HIGH-POWER TEST RESULTS OF A 10 MW, HIGH EFFICIENCY, L-BAND MULTIPLE BEAM KLYSTRON

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Application

- RF source for particle accelerators
- European X-ray Free Electron Laser (XFEL)
  - 10-20 GeV (electrons), X-ray laser wavelength from 0.085 to 6 nm
  - 2.1 km long accelerator tunnel
  - Approx. 3.4 km long facility at the DESY site in Hamburg
  - Horizontal prototype ordered by DESY for the XFEL
- International Linear Collider (ILC)
  - A proposed linear particle accelerator
  - 200-500 GeV center of mass collision energy (electrons – positrons)
  - Possible later upgrade to 1000 GeV
  - Klystron meets the GDE's ILC baseline design

Program Goals

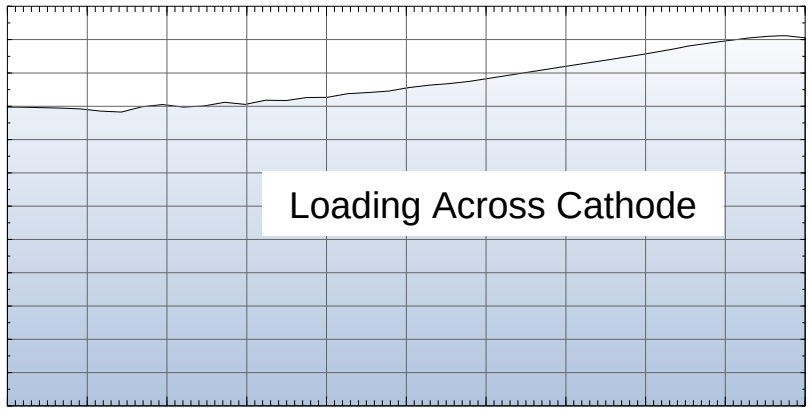
- Design and manufacture a Multi-Beam Klystron Amplifier (VKL-8301B)
  - 10 MW (peak), 150 kW (average)
  - 1.3 GHz fixed tuned
  - ≥ 65% Efficiency
  - 1.5 ms RF Pulse, 1.7 ms Video, 10 Hz rep. rate
  - ≥3 MHz -1dB Bandwidth
  - ≤120 kV Beam Voltage
  - Electromagnetic Focusing
  - Coaxial RF Input, Waveguide RF Output
  - Water-Cooled
  - "Industrial" version: Horizontally oriented, on a cart/support frame, featuring alignment capabilities and integrated X-ray shielding

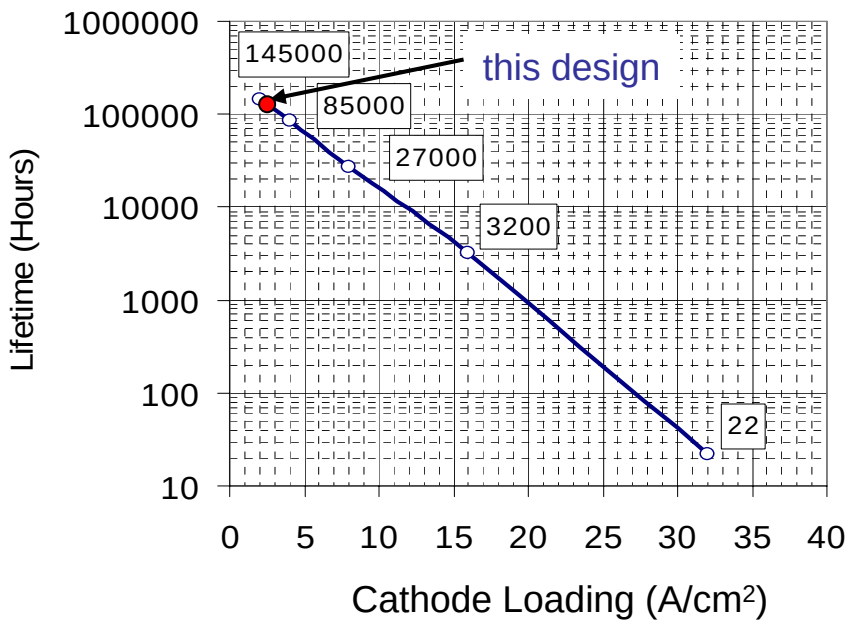
Basic Design Approach

- Second generation MBK: horizontal and smaller major diameter for cost effectiveness
- Seven coaxial TM_{010} cavities with external tunability (except for 2nd harmonic and output cavity)
- Six beams, confined flow focused
- 3.42 $\mu A/V^{1.5}$ overall perveance (low operating voltage)
- Maintain off-axis cathodes with large diameters for low current density loading and long cathode life
- Single collector with low pressure drop
- Small diameter solenoid with carefully balanced individual coils for low off-axis transverse magnetic field

