Status of the MAX IV accelerators

Magnus Sjöström on behalf of the MAX IV staff

ESLS XXVI 2018-11-27

MAX IV

Outline

- 2018 overview
- Statistics
- Highlights
  - 3.0 GeV storage ring
  - 1.5 GeV storage ring
  - Linear accelerator
- Next year

The MAX IV Accelerators

Installations, shutdowns

2018 overview

Recap of “Outline 2018: 3 GeV ring”

Shown at ESLS XXV in Dortmund:

- Continued vacuum interventions:
  - Reinstalling cavity 19 *(cavity conditioned in test stand, installation postponed)*
  - Further hot spot fixes to enable I_b > 250 mA *(done)*
  - Ne-venting test (June) *(done, successfully completed)*
  - 2 IVUs (DANMAX, COSAXS) *(COSAXS: FE+ID installed; DANMAX: FE installed, ID installation planned for summer 2019)*
  - 1 ID with chamber (SoftiMAX) *(chamber + FE installed; ID installation planned for w. 50)*
- Non-linear optics optimization (*for results, see David K. Olsson, “Online optimisation of the MAX IV 3 GeV ring dynamic aperture”, IPAC2018, Vancouver, BC, Canada*)
- Commissioning of Multipole Injection Kicker (MIK), long. kicker *(done)*
- Delivery with stretched bunches / current increase *(done)*
- COSAXS, SoftiMAX commissioning *(delayed)*
- Fast orbit feedback *(PS procured, limited test installation ongoing with first system tests in 2019)*

Additionally:

- *Coupling loop adjustment on other 5 cavities, $\beta = 2 \rightarrow \beta = 4.3$)*

Recap of "Outline 2018: 1.5 GeV ring"

Shown at ESLS XXV in Dortmund:

– ID + BL commissioning of 4 beamlines during Q1-Q2
– 5th ID installation (May) and commissioning
– First external users

Achieved:

– BLOCH, FinEstBeams currently in commissioning
– IDs and front-ends installed for MAXPEEM, SPECIES, FlexPES
– FinEstBeams received commissioning users

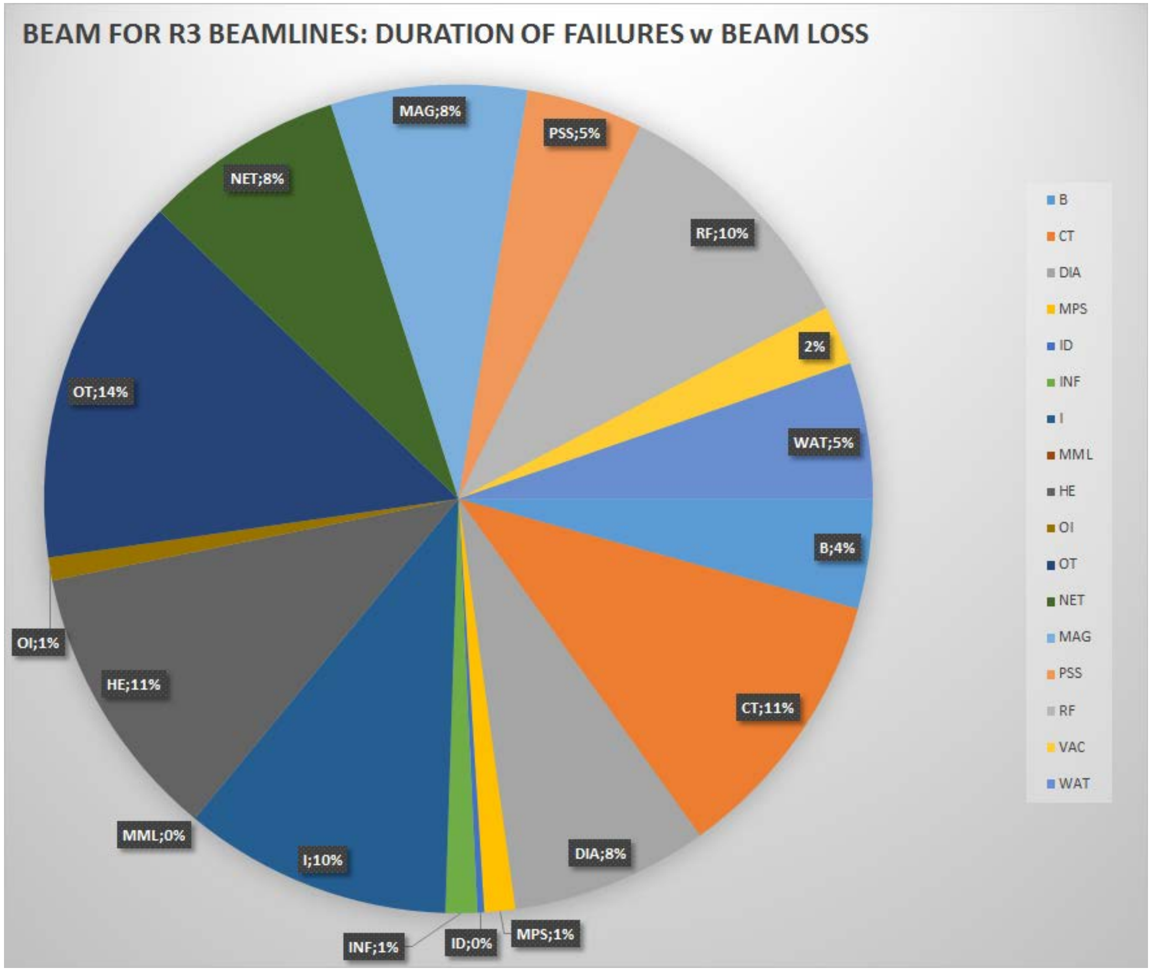
Recap of “Outline 2018: Linear accelerator”

- Measure and deliver 100 fs *(sub-100 fs verified after 1st BC)*
- Design and construct a transverse deflecting cavity for longitudinal phase space measurements *(ongoing)*
- Design and construct a 100 Hz, low emittance Photo cathode gun. To be tested in the Gun Test Facility. *(construction ongoing; GTF installation complete; rad. safety permit pending)*
- 10 Hz rep rate for injection and SPF *(rad. safety permit pending)*
- Characterization of bunch compressors *(polarity error discovered!)*
- Longitudinal beam shaping (laser, electron bunches, double bunches etc) *(proof-of-concept experiments performed for double bunches, laser shaping)*
- CDR for a Soft X-ray FEL funded *(work ongoing)*
- Build in redundancy for the Main Drive Line to be able to run the main linac without RF section 2 *(conceptual design ongoing)*

Delivery, January – November

Statistics

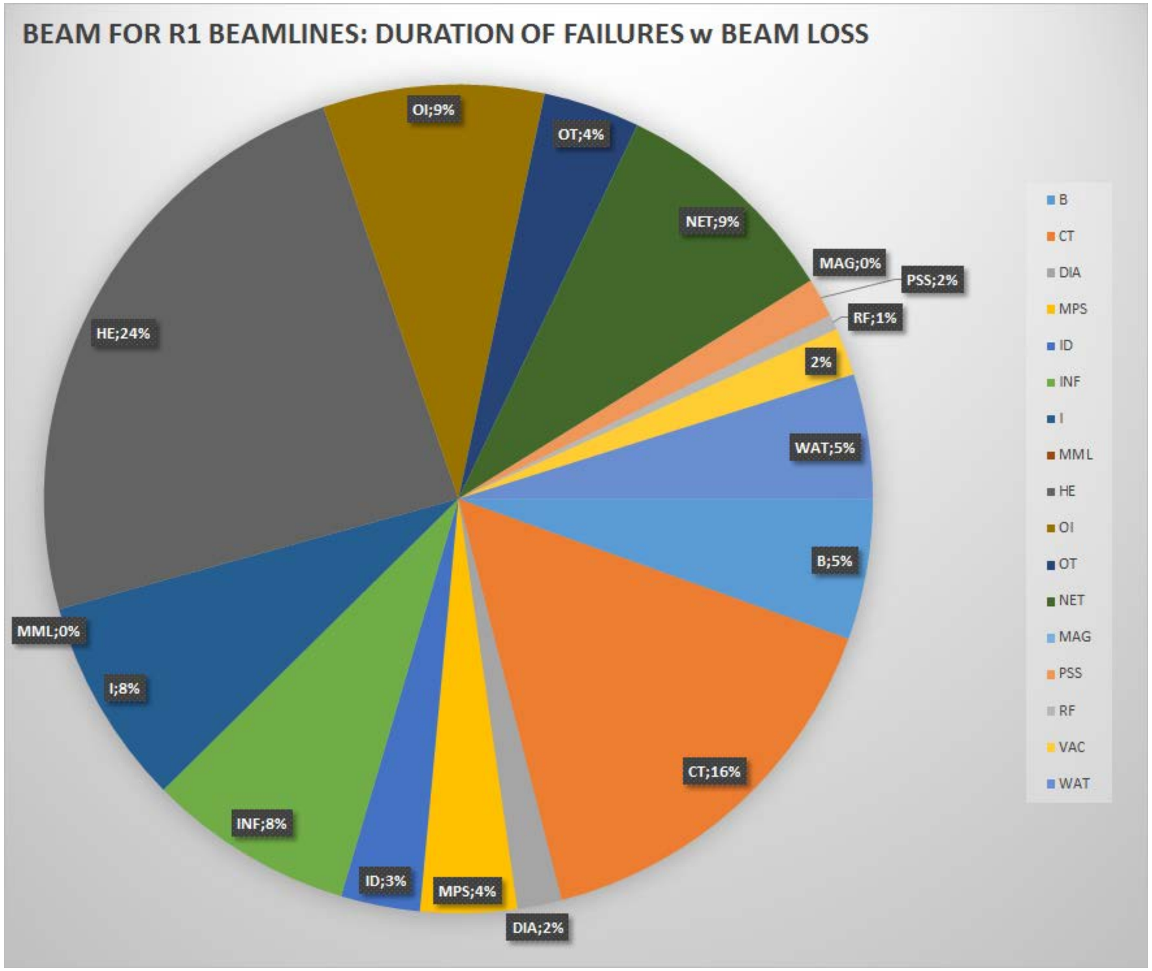
Year-to-date statistics
3 GeV ring



- Uptime: 96.5%
- MTTR: 1.2 hours
- MTBF: 35.1 hours
- 56% of downtime accounted for by:
  - “Others” -- Beam unstable, requiring scrape-down and reinject
  - “Human error” -- New operators, control room miscommunications
  - “Controls” -- Dominated by 1 event where a critical device was uncommunicative
  - “Injector” -- Modulator failures, problematic recovery after intervention
  - “RF” -- Cavity trips, BBB failure

Slide by S. Molloy

Year-to-date statistics
1.5 GeV ring

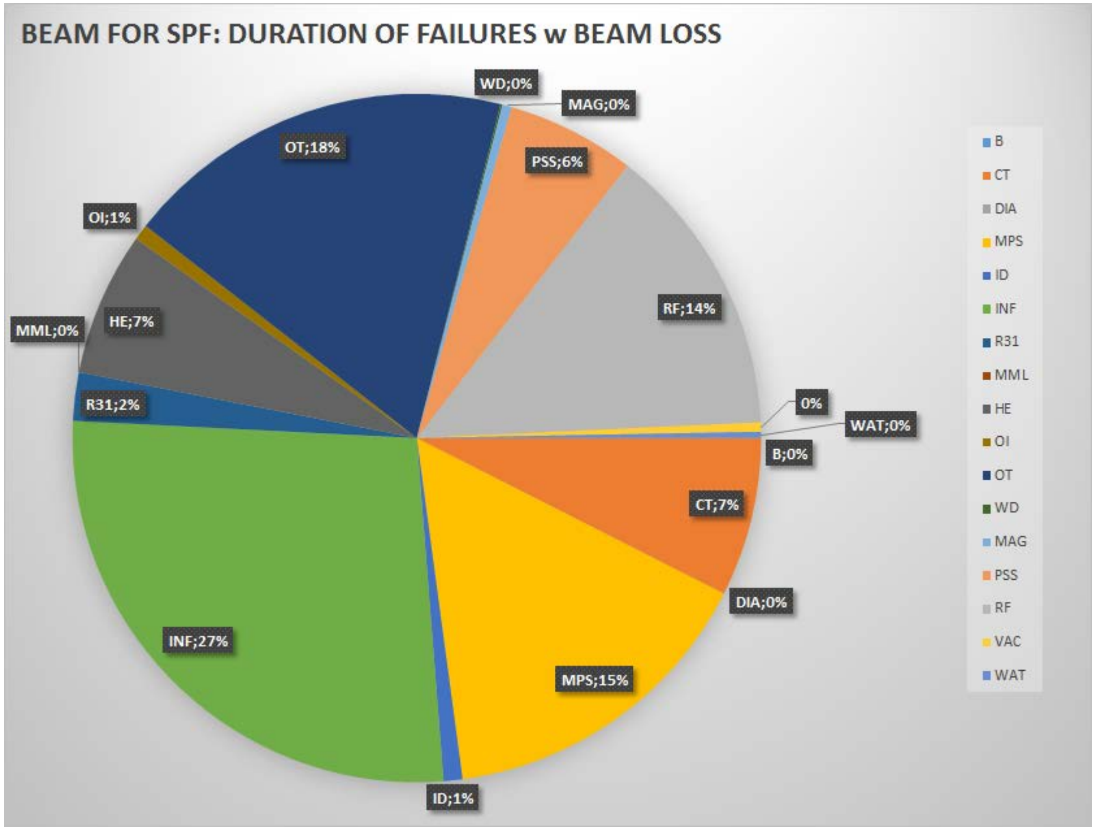


- Uptime: 96.2%
- MTTR: 1.9 hours
- MTBF: 49.7 hours
- ~50% of downtime accounted for by:
  - "Human error" -- Single event where incorrect value entered into GUI caused significant issue with IDs
  - "Controls" -- Dominated by 1 event where a critical device was uncommunicative
  - "Network" -- Single event where the core network node failed

Slide by S. Molloy

Year-to-date statistics

Short Pulse Facility (SPF)



- Uptime: 93.8%
- MTTR: 1.6 hours
- MTBF: 25.6 hours
- 60% of downtime accounted for by:
    - "Infrastructure" -- SPF hit by failure of green network and blue network
    - "Other" -- Failure of a critical component in the laser
    - "MPS" -- Beam jitter resulting in beam containment interlocks

Slide by S. Molloy

Developments and highlights

3.0 GEV STORAGE RING

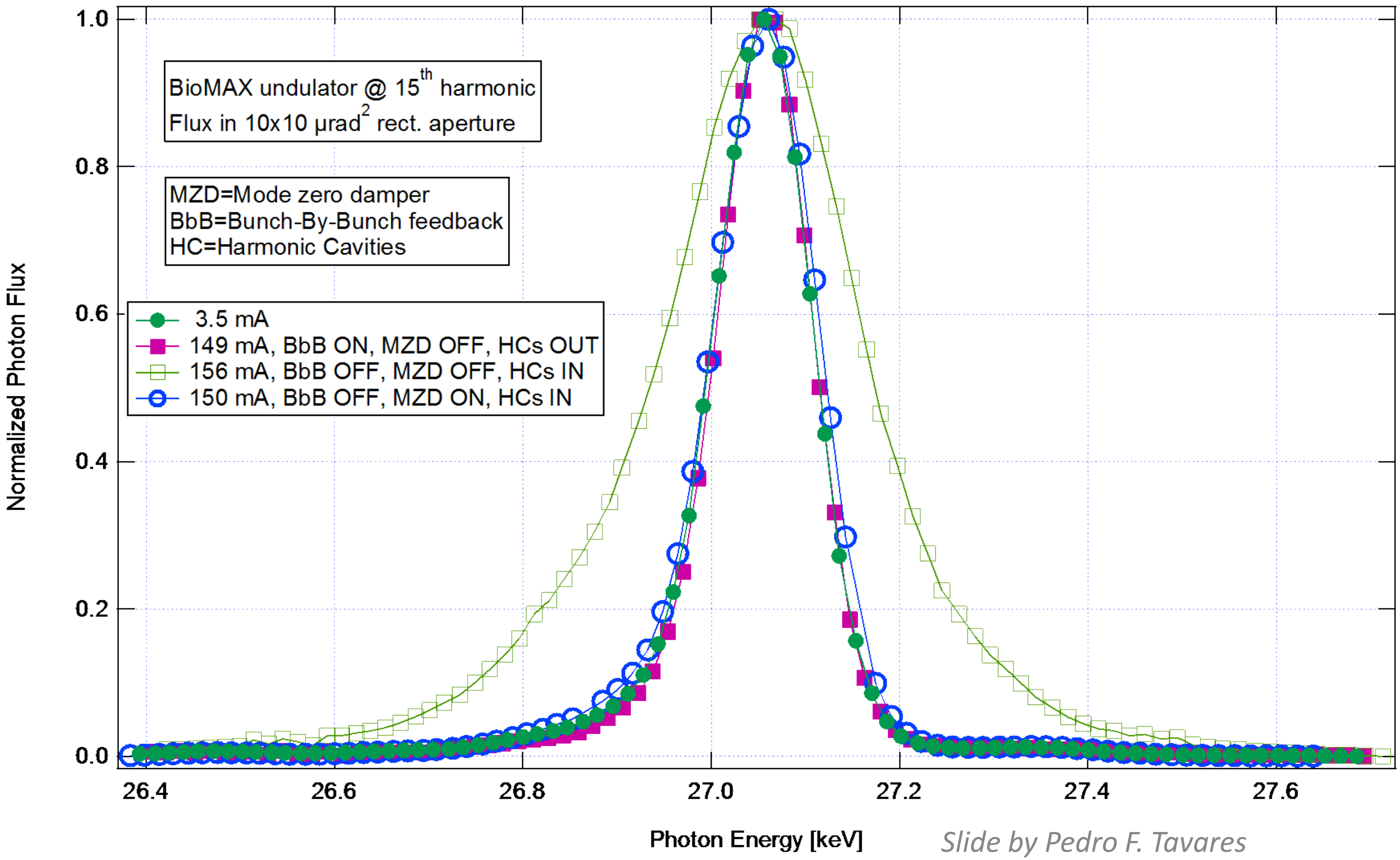
Transverse optics
Overview

- No significant changes or developments regarding linear optics; LOCO still used, minor improvements aimed towards automating the procedure.
- Typical vertical emittance during delivery ~4-6 pm rad
- Ongoing work:
  - Non-linear optics characterization (see presentation by David K. Olsson tomorrow)
  - Implementing local ID optics compensation in Feed-Forward; focus on the BALDER IVW.

Bunch lengthening
Delivery with long bunches

- Significant body of work done over the last year regarding HC characterization and tuning
- Current mode of delivery since 2018-11-08 is 150 mA with average bunch length ~500 ps (average BL > factor 5). Beam current level maintained at request from beamlines.
  - 5 main cavities (100 MHz) with 3 HC (300 MHz), and narrow-band mode 0 damper implemented by D. McGinnis over the past year
  - Gap leads to variations in bunch length along the bunch train
  - Bunch-by-bunch feedback not needed to achieve longitudinal stability
  - HC auto-tuning currently not used; manual tweaks needed by operators to maintain desired HC field voltage. ***Work in progress***
- For details, see tomorrows presentation by Å. Andersson.

