Future High-Energy Collider Projects:

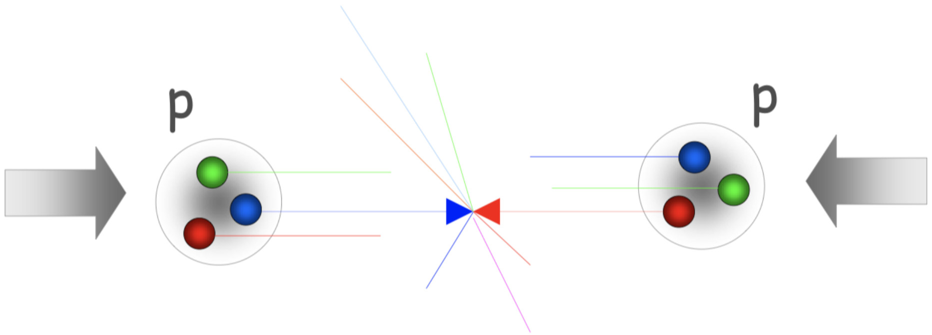
I. Linear Colliders

R. Corsini

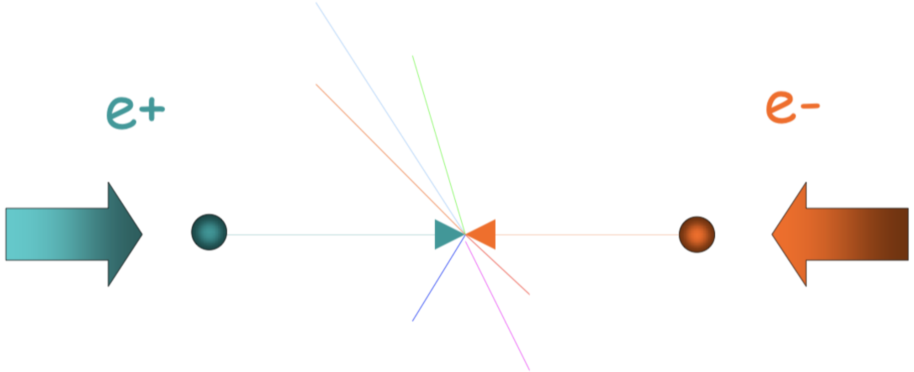
Largely based on last year's lectures on Future Colliders Technology by D. Schulte

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

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

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

Mentioned:

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

Collider Projects Worldwide

Ongoing	Immediate future 10 years	Near future ~ 20 years	Longer term future	Very long term future
Super KEKB HL-LHC	Electron-Ion (MEIC, eRHIC, **LHeC**)	ILC **CLIC** **CepC** **FCC-ee**	**HE-LHC** **FCC-hh** **FCC-he** **SppS hh**	**Muon Collider** **Plasma wakefield,…**

European Strategy for Particle Physics

“To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available.

CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.”

Adapted from O. Brüning, HEPAP Accelerator Sub-Panel Road Trip, August 2014

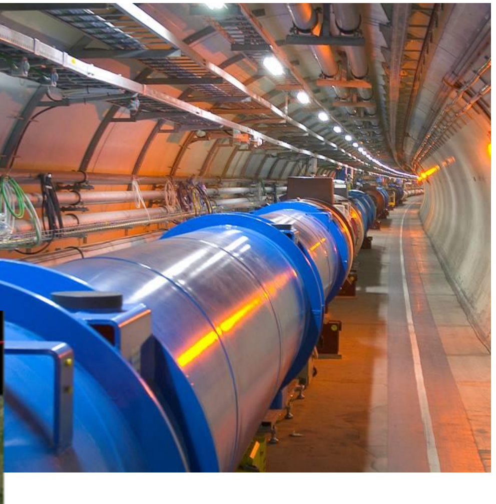
European Strategy for Particle Physics

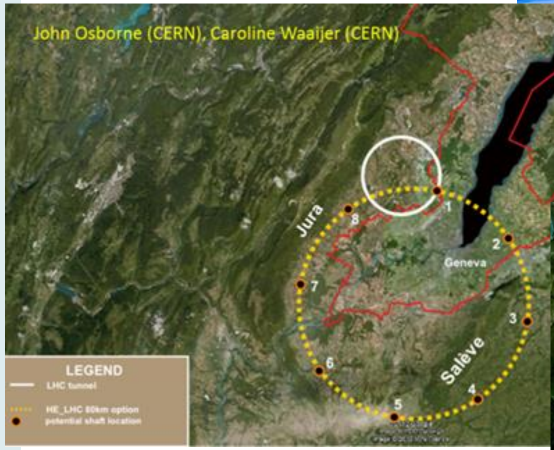
Conclusion in 2012

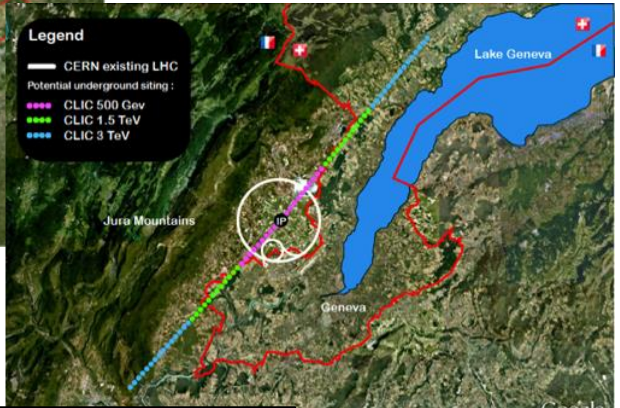
- Highest priority is exploitation of the LHC including luminosity upgrades
- Europe should be able to propose an ambitious project after the LHC
  - Either high energy proton collider (FCC-hh) with lepton collider (FCC-ee) as potential intermediate step
  - Or high energy linear lepton collider (CLIC)
- Europe welcomes Japan to make a proposal to host ILC
- Long baseline neutrino facility (not covered here)

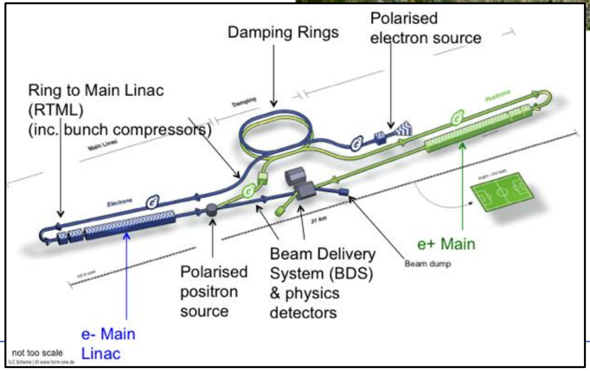
New process from 2018-2020

Input from projects are expected before end of 2018







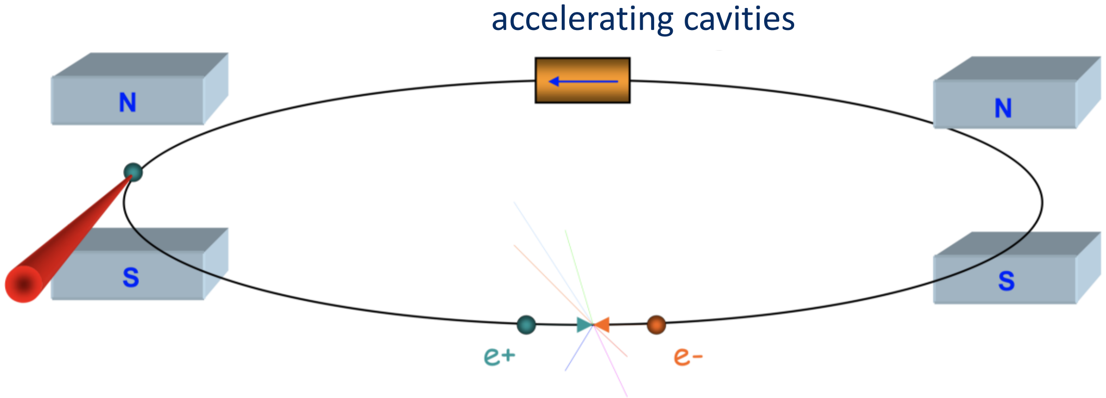


Linear Colliders

Ring vs. Linear Collider

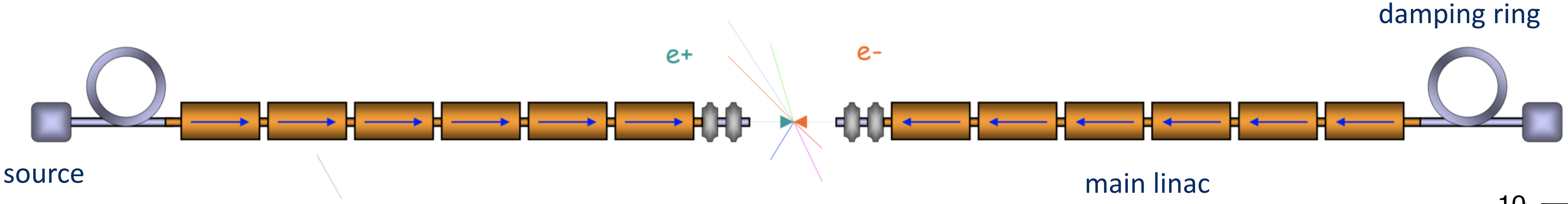
Accelerates beam over many turns
Can use beam many times in collision
However, charged particles emit synchrotron radiation in a magnetic field

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

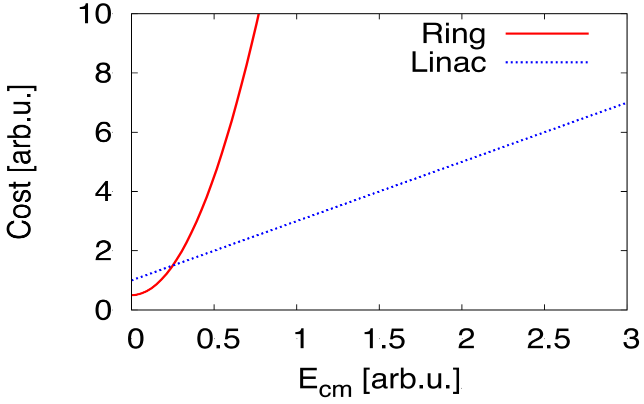


For light particles synchrotron radiation can be large

- 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



What matters in a linear collider ?

Energy reach

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

High gradient

X-band normal conducting accelerating structures

Luminosity

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

N.B.: $\sigma_{x,y} = \sqrt{\frac{\beta_{x,y}\epsilon_{x,y}}{\gamma}}$

CLIC specific Issues

- Acceleration efficiency
- Generation of small emittance
- Conservation of small emittance
- Extremely small beam spot at IP

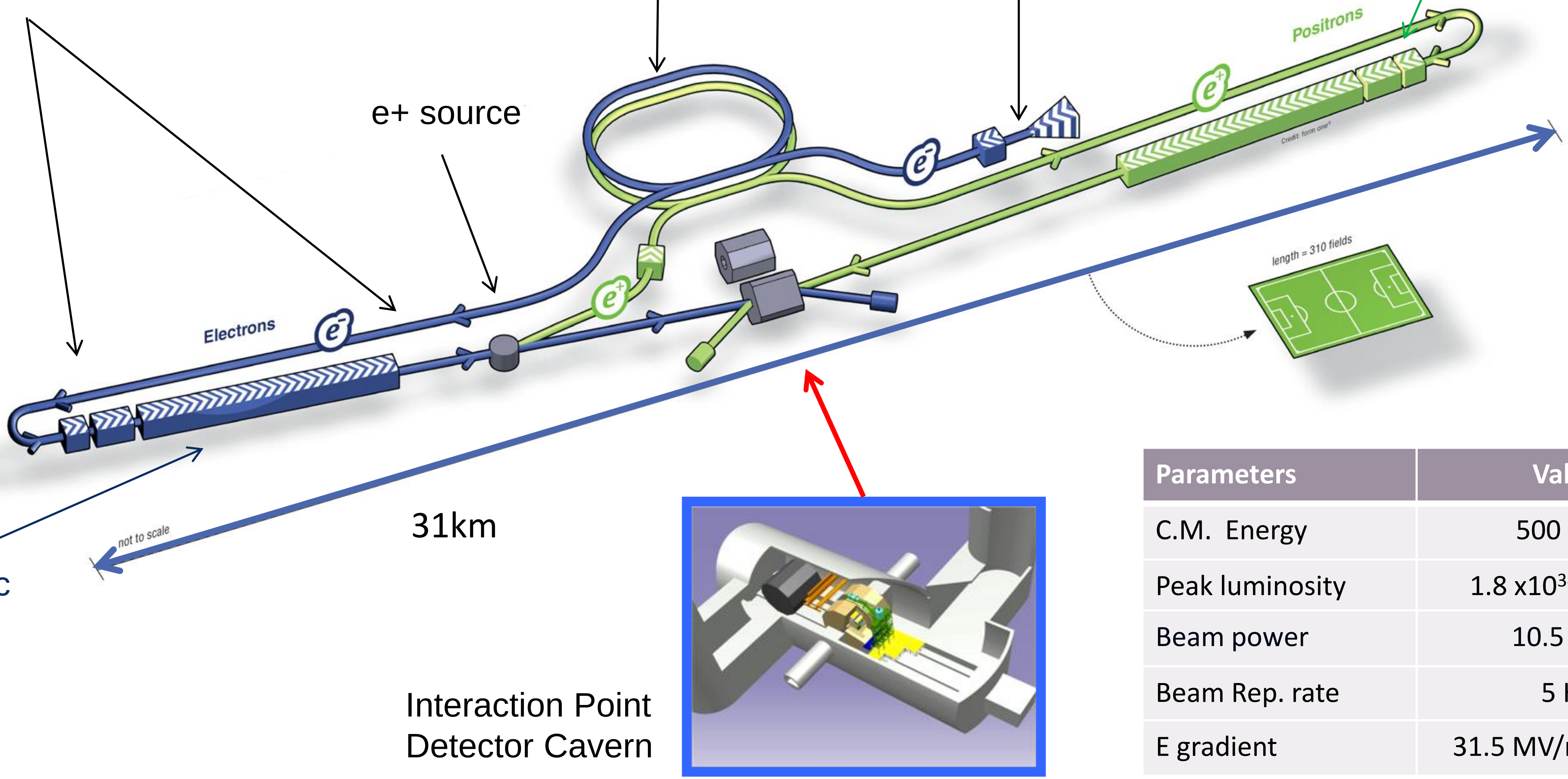
Two-beam scheme

Damping rings

Wake-fields, alignment, stability

Beam delivery system, stability

International Linear Collider - ILC



Ring to Main Linac (RTML)
(including
bunch compressors)

Damping Rings

Polarised electron
source

e+ Main Linac

e+ source

31km

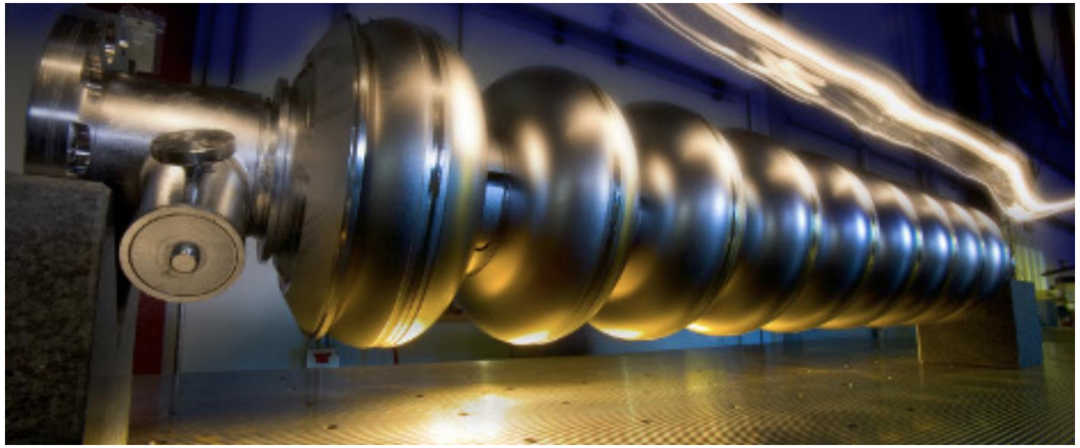
e- Main Linac

Interaction Point
Detector Cavern

ILC Scheme | © www.form-one.de

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} cm^{-2}s^{-1}
Beam power	10.5 MW
Beam Rep. rate	5 Hz
E gradient	31.5 MV/m +/-20%

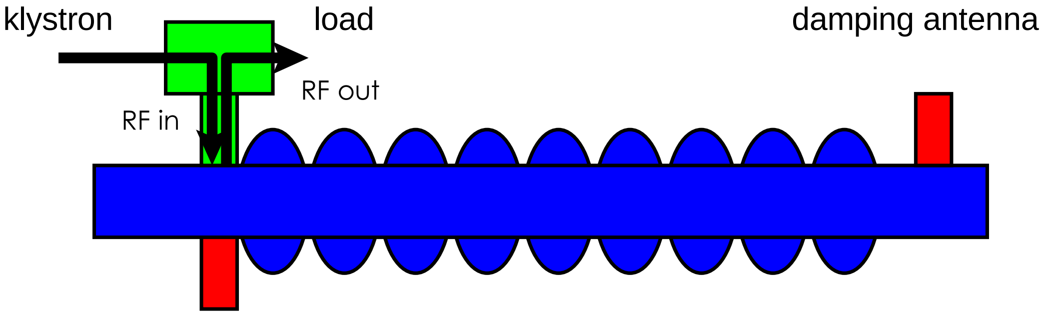
ILC Cavities



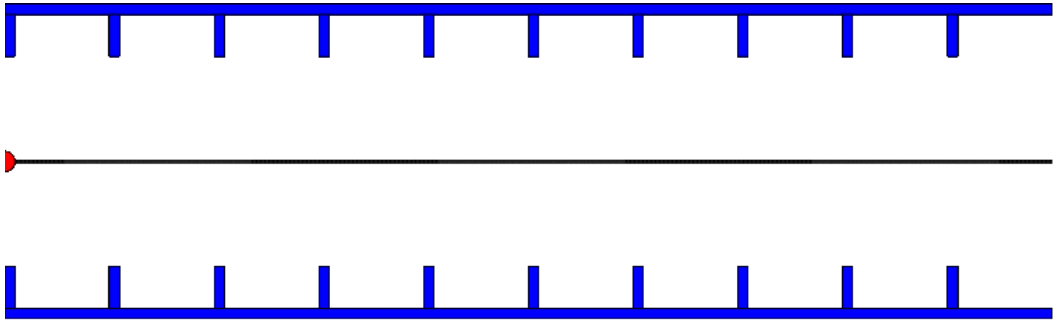
Superconducting cavity (Ni at 2 K)

RF frequency is 1.3 GHz, 23 cm wavelength

Length is 9 cells = 4.5 wavelengths = 1 m



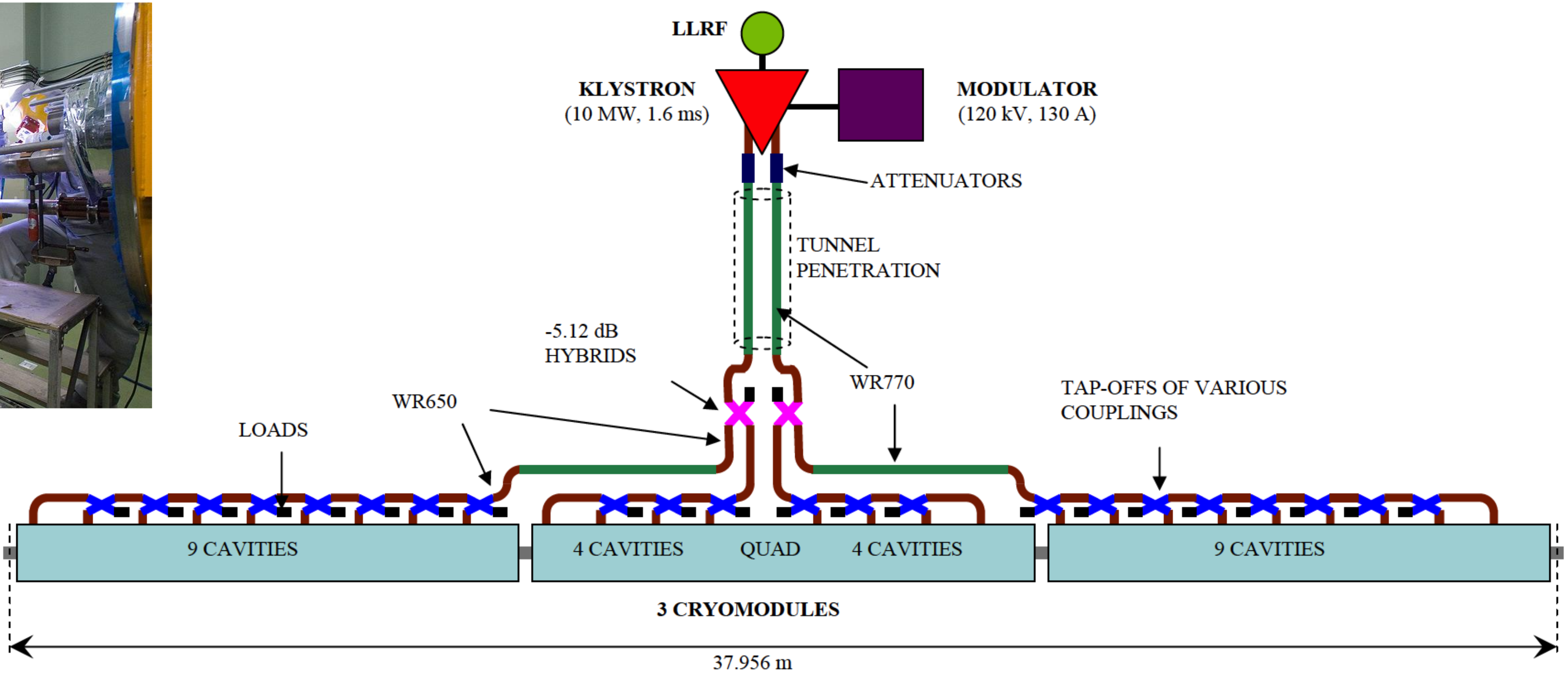
Standing wave structure



Gradient is 31.5 MV/m

Need about 16000 cavities

Main Linac Unit



Accelerating cavities

~ 65% of linac length

Quadrupole

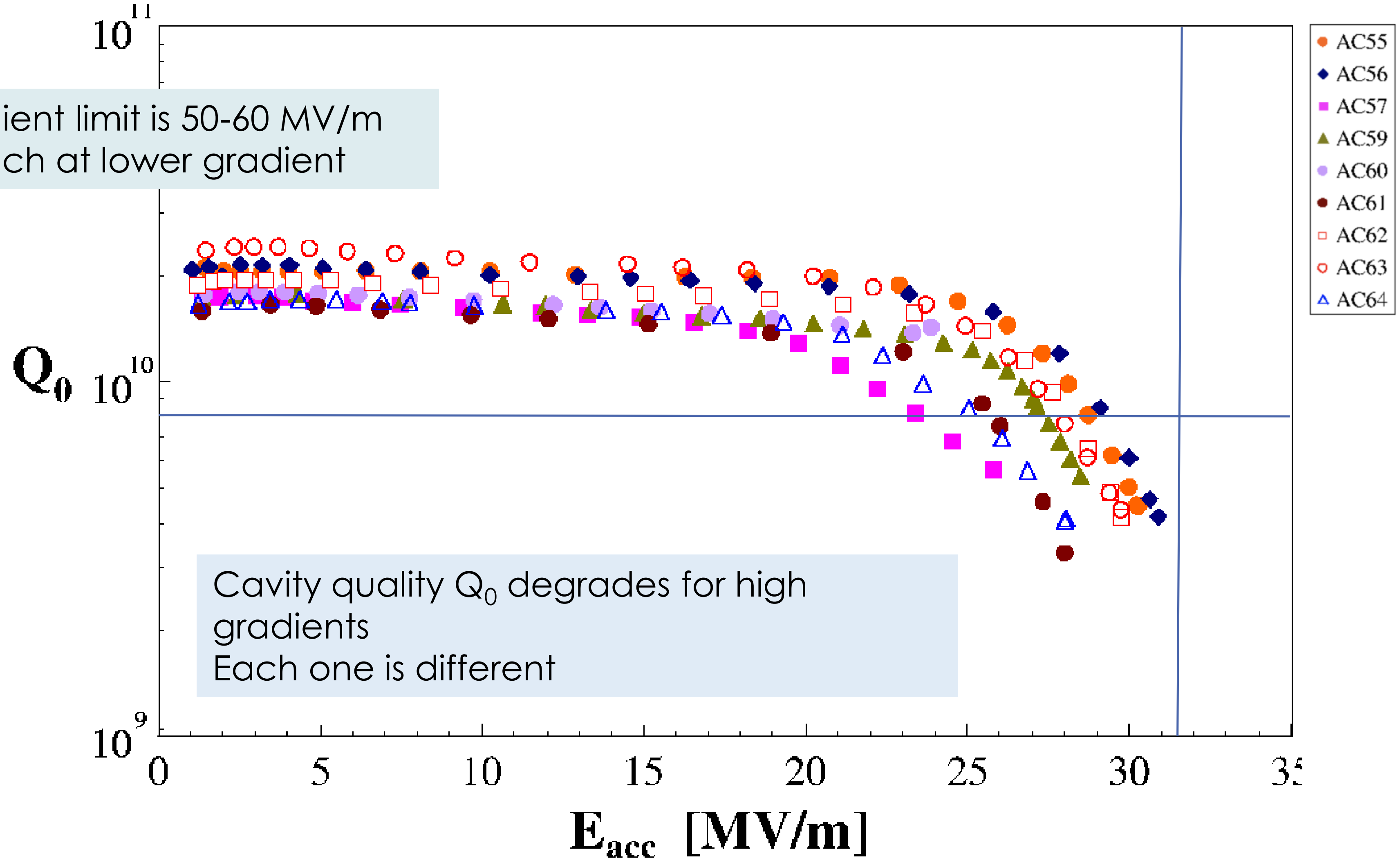
Beam position monitor

Corrector kicker

Accelerating cavities

Total length for 500 GeV cm 31 km, some length for beam cleaning and focusing

ILC Gradient Limitations



Theoretical gradient limit is 50-60 MV/m

- But can quench at lower gradient

Cavity quality Q_0 degrades for high gradients
Each one is different

ILC Cavity Treatment

Control of material

Avoid defects
Ensure high quality

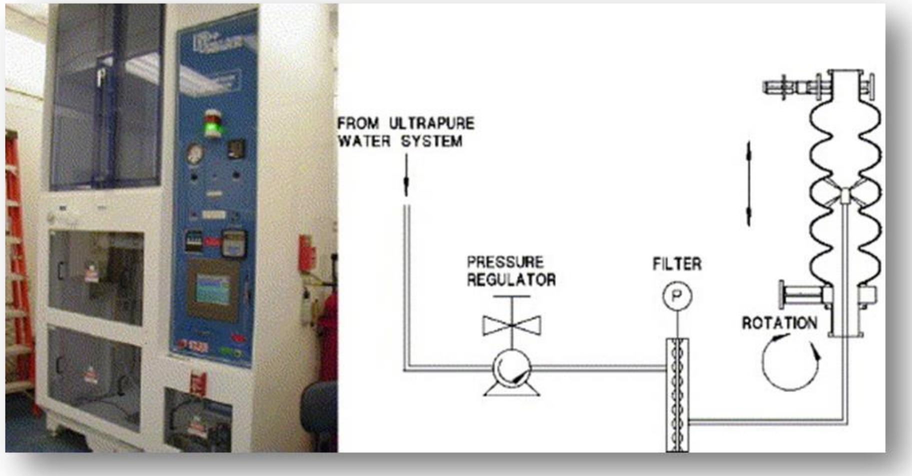
Electropolishing

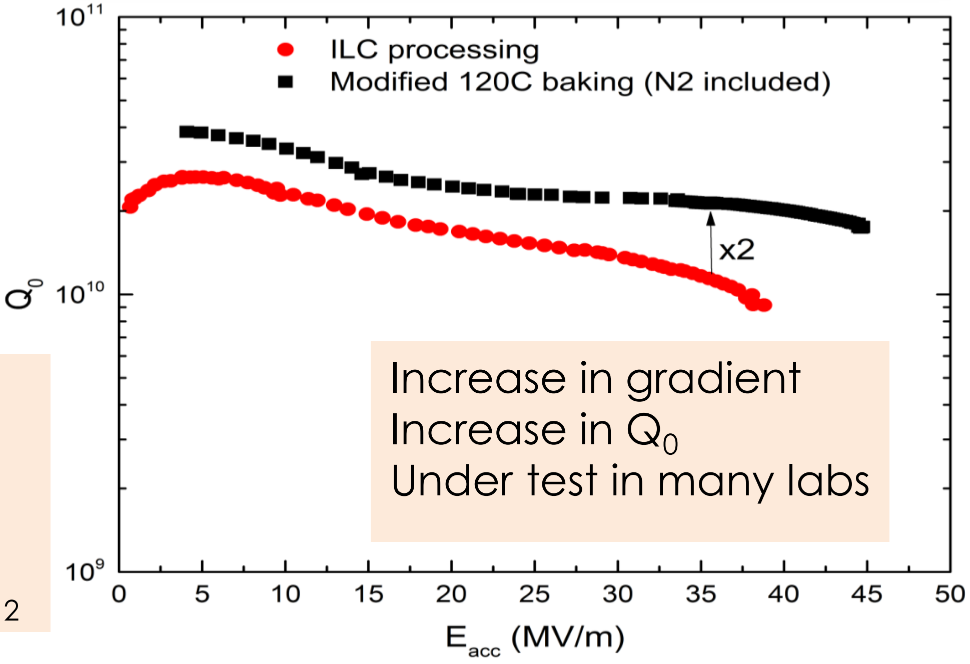
→ fill with H_2SO_4, apply current to remove thin surface layer

Bakeout

Novel process found (FNAL):
Nitrogen infusion
Fill cavity at 120°C for a day with low pressure of N_2

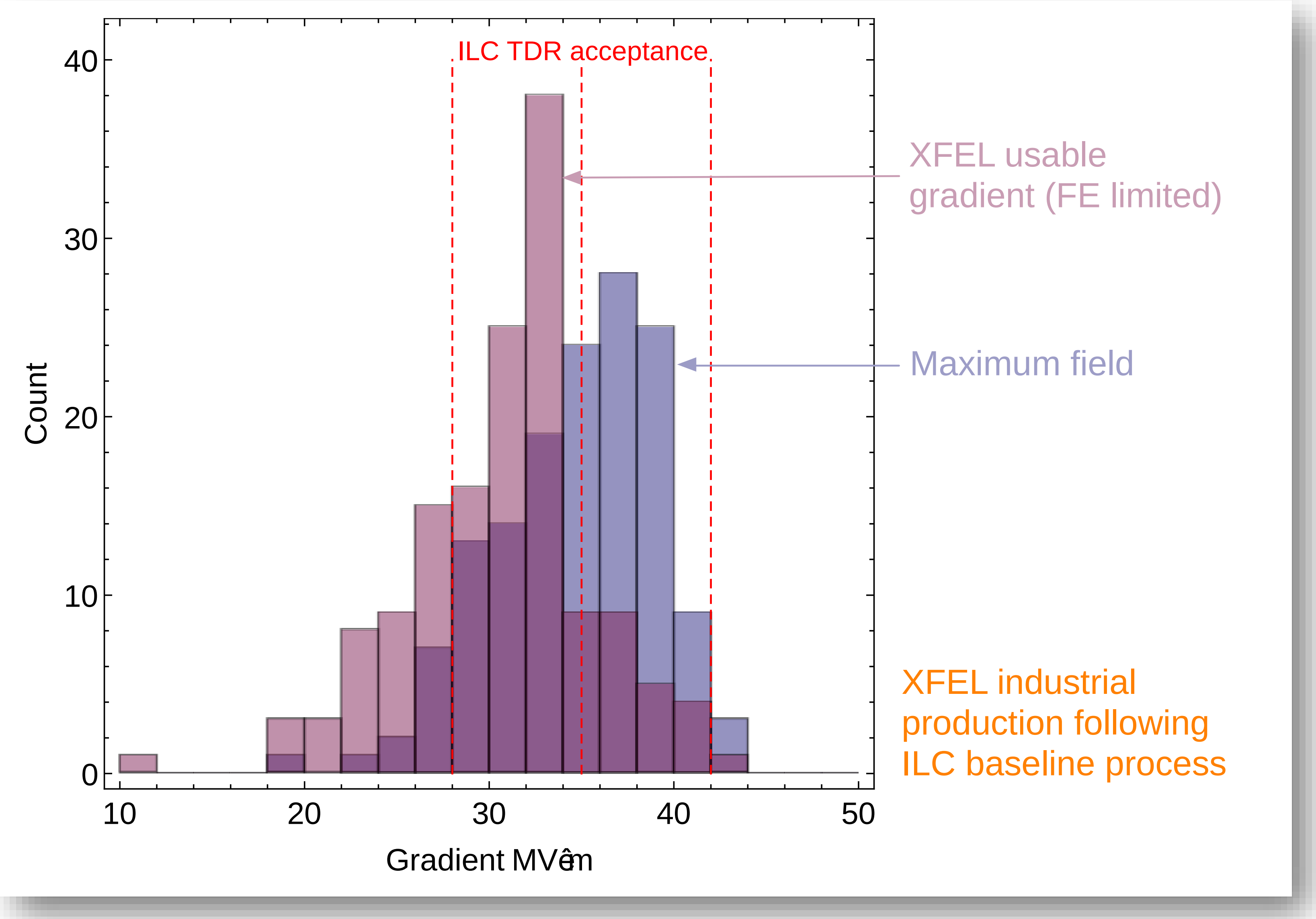
High pressure rinsing





Increase in gradient
Increase in Q_0
Under test in many labs

ILC Achieved Gradient



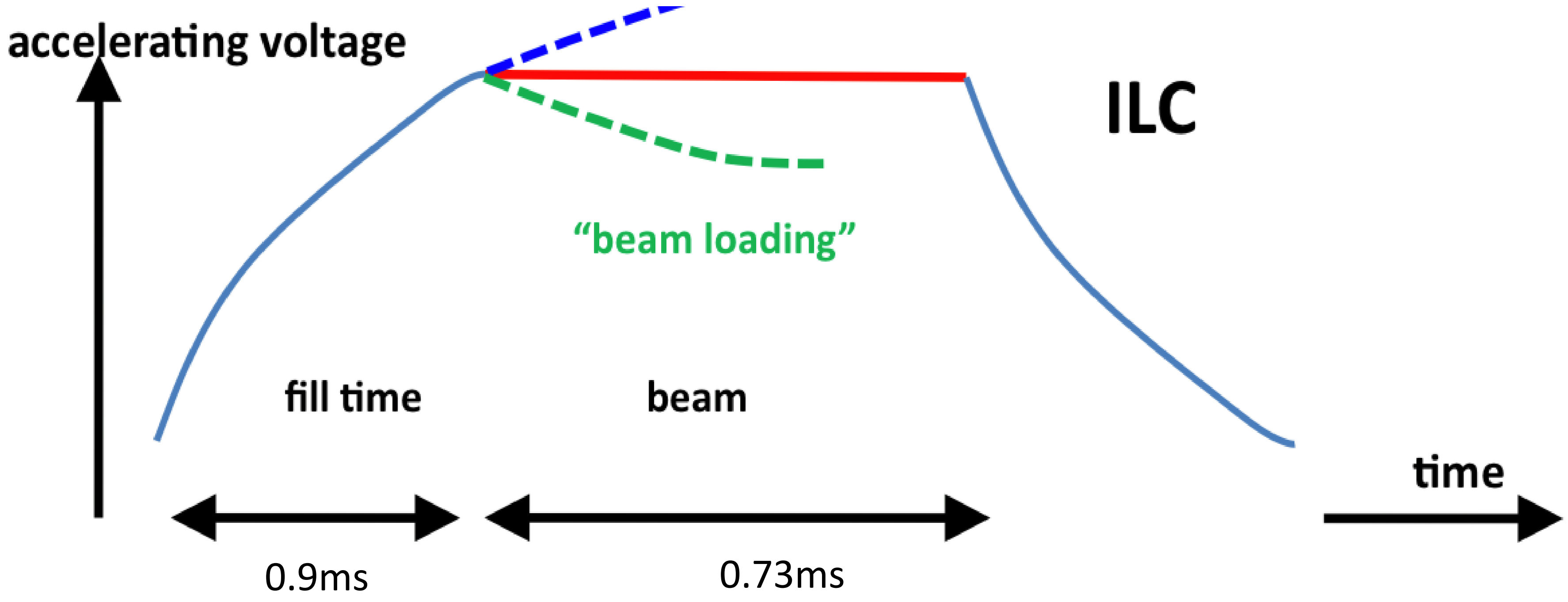
XFEL usable gradient (FE limited)

