DESY short BBS–2019 Travemünde 21.-22.02.2019

FLASH Status

Mathias Vogt (MFL) for the FLASH–team:

A.B., B.F., Ch.G., J.H., K.H., K.K., J.R.-S., S.S., J.Z., ...

- FLASH 2018/2019
- Highlights from User Run & Studies
- The RF-gun...
- Controls & Operations
- Outlook (short term)

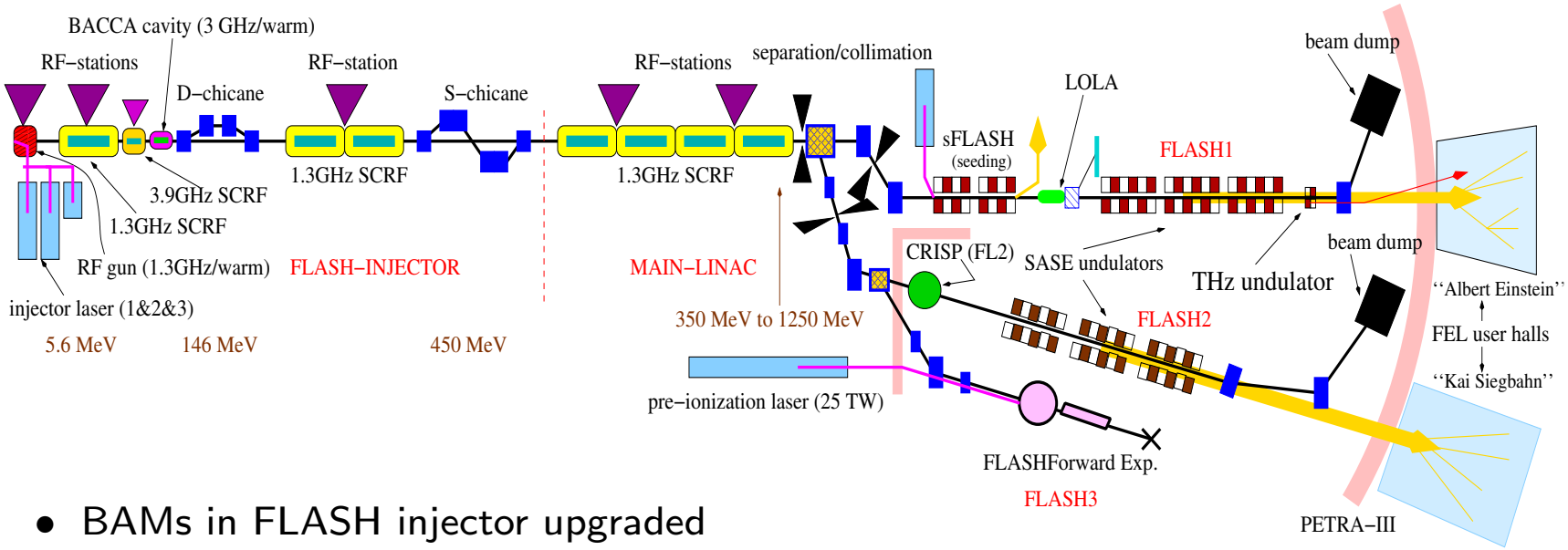
FLASH
Free–Electron Laser
in Hamburg

Who are "the FLASH Team" ?

(In alphabetical order)

- Arne Brinkmann (MSL) : technical coordinator, SRF, shift-leader
- Bart Faatz (FS-FLASH) : new projects, FEL-physics
- Christian Grün (MIN): technical coordinator, timing/MPS, FPGAs, operations
- Jürgen Haar (MBB) : technical coordinator, electricity/cooling/AC, safety, shift-leader
- Katja Honkavaara (MPY) : coordination, organization, scheduling
- Karsten Klose (MIN) : technical coordinator, injector lasers, operations
- Juliane Rönsch-Schulenburg (MFL) : coordination, deputy-SSB, beam dynamics, operations
- **Siegfried Schreiber (MFL)** : **Machine-coordinator**, SSB, safety officer
- Mathias Vogt (MFL) : coordination, beam dynamics, operations
- Johann Zemella (MPY1) : beam dynamics, operations

FLASH : 2018/2019



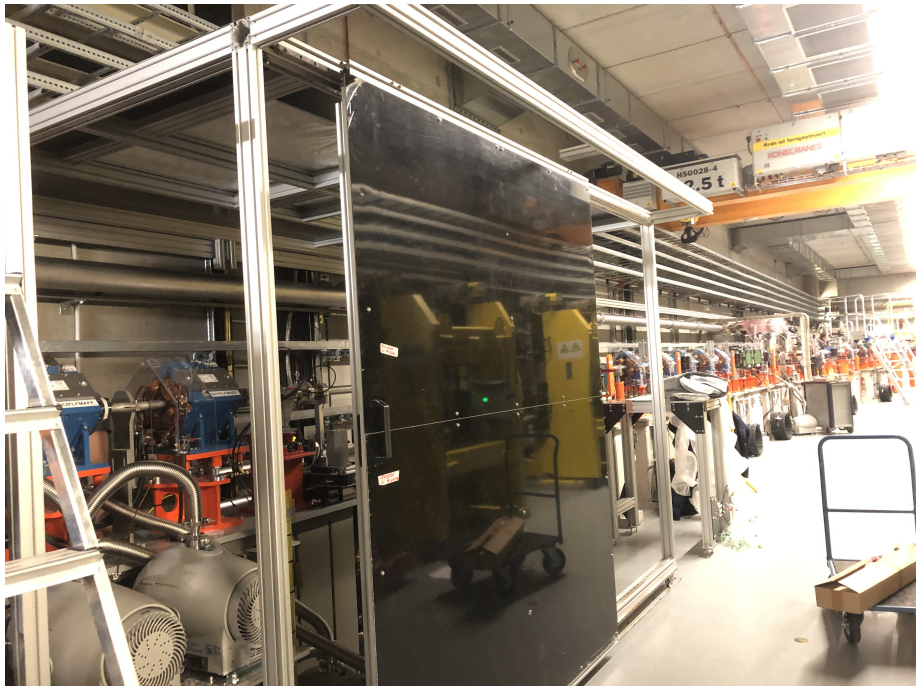
- BAMs in FLASH injector upgraded
  → **1UBC2**,3DBC2,4DBC3 modern pickups & upgr. electro-optics
  → ready for low charge operation
- Optical Synchronization upgraded
  → 3xBAMs, FL1/FL2-PP-laser, sFL-seed-laser, FL2-BL21 (THz streaking)

- **Master**Oscillator upgraded
- Two trenches dug in FLASH2
  → PolariX-TDS (for FL2&FLFwd)
- CRISP/FLASH2 being commissioned

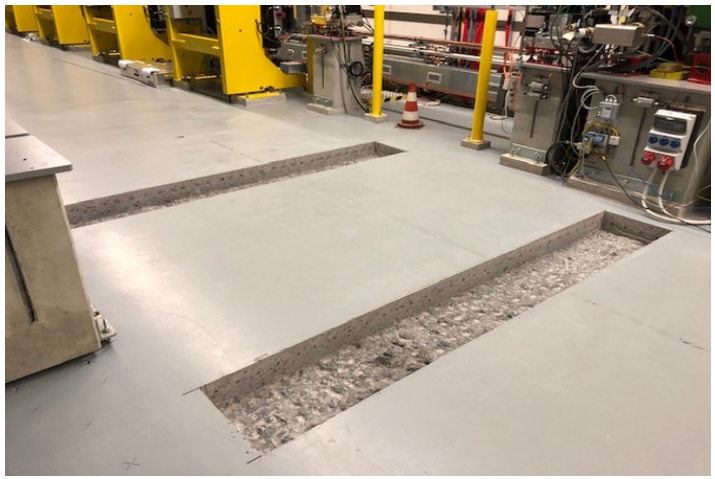
FLASHForward>> 2018/2019

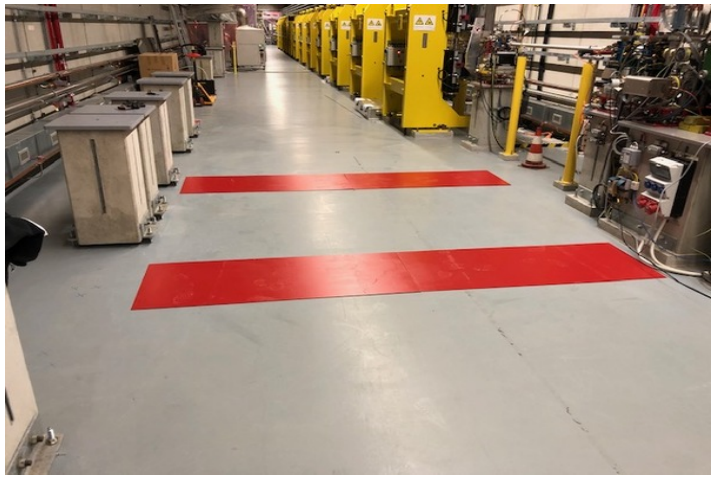
- FLASHForward>>
  laser hut around plasma cell (work in progress)

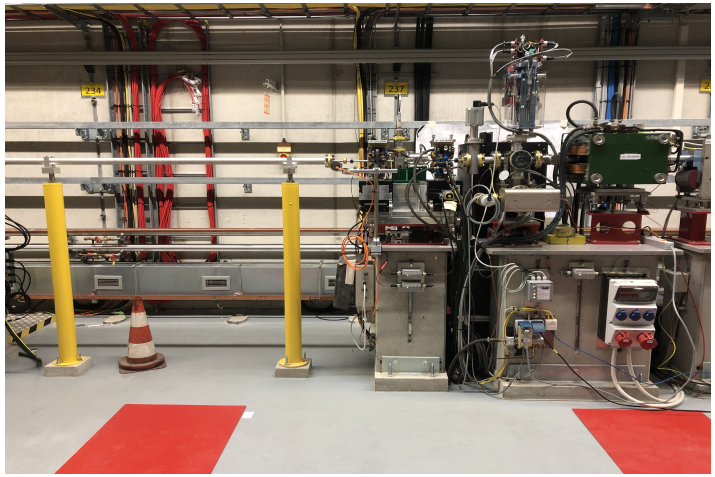
→ tunnel search procedure in this area: 3 search buttons



FLASH2 & FLASHForward>> 2018/2019

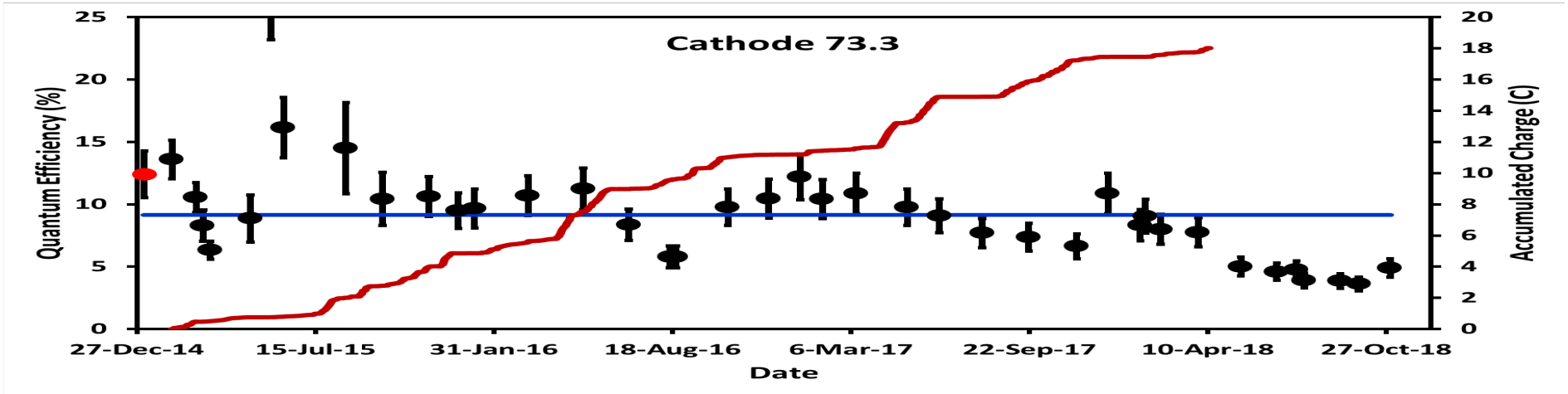






- For PolariX-TDS project (FL2 & FLFwd): (see "Outlook")
- Two trenches have been dug between FL2 & FLFwd
  → for RF-waveguides, cables, and cooling water
- approx. 15 cm deep 50 cm wide
- temporarily covered w/ steel plates ! HEAVY !

Photo Cathode Changed



- old cathode in since Jan/2015
  - → high and stable quantum efficiency (see pic ↑)
  - → very low dark current

+ changing the cathode:
  - → always danger of damaging the back plane (RF-gun)

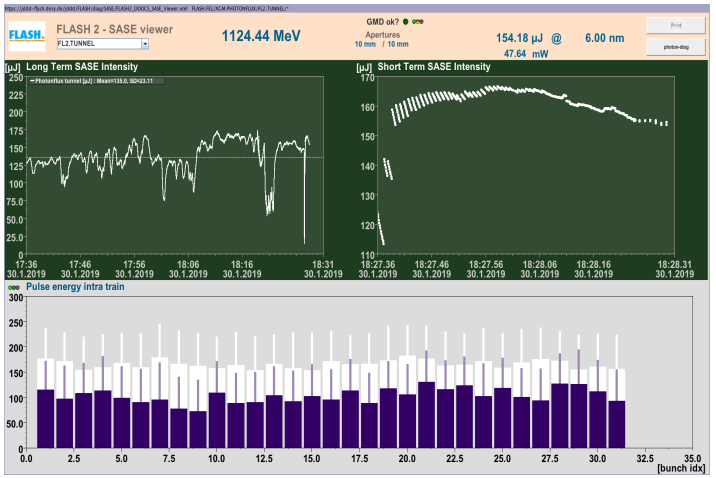
- New cathode in Winter shutdown
- Extremely high QE
- slightly ($\approx 2\times$) more dark current in the beginning

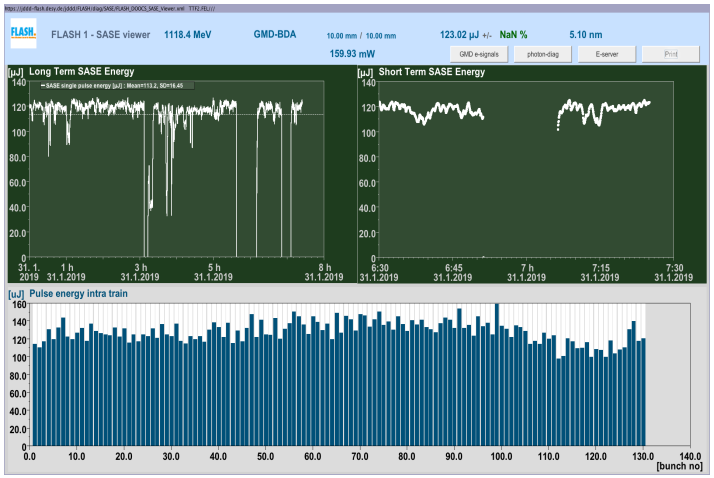
SASE around 5nm

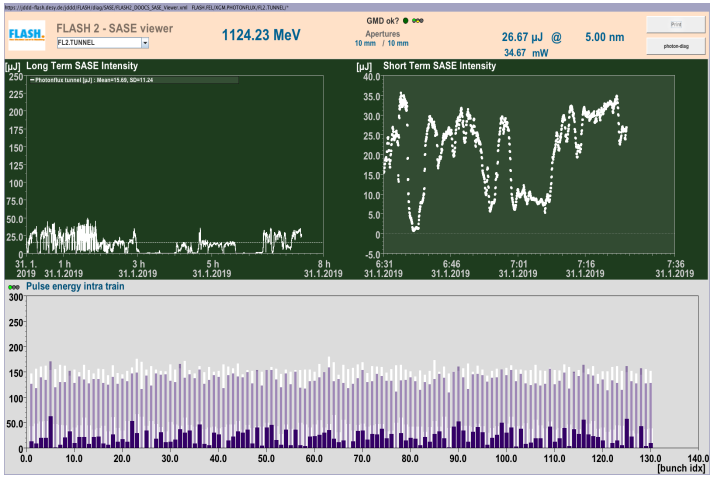
- 29.-31.01.2019: Set up of 1100 MeV reference file

→ gun flat to : yet only ∼300 μs

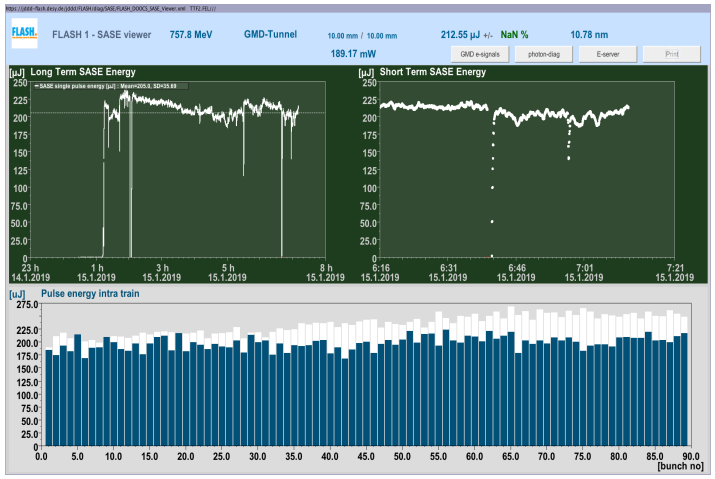
- FL1: 120 μJ at 5.1 nm w/ 130 bunches
- FL2: 160 μJ at 6.0 nm w/ 31 bunches
- FL2: ∼30 μJ at 5.0 nm w/ 130 bunches



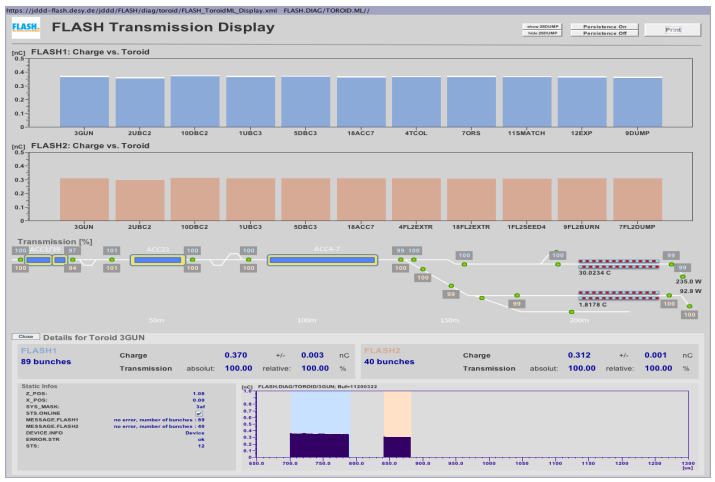




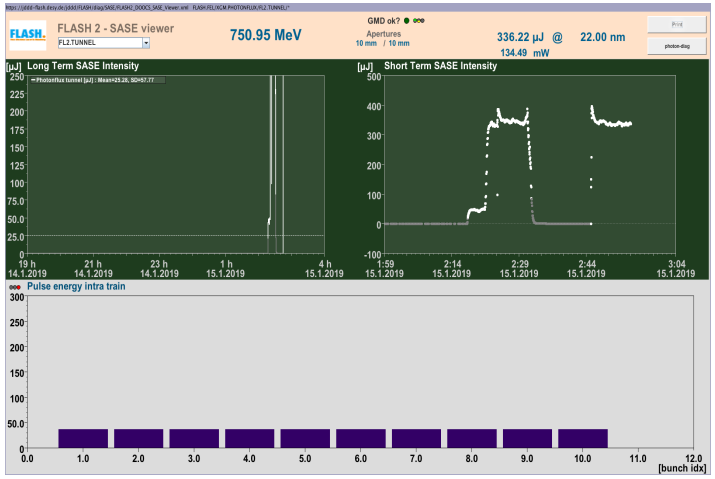
750 MeV Reference file 2019-01-15 usable flat top (90+50+40)μs



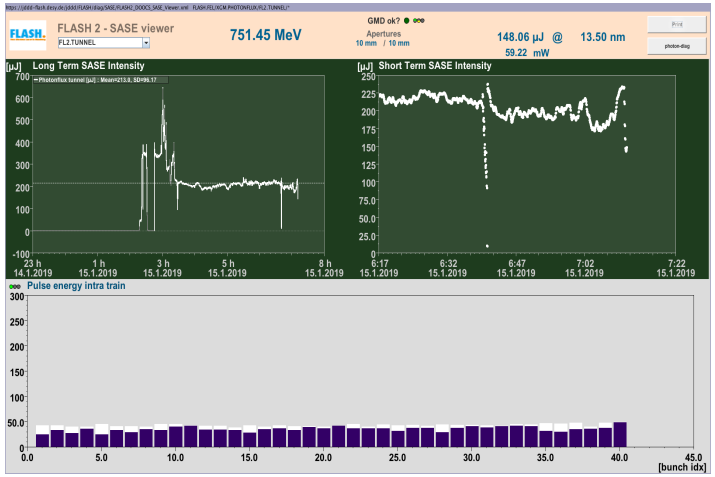
FL1: 90 bunches 205 μJ at 10.8 nm



FLASH: 81+40 bunches



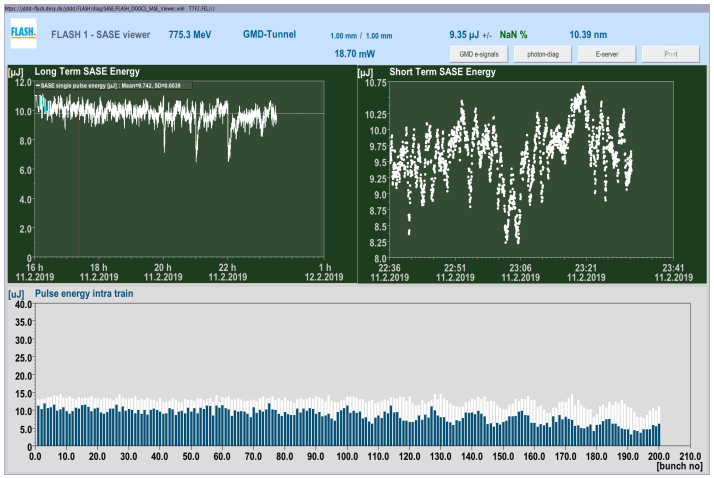
FL2: 10 bunches 350 μJ at 22.0 nm

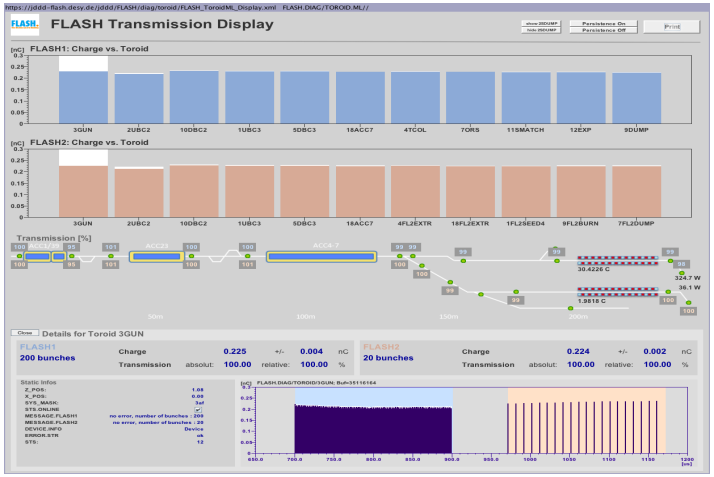


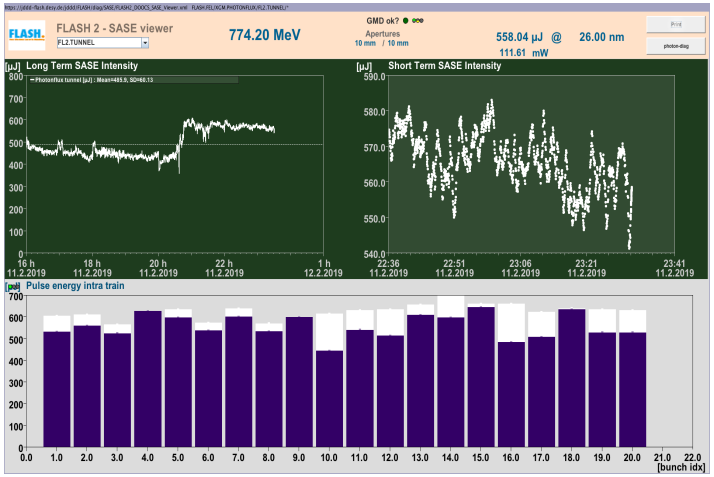
FL2: 10 bunches 210 μJ at 13.5 nm

Many Bunches FLASH1/FLASH2 (User Run)

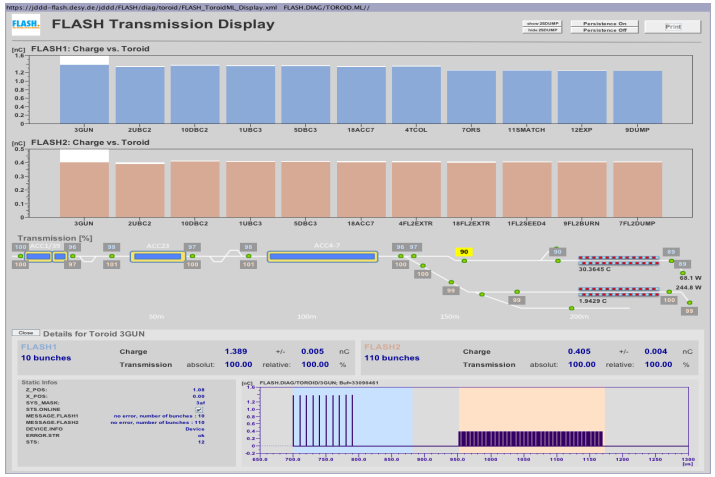
- usable flat top (210+70+210) μs
- FL1: 10 μJ (at 1/1 mm apert.!) 10.4 nm w/ 200 bu.
- FL2: 500—700 μJ at 26 nm w/ 20/40/50/100 bu. at .1/.2/.25/.5 MHz







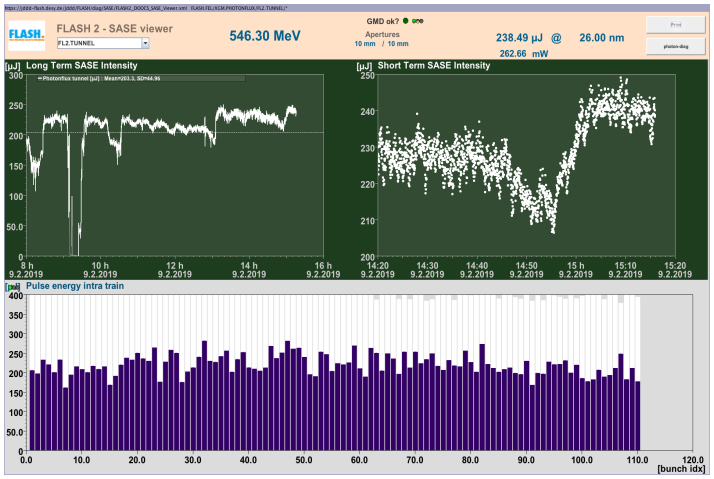
FLASH1 at THz w/ High Charge /FLASH2 SASE w/ 220 Bunches



- THz at FL1⇒ high charge (here **1.4 nC**)

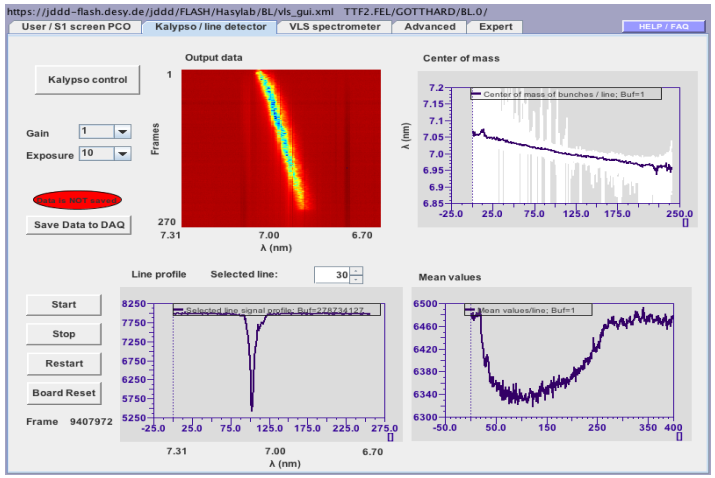
→ often not favorable state for FL2, however. . .

- FL1: 30 μJ at 21.8 nm & **up to 50 μJ at 15 μm THz** w/ 10 bunches at 100 kHz
- FL2: 200—250 μJ at 26 nm / 110 bunches at 1 MHz

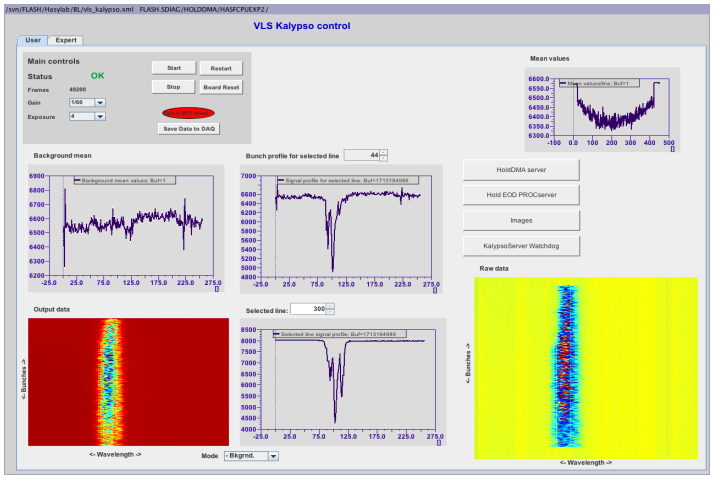


News from the Photon Side

- **FLASH2 now has optical pump-probe laser:**
- For many (potential FL2-) users P-P is a key feature
- Only since then can FLASH2 be fully scheduled for users



Kalypso:



- fast read-out 1-D hi-res CCD
- together w/ VLS spectrometer at BL (FL1)
- wavelength spectr. vs bunch-in-train
- **bot/left:** to verify that λ-distribution is flat
- **top/right:** mutually created wave-length chirp (RF ampl. slopes in ACC45/67)

FEL Experiments at FLASH

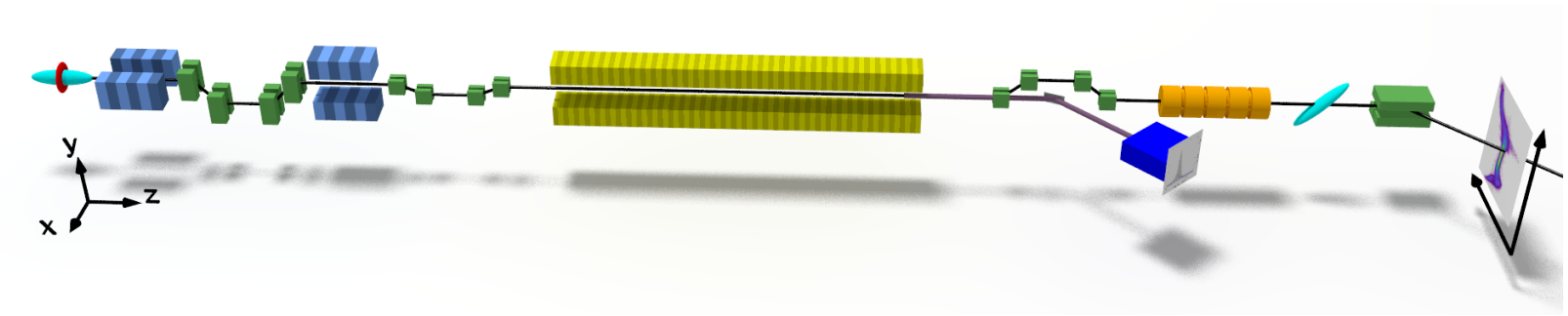
- (not HHG/HGHG/EEHG seeding)
- **E.Schneidmiller & M.Yurkov:**
- A gazillion of ideas, papers, experiments:
  → Harmonic Lasing (HL),
  HL-SelfSeeding (HLSS),
  Reverse Taper,
  Frequency Doubler,
  Two Color lasing, ...

⇒ a nice summary can be found in:

http://www.desy.de/xfel-beam/talks.html#a2019.01.15

- Let's concentrate on 2018:
- **first time HLSS for users !**
  (27.-28.02.+03.-06.03.2018)
- 22.10.2018:
  two color lasing:
  18 nm + 28 nm
- 15.11.2018:
  freq. doubler: 5u$\times\omega$,7u$\times 2\omega$
  → **3.18 nm (2 μJ) to**
  3.68 nm (7.5 μJ)

sFLASH



- Pics & infos:
  thanks to Ch.Lechner!
- Past: HHG
- Presently: HGHG
- TDS measurement for reconstruction of temporal FEL pulse envelope

← **first time done by sFLASH for seeded FEL**

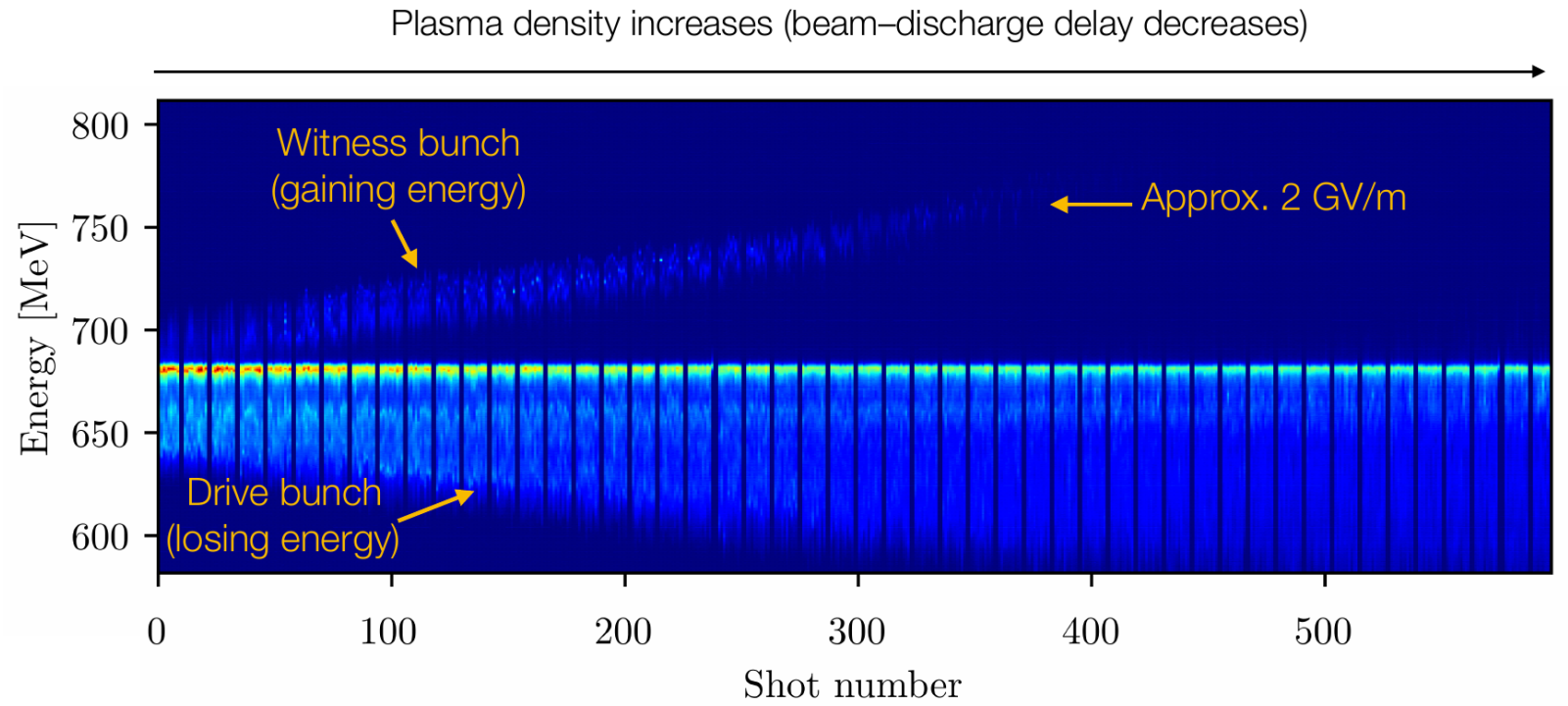
- Also: THz streaking of seeded FEL pulse
- Plan: EEHG :

→ demonstration of EEHG-seeding at sFLASH around 30 nm

→ upgrade of 1st sFLASH chicane for of EEHG seeding:
→ currently being engineered

FLASHForward>>

Mainly: See Stephan Wesch's talk Tomorrow!!! Pics & infos: thanks to R.D'Arcy!

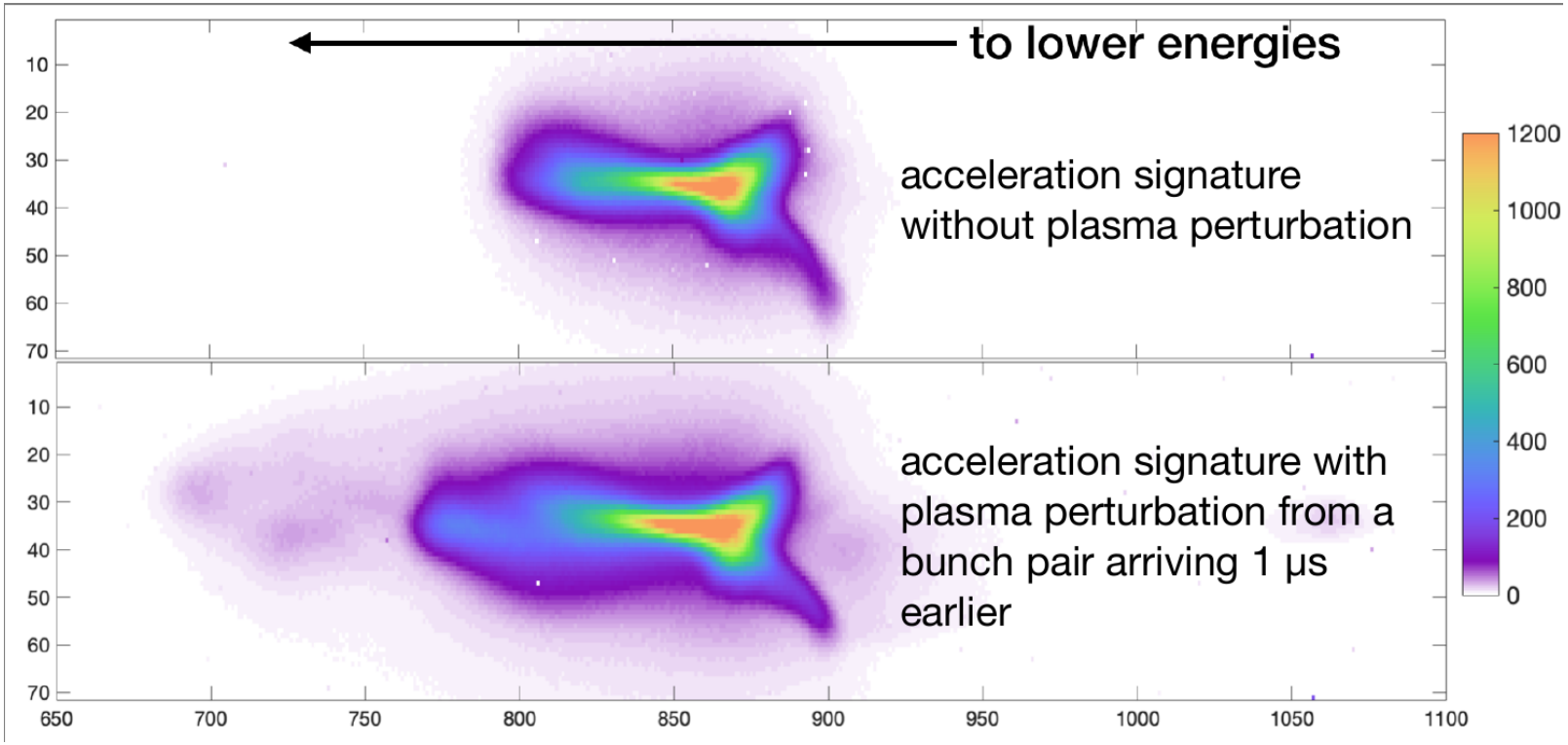


- 01/2019: (first at FLFwd) Acceleration of electrons with GV/m gradients

→ Externally injected electrons accelerated from ∼700 MeV to ∼770 MeV in 33 mm of plasma

→ >2 GV/m gradients, essential for application of PWFA as plasma booster to future facilities

FLASHForward>> (2)



- 01/2019: First *ever* studies of PWFA at effective MHz rep. rates

→ study effects of plasma relaxation at the μs level after perturbation by wakefield

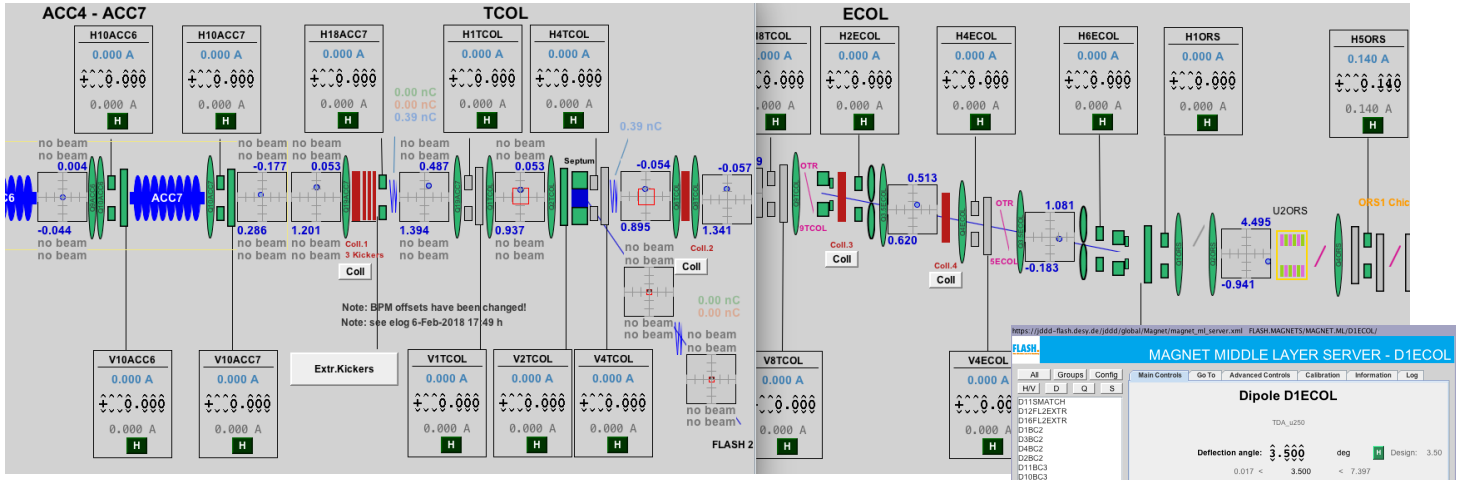
⇒ a different wakefield signature observed after wakefield perturbations created by 1st bunch

→ first steps towards understand reproducibility of PWFA at MHz rep. rates for future applications

Ballistic BBA in (FL1) DOGLEG

- Absolute energy measurement in a linac is intrinsically problematic!
- FLASH: dispersive dogleg (theory, direct measurement, indirect measurement, legacy data,...)

$$E = E_{\text{central}}(\phi_{\text{dip.}}, \{\text{calib}\}, I_{\text{dip.}}) + E_{\text{central}}(\ldots) \cdot (x_{\text{bpm}} - x_{\text{offs.}} - x_\beta)/D_x$$



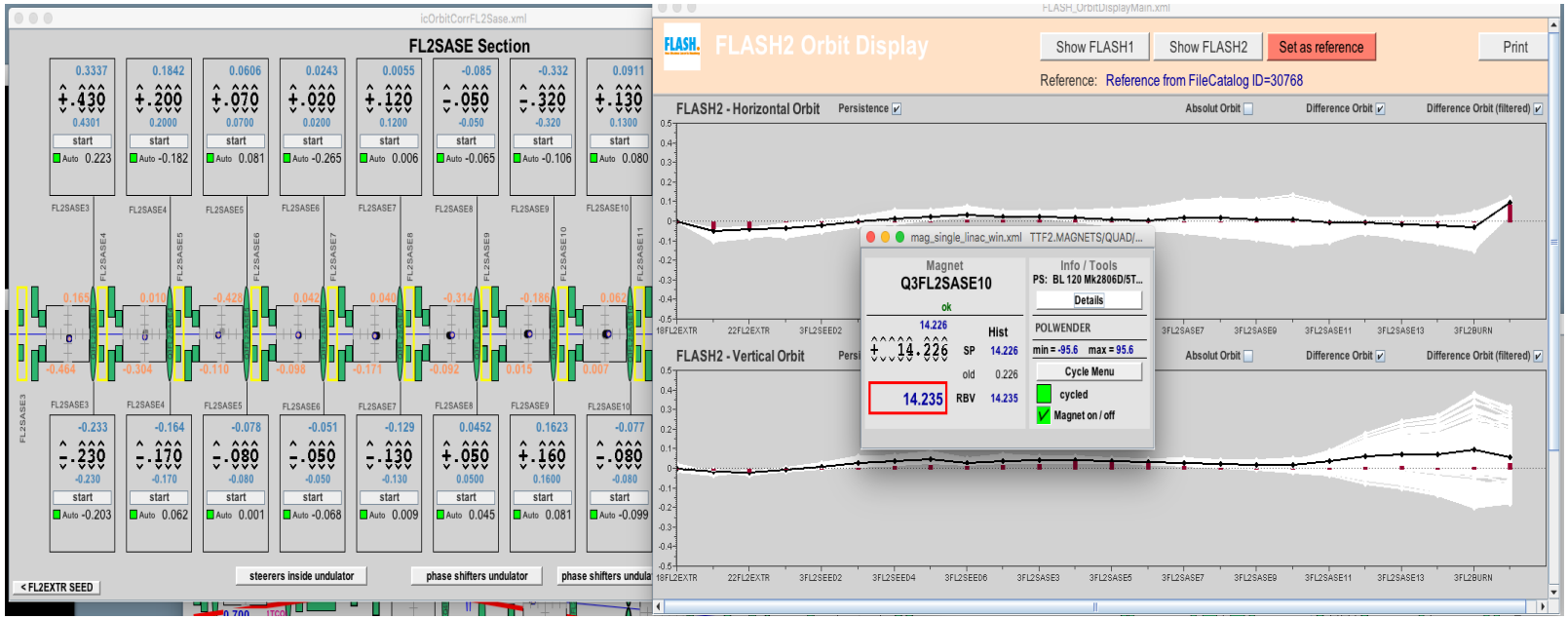
- Energy from SASE spectrometer and undulator K
- Dipole to design angle (accordingly)
- quads Q9/10ACC4–Q2ORS→0 (+sextup./septum/steerers)

⇒ traj. should be straight line with design arcs in dipoles

⇒ BPM offsets & check if dipole calib. is compatible

Ballistic Quad-BBA in FL2SASE

- FEL requires overlap of photon beam and electron beam ⇐ photons: straight line!!!
- But misaligned quads kick beam $\Delta p = \kappa q_{\mathrm{offs}}$ $(q := x, y, p := x', y', \kappa_y = -\kappa_x)$



- in FL2SASE section
- w/ open undulators

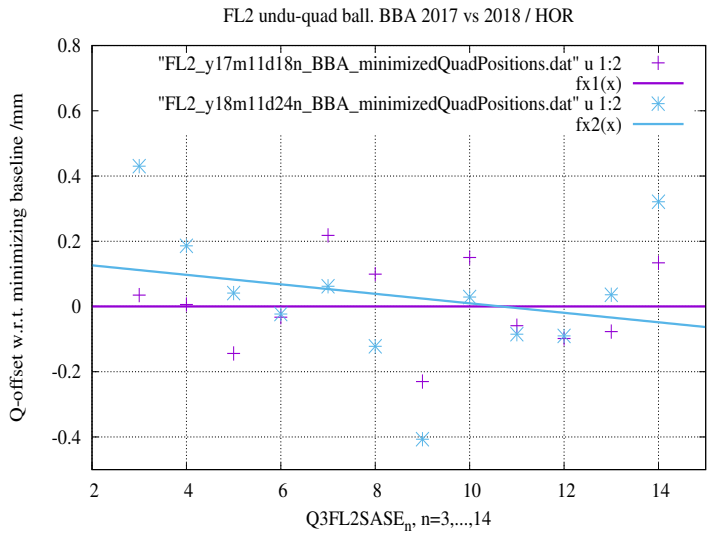
→ long beam waist (quads→0)

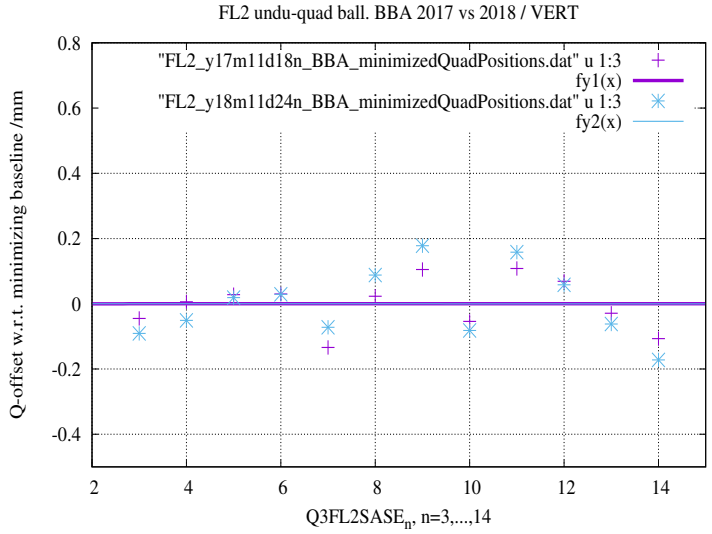
- foreach single quad:

→ crank up κ (I)

→ use **quad-movers** to restore orbit

Ballistic Quad-BBA in FL2SASE (2)





- . . . aligns quads along **some** straight line
- interactive cmndline tool to shift/rotate "this line"

  `/home/ttflinac/user/vogtm/f77/shiftBBA`
- pics: minimizing fit-lines and quad-shifts for: 2017 data and 2018 data for horizontal (top) and vertical (bottom) plane.

→ vertical agreement very good

→ horizontal: more difficult because of periodic slow orbit variations (E?)

Optics: Symmetric Quad Scan in (FL1) SFUND

- single quad scans are know to be fragile under optics perturbations
- so why at all bother?

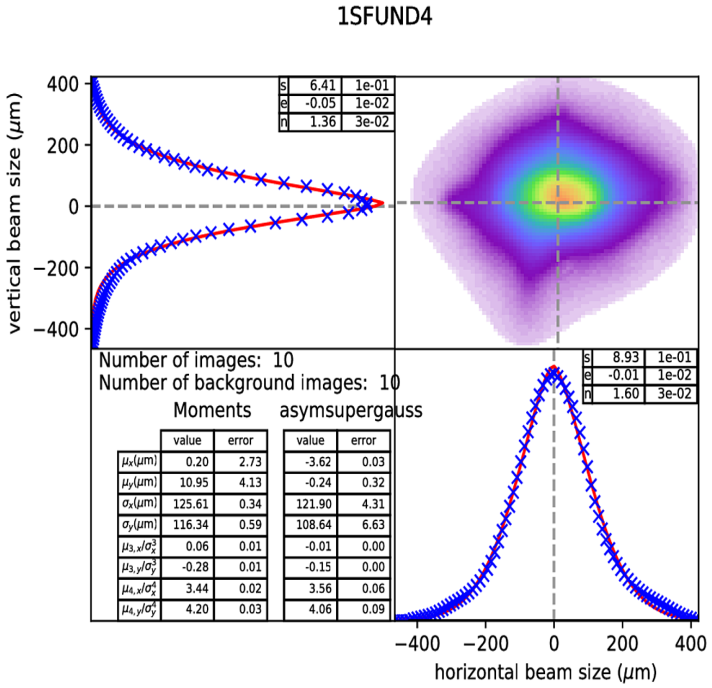
  (SFUND has 4 screens!)
- camera resolution limited:

  "medium to big beams rather than small to smaller beams"

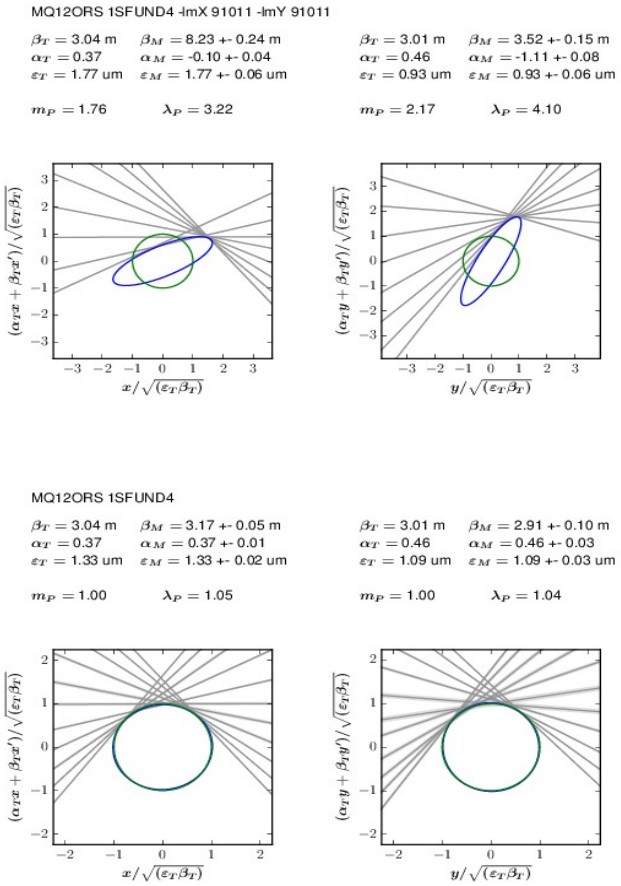
  $\rightarrow$ requires **high** β at high E, since $\epsilon \propto 1/E$
- but phase advance $d\mu = ds/\beta$ favors small β for given (restricted) Δs

$\Rightarrow$ design (**JZ**) **dedicated symmetric quad scan** optics w/ β at screen always high

$\Rightarrow$ scan more robust (both planes) & good resolution (pic $\downarrow$)



Optics: Symmetric Quad Scan in (FL1) SFUND (2)



- 2018-11-16/n: symmetric quad scan Q12ORS on OTR1SFUND4
- top: initial scan: mismatch ampl $x \rightarrow 3$, $y \rightarrow 4$
- after 3 iterations (rematch$\rightarrow$ remeasure)
- bottom: converged: mismatch ampl $x \rightarrow 1.05$, $y \rightarrow 1.04$, $\epsilon_{x/y} \rightarrow 1.33/1.09$ μm

$\Rightarrow$ obviously not resolution limited

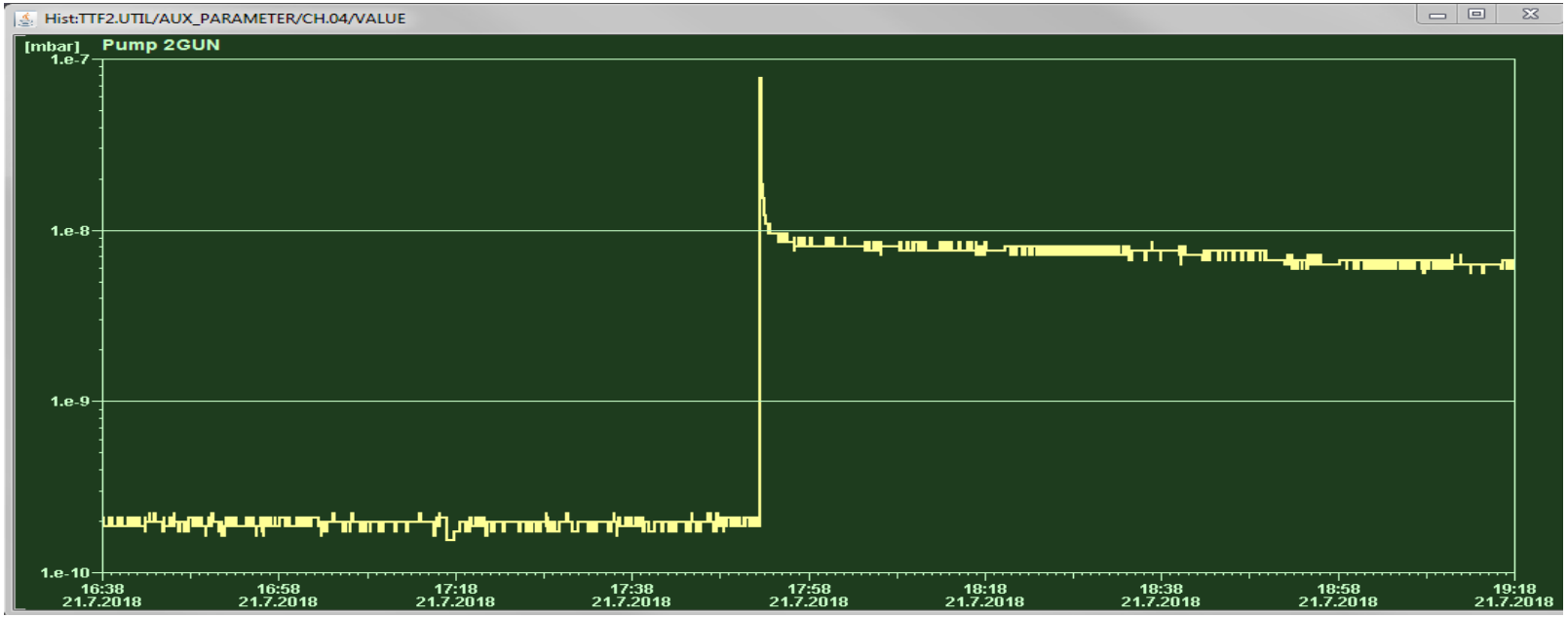
$\Rightarrow$ converged (from 3/4) $\Rightarrow$ reasonably robust!

$\Rightarrow$ great improvement

$\rightarrow$ also candidate for FL2SEED

The FLASH RF-Gun : Puzzle Picture (Bilderrätsel)

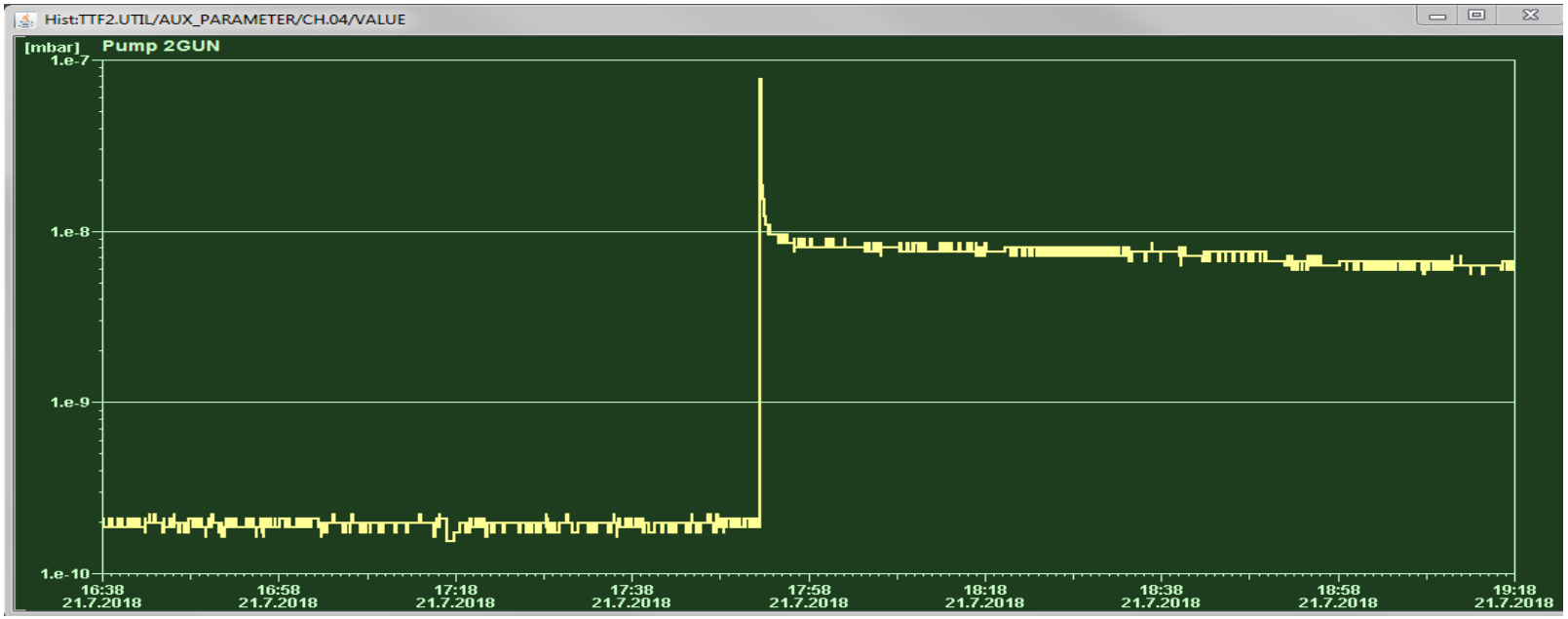
What do we see here ?



- After summer shutdown 2018
- during gun recovery. . .
- after increasing the flat top in one step from 120 μs to 350 μs. . .
- . . . roughly 24 h later. . .
- . . . during (my!) optics studies:
- ?????????????

The FLASH RF-Gun : Puzzle Picture (Bilderrätsel)

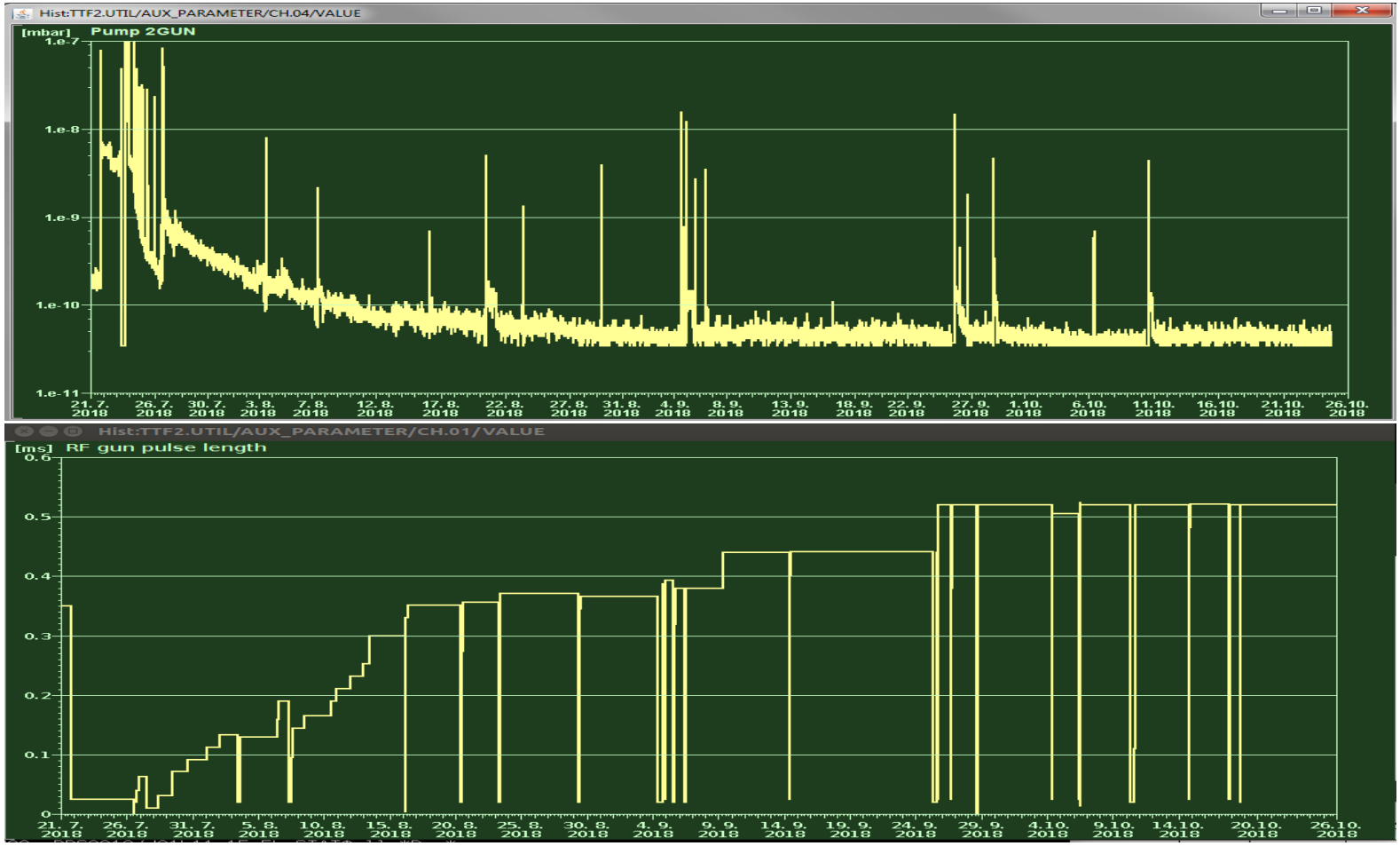
What do we see here ?



- After summer shutdown 2018
- during gun recovery. . .
- after increasing the flat top in one step from 120 μs to 350 μs. . .
- . . . roughly 24 h later. . .
- . . . during (my!) optics studies:
- **An RF-window leak !**
- . . . optics studies over :-(:-(:-(

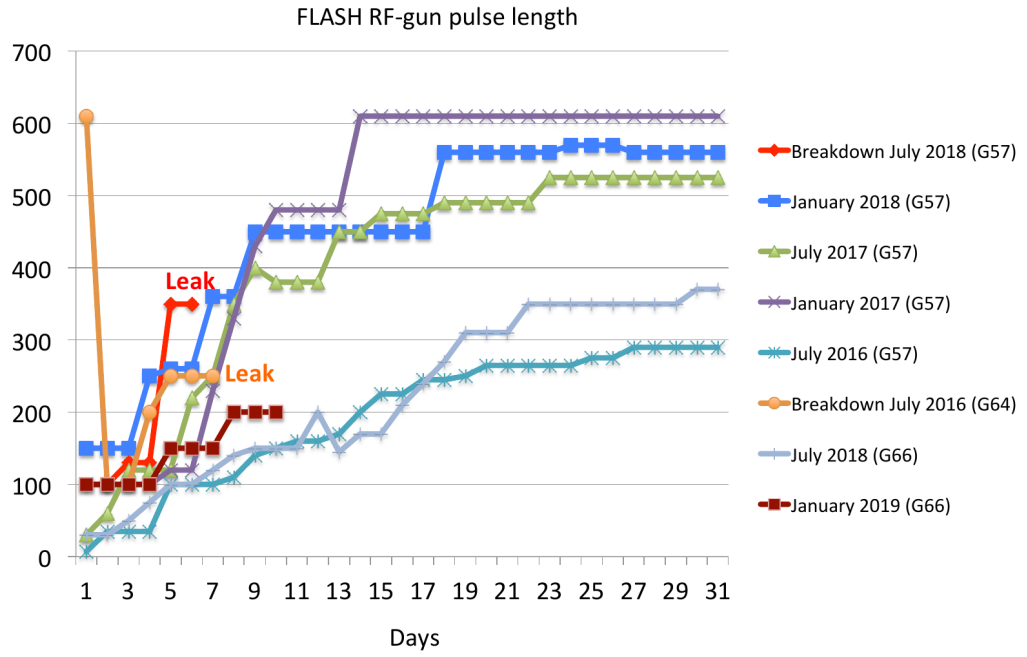
RF-Window Exchange Summer 2018 & Recovery

- Window was quickly exchanged → Vacuum recovered while flat top was slowly ramped up
- pics (↓) 21.07.2018 to 26.10.2018 IGP2GUN pressure/mbar (top) and RF-gun flat top/ms (bottom) (what *looks like* out-bursts are in fact mostly firings of the TSPs!)



