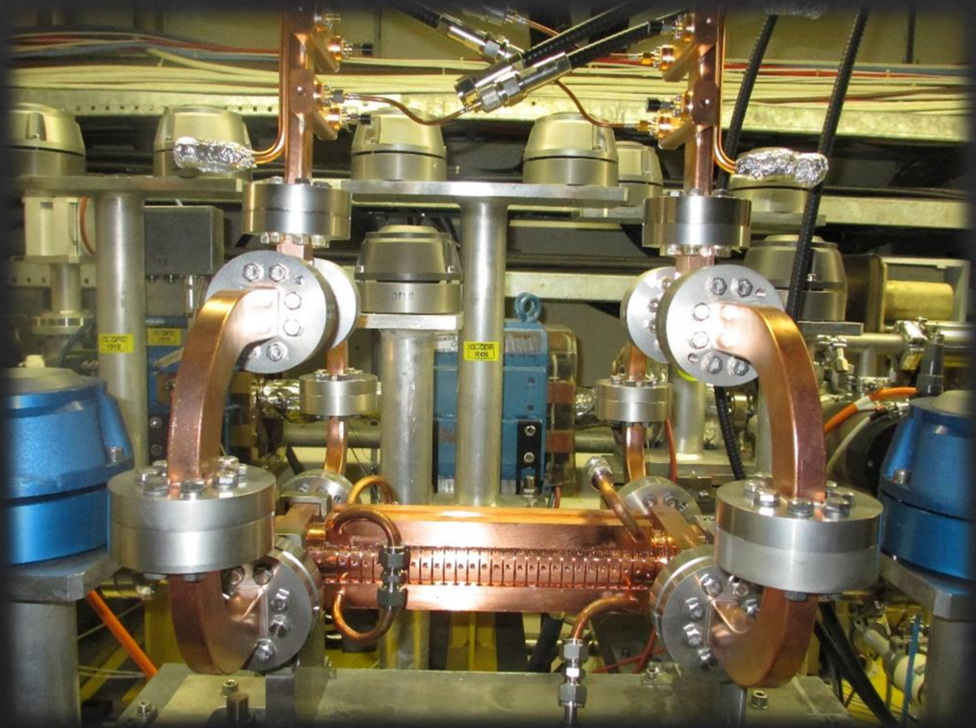
Beam-Loading Studies



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

Outline

- The breakdown problem
- The Dogleg experiment layout
- First Results
- Next steps
- Conclusions

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.

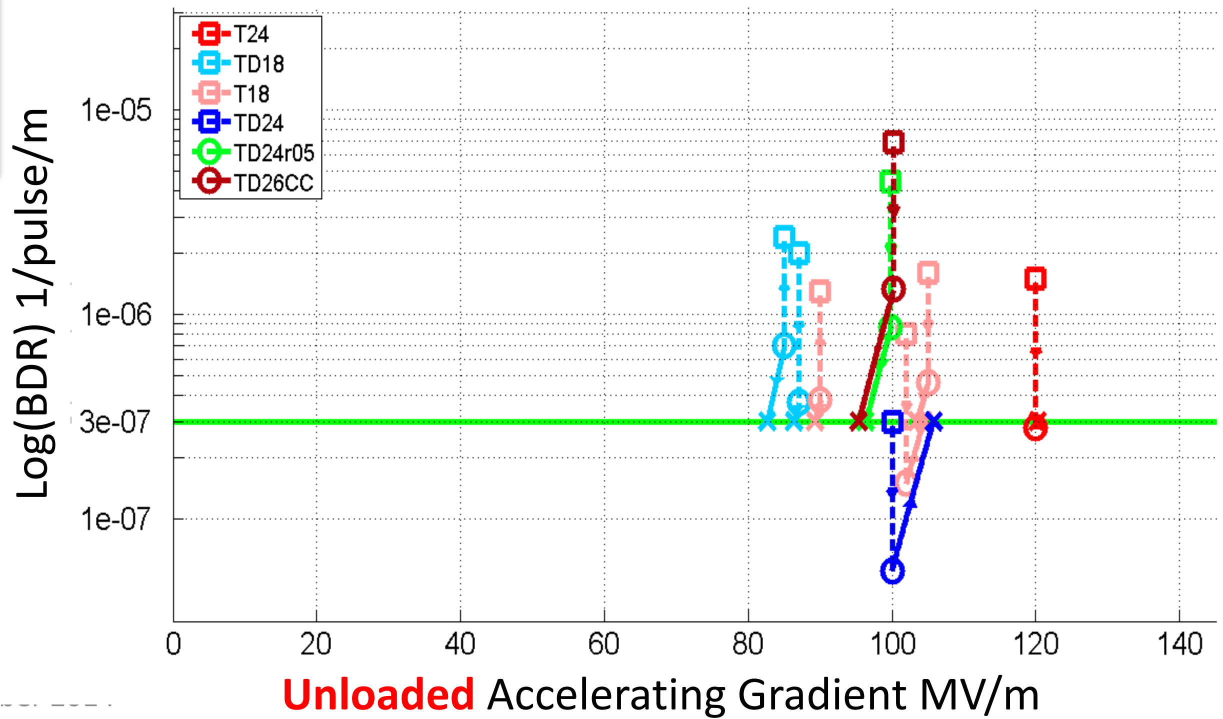
Undesired effects:

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

Luminosity Reduction:

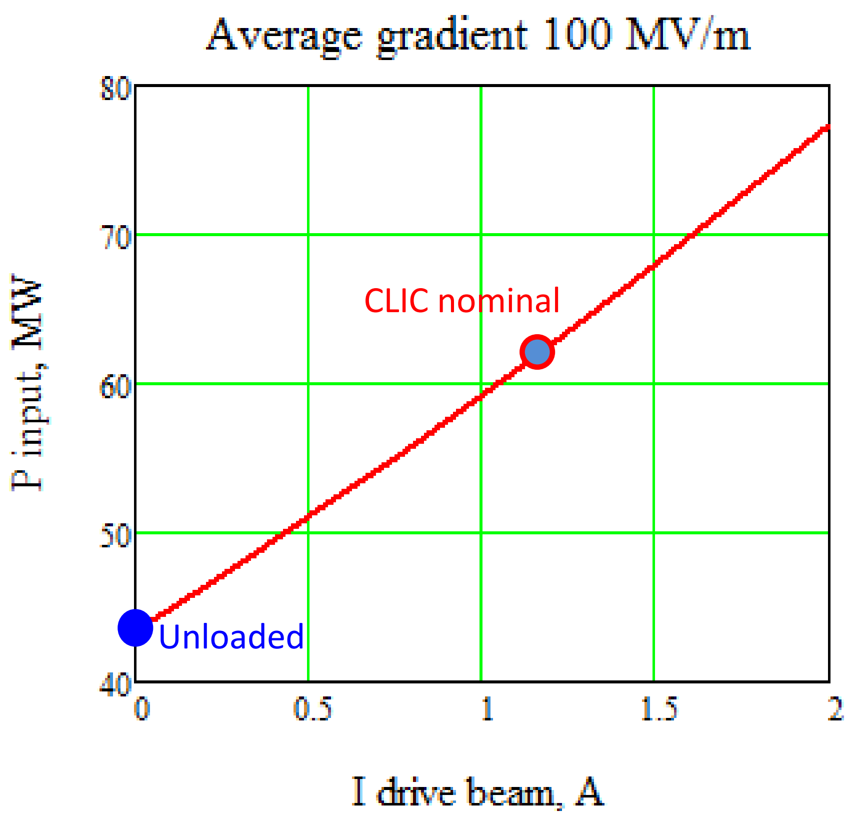
Max DB rate allow for CLIC specifications:

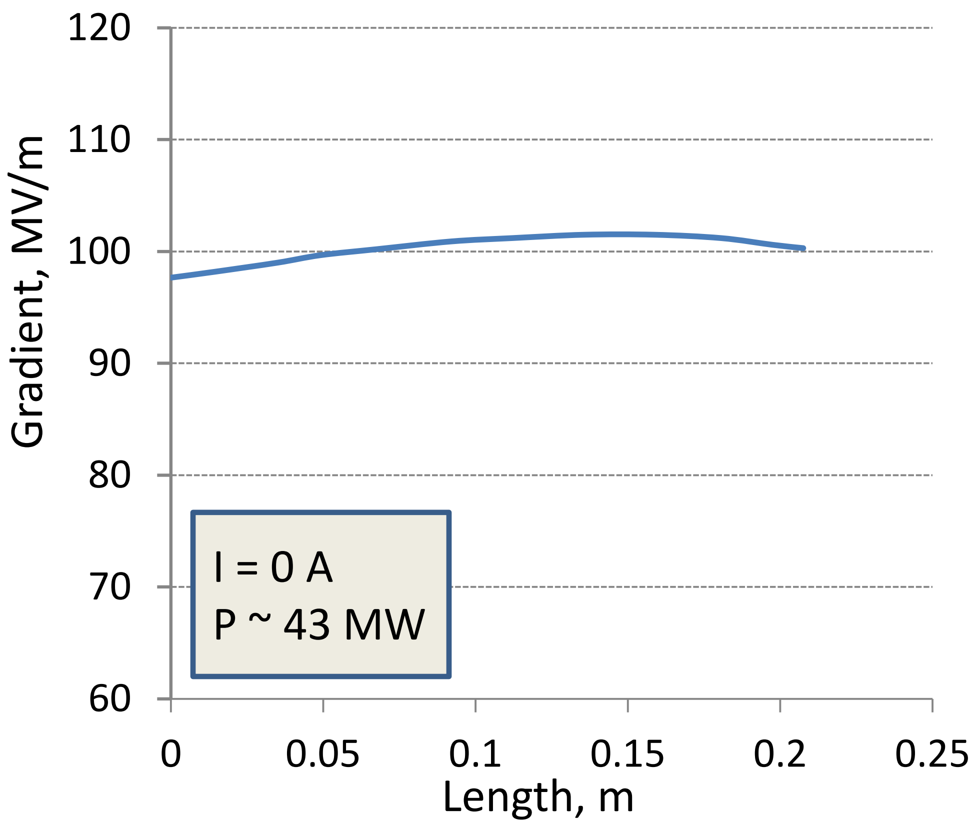
$3\ 10^{-7}$ BD $pulse^{-1}\ m^{-1}$



Beam loading effect

Beam Loading modifies the gradient distribution along the structure



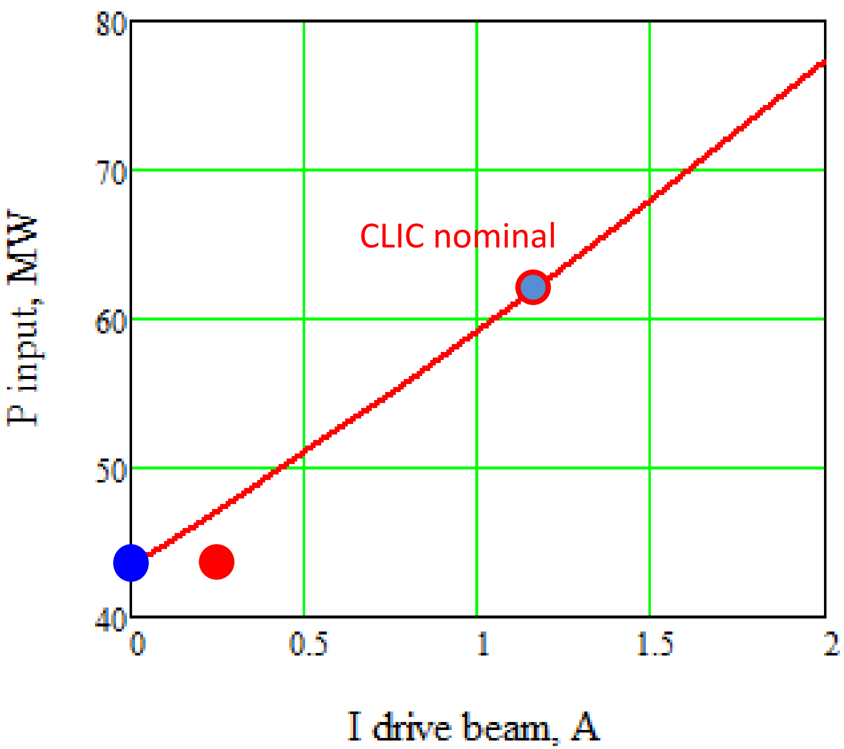


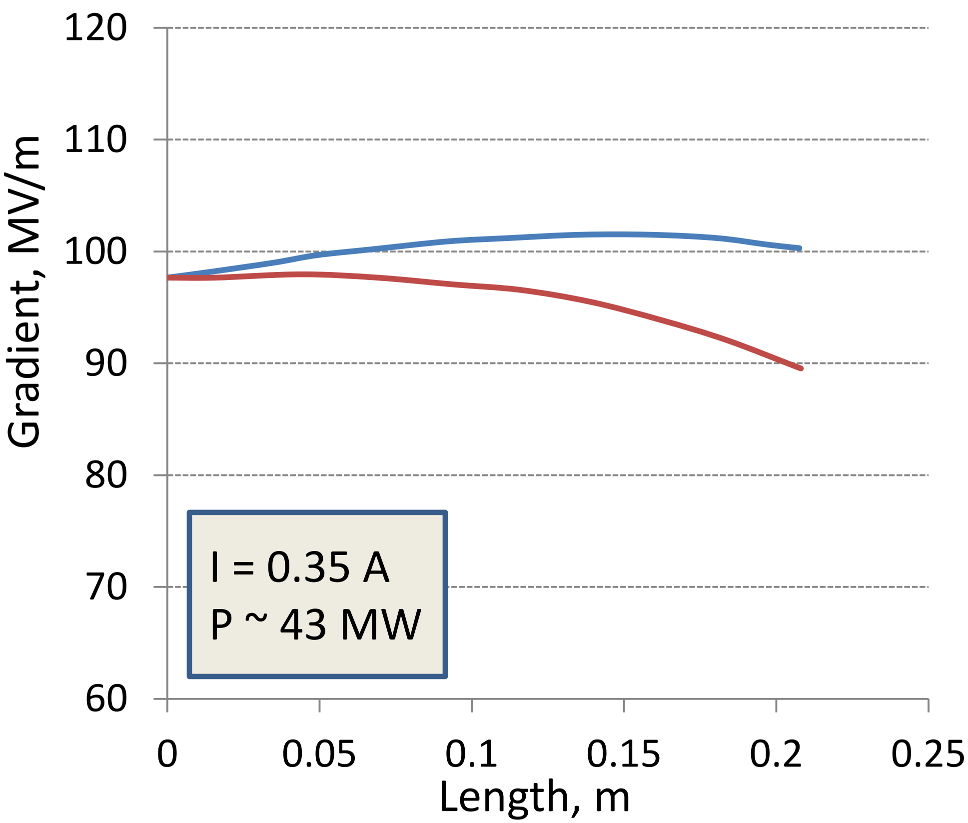
Gradient profile along the structure without beam loading

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

Average gradient 100 MV/m

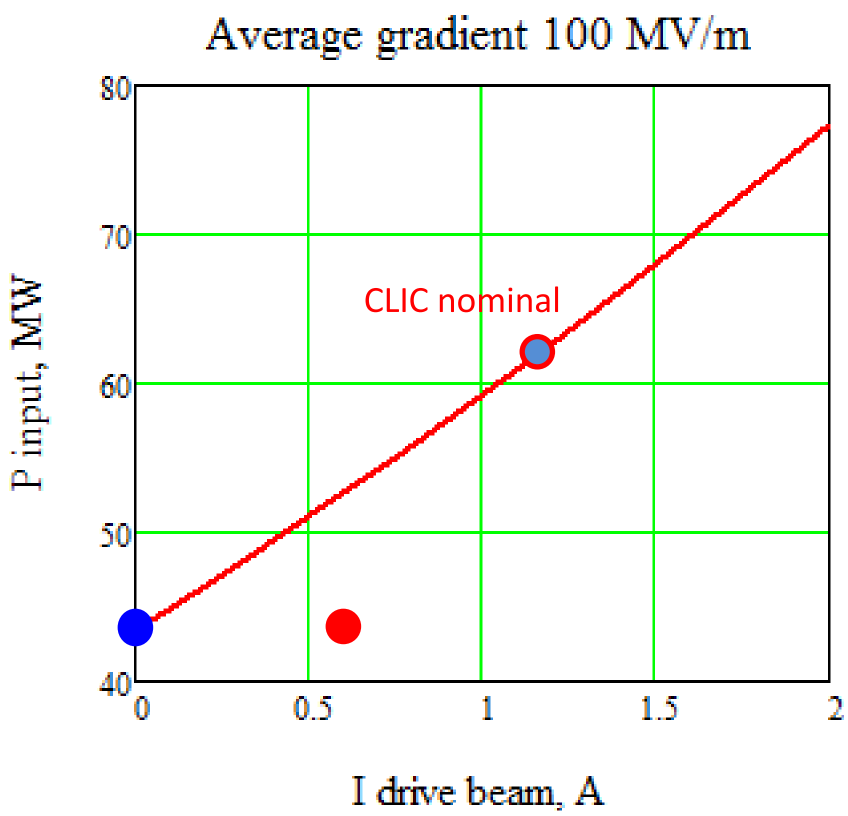


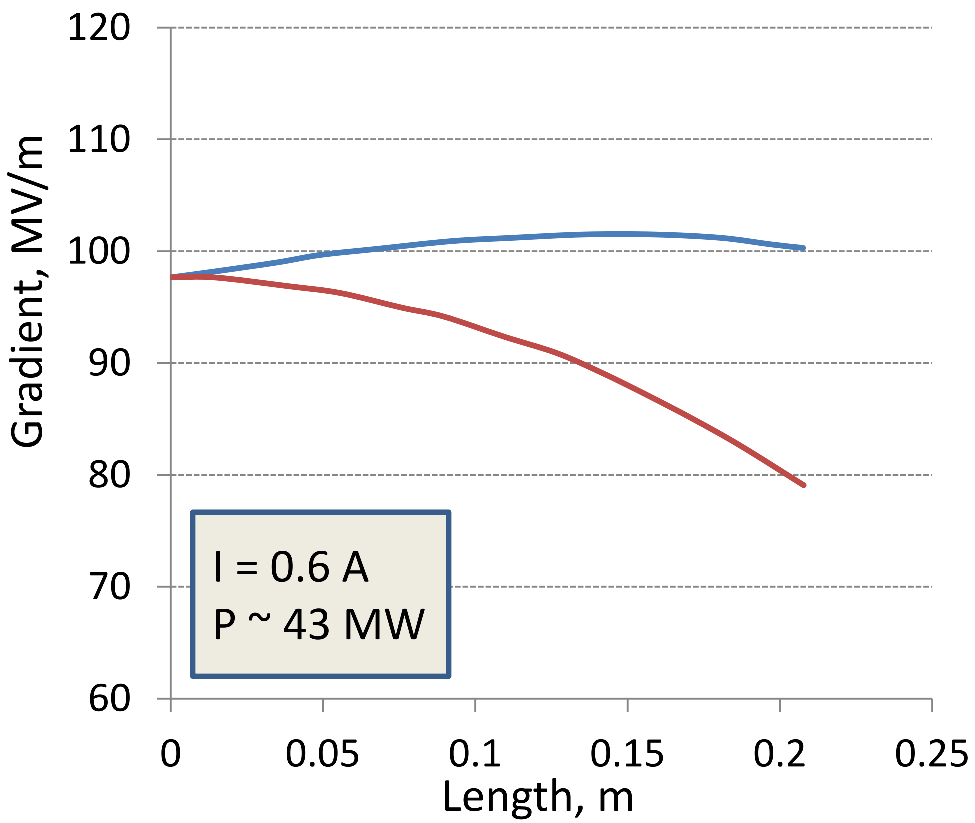


The beam loading modifies the gradient profile

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

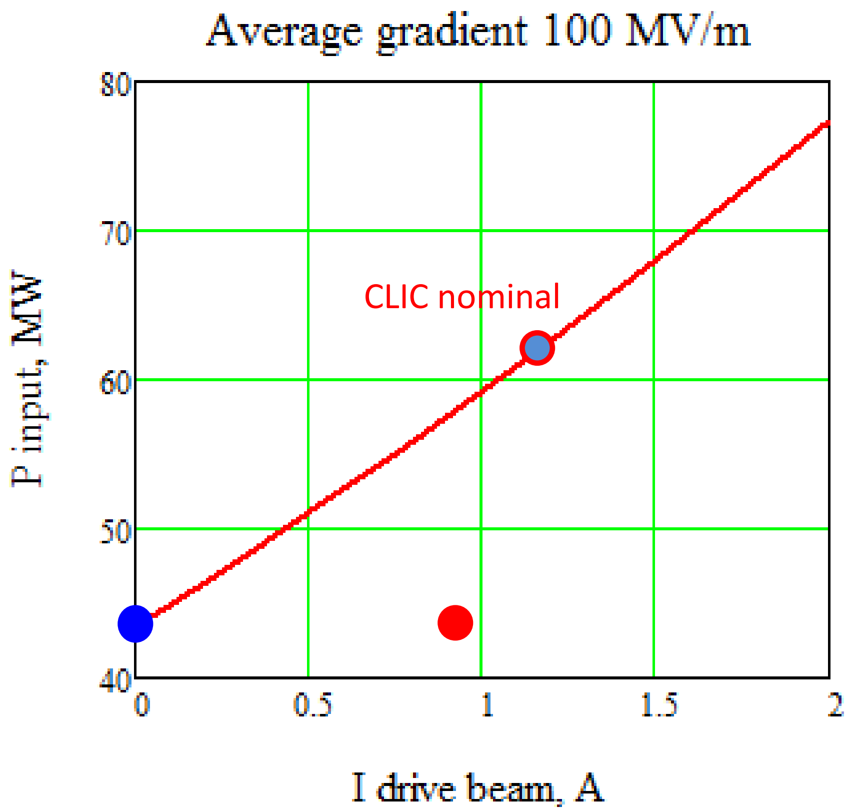


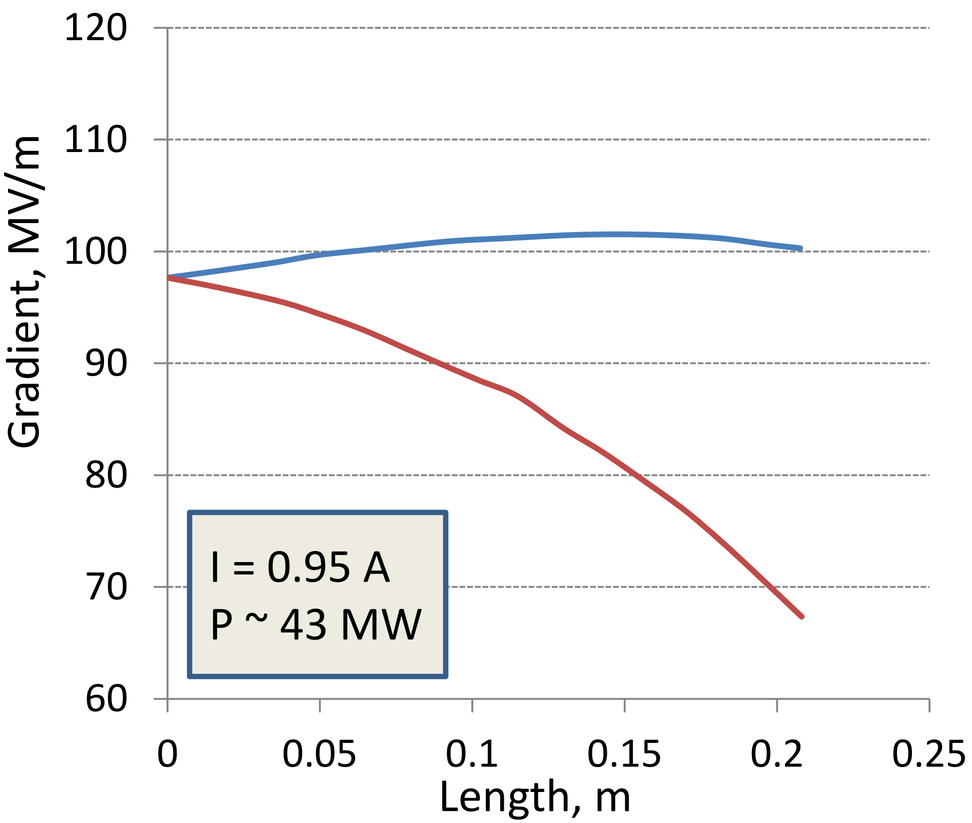


The beam loading modifies the gradient profile

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

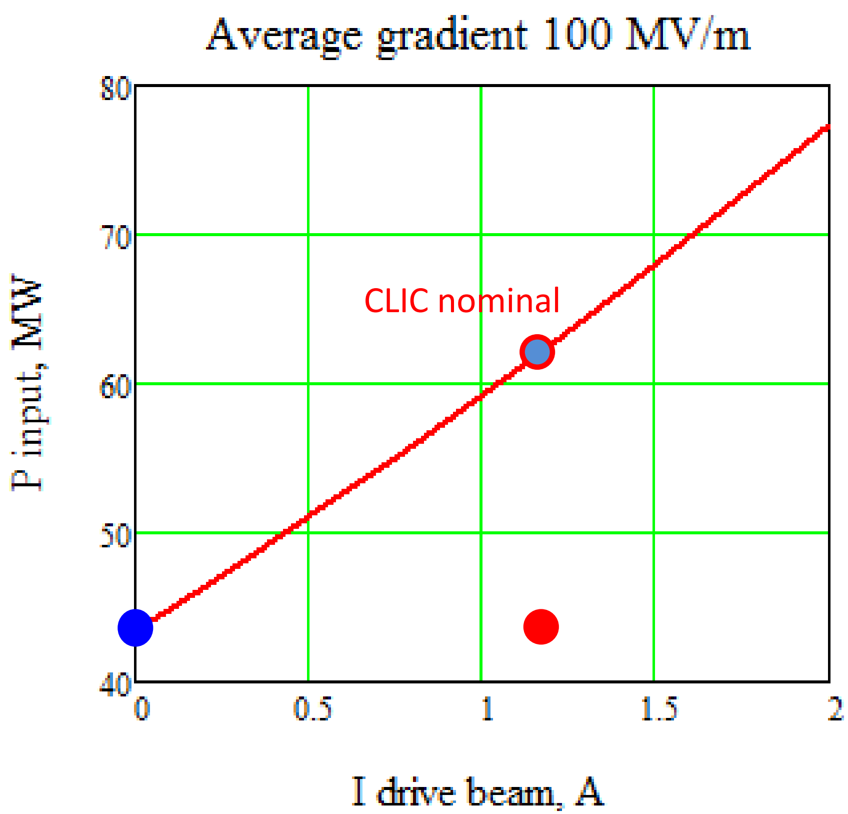


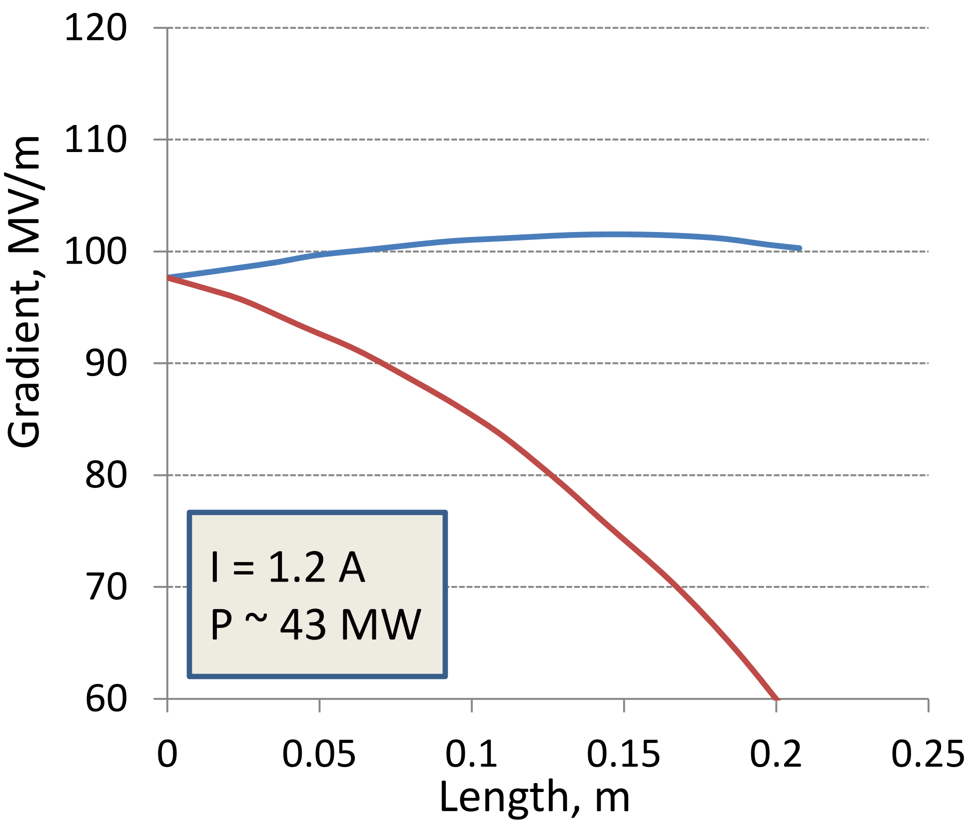


The beam loading modifies the gradient profile

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

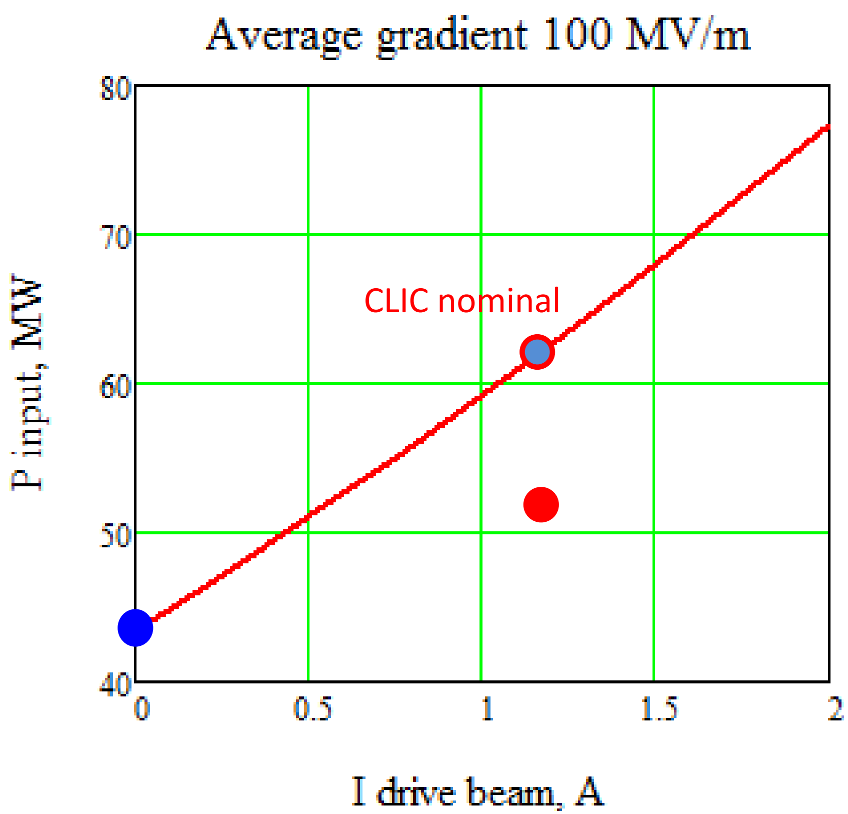


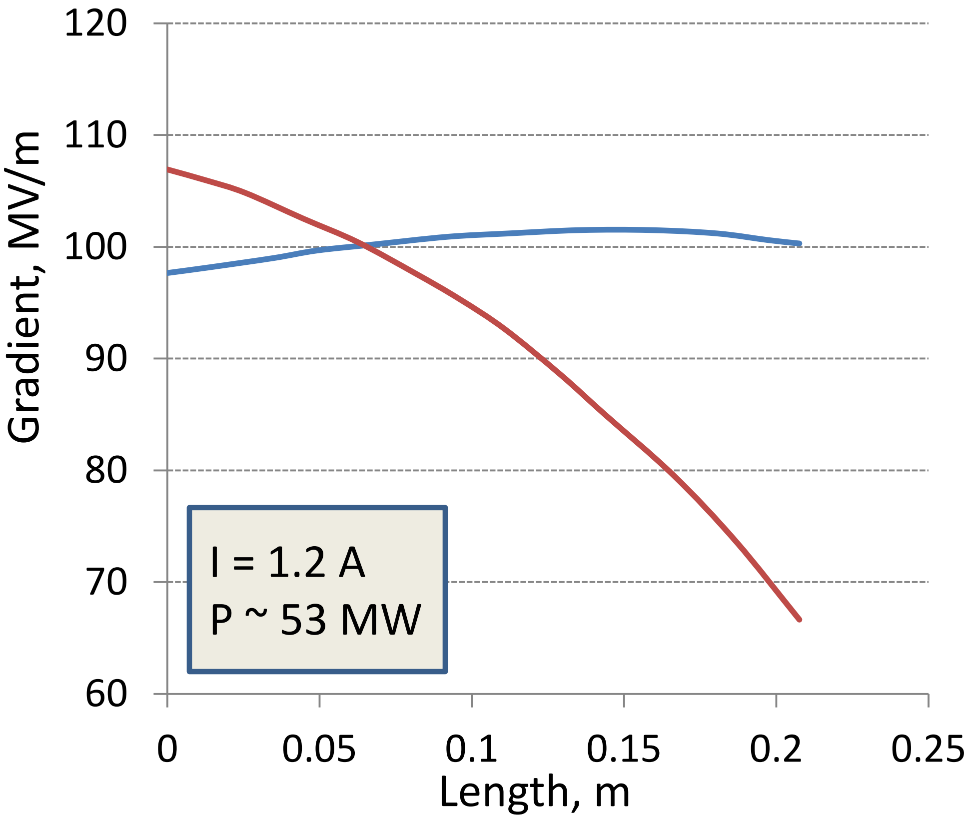


We do not have anymore 100 MV/m in average.

Beam loading effect

Beam Loading modifies the gradient distribution along the structure



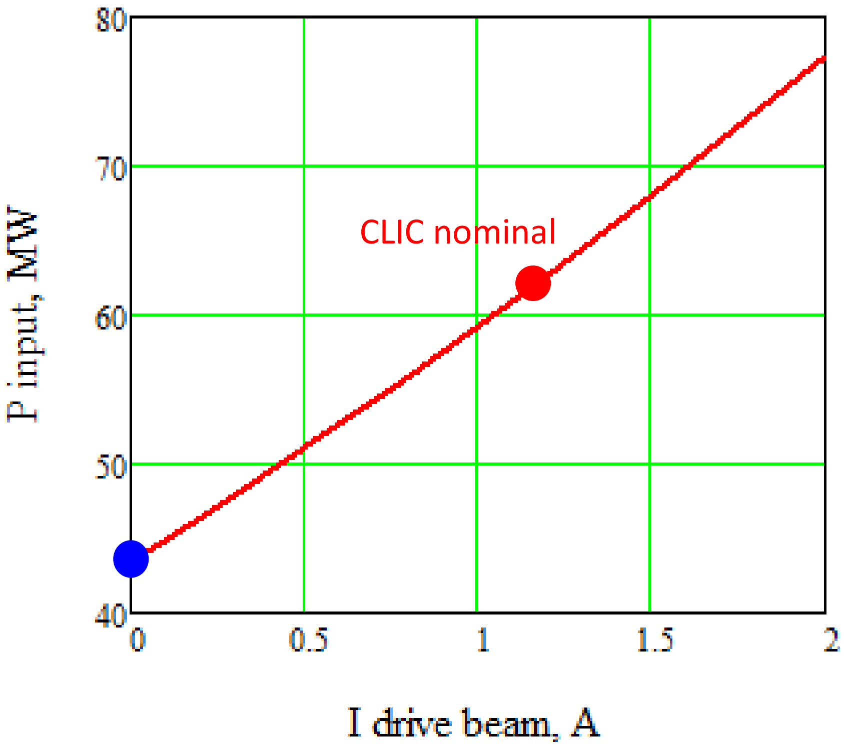


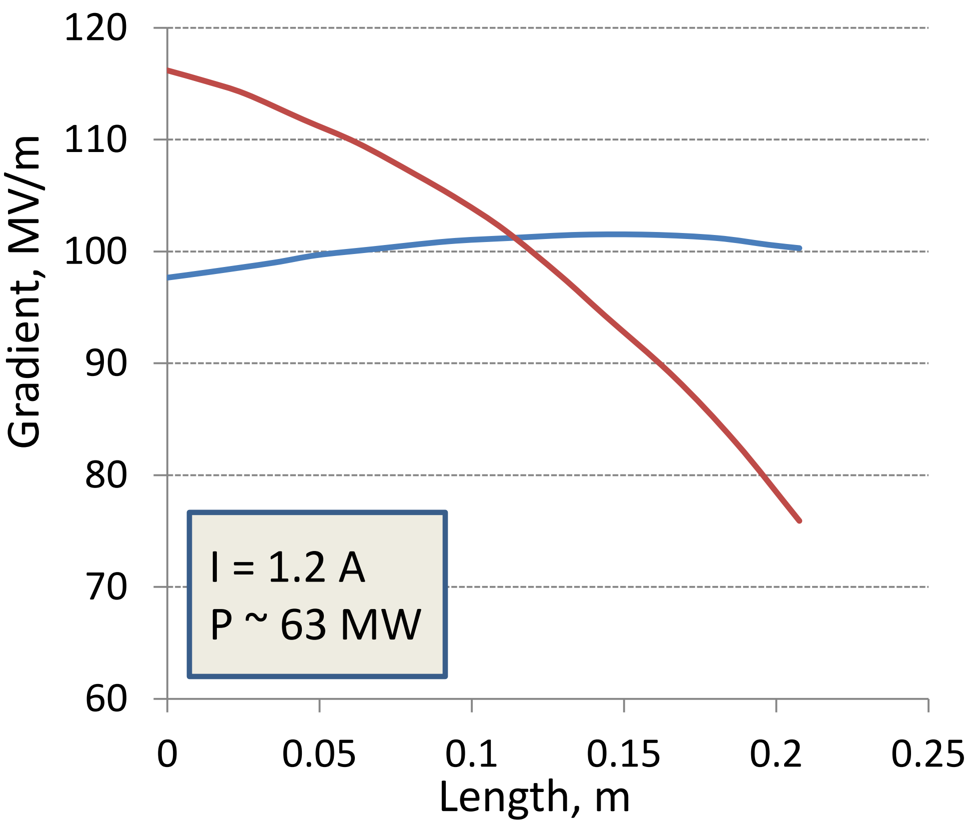
We compensate increasing the RF input power

Beam loading effect

Beam Loading modifies the gradient distribution along the structure

Average gradient 100 MV/m



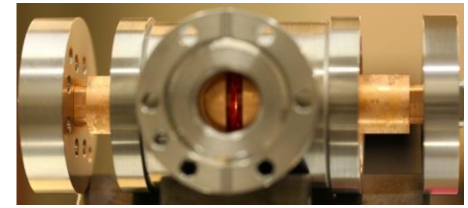


What is the effect on BD rate?

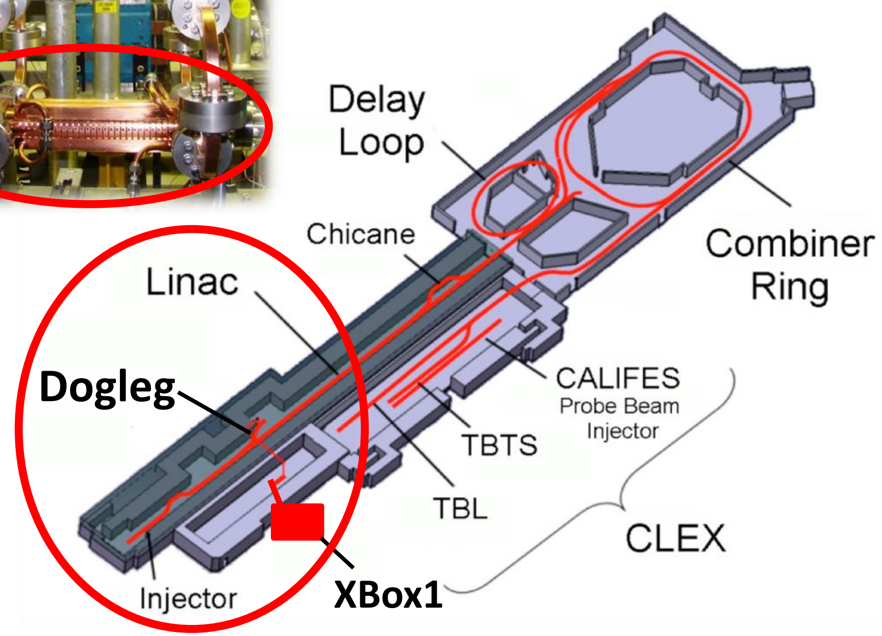
Experiment Mounting Instructions

1x

?x



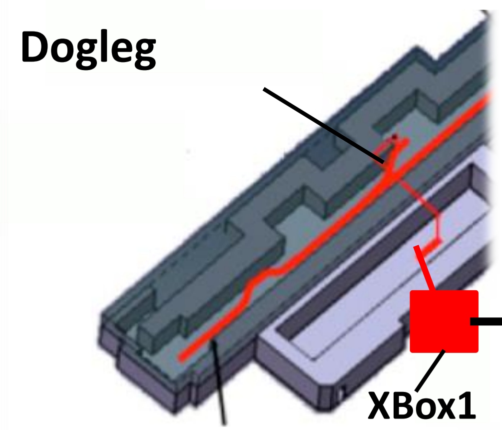
1x



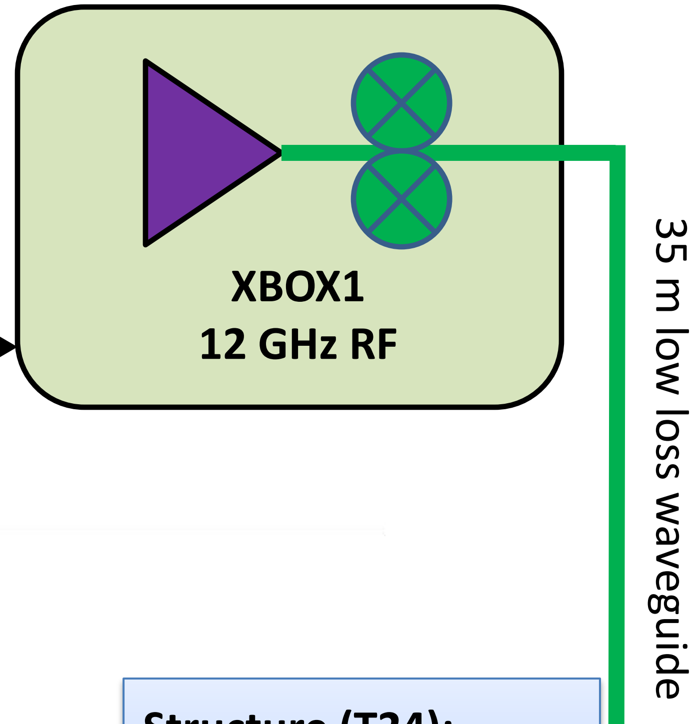
?x

1x

Experiment layout

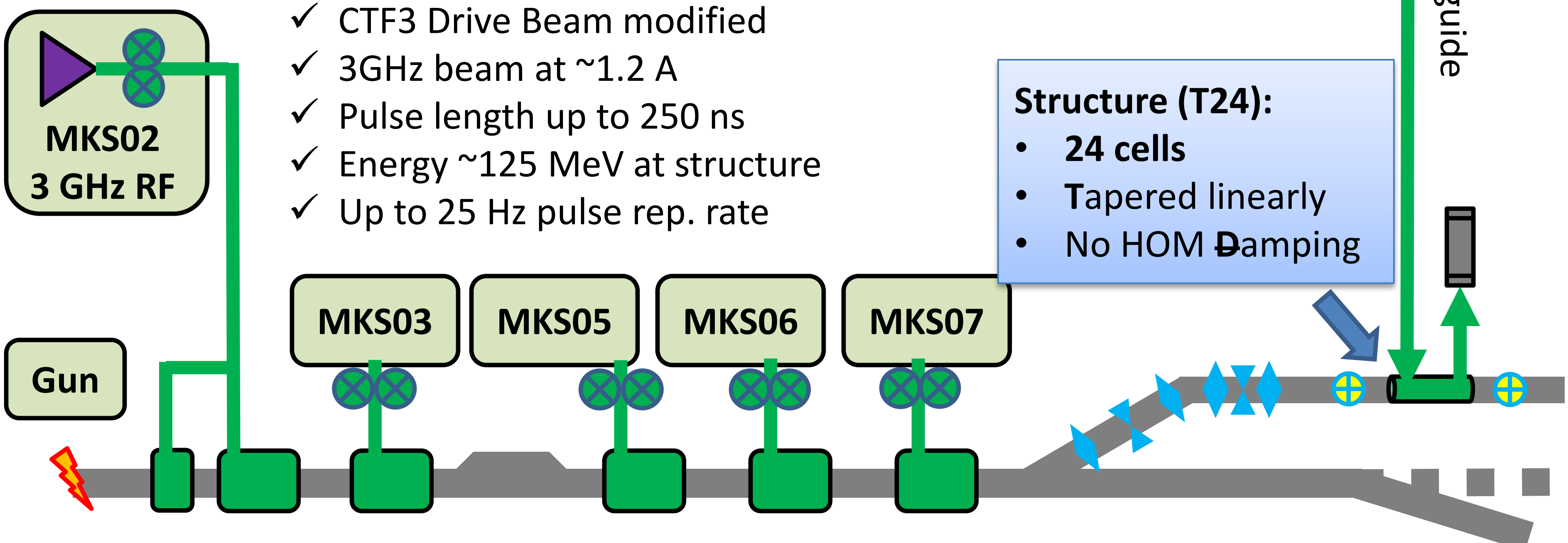


12 GHz RF:
- ✓ 90 MW RF power
- ✓ Up to 50 Hz rep. rate

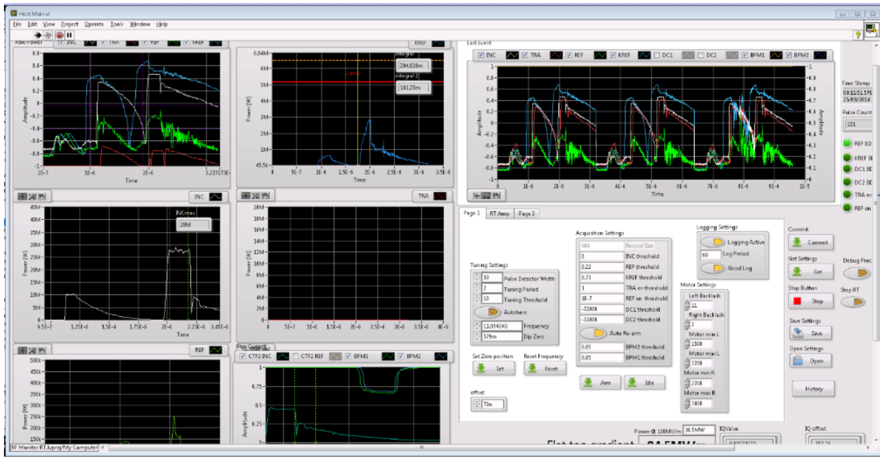


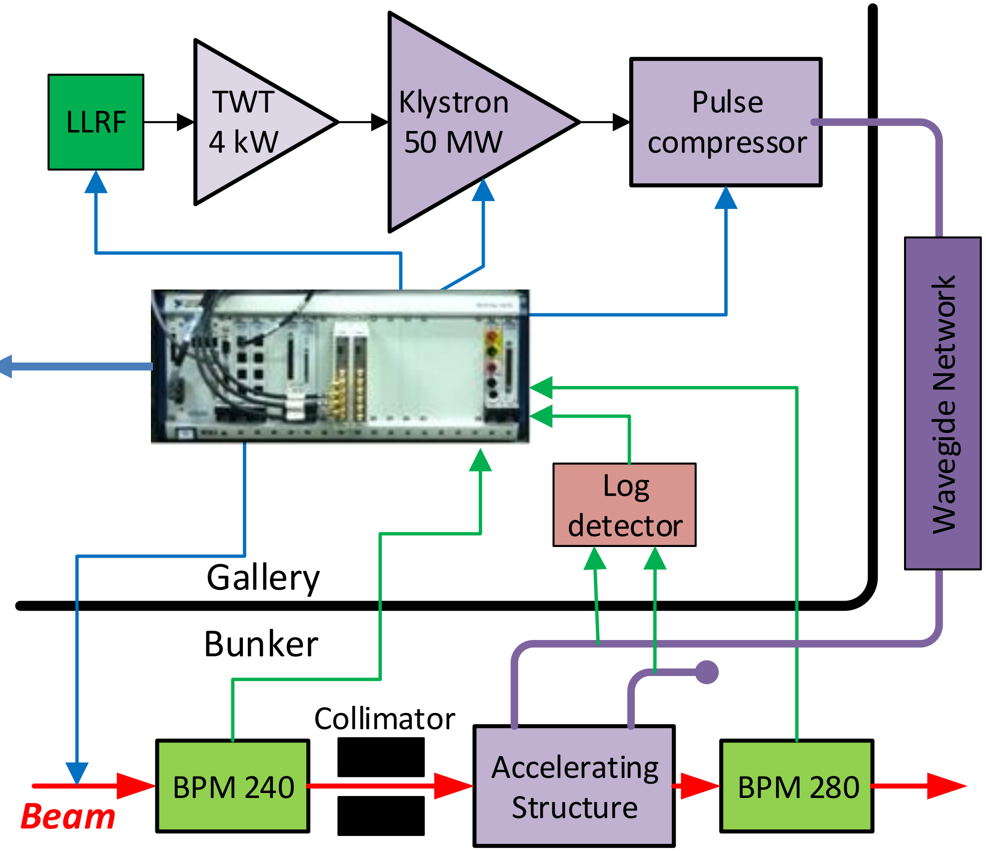
Beam:
- ✓ CTF3 Drive Beam modified
- ✓ 3GHz beam at ~1.2 A
- ✓ Pulse length up to 250 ns
- ✓ Energy ~125 MeV at structure
- ✓ Up to 25 Hz pulse rep. rate

Structure (T24):
- **24 cells**
- **T**apered linearly
- No HOM **D**amping



Control and DAQ system





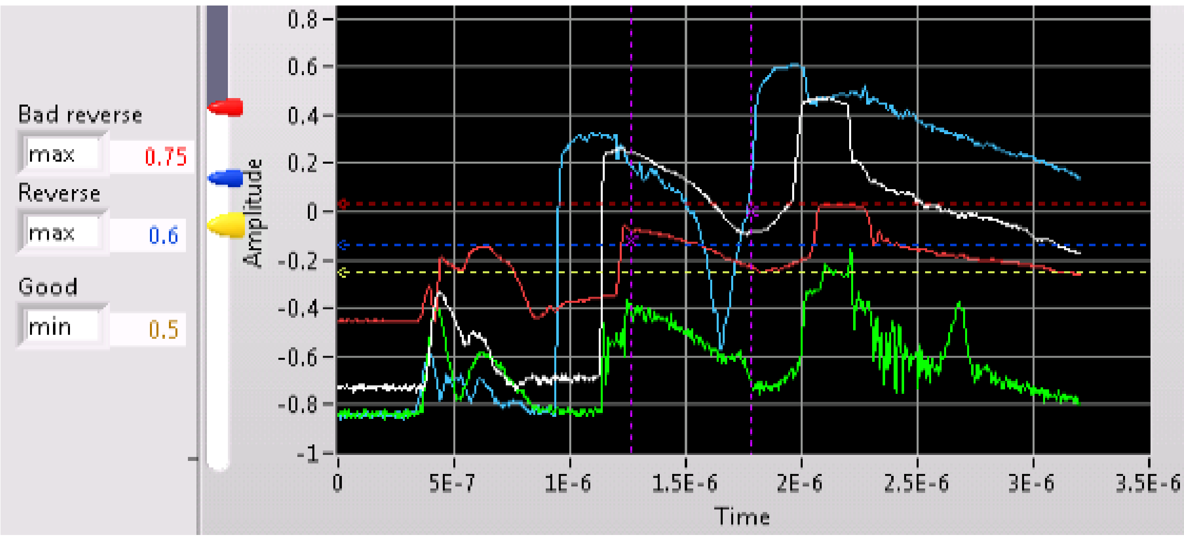
PXI NI unit:

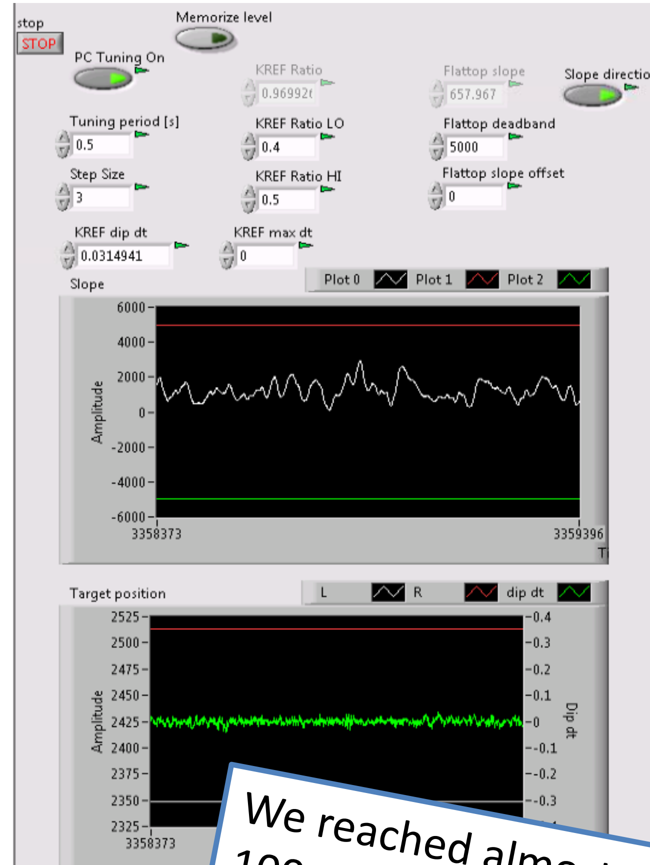
- Real time **interlocking**
- **Data taking** and storage
- 12 GHz RF **control**
- **User interfaced** with Labview

Big improvements in hardware/software

Big effort was done improving acquisition and control system:

- Implementation of beam control
- Modifications of tuning algorithm (pulse compressor)
- Debugging control and data logging



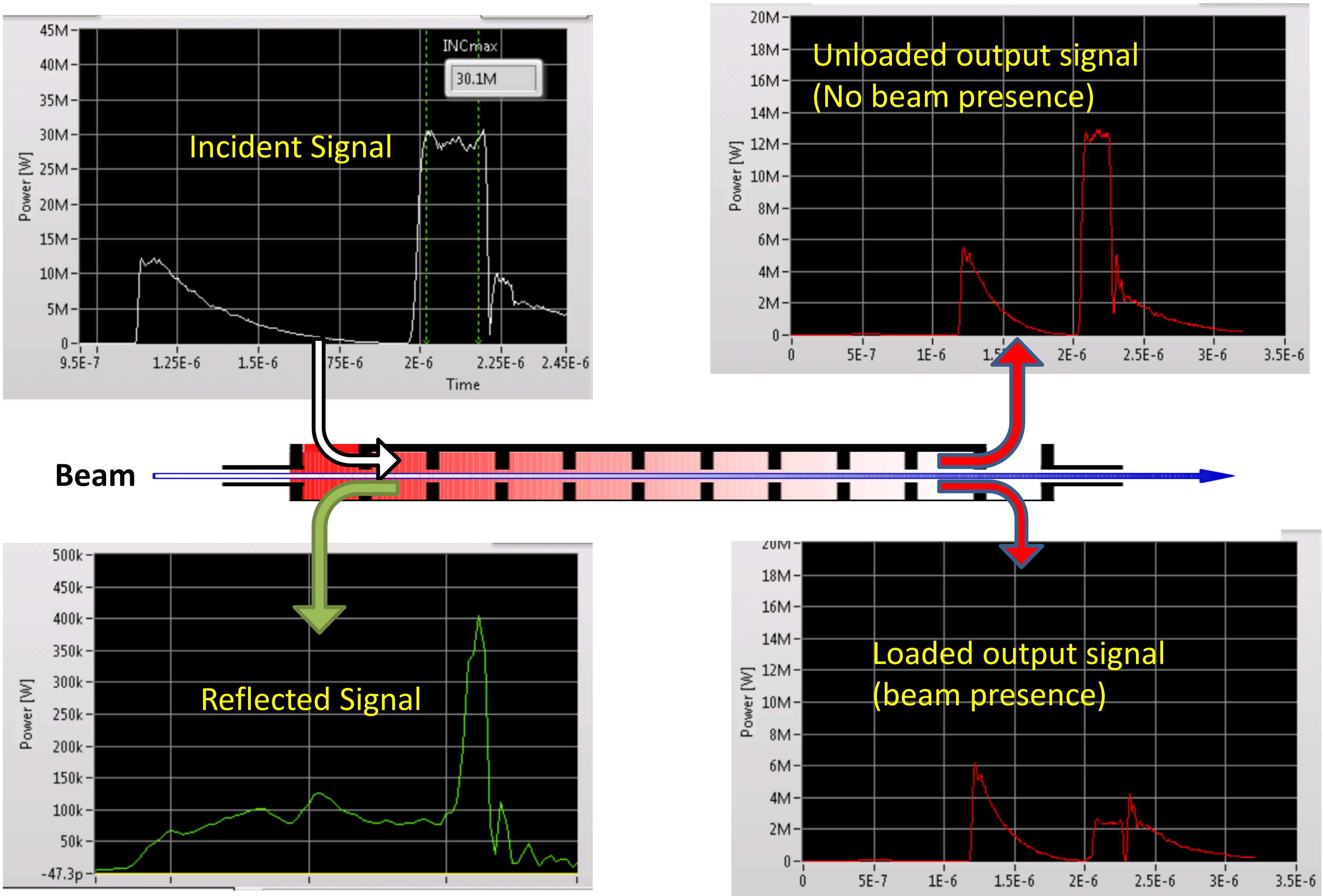


We reached almost 100 % running efficiency previous weekend.

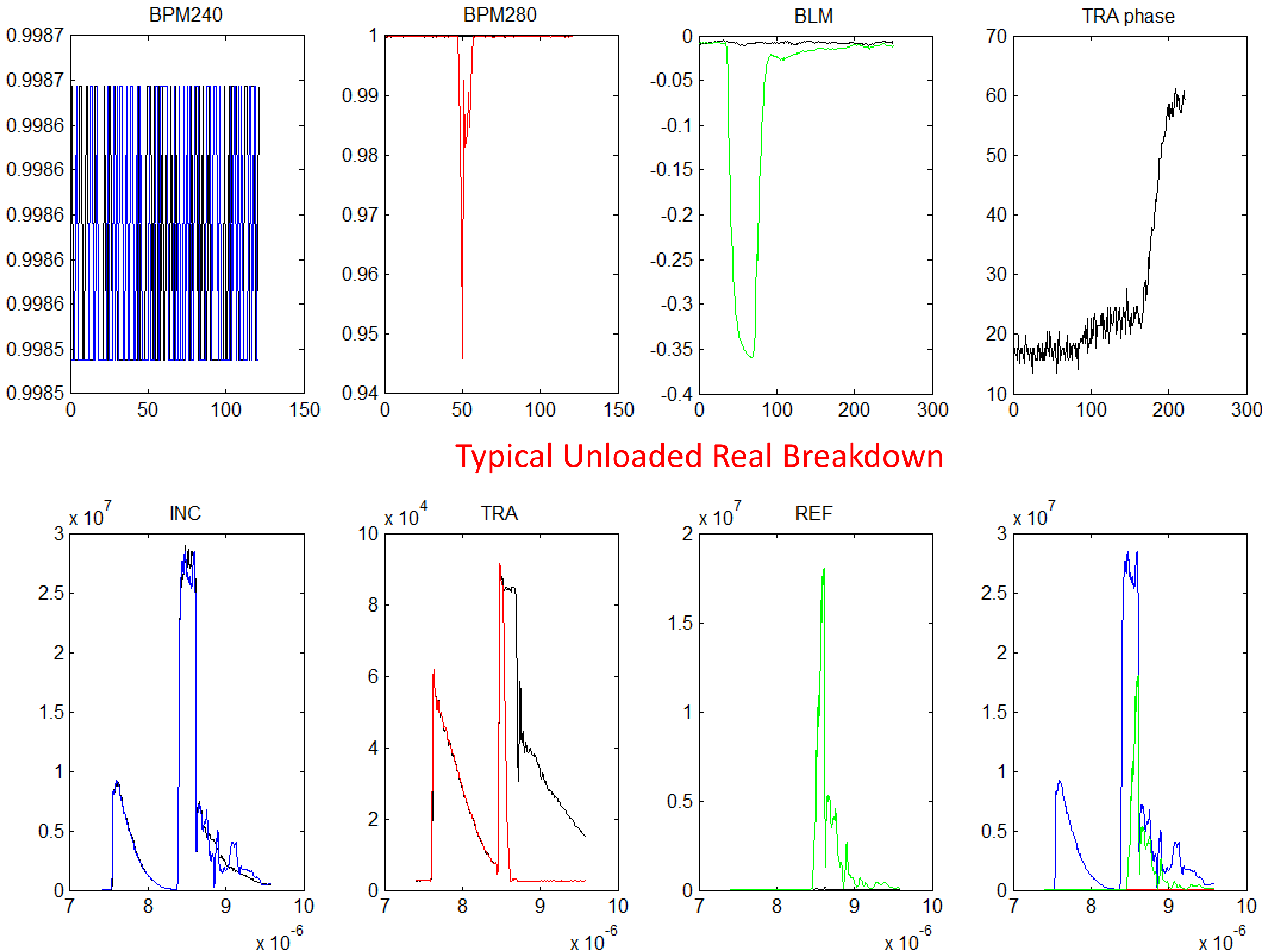
Thanks to **A. Degiovanni, D. Gamba, J. Giner, J. Tagg, F. Tecker and B. Woolley** for the efforts debugging and improving the software.

Still room for further improvements: Automatic flattening, beam loading feedback, ...

