The CLIC accelerator studies

CLICdp Advisory Board meeting, April 17th 2018

Steinar.Stapnes@CERN.CH

on behalf of the CLIC accelerator collaboration

Outline:
Part 1: Timeline and Accelerator concept
Part 2: Technical status of the CLIC study and implementation planning
Part 3: Plans for 2020-25
Summary

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

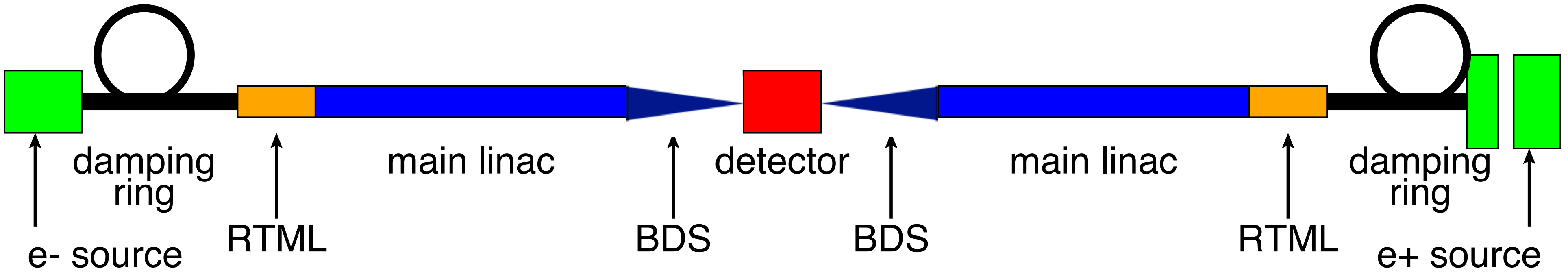
Ready for construction; start of excavations

2035 First Beams

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

Generic Linear Collider

The key parameters: Energy and luminosity

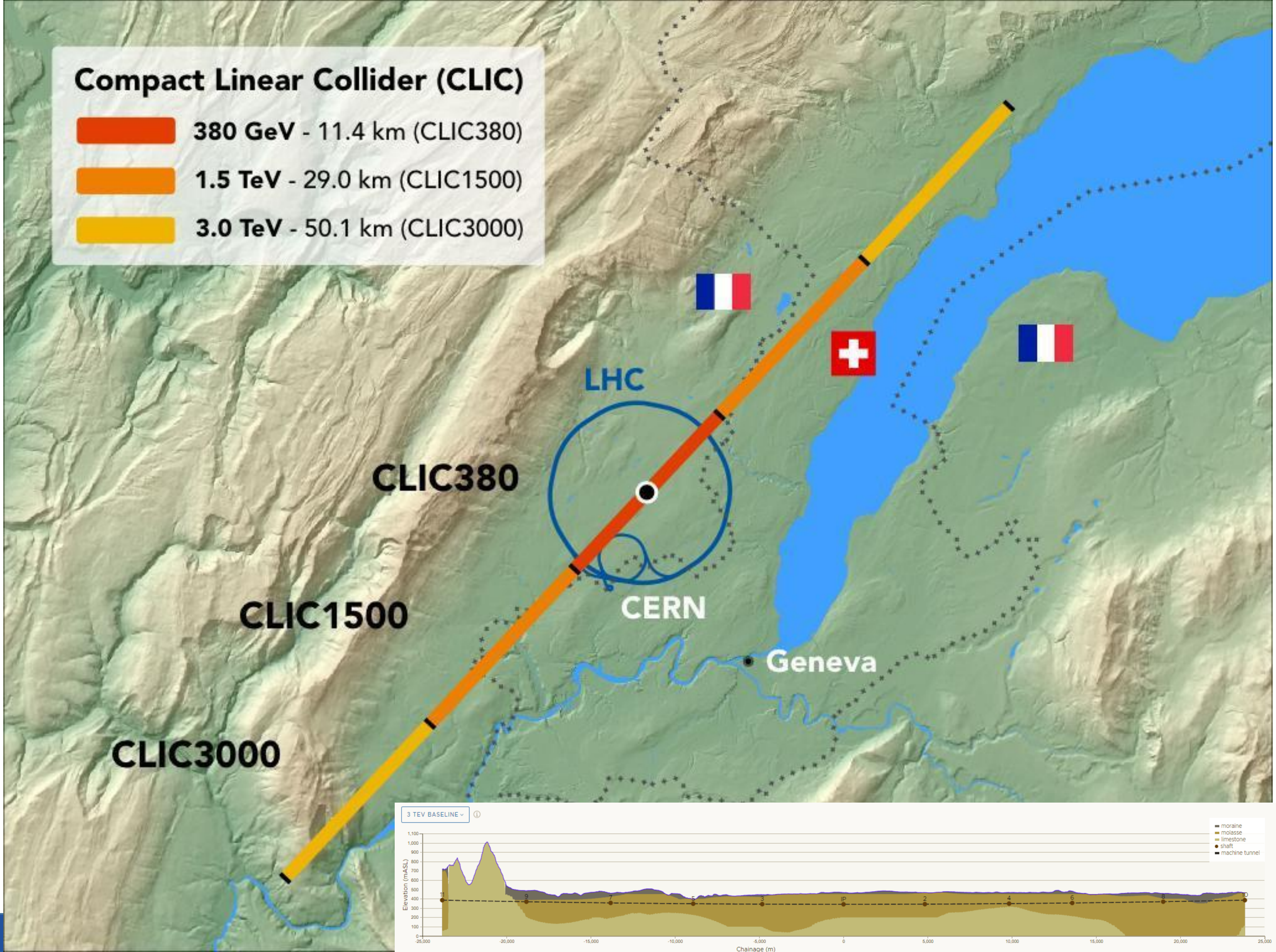


The critical steps:

1) Create low emittance beams (sources, injector, damping rings, ring to main linac - RTML)
2) Acceleration in main linac (energy increase per length)
3) Supply energy as efficiently as possible to beam (high power at 1, 1.3 and 12 GHz)
4) Nano-beams: Squeeze the beam (Beam Delivery System- BDS), i.e. reduce β

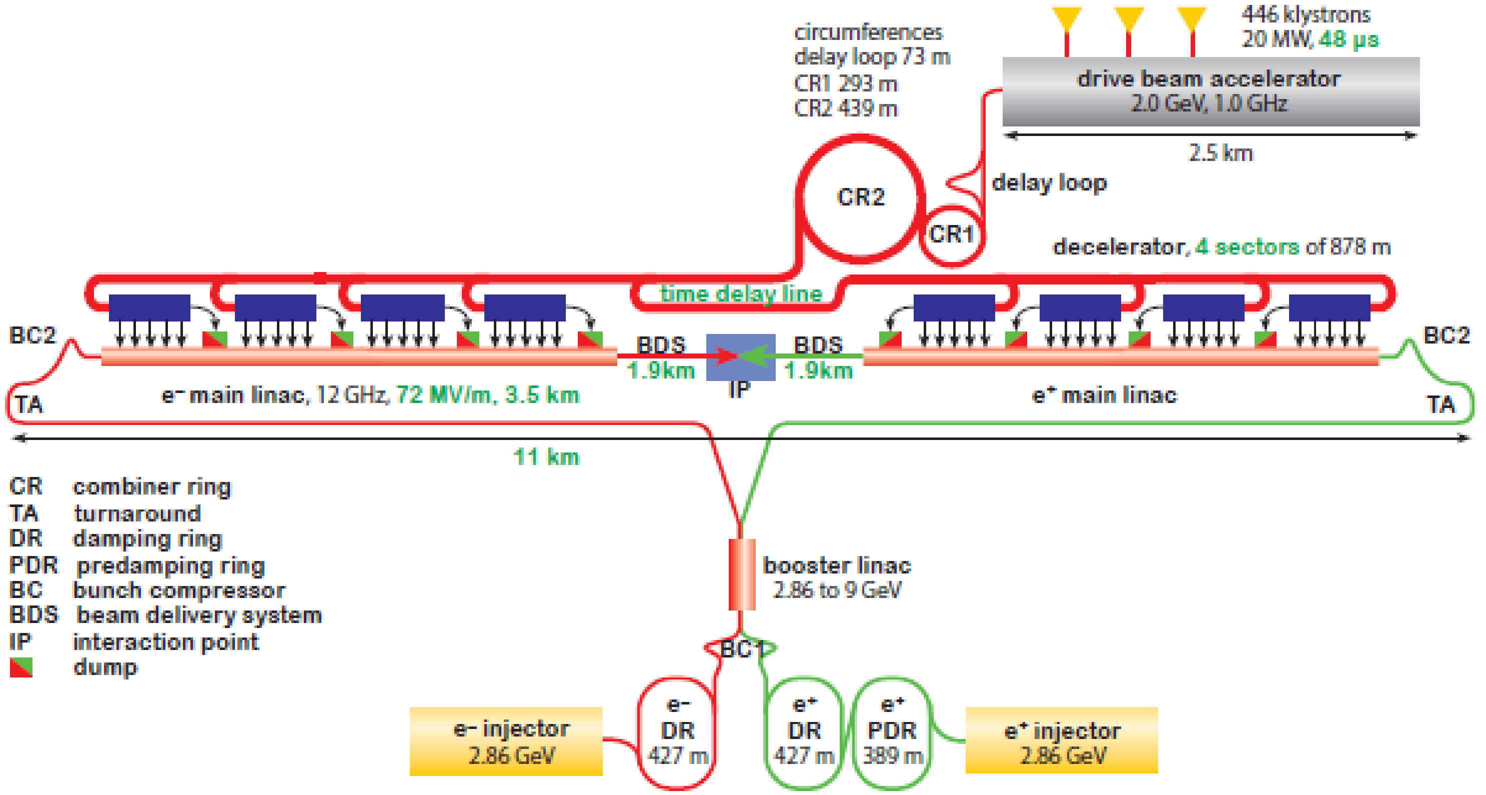
$$\mathcal{L} = H_D \frac{N^2}{4\pi\sigma_x\sigma_y} n_b f_r$$

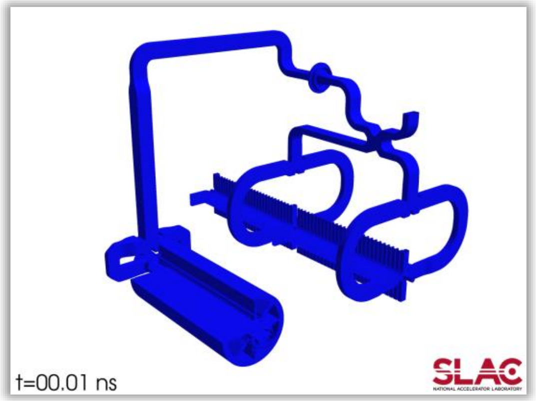
$$\sigma_{x,y} = \sqrt{\frac{\beta_{x,y}\epsilon_{x,y}}{\gamma}}$$

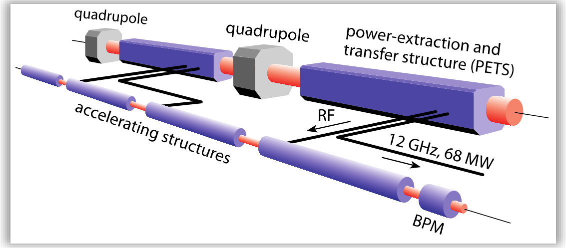

Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
1.5 TeV - 29.0 km (CLIC1500)
3.0 TeV - 50.1 km (CLIC3000)
LHC
CLIC380
CLIC1500
CLIC3000
CERN
Geneva
3 TEV BASELINE
moraine
molasse
limestone
shaft
machine tunnel
Elevation (mASL)
Chainage (m)

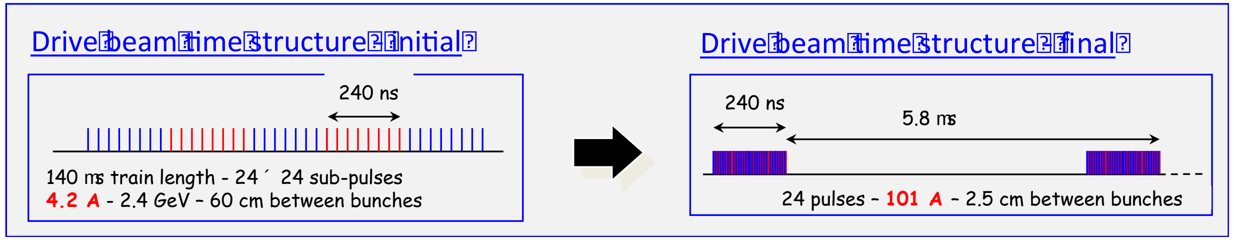
CLIC layout, power generation

Drive-beam (low energy, high intensity, long pulses) created by klystrons



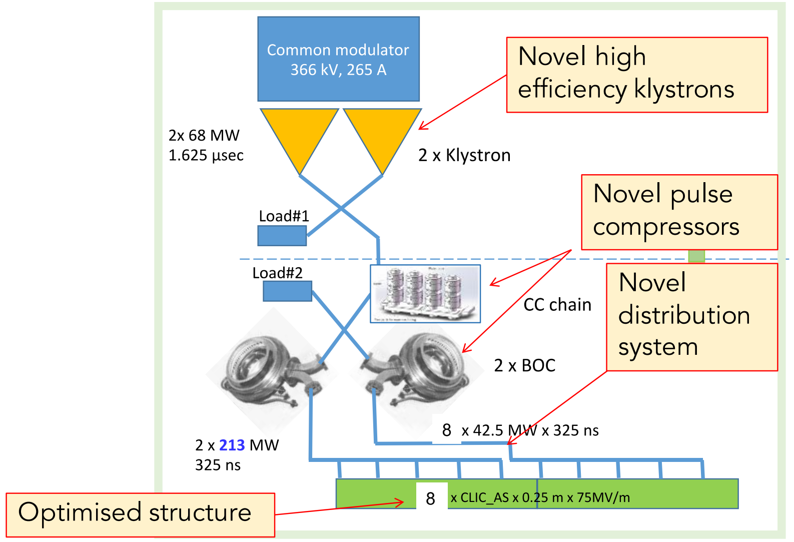






First stage energy ~ 380 GeV

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



Note: We also study a klystron driven 380 GeV version – replacing the drive-beam complex on the surface with modulators, klystrons in the tunnel

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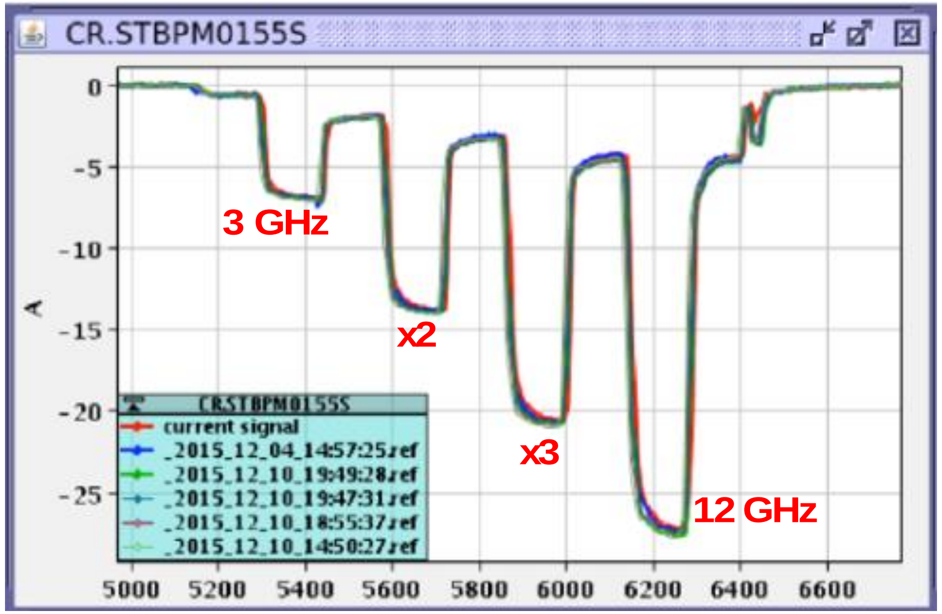
Drive beam quality

- Produced high-current drive beam bunched at 12 GHz

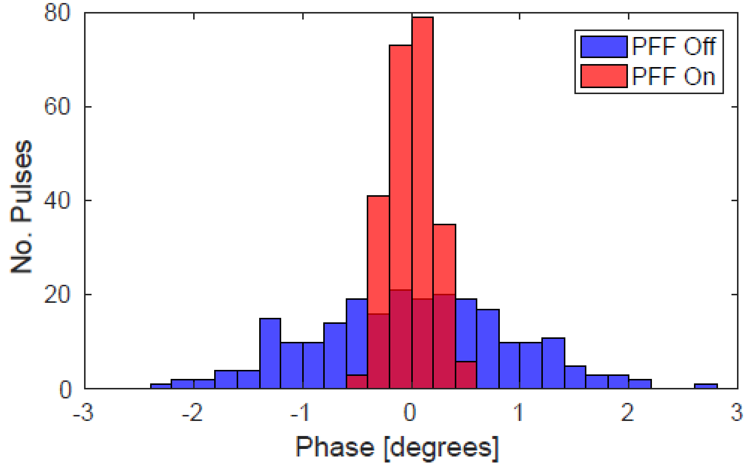
Three challenges:

- **High-current drive beam bunched at 12 GHz**
- Power transfer + main-beam acceleration
- ~100 MV/m gradient in main-beam cavities



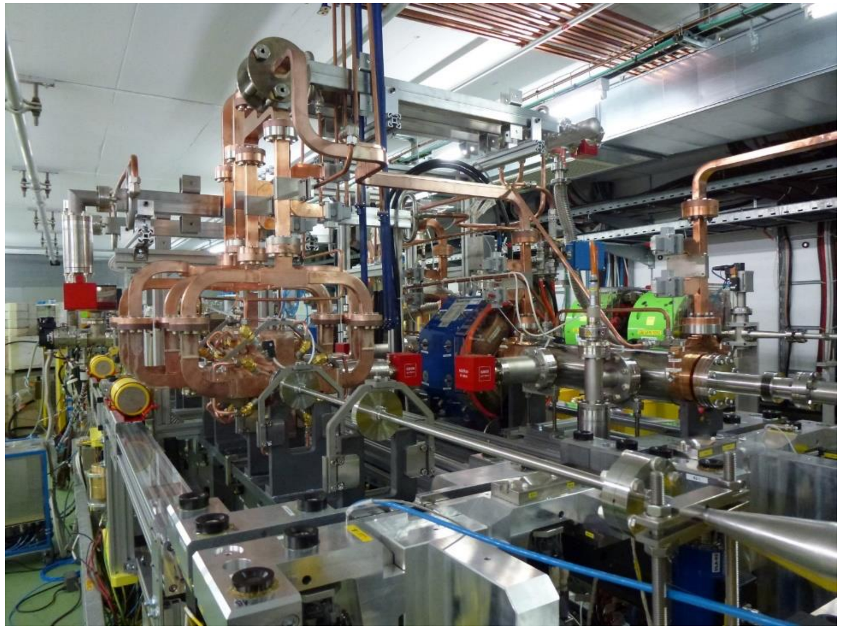
28A

Arrival time stabilised to 50 fs



Two beam acceleration

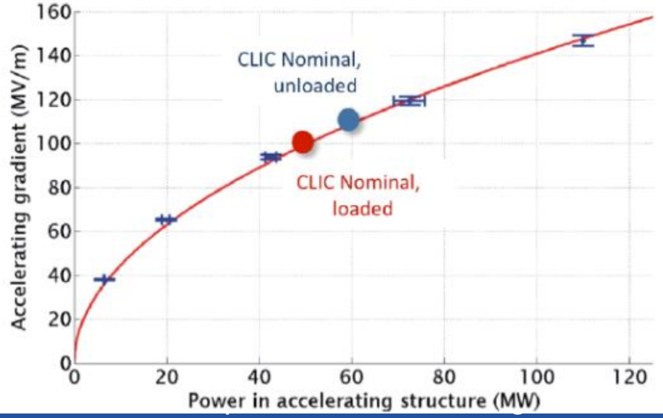
- **Demonstrated two-beam acceleration**

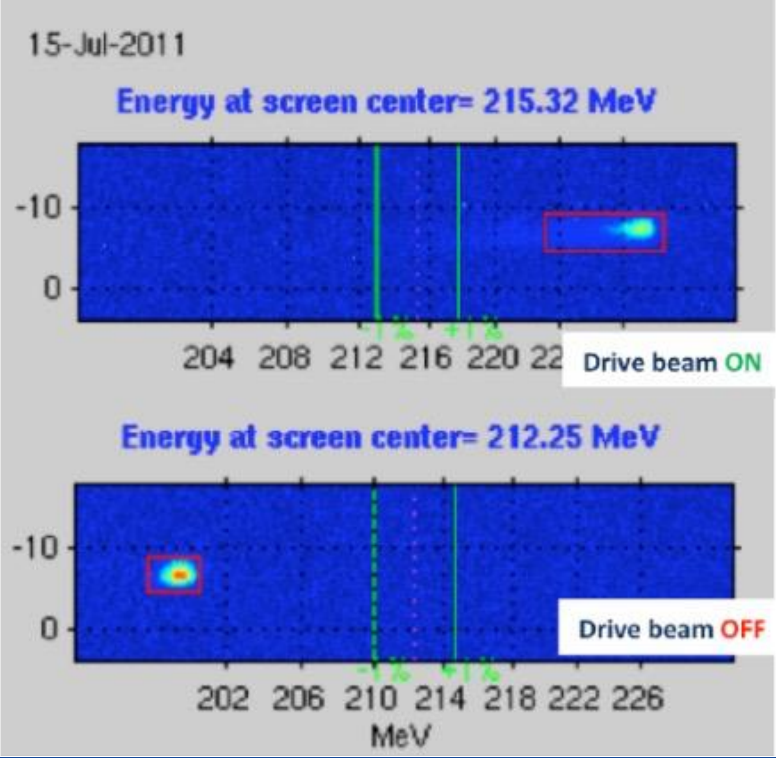


31 MeV = 145 MV/m

Three challenges:

- High-current drive beam bunched at 12 GHz
- **Power transfer + main-beam acceleration**
- ~100 MV/m gradient in main-beam cavities



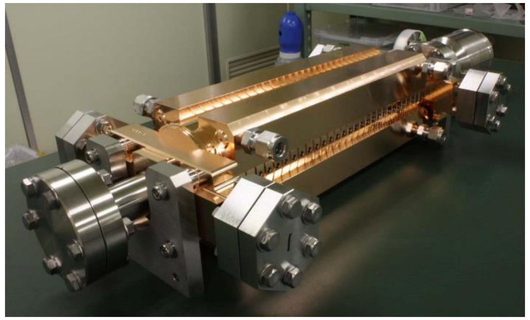


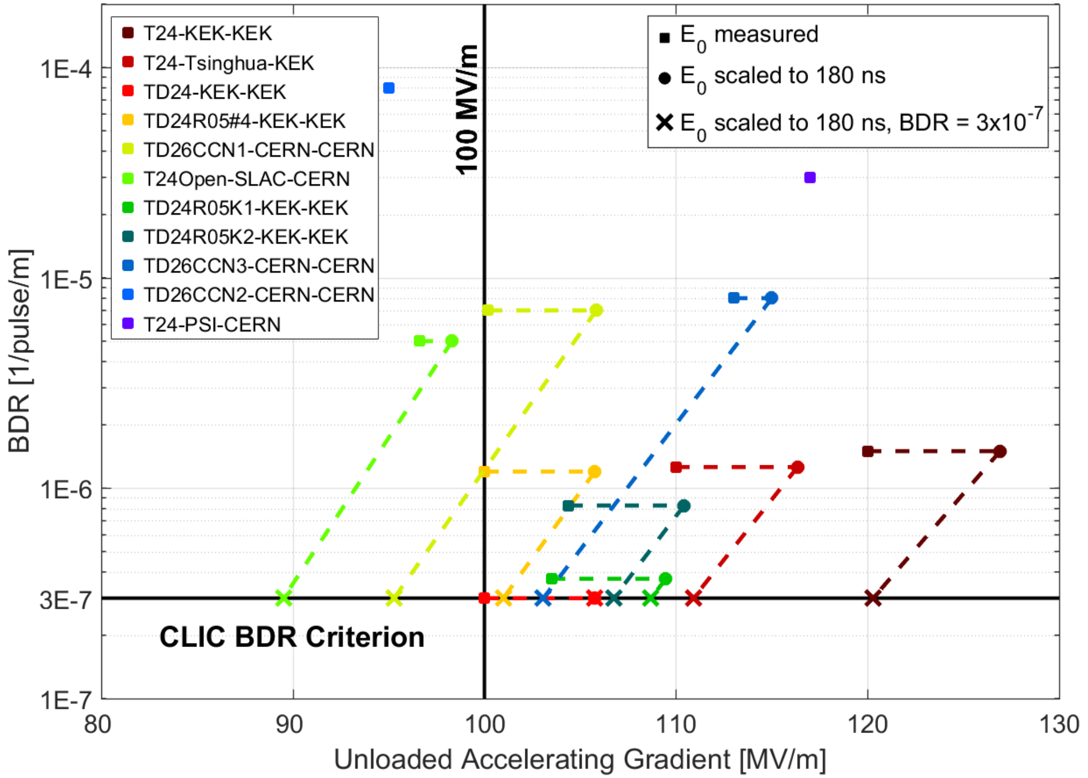
X-band performance

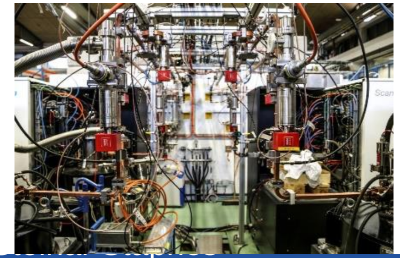
- Achieved 100 MV/m gradient in main-beam RF cavities

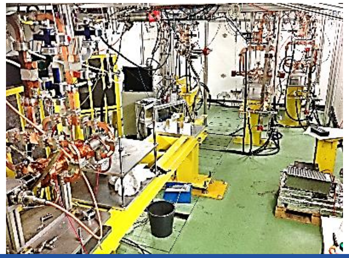
Three challenges:

- High-current drive beam bunched at 12 GHz
- Power transfer + main-beam acceleration
- **~100 MV/m gradient in main-beam cavities**

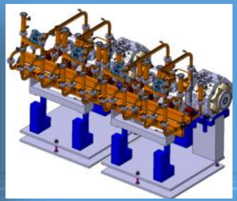
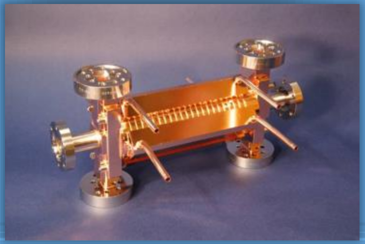
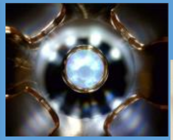
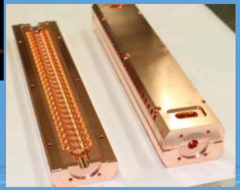
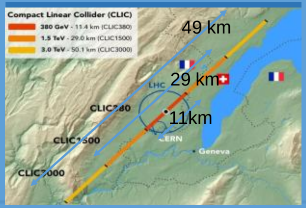
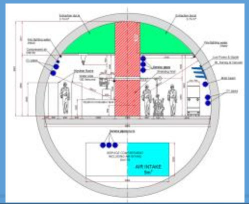






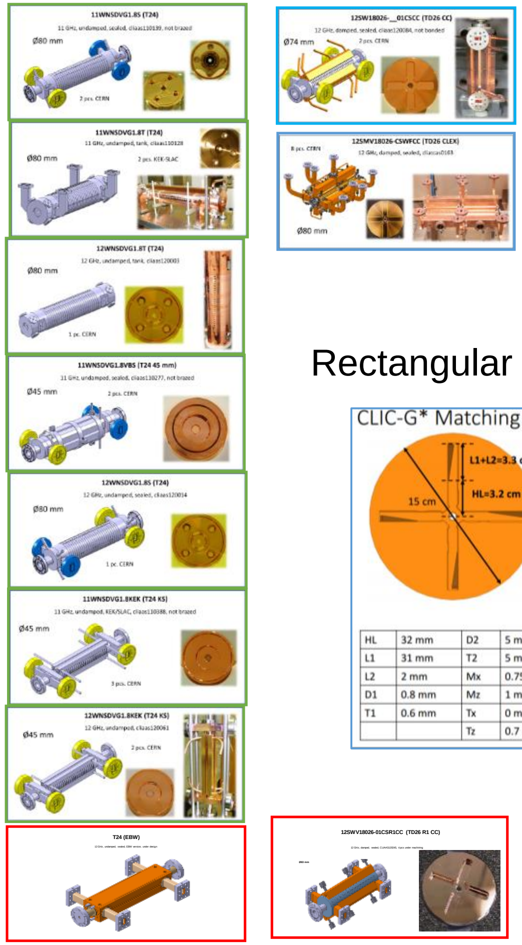


Key technical activities

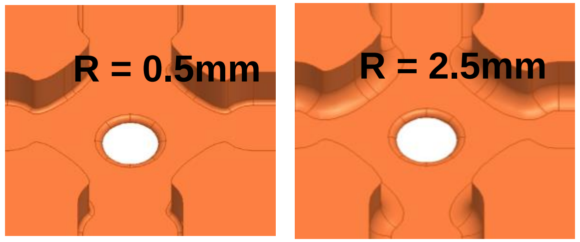
Now:		Next:
Module (drive-beam, klystron type) baseline	  	Final modules, from revised designs to industrial modules
Optimized structures and RF components	  	Finalize industrial structures: increase manufacturability, brazed, halves, conditioning. Use/maintain/operate existing test-stands for testing
High efficiency klystrons and modulators	  	Efficiency and costs improvements, significant gains possible for efficiency, industrial cost-models and optimization
Magnets design and prototypes	   	Permanent magnets, longit. variable magnets -> industrial production and cost-optimisation
Civil engineering, infrastructure	  	Detailed site layout and CE/infrastructure designs

Acc. Structures TD24&26 – new baseline optimised and alternatives for manufacturing and cost

Baseline: Machined disks,
damping structures, bonding steps

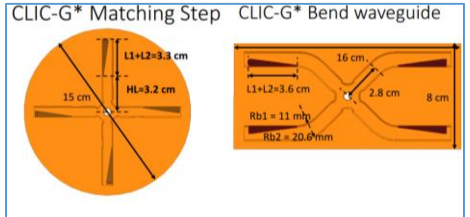


3 TeV structure CLIC G* (optimised)



SwissFEL Assembly (brazing)

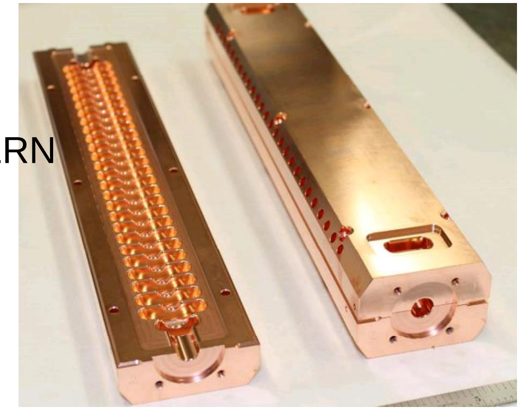
Rectangular (manufacturing)



HL	32 mm	D2	5 mm
L1	31 mm	T2	5 mm
L2	2 mm	Mx	0.75 mm
D1	0.8 mm	Mz	1 mm
T1	0.6 mm	Tx	0 mm
		Tz	0.7 mm

		D2	5.2 mm
L1	34 mm	T2	4.8 mm
L2	2 mm	Mx	0.2 mm
D1	1 mm	Mz	1 mm
T1	1 mm	Tx	0 mm
		Tz	0 mm

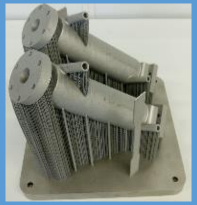
Halves: SLAC/CERN



Industrial considerations

(example – see general overview (N.Catalan))

Bodycote (FR)
Reuter (DE)
TMD (UK)



SWISSto12 (CH)
3T RPD (UK)
Concept Laser (DE)
INITIAL (FR)
Protoshop (DE)

VDL (NL)
LT-Ultra (DE)
Yvon Boyer (FR)
DMP (ES)
Morikawa (JP)
KERN (DE)

Thermocompact (FR)
BACMI (FR)
Multivalent (NL)

CINEL (IT)
VDL (NL)
BACMI (FR)
CECOM(IT)
Reuter (DE)
Nihon (JP)
COMEB (IT)
Viztrotech (KR)

Compact Linear Collider

Thales (FR)
CPI(US)
Toshiba (JP)

Scandinova (SE)
Jema (ES)
Picatron (CH)

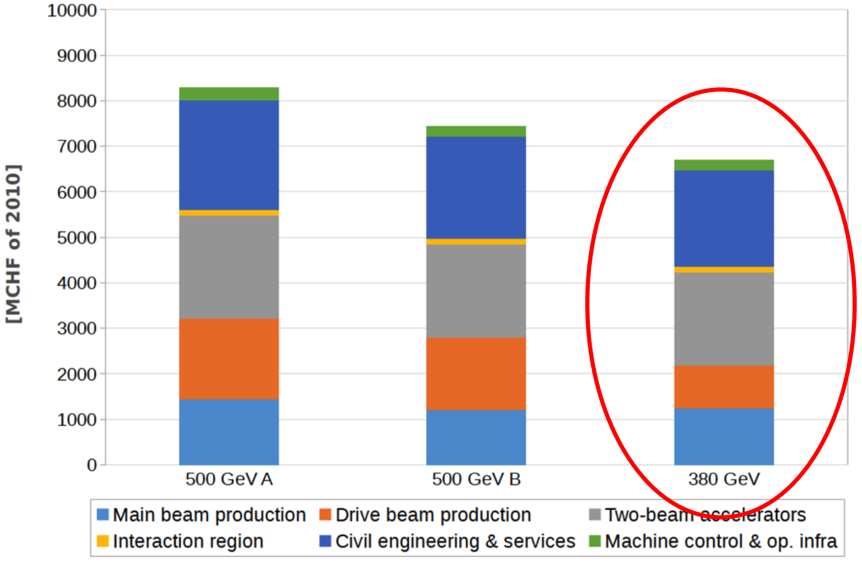
Next phase:

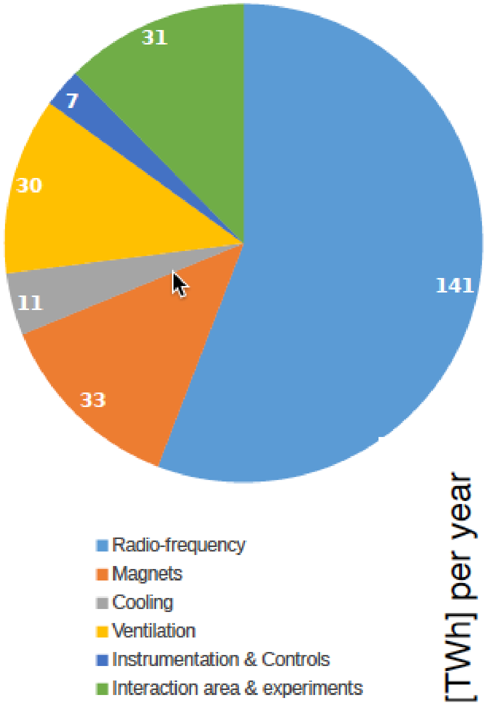
- Qualified companies, technical and commercial documentation, reliable costs (i.e. not first prototype), ideally (small) part of larger market

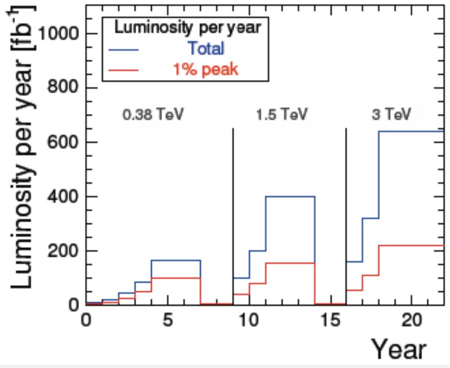
Cost and Power (update ongoing for ESU)

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

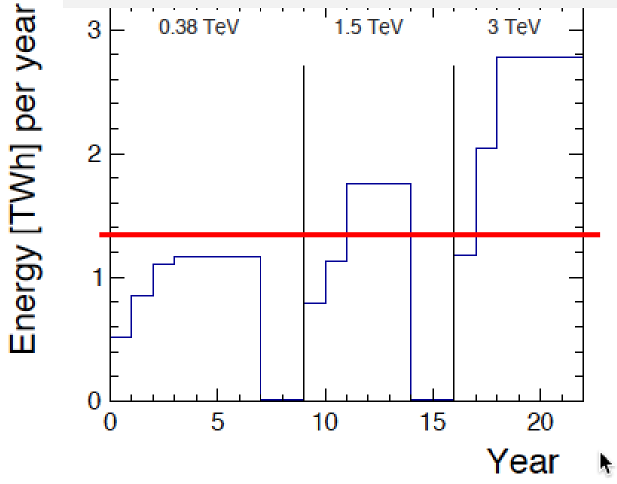
	Value [MCHF of December 2010]
Main beam production	1245
Drive beam production	974
Two-beam accelerators	2038
Interaction region	132
Civil engineering & services	2112
Accelerator control & operational infrastructure	216
Total	6690







CERN energy consumption 2012: 1.35 TWh

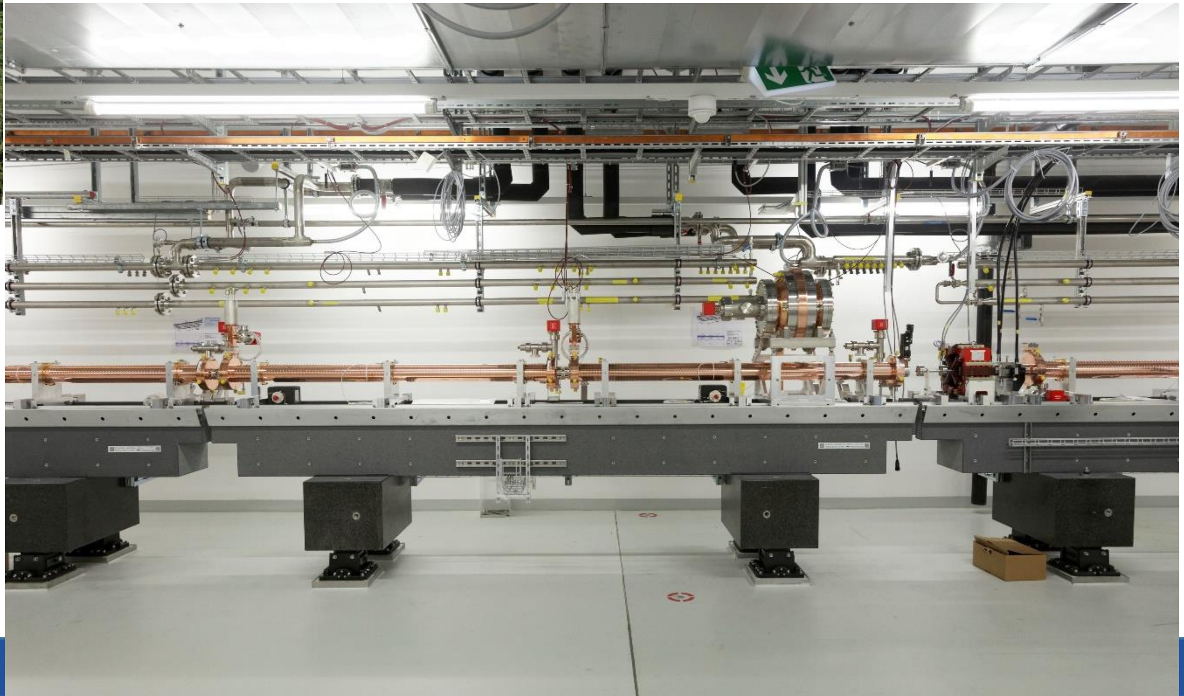


Revised bottom up costing and power estimate in progress
->A cost of ~6 BCHF and power ~200 MW remains "reasonable" goals

Reductions in next phase (before construction) possible but require larger projects with industry -> modules, RF and CE for costs; for power RF and magnets

SwissFEL – C-band linac

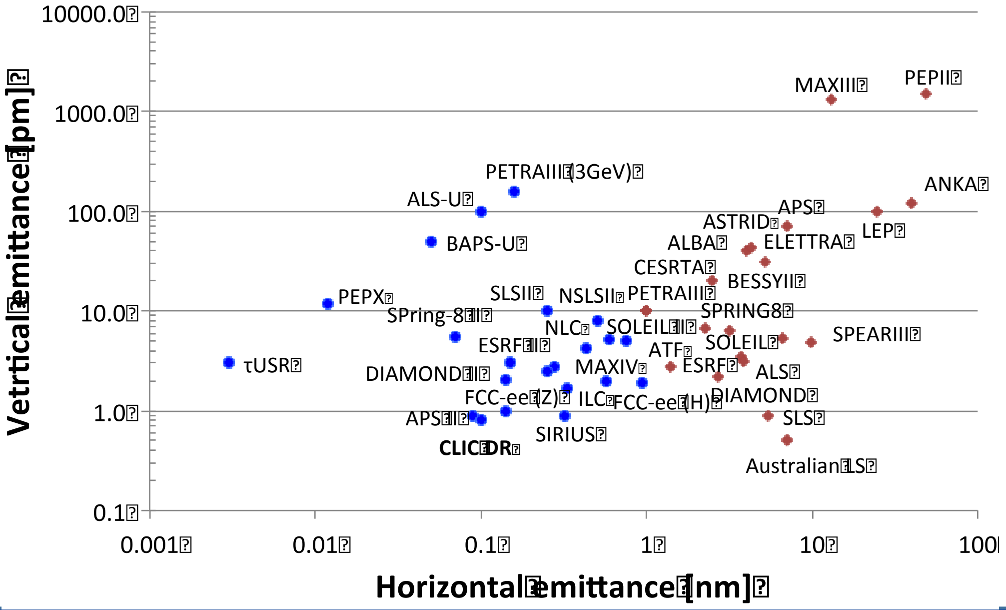
- 104 x 2m-long C-band structures
  (beam → 6 GeV @ 100 Hz)
- Similar um-level tolerances
- Length ~ 800 CLIC structures
- Being commissioned



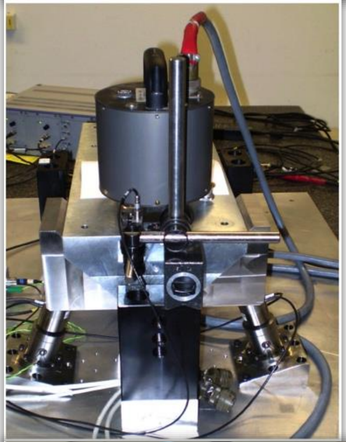
Nano-beams

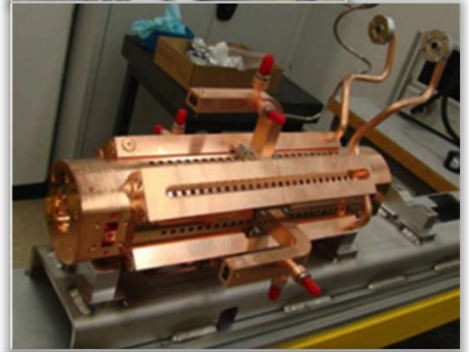
The CLIC strategy:

- Align components (10μm over 200m)
- Control/damp vibrations (from ground to accelerator)
- Measure beams well – allow to steer beam and optimize positions
- Algorithms for measurements, beam and component optimization, feedbacks
- Tests in small accelerators of equipment and algorithms (FACET at Stanford, ATF2 at KEK, CTF3, Light-sources)



[Summary of design and performances: Daniel](#)





Chapter	Section
Intro	
380 DB	
	Injectors
	DR
	RTML
	ML
	BDS
	MDI
	Post. Coll. and beam-dump
	Integrated studies
	DB acc
	DB recomb
	Beam transp
	Decelerators
	Dump lines
380 KL	
	Introduction and parameters
	Main linac design
	Main Linac technical unit
Higher energies (technical description)	
	Introduction, and example paramete
	upgrade from Klystron version
	Impact on systems
	Progress on 3 TeV BDS
	Energy upgrades with future techonl
Technologies	
	Sources and Injectors
	Magnets
	PETs and all acc. structures
	Klystrons
	Modulators
	Module
	Pulse compressors
	Vacuum
	Instrumentation
	Beam transfer
	Beam interception devices
	MDI
	Beamdumps
	Controls, timing, feedback
	Machine prot
	Alignment
	Stabilzation
	Ground motion measurements
	Undulators
CEIS	
	Civ. Eng
	Electicity supply
	CV
	Transp. and Install
	Safety systems
	Radiation studies
	Cryo
Implementation	
	Schedule and staging
	Cost
	Power
	Key issues (studies not complete)
Performance	
	Introduction
	Drive Beam
	BDS beam dynamics
	Main linac beam dynamics
	RF systems
	DR
	Availability studies
	Other effects

CLIC main acc. docu. in preparation

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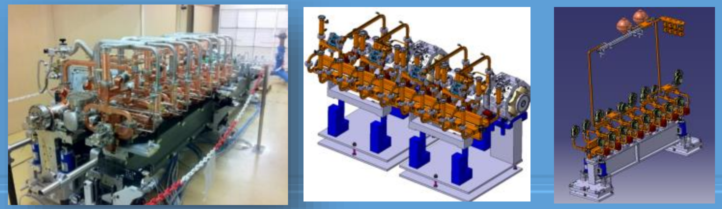
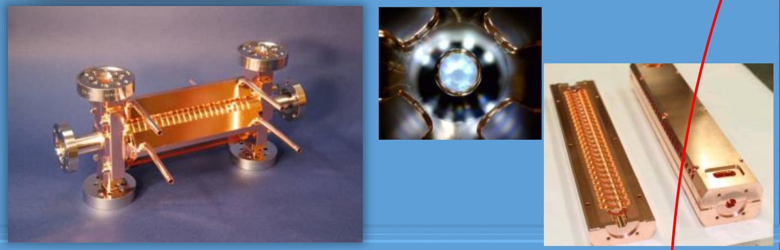
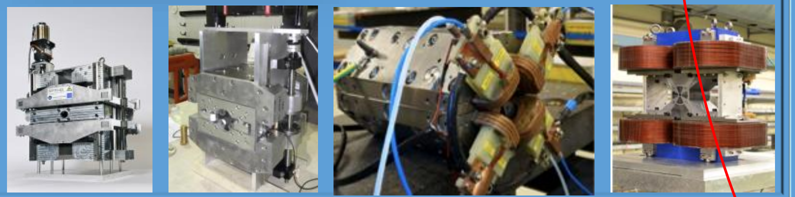
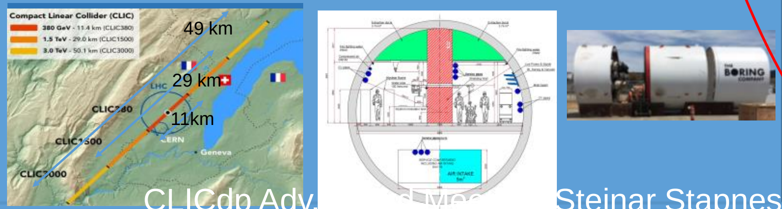
Getting ready for data taking by the time the LHC programme reaches completion

Among the documents prepared are overviews of the collaboration's plans for next period – the CLIC Preparation Phase 2020-2025:

- Such overviews are very important for the European Strategy Update and for planning at CERN
- The collaborators' plans in the same period are equally crucial – for making a coherent programme for developing "CLIC technologies"

Key technical activities

Now:		Next:
Module (drive-beam, klystron type) baseline		Final modules, from revised designs to industrial modules
Optimized structures and RF components		Finalize industrial structures: increase manufacturability, brazed, halves, conditioning. Use/maintain/operate existing test-stands for testing
High efficiency klystrons and modulators		Efficiency and costs improvements, significant gains possible for efficiency, industrial cost-models and optimization
Magnets design and prototypes		Permanent magnets, longit. variable magnets -> industrial production and cost-optimisation
Civil engineering, infrastructure		Detailed site layout and CE/infrastructure designs

Collaboration

Today the CLIC project preparation is a very collaborative effort

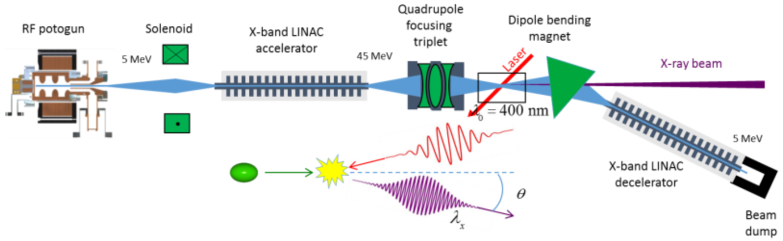
In next phase the potential is even larger:

Increasing use of X-band technologies in other projects

XFEL Design Study

Additionally: Medical applications (proton and very high energy electron therapy)

INFN Frascati advanced acceleration facility
EuPARXIA@SPARC_LAB



Eindhoven University led
SMART*LIGHT Compton Source

Status of applications (W.Wuensch)

X-band technology

CERN	XBox-1 test stand	50 MW	Operational, connection to CLEAR planned
	Xbox-2 test stand	50 MW	Operational
	XBox-3 test stand	4x6 MW	Operational
Trieste	Linearizer for Fermi	50 MW	Operational
PSI	Linearizer for SwissFEL	50 MW	Operational
	Deflector for SwissFEL	50 MW	Design and procurement
DESY	Deflector for FLASHforward	6 MW	Design and procurement
	Deflector for FLASH2	6 MW	Design and procurement
	Deflector for Sinbad	tbd	Planning
Tsinghua	Deflector for Compton source	50 MW	Commissioning
	Linearizer for Compton source	6 MW	Planning
SINAP	Linearizer for soft X-ray FEL	6 MW	Operational
	Deflectors for soft X-ray FEL	3x50 MW	Procurement

Australia	Test stand	2x6 MW	Proposal submission
Eindhoven	Compact Compton source, 100 MeV	6 MW	Design and procurement
Valencia	S-band test stand	2x10 MW	Installation and commissioning
KEK	NEXTEF test stand	2x50 MW	Operational
SLAC	Design of high-efficiency X-band klystron	60 MW	In progress
Daresbury	Linearizer	6 MW	Design and procurement
	Deflector	tbd	Planning
	Accelerator	tbd	Planning
Frascati	XFEL, plasma accelerator, 1 GeV	4(8)x50 MW	CDR
	Test stand	50 MW	Design and procurement
Groningen	1.4 GEV XFEL Accelerator, 1.4 GeV	tbd	NL roadmap, CDR

Above: EU Design Study for X-Band FELs 2018-2020: http://compact-light.web.cern.ch

Beyond being a collaboration for CLIC, many groups have their own X-band facilities and components (see overview on the left)

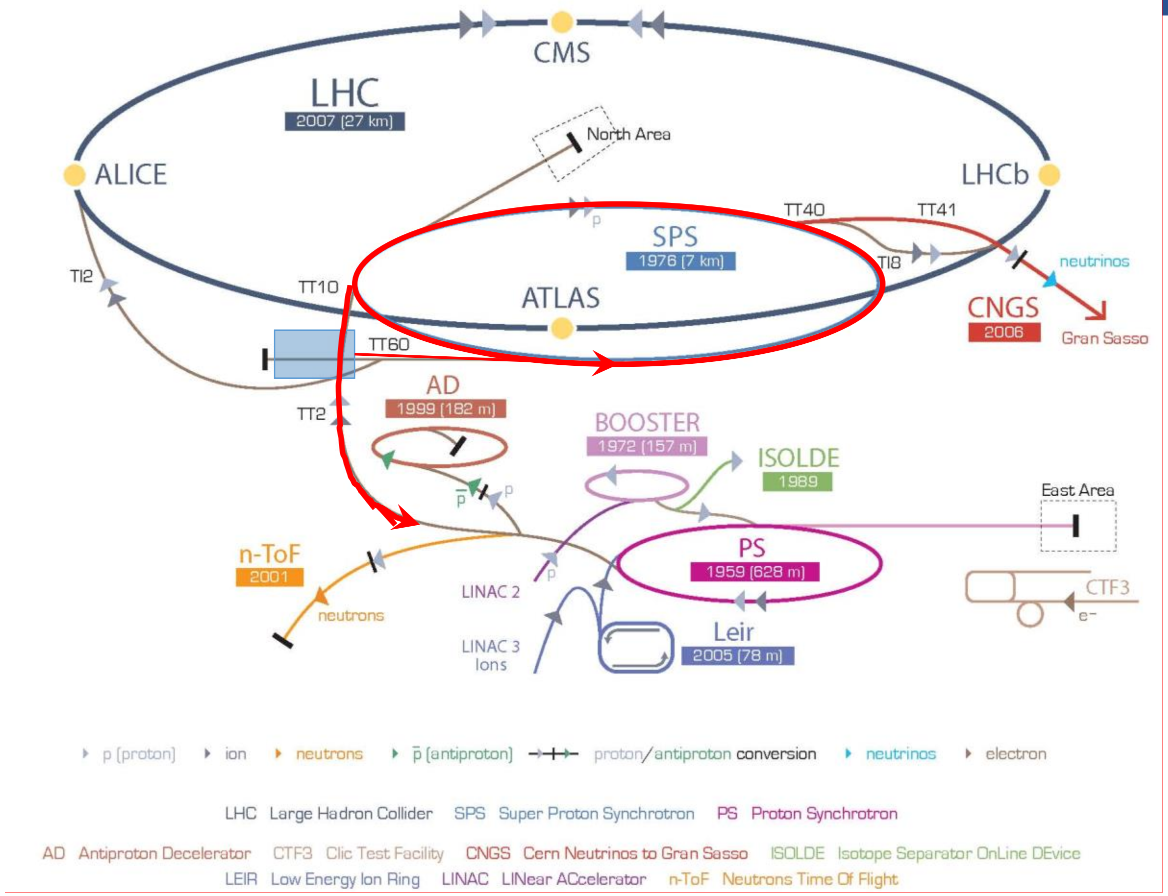
In the CLIC preparation phase:
Take advantage of the widespread use of electron linacs, and rapidly increasing use of X-band → increase collaboration

X-band linac at CERN in next phase ?

Accelerator implementation at CERN of LDMX type of beam (Physics Beyond Colliders)

X-band based 70m LINAC to ~3.5 GeV in TT4-5:

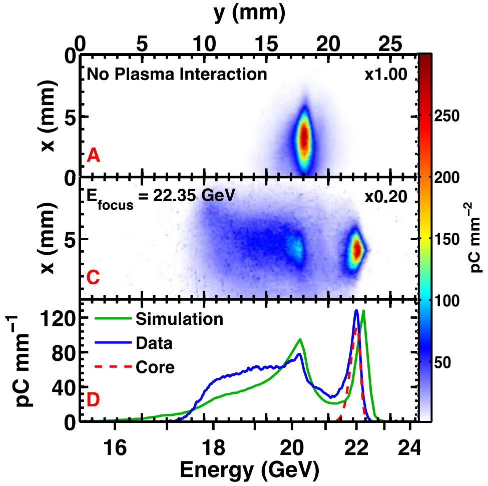
- Fill the SPS in 1-2s (bunches 5ns apart) via TT60
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment in 10s as part of the SPS super-cycle
- Experiment(s) considered by bringing beam back on Meyrin site using TT10



Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

Acc. R&D interests: Overlaps with CLIC next phase (klystron based), FEL linac modules, e-beams for plasma, medical/irradiation/detector-tests/training, impedance measurements, instrumentation. positrons and damping ring R&D

Far future: Towards TeV beams with new technology ?



1.7 GeV energy gain in 30 cm of pre-ionized Li vapor plasma.

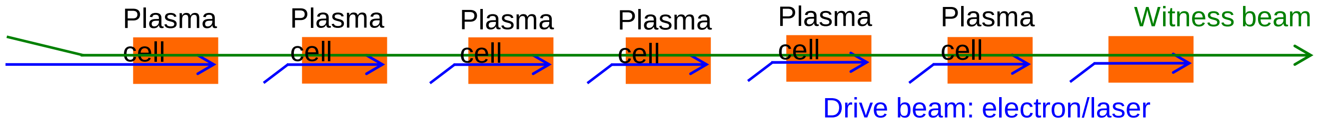
2% energy spread

Up to 30% wake-to-bunch energy transfer efficiency (mean 18%).

A possible “useful” beams:
Electrons: 10^{10} particles @ 1 TeV **~few kJ**

Existing driver beams options :
Lasers: up to 40 J/pulse
Electron driver: up to 60 J/bunch
Proton driver: SPS 19 kJ/bunch, LHC 300 kJ/bunch

While GeV acceleration in plasmas has been demonstrated for with both lasers and electron drivers reaching TeV scales requires **staging** of many drivers and plasma cells. Challenging.



Current focus on “small scale” applications – for LCs a long way to go:
Electrons and Positrons needed, staging, energy efficiency, suitable beam-parameters and luminosity

Mostly from E.Adli

From the CLIC workshop end January – 230 participant

Summary:

The CLIC collaboration is on track to present a Project Implementation Plan and provide input to the European Strategy Update:

- 380 GeV drivebeam baseline, klystron option, both upgradeable in stages to 3 TeV
- The initial phase accelerator is technically sound, compact and financially realistic – construction and operation
- It covers SM studies in an excellent manner, and it expandable in energy, length and technology as physics demands
- Wide interest in use of technology for smaller accelerators

Plans for next period 2020-2025 will be a part of ESU documentation – a collaborative plan with focus on industrial pre-series including agreements with main collaboration partners where X-band projects, or other core technologies, are put into use in the same timeframe

Construction can start ~2025 with completion ~2035

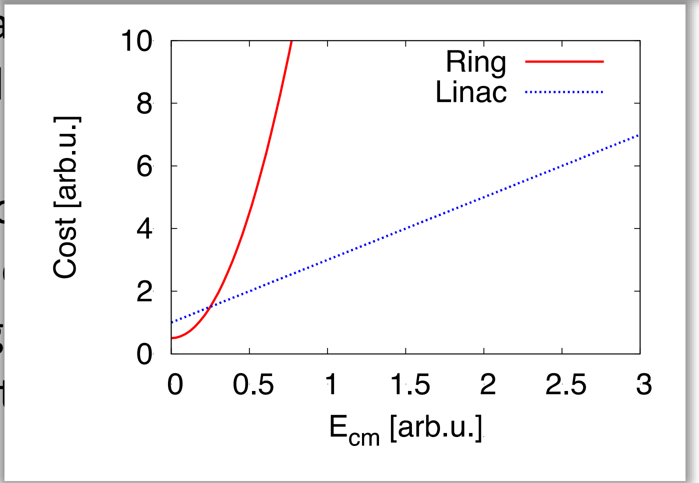
Limitations - synchrotron radiation

We want E_{cm} as high as possible for new particle accelerators
Circular colliders $\Rightarrow$ synchrotron radiation loss:

$$P_S = \frac{e^2 c}{6\pi\varepsilon_0} \frac{1}{(m_0 c^2)^4} \frac{E^4}{R^2}$$

For electrons a severe limita
explode – go l

Less of a problem with pro
driven by magnet technol
losses also there becoming
component

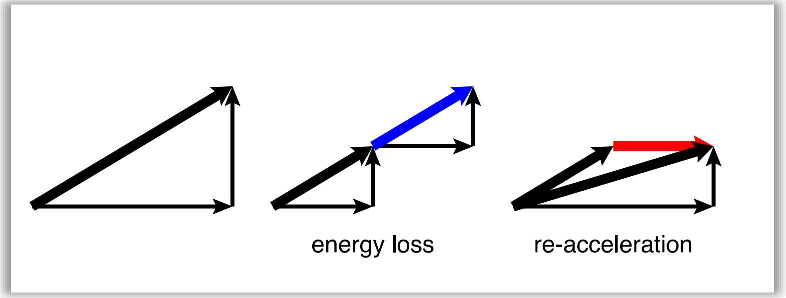


There are other reasons why linear colliders are pursued:

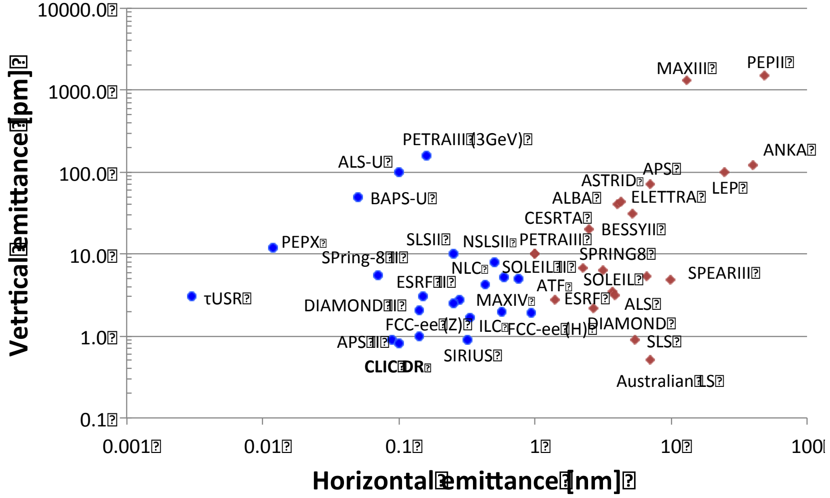
- Scalable (lengthen or shorten) and upgradable with new technology
- Very linked the main invest-area in accelerator construction – light-sources/FELs
- Affordable covering (most of) the Standard Model precision physics

Damping ring, experience from light sources

The damping rings reduce the phase space (emittance $\varepsilon_{x,y}$) of the beam – wigglers to stimulate energy losses (SR)

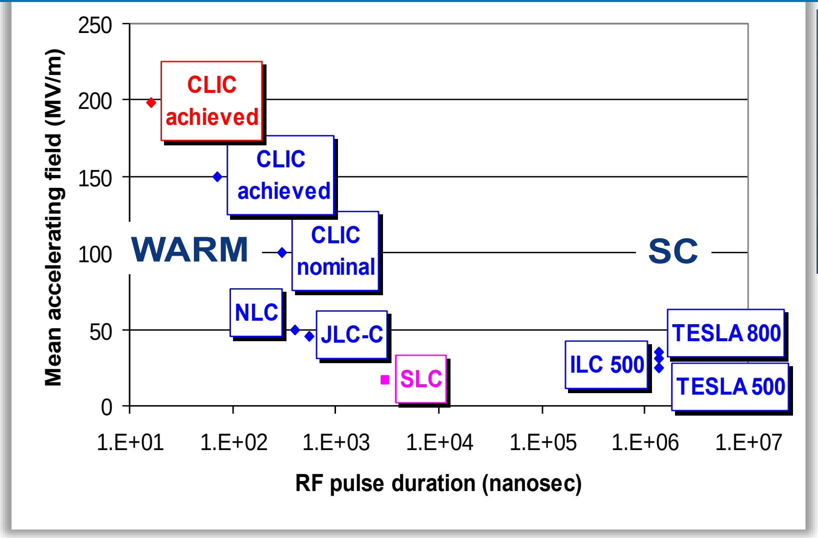


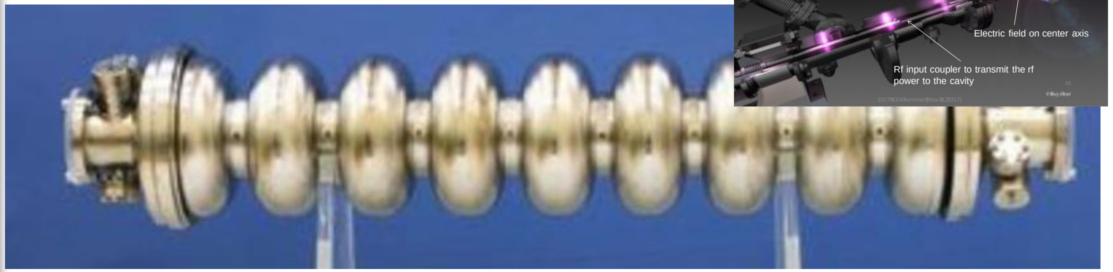
Light-sources need similar beams (picture: ALBA)

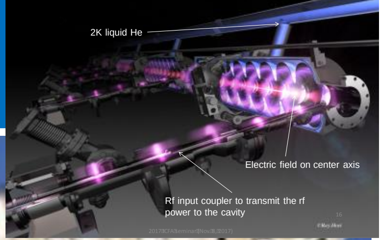


The RTML (ring-to-main linac transport) reduces the bunch length

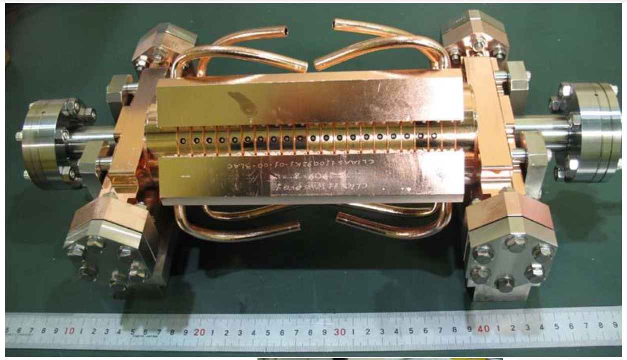
Maximize acceleration per meter

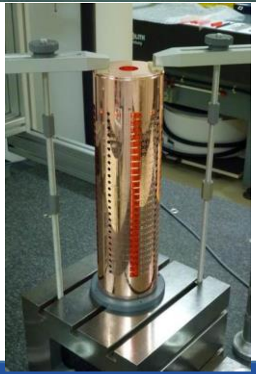






Below left: A high-gradient "warm" accelerating structure, 12 GHz for CLIC
Above: A superconducting 1.3 GHz Rf structure for ILC





Limitations by electrical and magnetic fields on surfaces, field emission and heating (key technology optimisation)

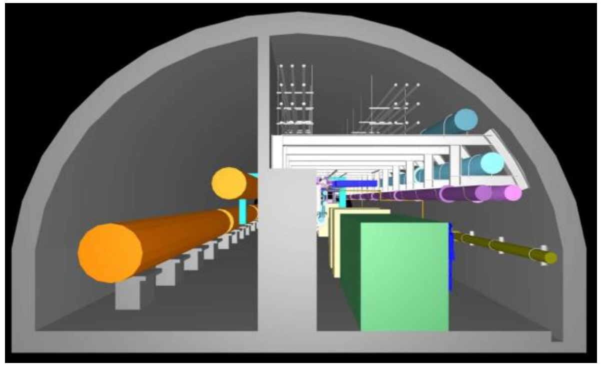
Different pulse lengths and bunch structure (ILC and CLIC):

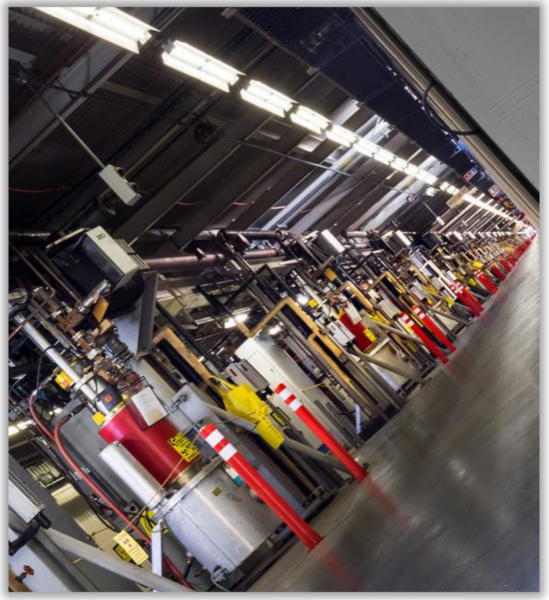
Bunches per pulse	n_b	1312	312
Distance between bunches	Δ t[ns]	554	0.5
Repetition rate	f_r [Hz]	5	50

… has ramifications for acc. size, beam dynamics , instrumentation, detectors, etc, ….

However, physics, cost, power, luminosities remarkably similar in the end (for similar collision energies)

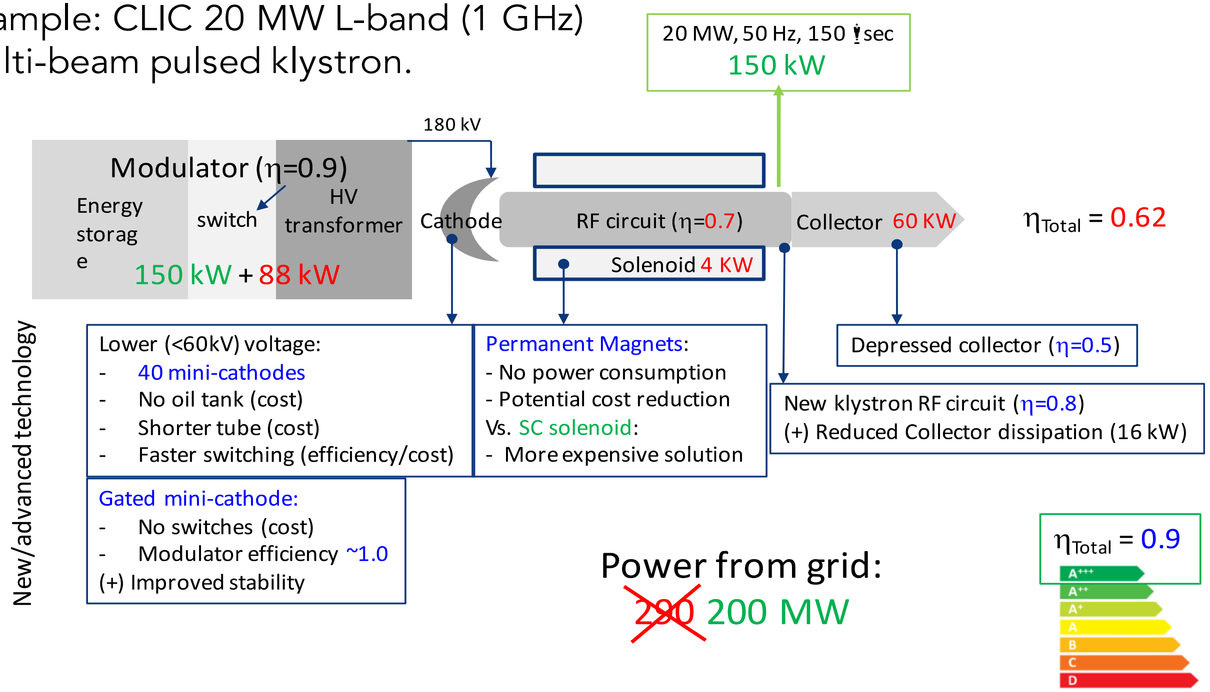
RF power, challenge





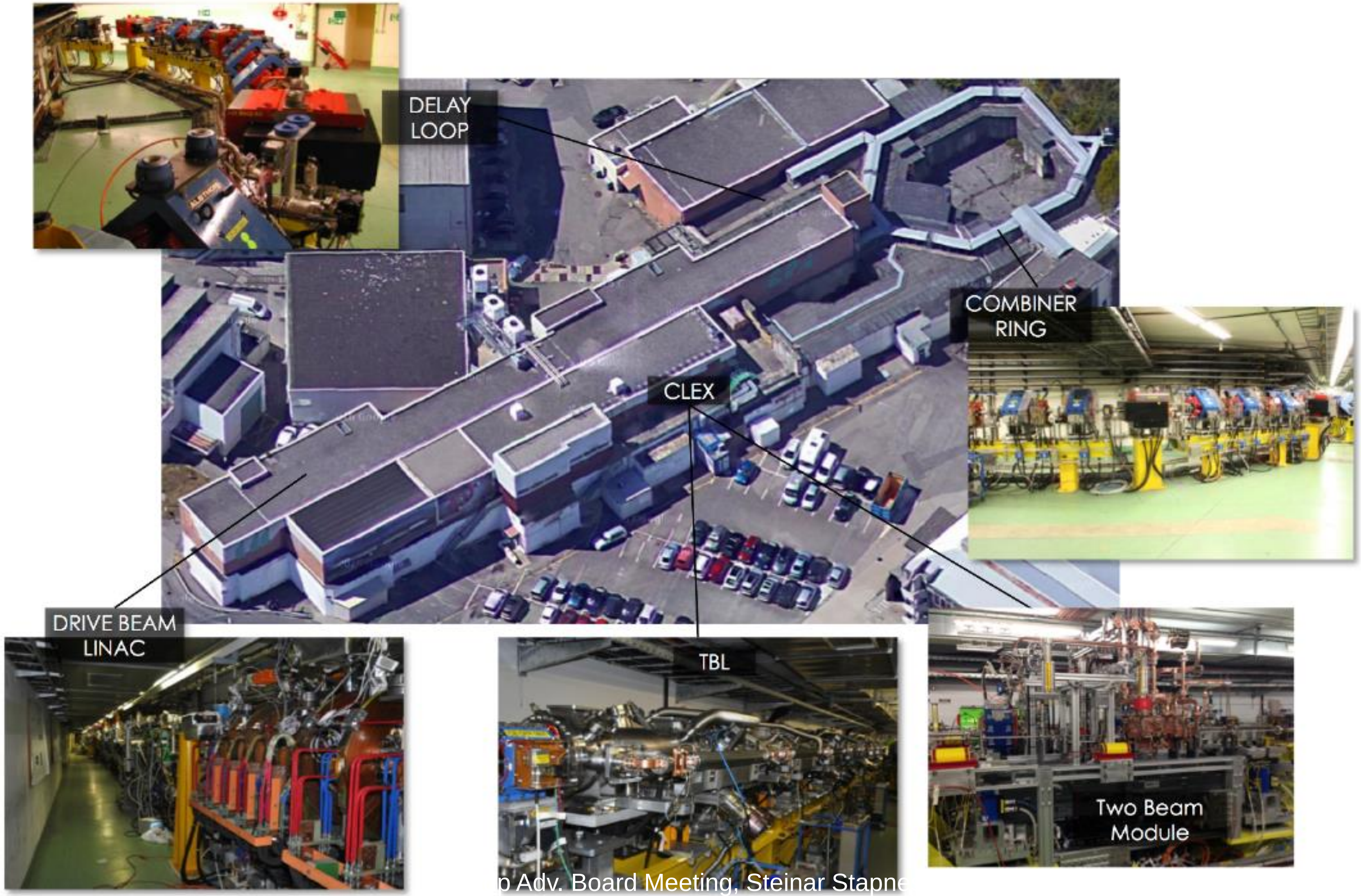
CLIC drivebeam: move klystrons/modulator to surface, energy scaleable by increasing pulse-lengths:

Example: CLIC 20 MW L-band (1 GHz)
Multi-beam pulsed klystron.



Power from grid:
~~290~~ 200 MW

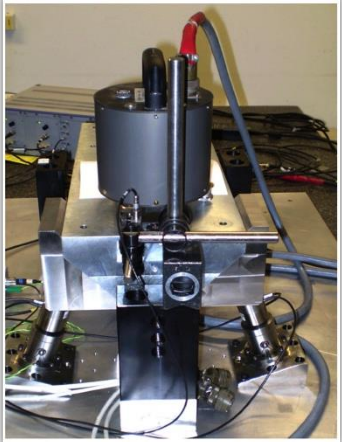
CLIC Test Facility (CTF3)

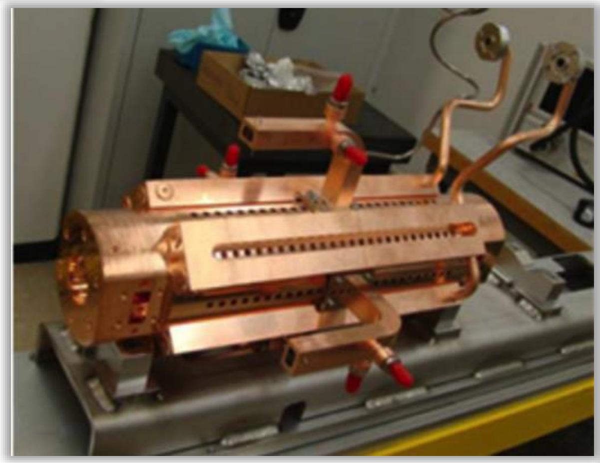


Technical activities – examples

Technical Developments are motivated by several possible reasons – and are now quite mature:

- Key components for system-tests (example magnets, instrumentation, modules)
- Critical for machine performance (example alignment, stabilization, damping ring studies)
- Aimed at cost or power reduction (example magnets, klystrons, modules)

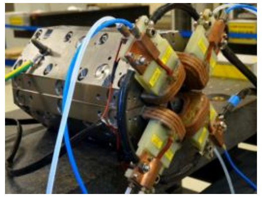




Information about some relevant suppliers and subcontractors participating to prototypes procurement for the CLIC Magnets R&D phase

Note: majority of coils and of other components manufacturing, magnet assembly, was done by CERN apart for the DBQ magnets (EM and PM versions).

1) **Main Beam Quadrupoles. 4 prototypes** procured: 3 Type1 (the shorter), 1 Type4 (the longer)



Relevant procurements:

- *Coils:* **TESLA** Engineering LTD, Storrington, West Sussex - UK
- *High Precision quadrants machining:*
- **DMP** 20850 Mendaro, Gipuzkoa - ES

2) **Drive Beam Quadrupoles** (EM version): **3 prototypes** procured:

Relevant manufacturers:

- *Complete manufacturing:*

Danfysik A/S 2630 Taastrup, DK

3) **Drive Beam Quadrupoles** (PM version): **2 prototypes** procured by Daresbury Laboratory

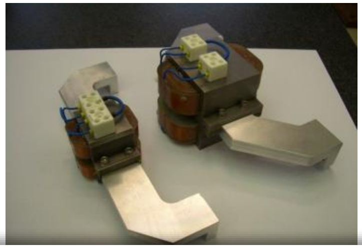
Rele

- *Des*
- *PM*

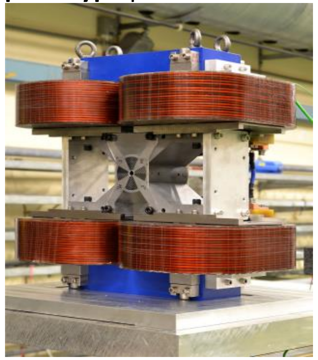
Hana

- *Hig*
- **SEN**
- **TSV**
- **Mc**

4) **Main Beam Steering Dipoles**: **2 prototypes** procured



5) **Final Focus Quadrupole QD0**: **1 prototype** procured



Relevant manufacturers:

- *PM blocks, Permendur EDM machining:* **Vacuumschmelze** GmbH & Co. KG, Hanau - D

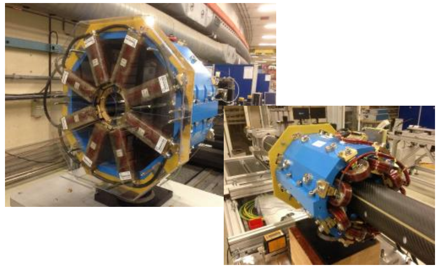
6) **Final Focus Sextupoles SD0:** *(**1 prototype** procurement **on-going**)*

Relevant manufacturers:

- *Permendur and PM blocks procurement:*

VDL Groep BV, Eindhoven - NL

7) **Octupoles for ATF** facility at KEK, Japan: **2 magnets** procured



Relevant manufacturers:

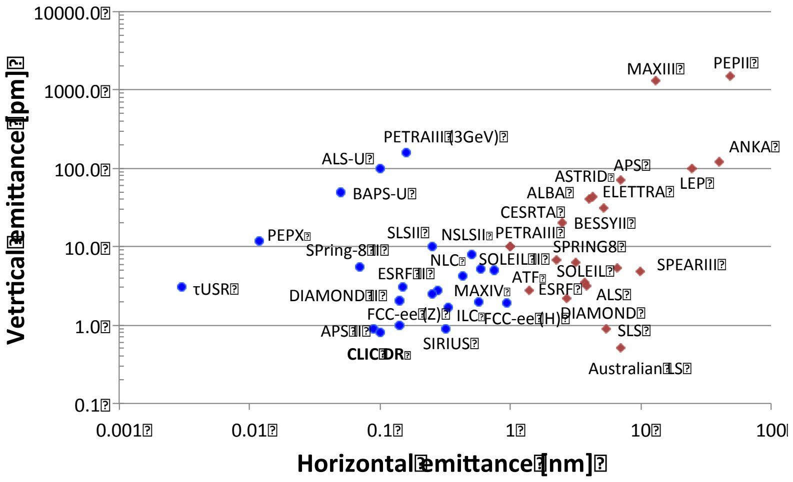
- *Coils:* **S.E.F.** Sarl, Labège - F
- *Iron Yokes EDM Machining:*

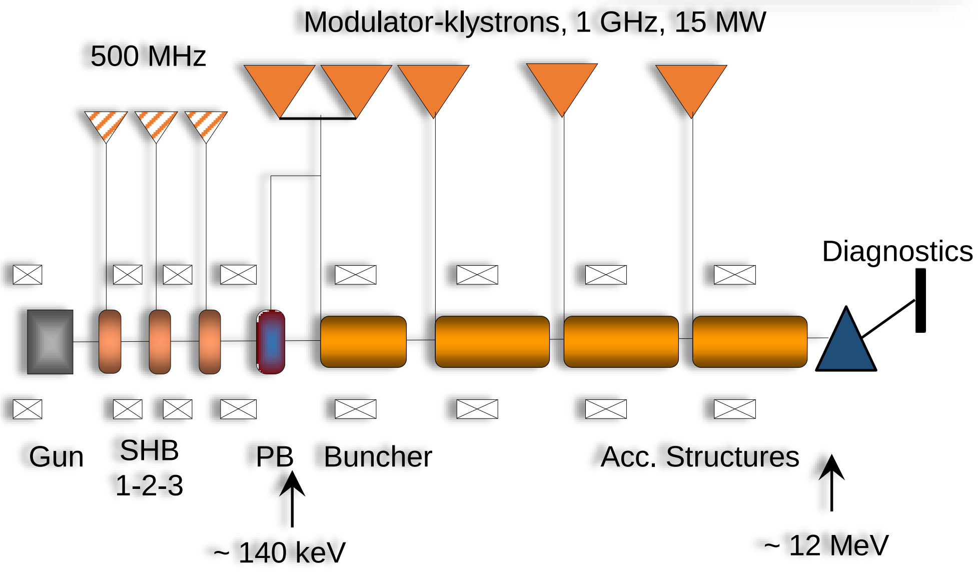
Röttgers Værktøj A/S Odense - DK

System tests

Light sources, FACET/FELs for emittance conservation, Final Focus studies (ATF2), Drive-beam Front End facility at CERN

Two examples:





[Summary of design and performances: Daniel Schulte]

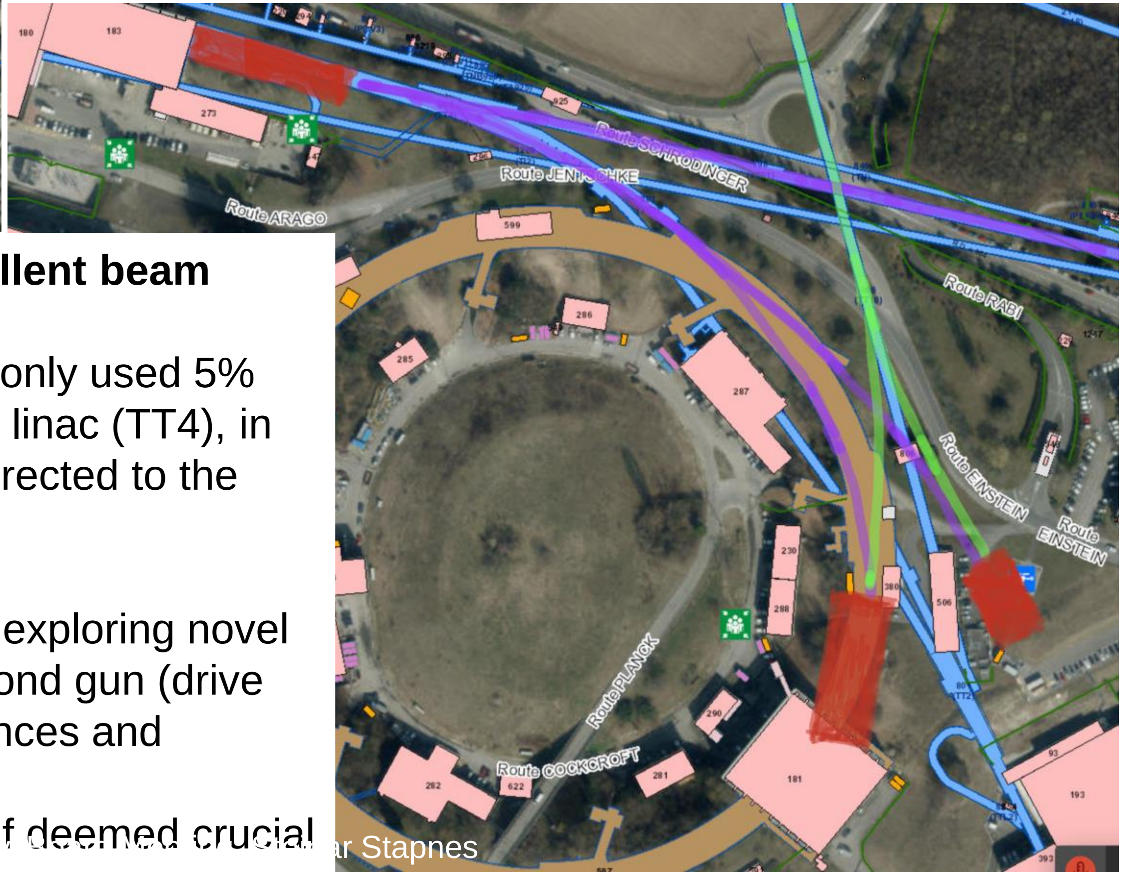
Four/five users groups:

- Physics
- CLIC TDR overlap large
- e-AWAKE
- CLEAR(er)
- DR, positrons and ATF-like studies (possible)

GREEN: ~15 GeV electron beam in SPS

Acc. in SPS, can also be a damped small emittance beam. Long bunches.

- Extracted to Meyrin side for LDMX like experiment.
- Can also – possibly – be guided to AWAKE.
- Other uses, either extracted or circulating to be worked out.



PURPLE: 3 GeV x-band linac with excellent beam quality

Short bunch electrons from X-band linac, only used 5% for filling the SPS. Can be used right after linac (TT4), in new experimental area, and/or possibly directed to the current AWAKE area.

- CLEAR type of research progamme.
- Electrons for drive and/or probe beam exploring novel accelerating techniques, including second gun (drive and probe bunches with variable distances and charges).
- Longer term possibilities for positrons if deemed crucial