High-Gradient structures at Tsinghua University

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outline

- Overview of high-gradient activities at Tsinghua Univ.
- X-band HG structure at THU
  - T24_THU_#1 structure
  - Choke-mode structure
  - ANL collaboration
  - New application in Thomson Scattering
- Breakdown study
  - Laser triggered RF breakdown
  - Field emission study
- Future plan

Overview of high-gradient at Tsinghua

- CLIC-study collaboration
  - Start from 2009
  - “Choke-mode damped structure”, design, producing, testing, …
- NSFC project on “research of physics and key technologies of high-gradient X-band accelerating structures”
  - 5-year program starting from 2012
  - Focus on RF breakdown study, X-band structure design, X-band structure manufacturing…
- ANL collaboration
  - X-band metallic PETS
  - X-band structure, C3
- HG structure application in compact Thomson source

Tsinghua Production – machine shop

high-precision machine tools and CNC Machine

ability to fabricate more than 100 low energy linac tubes per year

Tsinghua Production - Facility for brazing and baking

Hydrogen furnaces

Leak detector

Annealing furnace

Vacuum furnace

Baking oven

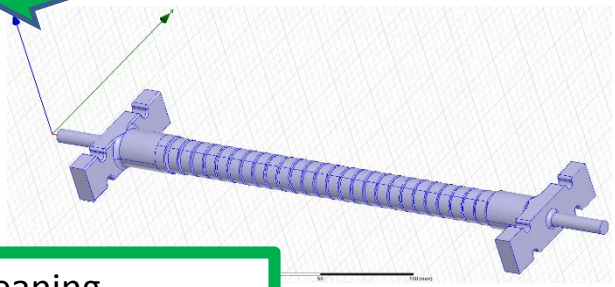
Assembly of T24

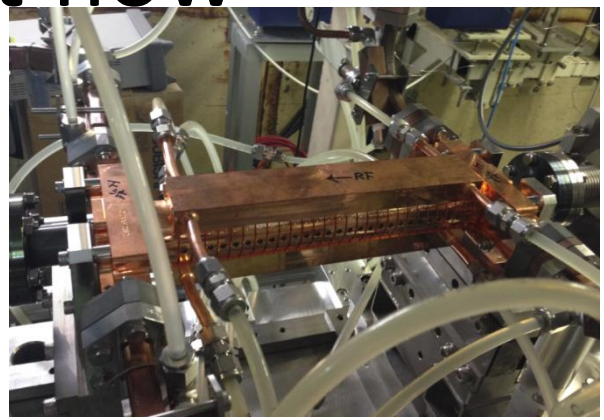
- The assembly of T24, with cells shipped from CERN, (machined at VDL)
- Validate the production capability at Tsinghua while we are still improve the machining.
- The procedure that includes etching and cleaning, bonding and brazing, tuning, baking

T24_THU_#1 fab/test flow

Fabrication of parts (VDL)

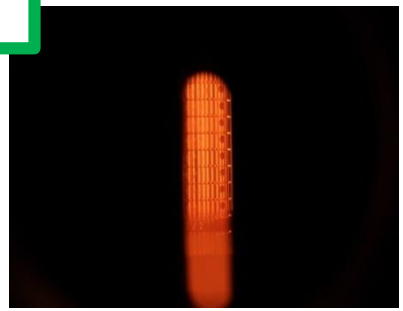
Design for CLIC (CERN)





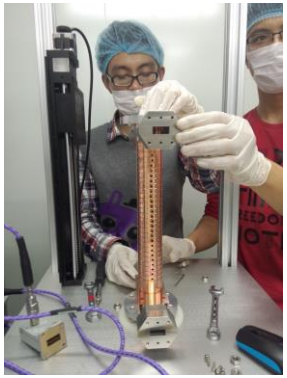
Cleaning
Etching
(Tsinghua Univ.)

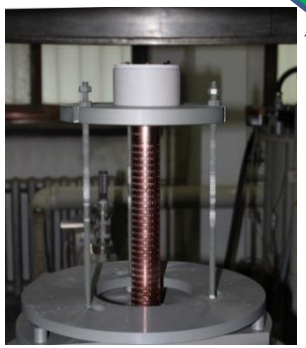
High power test
(Nextef-KEK)



Bench test (Tsinghua Univ.)

Vac bake (Tsinghua Univ.)





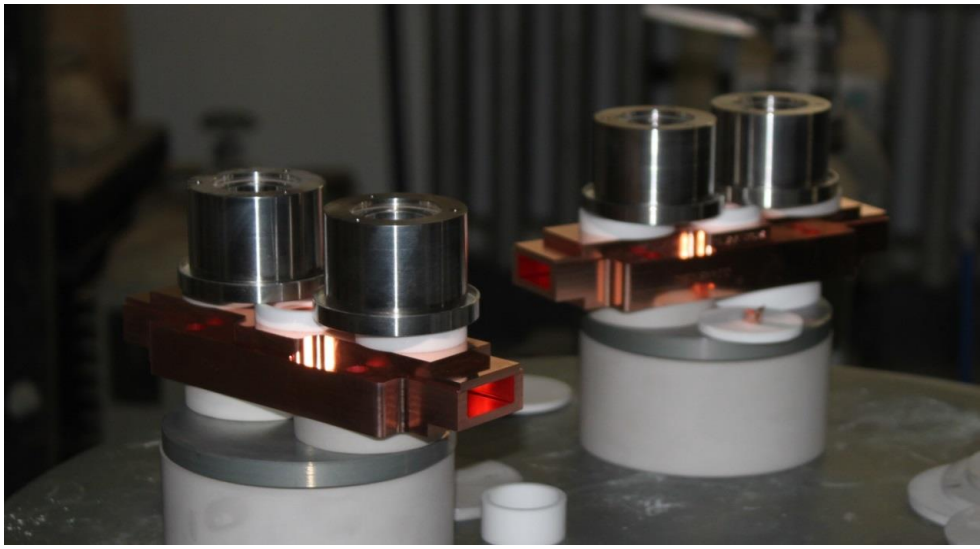
Bonding Brazing
(Tsinghua Univ.)

Tuning(Tsinghua Univ.)

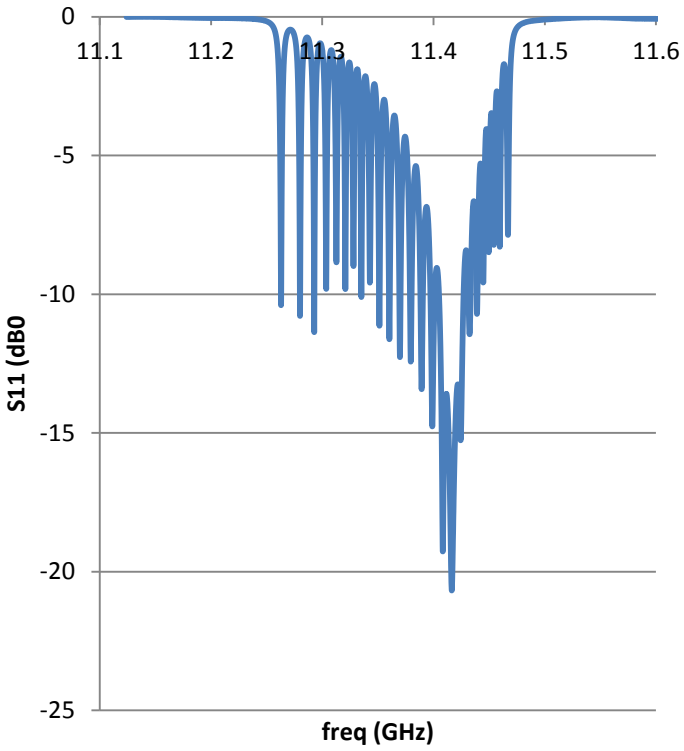
The assembly of T24_THU_#1 (1)