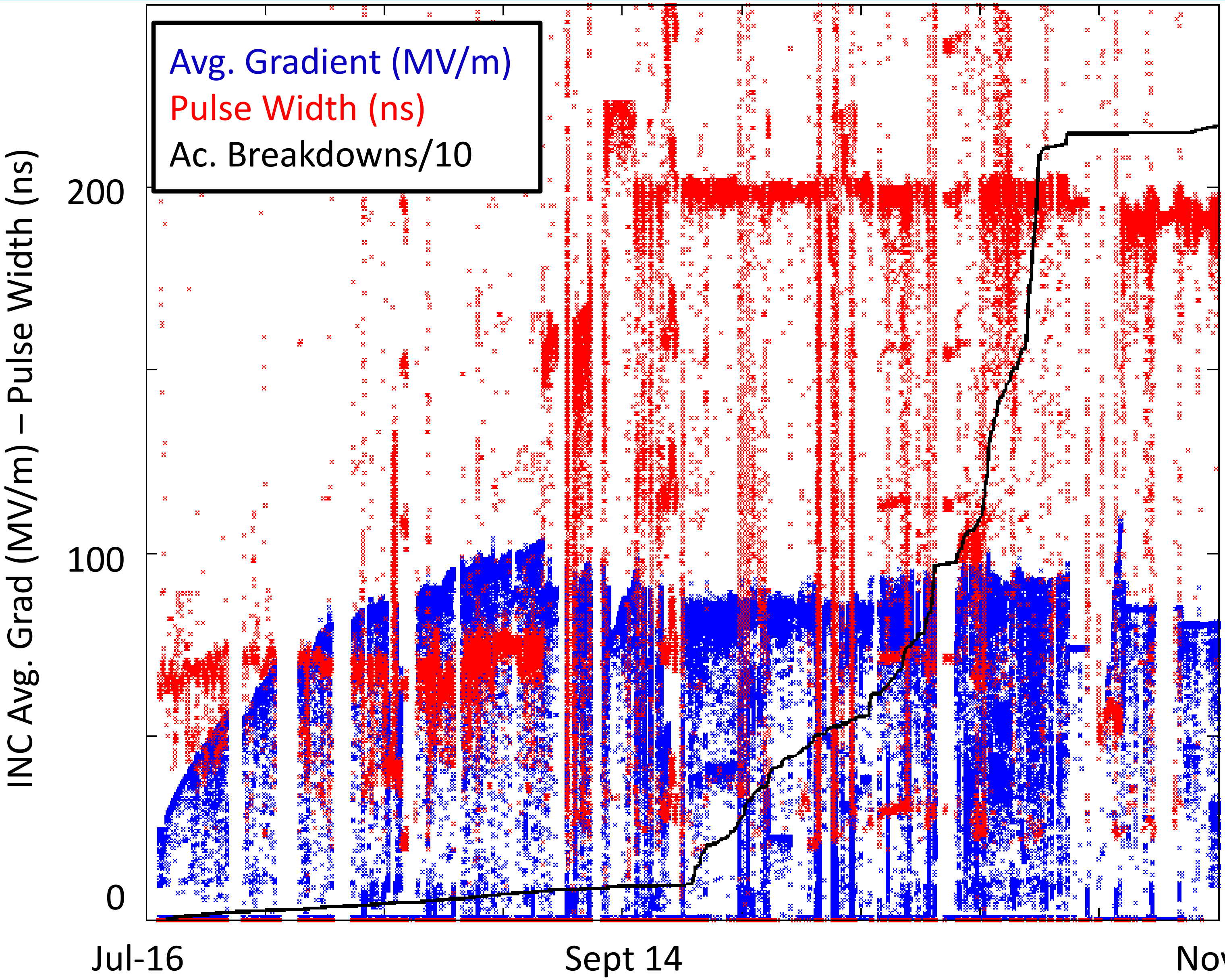
How the signals looks like?



How do we detect breakdowns?

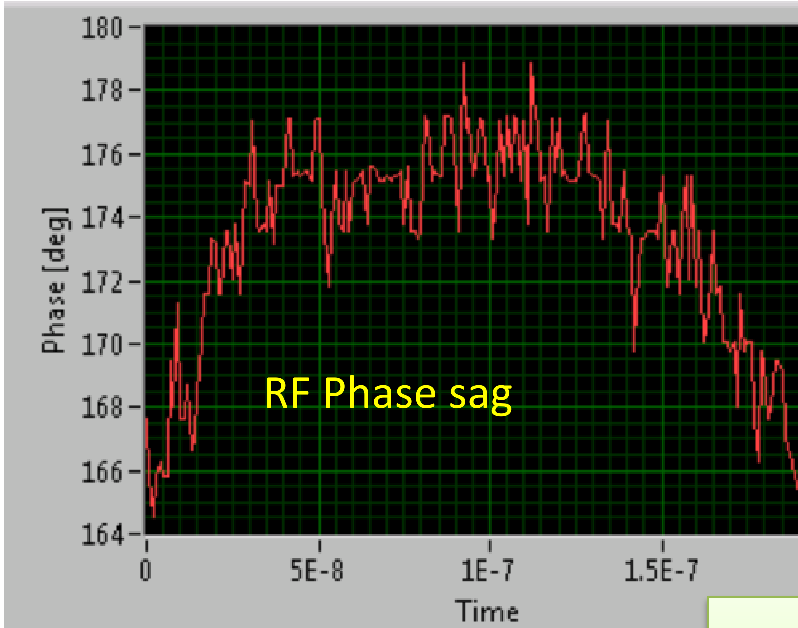


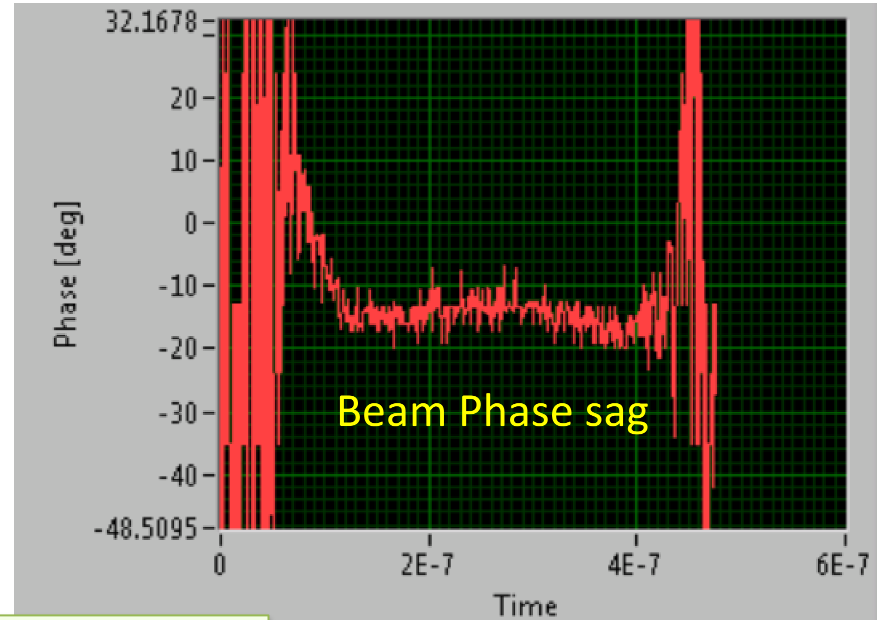
First Results



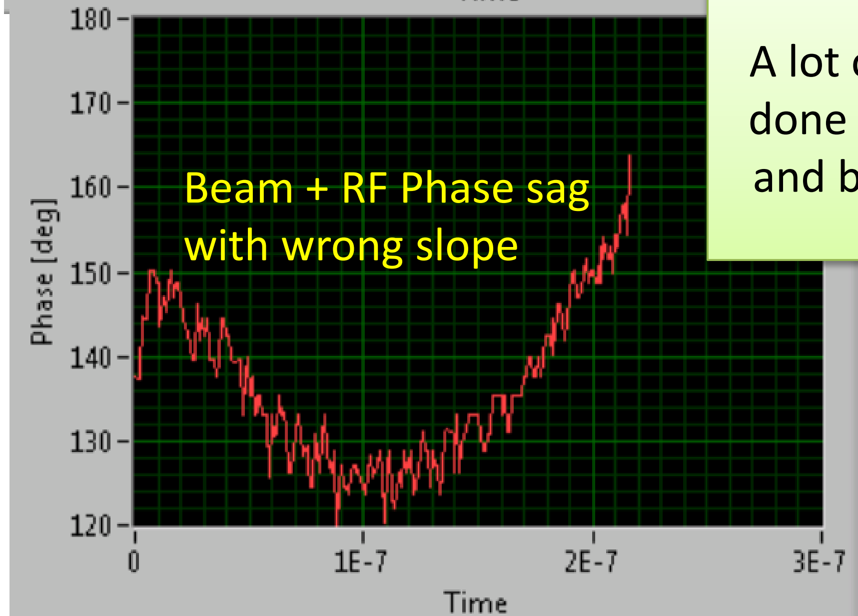
Plot provided by A. Degiovanni

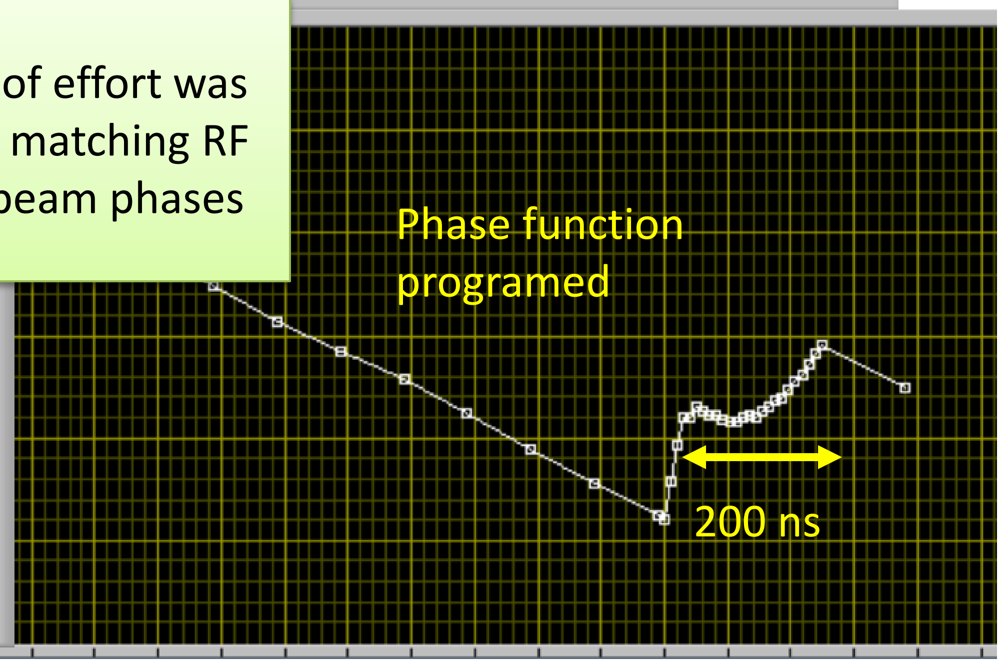
First Results: Phase program



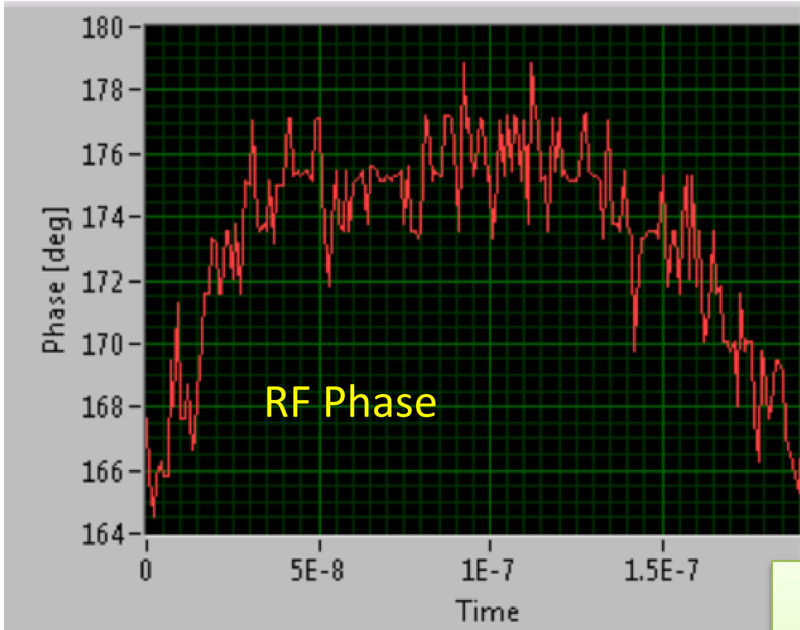


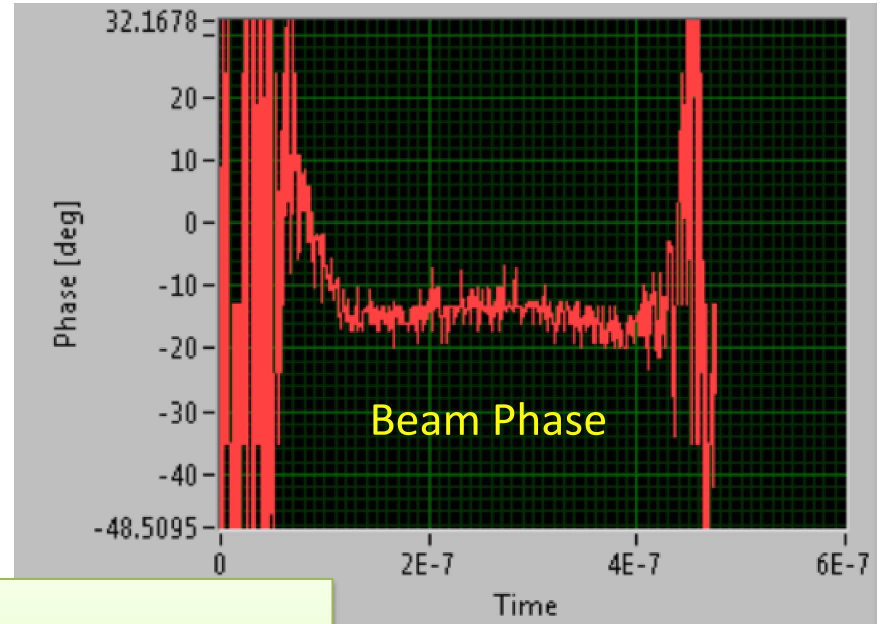
A lot of effort was done matching RF and beam phases

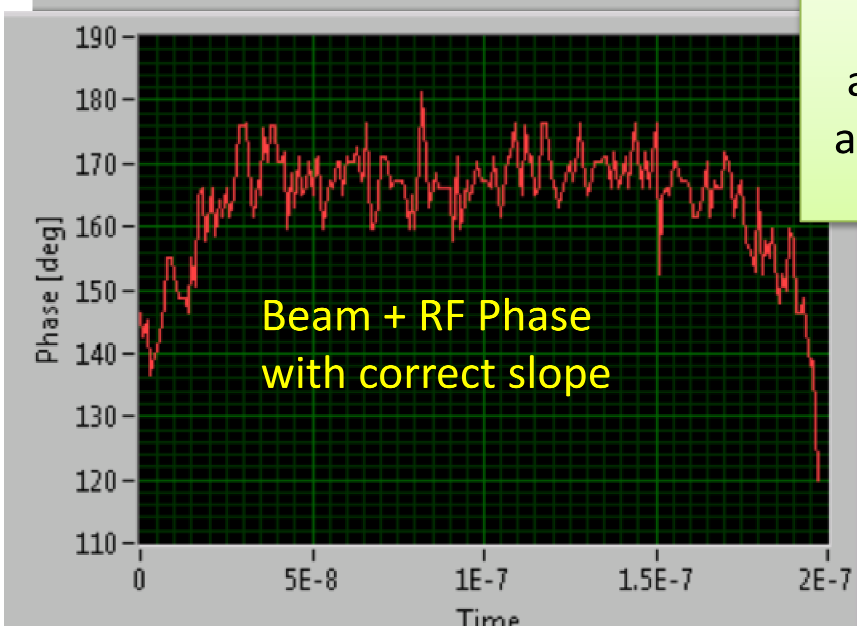




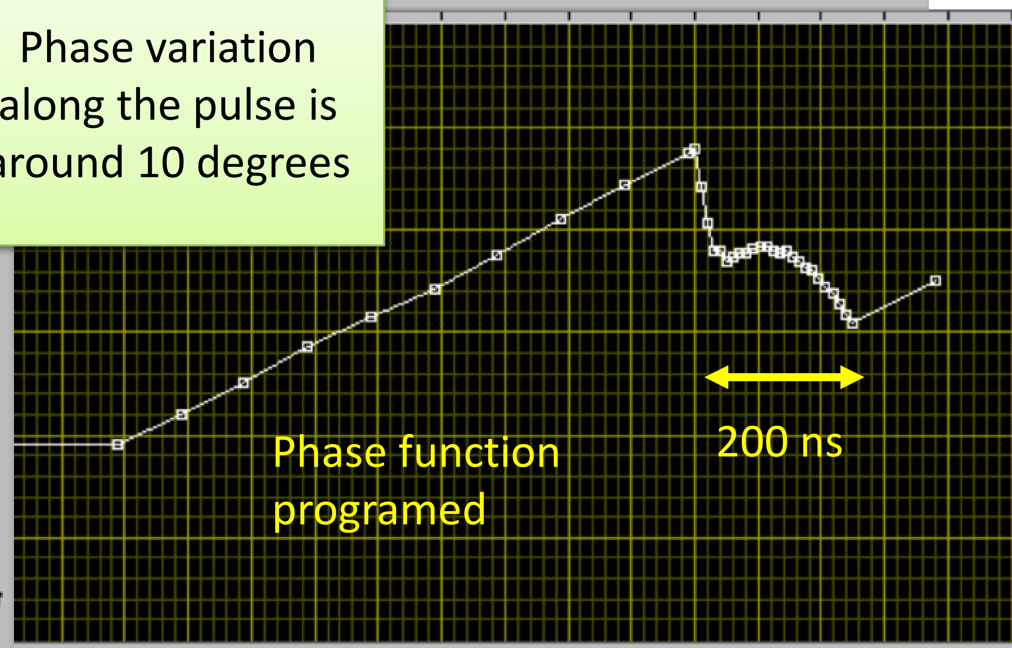
First Results: Phase program



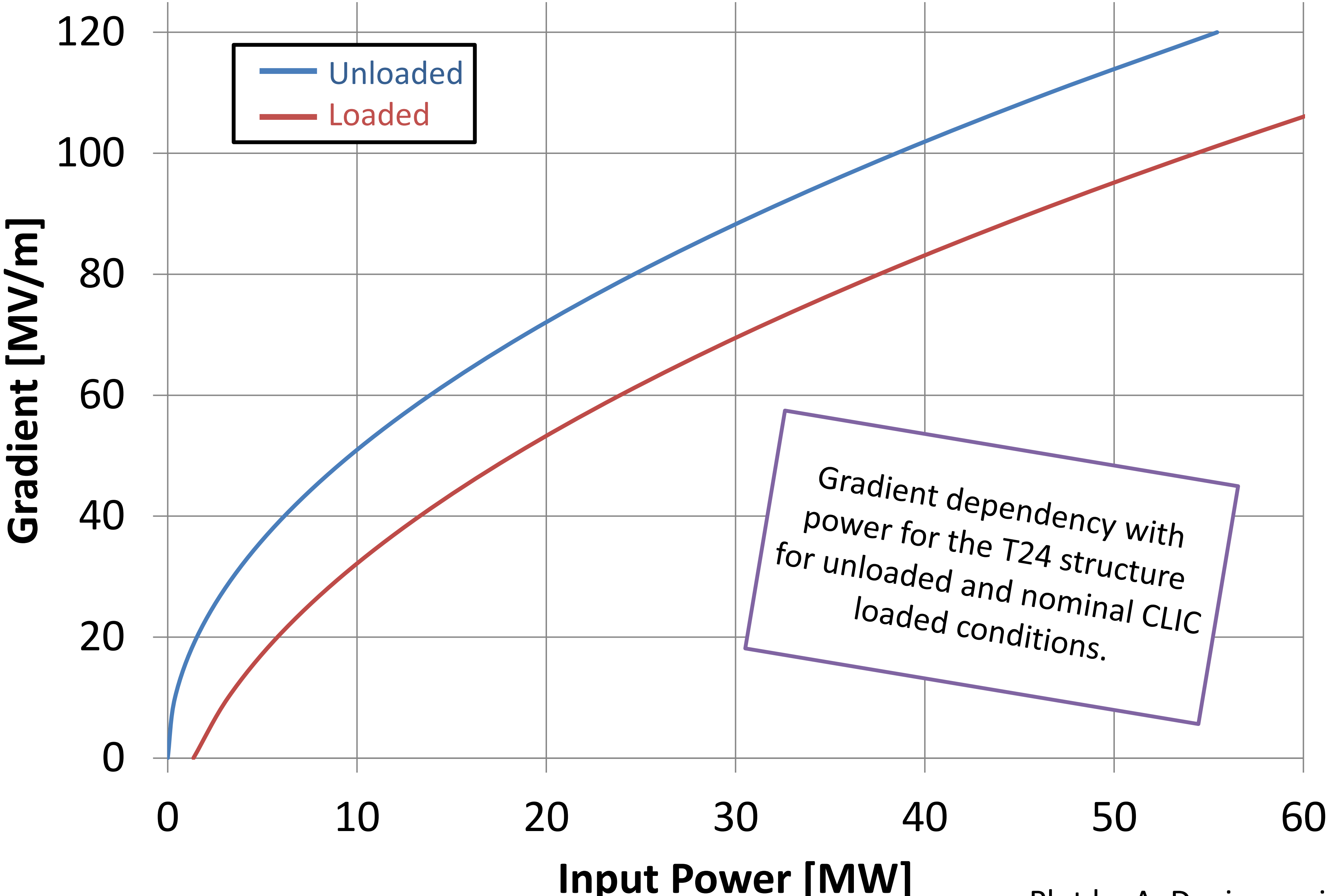




Phase variation along the pulse is around 10 degrees

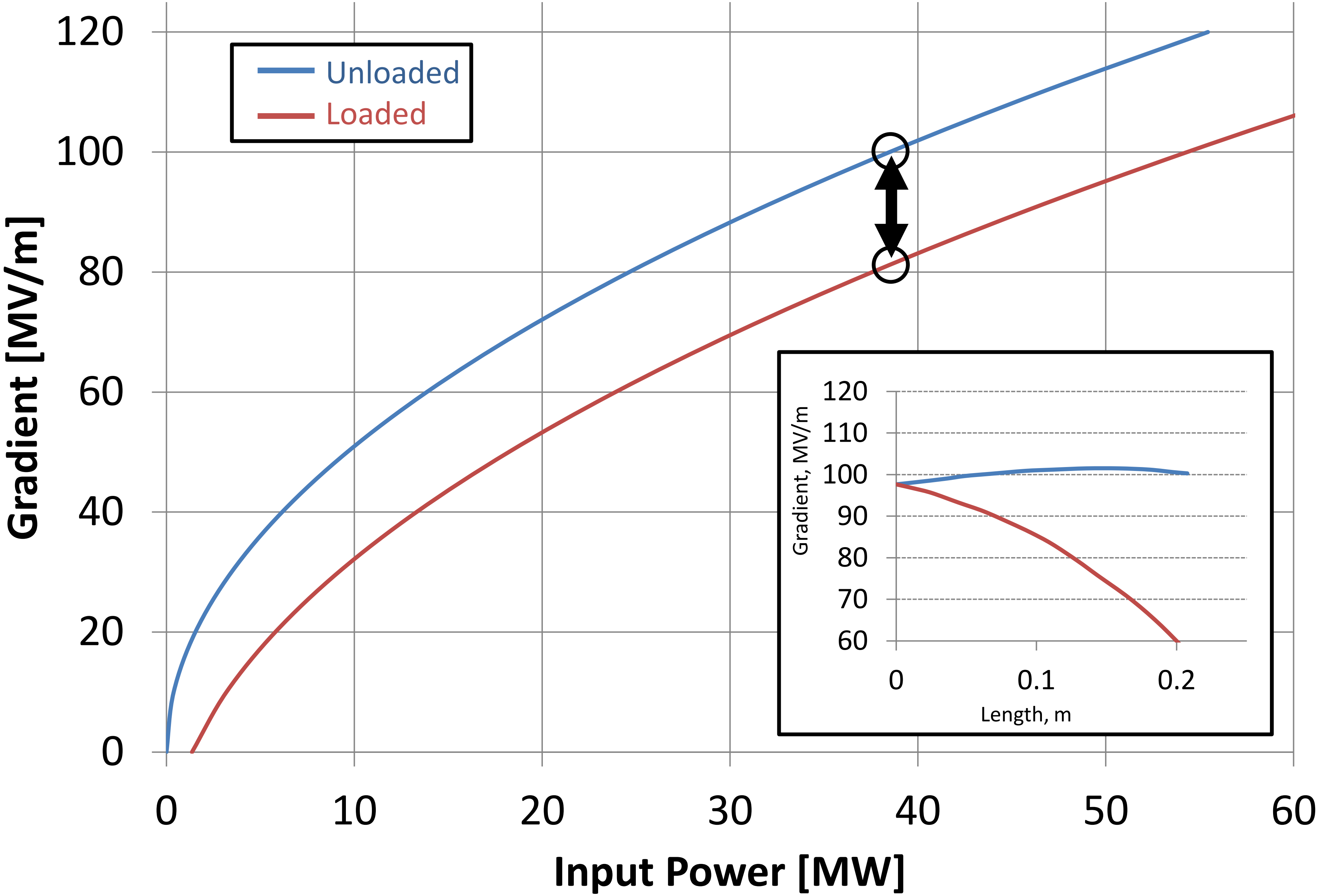


The loading effect for the T24 structure

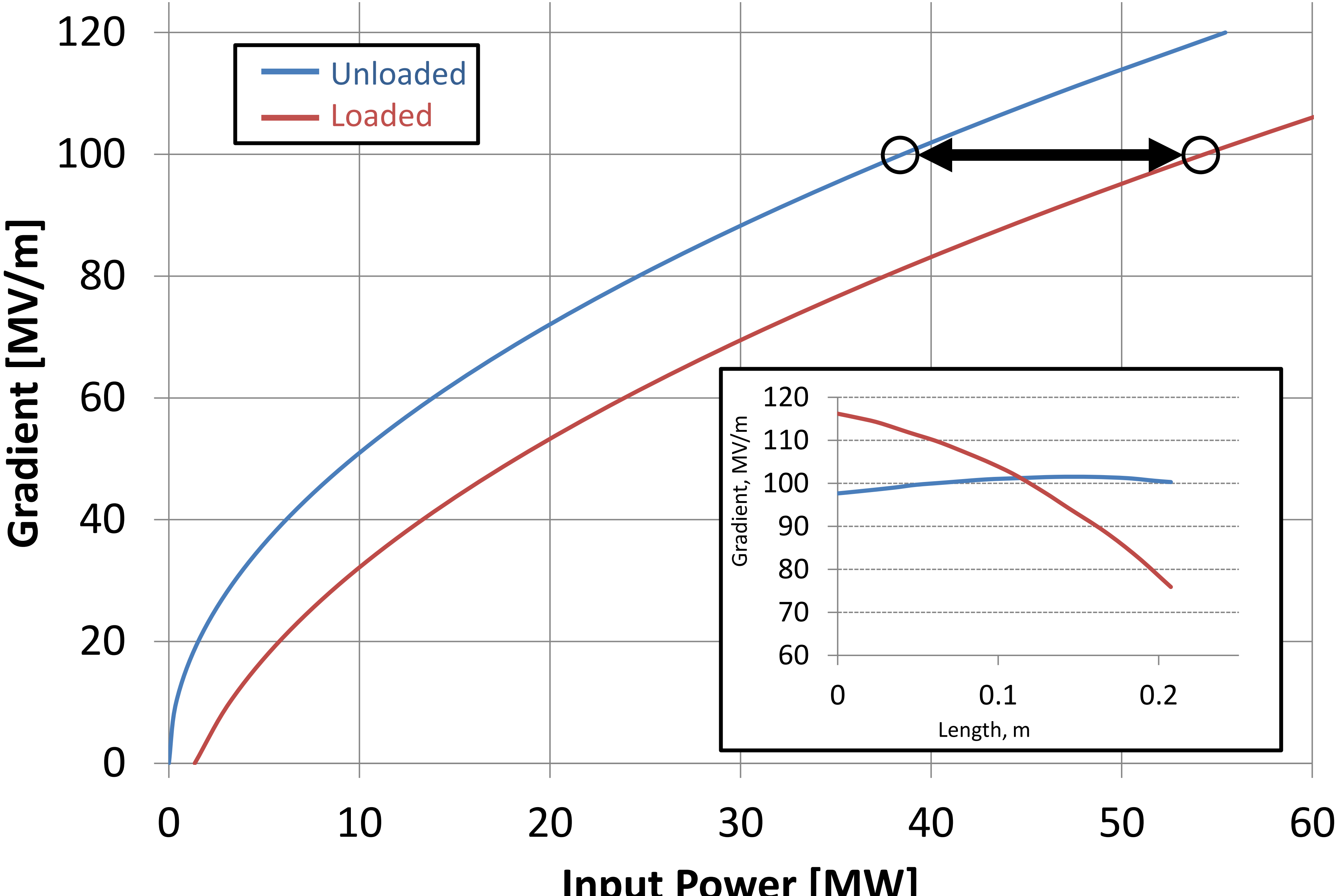


Plot by A. Degiovanni

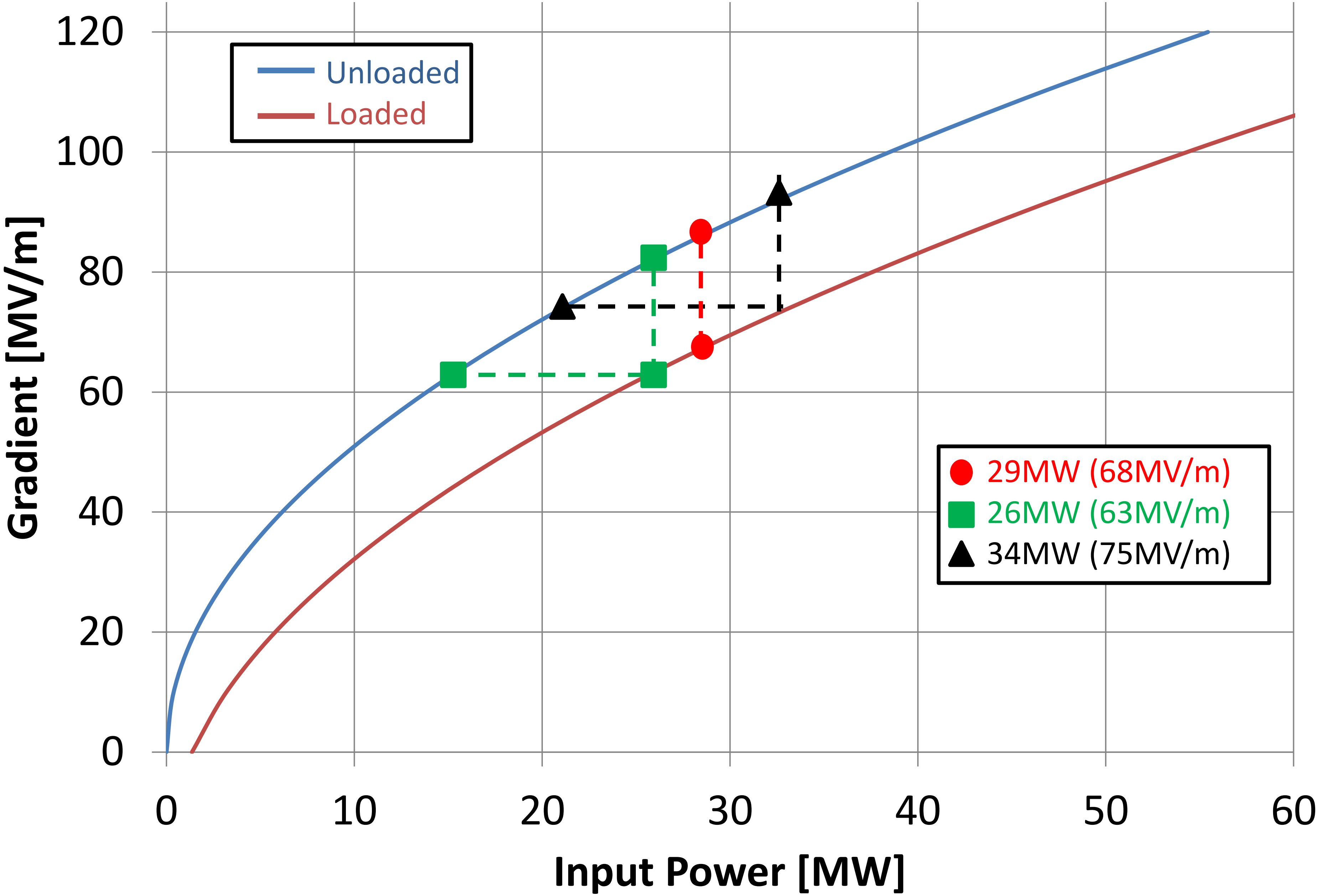
Measure at constant input power



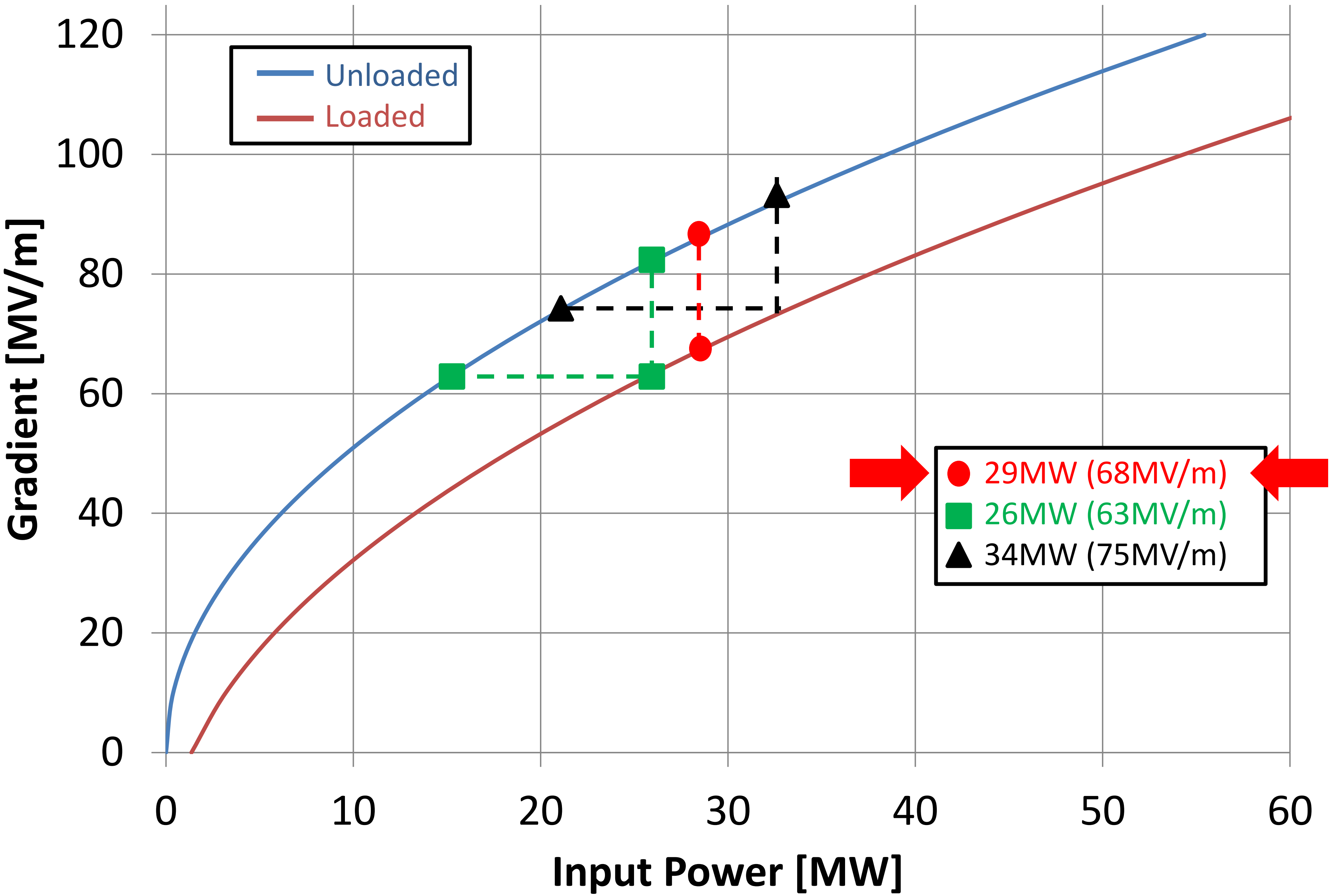
Measure at constant gradient



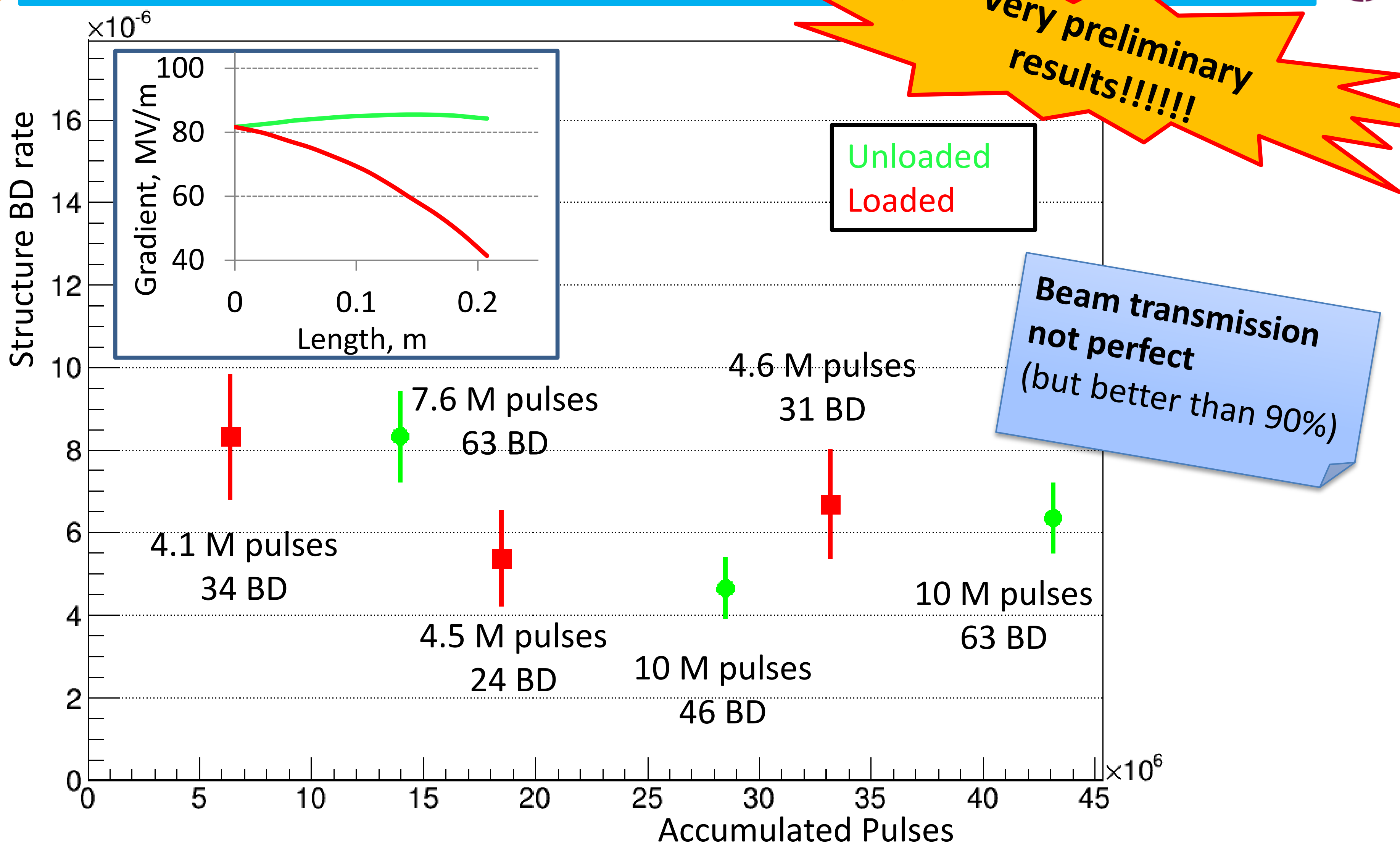
Experiments performed



First Results: BDr

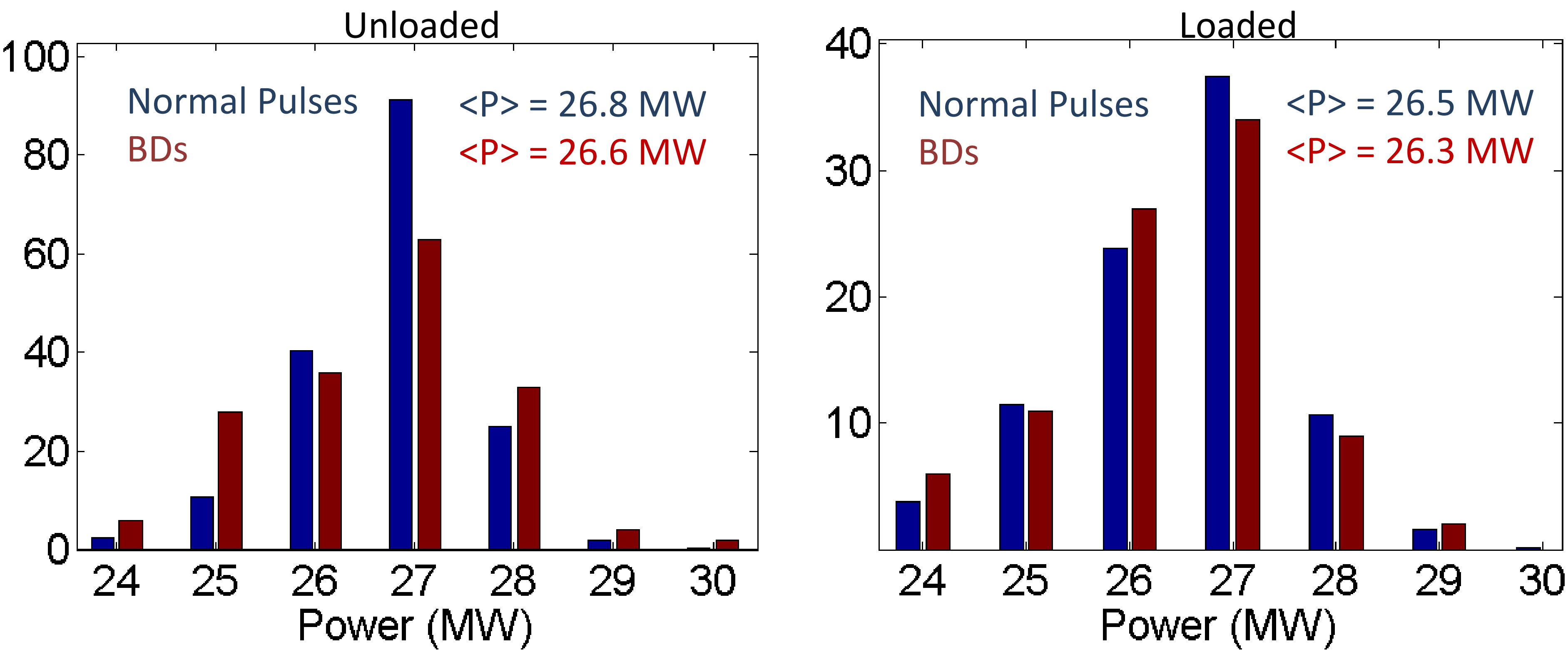


First Results: BDr



Central value and errors computed using 1σ Feldman-Cousins confident intervals.

First Results: BDr at constant input Power

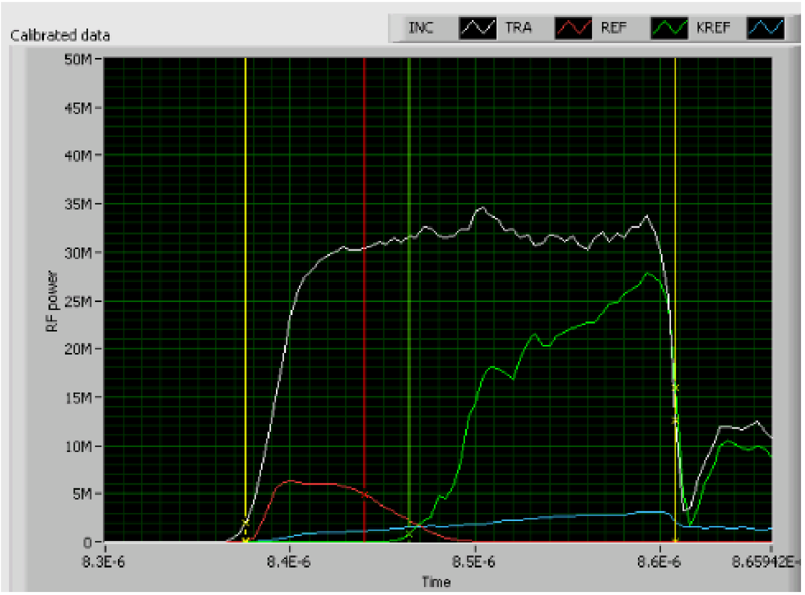


Combined Results at 29 MW RF input power:

- Unloaded BDr: (6.9 ± 0.5) 10^{-6}
- Loaded BDr: (6.7 ± 0.7) 10^{-6}

Preliminary Conclusion
Beam does not increase BDr at constant input power

First Results: BDr at constant input Power

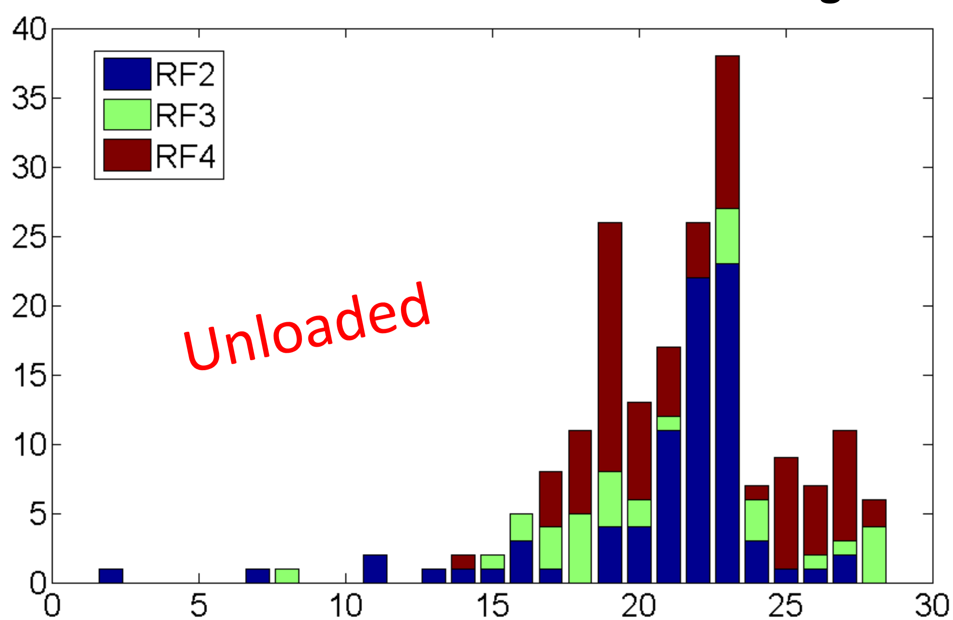


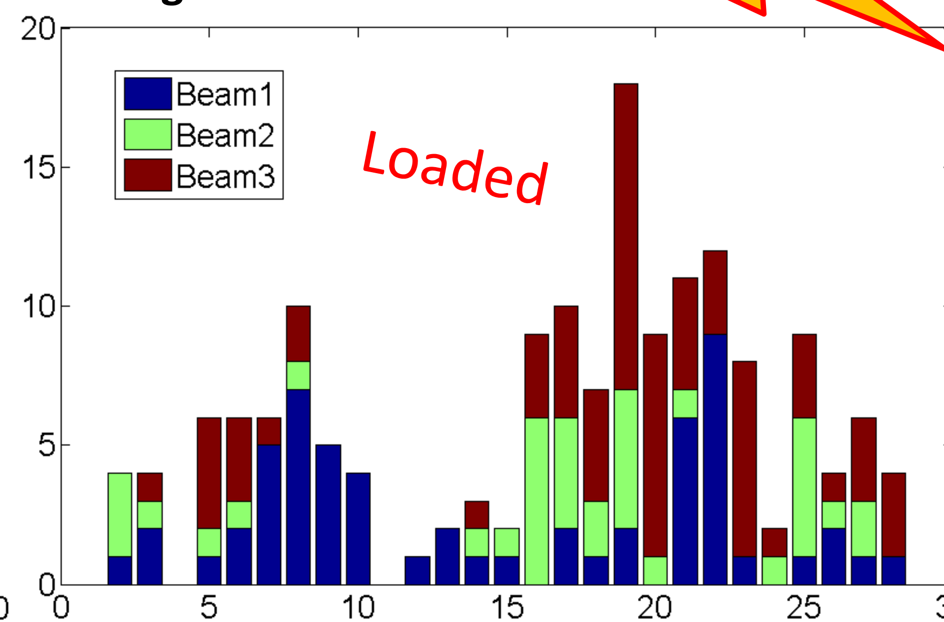
Break down cell distribution for unloaded data.

WARNING: Cell distribution still under analysis.

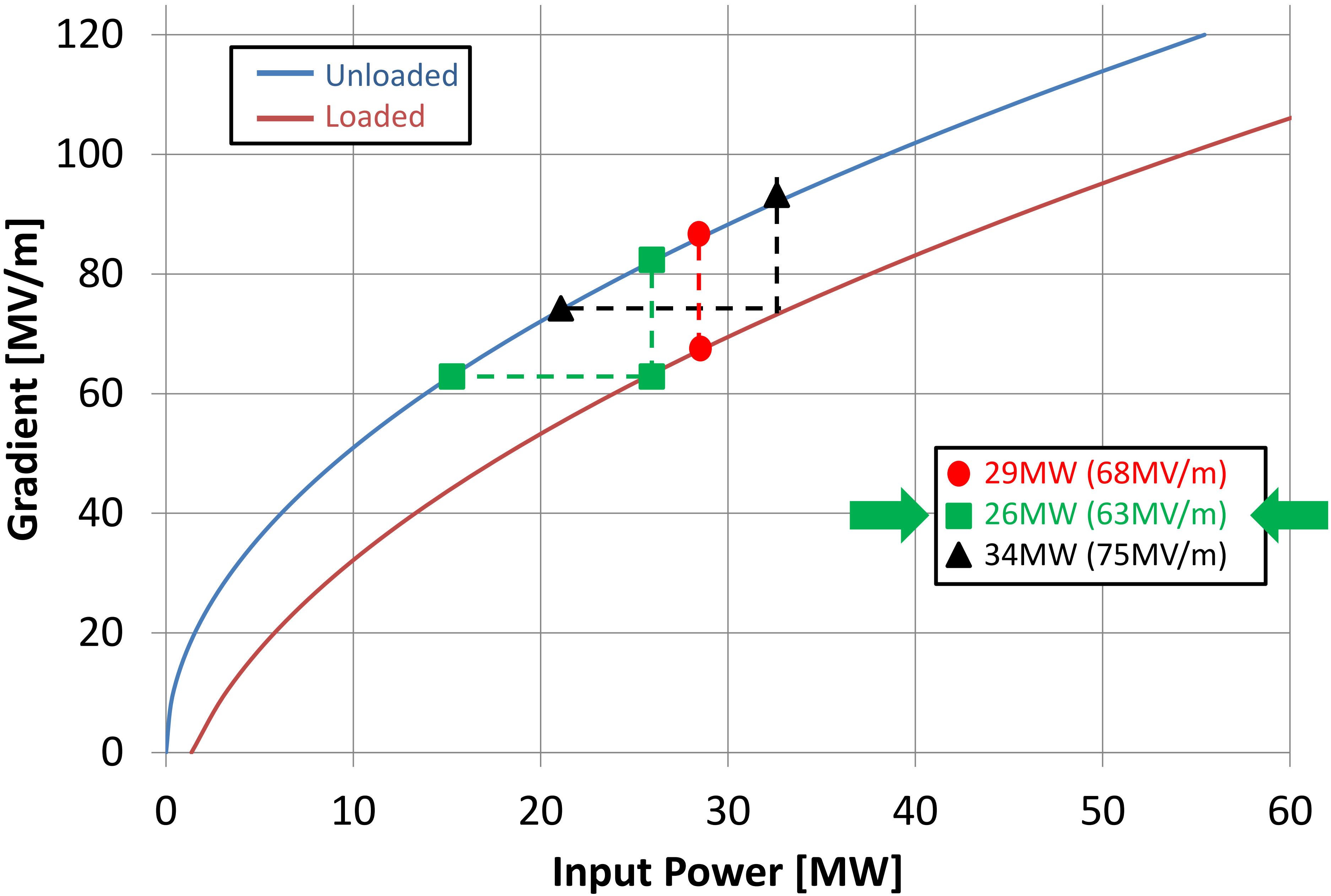
Very preliminary results!!!!!!

Acknowledgement: A. Degiovanni

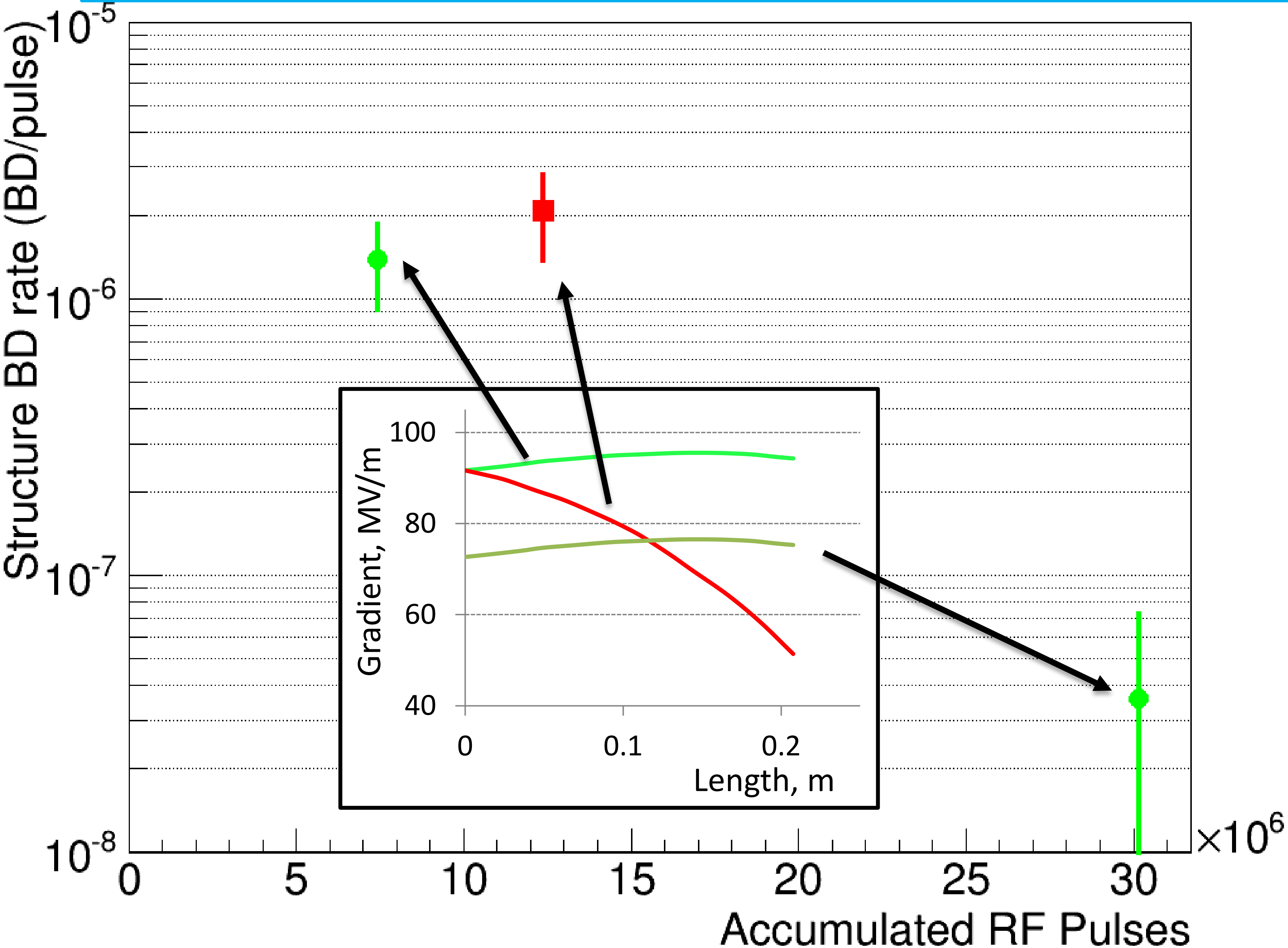




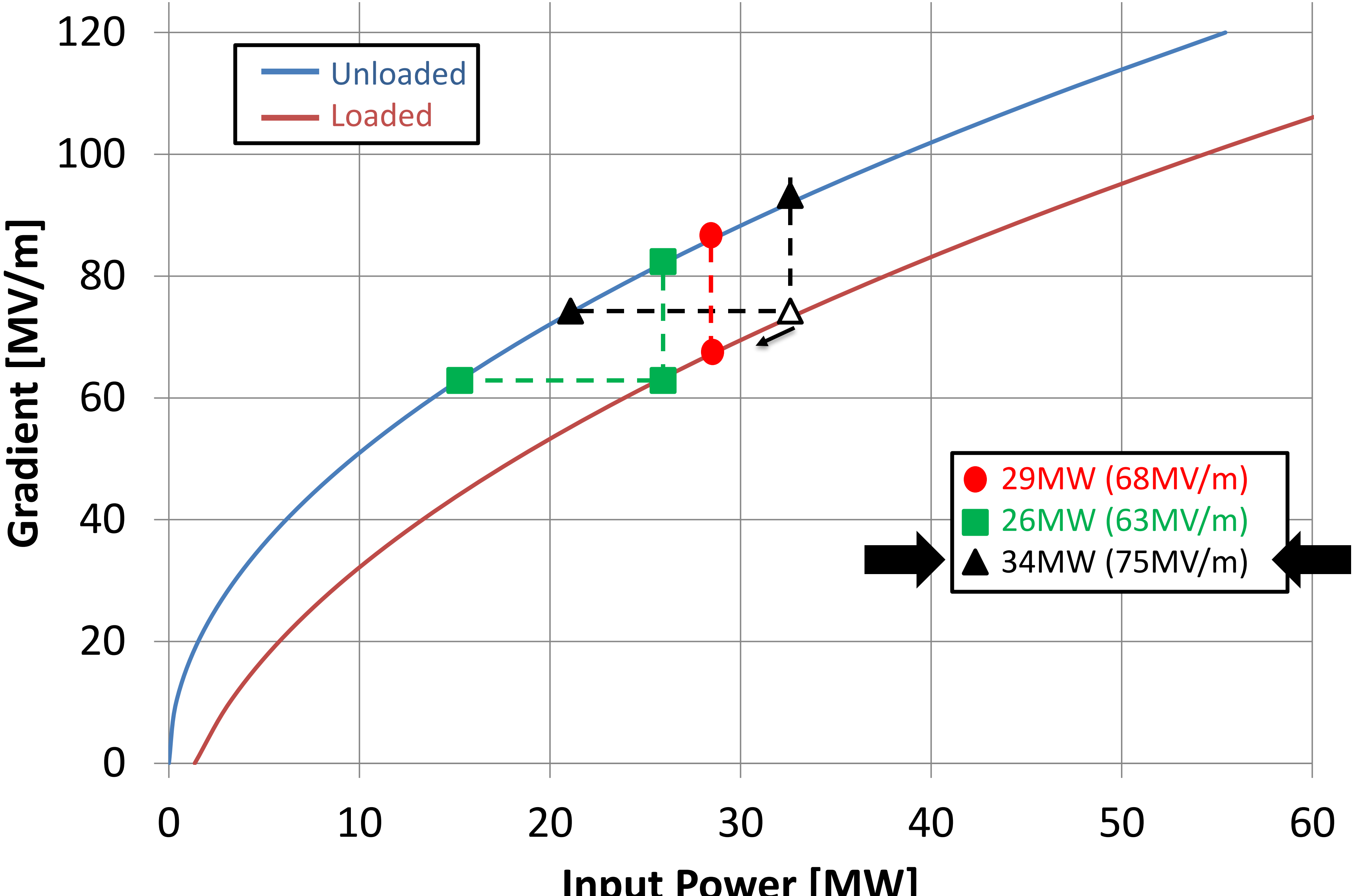
First Results: BDr



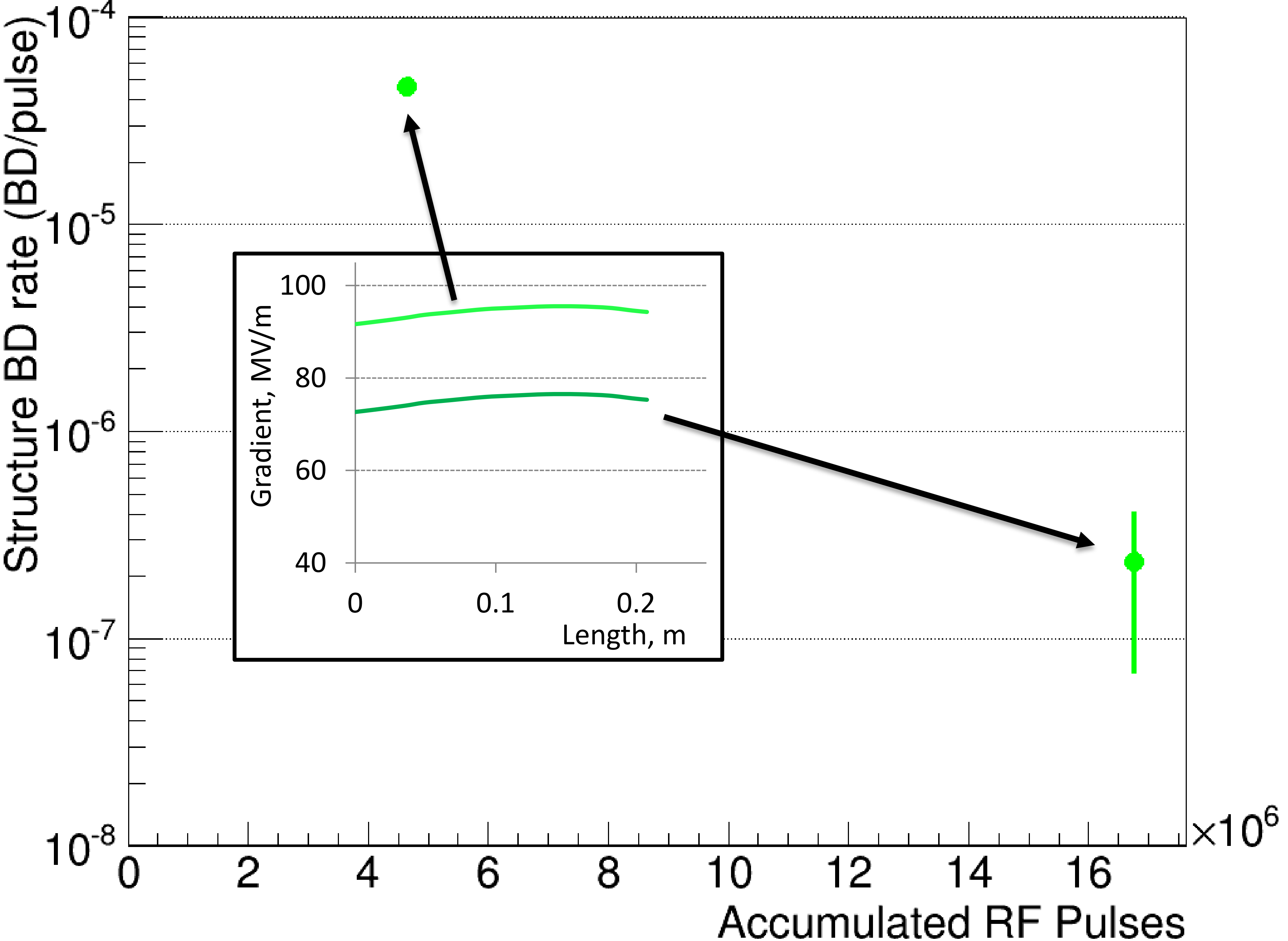
First Results: BDr



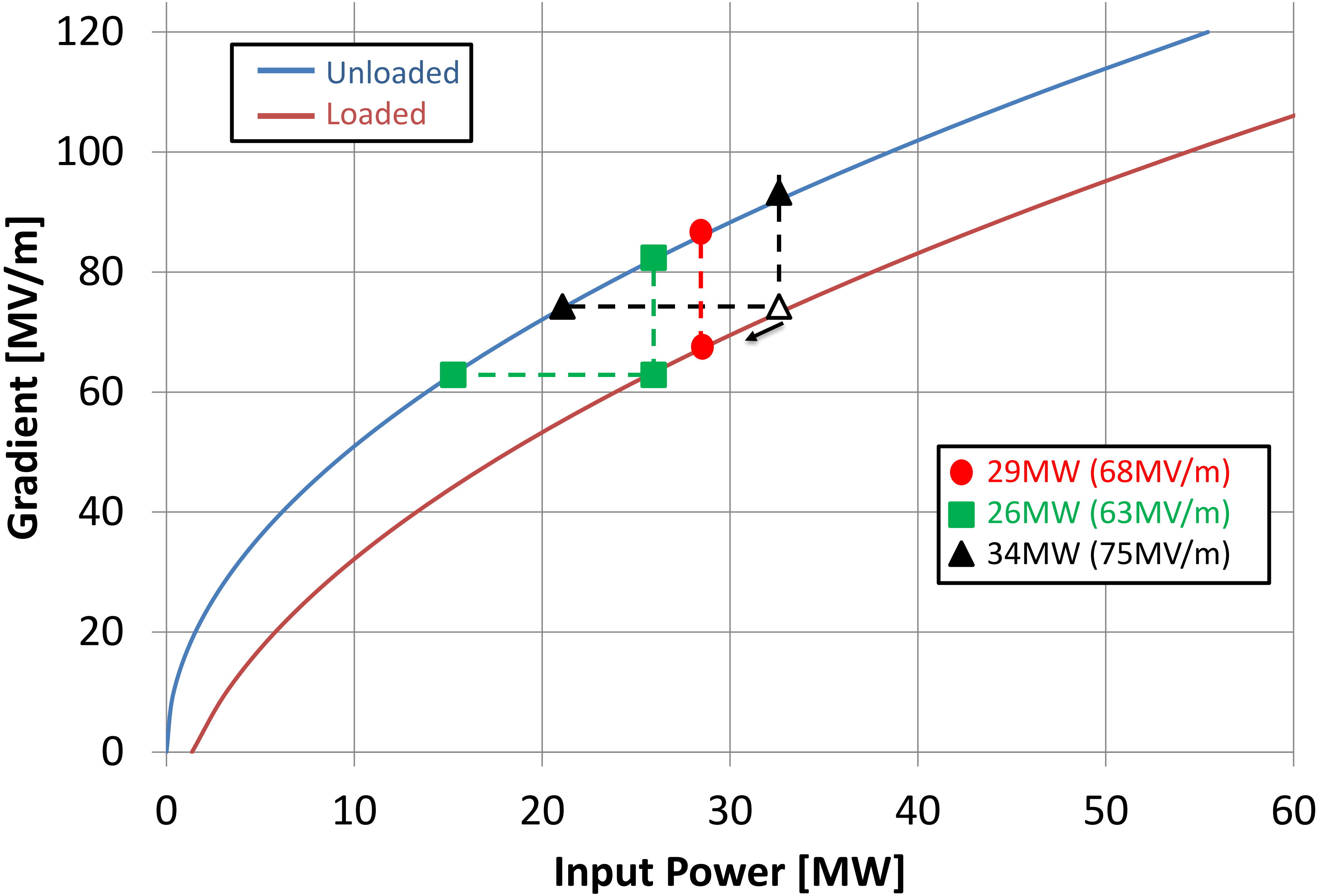
First Results: BDr



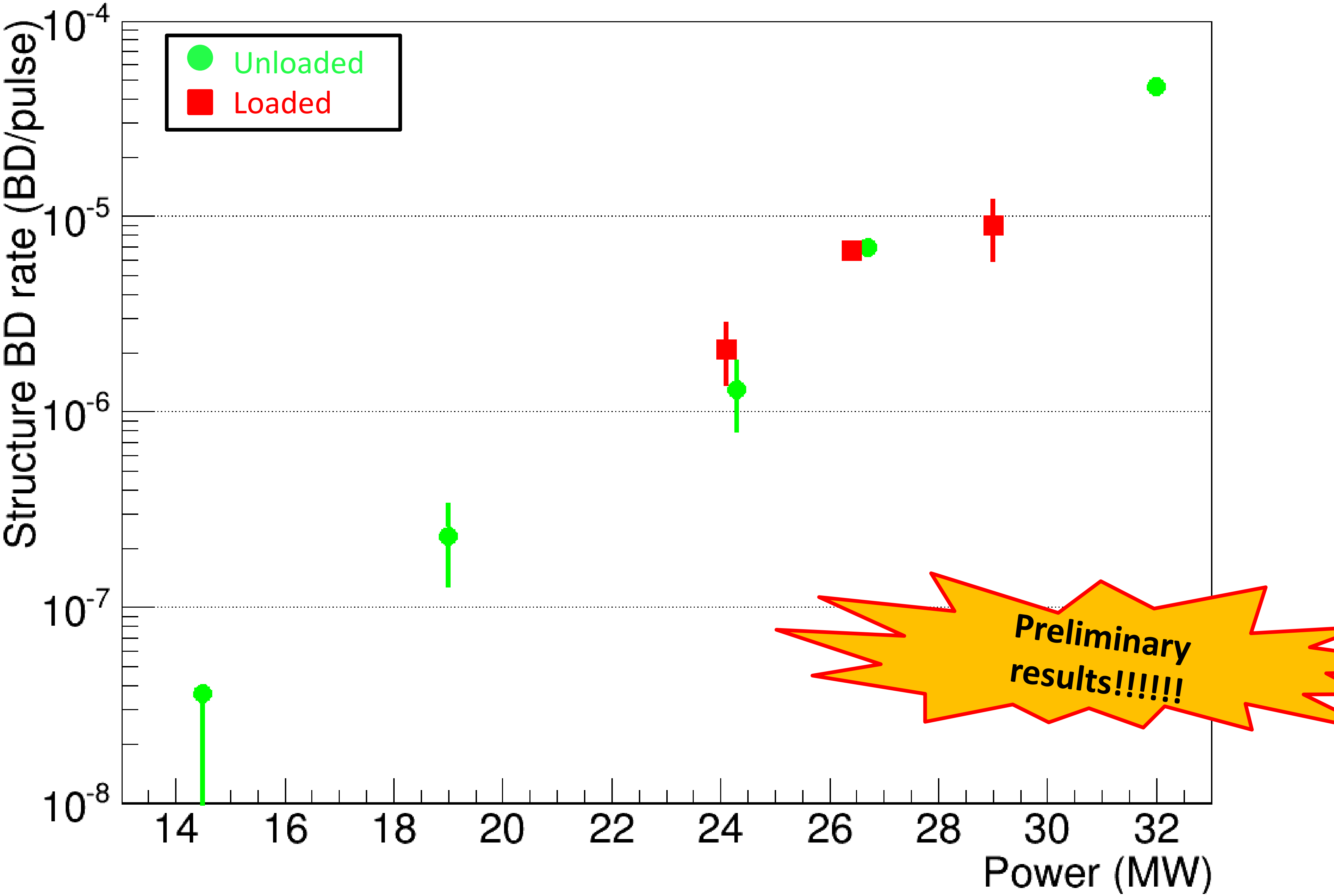
First attempt at constant average gradient



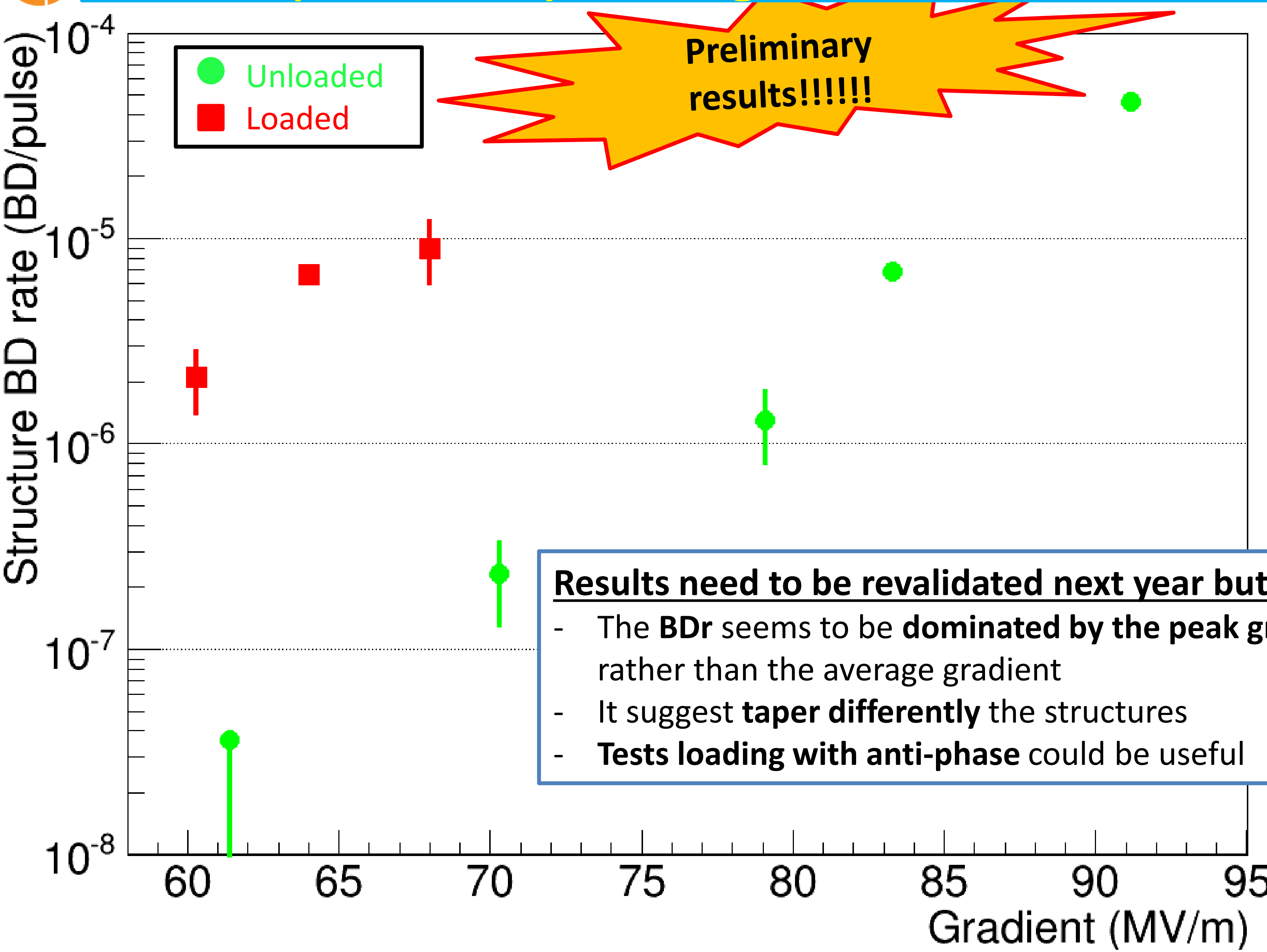
First Results: BDr



BDr dependency with input power



BDr dependency with gradient



Results need to be revalidated next year but:

- The **BDr** seems to be **dominated by the peak gradient** rather than the average gradient
- It suggest **taper differently** the structures
- **Tests loading with anti-phase** could be useful

Summary and future

- ✓ **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.
- ✓ Preliminary analysis shows that the **beam presence does not have a harmful effect on the breakdown rate at constant input power** while **at constant gradient** the breakdown rate **is dominated by the input power**.
- ✓ **More measurements** should be done **to validate the results.**
- ✓ A long-term program of test under beam loading conditions of new structures with a different tapering should be considered.
- ✓ **More detailed analysis will be done** to draw further conclusions.

We are ready for a exciting 2015 running!!!

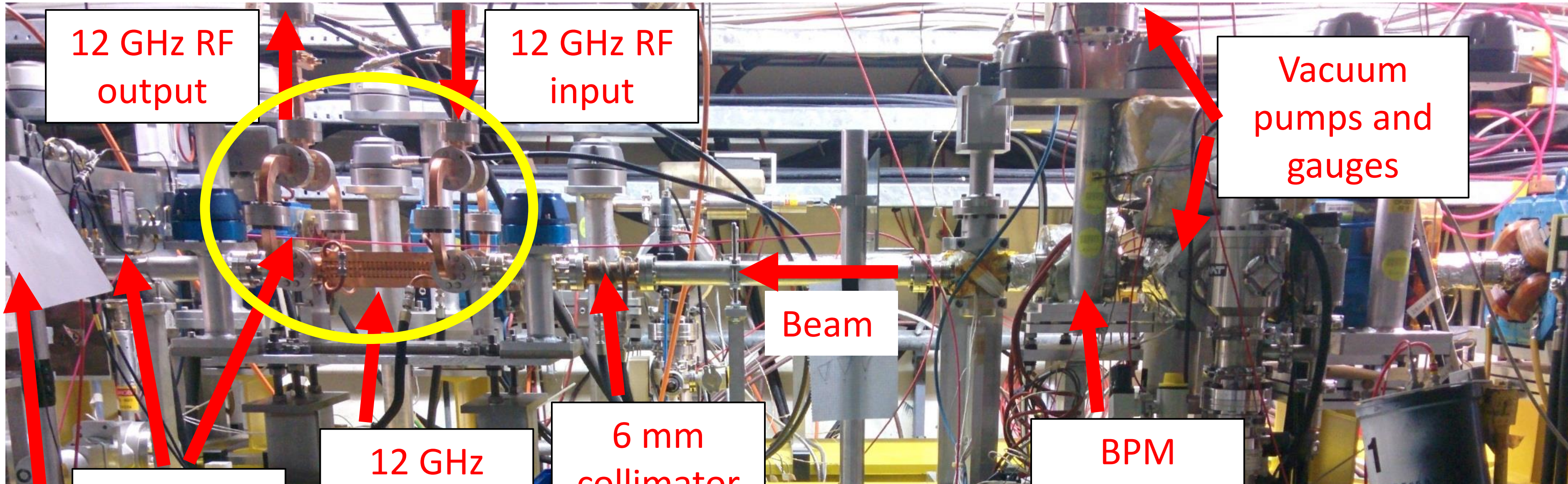
Acknowledgements

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

J.L. Navarro for the

CLIC/CTF3 Collaboration

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

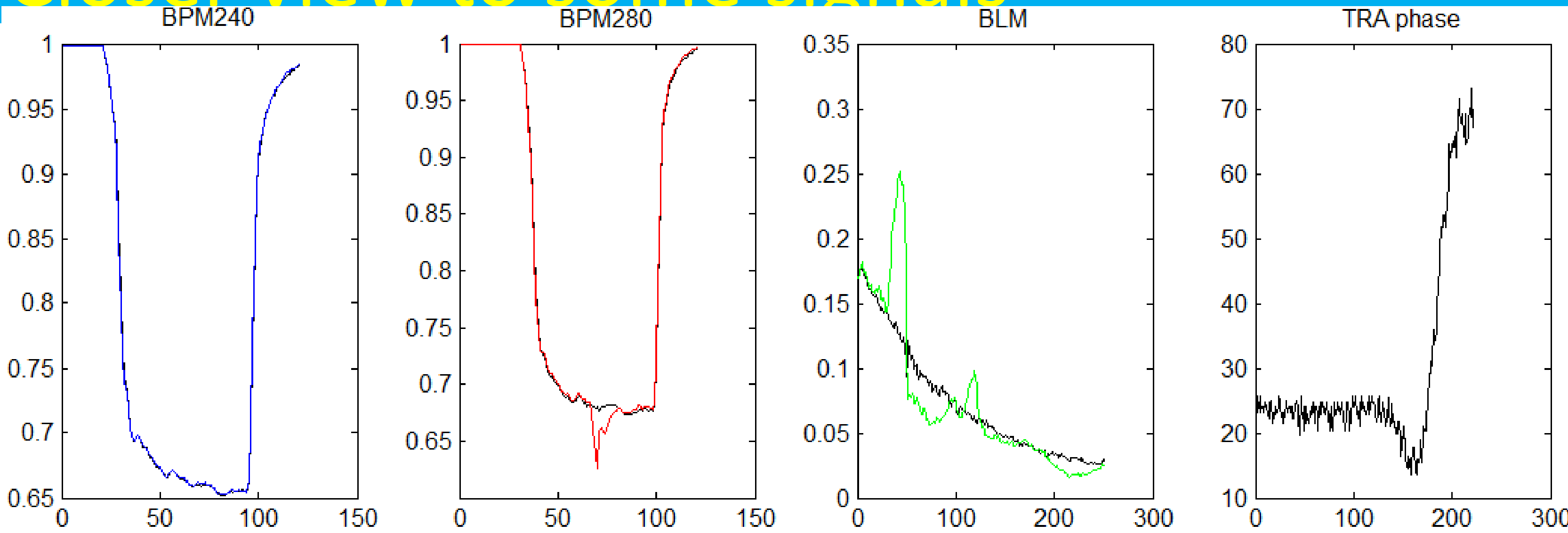
ScandiNova Modulator:
- Designed for 400kV, 300A, 3.25us HV pulse width FWHM, 1.5us RF pulse width at 50Hz repetition rate

CPI VKX-8311A klystron:
- 50MW, 1.5us rf pulses
- 50Hz repetition rate at 400kV, 300A, 5kW avg. power
- Working frequency 11.994GHz

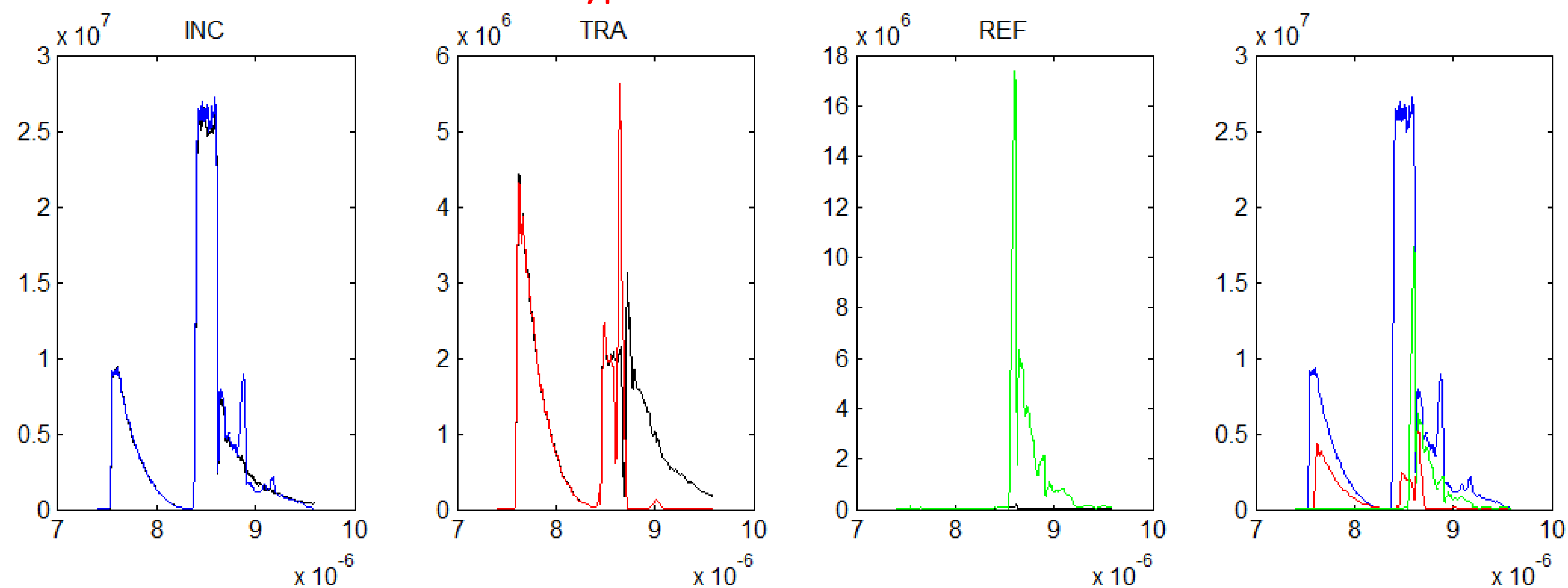
SLED I type pulse compressor:
- Power gain of 2.82
- $Q_{loaded} = 2.375 \times 10^4$,
- Beta = 4.27,
- $Q_0 = 1.31 \times 10^5$
- 5% power loss

