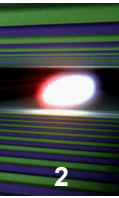


Accelerator Technical Progress and First Commissioning Results from the European XFEL

presented at the NAPAC16, Chicago, Oct. 11th, 2016

by Riko Wichmann, DESY, Hamburg



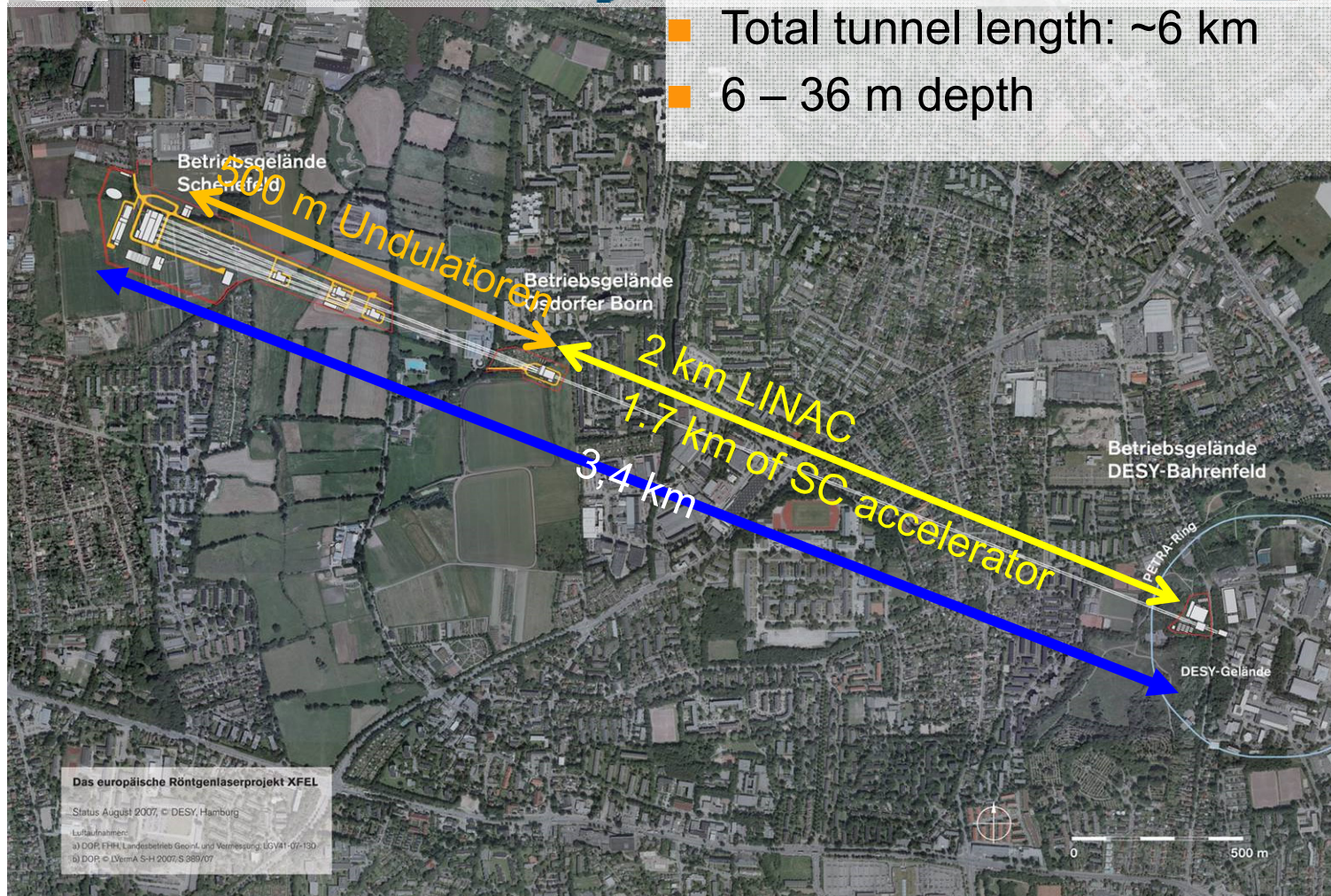


- Introduction European XFEL
- Status of the XFEL Accelerator
- First Commissioning Results
- Outlook



3

- Total tunnel length: ~6 km
- 6 – 36 m depth





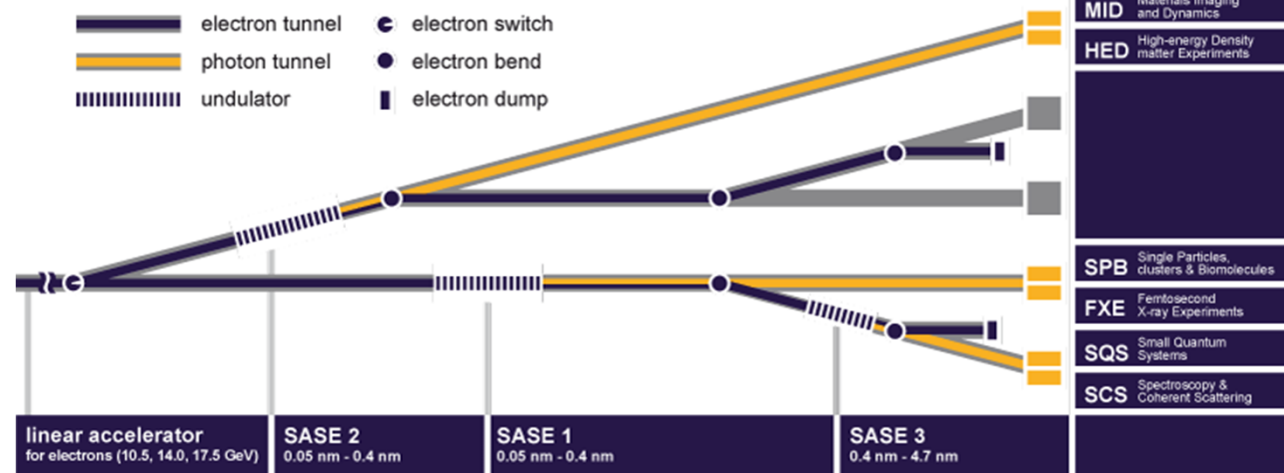
XFEL Parameter

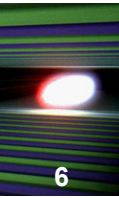
5

Electron beam energy	17.5 GeV
Bunch charge	0.02 - 1 nC
Peak current	2 - 5 kA
Slice emittance	0.4 - 1.0 mm mrad
Slice energy spread	4 - 2 MeV
Shortest SASE wavelength	0.05 nm
Pulse repetition rate	10 Hz
Bunches per pulse	2700
Pulse length	600 μ s

