Introduction to CLIC
and
High-Gradient and X-band Development

CERN, 14 December 2015

Walter Wuensch, CERN

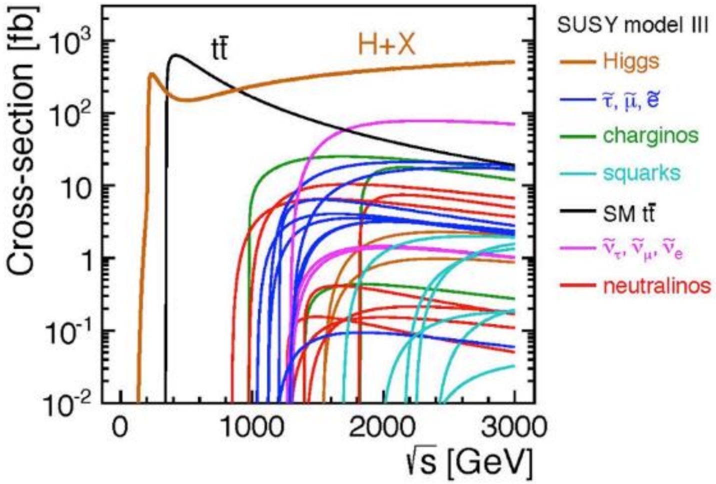
The CLIC Project

CERN, 14 December 2015

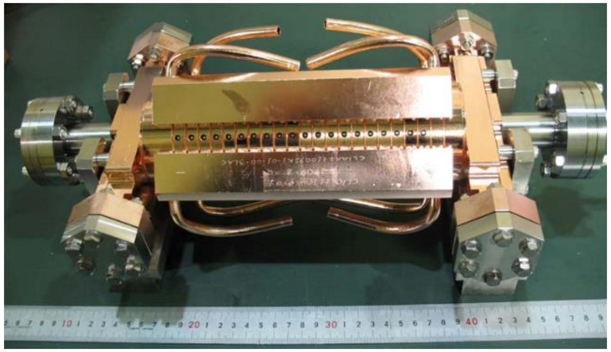
Walter Wuensch, CERN

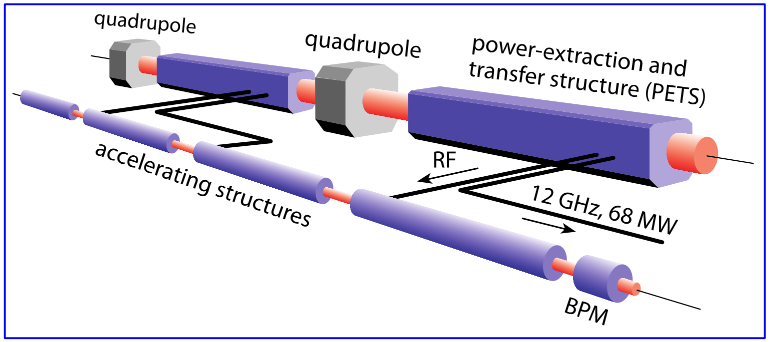
Introduction to CLIC

CLIC is an international collaboration based at CERN dedicated to developing the technology for an **e^+e^- linear collider** for the range of **250 GeV to 3 TeV.**



It is based on high-gradient,
100 MV/m,
normal conducting rf, low emittance beams and a two-beam power generation scheme. A klystron-based initial energy stage is also being considered.

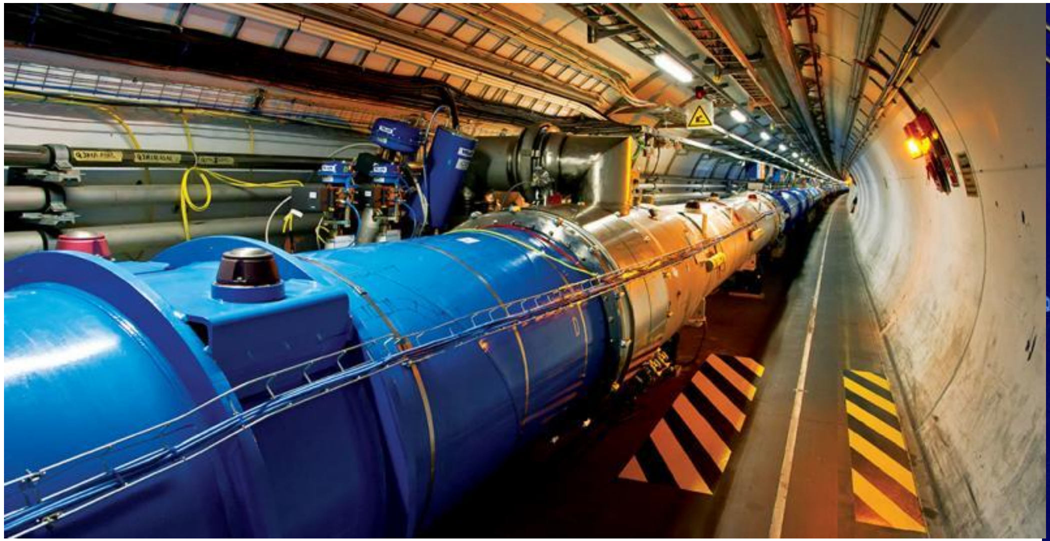


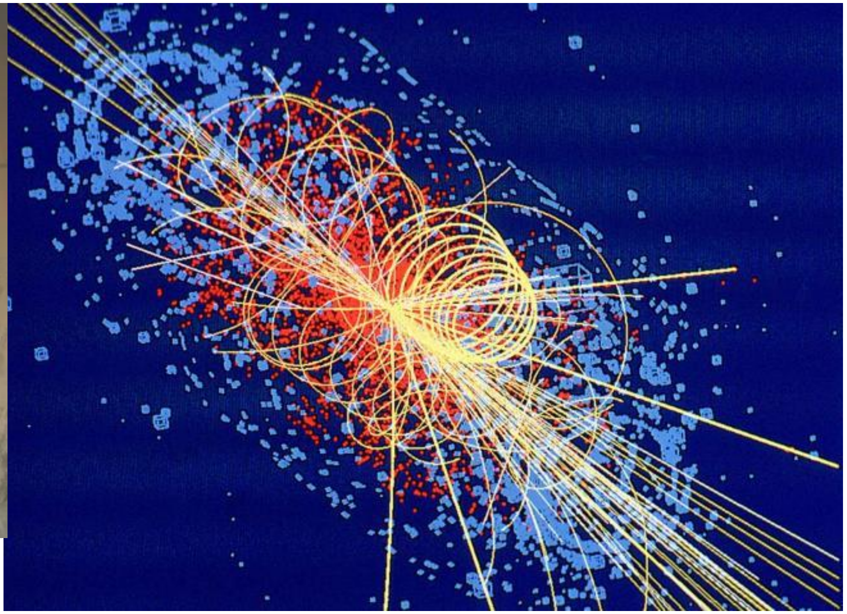


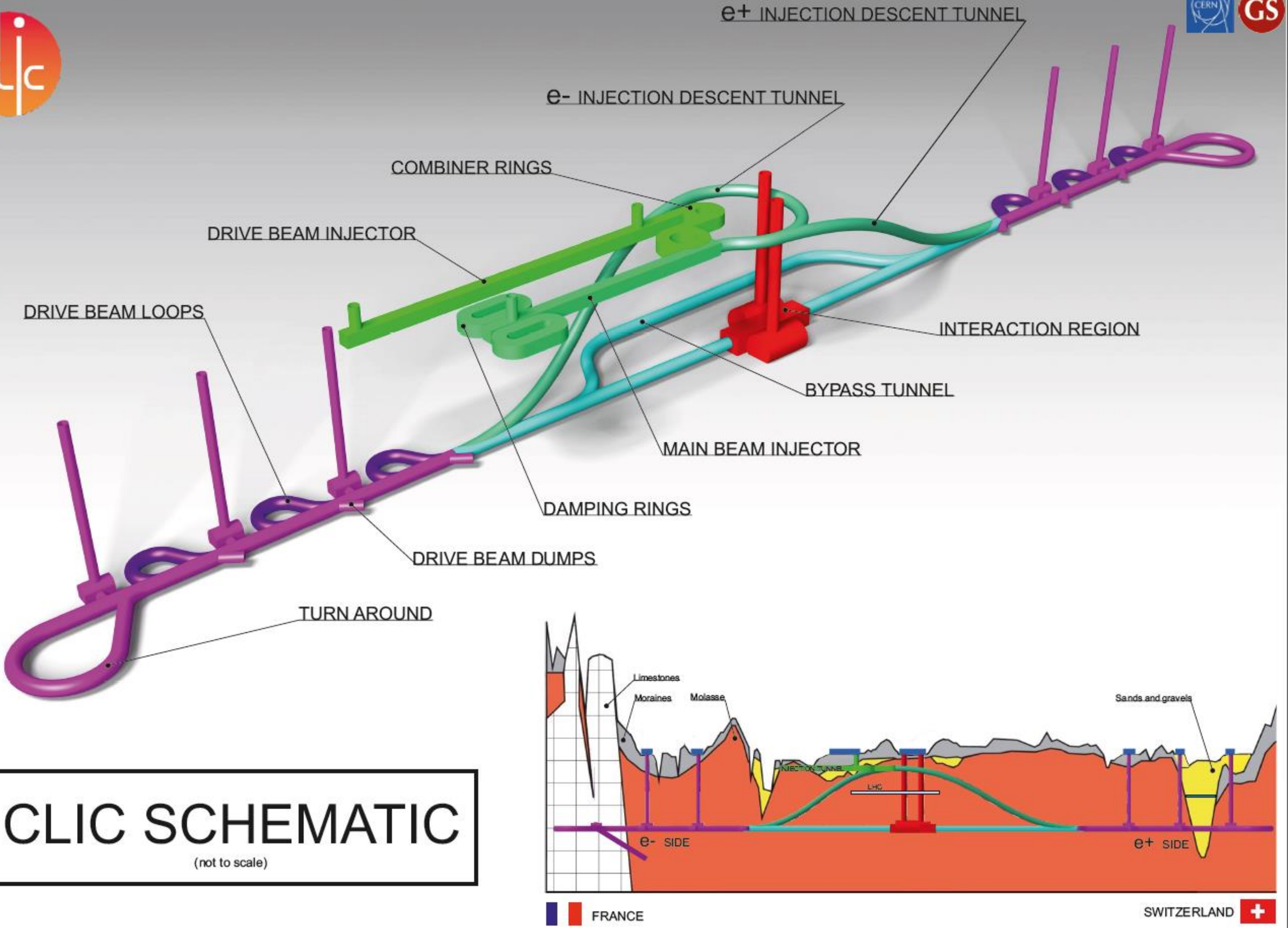
The big question

The crucial background for the CLIC study is LHC run 2. The LHC is running at nearly full energy, 13.5 TeV compared to 7 TeV in the first run.

The physics landscape in this energy range should emerge in the next two years or so. The nature of new discoveries, or their absence, will have a tremendous impact on future high energy physics studies.



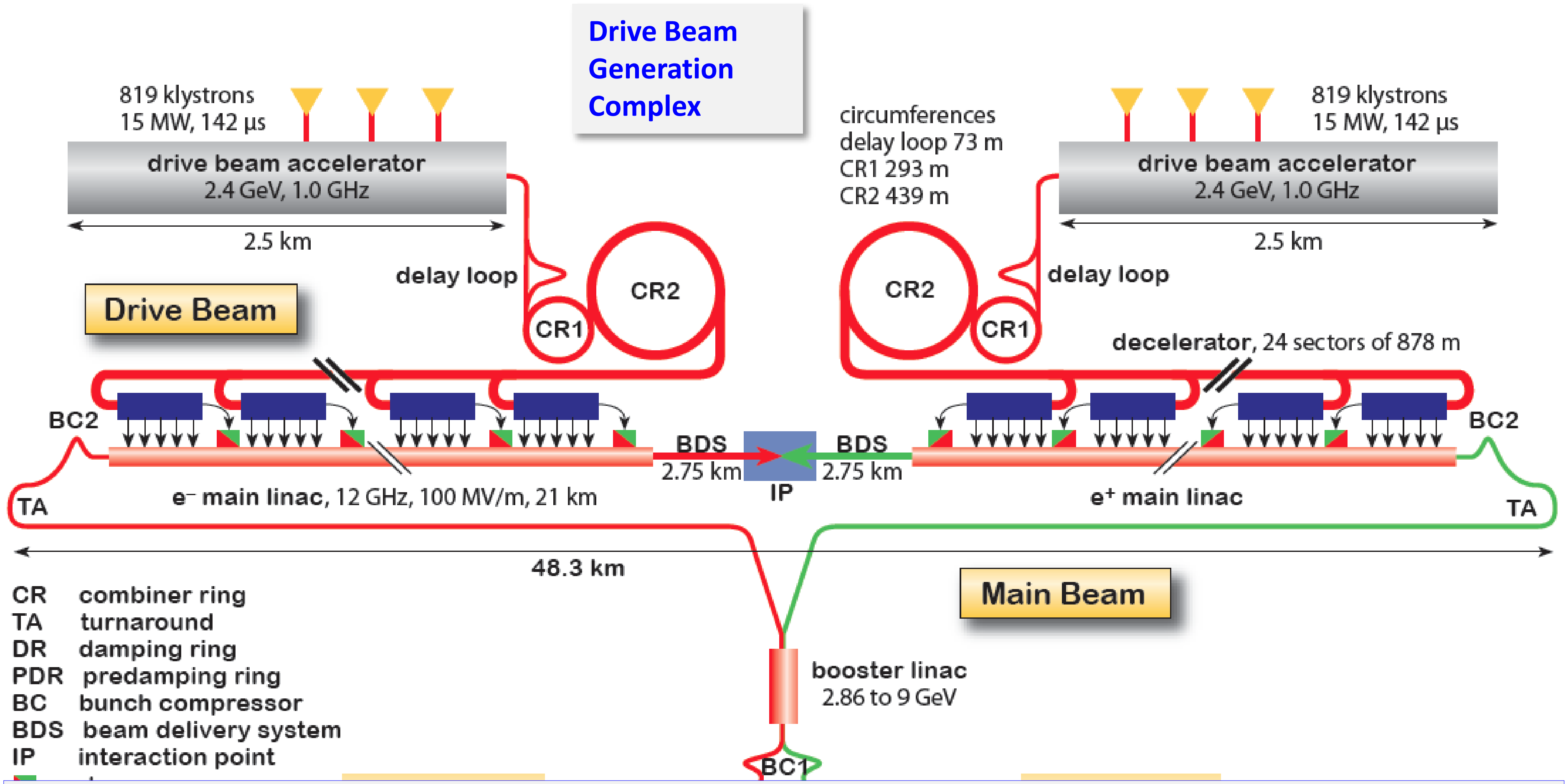




CLIC SCHEMATIC

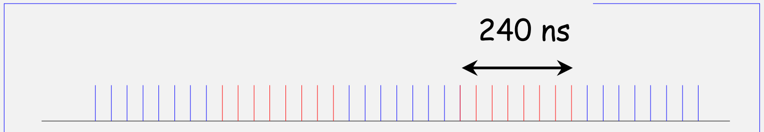
(not to scale)

CLIC Layout at 3 TeV



CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point

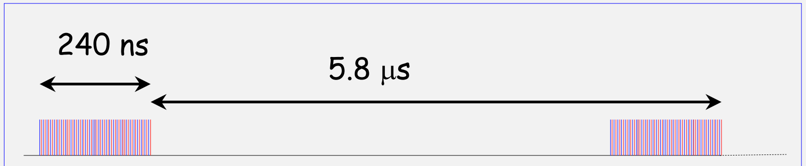
Drive beam time structure - initial



140 µs train length - 24 × 24 sub-pulses

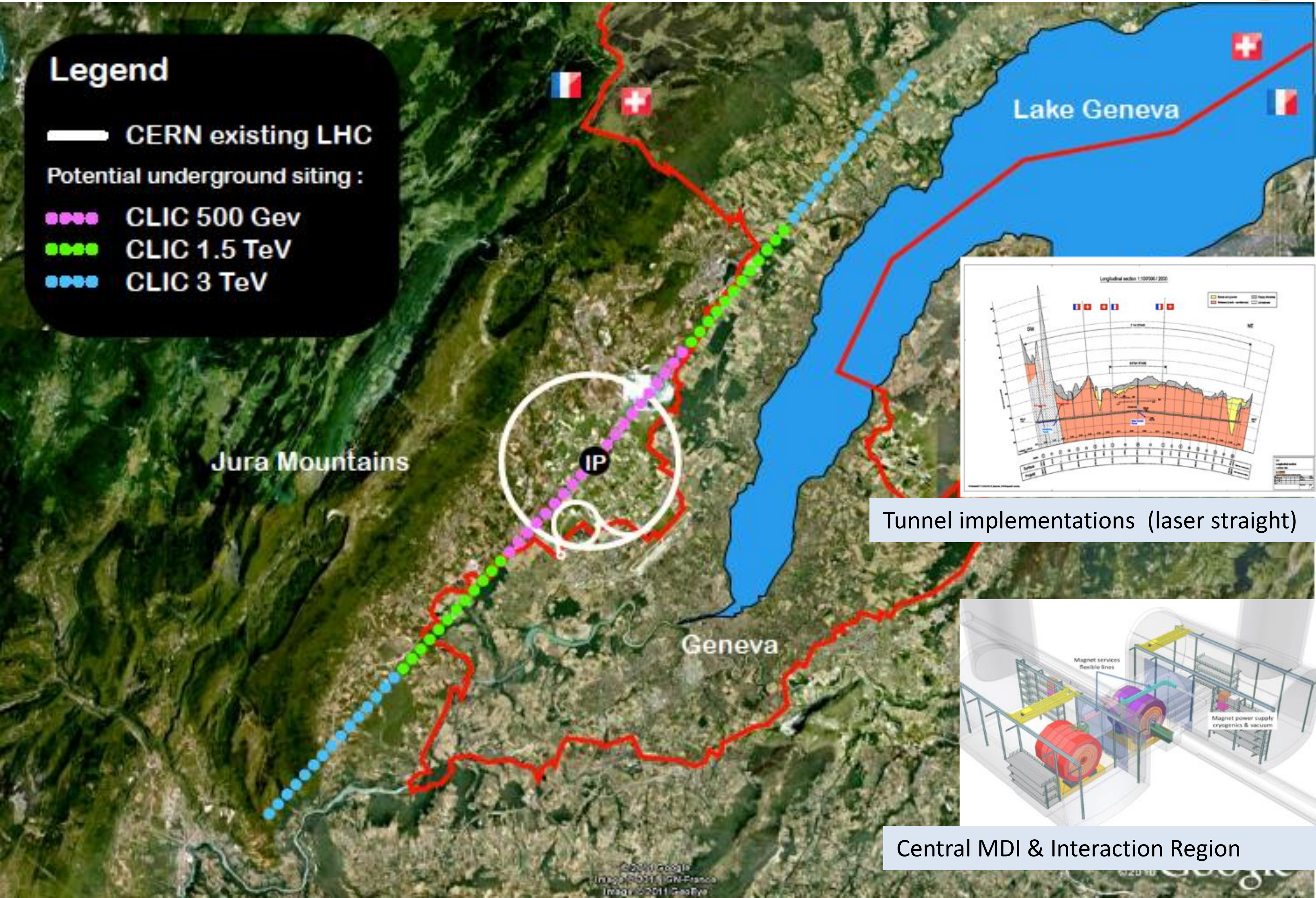
4.2 A - 2.4 GeV – 60 cm between bunches

Drive beam time structure - final



24 pulses – 101 A – 2.5 cm between bunches

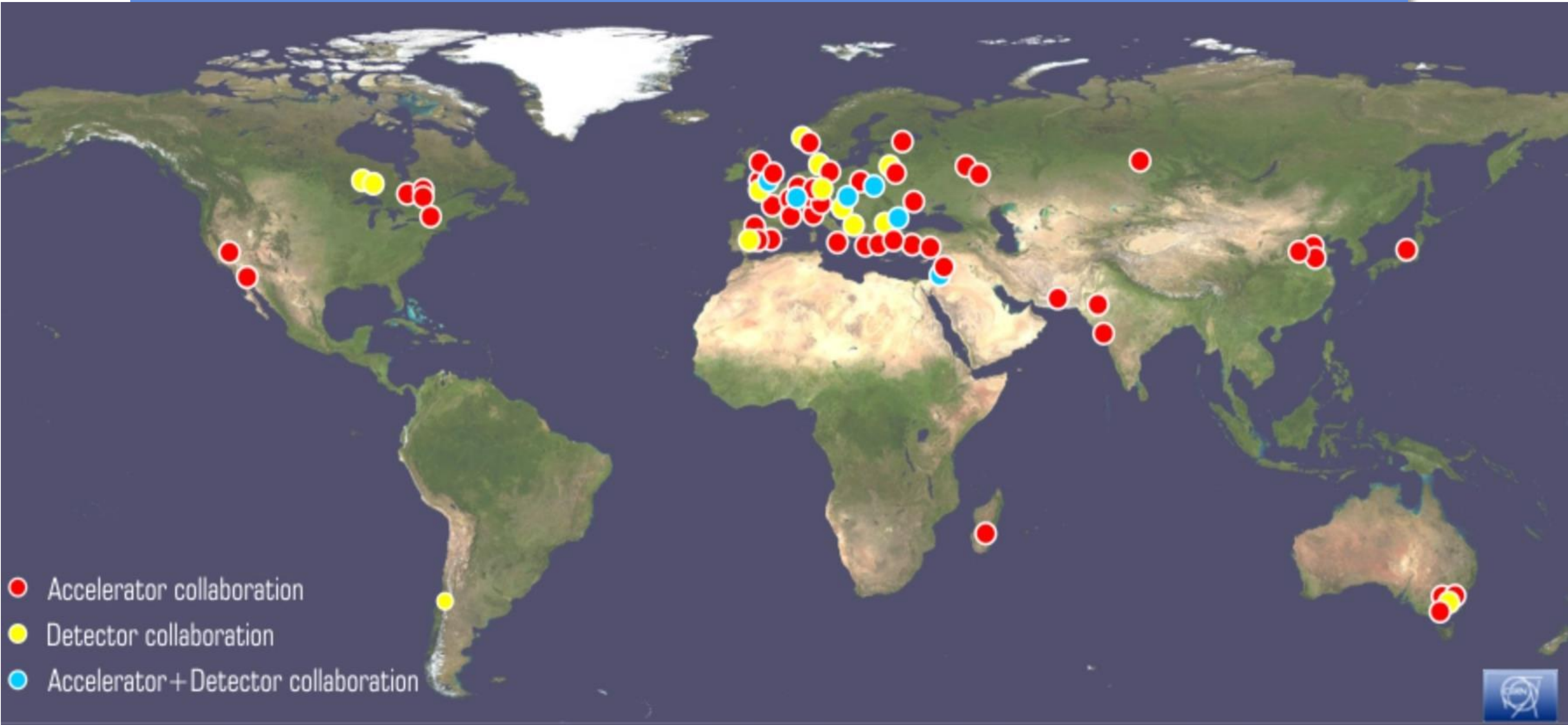
CLIC near CERN

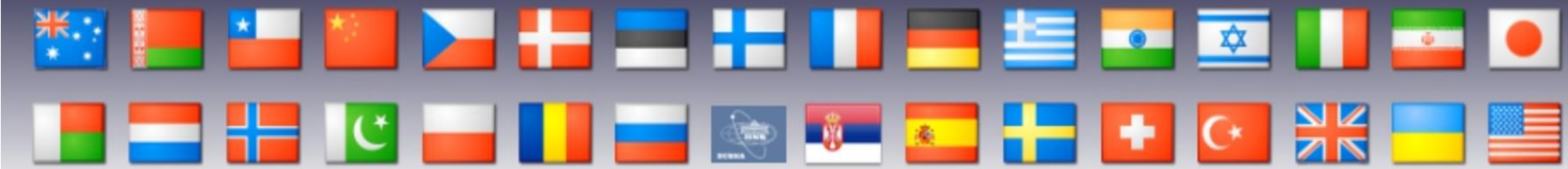


Tunnel implementations (laser straight)

Central MDI & Interaction Region

CLIC Collaboration





Accelerator collaboration has ≈ 50 institutes and the detector collaboration ≈ 25.

CDR

The CLIC collaboration has established a consistent set of baseline parameters for a 3 TeV version of CLIC and extrapolated downwards to 500 GeV.

These parameters, along with documentation of the experimental and technical work to demonstrate feasibility and a cost estimate for 500 GeV has been written up in a CDR in 2012.

A Multi-TeV Linear Collider based on CLIC Technology

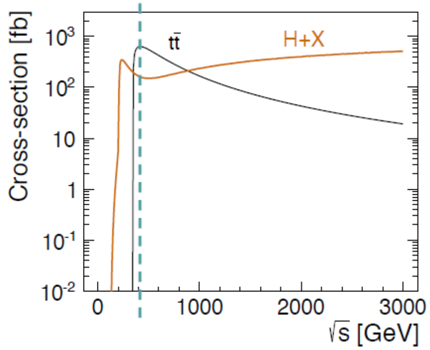
Physics and Detectors at CLIC

The CLIC Programme: towards a staged e^+e^- Linear Collider exploring the Terascale

http://clic-study.web.cern.ch/content/conceptual-design-report

CLIC Physics Landscape

CLIC is foreseen as a staged machine:
- ★ First stage focuses on precision SM physics
  - ~350-375 GeV : Higgs and top

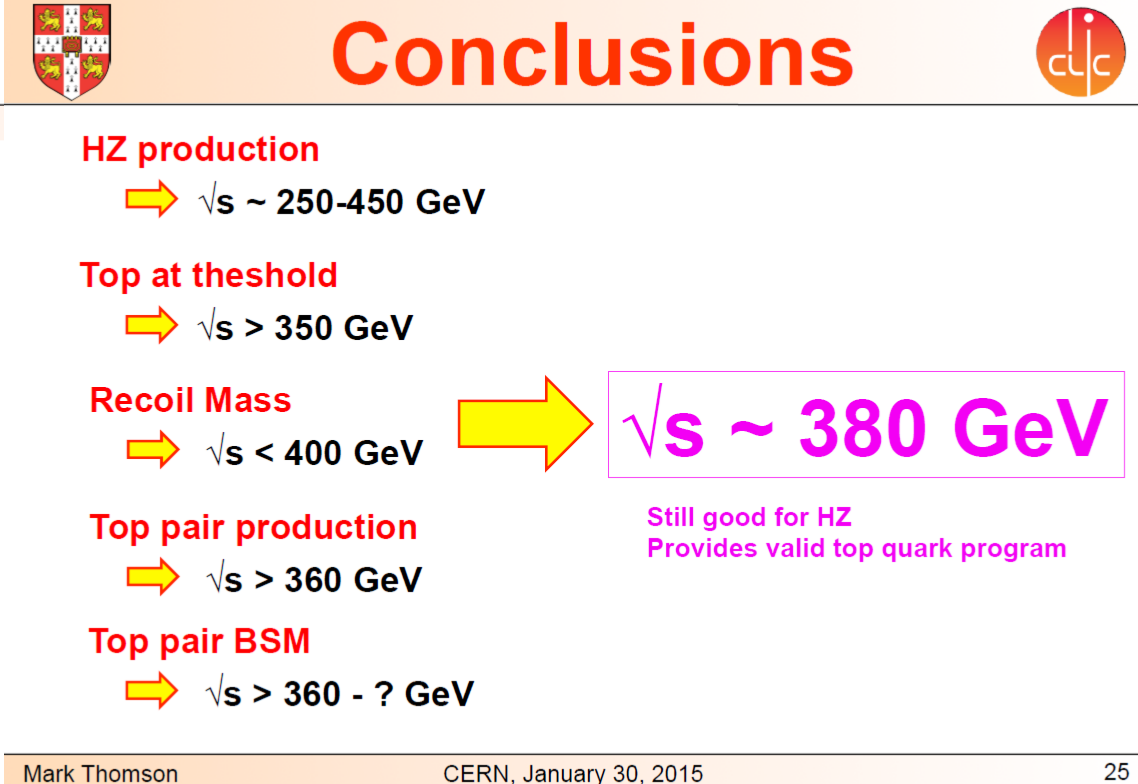


- ★ Not the peak of Higgs cross section
  - But, luminosity scales with √s
- ★ 250 GeV and 350 GeV give similar precision for coupling measurements
- ★ With >350 GeV as a first stage:
  - provides access to top physics
- ★ Energies of subsequent stages motivated by physics
  - results from ~14 TeV LHC operation
  - direct dark matter searches,

Mark Thomson CERN, January 30, 2015

CLIC re-baselining and energy staging exercise following CDR and LHC run 1.

Presentation at CLIC workshop: http://indico.cern.ch/event/336335/overview



Conclusions

HZ production
⇨ √s ~ 250-450 GeV

Top at theshold
⇨ √s > 350 GeV

Recoil Mass
⇨ √s < 400 GeV

Top pair production
⇨ √s > 360 GeV

Top pair BSM
⇨ √s > 360 - ? GeV

⇨ **√s ~ 380 GeV**

Still good for HZ
Provides valid top quark program

Mark Thomson CERN, January 30, 2015 25

Automatic Parameter Determination

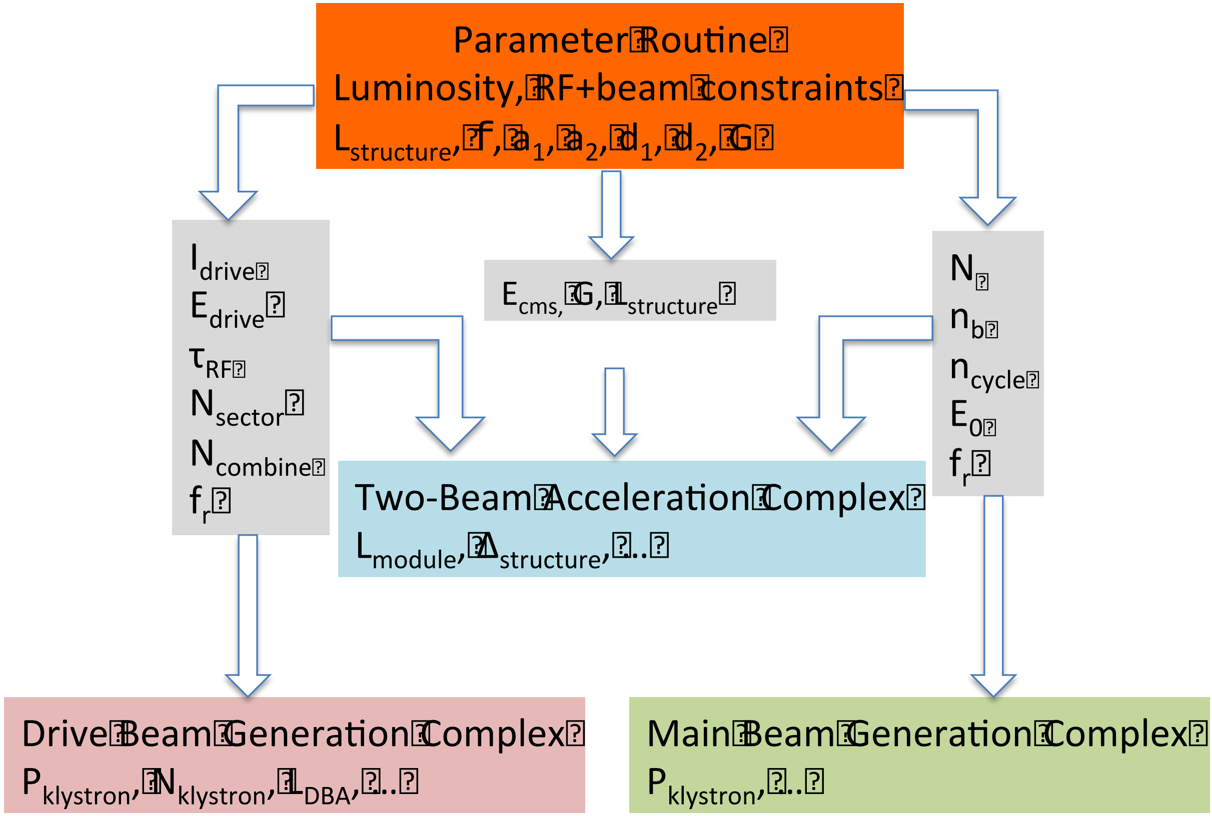
Structure design fixed by few parameters

$a_1,a_2,d_1,d_2,N_c,\phi,G$

Beam parameters derived automatically to reach specific energy and luminosity

Consistency of structure with RF constraints is checked

Repeat for 1.7 billion cases



Parameter Routine
Luminosity, RF+beam constraints
$L_{structure}, \phi, a_1, a_2, d_1, d_2, G$

I_{drive}
E_{drive}
τ_{RF}
N_{sector}
$N_{combine}$
f_r

$E_{cms}, G, L_{structure}$

N
n_b
n_{cycle}
E_0
f_r

Two-Beam Acceleration Complex
$L_{module}, \Delta_{structure}, \ldots$

Drive Beam Generation Complex
$P_{klystron}, N_{klystron}, L_{DBA}, \ldots$

Main Beam Generation Complex
$P_{klystron}, \ldots$

Design choices and specific studies

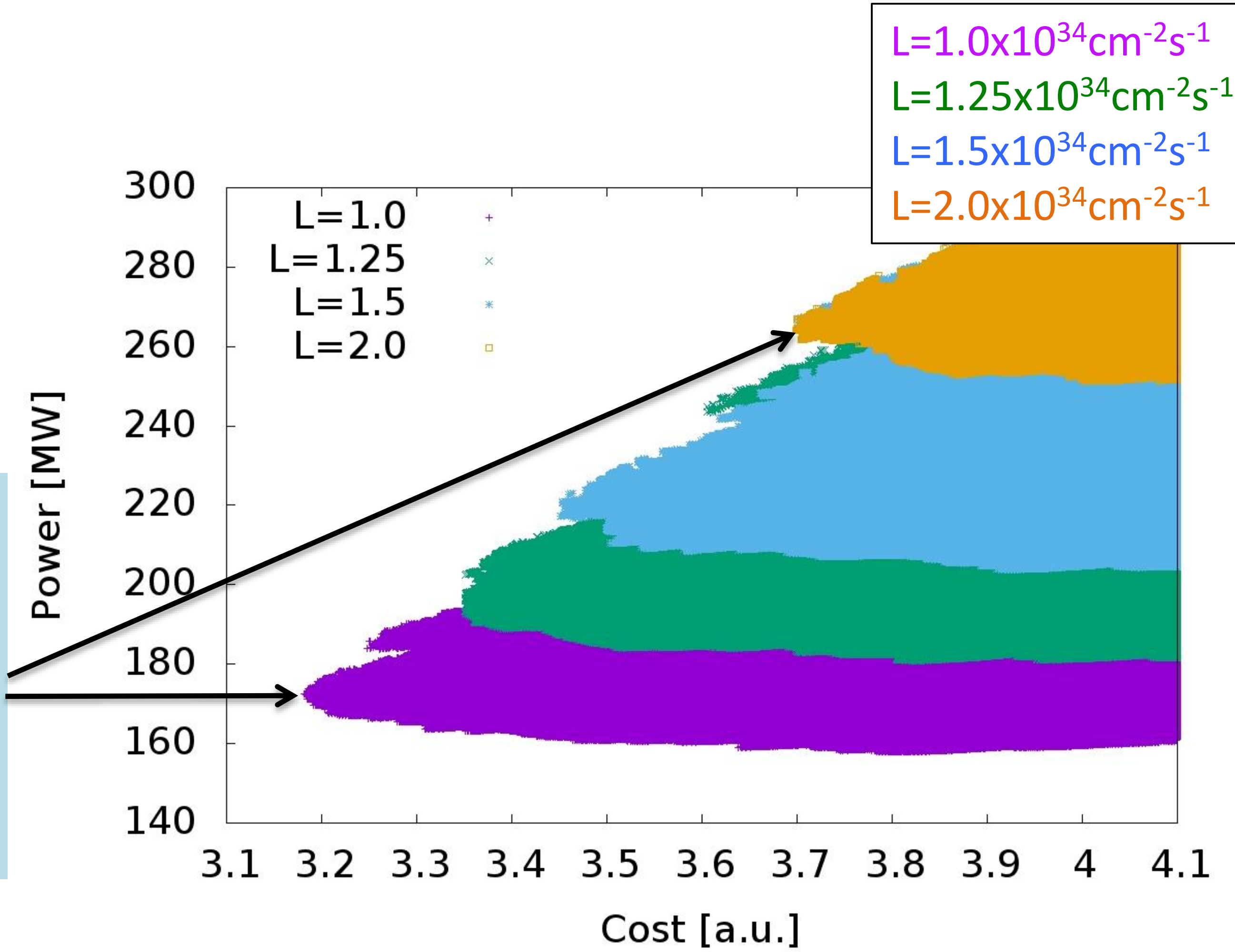
- Use 50Hz operation for beam stability
- Scale horizontal emittance with charge to keep the same risk in damping ring
- Scale for constant local stability in main linac, i.e. tolerances vary but stay above CDR values
- BDS design similar to CDR, use improved β_x-reach as reserve
- …

Optimisation at 380GeV

Many thanks to the rebaselining team that provided the models that are integrated in the code

Luminosity goal significantly impact minimum cost
For $L=1\times10^{34}cm^{-2}s^{-1}$ to $L=2\times10^{34}cm^{-2}s^{-1}$:

Costs 0.5 a.u.
And O(100MW)



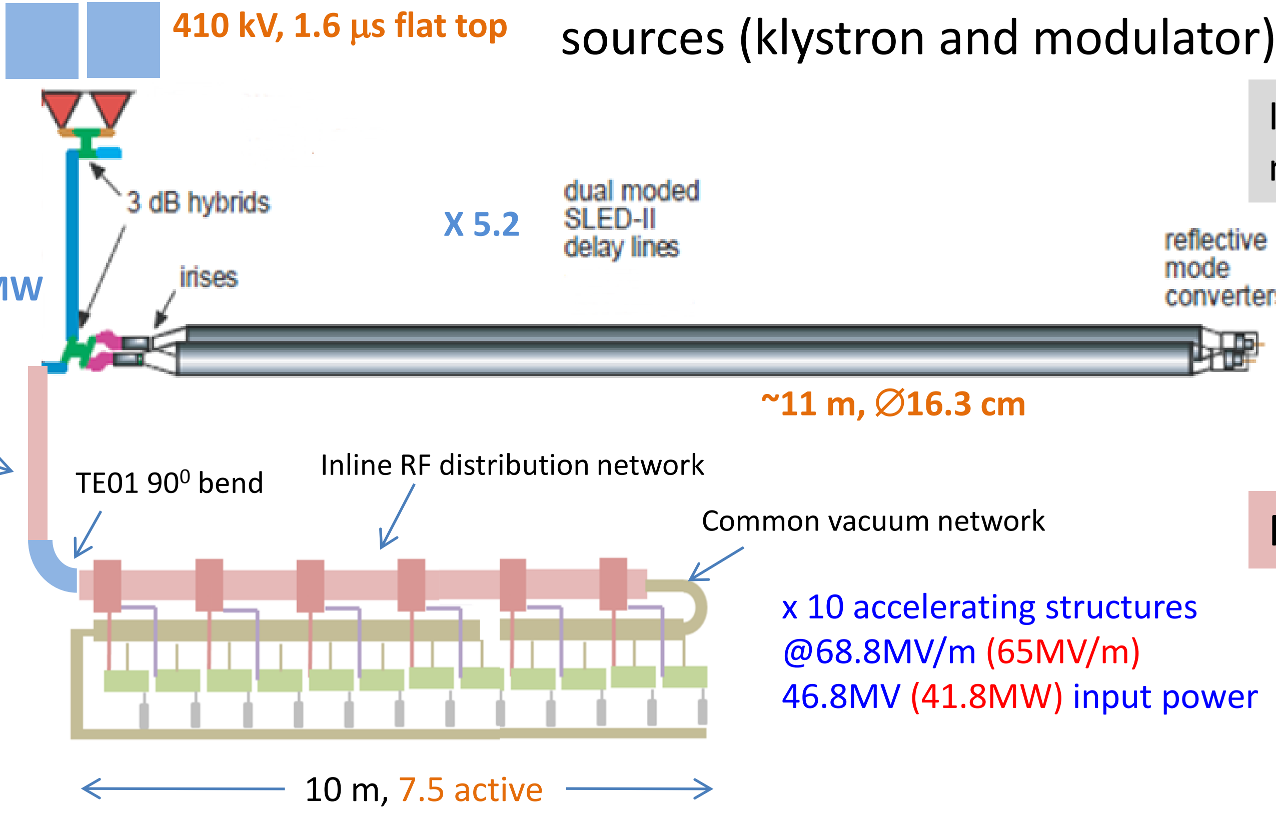
Cheapest machine is close to lowest power consumption => small potential for trade-off

Electron Linac RF Unit Layout

based on the existing (industrialized) RF sources (klystron and modulator)

I. Syratchev, modified by me

Preliminary



2x ScandiNova solid state modulators

2x CPI klystrons

410 kV, 1.6 μs flat top

50 MW
1.5 μs
(Operated @45MW)

100 (90) MW
1.5 μs

X 5.2

~11 m, $\varnothing$16.3 cm

TE01 transfer line (η_{RF}=0.9)

TE01 90^0 bend

Inline RF distribution network

Common vacuum network

468 MW
(418 MW)
150 ns

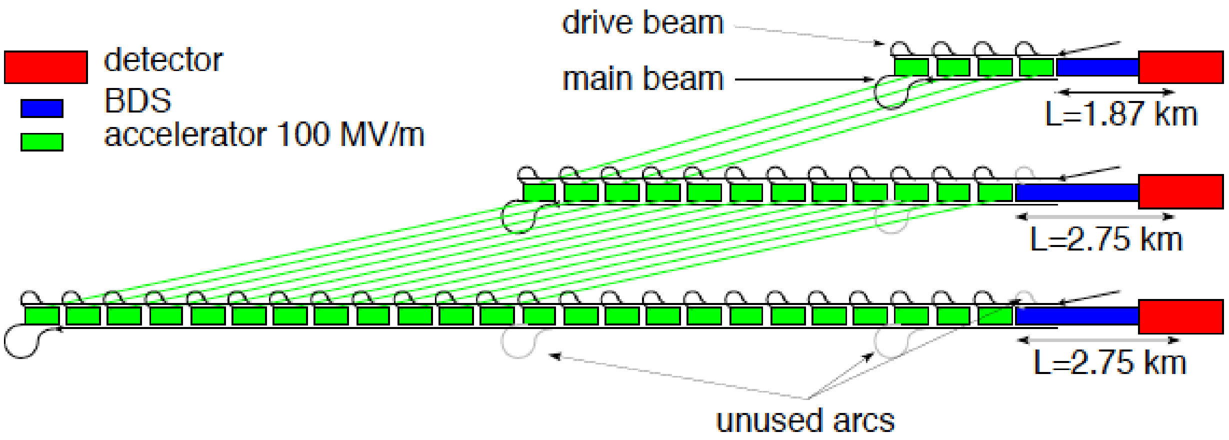
x 10 accelerating structures
@68.8MV/m (65MV/m)
46.8MV (41.8MW) input power

10 m, 7.5 active

This unit should provide ~488 MeV acceleration beam loading.
Need 12 RF units.
Cost 51.7 a.u., 4% more than optimum

Staged Design

Goal: Develop a staged design for CLIC to optimise physics and funding profile, using knowledge from CDR



- First stage: E_{cms}=~~360GeV~~ 380Gev, $L=1.5x10^{34}cm^{-2}s^{-1}$, $L_{0.01}/L>0.6$
  - Luminosity has been defined based on physics and machine studies in 2014
  - 420 GeV stage has also been explored, but physics prefers 360GeV
- Second stage: $E_{cms}=O(1.5TeV)$
- Final stage: $E_{cms}=3TeV$, $L_{0.01}=2x10^{34}cm^{-2}s^{-1}$, $L_{0.01}/L>0.3$

High-Gradient and X-Band Development

CERN, 14 December 2015

Walter Wuensch, CERN

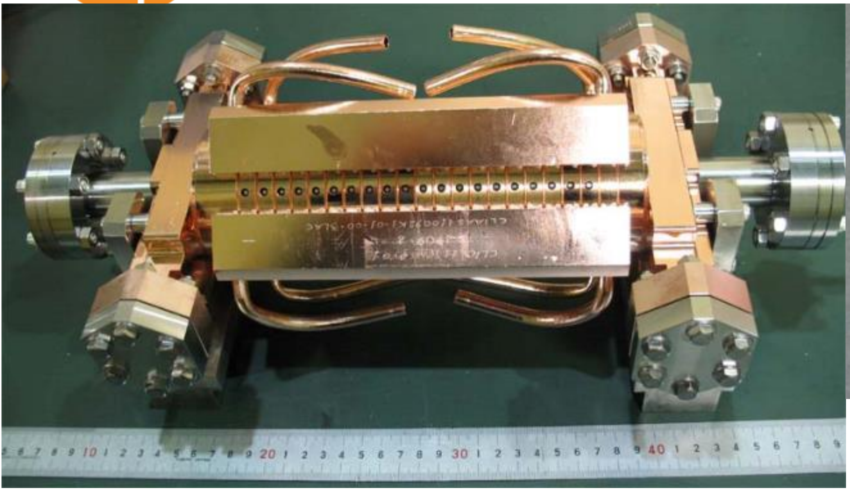
Objectives

One of the key objectives of the CLIC study has been to prove that we can achieve 100 MV/m accelerating gradient necessary for a 3 TeV center of mass collider.

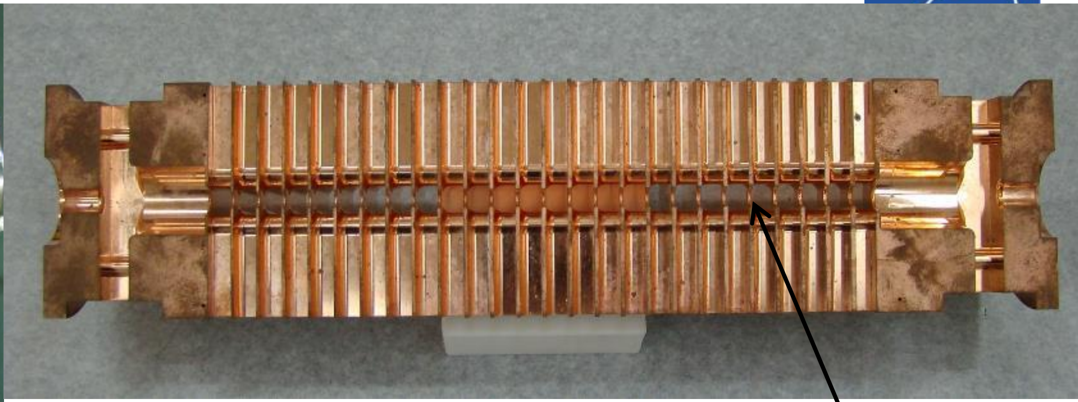
Along with this objective is the requirement that very low emittance bunch trains must be accelerated, meaning that long and short range wakefields must be controlled. This means micron-precision manufacture and assembly along with higher-order-mode suppression.

I will now describe some of these issues.

Accelerating structure



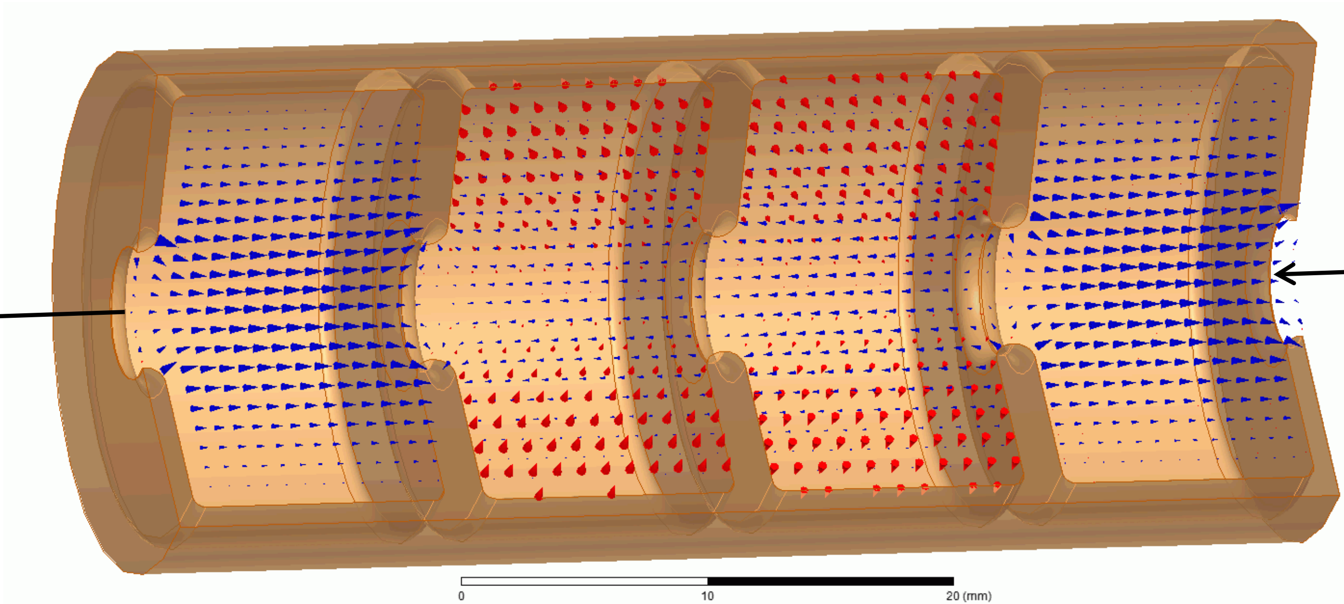
Outside



Inside

11.994 GHz X-band

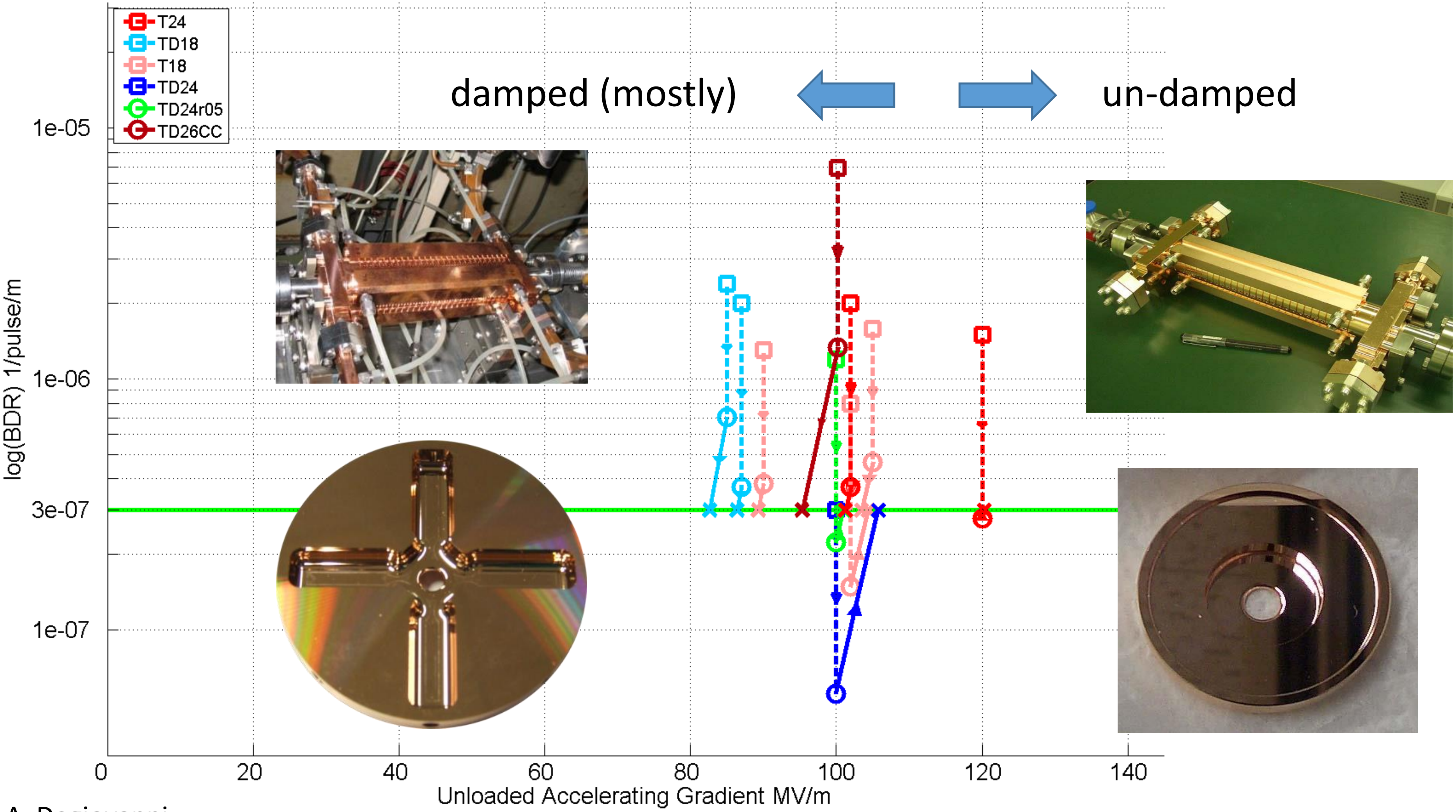
6 mm diameter beam aperture



beam propagation direction

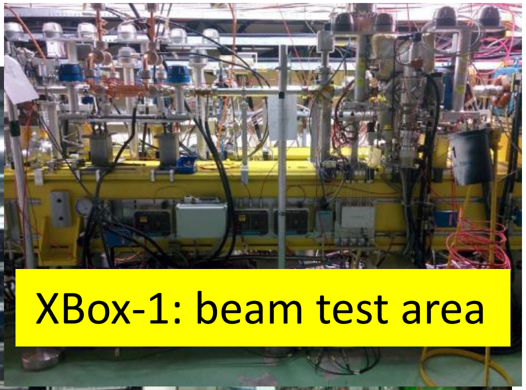
Concept

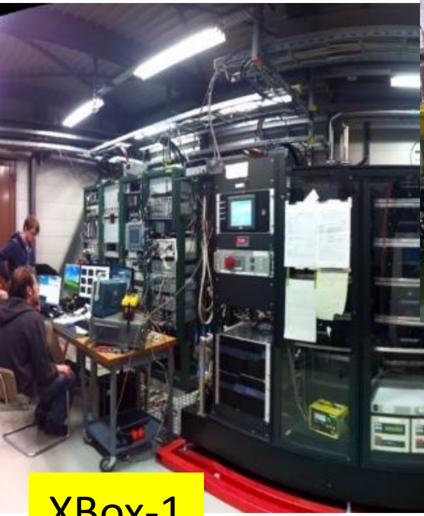
State of the gradient
Full length prototypes



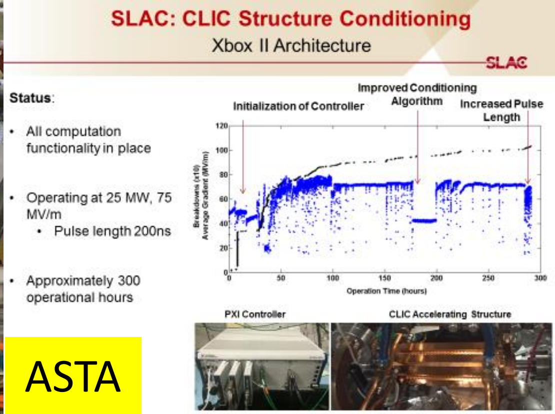
A. Degiovanni

X-band test stands around the world


XBox-1: beam test area


XBox-1


NEXTEF


SLAC: CLIC Structure Conditioning

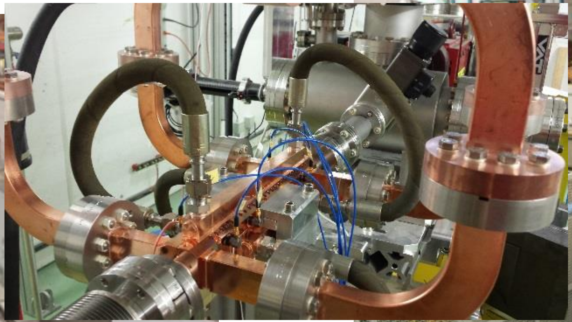
Xbox II Architecture

Status:

- All computation functionality in place
- Operating at 25 MW, 75 MV/m
  - Pulse length 200ns
- Approximately 300 operational hours

ASTA

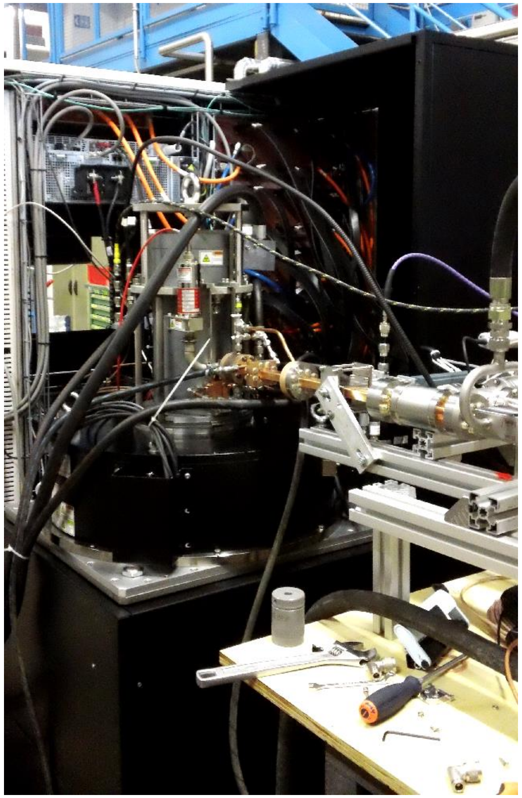

XBox-2



XBox-3

Commercial X-band rf power sources

CPI 50 MW, 1.5 µs, 50 Hz



Toshiba 6 MW, 5 µs, 400 Hz

Commercial X-band klystrons at CERN. Availability of **commercial** rf power sources essential for spread and development of technology.

I. Syratchev, G. McMonagle, N. Catalan

The Xboxes

CPI 50MW 1.5us klystron
Scandinova Modulator
Rep Rate 50Hz

Current test:
Dogleg beam-loading experiment, **TD26CC#1** (in CTF3 LINAC)

Previous tests:
TD24R05 (CTF2, 2013)
TD26CC#1 (CTF2, 2013)
T24 (Dogleg, 2014-15)

CPI 50MW 1.5us klystron
Scandinova Modulator
Rep Rate 50Hz

Current test:
T24_OPEN (in halves)

Previous test:
CLIC Crab cavity (2014-15)

4x Toshiba 6MW 5us klystron
4x Scandinova Modulators
Rep Rate 400Hz

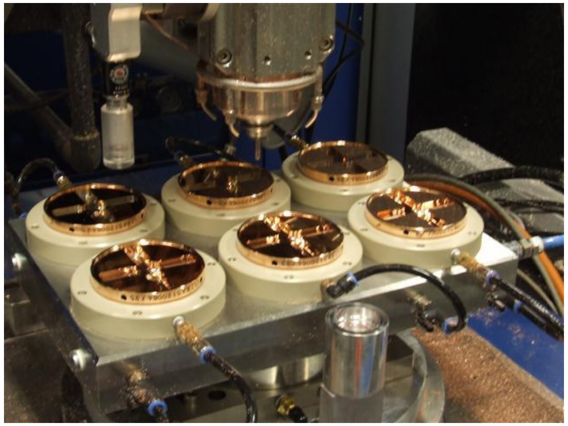
LLRF, pulse compressors and waveguide network to be completed at the end 2015

Medium power test:
3D printed Ti waveguide (Xbox-3A)

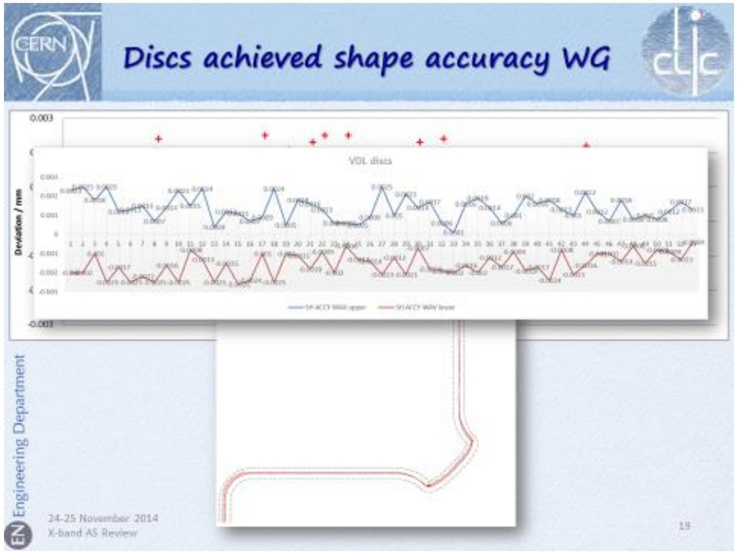
Commercial micron-precision machining

S. Atieh, A. Solodko

Micron-precision turning and milling.



High-gradients, high-frequencies and tight mechanical tolerances go together.
There is a solid industrial supplier base capable of making the micron tolerance parts we need.
The main risk is maintaining continuity – projects and orders are sporatic.



Discs achieved shape accuracy WG

EN Engineering Department

24-25 November 2014
X-band AS Review

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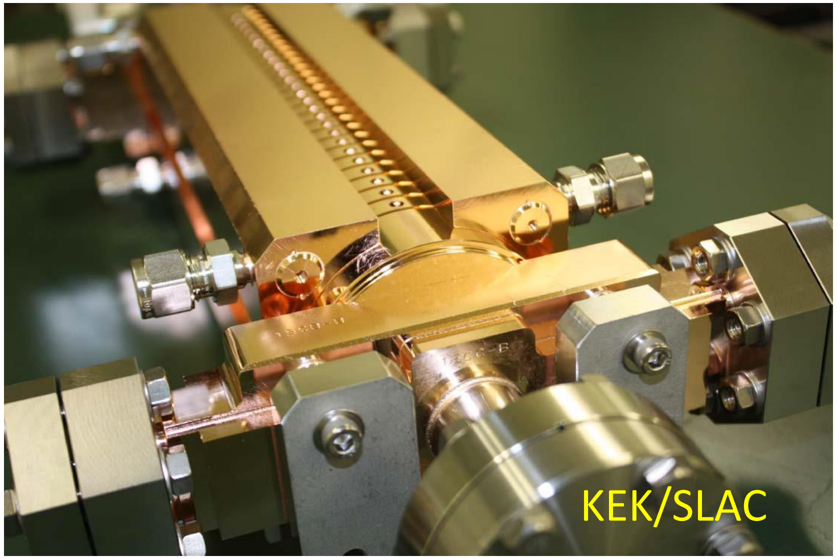
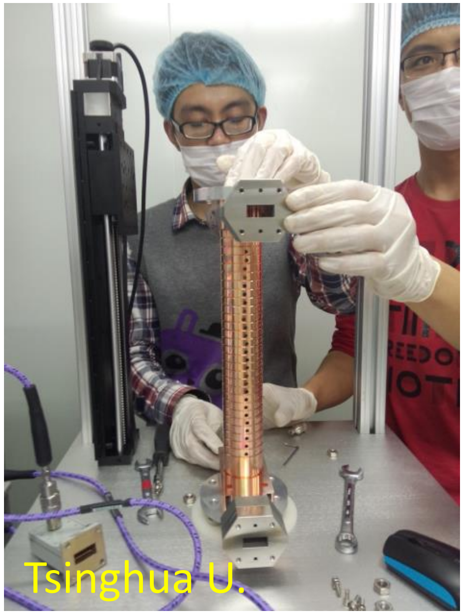
Assembly – still laboratory based

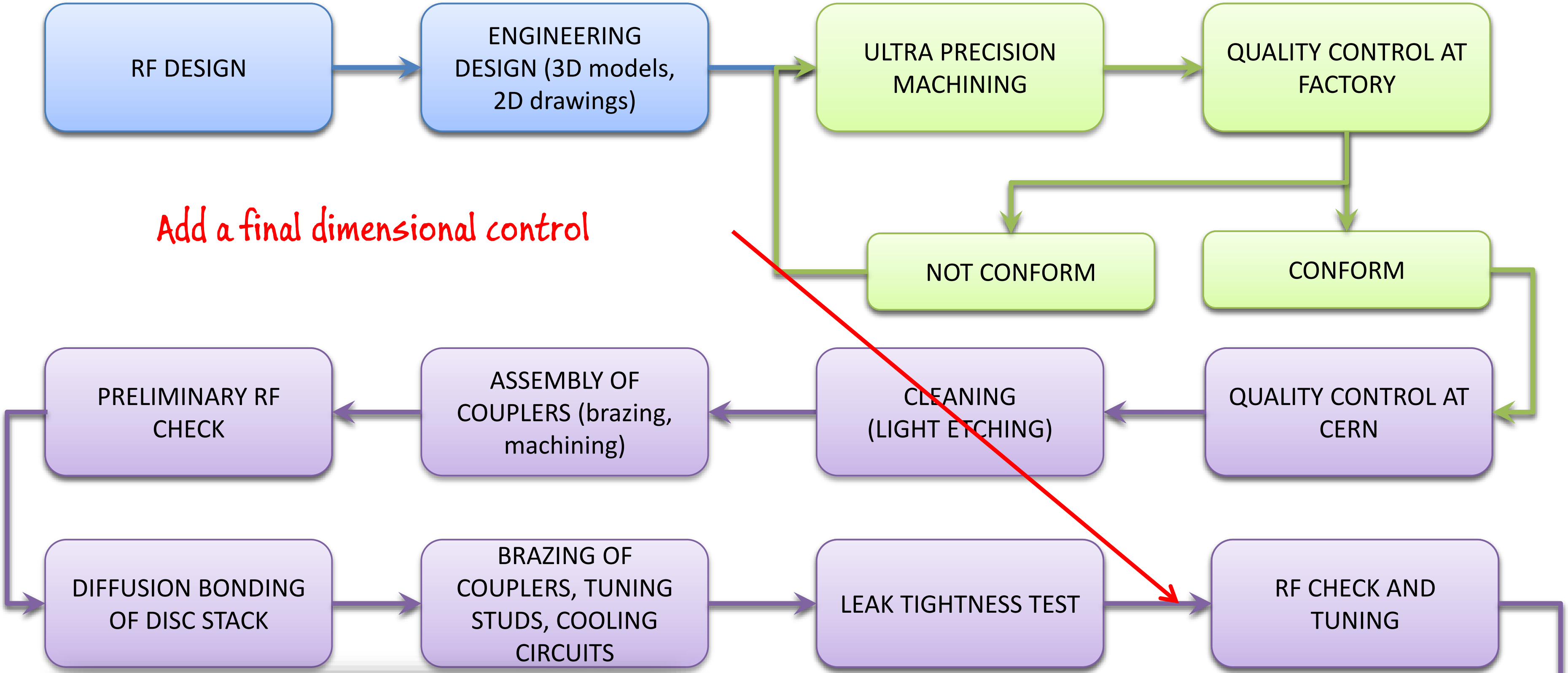
T. Higo



J. Shi



Baseline manufacturing flow



RF DESIGN

ENGINEERING DESIGN (3D models, 2D drawings)

ULTRA PRECISION MACHINING

QUALITY CONTROL AT FACTORY

NOT CONFORM

CONFORM

QUALITY CONTROL AT CERN

CLEANING (LIGHT ETCHING)

ASSEMBLY OF COUPLERS (brazing, machining)

PRELIMINARY RF CHECK

DIFFUSION BONDING OF DISC STACK

BRAZING OF COUPLERS, TUNING STUDS, COOLING CIRCUITS

LEAK TIGHTNESS TEST

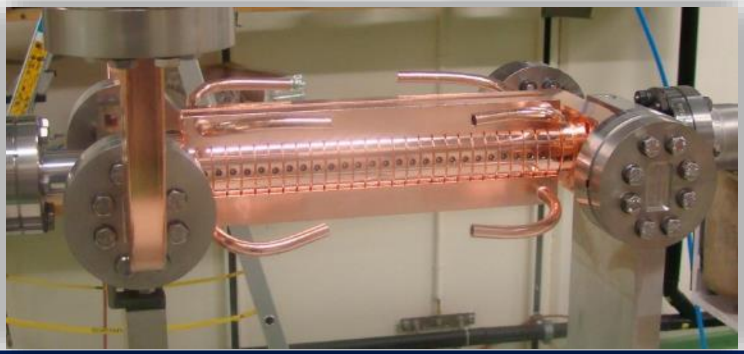
RF CHECK AND TUNING

BAKING (vacuum 650 °C, 10 days)

INSTALLATION

PACKAGING AND SHIPPING

Add a final dimensional control



Industrialization

- Currently we order all parts in industry, especially key-technology micron-precision diamond machining, but assemble the structures at CERN (but using commercial furnaces).
- Assembly is a big fraction of the cost.
- We are preparing to go to industry for complete prototype structures.
- This requires that we have our procedure appropriately documented.
- The assembly technology – chemistry, heat treatment, etc. – was originally taken from NLC/JLC program. Excellent fundamentally but we believe contains unnecessary and poorly justified steps so we are fine tuning it. Requires feedback from testing.
- No company has 50 MW of X-band power.

Introduction to the review.
Next accelerating structures and plans

N. Catalan Lasheras,
X-band accelerating structures review 24.11.2014

Participants

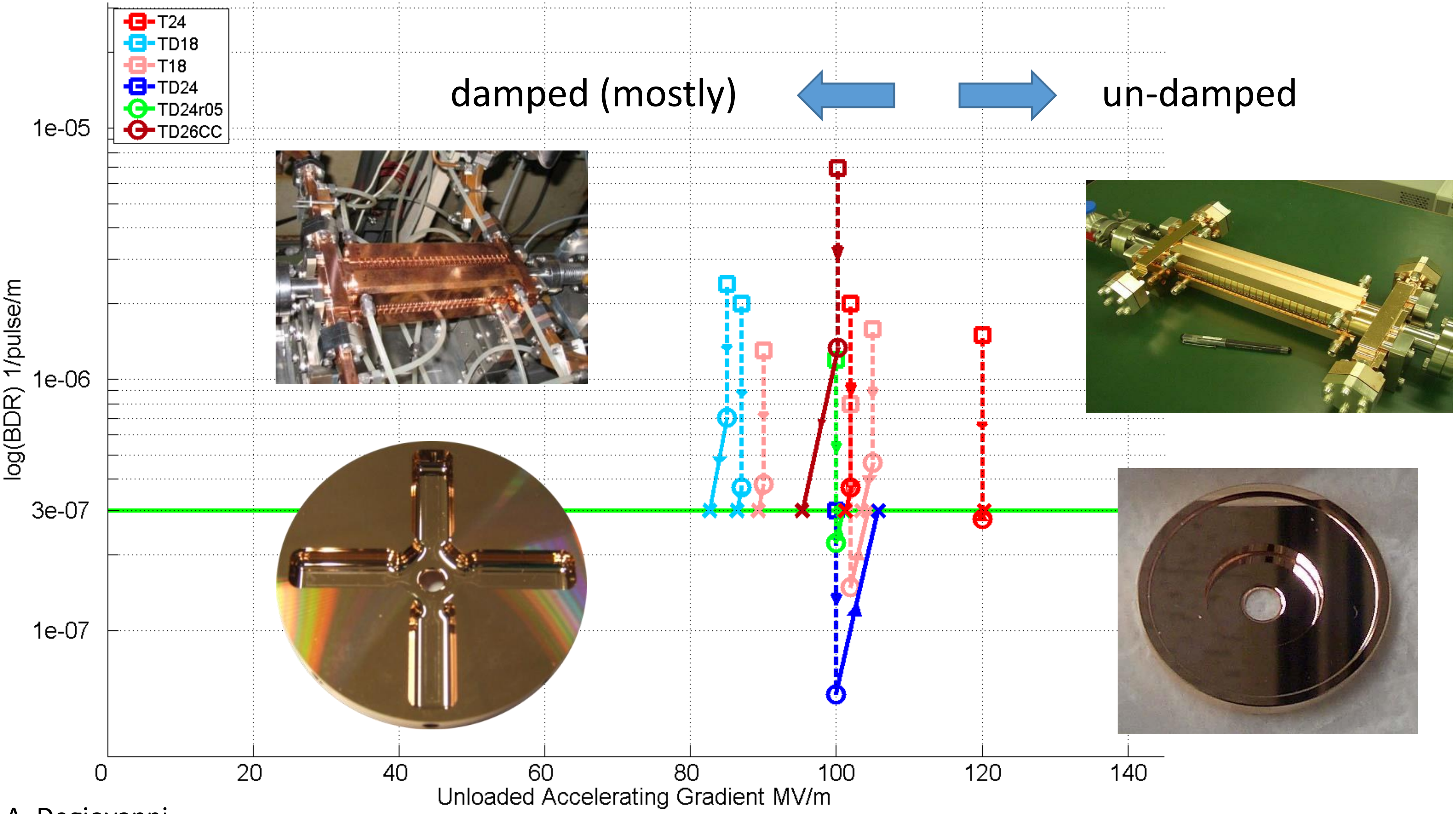
31 participants including outside laboratories

D. Schulte, **CERN/ABP**
PH. Lebrun, S. Stapnes, **CERN/DG**
S. Atieh, A. Cherif, G. Favre, M. Garlache, A. Perez Fontenla, **CERN/MME**
M. Aicheler, O. Brunner, N. Catalan Lasheras, M. Filippova, A. Grudjev, D. Gudkov, S. Lebet, A. Olyudnin, C. Rossi, A. Solodko, I. Syratchev, J. Vainola, A. Xydou, B. Woolley, W. Wuensch, **CERN/RF**
M. Taborelli, M. Thiebert, **CERN/VSC**
F. Toral, L. Sanchez, **Ciemat, Spain**
T. Higo, T. Abe, **KEK, Japan**
M. Franzi, J. Weng, **SLAC, USA**

23 talks plus discussions
2 long days

N. Catalan Lasheras

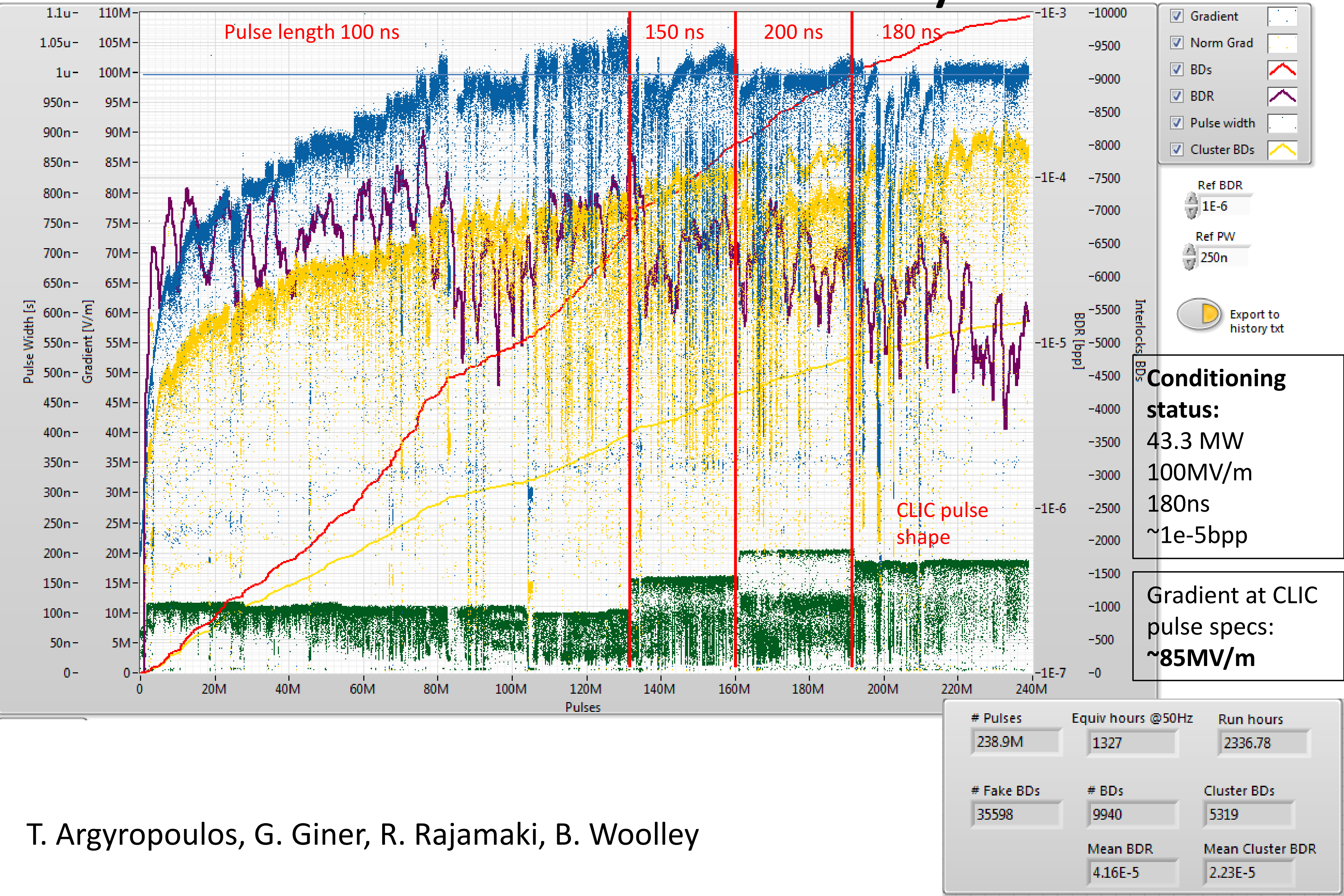
State of the gradient
Full length prototypes


damped (mostly)

un-damped

A. Degiovanni

TD26CC full history



☑ Gradient

☑ Norm Grad

☑ BDs

☑ BDR

☑ Pulse width

☑ Cluster BDs

Ref BDR 1E-6

Ref PW 250n

Pulses 238.9M

Equiv hours @50Hz 1327

Run hours 2336.78

Fake BDs 35598

BDs 9940

Cluster BDs 5319

Mean BDR 4.16E-5

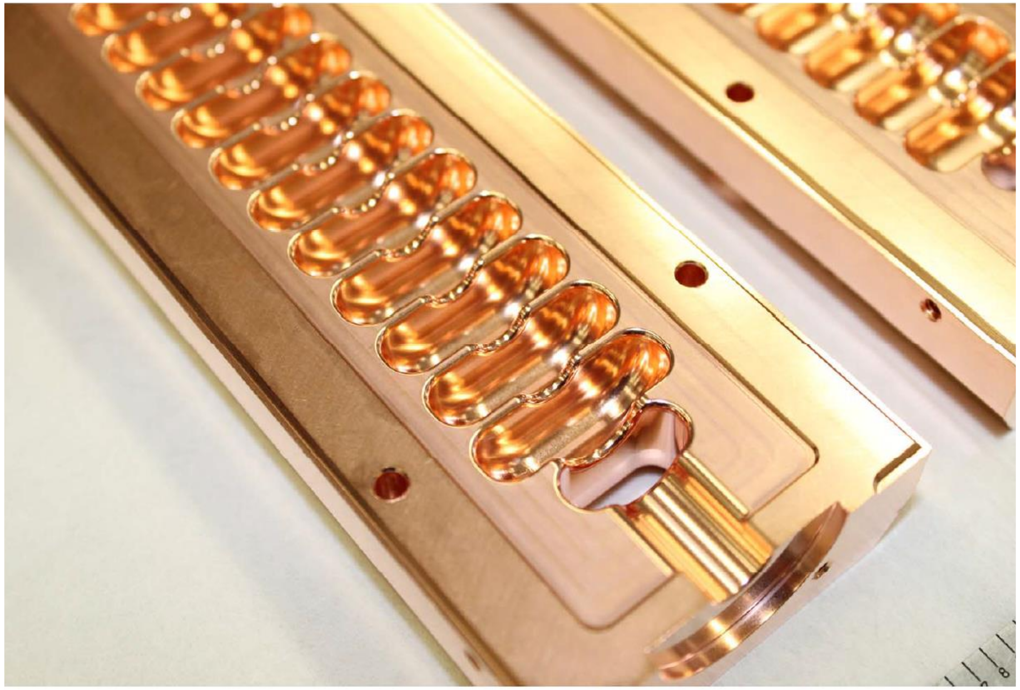
Mean Cluster BDR 2.23E-5

Conditioning status:
43.3 MW
100MV/m
180ns
~1e-5bpp

Gradient at CLIC pulse specs: **~85MV/m**

T. Argyropoulos, G. Giner, R. Rajamaki, B. Woolley

New directions – milled structures

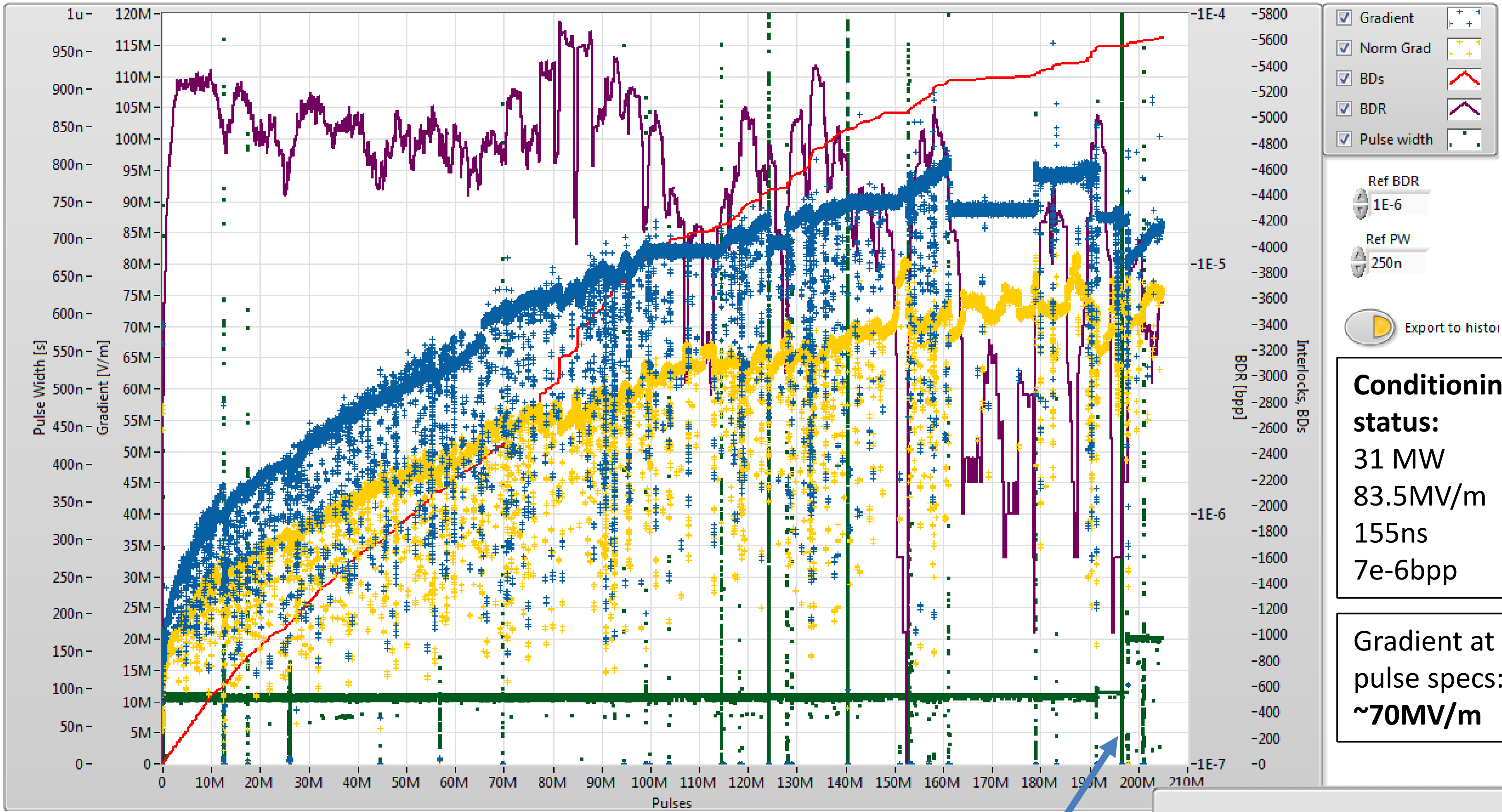


X-band structure in halves designed by CERN and built by SLAC

Milled structures have **huge potential advantages - cost, treatment, materials.** Early tries with quadrants yielded unsatisfactory results, but don't believe this was end of story. We're back!

A. Grudiev, H. Zha, V. Dolgashev

T24OPEN full history

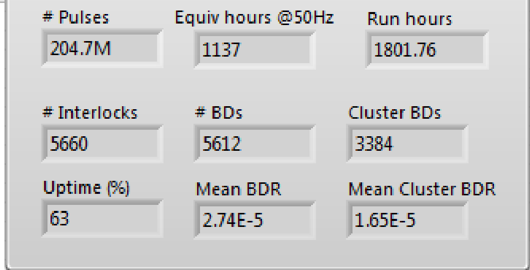


Ref BDR 1E-6

Ref PW 250n

Conditioning status:
31 MW
83.5MV/m
155ns
7e-6bpp

Gradient at CLIC pulse specs:
~70MV/m



# Pulses	Equiv hours @50Hz	Run hours
204.7M	1137	1801.76
# Interlocks	# BDs	Cluster BDs
5660	5612	3384
Uptime (%)	Mean BDR	Mean Cluster BDR
63	2.74E-5	1.65E-5

We changed pulse length to 155ns

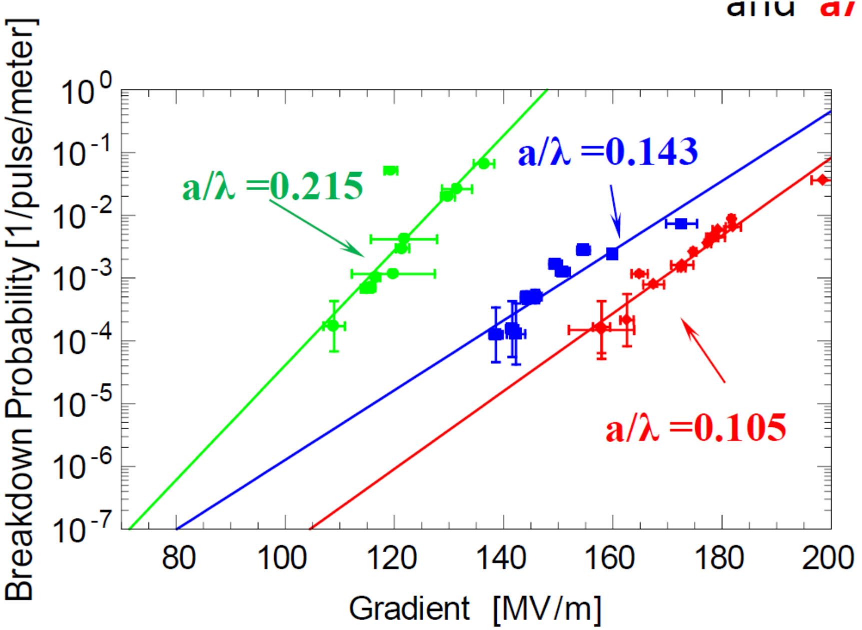
T. Argyropoulos, G. Giner, R. Rajamaki, B. Woolley

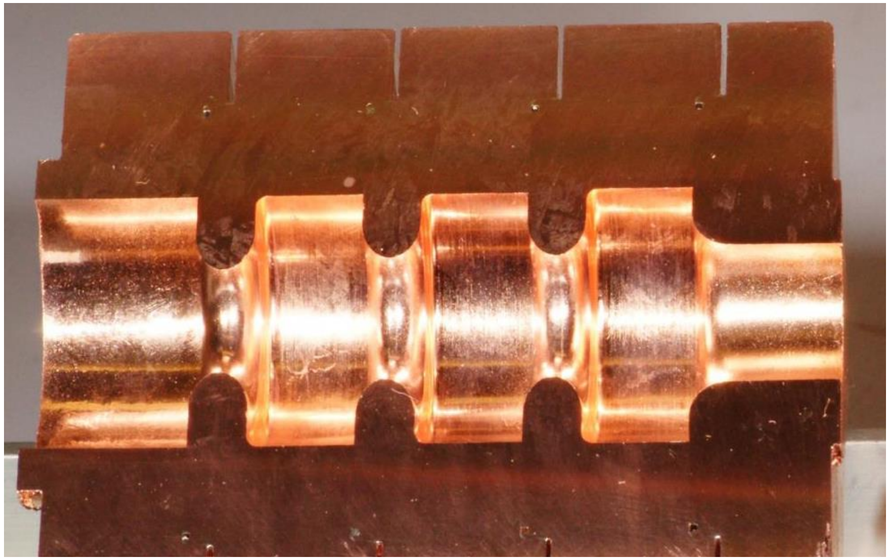
Single cells

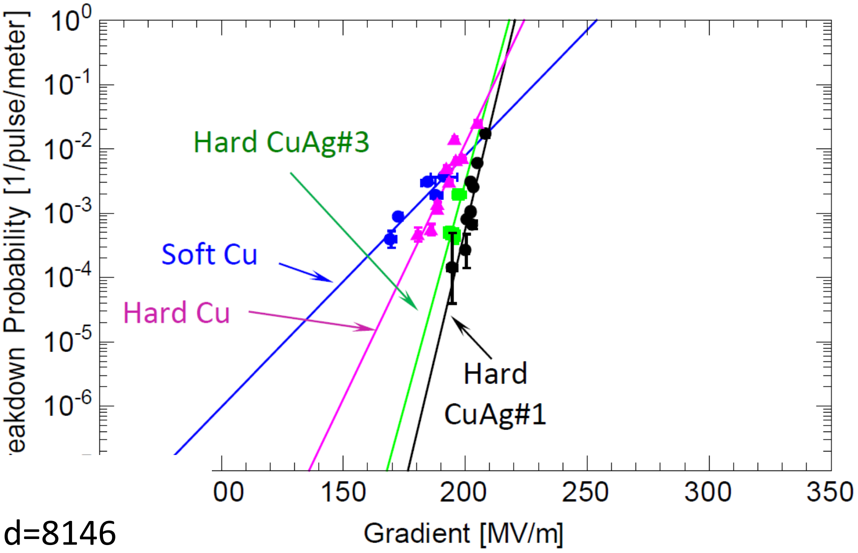
There's a hidden story behind the full structures which emerges when looking at single cells.

