# CLIC Conceptual Design and CTF3 Results

D. Schulte for the CLIC team

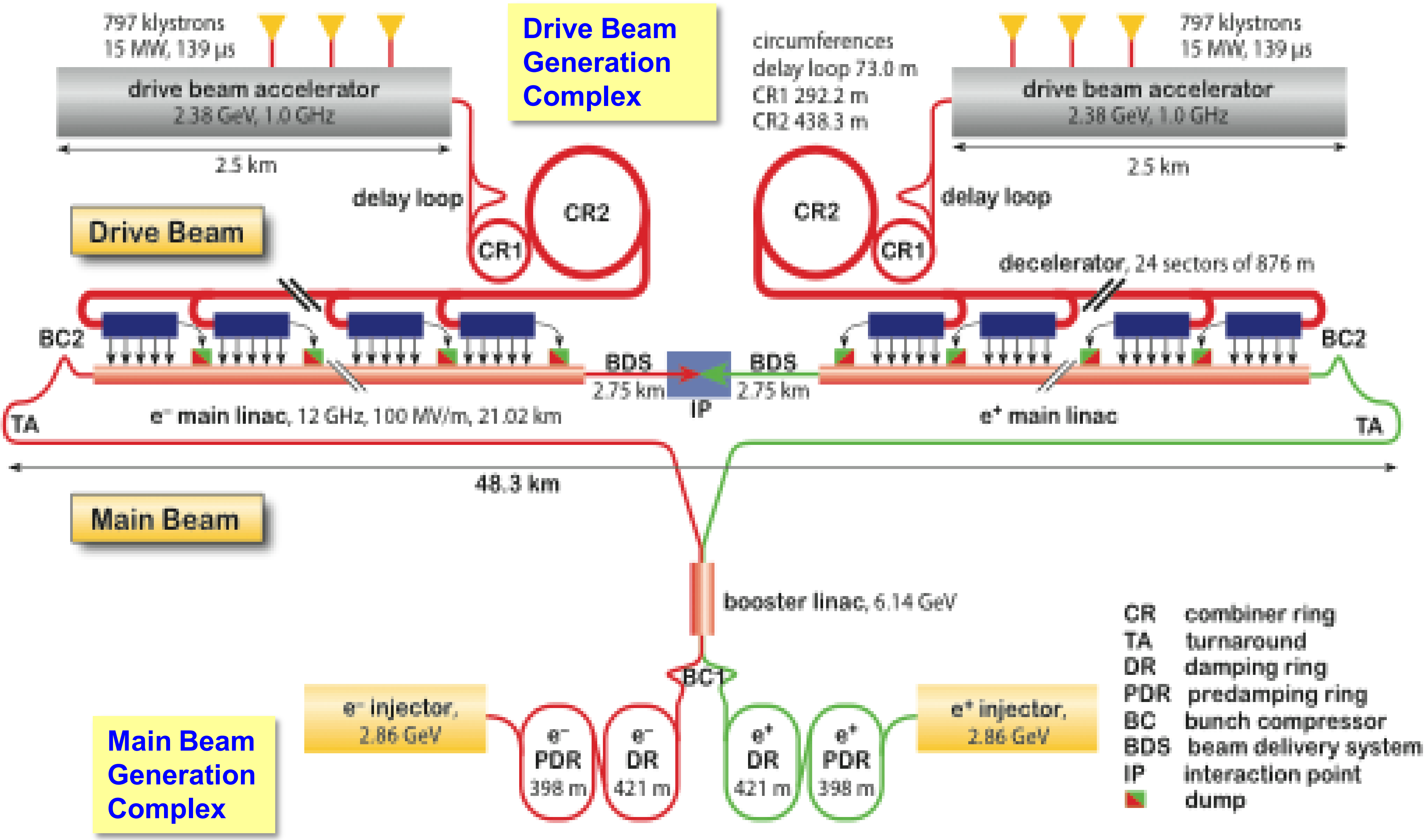
IPAC 2011

# CLIC&CTF3 Collaboration

41 Institutes from 21 countries

- ACAS (Australia)
- Aarhus University (Denmark)
- Ankara University (Turkey)
- Argonne National Laboratory (USA)
- Athens University (Greece)
- BINP (Russia)
- CERN
- CIEMAT (Spain)
- Cockcroft Institute (UK)
- ETHZurich (Switzerland)
- FERMILAB
- 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)
- John Adams Institute/RHUL (UK)
- JINR (Russia)
- Karlsruhe University (Germany)
- KEK (Japan)
- LAL / Orsay (France)
- LAPP / ESIA (France)
- NCP (Pakistan)
- NIKHEF/Amsterdam (Netherlands)
- North-West. Univ. Illinois (USA)
- Patras University (Greece)
- Polytech. University of Catalonia (Spain)
- PSI (Switzerland)
- RAL (UK)
- RRCAT / Indore (India)
- SLAC (USA)
- Thrace University (Greece)
- Tsinghua University (China)
- University of Oslo (Norway)
- Uppsala University (Sweden)
- UCSC SCIPP (USA)

# CLIC Layout at 3 TeV



# CLIC Main Parameters

| parameter | symbol | | |
|---|---|---|---|
| centre of mass energy | $E_{cm}$ [GeV] | 500 | 3000 |
| luminosity | $\mathcal{L}$ [$10^{34}$ cm$^{-2}$s$^{-1}$] | 2.3 | 5.9 |
| luminosity in peak | $\mathcal{L}_{0.01}$ [$10^{34}$ cm$^{-2}$s$^{-1}$] | 1.4 | 2 |
| gradient | $G$ [MV/m] | 80 | 100 |
| site length | [km] | 13 | 48.3 |
| charge per bunch | $N$ [$10^9$] | 6.8 | 3.72 |
| bunch length | $\sigma_z$ [$\mu$m] | 70 | 44 |
| IP beam size | $\sigma_x/\sigma_y$ [nm] | 200/2.26 | 40/1 |
| norm. emittance | $\epsilon_x/\epsilon_y$ [nm] | 2400/25 | 660/20 |
| bunches per pulse | $n_b$ | 354 | 312 |
| distance between bunches | $\Delta_b$ [ns] | 0.5 | 0.5 |
| repetition rate | $f_r$ [Hz] | 50 | 50 |
| est. power cons. | $P_{wall}$ [MW] | 240 | 560 |

# Key Design Issues

| | |
|---|---|
| Main linac gradient | – Accelerating structure |
| Drive beam scheme | – Drive beam generation<br>– PETS<br>– Two beam module<br>– Drive beam deceleration |
| Luminosity | – Main beam emittance generation and preservation, focusing<br>– Alignment and stabilisation |
| Operation and Machine Protection System (robustness) | |
| Detector (experimental conditions) | |

Design and feasibility issues will be covered in
CLIC Conceptual Design Report
In time for European strategy group

Volume 1: Accelerator
Volume 2: Physics and experiments
Volume 3: Executive summary

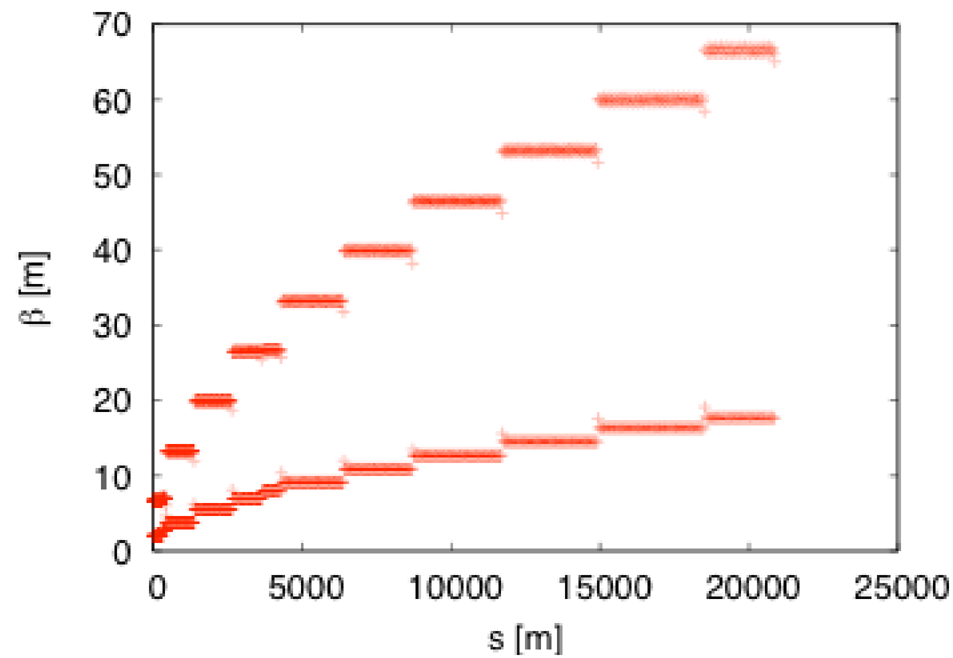
# Main Linac

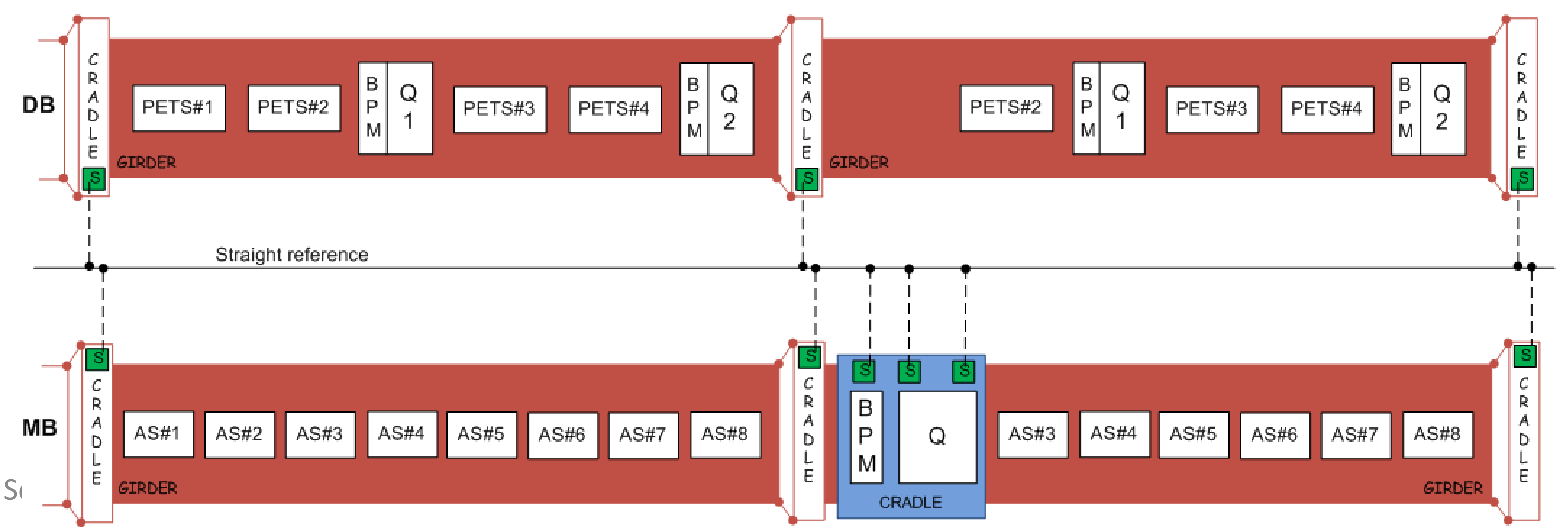
Maximise current to maximise efficiency/luminosity

