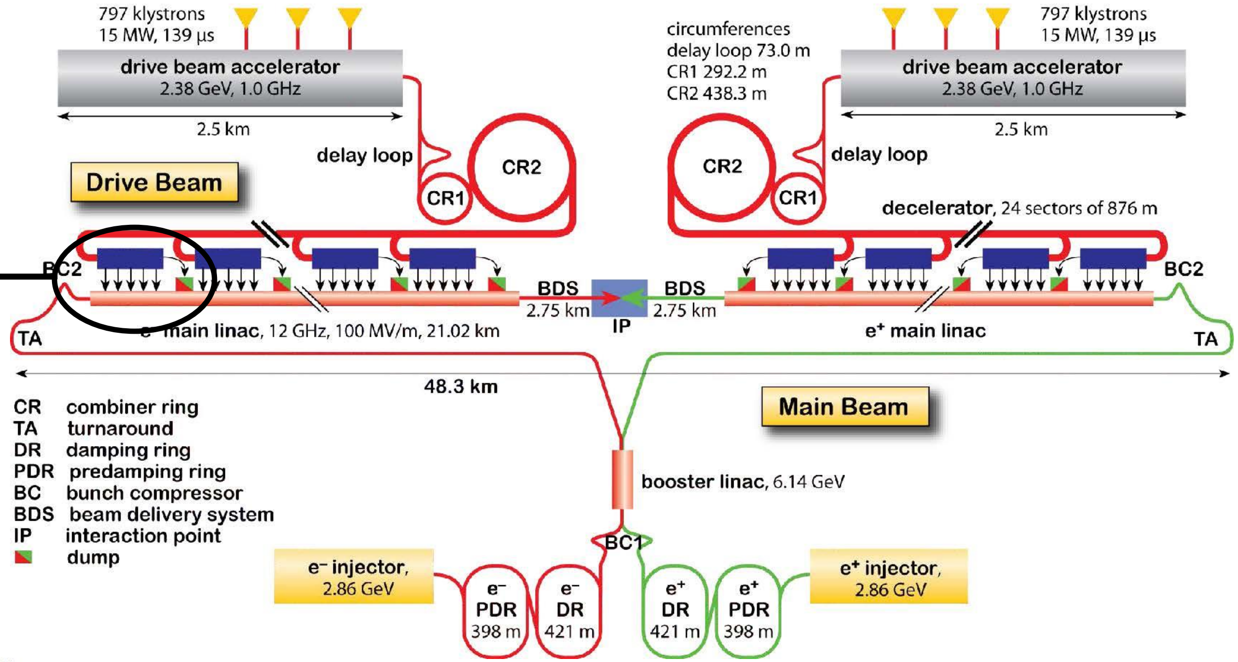
Low Breakdown rate operation of a high gradient accelerating structure under high beam loading conditions

J.L. Navarro (CERN), for the CLIC/CTF3 collaboration

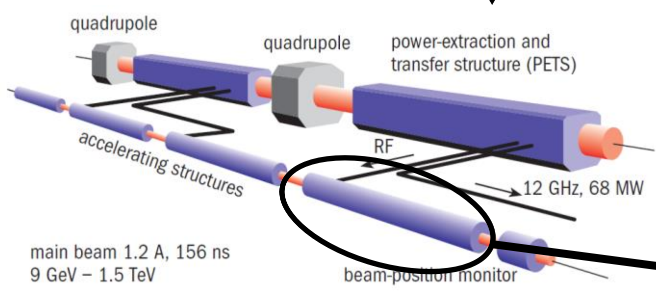
Outline

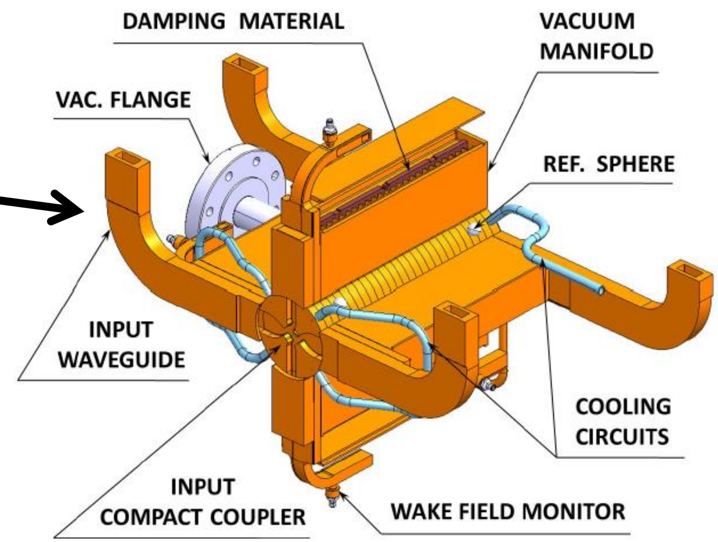
- From CLIC to the breakdown problem
- The Dogleg experiment layout
- First Results
- Next steps
- Conclusions

CLIC in a nutshell



- ✓ The study is focused on the **accelerating structures** of the **Main Beam Linac**





- **Traveling waves** cavities
- Nominal gradient ~ 100 MV/m
- Nominal RF pulse length ~ 240 ns (160 ns flat top)
- Peak Power ~ 61 MW
- Max. Surf. Field ~ 230MV/m

The breakdown problem

Strong Accelerating fields (~100 MV/m)

Problem of **Break Downs** (BD): Very fast (10 ns – 100 ns) and localized dissipation of stored energy in the structure.

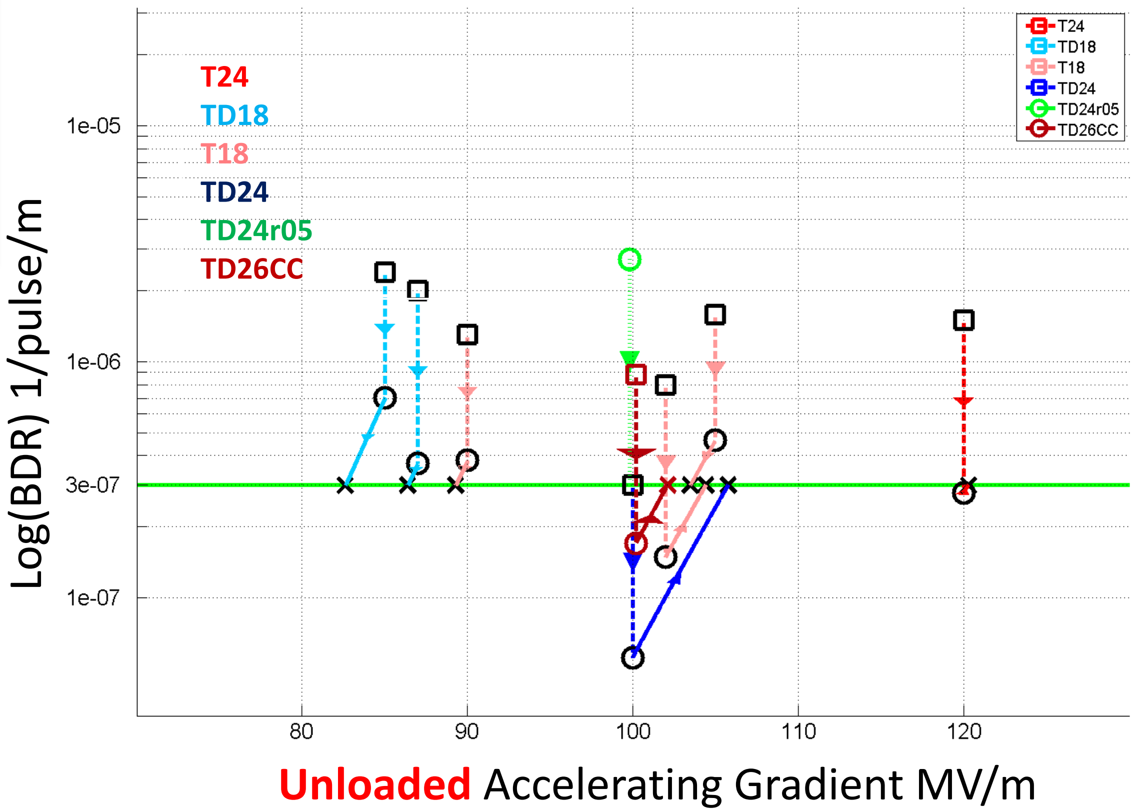
Undesired effects:

- Loss of acceleration
- Damage in the structure
- Kick in the beam
- …

Luminosity Reduction:

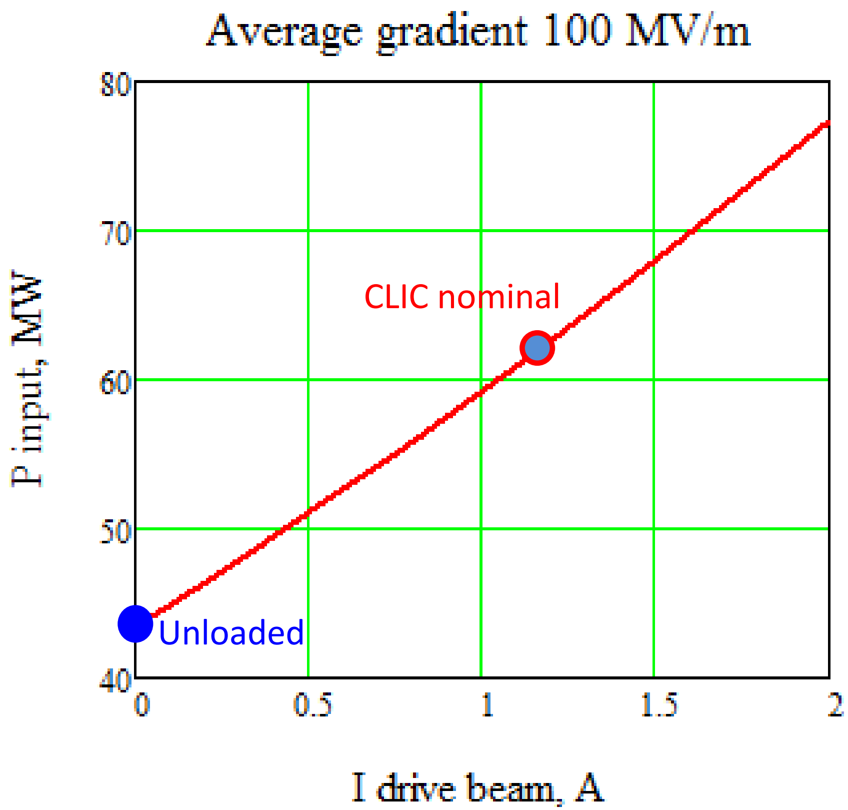
Max DB rate allow for CLIC specifications:

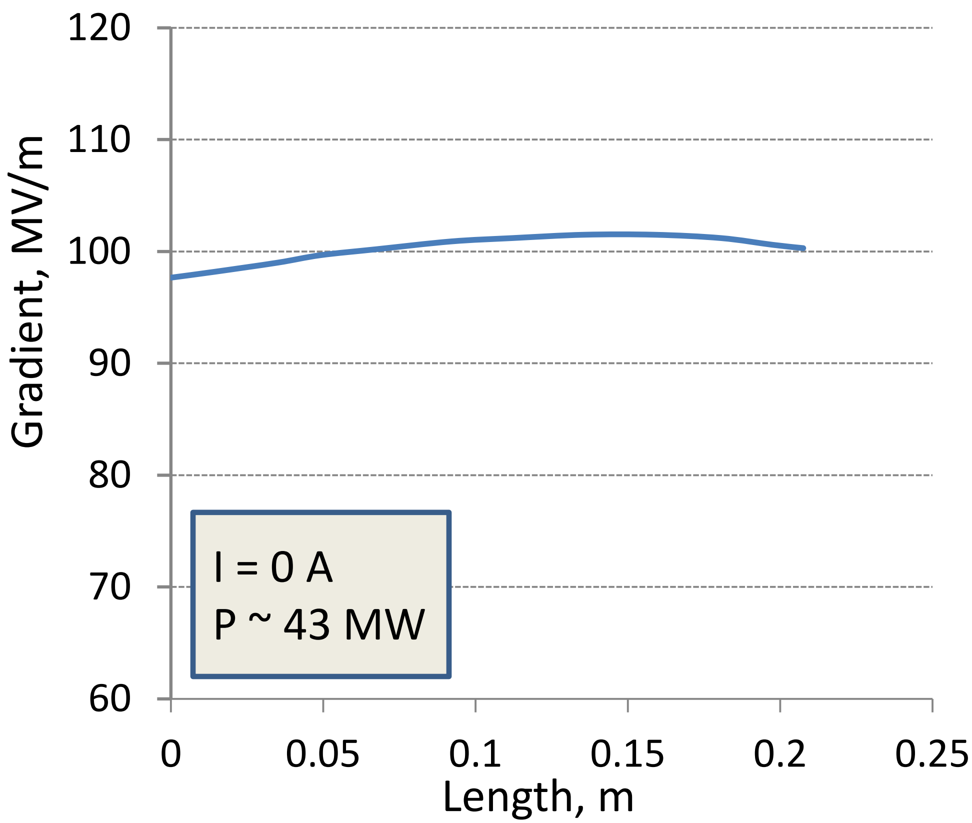
$3\ 10^{-7}$ BD pulse^{-1} m^{-1}



Beam loading effect

Beam Loading modifies the gradient distribution along the structure

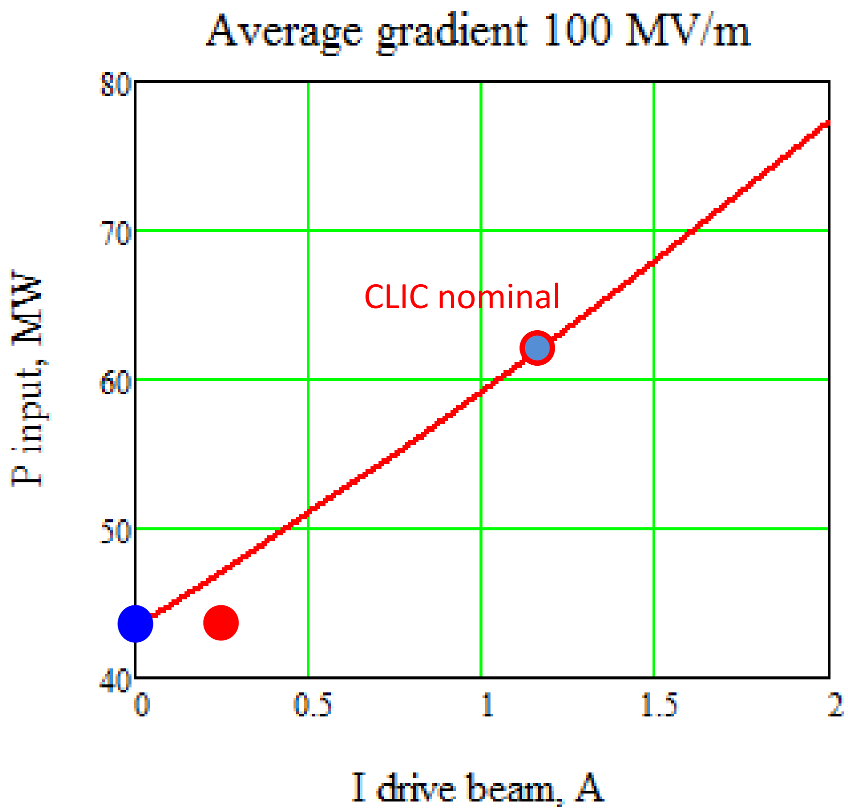


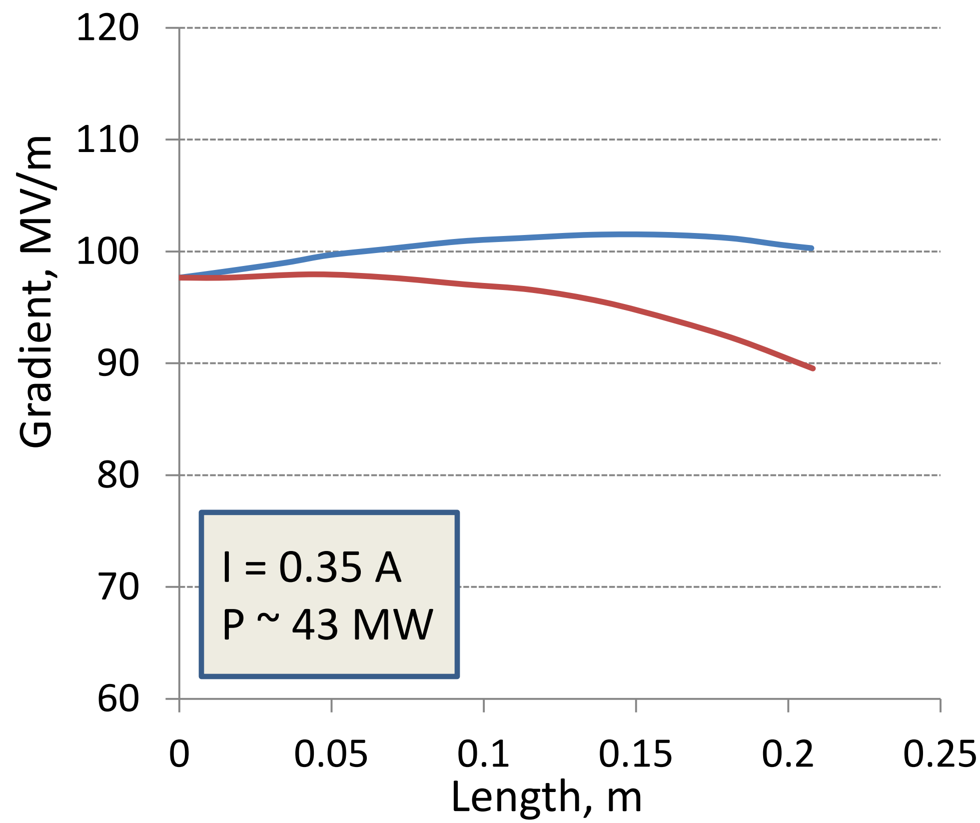


Gradient profile along the structure without beam loading

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

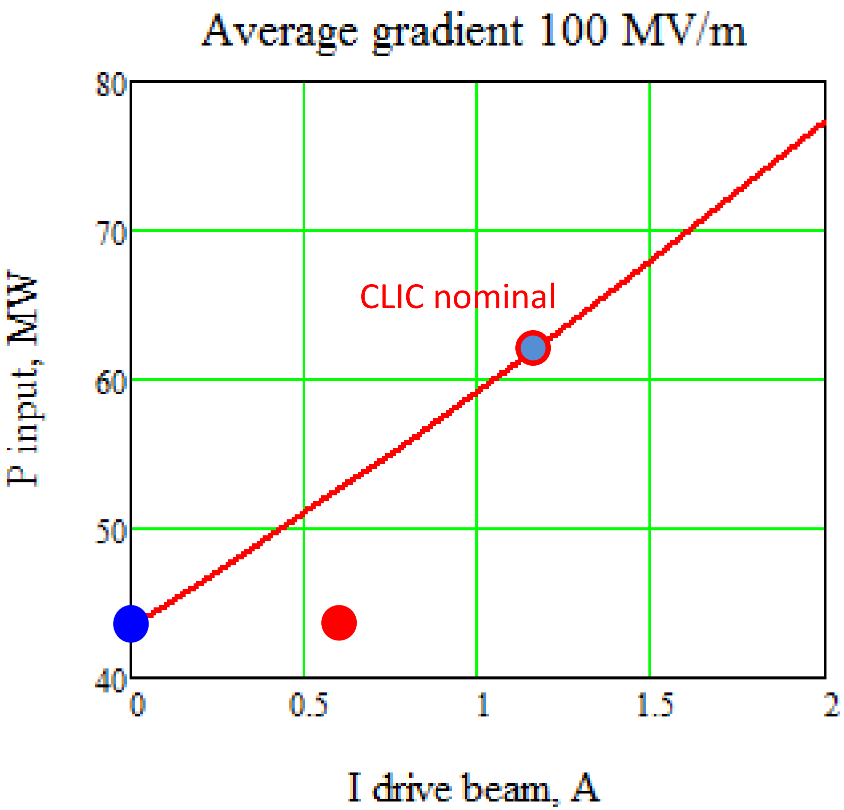


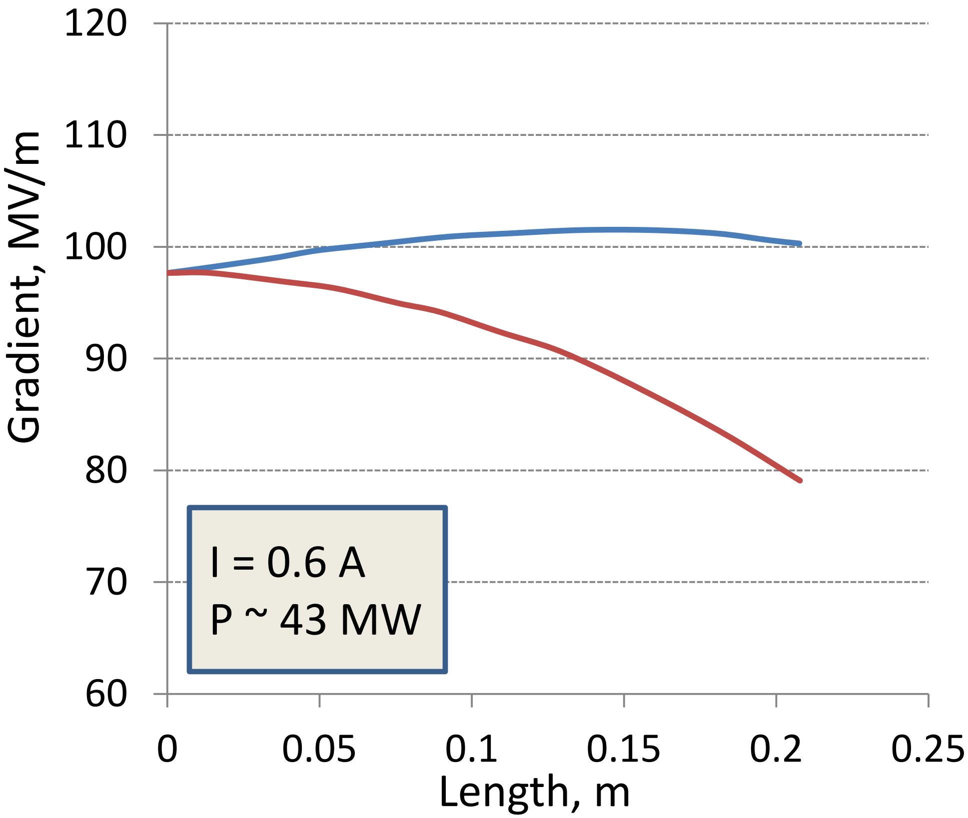


The beam loading modifies the gradient profile

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

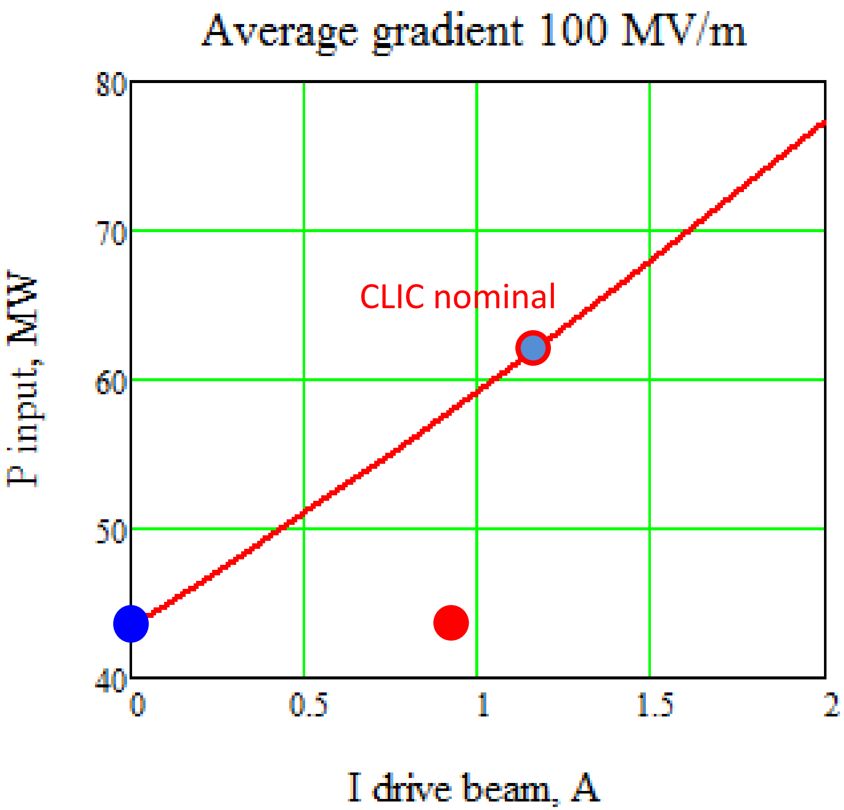


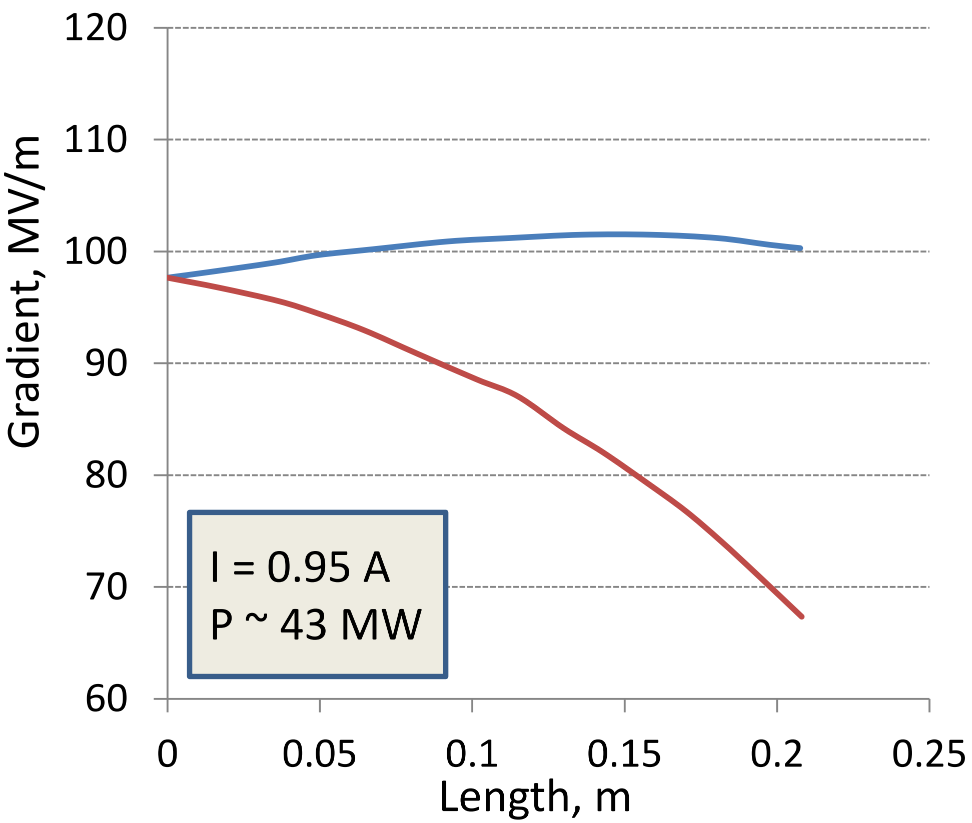


The beam loading modifies the gradient profile

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

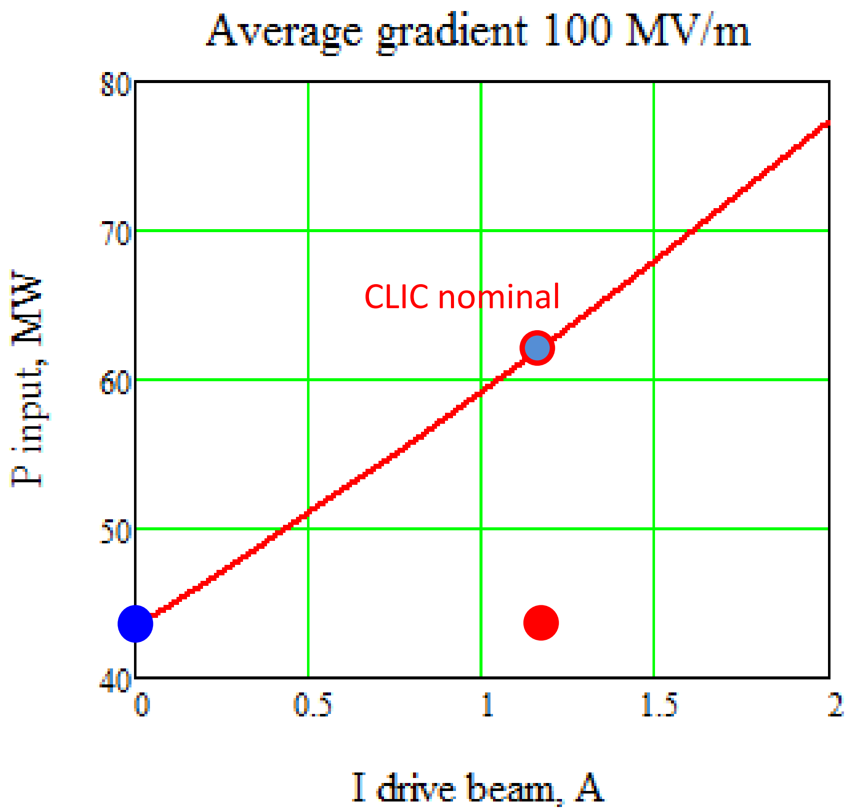


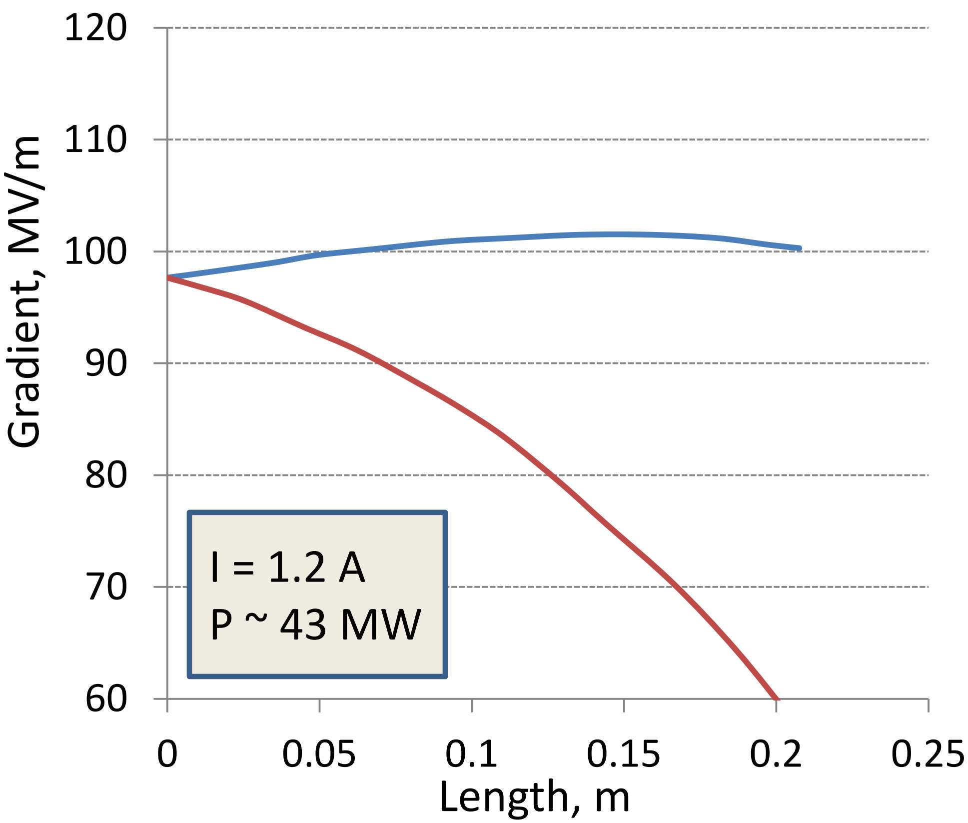


The beam loading modifies the gradient profile

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

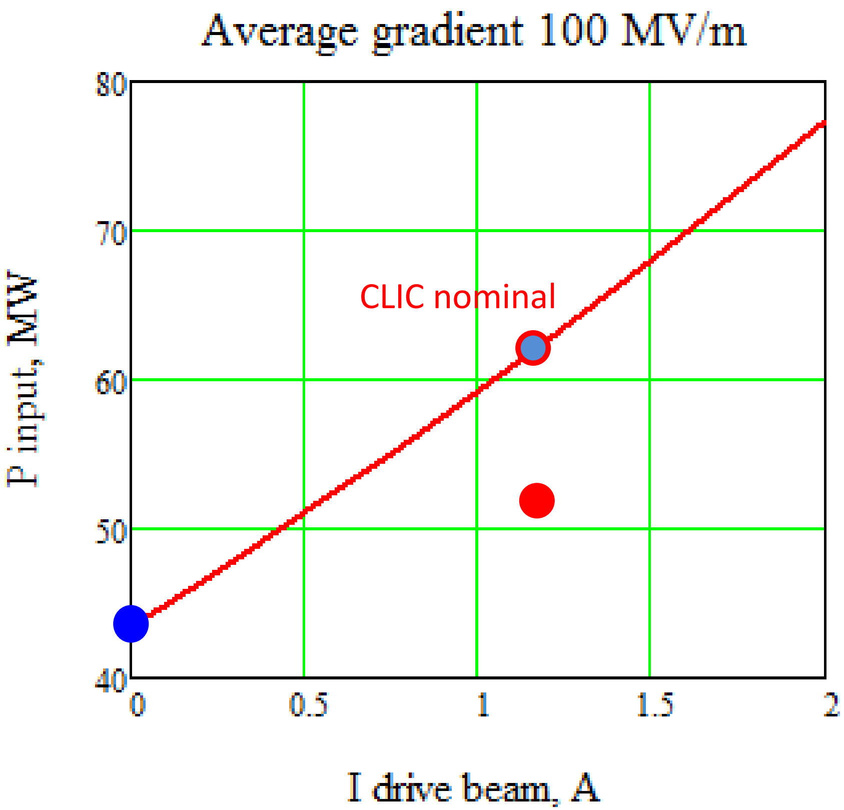


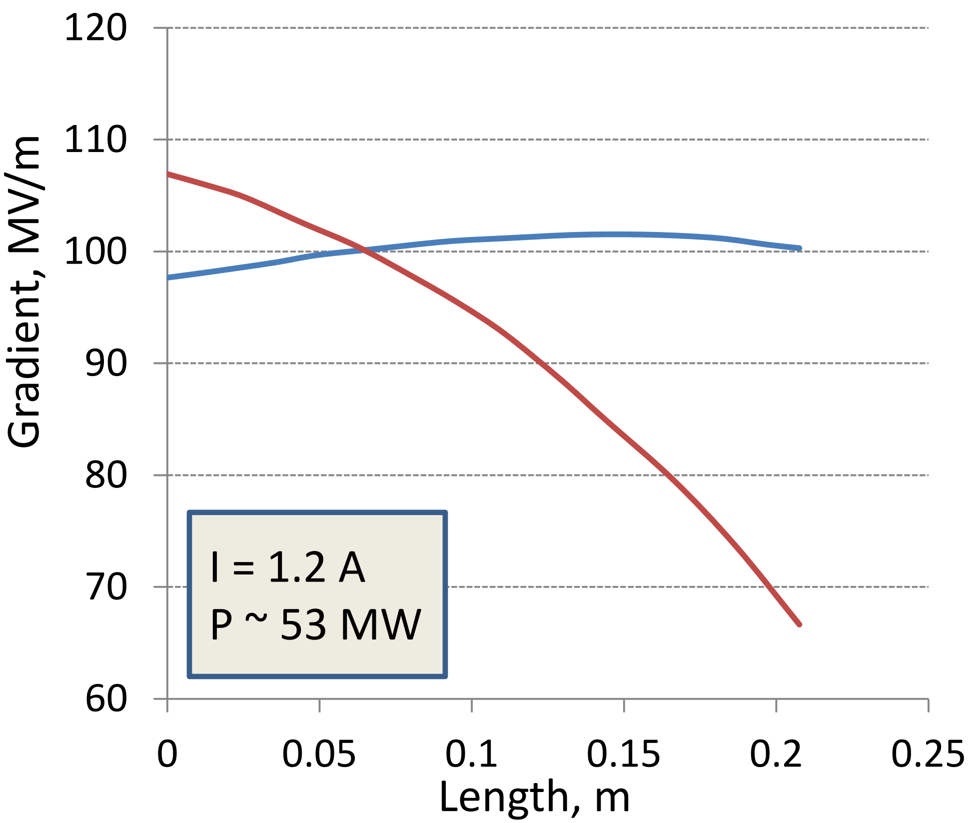


We do not have anymore 100 MV/m in average.

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

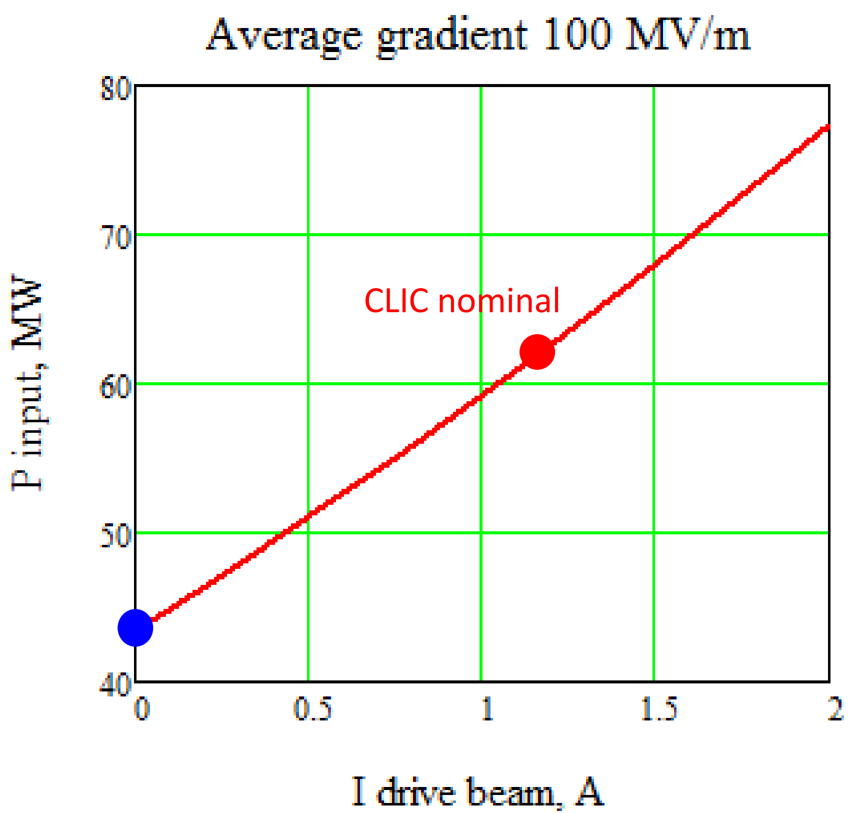


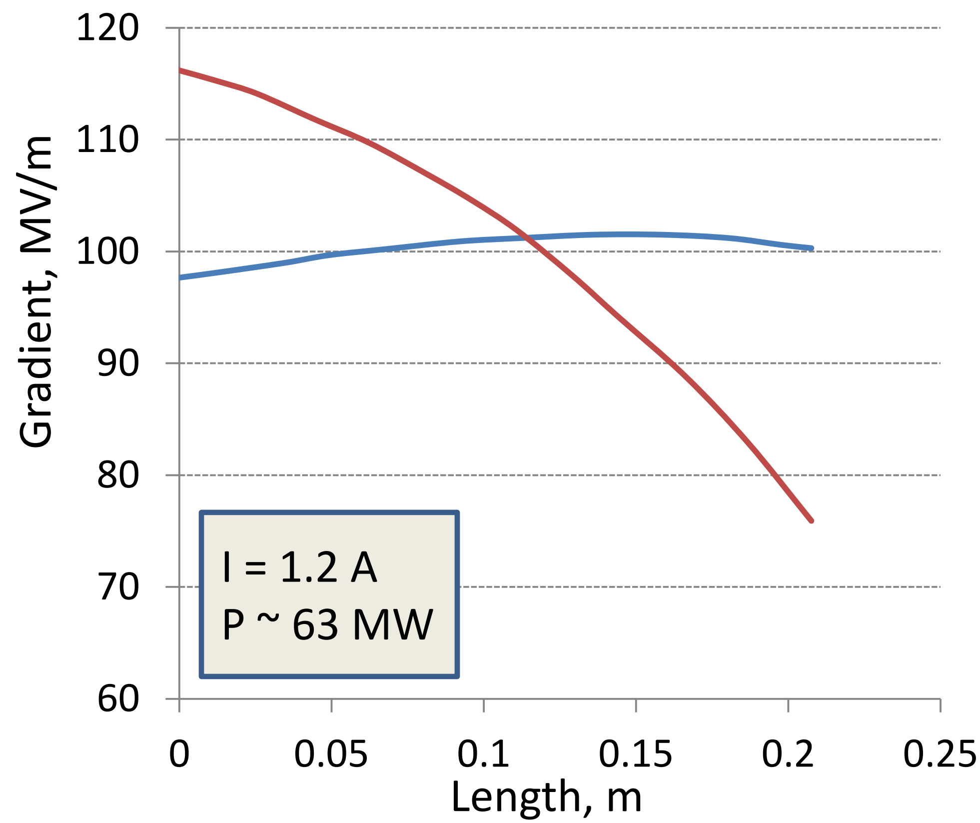


We compensate increasing the RF input power

Beam loading effect

Beam Loading modifies the gradient distribution along the structure



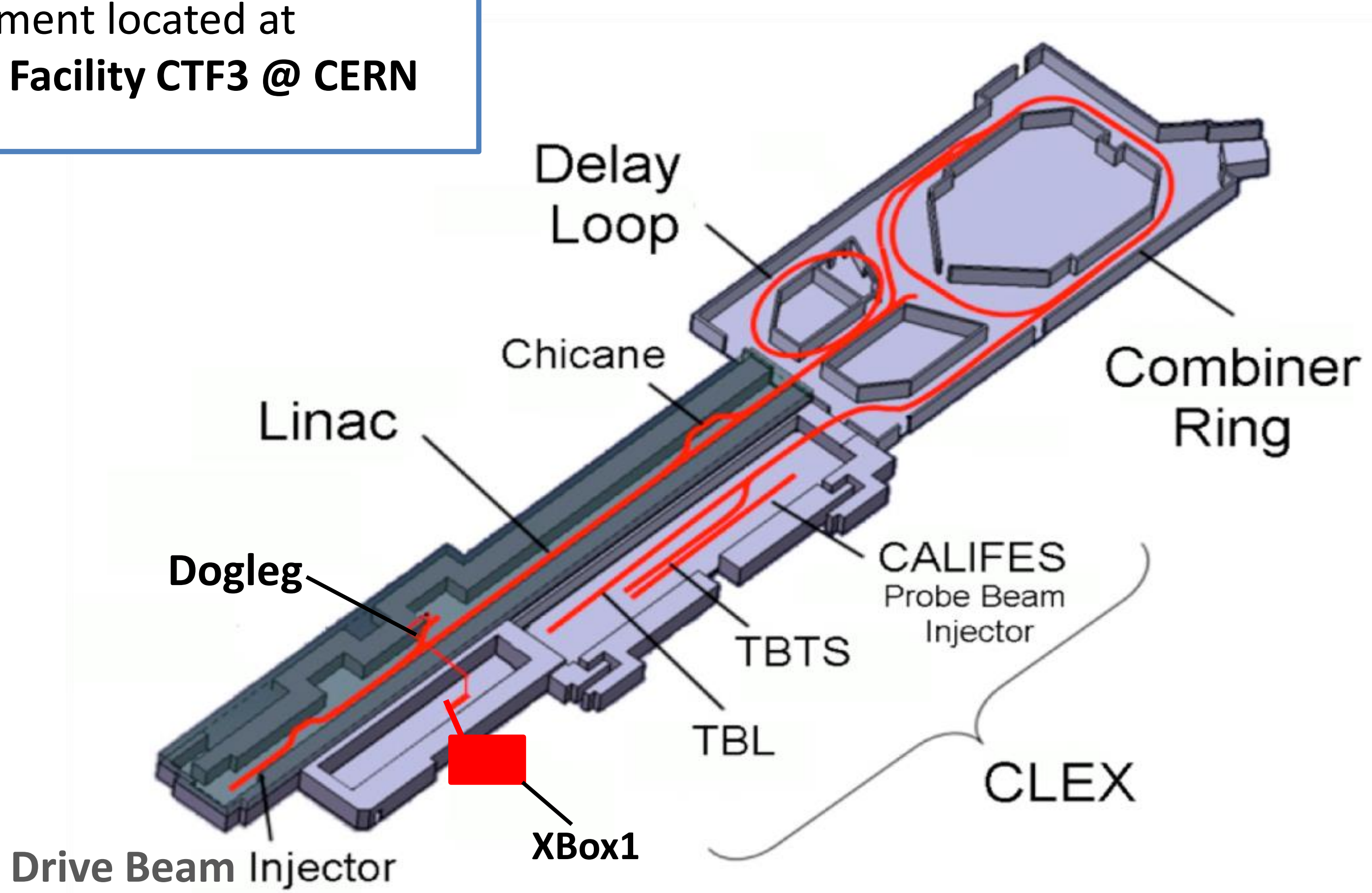


What is the effect on BD rate?

The Dogleg Experiment

Main goal: Measure and comparison (unloaded vs high beam loading) of the BD rate in high gradient accelerating structure

Experiment located at
the **CLIC Test Facility CTF3 @ CERN**

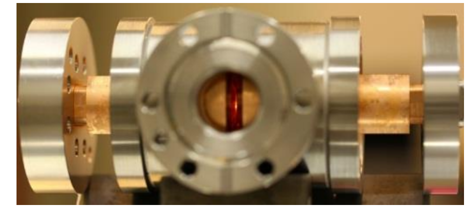


Experiment layout

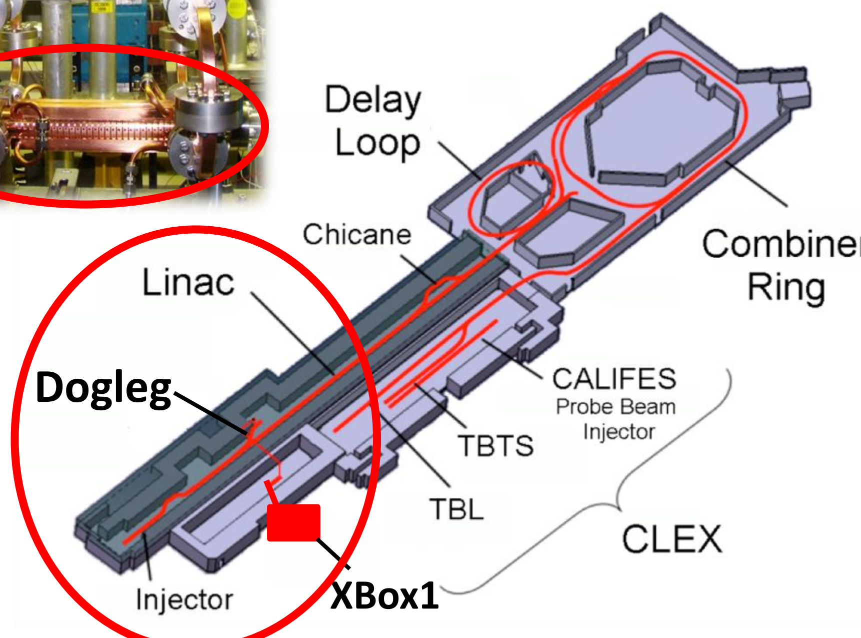
3000000x

1x

Nx

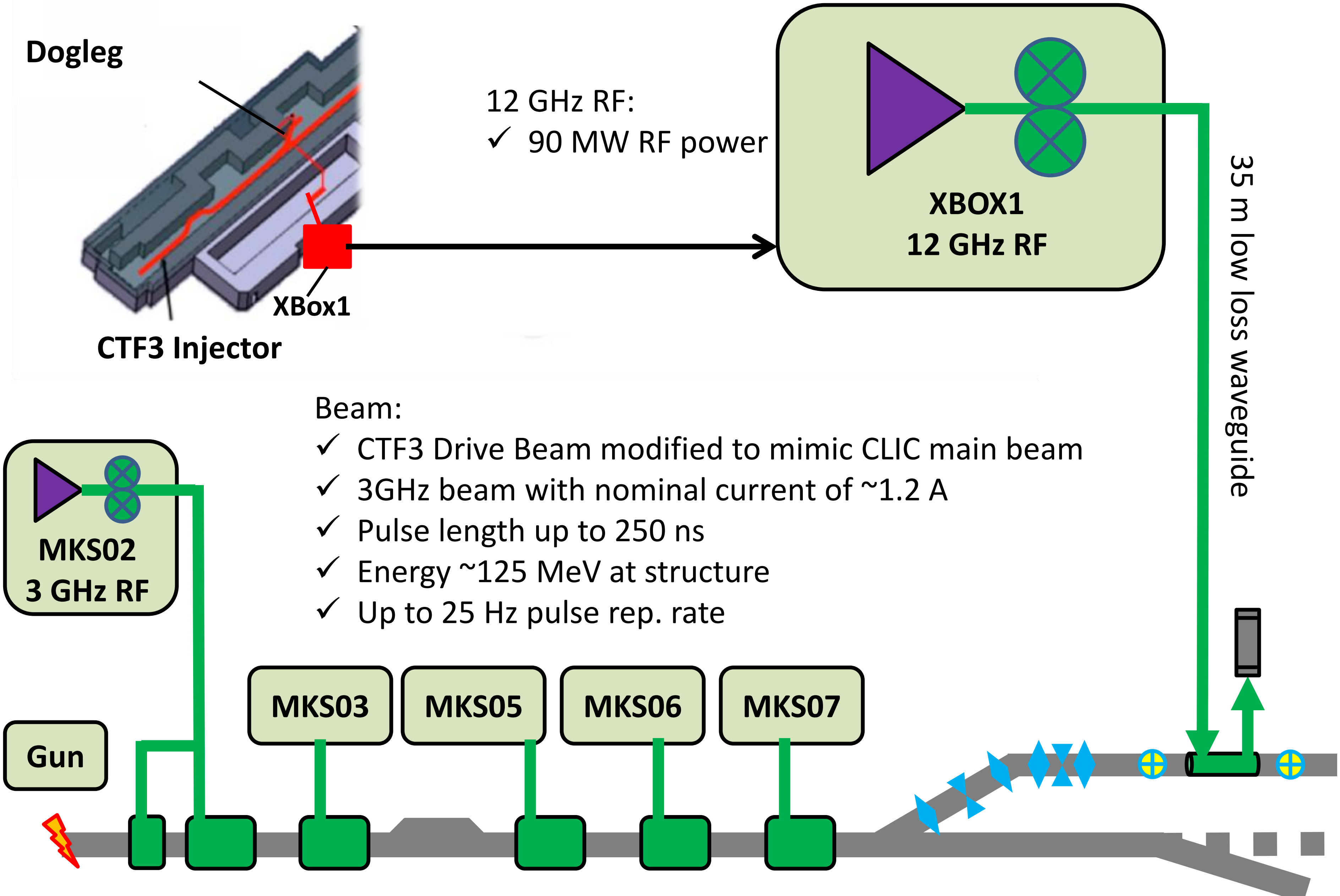


1x



1x

Experiment layout

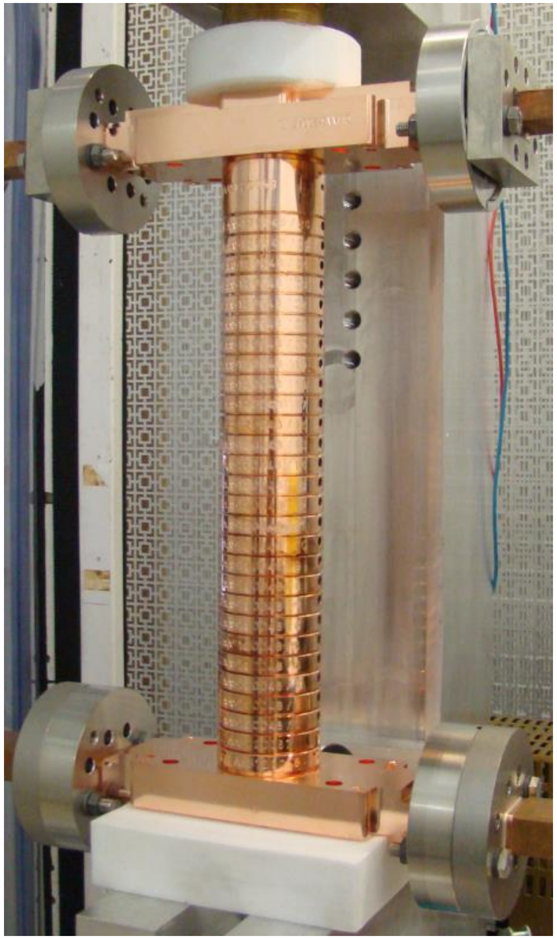


12 GHz RF:
- ✓ 90 MW RF power

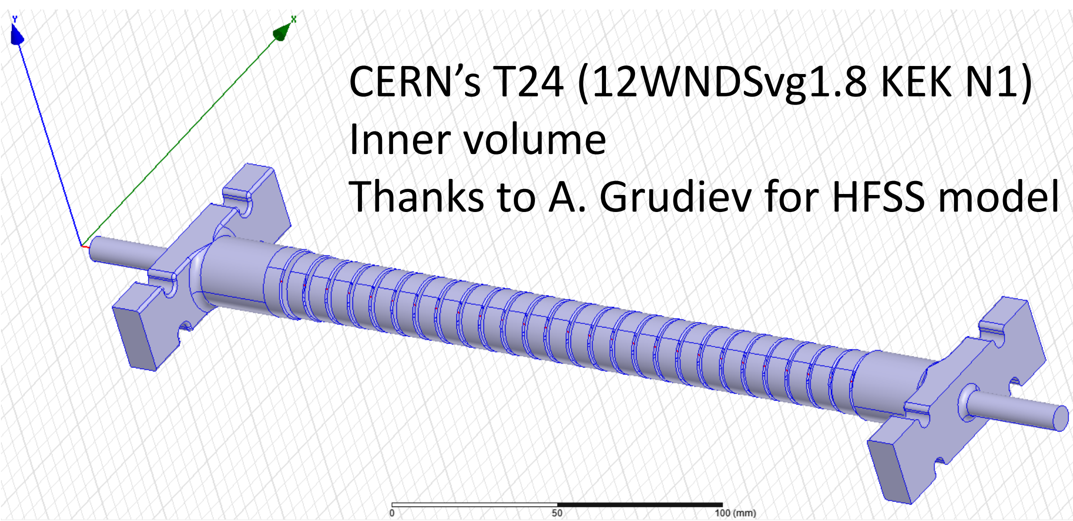
Beam:
- ✓ CTF3 Drive Beam modified to mimic CLIC main beam
- ✓ 3GHz beam with nominal current of ~1.2 A
- ✓ Pulse length up to 250 ns
- ✓ Energy ~125 MeV at structure
- ✓ Up to 25 Hz pulse rep. rate

The 12GHz Accelerating structure

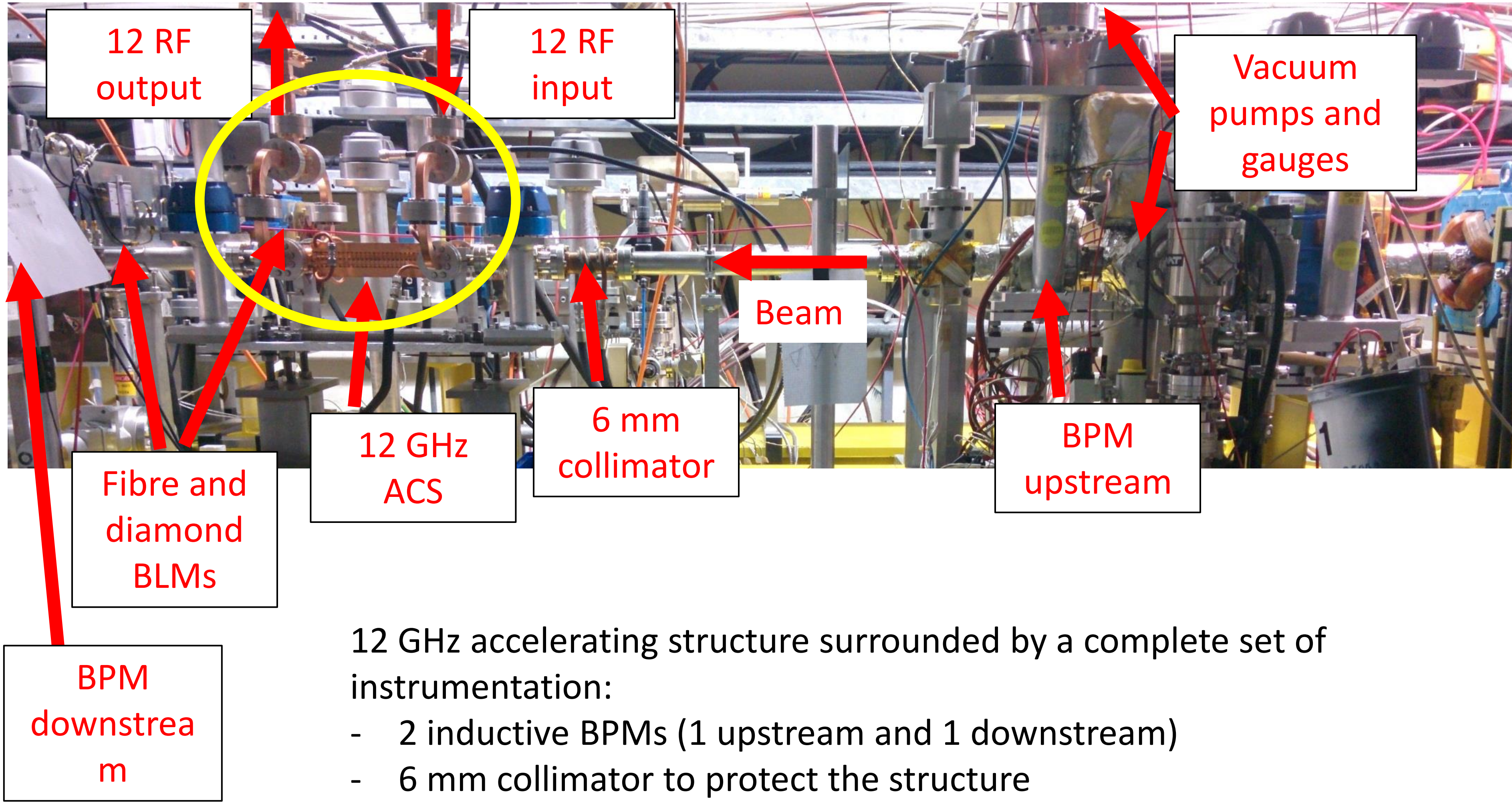
Normal conducting cooper structure
Travelling wave
Tapered linearly (Ø from 6.3 to 4.7 mm)
Without HOM ~~D~~amping waveguides
24 cells + 2 coupling cells
Nominal accelerating gradient 100 MV/m
v_g/c [%] = 1.8 to 0.9
Filling time = 57.25 ns
Q_{Cu} = 6815



CERN's T24 (12WNDSvg1.8 KEK N1)
Inner volume
Thanks to A. Grudiev for HFSS model



Diagnostic, control and protection



12 GHz accelerating structure surrounded by a complete set of instrumentation:

- 2 inductive BPMs (1 upstream and 1 downstream)
- 6 mm collimator to protect the structure
- Fibre optic and diamond beam loss monitors
- Vacuum pumps and gauges in beam chamber and RF waveguides

The 12GHz RF source

ScandiNova Modulator:

- Designed for 400kV, 300A, 3.25us HV pulse width FWHM, 1.5us RF pulse width at 50Hz repetition rate

Enough power to reach 100 MV/m loaded gradient (~43 MW)

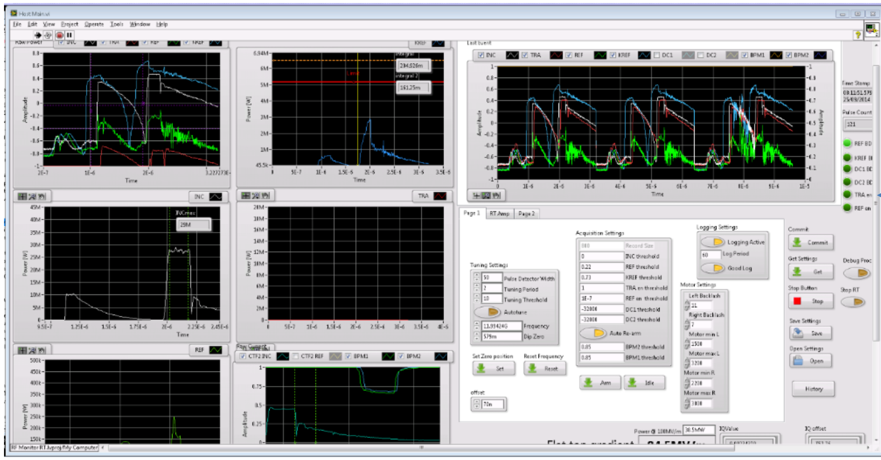
XL5 klystron:

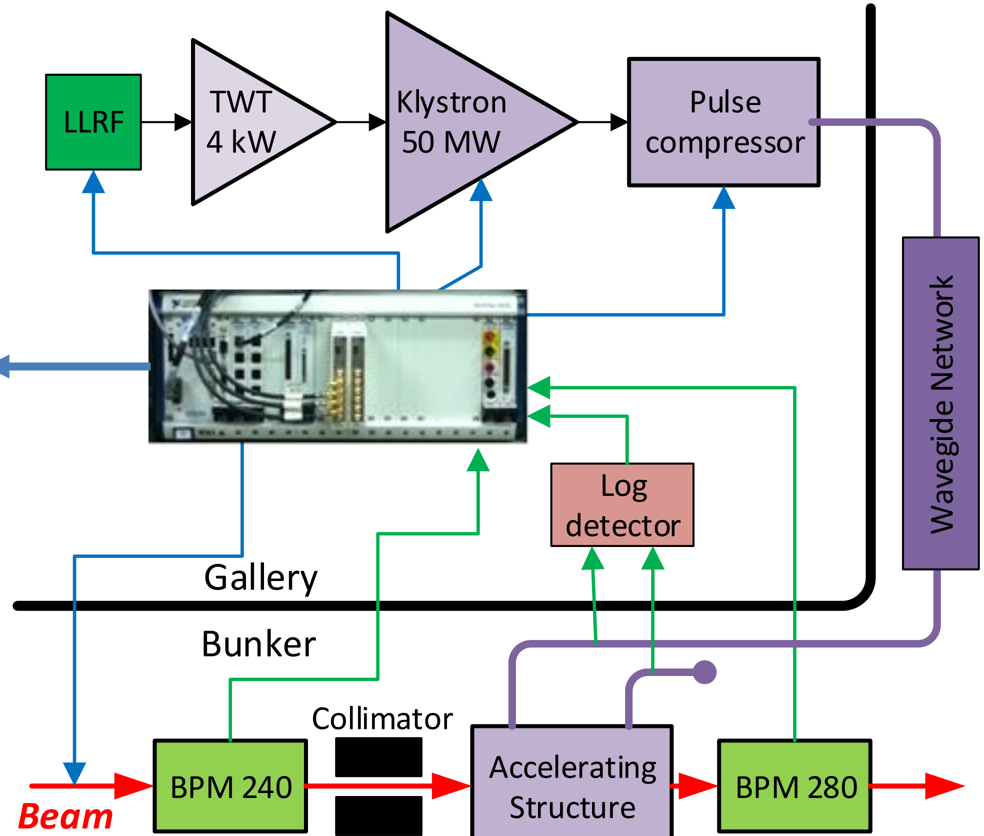
- 50MW, 1.5us rf pulses
- 50Hz repetition rate at 400kV, 300A, 600W rf drive power
- Working frequency 11.99424GHz

SLED II type pulse compressor:

- Power gain of 2.82
- $Q_{loaded} = 2.375 \times 10^4$,
- Beta = 4.27,
- $Q_0 = 1.31 \times 10^5$
- 5% power loss

Control and DAQ system

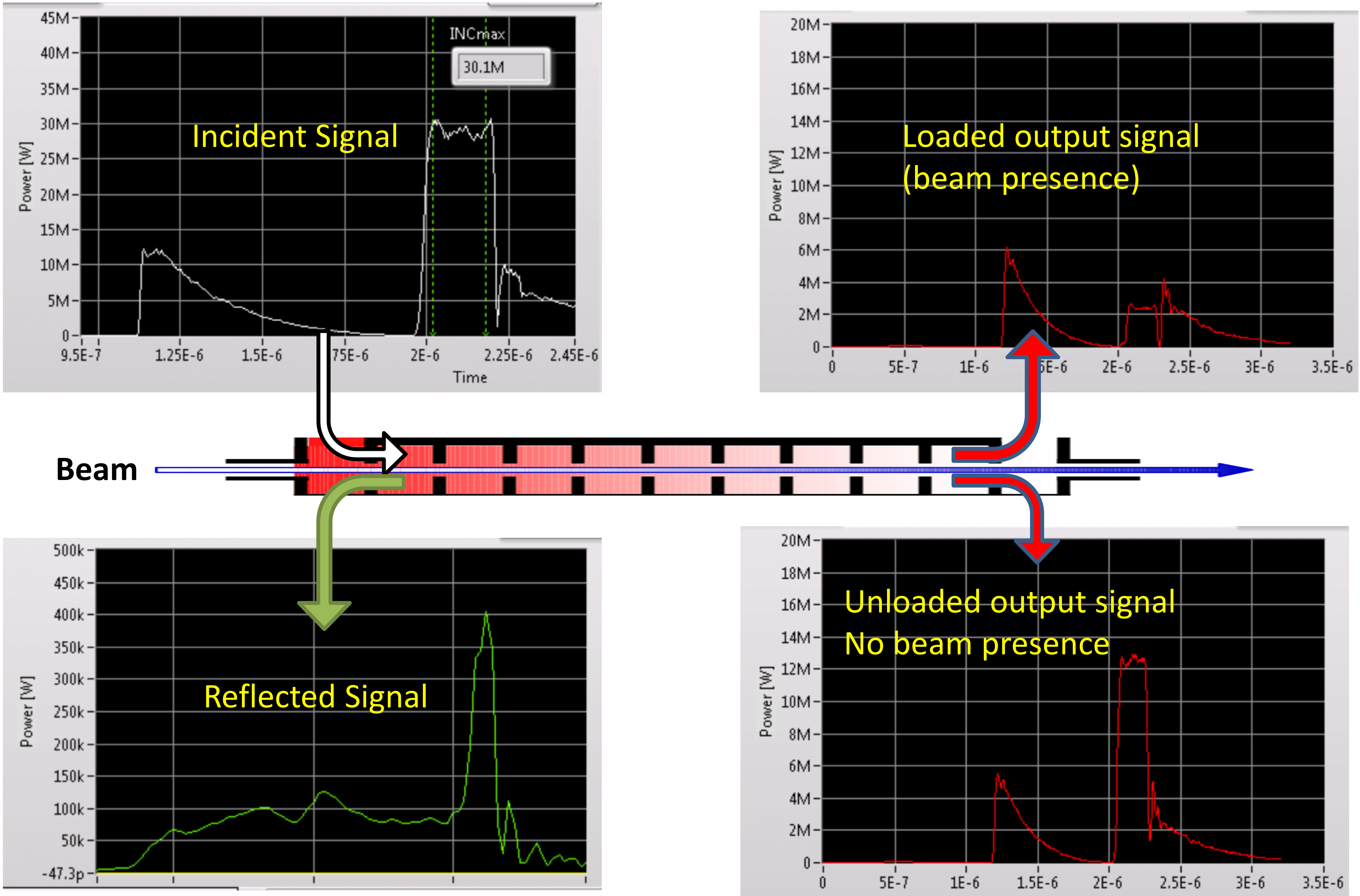




PXI NI unit:

- Real time interlocking
- Data taking and storage
- 12 GHz RF control
- Labview interface with user

How do we detect breakdowns



Data selection

Pulse repetition rate from 25 Hz to 50 Hz (a lot of data, needs pre-selection)

ACQ system stores:

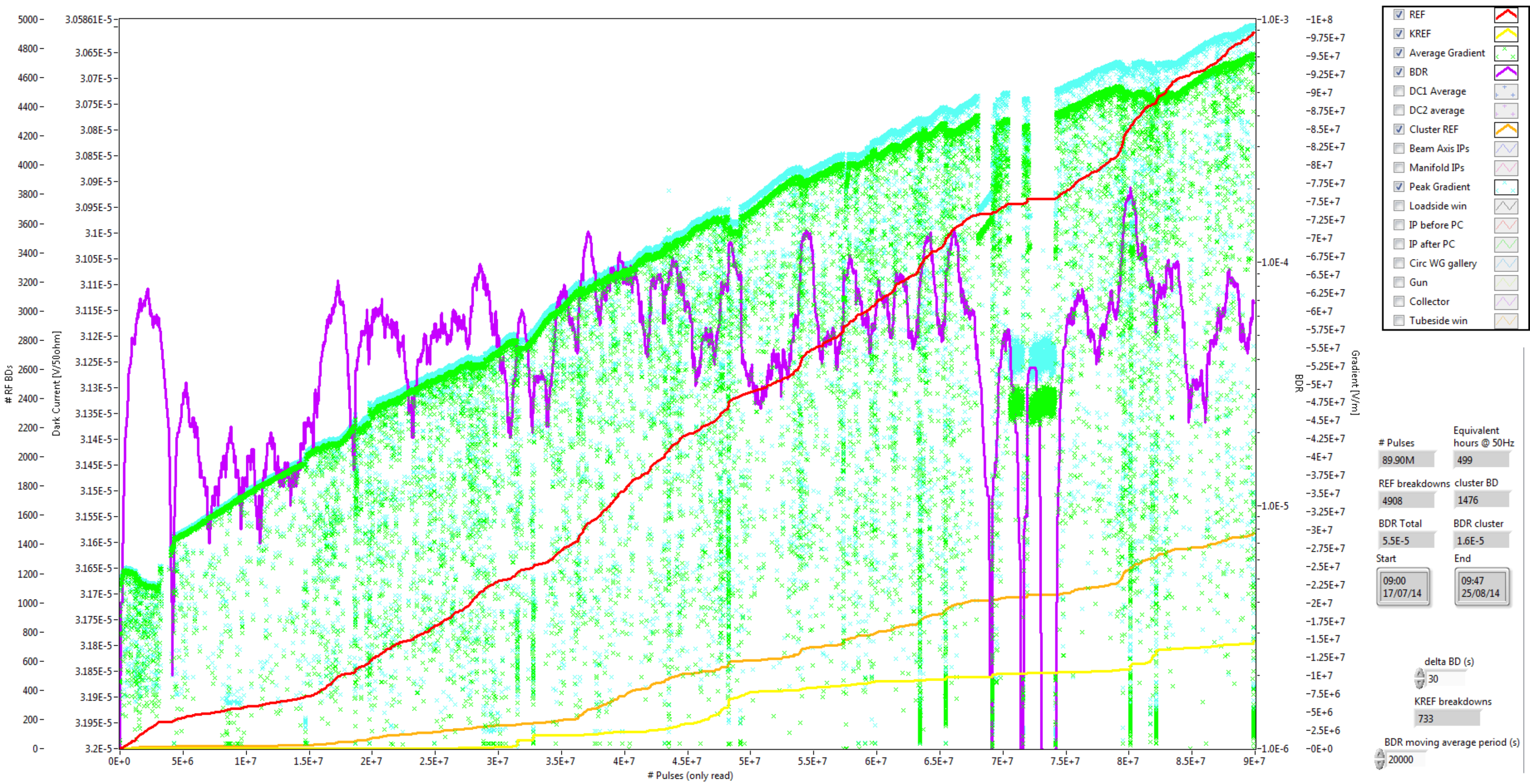
- 1 event per minute
- Breakdown-like events (soft criteria ~ 50% events are fake breakdowns)

Offline analysis selects breakdowns and nominal pulses, computes BDR

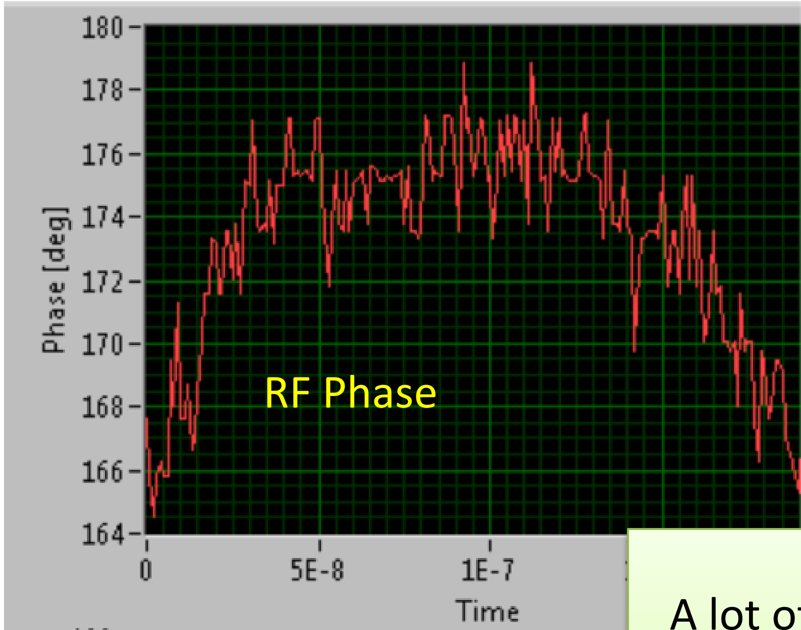
Final cuts for BD selection are not completely applied in the following results

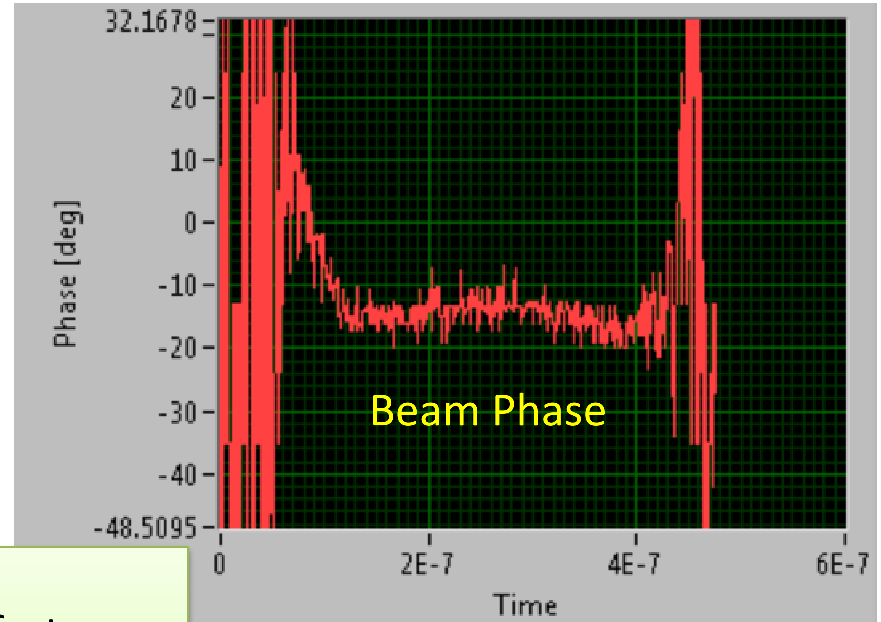
First Results

Conditioning period to reach 200 ns pulse length.

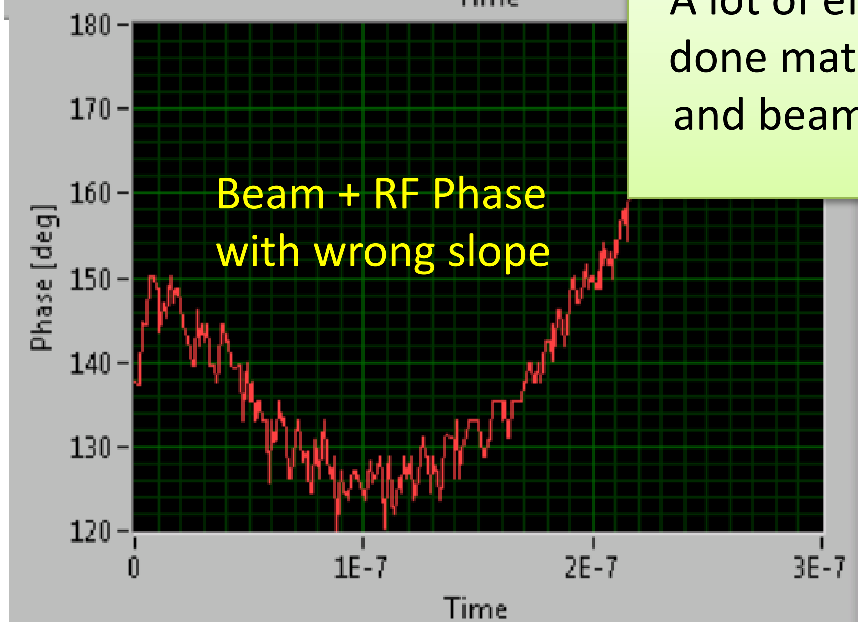


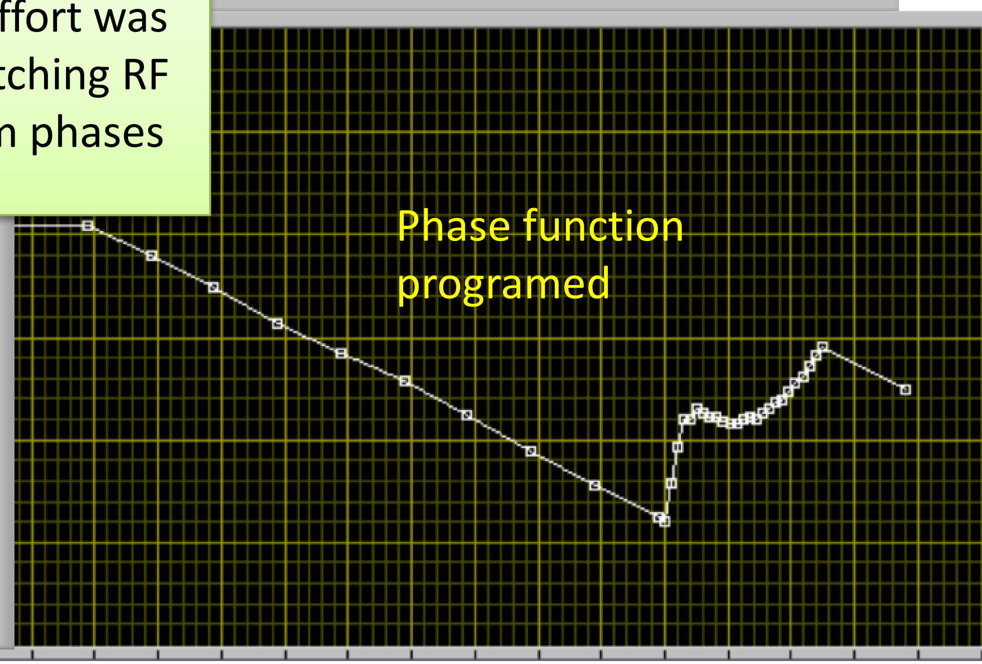
First Results



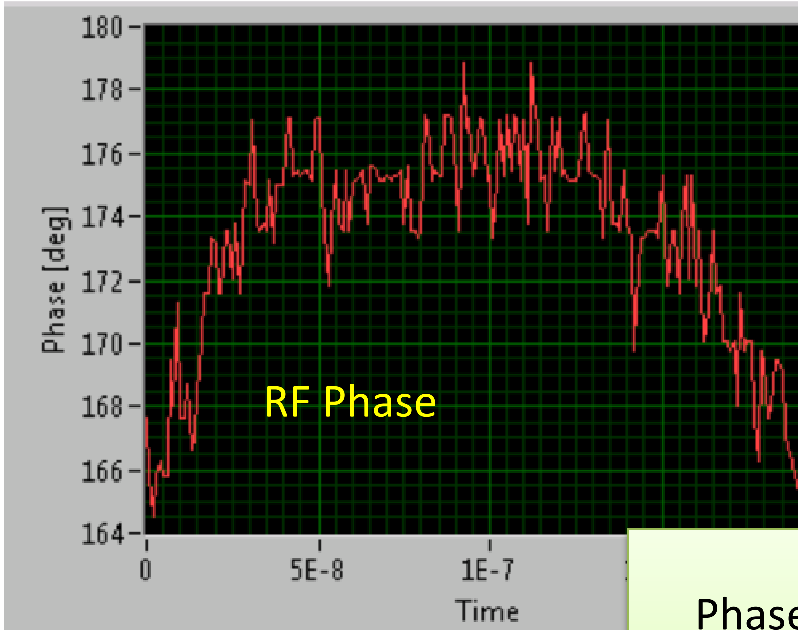


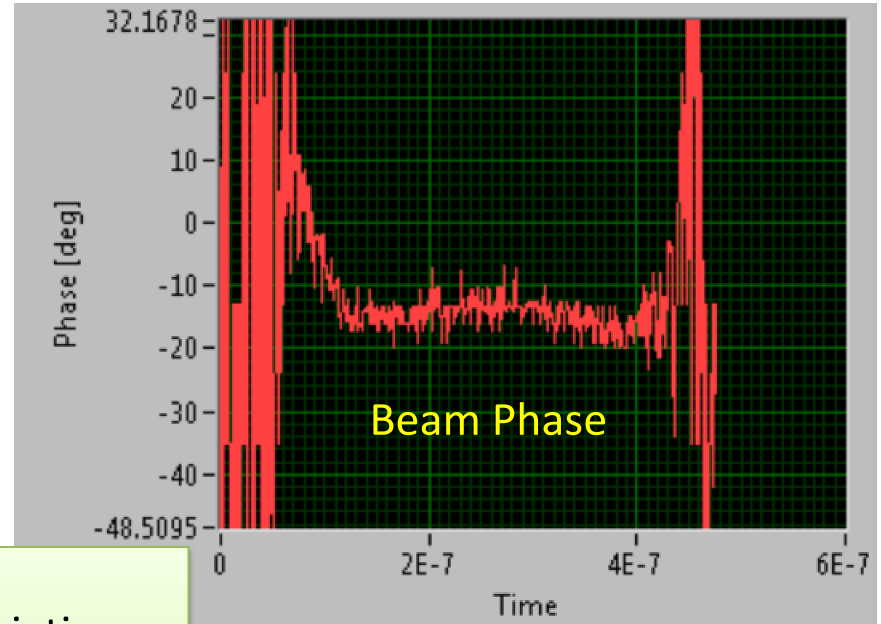
A lot of effort was done matching RF and beam phases



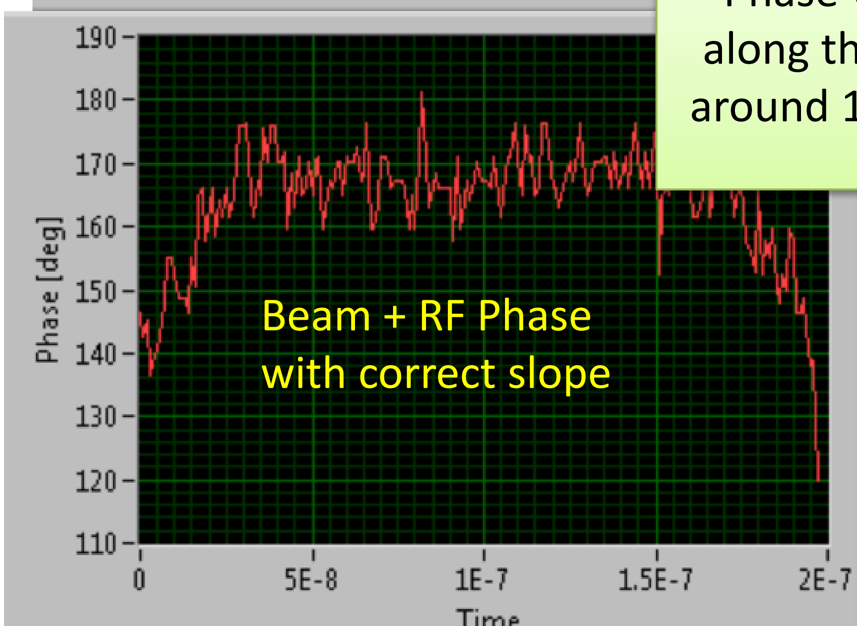


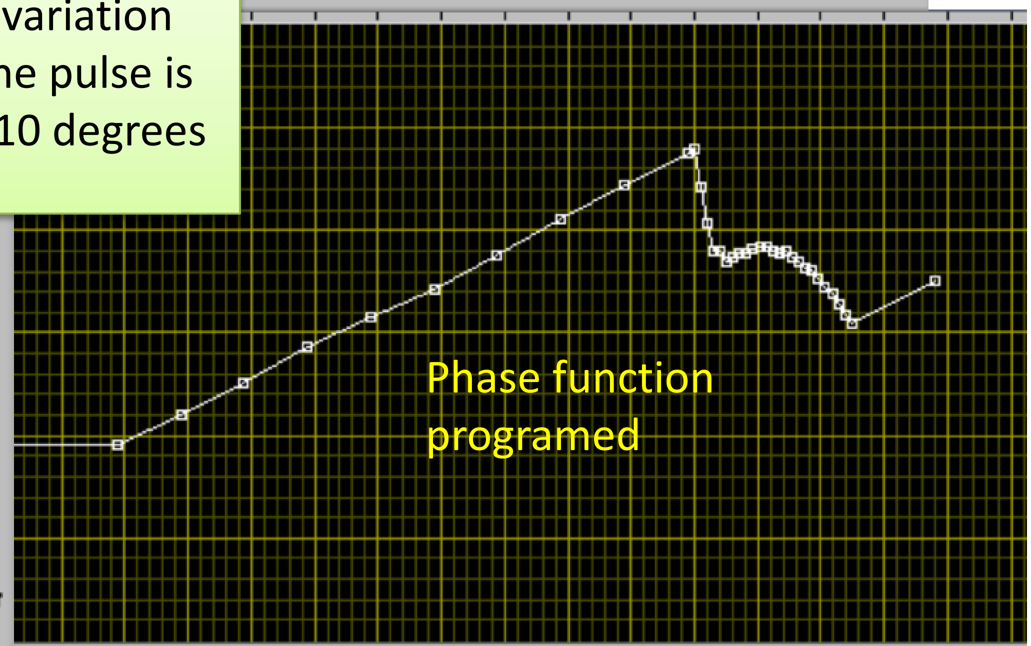
First Results





Phase variation along the pulse is around 10 degrees



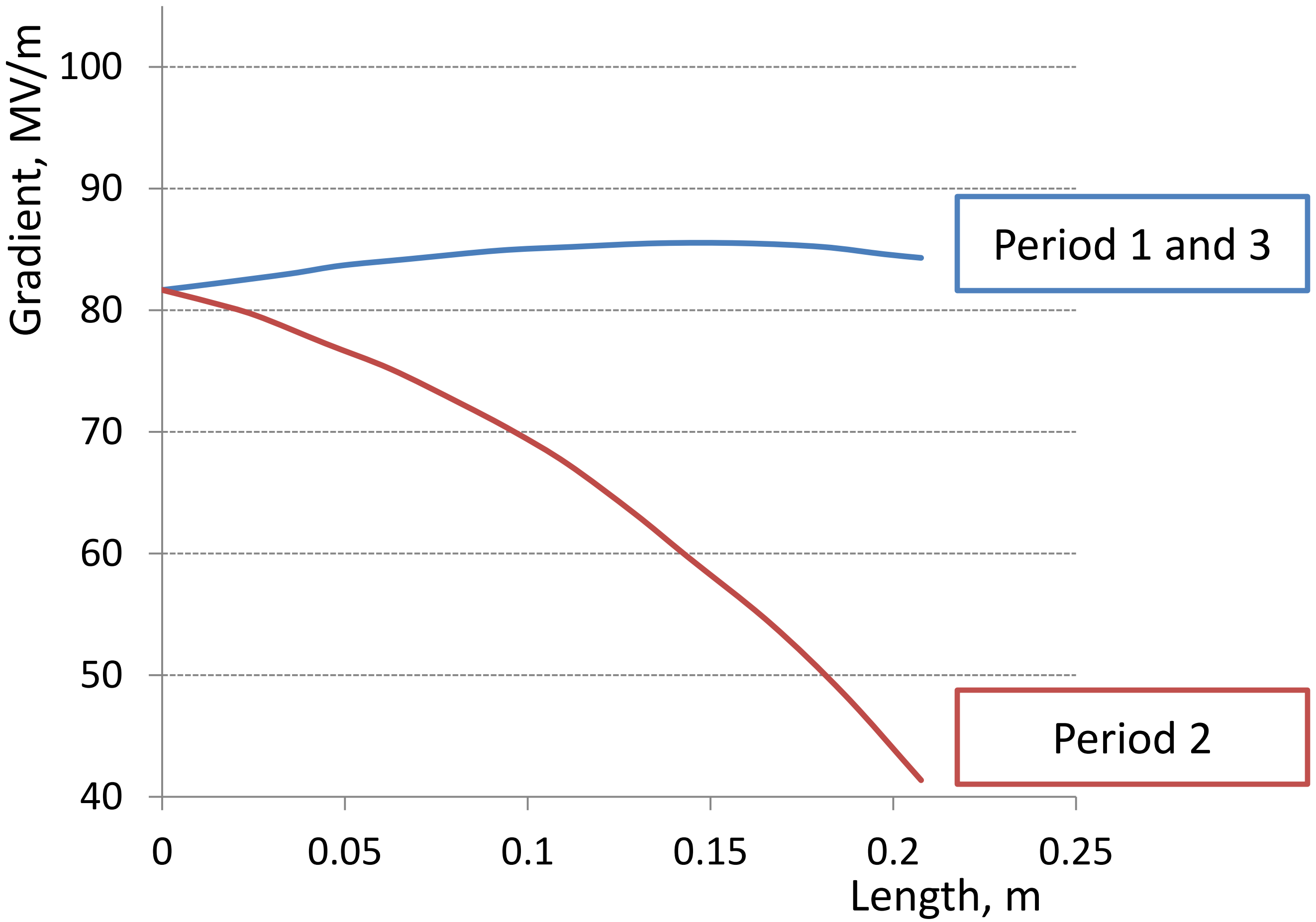


First Results

First Results

Very preliminary results!!!!!!

Data from 23/09/2014 to 02/10/2014



Period 1:
BD rate: $3.4\ 10^{-5} \pm 0.4$

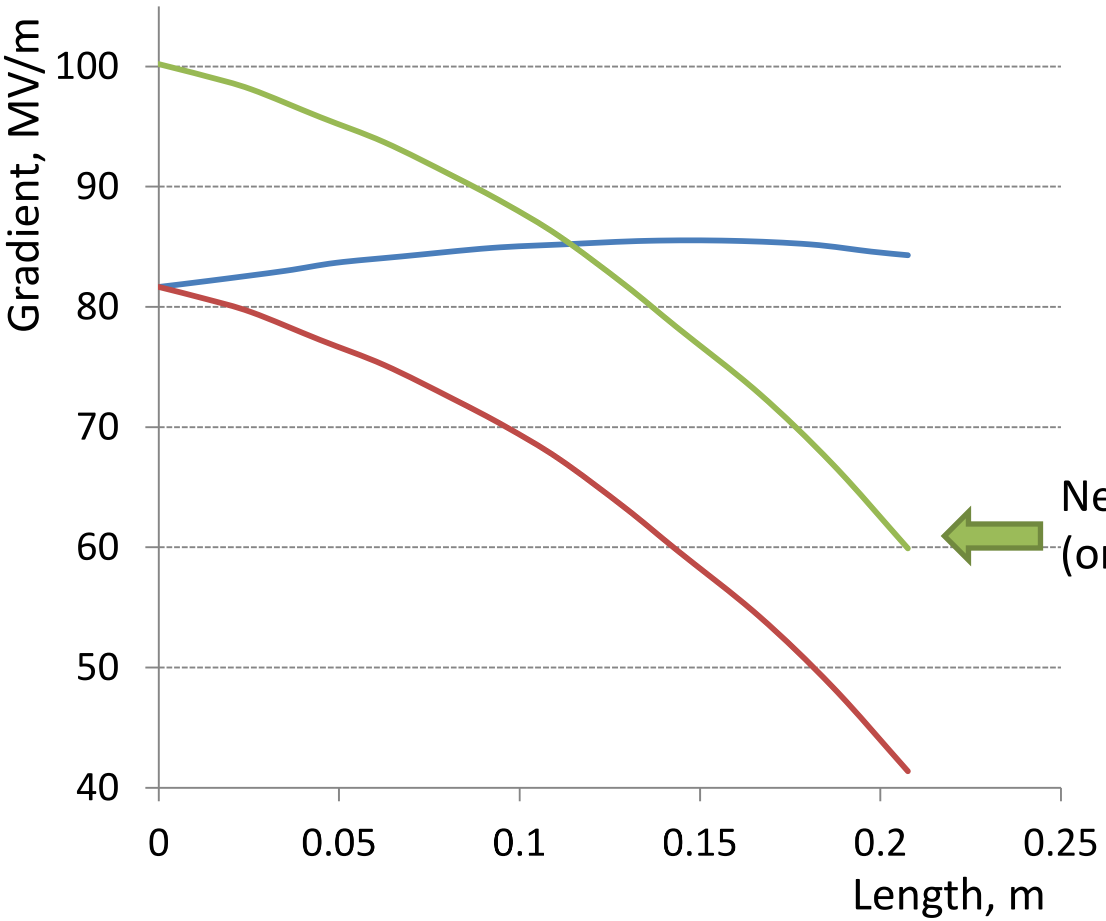
Period 2:
BD rate: $2.0\ 10^{-5} \pm 0.2$

Period 3:
BD rate: $1.2\ 10^{-5} \pm 0.1$

Systematic errors not included!!!

Preliminary Conclusion: Beam loading does not show an increased breakdown rate at constant input power

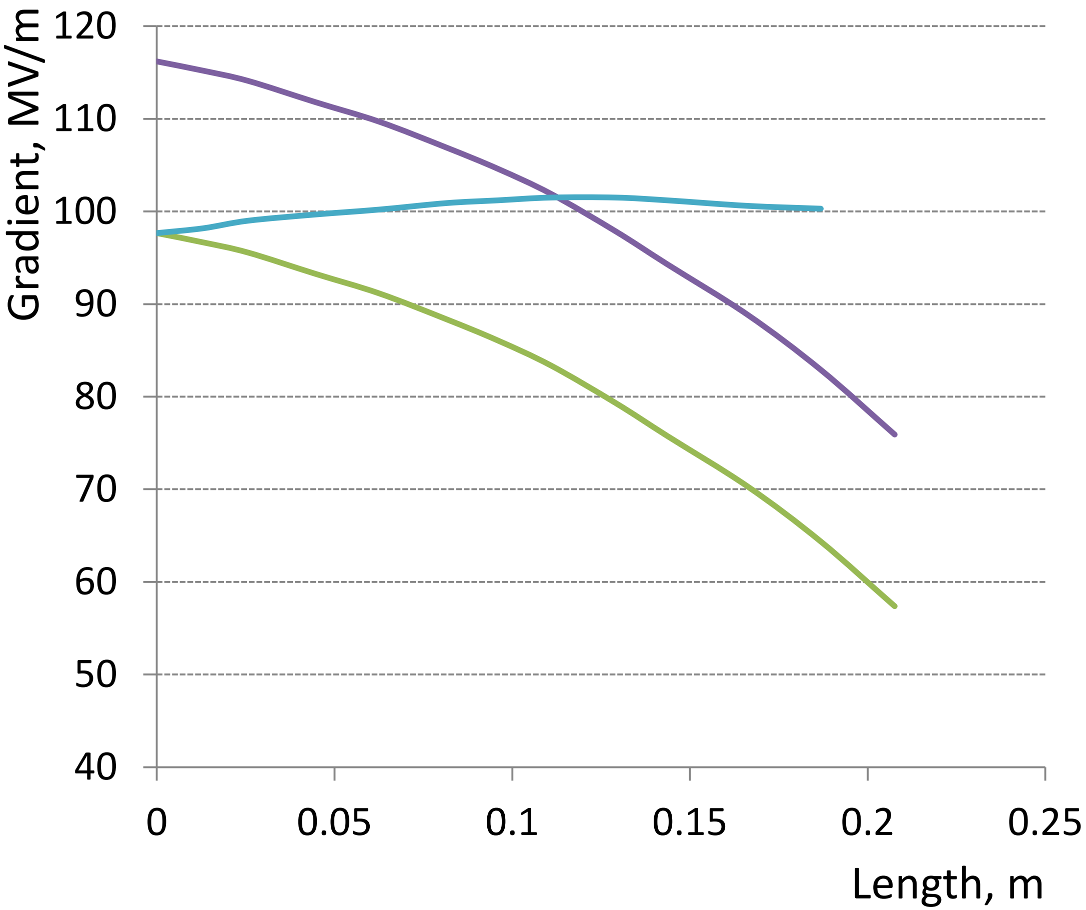
Ongoing measurements



Next measurement at ~85 MV/m loaded (ongoing during this week)

Further actions

Main goal: Measure breakdown rate for nominal CLIC parameters.



Other measurements:

- Cell distribution
- Loading levels (RF phase)
- Current dependencies
- Different structures
- …

Summary

- ✓ **Breakdown rate** measurements **in heavy loaded** high gradient structures was a **missing block** in the high gradient program
- ✓ **CTF3/CLIC** collaboration has **successfully set up an experiment** to measure the effect of beam loading at nominal CLIC gradients
- ✓ The experiment **has started collecting data** from end of September
- ✓ After one week of data preliminary analysis shows that the **beam presence does not have a harmful effect on the breakdown rate at constant input power**
- ✓ The experiment will **continue collecting data** to probe different power and loading levels
- ✓ **More detailed analysis will be done** to draw further conclusions

We are ready for new exciting results !!!

Aknowledgements

RF/PM	CTF3	XBOX	BI
M. Filippova	R. Corsini	S. Curt	M. Kastriotou
A. Grudiev	S. Doebert	A. Degiovanni	E. Nebot
D. Gudkov	D. Gamba	J. Giner	
P. Guyard	J.L. Navarro	G. McMonagle	
A. Olyunin	T. Persson	S. Rey	
A. Samochkine	P. Skowronski	J. Tagg	
I. Syratchev	F. Tecker	L. Timeo	
A. Solodko		B. Woolley	
P. De Souza			

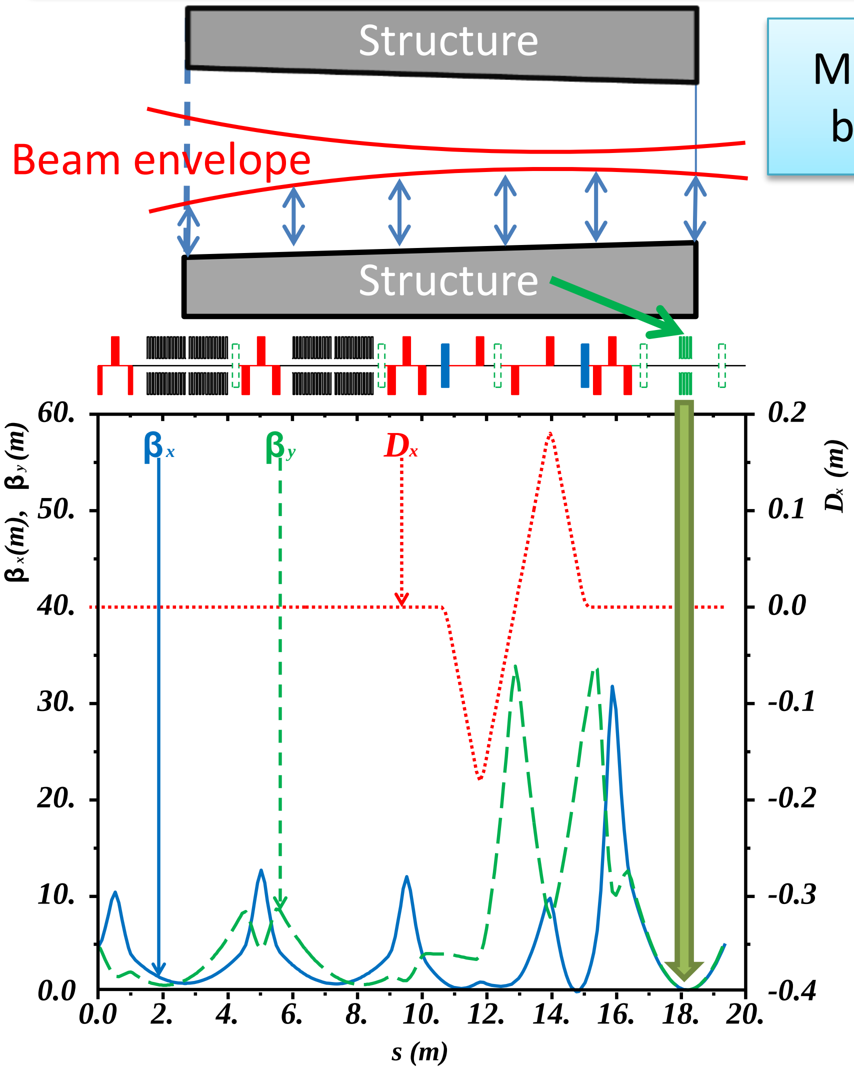
J.L. Navarro for the
CLIC/CTF3 Collaboration

Backup: CLIC Nominal parameters

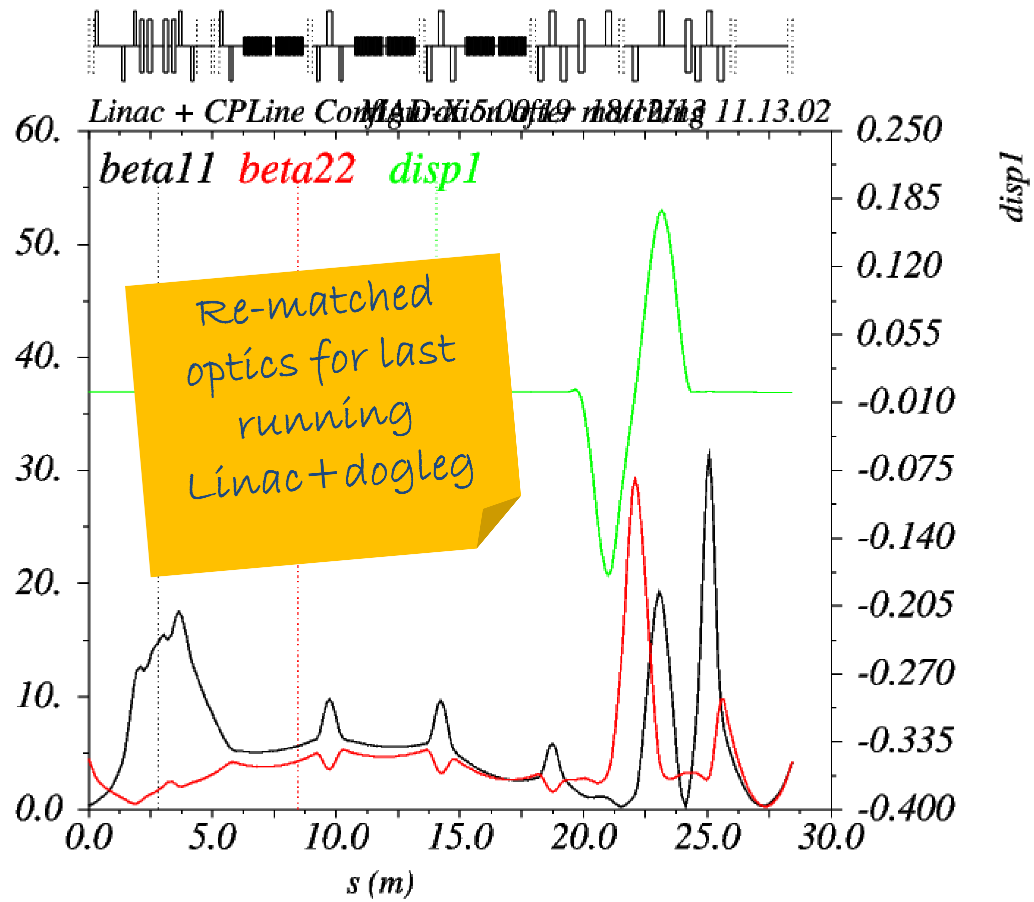
Average loaded accelerating gradient	100 MV/m
Frequency	12 GHz
RF phase advance per cell	$2\pi/3$ rad
Average iris radius to wavelength ratio	0.11
Input, output iris radii	3.15, 2.35 mm
Input, output iris thickness	1.67, 1.00 mm
Input, output group velocity	1.65, 0.83% of c
First and last cell Q-factor (Cu)	5536, 5738
First and last cell shunt impedance	81, 103 MΩ/m
Number of regular cells	26
Structure length including couplers	230 mm (active)
Bunch spacing	0.5 ns
Bunch population	3.72×10^9
Number of bunches in the train	312
Filling time, rise time	67 ns, 21 ns
Total pulse length	244 ns
Peak input power	61.3 MW
RF-to-beam efficiency	28,5 %
Maximum surface electric field	230 MV/m
Maximum pulsed surface heating temperature rise	45 K

Optics design

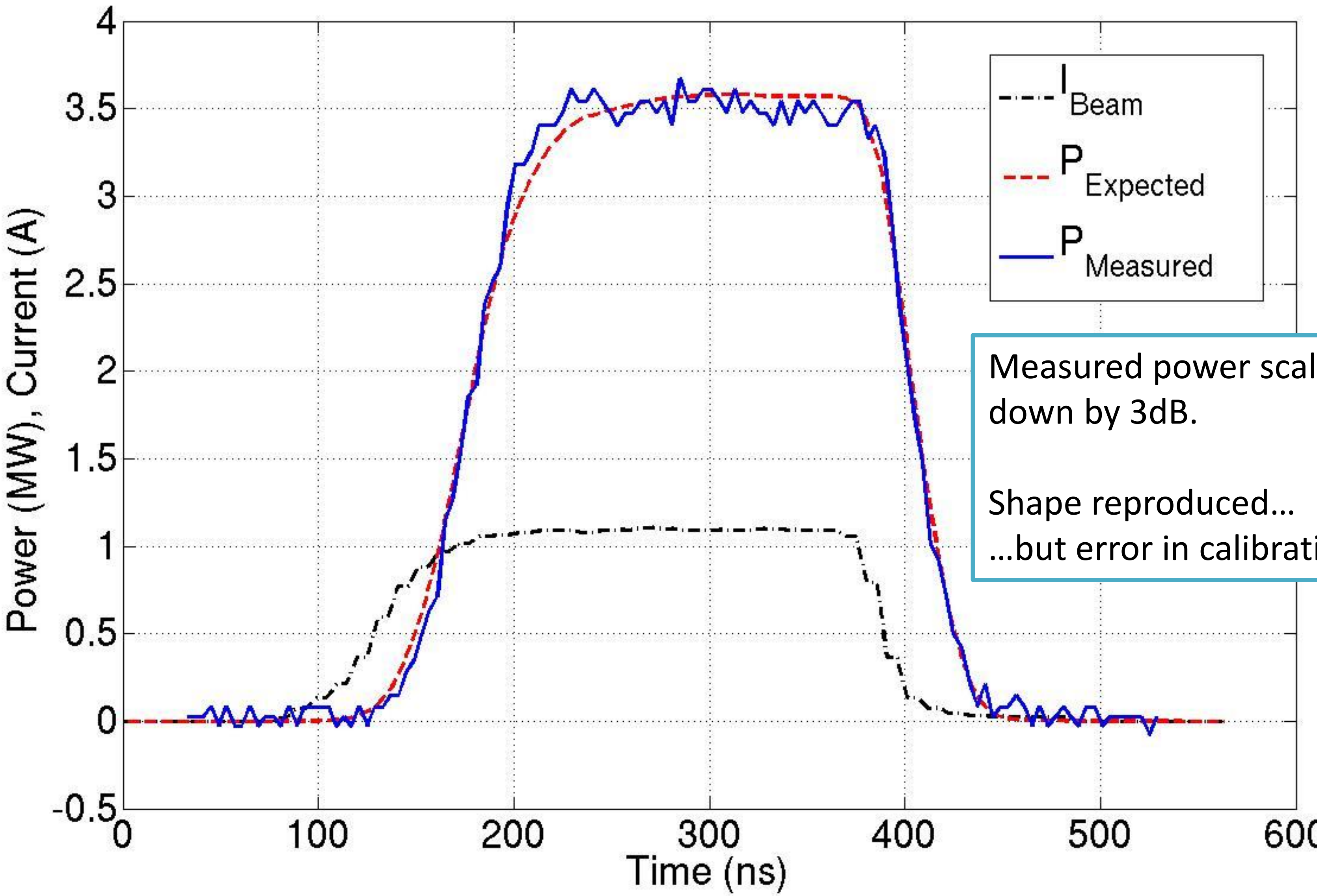
Objective: Transport the beam trough the Linac up to the structure requiring…
- Full transmission efficiency
- Minimum beam size on average inside the structure



Maximize relative distances between aperture and beam size (M. Dayyani). MAD model by F. Tecker.



Phase I Results: Running of May 2013

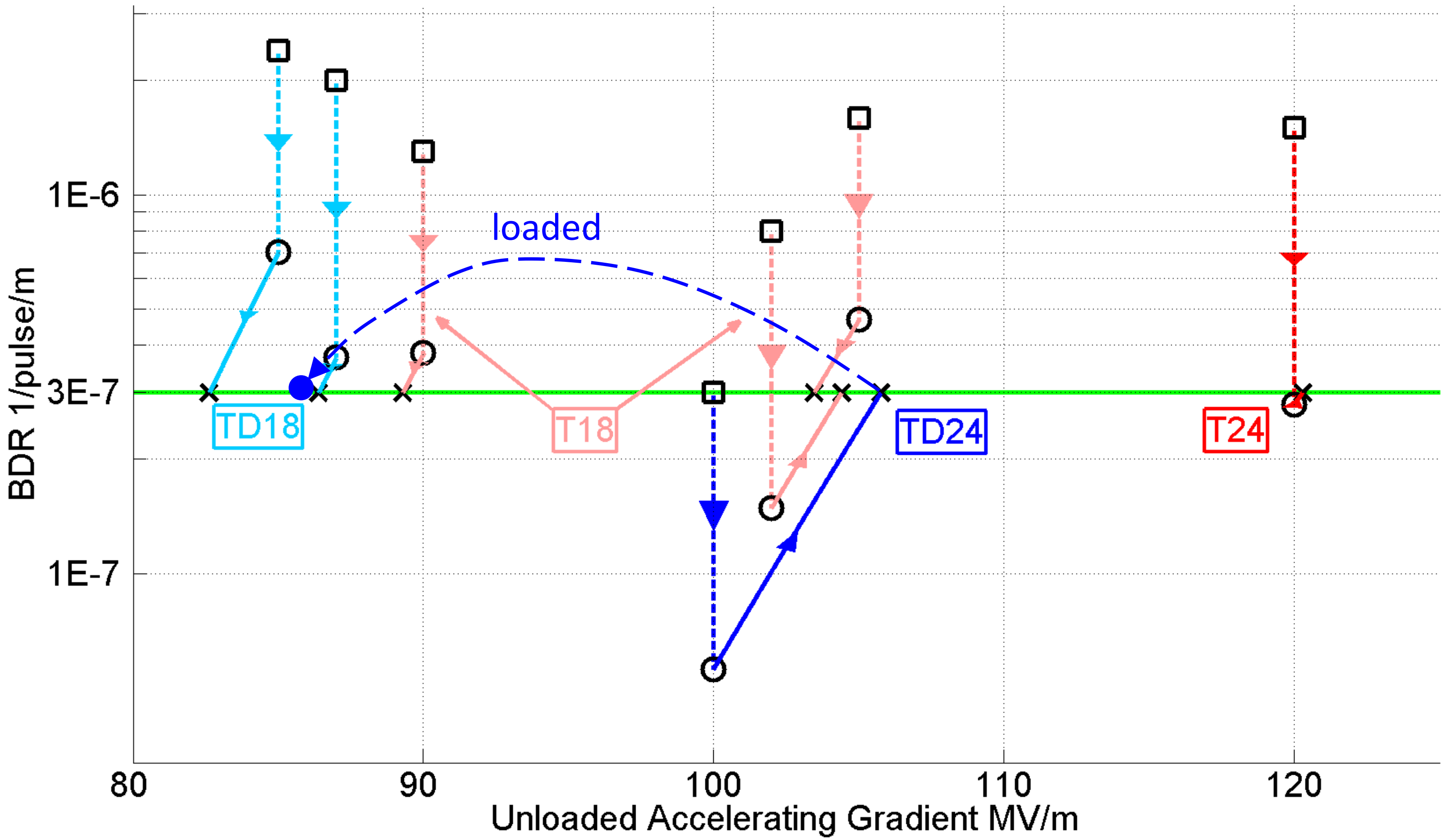


Measured power scaled down by 3dB.

Shape reproduced…
…but error in calibration

Backup

Accelerating gradients achieved in tests.
Status: 4-9-2012



Backup (I. Syrachev. CLIC Workshop 2013)

Structure under test:

CERN's T24 (12WNDSvg1.8 KEK N1)

No damping

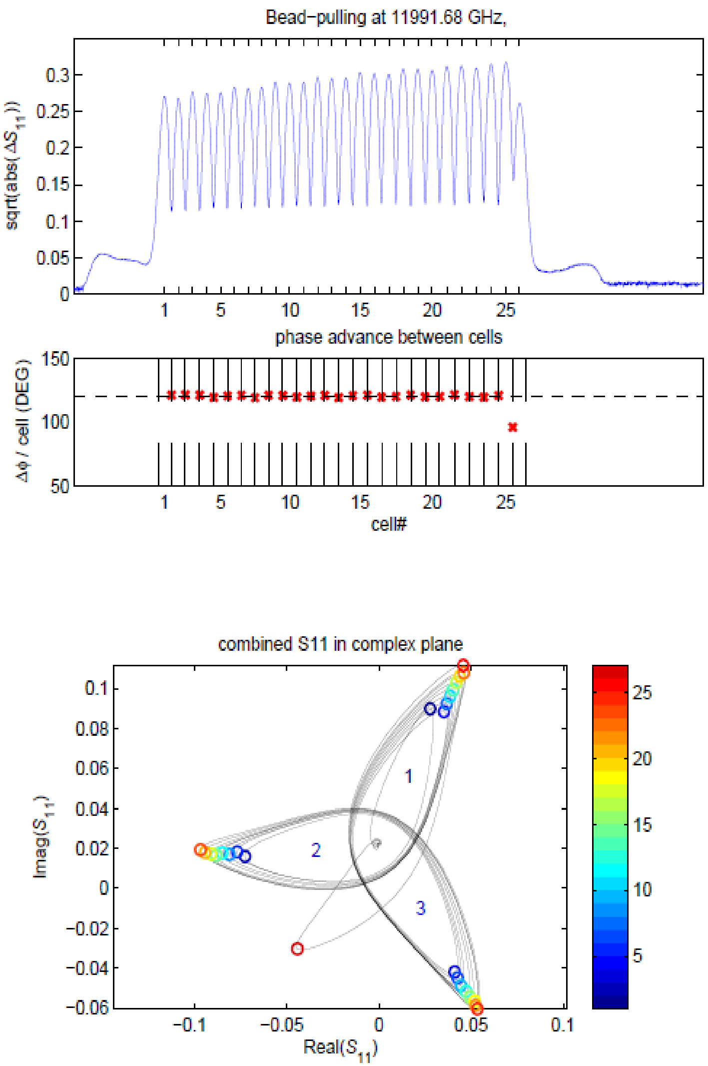


Figure 10: Bead-pulling at 11991.68 GHz

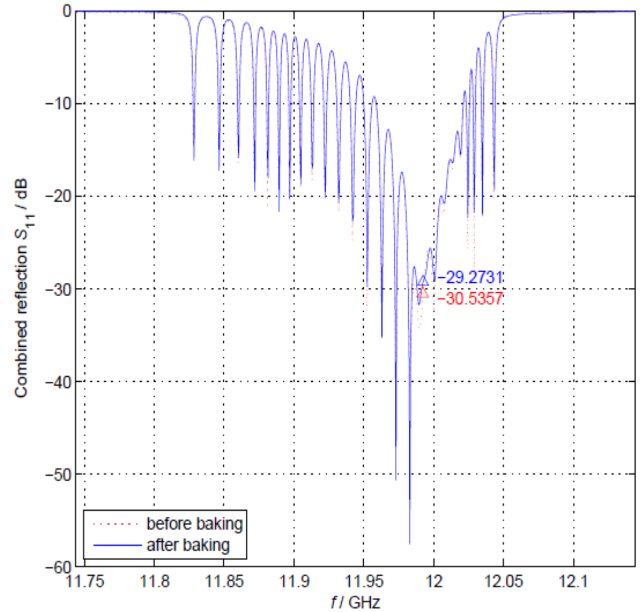


Figure 1: Reflection at input

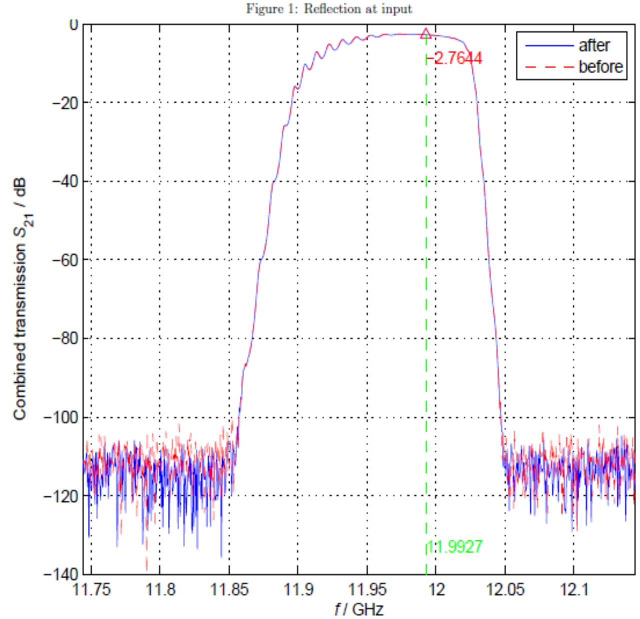
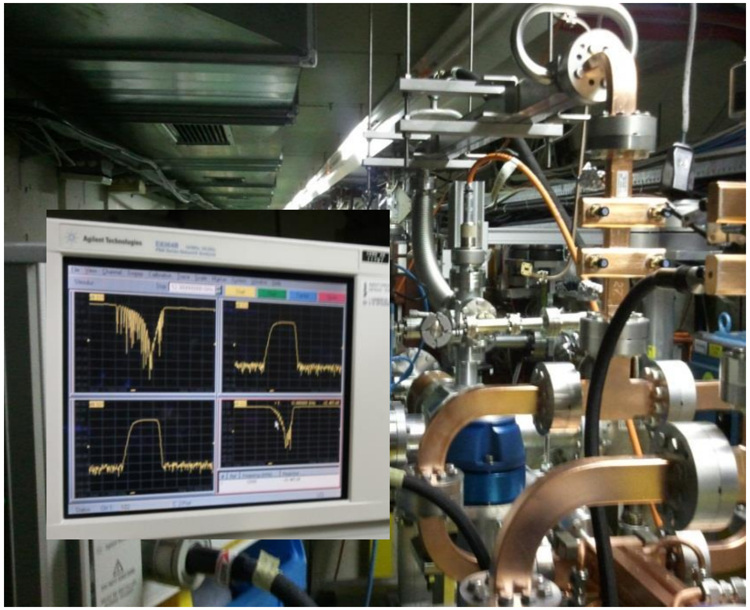
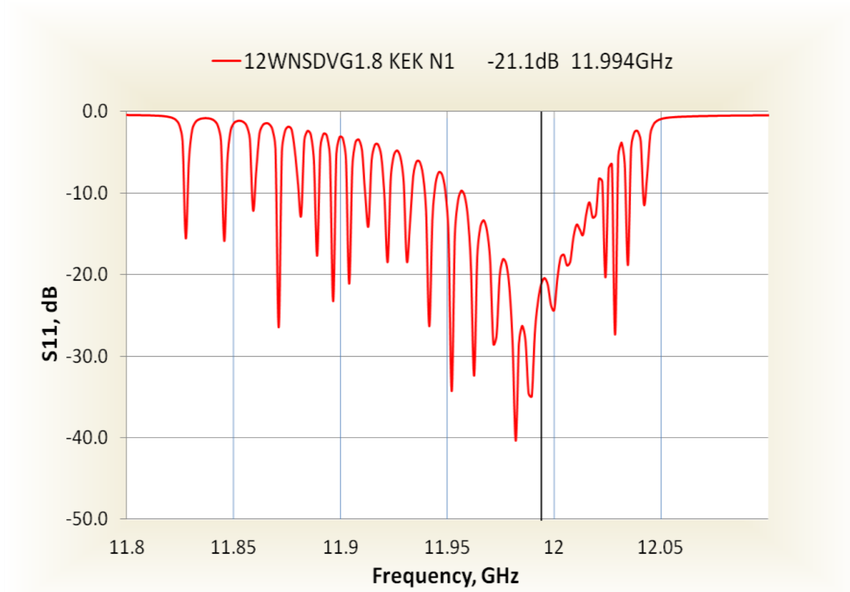
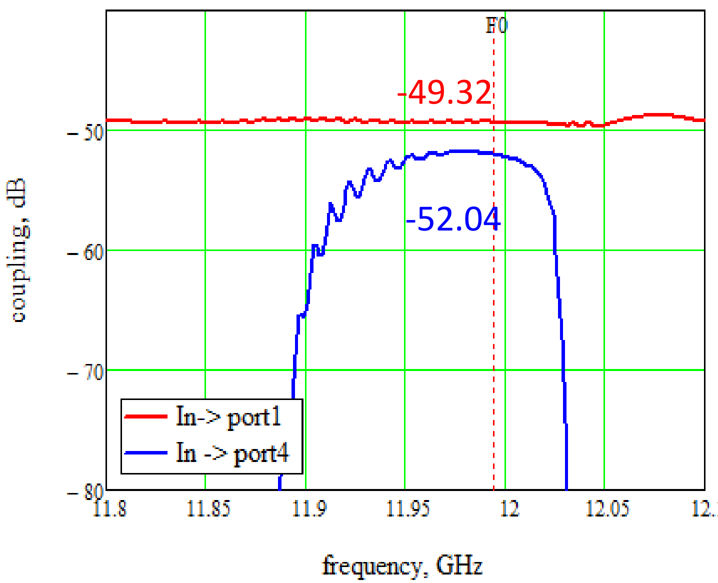


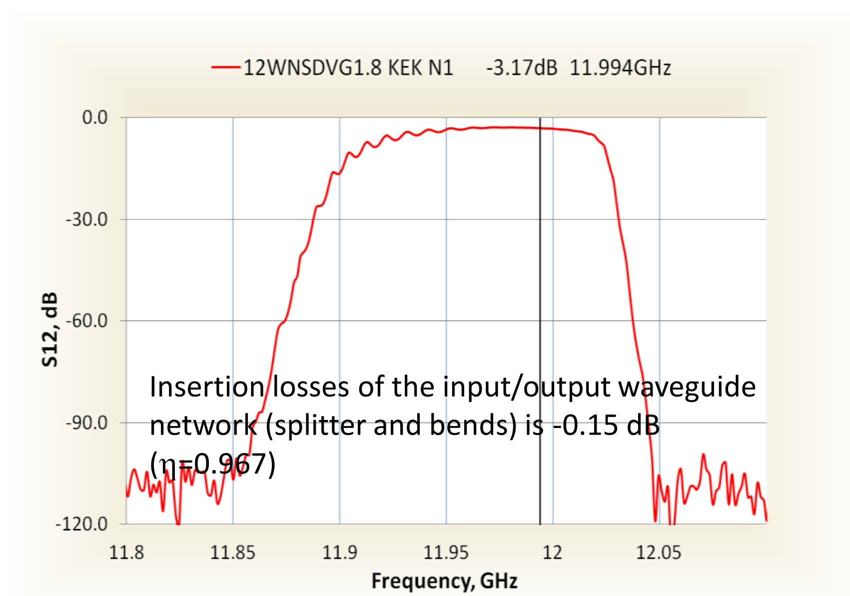
Figure 5: Combined transmission from input to output

Calibration (I. Syrachev. CLIC Workshop 2013)

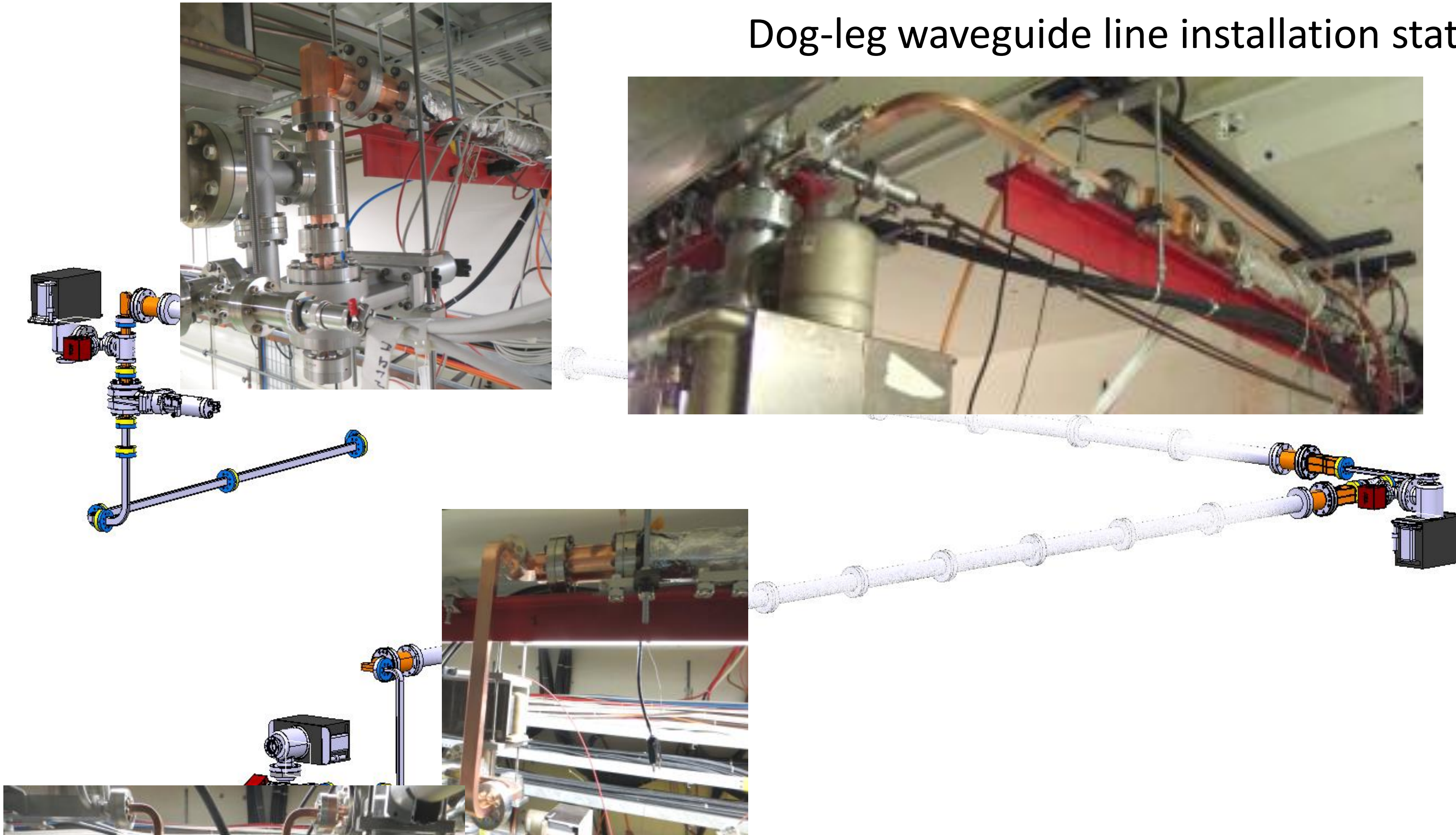


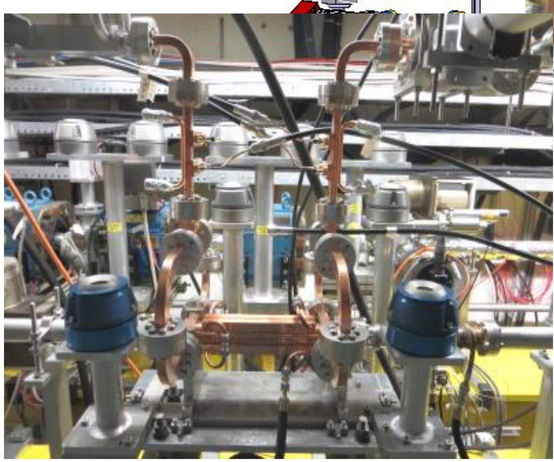






Dog-leg waveguide line installation status.



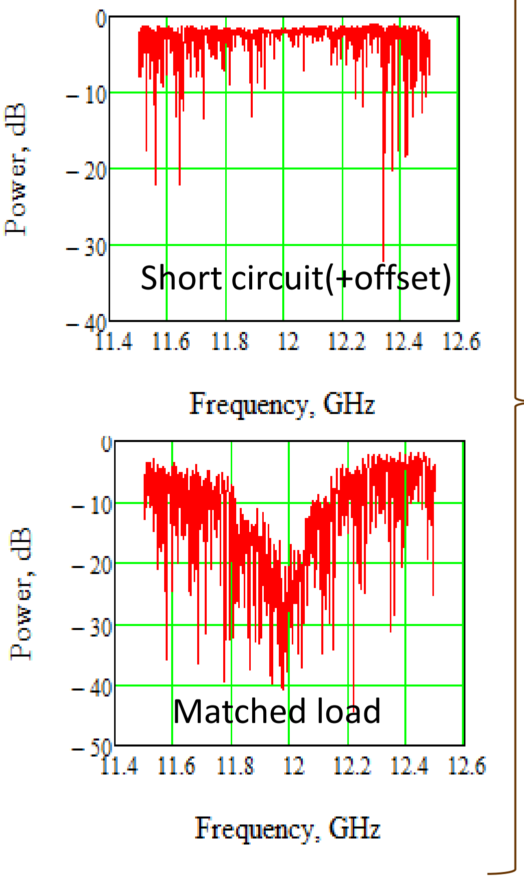


- ✓ All the components are installed.
- ✓ Connected to accelerated structure and closed for vacuu
- ✓ Vacuum leaks checked (tight).

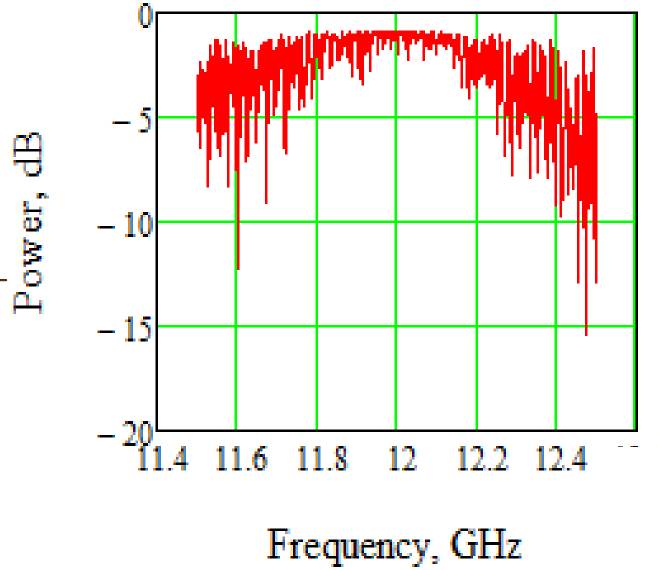
Ready to be connected to XBOX1

RF power transmission measurements

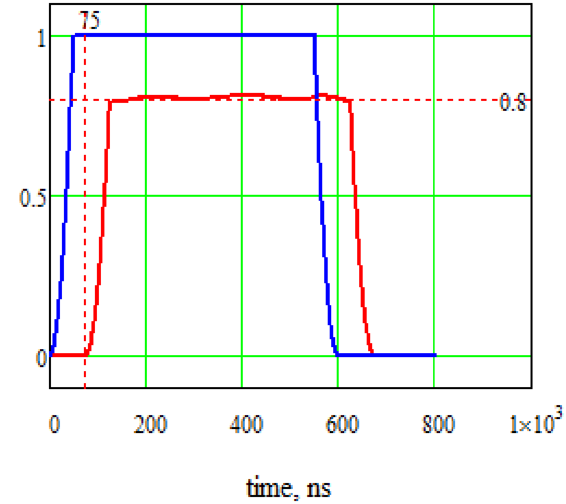
S11 data



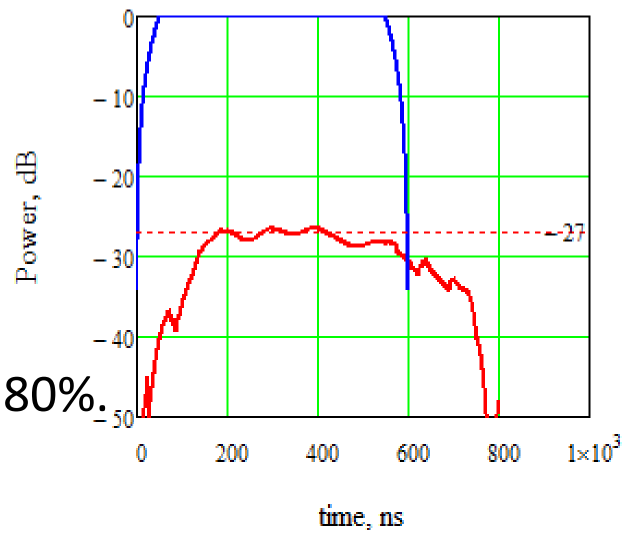
S21 Reconstructed
(Xiaowei Wu)



Transmission (simulated)



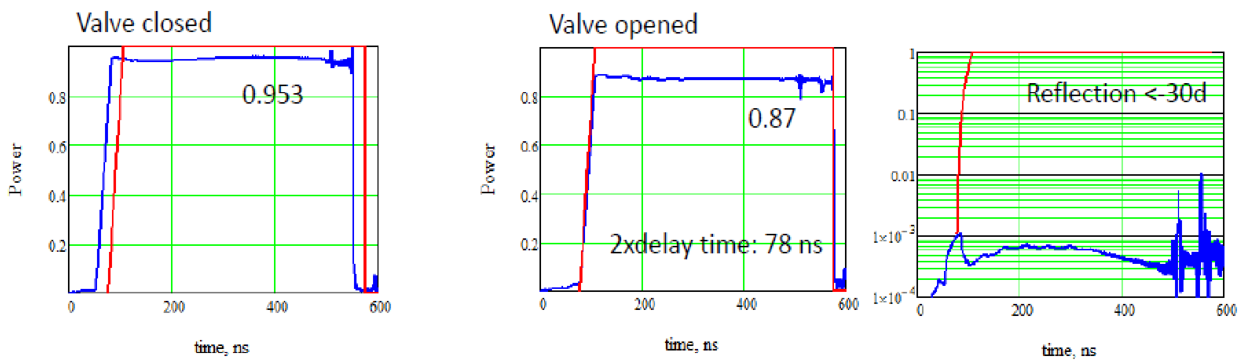
Reflection

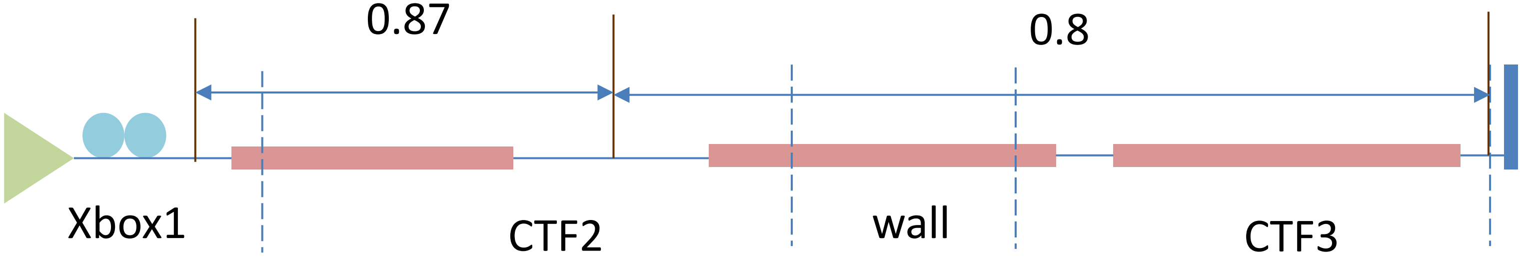


- The measured RF power transmission efficiency is 80%.
- Reflection is below -27dB.
- The group delay time is 75 ns (~23.5 m).

Overall power transmission efficiency

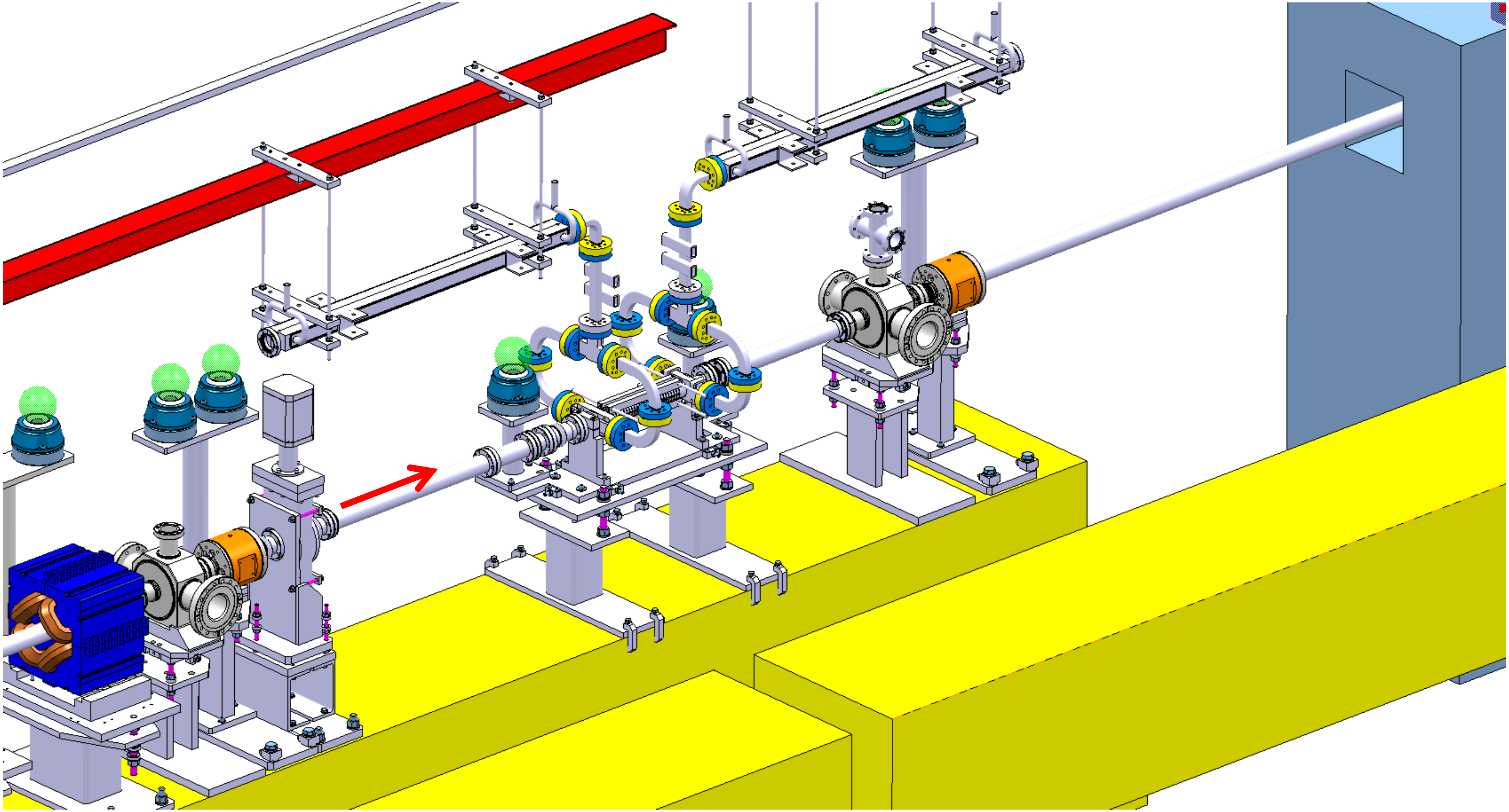
One way loses in the WG line. From just after PC to the -3dB hybrid in CTF#2



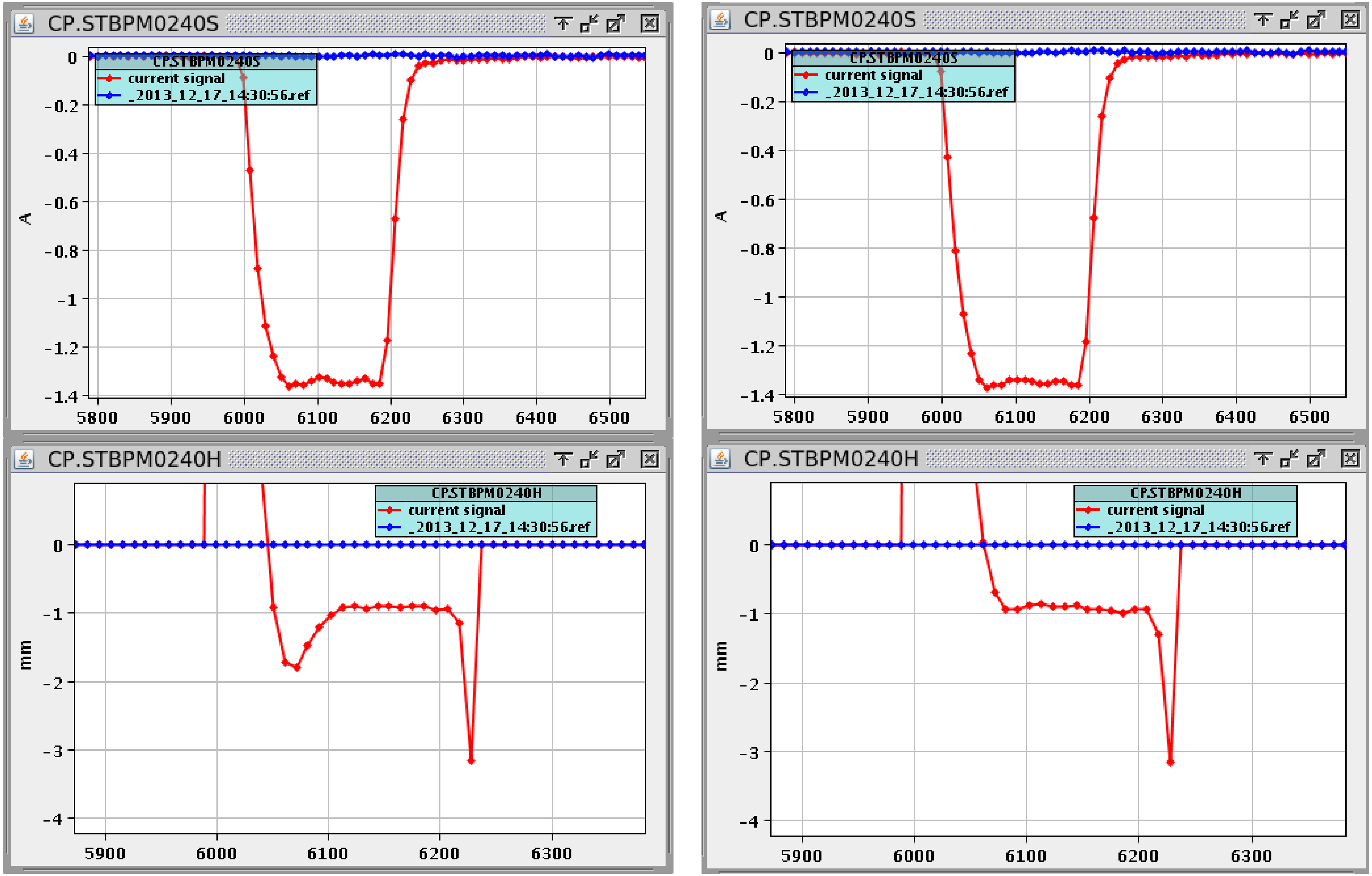


- The overall measured RF power transmission efficiency is 67%.
- The round group delay time is 230 ns (~35 m).
- To provide nominal CLIC RF pulse, XBOX1 klystrons needs to deliver 36 MW x 1.5

Backup



Backup


CP.STBPM0240S
CP.STBPM0240S
current signal
_2013_12_17_14:30:56.ref
A
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
5800
5900
6000
6100
6200
6300
6400
6500
CP.STBPM0240H
CP.STBPM0240H
current signal
_2013_12_17_14:30:56.ref
mm
0
-1
-2
-3
-4
5900
6000
6100
6200
6300

Phase I Results: Running of Dec 2013

And from the RF side: