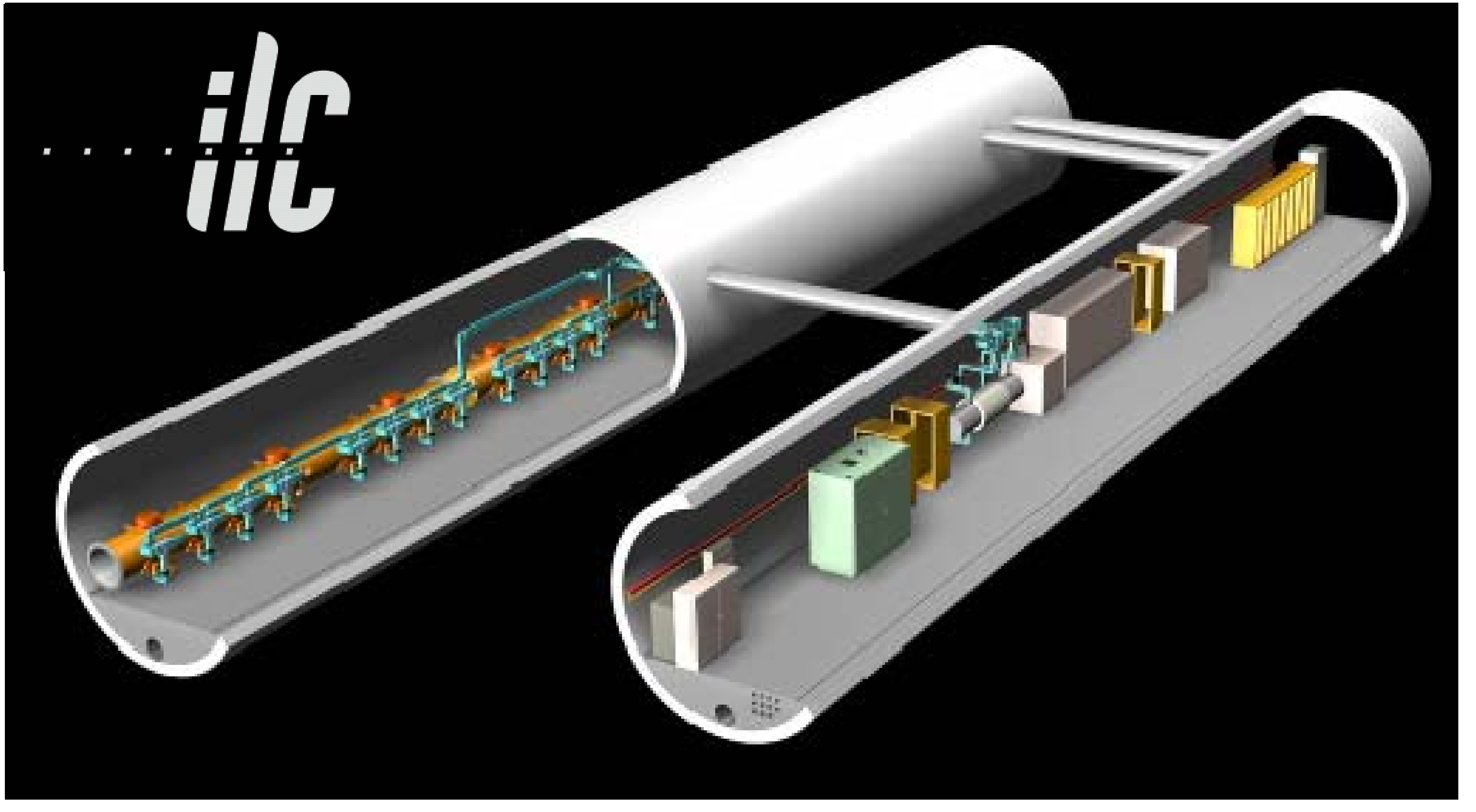
S7: RF Power



Chris Adolphsen

Feb 4-7, 2007 – Beijing GDE Meeting

BCD and ACD Modulators
(116 kV, 133 A, 1.6 ms, 5 Hz)

Baseline: Pulse Transformer Style Modulator

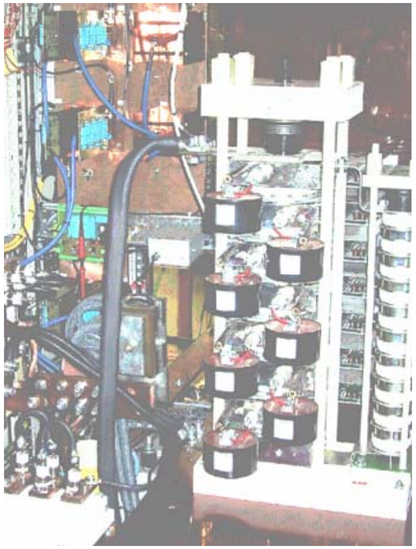
Alternative: Marx Generator Modulator

Reviewed in Next Talk

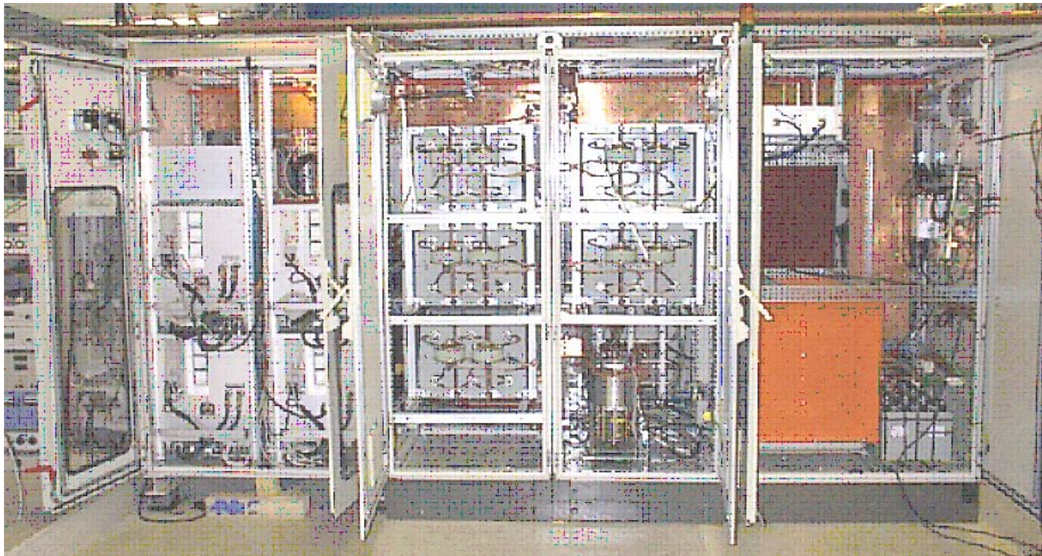
Pulse Transformer Modulator Status

- 11 units have been built, 3 by FNAL and 8 by industry (PPT with components from ABB, FUG, Poynting).
- 11 modulators are in operation.
- 10 years operation experience.
- Desire to improve
  - Reliability / MTTR
  - EMI / Noise