Strong focusing O(10%) quadrupoles

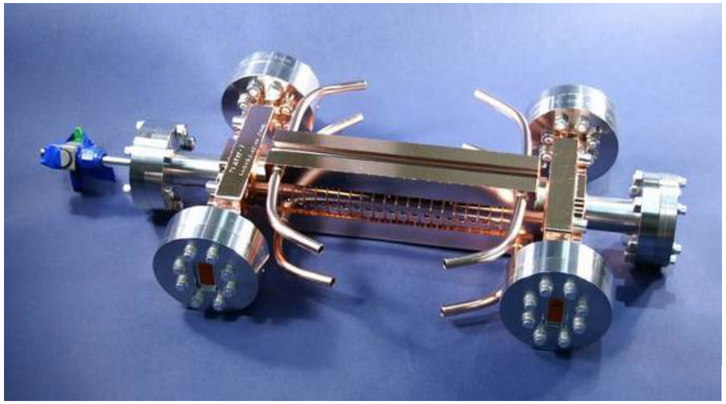
Sensitive to imperfections

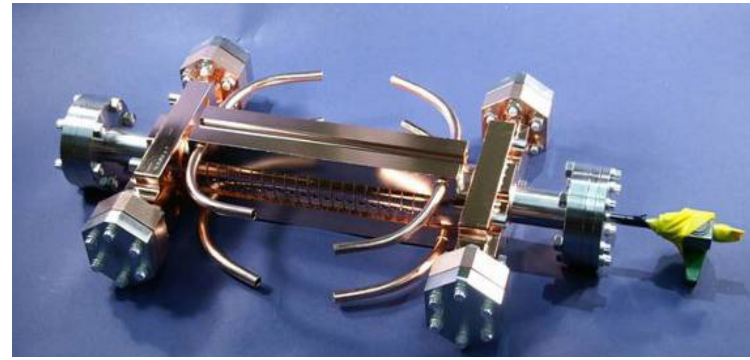
80% fill factor



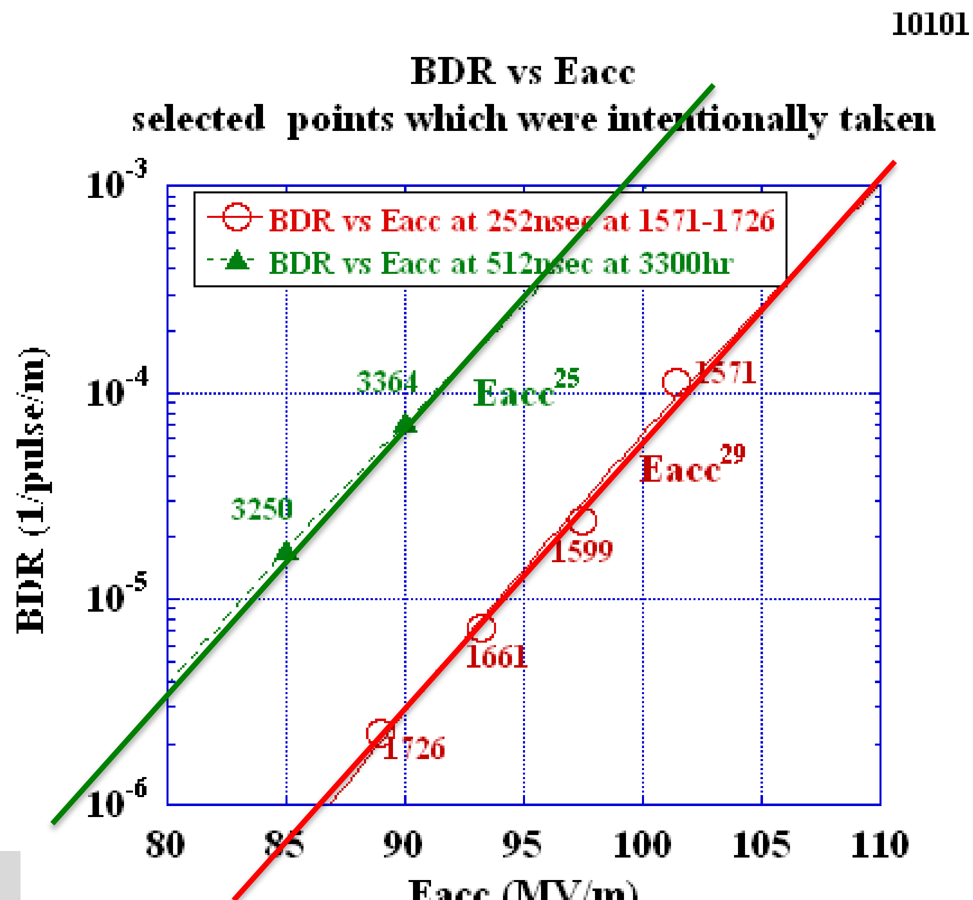
# Accelerating Structure





- Require breakdown probability 1% per pulse
  - $p \leq 3\times10^{-7} m^{-1} pulse^{-1}$

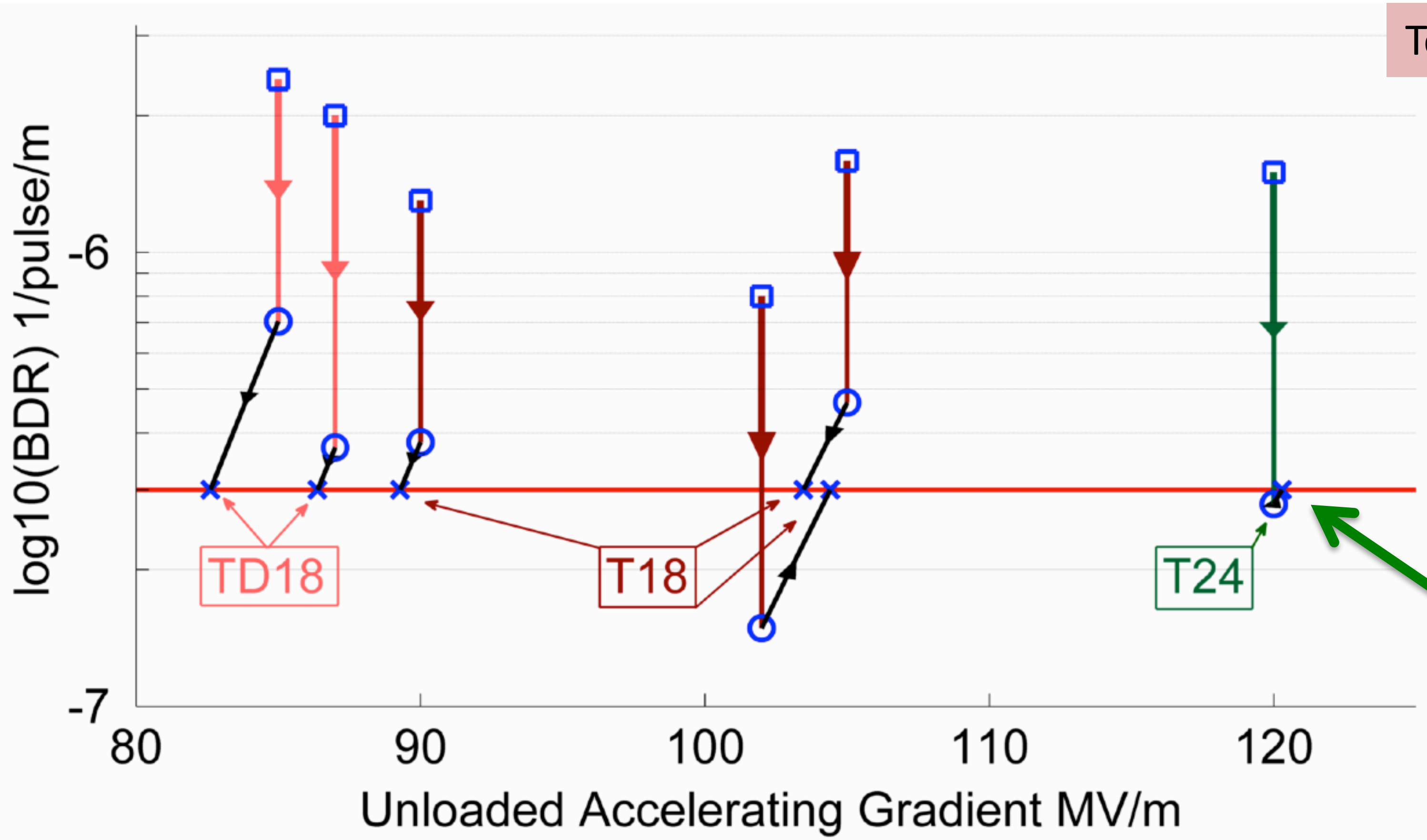
- Design based on empirical constraints
  - $E_{surf} < 260$MV/m
  - $\Delta T < 56$K
  - $P/(2\pi a)\tau^{1/3} < 18$MW/mm ns$^{1/3}$




D. Schulte

W. Wuensch et al.

# Achieved Gradient




Tests at KEK and SLAC

Measurements scaled according to

$$p \propto G^{30}\tau^{5}$$

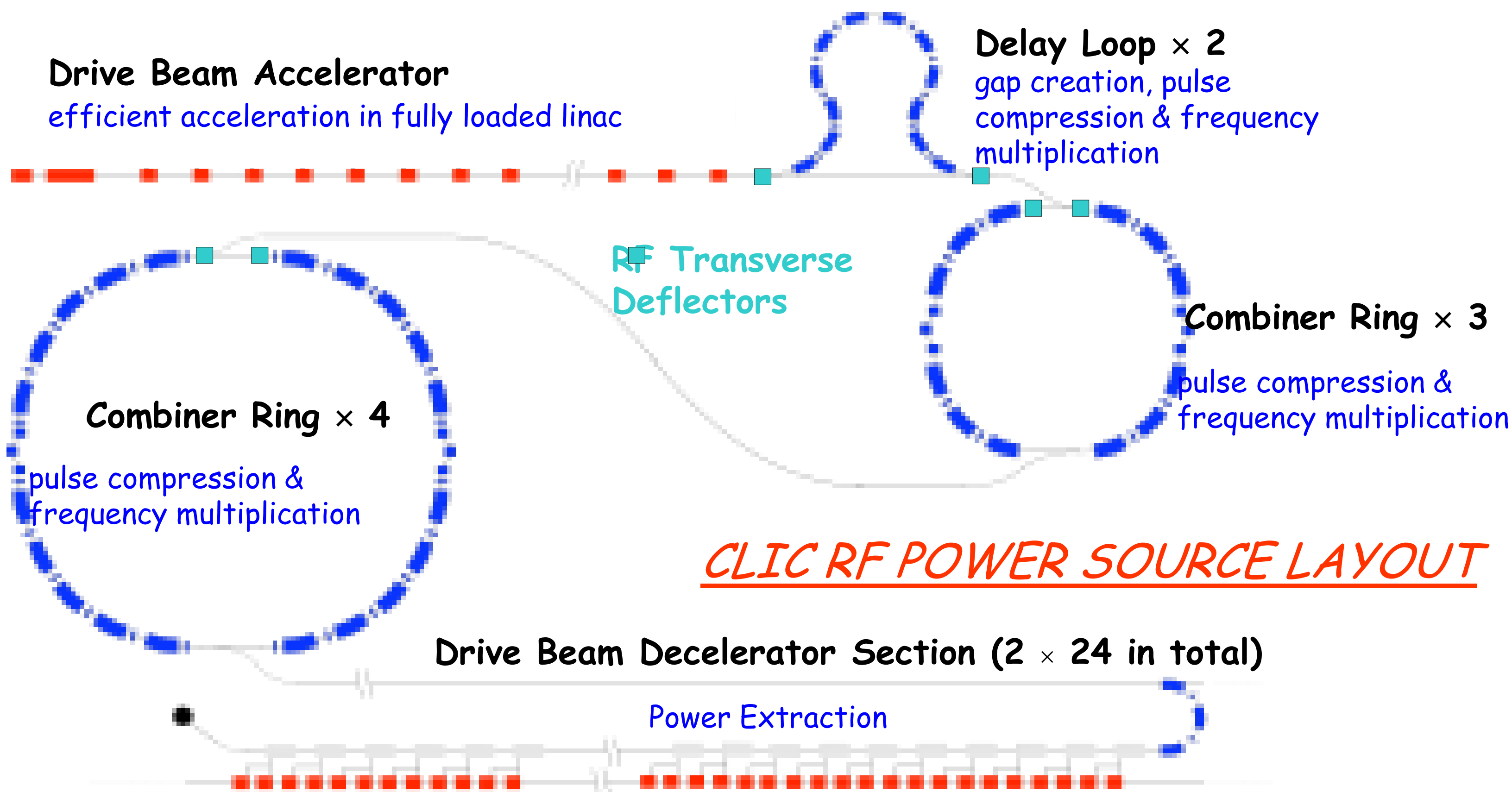
Some input power as 100MV/m loaded

| | Simple early design to get started | More efficient fully optimised structure |
|---|---|---|
| No damping waveguides | T18 | T24 |
| Damping waveguides | TD18 | TD24 = CLIC goal |