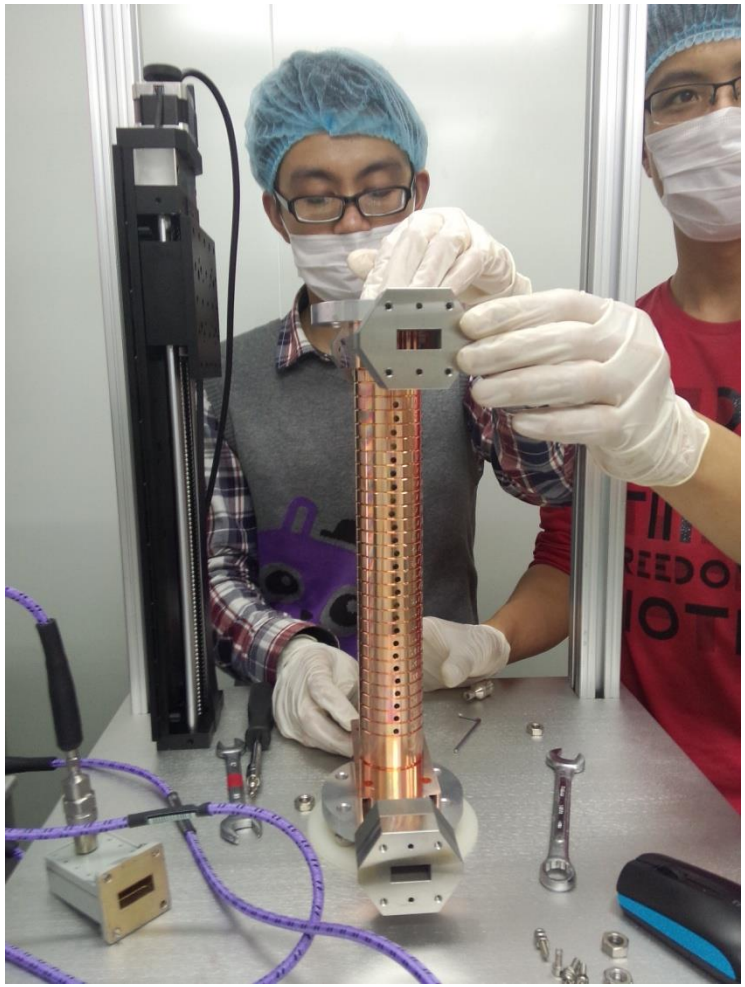
- Cleaning/etching

- Brazing of the couplers



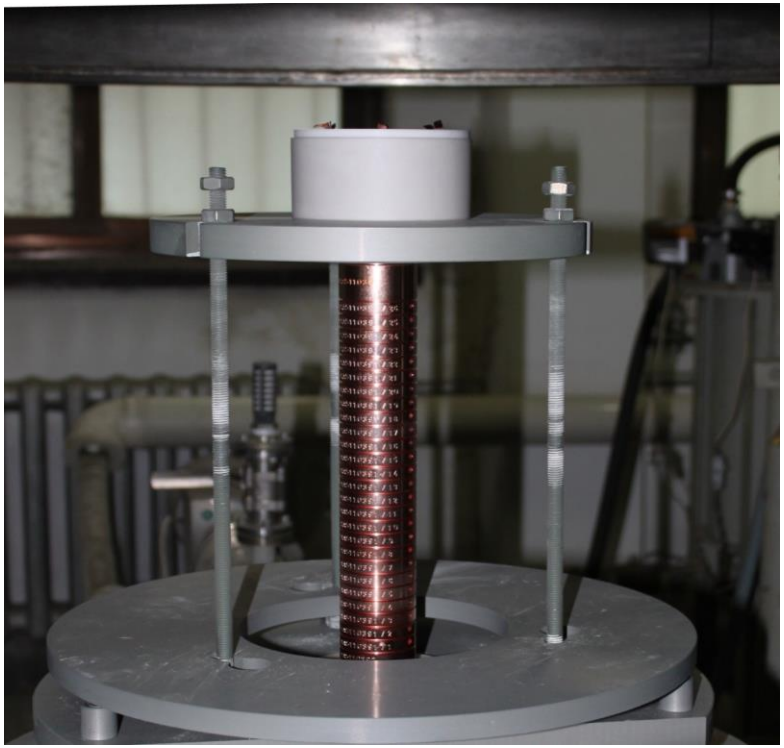
The assembly of T24_THU_#1 (2)
RF check before bonding

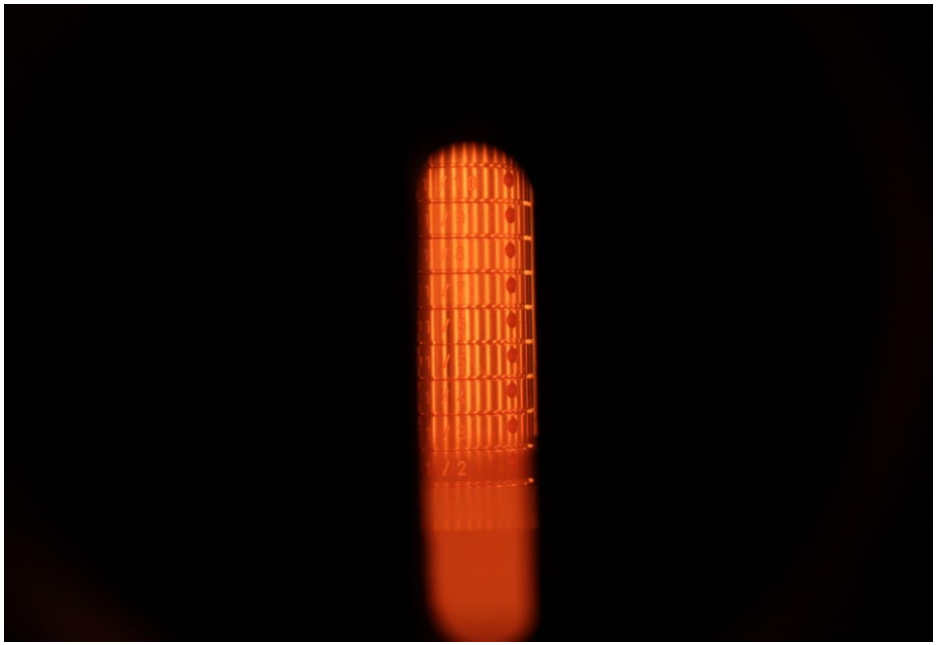




The assembly of T24_THU_#1 (3) Bonding

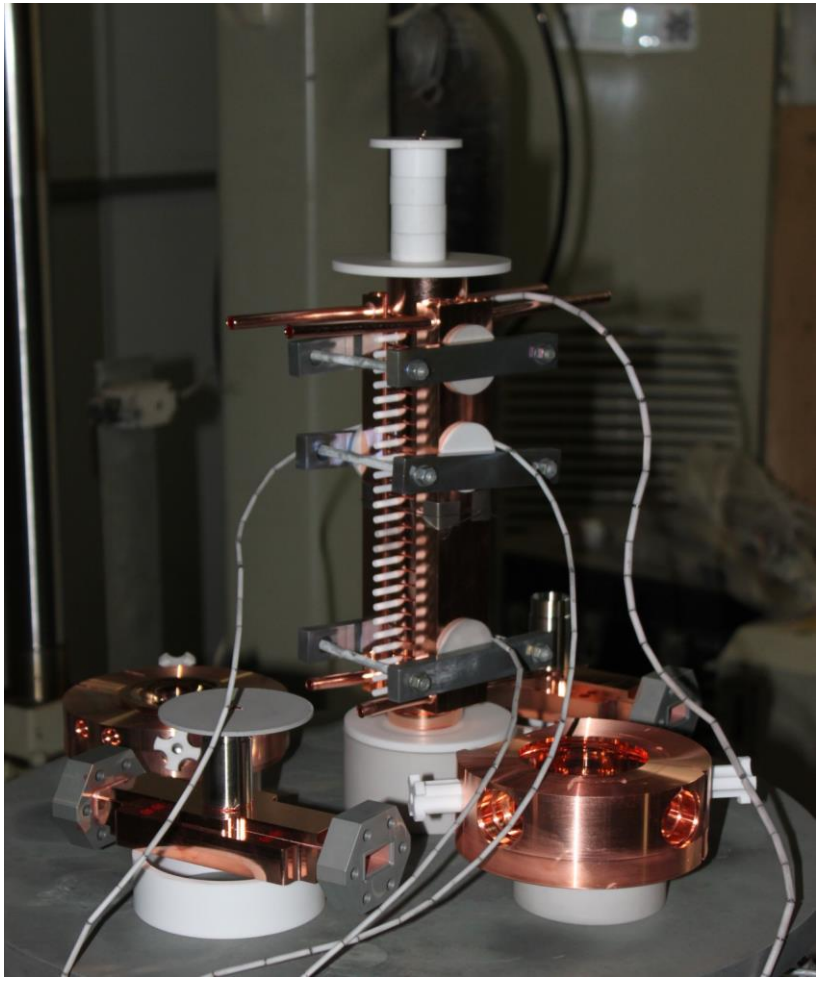
- Reduced pressure at 0.1MPa.





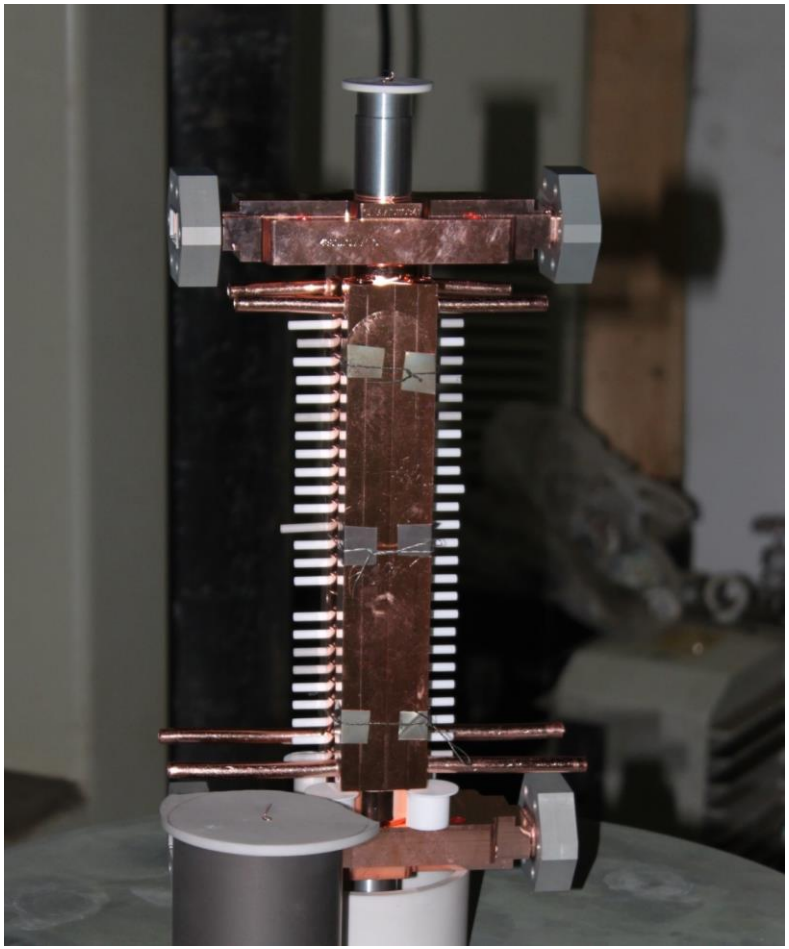
The assembly of T24_THU_#1 (4) Brazing step1

- AuCu75



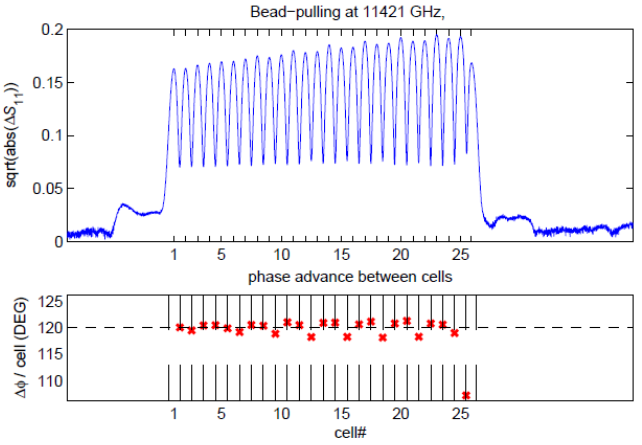
The assembly of T24_THU_#1 (5)
Brazing step 2

- AuCu65



The assembly of T24_THU_#1 (5) Tuning and baking

- Bench test showed an excellent result after Tuning



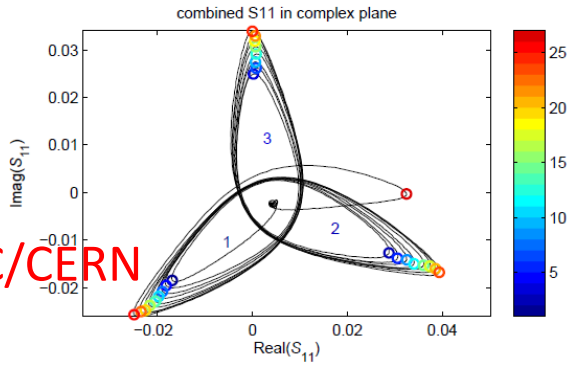
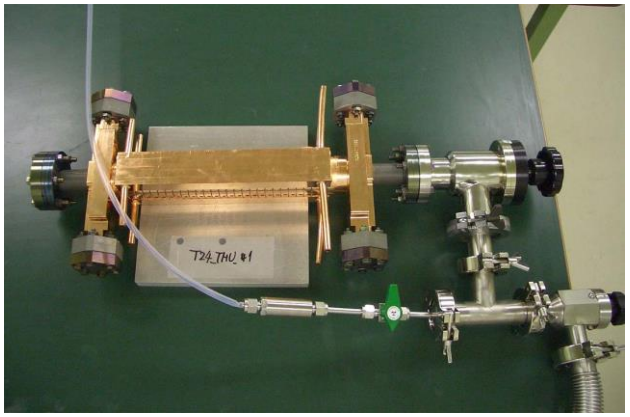


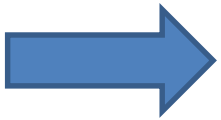
Figure 12: Bead-pulling at 11421 GHz

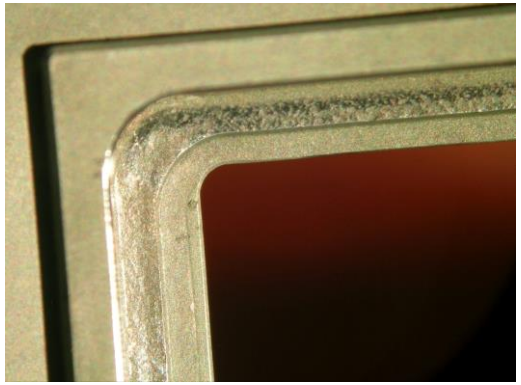
- Baking is done at 500 degree C, 4 days
  - Compare to 650 degree C, 10 days @KEK/SLAC/CERN

Installation in Nextef

Vacuum problem with ss RF flange. Hand lapping solved the problem







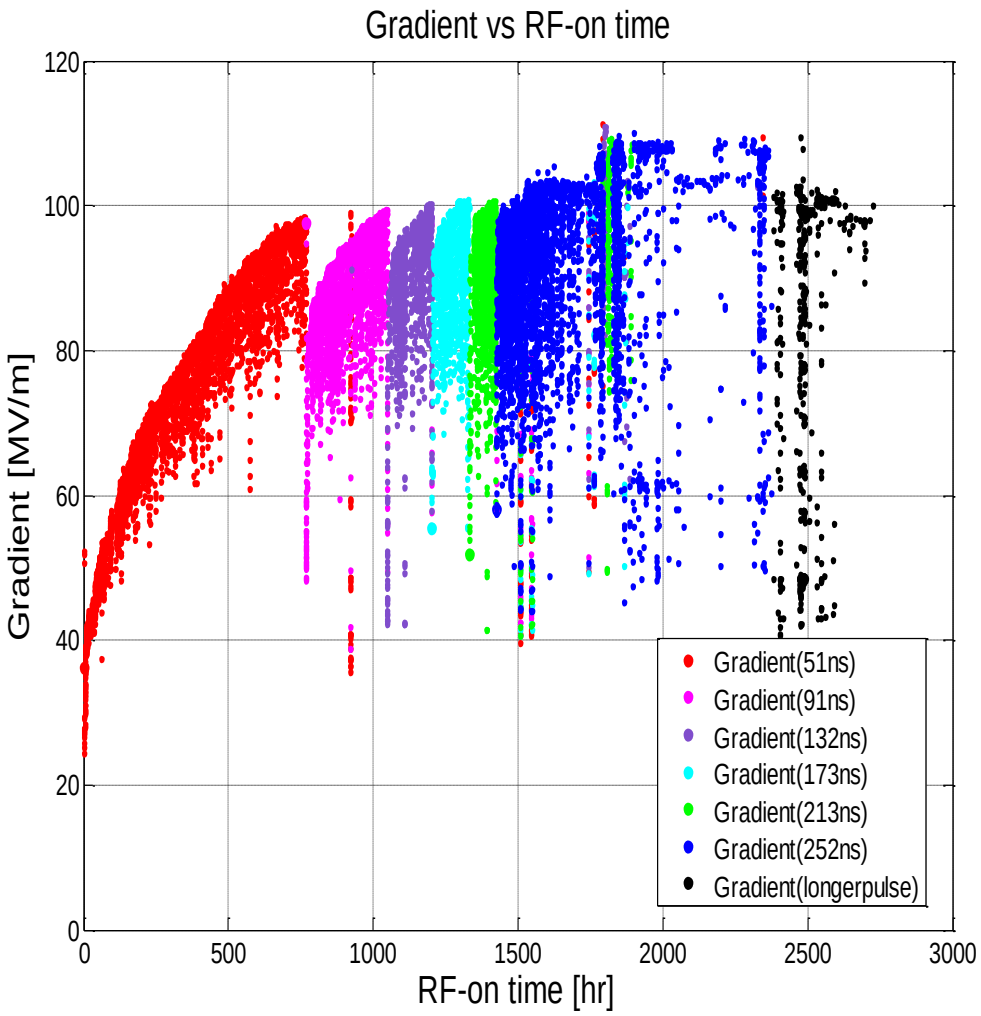
Edge before and after hand lapping
Question of heat cycle?

Photos from Higo @KEK

High power test Nextef@KEK, Sep 2014 - Jul 2015

Note: data of June and July not included

- **High gradient (100MV/m) was achieved**
- **Over 2700 hours RF-on time**
- **Focus on 252ns pulse width operation**
- **Try higher gradient (~110MV/m)**
- **Even go longer pulse operation (293ns/312ns/331ns/392ns/ 412ns pulse width)**



From HG2015 (Wu)

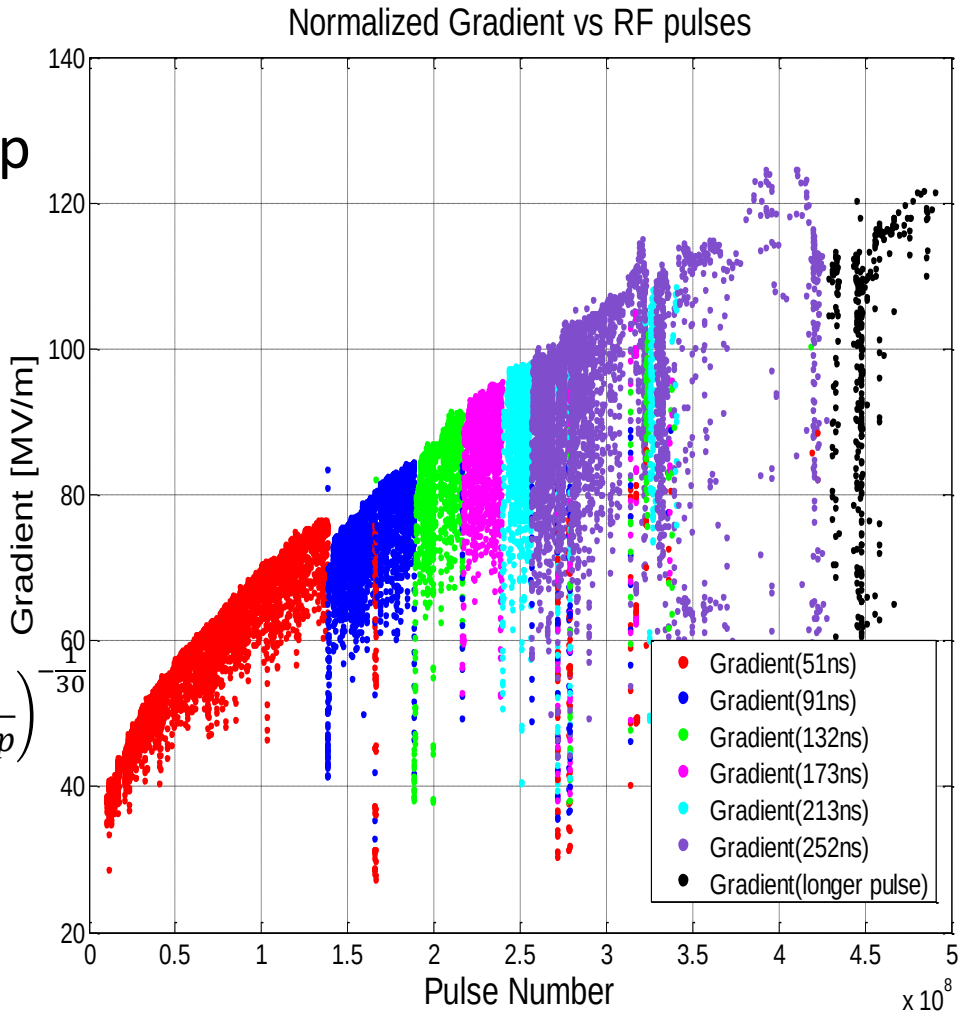
Normalized Gradient plot

- Normalize to 252ns, 2e-5 bpp
- BDR calculated by last 10M pulses

$$\frac{E_a^{30} \cdot t_p^5}{BDR} = const$$

$$E \propto t_{pulse}{}^{-\frac{1}{6}} * BDR^{\frac{1}{30}}$$

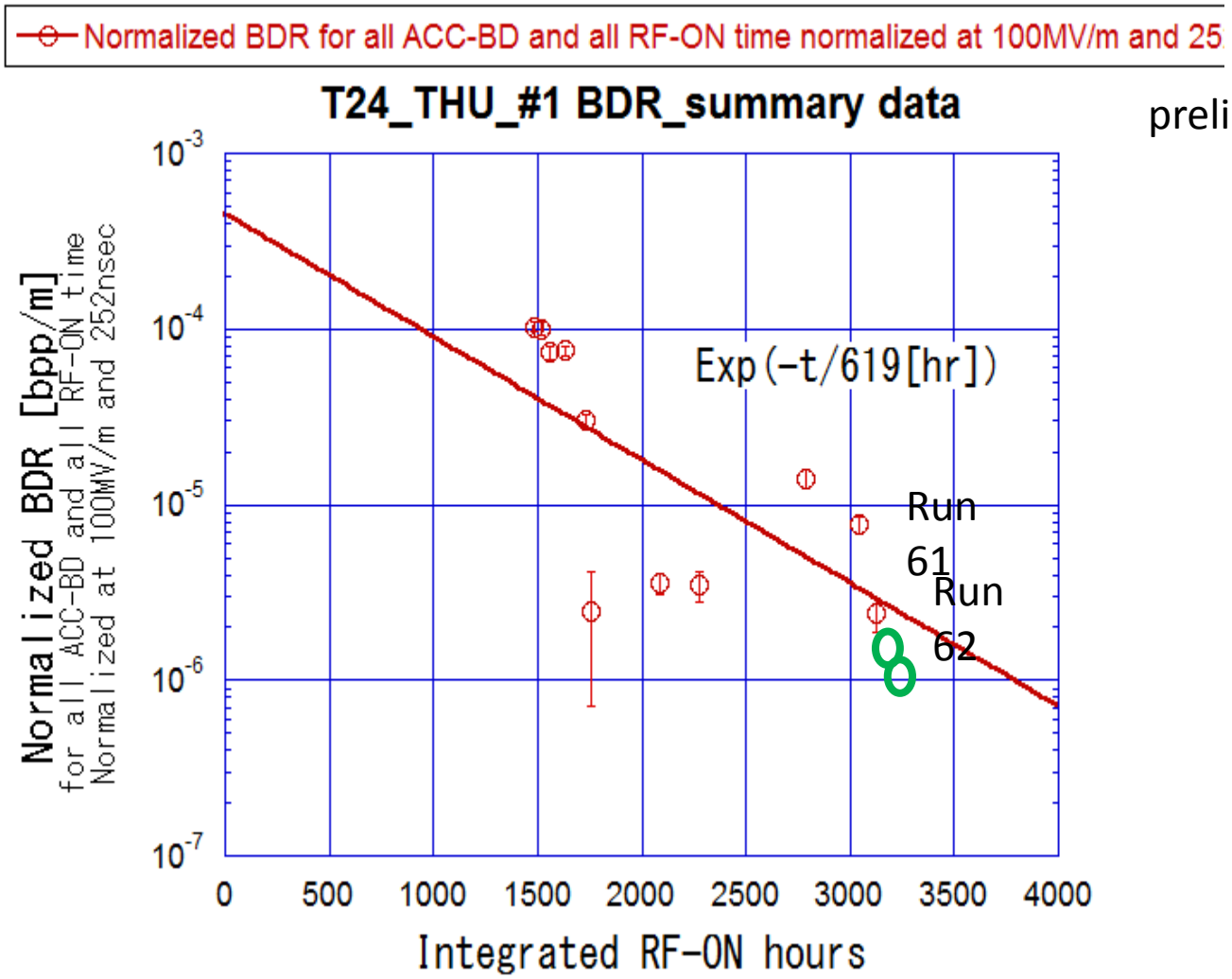
$$E^* = E \cdot \left(\frac{t_{pulse}}{252ns}\right)^{\frac{1}{6}} \cdot \left(\frac{BDR}{2 \times 10^{-5} bpp}\right)^{-\frac{1}{30}}$$



Note: data of June and July not included

From HG2015 (Wu)

T24THU#1 Normalized BDR vs RF-ON time

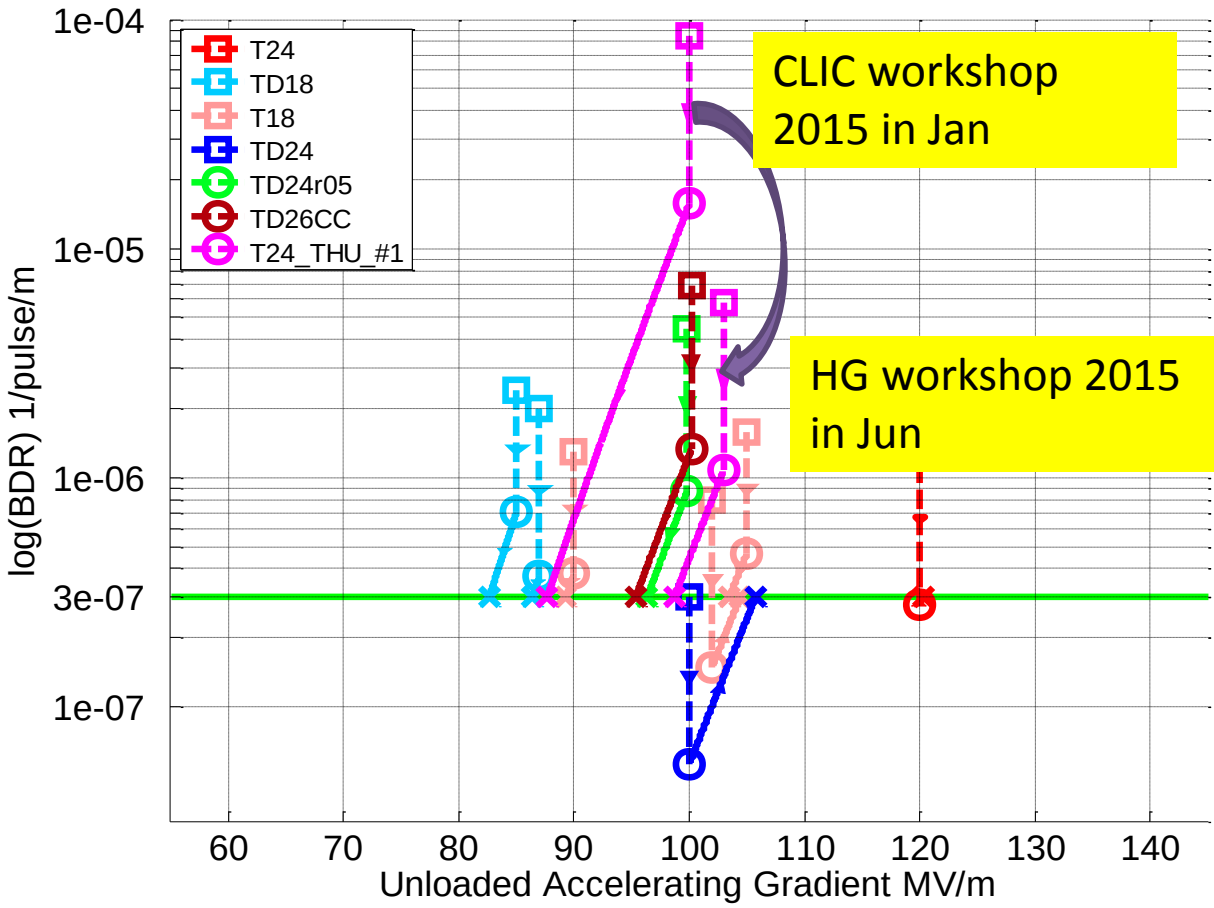


preliminary

From HG2015 (Wu)

Comparison of tested structures

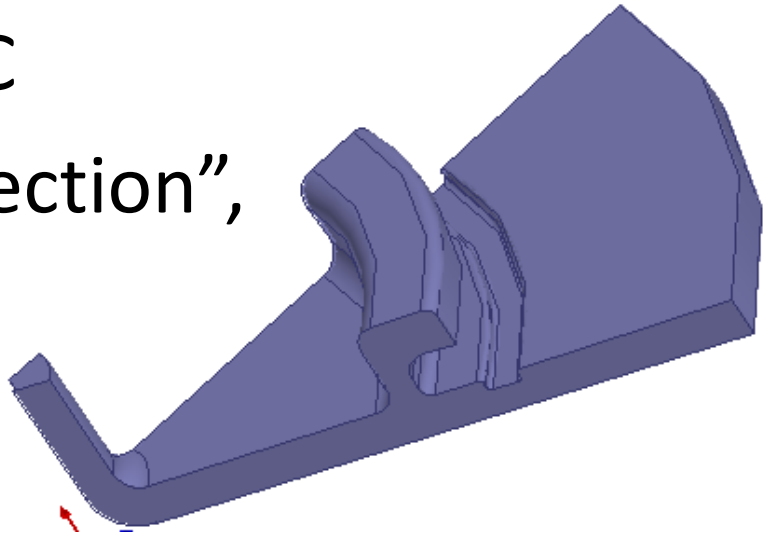
- **Data from run62: 20 BDs in 91 hours → 5.82e-6 bpp/m**
- **Gradient almost reached 100MV/m after normalized to CLIC standard**
- **Another 1500 hours RF-on time from CLIC workshop2015 to HG2015**

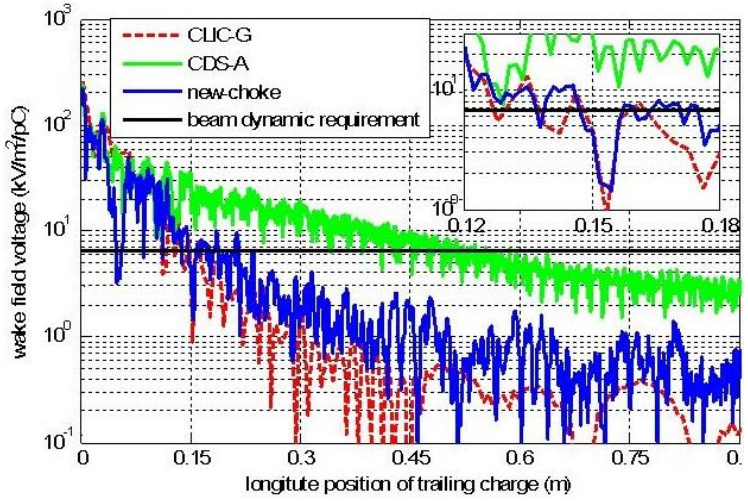


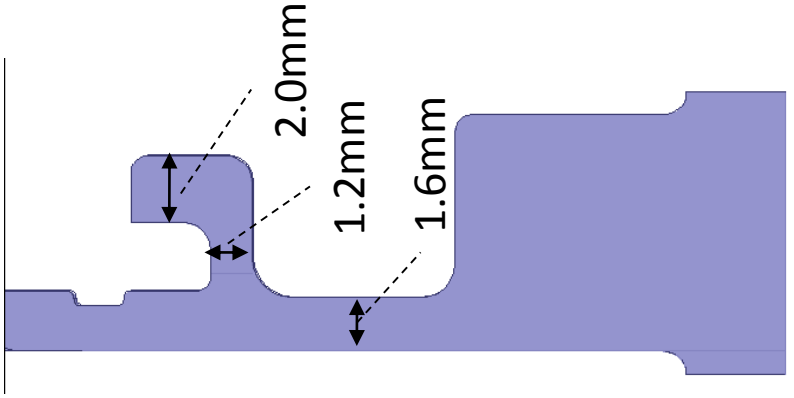
From HG2015 (Wu)

Choke-mode structure

- New choke design CDS-C
- Features include “two-section”, “impedance matching”, “detuning”



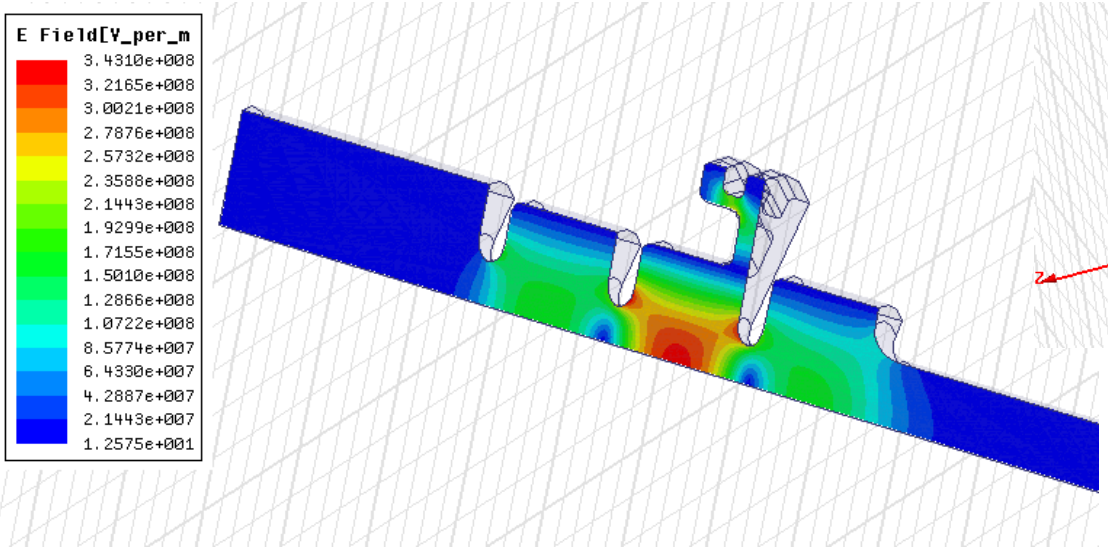


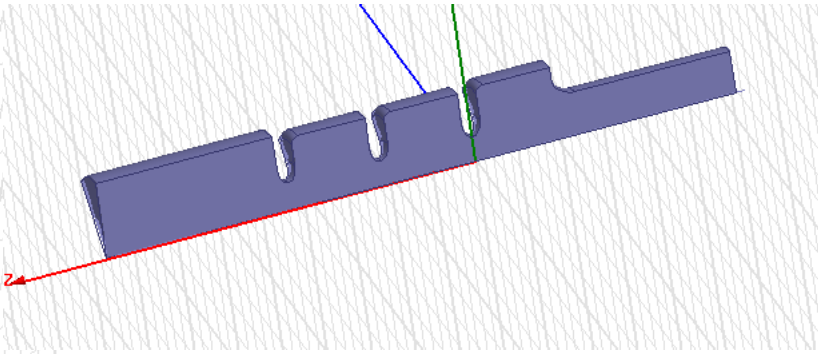


[1] Hao Zha

Single-cell SW test structure

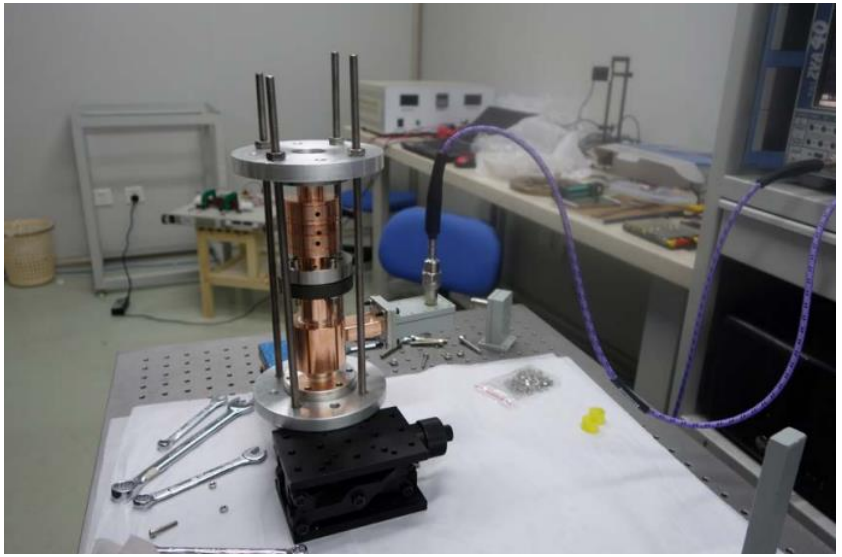
- Single cell standing wave
  - 1C-SW-A3.75-T2.6-CHOKE1.6 [Ref: V. Dolgashev]
  - To test breakdown behavior in the Choke
  - Also test un-damped to compare





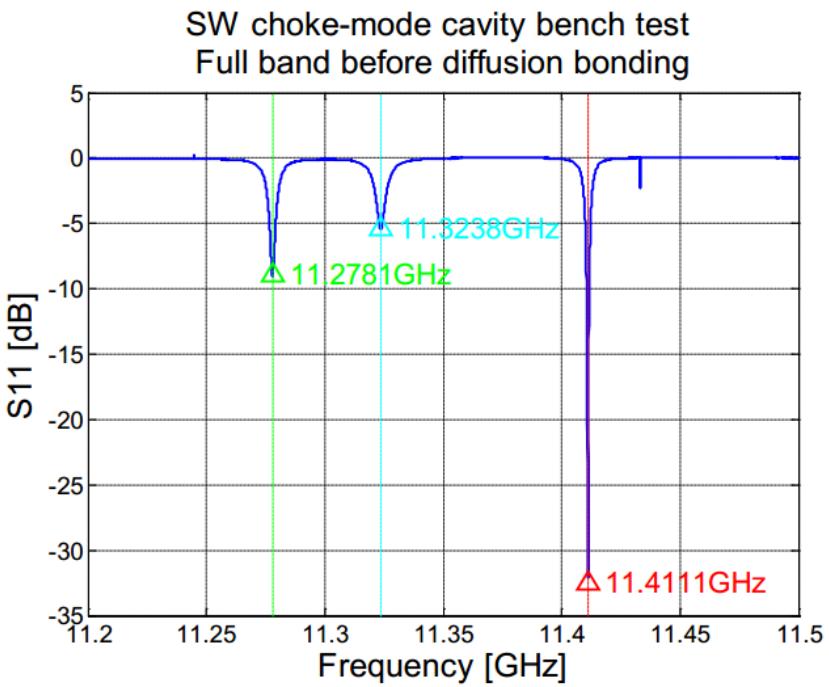
RF check before bonding(1)

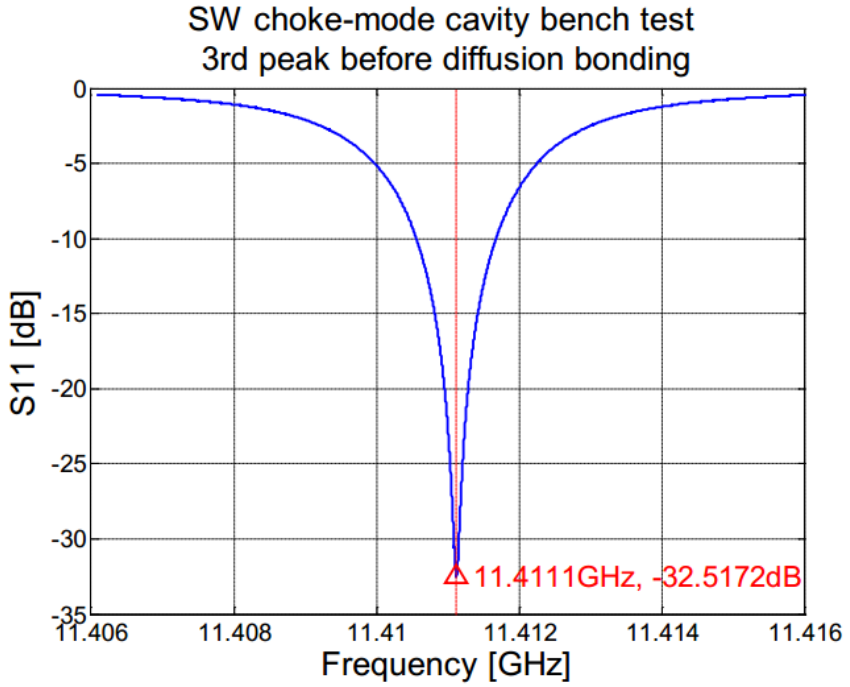
- Two sets of structures@11.424GHz
- Choke-mode cavity and undamped cavity



RF check before bonding(2)

- Good results for bench test
- Bonding completed mid. June/Brazing flanges completed August/Tuning coming soon
- high power test at KEK planned





Metallic X-band Power Extractor

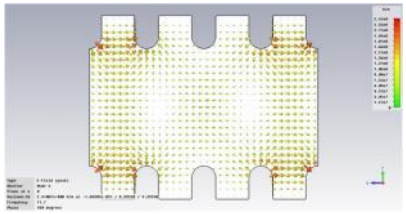
At 11.7GHz for RF power extraction at Argonne Wakefield Accelerator
Disk-loaded strucure

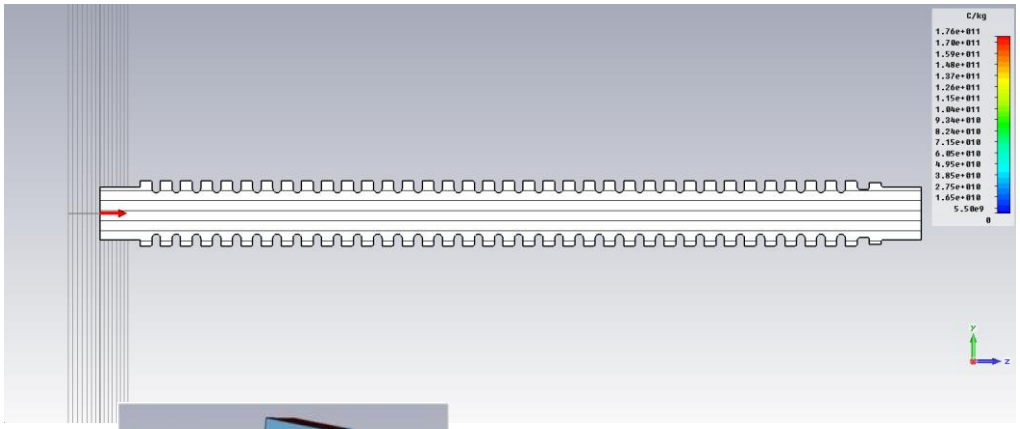
Table 1: RF design of the structure

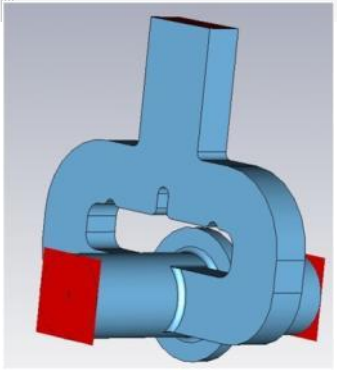
parameters		value
frequency	f_0 (GHz)	11.7
phase advance	φ (DEG)	120
aperture diameter	$2a$ (mm)	17.6
group velocity	v_g/c	0.22
shunt impedance	R/Q (kΩ/m)	3.92
length	L (cm)	30
quality vactor	Q	6500

Table 2: Output power of 11.7GHz metallic power extractor

parameters		value		
Charge/bunch	q (nC)	20	40	50
Bunch length	σ_z (mm)	2	2.3	2.3
RF power	P (MW)	51	187	293
Peak surface field	Es (MV/m)	30	57	72
Max. energy loss	E_{loss} (MeV)	4	7.6	95

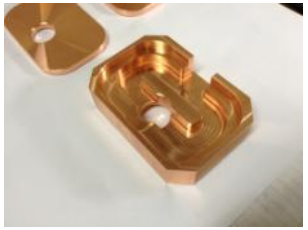


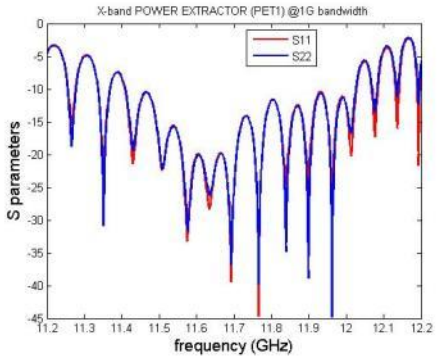


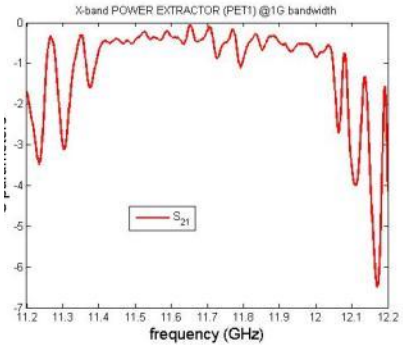


A X-band (Copper) Power Extractor for ANL

- disks brazing. (no HOM damping)
- mode-launcher

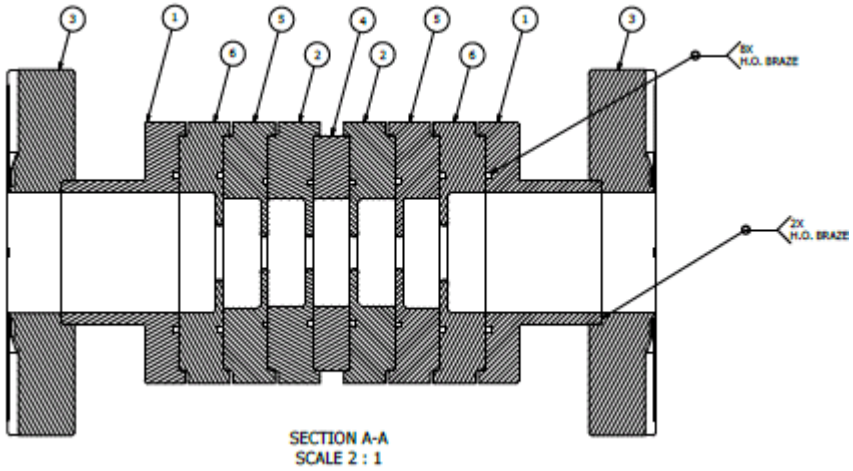


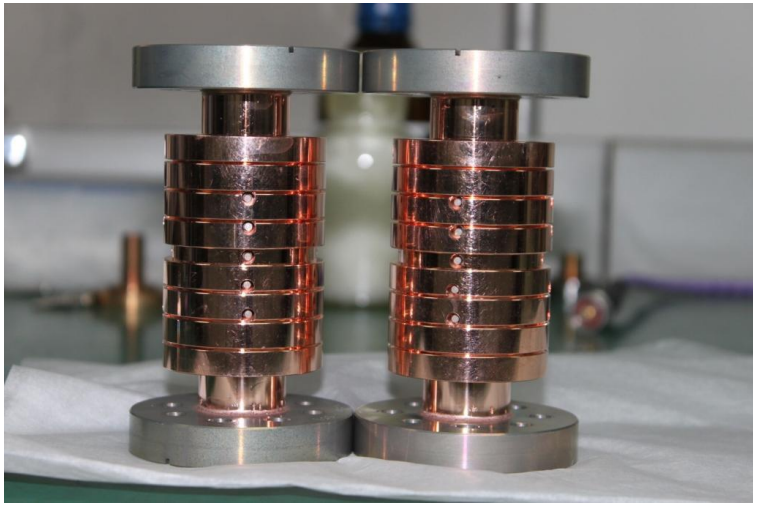




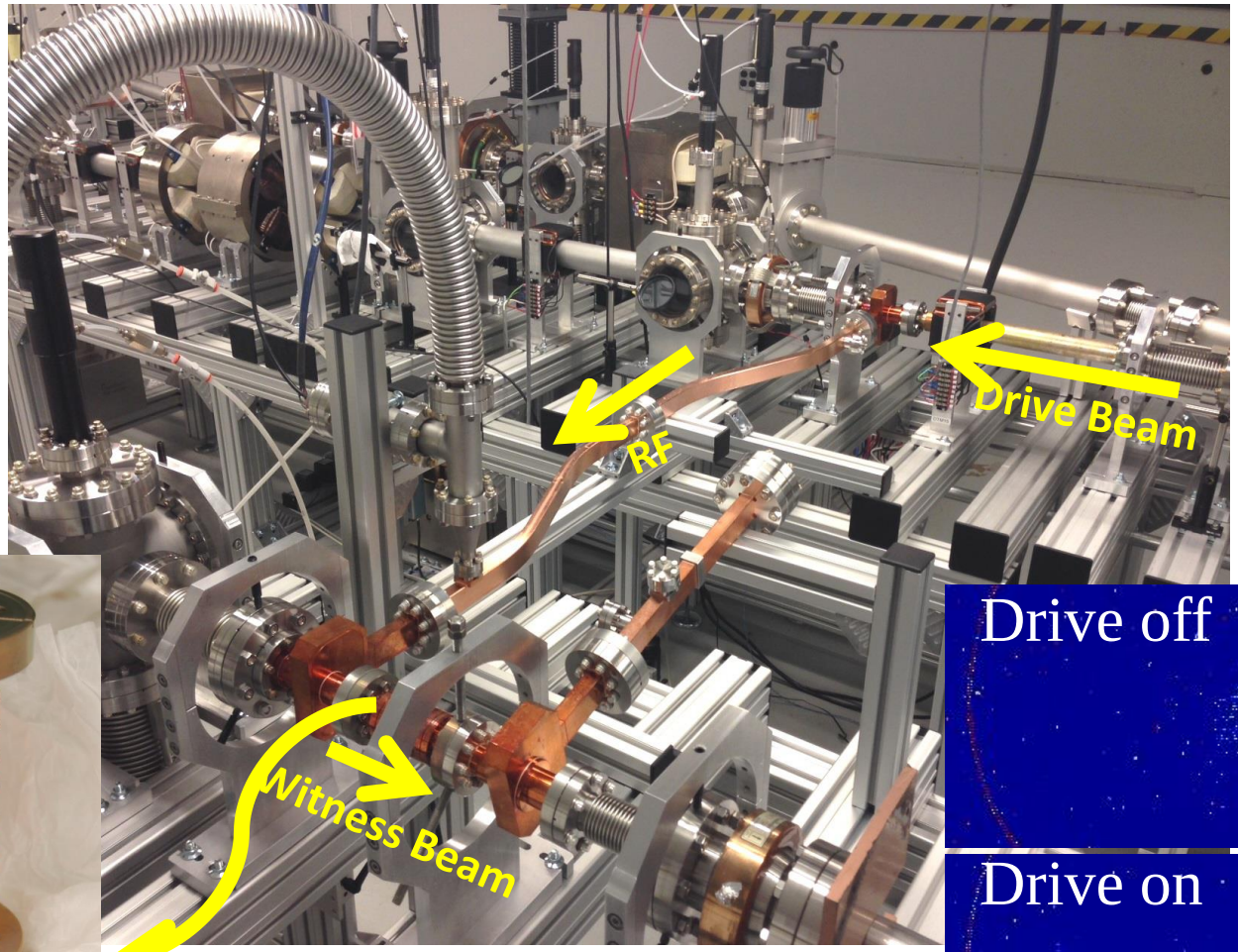
C3 structure at 11.7GHz

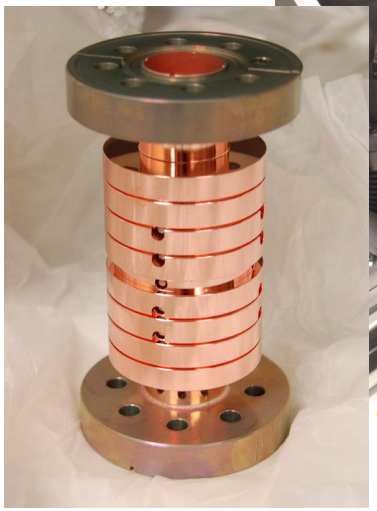
- Design at ANL, 3 regular cells + 2 matching cells
- Brazing design

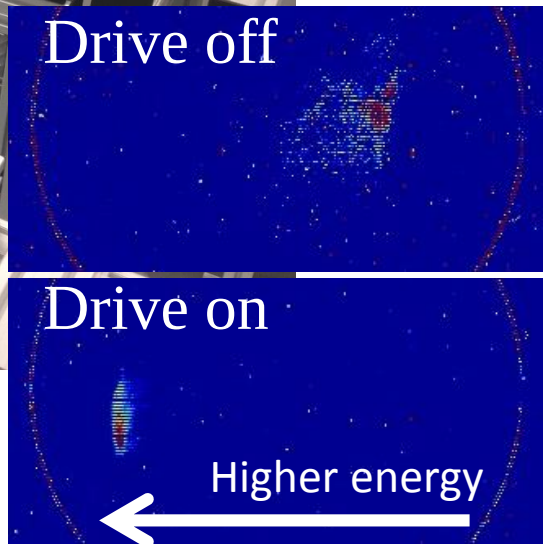




Setup at Argonne/runing now



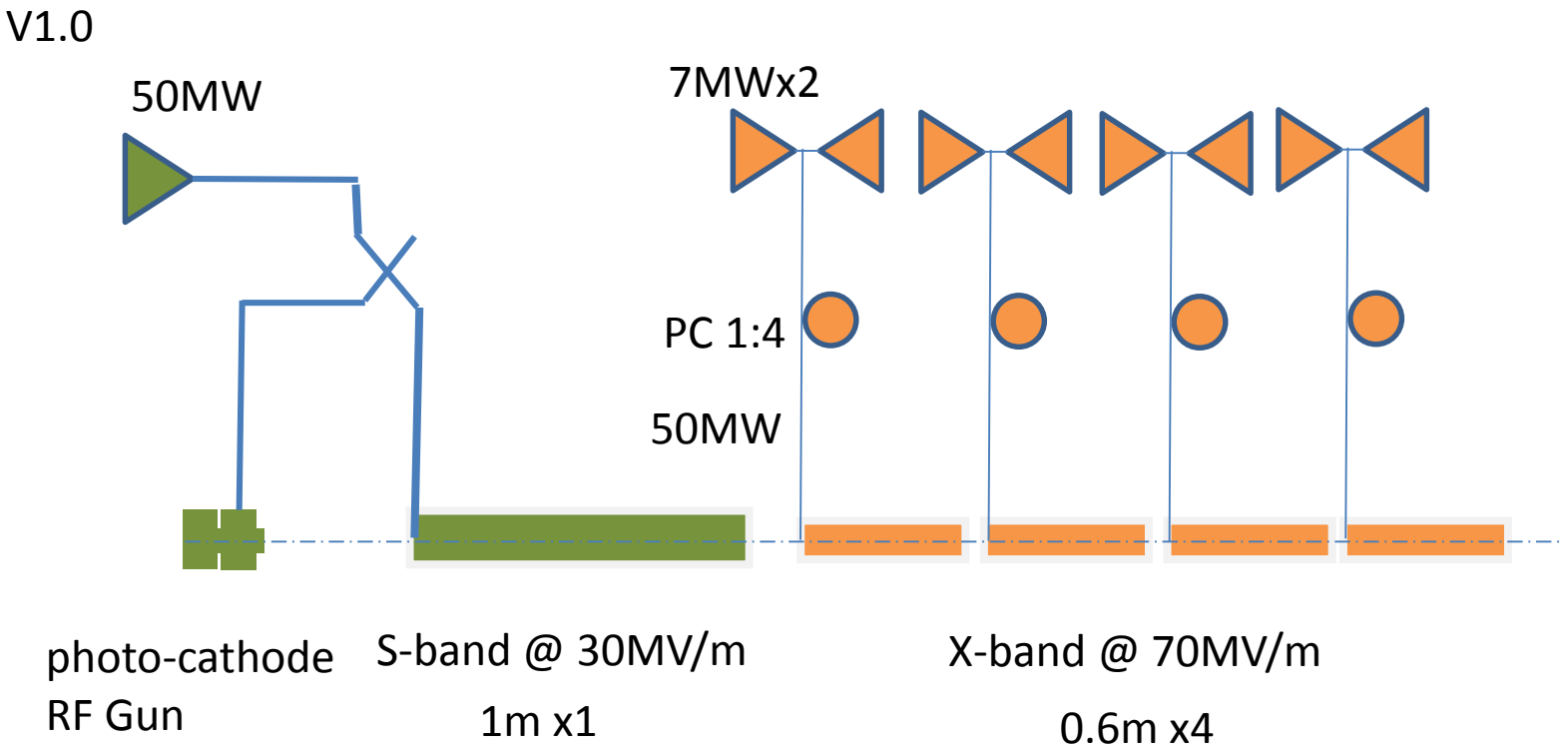




Courtesy: Jing, Chunguang

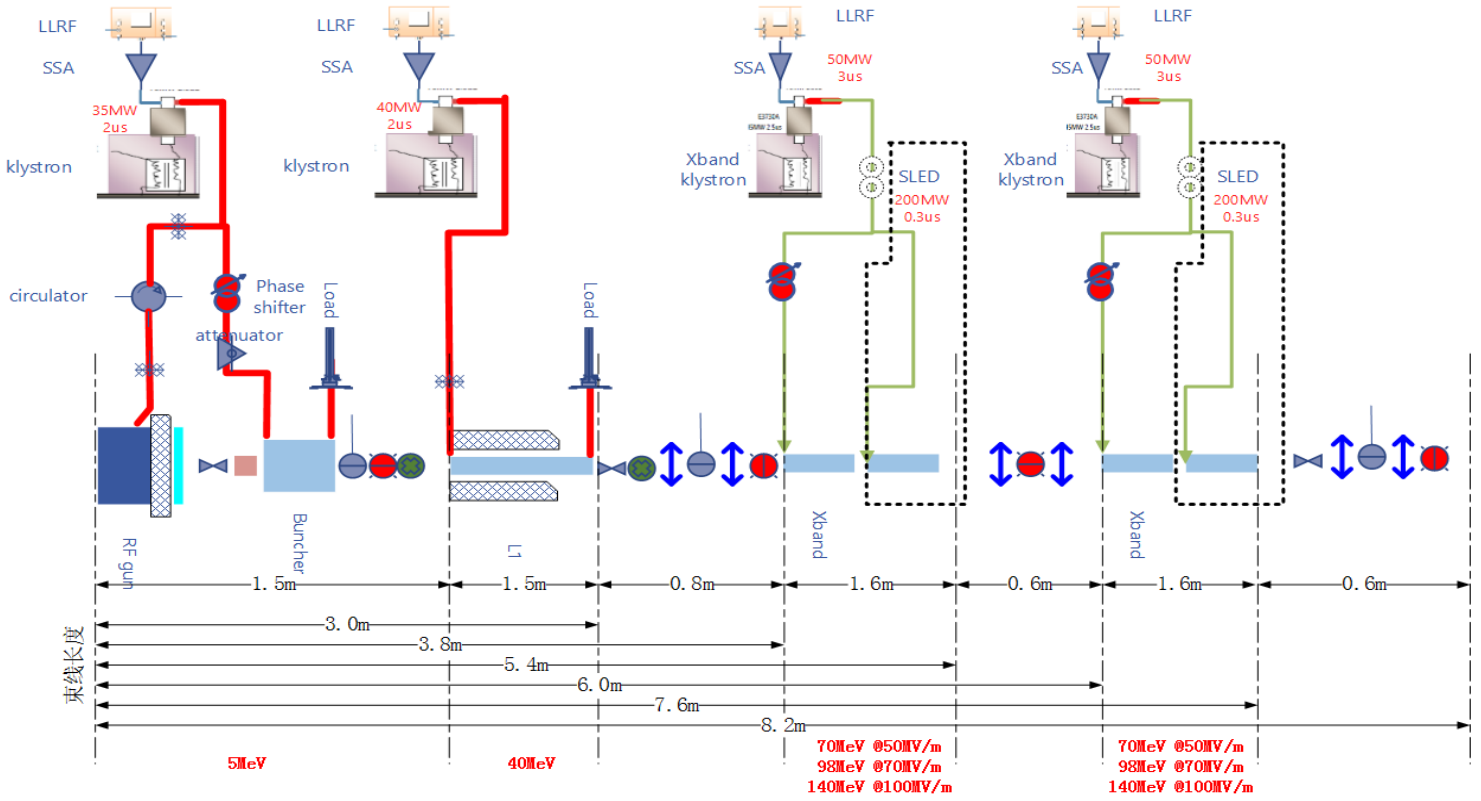
HG structure for compact Thomson source at THU

- photons above 2MeV with narrow energy spread.
  - Energy of e-beam: 200MeV
  - Compact within ~10m



New design with higher input power

V2.0

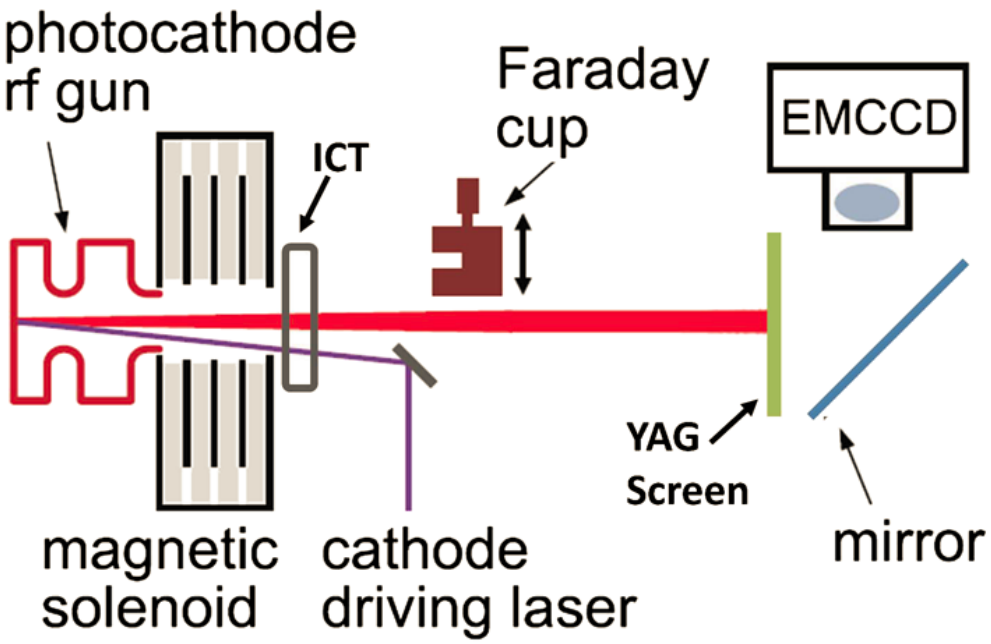


- Achieve 100MeV/m with 50MW klystron
- 325MeV beam line in 8.2m

RF Breakdown study

- Focused on field emission
- With experiments
  - Laser assist: schottky effect enabled photo-emission to study field enhancement
  - H. Chen, et al., PRL 109, 204802 (2012)
  - Laser assist: laser triggered RF breakdown
  - Field emission and dark current study (ANL, SLAC collaboration, J. Shao's talk)

Laser-triggered RF breakdown

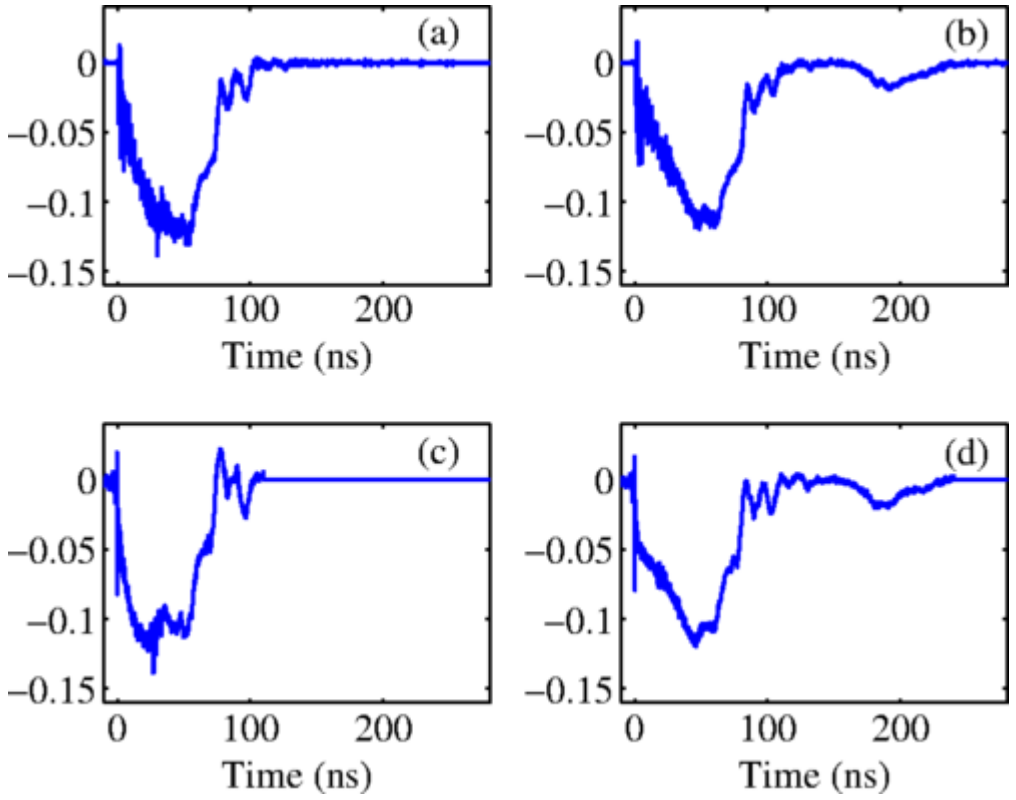


- laser
  - Laser: Ti:Sapphire, 800nm, 400nm and 266nm
  - 90 degree incident
  - Pulse duration: ~1ps
  - Max Energy： ~2mJ
    - 1/3 to cathode from clean room
  - Energy jitter: ~5%

Observation of temporal evolution following laser triggered rf breakdown in vacuum
J. Shao, et al, PRST-AB – July 2014

Discussions

- Study the time structure
- Compare the breakdown event with laser and w/o laser (self-triggered)
- FIG: single and multi-breakdown event
- More details:

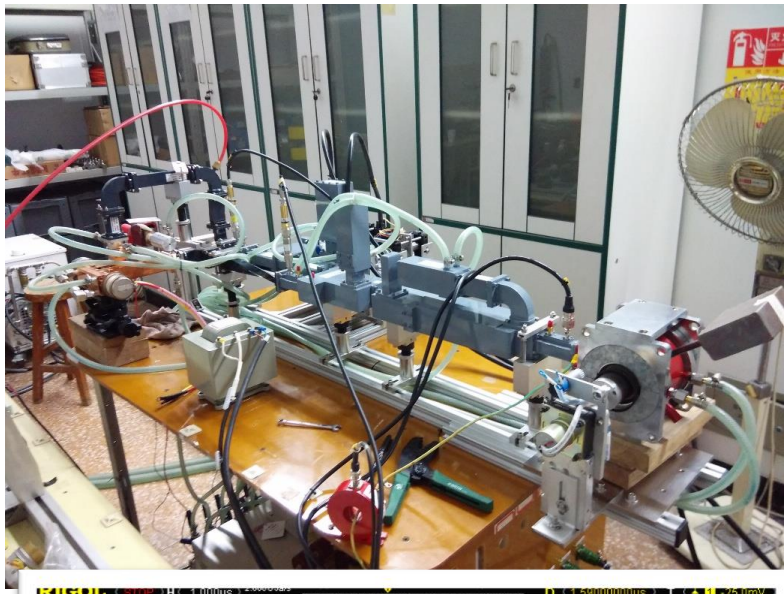


http://journals.aps.org/prstab/abstract/10.1103/PhysRevSTAB.17.072002

Future

X-band Klystron 11.424GHz

- 50MW klystron
- HG structures



X-band Magnetron 9.3GHz

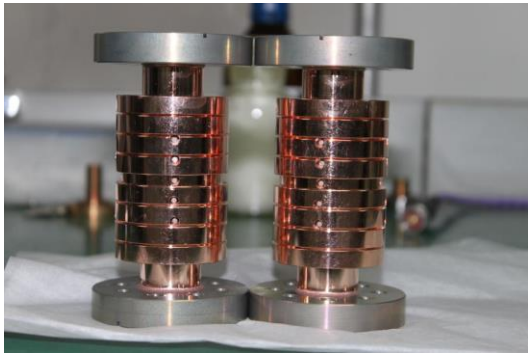
- Up to 1.7MW at ~4μs
- Simple system
- Special designed cavity for dark current/field emission study
- Ex: TM020 mode cavity with changeable cathode

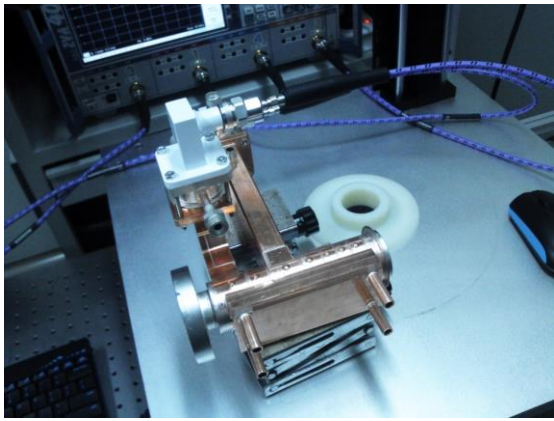
Summary

- T24_THU_#1 successfully assembled
  - Several problems: stainless steel in heat cycle?
  - High power test at Nextef@KEK finish early July
  - Discussion: 1) baking 2) careful handling/cleaning
  - next structures with cells machined in Tsinghua
- Choke-mode damped structures, SW single-cell test
  - complete soon, to be high-power tested @ KEK
  - Full length structure coming after

Summary(2)

- Several other X-band structures to validate machining/brazing
  - X-band power extractor @11.7GHz
  - X-band C3 accelerating structure @11.7GHz
  - X-band linac for industrial application @9.3GHz
- High-gradient structure for compact Thomson source





Summary (3)

- RF breakdown study
  - With S-band photocathode gun: Laser assisted experiments
  - Argonne collaboration
- New high-power testing capability
  - CPI 50MW X-band klystron and Scandinova modulator
    - Purchasing procedure started. Estimate start in 3 years
  - X-band magnetron
    - Specially designed cavities for dark current/field emission study
  - Advices/Suggestions are welcomed!

Thank you!