The MAX IV Accelerator Facility, concept, status and perspectives

Mikael Eriksson on behalf of the MAX IV team

SRF 2016

Diffraction Limited Storage Rings

$$\frac{\lambda}{4\pi}$$

Receipt for designing a very low emittance ring:

$$Brilliance \propto \frac{1}{\varepsilon^2} \qquad \varepsilon = C_q \frac{Energy^2}{(N_{magnets})^3}$$

Increasing the number of cells is a powerful way to increase brilliance.

But:

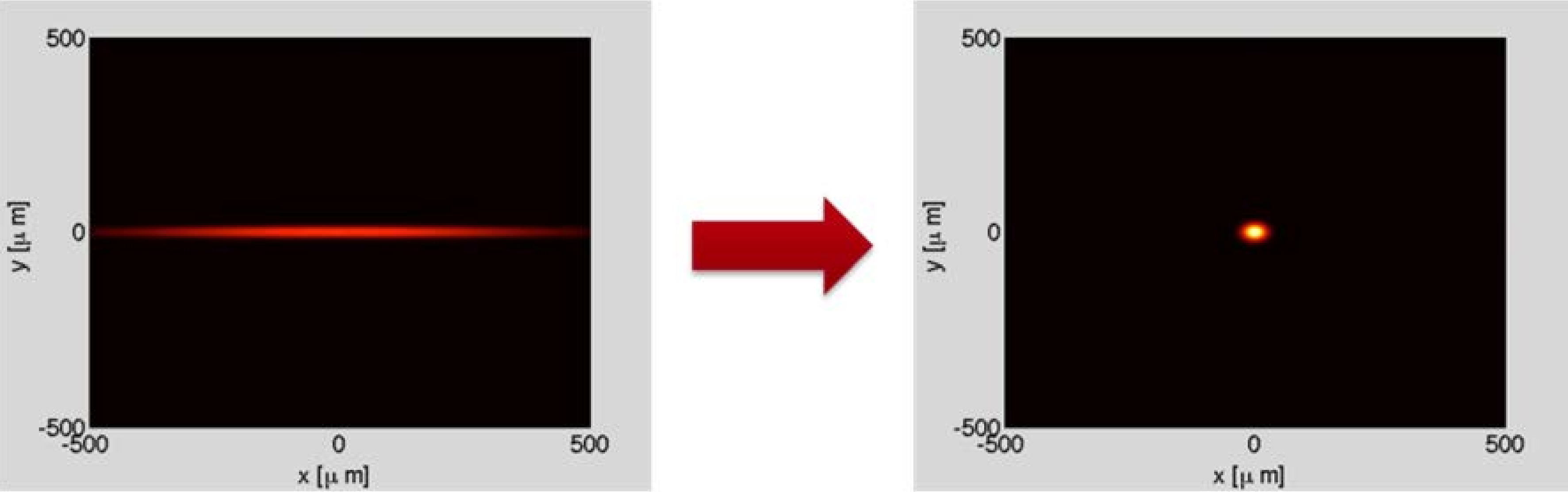
- The ring will get a 2 km or so circumference.
- The Dynamic Aperture is reduced

So:

- We make the componenets small to squeeze in a large number of magnets
- We design stable Multi-Bend Achromats (MBA)

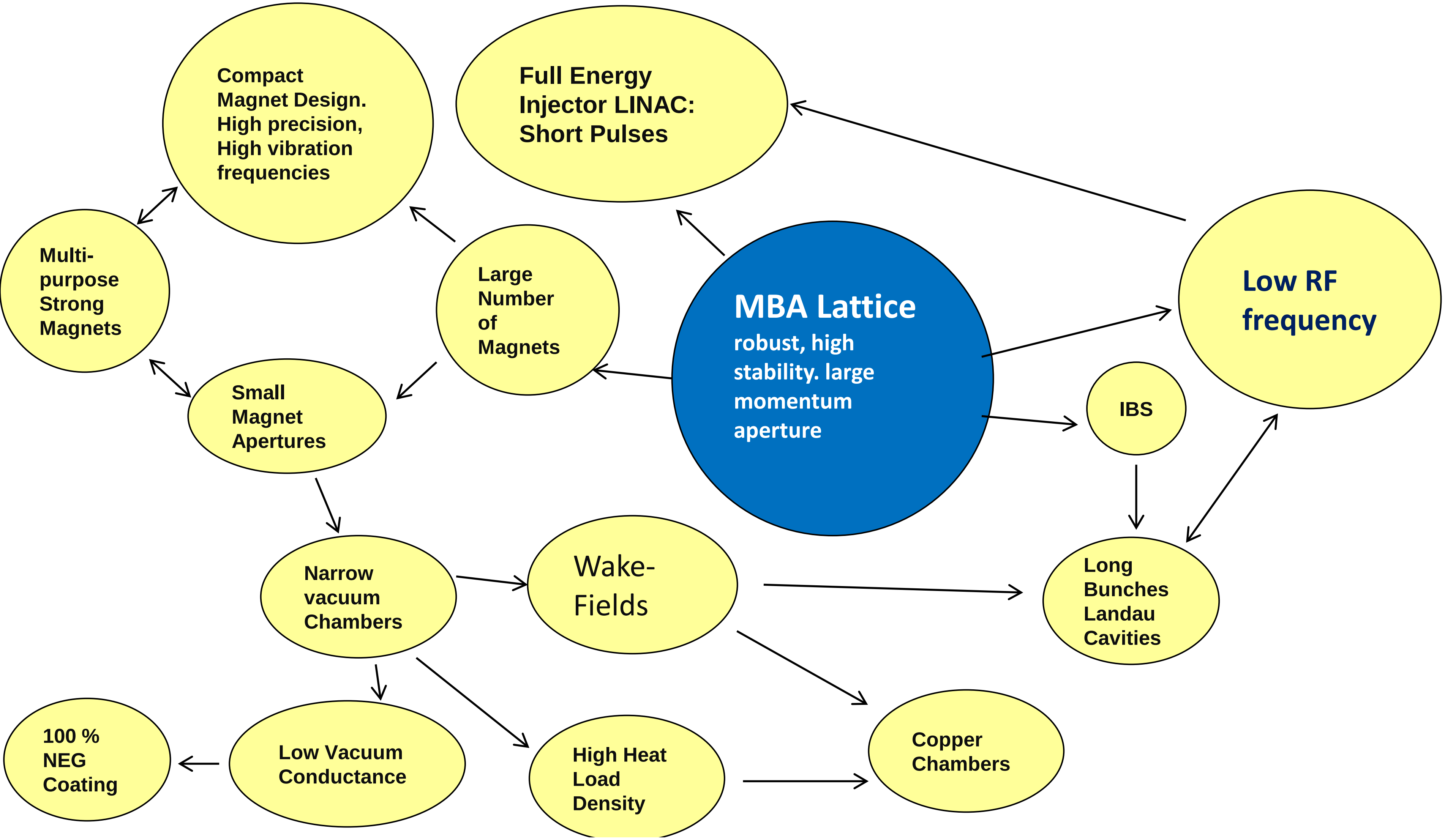
3rd Generation

MBA



courtesy of C. Steier

MAX IV - An integrated Solution



Compact Magnet Design. High precision, High vibration frequencies

Full Energy Injector LINAC: Short Pulses

Multi-purpose Strong Magnets

Large Number of Magnets

MBA Lattice

robust, high stability. large momentum aperture

Low RF frequency

Small Magnet Apertures

IBS

Narrow vacuum Chambers

Wake-Fields

Long Bunches Landau Cavities

100 % NEG Coating

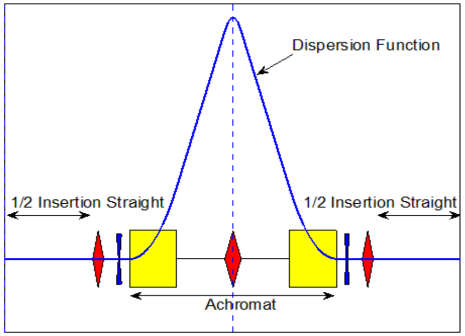
Low Vacuum Conductance

High Heat Load Density

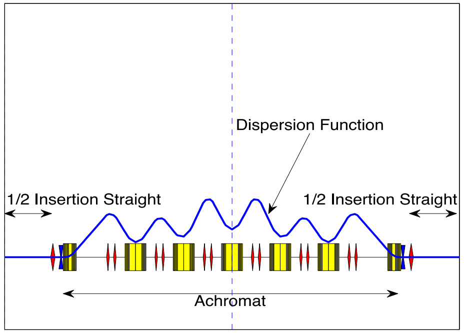
Copper Chambers

DLSRs: why not earlier? - lattices

DBA



7BA



Multibend achromat (MBA) lattices

- Lattice design evolution from DBA, TBA to 4BA,…MBA:
- History (partial):

1993: QDA by D. Einfeld at al. NIMA 335(3)

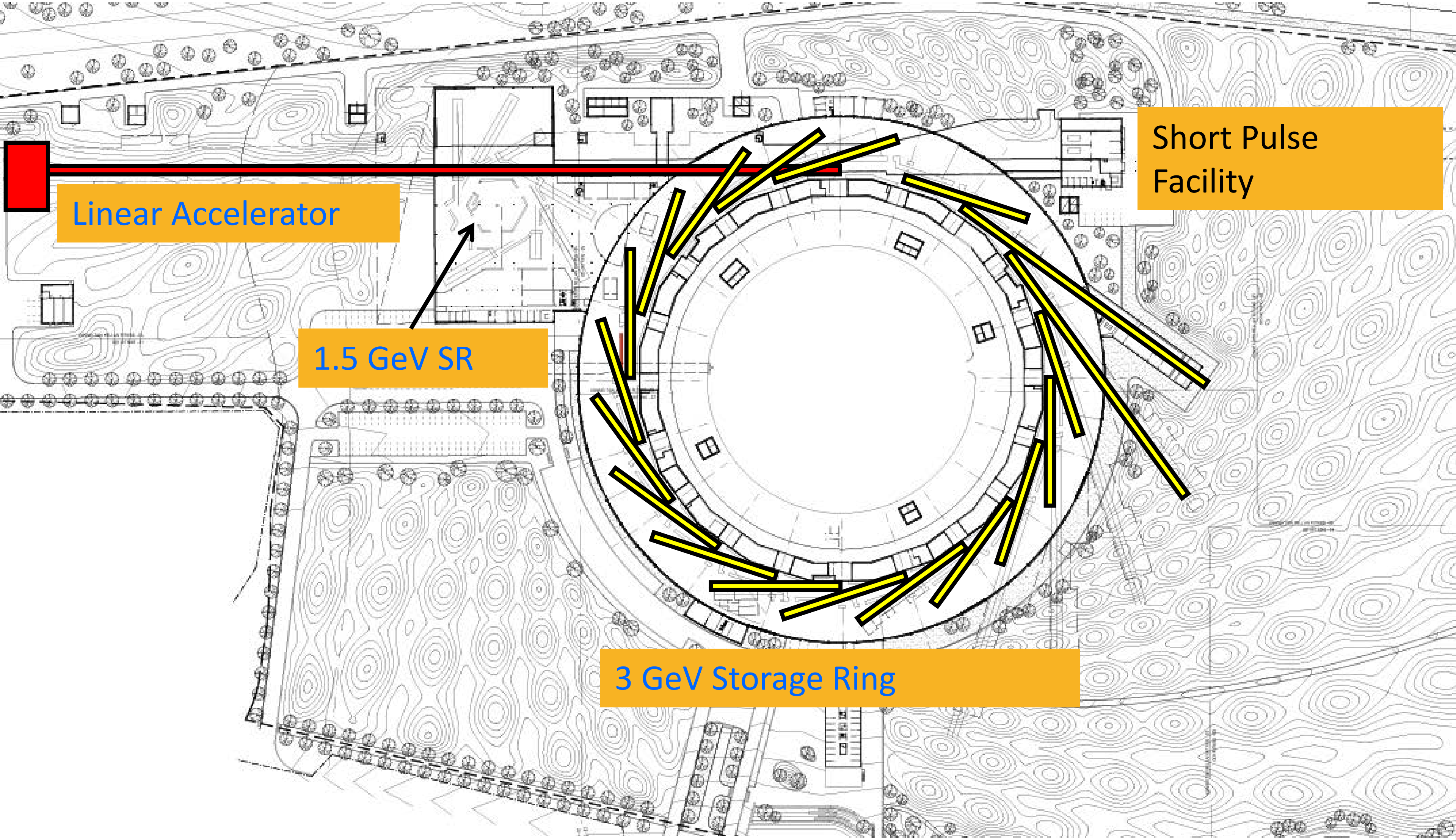
1994: SLS early design with 7BA, short superbend, provision for on-axis injection (W. Joho, P. Marchand, L. Rivkin, A. Streun, EPAC'1994)

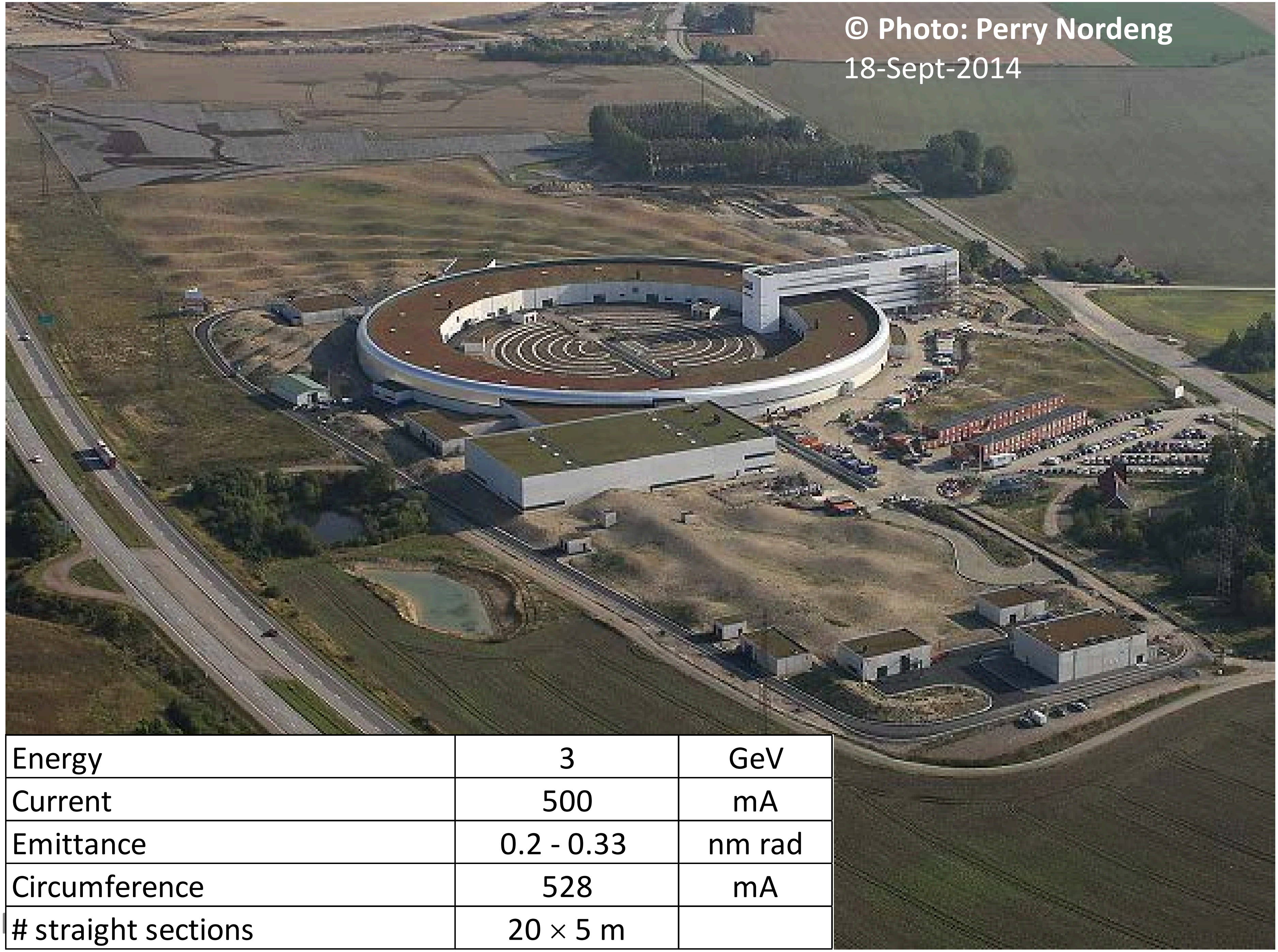
1995: 7BA by Einfeld et al. (0.5 nm-rad, 3 GeV, 400m, PAC 95)

2002: MAX-IV 7BA concept (M. Eriksson, Å. Andersson, S. Biedron, M. Demirkan, G. Leblanc, L. Lindgren, L. Malmgren, H. Tarawneh, E. Wallén, S. Werin, EPAC 2002)

Courtesy: R. Hettel

MAX IV – an overview

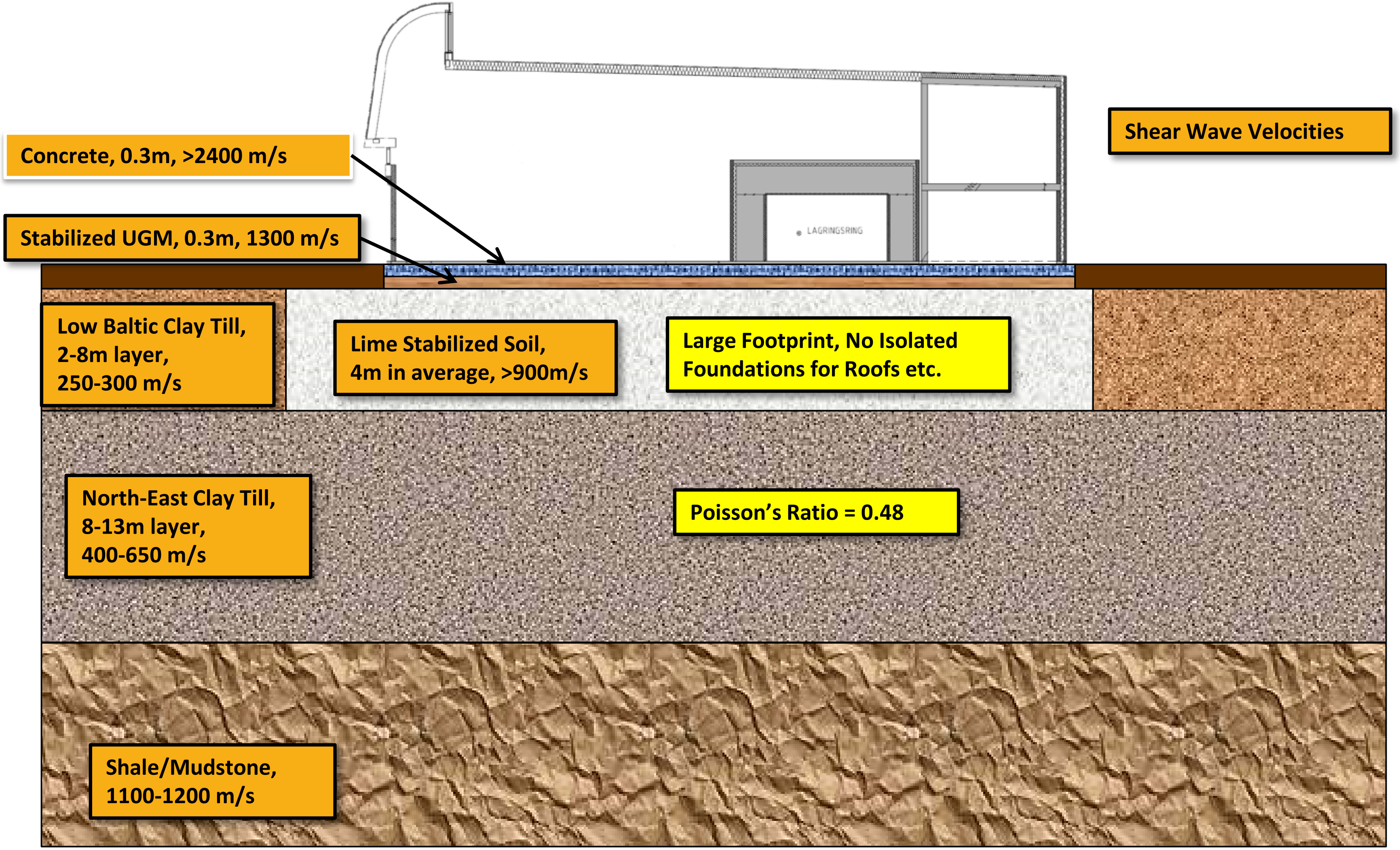




© Photo: Perry Nordeng
18-Sept-2014

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

Civil Engineering



Shear Wave Velocities

Concrete, 0.3m, >2400 m/s

Stabilized UGM, 0.3m, 1300 m/s

Low Baltic Clay Till,
2-8m layer,
250-300 m/s

Lime Stabilized Soil,
4m in average, >900m/s

Large Footprint, No Isolated
Foundations for Roofs etc.

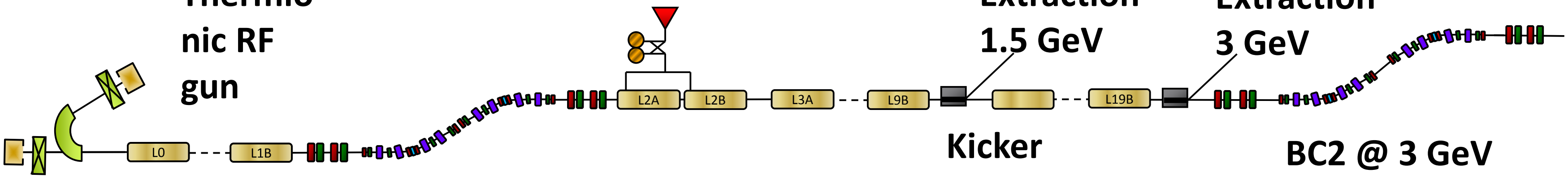
North-East Clay Till,
8-13m layer,
400-650 m/s

Poisson's Ratio = 0.48

Shale/Mudstone,
1100-1200 m/s

www.ekdahlgeo.se

Beam parameters Thermionic Gun



Thermionic RF gun

Extraction 1.5 GeV

Extraction 3 GeV

SPF

Kicker & septum

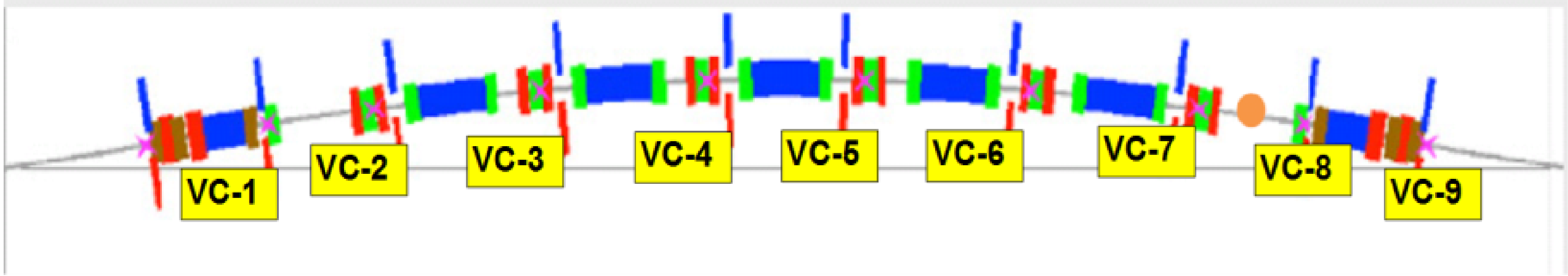
BC2 @ 3 GeV

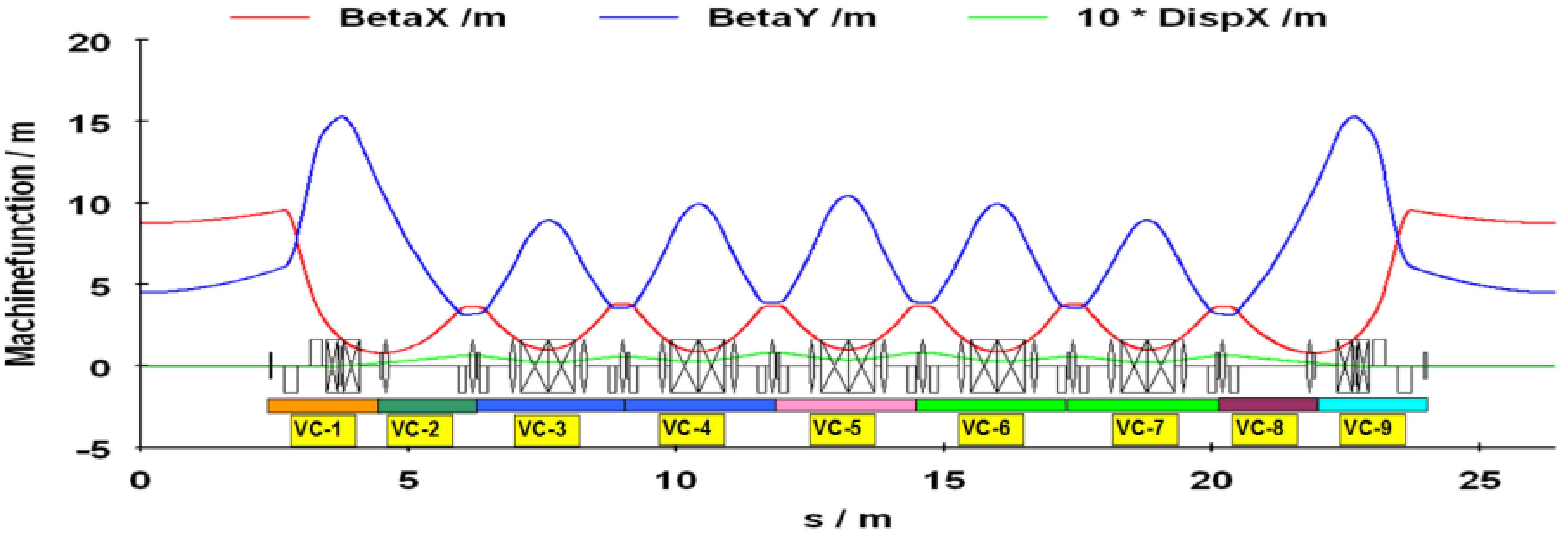
Photo cathode RF gun

BC1 @ 260 MeV

Slide by S.Thorin


Sect. 4
End
Första hjälpen

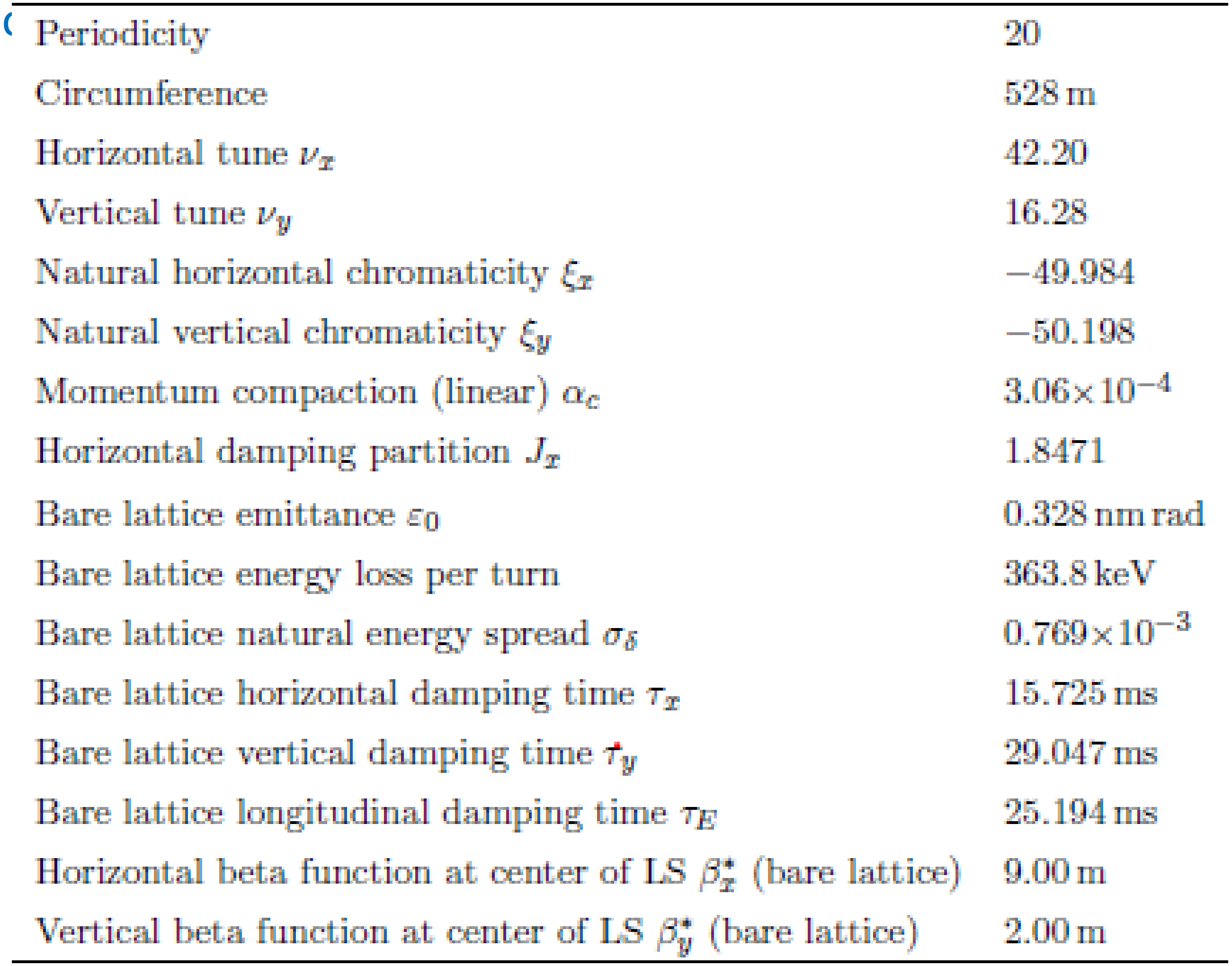

VC-1
VC-2
VC-3
VC-4
VC-5
VC-6
VC-7
VC-8
VC-9


BetaX /m
BetaY /m
10 * DispX /m
Machinefunction / m
20
15
10
5
0
-5
0
5
10
15
20
25
s / m
VC-1
VC-2
VC-3
VC-4
VC-5
VC-6
VC-7
VC-8
VC-9

The MAX IV 3 GeV ring Lattice

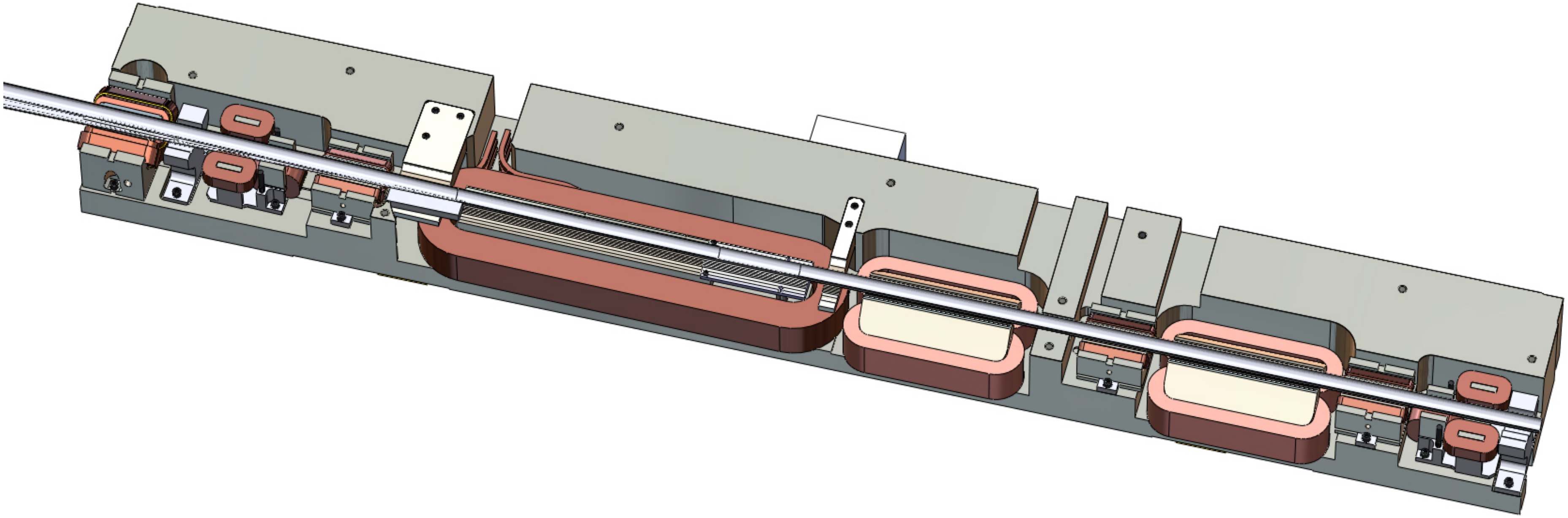
7-bend achromat

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

One of 7 integrated magnet blocks in a MAX IV achromat. The ring contains 20 achromats.



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

photo: Anna Olsson, Scanditronix Magnet AB

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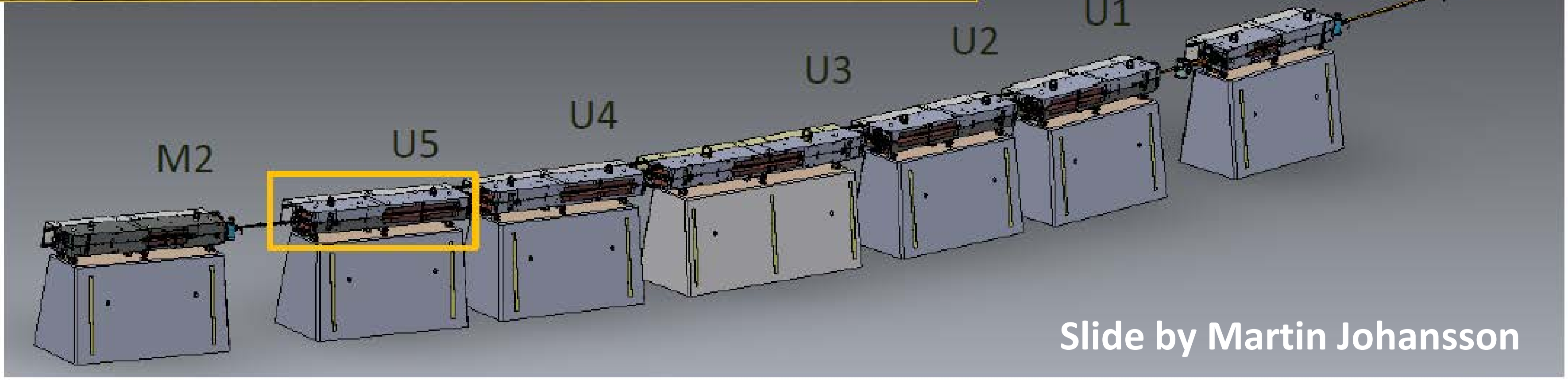
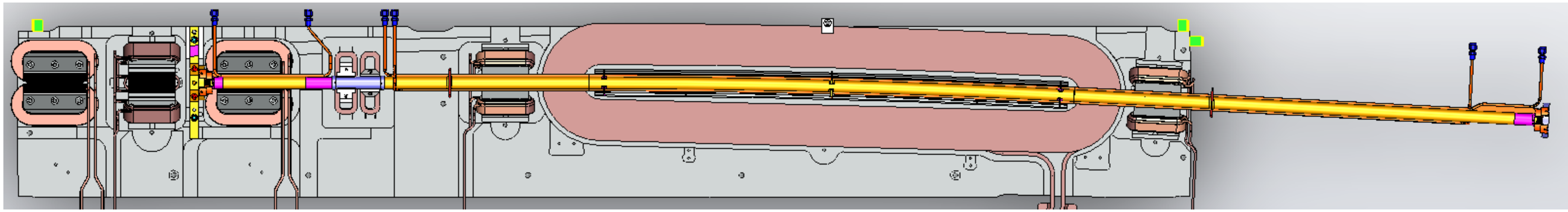
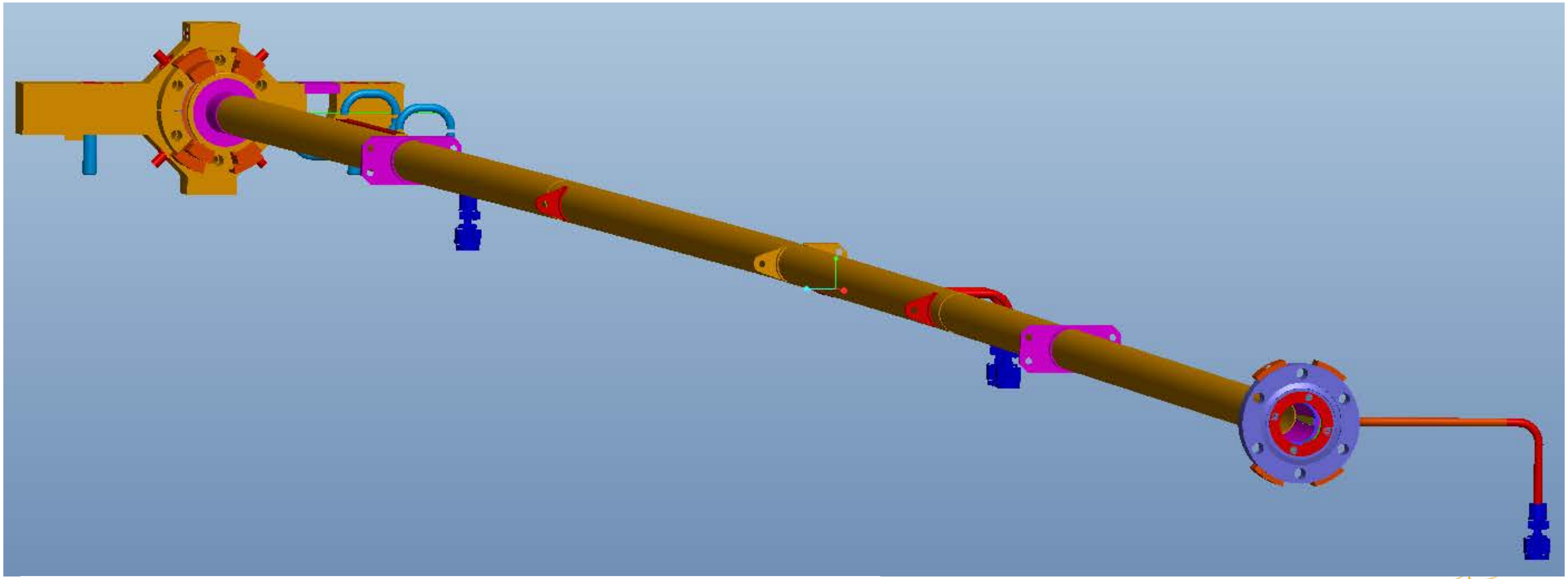


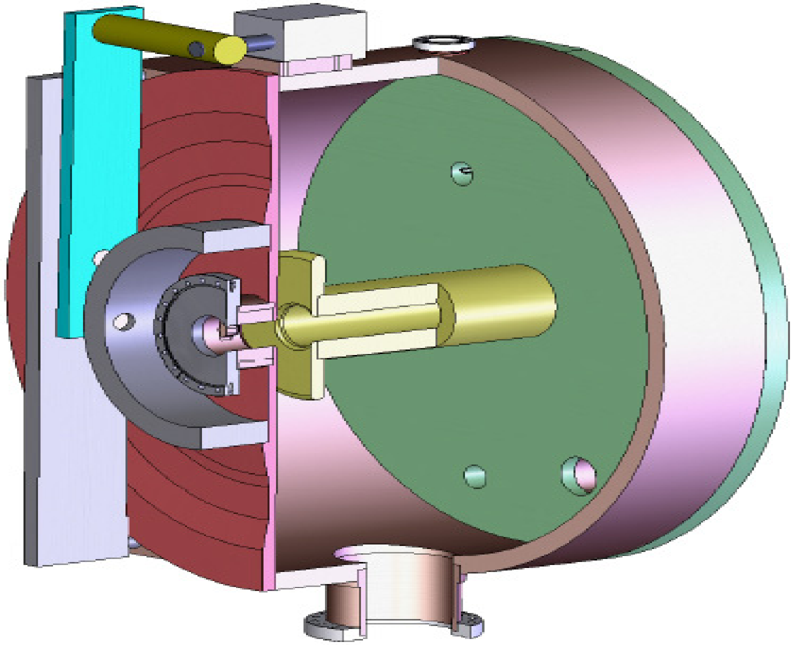
Slide by Martin Johansson

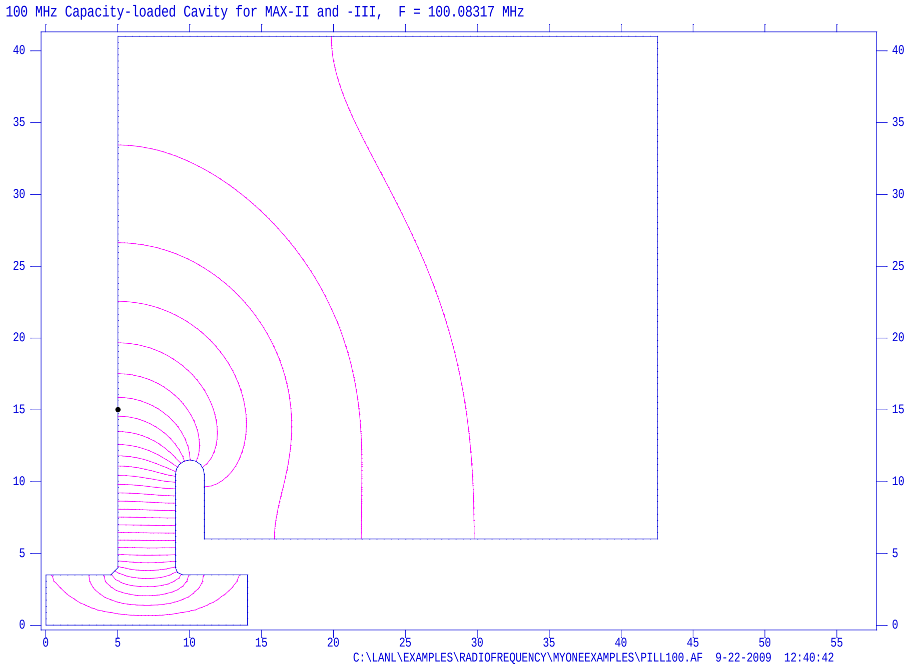
Cu, NEG-coated MAX IV Vacuum chamber



- BPM Bodies fixed to the Blocks.
- Geometry is as symmetrical as possible – if heat load changes , dimensions change but center (nearly) does not move.






100 MHz Capacity-loaded Cavity for MAX-II and -III, F = 100.08317 MHz
0
5
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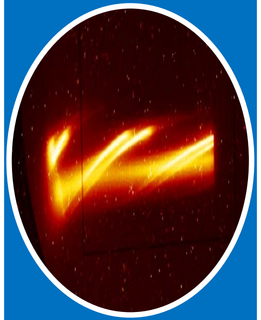
March 2016

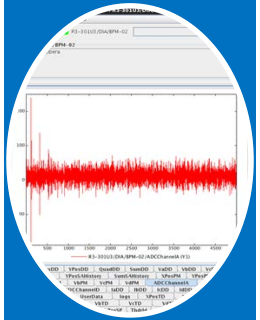
3 GeV Ring Commissioning Timeline



Beam in TR3

Aug 11

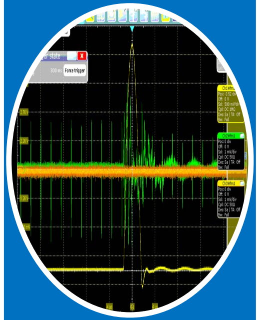
2015



First Turn

Aug 25

2015

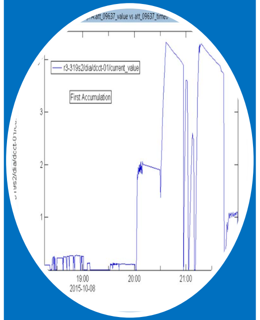


Stored Beam

0.1 mA

Sep 15

2015



Stacking

4 mA

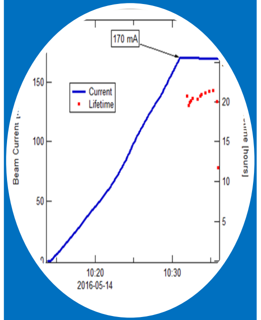
Oct 08

2015

First Light

Nov 2

2015

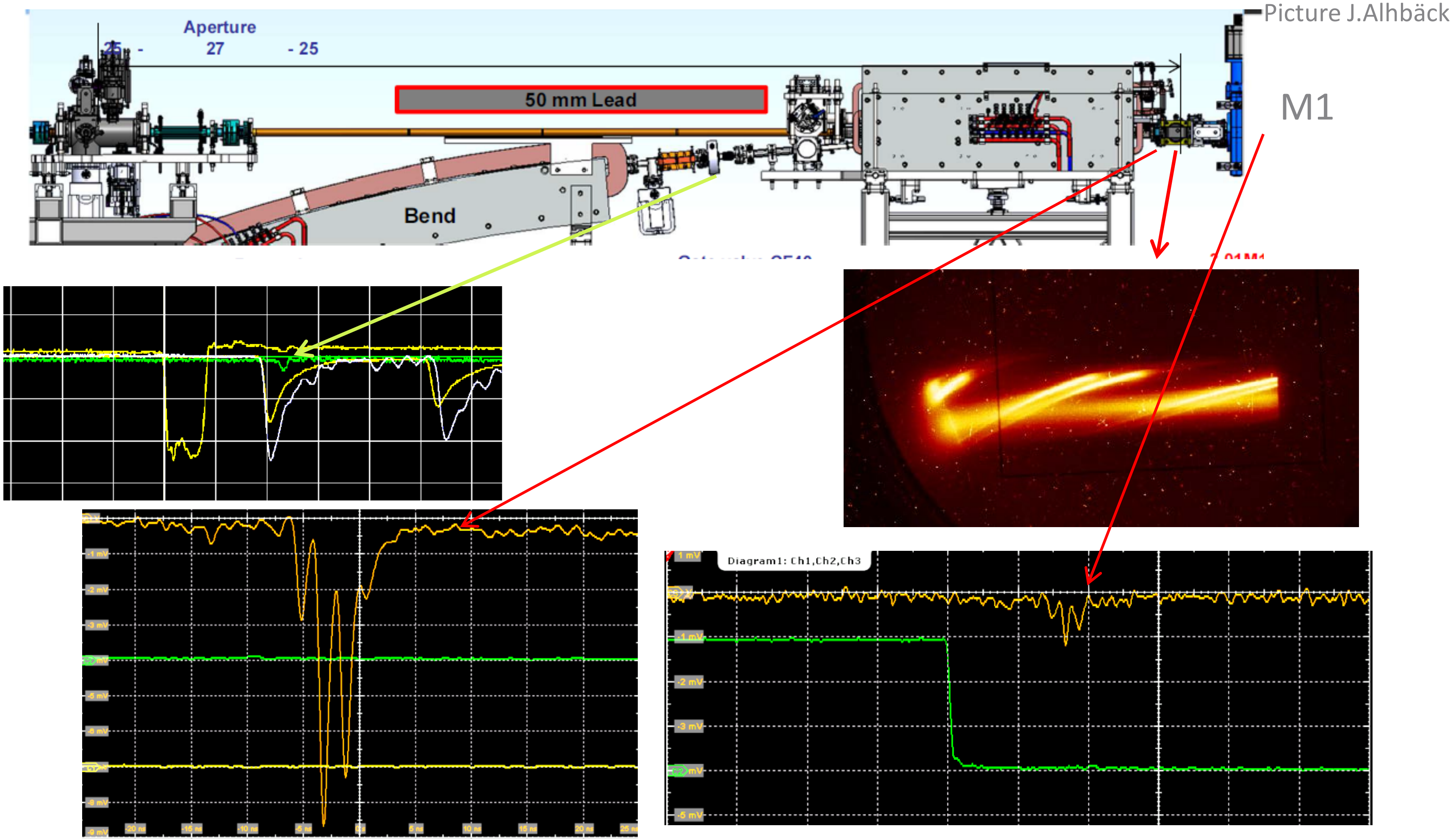


170 mA

May 14

2016

Early Commissioning Results

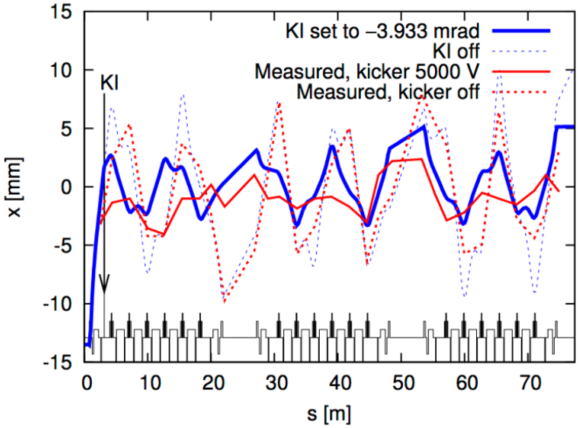


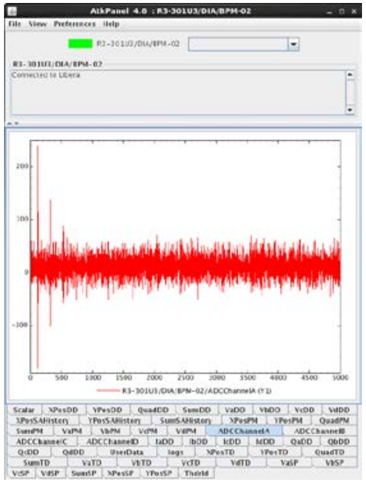
Picture J.Alhbäck

- Beam observed at the end of TR3 and into the ring.

2015/08/11

Threading the beam – first turn – many turns



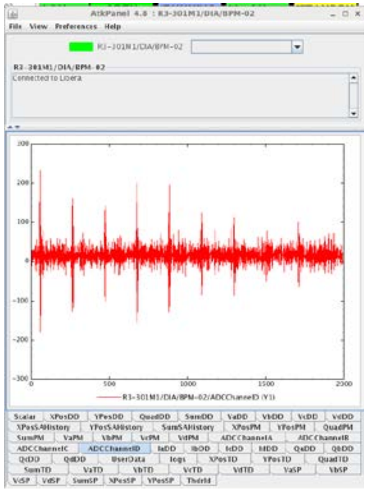


Connected to Libera

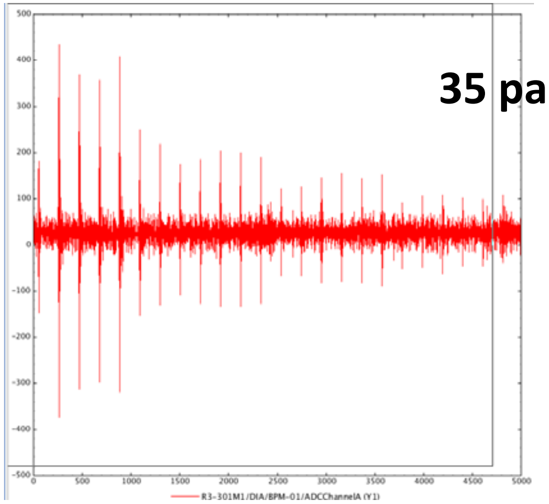
2015/08/25

3 passes

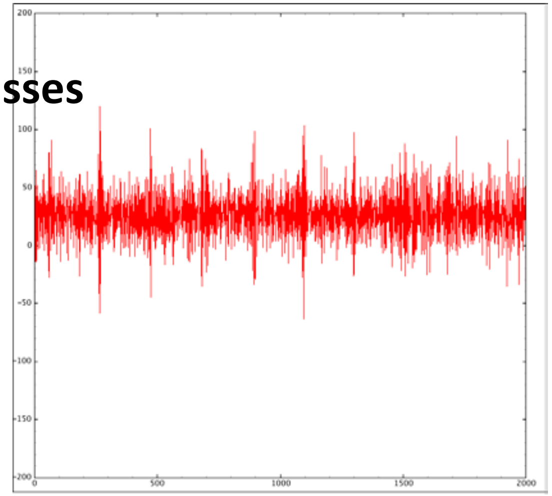
All correctors OFF



Connected to Libera



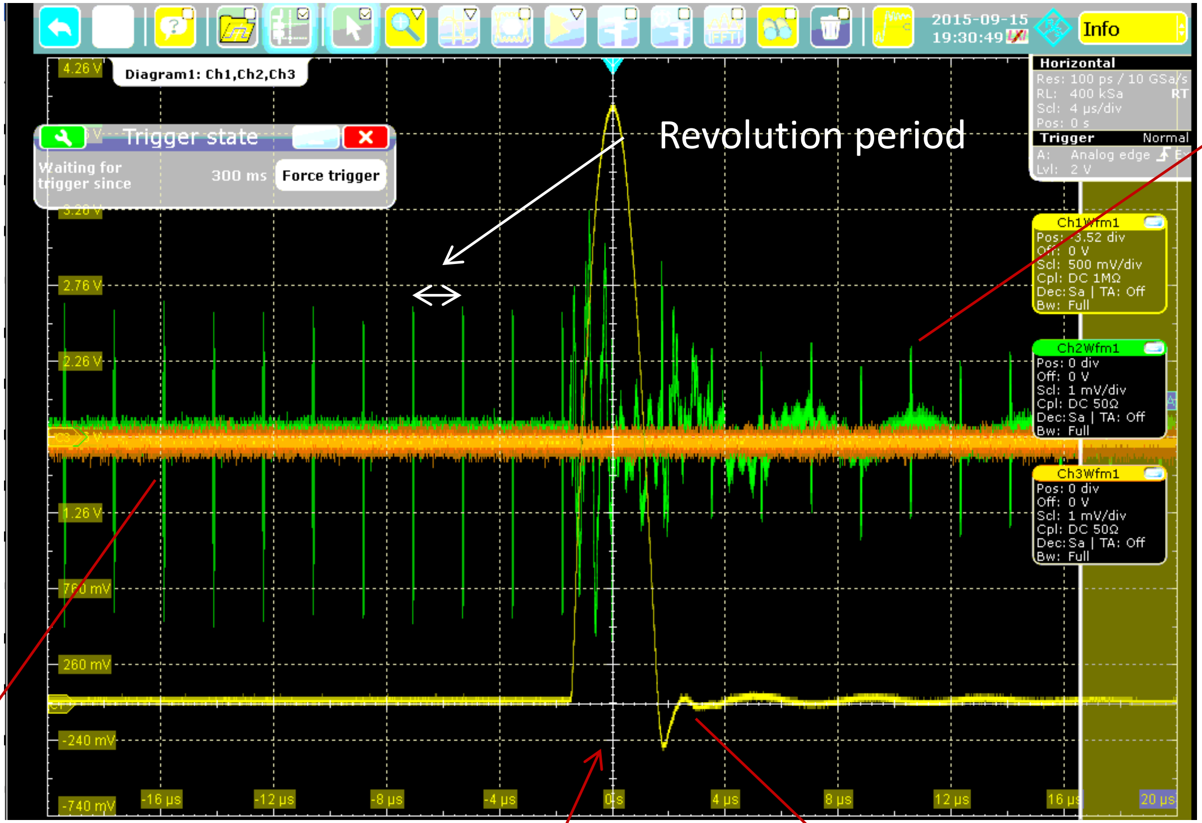
35 passes



2015/08/26

2015/08/27

First Stored Beam



Waiting for trigger since 300 ms

Horizontal
Res: 100 ps / 10 GSa/s
RL: 400 kSa RT
Scl: 4 µs/div
Pos: 0 s

Trigger Normal
A: Analog edge
Lvl: 2 V

Ch1Wfm1
Pos: 3.52 div
Off: 0 V
Scl: 500 mV/div
Cpl: DC 1MΩ
Dec: Sa | TA: Off
Bw: Full

Ch2Wfm1
Pos: 0 div
Off: 0 V
Scl: 1 mV/div
Cpl: DC 50Ω
Dec: Sa | TA: Off
Bw: Full

Ch3Wfm1
Pos: 0 div
Off: 0 V
Scl: 1 mV/div
Cpl: DC 50Ω
Dec: Sa | TA: Off
Bw: Full

Revolution period

Injected beam

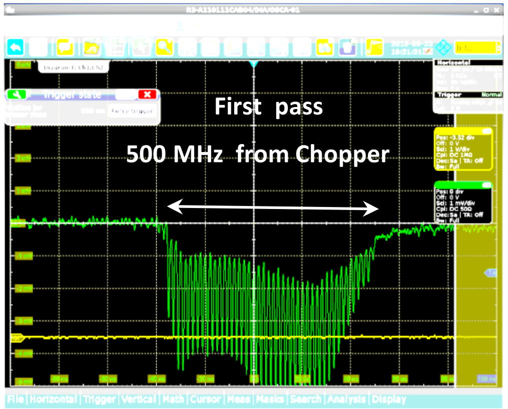
Stored beam 2 seconds after previous injection pulse

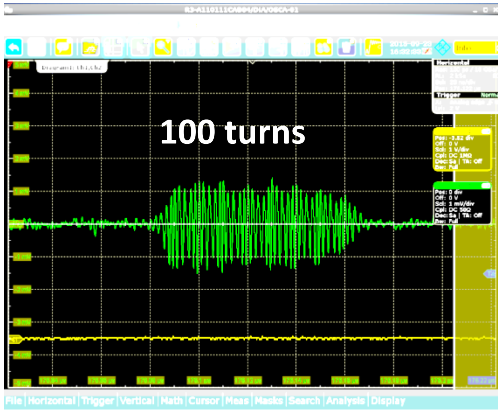
Injection

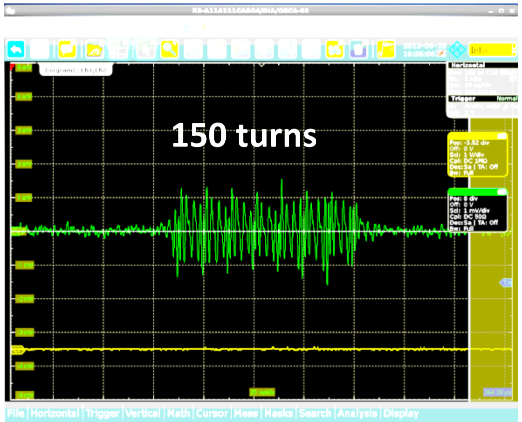
Kicker Current

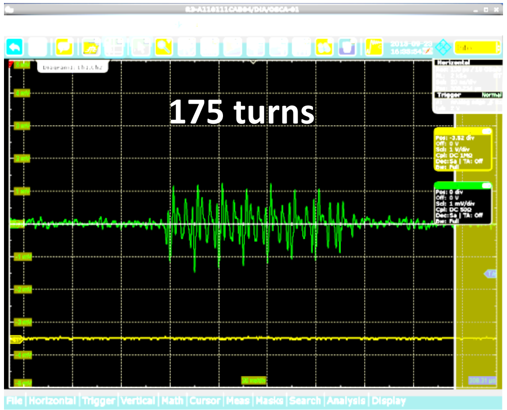
2015/09/15

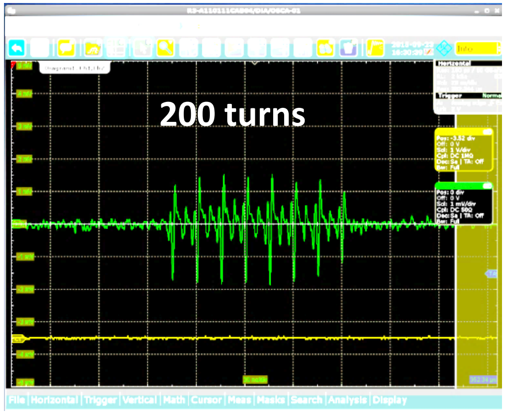
Capture and Bunching







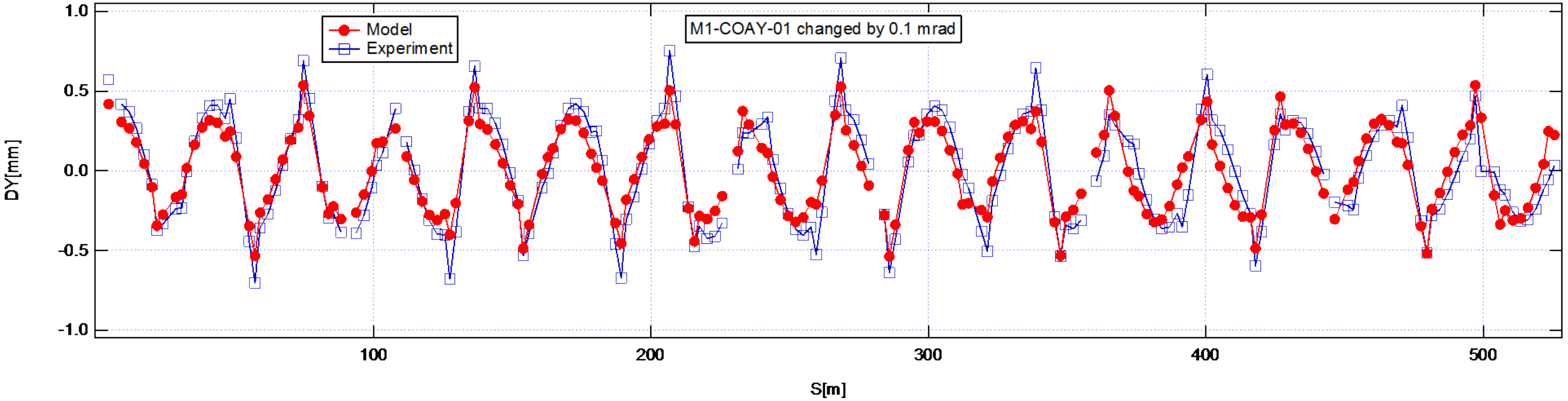


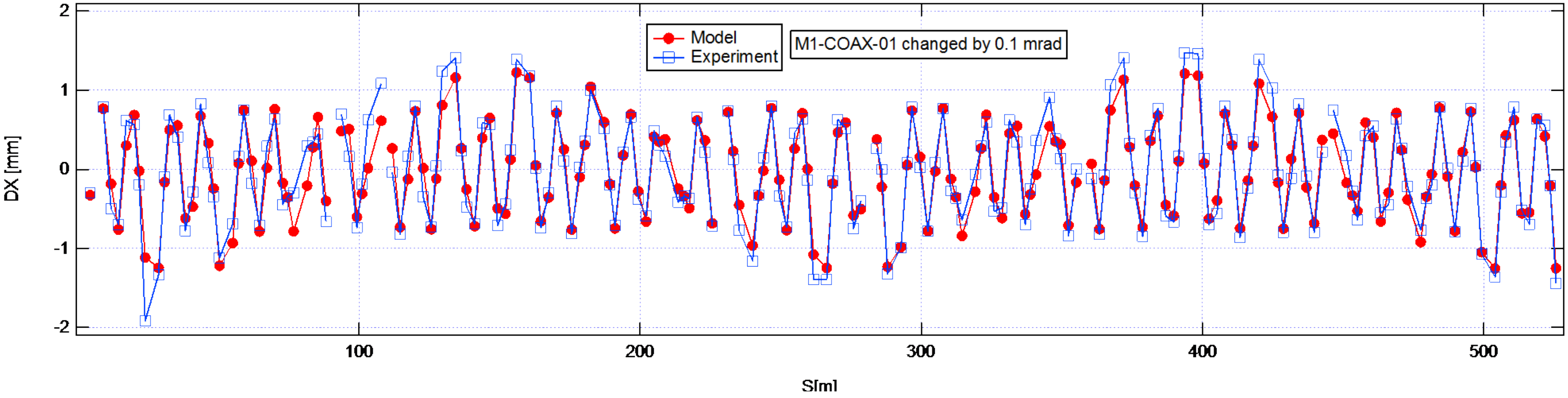


Plots S.Leeman

2015/09/23

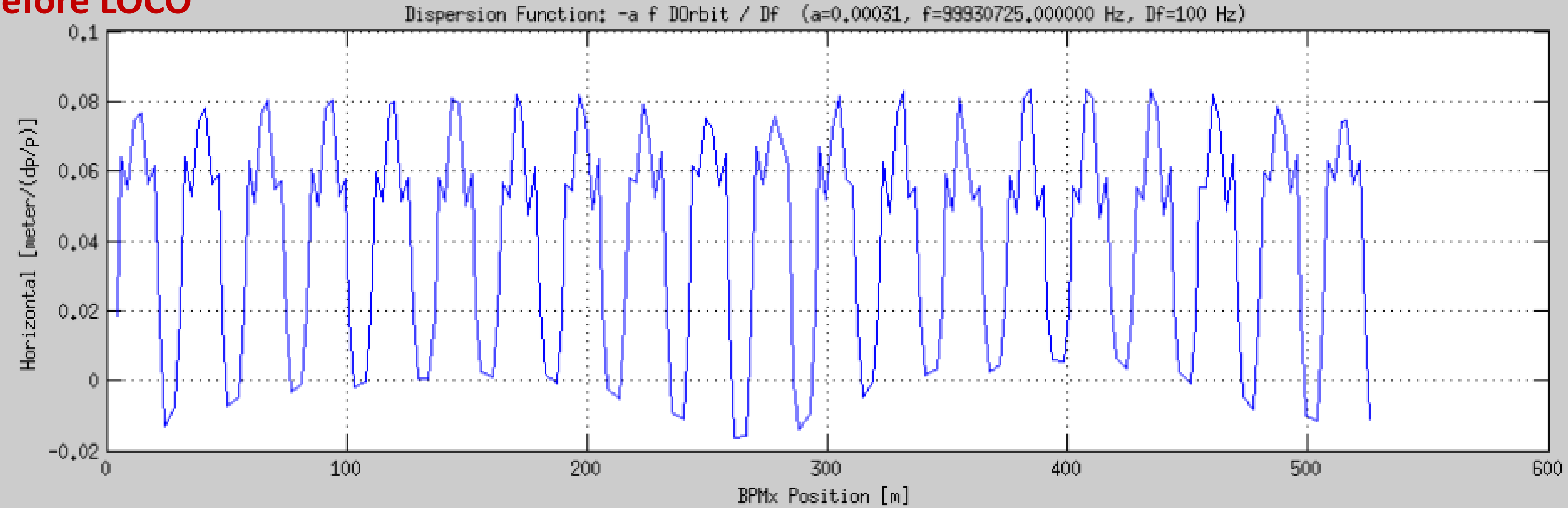
Linear Optics Characterization: Integer Tunes



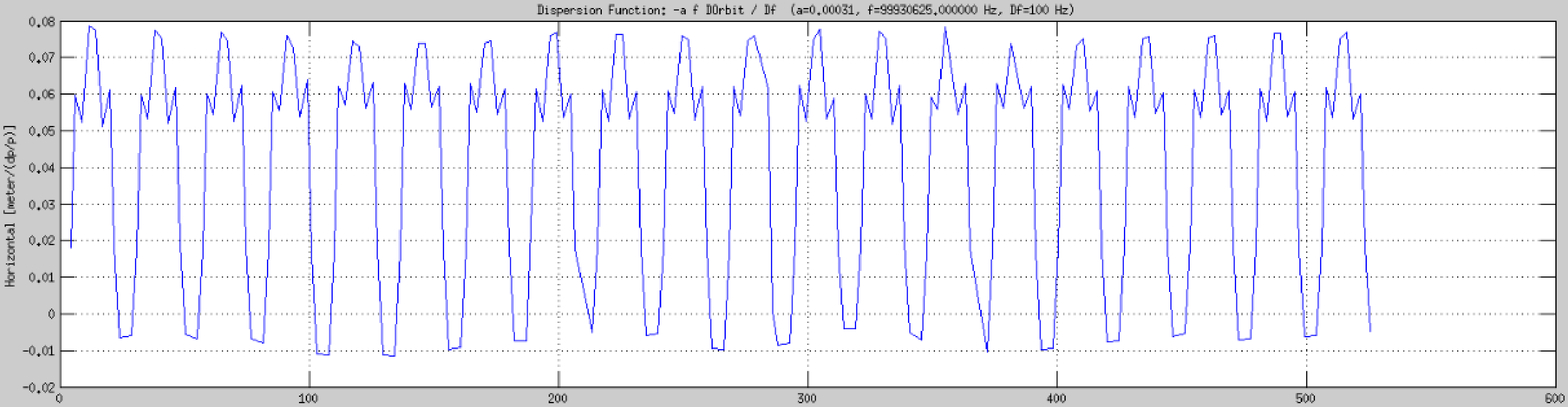


LOCO: reduction in dispersion beating

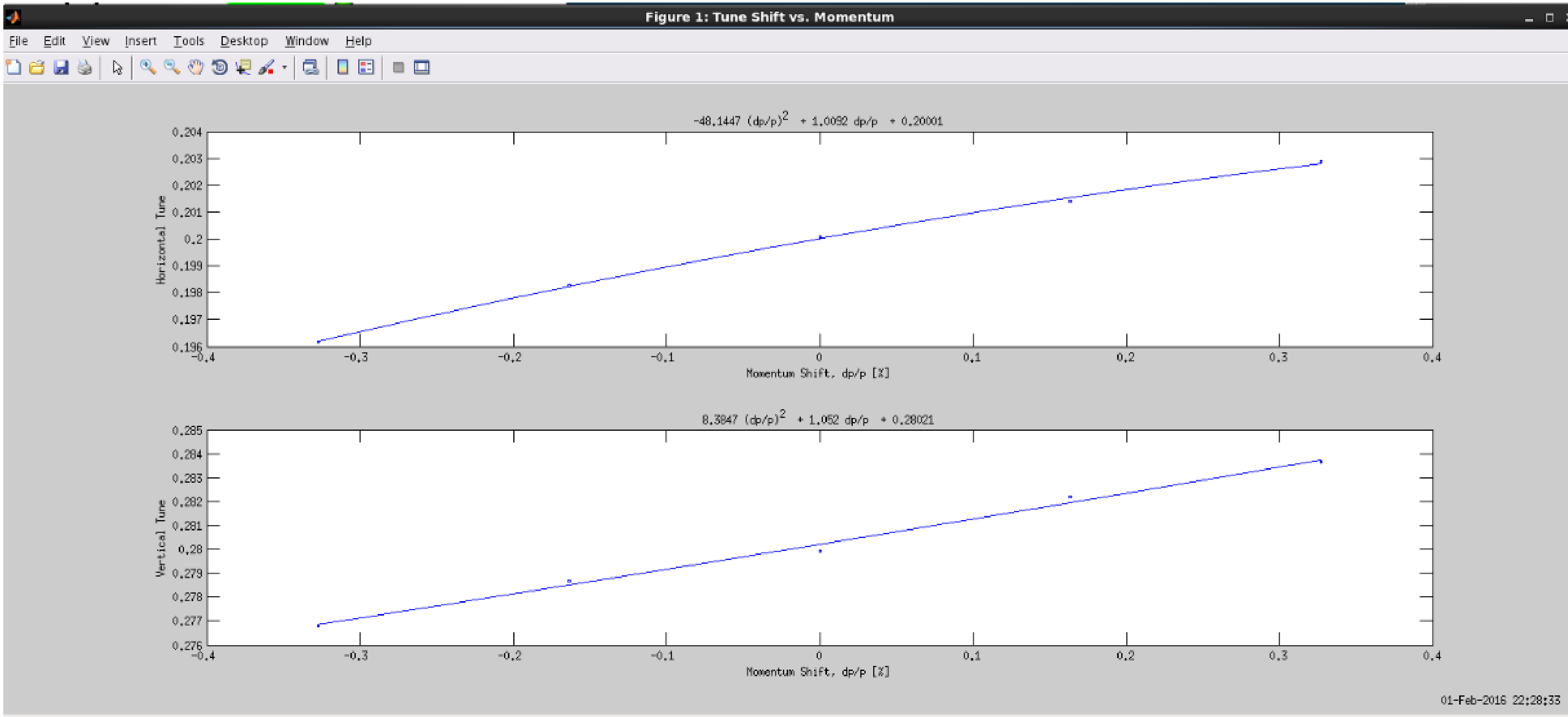
Before LOCO



After LOCO



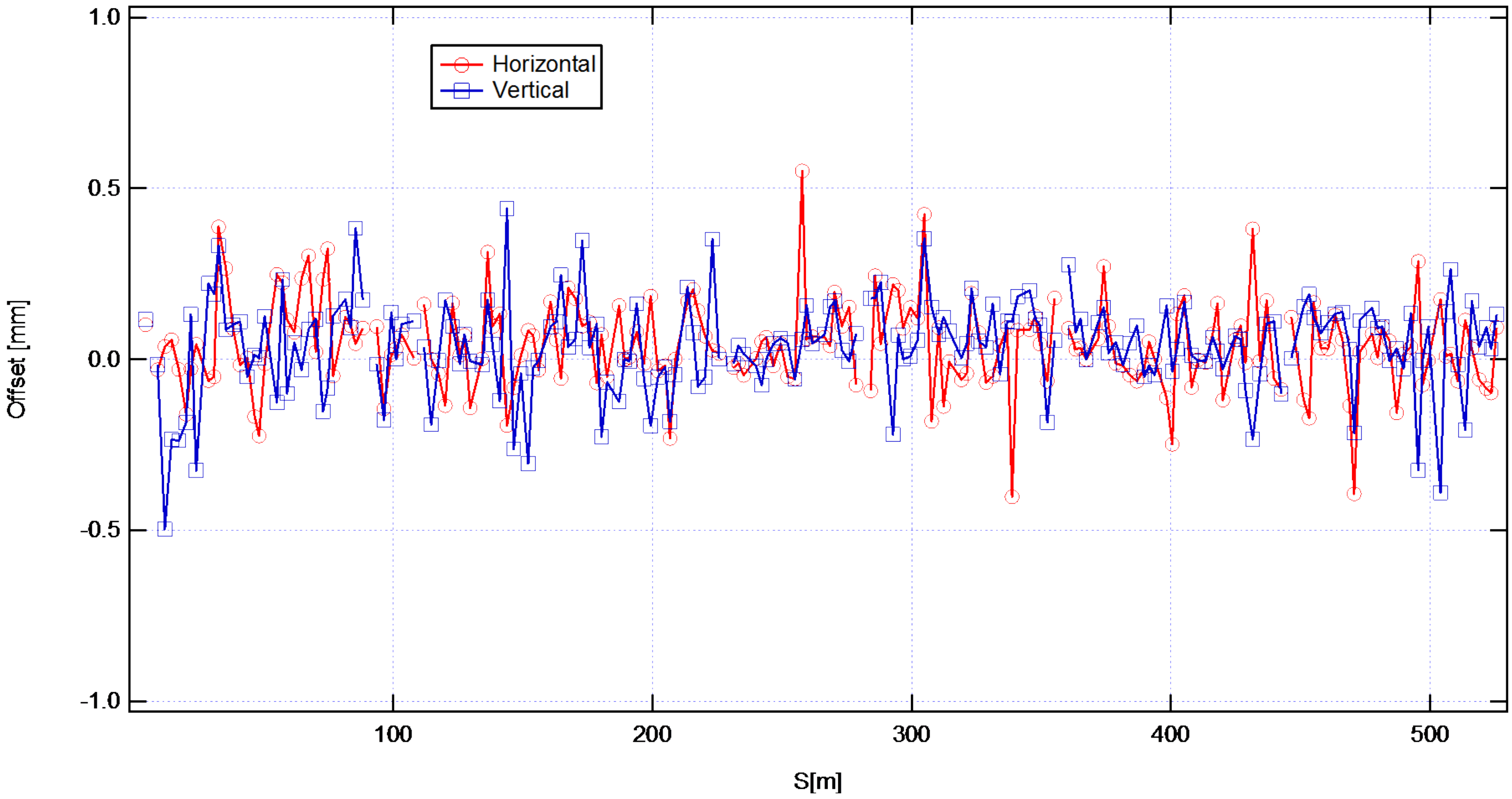
Chromaticities:



BPM Offsets

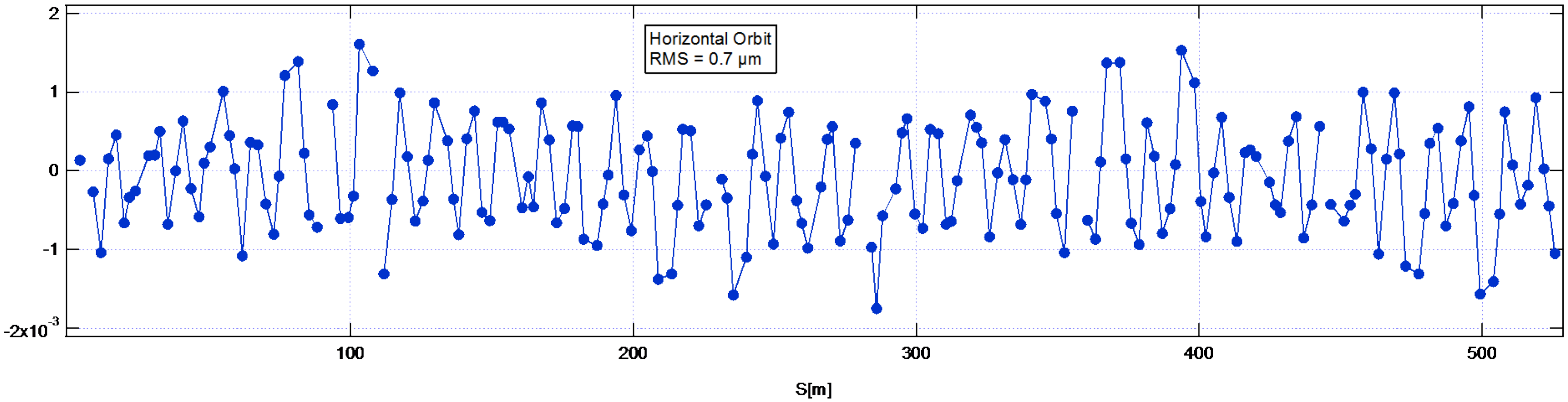
- Measured by BBC using trim coils in sextupole magnets

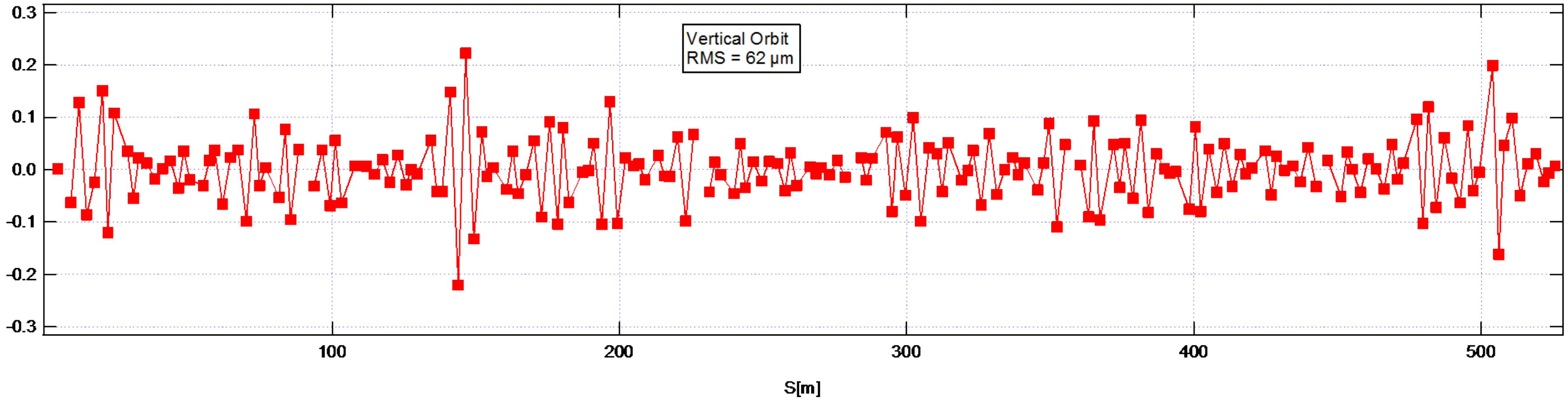
RMS: 144 µm H / 138 µm V



Orbit Correction

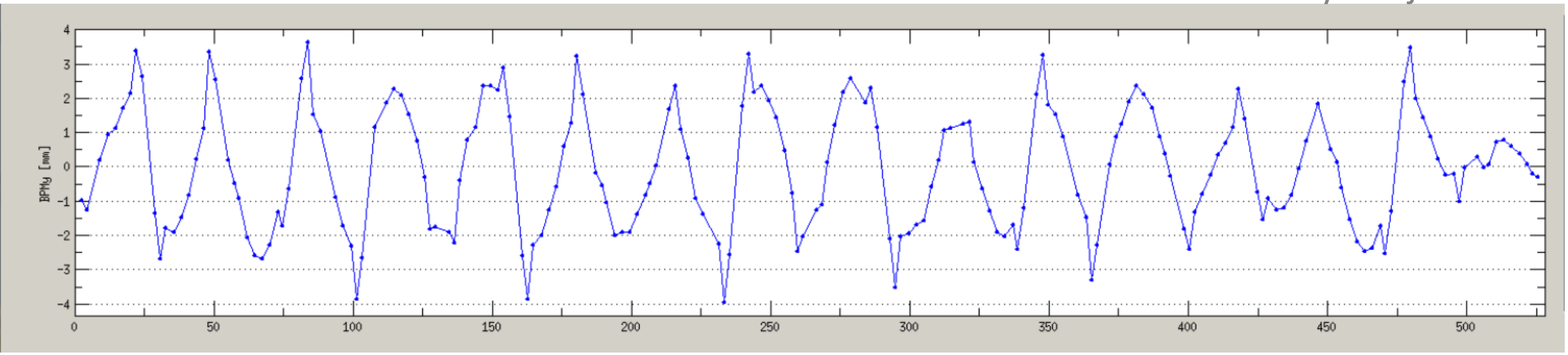
Residual RMS: 0.7 µm H / 62 µm V

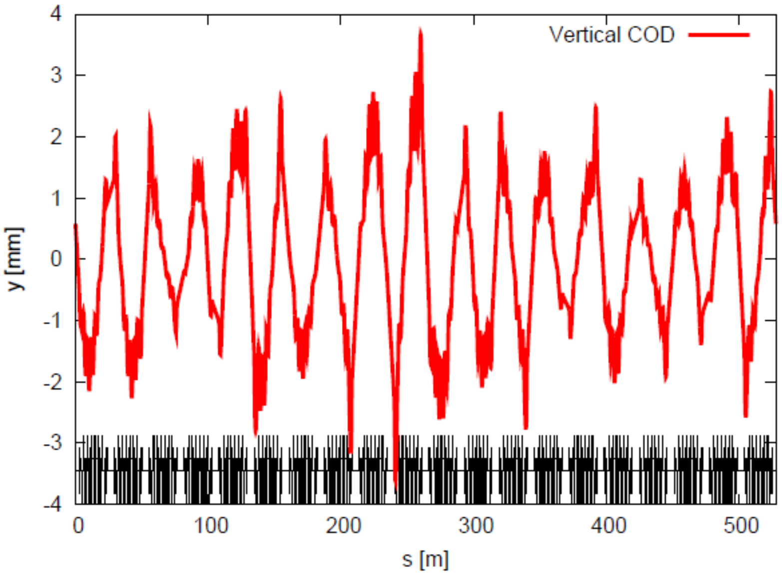




Bare Vertical Orbit

Plot by M.Sjöström

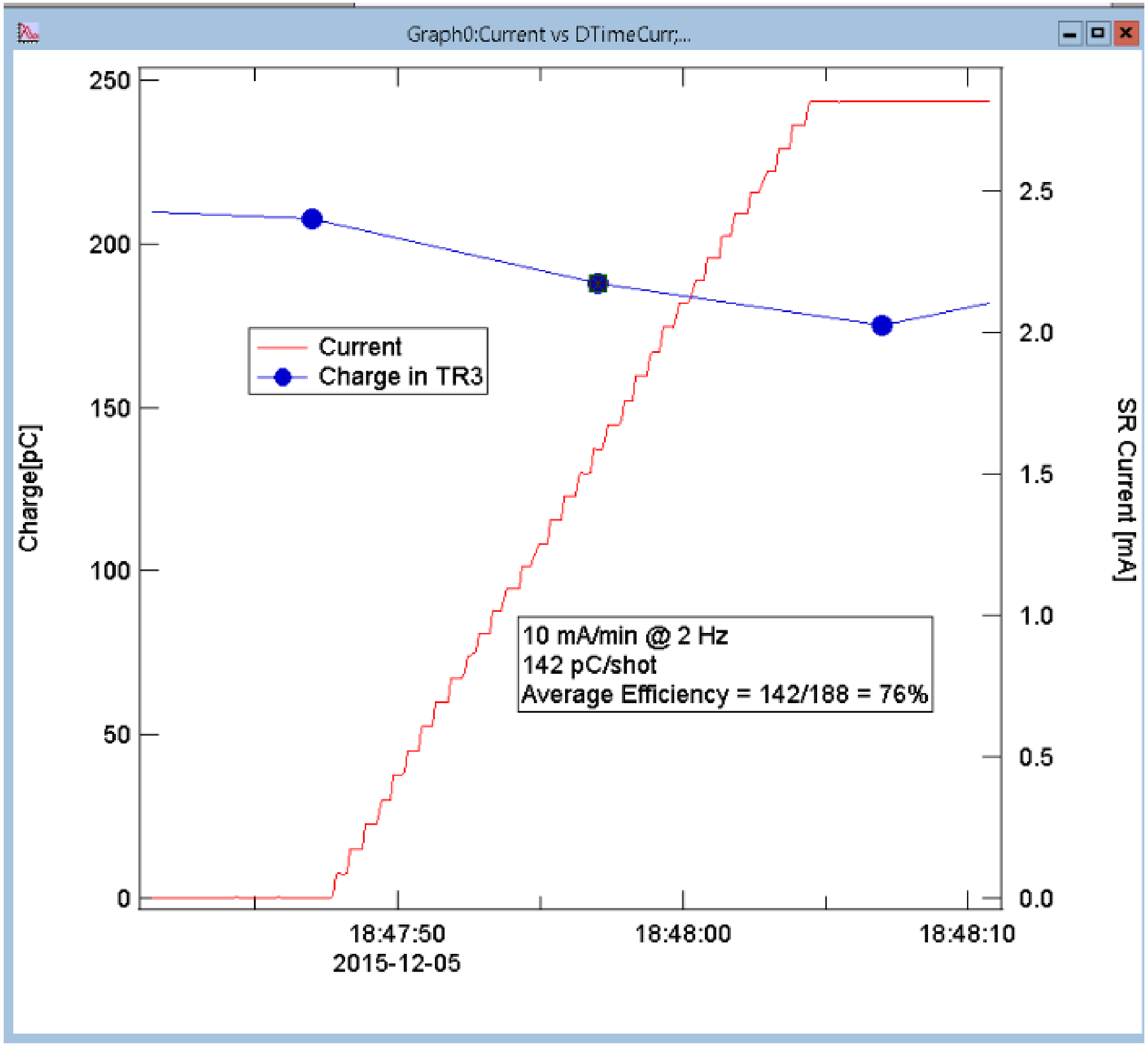




Example calculation for one random seed

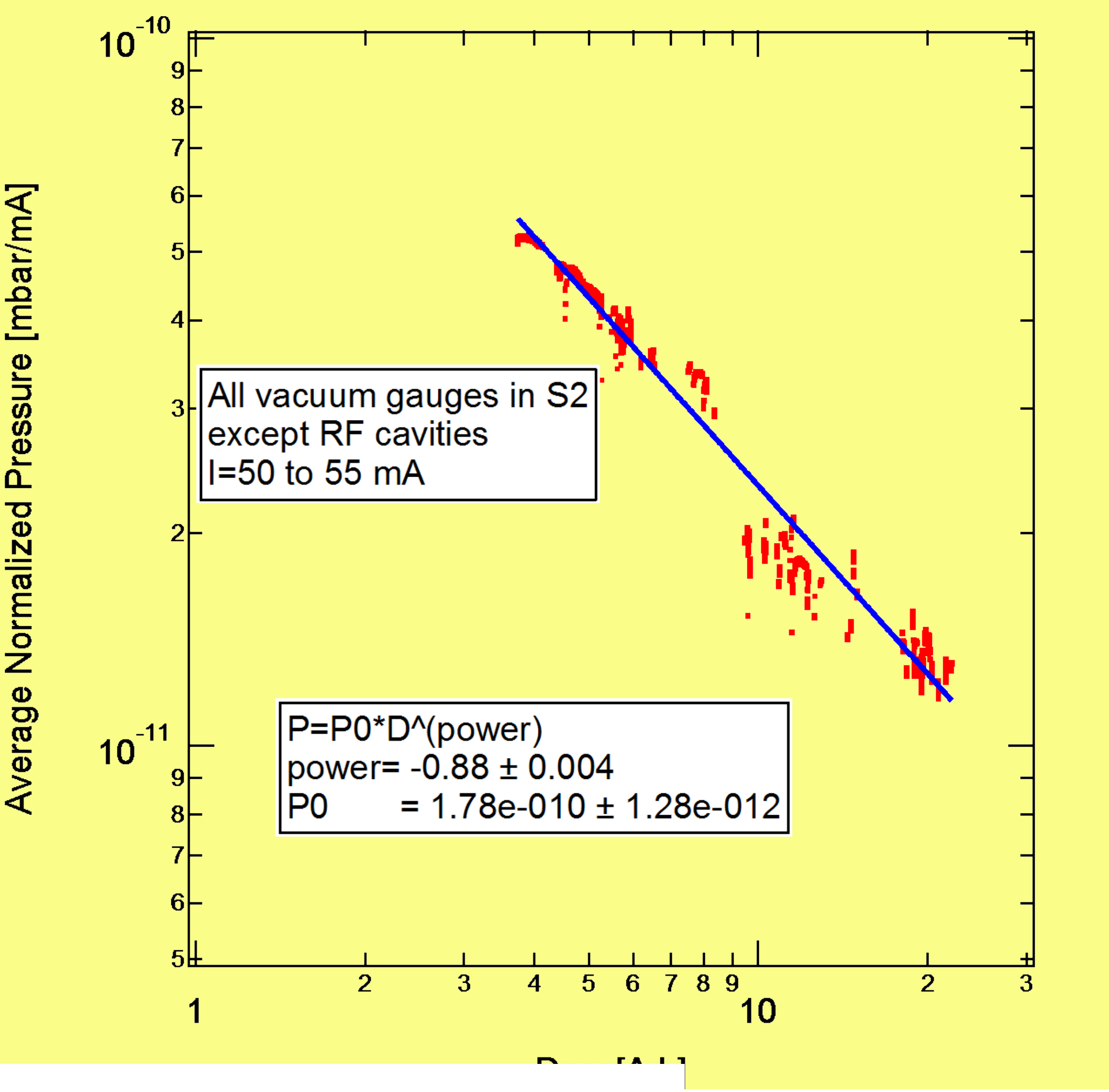
MAX-lab Internal Note 201211071 by S.Leemann

Injection Efficiency - 2



10 mA/min @ 2 Hz
142 pC/shot
Average Efficiency = 142/188 = 76%

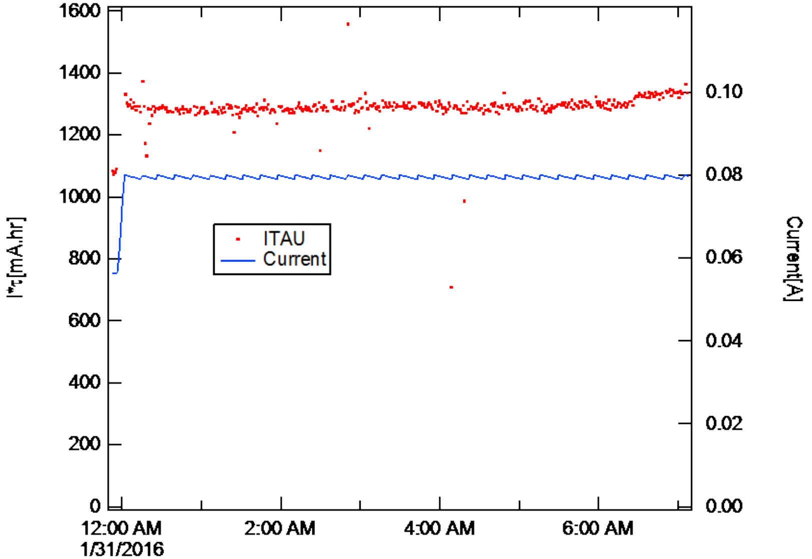
Vacuum Conditioning - pressure

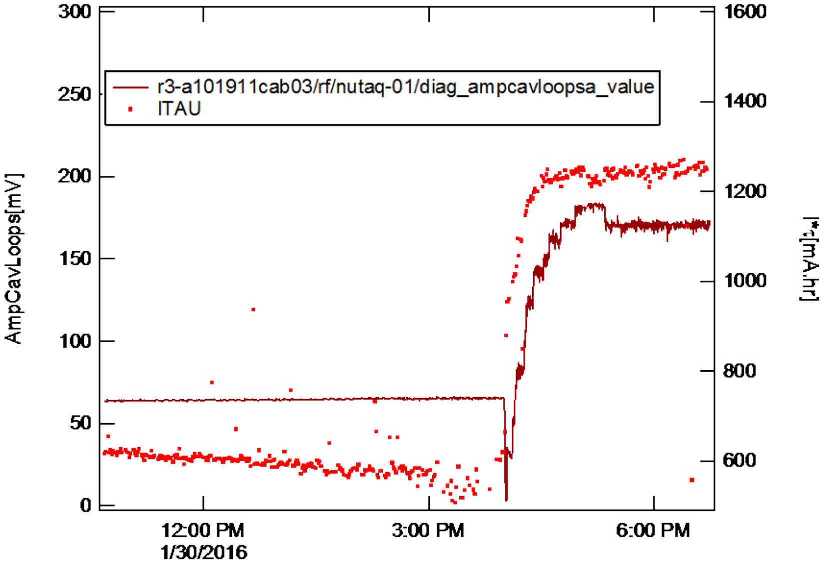


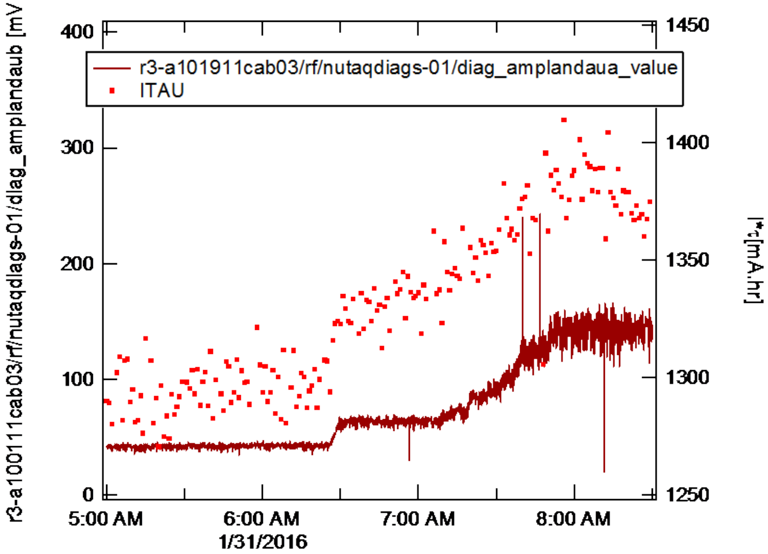
All vacuum gauges in S2
except RF cavities
I=50 to 55 mA

P=P0*D^(power)
power= -0.88 ± 0.004
P0 = 1.78e-010 ± 1.28e-012

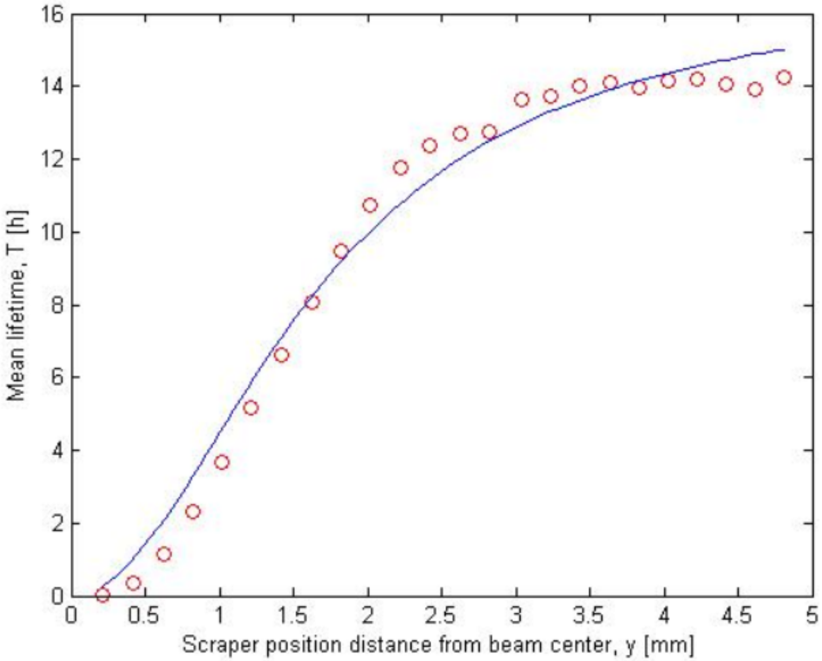
Beam Lifetime



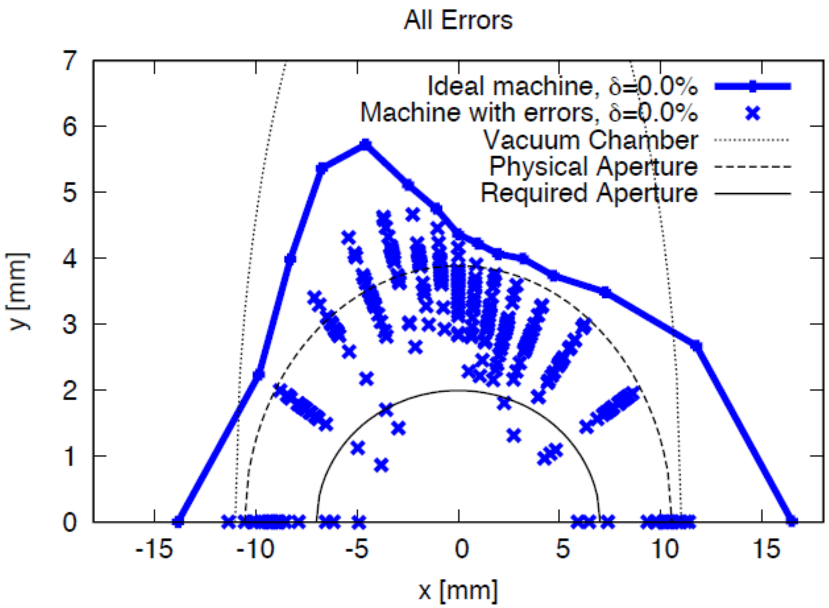




Aperture Scans – scraper measurements



Plot by Jens Sundberg

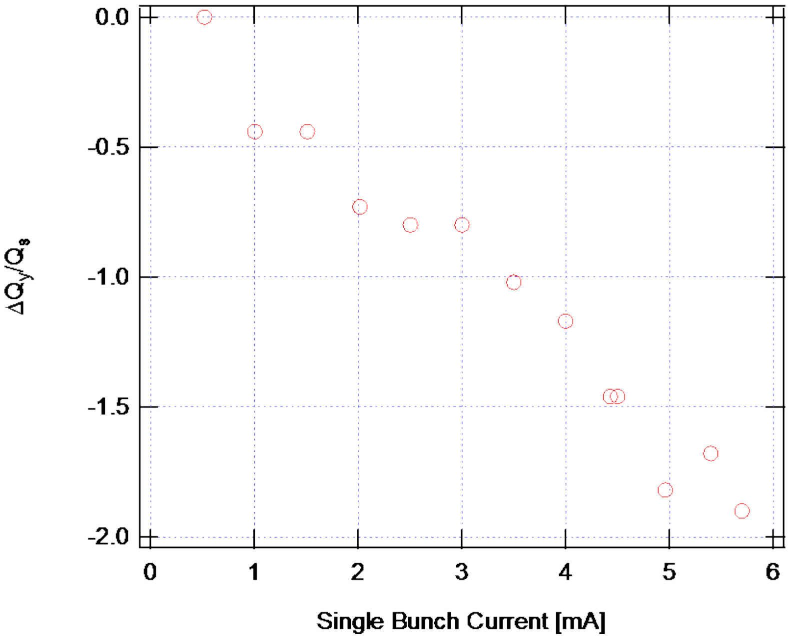


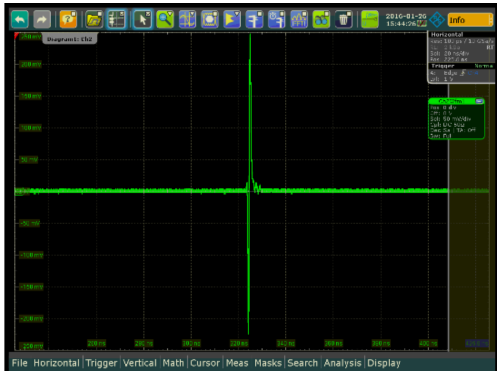
2011 simulations by S.Leemann

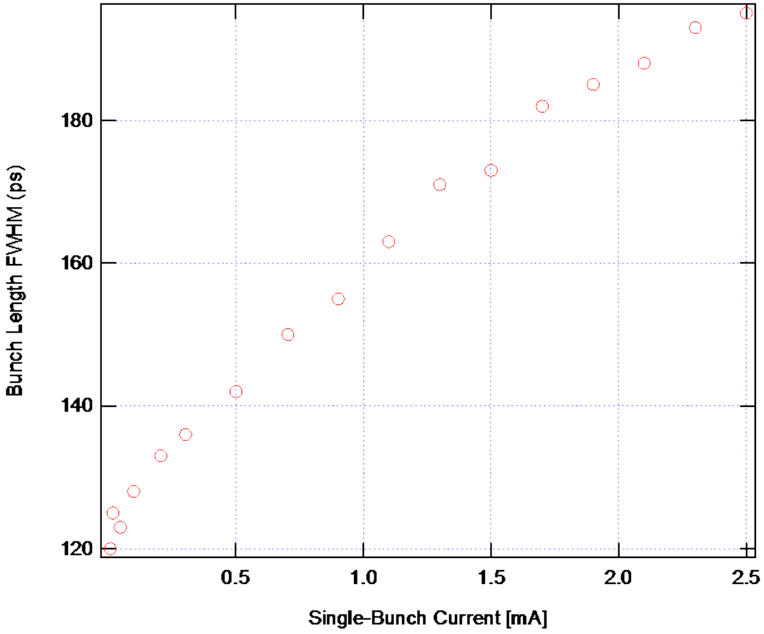
Vertical aperture scaled to center of LS 2.3 mm

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







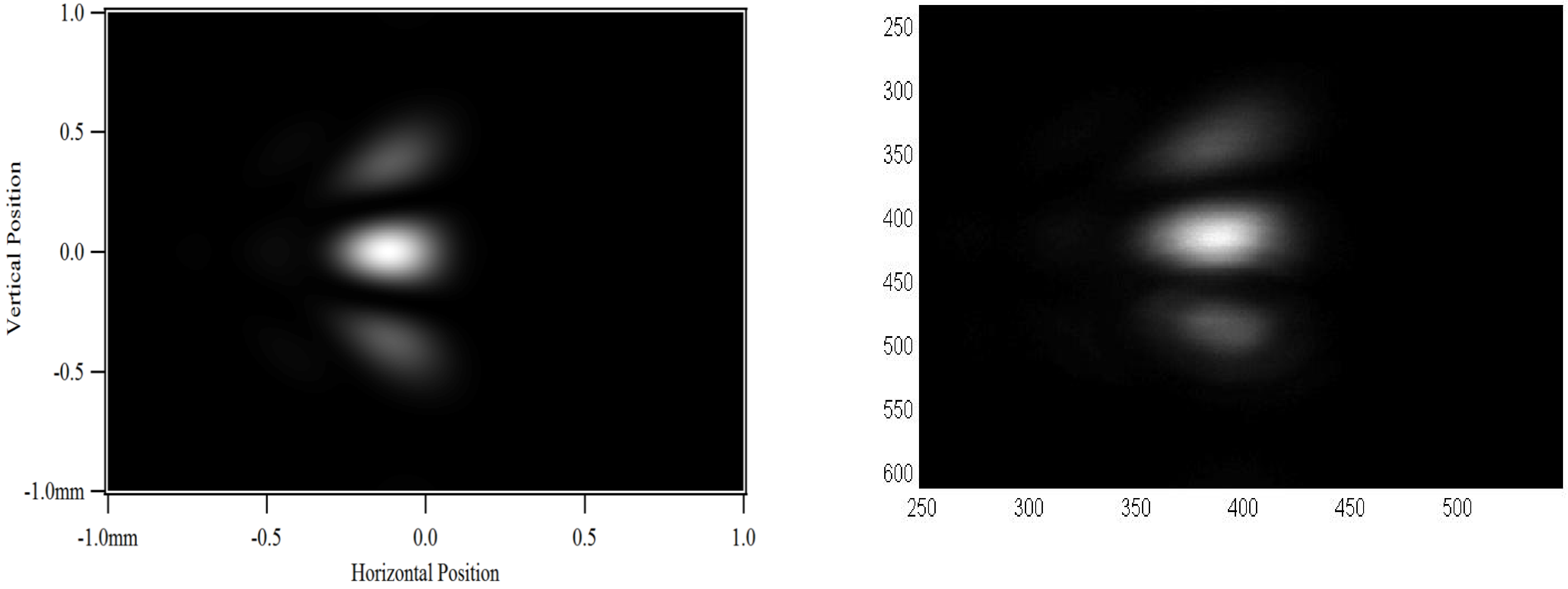
Data by J.Breunlin, A.Andersson, G.Skripka, R.Nagaoka

Collective Effects - Multibunch

- Possible to store >120 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.
- Harmonic Cavities not fully tuned-in in yet. Need more conditioning
- Preliminary BBB feedback tests using a short stripline showed a longitudinally stable beam up to 35 mA.
- Longer striplines for BBB feedback to be installed in february
- Longitudinal Actuator (cavity) under design

Emittance Measurement

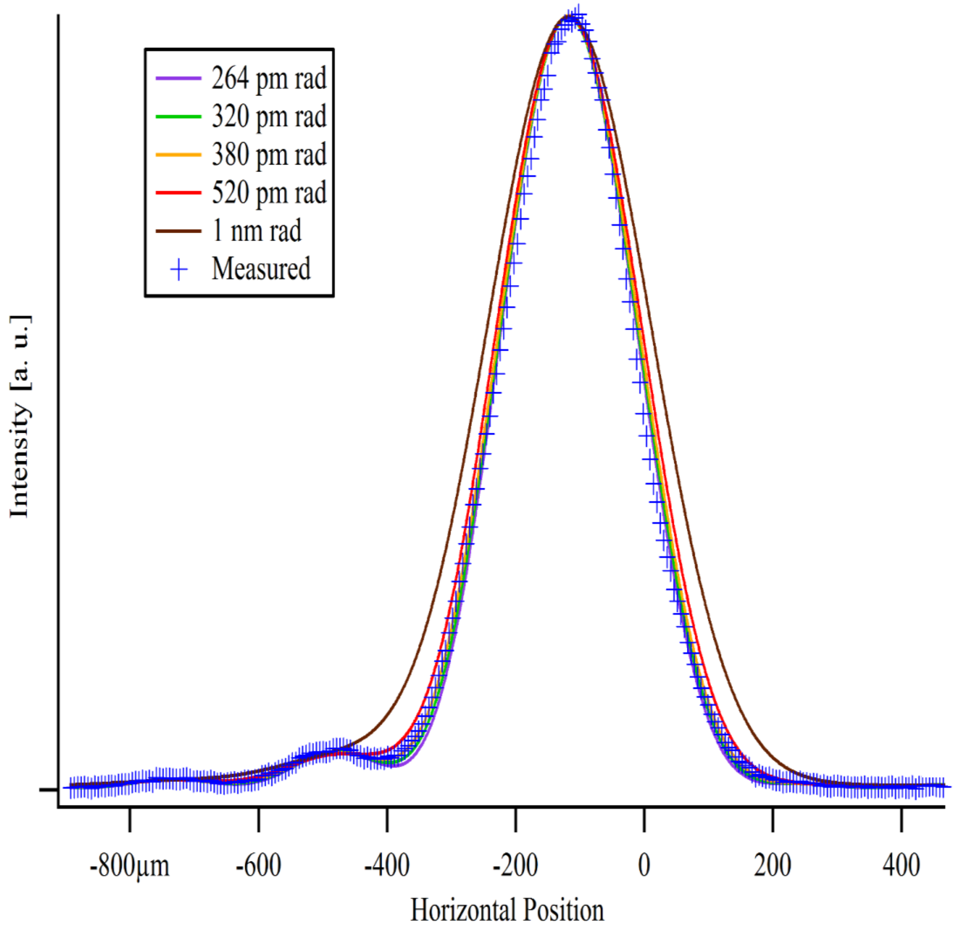
Slide by J.Breulin

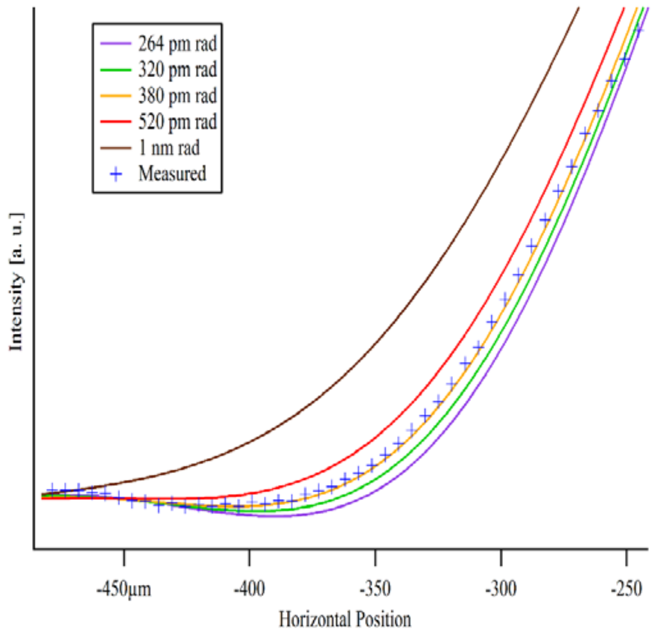


Sigma polarized SR, 632.8 nm, SRW calculation (left) and measured image (right). The simulation is done for $\varepsilon_x = 320$ pm rad, $\beta_y = 1.5$ m.
Both figures show a 2 x 2 mm^2 area of the image plane.
The fringe pattern is too weak to be visible.

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.

MAX IV

Main Problems/Difficulties

- RF Cavity Conditioning
- RF System commissioning (LLRF, Shunt Groups)
- Diagnostic System Commissioning
  - BPMs
- Kicker Magnet PS failure
- Gun Klystron Failures
- Long Radiation Surveys
- Cooling System Failures
- Control System Commissioning
- PS Failures

Help from friends:

BINP: Vacuum system installations

ESRF: Complicated NEG coating

MAC: Most valuable advices

Solaris: Operations

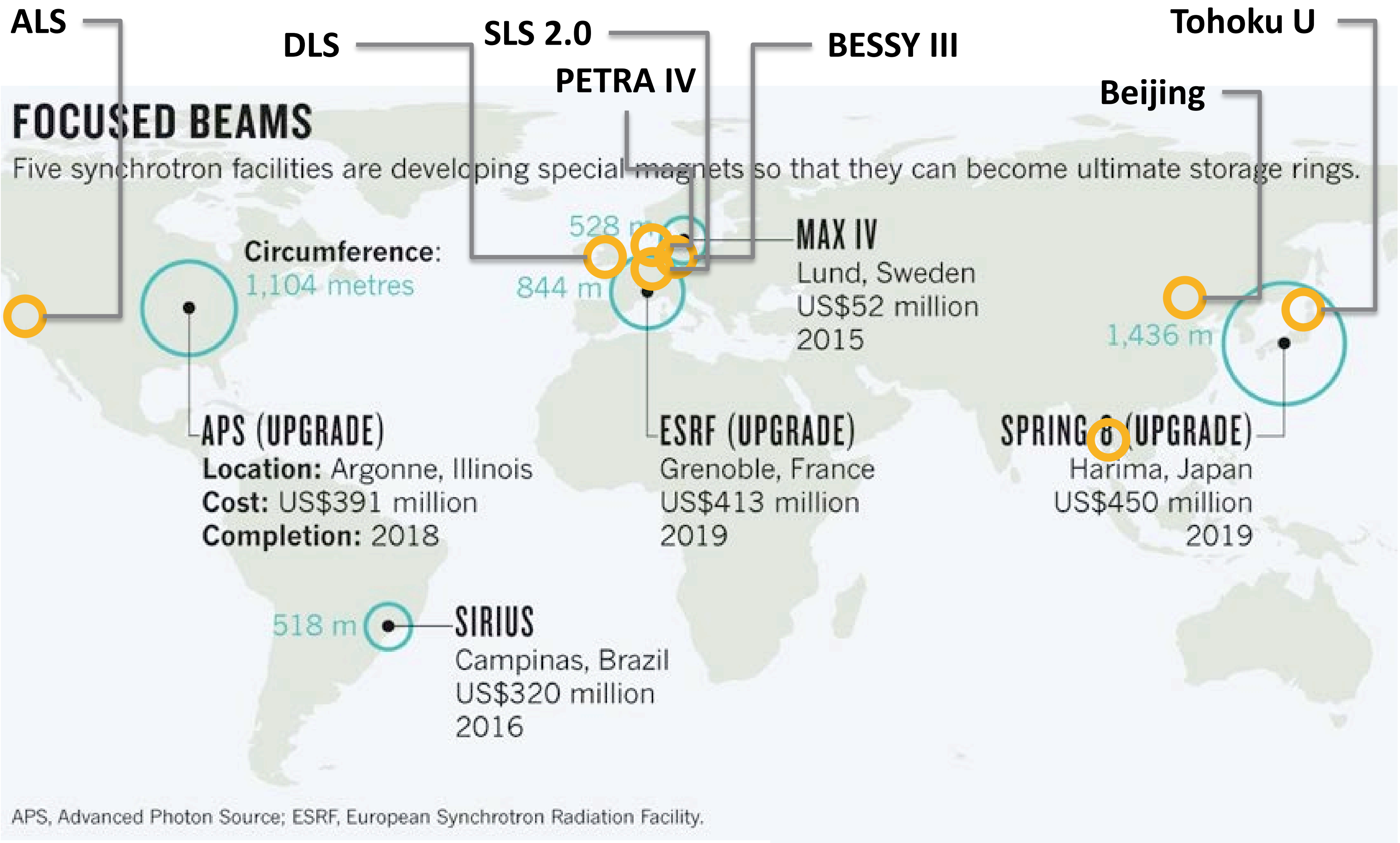
DESY: RF components

And many more…

Conclusions

- Progress with the initial phase of MAX IV 3 GeV ring commissioning gives us increased confidence that the MBA concept is sound.
- Much is still to be done to reach the final design specifications, but nothing indicates there is any fundamental obstacle ahead.
- Most difficulties are related to technical subystems that need time for conditioning/maturing

MAX IV: Forerunner of a new breed of accelerators



FOCUSED BEAMS

Five synchrotron facilities are developing special magnets so that they can become ultimate storage rings.

APS (UPGRADE)
Location: Argonne, Illinois
Cost: US$391 million
Completion: 2018

MAX IV
Lund, Sweden
US$52 million
2015

ESRF (UPGRADE)
Grenoble, France
US$413 million
2019

SPRING-8 (UPGRADE)
Harima, Japan
US$450 million
2019

SIRIUS
Campinas, Brazil
US$320 million
2016

APS, Advanced Photon Source; ESRF, European Synchrotron Radiation Facility.

Thank You !


Photo:H.Tarawneh


Photo:S.Thorin

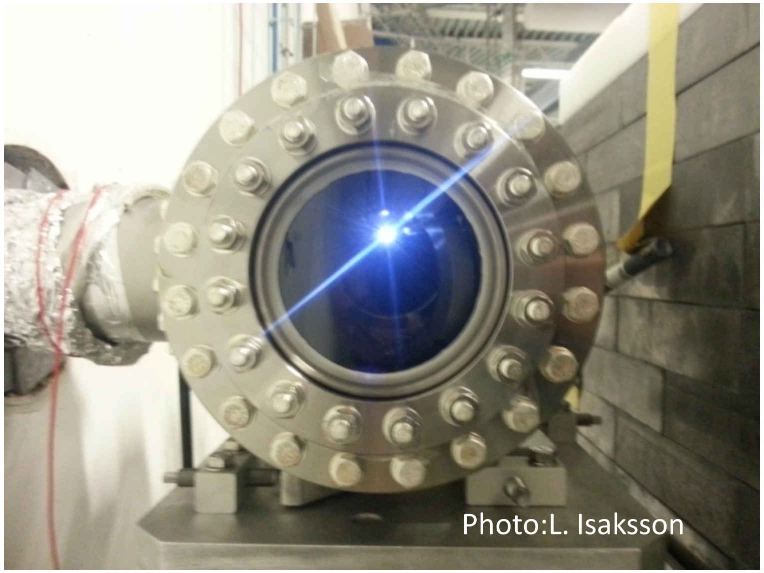


Photo:L. Isaksson