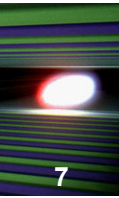
Several extensions

- more undulators
- more instruments
- *polarization*
- *self-seeding*
- *CW operation*





- 
- 07/2006 ■ TDR of the European XFEL published
 - 01/2009 ■ Start of underground civil construction
 - 08/2014 ■ Start installation of accelerator components
 - 02/2015 ■ First electron beam of the XFEL
 - 12/2015 ■ Start commissioning of XFEL injector
 - 07/2016 ■ Injector Commissioning finished
 - 10/2016 ■ *Start cool-down of XFEL linac*
 - 03/2017 ■ *First lasing possible*
 - 07/2017 ■ *Start user operation*



Status of the XFEL Accelerator

XFEL Super-Conducting Linac – Work of Many in the Accelerator Consortium

100 Accelerating Modules
(+1 in the injector)



800 + 8 sc cavities with power couplers

1.3 GHz / 23.6 MV/m



25 RF stations, 5.2 MW
(+2 in the injector)

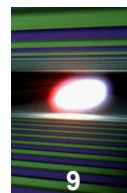


plus general infrastructure



Collaborative Effort: Linac on-tour

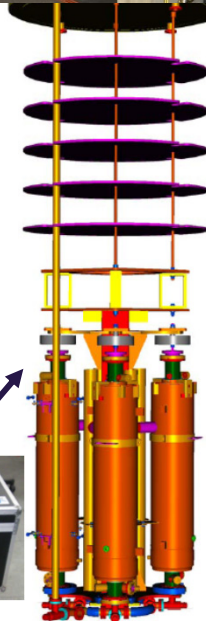
plus additional
components



research
instruments



E. ZANON



DESY Germany



IRFU /CEA France



irfu
cea
sacalay



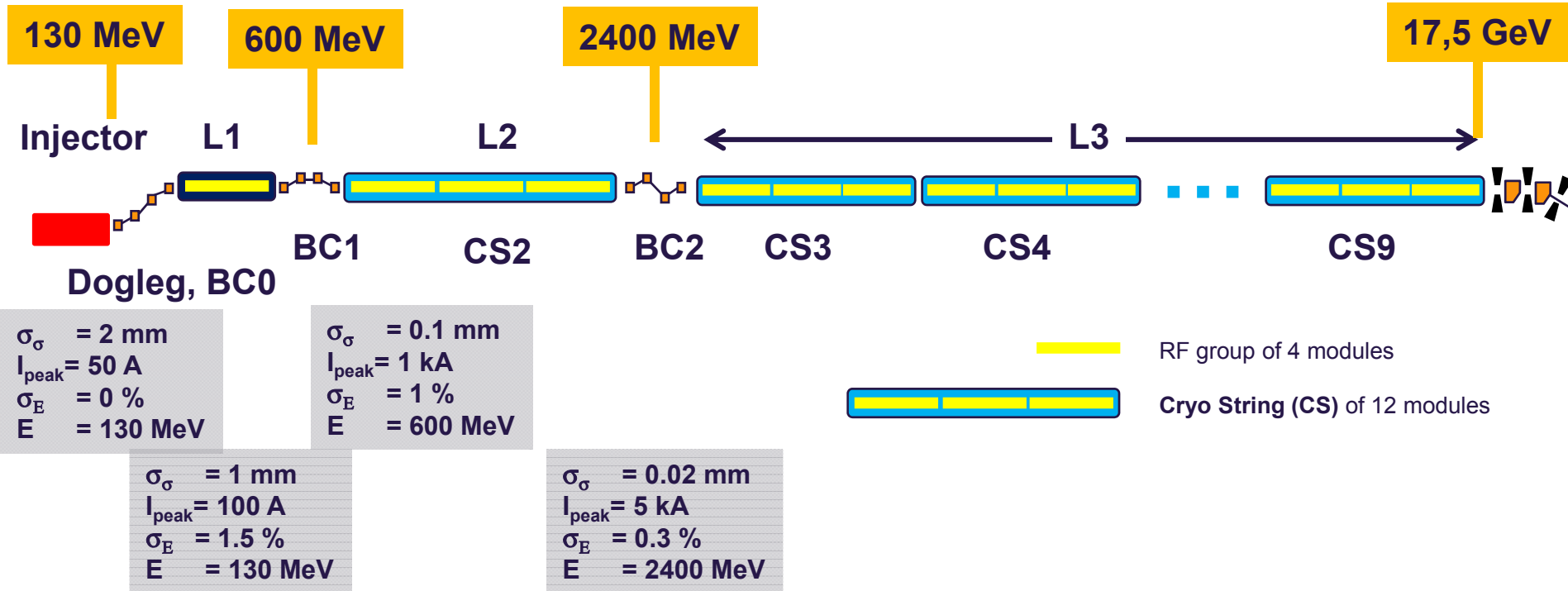
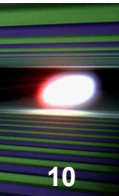
IHEP Beijing

E. ZANON

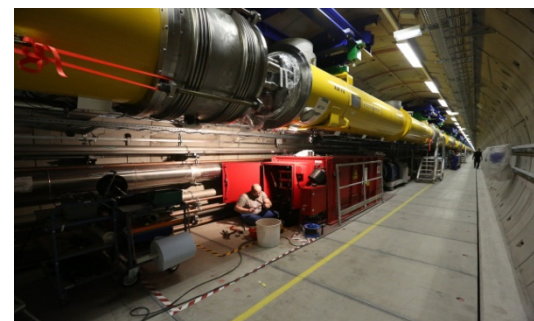
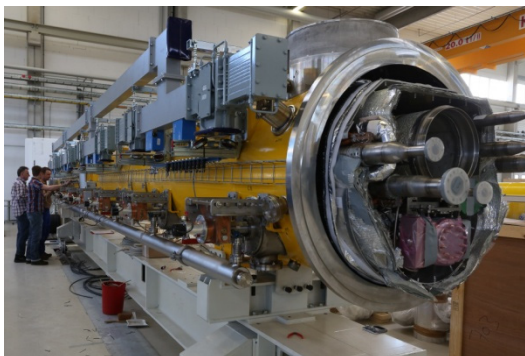


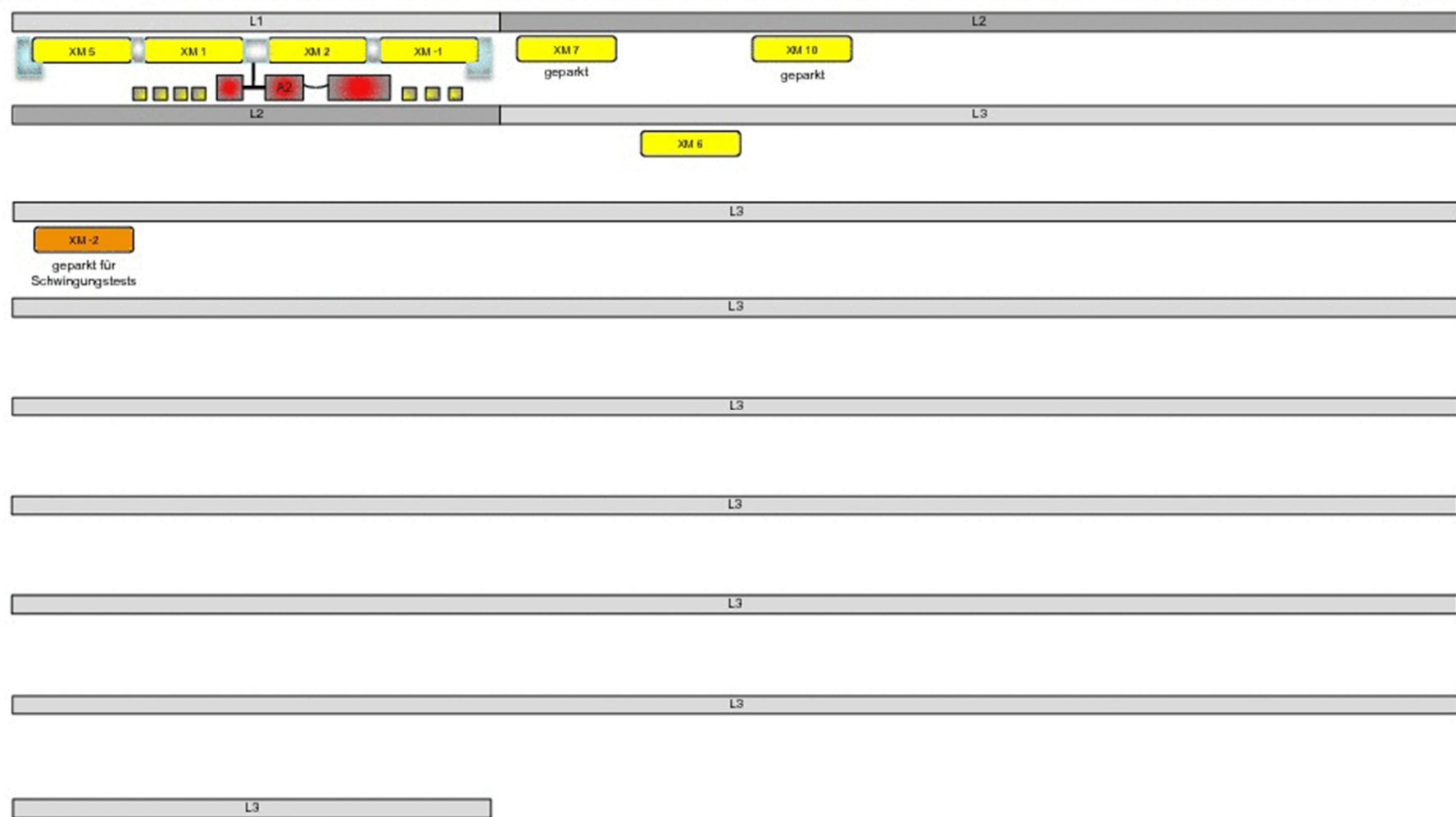
Cryostats

Schematic Layout and Nomenclature

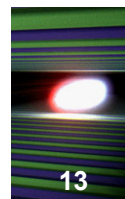


- Injector: 1x 1.3 GHz module, 1x 3.9 GHz Module
- L1: 4x 1.3 GHz modules = Cryo String 1 (CS1)
- L2: 12x Module (CS2)
- Main linac L3: 7x12 = 84 Module (CS7 – 9)
- L1-L3: 1 RF station powers four 1.3 GHz modules

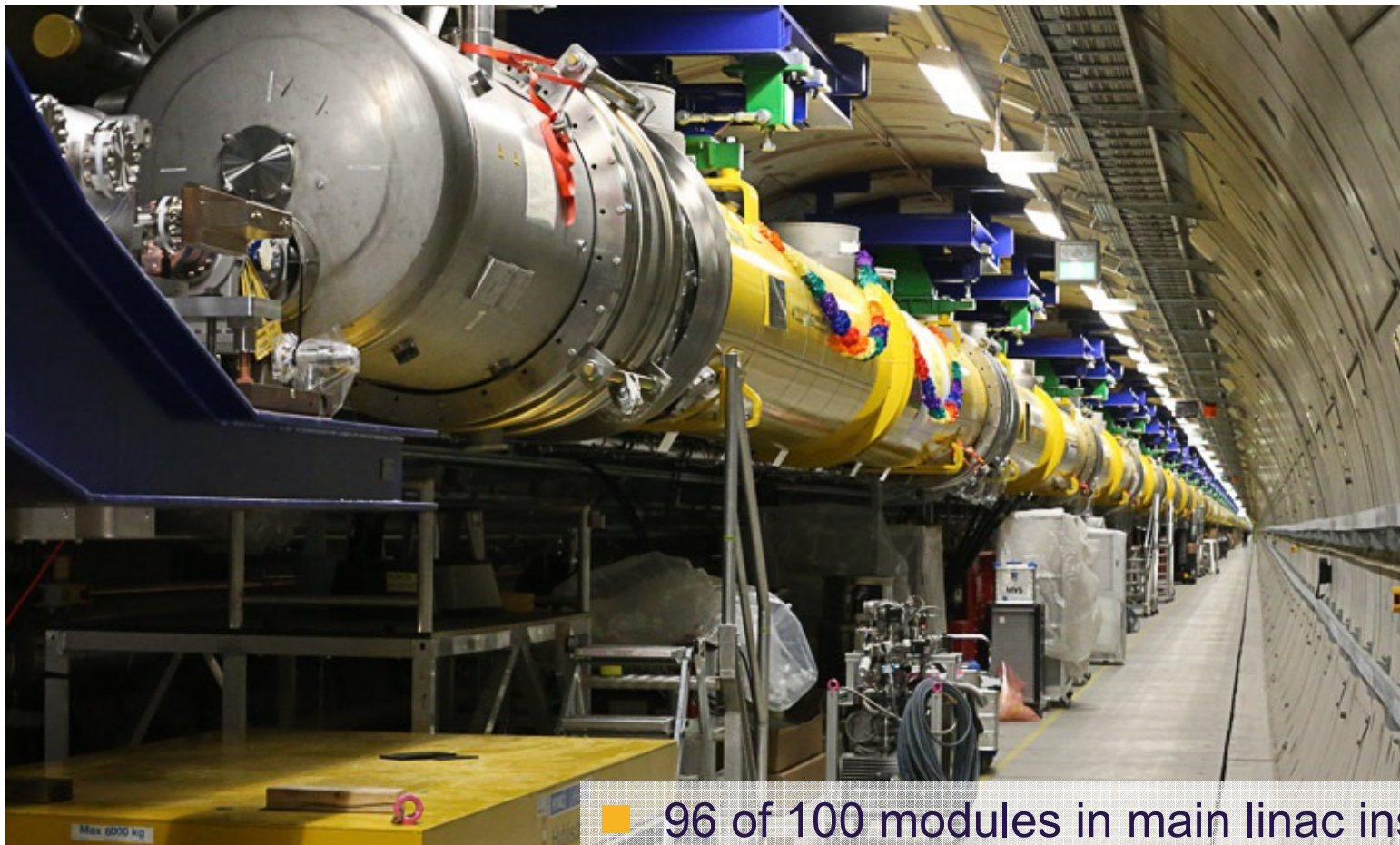




Installation of SC Modules finished



1st module July 1st, 2014 – last module (XM98) August 1st, 2016



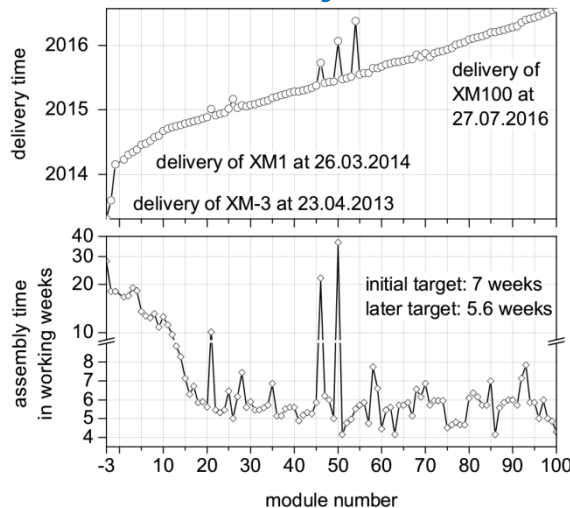
- 96 of 100 modules in main linac installed
- nominal beam energy assured

Module Fabrication and Installation Summary

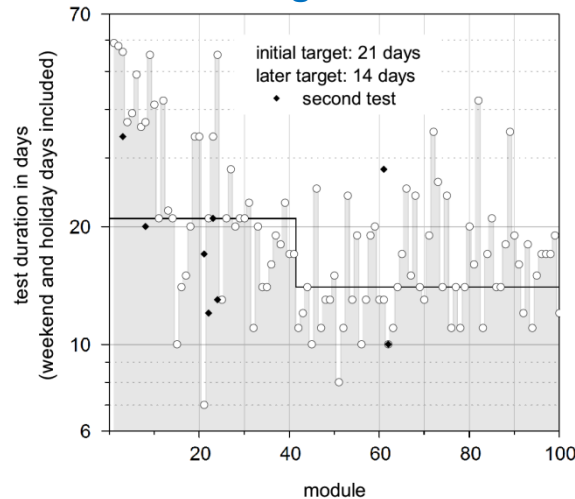
14

- Projected rate for module fabrication, test and installation
- ## 1 Module / week

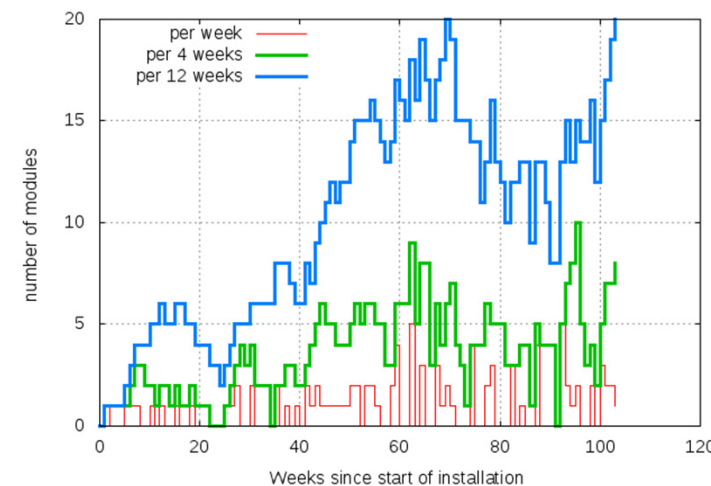
Assembly Rate



Testing Rate



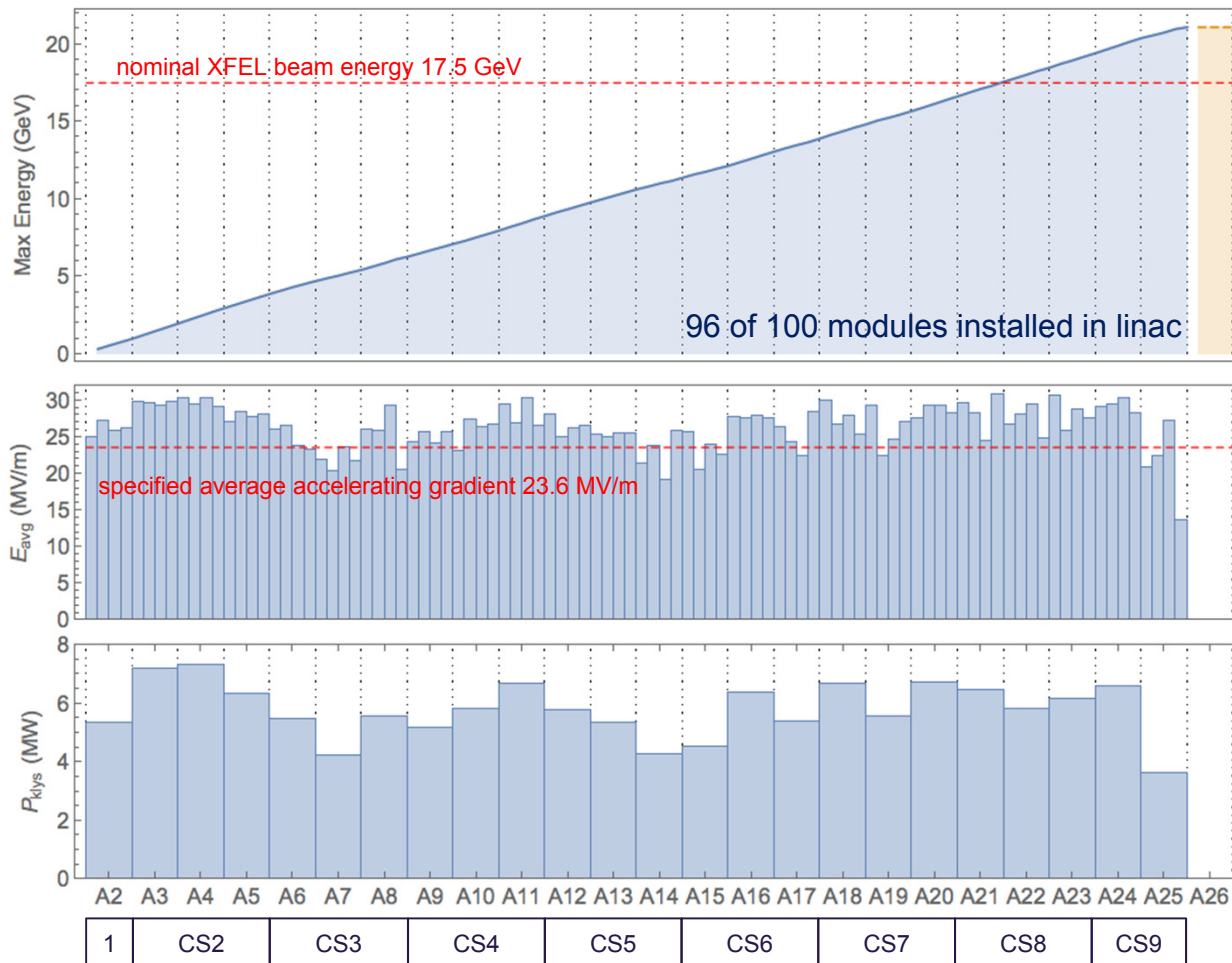
Installation Rate



- Availability of power couplers remained limiting factor throughout production
- Experience allowed significant increase of testing rate
- Additional personnel and experience accelerated wave guide tailoring and installation

Performance of XFEL Modules

15



BC1 BC2 (at nominal op. point)

600 MV 2.4 GeV

15.1

17.9

19.5

maximum energy reach

- according to accelerator module test
- and after tunnel installation

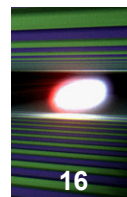
	N_{cavs}	Average	RMS
VT	815	28.3 MV/m	3.5
CM	815	27.5 MV/m	4.8

	Installed (GeV)	Module (GeV)
CS1	1.	1.05
CS2	3.89	4.06
CS3	6.29	6.72
CS4	8.91	9.49
CS5	11.38	12.09
CS6	13.92	14.76
CS7	16.63	17.62
CS8	19.42	20.44
CS9	21.09	22.23

FEL operation point:

- slightly lower due to working point of BC2
- gives higher safety margin for higher availability

More Impressions of Installations



BC Chicane



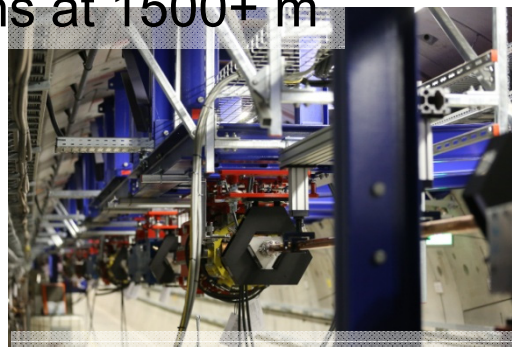
BC



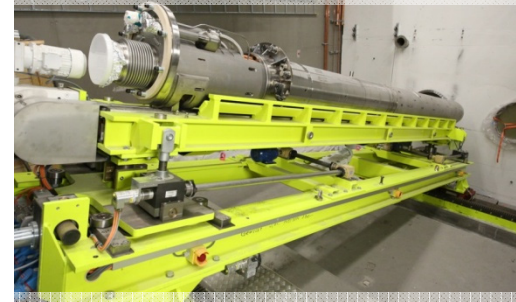
TDS in BC2



Linac Installations at 1500+ m



Beam Dump on Vehicle



Undulators

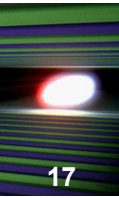


Photon Beam Lines



Experimental Hutches



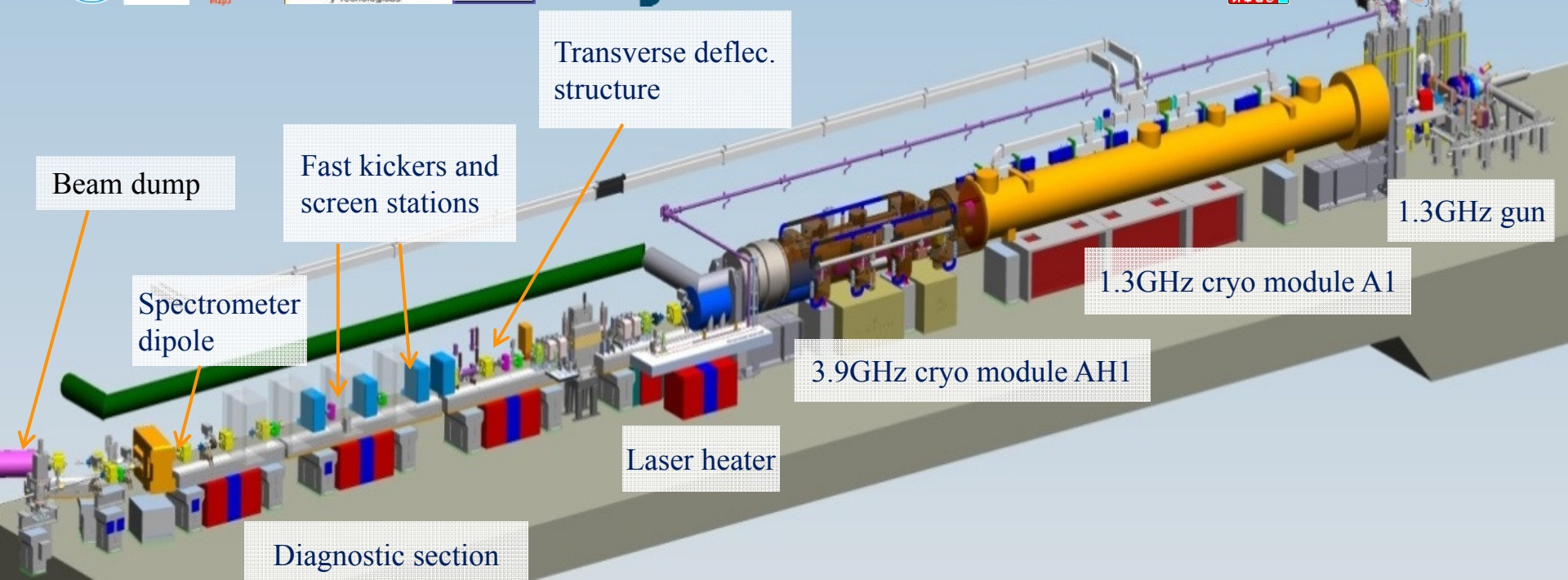


First Commissioning Results

from the XFEL Injector

Overview XFEL Injector

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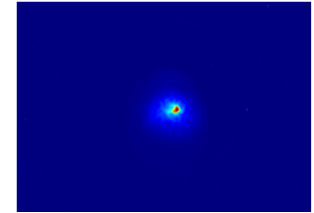


Injector Commissioning: staged approach

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02/2015

- First electrons from RF gun



11/11/2015

- Installation of injector finished

12/09/2015

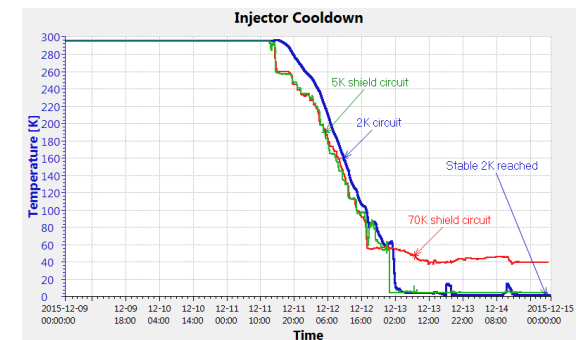
- Start cool down of injector

12/15/2015

- Injector stable at 2°K

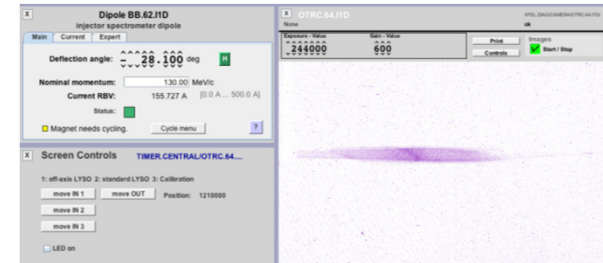
12/18/2015

- First beam to injector dump



05/2016

- First slice emittance measurement with TDS



07/25/2016

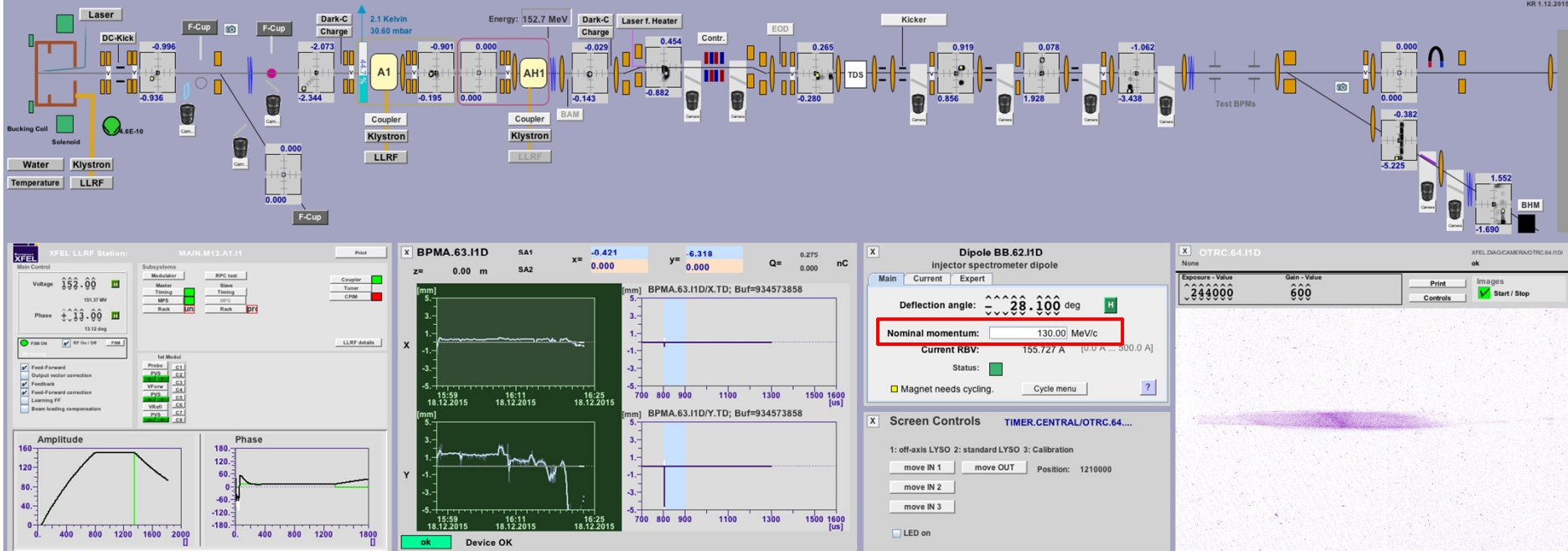
- Successful completion of injector commissioning, warm up of injector

First Beam to Injector Dump: Dec. 18th, 2015

20

/svn/XFEL/BeamLines/XFEL_inj_beamline.xml XFEL DIAG/TIMER.CENTRAL/MASTER/SASE

I1 Injector



Properties of 1st beam:

≈ 1% of accelerator length

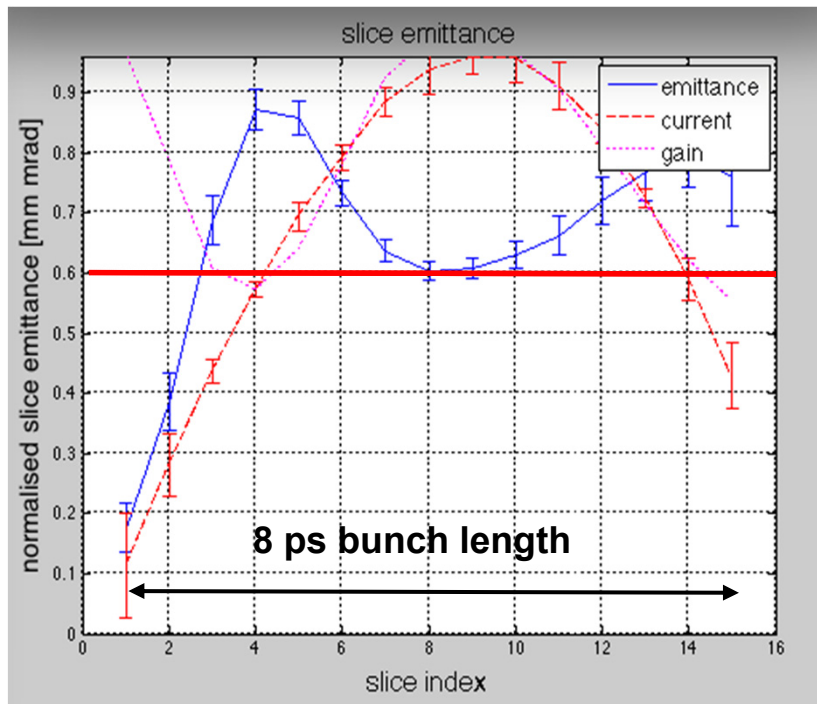
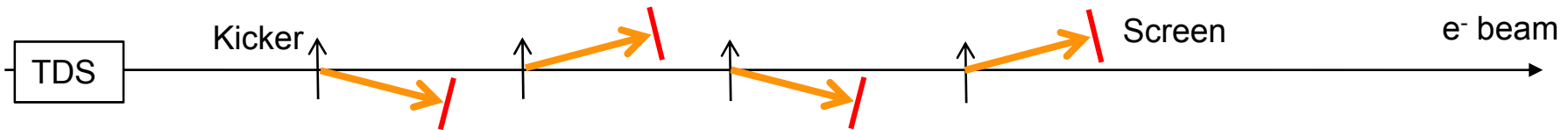
≈ 1% of final energy

≈ 1% of electrons/second

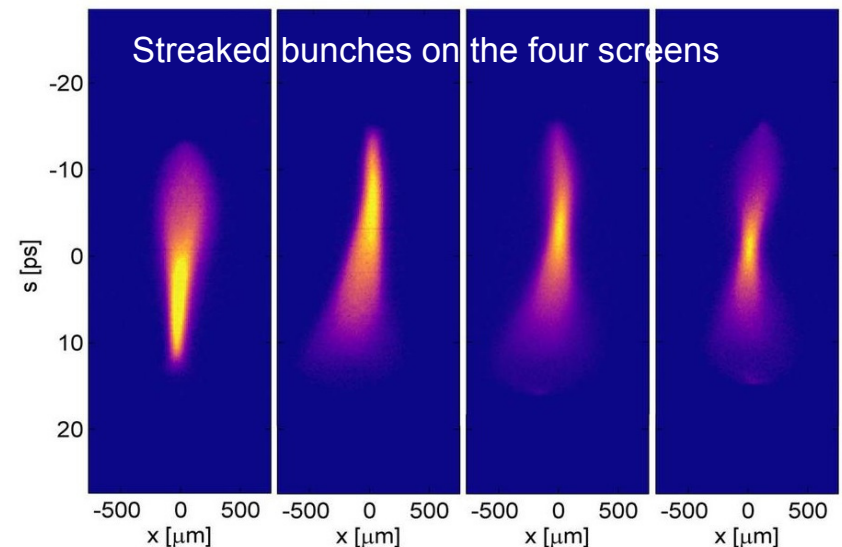
with all accelerator sub-systems needed and functional!

Slice Emittance Measurements with fast kickers and off-axis screens

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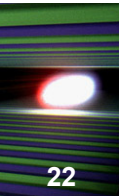
slice emittances can be measured and evaluated within 20 seconds using fast kickers and off-axis screens.



- center slices are reproducibly measured
- 0.6 mm mrad horiz. at 500 pC and 53 MV/m gun gradient
- the smallest slice emittance measured was 0.5 mm mrad at 60 MV/m

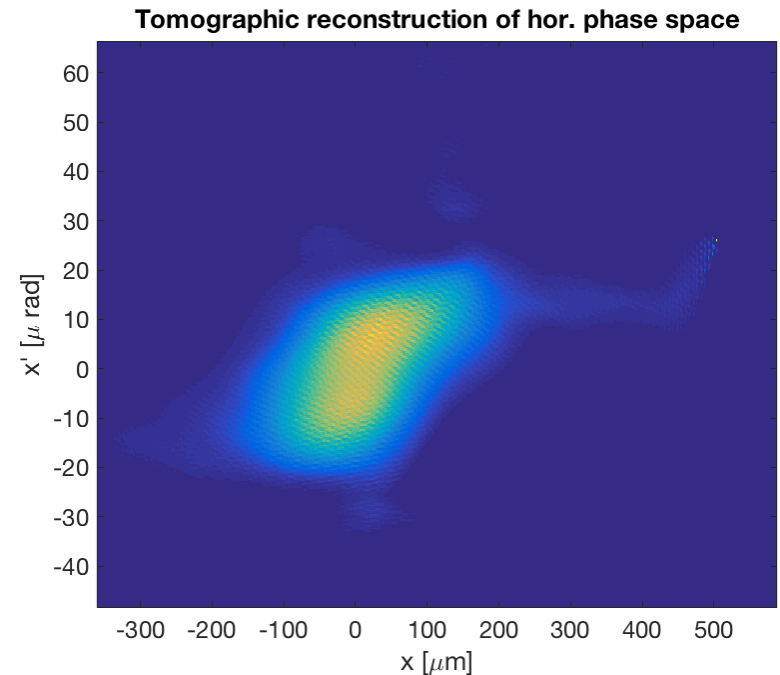
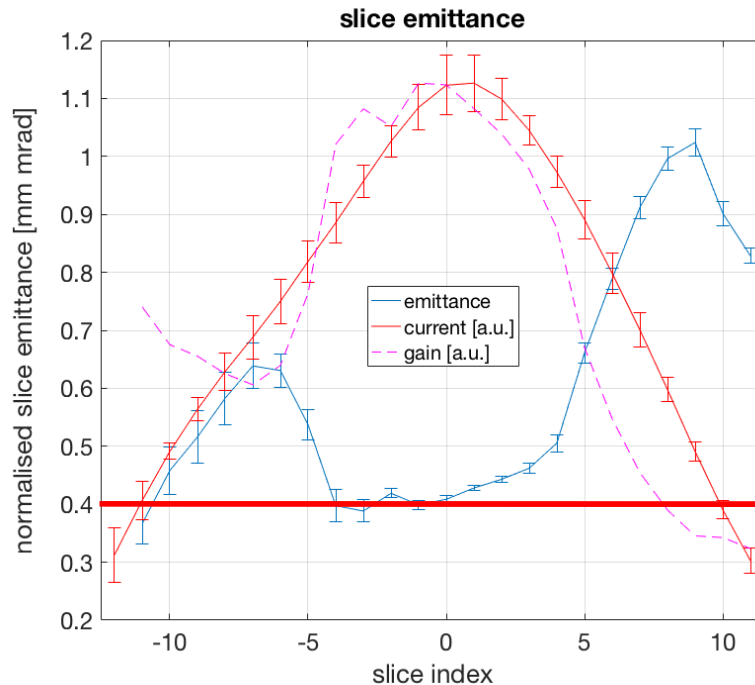
Slice Emittance Measurement Based on Quad Scan

Tomographic reconstruction of the hor. phase space scan



- Results from an **optics scan** with 5 quads and 17 different beam optics. The beam was analyzed on the last screen in the diagnostics section.
- The obtained data was used to **calculate slice emittances** and to reconstruct the hor. phase space of all bunch slices using a tomographic algorithm (MENT*). *MENT: Maximum entropy algorithm

Slice emittances along the bunch. This measurement led to a core slice emittance of 0.4 mm mrad. The gun was operated at 53 MV/m.



