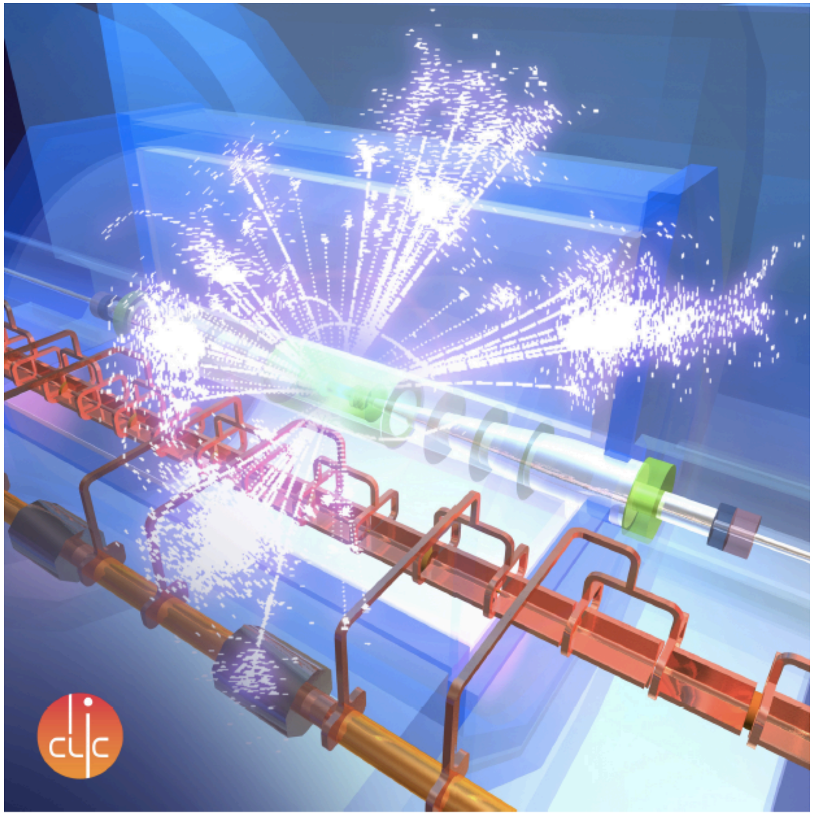
# The CLIC accelerator project



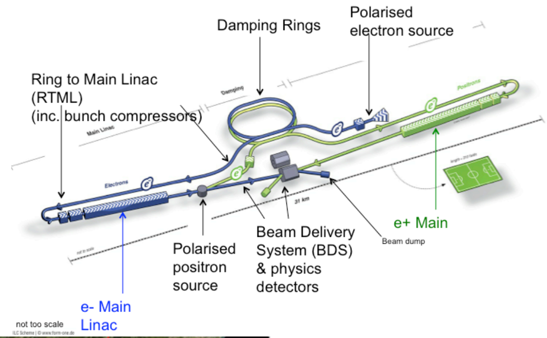
Lucie Linssen, CERN

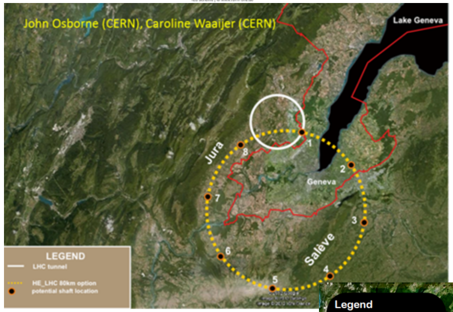
(material from Daniel Schulte and Steinar Stapnes)

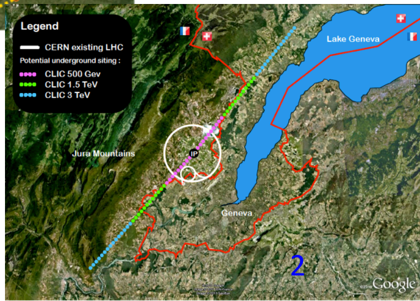
Como, miniworkshop, May 16+17 2013

# Context of the CLIC studies

- LHC and LHC luminosity upgrades (until ~2030)
  - Higgs and BSM physics
- ILC in Japan, a possibility for exploring the Higgs in detail, starting at 250 GeV
  - Requires significant integrated luminosities, energy increases in steps (at least to 500 GeV), also long programme
- What of New Physics shows up at LHC at 14 TeV (from 2015 onwards) ?
  - What are the best machines to access such physics directly post LHC …. we don't know but => prepare main options
  - Two alternatives considered, higher energy hadrons (HE-LHC or V-LHC), or highest possible energy e+e- (CLIC).




**CLIC is the only technology giving access to multi-TeV**

# European Strategy

**High-priority large-scale scientific activities**

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*

e) There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*

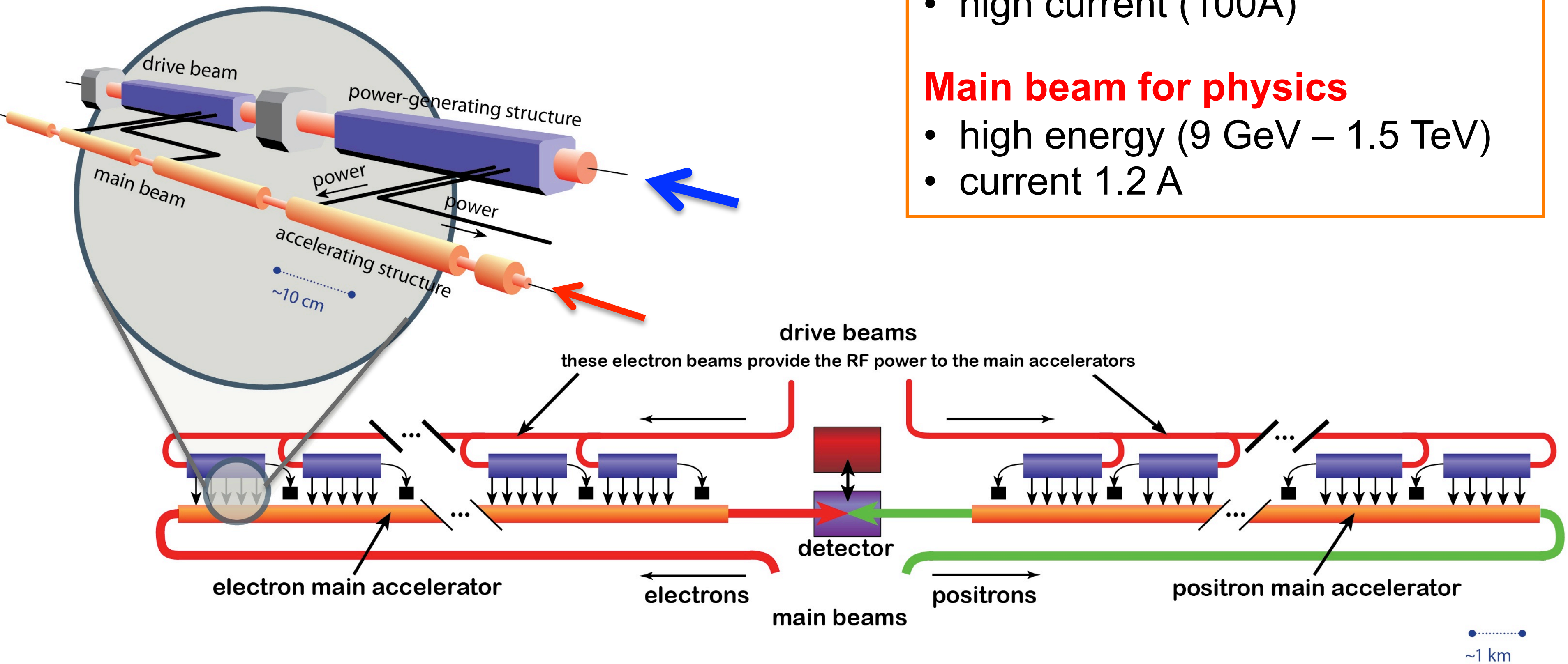
# CLIC two-beam acceleration scheme

**Two Beam Scheme:**

**Drive Beam supplies RF power**
- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

**Main beam for physics**
- high energy (9 GeV – 1.5 TeV)
- current 1.2 A

Accelerating gradient: 100 MV/m



# CLIC layout at 3 TeV

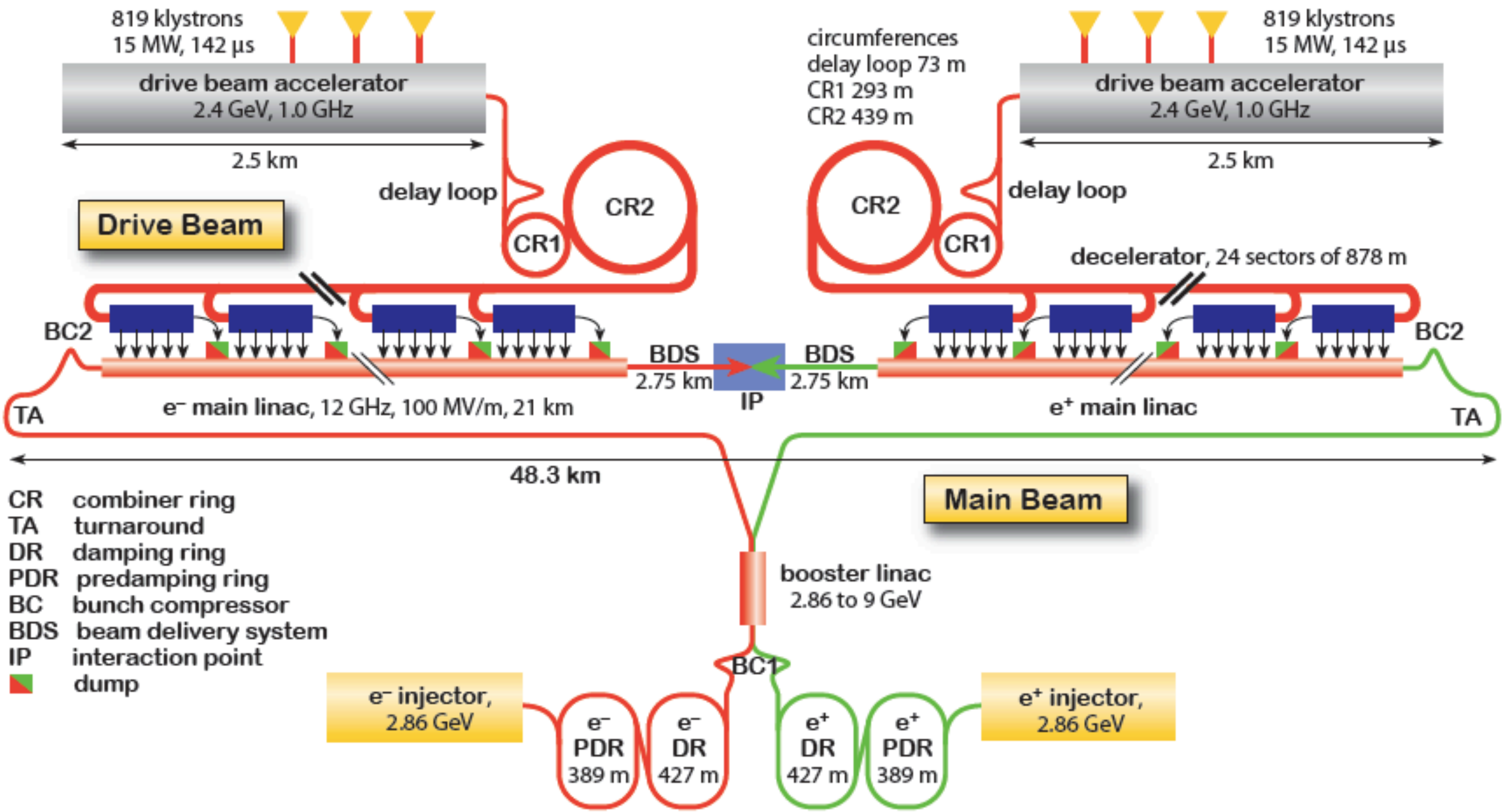
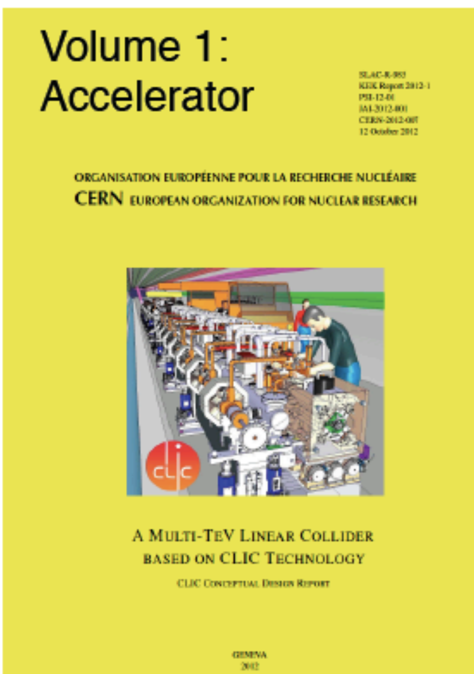
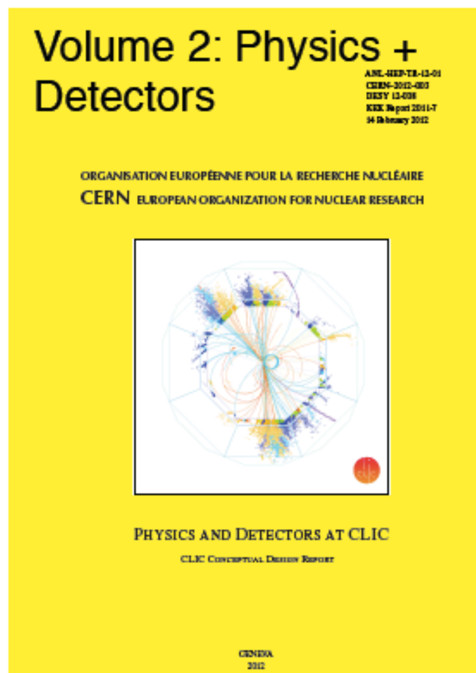


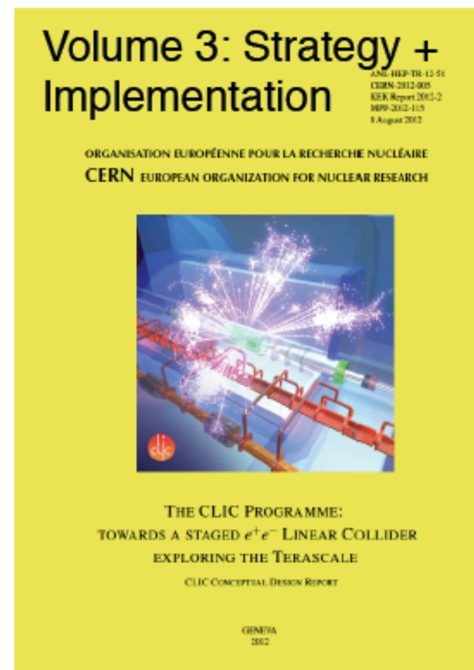

Fig. 3.1: Overview of the CLIC layout at $\sqrt{s} = 3$ TeV.

# CLIC conceptual design report

- **CLIC CDR** (#1), A Multi-TeV Linear Collider based on CLIC Technology, CERN-2012-003, https://edms.cern.ch/document/1234244/
- **CLIC CDR** (#2), Physics and Detectors at CLIC, CERN-2012-003, arXiv:1202.5940
- **CLIC CDR** (#3), The CLIC Programme: towards a staged $e^+e^-$ Linear Collider exploring the Terascale, CERN-2012-005, http://arxiv.org/abs/1209.2543

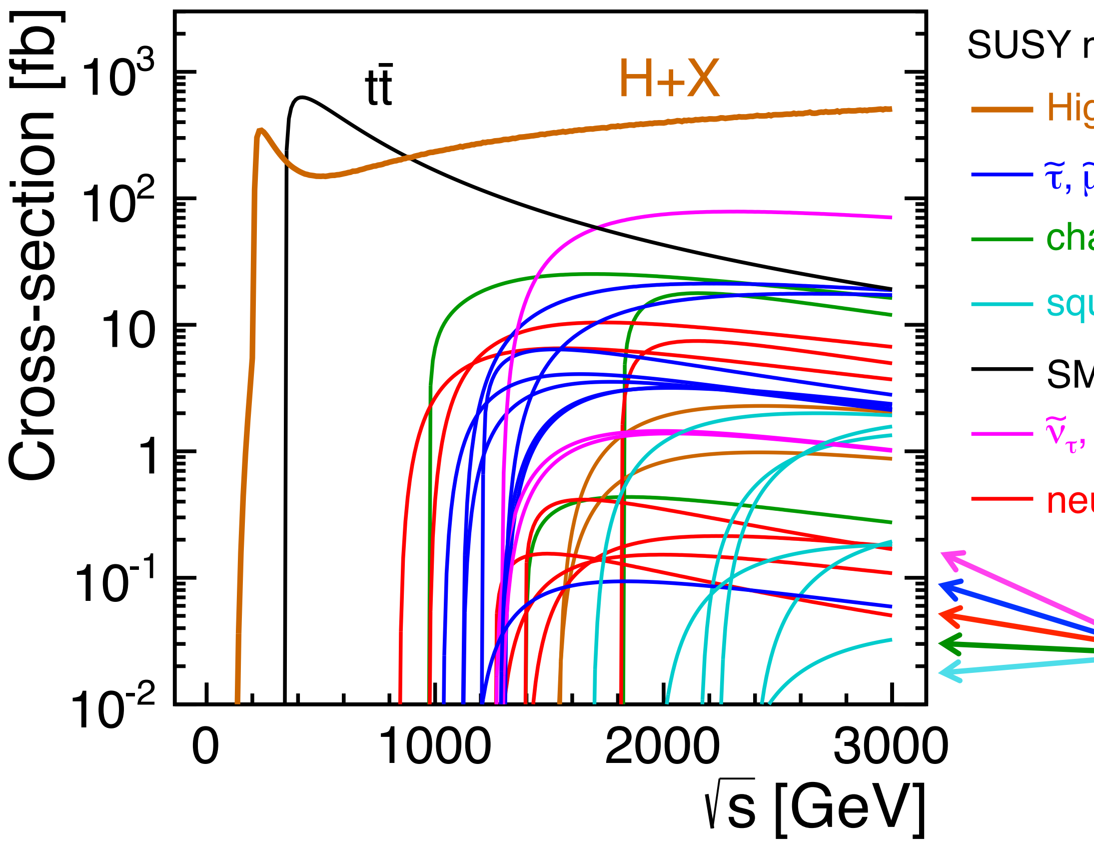


# Physics at CLIC

- Precision SM measurements: Higgs, top → √s≲350 GeV, and up to 3 TeV
- Discovery (direct searches) of new physics at TeV scale,
  unique sensitivity to particles with electroweak charge
- New Physics model discrimination through precision measurements



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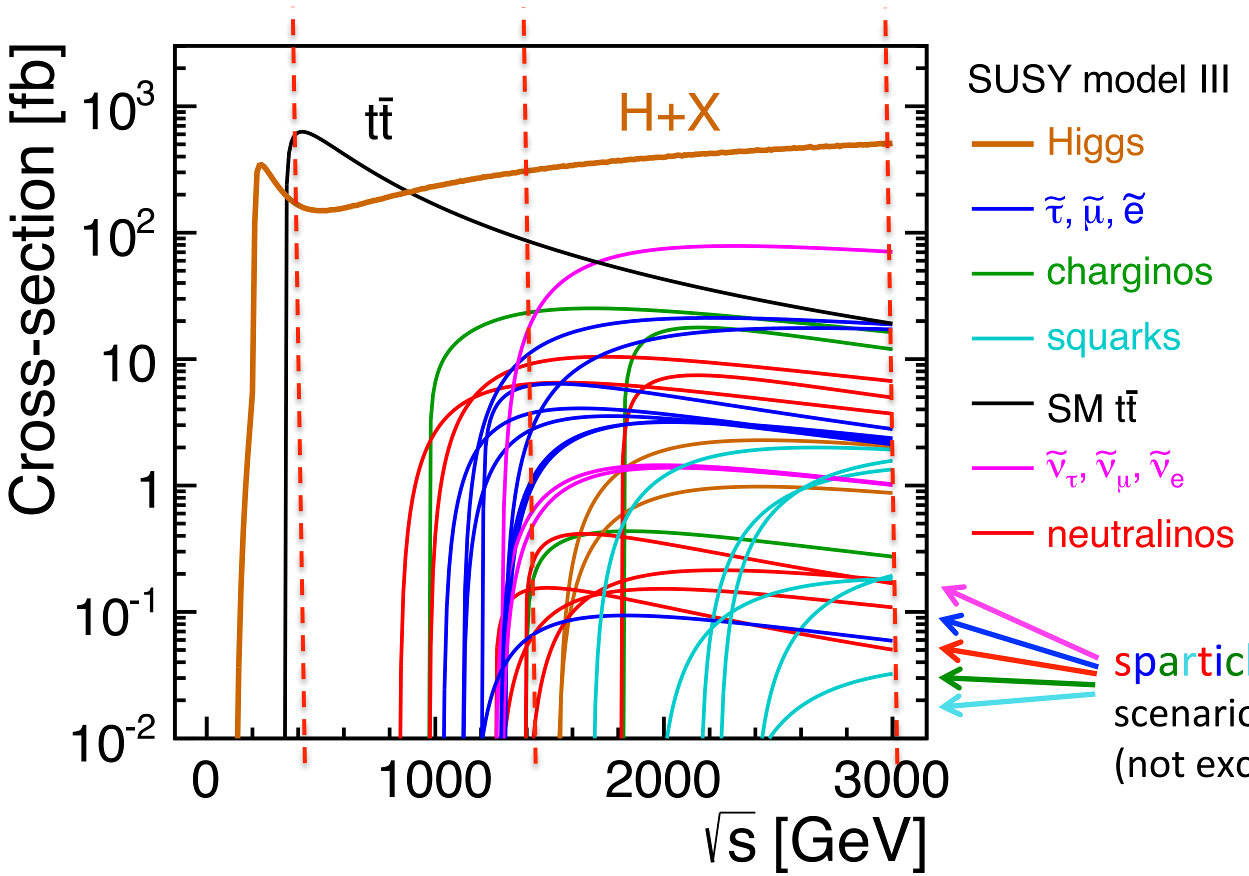
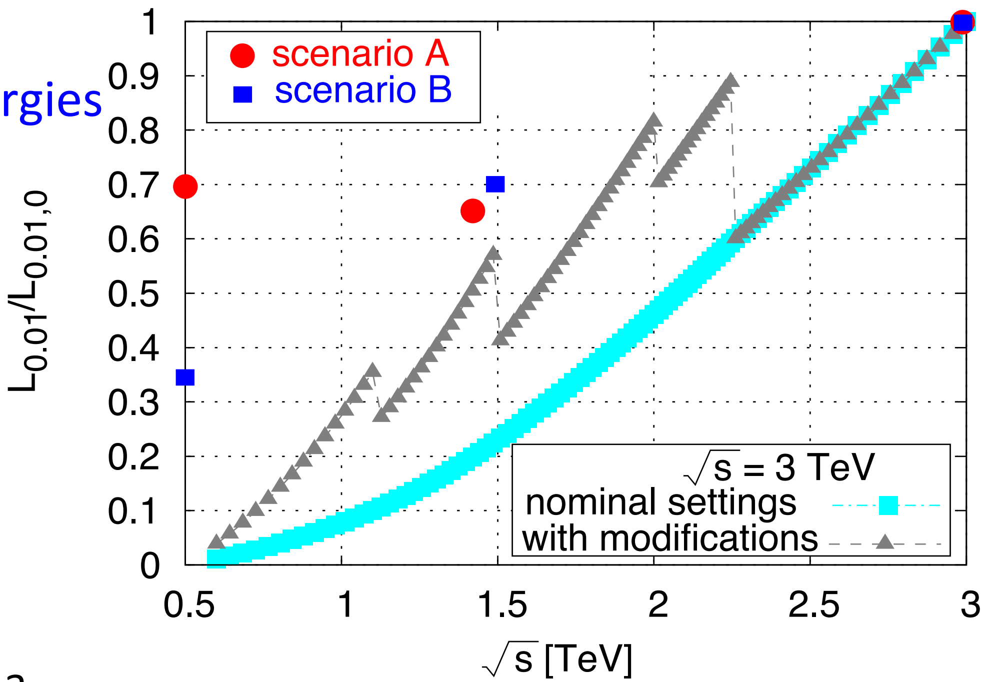



sparticles in **SUSY** example scenario (not excluded by LHC results)

# Motivation for energy staging

**CLIC physics potential:**

- Interesting physics at various CM energies
- Most studies require high luminosity




At each energy stage, the centre-of-mass energy can be tuned down by a factor ~3 with limited luminosity loss (e.g. for threshold scans)

Making optimal use of the capacities (luminosity) of CLIC, this is best studied with a **collider built in a few successive energy stages**.

The optimal choice of the actual energy stages will depend on the physics scenario, driven by 8 TeV + 14 TeV LHC results.

The scenarios "A" and "B" are therefore **"just examples"**

# Staged approach, scenario A+B

A

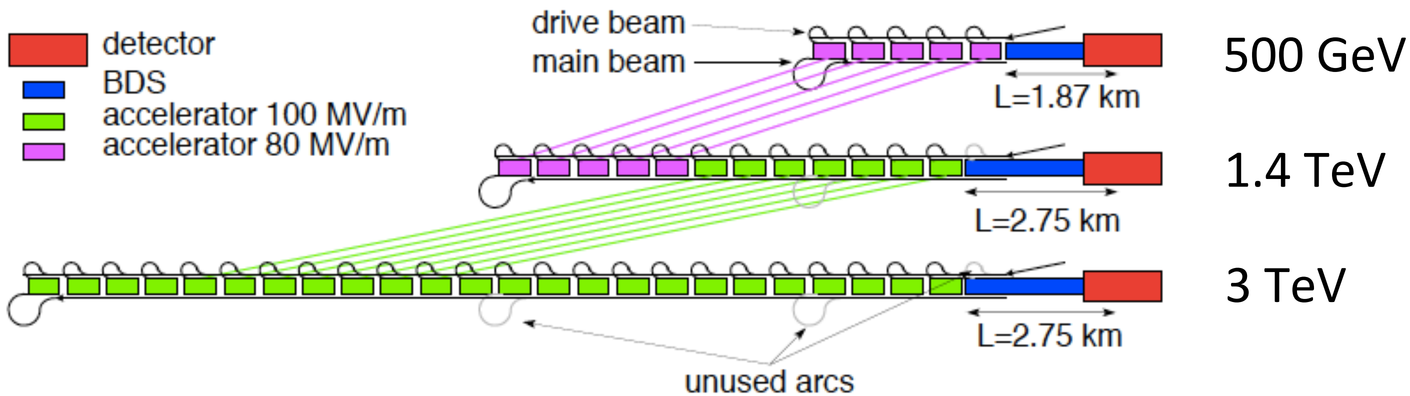
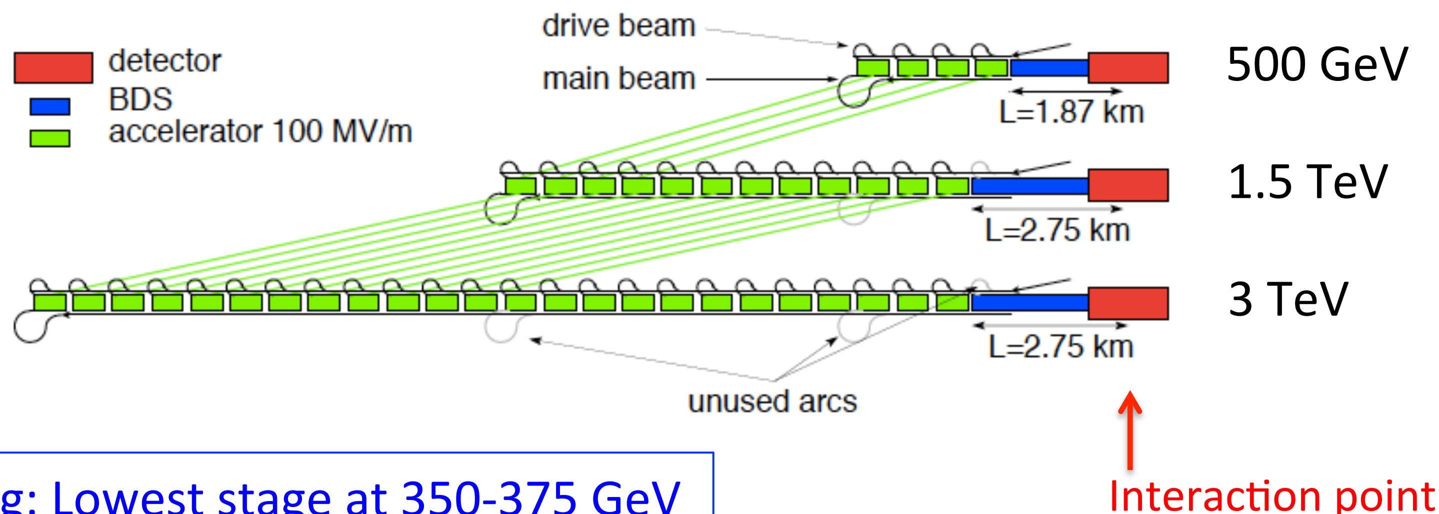



Fig. 3.5: Simplified upgrade scheme for CLIC staging scenario A. The coloured lines indicate the required movement of the modules from one stage to the next.

B




Current thinking: Lowest stage at 350-375 GeV to cover Higgs and top physics

# CLIC layout at 500 GeV

Only one drive beam complex needed up to 1.4/1.5 TeV

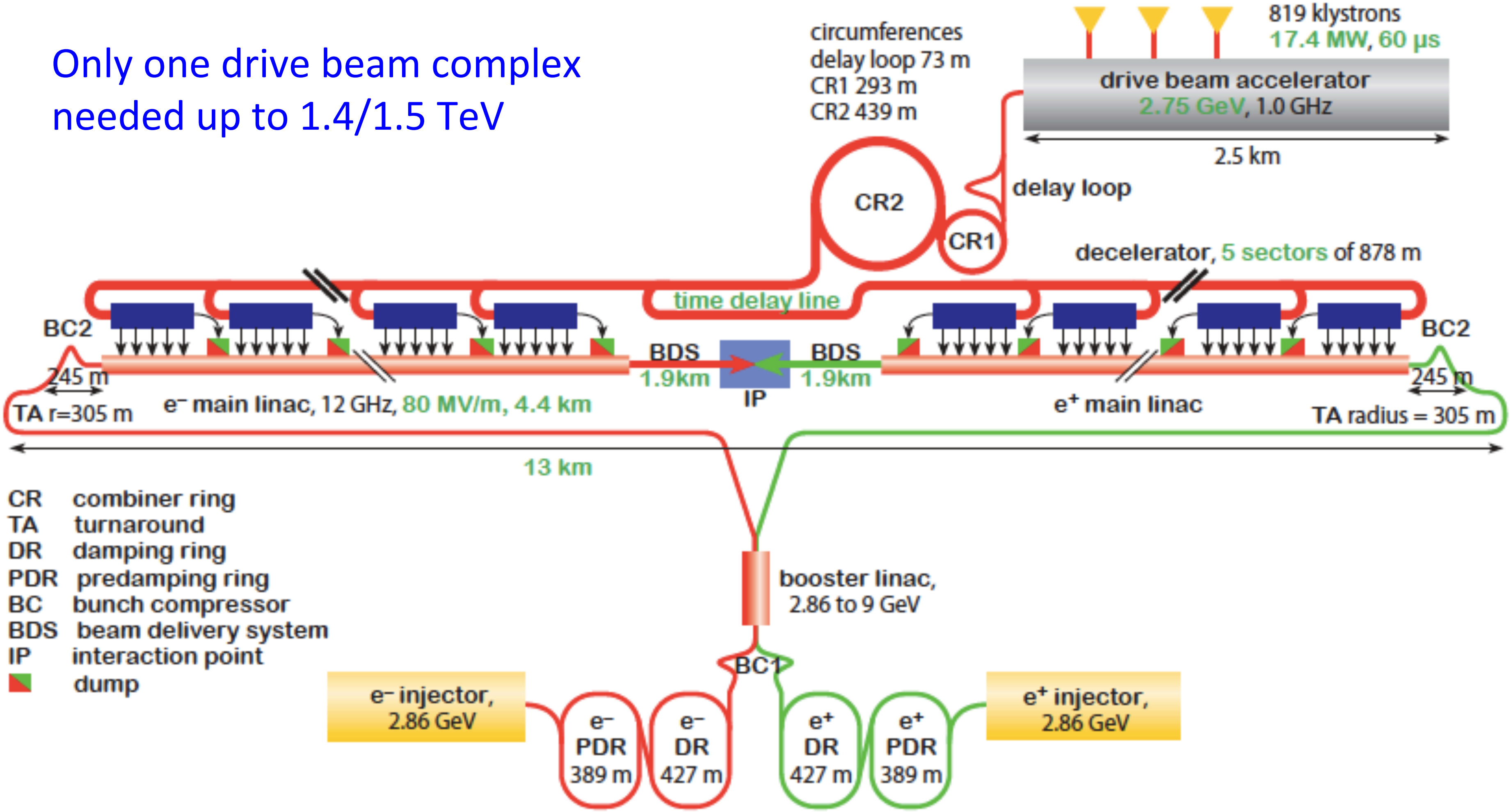



Fig. 3.2: Overview of the CLIC layout at $\sqrt{s}$ =500 GeV. (scenario A)

# Parameters, scenario A

Table 3.3: Parameters for the CLIC energy stages of scenario A.

| Parameter | Symbol | Unit | | | |
|---|---|---|---|---|---|
| Centre-of-mass energy | $\sqrt{s}$ | GeV | 500 | 1400 | 3000 |
| Repetition frequency | $f_{rep}$ | Hz | 50 | 50 | 50 |
| Number of bunches per train | $n_b$ | | 354 | 312 | 312 |
| Bunch separation | $\Delta_t$ | ns | 0.5 | 0.5 | 0.5 |
| Accelerating gradient | $G$ | MV/m | 80 | 80/100 | 100 |
| Total luminosity | $\mathscr{L}$ | $10^{34}$ cm$^{-2}$s$^{-1}$ | 2.3 | 3.2 | 5.9 |
| Luminosity above 99% of $\sqrt{s}$ | $\mathscr{L}_{0.01}$ | $10^{34}$ cm$^{-2}$s$^{-1}$ | 1.4 | 1.3 | 2 |
| Main tunnel length | | km | 13.2 | 27.2 | 48.3 |
| Charge per bunch | $N$ | $10^9$ | 6.8 | 3.7 | 3.7 |
| Bunch length | $\sigma_z$ | μm | 72 | 44 | 44 |
| IP beam size | $\sigma_x/\sigma_y$ | nm | 200/2.6 | $\approx$ 60/1.5 | $\approx$ 40/1 |
| Normalised emittance (end of linac) | $\varepsilon_x/\varepsilon_y$ | nm | 2350/20 | 660/20 | 660/20 |
| Normalised emittance (IP) | $\varepsilon_x/\varepsilon_y$ | nm | 2400/25 | — | — |
| Estimated power consumption | $P_{wall}$ | MW | 272 | 364 | 589 |

# Parameters, scenario B

Table 3.4: Parameters for the CLIC energy stages of scenario B.

| Parameter | Symbol | Unit | | | |
|---|---|---|---|---|---|
| Centre-of-mass energy | $\sqrt{s}$ | GeV | 500 | 1500 | 3000 |
| Repetition frequency | $f_{rep}$ | Hz | 50 | 50 | 50 |
| Number of bunches per train | $n_b$ | | 312 | 312 | 312 |
| Bunch separation | $\Delta_t$ | ns | 0.5 | 0.5 | 0.5 |
| Accelerating gradient | $G$ | MV/m | 100 | 100 | 100 |
| Total luminosity | $\mathscr{L}$ | $10^{34}$ cm$^{-2}$s$^{-1}$ | 1.3 | 3.7 | 5.9 |
| Luminosity above 99% of $\sqrt{s}$ | $\mathscr{L}_{0.01}$ | $10^{34}$ cm$^{-2}$s$^{-1}$ | 0.7 | 1.4 | 2 |
| Main tunnel length | | km | 11.4 | 27.2 | 48.3 |
| Charge per bunch | $N$ | $10^9$ | 3.7 | 3.7 | 3.7 |
| Bunch length | $\sigma_z$ | µm | 44 | 44 | 44 |
| IP beam size | $\sigma_x/\sigma_y$ | nm | 100/2.6 | $\approx$ 60/1.5 | $\approx$ 40/1 |
| Normalised emittance (end of linac) | $\epsilon_x/\epsilon_y$ | nm | — | 660/20 | 660/20 |
| Normalised emittance | $\epsilon_x/\epsilon_y$ | nm | 660/25 | — | — |
| Estimated power consumption | $P_{wall}$ | MW | 235 | 364 | 589 |

# Integrated luminosity

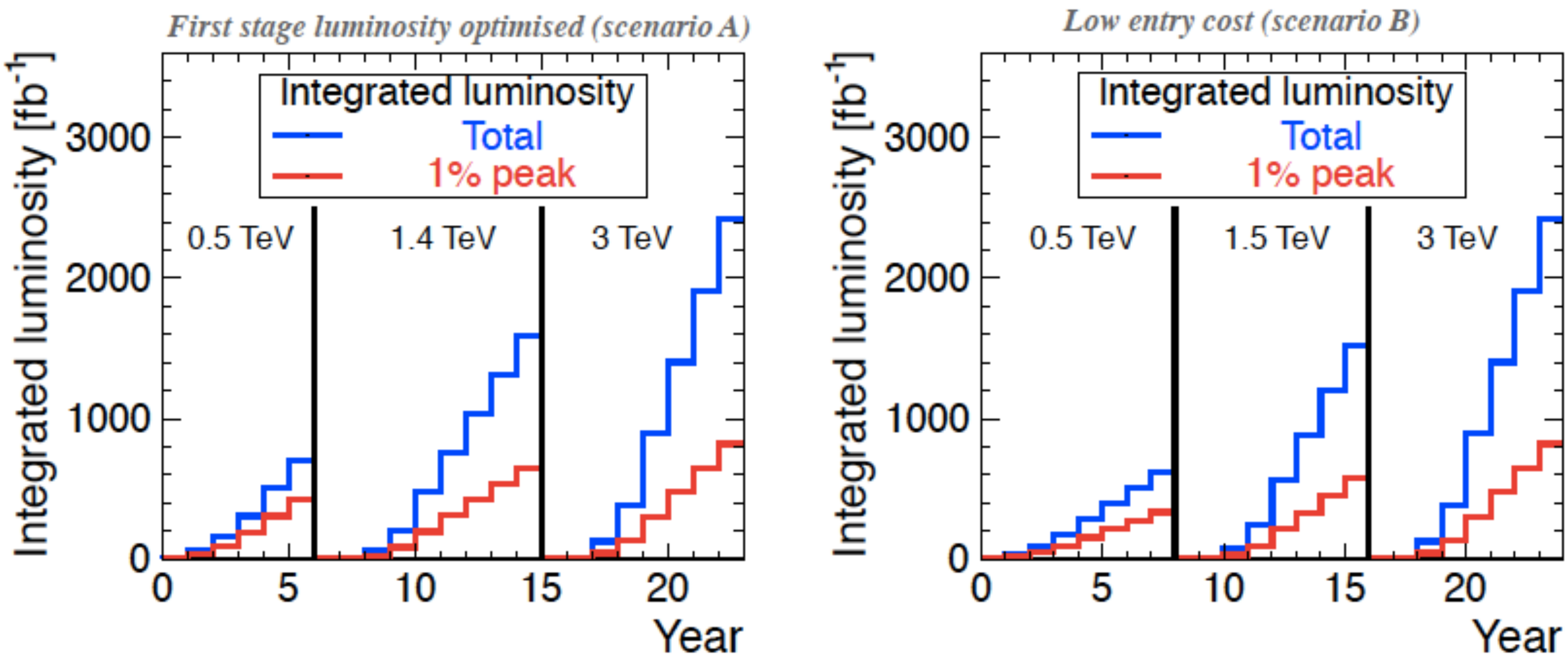



Fig. 5.2: Integrated luminosity in the scenarios optimised for luminosity in the first energy stage (left) and optimised for entry costs (right). Years are counted from the start of beam commissioning. These figures include luminosity ramp-up of four years (5%, 25%, 50%, 75%) in the first stage and two years (25%, 50%) in subsequent stages.

Based on 200 days/year at 50% efficiency (accelerator + data taking combined)
Target figures: >600 fb$^{-1}$ at first stage, 1.5 ab$^{-1}$ at second stage, 2 ab$^{-1}$ at third stage

# Scheduling of installation/operation

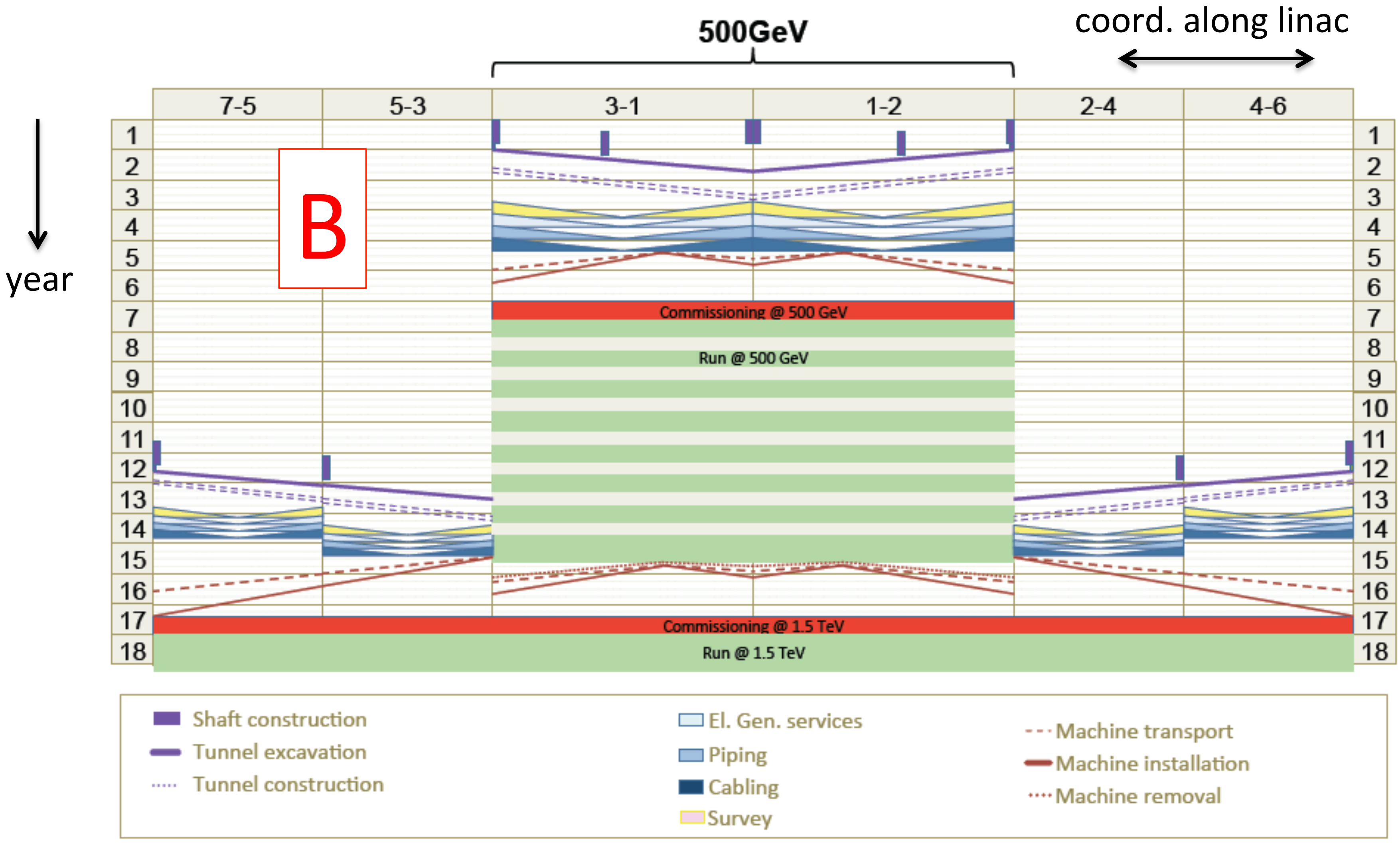
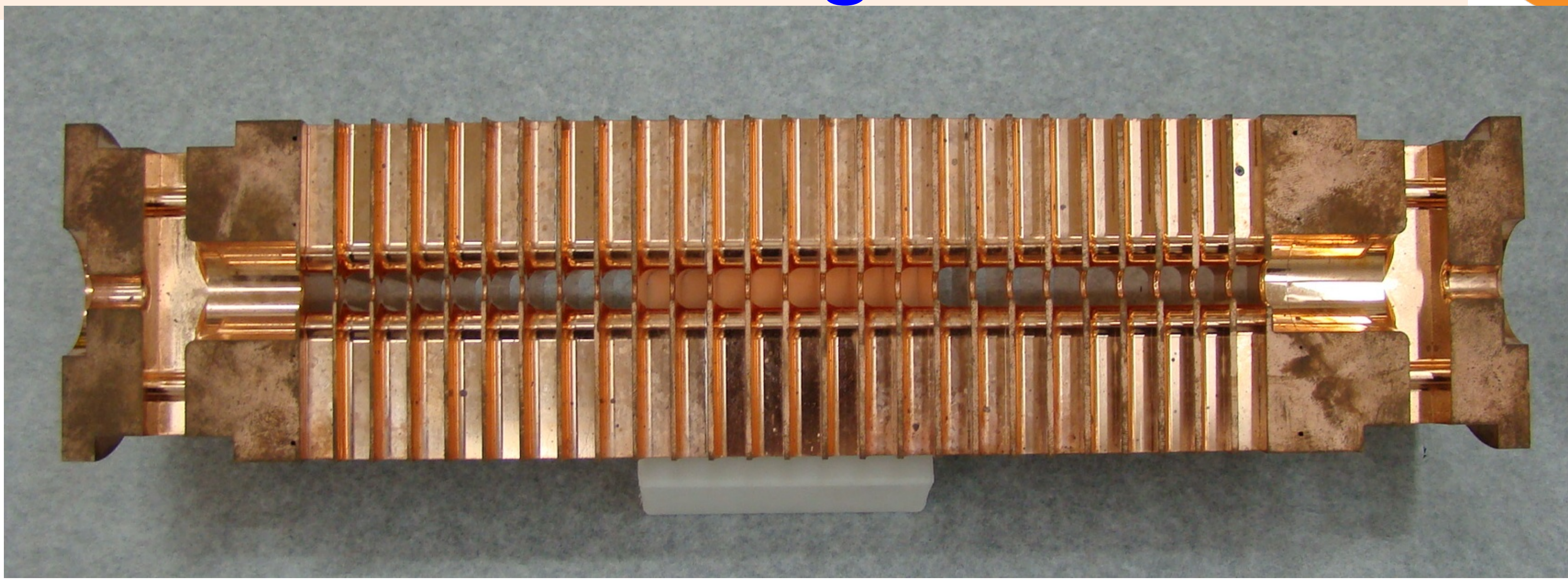



Fig. 5.4: Overall "railway" schedule for the first two stages of scenario B. The same conventions as in Figure 5.3 are used.

# CLIC accelerating structure

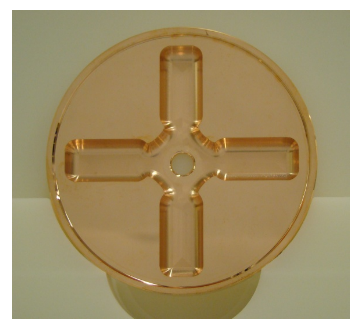


Loaded gradient 100MV/m

Require (soft) breakdown probability
prob. ≤ $3x10^{-7}m^{-1}pulse^{-1}$

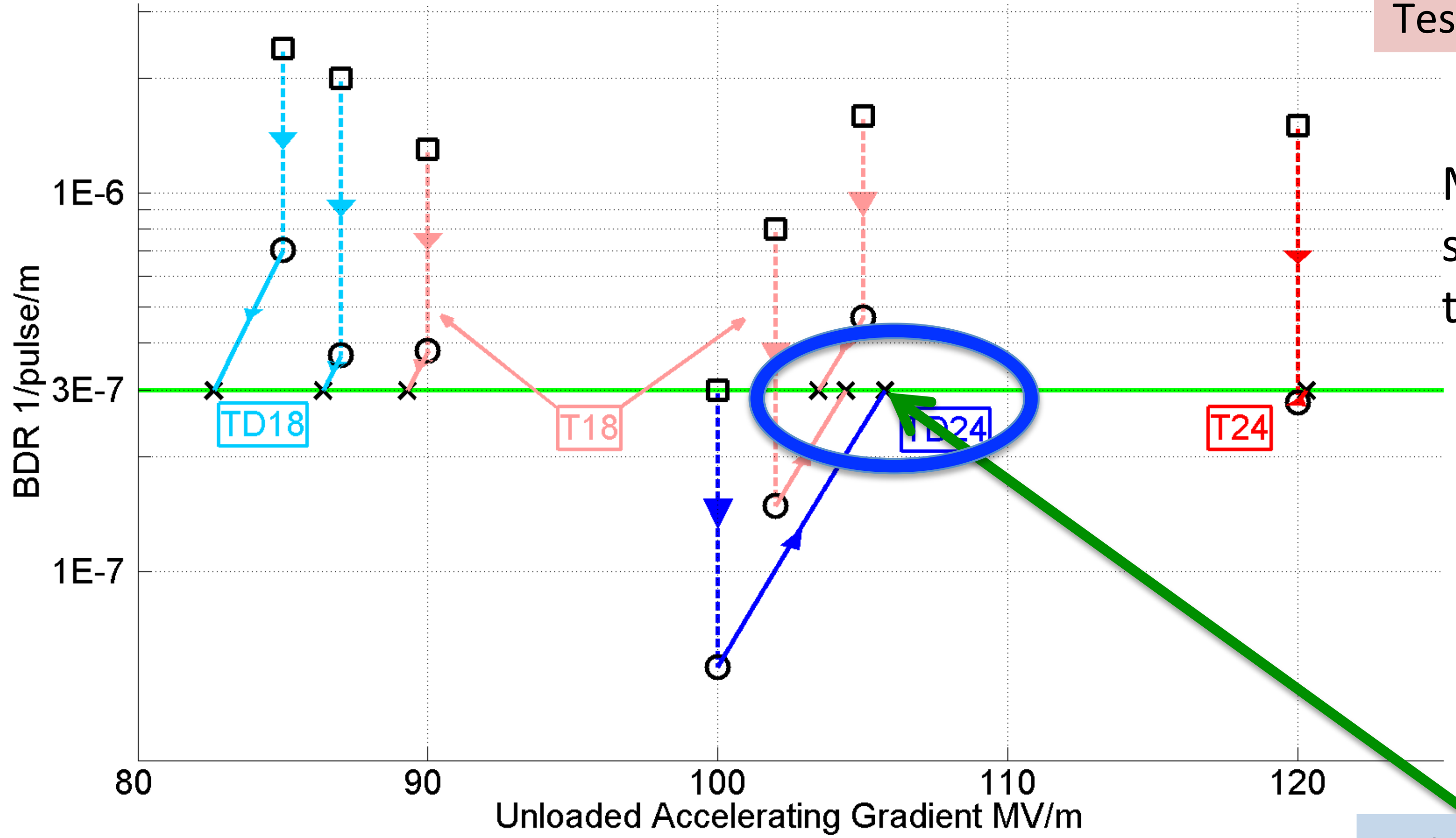
Structure design based on empirical constraints, not first principle

Experiments are essential to confirm the structure performance



# Achieved gradient for CLIC

Tests at KEK and SLAC



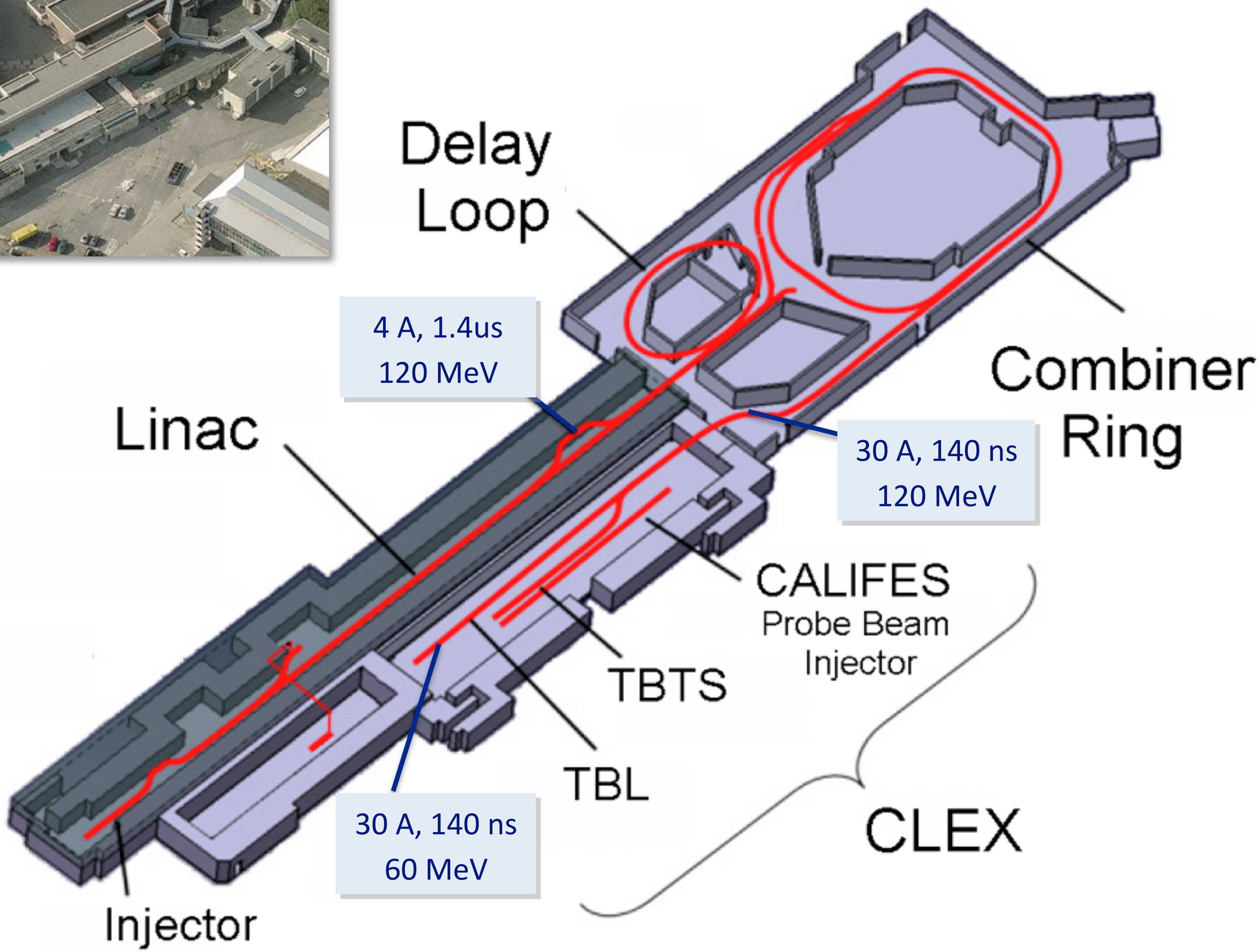

Measurements scaled according to

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

Unloaded 106MV/m
With loading 0-16% less

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

# CLIC Test Facility (CTF3)



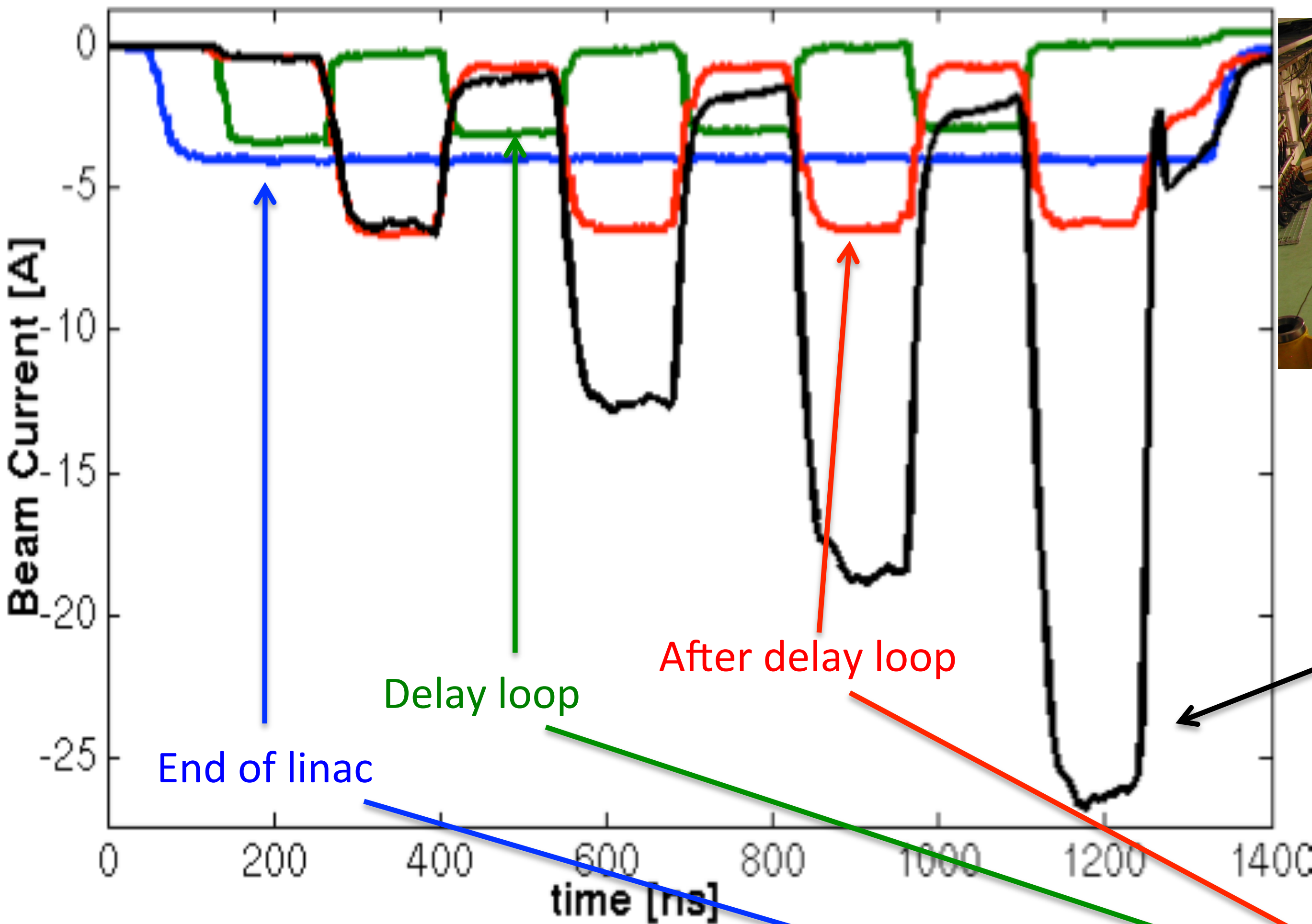
# Test-facilities

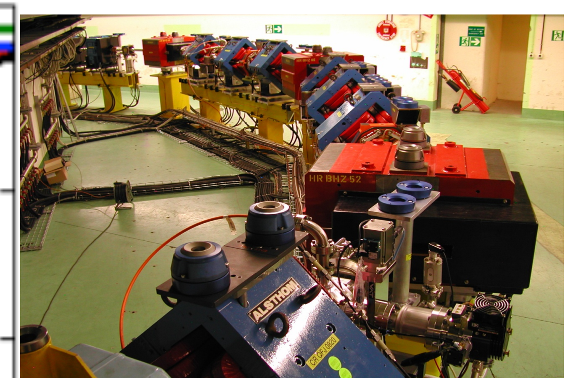
Several other test-facilities are important:

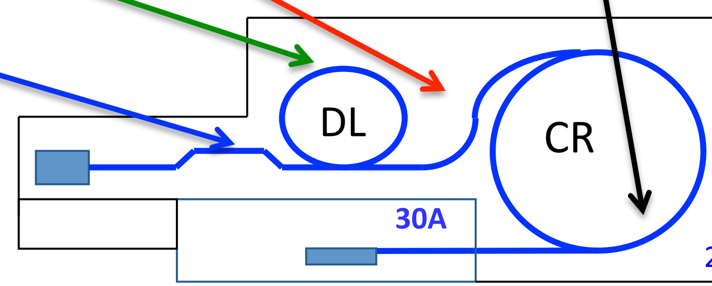
- ATF at KEK
- FACET at SLAC
- X-band test facilities at KEK and SLAC (more in progress)
- CesrTA for electron cloud studies

…. and several more for specific technical developments

# Drive Beam Combination in CTF3

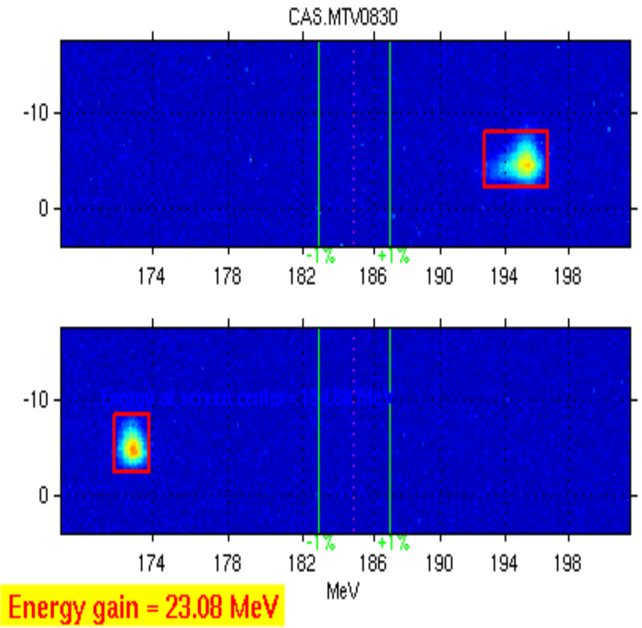


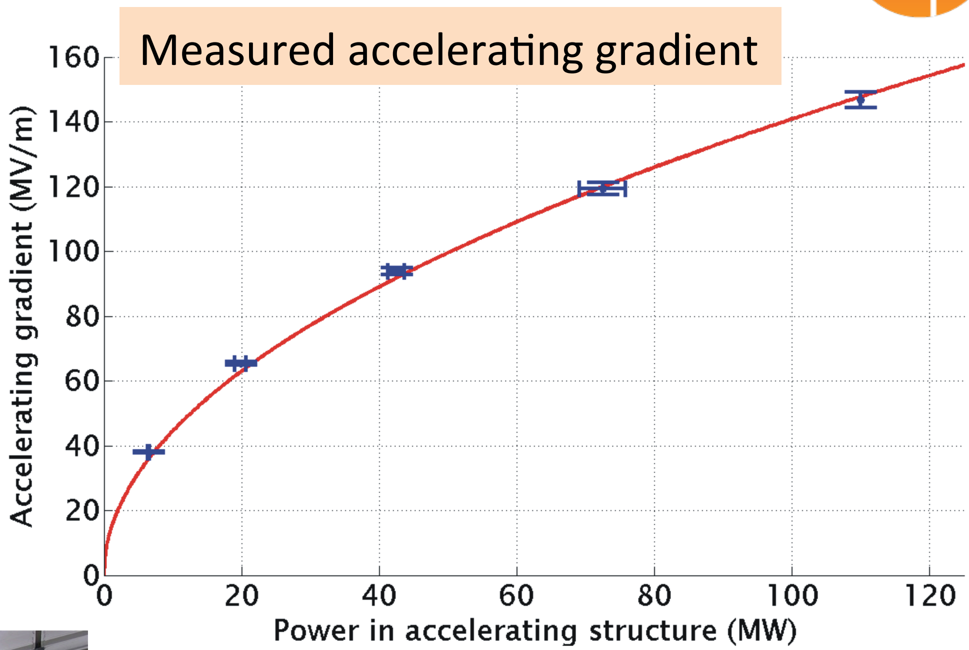



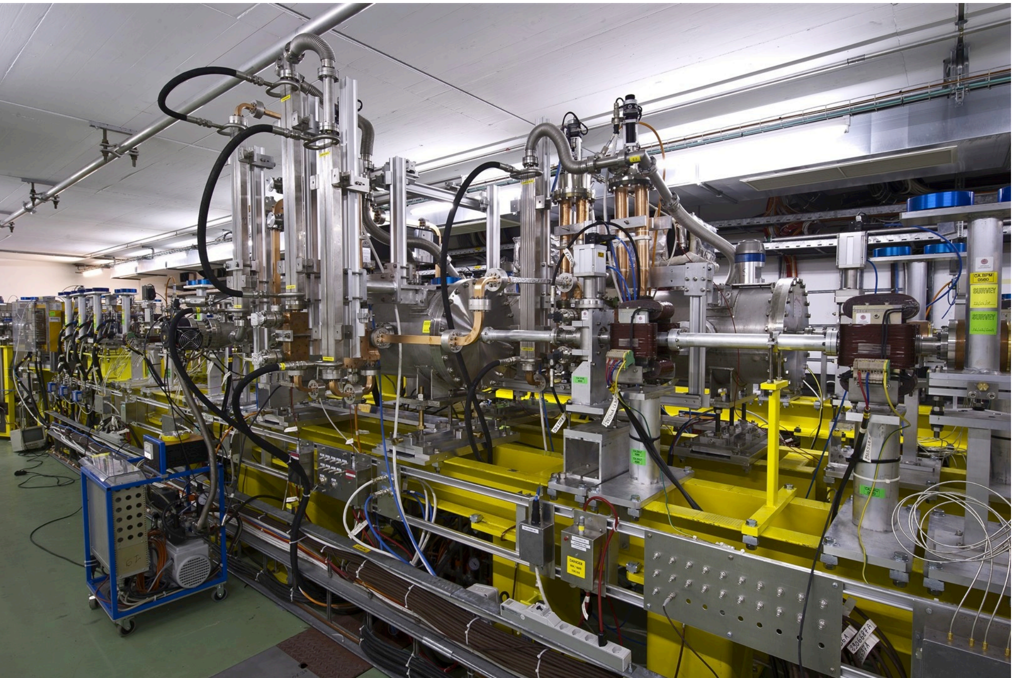



29 A reached, routinely 25A

# TBTS: Two Beam Acceleration



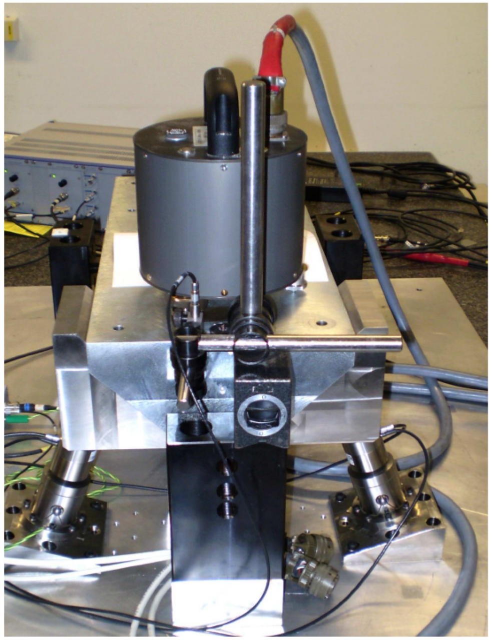



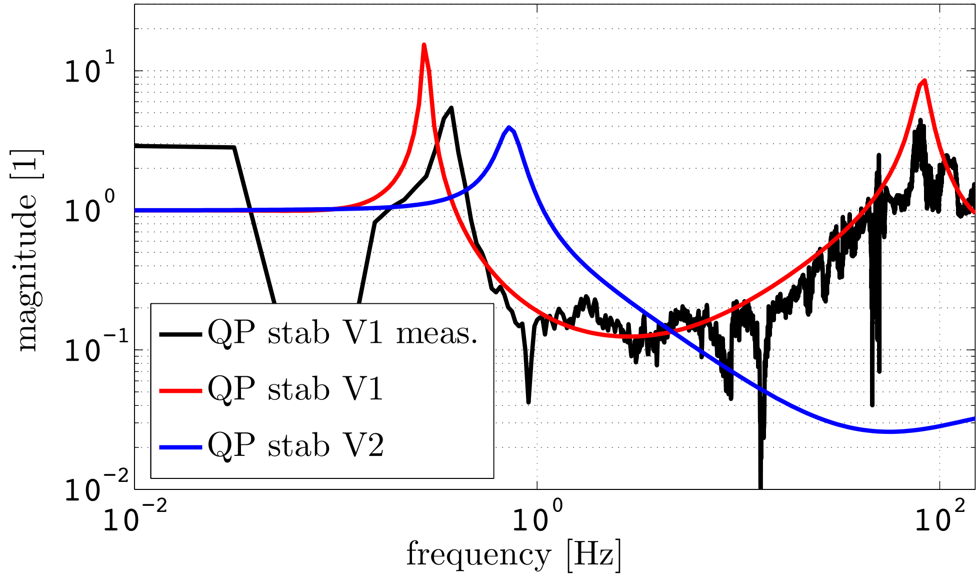



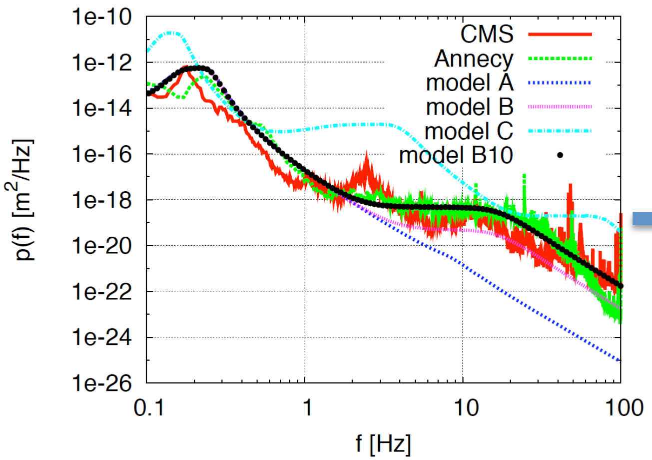
Maximum gradient 145 MV/m

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

# Active stabilisation results






Code

Machine model
Beam-based feedback

Luminosity achieved/lost [%]

| | B10 |
|---|---|
| No stab. | 53%/68% |
| Current stab. | 108%/13% |
| Future stab. | 118%/3% |

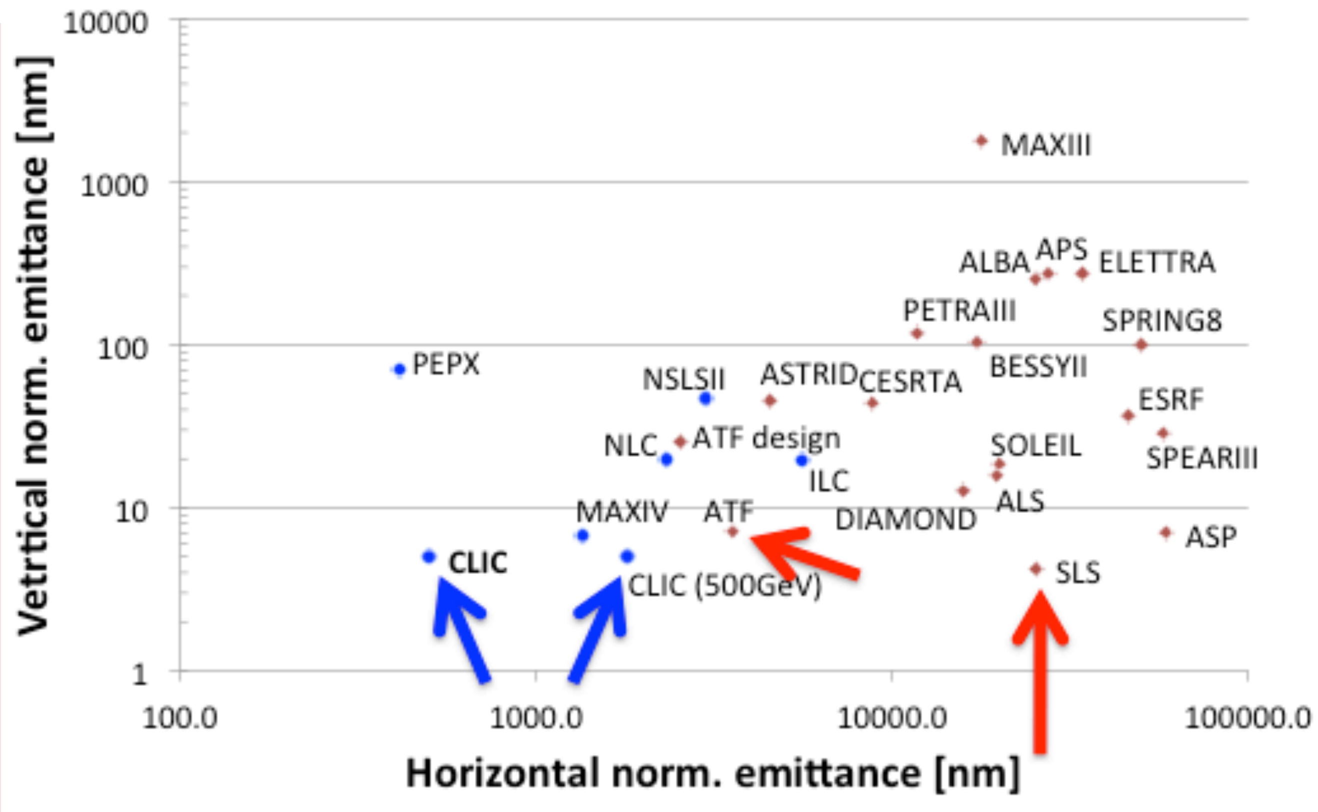
Close to/better than target

# Emittance generation/conservation

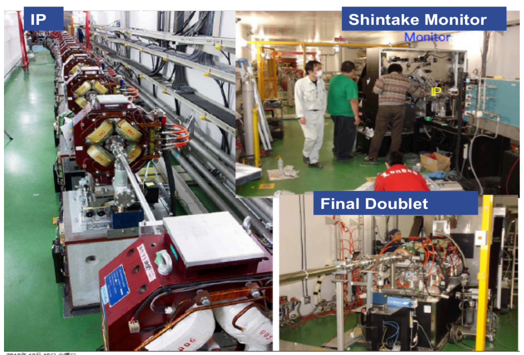
Many design issues addressed:

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

In addition: wiggler and kicker developments




CLIC @3 TeV would achieve 1/3 of luminosity with ATF performance (3800nm/15nm@4e9)



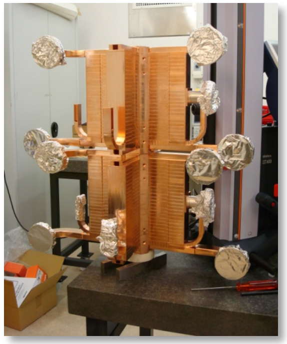

Damping ring design is consistent with target performance

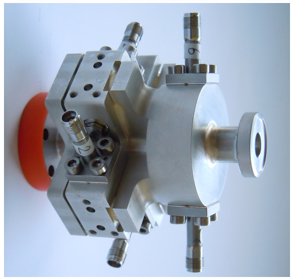
| | $\epsilon_x$ [nm] | $\epsilon_y$ [nm] |
|---|---|---|
| Damping ring exit | 500 | 5 |
| RTML exit | 600 | 10 |
| main linac exit | 660 | 20 |

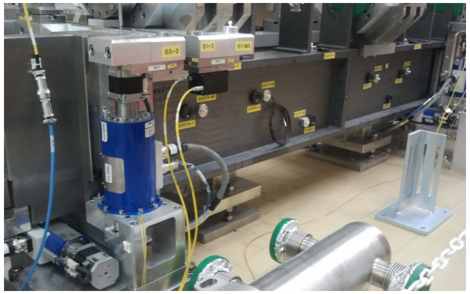
# Two-beam modules

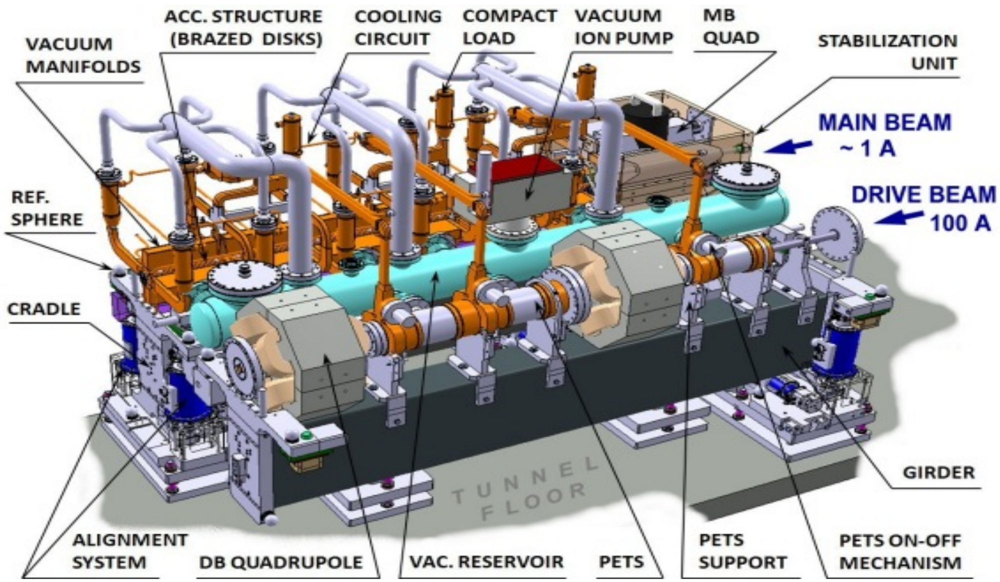
Next Steps:

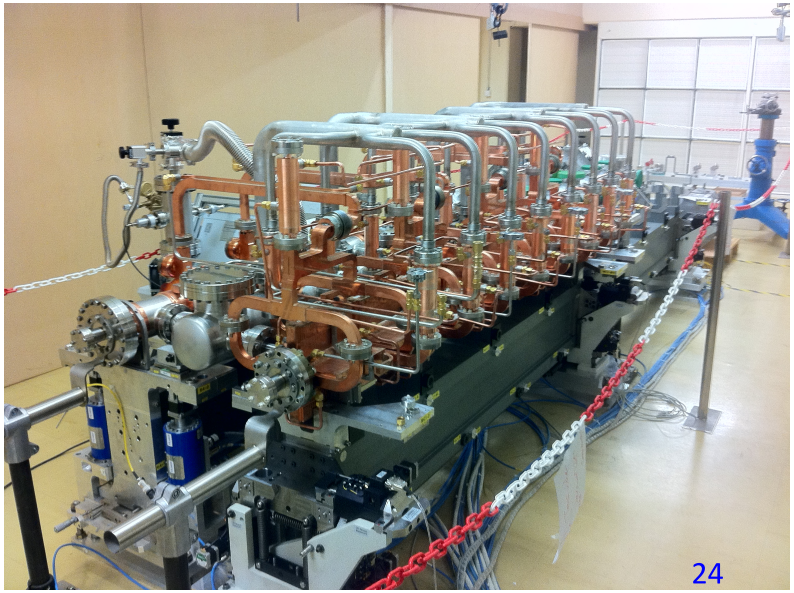
- Complete modules being assembled in lab and for beam-tests
- Installation and test of full-fledged Two-Beam Modules in CLEX
- First module in development, installation end 2013
- Three modules in 2014-2016









# CLIC, possible implementation

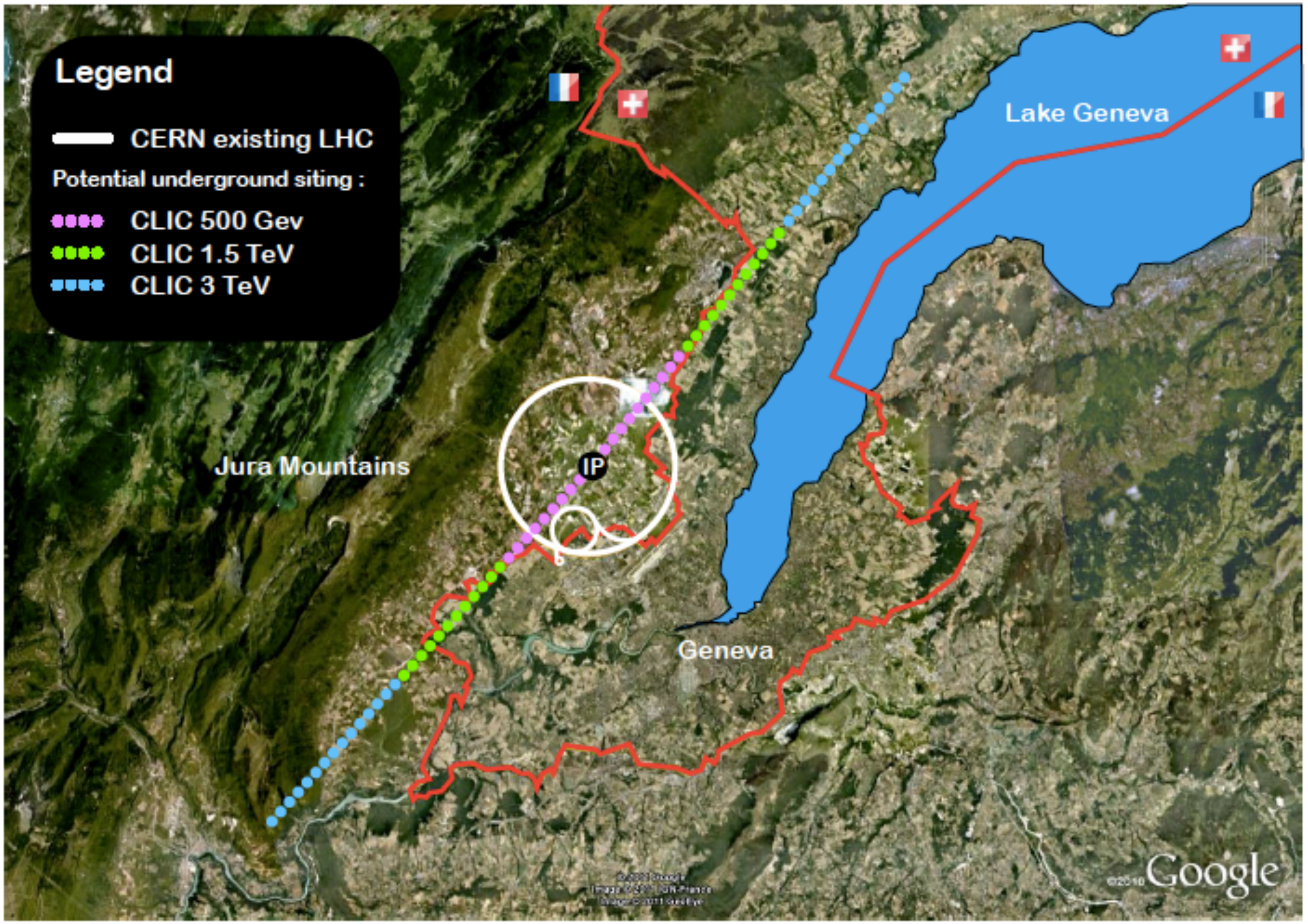



Fig. 7.2: CLIC footprints near CERN, showing various implementation stages [5].

The site specifications do not constrain the implementation to this location

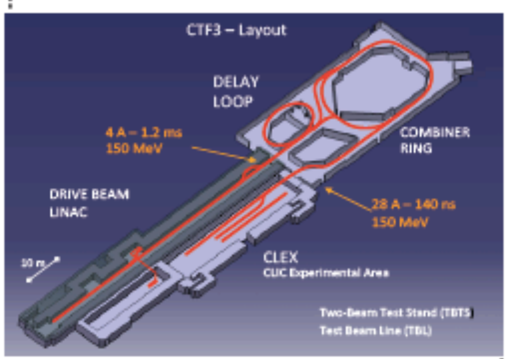
# CDR conclusion on key issues

| | |
|---|---|
| Main linac gradient | – Ongoing test close to or on target<br>– Uncertainty from beam loading |
| Drive beam scheme | – Generation tested, used to accelerate test beam, deceleration as expected<br>– Improvements on operation, reliability, losses, more deceleration (more PETS) to come |
| Luminosity | – Damping ring like an ambitious light source, no show stopper<br>– Alignment system principle demonstrated<br>– Stabilisation system developed, benchmarked, better system in pipeline<br>– Simulations seem on or close to the target |
| Operation<br>Machine Protection | – Start-up sequence defined<br>– Most critical failure studied<br>– First reliability studies<br>– Low energy operation developed |

# CLIC strategy and objectives

### 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.



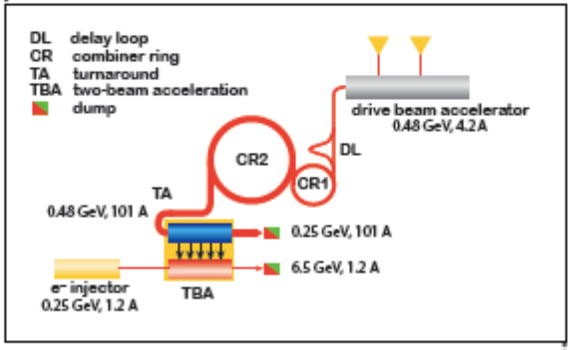

### 2016-17 Decisions

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.



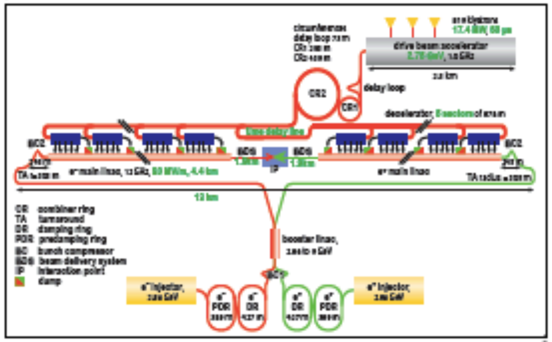

### 2022-23 Construction Start

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.

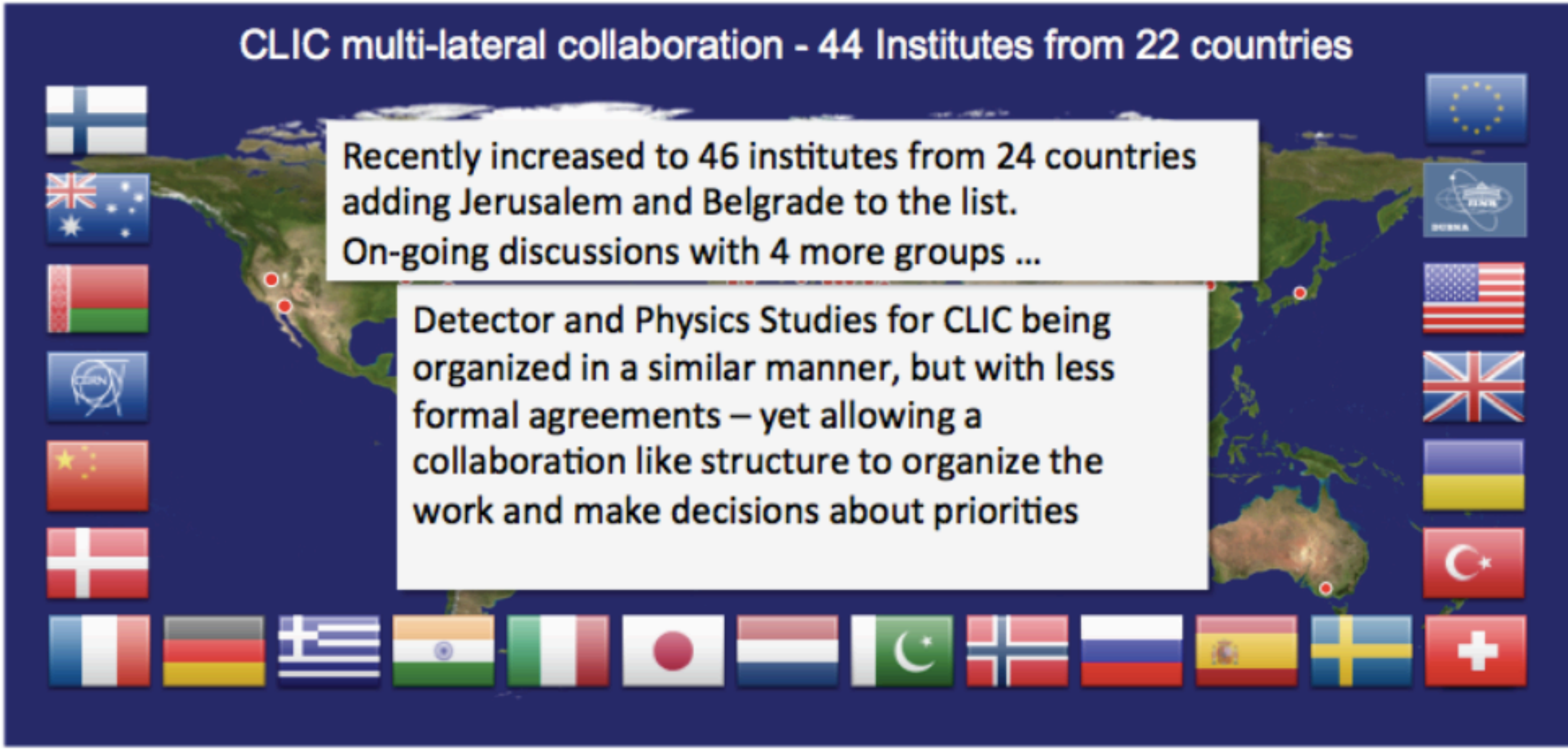



### 2030 Commissioning

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

Faster implementation possible, (e.g. for lower-energy Higgs factory): **klystron-based initial stage**

# CLIC collaboration/cooperation




Recently increased to 46 institutes from 24 countries adding Jerusalem and Belgrade to the list.
On-going discussions with 4 more groups ...

Detector and Physics Studies for CLIC being organized in a similar manner, but with less formal agreements – yet allowing a collaboration like structure to organize the work and make decisions about priorities

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)

3

# summary and outlook

## Summary of CLIC CDR studies

- CLIC accelerator feasibility demonstrated
- Feasibility of precision physics measurements demonstrated
- Staged implementation of CLIC => large potential for SM and BSM physics

**Development program for the next CLIC phases**

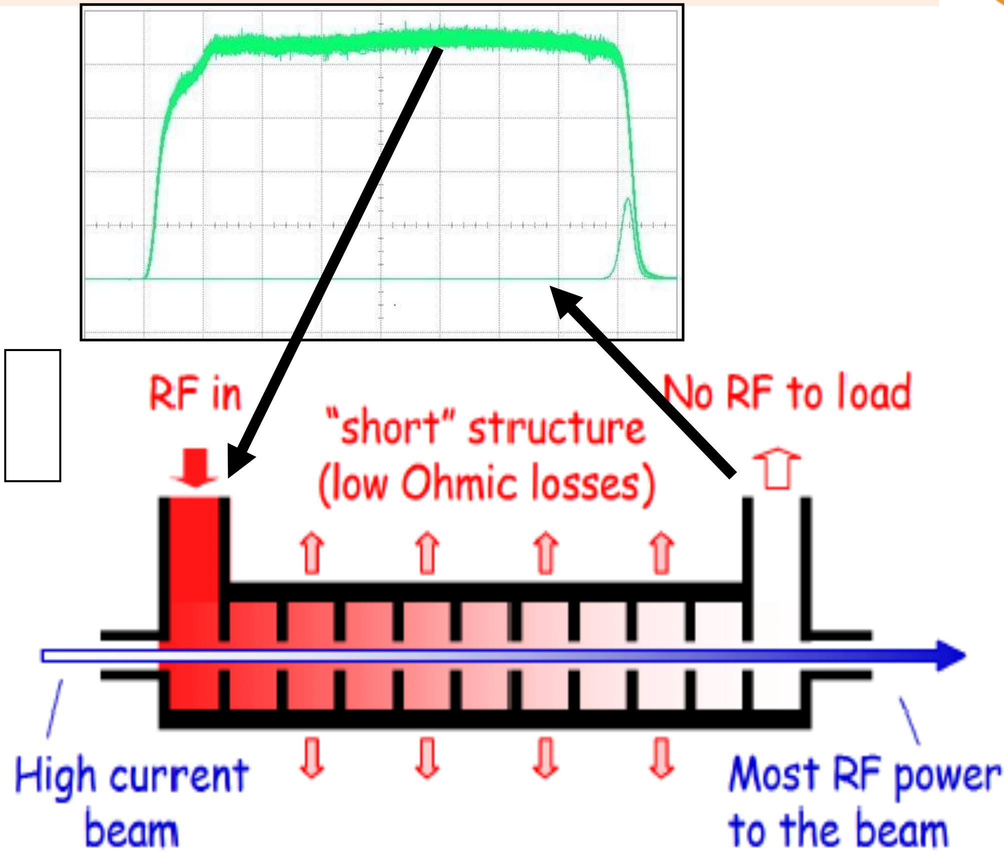
- Anticipating energy frontier machine choice 2016/2017
- Anticipating start of construction by 2022/2023

Excellent opportunities for universities and institutes
to participate in accelerator and detector R&D
- and well suited for student projects

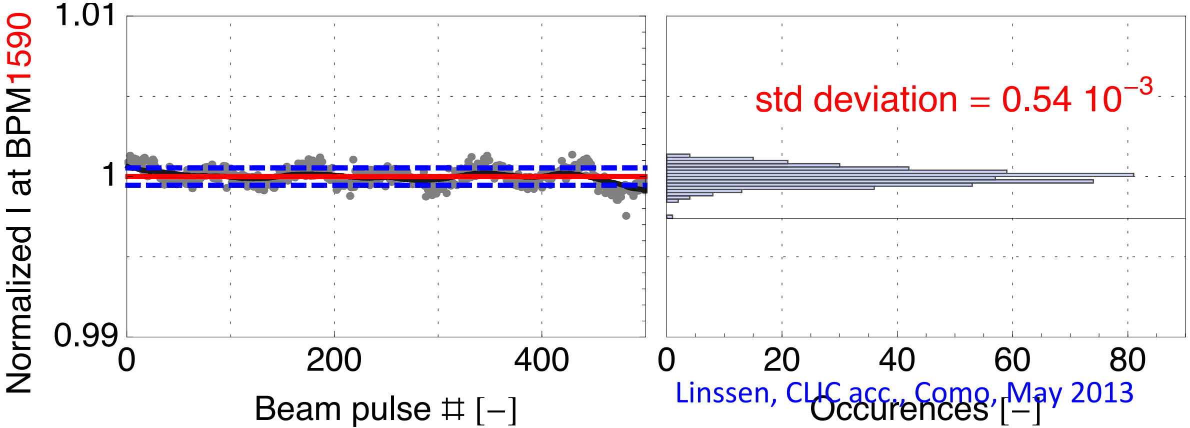
**Welcome to join !**

# SPARE SLIDES

# Drive Beam Linac




Pulse current measurement




95.3% RF to beam efficiency

No instabilities

Phase switch works OK

# Example Construction Schedule