SLAC has a long-standing single cell testing program.

Gradients up to 200 MV/m are possible.

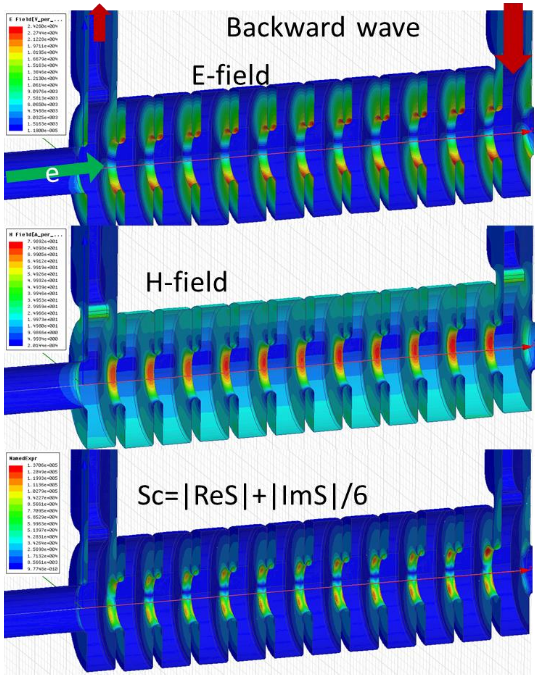






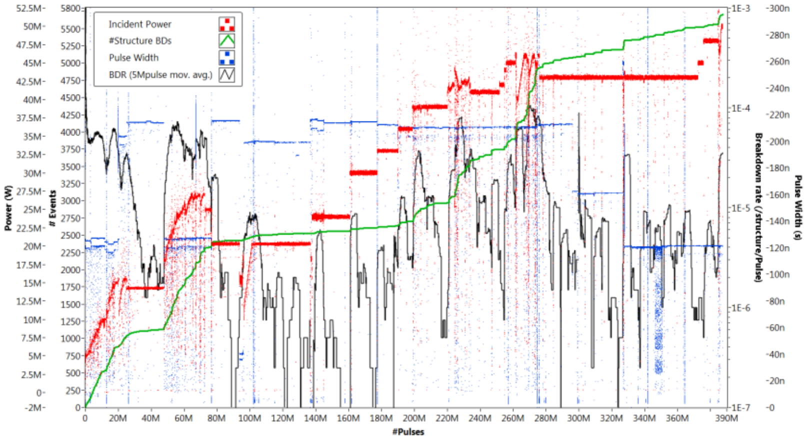
V. Dolgashev, EAAC2015
https://agenda.infn.it/contributionDisplay.py?contribId=227&confId=8146

Deflecting cavity



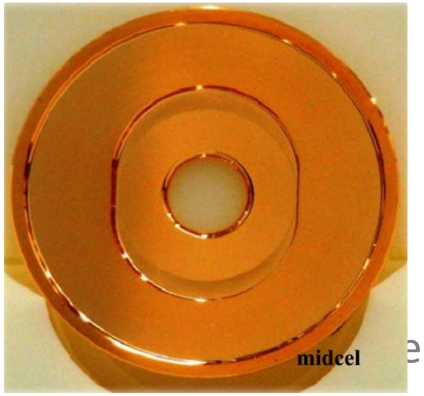
G. Burt

Lancaster crab cavity: rf design and installed in XBox-2.

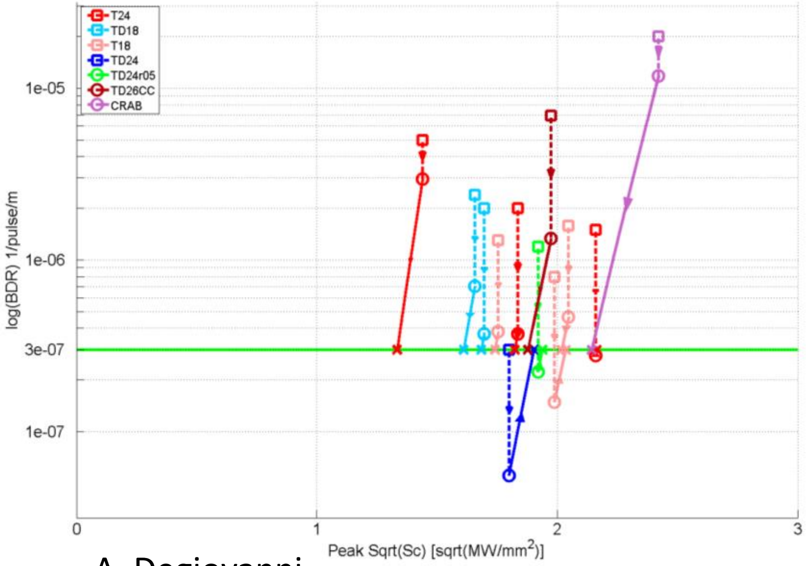


B. Woolley

Up to 47 MW!



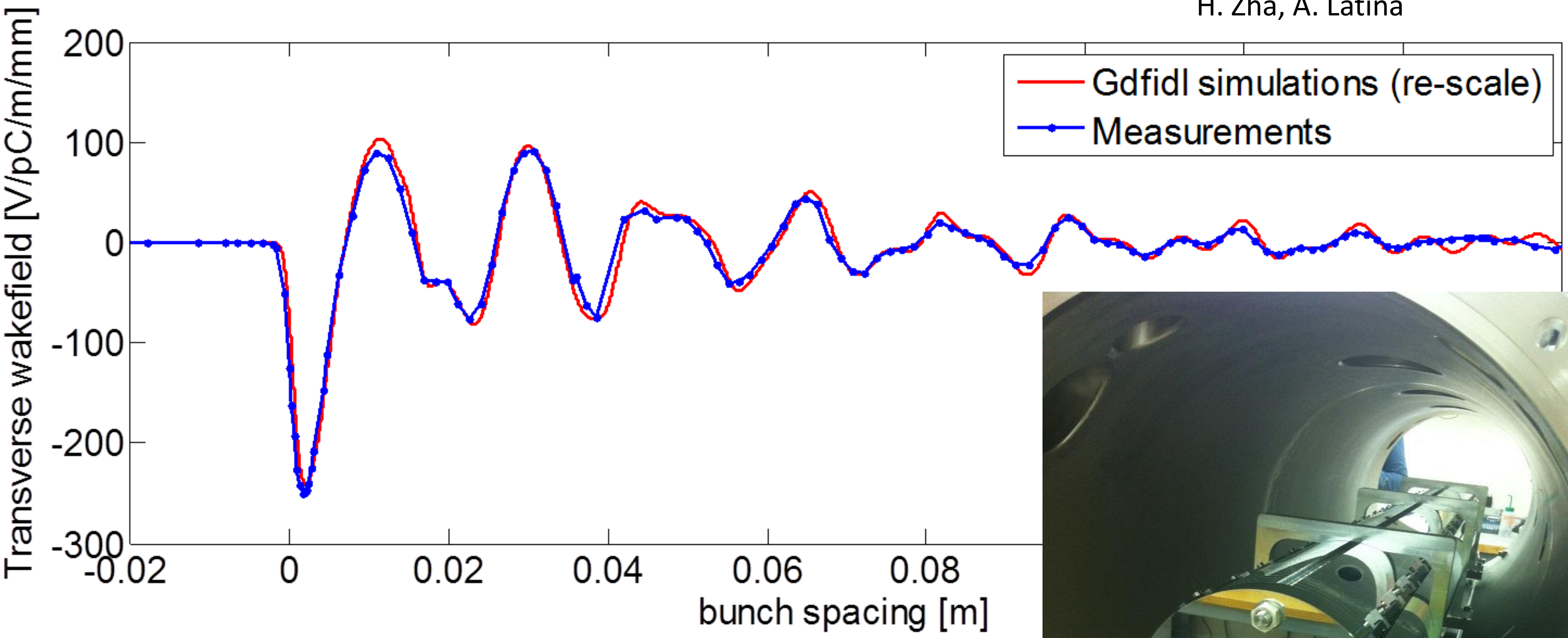
TM$_{1,1,0}$ dipole mode instead of monopole, still very consistent *Sc*, local power flow .



A. Degiovanni

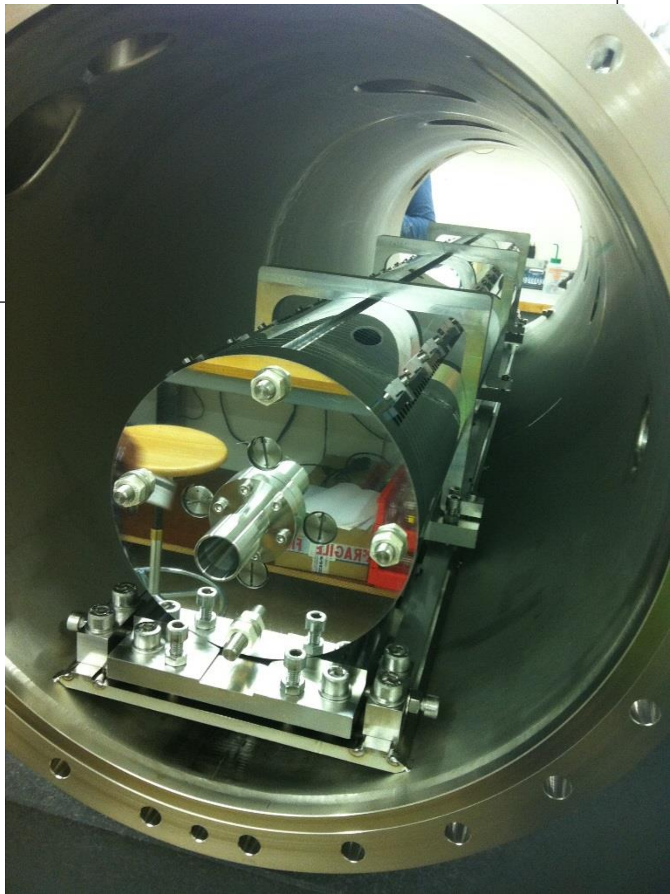
Wakefield suppression

H. Zha, A. Latina



Wakefield from 1.5 m long, 6 structure length, prototype measured directly with beam at the FACET facility at SLAC.

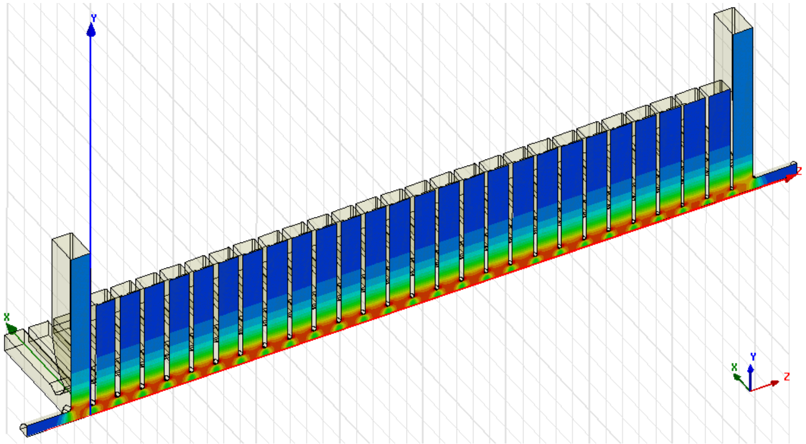
The agreement between measurement and simulation is a spectacular validation of our design capabilities and we meet our beam dynamics requirements!



RF design for high gradient

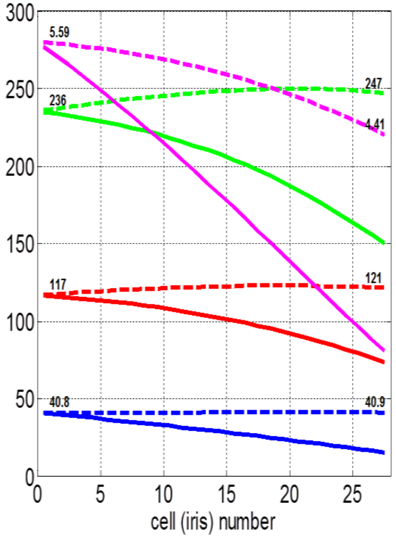
We have well developed rf design criteria which **predict the gradient** of pulsed high-gradient structures. The criteria cover the physical phenomena which limit accelerating gradient:

- Power flow
- Surface electric field
- Surface magnetic field/pulsed surface heating



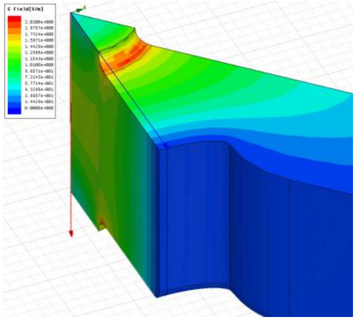
New CLIC 3 TeV baseline

H. Zha, A Grudiev

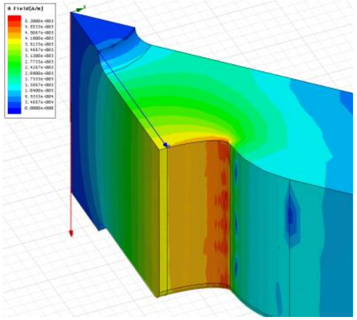


New local field quantity describing the high gradient limit of accelerating structures
A. Grudiev, S. Calatroni, W. Wuensch Phys.Rev.ST Accel.Beams 12 (2009) 102001

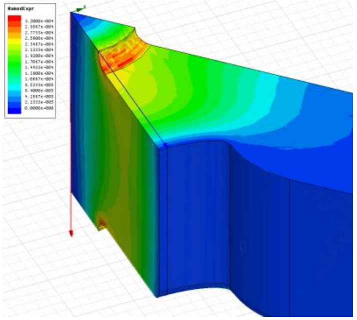
E_s/E_a



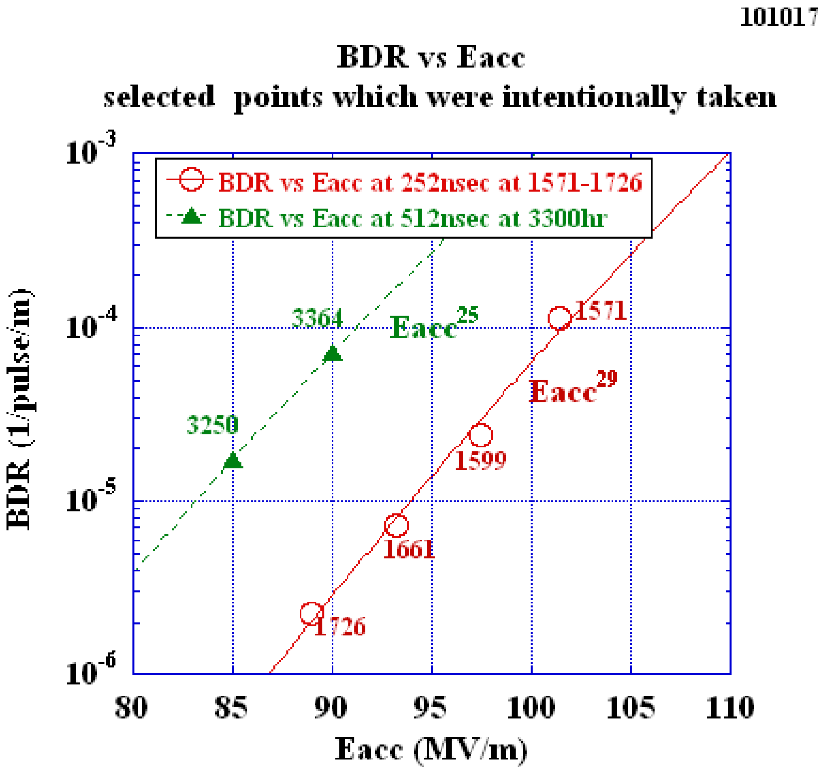
H_s/E_a

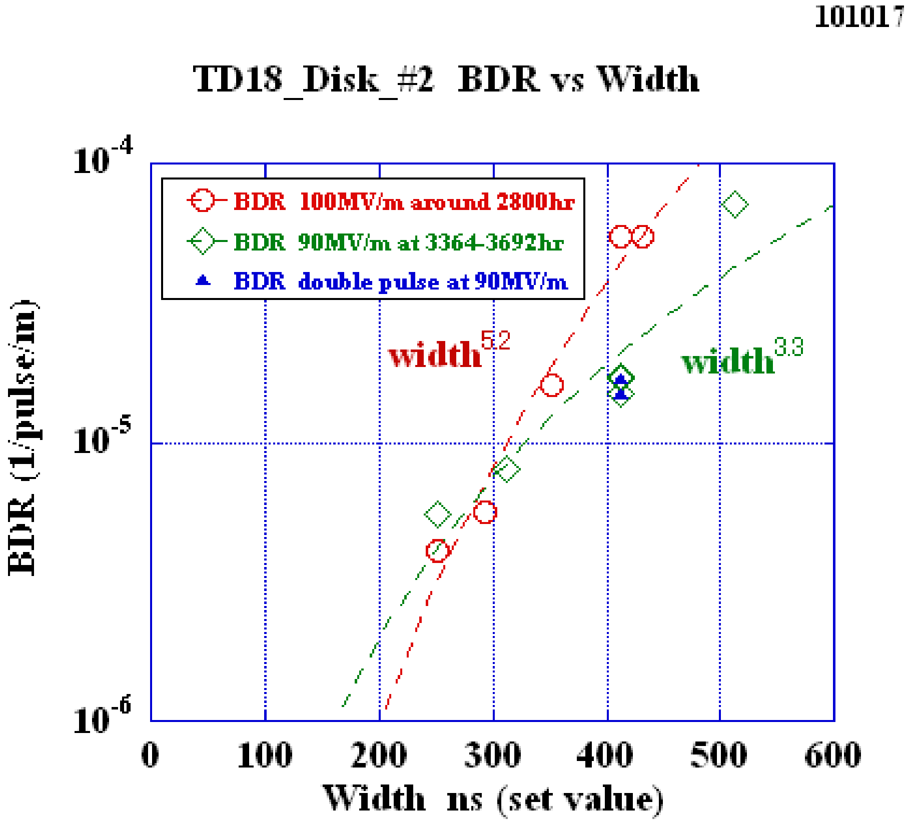


S_c/E_a^2



Important dependencies





T. Higo

For a fixed pulse length

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

For a fixed BDR

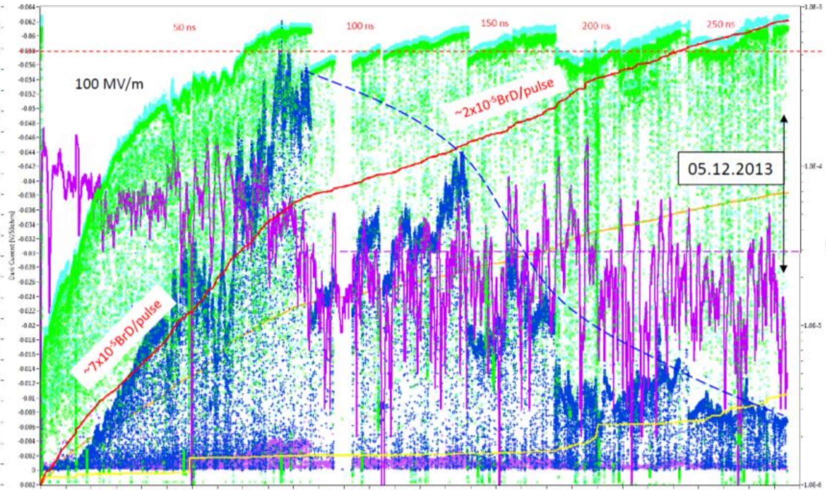
$$E_a \cdot t_p^{1/6} = const$$

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

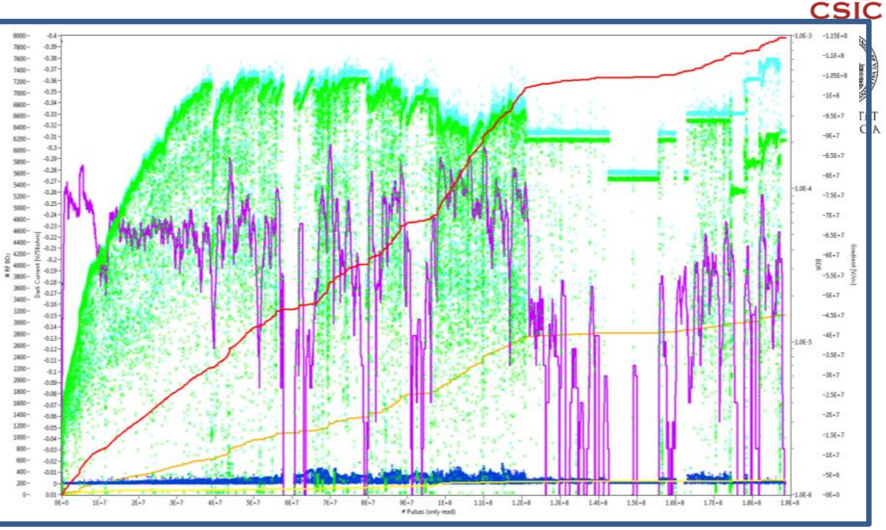
Collection of conditioning histories

CLIC damped (TD) structures

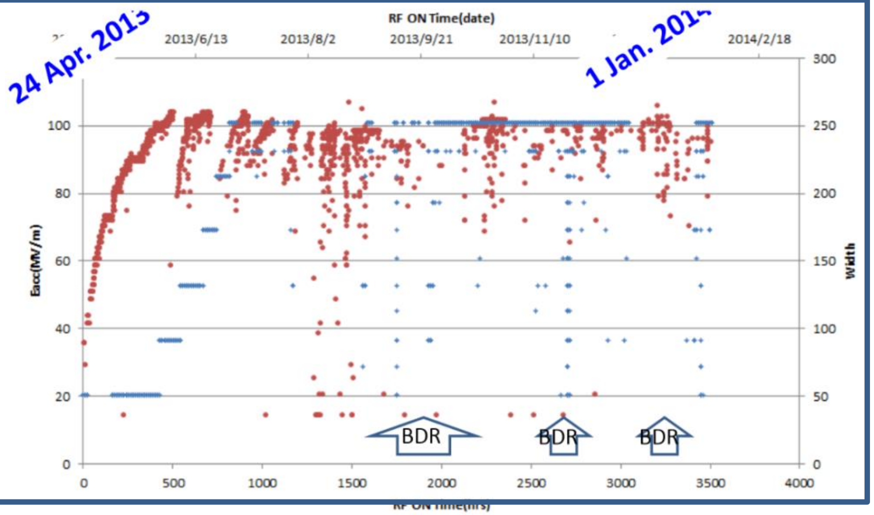
TD26CC (XBOX-1)



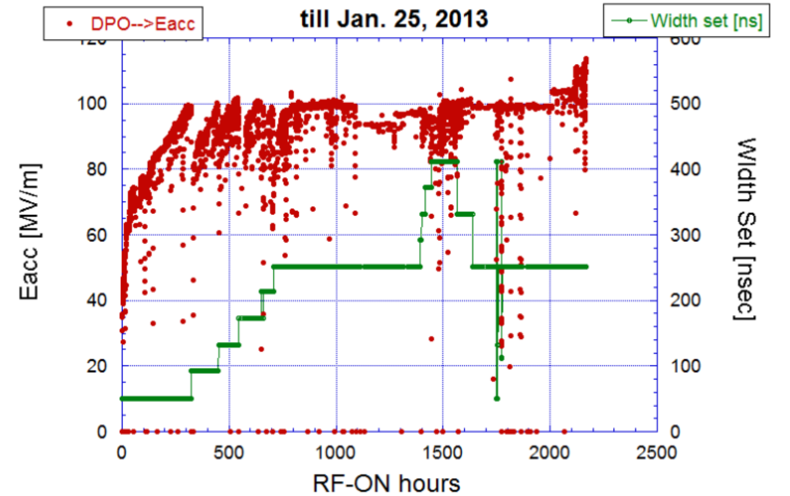
TD24R05 (XBOX-1)



TD24R05#4 (NEXTEF)



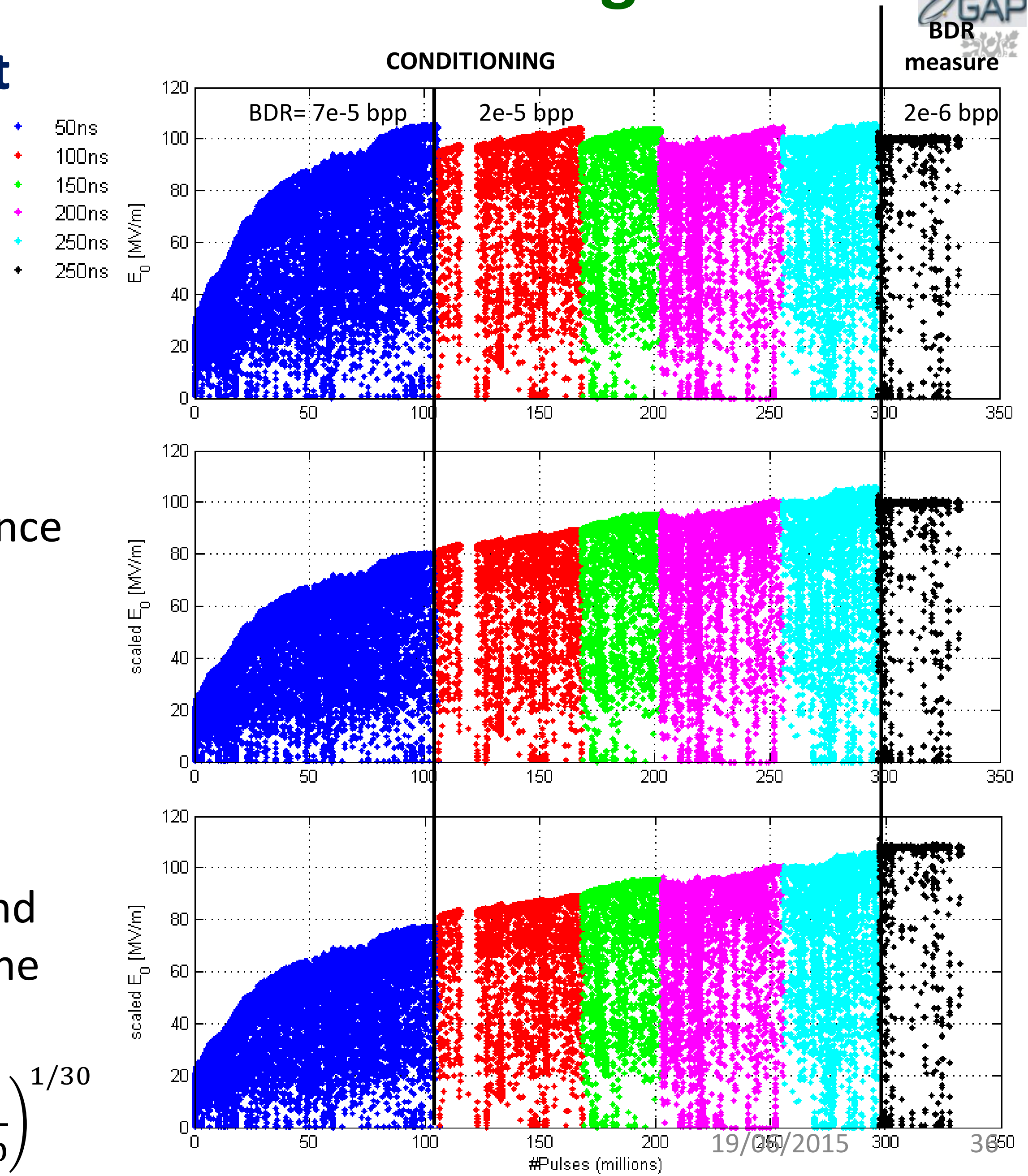
TD24R05#2 (NEXTEF)



Scaling: description of conditioning state

TD26CC#1 scaled gradient

Raw data full history



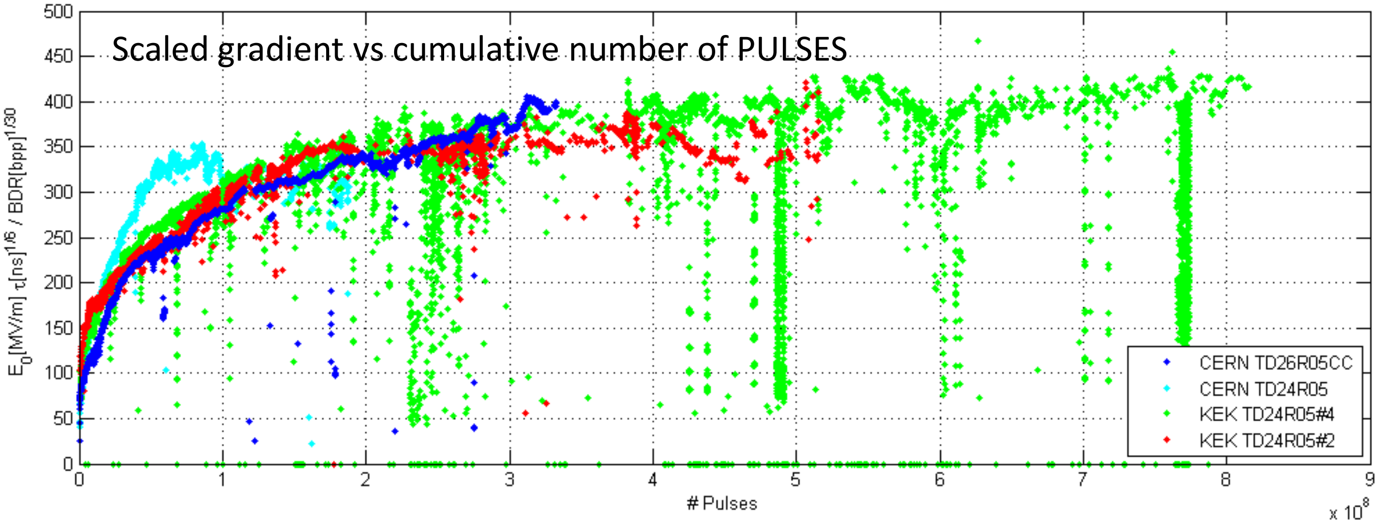
Equivalent gradient curve with constant pulse length of **250ns** since the beginning

$$E_0^{scaled} = E_0\left(\frac{t_p}{250\text{ns}}\right)^{-1/6}$$

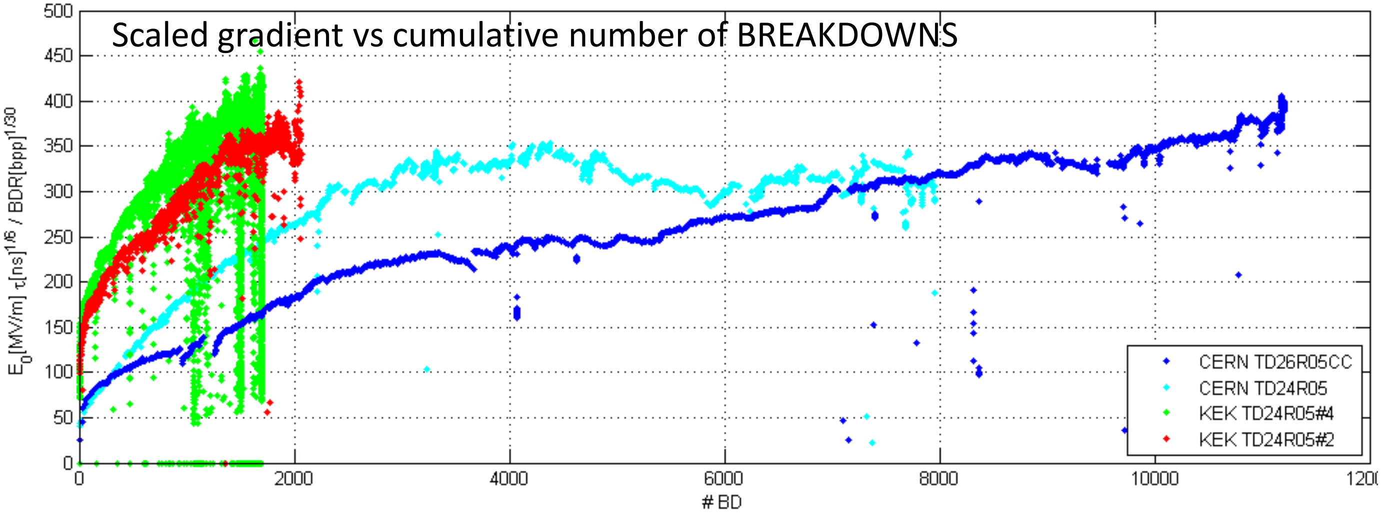
Equivalent gradient curve with constant pulse length of **250ns** and constant BDR of **2e-5 bpp** since the beginning

$$E_0^{scaled} = E_0\left(\frac{t_p}{250\text{ns}}\right)^{-1/6}\left(\frac{\text{BDR}}{2\cdot10^{-5}\text{bpp}}\right)^{1/30}$$

Now comparing structures

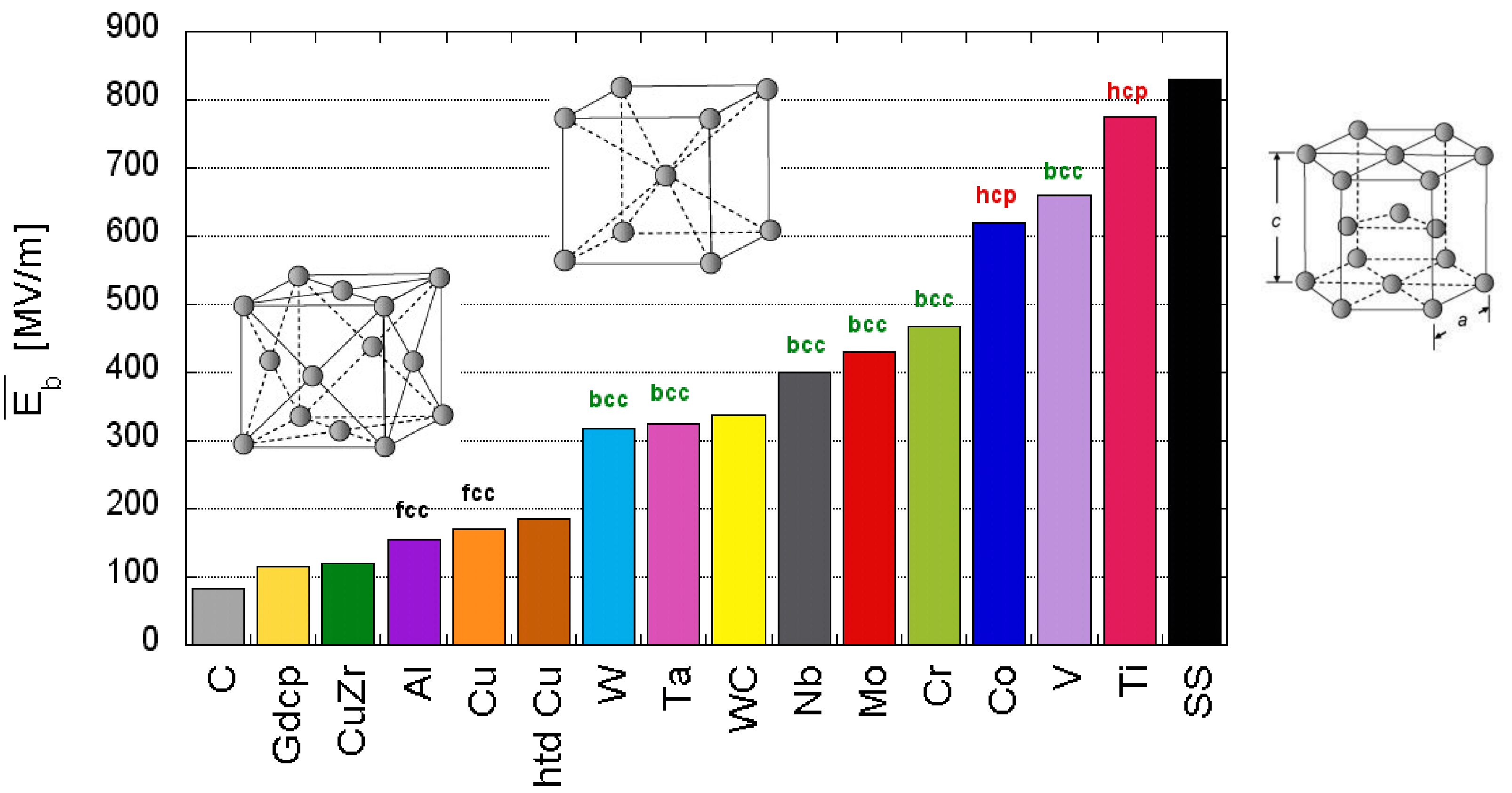

Scaled gradient vs cumulative number of PULSES

Pulses


Scaled gradient vs cumulative number of BREAKDOWNS

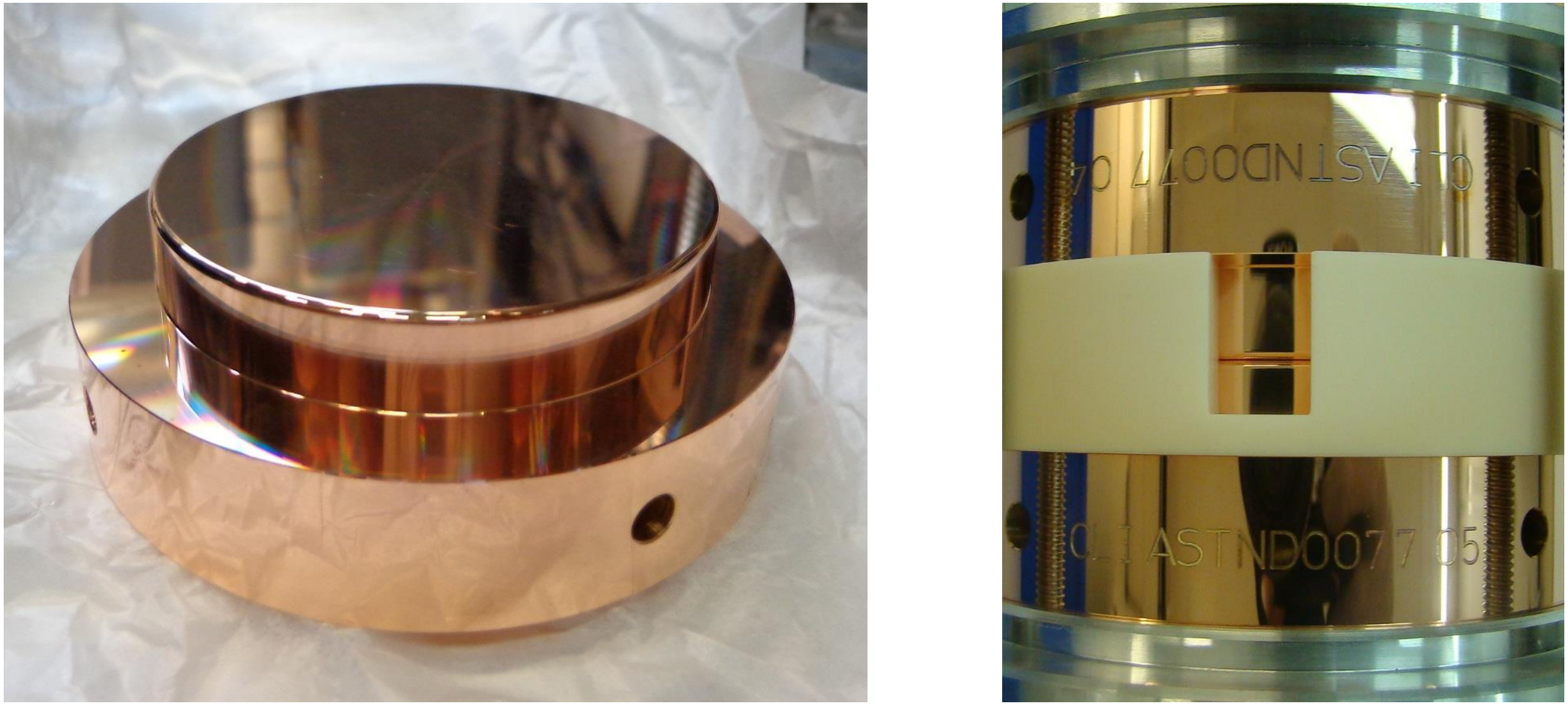
Breakdowns

Material dependence in pulsed dc



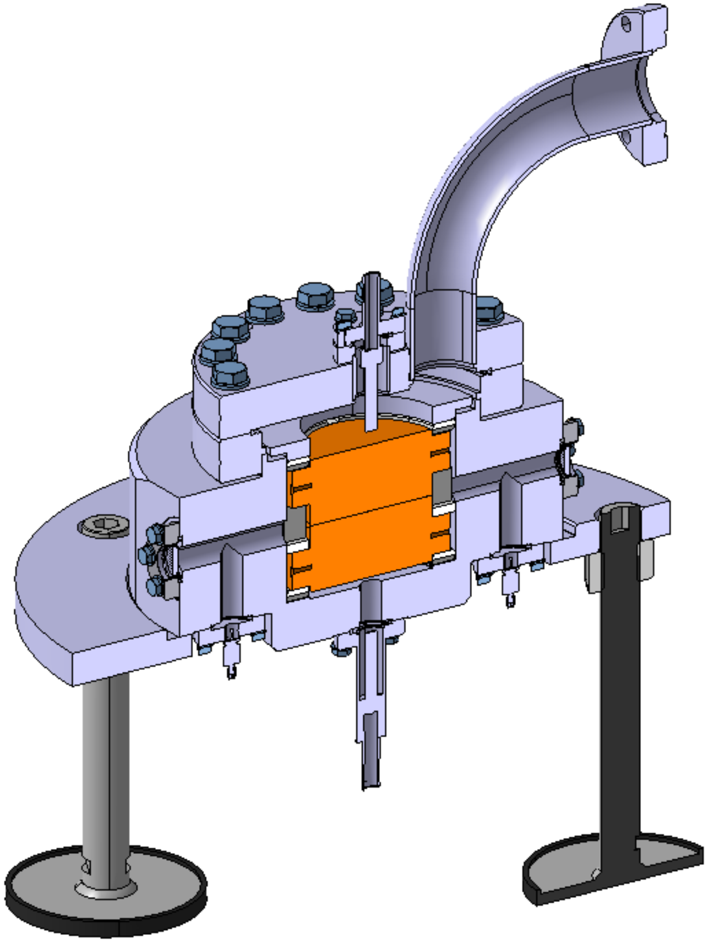
A. Descoeudres, F. Djurabekova, and K. Nordlund,
DC Breakdown experiments with cobalt electrodes,
CLIC-Note 875, 2011

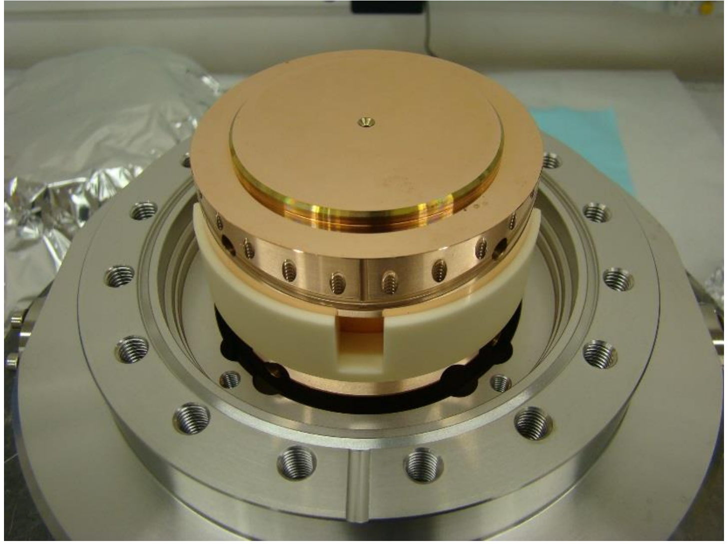
Hardware status and evolution: Large area electrodes

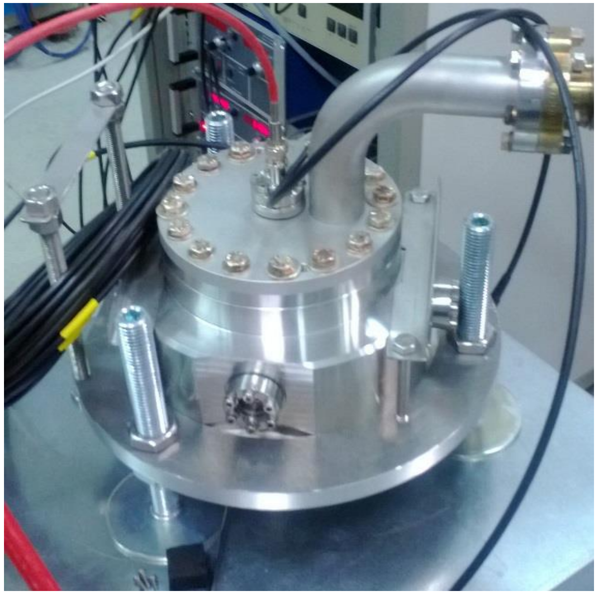


62 mm diameter electrodes separated by precision ceramic spacer, gaps between 10 and 60 µm. Very large surface both compared to breakdown crater size and high field region in rf cavities allows study of effects of production (machining, heat treatment, chemistry) and operation (conditioning, breakdown statistics) related issues.

Vacuum chamber

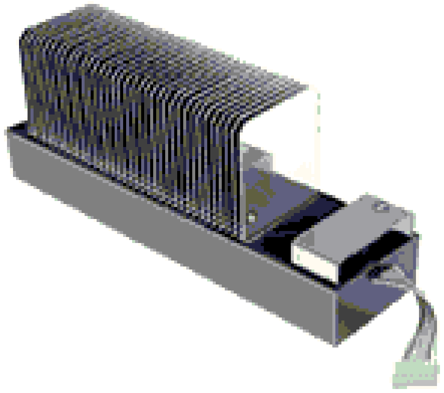


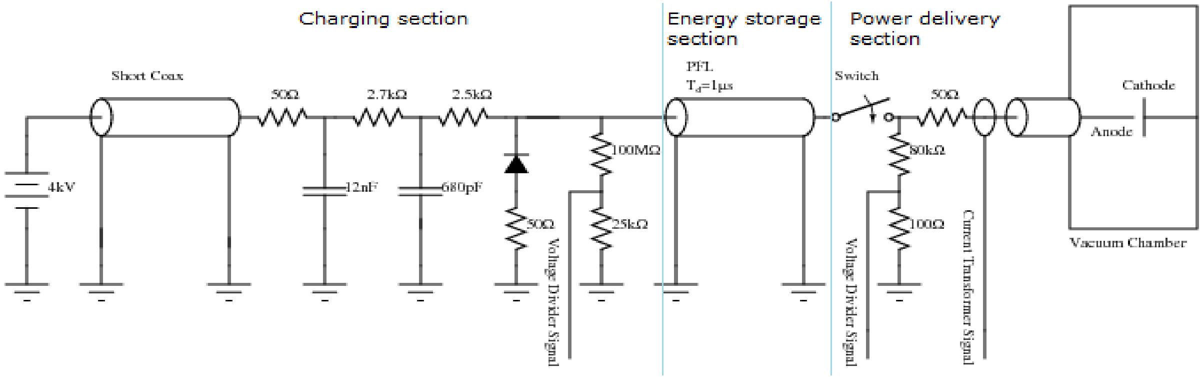


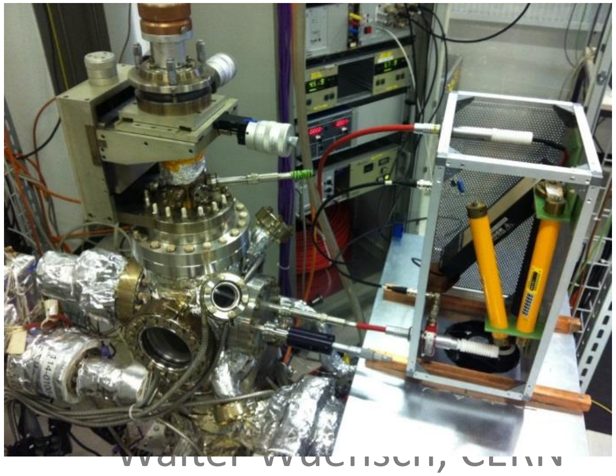


High repetition rate, high-voltage pulser

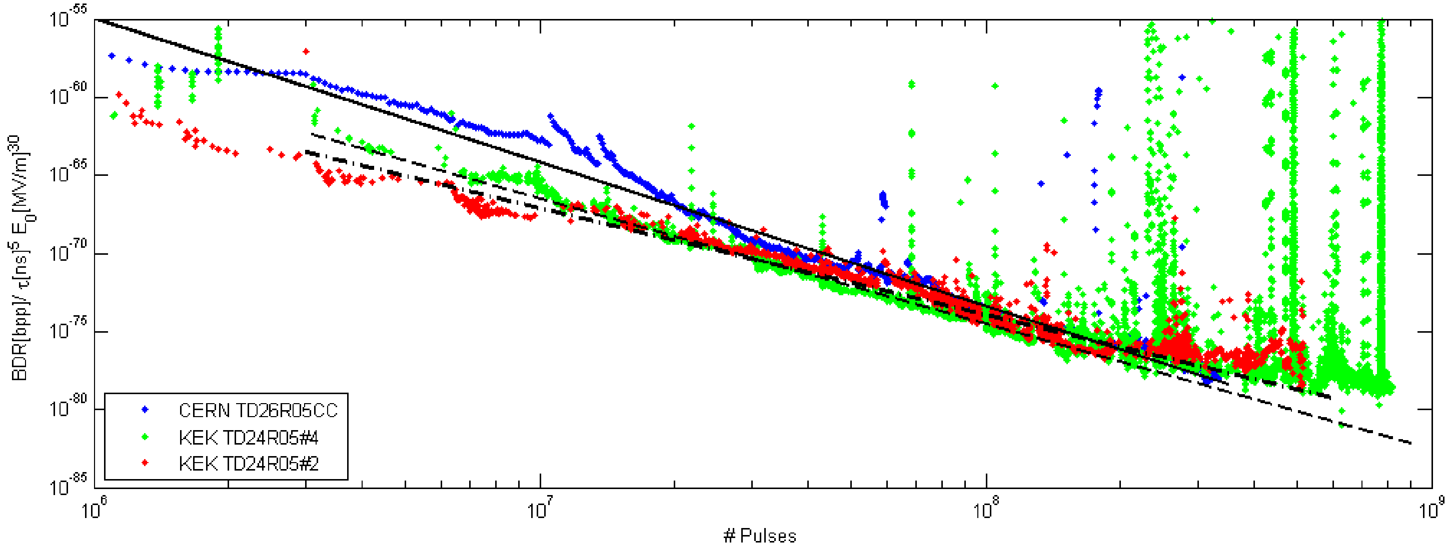
We now use a MOSFET-based commercial switch, which allows us to pulse up to 1 KHz with pulse lengths from 1 to around 8 μs (followed by exponential decay).







Pulsed dc and rf comparison

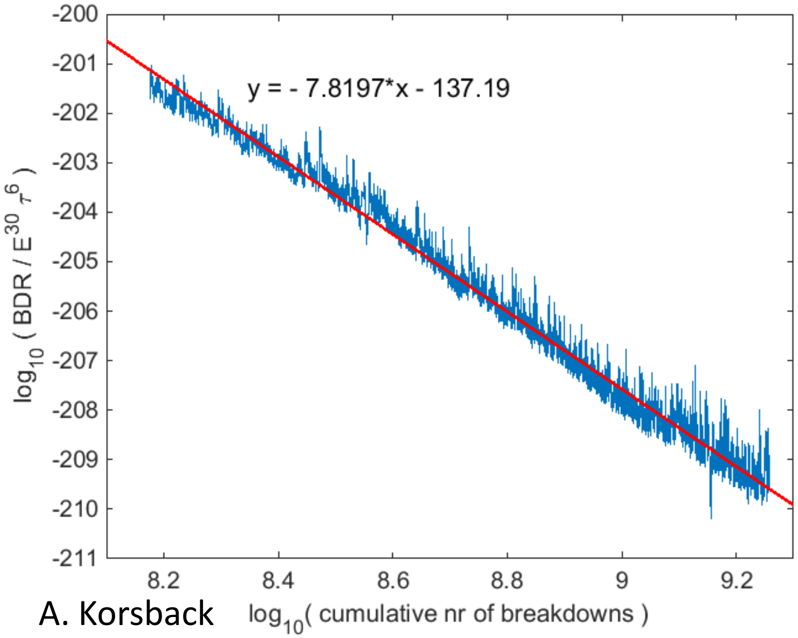


Our insight: pulses condition the structure rather than breakdowns.

What is the mechanism? Seems to be a hardening process.

Figuring this out could help us pre-process out structures and reduce conditioning time.

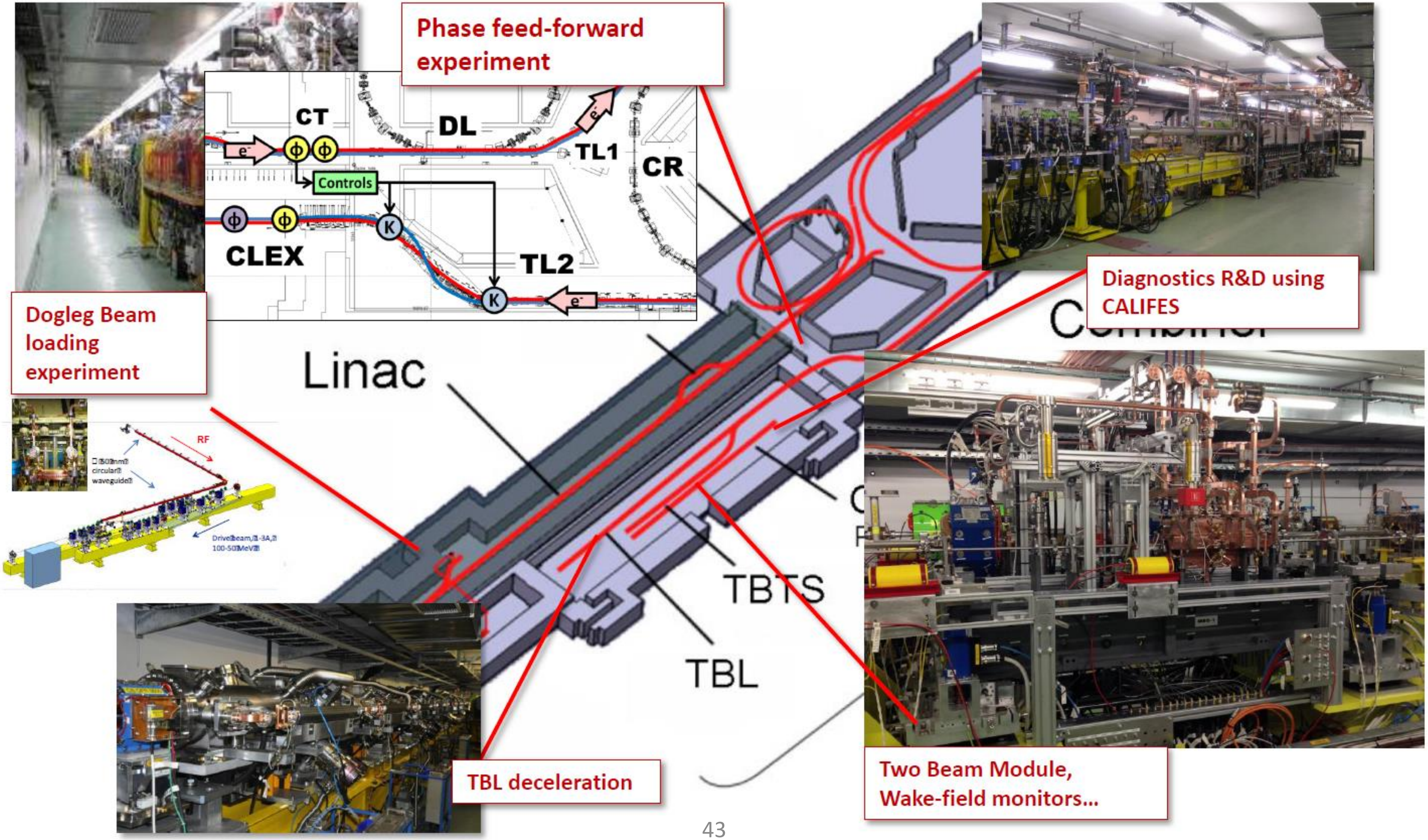
CERN pulsed dc system



A. Korsback

CERN, 14 December 2015

CTF3: 2015 - 2016



Phase feed-forward experiment

Diagnostics R&D using CALIFES

Dogleg Beam loading experiment

TBL deceleration

Two Beam Module, Wake-field monitors...

