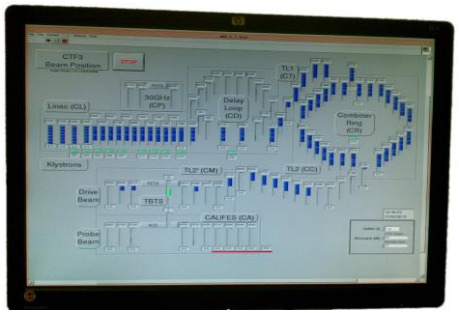


CTF3 status and plans

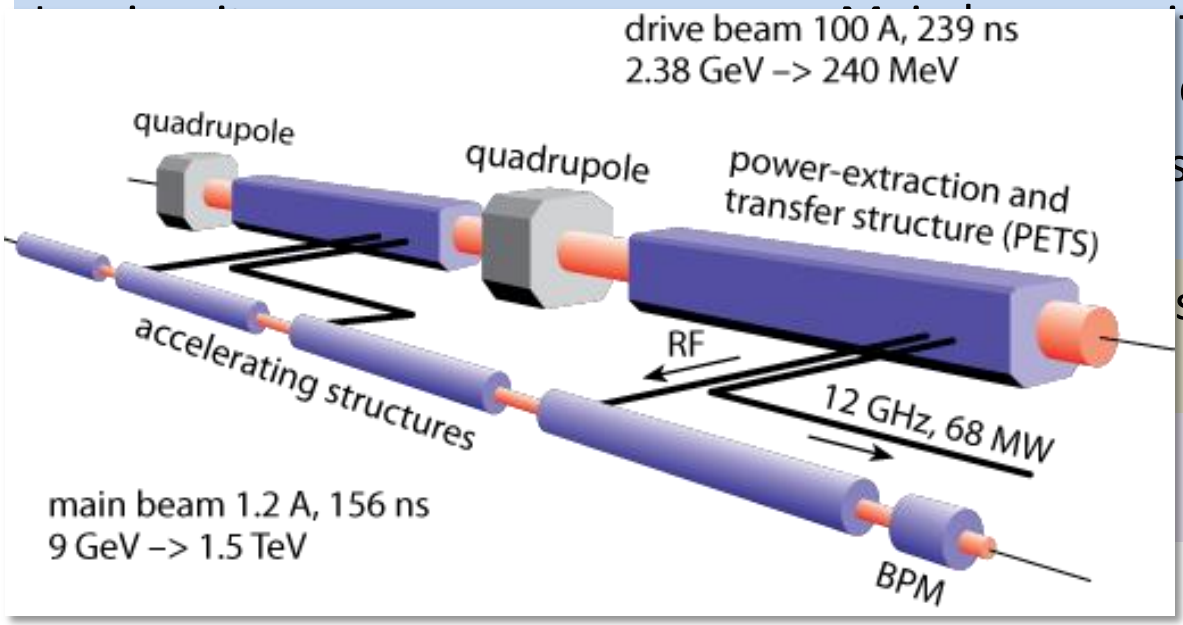
R. Corsini for the CLIC Collaboration

CONTENT:

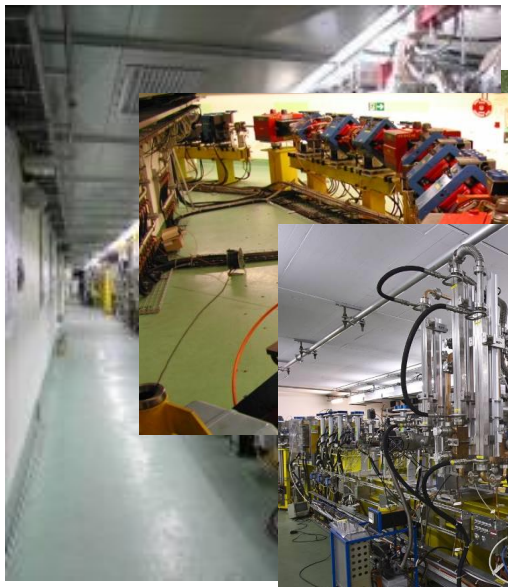
- Past results - completion of feasibility studies
  - Drive beam generation
  - Deceleration and RF power production
  - Two-Beam acceleration
- Highlights of 1st run of 2013 - program for 2nd run (autumn 2013)
- Outlook on the following years

CLIC Feasibility Benchmarks

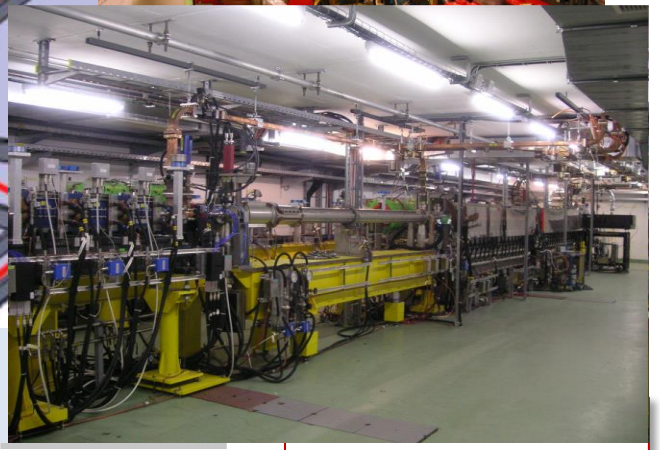
Main linac gradient	–	Accelerating structure	(CTF3)
Two beam scheme CTF3	–	Drive beam generation	
	–	PETS (power extraction and transfer structures)	
	–	Two beam acceleration	
	–	Drive beam deceleration	
		ttance generation, d focusing	
		stabilisation	(CTF3)
		ss)	(CTF3)



CLIC Test Facility (CTF3)



Operation of isochronous lines and rings



and current multiplication by RF deflectors

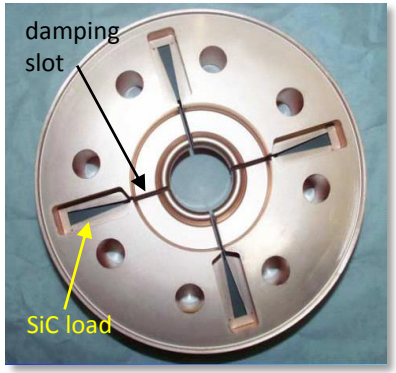
High current, full

30 A, 140 ns
60 MeV

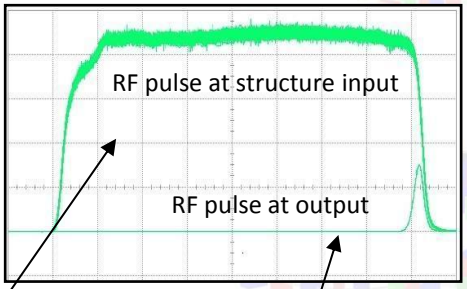
12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

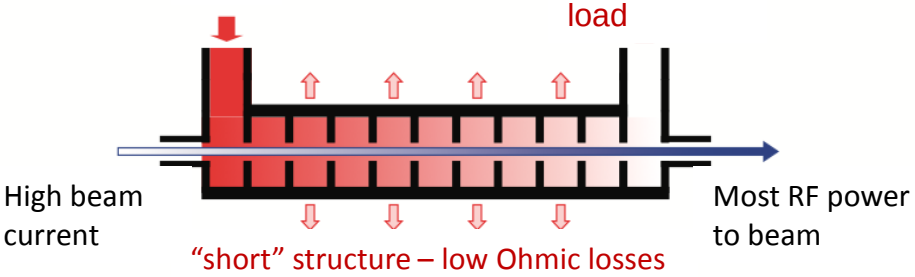
Drive Beam Generation

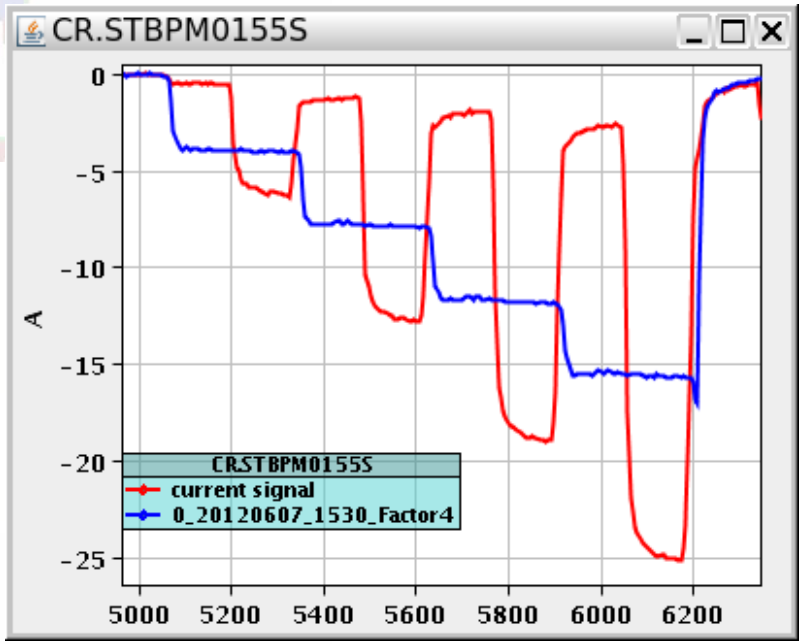


Full beam loading acceleration



95.3% RF to beam efficiency
Stable high current acceleration
Isochronicity, phase coding
Factor 8 current & frequency multiplication
Current stability





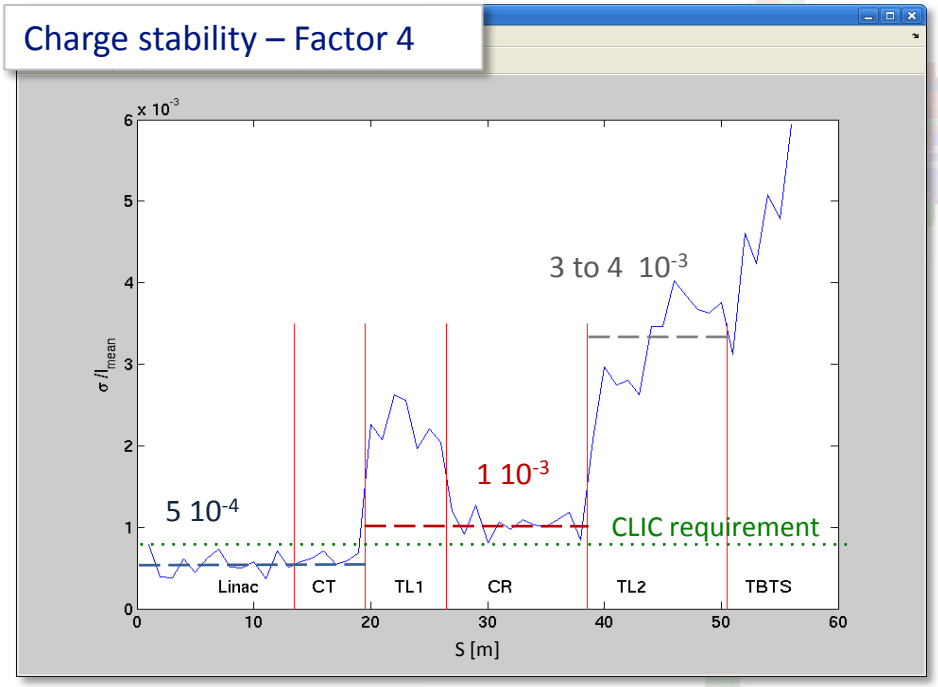
Factor 8 combination

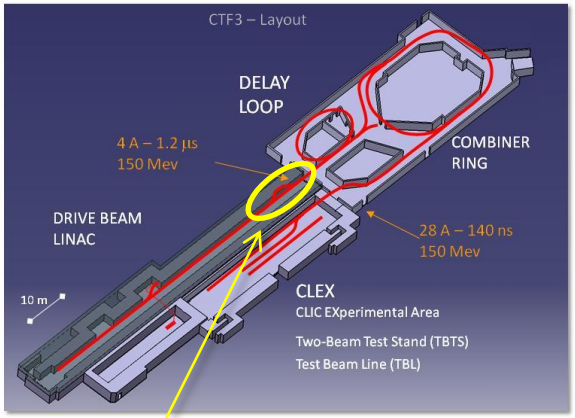
Drive Beam Stability

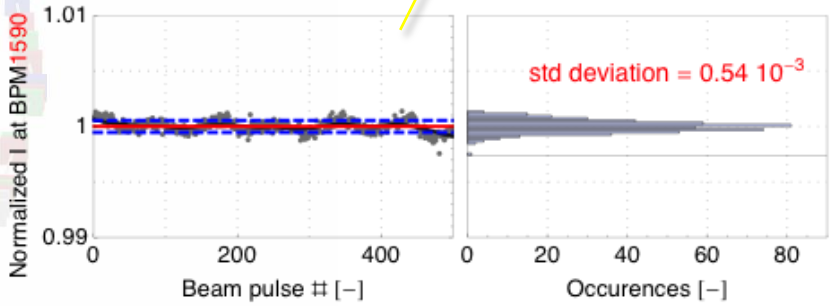
Repeatibility and long term current stability improved

Pulse charge stability at end of the linac better than CLIC requirements

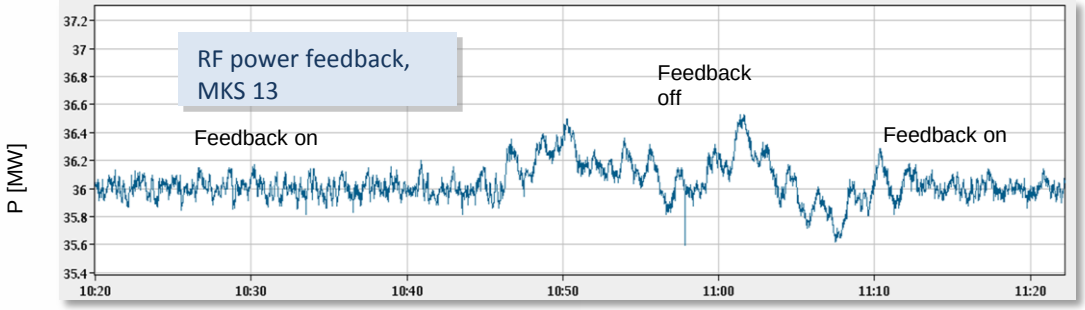
Charge stability – Factor 4



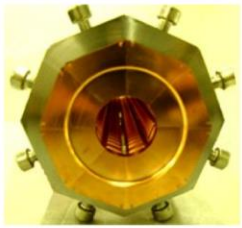


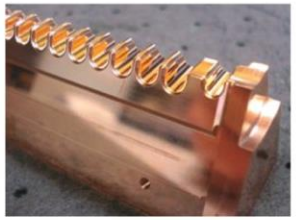


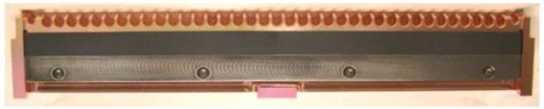
Several feed-back loops operational, for temperature, RF phase and power and gun current.



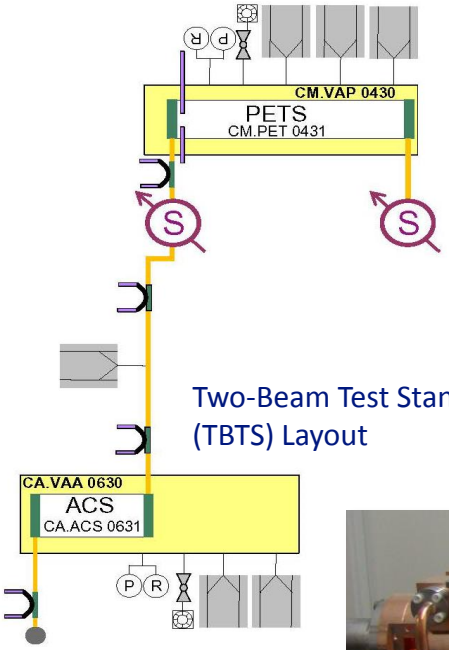
The Two-Beam Test Stand (TBTS)





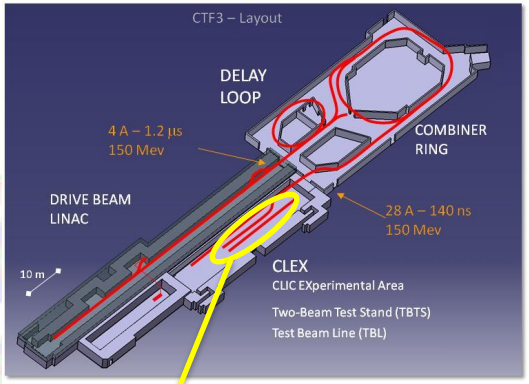


PETS – Power Extraction & Transfer Structure

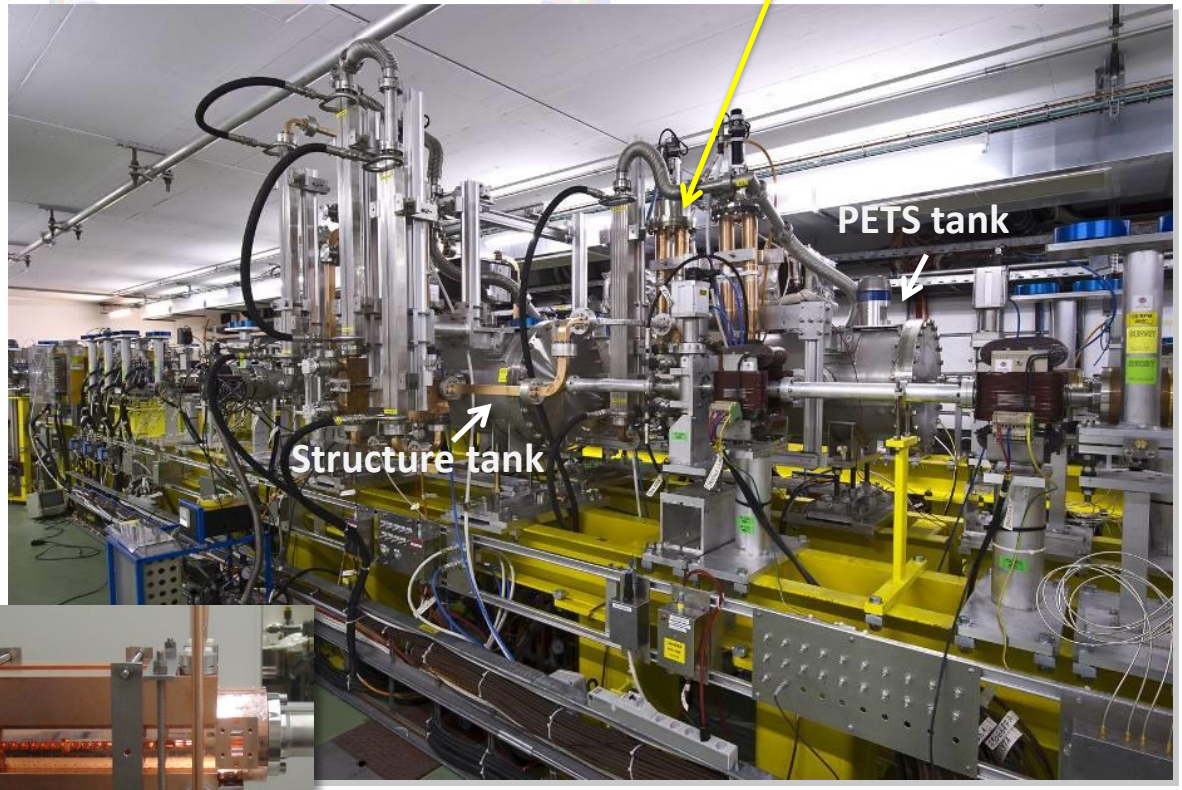


Two-Beam Test Stand (TBTS) Layout

TD 24 Accelerating structure



Two-Beam Test Stand in CLEX

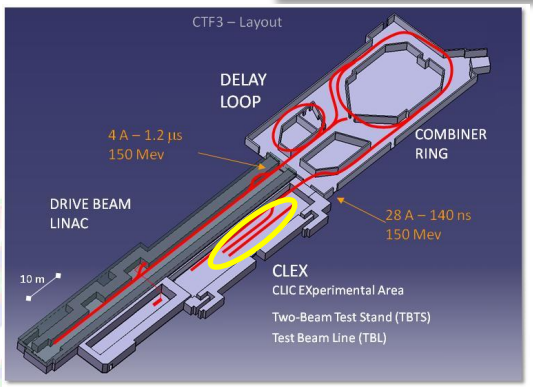


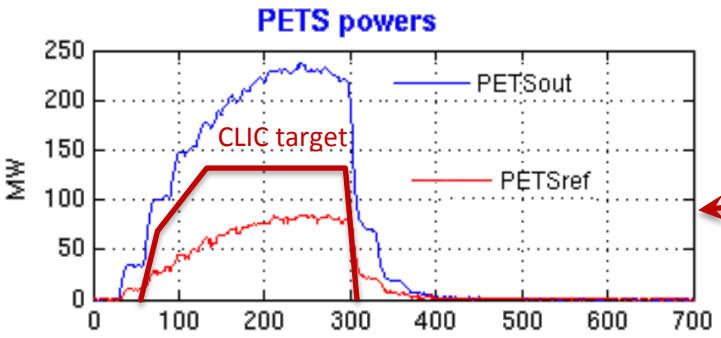
Power production in TBTS

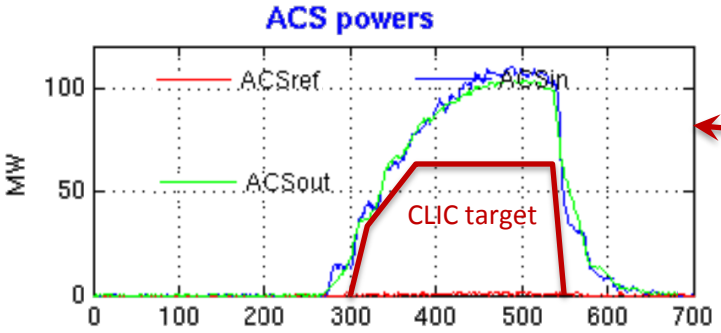
PETS operated routinely above **200 MW** peak RF power

providing reliably pulses ~ 100 MW peak to accelerating structure.

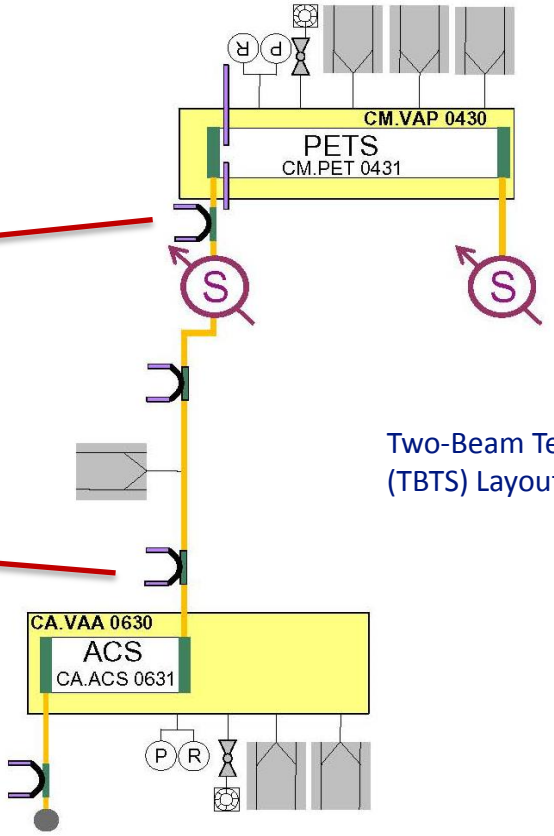
About twice the power needed to demonstrate 100 MV/m acceleration in a two-beam experiment with TD24 structure.





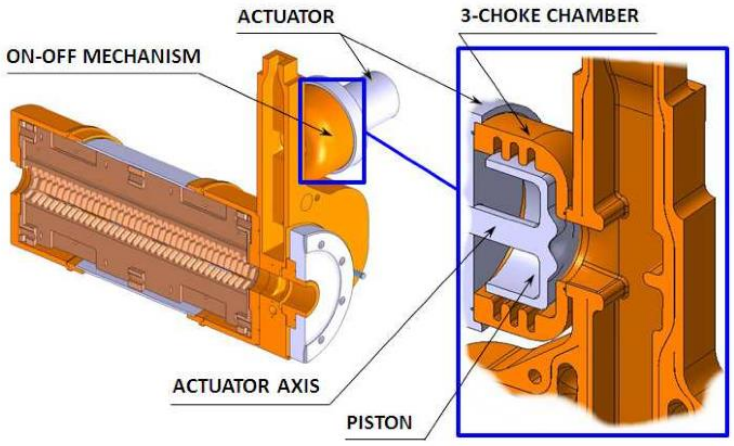


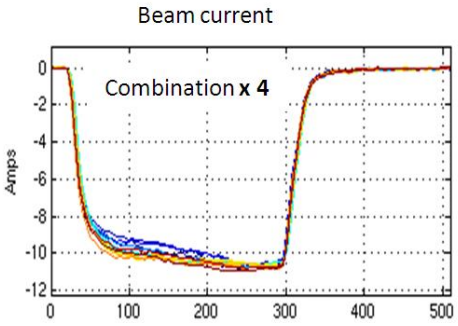
t [ns]

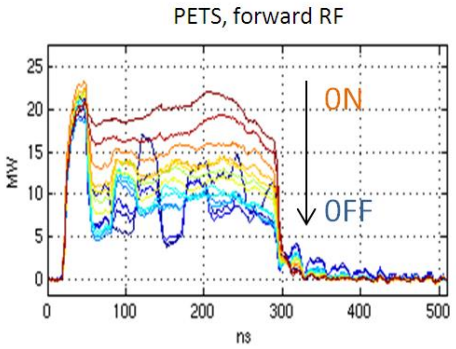


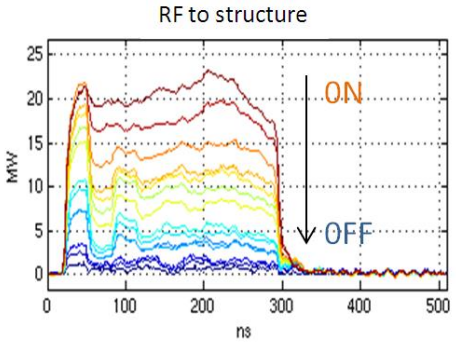
Two-Beam Test Stand (TBTS) Layout

TBTS – PETS On-off mechanism









Simulation vs. experiment

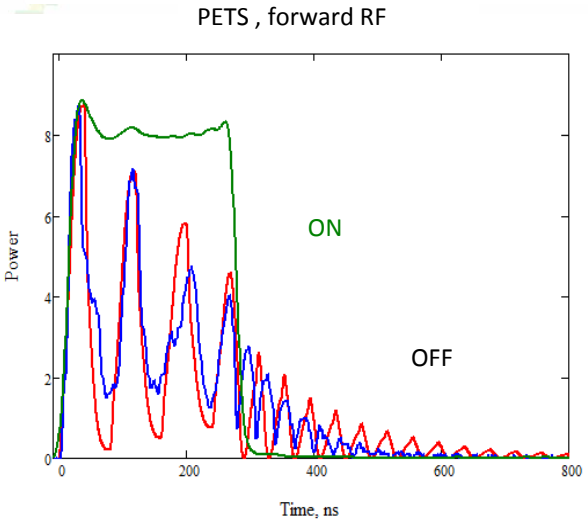
Demonstration of PETS of-off mechanism

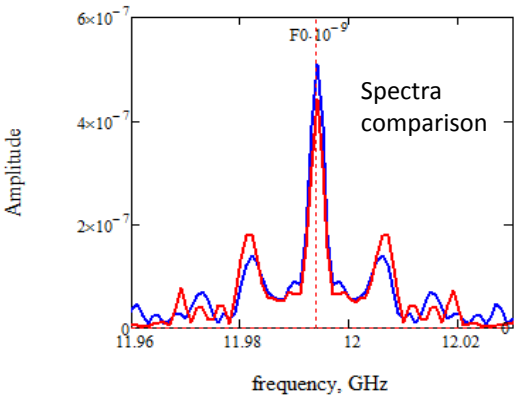
- Feasibility issue

- Switch off power from individual PETS to accelerating structure in case of breakdown
- Reduce substantially power in PETS, to cope with PETS breakdowns

- PETS on-off principle fully tested

- Conditioned at high power (135 MW - nominal) by recirculation



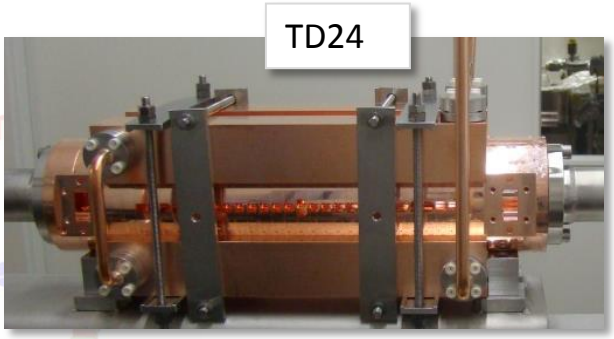


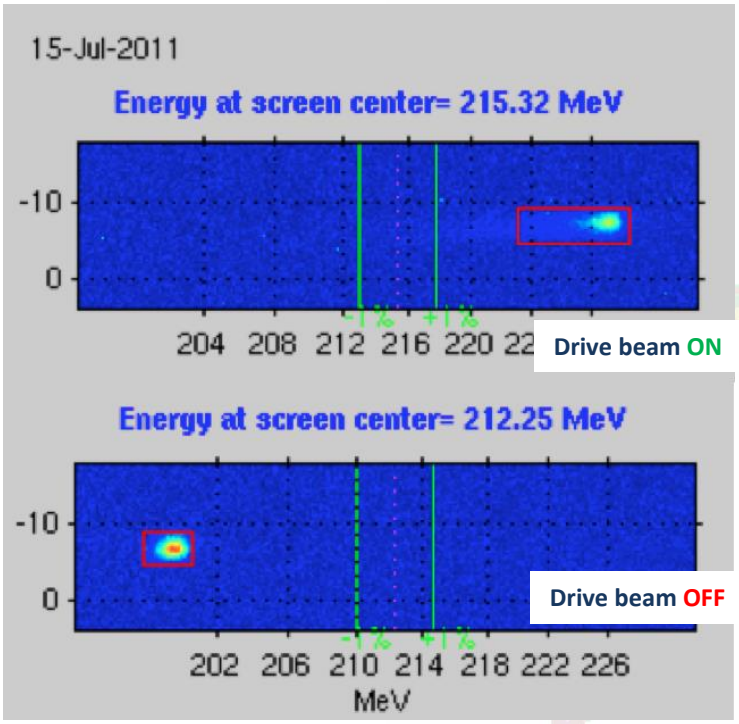
Two-Beam Acceleration

Two-Beam Acceleration demonstration in TBTS

Up to 145 MV/m measured gradient

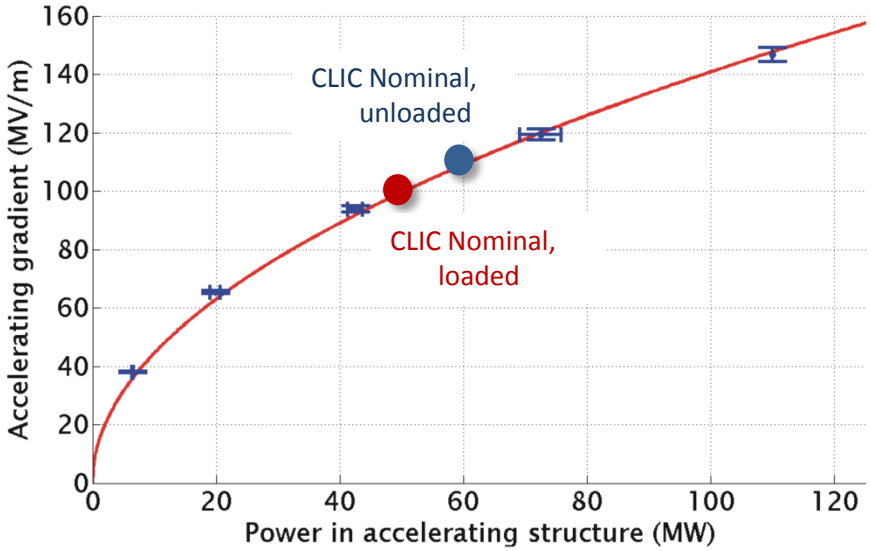
Good agreement with expectations (power vs. gradient)





Maximum stable probe beam acceleration measured: 31 MeV

⇒ Corresponding to a gradient of **145 MV/m**

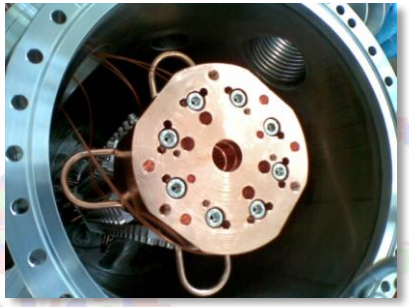


Test Beam Line

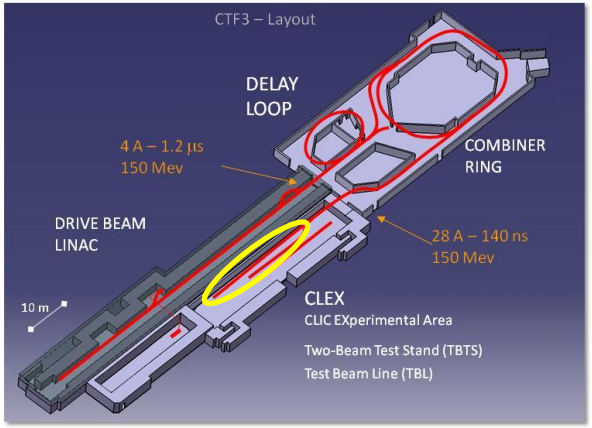
13 Power Extraction & Transfer Structures (PETS) installed and running in 2012

Full beam transport to end-of-line spectrometer, stable beam

Power produced (70 MW/PETS) fully consistent with drive beam current (21 A) and measured deceleration.

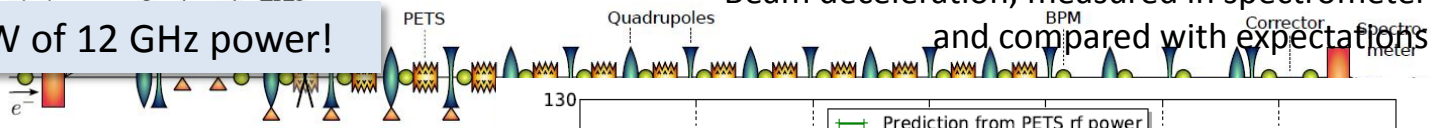


PETS tank during installation



More than half a GW of 12 GHz power!

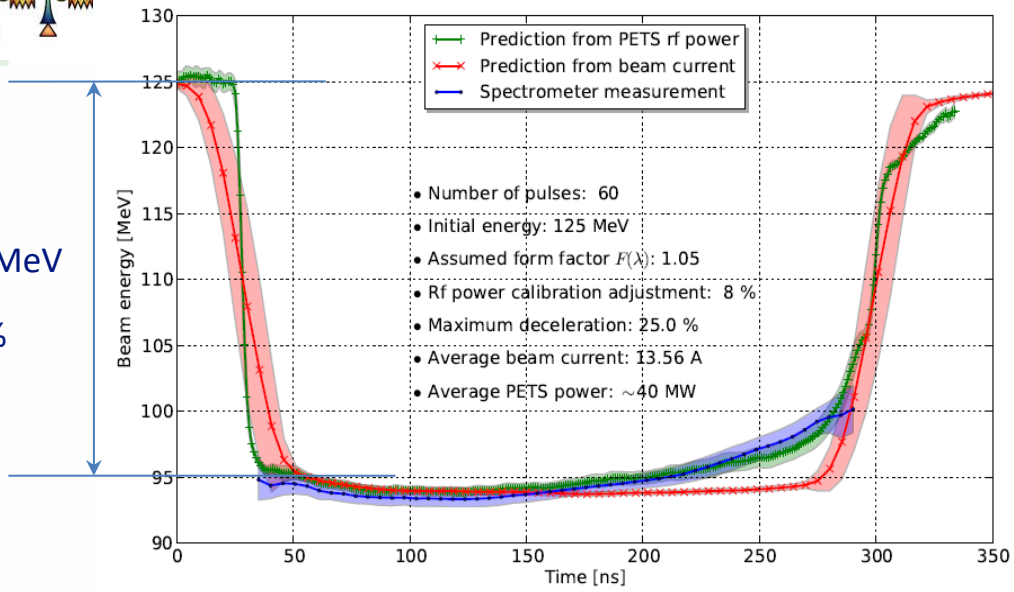
Beam deceleration, measured in spectrometer and compared with expectations



TBL line in CLEX

~ 30 MeV

25%



Highlights of 1st run
(February – May 2013)

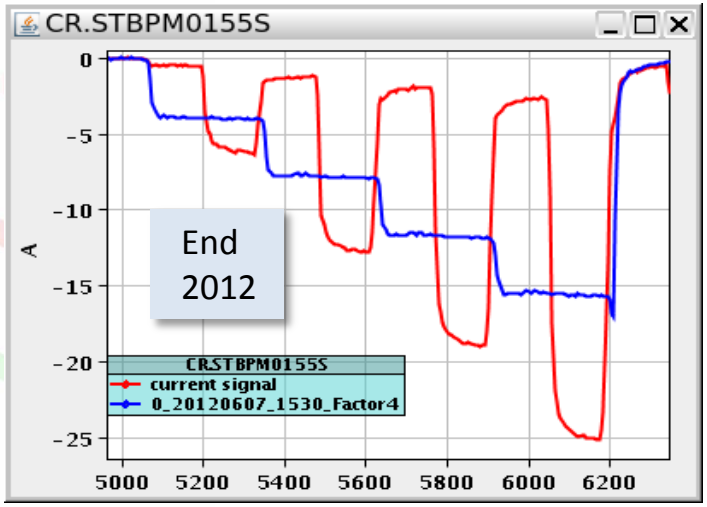
- Drive Beam generation
  - Routine operation of factor 8 in the last few weeks (25 - 26 A).
  - Still limited to 2 TWTs in Sub-Harmonic Bunching system (one at about ½ of nominal power).
  - Need improvements on emittance/stability (hopefully easier with 3 full TWTs).
- Two Beam Test Stand
  - Structures to about nominal CLIC power.
  - Wakefield monitors commissioned and measured, in the presence of X-band RF power.
- TBL
  - Deceleration to about 35% of a 22 – 24 A beam.
  - Commissioning and measurements of CLIC drive beam stripline BPM prototype.
- CALIFES
  - Commissioning and measurements of CLIC main beam BPM prototype.
  - First results from Electro-Optical (EO) bunch length monitor, bunch compression tests.
- Beam-Loading experiment in dog-leg
  - Beam line commissioning with beam and first RF measurements.
- Drive Beam phase feed-forward
  - Full commissioning of phase monitors, measured resolution, good indication on bandwidth.
  - First tests with FONT5 electronics.

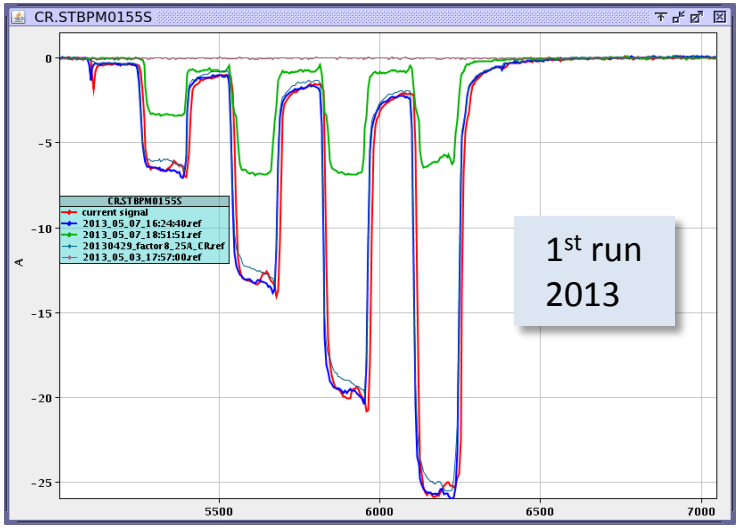
Drive Beam Generation

Beam recombination

Factor 8

- Routine operation of factor 8 in the last weeks.
- Still limited to 2 (out of 3) TWTs in SHB system.
- One TWT (well beyond expected lifetime) is slowly failing – oscillating around about ½ of nominal power.
- By switching the two TWT, managed to find good operating point, with performance slightly better than last year's.
- Still need some improvement (stability, emittance). Should be able to get back 2 fully operational TWTs at the restart, plus a 3rd before the end of the run.





Emittance

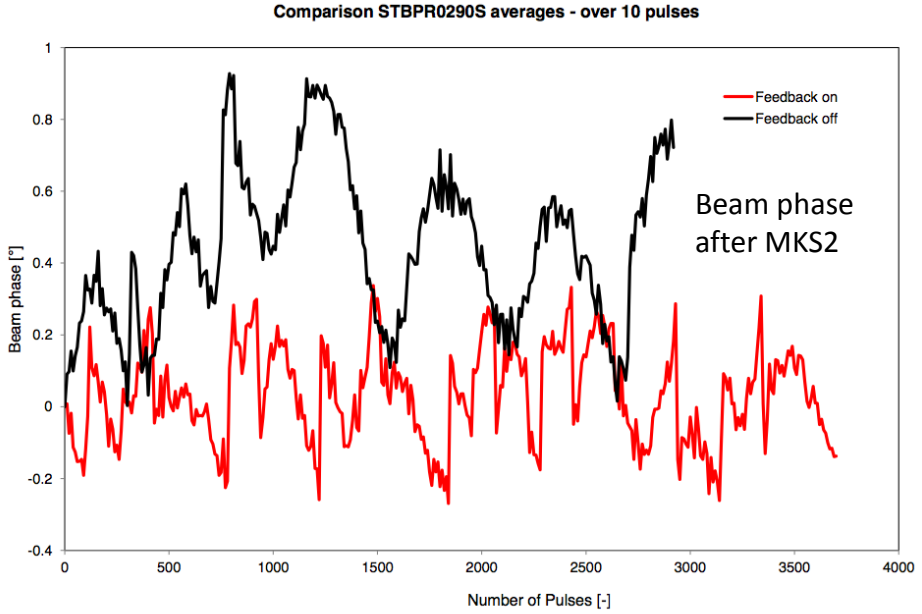
Best results in CLEX
for factor 4: ε_H= 170 um ε_V= 120 um
for factor 8: ε_H= 550 um ε_V= 170 um

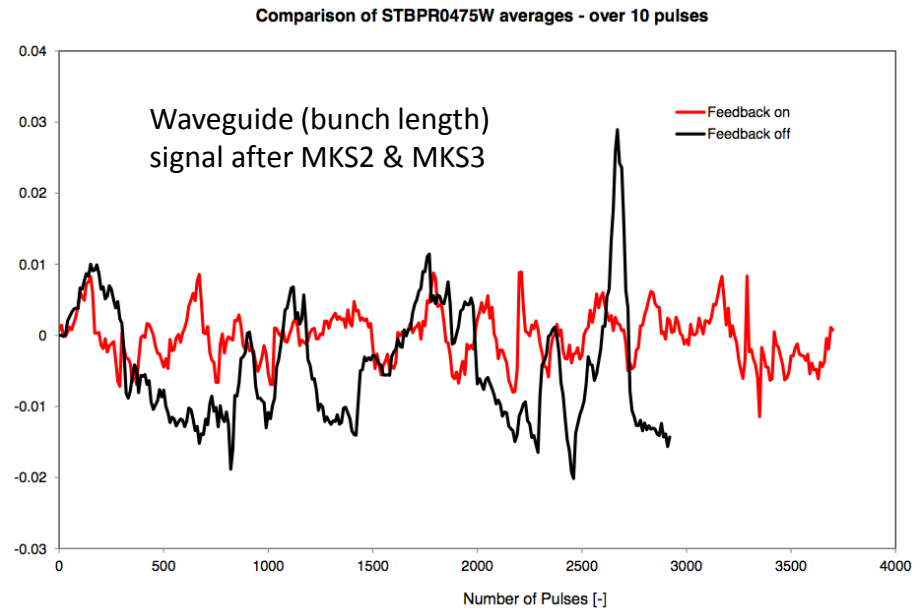
Different turns are ~ ok, no unknown effects
Emittance increase due to non perfect orbit

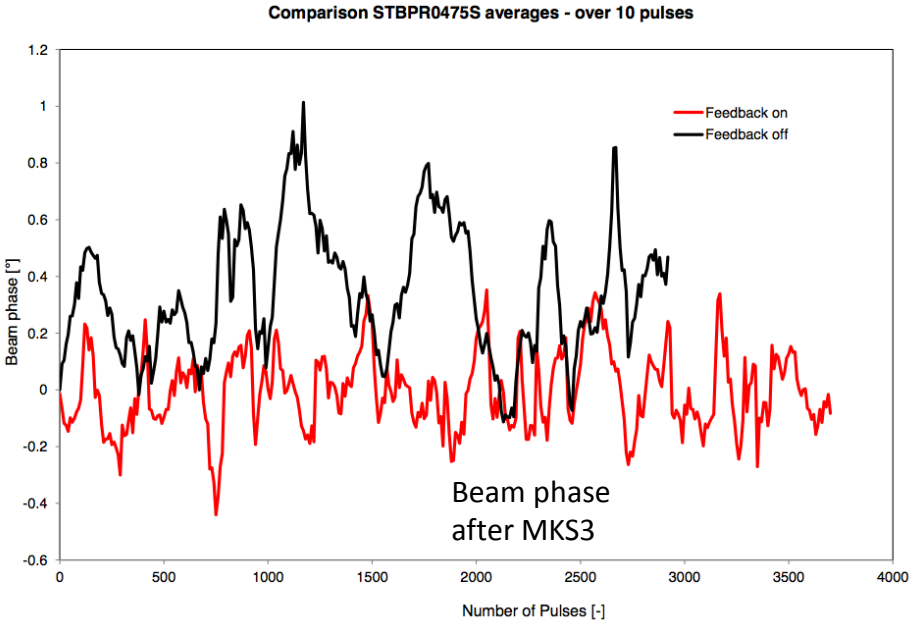
2013 Goals

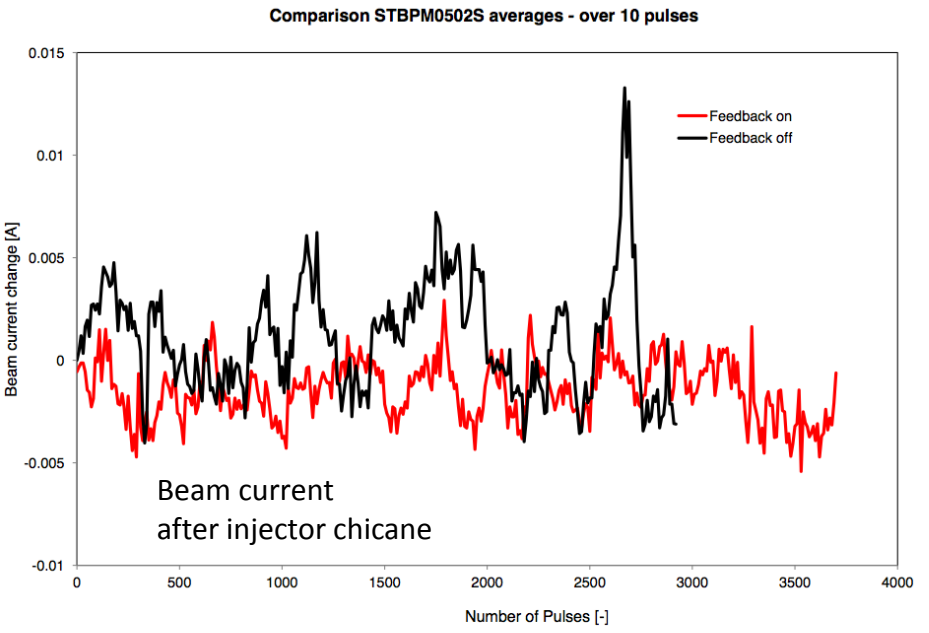
$\varepsilon_H = \varepsilon_V \cong$ 150 um for factor 8
charge stability $\sigma_Q \approx 10^{-3}$

Drive Beam Generation - feedbacks









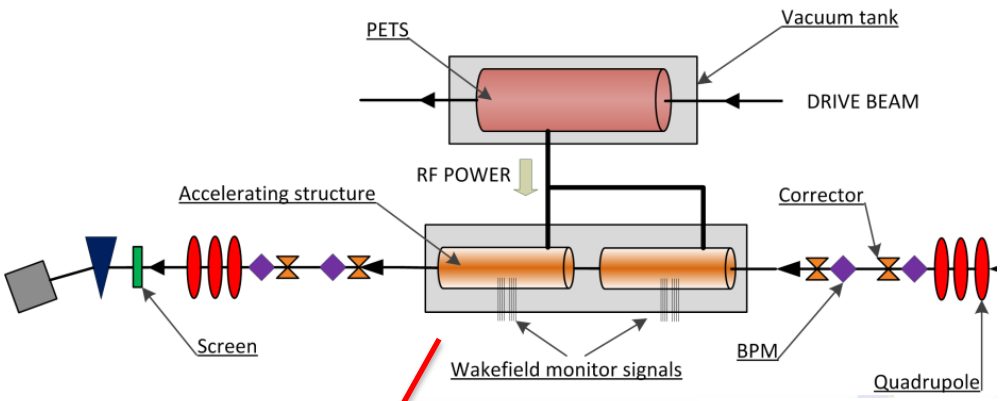
$\sigma_{475Soff}$ = 0.24°

σ_{475Son} = 0.16°

$\sigma_{502Soff}$ = 3.6 mA

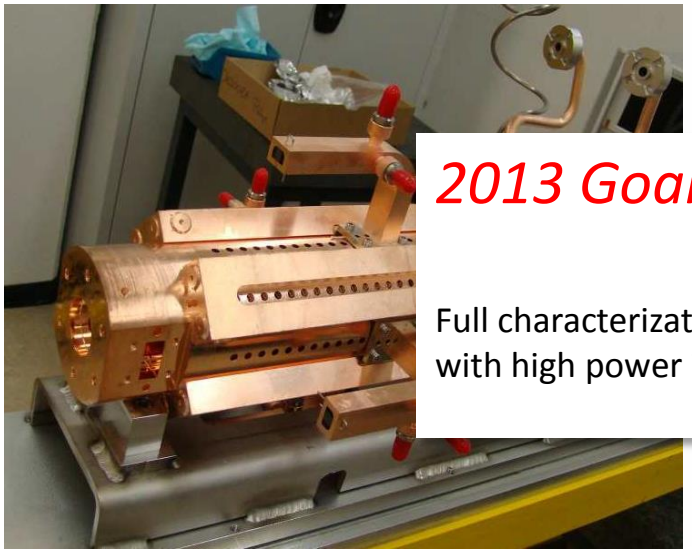
σ_{502Son} = 2.4 mA

TBTS – Present configuration



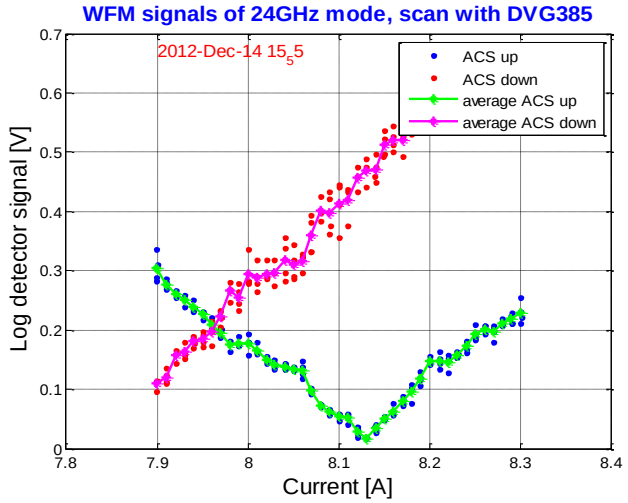
TD24 with wake-field monitors

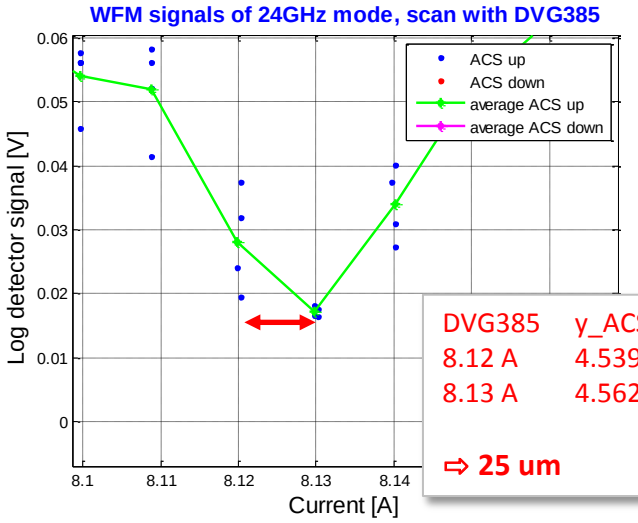
CEA IRFU - Saclay



2013 Goal

Full characterization of WF monitor, with high power in fundamental mode



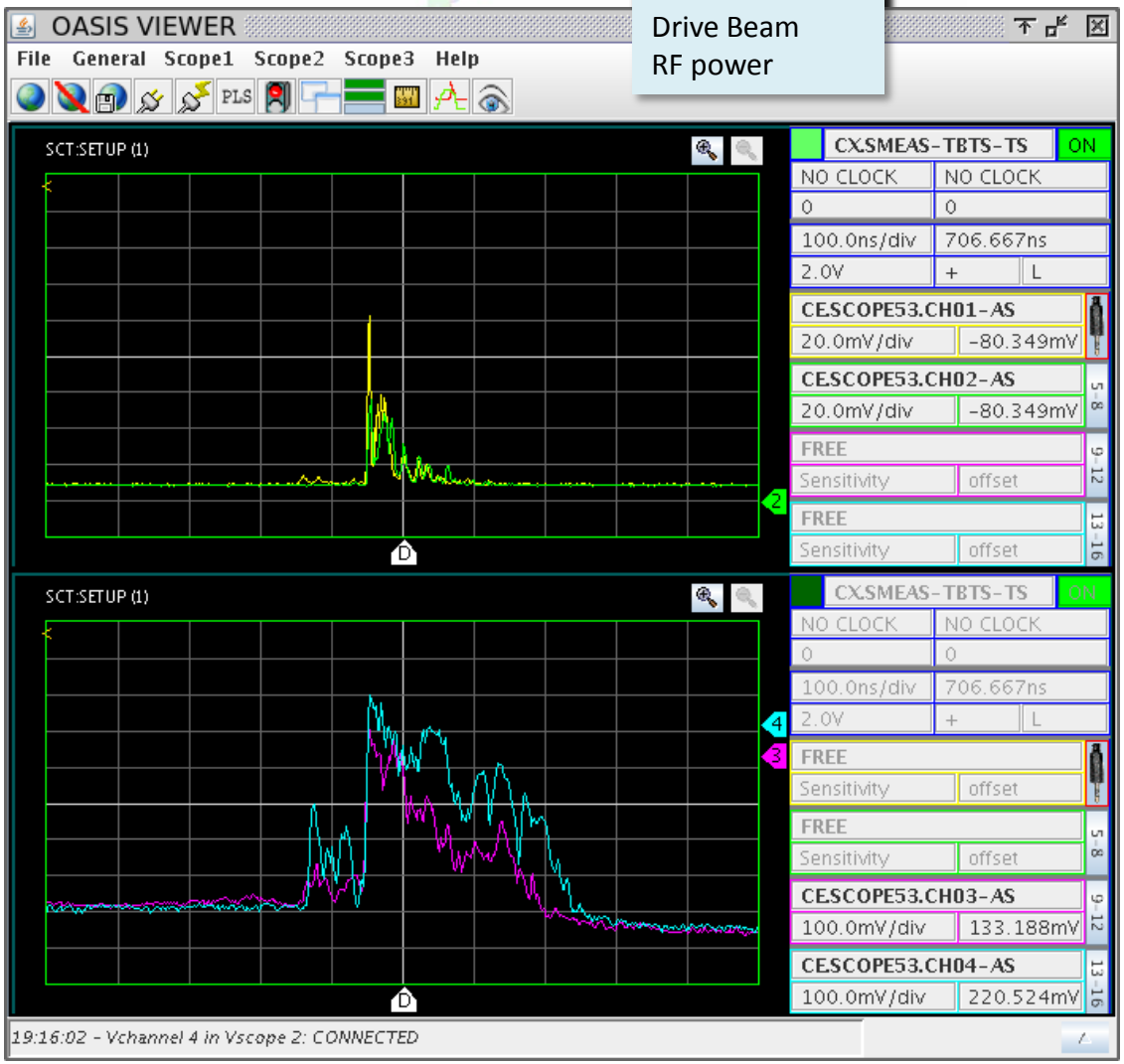


DVG385	y_ACSup
8.12 A	4.5391 mm
8.13 A	4.5623 mm

⇨ **25 um**

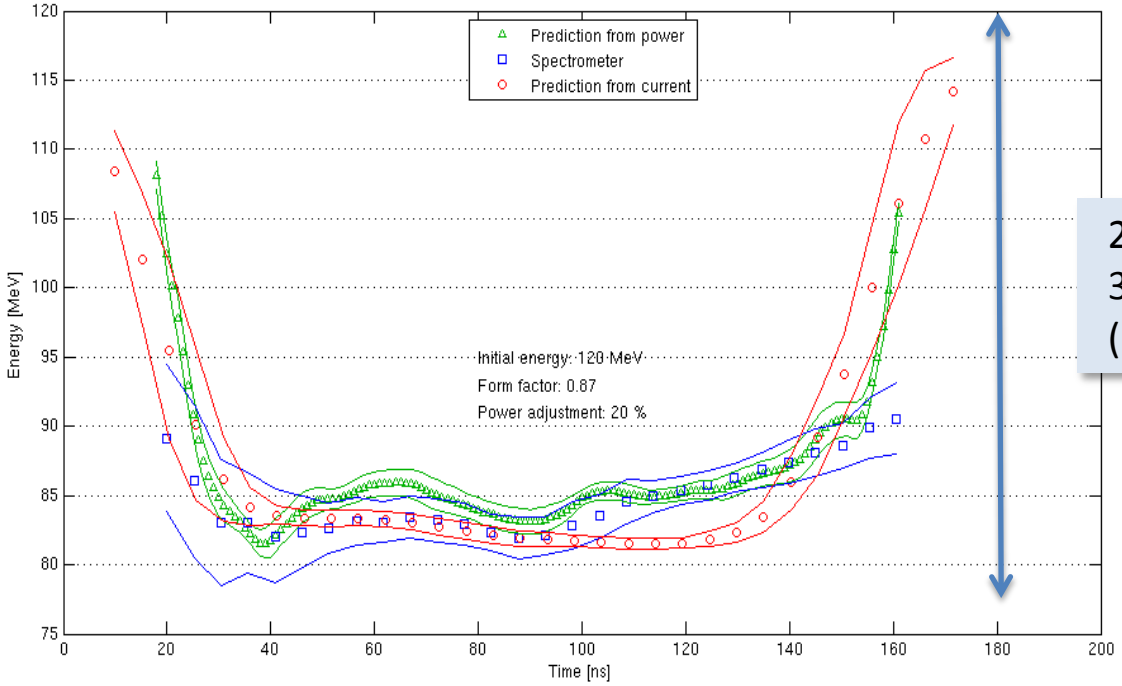
WF Monitor with Drive Beam – RF in fundamental mode

WFM signals
Probe Beam
Drive Beam
RF power



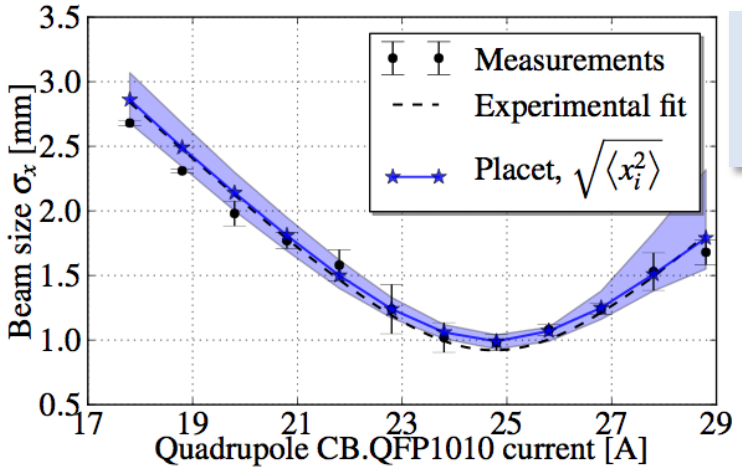
W. Farabolini

Test Beam Line



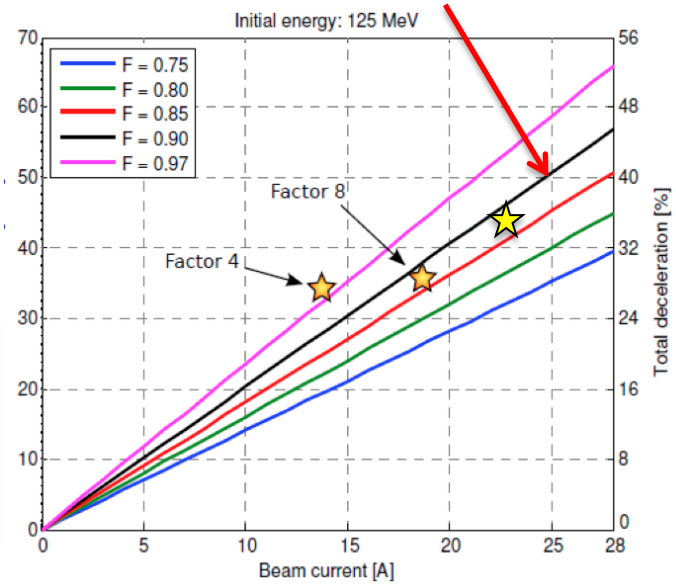
R. Lillenstol, S. Doebert

2013 1st run:
35% deceleration
(22 A beam)



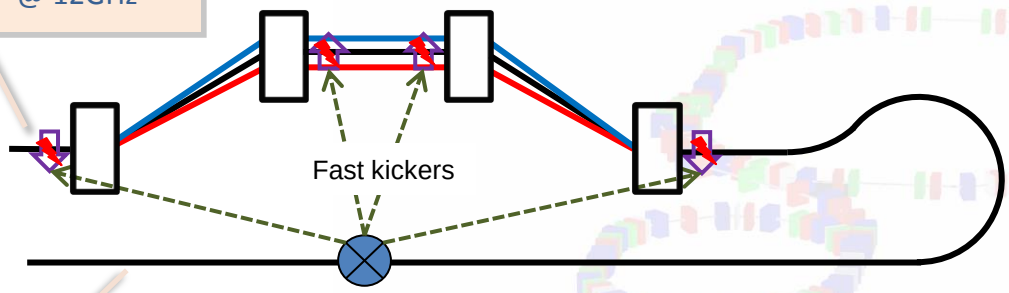
Quad scan
Downstream
end of TBL

2013 Goal



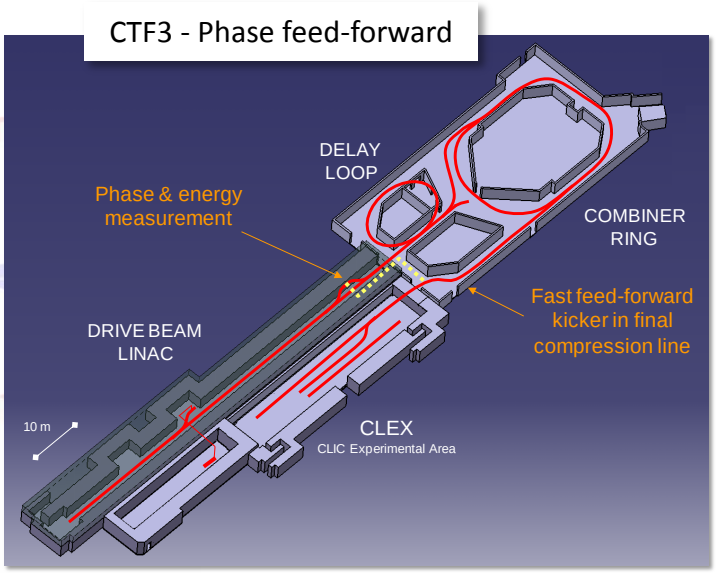
Drive Beam phase feed-forward tests

Phase stability
0.2° @ 12GHz



CLIC drive beam phase feed-forward concept

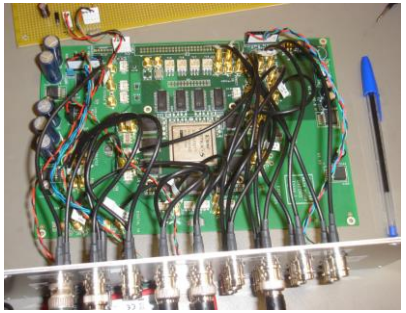
Phase stability 2.5° @ 12GHz
0.2° @ 1GHz



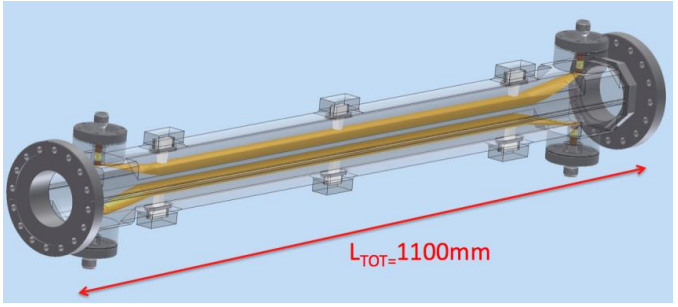
Series of related studies:

- Measure phase and energy jitter, identify sources, devise & implement cures, extrapolate to CLIC
- Show principle of CLIC fast feed-forward

FONT5 board (Oxford)



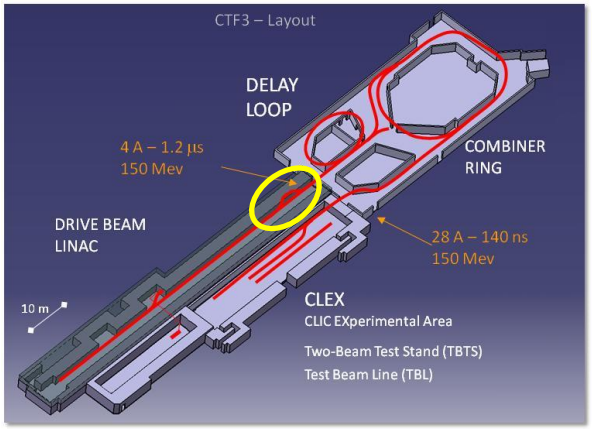
Stripline kicker (INFN-LNF)



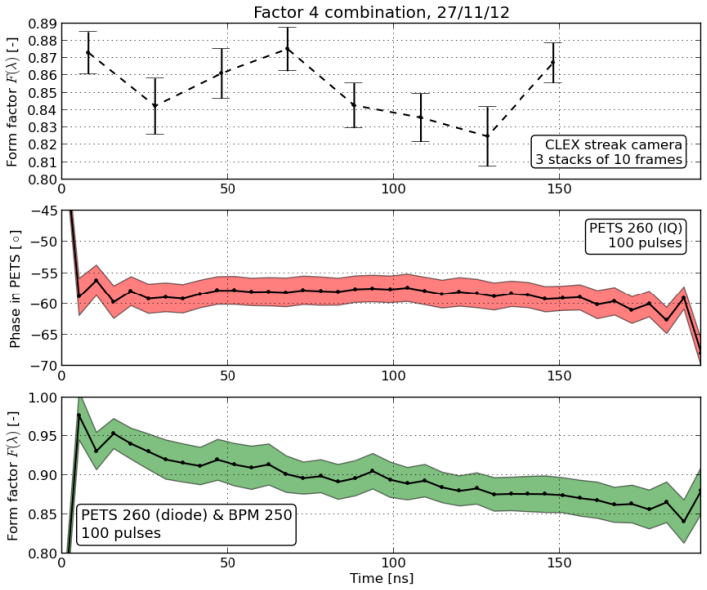
Close link to collaborating partners:

- *INFN-LNF: Phase monitors, stripline kickers*
- *Oxford University/JAI: feedback electronics, amplifiers*

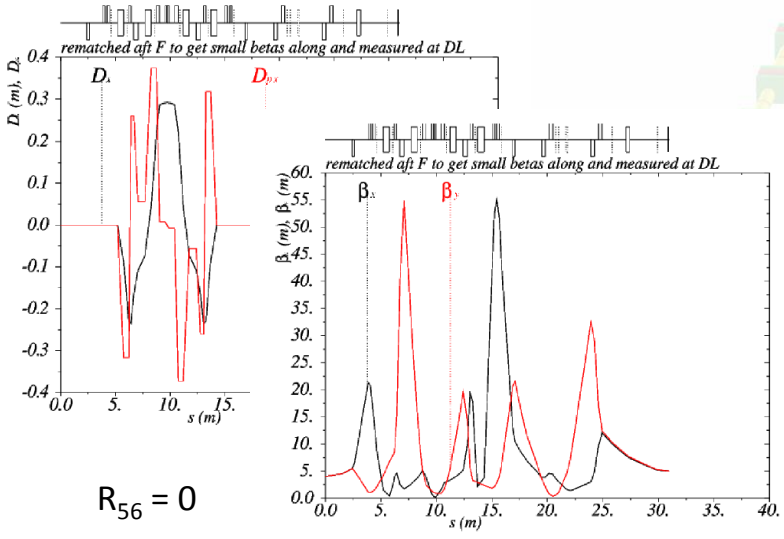
Bunch length, power production & phase stability



New chicane optics with low momentum compaction

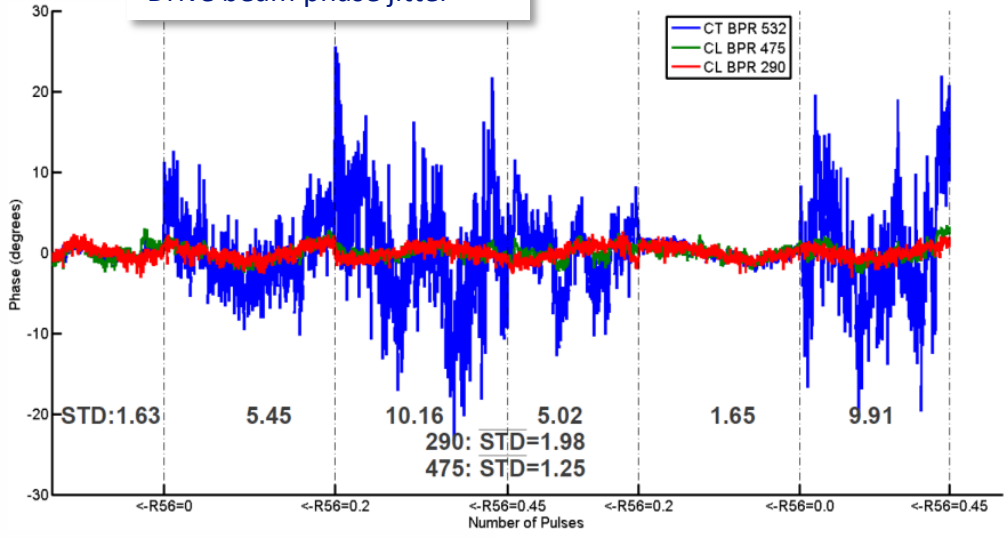


Power production in TBL consistent with streak camera bunch length measurements in CLEX

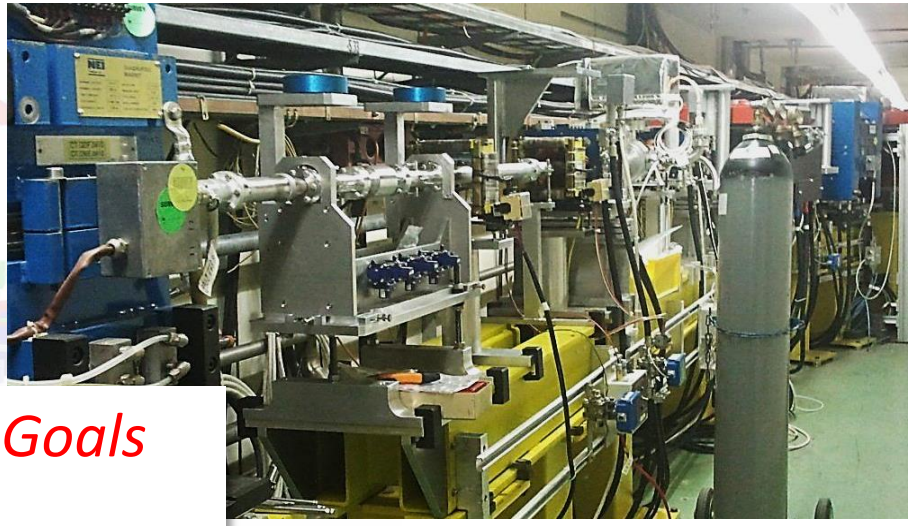


$R_{56} = 0$

Drive beam phase jitter

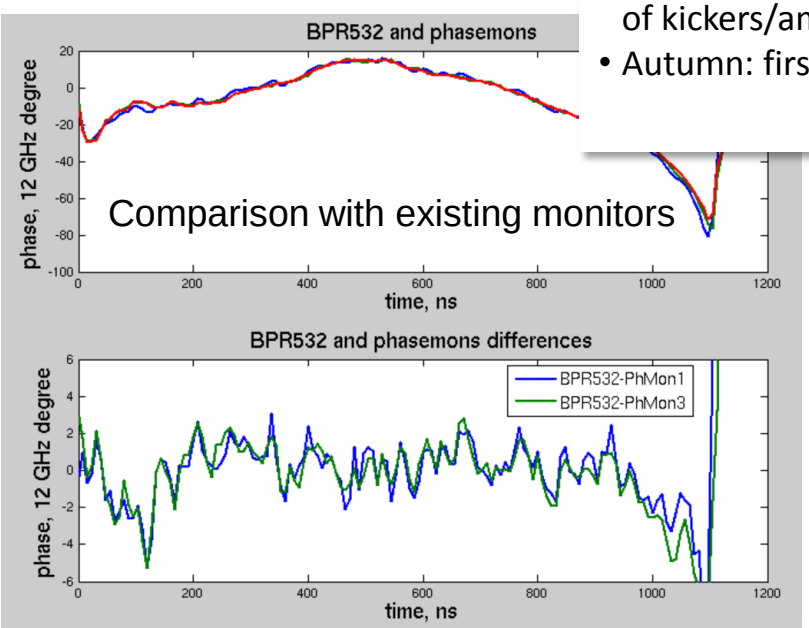


Commissioning of INFN Phase monitors

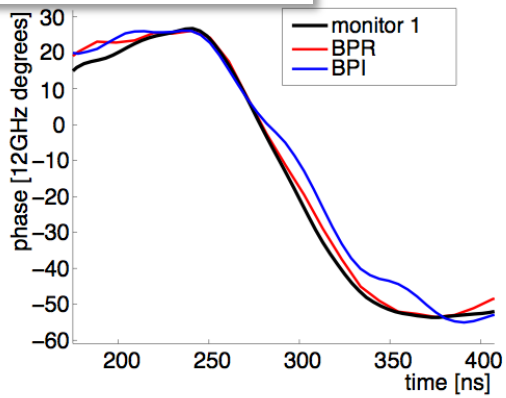


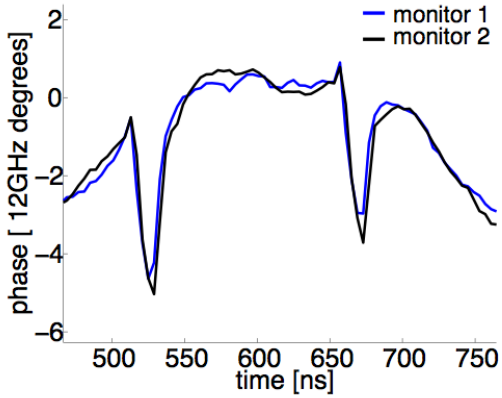
2013 2nd run Goals

- Summer shut-down: installation of kickers/amplifiers
- Autumn: first feed-forward tests



r resolution looks good.
degrees (12 GHz) per 1 mm vertical offset

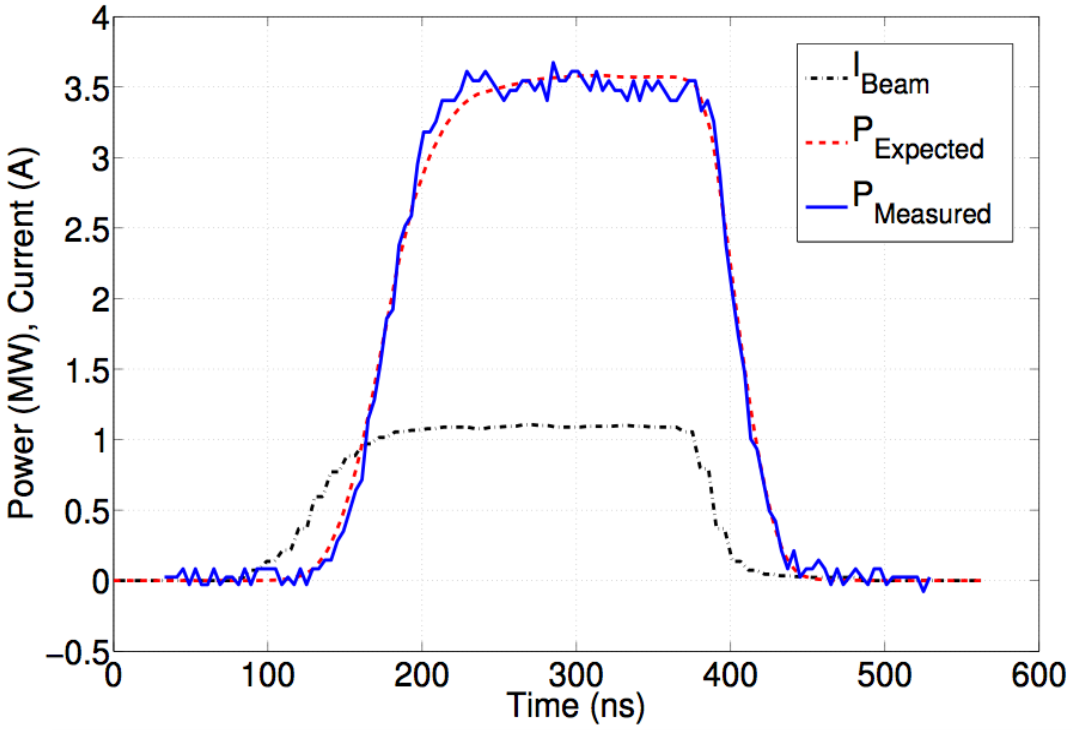




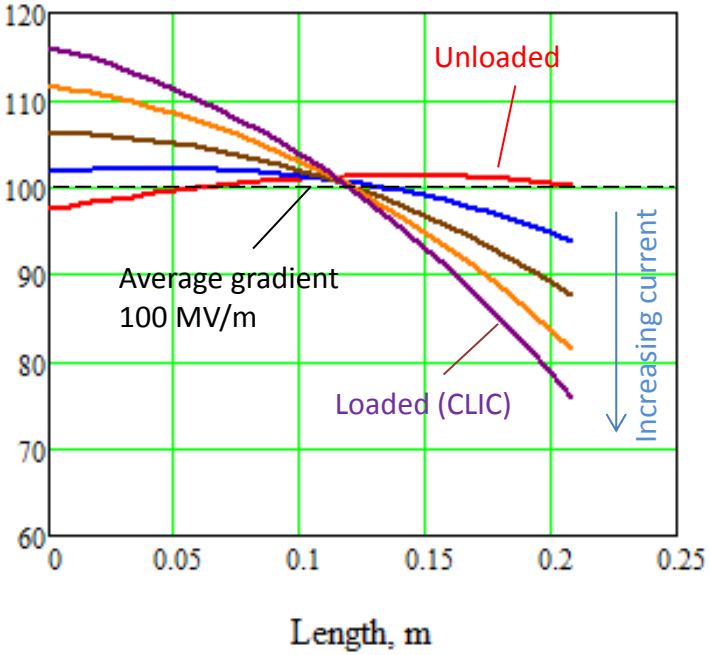
Time Response of Phase Monitors

Experiment on the effect of Beam-Loading on BD rate

Beam loading reduces field locally in the structure



Gradient along the structure



2013 1st run:

Beam line commissioning with beam (1 A) and first measurements of produced RF power

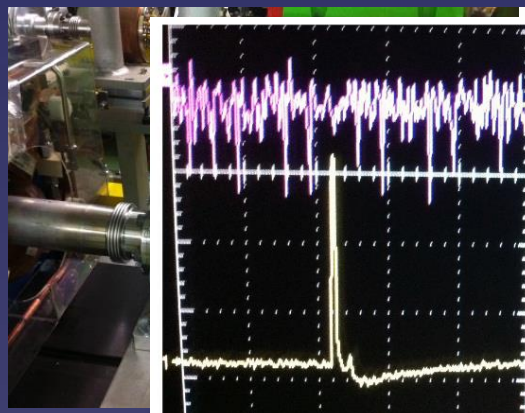
J.L. Navarro, F. Tecker

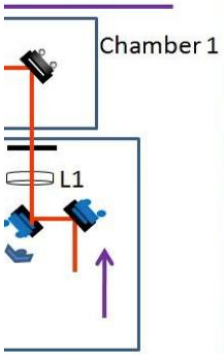
2013 Goals

- Beam set-up, transport, RF signals check
- After summer shut-down: structure conditioning with klystron, break-down rate measurements

CTF3 as diagnostics test bed

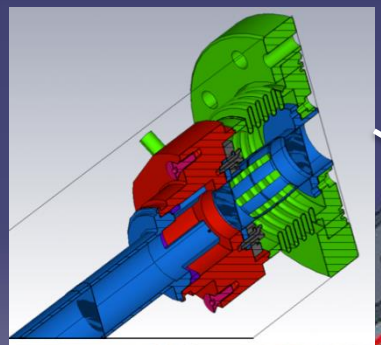
Electro-optic bunch profile monitor
in CALIFES
(CERN-Dundee University)

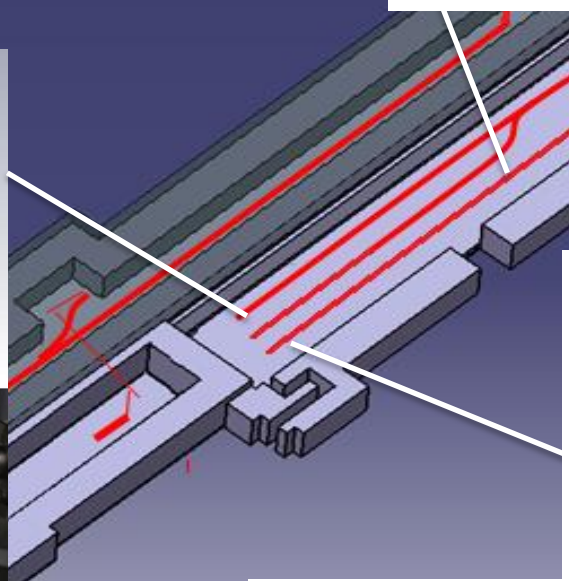




R. Pan, T. Lefebre

Stripline Drive Beam BPM
in TBL
(CERN-LAPP)

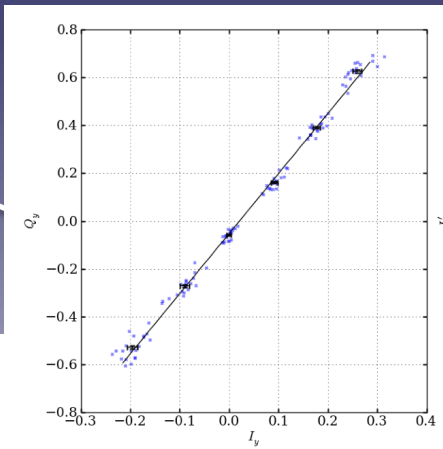


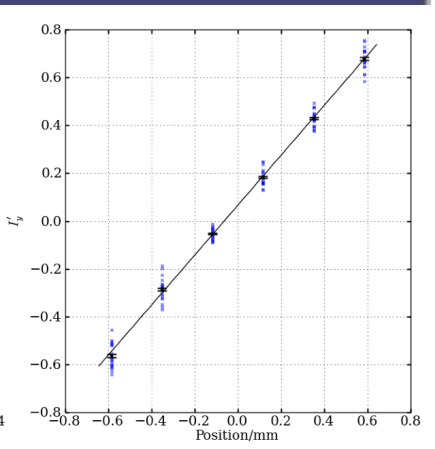


F. Cullinan, J. Towner, W. Farabolini, M. Wendt…

2013 Goals

Cavity Main Beam BPM
in CALIFES/TBTS
(CERN-JAI at Royal Holloway)





Milestones 2013

CTF3 Drive Beam generation & operation	★ $\varepsilon_H = \varepsilon_V \cong$ 150 um for factor 8 ★ Charge stability $\sigma_Q \approx 10^{-3}$ for factor 8 ★ Beam diagnostics experiments (DB and MB BPMs, EO bunch length monitor)
Beam Loading experiment	★ 1st phase: commissioning with beam ★ Start 2nd phase, RF conditioning and BDR measurements
TBTS	te measurements of f WF monitor, with high t pulse shape for beam m sioning of first module
TBL	★ Deceleration beyond 40% ★ TBL+ , get at least on new PETS constructed and installed with ON/OFF mechanism.
DB Phase Feed-Forward	★ Full characterization of monitors ★ Summer shut-down: installation of kickers/amplifiers ★ Autumn: first feed-forward tests

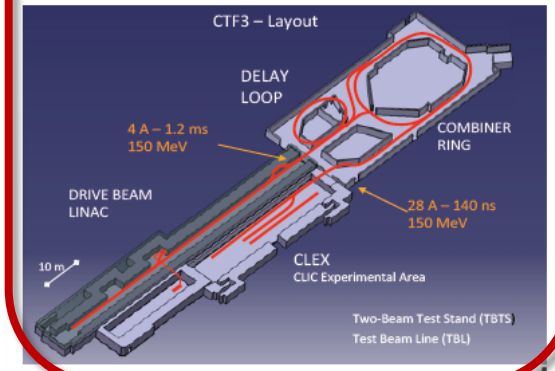
THANKS TO ALL THE CTF3 CREW!

(operation team, technical support & external collaborators)

CLIC project time-line

2012-16 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



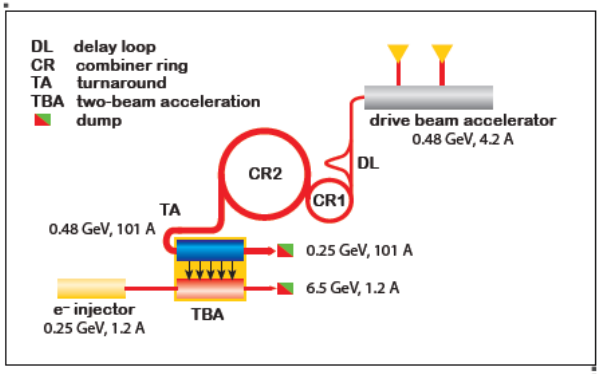
2016-17 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2017-22 Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



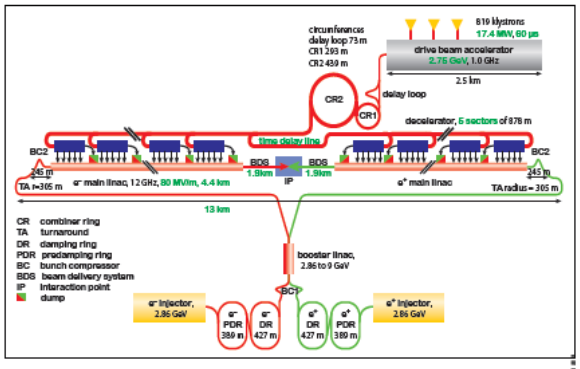
2022-23 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

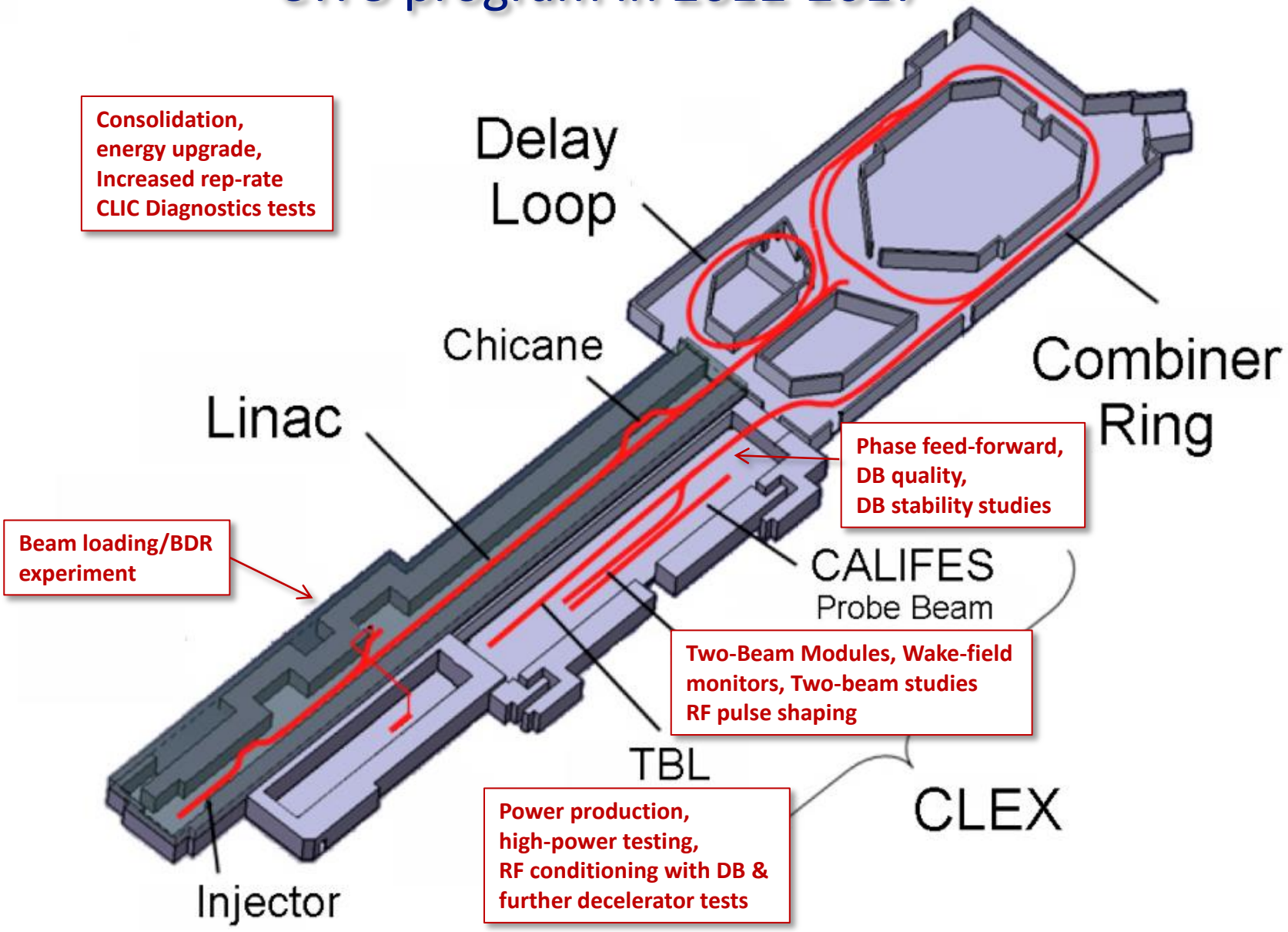
Preparation for implementation of further stages.



2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

CTF3 program in 2012-2017



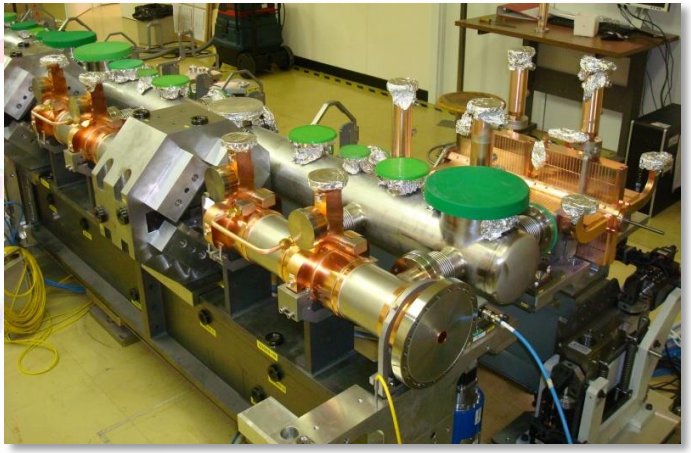
Two-Beam Modules

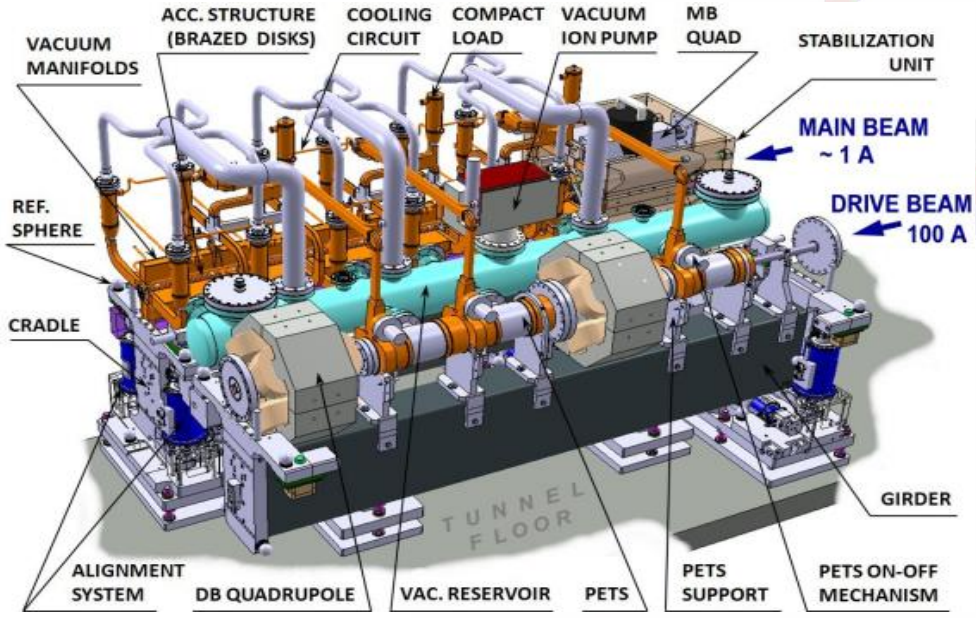
Ongoing: Fabrication of 4 modules to be mechanically tested in laboratory

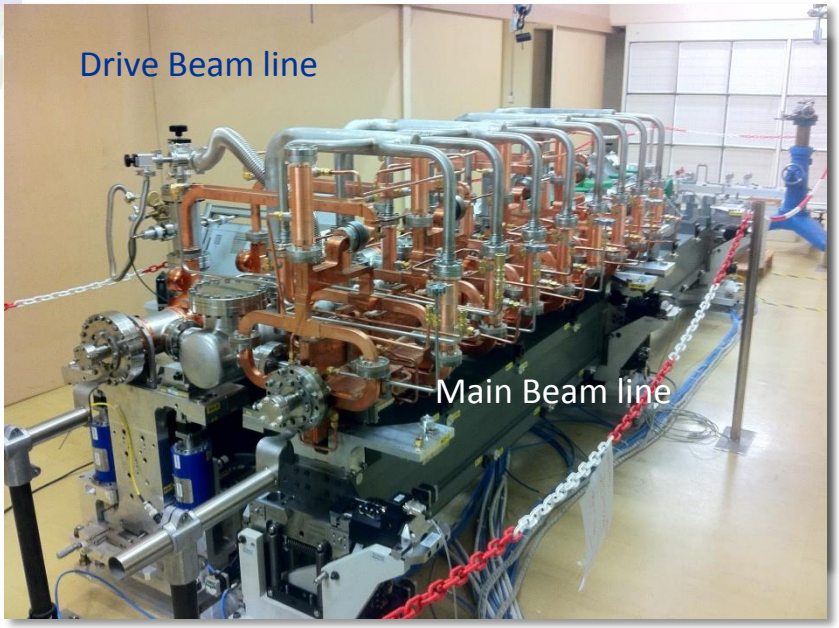
Next Step: Installation and test of full-fledged Two-Beam Modules in CLEX

First module in development, installation beginning 2014

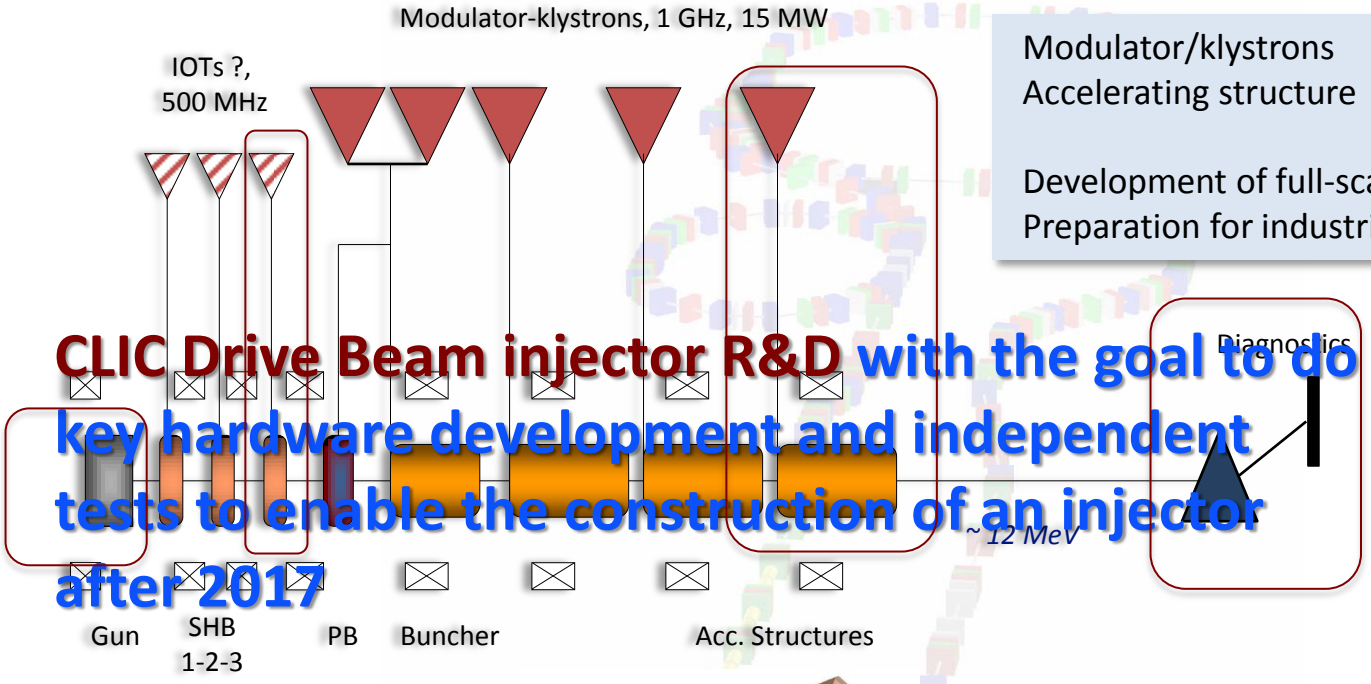
Three modules in 2014-2016







CLIC Drive Beam front-end
Post-CDR project



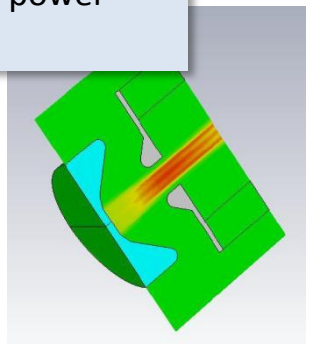
Modulator/klystrons
Accelerating structure

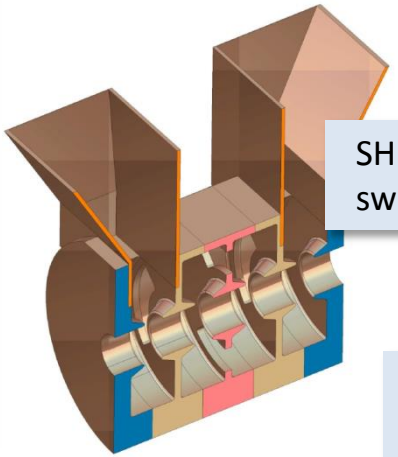
Development of full-scale system
Preparation for industrialization

CLIC Drive Beam injector R&D with the goal to do key hardware development and independent tests to enable the construction of an injector after 2017

Handling of long high-current pulses, Diagnostics…

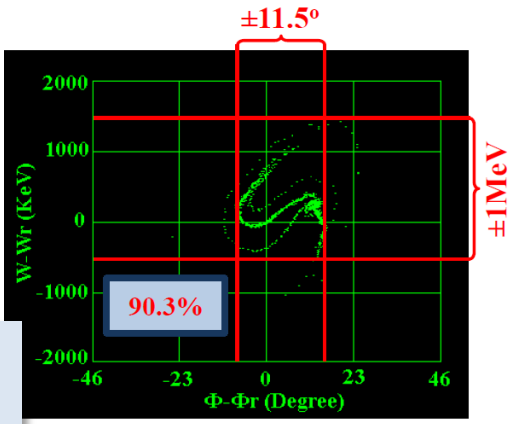
Gun – long pulse, high beam power issues





SHB – fast phase switching @ 500 MHz

Satellite population = 3.8%



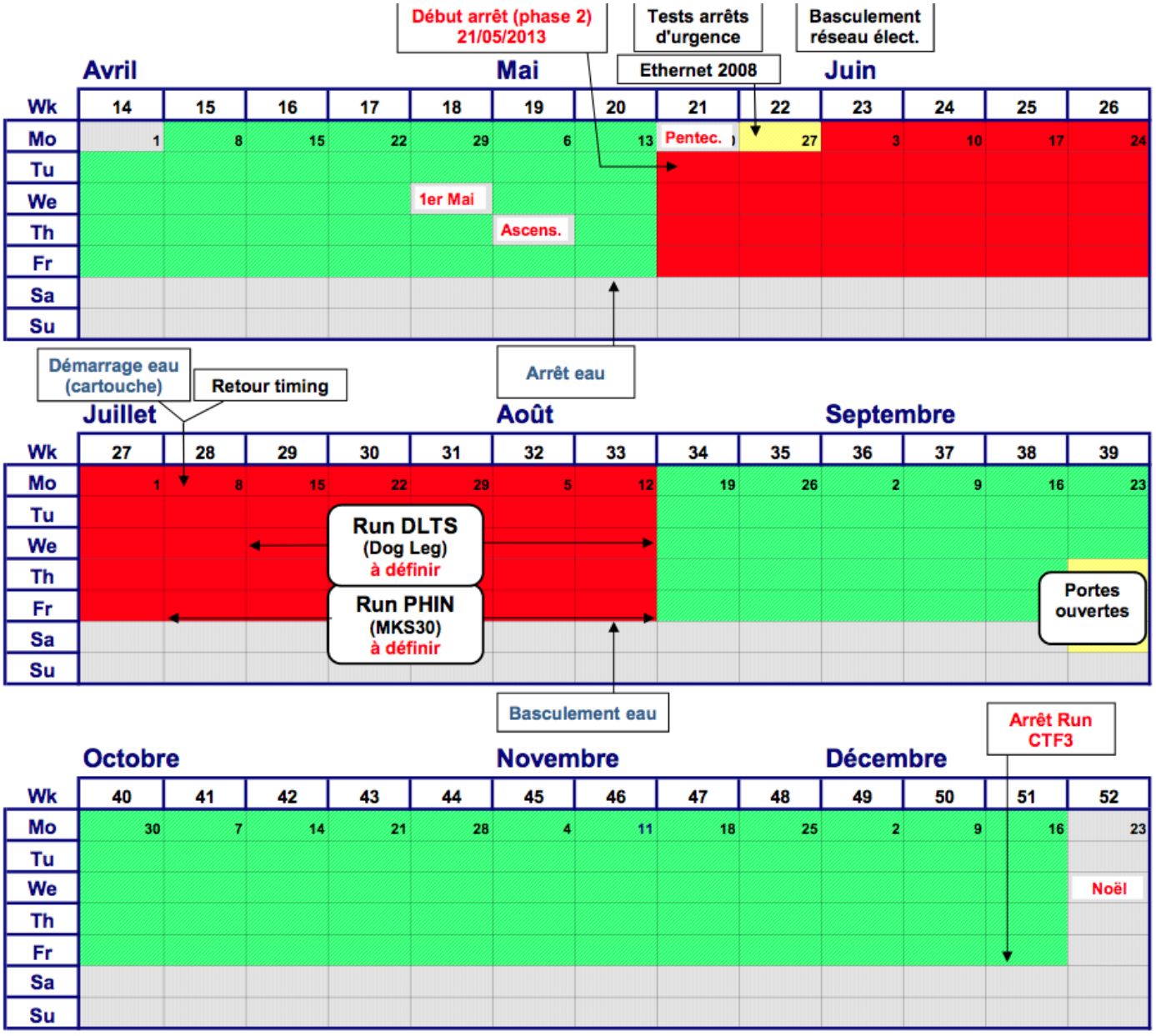
Phase-space optimization, satellite minimization

CLIC Collaboration

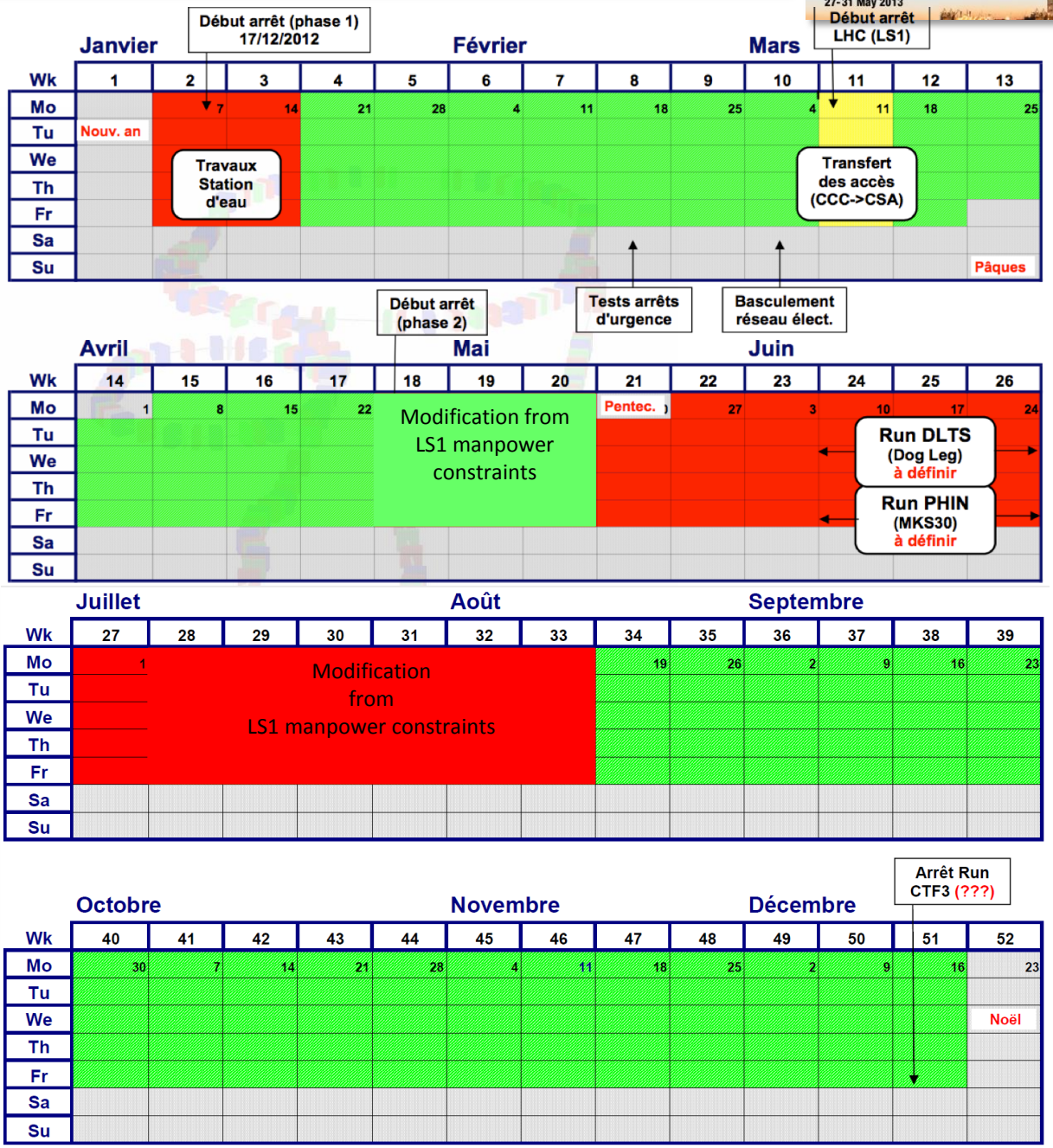
CLIC multi-lateral collaboration - 48 Institutes from 25 countries

ACAS (Australia)
Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
ETH Zurich (Switzerland)
FNAL (USA)
Gazi Universities (Turkey)
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
IHEP (China)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute/Oxford (UK)
Joint Institute for Power and Nuclear Research SOSNY /Minsk (Belarus)
John Adams Institute/RHUL (UK)
JINR
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NIKHEF/Amsterdam (Netherland)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Patras University (Greece)
Polytech. Univ. of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Sincrotrone Trieste/ELETTRA (Italy)
Thrace University (Greece)
Tsinghua University (China)
University of Oslo (Norway)
University of Vigo (Spain)
Uppsala University (Sweden)
UCSC SCIPP (USA)

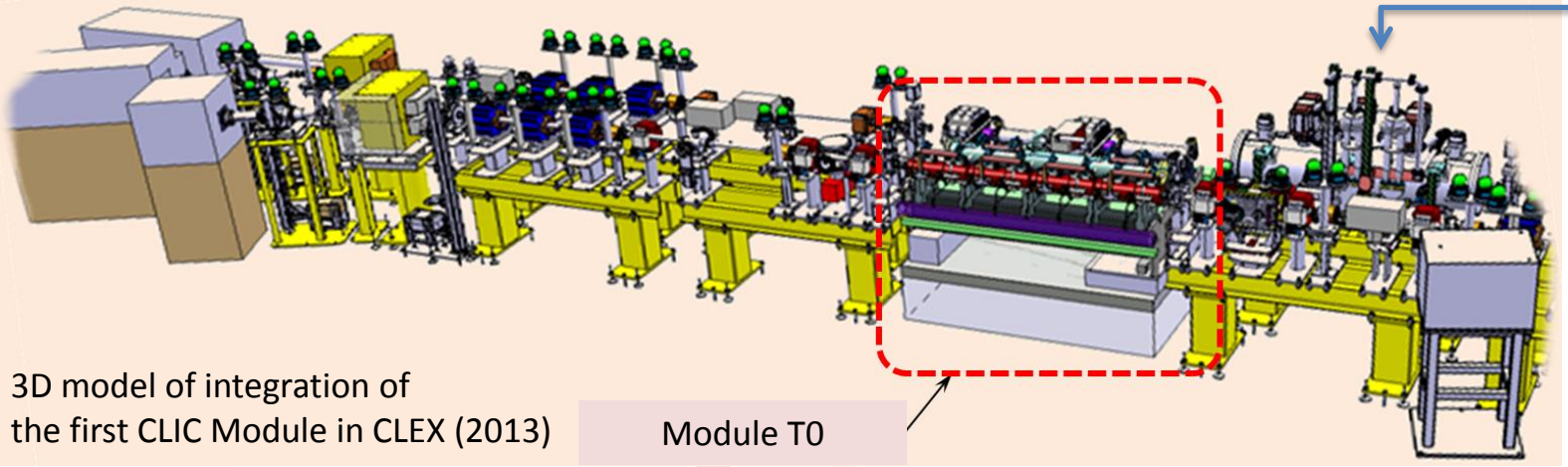
Reserve slides


Début arrêt (phase 2) 21/05/2013
Tests arrêts d'urgence
Basculement réseau élect.
Ethernet 2008
Avril
Mai
Juin
Wk 14 15 16 17 18 19 20 21 22 23 24 25 26
Mo 1 8 15 22 29 6 13 Pentec. 27 3 10 17 24
Tu
We 1er Mai
Th Ascens.
Fr
Sa
Su
Arrêt eau
Démarrage eau (cartouche)
Retour timing
Juillet
Août
Septembre
Wk 27 28 29 30 31 32 33 34 35 36 37 38 39
Mo 1 8 15 22 29 5 12 19 26 2 9 16 23
Tu
We Run DLTS (Dog Leg) à définir
Th
Fr Run PHIN (MKS30) à définir
Sa
Su
Portes ouvertes
Basculement eau
Arrêt Run CTF3
Octobre
Novembre
Décembre
Wk 40 41 42 43 44 45 46 47 48 49 50 51 52
Mo 30 7 14 21 28 4 11 18 25 2 9 16 23
Tu
We Noël
Th
Fr
Sa
Su

CTF3 schedule 2013



Two-Beam Modules

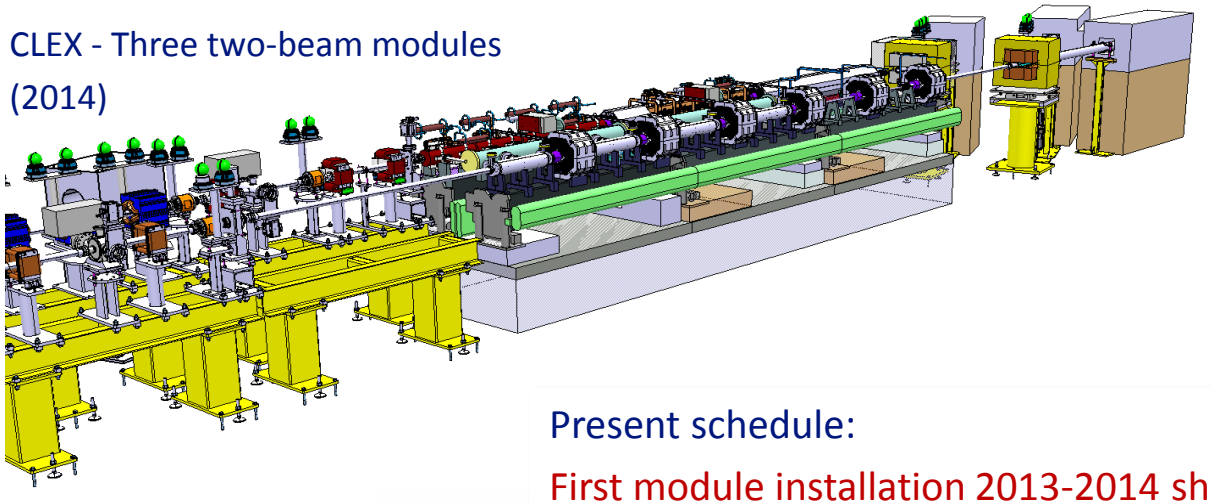


3D model of integration of the first CLIC Module in CLEX (2013)

Module T0

TBTS PETS tank

CLEX - Three two-beam modules (2014)



Present schedule:

First module installation 2013-2014 shutdown

(At least one year of testing)

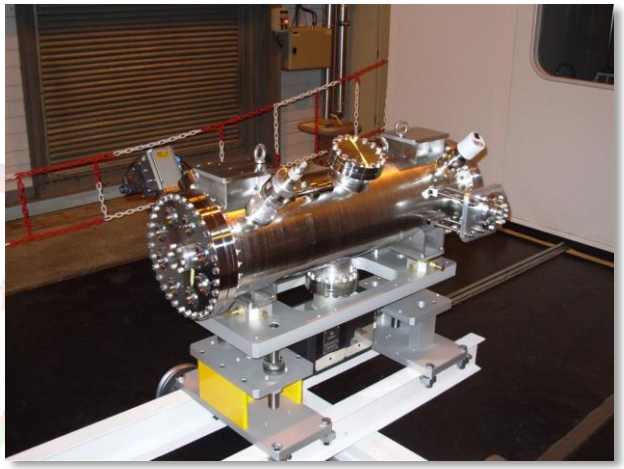
Module string installation 2014-2015

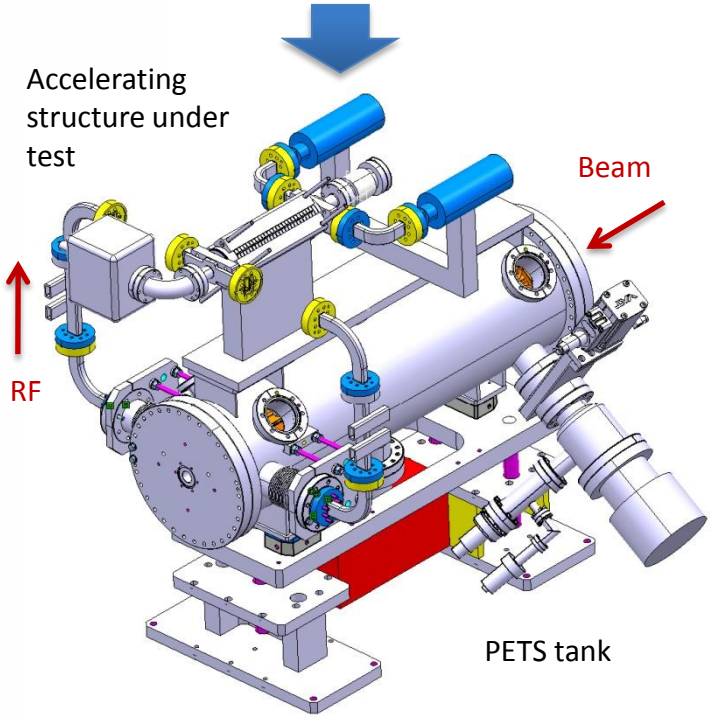
Evolution of TBL

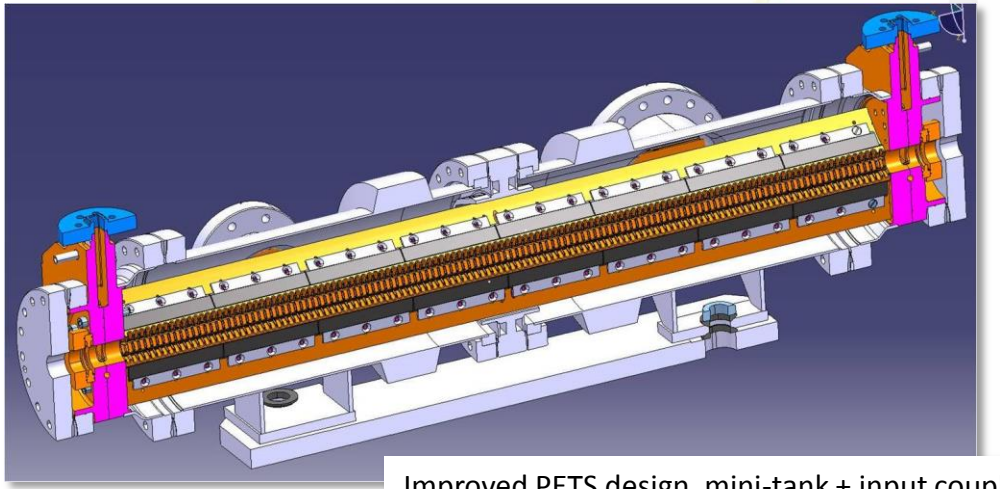
Upgrade TBL to a test facility relevant for future CLIC program

- 12 GHz power production for structure conditioning
  - Working experience with a real decelerator
  - Beam dynamics studies, pulse shaping, feedbacks, etc

- Last batch of PETS will be adapted to high-power testing (using internal recirculation)
- Gradual increase of slots to 4-8 slots and rep rate to 25-50 Hz

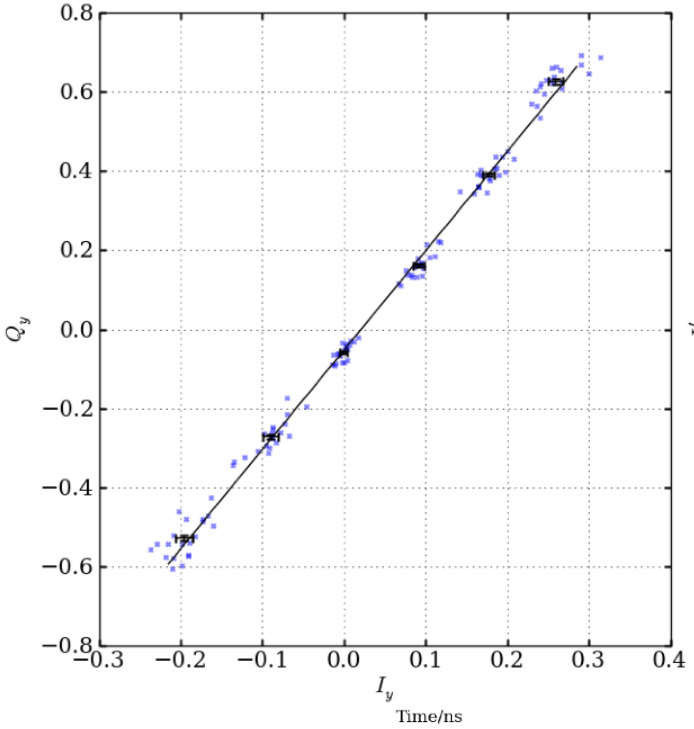


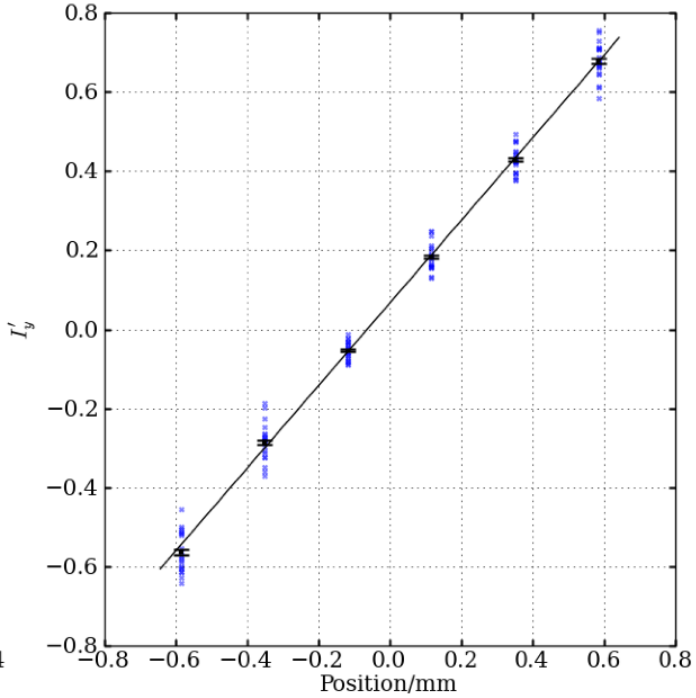




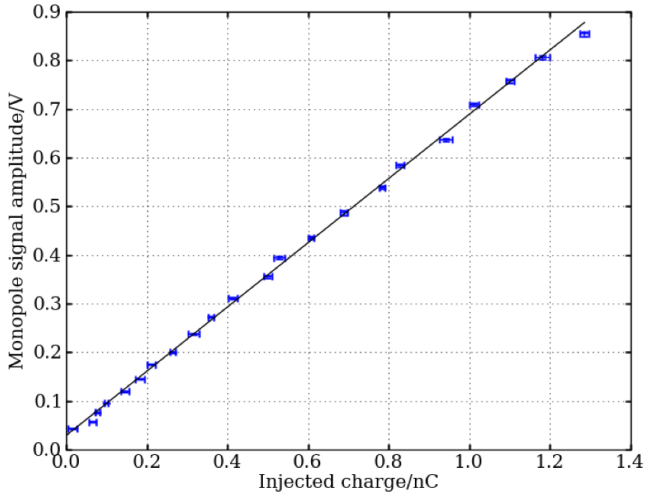
Improved PETS design, mini-tank + input coupler

Cavity Main Beam BPM in CALIFES/TBTS





F. Cullinan, J. Towner, W. Farabolini, M. Wendt…

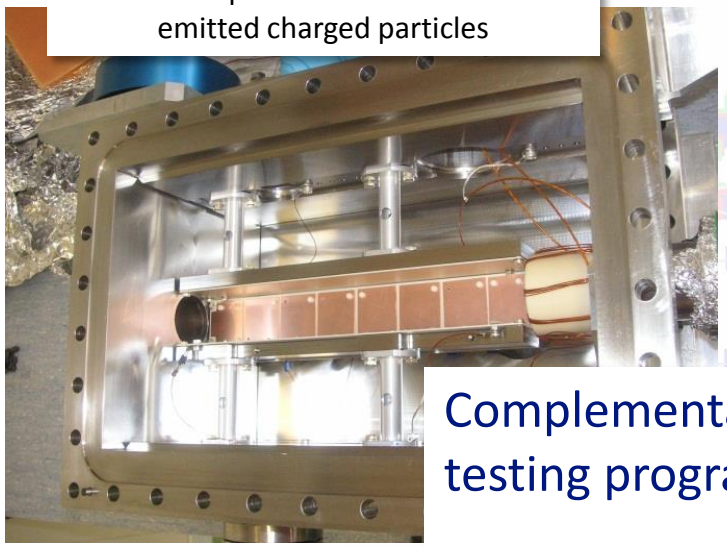


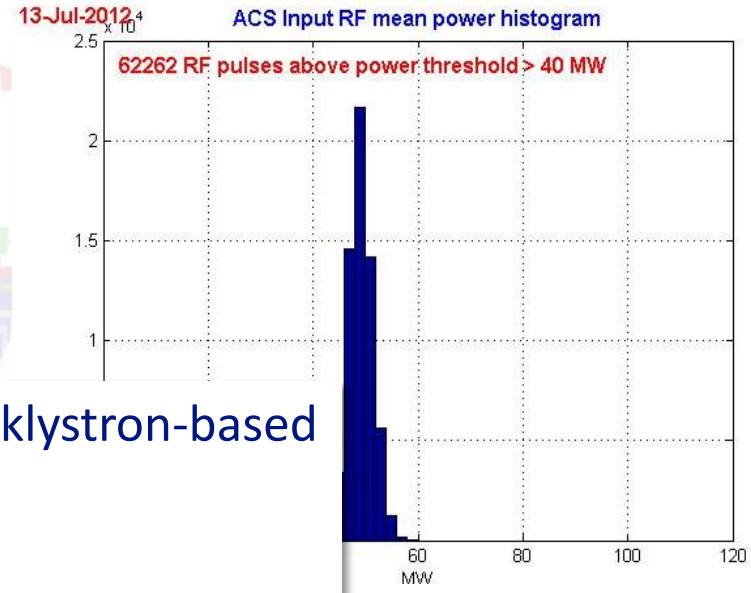
- Injected charge measured using beam charge monitor
- Gradient: 0.661+/0.004 V/nC
- Cavity sensitivity: 29.85+/-0.17 V/nC
- Compares to RF simulation (ACE3P/CST): 52 V/nC

Breakdown physics & statistics

CEA IRFU-Saclay &
Uppsala University

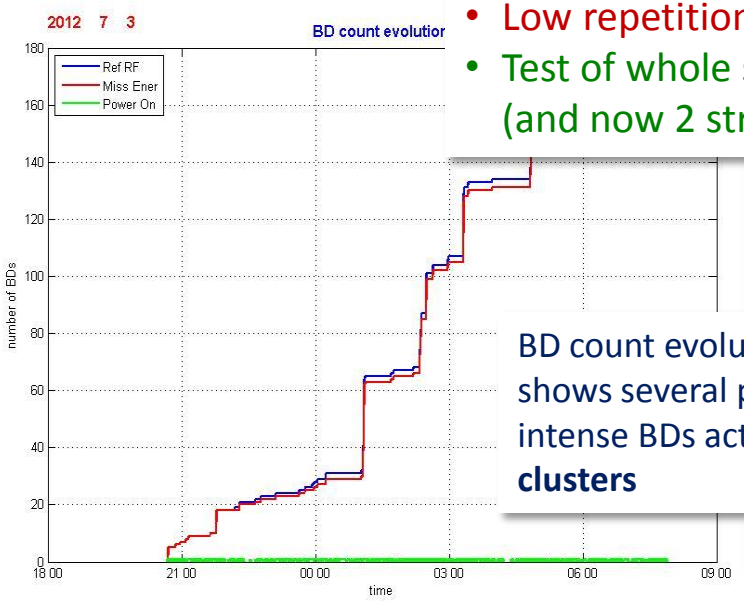
Flashbox – spectrum measurements of emitted charged particles



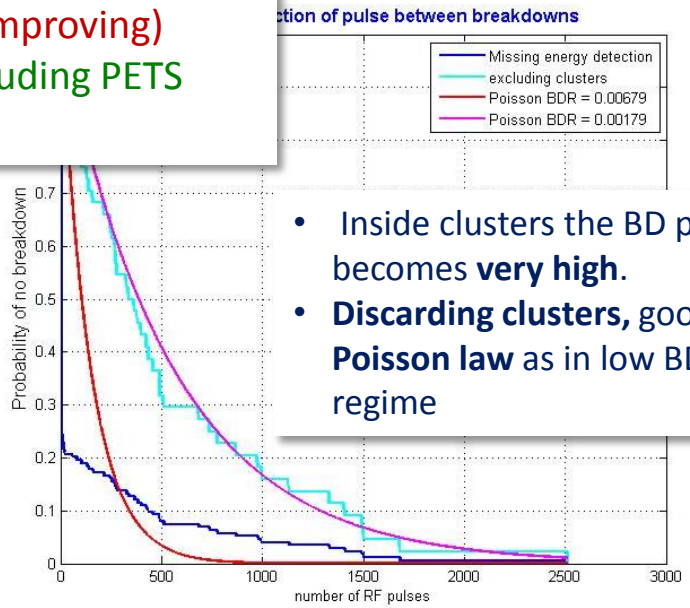


Complementary to klystron-based testing program

- Low repetition rate (but improving)
- Test of whole system, including PETS (and now 2 structures)

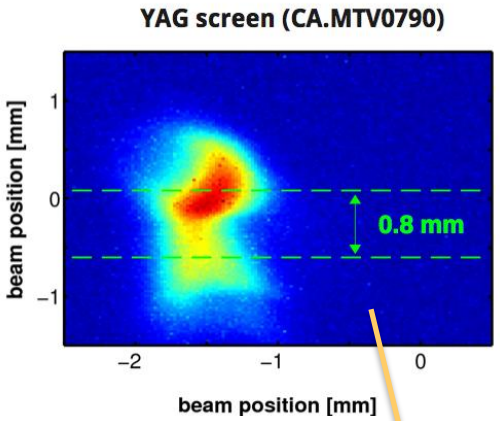


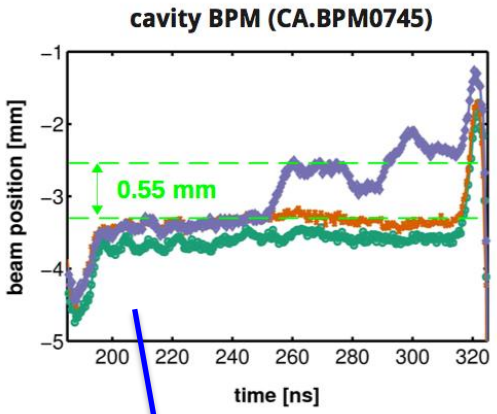
BD count evolution shows several period of intense BDs activity: **clusters**

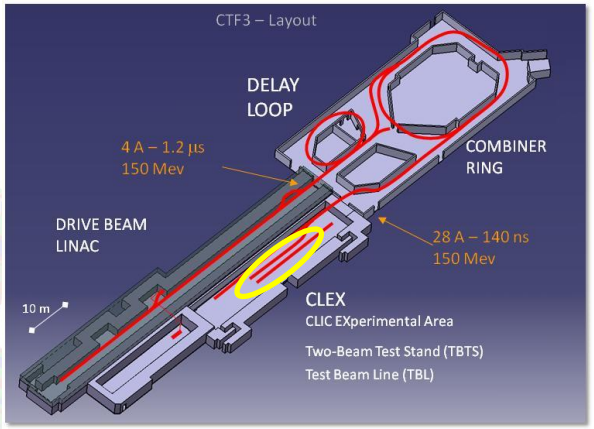


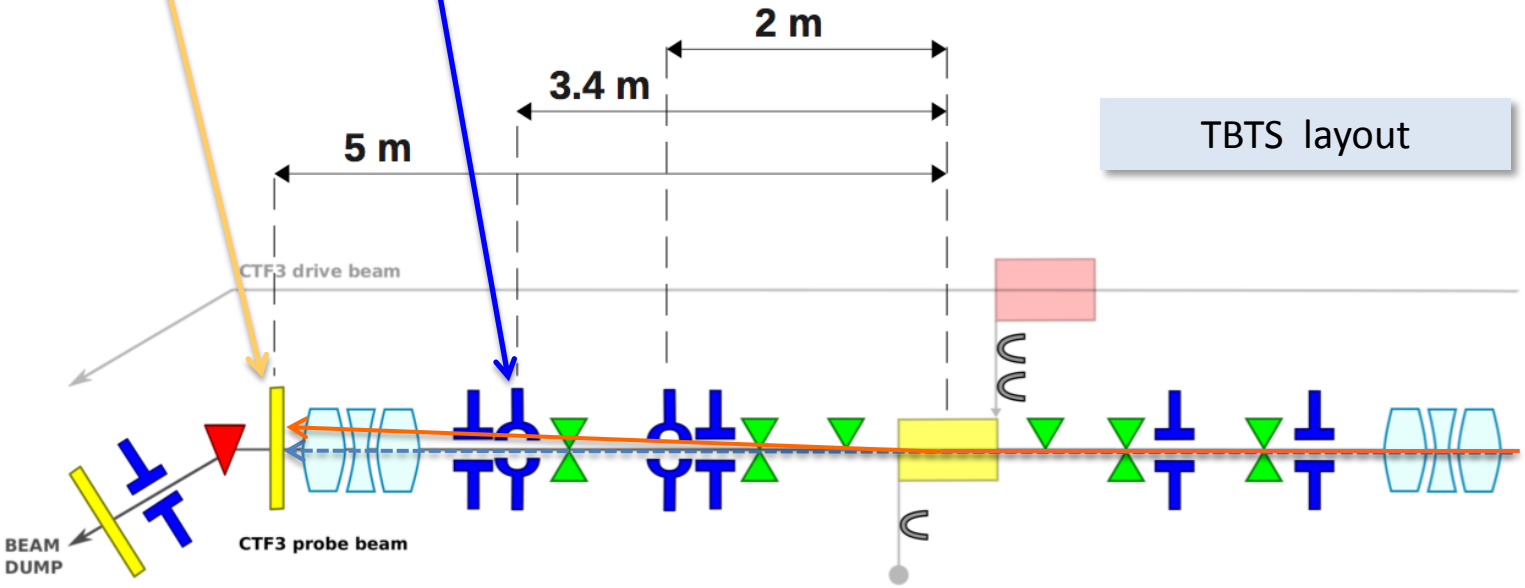
- Inside clusters the BD probability becomes **very high**.
- **Discarding clusters,** good fit by a **Poisson law** as in low BD rate regime

Breakdown kick studies





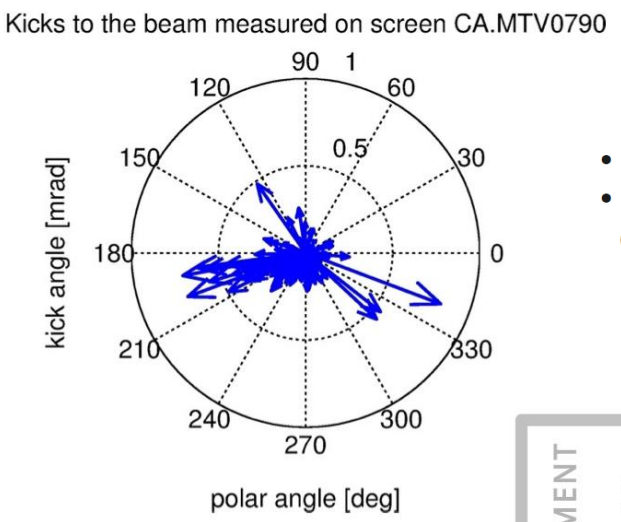




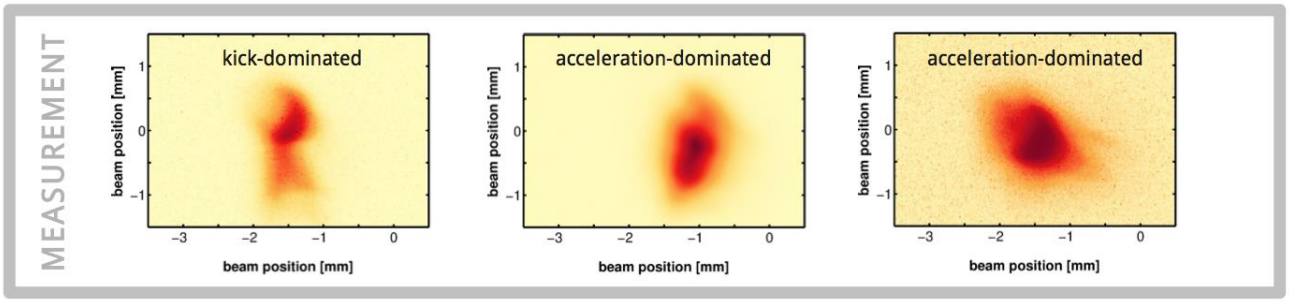
TBTS layout

Bending Magnet
Steering magnet (horizontal and vertical plane)
Defocusing Quadrupole
Focusing Quadrupole
Accelerator Structure
Power Extraction and Transfer Structure
Inductive Beam Position Monitor
Reentrant Cavity Beam Position Monitor
Directional coupler
Imaging screen

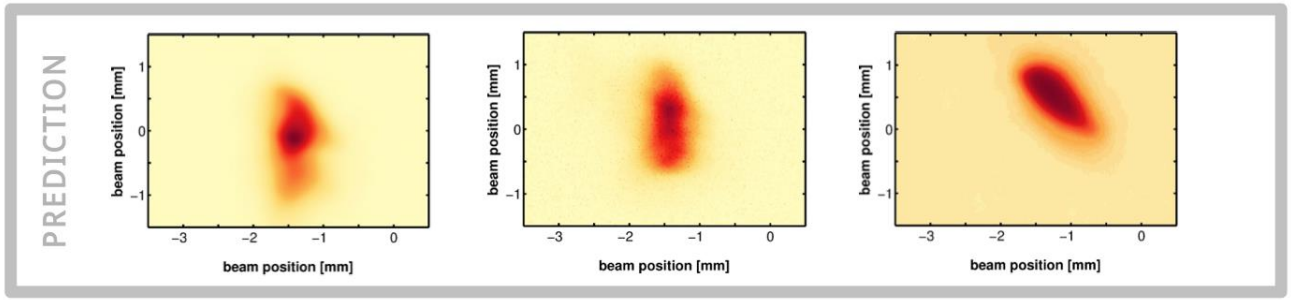
Breakdown kick studies



- kicks on horizontal and vertical planes between 0.02 and 0.2 mrad;
- kicks corresponding to a transverse momentum between 10 and 40 keV/c (measurements at NLCTA within 30 keV/c, Dolgashev et al., LINAC 2004);



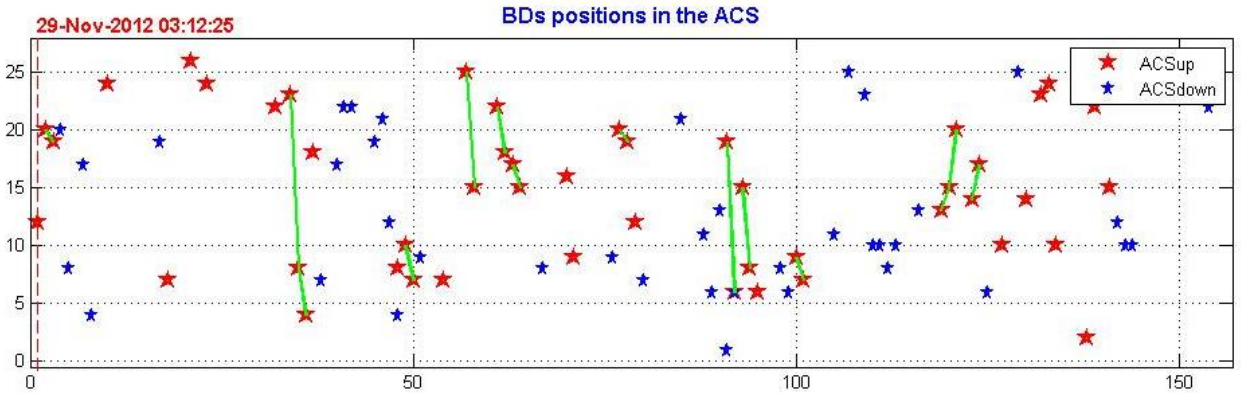
a linear combination of accelerated and non-accelerated beam spot according to distance of breakdown orbit from accelerated and non-accelerated orbit gives:



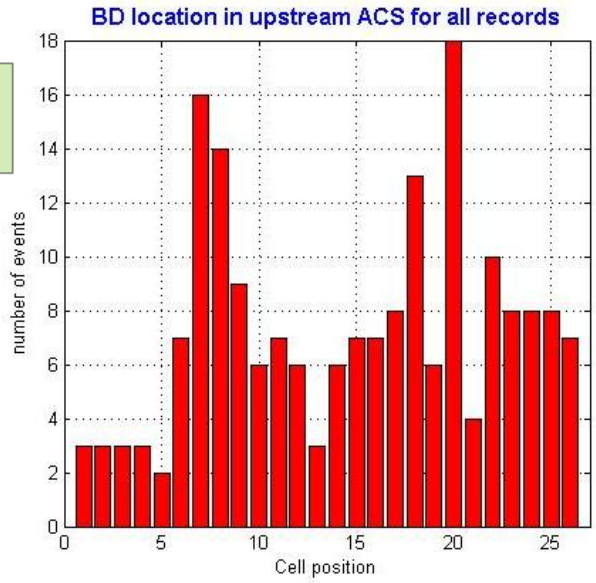
Uppsala University

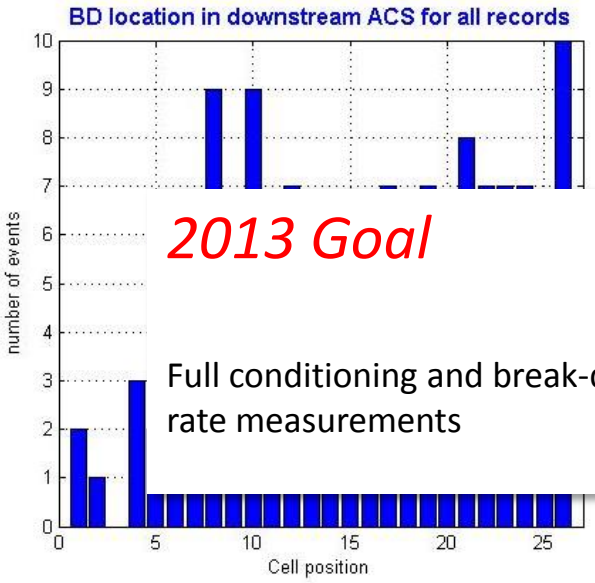
TBTS – Structure conditioning

In progress
No hot spot in the 2 present structures



Break-downs compilation





2013 Goal

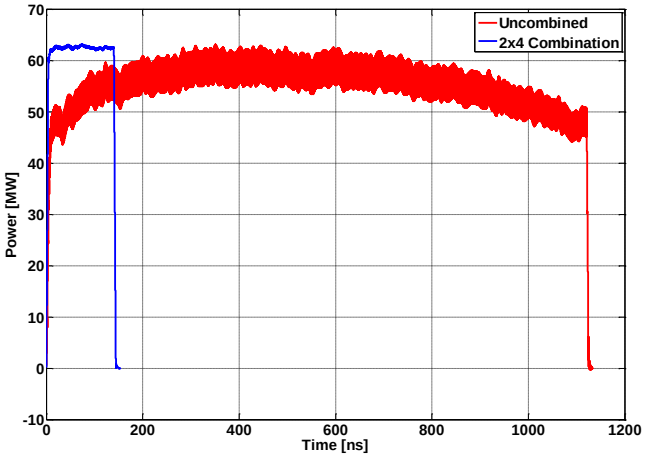
Full conditioning and break-down rate measurements

CEA-Saclay &
Uppsala University

Pulse shape experiment

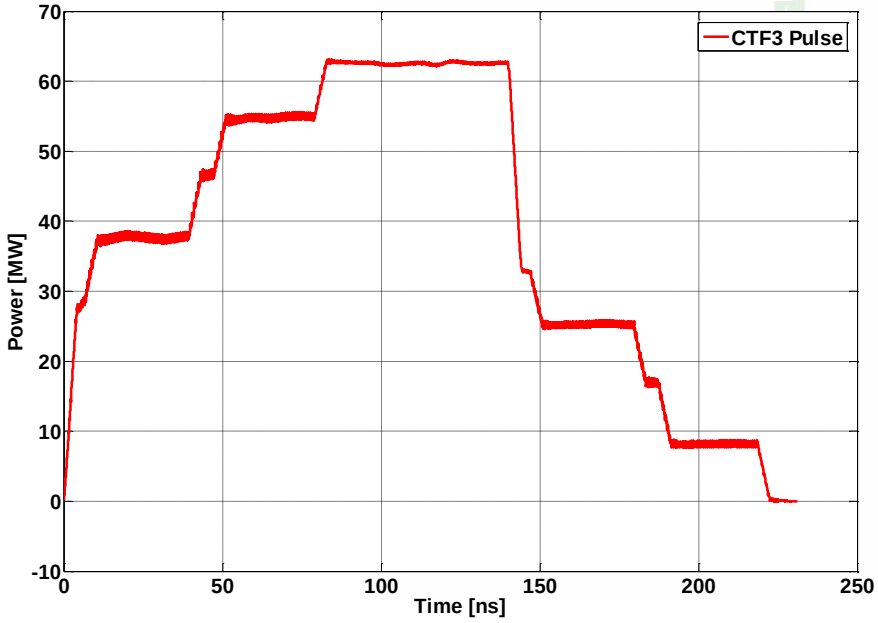
2013 Goal

Demonstrate power production with correct pulse shape for beam loading compensation of probe beam

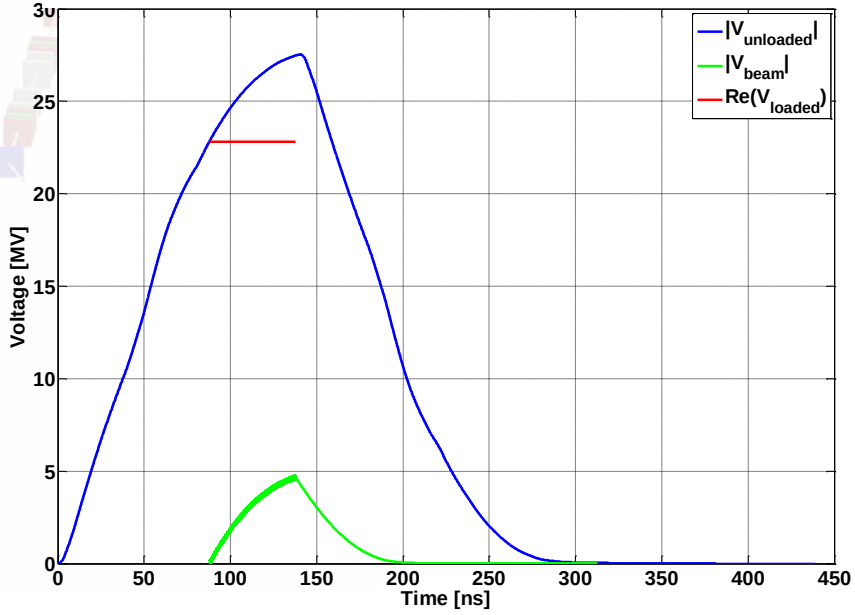


Simulation of power production with realistic beam conditions (current, bunch length and phase errors from measurements)

RF Power shape optimized with 7 knobs

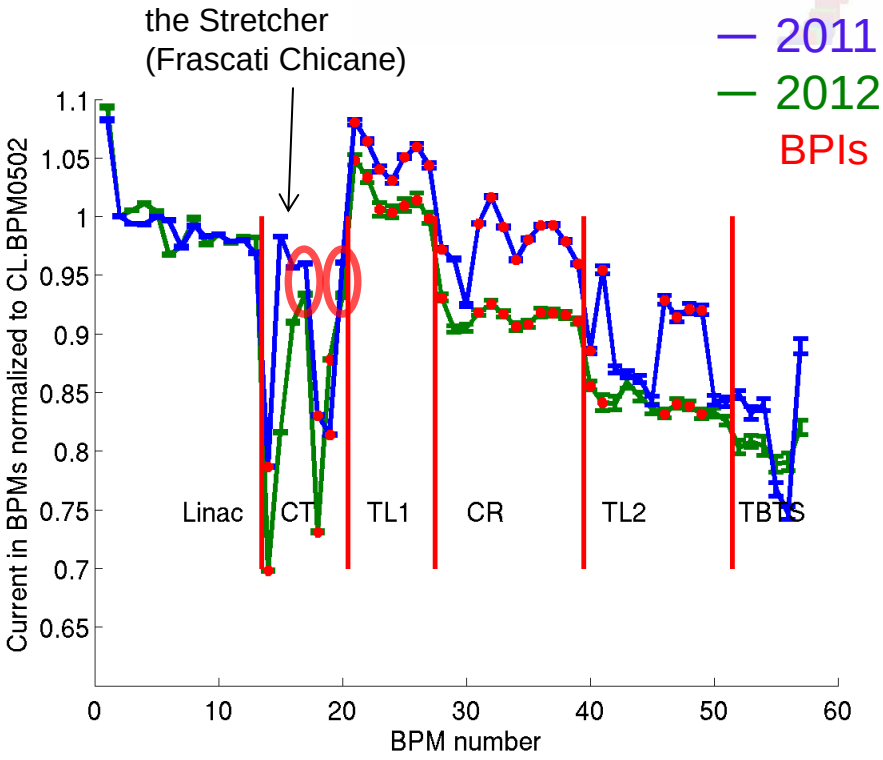


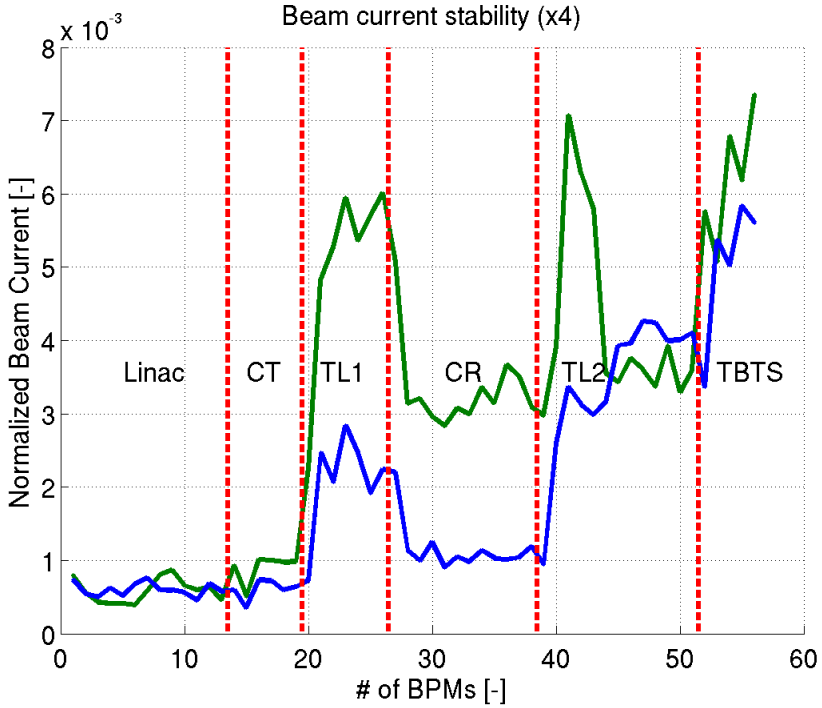
Unloaded/loaded/beam-induced voltages
Energy spread = 0.02%



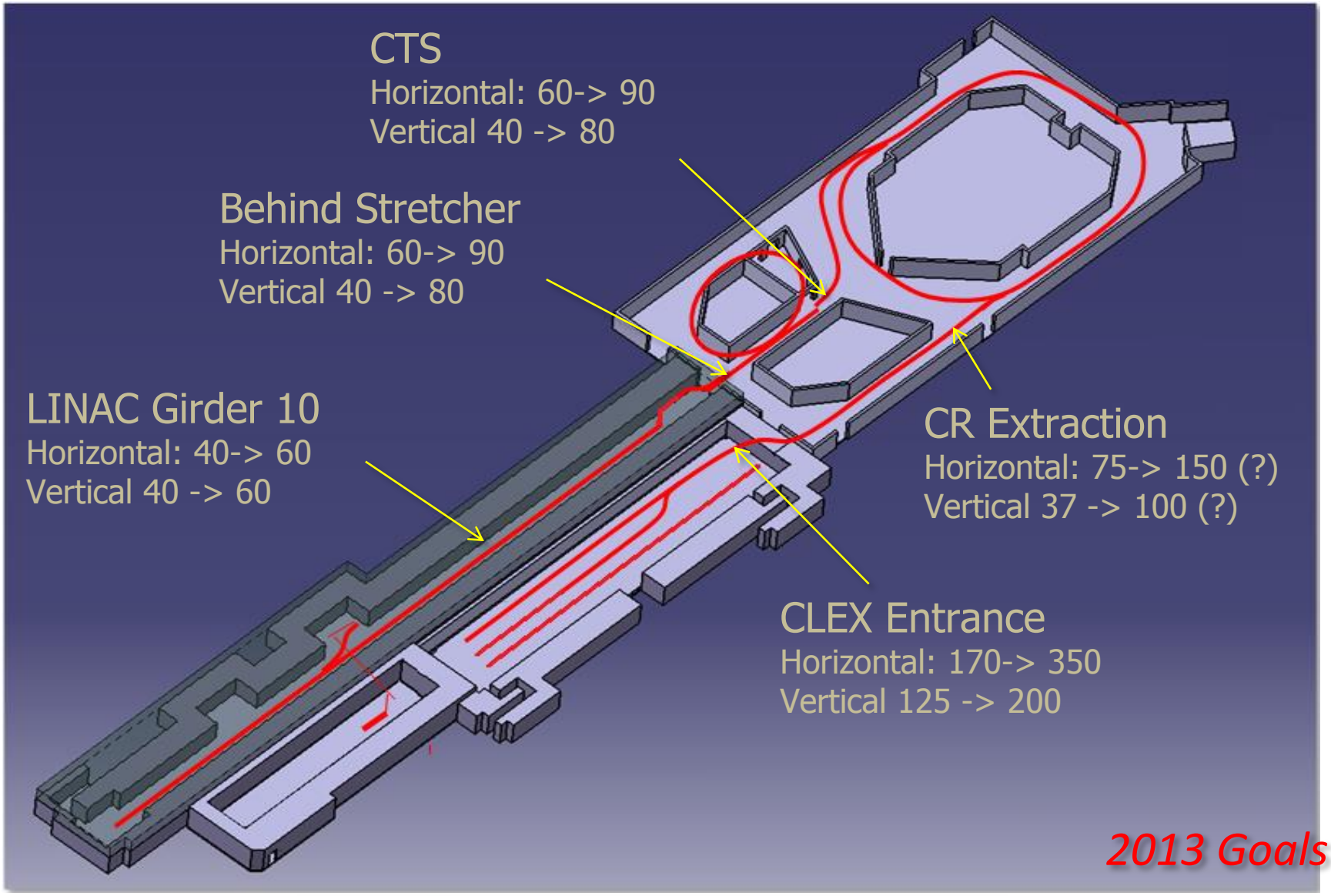
- 2012 we ran lower R56 optics → tails lost in the Stretcher
  - Beam intensity jitter showing off already there
  - Still achieving the same final performance in CLEX
- In 2012 the calibration of BPIs and their nonlinearity were corrected still calibration is not 100% certain (see Ben Constance talk)

Tobias Persson

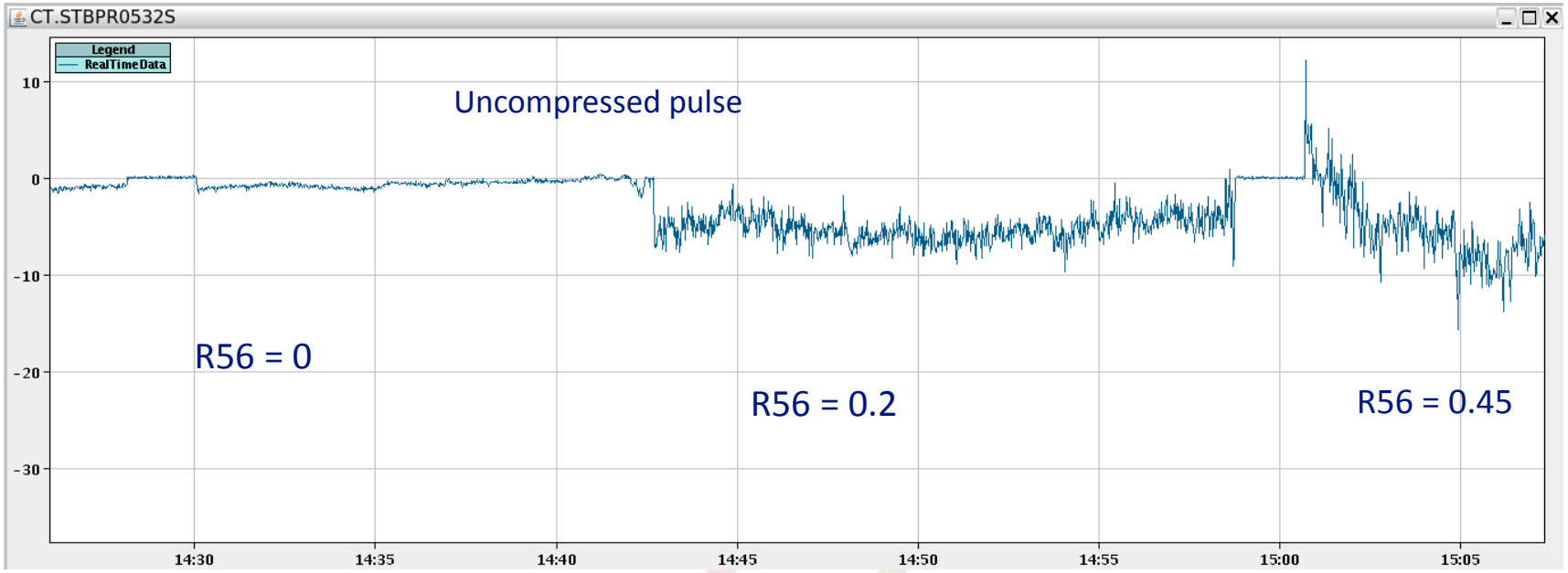




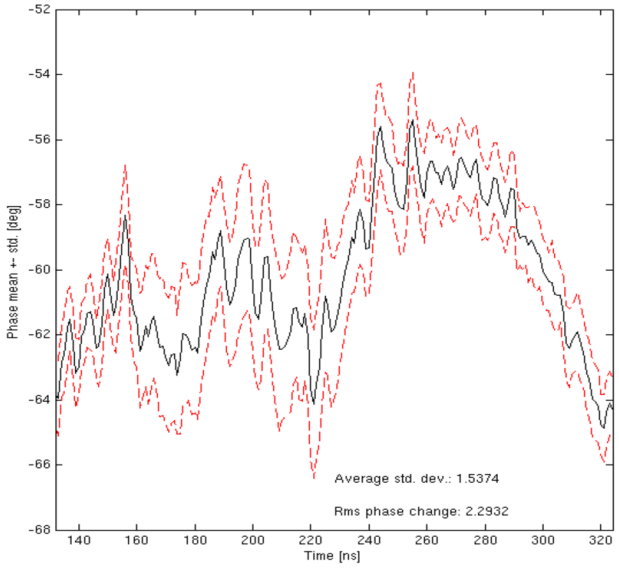
Drive Beam status & short term program

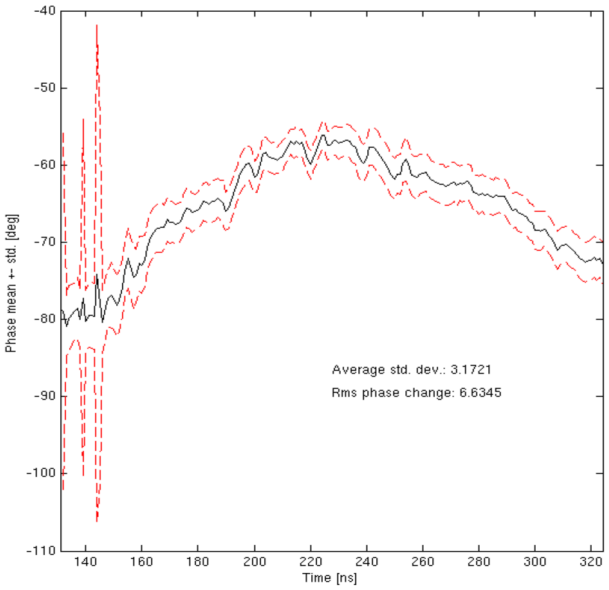


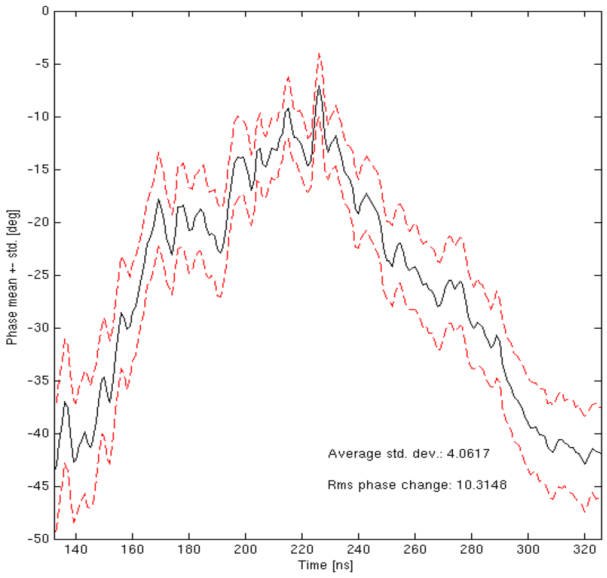
Drive Beam Phase



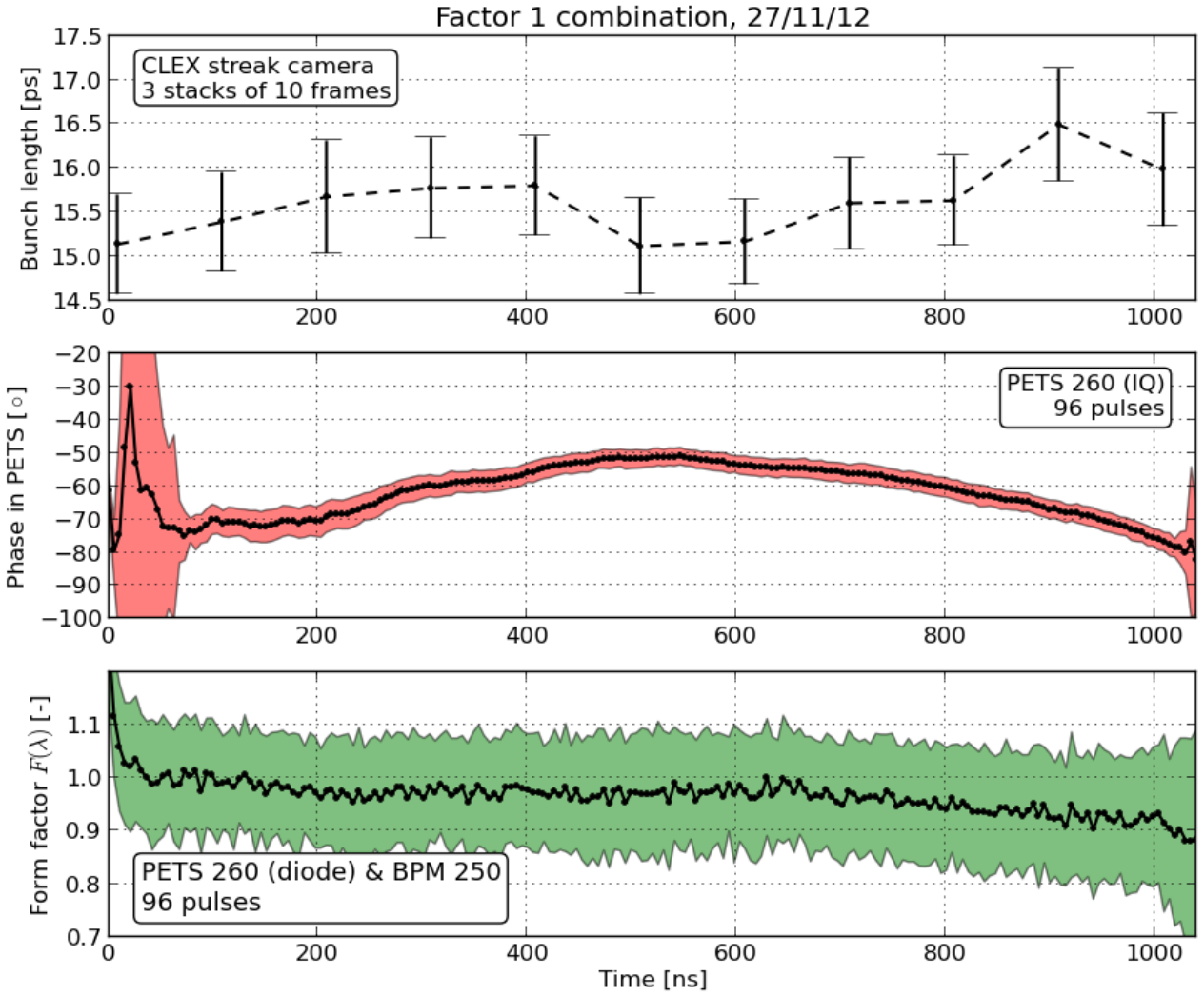
Compressed pulse



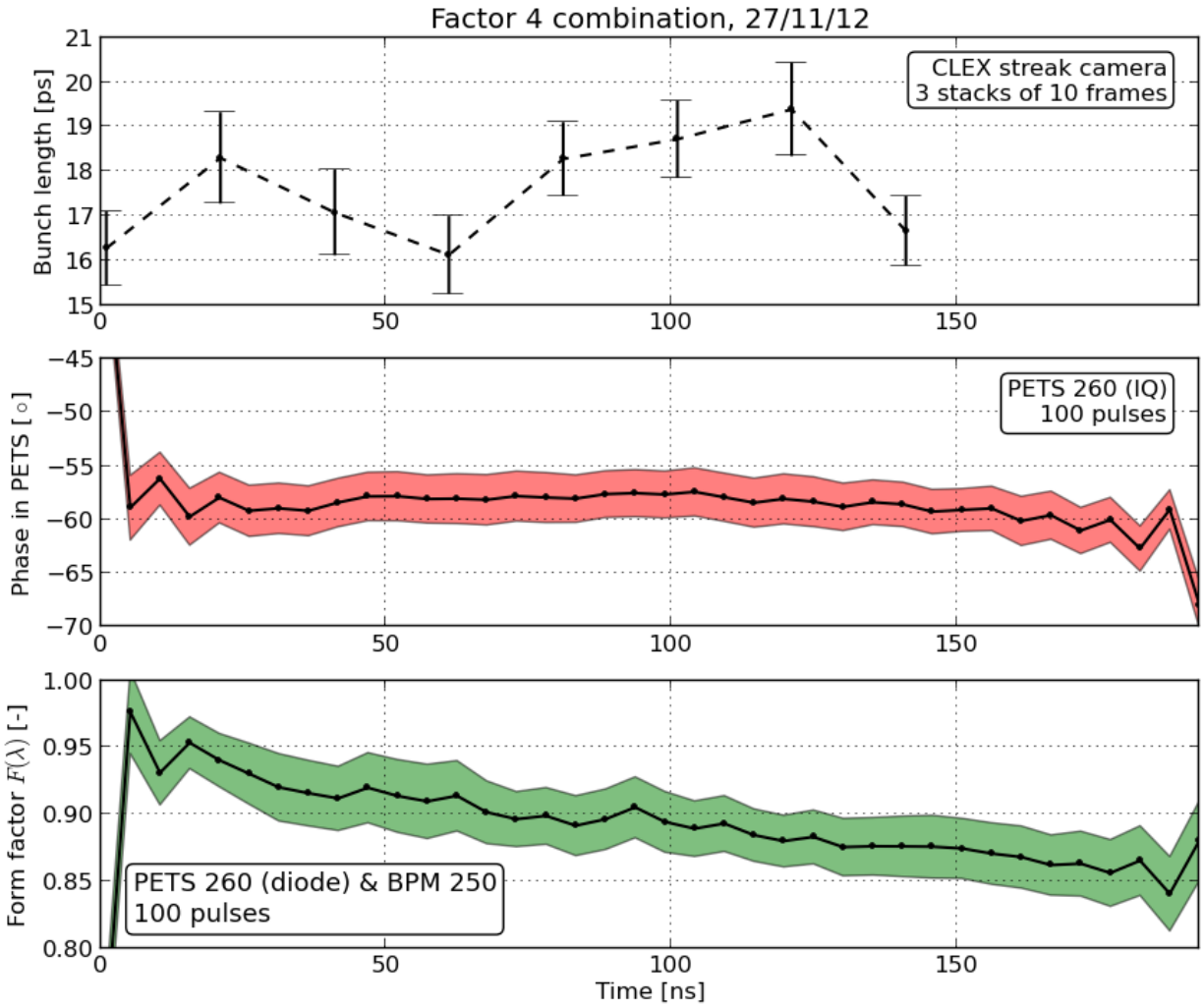




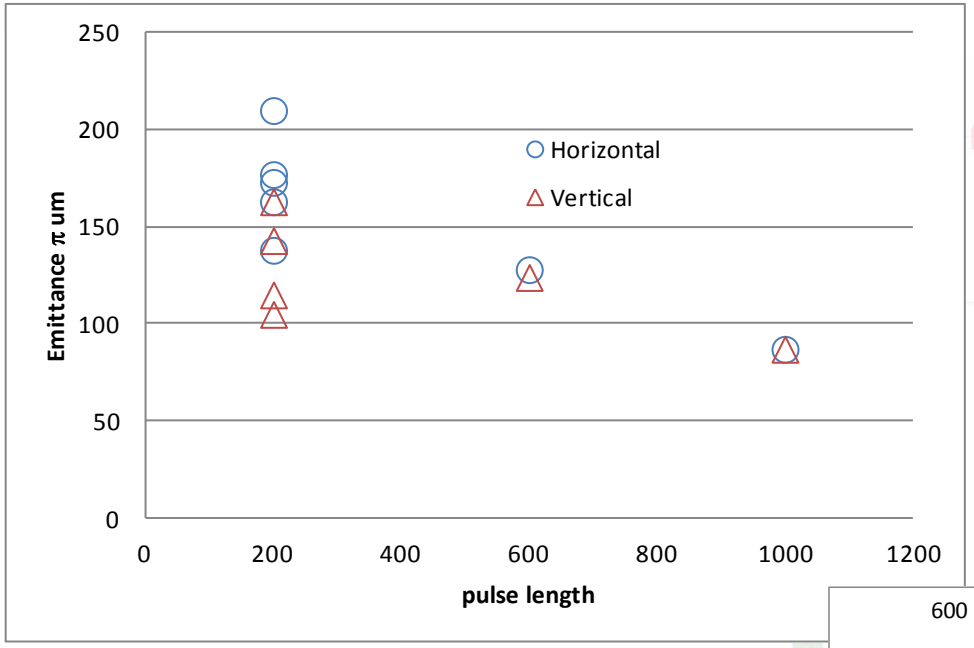
Bunch Length



Bunch Length



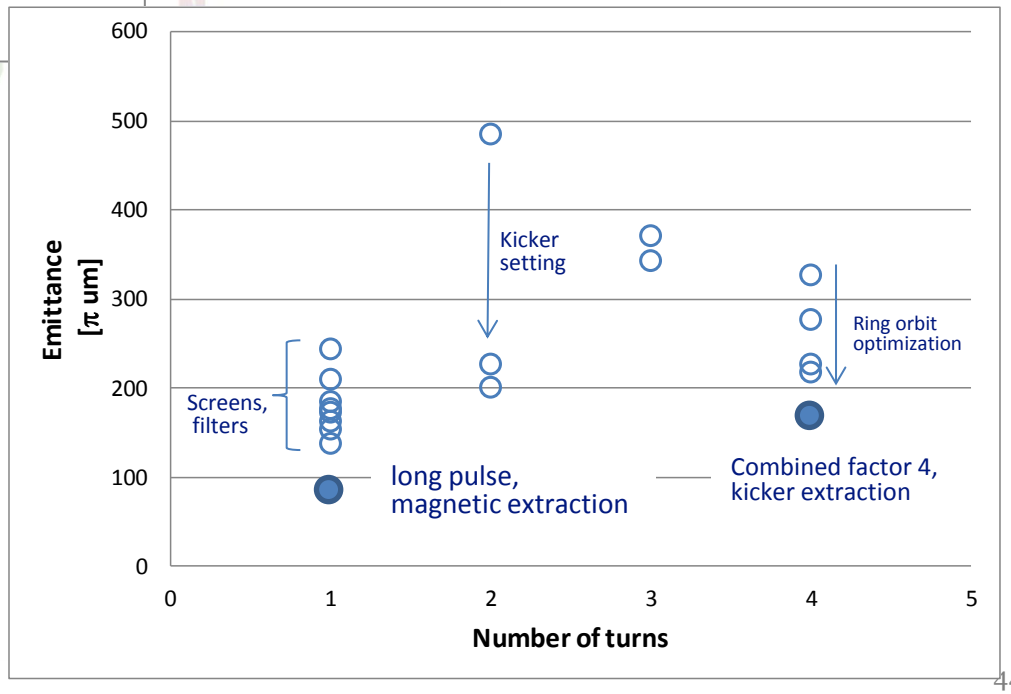
Emittance studies



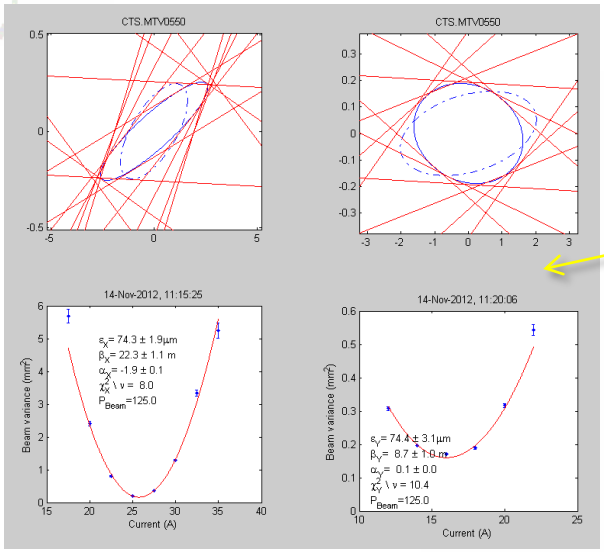
Uncombined beam, magnetic extraction

Short pulse, magnetic and kicker extraction

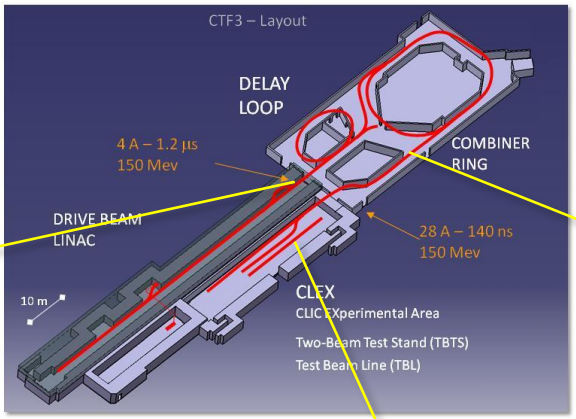
Horizontal Emittance

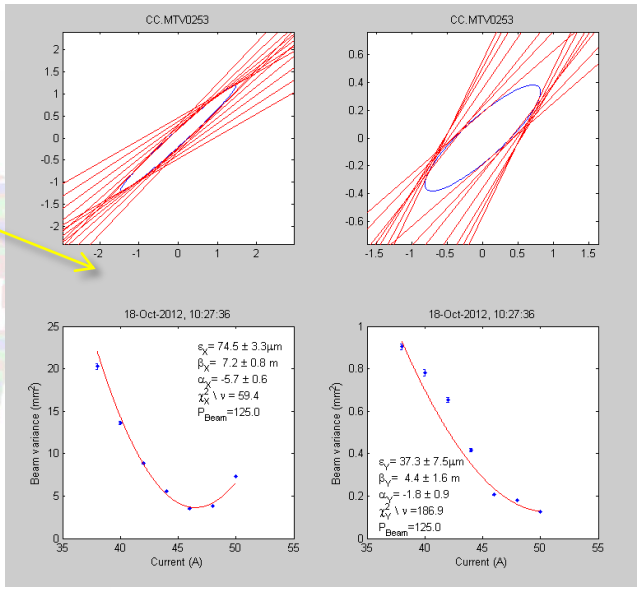


Emittance studies

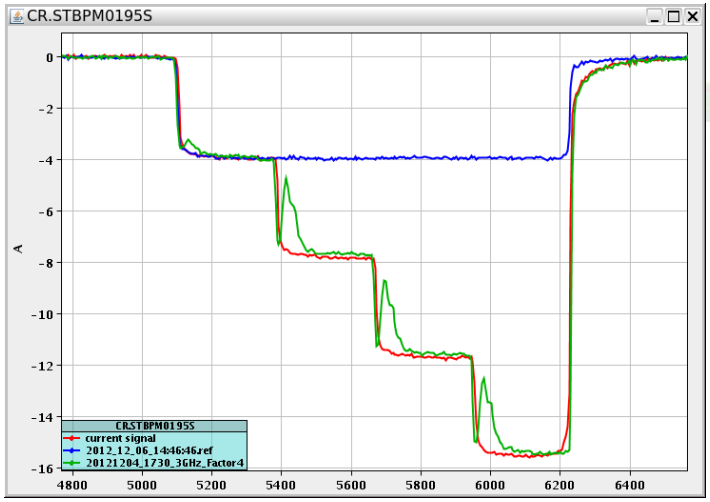


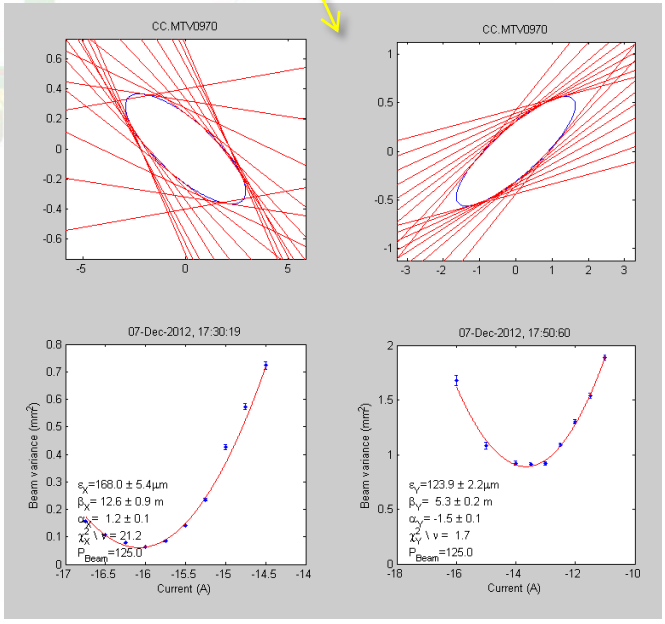
74 um both planes





74 um horizontal ?,
37 um vertical ?





168 um horizontal,
124 um vertical

CONCLUSIONS

Feasibility of the CLIC Two-Beam scheme has been established in the CLIC Test Facility CTF3

- Original experimental program basically completed
- Drive Beam generation demonstrated – emittance and stability shall be further improved this year
- Nominal parameters for RF production & two-beam acceleration reached and exceeded – 150 MV/m gradient measured with beam
- Deceleration by 30% of a 20 A beam of the drive beam with no losses, expect > 40% this year

CTF3 experimental program for the next five years established and under way

- Drive beam phase feed-forward experiment
- Beam loading / breakdown experiment
- High-power testing of structures in TBL
- Full fledged two-beam modules tested with beam in CLEX