Status of the Free Electron Laser User Facility FLASH

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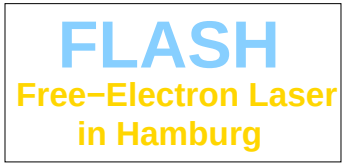
- The Upgraded FLASH Facility
- User Operation
- Highlights
- RF-gun Issues
- FLASH2: First Commissioning



FLASH...

- ... means

  Free electron **LAS**er in **H**amburg

→ **XUV and soft X–ray SASE FEL**

SASE=self amplified spontaneous emission

⇒ **peak brilliance:** 10^{29} - 10^{31}

photons/(s mm^2 mrad^2 0.1%bw)

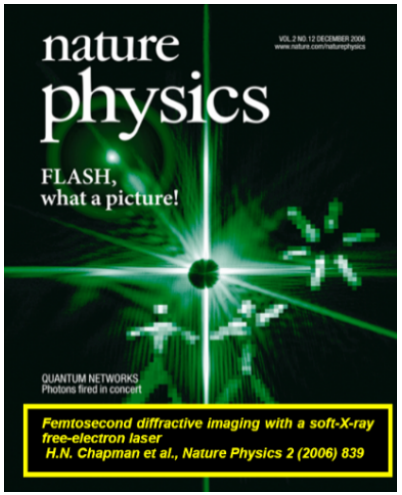
⇒ γ **pulse duration:** $<$**30 - 200 fs**

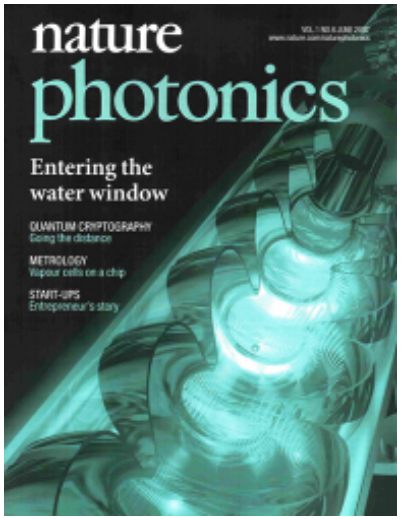
→ **Superconducting L–band linac:**

E **up to 1.25 GeV**

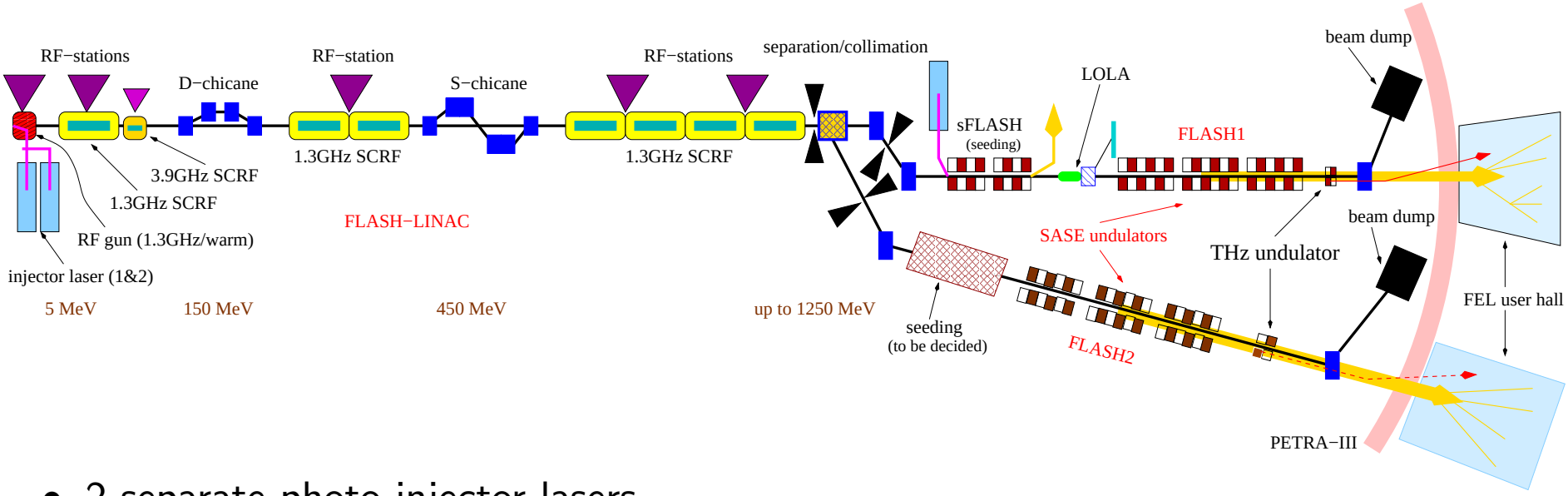
⇒ **up to 8000 bunches per second**

- Every year attracts more than 100 scientists from all over the world
- So far more then 200 publications, partly in highly ranked journals





