Research of High Gradient Acceleration Technology for Future Accelerators

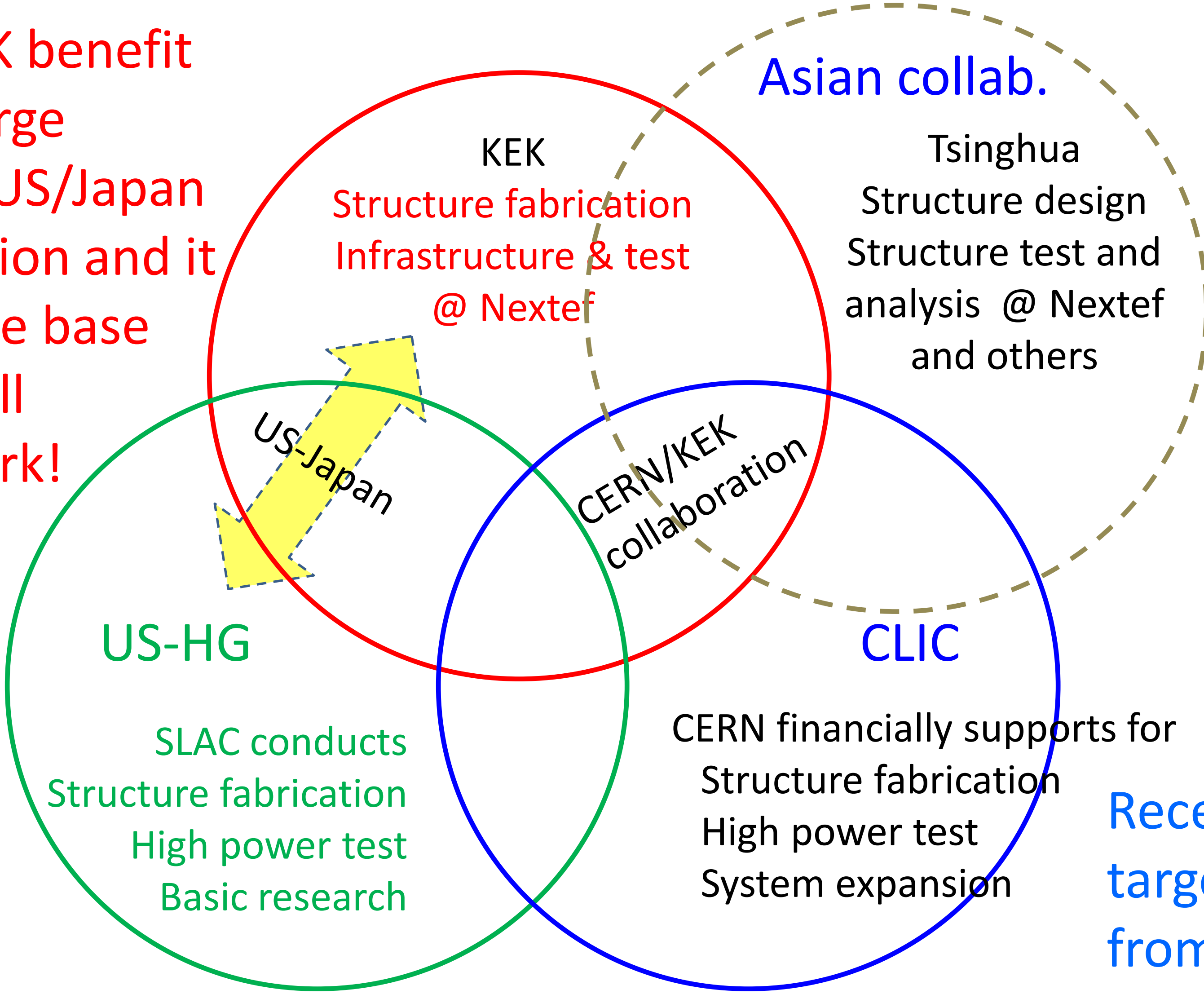
US/Japan cooperation

1 March 2012

Toshiyasu Higo (KEK)

US/Japan cooperation is a key for worldwide collaboration

SLAC/KEK benefit is very large through US/Japan cooperation and it makes the base for overall framework!



Recent test target comes from CLIC

Three-year plan

- 2011
  - KEK prepared basic study environment
  - Both labs. continued
    - Prototype fabrication TD24R05
    - Evaluation T24 and TD24
- 2012
  - Start basic research in a simple geoetry
  - Test prototype structures
    - TD24 and later TD24R05
- 2013
  - Understand the trigger mechanism
  - Make rough sketch of high gradient section for LC

Last year activities under US-Japan

- Twin prototype structures (TD24) have been made.
- This pair of structures now being tested show the feasibility of 80MV/m in copper.
- Studies in simple geometries were conducted at SLAC.
- System for tests with simple geometry was prepared at KEK.
- Magnetic field showed important role in breakdown rate.
- High magnetic field area showed indication of electromigration.
- Standing wave acceleration design is in progress at SLAC.

Extending key activities supported by US-Japan

- KEK
  - Parts fabrication
  - Long-term high gradient test
  - Specific tests in simple geometry
- SLAC
  - Chemical polishing
  - Hydrogen furnace bonding and vacuum baking
  - Various specific high power tests
- US high gradient collaboration
  - Exchange of ideas and experimental results

Who are contributing in what

Japan

- Main lab = KEK
  - **Accelerator high gradient test**
    - Nextef
    - Shield-B
  - **Mechanical engineering center**
    - Structure cell production
    - Test sample production

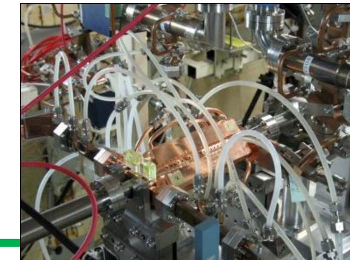
US

- Main lab = SLAC
  - **NLCTA high gradient test**
    - Station 1, 2
  - **ASTA high gradient test**
    - Single-cell
    - Pulse heating
  - **Klystron shop**
    - Structure fabrication

- Discussion and information exchange is important ⟺ US-HG collaboration

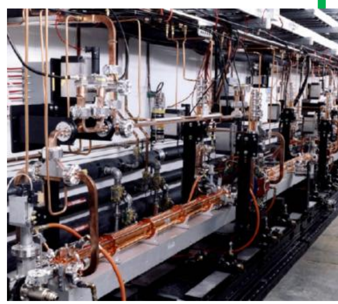
SLAC/KEK test flow (same as before)

Design for CLIC (CERN)



High power test (NLCTA-SLAC)

High power test (Nextef-KEK)

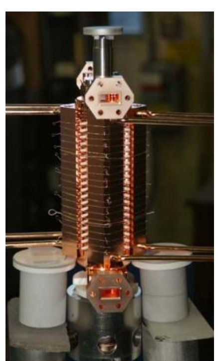


Fabrication of parts (KEK)

CP (SLAC)

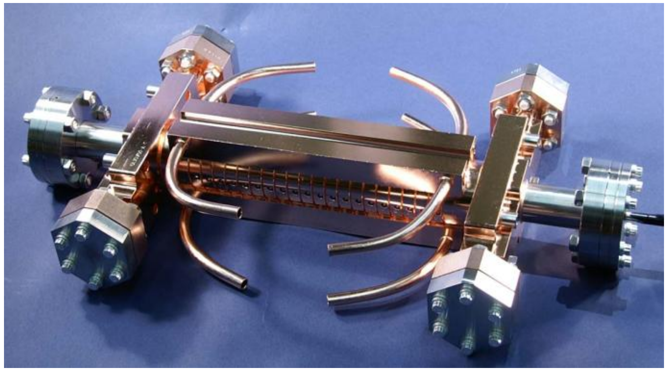
Bonding (SLAC)

VAC bake (SLAC)



