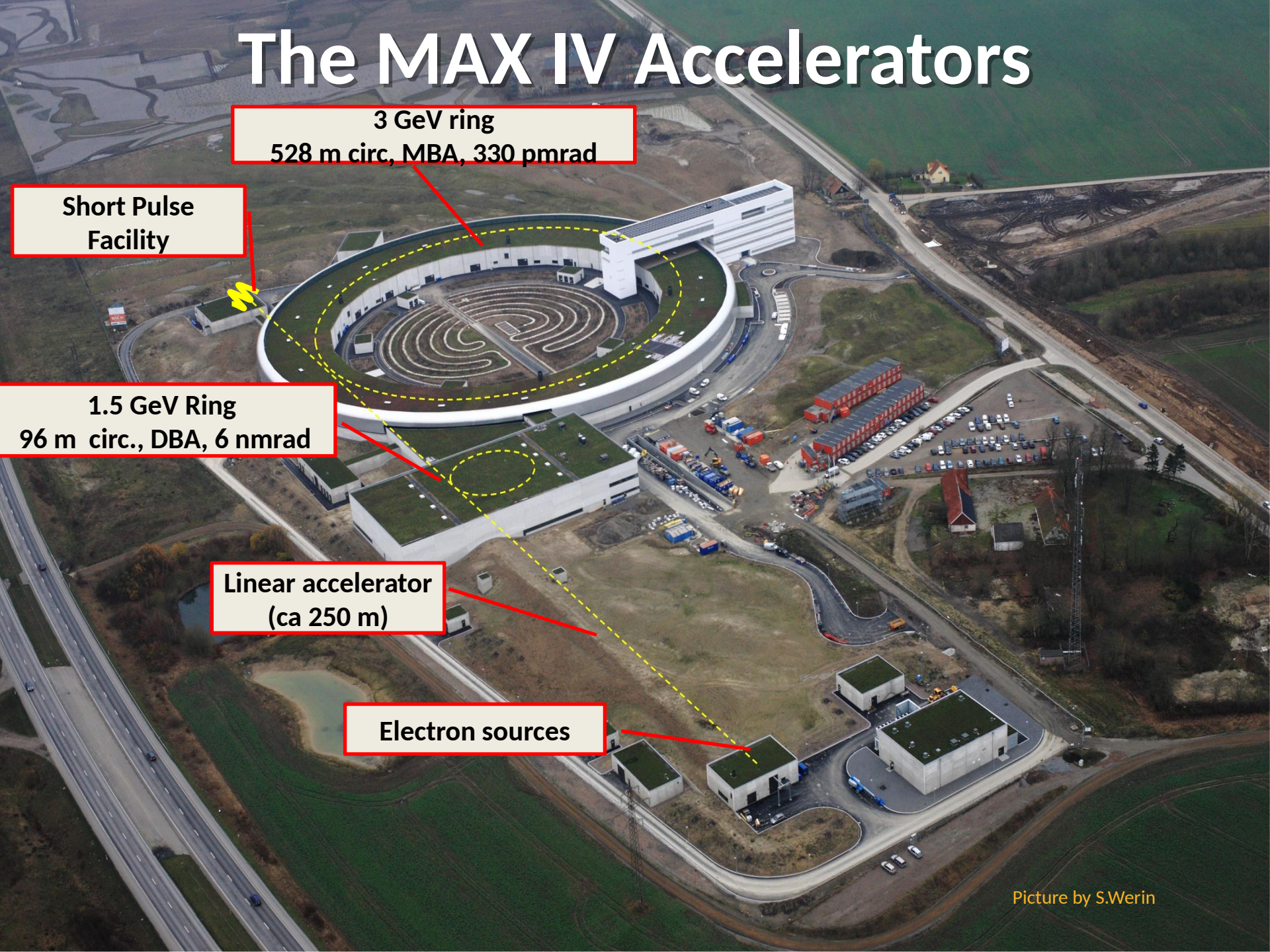
MAX IV Status Report

Magnus Sjöström on behalf of the
MAX IV team
ESLS XXV 2017-11-21

Outline

- 2017 overview
- Statistics
- Highlights
  - 3.0 GeV storage ring
  - 1.5 GeV storage ring
  - Linac
- Next year

The MAX IV Accelerators



Installations, shutdowns

2017 overview

2017 overview: linear accelerator

- Q1+Q2: mix of accelerator commissioning and beam delivery to rings & Short Pulse Facility (SPF)
- July – October in shutdown:
  - RF upgrade (2 new RF stations) to improve redundancy
  - Start-up delayed 5 weeks due to longer than expected wave-guide conditioning and a number of other issues
- Beam delivery to rings resumed in w. 45

2017 overview: 3.0 GeV ring

- Q1 focused on ID+BL installation and commissioning for 2 new beamlines → limited delivery hours for existing 3 beamlines.
- Q2 beam delivery
- July – mid-November in shutdown:
  - 3 achromat vacuum interventions (hotspots + DBL)
  - Longitudinal kicker cavity (previously striplines used)
  - Multipole kicker installation (coop. with SOLEIL)
  - Start-up delayed due to injector issues (6 days)
- Beam delivery has just resumed in w. 46 at reduced current (vacuum conditioning of new components)

2017 overview: 1.5 GeV ring

- Q1+Q2: commissioning, focus on offset, OC, LOCO.
- July – mid-November in shutdown
  - 5 narrow-gap ID chambers installed → vented 5/12 achr.
  - 3 IDs installed
- First delivery began w. 46 (delay by 2 weeks due to injector issues). First ID and BL are now in commissioning.

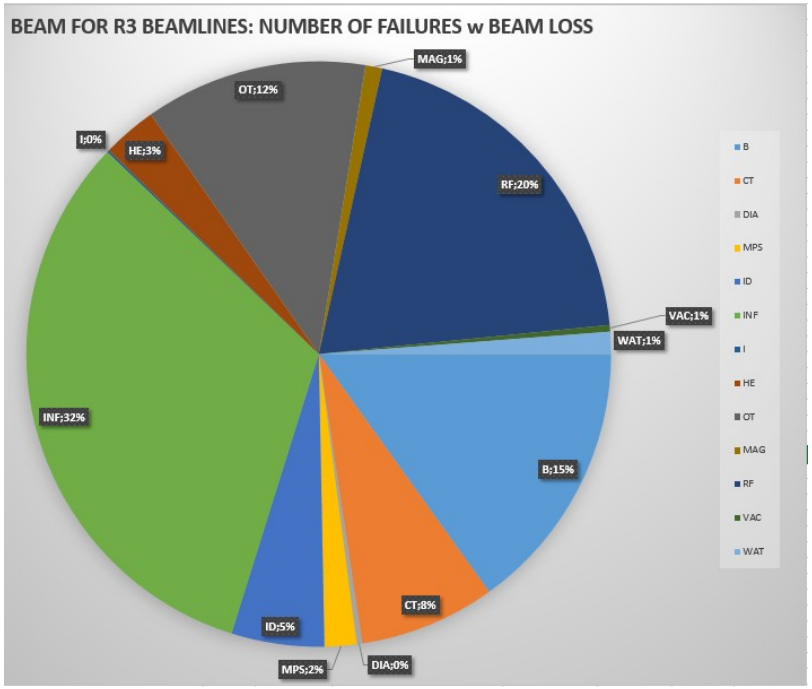
Delivery, January – June

Statistics

3 GeV ring, 1H 2017

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

Slide by Pedro F. Tavares

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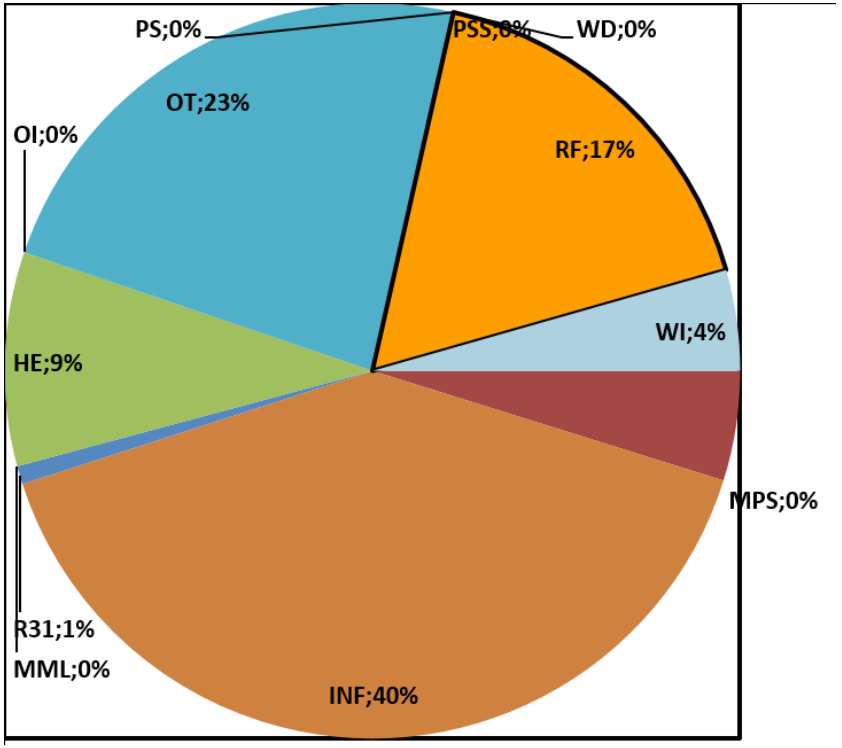
Linear accelerator, 1H 2017

Jan to June 2017

SPF delivery Hours: 764
Uptime: 90%



- Main causes of down-time:
  - Infrastructure (40%)
  - Other (mainly laser) (23%)
  - RF (17%)
- What we're doing about it:
  - New agreement with service providers
  - Implement routines
  - Rotating converter
  - RF upgrade made during summer shutdown

Slide by Sara Thorin

MAX IV

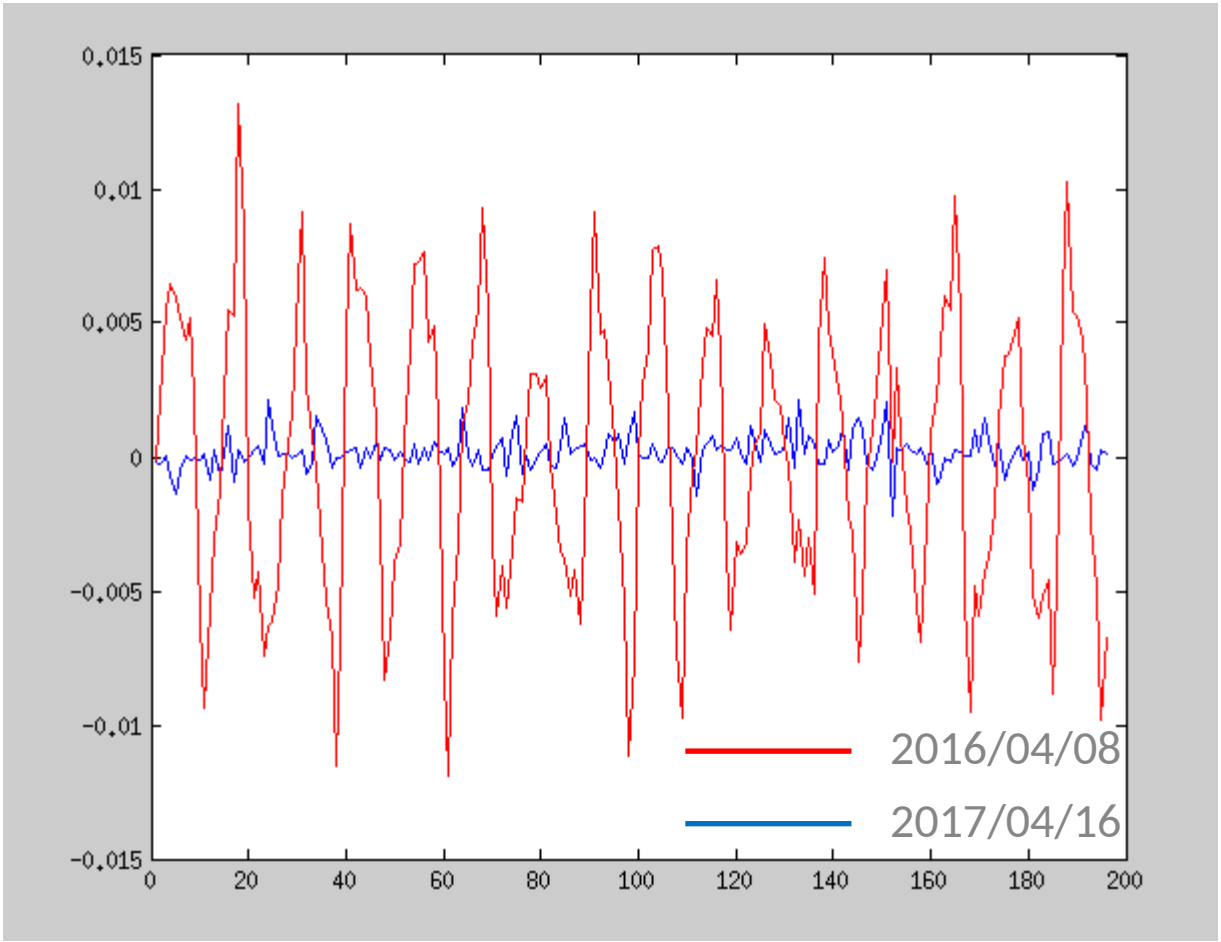
Developments and highlights

3.0 GeV storage ring

Highlights, 3 GeV ring optics

- Main part of offset measurement strangess (quad trims on sextupoles, octupoles) explained by saturation → switch off main coil during measurement. Measurements reproducible, campaigns largely automated
- LOCO now used routinely to restore linear optics, reduce vertical dispersion (skew quad trims). DIPC, DIPMC kept at nominal as these knobs are very sensitive to noise
- Coupling reduction trials with LOCO are ongoing
- First trials with non-linear optimization (RCDS)

Optics: η_y-correction



40 dispersive skew trims employed to reduce the vertical dispersion. Maximum strength is roughly half of the available.

RMS reduced from 5 mm to 0.6 mm

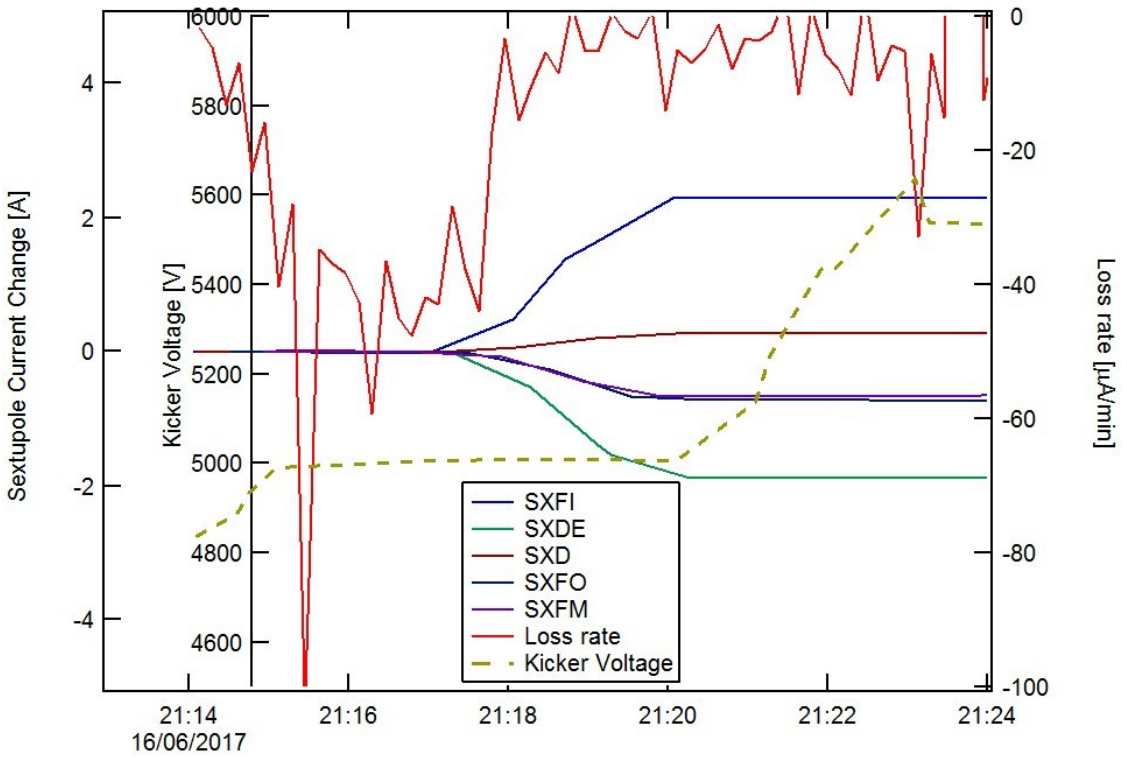
Slide by Pedro F. Tavares

Optics: Non-linear Lattice Optimization

RCDS (**Robust Conjugate Direction Search**) applied during June:

- Aim was to increase kick resilience of stored beam
- ”Chromaticity-neutral” knobs from SVD of chromaticity response matrix + octupoles (families)
- Beam loss rate while kicking the beam used as optimization parameter

Thanks to Xiaobiao Huang for providing the RCDS code

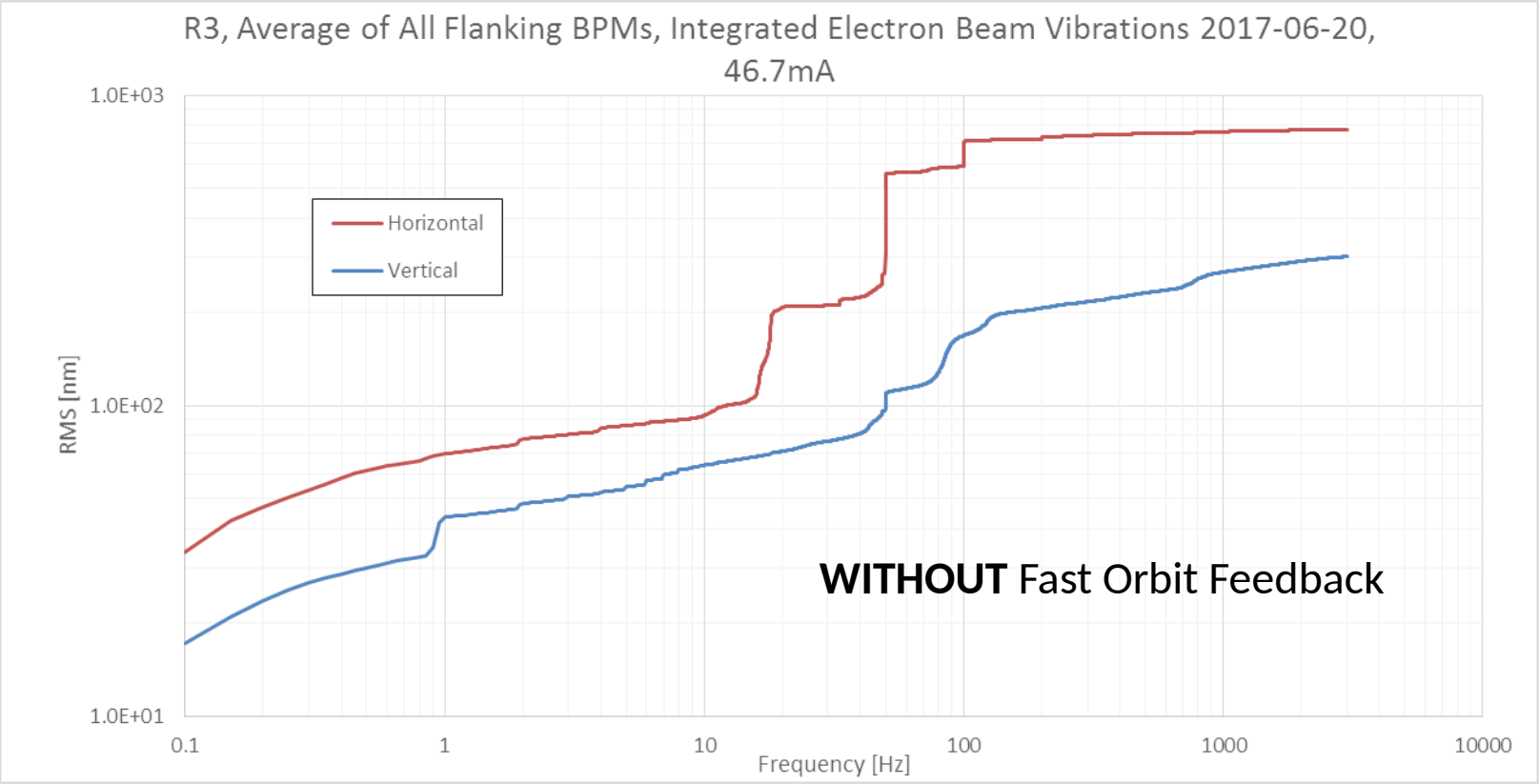


Data by M. Sjöström and D. K. Olsson

Xiaobiao Huang, Jeff Corbett, James Safranek, Juhao Wu *An algorithm for online optimization of accelerators* , NIM A 726 (2013) 77–83 .

Slide by Pedro F. Tavares

Stability: Orbit noise



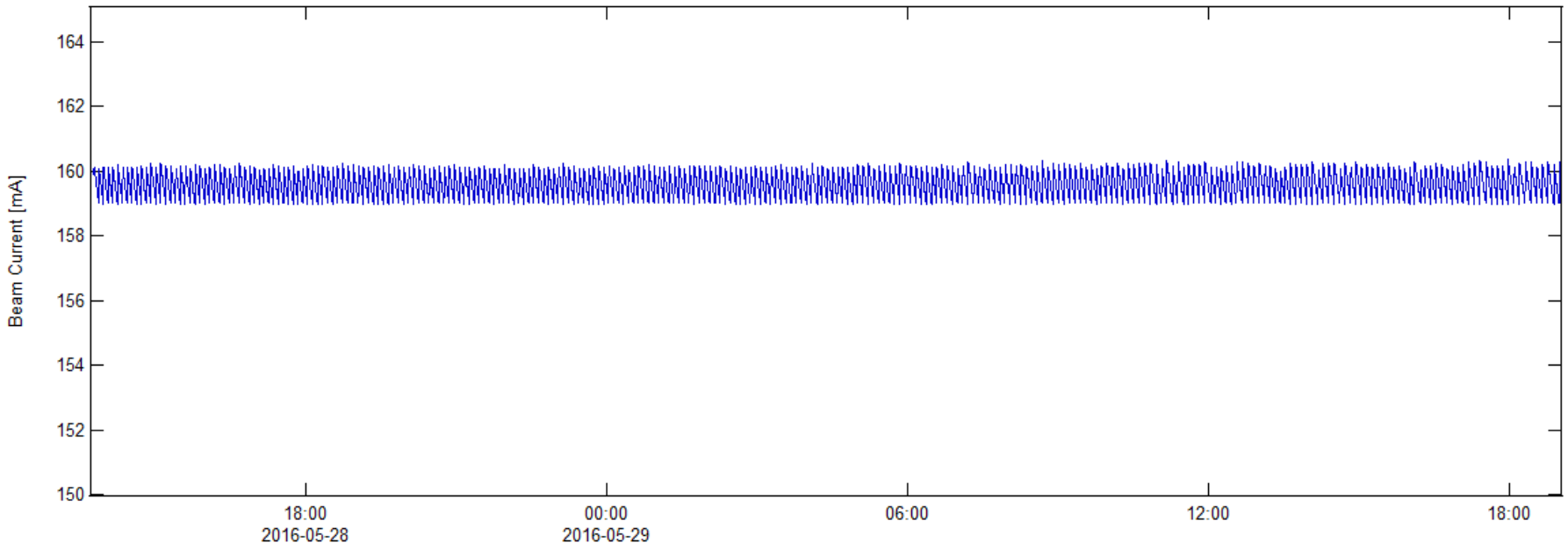
Plot By Brian Jensen

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

Injection: Top-up

- Top-up with closed shutters and open ID gaps has been running early on
- Top-up with ID gaps closed down to 4.5 mm and high injection efficiency (> 90%) May 2017
- Safety permit for top-up with open shutters given June 2017
- First beamline test during end of June 2017



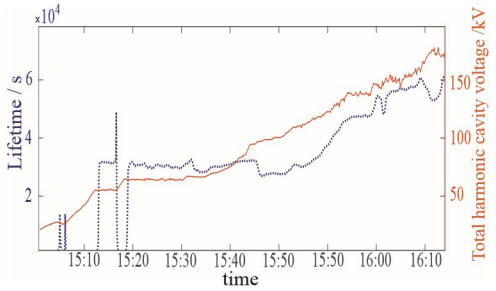
>24 hr top/up at 160 mA

Slide by Pedro F. Tavares

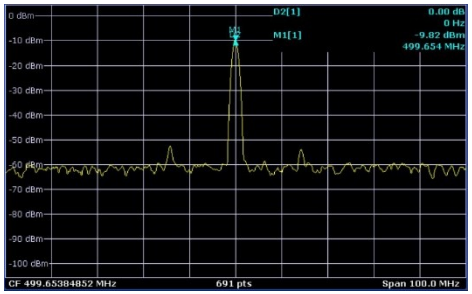
Collective Effects

- Longitudinal CBM stabilization/Lifetime Increase by use of Harmonic cavities

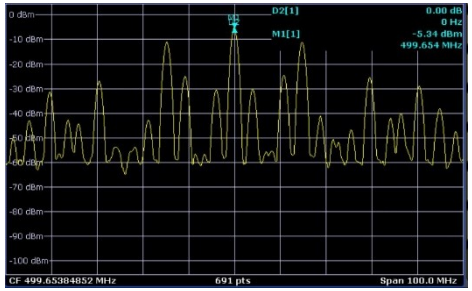
HCs tuned in- BbB feedback OFF



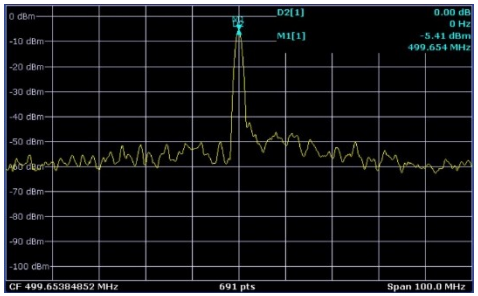
Plot by G.Skripka



46 mA

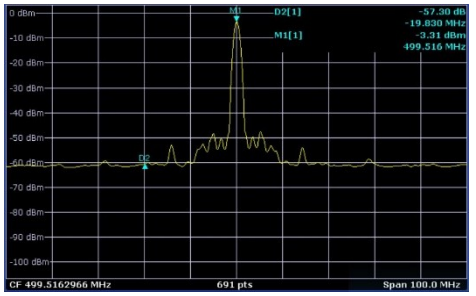


100 mA



160 mA

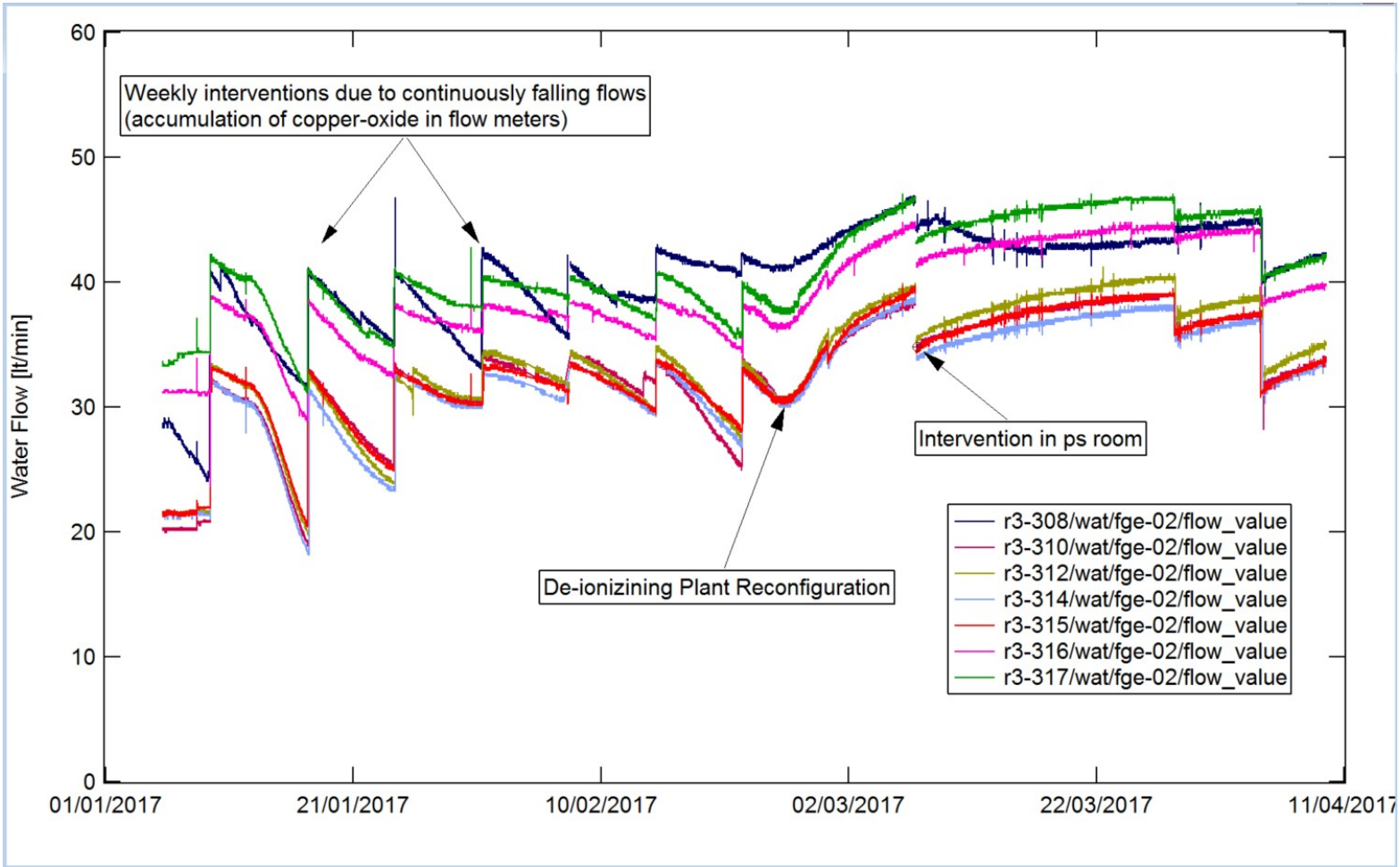
100 mA,
Landaus tuned out,
BbB feedback ON



Slide by Pedro F. Tavares

Fully Longitudinally stable beam up to 120 mA with BbB ON.

Technical issues: Chamber cooling

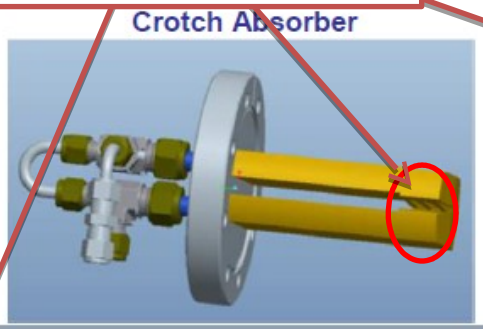


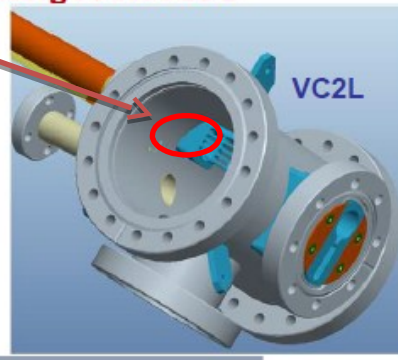
Slide by Pedro F. Tavares

Technical issues: Chamber hot spots

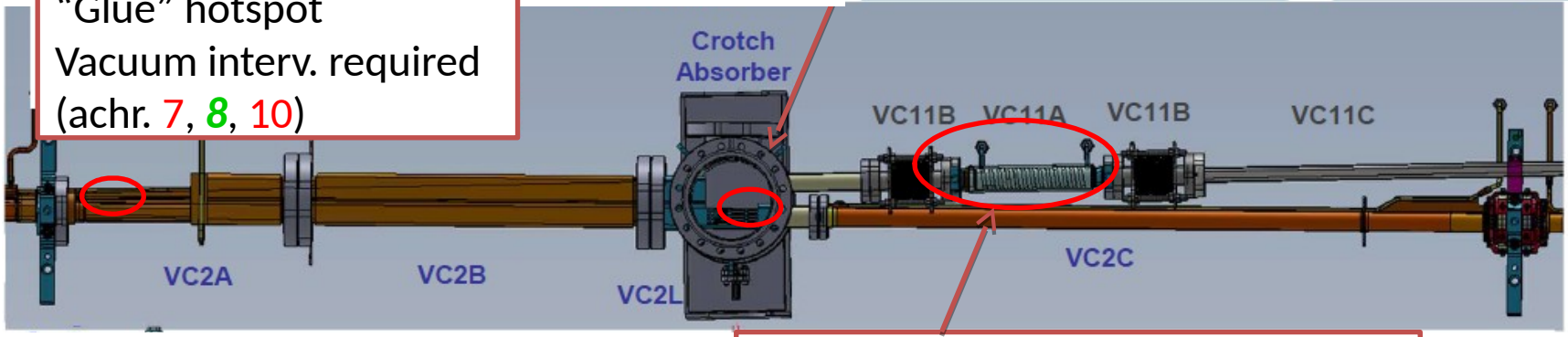
- 2 types of hotspots require vacuum intervention → 3-5 week downtime
- Ne-venting test during 2018
- Post-2017 SD max. current should be ~190 mA, to be verified!

Crotch absorber hotspot
Vacuum interv. required
(achr. 4, 10, 18)



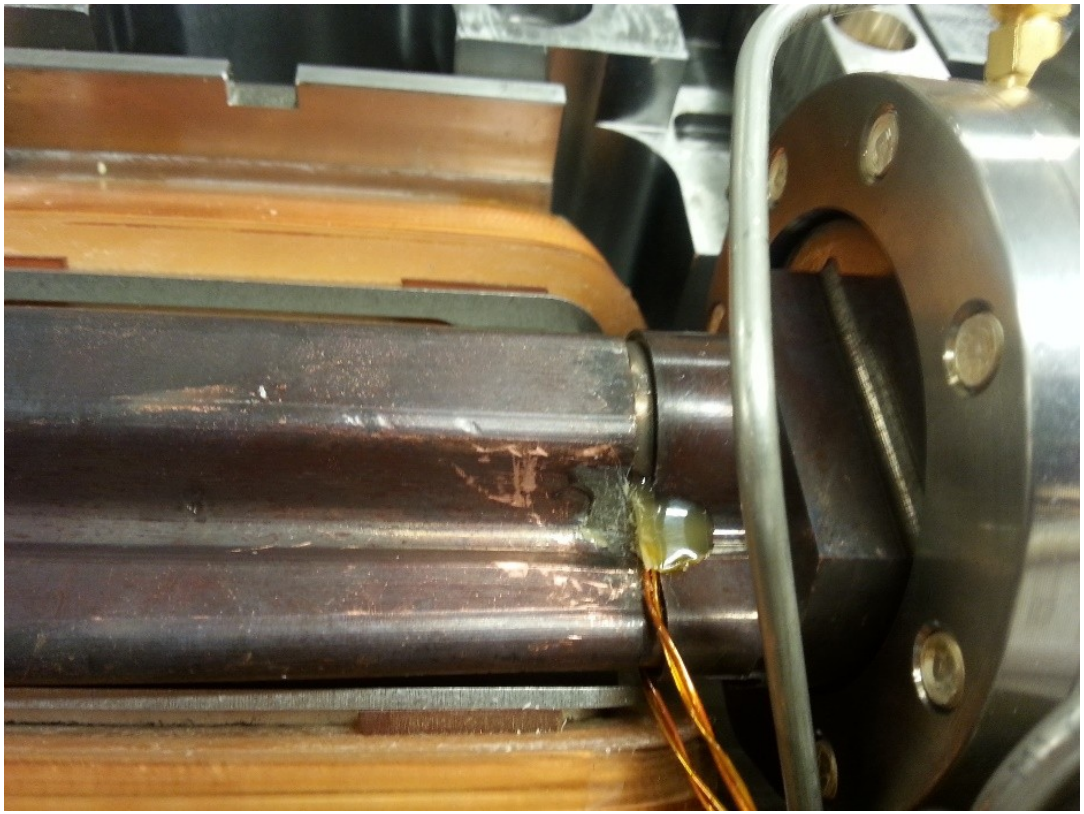


"Glue" hotspot
Vacuum interv. required
(achr. 7, 8, 10)



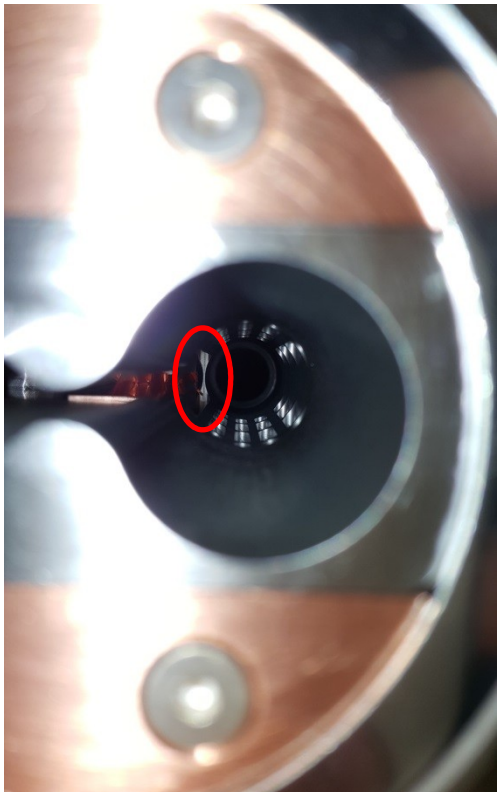
Photon pipe hotspot
(solved during maintenance stops)

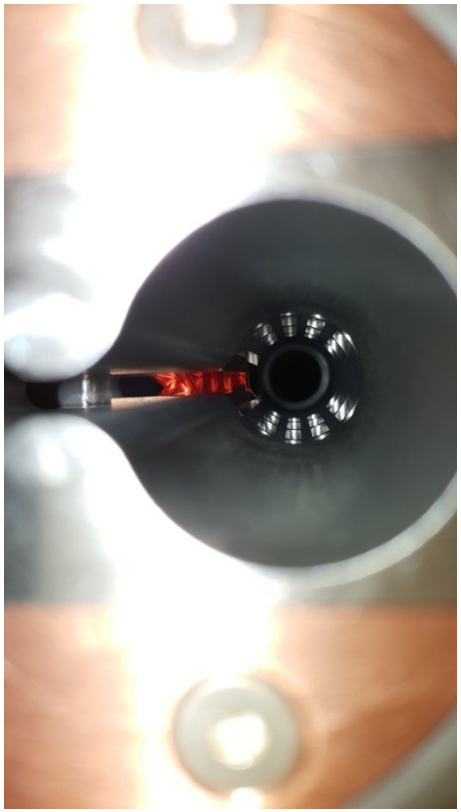
Technical issues: Chamber hot spots



In Achr. 8 M1, a chamber was compressed by thermocouple glue in the wrong place. Chamber replaced during shutdown. Dipole SR heating issue solved, tests underway with ID SR heating.

Technical issues: Chamber hot spots





In Achr. 4 S1 the crotch absorber did not properly shadow the e-beam exit pipe (stainless steel). Solved by installing a longer crotch absorber.

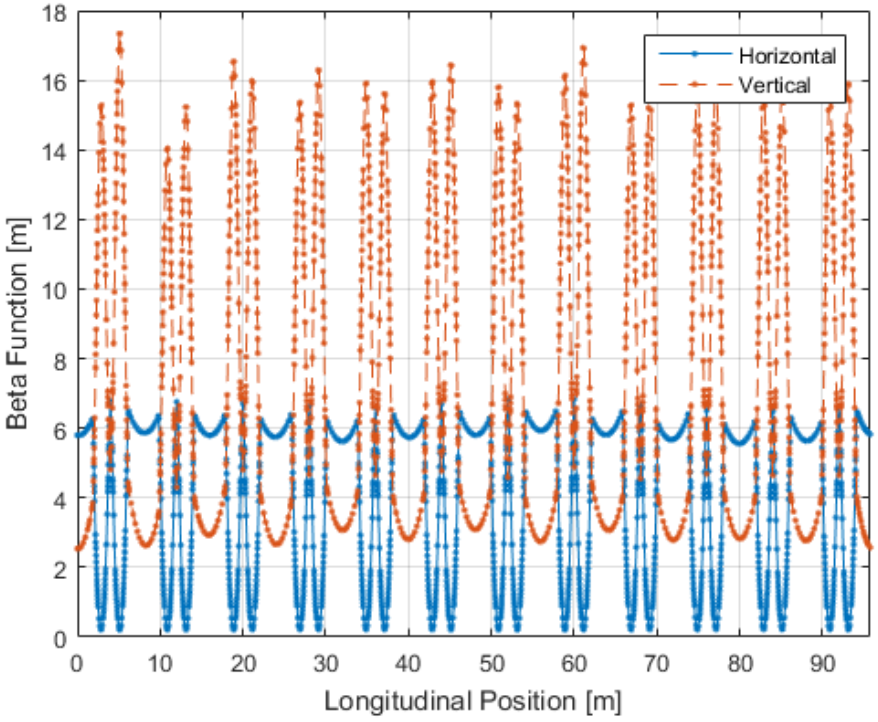
Developments and highlights

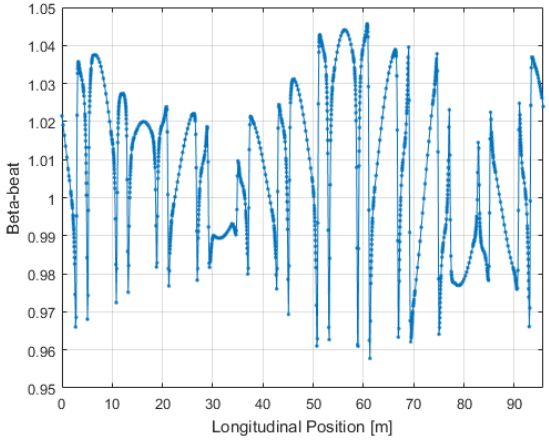
1.5 GeV storage ring

Current status

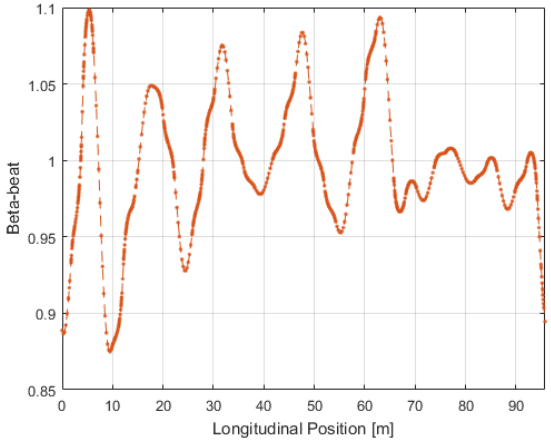
- Achieved multibunch current:
  - 91 mA → 262 mA @ 2017-05-24
  - Longitudinally stable beam at 170 – 175 mA using passive Landau cavities (inspection of rotation bands)
- Optics:
  - Offset measurement method benchmarked
  - Orbit correction able to lock down long straights, vertical orbit deviations in achromat interior. Sufficient for BL commissioning, further work on hold until magnet shunting performed.
  - LOCO deployed but only for families, no individual magnet shunting yet performed (analysis done, awaiting hardware)
- New installations during summer SD:
  - 5 narrow gap chambers + 3 IDs
  - ID + BL commissioning of FinEstBeams started w. 46
  - Delivery until w. 50, 4th ID to be installed w. 51

Highlights: Optics





Horizontal beta-beat



Vertical beta-beat

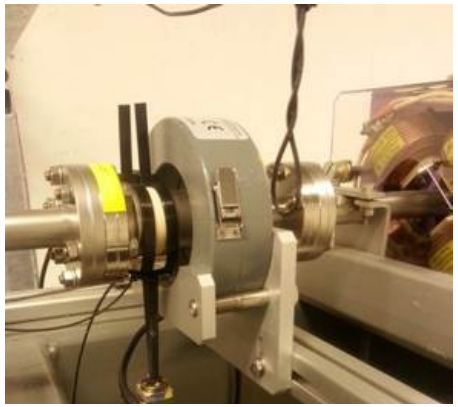
Offset + LOCO measurements done
Family-level correction applied
Beat correction remains (shunt boards)

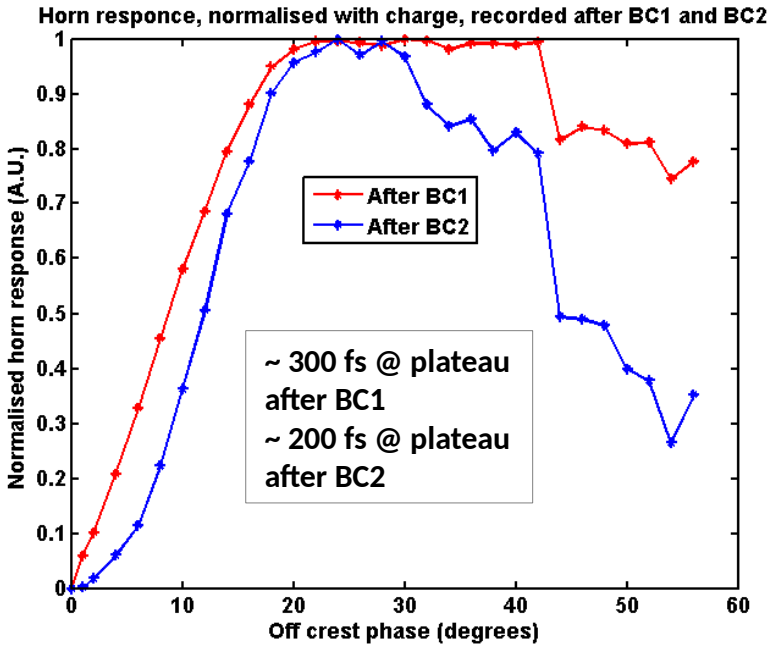
Developments and highlights

Linear accelerator

Highlights: Bunch length

- Bunch length measurements with horn antennas at a ceramic gap after each bunch compressor indicate that parts of the bunch reach below 200 fs after BC2.





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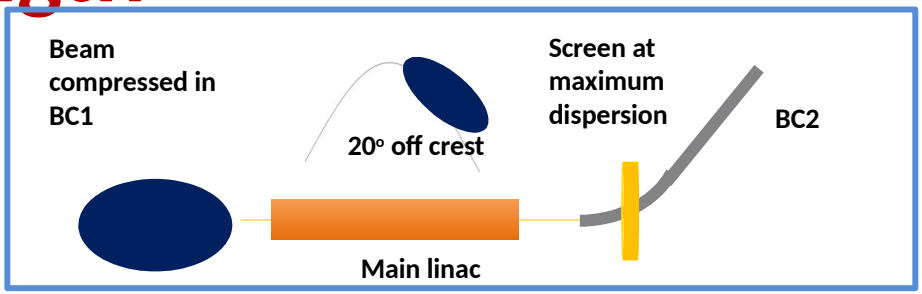
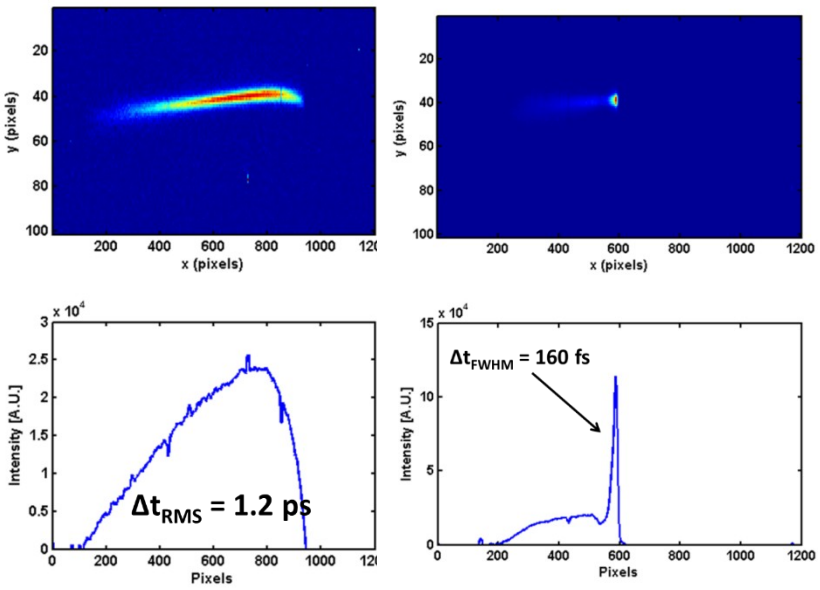


- Longitudinal profile measurement with variant of the zero-crossing method showed bunch length in the peak of 160 fs



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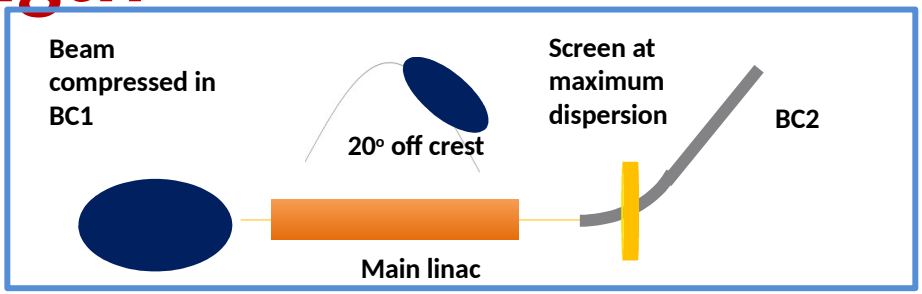
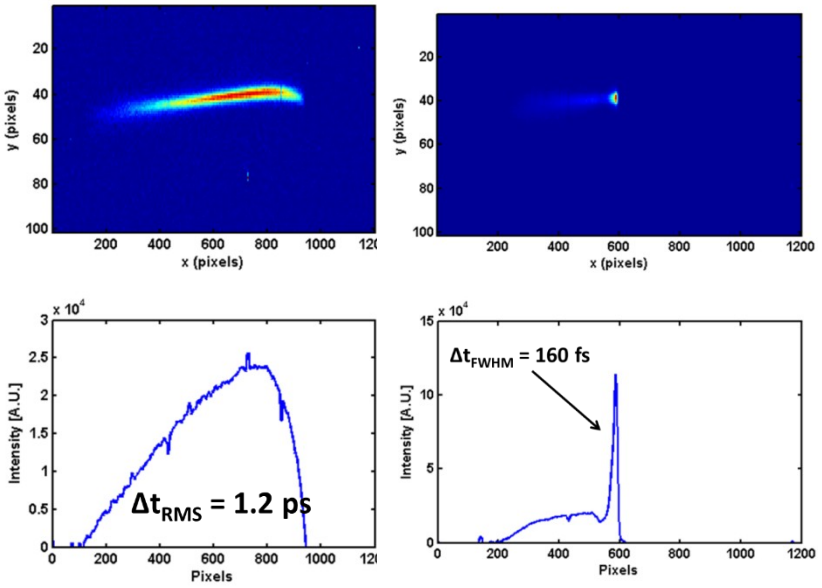




In order to deliver 100 fs, need to be able to measure accurately! Transverse Deflecting Cavity planned for 2019

The near future

Outline 2018

Outline 2018: storage rings

- 3 GeV ring:
  - Continued vacuum interventions:
    - Reinstalling cavity 19
    - Further hot spot fixes to enable I_b > 250 mA
    - Ne-venting test (June)
    - 2 IVUs (DANMAX, COSAXS)
    - 1 ID with chamber (SoftiMAX)
  - Non-linear optics optimization
  - Commissioning of Multipole Injection Kicker (MIK), long. kicker
  - Delivery with stretched bunches / current increase
  - COSAXS, SoftiMAX commissioning
  - Fast orbit feedback
- 1.5 GeV ring
  - ID + BL commissioning of 4 beamlines during Q1-Q2
  - 5th ID installation (May) and commissioning
  - First external users

Outline 2018: Linear accelerator

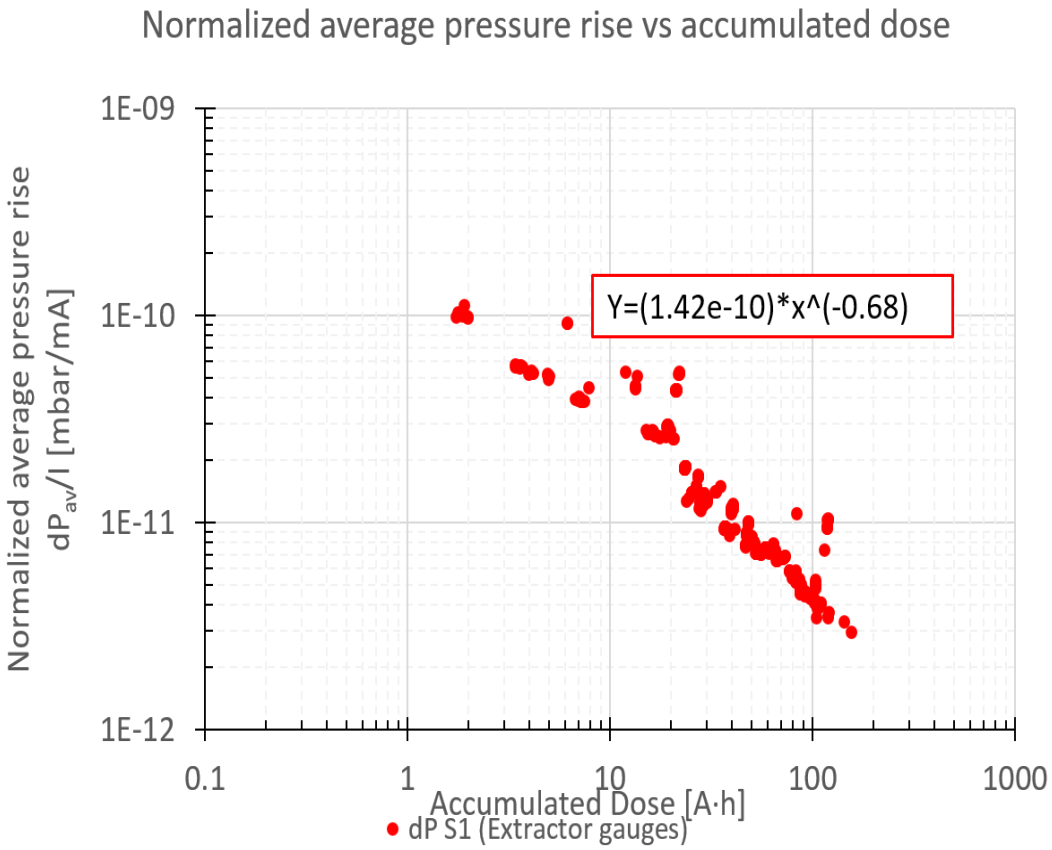
- Measure and deliver 100 fs
- Design and construct a transverse deflecting cavity for longitudinal phase space measurements
- Design and construct a 100 Hz, low emittance Photo cathode gun. To be tested in the Gun Test Facility.
- 10 Hz rep rate for injection and SPF
- Characterization of bunch compressors
- Longitudinal beam shaping (laser, electron bunches, double bunches etc)
- CDR for a Soft X-ray FEL funded
- Build in redundancy for the Main Drive Line to be able to run the main linac without RF section 2.

Thank you for your attention!

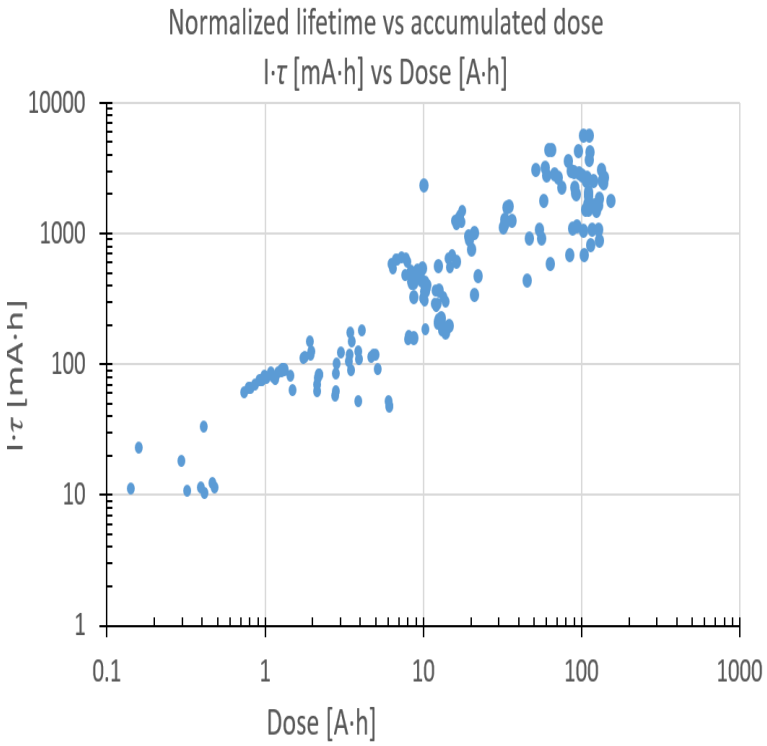
Extra slides

Vacuum conditioning

> 100 A.h Accumulated Dose



I*τ >6 A.h



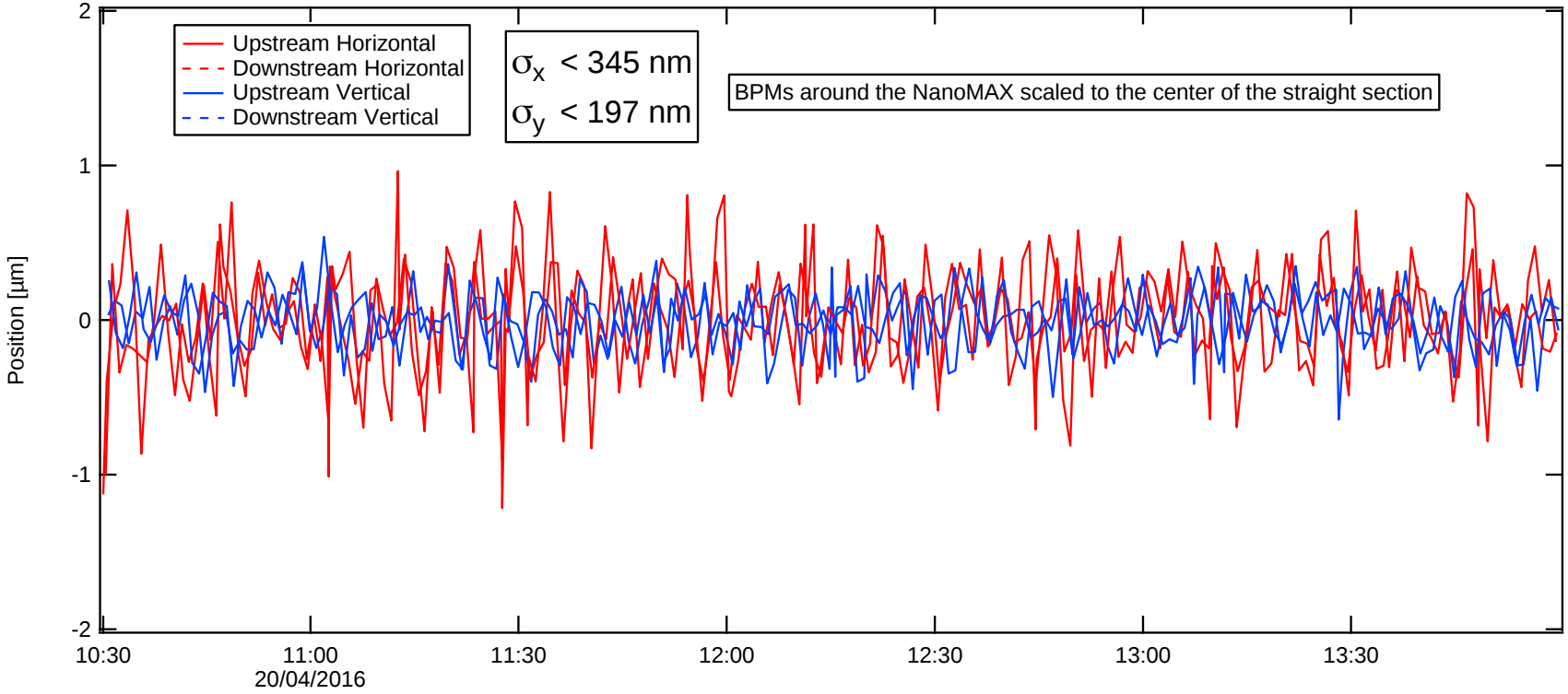
Rest gas composition: ~ 97 % H2 ; ~ 2 % CO ; ~ 0.6 % CH4
(measured by 6 RGAs)

Plots by E. Al-Dmour

Stability: Orbit, Long Term

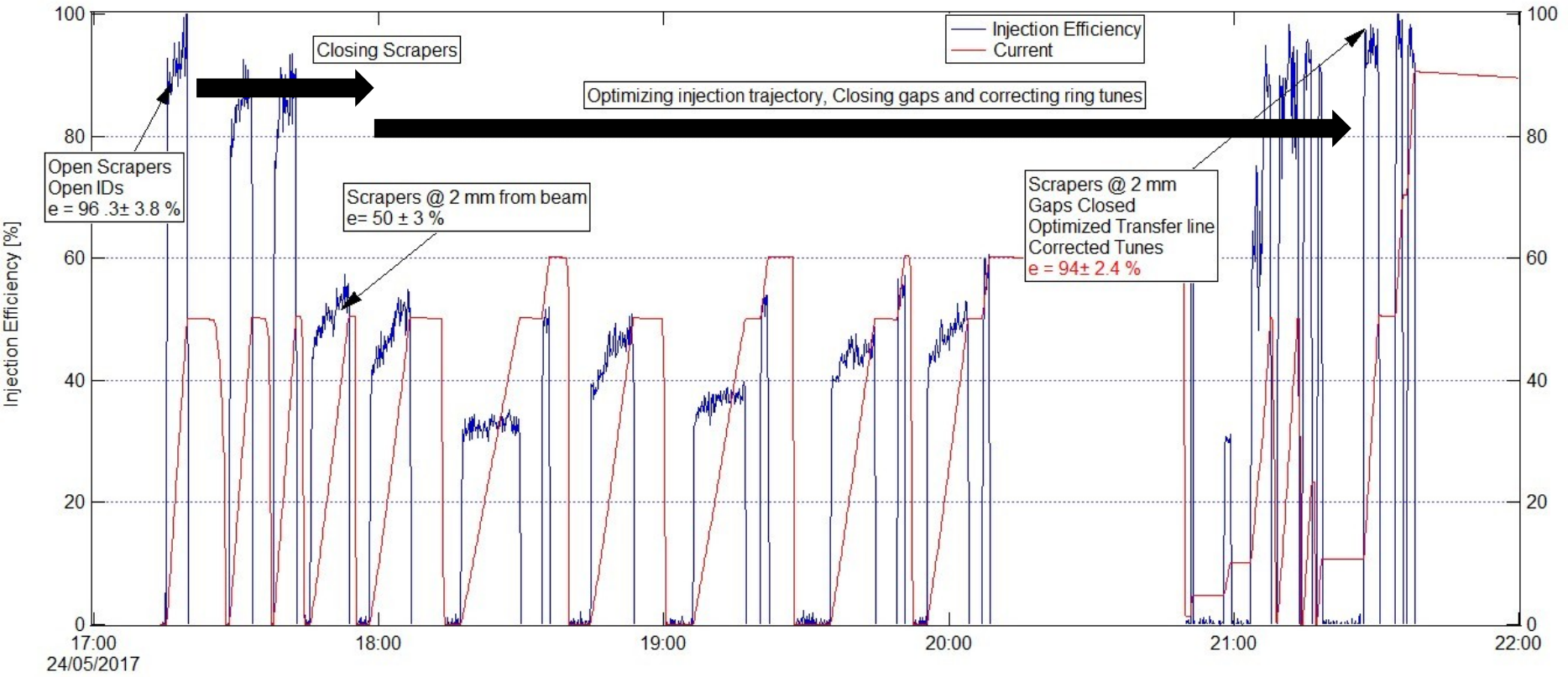
RMS beam sizes at source points
- Horizontal: 47 µm
- Vertical: 2 µm

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



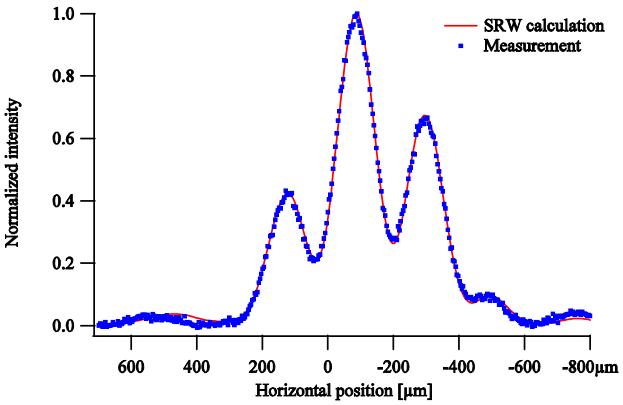
Slow Orbit feedback ON

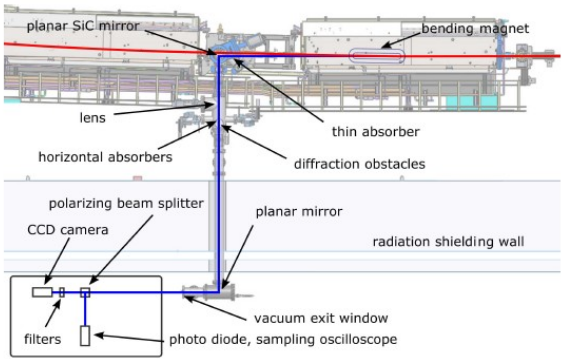
Injection: closed ID gaps



- 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.

R3: Emittance Measurement

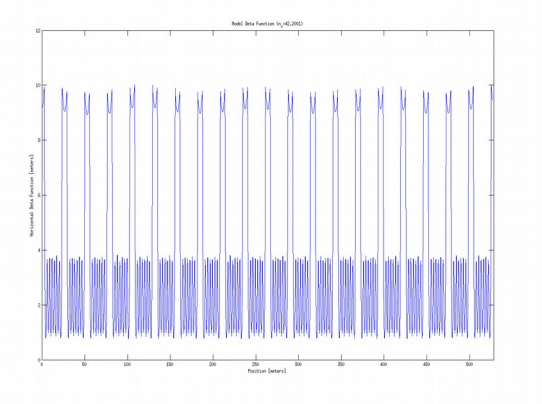




σ_x = 20.86 ± 0.14 μm (fit uncertainty)
σ_y = 15.70 ± 0.15 μm (fit uncertainty)

B320B diagnostic beamline
(visible SR radiation)

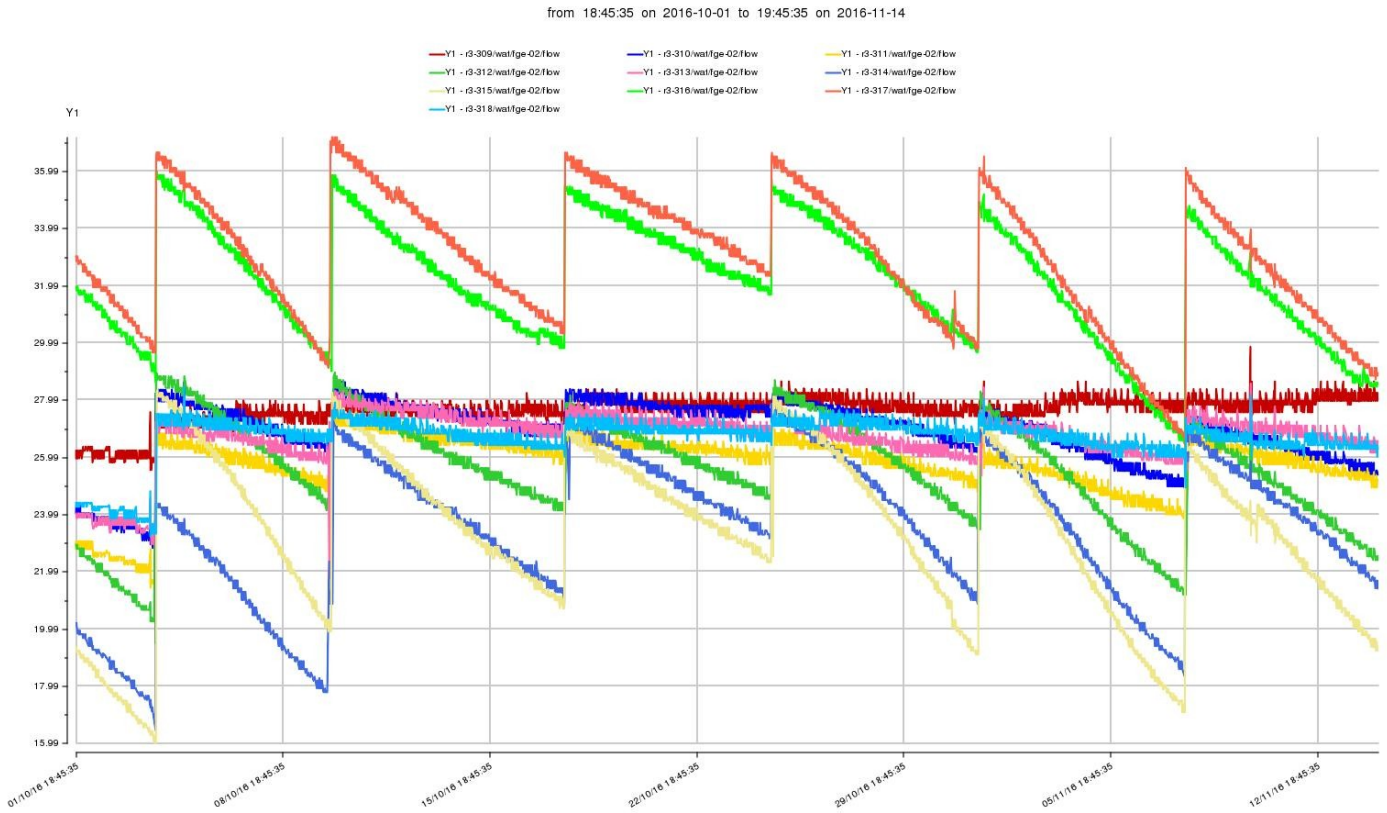
Figures by J. Breunlin and Å. Andersson



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

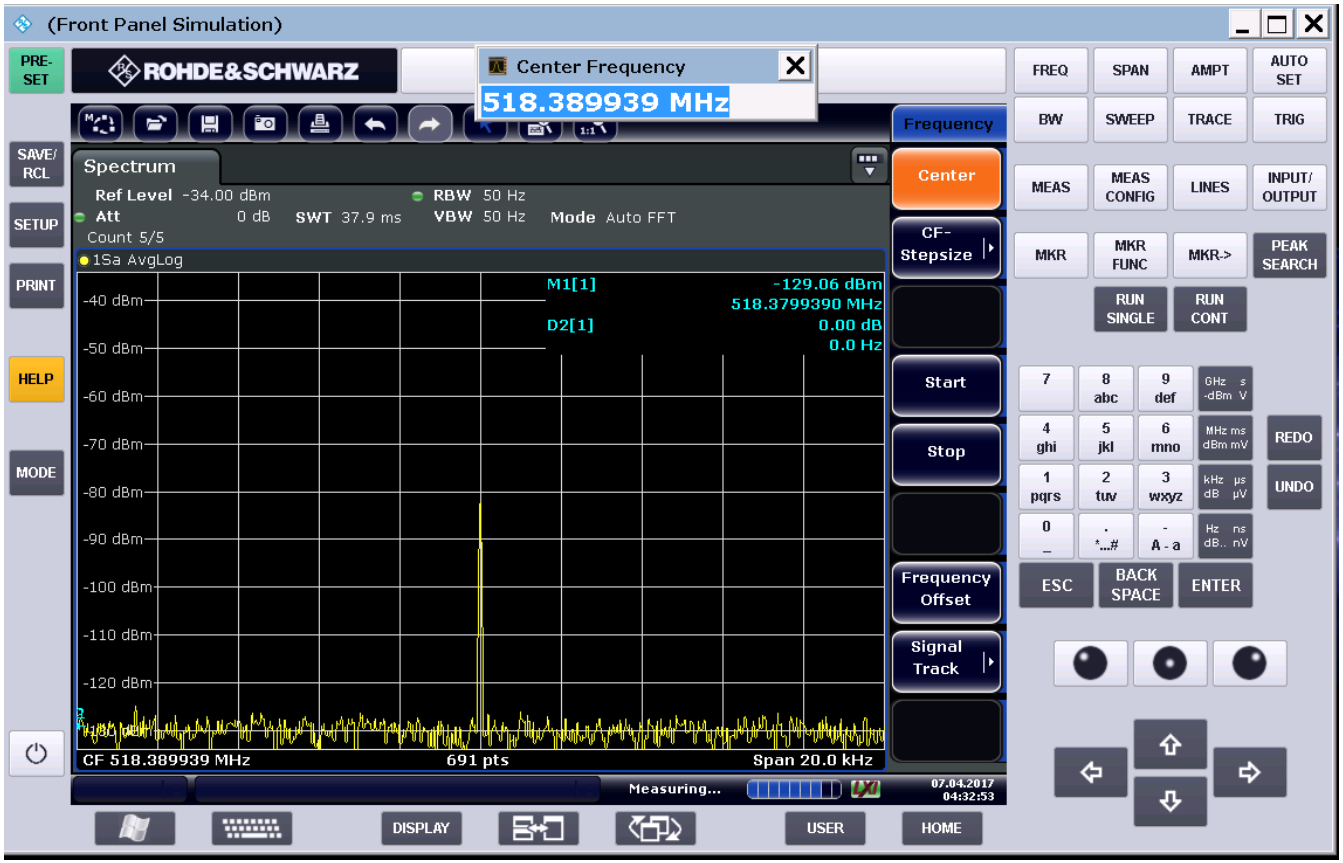
Assuming no significant modelling errors in either B320B optics or the AT lattice, emittances can be computed:
ε_x=339.4 ± 7.1 pm.rad
ε_y=15.7 ± 0.3 pm.rad

Technical issues: Chamber cooling



55C02 cooling circuit, vacuum chamber flows during 2016-10-01 -- 2016-11-16 period. N_2 bubbling active entire time period; new water added 2016-10-25 during installations.

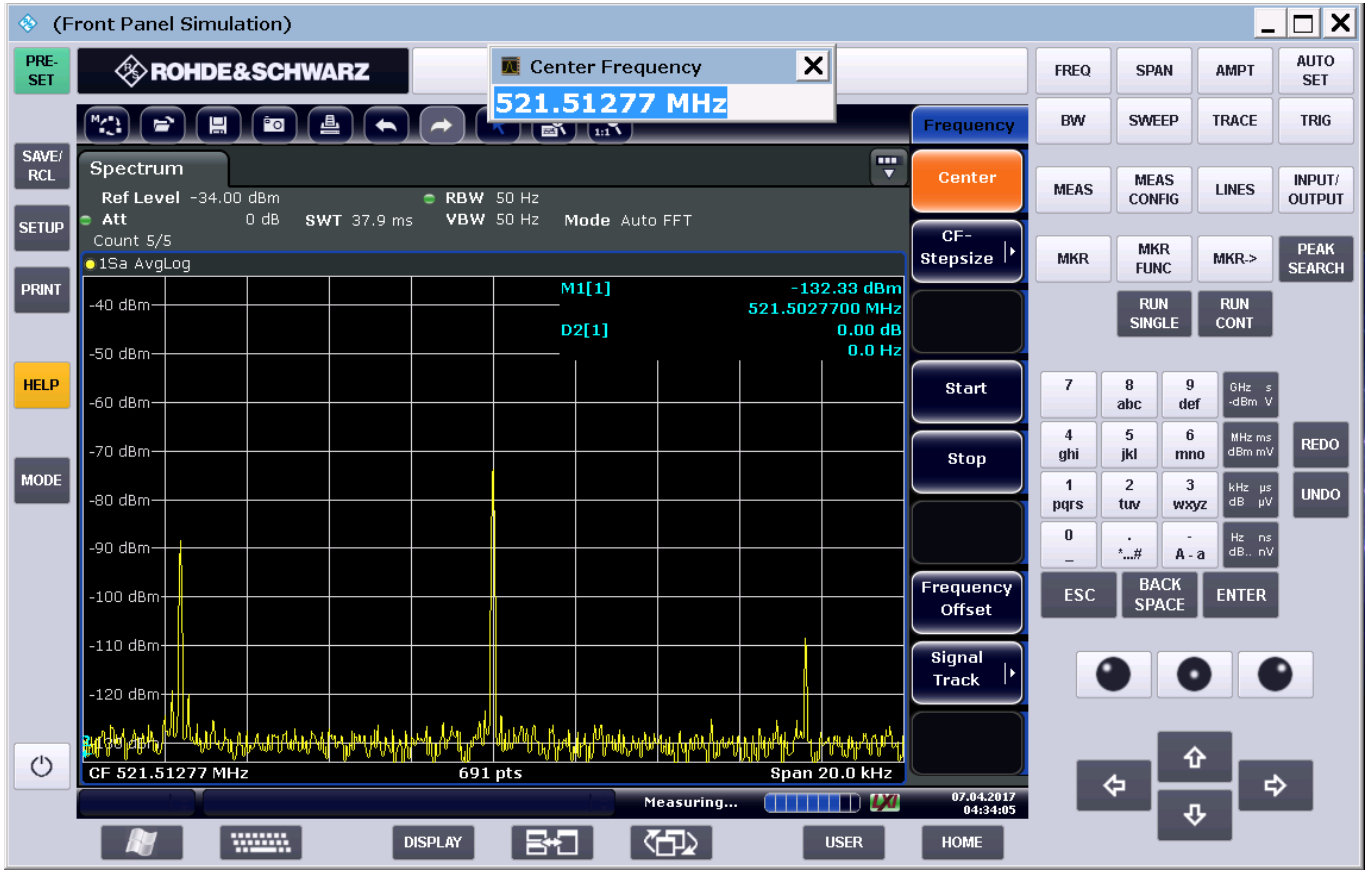
Harmonic cavities



Typical rotation band: fill apparently slightly uneven, no trace of sidebands

Figures by Å. Andersson

Harmonic cavities



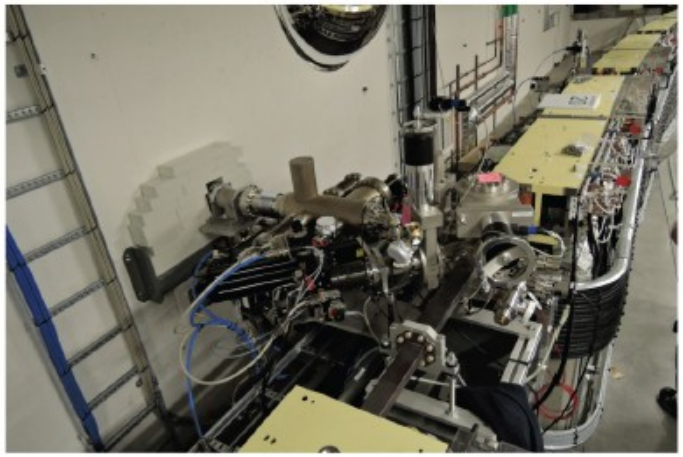
2 rotation bands had weak 2nd order synchrotron sidebands

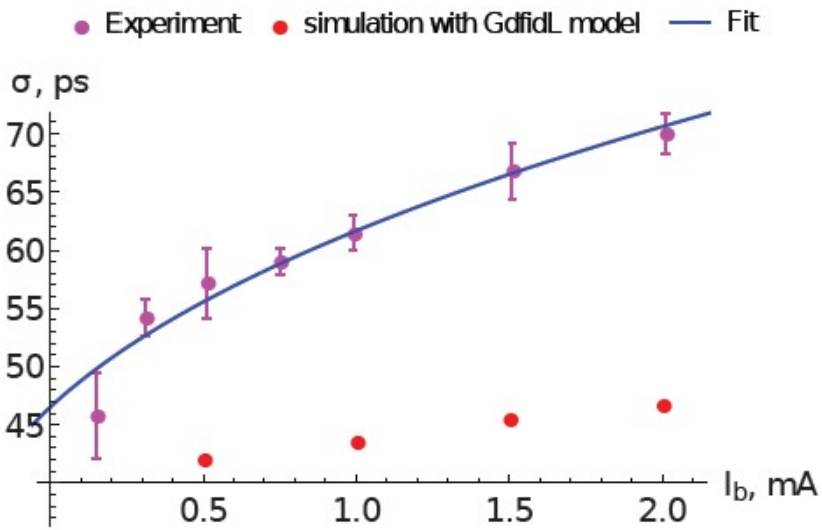
Figures by Å. Andersson

Longitudinal

- Diagnostics beamline taking synchrotron radiation from a dipole bending magnet
- Effective impedance from simulation about 2 times smaller than estimated from measurement
- 6 GHz resonator fit to reproduce lengthening:
  - Shunt impedance = 732 Ω
  - Quality factor = 1

Beam line inside ring tunnel

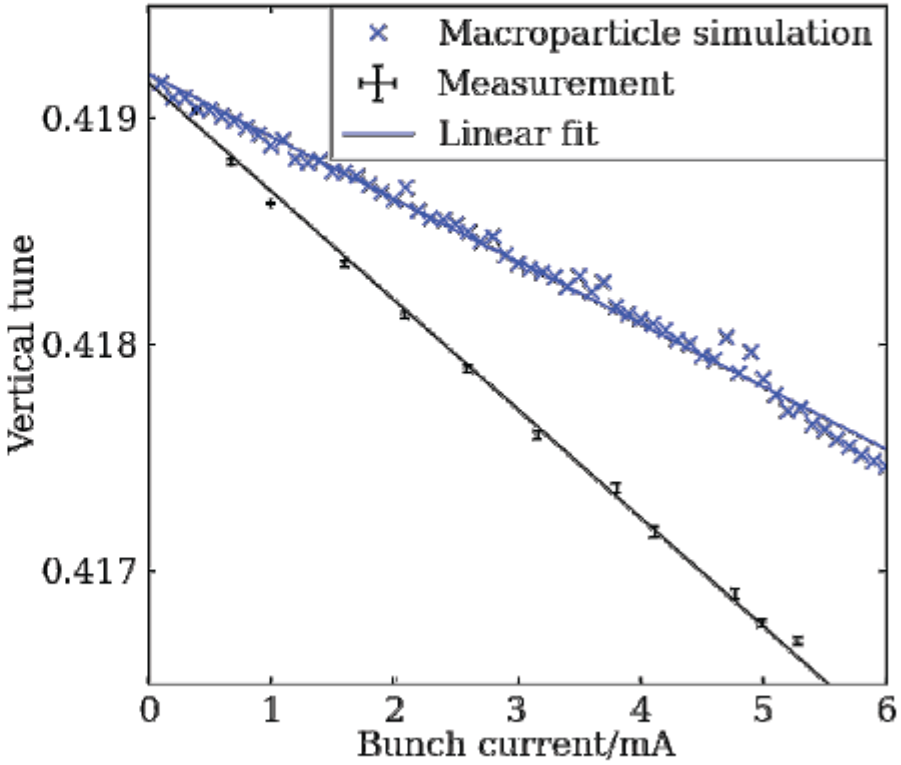




Slide by F. Cullinan (NAPAC 2016)

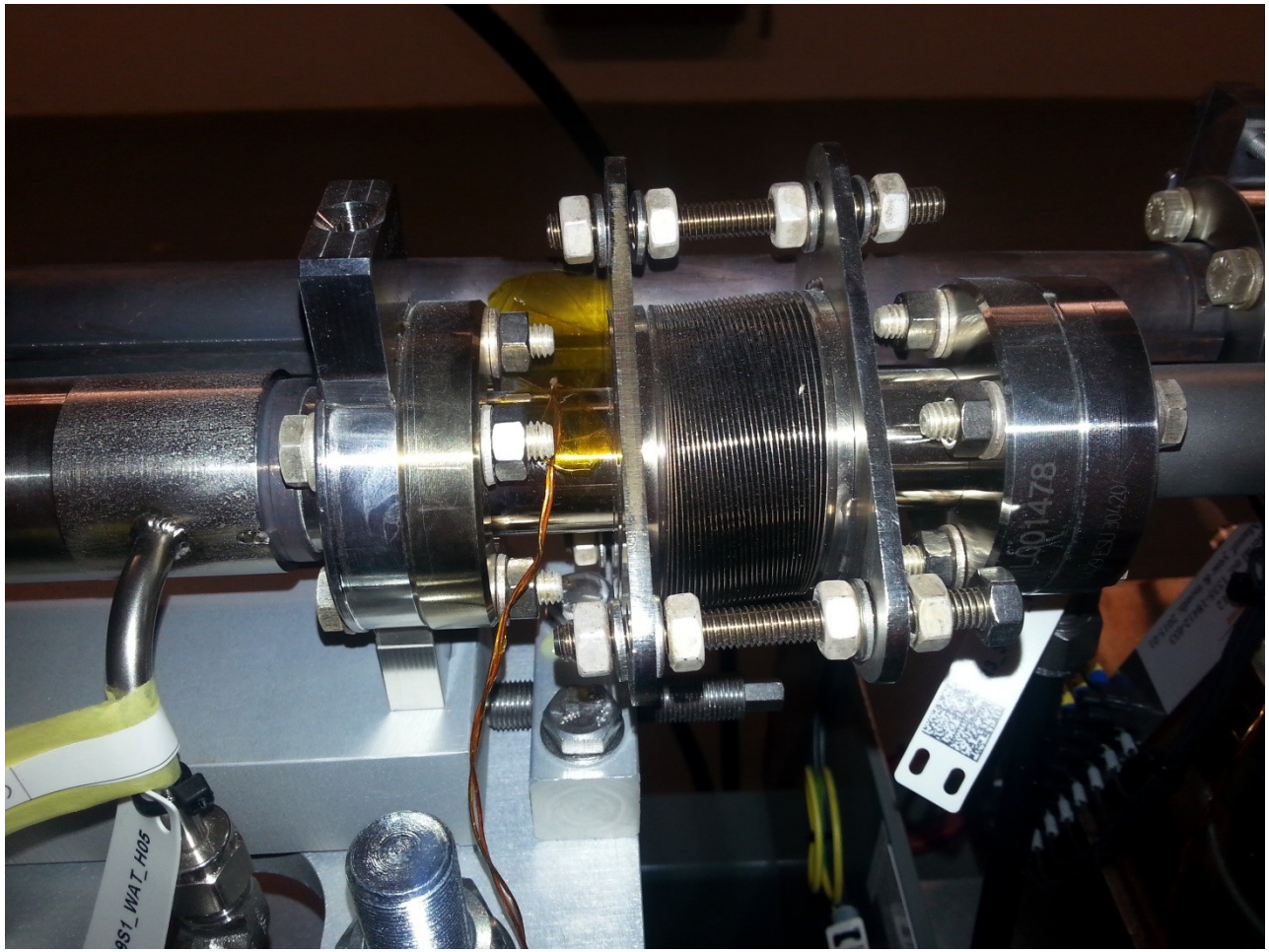
Single-Bunch Transverse

- Close to zero chromaticity
- Vertical tune shift with bunch current measured using turn-by-turn BPM data
  - Detuning: -0.481±0.002 A^{-1}
- Detuning about a factor of 1.8 larger than predicted in simulation
  - Similar discrepancy to longitudinal plane
- No clear signs of TMCI such as hard limit on injection or sudden beam loss
  - Simulation predicts threshold of 5.5 mA



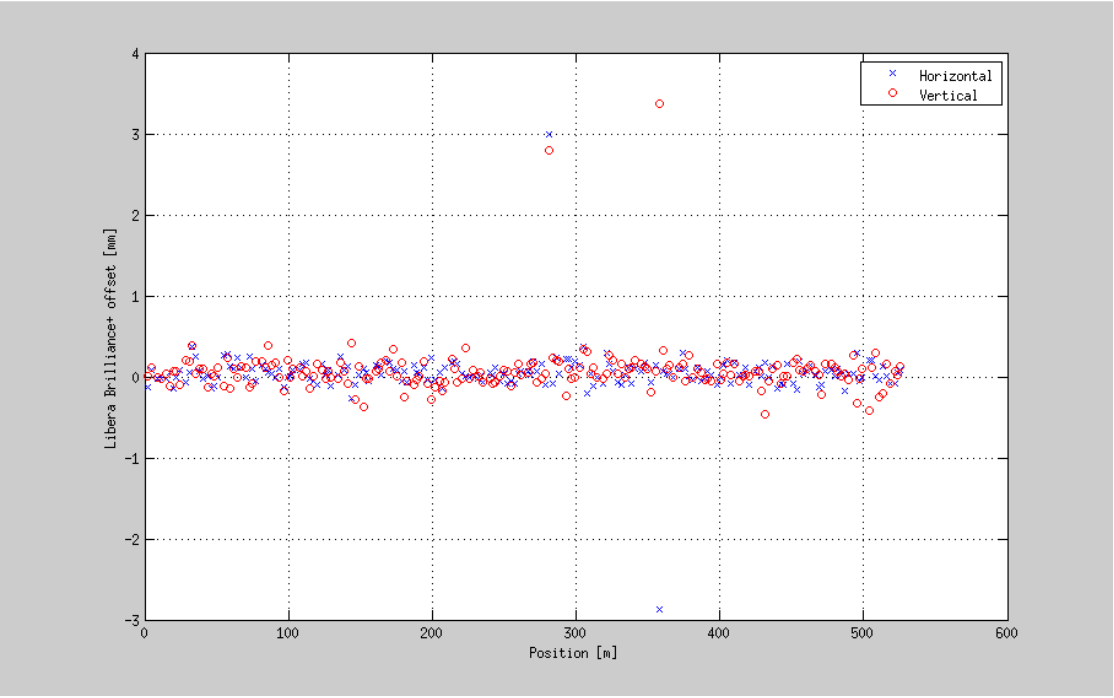
Slide by F. Cullinan (NAPAC 2016)

Chamber hot spot
R3_309S1/DIA/TCO-01



Offsets

- Measured by BBC using trim coils in sextupole magnets



RMS:
113 µm H
143 µm V