Future High-Energy Colliders:

The Compact Linear Collider (CLIC)

and Applications

https://clic.cern

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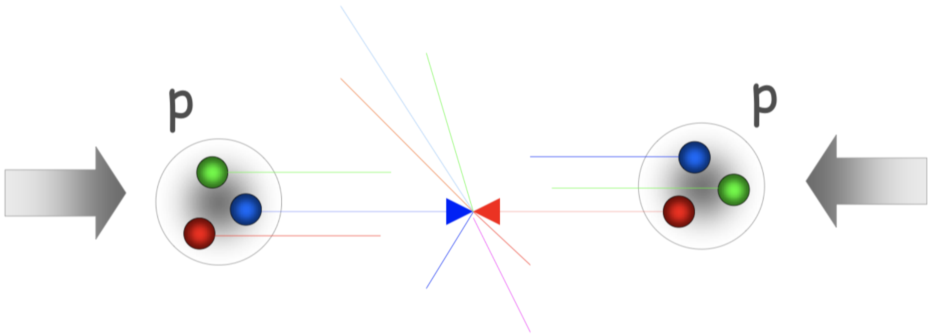
Collider Choices

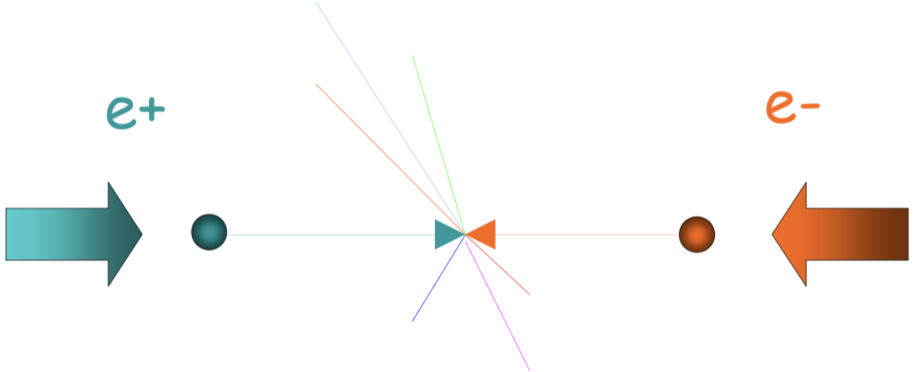
- Hadron collisions (p, ions):

  - Compound particles (mix of quarks, anti-quarks and gluons)
  - Parton energy spread, can only use PT conservation
  - QCD processes produce large background



- Lepton collisions(e-, e+, muons):

  - Elementary particles
  - Well defined initial state
  - Momentum conservation eases decay produce analysis
  - Less background
  - Polarization

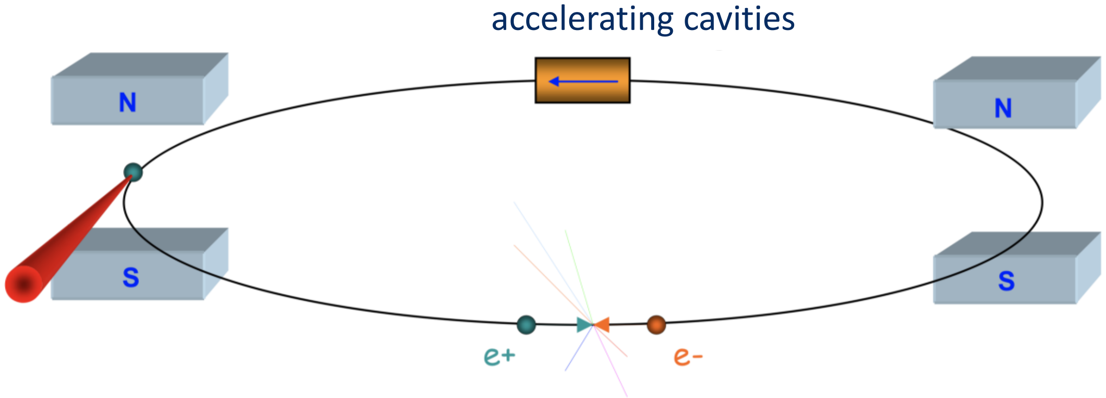


- Photons also possible

Circular vs. Linear Collider

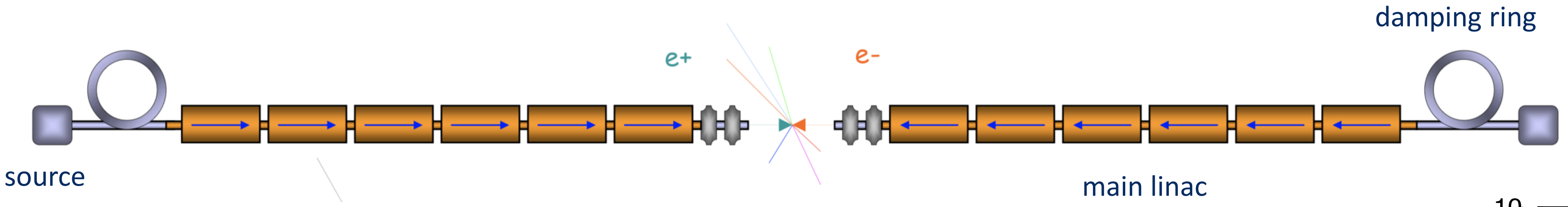
Accelerates beam over many turns
Can use beam many times in collision
However, charged particles emit synchrotron radiation in a magnetic field

$$\Delta E_{turn} = \frac{4}{3}\pi \frac{r_e}{(m_o c^2)^3} \frac{E^4}{\rho}$$

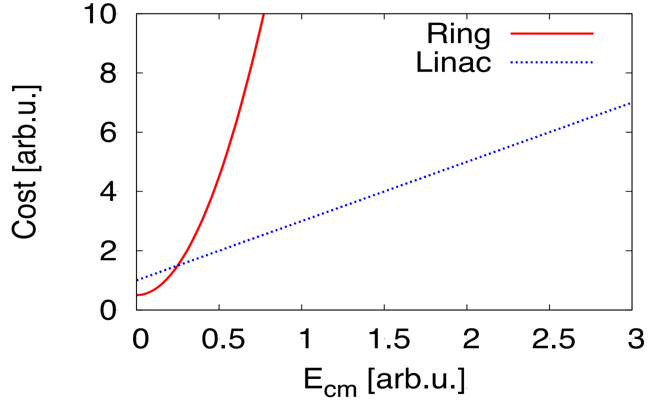


For light particles synchrotron radiation can be large

- At LEP2 lost 2.75GeV/turn for E = 105 GeV



Almost no radiation in a linac
Beam has to achieve energy in single pass
Must achieve luminosity with single beam collision



Considered High Energy Frontier Colliders

Circular colliders:

- FCC (Future Circular Collider)
    - FCC-hh 100 TeV cm energy proton-proton, ion operation possible
    - FCC-ee Potential intermediate step 90-350 GeV cm lepton collider
    - FCC-he Lepton-hadron option
- CEPC / SppC (Circular Electron-positron Collider/Super Proton-proton Collider)
    - CepC e^+e^- 90 - 240 GeV cm
    - SppC pp 70 TeV cm

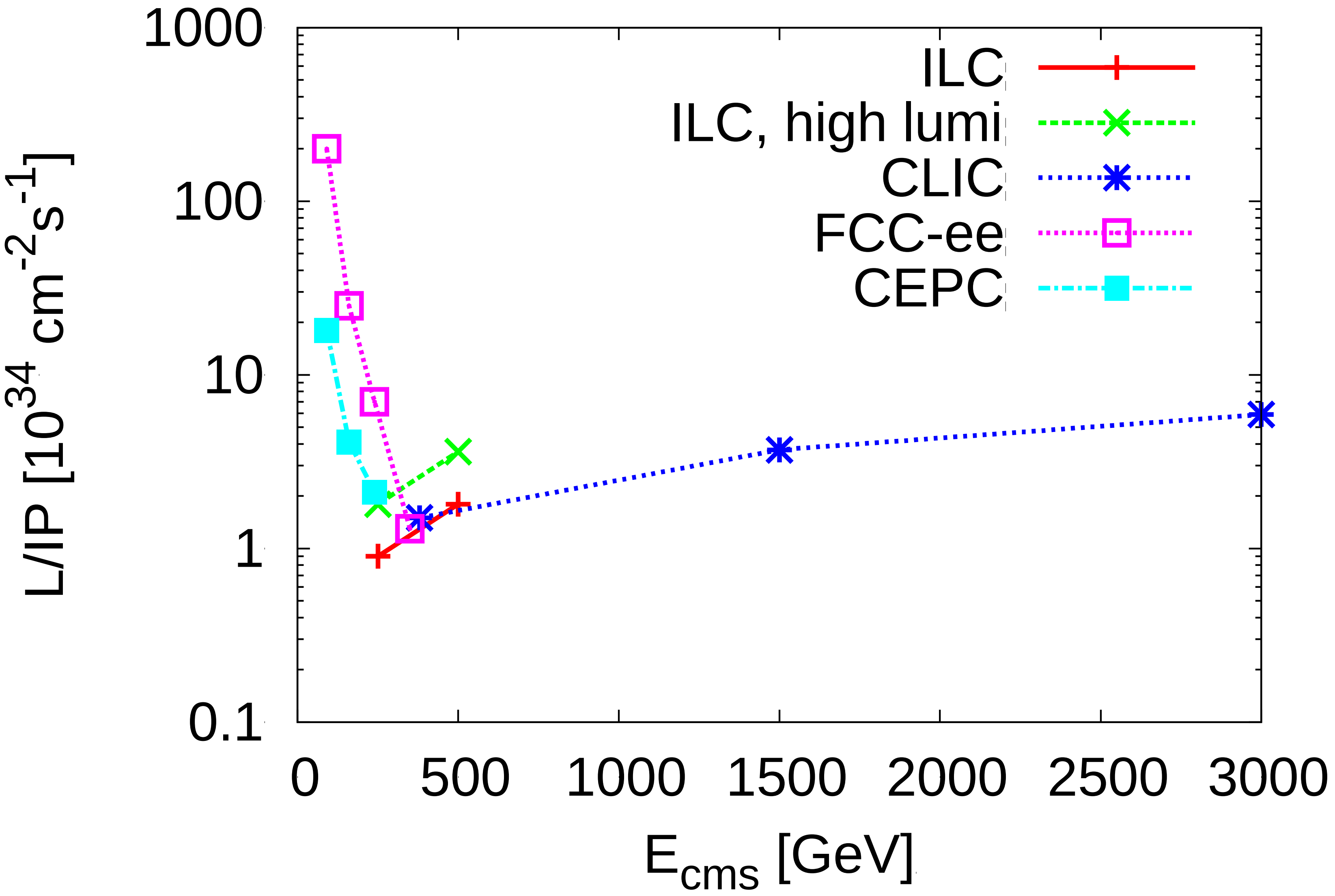
Linear colliders

- CLIC (Compact Linear Collider) e^+e^- 380 GeV - 3 TeV cm energy, CERN hosts collaboration
- ILC (International Linear Collider) e^+e^- 500 GeV cm energy, Japan considers hosting project

Mentioned:

- Muon collider, has been supported in the US but effort strongly reduced -> Europe Picking up
- Plasma acceleration in a linear collider
- Photon-photon collider
- LHeC

Circular vs. Linear Colliders



Recall, in rings:

$$\Delta E \propto \left(\frac{E}{m}\right)^4 \frac{1}{R}$$

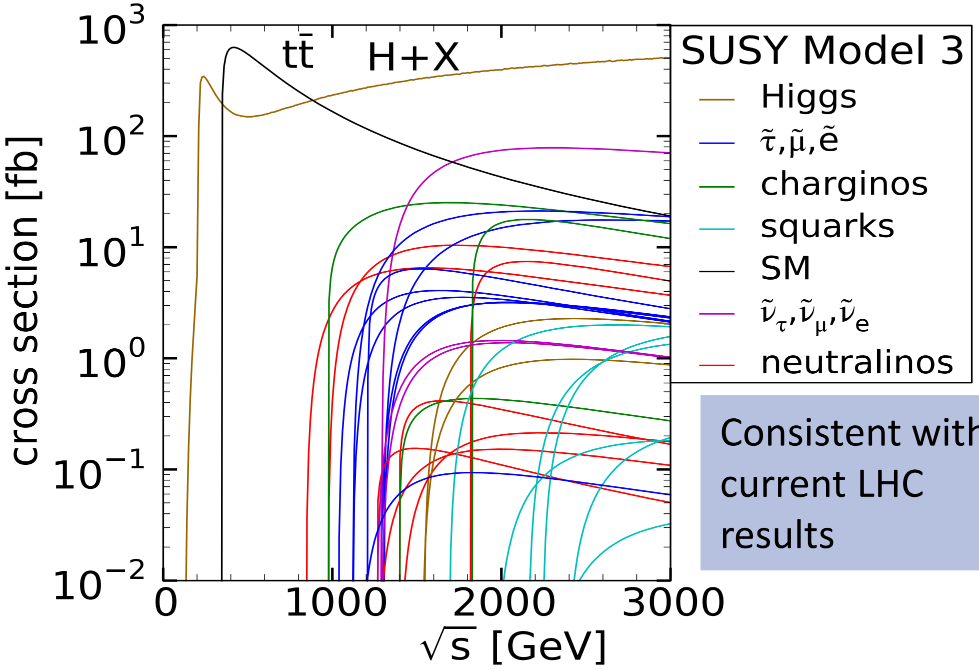
Lepton Collider Physics Case

Know physics for Higgs and top

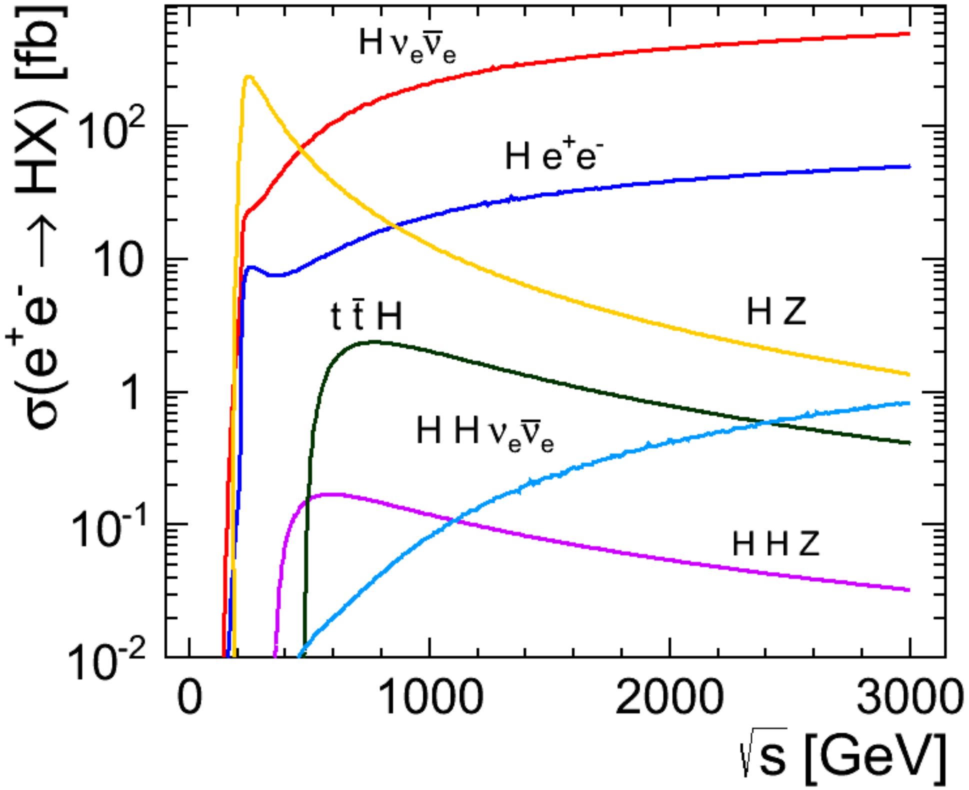
- low energies for many branching rations
- high energies for others, e.g. Hνν
- 350 GeV for top threshold scan
- maybe precision measurements at Z and W

Currently not known physics

- hope to get hints from LHC
- e.g. SUSY



Consistent with current LHC results



Have to wait for LHC input
But need to prepare scenarios

CLIC

CLIC Collaboration

CLIC accelerator

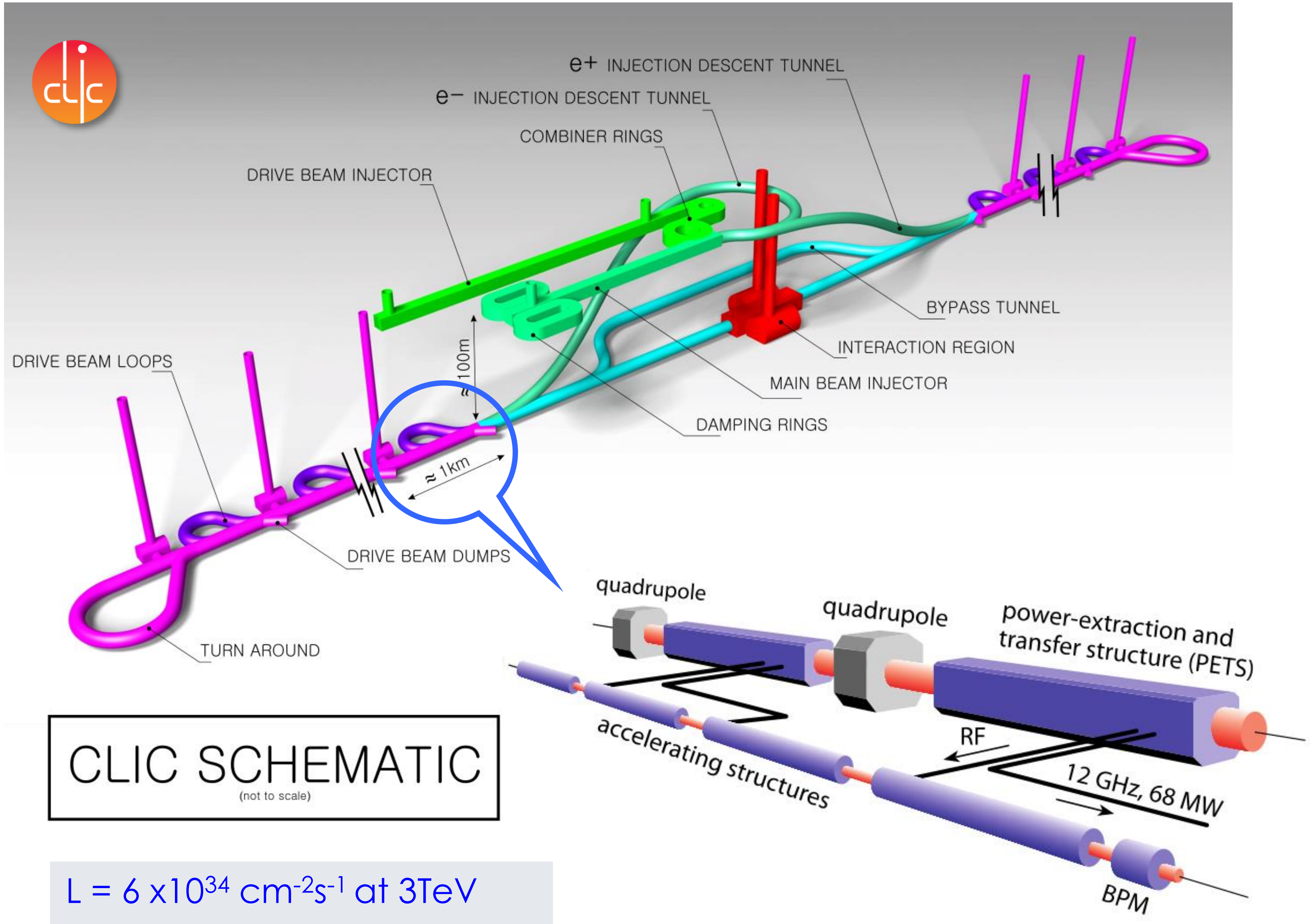
- ~50 institutes from 28 countries*
- CLIC accelerator studies
- CLIC accelerator design and development
- Construction and operation of CLIC Test Facility, CTF3

CLIC detector and physics (CLICdp)

- 30 institutes from 18 countries
- Physics prospects & simulations studies
- Detector optimisation + R&D for CLIC

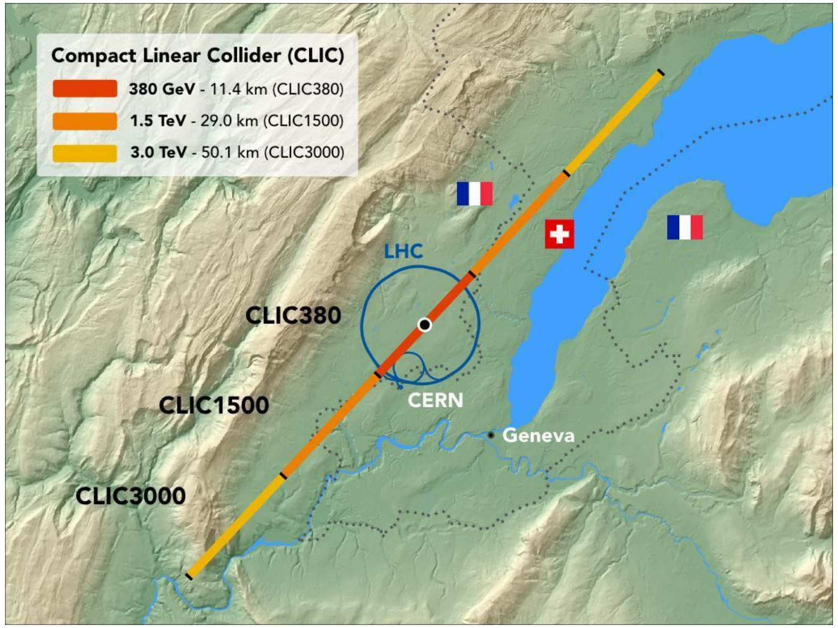
+ strong participation in the CALICE and FCAL Collaborations and in AIDA-2020/AIDAinnova

The CERN's Compact Linear Collider - CLIC



CLIC SCHEMATIC
(not to scale)

$L = 6 \times 10^{34}$ $\mathrm{cm^{-2}s^{-1}}$ at 3TeV
Beam power 30MW at 3TeV



CLIC will be built in stages of increasing collision energy: starting from 380 GeV, then ~ 1- 2 TeV, and up to a final energy of 3 TeV.

To limit the collider length, the accelerating gradient must be very high - CLIC aims at 100 MV/m, 20 times higher than the LHC.

CLIC is based on a two-beam acceleration scheme, in which a high current e- beam (the drive beam) is decelerated in special structures (PETS), and the generated RF power is used to accelerate the main beam.

What matters in a linear collider ?

Energy reach

$$E_{cm} \approx L_{linac} G_{acc}$$

High gradient

X-band normal conducting accelerating structures

Luminosity

$$L = \frac{n_b N^2 f_{rep}}{4\pi\sigma_x^*\sigma_y^*} \times H_D \propto \frac{\eta_{beam}^{AC} P_{AC}}{\varepsilon_y^{1/2}} \frac{\delta_{BS}^{1/2}}{E_{cm}}$$

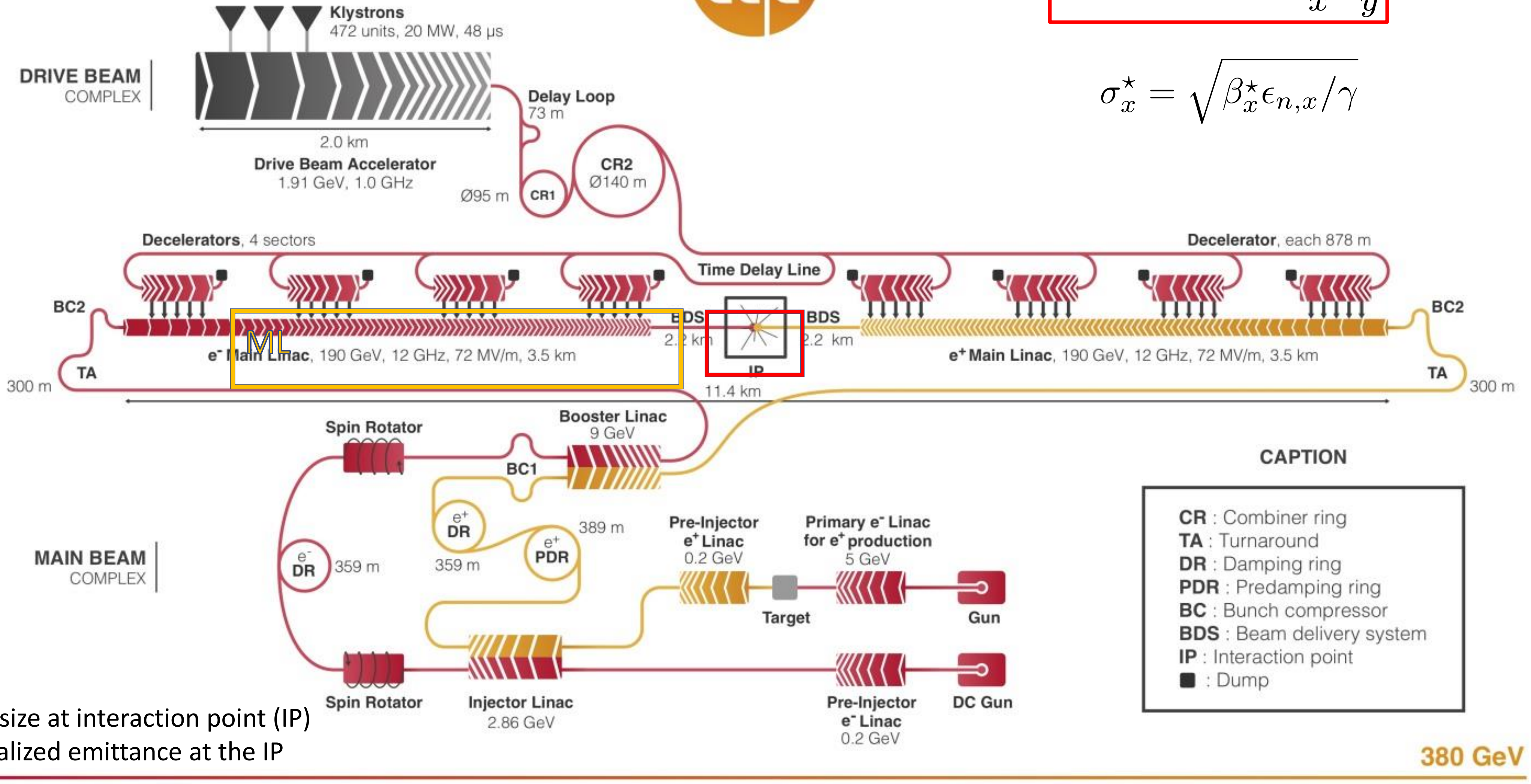
CLIC Specific Challenges

• Acceleration efficiency	Two-beam scheme
• Generation of small beams	Damping rings
• Conservation of small emittance	Wake-fields, alignment, stability
• Extremely small beam spot at IP	Beam delivery system, stability

CLIC 380 GeV in the center of mass

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

$$\sigma_x^\star = \sqrt{\beta_x^\star \epsilon_{n,x}/\gamma}$$



CLIC - Scheme of the Compact Linear Collider (CLIC)

σ* is the beam size at interaction point (IP)

$\varepsilon_{n,x}$ is the normalized emittance at the IP

https://videos.cern.ch/record/2688462

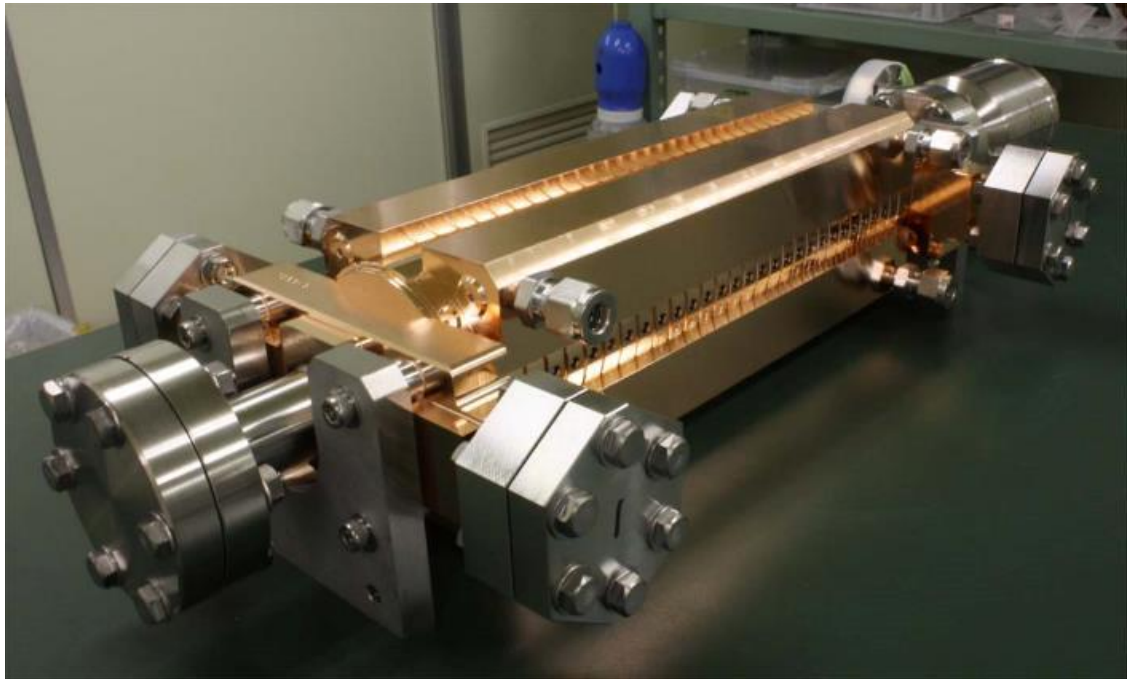
Accelerating Structure

12 GHz, 23cm long, normal conducting
Loaded gradient 100MV/m

⇒ Allows to reach higher energies
⇒ 140,000 structures at 3TeV

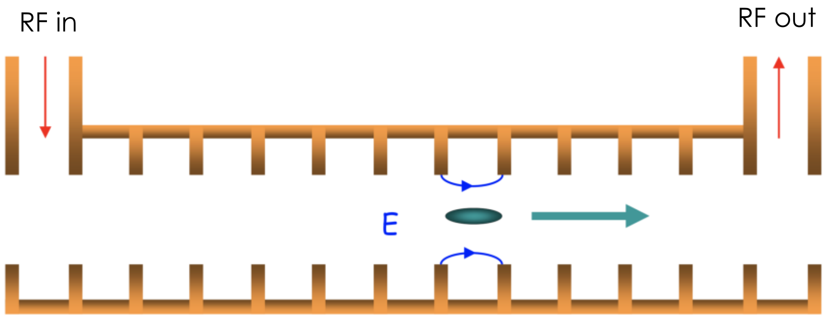
losses in the walls and in the load

⇒ 50 RF bursts per second
⇒ 240 ns, 60 MW, 312 bunches
⇒ Power during pulse 8.5 x 10^6 MW (3000 x ILC)



Power flow
- 1/3 lost in cavity walls
- 1/3 in filling the structure and into load
- 1/3 into the beam

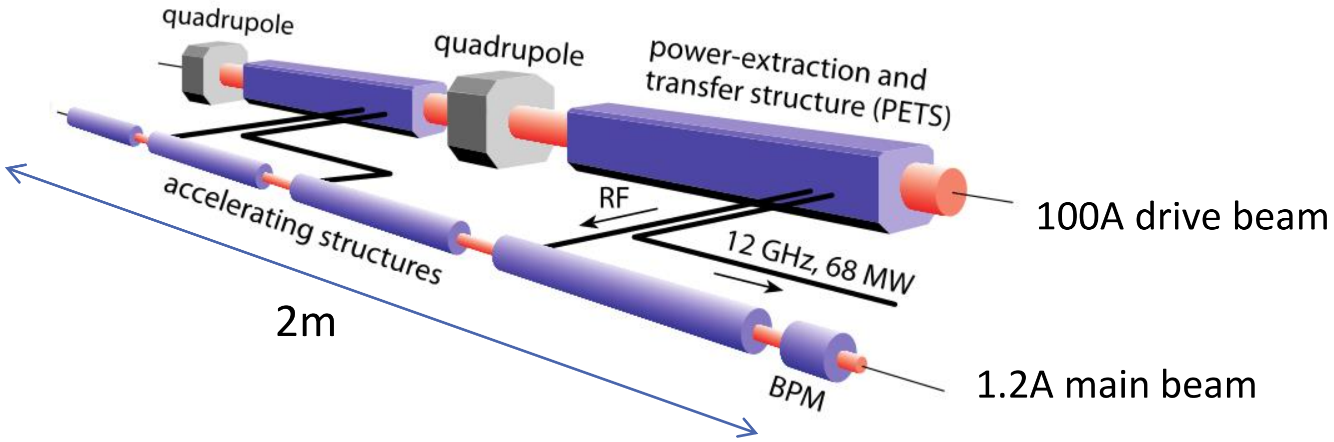
Average RF power about 3kW/m
About 1kW/m into beam

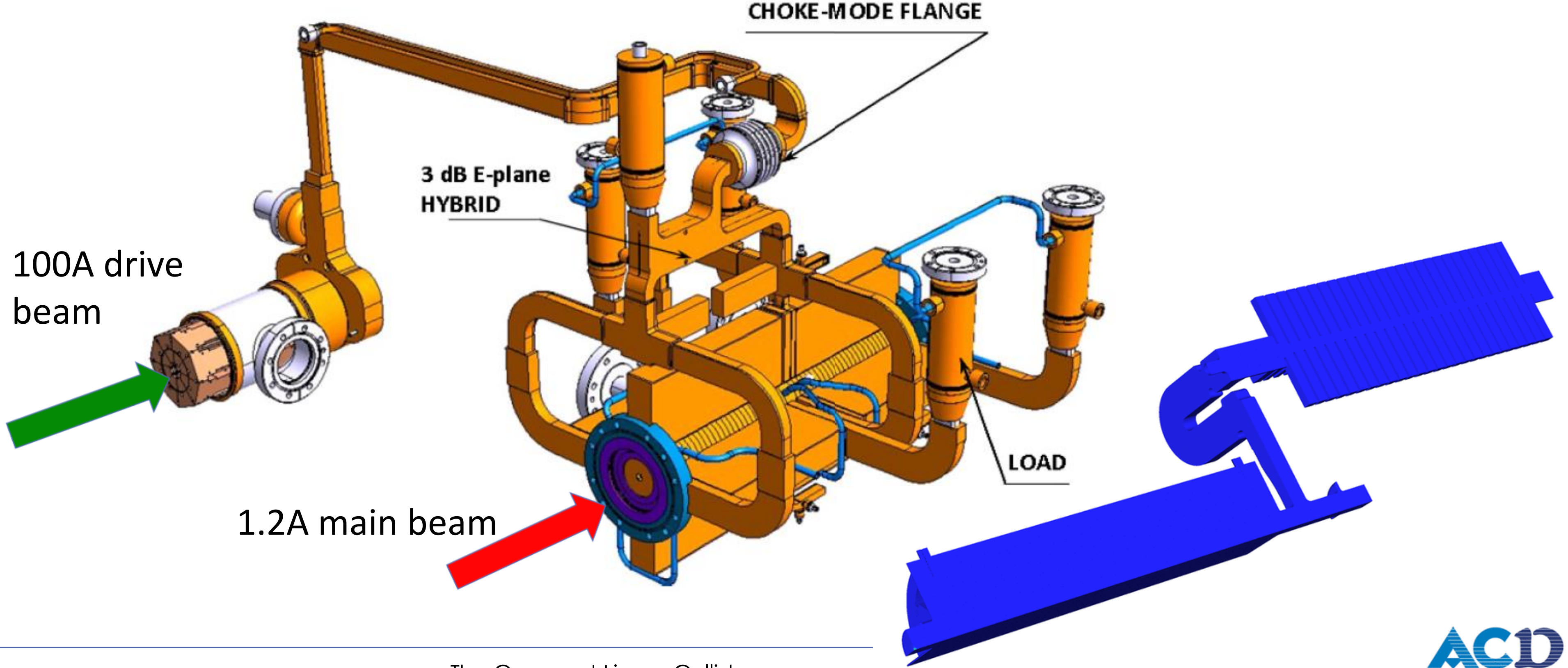


Travelling wave

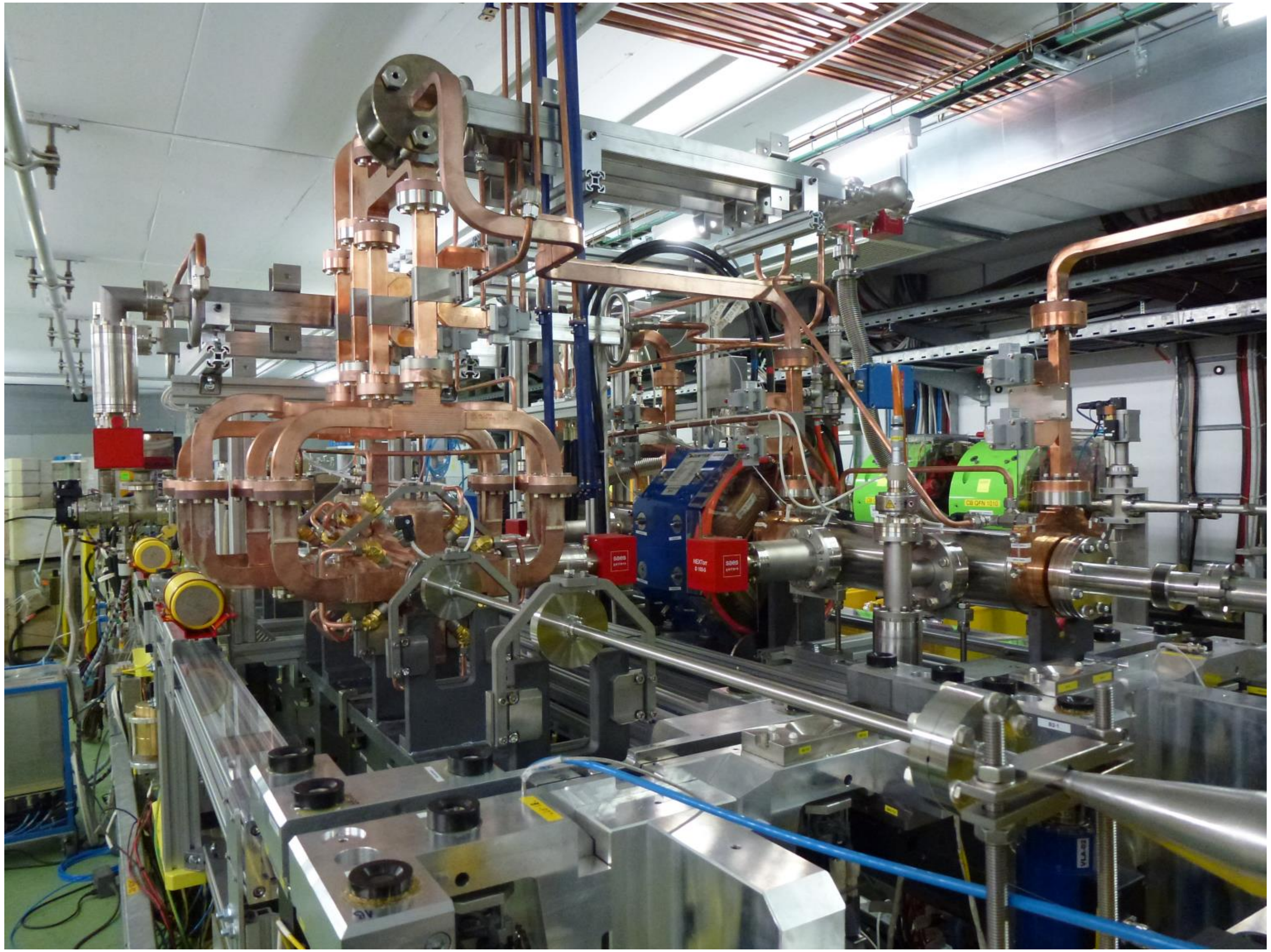
Particles “surf” the
electromagnetic wave

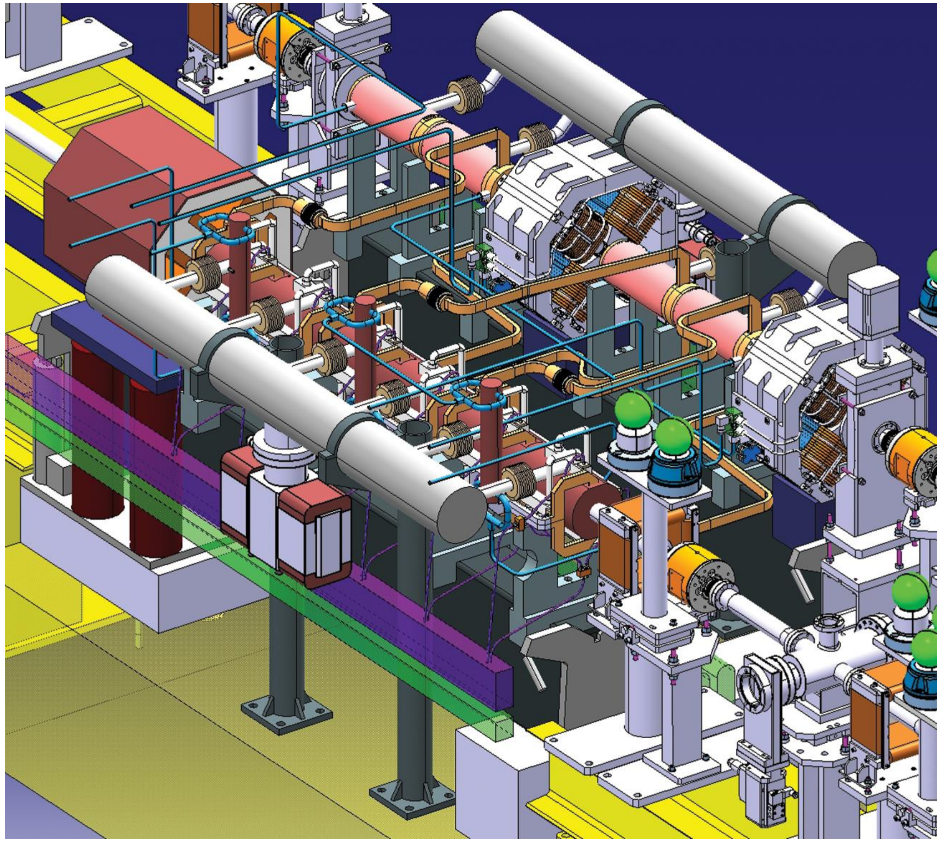
CLIC Two-beam Concept



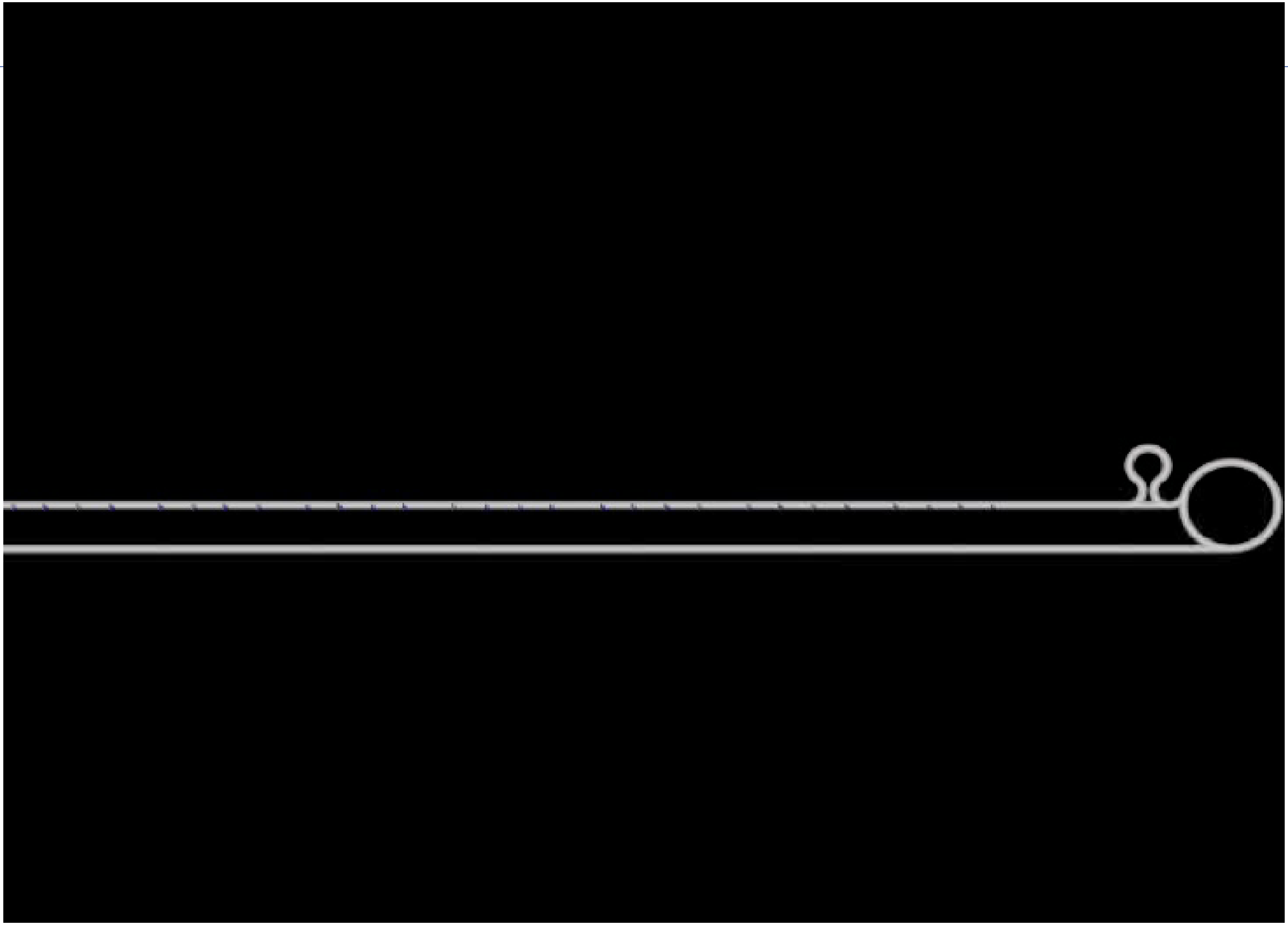


CLIC Two-beam Module





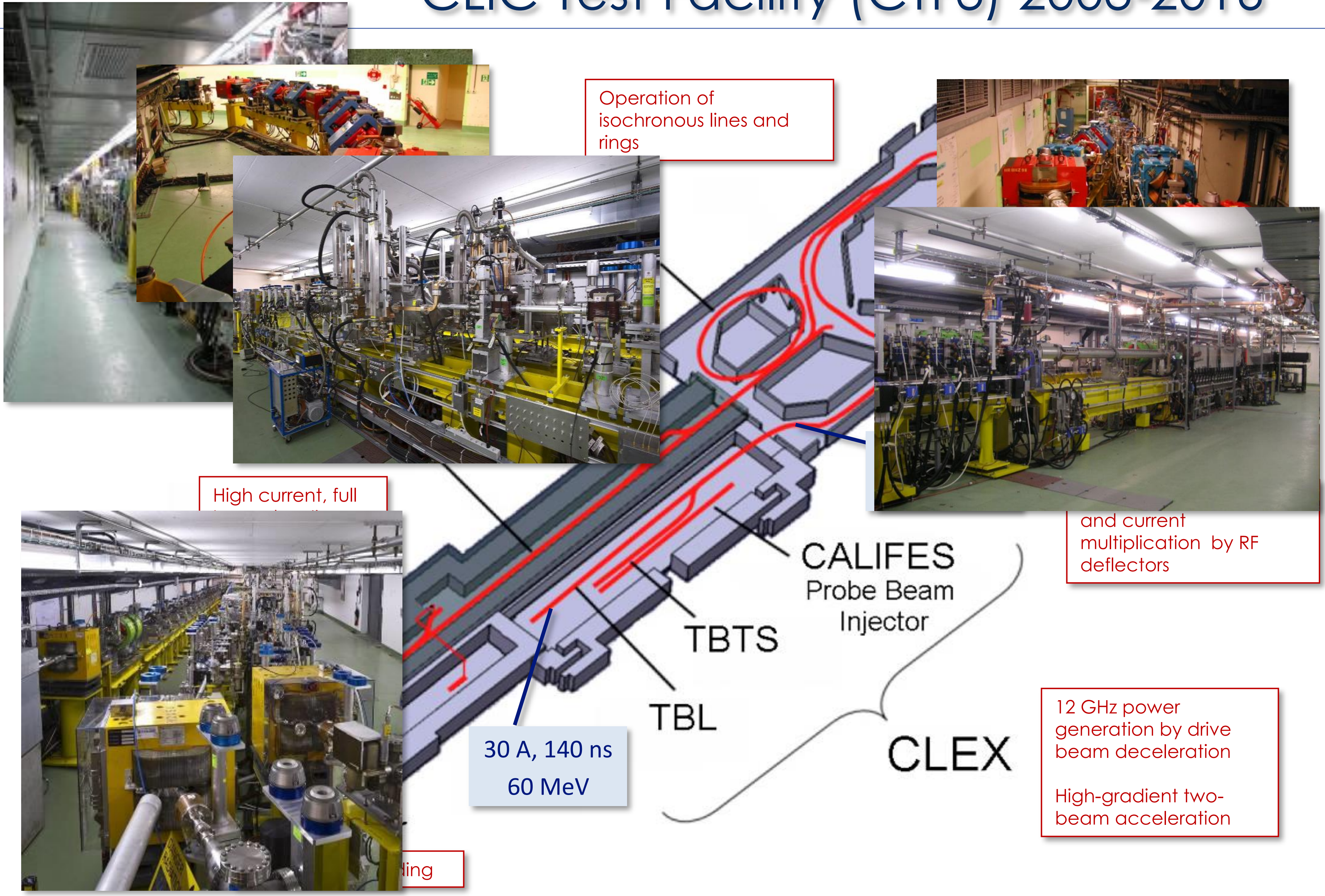
80 % filling with accelerating structures
11 km for 380 GeV cms
50 km for 3 TeV



A. Andersson

https://videos.cern.ch/record/2688462

CLIC Test Facility (CTF3) 2003-2016



Operation of isochronous lines and rings

High current, full

ing

and current multiplication by RF deflectors

30 A, 140 ns
60 MeV

12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

First beam
June 2003

Last beam
December 2016

CLIC is a mature design/study

The CLIC accelerator studies are mature:

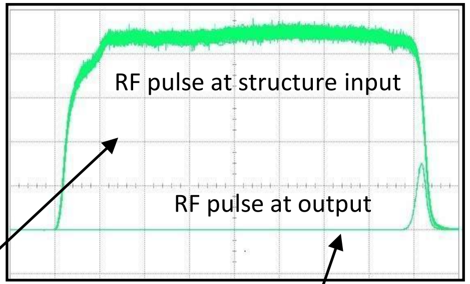
Optimised design for cost and power

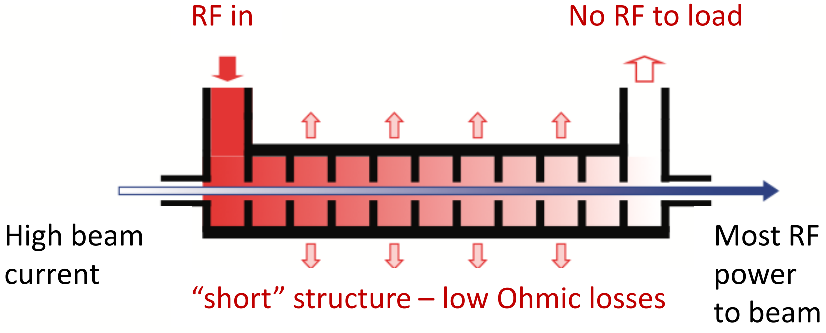
Many tests in CTF3, FELs, lightsources and test-stands

Technical developments of “all” key elements

Drive Beam Generation – Power Production

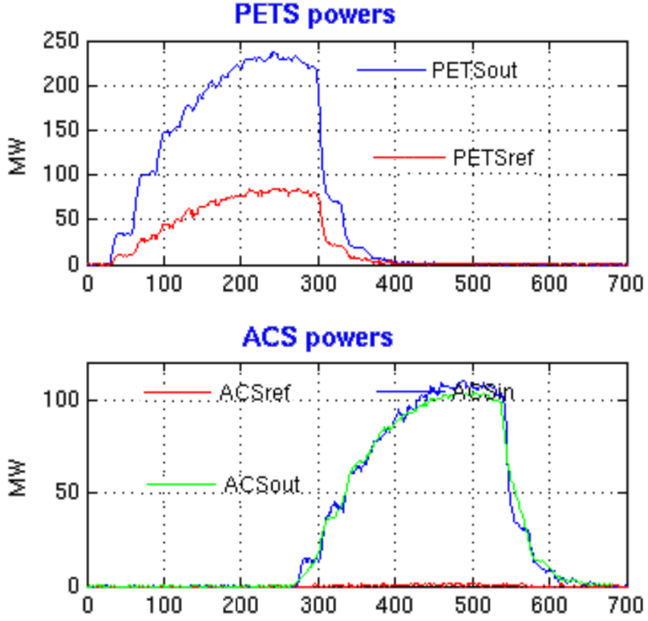
Full beam loading acceleration

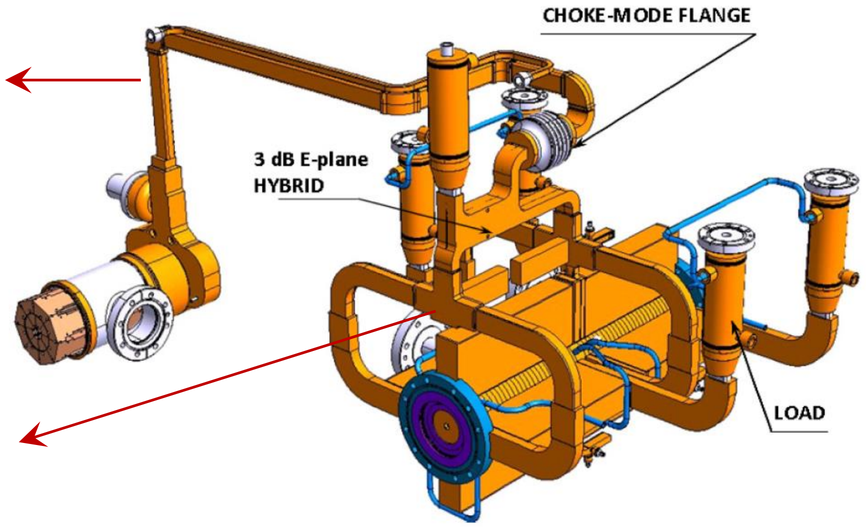


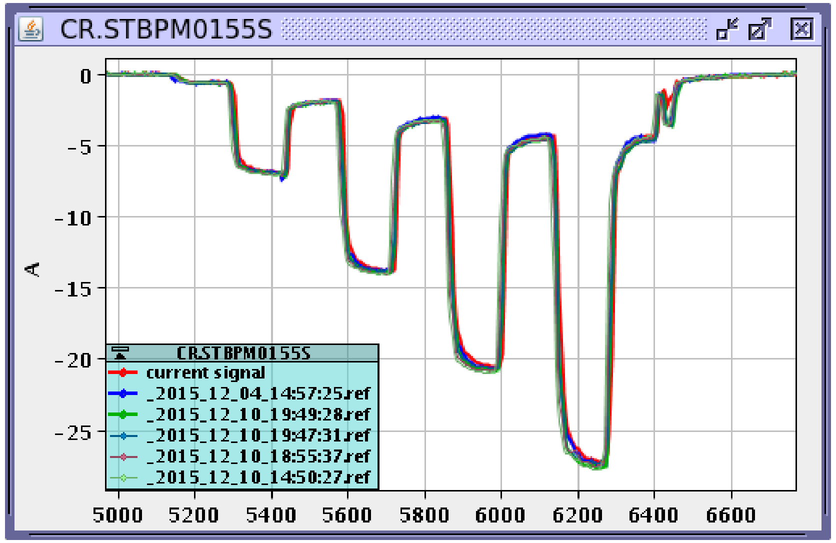


95.3% RF to beam efficiency
Stable high current acceleration

Factor 8 current & frequency multiplication







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

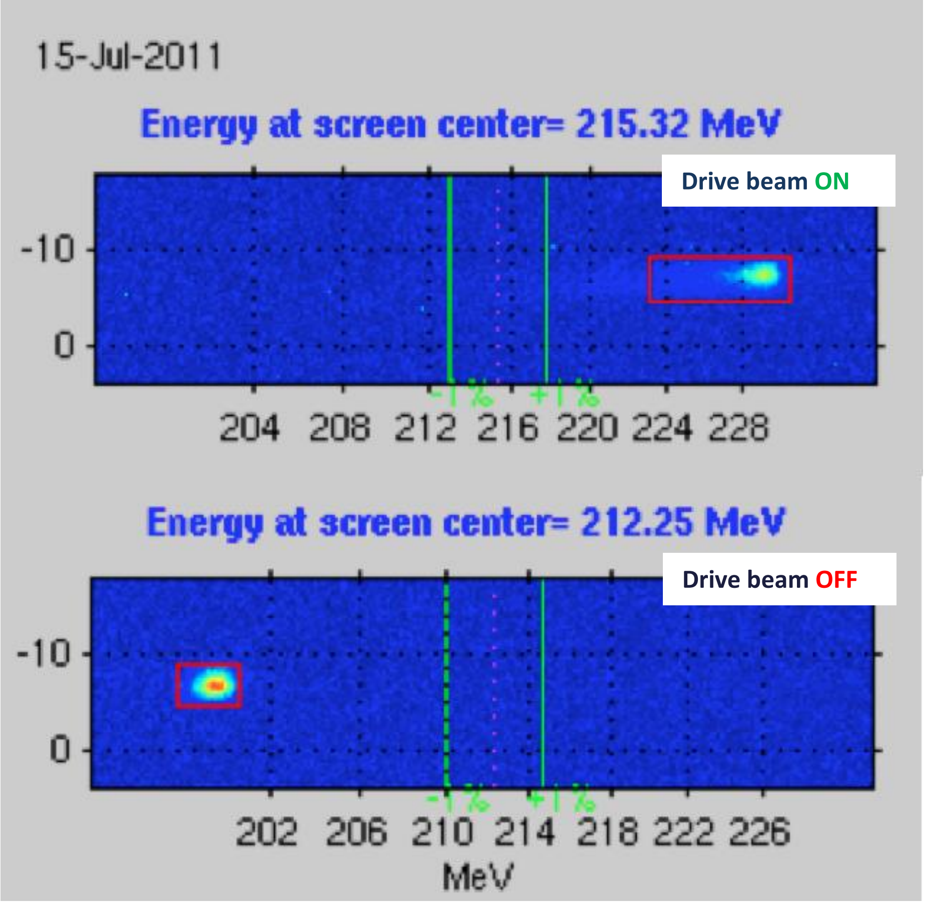
providing reliably pulses ~ 100 MW to accelerating structure.

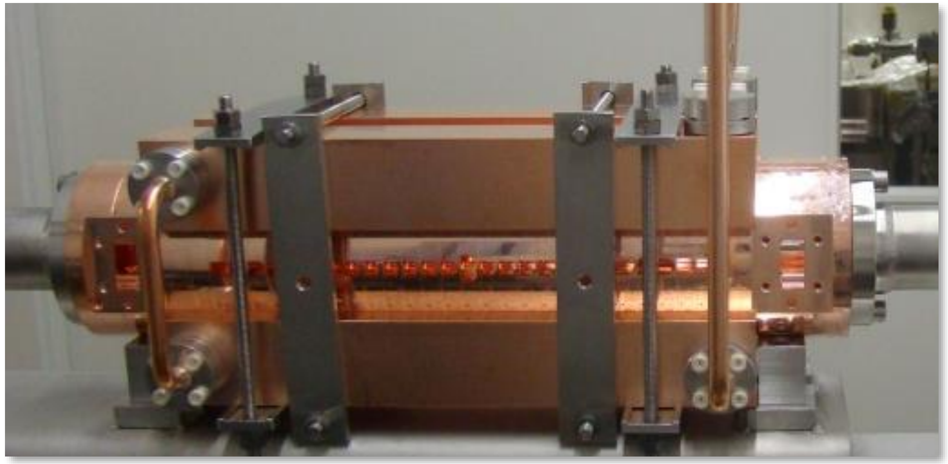
About twice the power needed to demonstrate 100 MV/m acceleration

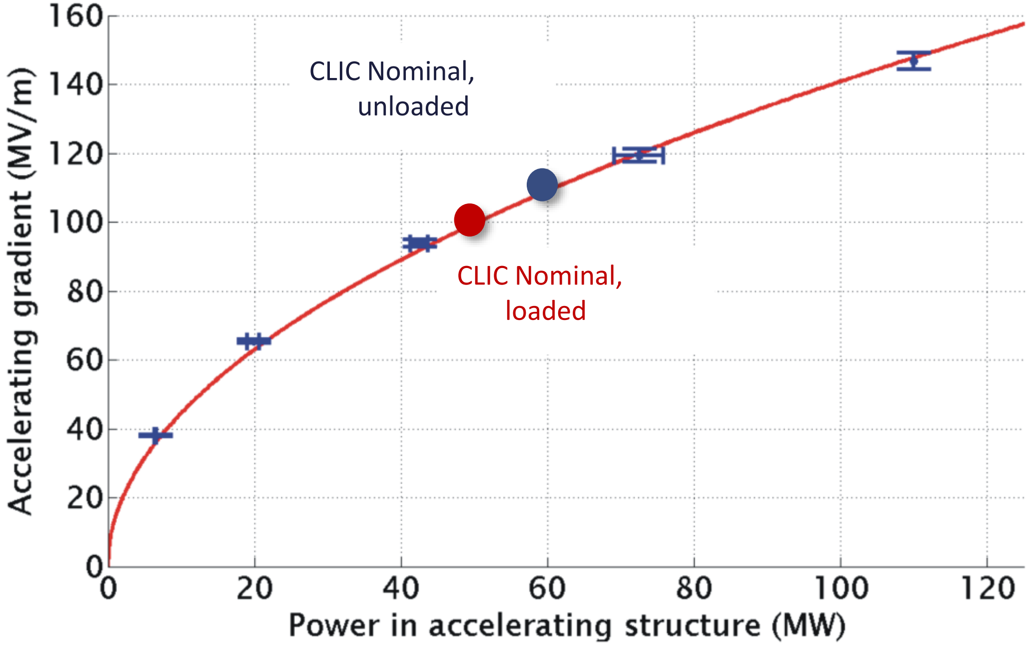
Two-Beam Acceleration demonstration in CTF3

Maximum stable probe beam acceleration measured: 31 MeV

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







Luminosity and Parameter Drivers

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

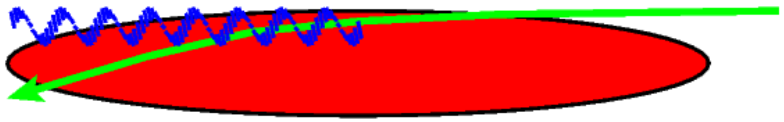
Can re-write normal luminosity formula in a slightly different way

$$\mathcal{L} \propto H_D \underbrace{\frac{N}{\sigma_x}}_{\text{Luminosity spectrum}} \underbrace{N n_b f_r}_{\text{Beam power}} \underbrace{\frac{1}{\sigma_y}}_{\text{Beam Quality}}$$

Need to ensure that we can achieve each parameter

Beam-beam Effect

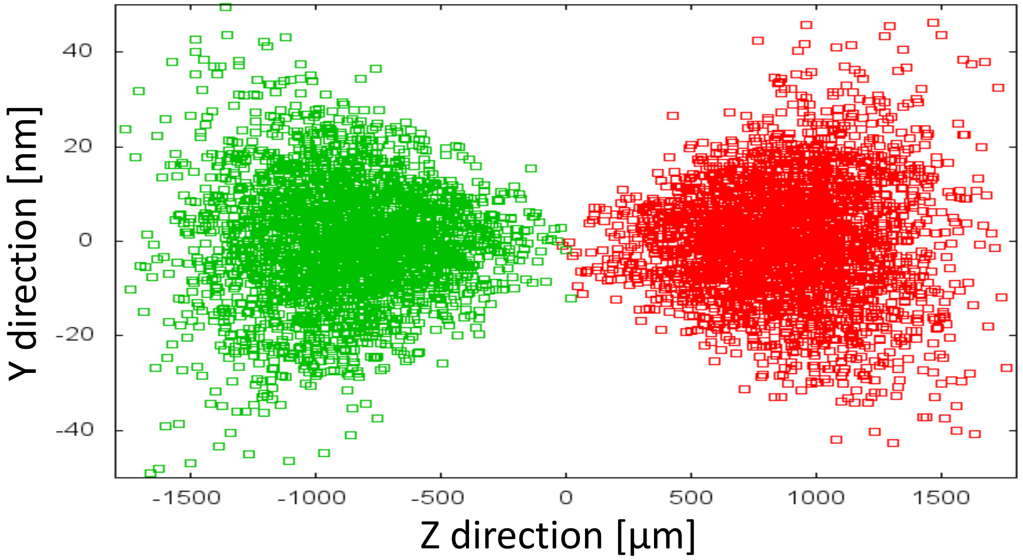
$$\mathcal{L} \propto H_D \boxed{\frac{N}{\sigma_x}} N n_b f_r \frac{1}{\sigma_y}$$



Intense beams to reach high luminosity

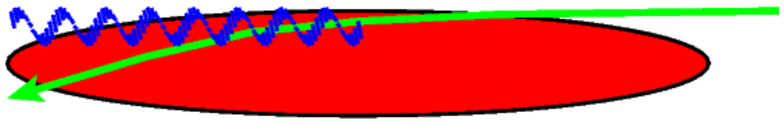
$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}$$

Beam-beam force switched off



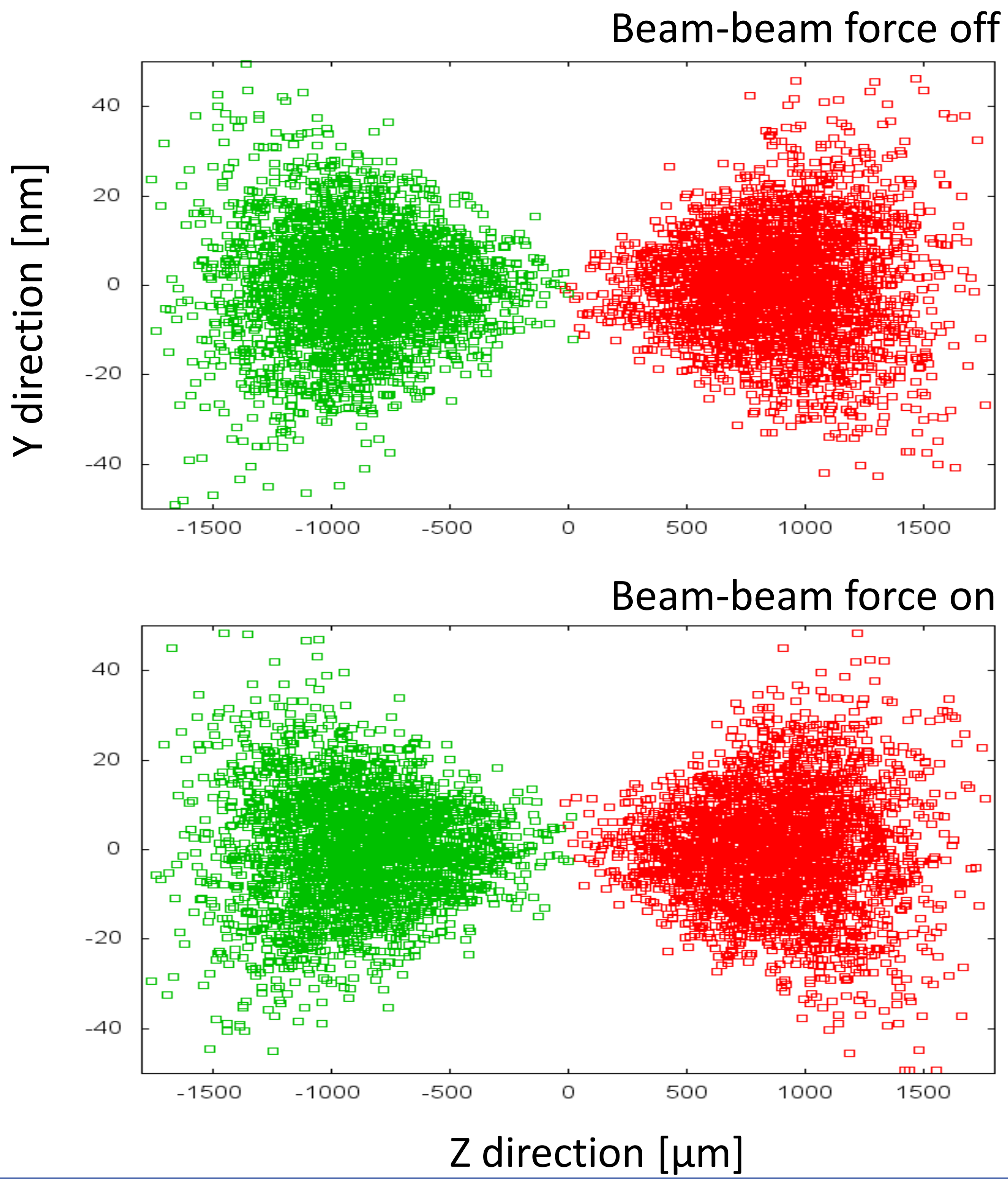
Beam-beam Effect

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



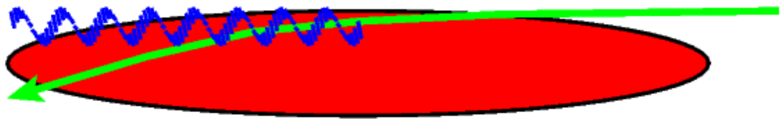
Beam focus each other

$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}$$



Beam-beam Effect

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

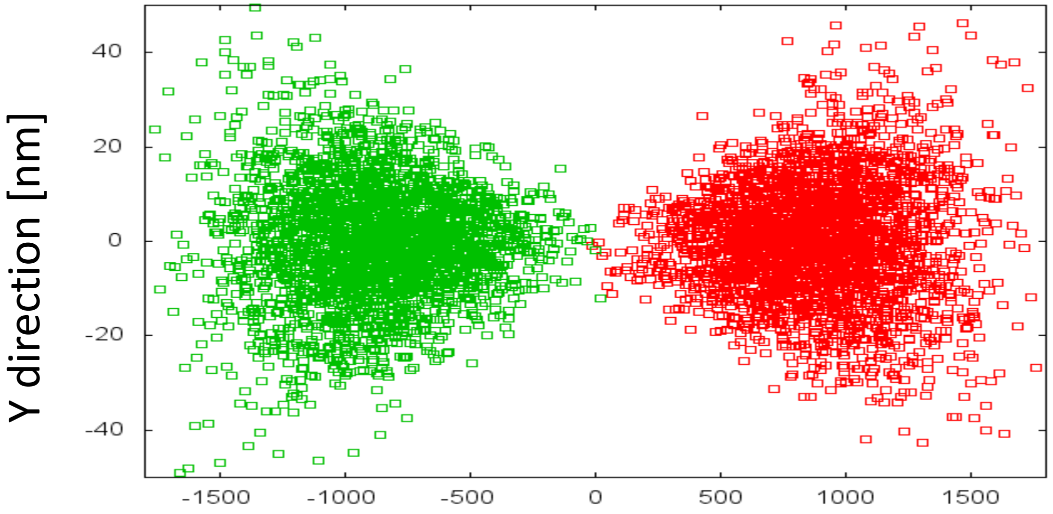


Emitt beamstrahlung

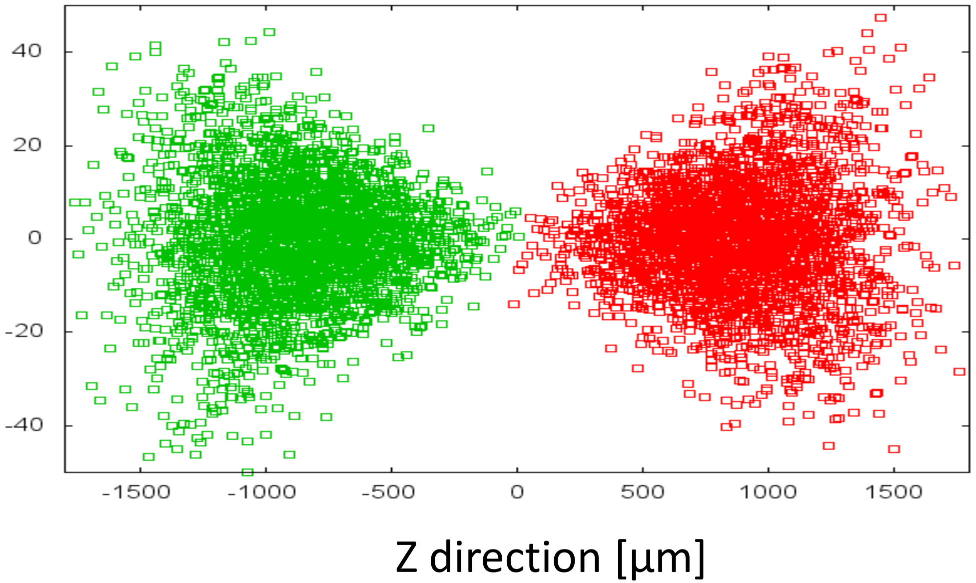
$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}$$

$$n_\gamma \propto E_\gamma \propto \frac{N}{\sigma_x + \sigma_y}$$

Beam-beam force off

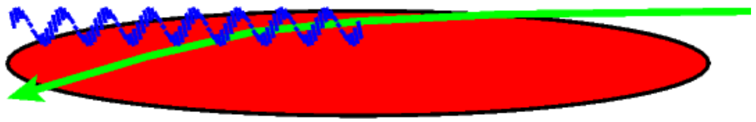


Beam-beam force on

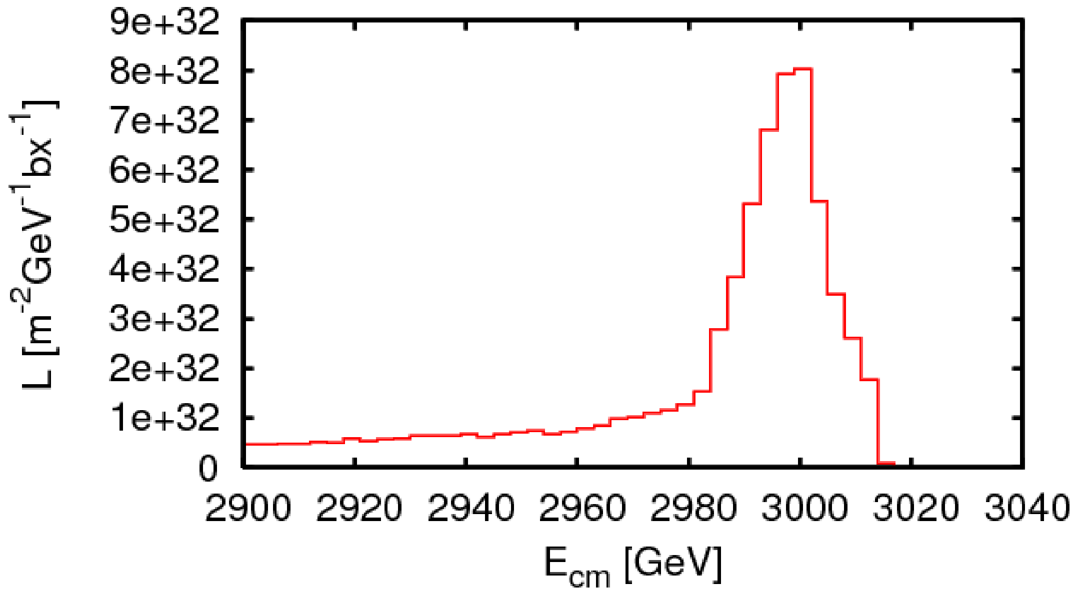


Beam-beam Effect

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



Develop luminosity spectrum

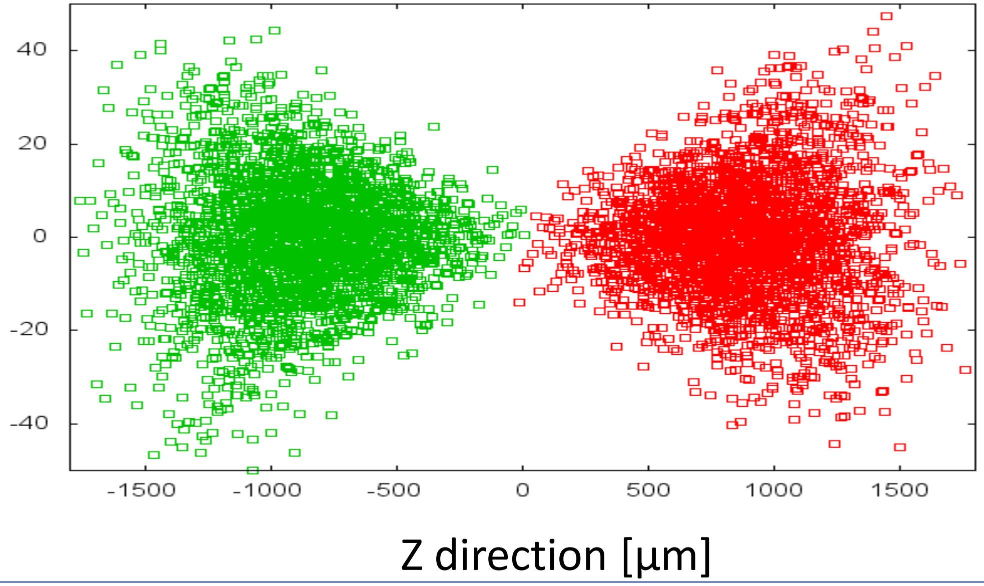


$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}$$

$$n_\gamma \propto E_\gamma \propto \frac{N}{\sigma_x + \sigma_y}$$

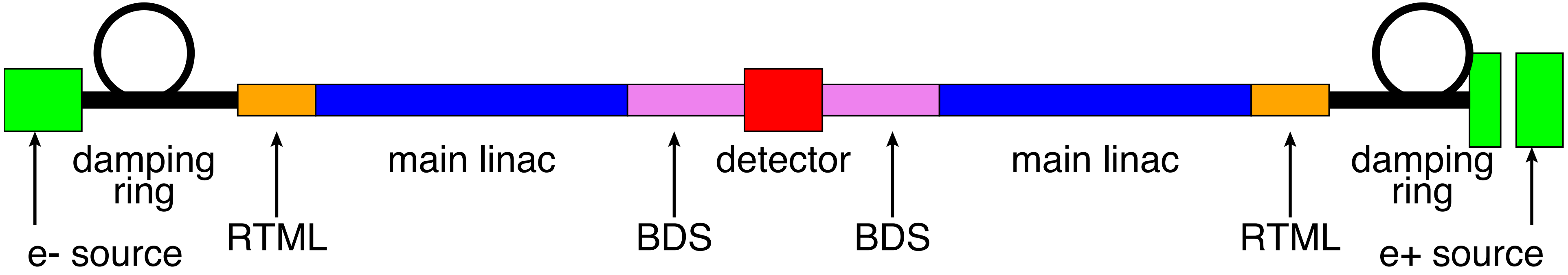
$$\sigma_x \gg \sigma_y \qquad \sigma_x + \sigma_y \approx \sigma_x$$

Beam-beam force on



Beam Quality

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



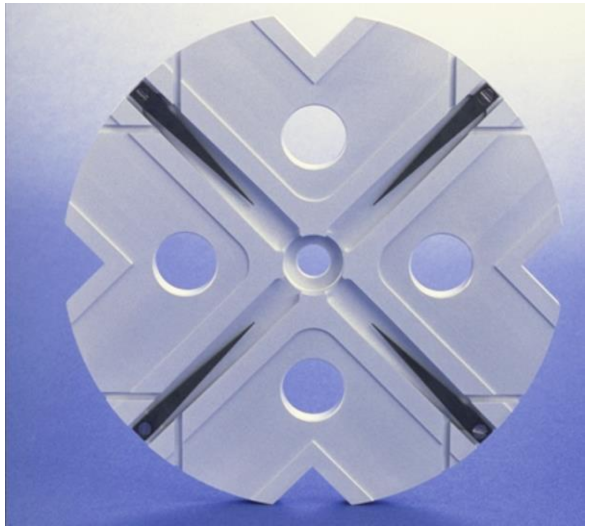
- Cannot cover the very rich field of studies
- Address the issue by
  - Clever system design
  - Clever tuning algorithms
  - Technical development of components
  - Experiments

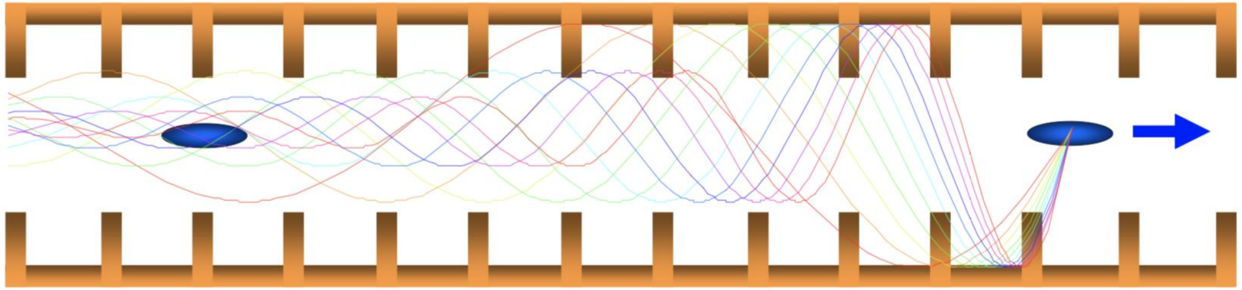
Example: Wakefields

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

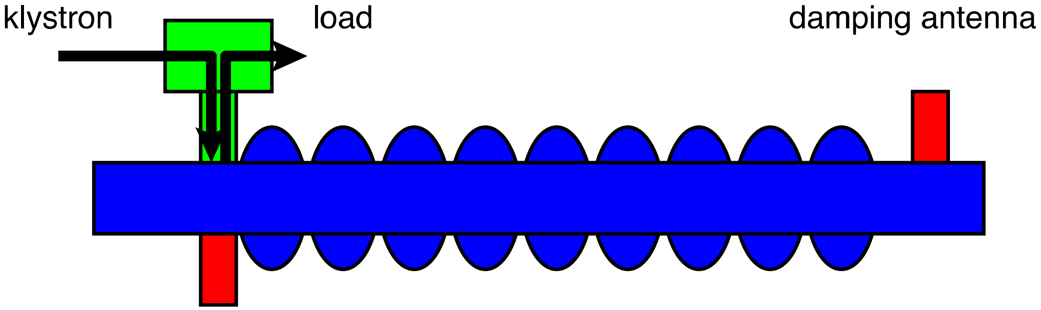
- Bunches traveling in accelerating structures induce fields which perturbs later bunches
- Bunches passing off-centre excite transverse higher order modes (HOM)
- Later bunches are kicked transversely

beam break-up ⇒ Emittance growth !!!



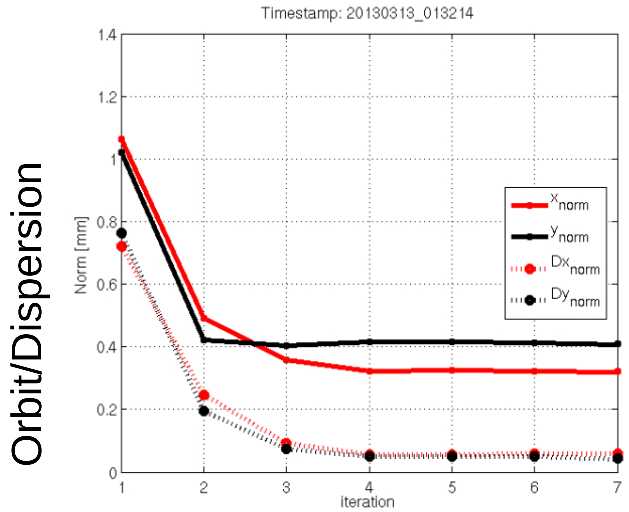


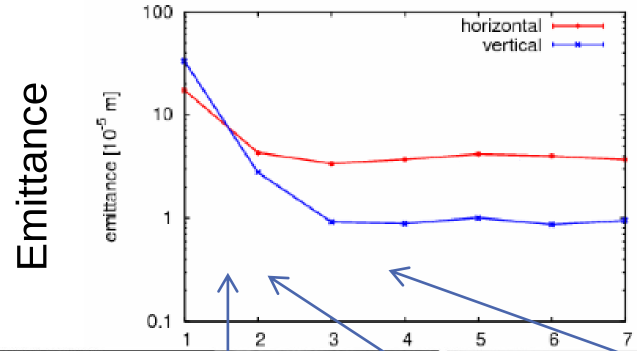
This effect is larger in higher frequency structures, hence N=2x10^{10} vs. N=4x10^{9}



CLIC Beam-Based Alignment Tests at FACET (SLAC)

Dispersion-free Steering (DFS) proof of principle

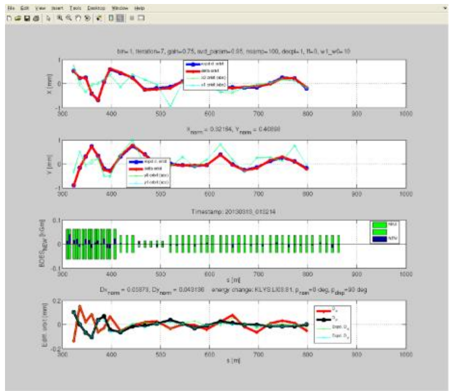


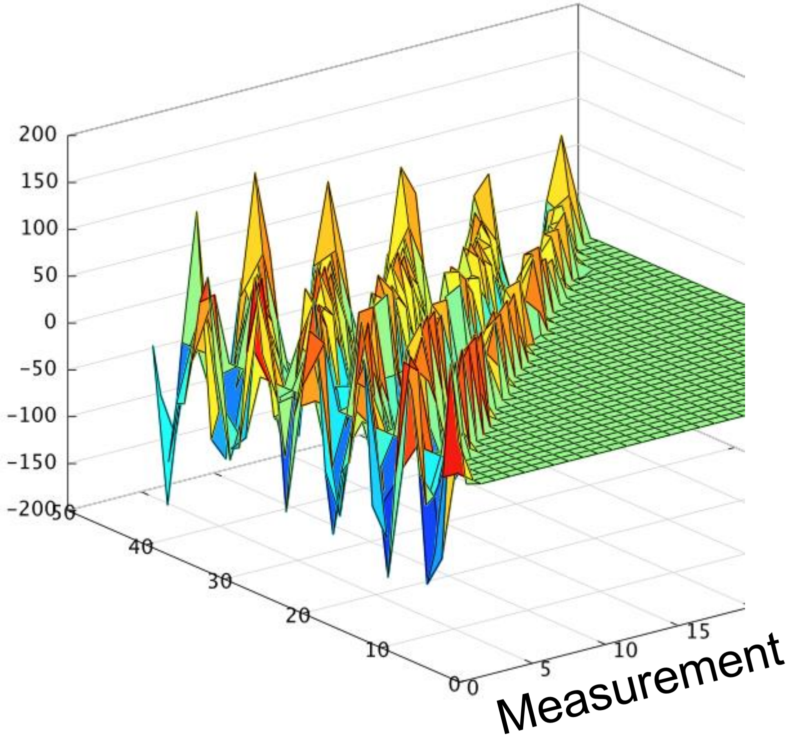


DFS correction applied to 500 meters of the SLC linac

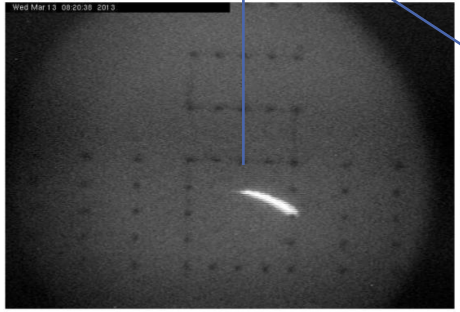
- SysID algorithms for model reconstruction
- DFS correction with GUI
- Emittance growth is measured

Graphic User Interface:

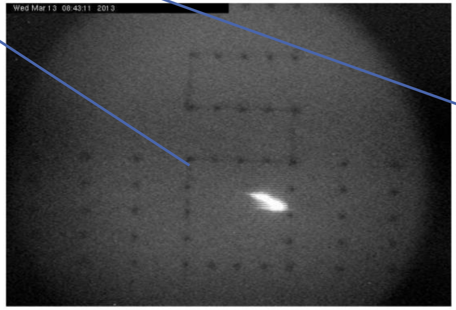




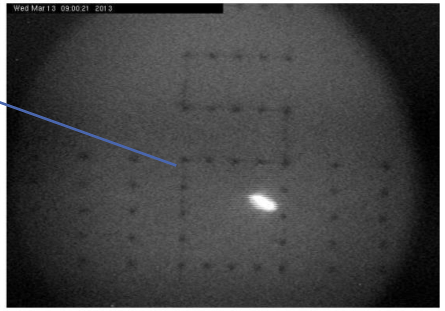
Beam profile measurement



Before correction



After 1 iteration



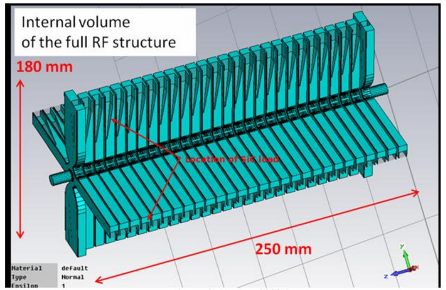
After 3 iterations

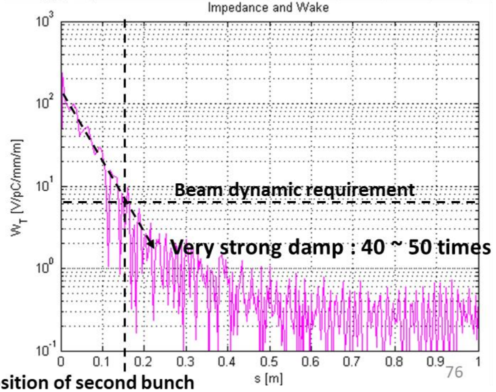
Incoming oscillation/dispersion is taken out and flattened; emittance in LI11 and emittance growth significantly reduced.

Measurement and validation of High-order Modes suppression

Transverse long-range Wakefield in CLIC-G structure

Structure name	CLIG-G TD26cc
Work frequency	11.994GHz
Cell	26 regular cells+ 2 couplers
Length (active)	230mm
Iris aperture	2.35mm - 3.15mm



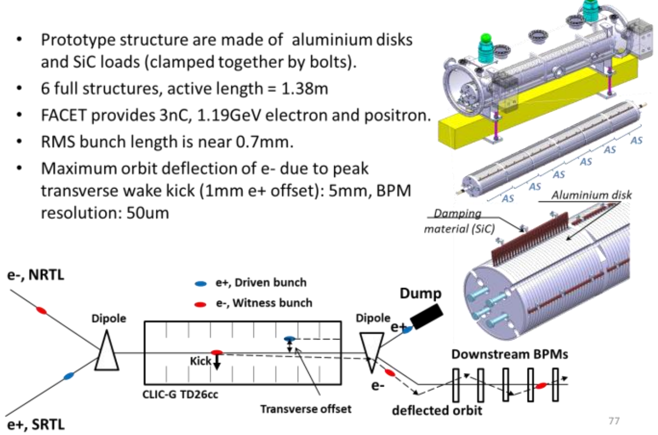


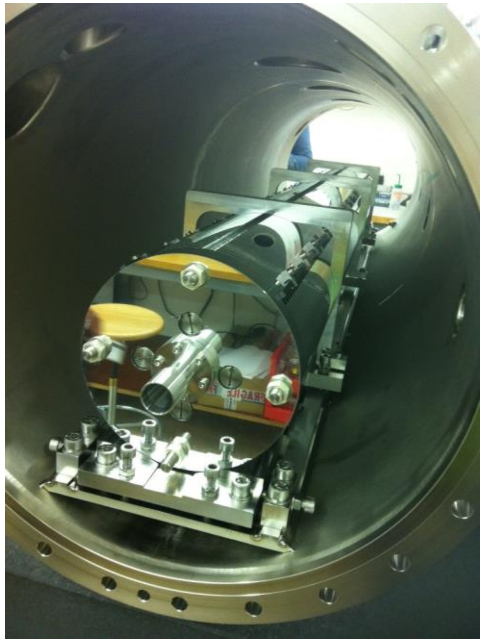
transverse long-range wakefield calculation using Gdfidl code:

Peak value :
250 V/pC/m/mm
At position of second bunch (0.15m):
5~6 V/pC/m/mm
Beam dynamic requirement:
< 6.6 V/pC/m/mm

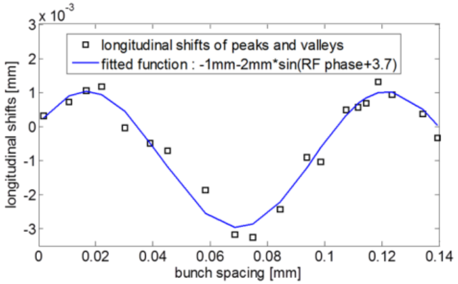
Direct wakefield measurement in FACET

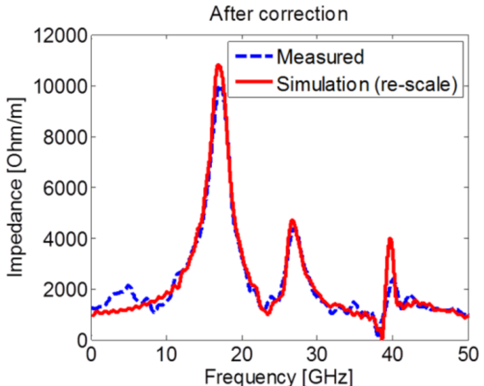
- Prototype structure are made of aluminium disks and SiC loads (clamped together by bolts).
- 6 full structures, active length = 1.38m
- FACET provides 3nC, 1.19GeV electron and positron.
- RMS bunch length is near 0.7mm.
- Maximum orbit deflection of e- due to peak transverse wake kick (1mm e+ offset): 5mm, BPM resolution: 50um

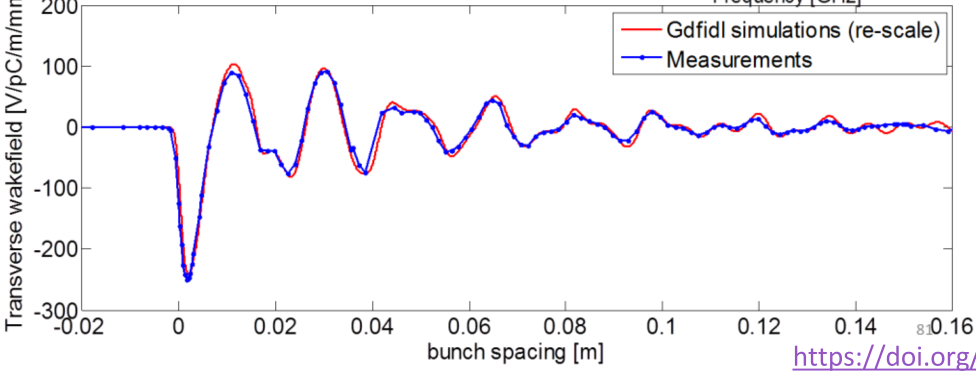




Timing correction



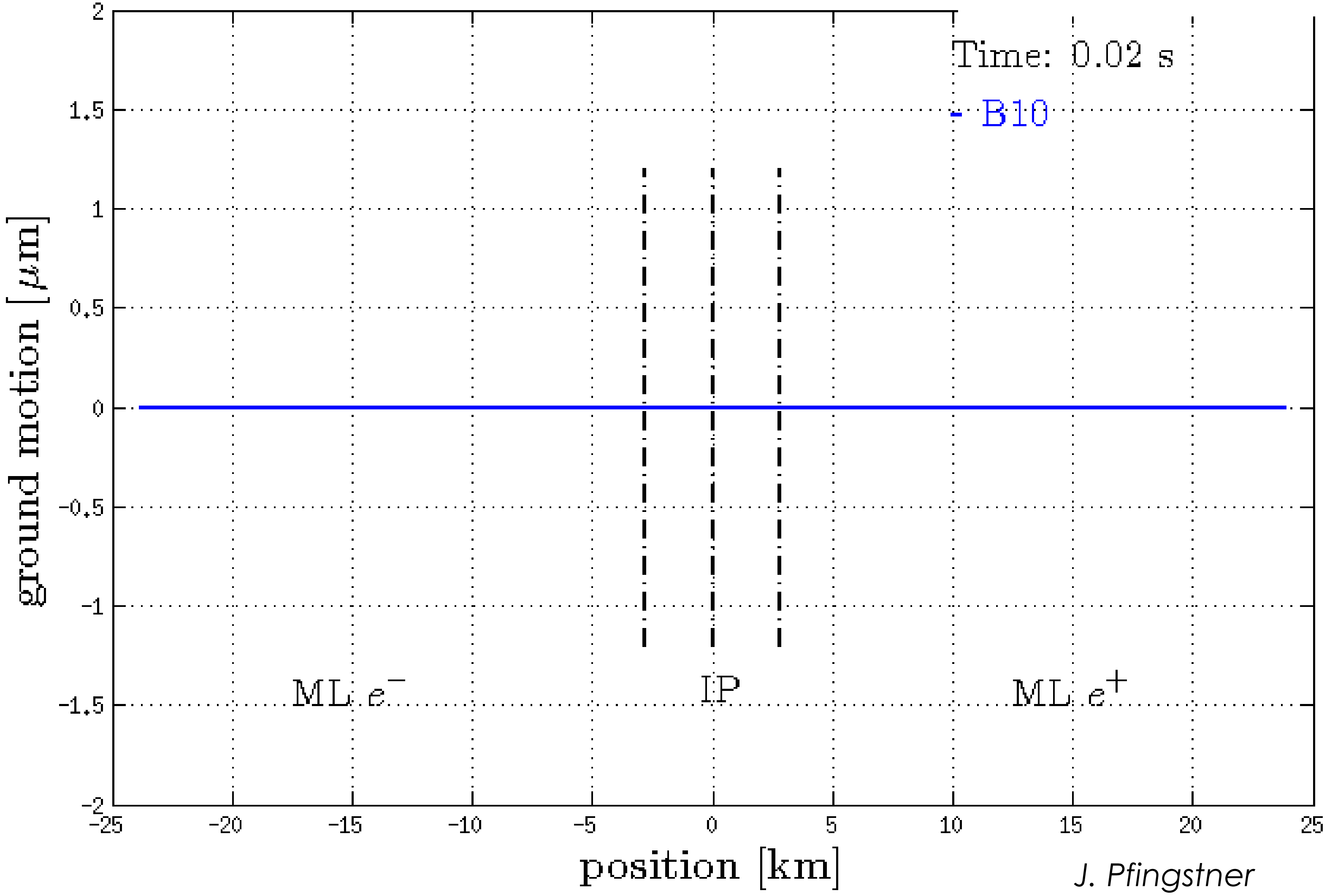




https://doi.org/10.1103/PhysRevAccelBeams.19.011001

Example Issue: Ground Motion at CLIC

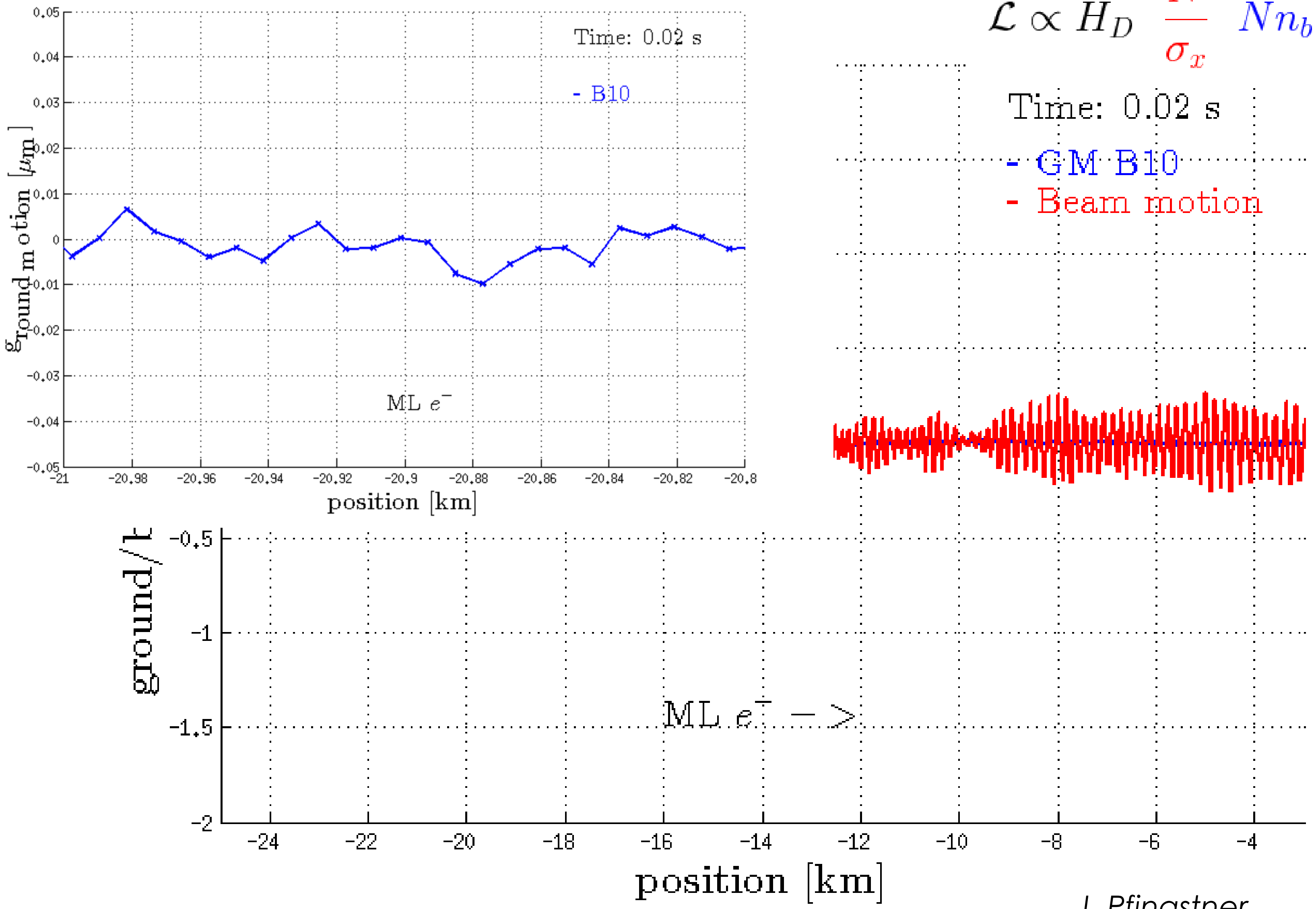
$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \boxed{\frac{1}{\sigma_y}}$$



J. Pfingstner

Resulting Beam Jitter

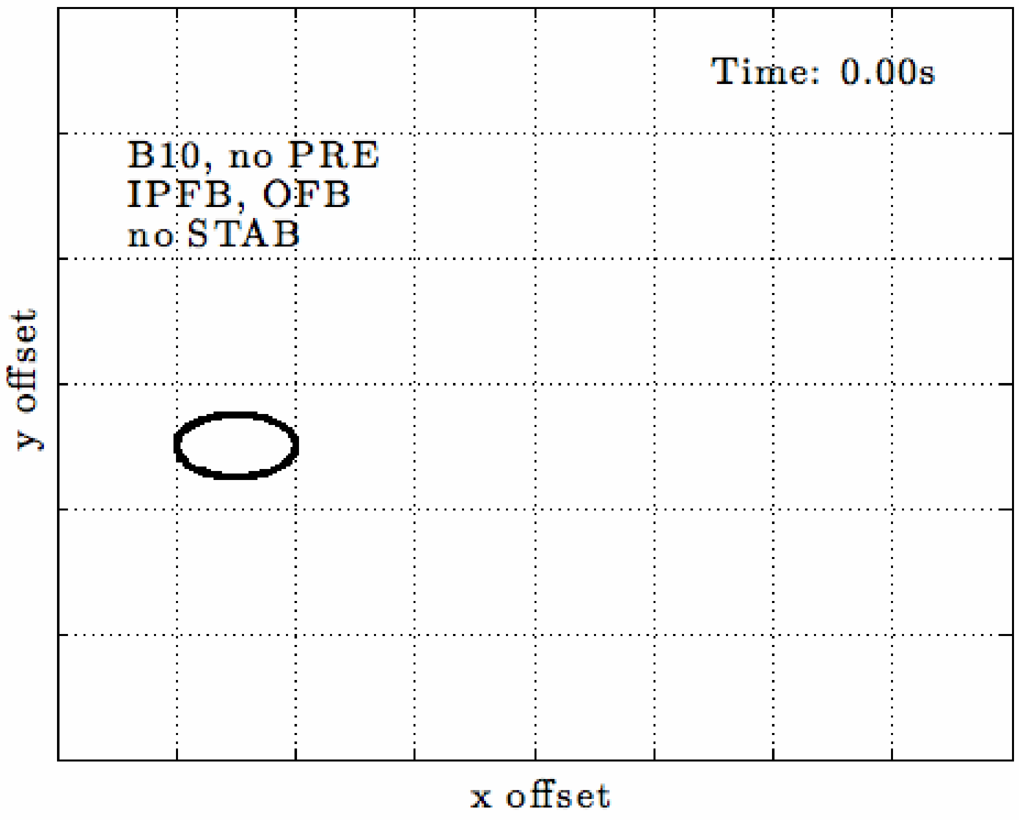
$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \boxed{\frac{1}{\sigma_y}}$$



J. Pfingstner

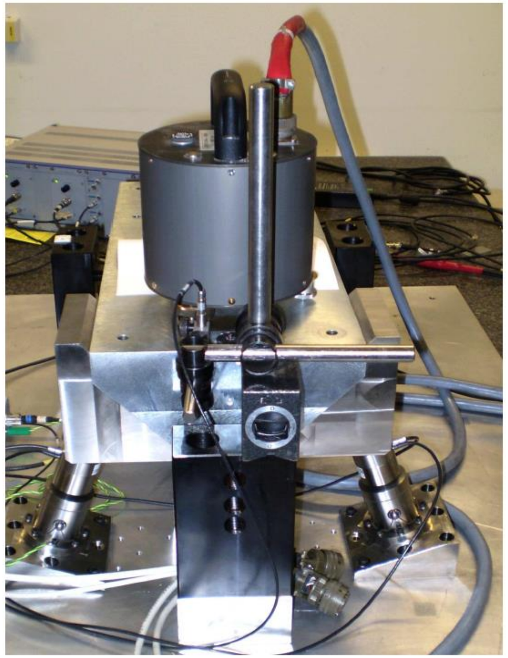
Beams at Collision

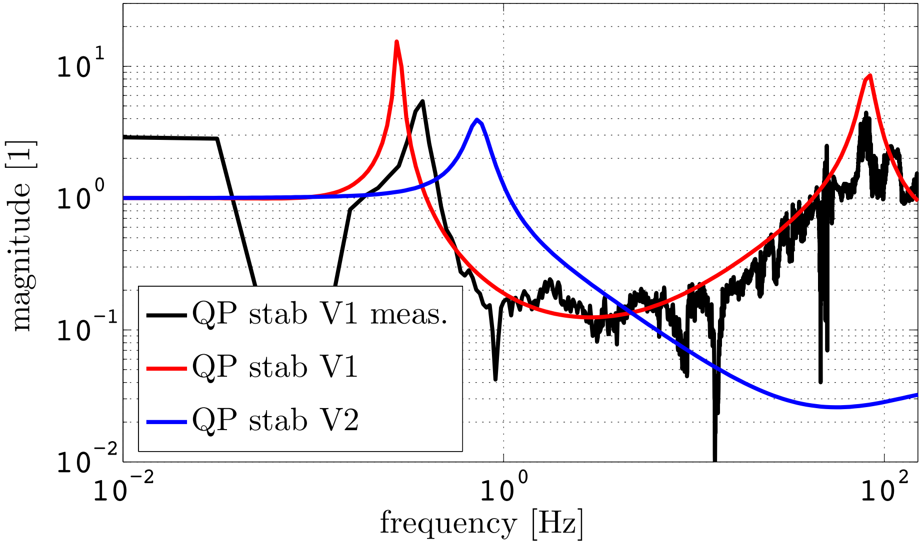
$$\mathcal{L} \propto H_D \, \frac{N}{\sigma_x} \, N n_b f_r \boxed{\frac{1}{\sigma_y}}$$



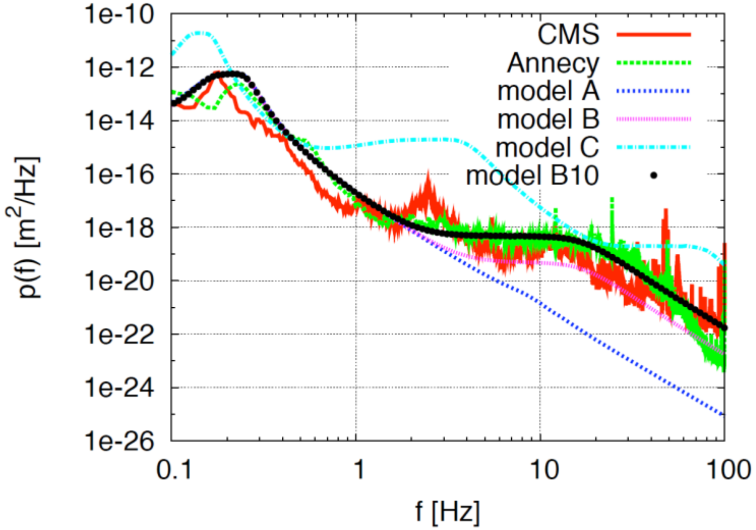
J. Pfingstner

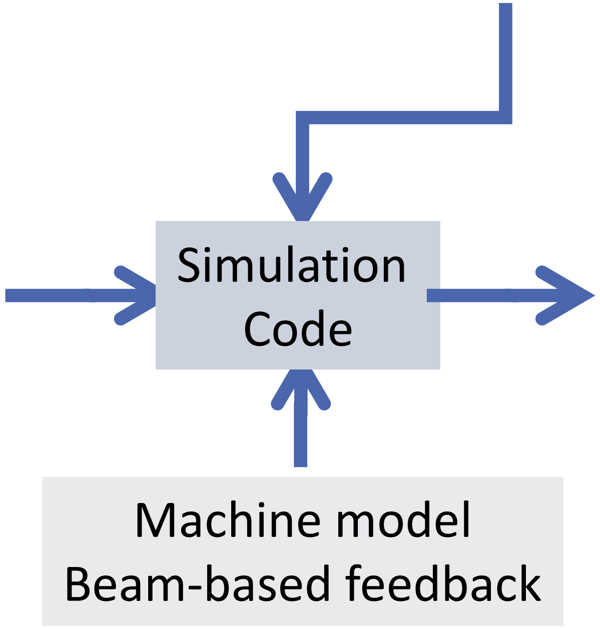
Stabilization System





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





Simulation Code

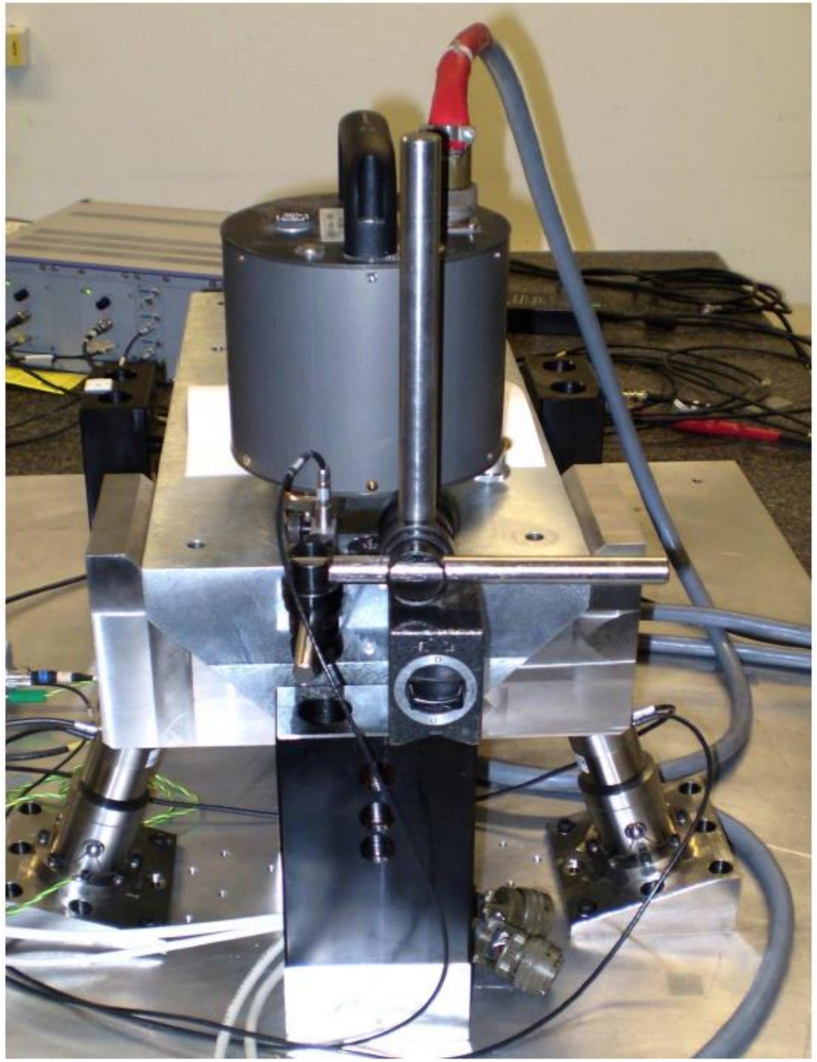
Machine model
Beam-based feedback

Luminosity achieved/lost

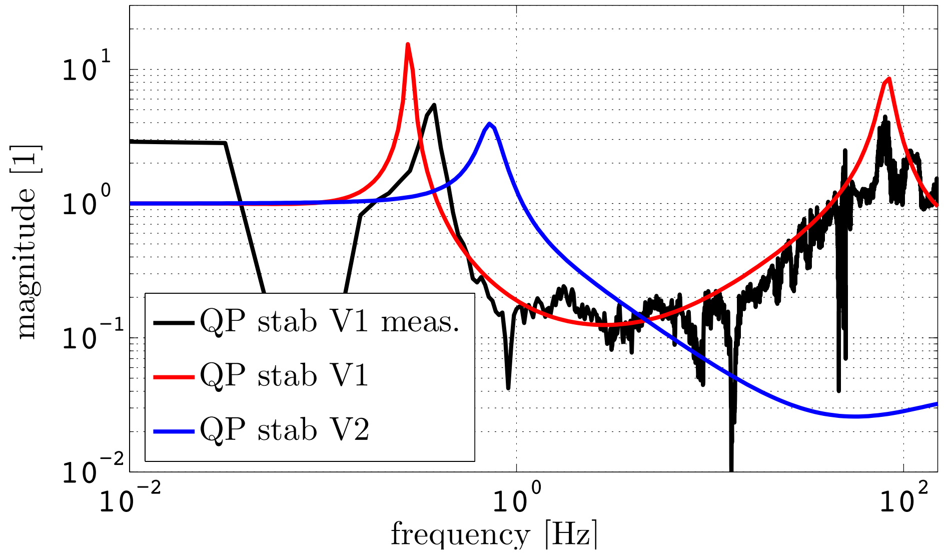
	B10
No stab.	53%/68%
Current stab.	114%/7%
Future stab.	118%/3%

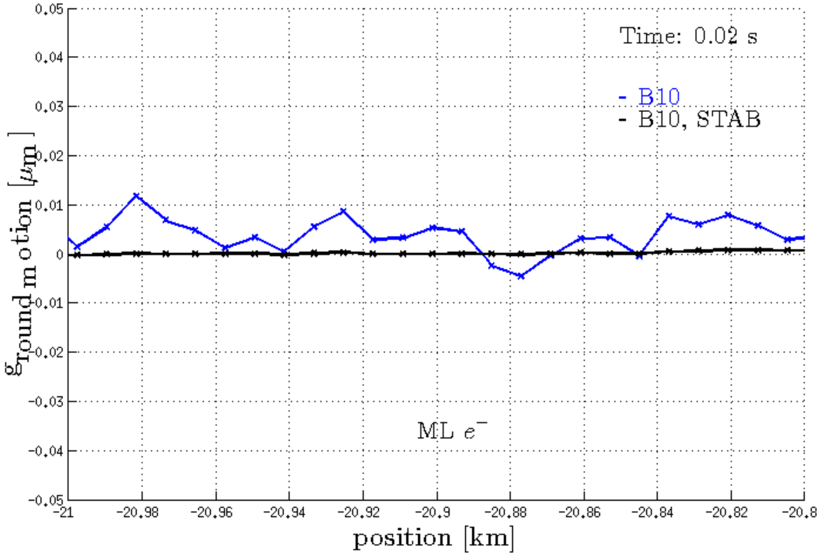
Close to/better than target

Stabilisation System



K. Artoos et al.

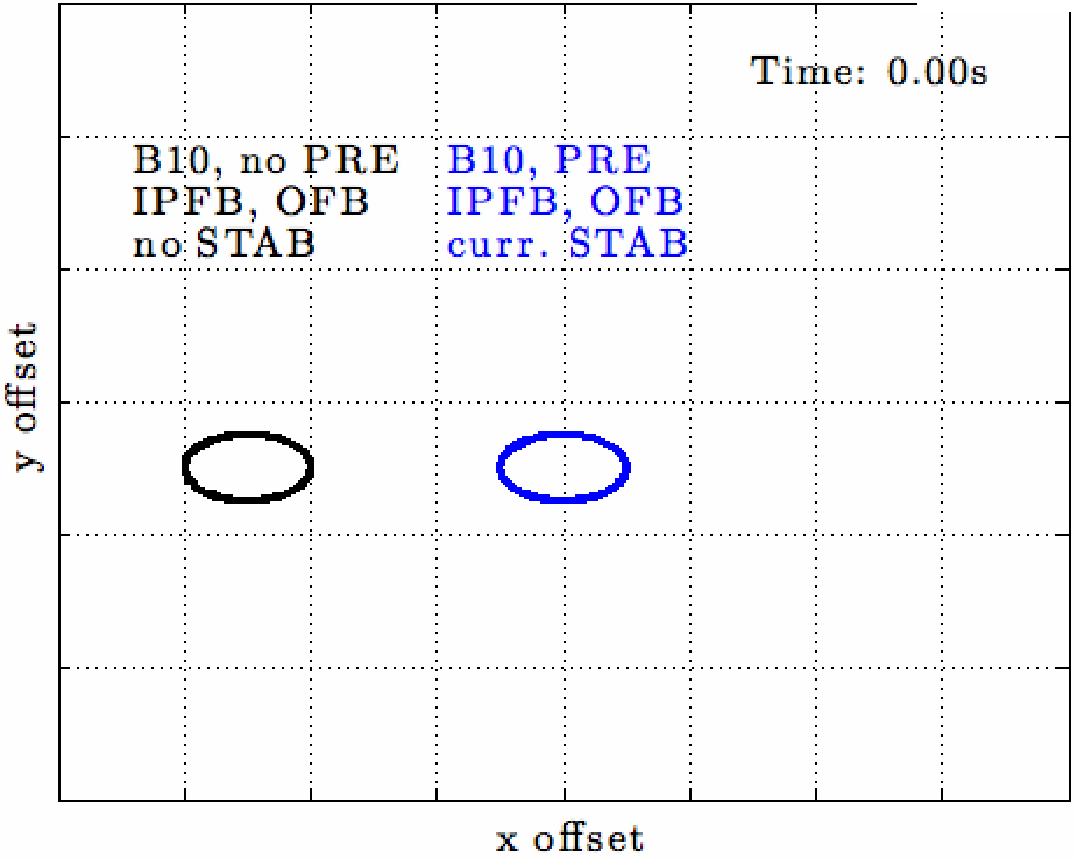




J. Snuverink, et al.

Beam at Collision

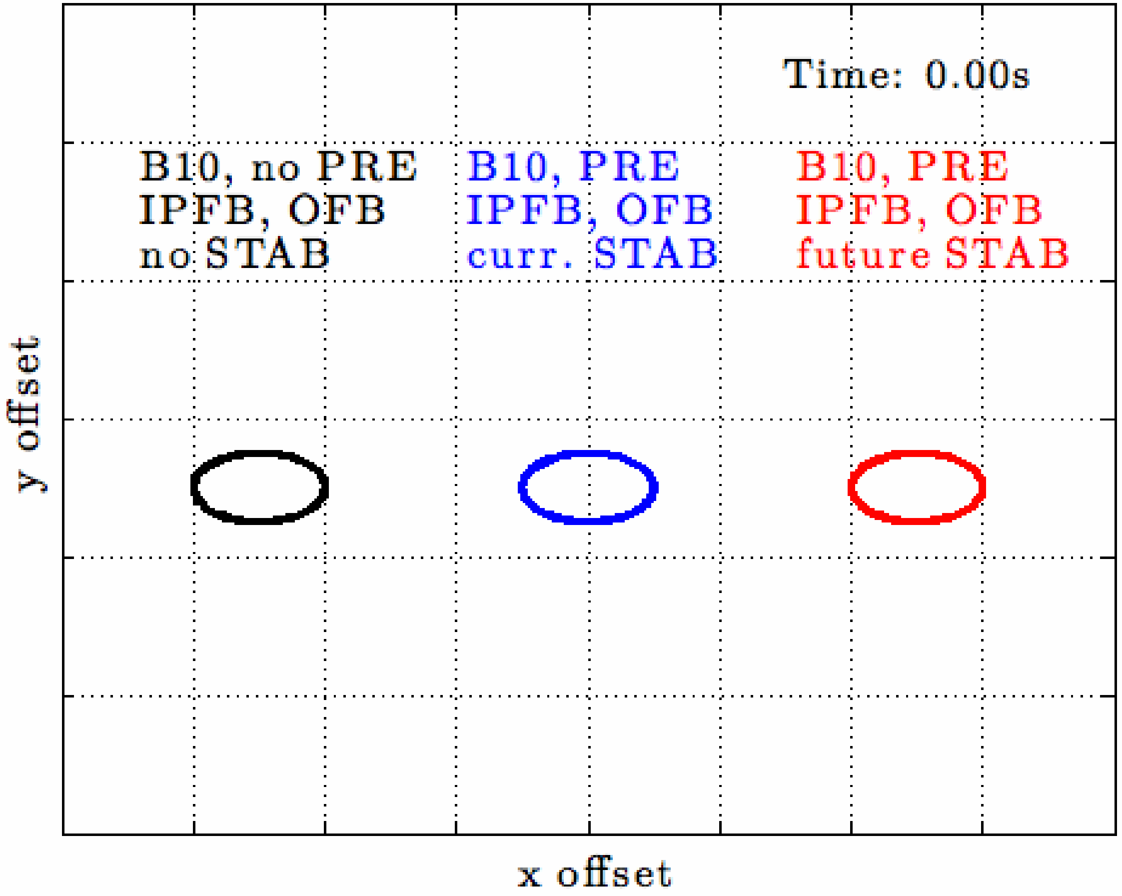
$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \boxed{\frac{1}{\sigma_y}}$$



J. Pfingstner

Beam at Collision

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



J. Pfingstner

Beam size and stability studies: ATF2 (KEK)

Goals of ATF2 project

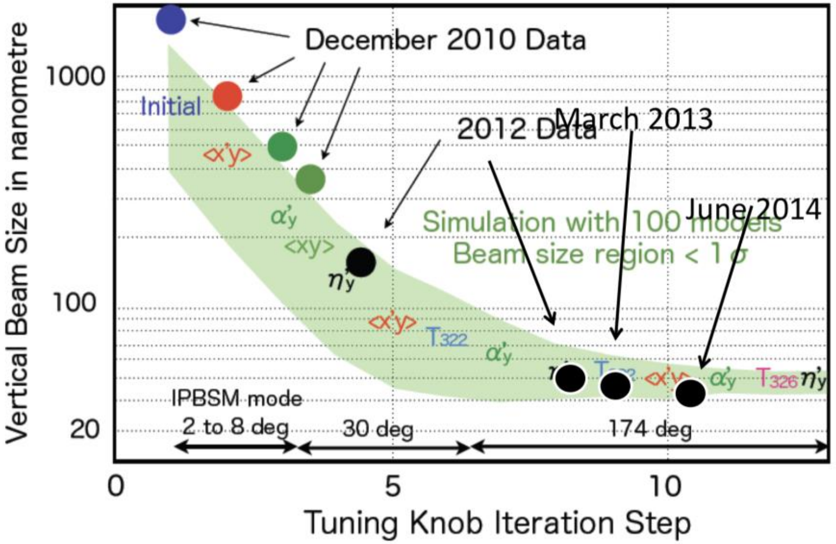
Goal1: Produce and Confirm Small Beam Size

- 37 nm (sigma) (Emittance 12 pm, beta* 0.1 mm)
- Single bunch

Goal2: Produce and Confirm Stable Beam

- 2 nm RMS position jitter at focal point (As required in ILC Interaction Point)
  - Tail bunch(es) in multi-bunch beam with fast feedback.

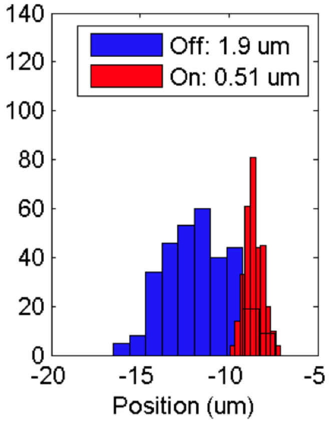
History of minimum beam size in ATF2



Common ILC/CLIC experimental activity

Measured beam jitter, tipically ~20% of rms beam size

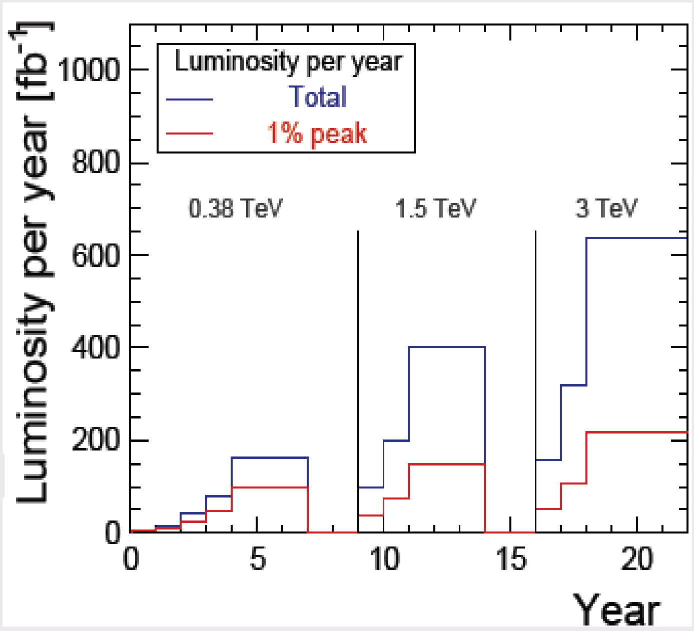
Intra pulse feedback results



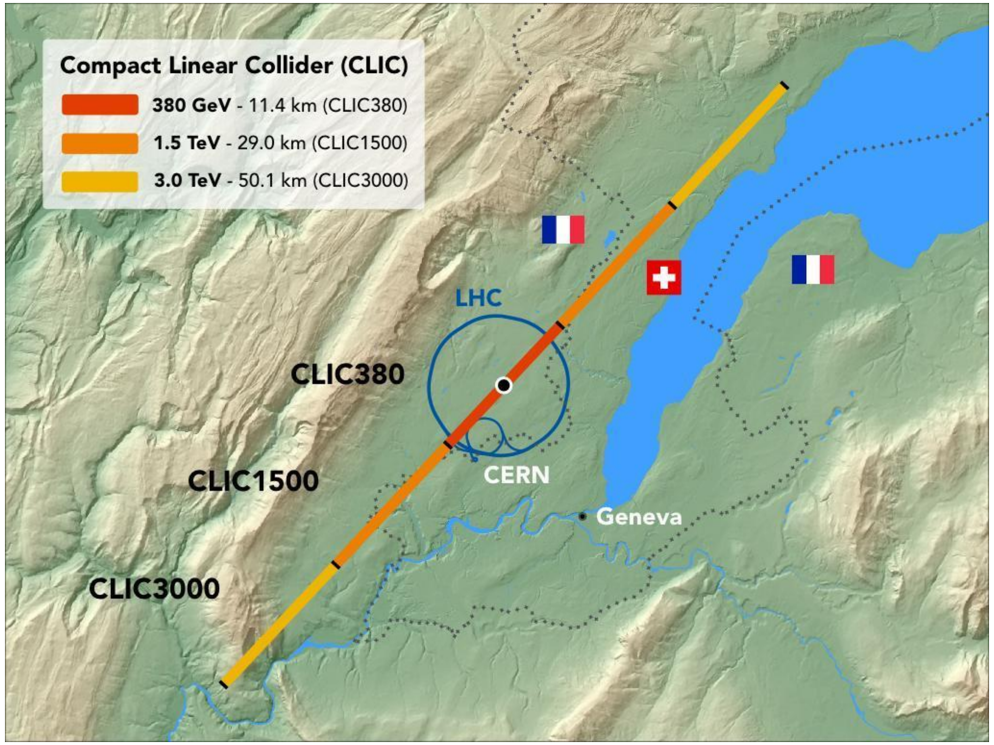
CLIC Staged Construction

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

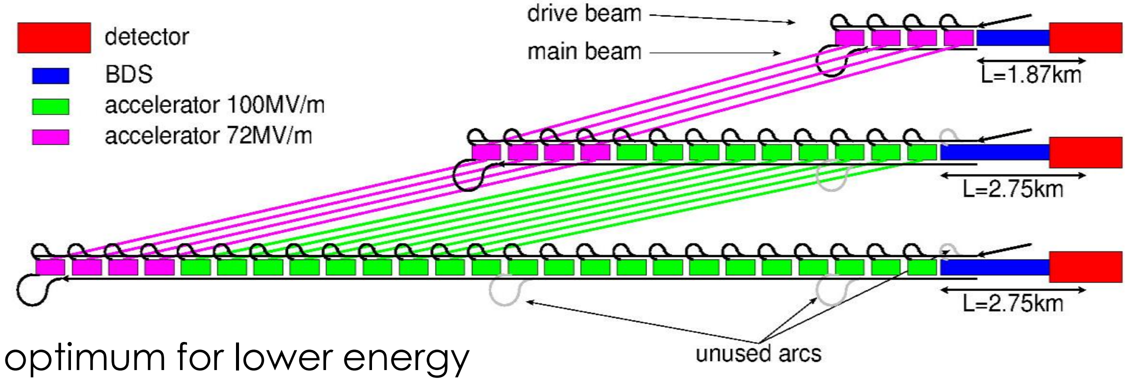
Luminosity targets from Physics Study group
Hopefully input from LHC



Luminosity evolution

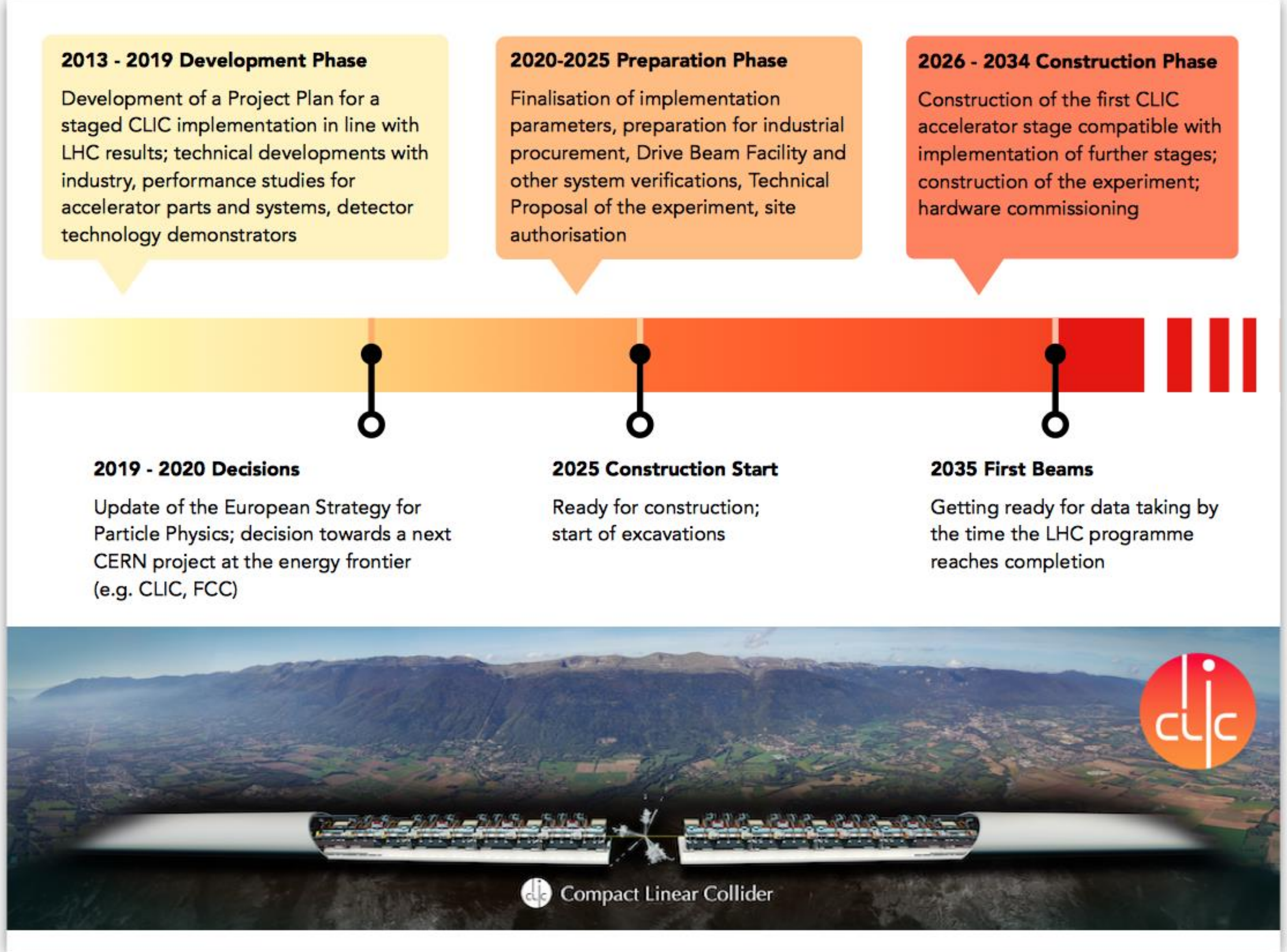


Central complex on Prevessin site



Lower gradient optimum for lower energy

CLIC Timeline



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)

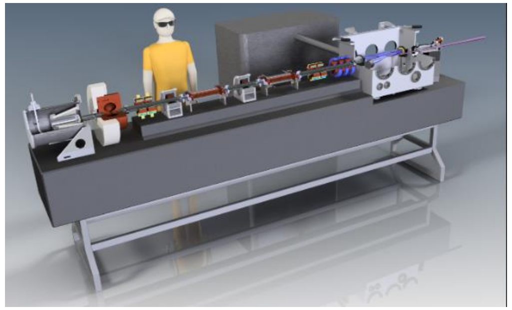
2025 Construction Start

Ready for construction; start of excavations

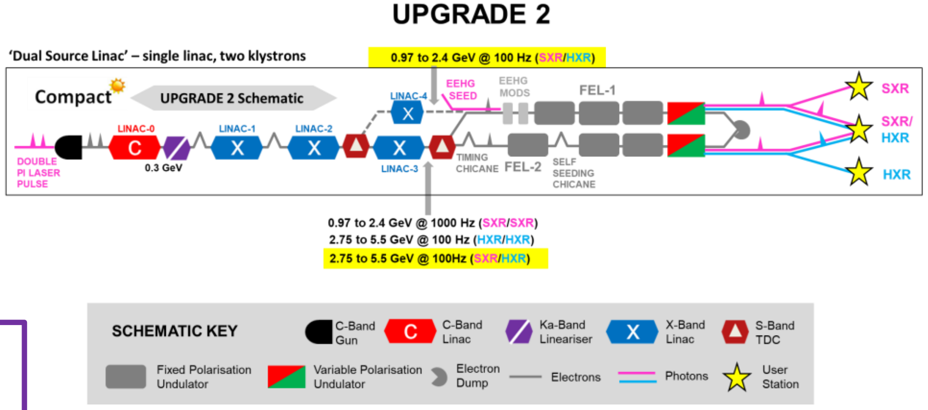
2035 First Beams

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

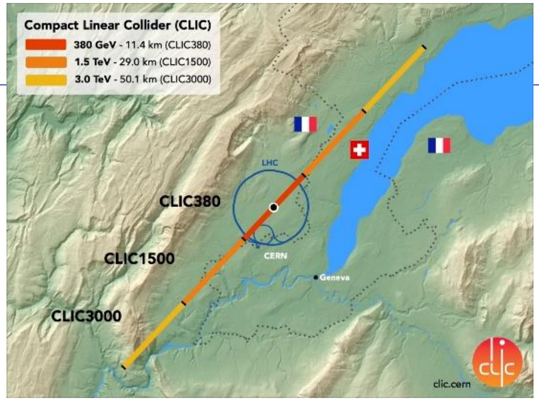
X-band and high-gradient applications overview



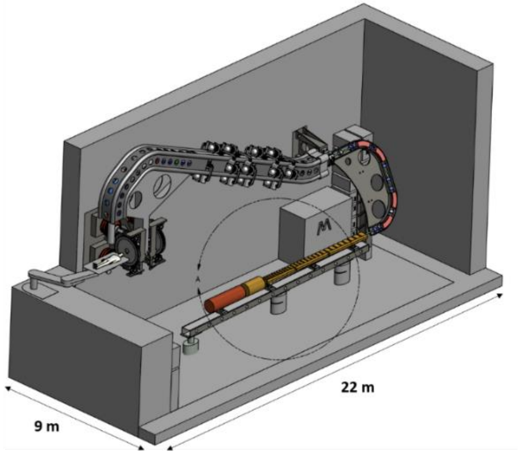
Light source - Inverse Compton Scattering Source



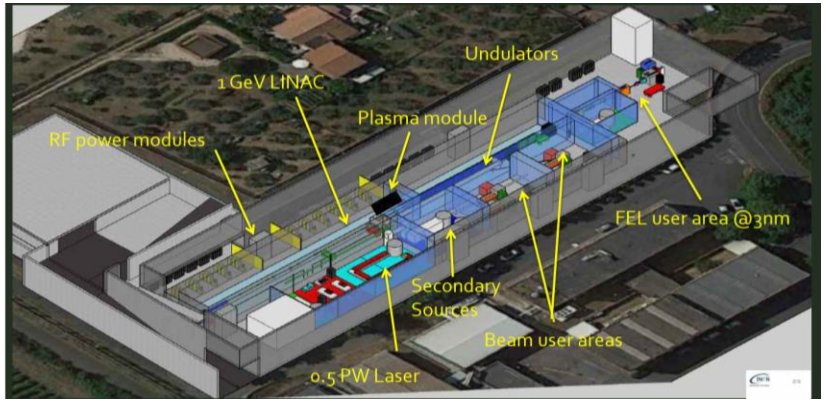
Light source - XFEL



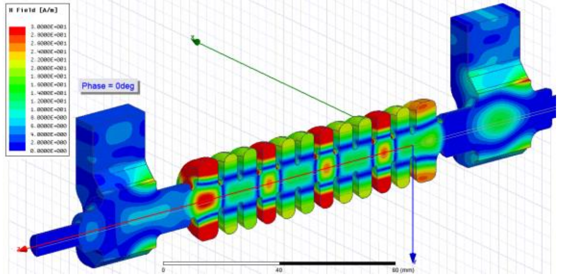
Linear collider

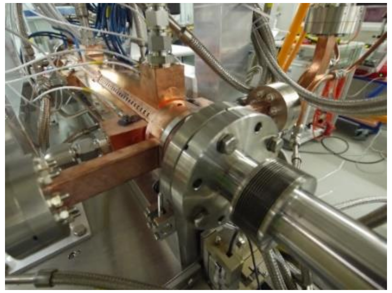


Medical applications



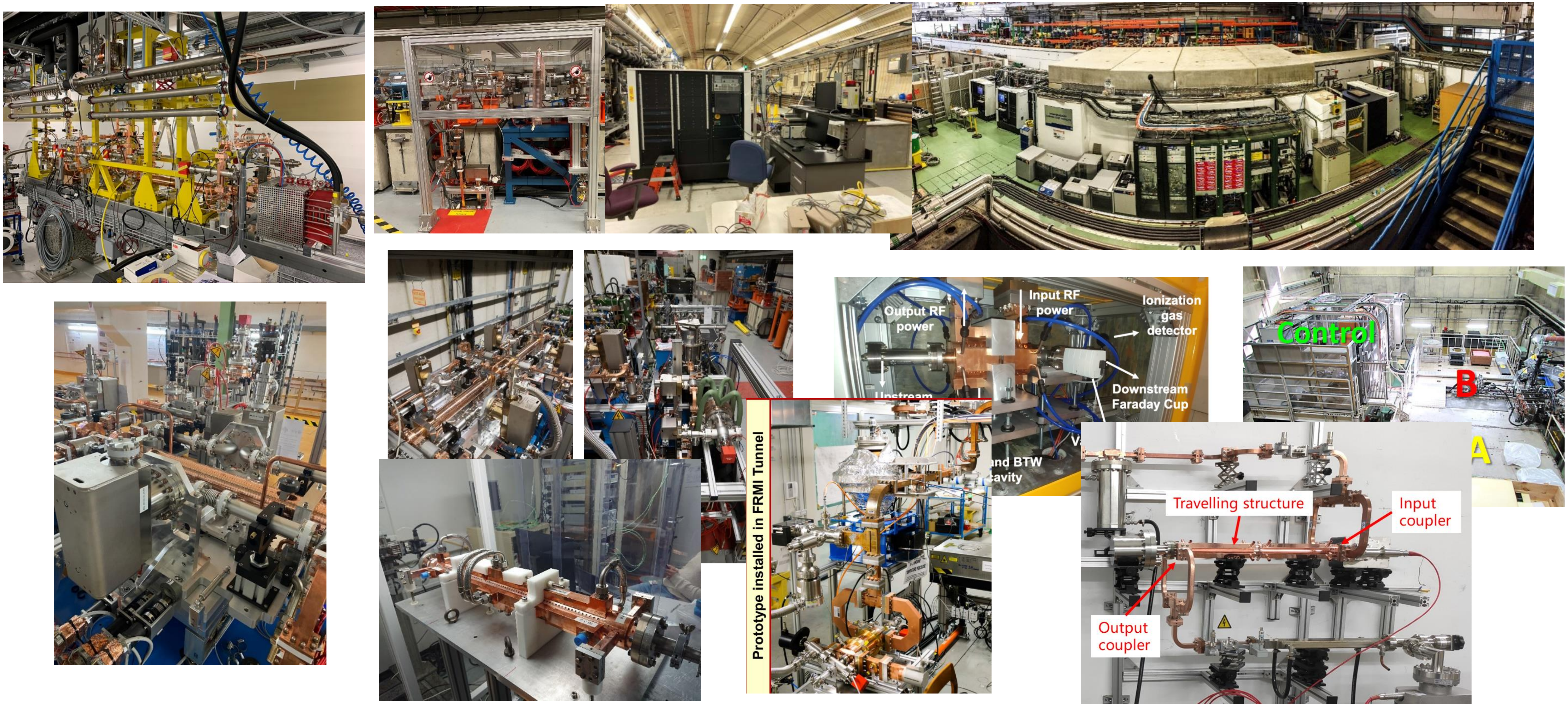
GeV-range research linacs





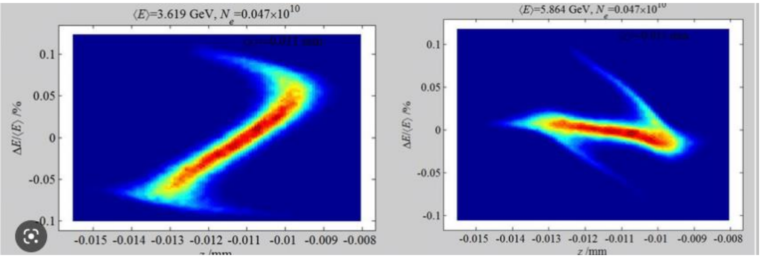
Beam manipulation

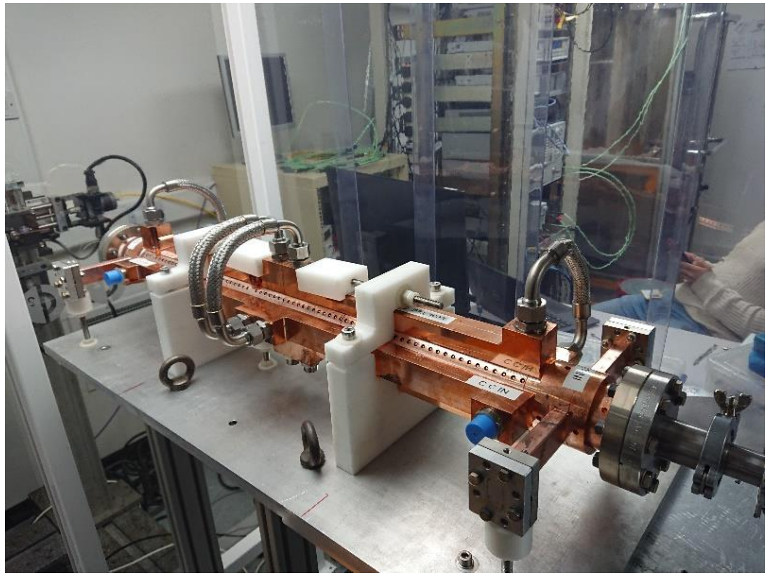
X-band and high-gradient infrastructure worldwide

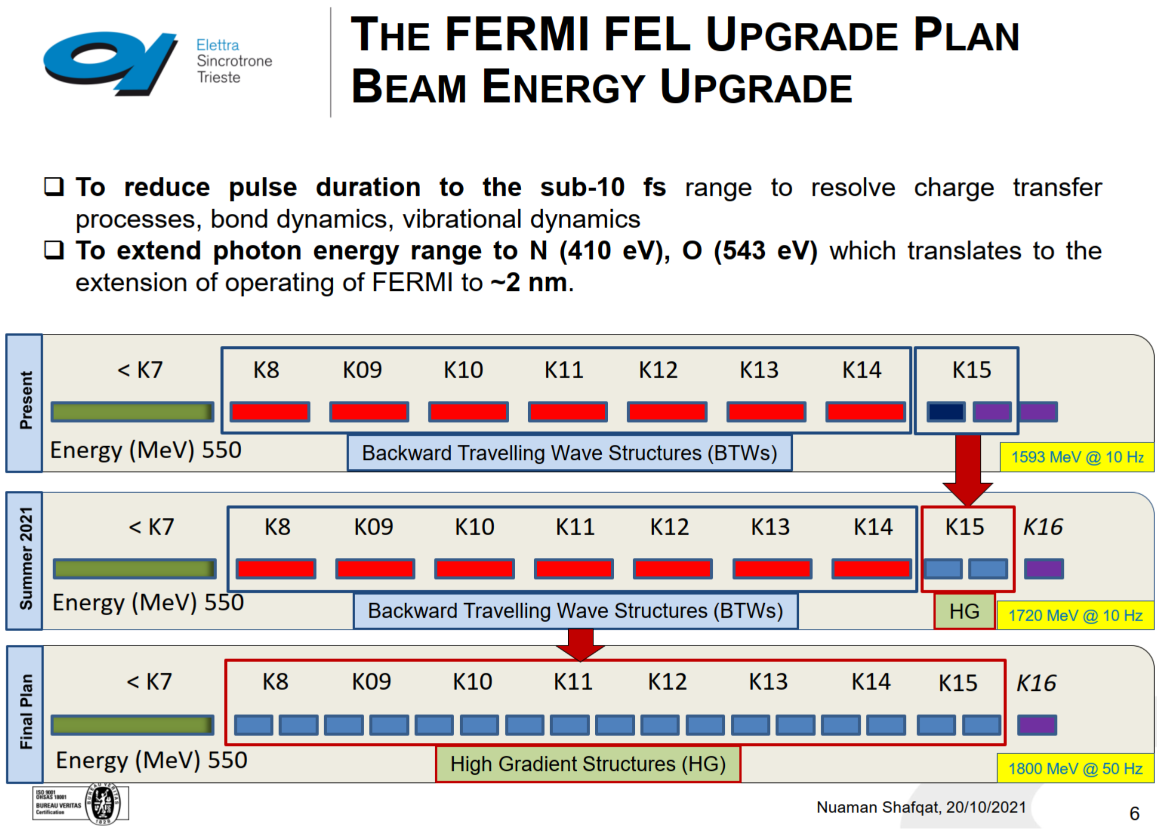


X-band in light sources

Phase space linearizers:
12 GHz natural harmonic for this application.
FERMI (Trieste), Swis FEL (PSI), SLAC, CLARA







Elettra Sincrotrone Trieste

THE FERMI FEL UPGRADE PLAN
BEAM ENERGY UPGRADE

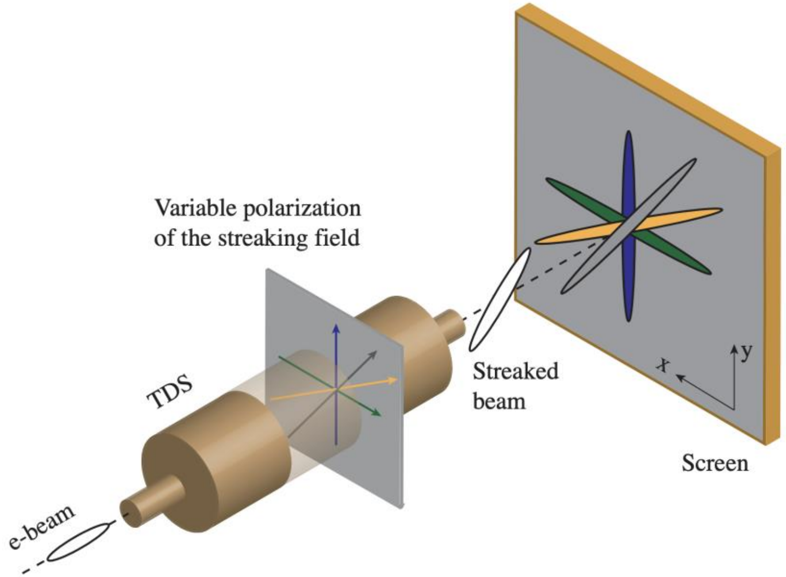
- ☐ **To reduce pulse duration to the sub-10 fs** range to resolve charge transfer processes, bond dynamics, vibrational dynamics
- ☐ **To extend photon energy range to N (410 eV), O (543 eV)** which translates to the extension of operating of FERMI to **~2 nm**.

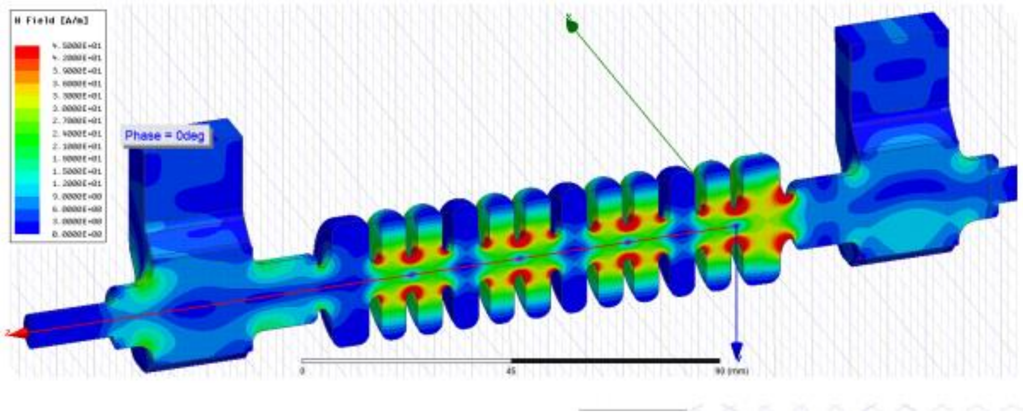
Nuaman Shafqat, 20/10/2021

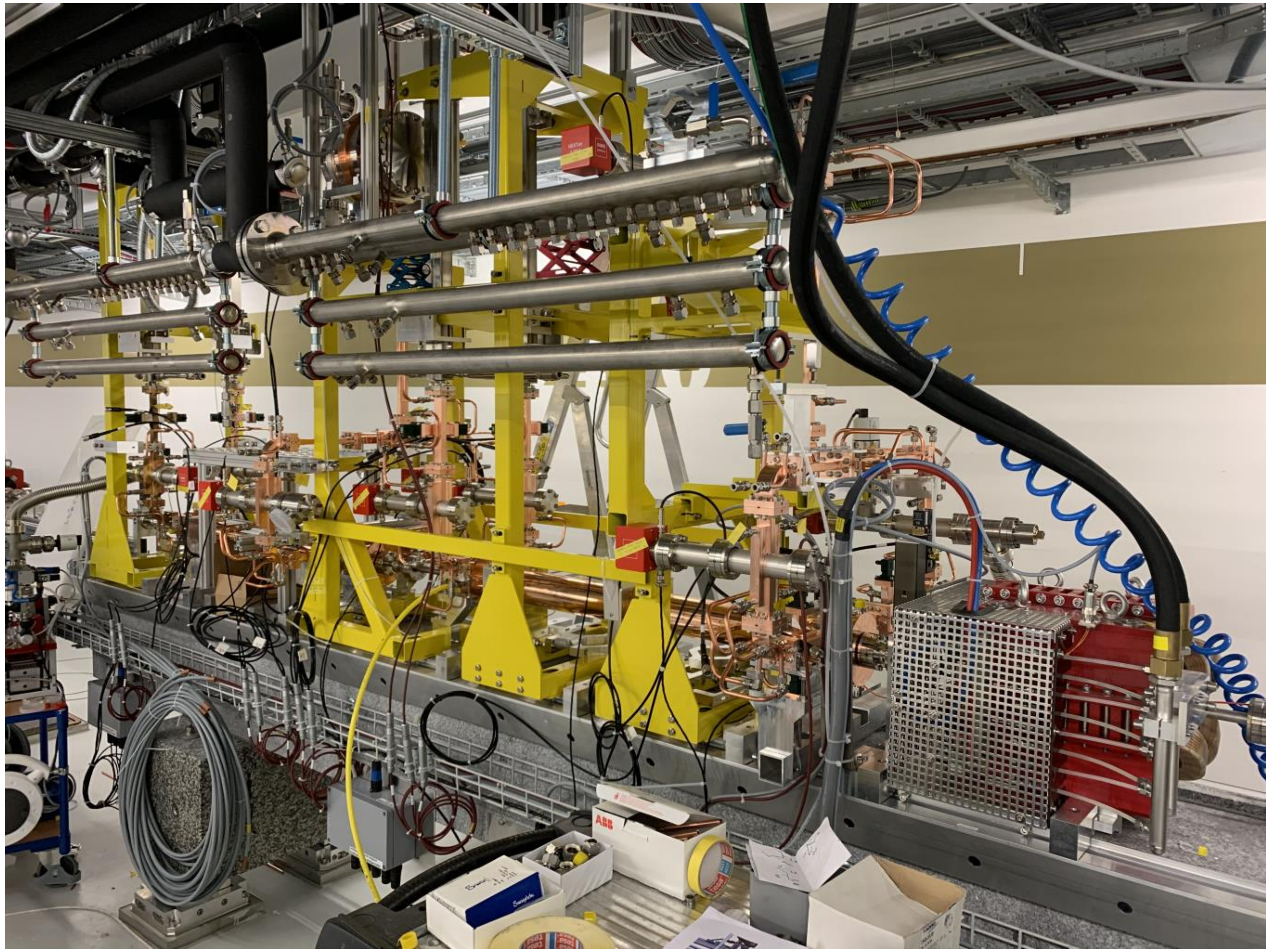
6

Transverse deflecting structures (PolariX)

Installations at PSI and DESY





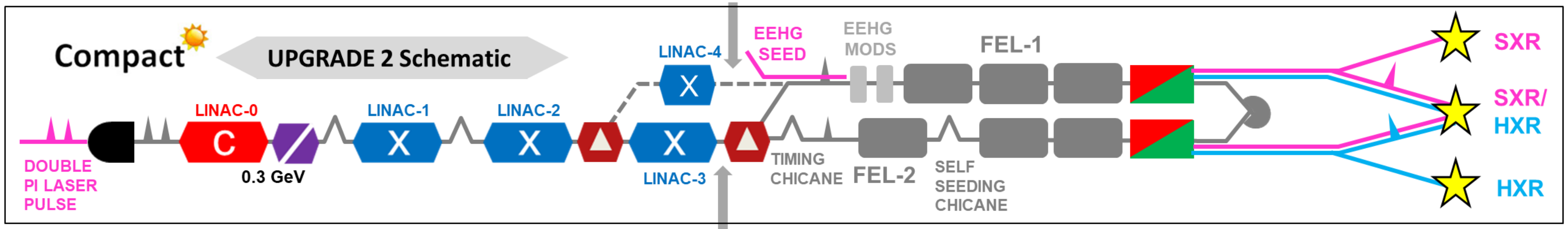


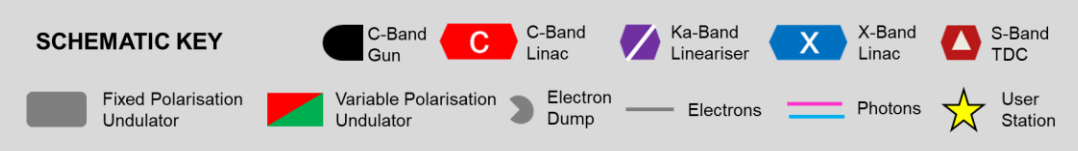
Compact, less power, better resolution

X-ray Free Electron Laser – CompactLight

'Dual Source Linac' – single linac, two klystrons

0.97 to 2.4 GeV @ 100 Hz (SXR/HXR)





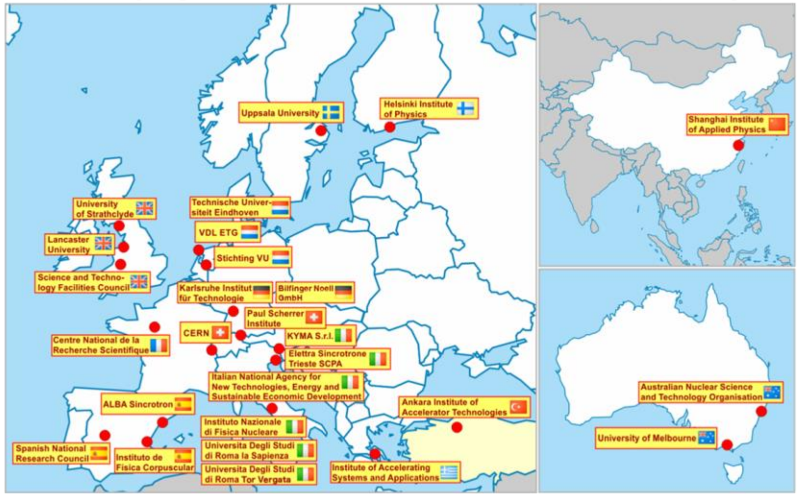
0.97 to 2.4 GeV @ 250 Hz (SXR/SXR)
2.75 to 5.5 GeV @ 100 Hz (HXR/HXR)

or 0.97 to 2.4 GeV @ 1000Hz (SXR/SXR) if UPGRADE 1 complete
or 2.75 to 5.5 GeV @ 100Hz (SXR/HXR)

CompactLight is a compact, low-cost XFEL based on X-band technology and advanced undulators.
Flexible, multi mode operation with hard X-rays at 100 Hz and soft at 1 kHz.
Dual bunch for pump-probe experiments.
EU funded design study with 26 collaborating institutes.

CompactLight@elettra.eu

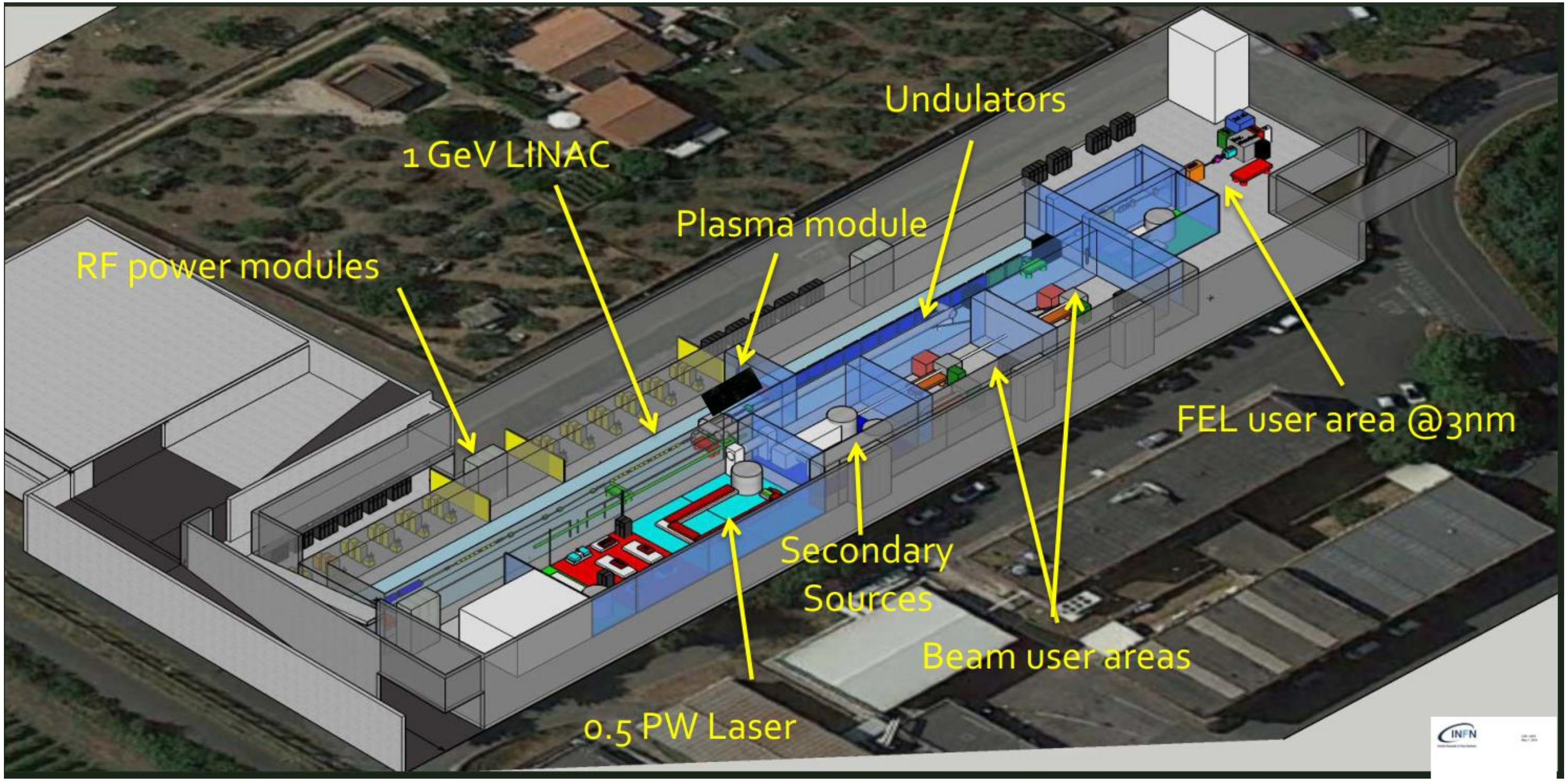
www.CompactLight.eu



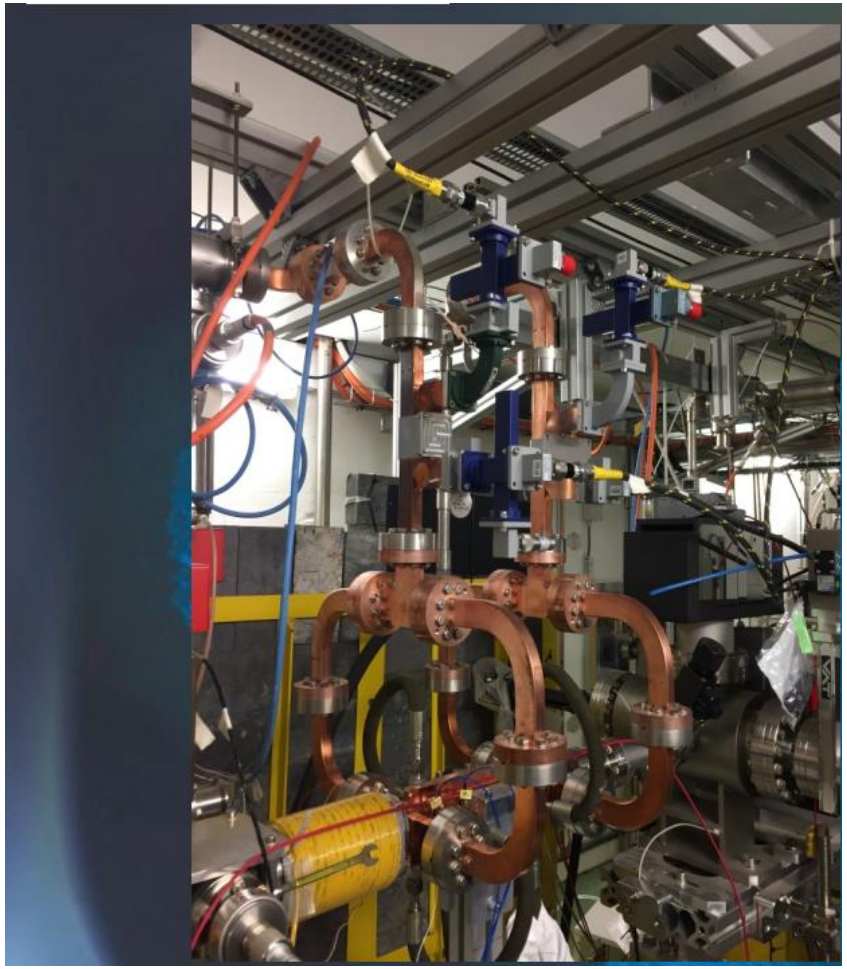
CompactLight is funded by the European Union's Horizon2020 research and innovation programme under Grant Agreement No. 777431.

EuPraxia@SPARC_LAB

Combining 1 GeV x-band linac with beam driven plasma wake field acceleration

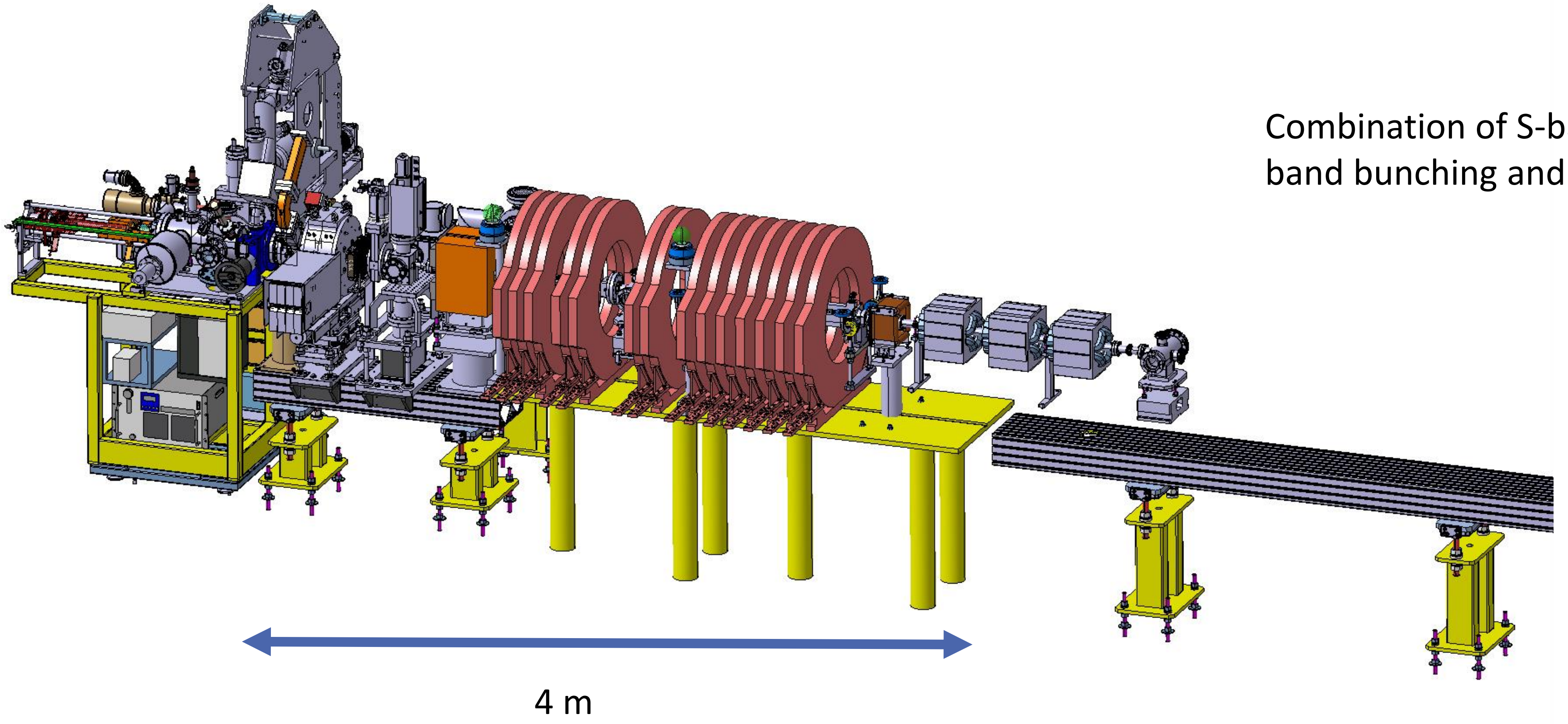


EuPraxia@SPARC_LAB



Building up infrastructure and new accelerating structure designs

Injector prototype in CTF2 for CLEAR and AWAKE



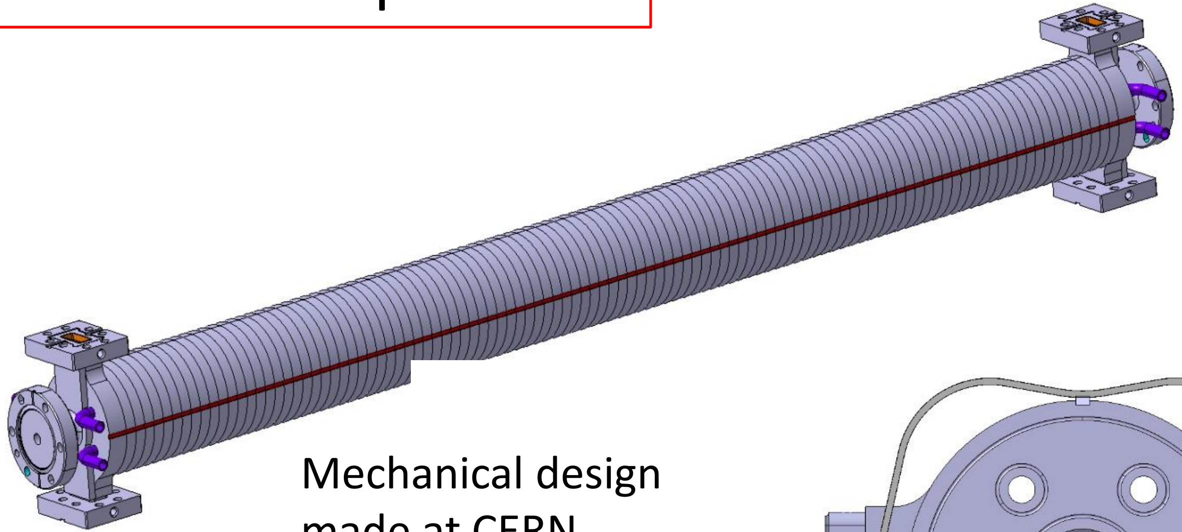
Combination of S-band RF-gun and X-band bunching and acceleration

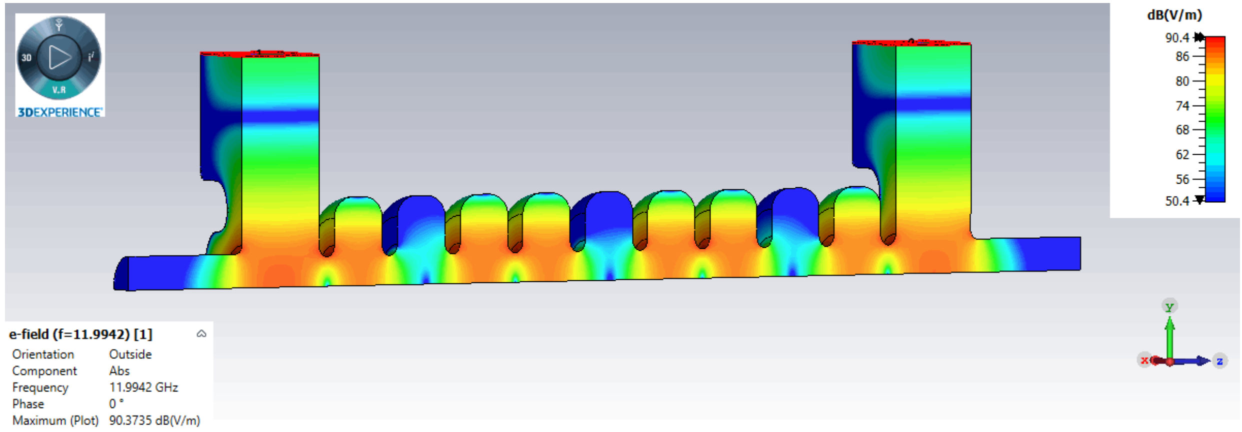
Reduced scale prototype, 60 MeV, T24 as buncher and PSI-linearizing structure for acceleration.
Goal: demonstrate the velocity bunching and emittance preservation with x-band
Prototyping of key hardware

X-band structure developments

Travelling wave Constant Impedance

Shunt Impedance [MΩ/m]	100
Group Velocity vg/c [%]	2.4
Q-Factor	7061
Attenuation [1/m]	0.7
Length [m]	0.9



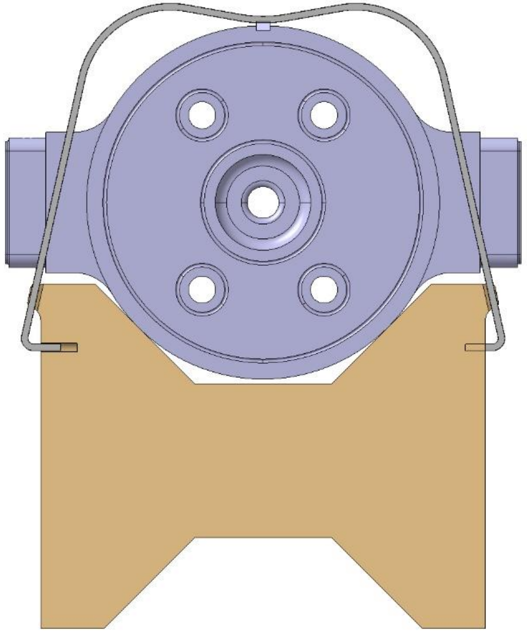


e-field (f=11.9942) [1]
Orientation Outside
Component Abs
Frequency 11.9942 GHz
Phase 0 °
Maximum (Plot) 90.3735 dB(V/m)

Mechanical design made at CERN

CLIC style tolerances
Vacuum brazing design

Structure to be inserted in a solenoid of 150 mm diameter bore radius

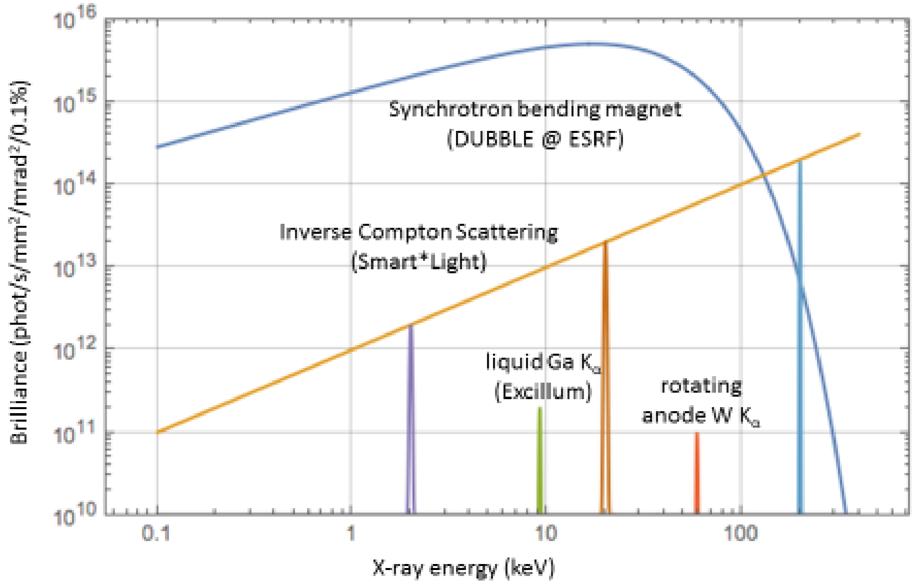


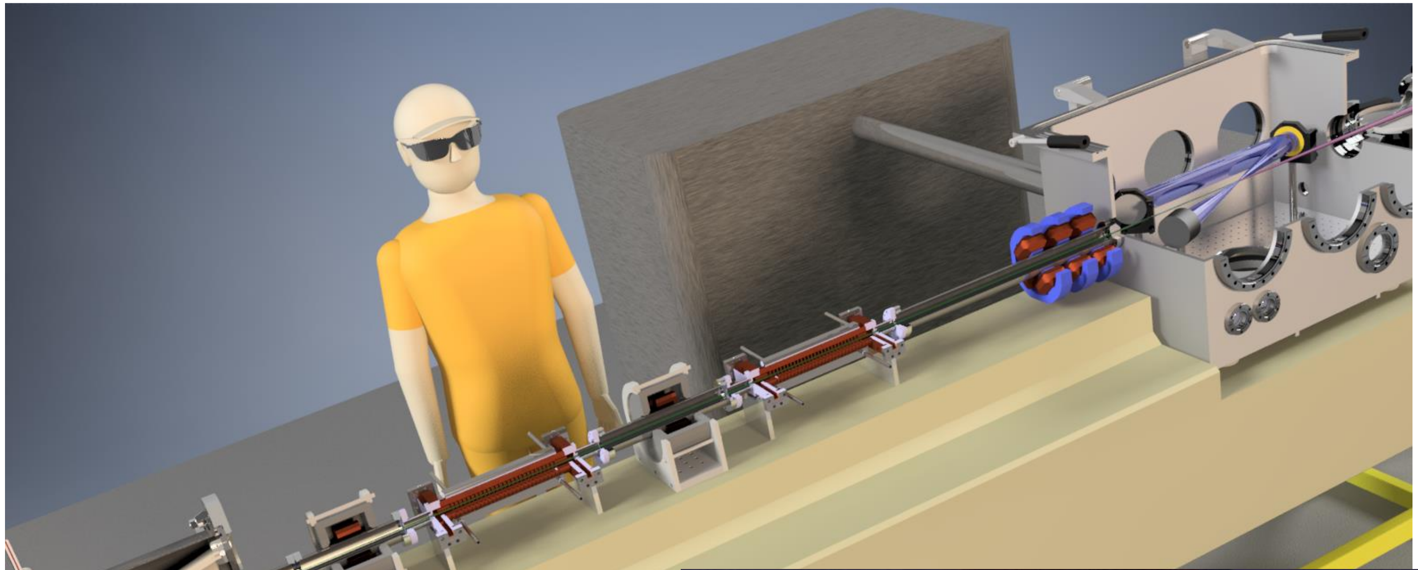
Designed by INFN Frascati, D. Alesini, M. Diomede,
for CompactLight and EuPraxia

Inverse Compton Scattering Source – Smart*Light

Compact, highly monochromatic X-ray source based on 50-100 MeV electron beam.
Complementary to X-ray tube and synchrotron light source.
Applications in cultural heritage, material science, medical, etc.

Brilliance





J. Luiten, TU/e
Eindhoven

Smart*Light: a linear-accelerator-based ICS source

Smart Light collaboration funded by EU Interreg

Interreg Vlaanderen-Nederland

Europees Fonds voor Regionale Ontwikkeling

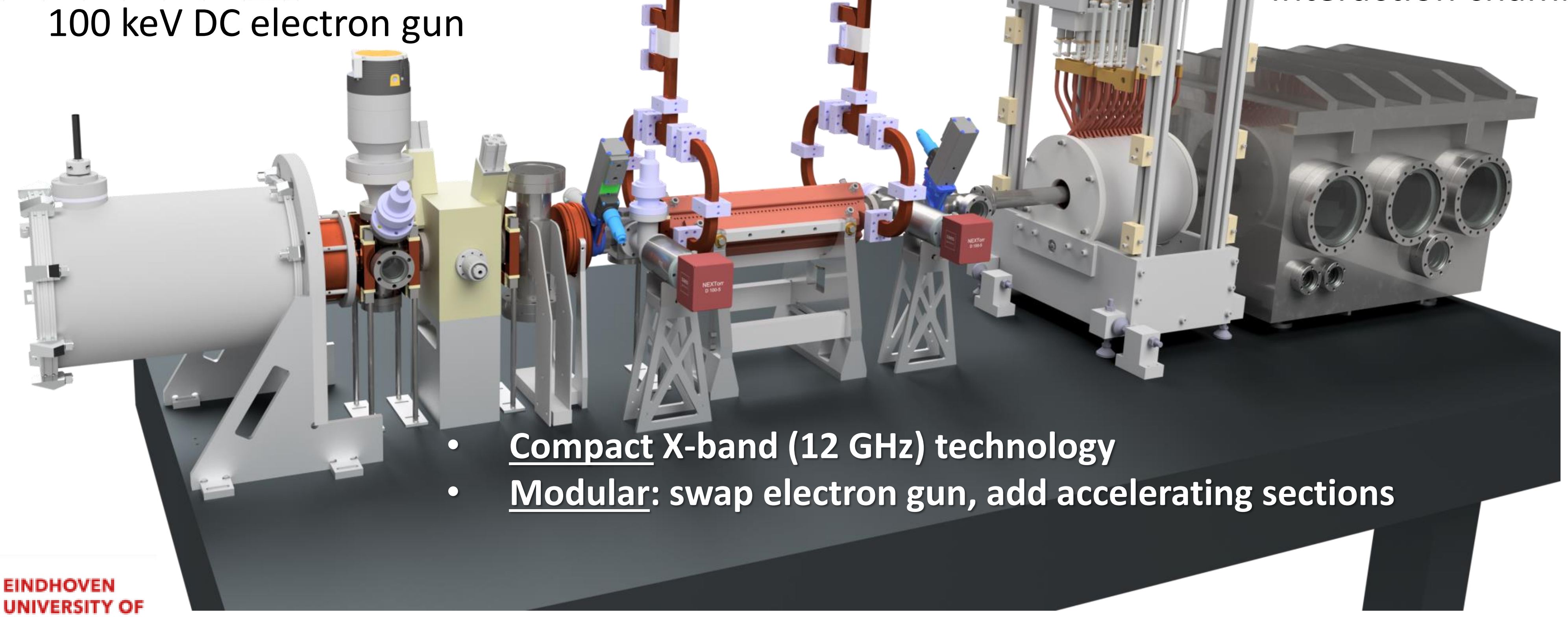
3 Seminar INFN Milano, 7 May 2021

TU/e

50-cell, 30 MeV X-band accelerator

100 keV DC electron gun

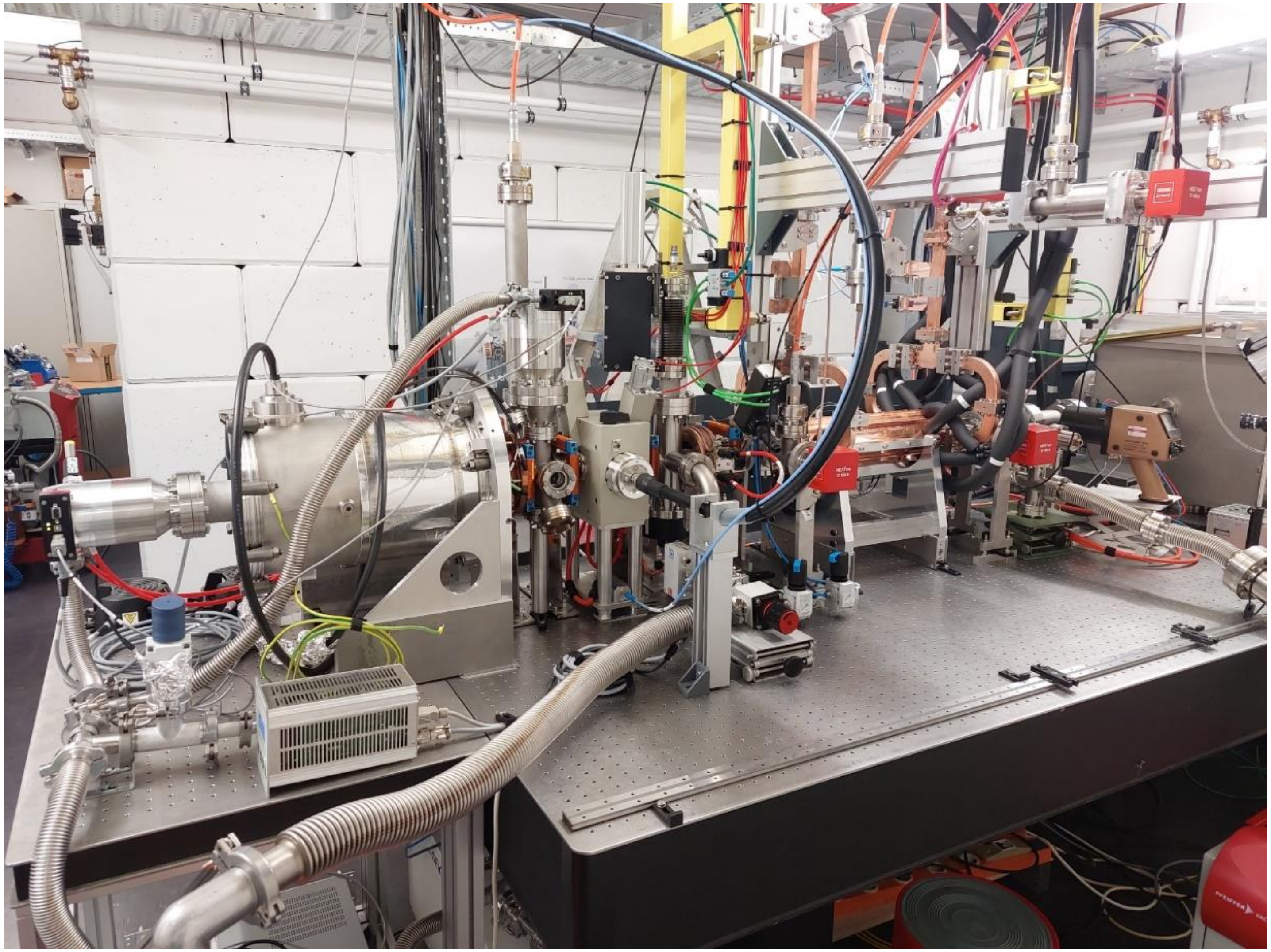
Interaction chamber



- Compact X-band (12 GHz) technology
- Modular: swap electron gun, add accelerating sections

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Smart*Light: a linear-accelerator-based ICS source



Under commissioning

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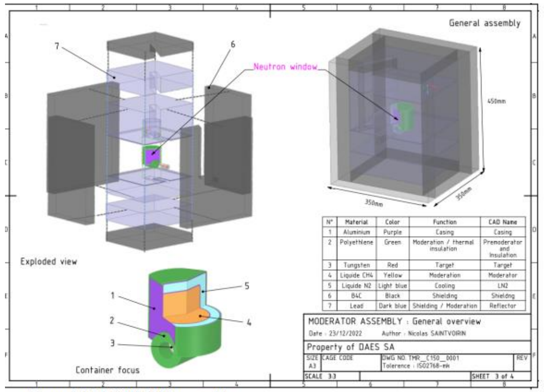
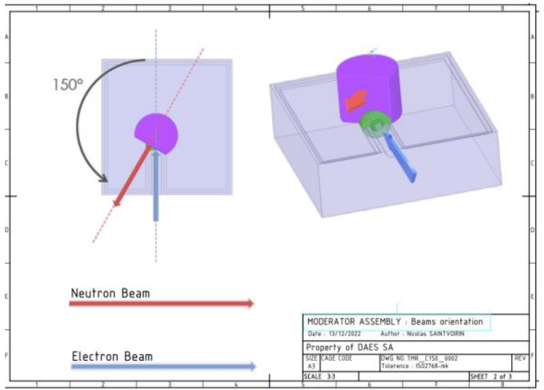
Ultra Compact Neutron Source for material testing



N°	Material	Color	Function	CAD Name
1	Aluminium	Purple	Casing	Casing
2	Polyethlene	Green	Moderation / thermal insulation	Premoderator and Insulation
3	Tungsten	Red	Target	Target
4	Liquide CH4	Yellow	Moderation	Moderator
5	Liquide N2	Light blue	Cooling	LN2
6	B4C	Black	Shielding	Shieldng
7	Lead	Dark blue	Shielding / Moderation	Reflector

Figure 1. VULCAN TMR assembly.



Development of a turn-key industrial compact neutron source for material testing.

Initial tests will be performed with the CLEAR test accelerator at CERN.

Supported by the CERN Innovation Programme on Environmental Applications.
Important tool for future battery development

Parameter	Value	Unit
Electron energy	30 to 40	MeV
Peak Current	≥ 0.2	mA
Pulse duration	1 to 5	µs
Repetition rates	≥ 100	Hz

CIPEA
CERN Innovation Programme
on Environmental Applications

DAES

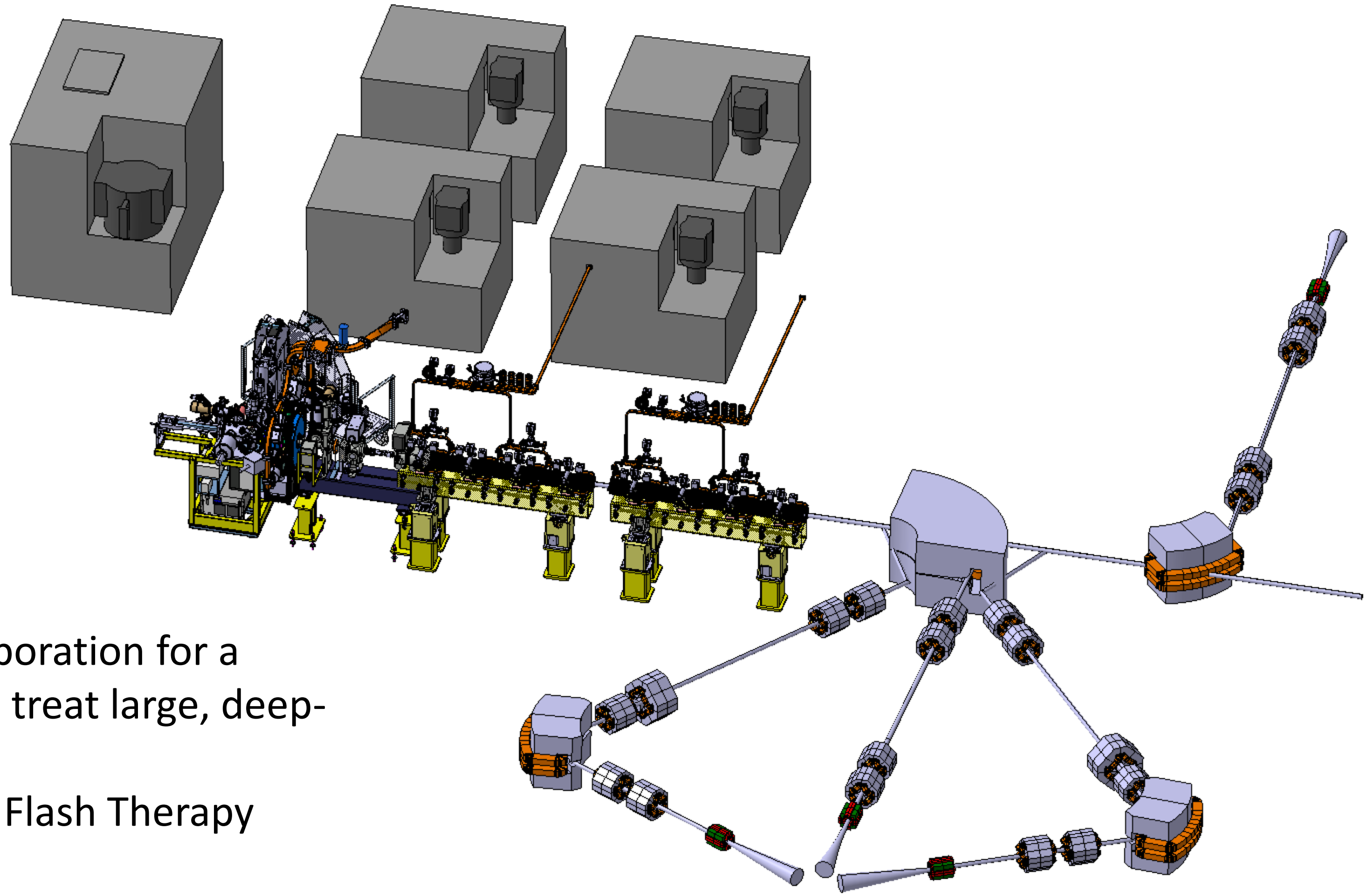
DANISH
TECHNOLOGICAL
INSTITUTE

xnovotech

Application of CLIC technology to cancer therapy

- A very hot topic in radiation oncology is so-called FLASH therapy which involves delivering an entire radiation treatment in a 1/10th of a second, as opposed to minutes as in conventional therapy.
- This fast delivery can reduce toxicity to healthy tissue while maintaining tumor control improving treatment
- Another trend in radiation oncology is a renewed interest in VHEE (Very High Energy Electron, range of 100 to 200 MeV) therapy. The main technique is based on X-Rays, but treatment is also done with protons.
- CLIC high-performance accelerator technology is extremely well adapted to realize such a clinical facility.

The DEFT Project



S-band photo injector
CLIC-like X-band accelerating modules

CHUV and CERN collaboration for a VHEE FLASH facility to treat large, deep-seated tumors.
DEFT – Deep Electron Flash Therapy

Taking VHEE *and* FLASH into the clinic.

Technology transfer to industry

Treatment from three directions in milliseconds

Summary

- CLIC
  - Given high priority by European strategy
  - Conceptual design for 3 TeV (CDR exists), feasibility demonstrated, many components developed, staged approach starting at 380 GeV, which will follow physics findings
  - Project implementation plan to be developed for 2019

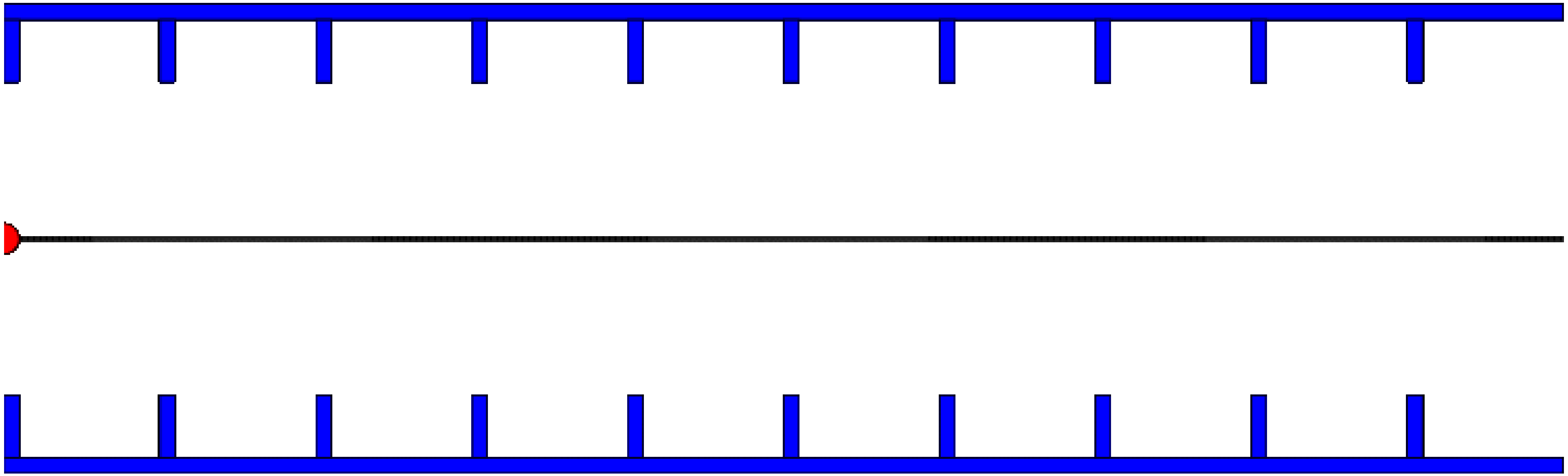
- Other possibilities
  - FCC-ee and FCC-hh
  - Plasma acceleration as long-term linear collider technology
  - LHeC
  - Muon collider
    - Cooling technology is still being explored, would be a long way to go

- CLIC is already having a great technological impact
  - X-band and related technologies developed by normal conducting collider projects are becoming increasingly attractive for small and medium scale accelerator applications. Compact and cost-effective solutions are possible.
  - This shows the maturity of the hardware developed originally for linear colliders
  - Excellent examples of "spin off" of developments in fundamental science.
    But as well important return to the high energy projects
  - Welcome reward for our community while waiting for the big linear collider

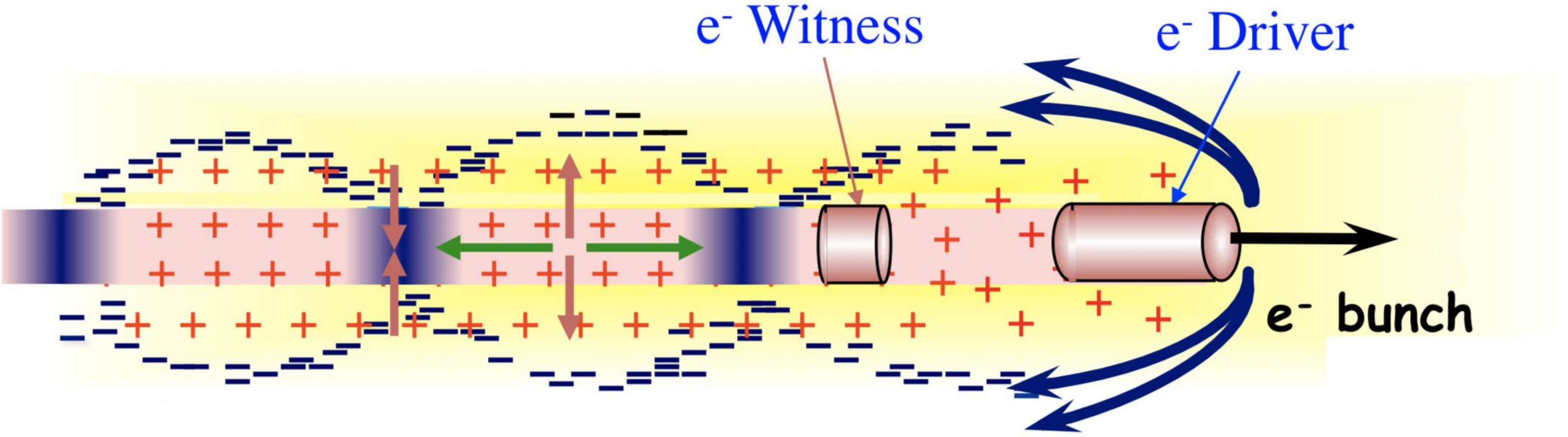
THANKS FOR YOUR ATTENTION

QUESTIONS?

Energy Recovery Principle



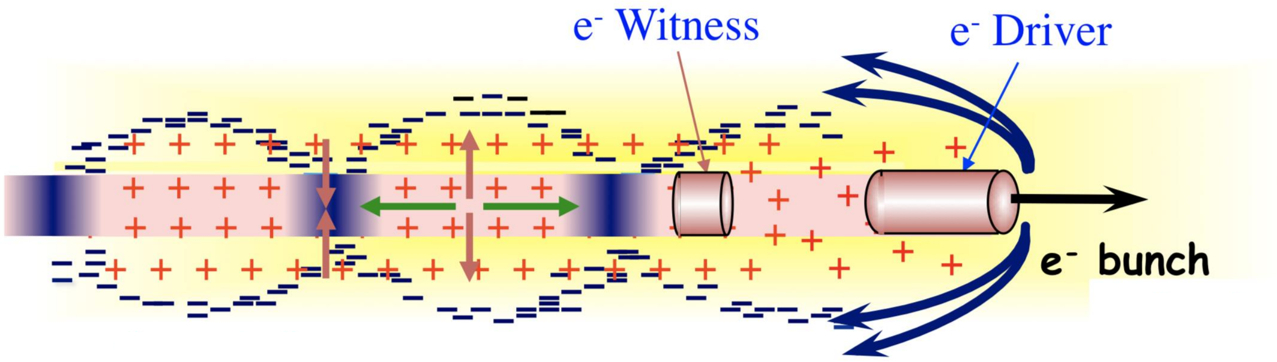
Note: Plasma Acceleration



Plasma can be generated by electron beam, proton beam or laser beam
Plasma can sustain large electrical fields

Plasma Collider Issues

- Practical solution for acceleration of positrons is missing
- Efficiency and beam quality has to be addressed



- Still need to derive parameters considering beam stability
  - E.g., plasma accelerator channel radius is factor 100 smaller than CLIC iris radius (20μm vs. 2.75mm)
  - Wake-fields scale about with a^{-4}
- Tolerances need to be worked out and addressed

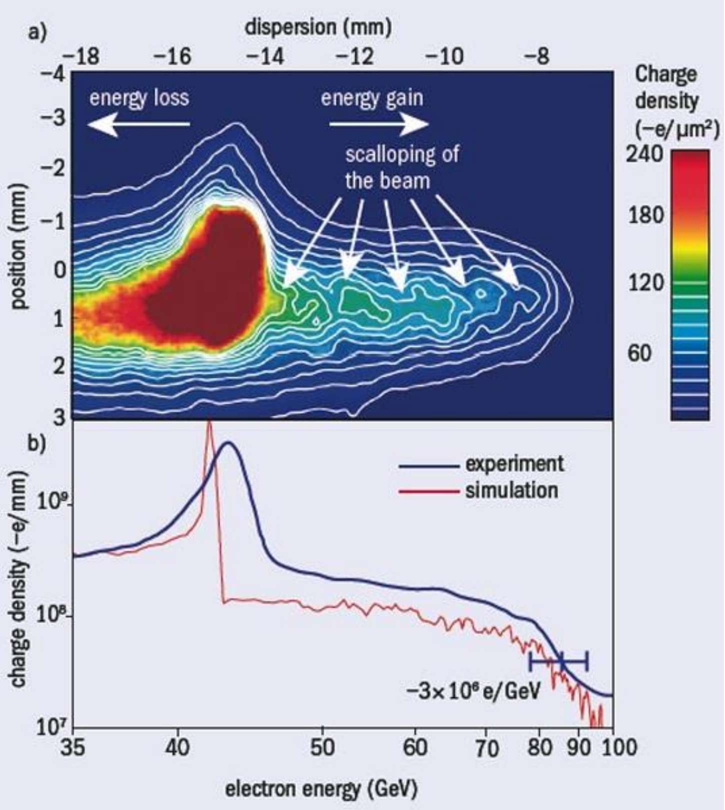
- Significant effort needed to arrive at a paper design
- Need very important technology development to make it real
- A long-term effort

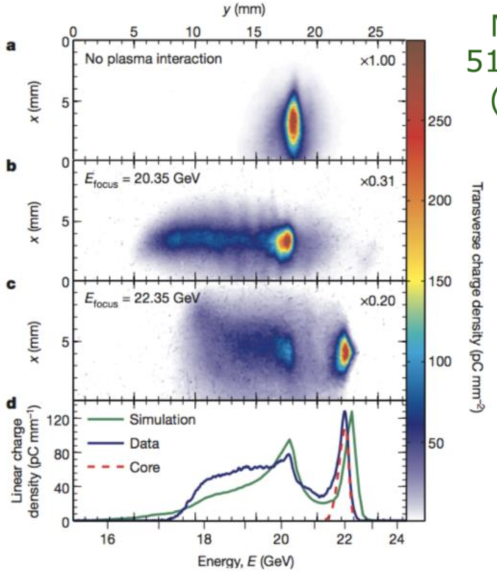
Examples of Achieved Accelerations

Using SLC beam L = 0.85 m, G ~ 50 GV/m
⇒ 42 GeV

E167 collaboration SLAC, UCLA, USC

I. Blumenfeld et al, Nature 445, p. 741 (2007)



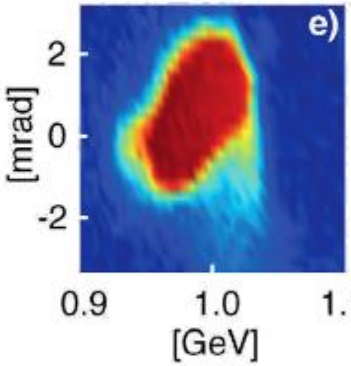


Litos, Nature 515(6),92 (2014)

ΔE/E~%
η~30%

Using laser beam to generate the plasma at Berkeley

=> 1GeV



Beam energy =1.0 GeV
Charge= Q~30 pC
1.6 mrad rms divergence
2.5% rms energy spread

Leemans *et al.*, Nature Phys. (2006).
Nakamura *et al.*, Phys. Plasmas (2007).

Driving plasma with protons is planned at CERN in the AWAKE experiment

Using proton-plasma interaction to create many microbunches

First tests showed successful acceleration (preliminary)

Example: Beam-driven Plasma Collider (PWFA)

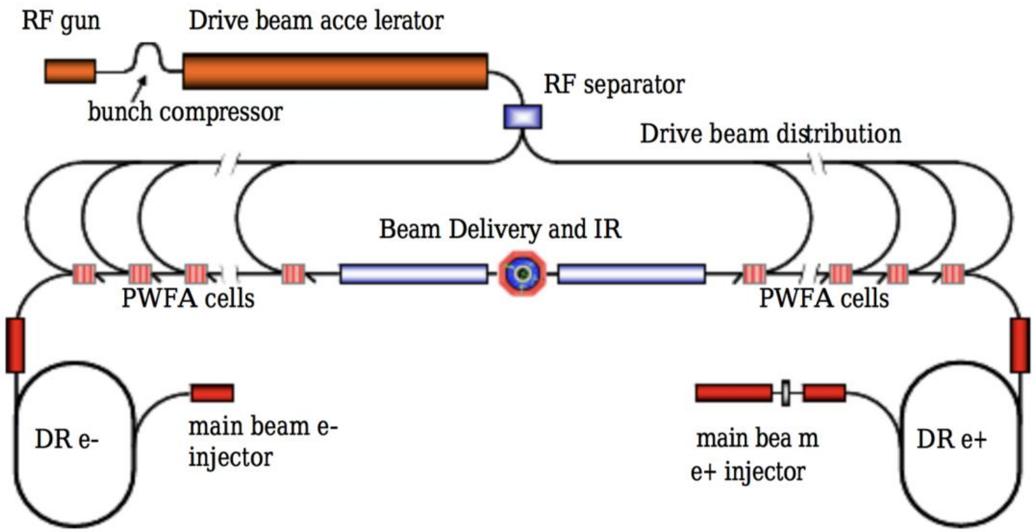


Fig. 1: Concept for a multi-stage PWFA Linear Collider.

WE6PFP081 Proceedings of PAC09, Vancouver, BC, Canada

A CONCEPT OF PLASMA WAKE FIELD ACCELERATION LINEAR COLLIDER (PWFA-LC)*

Andrei Seryi, Mark Hogan, Shilun Pei, Tor Raubenheimer, Peter Tenenbaum (SLAC), Tom Katsouleas (Duke University), Chengkun Huang, Chan Joshi, Warren Mori (UCLA, California), Patric Muggli (USC, California).

WE6PFP079 Proceedings of PAC09, Vancouver, BC, Canada

CONCEPTUAL DESIGN OF THE DRIVE BEAM FOR A PWFA-LC*

S. Pei#, M. J. Hogan, T. O. Raubenheimer, A. Seryi, SLAC, CA 94025, U.S.A.
H. H. Braun, R. Corsini, J. P. Delahaye, CERN, Geneva

SLAC-PUB-15426
arXiv:1308.1145

A Beam Driven Plasma-Wakefield Linear Collider: From Higgs Factory to Multi-TeV

Summarized for CSS2013

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