Long Pulse RF Systems at DESY

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Long Pulse RF Systems at DESY
Lund, Sweden
ESS-Klystron-Modulator-Workshop
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HELMHOLTZ ASSOCIATION

DESY

Overview

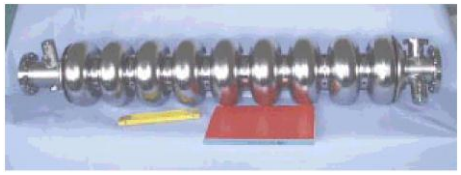
- Introduction
- Requirements for the Long Pulse RF Systems
- RF Sources
- Long Pulse Modulators

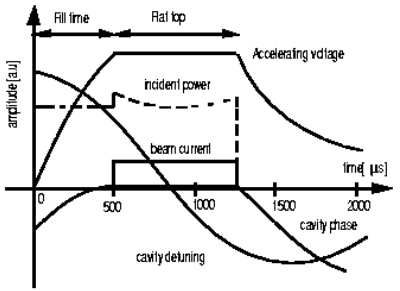
Introduction

- Early 1990s start of the TESLA collaboration. Its mission was the development of technology to construct a superconducting linear collider (500GeV$_{cm}$, SC cavities at 1.3GHz, RF systems at ~1.5ms pulse, ~5-10Hz rep. rate).
- In 1990s Tesla Test Facility (TTF) setup at DESY. TTF was conceived as a facility to develop, construct and operate technology for a sc linear accelerator.
- 2001 TESLA TDR of a linear collider with integrated XFEL.
- 2002 Supplement to the TDR on a dedicated linac for the XFEL, negotiations started to build the XFEL as European project at DESY.
- 2004 ITRP recommended superconducting technology for a future Linear Collider → ILC.
- 2006 TDR of the European XFEL.
- June 5, 2007 official launch of the European XFEL project at DESY, first beam expected for 2015.
- TTF (2006) → FLASH: VUVFEL User Facility based on 1.2GeV sc accelerator.

TESLA 500 RF System Requirements

Number of sc cavities:	21024 total
Power per cavity:	231kW
Gradient at 500GeV:	23.4MV/m
Power per 36 cavities (3 cryo modules):	8.3MW
Power per RF station:	**9.7MW** (including 6% losses in waveguides and circulators and a regulation reserve of 10%)
Number of RF stations:	**572**
Macro beam pulse duration:	950μs
RF pulse duration:	**1.37ms**
Repetition rate:	**5Hz**
Average RF power per station:	**66.5kW**

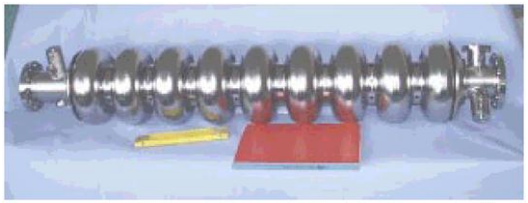


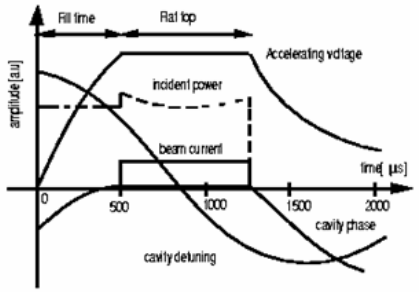


For TESLA 800 the number of stations must be doubled.
The gradient is 35MV/m.

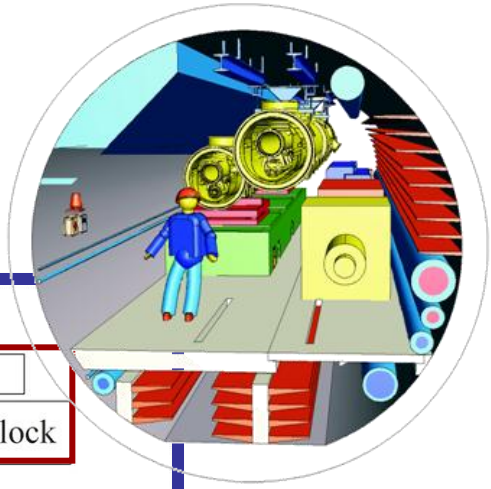
XFEL RF System Requirements

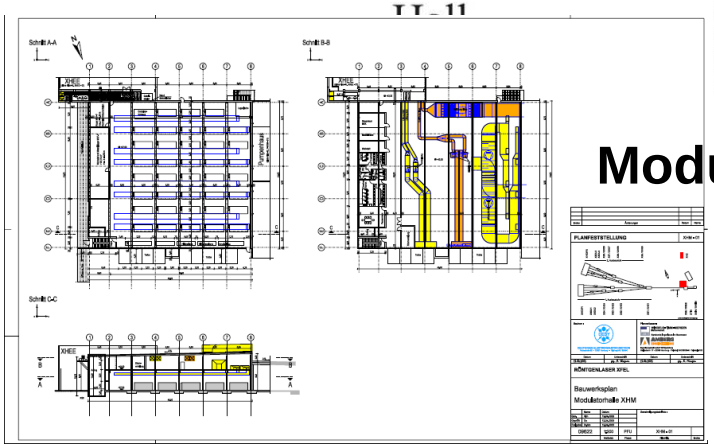
Number of sc cavities:	800 total for 17.5GeV
Power per cavity:	122 kW
Gradient at 20GeV:	23.6 MV/m
Power per 32 cavities (4 cryo modules):	3.9MW
Power per RF station:	**5.2MW** (including 10% losses in waveguides and circulators and a regulation reserve of 15%)
Number of RF stations:	**25** (27), active **23** (25)
Number of RF stations for injectors:	**2**
Macro beam pulse duration:	650µs
RF pulse duration:	**1.38ms**
Repetition rate:	**10Hz (30Hz)**
Average RF power per station:	**72kW (150kW)**



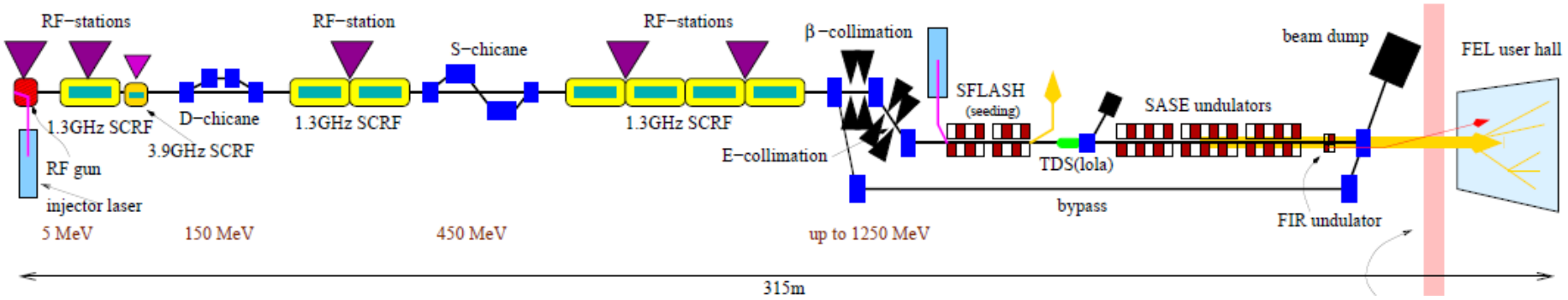


Layout of one RF Station

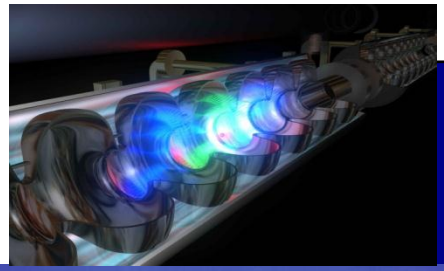


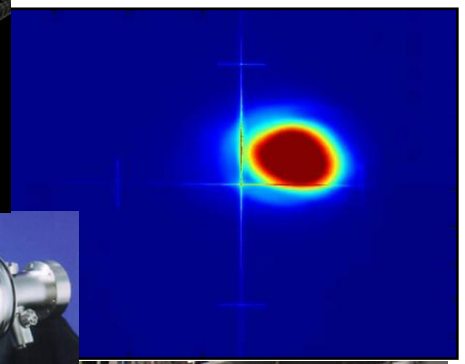


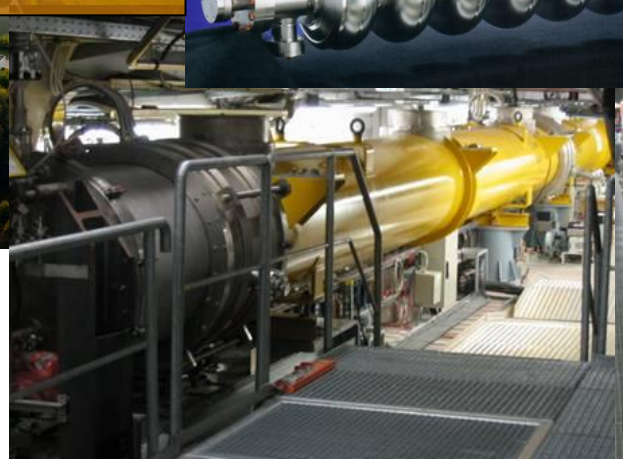
TTF/FLASH

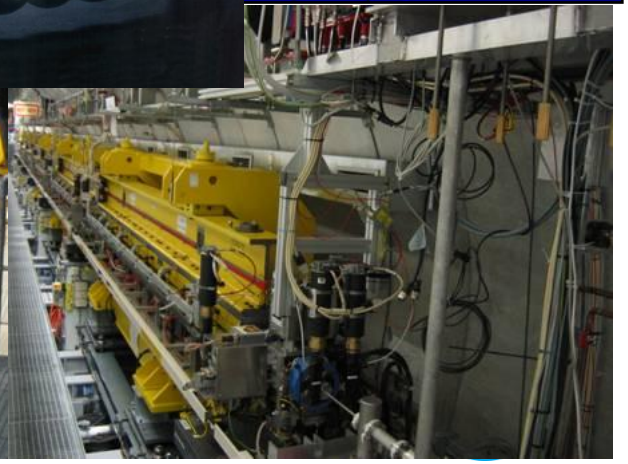

RF−stations
RF−station
S−chicane
RF−stations
β −collimation
beam dump
FEL user hall
SFLASH
(seeding)
SASE undulators
1.3GHz SCRF
D−chicane
1.3GHz SCRF
1.3GHz SCRF
3.9GHz SCRF
E−collimation
TDS(lola)
RF gun
injector laser
bypass
FIR undulator
5 MeV
150 MeV
450 MeV
up to 1250 MeV
315m


FLASH

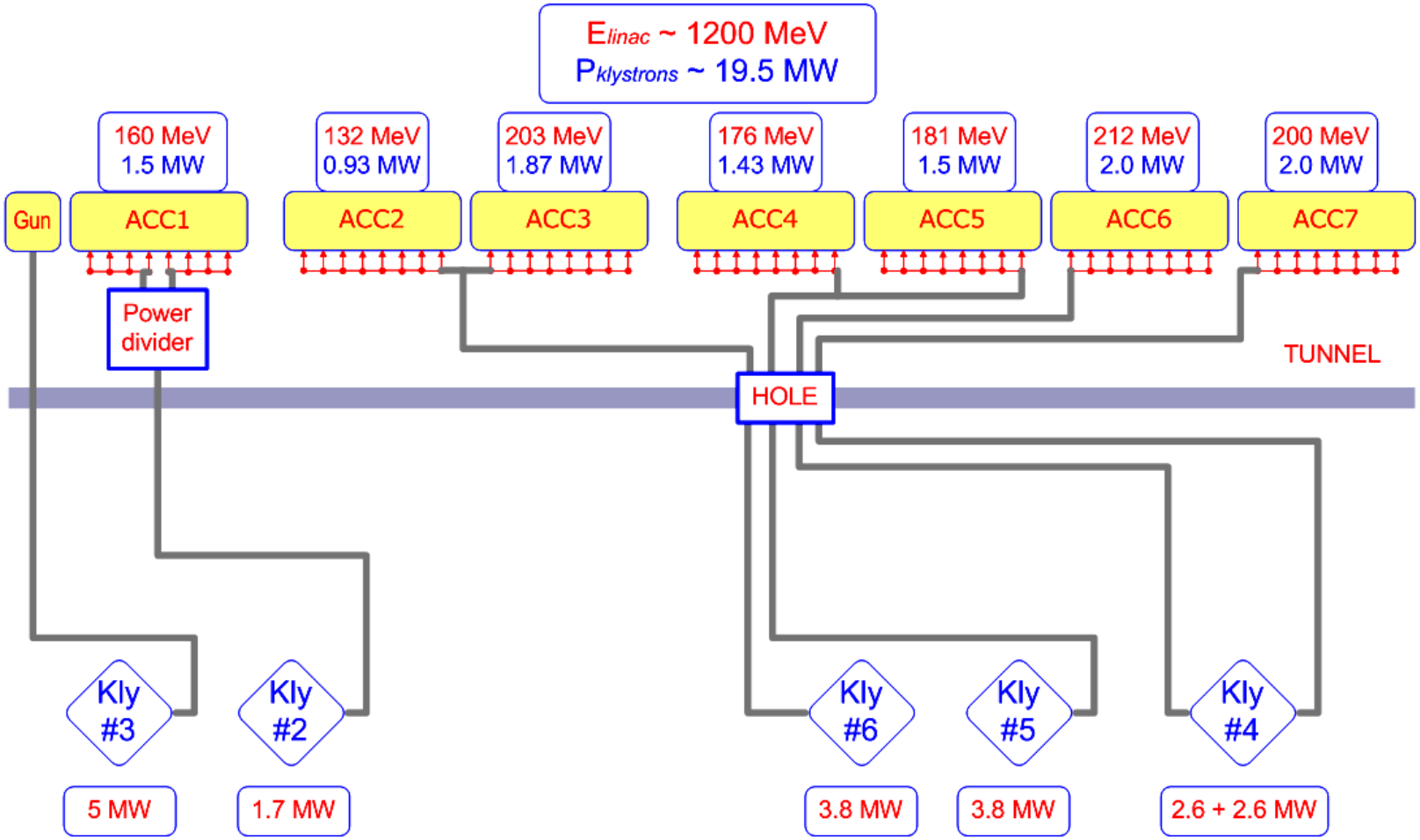








FLASH RF System 2011



Additional 8 RF stations in operation for test of XFEL RF system components and cavities at DESY Hamburg and for RF gun development at DESY Zeuthen plus 3 in construction for XFEL module test at DESY Hamburg.

RF Power Source for TESLA and XFEL

- Operation Frequency: 1.3GHz
- Cathode Voltage: < 120 kV
- Beam Current: < 140 A
- Max. RF Peak Power: 10MW
- RF Pulse Duration: 1.5ms
- Repetition Rate: 10Hz
- RF Average Power: 150kW
- Efficiency: 63%
- Solenoid Power: < 5.5kW
- Length: 2.5m

Multi Beam Klystrons

Multi Beam Klystrons (MBK) have been chosen.
Three vendors have developed and manufactured MBKs, meeting the XFEL requirements.

THALES TH1801

CPI VKL8301

TOSHIBA E3736

Horizontal MBKs for XFEL

- Since vertical MBKs would not fit in the XFEL tunnel horizontal version have been developed.
- All three vendors of MBKs have developed and manufactured horizontal versions of their MBK.
- These klystrons have been successfully tested at the klystron test facility at DESY.
- Finally two vendors are producing MBKs for the XFEL.

Horizontal multibeam klystron prototypes at the klystron test facility (KTF)

FLASH RF Power Sources

- At FLASH vertical klystrons are used.
- TH1801 10MW, 117kV, 135A, 1.5ms, 10Hz
- TH2104C 5MW, 128kV, 89A, 1.5ms, 10Hz

TH2104C

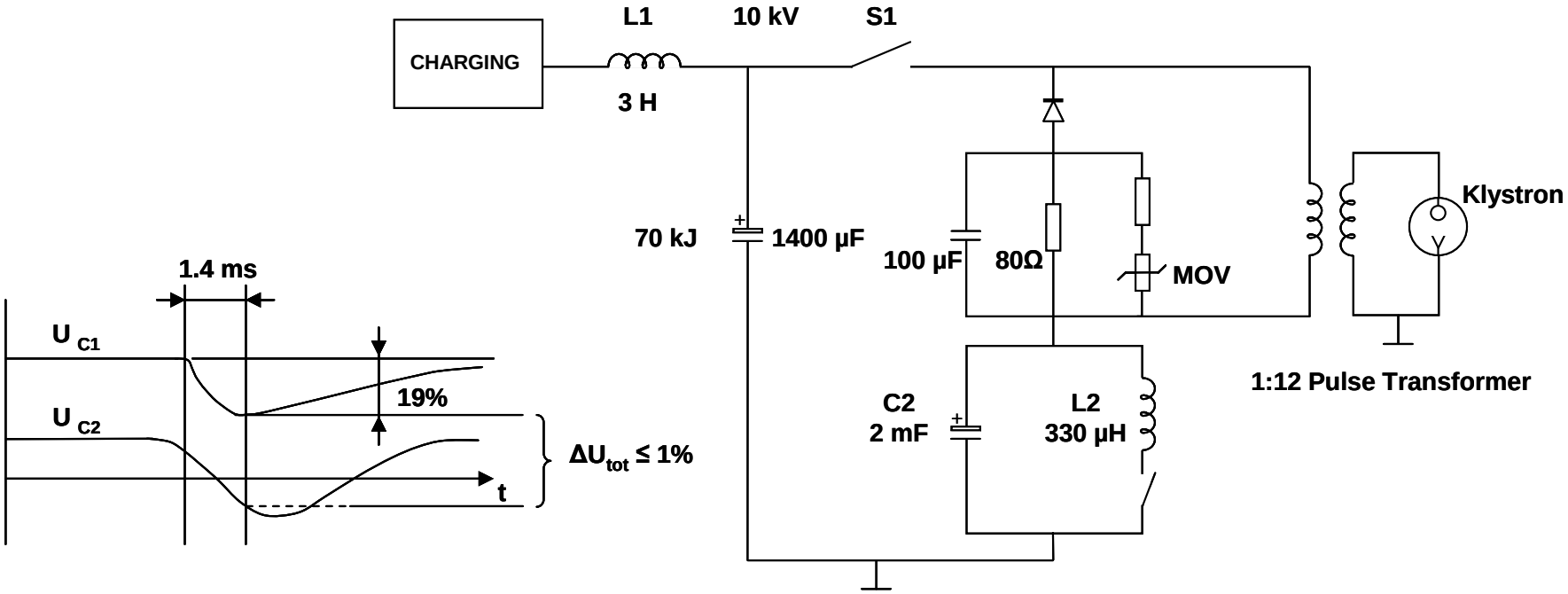
TH1801

Modulator Requirements

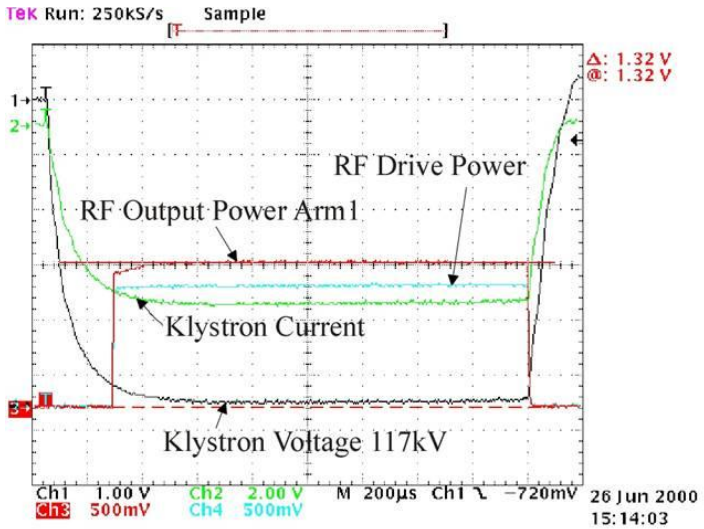
	typical	max.
Modulator Pulse Voltage/ Pulse Transformer Primary Voltage	9.6kV	12kV
Modulator Pulse Current Voltage/ Pulse Transformer Primary Current	1.62kA	1.8kA
Pulse Transformer Secondary Voltage / Klystron Gun Voltage	115kV	132kV
Pulse Transformer Secondary Current / Klystron Gun Current	135A	150A
High Voltage Pulse Duration (70% to 70%)	1.57ms	1.7ms
High Voltage Rise and Fall Time (0 to 99%)	0.15ms	0.2ms
High Voltage Flat Top (99% to 99%)	1.37ms	1.5ms
Pulse Flatness during Flat Top	±0.2%(0.3%)	±0.3%(0.5%)
Pulse-to-Pulse Voltage fluctuation	±0.1%(0.3%)	±0.1%(0.5%)
Energy Deposit in Klystron in Case of Gun Spark	<20J	20J
Pulse Repetition Rate	10Hz	10Hz (30Hz)
Pulse Transformer Ratio	1 :12	NA

Bouncer Modulator

•Bouncer modulators have been proposed for TESLA and are in use at FLASH and at the XFEL test facilities.



Bouncer Modulators by FNAL



- 3 modulators have been developed, built and delivered to TTF by FNAL since 1994
- 1 modulator is still in use, 2 others have been united and modified to 1 new modulator

Industry made bouncer modulator

- Industry made subunits (PPT, ABB, FUG, Poynting)
- Constant power power supply for suppression of 10Hz repetition rate disturbances in the mains
- Compact storage capacitor bank with self healing capacitors
- IGCT Stack (ABB); 7 IGCTs in series, 2 are redundant
- Low leakage inductance pulse transformer (ABB) L<200μH resulting in shorter HV pulse rise time of <200μs
- Light Triggered Thyristor crowbar avoiding mercury of ignitrons

FLASH RF Station 3

Modulator control racks

RF station 3

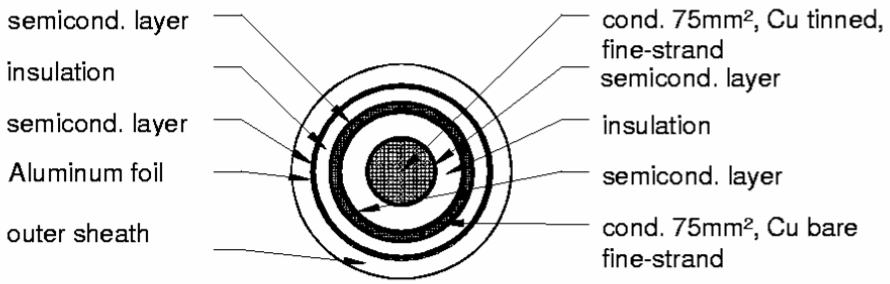
Bouncer

Output cabinet

IGCT stack

HV Pulse Cable for XFEL

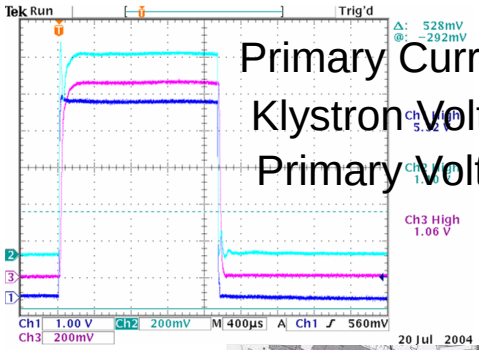
- Transmission of HV pulses (10kV, 1.6kA, 1.57ms, 10Hz (30Hz)) from the pulse generating unit (modulator hall) to the pulse transformer (accelerator tunnel)
- Maximum length 1.5km
- Impedance of 25 Ohms (4 cables in parallel will give 6.25 Ohms in total) to match the klystron impedance
- Triaxial construction (inner conductor, middle conductor, outer conductor at ground)



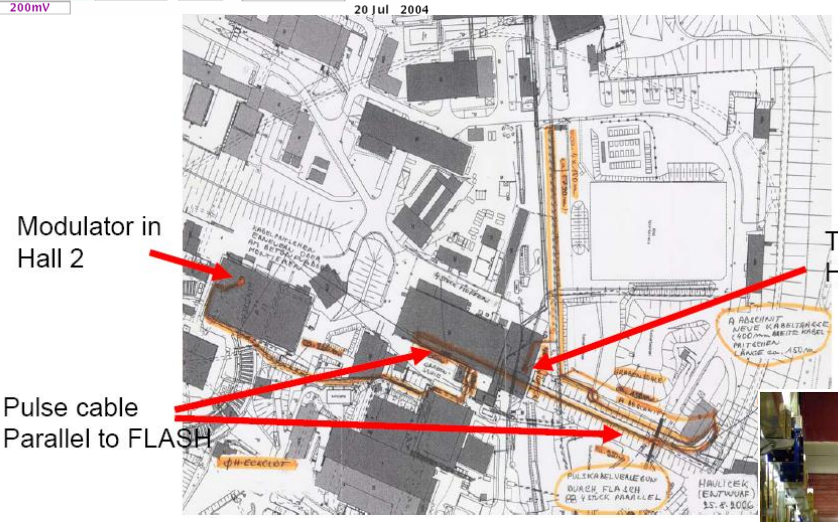
diameter 30mm
dielectric material: XLPE

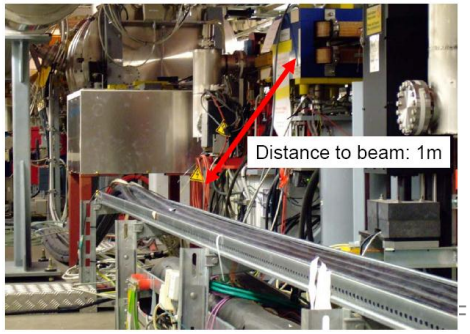
HV Pulse Cable Test

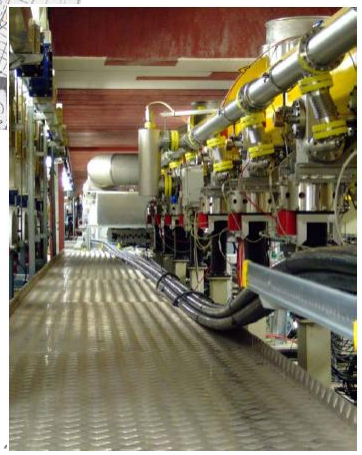
- Pulse transmission has been tested successfully at TTF/FLASH Modulator 5.
- EMI caused by cable required modification of modulator internal layout (lower leakage inductances, EMC cabinets, bouncer at high voltage potential).
- New modified modulator has been installed at DESY hall 2 and supplied HV pulses via a 1.5km long cable to a PT/Klystron in hall 3 (FLASH) during part of the 2007/08 operation period of FLASH, test has been successful.



Primary Current 1.1kA
Klystron Voltage 128kV
Primary Voltage 10.6kV



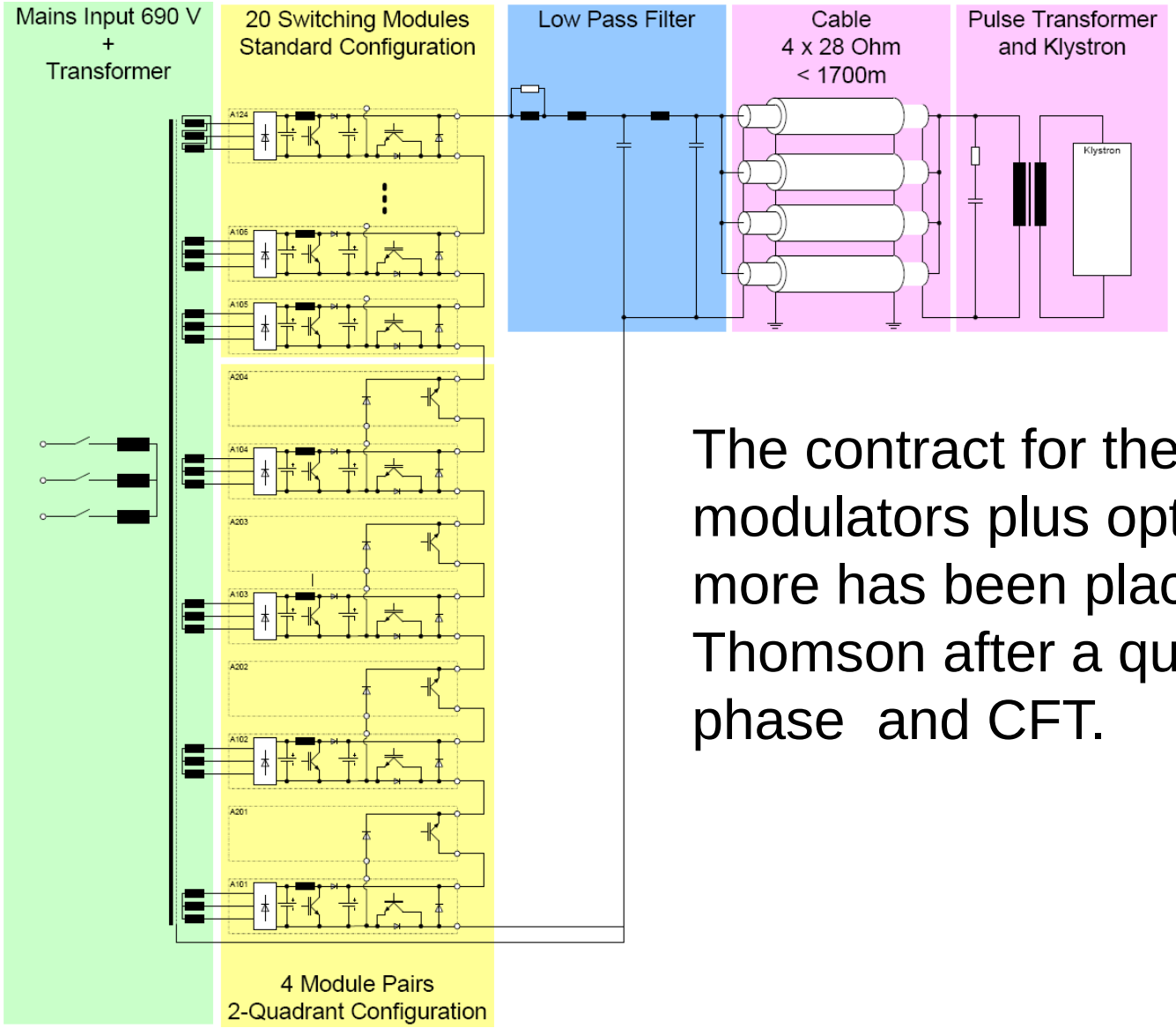




Status Bouncer Modulator

- 17 bouncer modulators have been built, 3 by FNAL and 14 together with industry
- 13 modulators are in operation at present (FLASH, PITZ, XFEL test stands)
- Almost 20 years of operation experience
- The actual internal layout of the bouncer modulators has been modified over the years (e.g. EMI reduction, regulation improvement, new (more reliable or smaller) components)
- Some downtime was caused by failure of components due to mechanical stress (e.g. broken transformer, loose cables, broken crow bar resistors)
- FLASH downtime during user run between Nov. 07 and Sep. 08 6%, 31% of these 6% were caused by 1.3GHz RF stations
- FLASH downtime during user run between Sep. 10 and July 11 4%, 9% of these 4% were caused by 1.3GHz RF stations

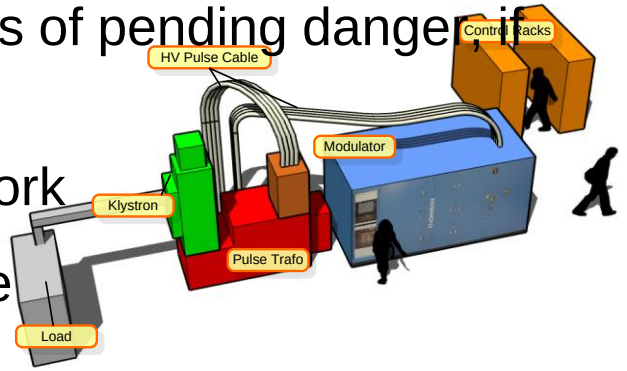
The Pulse Step Modulator for XFEL



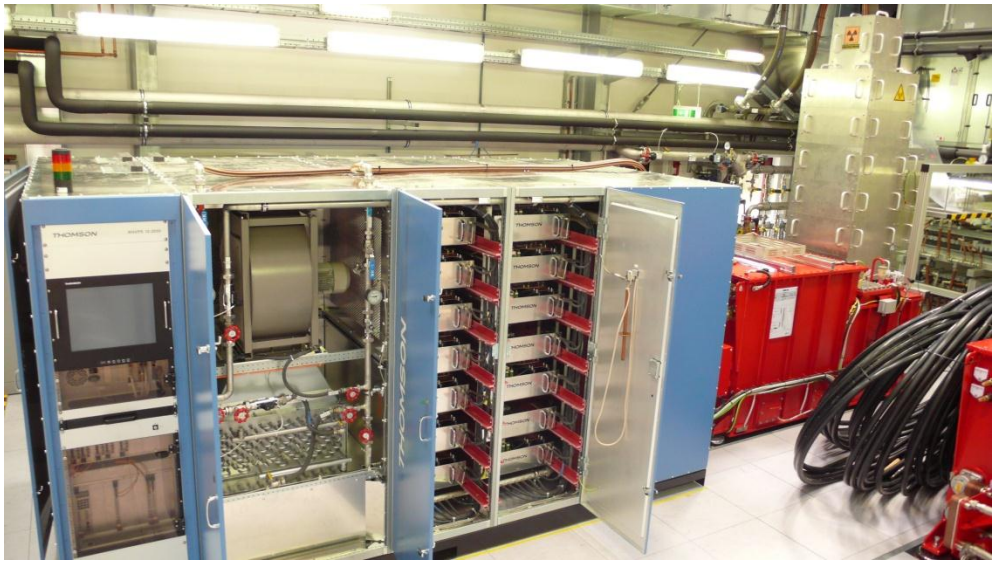
The contract for the 22 XFEL modulators plus option for 5 more has been placed at Thomson after a qualification phase and CFT.

Testing the PSM Prototype

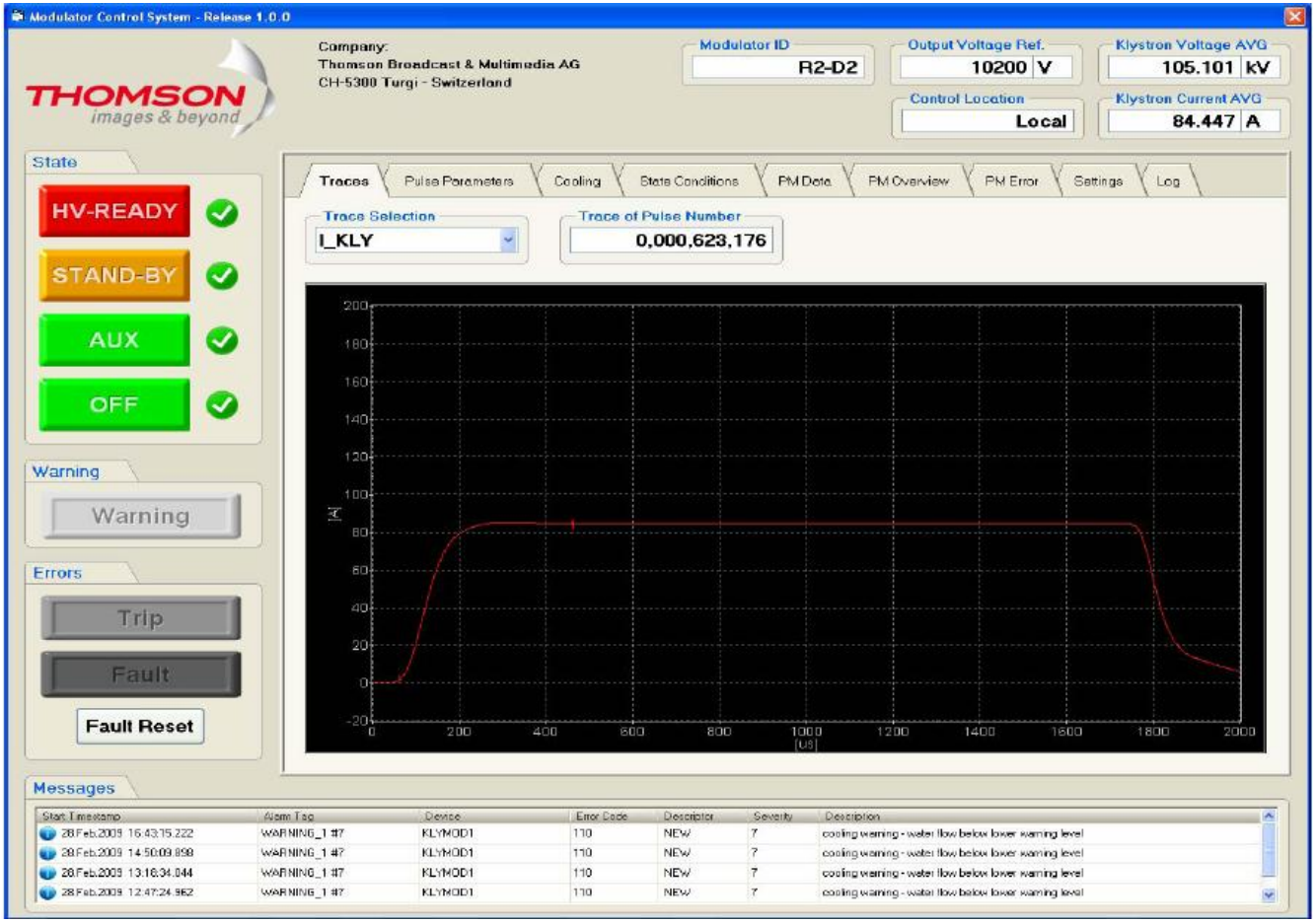
- verification of all parameters as written in the specification
- Determine *meantime between failure & repair* while long term testing
- Testing with *different klystron types* (5 MW and 10 MW) at different operation conditions
- Test of the *build-in klystron protection* (<20J)
- Analysis of amplitude/phase stability of RF-Power
- Drift of parameters and pulse-to-pulse variation
- Testing certain fault conditions and situations of pending danger, if handled correct and safe
- Adjustment of the cable compensation network
- Test pulse transmission over the pulse cable
- Analyzing EMI behavior



The Pulse Step Modulator at DESY Zeuthen



PSM experience



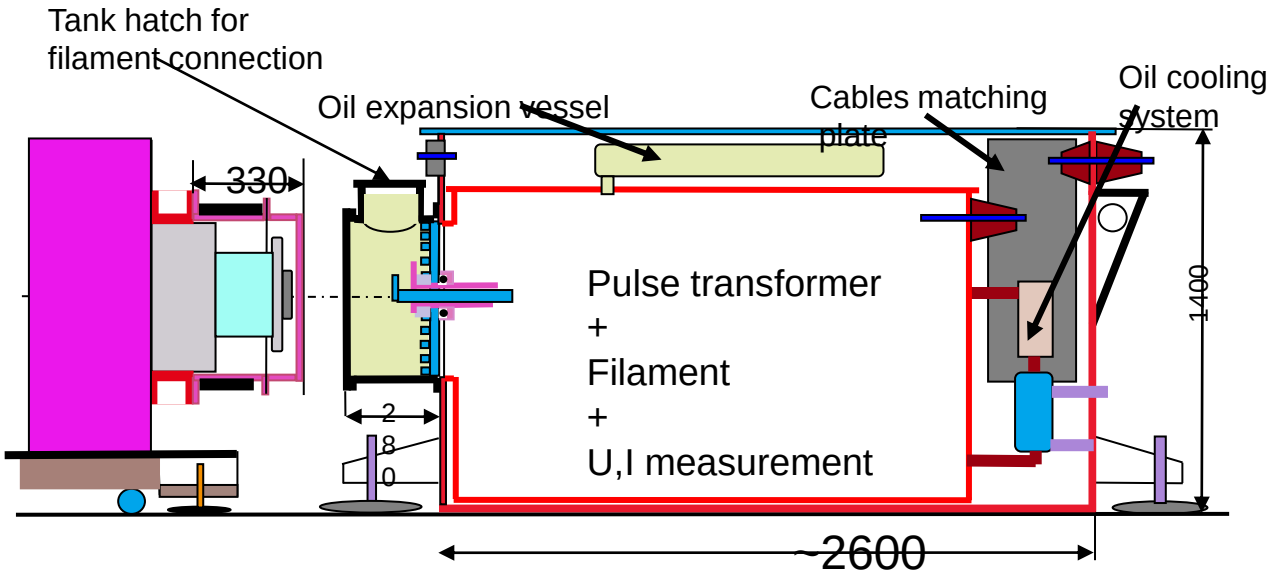
- PSM meets XFEL requirements
- Operation time: 5300h
- Efficiency: 87% (wallplug to 10kV modulator output)

MBK to Pulse Transformer Connection

Base line:

direct connection

Klystron/PT

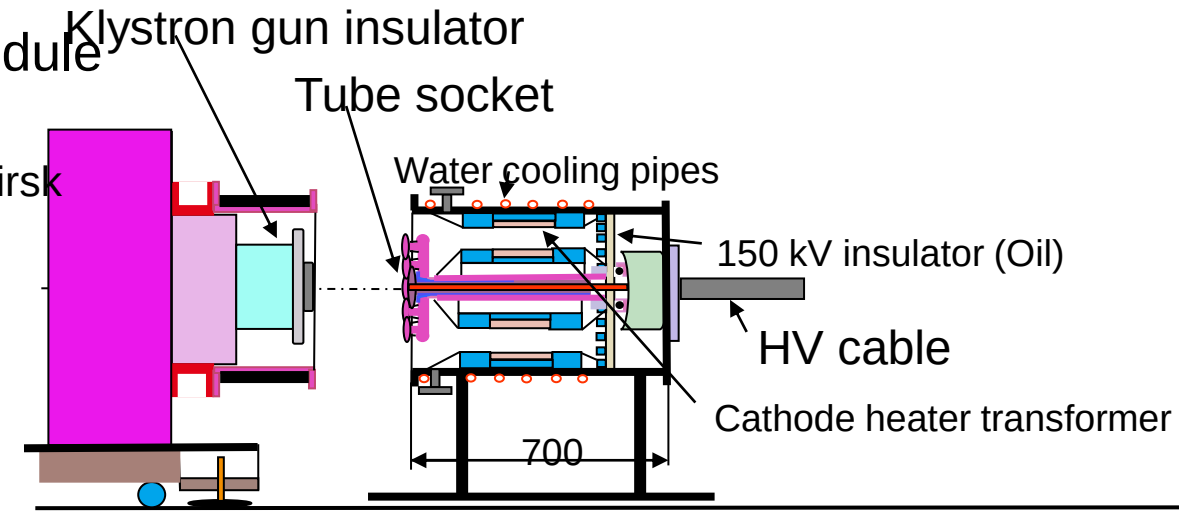


Alternative:

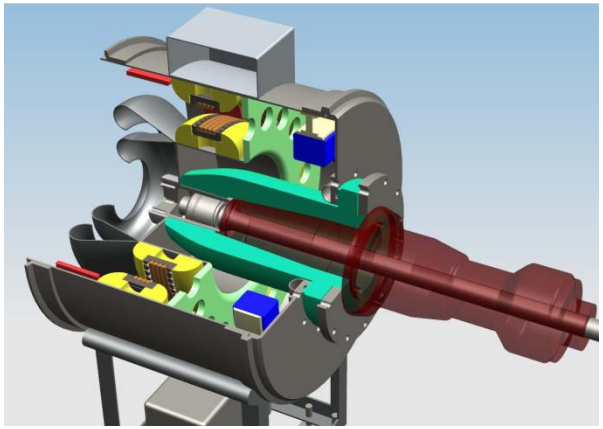
Connection module

being investigated

with BINP/Novosibirsk

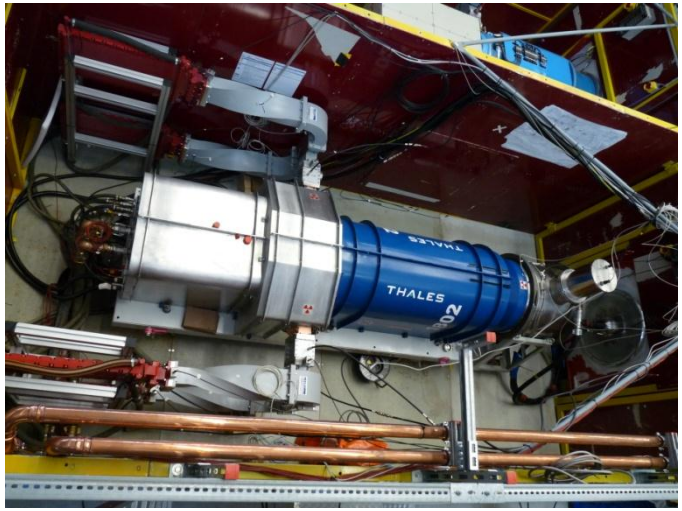


Pulse Transformer and Connection Module for XFEL



Double wall pulse transformer (XFEL prototype) on DESY site

Connection module has been tested with horizontal klystron.



> Thank you for your attention

European XFEL

Linac energy:	17.5GeV
Wavelength:	down to 0.1nm
Beam pulse length:	650μs
Repetition rate:	10Hz (30Hz at lower energy)
# of bunches in pulse:	3250
Bunch to bunch spacing:	200ns
Bunch charge:	1nC