Bunch lengthening
ID spectra



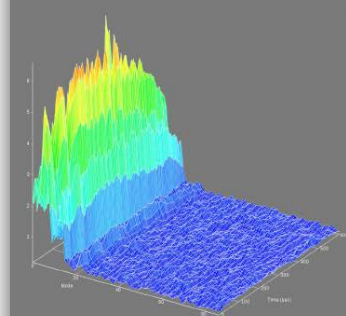
Slide by Pedro F. Tavares

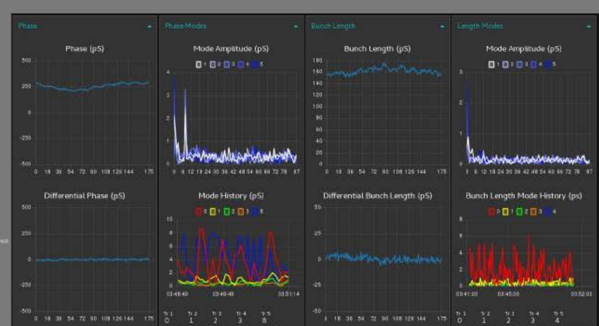
Bunch lengthening
Mode 0 Damper

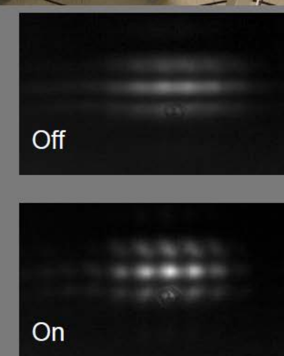
Mode 0 Damper

Max IV RF Group

- The Oscillation Overthruster
  - is an instrumentation system that displays the azimuthal Fourier analysis of the longitudinal dipole mode of the bunch pattern in R3
  - It is used for diagnosing longitudinal coupled bunch mode instabilities in R3The Mode 0 Damper
- The Mode 0 damper uses the Oscillation Overthruster front-end to detect the Mode 0 pattern and remove ("damp") the pattern from the beam by modulating the RF phase in Cavity 18 at the synchrotron frequency (~1 kHz)





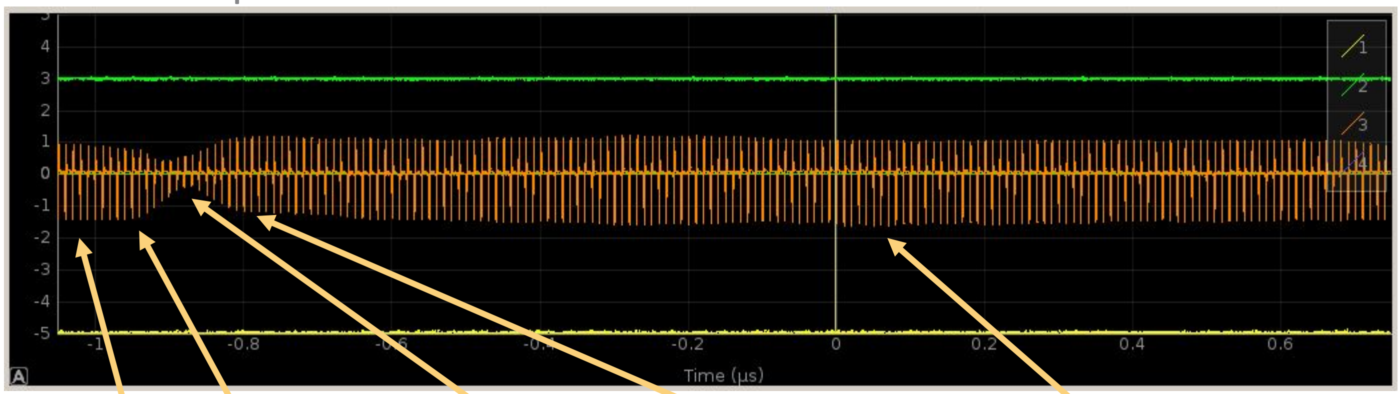


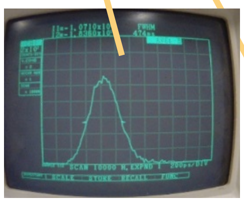
Slide by D. McGinnis

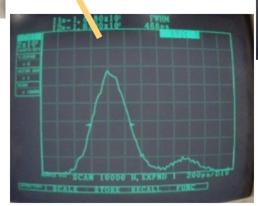
Bunch lengthening

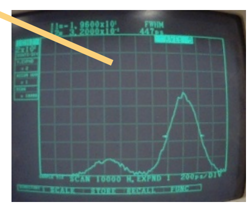
Bunch train transient in σ_t and φ_s

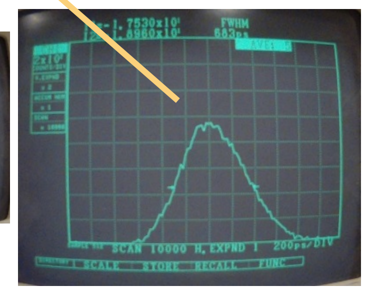
Bunch fill-pattern seen on BPM sum









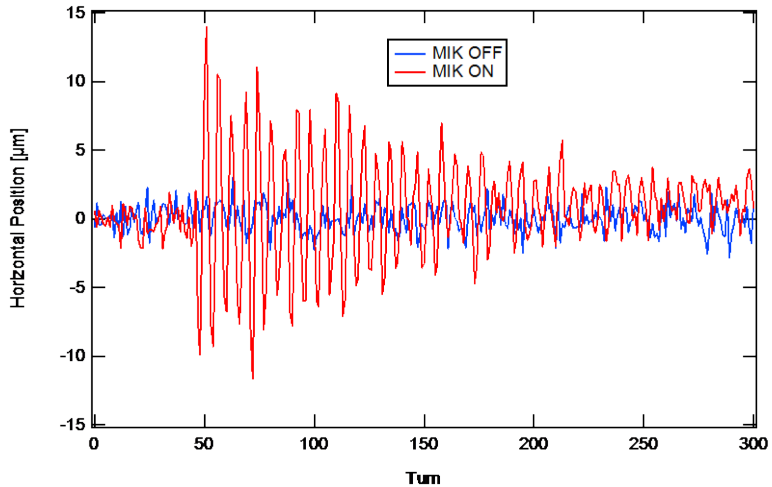


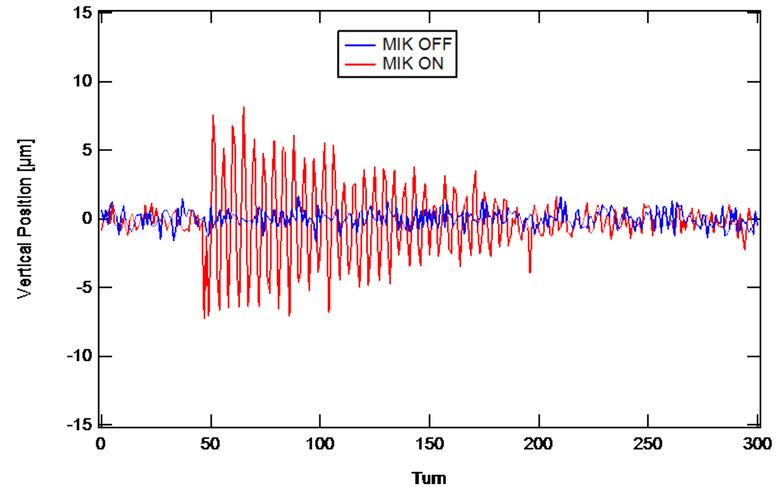
Longest bunches ~ 680 ps (FWHM)
Natural bunch length = 95 ps (FWHM)

Slide by Pedro F. Tavares

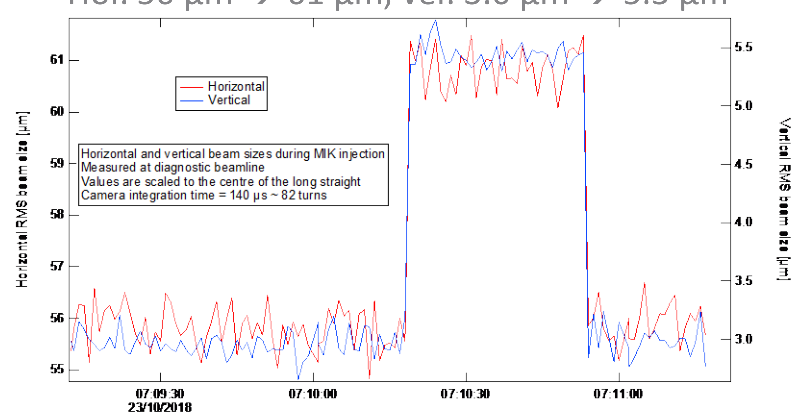
Injection
Multipole Injection Kicker (MIK)

Orbit distortion (from BPM TbT-data) = $\pm 13\ \mu m$ / $\pm 8\ \mu m$ (H/V @ middle of long straight)





