Xband Klystron/modulator experience at CERN

HG2017

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16/06/2017

On behalf of all the Xbox team

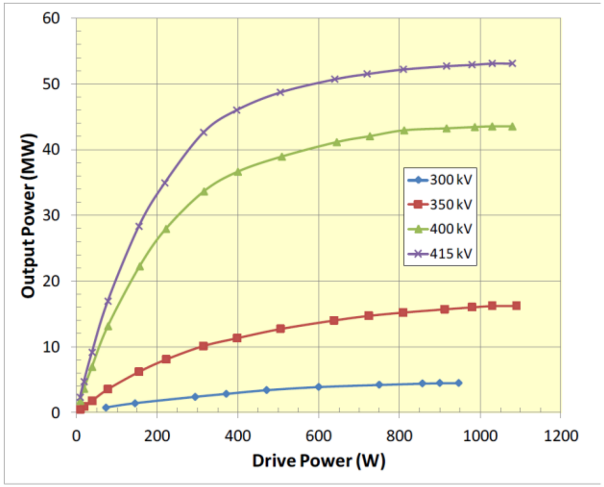
OUTLINE

- Xbox1 and Xbox2
  - (summary)
- Xbox3
  - Modulators
  - klystrons
- IUWR90 Flanges
- Future

Xbox1 and Xbox2

Scandinova solid state modulators

CPI Klystron (commercial SLAC XL5)



Parameters	Specifications	units
	VKX-8311A	
RF Frequency	11.9942	GHz
Peak RF power	50	MW
RF pulse length	1.5	µs
Pulse repetition rate	50 (100)	Hz
Klystron voltage	410-470	kV
Micro perveance	1.15E-6	

Xbox1 and Xbox2

- Xbox1
  - Modulator installed since 2010 in CERN, first generation solid state K300
  - Initially with XL5 klystron now CPI
  - Structure testing in CTF2 or dogleg (beam tests CTF3)
  - LLRF getting ‘tired’, pulse compressor difficult to tune
  - Still running reasonably well with lots of babysitting
  - Never reached nominal power out of klystron , limited by the high power RF network
  - Using solid state 1.2KW klystron driver

Xbox1 and Xbox2

- Xbox2
  - same configuration as Xbox1 for modulator and klystron, (modulator more recent generation)
  - LLRF, National Instrument PXI development
  - New generation pulse compressor
- In commissioning with CPI klystron, oscillations observed (now disappeared)
- has been running very reliably this year, really good pulse to pulse stability
- TWT driver will be replaced with solid state amp next week

Spare Klystron

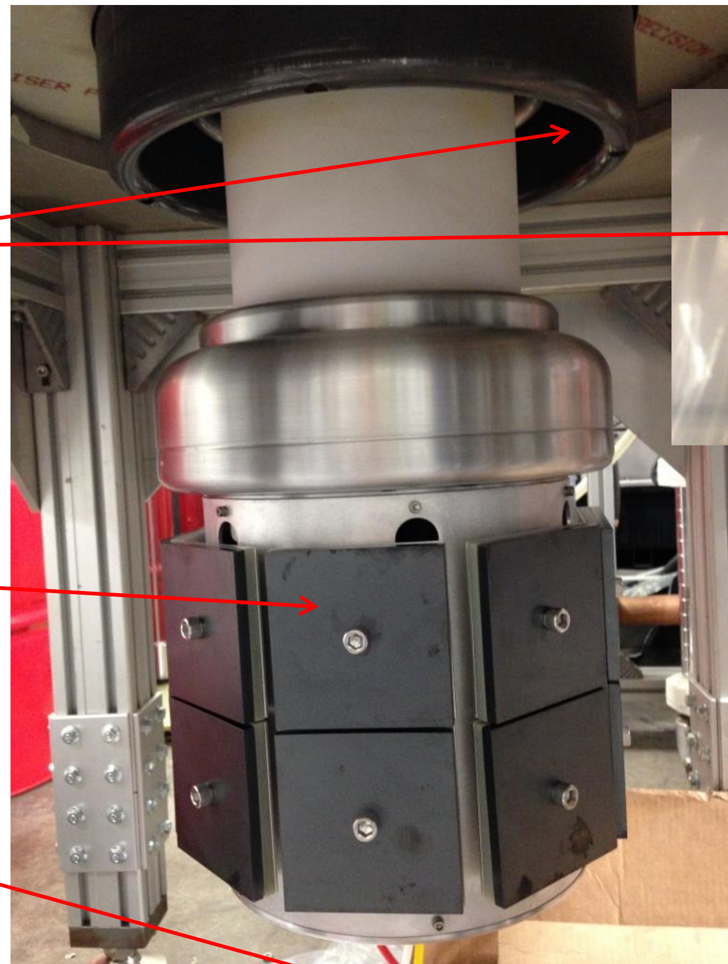
- 3rd Klystron ordered from CPI
- Klystron acceptance was done in January 2016
- When dismantling test load klystron went up to air
- Broken window
- Klystron repaired
- Initial testing (~January 2017) gun oscillation observed
- Discussions between CPI and SLAC
- Modification to gun and modulator tank (ferrite tiles)

- Acceptance tests next week

Spare Klystron

S/N 003 Mitigation at CPI

Ferrites added to inside of lead cylinder on subsequent iteration



Ferrite tiles on gun corona can

Ferrite tiles also on a plate resting on bottom of oil tank below gun

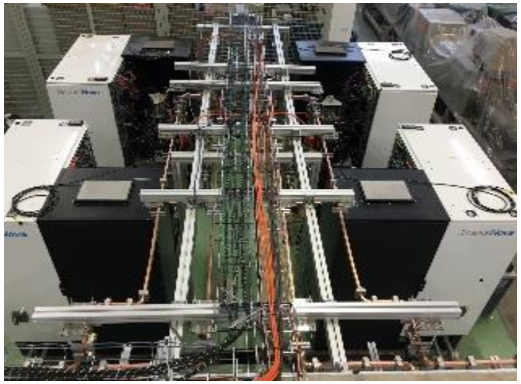
Hoping this is compatible with CERN modulator connectivity

Xbox3

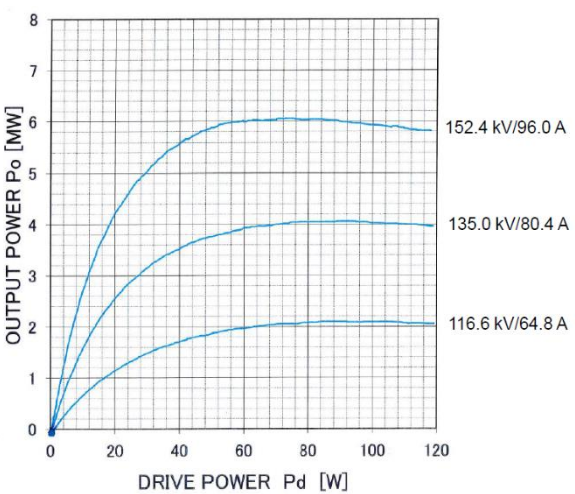
multi slot High Gradient Test Facility

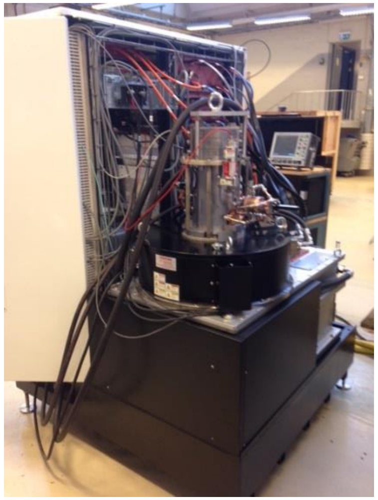
Turnkey solution

Toshiba E37113 klystrons
Scandinova solid state modulators

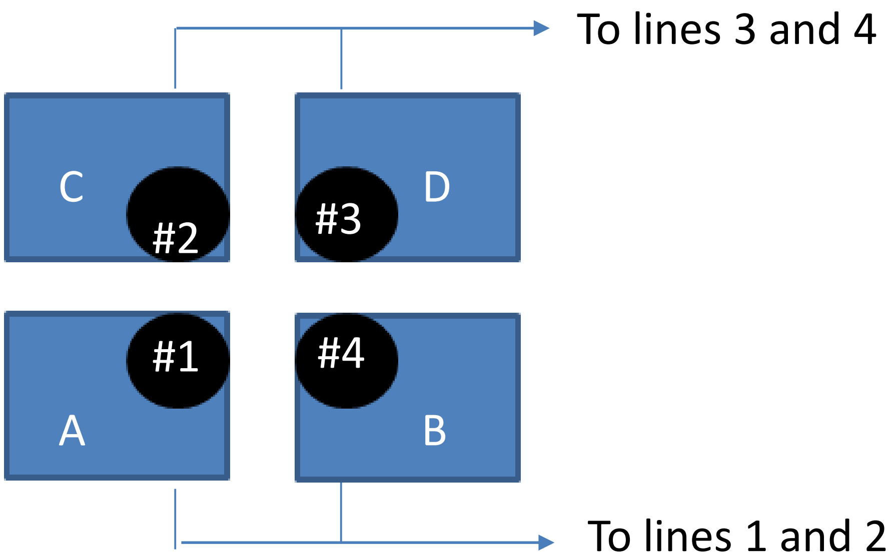


Parameters	Specifications	units
	E37113	
RF Frequency	11.9942	GHz
Peak RF power	6	MW
RF pulse length	5	µs
Pulse repetition rate	400	Hz
Klystron voltage	150	kV
Micro perveance	1.5	





Xbox3_initial configuration



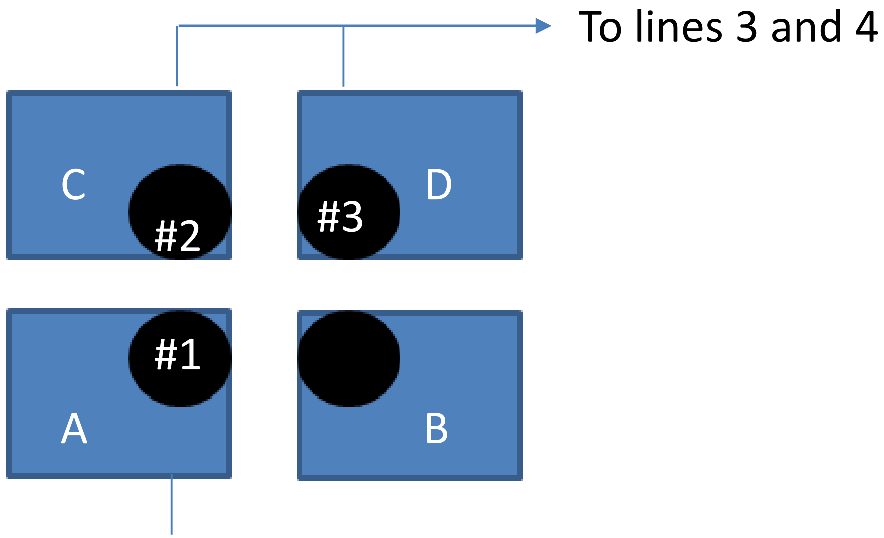
Xbox3_modulators

- all 4 modulators tested successfully in factory with klystron serial #1
- All four modulators delivered to CERN and installed with tubes serial #1-4
- SAT test in diode mode with Scandinova technicians completed

- Software problem (while in remote mode) caused soft start board to burn out in charging supplies, resolved by Scandinova,
- performance of modulator now excellent, more user friendly GUI

Xbox3_klystrons

- Initial RF tests started with individual klystrons
- First three ok
- Fourth tube did not give any RF power output
- Full reflection on input cavity back to driver
- VNA measurement showed cavity detuned
- Sent back to Toshiba with solenoid



Klystron check at TETD

3-1. The klystron appearance check

・No visible damage of the klystron outside

No problem

3-2. Diode operation with the returned focusing magnet.

— Operating parameter check

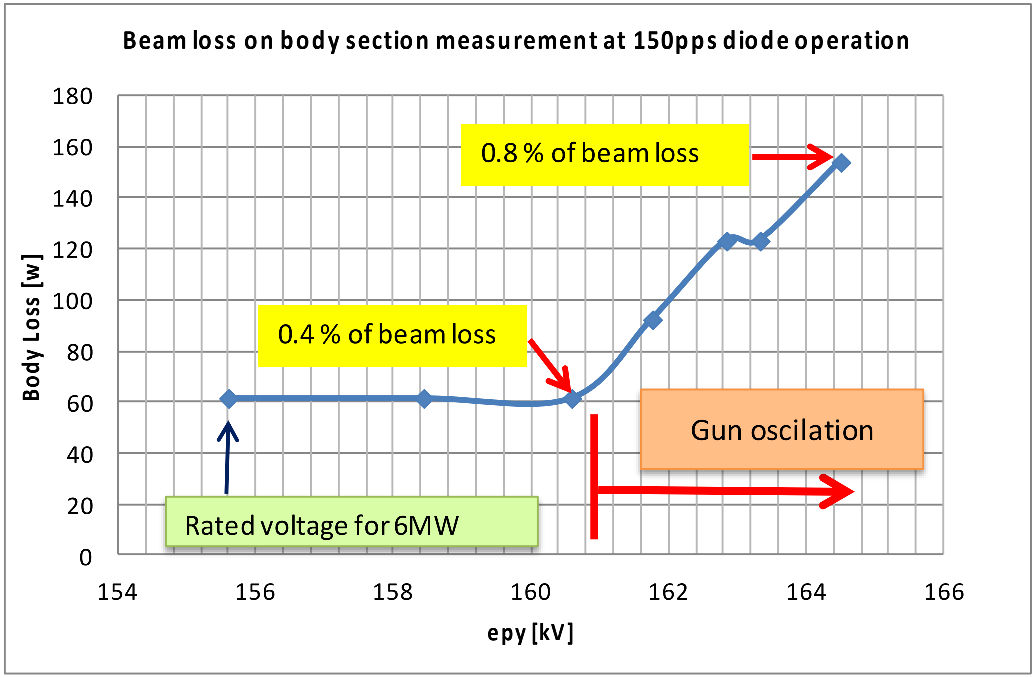
	Heater current	Heater voltage	Beam voltage	Beam current	Perveance
Prior to shipment	10.4A	15.2V	154.5kV	94.2A	1.55μP
Return after	10.4A	14.8V	155.6kV	94.1A	1.53μP

No problem

Klystron check at TETD

3-2. Diode operation with the returned focusing magnet.

 Beam loss measurement
(Kicked beam by gun oscillation)



Operation at the beam voltage of gun oscillation range was increased beam loss, but the value was within operation criteria.

No problem

Toshiba investigation #4

Klystron check at TETD

3-3. Cavity resonant frequency check after disassembling

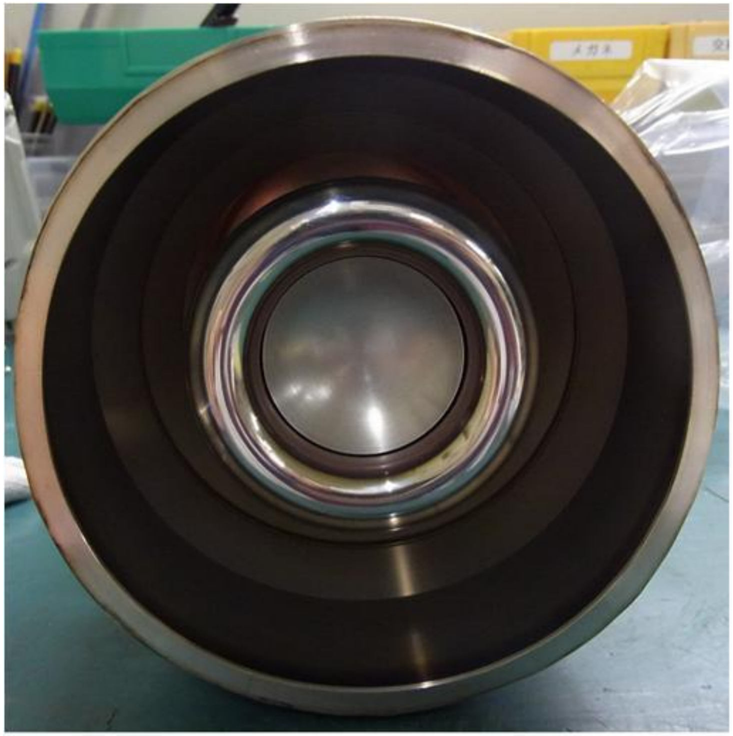
	Difference between the set value and the measured value
Input cavity freq	Δ -640MHz
2nd cavity freq	Δ -16MHz
3rd cavity freq	Δ -2MHz
4th cavity freq	Δ -2MHz

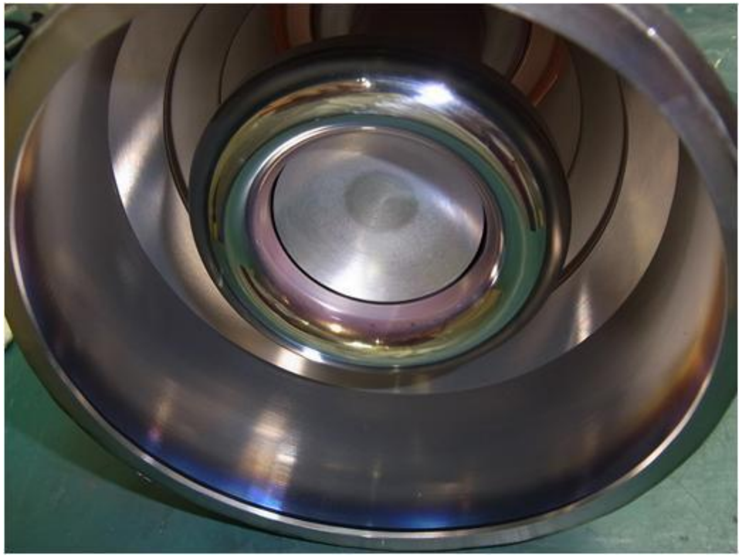
Resonant frequency of the input and the 2nd cavity was changed.

Toshiba investigation #4

Klystron check at TETD

3-3. Inside check after disassembling
— Condition check of gun electrodes and cathode

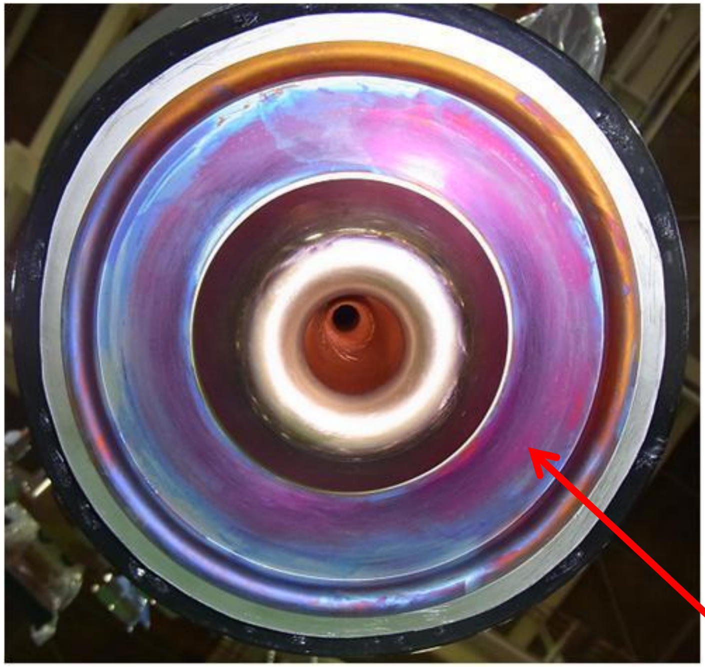




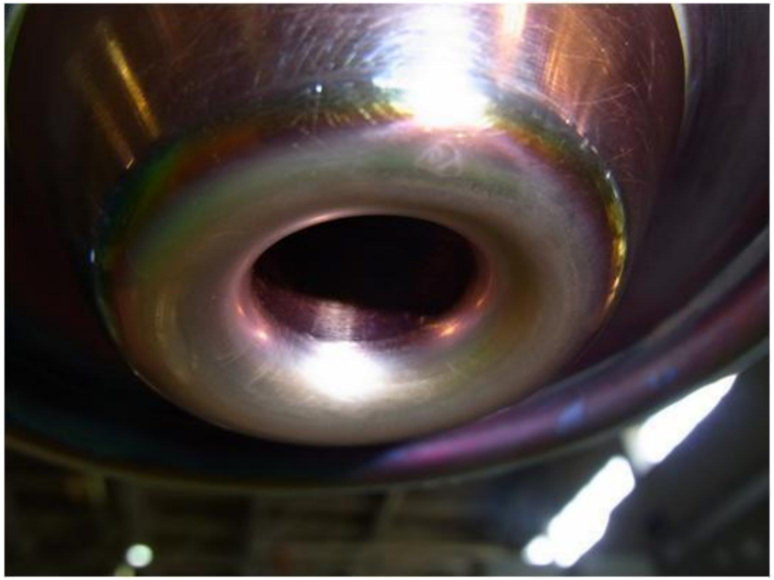
No change in appearance.

Electron gun

Klystron check at TETD



Anode electrode

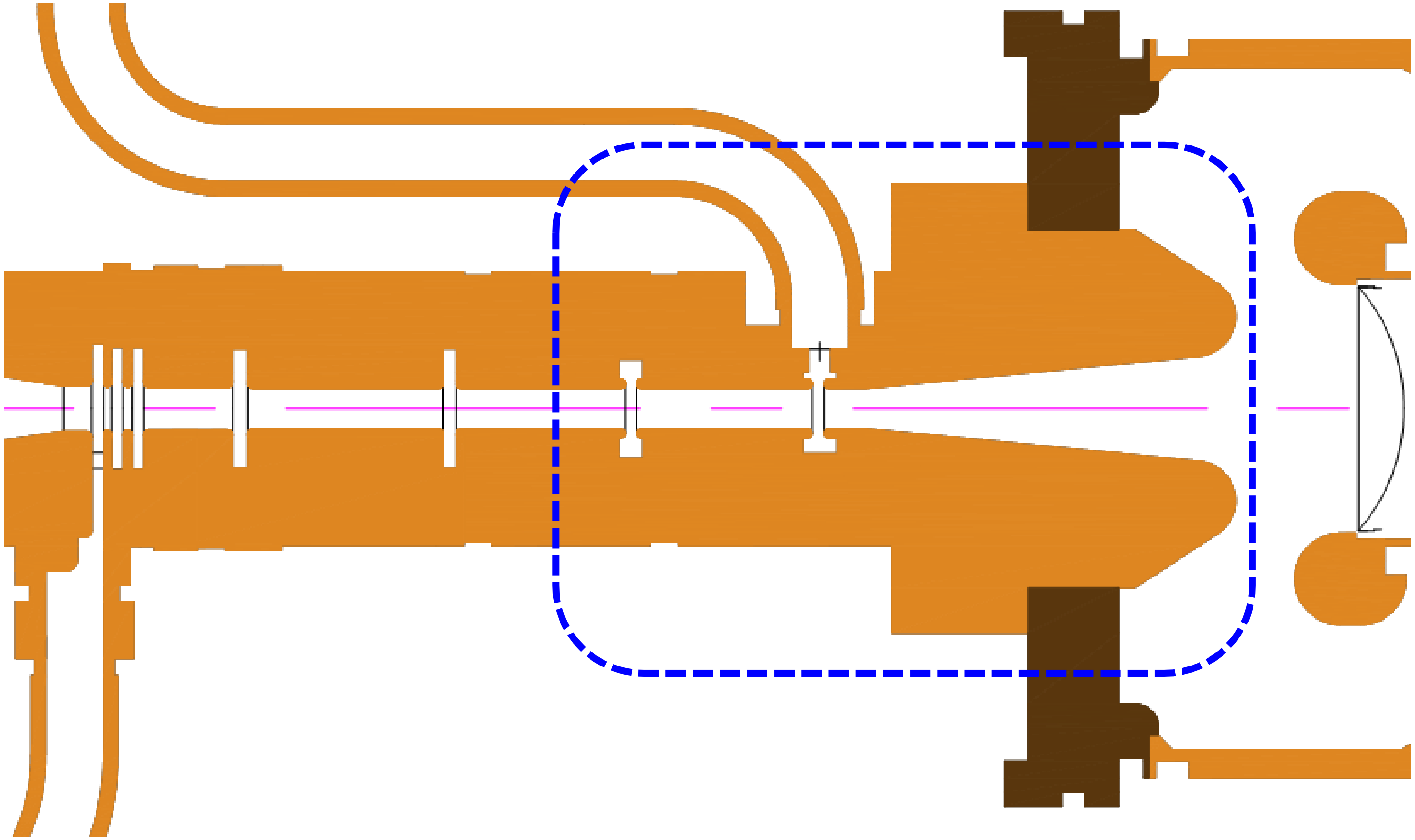


Discolored

Klystron check at TETD

3-3. Inside check after disassembling

— Condition check of input cavity section

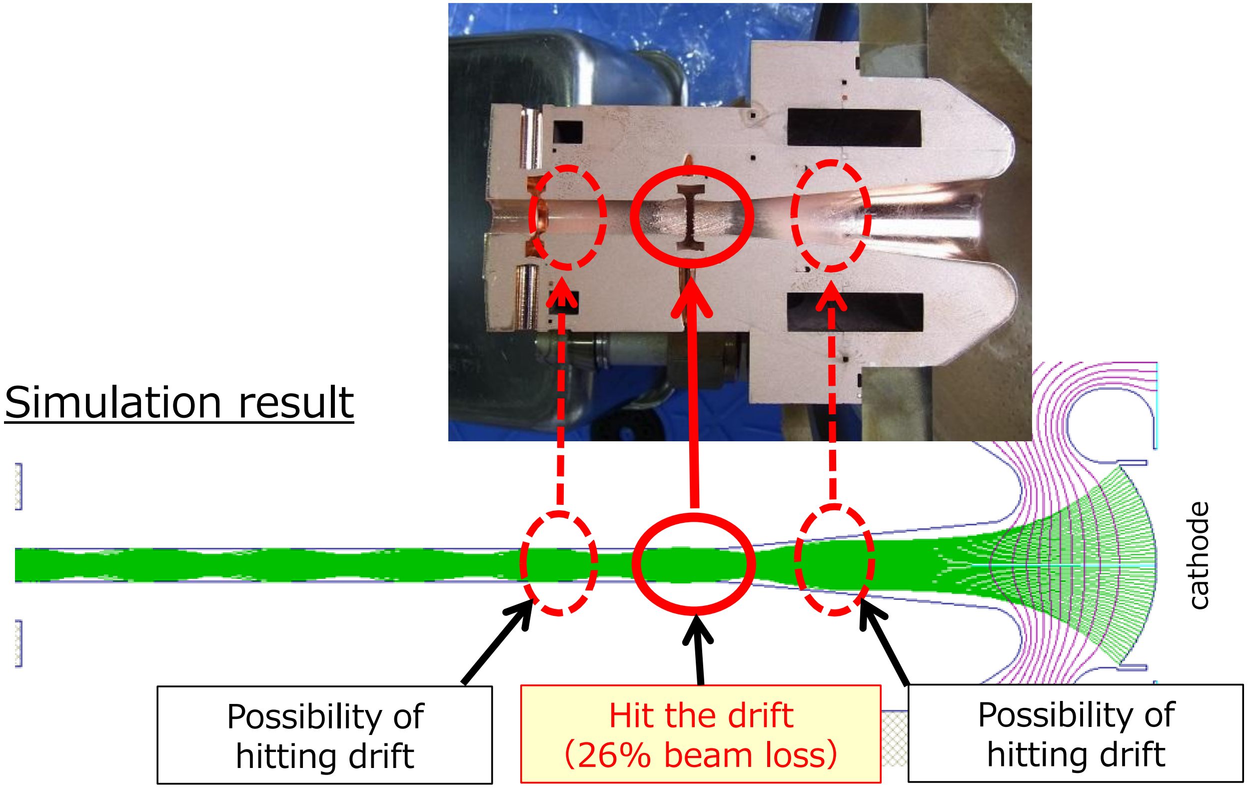


4. Consideration

4-1 Comparison with the simulation

— Reverse polarity of counter coil field

<u>Simulation result</u>

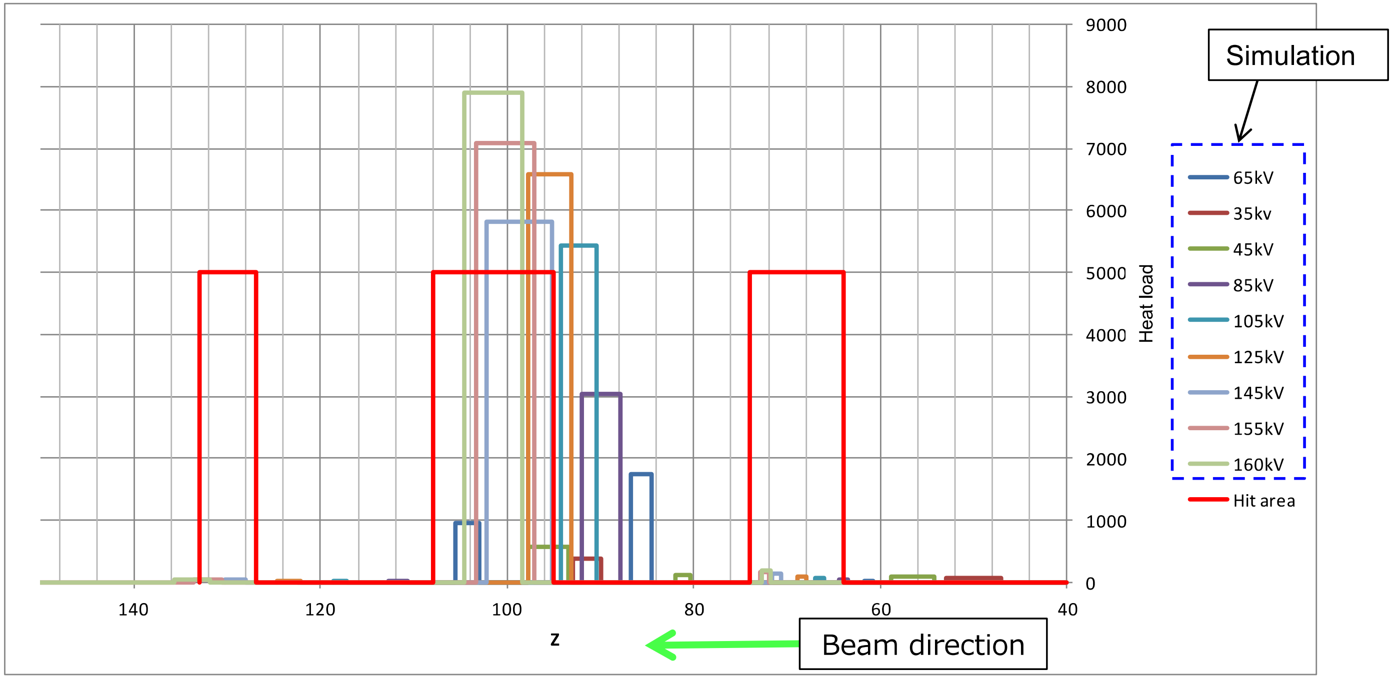


Hit the drift in same place with simulation

Toshiba investigation #4

— Reverse polarity of counter coil field

Beam landing position of reverse counter coil current operation

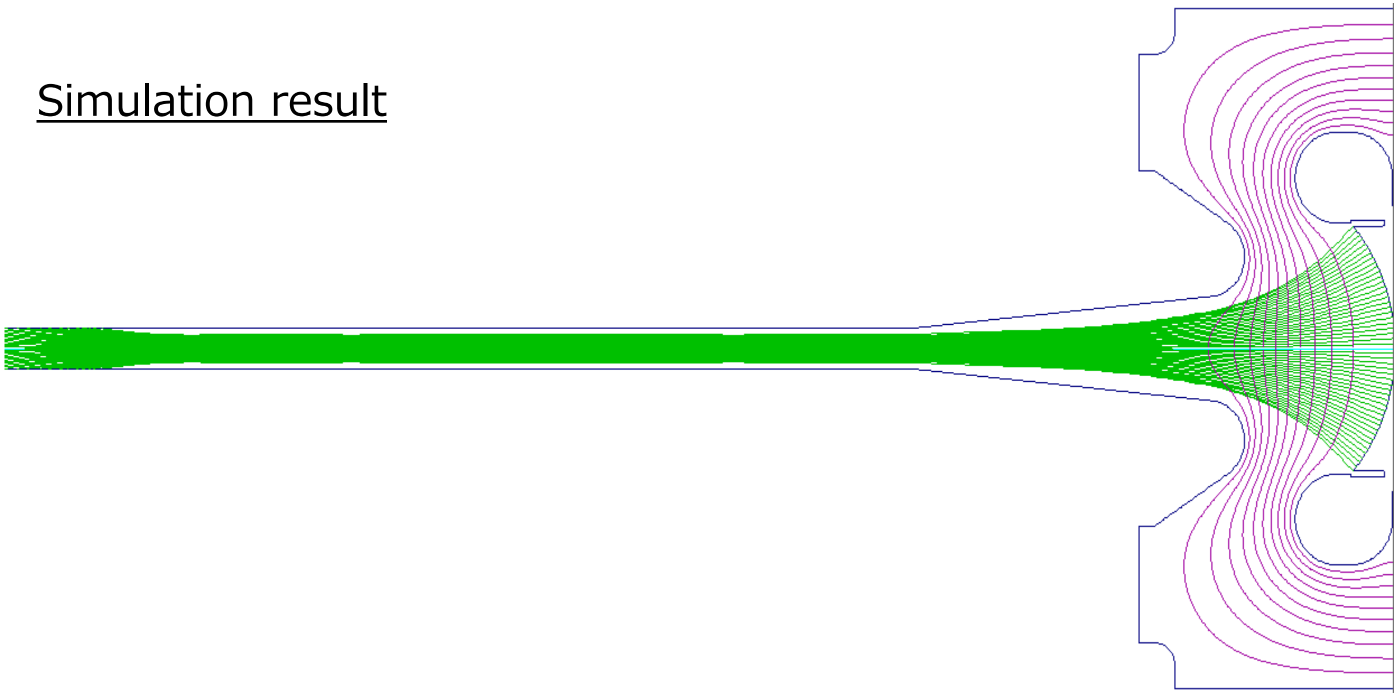


Simulation and the same trend [○]

Toshiba investigation #4

— Normal magnetic field

Simulation result

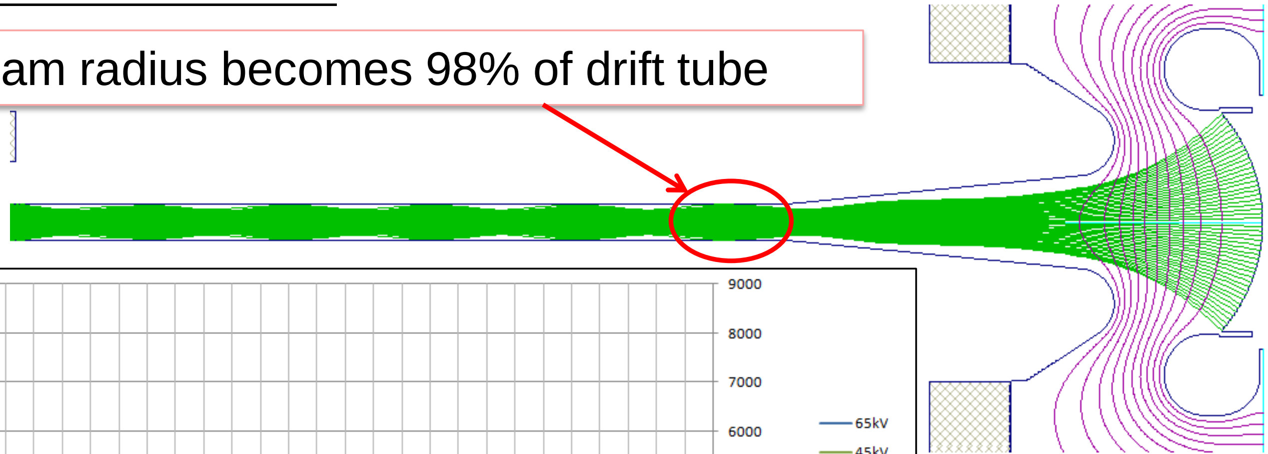


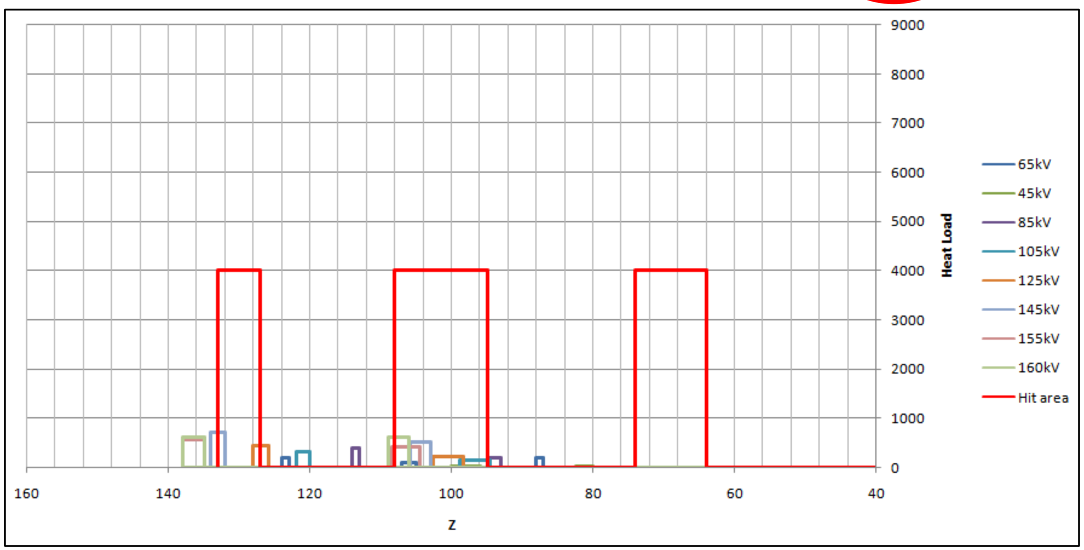
Toshiba investigation #4

- Without counter coil current

<u>Simulation result</u>

Beam radius becomes 98% of drift tube



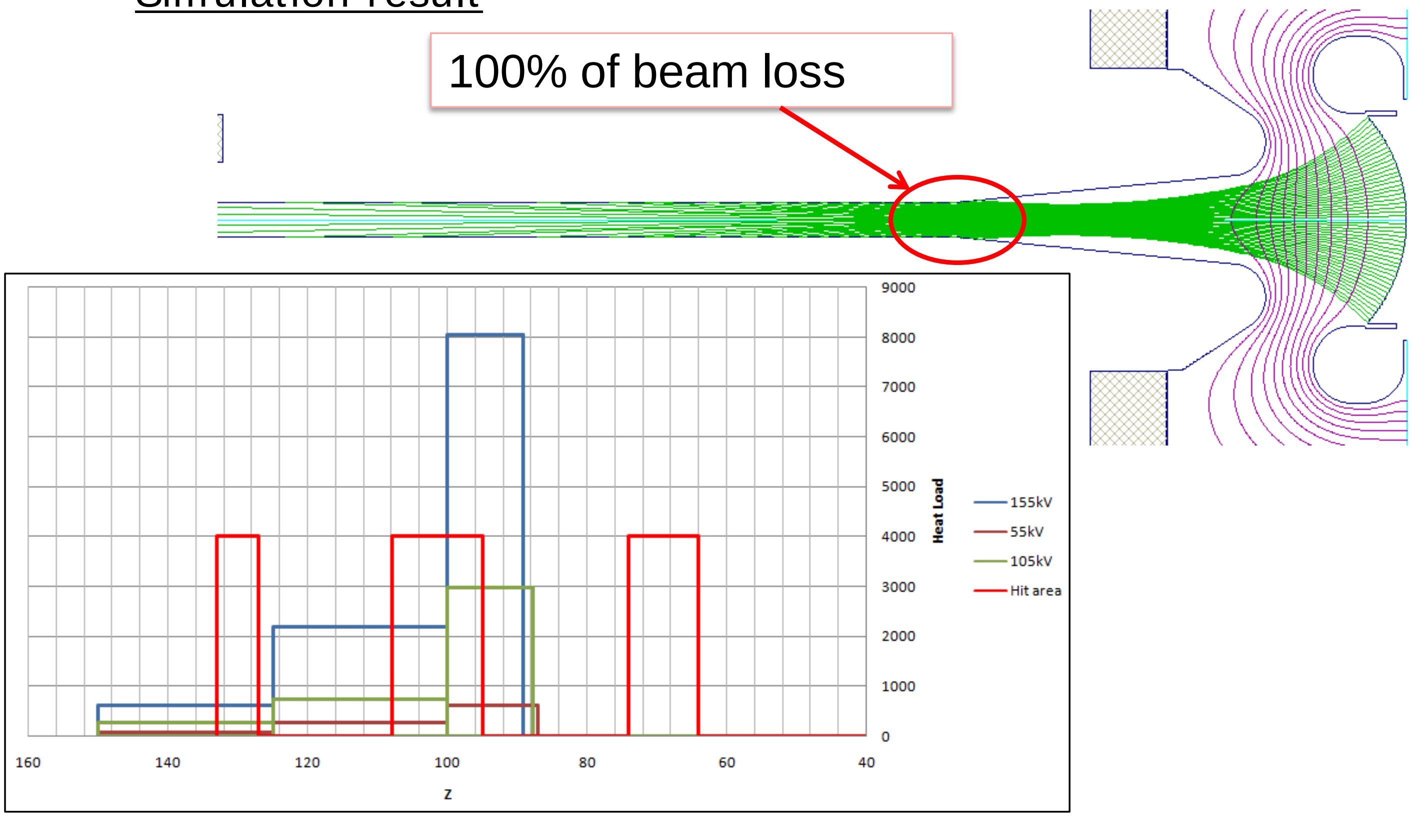


Simulation and the similar trend

Toshiba investigation #4

- Without focusing magnetic field

<u>Simulation result</u>



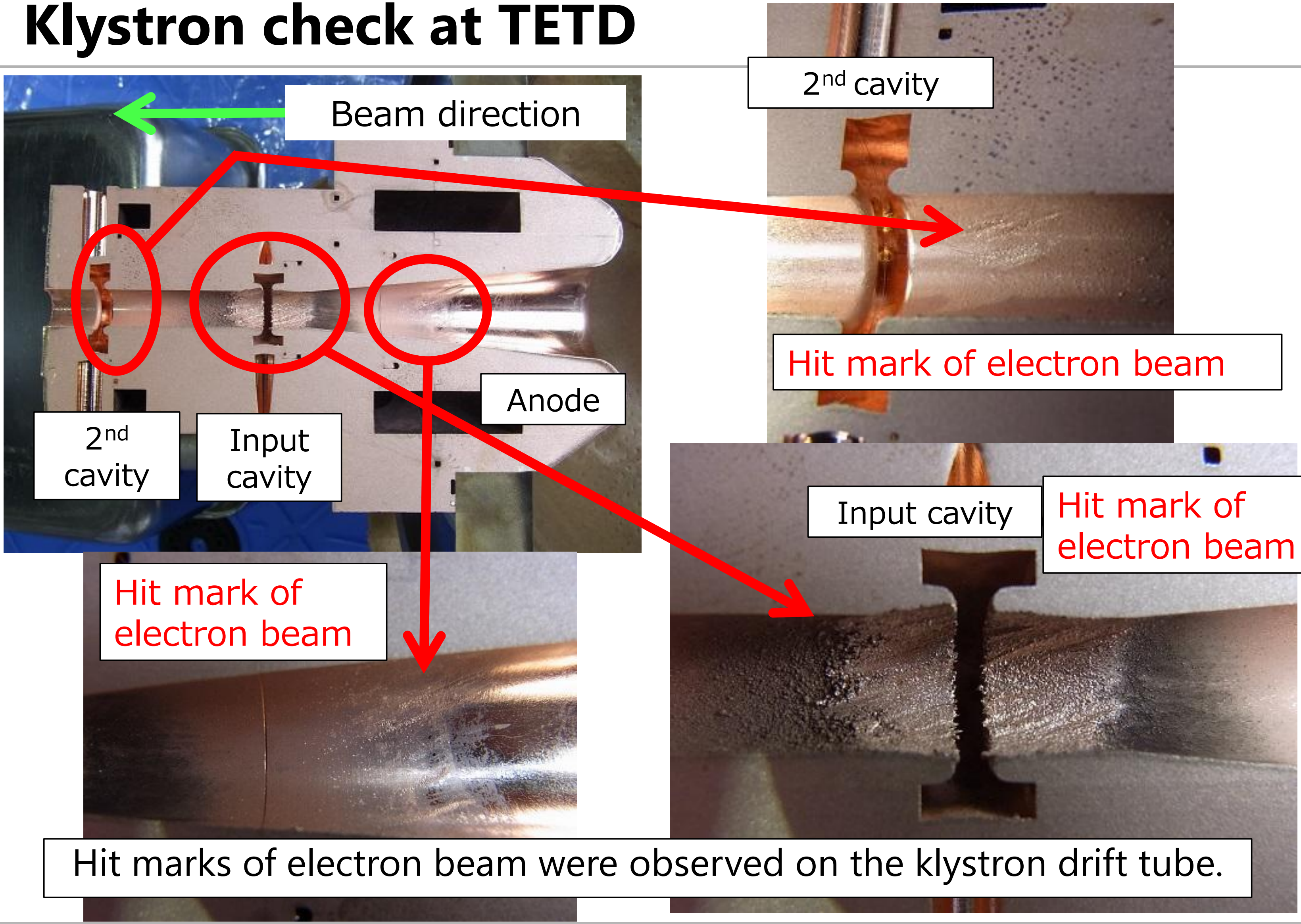
Simulation and the different trend

4-2. Wiring of counter coil check

While checking the polarity of the power supply side.

CERN confirmed the correct connection.

Klystron check at TETD



Hit marks of electron beam were observed on the klystron drift tube.

Toshiba investigation #4

5. Conclusion

- Hit marks of electron beam were observed on the klystron drift tube.
- Hit the drift in same place with reverse polarity or without current of counter coil simulation.
- Wiring of counter coil check
  - While checking the polarity of the power supply side.

  Unknown when the polarity is reversed.

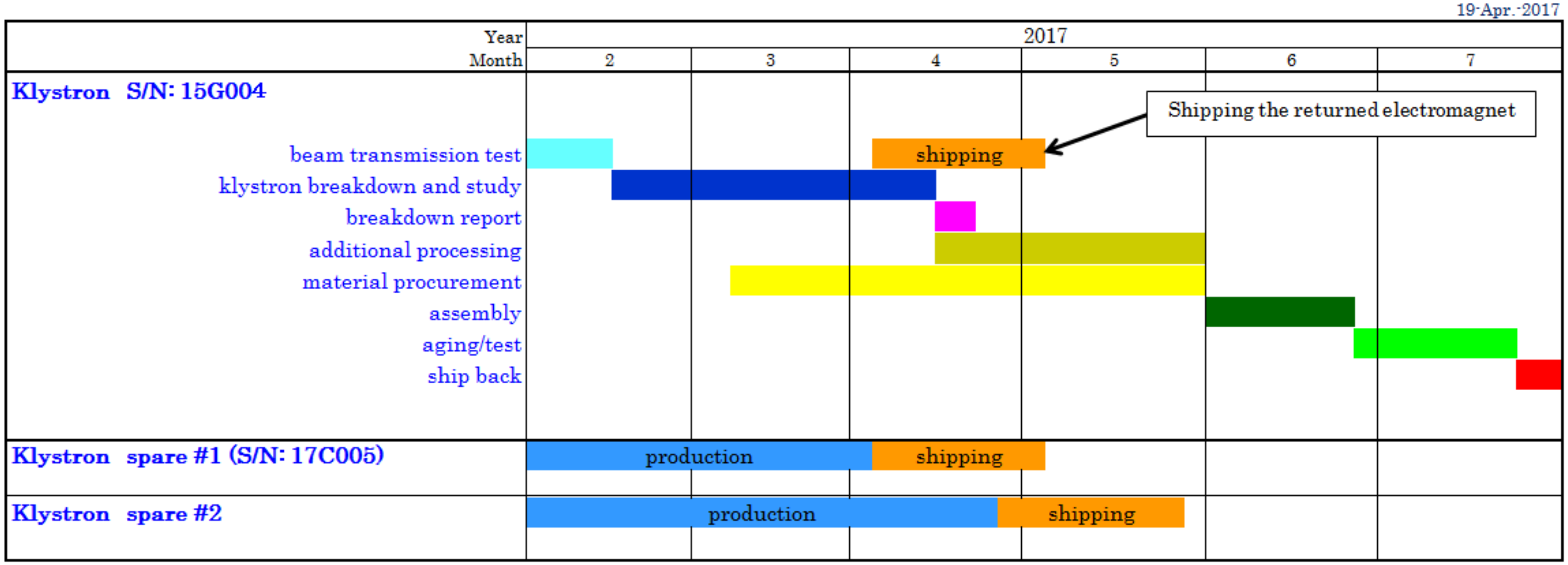
When did this happen ?
Why ?
Why did the body delta T interlock not work ?
Was it damaged at low rep rate
hence no large temperature difference ?

Toshiba investigation #4

7. Refurbish schedule

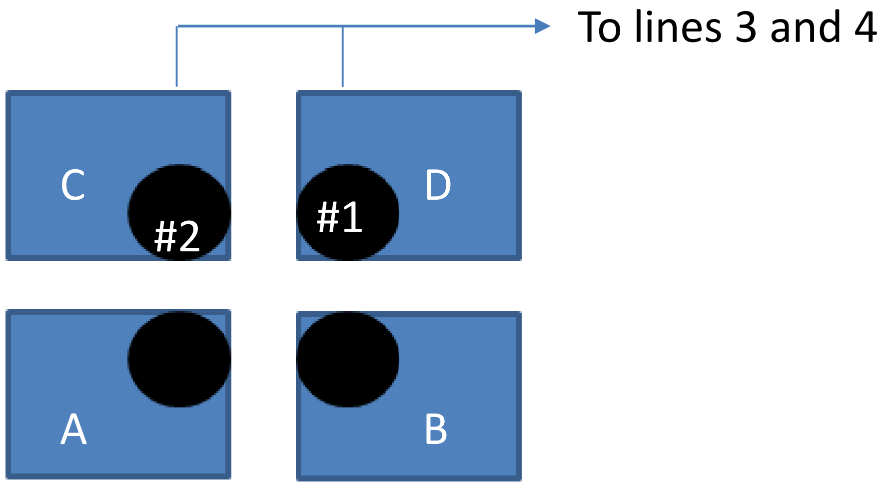
12 GHz Klystron Refurbish schedule

TOSHIBA Electron Tubes & Devices Co., Ltd.
Electron Tube Engineering Dept.
19-Apr.-2017



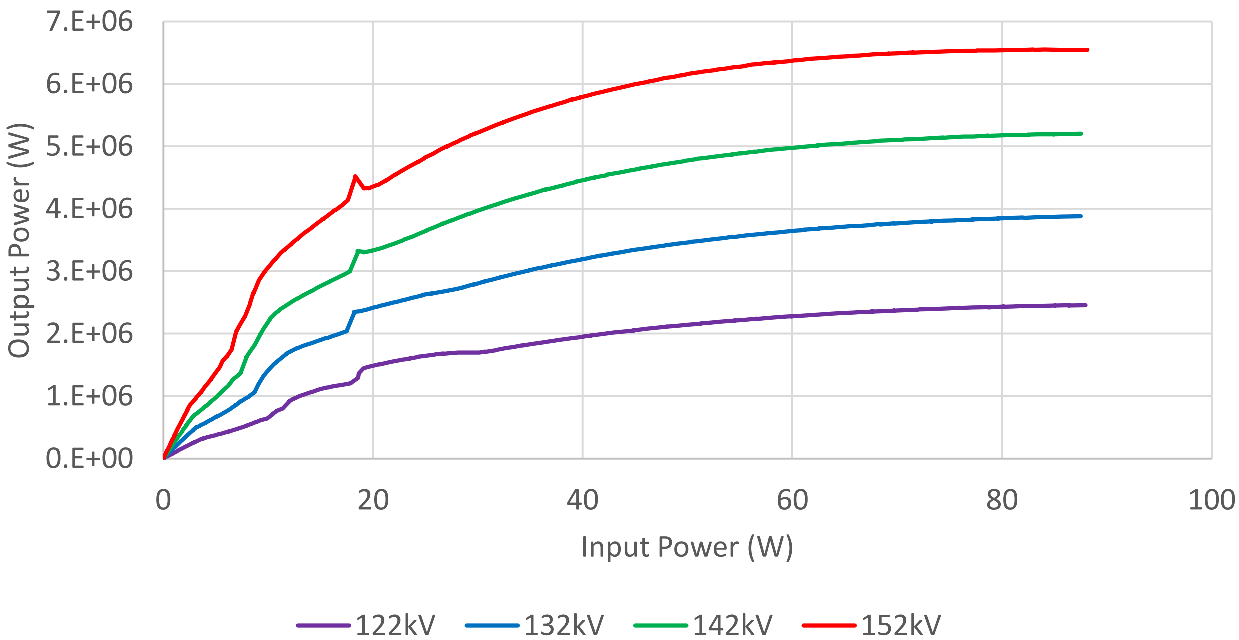
Xbox3_klystrons

- #2 and #3 combined together
- #1 used to condition loads
- LLRF works very well
- Conditioned RF network without structure lines 3&4
- Opened network to install structure , klystron #3 vacuum problem ,
- Toshiba engineer diagnoses window problem, tube sent back to Toshiba for evaluation last week
- Install #1 in modulator D to allow two klystron operation for lines 3 and 4



Implementation LLRF algorithm

- Works well in test bench
- Implemented on modulators C and D
- Combination of high power very good and switching between lines worked well (Matteo's talk)
- Operation problem when ramping up after breakdown, phase instability
- Investigation shows problem with tube #2
- FIlament hours 4619 , high voltage hours 3229

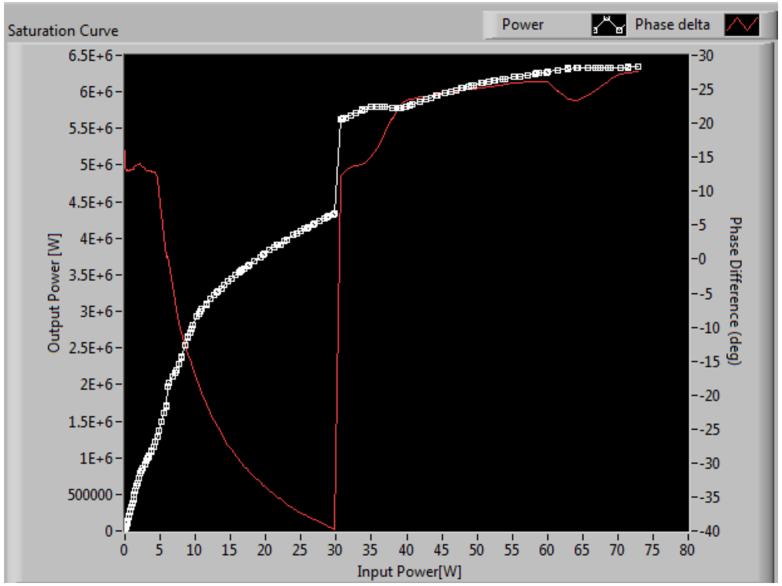


Solid state amplifier and low level changed
Problem stayed with klystron

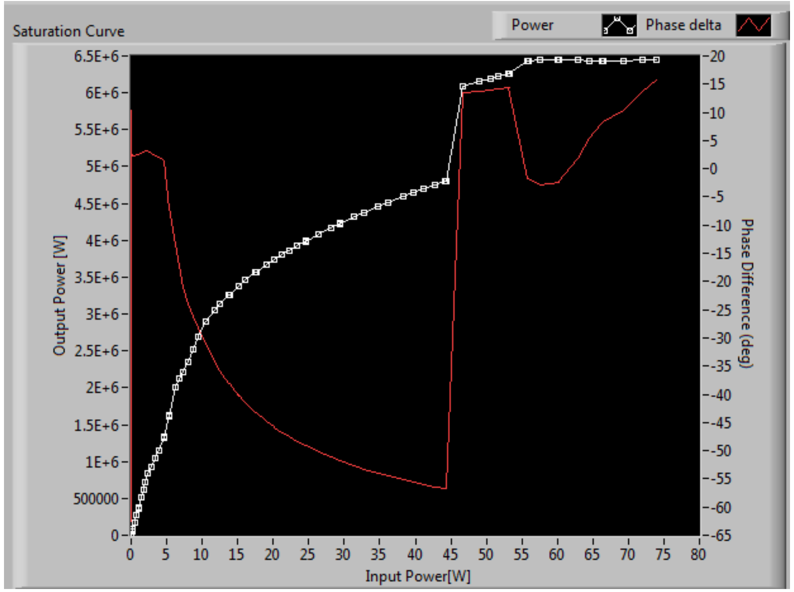
Small changes in solenoid or counter coil only shifted the problem to different input power

VNA measurement on input cavity , frequency ok

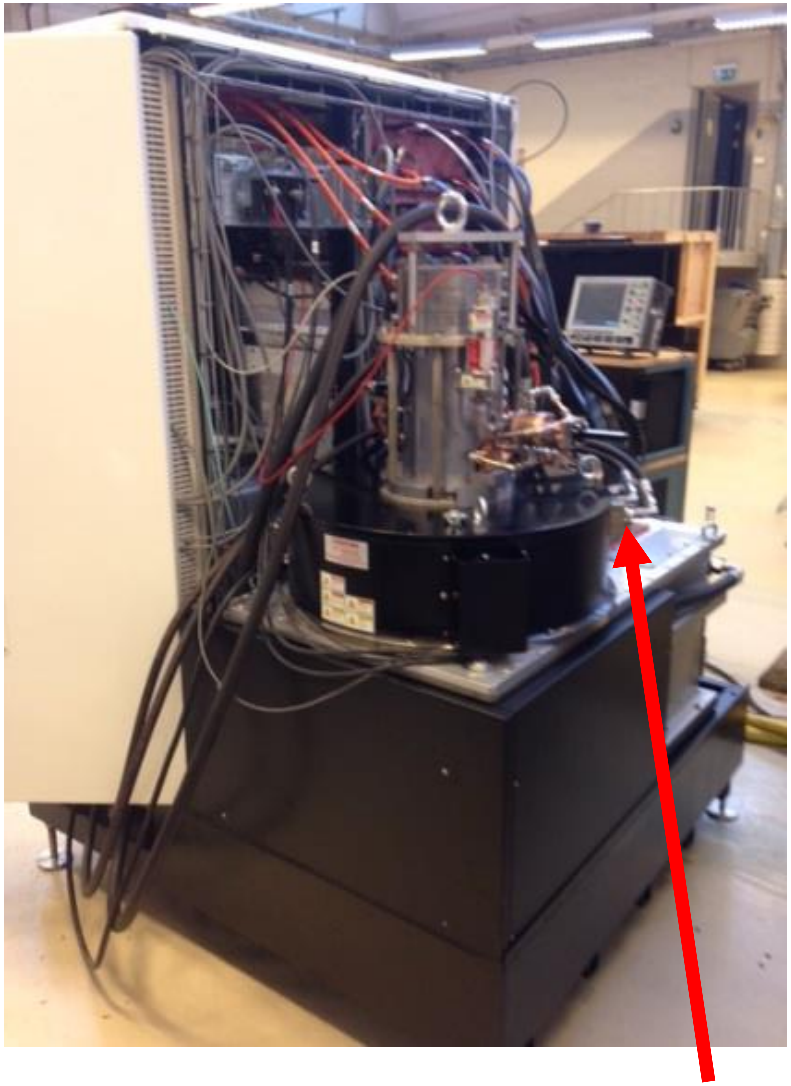
Implementation LLRF algorithm



26th May

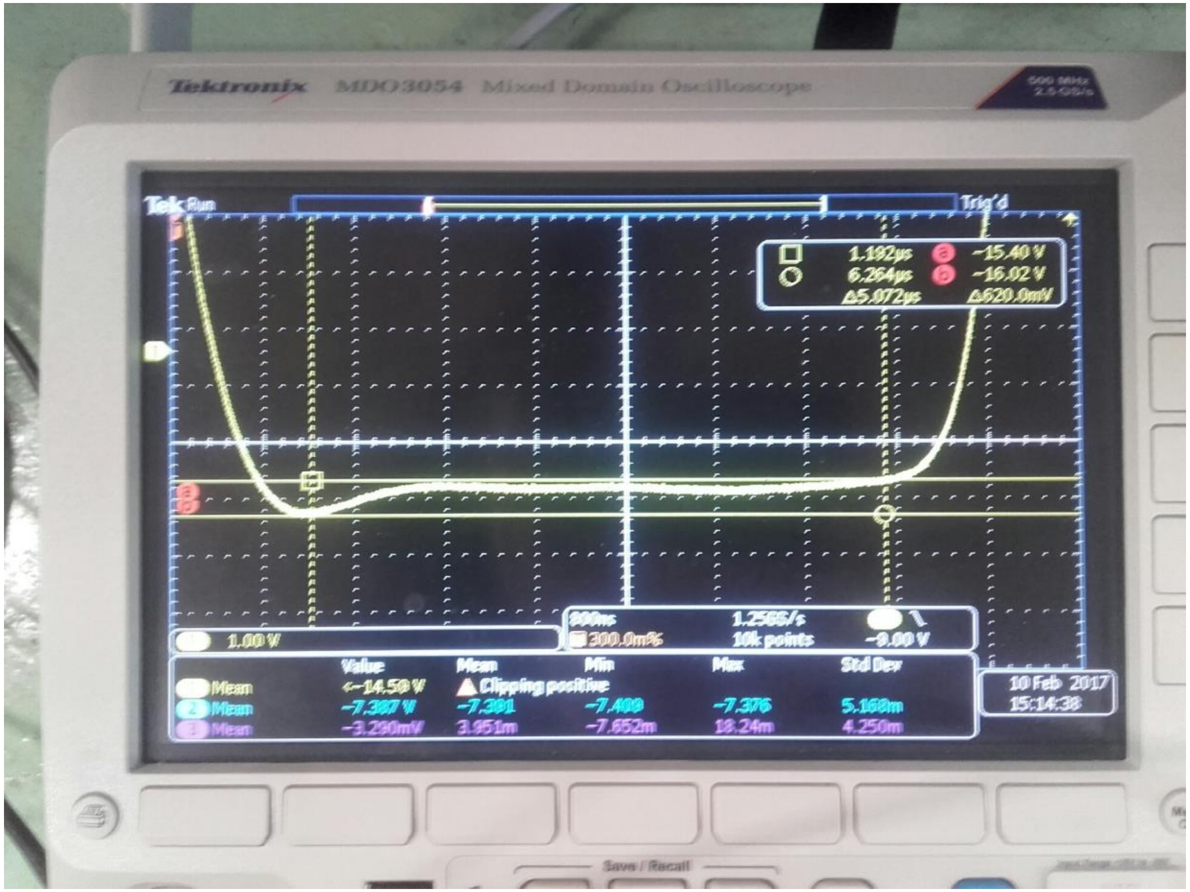


9th June



Increased radiation levels
Water cooling outlet of solenoid

Perveance change of #2 with rep rate



Initially asked to investigate why power output had reduced on klystron

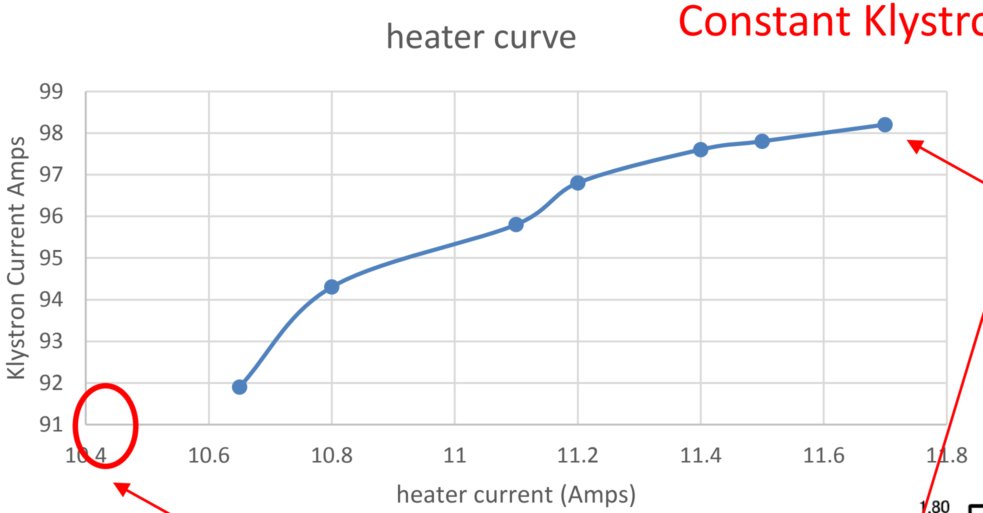
Noticed perveance change

Increased heater current by 1 amp and recovered tube perveance

Rep rate changed
again perveance changed
More investigations

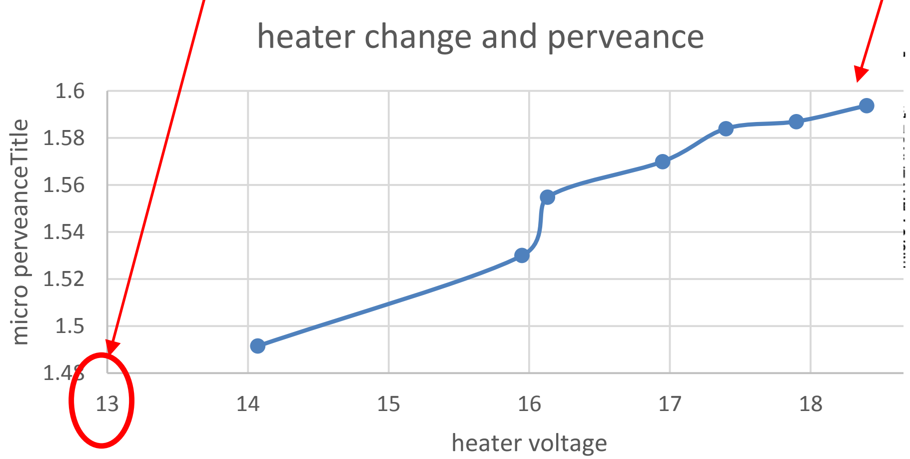
Heater curves #2

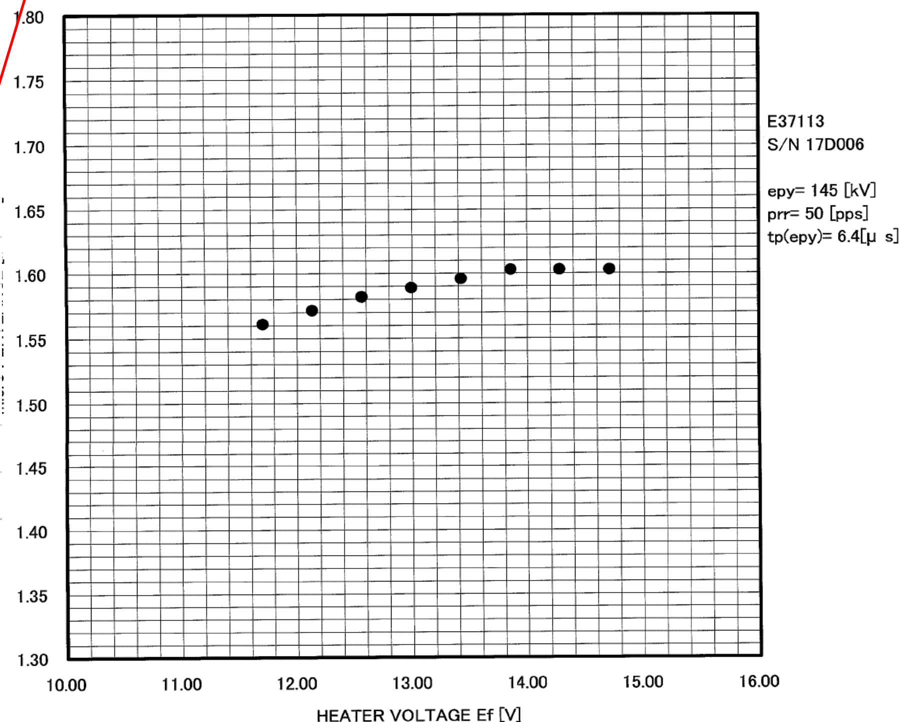
Constant Klystron Voltage 150kV



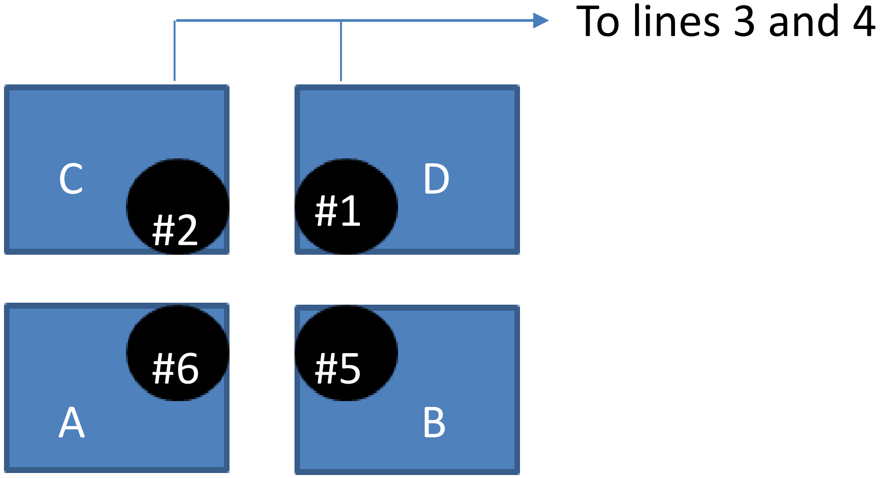
Limit of heater power supply in modulator

Nominal operating point from factory test





Xbox3 today

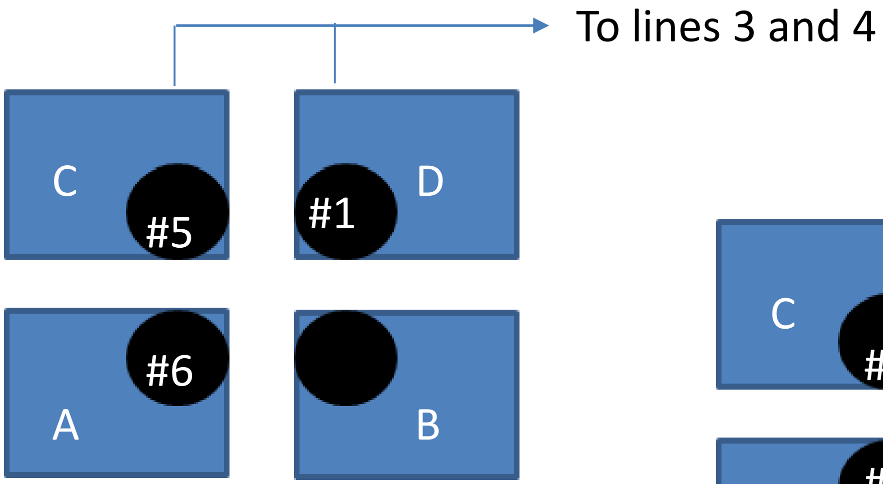


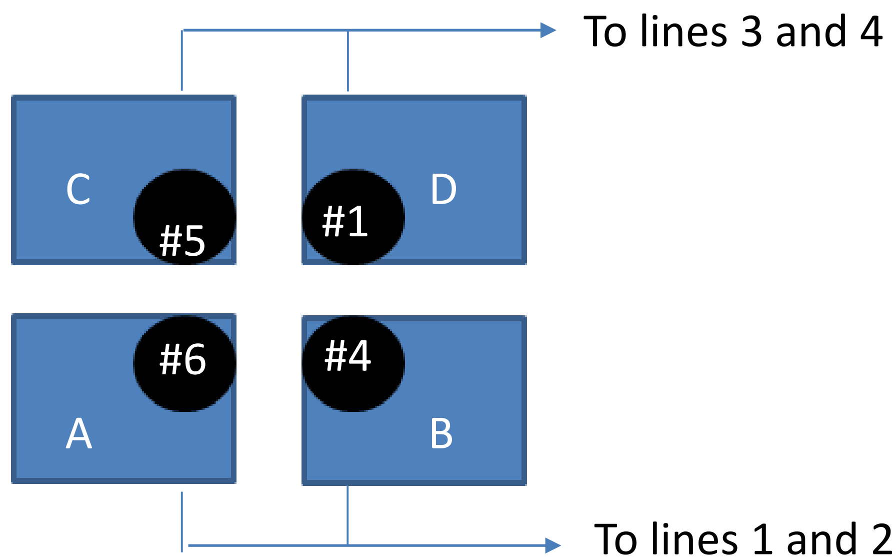
Continue testing lines 3 an 4
With instability

First week in July do commissioning of #5 and #6 with Toshiba engineer

After successful tests remove #2 and replace with one of the new tubes

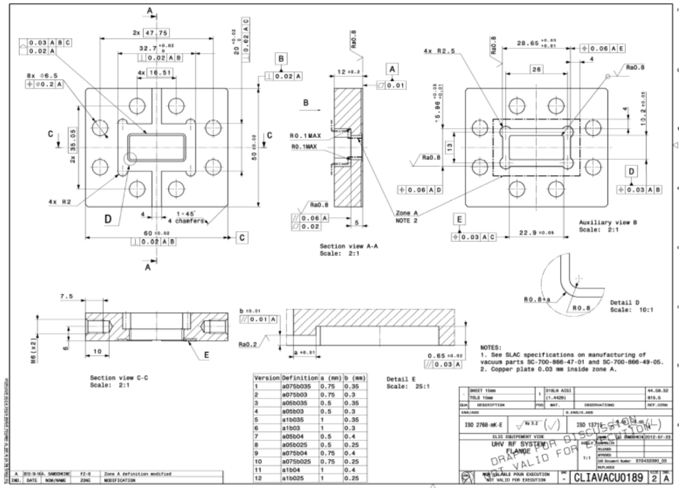
July/August hopefully receive refurbished #4 to complete lines 1 and 2

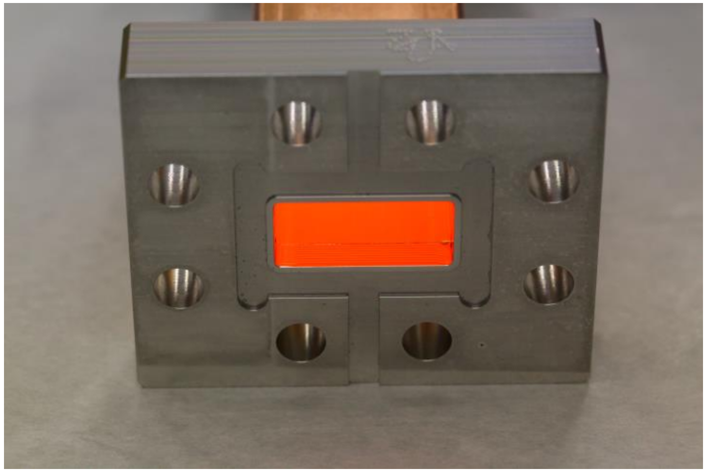




IUWR90 flanges

- New unisex Xband flanges are used in Xbox3
  - International committee with representatives of KEK, SLAC and CERN
  - Tested in SLAC up to 40 MW,1us and 10MW,200 ns
  - Tested at CERN, 5us, 5MW, 400Hz and ~42 MW, 200ns, 200Hz
  - Copper plating optimised
  - Vacuum gasket optimised, tried machined gasket and stamped gasket

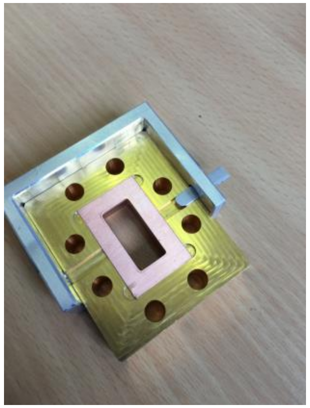




IUWR90 flanges

- Stamped gaskets
  - Friction fit
  - No problem in mounting
  - external machined edges of flange allowed alignment by touch

- Machined gasket
  - Loose fit needs to be held in place
  - Mounting jig needed



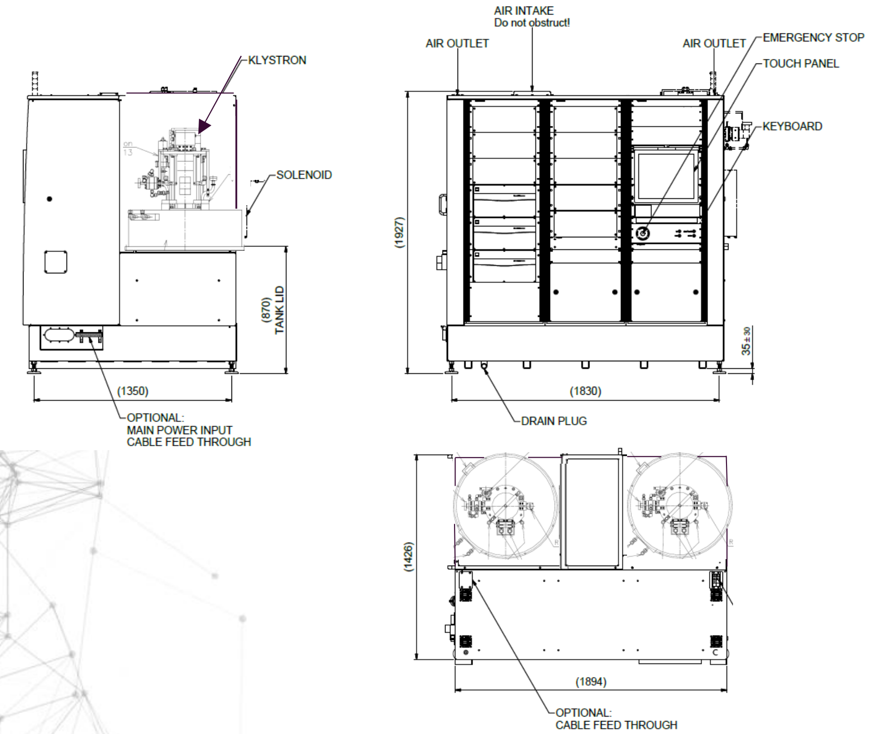
- Stamped gasket with friction fit is now being used

FUTURE

- Complete high gradient structure testing program by 2019
- Complete commissioning Xbox3 this year
- Configure Xbox1 to power structure in CLEAR (2018)
    - Upgrade LLRF ? And change pulse compressor?
    - Upgrade existing modulator to 100Hz?
- Upgrade Xbox2
    - Two structure testing, variable attenuator (Veronicas talk)
    - Upgrade existing modulator to 100Hz
- Xbox3
    - 50% of Xbox3 to Melbourne, collaboration
    - Conditioning structures seems to be dependant on number of pulses
    - Higher rep rate faster conditioning ?

ScandiNova

DUAL X-BAND 2X 6MW RF UNIT BASED ON K300 PLATFORM



K300 Platform front/side view

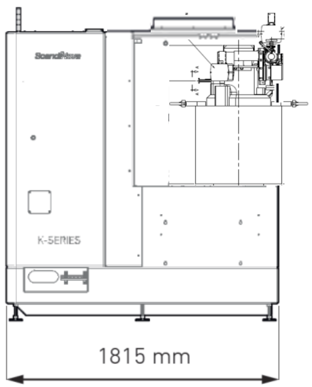
FUTURE

- Klystron based CLIC
- High efficiency klystron development (Igor's talk) ?

- Would need two klystrons per 2 m of LINAC
- Compact modulator needed for tunnel integration
- Test stand at CERN?

ScandiNova

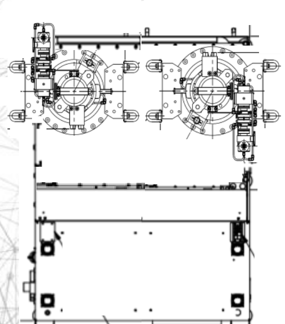
DUAL X-BAND 2X 50MW RF UNIT BASED ON K200 EXTENDED PLATFORM



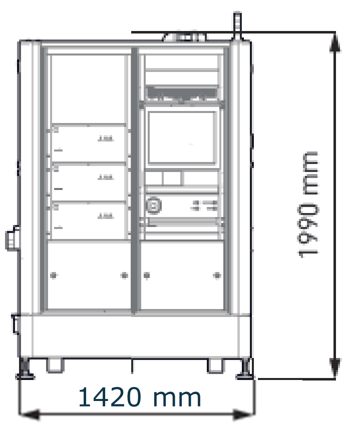
Side View

K200 Platform front/side view

Main Parameters	Values
RF Peak Power	100 MW (2x50)
RF Average Power	7.5 kW
Pulse Width	1.5 μs
Pulse repetition	50 Hz
Klystron Efficiency	75%
Perveance	0.86 μperv
Pulse Voltage	360 kV
Pulse Current	185 A
Mod. Average Power	21 kW
Length	1420 mm
Depth	1815 mm
Height	1990 mm



Top View



Front View

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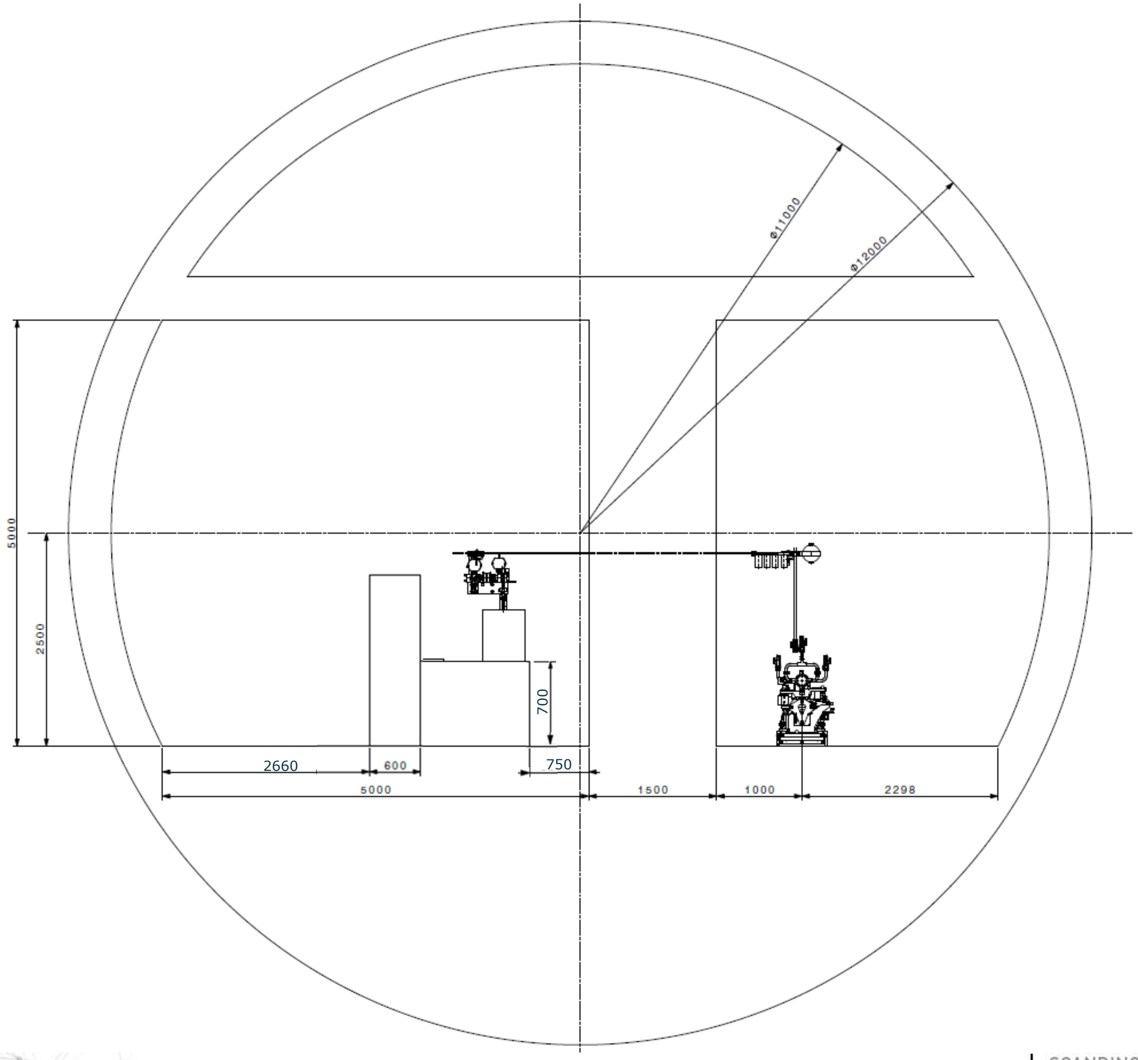
TUNNEL SIDE VIEW



Thanks for your attenti

ANY QUESTIONS ?