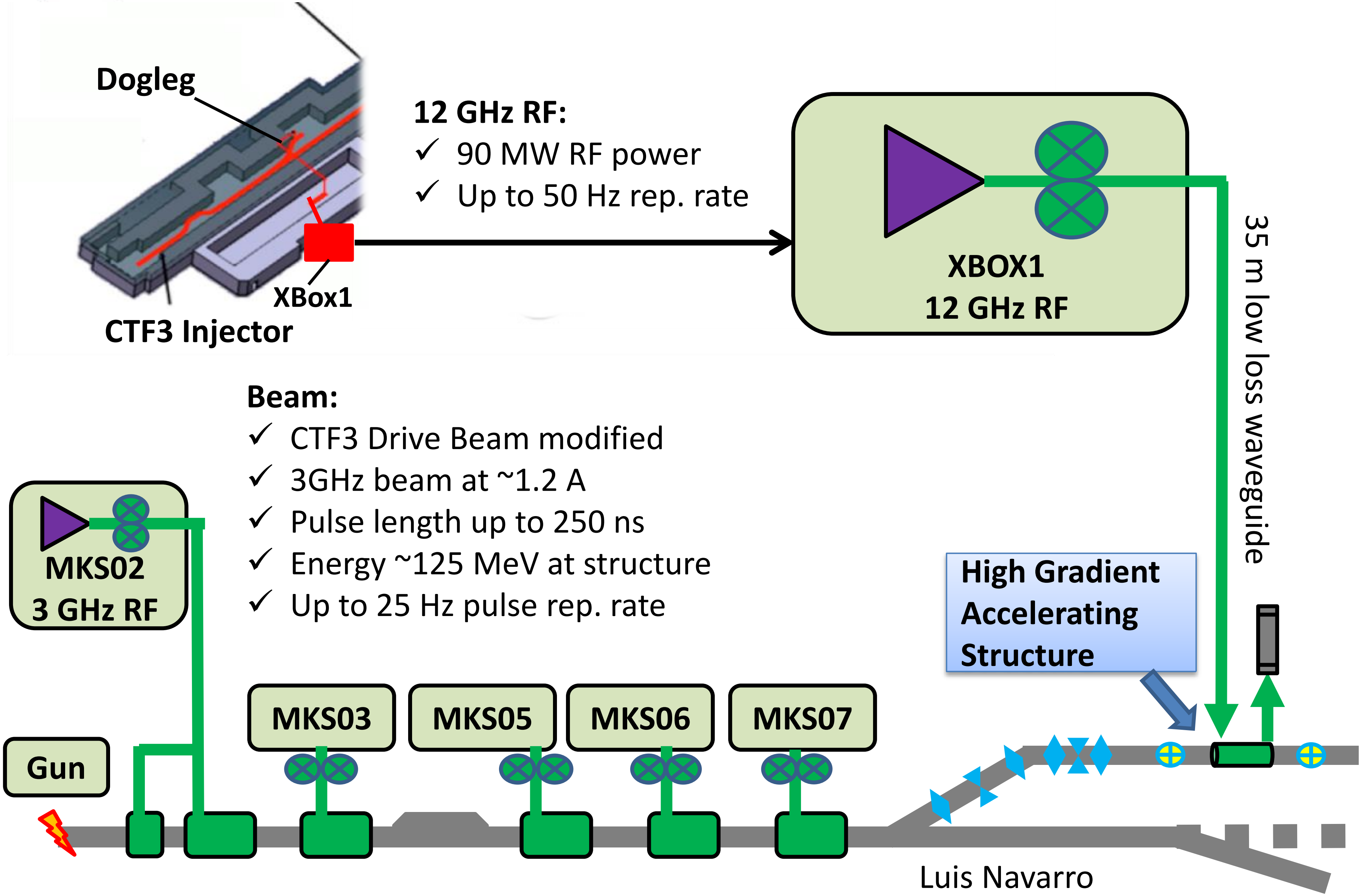
CTF3 Operations

- Difficult spring and summer

- Very good autumn

- Programme
  - Phase Feed Forward
  - Two beam tests with the new module (Wilfrid’s talk)
  - The Dogleg Experiment (BDR in presence of beam)
  - Machine Development
    - Dispersion Control
    - Combined beam emittance reduction
  - Beam instrumentation tests in CALIFES (Wilfrid’s talk)

Dogleg Experiment



12 GHz RF:

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

Beam:

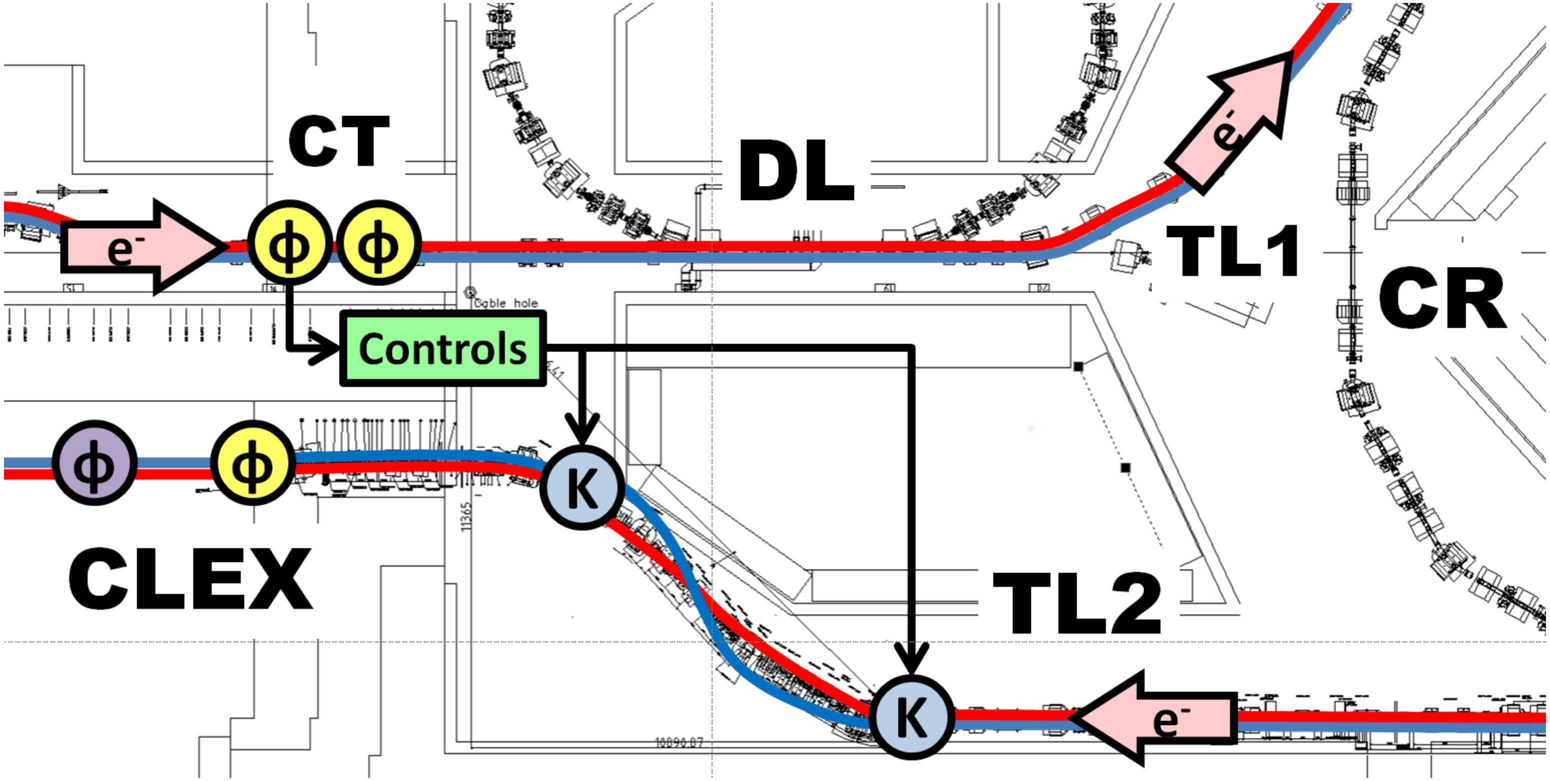
- ✓ CTF3 Drive Beam modified
- ✓ 3GHz beam at ~1.2 A
- ✓ Pulse length up to 250 ns
- ✓ Energy ~125 MeV at structure
- ✓ Up to 25 Hz pulse rep. rate

High Gradient Accelerating Structure

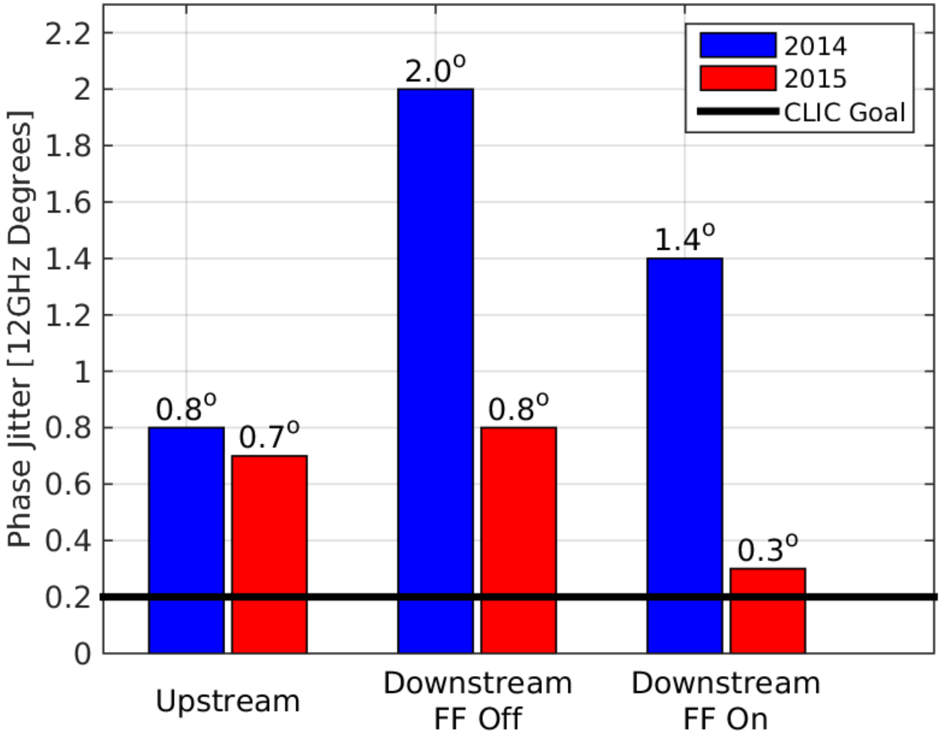
Luis Navarro

Phase Feedforward Status at CTF3

J. Roberts (CERN, Geneva, Switzerland; JAI, Oxford, UK),
P.K. Skowroński, R. Corsini (CERN, Geneva, Switzerland),
P.N. Burrows, G.B. Christian, C. Perry (JAI, Oxford University, UK),
A. Ghigo, F. Marcellini (INFN/LNF Frascati, Italy).

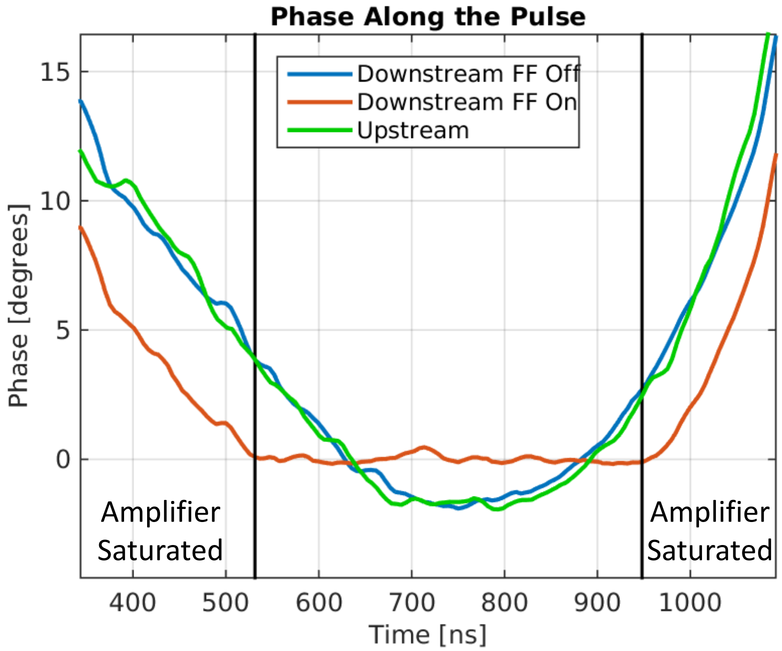


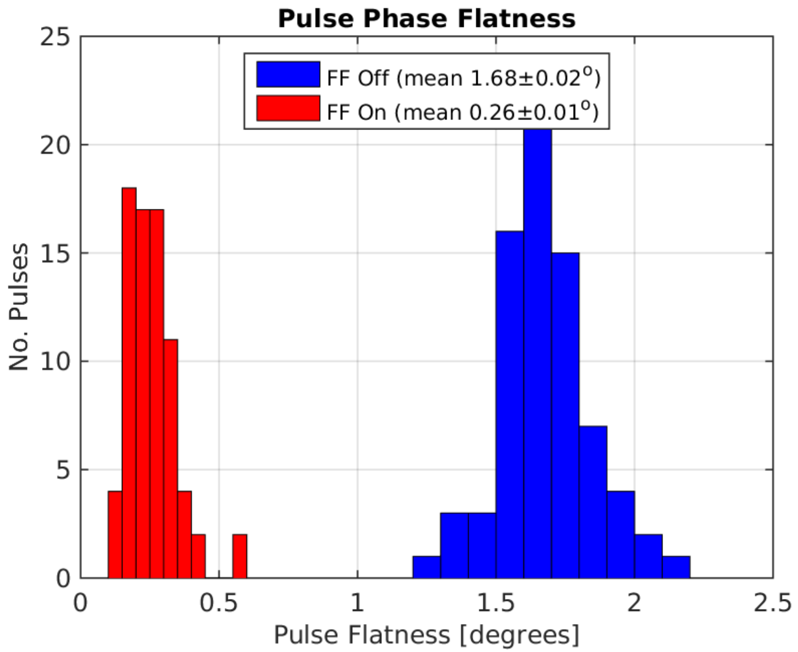
Status 2015



- 2.5x lower uncorrected downstream phase jitter (2 degrees -> 0.8 degrees).
- 5x lower corrected downstream phase jitter (1.4 degrees -> below 0.3 degrees).

Phase Feedforward: Current Jitter Record

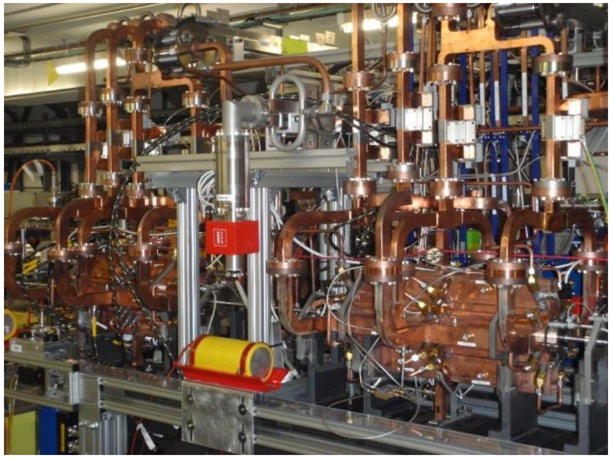




- High bandwidth (~30 MHz) correction: Correct variations along the pulse not only jitter on the mean.
- Phase variation along the pulse (between black lines) reduced from 1.68 to 0.26 degrees (mean deviation of samples along pulse).

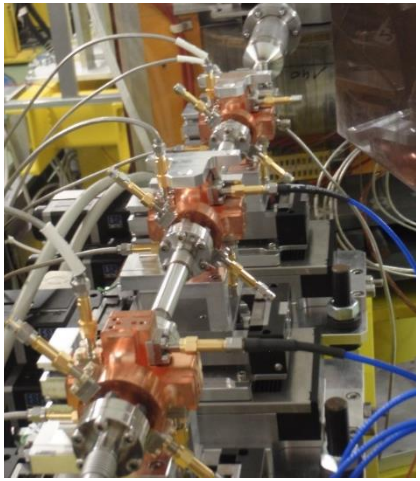
Shutdown Periods and New Installations

17 Dec. 2014
– 9 Mar. 2015

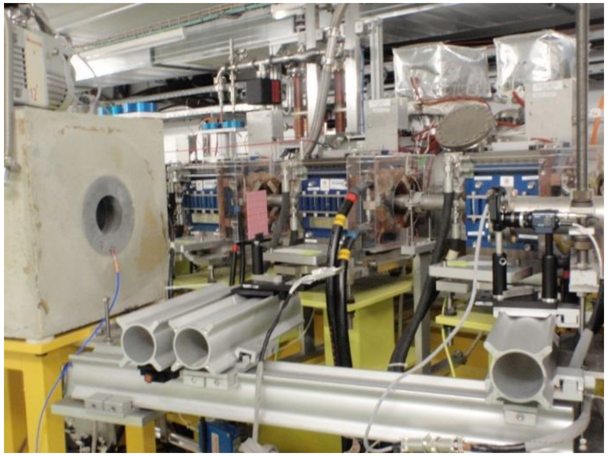


Second Super-structure on the TBM

- ➢ Survey of the whole line
- ➢ In situ RF measure with network analyser
- ➢ RF power chain calibrations



3 High Resolution Cavity BPMs on motorized stages

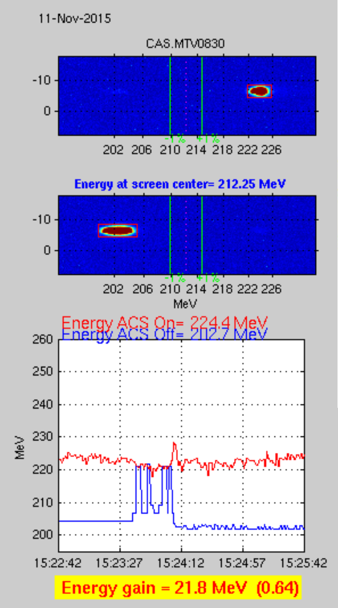


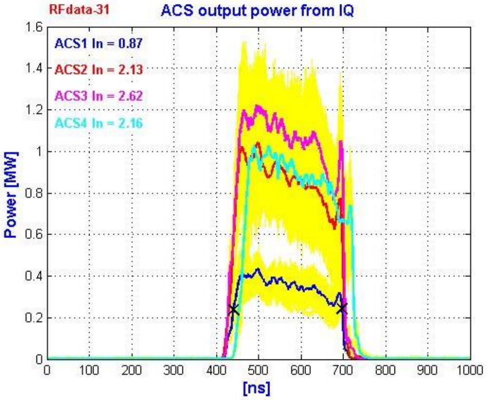
Irradiation Test Bench (E. Del Busto)

- Rare days of beam unavailability (Laser Pulse Picker power supply, Klystron focalisation coil power supply)
- Nearly no klystron trips (19 411 working hours)

Energy gain performance

Without Priming





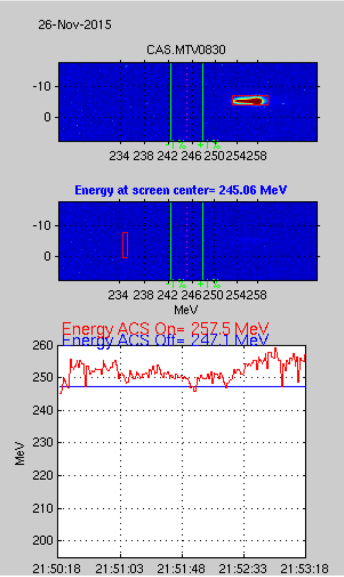
$$
\begin{aligned}
E_{gain} = \text{coef}* \quad & ((\text{ACS4}_{in})^{\wedge}.5 \\
& + (\text{ACS3}_{in})^{\wedge}.5 \\
& + (\text{ACS2}_{in})^{\wedge}.5 \\
& + (2.65 * \text{ACS1}_{in})^{\wedge}.5\ ) \\
= 21.6\ \text{MeV} &
\end{aligned}
$$

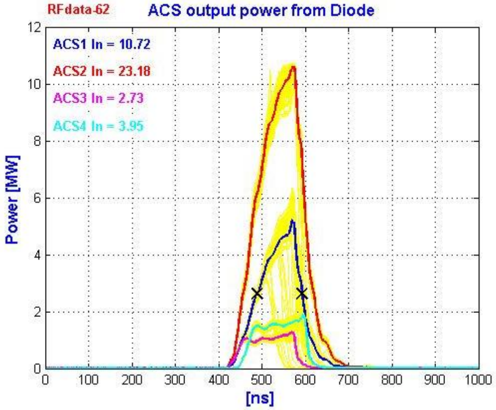
Power In / Power Out = 2.44 $(S_{12} = 0.64)$

E_{gain} [MeV] $= 100/\text{sqrt}(42.6)*0.23 * \text{sqrt}(P_{In}$ [MW])

$= \text{coef} * \text{sqrt}(P_{In}$ [MW])

With Priming



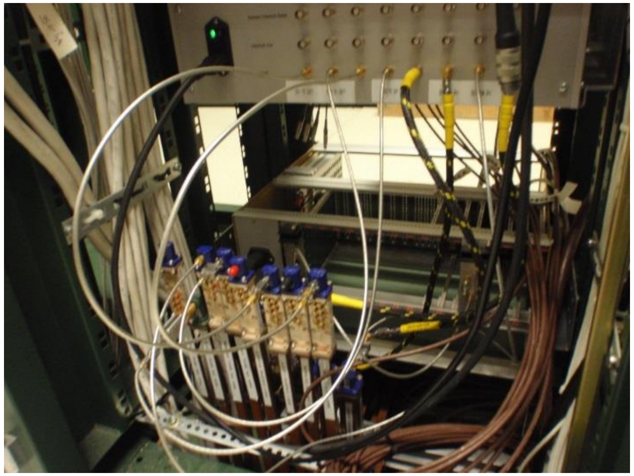


Energy gain = 55 MeV

$$
\begin{aligned}
E_{gain} = \quad & 7.1 \\
+ \quad & 5.9 \\
+ \quad & 17.2 \\
+ \quad & 19.0 \\
= \quad & 49.2\ \text{MeV}
\end{aligned}
$$

Wake Fields Monitors

Connection by waveguide to the gallery



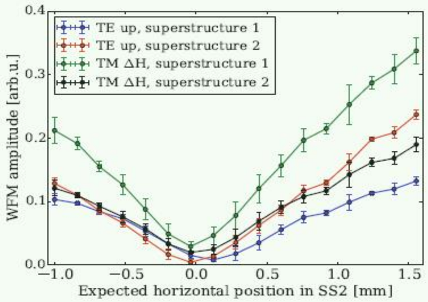
waveguide filters and log-detector crate

- The present installation (16 waveguides + filters) has been developed for the previous TD24.
- The location of the WFM pick-up have changed (2nd cell instead of central cell)
- The TE-like and TM-like frequencies are now different (27.3 GHz instead of 24 GHz, and 16.5 GHz instead of 18 GHz)
- Some problems with the log-detector crates (too low bandwidth -> short the final amplifier)

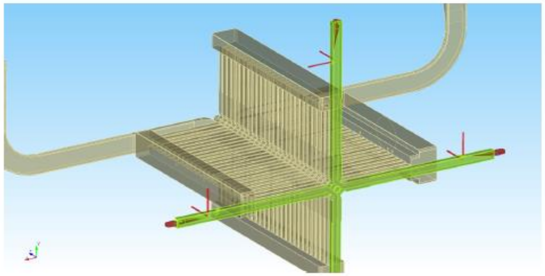
WFM resolution

R. Lillestol

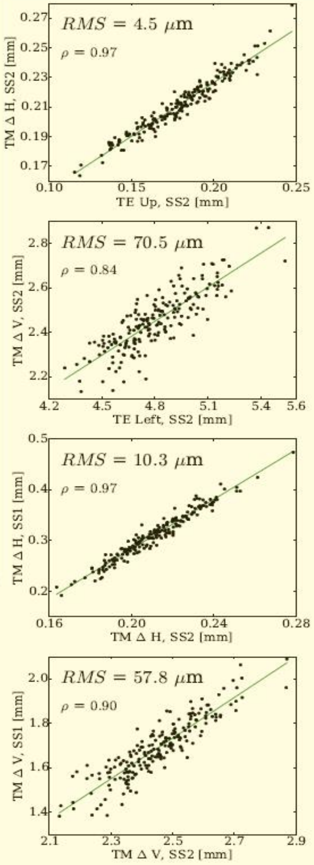
- **WFMs**: Accurate determination of the beam position in accelerating structures
- 4 HOM waveguides used for measuring dipole modes
- A TE-like mode at ~27 GHz and a TM-like mode at ~17 GHz are measured (on different sides of the waveguides)



Scan: Good agreement of structure centers between signals, after online module alignment

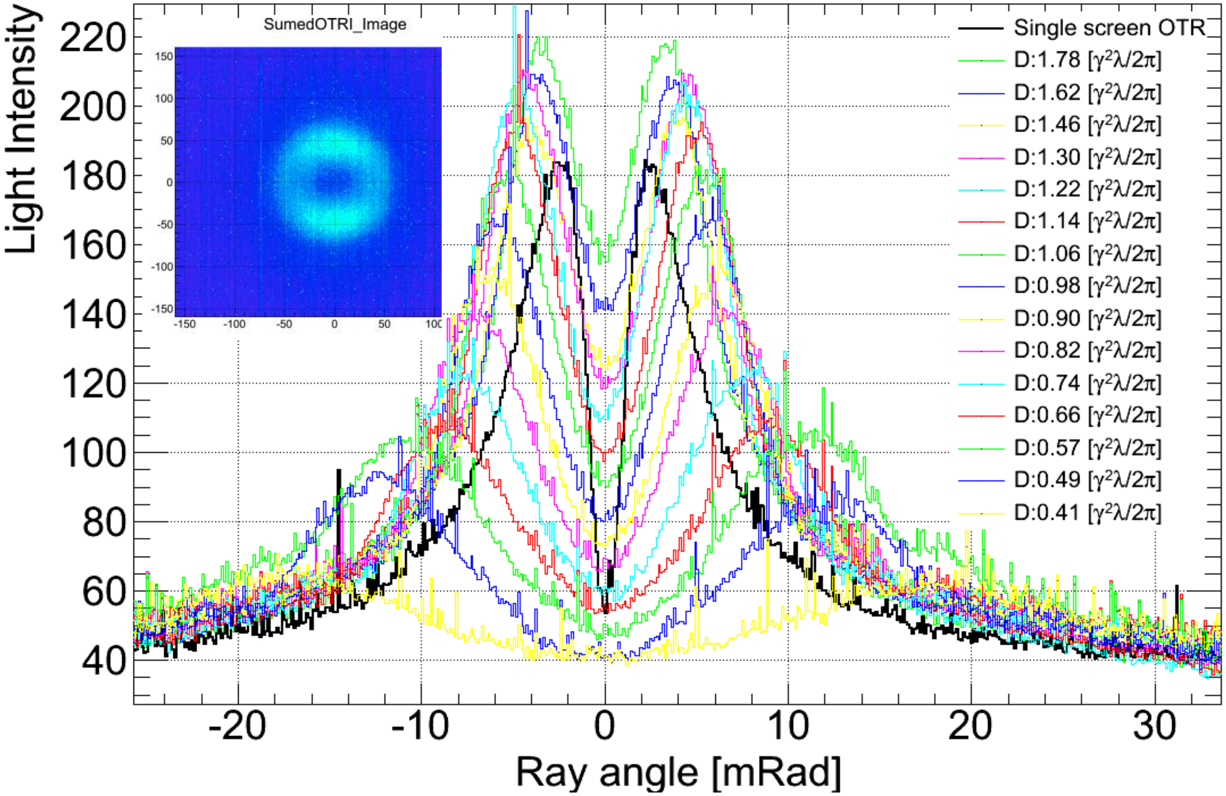


Resolution estimates near the structure center when the beam is kept still for many pulses
→ However, large discrepancies between channels (to be followed up)



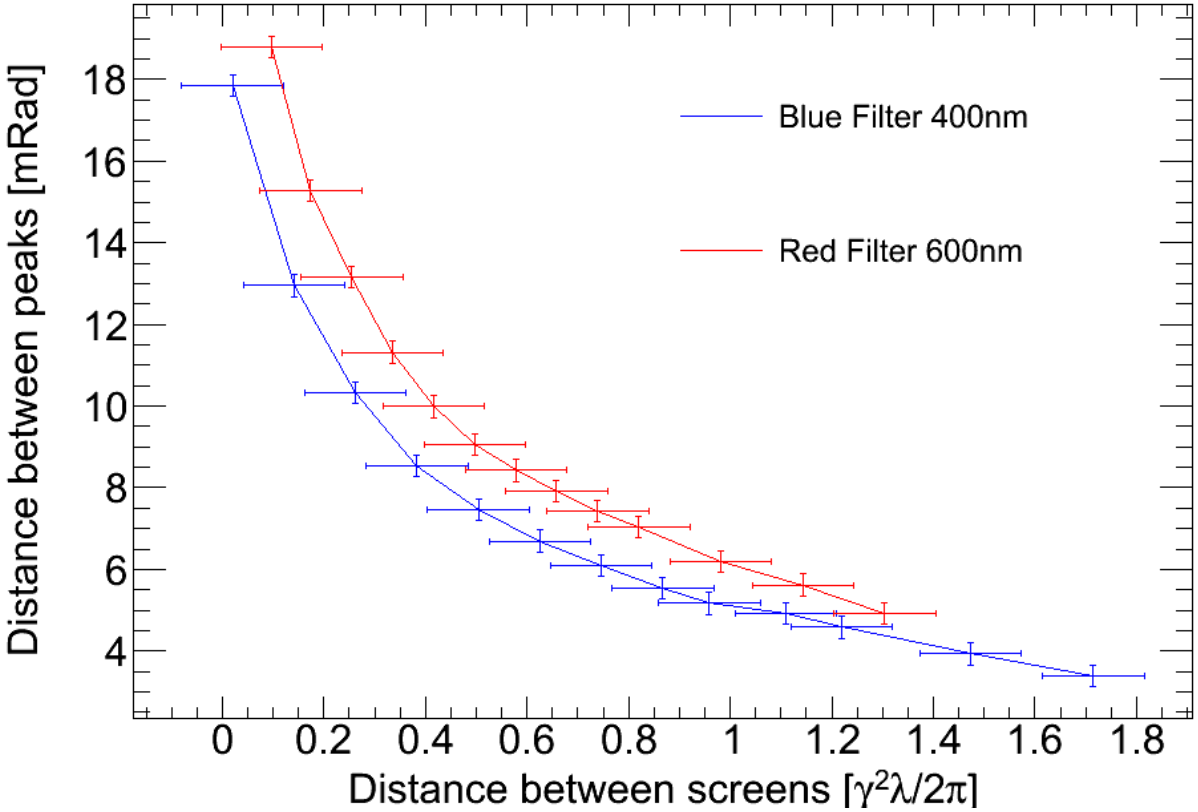
Angular observation 600-40nm Red Filter OTRI Vertical Polarization

R. Kieffer



Angular Distance Between peaks
Vertical Polarization

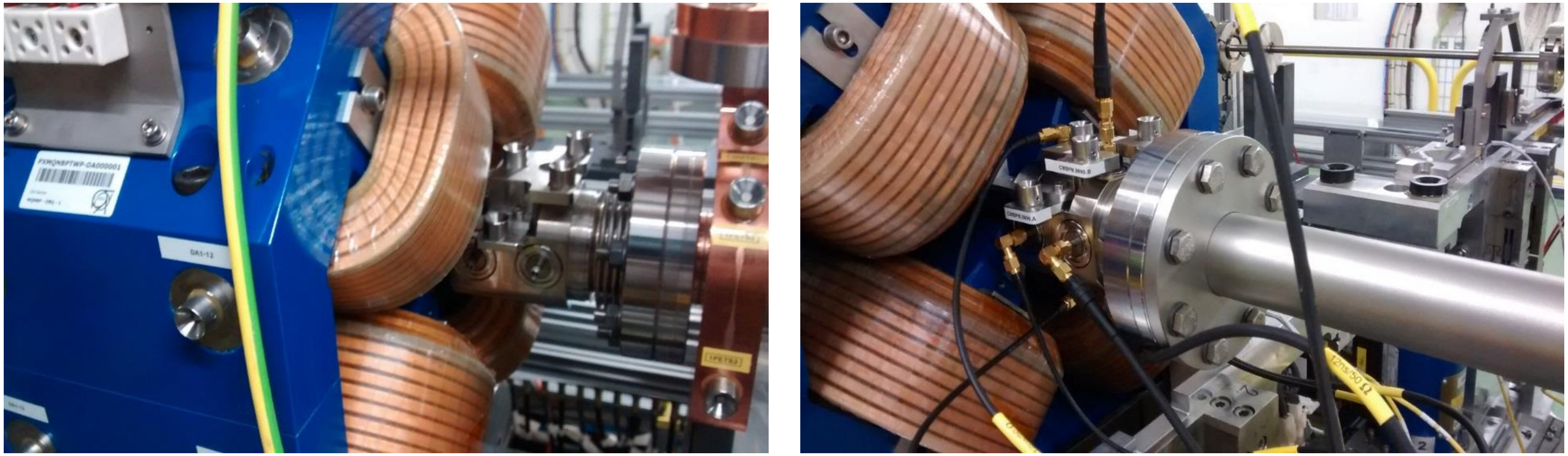
R. Kieffer



Terminated Stripline BPM for CLIC TBM

A. B. Morell

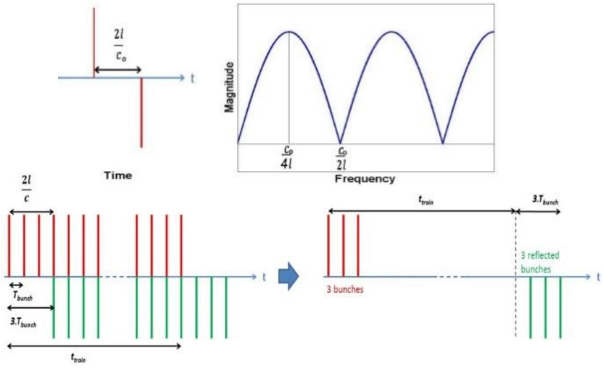
- Two units installed: CM.BPL0645, CM.BPL0685



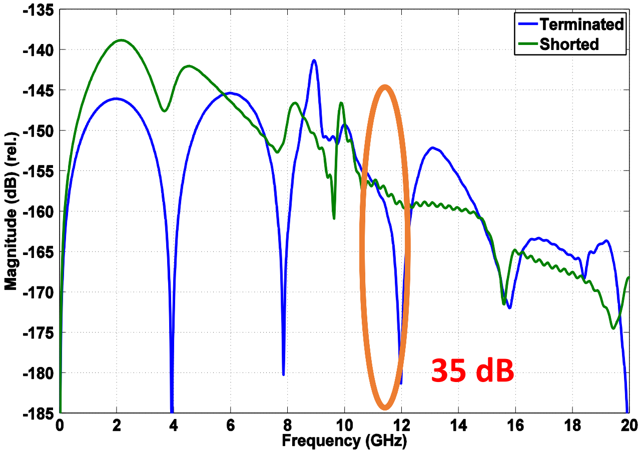
- New FESA class developed for BPM control and data acquisition (TBM and TBL): CLEXBPM.

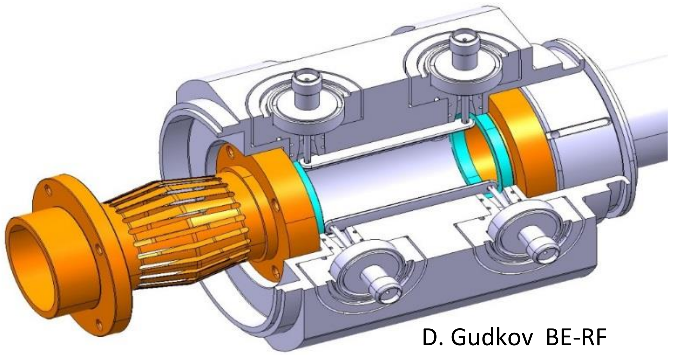
Terminated Stripline BPM for CLIC TBM

A. B. Morell



Parameter	Shorted BPM	Terminated BPM
Stripline length	25 mm	37.5 mm
Angular coverage	12.5% (45°)	5.55% (20°)
Electrode thickness	3.1 mm	1 mm
Outer radius	17 mm	13.54 mm
Ch. Impedance	37 Ω	50 Ω
Duct aperture	23 mm	23 mm
Resolution	2 μm	**2 μm**
Accuracy	20 μm	20 μm
Time Resolution	10 ns	10 ns





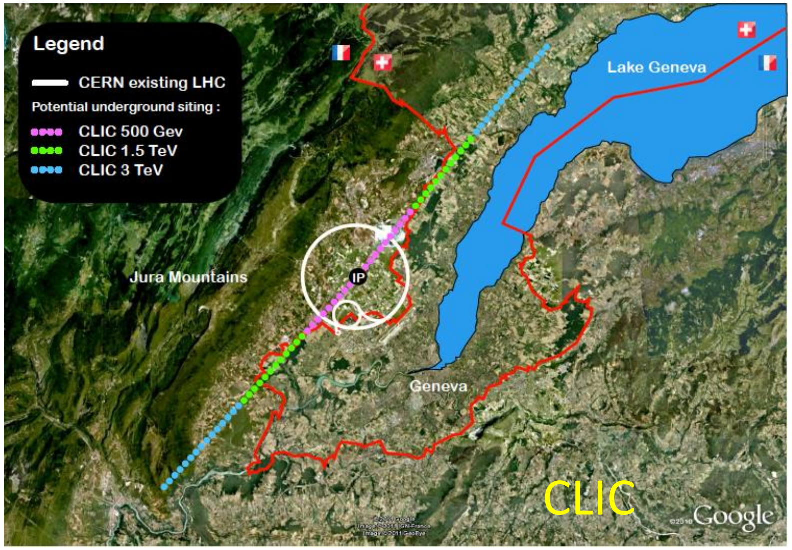
D. Gudkov BE-RF

Applications

Selected high-gradient ncrf applications

- Linear Colliders – High-energy physics facility
- XFELs – User facilities for material science, biology, chemistry, etc.
- Compton-scattering sources – Laboratory to room-sized X-ray sources, user facility
- Medical – compact linacs for proton and carbon ion cancer treatment
- Sub-system – energy spread linearizer, deflecting cavity

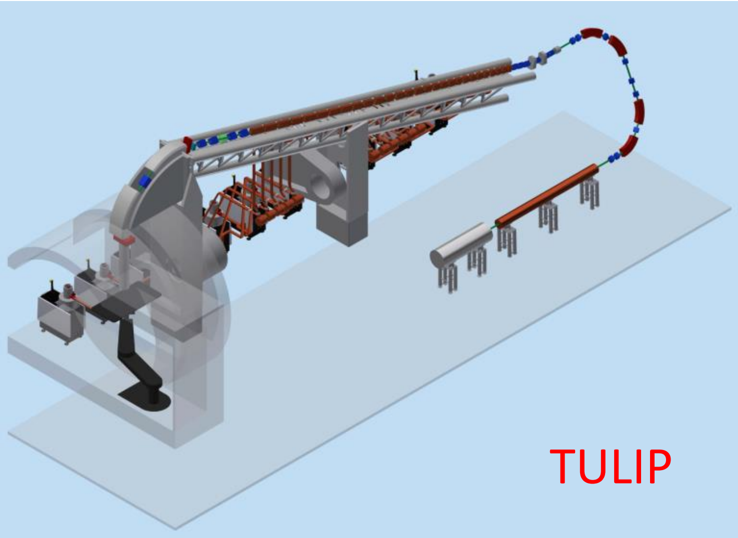
Scale of applications



http://www.lightsources.org/facility/sacla

Linear collider

XFEL



https://indico.cern.ch/event/358352/session/7/contribution/40

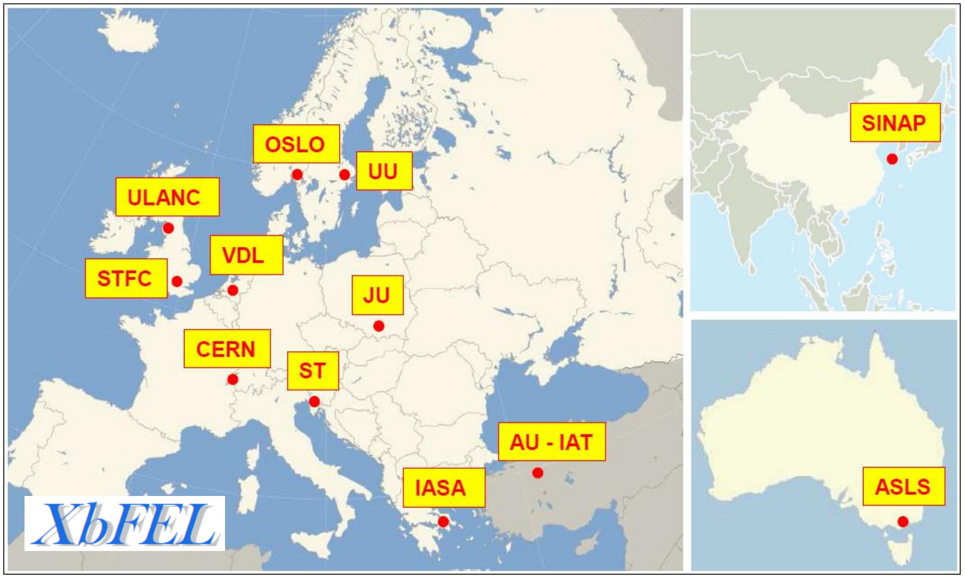
Proton therapy

Thompson/Compton source

The XbFEL Collaboration

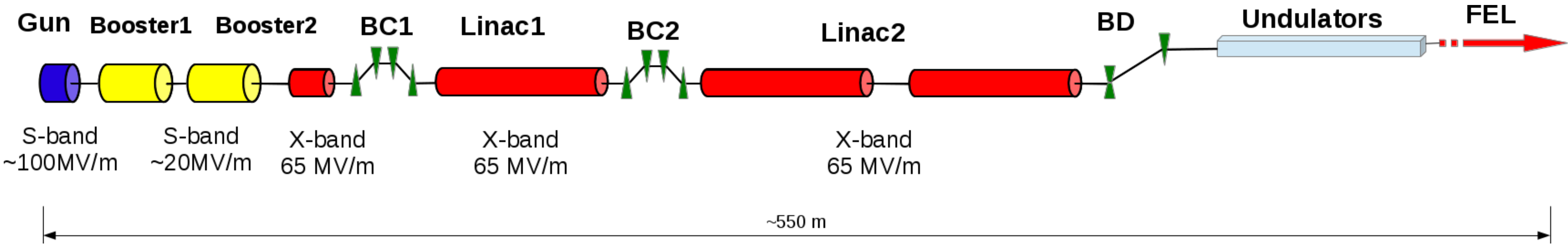
The aim of the XbFEL Collaboration is to promote the use of X-band technology for FEL based photon sources.

→ ***http://xbandfel.web.cern.ch/***



ST	*Elettra - Sincrotrone Trieste, Italy.*
CERN	*CERN Geneva, Switzerland.*
JU	*Jagiellonian University, Krakow, Poland.*
STFC	*Daresbury Laboratory Cockcroft Institute, Daresbury, UK*
SINAP	*Shangai Institute of Applied Physics, Shanghai, China.*
VDL	*VDL ETG T&D B.V., Eindhoven, Netherlands.*
OSLO	*University of Oslo, Norway.*
IASA	*National Technical University of Athens, Greece.*
UU	*Uppsala University, Uppsala, Sweden.*
ASLS	*Australian Synchrotron, Clayton, Australia.*
UA-IAT	*Institute of Accelerator Technologies, Ankara, Turkey.*
ULANC	*Lancaster University, Lancaster, UK.*

Proposed Layout



It consist of:

- **RF photocathode gun** → S band structure delivering beam @7 MeV with 250 pC charge, 2.5 ps (800µm) lengt and 0.25 mm rad emittance
- **Injector** → S-band structures and one X-band structure as linearizer, accelerating beam up to 300 MeV
- **Two main linacs** → Two X-band modules: stage one 0.3 GeV → 2.0 GeV
  stage two 2.0 GeV → 6.0 GeV
- Two bunch compressors , Beam delivery lines , Undulator(s), Laser transport line(s)

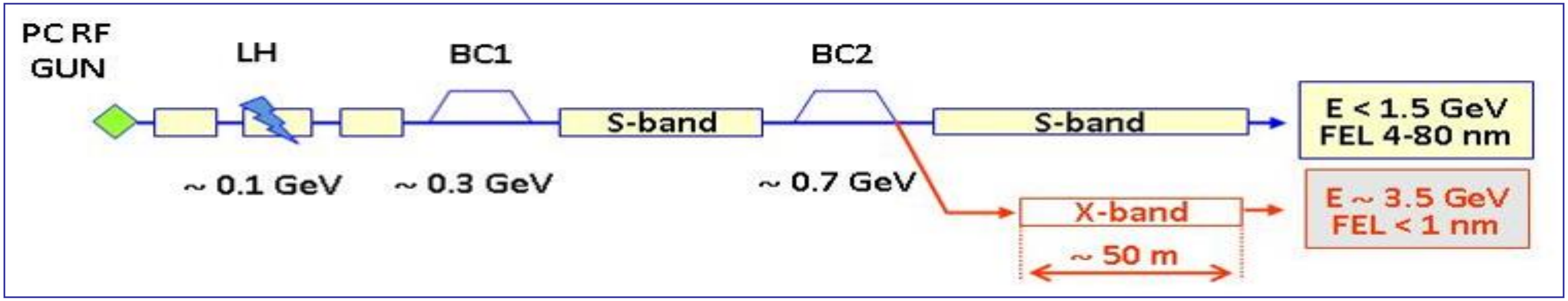
The advantage of using X-band:

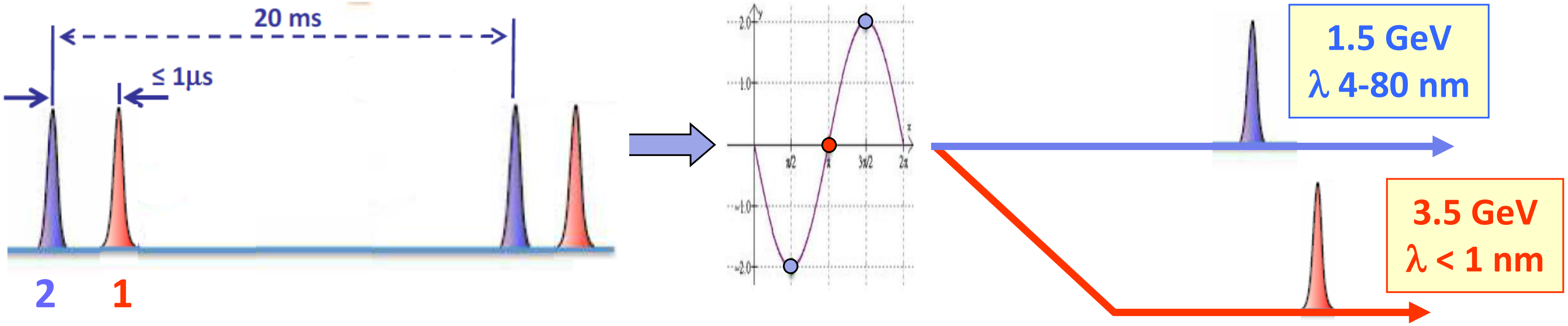
- Compact reduction of length with high gradient
- Costs reduction
- Possibility to go to a high repetition rate (up to kHz regime)

Turkish project

Courtesy of A. Aksoy

FERMI perspectives





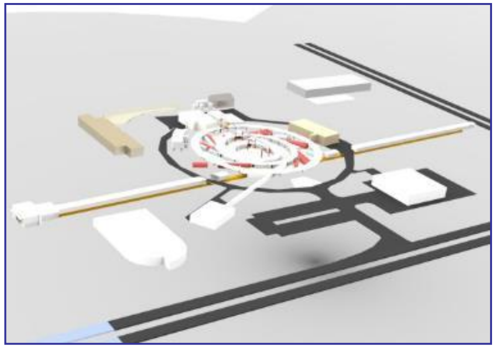
S-band linac
two e-bunches/RF pulse

HF bunch separator

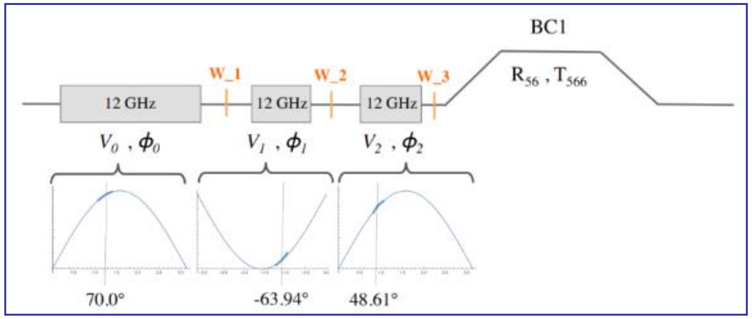
Two separate linacs at 50 Hz
S-band → 1.5 GeV
X-band → 3.5 GeV

X-Band Activities in Australia

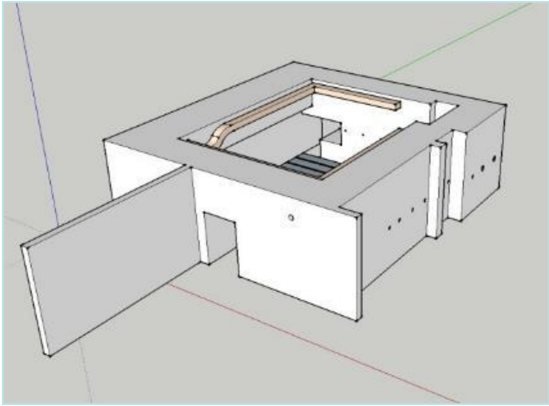
- **Part of the XbFEL Collaboration spun out from CLIC, planning XbFEL as an upgrade path for the Australian Synchrotron light source.**
- **Modelling all XbFEL linac with novel linearlisation scheme.**
- **Propose an "XBOX3" type test stand at the University of Melbourne.**



Concept drawing of AXXS Australian X-Band X-Ray Source. (M. Boland)



Phase Modulation Linerisation in an all X-band Linac (T. Charles *et. al.* , Proceedings of IPAC 2015)



Bunker for former 35 MeV betatron at the University of Melbourne. (M. Boland)

Courtesy of M. Boland

Shanghai Photon Science Center at SINAP

SXFEL: Shanghai Soft X-ray FEL

S-band, C-band, X-band

Energy: 0.84GeV (Phase I),

1.3GeV (Phase II)

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

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

Total length: About 550 meters

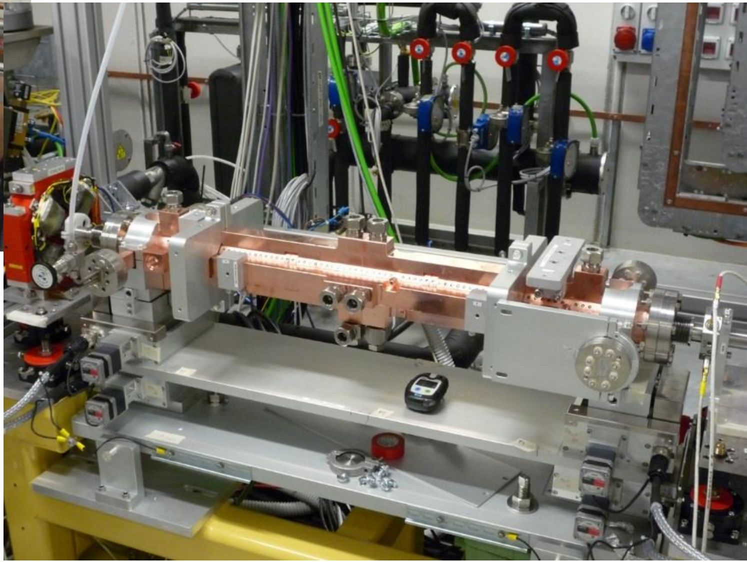
SSRF: Shanghai Synchrotron Radiation Facility

Energy: 3.5GeV, user operation

Courtesy of W

Energy spread linearizer FERMI@Elettra

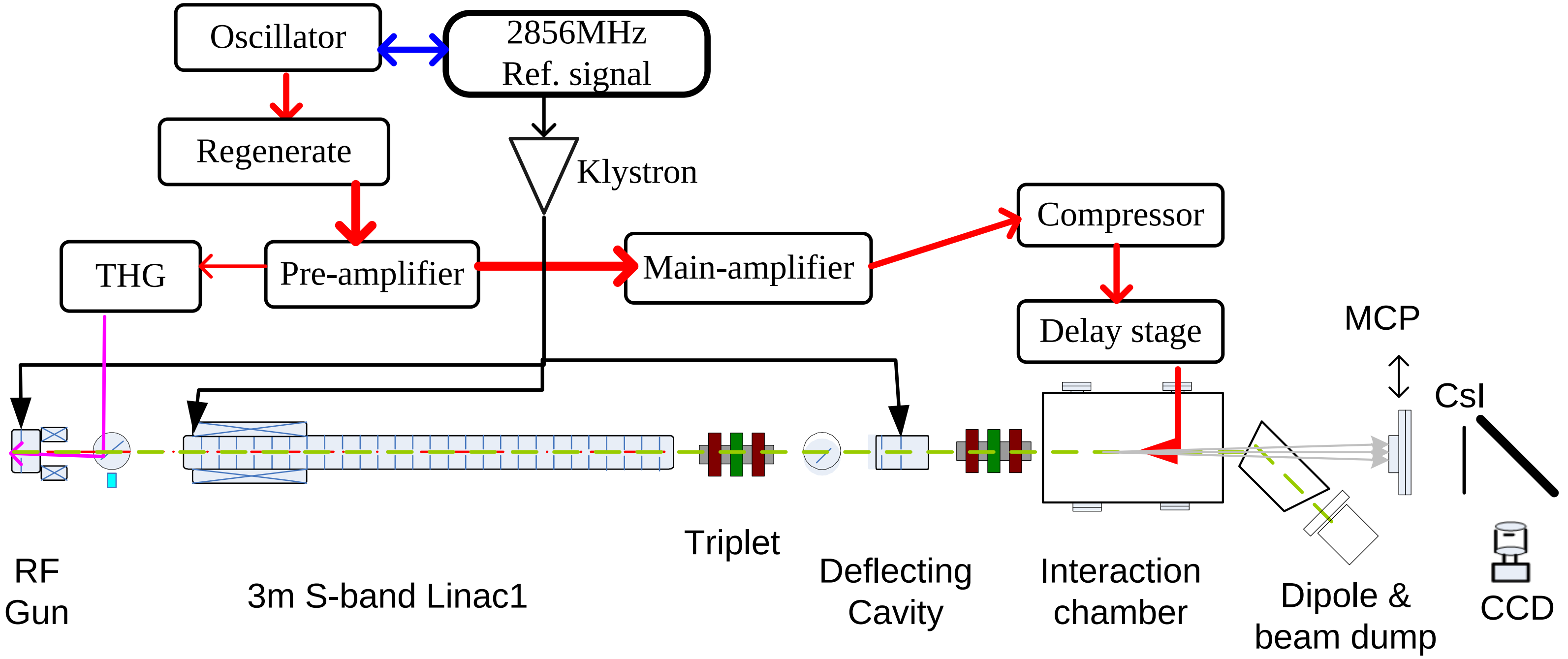
Routine operation of X-band system for energy spread linearization at FERMI@Elettra based on SLAC XL-5 klystron. Same system installed at PSI.



G. D'Auria

Deflectors for longitudinal bunch profile measurements are another big area.

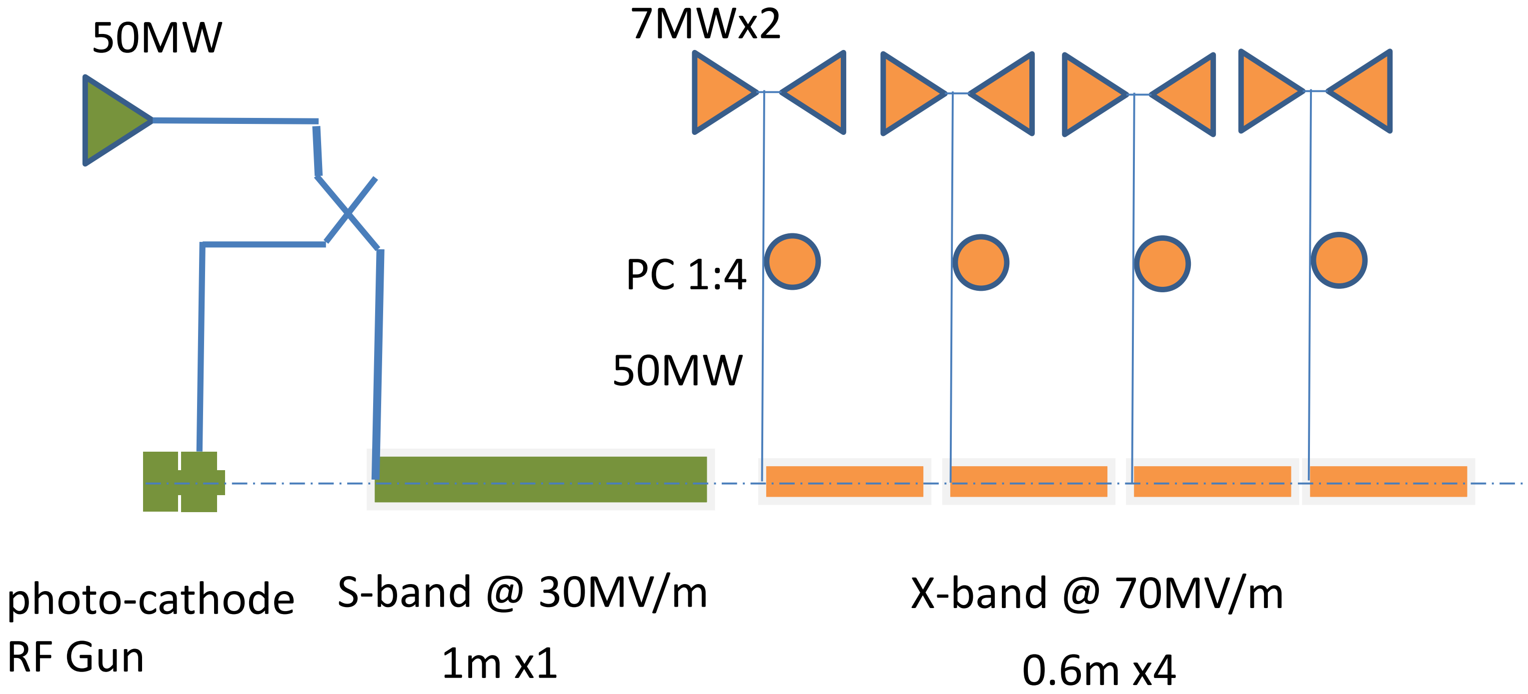
Tsinghua Thomson scattering X-ray source (TTX)



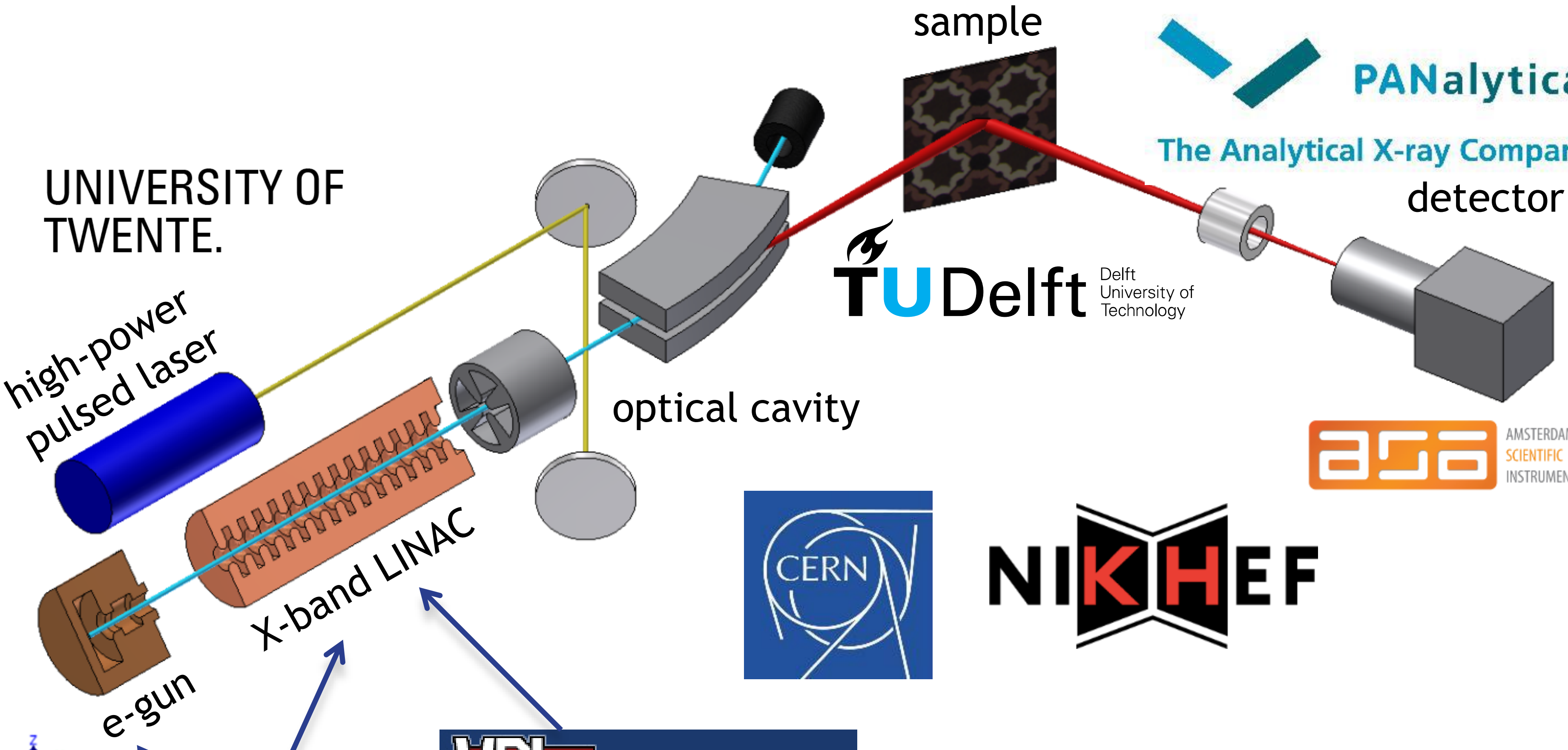
Electron beam		Laser beam	
Energy	45MeV	Wavelength	800nm
Bunch length	1~4ps	Pulse duration	~30fs
Charge	~0.7nC	Pulse energy	~500mJ
Beam size	30x25um	Beam size	~30um

Parameters of Scattering X-ray	
Photon energy	24(90deg)~48(180deg)kev
Pulse duration	0.16(90deg)~3(180deg)ps
Number photons	8.4X10^{6}(90deg)~5.5X10^{7}(180deg)

200MeV linac layout
(Preliminary design)



Compton Back Scattering source



UNIVERSITY OF TWENTE.

PANalytical
The Analytical X-ray Company

TU Delft Delft University of Technology

AMSTERDAM SCIENTIFIC INSTRUMENTS

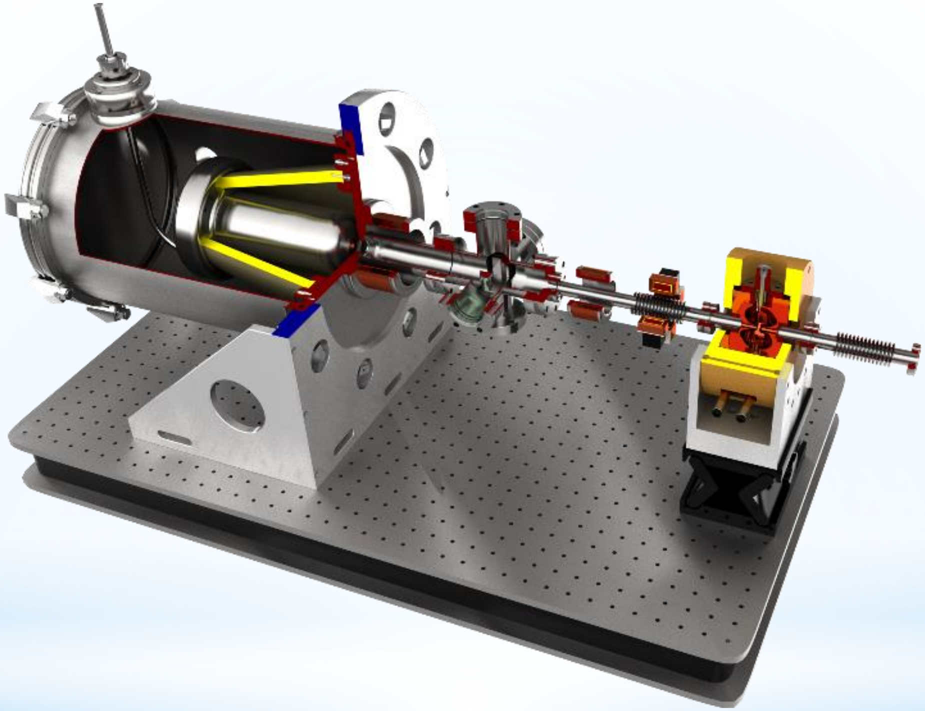
CERN

NIKHEF

VDL
VDL Enabling Technologies Group

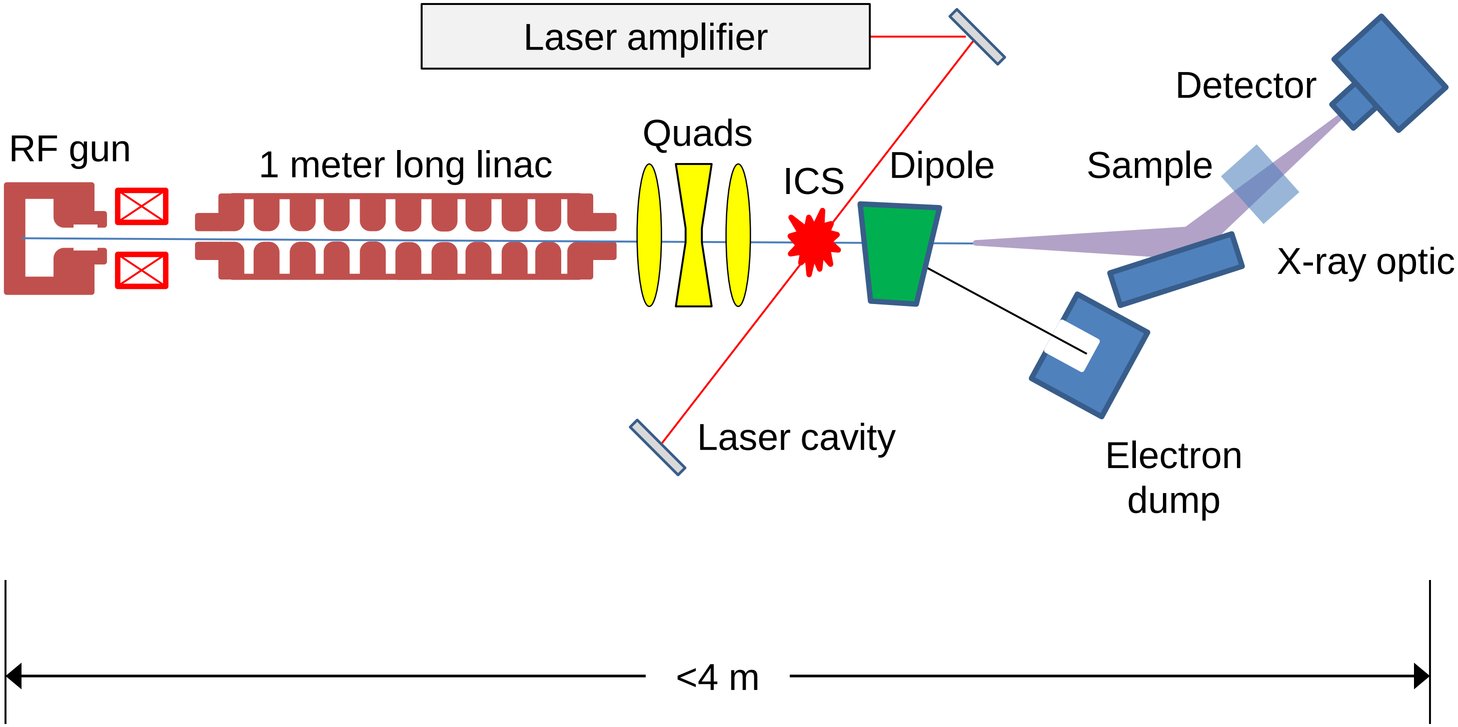
TU/e Technische Universiteit Eindhoven University of Technology

Low-emittance pulsed electron gun

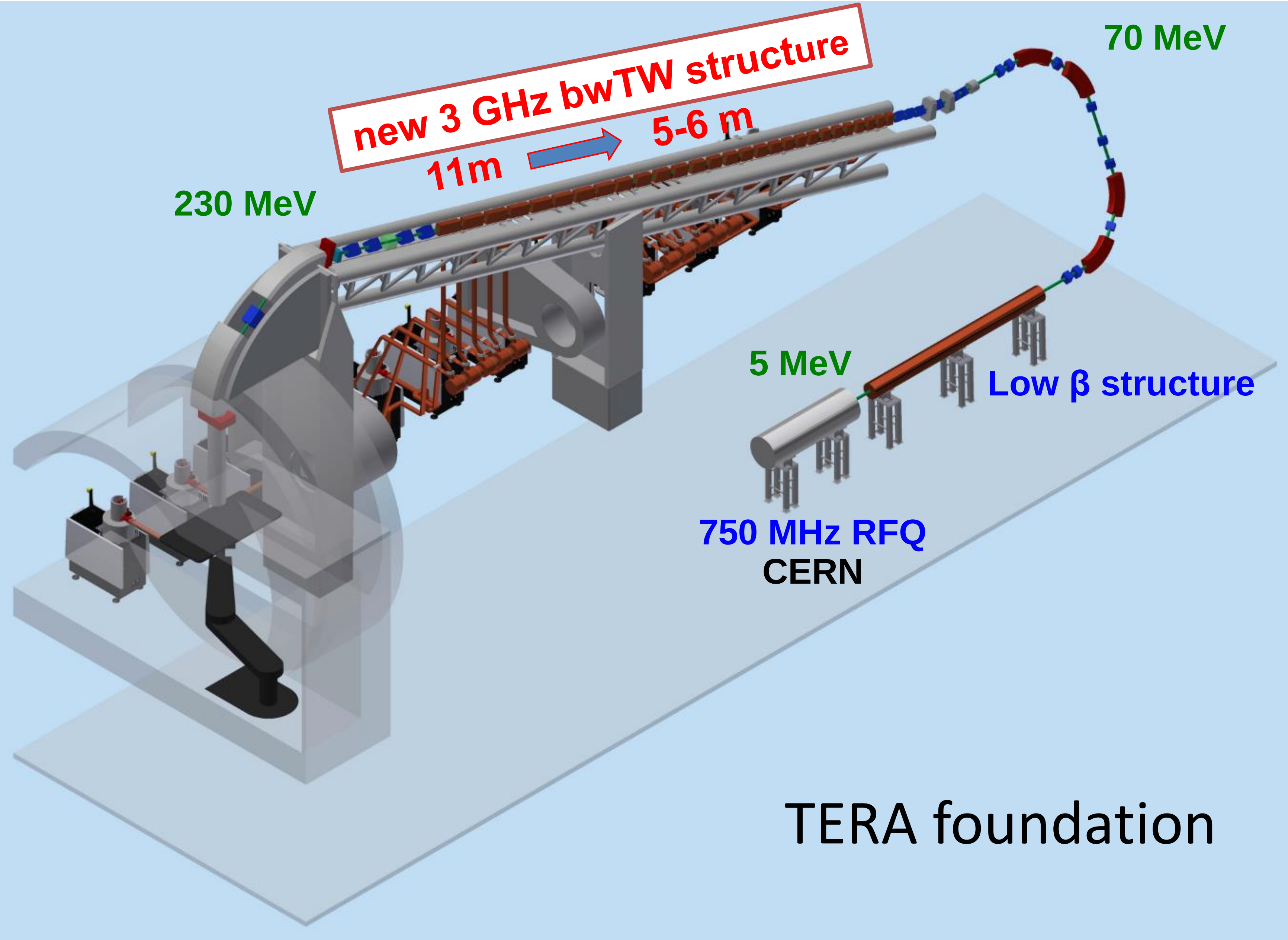


- 100 keV DC electron gun;
- pulsed operation by femtosecond laser photoemission;
- 1 pC bunches @ 40 nm rad normalized emittance;
- 10 pC bunches @ 120 nm rad normalized emittance;
- developed @ TU/e, sold through AccTec BV;
- currently under development: pulsed CeB_6 thermionic operation.

Basic Layout for ICS

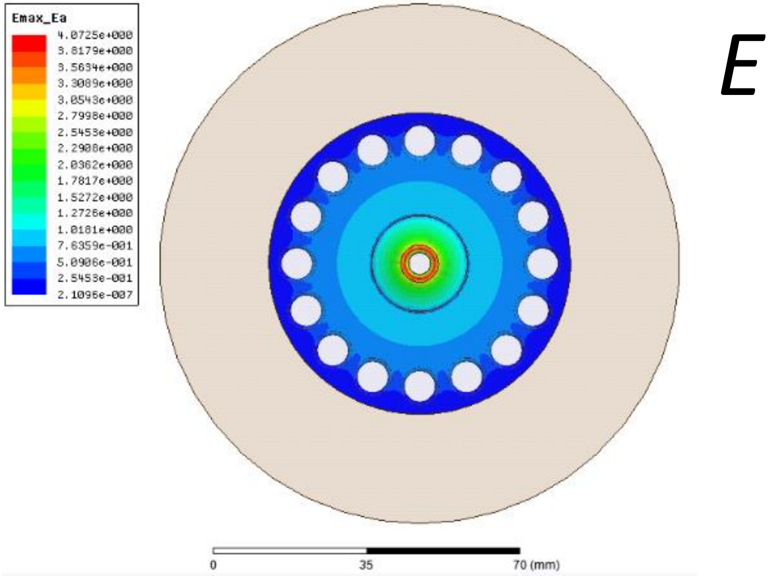


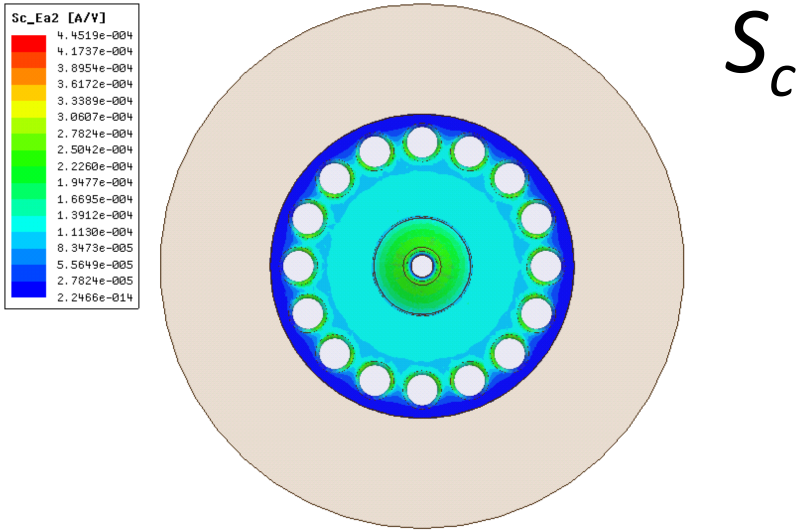
The TULIP Project

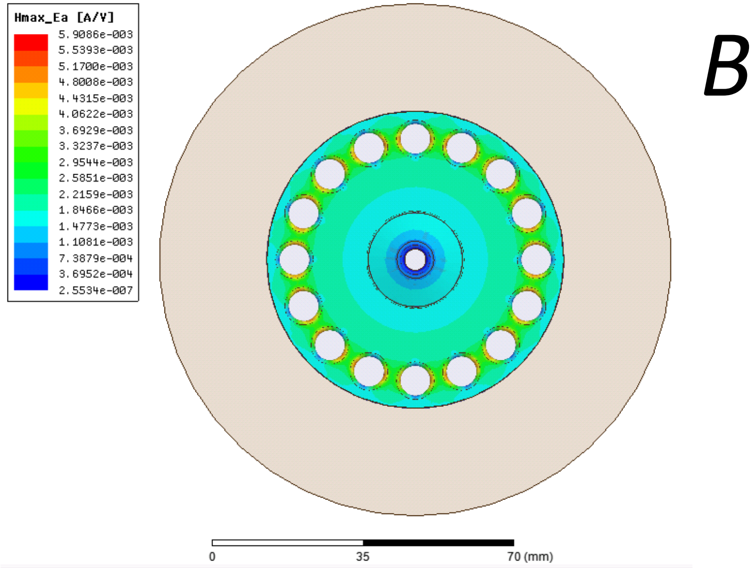


TERA foundation

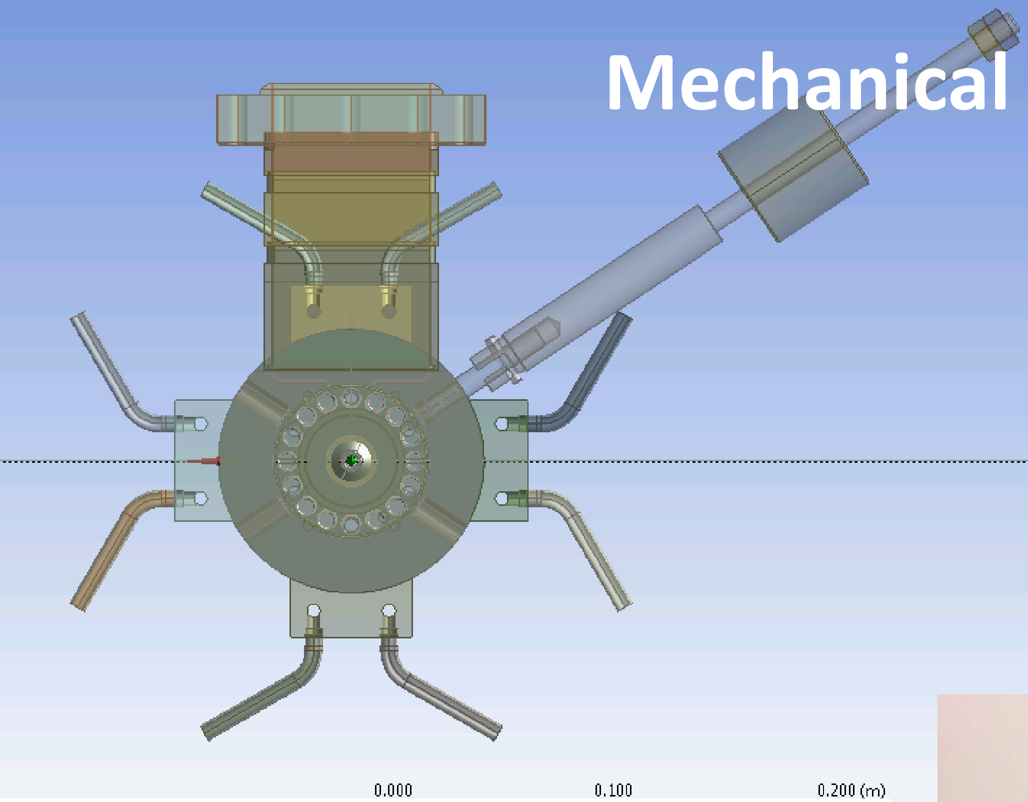
RF design and diamond machined disk

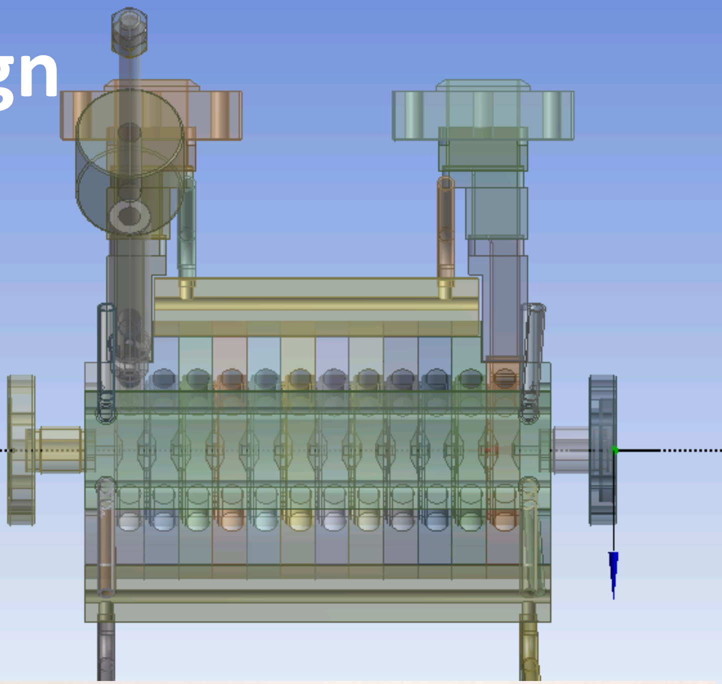


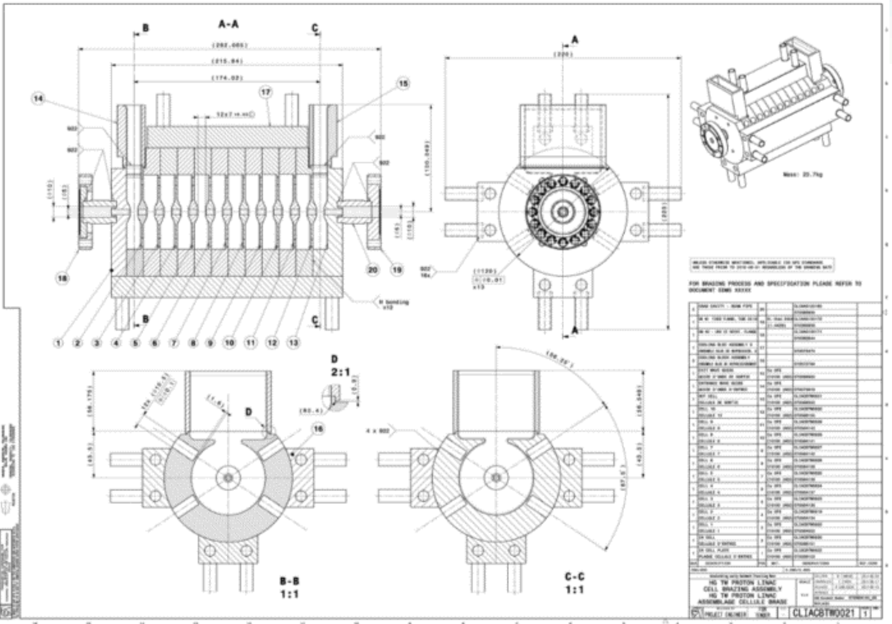


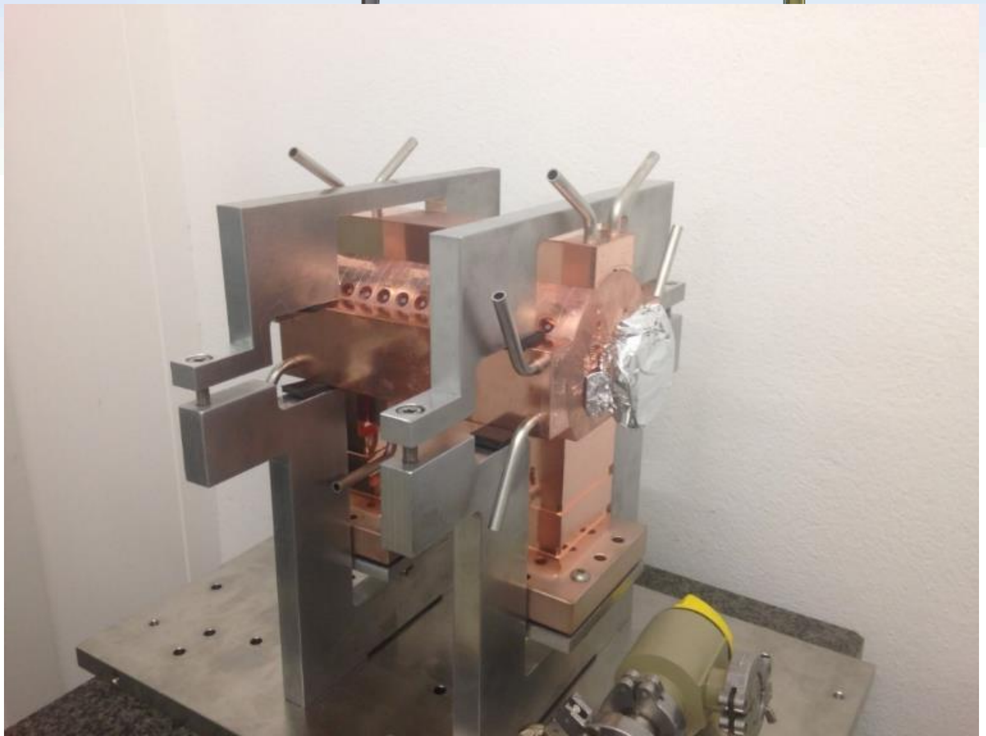


Mechanical design









X-band and high-gradient rf community

Our high-gradient and X-band applications community recently held a workshop in Beijing: https://indico.cern.ch/event/358352/.

International Workshop on Breakdown Science and High Gradient Technology
(H G 2 0 1 5)

June 16-19, 2015
Tsinghua University
Beijing, China
https://indico.cern.ch/event/358352/

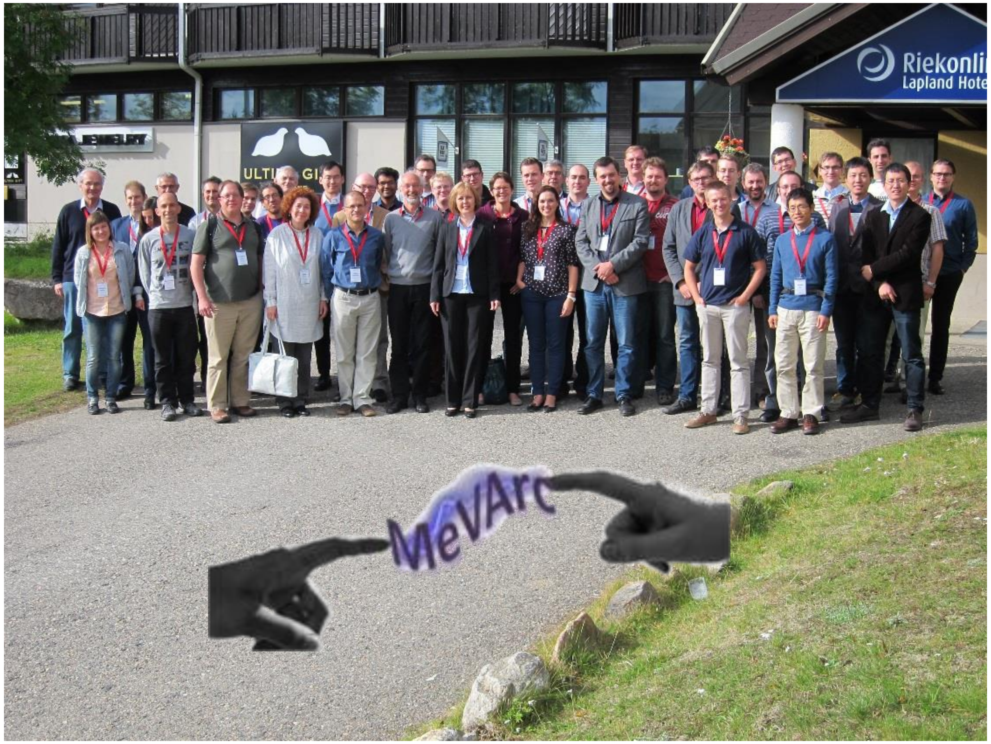
Meeting Chair
Tang, Chuanxiang

International Organizing Committee
D'Auria, Gerardo (Sincrotrone Trieste)
Gai, Wei (ANL)
Higo, Toshiyasu (KEK)
Tantawi, Sami (SLAC)
Wuensch, Walter (CERN)

Local Organizing Committee
Chen, Huaibi (Chair)
Huang, Wenhui
Shi, Jiaru
Zhang, Liang
Wang, Ping
Fan, Xue

Fundamental studies of high fields

And a workshop dedicated to vacuum arcs https://indico.cern.ch/event/354854/.



Mechanisms of Vacuum Arcs-5

2-4 September, 2015

The workshop aims to combine the efforts of researchers in different fields to understand the mechanisms underlying the highly intriguing phenomenon of electrical breakdown. The workshop will cover rf and dc types of electrical breakdowns, including theory, experiment, and simulation. The workshop will be preceded by a half-day mini-school on modeling surface (electrode) evolution processes relevant to electrical breakdown phenomena.

Topics

Experiments: vacuum arcs, dc spark systems, rf accelerating structures, materials, diagnostics, techniques and technologies for high gradients, and arcing in fusion devices.

Theory and simulations: surface modification under electric and electromagnetic fields, PIC and PIC-DSMC plasma simulations, dislocation activity, plasma-wall interactions, and surface damage and evolution.

Applications: particle accelerators, discharge-based devices, electrostatic failure mitigation, fusion devices, satellites and other industrial interests.

Venue

The workshop will be held in Saariselkä, Lapland. Lappish ruska is the time of beautiful autumn colors.

Organizers

Flyura Djurabekova
HIP, University of Helsinki, Finland
Walter Wuensch, Sergio Calatroni
CERN, Switzerland
Matthew Hopkins
Sandia National Laboratories, USA
Yinon Ashkenazy
Hebrew University of Jerusalem, Israel

http://indico.cern.ch/event/354854

CERN, 14 December 2015

Conclusions

The field of high-gradient and high-frequency rf is in a phase of rapid development.

It is benefiting from a confluence of a number of trends: 3-D simulation, precision 3-D machining, power sources, material science, etc.

We understand high-gradient phenomena rather well now and this is resulting in robust optimized designs with still some 10’s% increase in gradient in the pipeline.

Significant improvements in cost should be possible.

The potential applications range from very large to rather small scale facilities. We hope to see a few take off in the coming years.

Thank you for your attention!