The (Upgraded) FLASH Facility



- 2 separate photo injector lasers
- warm 1.6 cell RF gun (L–band)
- 1st cold module (ACC1)
  + 1st bunch compressor chicane
- 2 more cold modules (ACC2+3)
  + 2nd bunch compressor chicane
- main linac (ACC4+5+6+7)
- 2 beamlines :
  FLASH1 (since 2005)
- **New 2nd beamline : FLASH2**

→ commissioning ongoing

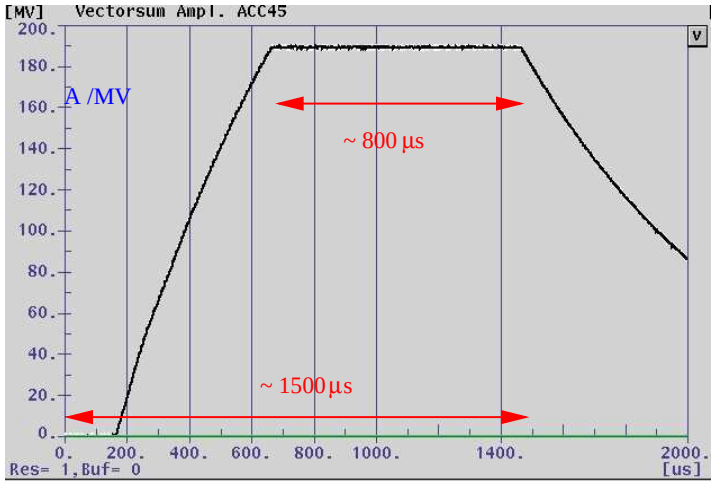
FLASH parameters 2013/2014

$\mathbf{e}^-$:		
emittance $\beta\gamma\varepsilon_{x,y}$		
(1 nC, on-crest, 90% rms)	1.4	mm mrad
charge	0.08 - 1.0	nC
peak current	0.8 - 2.0	kA
beam energy	380 - 1250	MeV
bunches / train	1 - 450	
bunch spacing	1 - 25	μs
train repetition frequency	10	Hz
γ (FLASH1 only):		
wavelength (fundamental)	4.2 - 45	nm
average single pulse energy	10 - 540	μJ
pulse duration (fwhm)	$<$30 - 200	fs
spectral width (fwhm)	0.7 - 2.0	%
peak power	1 - 3	GW
peak brilliance	10^{29} - 10^{31}	$(+)$

$(+)$: photons/(s mm^2 mrad^2 0.1%bw)

SCRF

Vectorsum Amplitude ACC45:



- RF–Pulse rep. rate: **10 Hz**
- nominal flat top duration: **800 μs**
- with fill time: duty factor 1.5%
- At **1 MHz** bunch frequency
  $\rightarrow$ **8000 bu/s**
  in 10 trains of 800 bu each

- 7$\times$ SC L-band modules

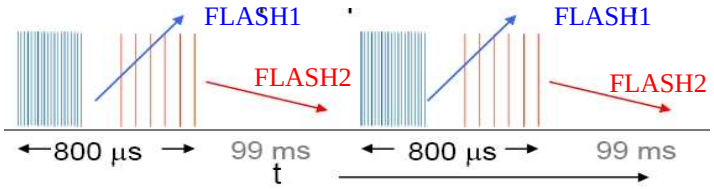
. . . of various designs, ages, gradients

- E gain/module : 160 MeV (older) to 240 MeV (X–FEL prototype!)
- 1$\times$ 3rd harmonic (3.9 GHz) module for linearizing the compr.

Fotoshooting bei DESY, FLASH-Tunnel, Februar 2012
Fotos: Heiner Müller-Elsner

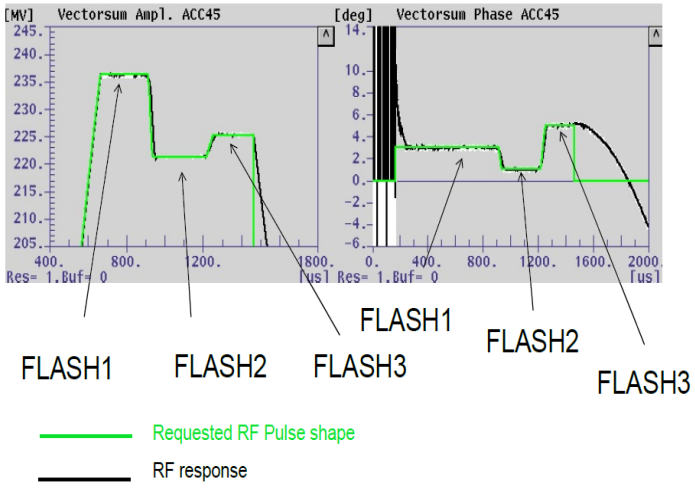
	1st chic.	2nd chic.	E_{final}
E /MeV	150	450	380 - 1250

SCRF for 2 (or more) Beamlines



this example ↑:

- 1st sub train to FLASH2
  ← sparse pattern
- 2nd sub train to FLASH1
  ← dense pattern
- $>$ 30 μs gap for kicker
  $\sim$ 50 μs gap for RF ↓



- long RF flat tops capable of acc. 800 bunches

→ split each train and divide between 2 (or more beamlines)

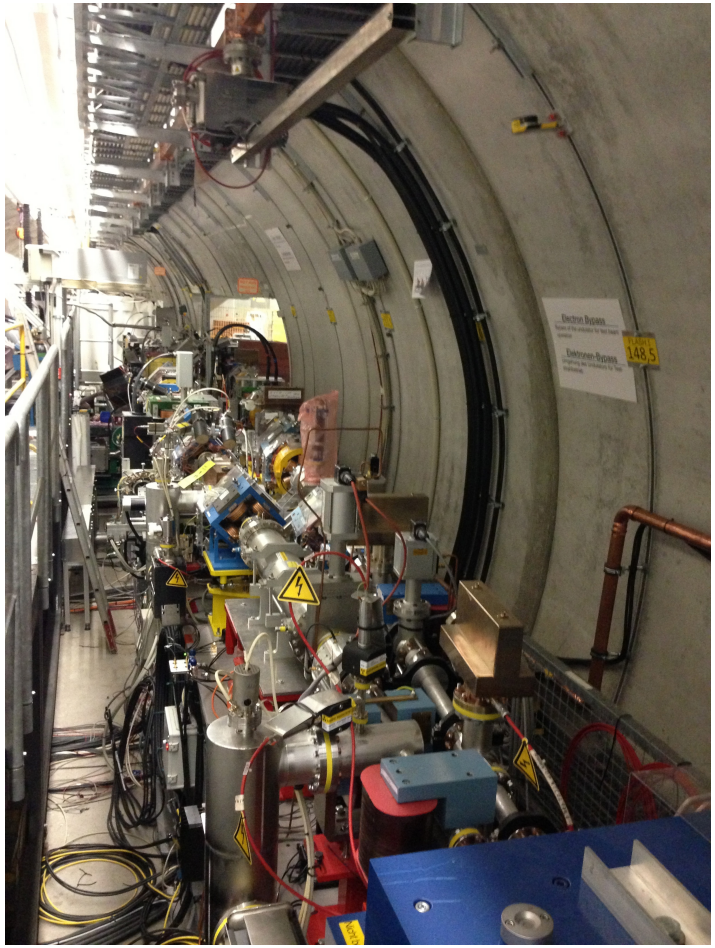
- 2 lasers :
  → 2 bunch patterns
  → 2 bunch charges

← needs 2 compression modes

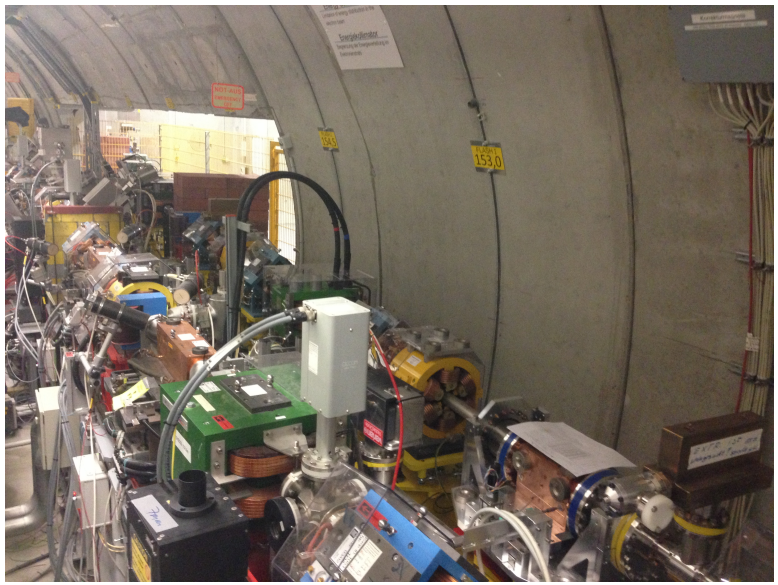
⇒ split flat tops

- tested w/ two different charges // /compr. schemes → **SASE**
- 3rd flat top : see plasma wake field proposal FLASHForward → TUPME066 & TUPME068

New: Switch Yard FLASH1/FLASH2



- Switches in **each** flat top
- Gap $\sim$ 30 μs



- 2$\times$ vertical kicker (+1 spare)

  $\rightarrow$ flat top extremely stable

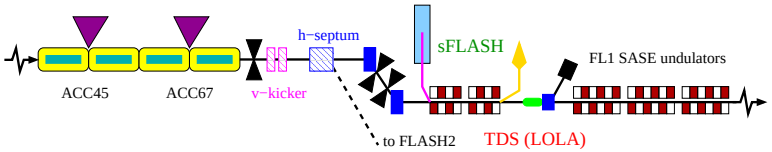
  $\rightarrow$ very little ringing!

- optics (3 quads)

  $\Rightarrow$ 20 mm v–separation at septum

- horizontally deflecting Lambertson septum : 6.5°

Seeding / Special Diagnostics (FLASH1)



Seeding:

- sFLASH experiment :
  HHG (High Harmonic Generation)

→ now also test bench for
→ HGHG
(High Gain Harmonic Generation)
→ EEHG
(Echo Enabled Harmonic Generation)

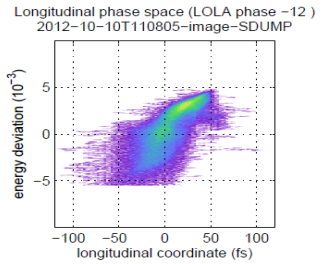
- Decision on seeding scheme for **FLASH2** still pending

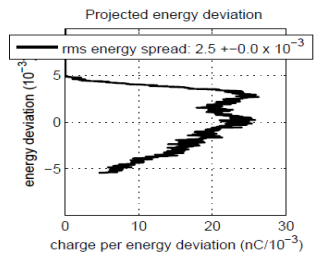
Transverse Deflecting Structure (LOLA):

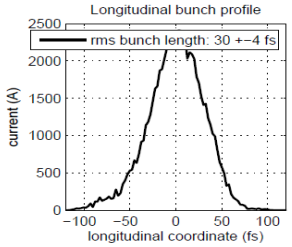
→ vertical streak / **2 modes:**

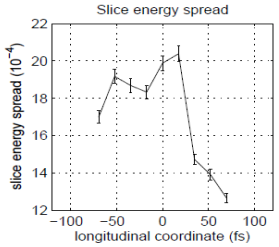
1: minimally invasive → live
→ kick selected bunch to off–axis screen
→ only bunch length measurement

2: dispersive → destructive:
→ horizontal dipole (spectrometer)
→ long. phase space mapped to x–y space

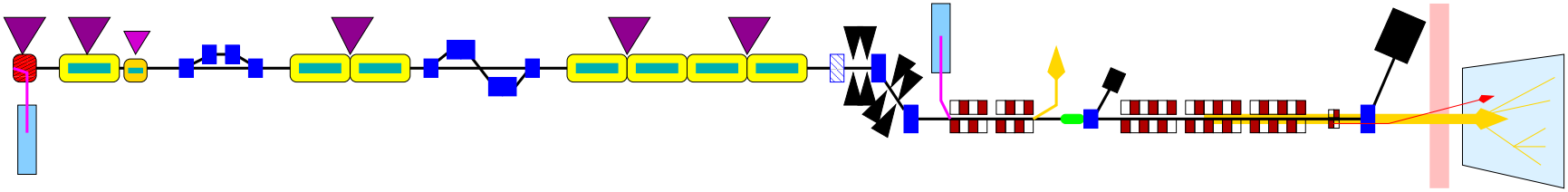








User Operation (FLASH1 only)



- 2013 :
  long shutdown
  ← FLASH2
- 2014 :
  planned 24 weeks of
  γ–user operation
- remaining time:
  → FLASH2 commissioning
  → MD's, user preparation

User Requests 2013/2014

all wavelengths : 40 nm down to 4.2 nm

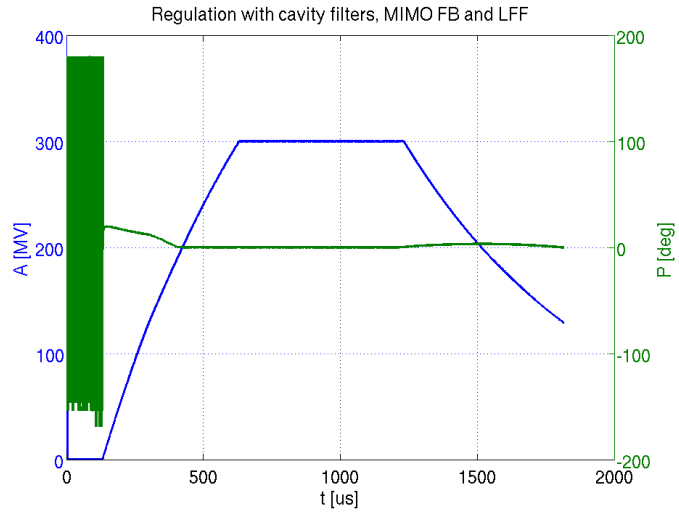
Pulse Pattern		**2013/14**	
Single Bunch		47%	
Multi Bunch		53 %	35% $>$ 200 b.
Bunch Spacing	1 MHz	30 %	
	200 kHz	43 %	
	other	27 %	40, 100, 250, 500 kHz
FEL pulse duration (FWHM)			
$<$ 50 fs		42%	56% multi bunch
50 - 100 fs		33%	64% single bunch
not critical		26%	83% max energy

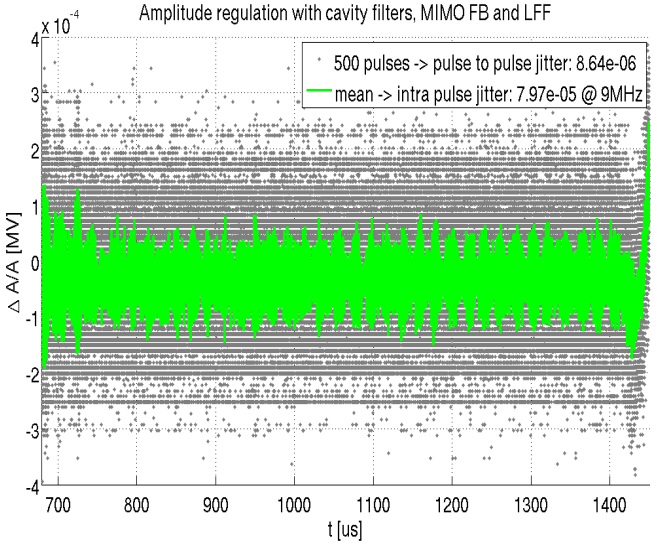
Highlights: New Low Level RF System Commissioned

- Long flat top
  $\Rightarrow$ fancy regulation
- New LLRF system :
  $\rightarrow \mu$TCA.4 based
  $\leftarrow$X–FEL standard
- After commissioning:

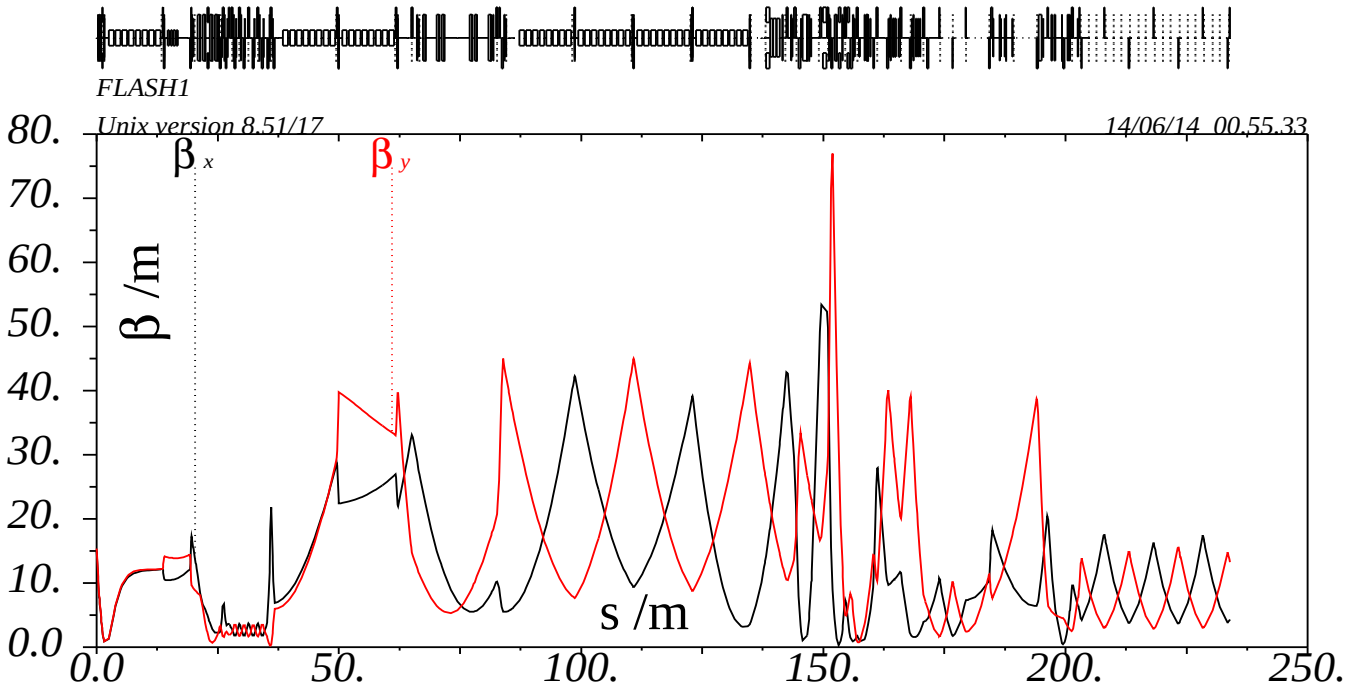
$\rightarrow$ higher sampling rate

$\rightarrow$ effective energy jitter
(intra train & train to train)
reduced by factor ~ 2.





Highlights: Relaxed Optics in Main Linac

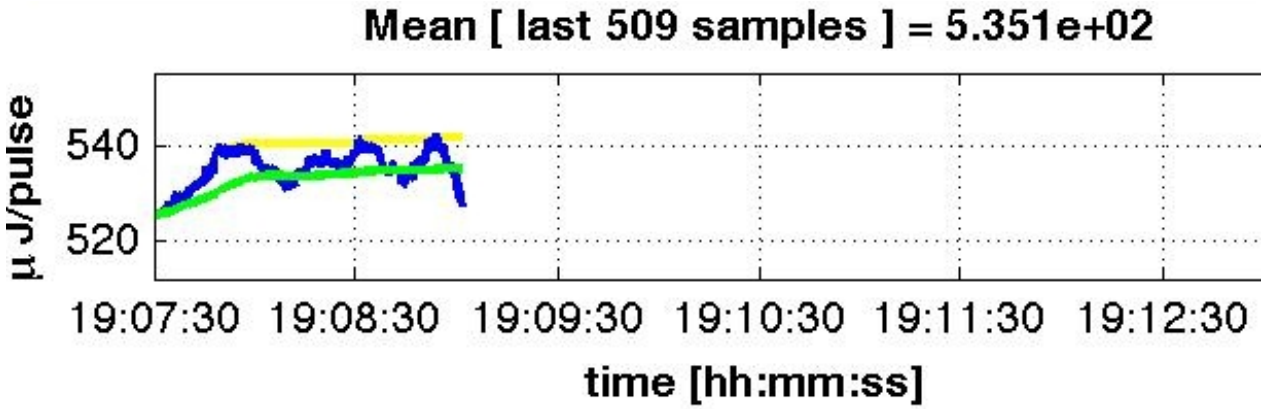


- Matching into modified optic in switch yard
- Took the opportunity to relax optics in main linac

- Was **doublet**
- Is **FODO** now
- **Improved chromatic behavior**

Highlights: New SASE Pulse Energy Record

- With improved optics . . .
- . . . and of course after skillful expert tuning:
- New record in pulse energy : 540 μJ at 8.7 nm
- with 1 bunch of 0.6nC.

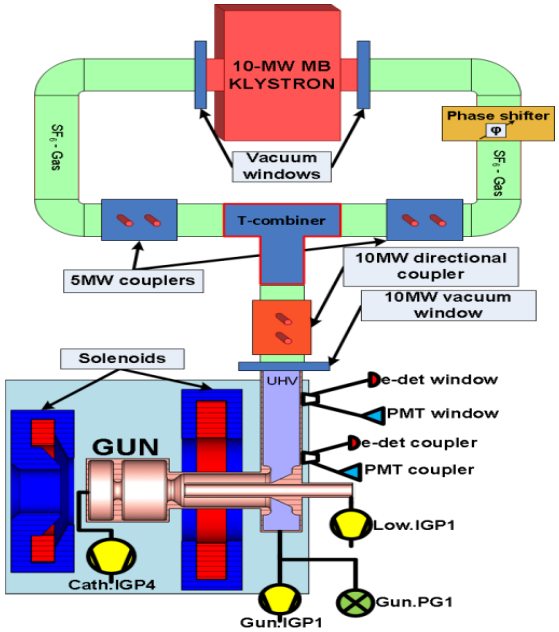


RF–Gun Issues

With increased average power (since 2010) the RF gun causes non–negligible downtime:

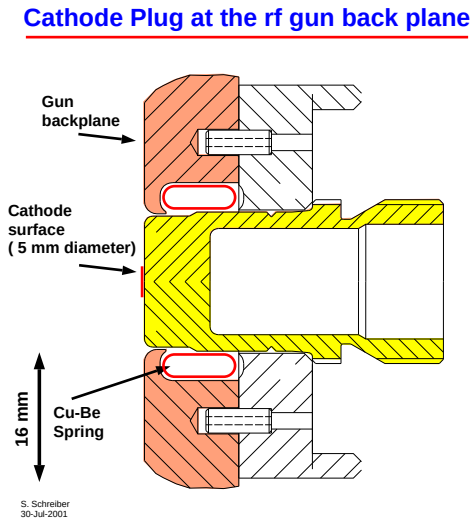
- Bursts of vacuum, light and multipacting close to the vacuum side of the RF window

→ testing new window types

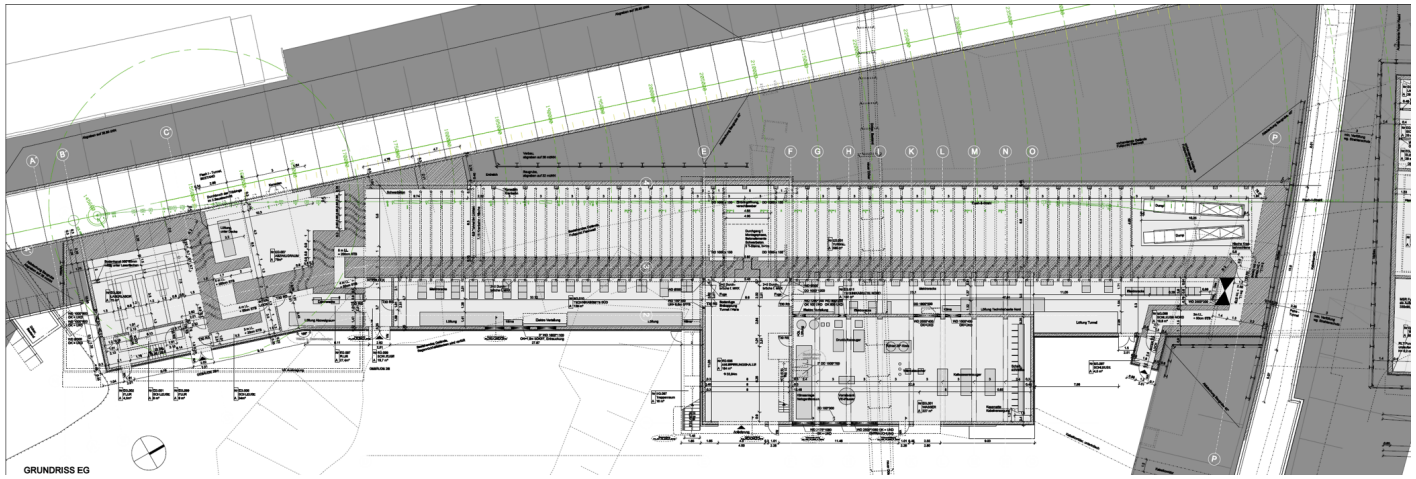


- discharge in gap between back plane and cathode plug
- destroys the RF contact and the cavity back plane

→ testing new spring / back plane design (old ↓)

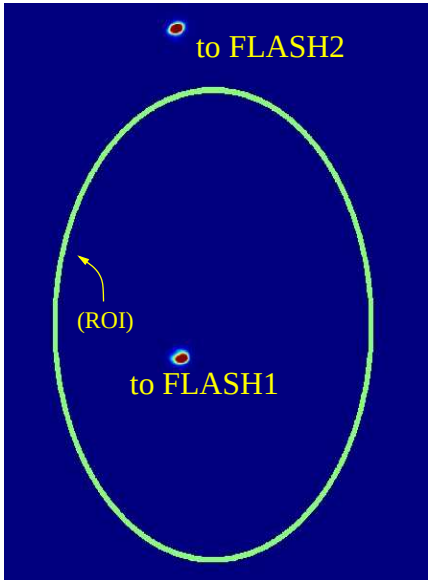


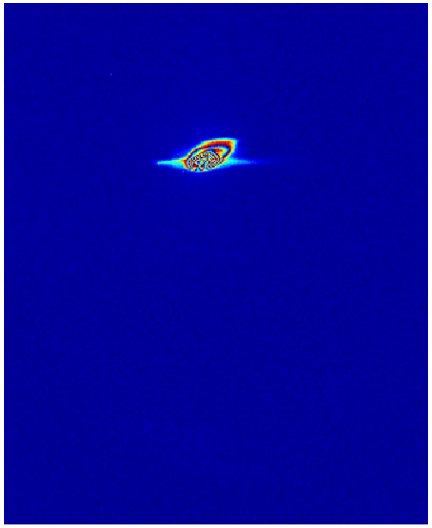
FLASH2



FLASH2 Commissioning

- Delayed by late construction of the buildings and infrastructure
- Official permission to operate FLASH2 : February 7th 2014
- **First beam extracted** through septum on March 4th
- Top left: screen right before the septum with the FLASH1 beam (bottom) and the FLASH2 beam (top)
- **First beam on the FLASH2 dump** on May 23th
- Bottom left: beam on dump screen
- Always: ran FLASH2 in parallel to FLASH1





Summary / Conclusion / Outlook

- FLASH (FLASH1) provides up to 8000 photon pulses/s in the wavelength range from 45 nm down to 4.2 nm and with pulse durations from 200 fs down to $<$ 30 fs.
- With increased average power (since 2010) the RF gun causes non–negligible downtime:

$\leftarrow$ The 2 main problems have been identified and are being investigated (component redesign).

- A 2nd beamline has been connected to FLASH. Commissioning is still ongoing.
- The modifications to FLASH1 necessary for operating FLASH2 have so far rather improved the FLASH1 performance:

$\rightarrow$ New intensity record of 540 μJ

- We are looking forward to proceed commissioning FLASH2 and to operating FLASH with two beamlines.

I (we) would like to thank all the colleagues at DESY and from the collaborating institutes for their continuous dedication in operation, maintenance and upgrade of FLASH and in particular during the construction and commissioning of the FLASH2 beamline !!!

. . . and of course thank **you** for Listening !!!

More Talks and Posters on/related to FLASH

Injector:

THPRO043,044

LLRF:

TUPRI105

TUPRI107

WEPME066 . . . 069

WEPME075,076

WEPRI115

Diagnostics/ Control System:

WEPRI029

THXA01

THPME106

THPME115

THPME117

THPRO104

Beam Dynamics:

TUPRI040

TUPRO047

TUPRO050

THPME116

Photons:

TUPRO084

WEPRO031,032,034

WEPRO093

THPRO011

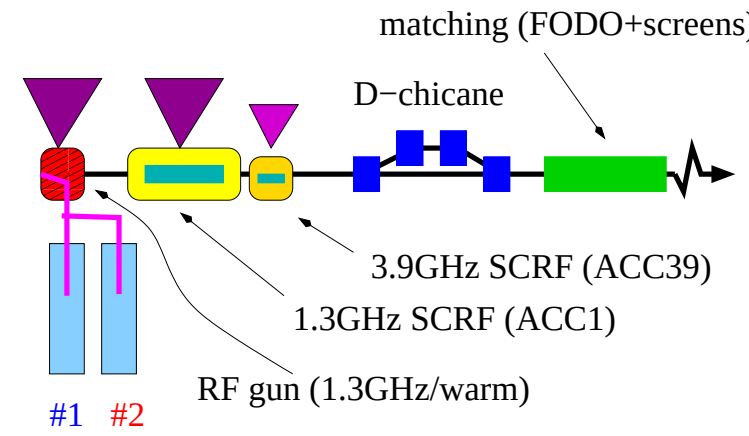
FLASHForward:

TUPME066

TUPME068

BACKUP SLIDES

The Photo Injector



- Two independent lasers
  → UV laser pulses of 262 nm
- transversely approximately flat
  typical diameter on cathode: 1.2 mm
- longitudinally approximately Gaussian:
  σ = 6 - 7 ps.
- Cs_2Te cathode at cavity back plane

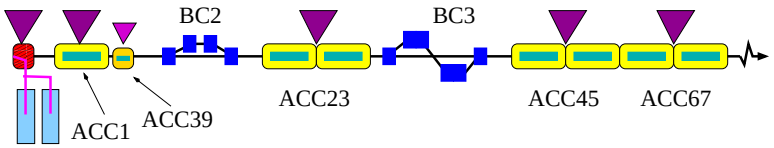
- Normalconducting 1.6 cell
  1.3 GHz copper cavity
- Emittance at 1nC $\approx$ 1.4 μm
  → smaller at lower charge
- E after gun cavity: 5.2 - 5.7 MeV
- Solenoidal emittance compensation
- ACC1: acceleration to 166 - 169 MeV
  ($\sim 5^\circ$ off crest)
- ACC39: deceleration to 150 - 147 MeV
  → chirp linearization
- Chicane: compr. by factor $\sim$ 5
- FODO channel : match space charge dominated beam from gun to design Twiss parameters

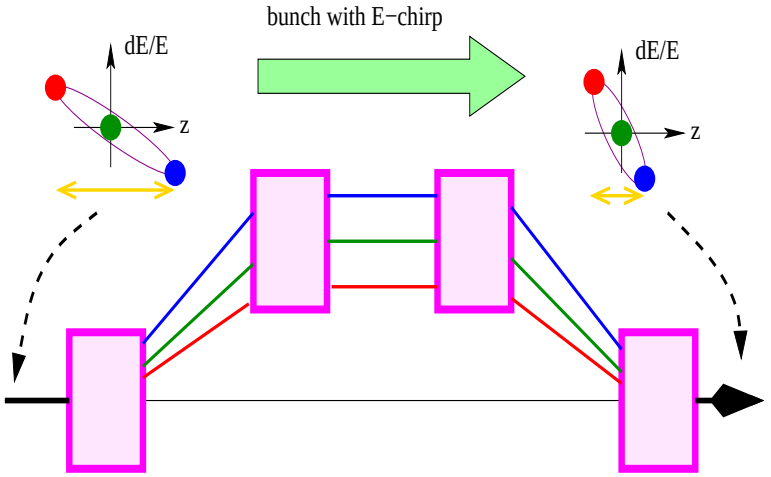
Compression of Ultra Relativistic Bunches

- magnetic **chicane** ∘ **off crest** RF = **bunch compressor**
- FLASH : 2× cascaded →

1: BC2 ∘ ACC1

2: BC3 ∘ ACC23





- small initial uncorrelated E–spread

⇒ sinusoidal RF → curved bunch ("banana")

→ linearize using 3rd harmonic module (ACC39)

Example : **long!** bunch: