CLIC Status

Philip Burrows

John Adams Institute

Oxford University

On behalf of the CLIC Collaborations

Thanks to all colleagues for materials

CLIC Collaborations

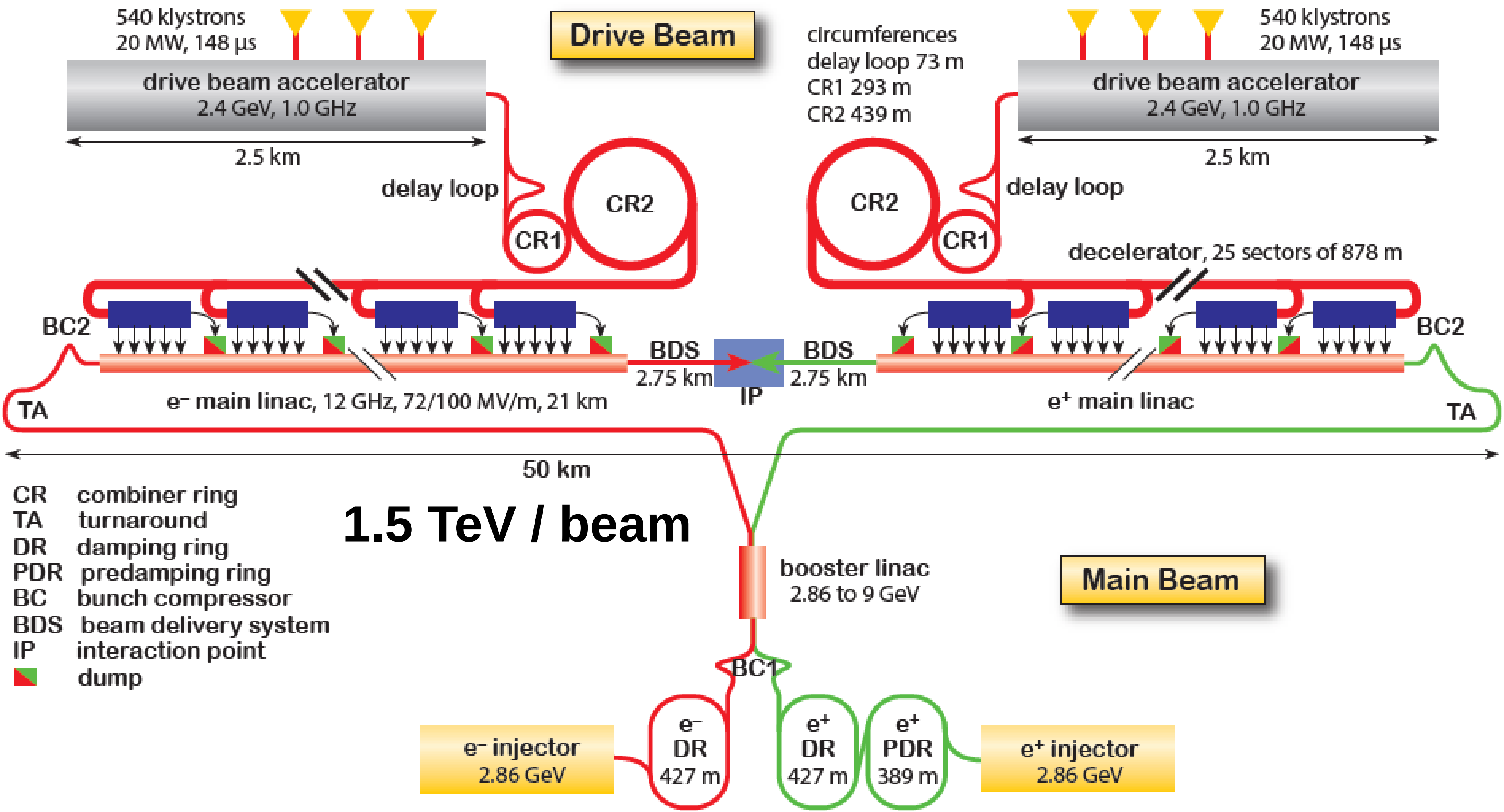
31 Countries – over 70 Institutes

Outline

- Brief introduction to CLIC
- CLIC Review
- Rebaselining + project staging
- Strategic plans → 2019 and beyond

Apologies for skipping many results + details

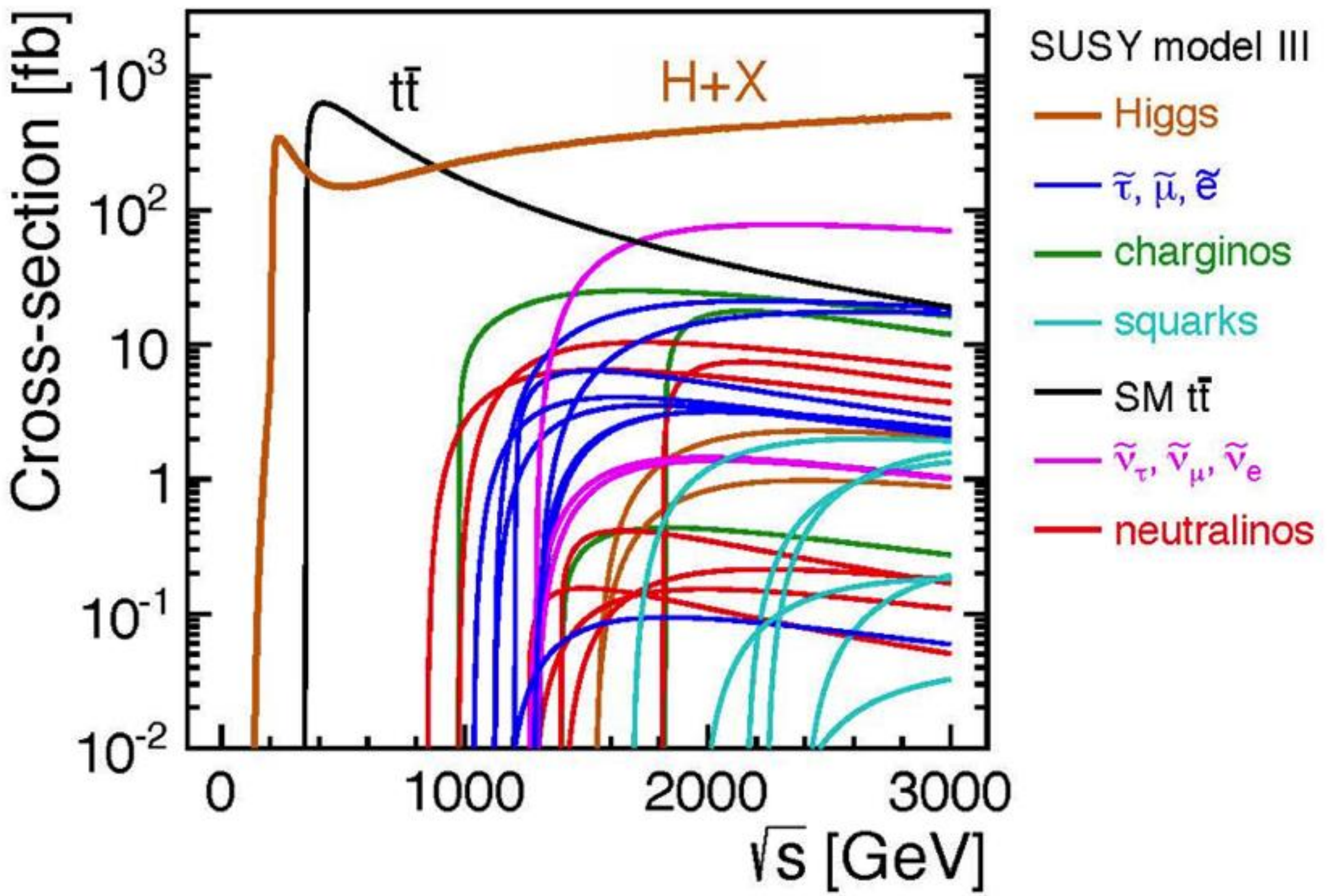
CLIC layout (3 TeV)



CLIC physics context

Energy-frontier capability for electron-positron collisions,

for precision exploration of potential new physics that may emerge from LHC



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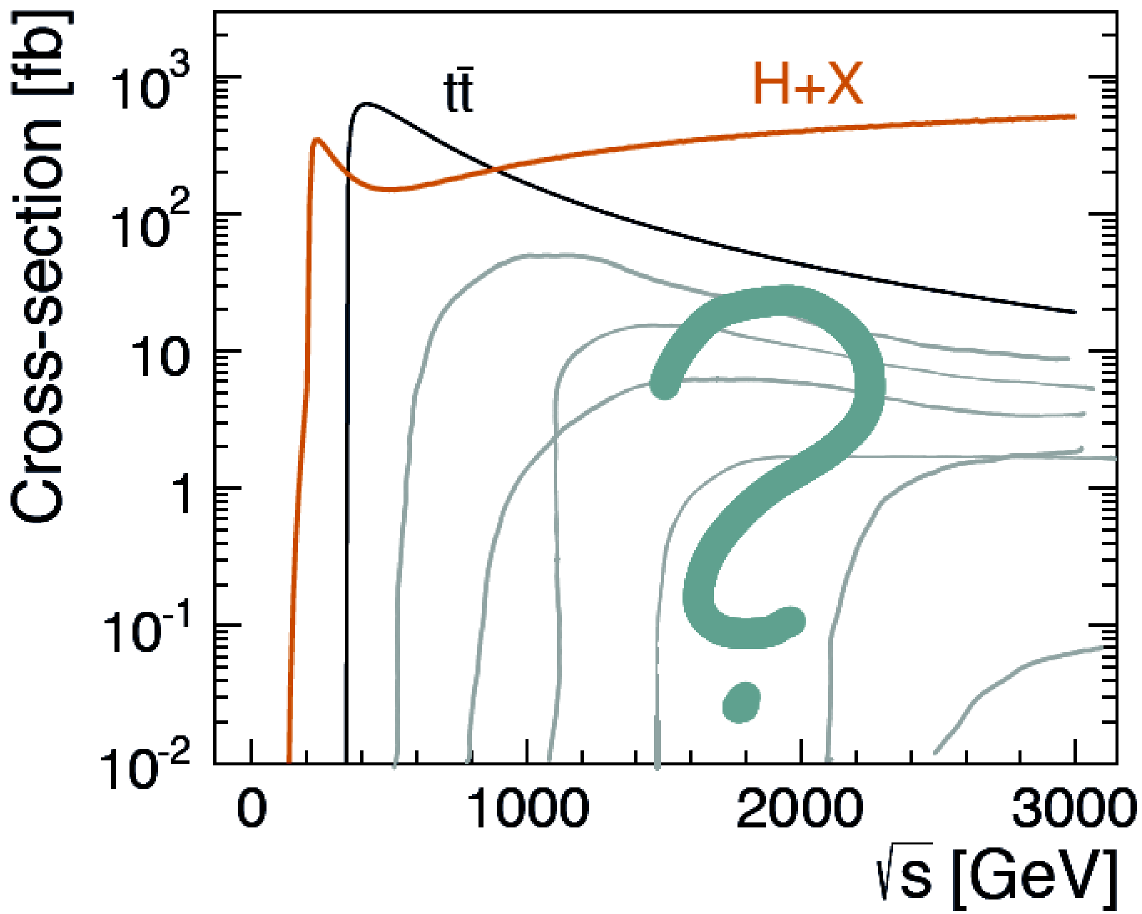

CERN scientific strategy: 3 main pillars

Full exploitation of the LHC:

- ❑ successful operation of the nominal LHC (Run 2, LS2, Run 3)
- ❑ construction and installation of LHC upgrades: LIU (LHC Injectors Upgrade) and HL-LHC

Scientific diversity programme serving a broad community:

- ❑ current experiments and facilities at Booster, PS, SPS and their upgrades (Antiproton Decelerator/ELENA, ISOLDE/HIE-ISOLDE, etc.)
- ❑ participation in accelerator-based neutrino projects outside Europe (presently mainly LBNF in the US) through CERN Neutrino Platform

Preparation of CERN's future:

- ❑ vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness (including superconducting high-field magnets, AWAKE, etc.)
- ❑ design studies for future accelerators: CLIC, FCC (includes HE-LHC)
- ❑ future opportunities of scientific diversity programme ("Physics Beyond Colliders" Study Group)

Important milestone: update of the European Strategy for Particle Physics (ESPP), to be concluded in May 2020

F. Gianotti 11/1/17

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We are vigorously preparing input for European Strategy PP Update:

- **Project Plan for CLIC as a credible post-LHC option for CERN**
- **Initial costs compatible with CERN budget**
- **Upgradeable in stages over 20-30 years**

CLIC Review

CLIC Accelerator Study – Review of objectives for the MTP 2016-2019

March 1st, 2016

Report from the Review Panel

Members: O. Brüning; P. Collier, J.M. Jimenez, R. Losito; R. Saban, R. Schmidt; F. Sonnemann; M. Vretenar (Chair).

Introduction and general remarks

The Panel was very impressed by the enormous amount of work that was presented, by the enthusiasm of the CLIC team and by the wealth of knowledge accumulated by the CLIC study. The CLIC accelerator study has reached a high level of maturity and has been able to establish a large community consisting in about 50 collaborating laboratories and universities, working together on a number of technical challenges

After the publication of the Conceptual Design report in 2012, the CLIC Study is presently in the Development Phase, to prepare a more detailed design and an implementation plan for the next European Strategy Upgrade in 2018-19. This phase is expected to be followed by a Preparation Phase covering the period 2019-25; in case of a positive decision, a construction

Report: some key points

- Produce optimized, staged design: 380 GeV → 3 TeV
- Optimise cost and power consumption
- Support efforts to develop high-efficiency klystrons
- Support 380 GeV klystron-only version as alternative
- Consolidate high-gradient structure test results
- Exploit Xboxes + nurture high-gradient test capabilities
- Develop plans for 2020-25 (‘preparation phase’) + structure conditioning strategy
- Continuing and enhanced participation in KEK/ATF2

‘Rebaselining’

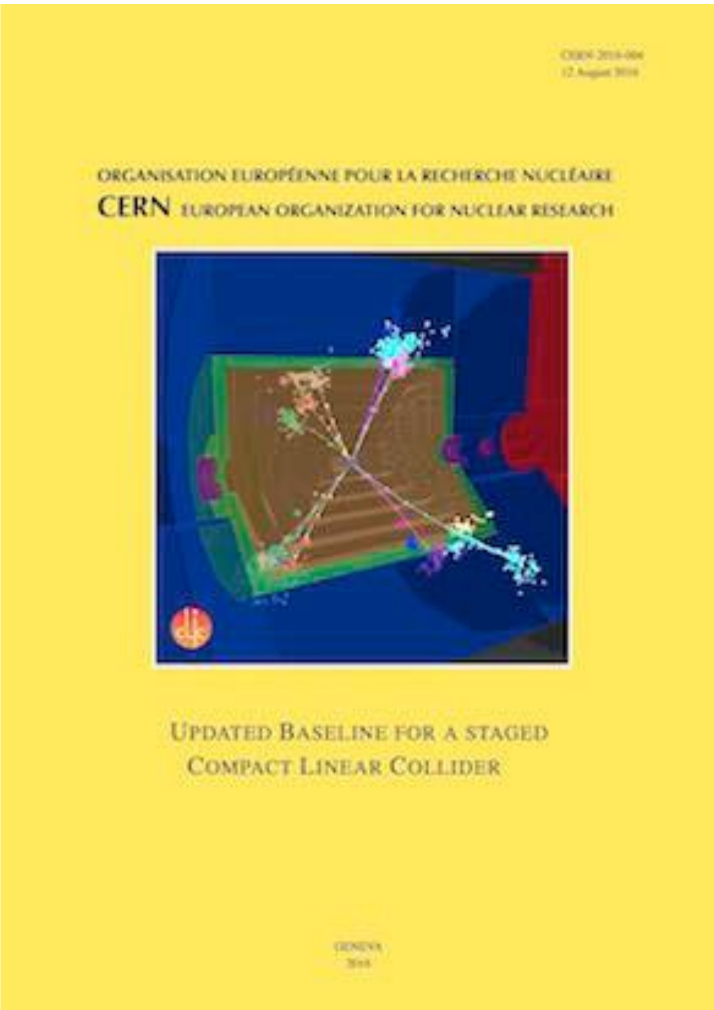
Optimize machine design w.r.t. cost and power for a staged approach to reach multi-TeV scales:

~ 380 GeV (optimised for Higgs + top physics)
~ 1500 GeV
~ 3000 GeV
(working assumptions: exact choices of higher c.m. energies depend on LHC findings)

for various luminosities and safety factors

- **Expect to make significant cost and power reductions for the initial stages**
- **Choose new staged parameter sets, with a corresponding consistent upgrade path, also considering the possibility of the initial-stage being klystron-powered**

Rebaselining document



The Compact Linear Collider (CLIC) is a multi-TeV high-luminosity linear e^+e^- collider under development. For an optimal exploitation of its physics potential, CLIC is foreseen to be built and operated in a staged approach with three centre-of-mass energy stages ranging from a few hundred GeV up to 3 TeV. The first stage will focus on precision Standard Model physics, in particular Higgs and top measurements. Subsequent stages will focus on measurements of rare Higgs processes, as wells as searches for new physics processes and precision measurements of new states, e.g. states previously discovered at LHC or at CLIC itself. In the 2012 CLIC Conceptual Design Report, a fully optimised 3 TeV collider was presented, while the proposed lower energy stages were not studied to the same level of detail. This report presents an updated baseline staging scenario for CLIC. The scenario is the result of a comprehensive study addressing the performance, cost and power of the CLIC accelerator complex as a function of centre-of-mass energy and it targets optimal physics output based on the current physics landscape. The optimised staging scenario foresees three main centre-of-mass energy stages at 380 GeV, 1.5 TeV and 3 TeV for a full CLIC programme spanning 22 years. For the first stage, an alternative to the CLIC drive beam scheme is presented in which the main linac power is produced using X-band klystrons.