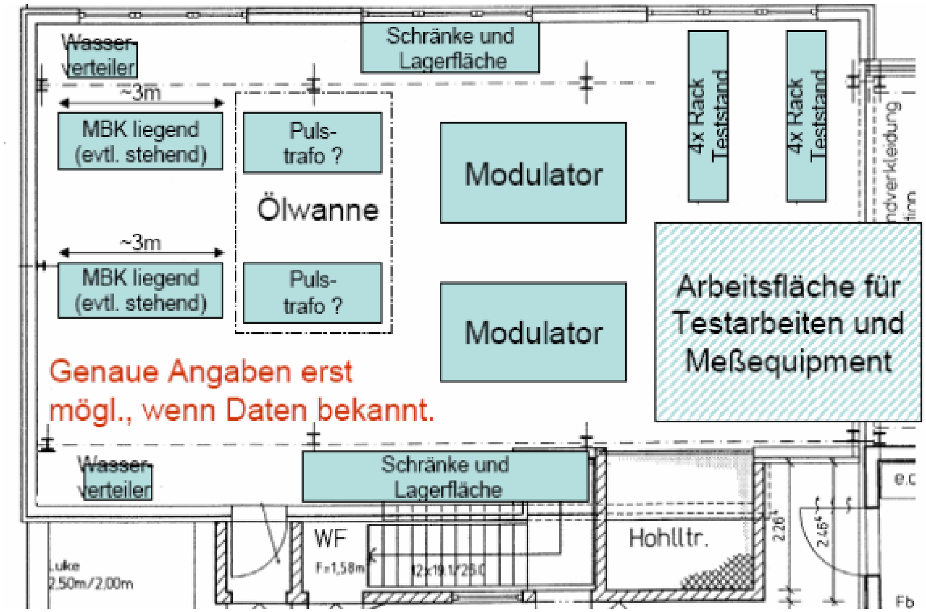
IGCT Stack



HVPS and Pulse Forming Unit



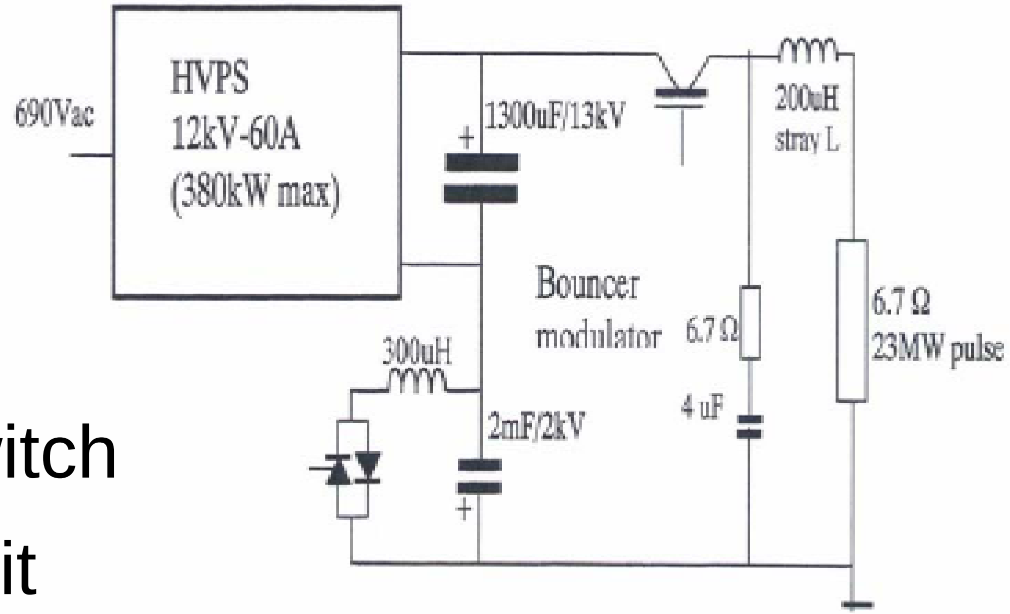
XFEL Modulator Development



- Ordered Prototypes
  - Two different prototypes from two vendors
    - Imtech-Vonk
    - Thales
  - Delivery ~ Dec 2007
  - Test in new facility in Zuethen that includes the modulator, cable, pulse transformer, klystron, interlocks and controls
- Complete evaluation, submit RFQs in 2008/2009
- Expect delivery of 30-40 modulators in 2009-2011
- For ILC, compliments Marx/Direct transformer-less designs

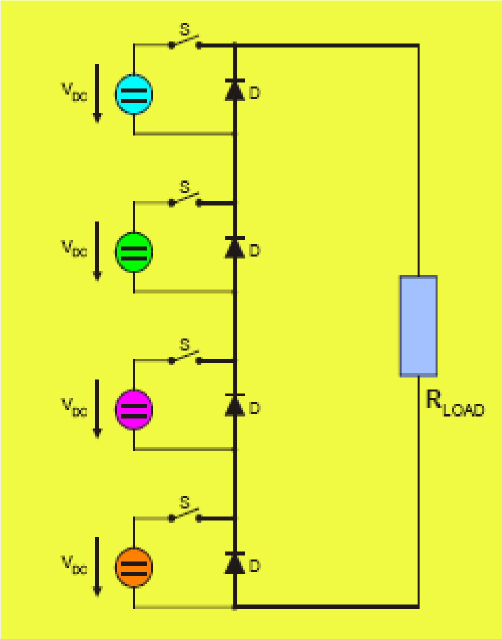
Prototype #1 (Imtech-Vonk)

- Bouncer Type
  - Specified by DESY
  - 12kV HVPS
  - Bouncer 300uH/4.6kA
- 7 stage IGCT main switch
- Digital regulation circuit
- Analog inputs/outputs
- Well known and tested principle



Prototype #2 (Thales)

- Pulse Step Modulator
  - 24, ~ 0.5 kV, Marx-like cells are summed to drive a 12:1 transformer
  - Bouncer circuit eliminated
  - FPGA based control
  - 2 stages for redundancy
  - Pulse width modulation for fine control
- Slew rate and pulse shape controllable
- Concept used in PS's Thales built for the W7-X experimental fusion reactor



Klystrons

Baseline: 10 MW Multi-Beam Klystrons (MBKs) with ~ 65% Efficiency: Being Developed by Three Tube Companies in Collaboration with DESY

Thales

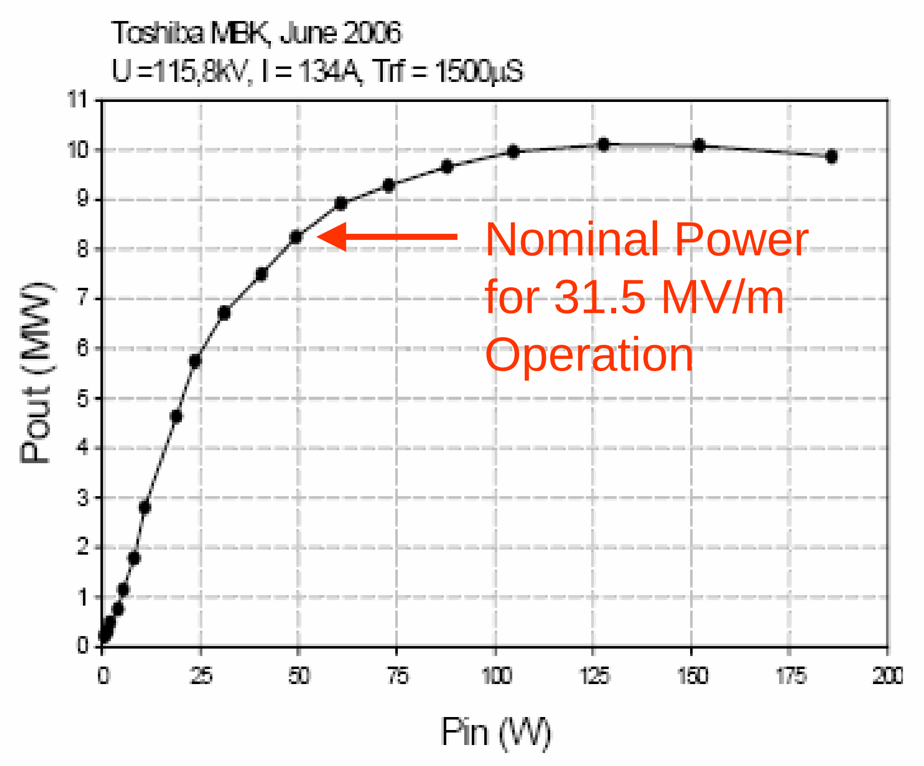
CPI

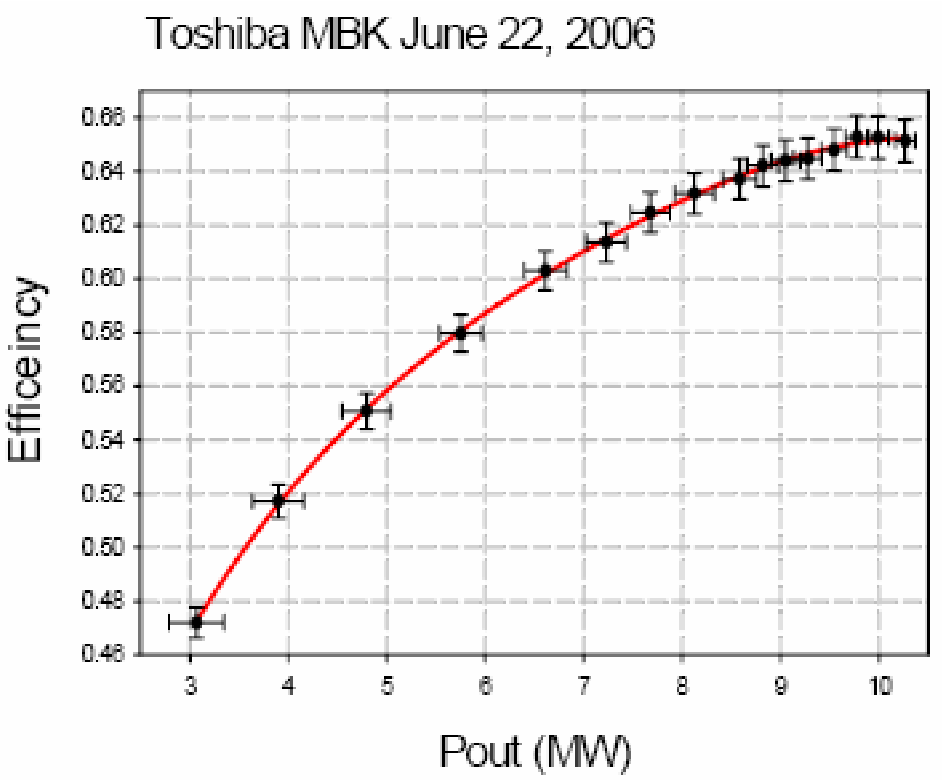
Toshiba

2006 Test of Toshiba MBK

- June 8: Start installation
- June 14: Adjust filament setting
- June 16: Modify tube socket
- June 19: Run at 115kV, 134 A, 1.7mS, 10 Hz
- June 20: Achieve 10 MW, 1.5 ms rf pulses at 10 Hz (150 kW average output power)
- July 4-5: Test for 24 hours
- October 12: Removed from test stand
- Total time of operation on the test stand = 750 hours, 80 % at full power