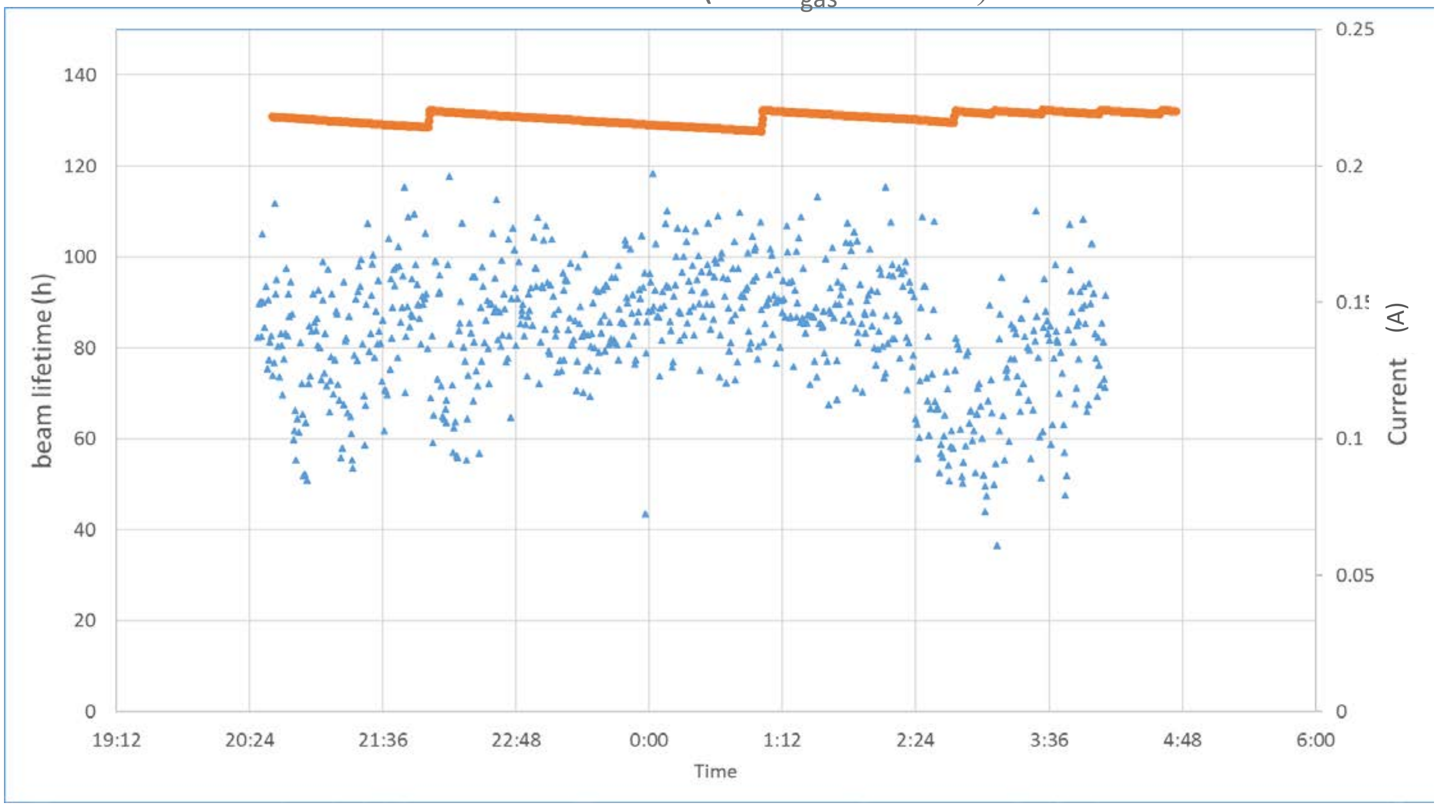
RMS size distortion (from CCD-camera):
Hor. 56 µm → 61 µm, ver. 3.0 µm → 5.5 µm



- MIK system incl. pulser unit produced at SOLEIL (Pierre Lebasque and Patrick Alexandre)
- Installation in 3 GeV ring during the 2017 shutdown for evaluation, now standard injection kicker
- New kicker chamber produced at SOLEIL; installation planned for 2019 summer shutdown

Vacuum
Lifetime

Test was done where the effective bunch length was very large (beam longitudinally unstable), the total lifetime is mainly gas lifetime, total lifetime was around 90h (I.tau $_{gas} \approx 20\mathrm{Ah}$).



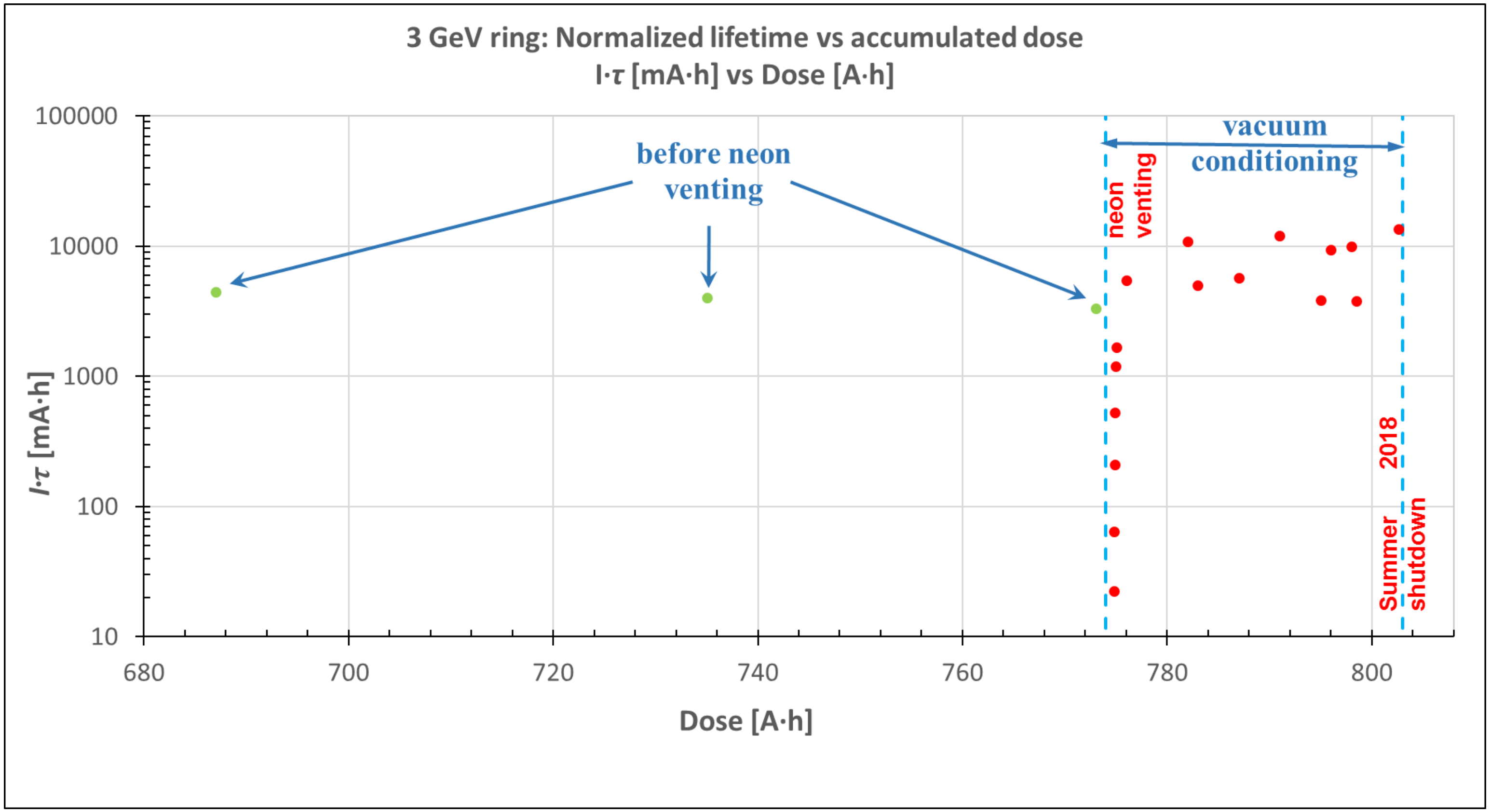
Slide by E. Al-Dmour

Vacuum
Neon venting for vacuum interventions

- Neon venting is a procedure used at LHC for interventions for chambers with NEG coating.
- The procedure implies venting the chambers to atmospheric pressure using pure neon gas and keeping the section at over pressure of neon gas during the intervention.
- Neon is a noble gas and it is not pumped down by NEG coating, subsequently the performance of the NEG coating is preserved, and there is no need for activation.
- If standard procedure which includes NEG activation was done, then we would have needed 2-4 weeks.
- The intervention with Neon venting took 5 days.
- Dedicated beam time for vacuum conditioning and machine performance studies after the intervention.
- MAX IV is the first synchrotron facility to test this procedure in the storage ring in two achromats.

Slide by E. Al-Dmour

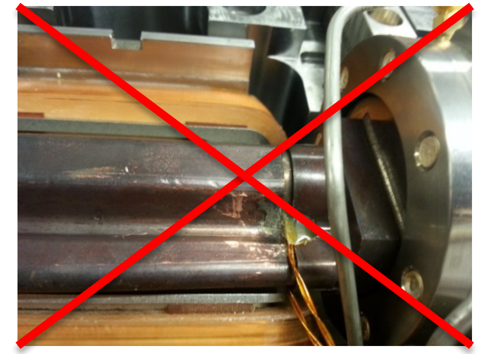
Vacuum
Lifetime recovery post Ne-venting



Plot by E. Al-Dmour

Vacuum
Hot spots resolved

- All hotspots related to dipole SR resolved during the 2018 summer SD
- ID SR hotspots:
  - BALDER wiggler: current chamber can withstand 500 mA with closed gaps for many years. Modified version (SD 2019) with > 15 years.
- RF heating hot spots: MIK chamber
  - Previous delivery configuration (using BBB and very limited bunch lengthening) resulted in significant heating of the MIK chamber (T > 80°C)
  - Current delivery configuration w. HCs strongly reduce RF heating (T < 50°C)
- Post-intervention 400 mA stored (2018-09-11) with no significant heating due to dipole SR



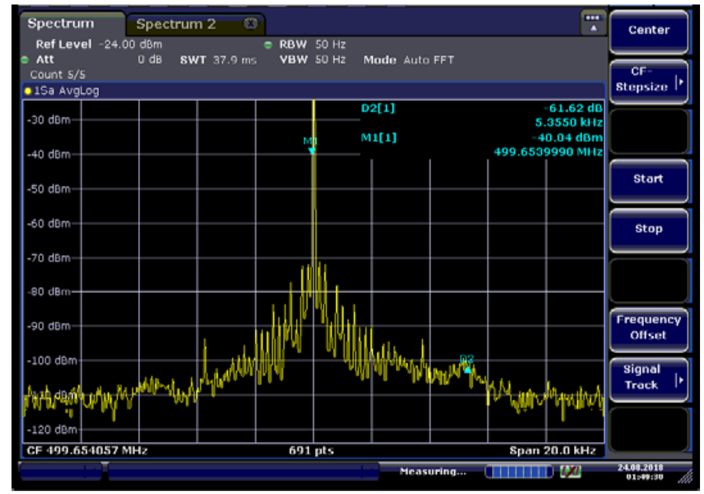
Developments and highlights

1.5 GEV STORAGE RING

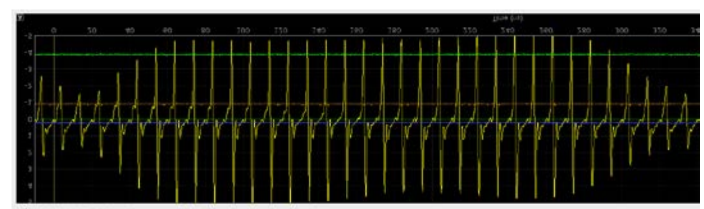
Beam current

Design current reached

- 500 mA reached 2018-06-05
- Stable settings found 2018-06-12:
  - No bunch-by-bunch needed
  - Bunch train gap required when I > 200 mA (limit slowly increasing, now around ~400 mA) → bunch length transient along the train present
  - 2 HCs and 2 main cavities used, no mode 0 damper
- 2018-06-18 17:00 – FinEstBeams beamline takes light @ 500 mA
- Post-summer SD current has been limited to 200 mA at request from beamlines
- Single-bunch current of 22 mA achieved and possible to deliver



5th RF harmonic during vac. conditioning shift @ 500 mA (SA)



Fill pattern

Figures by Viktor Abelin, Andreas Johansson, David Winchester

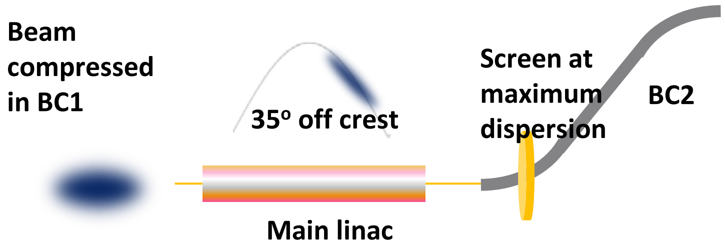
Linear optics
Correction attempts

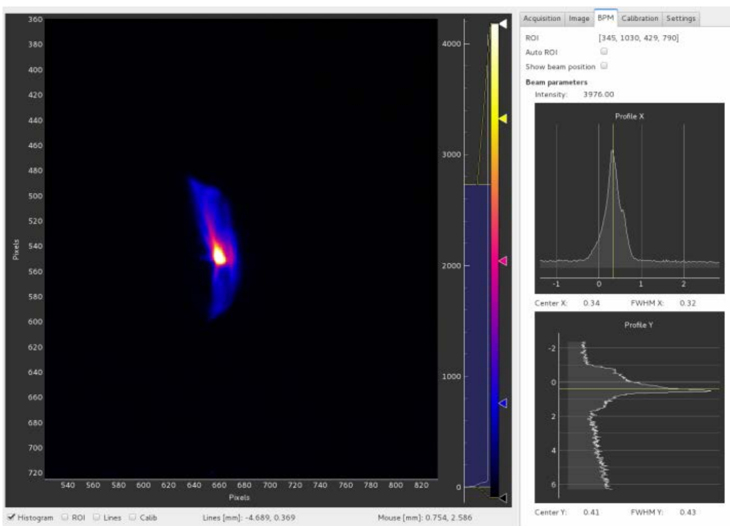
- Unlike in the 3 GeV ring, families are global and individual magnet strengths are adjusted using manual shunts
  - Shunting of main quadrupole families (SQFO, SQFI) done using LOCO fit results → reduction in horizontal beta-beat
  - Shunting of gradient dipoles (required for vertical beta-beat correction) on hold; required amplitude of shunt currents would saturate the orbit correctors
- Strong ID focusing has on occasion caused trouble; tune feedback trials ongoing to mitigate issues (BBB tune read-out as sensors, SQFO and poleface strips as actuators)
- Project started to split up the SQFO, DIPC and SCO-SKW global circuits, currently preparing for procurement.

Developments and highlights

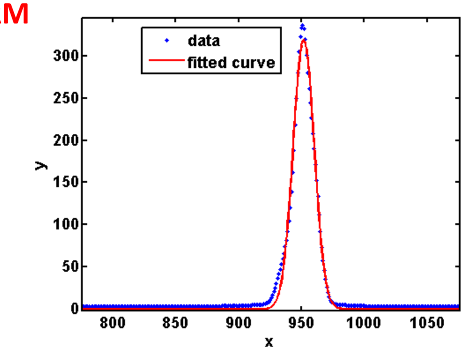
LINEAR ACCELERATOR

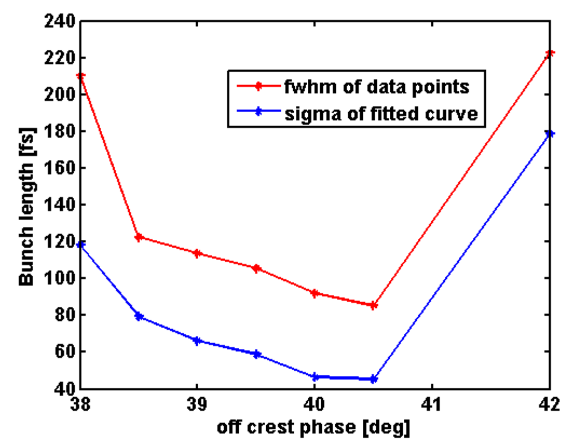
Highlights: Measured bunch length after BC1





On May 23 we measured below 100 fs fwhm for the first time. Lowest measurement was 45 fs FWHM, and 28 fs RM



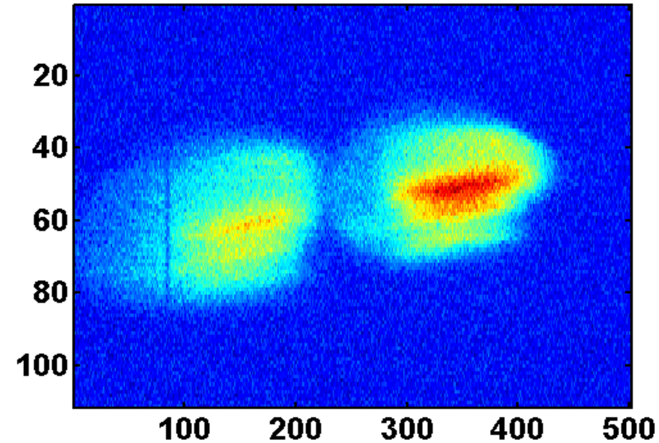


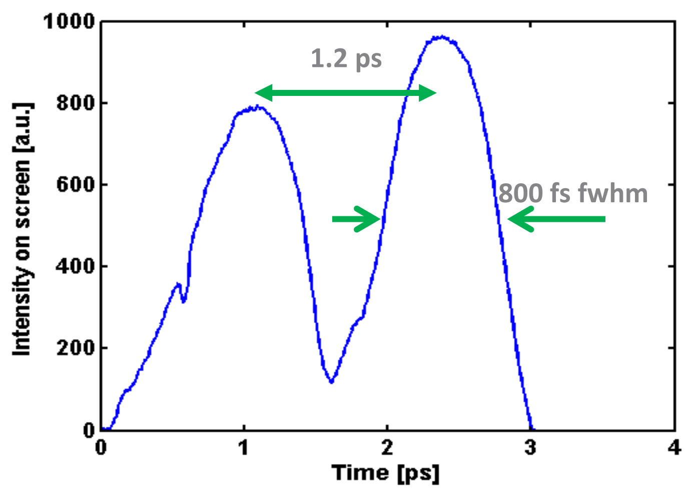
We could compress more, but didn't have resolution to measure anything shorter.

Slide by S. Thorin

Highlights: First attempt at double bunches

- Compressed only in BC1
- Same method as previous slide to measure
- Two electron bunches within one RF-bucket
- First attempt, used only the crystals in the laser pulse stretcher to achieve two laser pulses.
- Only lightly compressed





Slide by S. Thorin

Technical issues

Main Drive Line (MDL)

- MAX IV linac uses a high-power MDL that siphons off power from the K02 RF station.
- Intermittent sparking long present in the K02 area had gradually decreased the voltage, risking SPF and R3 delivery. Conditioning did not resolve the issue.
- Upon finally opening the MDL, a slight impedance mismatch was found (see picture)
- Post-intervention beam jitter has also significantly improved, enabling 3.5 mm FemtoMAX ID gaps

Picture by A. Mitrovic

The near future

Outline 2019

Outline 2019: Storage rings

- 3 GeV ring:
  - Increasing delivery current with stretched bunches (full current with full load depends on RF power plant upgrade)
  - Fast-Orbit Feedback: evaluation of test installation, prepare full installation
  - Installation of 2nd MIK chamber
- 1.5 GeV ring
  - Alignment survey
  - Commission online tune feedback
  - Power supply installation for local optics compensation of IDs (SQFO, DIPC, SCO-SKW)

Outline 2019: Linear accelerator

Continuation of 2018 work

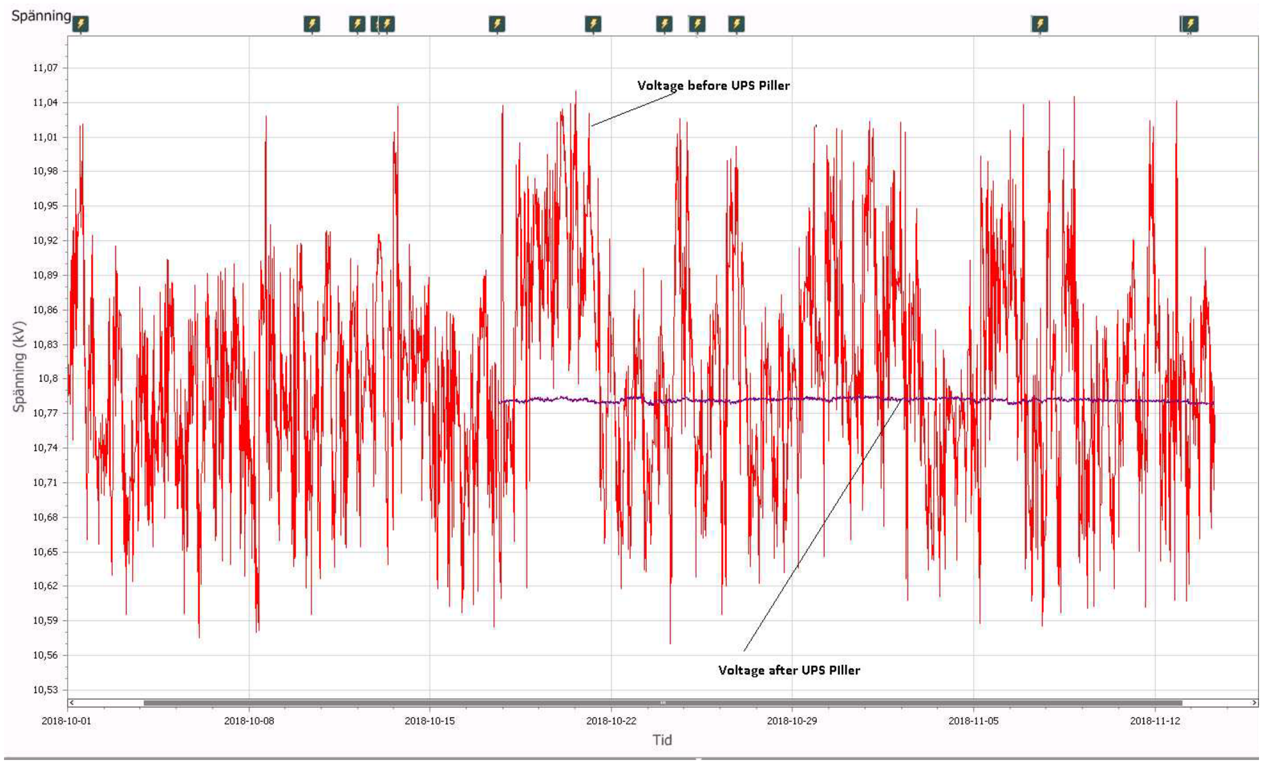
- Continue work on CDR for Soft X-ray FEL
- Construct and test 100 Hz gun in the test stand
- Install and commission Transverse Deflecting Cavity (TDC)
- 10 Hz rep. Rate
- Bunch Compressor (BC) characterization
- Design for Main Drive Line (MDL) redundancy
- Long. beam shaping

THANK YOU FOR YOUR ATTENTION!

EXTRA SLIDES

Facility
UPS operational

Facility UPS (3 fly-wheels) went into operation 2018-09-25



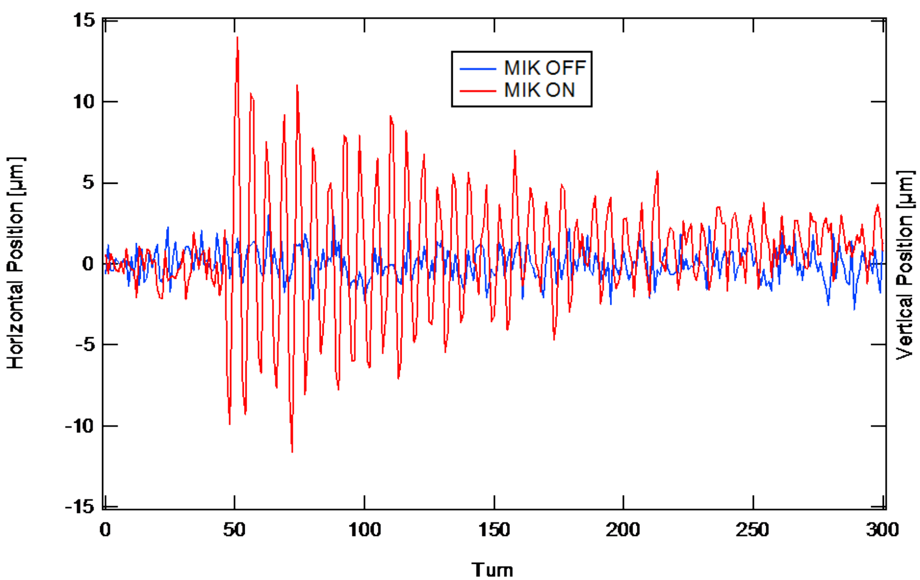
Voltage fluctuations before and after UPS went into operation

Downtime evaluation

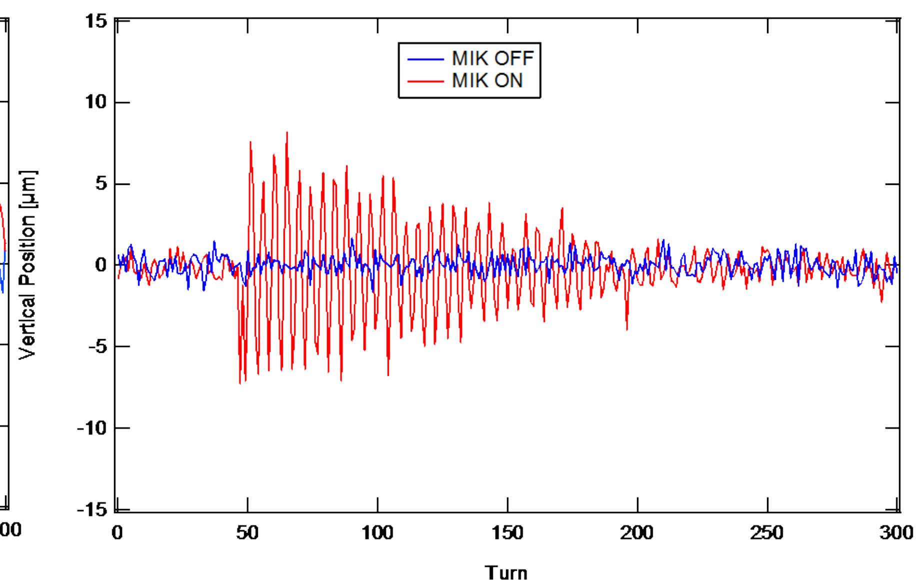
- Downtime is recorded only during delivery
  - No records (beyond the log book) kept during accelerator commissioning periods
- Downtime for the rings
  - Zero current (i.e., after a beam dump)
  - <90% of nominal (i.e., failure of the top-up system)
- Downtime for SPF
  - Zero charge (i.e., complete failure of the linac)
  - Excessive jitter (i.e., FemtoMAX unable to make use of the beam)
  - Excessive interruptions (i.e., beam containment system)
- Nota bene:
  - The MAC critiqued the 90% level as too conservative, and advised a reduction of this value
    - Discussions are ongoing, with the intention of altering the downtime rules for 2019.

Injection
Multipole Injection Kicker

- Store 10 consecutive bunches
- Scan of stored beam position at the MIK
- Amplitudes measured from Turn-By-Turn libera data stream
- One BPM at $\beta_x = 9.6\ m\ \beta_y = 4.80\ m$
- Amplitudes scaled to centre of long straight where $\beta_x = 9.0\ m\ \beta_y = 2.0\ m$



Horizontal = $\pm 13\ \mu m$



Vertical = $\pm 8\ \mu m$

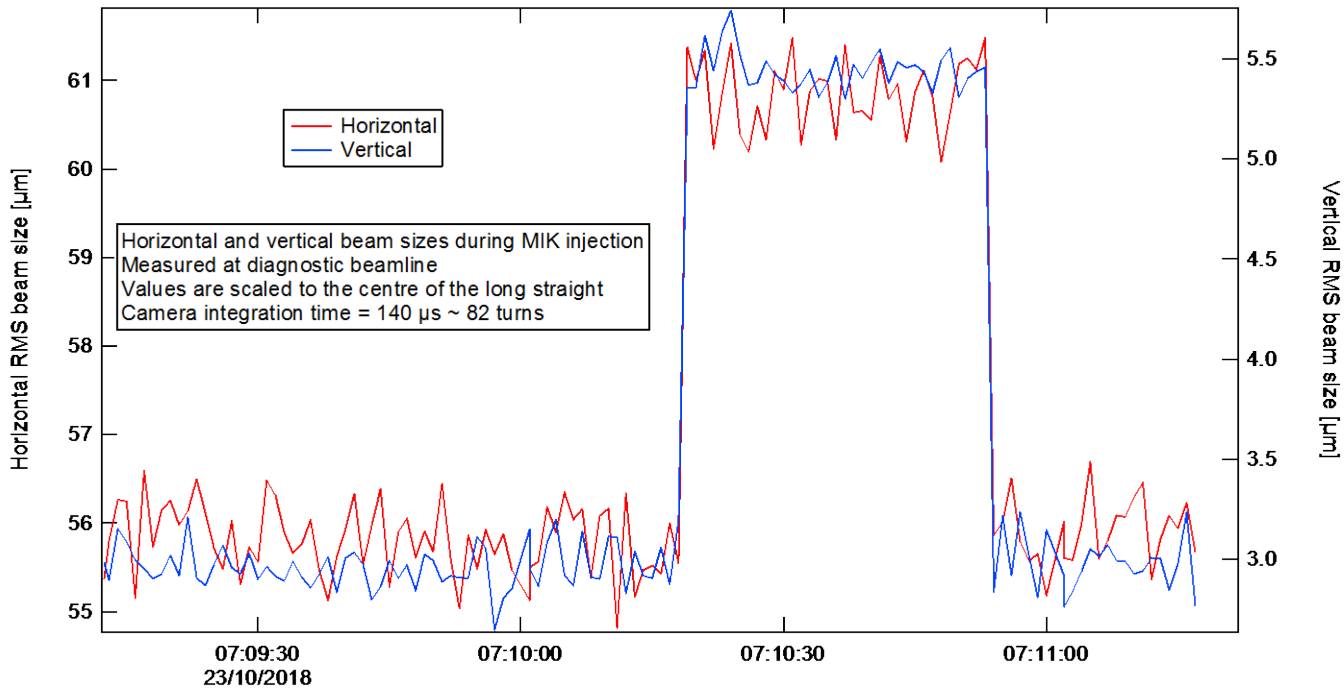
Slide by Pedro F. Tavares

Injection

Multipole Injection Kicker

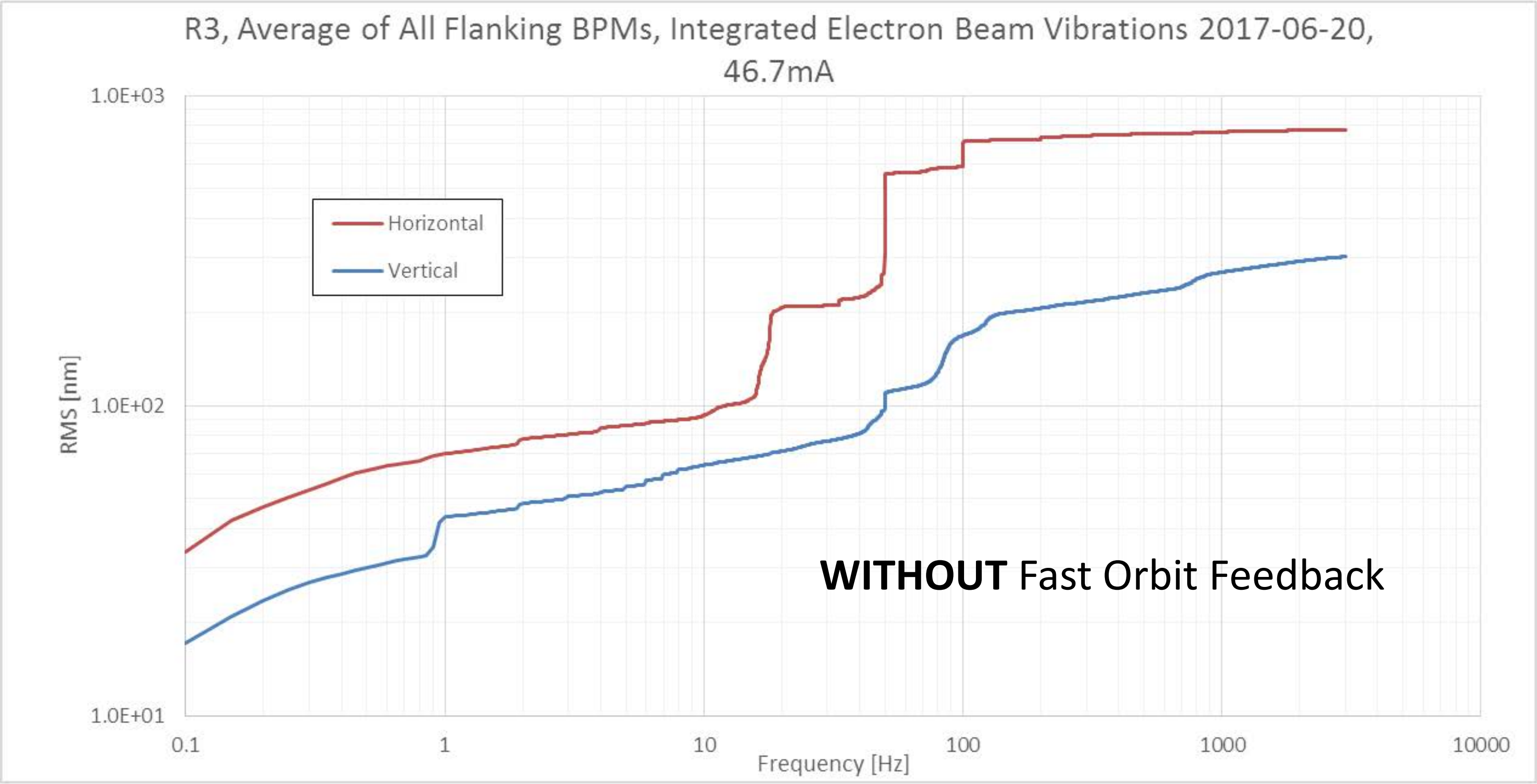
Transverse beam profile in a diagnostic beamline during MIK injection

- Multi-bunch fill at 150 mA
- Camera integration time: ~82 turns
- Camera acquisition synchronized with kicks



Slide by Pedro F. Tavares

Stability: Orbit noise

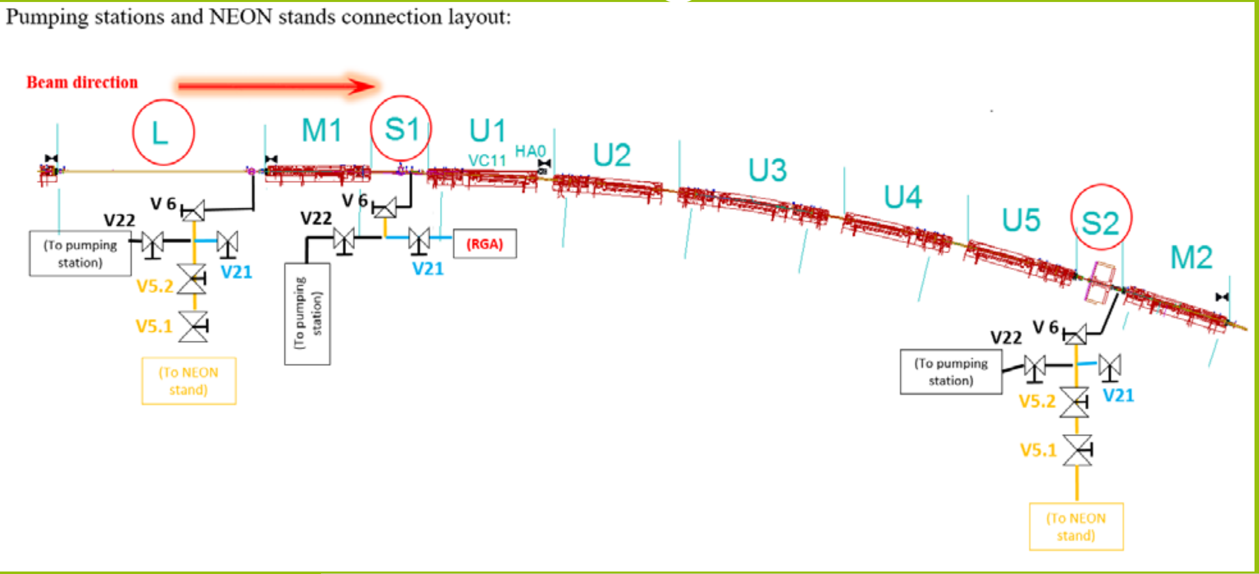


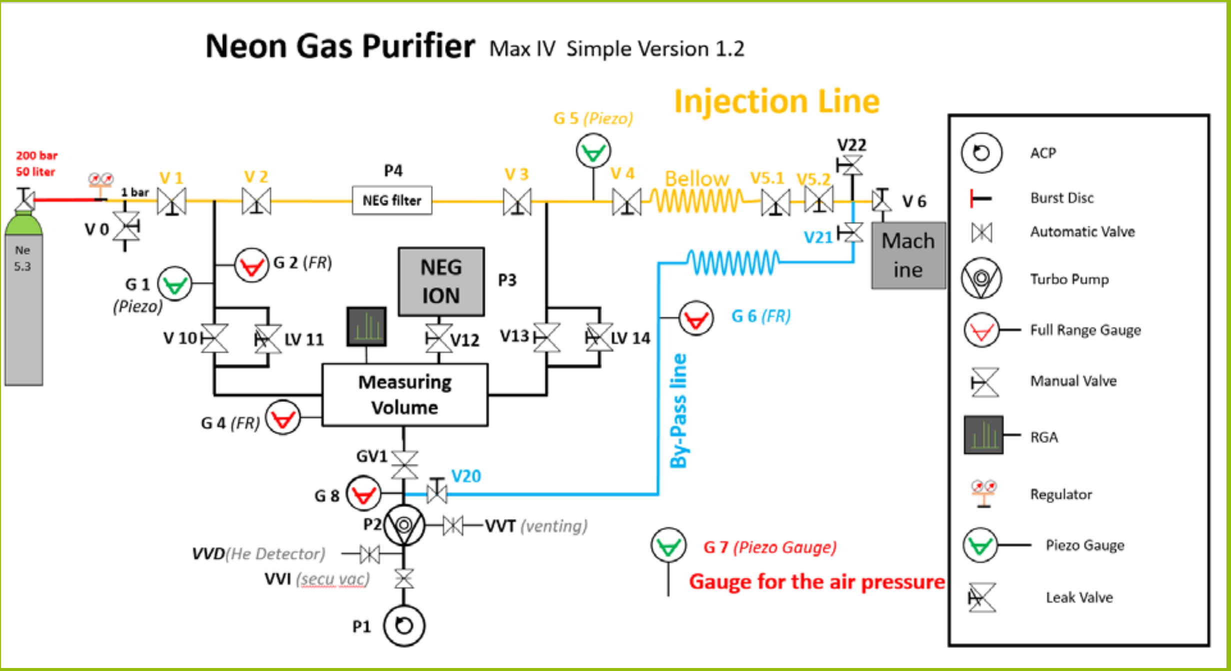
Plot by B. Jensen

Integrated up to 100 Hz

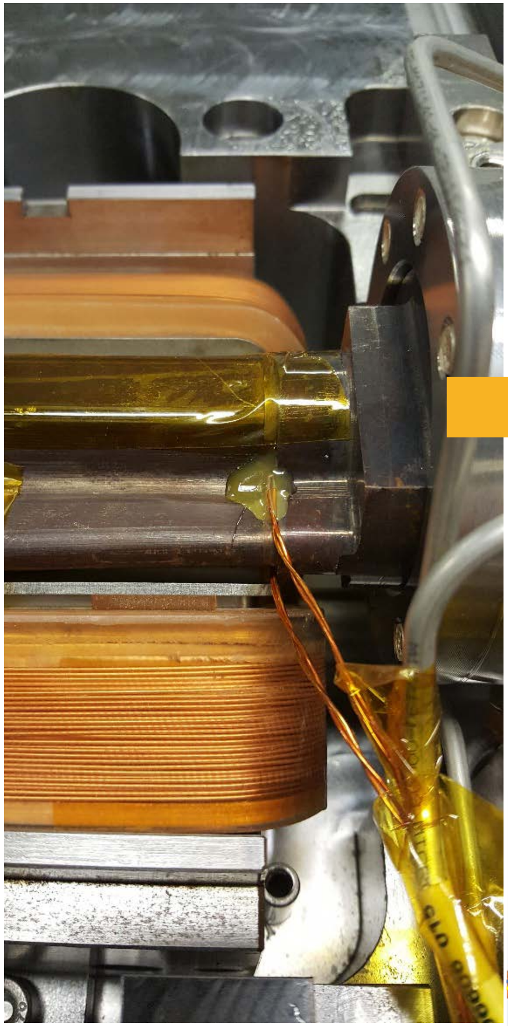
- ❑ Horizontal RMS < 710 nm ~ 1.3 % of RMS beam size at BPM position
- ❑ Vertical RMS < 170 nm ~ 5.5 % of RMS beam size at BPM Position

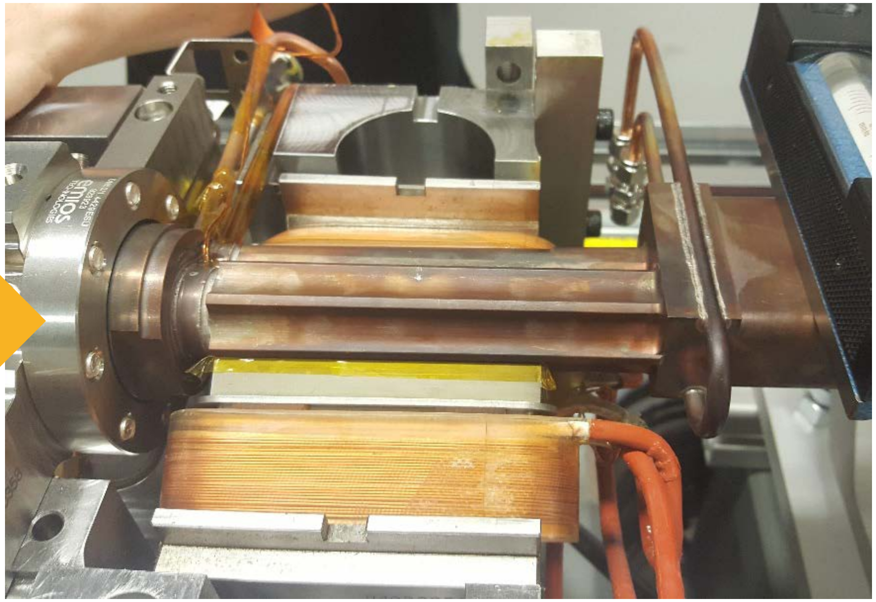
Neon venting for vacuum interventions

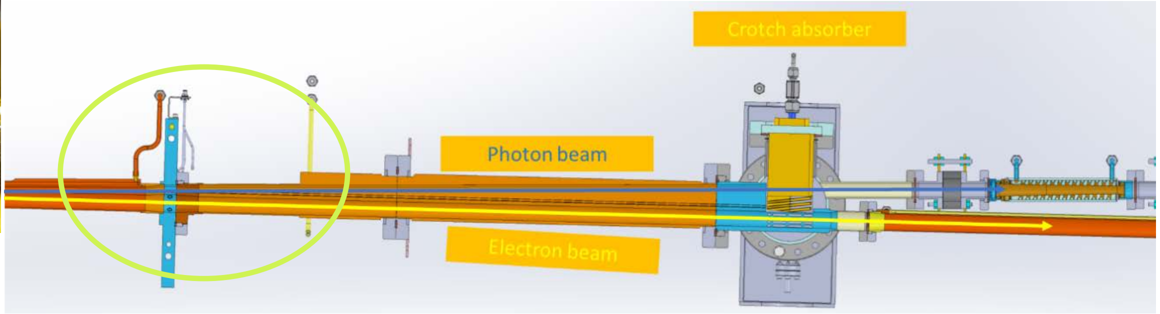




Neon venting for vacuum interventions

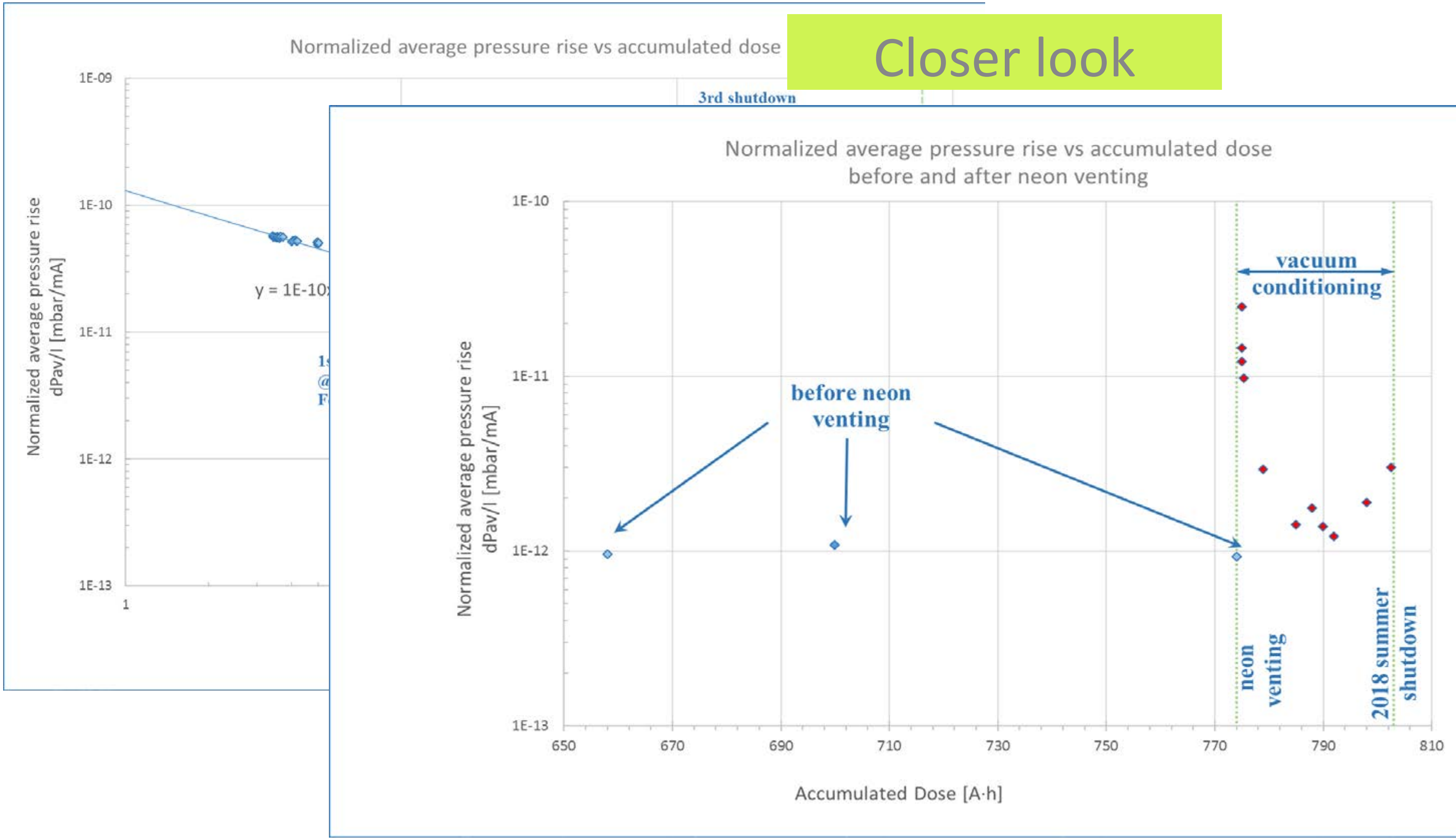






Neon venting for vacuum interventions

Vacuum conditioning after neon venting intervention.



The average pressure has recovered after around 18Ah, highest pressure readings were close to the areas were we have exchanged the vacuum chambers.

6th DLSR workshop: Oct. 2018. Experience with NEG coated chambers as absorbers and pumps E. Al-Dmour

1.5 GeV ring
Single bunch current