CLIC test structures; fabrication and test

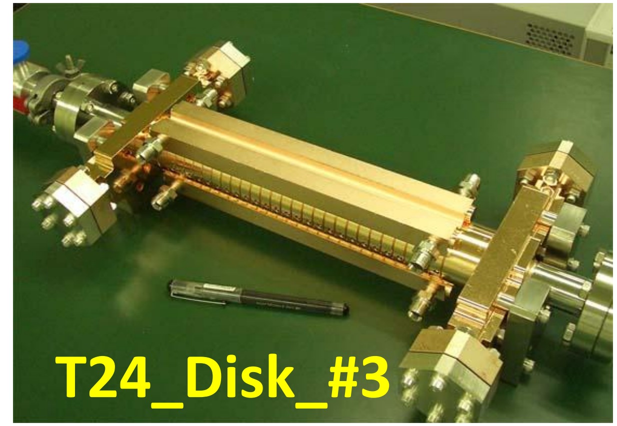
T18 →TD18→T24→TD24



T18_Disk_#2

2009

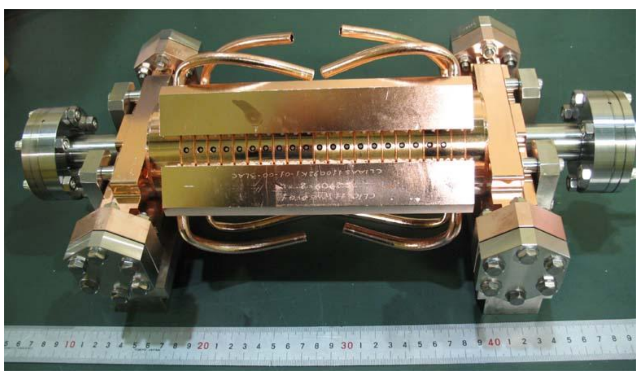
undamped



2011

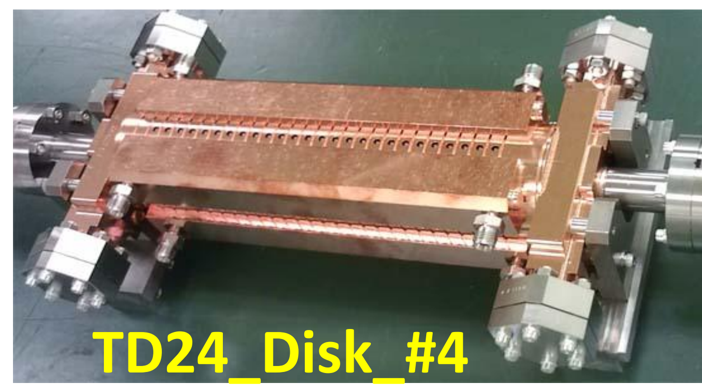
2010

2011

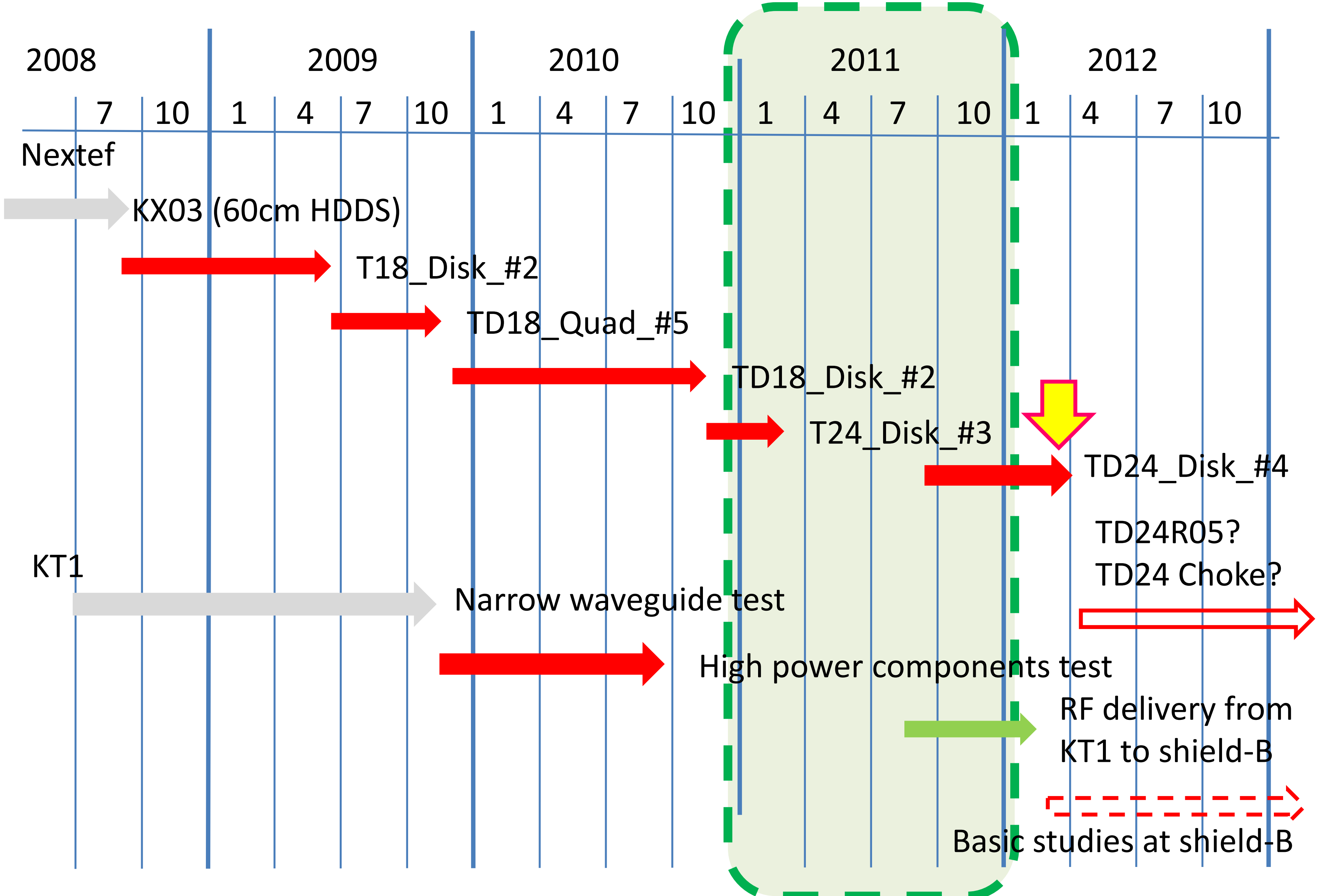


TD18_Disk_#2

damped



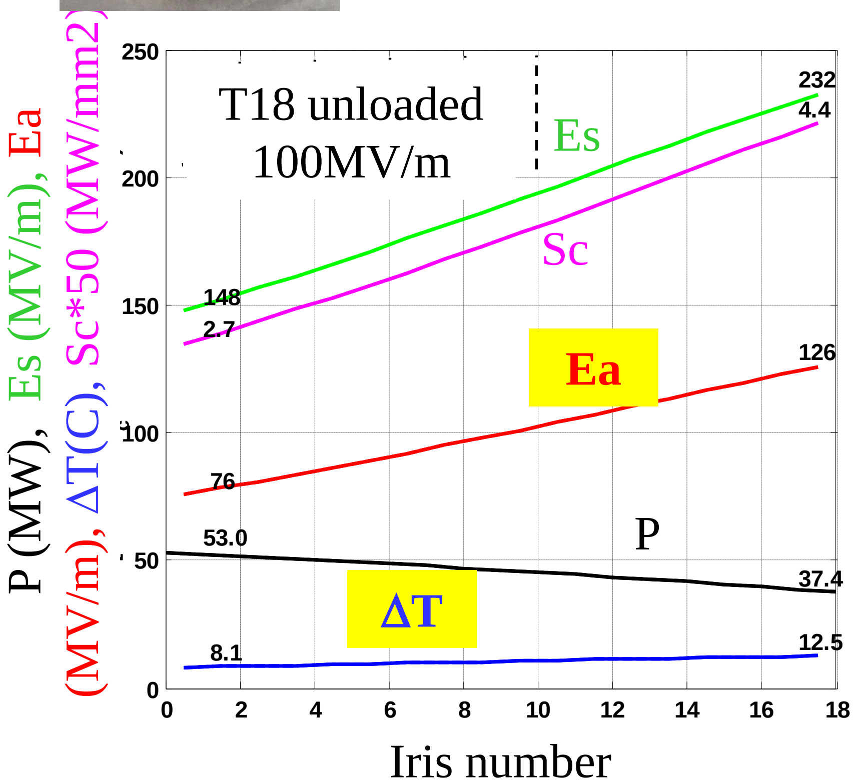
High-gradient test at Nextef



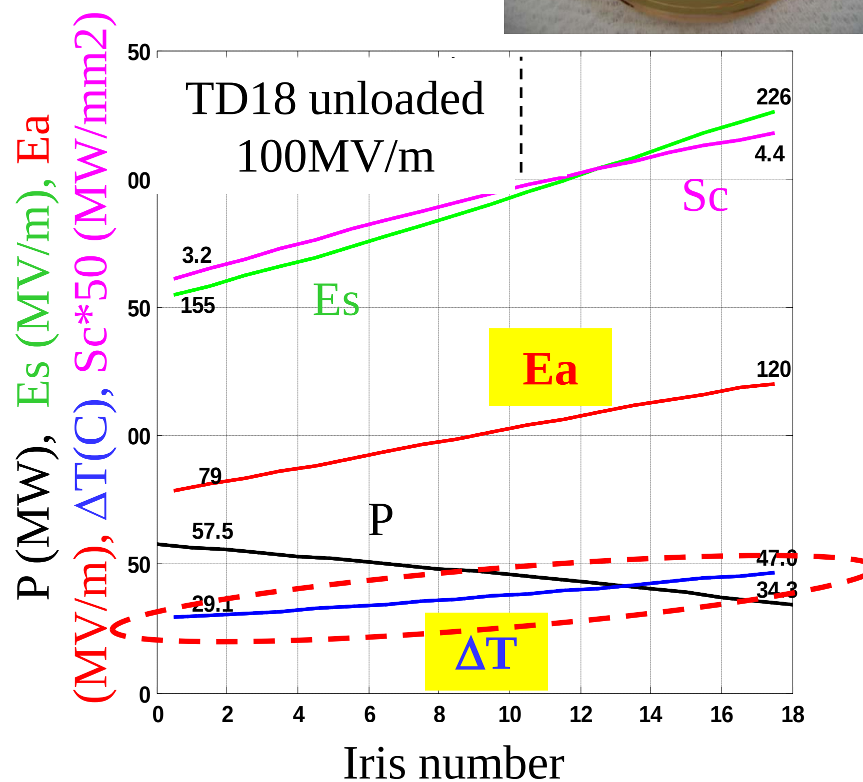
Initial evaluation toward 100MV/m

T18
undamped

TD18
Damped



High Eacc and Es



High Eacc and Es and ΔT

Breakdown rate undamped vs damped

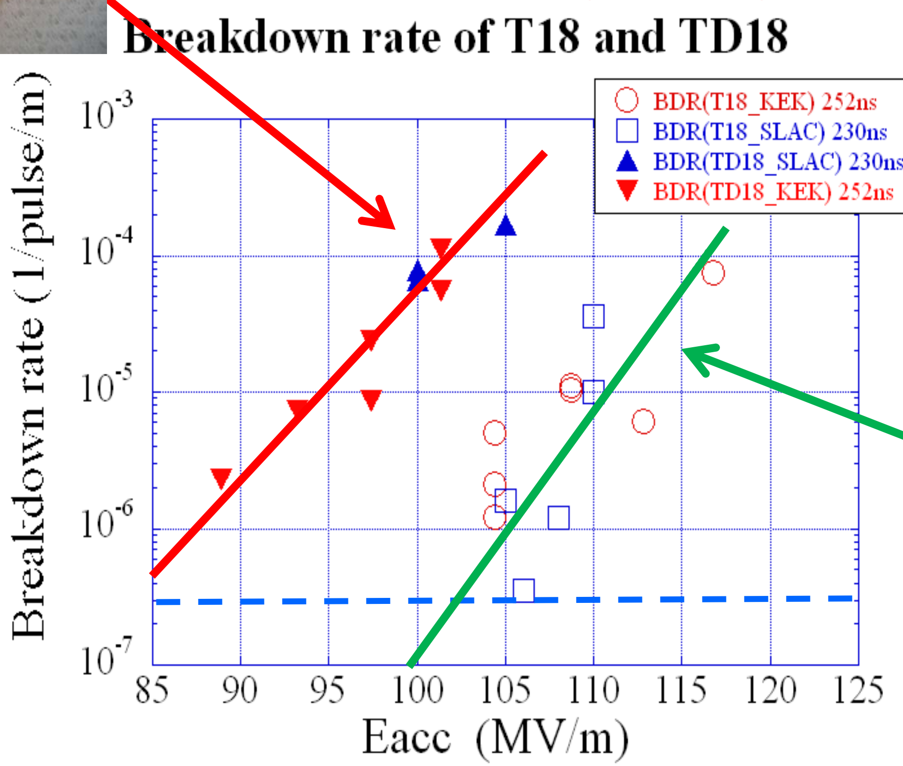
Higher breakdown rate in damped than undamped.

Feasibility:

Undmaped > 100MV/m

Damped up to 80MV/m

TD18
Damped



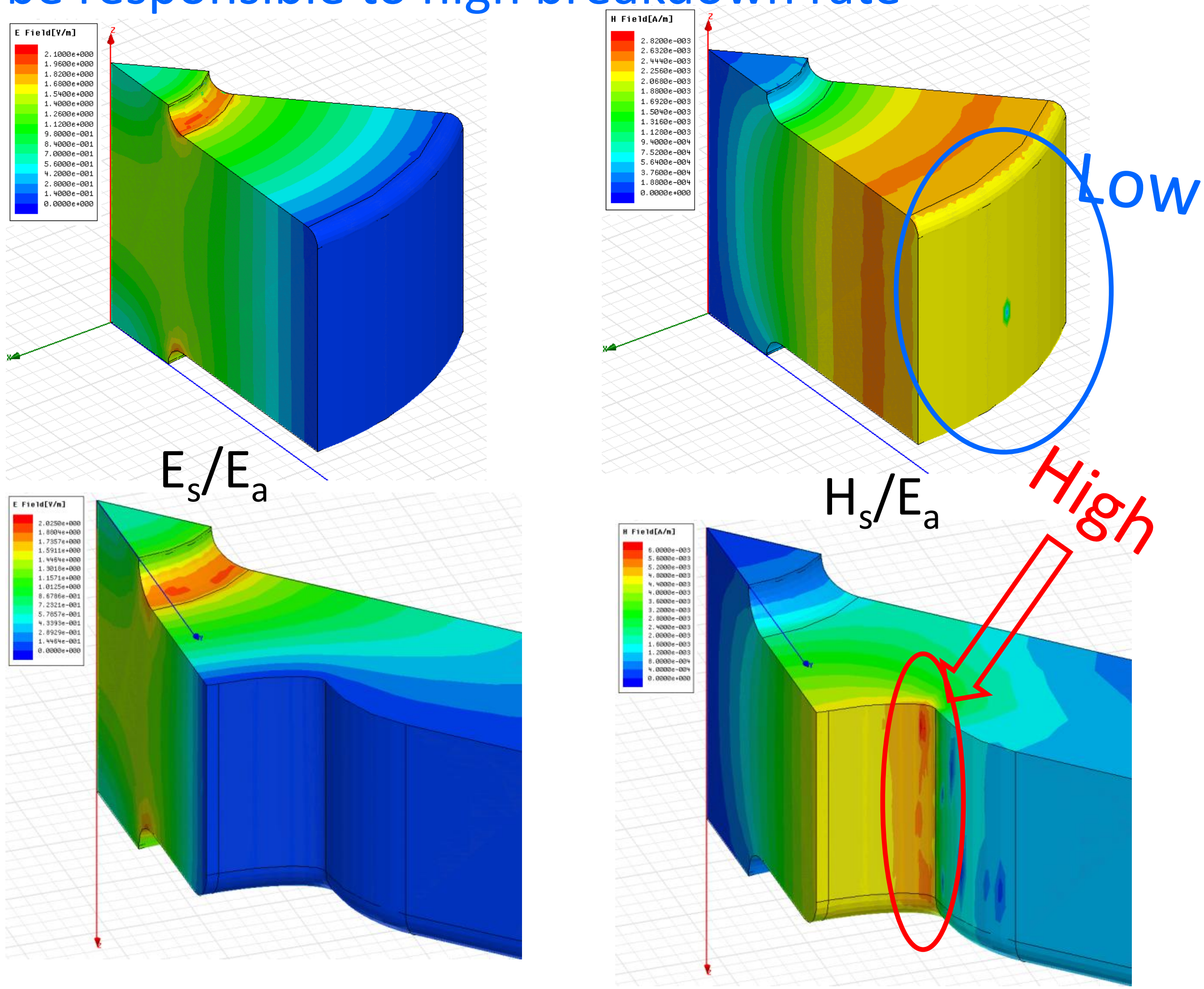
T18
Undamped

High magnetic field in damped cell

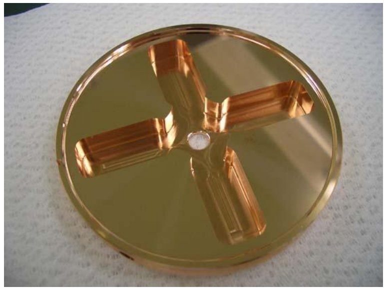
May be responsible to high breakdown rate

Undamped cell

Damped cell

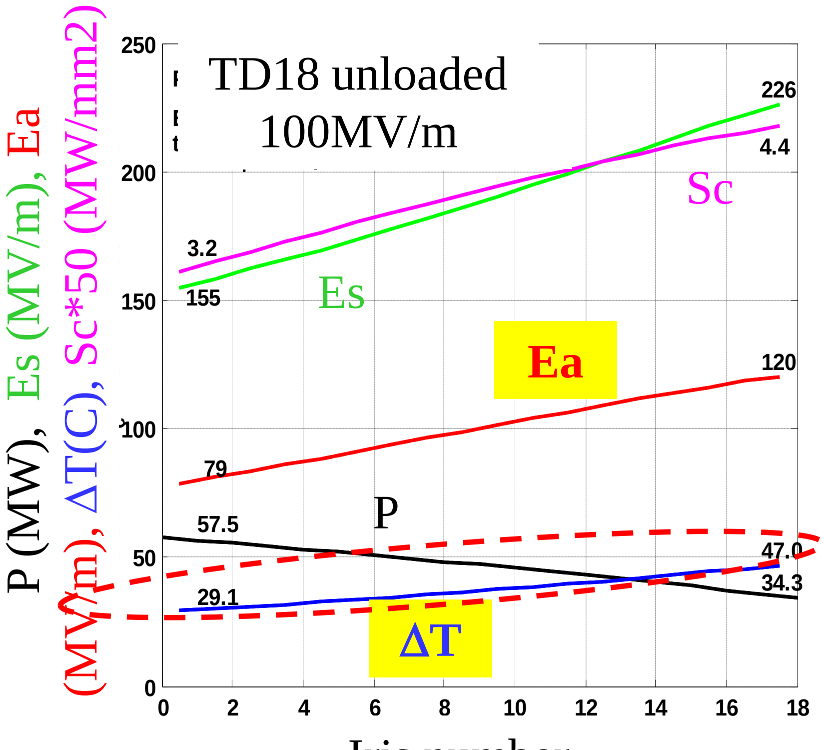


Reduced magnetic field 18 → 24

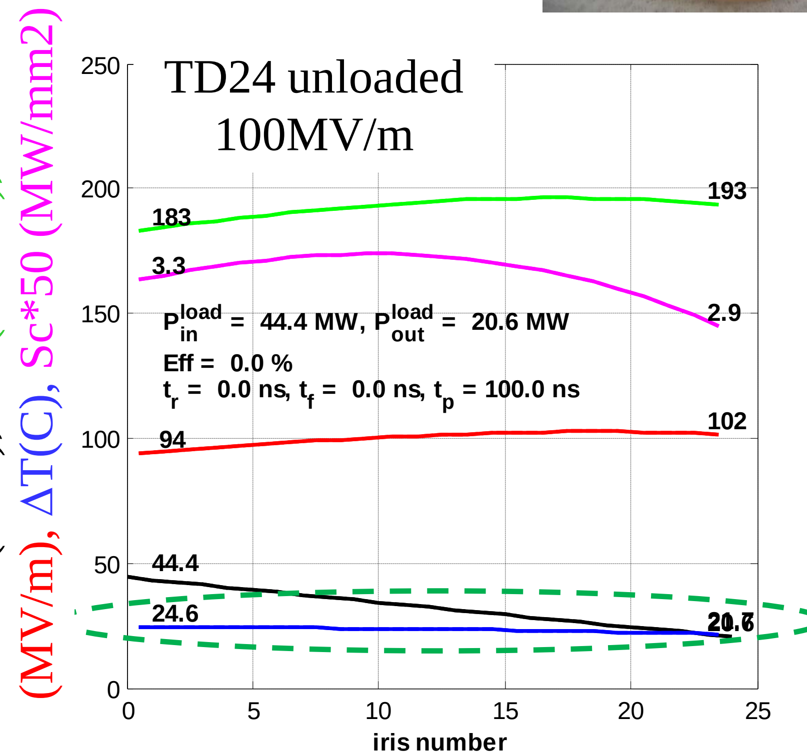


TD18
Damped

TD24
Damped



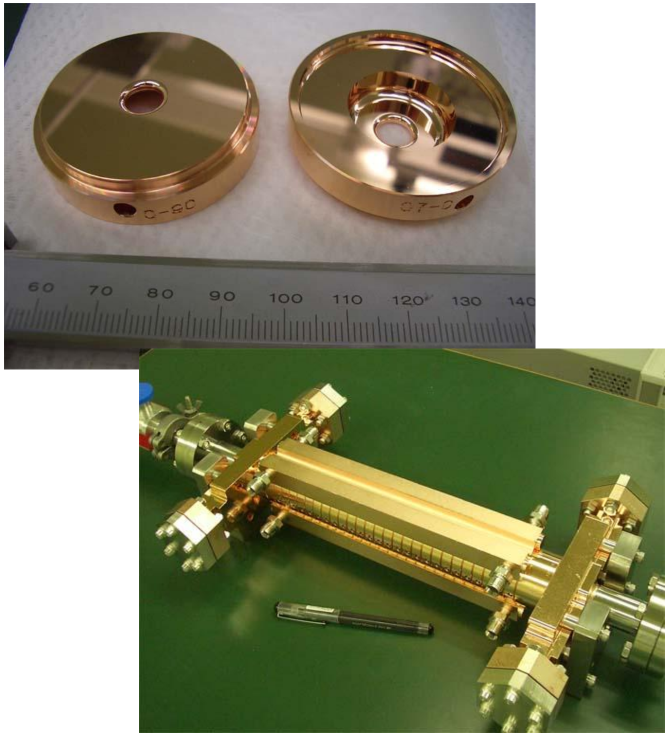
High Eacc and Es and ΔT

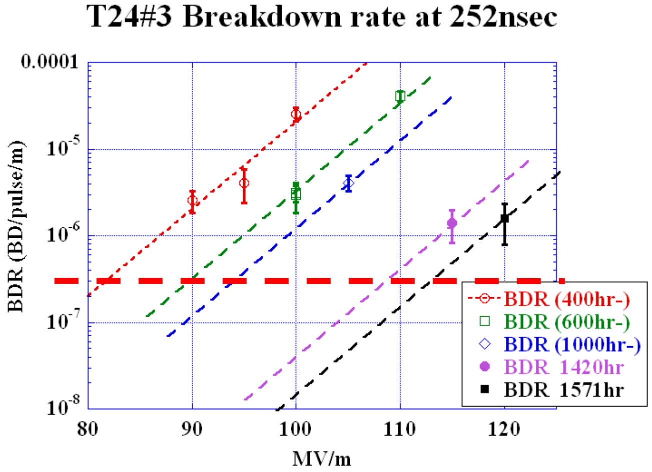


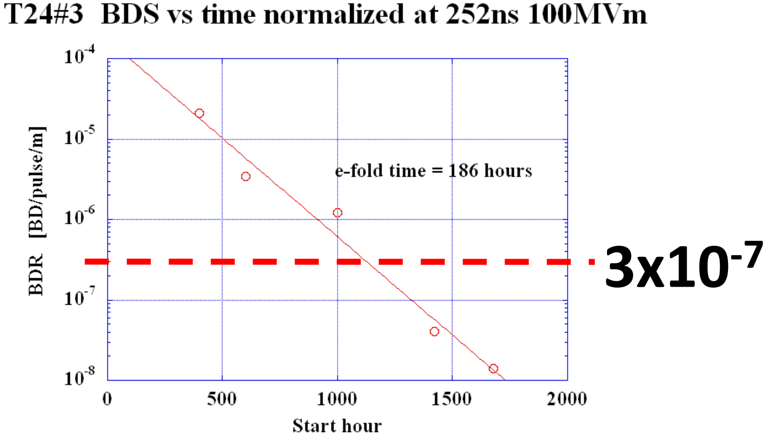
Reduce ΔT

State of the art for LC undamped T24

T24 was found much better than T18







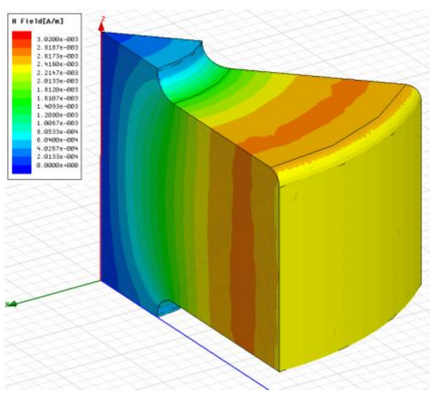
Faster processing

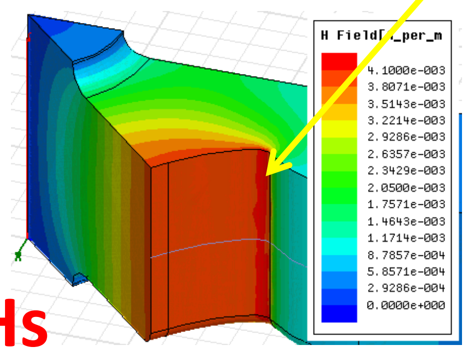
Reached low breakdown rate

How about breakdown rate if T24 parameters applied to damped TD24

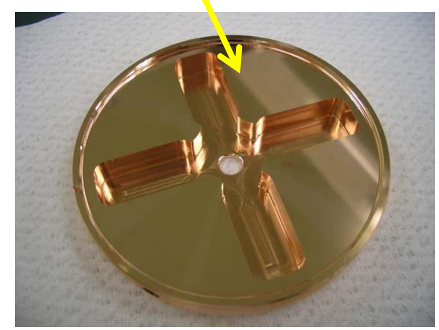
Param.	Unit	T24	TD24
<Eacc>	A/m	100	100
Es/Ea	1	1.95	1.95
Es	MV/m	195	195
Hs/Ea	mA/V	2.6	4.1
Hs	kA/m	260	410

Still high magnetic field in damped

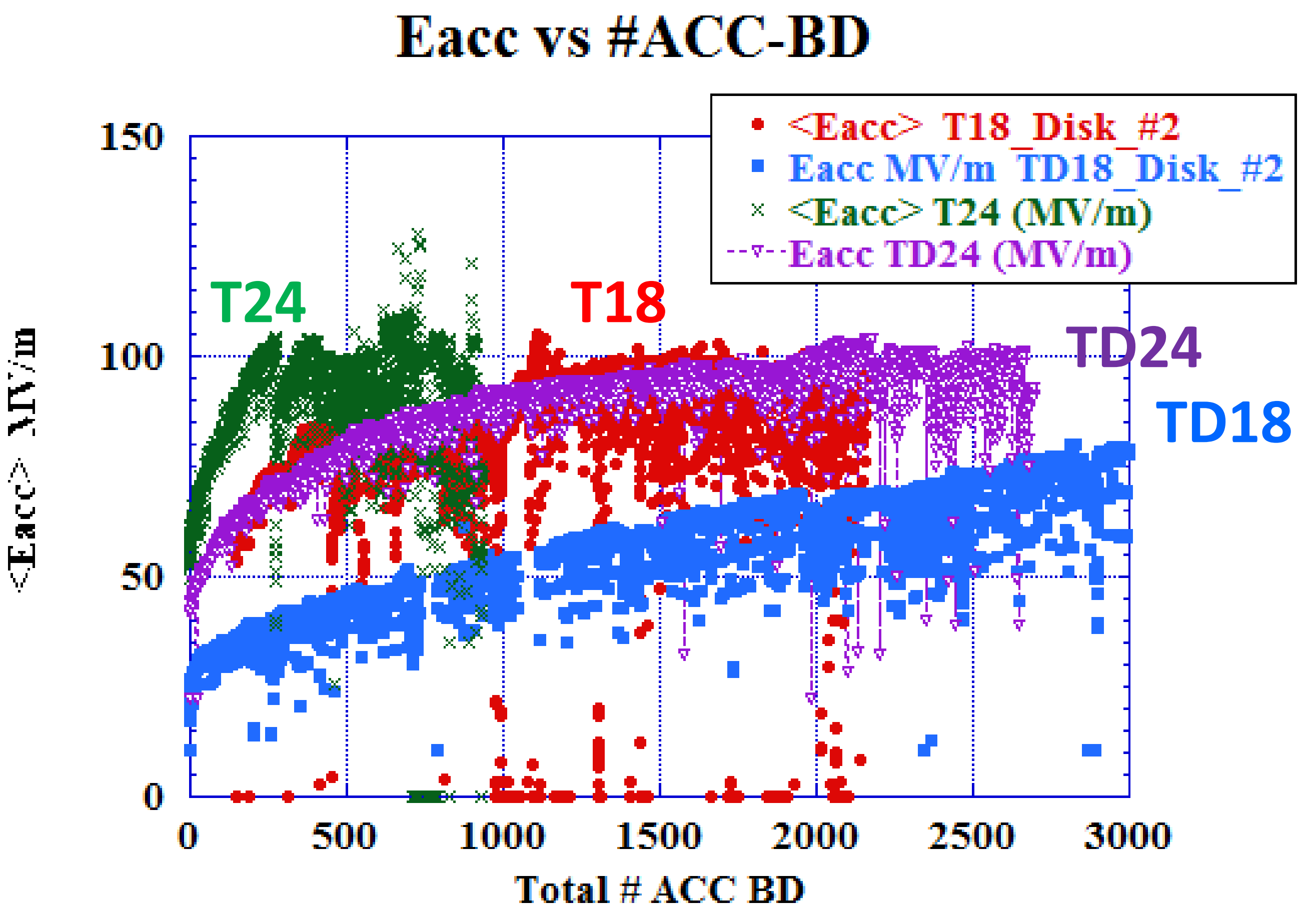




Hs



Difference in processing speed among four structures
Breakdowns are needed or can be avoided?

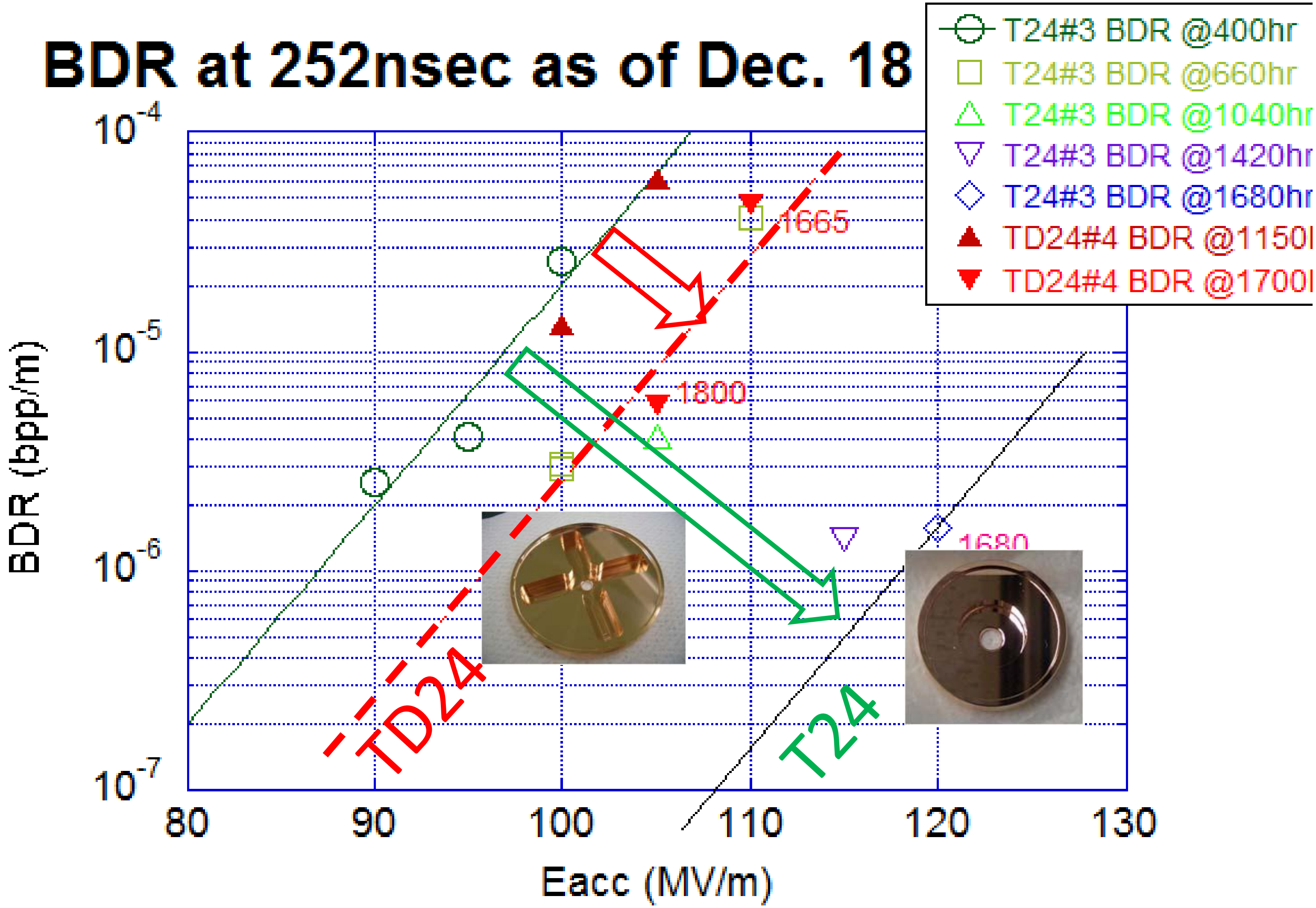


More BD's are required for damped!? Why?

Can it be reduced?

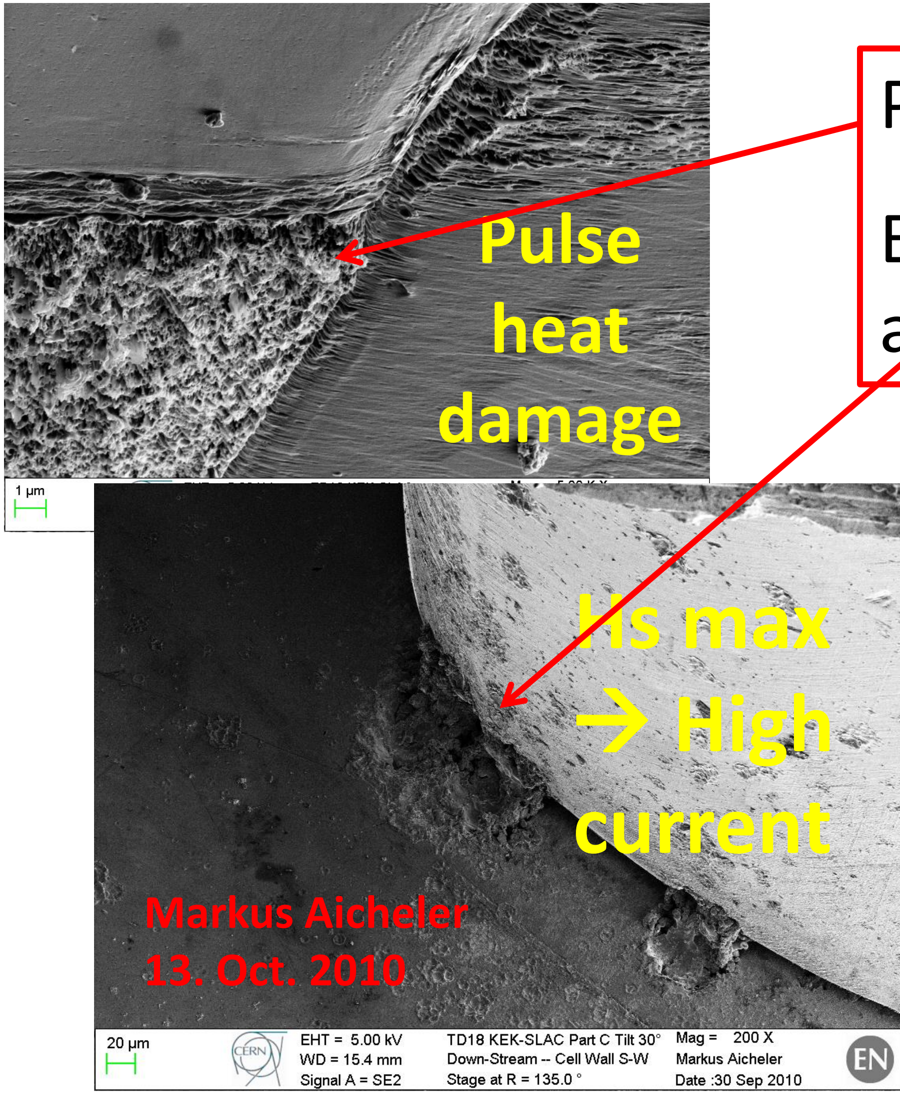
BD's are essentially needed for processing?

Preliminary and at 240ns FLT pulse



90 MV/m seems feasible in damped structure TD24.

Where breakdown triggers come from high magnetic field area?



Pulse surface heated damage.

Electromigration and related arcs at Hs?

Surface current is large!

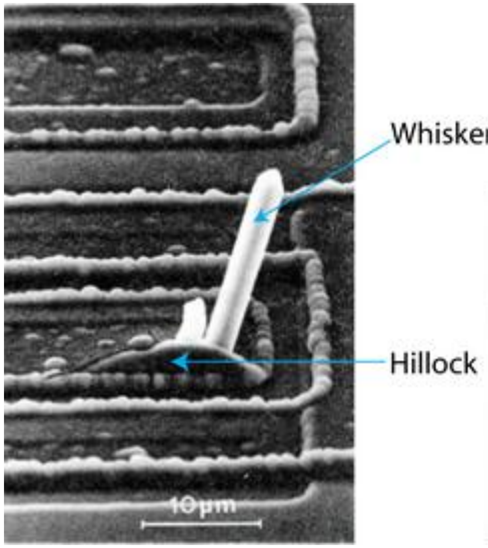
400kA/m over 0.5μm thick

→ 1A/μm^2

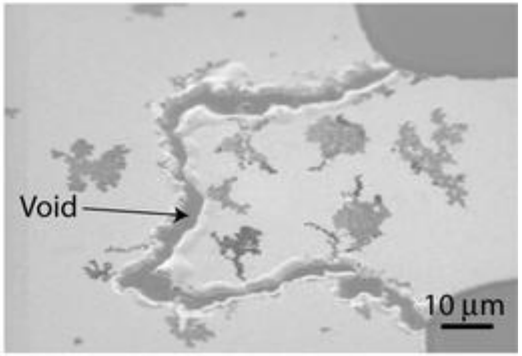
>> Problem in IC

(~0.1A/μm^2)

Electromigration?



Taken from web:
University of Cambridge.



Direct electric field

a=screening factor

$$F_d = aZeE$$

Conduction electron wind

σ=collision cross section

λ=mean free path

$$F_w = -e n_e \lambda \sigma_i E$$

Diffusion process

Q=Activation energy

$$D = D_0 \exp(-Q/RT)$$

Crystal
defect, boundary, void, etc.
are related

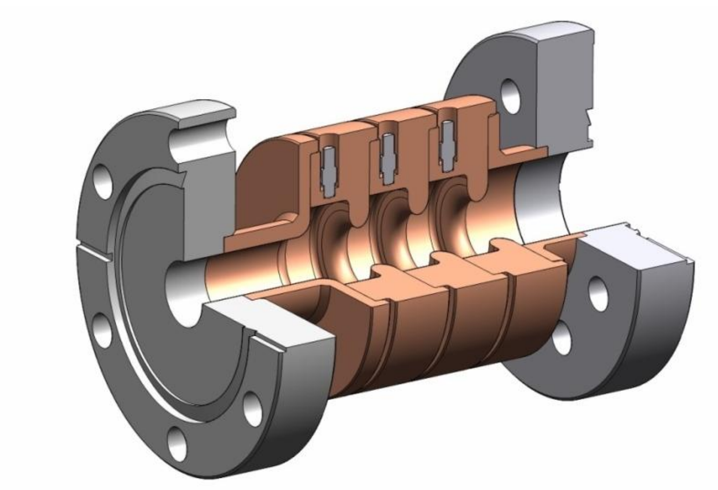
We need to understand physical mechanism of vacuum arc

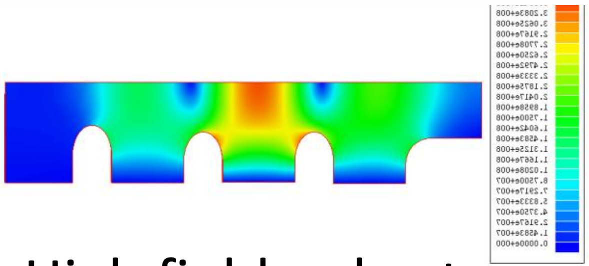
- Possible and proposed mechanisms
  - Sharp edge → Es enhancement → FE
  - Es → Maxwell's stress → pull up crystal → FE → plasma development
  - Hs → pulse heating → fatigue → edges and ruptures → high Es
  - Hs → high current density → electromigration
- BD Trigger and evolution to discharge
  - Understand mechanism
  - Estimate degree of damage

How to study mechanism and develop suppression technology

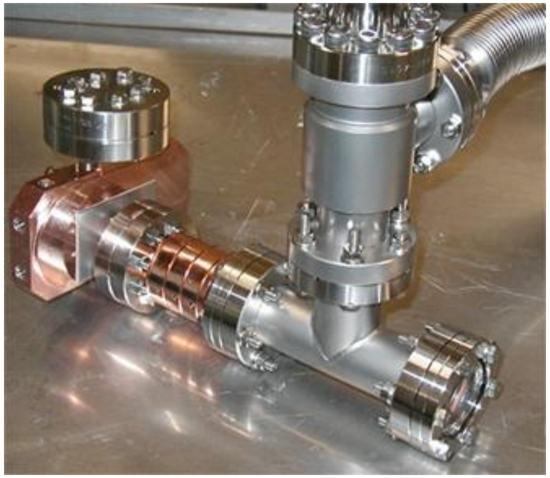
- Prototype test
  - GLC/NLC → CLIC
- Study in simple geometry
  - Single-cell setup, waveguide, DC, etc.
- Study with simple material
  - Test setup with large-grain material
- Improve in the area such as
  - Geometry, fabrication, assembly technique
  - Installation with after-assembly cleaning
  - Processing method

Basic study setups





High field only at center cell



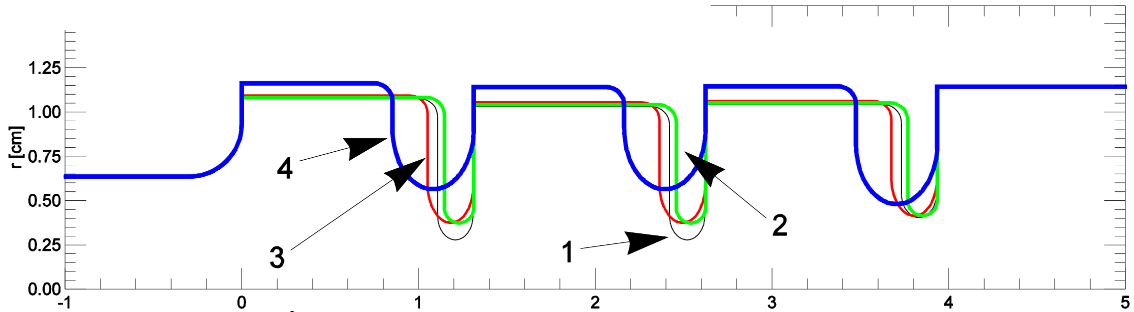
Clean setup

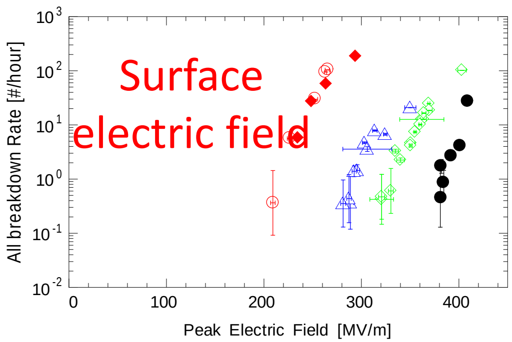
Large grain material

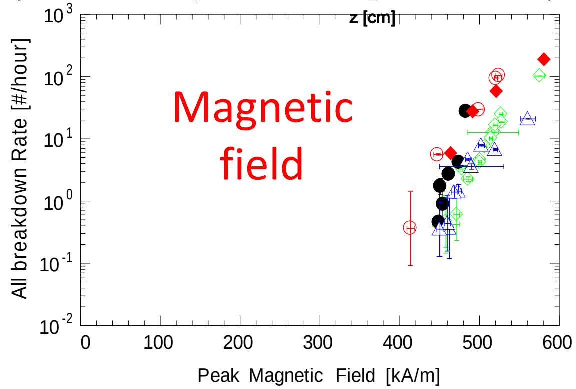
Simple crystal characteristics

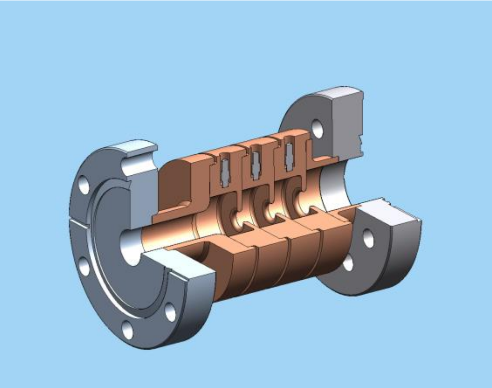
V. Dolgashev, AAS 2010

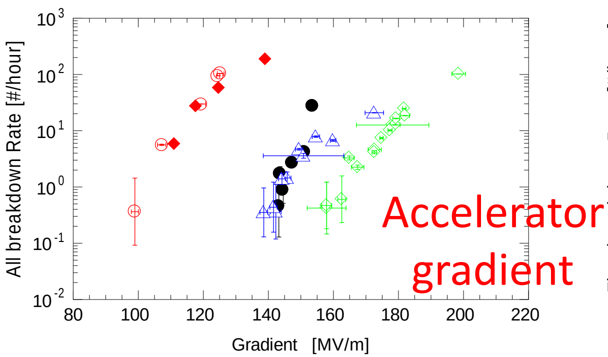
Magnetic field (test at SLAC)

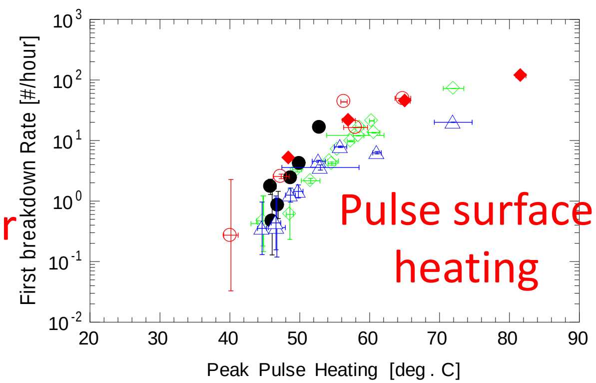






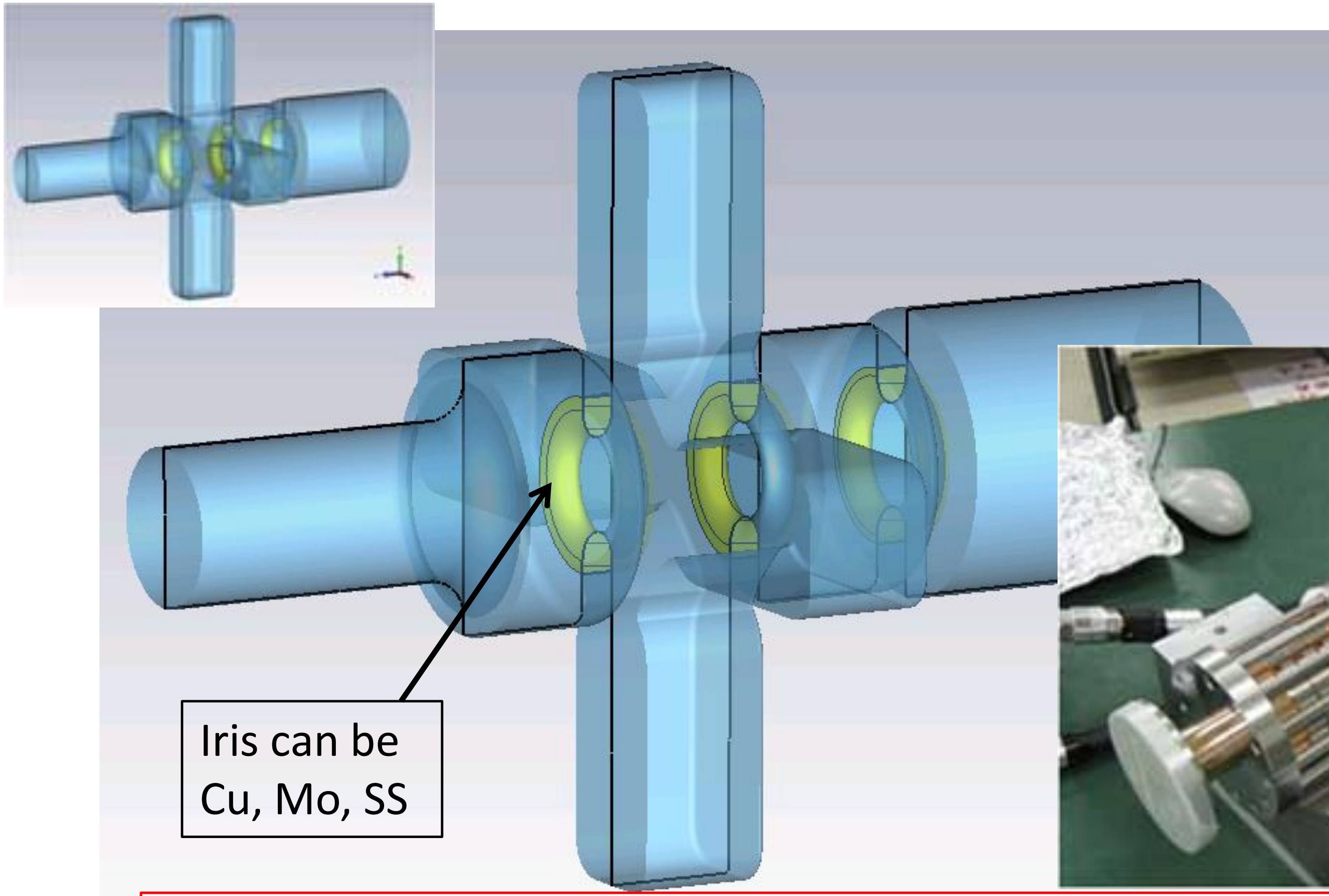






Magnetic field plays an important role, rather than geometry.

High Hs in nominal heavy damped cell



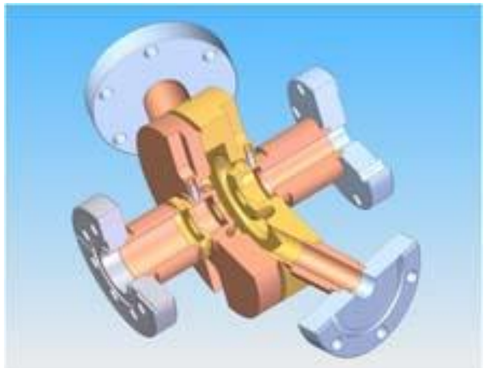
Test setup being prepared at KEK

Study items in preparation or in mind

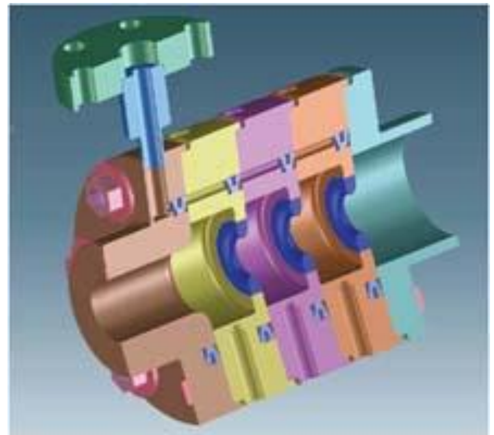
- Explore basic research in a simple geometry
- Center cell is such as the following
  1. Standard: KEK made – SLAC test
  2. Nominal: Heavily-damped
  3. Made of large-grain material
  4. Undamped but all-milled
  5. All milled quadrant type
  6. Choke-mode type

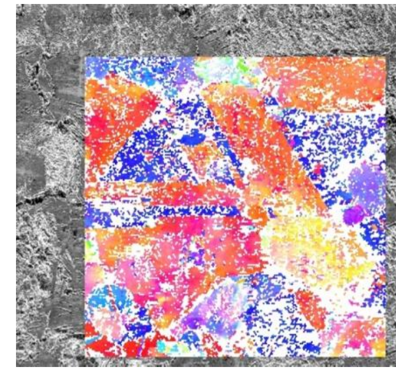
These are under preparation

Other basic tests ongoing and may also happen in next year

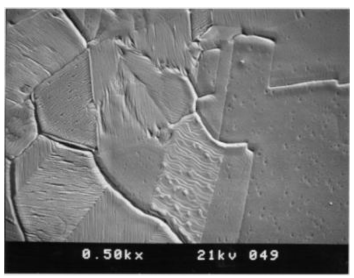


In-situ inspection

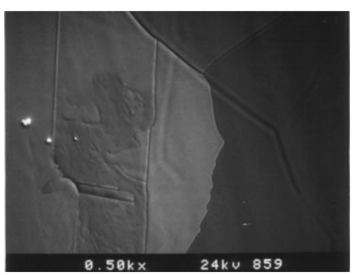




Crystal orientation
SEM & X-ray
Field Emission Microscope



VAC

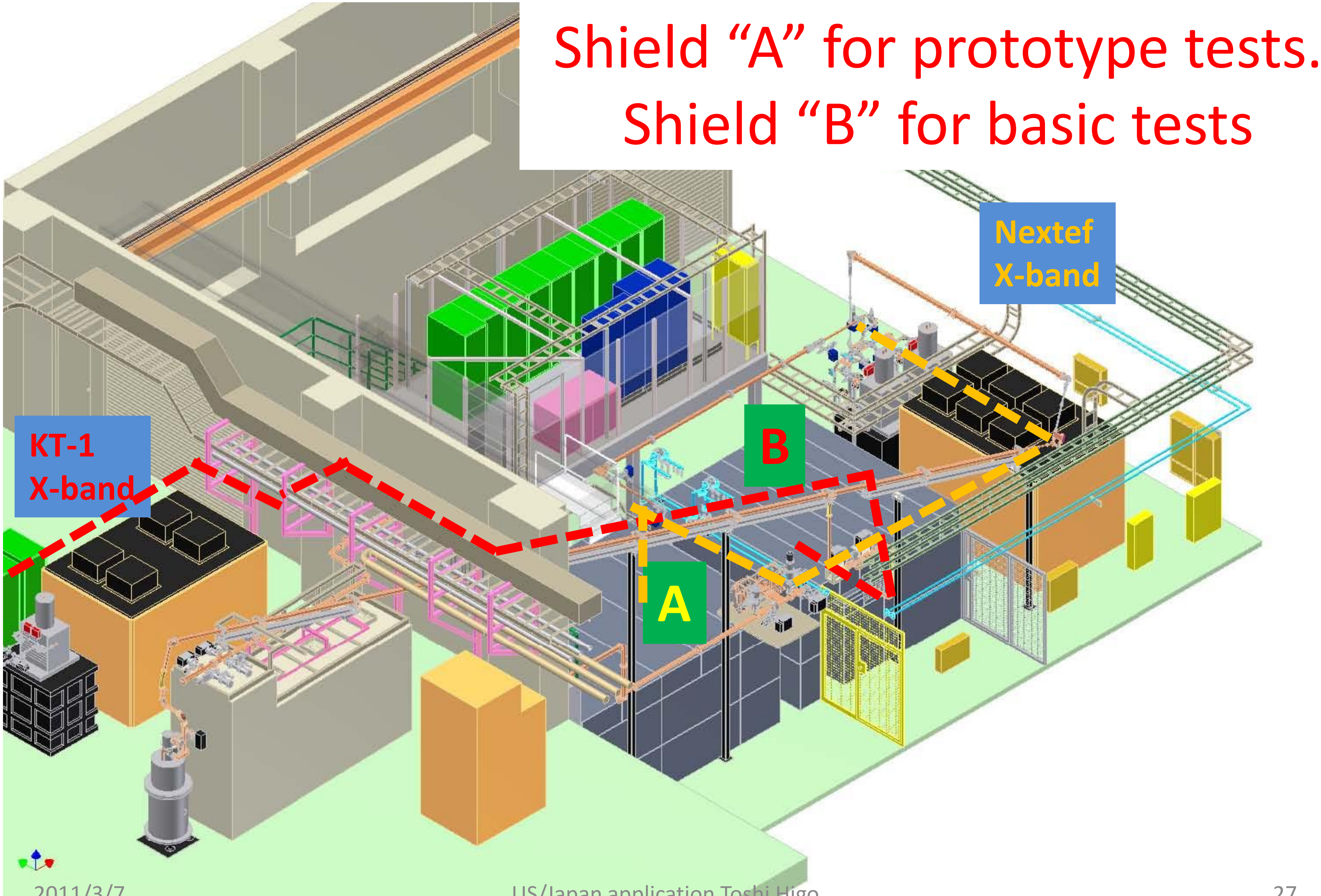


Hydrogen

Heat treatment

Material:
Clad (Cu/SS, Cu/Mo)

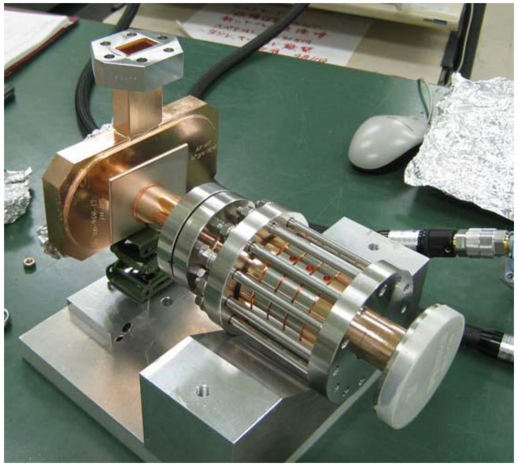
Nextef expansion at KEK



RF distribution to shield-B at KEK was almost completed

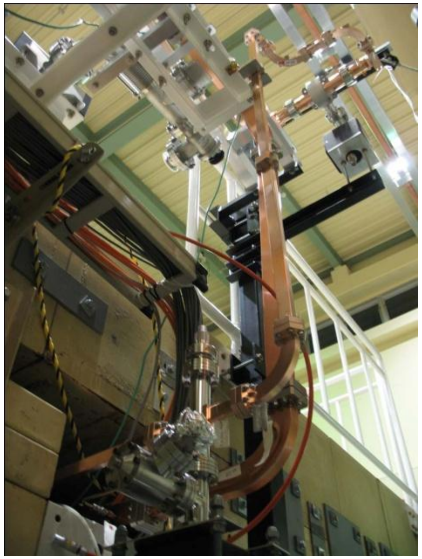
From a single klystron

Now ready for test at KEK in JFY2012



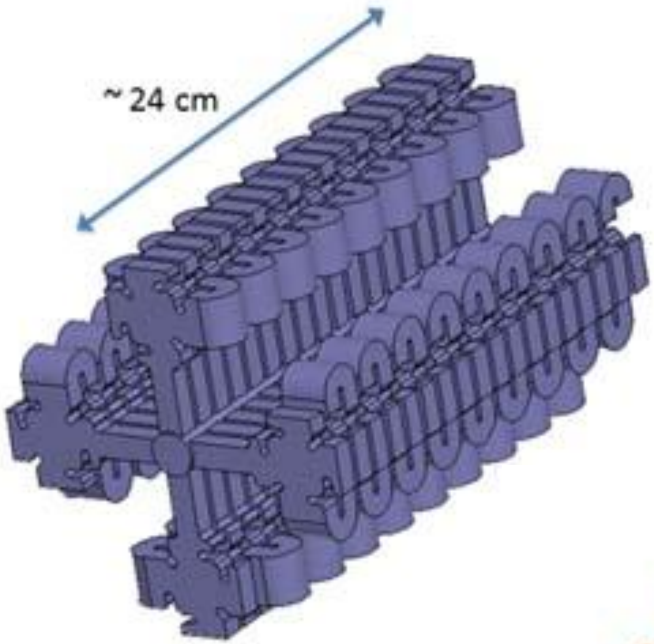
Test setups being prepared at KEK

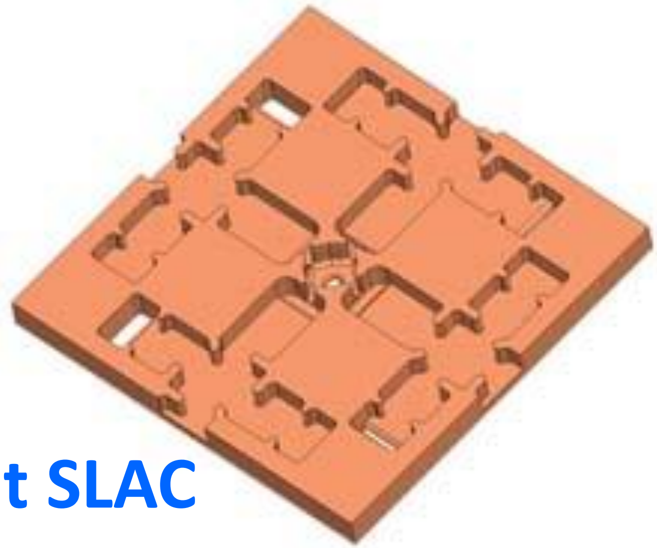
Inlet to shield-B



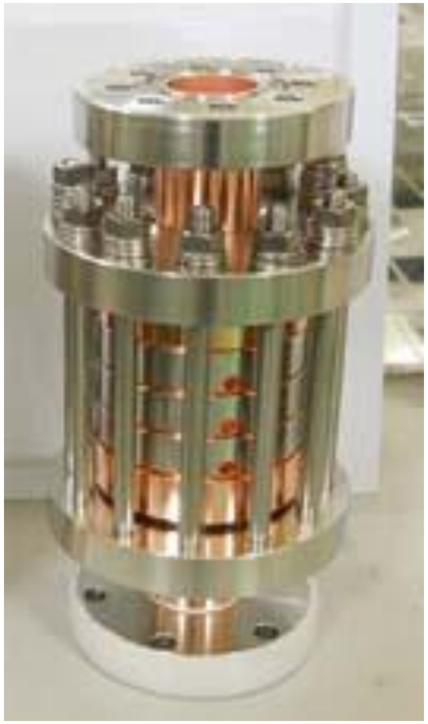
Inside shield-B

SLAC study toward much higher gradient



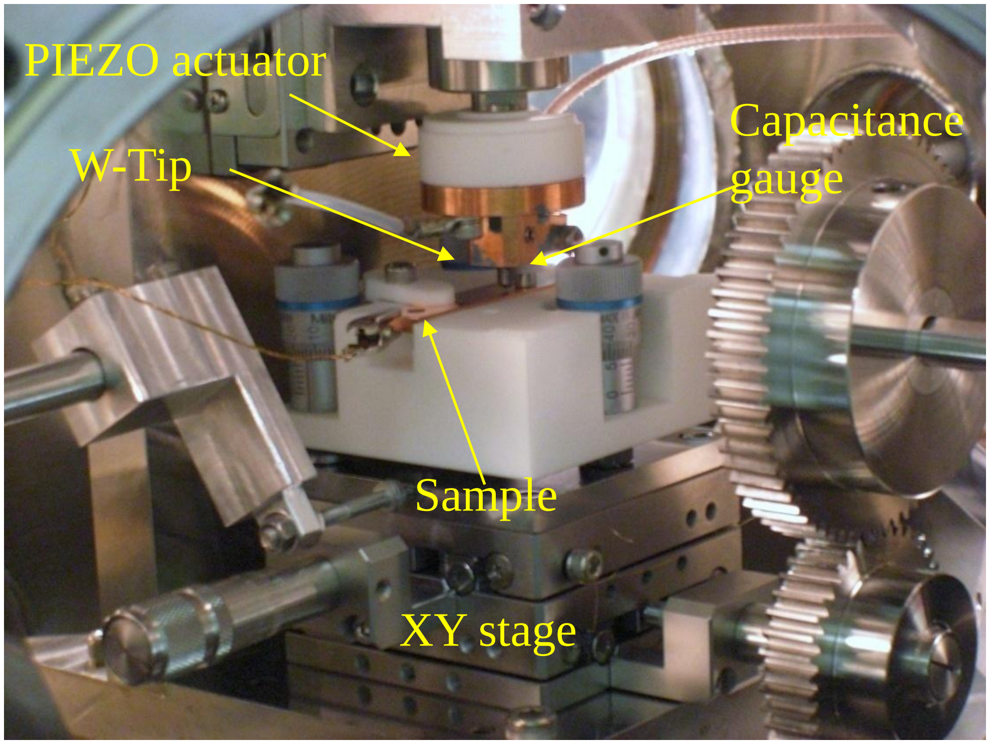


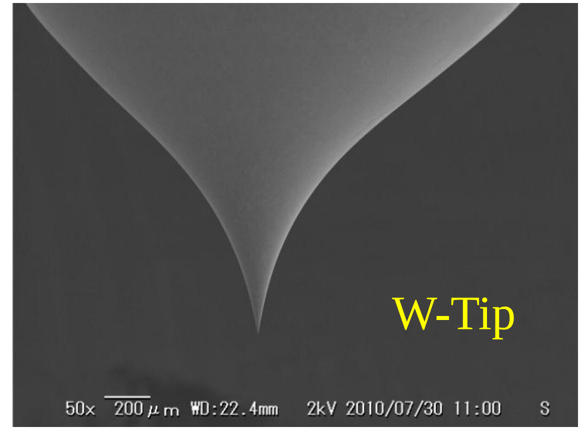
SW study at SLAC

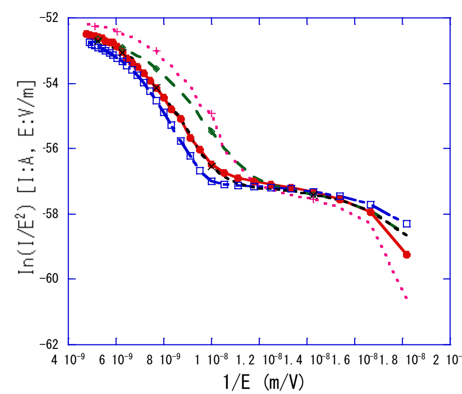


Cu/Moly clamp prepared by KEK

Scanning field emission microscope at KEK







Field emission and surface of crystal characteristics.

Summary and conclusion

JFY2011:

- Roughly 80MV/m was found feasible in copper damped structure, TD24.
- Magnetic field and associated high current on a crystal structure play an important role.
- Basic study environments were prepared at KEK.

JFY2012:

- Start test with simple geometry cavity at Shield-B in KEK.
- Continue prototype structure fabrication and test.

JFY2013:

- Based on above studies to understand the physics on breakdown trigger.
- Propose a possible RF system for high energy machine.

Background:

- US pursuits real high gradient while Japan evaluates below 100 MV/m. These studies are complementally and offer a baseline idea for linear collider application.