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

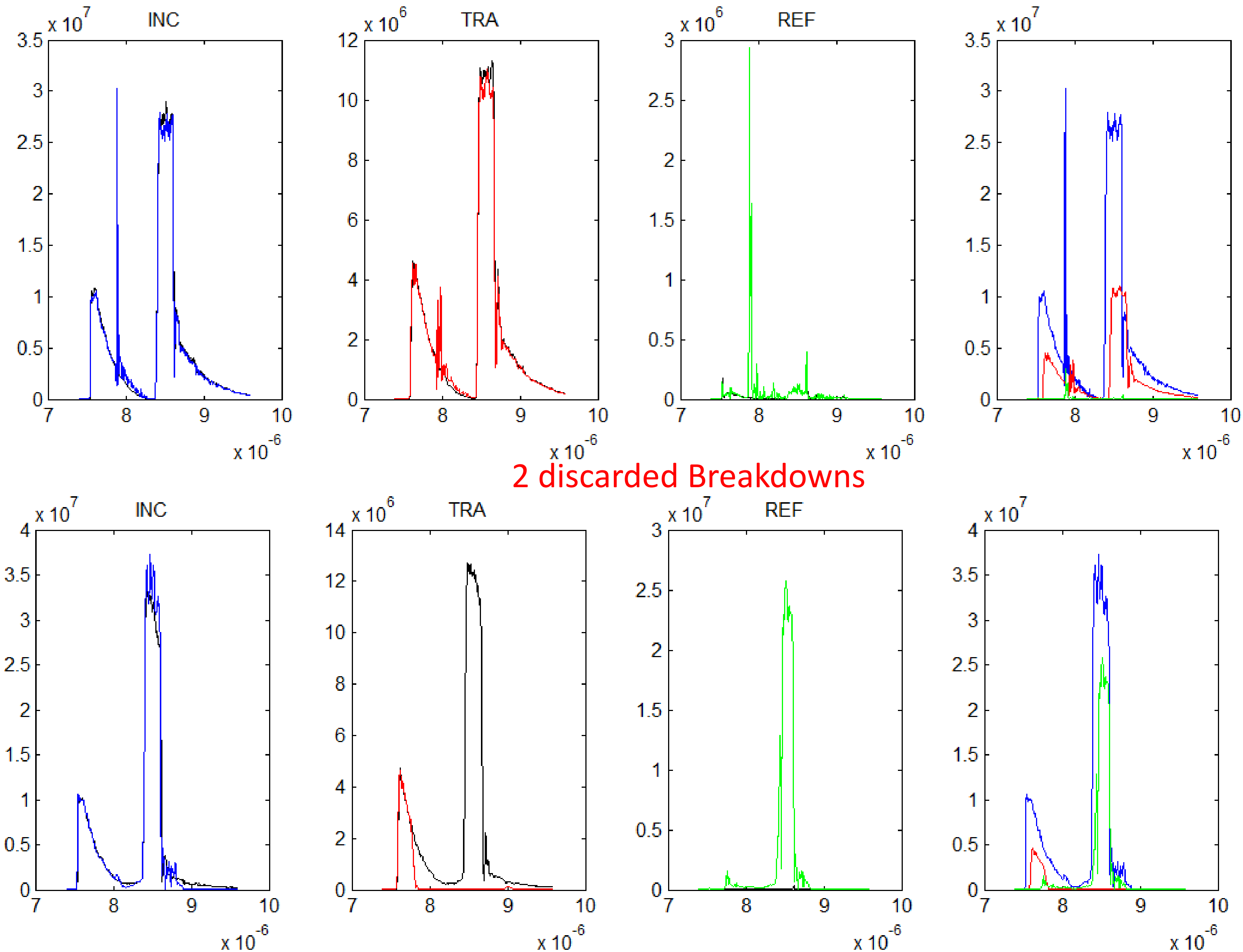
Closer view to some signals



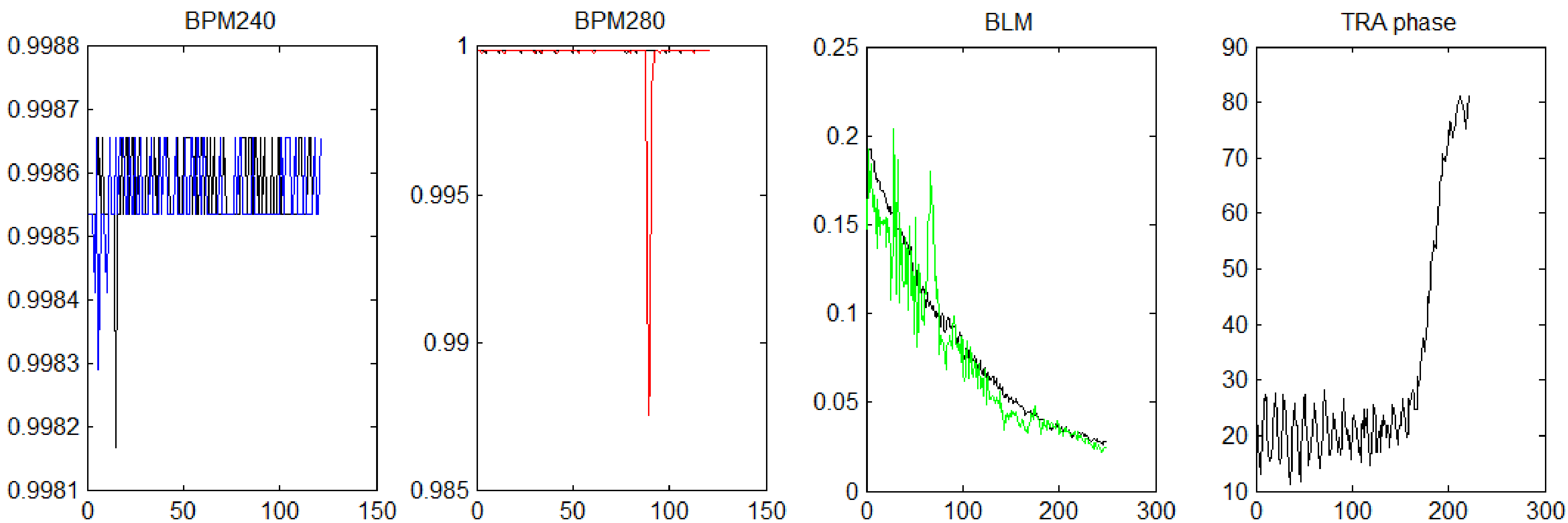
Typical loaded Breakdown



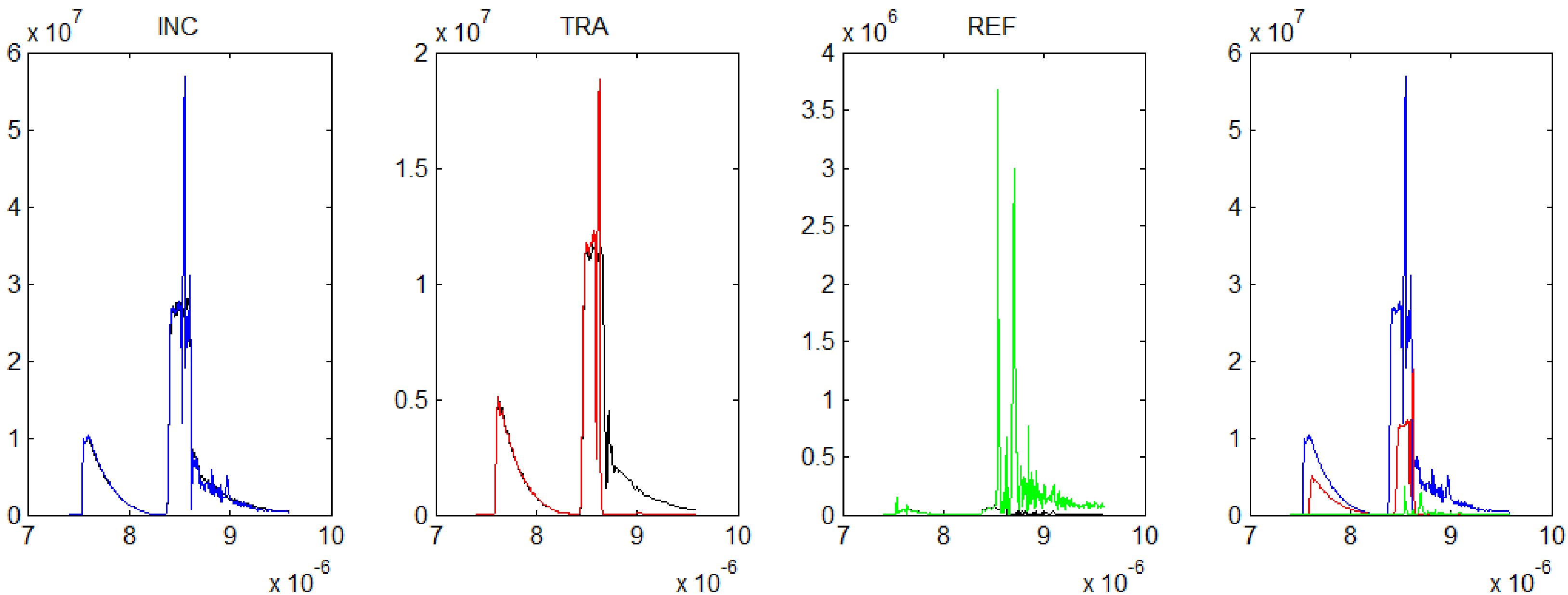
Closer view to some signals



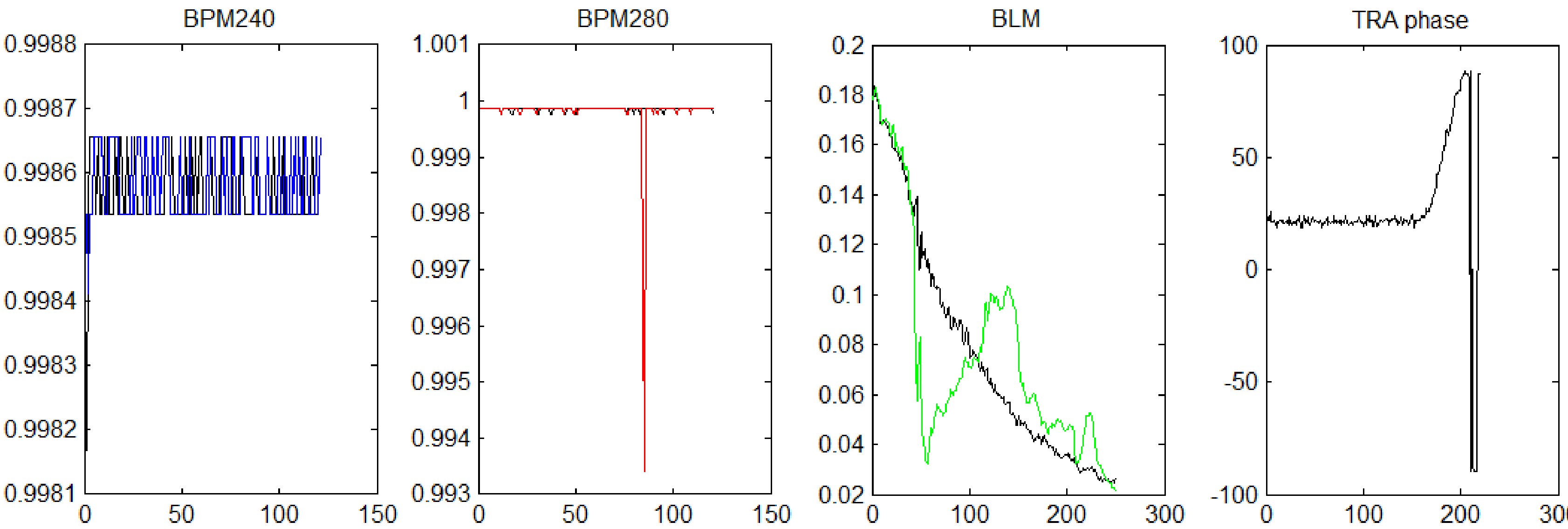
Closer view to some signals



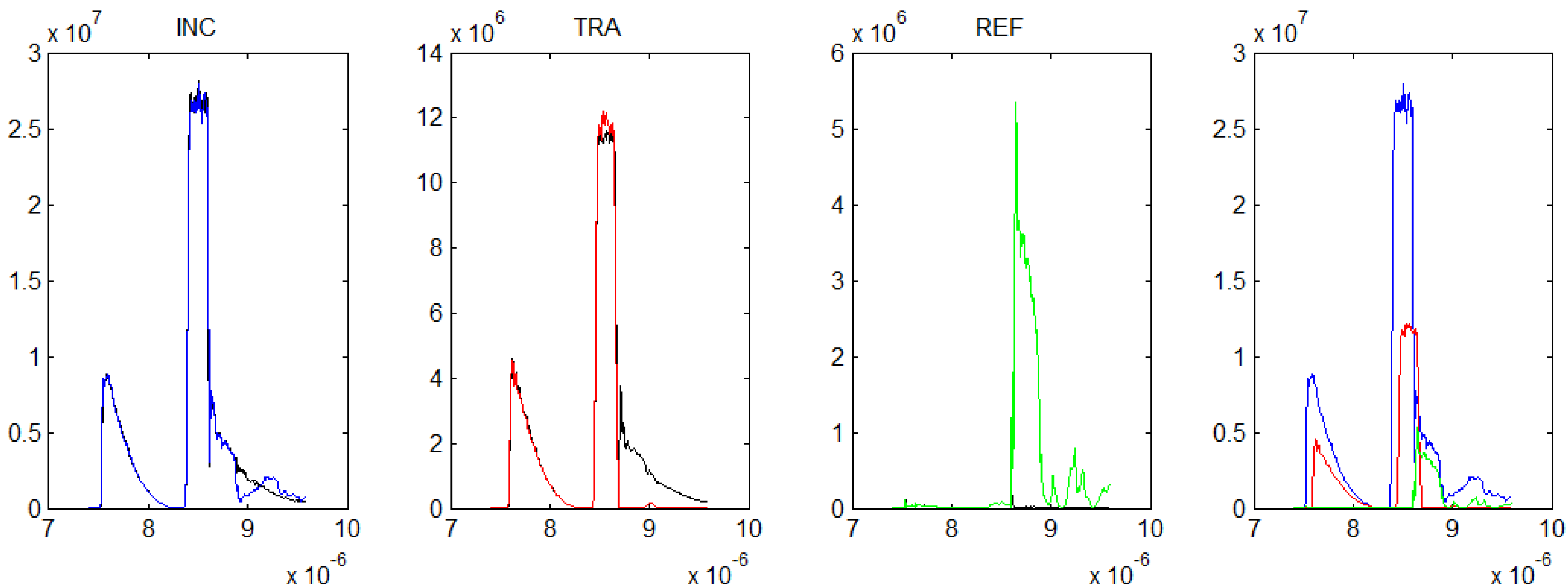
Event selected in this analysis



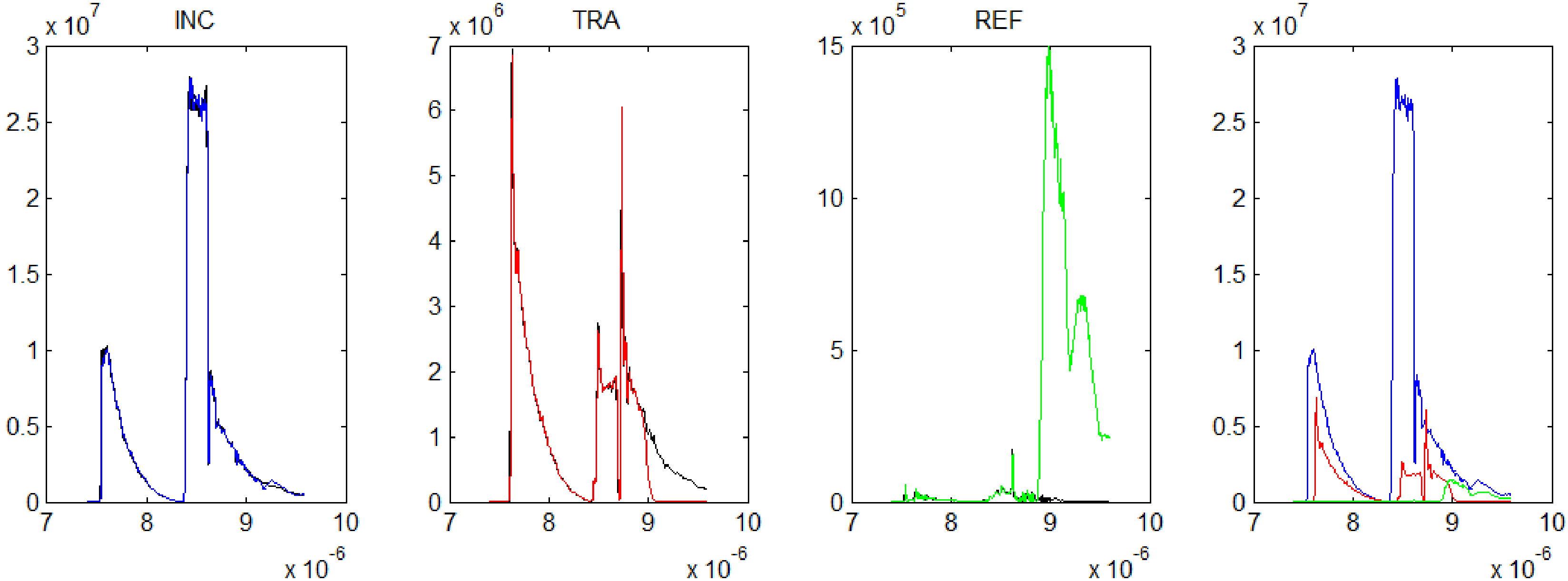
Closer view to some signals



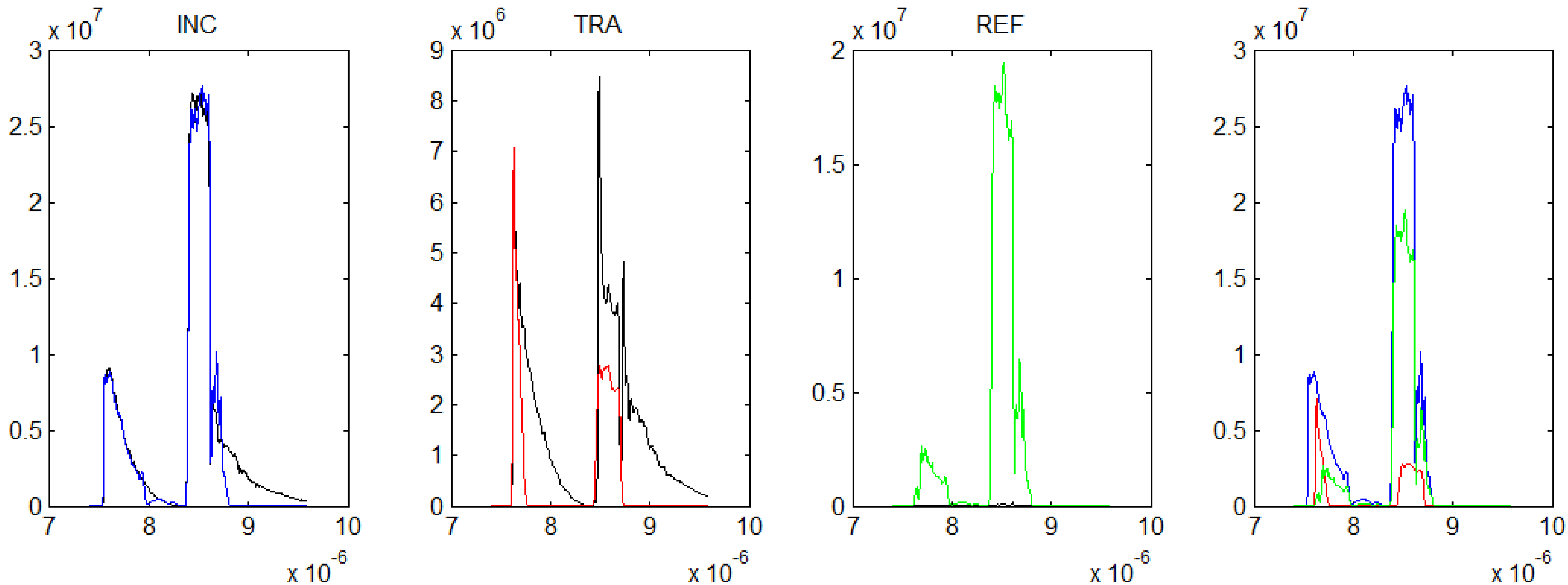
Selected in this analysis but in the limit



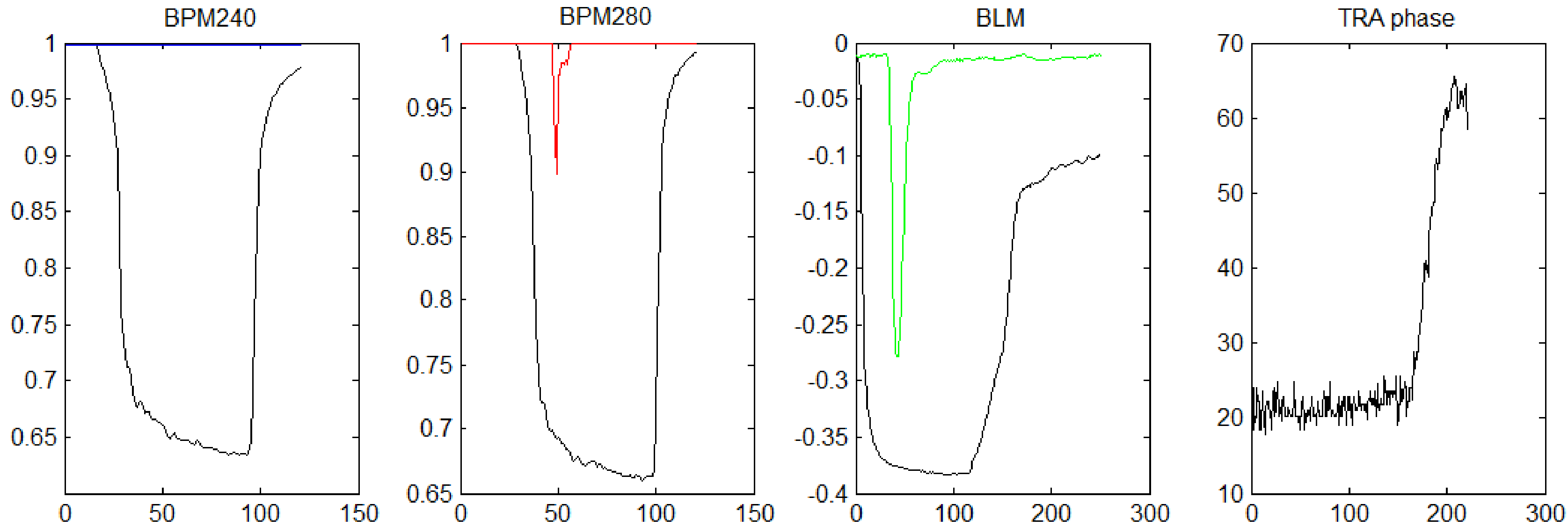
Closer view to some signals



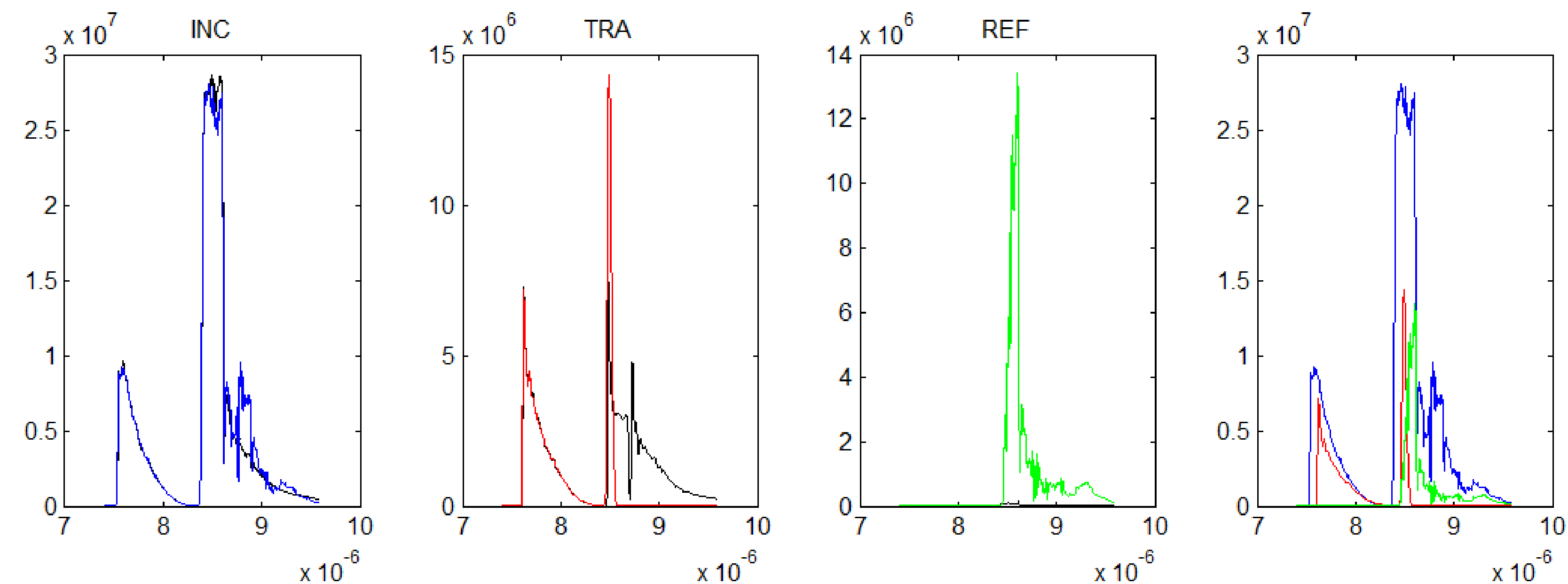
Two not selected breakdowns in loaded condition



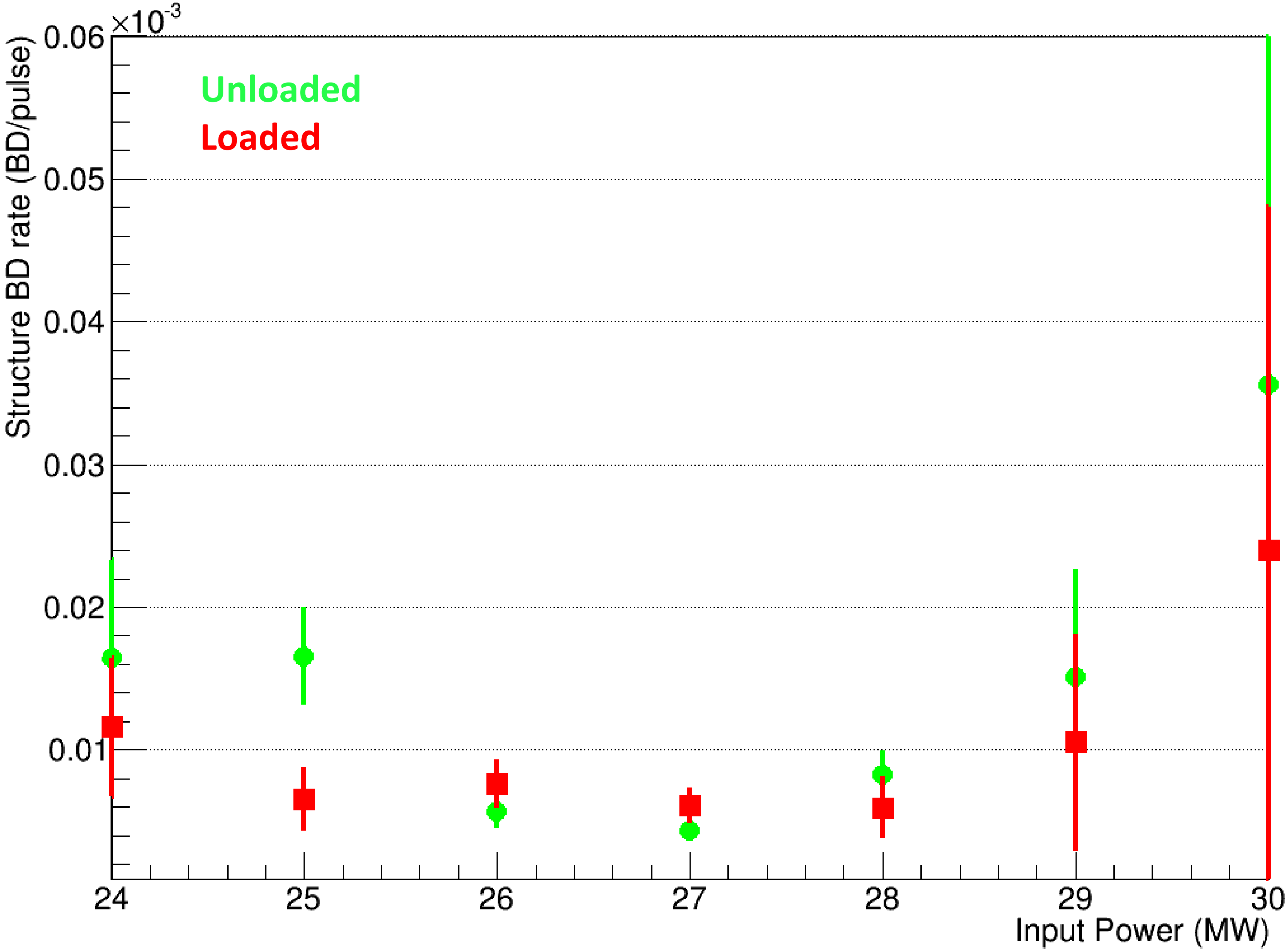
Closer view to some signals



Breakdown in a missed beam pulse. Not selected.

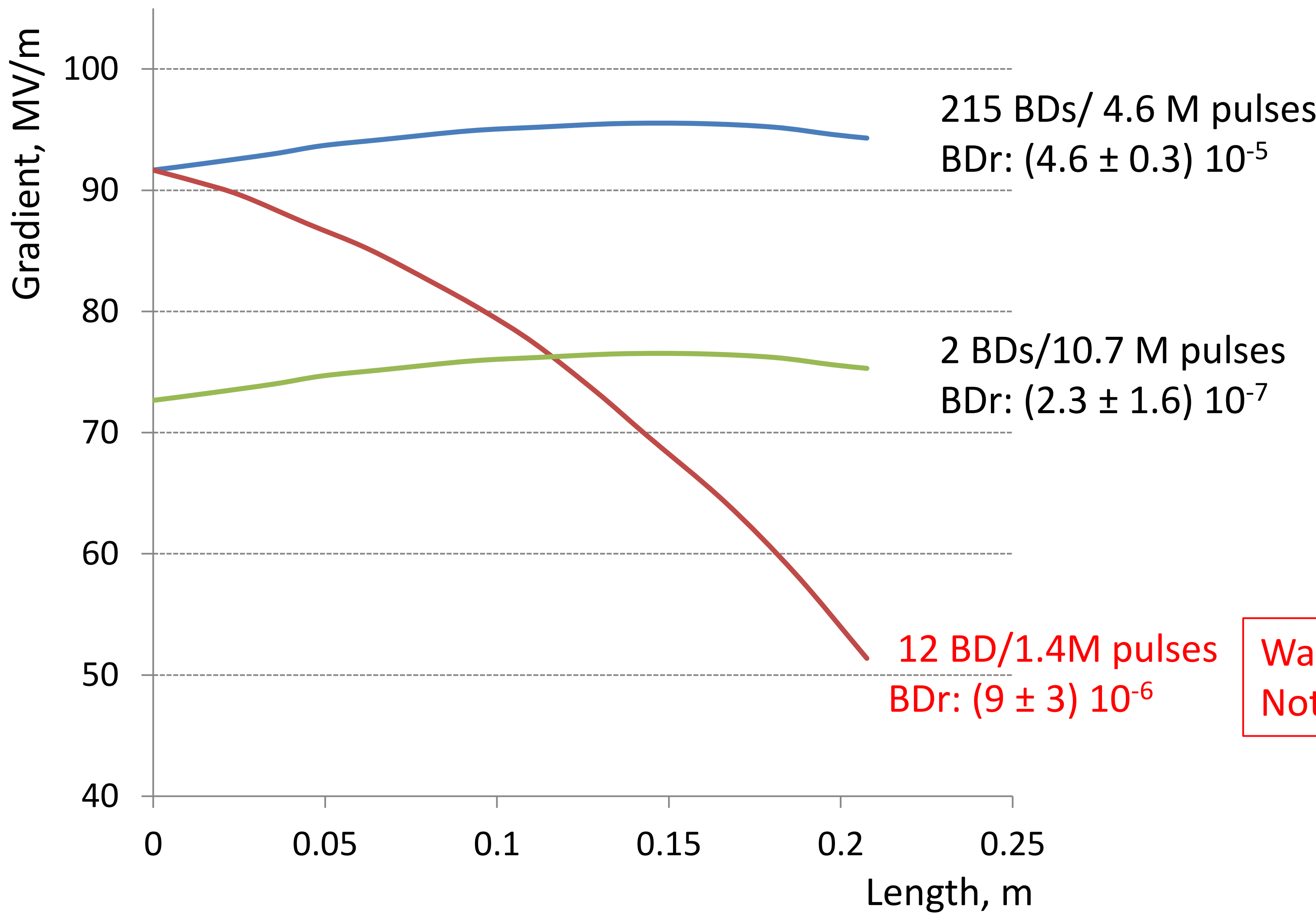


First Results: BDr at constant input Power



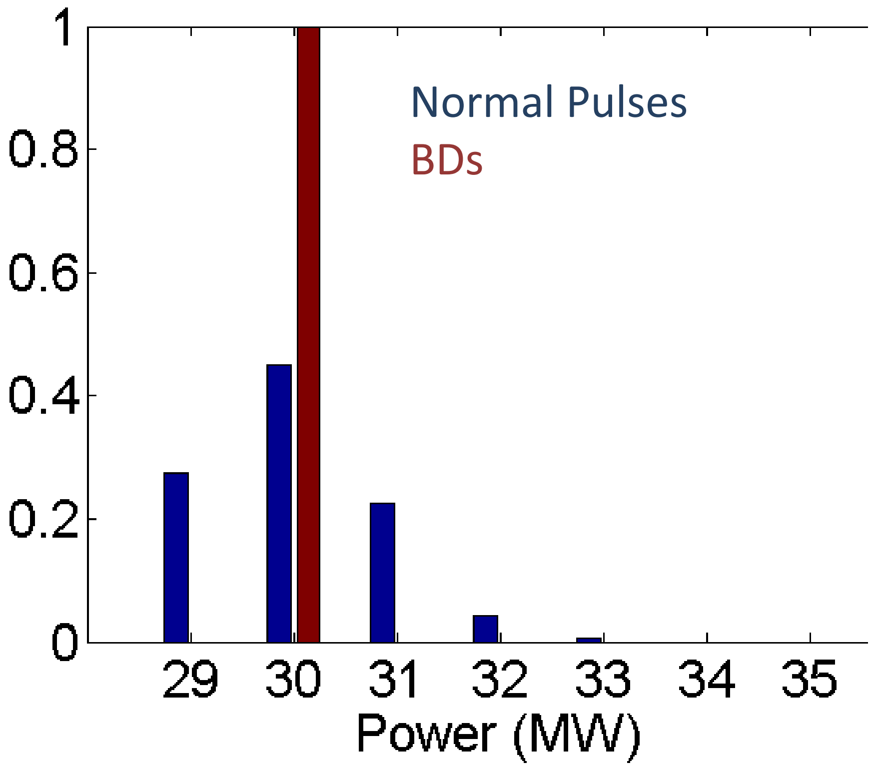
First attempt at constant average gradient

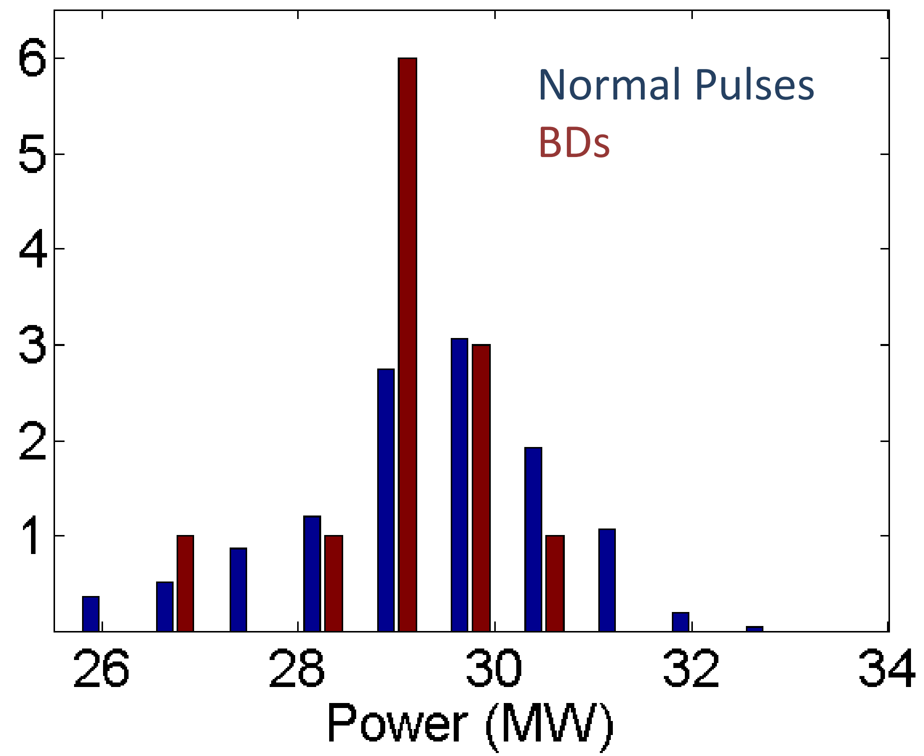
Main goal: Measure loaded and unloaded breakdown rate at same gradient



Warning!!
Not clean conditions

First attempt at constant average gradient



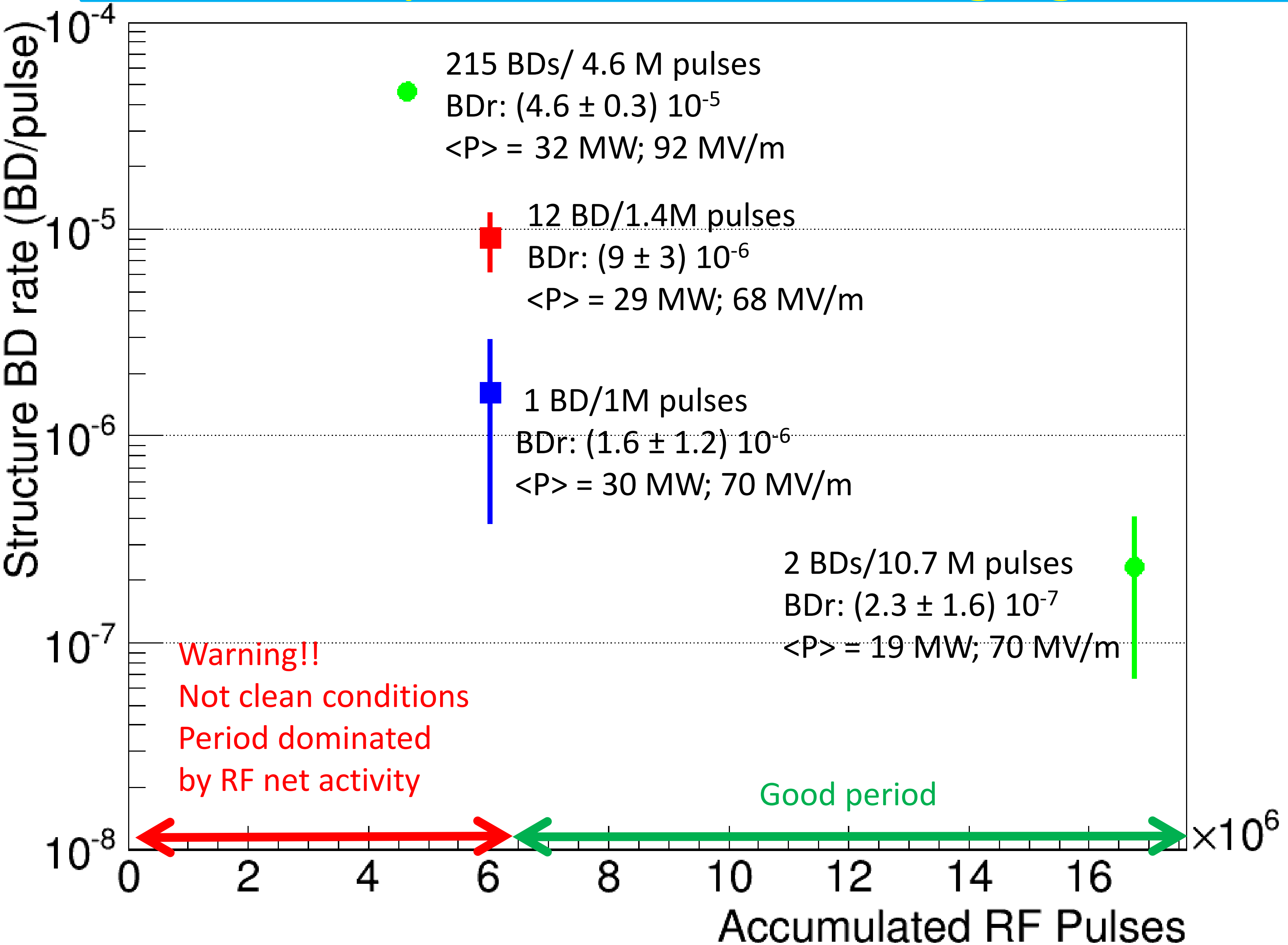


1 BD; <P> = 30MW
1M pulses; <P> = 30MW
BDr: $(1.6 \pm 1.2)\ 10^{-6}$

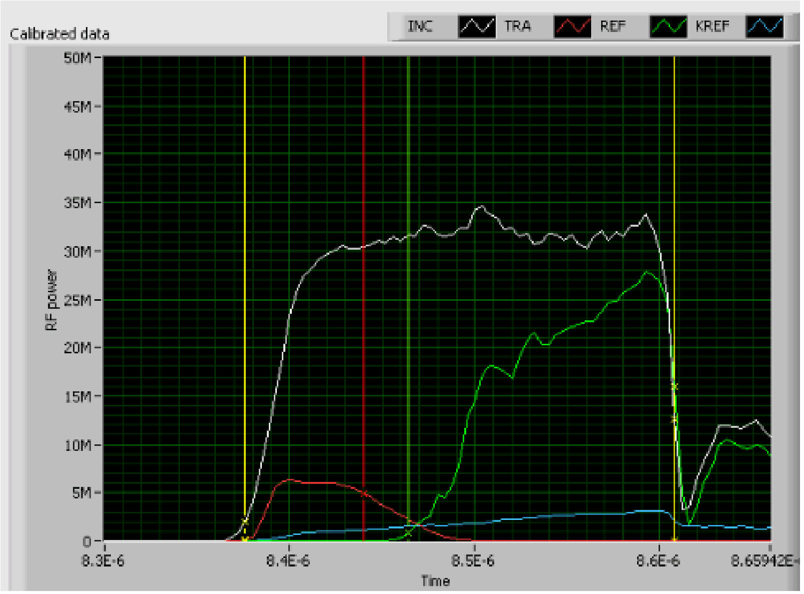
12 BD; <P> = 29 MW
1.4M pulses; <P> = 29.3 MW
BDr: $(9 \pm 3)\ 10^{-6}$

Loaded measurement with different cuts in power

First attempt at constant average gradient



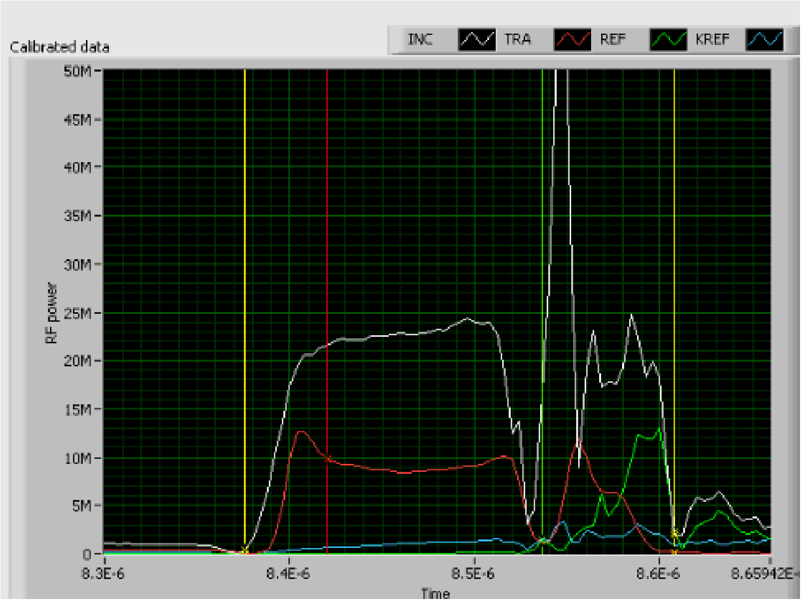
First Results: BDr at constant input Power

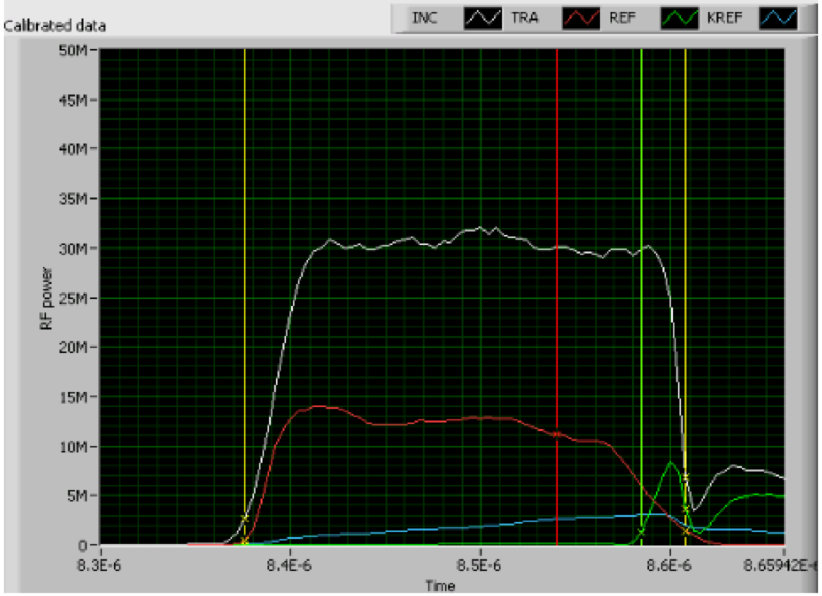


Break down cell distribution for unloaded data.

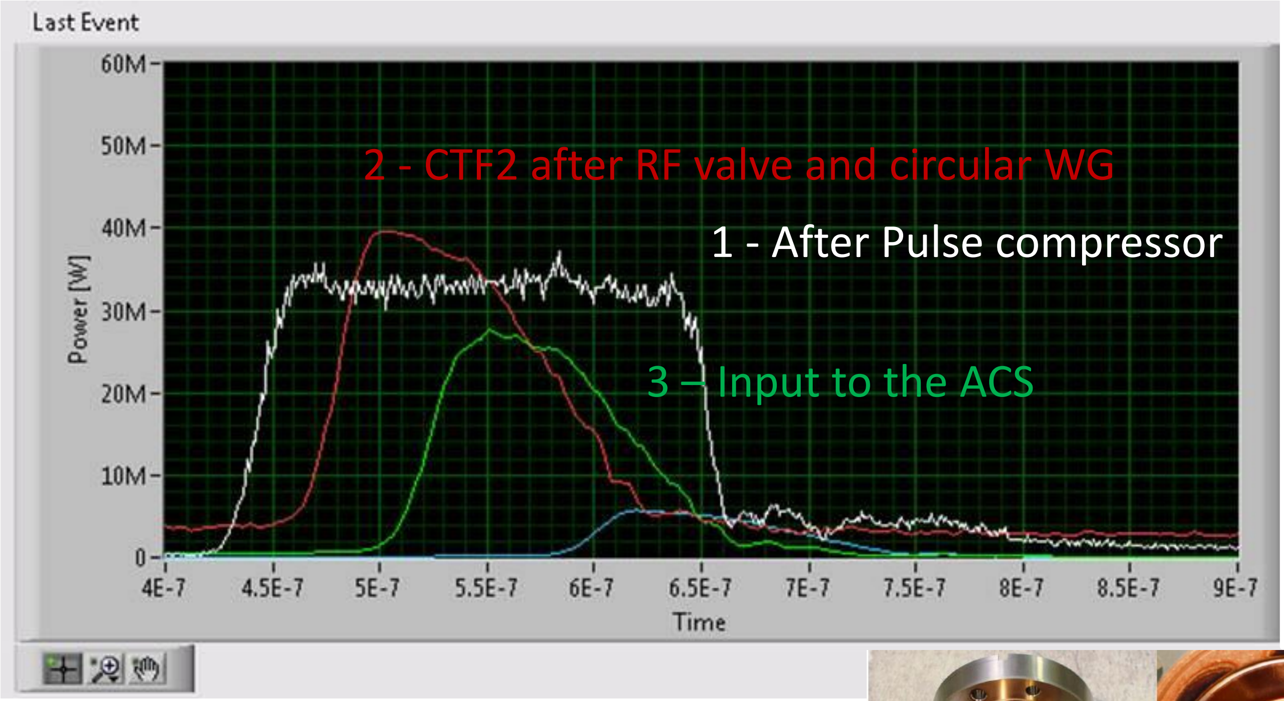
Cell distribution for loaded periods still under analysis.

Acknowledgement: A. Degiovanni





Current limitation

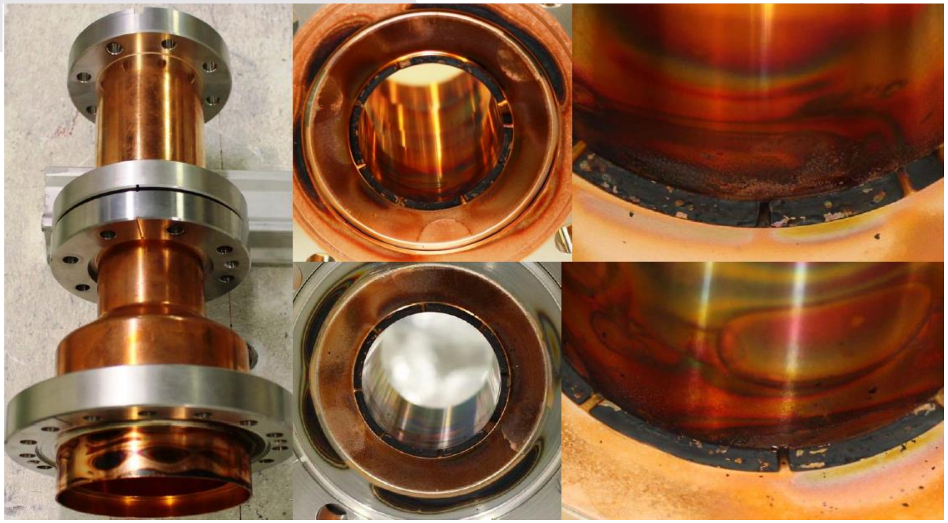


Signals collected by A. Degiovanni

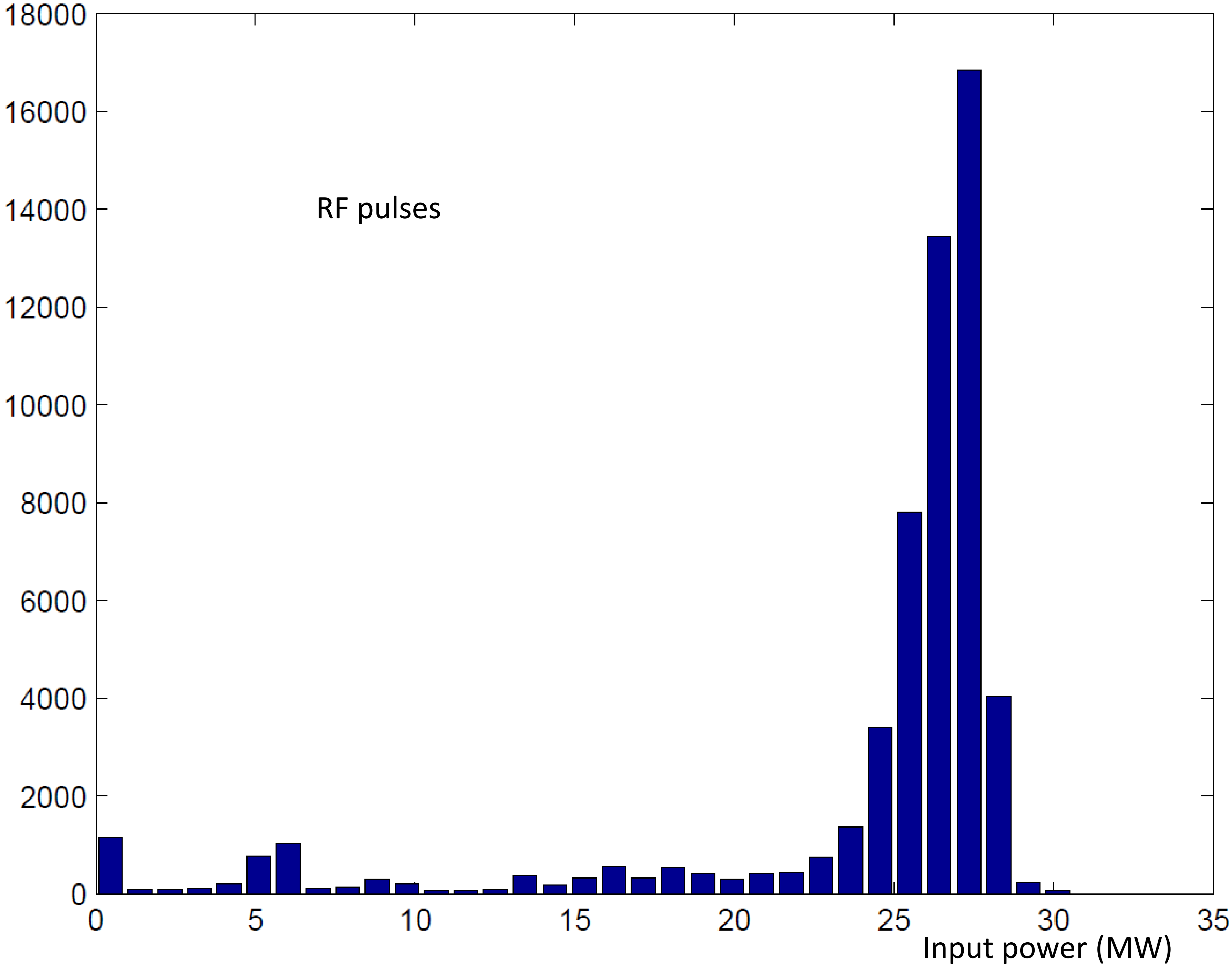
Pulse is chopped after the circular waveguide

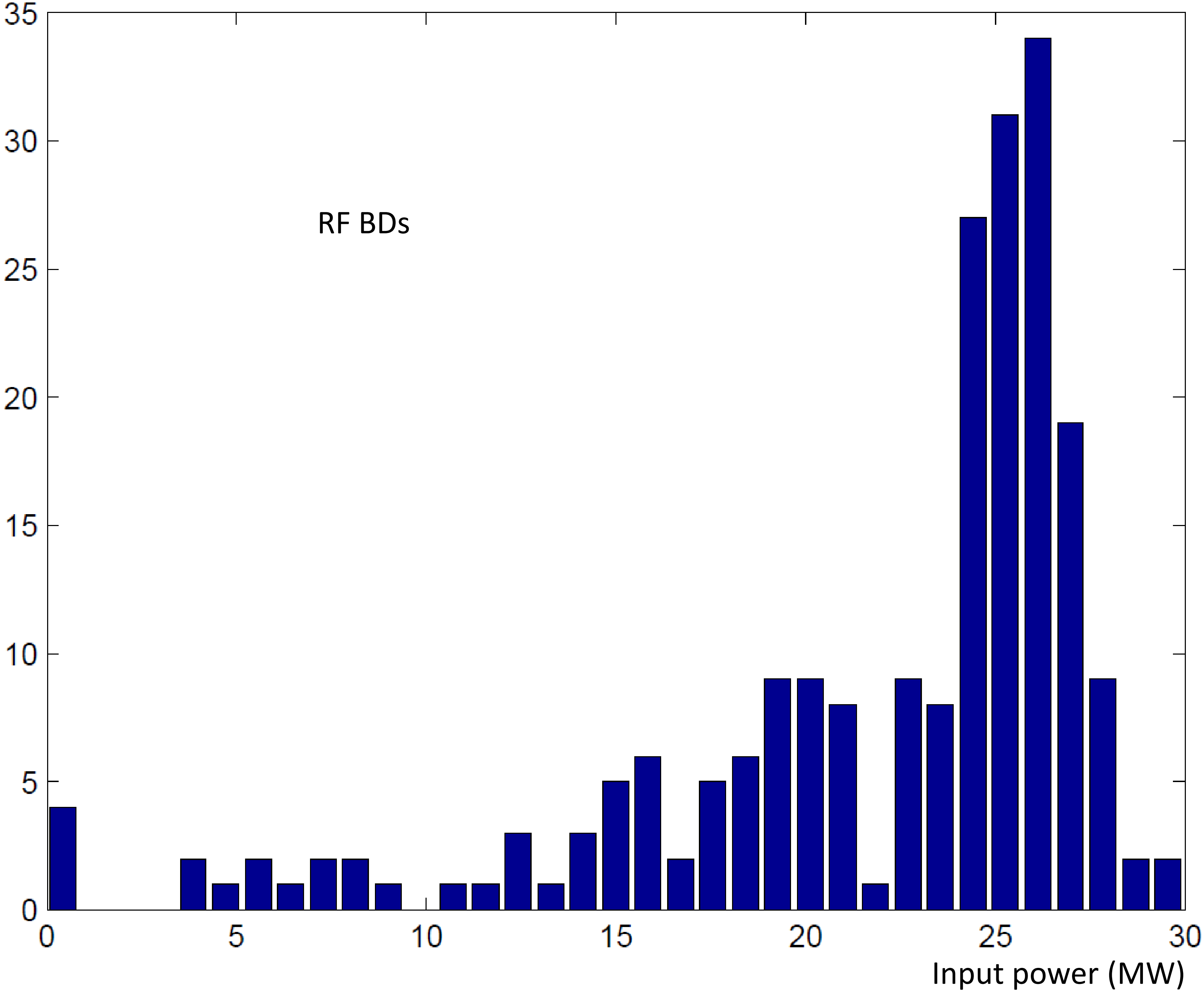
High activity in the RF network near a RF valve above 31 MW (at the structure)

High power is real!



Courtesy of A. Olyunin and I. Syratchev


18000
16000
14000
12000
10000
8000
6000
4000
2000
0
RF pulses
0
5
10
15
20
25
30
35
Input power (MW)


35
30
25
20
15
10
5
0
RF BDs
0
5
10
15
20
25
30
Input power (MW)

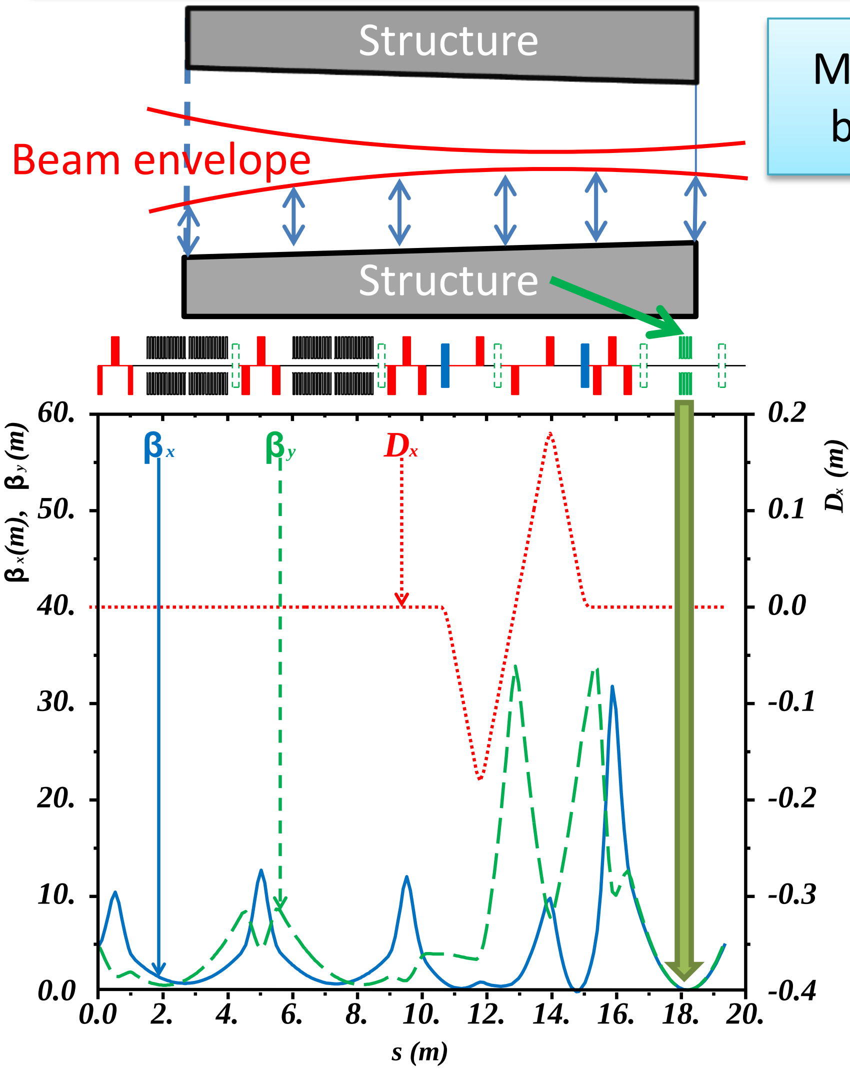
Backup: CLIC Nominal parameters

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

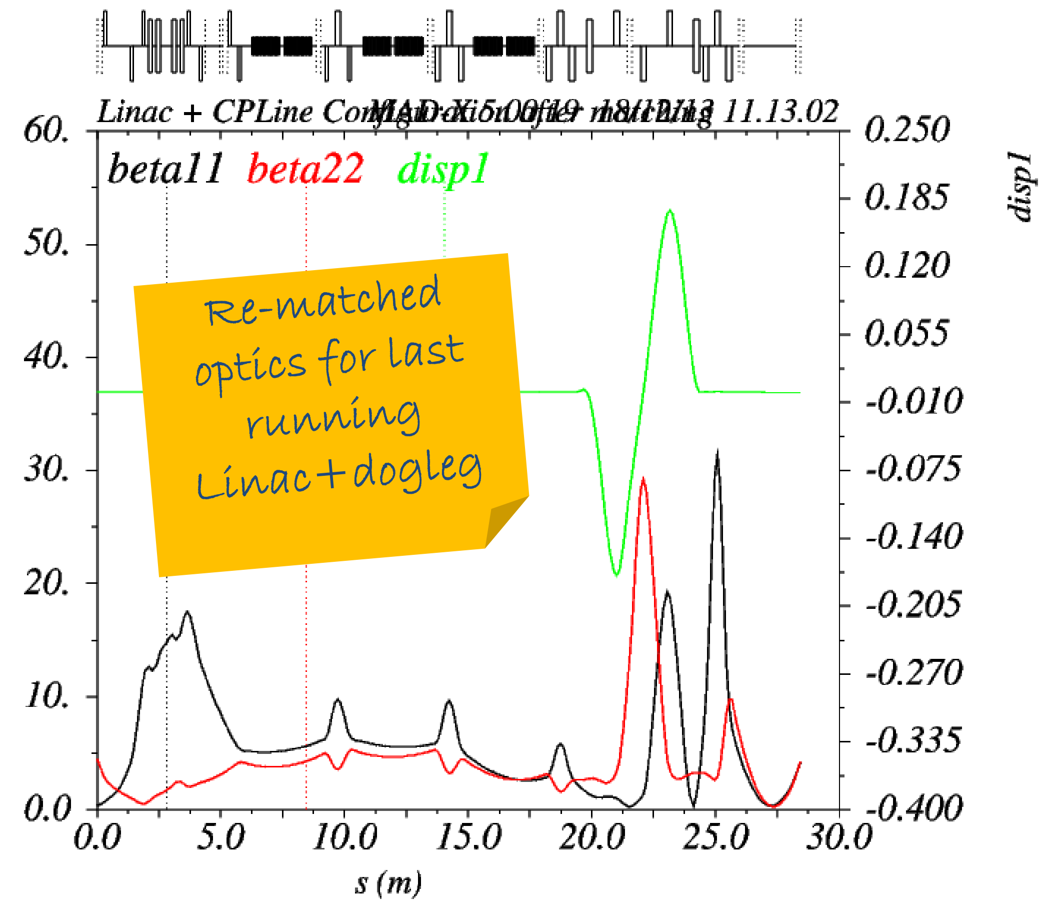
J.L. Navarro. CLIC Project Meeting, 16 December 2014

Optics design

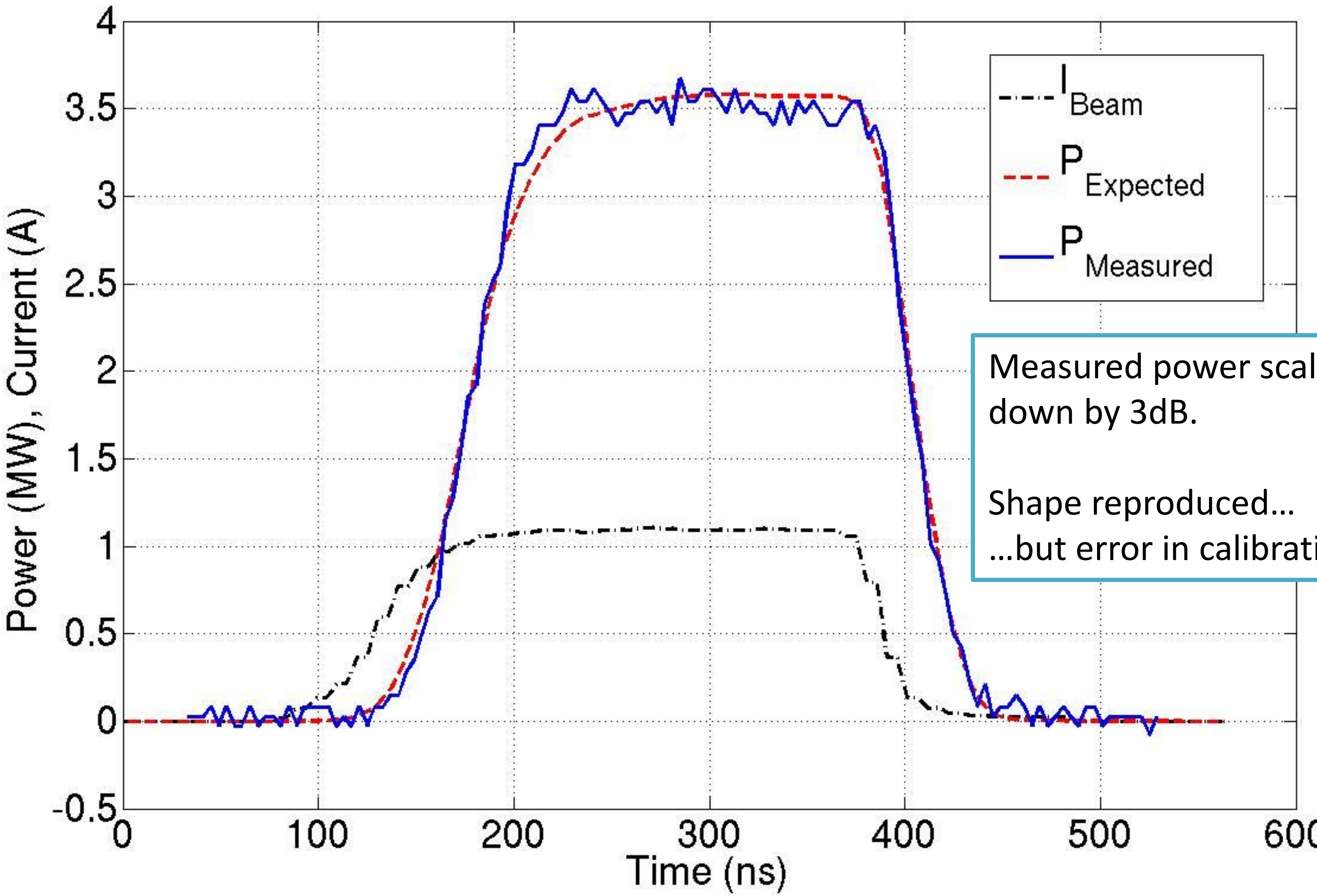
Objective: Transport the beam trough the Linac up to the structure requiring…
- Full transmission efficiency
- Minimum beam size on average inside the structure



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



Phase I Results: Running of May 2013

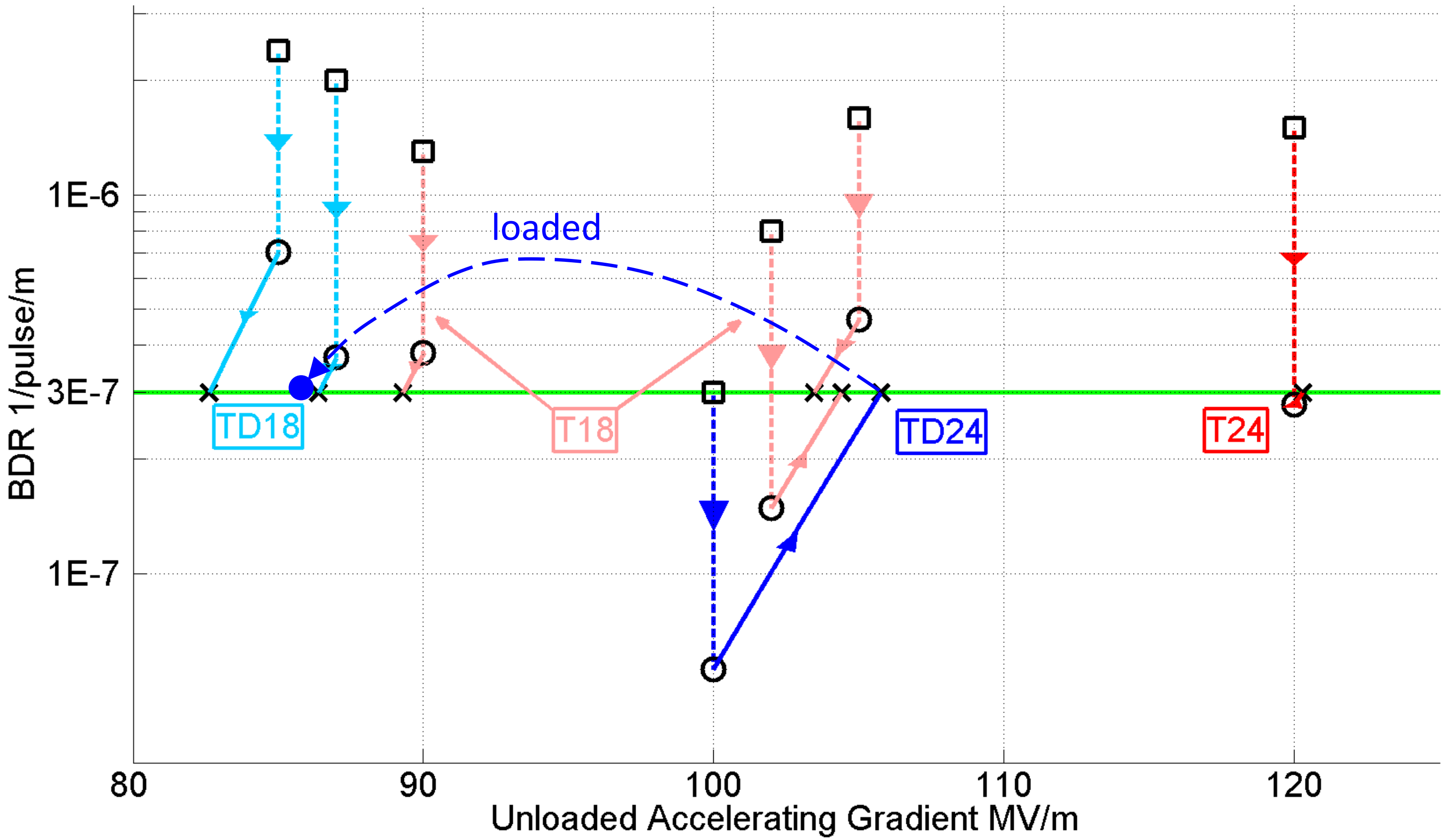


Measured power scaled down by 3dB.

Shape reproduced…
…but error in calibration

Backup

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

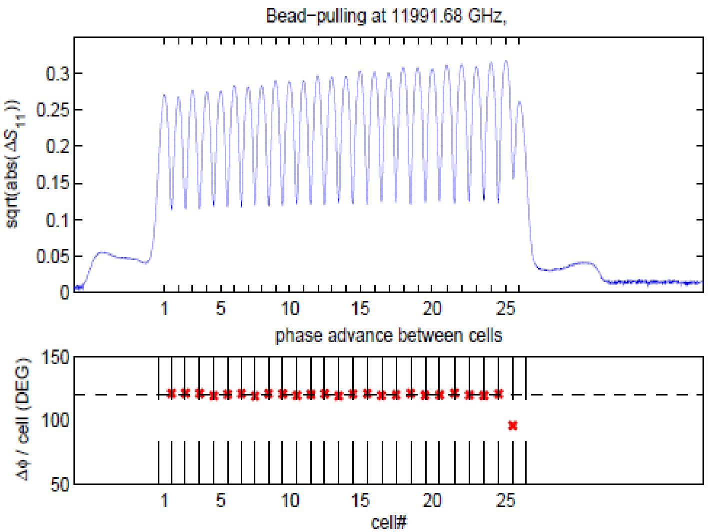


Backup (I. Syrachev. CLIC Workshop 2013)

Structure under test:

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

No damping



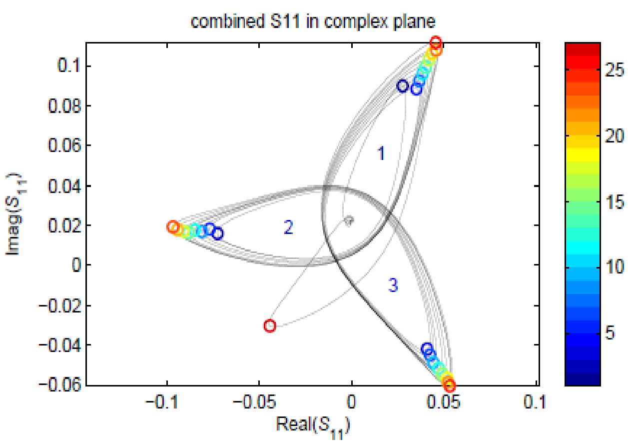


Figure 10: Bead-pulling at 11991.68 GHz

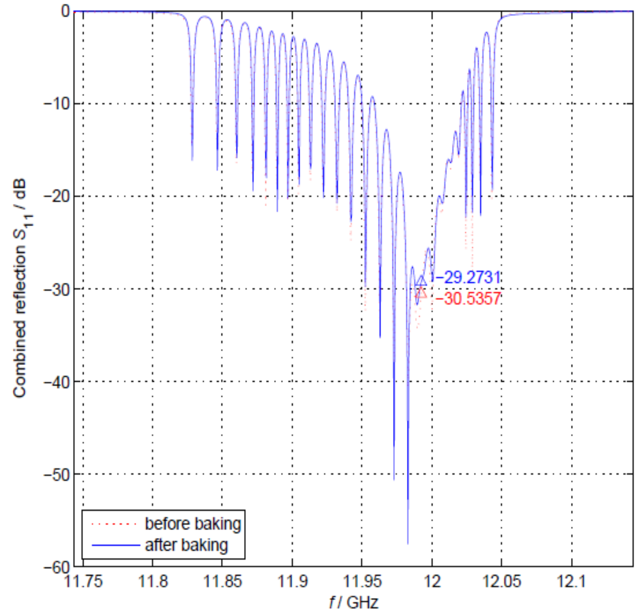


Figure 1: Reflection at input

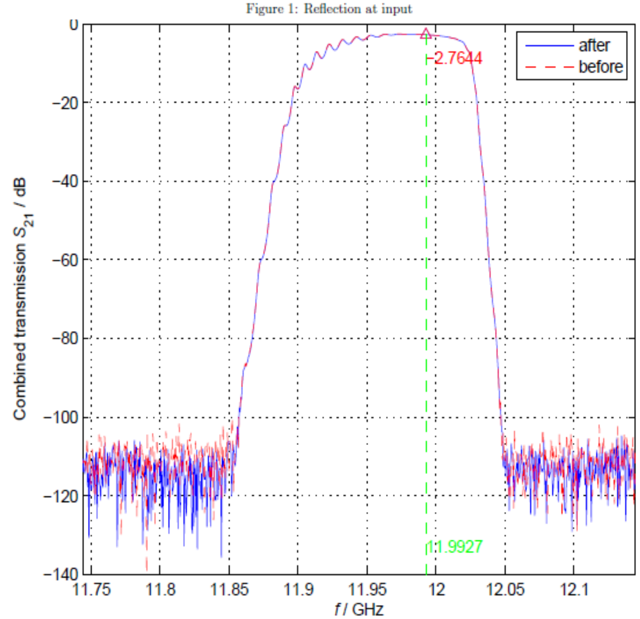
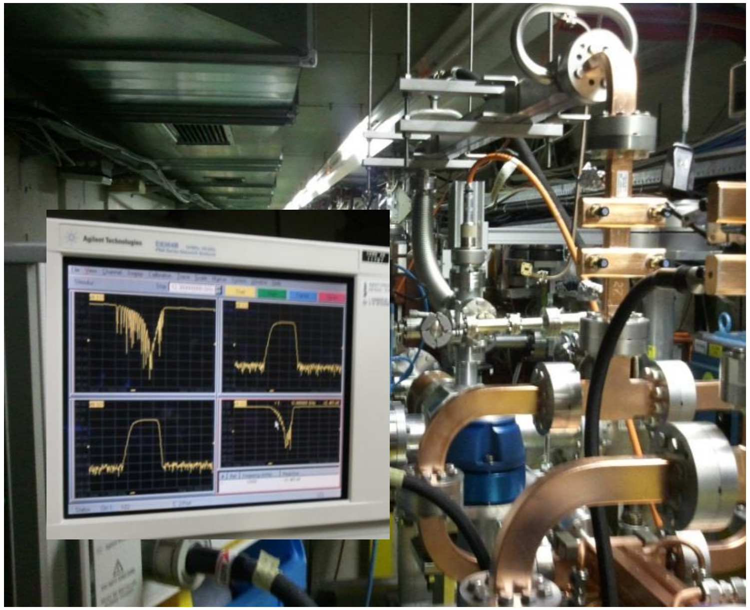
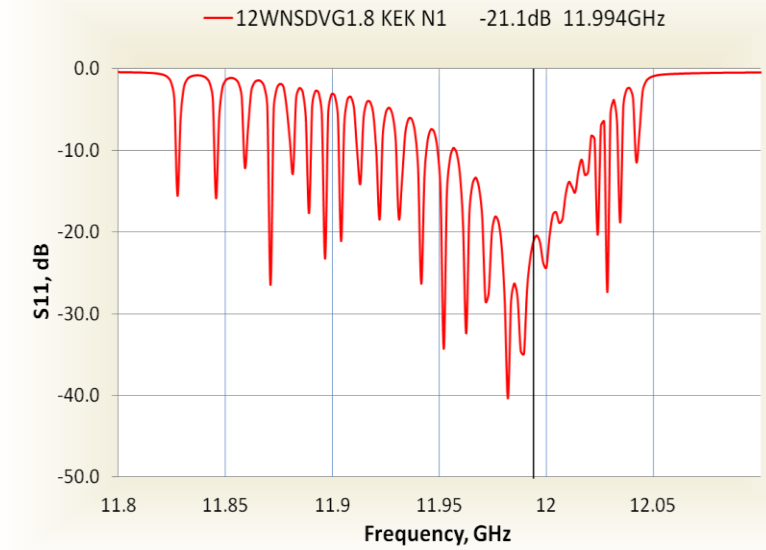
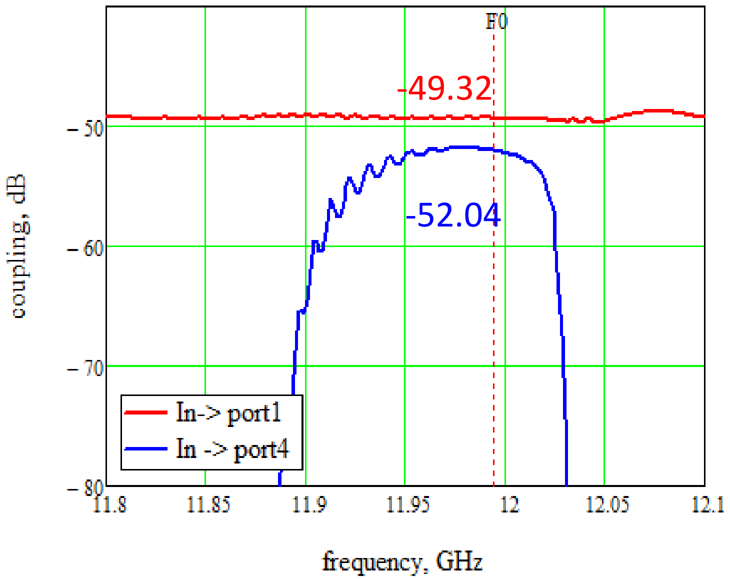


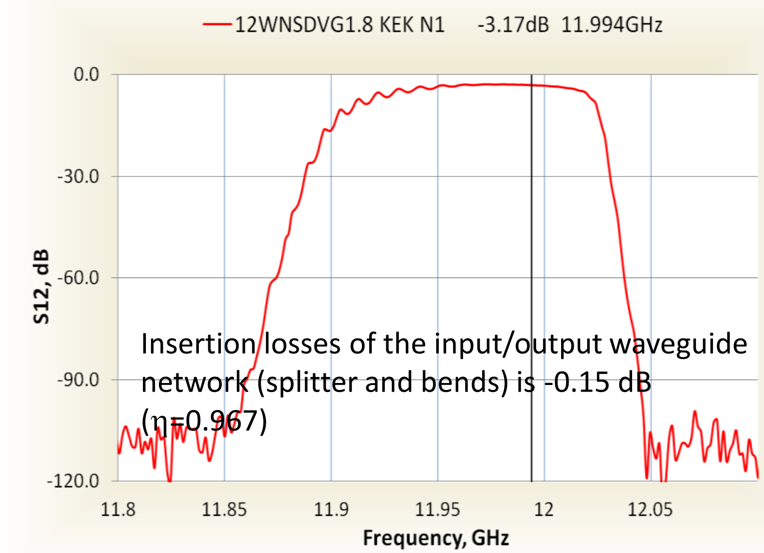
Figure 5: Combined transmission from input to output

Calibration (I. Syrachev. CLIC Workshop 2013)

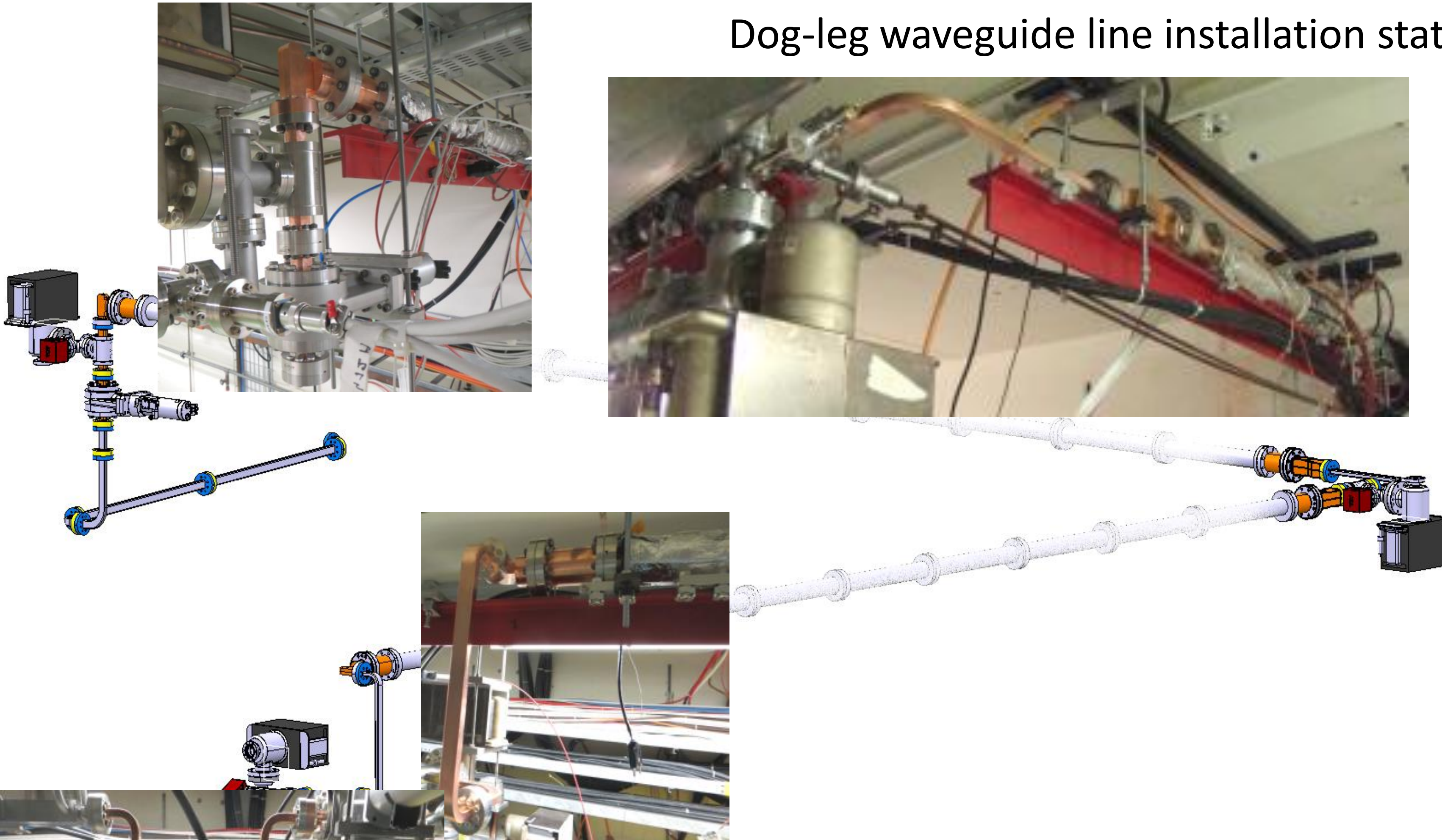


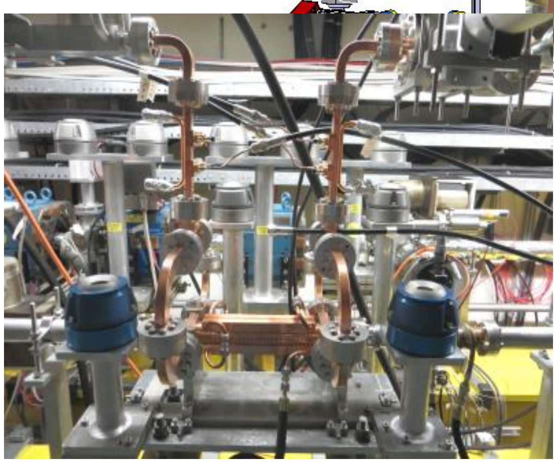






Dog-leg waveguide line installation status.



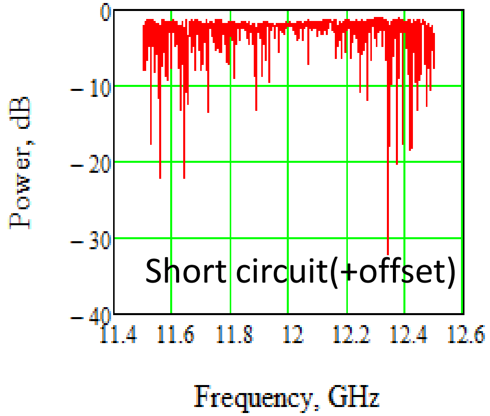


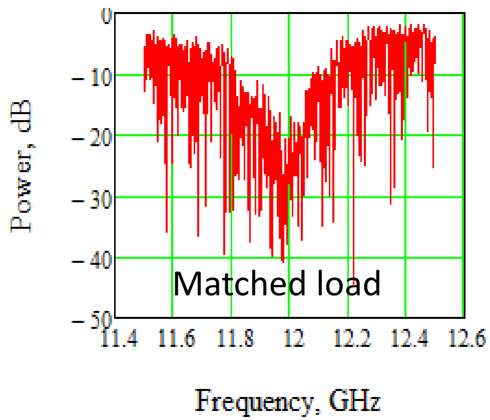
- ✓ All the components are installed.
- ✓ Connected to accelerated structure and closed for vacuu
- ✓ Vacuum leaks checked (tight).

Ready to be connected to XBOX1

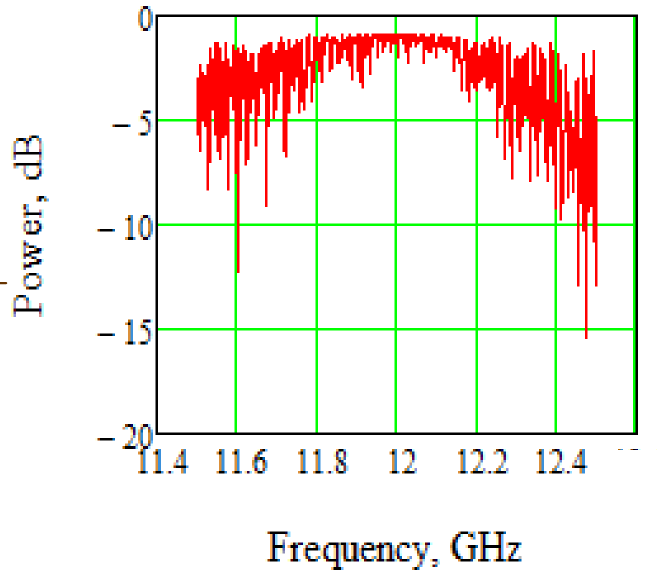
RF power transmission measurements

S11 data

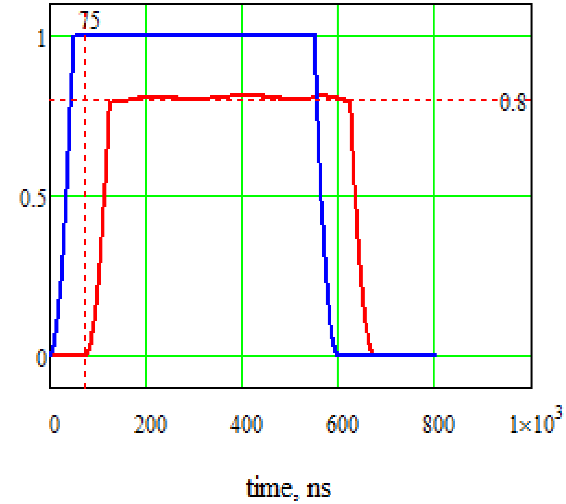




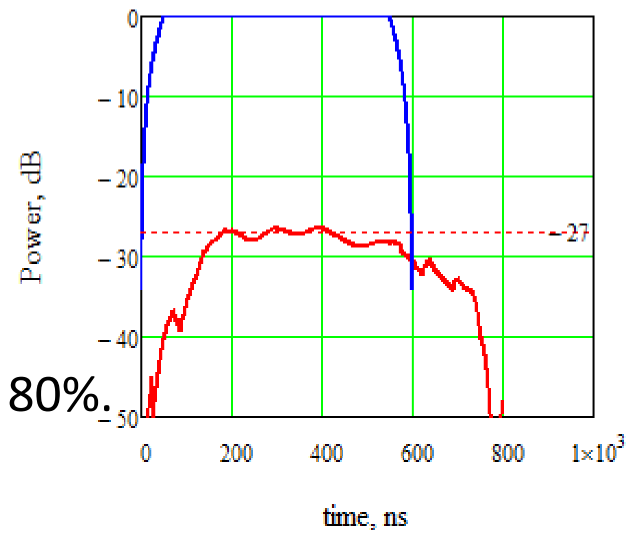
S21 Reconstructed
(Xiaowei Wu)



Transmission (simulated)



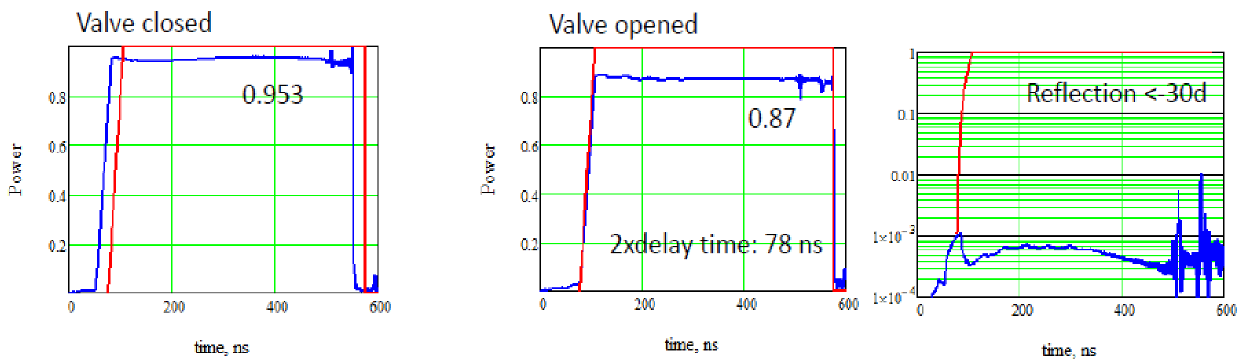
Reflection

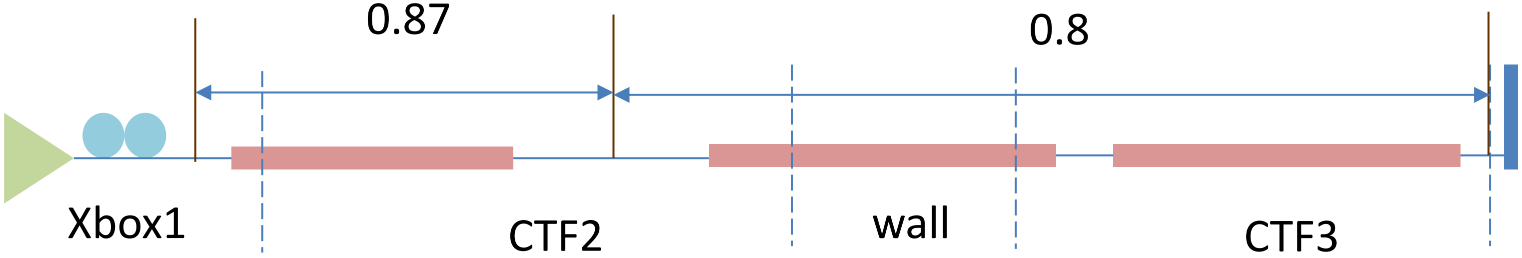


- The measured RF power transmission efficiency is 80%.
- Reflection is below -27dB.
- The group delay time is 75 ns (~23.5 m).

Overall power transmission efficiency

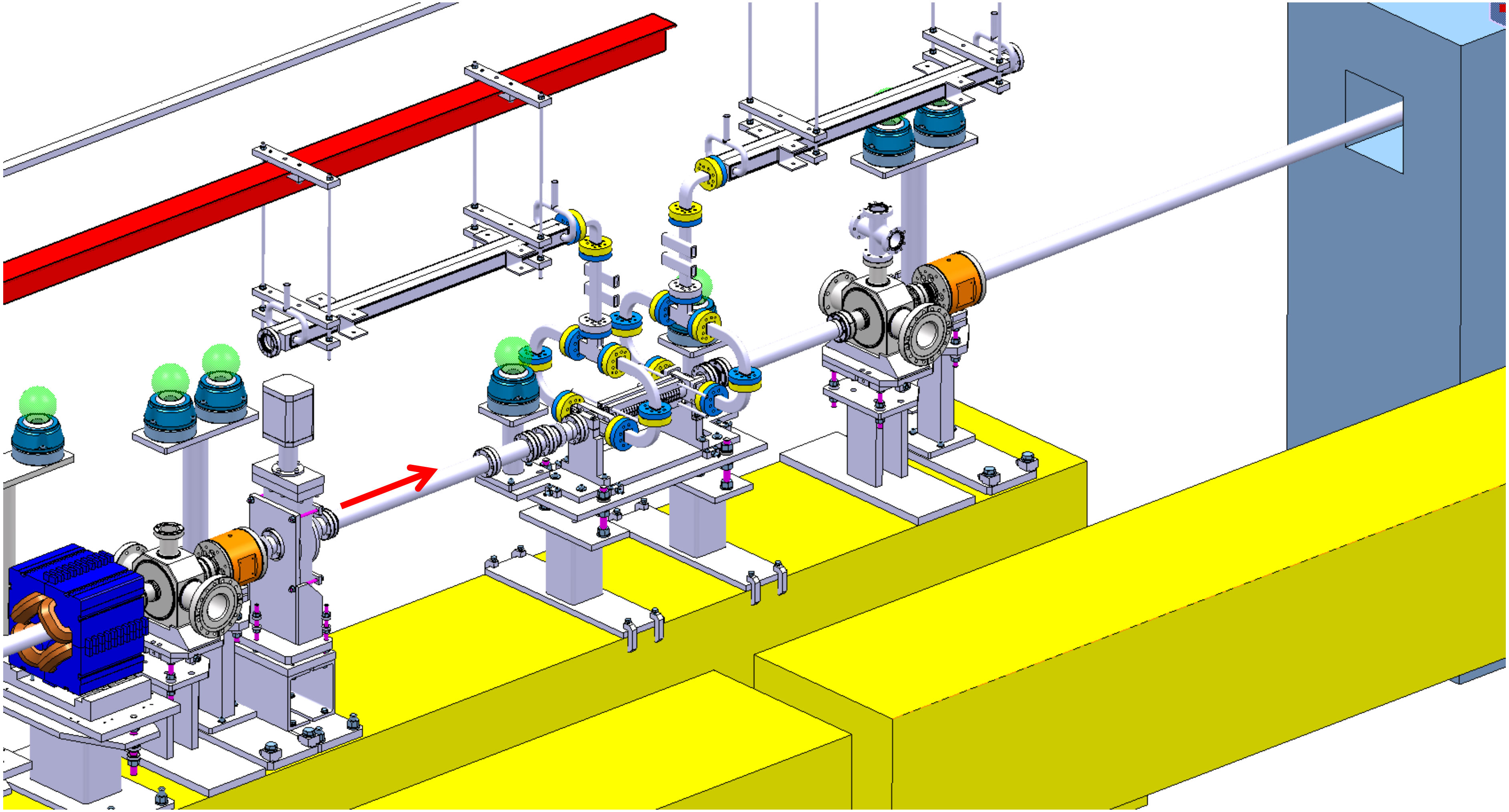
One way loses in the WG line. From just after PC to the -3dB hybrid in CTF#2



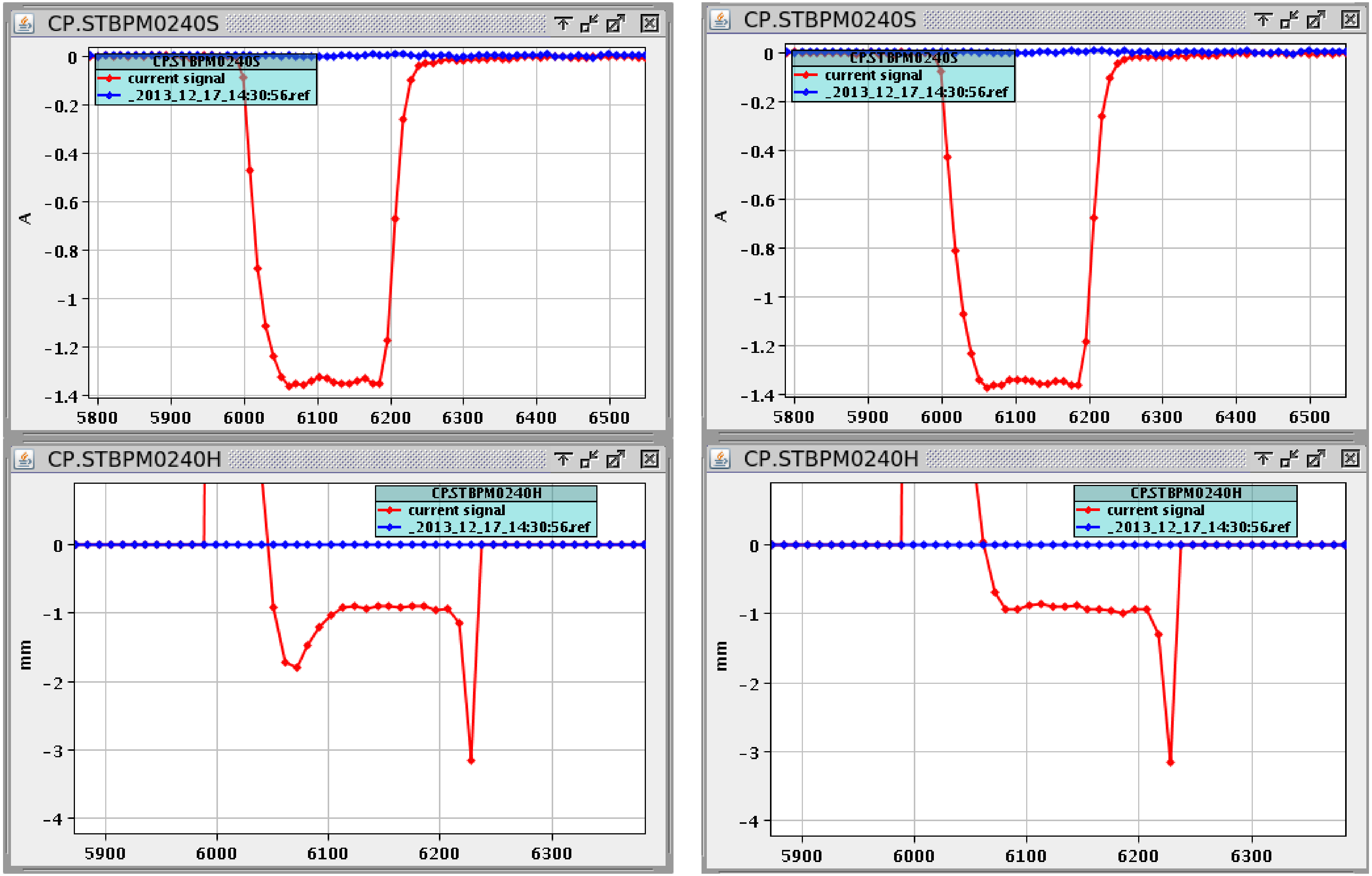


- The overall measured RF power transmission efficiency is 67%.
- The round group delay time is 230 ns (~35 m).
- To provide nominal CLIC RF pulse, XBOX1 klystrons needs to deliver 36 MW x 1.5

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
current signal
_2013_12_17_14:30:56.ref
mm
-1
-2
-3
-4
6000
6100
6200
6300

Phase I Results: Running of Dec 2013

And from the RF side: