Update of Nextef activity and TD26CC high-gradient result

CLIC2019 at CERN
21 January 2019
On behalf of X-band team
T. Higo, KEK

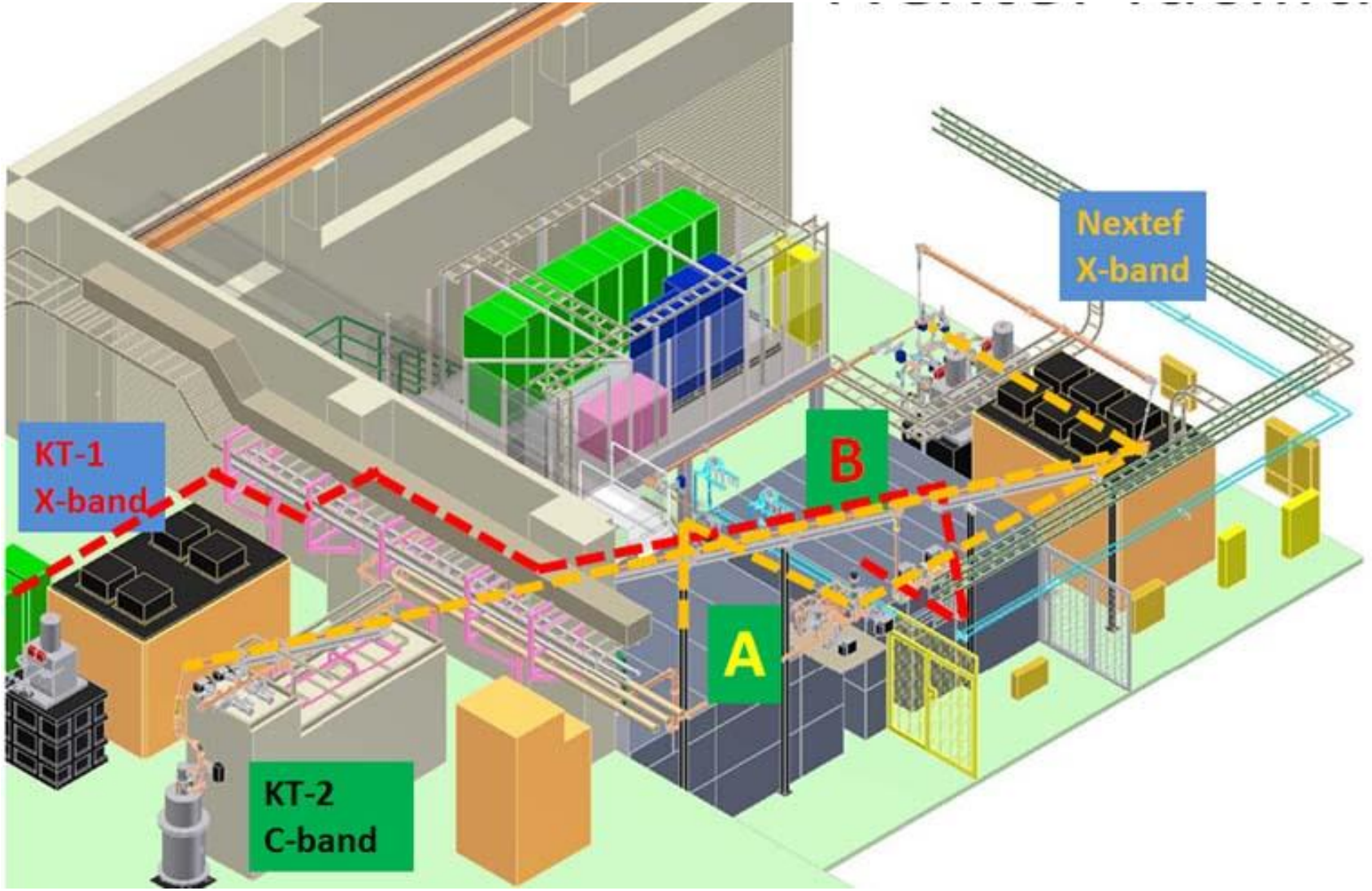
Contents

1. High gradient test of CLIC prototype structures
   – TD26CC-K1, SLAC-DCS #2 (Weatherford)
2. High gradient test with single-cell SW cavities
   – Quadrant (Abe), Full-choke cavity with laser (Abe)
3. Manufacturing prototype structures
   – Full quadrant (Abe), Three T24's
4. Others
   – DC-HV electrode
5. High gradient activity at KEK, a consideration

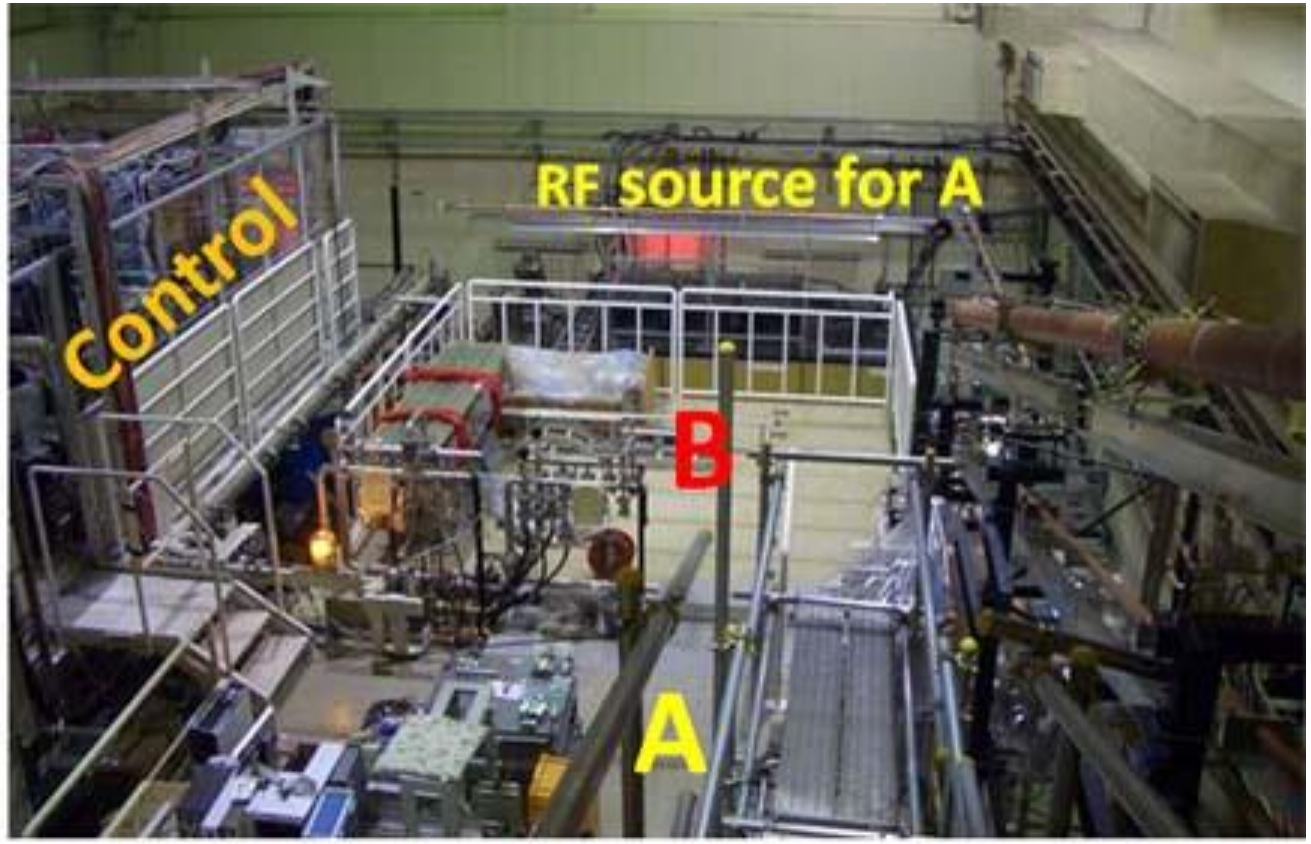
Highlights in 2018

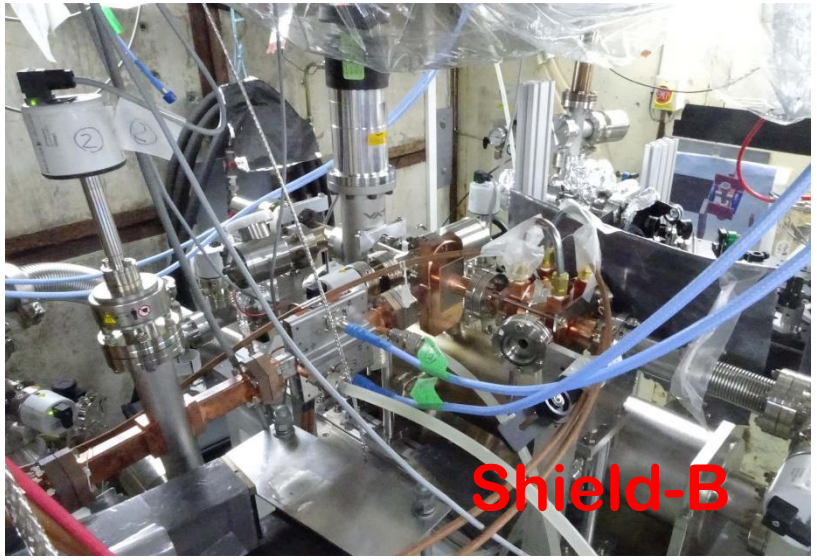
- **Nextef-A on CLIC prototype structures**
  - **TD26CC-K1 high gradient showed good result for CLIC**
  - **SLAC-DCS high gradient showed good result at > 100 MV/m**
- **Nextef-B with single-cell SW cavities**
  - **Quadrant 0.1mm gap worked at 120 MV/m well**
  - **Cavity with 532nm laser was prepared**
- **Production by KEK**
  - **TW full-size quadrant TD24R10_QUAD-K1 underway**
  - **Assembly of T24's has started**

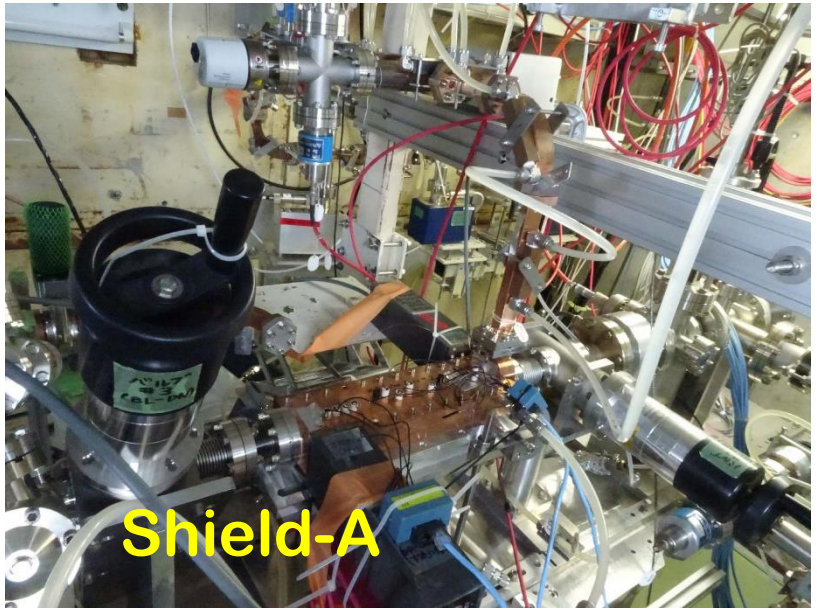
KEK Nextef Shield-A & B



Nextef





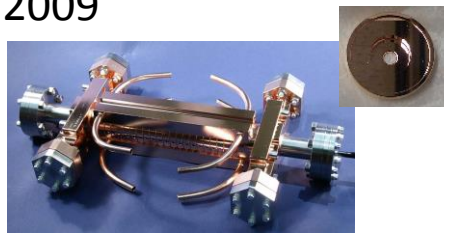


Nextef-A: Study of prototype structures

Prototype structure high-gradient test at Nextef

T18 → Quad → TD18 → T24 → TD24 → TD24R05 → TD24R05 → T24THU → TD24R05 → Deflector → TD24R05 → TD26CC → DCS → T24-K1

2009

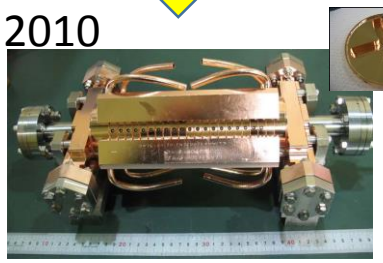


T18_Disk_#2

2009

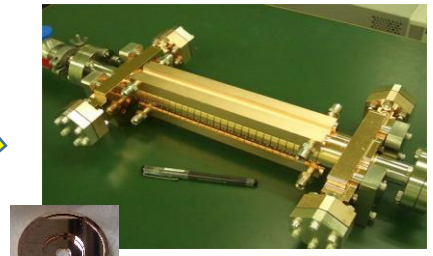
TD18_Quad

2010



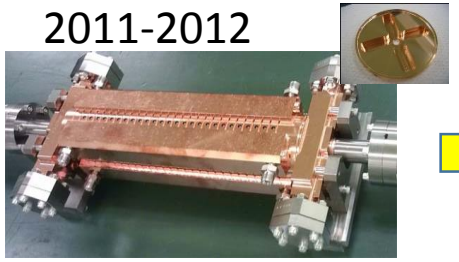
TD18_Disk_#2

2011



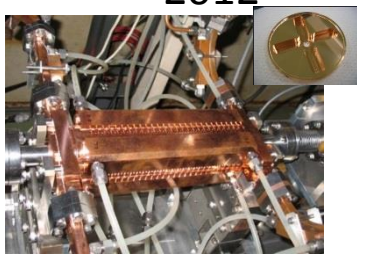
T24_Disk_#3

2011-2012



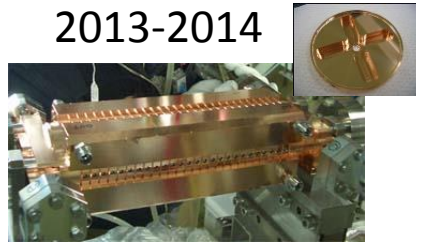
TD24_Disk_#4

2012



TD24R05_#2

2013-2014

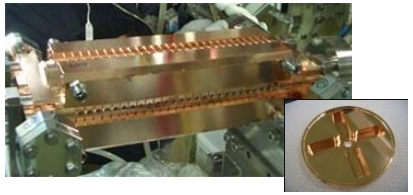


TD24R05_#4

2014-2015

T24THU_#1

2015



TD24R05_K1

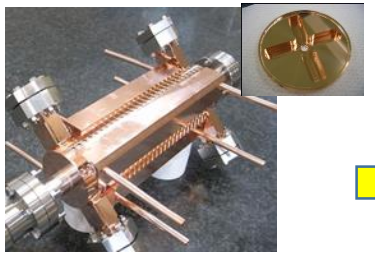
2016

Deflector (SINAP)

2016-2017

TD24R05_K2

2018



TD26CC_K1

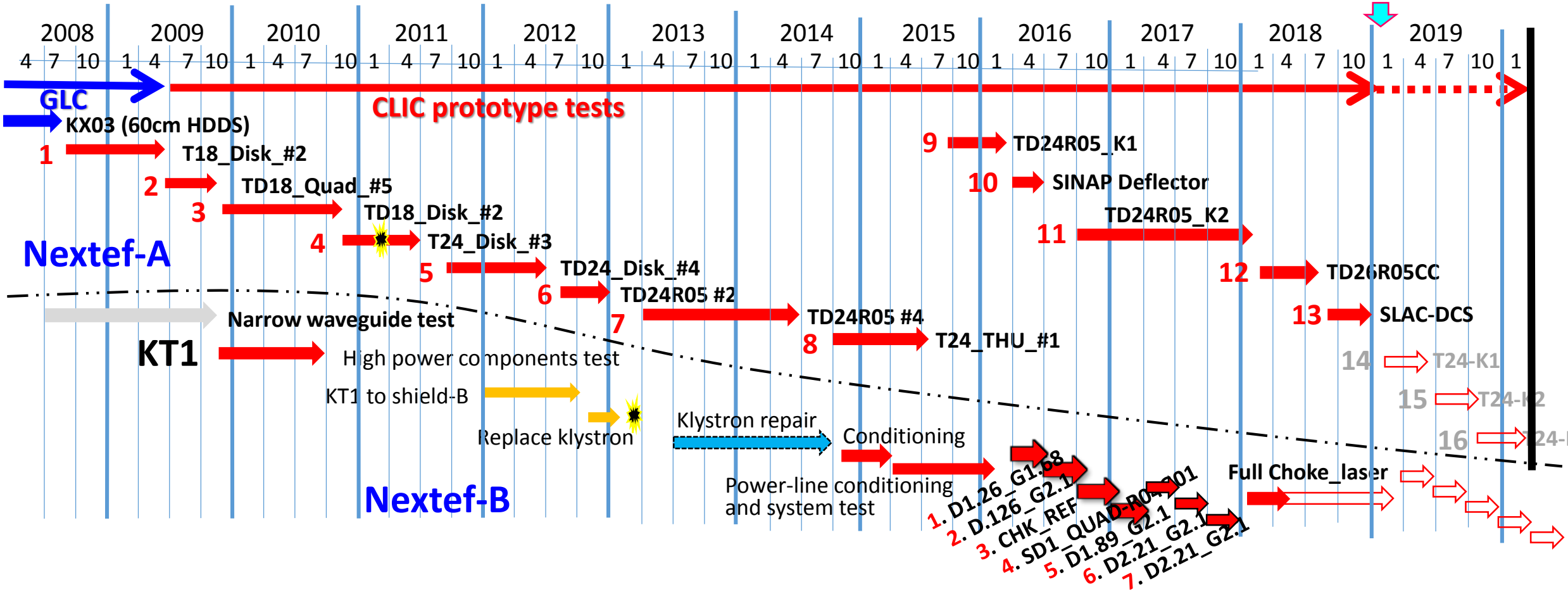
2018

SLAC-DCS

2019

T24-K1

CLIC prototype high-gradient test at Nextef

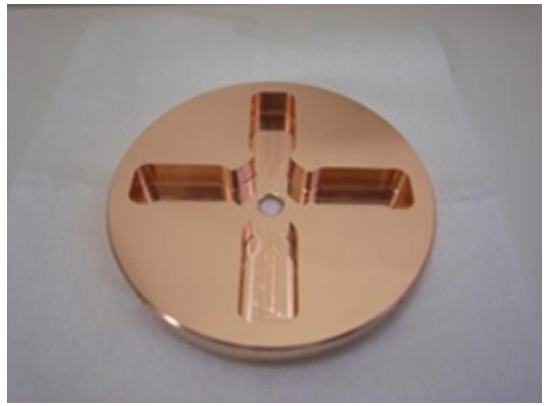


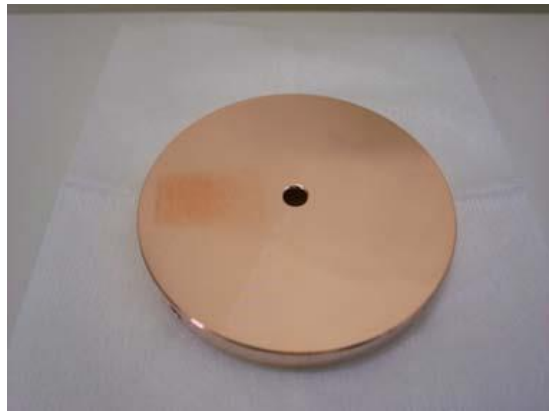
TD26CC-K1

- **Design** scaled from 12GHz by KEK
- **Worries**
  - Long storage time (2 years) of parts, leakage in wave guide insertion, 3 months for tuning in N_2/air, non-perfect field flatness ±5%
- Ramping (processing protocol)
  - Carefully and automatically controlled, keep BDR < 5 BD/hr
- High-gradient feature
  - Field emission stays as typical good one, 10μA at 100 MV/m
  - BDR also show good, $<10^{-7}$ bpp/m (scaled to 100 MV/m)

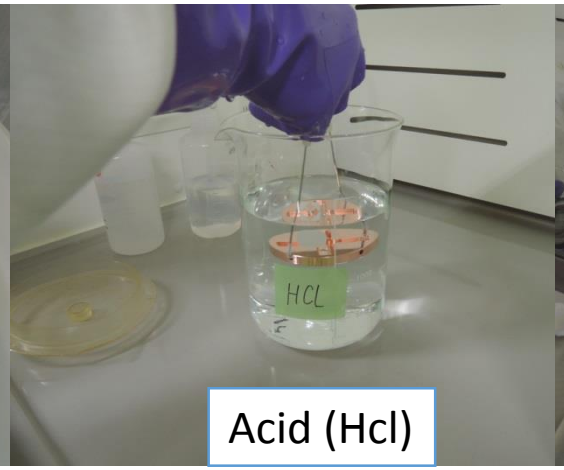
Manufacturing of TD26CC-K1 Cell preparation

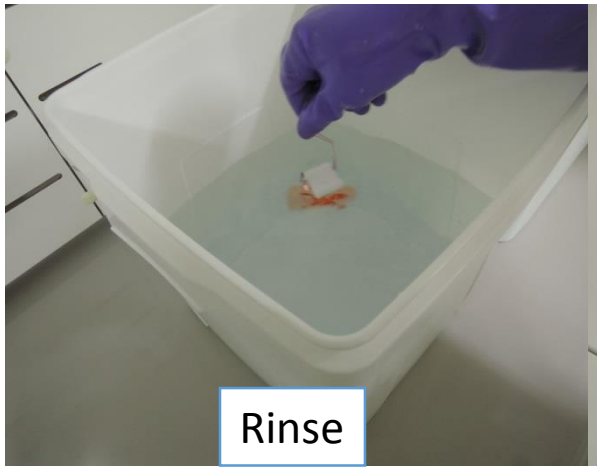
Machining by vendor company

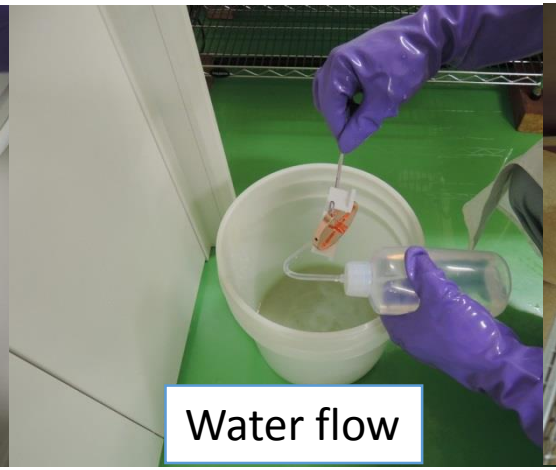


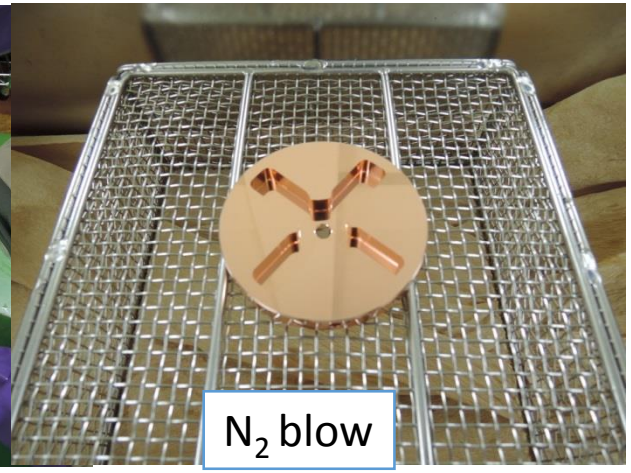


Chemical etching following SLAC recipe and proceeded in KEK



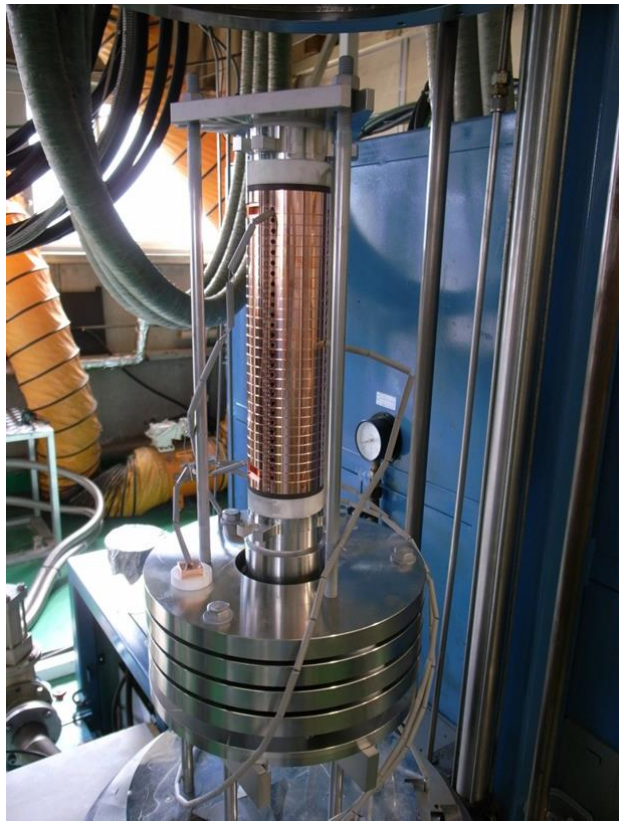




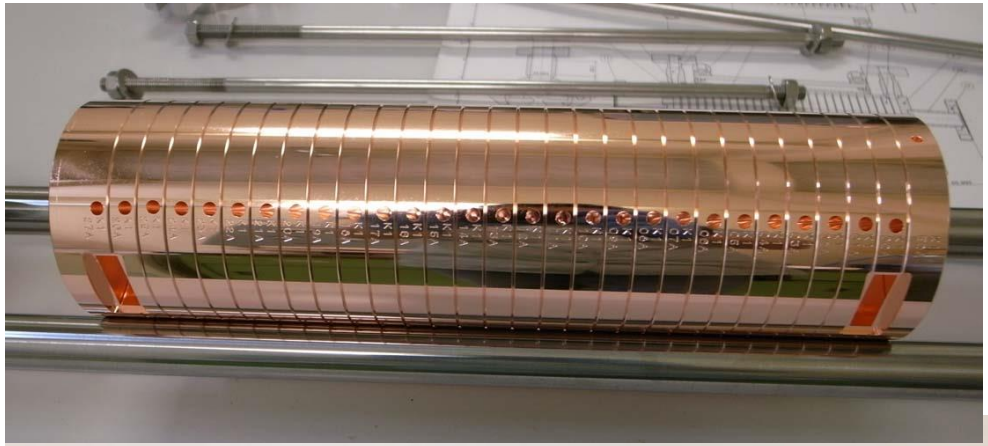


TD26CC-K1 DB in H_2 – followed by brazing where a leakage found and fixed in the following brazing

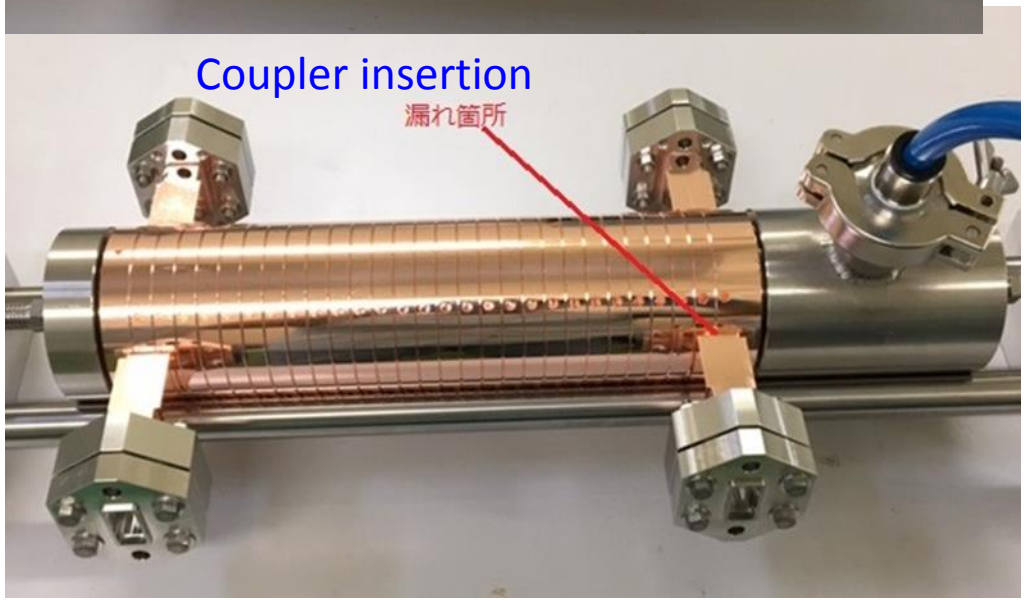
KEK H_2 furnace



DB of main body

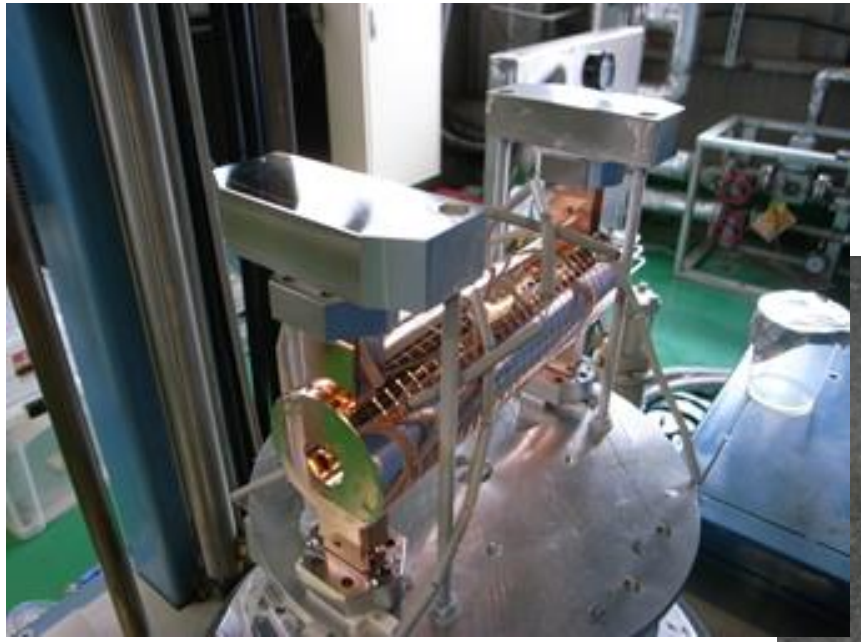


Coupler insertion



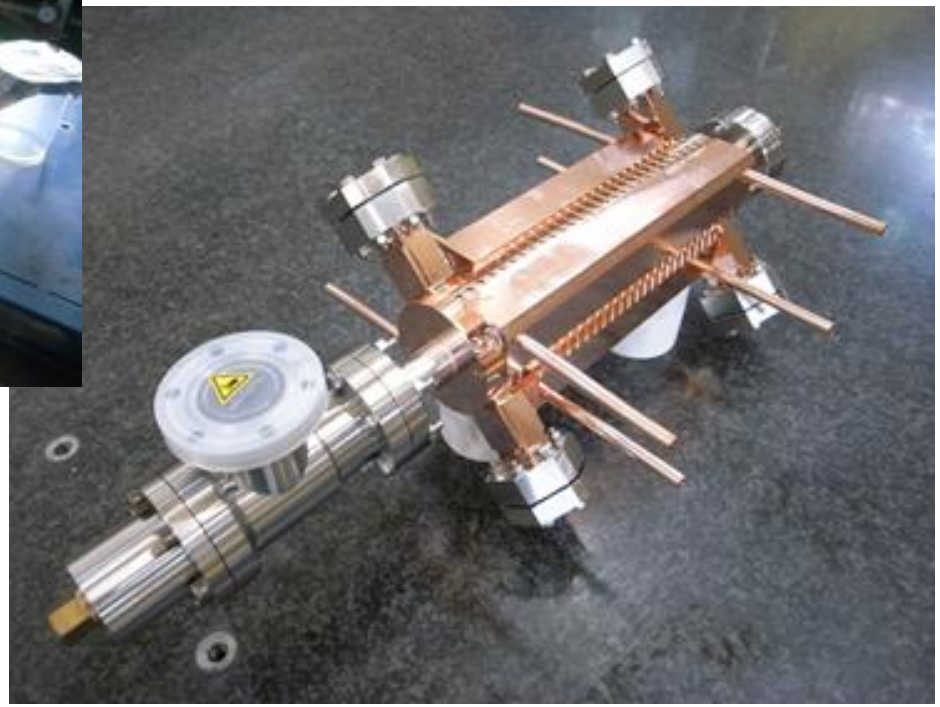
Brazing tuning pin and water cooling

TD26CC-K1 final brazing and tuning

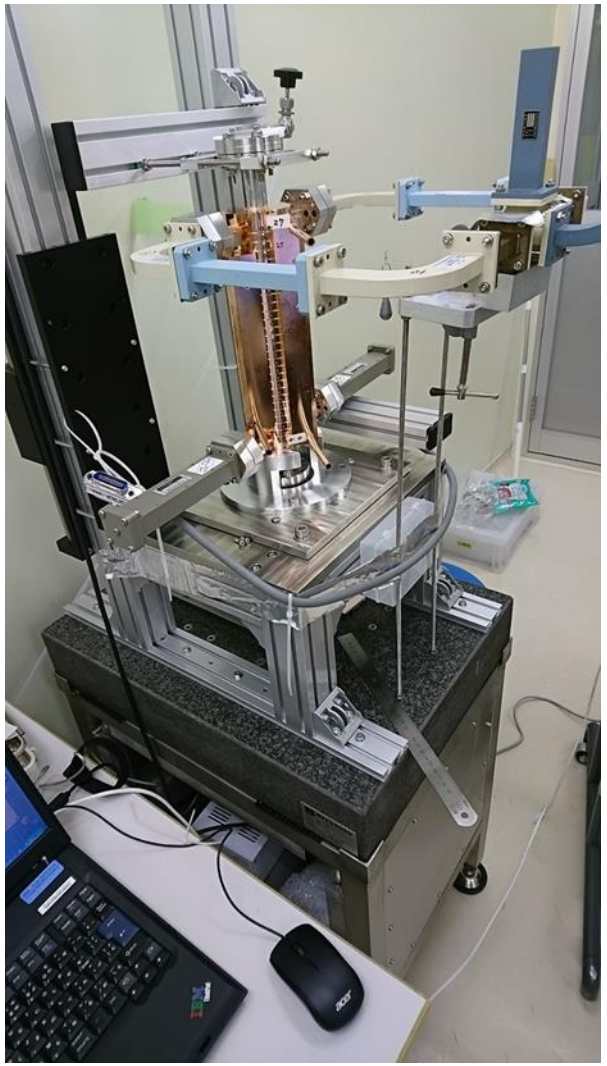


Fixing leakage in KEK H_2 furnace

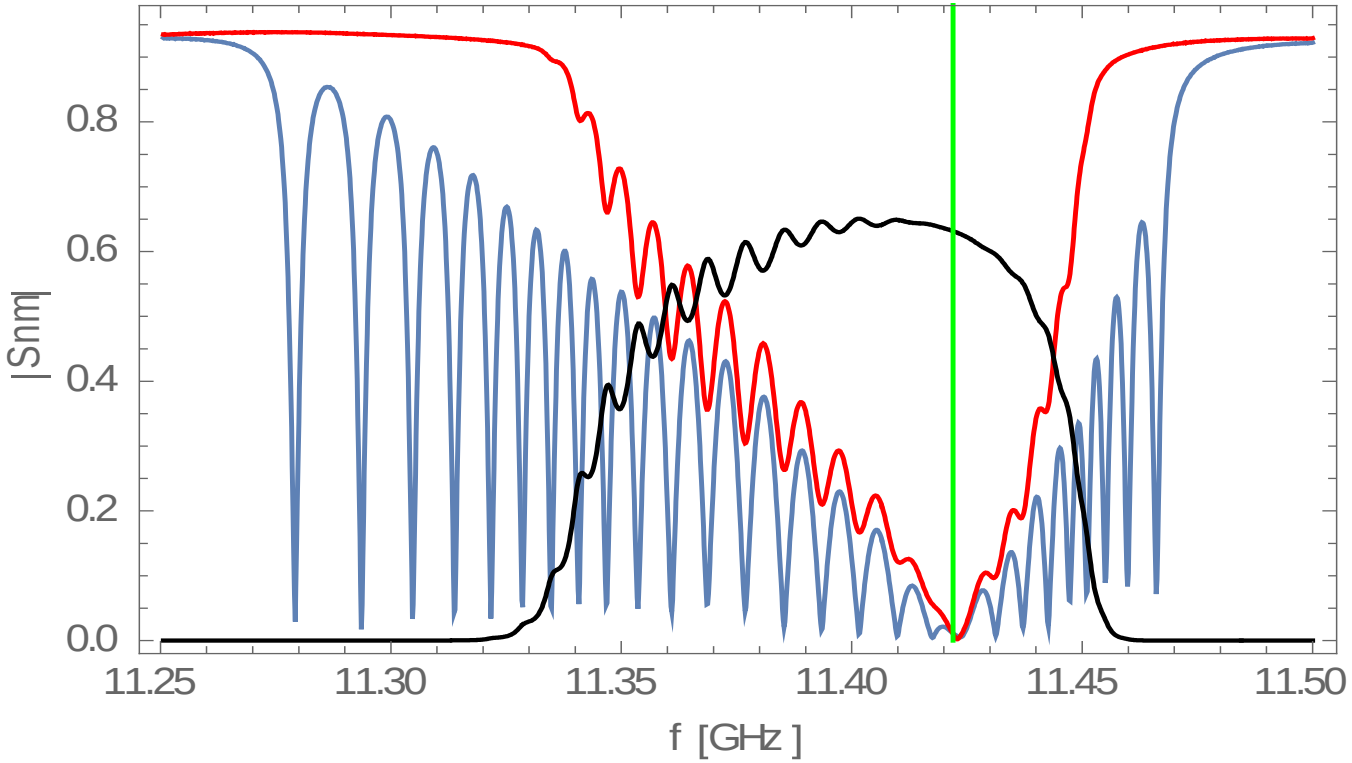
Completed TD26CC-K1



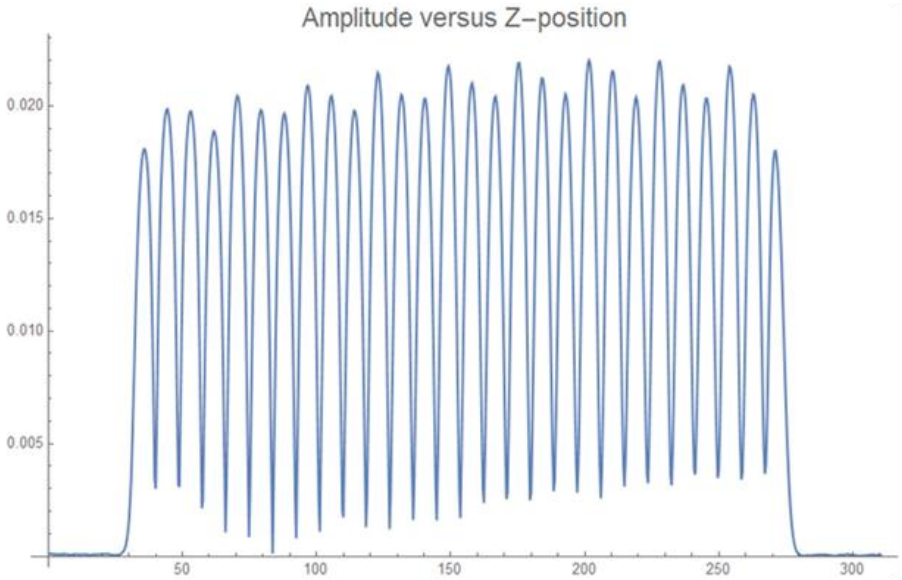
Tuning TD26CC-K1



Tuning of TD26CC-K1



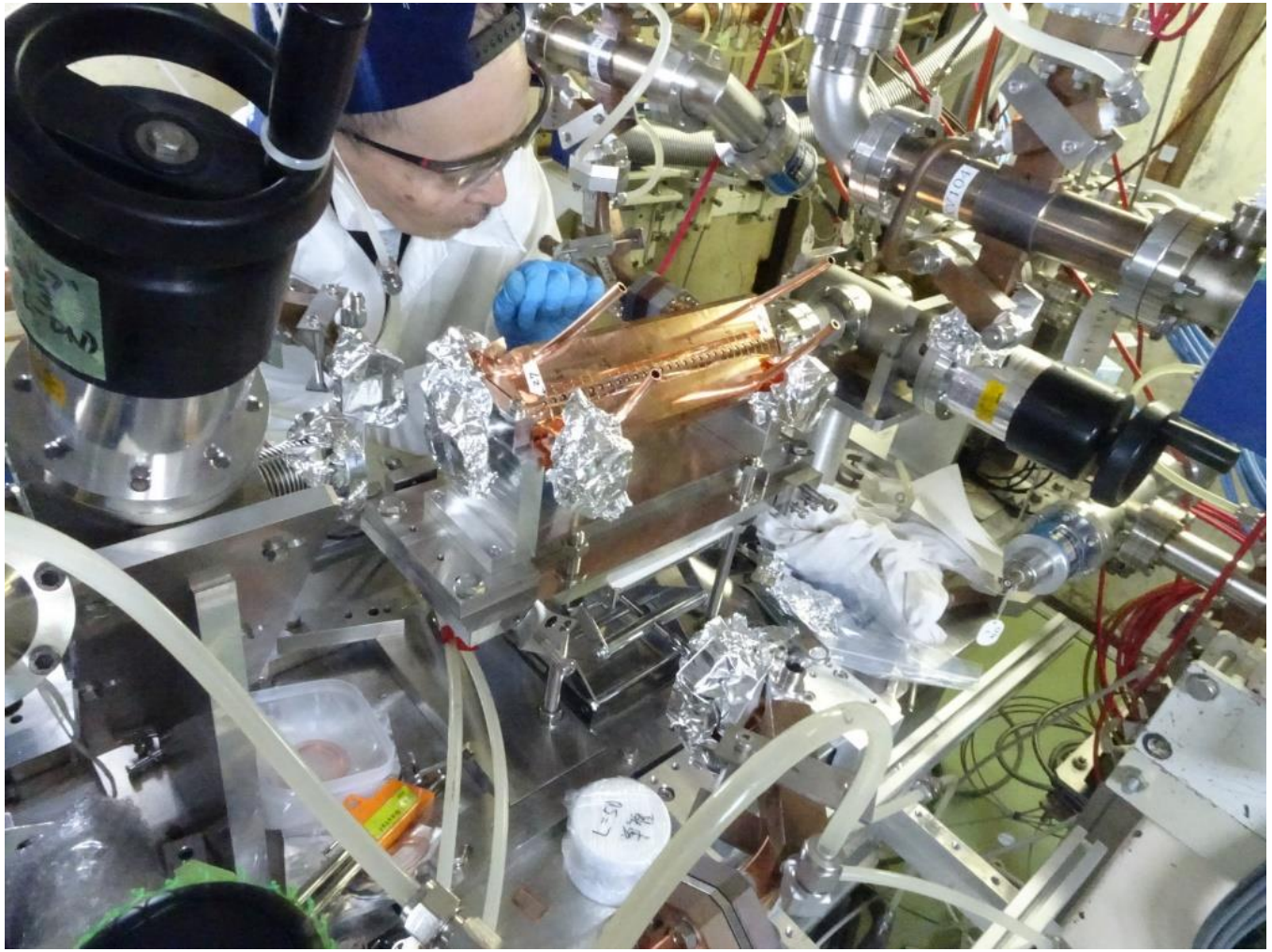
After tuning



Some ripples exists but accepted and went into high power

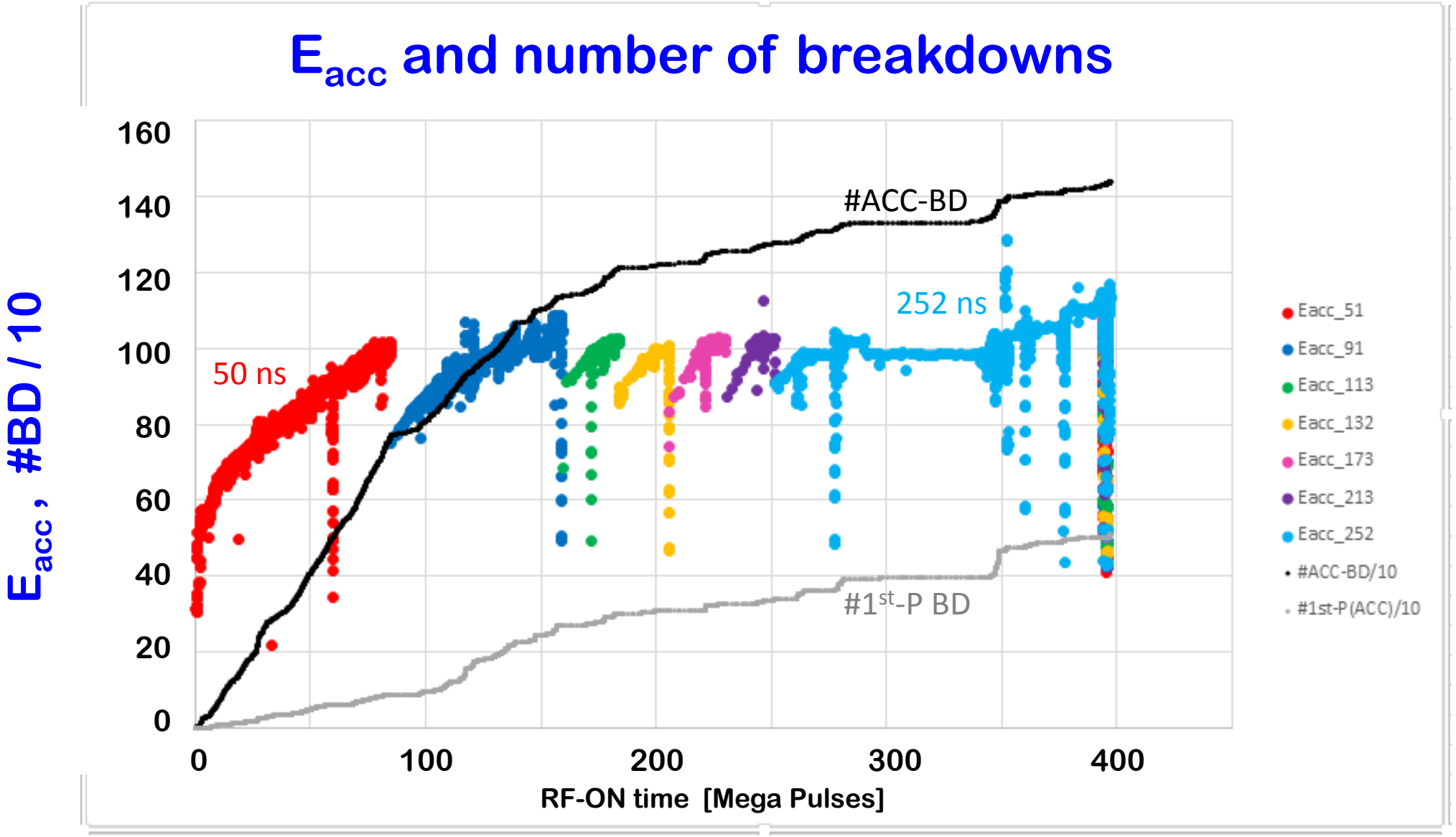
KEK, 23:29, 9 February 2018

TD26CC-K1
Installation into Nextef-A as usual

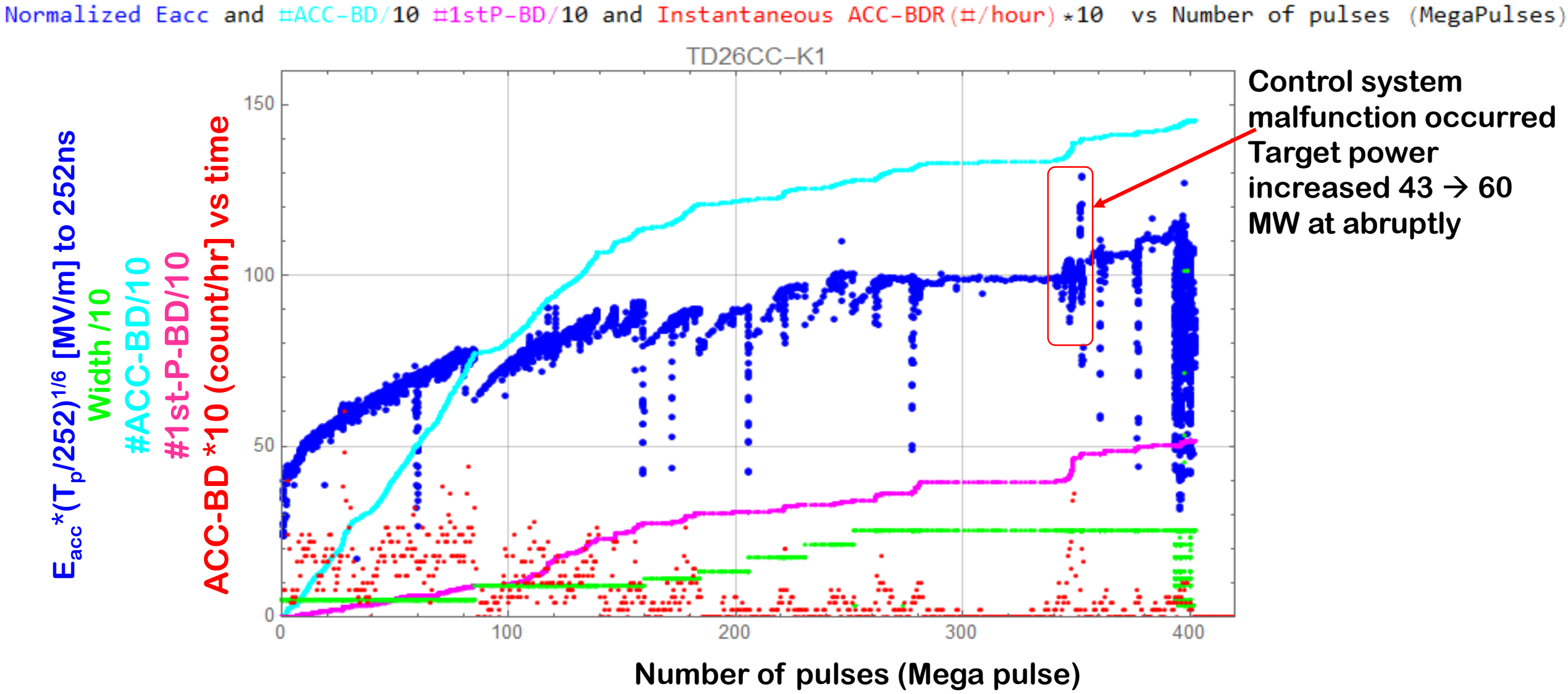


Just try to make a N2 flow from inside structure toward outside

TD26CC-K1 whole processing history

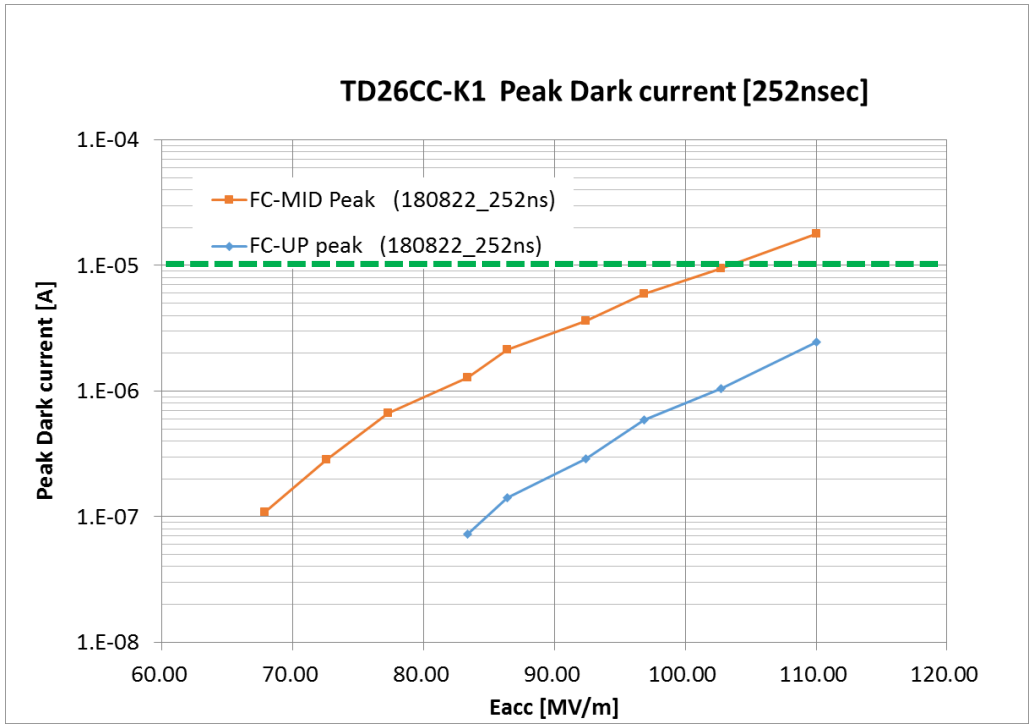


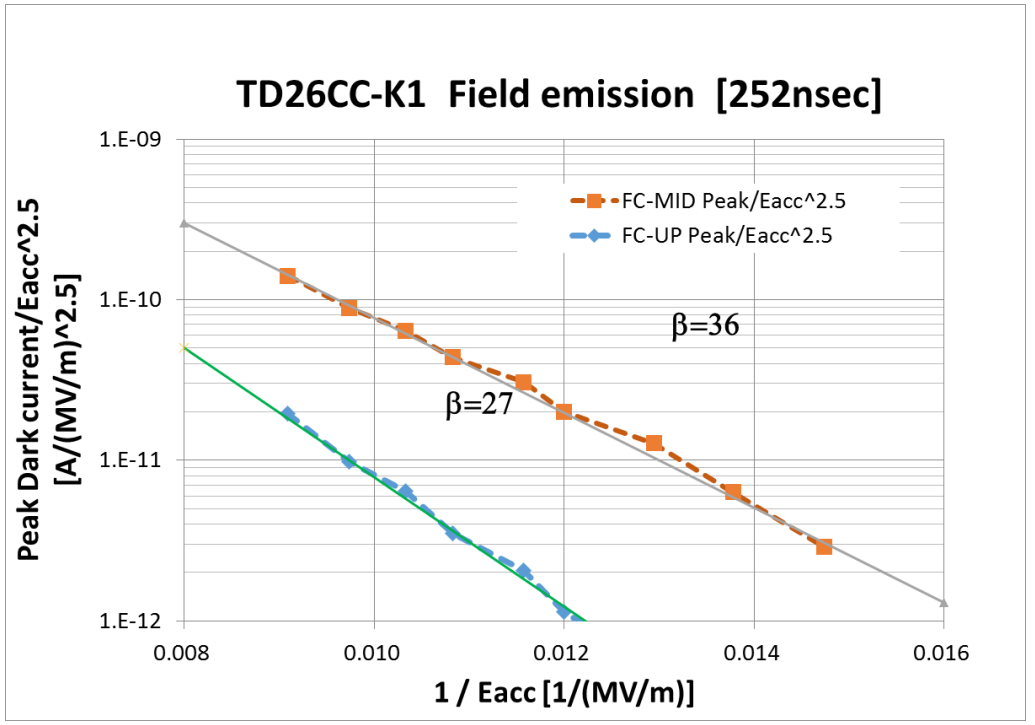
TD26CC-K1 status



Control system malfunction occurred
Target power increased 43 → 60 MW at abruptly

Dark current of TD26CC-K1 measured on 28 August

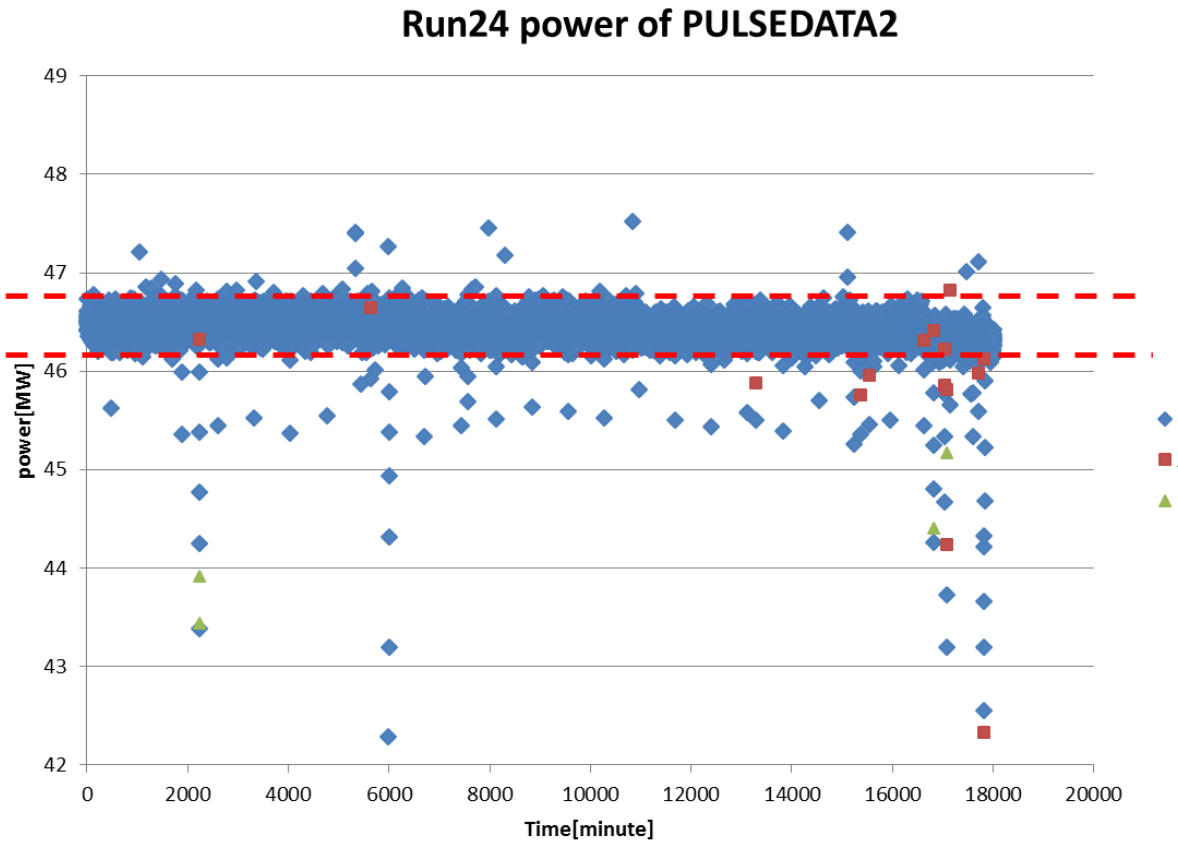


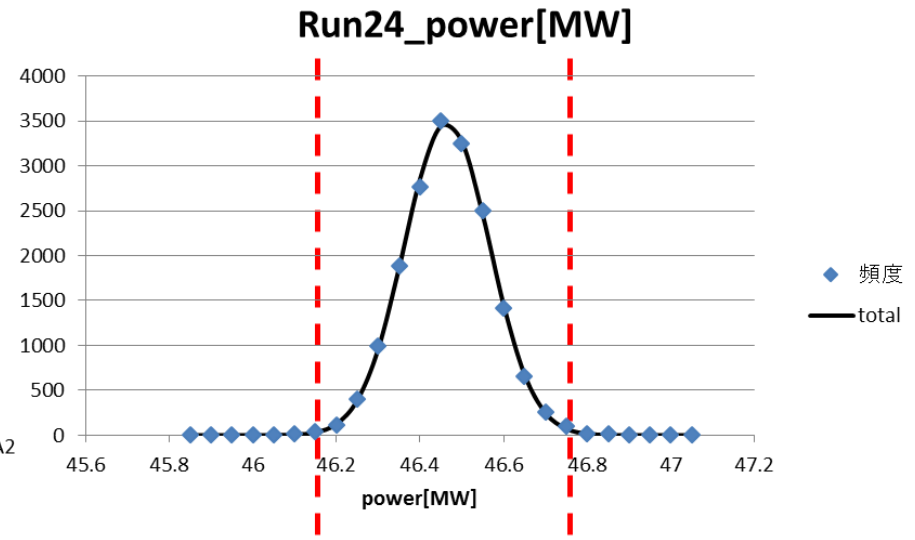


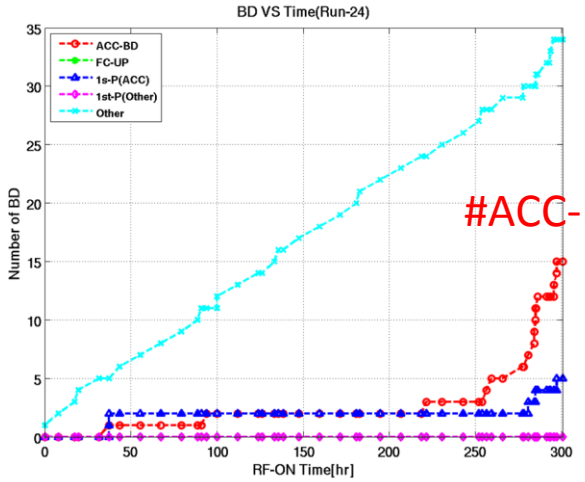
103 MV/m at FC-Mid=10 μA after running 400 MegaPulses

Es/Ea=1.95

Typical run with fixed target 95 MV/m
for 300 hours in Run 24







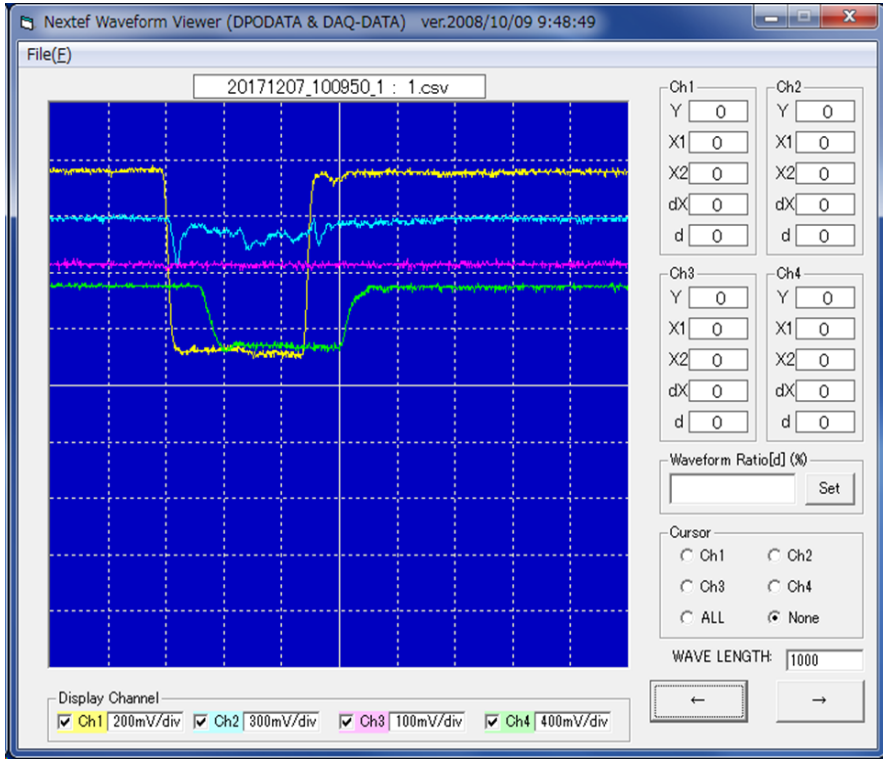
#ACC-BD

#1st-P-BD

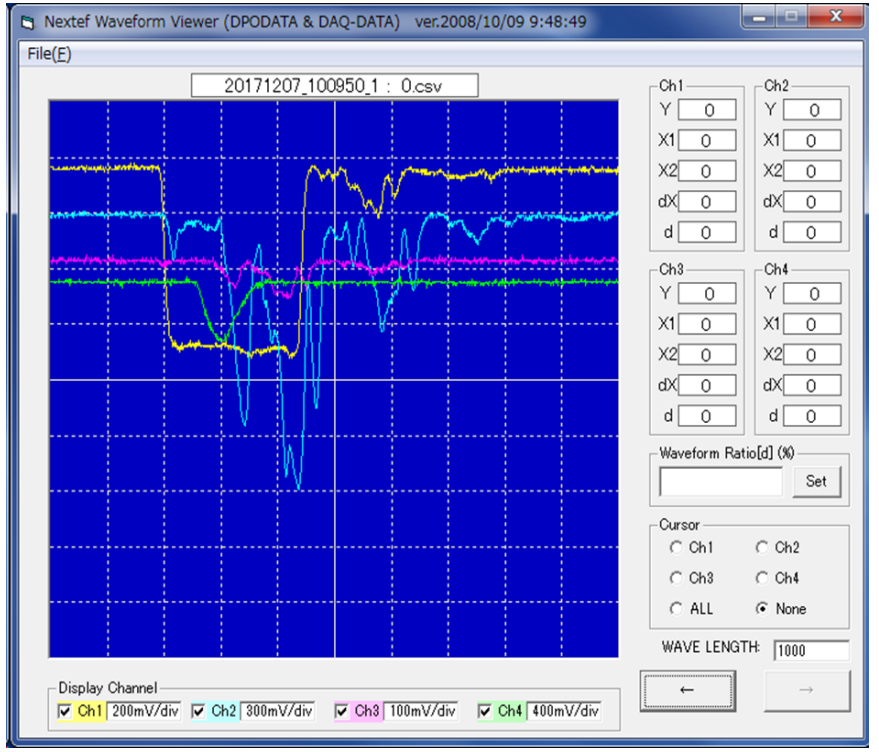
Showed typical statistical fluctuation pattern

Typical BD pulse

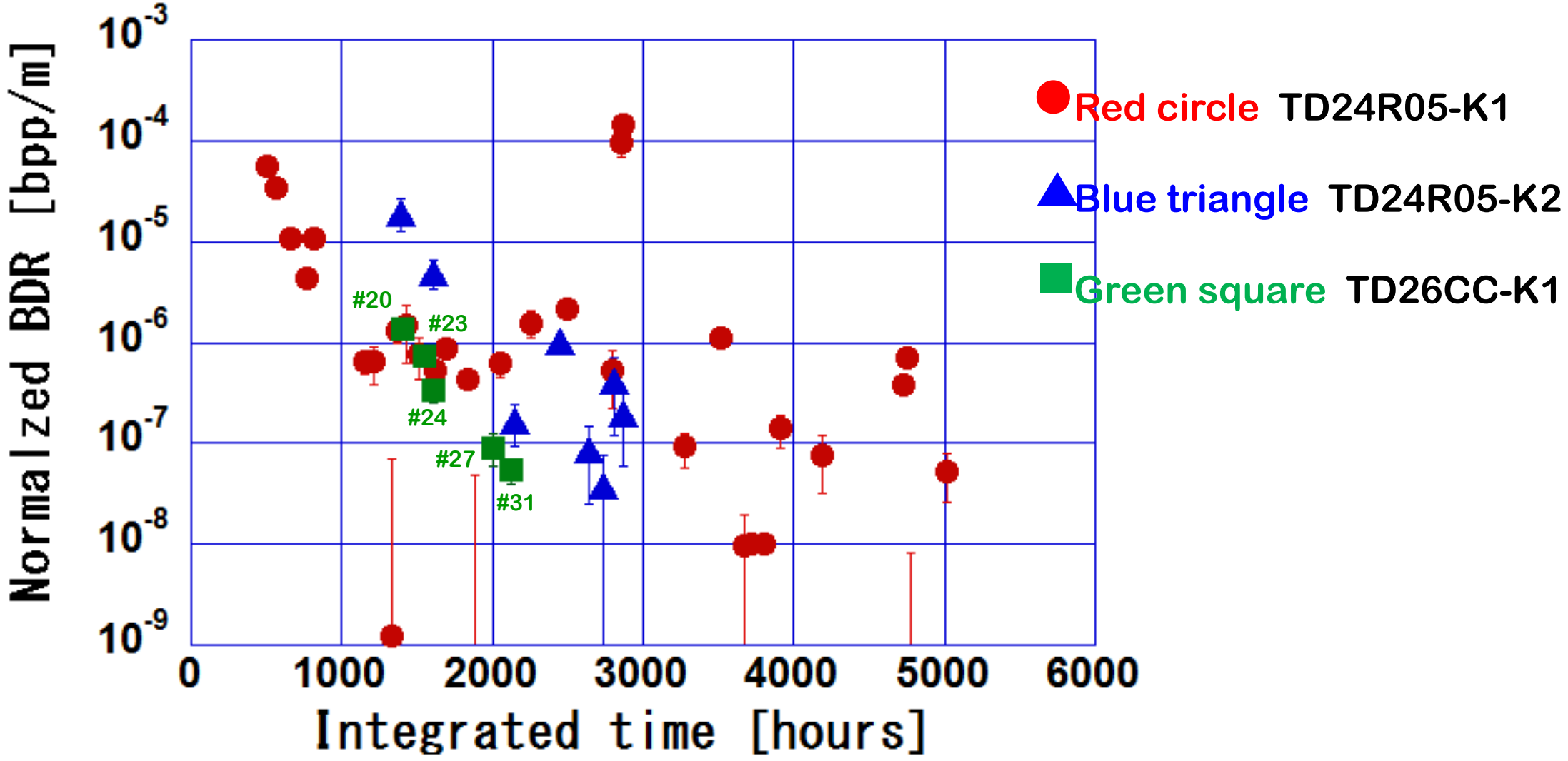
Normal pulse before BD



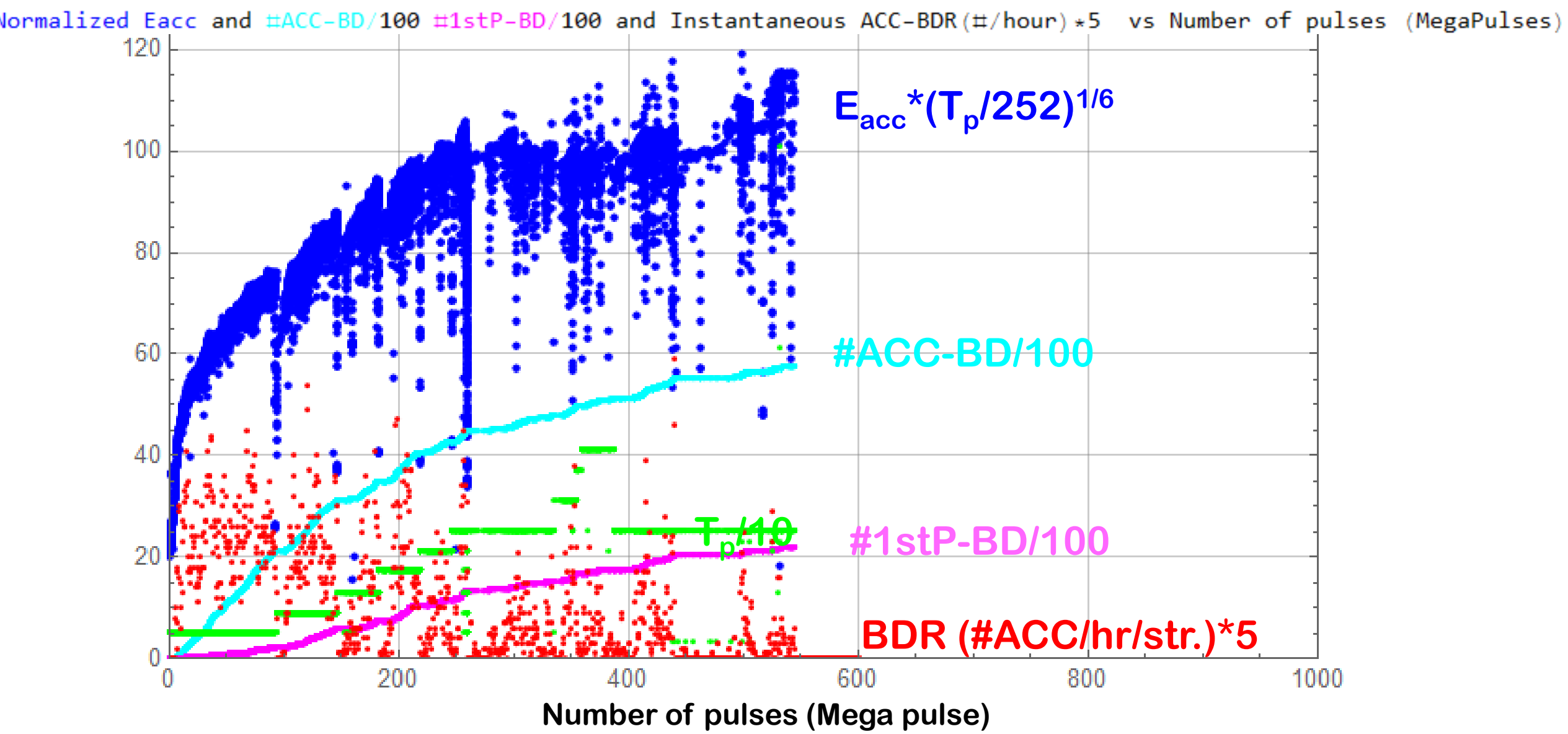
BD pulse



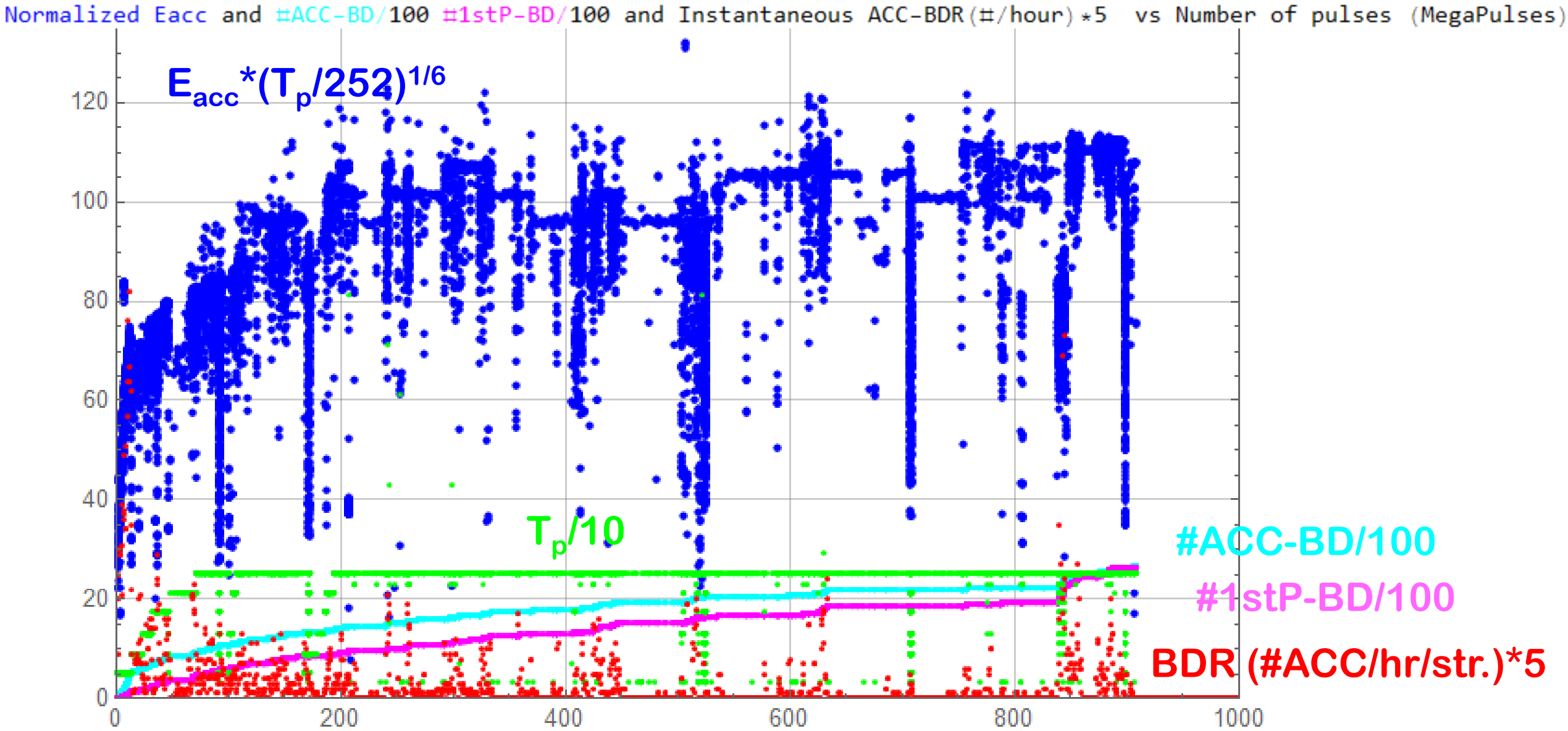
BDR of TD24R05-K1 & K2 and TD26CC



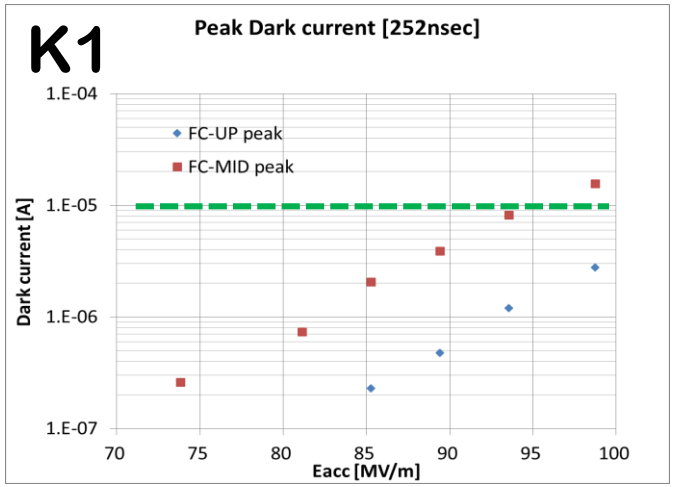
TD24R05-K1


Normalized Eacc and #ACC-BD/100 #1stP-BD/100 and Instantaneous ACC-BDR(#/hour)*5 vs Number of pulses (MegaPulses)
120
100
80
60
40
20
0
0
200
400
600
800
1000
Eacc*(Tp/252)1/6
#ACC-BD/100
Tp/10
#1stP-BD/100
BDR (#ACC/hr/str.)*5
Number of pulses (Mega pulse)

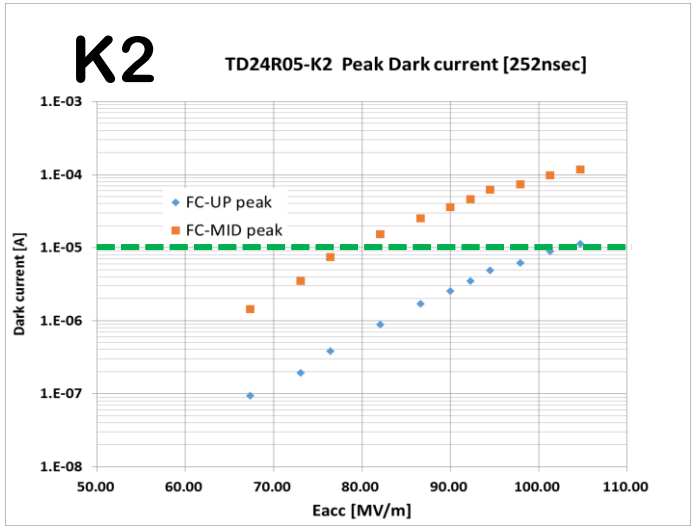
TD24R05-K2


Normalized Eacc and #ACC-BD/100 #1stP-BD/100 and Instantaneous ACC-BDR(#/hour)*5 vs Number of pulses (MegaPulses)
$E_{acc}*(T_p/252)^{1/6}$
$T_p/10$
#ACC-BD/100
#1stP-BD/100
BDR (#ACC/hr/str.)*5
0
20
40
60
80
100
120
0
200
400
600
800
1000
Number of pulses (Mega pulse)

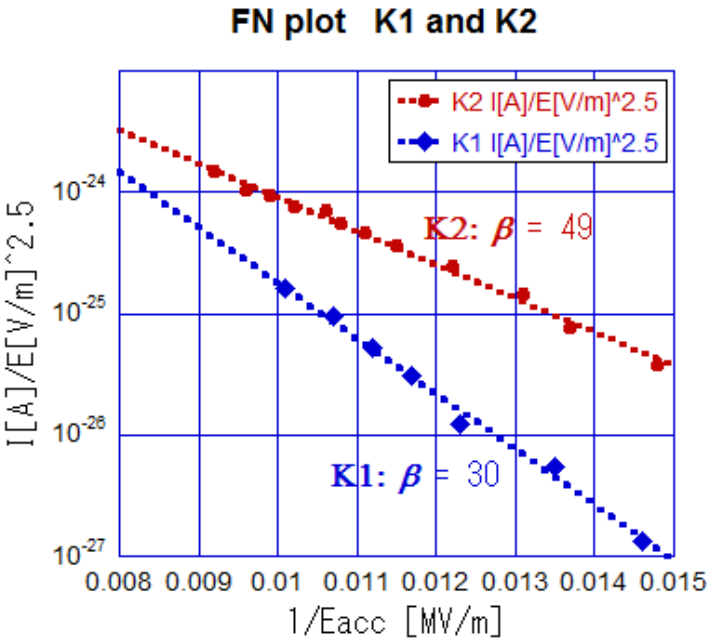
TD24R05-K1,2 Dark current



FC-Mid
at 1500 hours (280Mega Pulses)
20 μA at 100 MV/m
Lower dark current



FC-Mid
at 1330 hours (240 Mega pulses)
100 μA at 100 MV/m
Higher dark current



Comparison with previous TD24R05 structures

	Unit	TD24R05-K1	TD24R05-K2	TD26CC-K1
Ramping period	Mega Pulses	300	150	260
BDR during ramping	BD / hour / structure	8	3 *	3
BDR #	1 e^{-6} [bpp/m]	< 1	< 1	< 0.1
Dark current	microA meas at MegaPulses	20 at 280MP	100 at 240 MP	8 at 400MP
Field enhancement factor β	-	30	49	36

Ramping period: up to 100 MV/m with 252 nsec

* The very beginning of TD24R05-K2 at 50nsec BDR as high as ~15

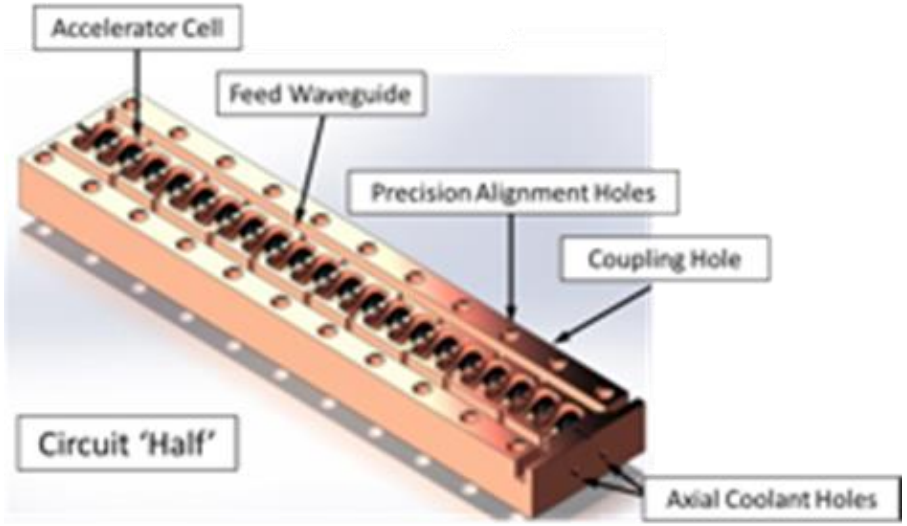
Listed nominal BDR's (breakdown rate) are read at ~400 Mega Pulses

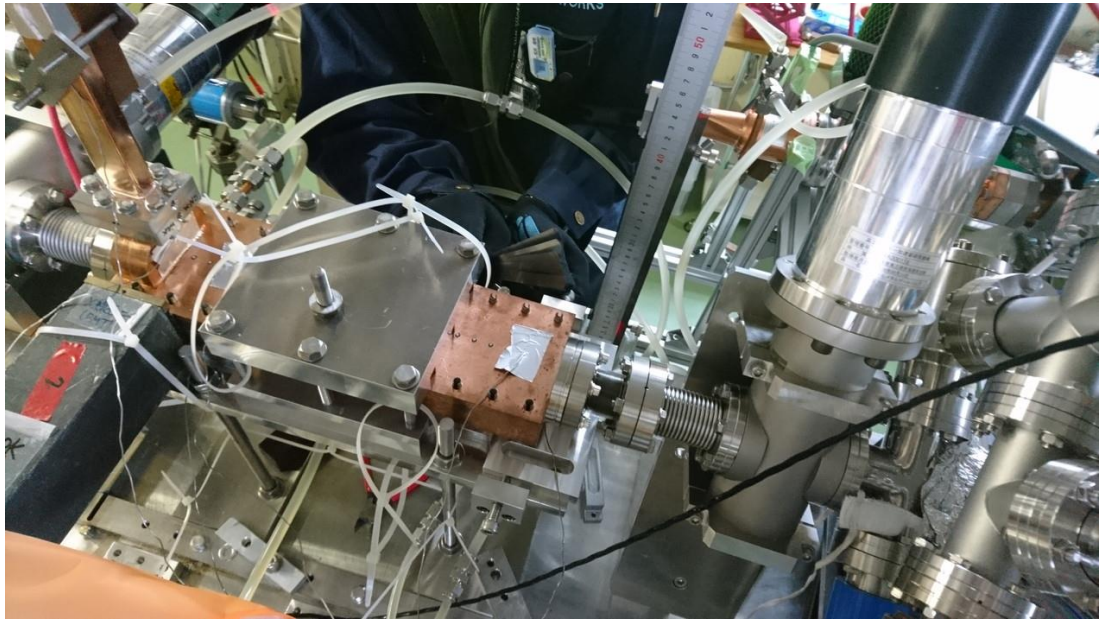
Summary of TD26CC-K1

- Design scaled from 12GHz by KEK
- Worries
  - Long storage time (2 years) of parts, leakage in wave guide insertion, 3 months for tuning in N_2/air, non-perfect field flatness ±5%
- **Ramping** (processing protocol)
  - Carefully and automatically controlled, keep **BDR** < 5 BD/hr
- **High-gradient feature**
  - **BDR** also show good, <10^{-7} bpp/m (scaled to 100 MV/m)
  - **Field emission** stays as typical good one, 10μA at 100 MV/m

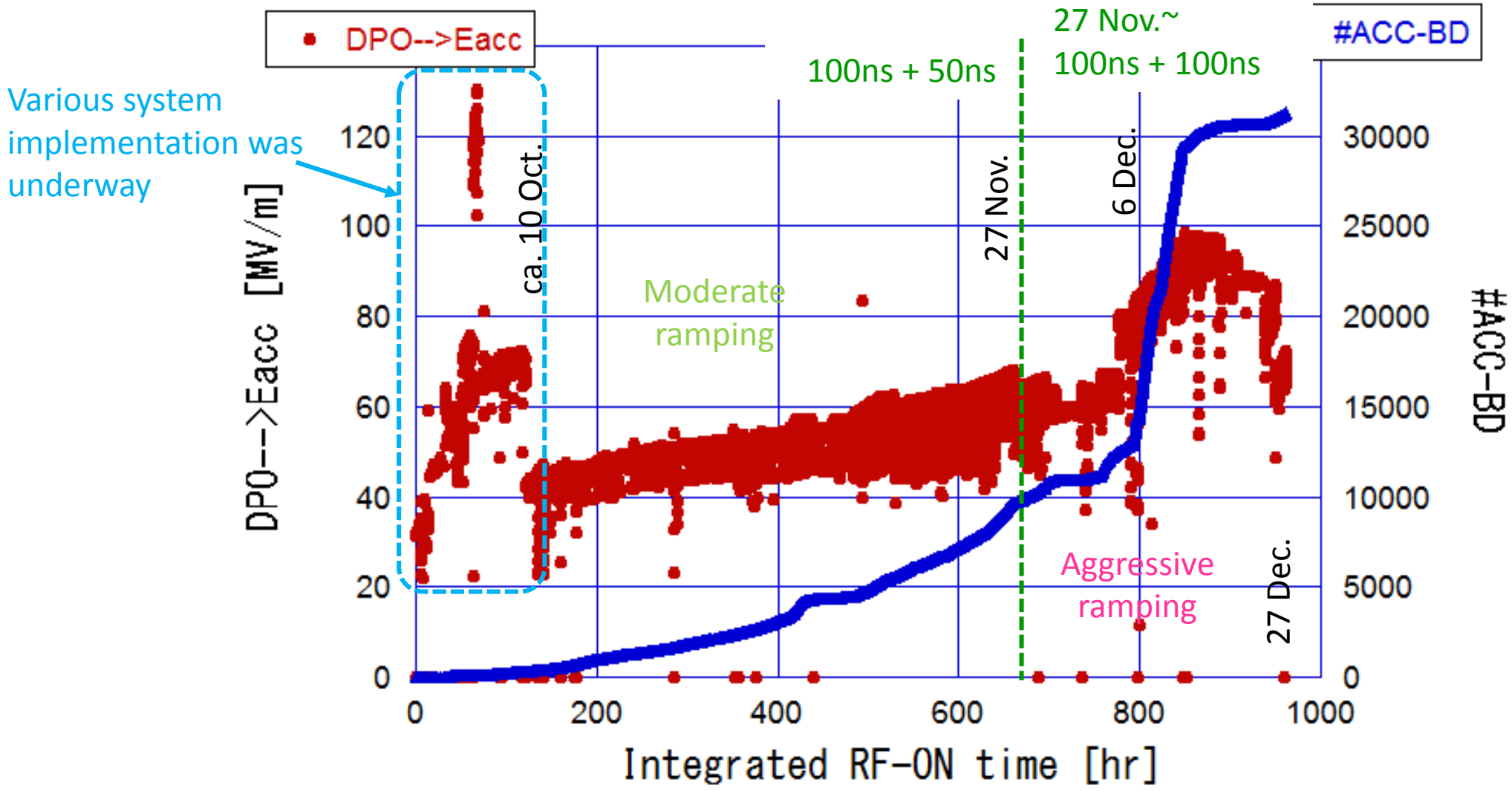
SLAC-DCS #2 high-gradient test result

- To be presented by Brandon Weatherford in detail

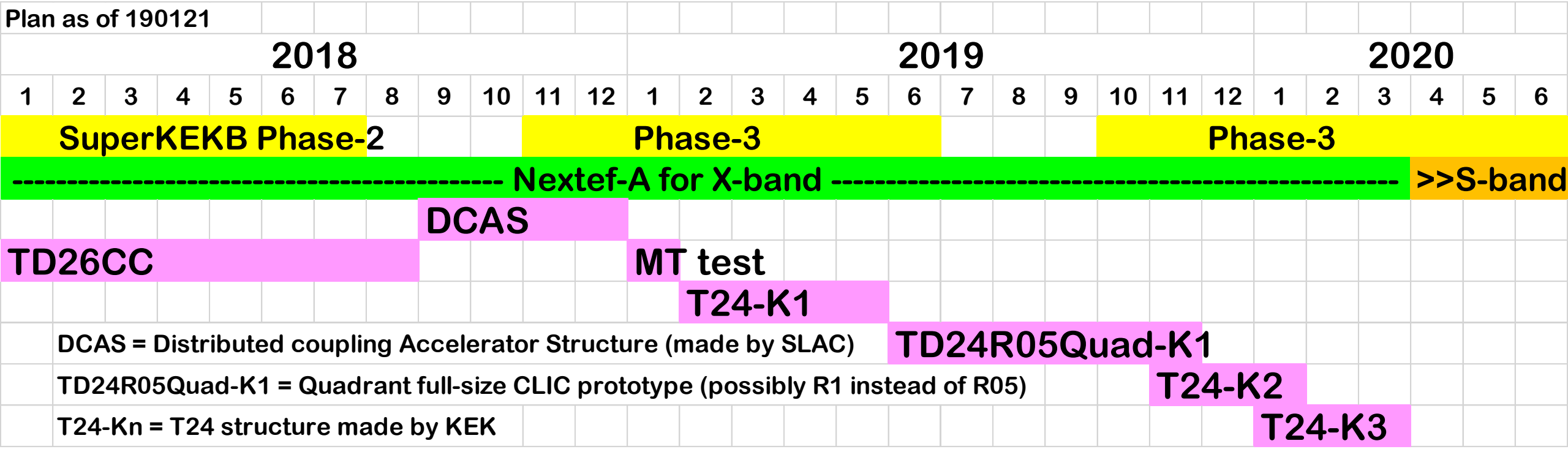




SLAC-DCS#2_from master file whole history



Nextef-A gross planning in a year

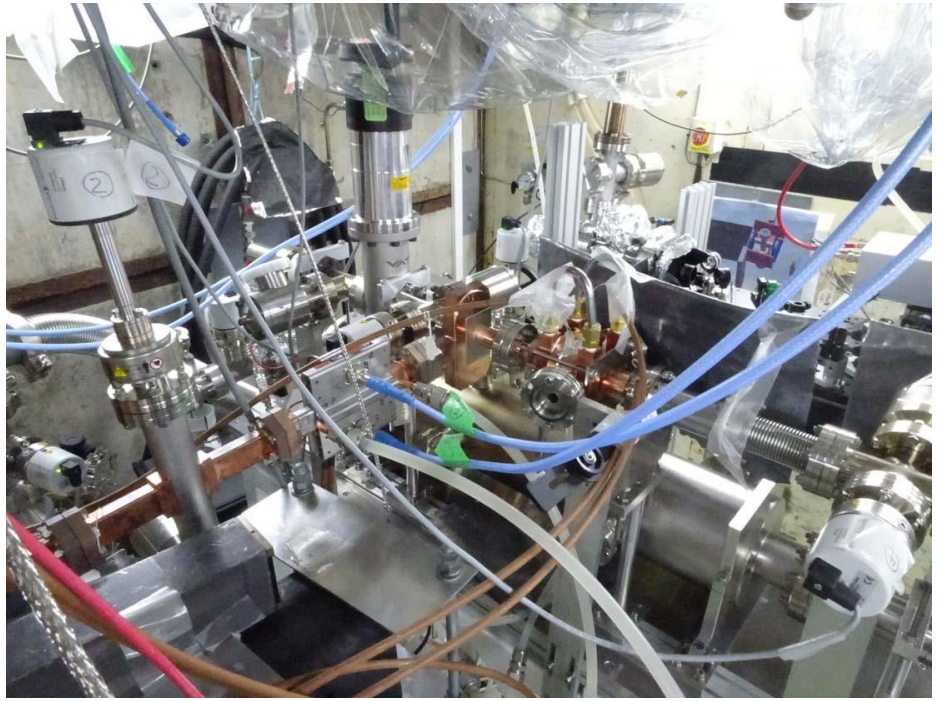


Nextef-A test setup for configuration with Magic Tee for preparation to test T24-K1

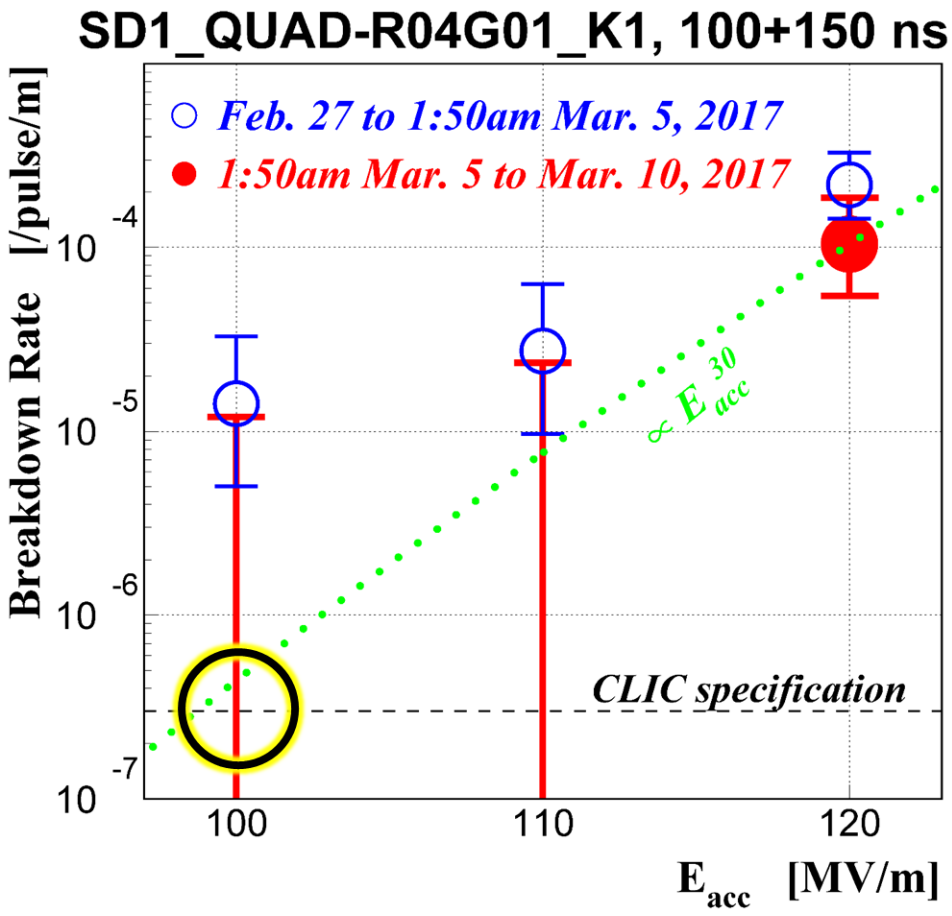
Nextef-B: Study with SW cavities

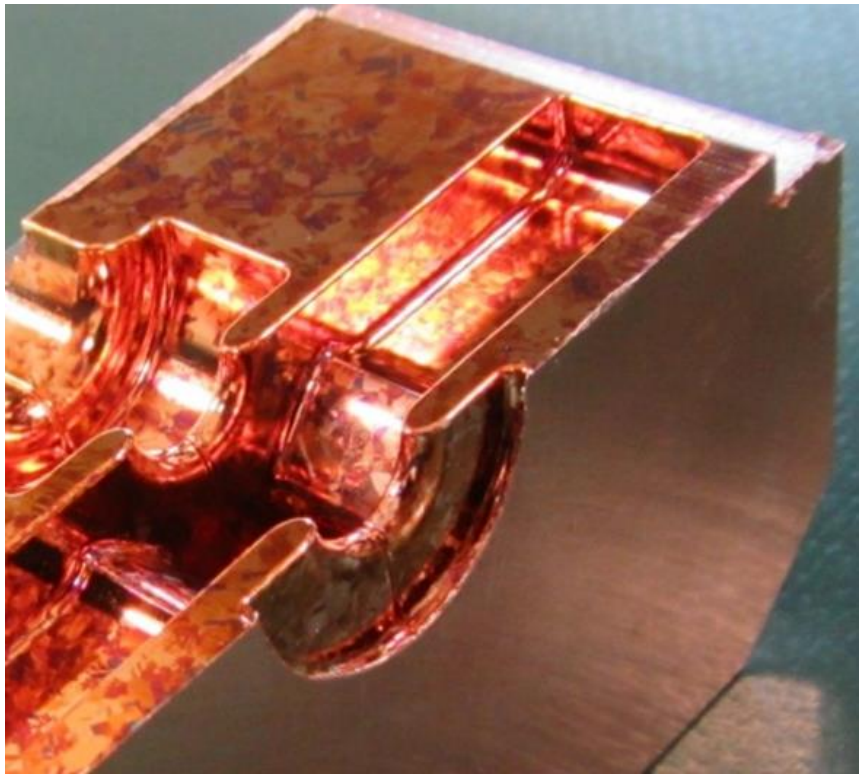
To be presented by T. Abe

- **Waveguide damped quadrant**
  - With a small gap 0.1mm
  - Reached 125 MV/m (width: 100+300ns)
  - BDR ~ a few 10^{-7} bpp/m at 100 MV/m (100ns ramp + 150ns flat)
- **Full-choke** cavity
  - Reference BDR taken, cavity is ready
  - Laser just ready



Quad test result





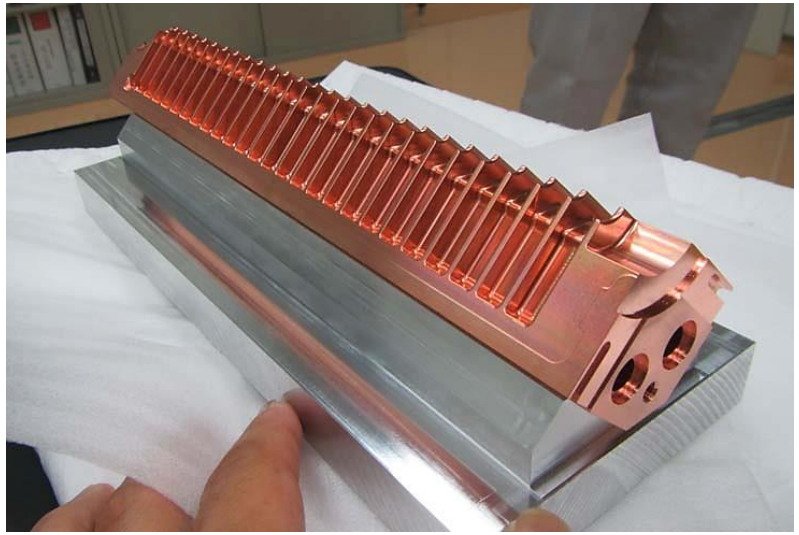
- Pulse heating pattern appeared
- Most BD spots are on iris area
- Few BD spots in the 0.1mm gap

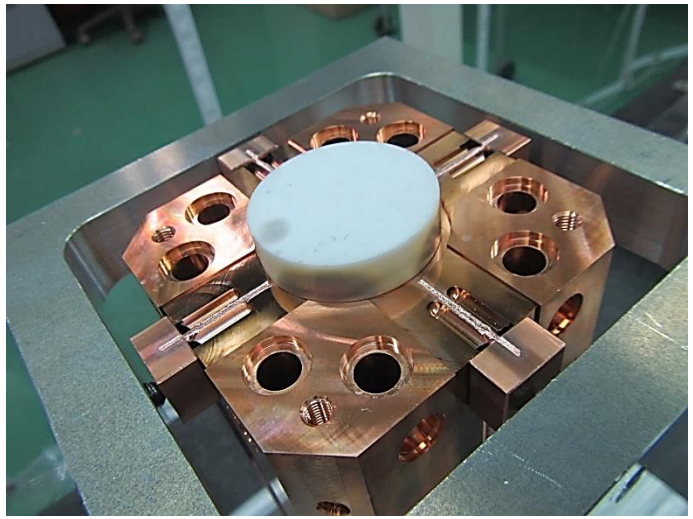
We are making full TW structure based on the same manufacturing

Structure fabrications

- **Full quadrant**
  - Found as of final brazing that we mistook CuZr material
  - Final cut in the second round is underway
  - High gradient test to be started before summer 2019
- **T24-Kn**
  - K1: Assembly finished last week in KEK hydrogen furnace and waiting for tuning
  - K2, K3: Parts have been in hand and manufacturing in detail to be finalized

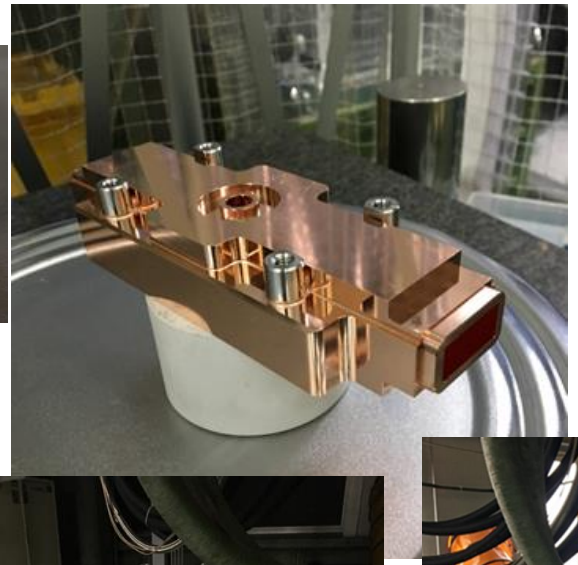
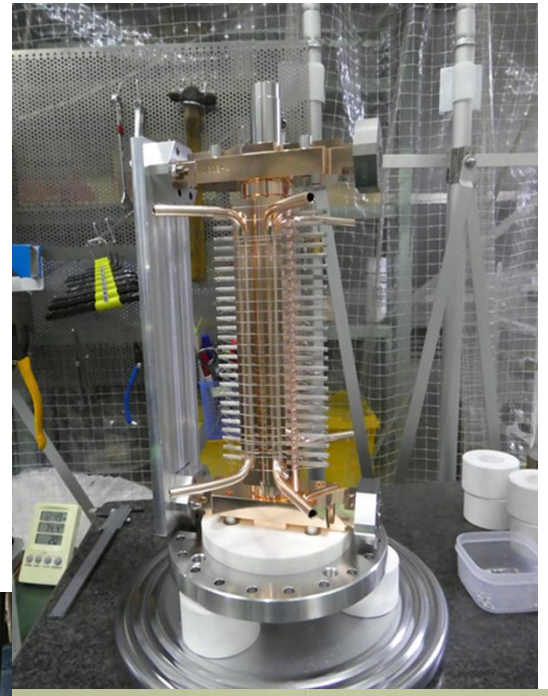
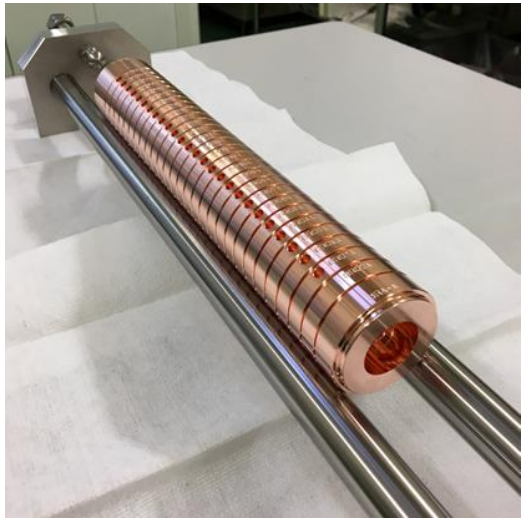
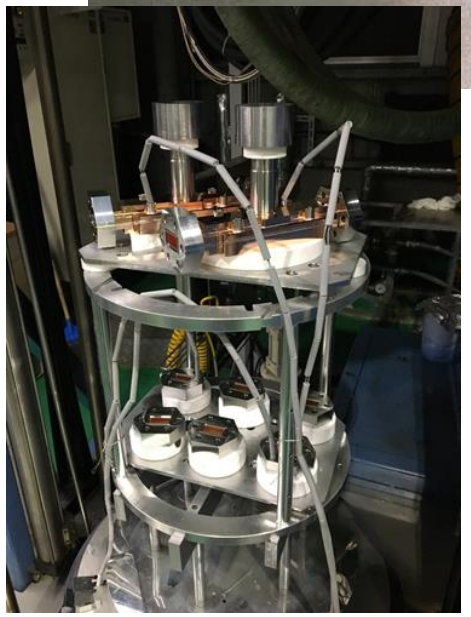
TW full quad: “TD24R10_QUAD-R04G01”





T24-K1 production

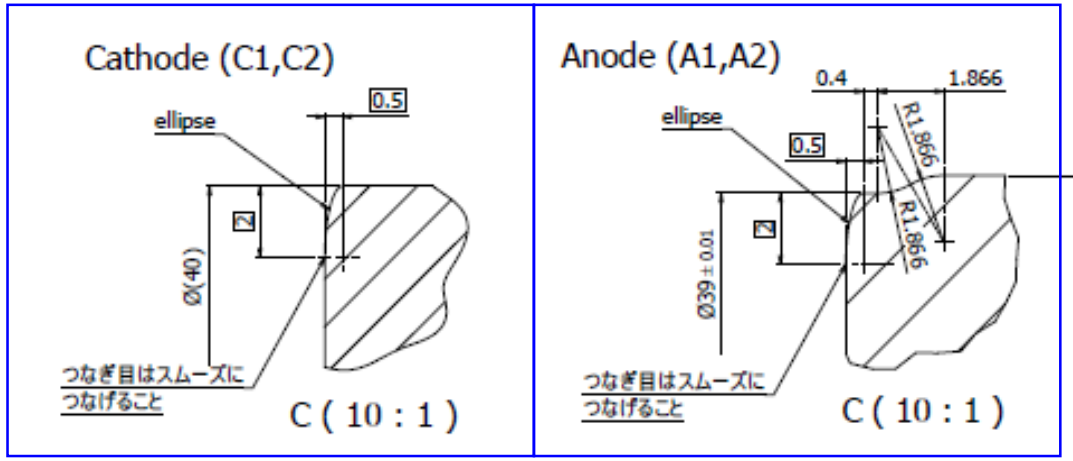


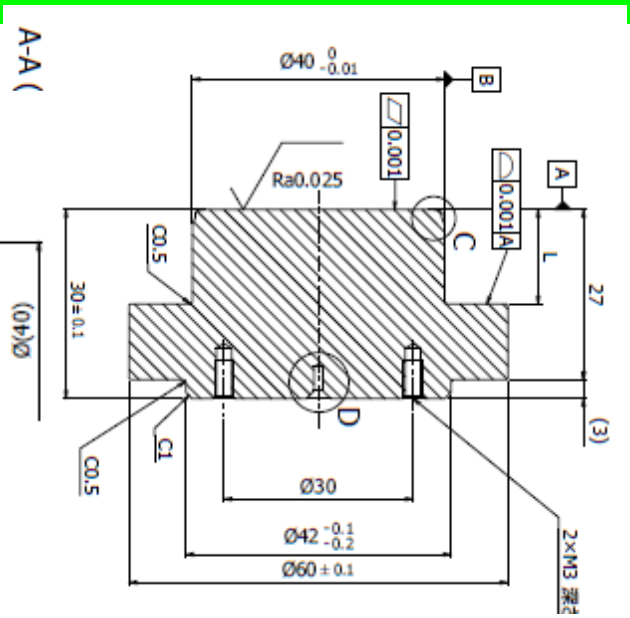





Study idea on the key to high-gradient should be revisited for the year 2019 and for future

- **T24 in 2019**
  - Mission: Confirm good result of T24-#3
  - Issues: What can we learn from the last series of T24 experiment
    - Ramping protocol, slow vs. fast
    - Hydrogen, with-without vacuum baking
    - Much higher gradient its sustainability or BDR evolution
- **Quad in 2019 and Quad/Half in future**
  - Mission: See the result of the first TW and think future
- **Further studies for higher field and fast conditioning**
  - Material study in crystal in mind
  - Beam hole iris (hard spinning, good HV stainless steel, polish surface, …)
  - Water rinsing for dust removal
  - Expand technology based on DC-HV feature

DC-HV test electrode





No.	Code	Aim	Mech. Design	Prod.	Depth	Treatment		Shipping	HV	Material	Parts	Description
1	HC	Hard copper	C1/A1	1/M	15.000	Non		1/E	2/M	OFC class-1	One	Reference(hard), as machined
2	SC	Soft copper	C1/A1	1/M	15.000	H2 anneal	1/E	1/E		OFC class-1	One	Reference(soft), H2 furnace anneal at KEK
3	SP	Spinning	C2/A2	2/M	15.100	Spinning	4/E	May		OFC class-1	One	Spinning after as machiend surface
4	PO	Polish	C2/A2	2/M	15.100	Polish	4/E	May		OFC class-1	One	Mechano-chemical polishing
5	LG	Large grain	C1/A1	2/M	15.000	Anneal	4/E	May		6N copper	Two	Mitsubishi material grain size 5-50mm

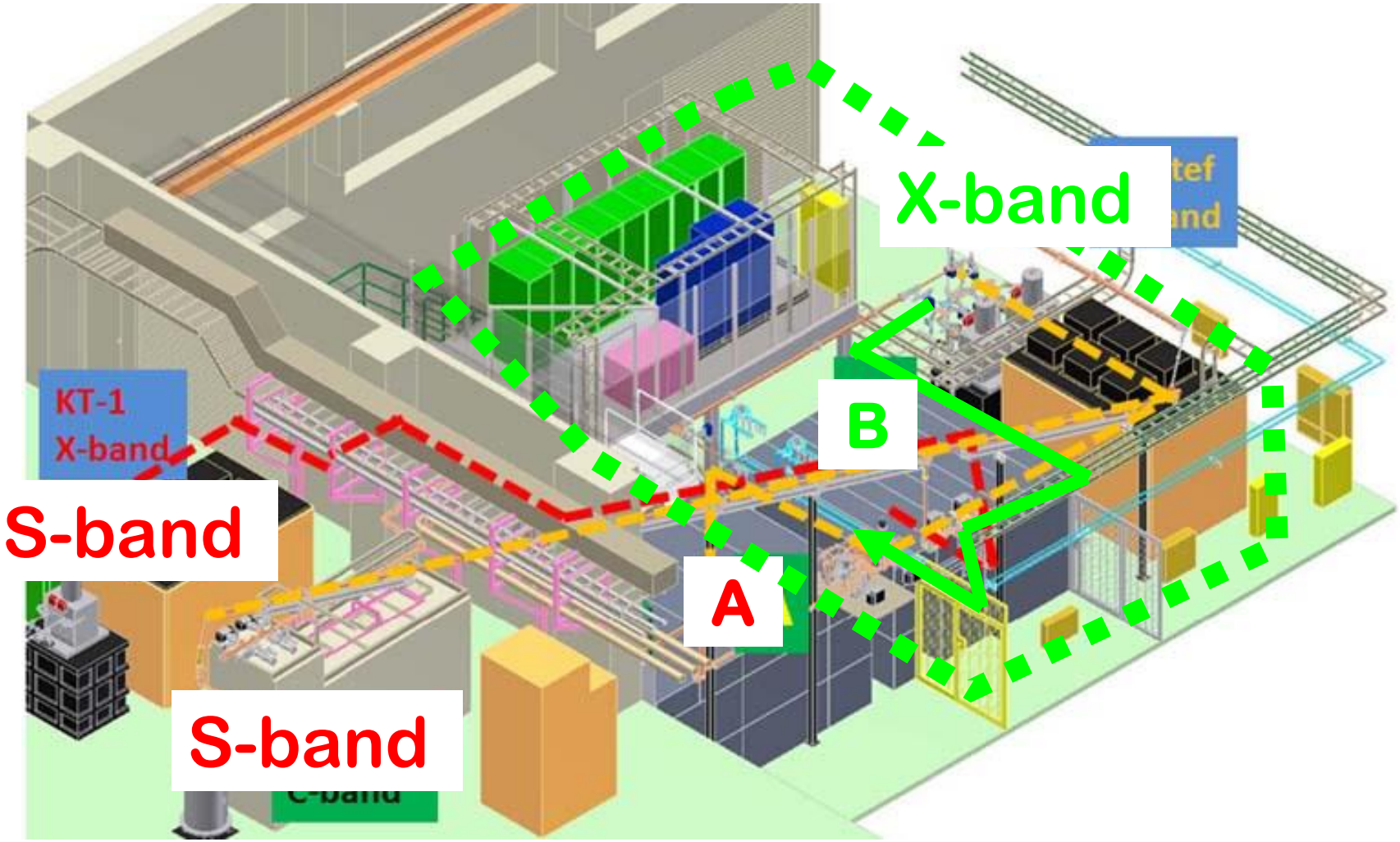
Summary of 2018

1. High gradient study of prototype structures
   - TD26CC-K1
   - SLAC-DCS
2. High-gradient study with single-cell SW cavities
   - Quadrant met CLIC BDR criteria
   - Full choke cavity ready for studying surface modification by pulse heating
3. Manufacturing structures
   - Assembly of T24-K1 done
   - Full TW quadrant underway
4. DC-HV electrode
   - Started for evaluation of various fabrication techniques
5. Perspective / strategy
   - We need to establish longer scale perspective in addition to continuing basic high-gradient experiment in small size

Nextef from 2020 needs wise strategy

- System configuration
  - 2 klystrons in 1 modulator with 1 small bunker, Nextef-B
  - Modulator 50 Hz, higher rep-rate in design
  - Klystrons will be driven by 2 independent LLRF
- Power manipulation
  - Combined power as now ~50MW
    - Higher field in single-cell SW and possible test of TW structure
  - Thinking
    - Two independent tests
    - Rep rate more than 50Hz
    - Pulse compression

KEK Nextef Shield-B



Conclusion: What to be realized in KEK

- To keep stand point
  - We need more formally defined mission and better supported by KEK laboratory
  - Continuation of such collaboration with CERN, SLAC, Chinese and others based on high gradient is very important
- We need realization
  - Basic research in a small experimental activities should be expanded
    - Higher gradient, higher frequency, etc.
  - We want KEK to acknowledge study for higher energy
  - We need to find any application
    - Compact NDT-type example
    - High-gradient /medium gradient machine
    - Help actual projects in collaboration with other laboratories