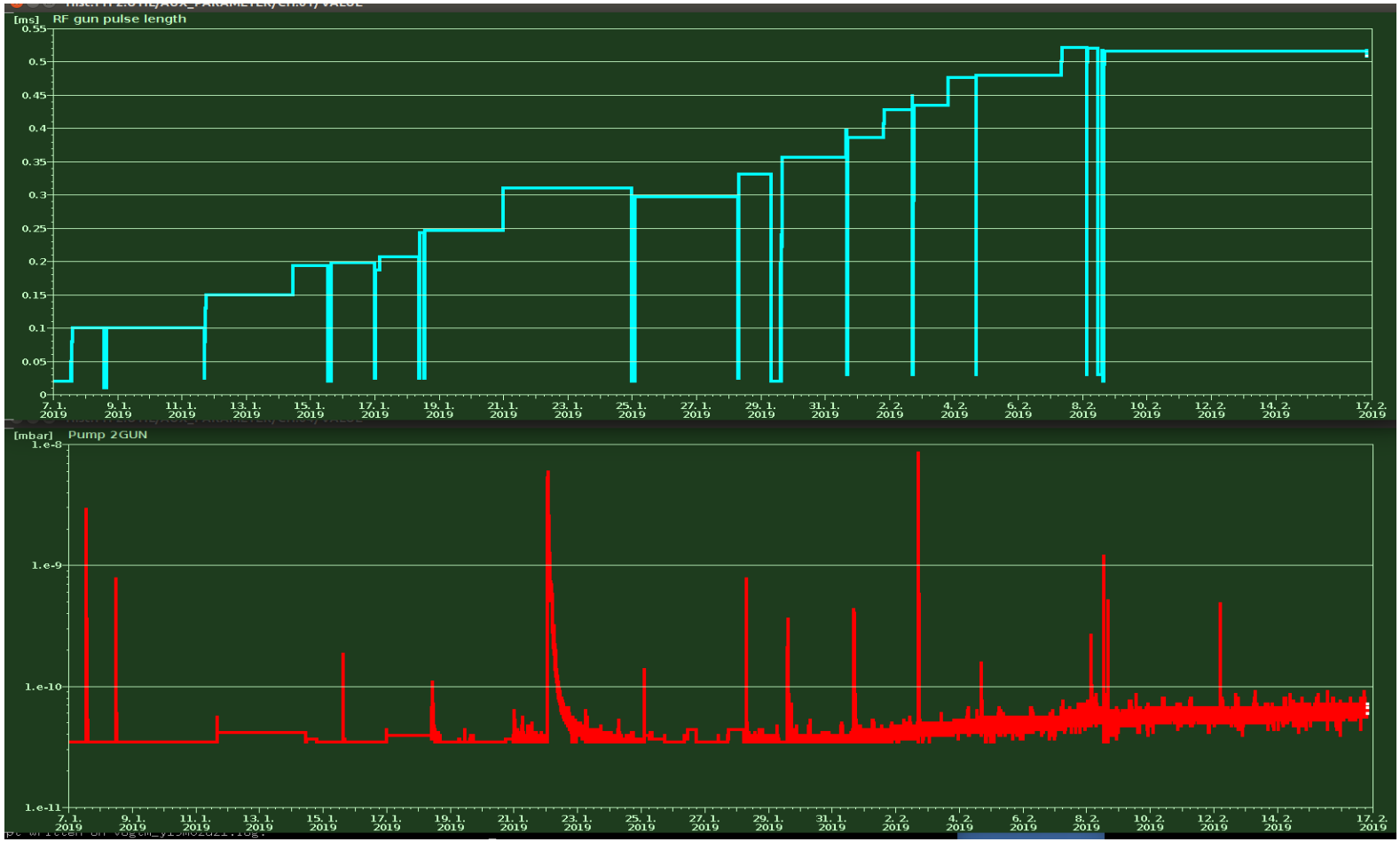
RF-Gun Ramp Up Procedures

- In general we have bad experience with too bravely ramping up the flat top.
- However, by slowly ramping it up, we have reached about 600 μs and stable operation for months.



K. Honkavaara,17.01.2019

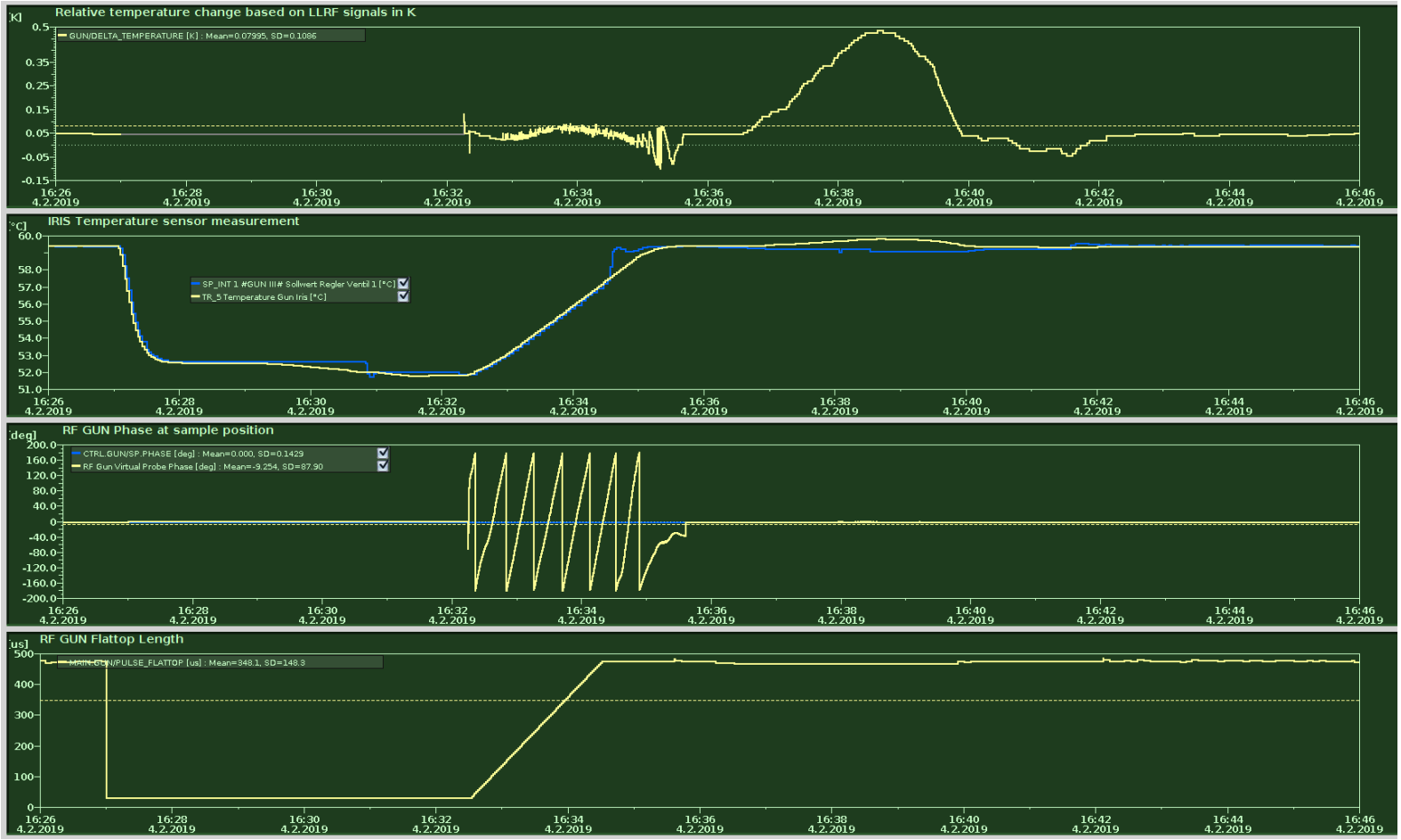
RF-Gun Restart after Winter Shutdown and Cathode Exchange



- Window was quickly exchanged → Vacuum recovered while flat top was slowly ramped up
- pics (↑) 07.01.2019 to 17.02.2019 RF-gun flat top/ms (top) and IGP2GUN pressure/mbar (bottom) (what looks like **moderate** out-bursts are in fact exactly these!)

New Automated RF-Gun Ramp-Up by FSM, LLRF, and PWM

Trip: **FSM** lets iris-temp. SP follow the falling actual temp. (valves not closed!), then: **LLRF** phase modulation keeps frequency on resonance during ramp-up (only little P_{ref} but eff. RF heating$\rightarrow$ nominal temp.), finally **PWM** controls temp-overshoot and settles at nominal parameters.



Controls and Operations

- (RF-gun-rampomat)
- new LLRF firm-/soft-ware:

→ stronger more versatile FB

→ less strict limits on **split flat tops**

→ **might** take over the role of the LearningFFwd completely!

- Wire scanner svr ported to XFEL standard:

  → still needs some testing

  → potentially solve many little probl.

- new CentralMagnetSvr/MagnetMLayerSvr:

  → will redistribute responsibilities

  ← preserve FLASH procedures

  → work in progress!

- Operator training:

  → re-started hands-on tutorials

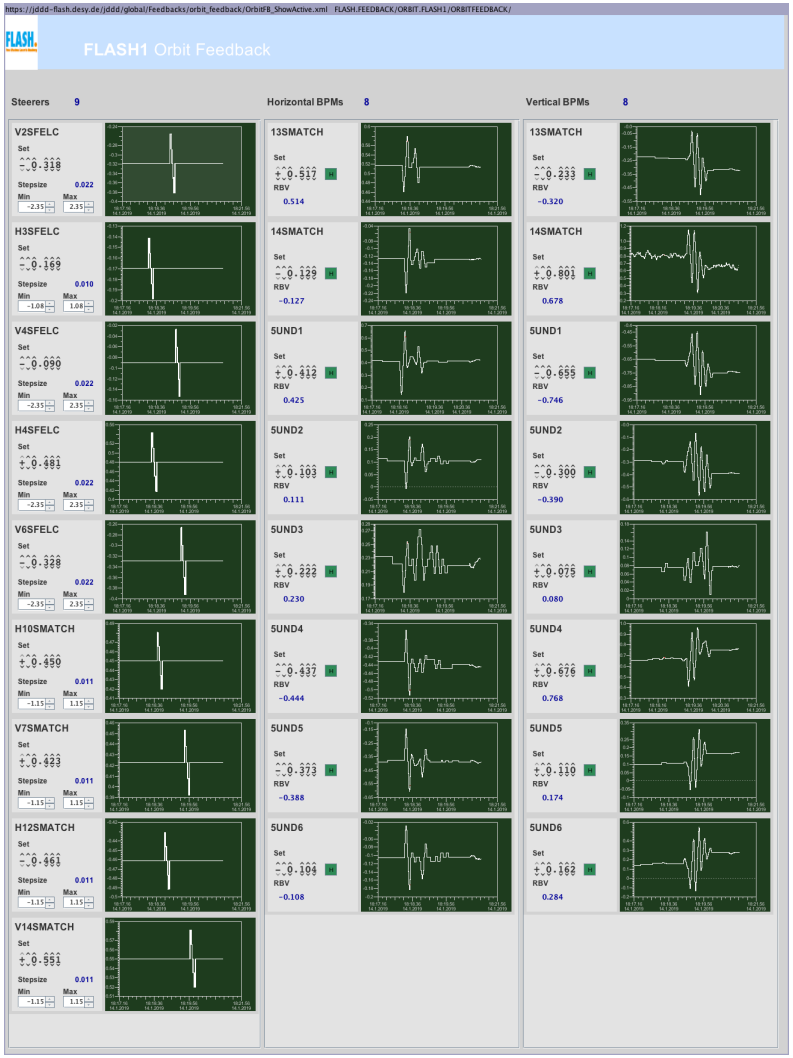
  ← in addition to classroom lectures

Orbit Feedbacks Consolidated

- clearer structure of sections, many bugs fixed, cleaner ORM-measurement procedure
- Now it needs some psychology: operators **must** set it up properly **before** passing the beam to users!

- Select std-Set-up for section
- temporarily: 1 bunch
  maybe disable slow-protection
- **set "golden orbit"!**
- ORM-measurement
- **close loop!**

Orbit Feedbacks Consolidated (2)



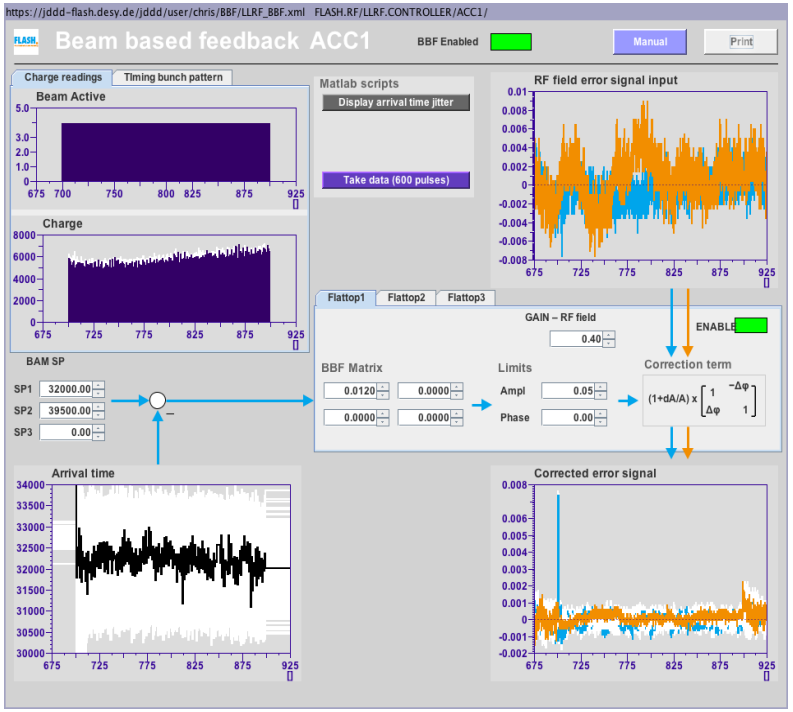
- OrbitResponseMatrix (ORM)

→ most difficulties removed

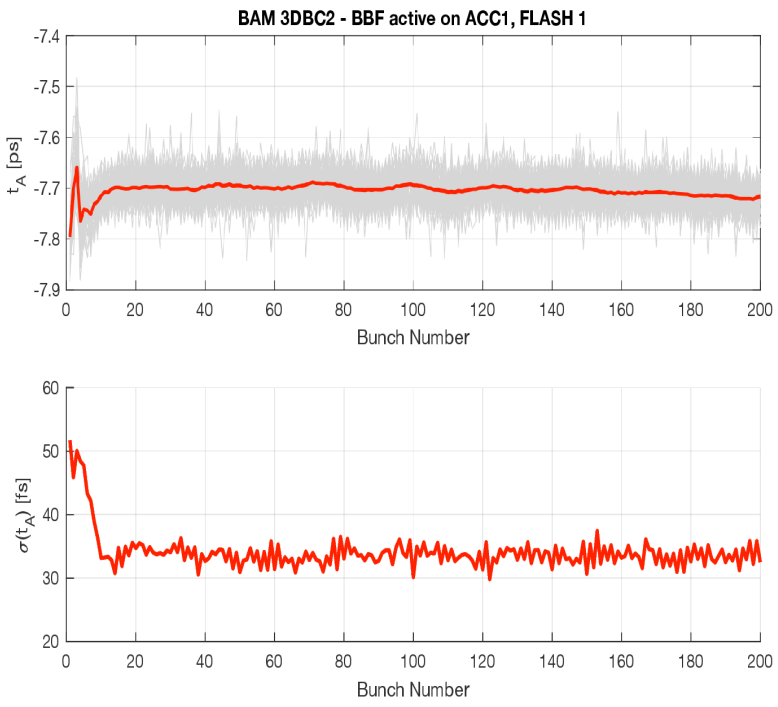
- however:
  - → choose reasonable kick-strength (server remembers!)
  - → must check for transmission
  - ← in complete **section**
  - ← during compl. measurement
  - → check readings (see pic←)

