

HPRF Systems of Electron Linac at TRIUMF

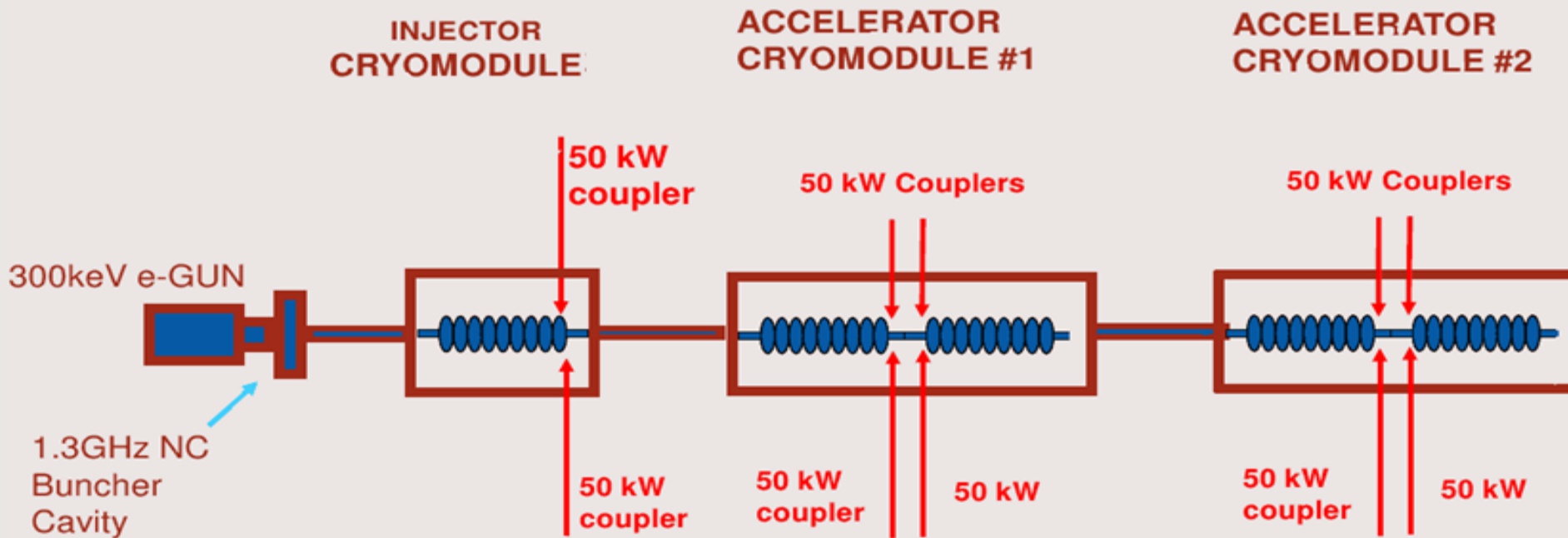
Zheng-ting ANG and RF Group

June 21-24, 2016



- **Introduction**
- **Choosing of Klystron and DC power supply**
- **Variable Power Divider & waveguide components**
- **First 300kW CW klystron tests at Triumf**
- **Waveguide components tests**
- **Commission of E-Linac**
- **Summary**

Introduction (0.5 MW SRF E-Linac at TRIUMF)



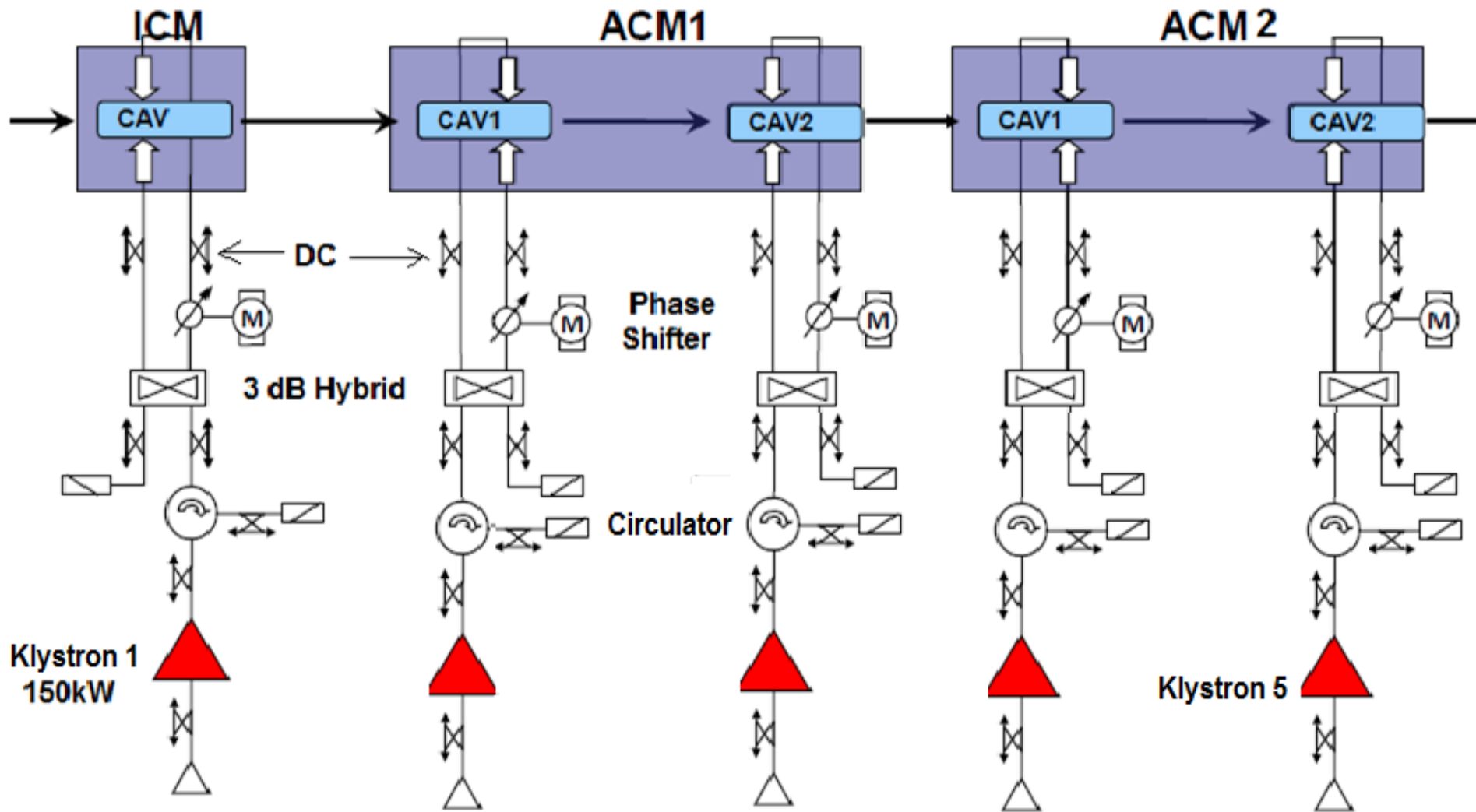
Triumf e-linac based on **1.3 GHz Superconducting RF technology**

(SRF) in **CW operation**, (50 MeV, 10 mA 500 kW rf power);

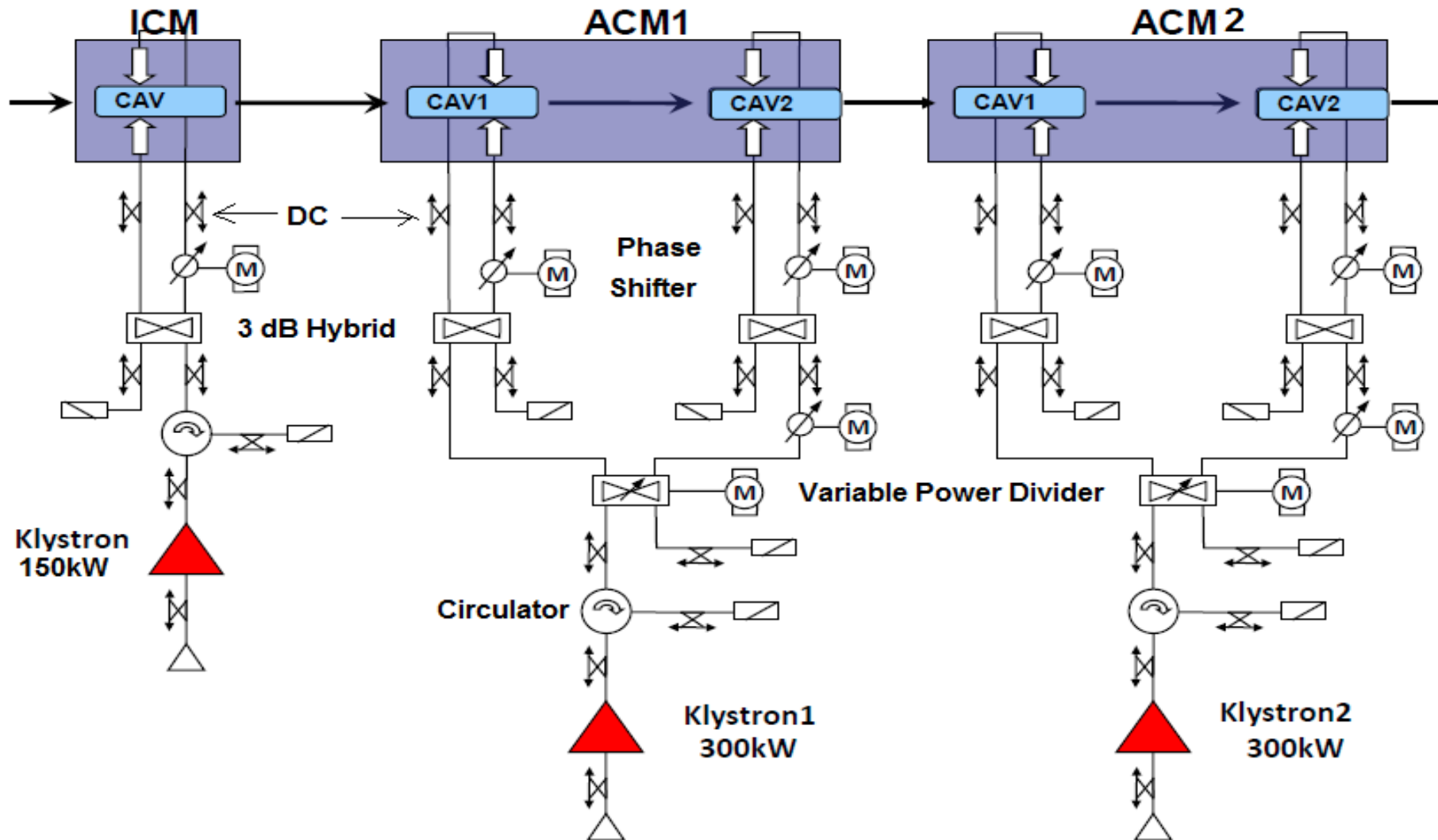
100 kW cw rf power to each cavity (5 X 100kW = 0.5 MW)

50 kW rf power coupler (2 couplers each cavity)

Consideration and Distribution of RF Systems for E-Linac



Consideration and Distribution of RF Systems for E-Linac (con.)



Costs of Klystron and DC PS for E-Linac

Costs Comparisons for Klystron and DC Power Supply

	Klystron (5) 150 kW	DC Power Supply for 150 kW	Klystron (3) 300 kW	DC Power Supply for 300 kW
	Each (x 5)	$V_{dc} = 48 \text{ kV},$ $I_{dc} = 6 \text{ A}$	Each (X 3)	$V_{dc} = 60 \text{ kV},$ $I_{dc} = 8.5 \text{ A}$
Cost	\$ 330 k / \$ 509 k	\$ 340 k / \$ 365 k	\$ 408 k / \$ 541 k	\$ 670 k / \$ 677 k
Sum	\$1,650 k / \$2,545 k	\$1,700 k / \$1,825 k	\$1,224 k / \$1,623 k	\$2,010 k / \$2,031k
Total	5 X 150 kW Klystron + DC PS \$ 3,350 k / \$ 4,370 K		3 X 300 kW Klystron + DC PS \$ 3,234 k / \$ 3,654 K	

DC Power Supply for Electro Magnet: 300V ; 40A

Heater for Klystron : 9.5V ; 15A

The Prices of DC PS were estimated, based on Wolfhard Merz DESY “DC Power Supply for Klystron”

The prices of klystron were estimated from manufactures

300kW CW Klystron, DC PS and WG Components

- **Klystron and DC Power Supply**
 - 3 X 300 kW Klystrons / DC PS (600 kW)
 - 2 X 300 kW + 1 X 150 kW Klystrons(IOT) / DC PS; SS PA
- **High Power Transfer Components for a Klystron System**
 - 300 KW (Circulator X 1, VPD X 1, Water Load X 1)
 - 150 kW (360 deg. V. Phase Shifter X 3 , 3 dB Hybrid X 2, WL X 3)
 - Duel Directional Couplers X 12 , Waveguides, Bellows, E/H bends
 - 4 X 75 kW Couplers (working at 50 kW level), Phase I
- **Low Level & High Power RF Tests of Wave Guide Components**
 - 300 KW klystron tests
 - Signal level rf tests for all WG components

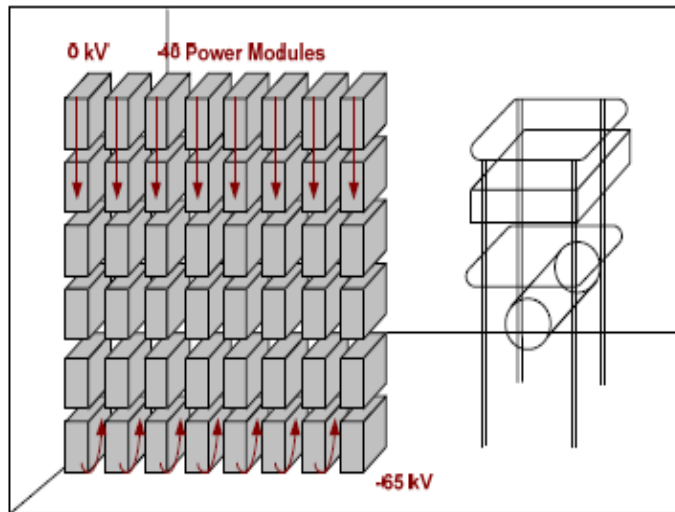
AMPENGON High Voltage Power Supply for 300 KW cw Klystron



KPS Klystron Power Supply, AMPENGON, Switzerland

600 kW KPS - Parameters
65 KV, 9.3 A HVPS
Mains Input: 12.5KV, 60Hz
HV-Deck including output filter and Filament PS
Control rack (Focus PS.s, Ion Pump PS, 50w SS Driver, Monitor panel)
Cooling cabinet
Control room with analogue/digital filter wall
All states & signals of PLC implemented EPICs database (read out over a TCP/IP connection)

AMPENGON High Voltage Power Supply for 300 KW Klystron (con.)



Power Module Arrangement



Power Module Section

PSM Transformer with 48 Secondary windings
 Output filter
 V measurement
 I measurement
 HV Deck with filament supply

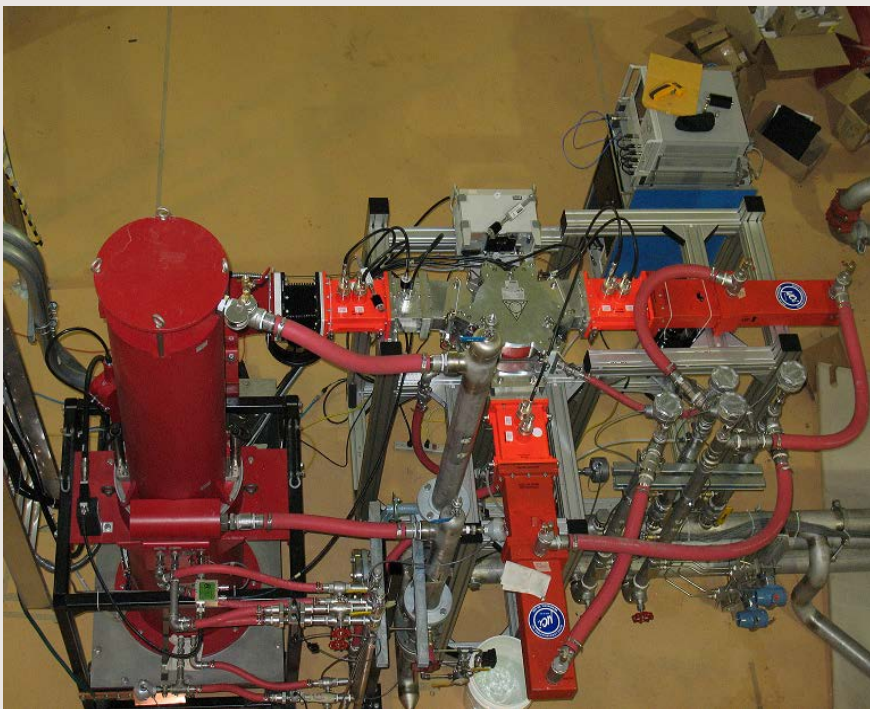


Parameter	Required Figure
Mains Input Voltage:	12.47 kV 3 Phase + Ground
Frequency	60 Hz
Input Power	620 kW
Output Voltage	65kV
Output Current	9.3 A
Ripple	+ - 0.1% of Output Voltage
Redundancy	3 Power Modules @ -10% input voltage
Fast Shutdown time	< 10 us
Short Circuit Energy	< 10 Joule
Efficiency	96%

KPS is based on voltage controlled power module type, PM14-10-VR-1.

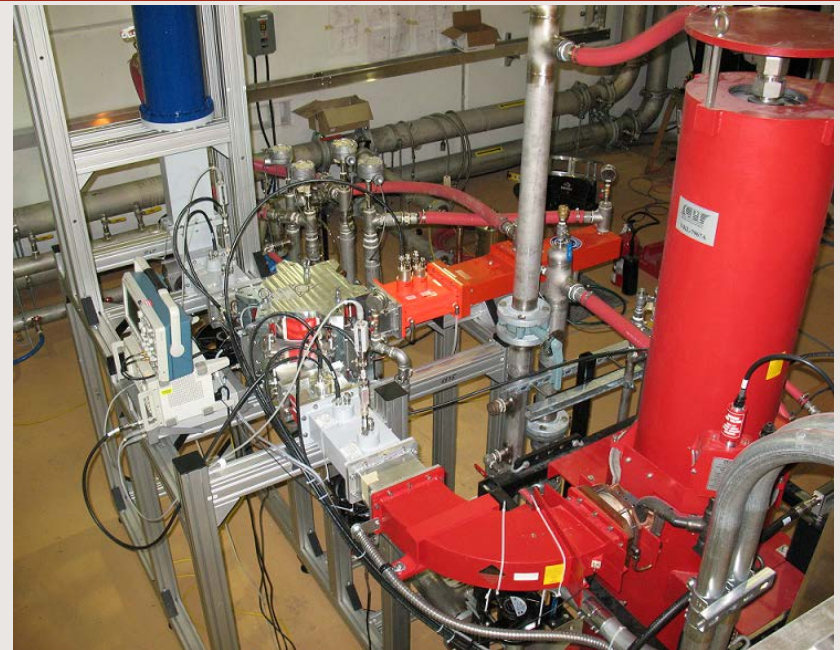
48 Power Modules, each @ 1.45 kV

300 KW cw Klystron and HVPS Tests at TRIUMF



First Klystron in e-hall for high RF power test

Sparking happened at about 120 KW cw and trip rf by interlock (bellow, DC.s, water load, WG flanges)

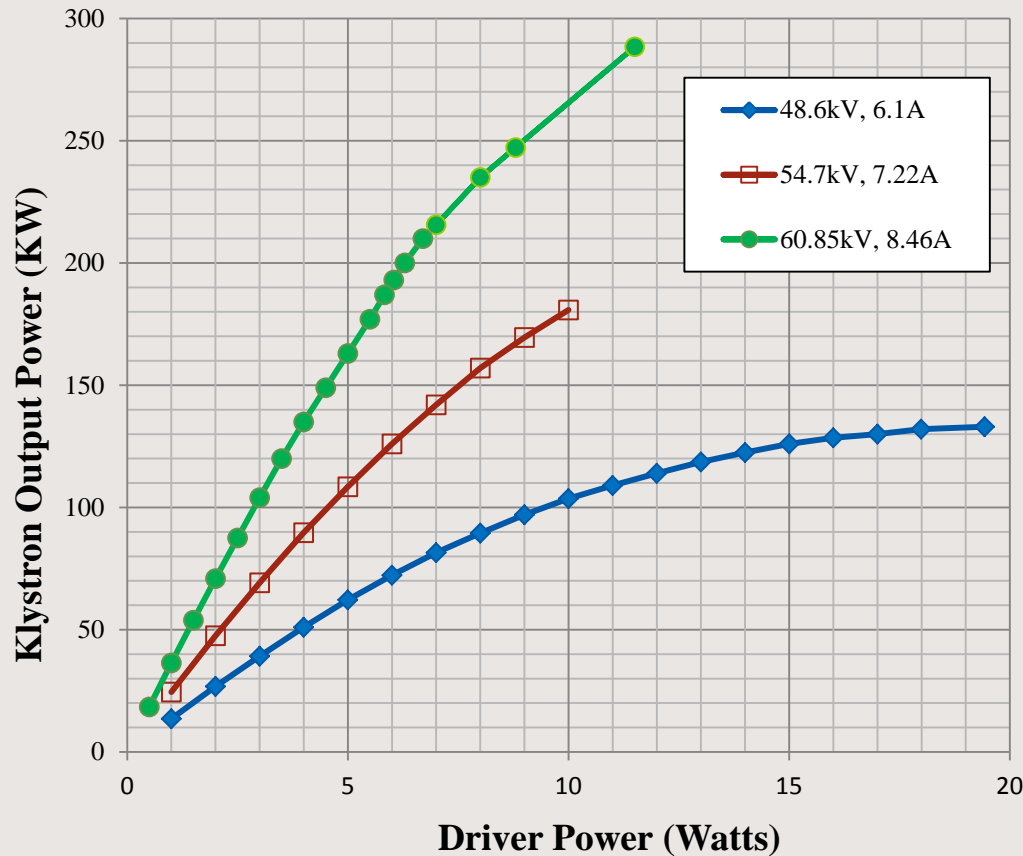


250 KW MEGA water load installed instead of MCI 300 KW water load and MEGA DC.s, Bellow WG components for rf high power tests

275 KW cw in success on MEGA 250 KW water load, and directional couplers

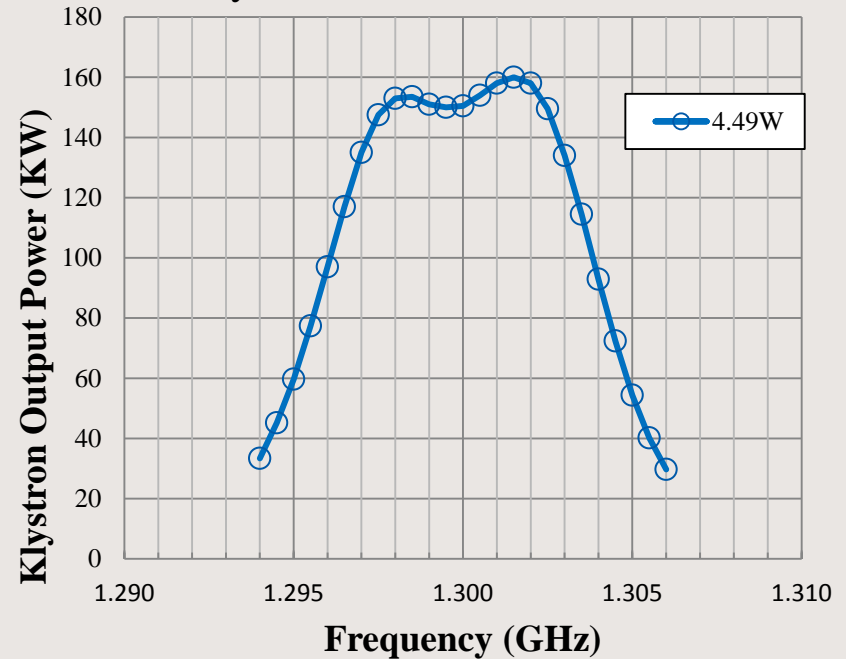
300 KW CW Klystron and HVPS Tests at TRIUMF (con.)

First Klystron High Power RF Measurements: Gains (38 - 43) and Performs



The goal is to reach full rated power of 275 kW and perform measurements for transfer

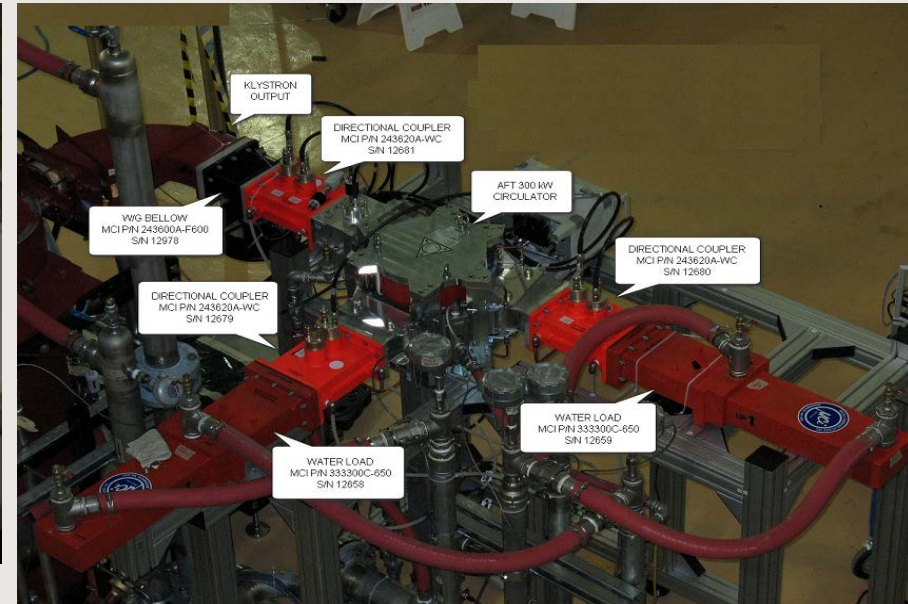
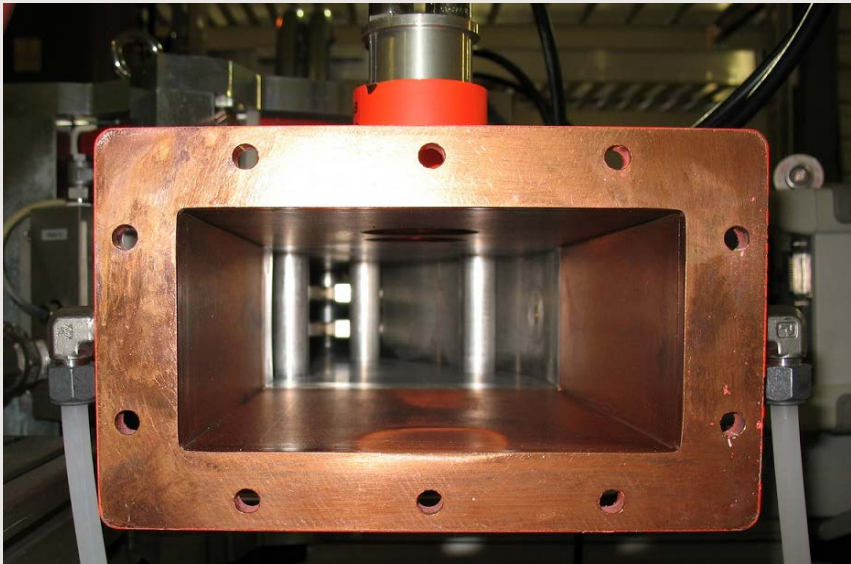
Klystron Bandwidth Measurements



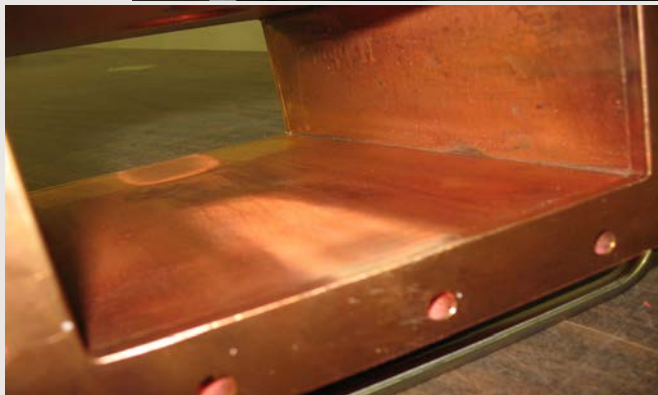
First Klystron Bandwidth Tests

fo	P_o (kW)	Delta P_o
1.2995	150	-0.0145
1.3	150.5	0.0000
1.3005	154	0.0998

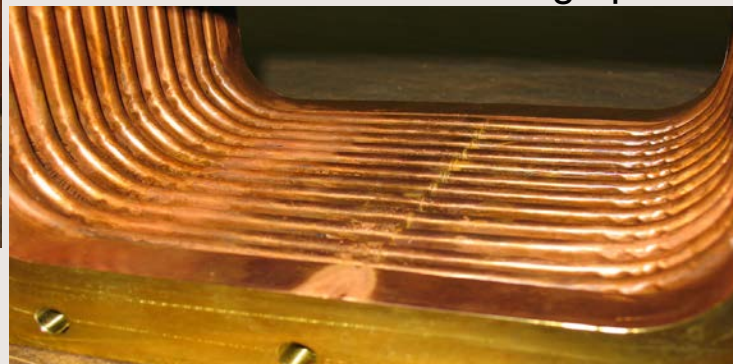
First 300 KW Klystron and HVPS Tests at TRIUMF (con.)



Details of waveguide components , water load for high power rf tests



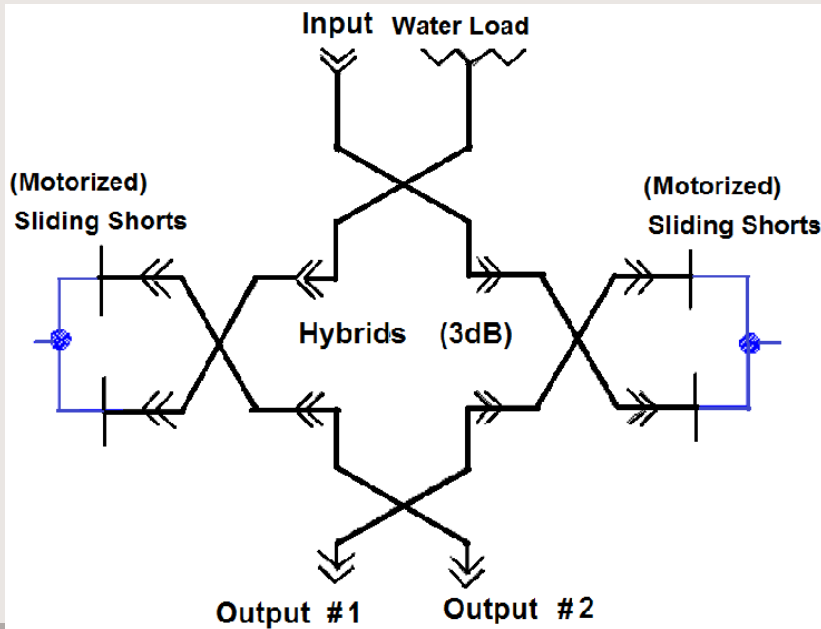
Severe sparking of WG components, CPI (< 120 KW level) in high Power test



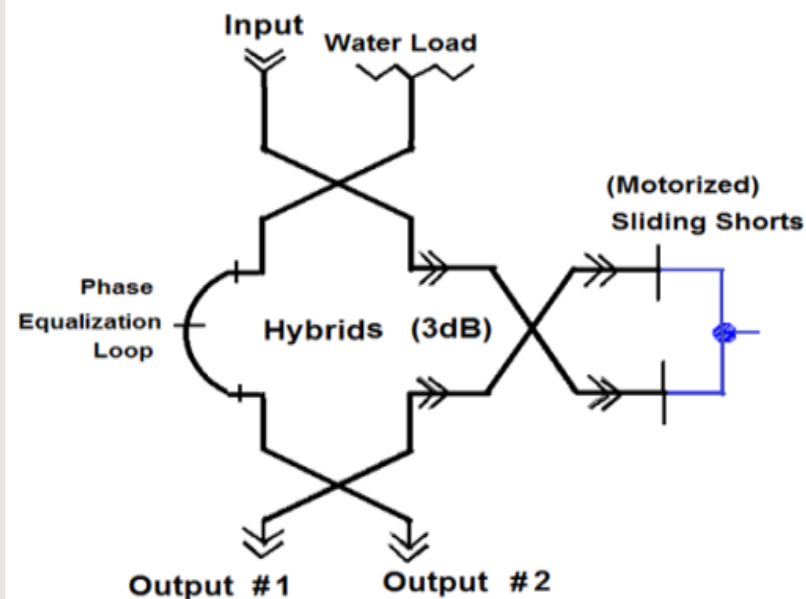
6/20/2016

300 kW CW Variable Power Divider

Frequency	[MHz]	1300 ±10
Average power	[kW]	300
Peak rf Power (full Reflected)	[kW]	>1200
Insertion Loss (maximum)	[dB]	0.3
VSWR (Max.), return loss 28.3dB		1.08 : 1
Continuously variable attenuation, with resolution better than 1.0%	[dB]	0 - 30
Operational position	[dB]	3 ± 0.05



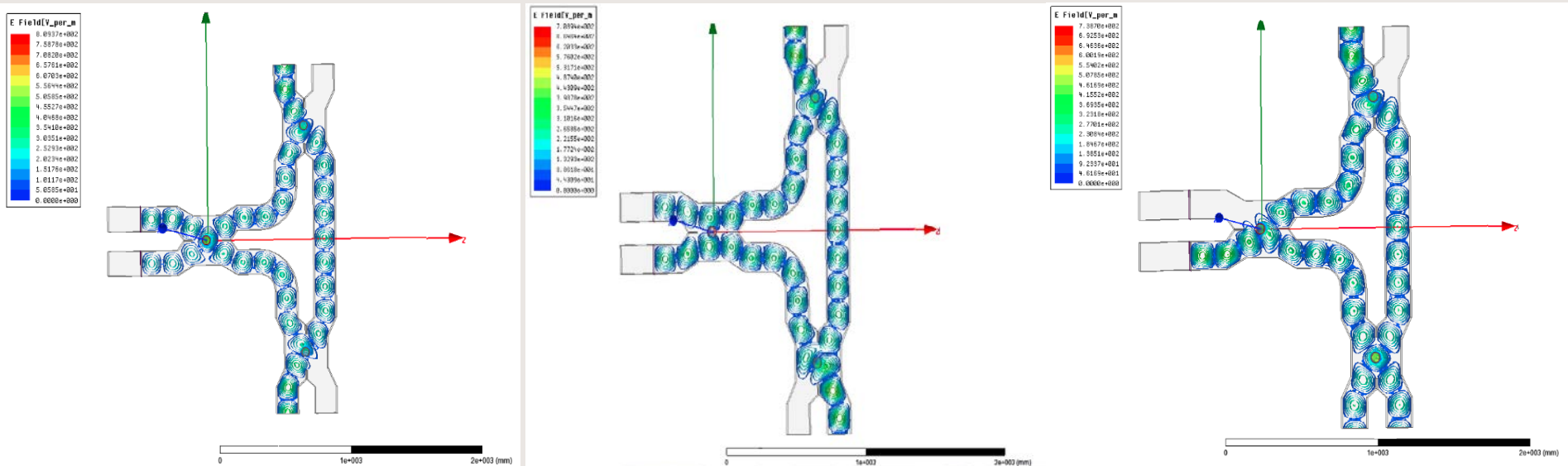
Two ways for VPD



300 KW CW Variable Power Divider (con.)

One typical simulation results and illustrations

Position of Slide Shorts	S_{21}	S_{41}	S_{11}	S_{31}
[mm]	[dB]	[dB]	[dB]	[dB]
-38.5	-0.01	-38.7	-37.5	-34.89
0	-3.02	-3.02	-29.2	-31.95
41.5	-37.04	-0.03	-29.71	-35.51



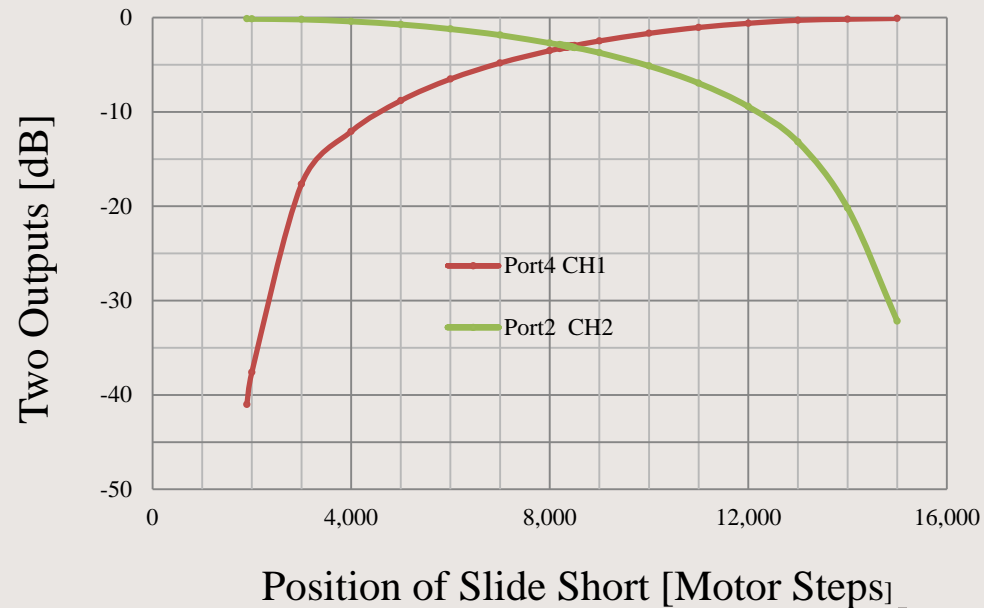
300 kW CW Variable Power Divider from Mega(con.)

RF signal level measurement results of the VPD



Position of Slide Shorts [motor steps]	S_{21} [dB]	S_{41} [dB]
1900	-0.132	-41.02
8400	-3.08	-3.07
15000	-32.18	-0.092

Two Outputs Vs. Position of Slide Short



The VPD was testing at TRIUMF

Measuring results of the VPD
better than simulations

Insertion Loss (Max.): 0.17 dB

S parameters better than - 30 dB

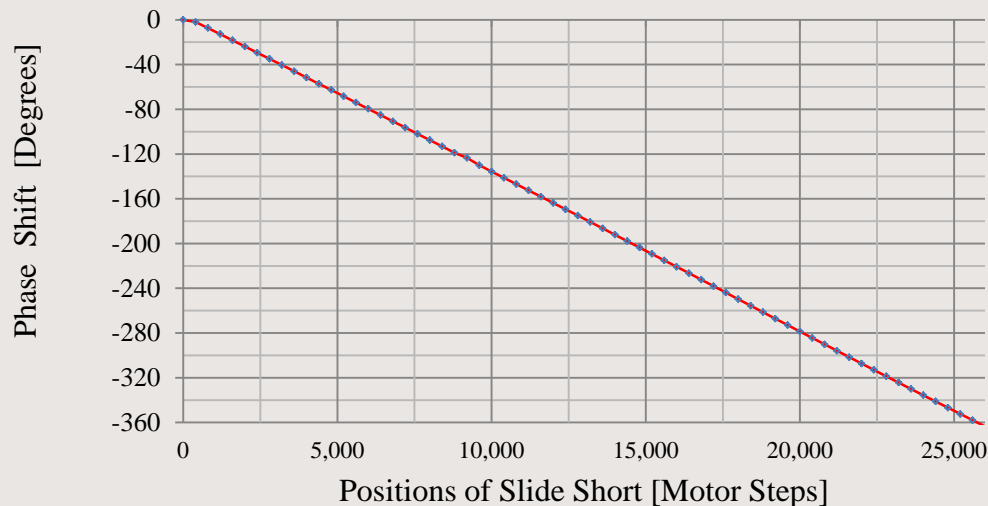
150kW, 360 degree Variable Phase Shifter(Mega) tests

	TRIUMF Specification	Manufacture Reports	RF Signal Test
Frequency [MHz]	1300	1300	1300
Phase shift	360°	360°	360°
Phase resolution	< 0.2°	< 0.1°	< 0.1°
VSWR _{Max}	1.06 : 1	1.08 : 1	1.07 : 1
Return loss [dB]	> 30	> 28.3	> 29.4
Insertion loss [dB]	< 0.1	0.05	0.058-0.12

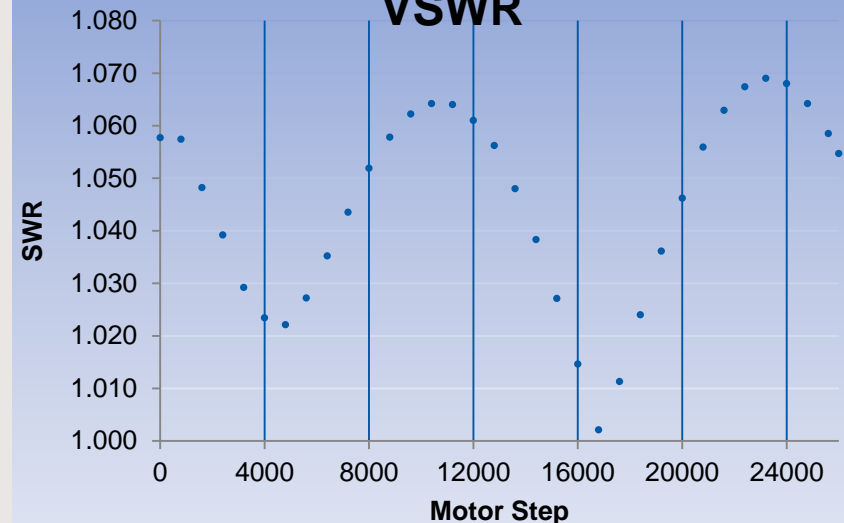
Four 150 kW, 0-360° Variable Phase Shifters

- One for ICM (Injector)
- Three for ACM (EACA)
- *Remote motor controlled*

Phase Shift vs Positions of Slide Short



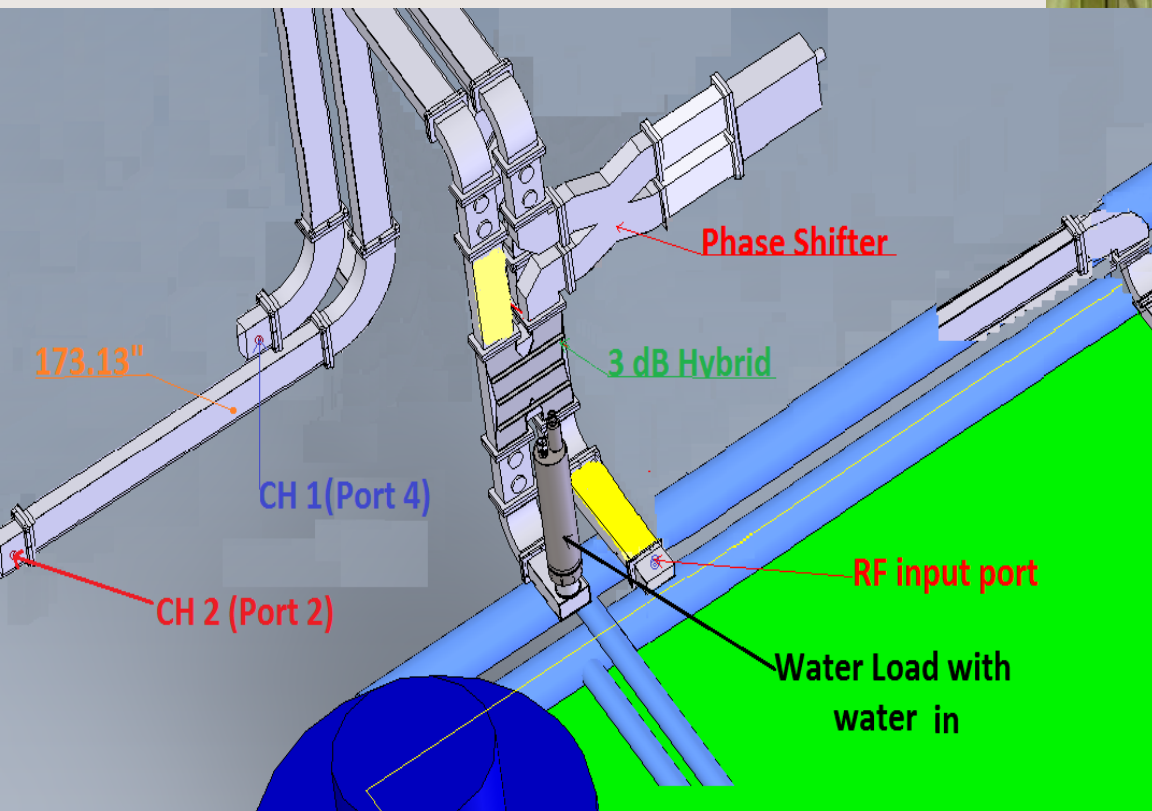
VSWR



360 degree Variable Phase Shifter and Waveguide components tests(con.)

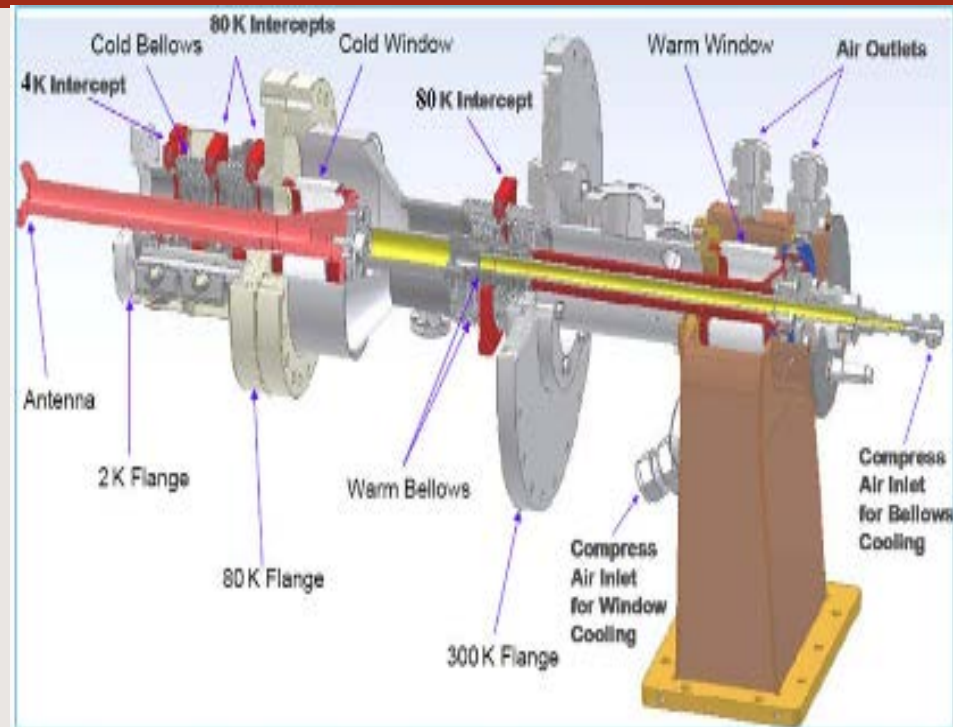
RF signal level measurement of phase balance in two WG path of ICM done

- Phase difference: 0.01 degree
- Better than the specification



RF signal level measurement of phase balance in two WG path of Injector
(Water load, 3 dB hybrid and Ph.S.)

IOT and Power Coupler Test Stand



CPI VWP3032 75kW CW Coupler

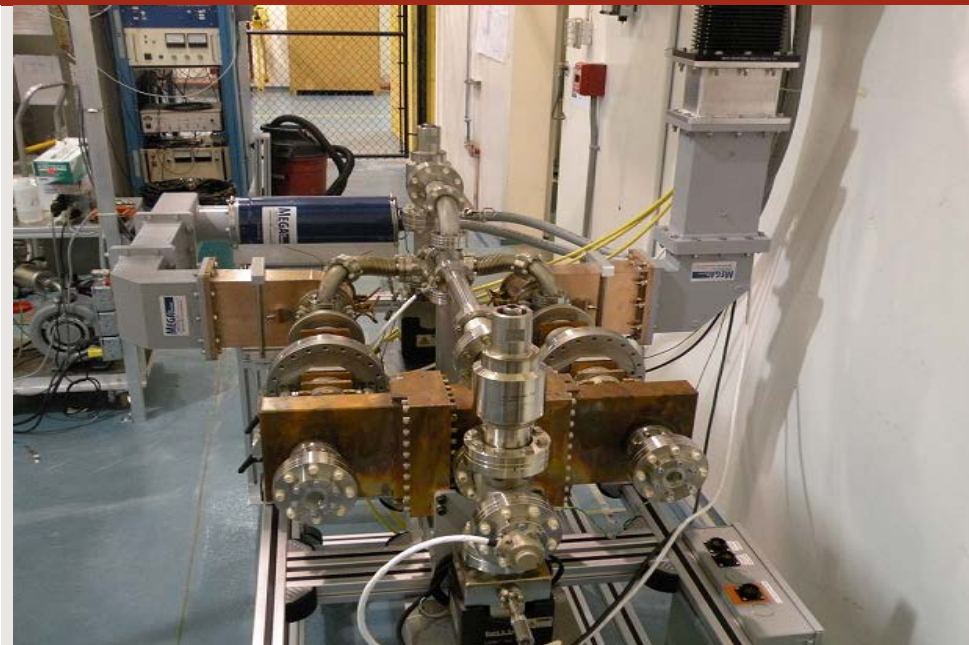
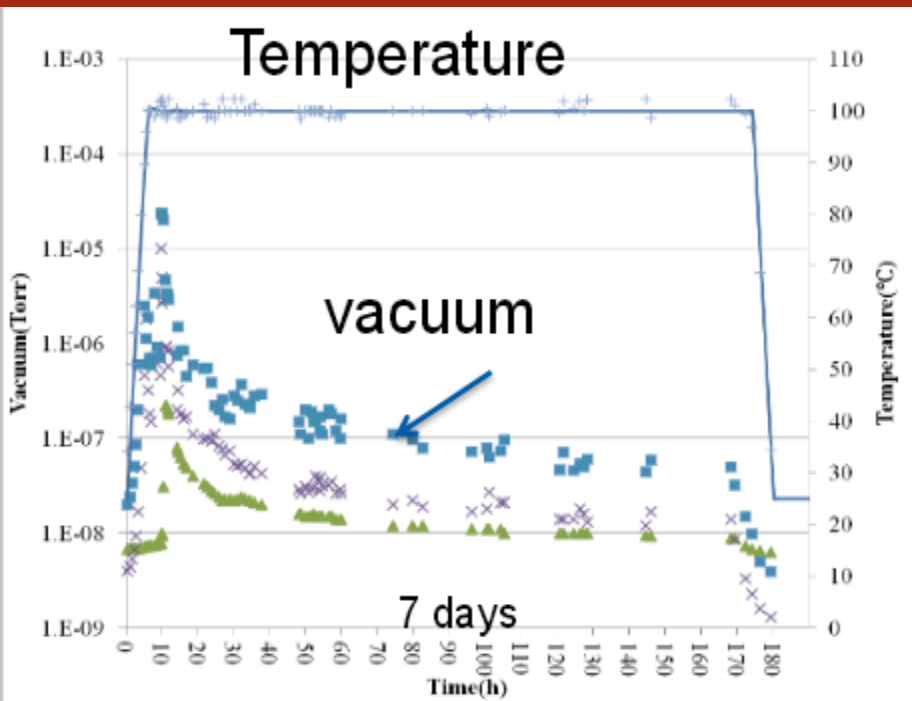
CPI IOT – 07188; Bruker Transmitter

Beam V:	35 kV	Beam I:	1.4 A
Output P:	30kW	Driver:	124 W
Efficiency:	60.4%	Gain:	23.8 dB
Bandwidth (-1 dB):	2.7 MHz		

Handing of Power Coupler

- Assembly in clean room
- Keep seal with filtered N₂ gas
- Install into cavity

IOT and Power Coupler Test Stand (con.)



Power Coupler Baking

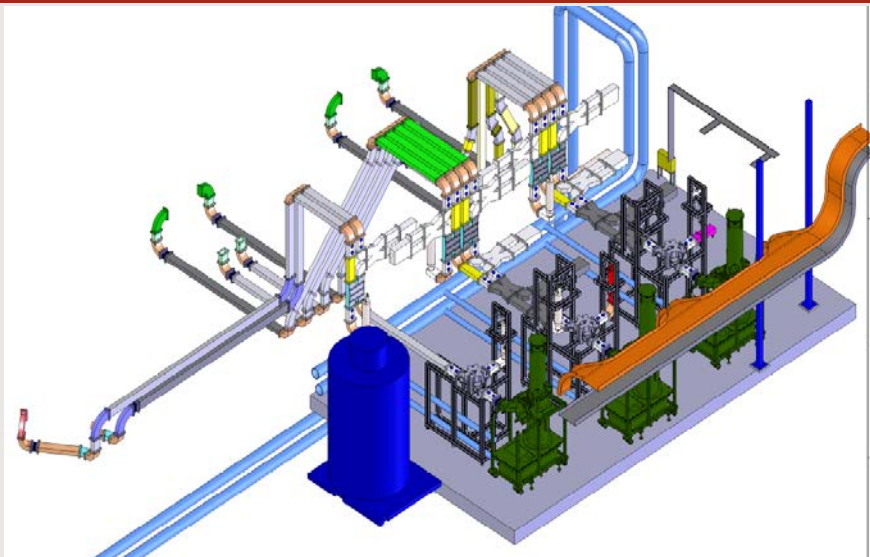
Warm window, outer conductors (heaters)
inner conductors (hot filtered air)

- 100 c for 7 days
- 10 c/hr ramp up/down
- N2 filtered air flow warm parts with shroud covered

Power Coupler rf Conditioning

- TW CW upto 19.5 kW - takes 3-5 days
- SW pulse mode - takes 3 days
 - Sliding short plate (3 positions)
 - Pulse with duty factor 1%, 10 Hz power upto 10 kW (equivalent 40 kW in TW)

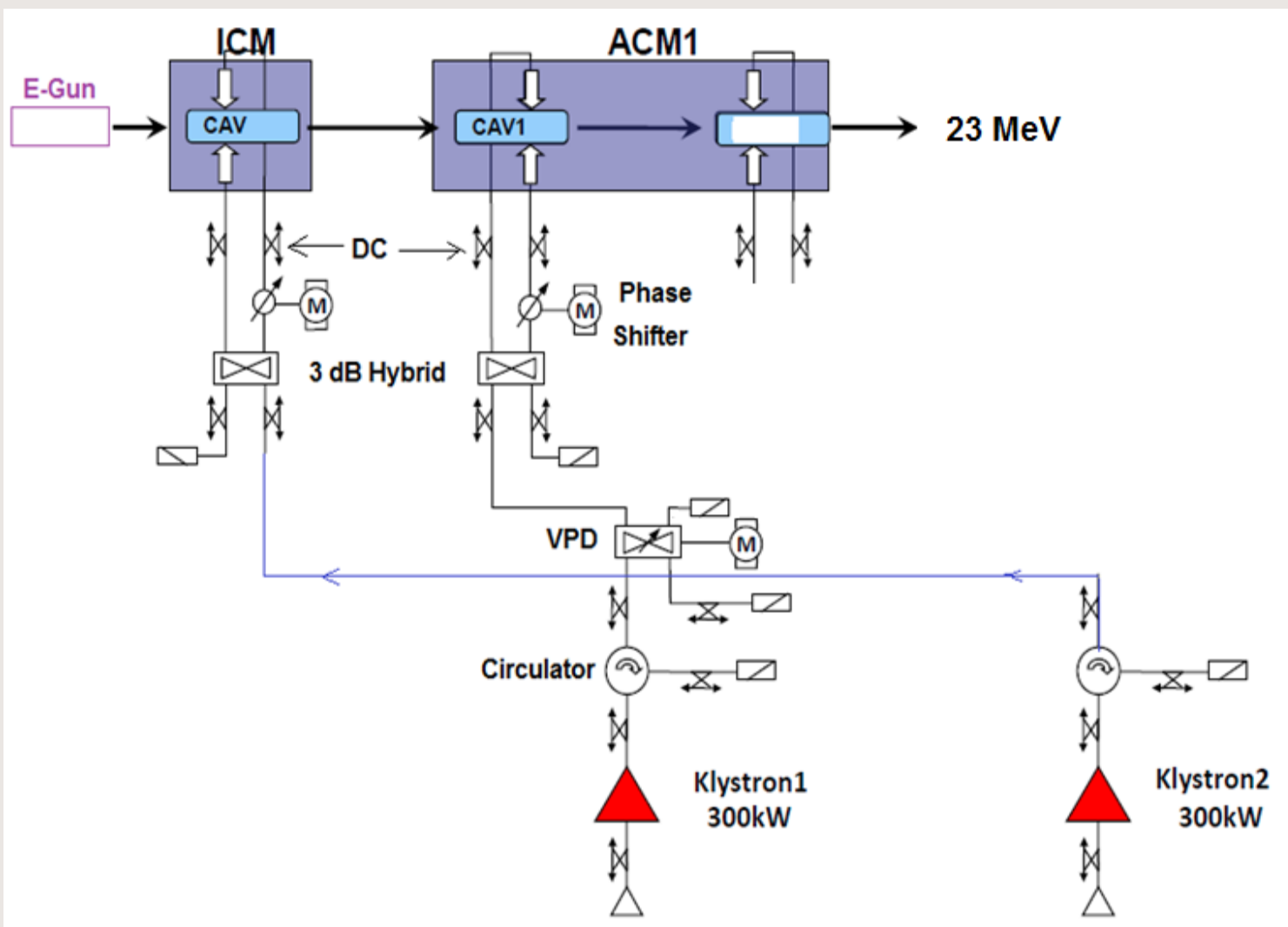
E-Linac RF system assemblies for commission



Two 300 kW Klystrons, 600kW DC PS & MEGA WG components (VPD, Ph.S., DCs, 3 dB Hybrids water loads) assembled for beam tests

Two 600 kW DC
Power Supplies from
**AMPENCON,
SWITZERLAND**

RF Configuration for Commission





- **Two Klystron and HV Power Supply Commission with Beams**
 - One Klystron run up to 275 kW on water load another up to 150 kW at Triumph
 - 100 kW beam power is testing (30 MeV, 3 mA, limited by operation licence)
- **High Power Coupler Tested for Beam**
 - Four 75 kW cw power couplers in operation after being tested in TS
 - Couplers run beams up to 23 MeV of 4 couplers – 2 cavities
 - 2 more power coupler is testing beams now for the 3rd cavity
- **Low Level & High Level RF Commissioning**
 - 300 kW CW and 150 kW CW circulator tests well on water loads
 - 300 kW Variable Power Divider test well, meet specification for E-Linac operation
 - 360 degree Variable Phase Shifters work well in signal level and beam tests
- **E-Linac Operations and Future Plan**
 - 3 cavities in ICM & ACM for beam tests; (5 cavities run 2 years later)
 - 100 kW beam power is testing (30 Mev, 3 mA, limited by operation licence)
 - Need a 3rd RF source for injector when 5 cavities operation to 0.5 MW beam power

Thank you for your attention