CLIC High-Gradient Development Program Update

LCWS2014, Belgrade, 9 October 2014

Walter Wuensch, CERN

Where are we now?

Overall - we can build prototype accelerating structures and run them (very close) to specification in our test stands. We have identified priorities for the coming years:

- Higher performance – gradient, BDR and power efficiency through rf optimization, linac re-baselining and optimization, improved high-gradient physics understanding. New materials…
- Run much more – statistics, yield, lifetime through increased testing capacity, commercial klystrons, expanded X-band and high gradient user community
- Bring the cost down – rf and linac optimization, process optimization, mechanical design, expanded X-band and high gradient user community

Overview of our development program

- Rf structure development program
  - Integrated linac/rf design
  - High-power prototype test structures
  - Manufacturing, procedure optimization
- Klystron-based test stands
  - Klystron/modulator procurement and recently also design
  - High-power rf component zoo
  - High-power prototype tests
  - Conditioning and operation algorithm development
- Fundamental high-gradient studies
  - dc experiments
  - Theory and simulation
  - Fabrication and surface preparation process optimization
- X-band outreach
  - Accelerator components – energy spread linearizers, transverse deflectors, crab cavities
  - Applications – XFELs, medical linacs, etc.

Introduction

My colleagues and I will present to you some important highlights from the high-gradient program. My colleagues will cover:

- Status of high-power rf at CERN – klystrons, waveguide components and test stands Igor Syratchev
- An experiment to determine the effect of beam loading on breakdown rate Luis Navaro
- Structure production – current status and future directions Anastasia Solodko and Carlo Rossi
- High-efficiency klystron development (in general, not just X-band and high-gradient) Igor Syratchev

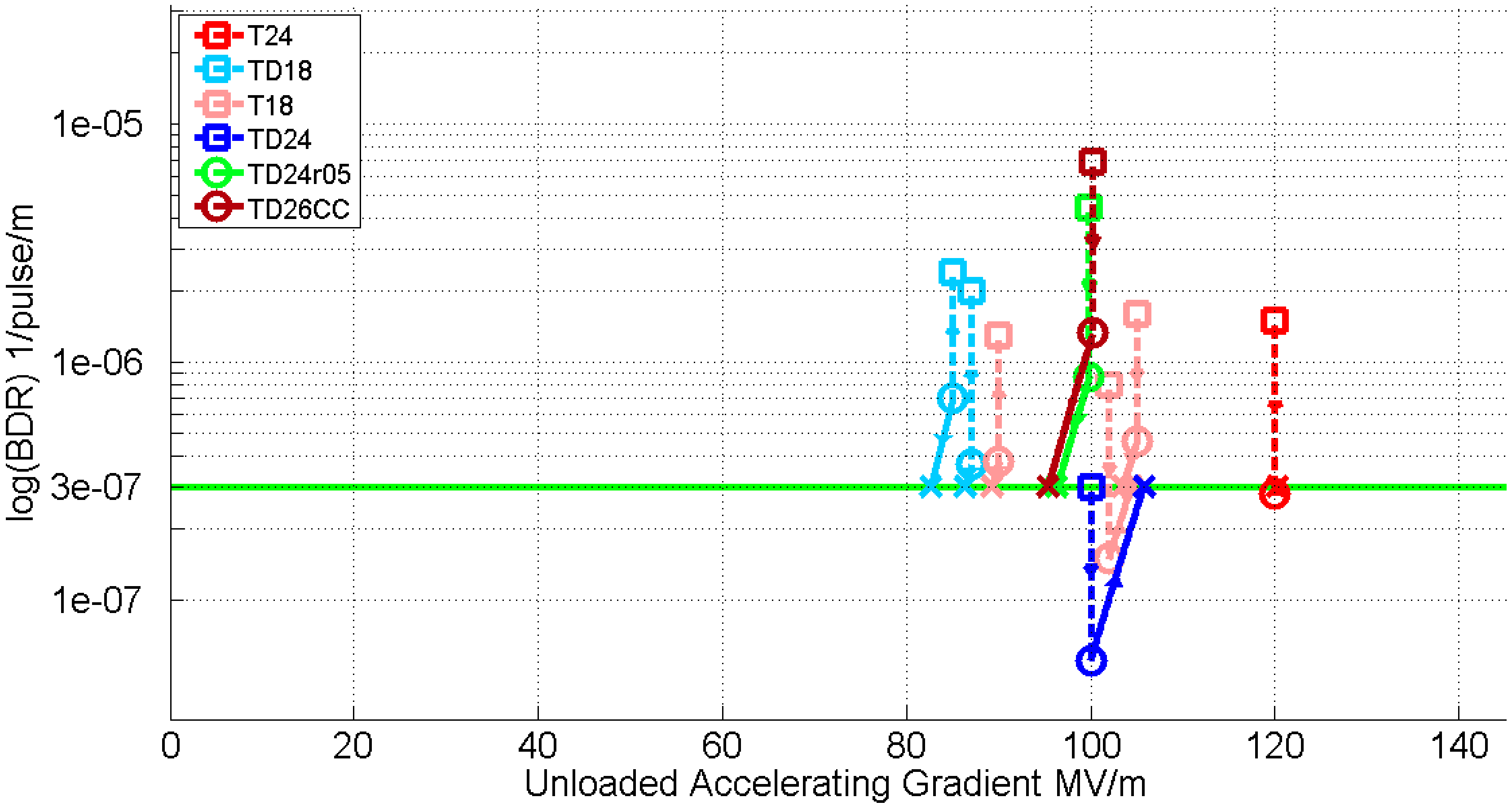
Introduction

I’ll now cover:

- Insights into conditioning
- dc high-gradient for process optimization
- Rf design progress
- X-band and high-gradient outreach efforts (also covered by Daniel Schulte on Monday)

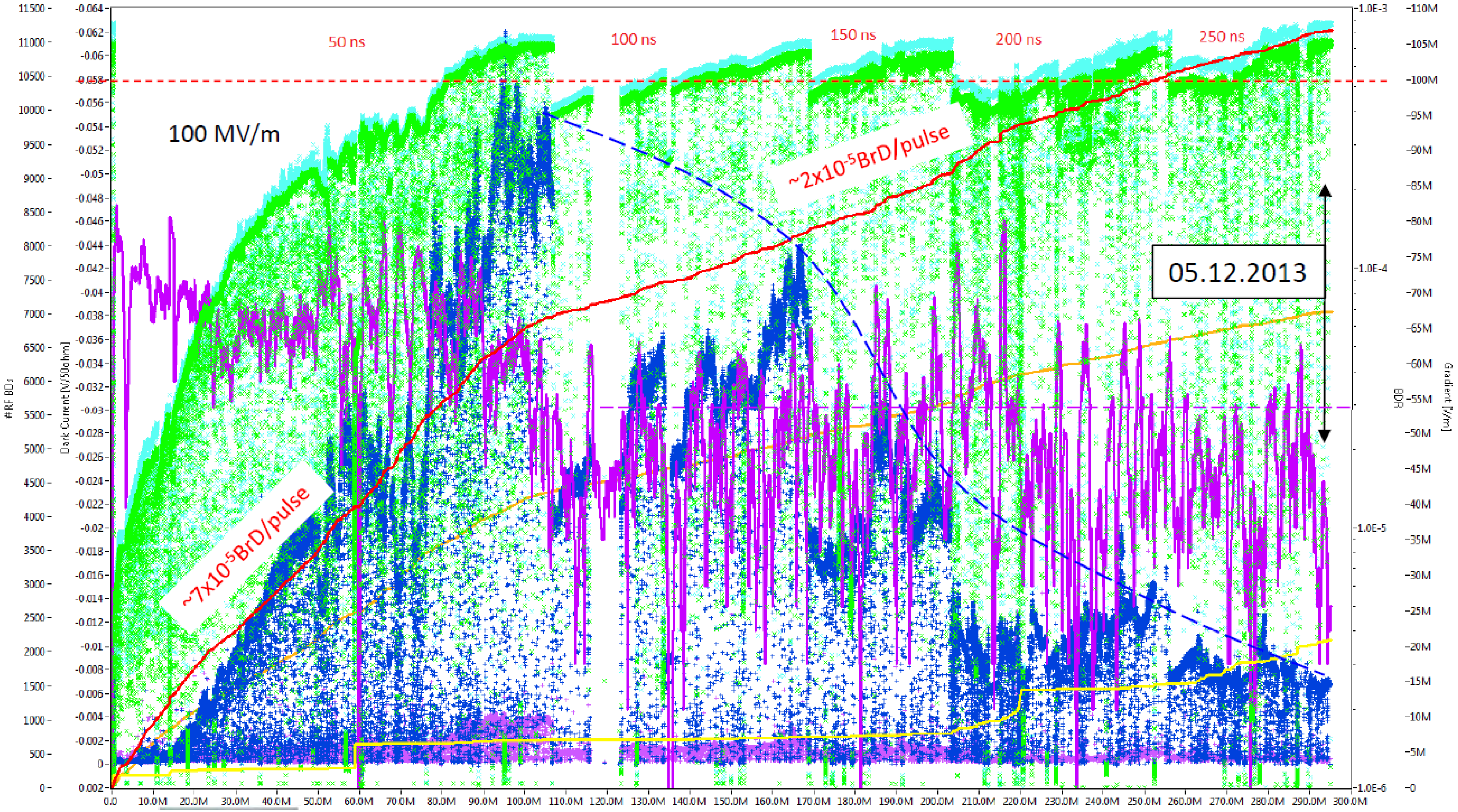
Status

High-gradient performance summary



Conditioning

CERN TD26R05CC conditioning history plot



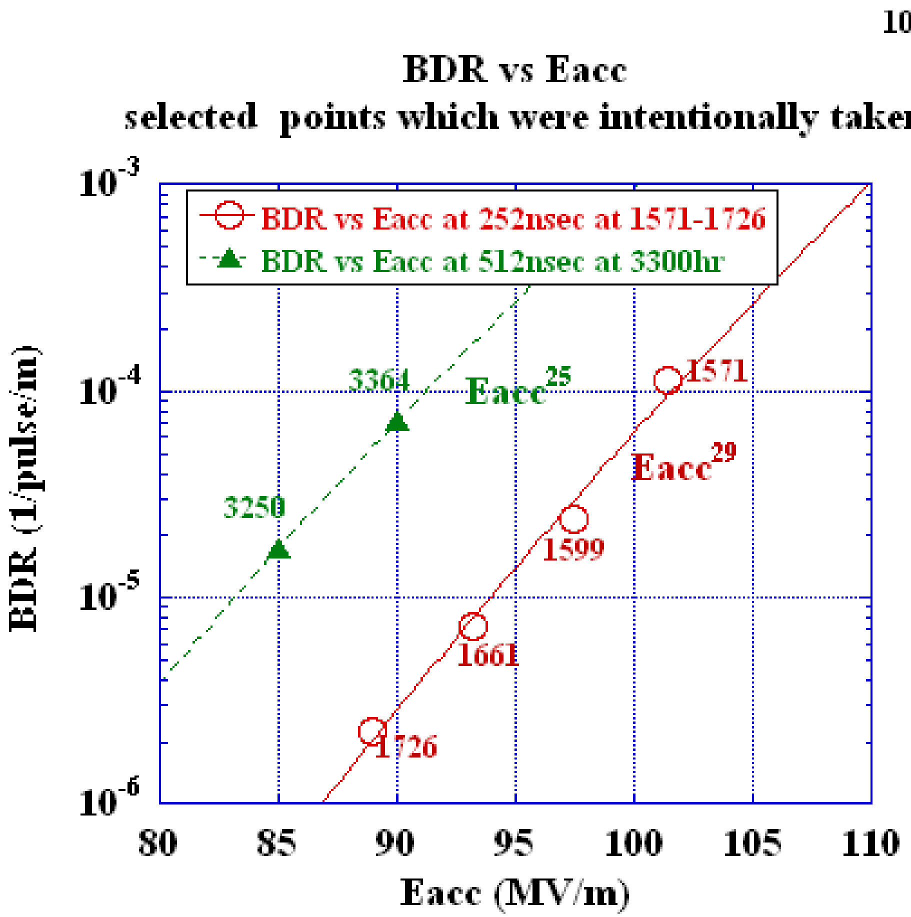
11168 BDs

~7x10^{-5}BrD/pulse

~2x10^{-5}BrD/pulse

05.12.2013

Relevant data points of BDR vs Eacc

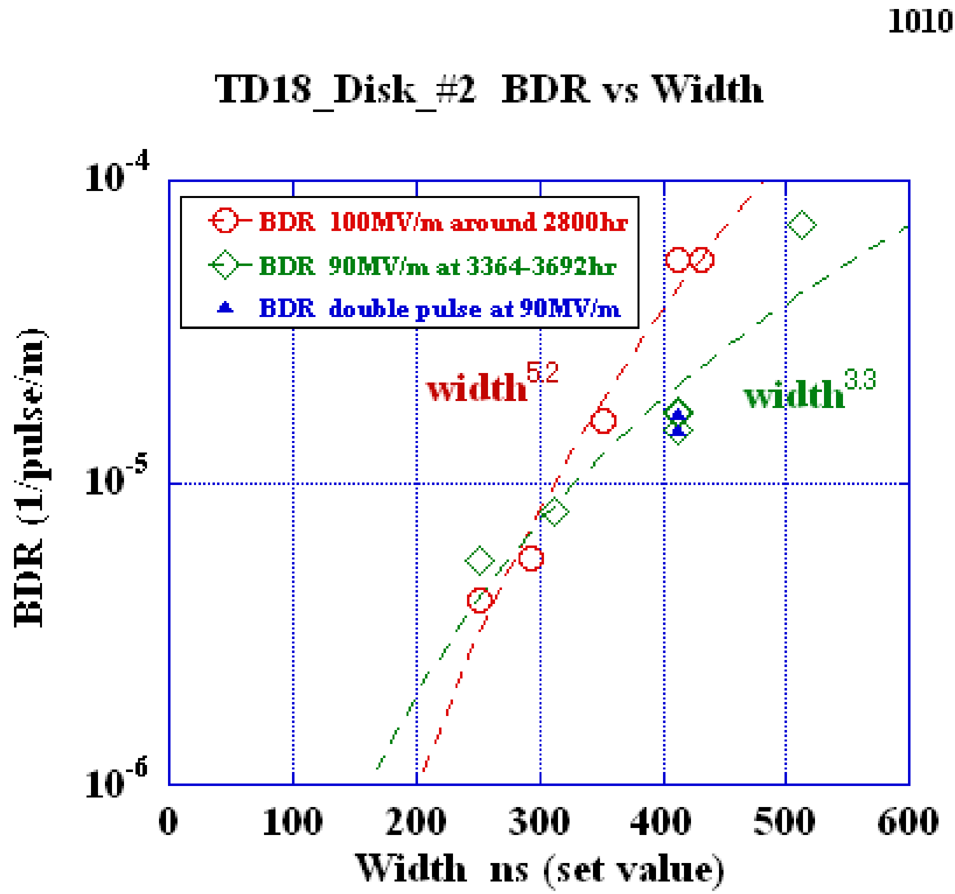


TD18

Steep rise as Eacc, 10 times per 10 MV/m, less steep than T18

TD18_#2 BDR versus width

at 100MV/m around 2800hr and at 90MV/m around 3500hr



TD18

Similar dependence at 90 and 100 if take usual single pulse?

T. Higo, KEK

Most important empirical dependencies

For a fixed pulse length

$$\boxed{BDR \sim E_a^{30}}$$

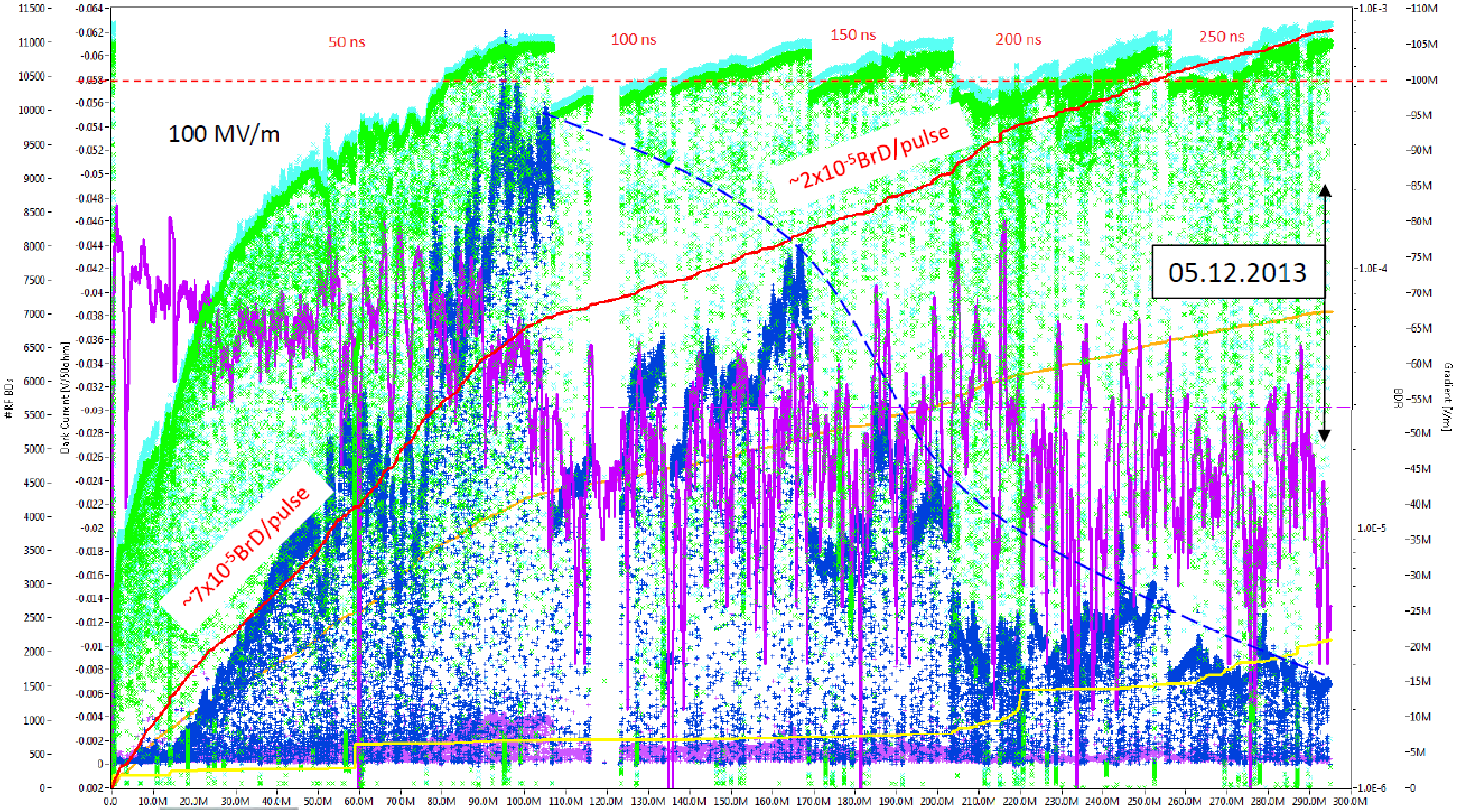
For a fixed BDR

$$\boxed{E_a \cdot t_p^{1/6} = const}$$

$$\boxed{\frac{E_a^{30} \cdot t_p^{5}}{BDR} = const}$$

CERN TD26R05CC conditioning history plot

11168 BDs



100 MV/m

$\sim 7\times10^{-5}$ BrD/pulse

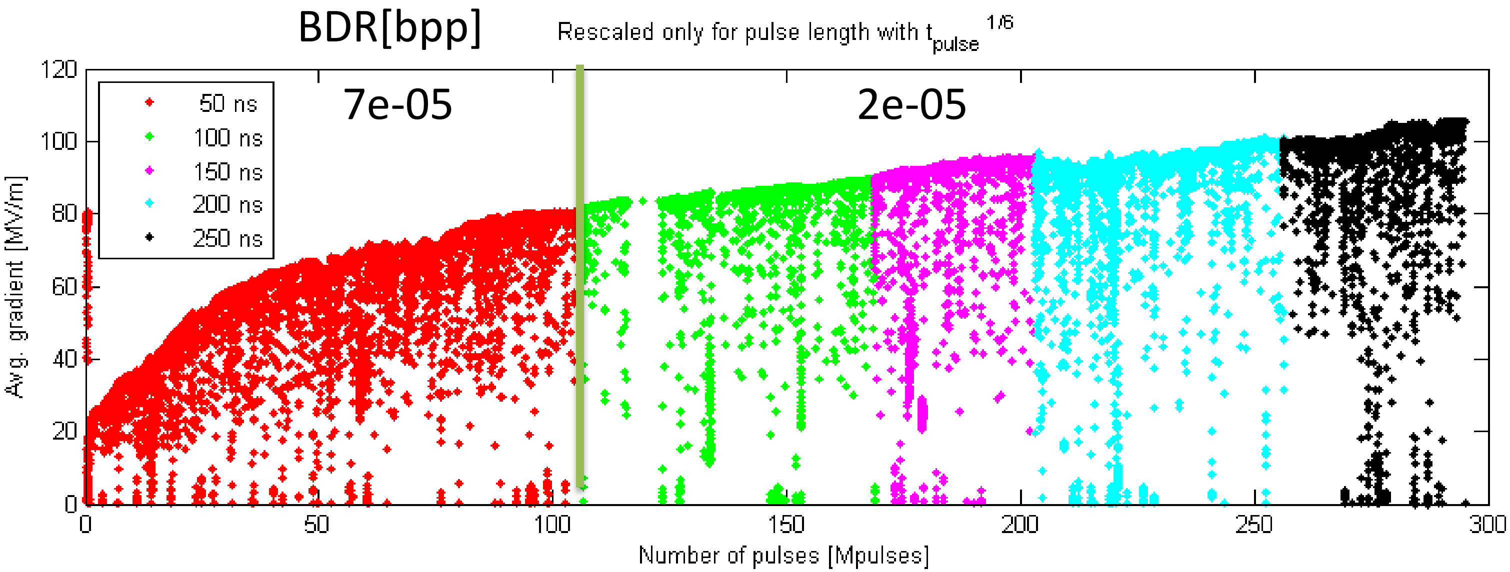
$\sim 2\times10^{-5}$ BrD/pulse

05.12.2013

TD26R05CC conditioning at X-BOX1 (CERN)

$$E \propto t_{pulse}^{-\frac{1}{6}}$$

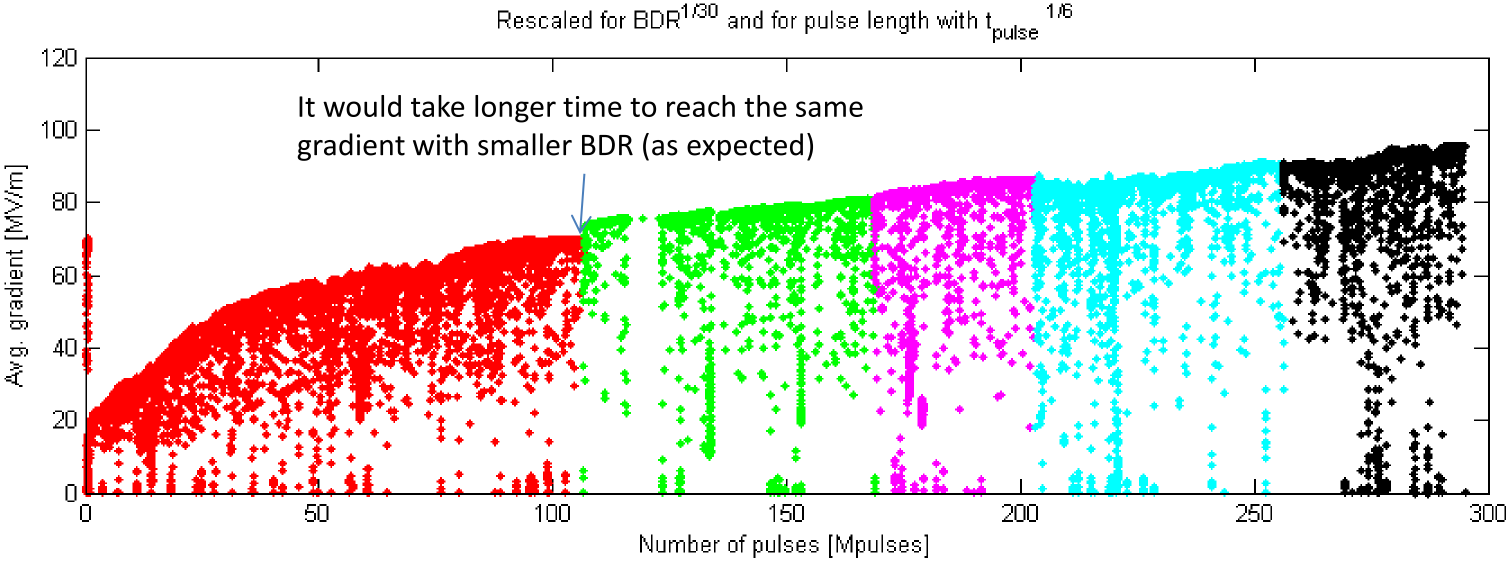
equivalent conditioning curve with constant pulse length of 250 ns since the beginning



$$E \propto BDR^{\frac{1}{30}} t_{pulse}^{-\frac{1}{6}}$$

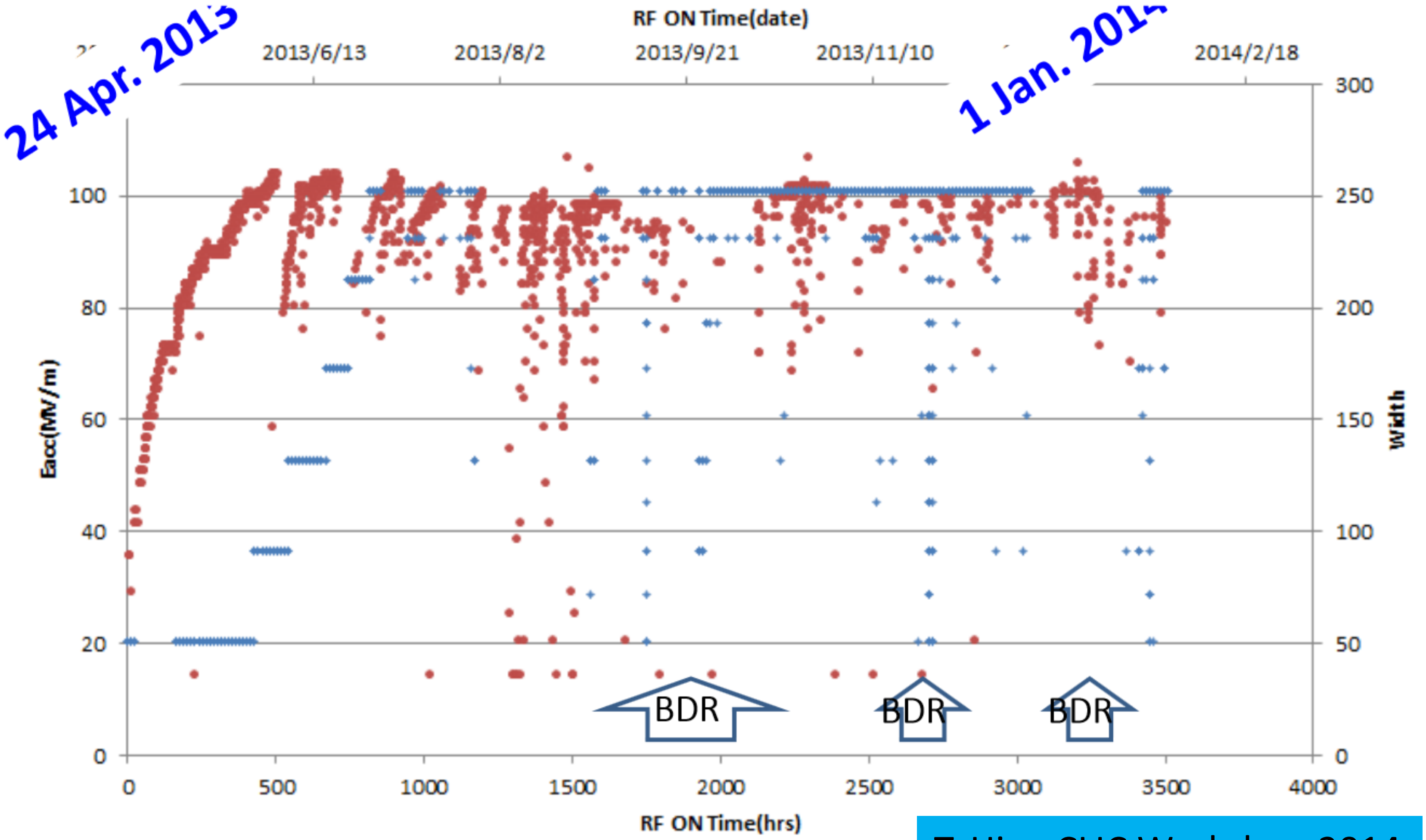
equivalent conditioning curve with:

- constant pulse length of 250 ns since the beginning
- constant BDR of 1e-6 bpp/m


It would take longer time to reach the same gradient with smaller BDR (as expected)

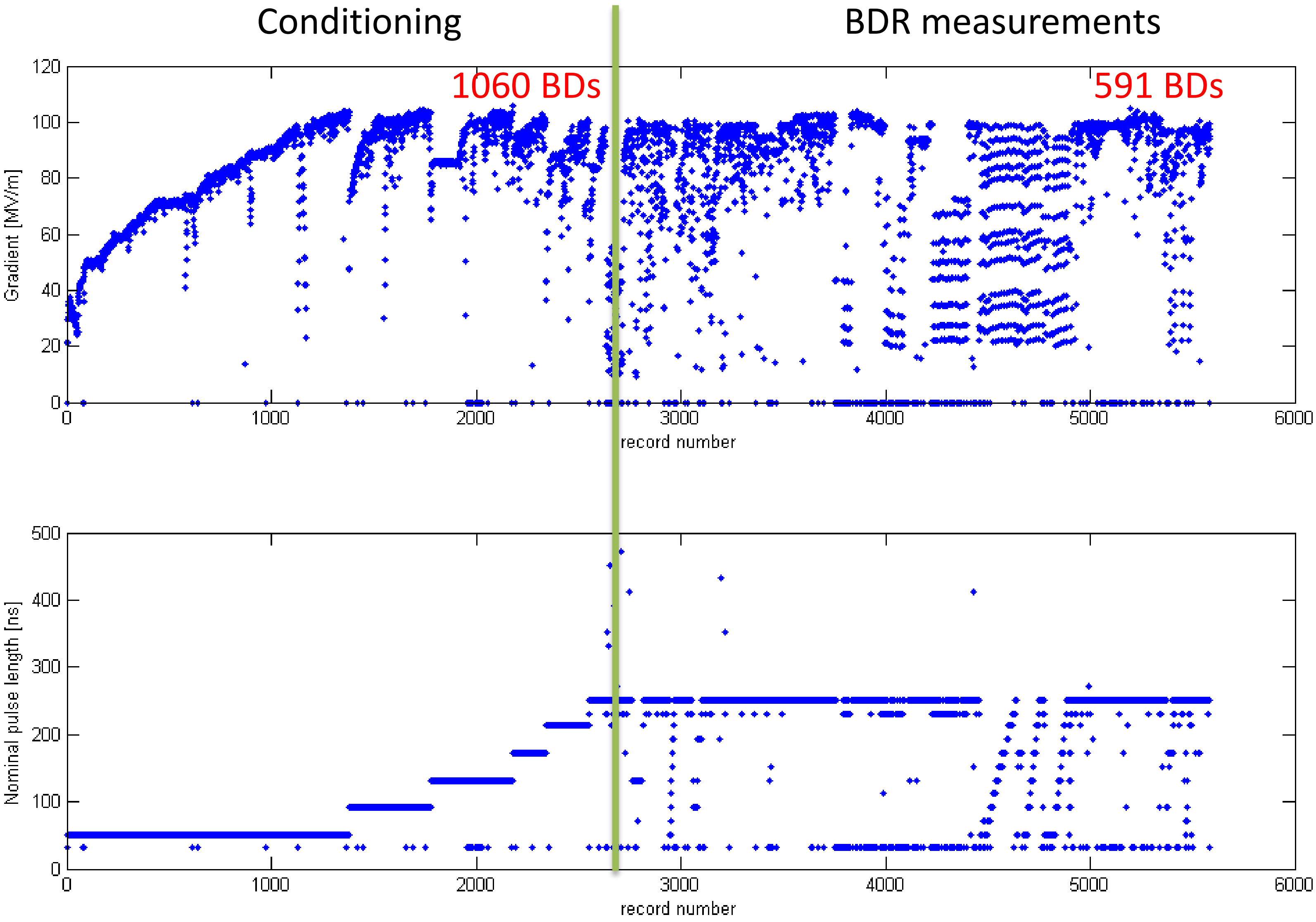
Conditioning history of two structures at KEK and CERN