Electron Gun

- *M-type dispenser cathode*
- *Off-axis beams for larger cathode diameter*
- *Low current density loading achieved*
  - ⇨ *2.2 A/cm²*
  - ⇨ *>100,000 hours of heater life projected*
- *Low max voltage gradient of 60 kV/cm*
- *Confined flow focusing*
- *Low beam scalloping for 100 to 120 kV operation*





(Source: L.Falce)

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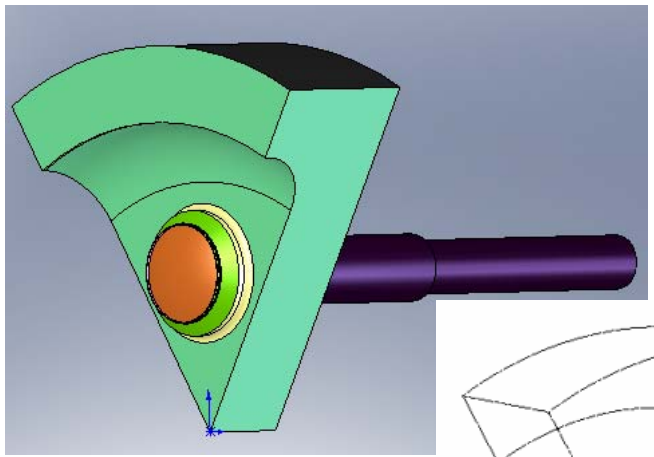
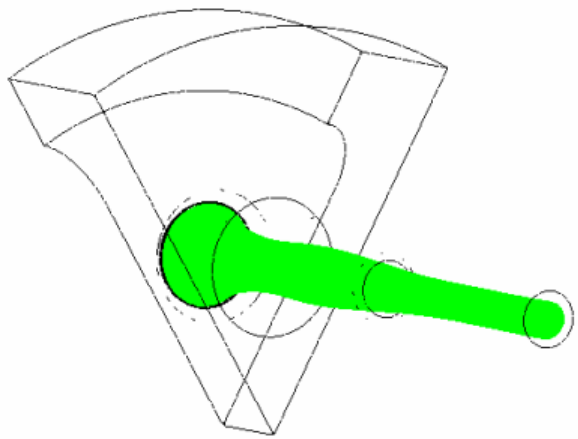
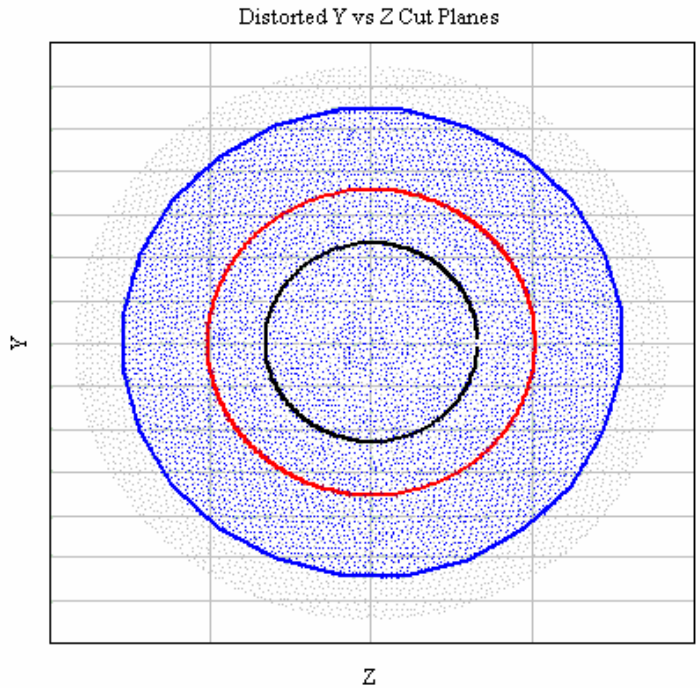
Focusing and Beam Transport

- 2D initial design in CPI code XGUN
- 3D MagNet and MICHELLE (NRL/SAIC) runs for final optics
  - transverse field effects
    - scallop and corkscrew
    - beam drift from cathode centerline





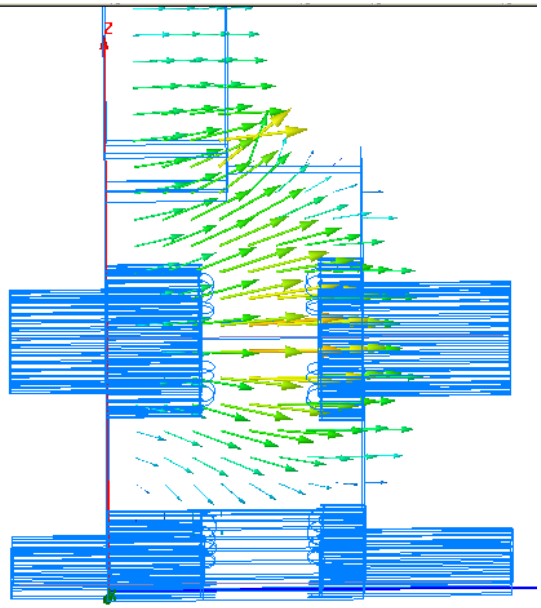
1/6th model
E_b = 115 kV
I_b = 22.2 A (per beam)

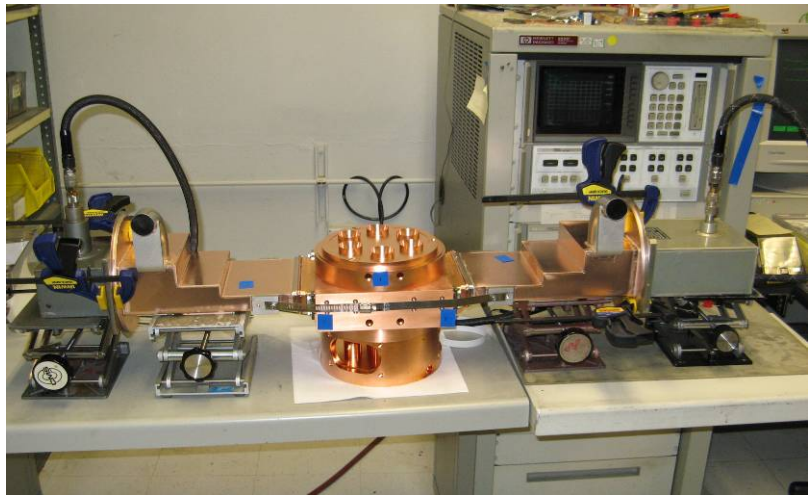


- Collector Power densities (MICHELLE-simulated) well within safe limits

RF Cavities

Electric Field in Output Cavity





- TM_{01} coaxial cavities
- Diaphragm tunable
- Integral water cooling

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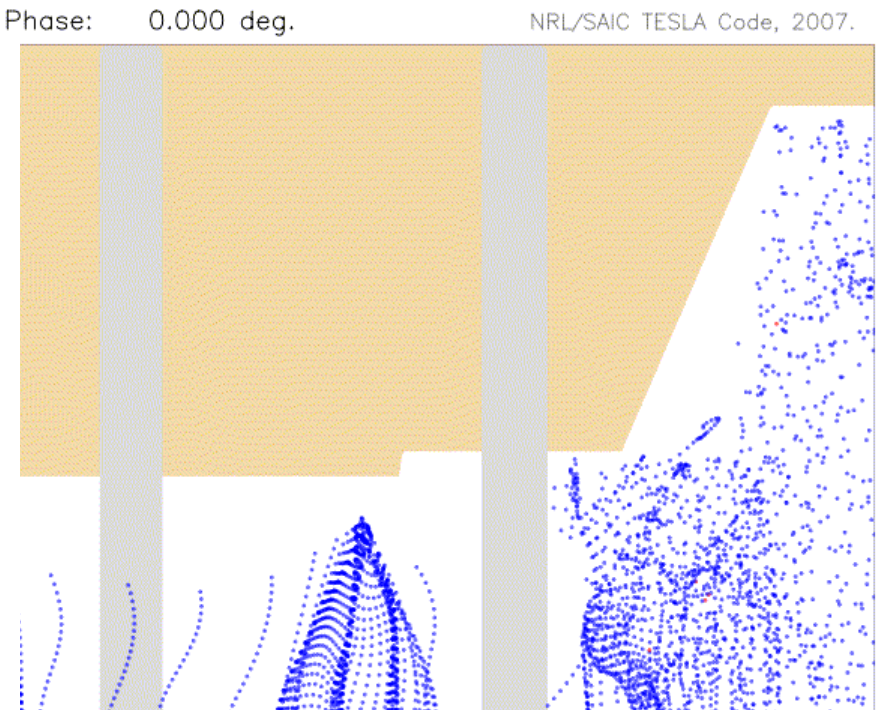
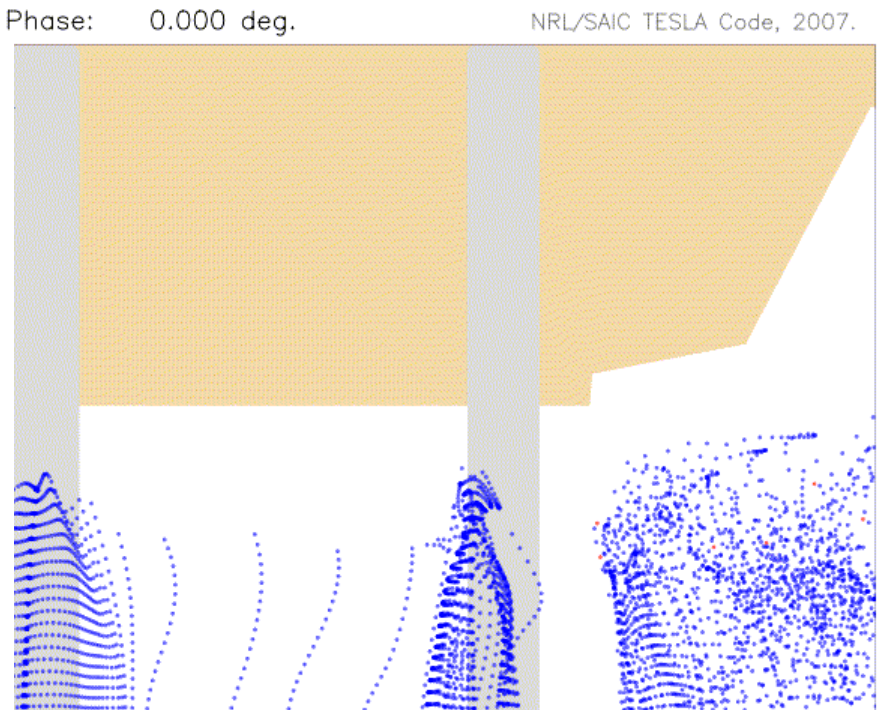
Large-Signal RF Design

- Challenge is high efficiency, high gain and stability under various operating conditions
  - matched load
  - 1.2:1 mismatch any phase
  - reduced power operation
- Use SNS klystron (VKP-8291A) as guideline
  - 550 to 700 kW at 805 MHz
  - consistently achieves over 65% efficiency stably
  - over 100 manufactured
- Utilize TESLA to investigate 2D effects
  - optimize 7-cavity design for efficiency, interception, stability
  - compare to known SNS example

VKP-8291A

Comparison with SNS





TESLA, trajectories:

VKL-8301B: 71.3% efficiency,

VKP-8291A: 71.1% efficiency

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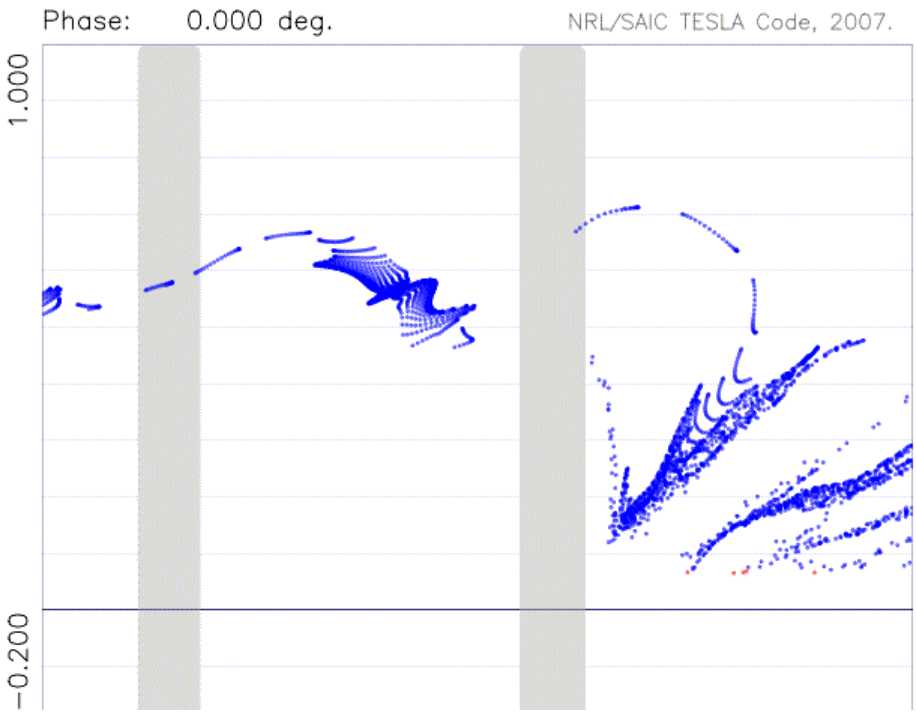
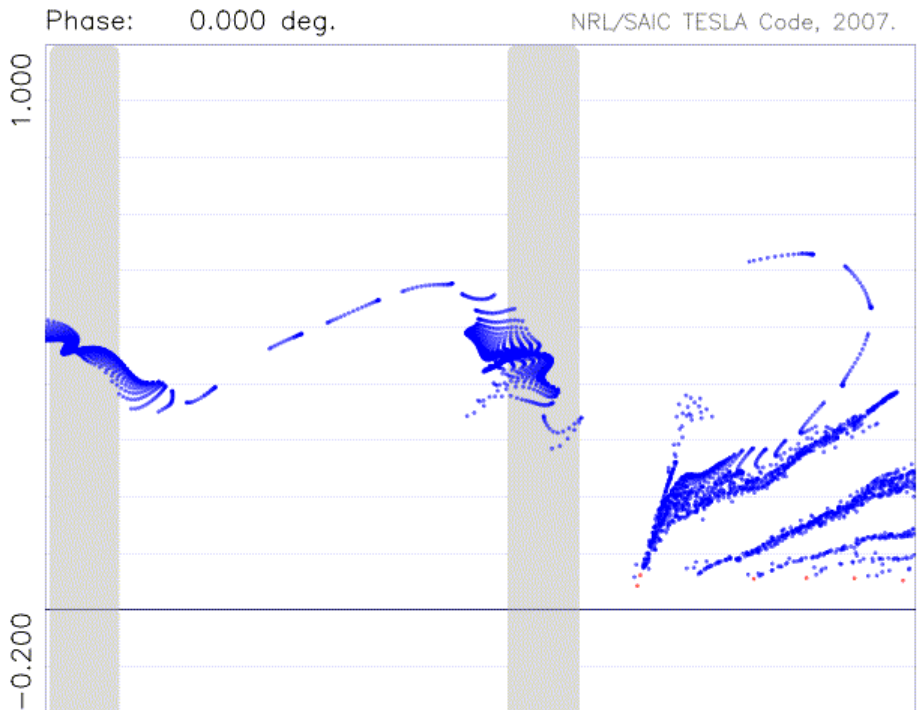
Comparison with SNS





TESLA, velocity:

VKL-8301B: 71.3% efficiency,

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VKL-8301B MBK Prototype

Klystron after exhaust

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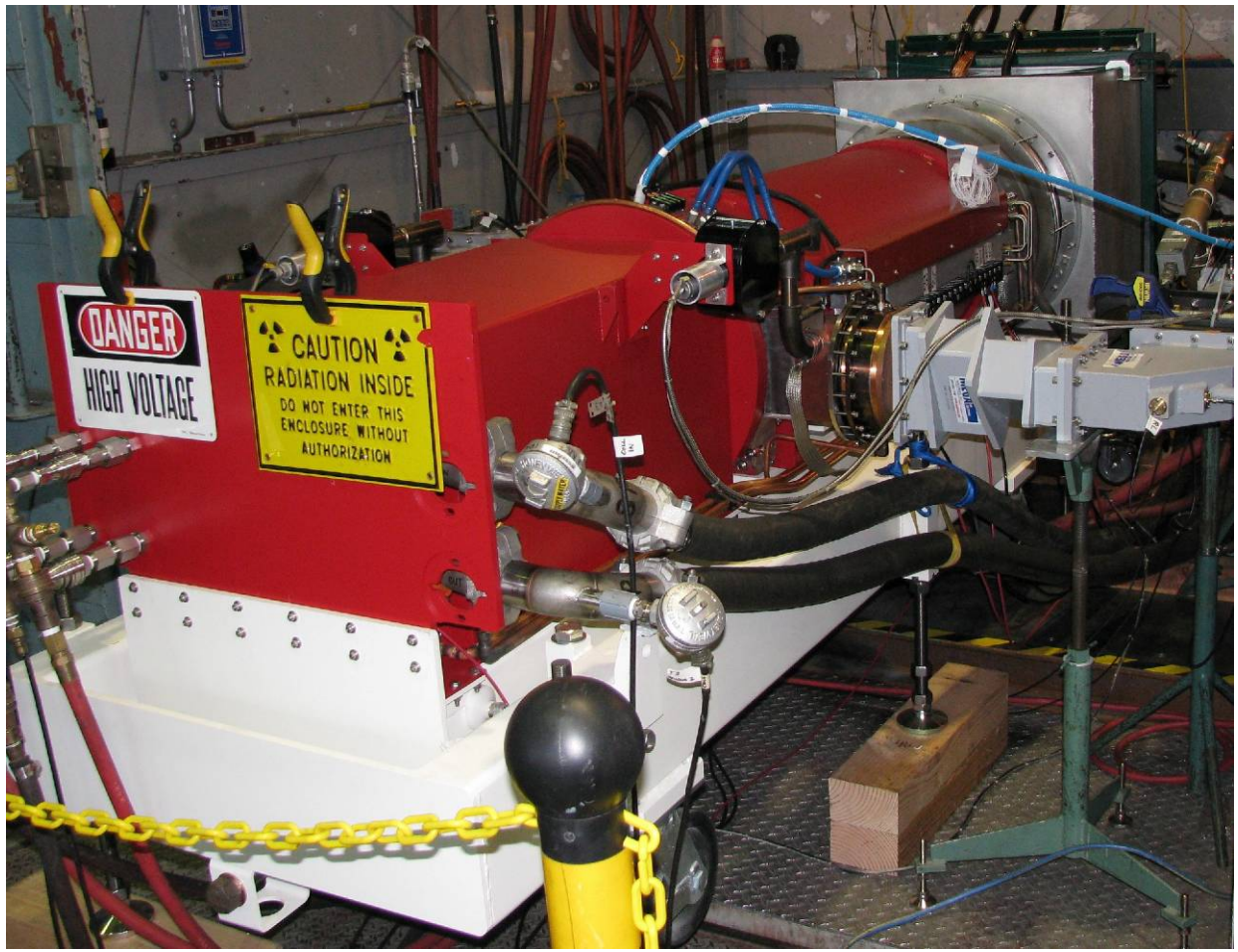
Test

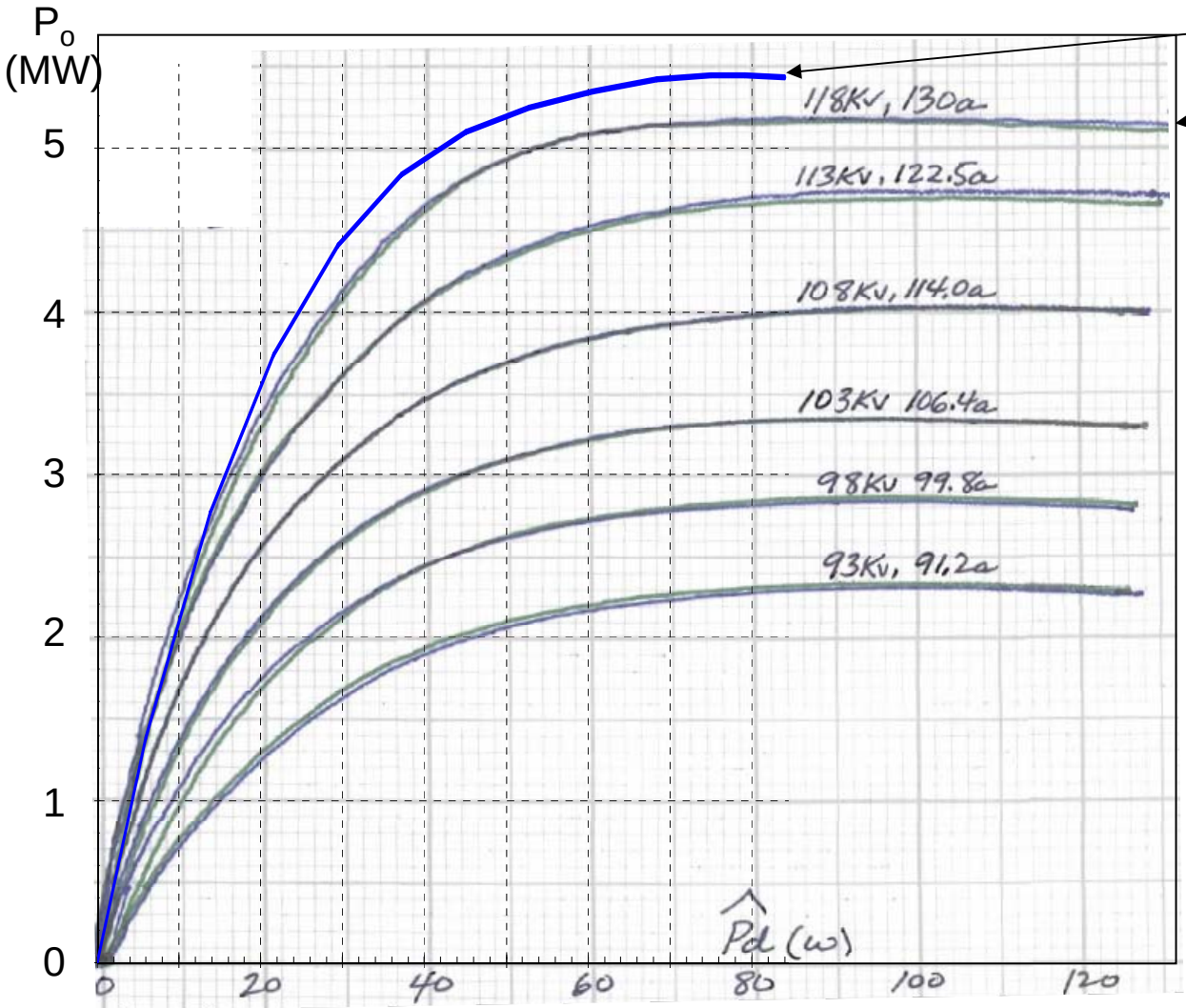
Klystron in vertical and horizontal test



Test Results Summary

Parameter	Design	Actual	Units
Peak Output Power	≥10	10.4	MW
Average Output Power	≥150	156	kW
Beam Voltage	115	118	kV
Beam Current	133	130	A
Efficiency	≥65	67.8	%
Frequency	1300		MHz
-1dB Bandwidth	≥3	5.3	MHz
Gain	>46	50.1	dB
RF Pulse Duration	1.5	1.5	ms
Pulse Repetition Rate	10	10	Hz
Number of Electron Beams	6	6	
Number of Cavities	7	7	
Peak Cathode Loading	2.2	- - -	A/cm²
Solenoid Power	<5500	4736	W

Test Results: Simulated vs. Measured



TESLA*

Measured at various beam voltages (curves for two outputs)

*Approximate prediction (some measured electrical parameters were different from design values used in TESLA)

Transfer Curve

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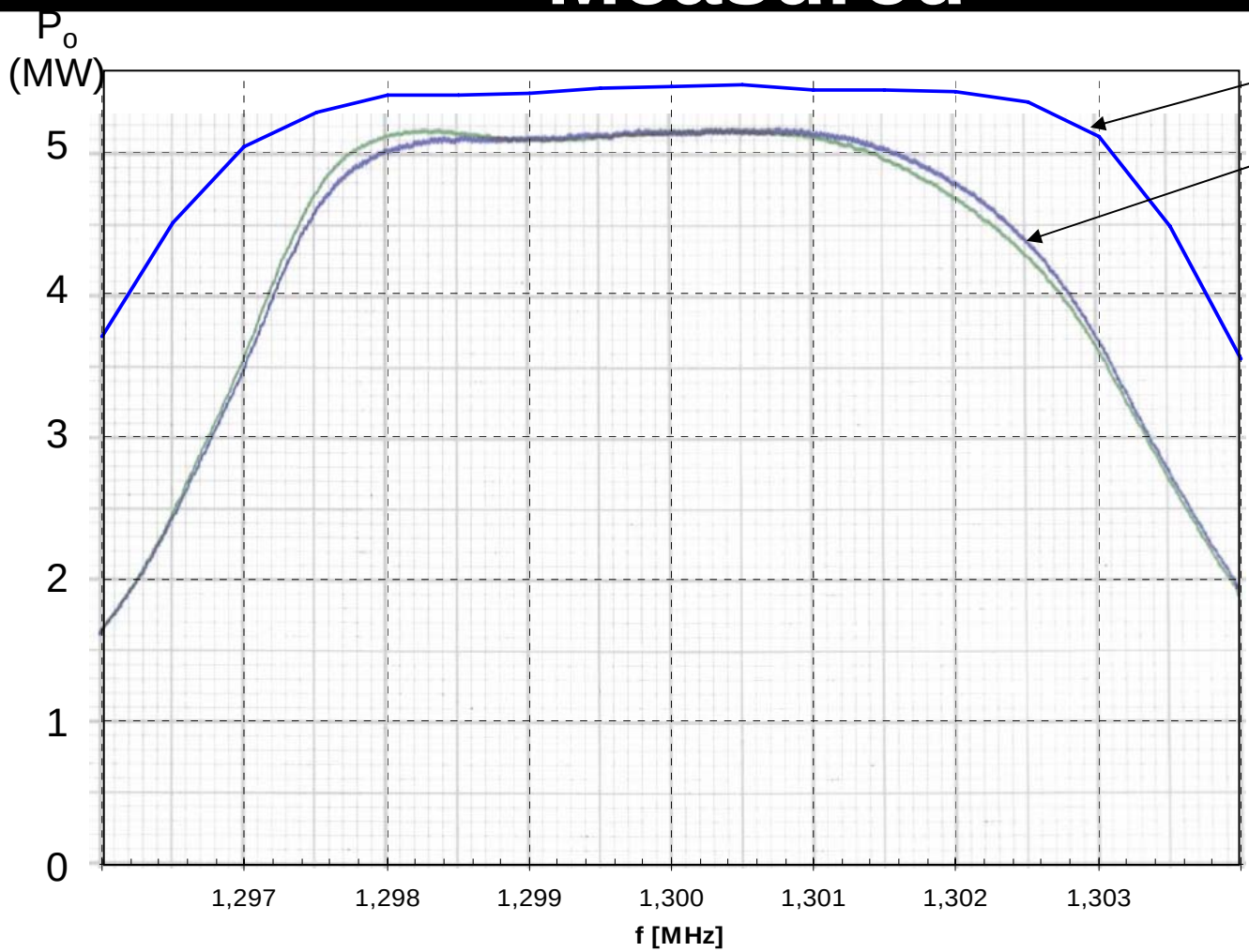
VKL-8301B: TESLA-Simulated vs. Measured



TESLA*

Measured on prototype S/N 002 ("left" and "right" output)

*Approximate prediction (some measured electrical parameters were different from design values used in TESLA)

Bandpass Characteristics

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Conclusions

- Successfully designed and manufactured a 10 MW (peak), 1.5% duty, horizontally oriented L-band multiple beam klystron for the European XFEL that demonstrated
  - >65% efficiency
  - stable operation into a 1.2:1 load (any phase)
  - arc-free heat run (no fault operation)
- DESY engineers have witnessed final testing at CPI
  - klystron is currently being prepared for shipping
- The measured performance of the klystron instills high confidence in the design codes that are available
- The authors thank DESY for their support on this project and thank SLAC for the loan of a high power load for the testing of the device