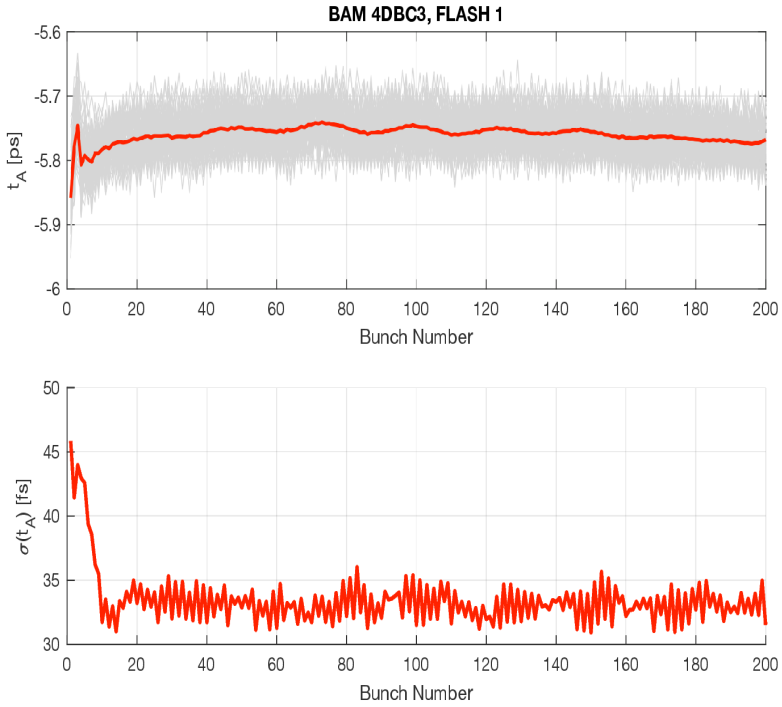
μTCA Intra-Train BAM Feedback

- We used to have it before. . .
- when BAMs & LLRF were still VME
- Now it's both μTCA!
- Now in std-operation (user runs)
- Will employ BACCA once fully commissioned



μTCA Intra-Train BAM Feedback (2)

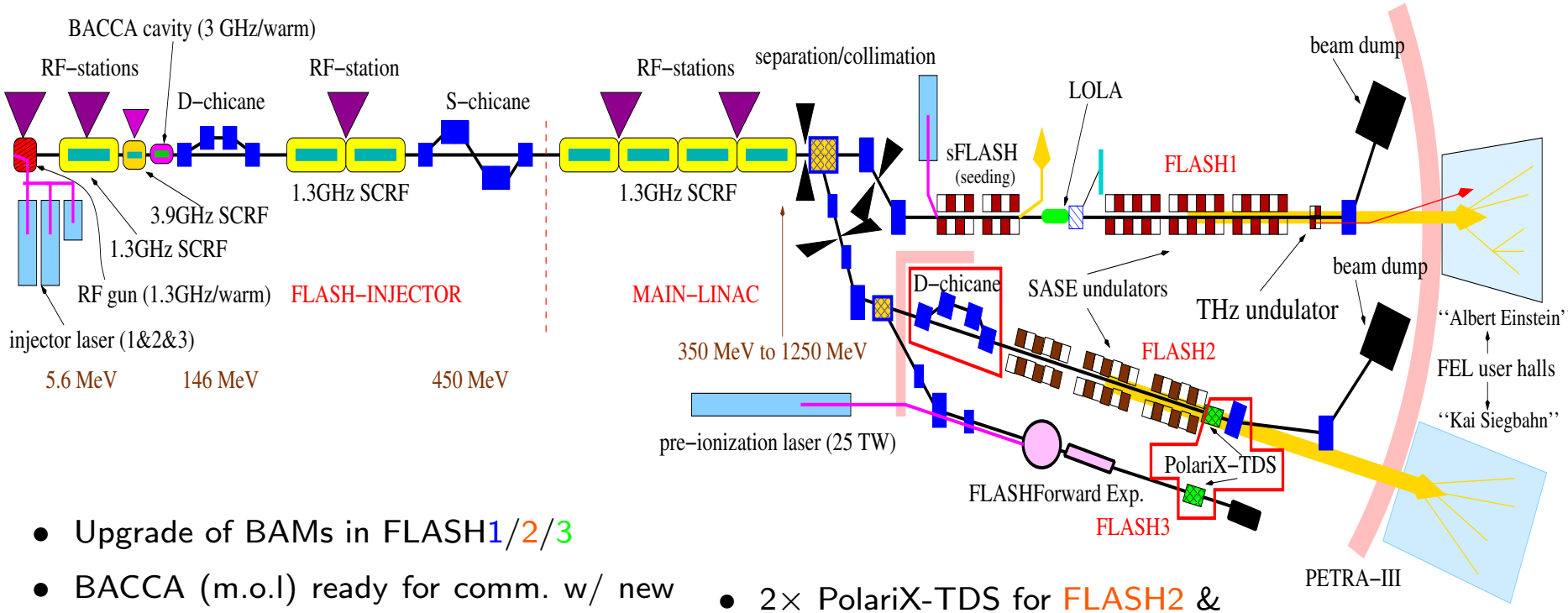




- BAM 3DBC2 (in loop)
- after 10—15 bunches:
  $\rightarrow$ less than 35 fs jitter

- BAM 4DBC3
- after 10 bunches:
  $\rightarrow$ less than 35 fs jitter

Short Term Outlook



- Upgrade of BAMs in FLASH1/2/3
- BACCA (m.o.l) ready for comm. w/ new μTCA IT-BAM-FB.
- Additional bunch compressor chicane in FLASH2 (FL2BC1?4?)

→ Ultimate compression **downstream** of the extraction arc

⇒ Compression in BC2 & BC3 can be reduced!

- 2× PolariX-TDS for FLASH2 & 1× for FLASHForward>>

→ Enhanced resolution w.r.t. good ol' LOLA

→ Energy distribution with/without SASE
⇒ lower bound for photon pulse duration

- **More refurbishments → Siggi's talk**

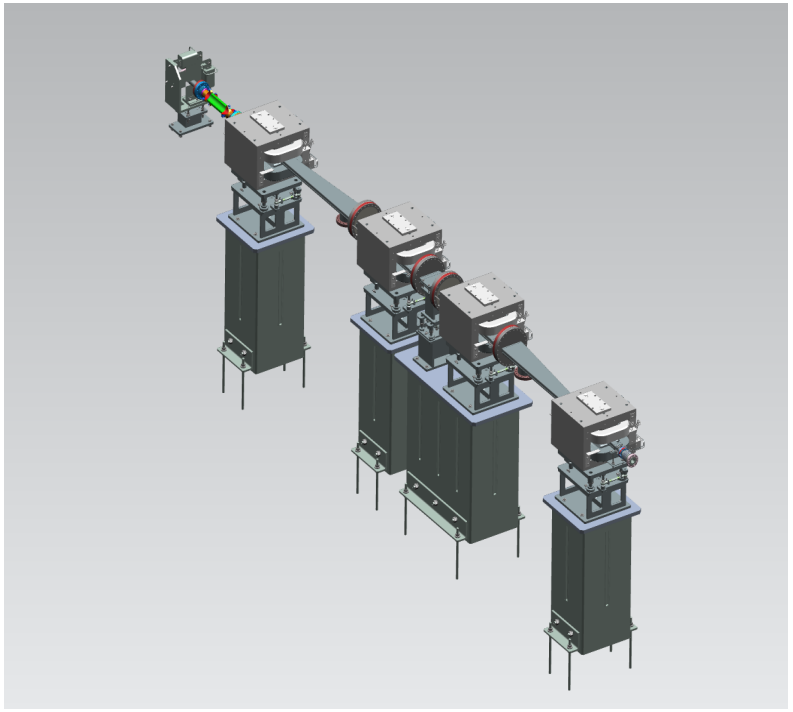
A 3rd Bunch compressor Chicane for FLASH2

- 5–6 m long C-chicane,
  R_{56}: 8–25 mm see pic↘
- Replaces most of sections SEED1 & SEED2
- Reasons:

→ compress less hard in 1st and 2nd BC:
⇒ less peak current at low energy
⇒ less space charge/CSR

→ compress less hard upstream of extraction arc
⇒ less peak current in extraction bends

- and *independent* knob for FL2

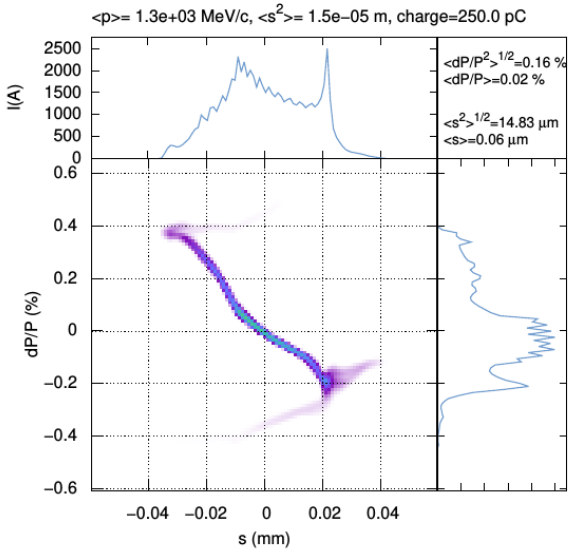


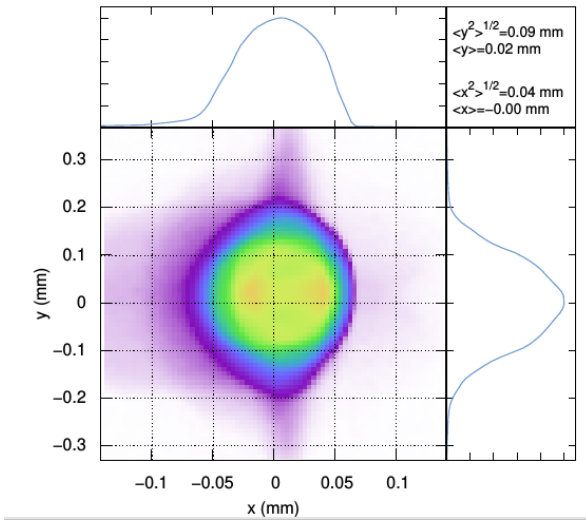
A 3rd Bunch compressor Chicane for FLASH2 (2)

- Simulation : **JZ** w/ X-Track(**MD**)
- Example: 250 pC $C_1 = 3.75$, $C_2 = 9.17$, $C_1 = 3.64$
- (actually FL2020+ stuff but w/o laser heater)
- Gun to SEED7
- pic (here) $\psi^{(2d)}(z, dP/P)$ (top) & $\psi^{(2d)}(x, y)$ (bottom)
- next slide:

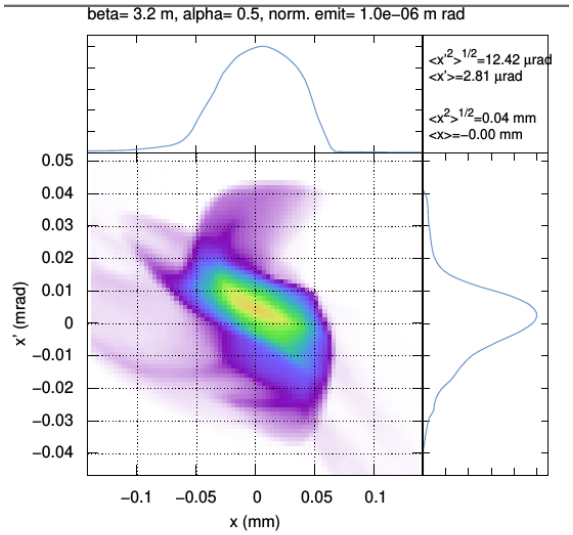
  $\psi^{(2d)}(x, x')$ (top/l) & $\psi^{(2d)}(z, x)$ (top/r)

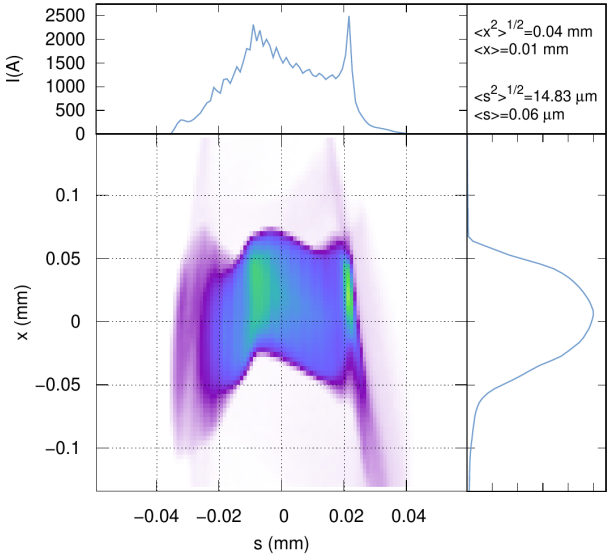
  $\psi^{(2d)}(y, y')$ (bot/l) & $\psi^{(2d)}(z, y)$ (bot/r)
- next-2-next: slice properties

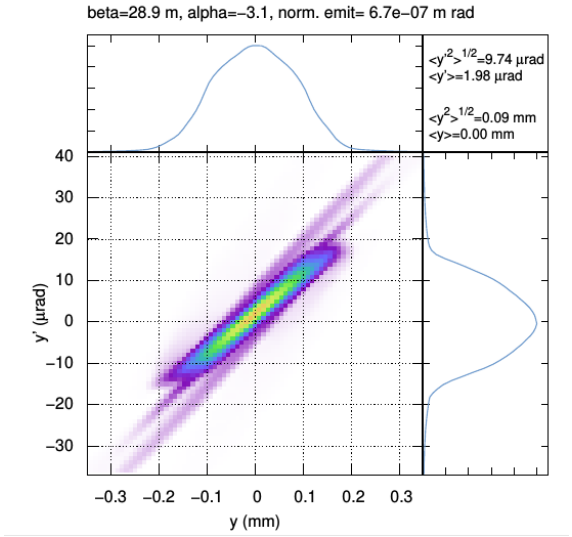


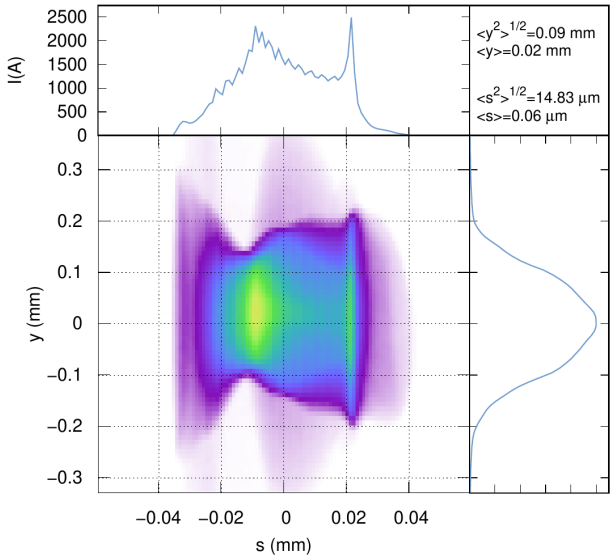


A 3rd Bunch compressor Chicane for FLASH2(3)

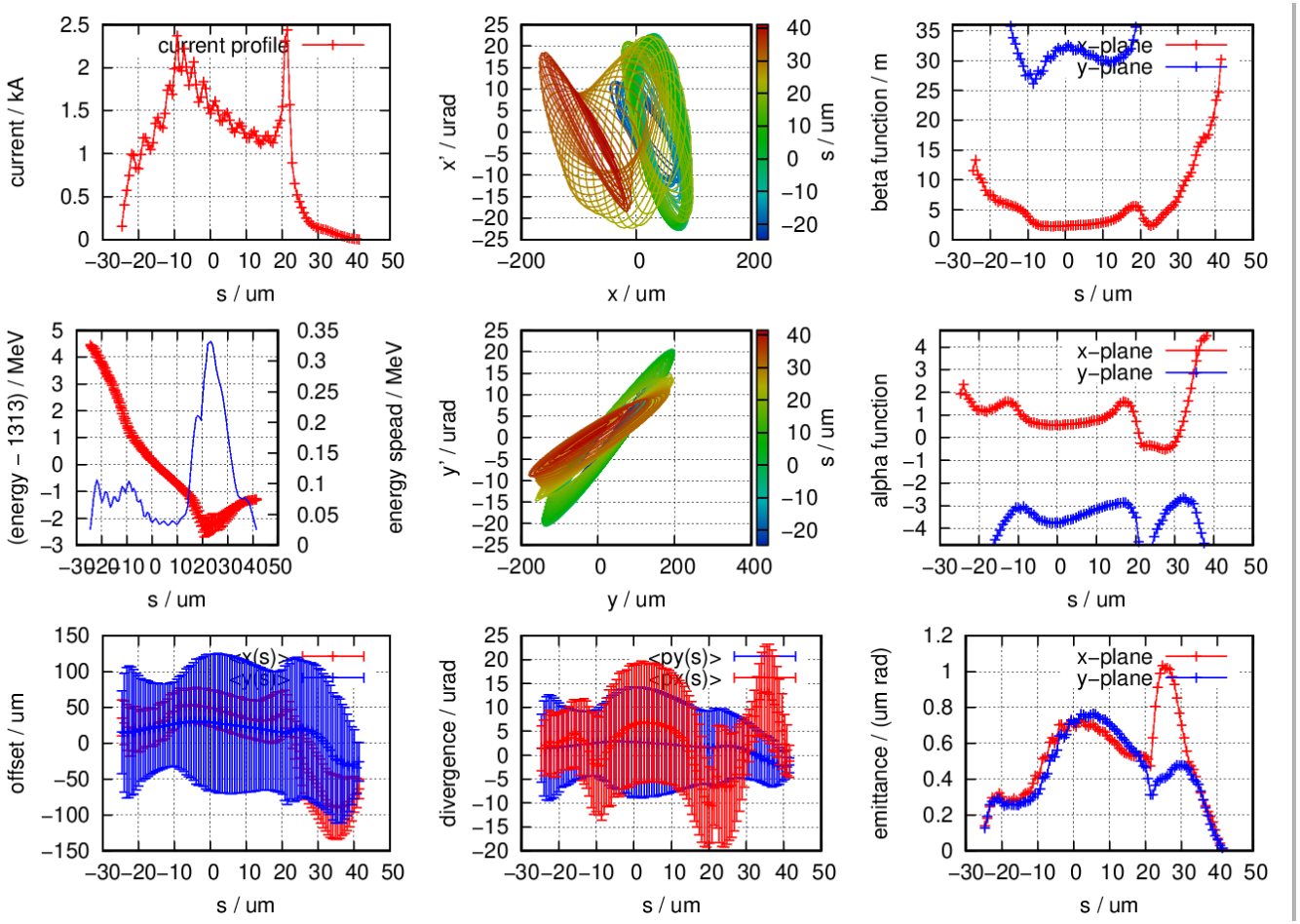






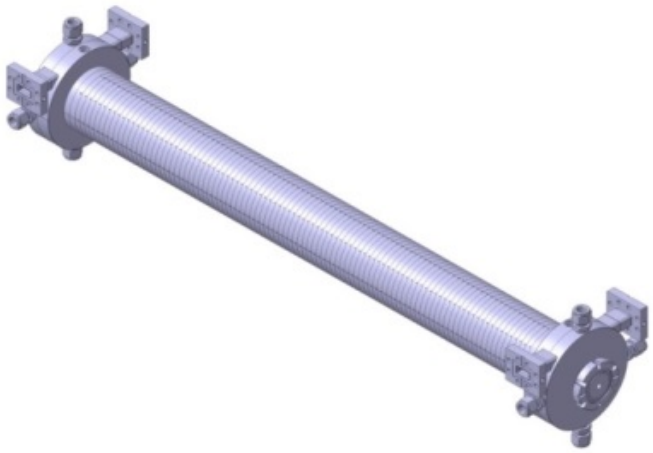


A 3rd Bunch compressor Chicane for FLASH2(4)

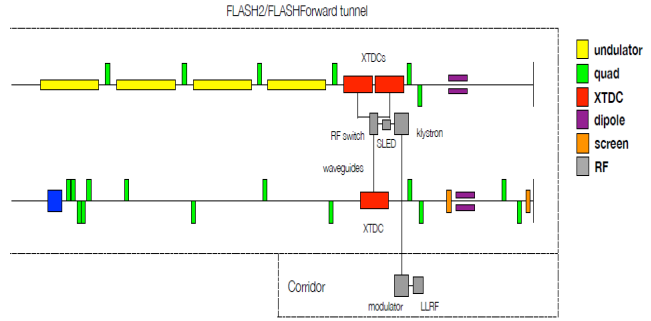


PolariX-TDS

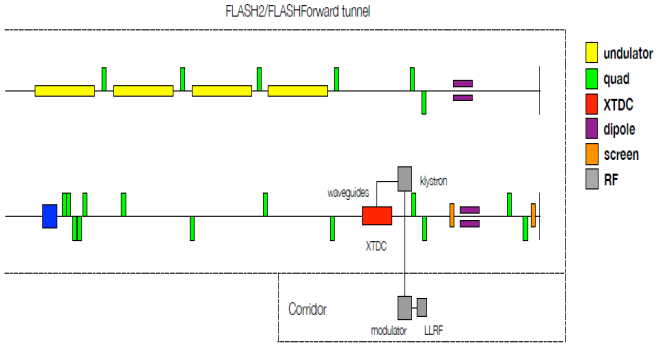
- **X-band (≡ 12 GHz) "super-LOLA"**
- CERN design: variable streak polarization
- PSI production: w/ super-accurate robot to stack the cups
- Order: 2× FL2, 1× FLFwd, 2× SINBAD, 1×(longer) PSI
- Prototype goes to FLASHForward>> this summer
- FL2/FLFwd: shared kly/mod with HF-switch to either/or FL2/FLFwd



FLASHFORWARD▸▸/FLASH2 X-BAND SCHEME – 2020

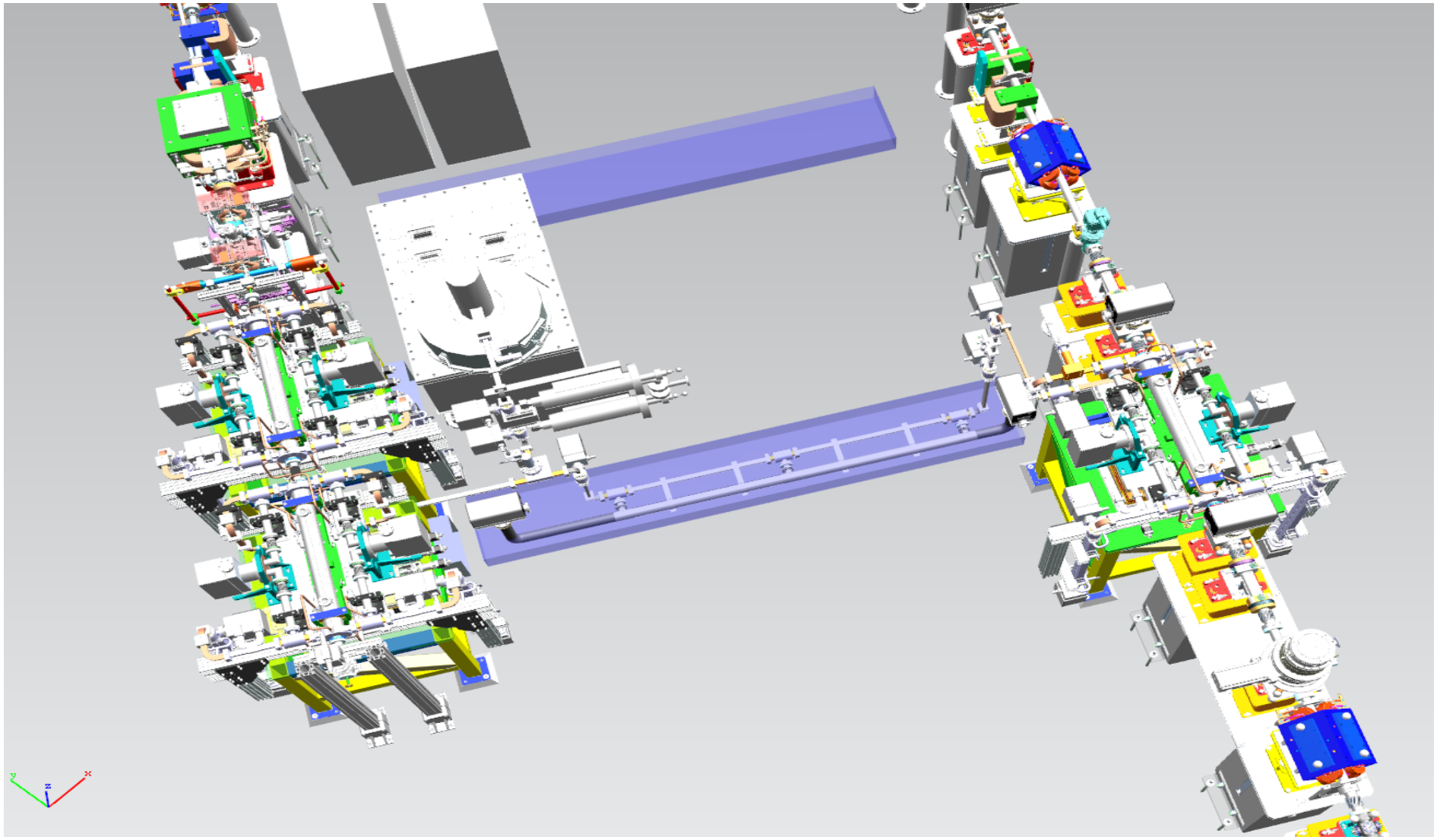


FLASHFORWARD▸▸/FLASH2 X-BAND SCHEME – 2019

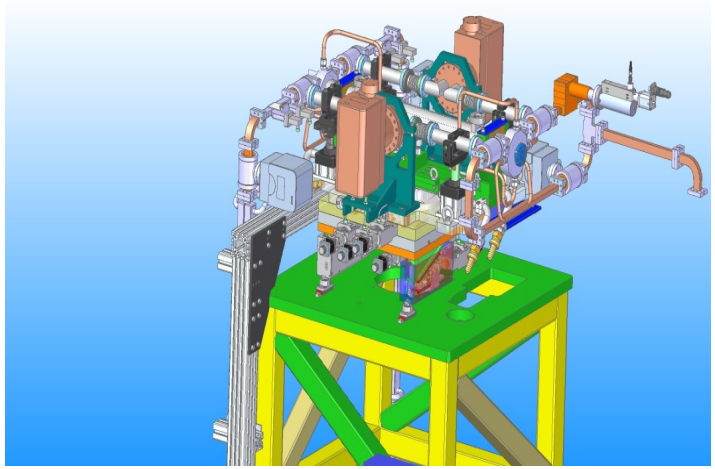


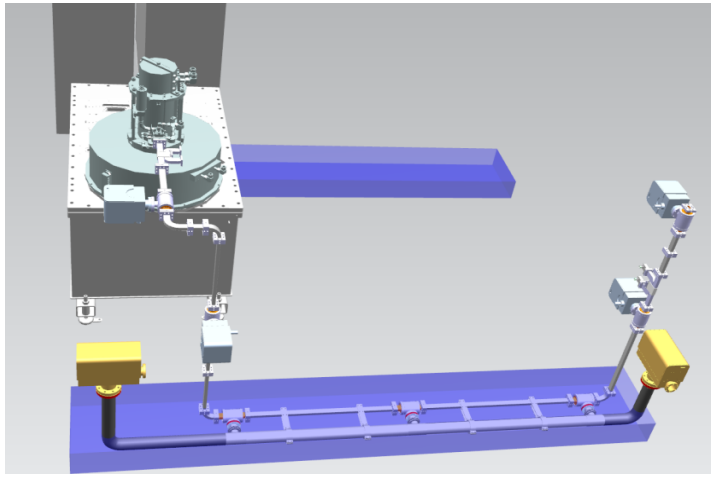
- FL2: downstream of FL2SASE
  ⇒ measure lasing part of bunch!

PolariX-TDS (2)



PolariX-TDS (3)





← top/l: TDS w/ vacuum, waveguides, movers & support

↙ bot/l: kly-tank connected to FLFwd through trench

↓ bot/r: Ampegon modulator w/ kly-tank ; Toshiba kly w/o solenoid

A big thank you to **all**, who participated and helped in operations, maintenance, development of FLASH, and in the planning and design of the future of FLASH, and in particular to those that plan to keep doing this!!!

and . . .

Thank you for Listening!