- TD24R05#4 at KEK



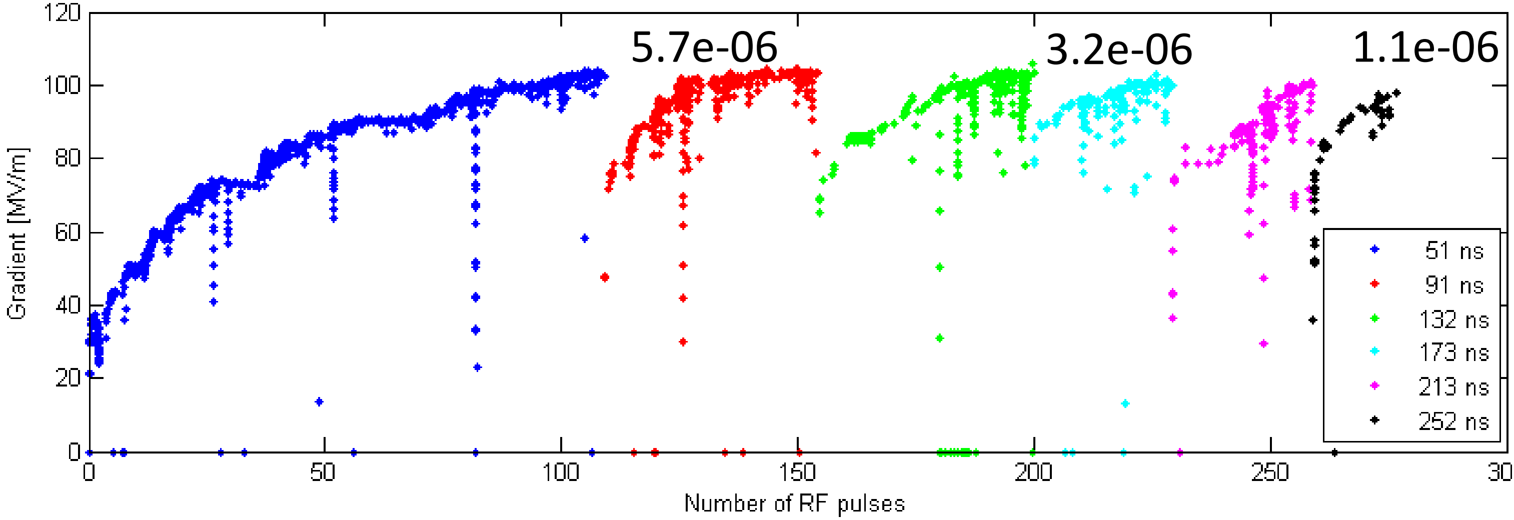
T. Higo CLIC Workshop 2014

TD24R05#4 conditioned at KEK - history



TD24R05#4 conditioned at KEK

Conditioning curve of TD24R05 at KEK



BDR[bpp]= 6.6e-06

5.7e-06

2.8e-06

3.2e-06

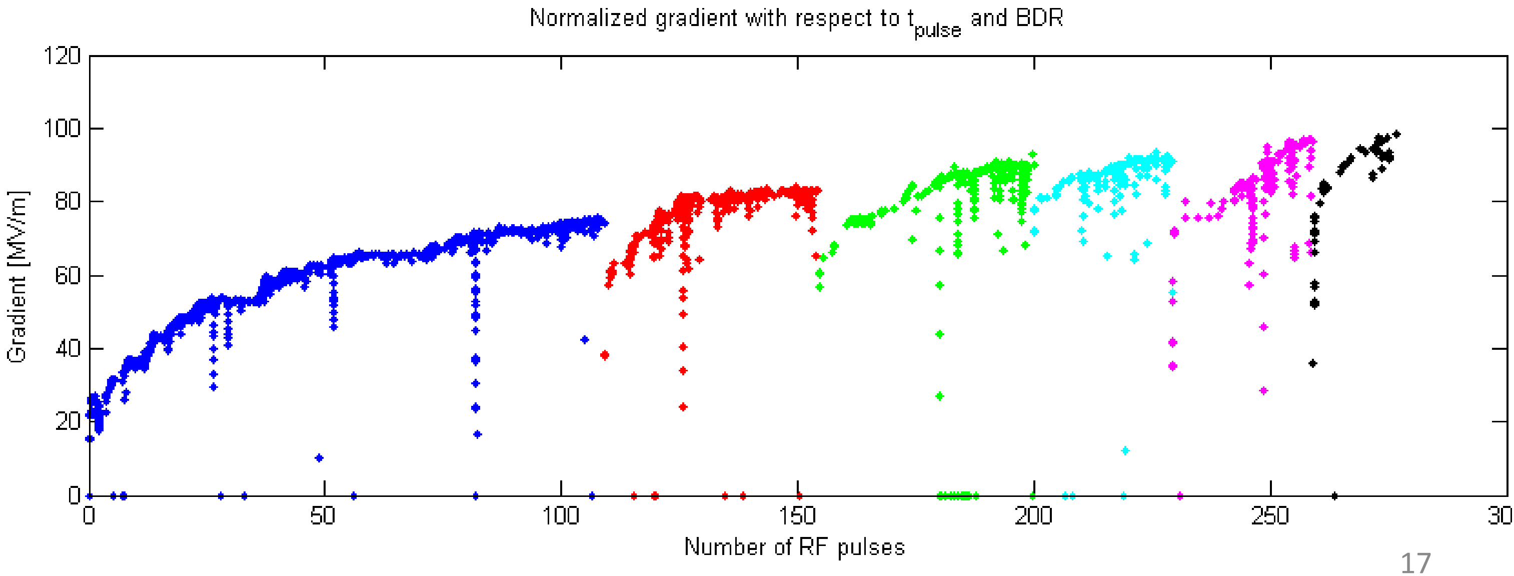
1.6e-06

1.1e-06

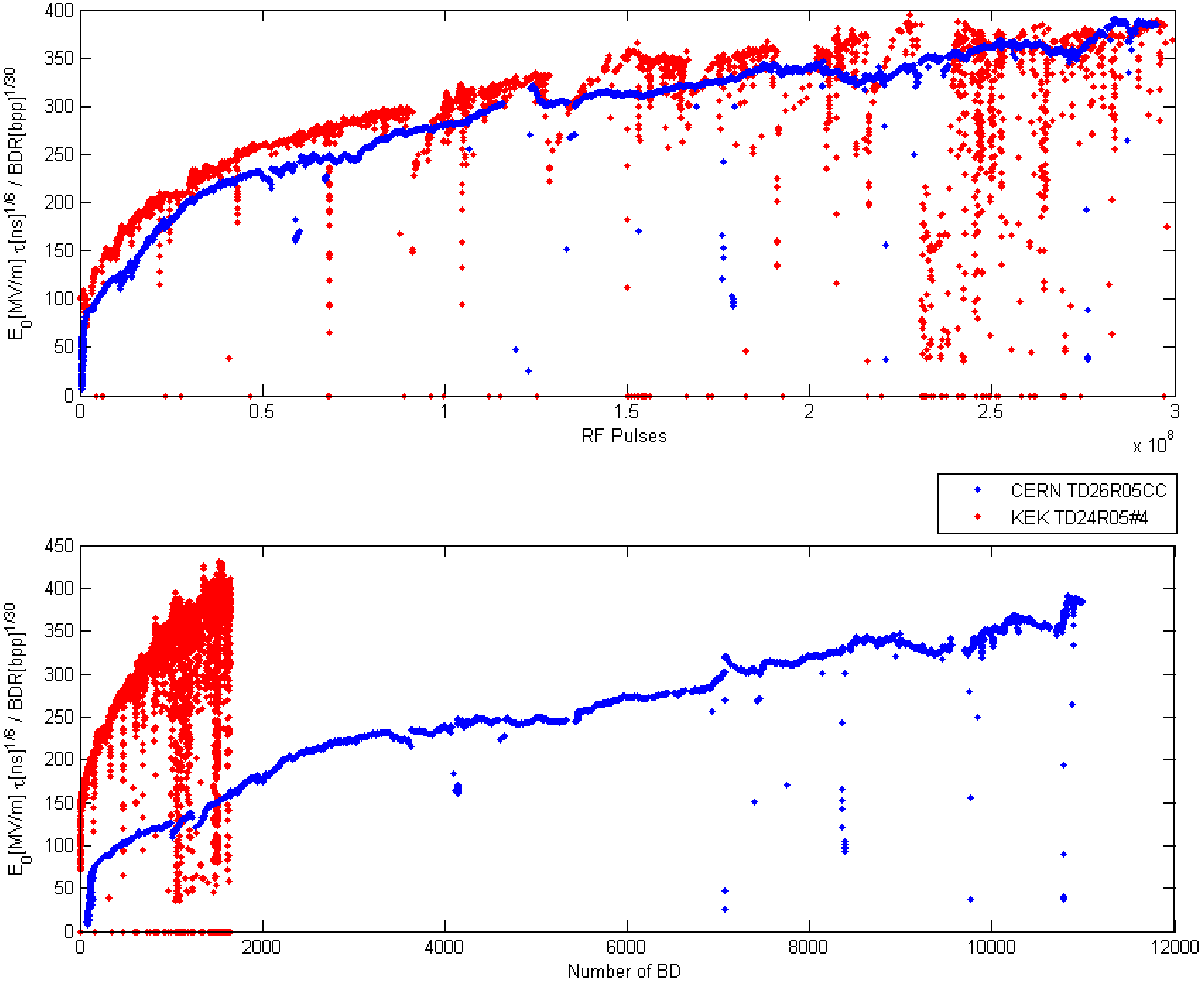
$$E_0 \propto BDR^{\frac{1}{30}} t_{pulse}^{-\frac{1}{6}}$$

equivalent conditioning curve with:

- constant pulse length of **250 ns** since the beginning
- constant **BDR** of **1e-6 bpp/m**

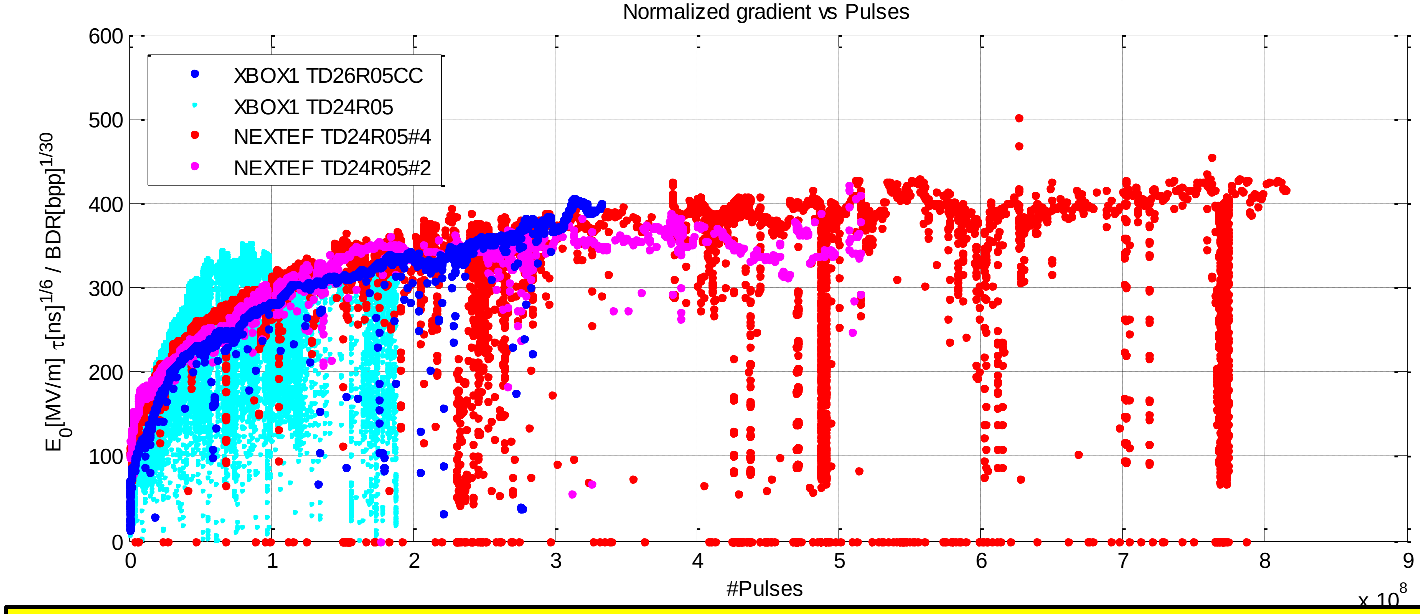


Comparison of E_0* vs #BD

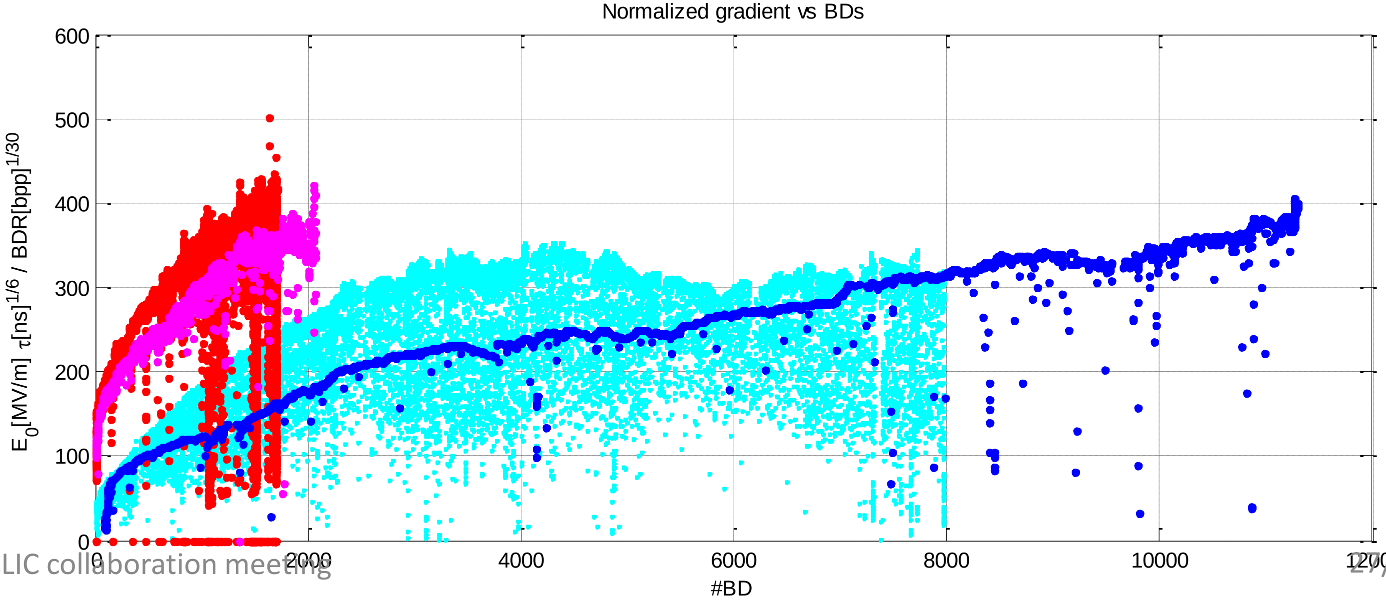


Same conditioning level at different number of BD.

Comparison of conditioning curves

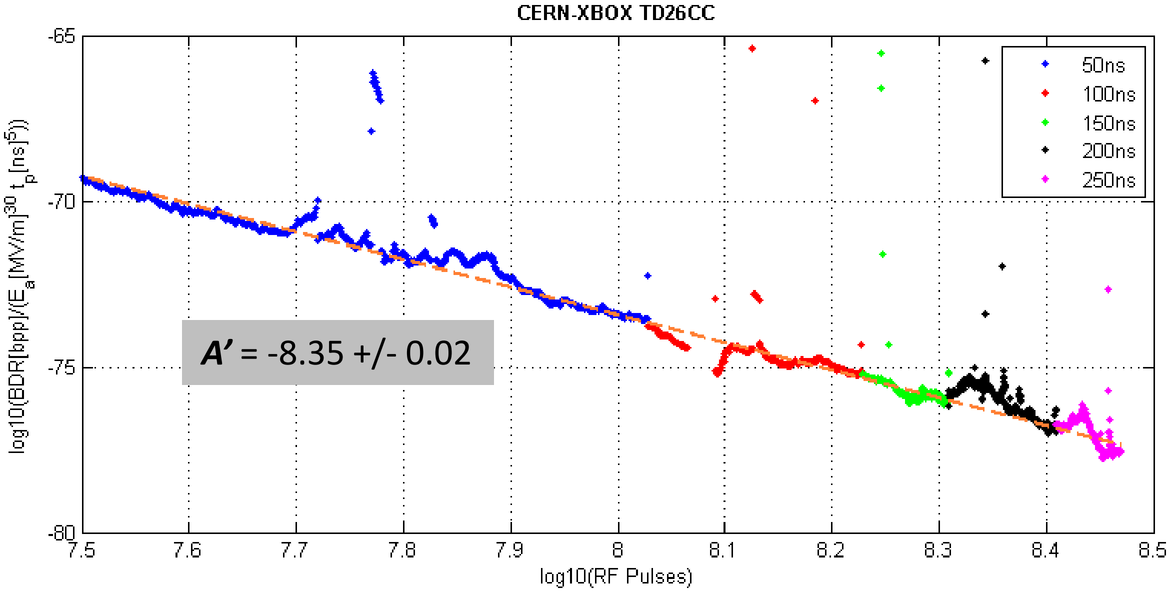


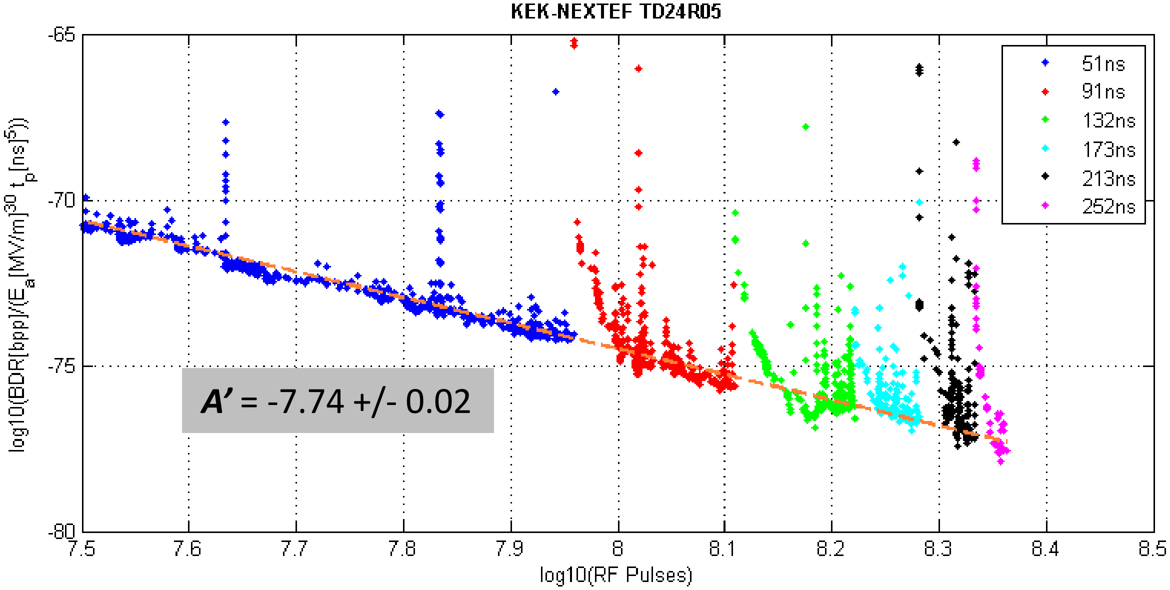
Conditioning to high-gradient is given by the pulses not the breakdowns!



Normalized BDR in LOG-LOG scale – Linear fit

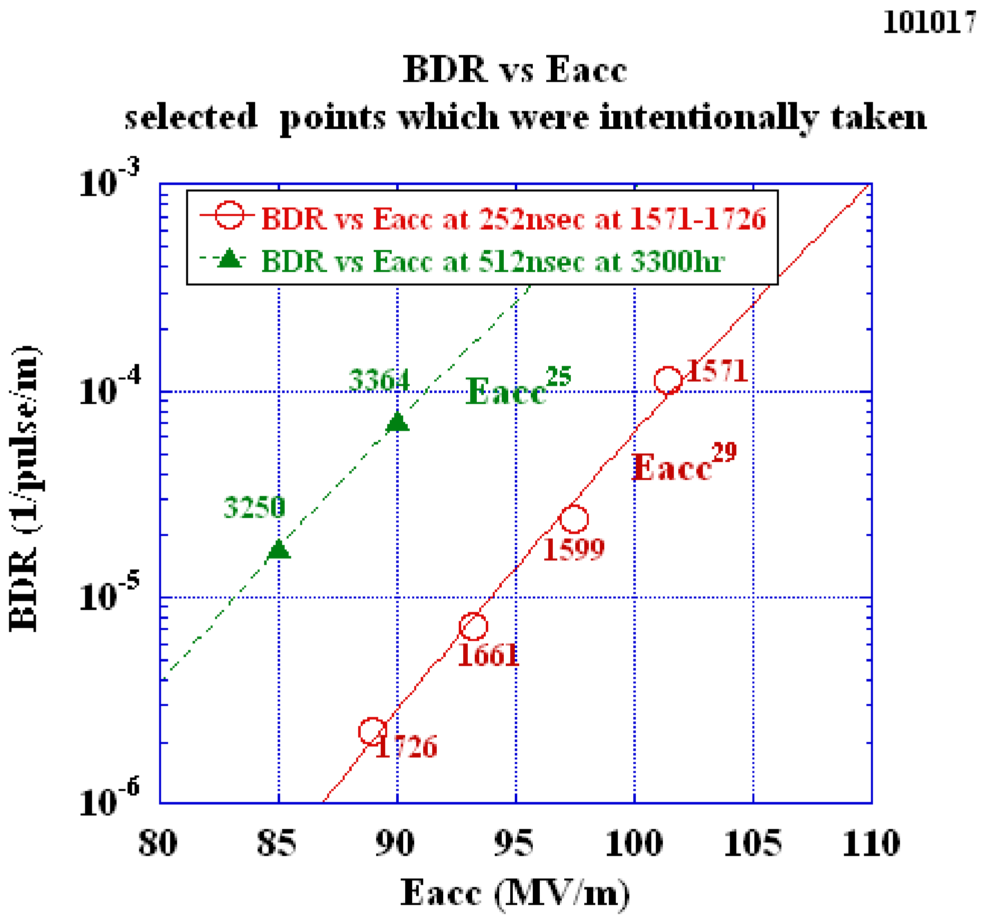
$$\frac{BDR}{E_a^{30} t_p^5}$$





dc system

Relevant data points of BDR vs Eacc

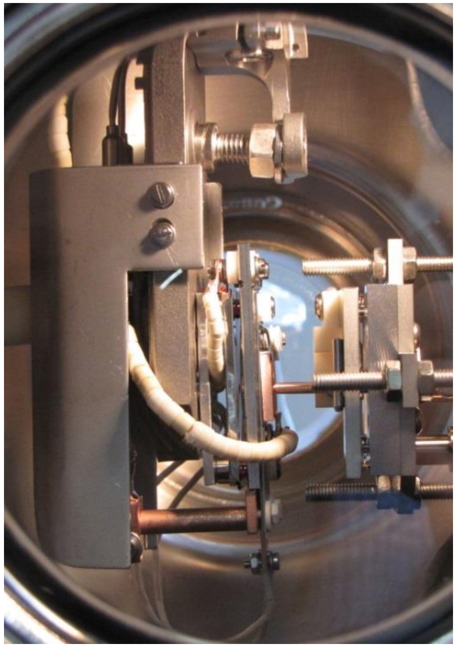


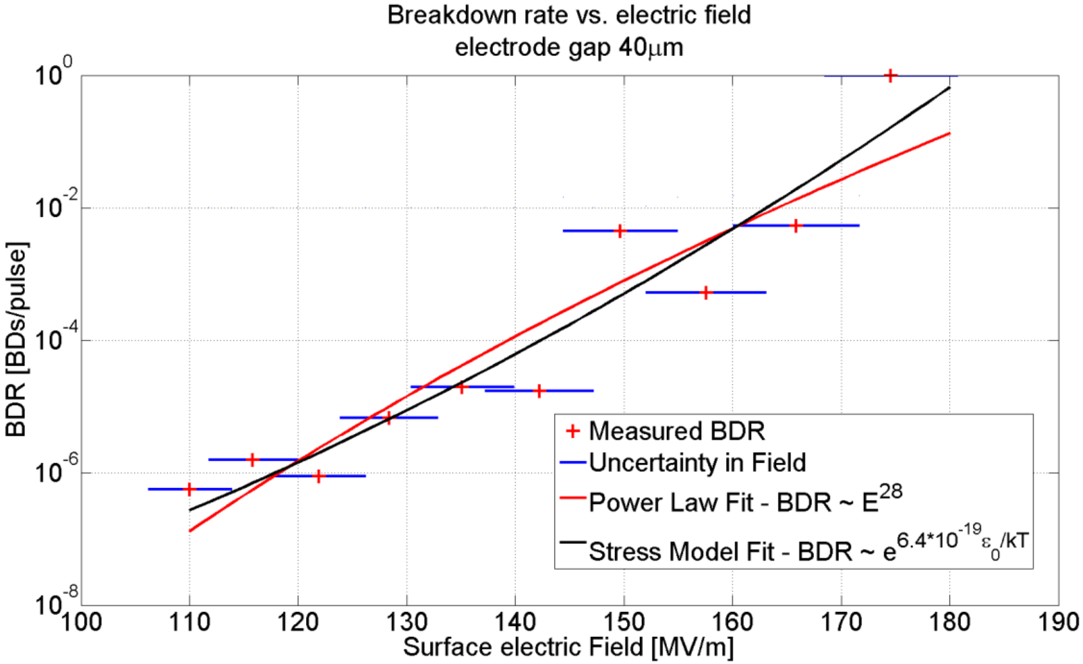
TD18

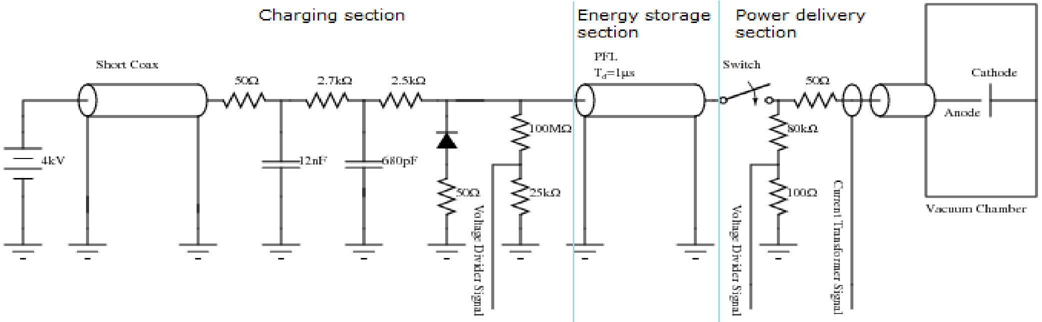
Steep rise as Eacc, 10 times per 10 MV/m, less steep than T18

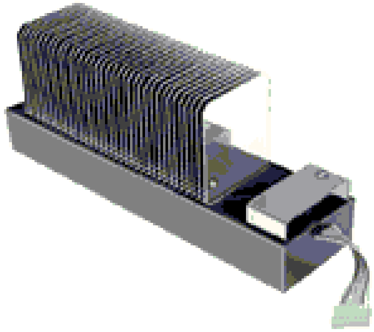
T. Higo, KEK

Same thing with pulsed dc

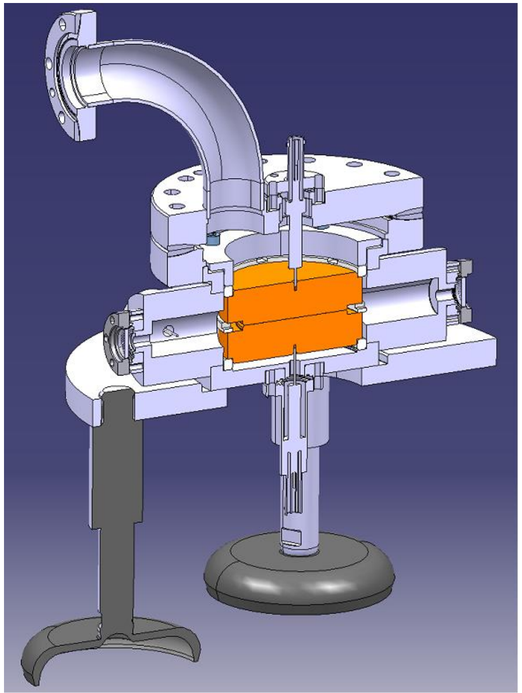






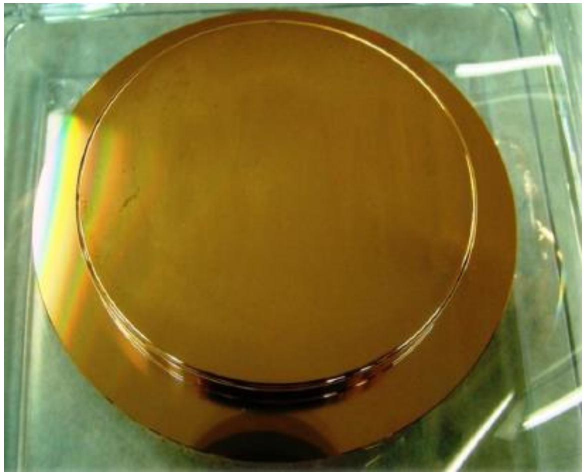


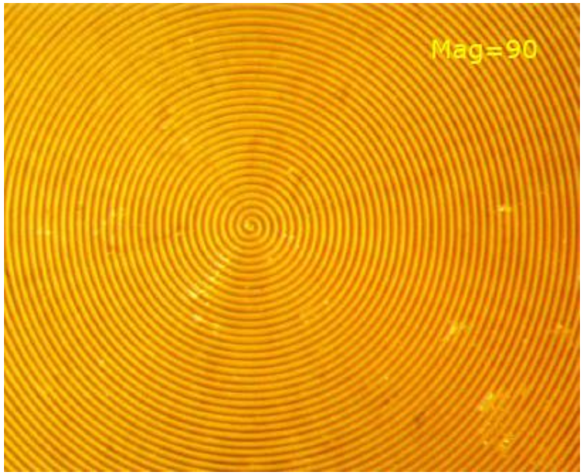
MOSFET switch 1kHz



What is the Fixed Gap System

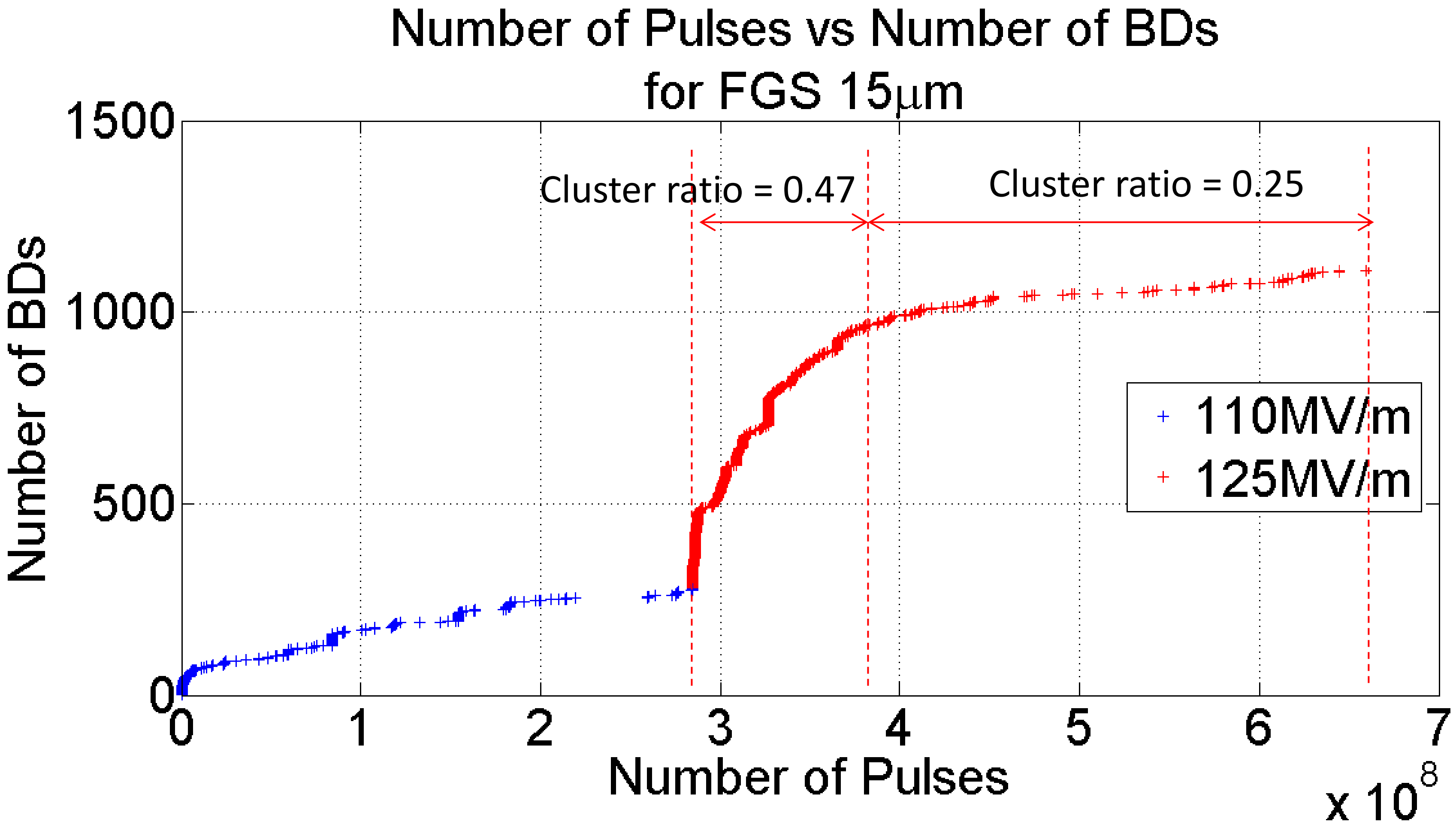
Despite the comparatively large size of the anodes, the system is very compact. Four antennas are included in the design to pick up the radiation from breakdowns.





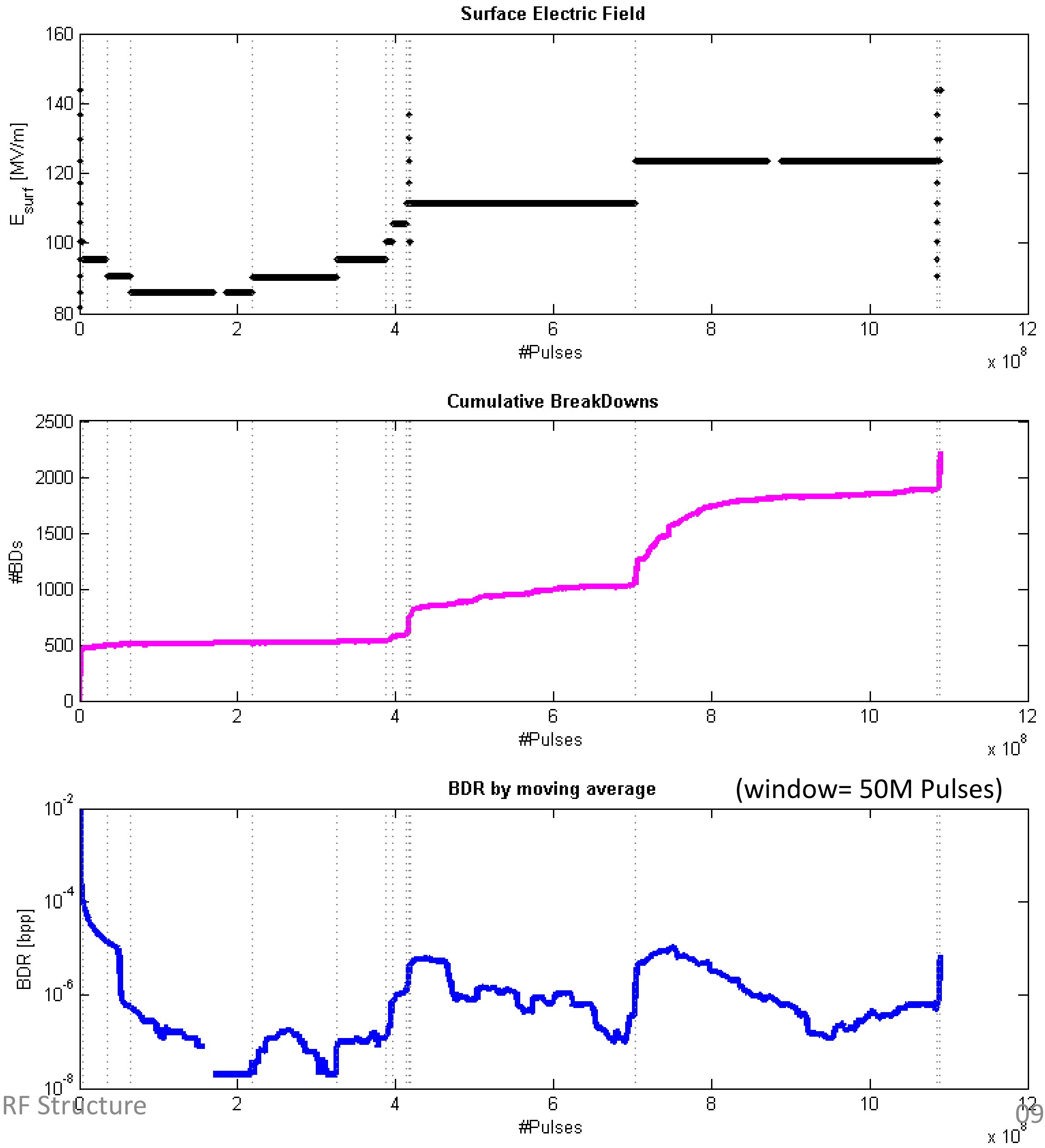
The surface of the electrodes are 60mm in diameter and have a shape tolerance of <1um. The picture on the right shows the high precision turning.

Conditioning in FGS



The flattening of these curves is evidence of conditioning. The BDR increases sharply when the voltage is increased. The cluster ratio define as BDs in a cluster/Total BDs is higher for higher BDRs.

History plot of HRR Fixed-Gap System at DC Spark lab

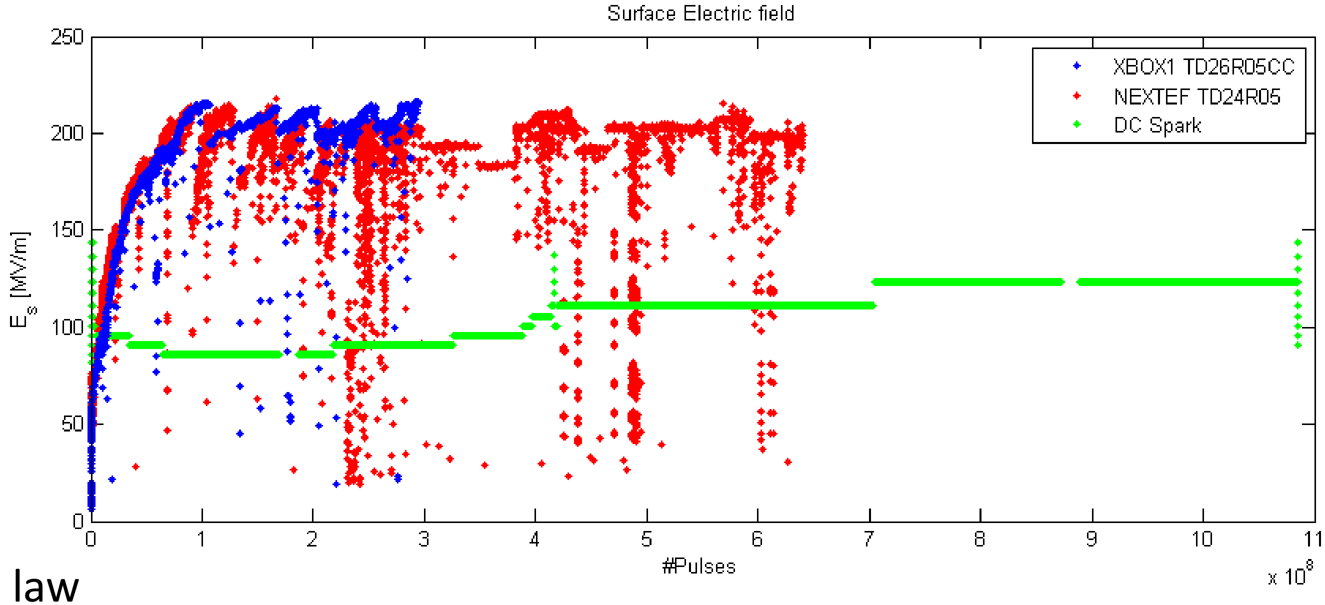


(window= 50M Pulses)

Voltage pulse length
t_p=12 µs

Gap = 15µm

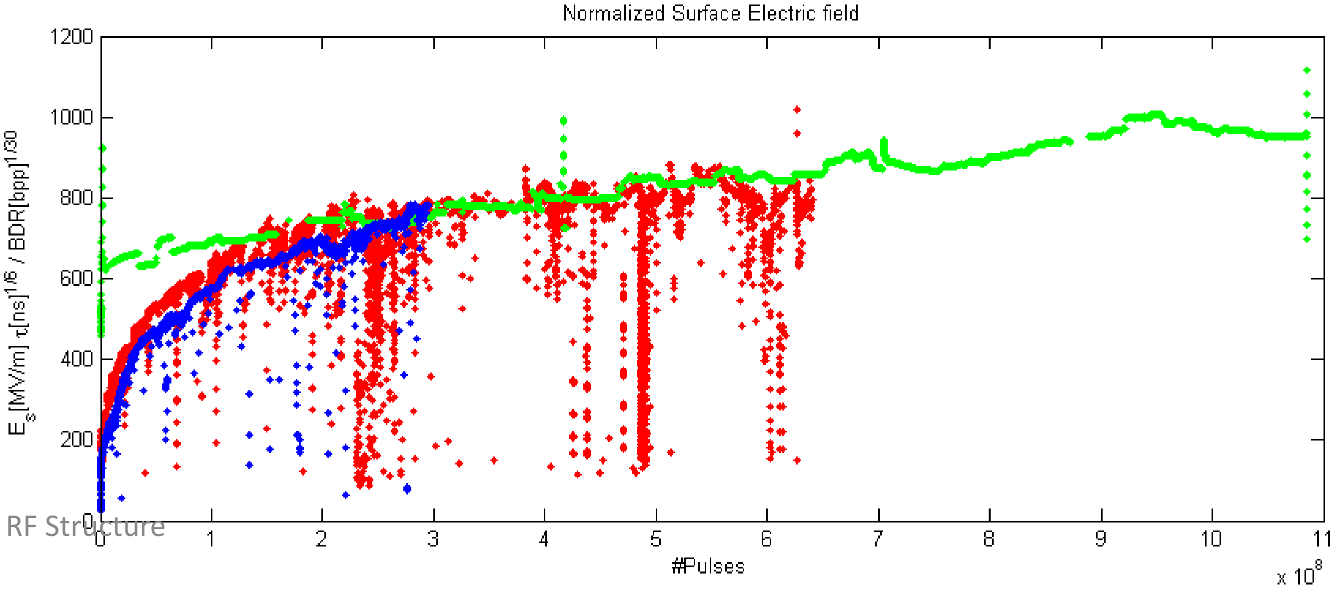
Normalized Surface Electric Field



Gradient scaling law

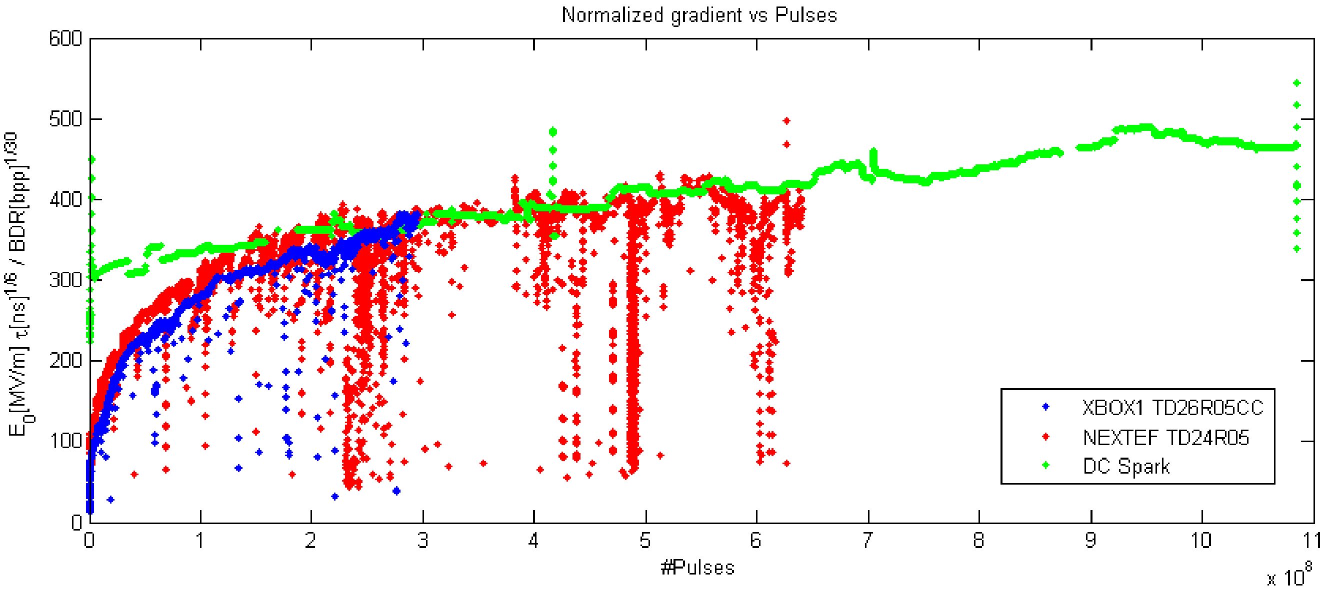
$$E_s \propto E_0 \propto t_p^{-1/6}\mathrm{BDR}^{1/30}$$

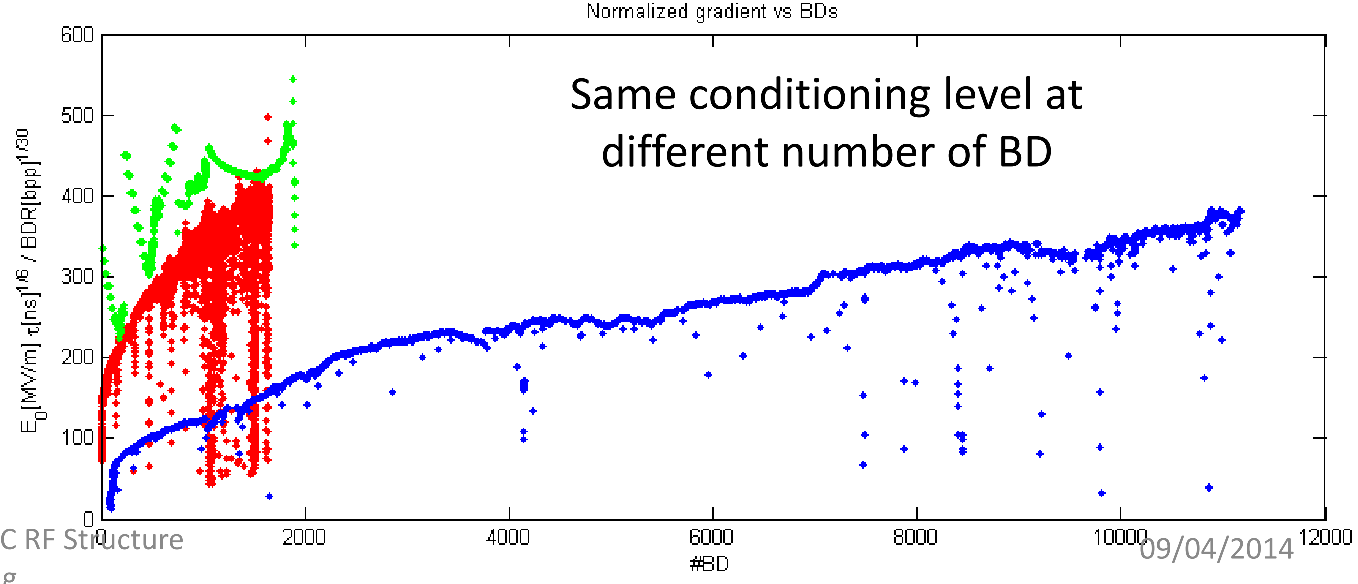
$$\frac{E_s}{t_p^{-1/6}\mathrm{BDR}^{1/30}}$$



Normalized Surface Electric Field

$$\frac{E_s}{t_p^{-1/6}\mathrm{BDR}^{1/30}}$$





Same conditioning level at different number of BD

rf design

Geometry of CLIC-G cell

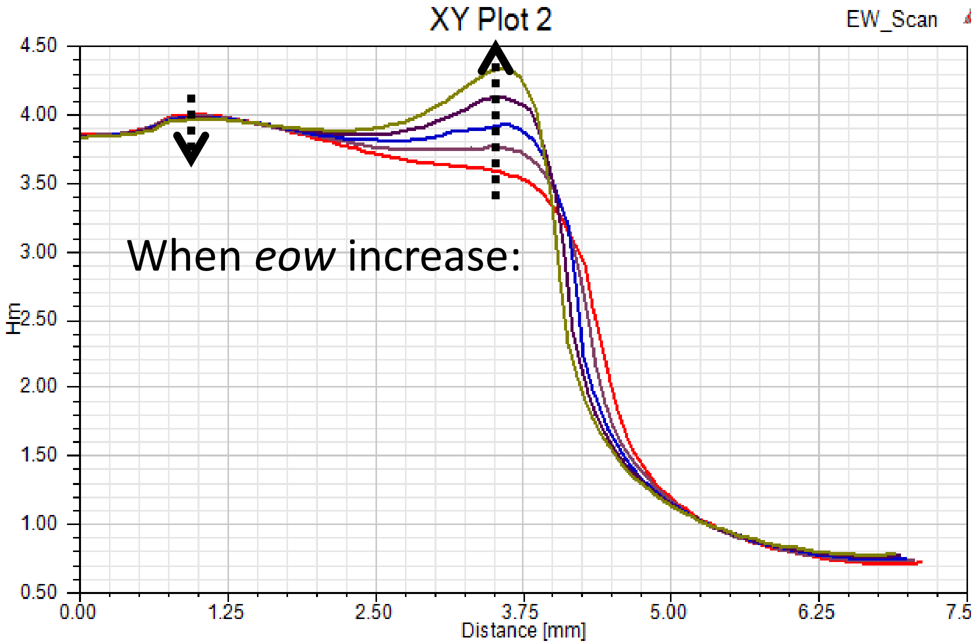
Independed parameters:

- -- *c*
- -- *eow*=ac/bc

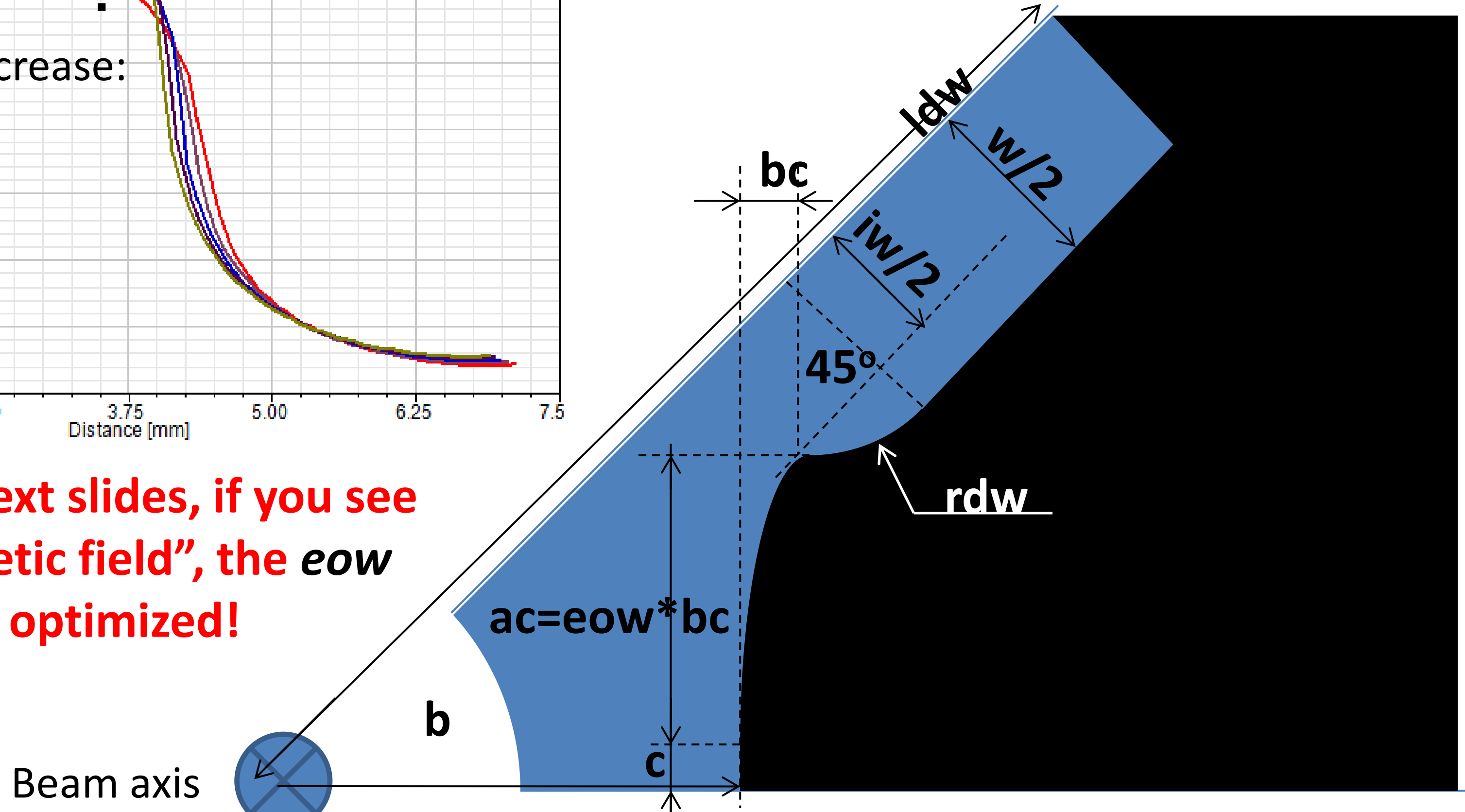
} Optimized for magnetic field

- **-- *iw*: waveguide opening**
- **-- *w*: wavegude width**

} Optimized for wakefield damping

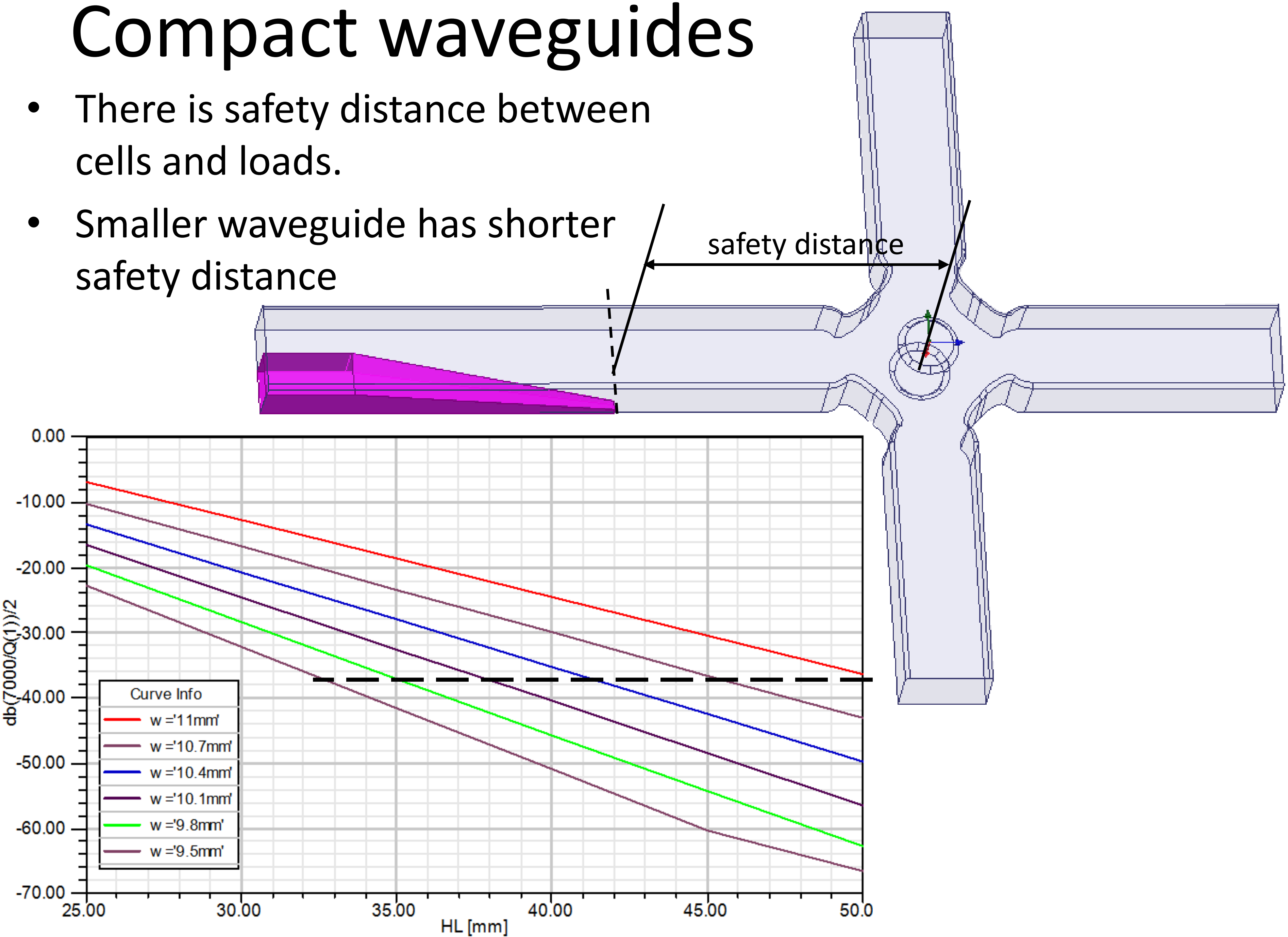


Note : In all the next slides, if you see "maximum magnetic field", the *eow* should have been optimized!



Compact waveguides

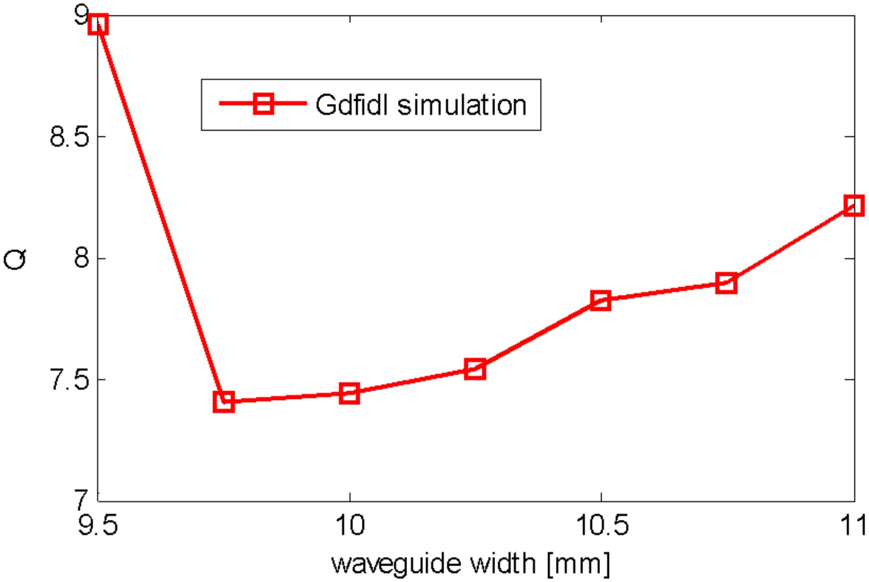
- There is safety distance between cells and loads.
- Smaller waveguide has shorter safety distance



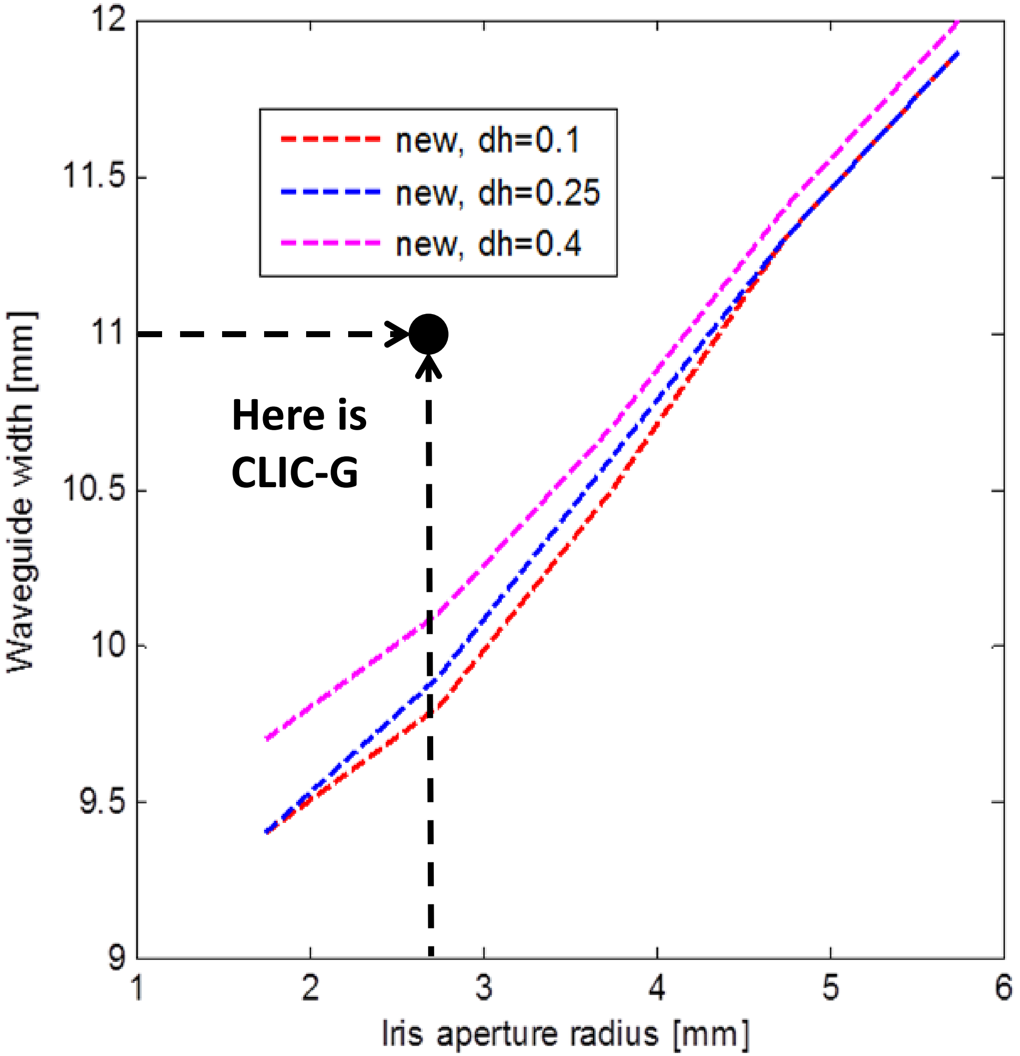
Optimum waveguide width

- Why smaller width have better damping effect:
- **Impedance match**

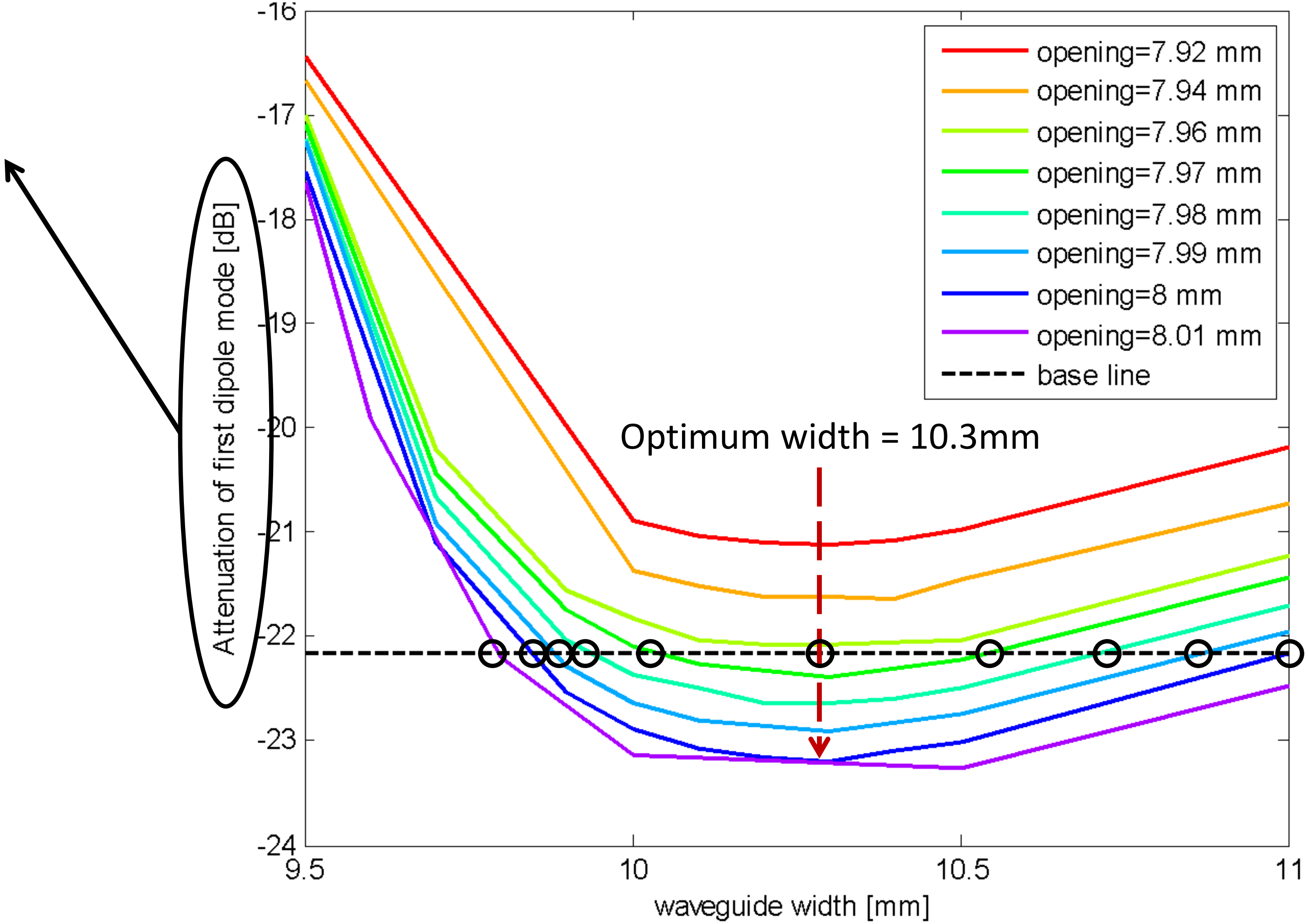
Different waveguide width for middle cell



Optimum waveguide width for cells



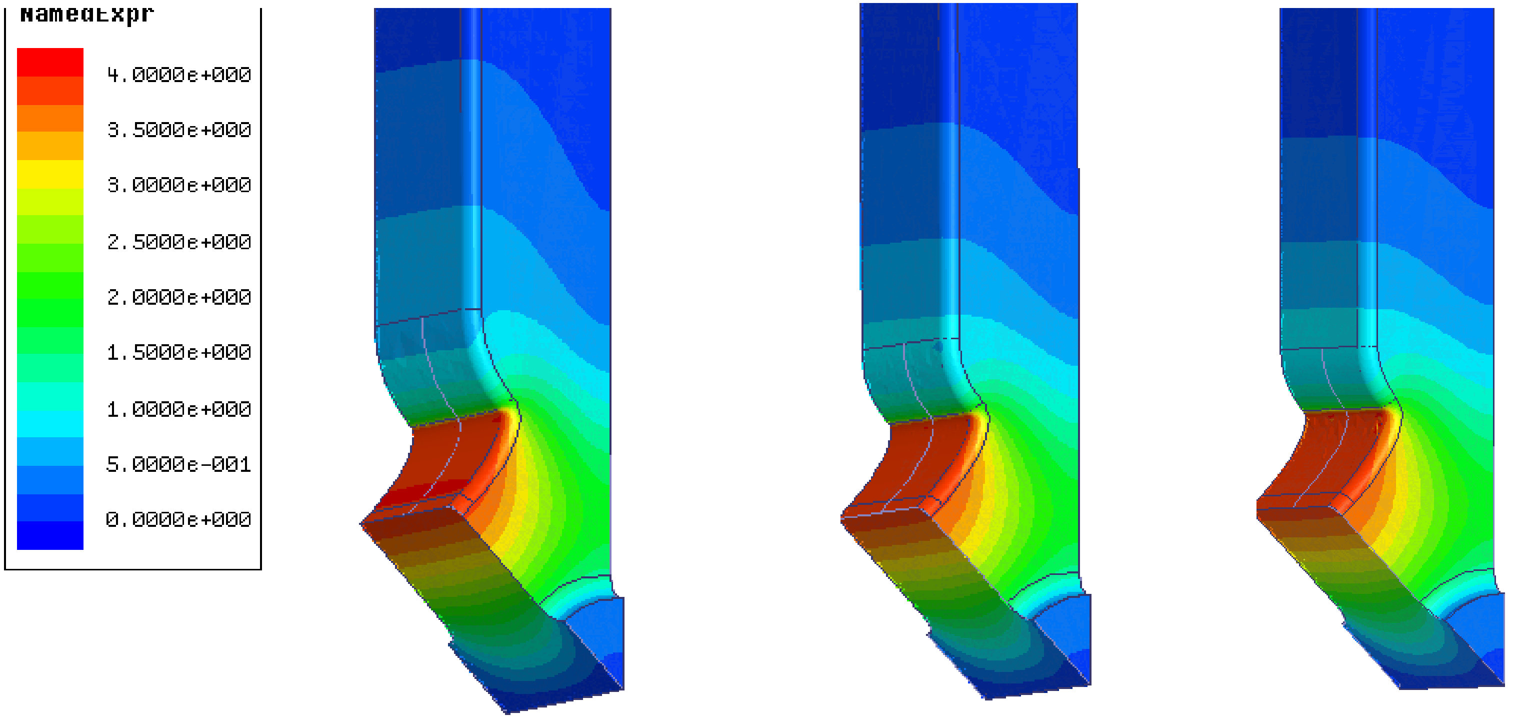
Sweep on First cell



Optimum width = 10.3mm

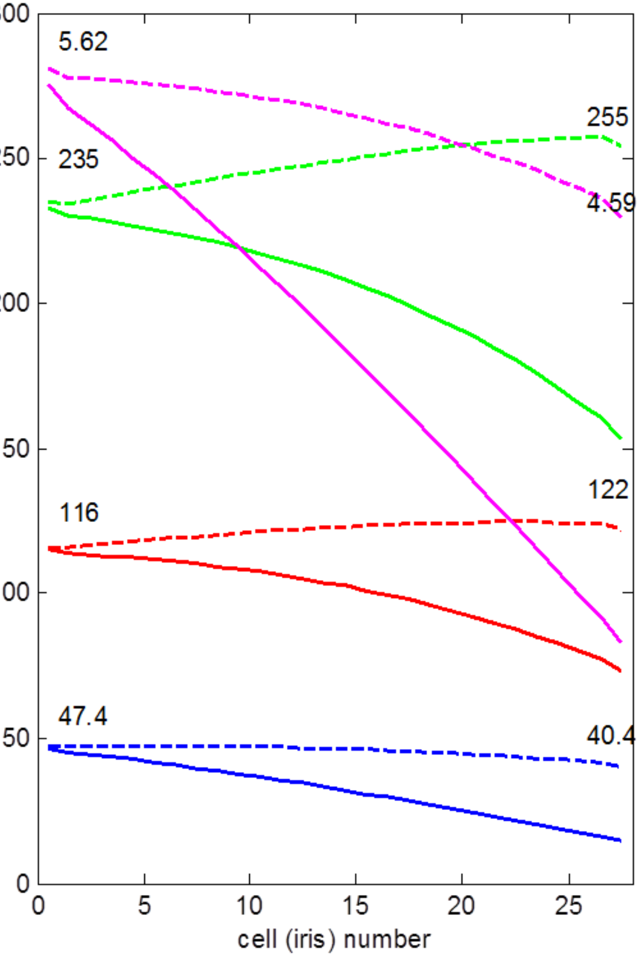
New design for CLIC-G

Cells	Optimized width		Optimized width & opening	
	width	Opening	Width	opening
First	10.3mm	8mm	9.9mm	7.98mm
Middle	10.0mm	8mm	9.8mm	7.94mm
Last	9.7mm	8mm	9.7mm	7.90mm

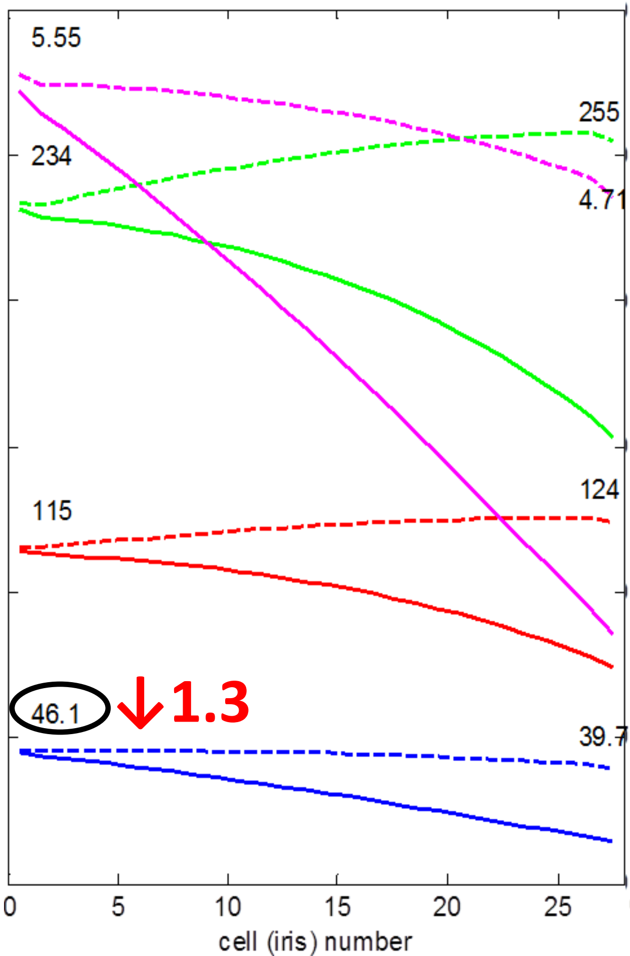

Original cell **Optimized width** **Optimized width & opening**

Tapered cells (26 regular cell+2matching cell)

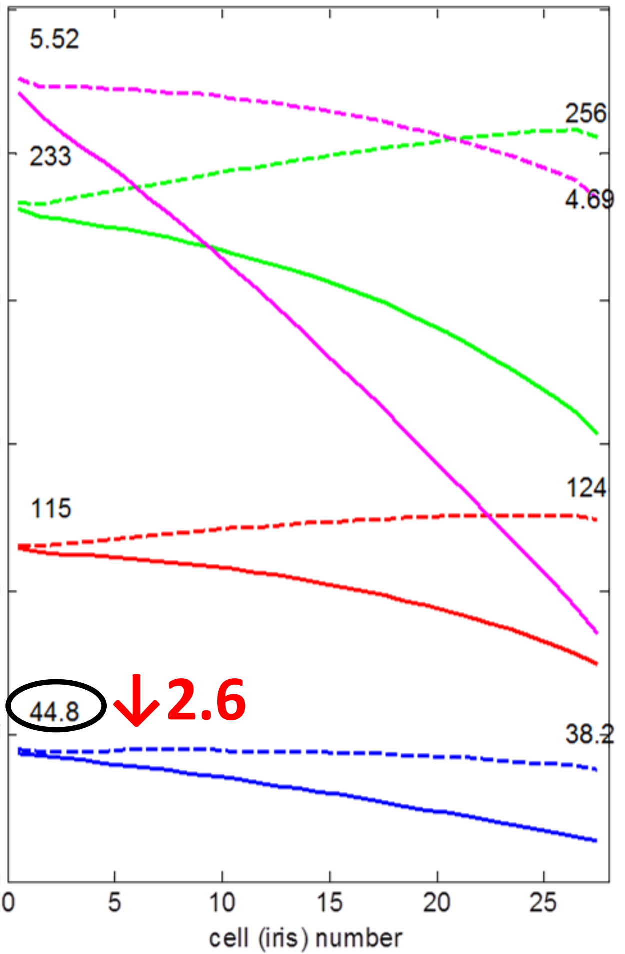
Original cell
Input power = 63.1 MW



Optimized width
Input power = 62.4 MW



Optimized width & opening
Input power = 62.1 MW



Outreach

High-gradient medical accelerator

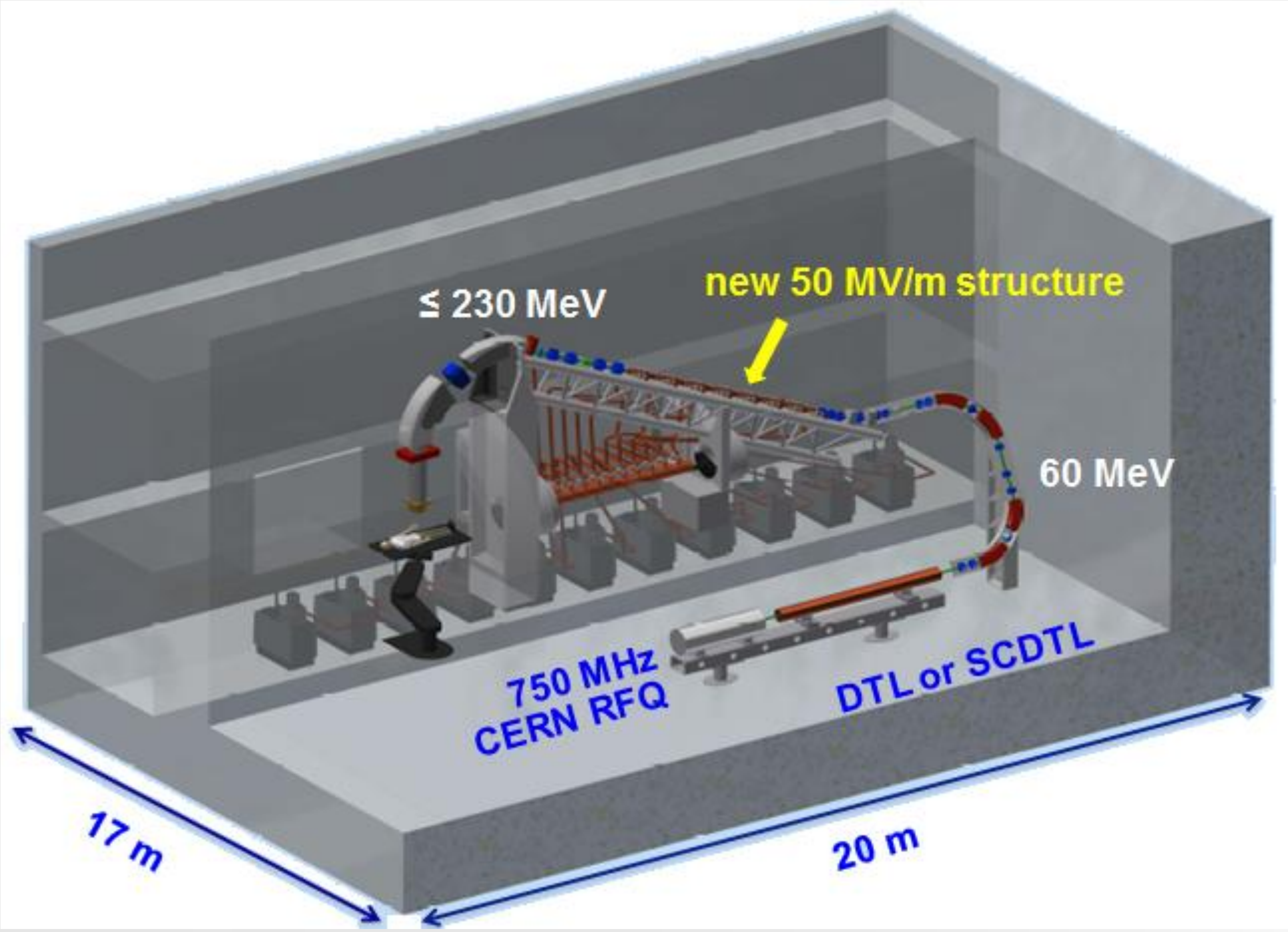
Objective – high gradient for proton and ion acceleration by applying CLIC technology.

Target application is TERA's TULIP project.

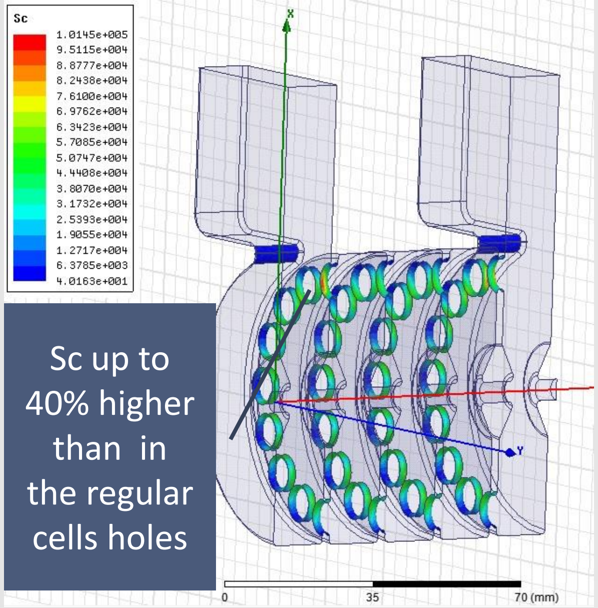
Collaboration between CLIC and TERA.

Prototype structure and experimental electronics funded by CERN KT (Knowledge Transfer) fund.

A single room protontherapy facility has been designed by TERA Foundation at CERN in collaboration with the CLIC group.



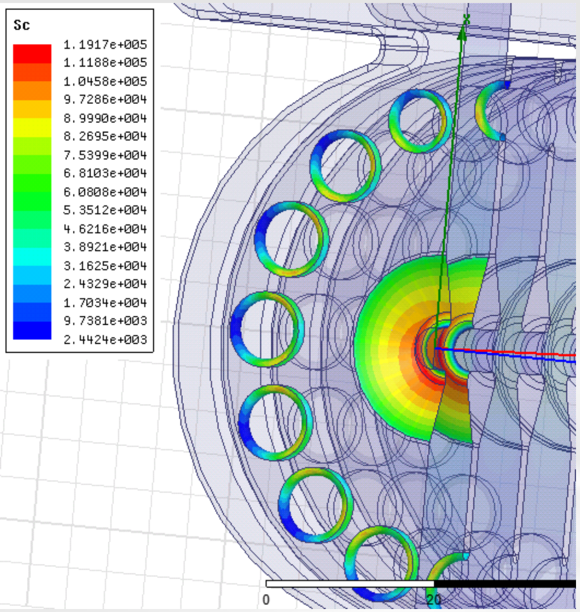
A linac based proton therapy facility



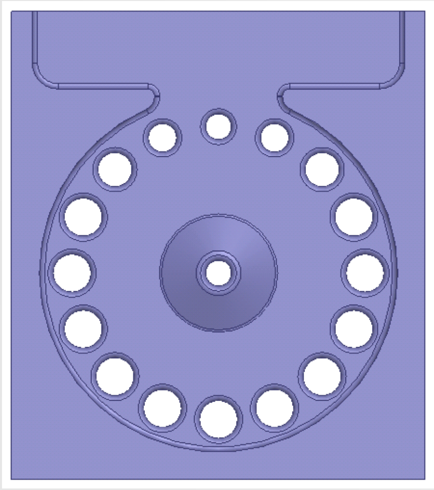
Sc up to 40% higher than in the regular cells holes

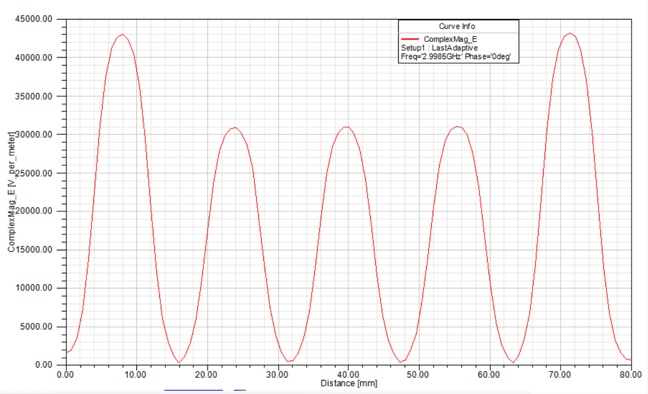
By reducing the coupling holes radius closer to the coupling slot the problem is solved

But we affect the vg, so the Ez



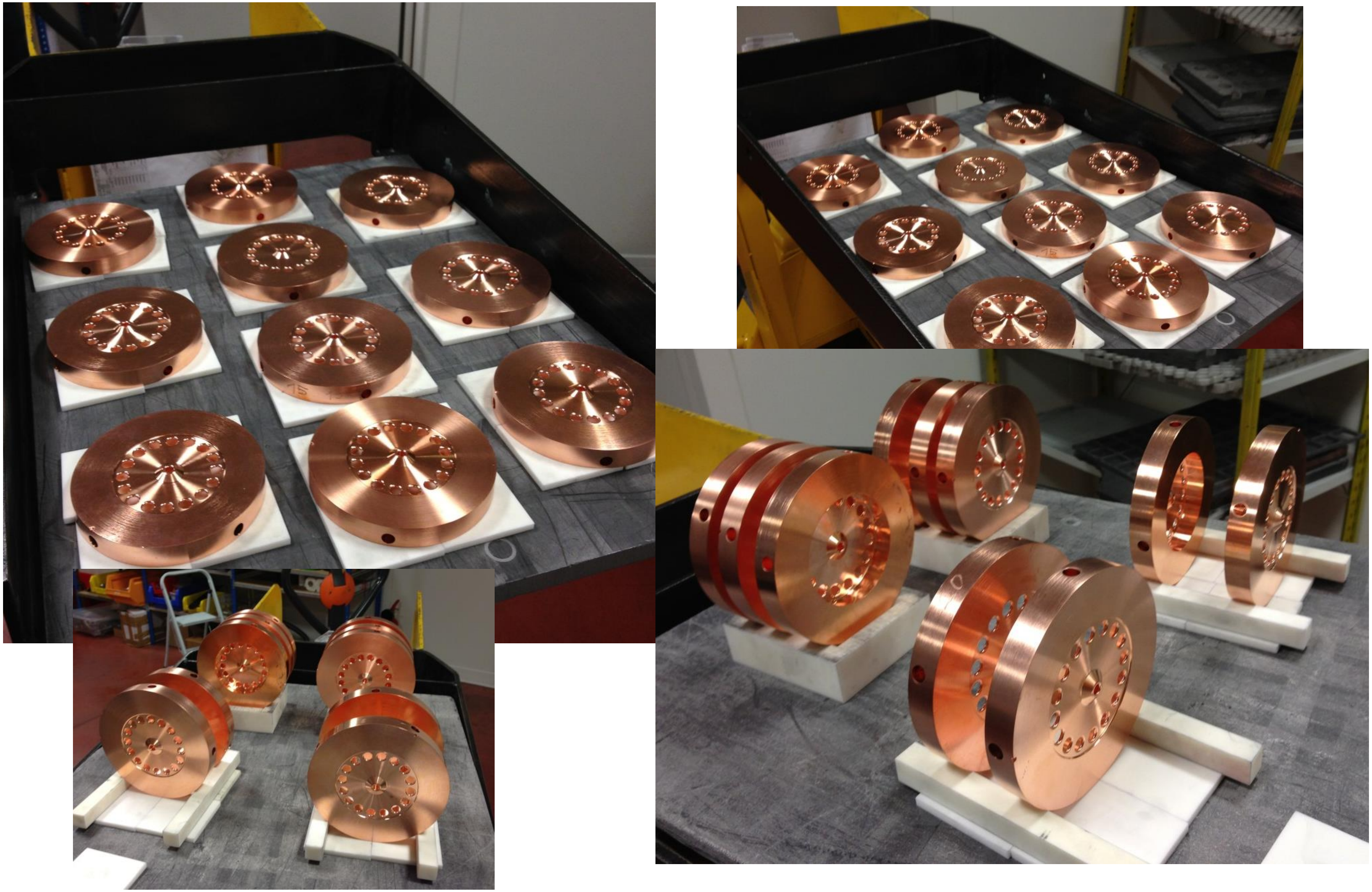
- **Particular effort dedicated to the input coupler design**
- **Asymmetric design of the coupling hole radii to compensate for local enhancement of Sc**





Couplers design

Thermal Test at Bodycote



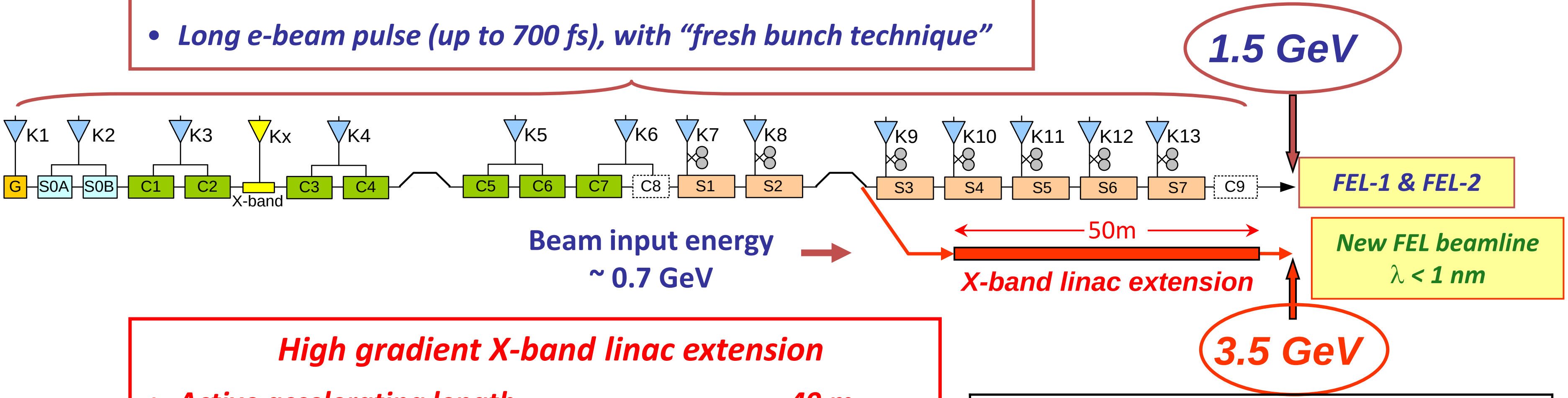
FERMI@Elettra: present layout and energy upgrade

FERMI@Elettra: present layout and energy upgrade

FERMI current layout and performance

- *E_{beam} up to 1.5 GeV*
- *FEL-1 at 80-10 nm and FEL-2 at 10-4 nm*
- *Long e-beam pulse (up to 700 fs), with "fresh bunch technique"*

More details in MOPP023



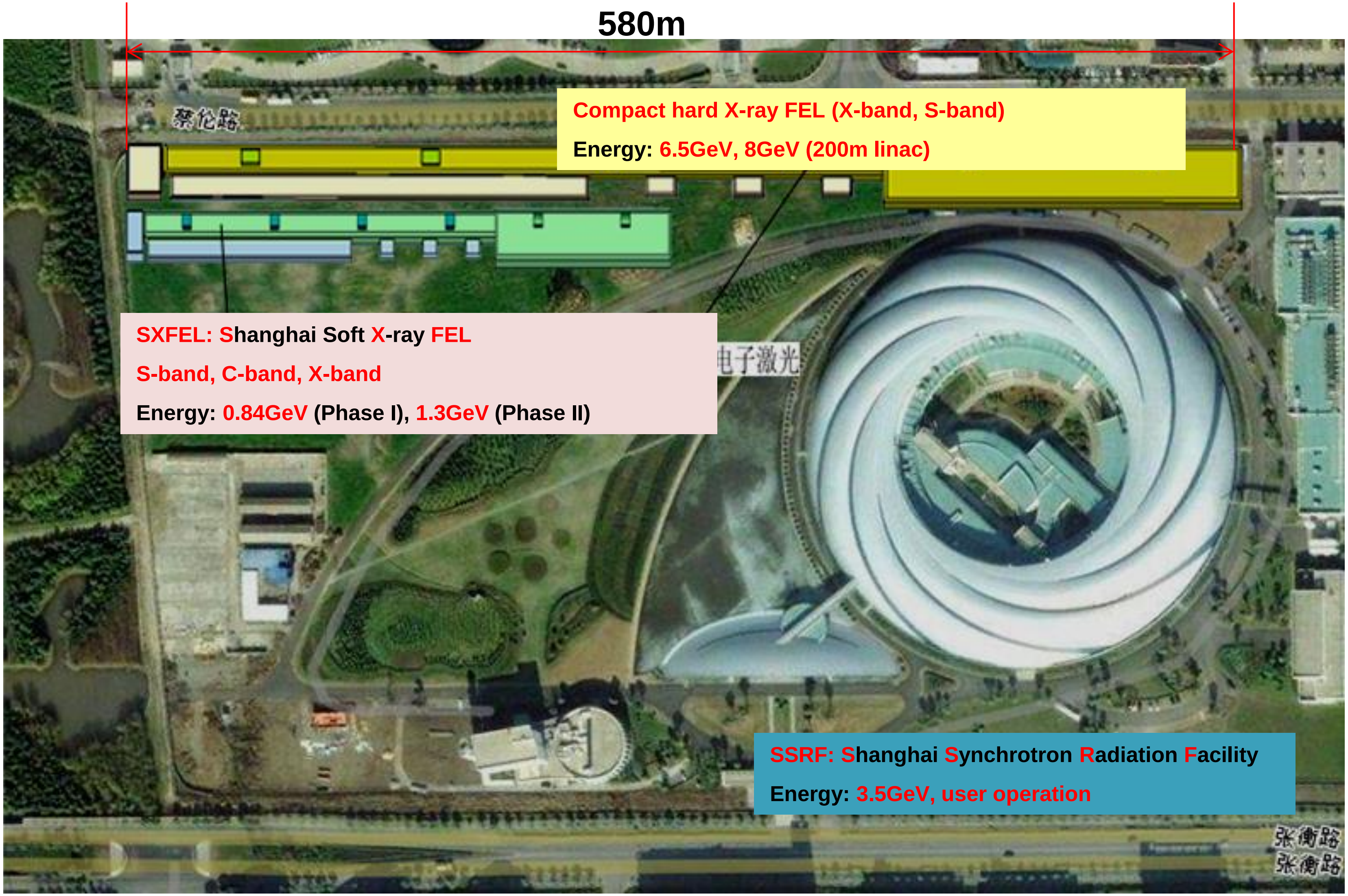
High gradient X-band linac extension

Active accelerating length	*40 m*
Accelerating gradient	*70 MV/m*
Beam energy gain	*2.8 GeV*
Injection energy	*0.7 GeV*

New FEL beamline expected performance	
Undulator period	30 mm
Undulator parameter	1
Fundamental wavelength	**0.5 nm**
Peak power at saturation	5.6 GW

N.B. The new layout could also provide two electron beams at the same time (@25 Hz) with different energies

Shanghai Photon Science Center at SINAP



Compact hard X-ray FEL (X-band, S-band)

Energy: 6.5GeV, 8GeV (200m linac)

SXFEL: Shanghai Soft X-ray FEL

S-band, C-band, X-band

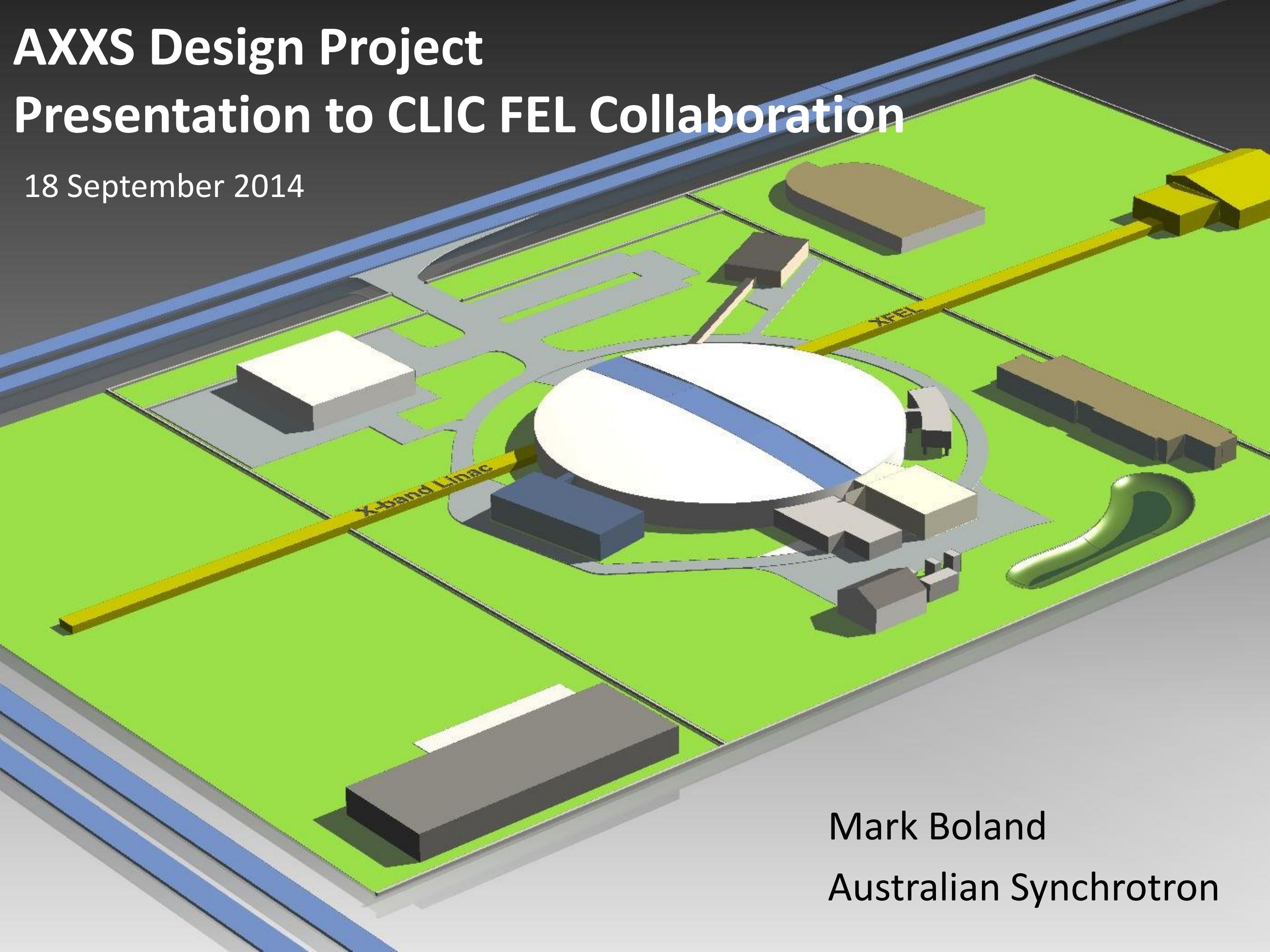
Energy: 0.84GeV (Phase I), 1.3GeV (Phase II)

SSRF: Shanghai Synchrotron Radiation Facility

Energy: 3.5GeV, user operation

AXXS Design Project
Presentation to CLIC FEL Collaboration

18 September 2014



Mark Boland
Australian Synchrotron

Horizon2020 application for X-band XFEL

Research and Innovation actions
Innovation actions

proposal full title	**X-band technology for FELs**
proposal acronym	**XbFEL**
type of funding scheme	**H2020**; Funding scheme **RIA**: **Research and Innovation actions – innovation actions**; proposal ID: **SEP-210171536**
work programme topic addressed	Topic: **INFRADEV-1-2014**: CALL IDENTIFIER **H2020-INFRADEV-1-2014-1**
name of the coordinating person	Gerardo d'Auria Project leader X-band systems for FERMI@Elettra project, at Elettra - Sincrotrone Trieste S.C.p.A.

LIST OF PARTICIPANTS

Participant No	Participant organisation name	Short name	Country
1 (Coordinator)	**Elettra – Sincrotrone Trieste S.C.p.A.**	ST	Italy
2	**CERN - European Organization for Nuclear Research**	CERN	Switzerland
3	**Uniwersytet Jagiellonski**	UJ	Poland
4	**Science and Technology Facilities Council**	STFC	United Kingdom
5	**Shanghai Institute of Applied Physics, Chinese Academy of Sciences**	SINAP	China
6	**VDL ETG Technology & Development B.V.**	VDL	Netherlands
7	**Universitetet i Oslo**	OSLO	Norway
8	**Institute of Accelerating Systems and Applications**	IASA	Greece
9	**Uppsala Universitet**	UU	Sweden
10	**Australian Synchrotron**	ASLS	Australia
11	**Ankara University Institute of Accelerator Technology**	AU-IAT	Turkey
12	**Lancaster University**	ULANC	United Kingdom

Collaborative X-band and high-gradient structure production

Institute	Structure	Status
KEK	Long history – latest TD26CC	Mechanical design
Tsinghua	T24 - VDL machined, Tsinghua assembled, H bonding, KEK high-power test	At KEK
	CLIC choke	manufacturing tests
SINAP	XFEL structure, KEK high-power test	rf design phase
	T24, CERN high-power test	Agreement signed
	Four XFEL structures	H2020 proposal
CIEMAT	TD24CC	Agreement signed
PSI	Two T24 structures made at PSI using SwissFEL production line including vacuum brazing	Mechanical design work underway
VDL	XFEL structure	H2020 proposal
SLAC	T24 in milled halves	machining
CERN	see Anastasiya’s talk	
	KT (Knowledge Transfer) funded medical linac	machining

Conclusions from my talk

Structure performance – Numerous prototypes at or near 100 MV/m (unloaded). Some more gradient may come out of near-term testing, rf design has some new tricks (current design dates from 2008) and we may to chose to add some margin in our re-baselining/re-optimization.

Conditioning – New analysis is yielding insights into the process and with insight may come improvements. DC system duplicating results which may give dramatically increased options for testing ideas through experiment.

Outreach – Steadily growing community interested in high-gradient and high-frequency linacs and in the technology itself.


1 µm
EHT = 20.00 kV
WD = 34.7 mm
Signal A = SE2
Disc #6 Front side
Stage at T = 45.0 °
Mag = 5.00 K X
Anite Perez Fontenla
Date :19 Jun 2014

Thank you