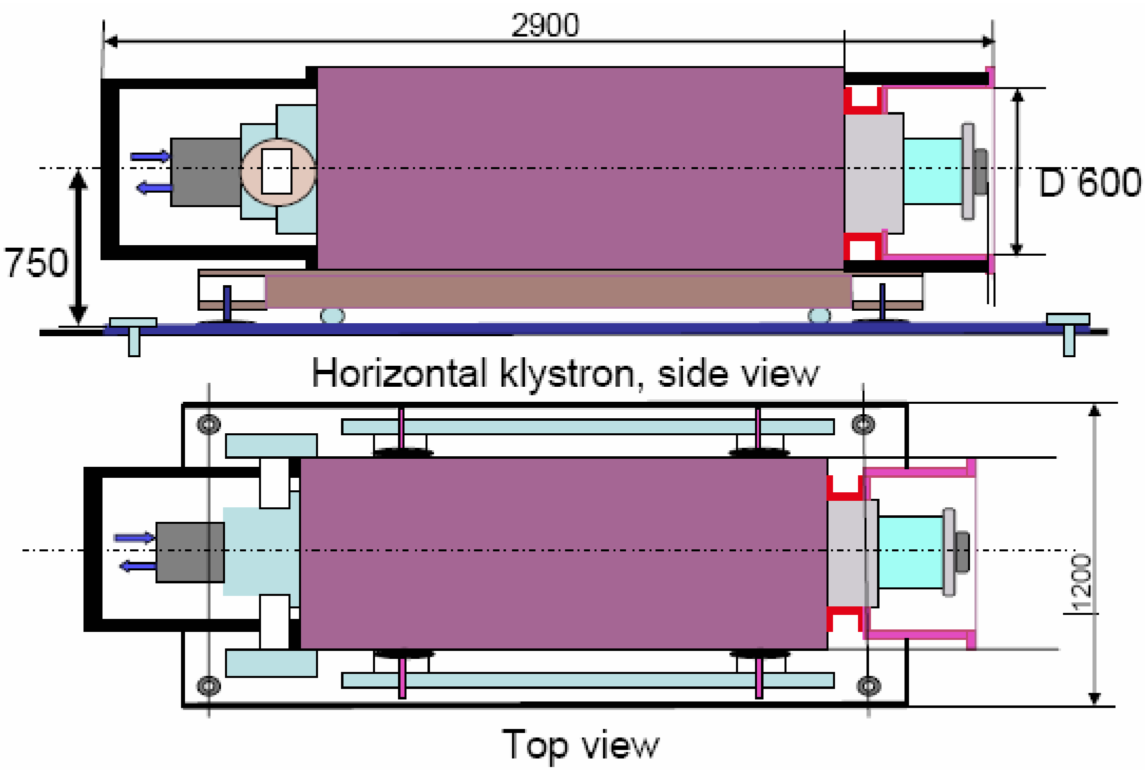
Toshiba MBK Test Data

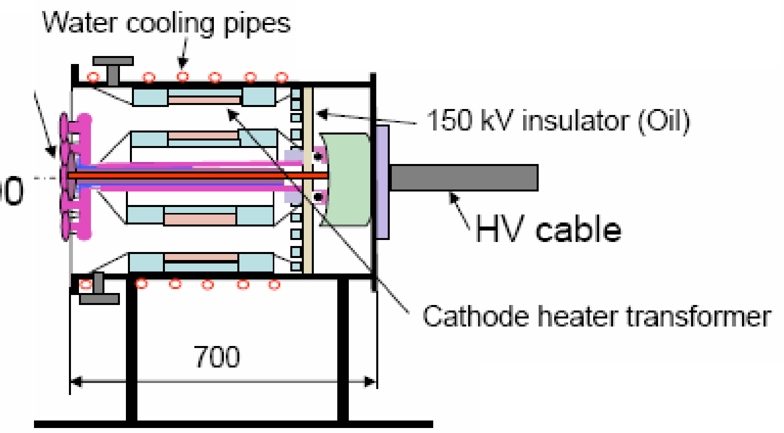




Horizontal MBK for XFEL

Expect the first horizontal MBK in 03/08. DESY is currently working with three companies to design the klystron interface to the transformer tank

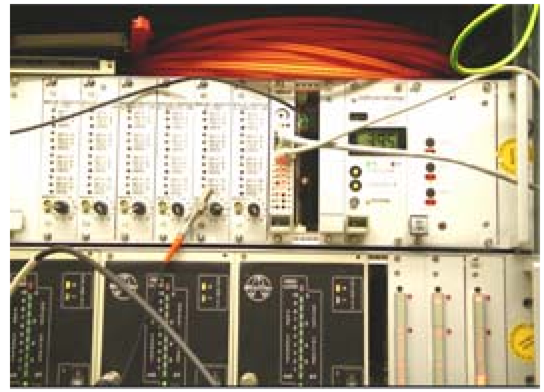


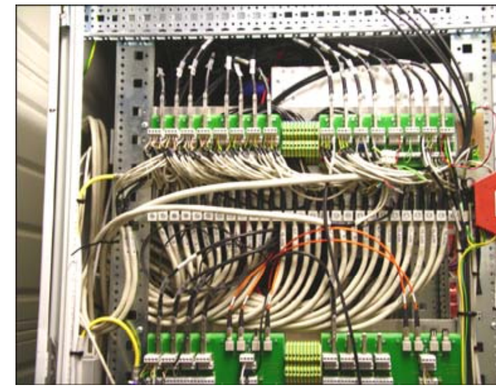


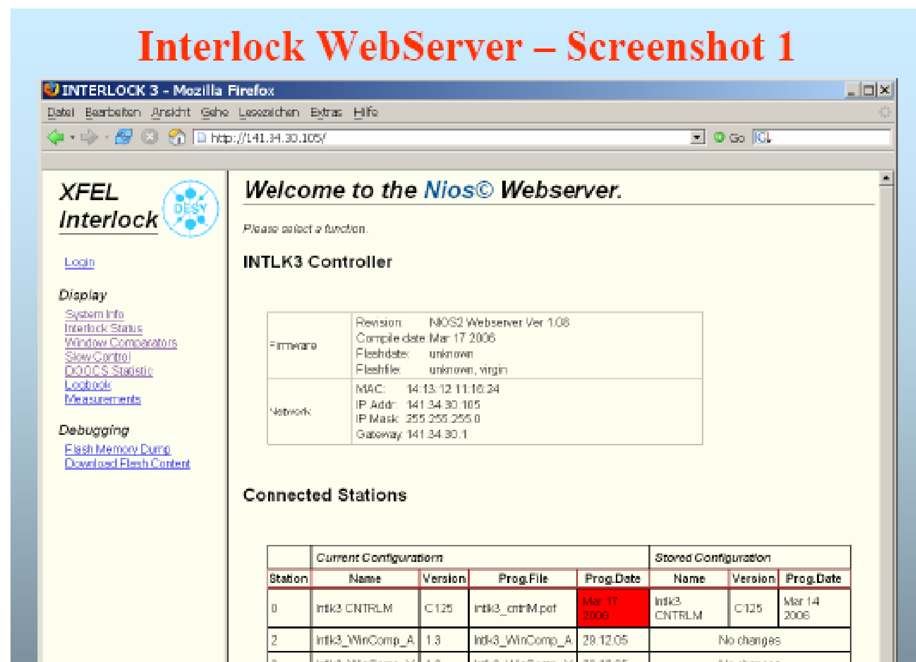
Vladimir Vogel

RF Interlocks for XFEL

- Zeuthen / HH development
- FPGA Based
- Version #2 installed at FLASH
- Version #3 installed at PITZ and module test facility, will also be tested at FLASH
- Version #3 allows remote controlled setting of interlocks

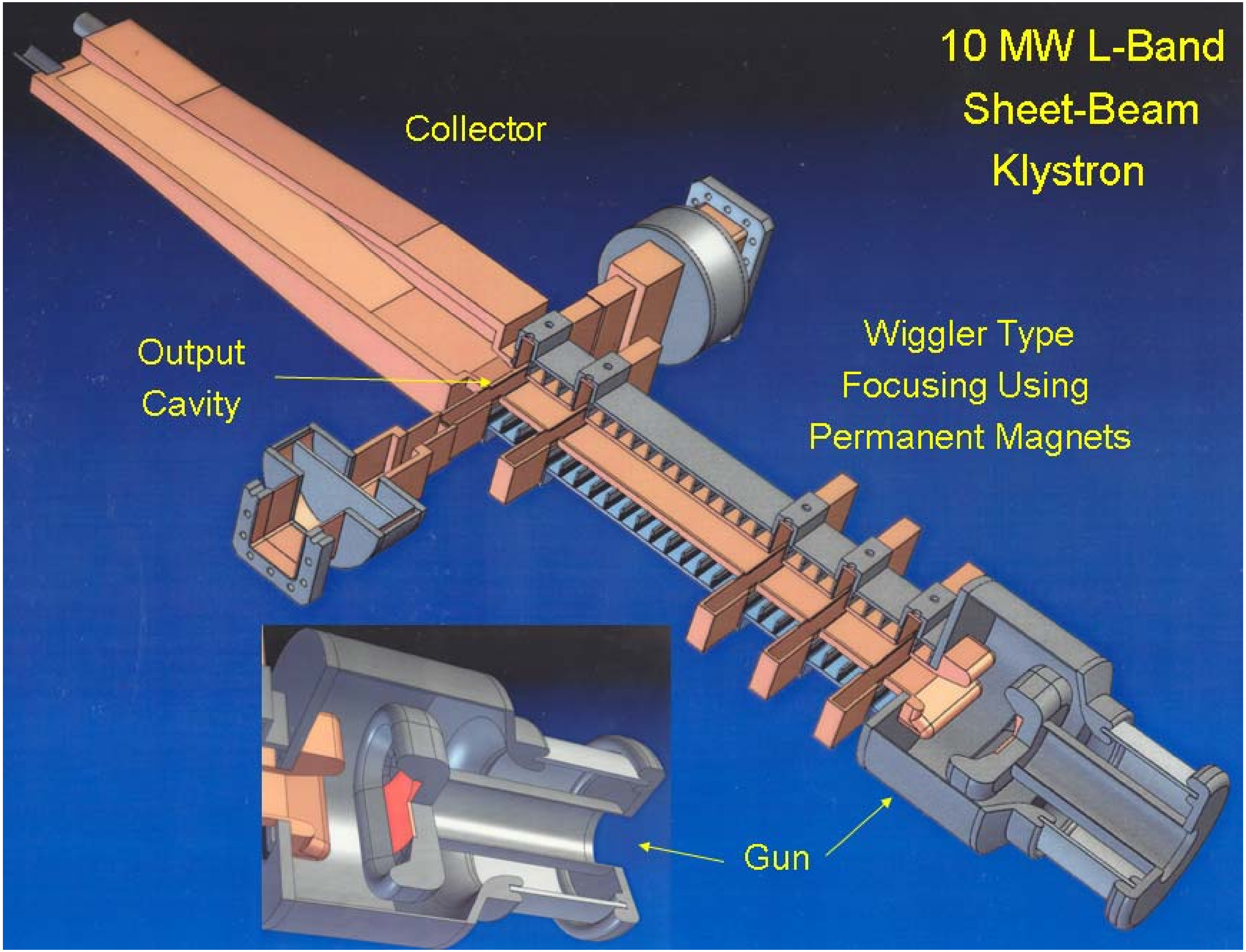






XFEL Klystron Program

- New Thales tube (SN5) with modifications will arrive 02/07 for test.
- Preparing for horizontal MBK test using existing (ABB) pulse transformer.
- Test HV cable connection.
- Continue investigation of phase, output power and perveance stability of MBK.
- Study breakdown rate of rf components and klystron windows as a function of waveguide pressure.
- Develop fast klystron protection against RF breakdown.

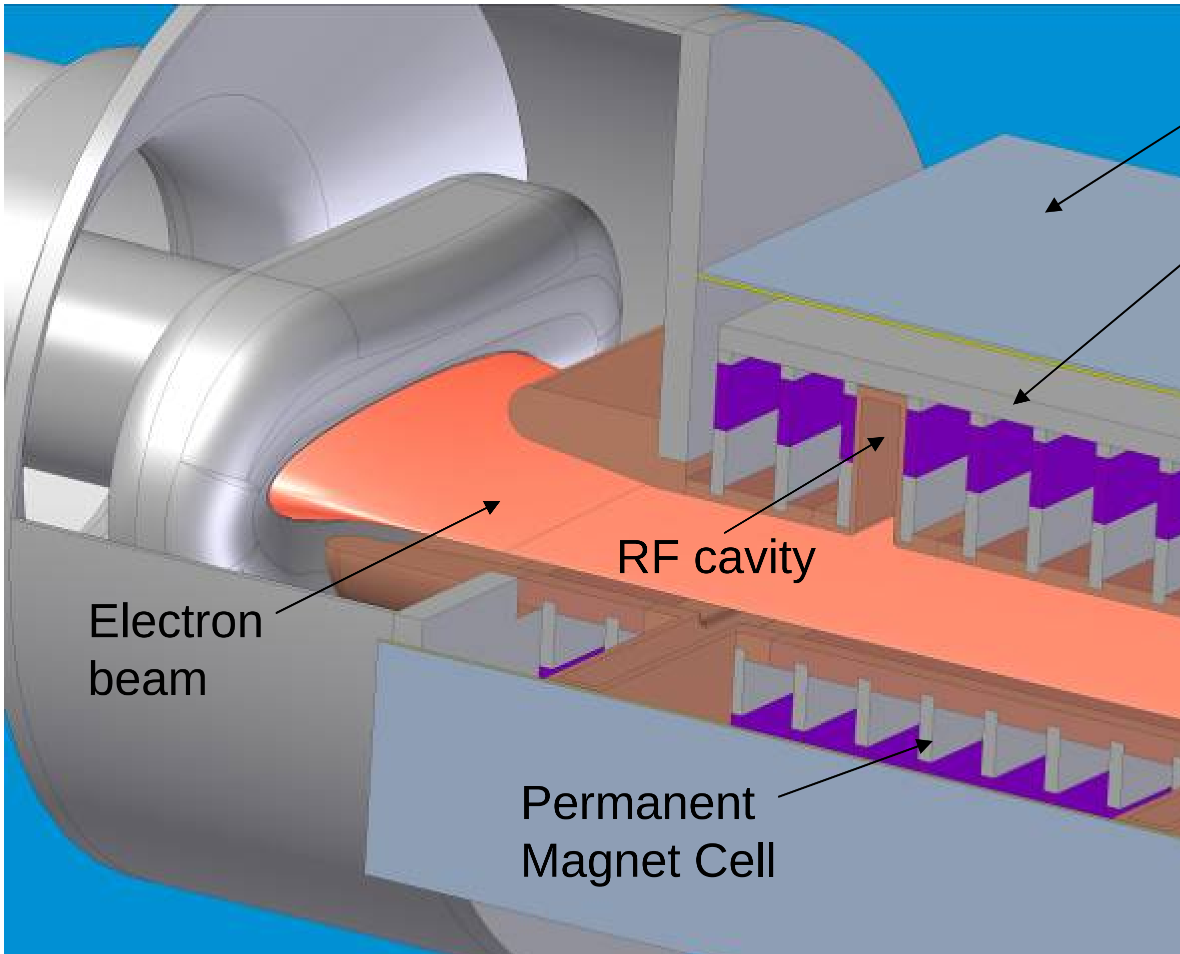

10 MW L-Band
Sheet-Beam
Klystron
Collector
Output
Cavity
Wiggler Type
Focusing Using
Permanent Magnets
Gun

SBK Design Organization

- Erik Jongewaard (Program Manager/ME)
  - Magnet structure and RF circuit/drift tunnel design
- Daryl Sprehn (Chief EE)
  - Magic and AJdisk RF sims, 3D RF sims, egun sims
- Andy Haase (ME)
  - Couplers, Window and beam diagnostics design
- Rich Schumacher (ME)
  - Anode and device interface (supports, tank, etc.) design
- David Martin (ME)
  - Global design coord, egun and collector design
- Alex Burke (EE)
  - Michelle egun sims, Magnet magnetics sims
- Aaron Jensen (EE)
  - FLUKA beam interaction sims, 3D RF sims

Beam Transport and RF

The elliptical beam is focused in a periodic permanent magnet stack that is interspersed with rf cavities

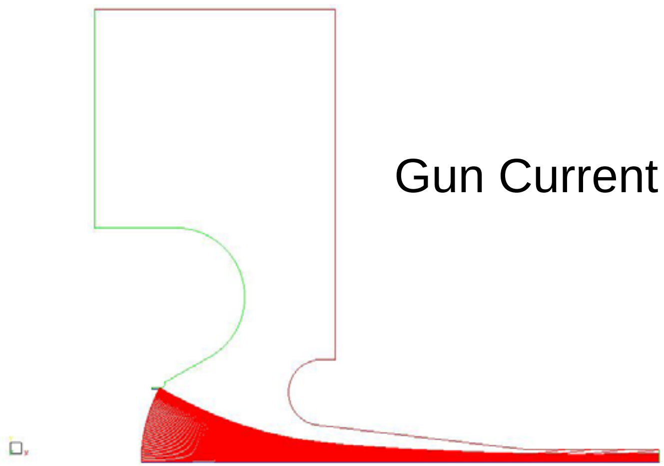


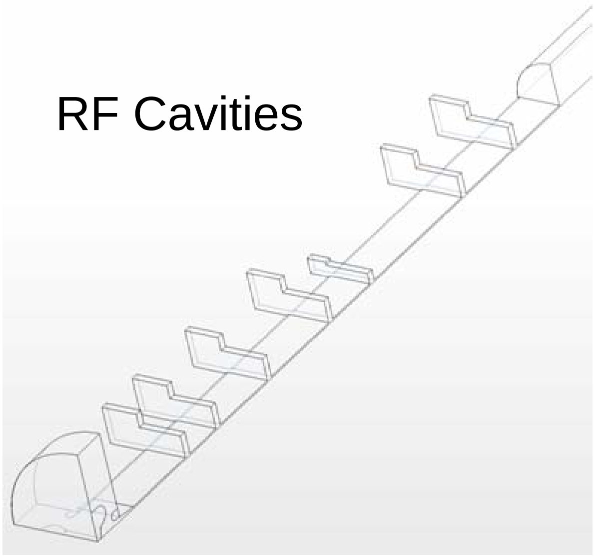
Have done:

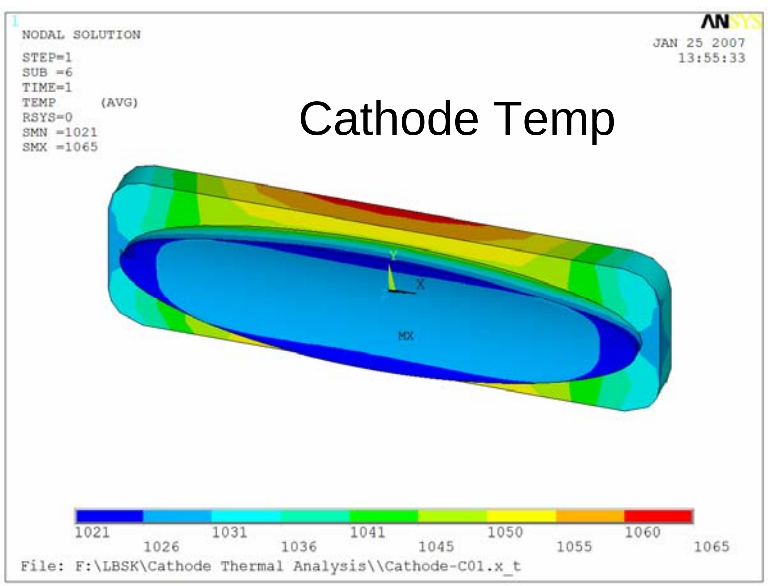
3D Gun simulations of a 130 A, 40:1 aspect ratio elliptical beam traversing 30 period structures.

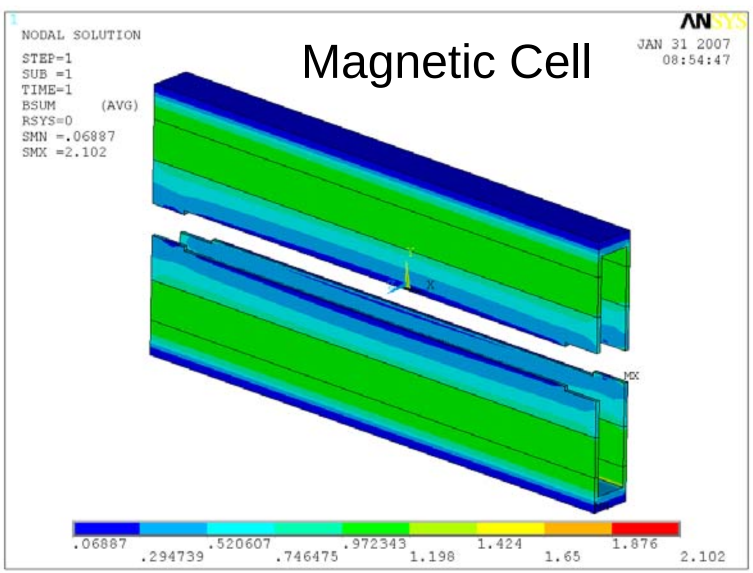
3D PIC Code simulations of rf interaction with the beam.

SBK Simulations





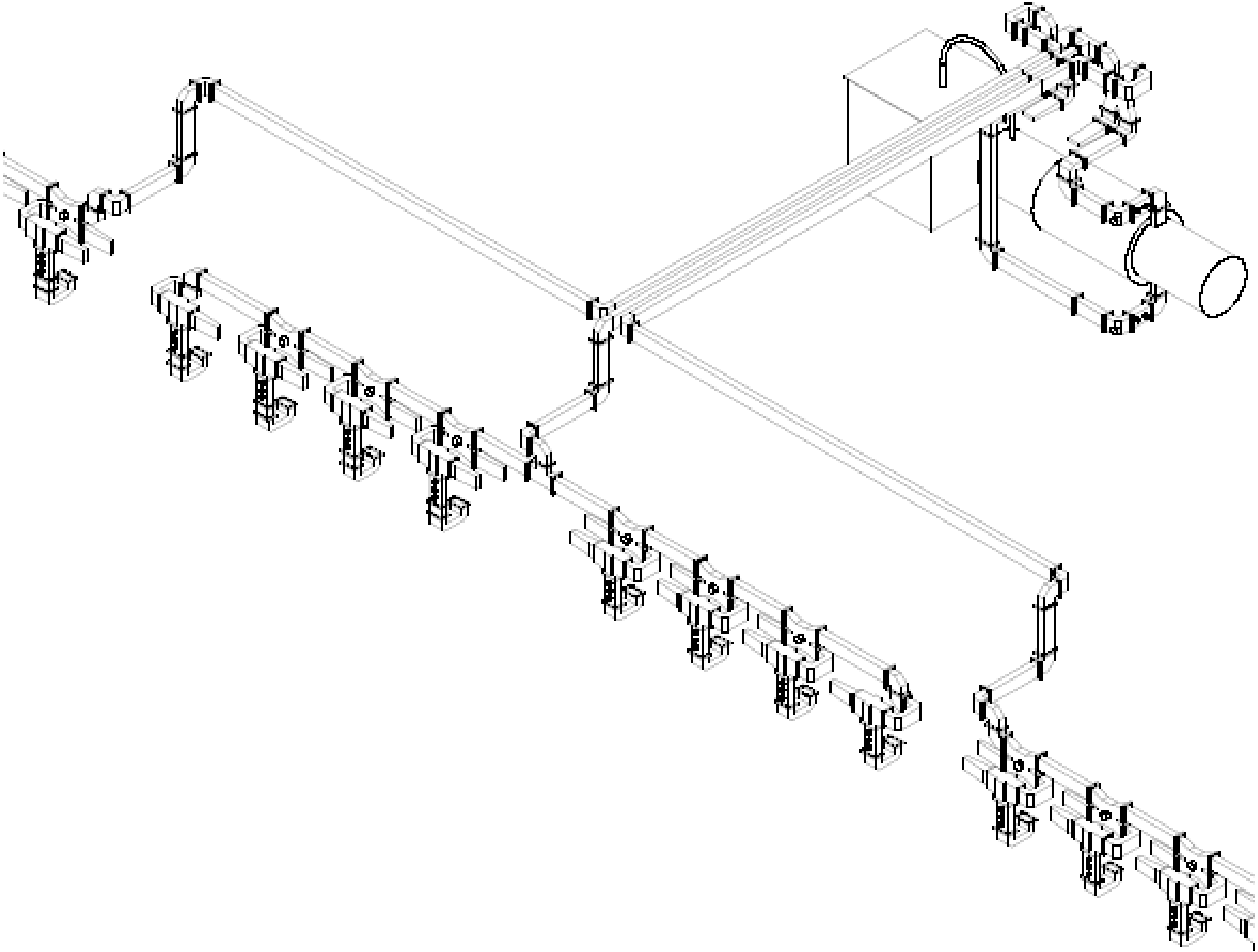




Sheet Beam Program

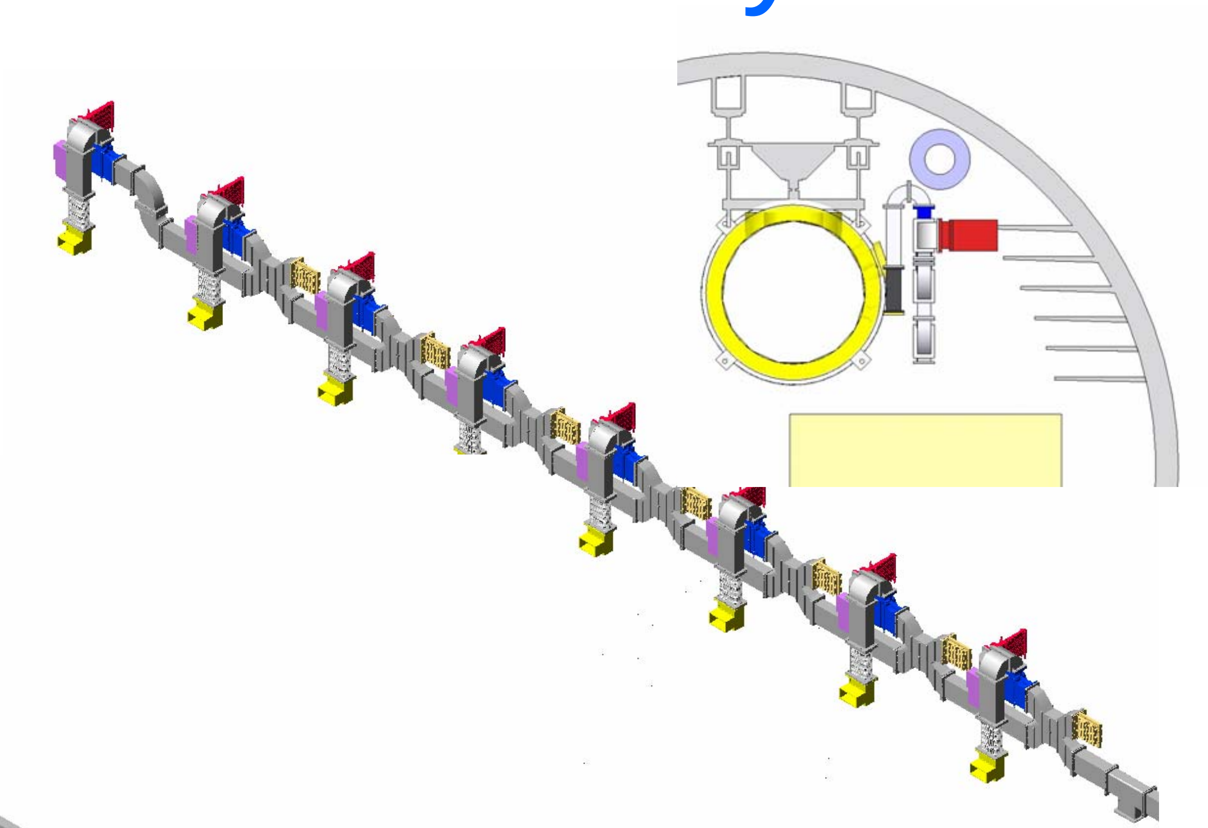
- Build beam tester and klystron by Summer 2008
- The beam tester will validate 3-D beam transport simulations and allow a more rapid turnaround for electron gun changes
- The klystron will be developed in parallel with little feedback from the beam tester. A rebuild of the klystron can incorporate design changes motivated by the beam tester

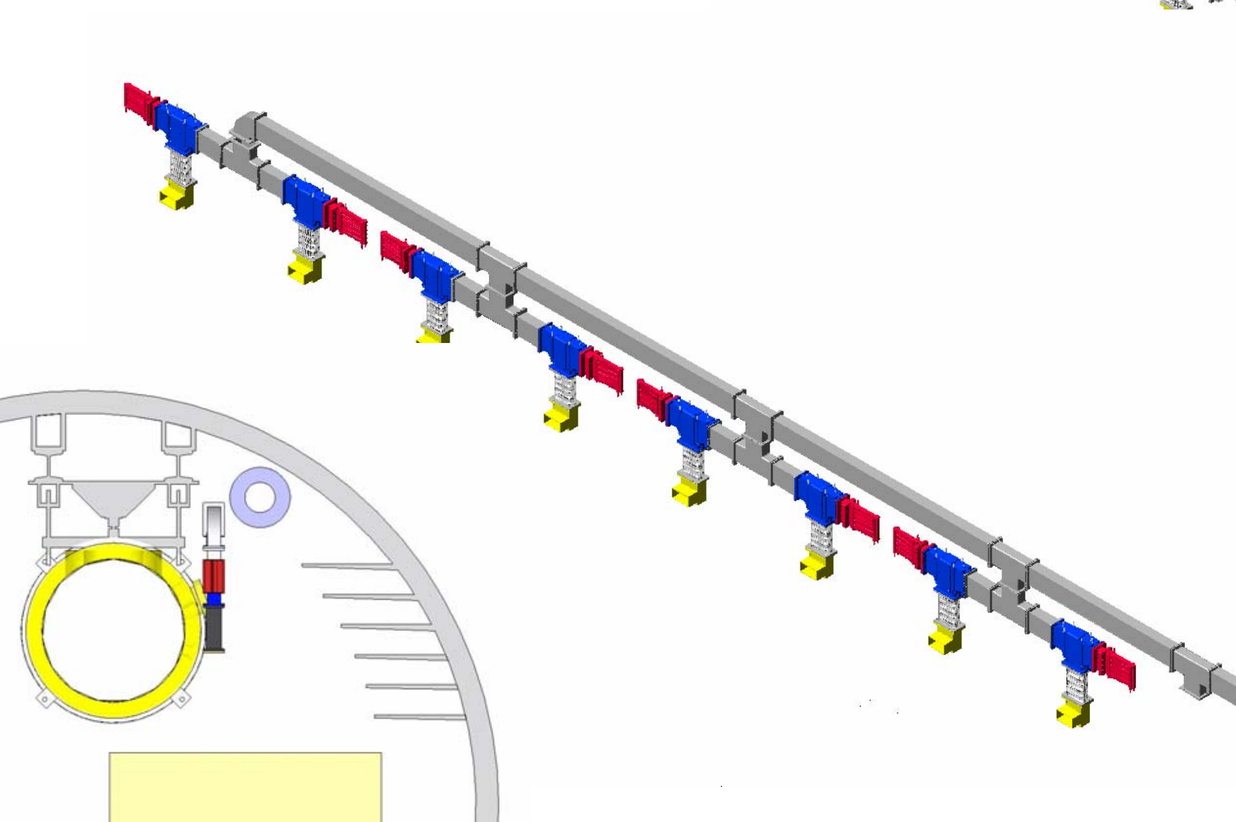
RF Distribution Development



XFEL RF Distribution System

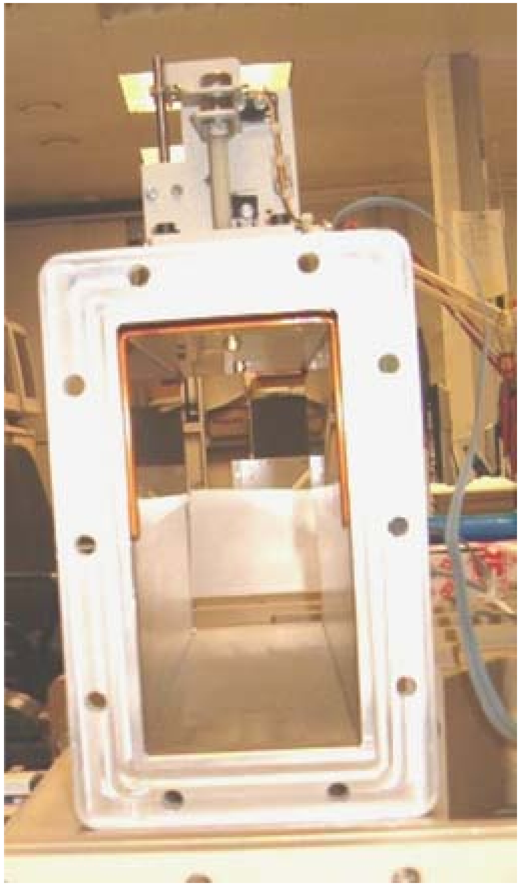
Switched from a TTF-Like (3D) System





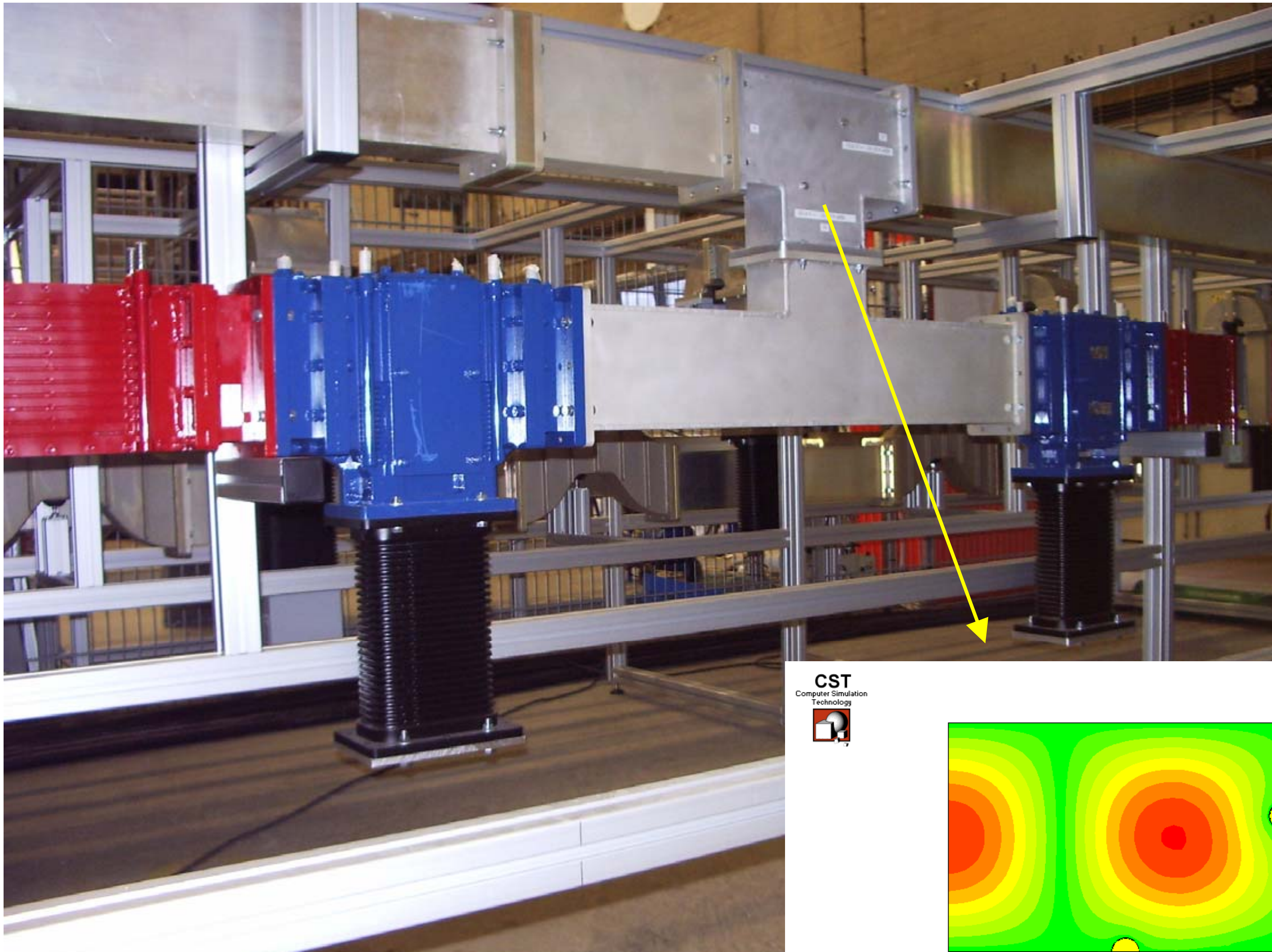
To a Tree-Like (2D) System

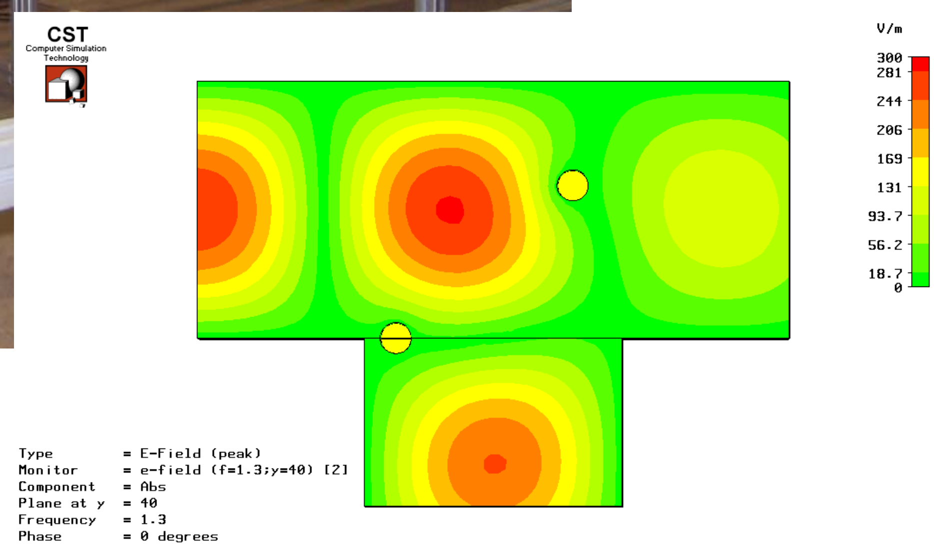
Replaced 3-Stub Tuner with Phase Shifter



V. Katalev

Feed Cavities In Pairs



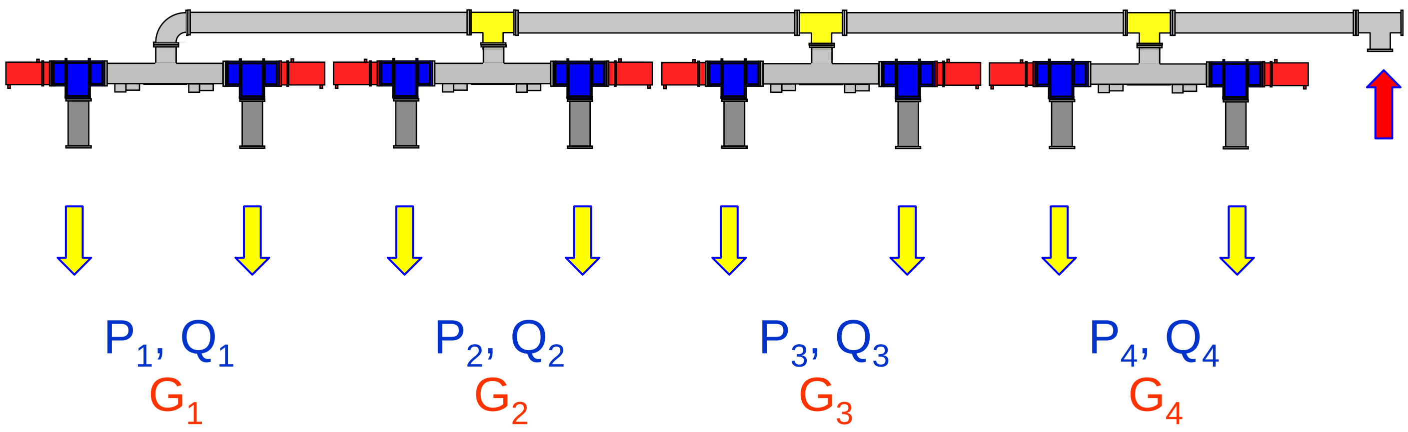


HELMHOLTZ | GEMEINSCHAFT DESY

V. Katalev

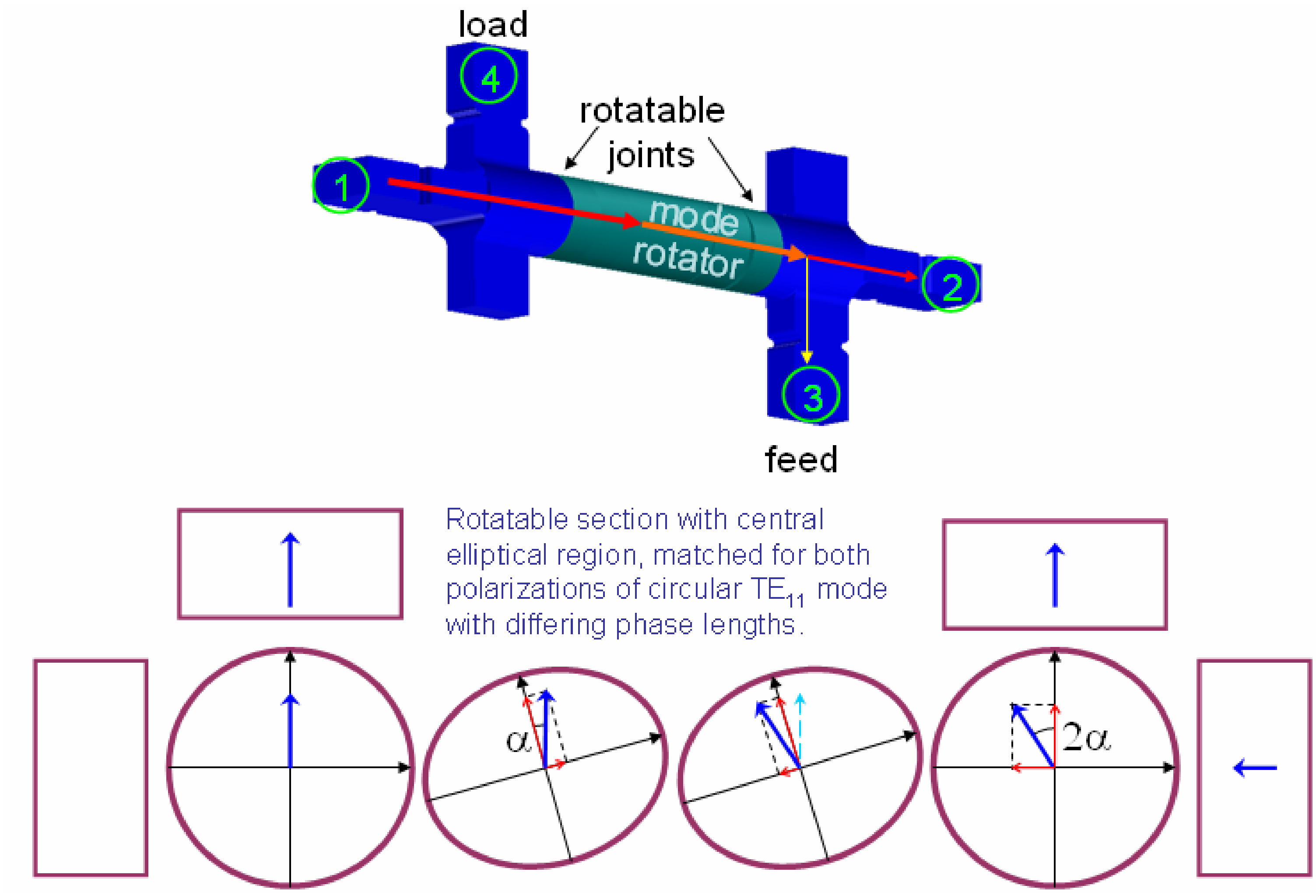
Adjustability

With customizable (2 post) asymmetric shunt tees, have a tunable waveguide system that eliminates the "weak cavity" limit in the cryomodules



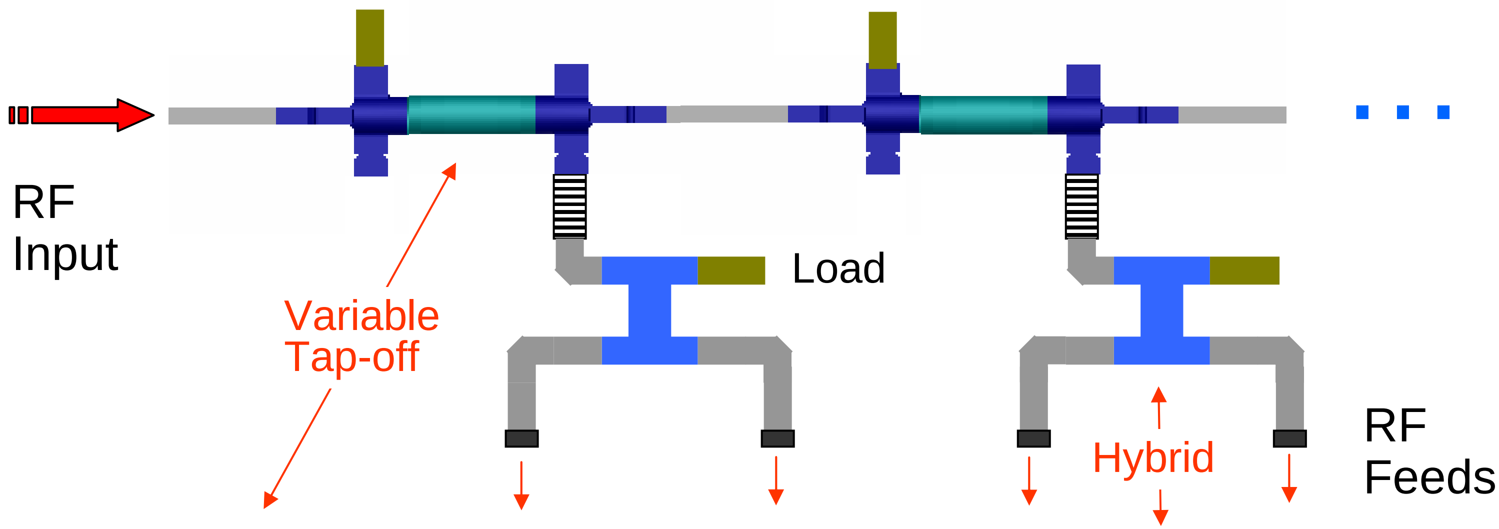
Adjust Input Power (P) and Cavity External Q to optimize for Gradient (G)

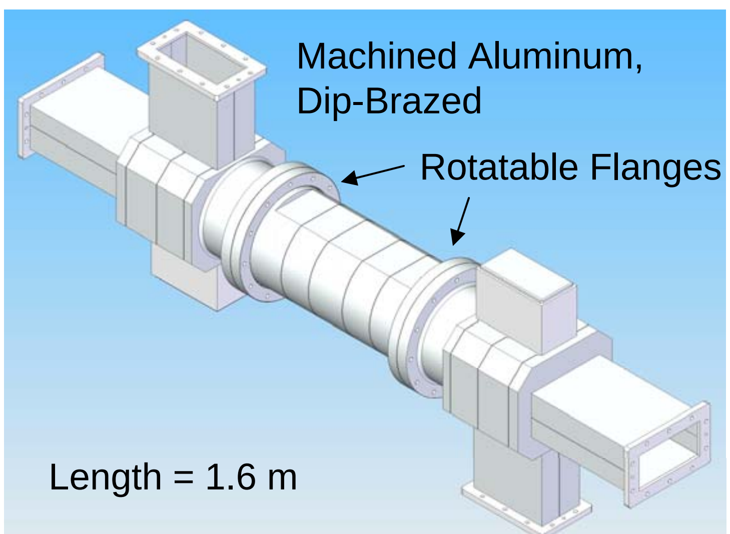
At SLAC, Developing Variable Tap-Offs Using Mode Rotation

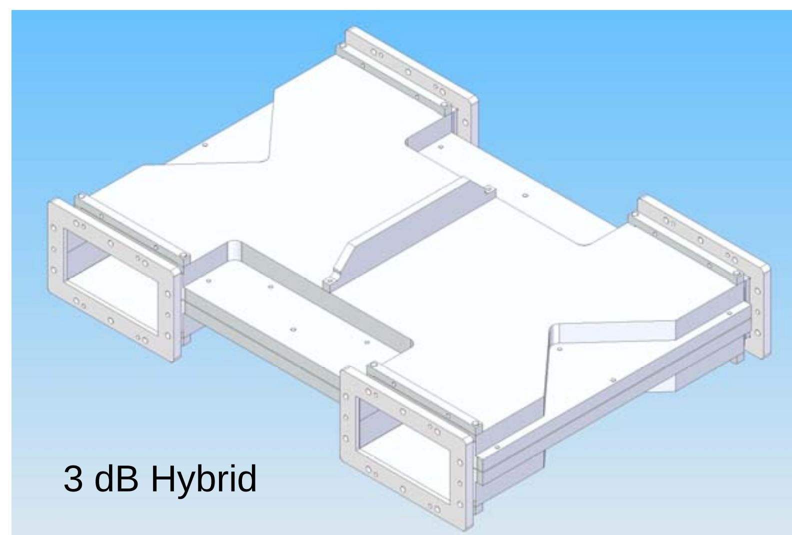


C. Nantista

RF Distribution System without Circulators and with Variable Tap-offs







Linac Operation with Variable Tap-Offs (VTOs) and Large Gradient Spread

- Assume cavities produced with flat distribution of sustainable gradients (G) from 22 MV/m to 34 MV/m with <G> = 28 MV/m
- With Qeo optimized for Go = <G>, achieve flat cavity field at G with
  - $Qe = Qeo * \ln(2) / \ln(1 + G/Go * Qeo/Qe)$
  - $\text{Input Power} = Po * (1/4) * (1 + G/Go * Qeo/Qe)^2 * (Qe/Qeo)$
- Requires 6.8% more power on average per rf unit
- Maintain rf unit layout but increase linac length by 31.5/28 -1 = 12.5%
- At 31 MV/m, which is a +3-sigma variation in the mean gradient of a half rf unit, have same 16% tuning overhead as present design at 33 MV/m.
- Considering all changes, ILC cost increases by about 7%

RF Source Summary

- XFEL considering new modulator design and have revamped their rf distribution system to be more compact and adjustable.
- Toshiba 10 MW MBK appears robust in tests so far – horizontal versions being developed.
- SLAC is in design phase to build a sheet beam klystron, which should be more compact, lighter and less expensive than the MBK
- SLAC is well along on Marx development – see next talk