Maximum field

XFEL industrial production following ILC baseline process

From N. Walker

Note: Pulsed Operation



5 RF pulses of 1.6 ms per second (1312 bunches in 0.73 ms):

Losses in walls reduced by factor 8 x 10^{-3}

RF power in pulse: 10.5 MW / (5 x 0.73 ms) = ~ 3000 MW = ~ 300 klystrons

Note: Cryogenics

Cavities have small losses

$$P_{loss} = const \frac{1}{Q_0} \times G^2$$

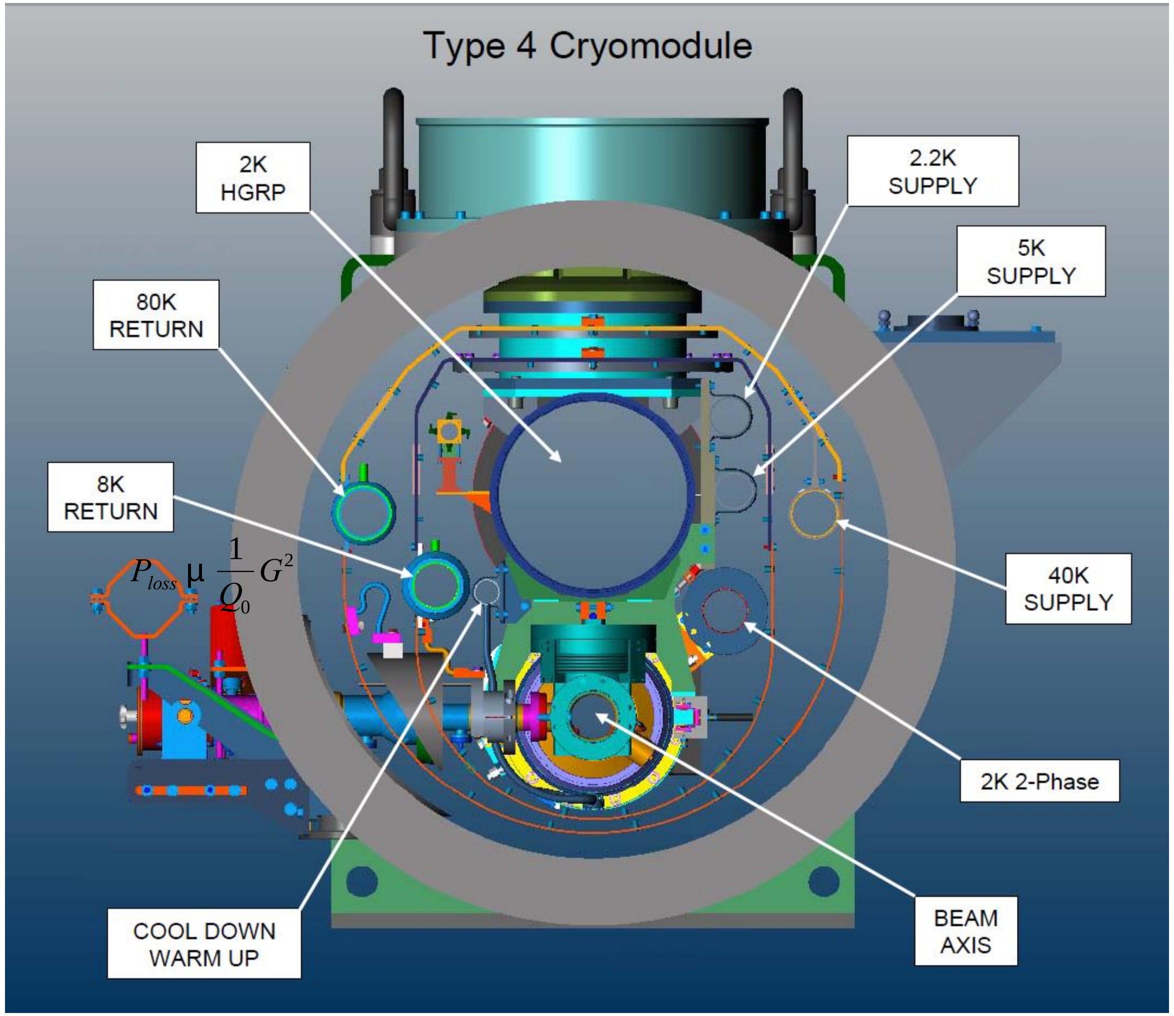
About 1W/m

But cooling costly at low temperatures

Remember Carnot:

$$P_{cryo} = \frac{1}{\eta} \frac{T_{room} - T_{source}}{T_{source}} \times P_{loss}$$

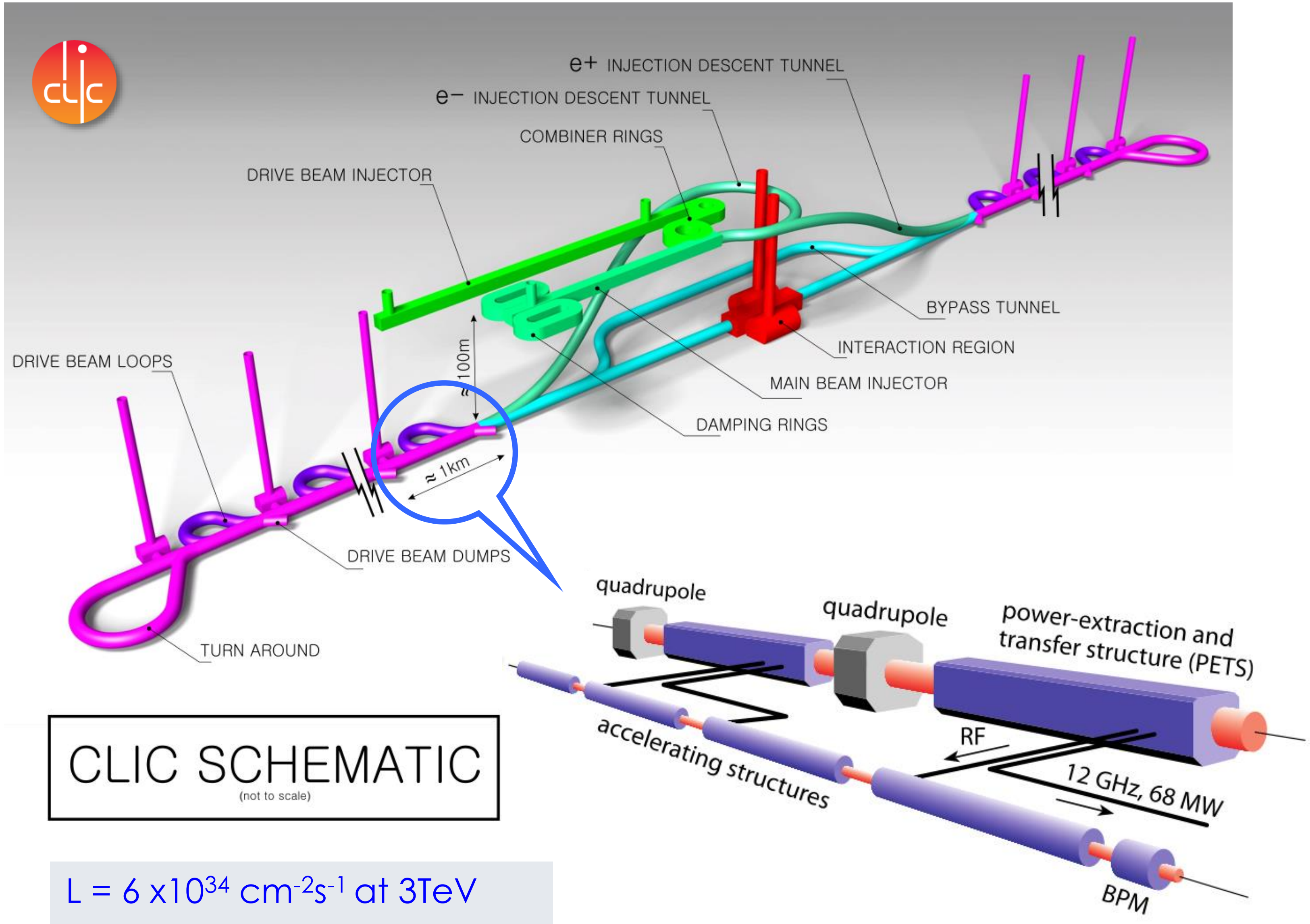
$$P_{cryo} \approx 700 \times P_{loss}$$



Typical heat load ~ 1 W/m
⇒ about 1 kW/m for cryogenics

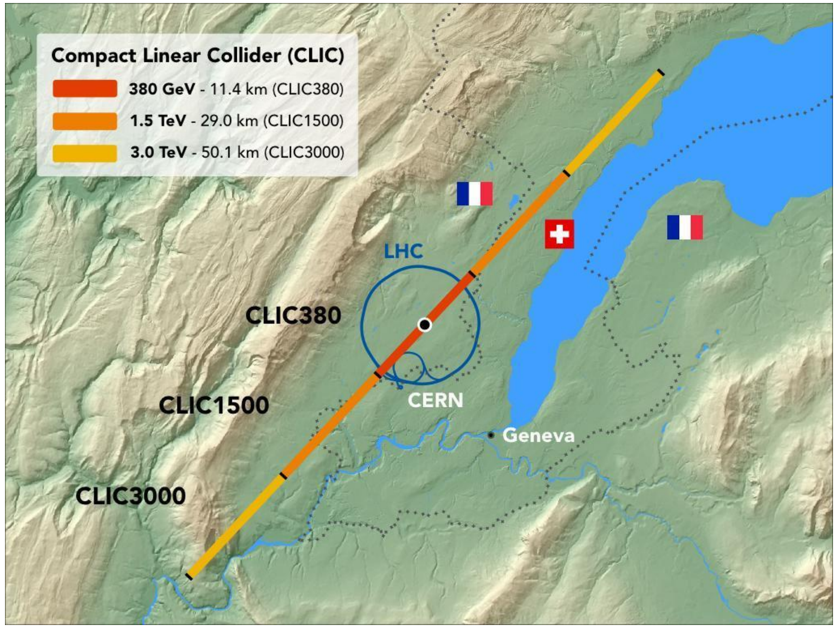
Average RF power: 1.6kW/m (3kW/m)
Power into beam about 0.7kW/m

The Compact Linear Collider - CLIC



CLIC SCHEMATIC
(not to scale)

L = 6 x10^{34} $cm^{-2}s^{-1}$ 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.

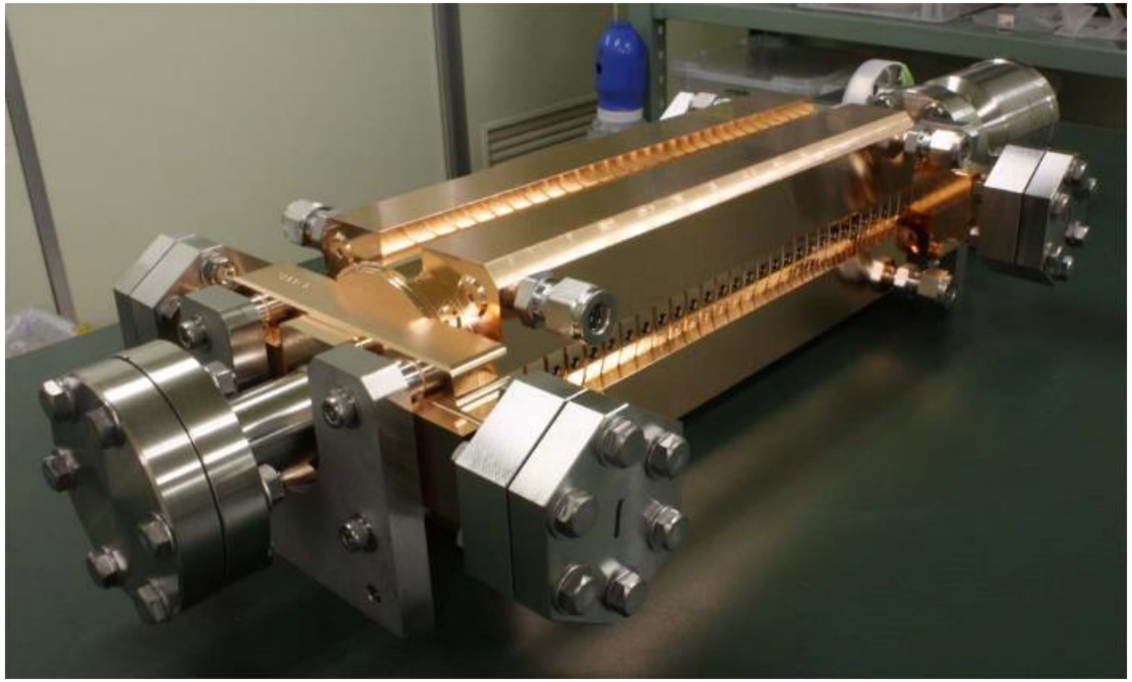
Accelerating Structure

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

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

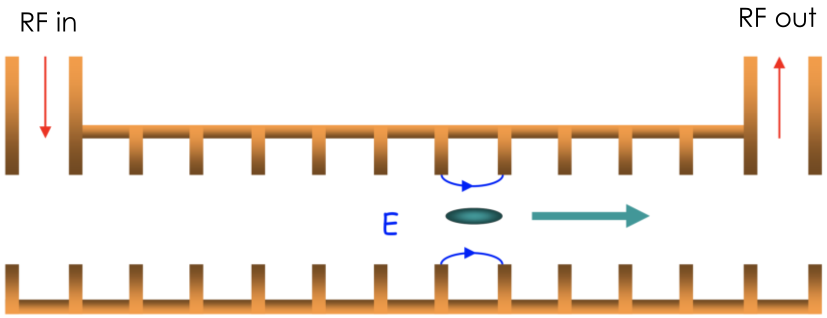
losses in the walls and in the load

⇒ 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

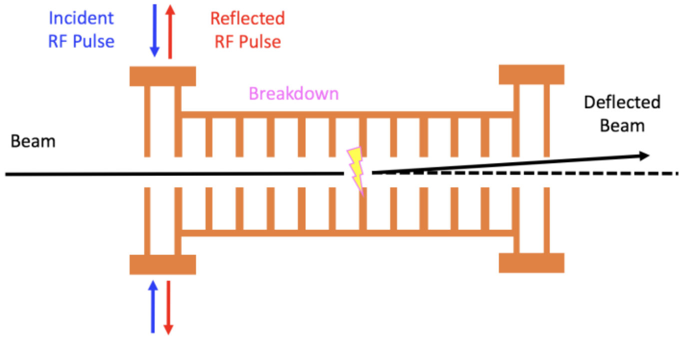
CLIC Gradient Limitations

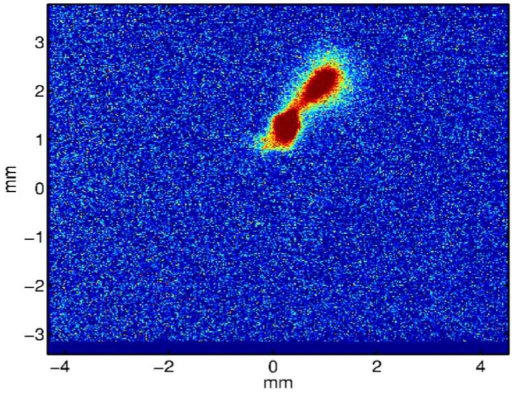
Breakdowns (discharges during the RF pulse)

- Require breakdown rate (BDR) ≤ 3 x 10^{-7} $m^{-1}pulse^{-1}$

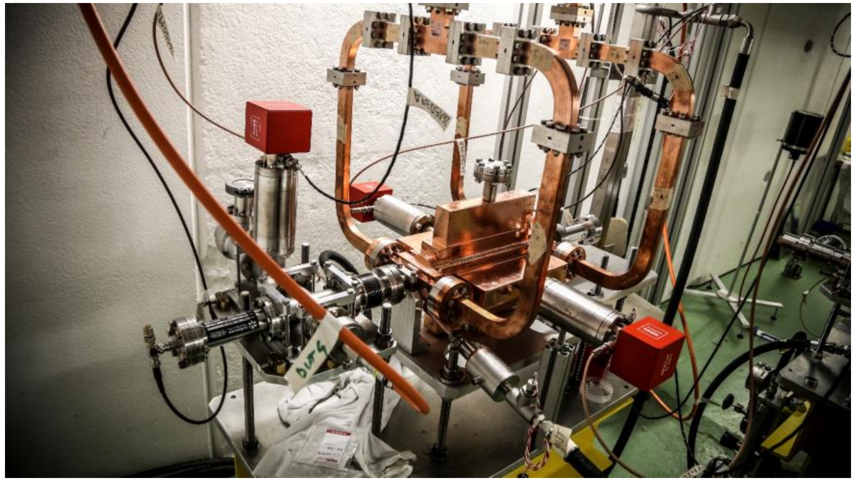
Structure design based on empirical constraints, not first principles

- Maximum surface field
- Maximum temperature rise
- Maximum power flow
- Pulse length dependence ~ $t^{-1/2}$





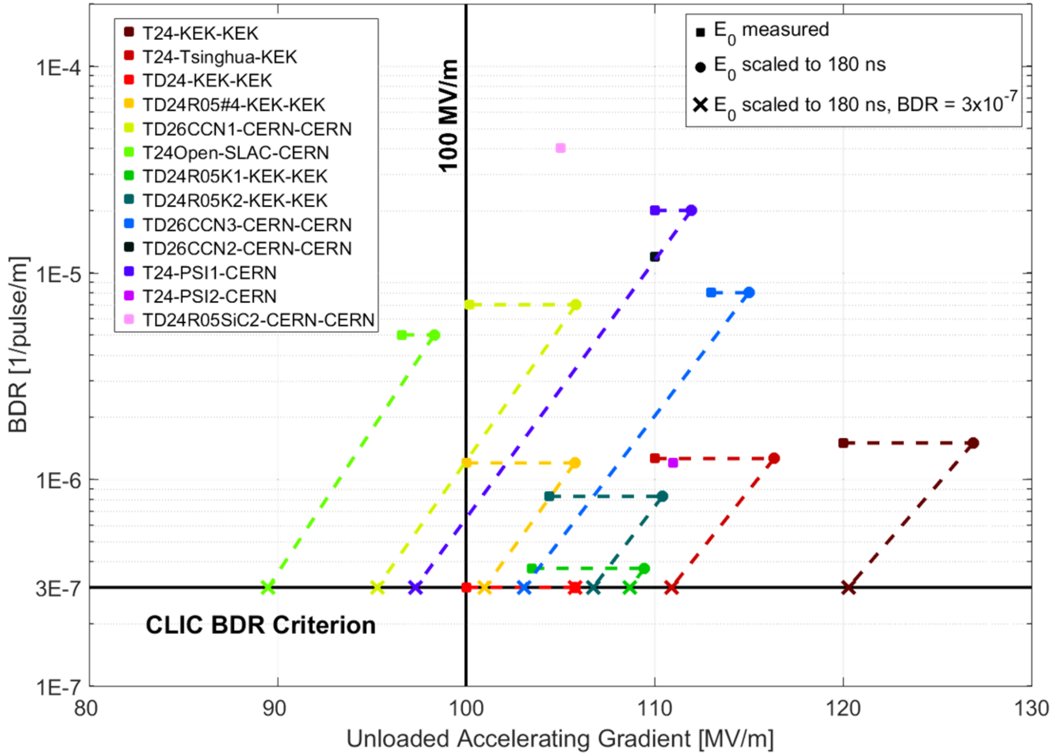
R&D programme established



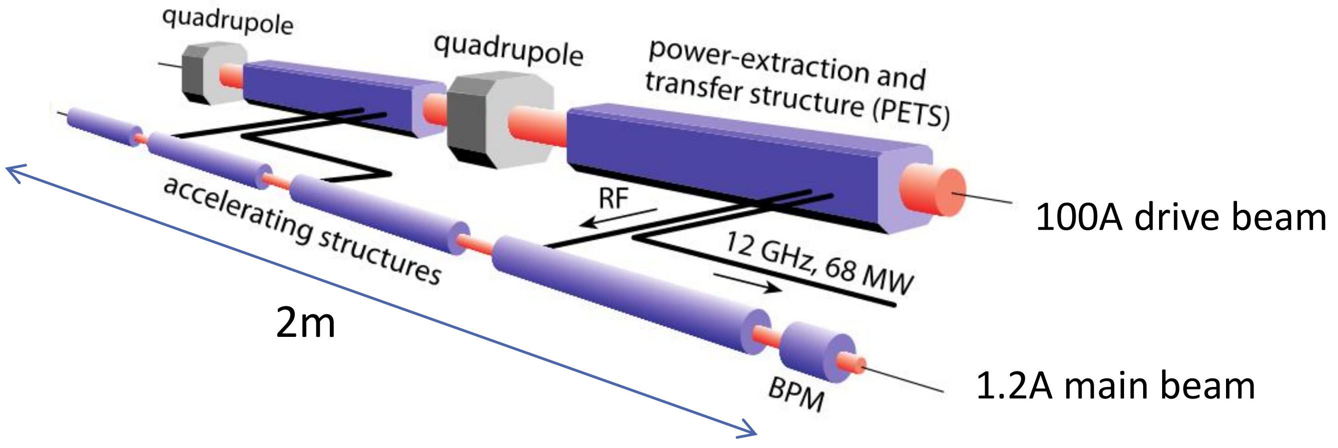
achieved gradient

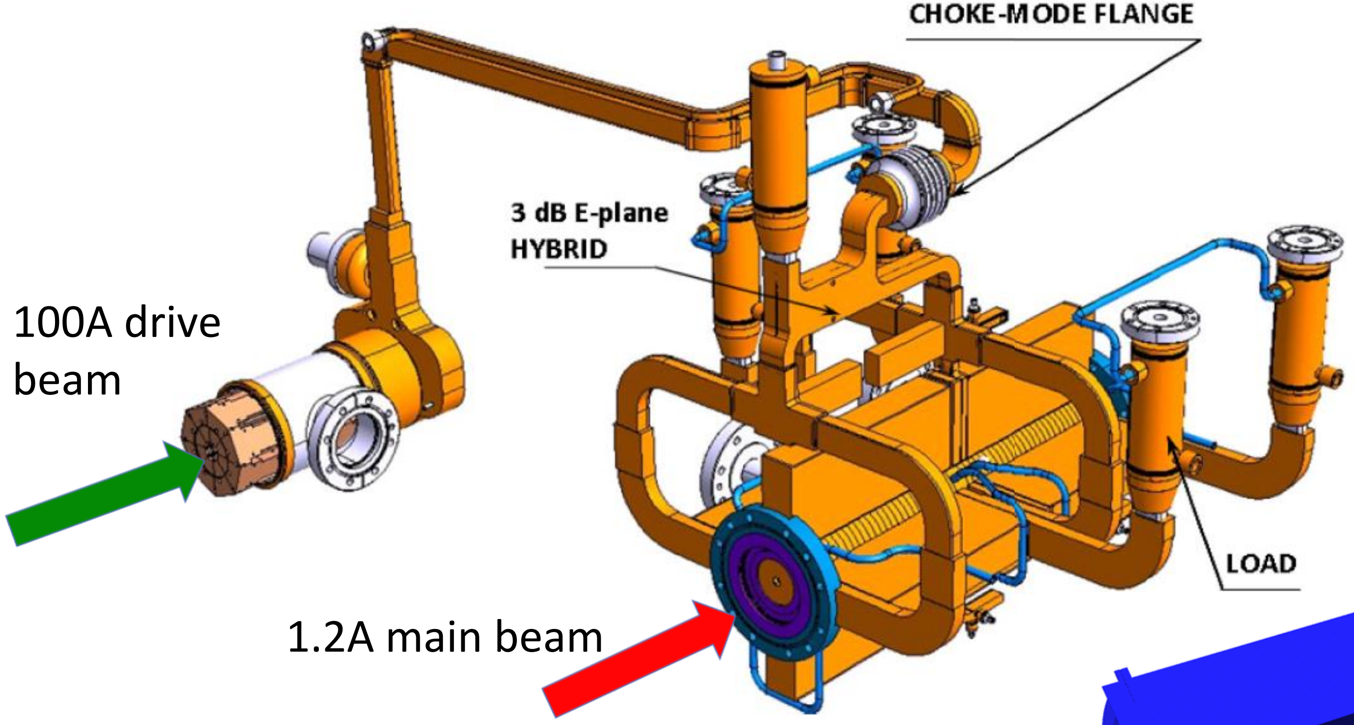
~ 100 MV/m

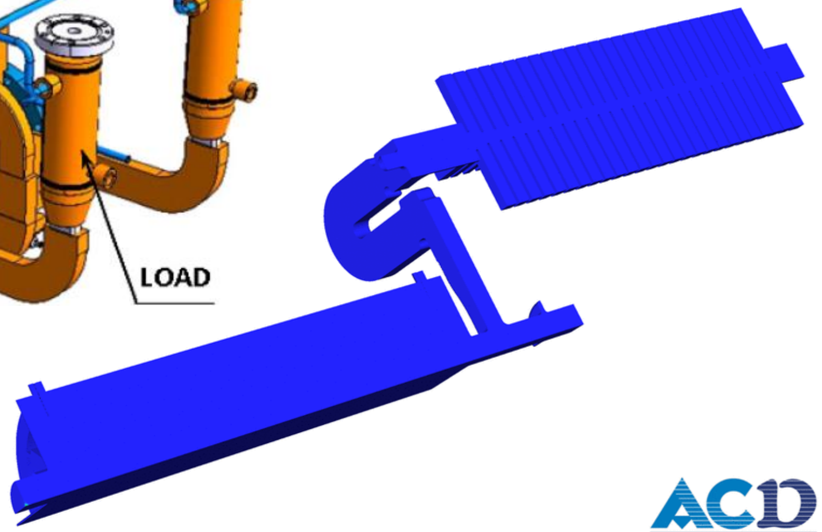
@BDR ≤ 3 x 10^{-7} $m^{-1}pulse^{-1}$ and 240 ns



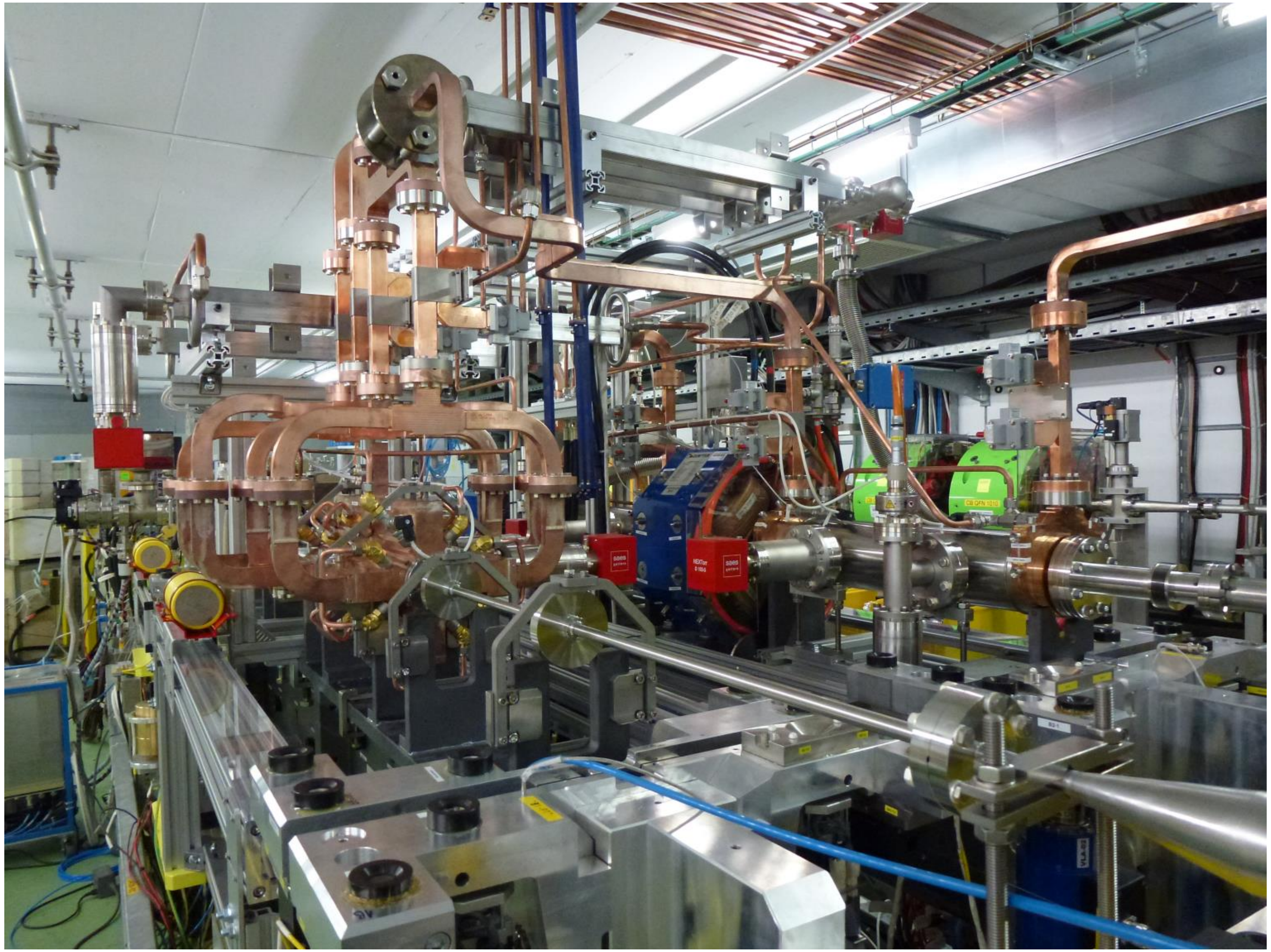
CLIC Two-beam Concept

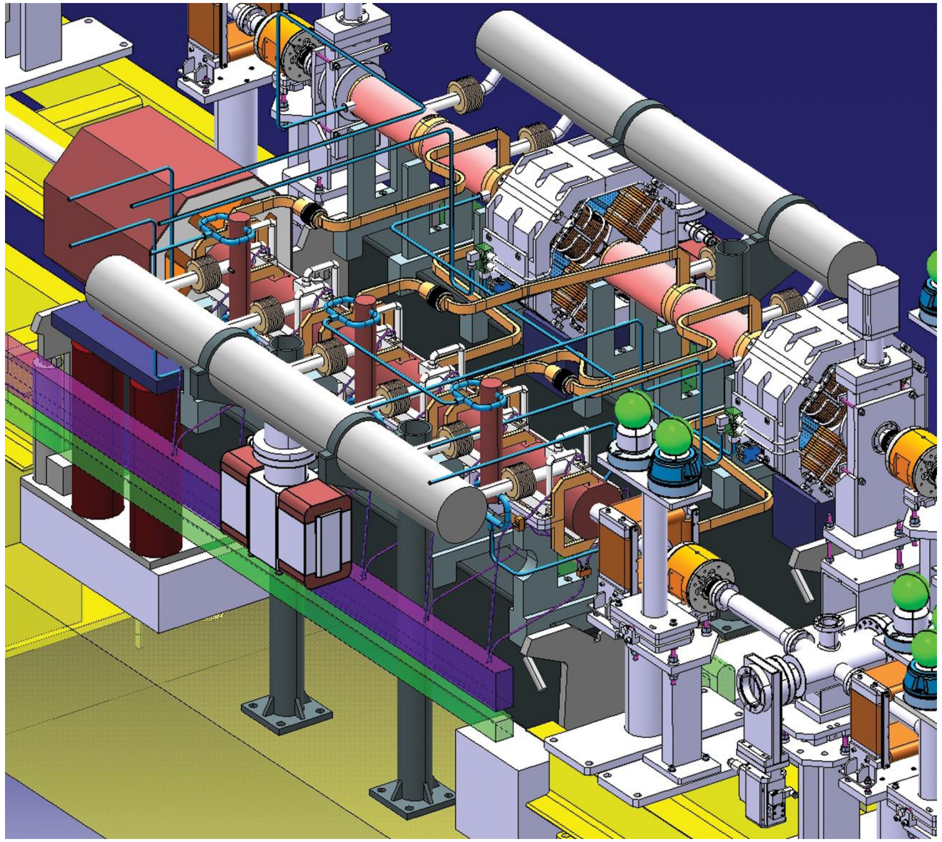






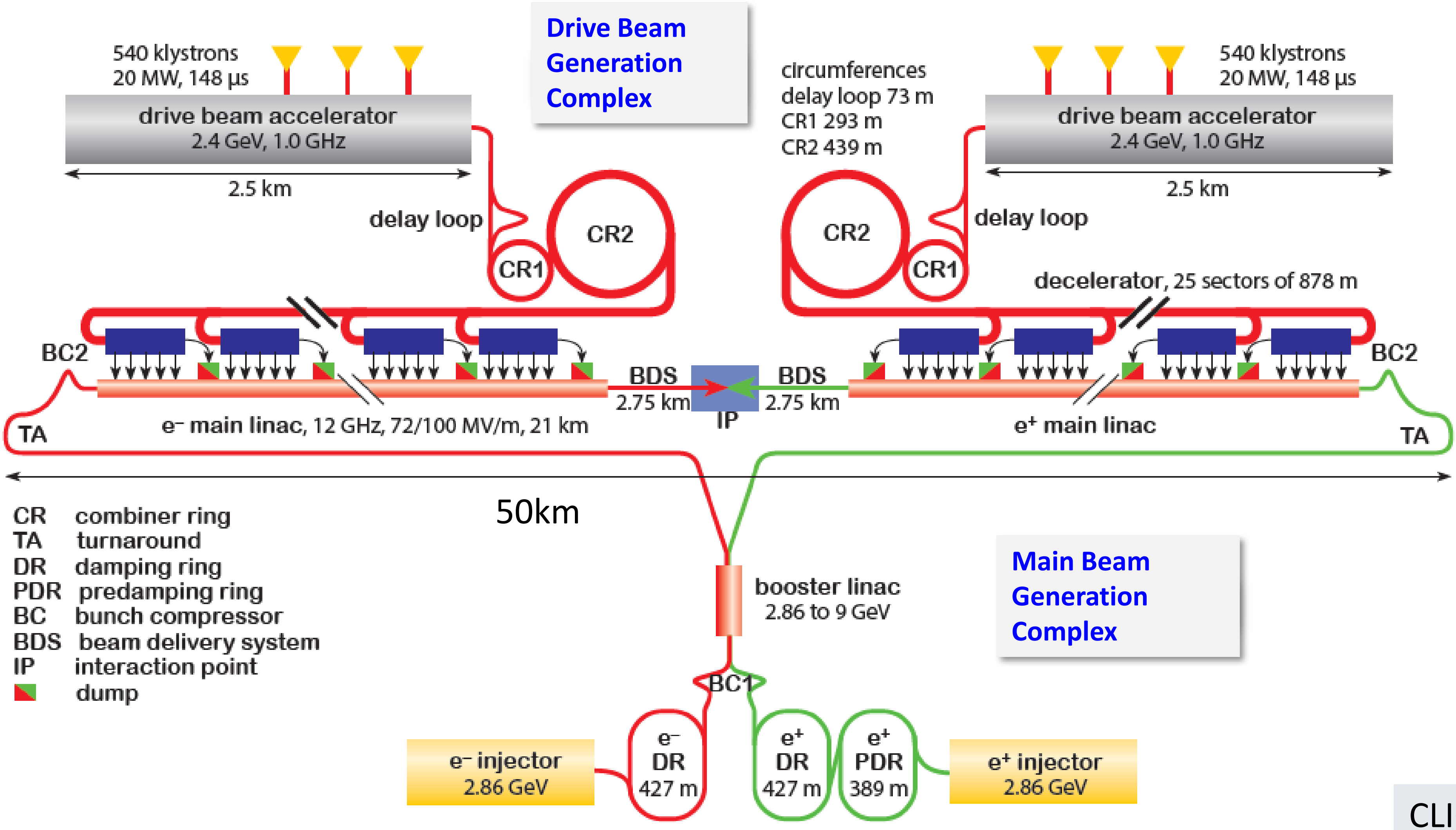
CLIC Two-beam Module





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

CLIC: Schematic Layout

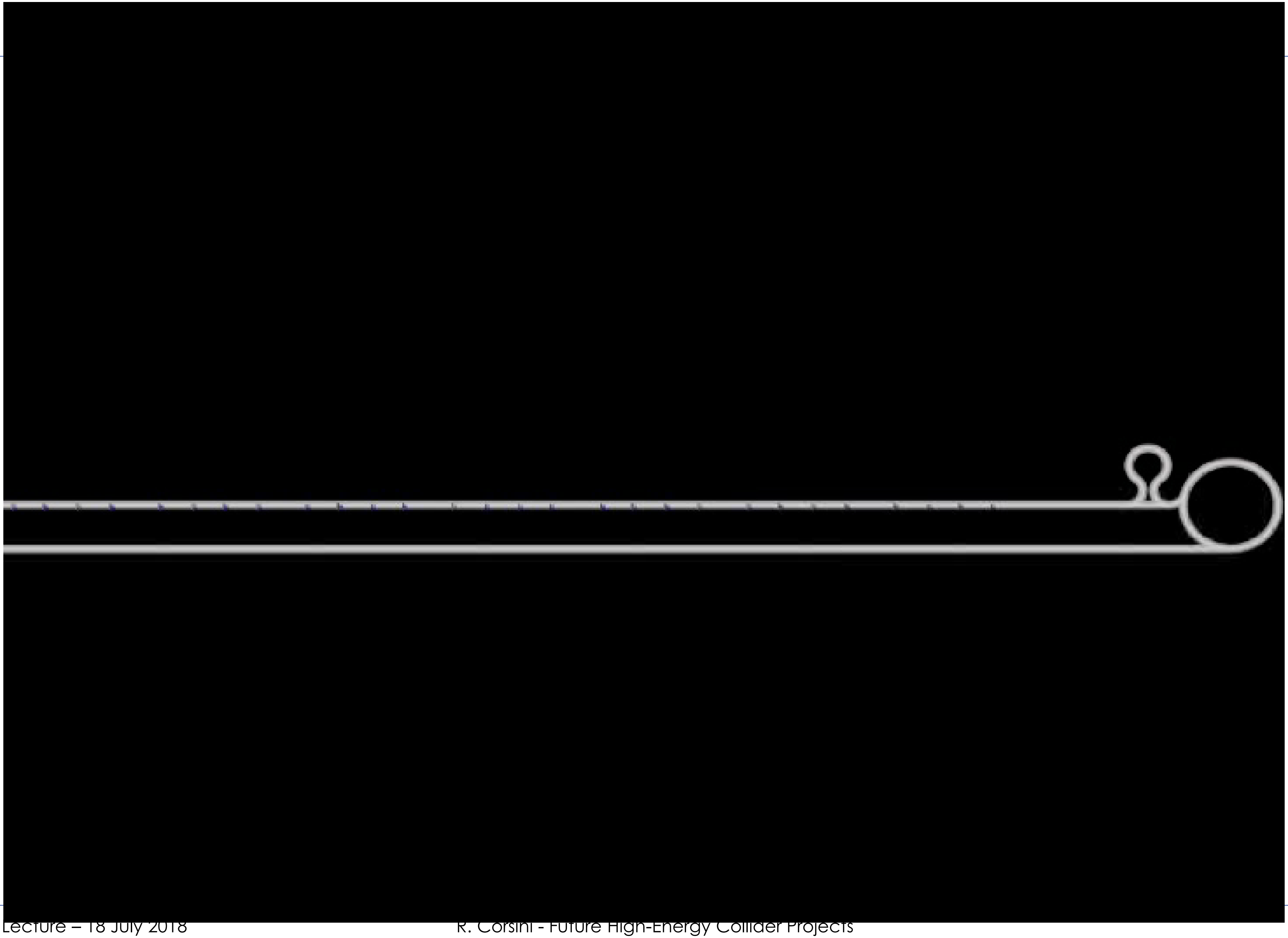


Drive Beam Generation Complex

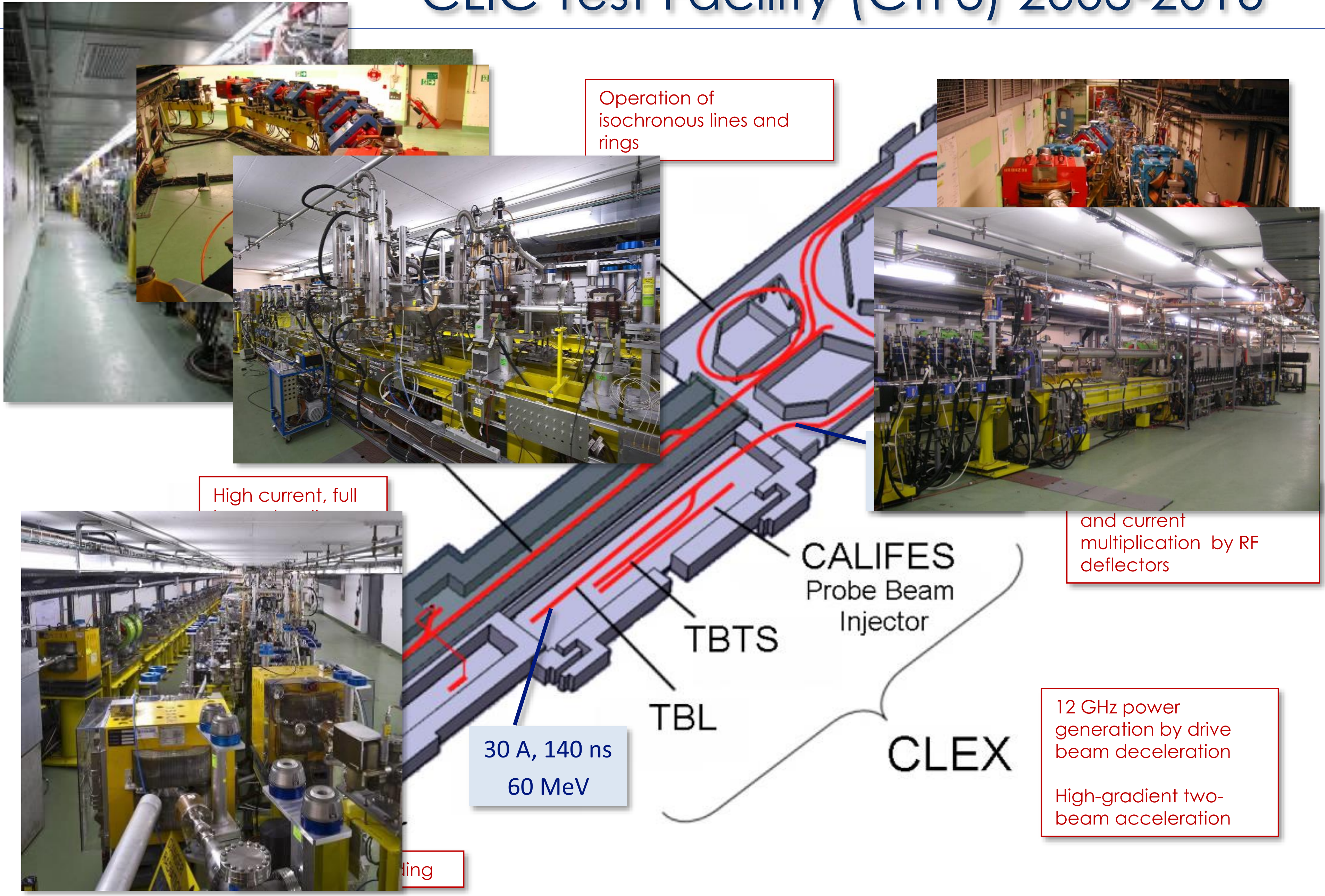
CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
🟥	dump

Main Beam Generation Complex

CLIC at 3TeV cm



CLIC Test Facility (CTF3) 2003-2016



Operation of isochronous lines and rings

High current, full

ling

and current multiplication by RF deflectors

30 A, 140 ns

60 MeV

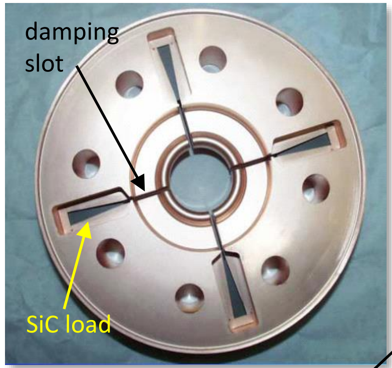
12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

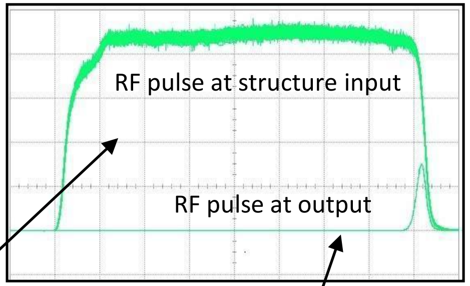
First beam
June 2003

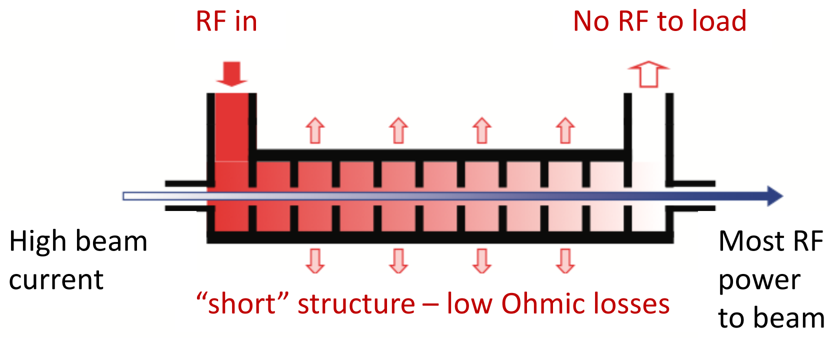
Last beam
December 2016

Drive Beam Generation – Power Production



Full beam loading acceleration

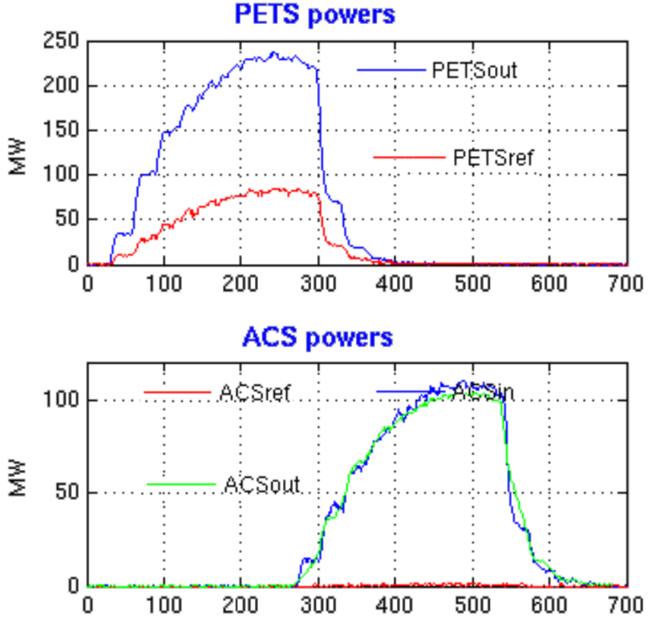


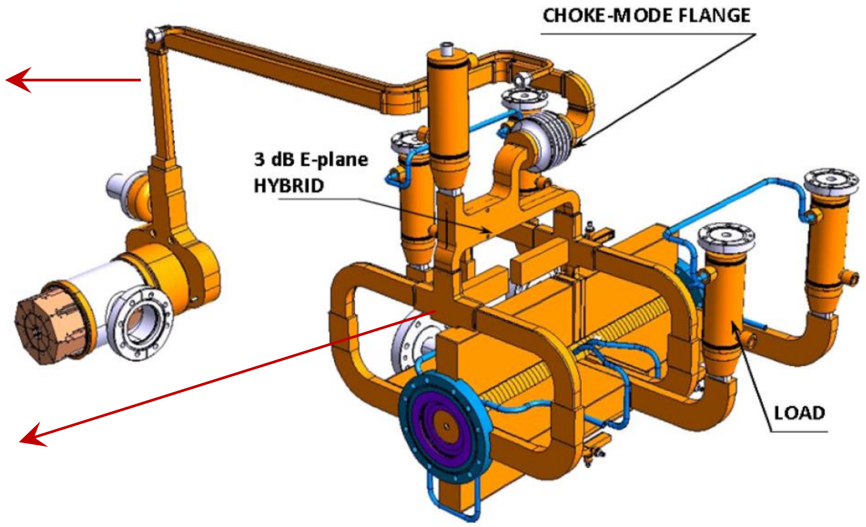


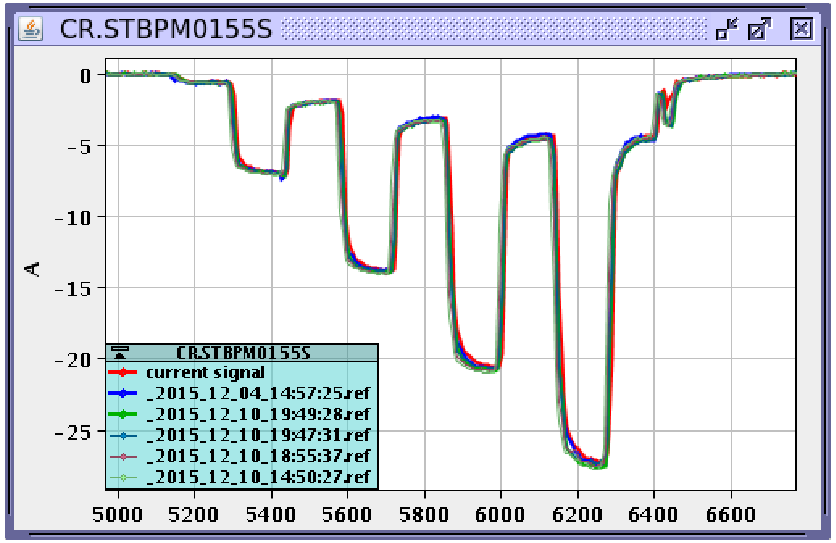
95.3% RF to beam efficiency

Stable high current acceleration

Factor 8 current & frequency multiplication







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

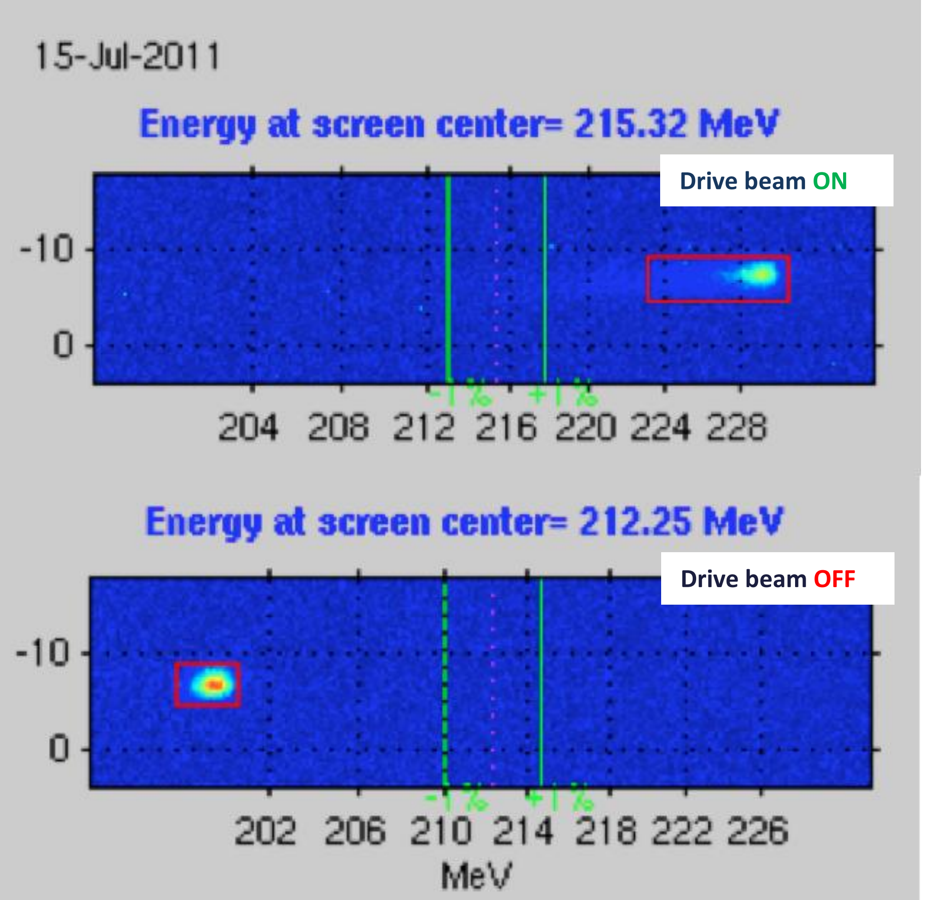
providing reliably pulses ~ 100 MW to accelerating structure.

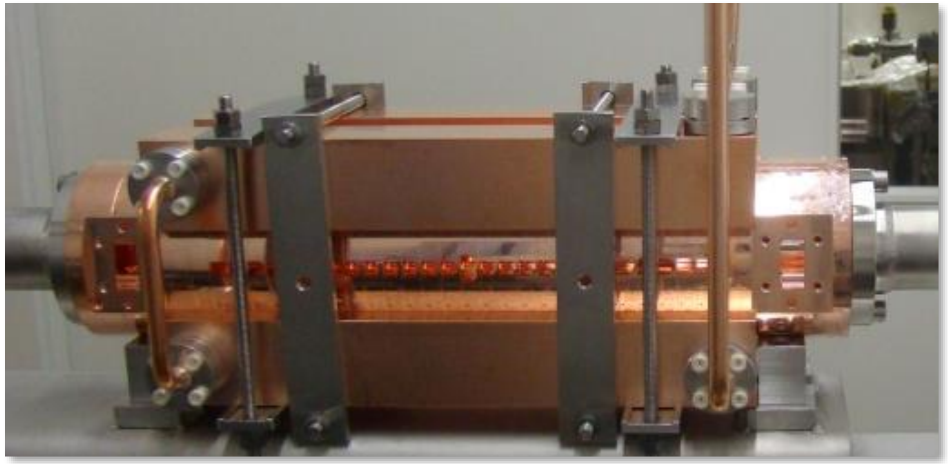
About twice the power needed to demonstrate 100 MV/m acceleration

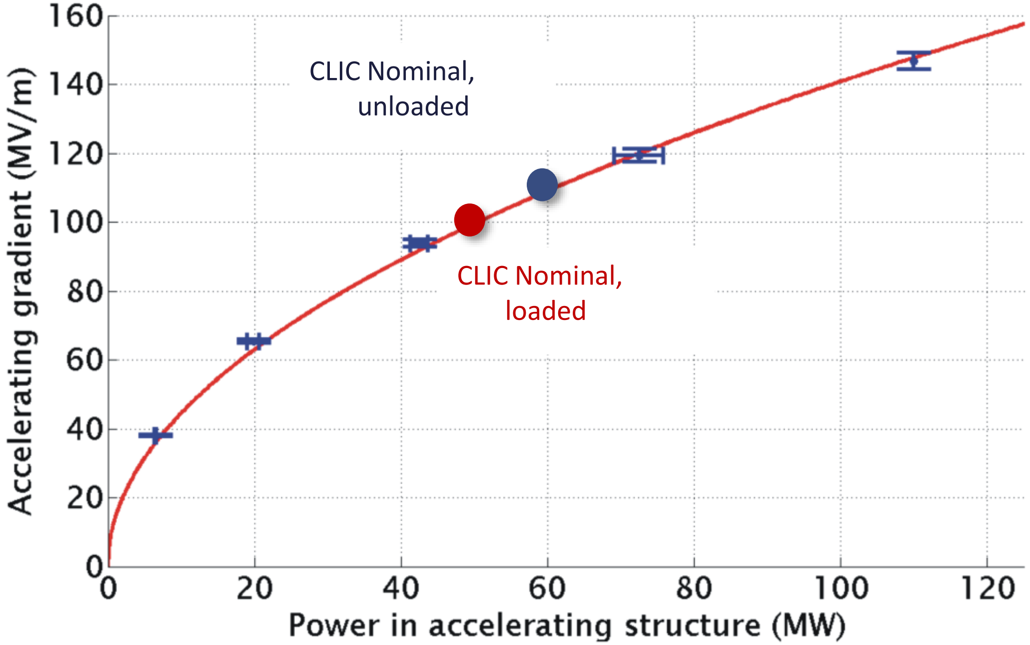
Two-Beam Acceleration demonstration in CTF3

Maximum stable probe beam acceleration measured: 31 MeV

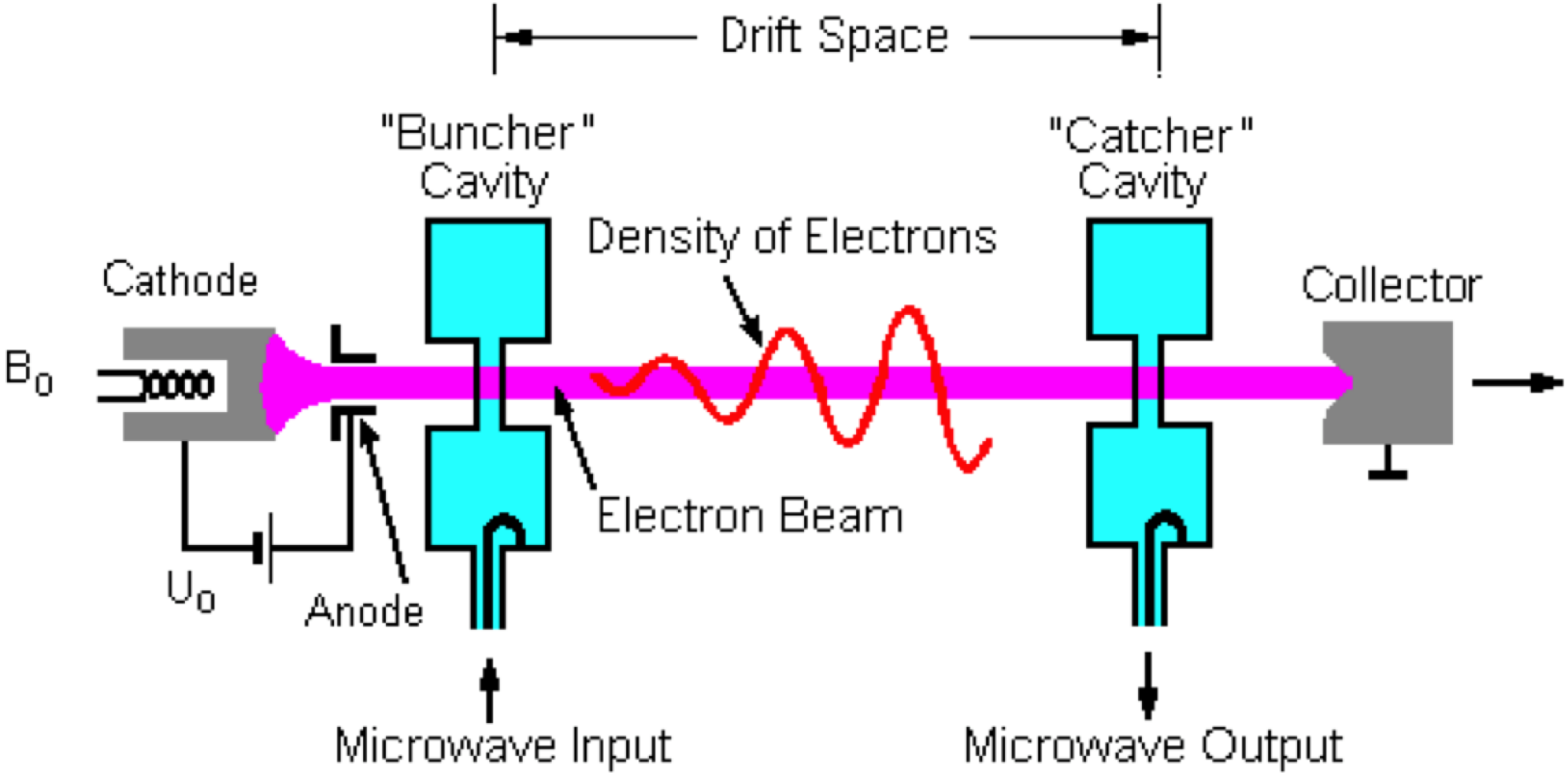
⇒ Corresponding to a gradient of **145 MV/m**







Note: Klystron



Beam is not relativistic
So that it can be bunched

ILC and CLIC Main Parameters

Parameter	Symbol [unit]	SLC	ILC	CLIC	CLIC
Centre of mass energy	E_{cm} [GeV]	92	500	380	3000
Luminosity	L [$10^{34}cm^{-2}s^{-1}$]	0.0003	1.8	1.5	6
Luminosity in peak	$L_{0.01}$ [$10^{34}cm^{-2}s^{-1}$]	0.0003	1	0.9	2
Gradient	G [MV/m]	20	31.5	72	100
Particles per bunch	N [10^9]	37	20	5.2	3.72
Bunch length	σ_z [µm]	1000	300	70	44
Collision beam size	$\sigma_{x,y}$ [nm/nm]	1700/600	474/5.9	143/2.9	40/1
Vertical emittance	$\varepsilon_{x,y}$ [nm]	3000	35	30	20*
Bunches per pulse	n_b	1	1312	352	312
Bunch distance	Δz [mm]	-	554	0.5	0.5
Repetition rate	f_r [Hz]	120	5	50	50

Luminosity and Parameter Drivers

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

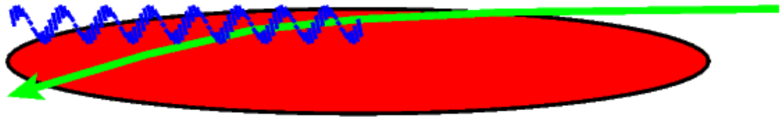
Can re-write normal luminosity formula in a slightly different way

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

Need to ensure that we can achieve each parameter

Beam-beam Effect

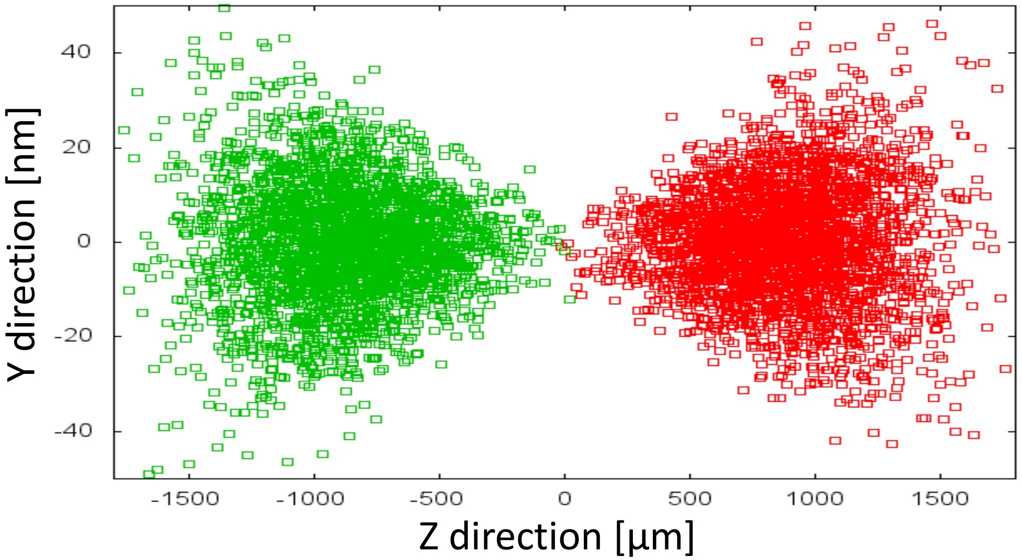
$$\mathcal{L} \propto H_D \boxed{\frac{N}{\sigma_x}} N n_b f_r \frac{1}{\sigma_y}$$



Intense beams to reach high luminosity

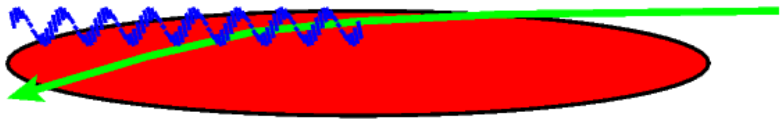
$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}$$

Beam-beam force switched off



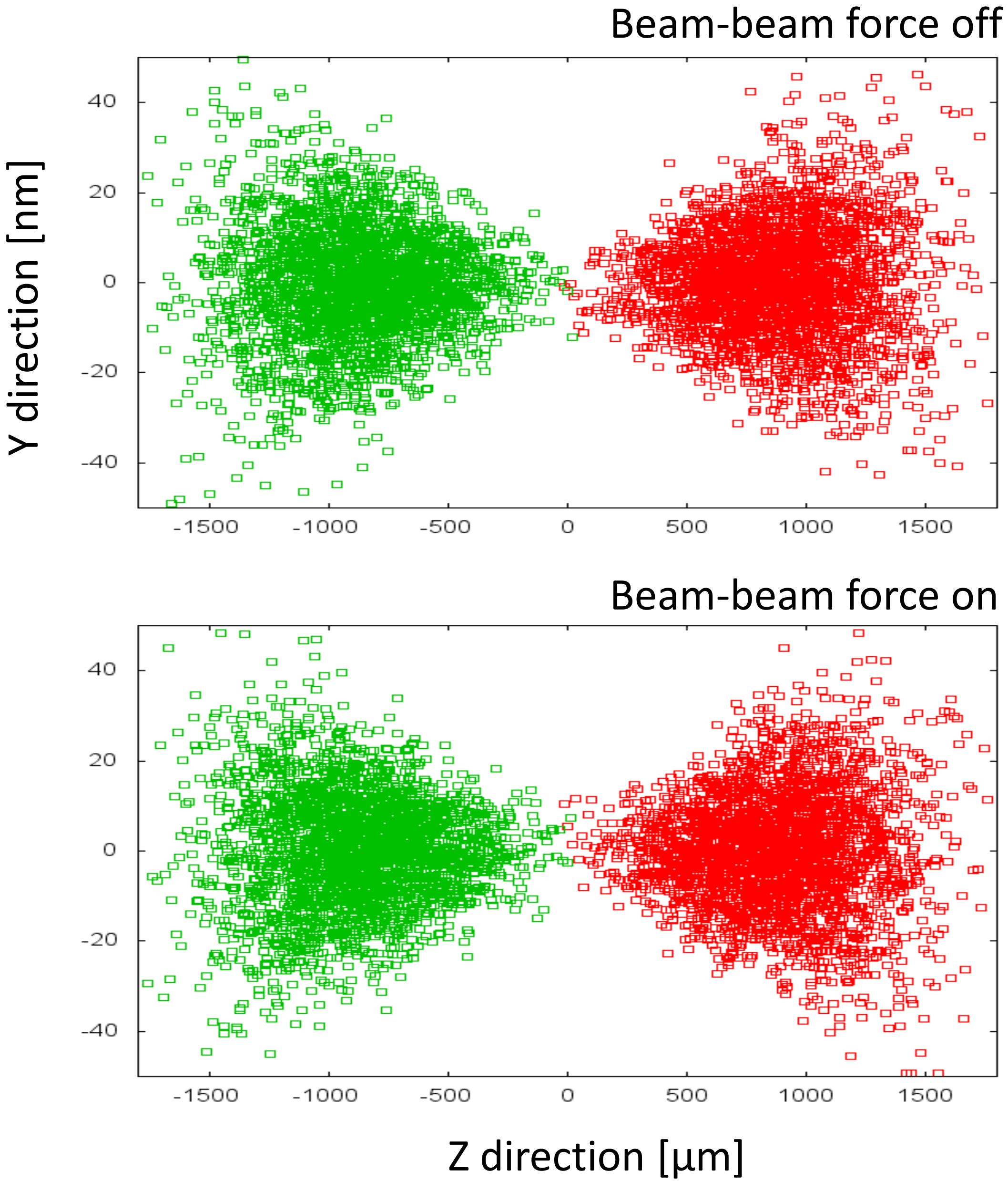
Beam-beam Effect

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



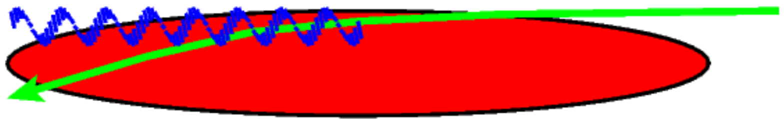
Beam focus each other

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



Beam-beam Effect

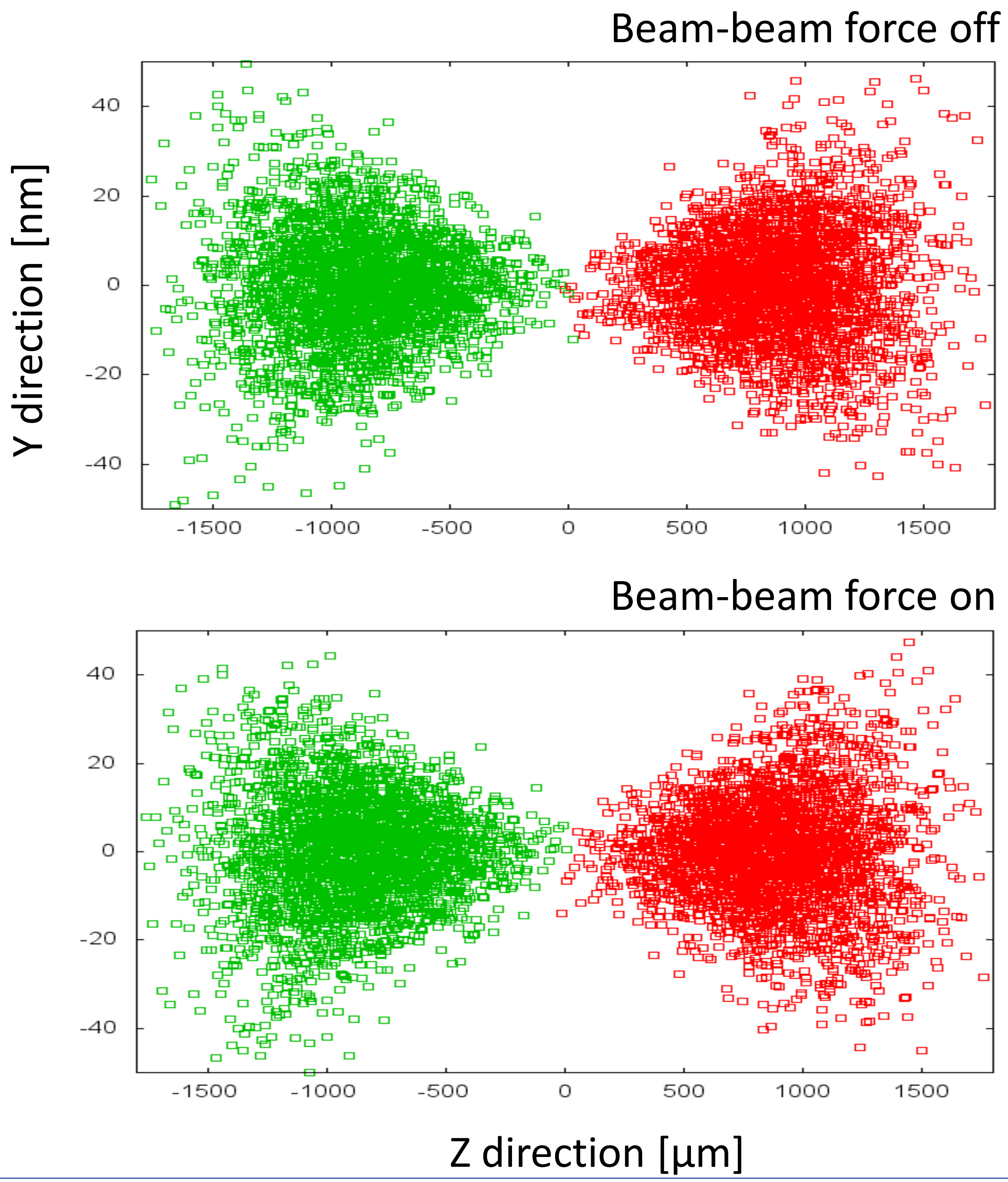
$$\mathcal{L} \propto H_D \boxed{\frac{N}{\sigma_x}} N n_b f_r \frac{1}{\sigma_y}$$



Emitt beamstrahlung

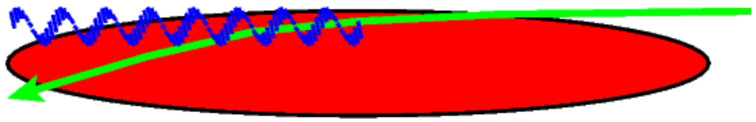
$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}$$

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

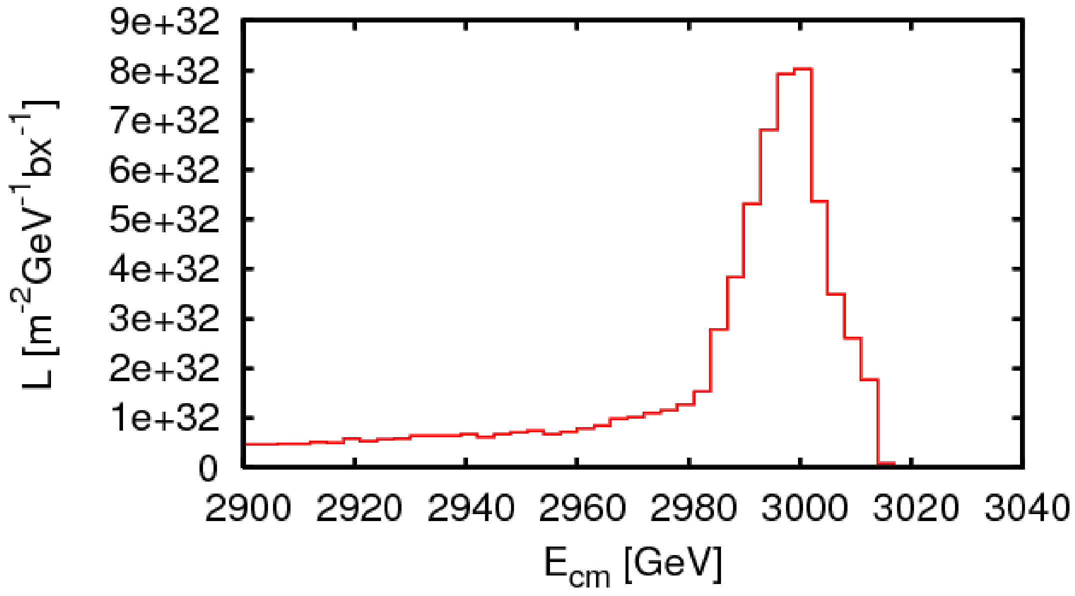


Beam-beam Effect

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



Develop luminosity spectrum

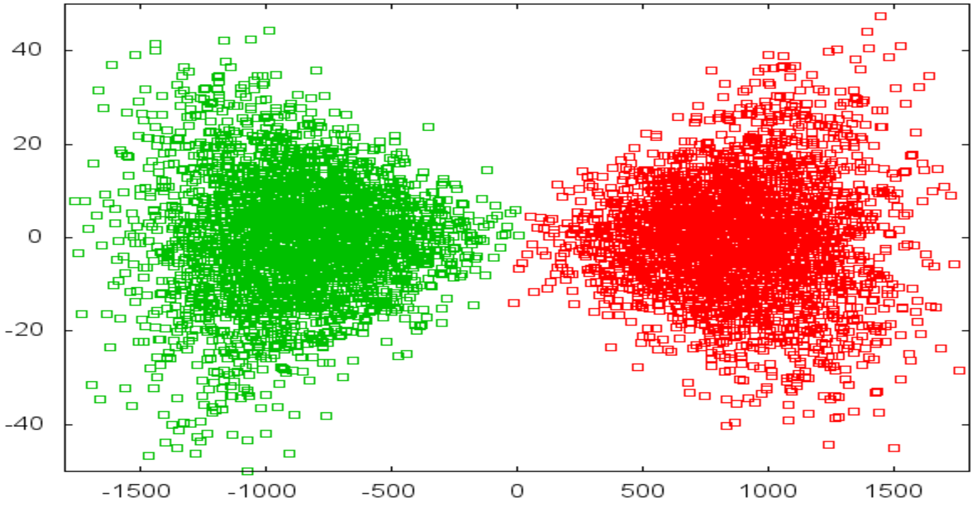


$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}$$

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

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

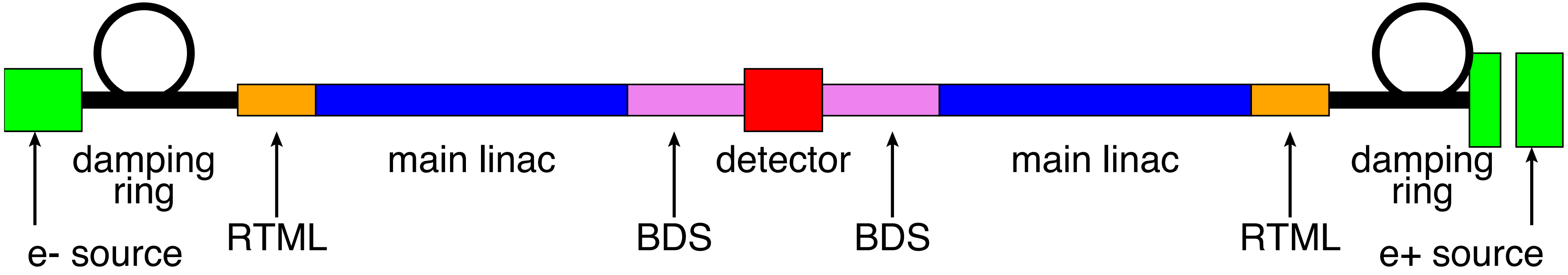
Beam-beam force on



Z direction [μm]

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

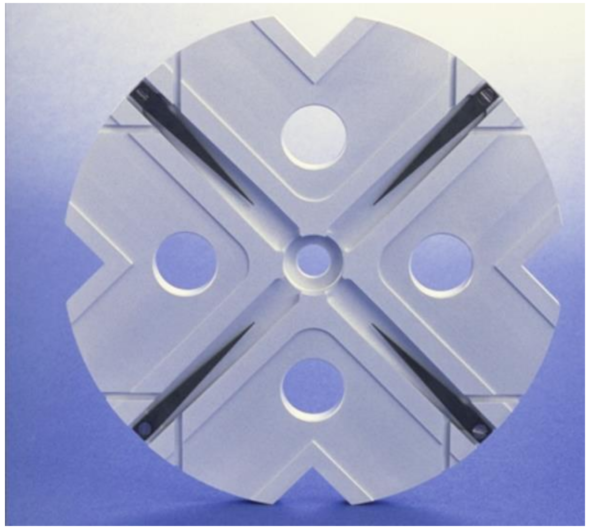
- Address the issue by
  - Clever system design
  - Clever tuning algorithms
  - Technical development of components
  - Experiments

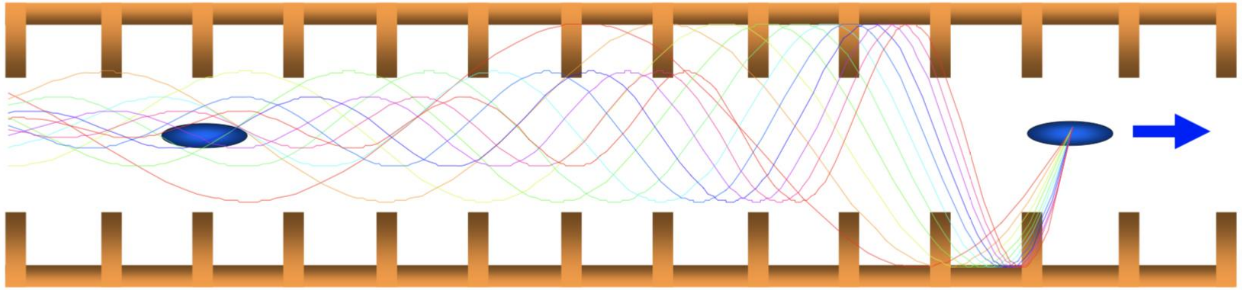
Example: Wakefields

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

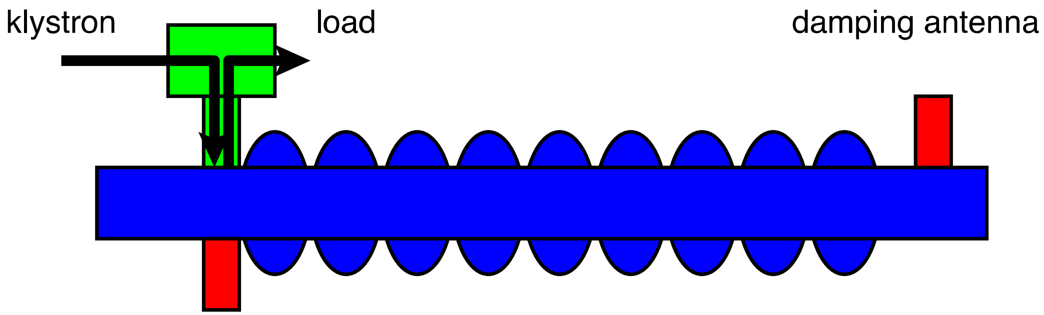
- Bunches traveling in accelerating structures induce fields which perturbs later bunches
- Bunches passing off-centre excite transverse higher order modes (HOM)
- Later bunches are kicked transversely

beam break-up ⇒ Emittance growth !!!



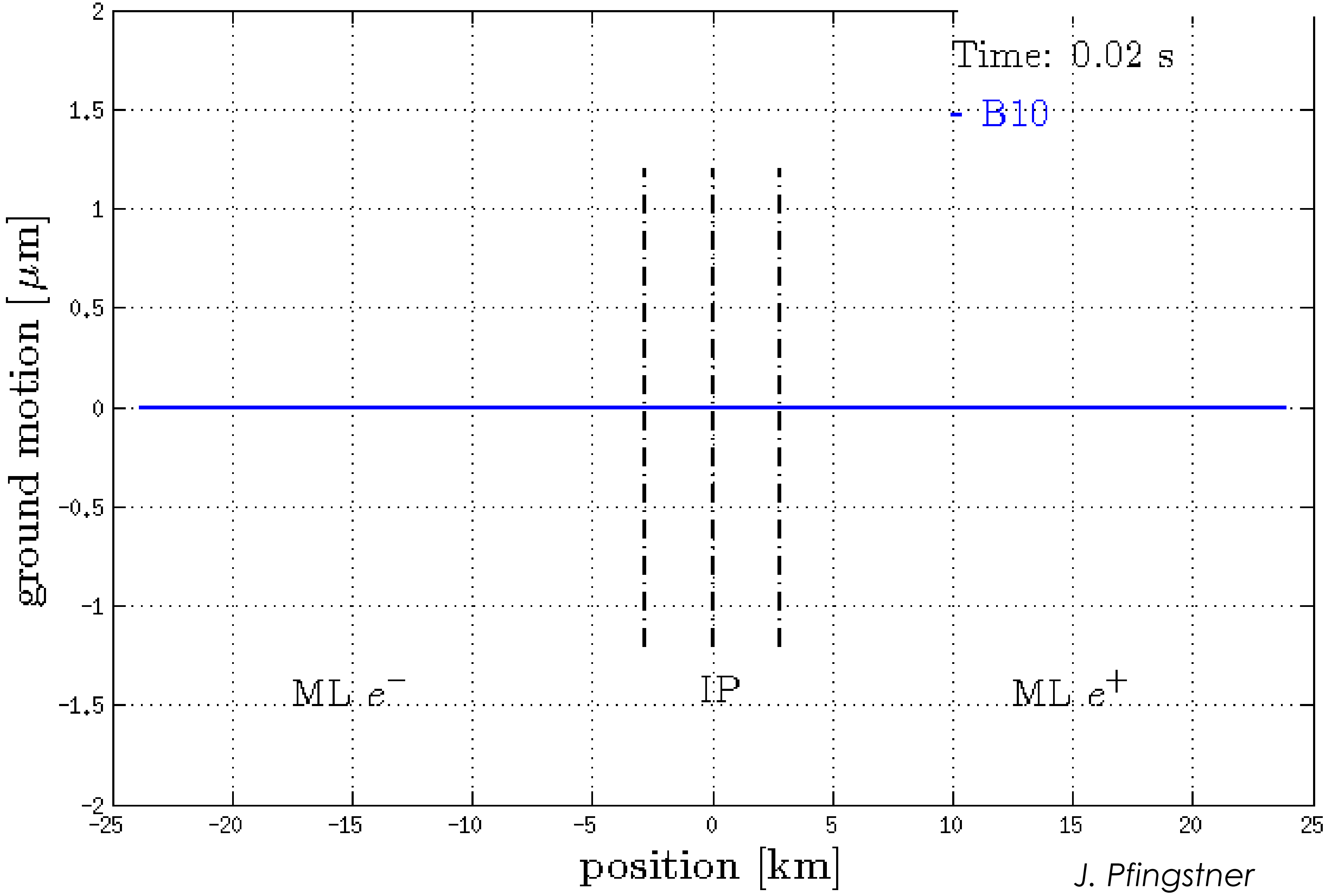


This effect is larger in higher frequency structures, hence $N=2x10^{10}$ vs. $N=4x10^{9}$



Example Issue: Ground Motion at CLIC

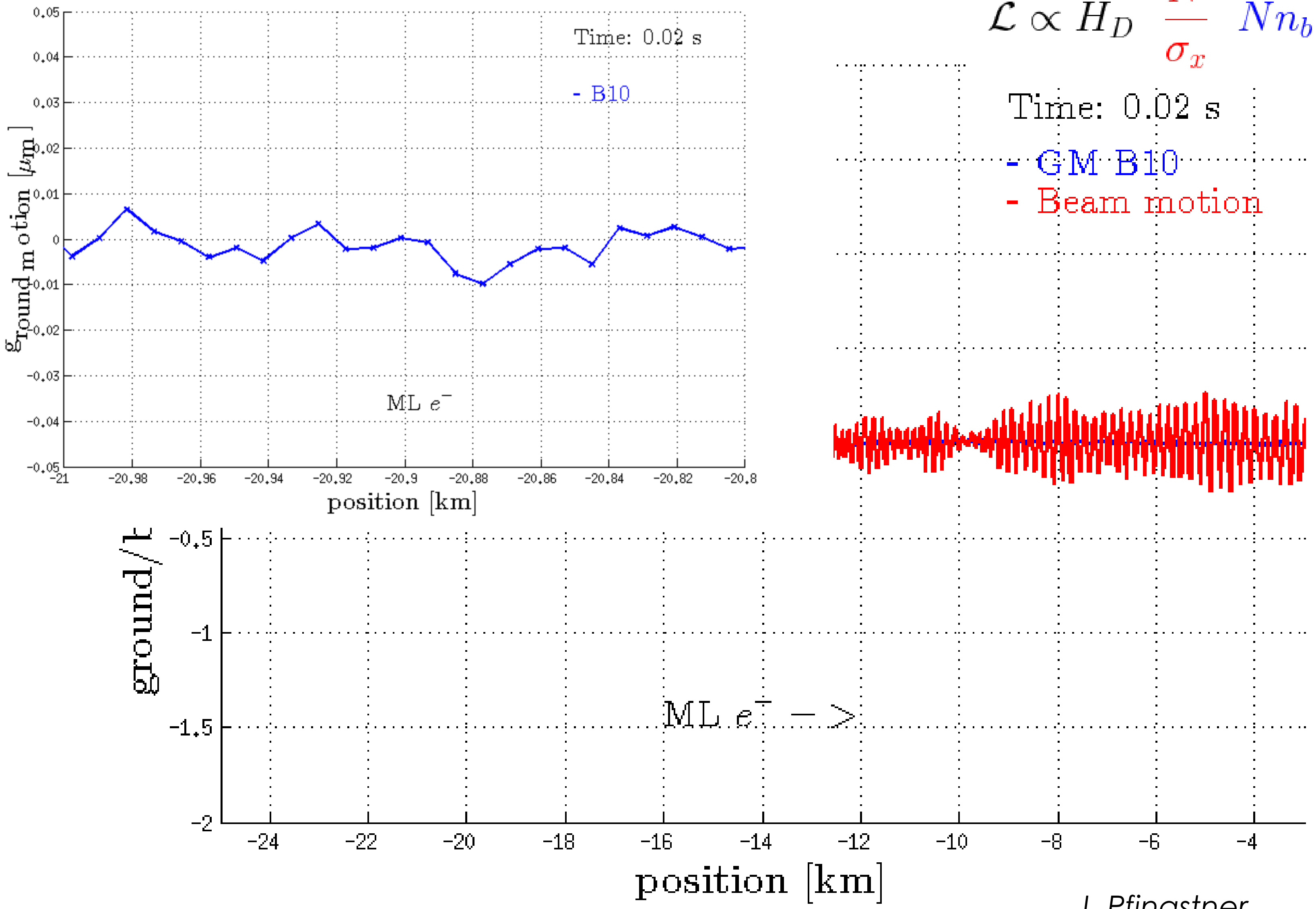
$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \boxed{\frac{1}{\sigma_y}}$$



J. Pfingstner

Resulting Beam Jitter

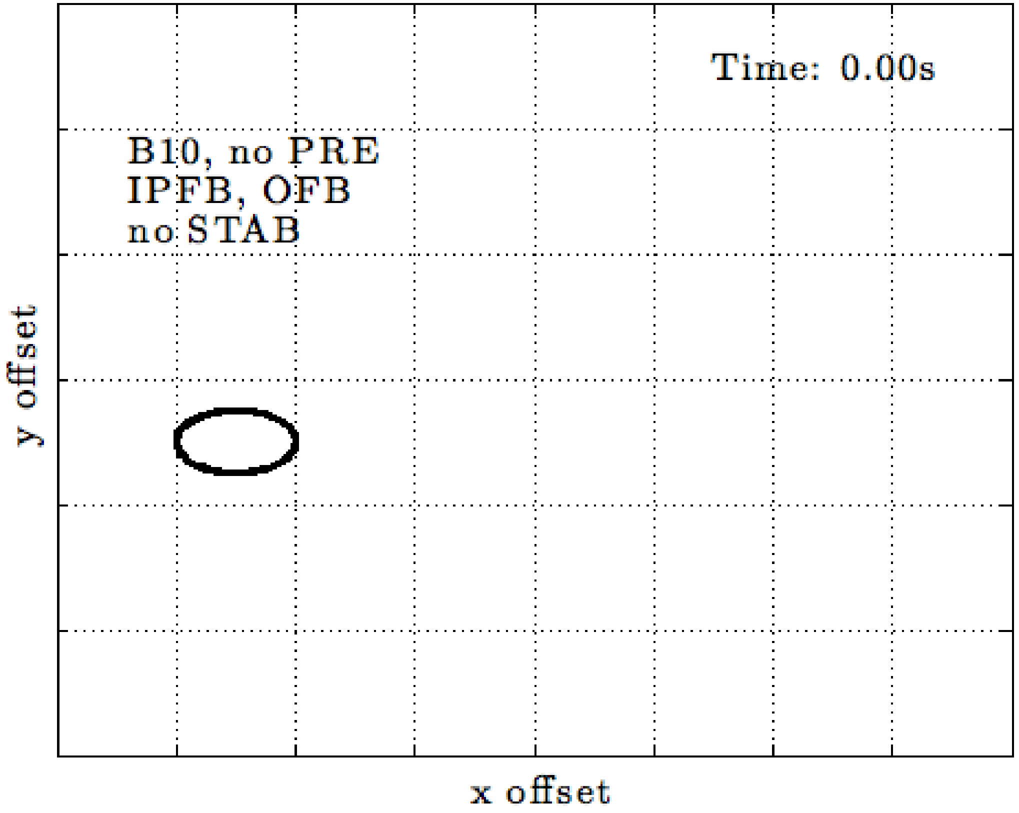
$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \boxed{\frac{1}{\sigma_y}}$$



J. Pfingstner

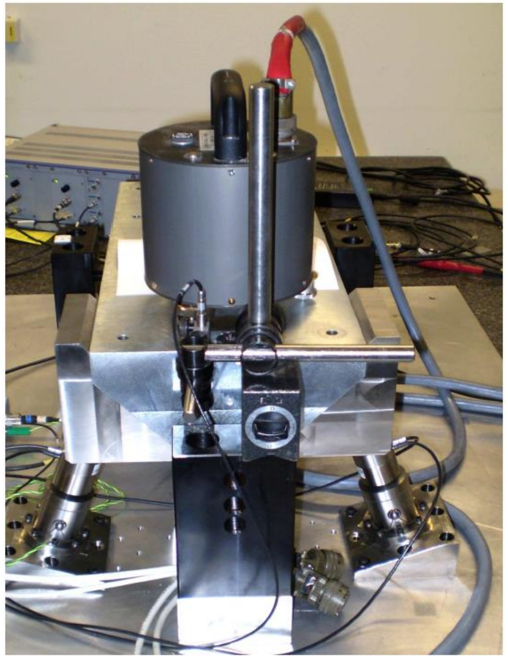
Beams at Collision

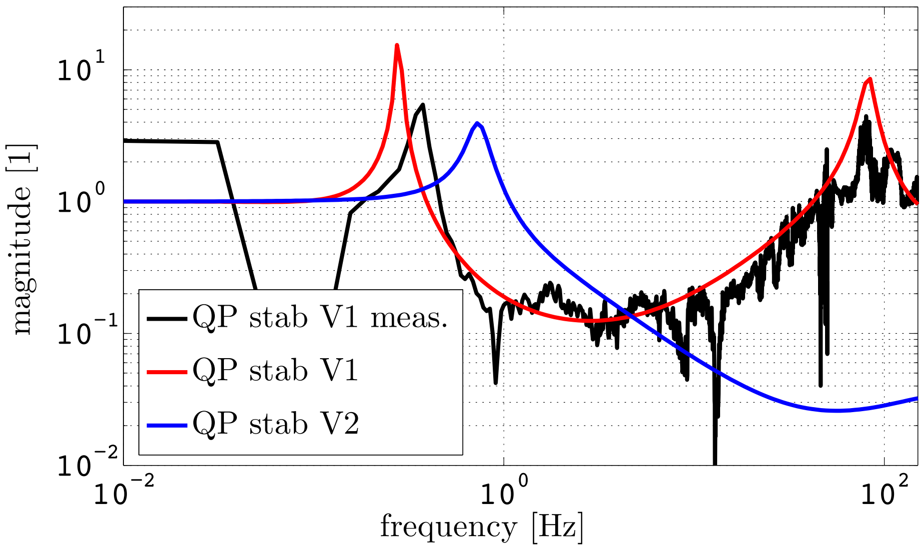
$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \boxed{\frac{1}{\sigma_y}}$$



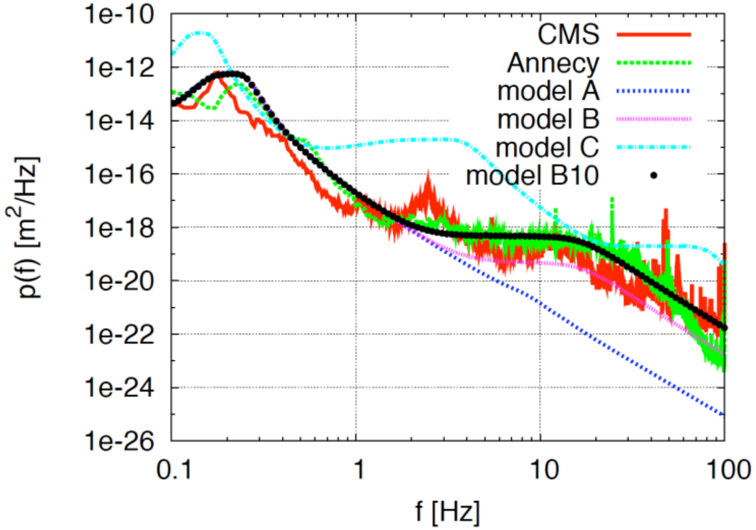
J. Pfingstner

Stabilization System





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



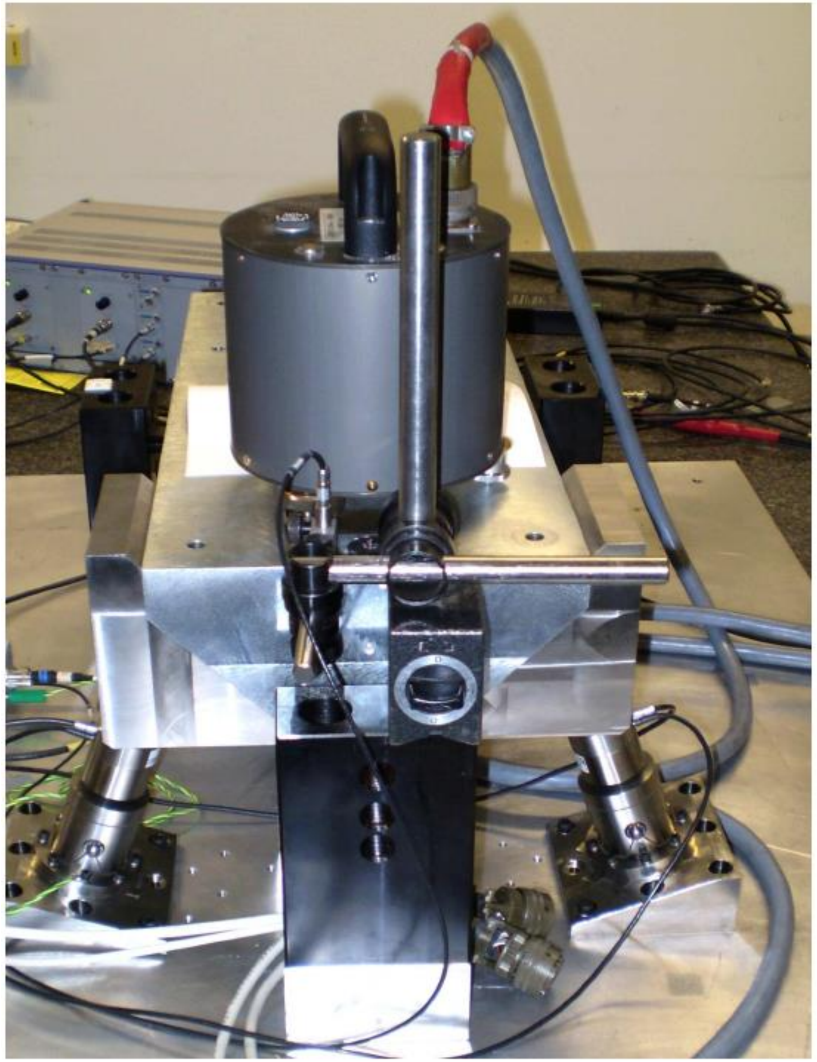
Code

Machine model
Beam-based feedback

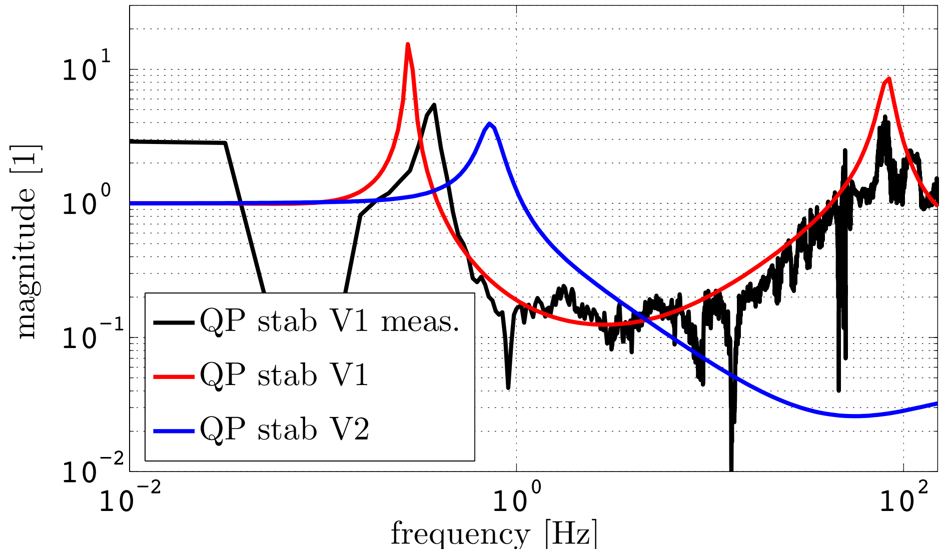
Luminosity achieved/lost

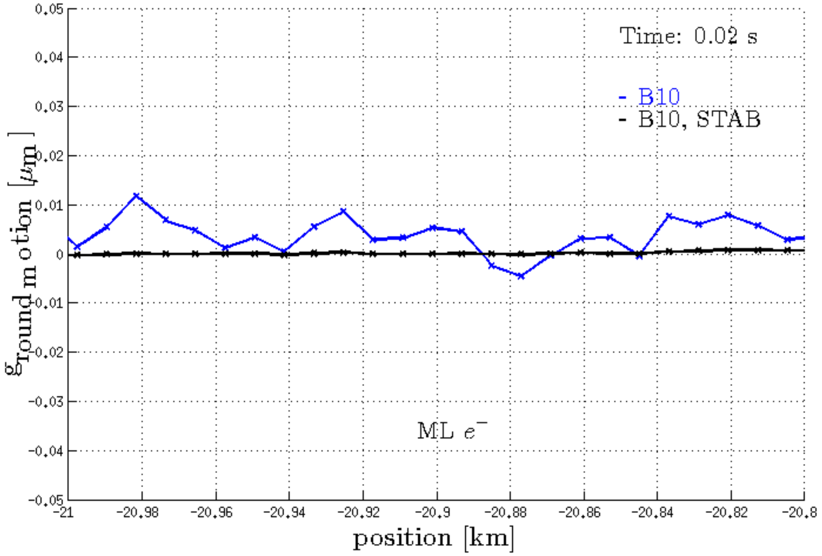
	B10
No stab.	53%/68%
Current stab.	114%/7%
Future stab.	118%/3%
Close to/better than target	

Stabilisation System



K. Artoos et al.

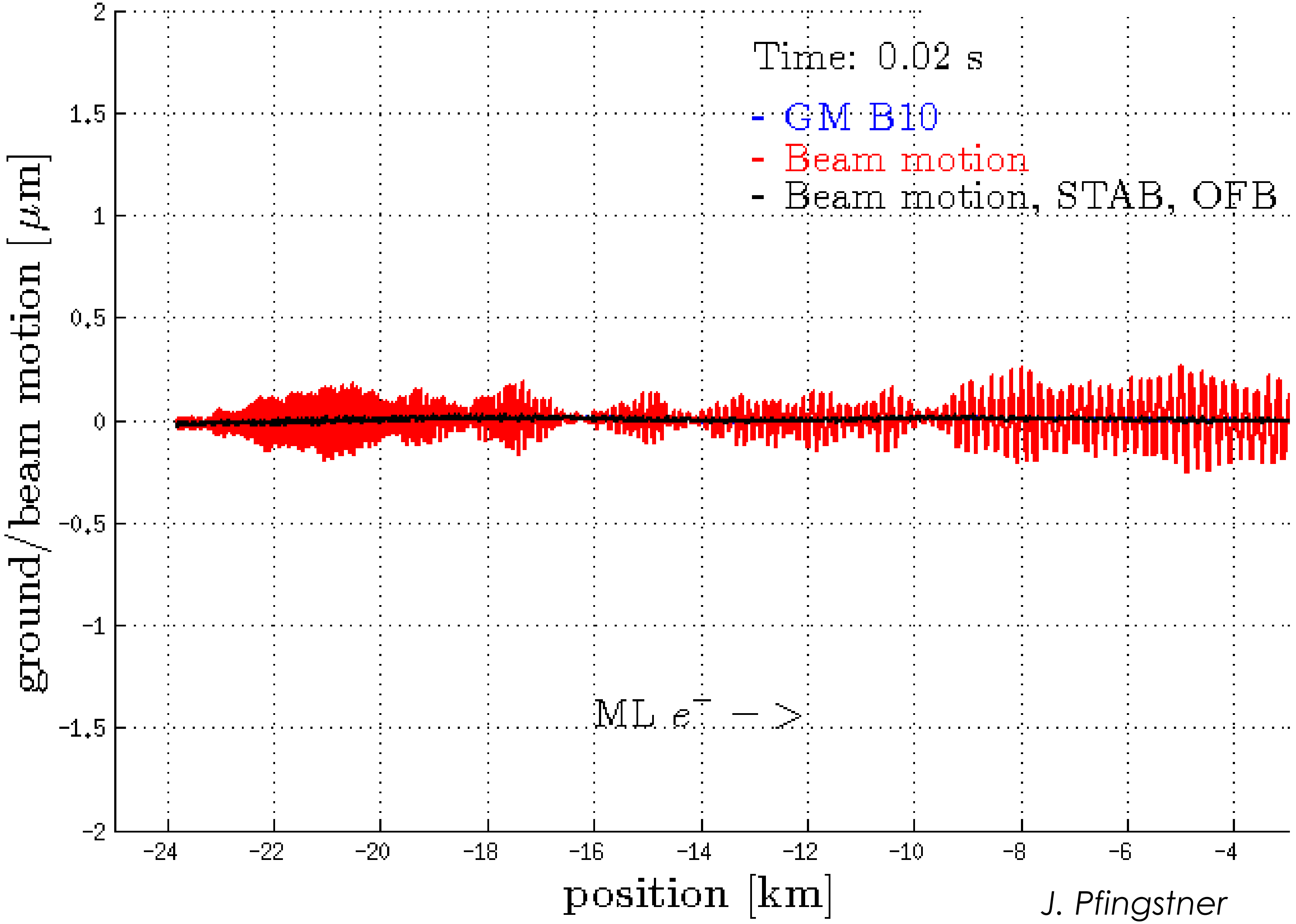




J. Snuverink, et al.

Impact of Stabilisation on Beam

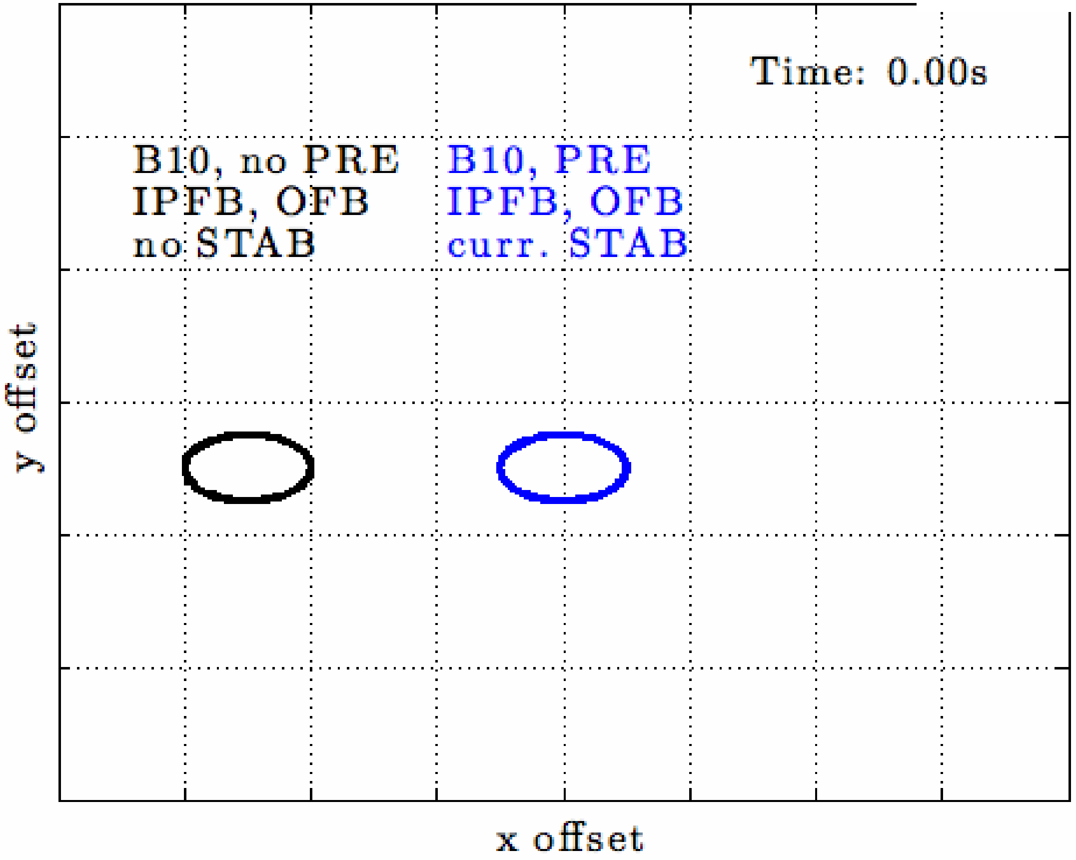
$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$



J. Pfingstner

Beam at Collision

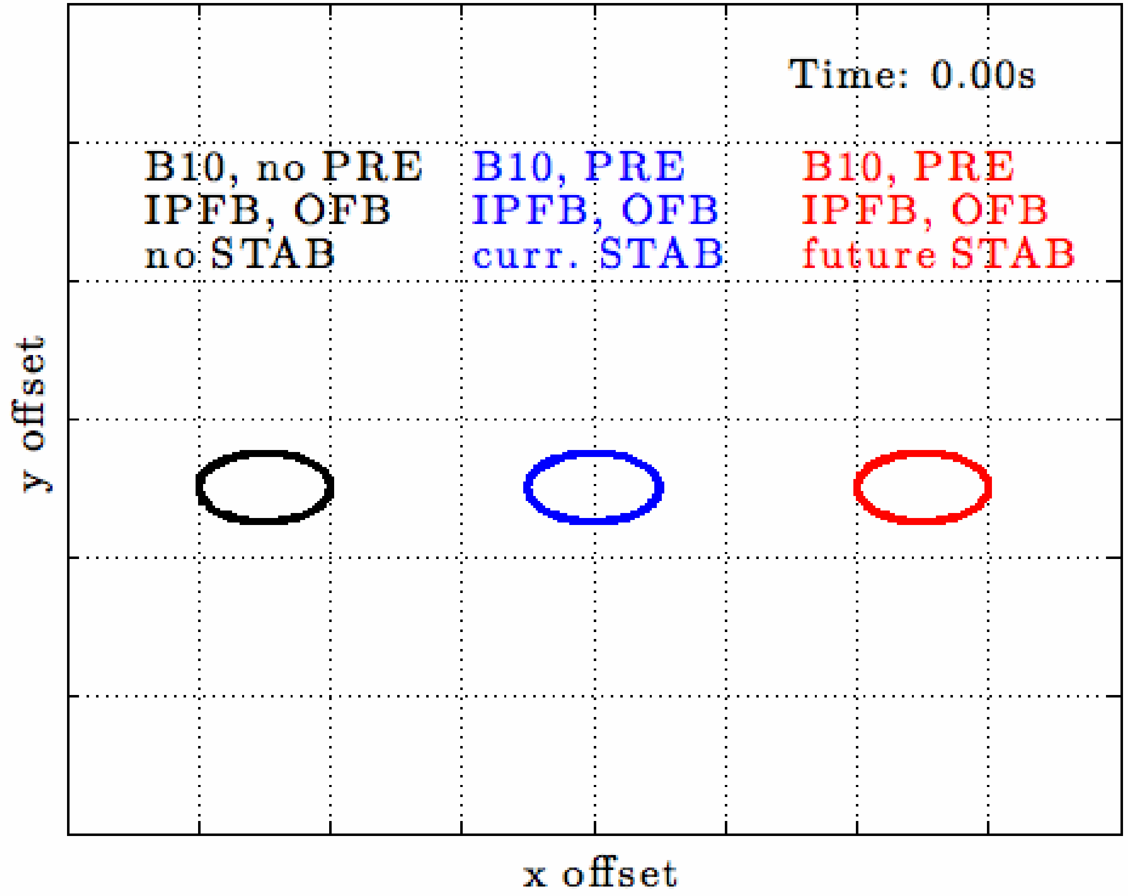
$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \boxed{\frac{1}{\sigma_y}}$$



J. Pfingstner

Beam 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

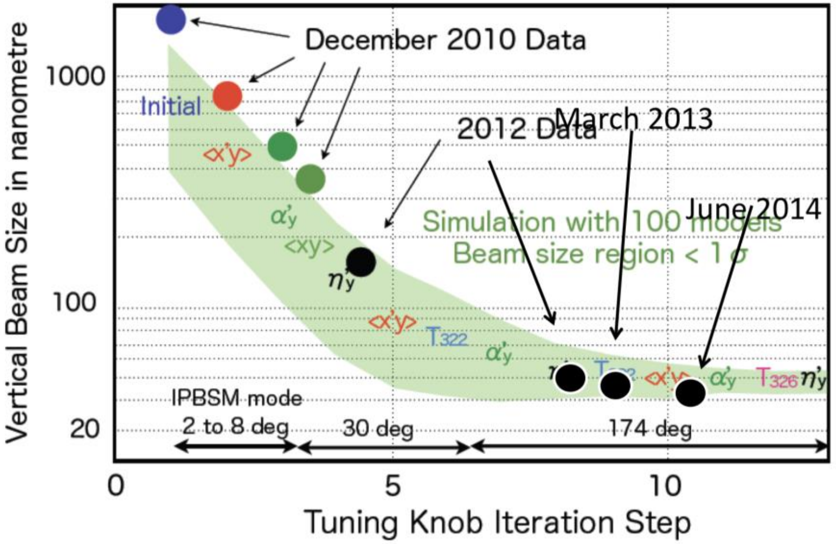
Goal1: Produce and Confirm Small Beam Size

- 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.

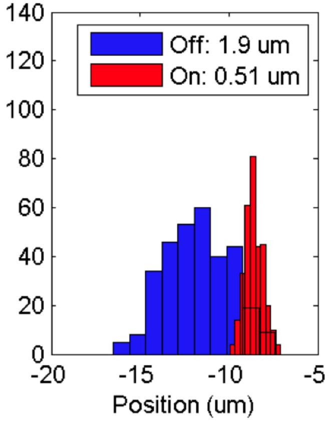
History of minimum beam size in ATF2



Common ILC/CLIC experimental activity

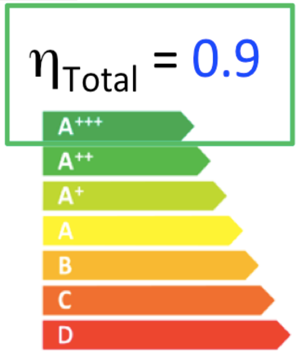
Measured beam jitter, tipically ~20% of rms beam size

Intra pulse feedback results

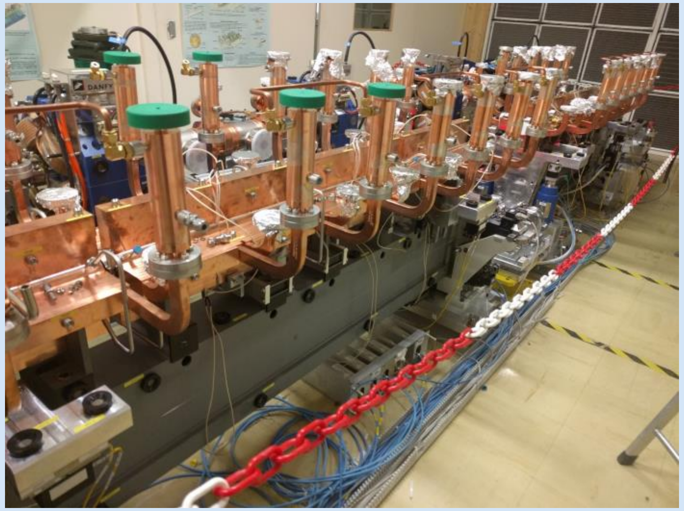


Other CLIC Technology Development

Redesign CLIC modulators and klystrons
Increase efficiency from 62% to 90%
Reduce cost (low voltage, no oil)


$\eta_{Total} = 0.9$

Permanent magnets
Use tunable permanent magnets where possible
- Quadruoles in drive beam
- Strongest permanent magnet developed in UK



New module design
Reduce cost of mechanical system and control

Klystron-based first energy stage
As alternative

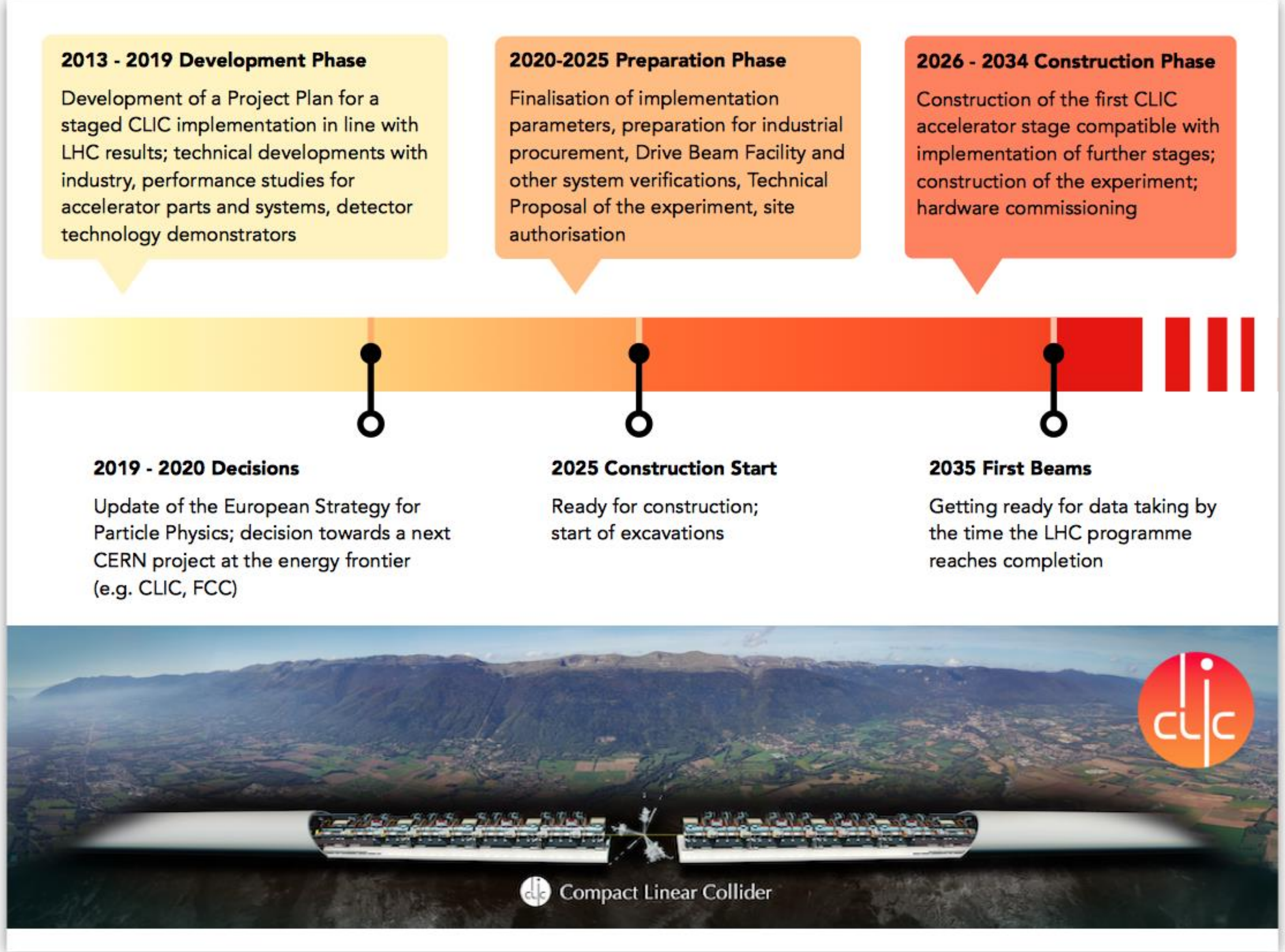
Main beam injector
e.g. halved power for positron production

Instrumentation
Further improvements

Active alignment
Further improvements

And many more …

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

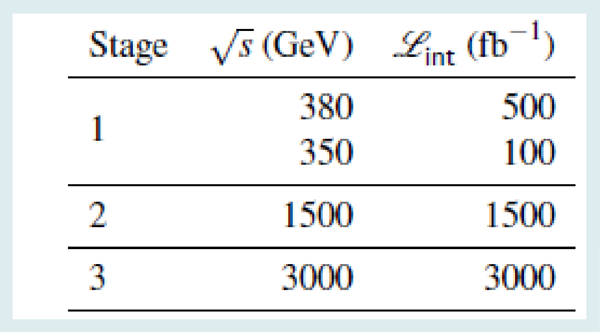
Ready for construction; start of excavations

2035 First Beams

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

Compact Linear Collider

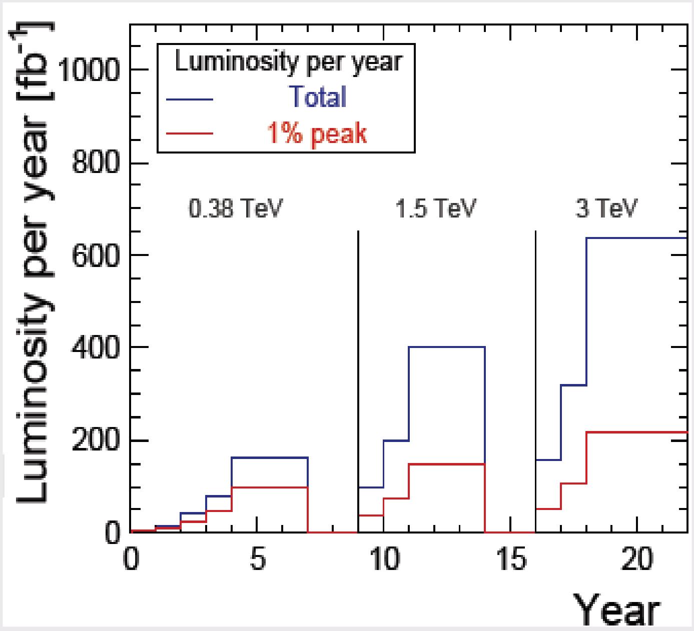
CLIC Staged Scenario



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

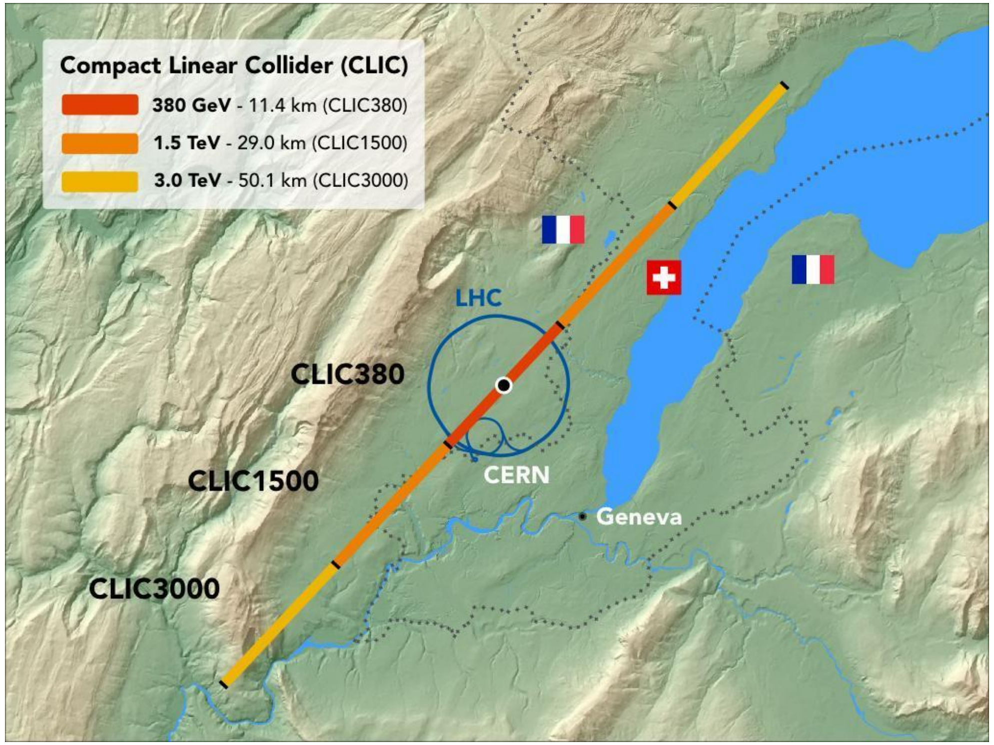
Luminosity targets from Physics Study group

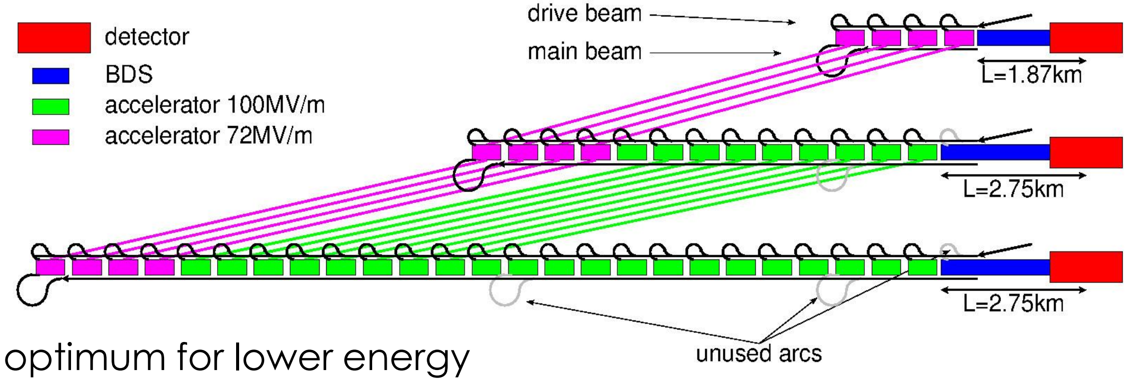
Hopefully input from LHC



Luminosity evolution

Central complex on Prevessin site





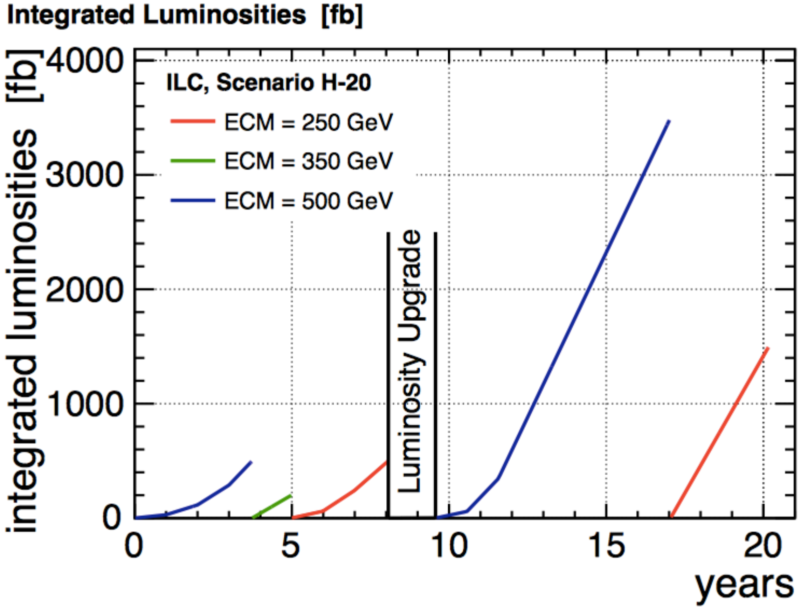
Lower gradient optimum for lower energy

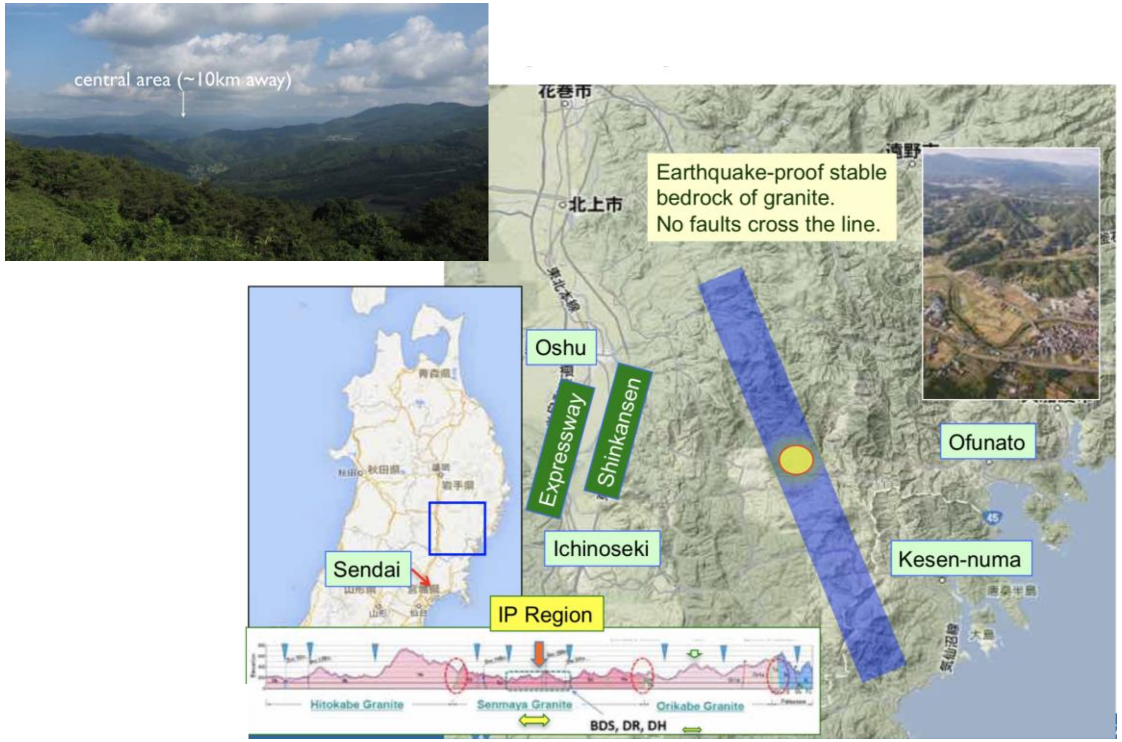
ILC Scenarios

Waiting for Japan to make a commitment

- Site identified and being investigated
- But executive has to endorse project

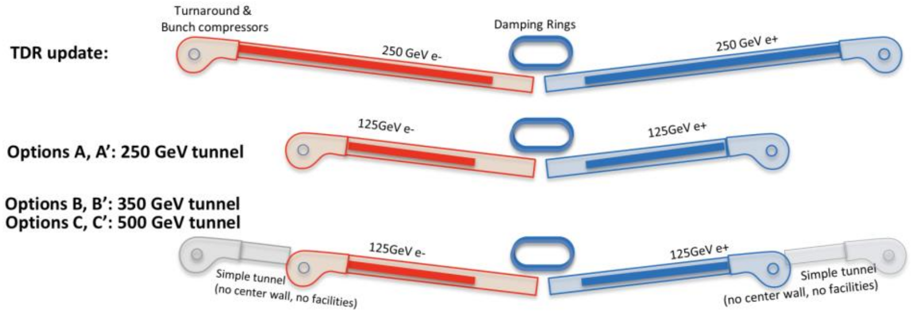
Baseline 500 GeV running example





Cost is a concern

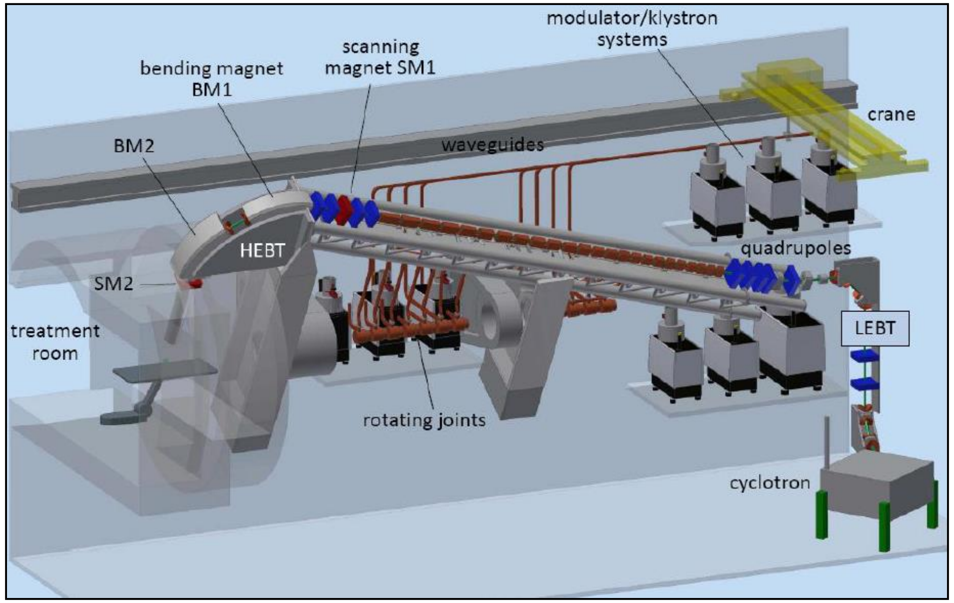
Project at 250 GeV cms is now being proposed

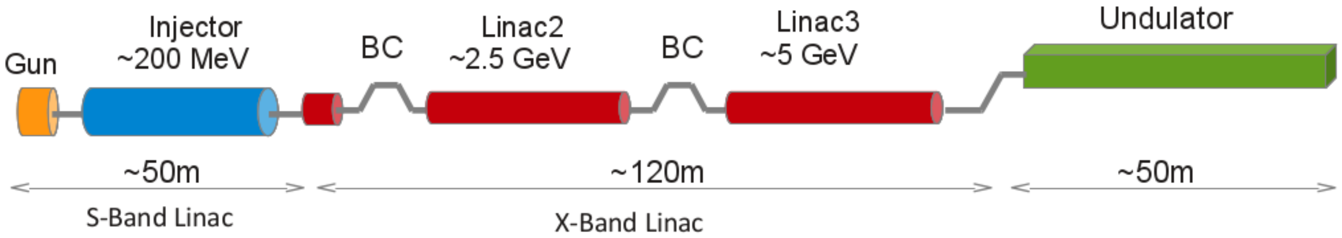


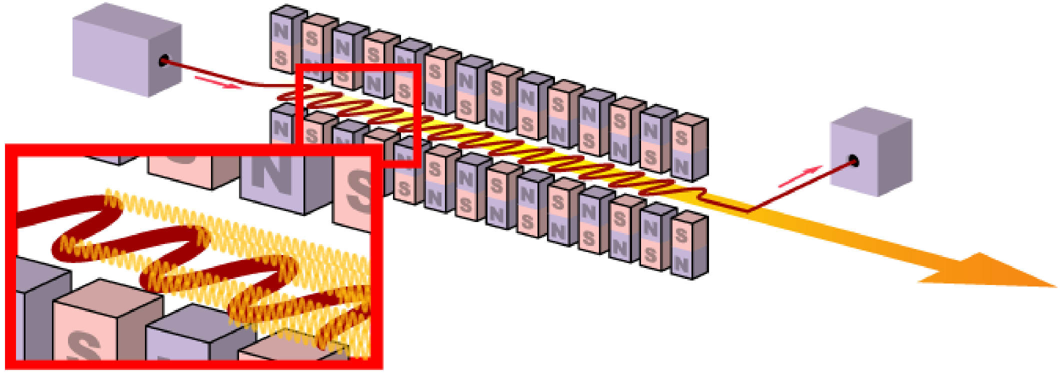
Note: Technology Transfer

The technology developed for linear colliders is useful for other fields, e.g.

- FELs (Examples: European X-FEL in Hamburg, LCLS at SLAC, SACLA in Japan, Swiss FEL, …)
- Medical facilities
- Safety
- Industrial applications







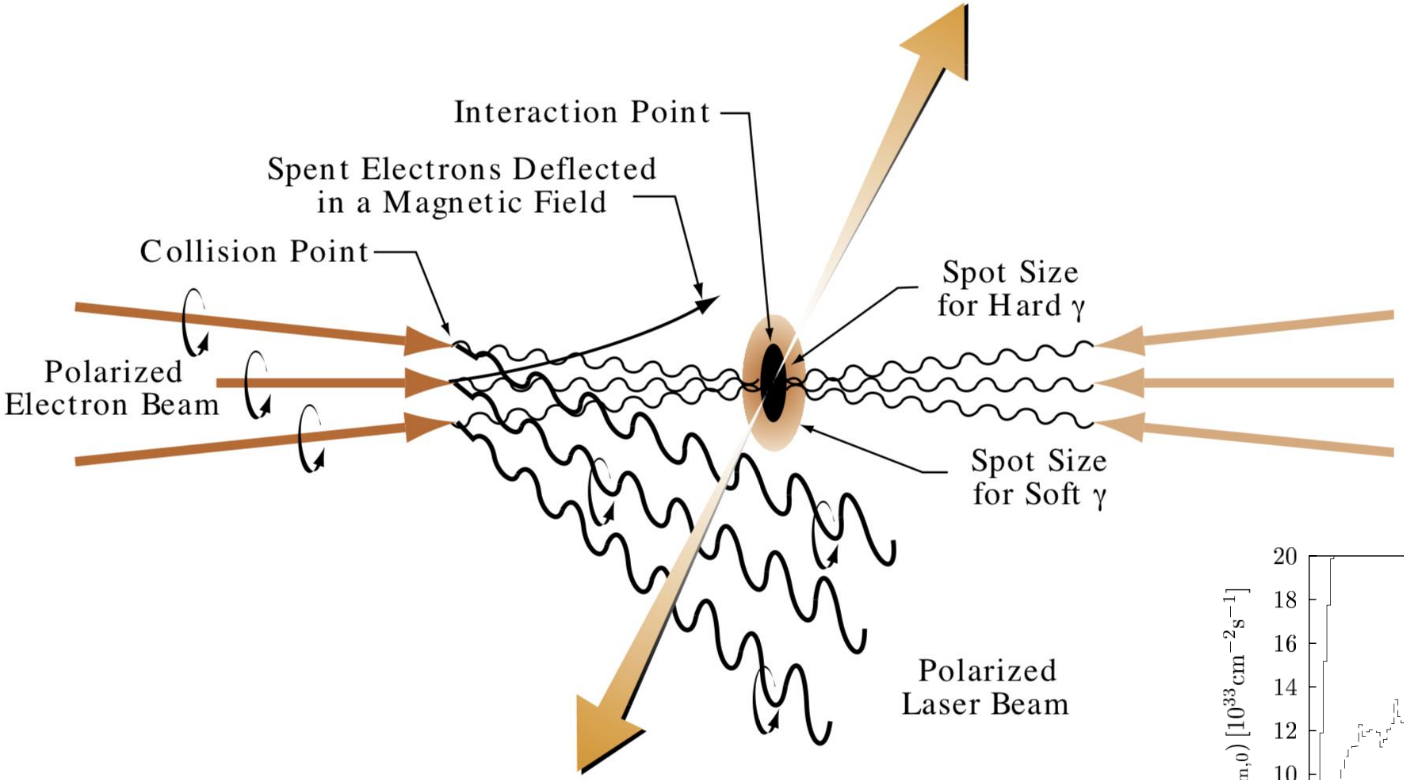
Note: Gamma-gamma Collider Concept

Based on e^-e^- collider

Collide electron beam with laser beam before the IP

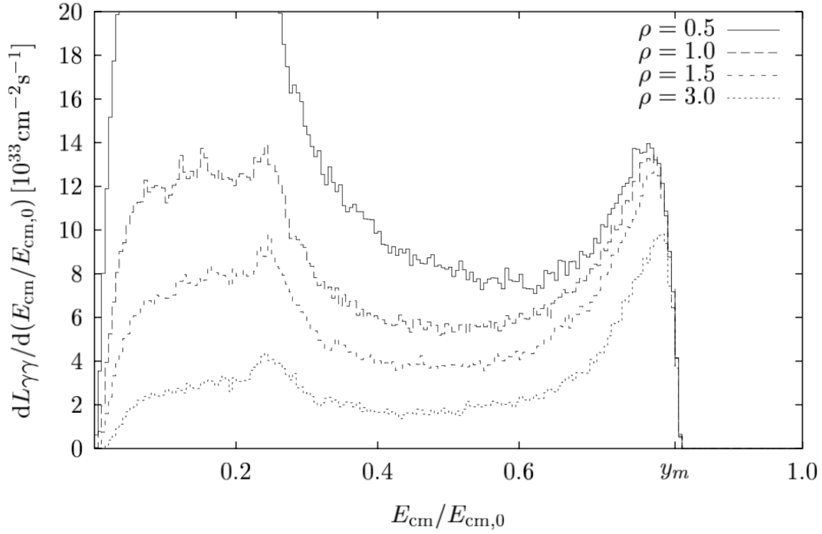
$$x = \frac{4E_0\hbar\omega_0}{m^2c^4}$$

$$\hbar\omega_m = \frac{x}{x+1}E_0$$

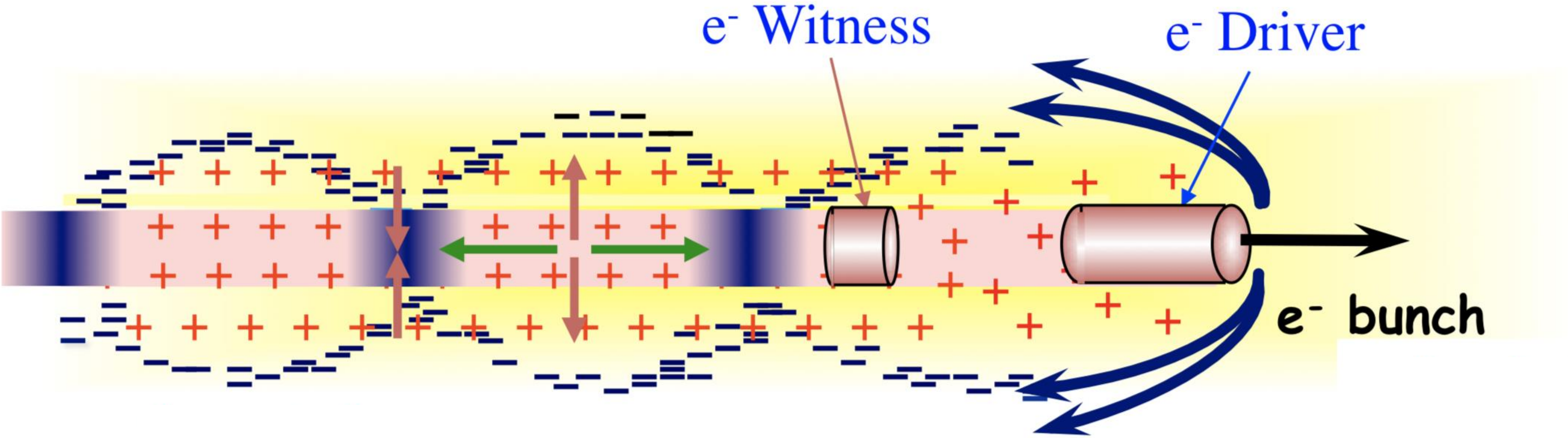


Backscattered photons form a spectrum

Practical maximum energy is 83% of electron energy



Note: Plasma Acceleration



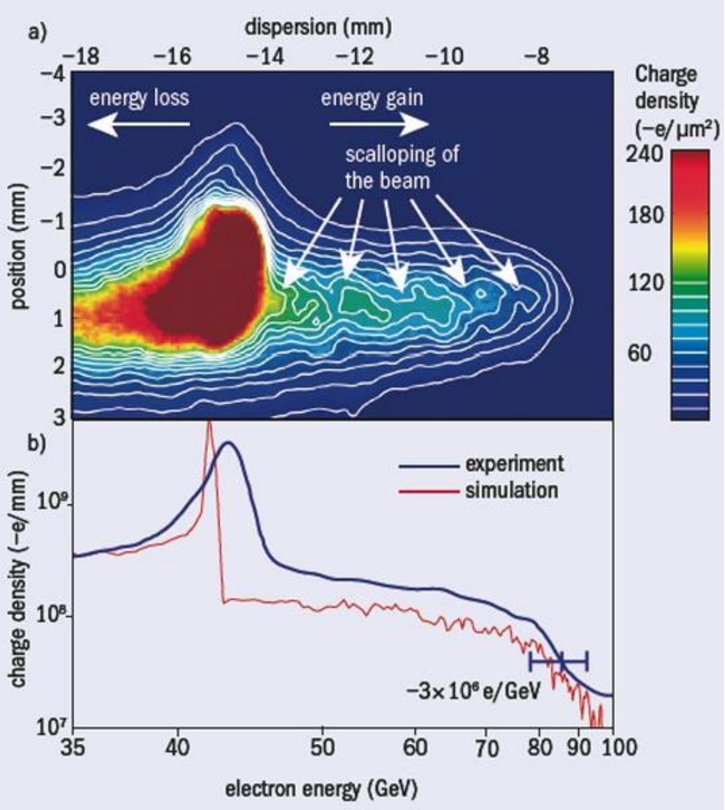
Plasma can be generated by electron beam, proton beam or laser beam
Plasma can sustain large electrical fields

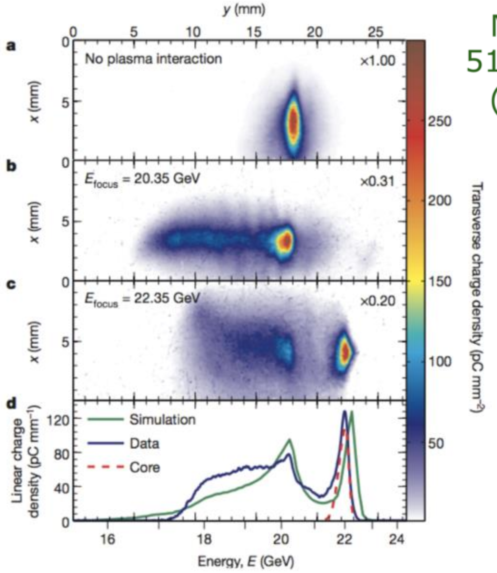
Examples of Achieved Accelerations

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)



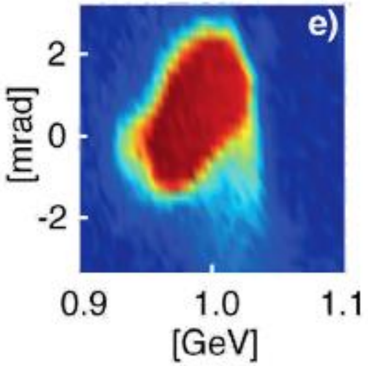


Litos, Nature 515(6),92 (2014)

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)

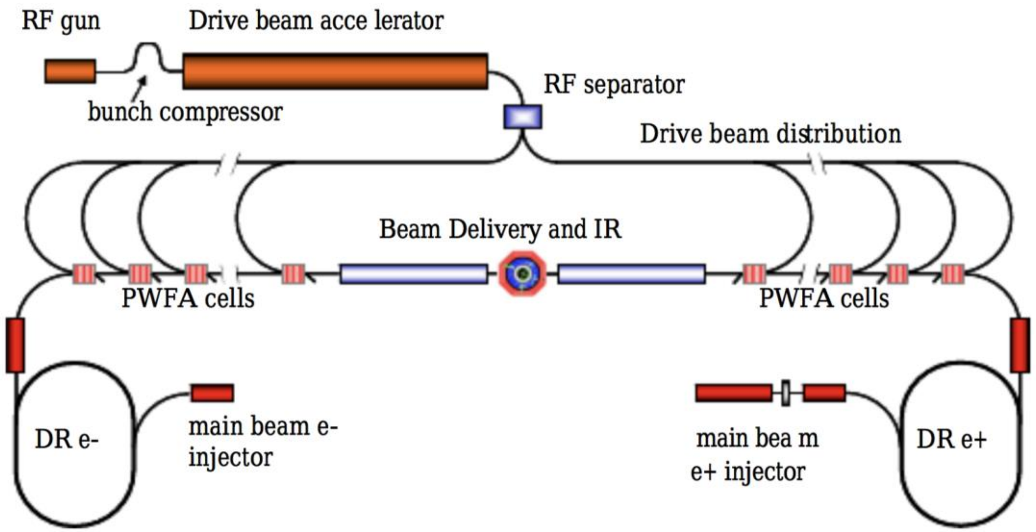
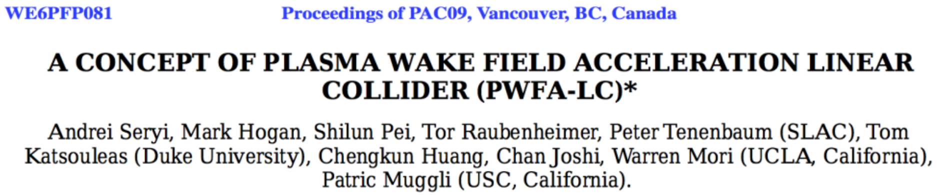


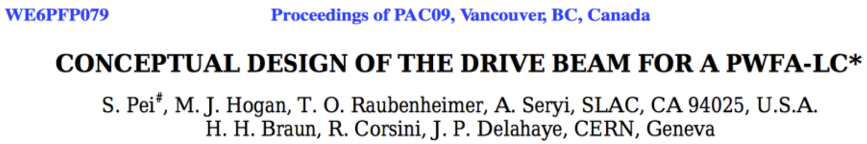
Fig. 1: Concept for a multi-stage PWFA Linear Collider.



WE6PFP081 **Proceedings of PAC09, Vancouver, BC, Canada**

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

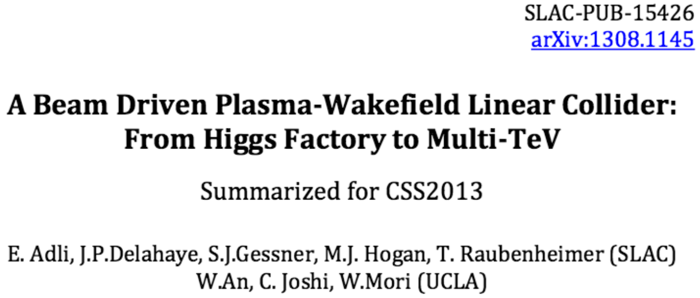
Andrei Seryi, Mark Hogan, Shilun Pei, Tor Raubenheimer, Peter Tenenbaum (SLAC), Tom Katsouleas (Duke University), Chengkun Huang, Chan Joshi, Warren Mori (UCLA, California), Patric Muggli (USC, California).



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

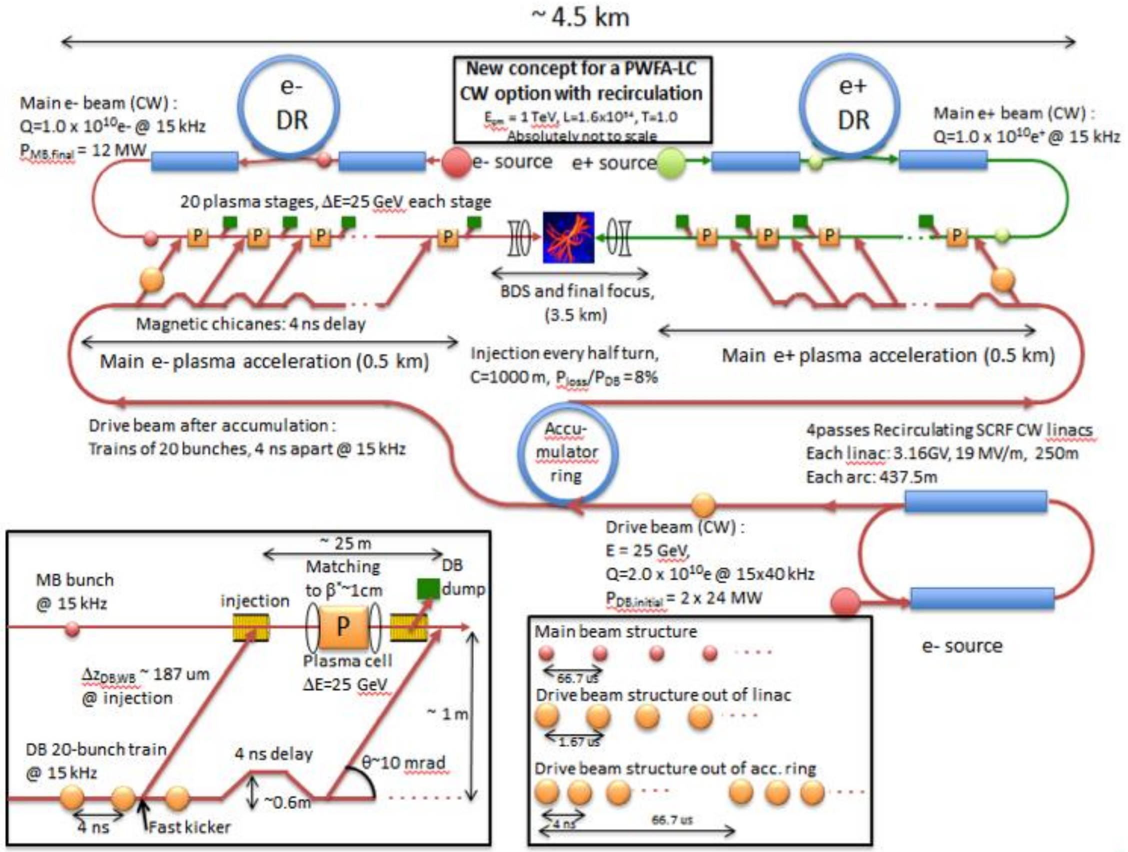


SLAC-PUB-15426
arXiv:1308.1145

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

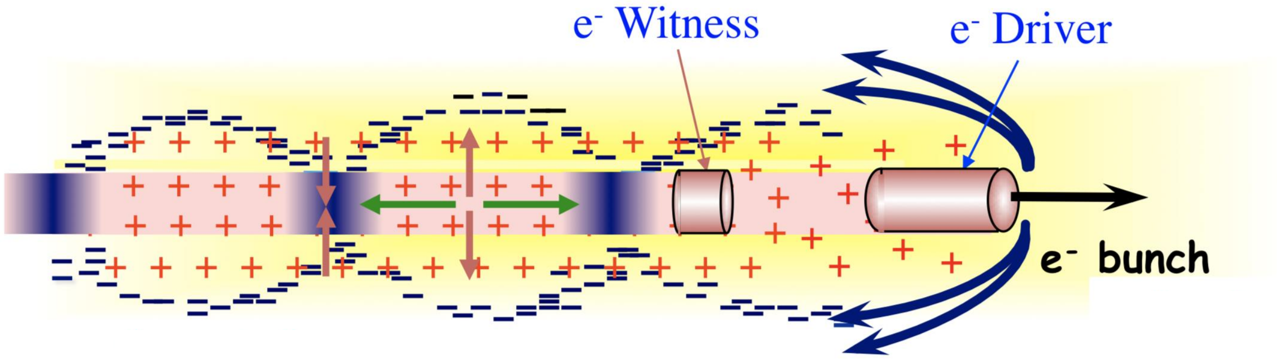
Summarized for CSS2013

E. Adli, J.P.Delahaye, S.J.Gessner, M.J. Hogan, T. Raubenheimer (SLAC)
W.An, C. Joshi, W.Mori (UCLA)



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

Note: ILC TDR

Volume 1 - Executive Summary

Download the pdf (9.5 MB)

Volume 2 - Physics

Download the pdf (9.5 MB)

Volume 3 - Accelerator

Part I:
R&D in the Technical Design Phase

Download the pdf (91 MB)

Volume 3 - Accelerator

Part II:
Baseline Design

Download the pdf (72 MB)

Volume 4 - Detectors

Download the pdf (66 MB)

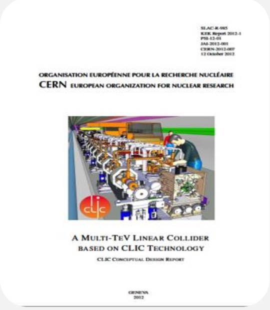
From Design to Reality

Download the pdf (5.5 MB)

Visit the web site

http://www.linearcollider.org/ILC/Publications/Technical-Design-Report

The CLIC CDR documents



SLAC-R-985
KEK Report 2012-1
PSI-12-01
JAI-2012-001
CERN-2012-007
12 October 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

A Multi-TeV Linear Collider
based on CLIC Technology
CLIC Conceptual Design Report

GENEVA
2012

Vol 1: The CLIC accelerator and site facilities

- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- https://edms.cern.ch/document/1234244/

ANL-HEP-TR-12-01
CERN-2012-003
DESY 12-008
KEK Report 2011-7
14 February 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Physics and Detectors at CLIC
CLIC Conceptual Design Report

GENEVA
2012

Vol 2: Physics and detectors at CLIC

- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- http://arxiv.org/pdf/1202.5940v1

ANL-HEP-TR-12-51
CERN-2012-XXX
KEK Report 2012-2
MPP-2012-115
August 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

The CLIC Programme:
towards a staged e^+e^- Linear Collider
exploring the Terascale
CLIC Conceptual Design Report

GENEVA
2012

Vol 3: “CLIC study summary”

- Summary and available for the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
- Proposing objectives and work plan of post CDR phase (2012-16)
- http://arxiv.org/pdf/1209.2543v1

In addition a shorter overview document was submitted as input to the European Strategy update, available at: http://arxiv.org/pdf/1208.1402v1

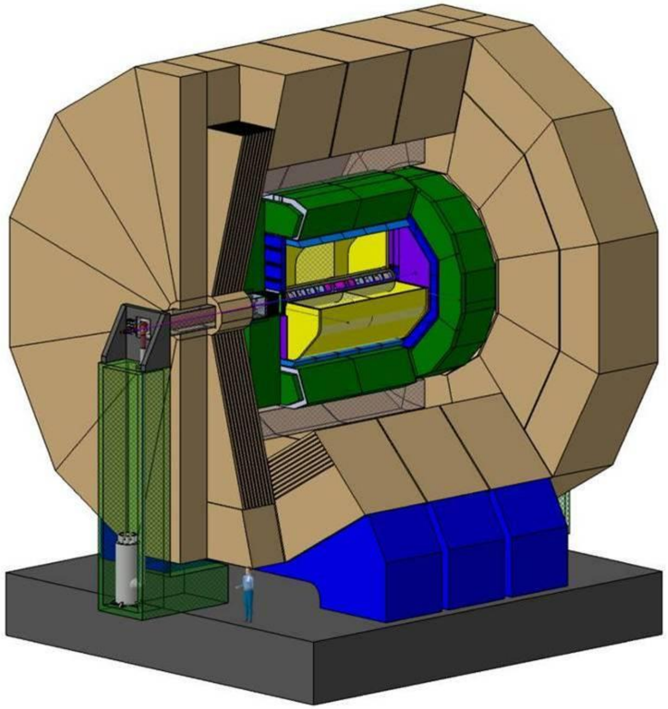
An input document to Snowmass 2013 has also been submitted: http://arxiv.org/abs/1305.5766

HANKS FOR YOUR ATTENTIC

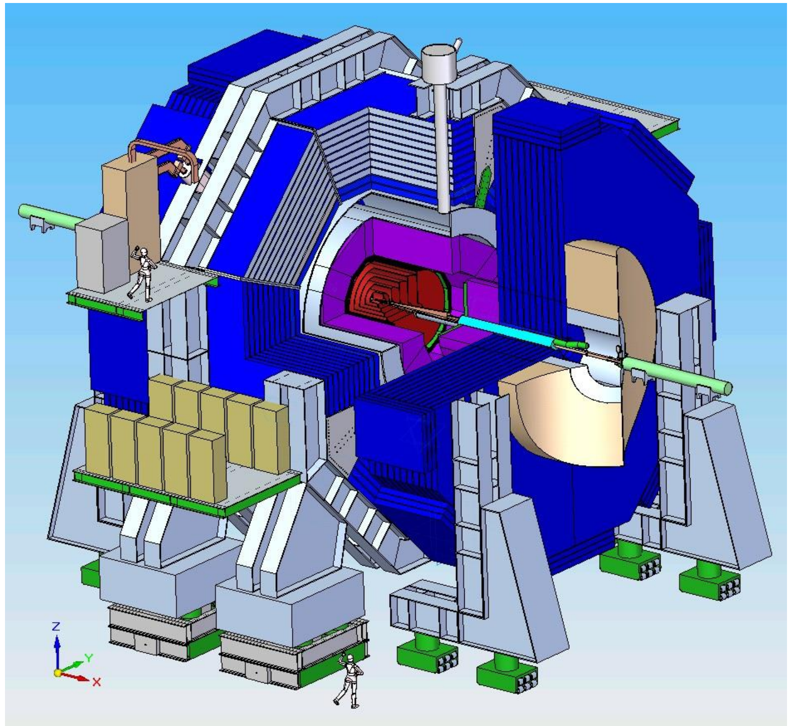
QUESTIONS?

Reserve

ILC Detector Concepts



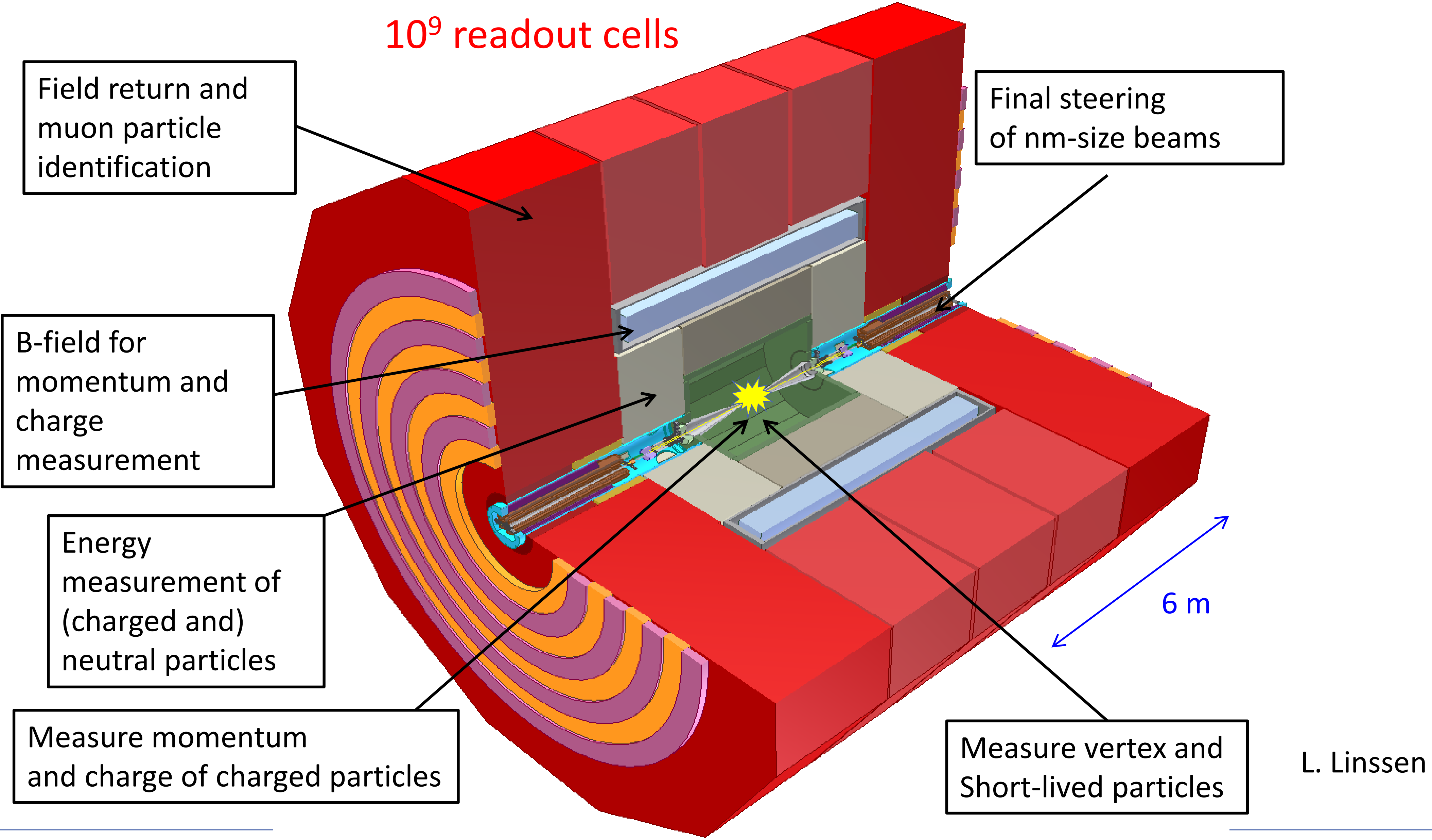
ILD



SiD

CLIC detector concepts are based on SiD and ILD.
Modified to meet CLIC requirements

Linear Collider Experiment



10^9 readout cells

Field return and muon particle identification

B-field for momentum and charge measurement

Energy measurement of (charged and) neutral particles

Measure momentum and charge of charged particles

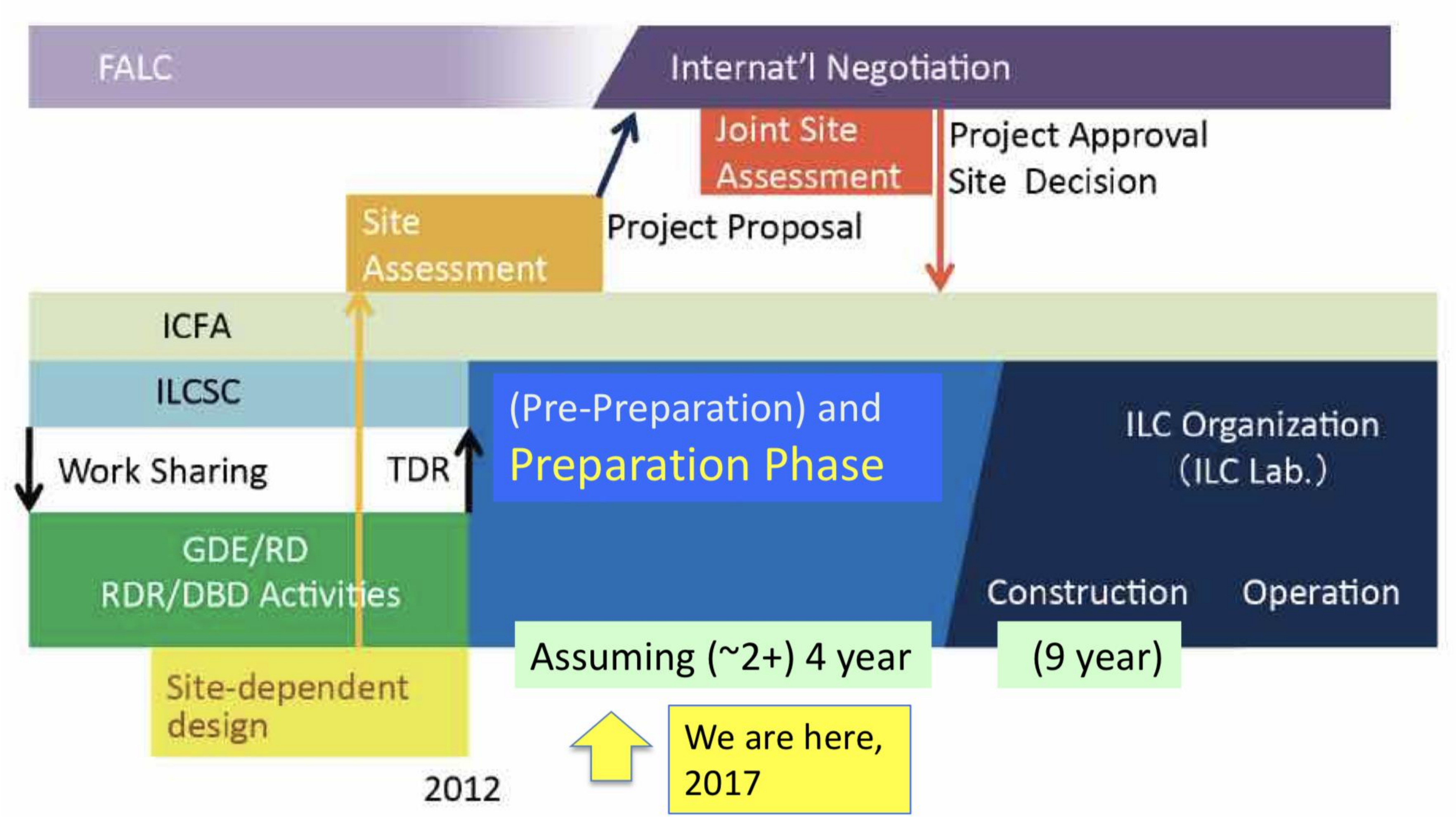
Final steering of nm-size beams

Measure vertex and Short-lived particles

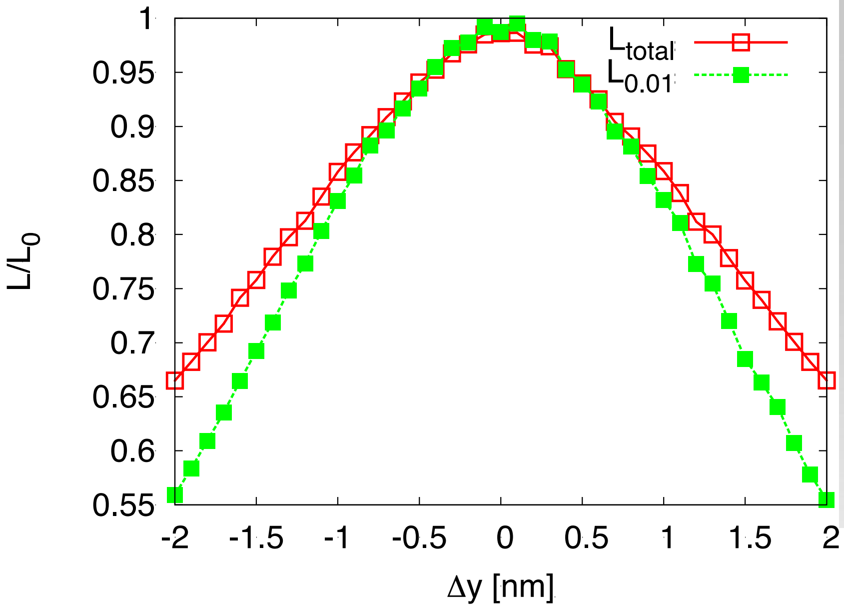
6 m

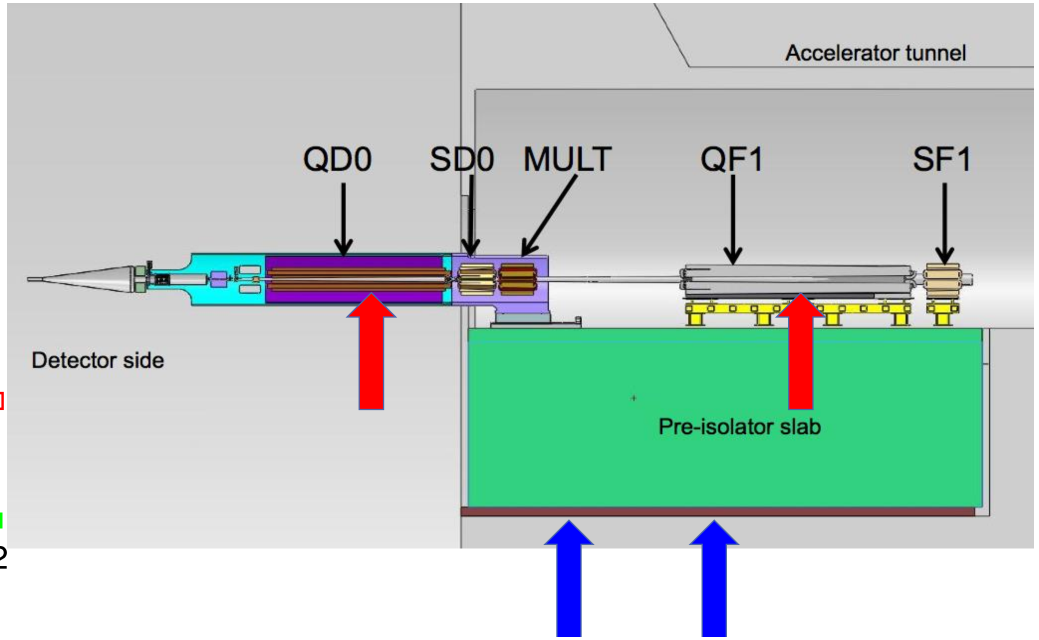
L. Linssen

ILC timeline



Ground Motion and Its Mitigation

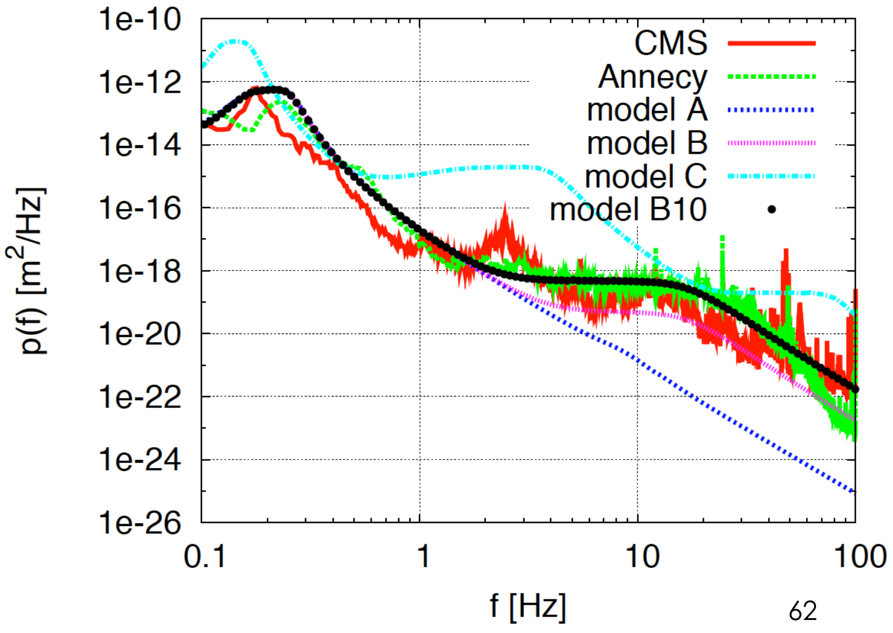




Natural ground motion can impact the luminosity

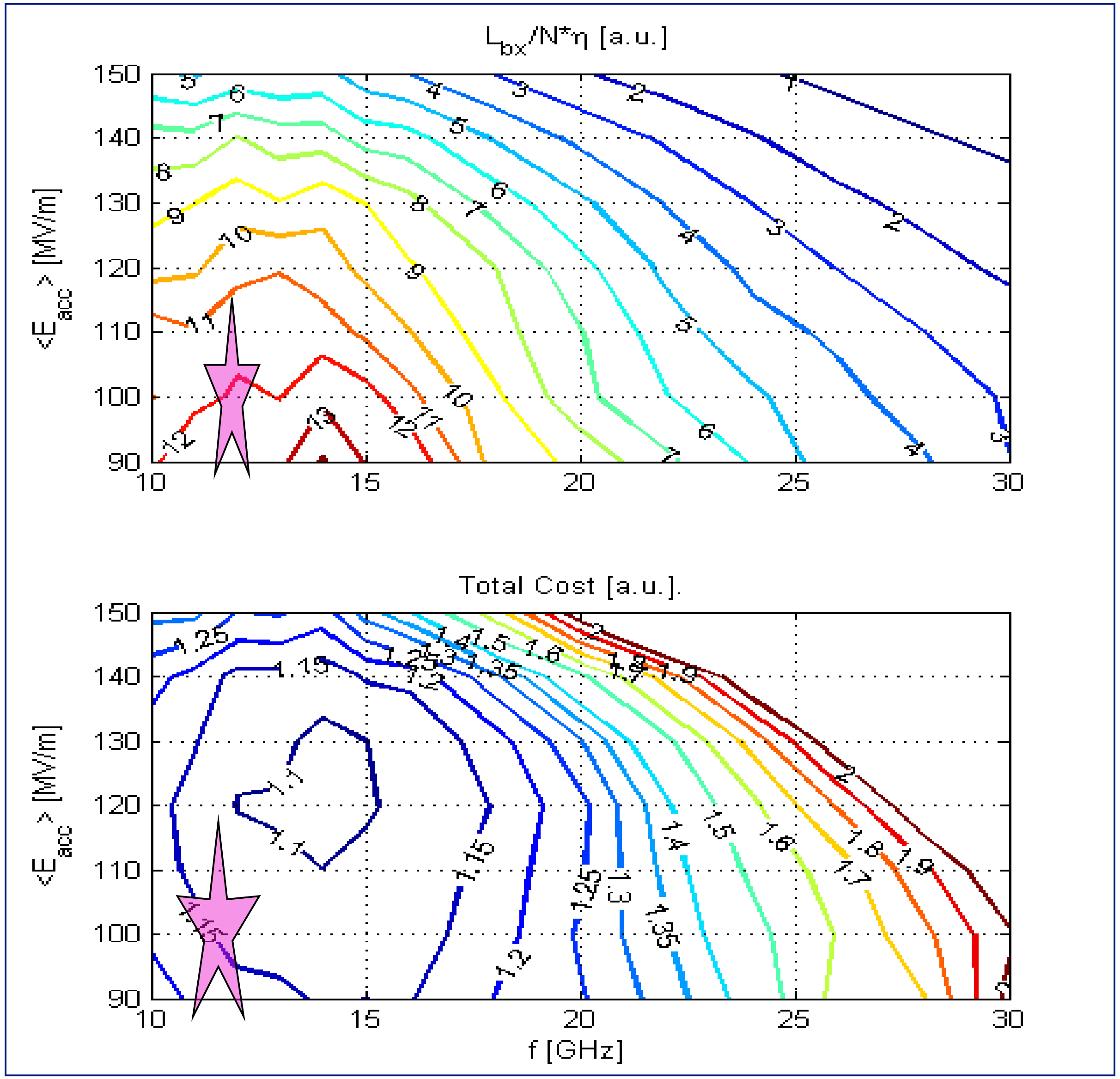
- typical quadrupole jitter tolerance O(1nm) in main linac and O(0.1nm) in final doublet

-> develop stabilisation for beam guiding magnets



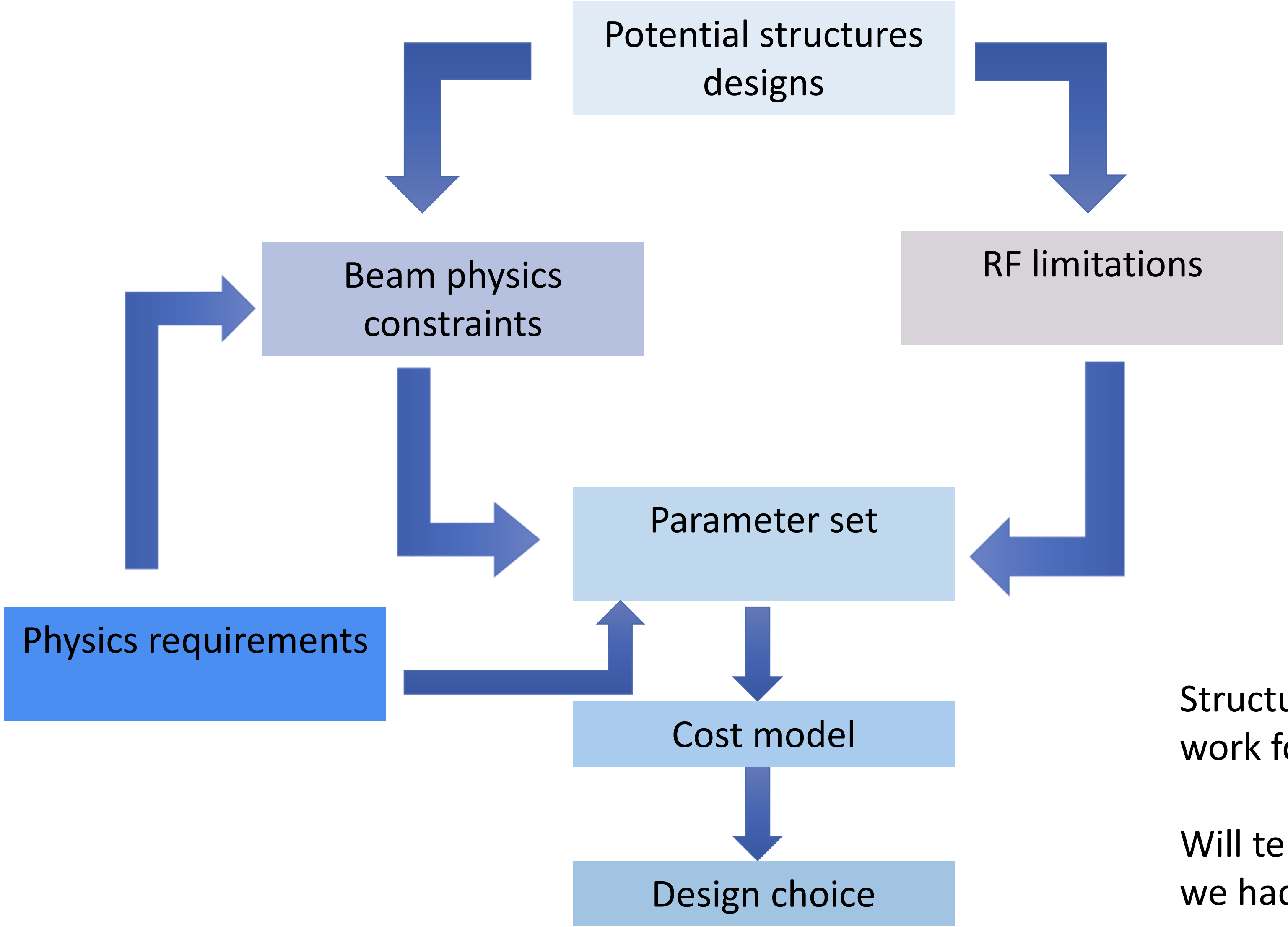
CLIC: Why 100 MV/m and 12 GHz ?

- Optimisation 1
  - Luminosity per linac input power
- Optimisation 2
  - Total project cost



A.Grudiev

Parameter and Structure Choice

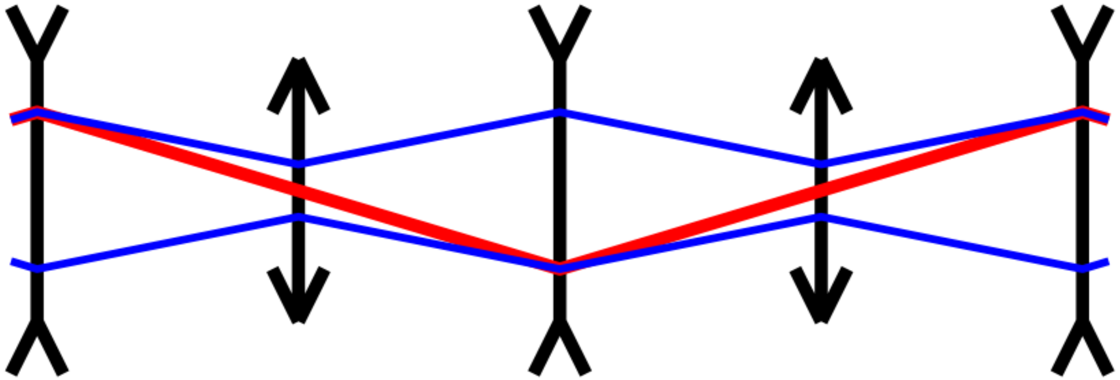


Structure chosen to work for beam physics

Will tell the story as if we had a structure given

Pushing the Bunch Charge

Single bunch wakefields kick the tail of a bunch



Guiding quadrupoles act like a spring

Comparable to driven oscillator

$$x'' + \frac{1}{\beta^2}x = \frac{F(s)}{E(s)}$$

Increasing spring strength reduces oscillation

→

Put in as many strong quadrupoles as reasonable (O(10%) of CLIC main linac)

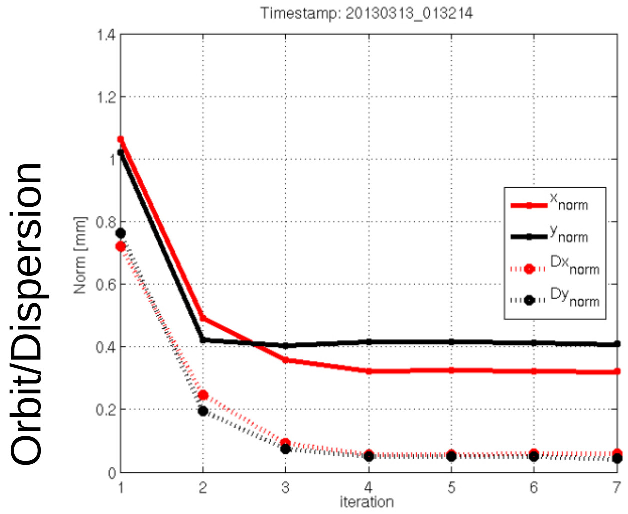
→

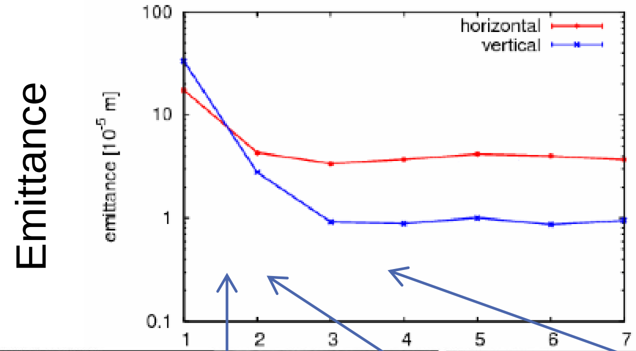
Become sensitive to quadrupole position errors

CLIC Beam-Based Alignment Tests at FACET

Dispersion-free Steering (DFS) proof of principle – March 2013

A. Latina,
J. Pfingstner,
E. Adli,
D. Schulte

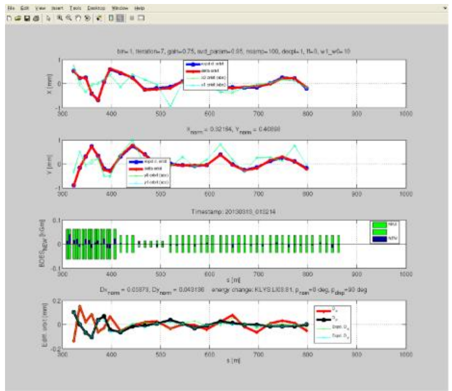


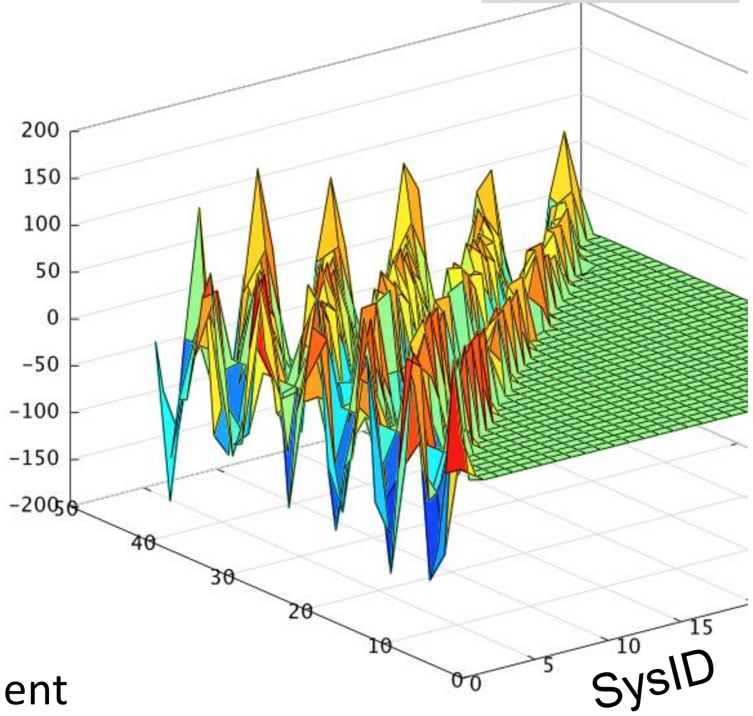


DFS correction applied to 500 meters of the SLC linac

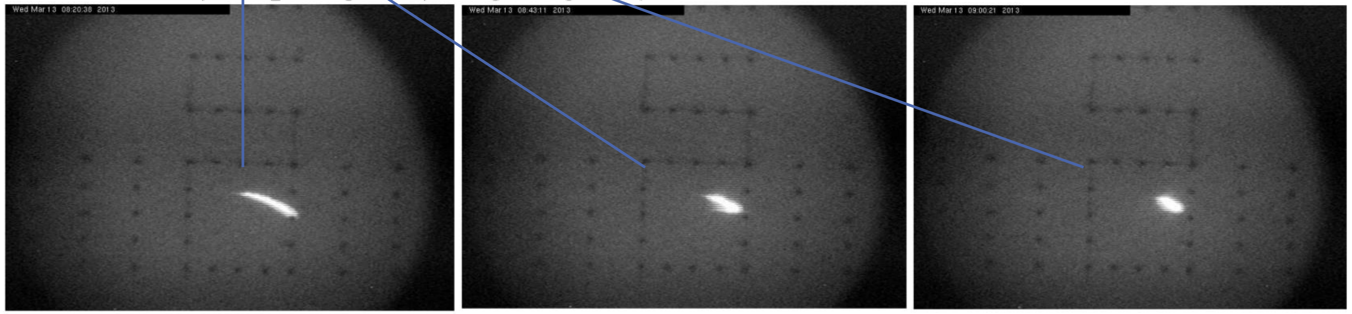
- SysID algorithms for model reconstruction
- DFS correction with GUI
- Emittance growth is measured

Graphic User Interface:





Beam profile measurement



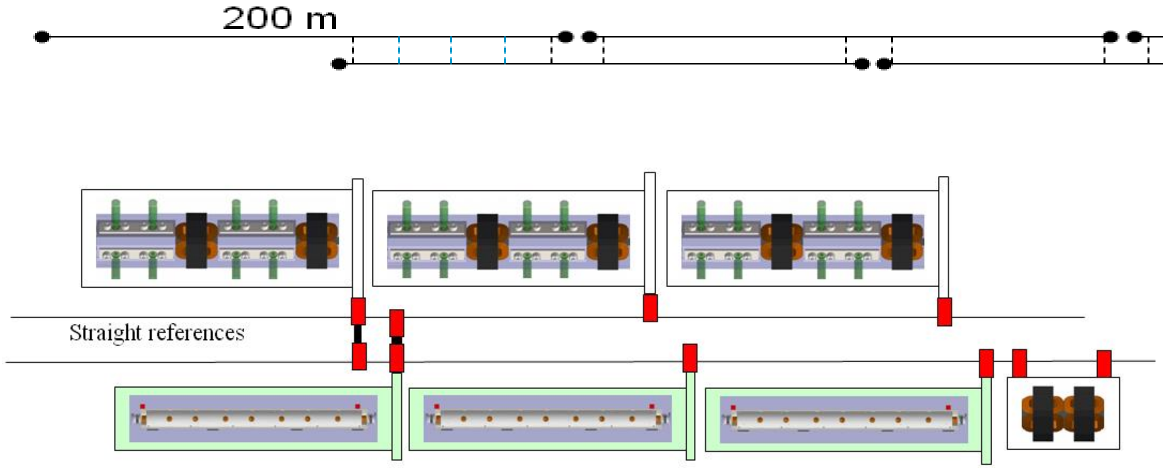
Before correction

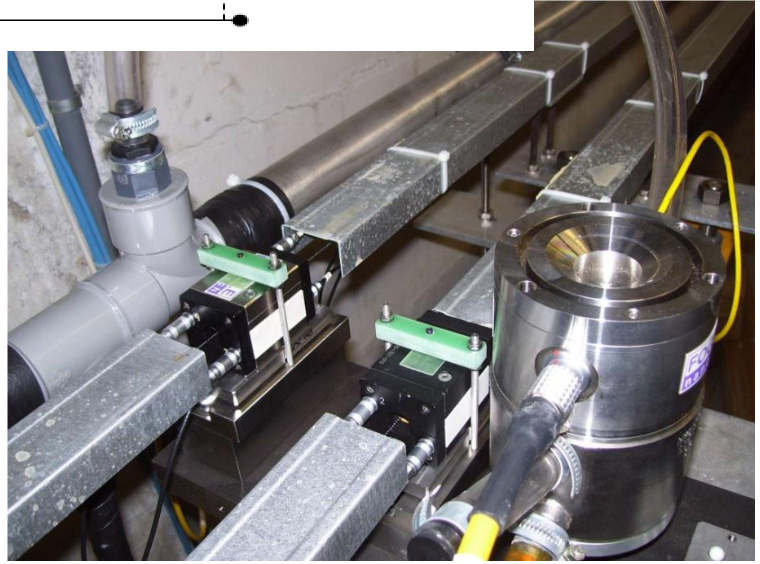
After 1 iteration

After 3 iterations

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

CLIC Pre-alignment System

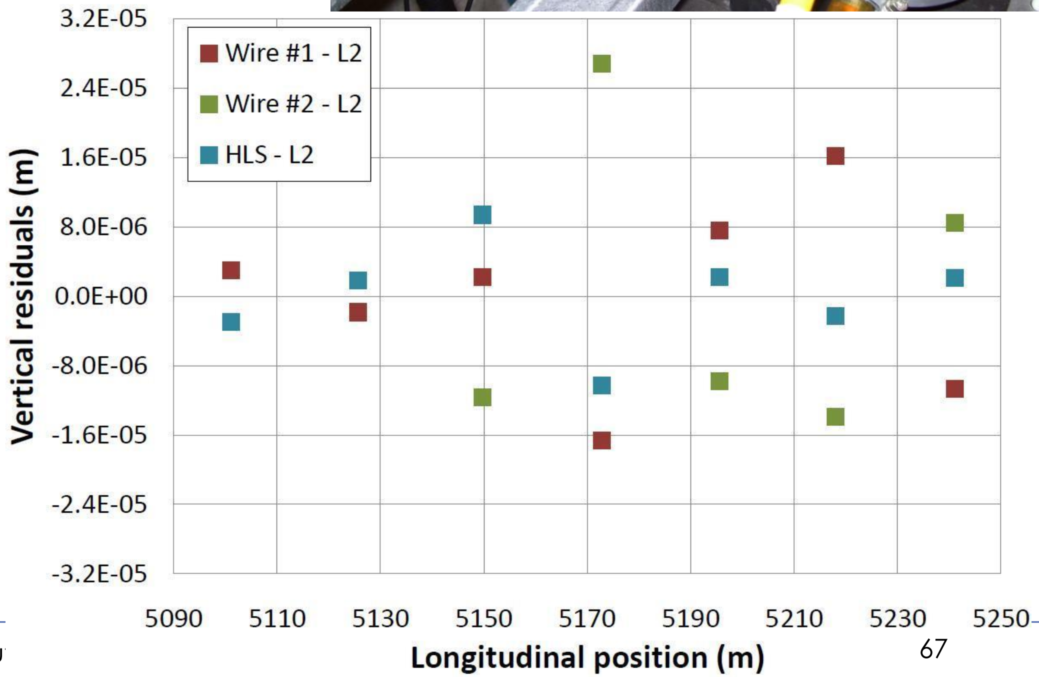




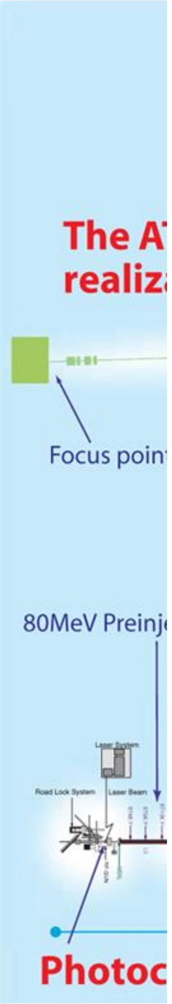
- Required accuracy of reference points is 10µm

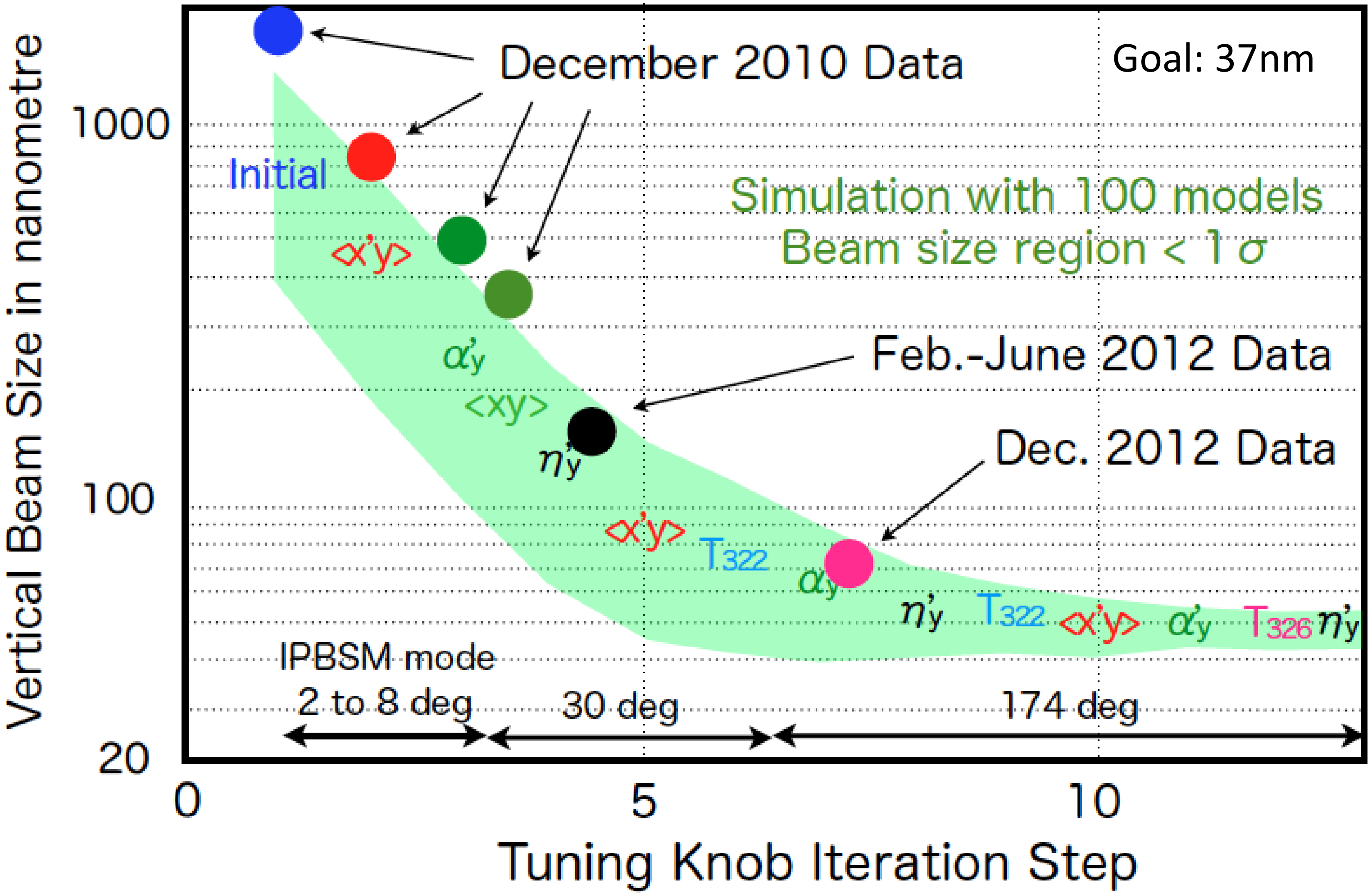
- Test of prototype shows
    - vertical RMS error of 11µm
    - i.e. accuracy is approx. 13.5µm

- Improvement path identified



Beam Delivery System Test





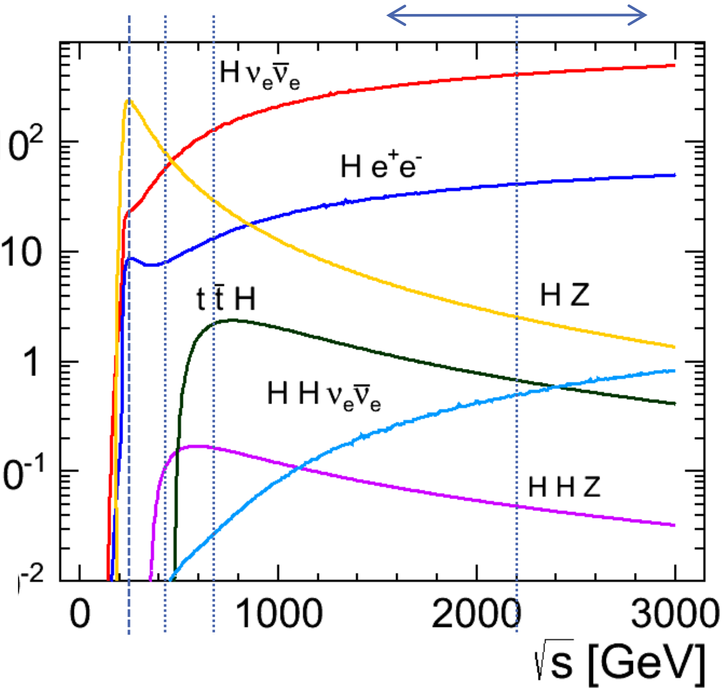
Lepton Collider Physics Case

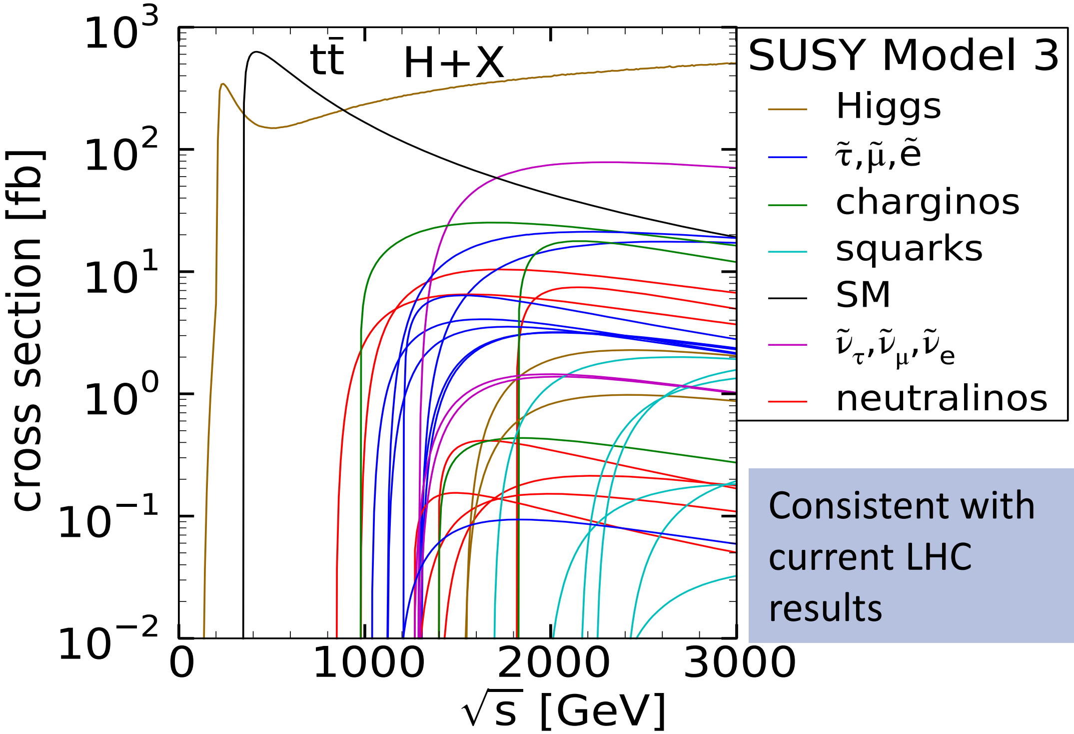
Know physics for Higgs and top

- low energies for many branching rations
- high energies for others, e.g. Hνν
- 350GeV 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

Beamstrahlung Optimisation

For low energies (classical regime) number of emitted photons

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

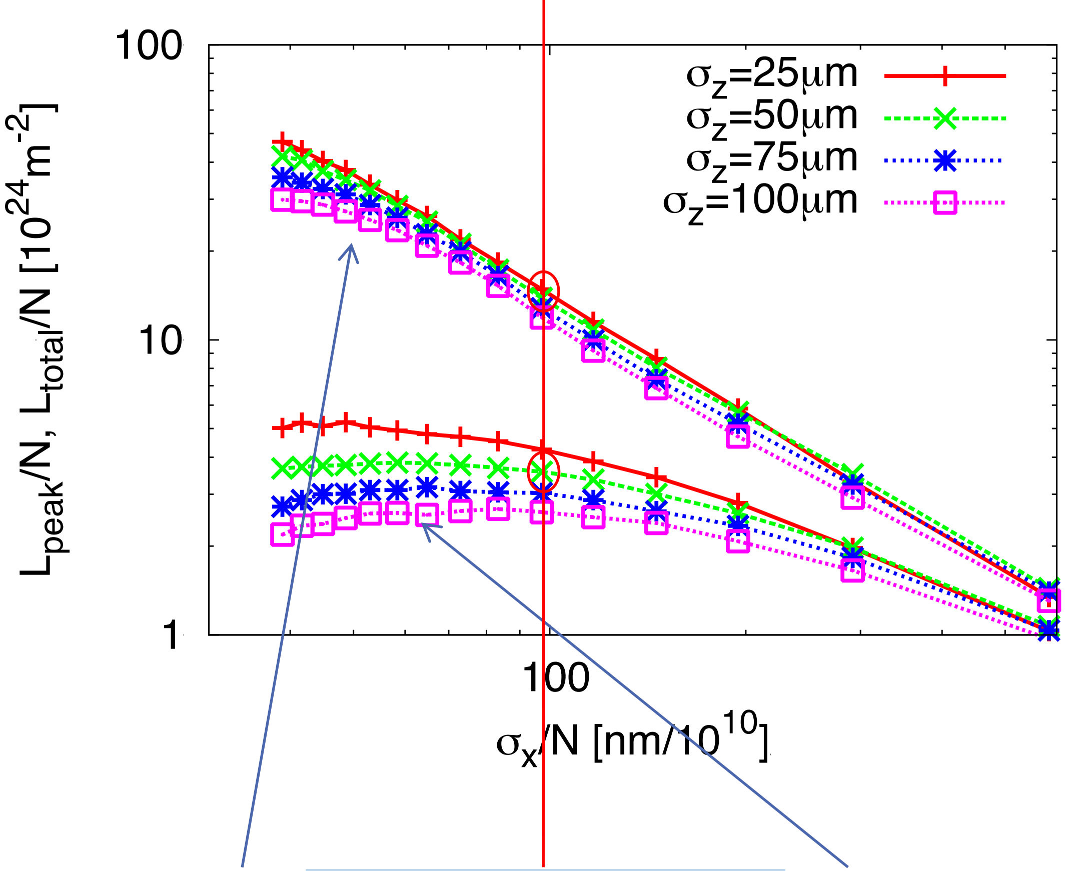
$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}$$

Hence use $\sigma_x \gg \sigma_y$

$$\sigma_x + \sigma_y \approx \sigma_x$$

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

For CLIC at 3TeV (quantum regime)



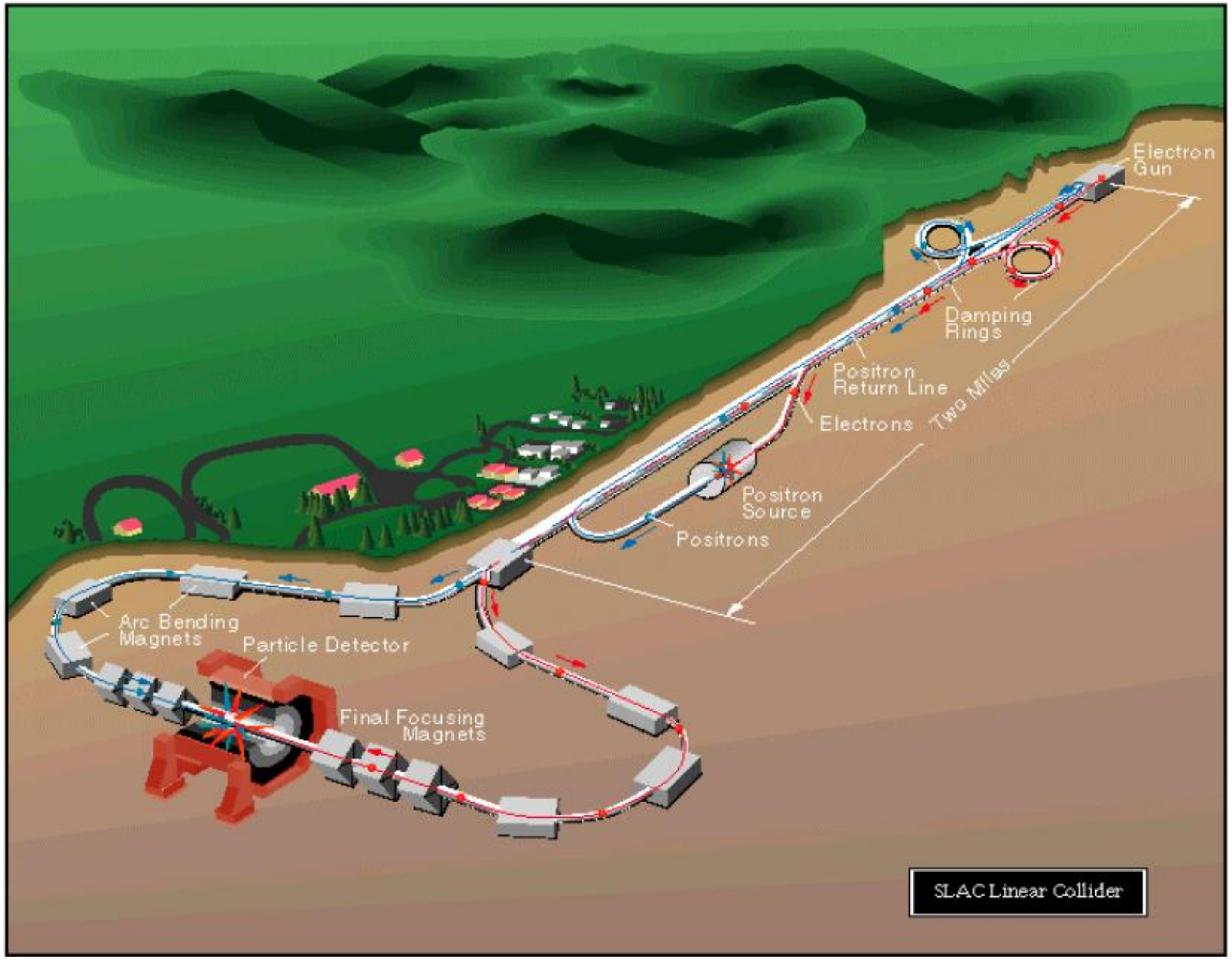
Total lumin

CLIC parameter choice

ninosity in peak starts to decrease again

grows for smaller beams

SLC: The only Linear Collider that existed



Built to study the Z^0 and demonstrate linear collider feasibility

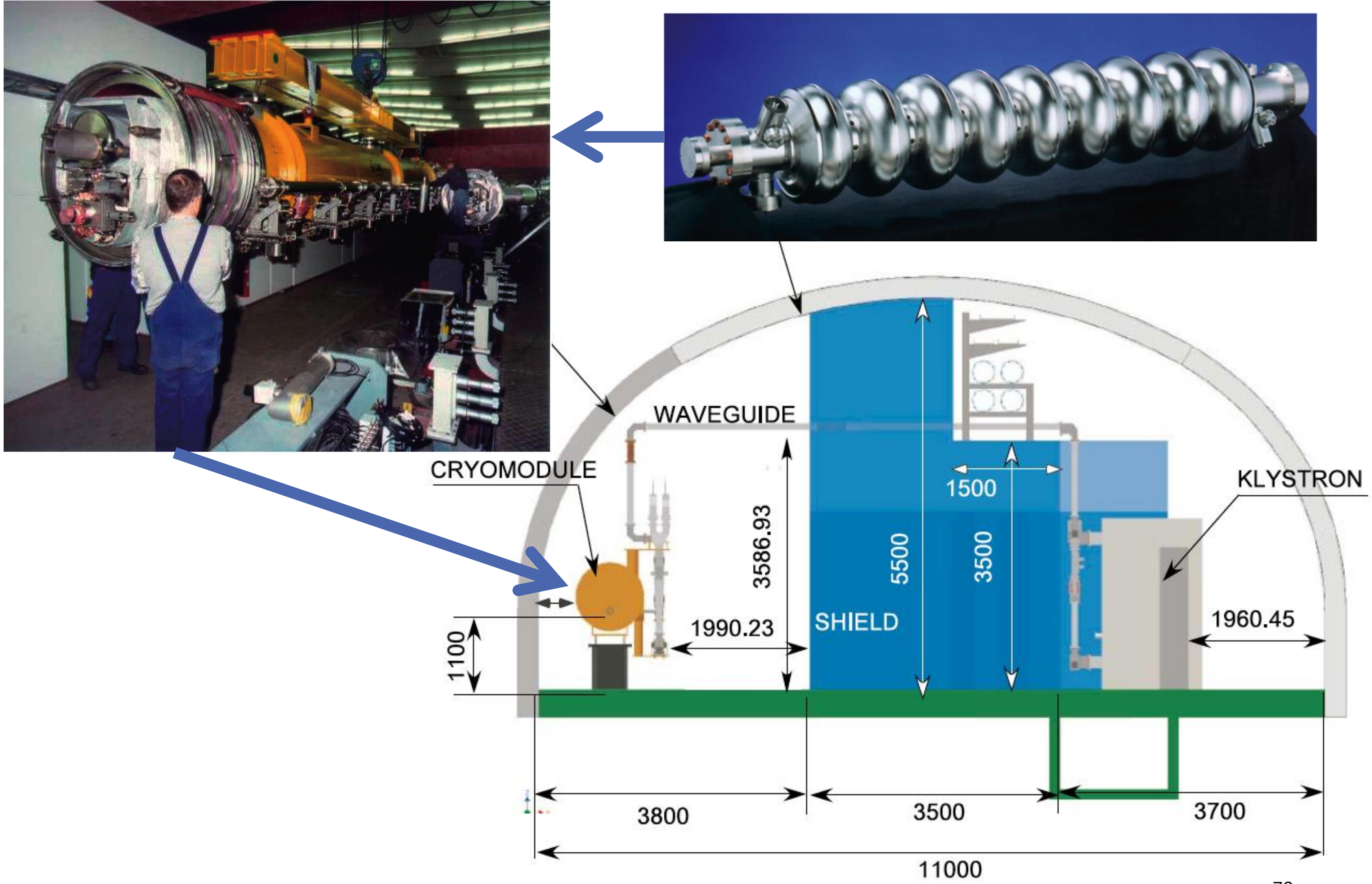
Energy = 92 GeV

Luminosity = 2e30

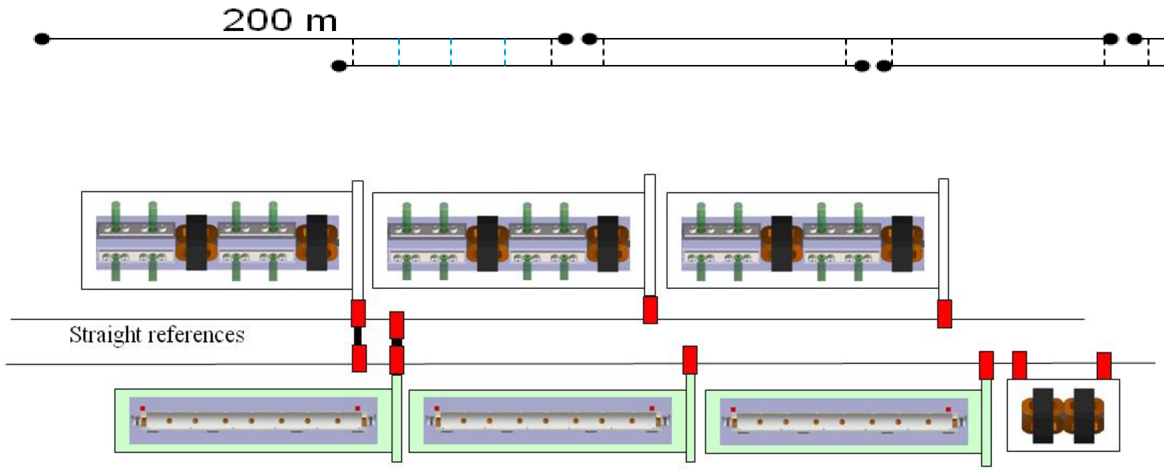
Has all the features of a 2nd gen. LC except both e+ and e- used the same linac

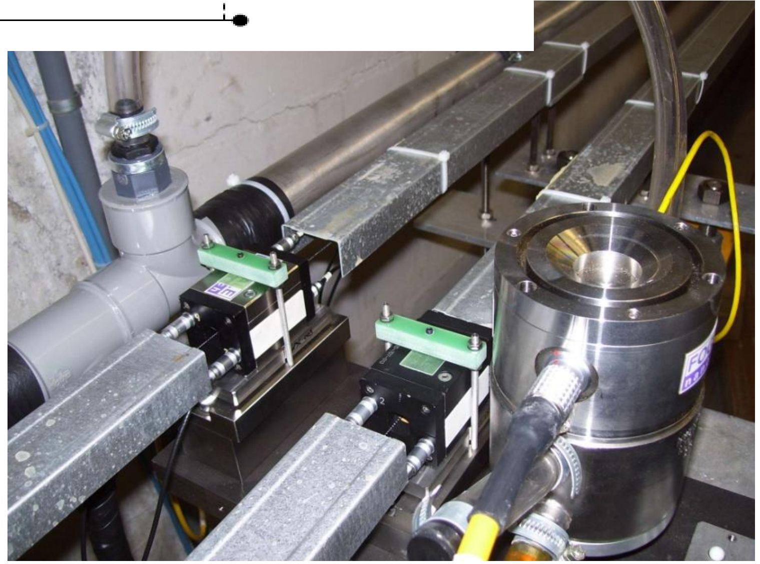
A 10% prototype!

ILC Main Linac Layout



CLIC Pre-alignment System





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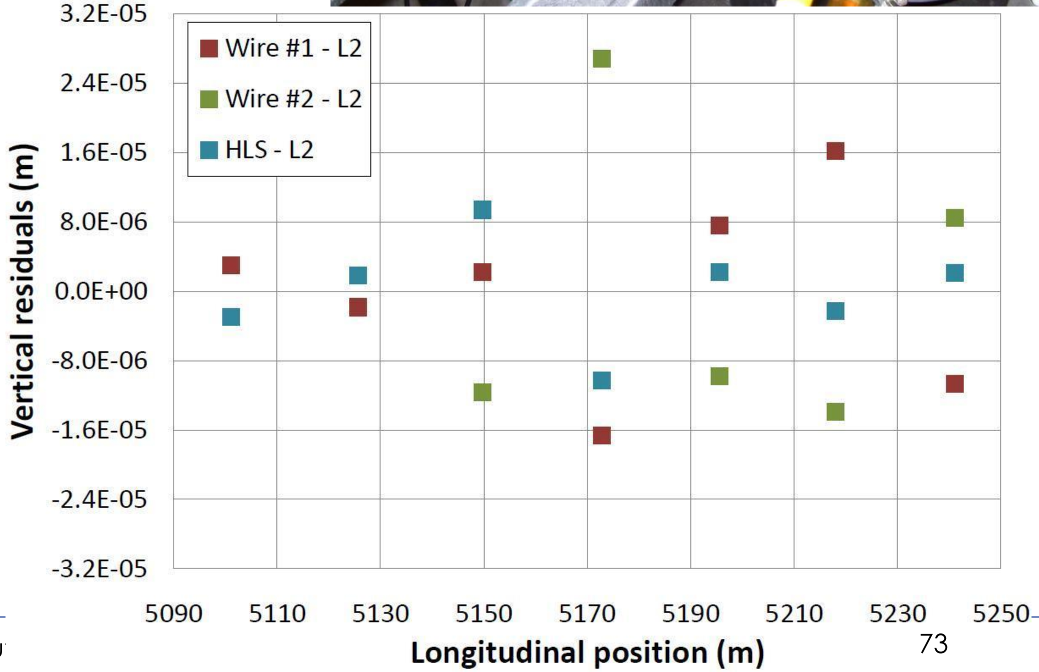
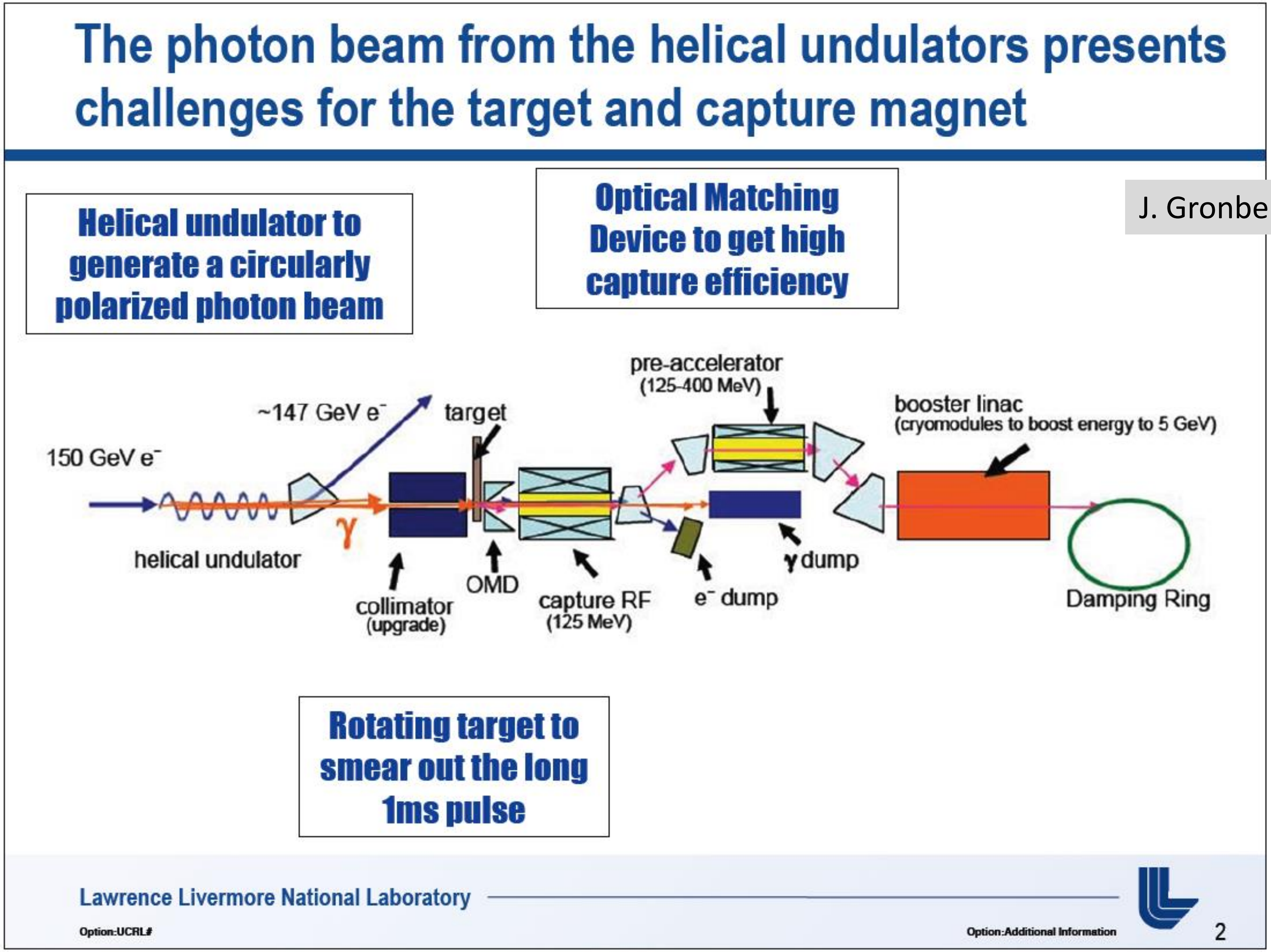




The photon beam from the helical undulators presents challenges for the target and capture magnet

J. Gronberg

Helical undulator to generate a circularly polarized photon beam

Optical Matching Device to get high capture efficiency

Rotating target to smear out the long 1ms pulse

Lawrence Livermore National Laboratory

Option:UCRL#

Option:Additional Information

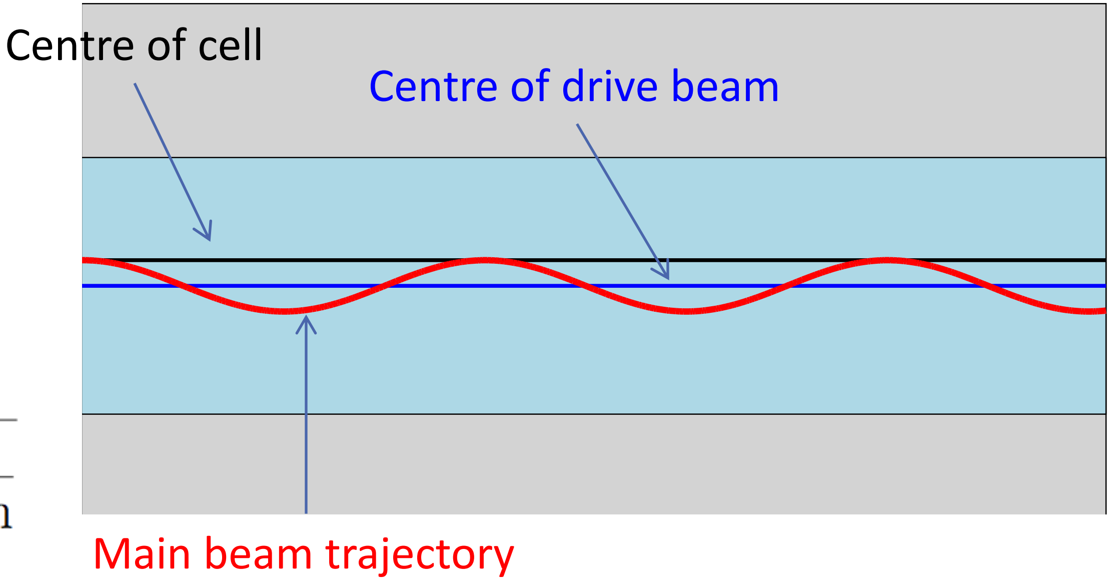
2

Example Transverse Tolerance

First order estimate for middle part of cell

Laser or drive beam centre defines centre of the focusing

$$\sigma_y \approx 42\ \mathrm{nm} \left(\frac{\mathrm{GeV}}{\mathrm{E}} \frac{10^{16}\ \mathrm{cm}^{-3}}{\mathrm{n}_0} \right)^{\frac{1}{4}} \sqrt{\frac{\epsilon_y}{\mathrm{nm}}}$$



PWFA beam at 1.5TeV has σ_y=O(30 nm) for $n_0=2\times10^{16}\mathrm{cm}^{-3}$

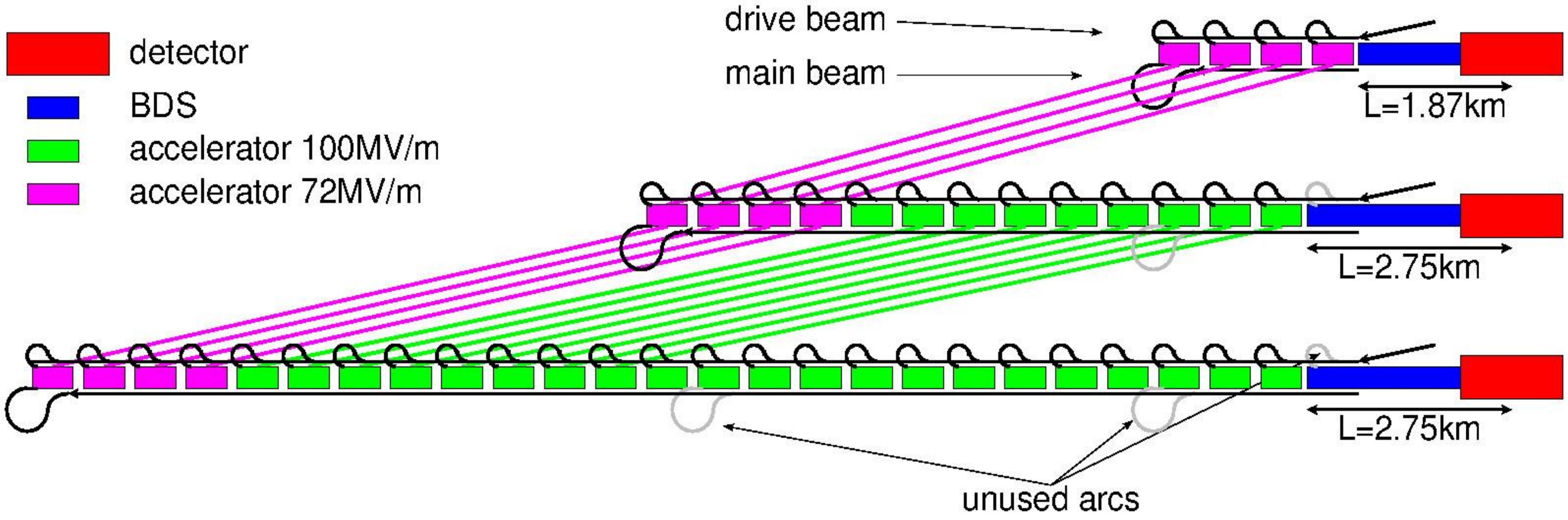
- ⇒ Beam jitter stability O(1 nm)?
  - ⇒ Tough for laser/drive beam
- ⇒ Static misalignment is also critical
  - ⇒ but depends on beam energy spread and tuning methods

Important to understand tolerances correctly

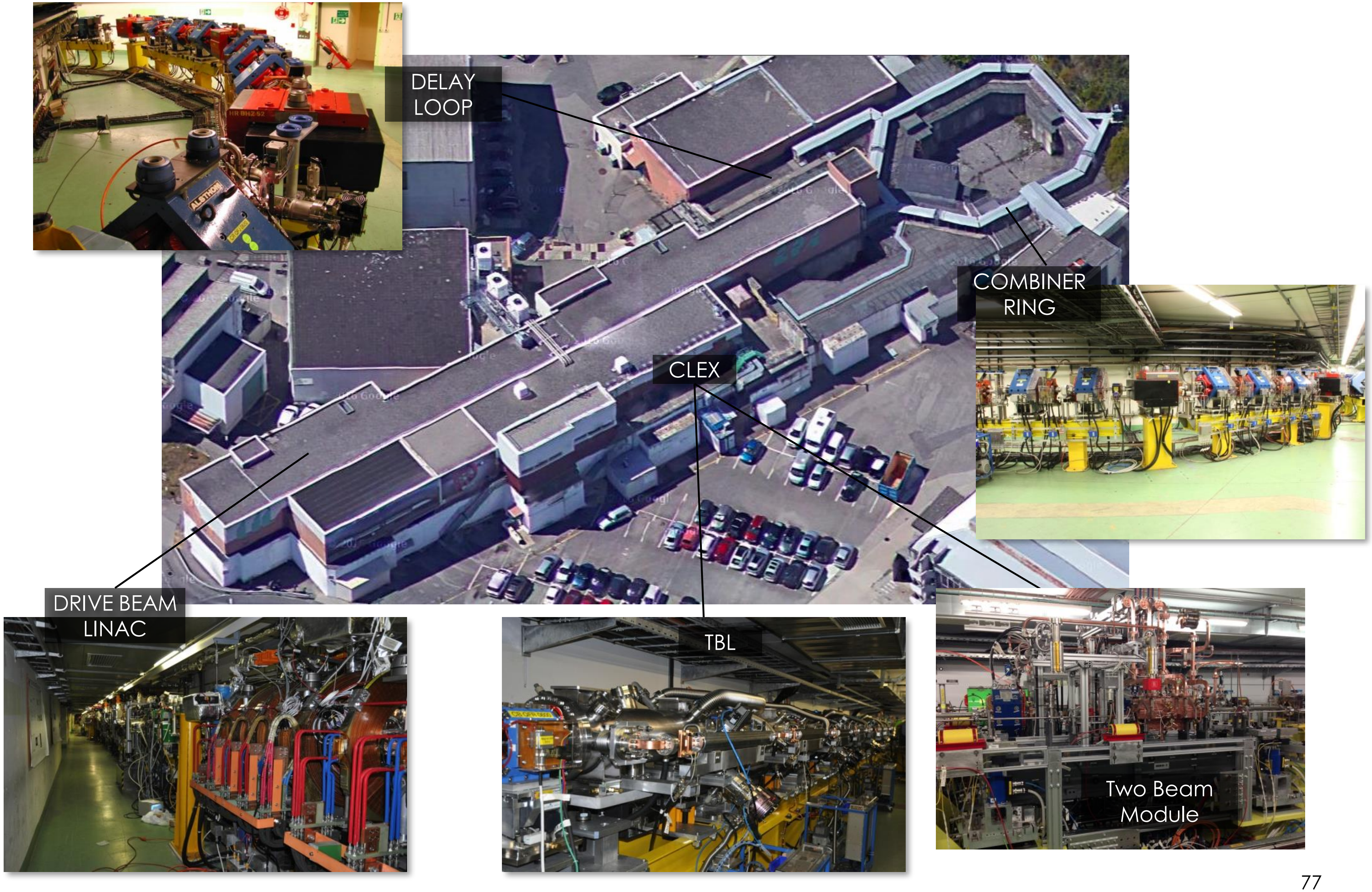
R&D programme essential on transverse alignment and stabilisation

Note: Linear Collider Staging

- Design has been done for 500 GeV (ILC) and 3 TeV (CLIC)
  - Staging is a good option
- CLIC is planned to be constructed in stages
  - 0.38, 1.5 and 3 TeV
  - Just add more length as needed/money becomes available
- ILC could also be done in stages (250 GeV)



CLIC Test Facility (CTF3) 2003-2016



DELAY LOOP

COMBINER RING

CLEX

DRIVE BEAM LINAC

TBL

Two Beam Module