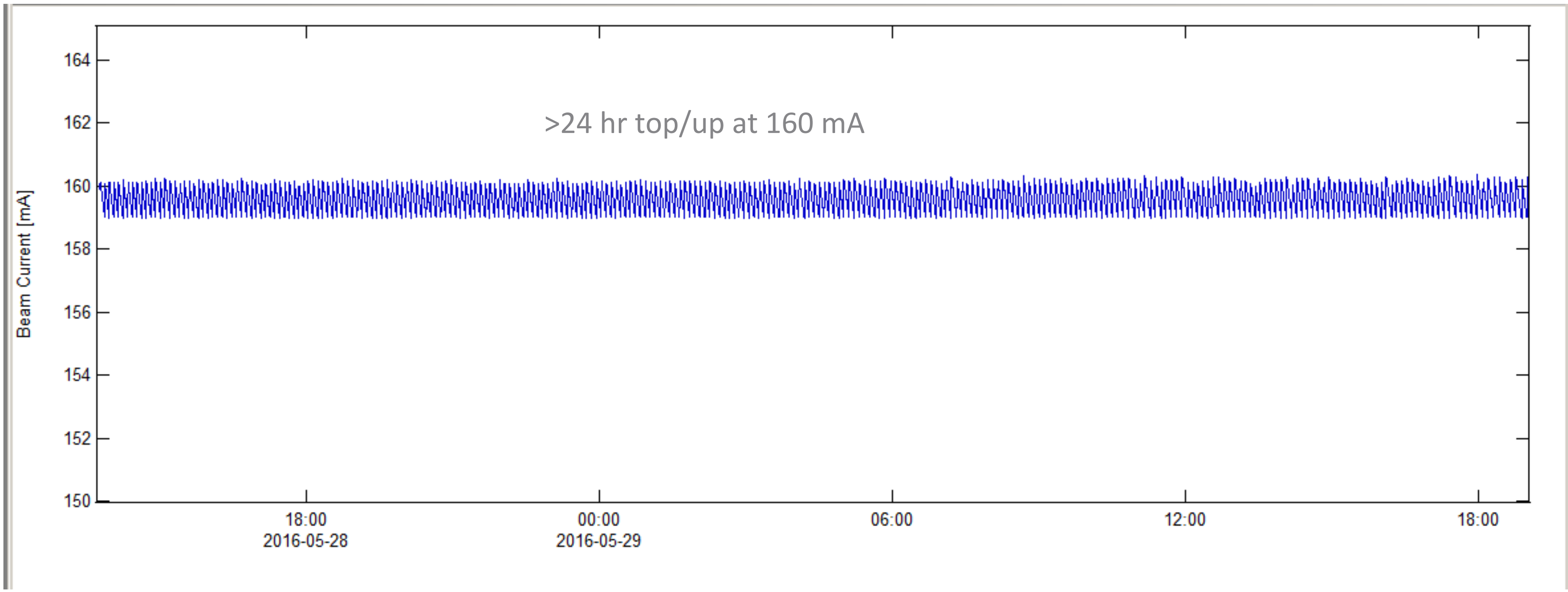
Biomax in-vac undulator
18 mm period
2 m length
4.2 mm min gap





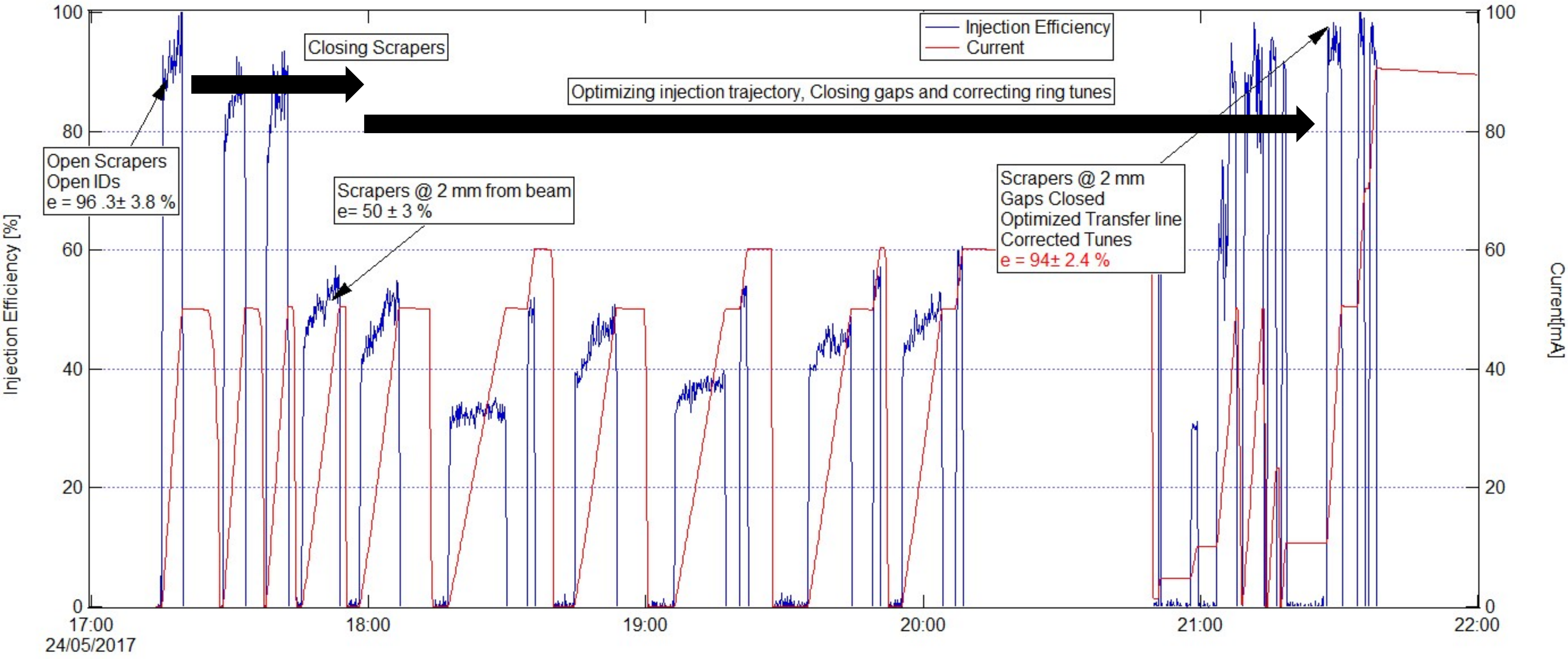
Top-up Injection

- Top-up with closed shutters and open ID gaps has been running since early on
- Top-up with ID gaps closed down to 4.5 mm and high injection efficiency (> 90%) since May 2017.



- Permit for top-up with open shutters in place since June 2017
- First tests with beamlines end of June 2017
- **Top-up is the standard operation mode from Autumn 2017**

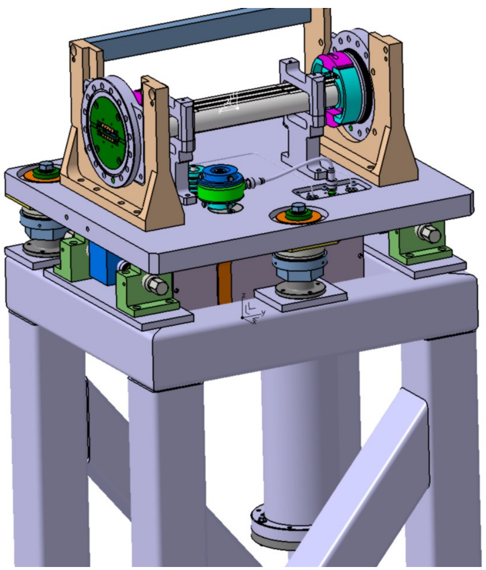
Injection with closed ID gaps



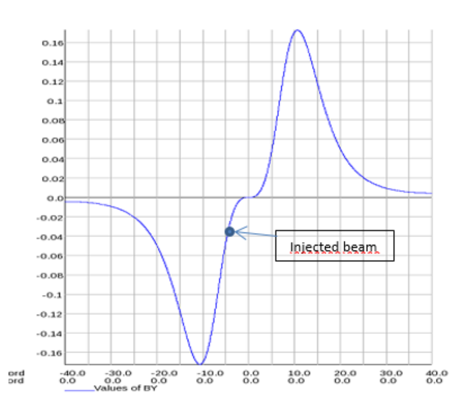
- Vertical Scrapers used to protect the IDs.
- Trimming of the transfer line trajectory and storage ring tunes allows recovery of > 90 % injection efficiency for gaps closed and scrapers at 2 mm from the beam.

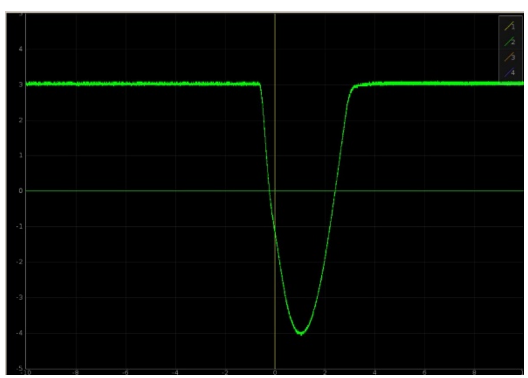
Multipole Injection Kicker (MIK)

- Objective: achieve near transparent top-up injection.
- Joint project with **SOLEIL** based on original concept from **BESSY**.
- **First prototype** installed in the 2017 shutdown.
- Injection with MIK (up to 200 mA) demonstrated.
- Perturbation to the stored beam reduced by a factor ~60.

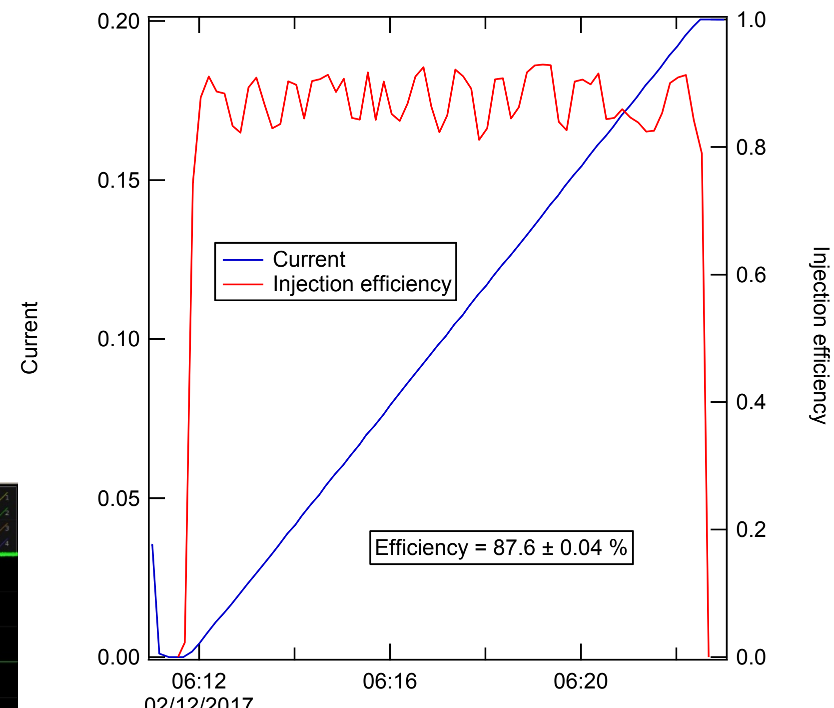


Drawings by SOLEIL
P.Lebasque
P.Alexandre



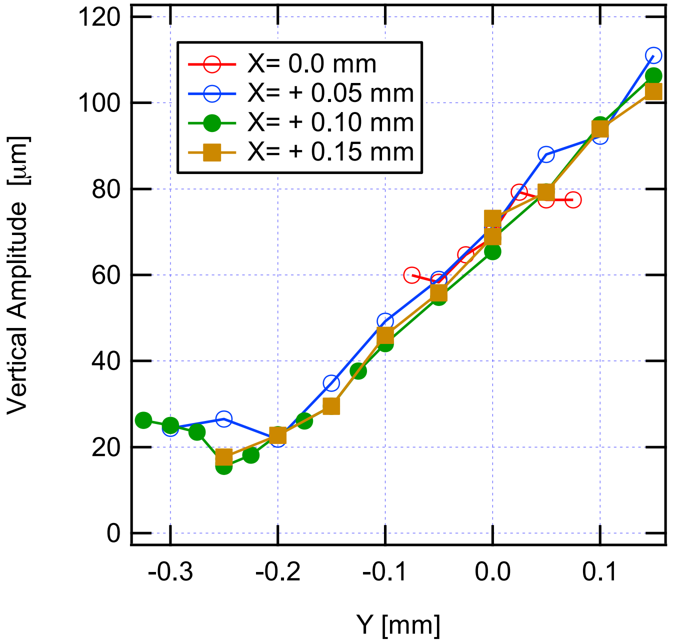


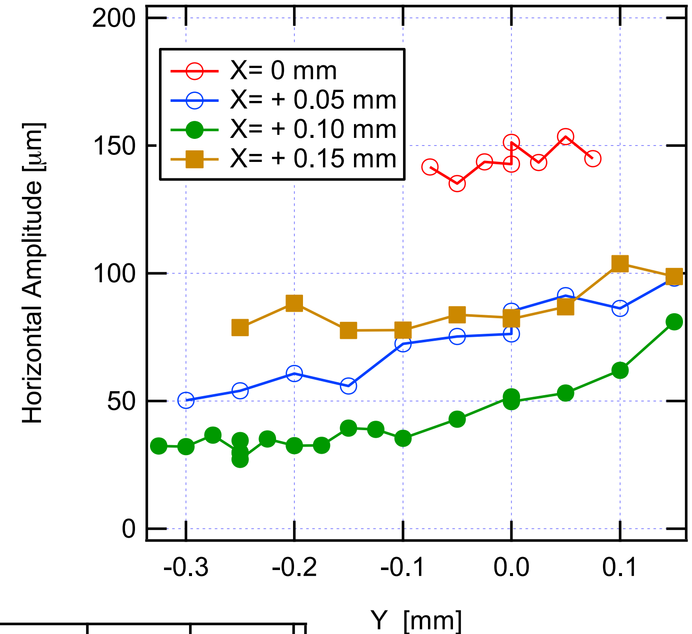
Injection with the MIK up to 200 mA



MAX IV

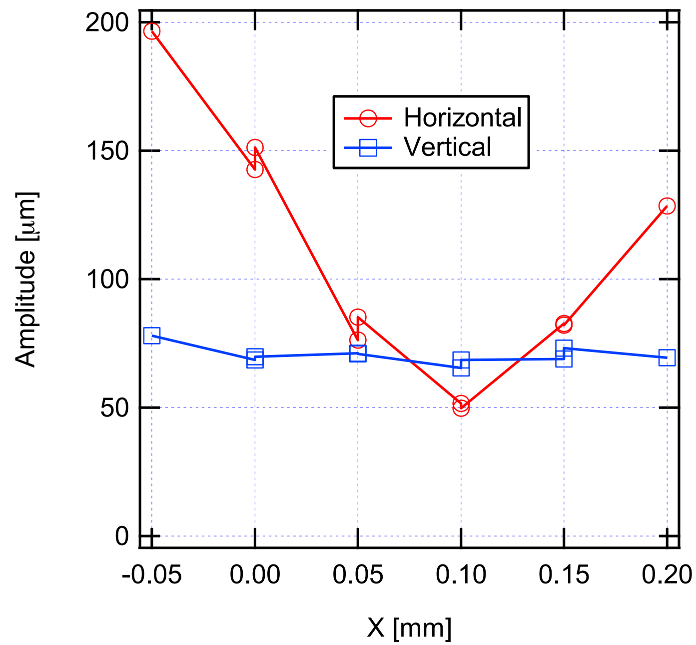
Residual Orbit Perturbations





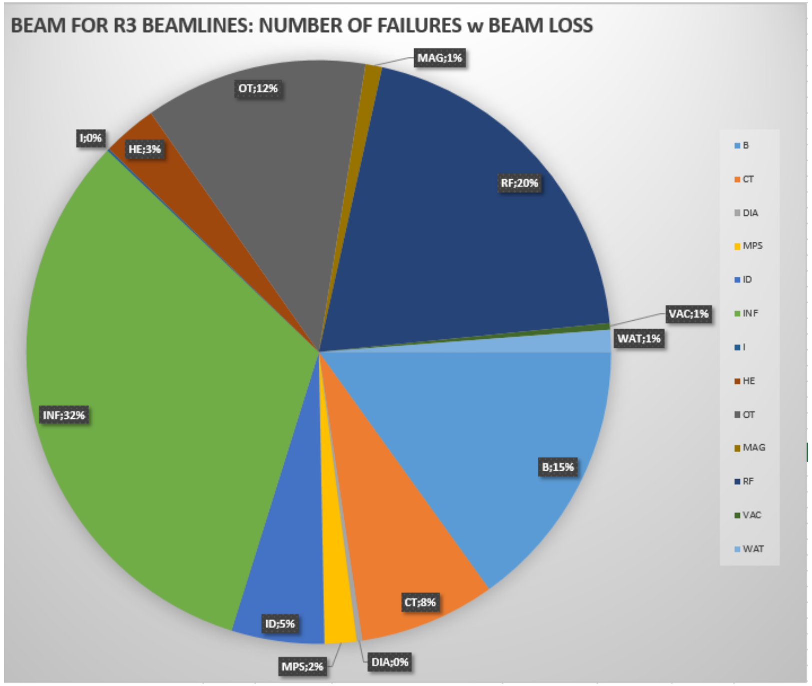
Amplitudes (half of peak-to-peak over first 500 turns)
at x=0.1 mm, y=-0.25 mm:

H: 27 µm
V: 16 µm



Accelerator Operations 1H - 2017

3 GeV Ring operation statistics



Jan to June 2017

Delivery Hours: 1024
Uptime: 92%

- Main causes of downtime:
  - Infrastructure
  - Beamline conditioning
  - RF system (power cuts)

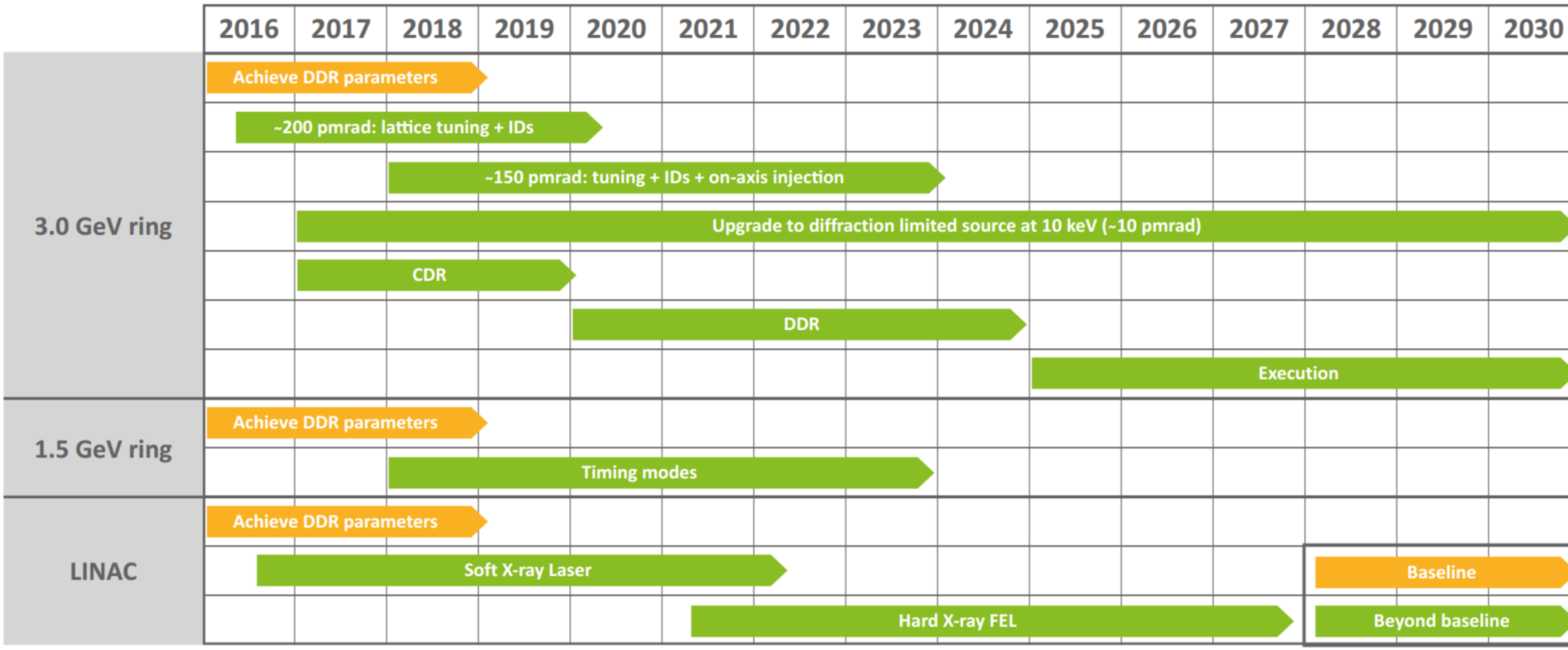
- What we are doing about it:
  - New agreement with service providers
  - Review procedures
  - Rotating Converter
  - Cavity Conditioning Station

MAX IV

Future pespectives – short term

- Multipole Kicker further trimming and second improved version
- Further Non-linear optics trimming
- Further commisioning/conditioning of harmonic cavities
- New Ids: 2 IVUs (CoSAXS, DanMAX) + 1 EPU (SoftiMAX)
- Slow orbit feedback improvements
- Fast orbit feedback

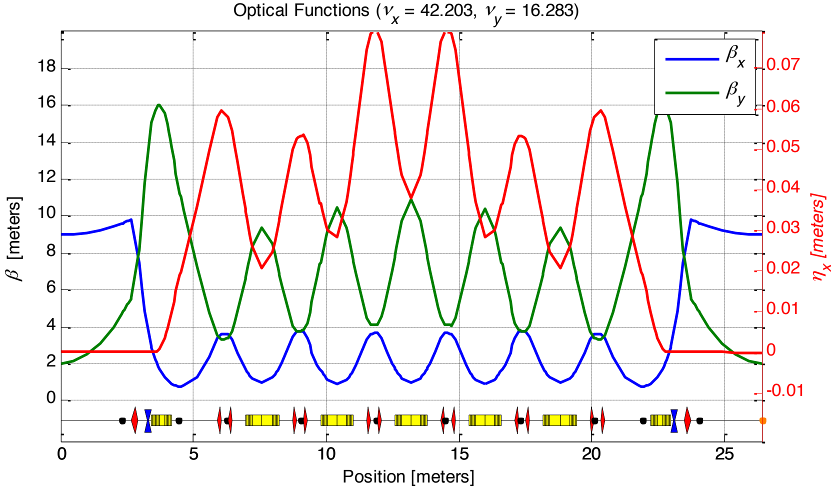
MAX IV Accelerators RoadMap: 2016-2030



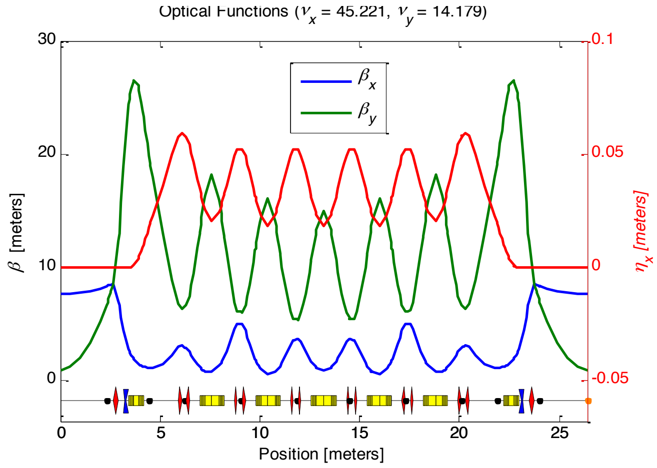
Brightness upgrade

Data and plots by Hamed Tarawneh

328 pm.rad

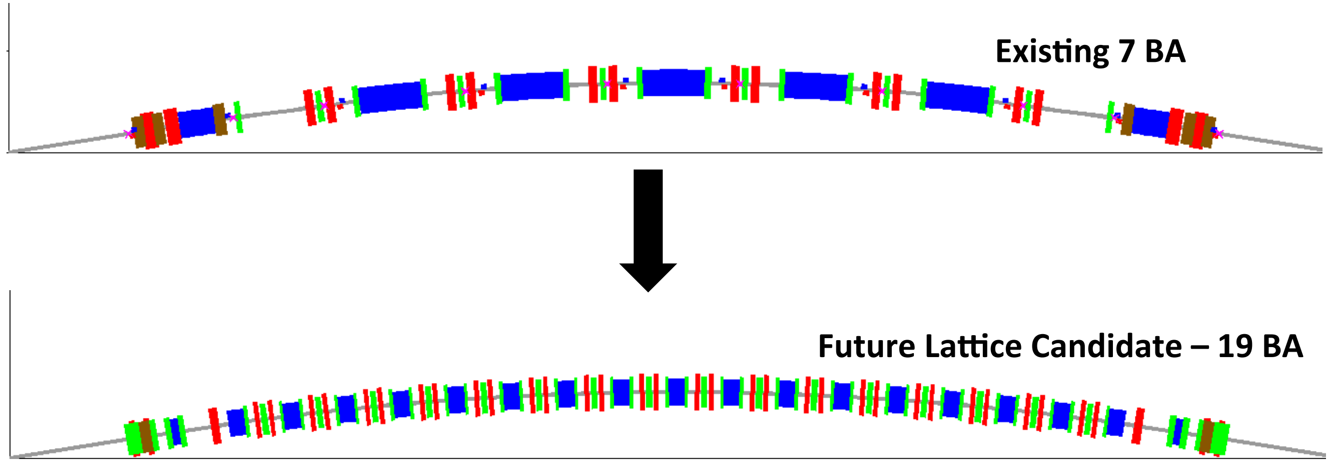


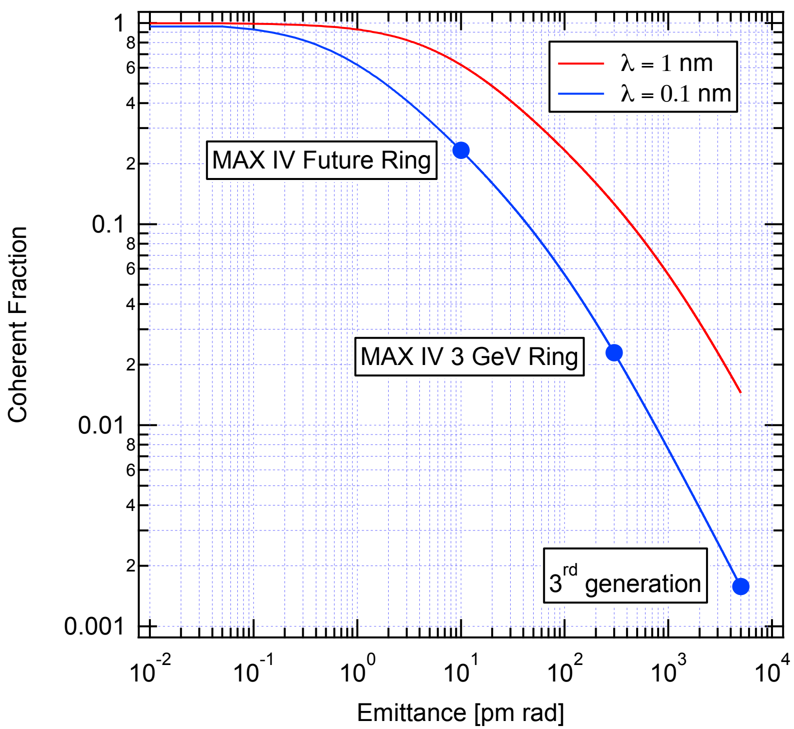
248 pm.rad



	Baseline Lattice (328 pm.rad)	Lattice(248 pm.rad)	Change in strength
QF1	4.030076	4.535	+12.5 %
QF2	4.030076	4.6314	+14.9 %
QFM	3.773995	3.7947	+0.6 %
QFEND	3.653849	3.5105	-3.9 %
QDEND	-2.503663	-2.4302	-2.9 %
D0 (unit cell)	-0.697 (all slices)	-0.721	+3.4 % (max. 4.2%)
DS0 (matching cell	-0.870701 (all slices)	-0.90480	+1.65 % (max. 4.2%)

Beyond MAX IV – An exercise



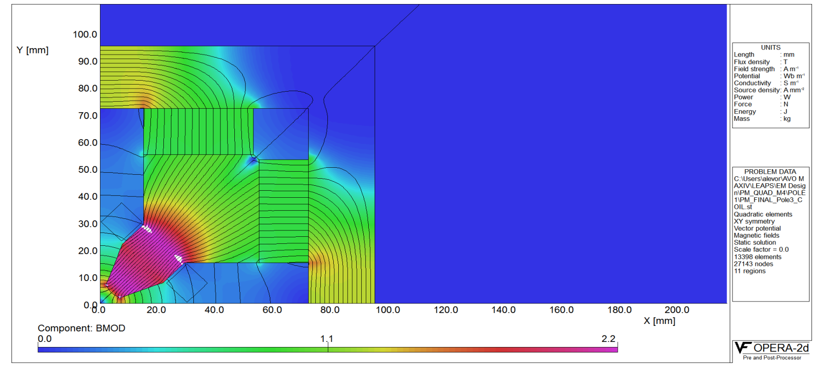


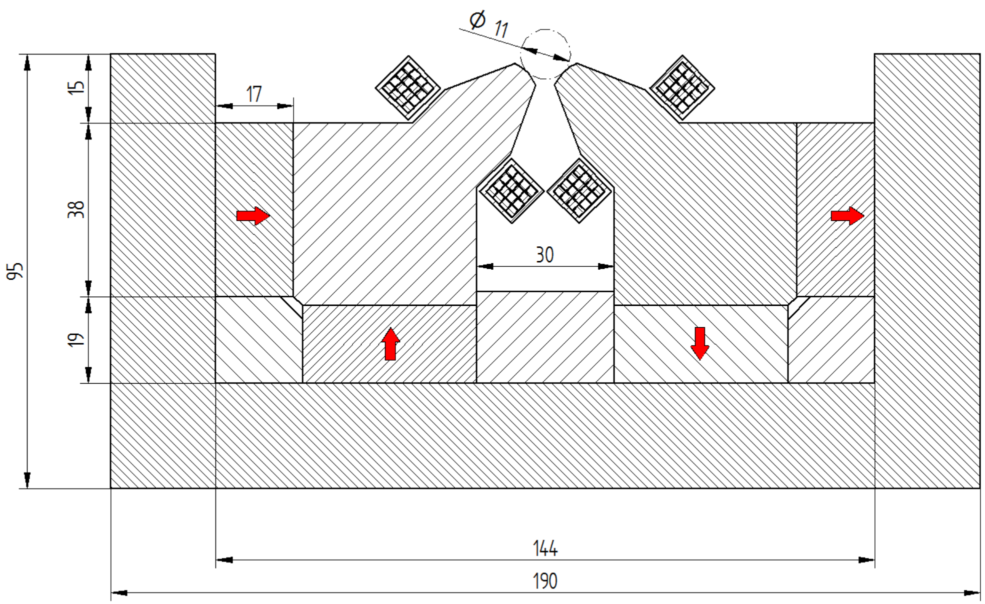
Parameter	Value	Unit
Energy	3	GeV
Number of periods	20	
Circumference	528	m
Straight section length	5	m
Natural Emittance	16	pm.rad
Natural energy spread	0.09	%
Horizontal Tune	101.2	
Vertical Tune	27.28	
Natural horizontal chromaticity	-100.21	
Natural vertical chromaticity	-126.1	

High Gradient permanent magnet quadrupole

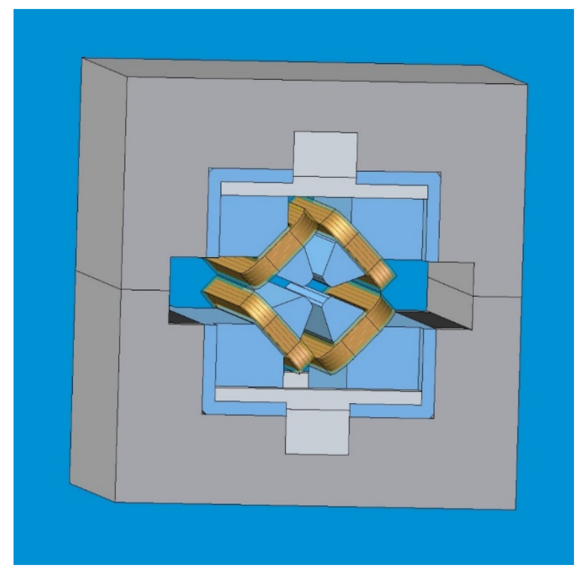
Design and images by Alexey Vorozhtsov

- 237 T/m in 11 mm bore diameter
- ±3 mm good field region
- Sm2Co17 permanent magnets
- Trim coils for ± 1.5 % adjustments





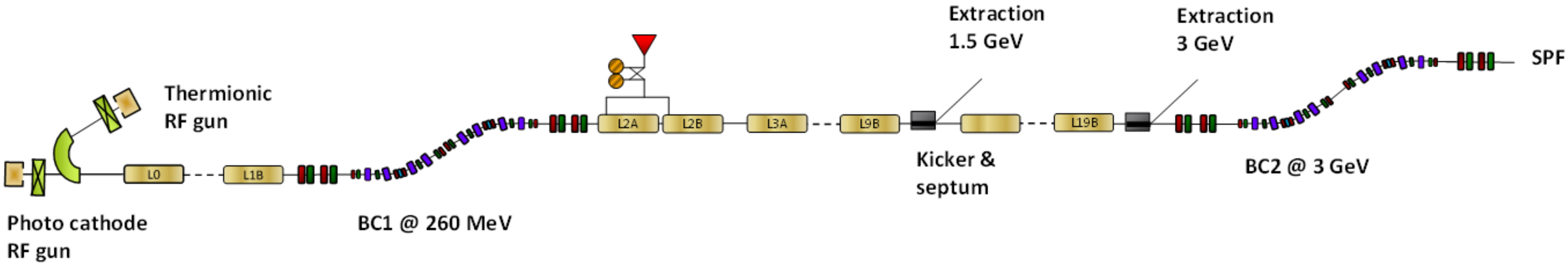
SECTION A-A

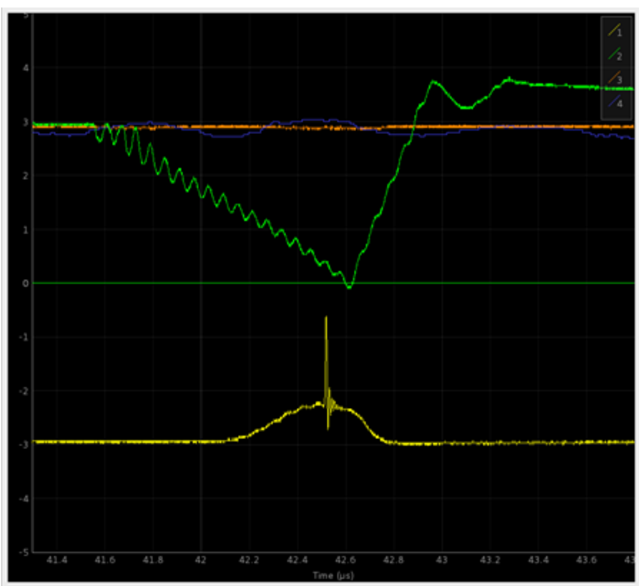


Thank you for your attention !

Back up slides

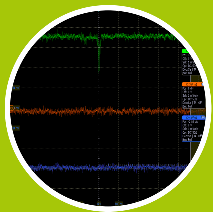
The Linear Accelerator



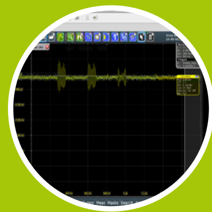


- Warm s-band full energy linac
- Thermionic RF gun for ring injection
- Photo cathode RF gun for SPF
- Solid state stable modulators
- Bunch compressors : down to 100 fs pulse length

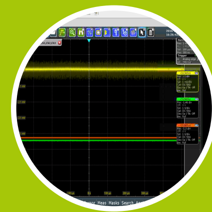
1.5 GeV Ring Commissioning Highlights & Timeline



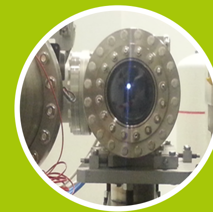
Beam in TR1
Sep 06
2016



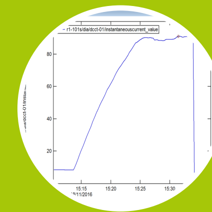
First Turn
Sep 14
2016



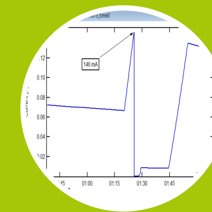
Stored Beam
Sep 30
2016



First Light
Sep 30
2016



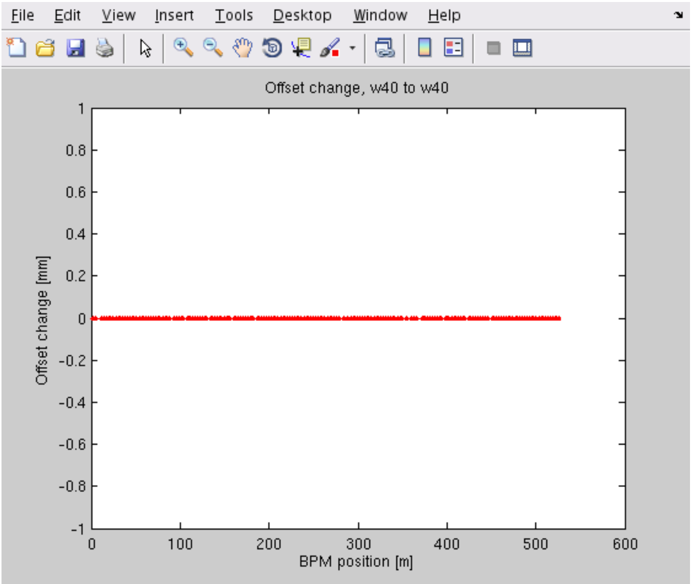
90 mA
Nov 18
2016



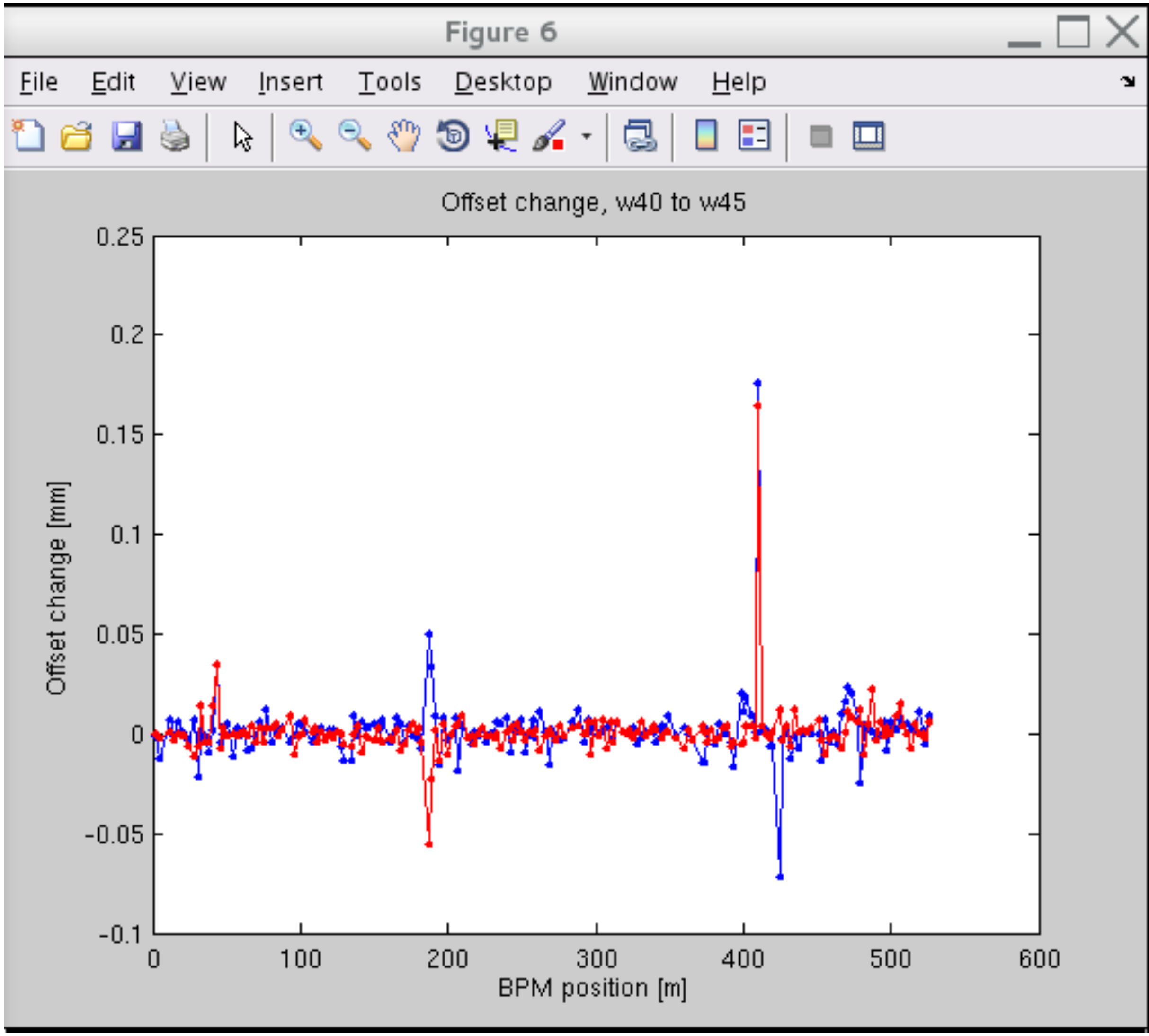
198 mA
Apr 08
2017

- Performance achieved so far
  - 250 mA stored current (multibunch)
  - 17 mA stored current (single-bunch)
  - ~ 120 A.h accumulated dose , I*τ > 1.3 A.h
  - Longitudinally stable beam at 170 mA with Harmonic Cavities

Changes in BPM offsets after 5 weeks

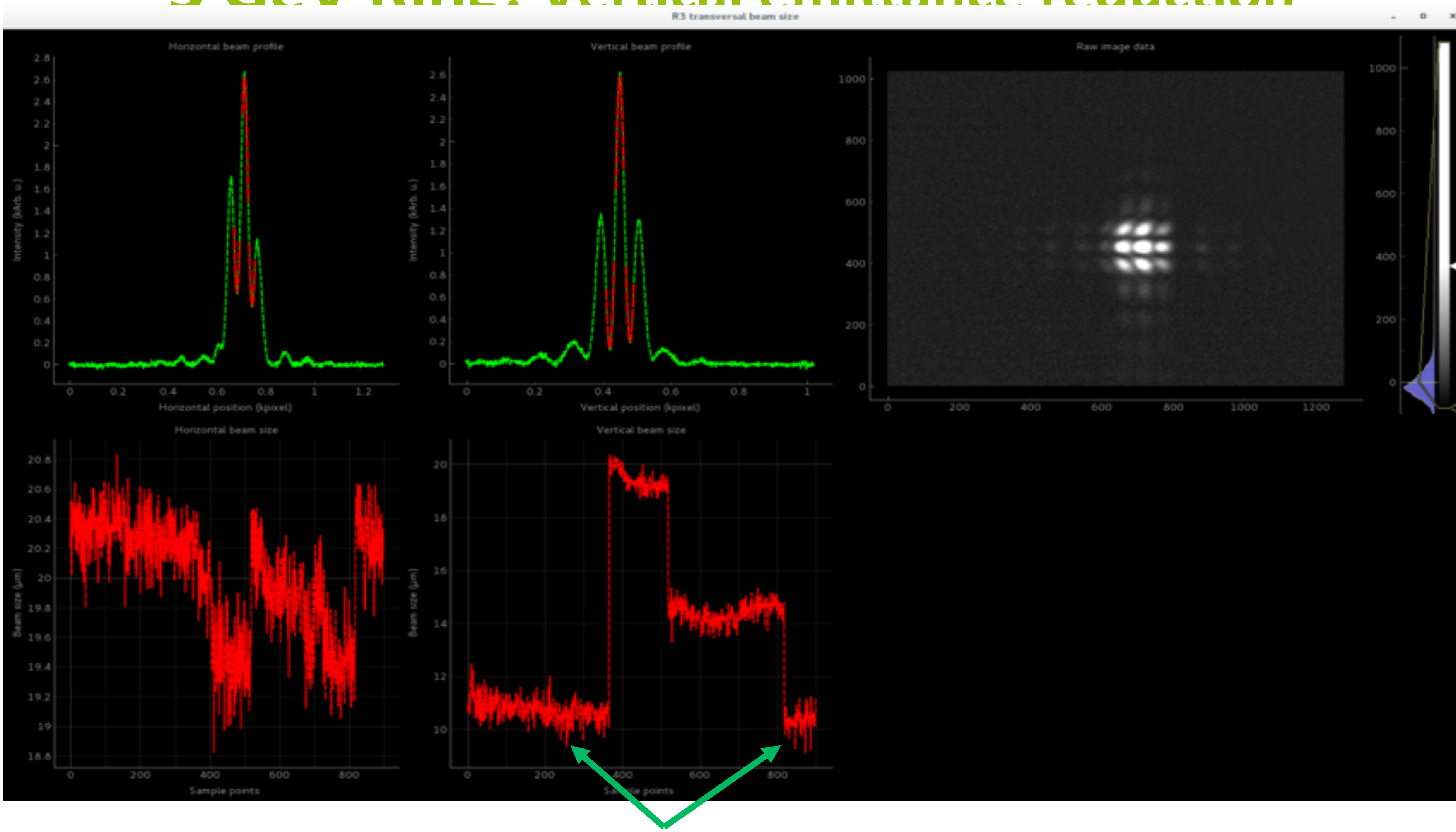


Consecutive measurements give results within 1 -2 um.



Current dependance measurements have started: Some BPMs show up to 10 um drifts over 20 mA

3 GeV Ring: Vertical emittance reduction

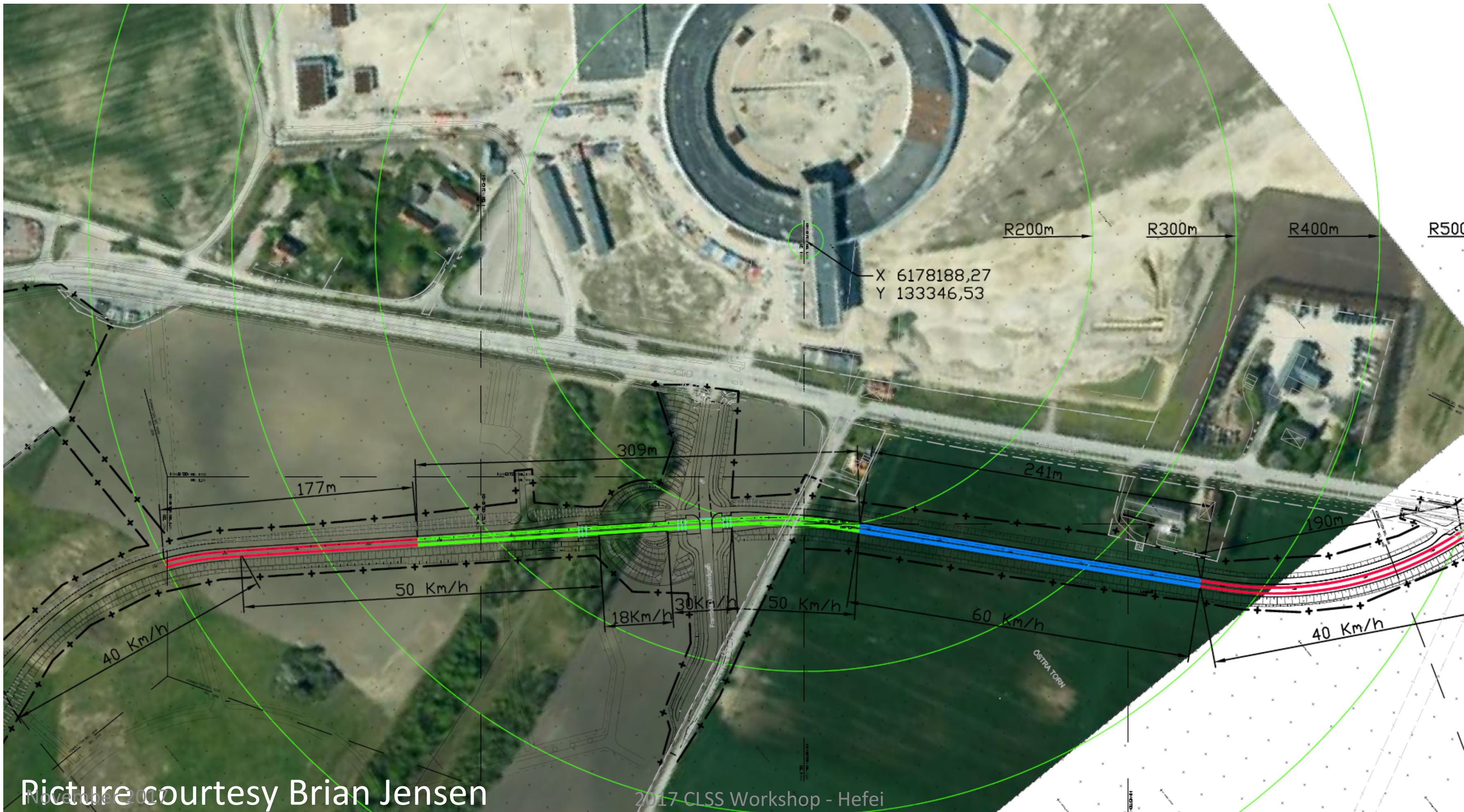


ε_y=6.4 ± 1 pm.rad

Measured values after vertical dispersion and coupling correction.

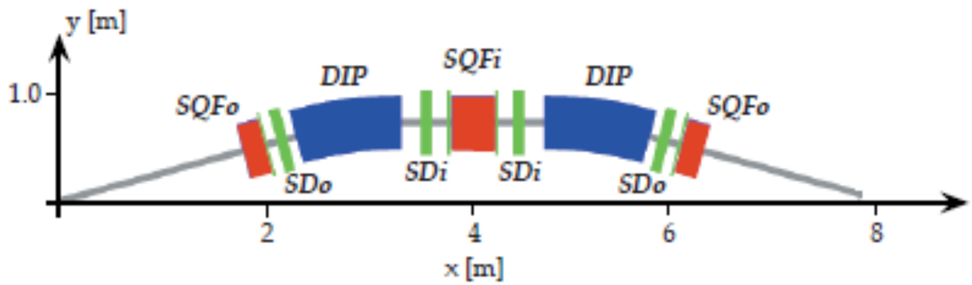
Accelerator highlights since last Board Meeting: *Stability*

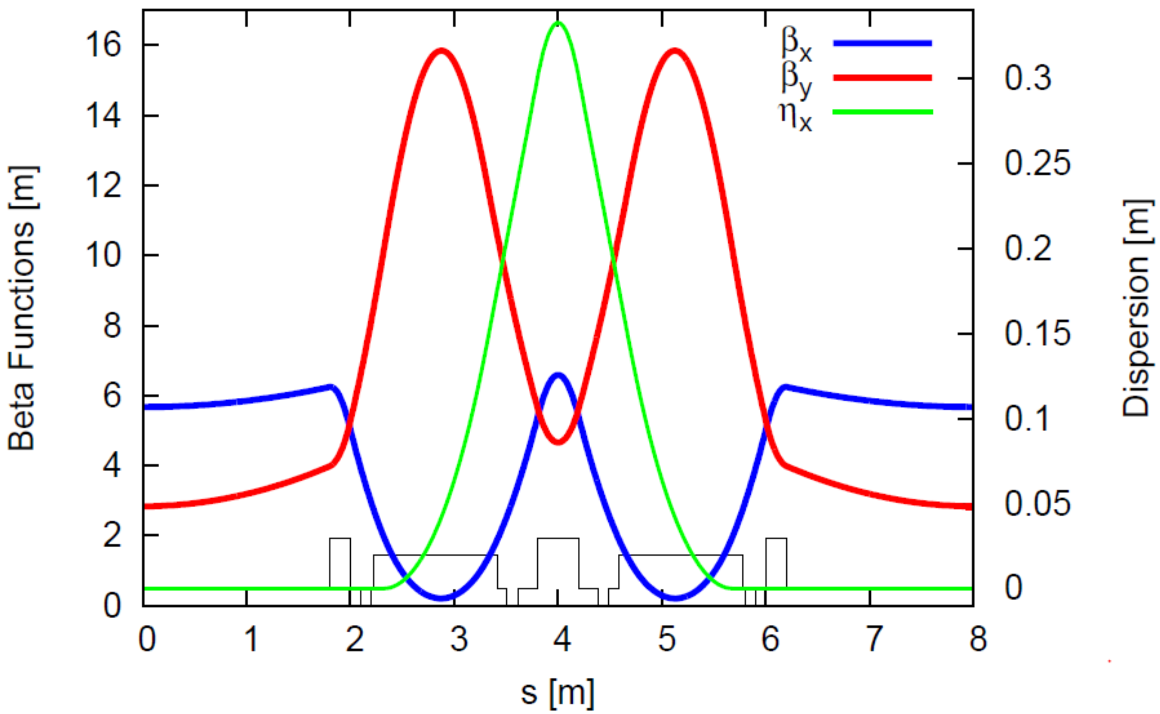
- Agreement with LK regarding isolation of tram line



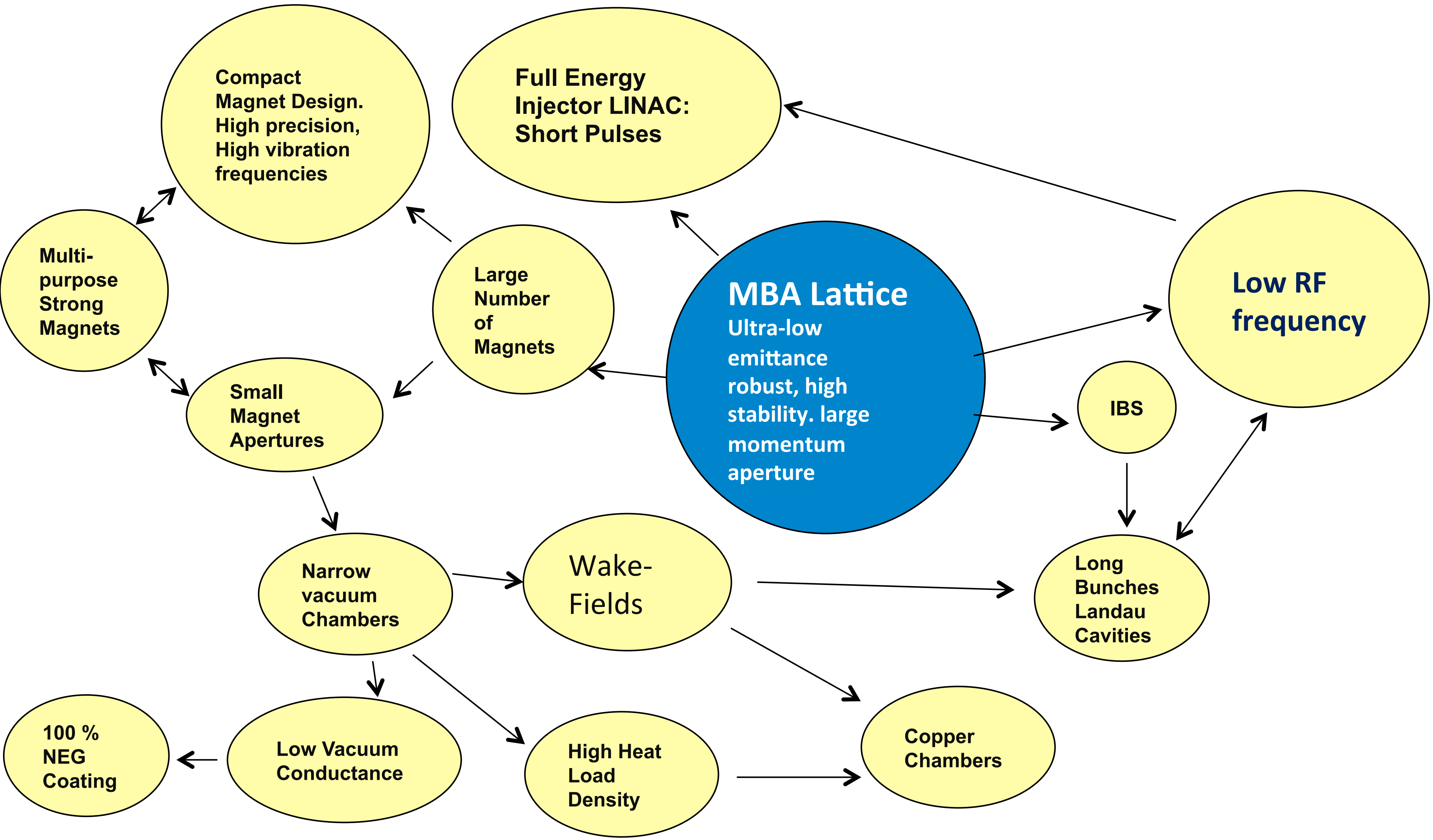
1.5 GeV Ring

Double bend achromat
12periods
6 nmrad

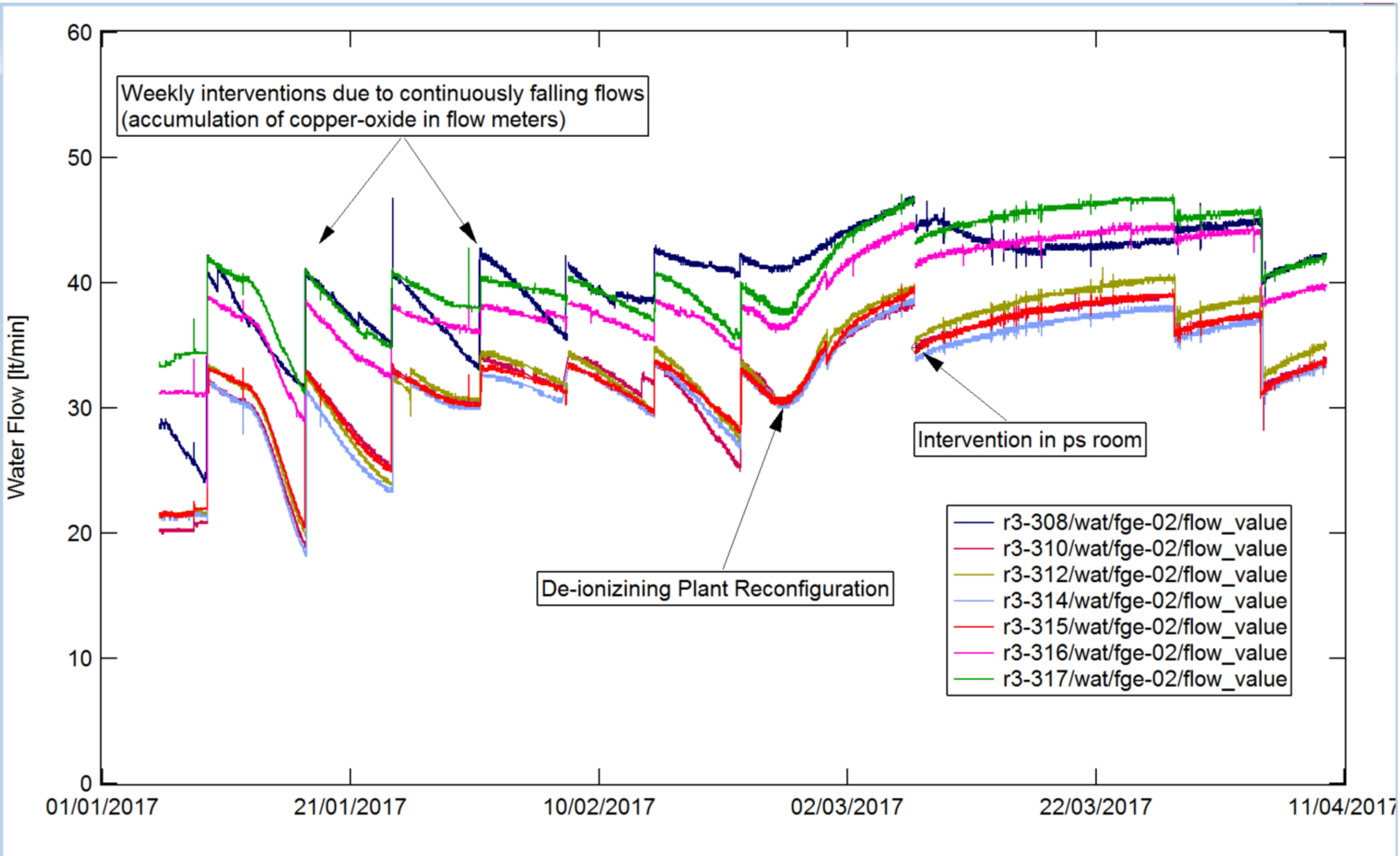




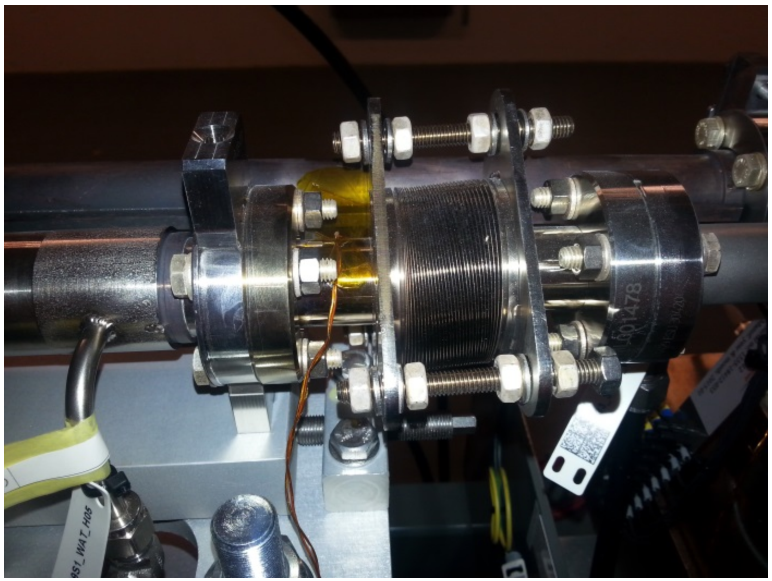
The MAX IV approach to implementation of the MBA



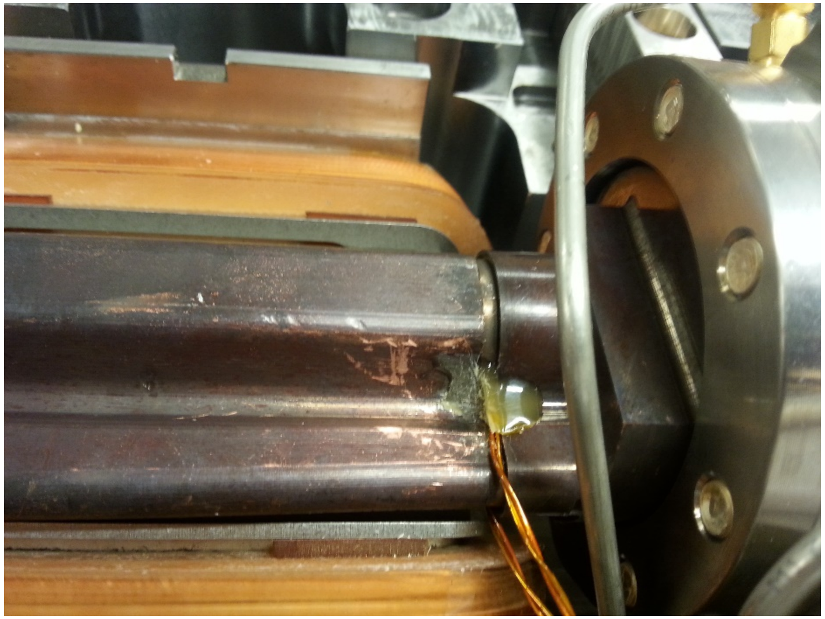
3 GeV Ring: Technical issues
Chamber cooling issues solved



Technical issues
Vacuum chambers locally hit by SR



In Ach 4 S1, replaced an absorber (outside mechanical tolerances). Test ongoing

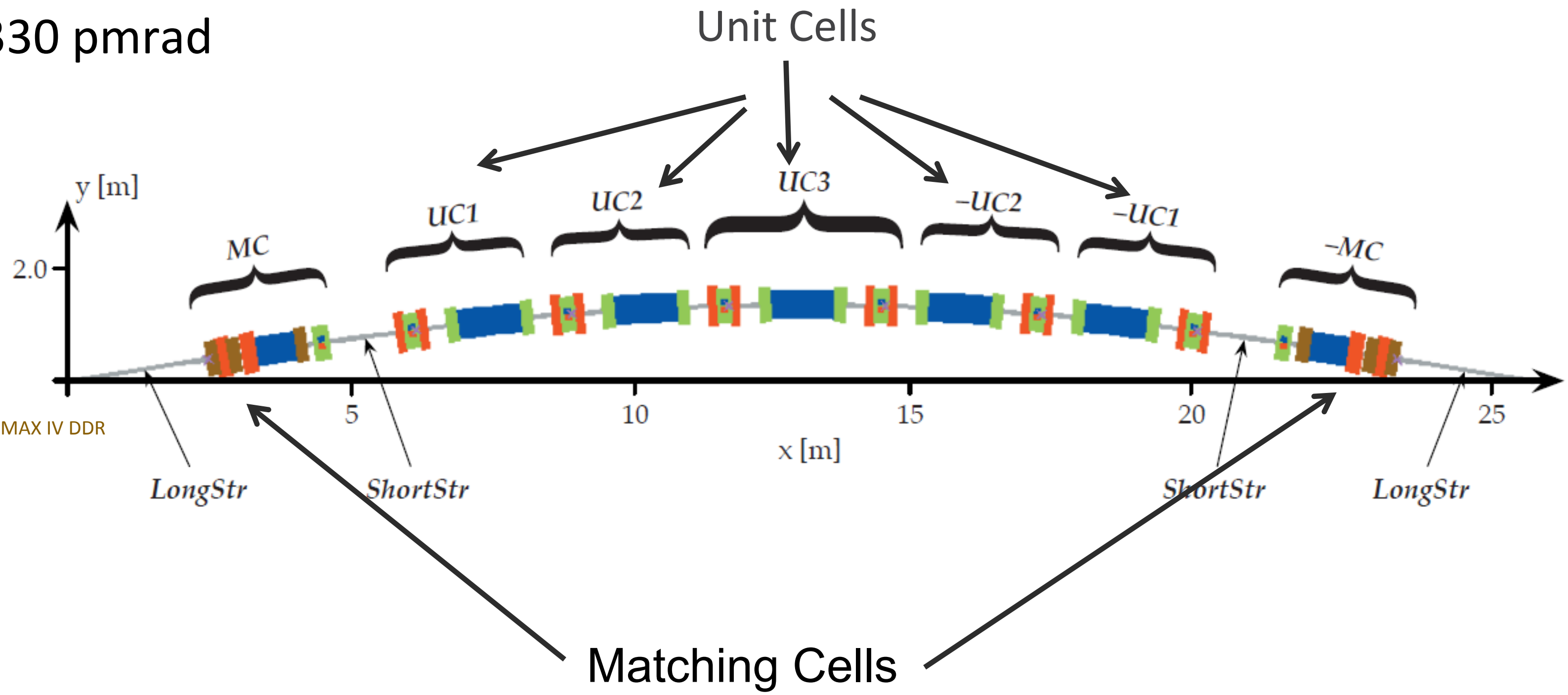


In Ach 8 M1, a chamber was damaged little too much thermocouple glue. Replaced, test ongoing

Slide by Å. Andersson

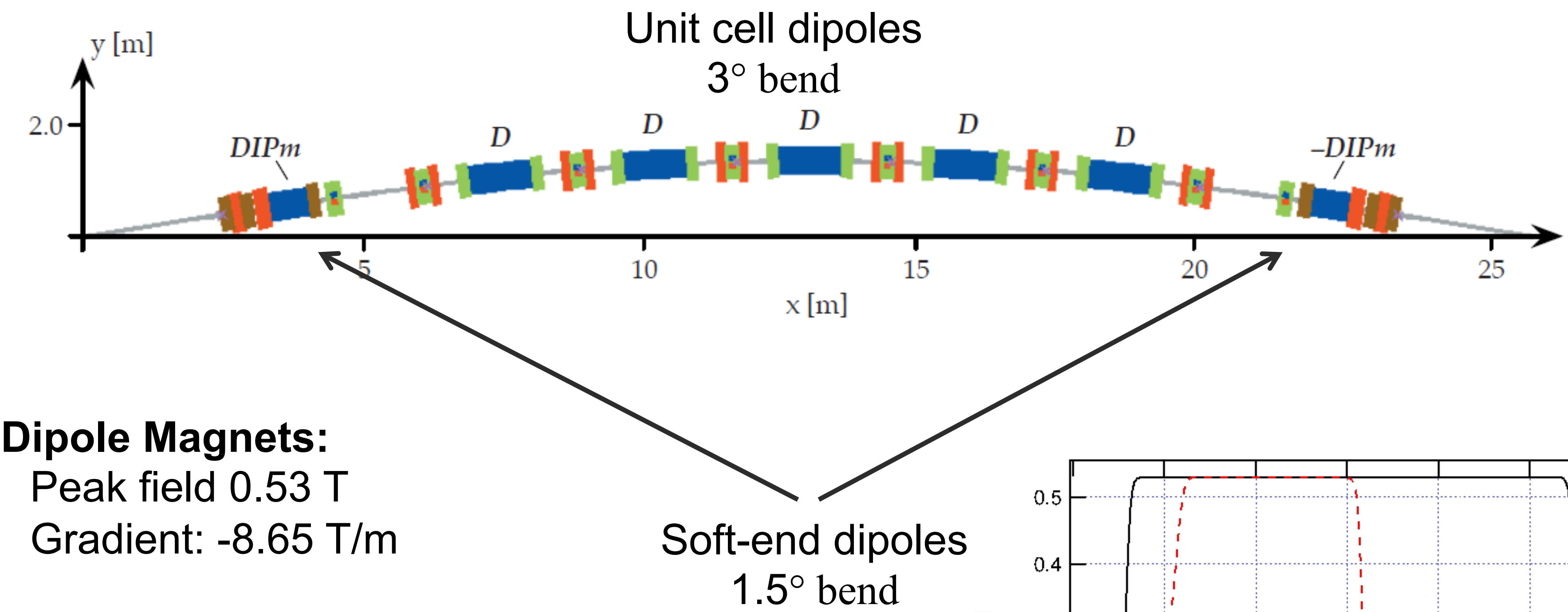
The MAX IV 3 GeV Lattice

7-bend achromat
20 periods
330 pmrad

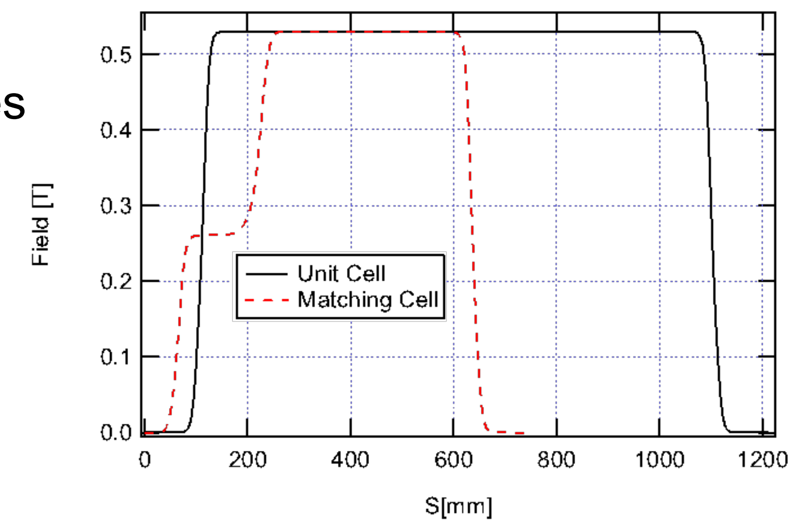


Picture MAX IV DDR

The 3 GeV Ring Lattice: Dipoles

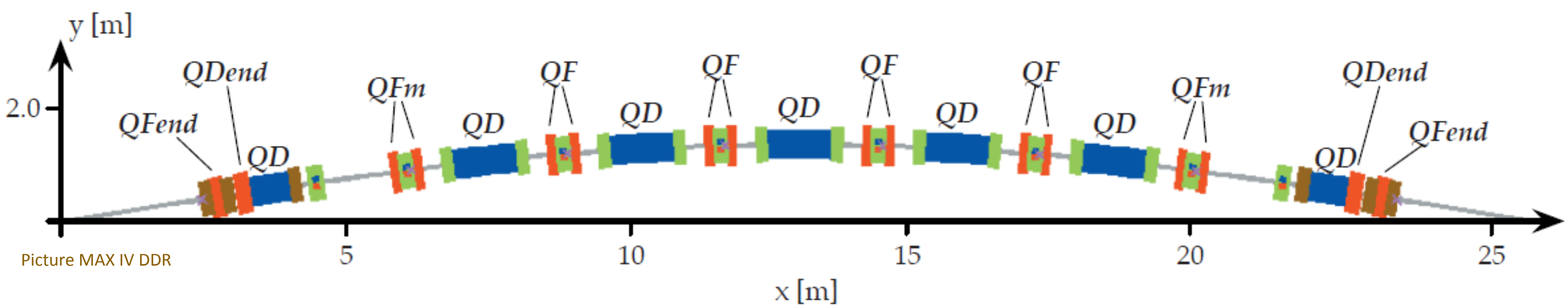


Dipole Magnets:
Peak field 0.53 T
Gradient: -8.65 T/m



The 3 GeV Ring lattice: Quads

Quadrupole Magnets:
Gradients: 25 to 40 T/m



Picture MAX IV DDR

- **All vertical focussing (along the arch) from the bends**
- **Qfends/Qdends for local ID compensation**

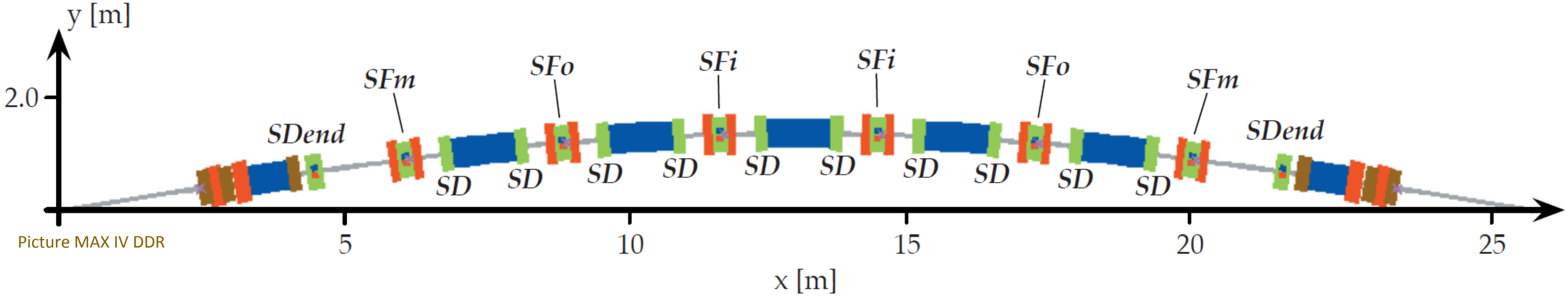
MAX IV

The 3 GeV Ring lattice: Sextupoles&Octupoles

Non –Linear Corrections

Sextupoles

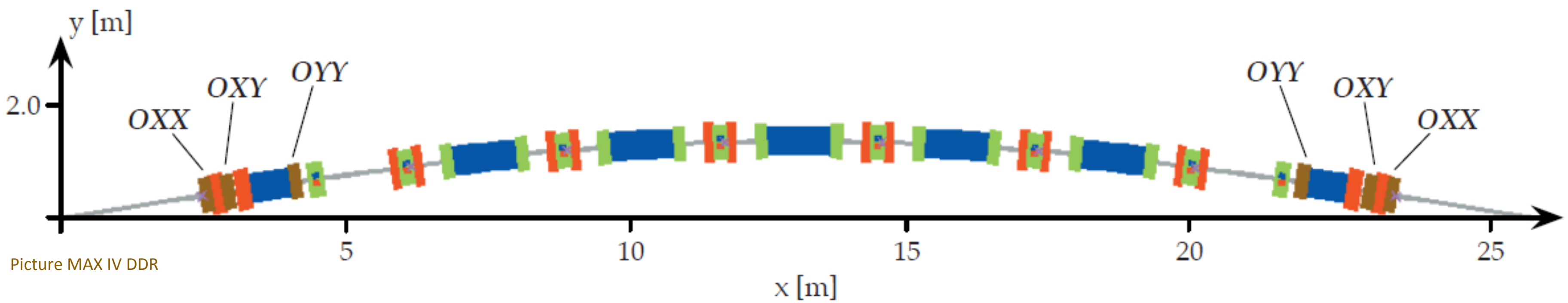
Chromaticity correction , Minimization of Resonance Driving Terms



Picture MAX IV DDR

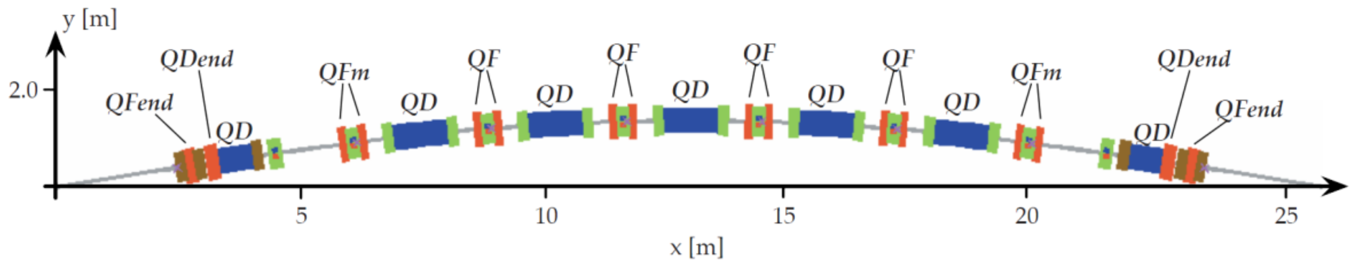
Octupoles

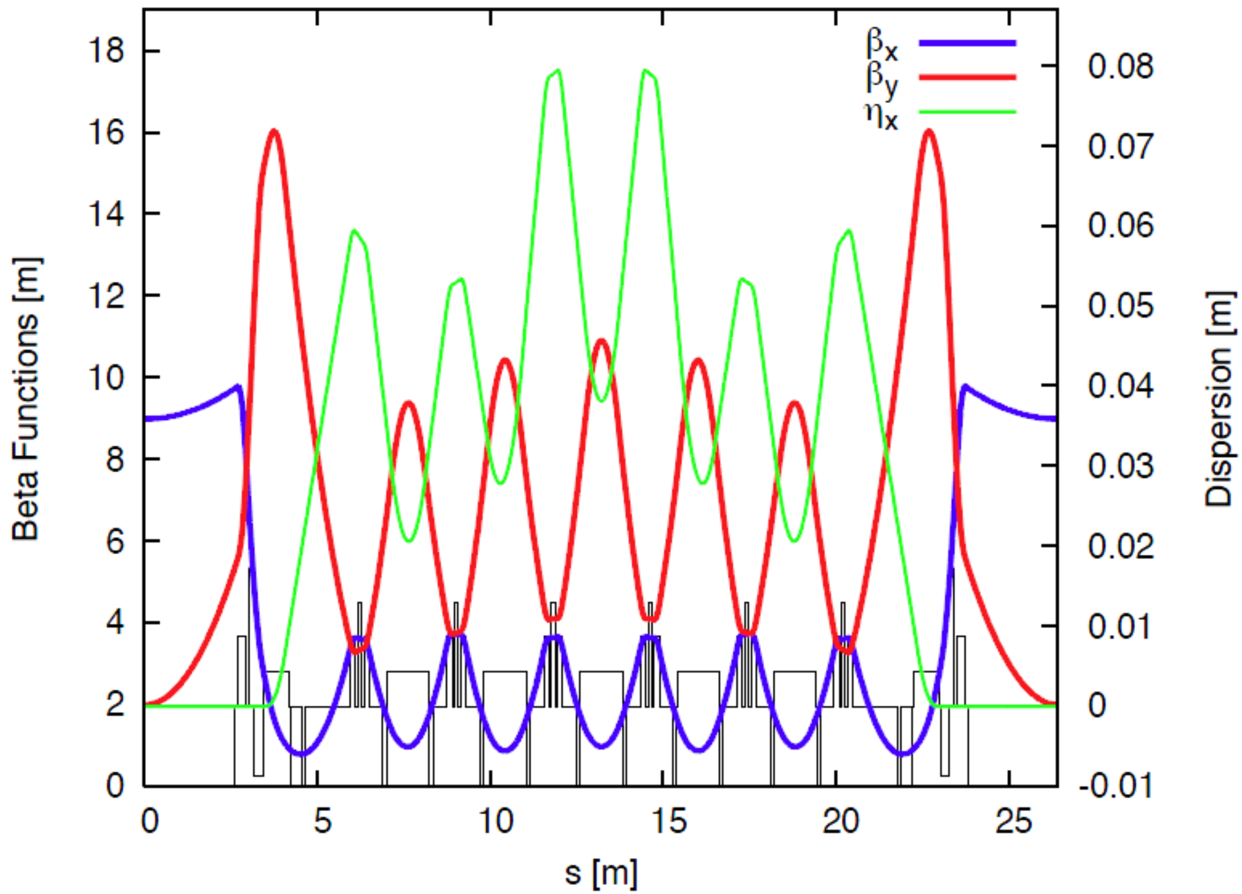
Minimization of Amplitude Dependent Tune Shifts



Picture MAX IV DDR

The 3 GeV Ring Lattice



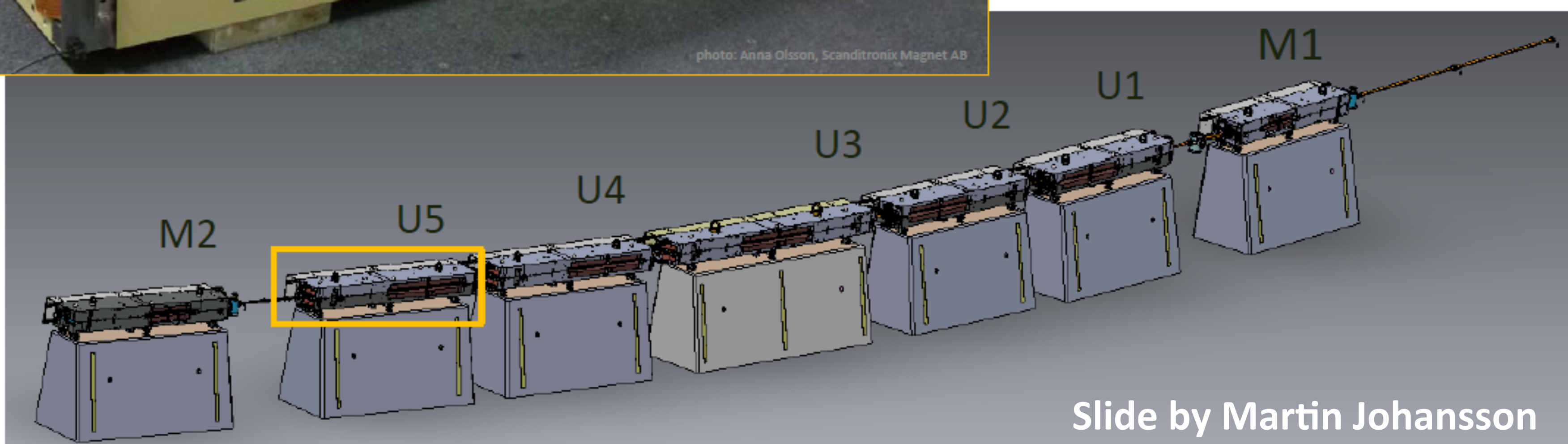


Pictures MAX IV DDR

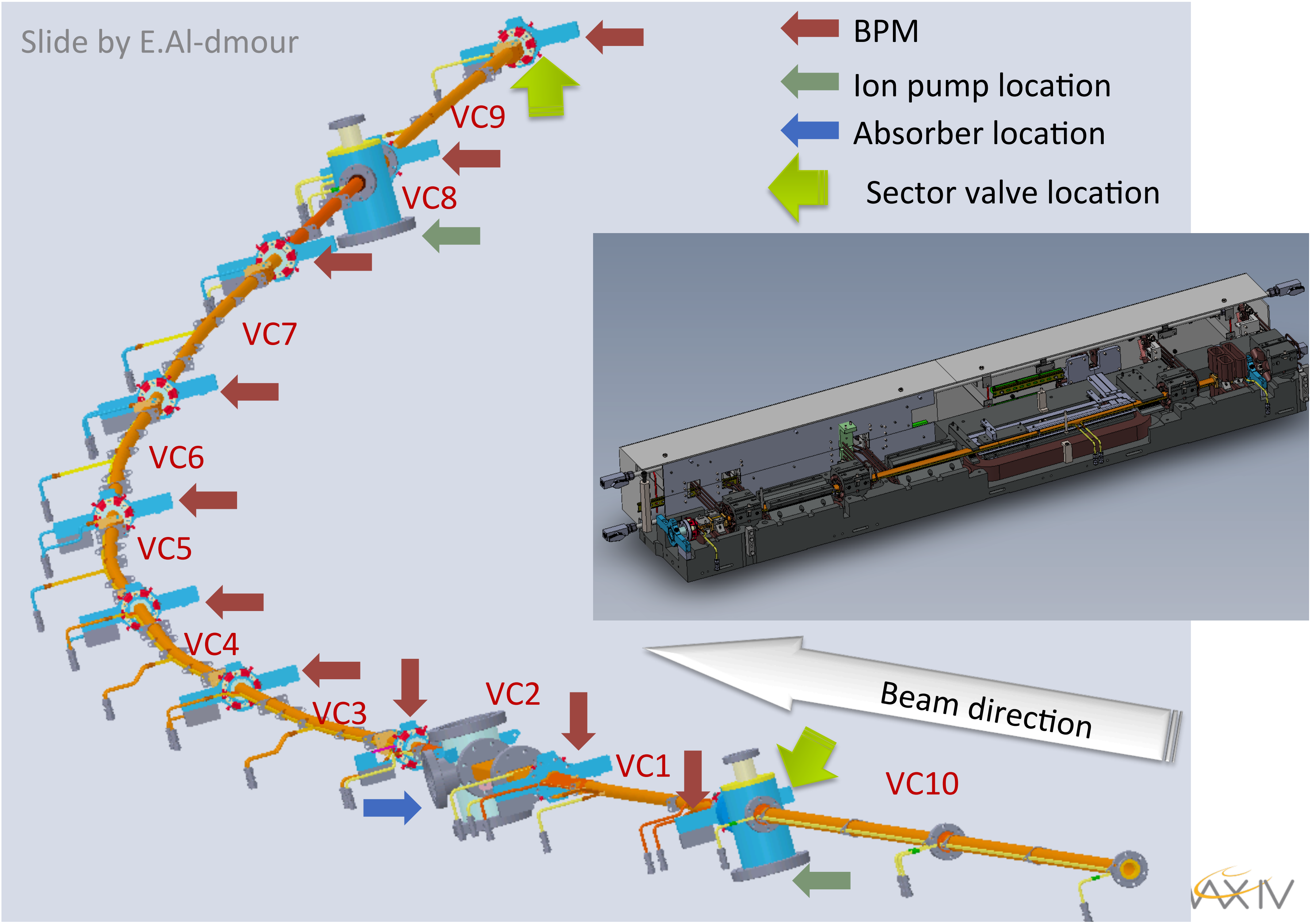
MAX IV 3 GeV Ring DC Magnets

- *Each cell is realized as one mechanical unit containing all magnet elements.*
- *Each unit consists of a bottom and a top yoke half, machined out of one solid iron block, 2.3-3.4 m long.*

- a U5 bottom half →
- ↓ an assembled U5



Max IV 3 GeV Ring Vacuum System



MAX IV 3 GeV ring RF System

100 MHz Main Cavities

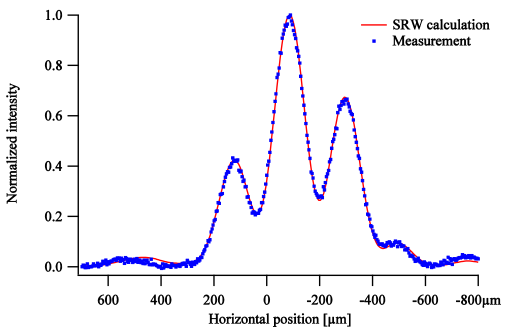
Normal Conducting
Copper
Capacity loaded

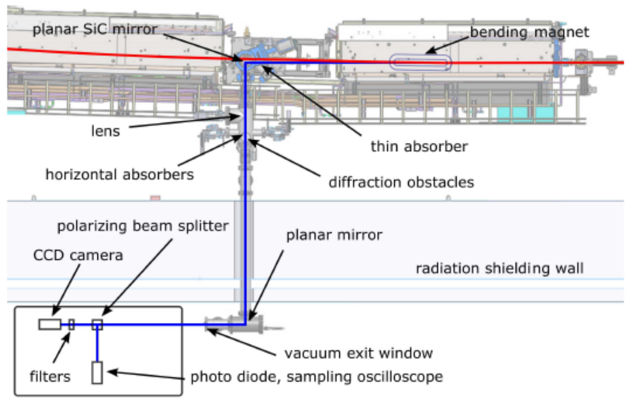
SS UHF Transmitters

Standard commercial
equipment

Passive 3rd Harmonic Cavities

Emittance Measurement

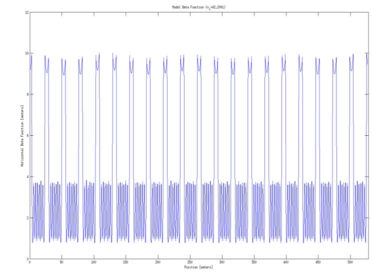




B320B diagnostic beamline
(visible SR radiation)

σ_x = 20.86 ± 0.14 µm (fit uncertainty)
σ_y = 15.70 ± 0.15 µm (fit uncertainty)

Figures by J. Breunlin and Å. Andersson

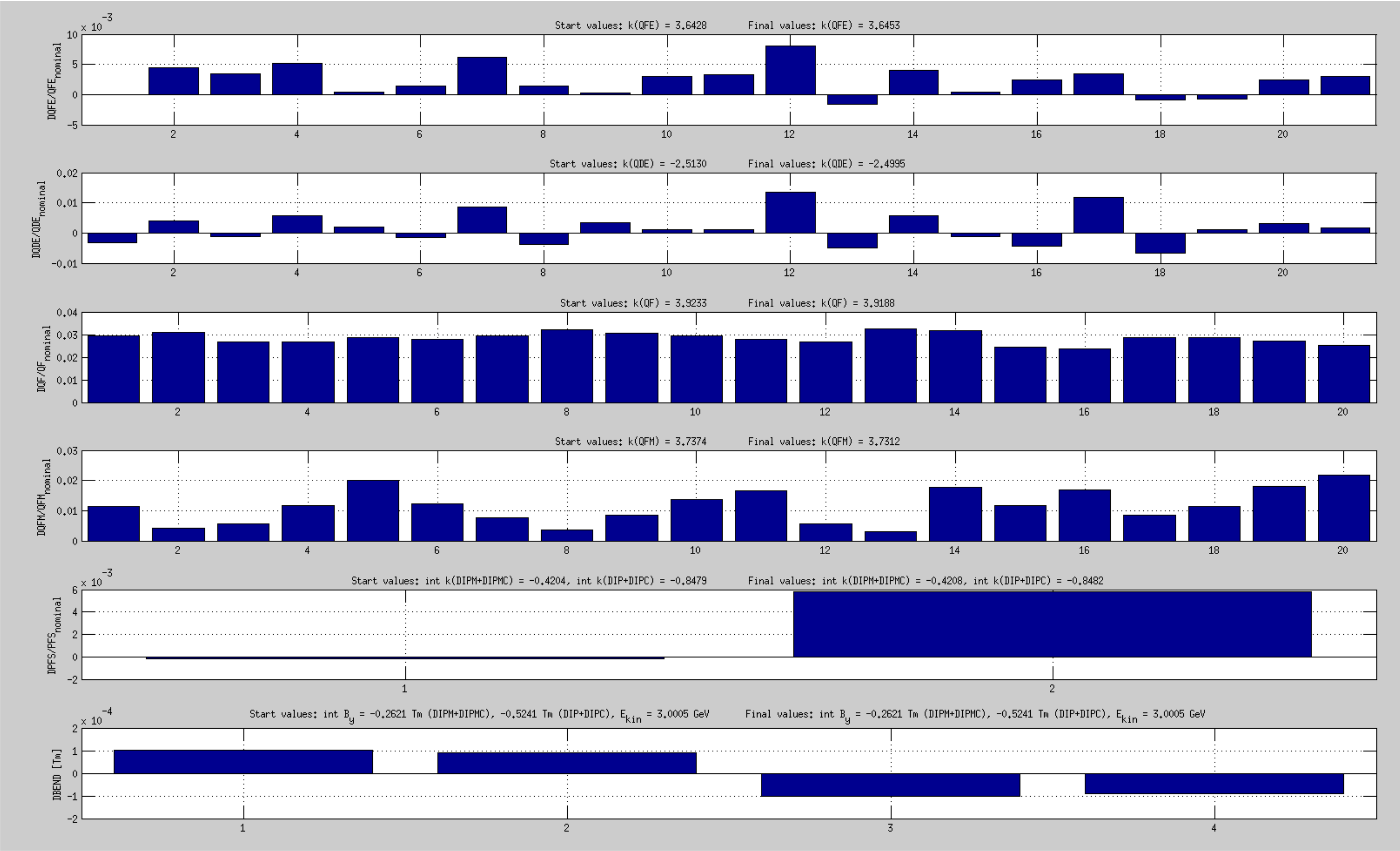


β_x = 1.26 ± 0.02 m
β_y = 15.66 ± 0.08 m
η_x = 3.59 ± 0.06 mm
Errors computed based on 5 separate LOCO measurements

ε_x=339.4 ± 30 pm.rad
ε_y=15.7 ± 0.3 pm.rad

Changes Implemented by LOCO

Plots by J.Sjögren

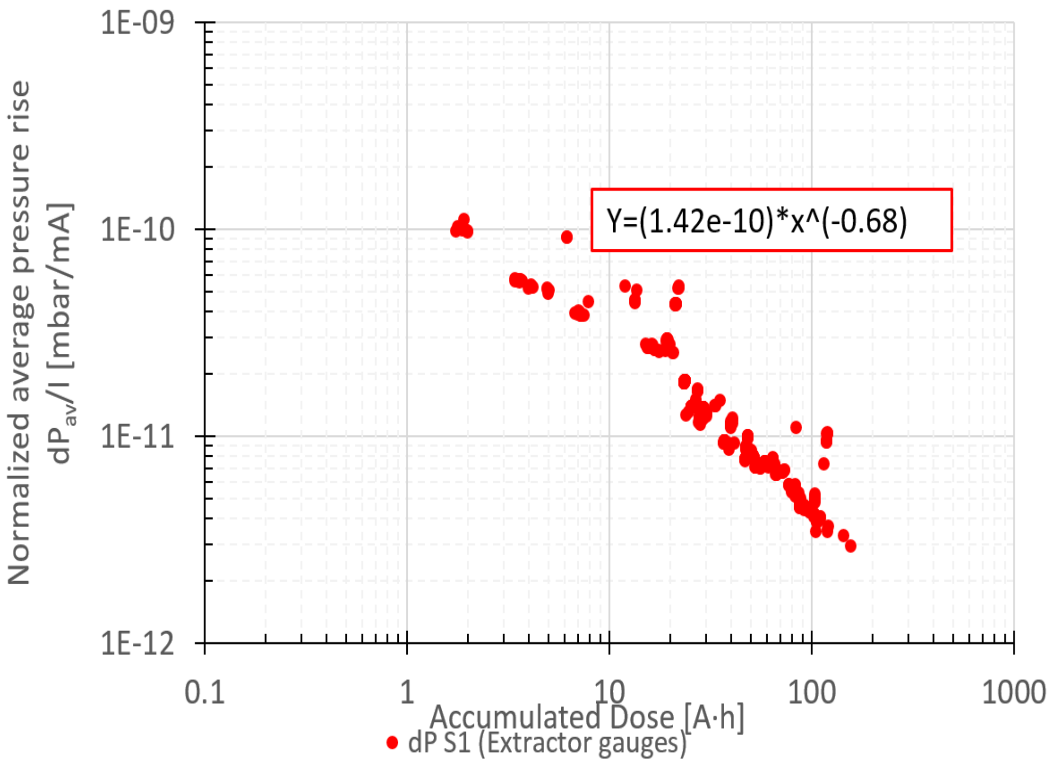


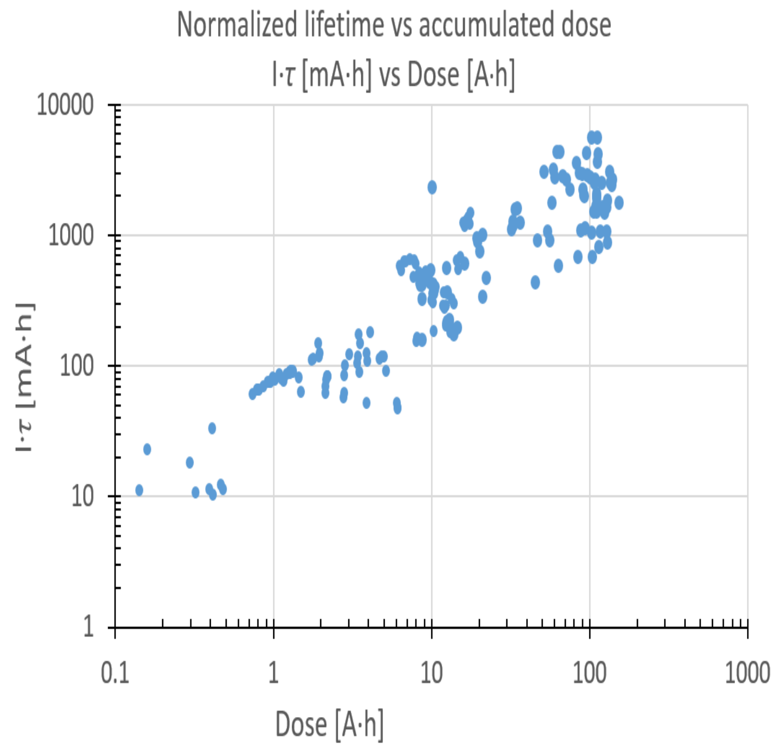
Vacuum conditioning

> 100 A.h Accumulated Dose

$I^*\tau$ >6 A.h

Normalized average pressure rise vs accumulated dose





Rest gas composition: ~ 97 % H2 ; ~ 2 % CO ; ~ 0.6 % CH4
(measured by 6 RGAs)

Plots by E. Al-Dmour