HZB BESSY II Light Source

BESSY II

status & upgrade

14.12.2022

Meghan McAteer on behalf of the machine group

ESLS 2022

ESRF

BESSY II Machine Group

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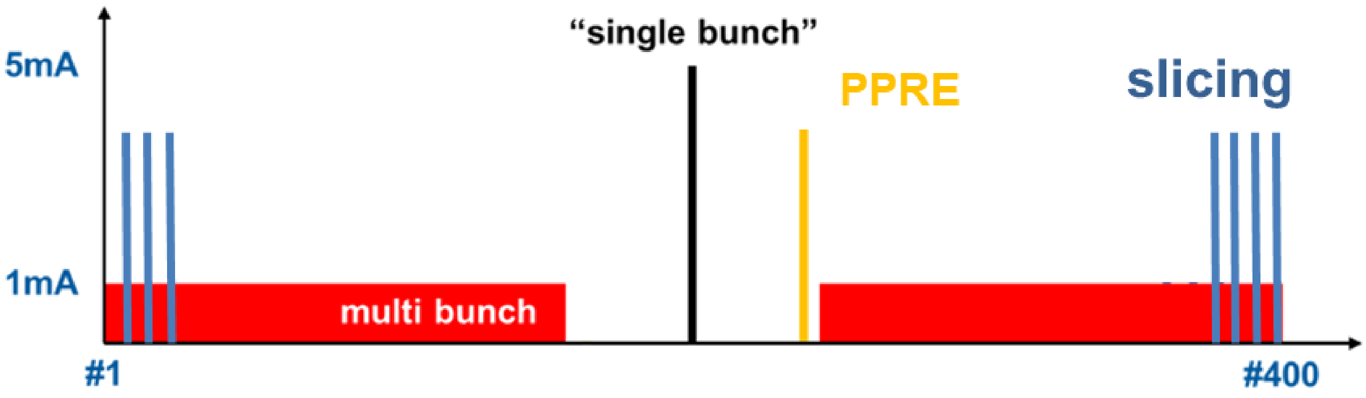
and many more



Parameters	
Energy	1.7 GeV
Circumference	240 m
Horizontal emittance	7 nm rad
Beam current	300 mA
RF frequency	500 MHz
max. RF voltage	2 MV
Bunch length (zero current) low-α	10 ps 2 ps
Mom. Comp. factor low-α	7.5×10^{-4} 3.5×10^{-5}

- in user operation since 1998
- diverse user community
- offering short x-ray pulses and timing

Outline

- Operation status
- Economy and energy plan
- Developments, upgrades, plans

Operation Status

OPERATION SCHEDULE FOR 2022

--	Access - no beam
AS	Accelerator Start-up
CU	Commissioning/User user shift
FB	Few Bunch Mode user shift
low-a	Low-alpha user shift
MB	Multi bunch user shift
MC	ID/beamline Commissioning
MS	Machine Studies
PTB	special PTB
SB	Single bunch user shift
SC	set-up/commissioning
SD	Maintenance shut down
Test	Test mode user shift
W	beam scrubbing

Beamtime: 2022/1 — Month: January, February, March

Week	operation-mode	Day
52	SD	1 2
1	MS	3 4 5 6 7 8 9
2	MB	10 11 12 13 14 15 16
3	MB	17 18 19 20 21 22 23
4	MB	24 25 26 27 28 29 30
5	MB	31 1 2 3 4 5 6
6	SB	7 8 9 10 11 12 13
7	MC	14 15 16 17 18 19 20
8	low-a	21 22 23 24 25 26 27
9	MB	28 1 2 3 4 5 6
10	MB	7 8 9 10 11 12 13
11	MB	14 15 16 17 18 19 20
12	MS	21 22 23 24 25 26 27
13	MB	28 29 30 31

Beamtime: 2022/1, 2022/2 — Month: April, May, June

Week	operation-mode	Day
13	MB	1 2 3
14	MB	4 5 6 7 8 9 10
15	SD	11 12 13 14 15 16 17
16	MB	18 19 20 21 22 23 24
17	MB	25 26 27 28 29 30 1
18	SD	2 3 4 5 6 7 8
19	SD	9 10 11 12 13 14 15
20	SD	16 17 18 19 20 21 22
21	SD	23 24 25 26 27 28 29
22	SD	30 31 1 2 3 4 5
23	SD	6 7 8 9 10 11 12
24	SD	13 14 15 16 17 18 19
25	SD	20 21 22 23 24 25 26
26	SD	27 28 29 30

Beamtime: 2022/2 — Month: July, August, September

Week	operation-mode	Day
26	SD	1 2 3
27	SD	4 5 6 7 8 9 10
28	SD	11 12 13 14 15 16 17
29	SD	18 19 20 21 22 23 24
30	SD	25 26 27 28 29 30 31
31	AS	1 2 3 4 5 6 7
32	W	8 9 10 11 12 13 14
33	MC	15 16 17 18 19 20 21
34	MS	22 23 24 25 26 27 28
35	MB	29 30 31 1 2 3 4
36	MB	5 6 7 8 9 10 11
37	MB	12 13 14 15 16 17 18
38	MB	19 20 21 22 23 24 25
39	MS	26 27 28 29 30

Beamtime: 2022/2 — Month: October, November, December

Week	operation-mode	Day
39	MS	1 2
40	MB	3 4 5 6 7 8 9
41	MB	10 11 12 13 14 15 16
42	MB	17 18 19 20 21 22 23
43	MB	24 25 26 27 28 29 30
44	Test	31 1 2 3 4 5 6
45	MC	7 8 9 10 11 12 13
46	low-a	14 15 16 17 18 19 20
47	SB	21 22 23 24 25 26 27
48	MB	28 29 30 1 2 3 4
49	MB	5 6 7 8 9 10 11
50	MB	12 13 14 15 16 17 18
51	SD	19 20 21 22 23 24 25
52	SD	26 27 28 29 30 31

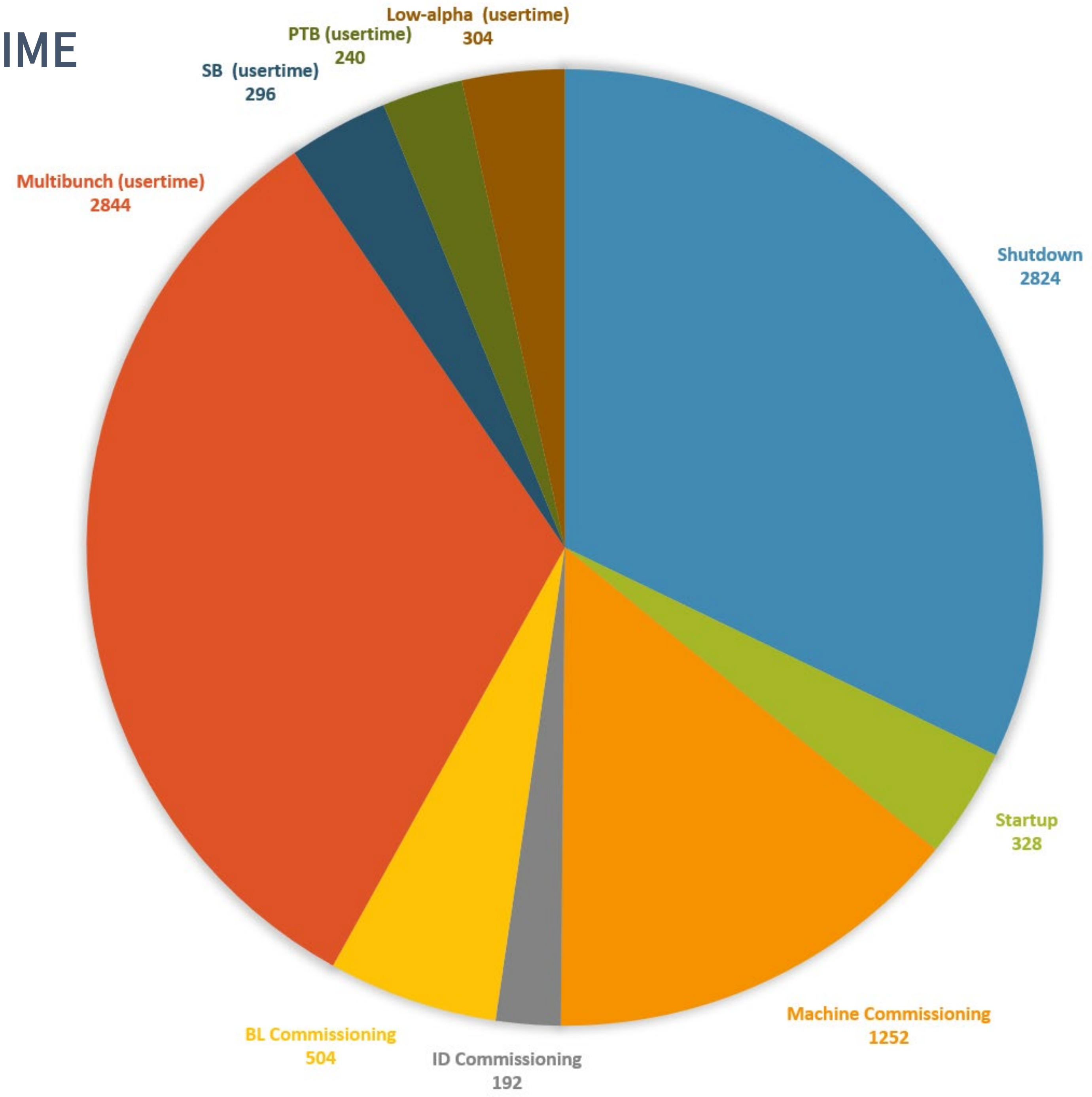
Shift 1 (07:00 - 15:00), Shift 2 (15:00 - 23:00), Shift 3 (23:00 - 7:00)

SCHEDULED ACCELERATOR TIME DISTRIBUTION FOR 2022

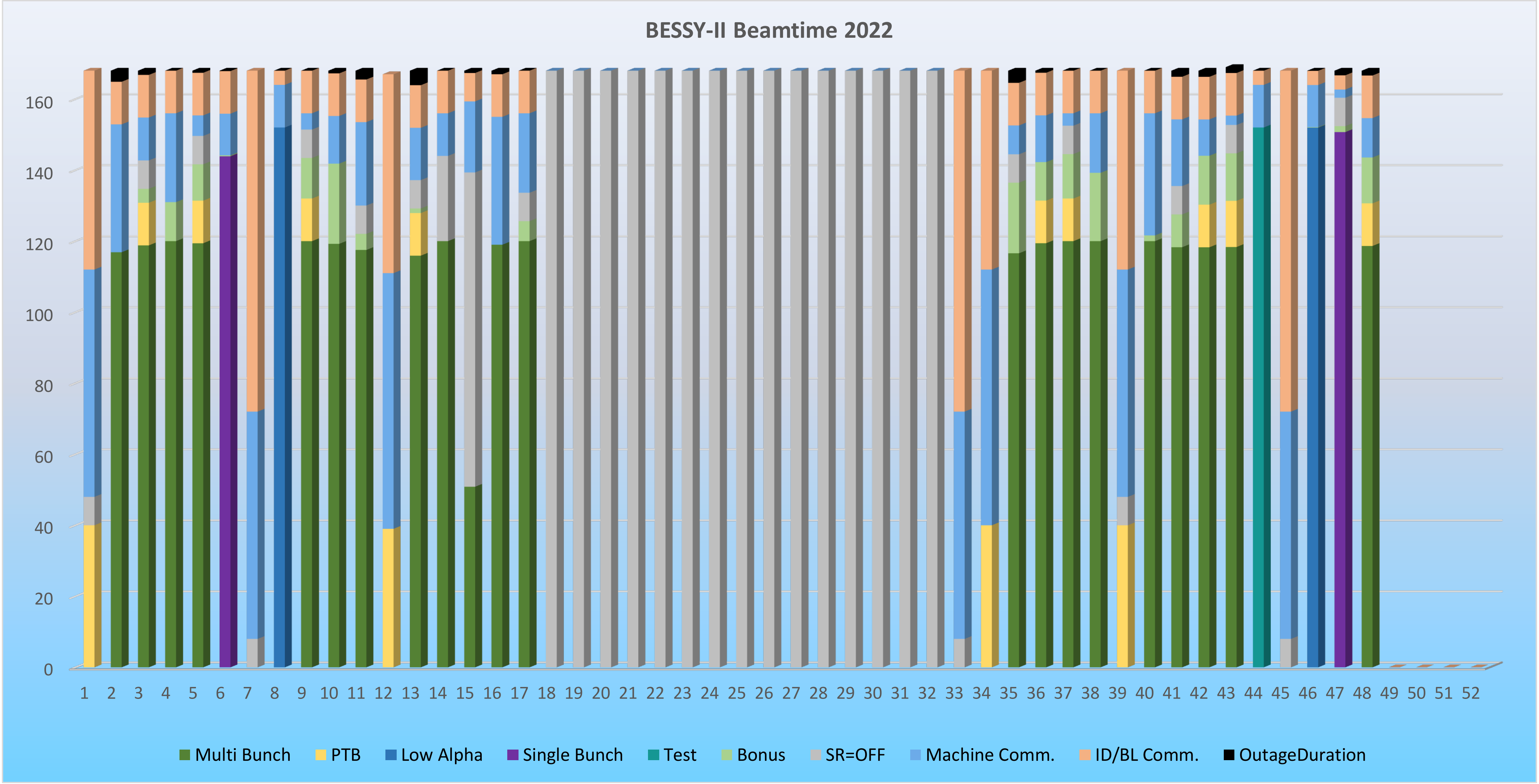
user time: 3724 h

delivering beam: 4208 h (+ 186 h)

accelerator uptime: 5960 h



DELIVERED ACCELERATOR TIME

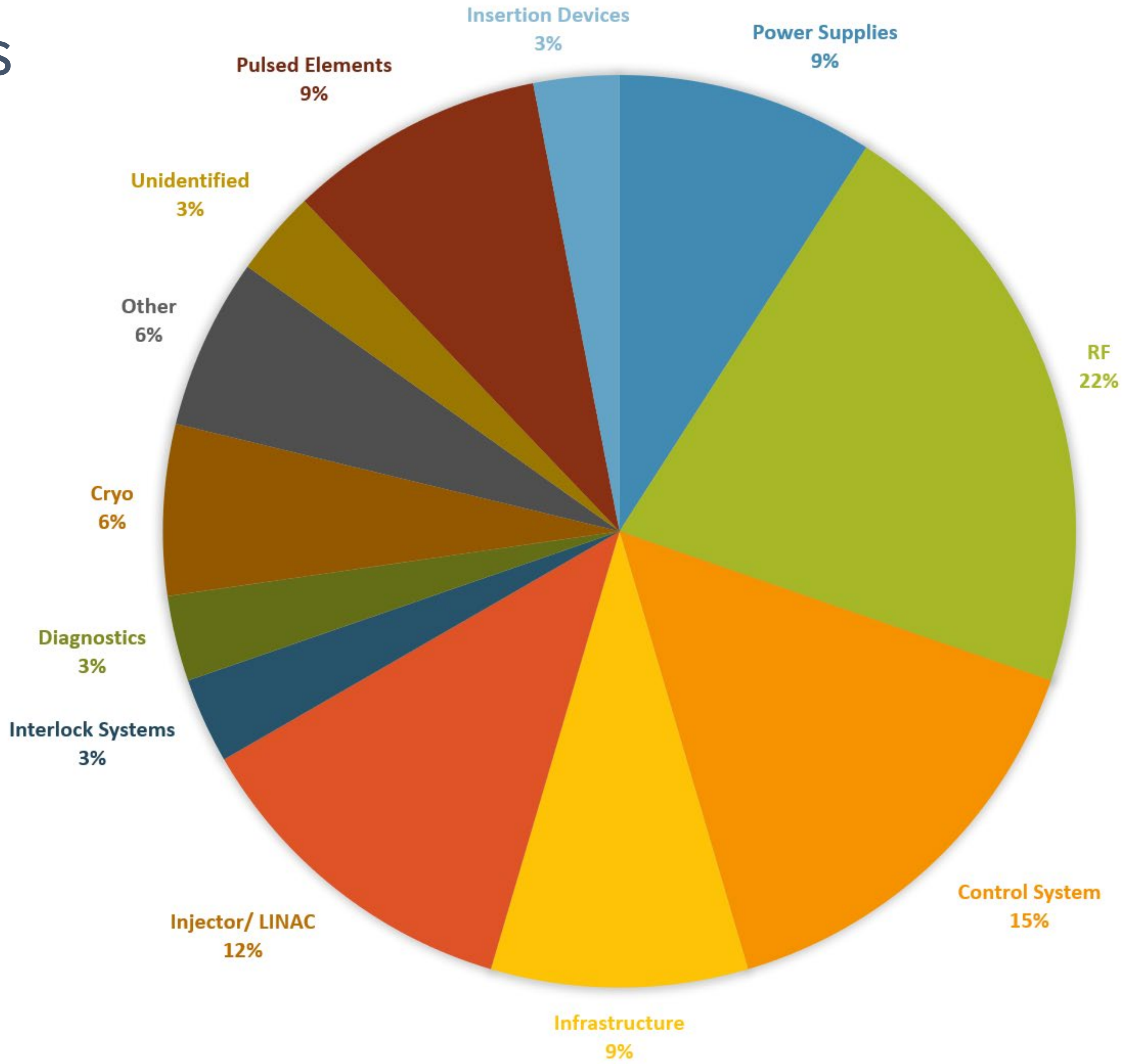


AVAILABILITY AND OUTAGE STATISTICS

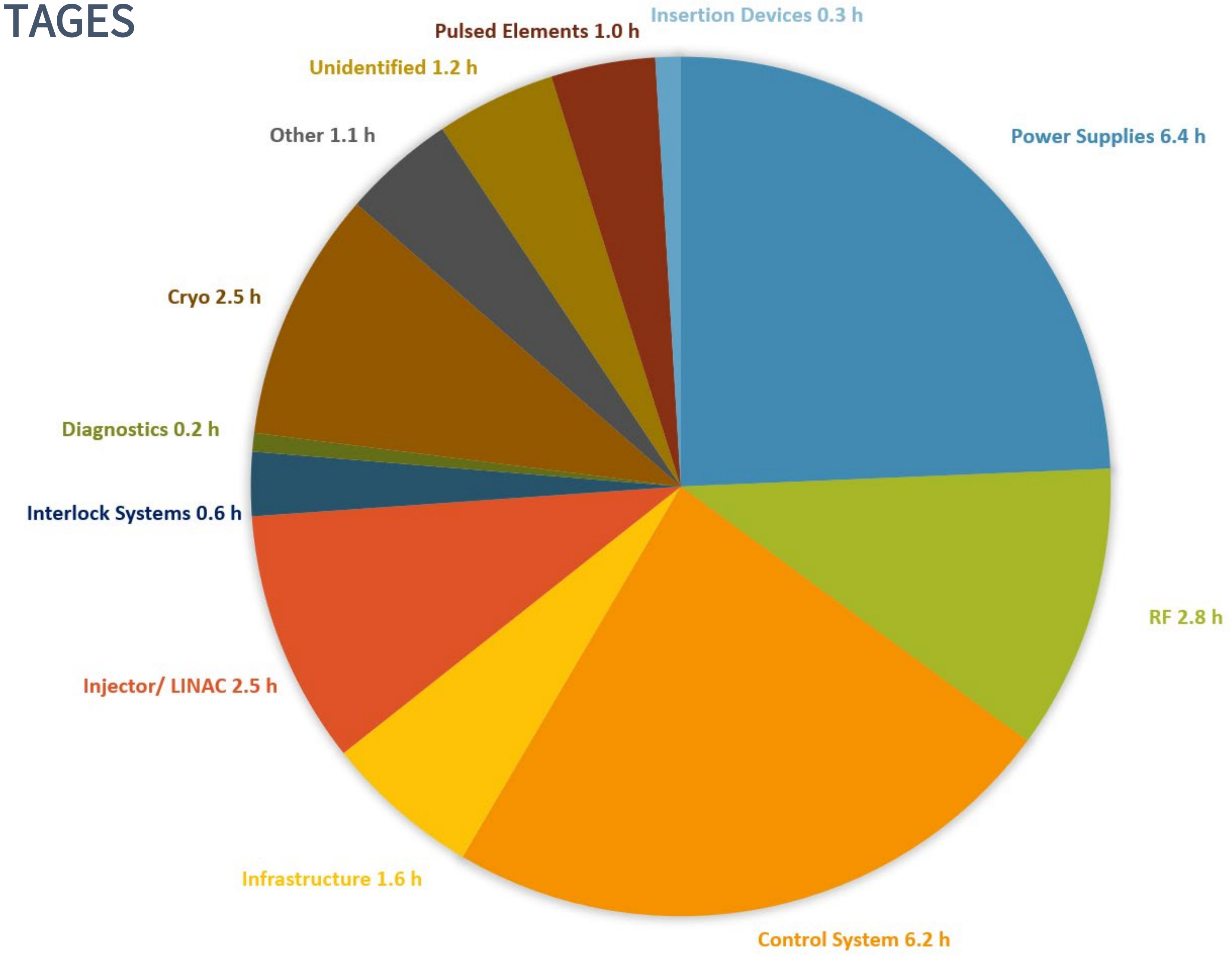
Year	Scheduled	Availability	Outages	MTBF	MTTR
2013	4505 h	96.5 %	105	42.9 h	1.5 h
2014	5408 h	92.9%	136	39.8 h	2.8 h
2015	3896 h	97.6 %	90	43.3 h	1.0 h
2016	4855 h	98.7 %	69	70.4 h	0.9 h
2017	4299 h	94.2 %	62	69.3 h	4.0 h
2018	3578 h	99.2 %	51	70.2 h	0.6 h
2019	4058 h	98.3 %	67	60.6 h	1.0 h
2020	3455 h	98.5 %	49	70.5 h	1.0 h
2021	4960 h	98.9 %	55	83.3 h	0.9 h
2022*	3472 h	99.3 %	33	105.2 h	0.8 h

* Until 2022.12.05

NUMBER OF OUTAGES (TOTAL = 33)



DURATION OF OUTAGES (TOTAL = 26H)

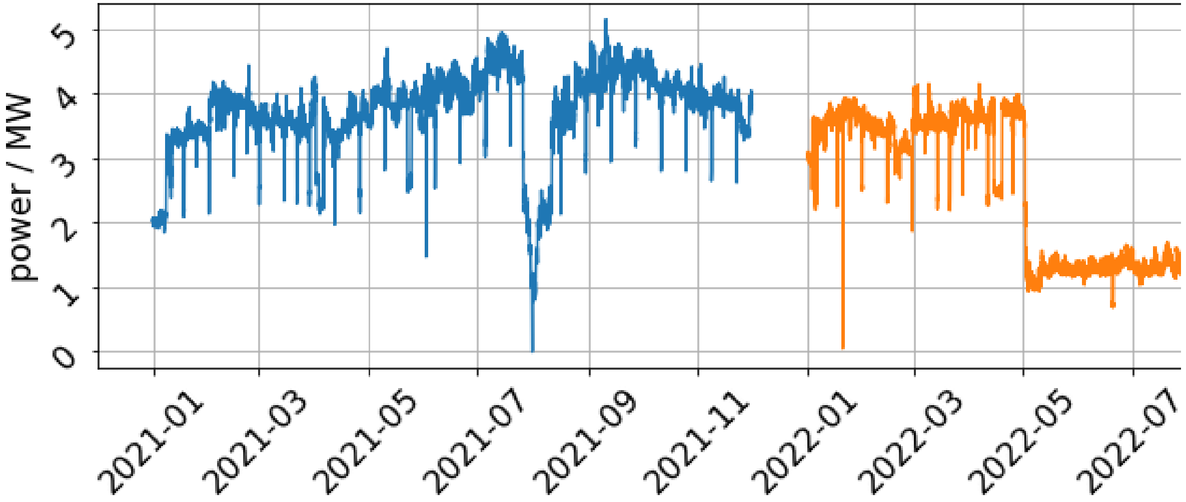


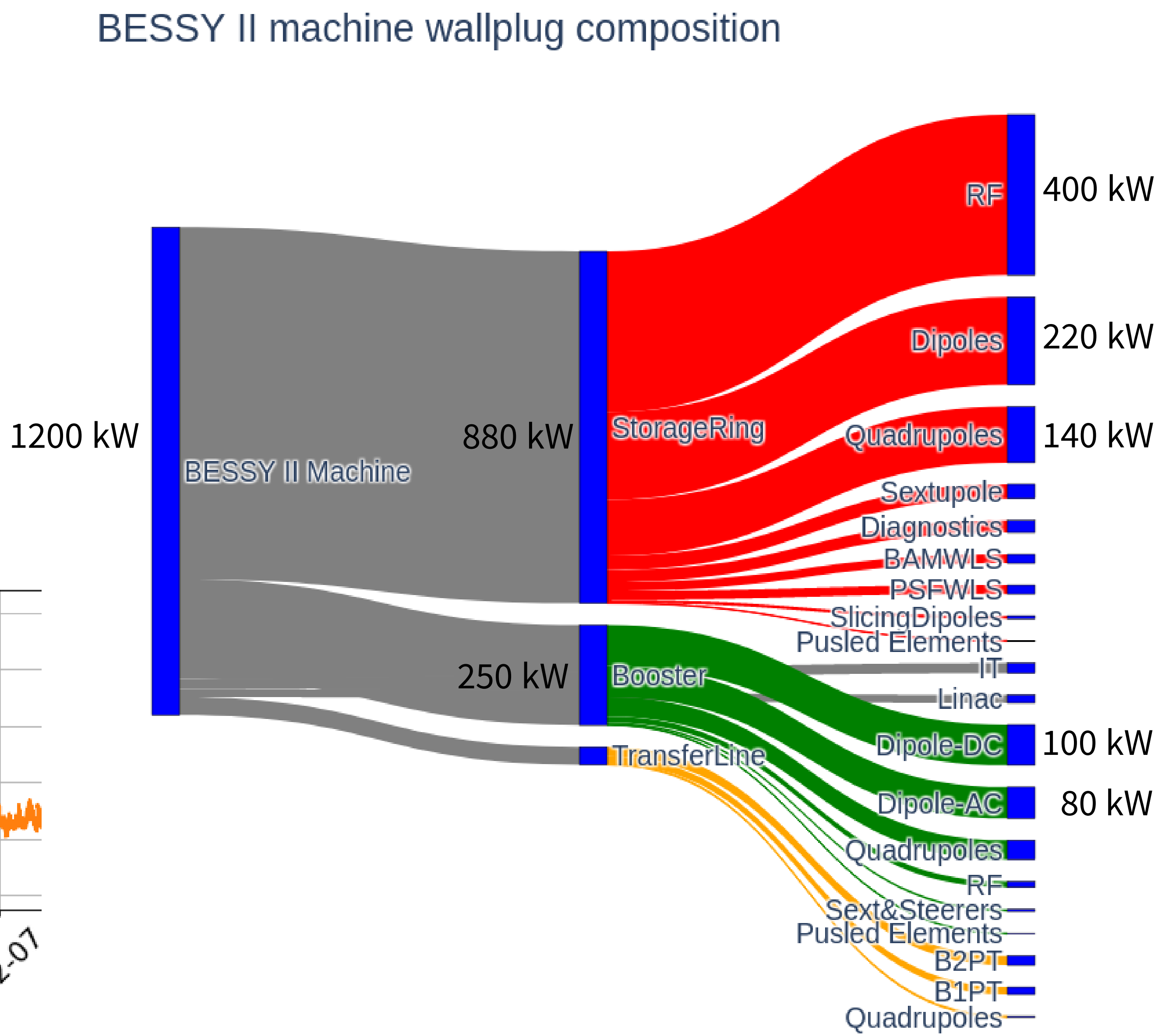
RF COAXIAL BURN

Economy and Energy Plan

ENERGY USE SURVEY

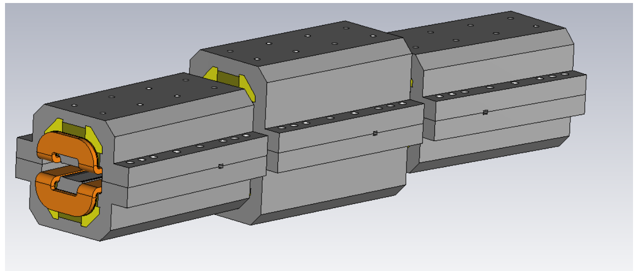
- identification / review of main power consumers
- initiated implementation of power meters for subsystem distribution in machine control system





ENERGY-SAVING MEASURES

- Measures with no operational downside, either done already or in progress
  - 1 Hz booster RF
  - Removal of 33rd dipole
  - Replacement of power-hungry bend in TL
  - Improvements in RF transmitter efficiency
- Potential measures with slight to moderate user impact which could be considered in the future
  - Reduction of top-up rate and switching off booster between shots
  - (Reduction of main SR RF voltage)
  - (Modification of multibunch fillpattern, reduction of harmonic voltage)

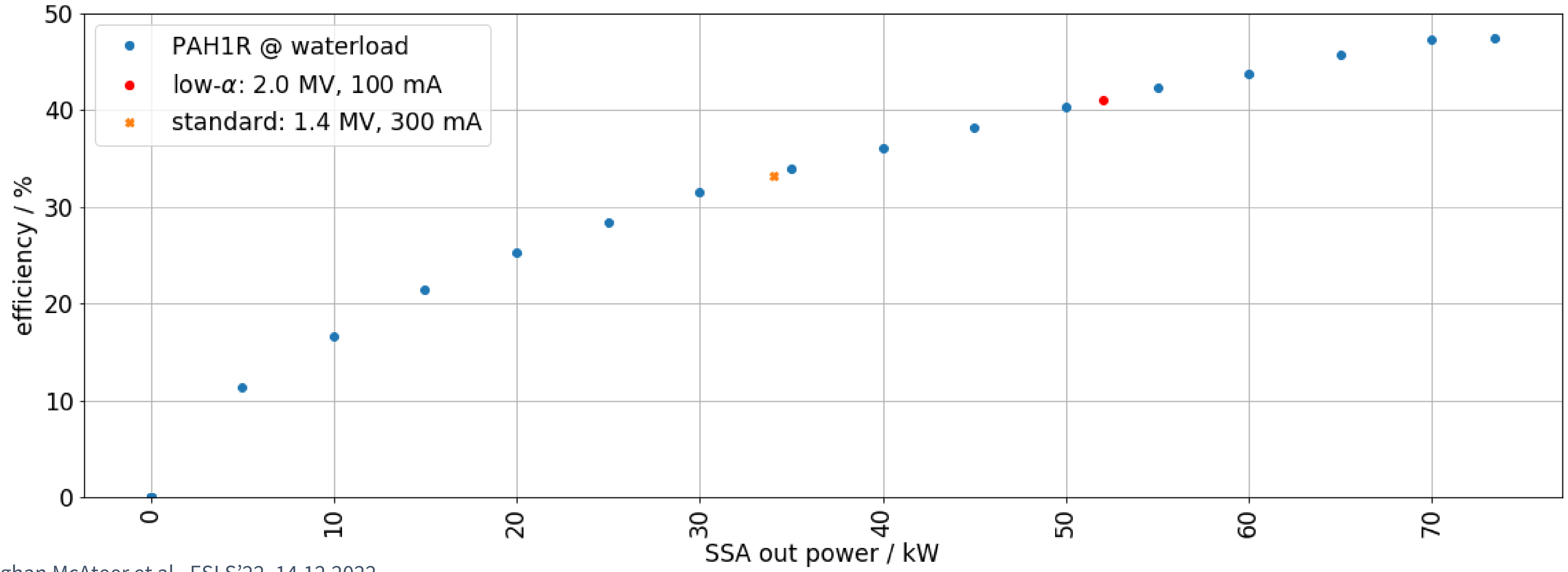


There is no intention of switching off BESSY II for reasons of operation cost

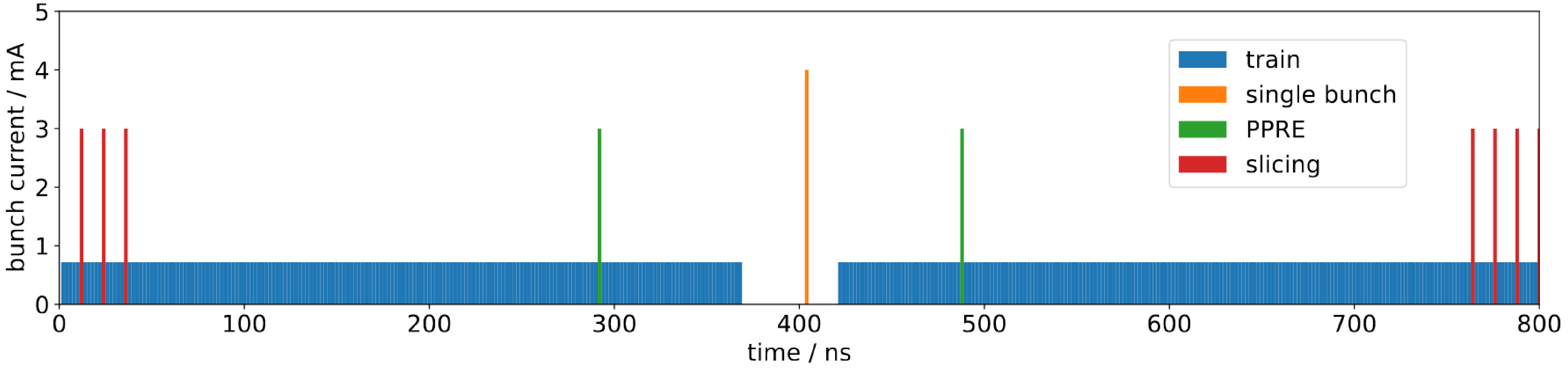
RF EFFICIENCY MEASUREMENTS

- Efficiency of RF transmitters lower than expected at low power
- Reduction of transistor voltage by a few volts →

  reduction of wallplug power consumption by almost 10%



USER OPERATION WITH ALTERNATE FILLING PATTERN FOR ONE WEEK



What was changed?

- much shorter gap (200ns → 56ns)
- 2x PPRE
- single bunch asymmetric in gap

Delivered what was expected:

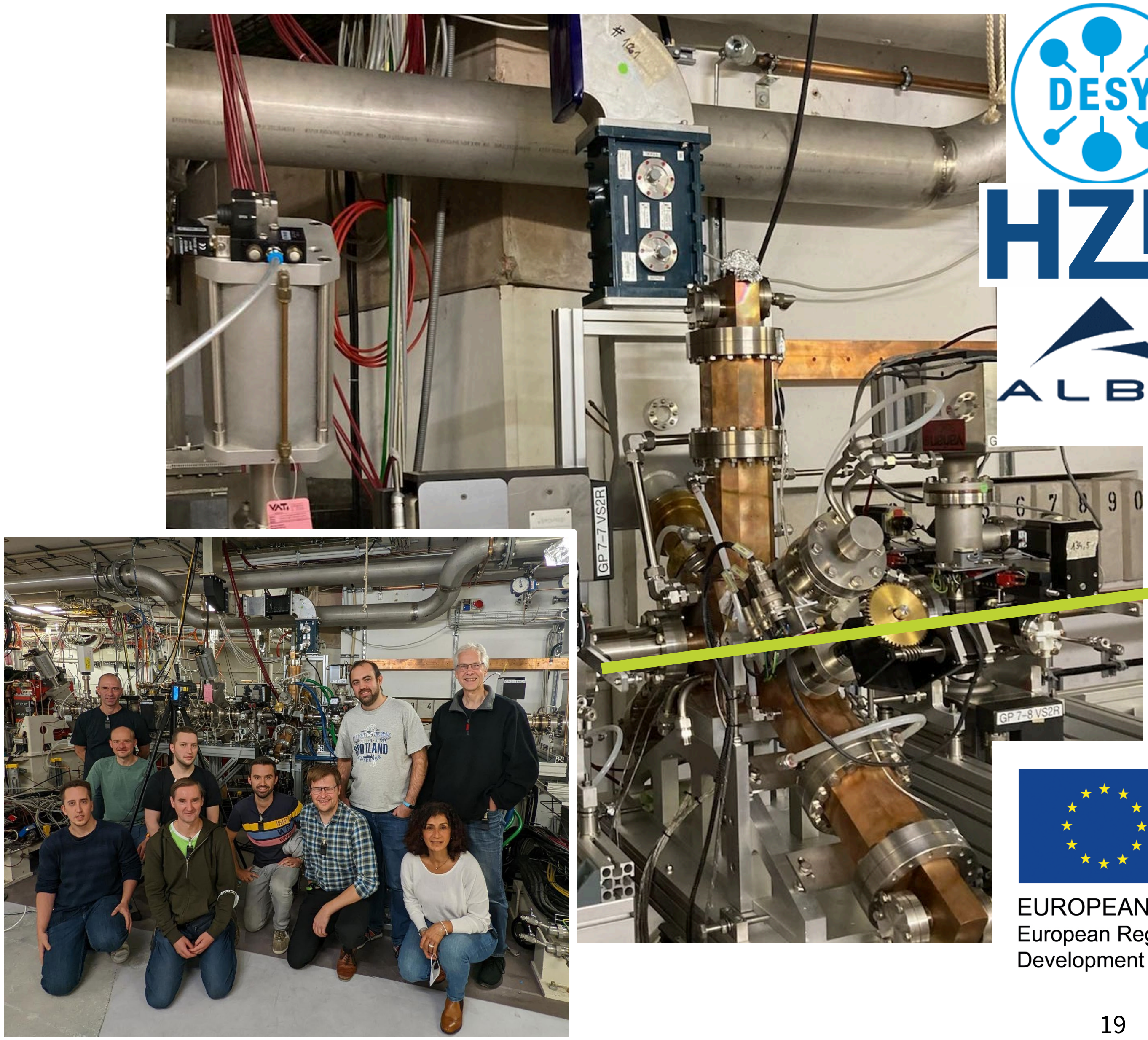
- Increased lifetime
- Reduced transient
- More efficient bunch lengthening
  (less power required for same average bunch length)

Development and Upgrades

HARMONIC EU CAVITY - ALBA ACTIVE DESIGN

EU-level collaboration

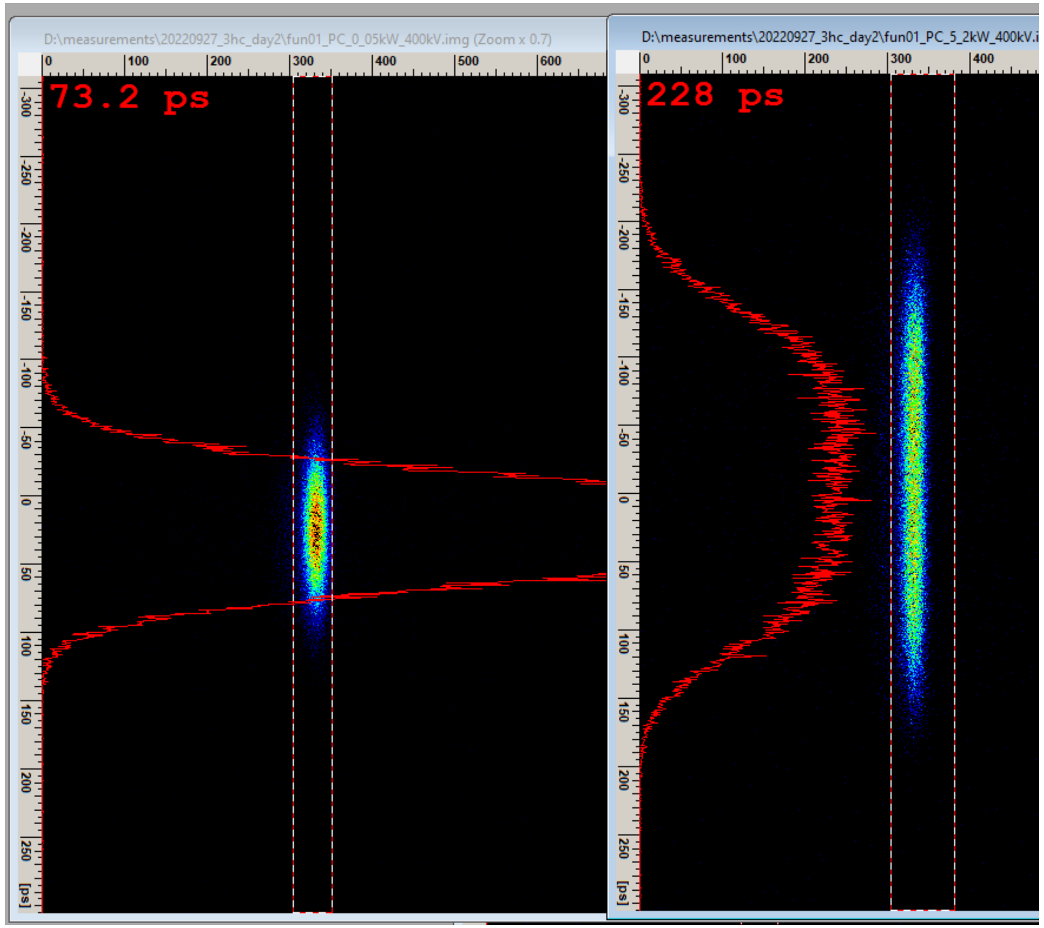
- Design of active 1.5 GHz normal-conductive cavity started by ALBA in 2015
- ALBA started construction of prototype(with EU funds) in 2018
- Agreement in 2020 between ALBA, DESY, and HZB for testing cavity
- Tested with beam at HZB in 2022

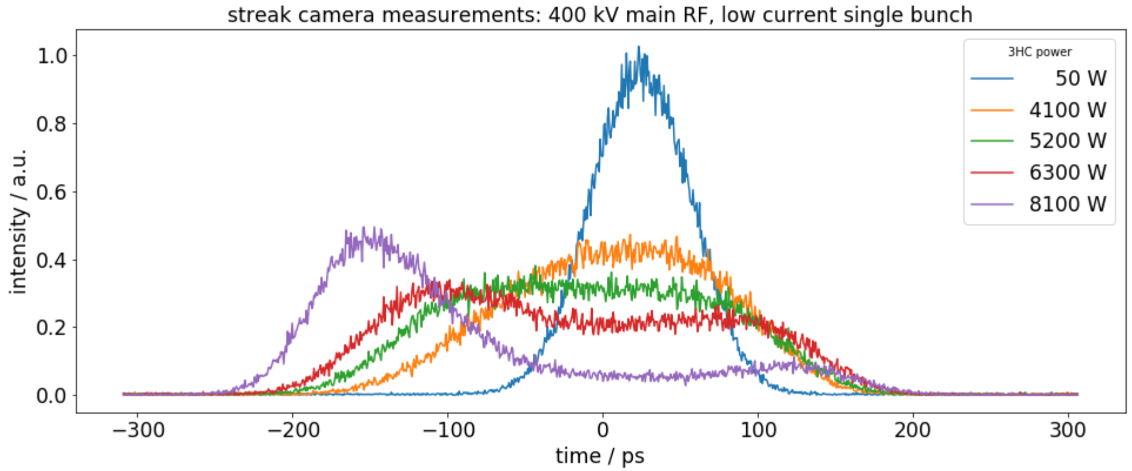


EUROPEAN UNION
European Regional Development Fund

TEST OF HARMONIC EU CAVITY IN BESSYII

- Current hardware in BII kept alive beyond lifecycle
  - no spares left
  - already failed once
  - next fail -> beam current reduction to 250 mA & high stress on vacuum components & IVUs
- Relevant for
  - BESSY II and MLS
  - all 4th generation storage ring based light sources (e.g. BESSY III, MLS 2)





INJECTOR DEVELOPMENT

- The Booster has been reliably delivering beam to BESSY II for 24 years
- Recent investment in diagnostics:
  - turn-by-turn BPM electronics
  - bunch-by-bunch feedback
  - optical beamline
- For reliable, efficient top-up operation:
  - understanding and control of basic beam dynamics
  - robustness against instabilities

    → control of orbit through ramp

    → extraction orbit bump control

    → control of tunes through ramp

    → chromaticity control through ramp

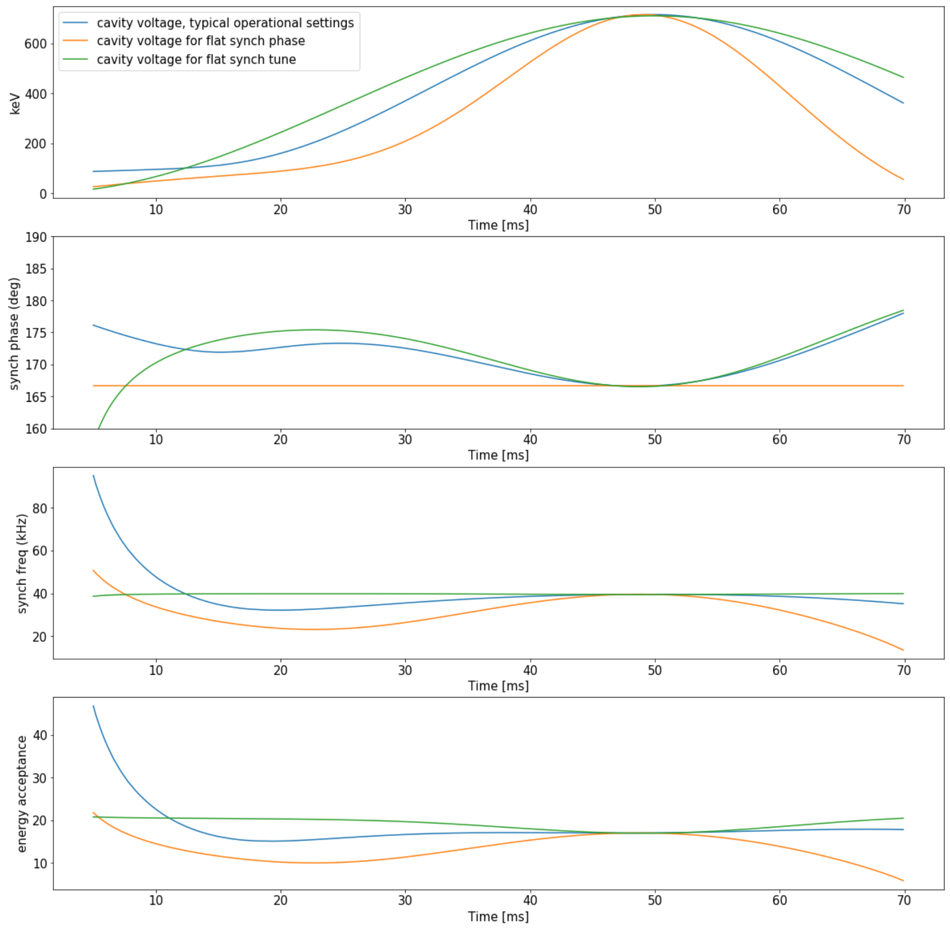
    → homogeneity of bunches from linac

    → bunch-by-bunch feedback

      → RF ramp/control of longitudinal parameters

      → beam loading

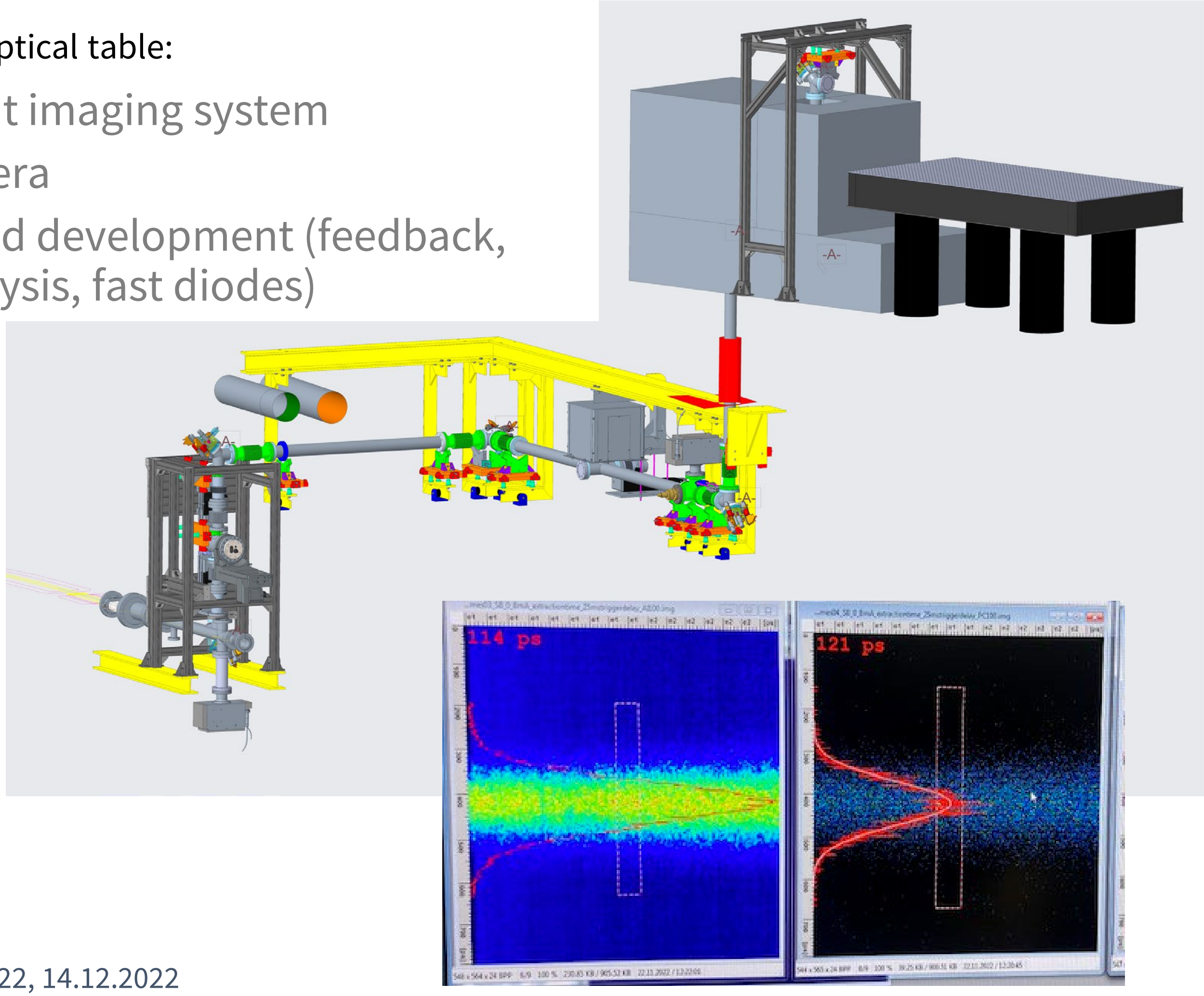
RF ramp and longitudinal parameters



INJECTOR DIAGNOSTICS UPGRADES

New optical beamline

- 13m long optical beamline from bending magnet in booster
- 3 beamlines on the optical table:
    - source point imaging system
    - streak camera
    - research and development (feedback, source analysis, fast diodes)