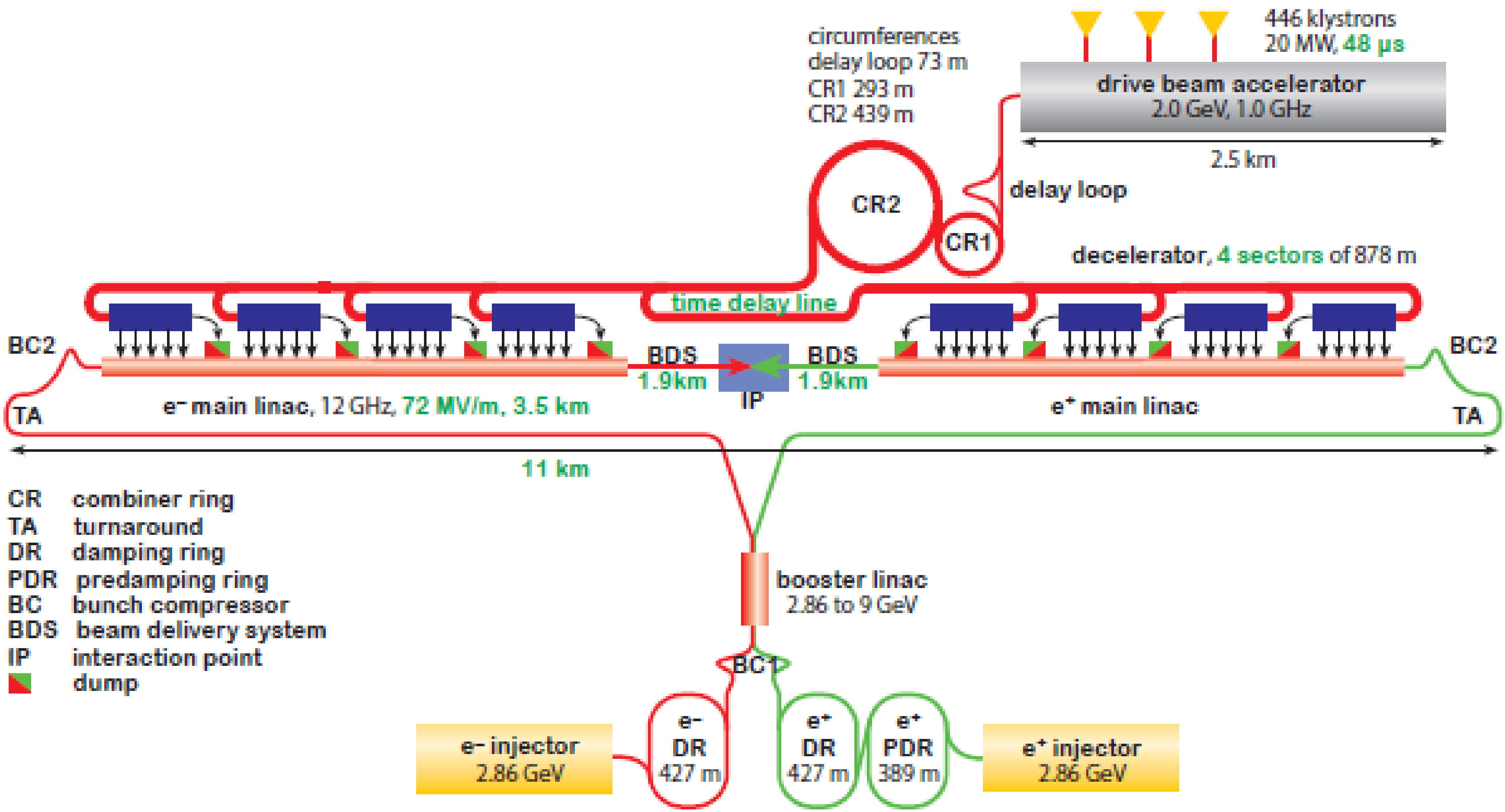
CERN-2016-004

arXiv:1608.07537

Rebaselining: first stage energy ~ 380 GeV

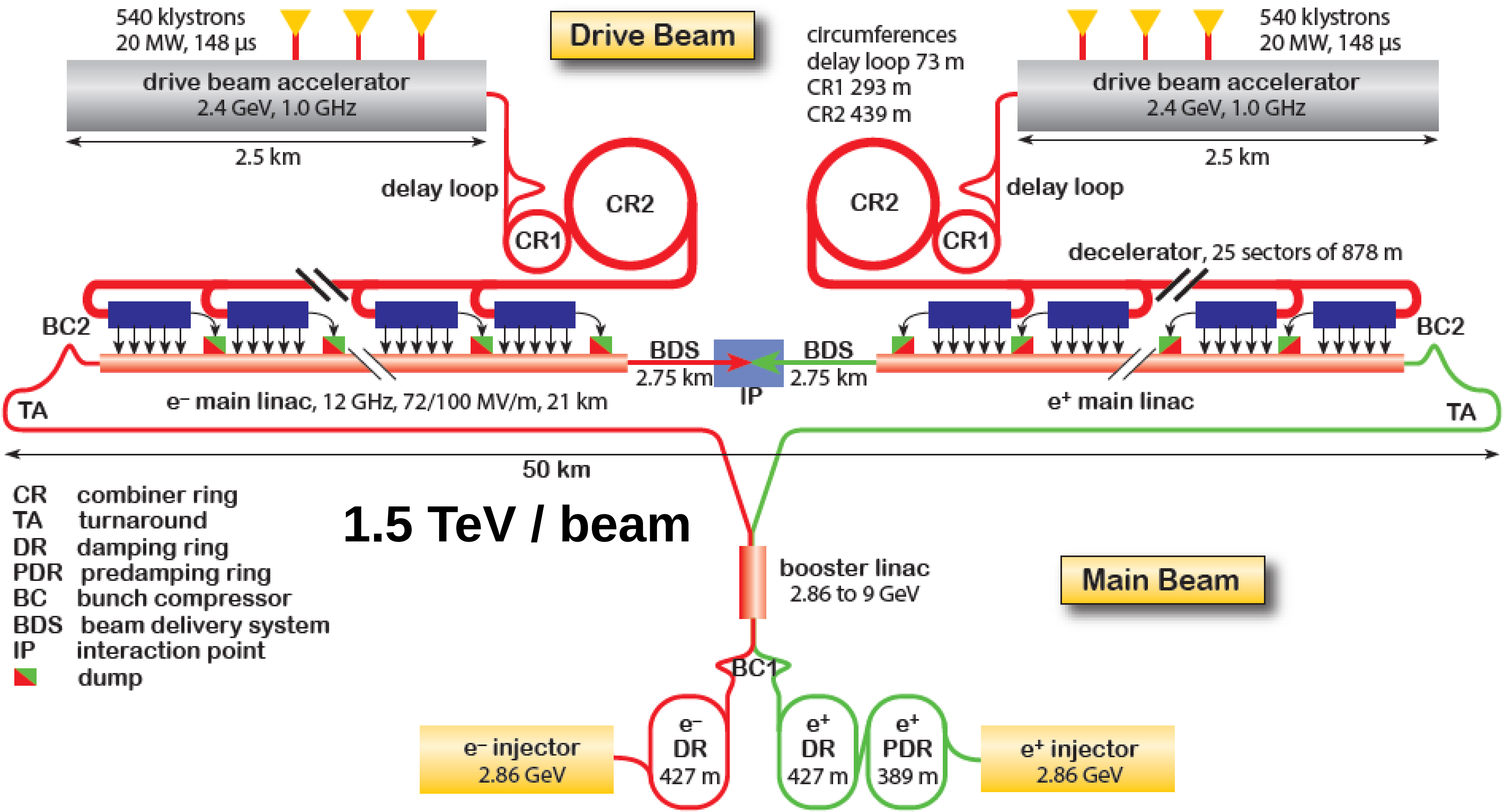
Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of √s	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100
Site length	km	11	50

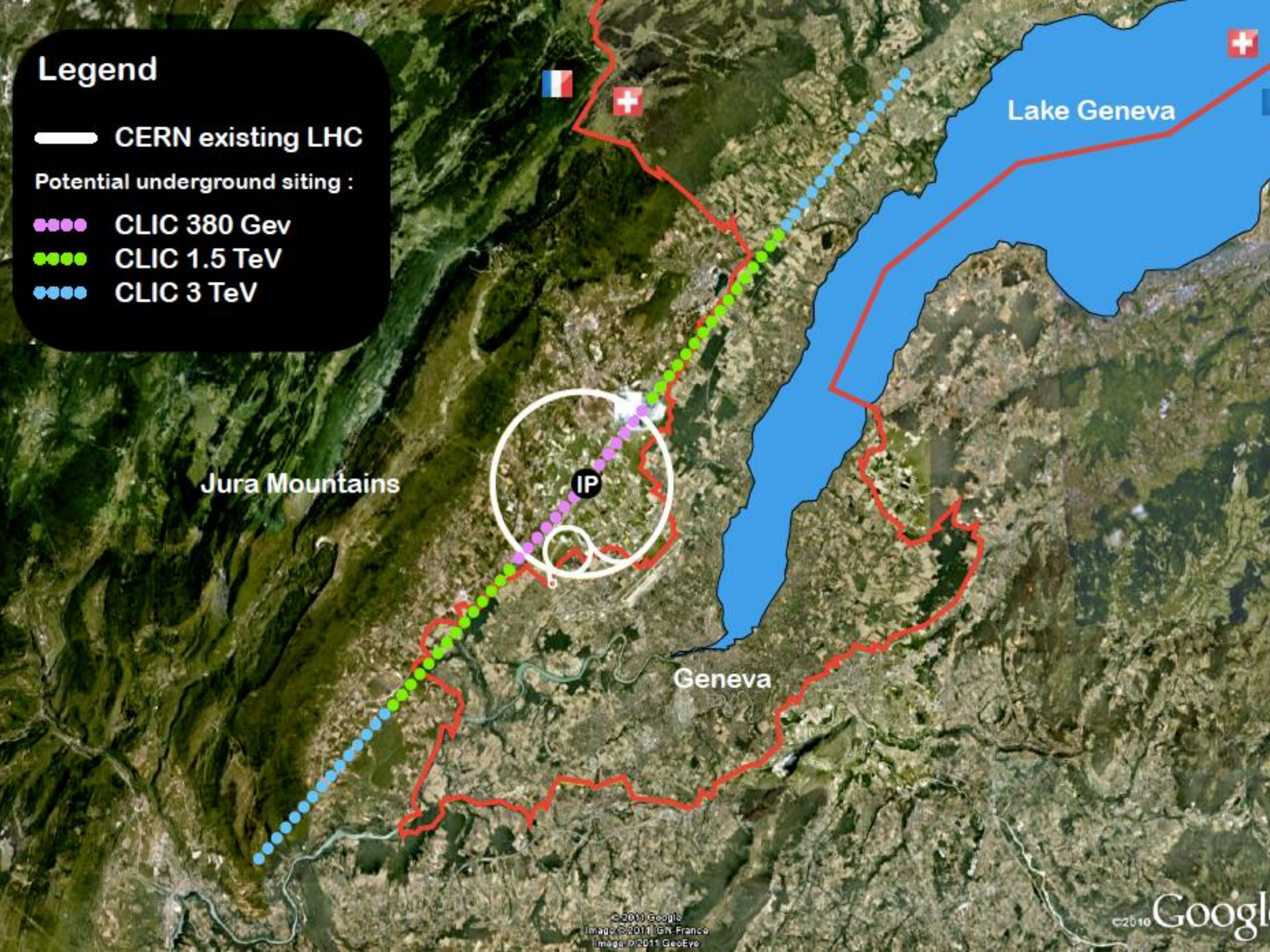
New CLIC layout 380 GeV



LINEAR COLLIDER COLLABORATION

New CLIC layout 3 TeV





Legend
CERN existing LHC
Potential underground siting :
CLIC 380 Gev
CLIC 1.5 TeV
CLIC 3 TeV
Lake Geneva
Jura Mountains
IP
Geneva
©2011 Google
Image ©2011 IGN-France
Image ©2011 GeoEye
©2010 Google

Current rebaselined parameters

Table 8: Parameters for the CLIC energy stages. The power consumptions for the 1.5 and 3 TeV stages are from the CDR; depending on the details of the upgrade they can change at the percent level.

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Pulse length	τ_{pulse}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	1.5	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.9	1.4	2
Main tunnel length		km	11.4	29.0	50.1
Charge per bunch	N	10^9	5.2	3.7	3.7
Bunch length	σ_z	µm	70	44	44
IP beam size	σ_x/σ_y	nm	149/2.9	$\sim$ 60/1.5	$\sim$ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	—	660/20	660/20
Normalised emittance	$\varepsilon_x/\varepsilon_y$	nm	950/30	—	—
Estimated power consumption	P_{wall}	MW	252	364	589

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Preliminary cost estimate (380GeV)

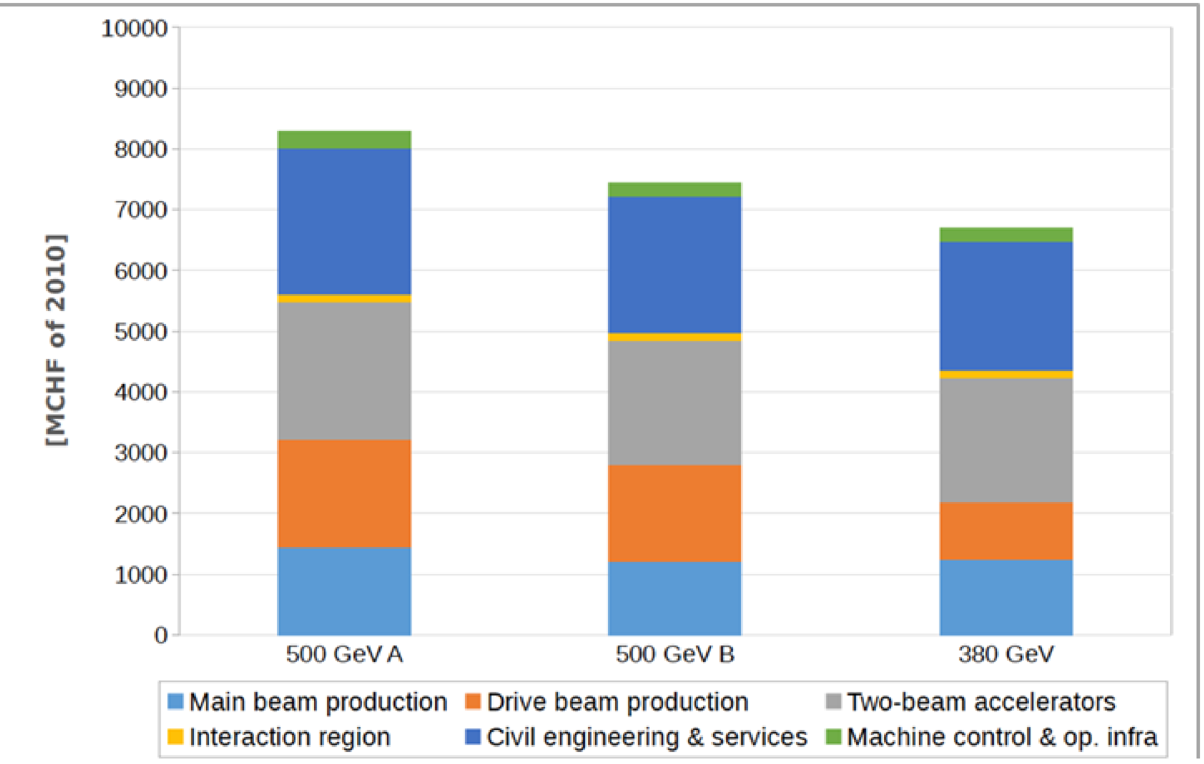
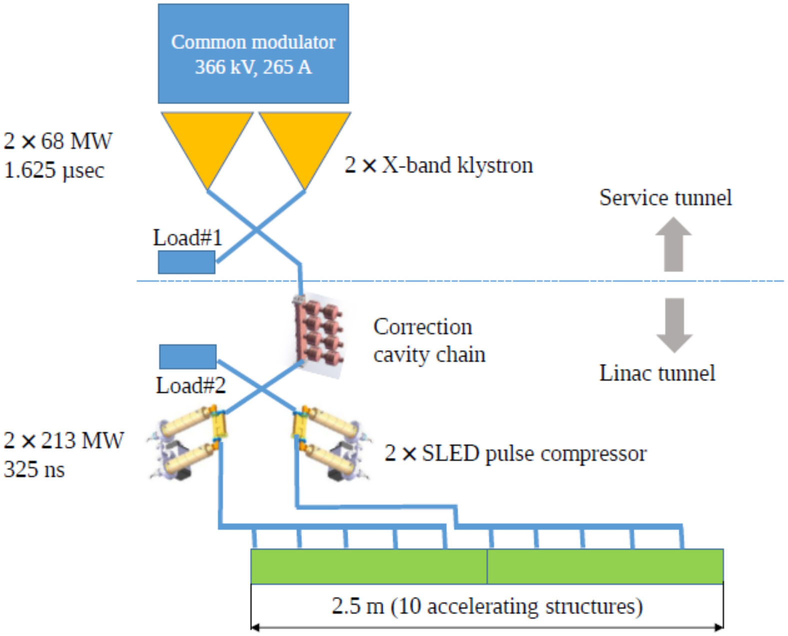


Table 11: Value estimate of CLIC at 380 GeV centre-of-mass energy.

	Value [MCHF of December 2010]
Main beam production	1245
Drive beam production	974
Two-beam accelerators	2038
Interaction region	132
Civil engineering & services	2112
Accelerator control & operational infrastructure	216
Total	6690

Klystron version (380 GeV)



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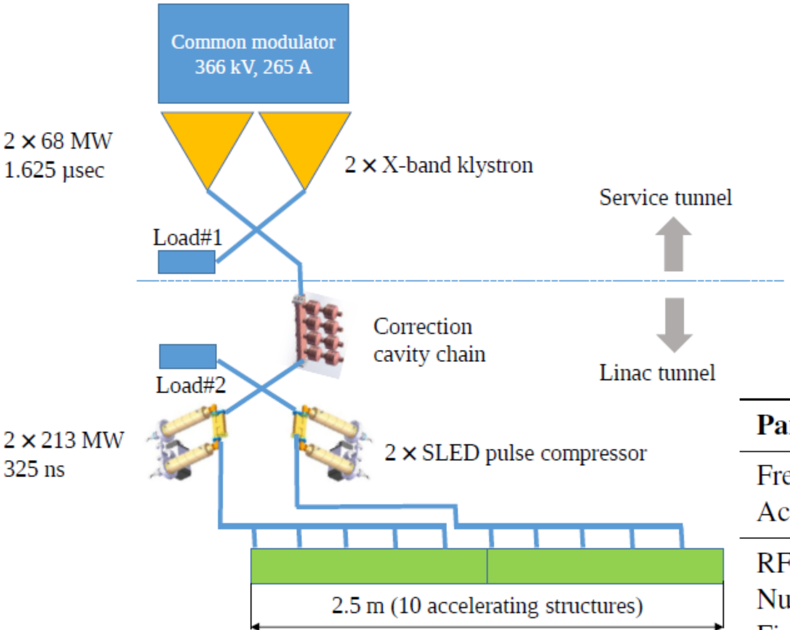

Table 12: The parameters for the structure designs that are detailed in the text.

Parameter	Symbol	Unit	DB	K	DB244	K244
Frequency	f	GHz	12	12	12	12
Acceleration gradient	G	MV/m	72.5	75	72	79
RF phase advance per cell	$\Delta\phi$	°	120	120	120	120
Number of cells	N_c		36	28	33	26
First iris radius / RF wavelength	a_1/λ		0.1525	0.145	0.1625	0.15
Last iris radius / RF wavelength	a_2/λ		0.0875	0.09	0.104	0.1044
First iris thickness / cell length	d_1/L_c		0.297	0.25	0.303	0.28
Last iris thickness / cell length	d_2/L_c		0.11	0.134	0.172	0.17
Number of particles per bunch	N	10^9	3.98	3.87	5.2	4.88
Number of bunches per train	n_b		454	485	352	366
Pulse length	τ_{RF}	ns	321	325	244	244
Peak input power into the structure	P_{in}	MW	50.9	42.5	59.5	54.3
Cost difference (w. drive beam)	$\Delta C_{w.\ DB}$	MCHF	-50	(20)	0	(20)
Cost difference (w. klystrons)	$\Delta C_{w.\ K}$	MCHF	(120)	50	(330)	240

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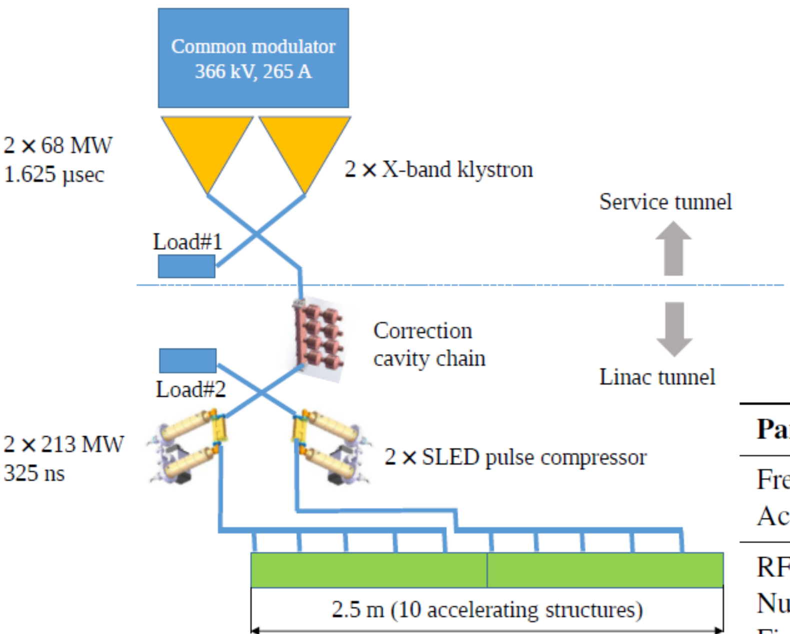

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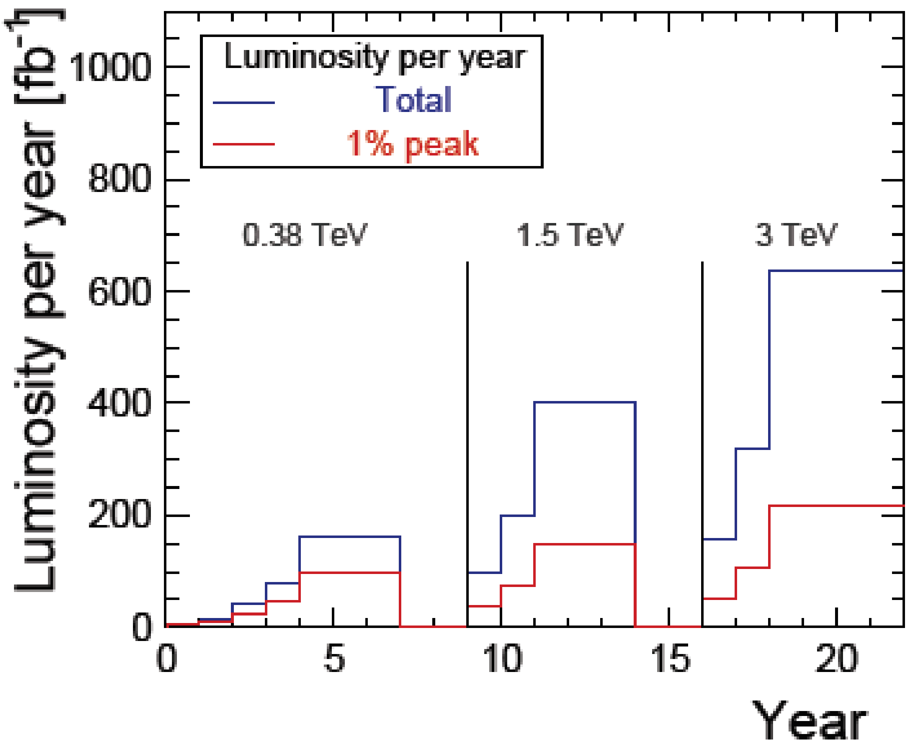
Costings relative to drive-beam version may be lower ~ 5%

Updated CLIC run model



Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{\text{int}}$ (fb^{-1})
1	380	500
	350	100
2	1500	1500
3	3000	3000

CLIC Higgs physics processes

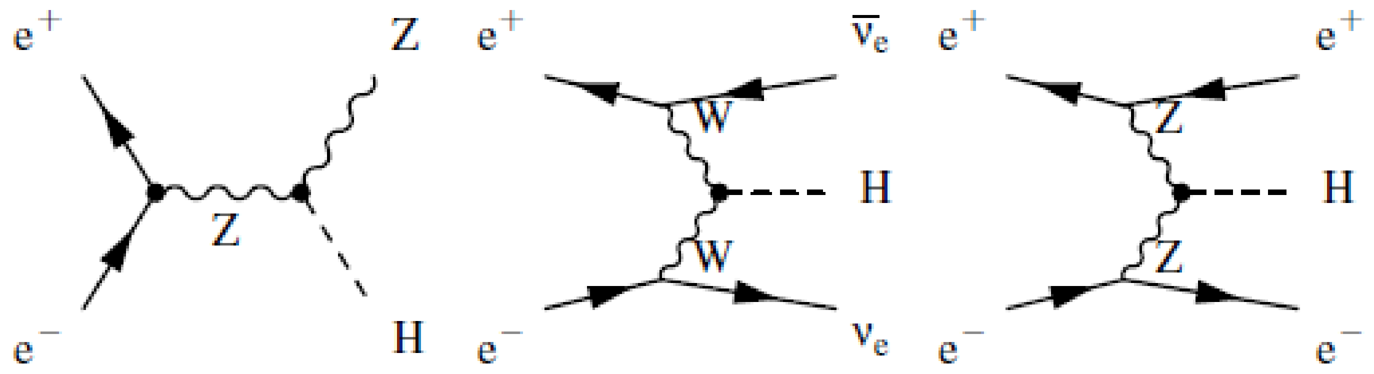


Figure 2: The three highest cross section Higgs production processes at CLIC.

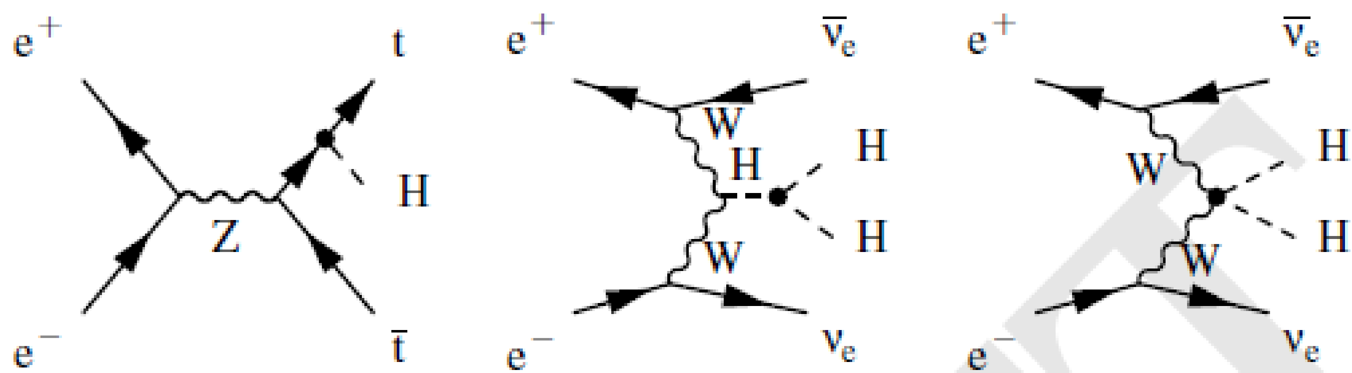
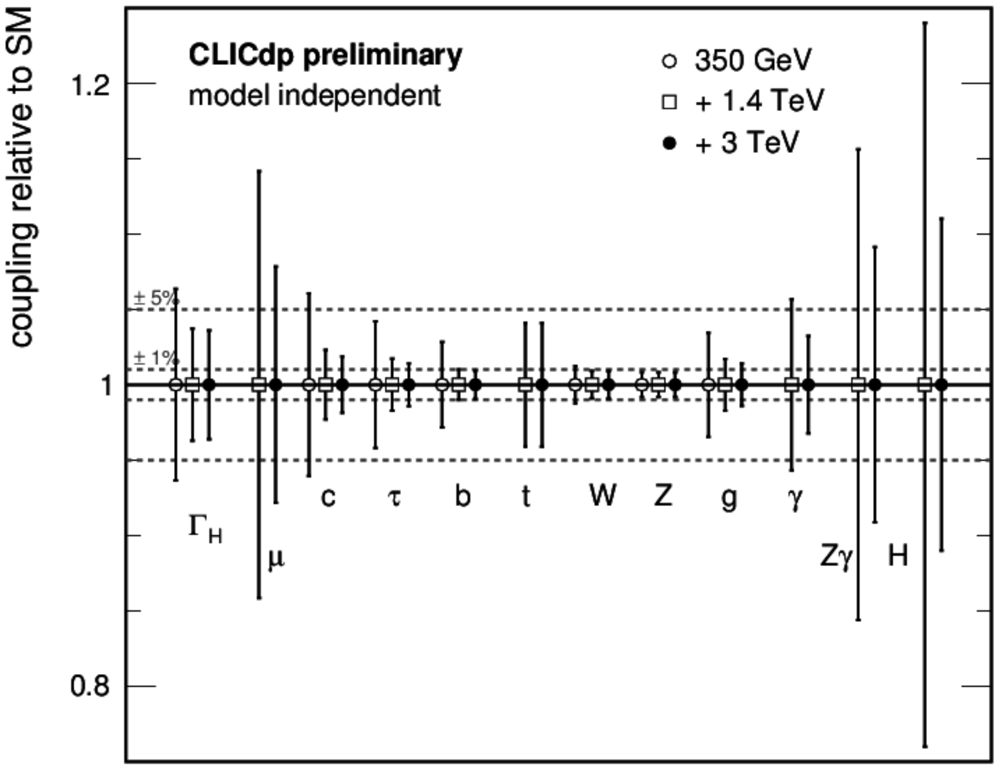


Figure 3: The main processes at CLIC involving the top Yukawa coupling g_{Htt}, the Higgs boson trilinear self-coupling λ and the quartic coupling g_{HHWW}.

CLIC Higgs physics capabilities



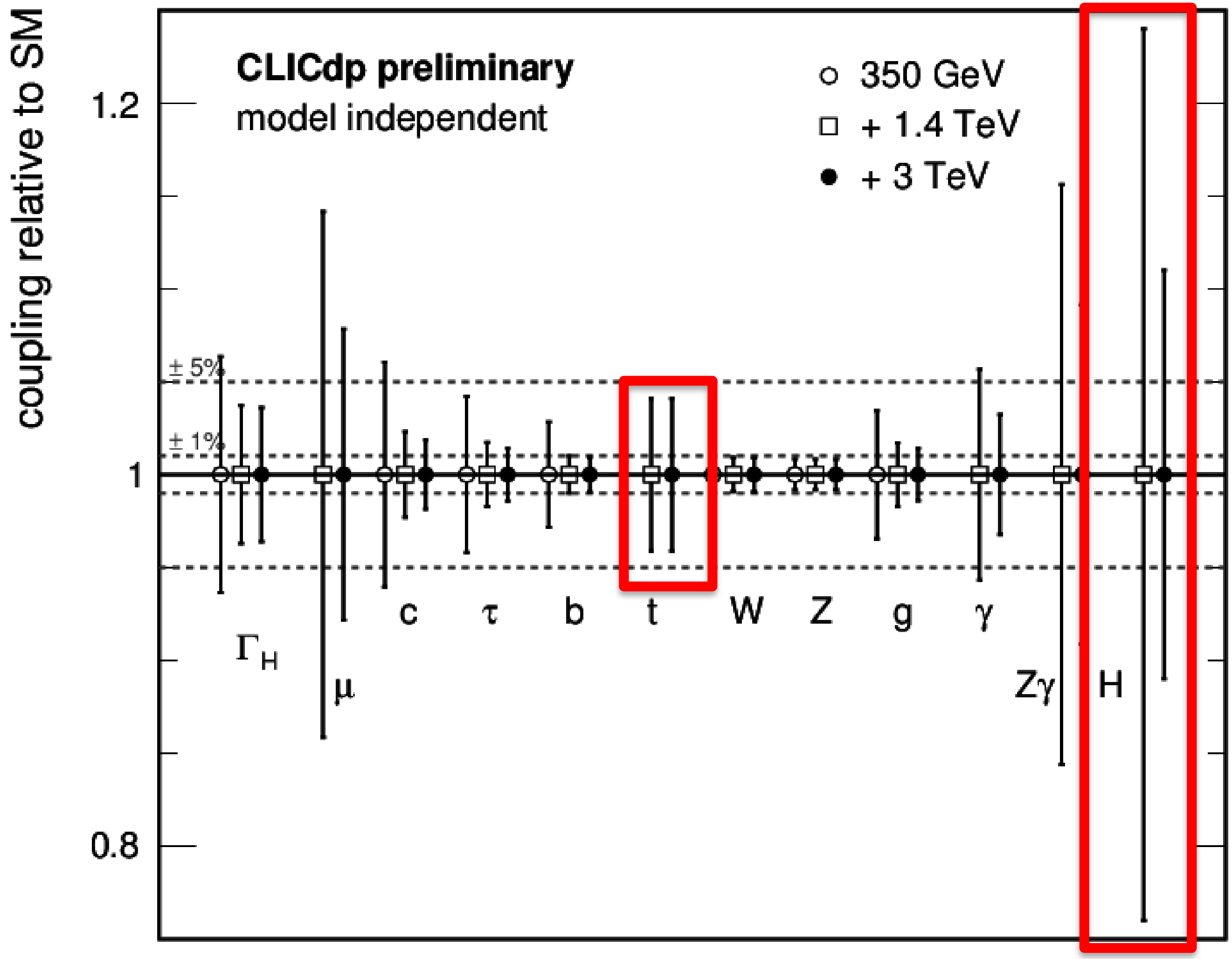
Parameter	Relative precision		
	350 GeV $500\,\mathrm{fb}^{-1}$	+ 1.4 TeV + $1.5\,\mathrm{ab}^{-1}$	+ 3 TeV + $2\,\mathrm{ab}^{-1}$
g_{HZZ}	0.8%	0.8%	0.8%
g_{HWW}	1.3%	0.9%	0.9%
g_{Hbb}	2.8%	1.0%	0.9%
g_{Hcc}	6.0%	2.3%	1.9%
$g_{H\tau\tau}$	4.2%	1.7%	1.4%
$g_{H\mu\mu}$	–	14.1%	7.8%
g_{Htt}	–	4.1%	4.1%
$g^{\dagger}_{Hgg}$	3.6%	1.7%	1.4%
$g^{\dagger}_{H\gamma\gamma}$	–	5.7%	3.2%
$g^{\dagger}_{HZ\gamma}$	–	15.6%	9.1%
Γ_H	6.4%	3.7%	3.6%

CLIC Higgs physics capabilities

Higgs couplings to heavy particles benefit from higher c.m. energies:

ttH ~ 4%

HH ~ 10%



CLIC Higgs physics paper

Higgs Physics at the CLIC Electron-Positron Linear Collider (CLICdp collaboration paper)

40 pages, 123 authors, >25 full-simulation studies

CLICdp-Pub-2016-001 and arXiv:1608.07538 (29/8/2016)

Submitted to EPJC – now addressing referees' comments

CLIC top physics example:
form factors (380 GeV)

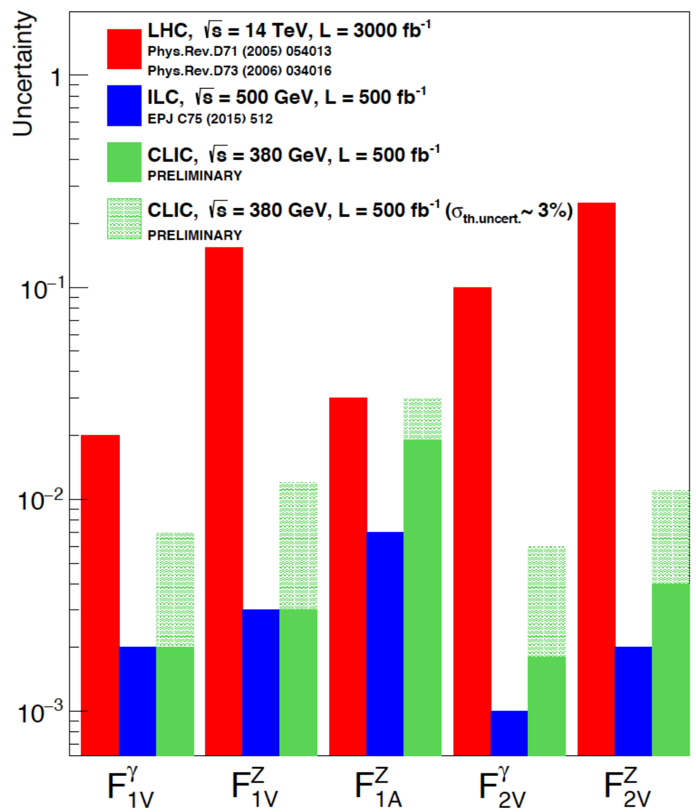


Figure 9: Uncertainties of the top quark form factors (assuming SM values for the remaining form factors) compared between estimations for LHC, ILC and CLIC [10]. The form factors are extracted from the measured forward backward asymmetry and cross-section. For the ILC, $\pm 80\%$ e^- polarisation and $\mp 30\%$ e^+ polarisation are considered and for CLIC, $\pm 80\%$ e^-

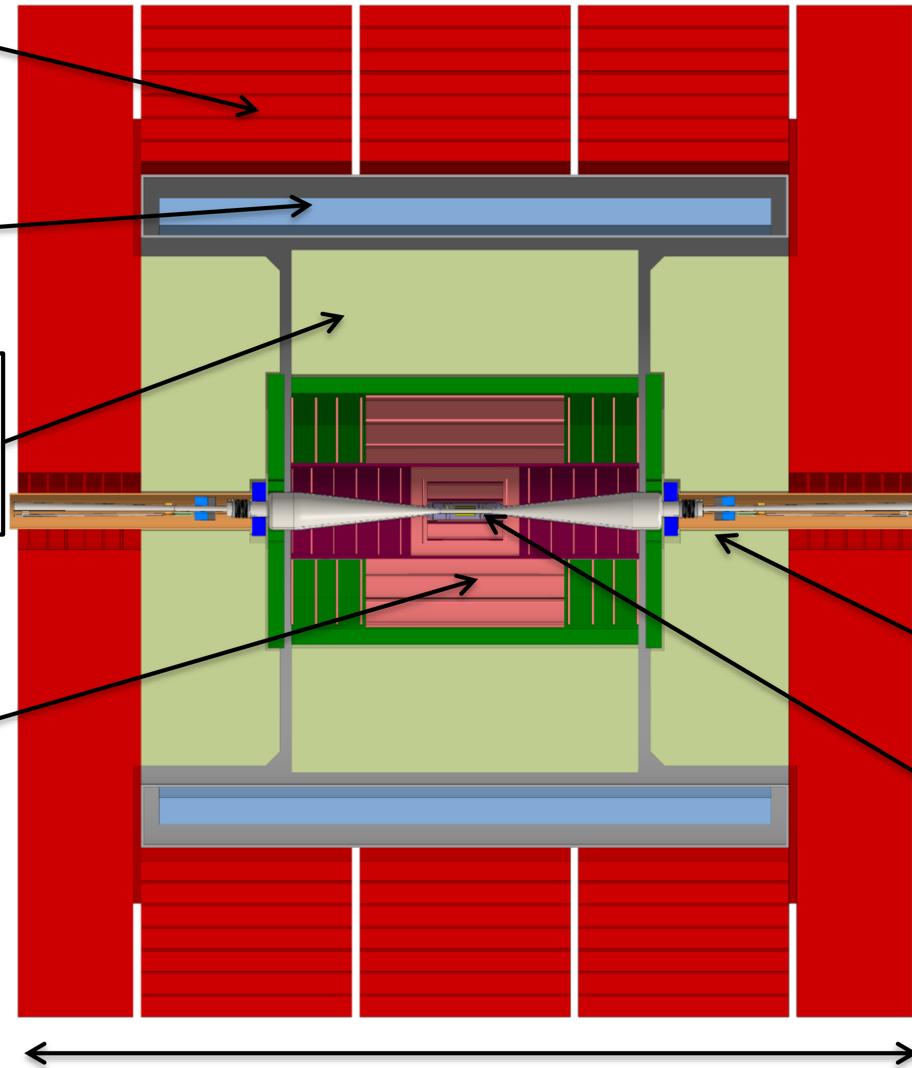
New CLIC detector model

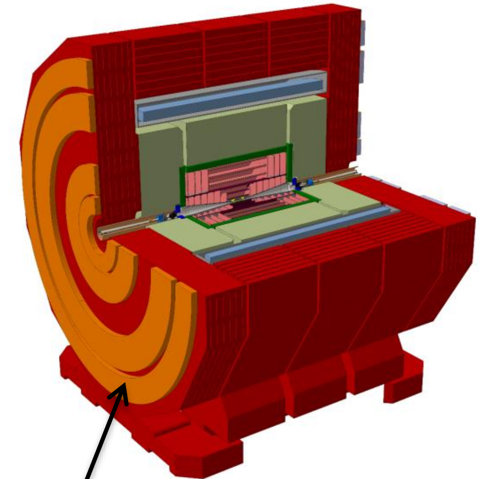
return yoke (Fe) with muon-ID detectors

superconducting solenoid, 4 Tesla

fine grained (PFA) calorimetry, 1 + 7.5 Λ_i, Si-W ECAL, Sc-FE HCAL

silicon tracker, (large pixels / short strips)





end-coils for field shaping

forward region with compact forward calorimeters

ultra low-mass vertex detector, ~25 μm pixels

Note: final beam focusing is outside the detector

Lucie Linssen

Rebaselining: ongoing studies

Optimize drive beam accelerator klystron system: higher-efficiency klystrons

Eliminated electron pre-damping ring (better e- injector)

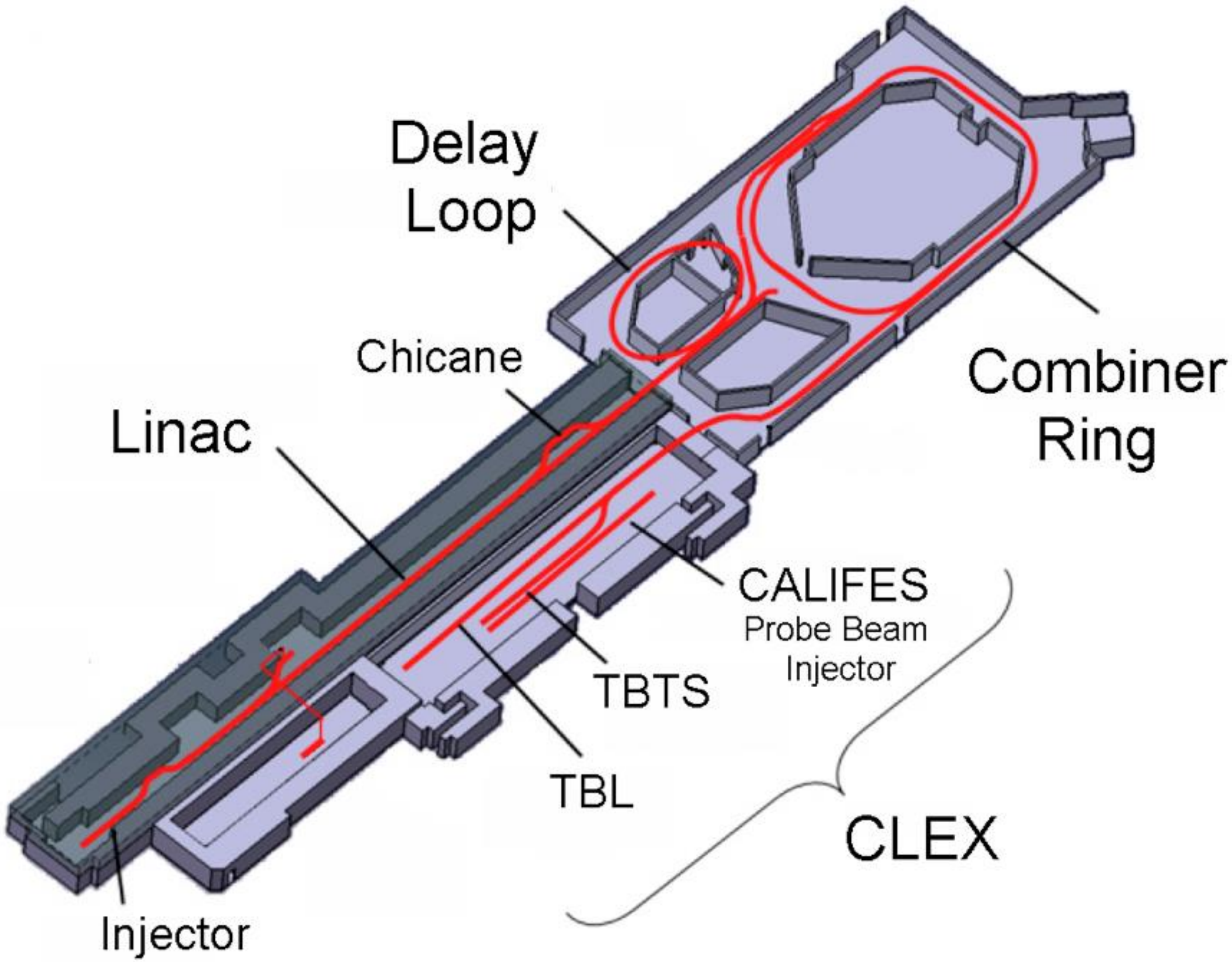
Systematic optimization of injector-complex linacs

Optimize / reduce power overhead estimates

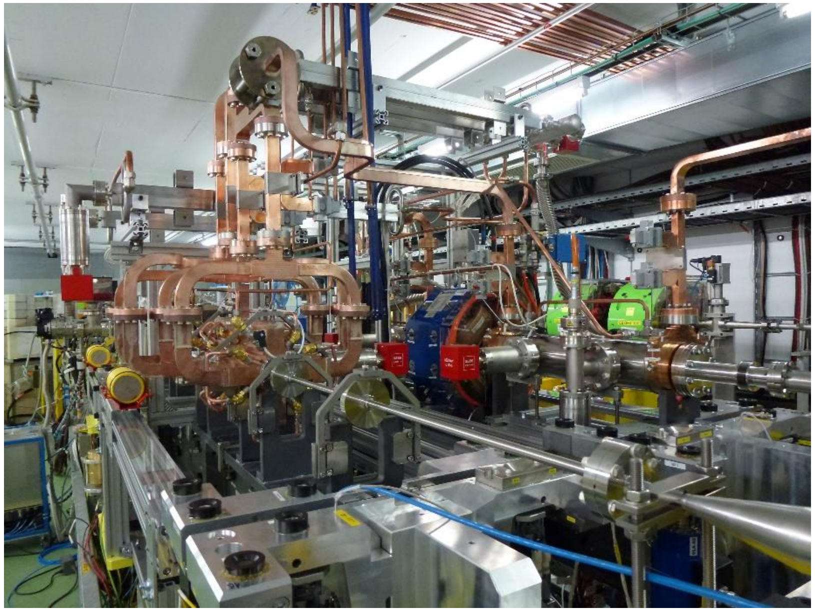
Use of permanent or hybrid magnets for the drive beam (order of 50,000 magnets)

… … …

CTF3

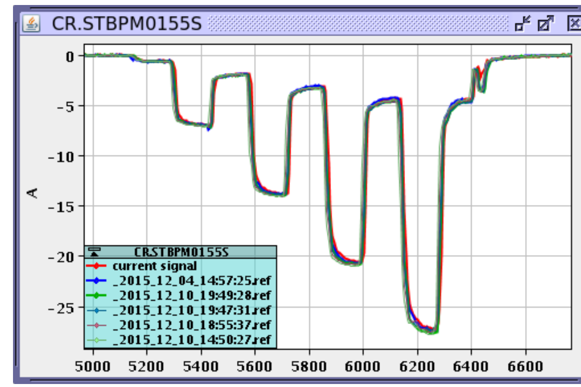

Delay
Loop
Chicane
Linac
Combiner
Ring
CALIFES
Probe Beam
Injector
TBTS
TBL
CLEX
Injector

CTF3 Experimental Program 2016



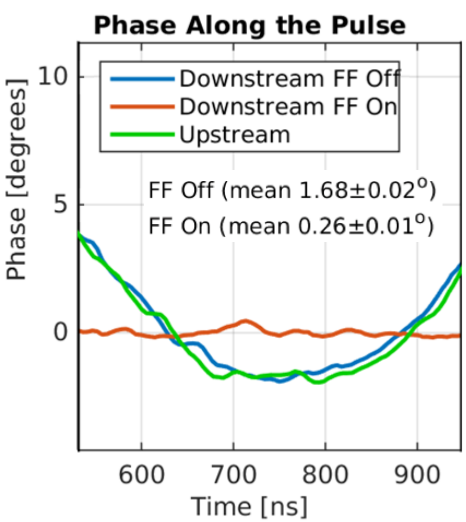
CLIC two-beam module tests

- Power production, stability + control of RF profile (beam loading compensation)
- RF phase/amplitude drifts along TBL, PETS switching at full power
- Alignment tests



Drive Beam

- Dispersion free-steering, dispersion matching, orbit control, chromatic corrections, emittance, stability
- Beam deceleration + optics check in TBL

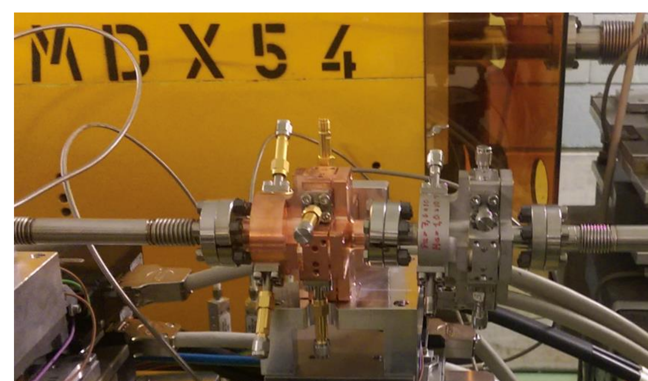


Drive-beam phase feed-forward tests

- Increase reproducibility
- Demonstrate factor ~ 10 jitter reduction

Ongoing instrumentation tests

- Wake-Field Monitors
- Main and Drive beam BPMs …



CALIFES

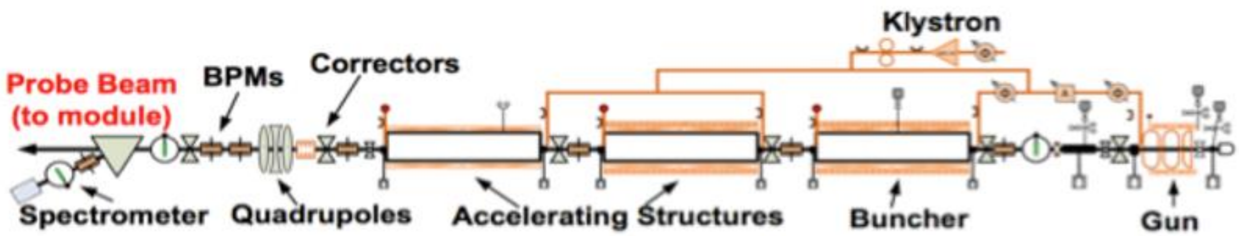


Figure 1: The current CALIFES beam line. The length of the facility (as shown) is ~20m.

Beam parameter (end of linac)	Value range
Energy	80 - 220 MeV
Bunch charge	0.01 - 1.5 nC
Normalized emittances	2 um in both planes
Bunch length	300 um -1.2 mm
Relative energy spread	1 %
Repetition rate	1 - 5 Hz
Number of micro-bunches in train	Selectable between 1 and >100
Micro-bunch spacing	1.5 GHz

Table 1: CALIFES parameters.

- **Continuation of the CLIC high-gradient research**
- **X-band FEL collaboration (preparation for EU-proposal)**
- **Instrumentation tests (including WFMs)**
- **Discharge plasma wakefield experiments**
- **Impedance measurements**
- **Irradiation facility**
- **THz production**
- **General interest from AWAKE (including instrumentation)**

CALIFES workshop

Workshop on exploitation of CALIFES as an e- beam user facility: CERN 10-12 October 2016

https://indico.cern.ch/event/533052/

LINEAR COLLIDER COLLABORATION

CALIFES → 'CLEAR' CERN Linear Electron Accelerator for Research

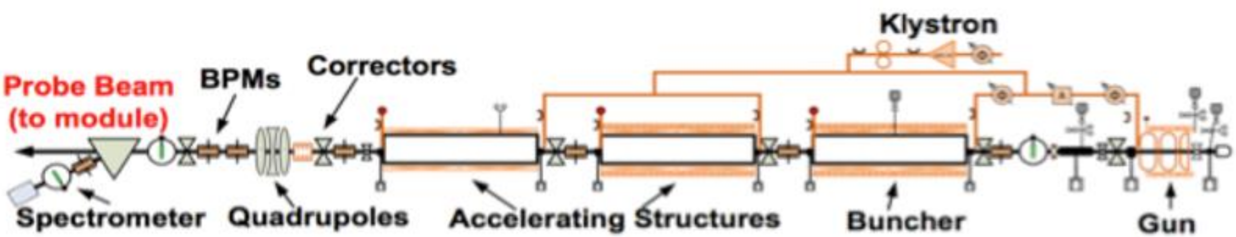


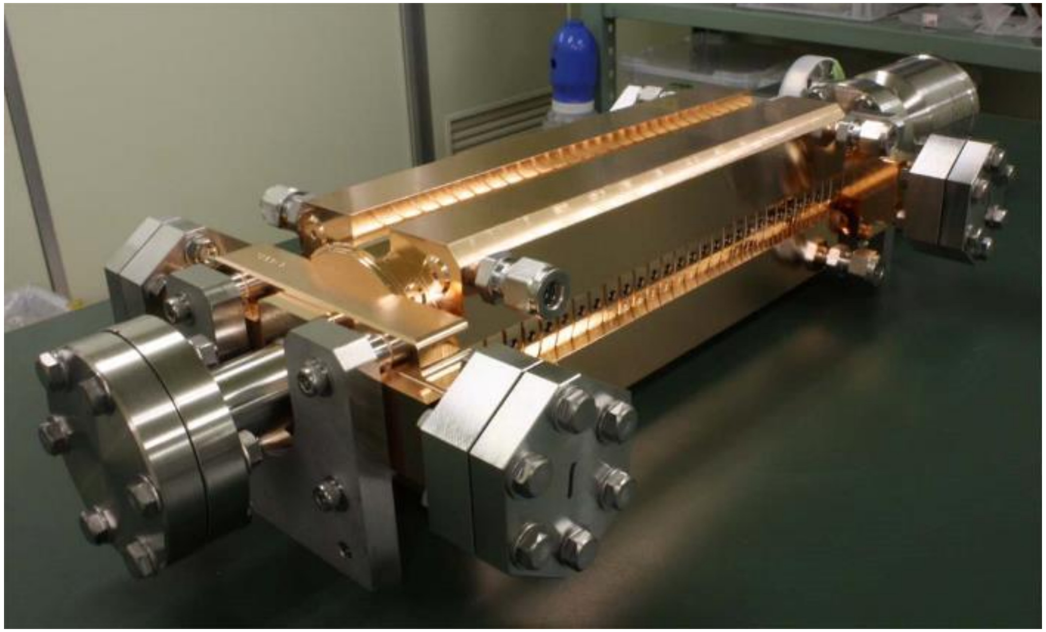
Figure 1: The current CALIFES beam line. The length of the facility (as shown) is ~20m.

Beam parameter (end of linac)	Value range
Energy	80 - 220 MeV
Bunch charge	0.01 - 1.5 nC
Normalized emittances	2 um in both planes
Bunch length	300 um -1.2 mm
Relative energy spread	1 %
Repetition rate	1 - 5 Hz
Number of micro-bunches in train	Selectable between 1 and >100
Micro-bunch spacing	1.5 GHz

Table 1: CALIFES parameters.

CLIC accelerating structure

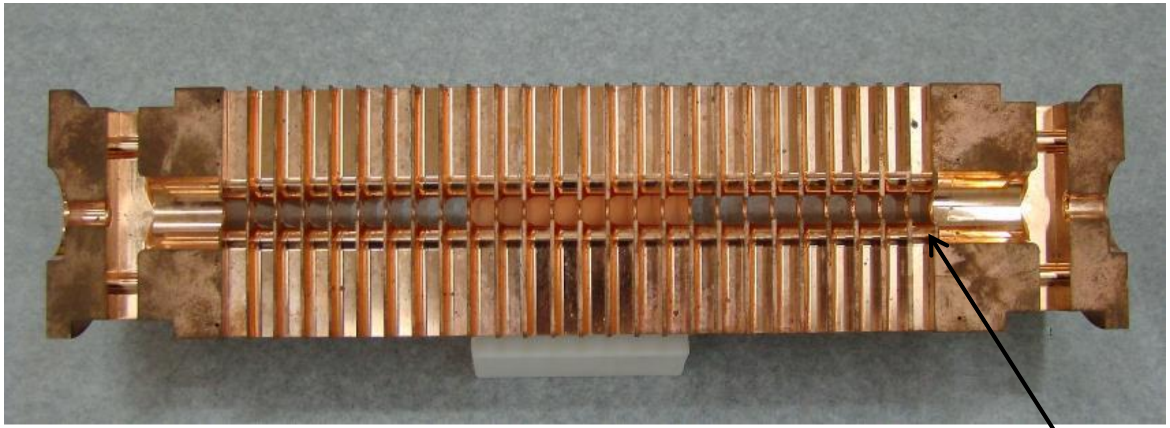
Outside



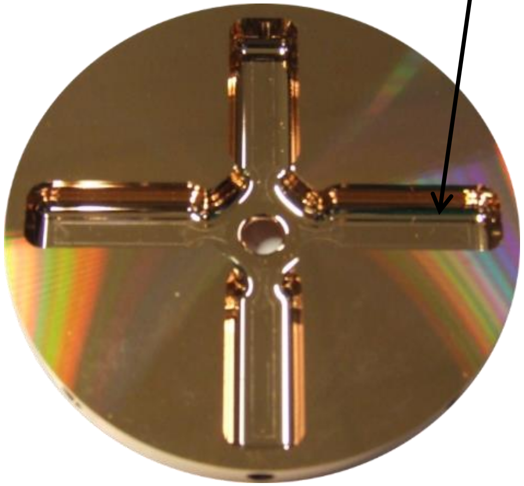
11.994 GHz X-band
100 MV/m
Input power ≈50 MW
Pulse length ≈200 ns
Repetition rate 50 Hz

HOM damping waveguide

Inside



Micron–precision disk

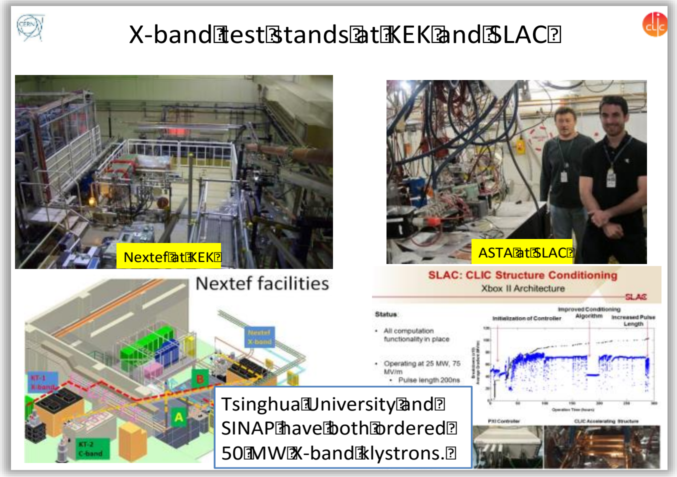


25 cm

6 mm diameter beam aperture

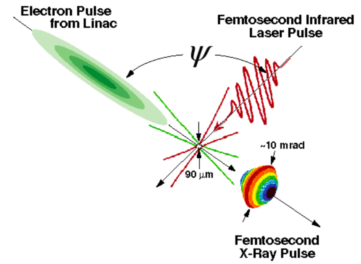
Existing and planned Xband infrastructures

CERN	XBox-1 test stand	50 MW	Operational
	Xbox-2 test stand	50 MW	Operational
	XBox-3 test stand	4x6 MW	Commissioning
KEK	NEXTEF	2x50 MW	Operational, supported in part by CERN
SLAC	ASTA	50 MW	Operational, one structure test supported by CERN
	Design of high-efficiency X-band klystron	30 MW	Under discussion
Trieste	Linearizer for Fermi	50 MW	Operational
PSI	Linearizer for SwissFEL	50 MW	Operational
	Deflector for SwissFEL	50 MW	Planning
DESY	Deflector for FLASHforward	50 MW	Planning (note first two may share power unit)
	Deflector for FLASH2	50 MW	Planning
	Deflector for Sinbad	50 MW	Planning

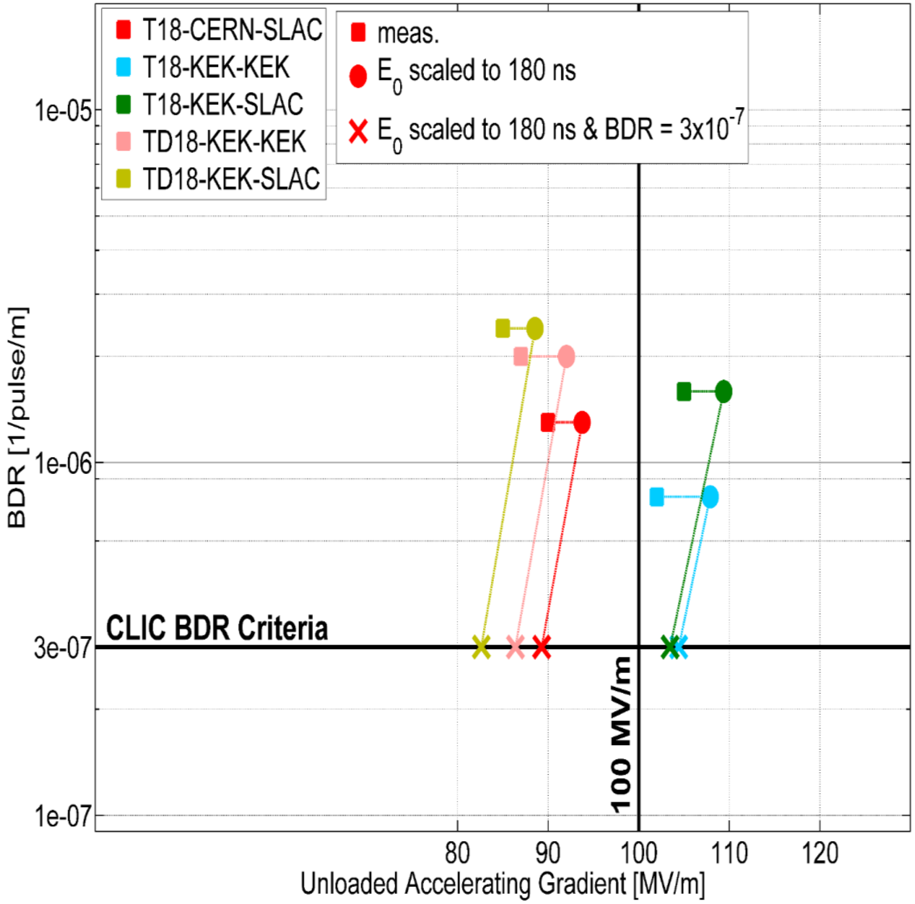


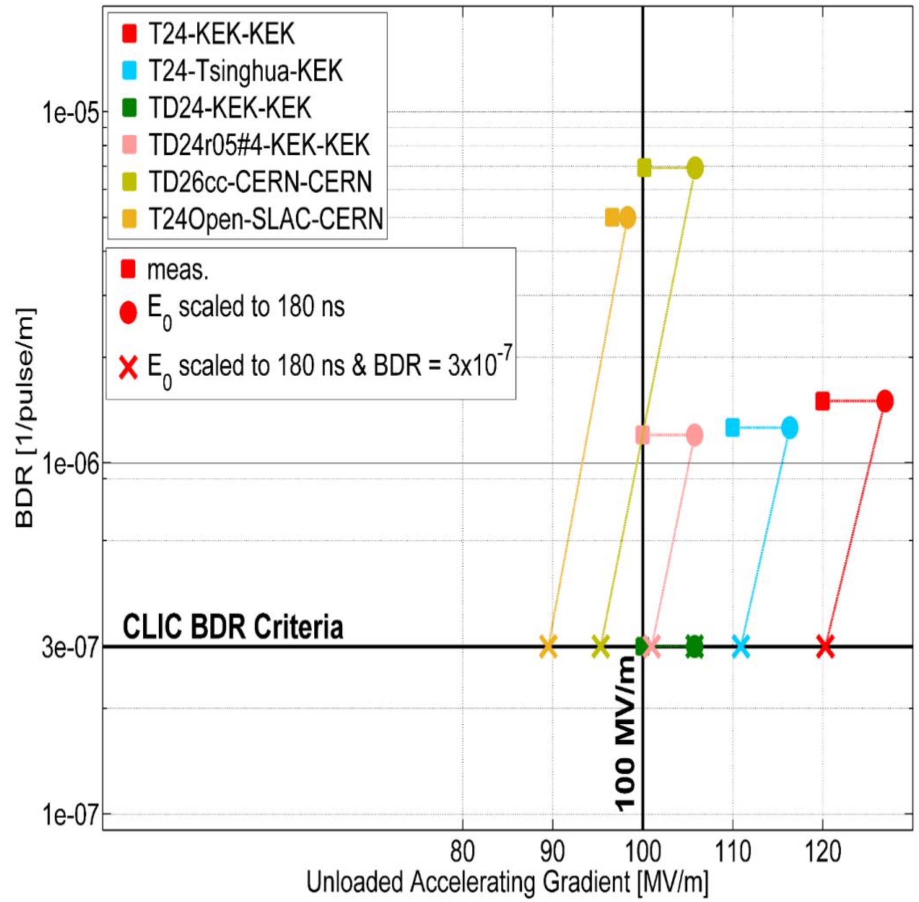
Existing and planned Xband infrastructures

Australia	Test stand	2x6 MW	Proposal, loan agreement from CERN
Eindhoven	Compact Compton source	6 MW	Proposal, request for loan from CERN
Uppsala	Test stand	50 MW	Proposal, request for loan of spare klystron from CERN
Tsinghua	Deflector for Compton source	50 MW	Ordered
	Linearizer for Compton source	6 MW	Planning
SINAP	Linearizer for soft X-ray FEL	6 MW	Ordered
	Deflectors for soft X-ray FEL	3x50 MW	Planning
Valencia	S-band test stand	2x10 MW	Under construction
STFC	Linearizer	6 MW	Under discussion
	Deflector	10 MW	Under discussion
	Accelerator	tbd	Under discussion



Accelerating gradient summary



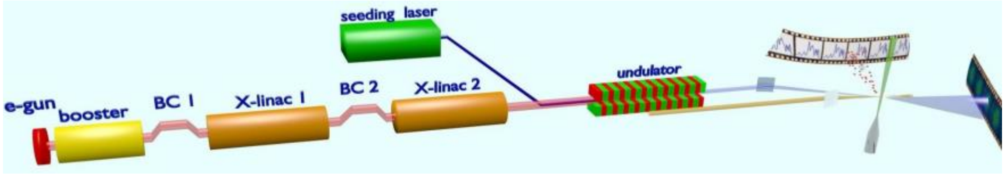


Original test structure geometry.

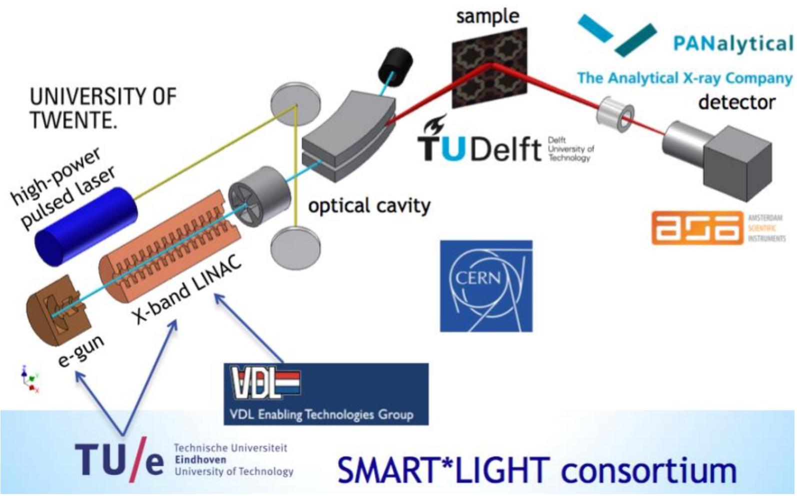
Baseline geometry, CLIC-G.
Newly optimized geometry, based on these results,
CLIC-G* now in production pipeline.

Walter Wuensch

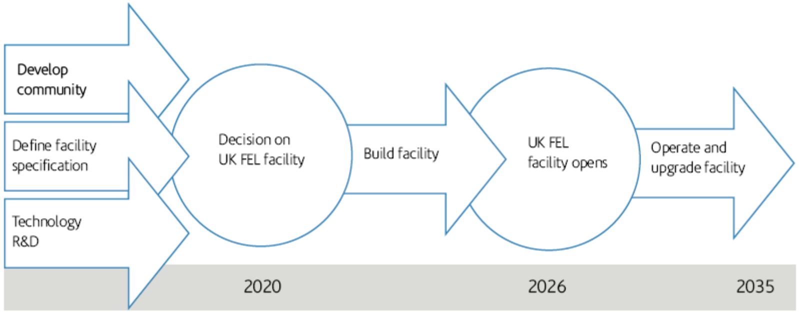
European National/Institute Ambitions



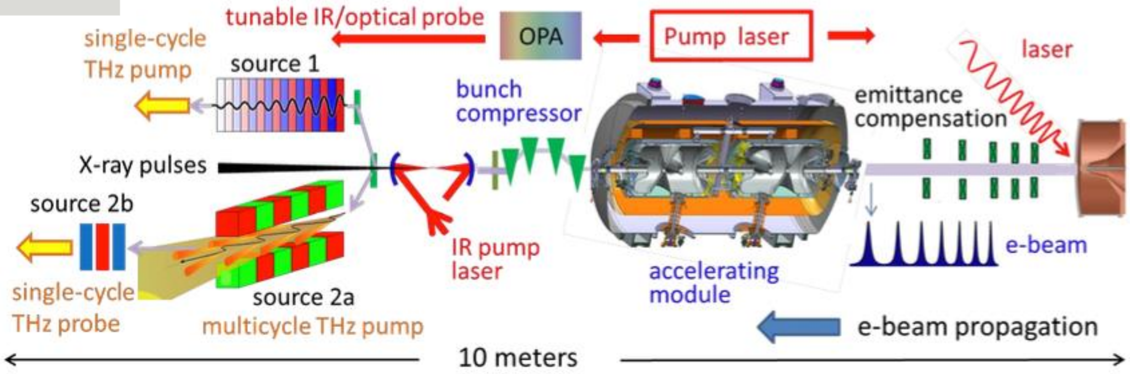
University of Groningen: FEL-NL



Eindhoven University of Technology: Smart*Light



UK FEL Strategy & Timeline towards Hard X-ray FEL



Stockholm/Uppsala FEL centre: X-ray & THz radiation

Andrea Latina

CompactLight – EU Horizon2020 proposal

- From previous application:
  - **ST** Elettra - Sincrotrone Trieste, Italy.
  - **CERN** CERN Geneva, Switzerland.
  - **STFC** Daresbury Laboratory, UK
  - **SINAP** Shanghai 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.
- New, additional, participants:
  - **TU** Eindhoven Technical University, Netherlands
  - **LNF** Frascati National Laboratory, INFN, Italy
  - **Kyma** Undulators production, Italy-Slovenia
  - **PSI** Paul Scherrer Institute, Switzerland
  - **RUG** University of Groningen, Netherlands
  - **IFIC** CSIC/Valencia, Spain
  - **ALBA** CELLS, Spain
  - **LAL** CNRS, France
  - **KIT** Karlsruhe, Germany
- Discussing with: **Singapore, CIEMAT, DESY, Milan, ENEA**

to be submitted March 2017

Outlook → European Strategy

Aim to:

- **Present CLIC as a credible post-LHC option for CERN**
- **Provide optimized, staged approach starting at 380 GeV, with costs and power not excessive compared with LHC, and leading to 3 TeV**
- **Upgrades in 2-3 stages over 20-30 year horizon**
- **Maintain flexibility and align with LHC physics outcomes**

CLIC roadmap

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

Outlook → European Strategy

Key deliverables:

Project plan: physics, machine parameters, cost, power, site, staging, construction schedule, summary of main tech. issues, prep. phase (2020-2025) summary, detector studies

Preparation-phase plan: critical parameters, status and next steps - what is needed before project construction, strategy, risks and how to address them

CLIC Workshop 2017

6-10 March 2017
CERN
Europe/Zurich timezone

Overview

CERN Shuttle service

CERN Bike Sharing Service

How to come to CERN

Visitors' Portable Computers Registration

CLIC Study Website

CLIC detector and physics website

The **CLIC workshop 2017** covers Accelerator as well as the Detector and Physics studies, with its present status and programme for the coming years.

For the Accelerator studies, the workshop spans over 5 days: 6th - 10th of March.
For CLICdp, the workshop is scheduled from Tuesday afternoon 7th to lunchtime on Friday 10th.

Registration will be opened soon.

Programme

Common parts:
1- An open plenary session on Wednesday afternoon March 8th, giving an overview of the CLIC project (accelerator, physics/detector), placed in the context of LHC results. This session also addresses the use of CLIC-related developments in other applications.
2- A common plenary accelerator/detector&physics session on Friday morning March 10th.
3- The workshop dinner on Wednesday evening.

Dedicated Accelerator sessions:
1- Parallel sessions on Monday afternoon, Tuesday and Wednesday morning

2- A session on Thursday covering High-Efficiency RF Power sources developments for CLIC and for other accelerator applications like ESS, FCC and other high-power electron and proton linacs.

3- A CLIC/CTF3 Collaboration Board on Friday afternoon

Dedicated Detector and Physics sessions:
1- Topical sessions on Tuesday afternoon, Wednesday morning and all of Thursday.
2- The CLICdp Institute Board meeting will take place over lunch on Thursday.

3- A CLICdp dinner is organised for Thursday evening.

(Note that an FCAL meeting is scheduled at the beginning of the week, prior to the CLICdp sessions).

We are looking for the widest possible participation and encourage in particular the involvement of young colleagues.

CERN Courier article

"CLIC steps up to the TeV challenge"

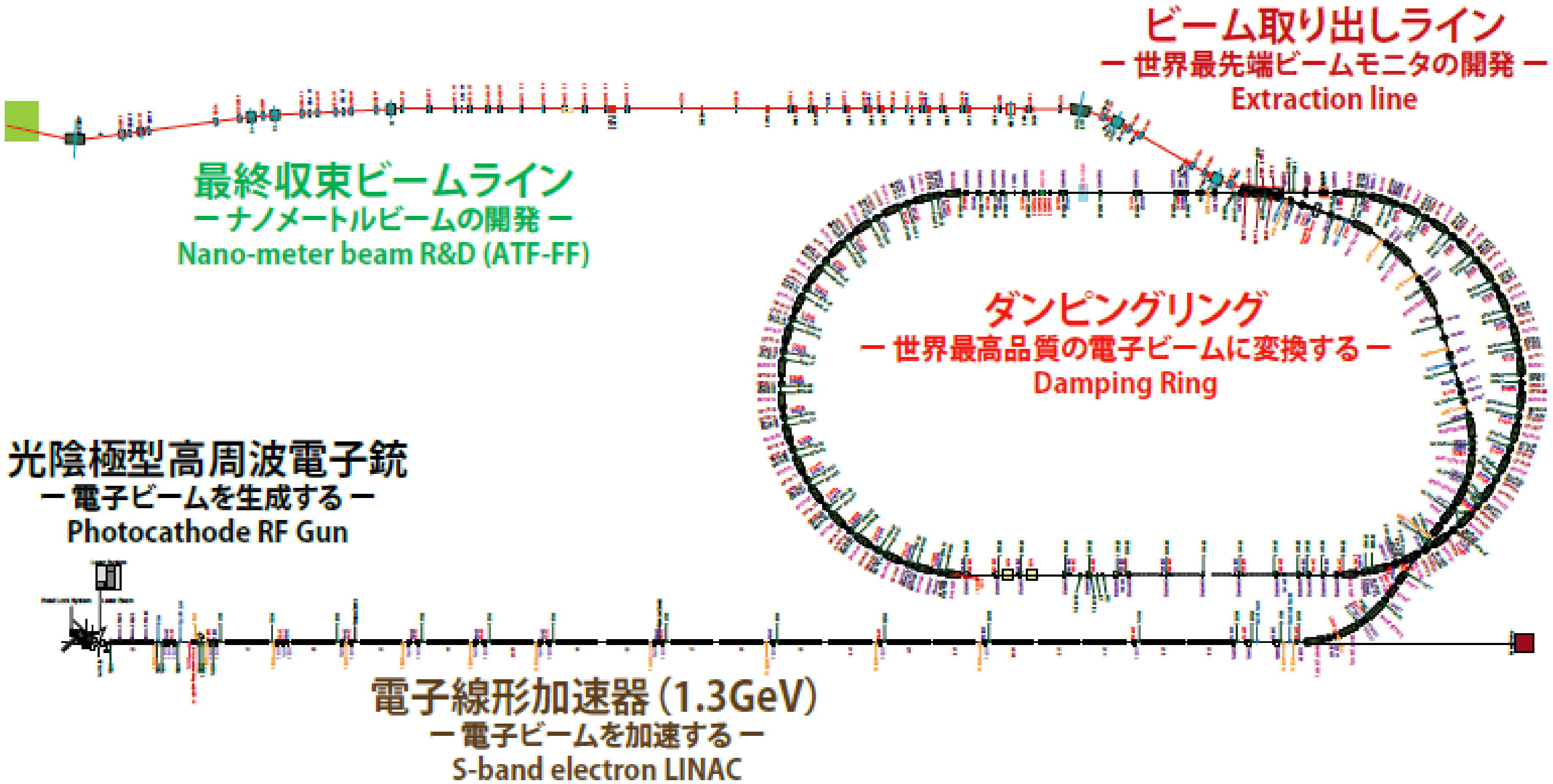
by Philipp Roloff and Daniel Schulte

(November 2016)

http://cerncourier.com/cws/article/cern/66567

Backup slides

ATF/ATF2 (KEK)


ビーム取り出しライン
ー 世界最先端ビームモニタの開発 ー
Extraction line
最終収束ビームライン
ーナノメートルビームの開発 ー
Nano-meter beam R&D (ATF-FF)
ダンピングリング
ー 世界最高品質の電子ビームに変換する ー
Damping Ring
光陰極型高周波電子銃
ー 電子ビームを生成する ー
Photocathode RF Gun
電子線形加速器 (1.3GeV)
ー 電子ビームを加速する ー
S-band electron LINAC

CLIC + ATF/ATF2

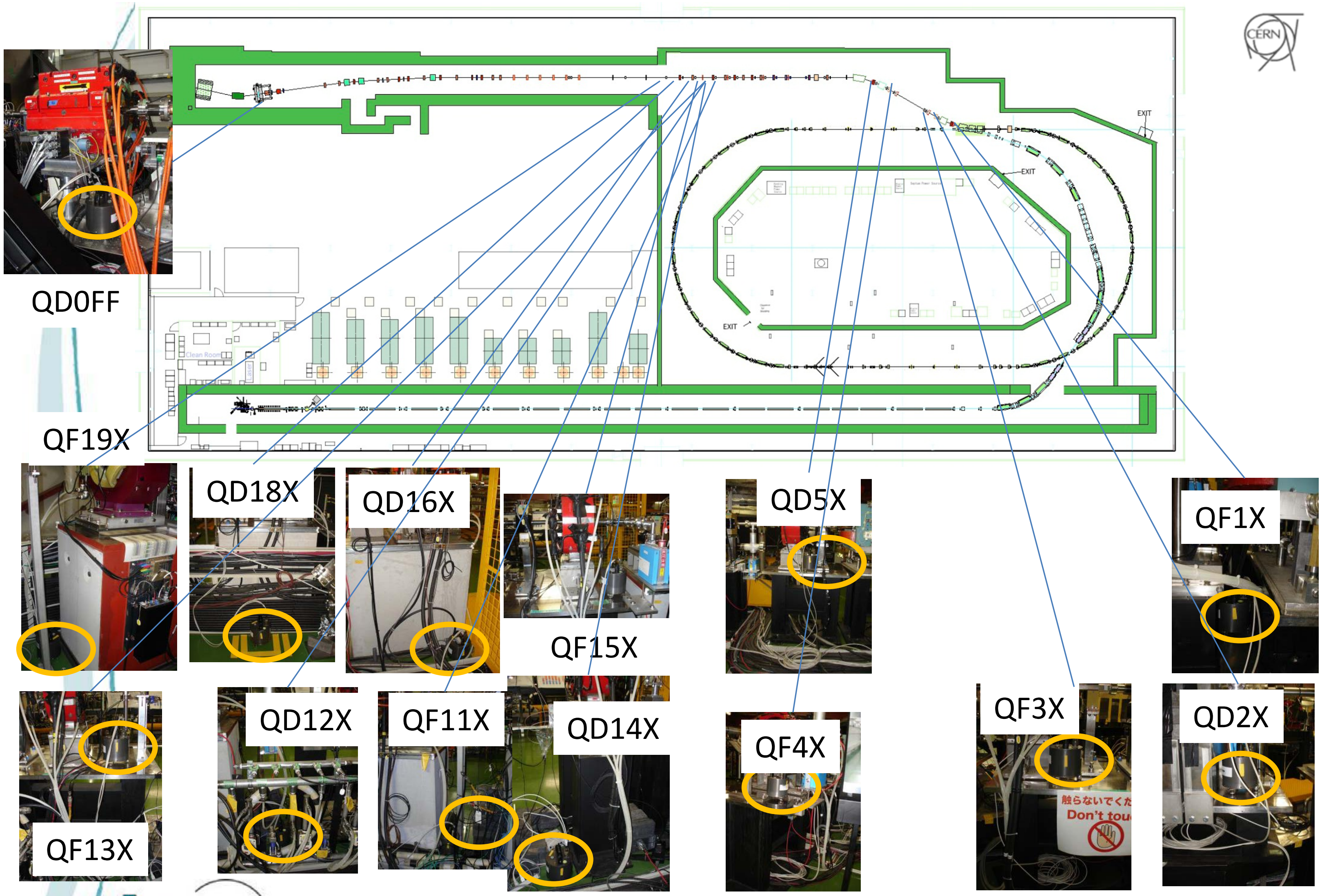
Demonstration of nanometer-scale beam (~41nm achieved)

Beam stabilisation at nanometre level

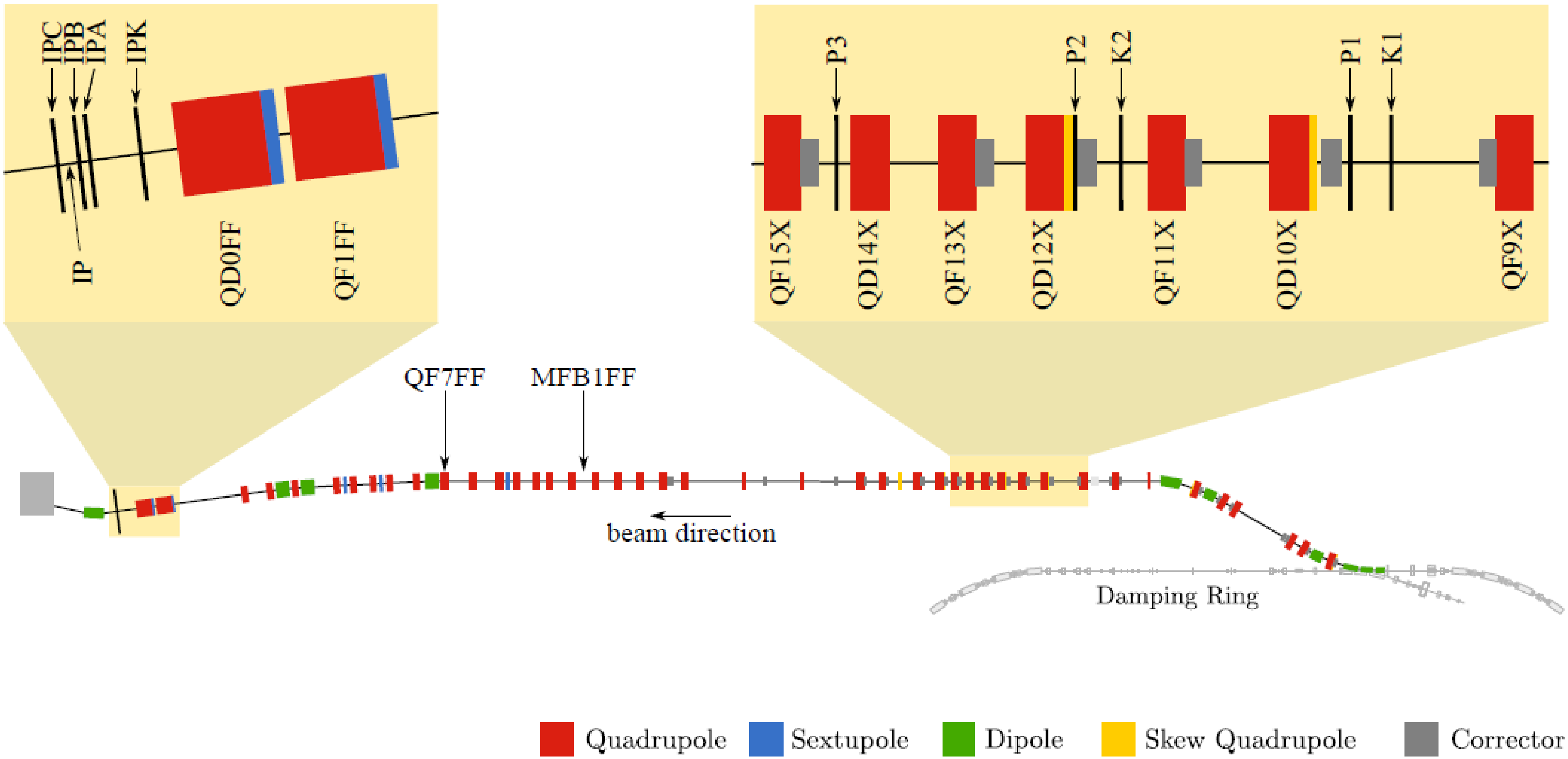
Also:

- **Beam tuning techniques**
- **Beam jitter characterisation and amelioration**
- **Beam feedback + feed-forward**
- **Magnet development (hybrid QD0, PM octupoles)**
- **Beam instrumentation: BPMs, transverse beam size …**
- **DR extraction kicker tests …**

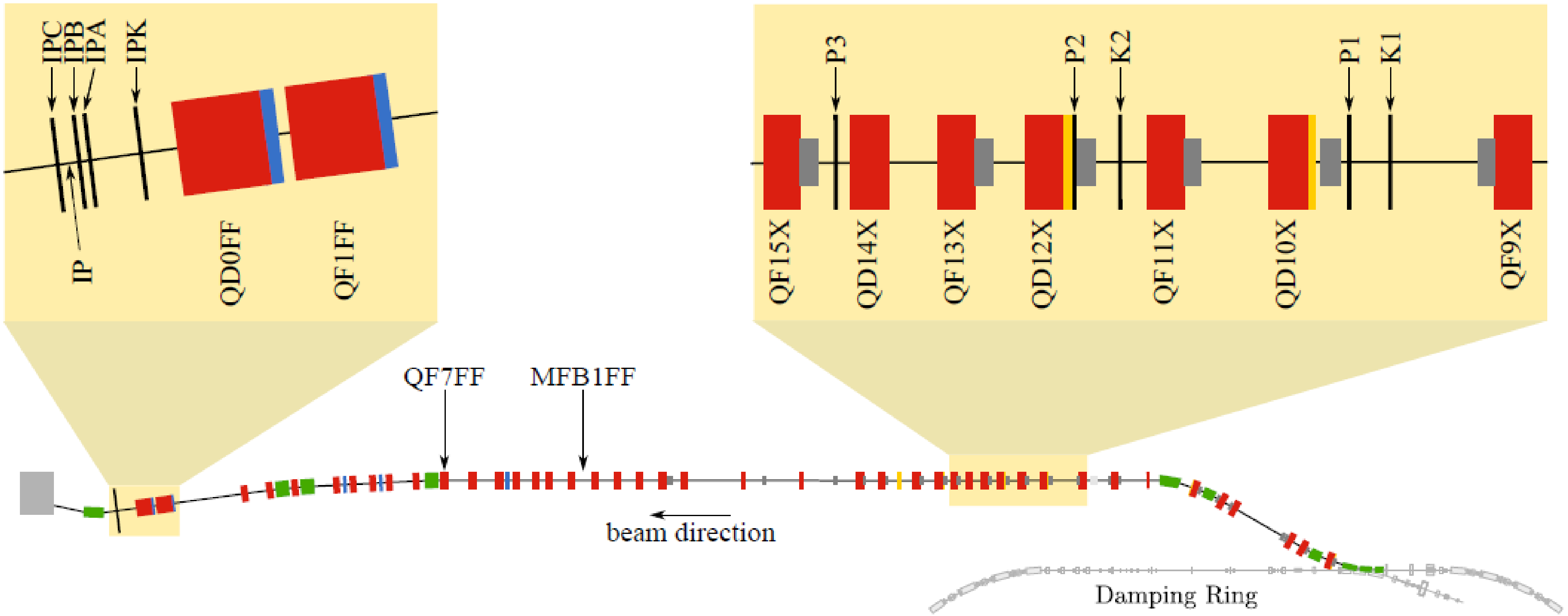
Ground-motion sensor array



FONT5 'intra-train' feedbacks



Stabilising beam near IP

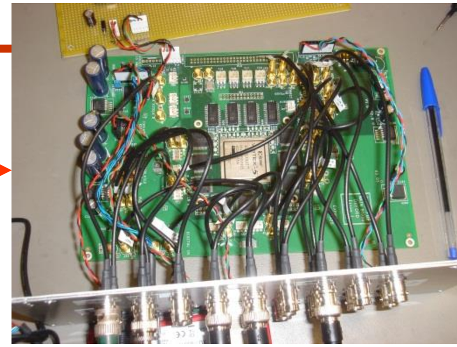


1. **Upstream FB:** monitor beam at IP
2. **Feed-forward:** from upstream BPMs → IP kicker
3. **Local IP FB:** using IPBPM signal and IP kicker

Upstream FONT5 System

Analogue Front-end

BPM processor

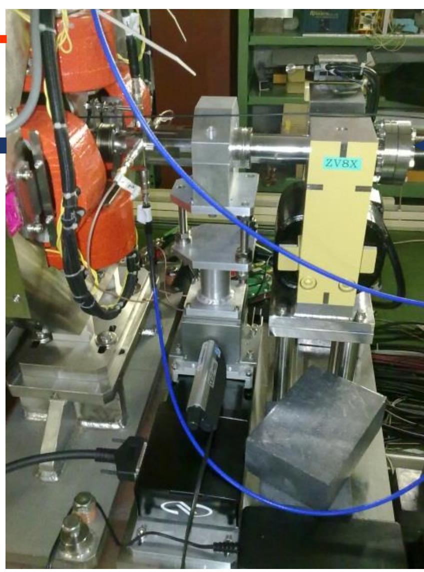


FPGA-based digital processor

Kicker drive amplifier

Strip-line kicker

Beam



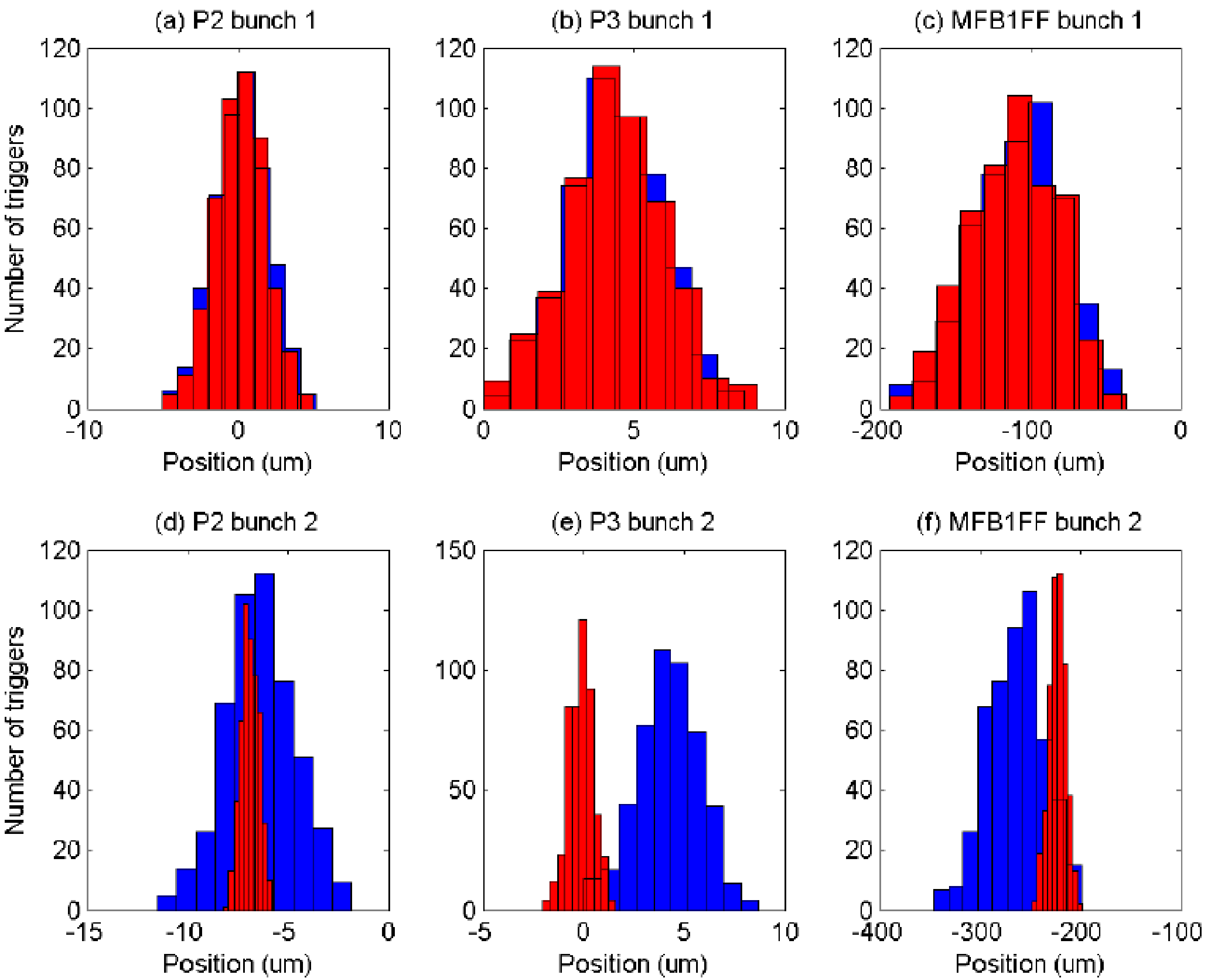
Stripline BPM with mover system

Meets ILC requirements: BPM resolution

Dynamic range

Latency

FONT5 system performance



Bunch 1: input to FB

FB off
FB on

Bunch 2: corrected

FB off
FB on

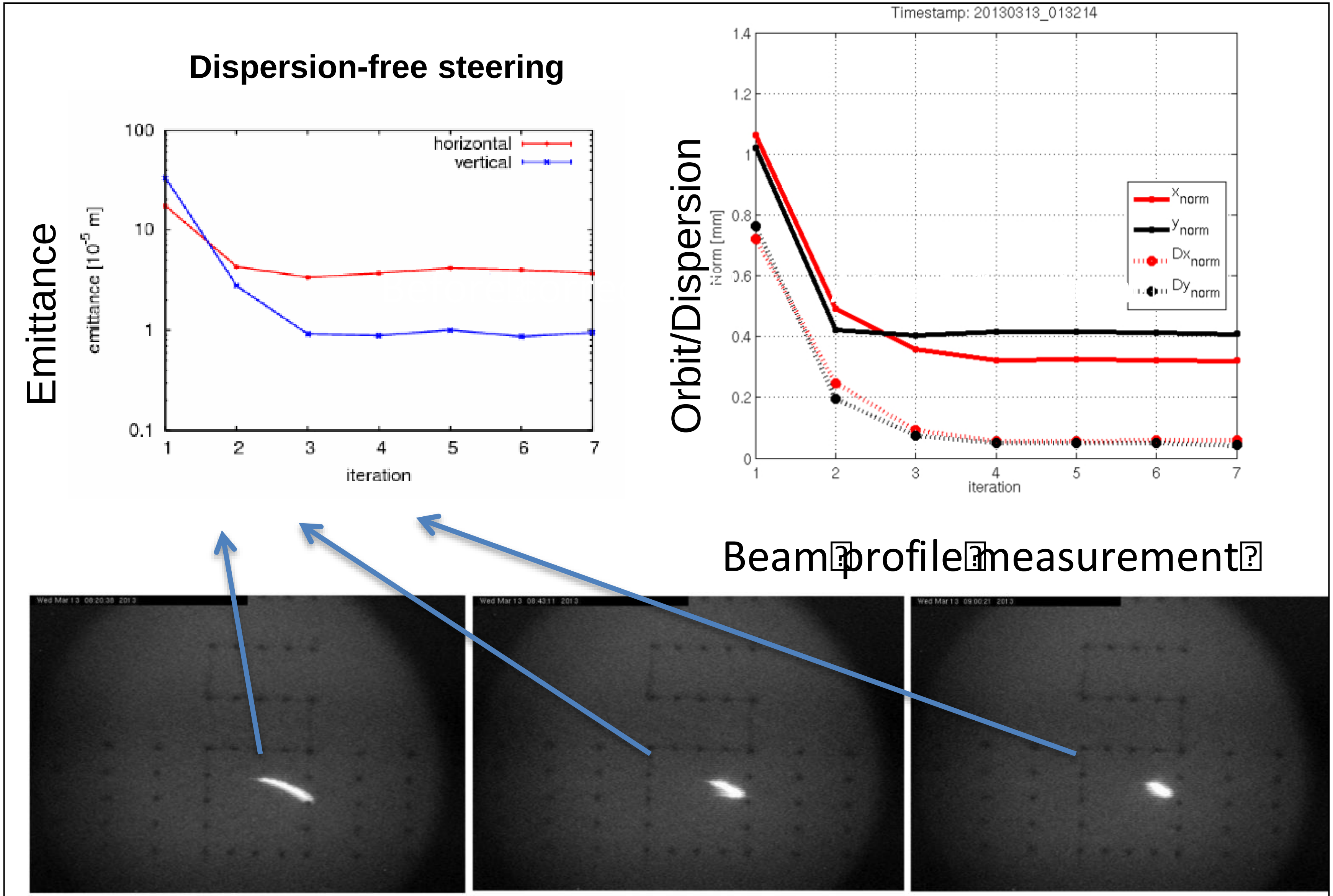
Predicted jitter reduction at IP

	Position y jitter (nm)		Angle y' jitter (urad)	
Bunch	Feedback off	Feedback on	Feedback off	Feedback on
1	9.5 ± 0.3	10.1 ± 0.3	89 ± 3	87 ± 3
2	$\boxed{9.4 \pm 0.3}$	$\boxed{3.6 \pm 0.1}$	87 ± 3	28 ± 1

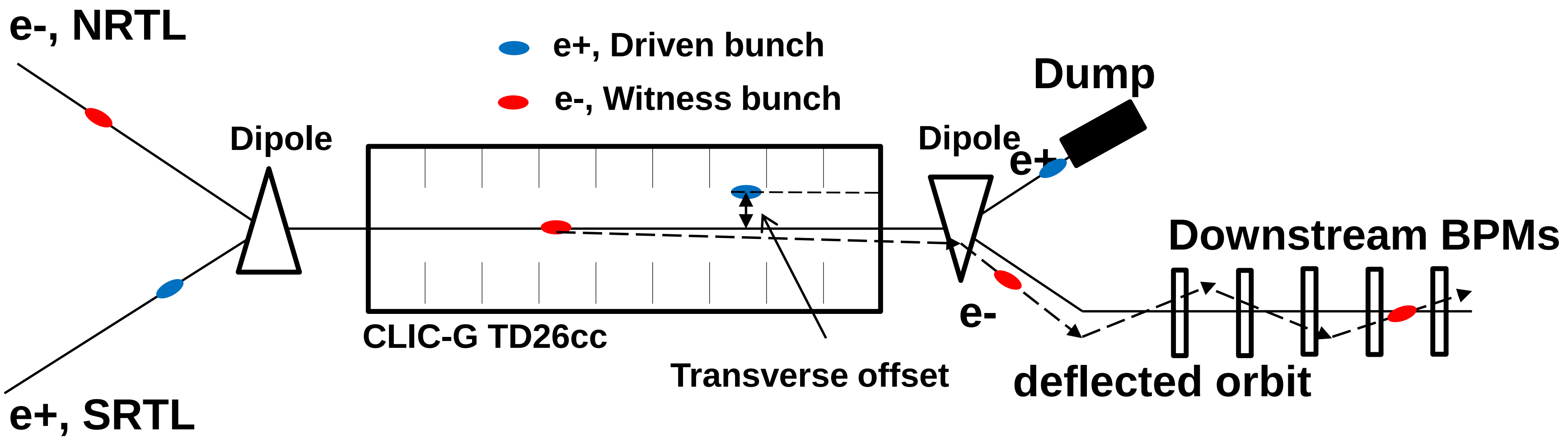
Predict position stabilised at few nanometre level…

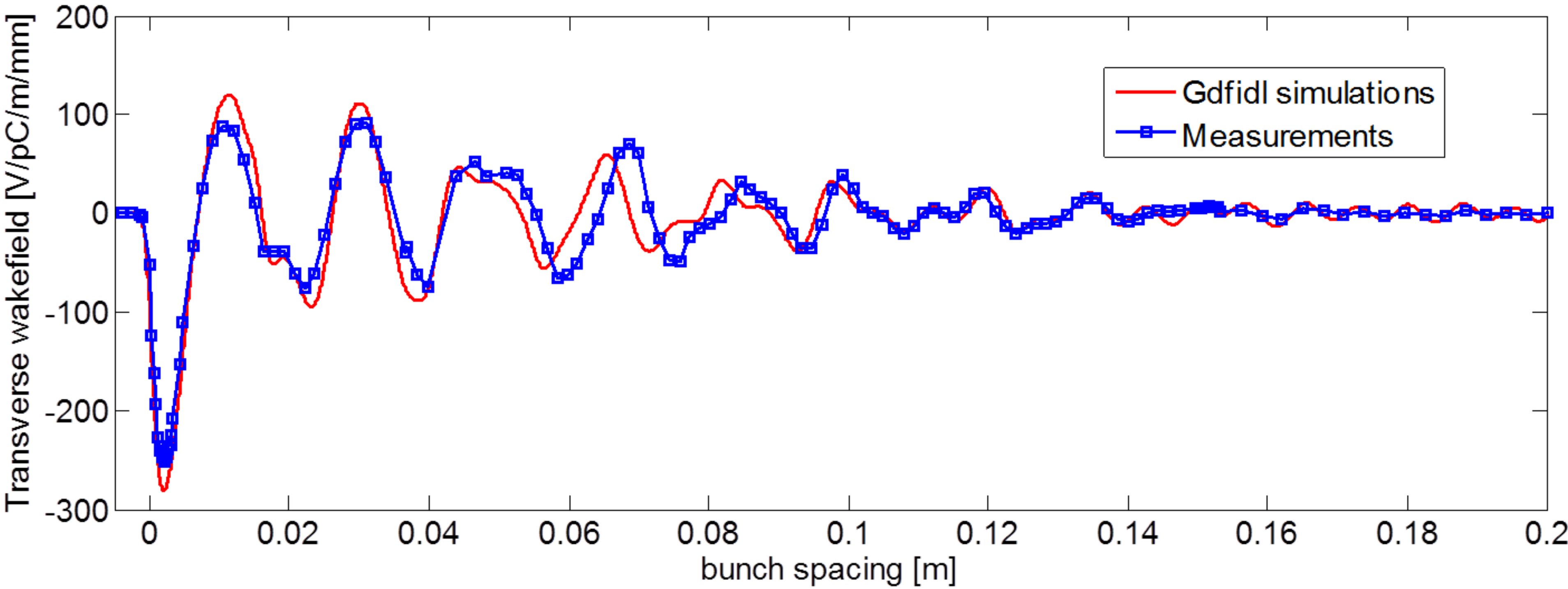
How to measure it?!

Beam tuning at FACET (SLAC)

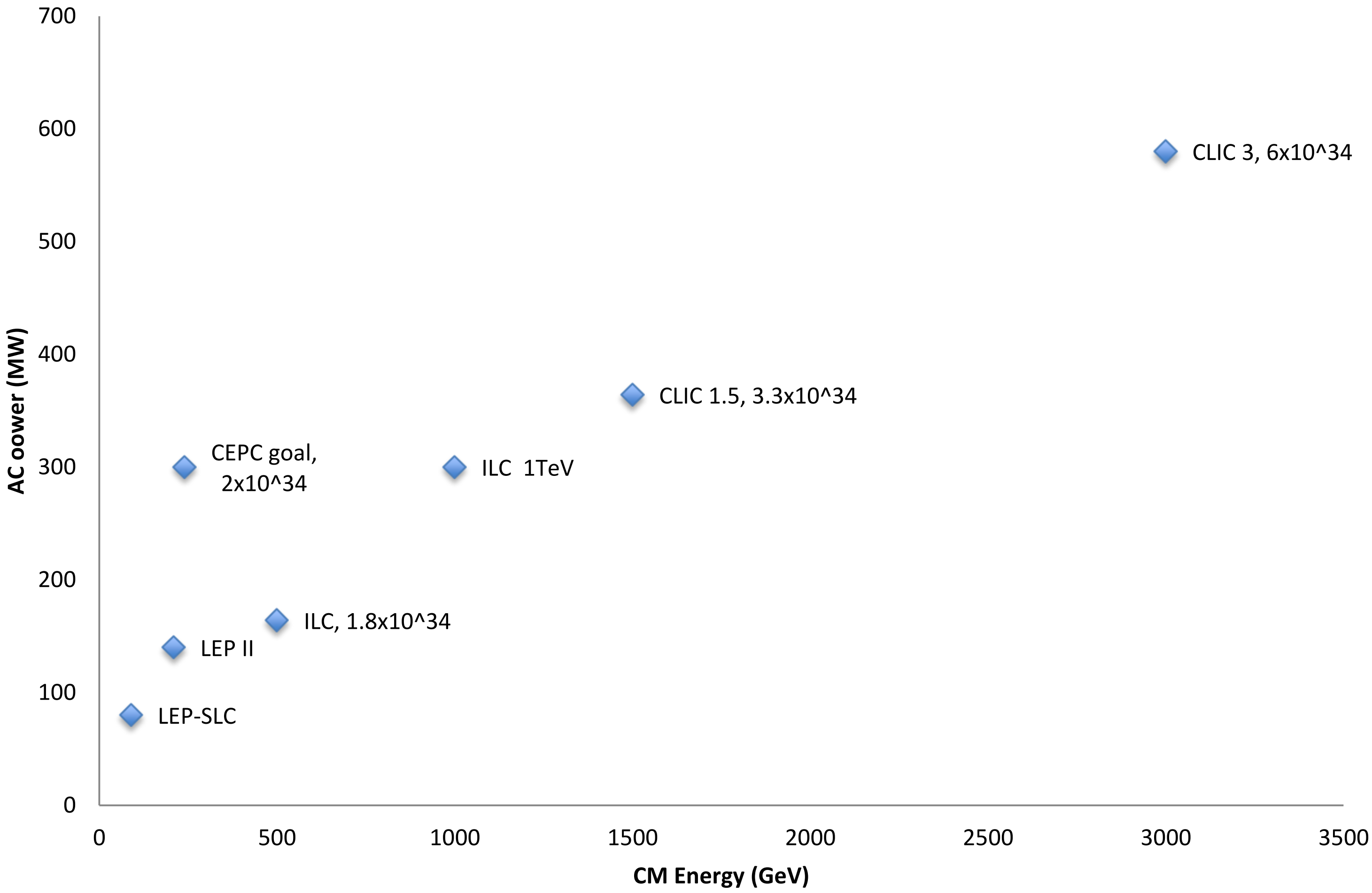


FACET measurements of wakefields



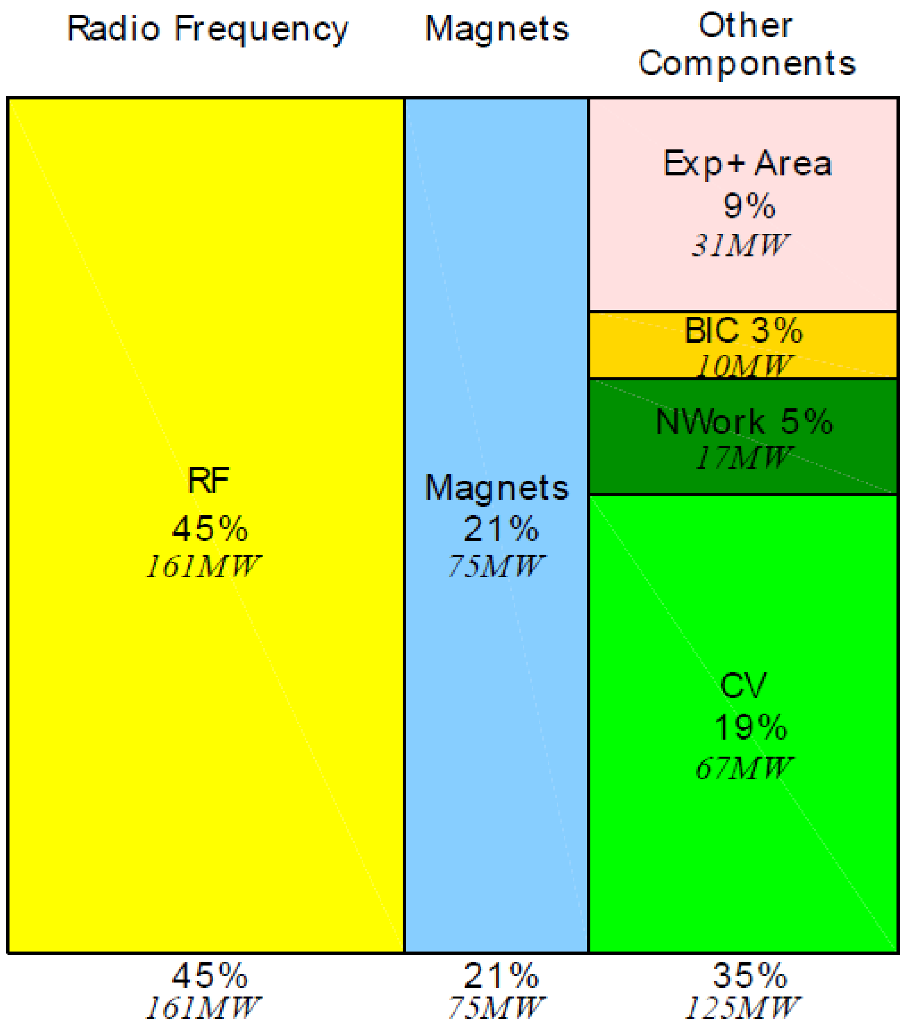


AC power

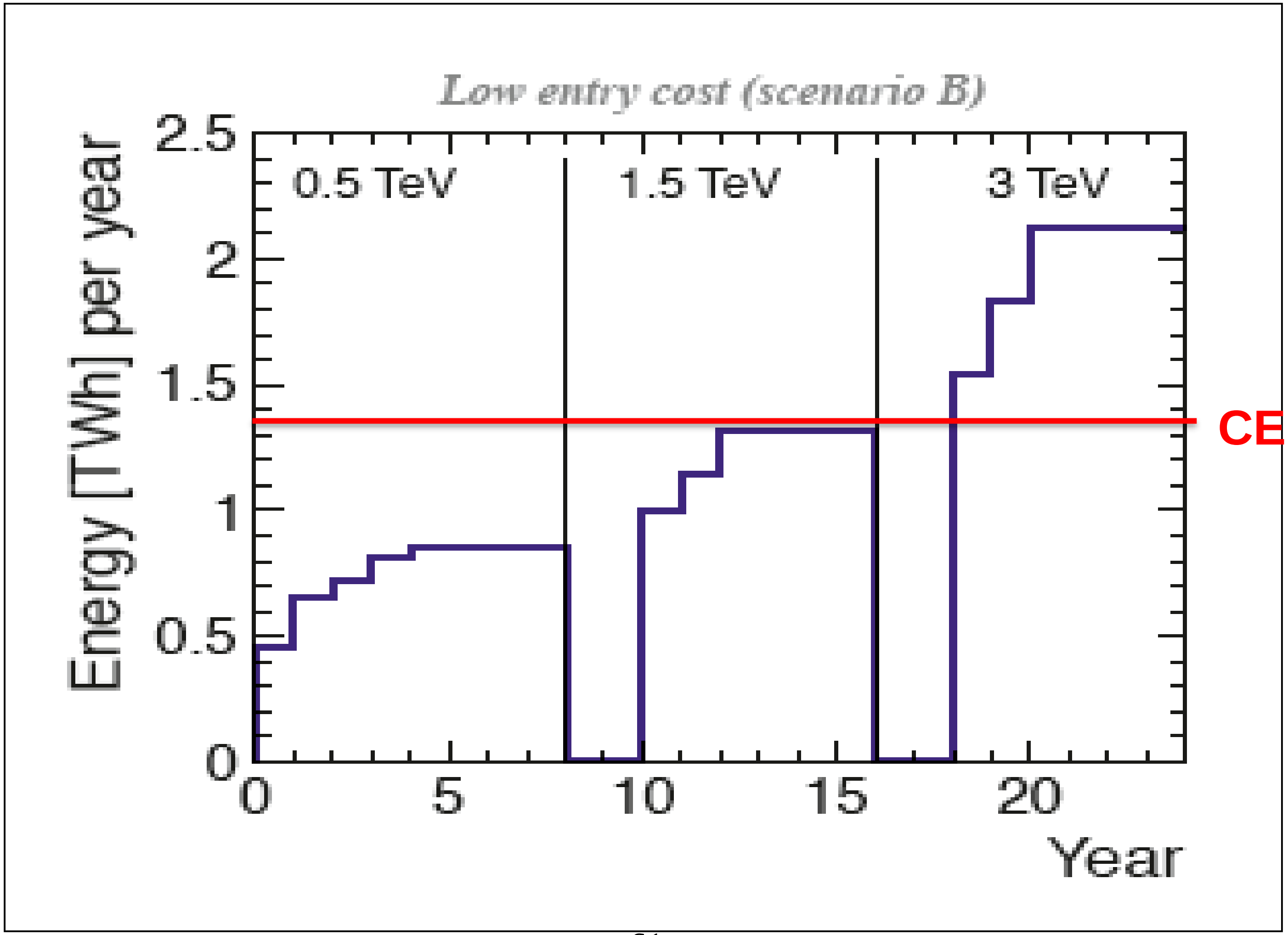


700
600
500
400
300
200
100
0
AC oower (MW)
CLIC 3, 6x10^34
CLIC 1.5, 3.3x10^34
CEPC goal,
2x10^34
ILC 1TeV
ILC, 1.8x10^34
LEP II
LEP-SLC
0
500
1000
1500
2000
2500
3000
3500
CM Energy (GeV)

AC power (1.5 TeV)



Energy consumption



‘Automatic’ parameter determination

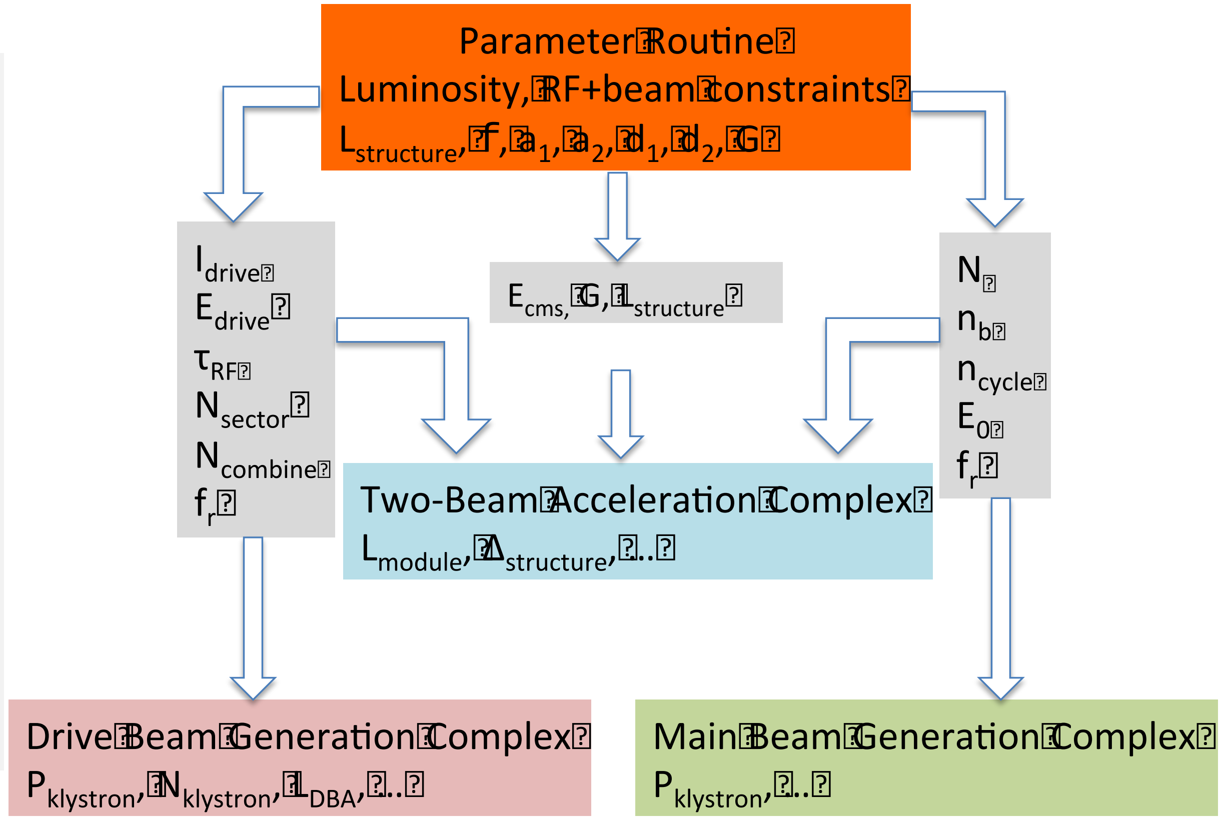
Structure design fixed by few parameters

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

Beam parameters derived automatically to reach specific energy and luminosity

Consistency of structure with RF constraints is checked

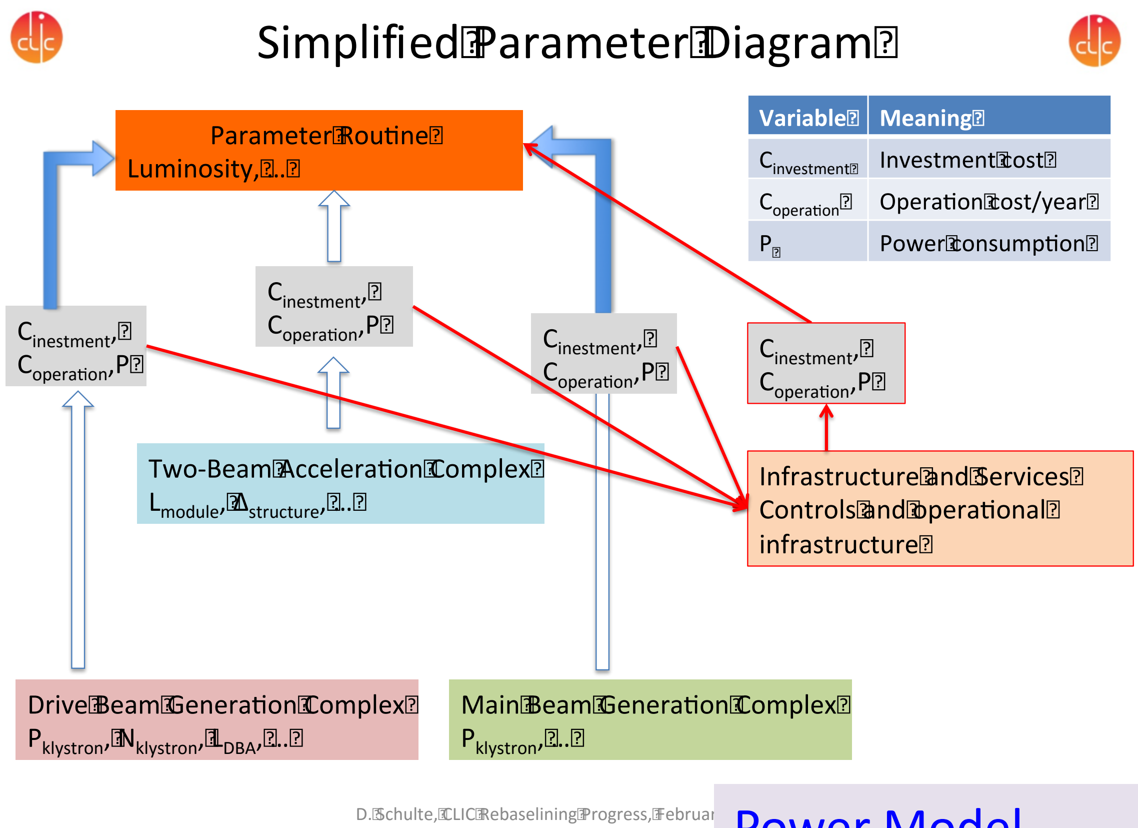
Repeat for 1.7 billion cases



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

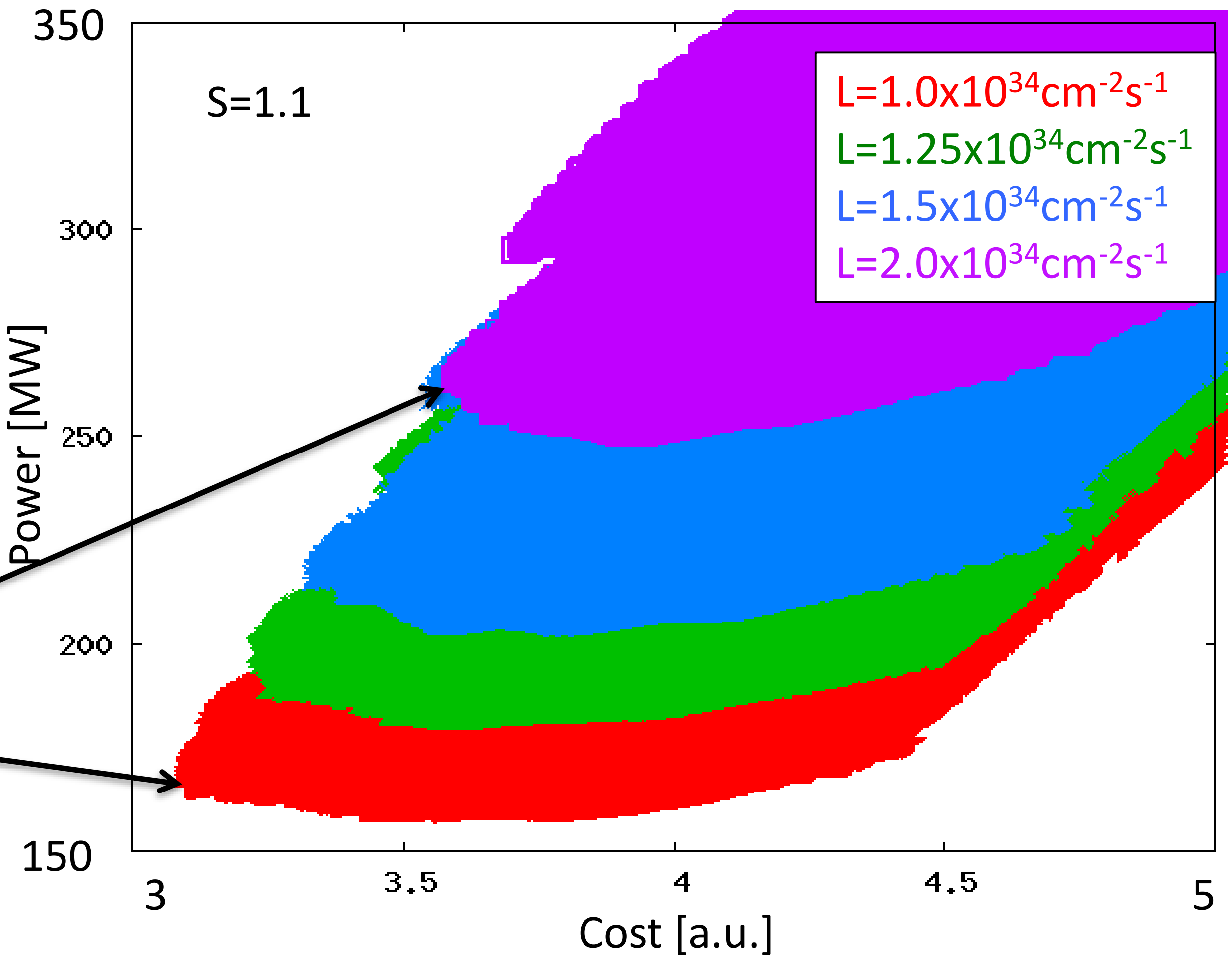
Cost / power model



Power Model

- Does not contain BDS and experiments
- Main beam injector power scaled with charge per train
- Some improvement is possible (e.g. drive beam turn-around magnets, booster linac, ...)

Example output (360 GeV)



Luminosity goal impacts 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

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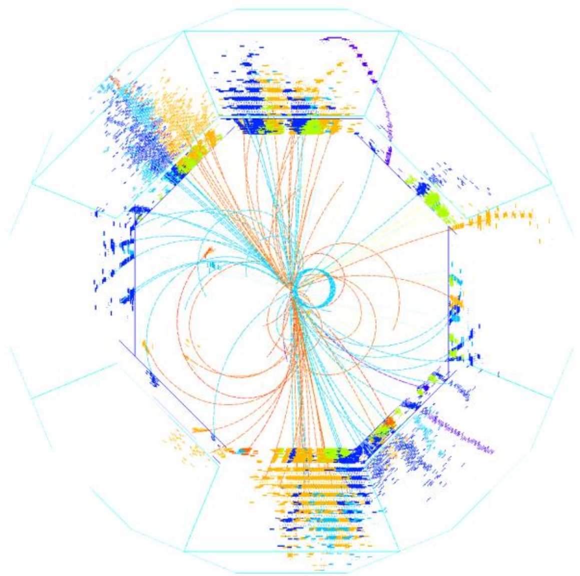
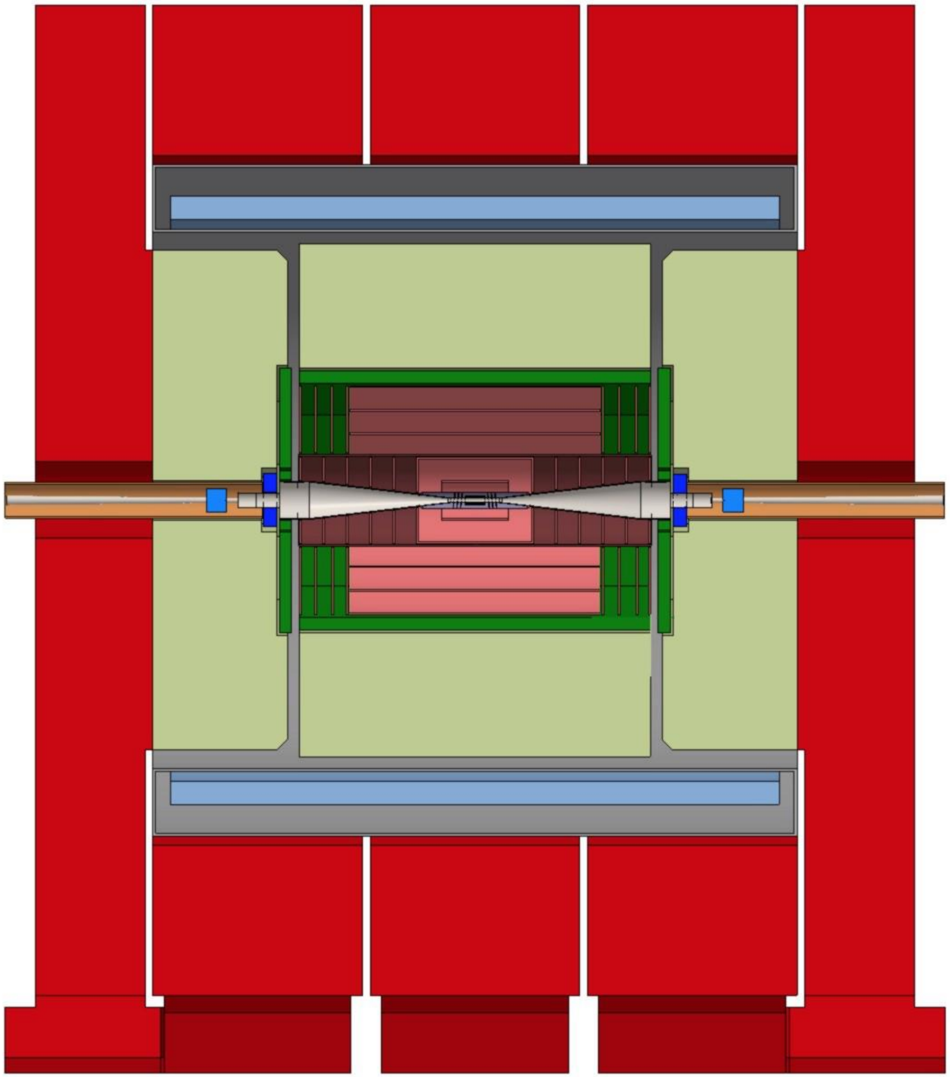
CLIC detector concept

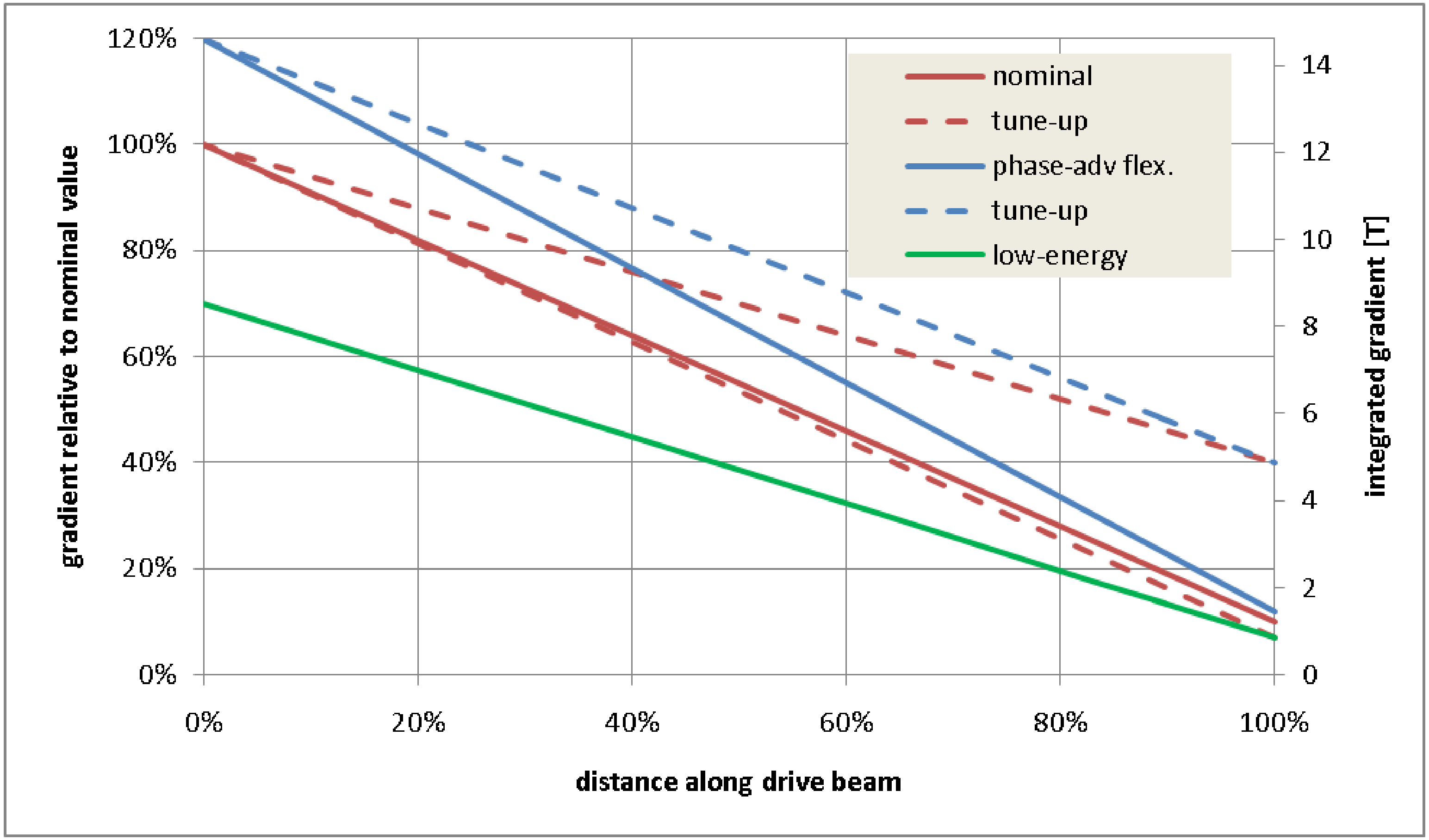
ILC concepts adapted to a single detector for CLIC:

- **Highly-granular, deep calorimeter**
- **4T solenoid**
- **Low-mass Si tracking system**
- **Precision vertexing close to IP**
- **10ns time-stamping**



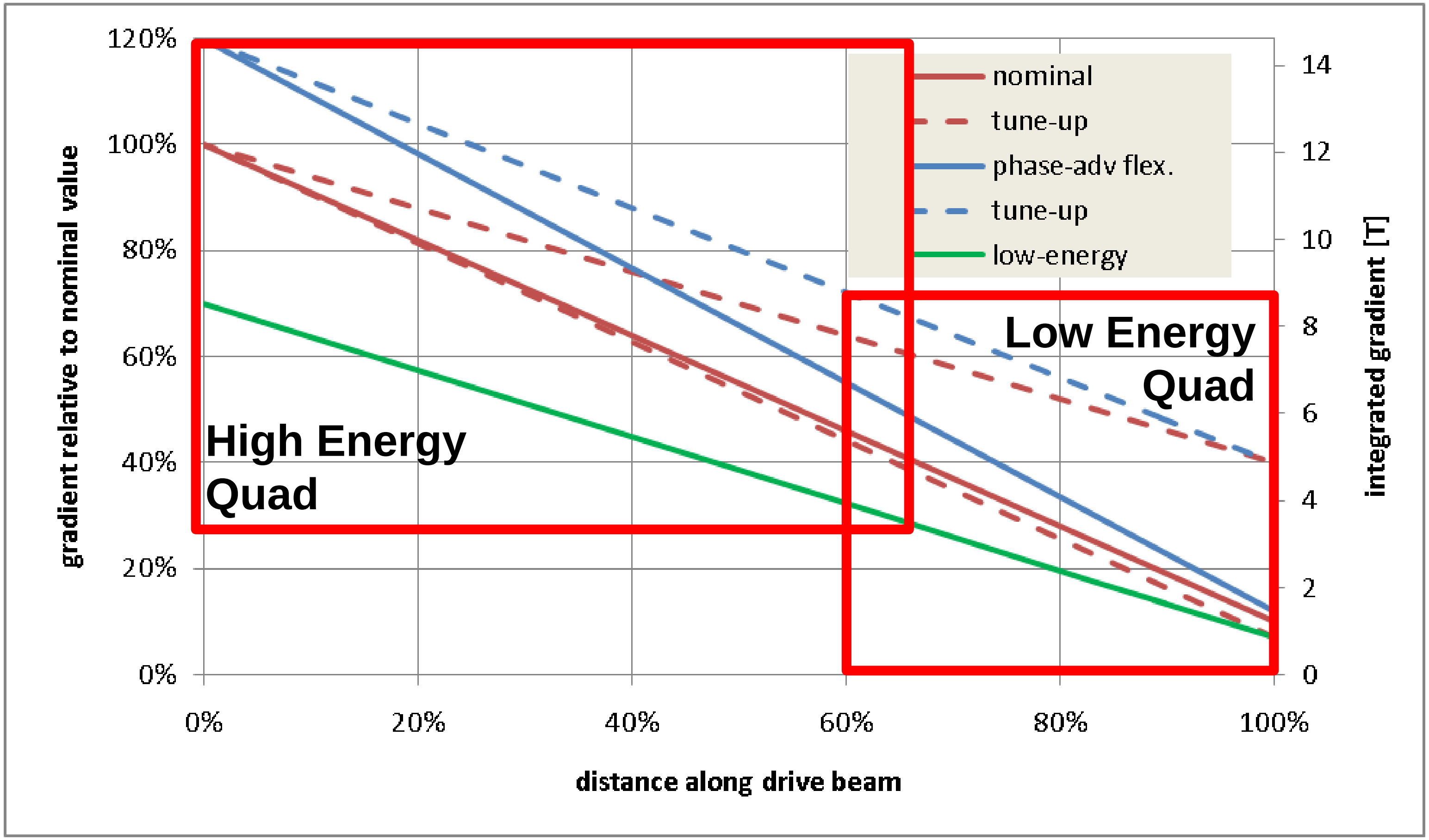


Drive beam quadrupoles (40 MW @ 3 TeV)



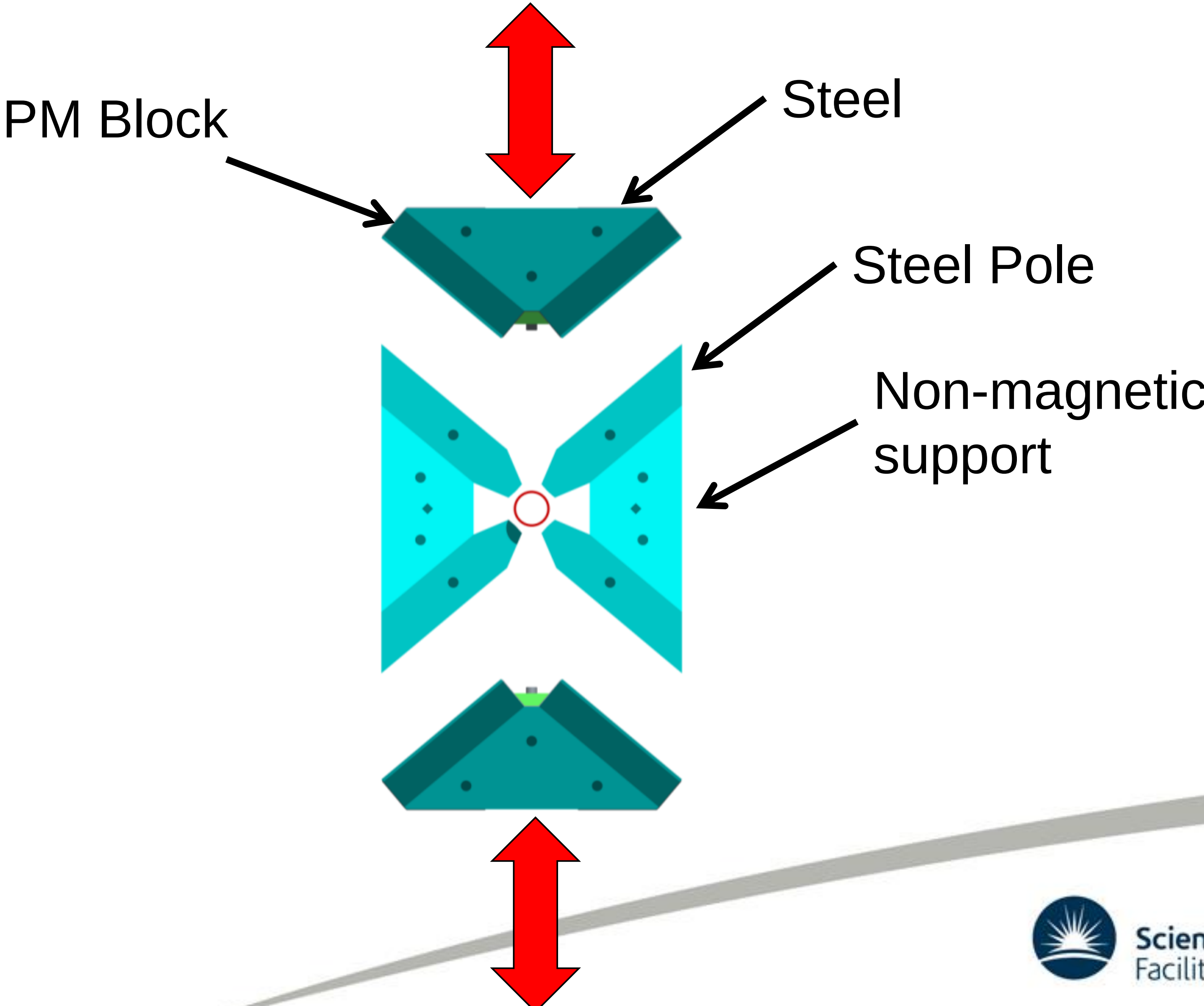
High energy quad – Gradient very high
Low energy quad – Very large dynamic range

Permanent Magnet solution



High energy quad – Gradient very high
Low energy quad – Very large dynamic range

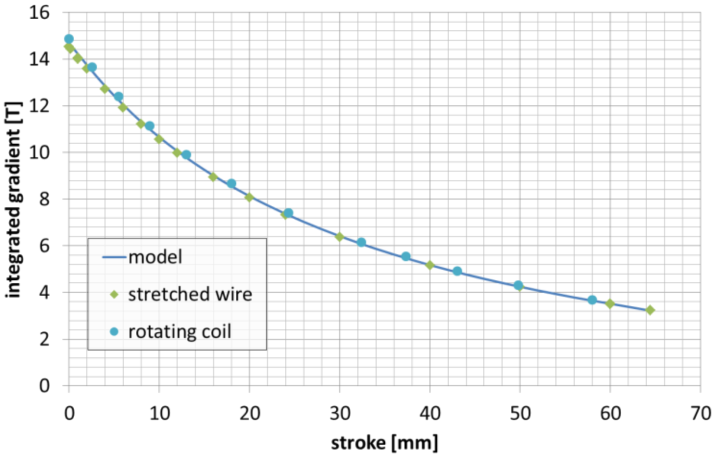
PM engineering concept



Science & Technology
Facilities Council

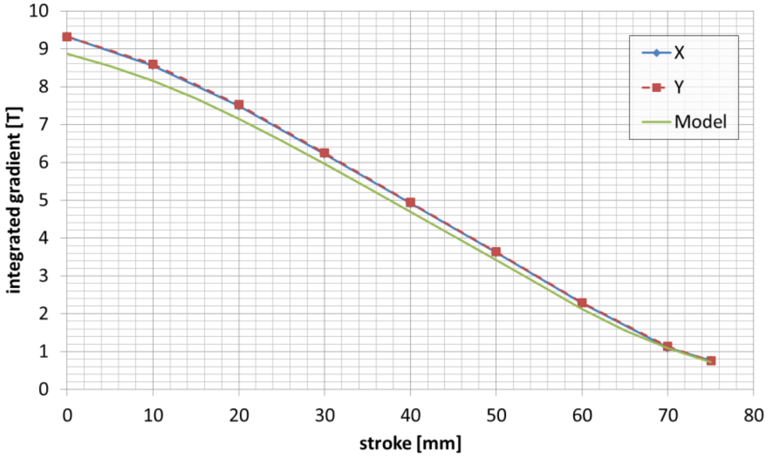
Permanent Magnet prototypes

High Energy Quad



BJA Shepherd et al, Tunable high-gradient permanent magnet quadrupoles, 2014 JINST 9 T11006

Low Energy Quad



Patent granted to cover both designs

Team now focussed on PM Dipoles

LINEAR COLLIDER COLLABORATION

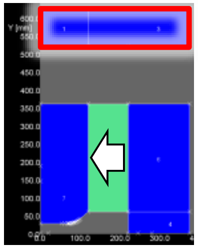
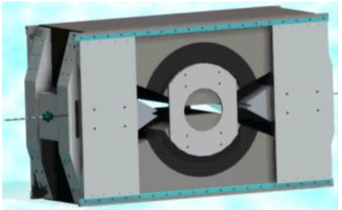
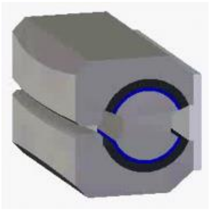
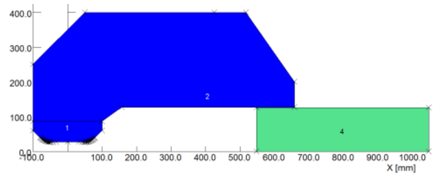
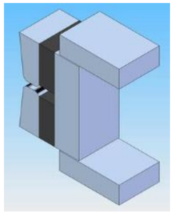
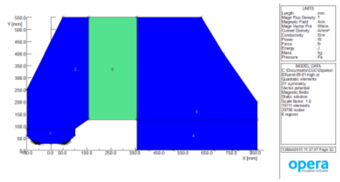
Now looking at PM dipoles

Type	Quantity	Length (m)	Strength (T)	Pole Gap (mm)	Good Field Region (mm)	Field Quality	Range (%)
MB RTML	666	2.0	0.5	30	20 x 20	1×10^{-4}	± 10
DB TAL	576	1.5	1.6	53	40 x 40	1×10^{-4}	50–100

- **Drive Beam Turn Around Loop (DB TAL)**
- **Main Beam Ring to Main Linac (MB RTML)**

Total power consumed by both types: 15 MW

Several possible designs considered:

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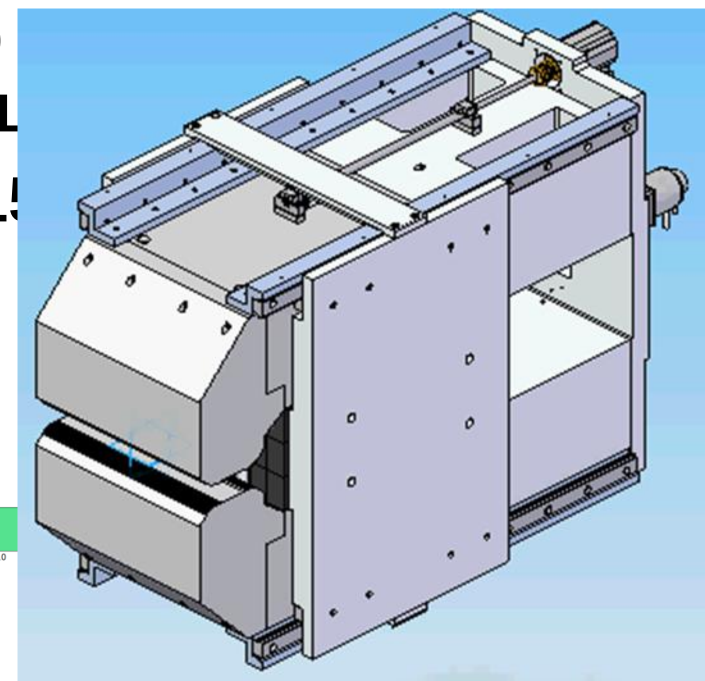
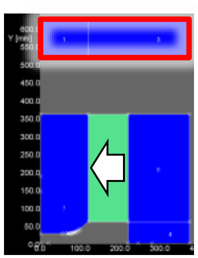
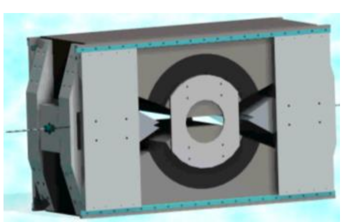
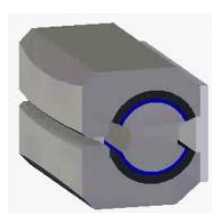
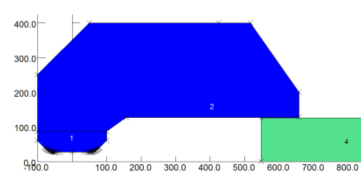
- **Main Beam Ring to Main Linac (MB RTML**



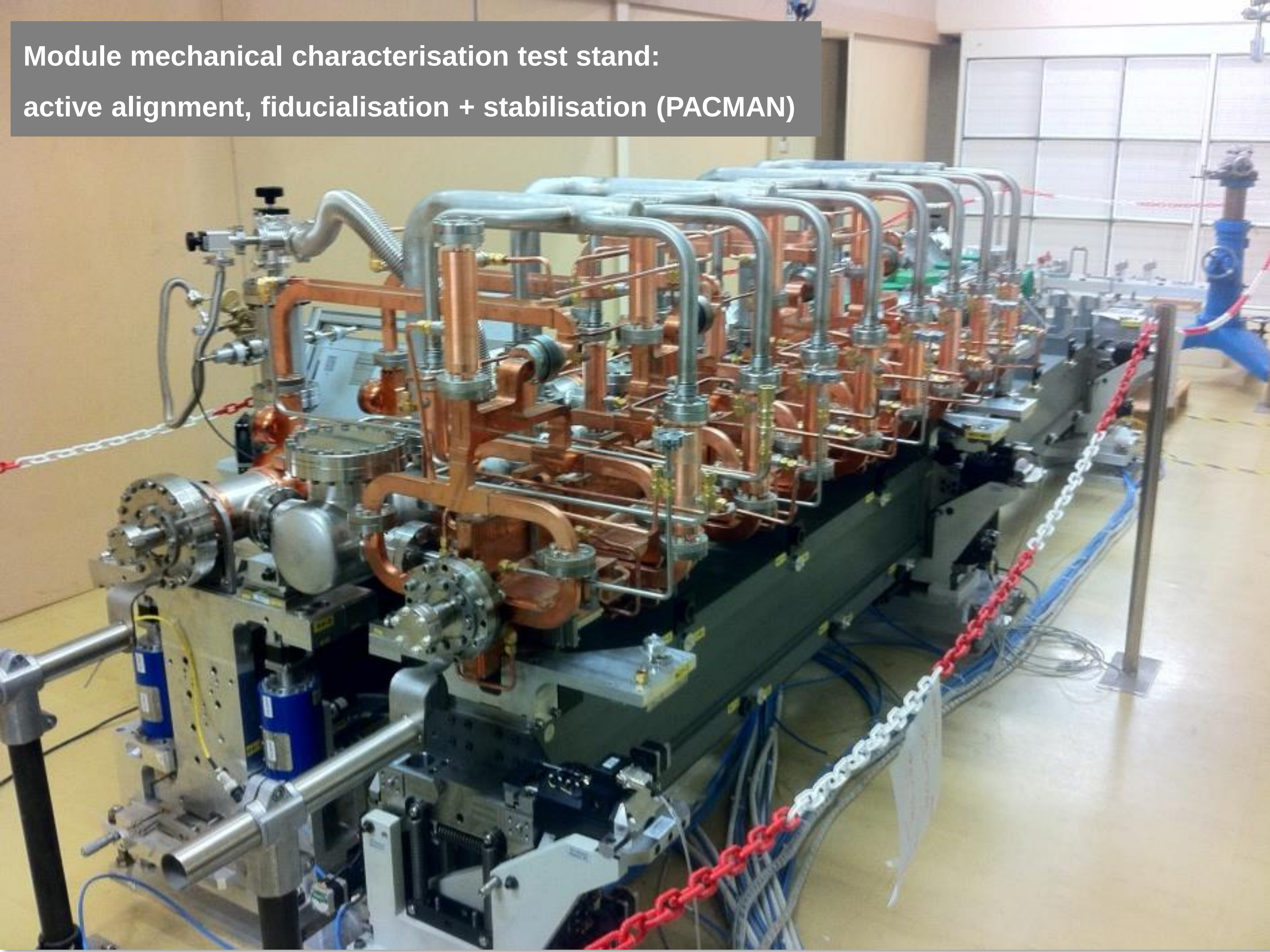
Total power consumed by both types: 1

Several possible designs considered:

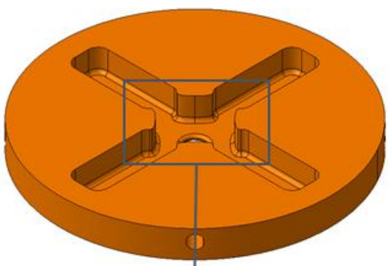
Recently installed 2-beam acceleration module in CTF3
(according to latest CLIC design)

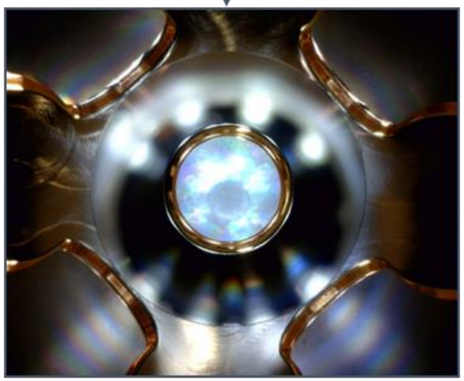
Module mechanical characterisation test stand:
active alignment, fiducialisation + stabilisation (PACMAN)



Assembly – towards industrialization

AS DISC

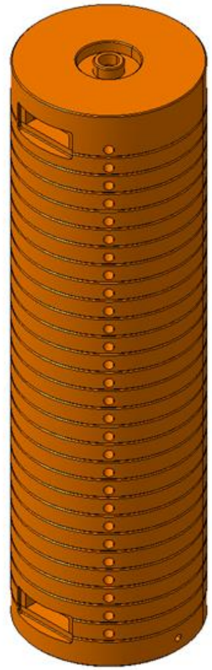




Cell shape accuracy - 0.004 mm
Flatness - 0.001 mm
Surface roughness - Ra 0.025 µm

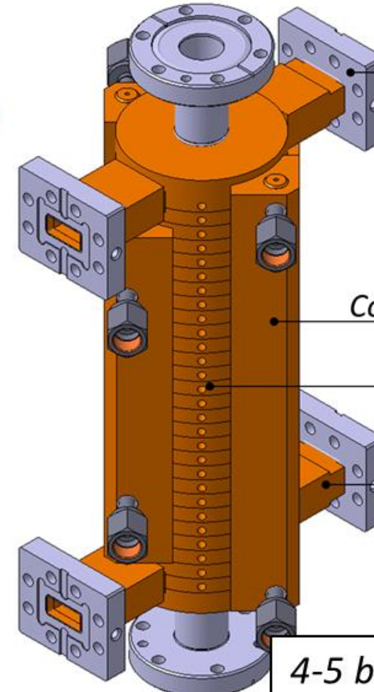
Acceptance at CERN

AS DISC STACK BONDING



Acceptance at CERN

AS ASSEMBLY



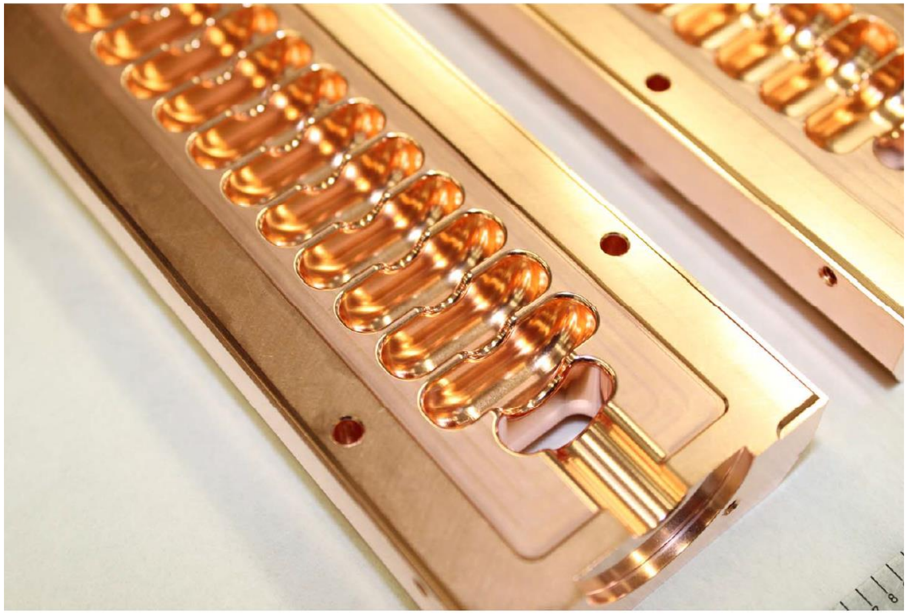
4-5 brazing steps

REQUIREMENTS:
- Alignment
- Special tooling
- Clean environment

Commercial suppliers:
- 4 qualified companies for UP machining;
- Single-crystal diamond tool required.

Suppliers:
- 3 qualified companies for brazing/bonding operations, supervision by CERN;
- Collaborators.

Symmetry plane structures



vs.

Structures in parts along symmetry planes have **significant potential advantages - cost, joining, heat and chemical treatment, materials.** Does require 3-D micron precision milling which is now possible.

Early tries with quadrants yielded unsatisfactory results, but don't believe this was end of story. We're back!