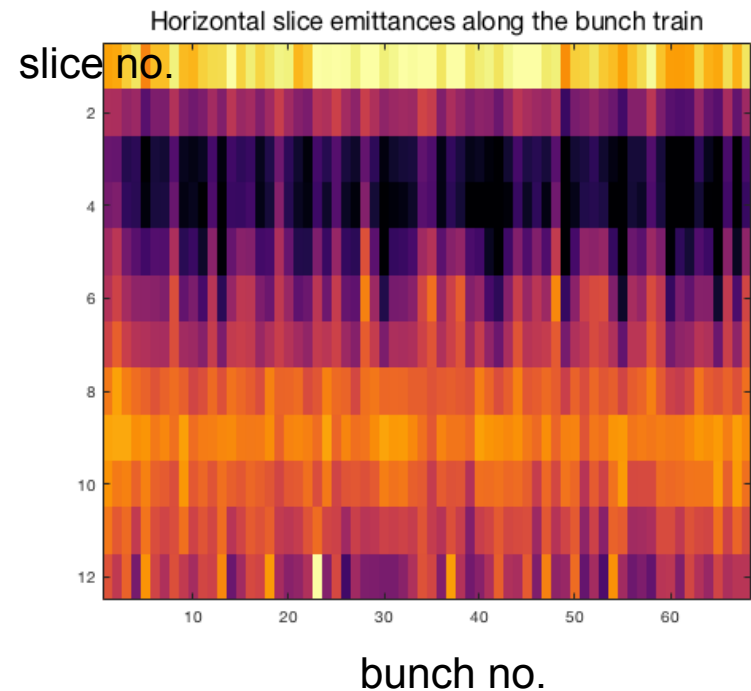
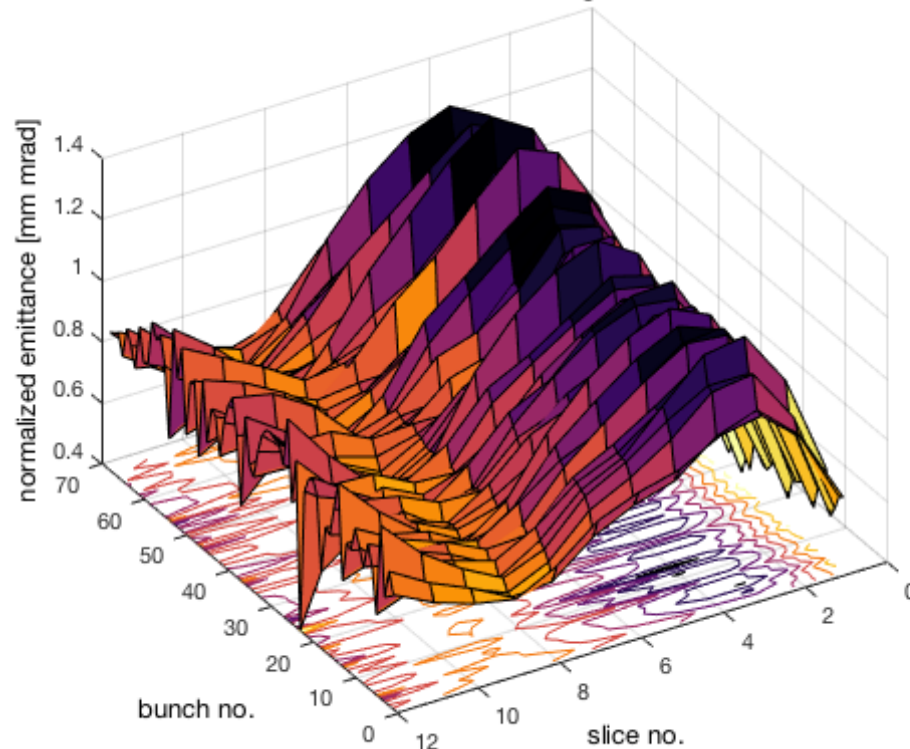
Tomographic reconstruction of the horizontal phase space for the center slice.

Emittance Measurements along Bunch Trains

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- The TDS also allows to measure slice emittances along the bunch train.
- The behavior of the slice emittances along the bunch is reproducible over the bunch train. The smallest slice emittance is measured for the core of the bunch.

Horizontal slice emittances along the bunch train

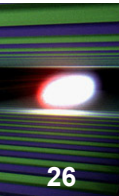


Injector Commissioning Goals

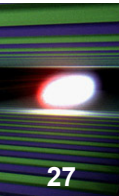
Quantity	Min. Goals 1 st Lasing	TDR Specs	Achieved
macro pulse repetition rate [Hz]	10	10	10
RF pulse length (flat top) [μ s]	100	600	650
bunch repetition frequency within pulse [MHz]	1.0	4.5	4.5
bunch charge [nC]	0.5	0.02 – 1	0.02 – 1
Slice emittance [mm mrad]	1.0 @ 50 MV/m	0.4 - 1.0 @60 MV/m	0.5 @52 MV/m

- Emittance measurements done on a routine basis
- Full bunch train length (2700 bunches) reached and beam stopped in injector beam dump
- 24/7 operation of injector from control room
- Transverse Deflecting System operated
 - Slice emittance measured: 0.5 mm mrad for 500 pC

Outlook: from now to operation



- **Goal: close the Linac tunnel mid October**
 - Start cool down of the facility
 - Estimated 4 weeks
 - Restart injector operation as soon as possible
 - Full operation possible CS1 to C7 (76 modules , 15 GeV)
 - CS8: hardware ready (88 modules, 18 GeV)
 - CS9 with 8 modules / 2 RF station: prepared but cabling etc still to be done
- **Some work still be done in maintenance days / weeks during commissioning**



- **Successful commissioning injector** completed 2016
 - all TDR design parameters reached
- **Linac tunnel closed: T0 = Oct 20th, 2016**
 - 96 modules but energy reach above spec
 - Start cool down
 - Some work remains for maintenance periods during commissioning
- **First lasing possible: 6 month after T0**
- User operation scheduled for mid 2017
- Full (photon) performance expected 2 years after T0