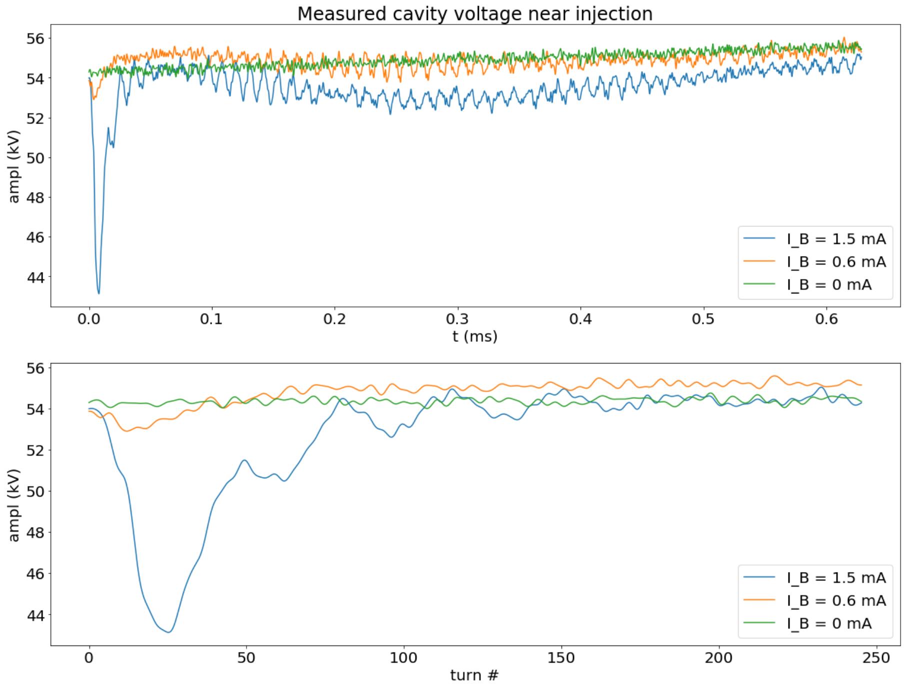


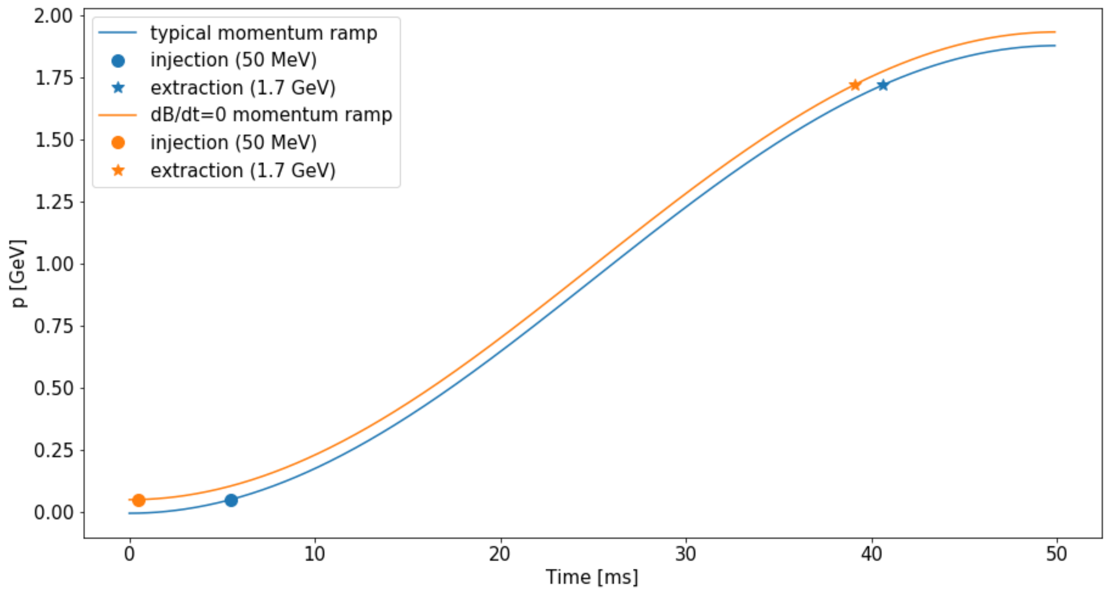
New BPM electronics

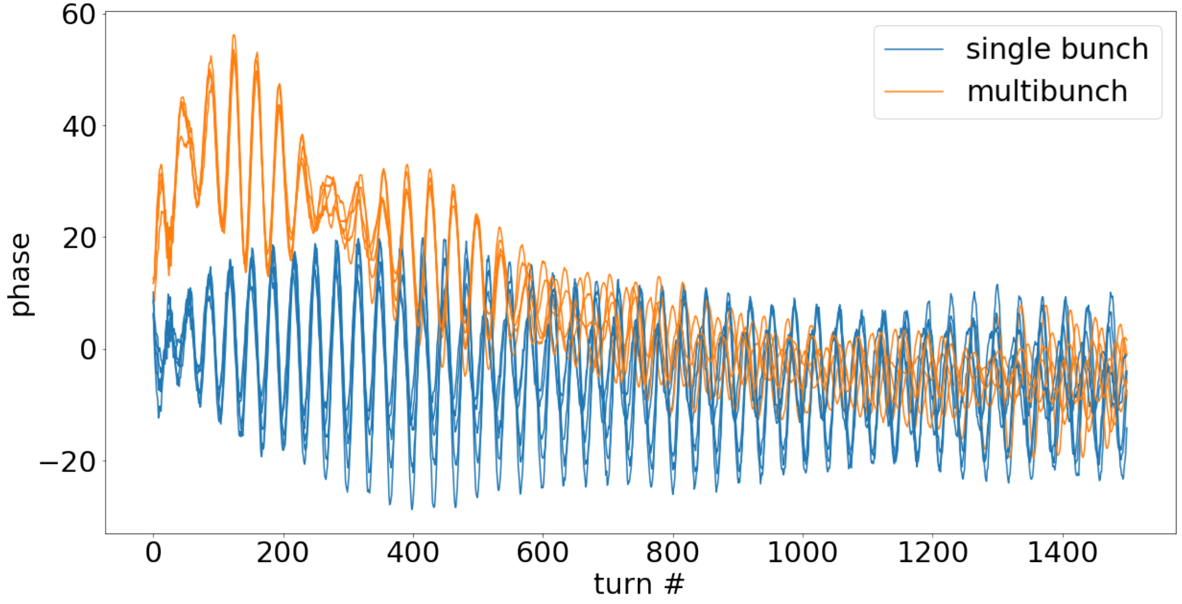
- 48 Libera Spark units for BPMs in
    - Injection Line
    - Booster
    - Transfer Line

BEAM LOADING AT INJECTION

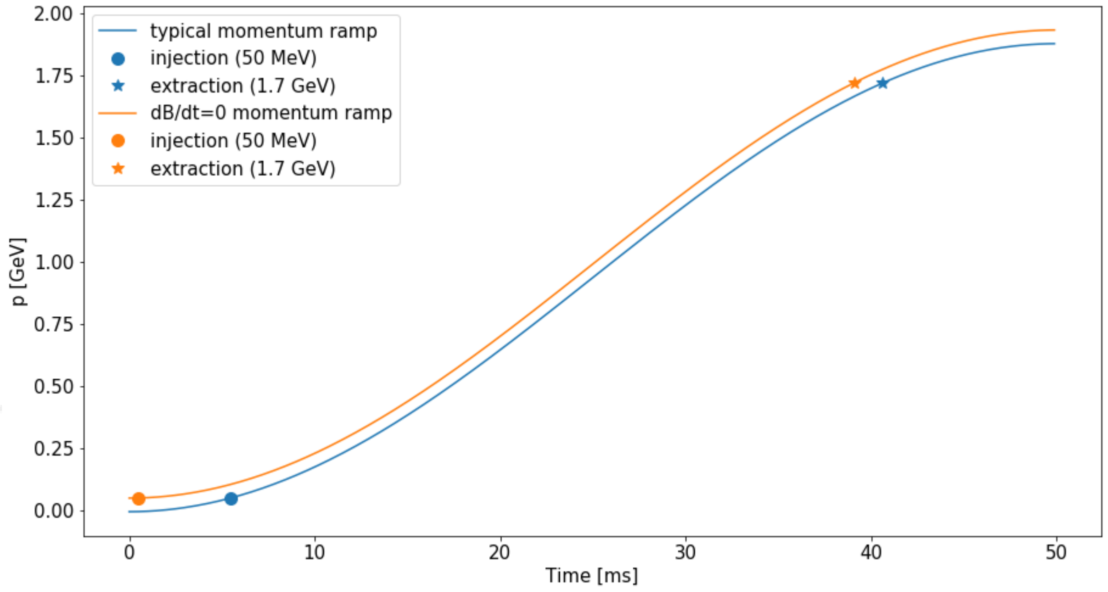
- Beam arrives in booster after dipoles have started ramping up
  - beam loading in cavities → charge-dependent voltage drop when beam arrives
  - not possible to inject longitudinally on-axis for both single-bunch and multi-bunch shots



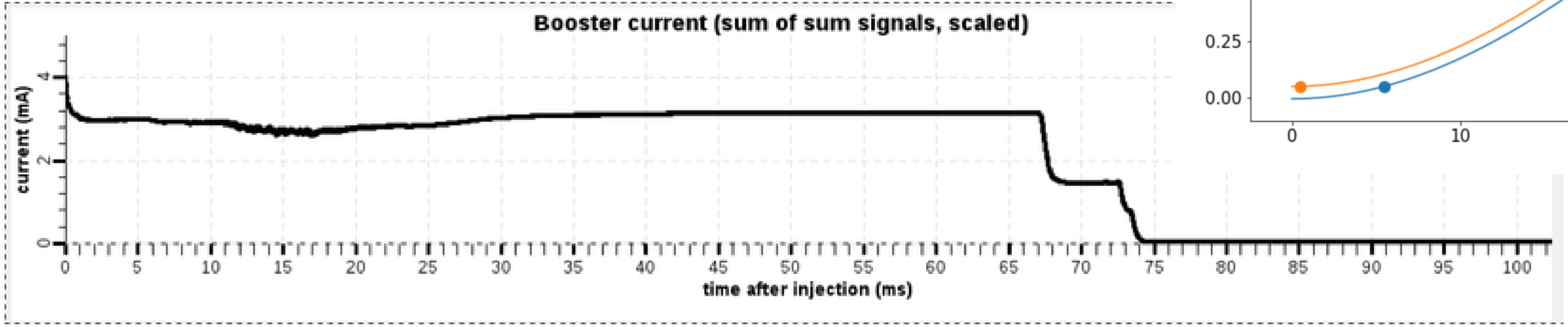




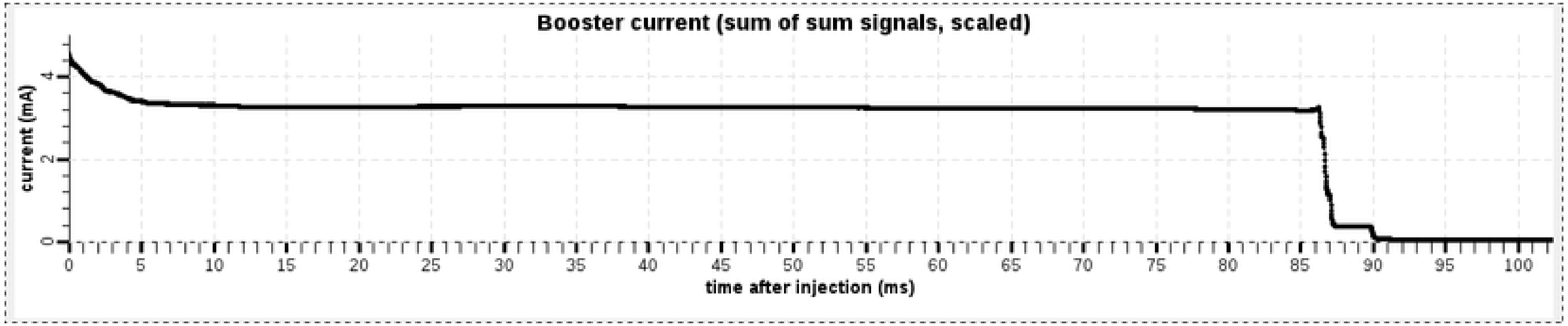
INJECTION WITH $\dot{B} = 0$



Booster current with typical injection scheme:

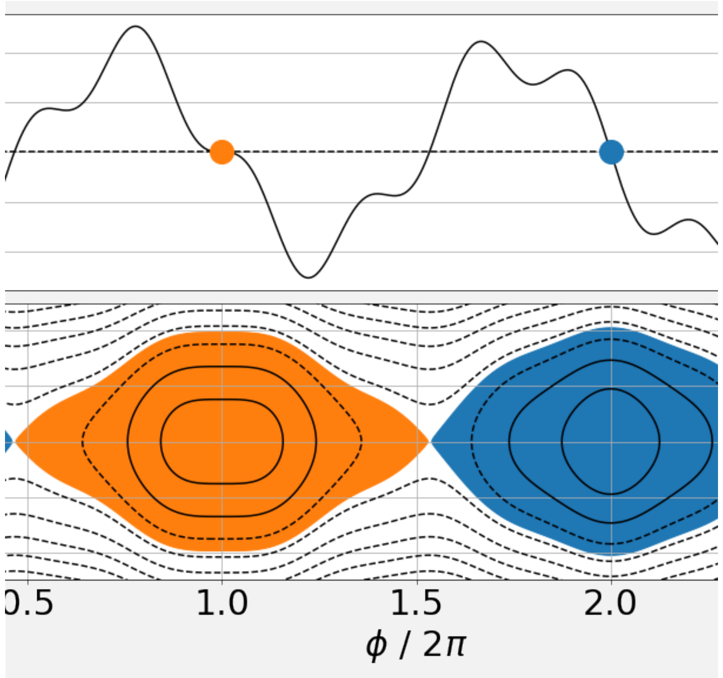


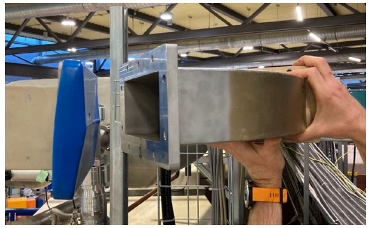
Booster current with $\dot{B} = 0$ injection scheme:



BII PERSPECTIVES UNTIL 2035

- During 2022 shutdown:
  - complete renewal of low voltage distribution after 25 years
- Planned:
  - Renovation (timing system, vacuum systems, uninterruptable power supply)
  - 1.75 GHz cavities
  - New WLS
  - Permanent magnets
  - Digital Twin




BESSY III

Slides courtesy of P. Goslawski et al.

pre-CDR: https://doi.org/10.5442/r0004

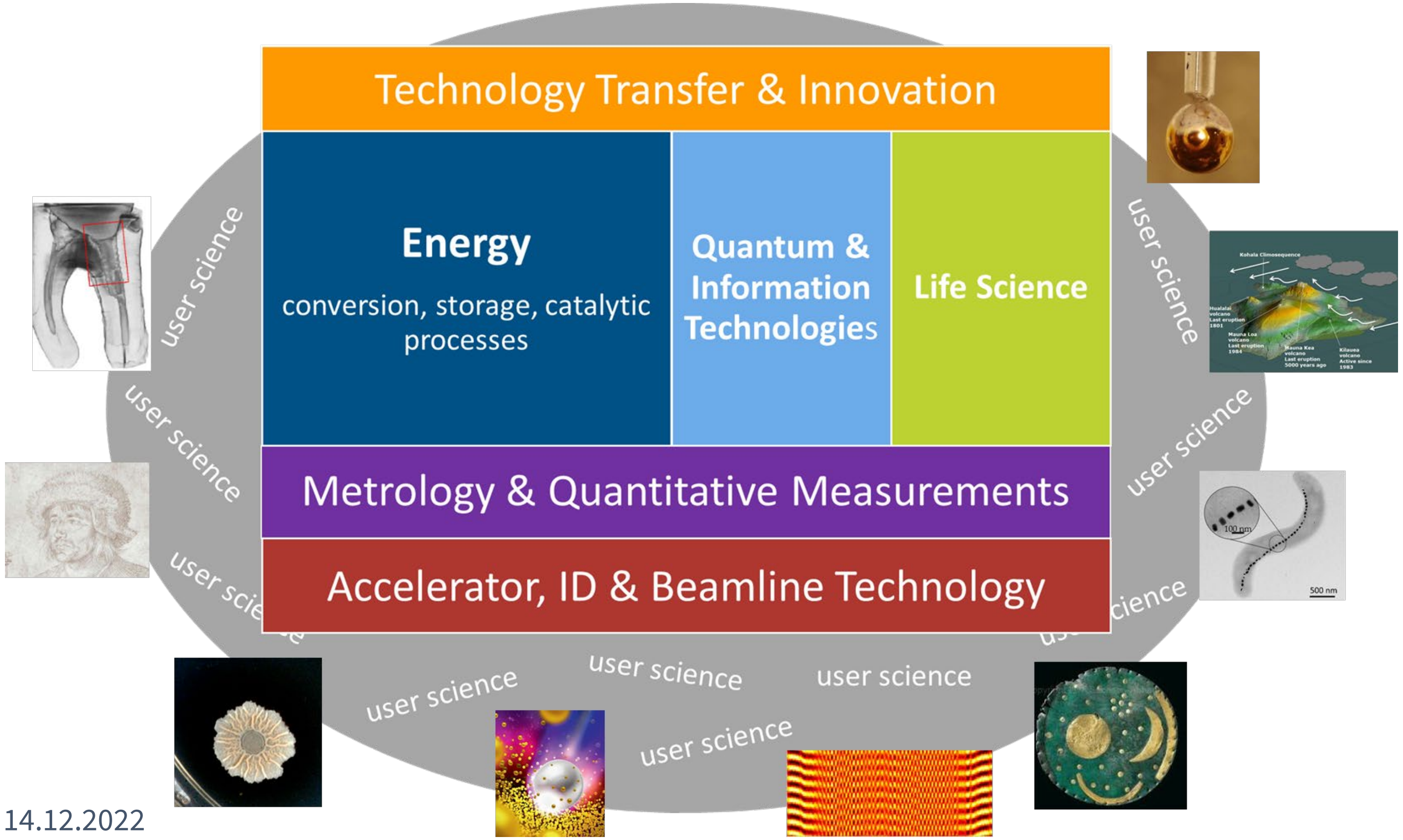
BESSY III – THE TRIAD FOR A WORLD LEADING FACILITY FOR MATERIALS DISCOVERY

Courtesy of P. Goslawski et al.

① a globally competitive 4th generation synchrotron radiation source

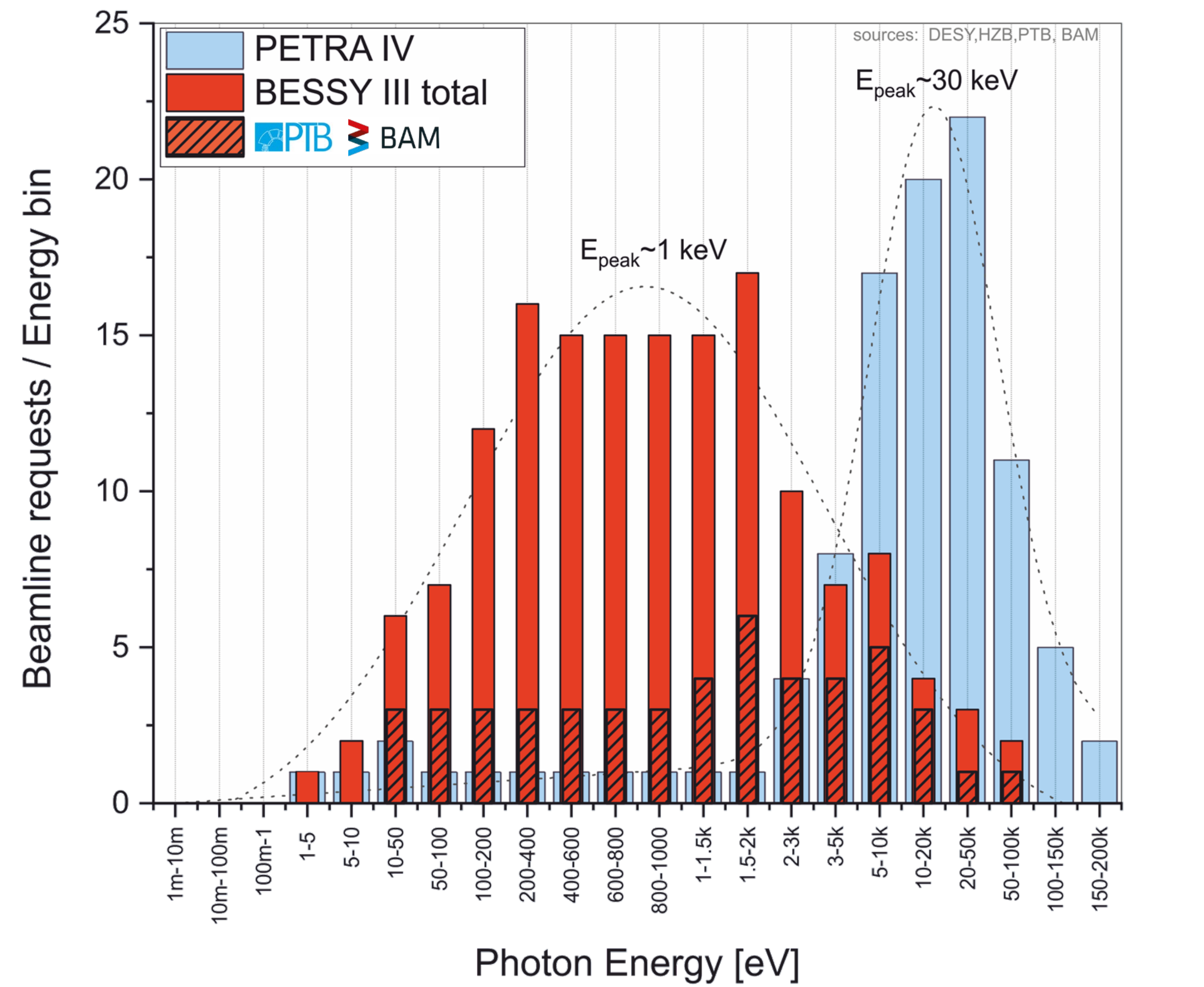
② embedded in the integrated research campus Berlin-Adlershof

③ dedicated to metrology and quantitative materials science



BESSY III – DEMAND-DRIVEN DESIGN PARAMETERS

Courtesy of P. Goslawski et al.



- sweet spot photon energy: 1 keV
- main photon energy range: soft to tender X-rays

  → **100 pm rad emittance**
  → **50 m long beamlines**

- 1st undulator harmonic with broad spectral coverage @ 1 keV, tender X-ray range
- partner request for useable photons > 20 keV
- lifetime, stability, …

  → **2.5 GeV beam energy**

- capacity request (HZB, PTB & BAM, user) & advanced ID systems

  → **16 straights, up to 5 m free length for IDs**
  → **minimum one dipole source per arc plus**
  → **calculable dipole source (homogenous bend) for metrology**

- **BESSY III must be part of the material science campus in Adlershof!**

  → **max. 350 m circumference of the machine**

BESSY III - SPECIAL REQUESTS FOR THE MACHINE DESIGN / ACCELERATOR LAYOUT

Courtesy of P. Goslawski et al.

PTB request **special radiation source for metrology**. Magnetic field has to be measured with a NMR precision at beam position within the volume of 10x10x10 mm³ and no contamination of other sources!

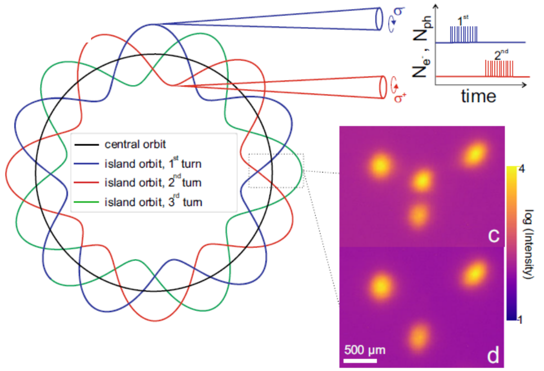
→ **homogenous bending magnet(s)**

Covering a wide spectral range in one beamline.

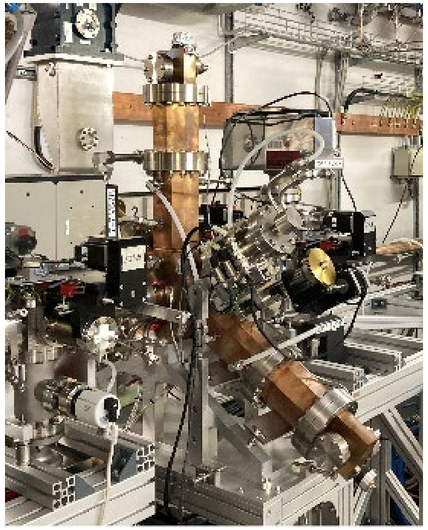
→ **Special insertion devices**, e.g. in-vacuum IDs with small gap and/or APPLE knot for lowest photon energies

Support of Timing experiments

→ **TRIBs** (second orbit operation, under study)
→ **Higher-Harmonic-Cavities** for pulse length shaping (long=lifetime and short=timing)



Holldack, K., Schüssler-Langeheine, C., Goslawski P.et al.
Flipping the helicity of X-rays from an undulator at unprecedented speed.
Commun. Phys. 3, 61 (2020).



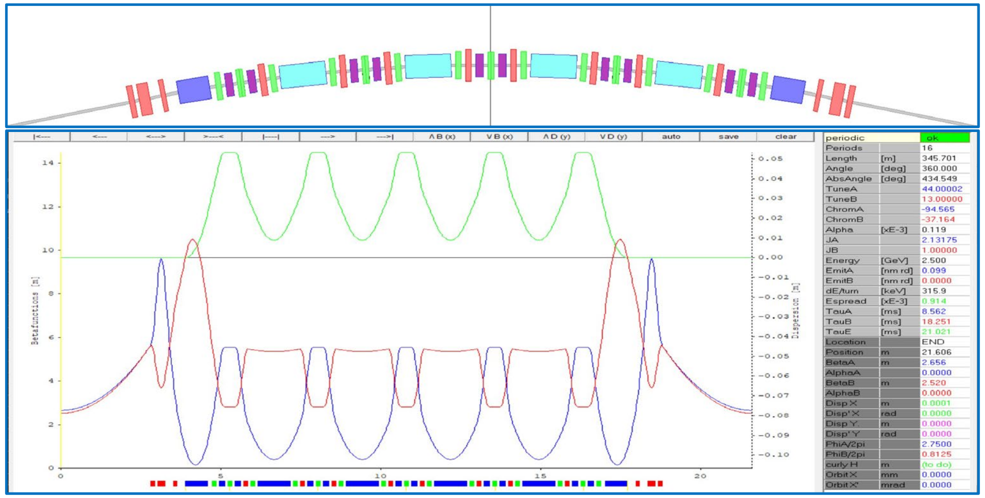
ALBA, DESY, HZB collaboration
1.5 GHz active normalconducting Higher Harmonic Cavity installed in BESSY II for beam test (ongoing)
1.75 GHz under development

BESSY III LATTICE DESIGN – UNCONVENTIONAL BUT COMPETITIVE

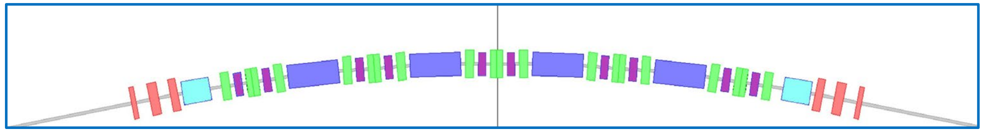
Courtesy of P. Goslawski et al.

- 6 Bend Higher Order Achromat, with reverse bends
- 2 solutions studied: separate function **SF** / combined function **CF**
- 2.5 GeV, 100 pmrad emittance
- 16 long (5.6 m), low beta straights ($\beta_{h,v}$ < 3 m)
- Robust hardware specifications → reduced technical risk
- Extensive usage of permanent magnets for energy efficiency
- **First evidences that separate function (SF) lattice is superior solution**
- Integrated dipole sources, including homogenous metrology bends
- Non-linear optimization & study of collective effects on the way
- R&D topics
  active multi-frequency Higher-Harmonic-Cavities, hybrid PM multipoles, transparent injection with accumulation, full coupling control, … partly addressed already within the BESSY II+ project
- 150 MeV injector linac, low emittance "in tunnel" booster,
  NEG coated vacuum system, top-up injection (accumulation)

SF: A more than competitive "separated function" lattice with 4 homogenous bends



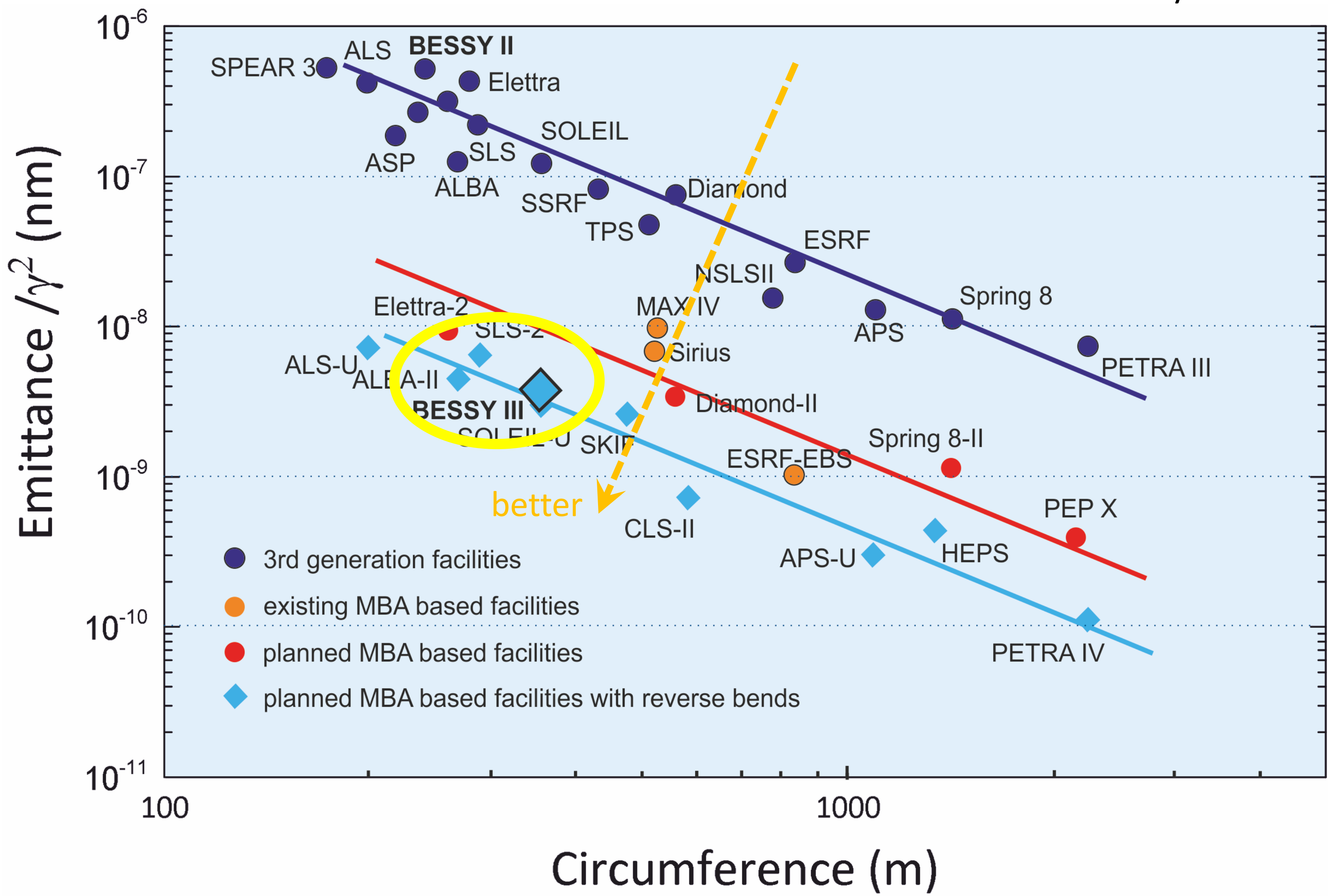
CF: The more "classical" approach with combined function dipoles and only 2 homogenous bends

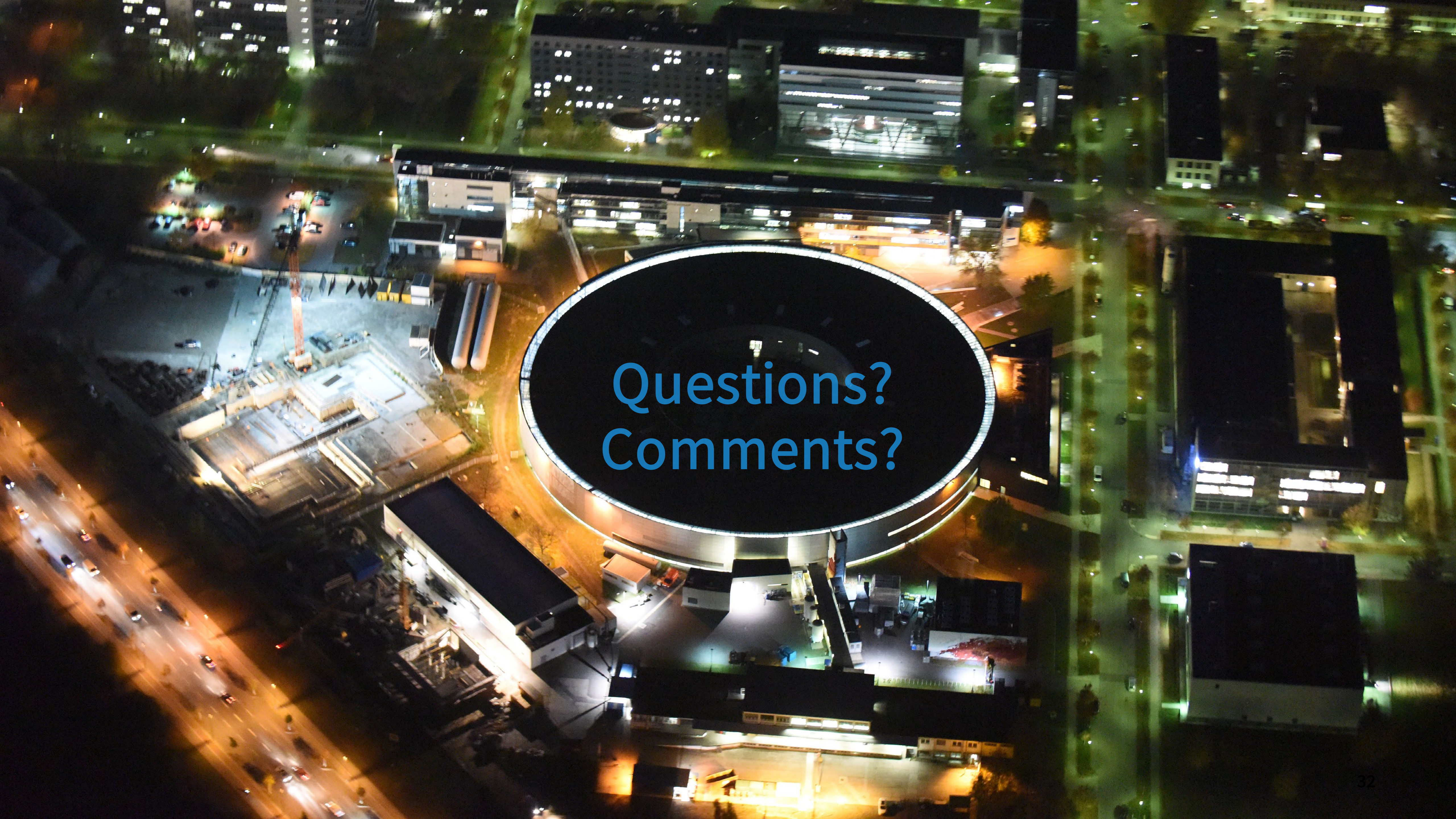


P. Goslawski et al.

BESSY III LATTICE PERFORMANCE – FULLY IN LINE WITH OTHER ADVANCED DESIGNS

Courtesy of P. Goslawski et al.




Questions?
Comments?

BACKUP SLIDES

INJECTOR STUDIES

Energy spread of linac

Bumper-bump closure

orbit correction

tune correction during ramp

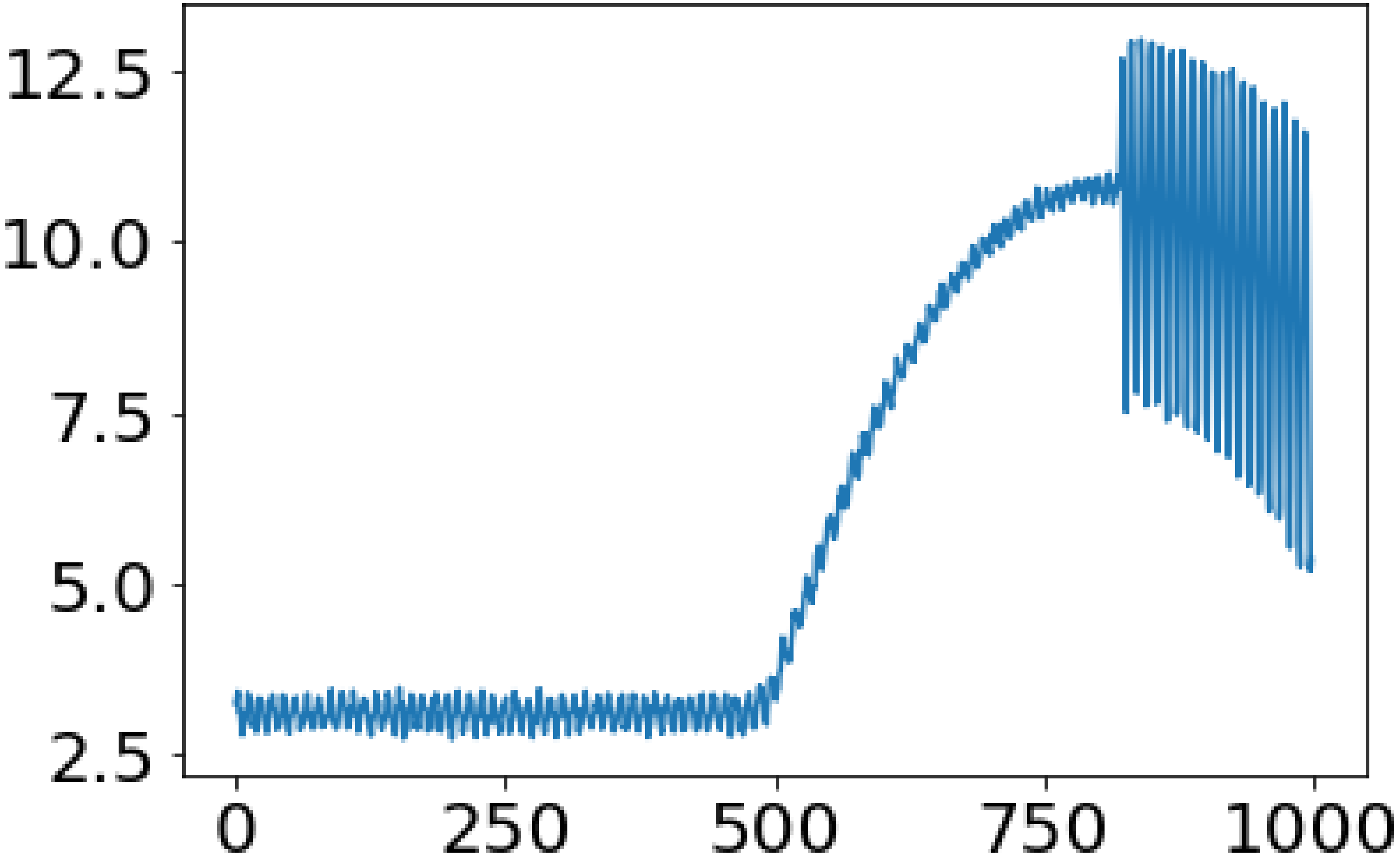
on axis injection

BBFB

Beam loading at injection

RF waveform shaping

TbT BPM upgrade ahead



Lots do to and to see

SHUTDOWN ACTIVITIES

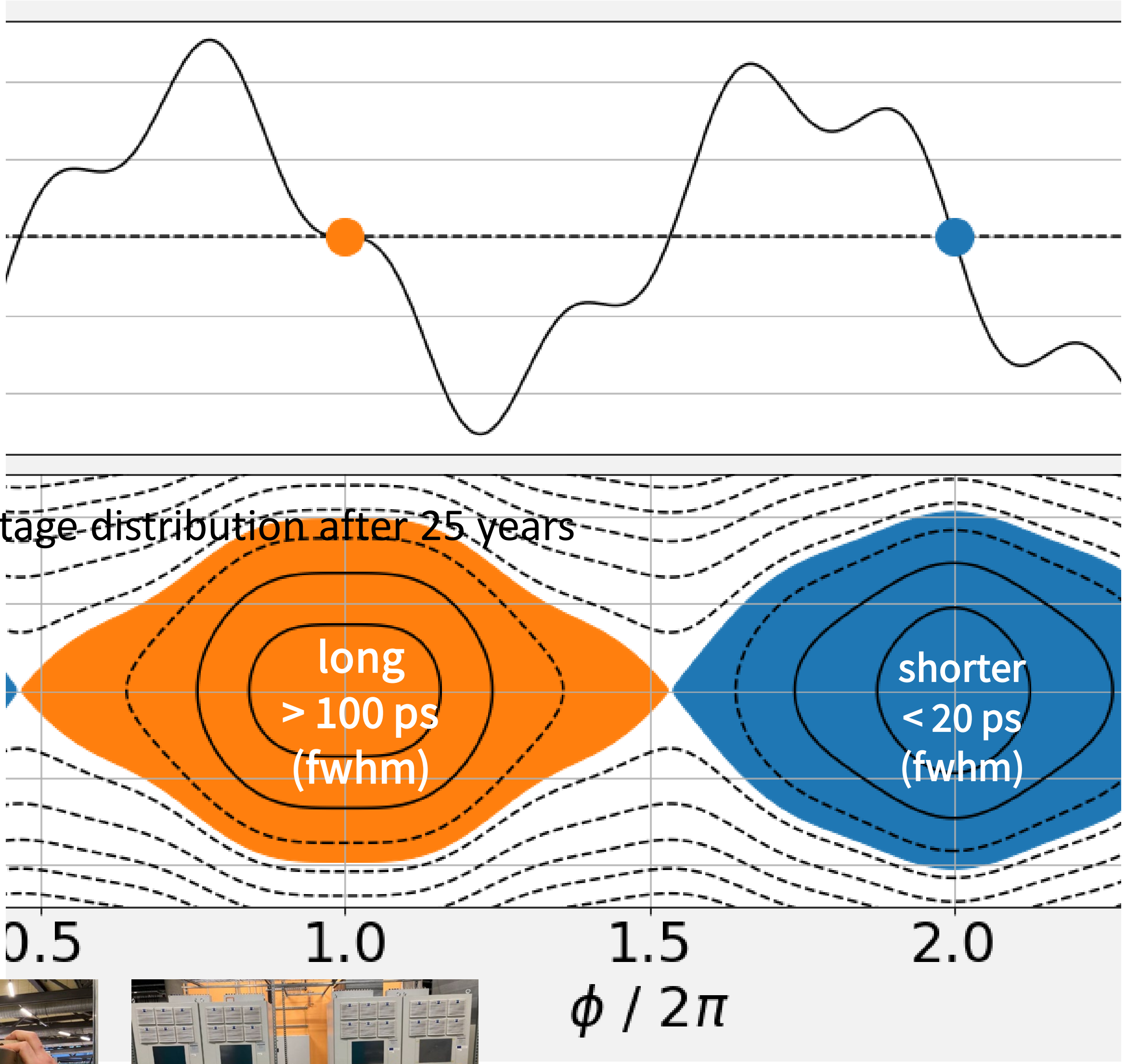
- complete renewal of low voltage distribution after 25 years
  - extensive preparation to supply backup power
  - no significant damage
  - smooth restart
  - created conditions for real time monitoring, archiving and therefor optimization of machine sided energy consumption

new power…

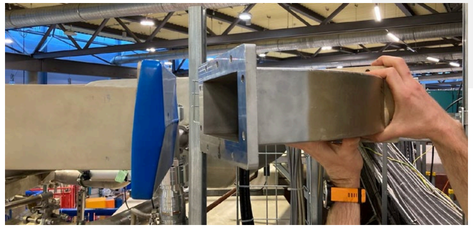
1.75 GHZ BEATING

- Followed towards BESSY III
- Maintain access to the 10 ps scale at 4th generation light sources
- all the infrastructure is already there
- just the cavity is missing
- could be actually used if working at BESSY II

complete renewal of low voltage distribution after 25 years



exploring uncharted territory, exploiting existing infrastructures, breakthrough potential



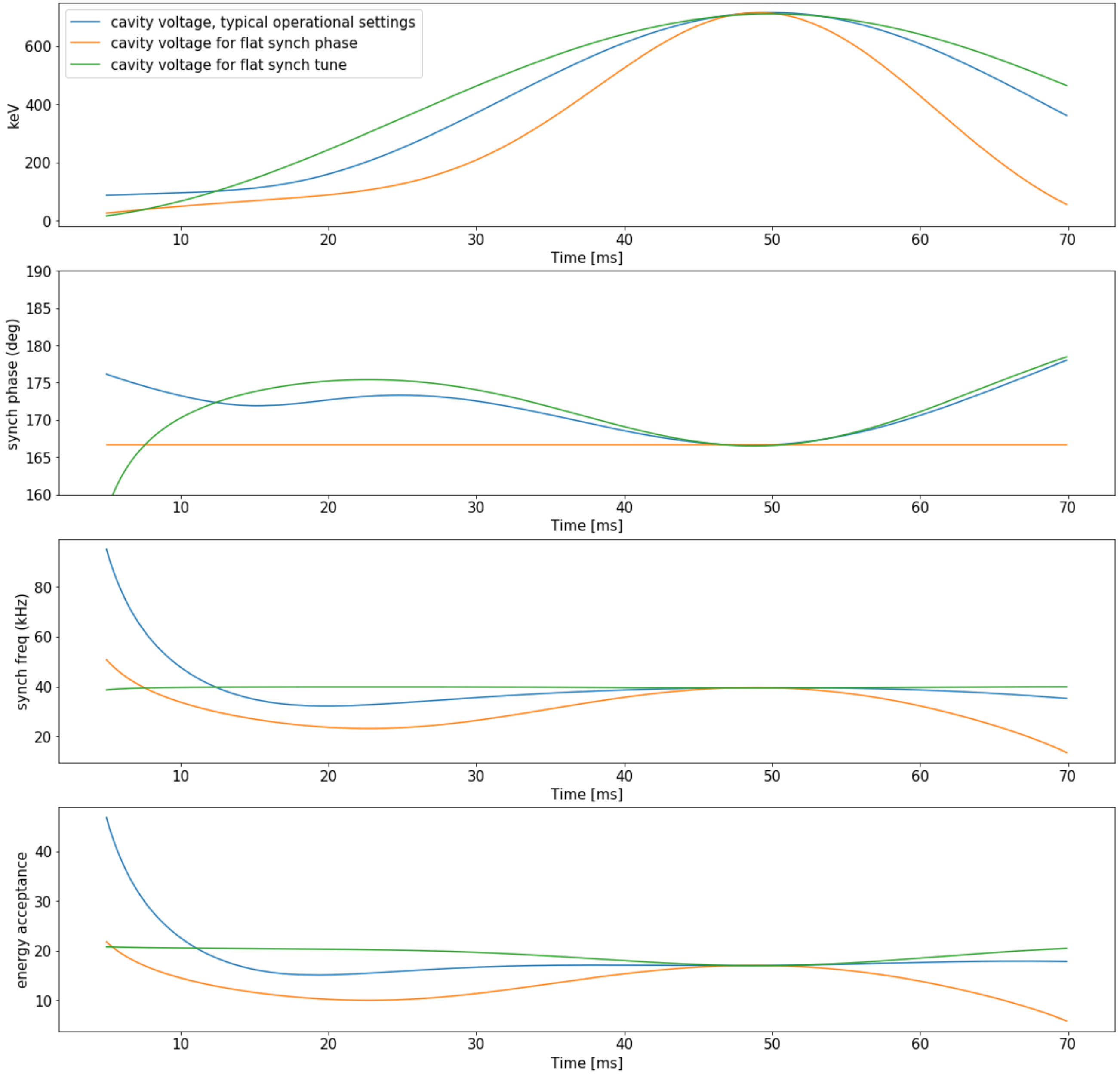
Calculations of Longitudinal Parameters

Blue curves: typical operational RF waveform

Orange curves: RF waveform chosen for constant synchronous phase

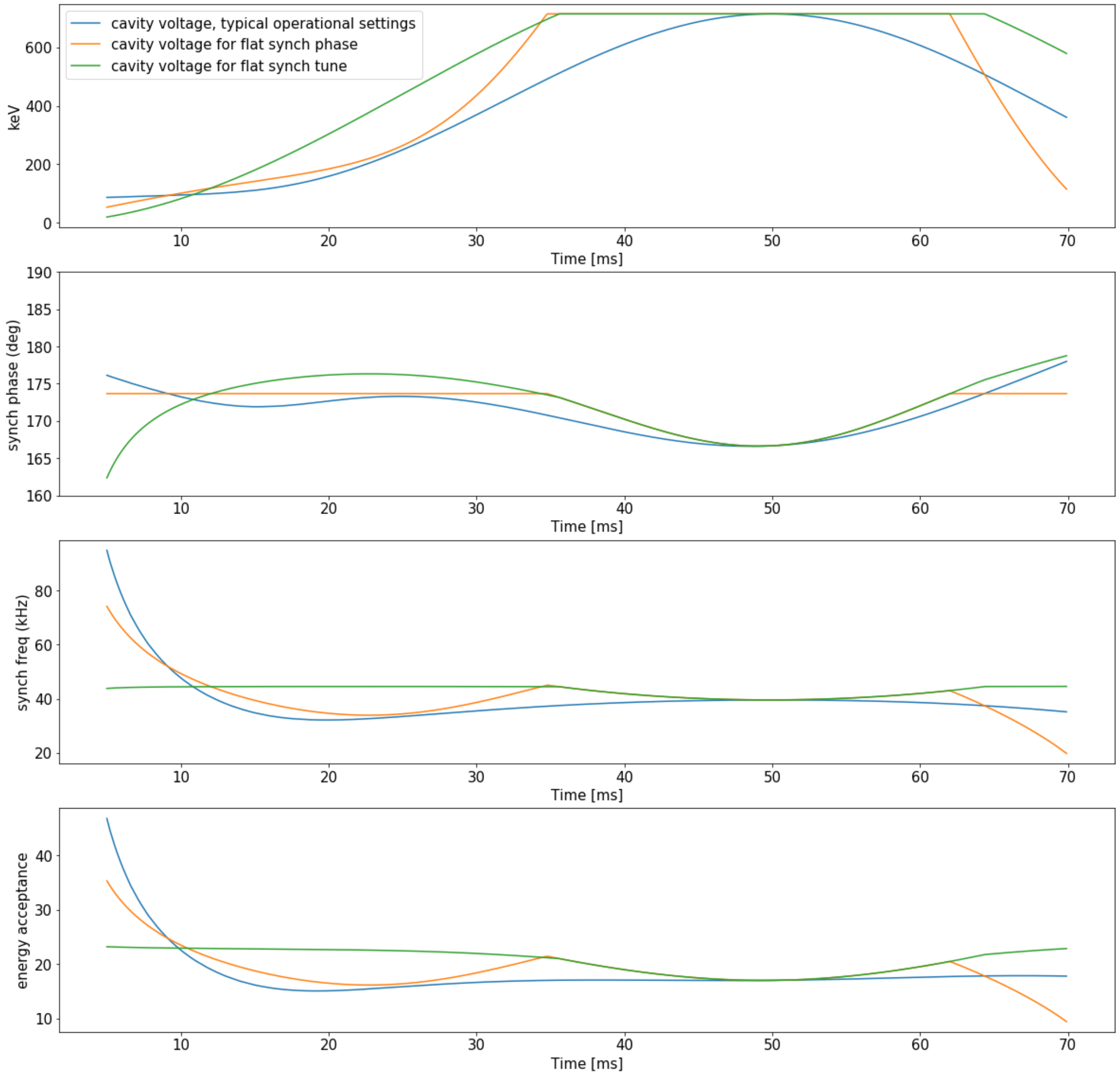
Green curves: RF waveform chosen for constant synchrotron tune

- Maximum voltage is around 715 kV
- typical operational RF waveform increases energy acceptance at injection at the expense of flatness of Q_s and ϕ_s



Calculations of Longitudinal Parameters

- Could get slightly better results (ie slightly larger energy acceptance at injection) by letting the RF curve flatten after beam is extracted



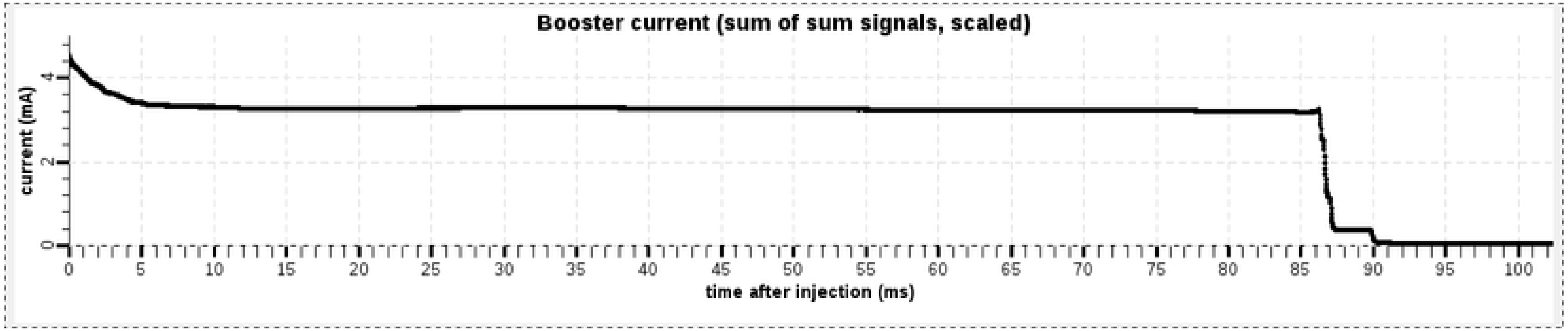
Injection into stationary bucket ($\dot{B} = 0$)

Booster current with typical injection scheme:

Injection into stationary bucket ($\dot{B} = 0$)

Test of $\dot{B} = 0$ injection scheme successful; reduced the beam loss immediately following injection which is typically seen with MB beam

Booster current with $\dot{B} = 0$ injection scheme:



DIGITAL TWIN DEVELOPMENT

Courtesy of P. Schnizer, J. Bengtsson, W. Sulaiman Khail

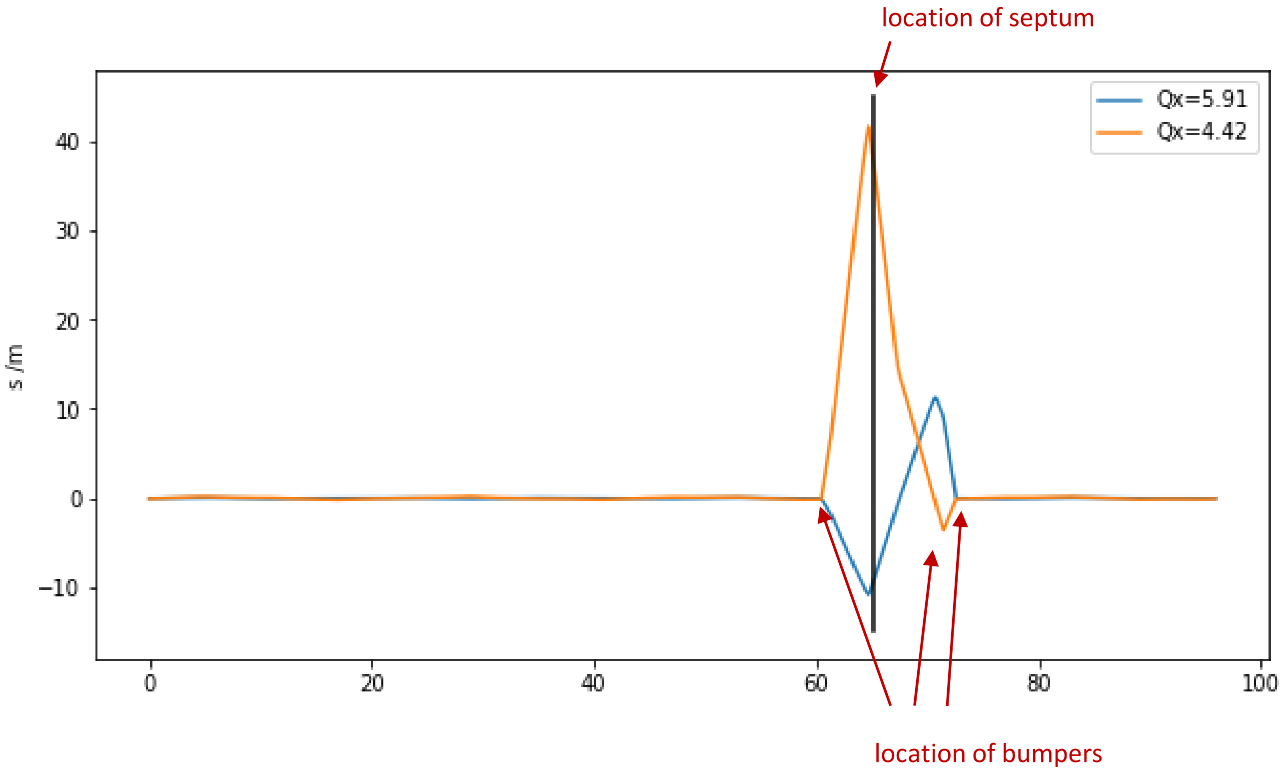
Engine: Tracy[1] → thor-scsi[2]

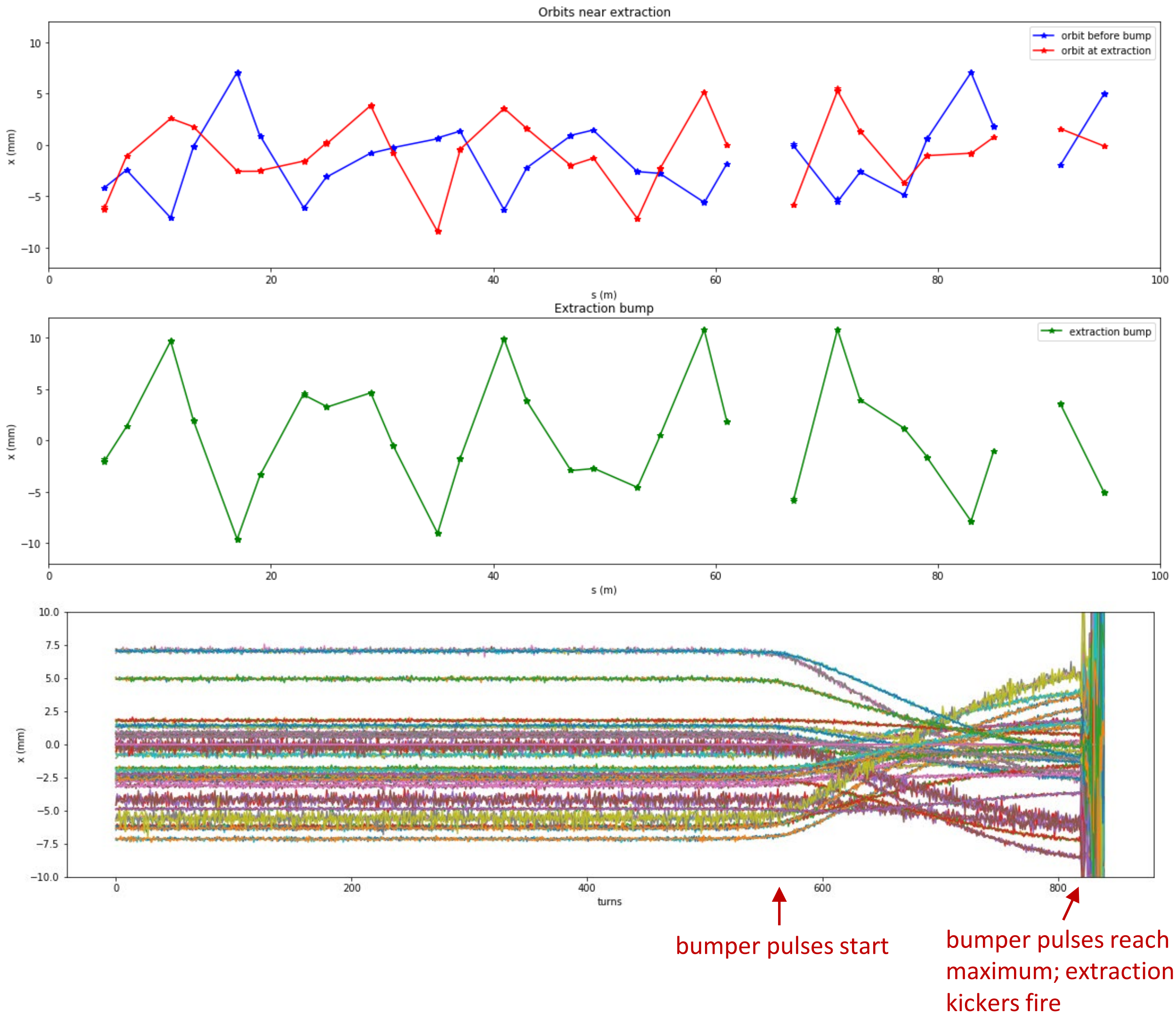
- C++17 /Pybind 11 python interface
- gtpsa ← mad-ng[3]
- parser ← flame[4] (bison/ flex)

[1] J. Bengtsson, M. Meddahi, pp. 1021, Epac94,
[2] P. Schnizer, J. Bengtsson, W. Sulaiman Khail, TUPOST029, IPAC22
[3] L. Deniau, C. I. Tomoiagă, MOPJE039 IPAC15
[4] Z. He, J. Bengtsson, M. Davidaver et al https://arxiv.org/abs/1611.04637

- “First model“ as EPICS IOC
- Eng → phys with records
- Pydev records (github.com/klemenv/pydev) → communication with thor-sci
- Measurement scripts based on bluesky / ophyd
- Next steps:
  - Analysis of code base
  - Use case analysis
  - Mind / apply patterns
  - Modernize code base

BOOSTER EXTRACTION BUMP

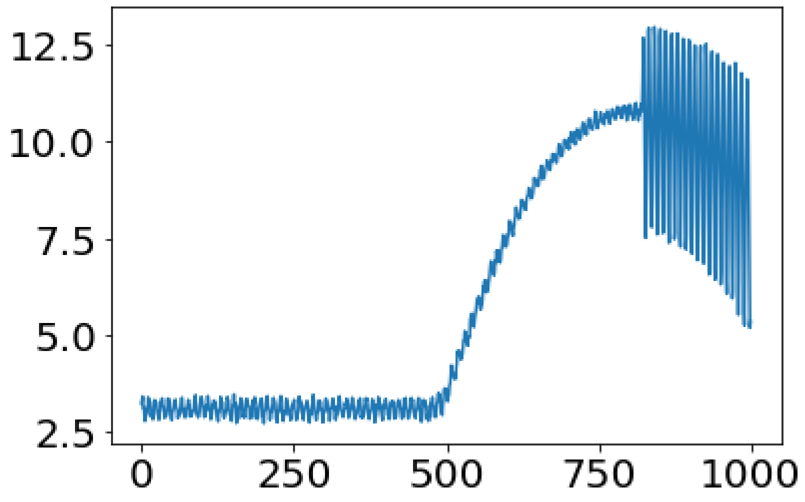


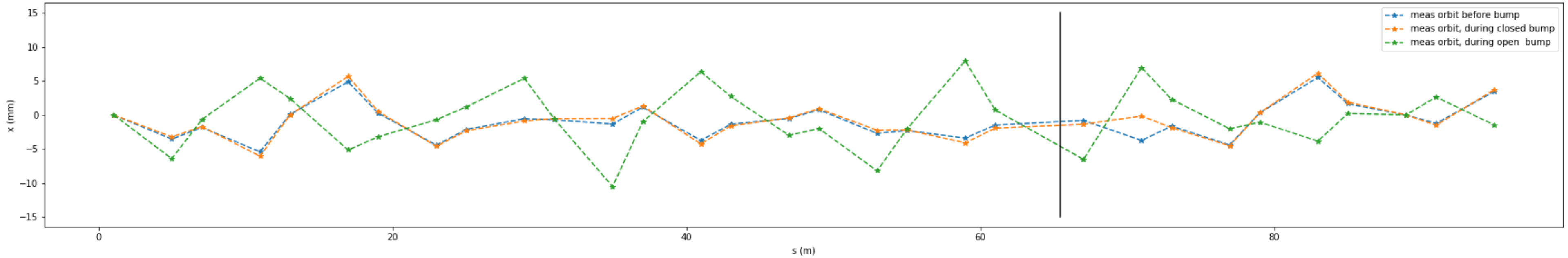


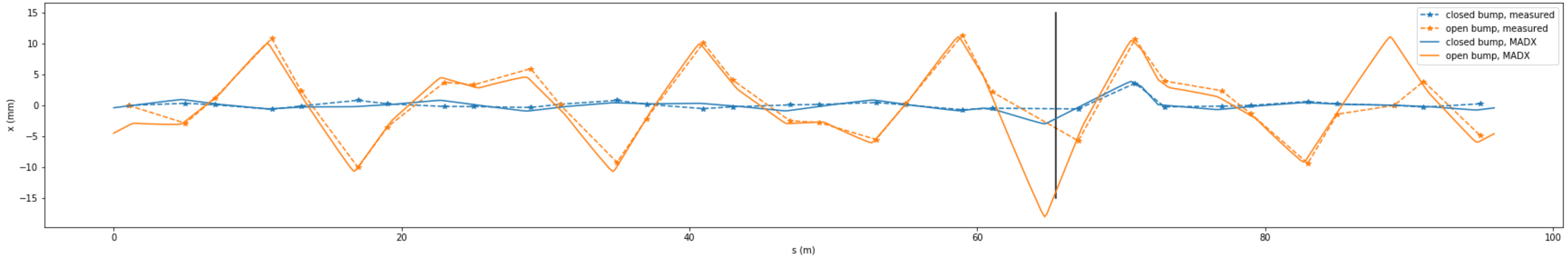
MEASURED BOOSTER ORBIT NEAR EXTRACTION - CLOSED BUMP

- Max orbit displacement at the septum from a closed bump: ~9 mm
  - Extraction on 2nd turn after kick
- Orbit displacement at the septum from the unclosed bump: ~15 mm

(estimate based on fitting steering errors to MADX model to get an idea of orbit between BPMs)

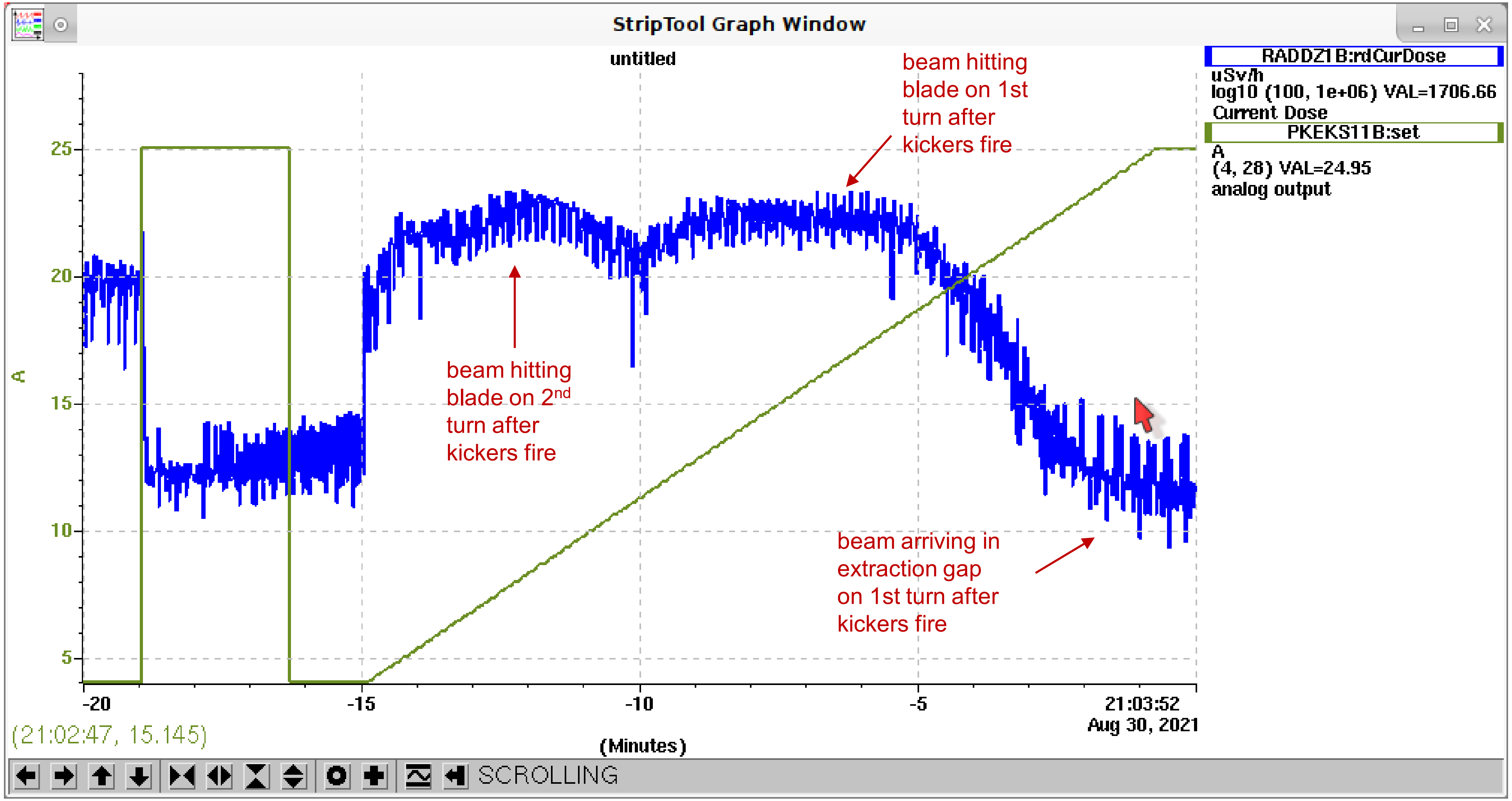






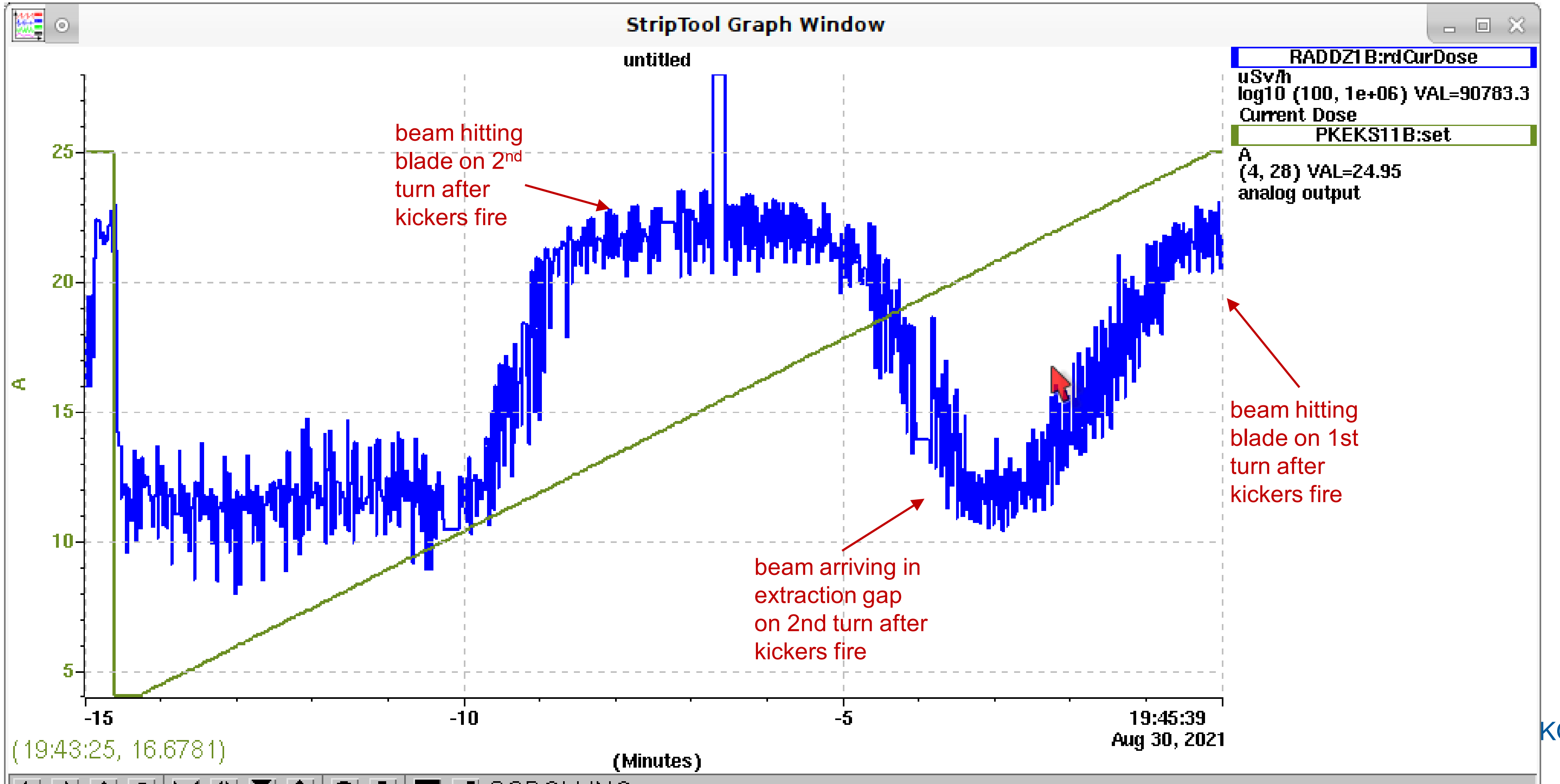
SCAN OF SEPTUM RADIATION VS EXTRACTION KICKER STRENGTH, WITH TYPICAL (UNCLOSED) ORBIT BUMP

typical extraction settings (unclosed bump)

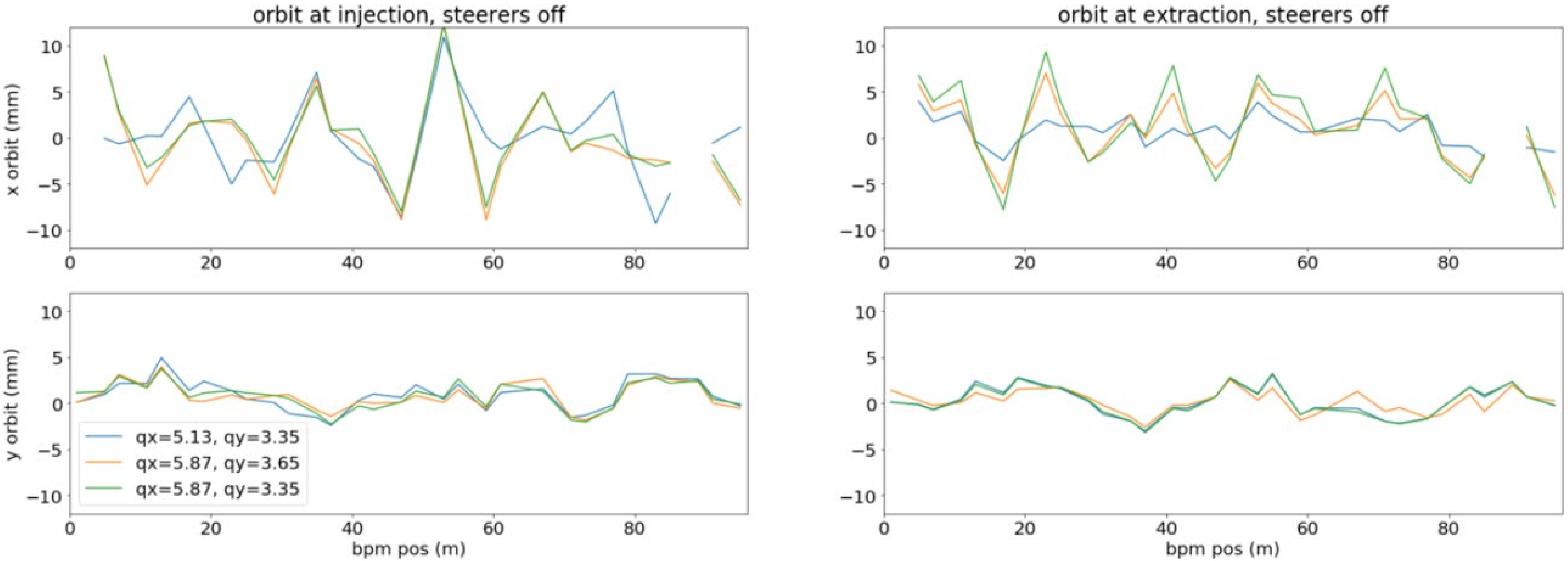


SCAN OF SEPTUM RADIATION VS EXTRACTION KICKER STRENGTH, WITH CLOSED ORBIT BUMP

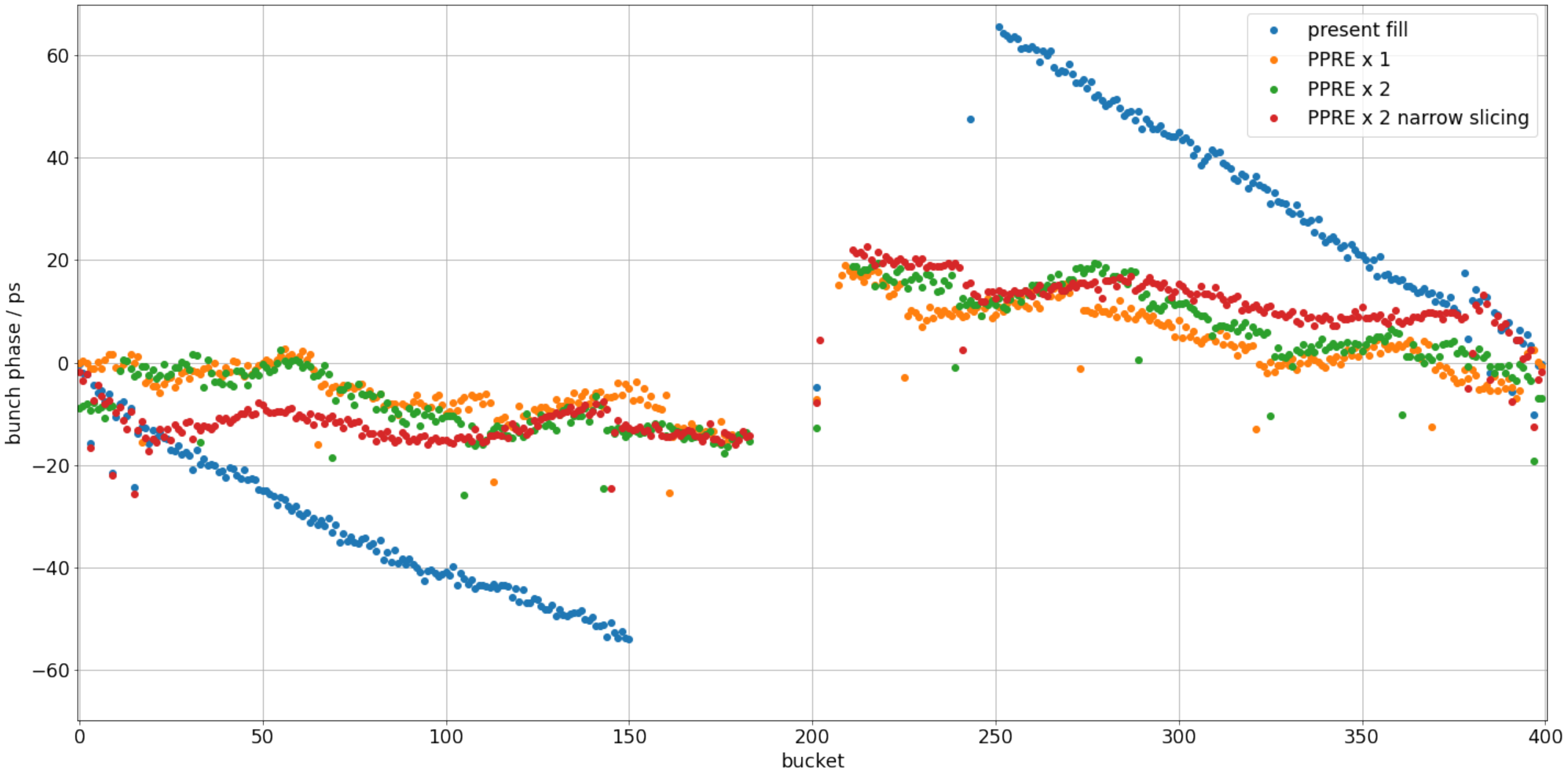
- Usual orbit, and strongest possible closed bump
- beam seemed to be extracted on second turn after kickers fired; to match bucket when injecting into SR, itwas necessary to decrease kicker delay by 320 ns



CLOSED ORBIT DISTORTION AT DIFFERENT WORKING POINTS

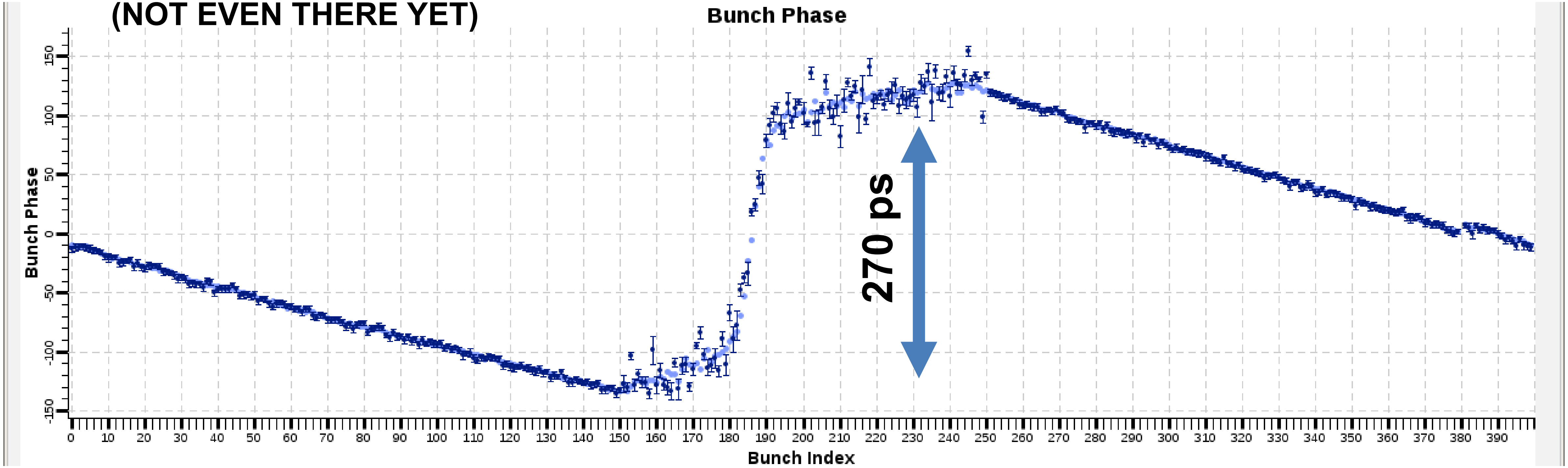


Transient synchronous phase



Transient synchronous phase

A FEW STEPS FURTHER TOWARDS BESSY III
(NOT EVEN THERE YET)



HZB BESSY II Light Source