# Dealing with rf breakdowns in the CLIC main linacs

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Machine protection workshop

8 June 2012

# Introduction

**Caveat Emptor** – We have barely started dedicated study of the operational aspects of the main linac rf system. We need much more experience running structures at CLIC parameters and many more measurements before we can be confident in how our system will behave.

Still I'll present the main issues of operating the main linac rf system and our current ideas about operation.

Underlying assumptions and issues:

- An rf breakdown kicks the beam(s) resulting in luminosity loss but not damage to the accelerator (see Daniel's and Frank's talks).
- You can't do anything about breakdowns on the pulse itself
- We don't allow more that 1% luminosity loss due to breakdown (but we assume we lose the whole pulse even if breakdowns occur at roughly random times inside the pulse). So for 3 TeV with $3x10^4$ m of active length we get our BDR specification of $3x10^{-7}$/pulse/m.
- Breakdowns are statistically regular events and are part of normal operation.
- Most of the breakdowns will come from the high-gradient accelerating structures.

# The big question – do we have single breakdowns or sequences?

If most breakdowns are single events then machine operation becomes just carrying on, most of the time you do nothing to prepare for the pulse after breakdown.

But breakdowns sometimes, with some probability, come in sequences. In these cases we may need to back off the power and ramp back up with some kind of algorithm.

We have developed the PETS on/off in reserve in case the power needs to be ramped or a structure needs to be switched off.

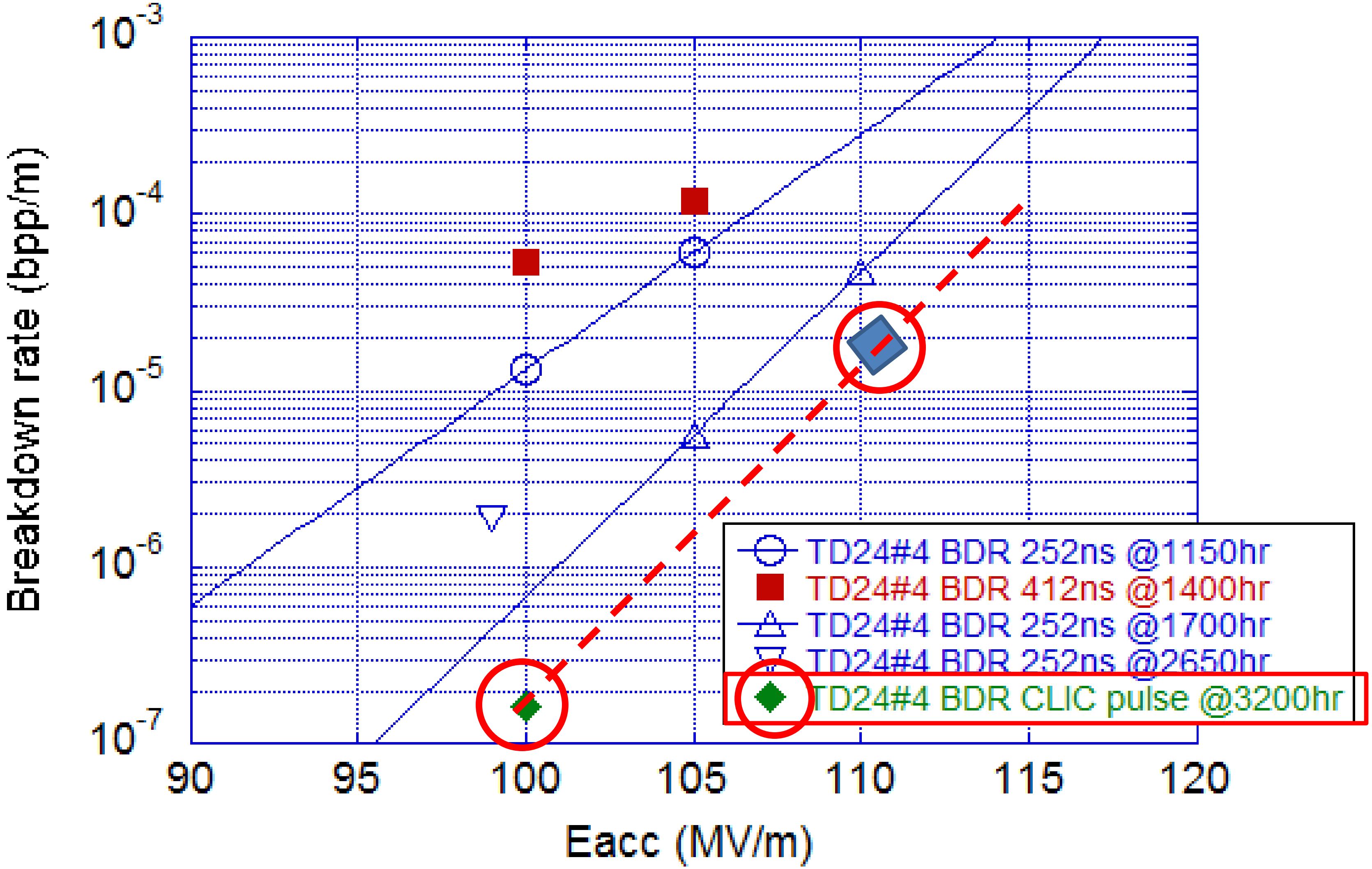
If we start ramping, or shutting off power we need to consider global compensation of lost energy. We also need to compensate 'lost' transverse kicks due to structure misalignments which have been compensated for by the beam-based alignment.

We currently have about 5% gradient overhead to compensate with lost acceleration in the form of de-phased drive beam sectors. We have beam-based alignment feedbacks to deal with the missing kicks.

It is natural to turn structures back on gradually so that energy and transverse kick compensation can adapt to changing conditions.

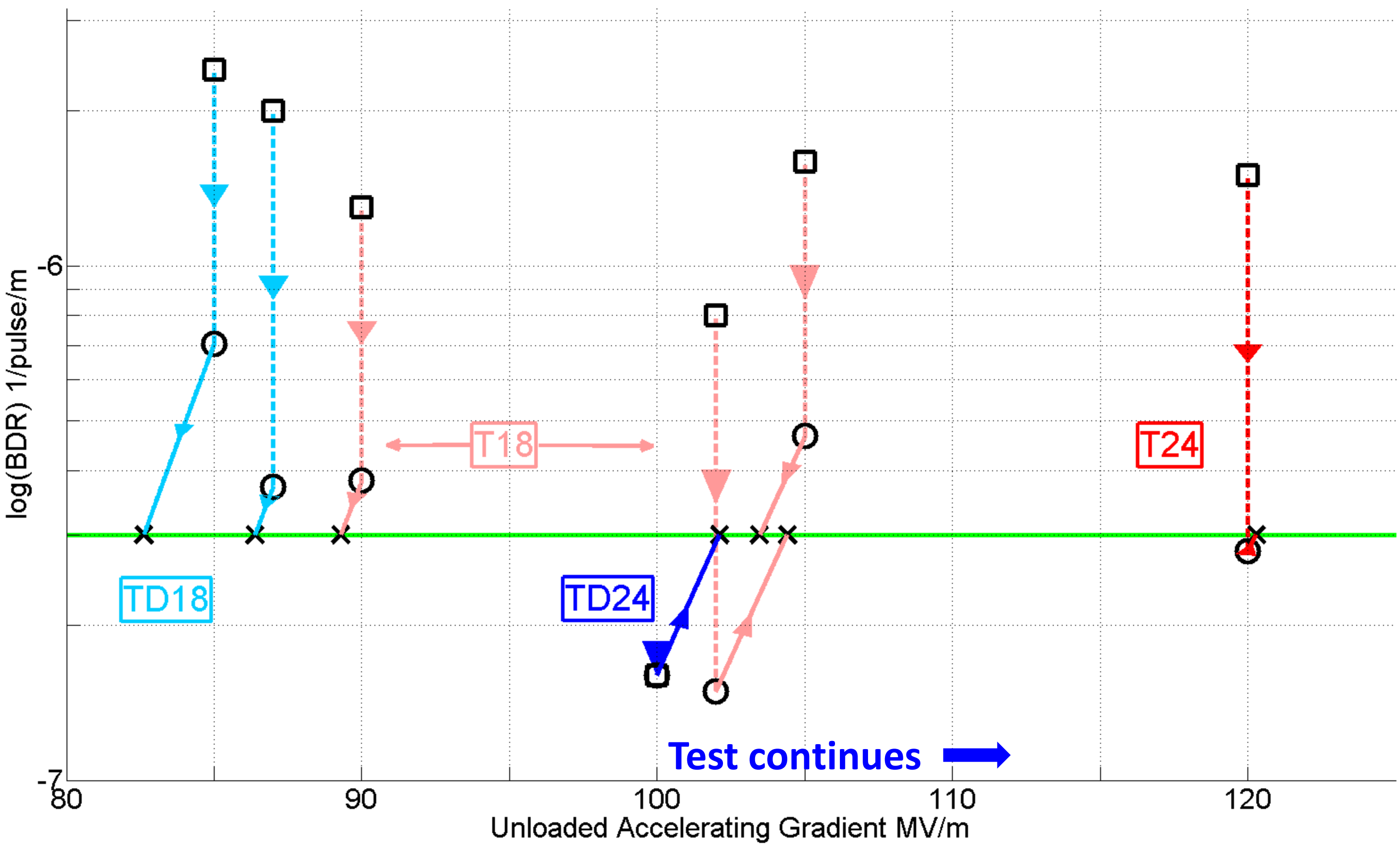
But let's now look at how structures are actually behaving before going into more detail.

# TD24#4 BDR with CLIC pulse at FLT=100MV/m

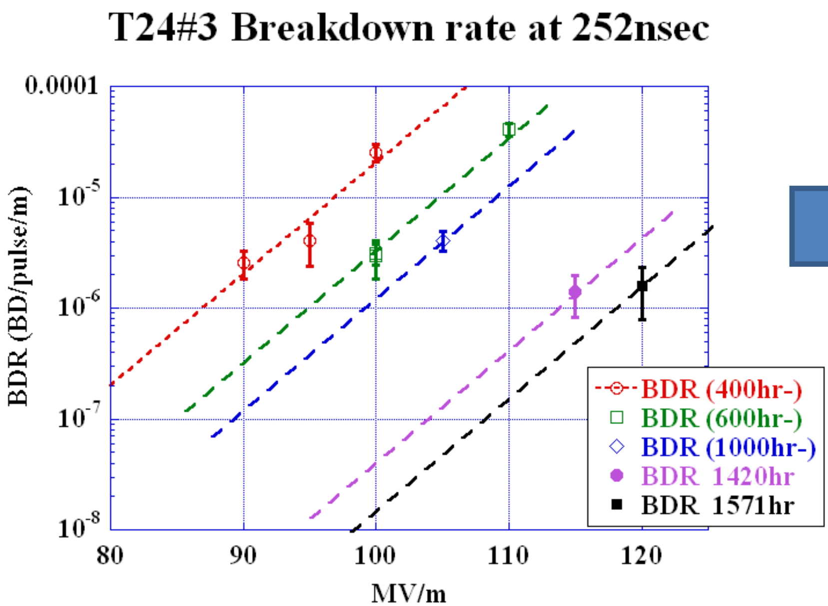


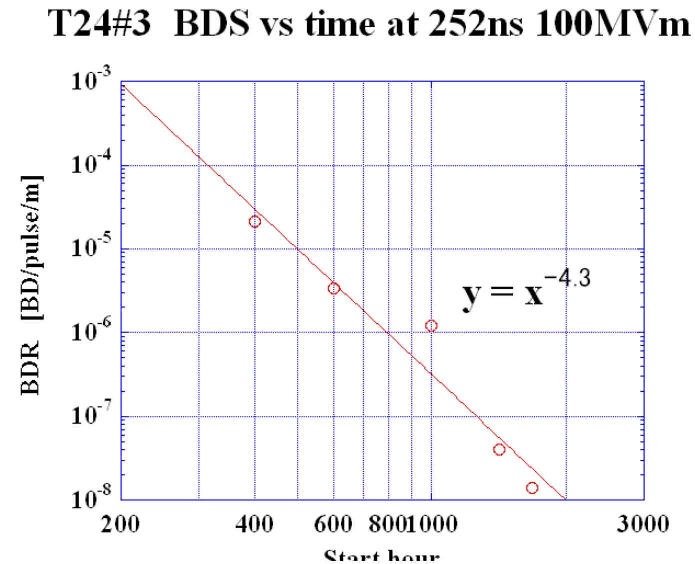
# Gradient summary

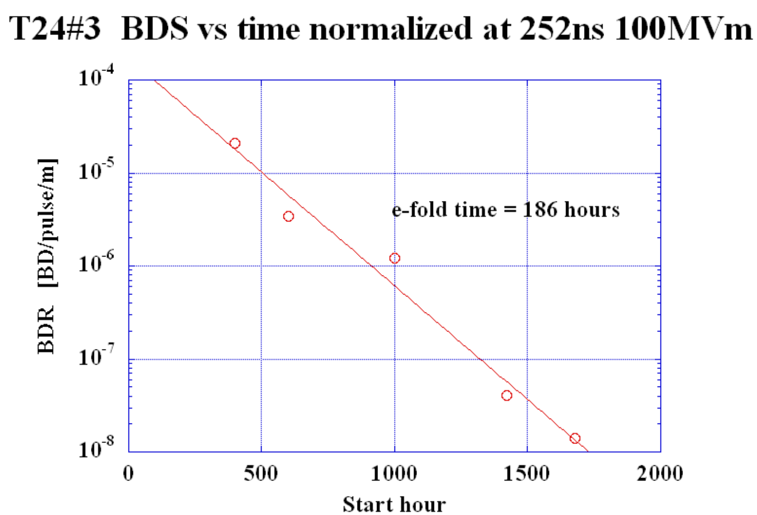
Status 29-3-2012



# T24#3
# BDR evolution at 252ns normalized 100MV/m




Assuming the same exponential slope as that at 400hr

We understand the BDR has been kept decreasing.

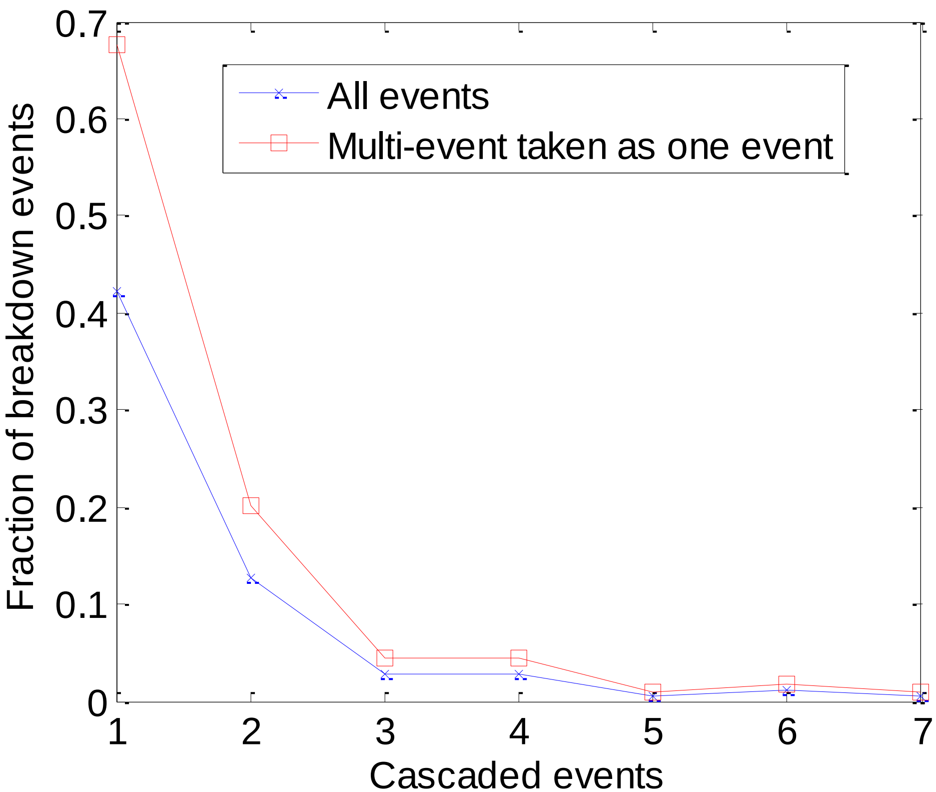


From T. Higo

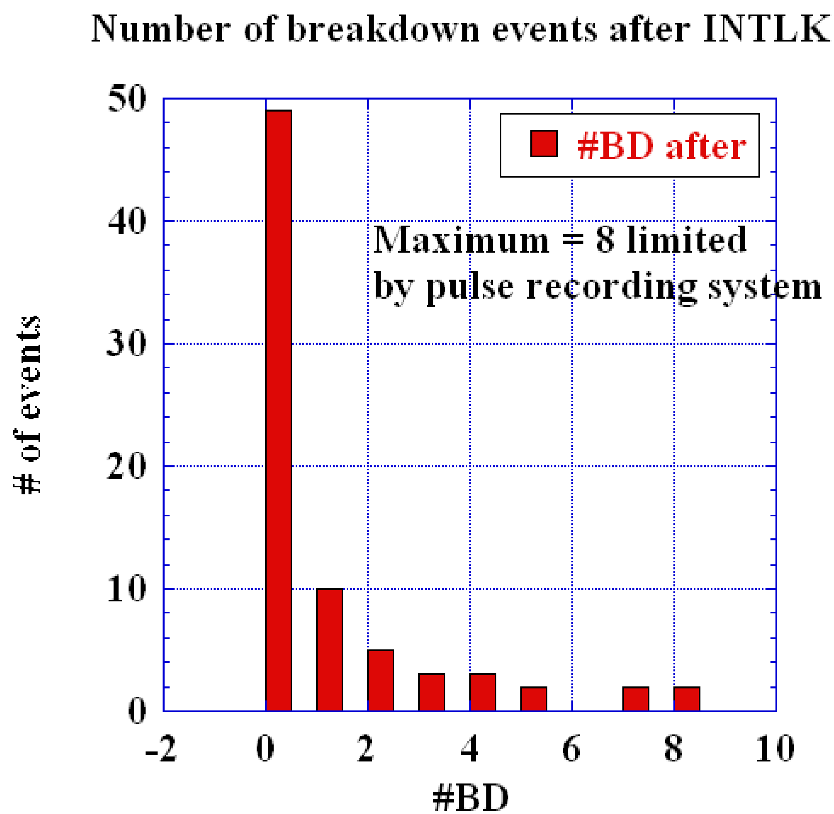
# First measurements of breakdown sequence statistics

101028

Both sets of measurements were made on TD18s




SLAC - NLCTA

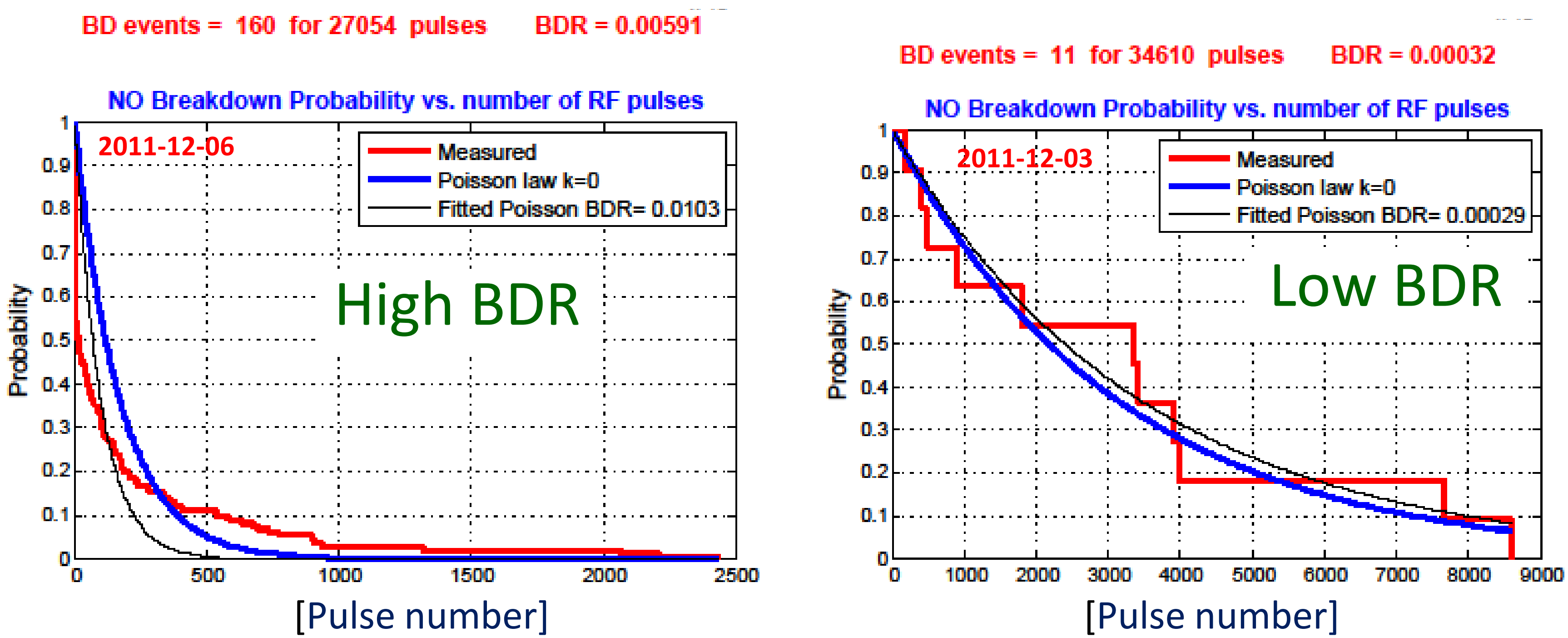



KEK - NEXTEF

Not sure about BDR during data taking, but probably around nearly $10^{-5}$.

TD24 in the two-beam test stand

# BDs time distribution and Poisson law



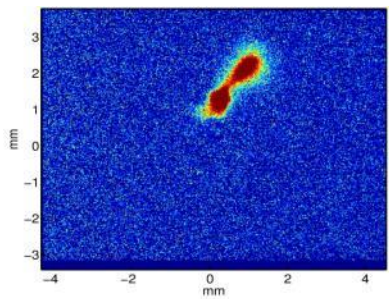

- Randomly distributed events should follow the Poisson law.

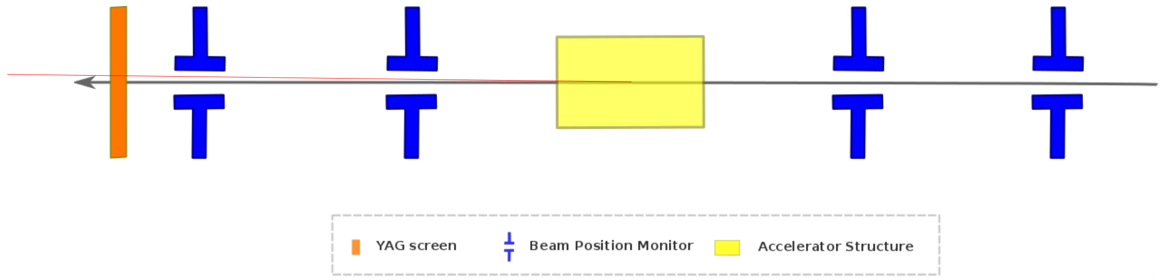
$$P(k,\lambda) = \frac{\lambda^k}{k!}\exp(-\lambda)$$

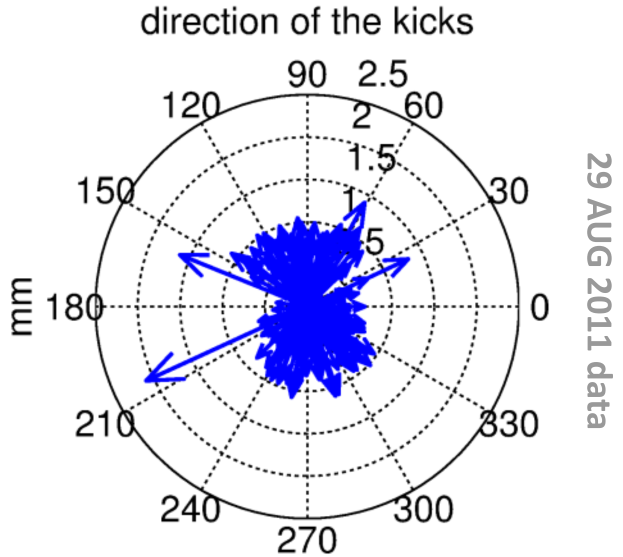
k : number of BDs, λ : BDR x number of pulses

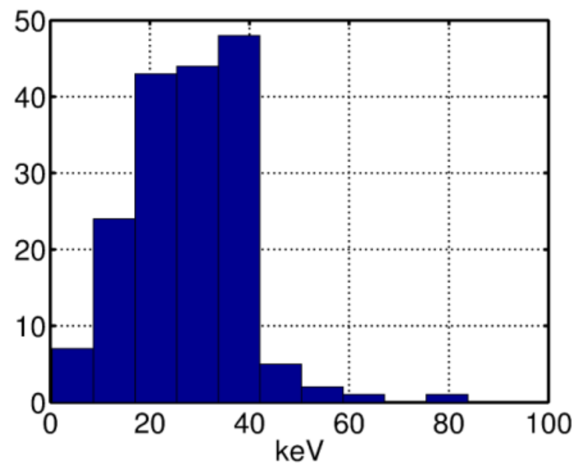
- Clusters make the BD probability (BDR) non stationary

# Kick Measurement




**preliminary** result (to be confirmed);

- Analysis on ~170 BD events, 2-Gaussian fit on the screen
- kicks corresponding to a transverse momentum between 10 and 40 keV/c (measurements at NLCTA within 30 keV/c, cfr. Dolgashev, SLAC-PUB-10668)

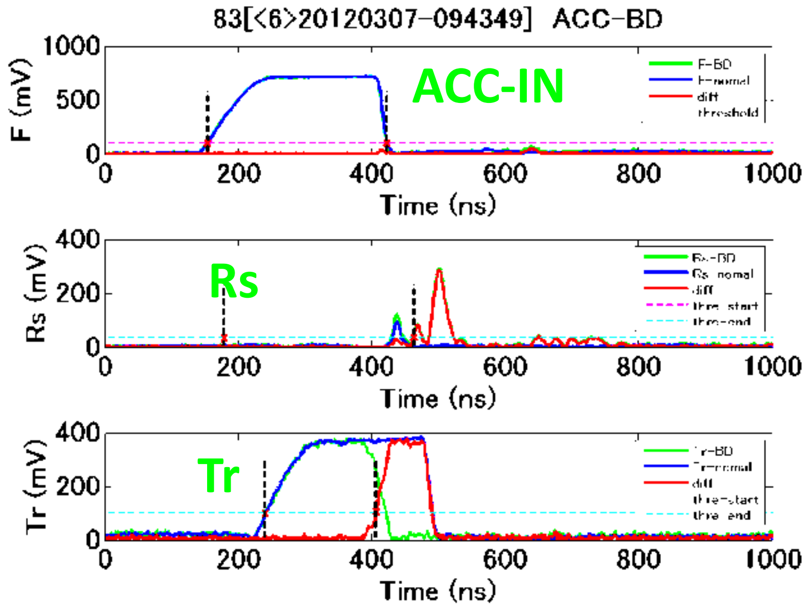
# Breakdown statistics at low breakdown rate

Recent data from KEK. TD24 (CLIC nominal geometry) 484 hr run with CLIC nominal pulse (unloaded), three breakdowns gives BDR=1.6x10$^{-7}$/pulse/m.

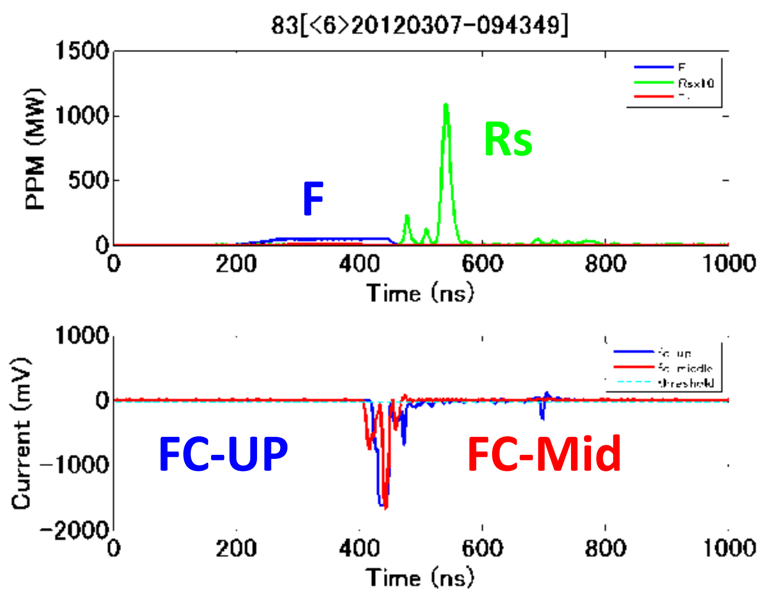
| Event number | Cell number | Time |
|---|---|---|
| 1 | 26 | 7 March 9:43 |
| 2 | 22 | 7 March 9:54 |
| 3 | 24 | 14 March 0:38 |

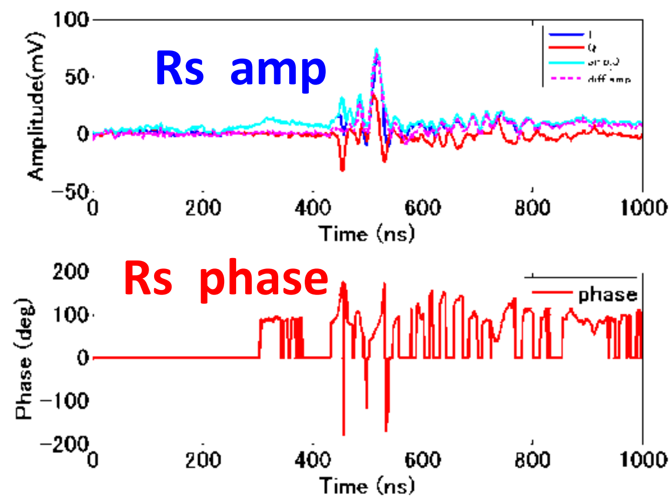
Good news – we haven't seen a single sequence of breakdowns with the CLIC pulse at the nominal breakdown rate, but I suspect they ramped power after breakdown. Plus you've gotta be a real optimist to draw a conclusion from just three points.

# BD pulse shapes Run 83 first event

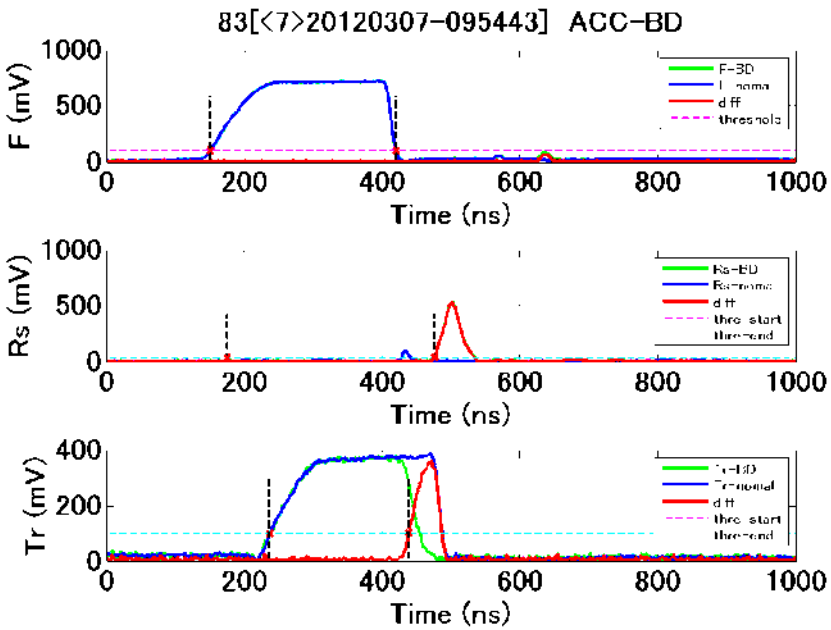



On 7 Mar. 9:43
BD at cell 26

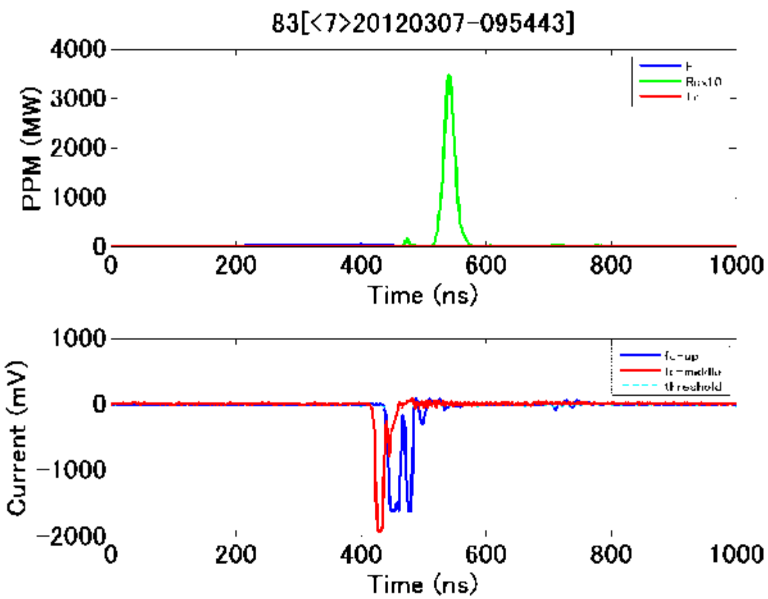


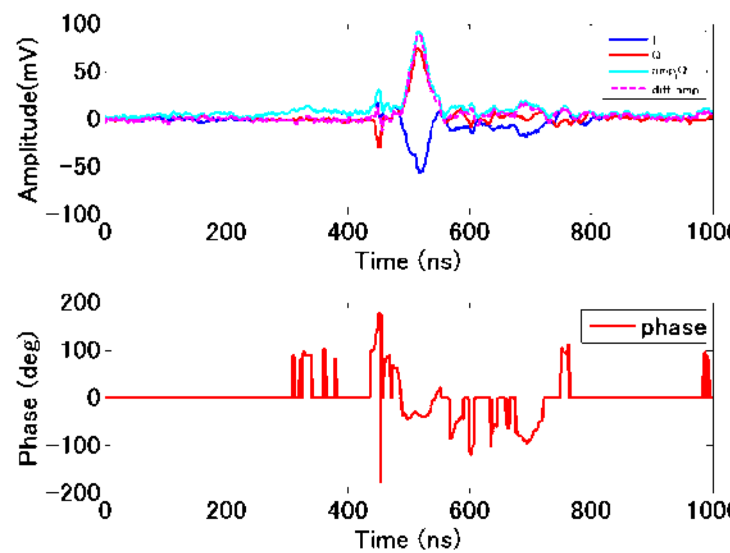



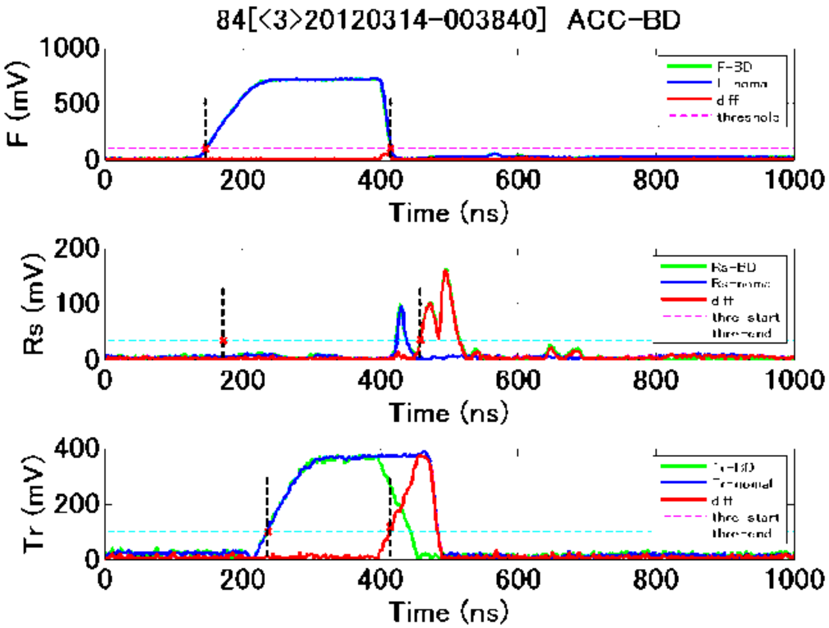
# BD pulse shapes Run 83 second event




On 7 Mar. 9:54
BD at cell 22

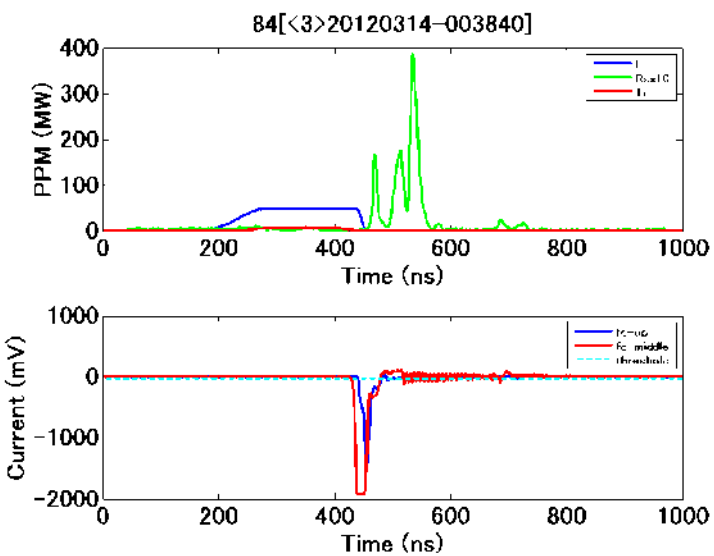


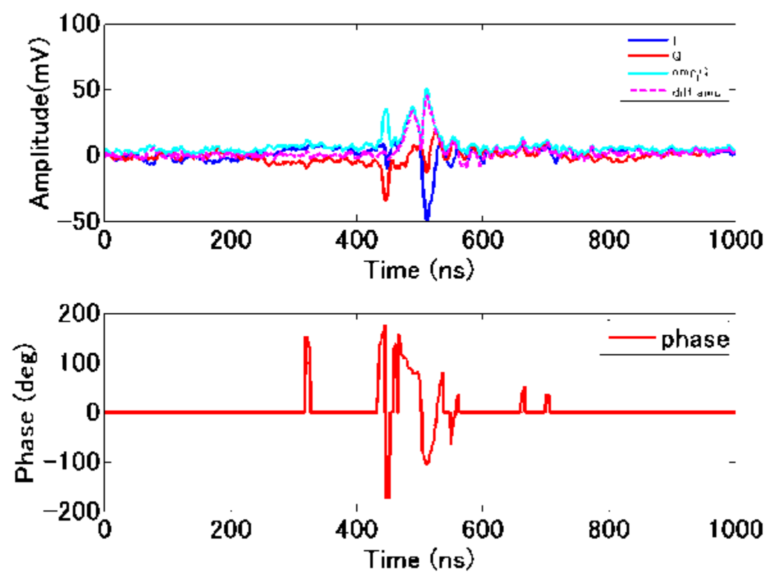






# BD pulse shapes Run 84 first & unique event

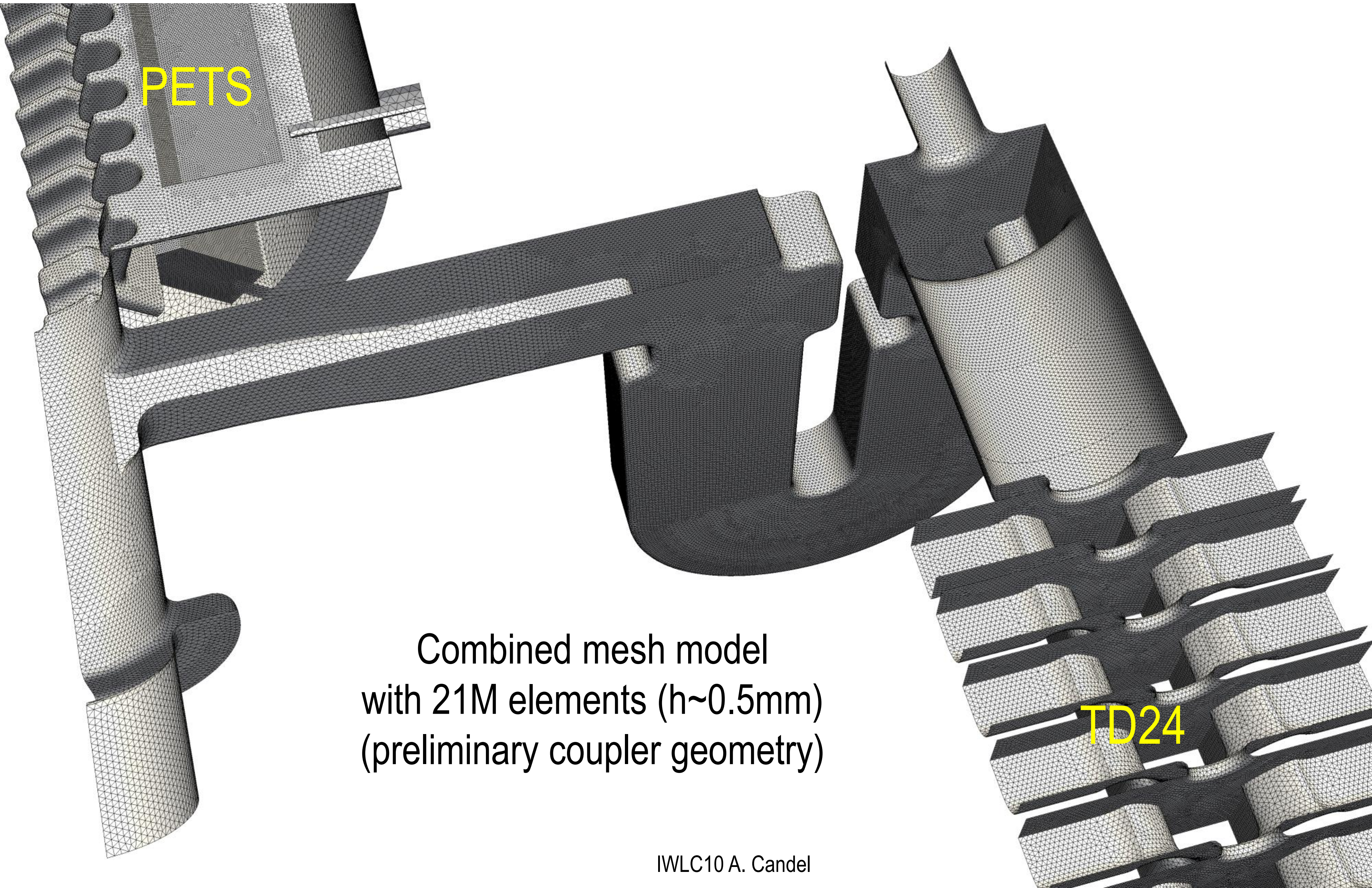
On 14 Mar. 0:38
BD at cell 24



# How we can ramp the power – in the accelerating structure and even in the PETS

# T3P: Wakefield Coupling PETS <-> TD24




Combined mesh model
with 21M elements (h~0.5mm)
(preliminary coupler geometry)

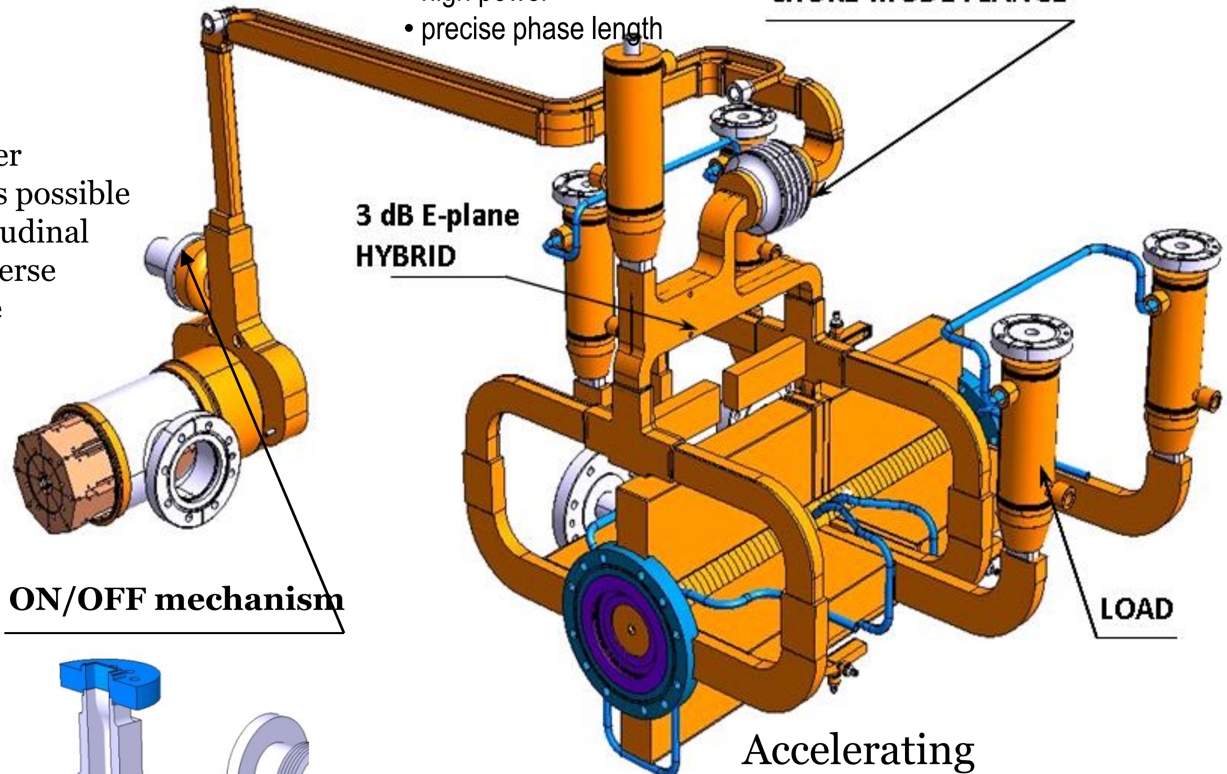
# Two-beam RF components

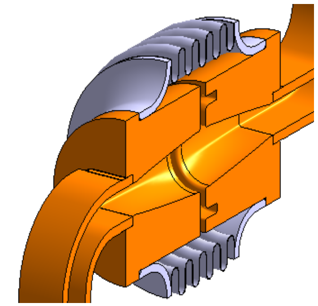
Waveguide network

- high power
- precise phase length

PETS

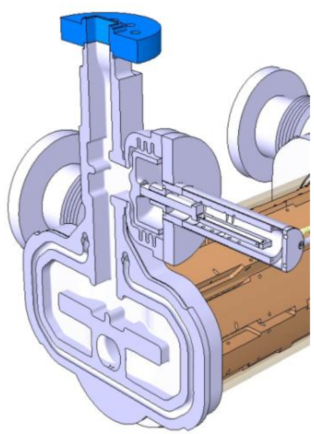
- high-power
- as short as possible
- low longitudinal and transverse impedance



Choke mode flange

- independent alignment of main and drive beam

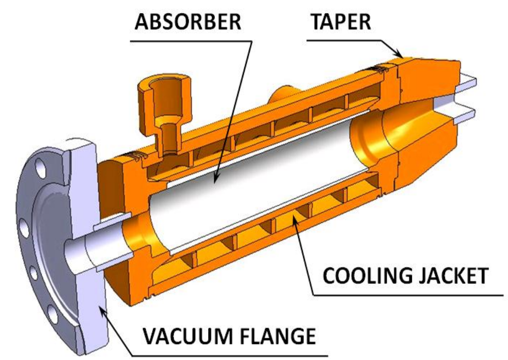


On/ramp/off

- necessary (?) to react to breakdown and/or failure

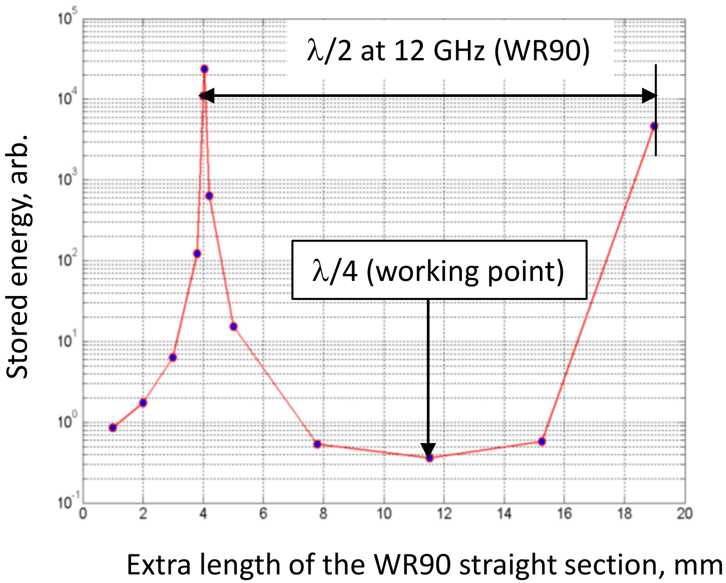
Accelerating structure

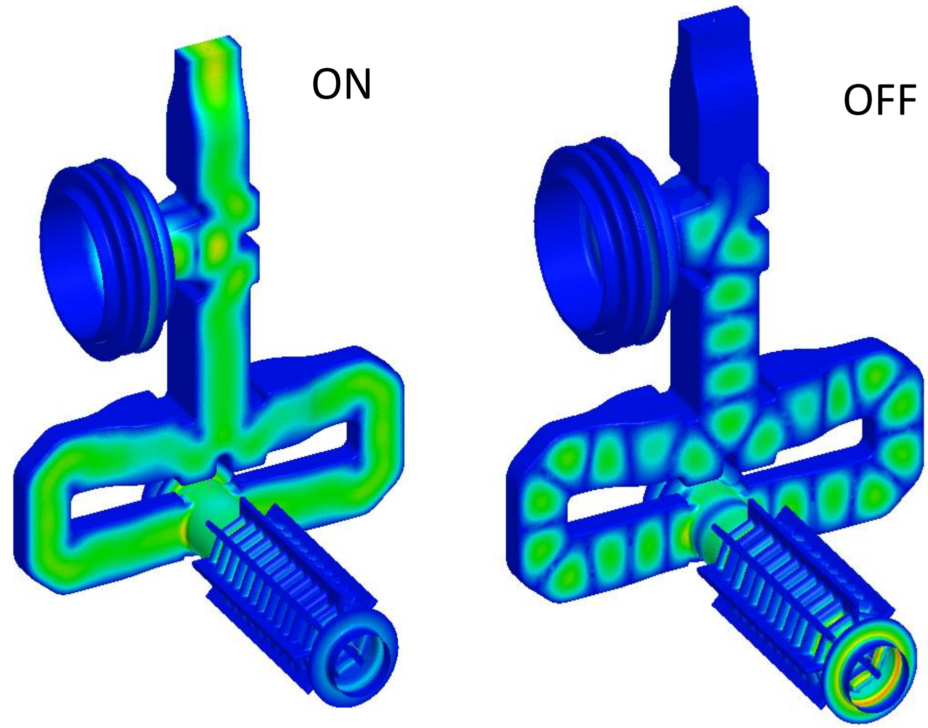
- high-gradient
- as long as possible
- micron precision
- transverse wake-field suppression

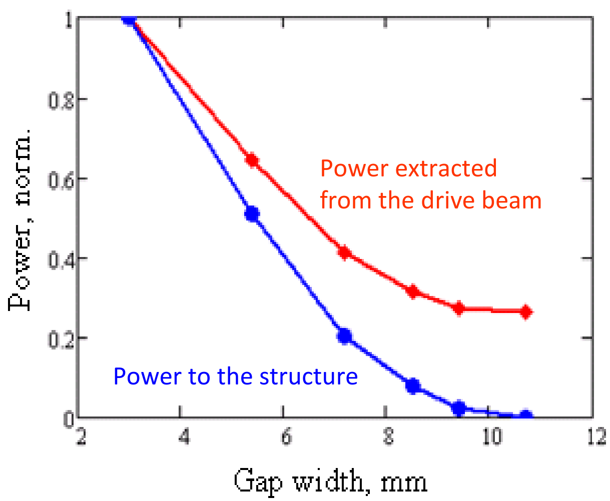


# PETS ON/OFF operation (CLIC PETS)

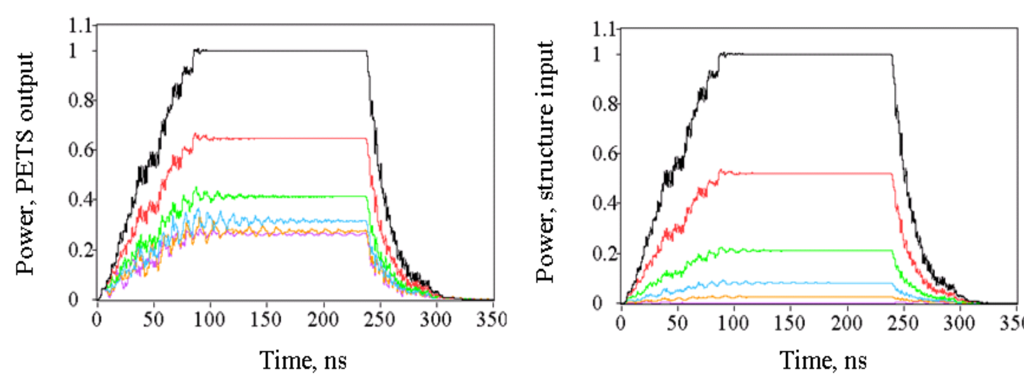
"Closed" circuit RF phase was tuned using HFSS simulations with beam.



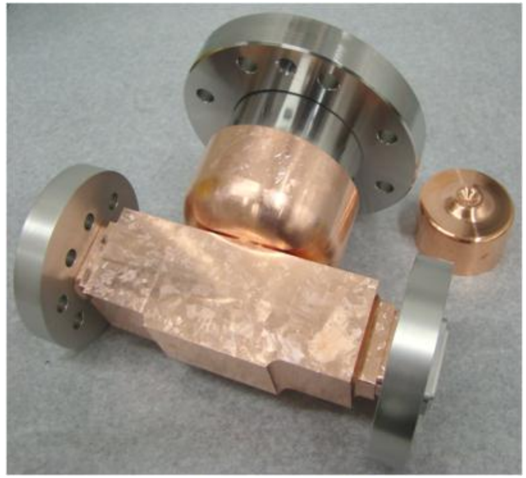



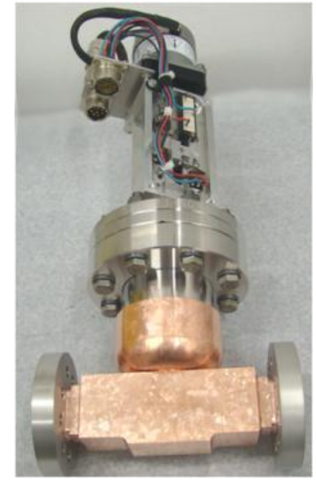

Full model analysis (GDFIDL + HFSS)



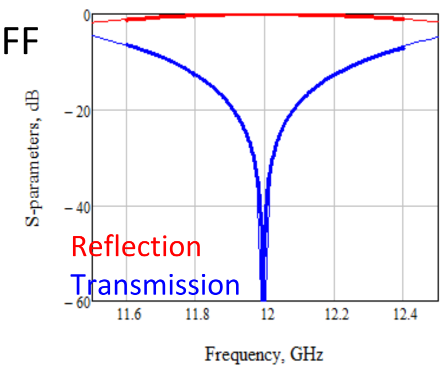

I. Syratchev, HGW 2012, KEK, Japan

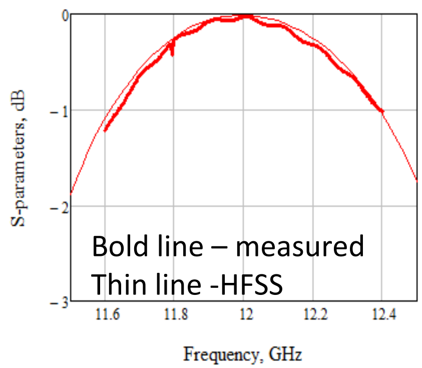
# The variable RF reflector.



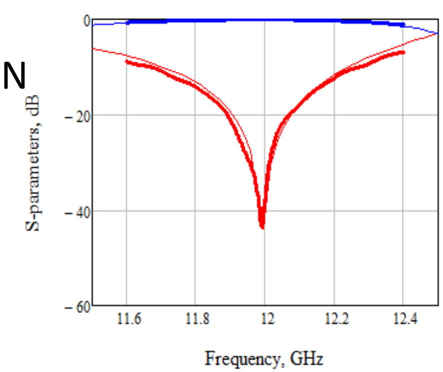


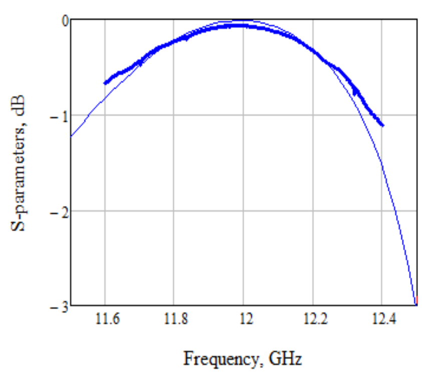
OFF



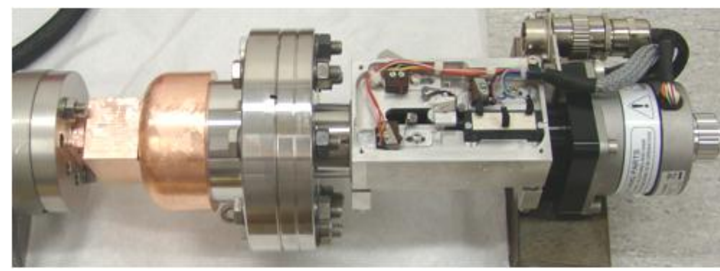



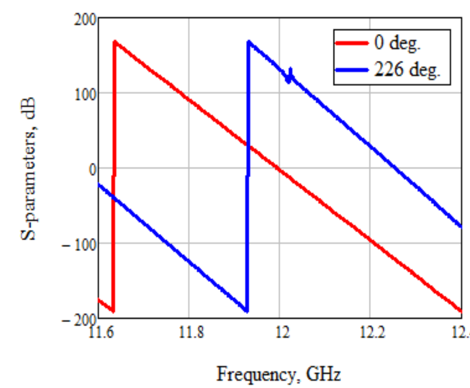

ON




## The variable RF short circuit

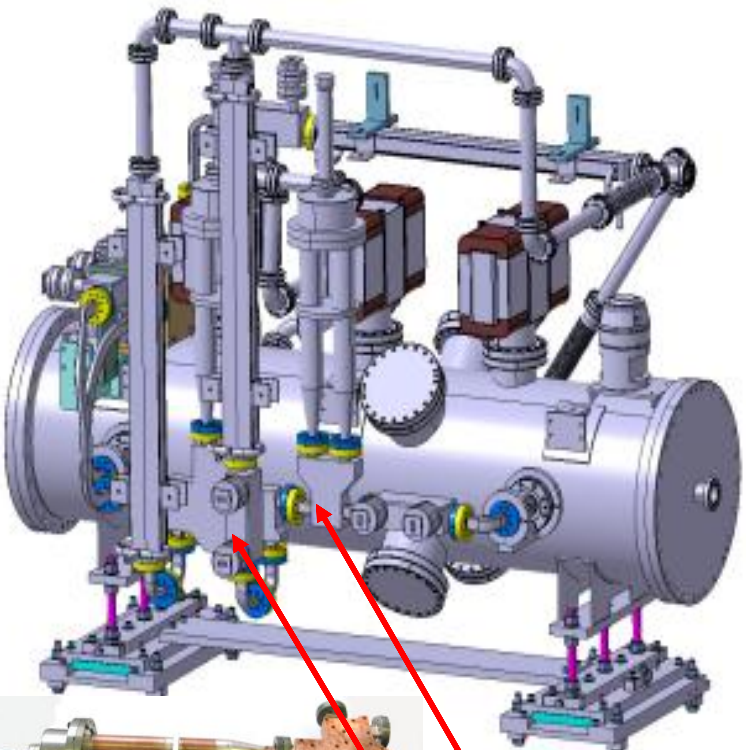





I. Syratchev, HGW 2012, KEK, Japan

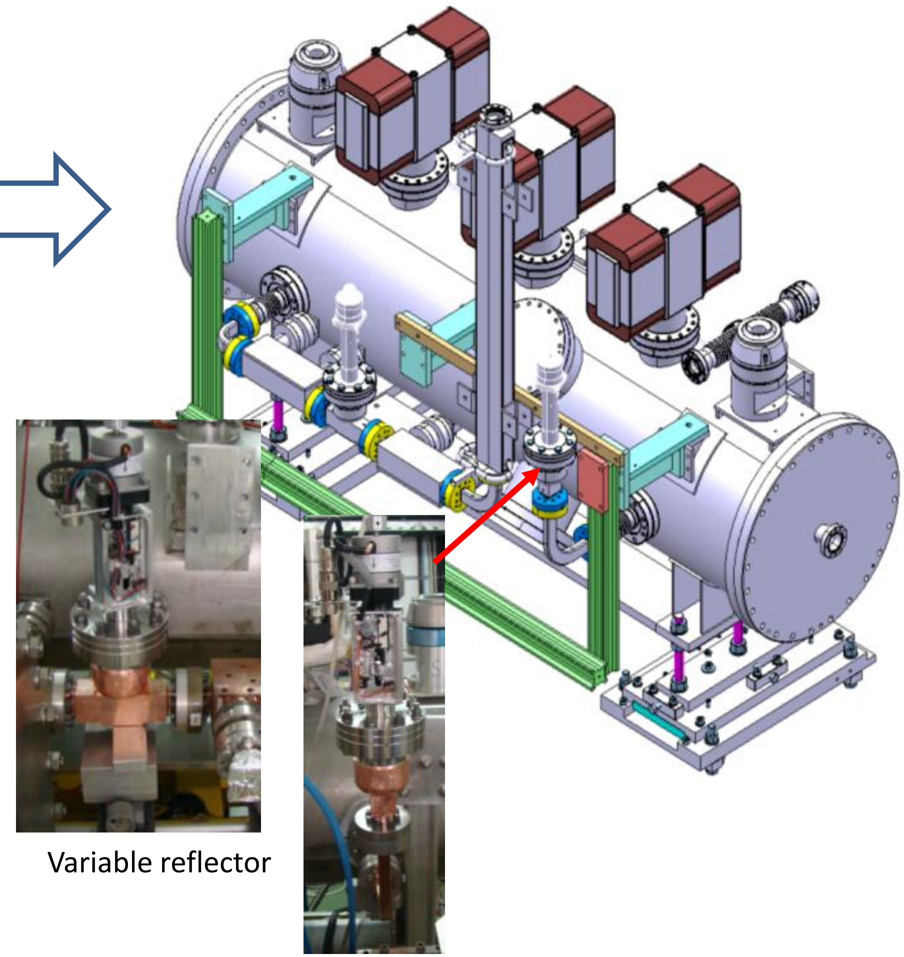
# Modification of the TBTS PETS tank layout in 2011.

## External recirculation loop



Variable Power splitter and Phase shifter, GYCOM (Russia).

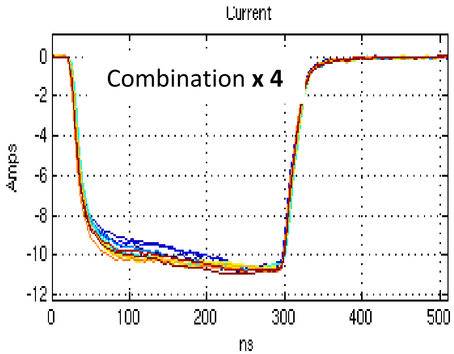
## Internal recirculation

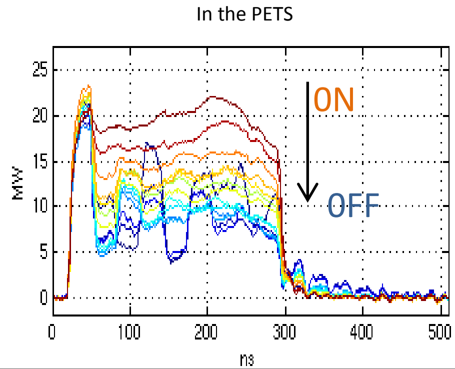


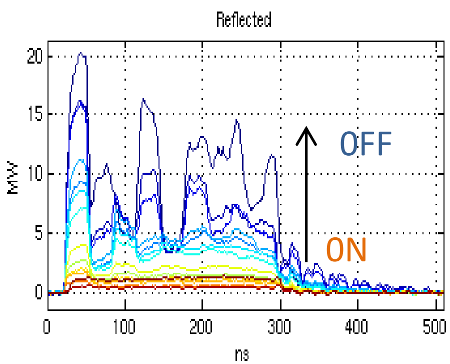
Variable reflector

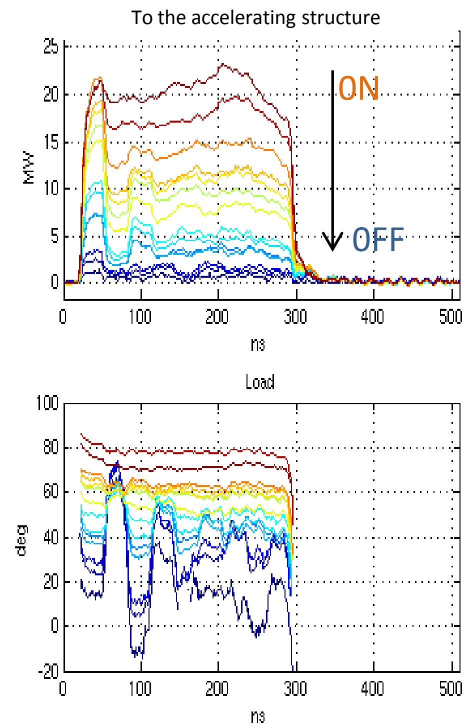
Variable short circuit

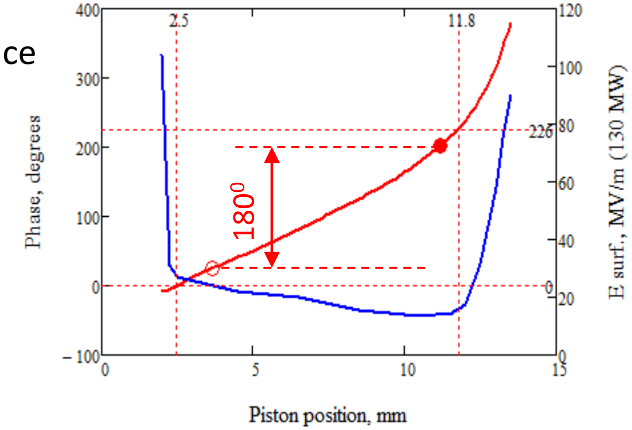
# Waveform for the different reflection and fixed ($180^0$) phase advance

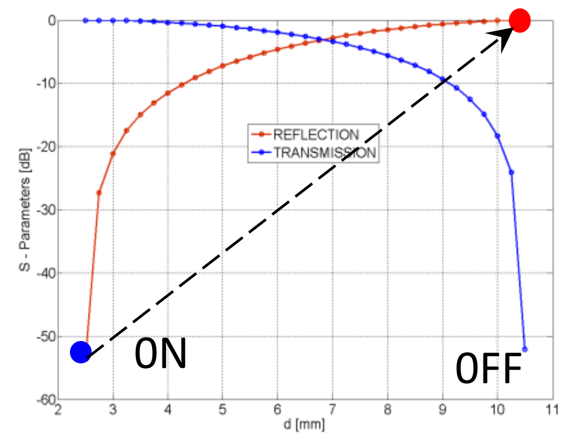



Summarized
by Alexey Dubrovskiy

Procedure:

- Medium (10 A) current, long (240 ns) pulse
- The short circuit was set on the expected $180^0$ phase advance position.
- The variable reflector position was change from full transmission to the full reflection.

# A special two-beam issue

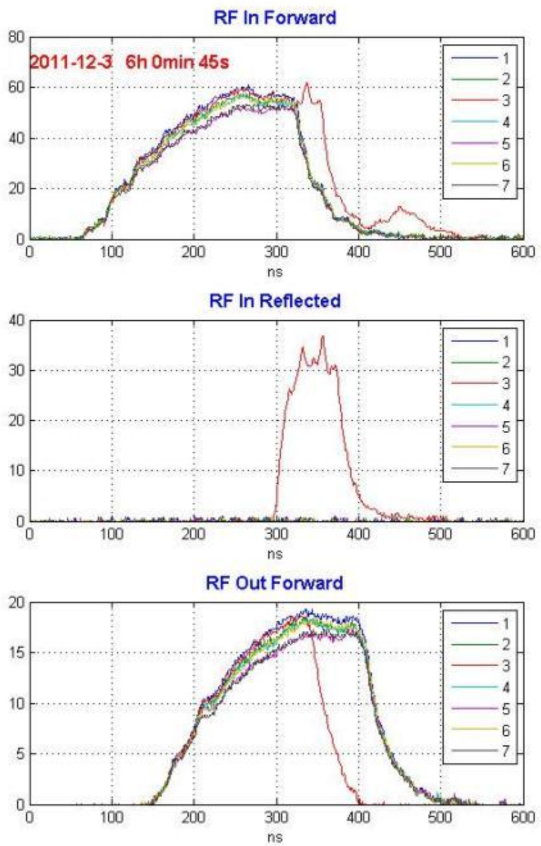
In a two-beam accelerator reflected power from a breakdown can go back to the PETS.

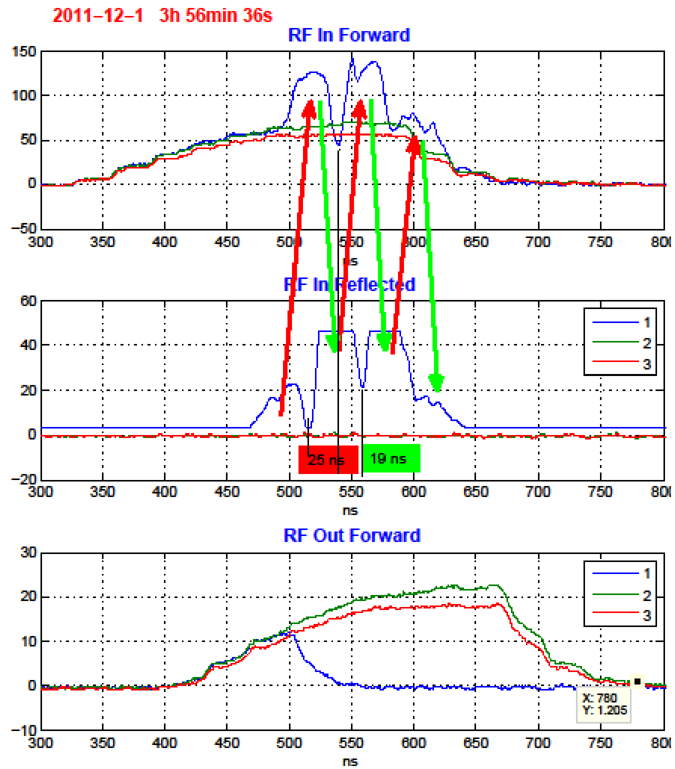
So *both* the main and drive beam can be affected by a breakdown in an accelerating structure!

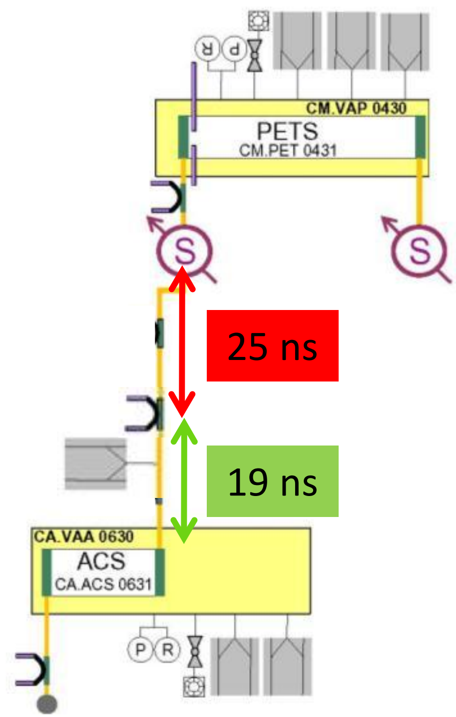
In particular, power reflected from an rf breakdown goes back to the PETS, reflects off the upstream end and, if it has the right phase, adds to deceleration of the drive beam generating *higher* power. This also means the drive beam is decelerated more.

We've seen this effect in the two-beam test stand.

# Evidence of ACS BDs effect on input power




A BD in the ACS affects the PETS output

Bouncing of an early BD reflected power

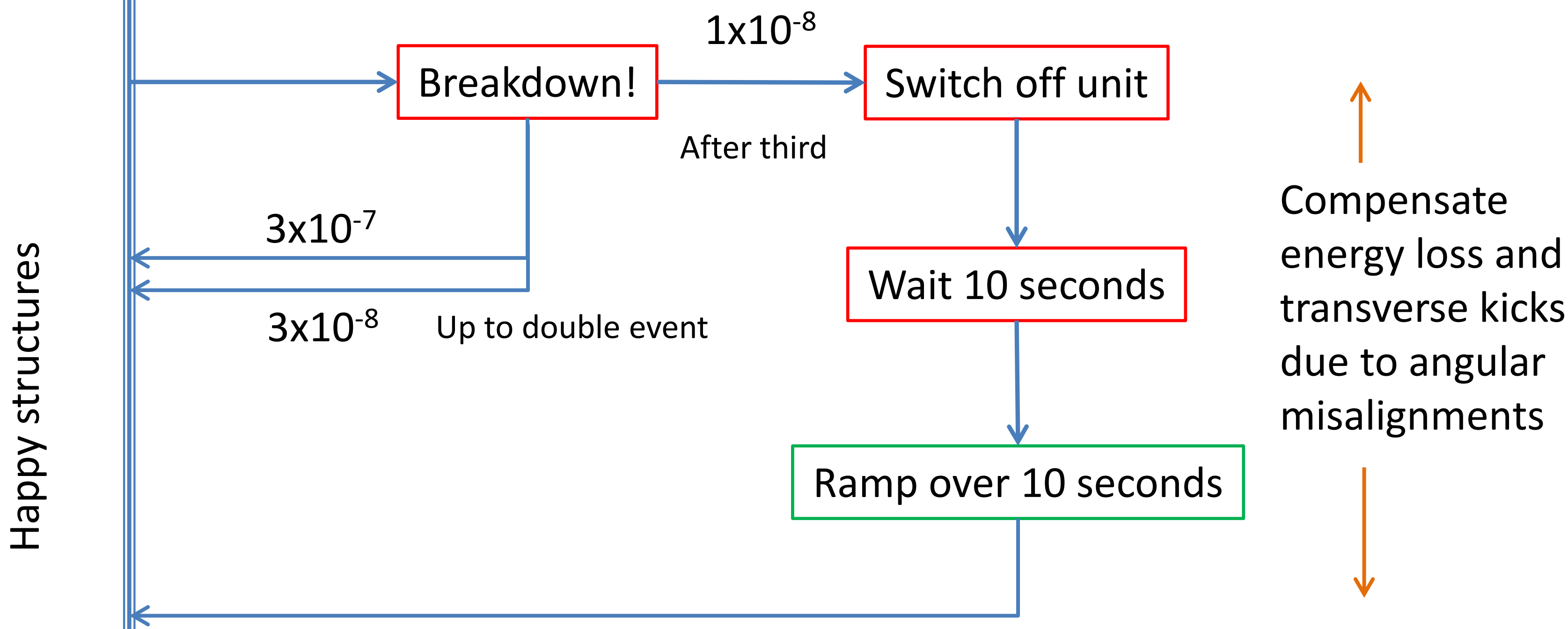
- The reflected power is likely to change randomly the phase of the PETS recirculation loop and consequently to modify the produced power

# A special two-beam issue

One solution for this problem is to install an on/off mechanism also on the upstream end of the PETS, terminating it when under full power mode.

Issue under active study.

# Current breakdown response scenario




Takes 1000 pulses so $10^{-5}$x30km=0.3m are off or being ramped on average.

Probabilities [/pulse/m] and times are approximate – fixed to simplify explanation.