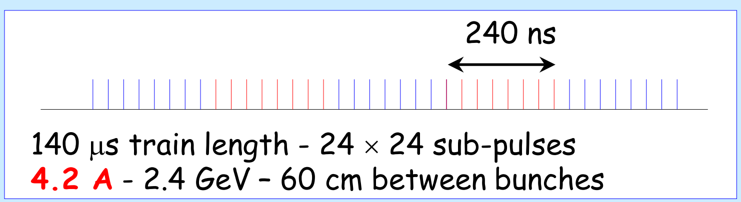
CLIC RF team
N. Shipman

TD24: September 15th @ KEK
mid-November @ SLAC
Soon @ CERN

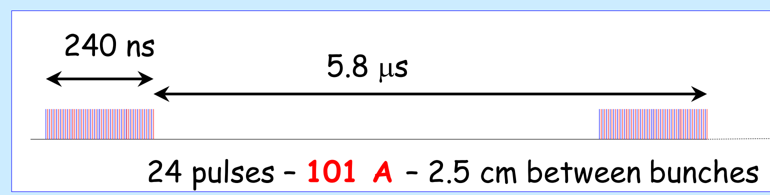
# CLIC Power Source Concept

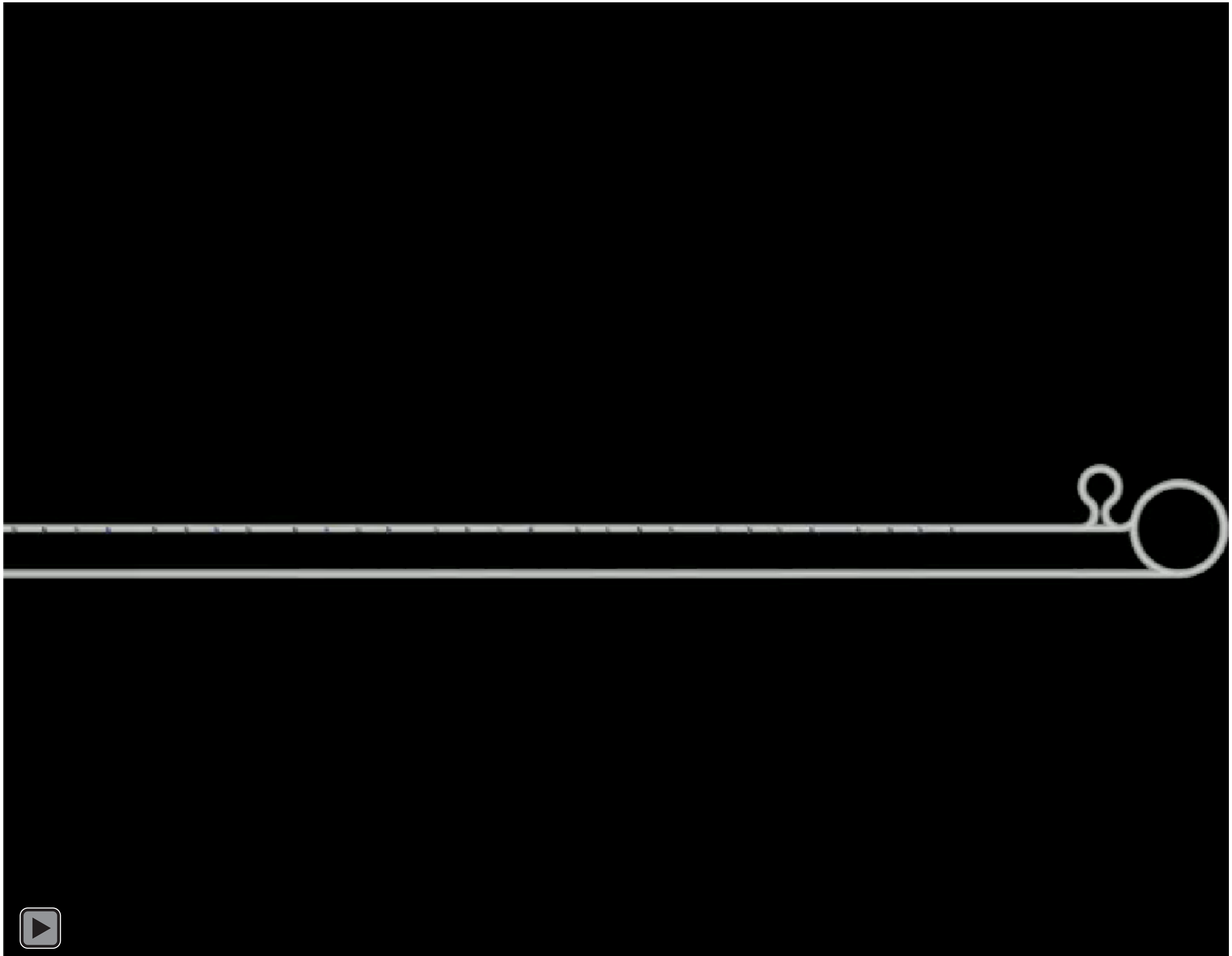



## Drive beam time structure - initial




## Drive beam time structure - final

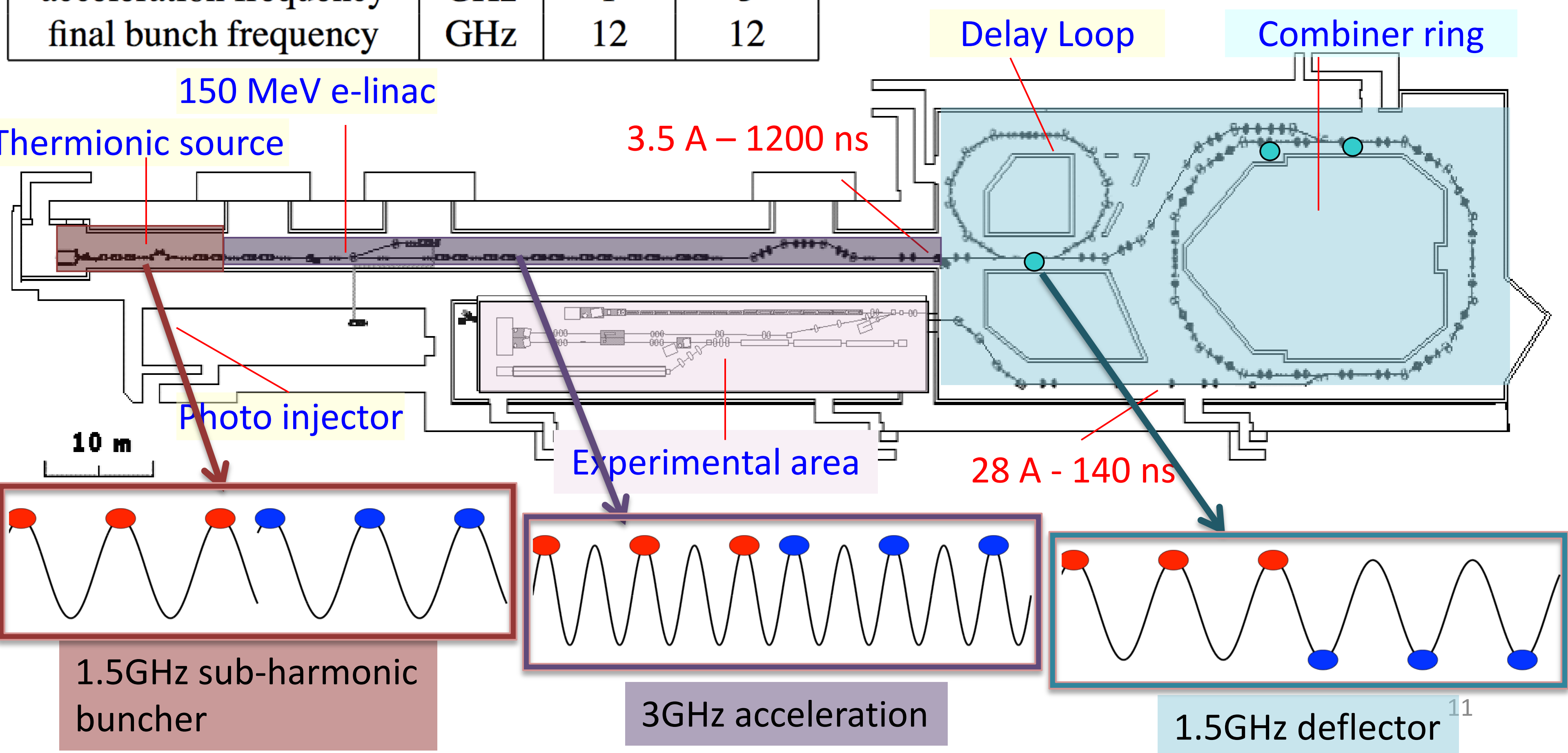




# CLIC Test Facility (CTF3)

| parameter | unit | CLIC | CTF3 |
|---|---|---|---|
| accelerated current | A | 4.2 | 3.5 |
| combined current | A | 101 | 28 |
| final energy | MeV | 2400 | $\approx$ 120 |
| accelerated pulse length | $\mu$s | 140 | 1.2 |
| final pulse length | ns | 240 | 140 |
| acceleration frequency | GHz | 1 | 3 |
| final bunch frequency | GHz | 12 | 12 |

Recycled infrastructure
- made it affordable
- causes lots of headache



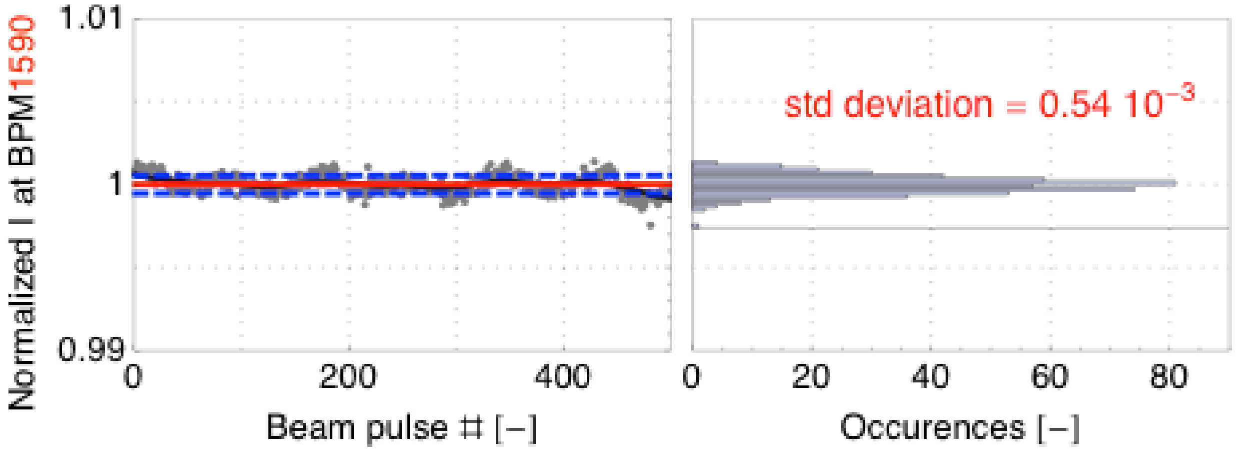
# Drive Beam Linac

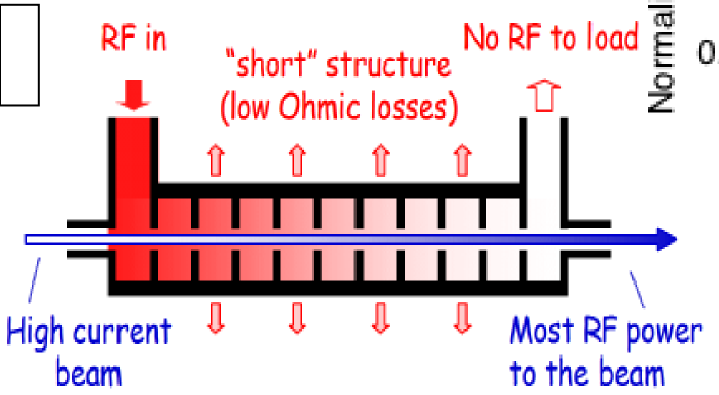
CTF3 team

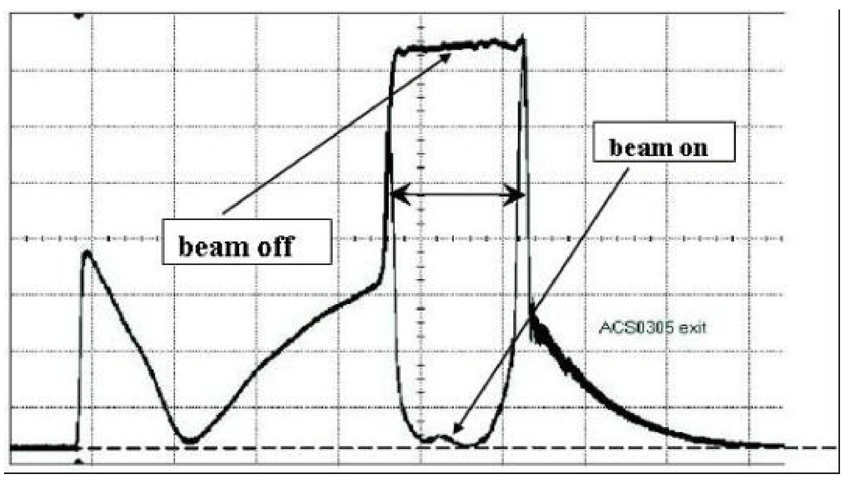
95.3% RF to beam efficiency

No instabilities

Phase switch works OK



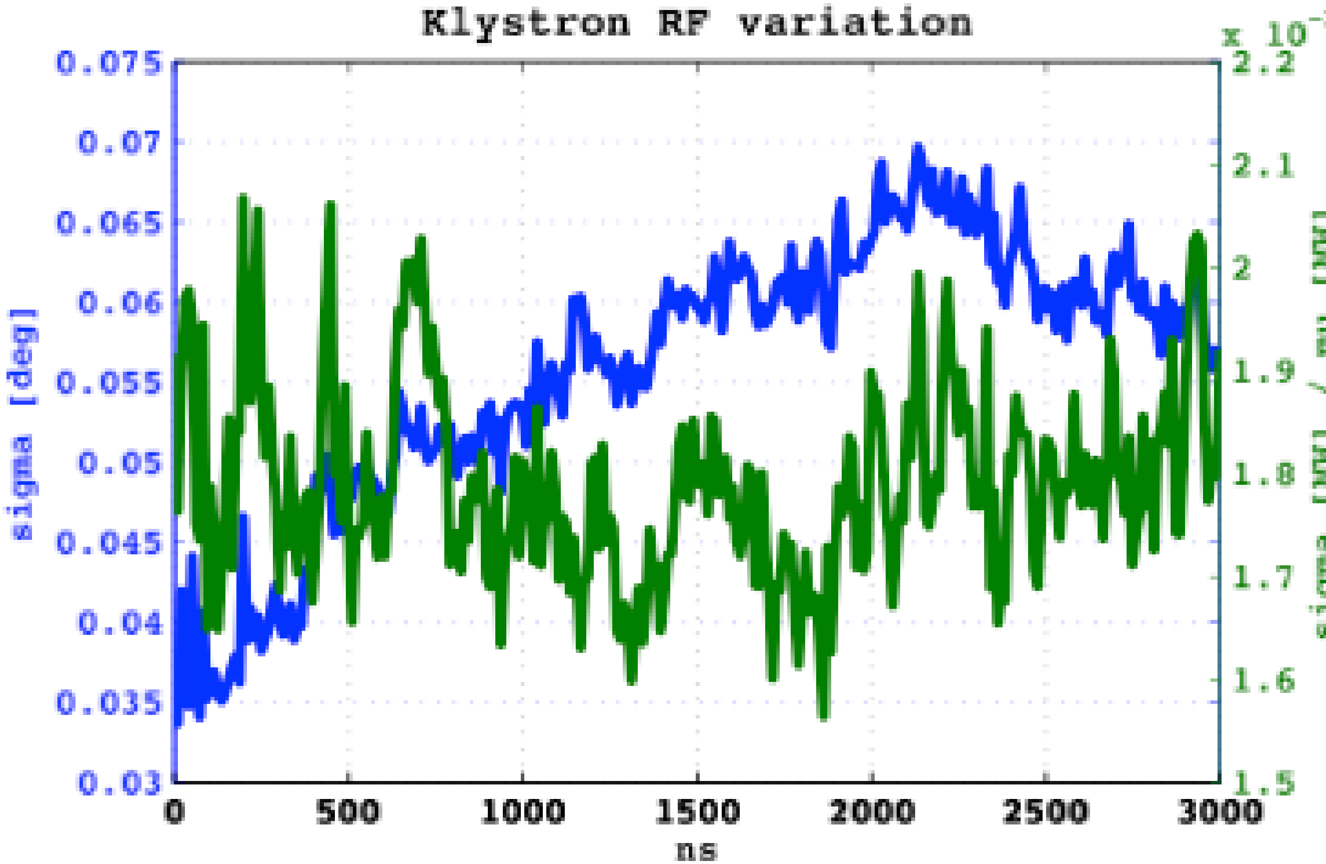




| Parameter | CLIC goal | CTF3 routine at end of linac |
|---|---|---|
| Transverse emittance | 100µm | 50-60µm |
| Pulse current | 7.5e-4 | 5.4e-4 |

G. Sterbini, T. Persson

# RF Stability

Cannot measure beam phase jitter accurately enough
- monitor being developed (Frascati)
- measure RF instead




| | Tolerance | Measured |
|---|---|---|
| RF Power | 0.2% | 0.21% |
| RF Phase | 0.05° | 0.07° (0.035°) |

Good CTF3 klystron
- pulse-to-pulse
- 10ns time slices
- with respect to local phase reference

A. Dubrovskiy

# Drive Beam Combination

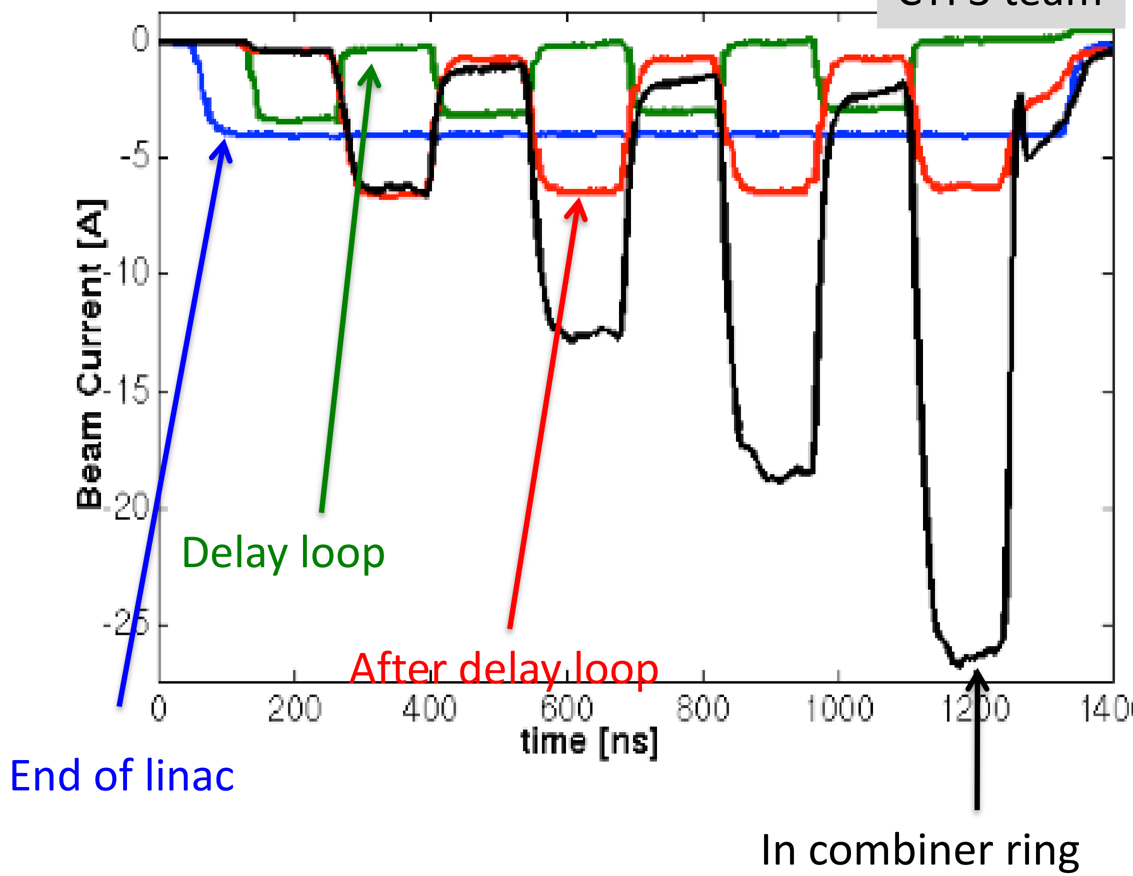
29 A reached, routinely 25A

Significant increase of transverse emittance
Current jitter increases to O(1%)

Focus has been on current
- will now further improve beam quality

CTF3 specific issues need to be addressed and limits identified
- RF pulse compression
- Beam energy in combiner ring is 5% of that in CLIC
- Geometric emittance 20 times larger
- …
- …

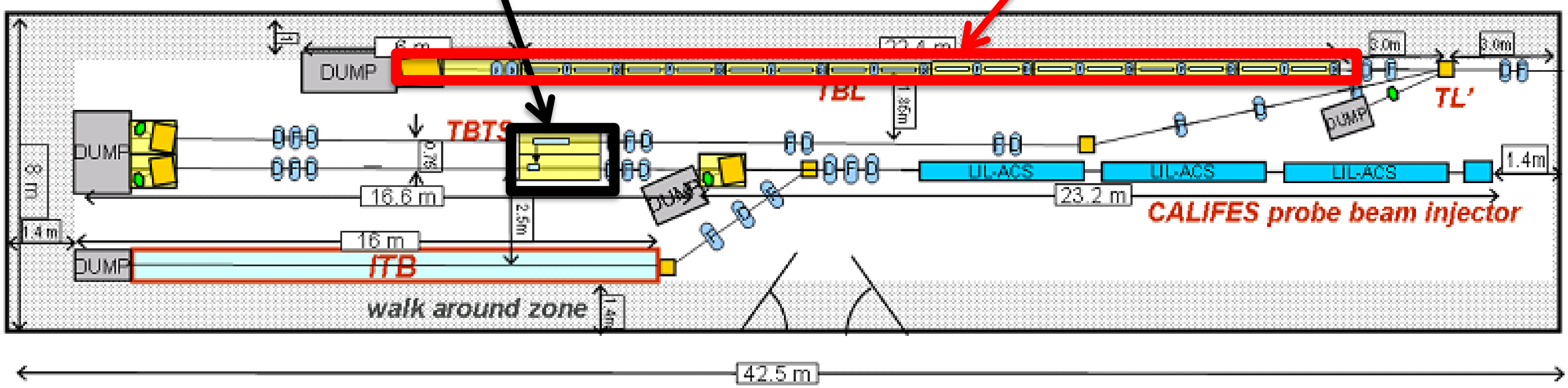
CTF3 team



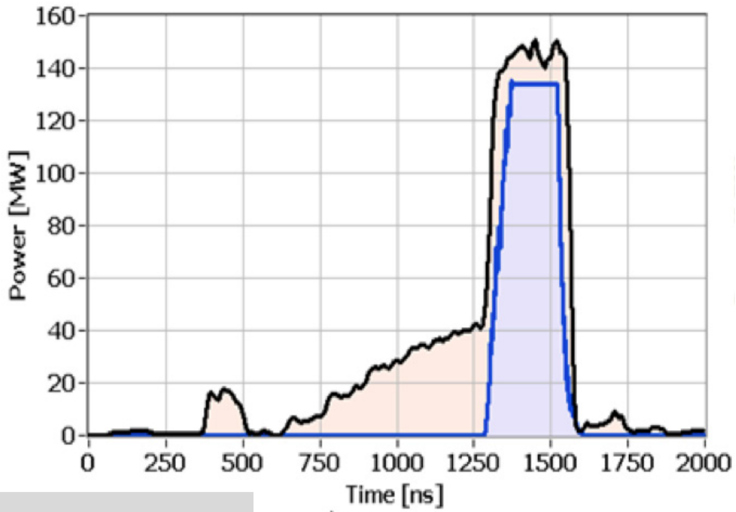
# Drive Beam Deceleration and Module: CLEX

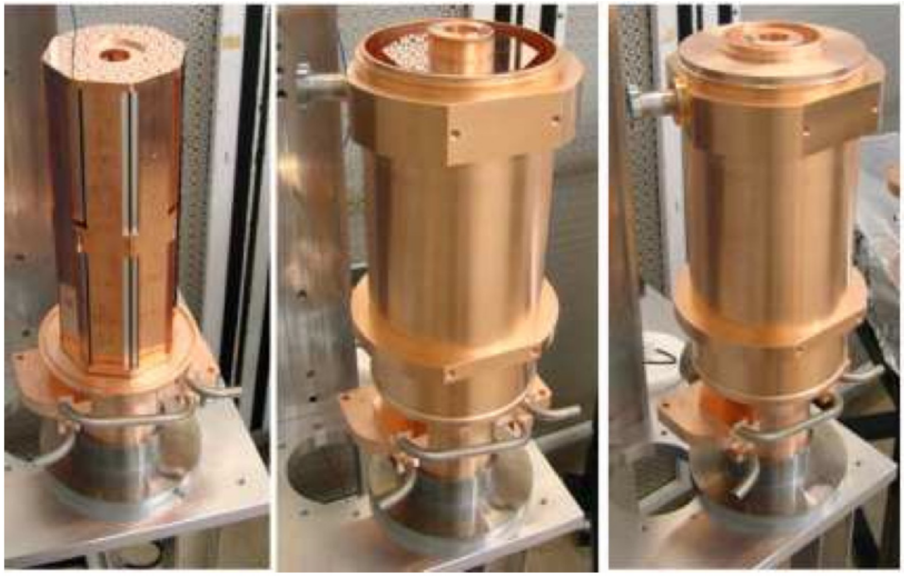
TBTS (two-beam test stand)
- power transfer to main beam
- module design

TBL (test beam line)
- drive beam stability during deceleration



# PETS Breakdown Rate at SLAC (ASTA)

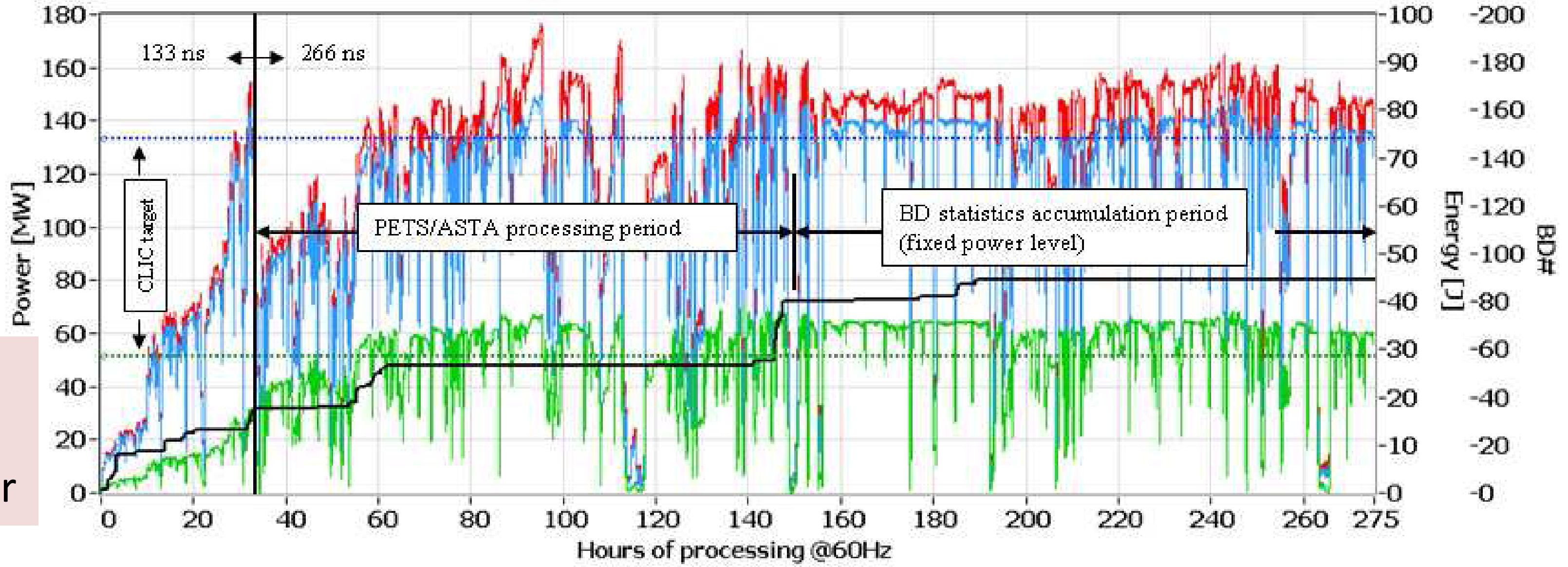


A. Cappelletti et al.

Power

Energy/pulse



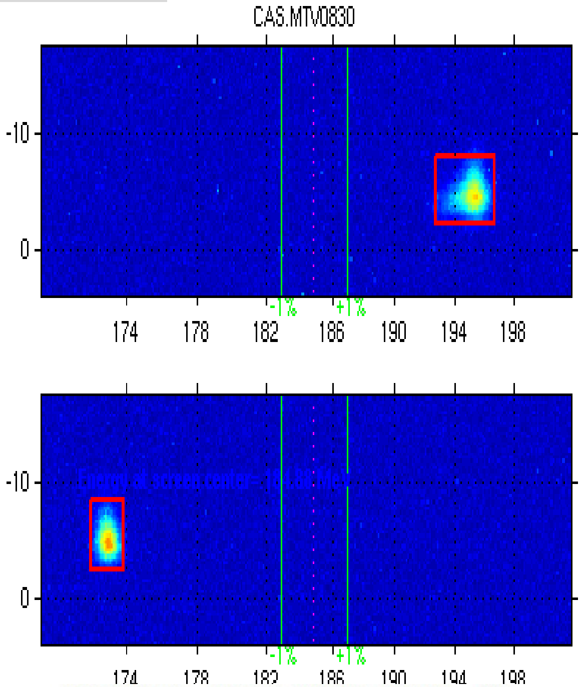

Test with
on-off
In September

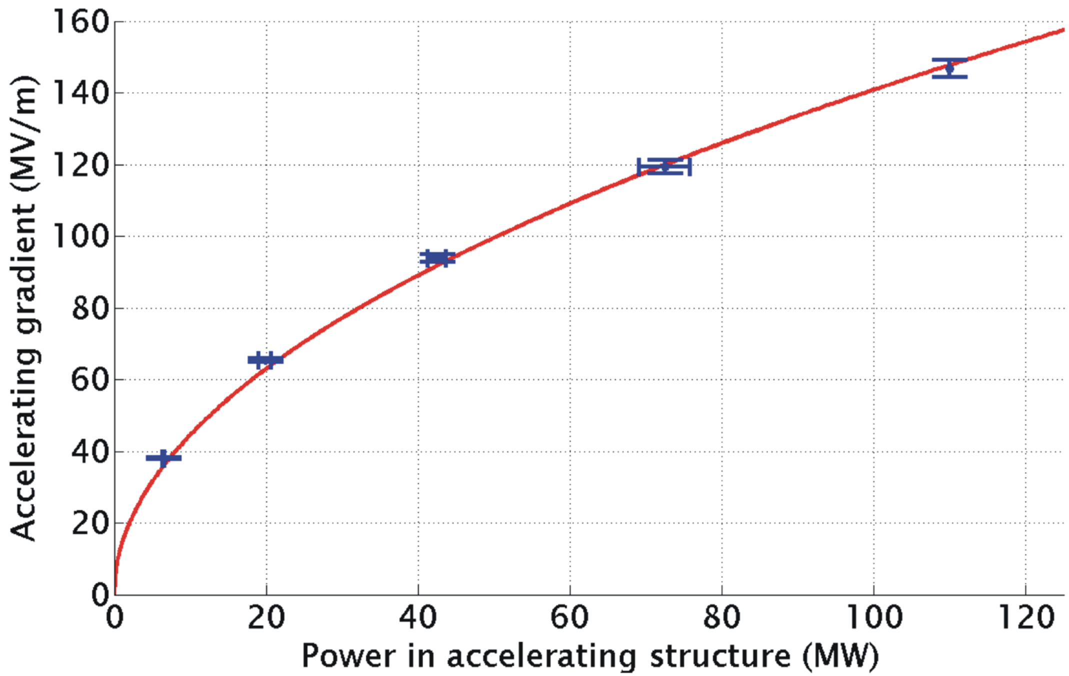


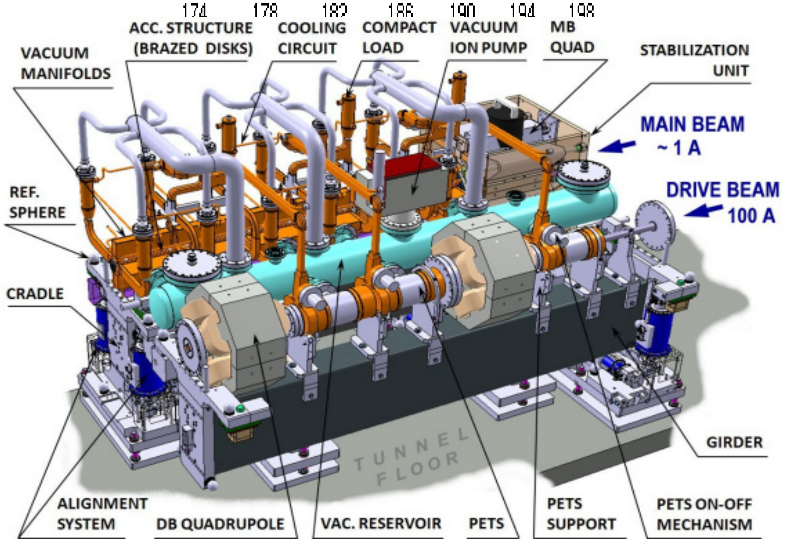
No breakdown last O($8\ 10^6$ pulses) -> P about consistent with p=$2.4\ 10^{-7}$/m/pulse

# TBTS: Two Beam Acceleration

CTF3 team



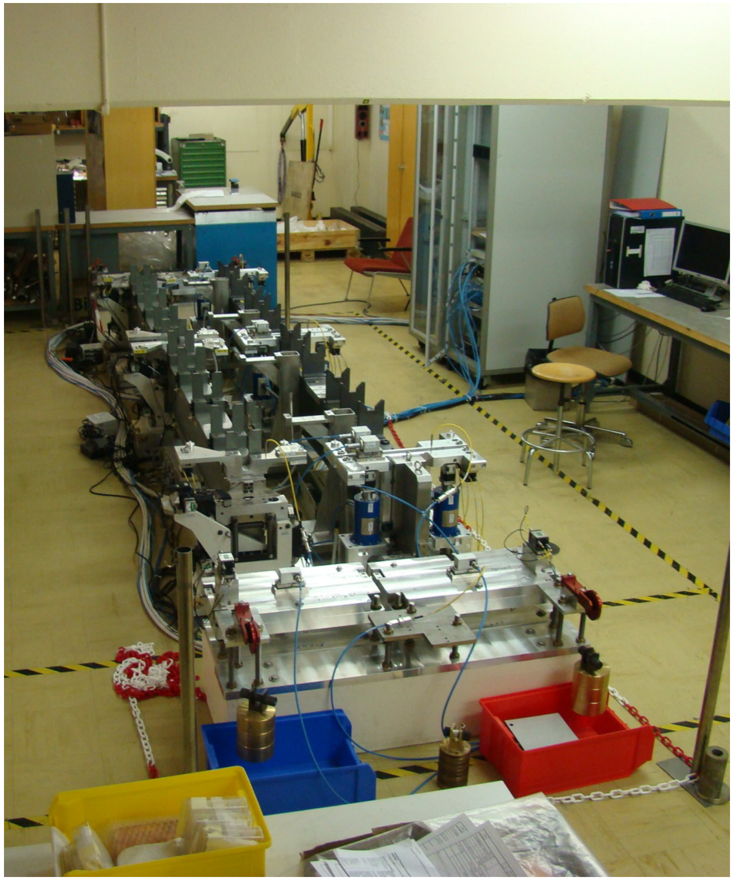



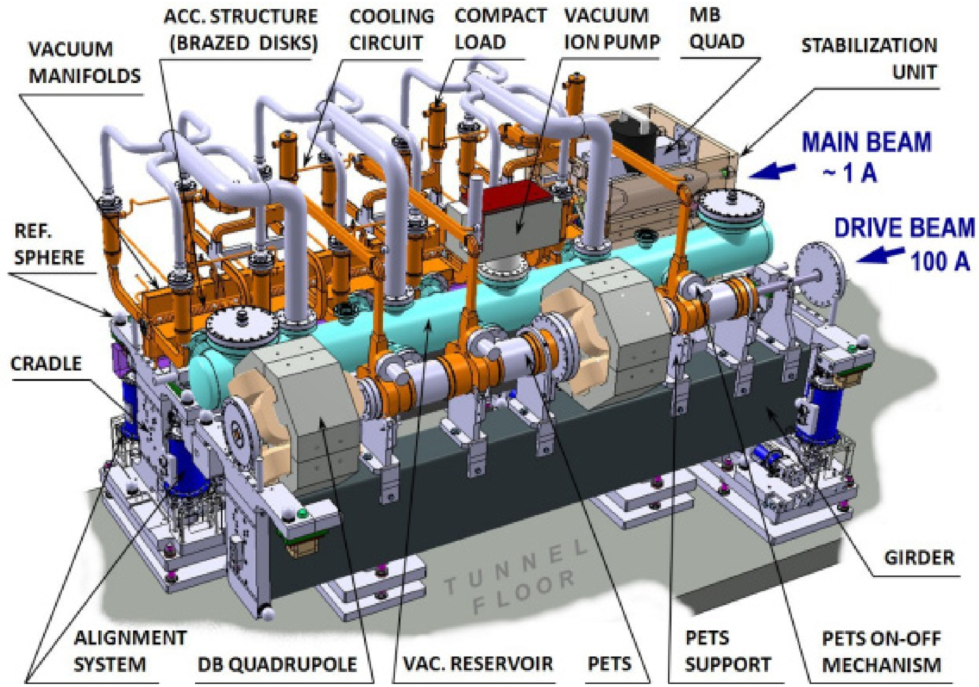




Maximum gradient
145 MV/m

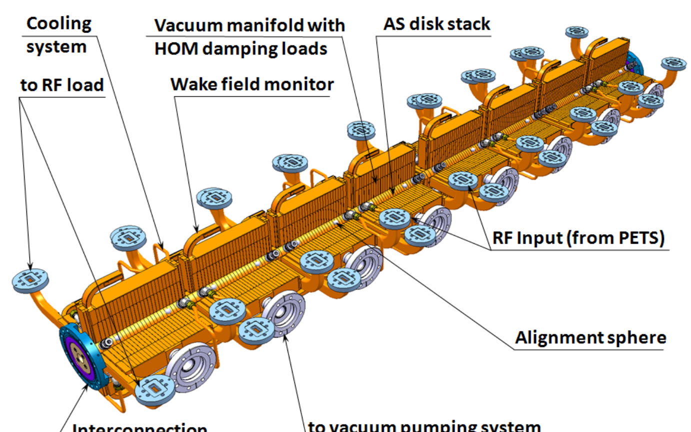
Consistency between
- produced power
- drive beam current
- test beam acceleration

# Two-beam Module Development






Installation and validation of first two prototype modules under way




Stack of 8 ac. structures under assembly

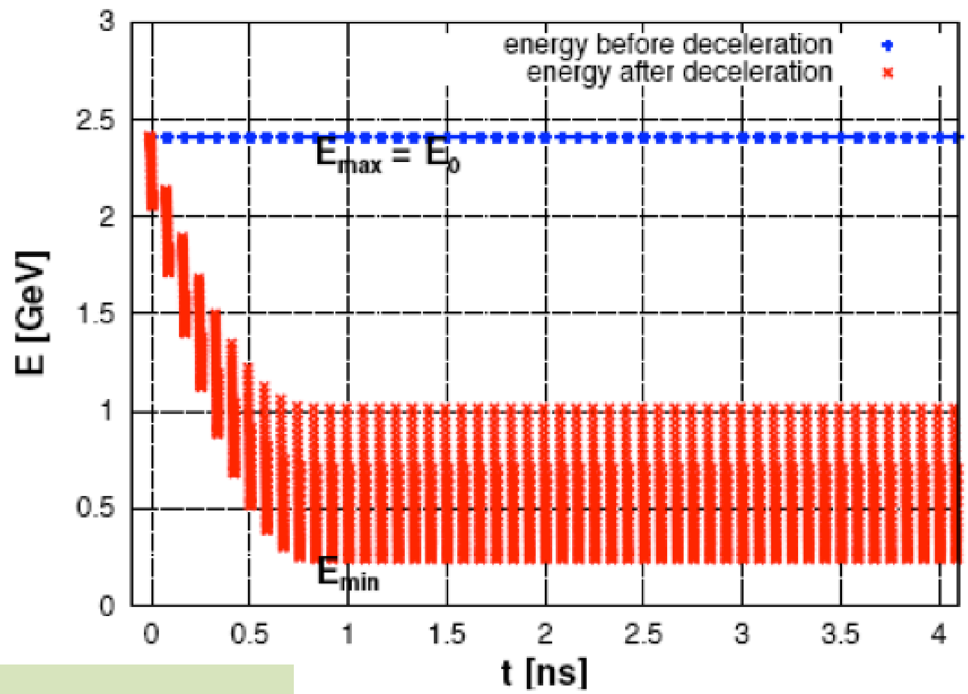
Structure design modified slightly TD26

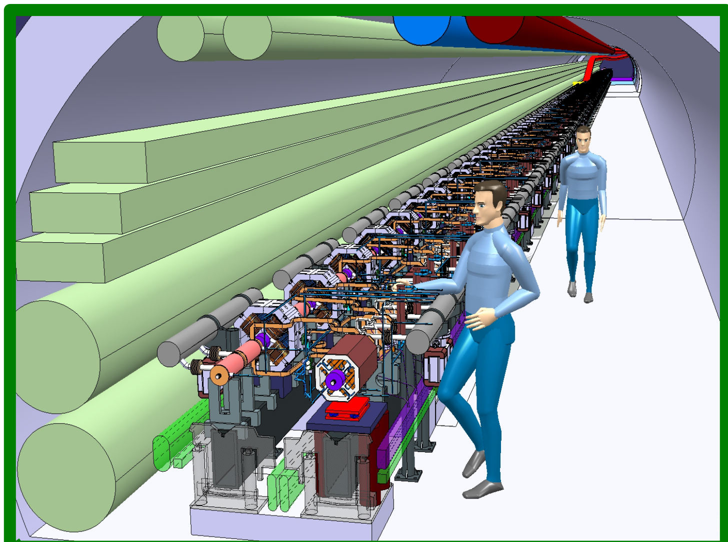
G. Riddone et al.

# Decelerator Design

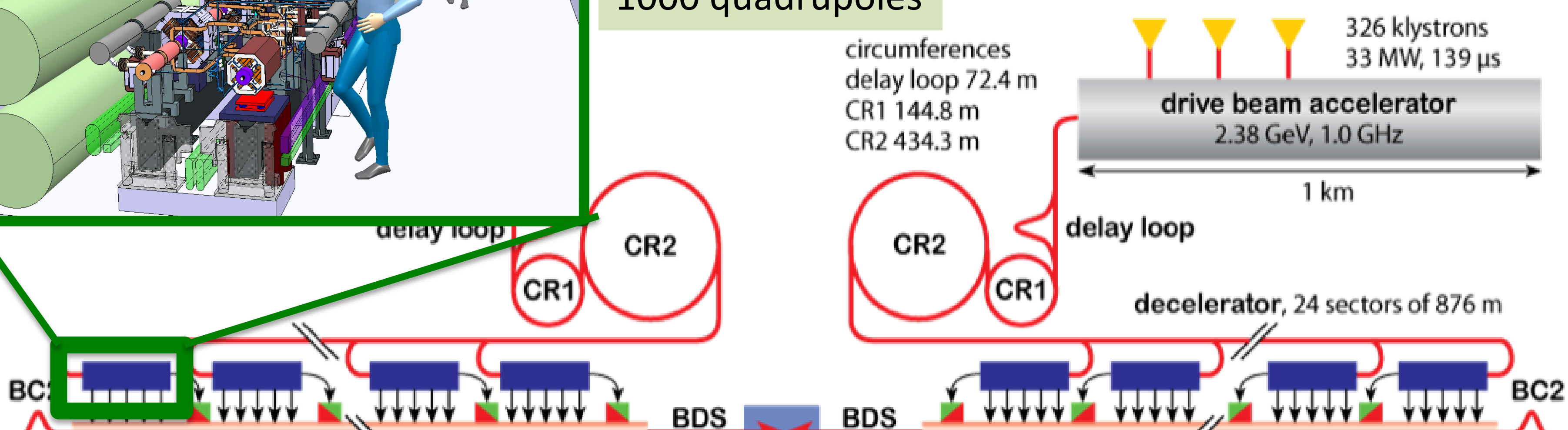
Avoid losses
- 100A, 2.4-0.24GeV beam
- aperture ≈ 10σ
- large energy spread
- significant wakefields

Design and simulations are OK

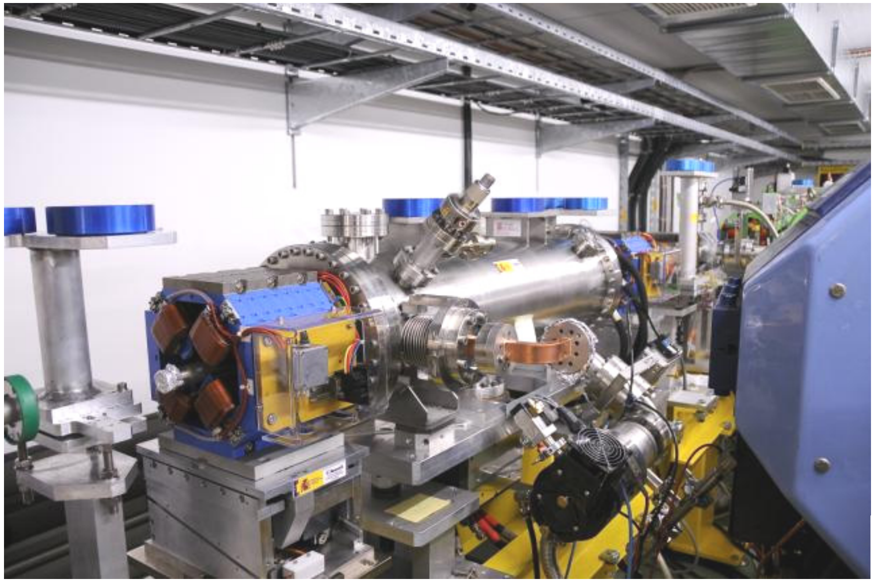


≈ 1km
1000 quadrupoles



# TBL: Drive Beam Deceleration



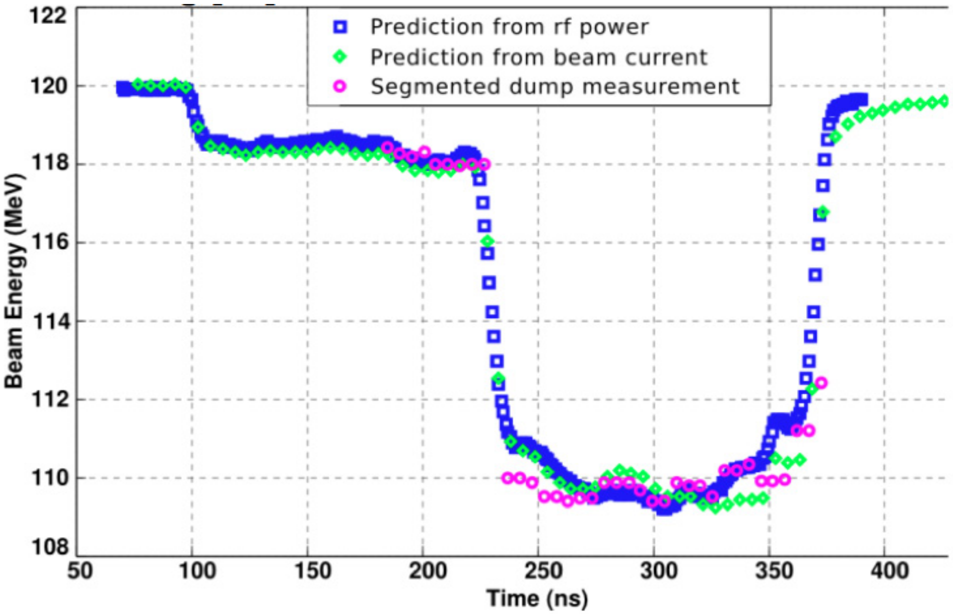
Goal is 50% deceleration

16 PETS maximum

4 PETS installed
4 to come in September
More next year

Up to 19A current
- optics understood
- no losses in TBL

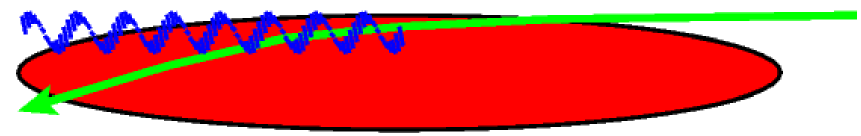
Good agreement
- power production
- beam current
- beam deceleration



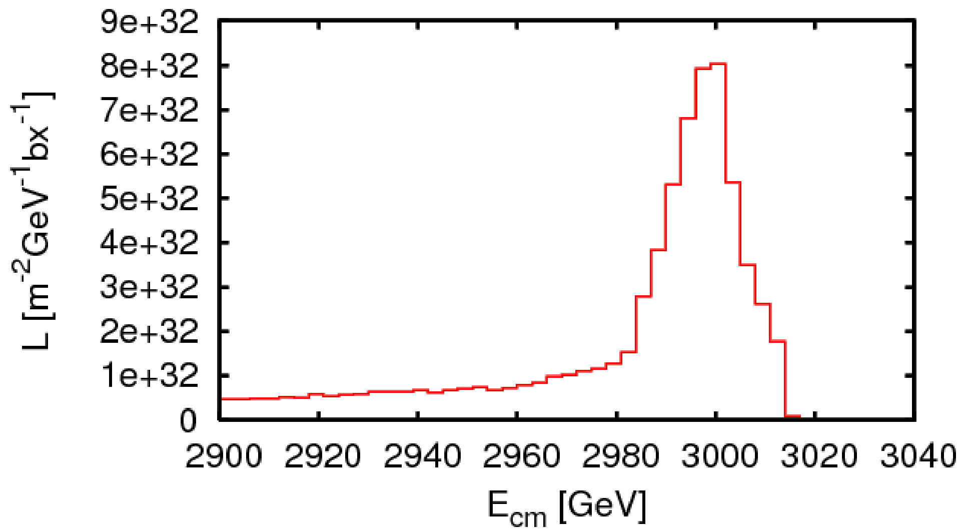

S. Doebert et al.

# Main Beam Emittances

| | $\epsilon_x$ [nm] | $\epsilon_y$ [nm] |
|---|---|---|
| Damping ring exit | 500 | 5 |
| RTML exit | 600 | 10 |
| main linac exit | 660 | 20 |



$$\mathcal{L} = H_D \frac{N^2}{4\pi\sigma_x\sigma_y} n_b f_r$$




$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$

Beam power

Luminosity spectrum

Beam Quality (+bunch length)

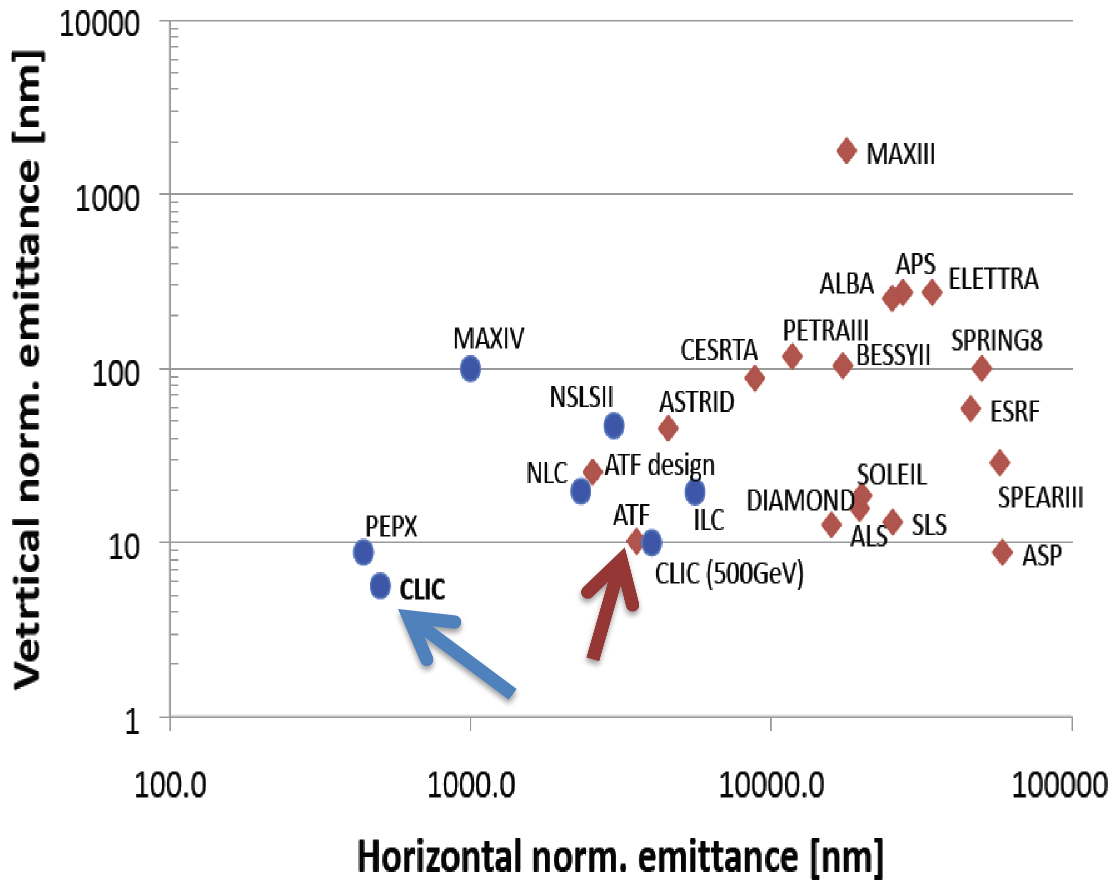
# Emittance Generation

Y. Papaphilippou et al.

Damping ring design is consistent with target performance

Many design issues addressed
- lattice design
- dynamic aperture
- tolerances
- intra-beam scattering
- space charge
- wigglers
- RF system
- vacuum
- electron cloud
- kickers

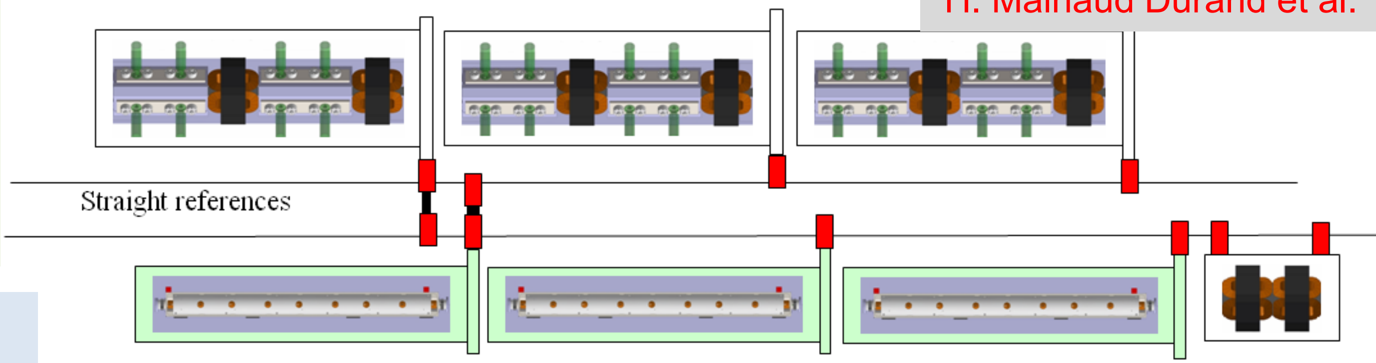
CLIC @3 TeV would achieve 40% of luminosity with ATF performance (3800nm/15nm@4e9)




ICFA Beam Dynamics Mini Workshop on Low Emittance Rings 2011
3-5 October 2011

# Main Linac Alignment Concept

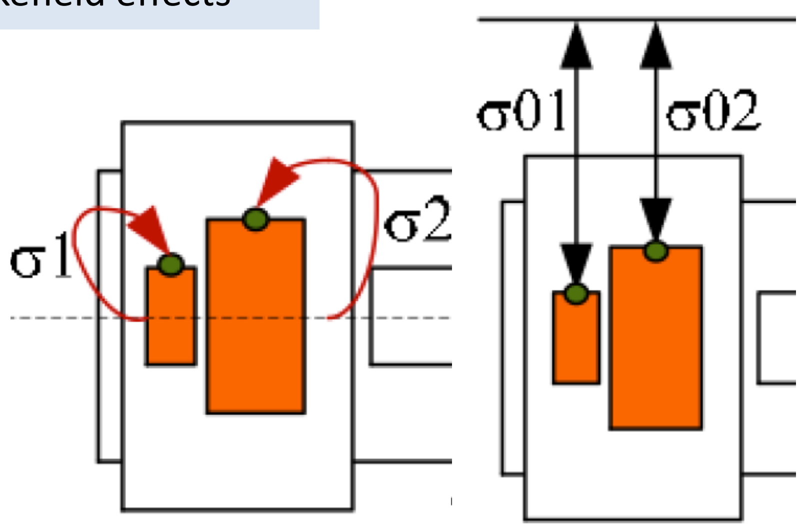

H. Mainaud Durand et al.




Pre-alignment O(10um)
- with wire system
- detailed model in simulations
- BPM shown as example

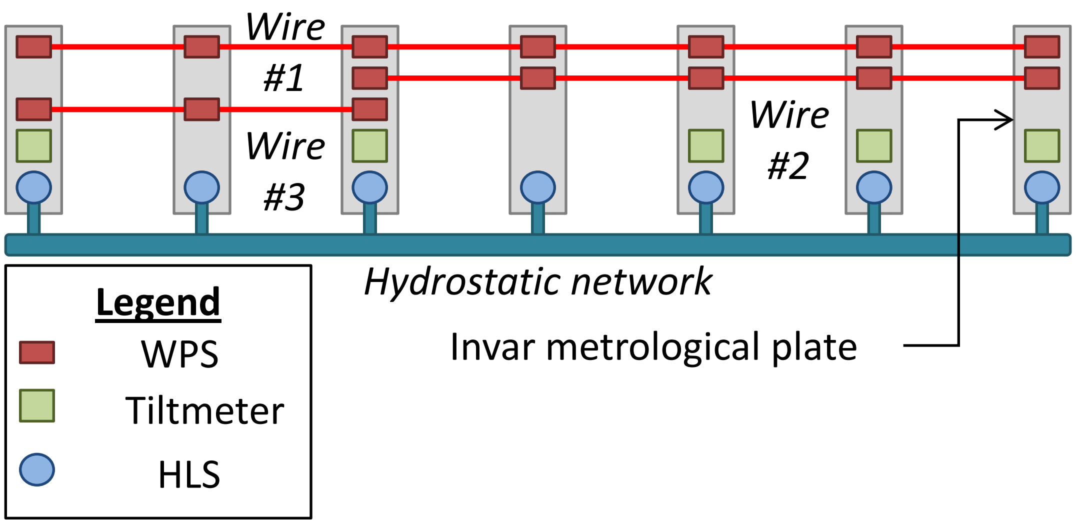
Dispersion free steering
- aligns BPMs and quadrupoles

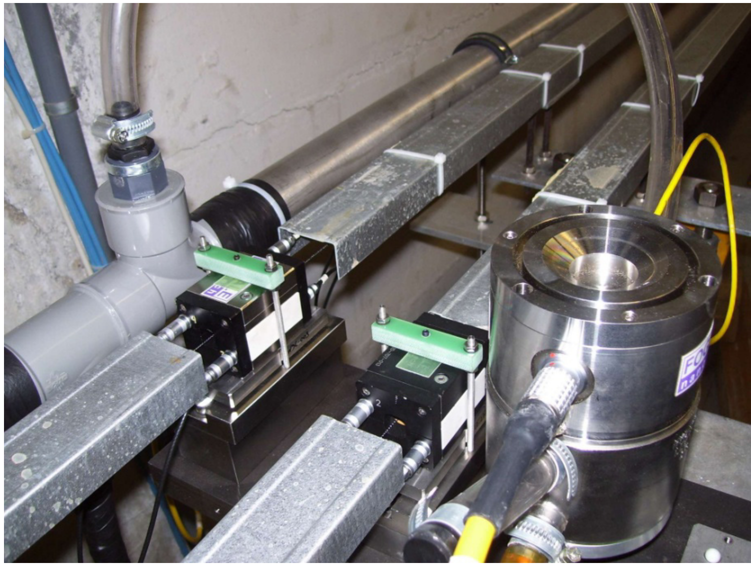
Move girders onto the beam
- use wakemonitors
- removes wakefield effects



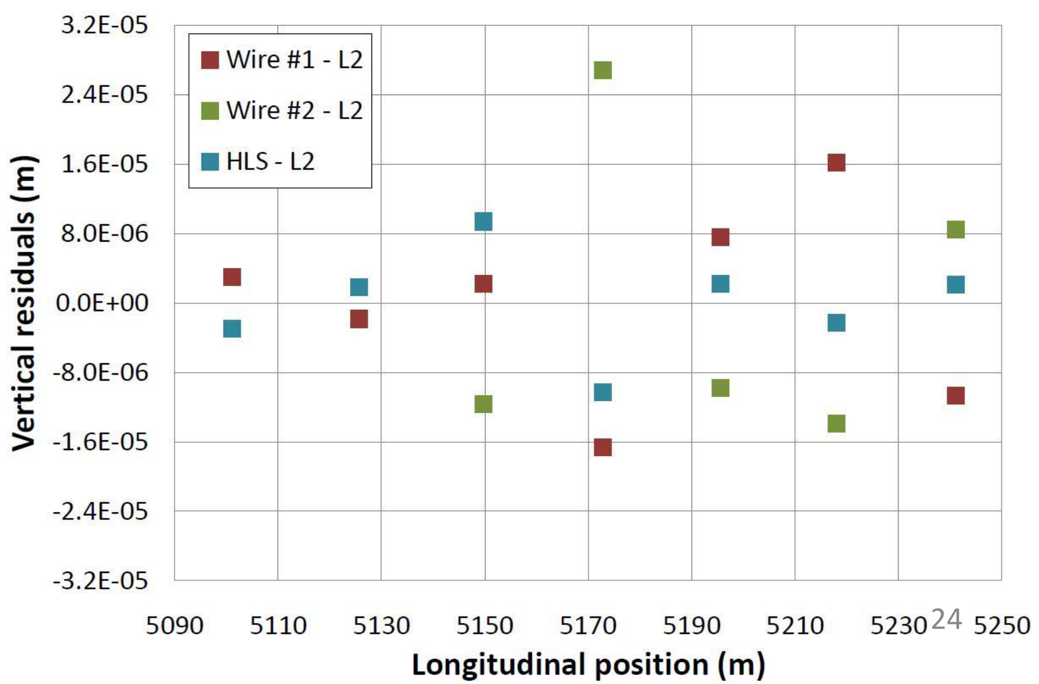

| BPM alignment errors | |
|---|---|
| Reference | 10µm |
| Sensor | 5µm |
| Sensor-cradle | 5µm |
| Cradle-BPM | 5µm |
| BPM internal | 5µm |
| TOTAL | 14µm |

# TT1 Alignment Results



- RMS error of 11µm found
  - accuracy is approx. 13.5µm
  - Target is 10µm
- More work remains to be done
  - Found two bad points due to mechanical problem
  - Stake-out error needs to be determined






Th. Touze et al.

# BDS Design and Alignment

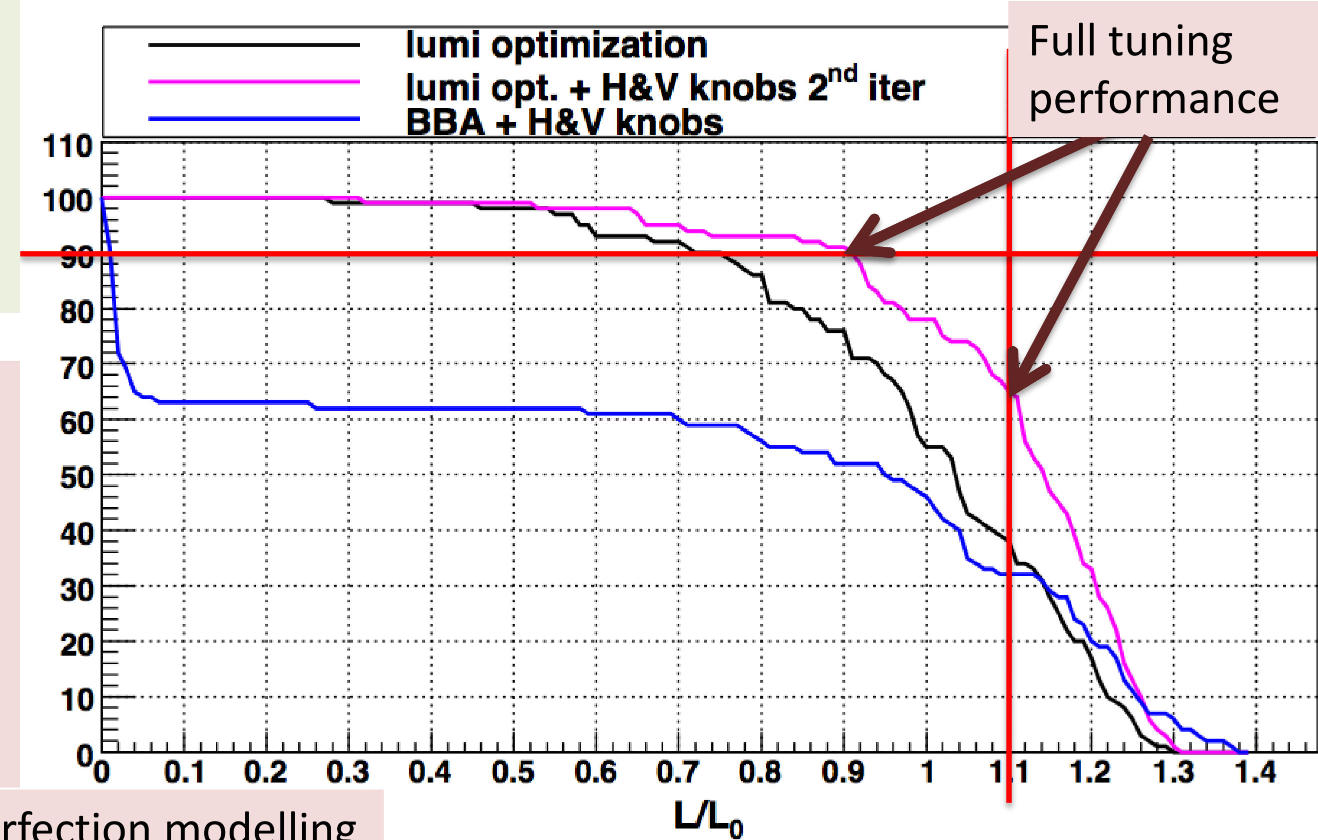
Main design issues
- chromaticity
- non-linear effects
- synchrotron radiation
- tuning
- stability

Static imperfections:
- Goal is $L \geq 110\% \ L_0$
- with probability of 90%

Convergence is slow
- faster method is being developed

Need more complete imperfection modelling
- independent sides
- field errors
- dynamic imperfections during tuning
- realistic signals

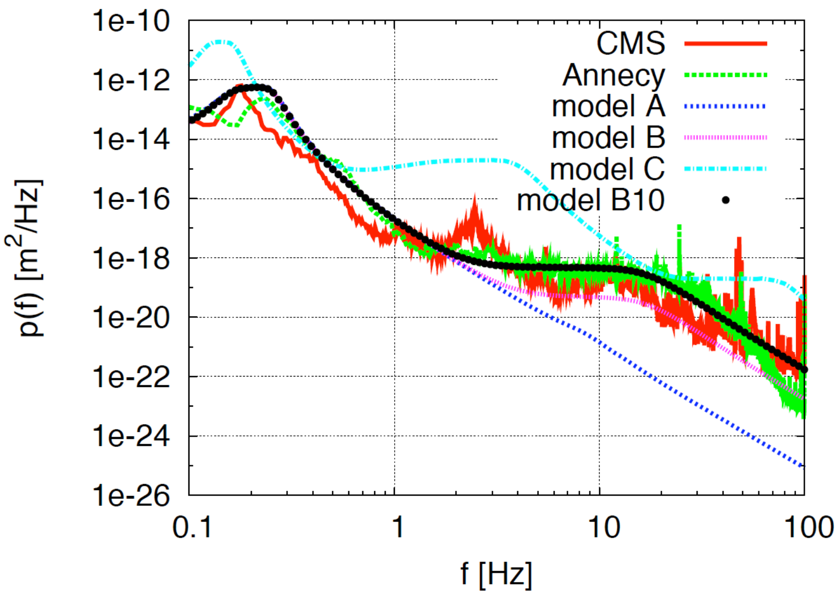
Including 10µm RMS misalignments

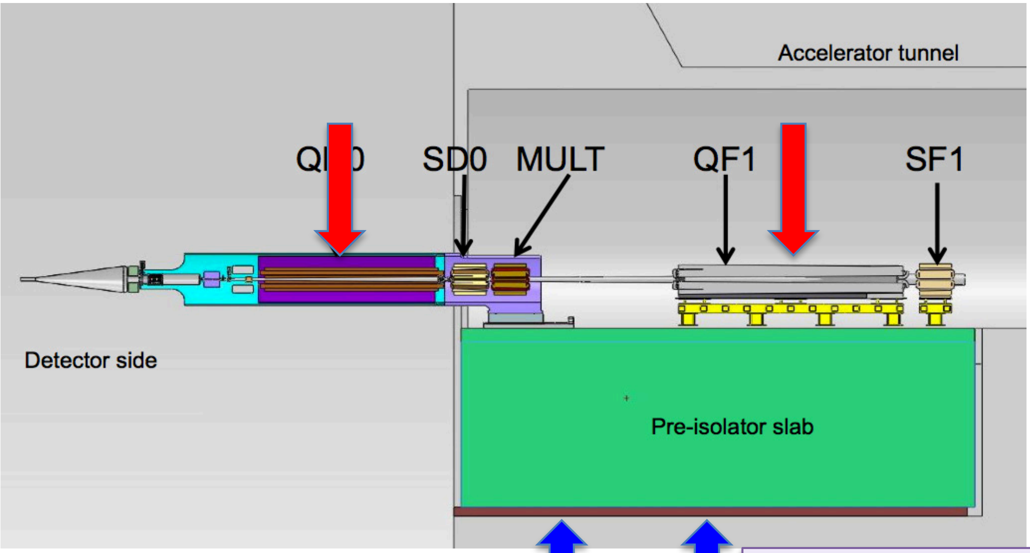



R. Tomas,
B. Dalena et al.

Tests programme at ATF2 at KEK

# Ground Motion and Its Mitigation



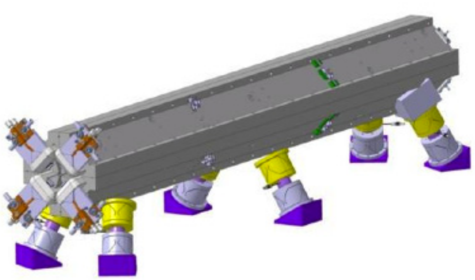



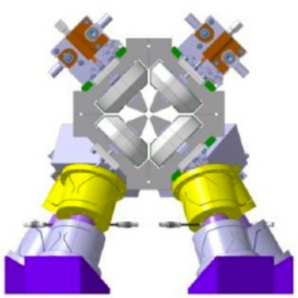

A. Gaddi et al.

Natural ground motion can impact the luminosity

- typical quadrupole jitter tolerance O(1nm) in main linac and O(0.1nm) in final doublet

-> develop stabilisation for beam guiding magnets

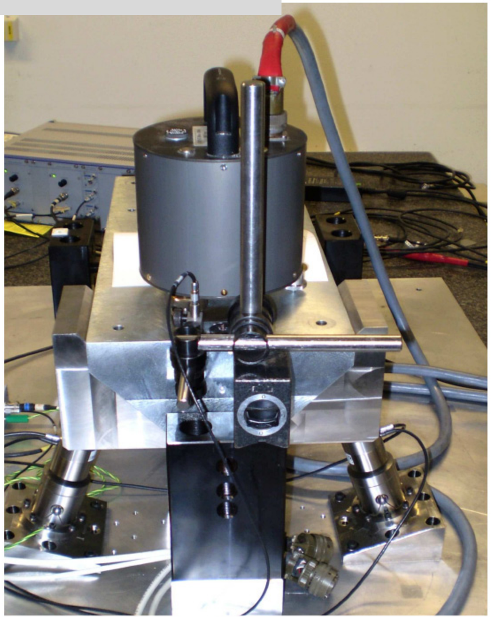


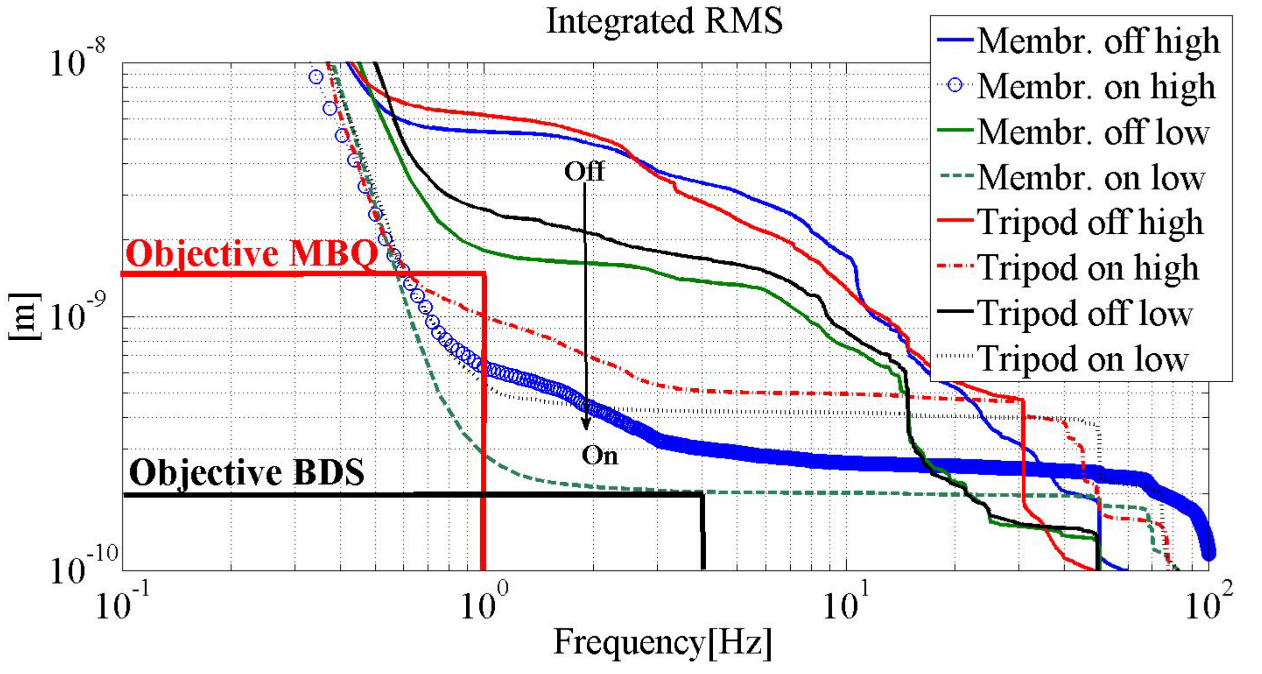


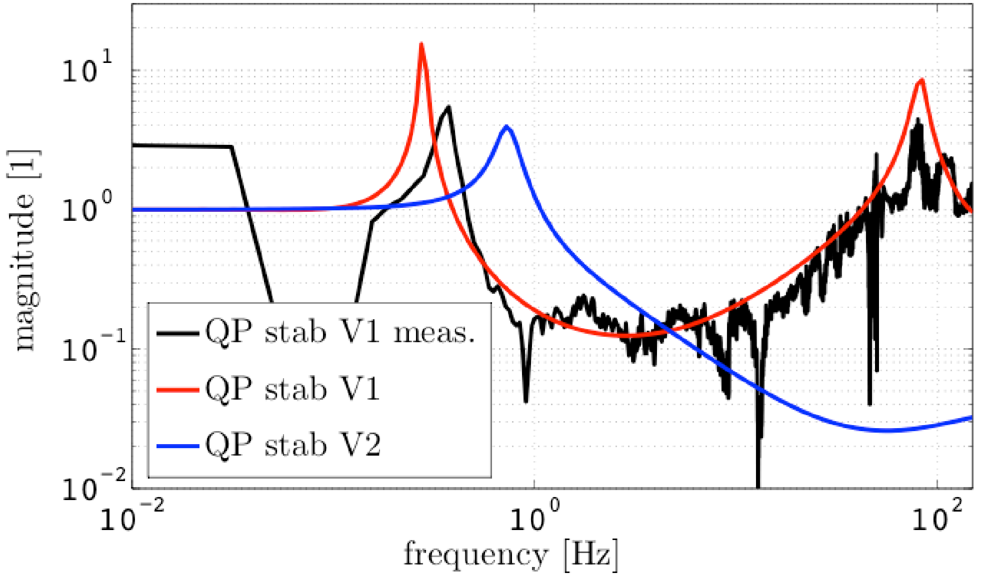
K. Artoos et al.

# Active Stabilisation Results

K. Artoos et al.






| Luminosity achieved/lost [%] | | |
|---|---|---|
| | A | B10 |
| No stab. | 119%/2% | 53%/68% |
| Current stab. | 116%/5% | 108%/13% |
| Future stab. | | 118%/3% |

J. Snuverink, J. Pfingstner

# Machine Protection/Operation

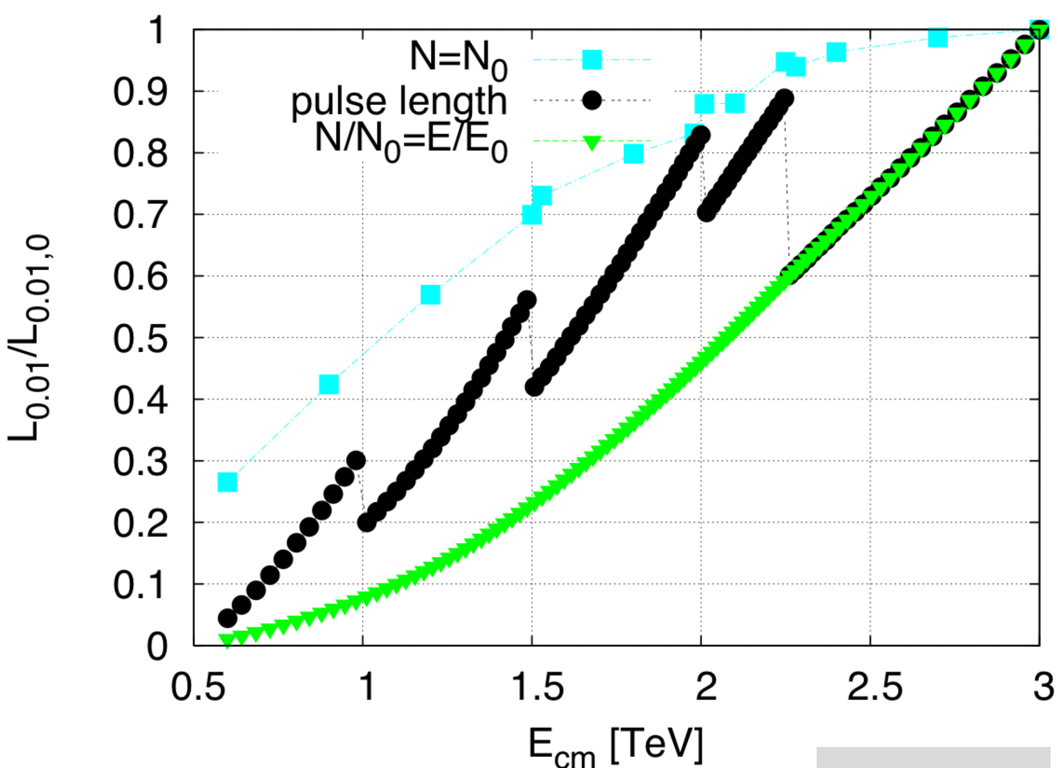
M. Jonker et al.

Machine protection concept
- inherently robust against fast failures
- detect slow failures

Most important example BDS collimation
- energy collimators supposed to take a pulse
- betatron collimators not

Concept for start-up developed
- based on CTF3/LHC experience

Concept developed to operate 3TeV-CLIC at lower energy for physics studies
- based on reduced beam current/longer pulses
- can cover factor 3 in energy

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# Outlook

Develop staged approach to project
- taking into account LHC and other findings
- e.g. start for Higgs and top then go up in energy

CLIC0, a facility with real prototypes
- prototypes of hardware components at real frequency
- final validation of drive beam quality/main beam emittance preservation
- facility for reception tests

More technical design
- many workpackages defined

| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | .... |
|---|---|---|---|---|---|---|---|---|---|
| Feasibility issues (Accelerator&Detector) | | | | | | | | | |
| Conceptual design & preliminary cost estimation | | | | | | | | | |
| Engineering, industrialisation & cost optimisation | | | | | | | | | ? |
| Project Preparation | | | | | | | | | |
| Project Implementation | | | | | | | | | ? |

# Conclusion

Conceptual Design Report is converging

Key issues have been addressed
- very good progress
- more work remains on some

A road to the future is visible
- please join and help
- ILC-CLIC workshop in Granada, September 26-30
- CLIC workpackage meeting at CERN, November 3-4

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