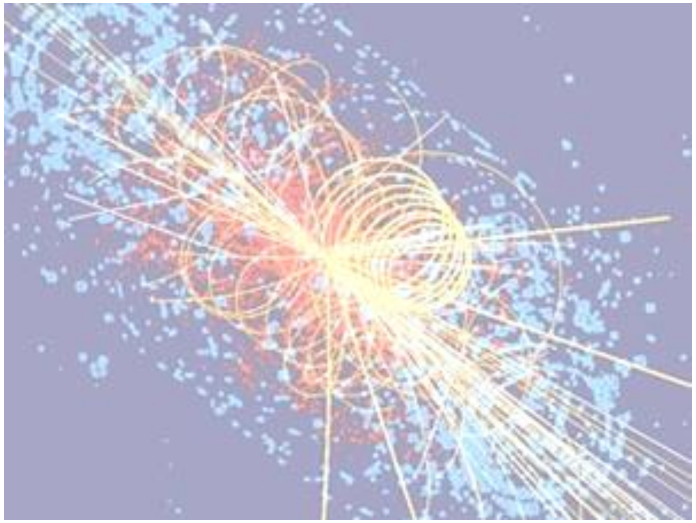
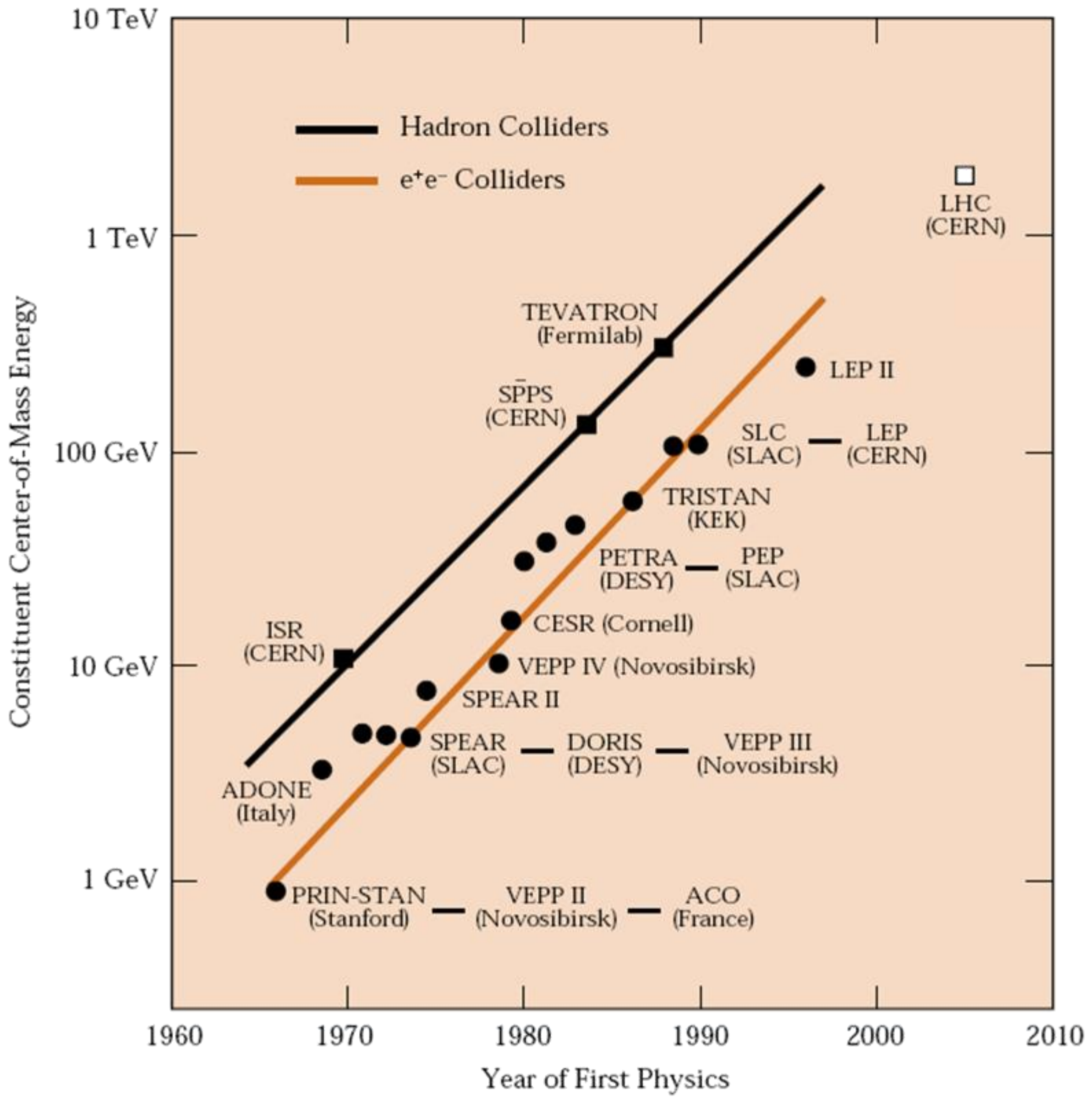


1. Esittely
2. Vierailu show-room

CLIC-TUTKIMUSPROJEKTI

Mitä LHC:n jälkeen?

Hiukkastörmäyttimien historiaa (ja tulevaisuutta)



CLIC 3 TeV
ILC 0.5 TeV

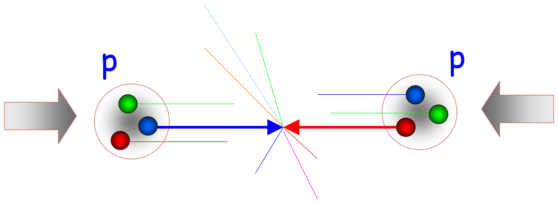
!!
LHC 7 TeV
SLHC 13 TeV

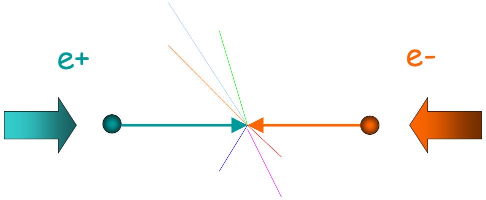
1 TeV ≈ yhden lentävän hyttysen liike-energia

Miksi multi TeV $e^- e^+$ törmäytin?

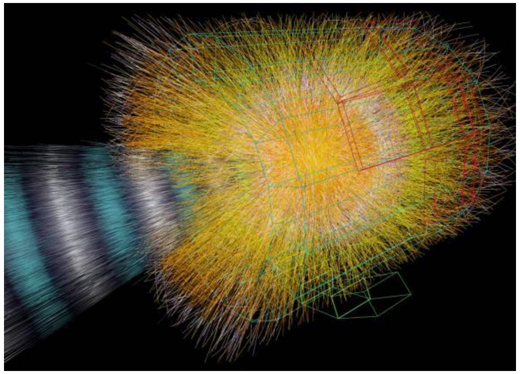
Miksi lineaaritörmäytin?

Hadroni-törmäyttimet (esim. LHC) Leptoni-törmäyttimet (esim. LEP, CLIC & ILC)





- Hadronit, esim. protonit, koostuvat kvarkeista eli alkeishiukkasista
- Leptonit, esim. elektronit, taas ovat alkeishiukkasia, mutta
- Elektronit noin 2000 kertaa protoneja pienempiä
- Feynman: ”*What will one ever learn colliding Swiss watches against Swiss watches?”* (about collisions between protons)



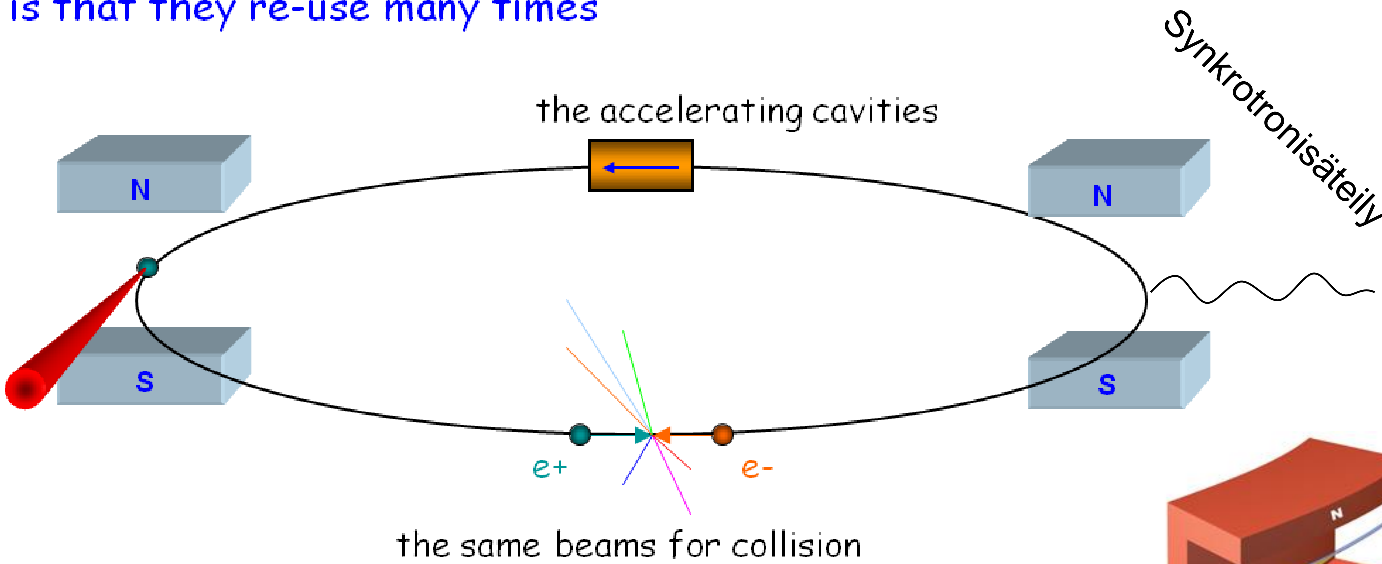
Leptonit mahdollistavat hyvin tarkkojen mittauksien tekemisen

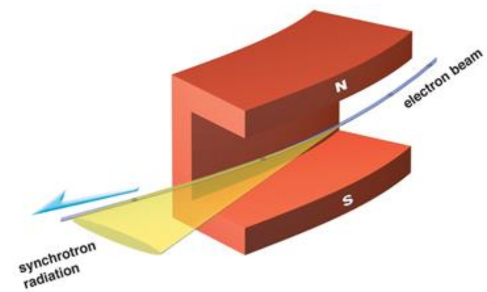
Yleinen näkemys tiedemaailmassa siitä että LHC:n jälkeen rakennettava kiihdytinlaitteisto on lineaarikiihdytin

Courtesy of F. Tecker

Miksi lineaaritörmäytin?

Circular colliders use magnets to bend particle trajectories
Their advantage is that they re-use many times





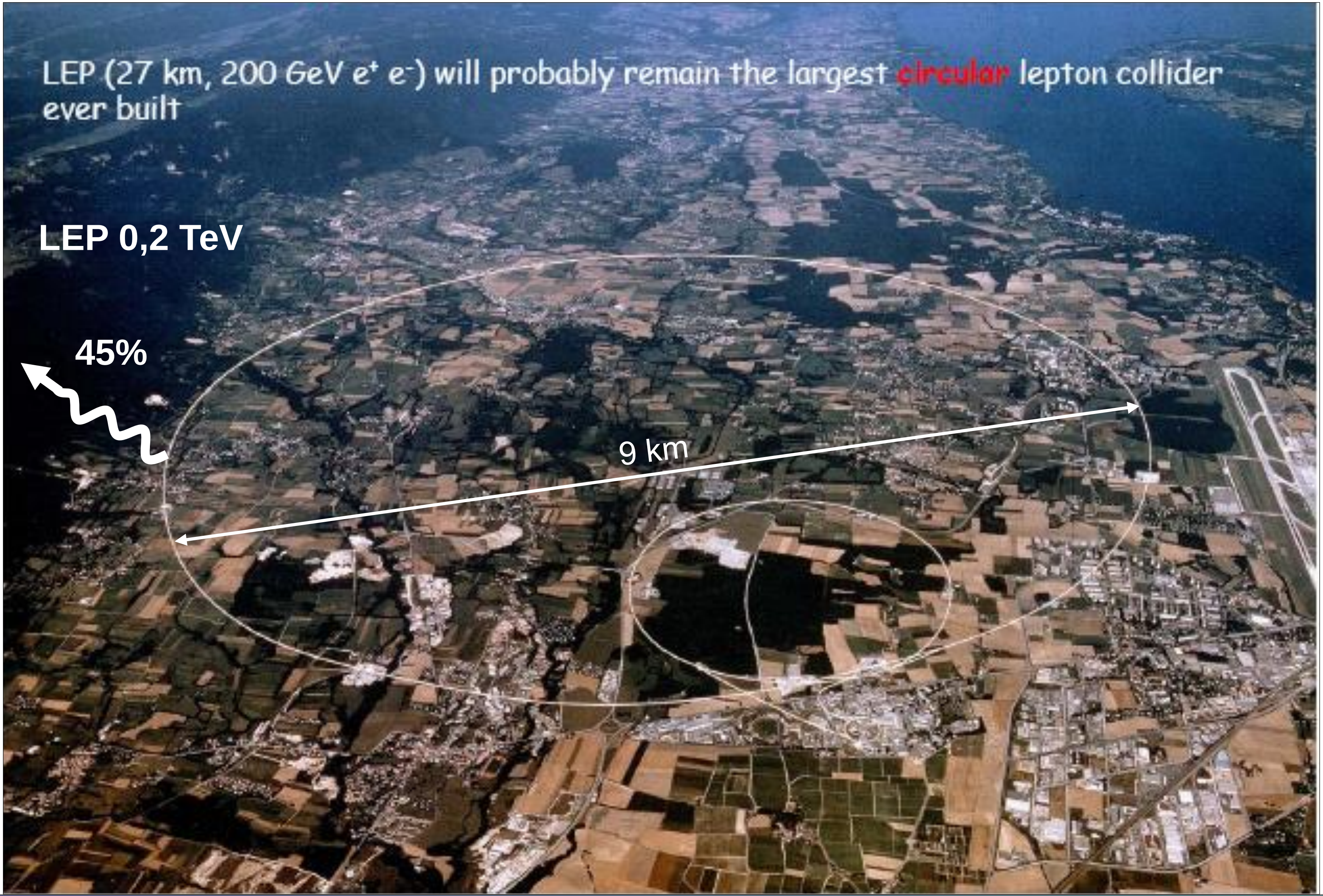
- Kaikkien ympyrän muotoisten törmäyttimien ongelma
- Säteilyenergia kasvaa hiukkasten energian kasvaessa suhteessa E^4

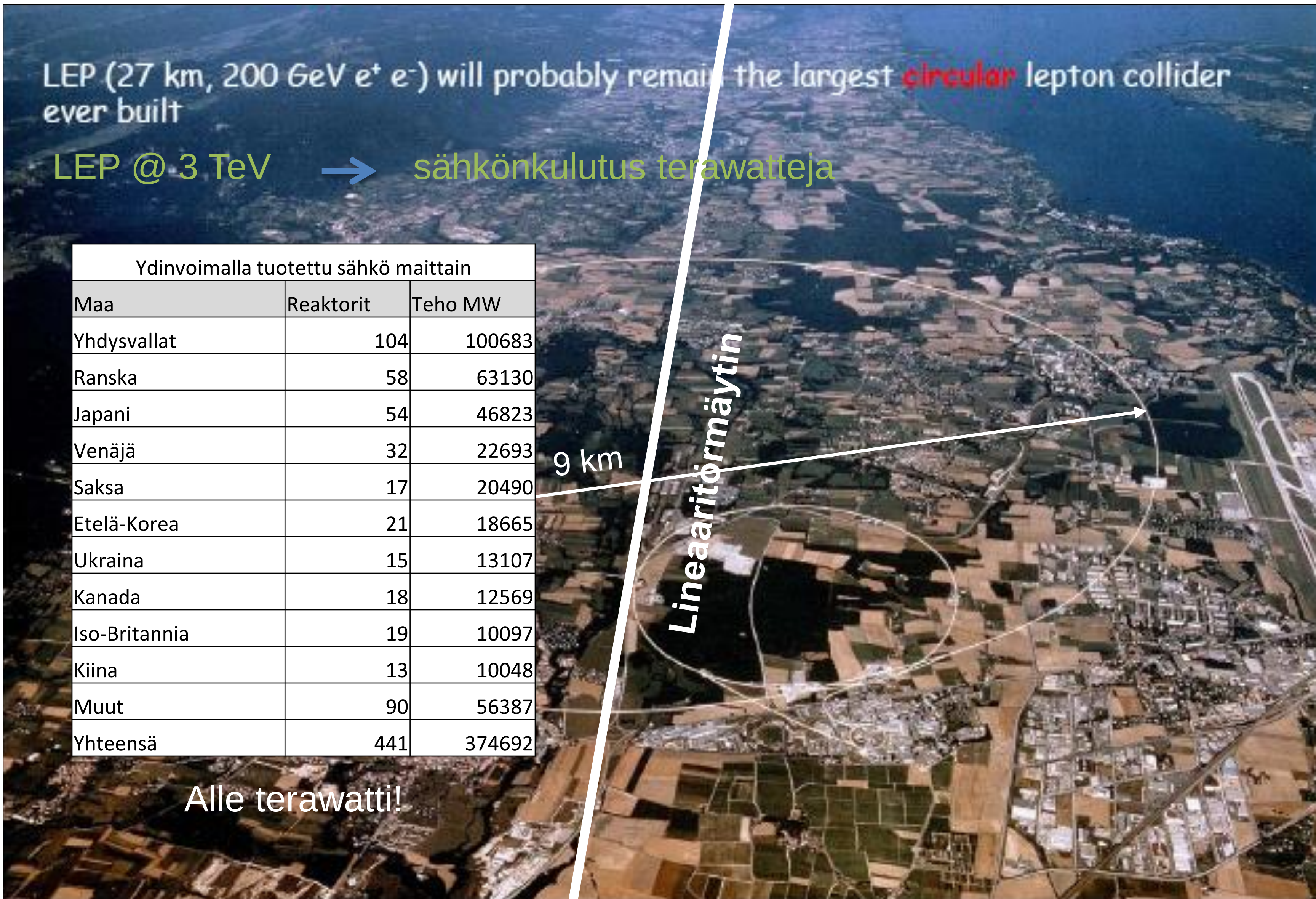
$$P \propto \frac{E^4}{m^4 r}$$

➔ ei ole niin suuri ongelma painavilla hiukkasilla (kuten esimerkiksi protoneilla LHC:ssa)

Courtesy of H. Schmickler

Miksi lineaaritörmäytin?


LEP (27 km, 200 GeV e+ e-) will probably remain the largest circular lepton collider ever built
LEP 0,2 TeV
45%
9 km

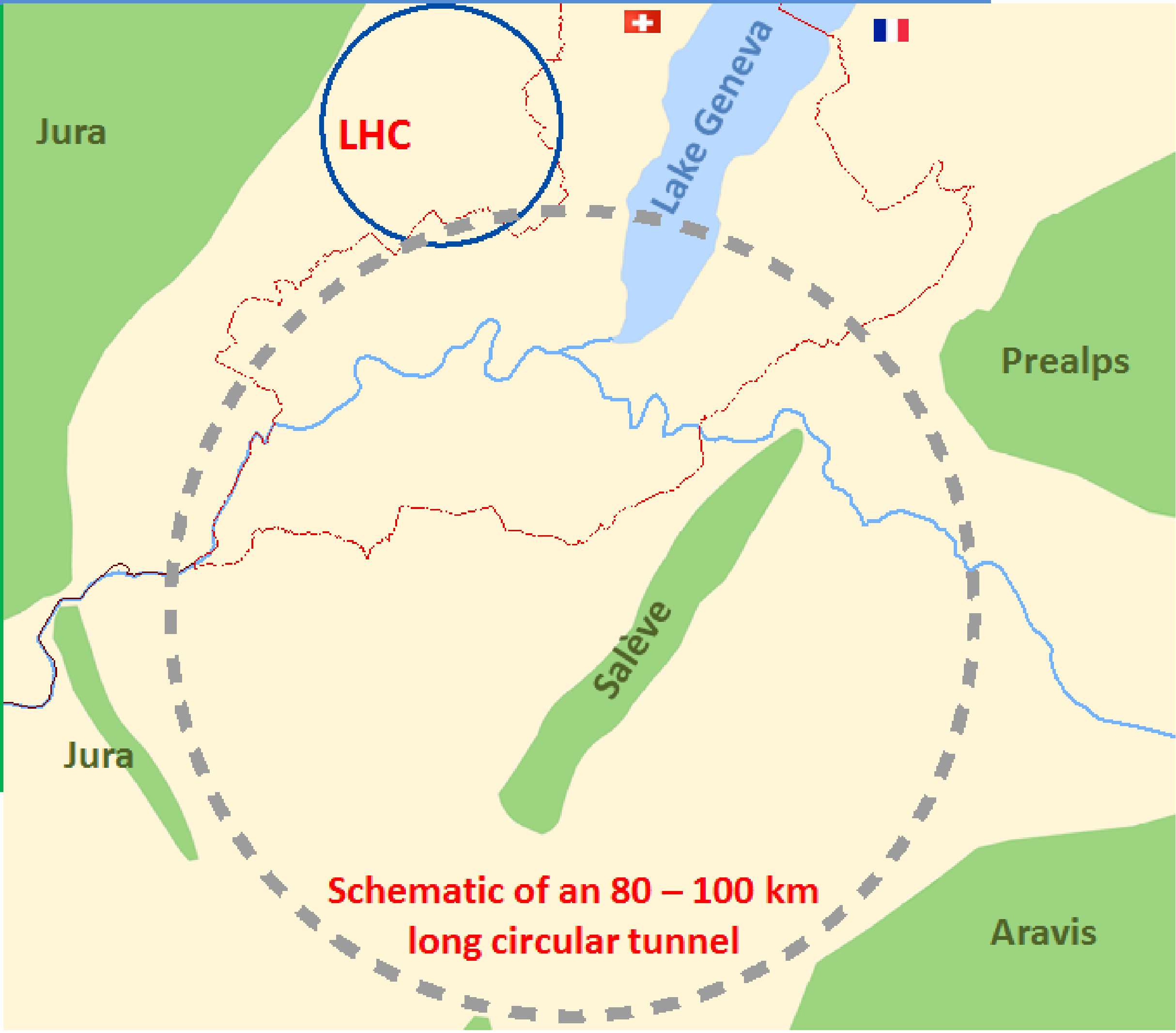


Ydinvoimalla tuotettu sähkö maittain		
Maa	Reaktorit	Teho MW
Yhdysvallat	104	100683
Ranska	58	63130
Japani	54	46823
Venäjä	32	22693
Saksa	17	20490
Etelä-Korea	21	18665
Ukraina	15	13107
Kanada	18	12569
Iso-Britannia	19	10097
Kiina	13	10048
Muut	90	56387
Yhteensä	441	374692

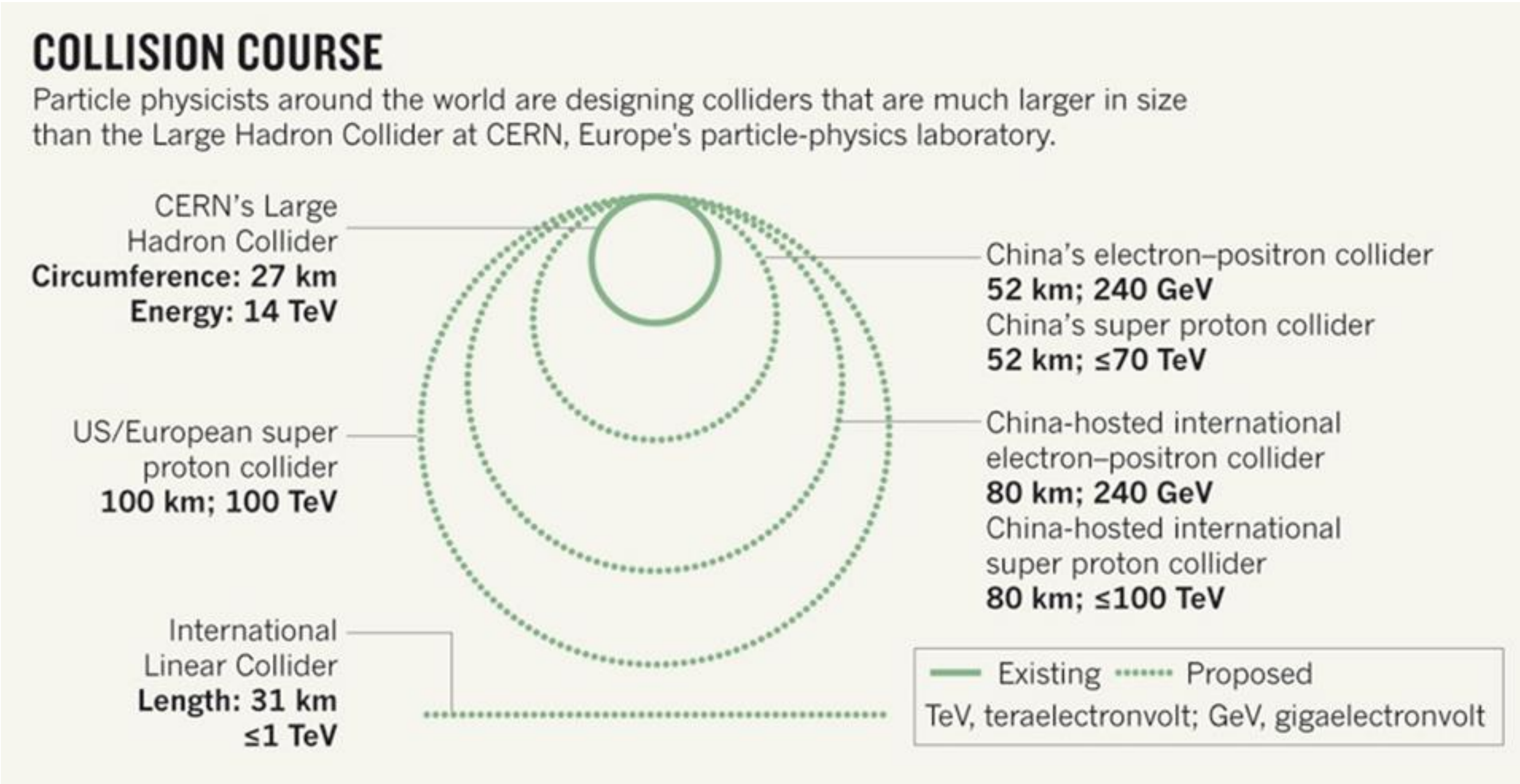
CDR and cost review for the next ESU (2018)

- 80-100 km tunnel infrastructure in Geneva area
- pp-collider (VHE-LHC) defining the infrastructure requirements
- e+e- collider (TLEP) as potential intermed. step and p-e (VLHeC) option
- CERN-hosted study performed in international collaboration

~15 T ⇒ 100 TeV in 100 km
~20 T ⇒ 100 TeV in 80 km

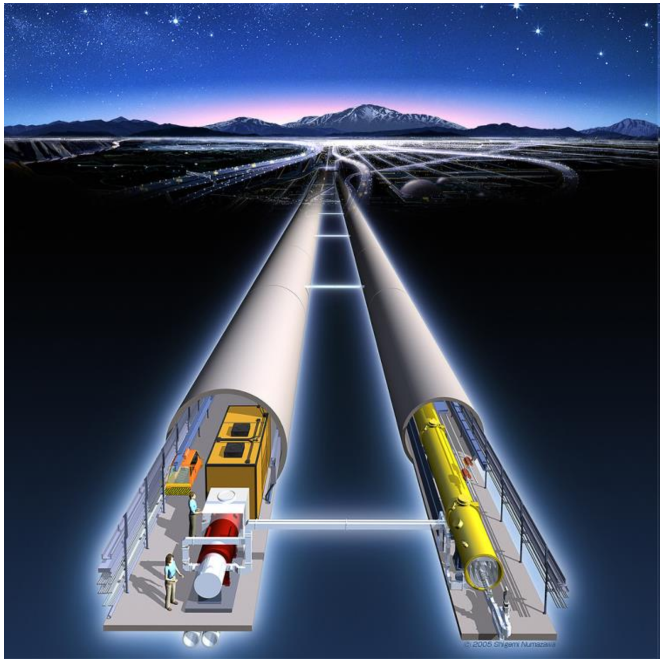


Mitä LHC:n jälkeen?



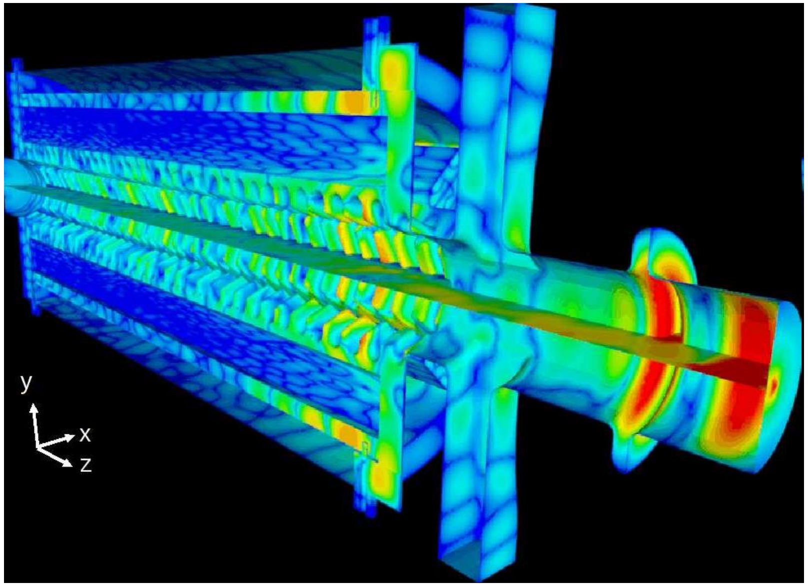
ILC 0.5 TeV

Suprajohtava



CLIC – 3 TeV

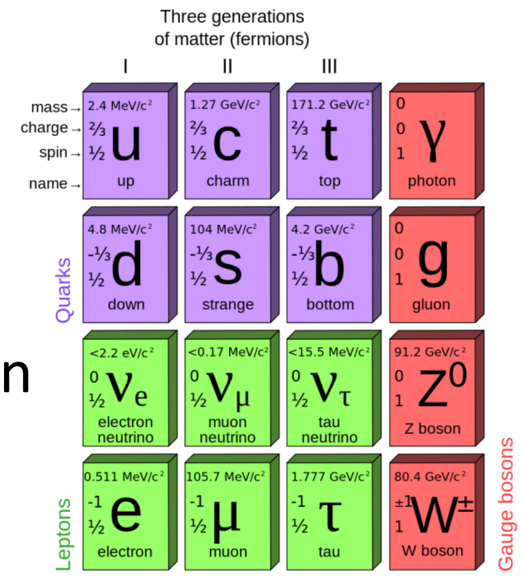
Normaalikonduktiivinen



Suunnitelmat tulevaisuuden lineaaritörmäyttimeksi

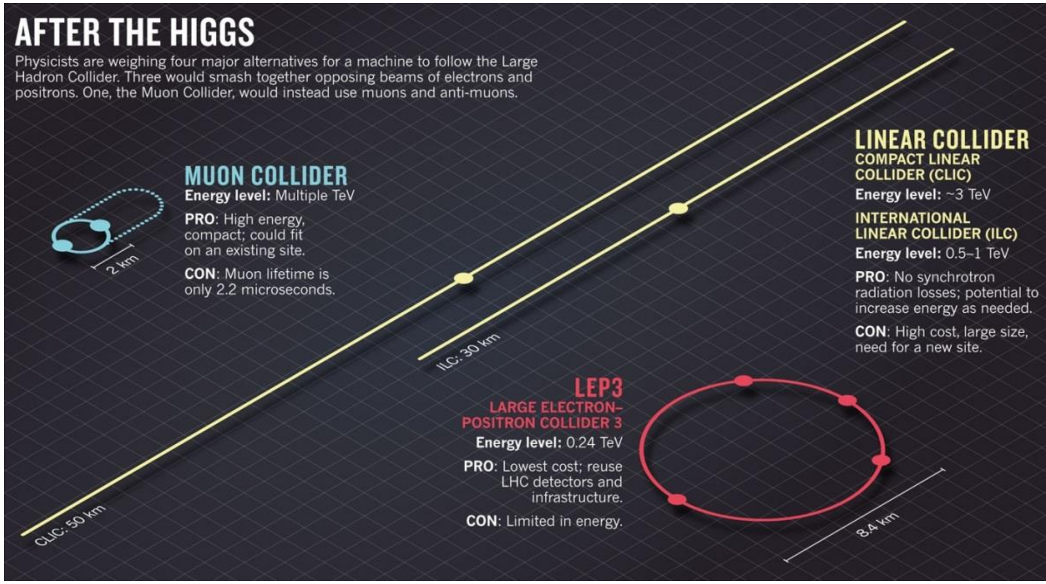
Tutkimuskohteet

- “It is an exiting time to live in for a physicist!”
- Perusfysiikan ja LHC:n tulosten täydentäminen
  – Standardimallin vahvistaminen ja fysiikka sen takana
  – Uudet Gauge, Higgs bosonit ym.
  – Supersymmetria
- Nämä tutkimuskohteet täsmentyvät ja uusia saattaa ilmaantua LHC:n tulosten perusteella

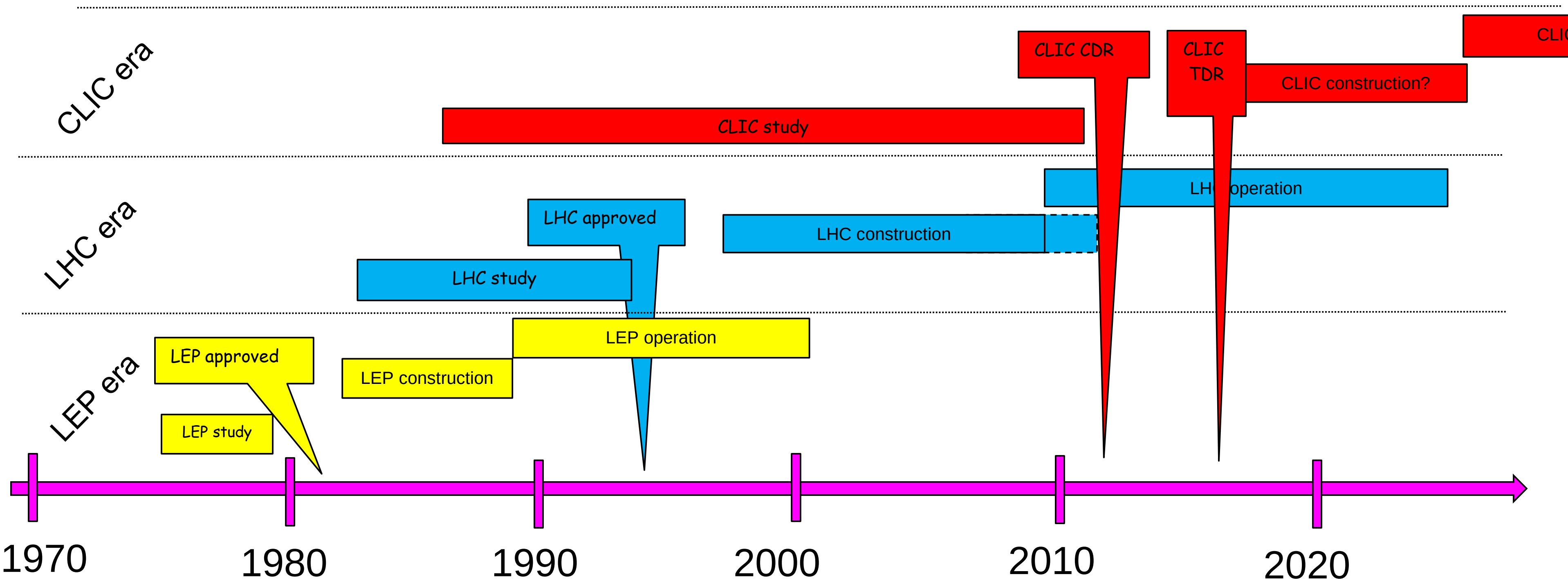


Mikä on CLIC?

- CLIC: Compact Linear Collider.
- Lineaarinen kiihdytin synkrotronisätelyn ja energiahäviöiden minimioimiseksi kun tavoitellaan korkeita energiatasoja.
- Törmäysenergia (center of mass) 380GeV-3TeV.
- Elektronit vastaan positronit
- Kompakti? Mutta 50km pitkä?
- CLIC:ssä elekromagneettinen kiihdyttävä gradientti 100 MV/metri!
- ILC 35 MV/metri suprajohtavalla tekniikalla.



LEP → LHC → CLIC?


CLIC era
LHC era
LEP era
CLIC CDR
CLIC TDR
CLIC construction?
CLIC study
LHC operation
LHC approved
LHC construction
LHC study
LEP approved
LEP construction
LEP operation
LEP study
1970
1980
1990
2000
2010
2020

KANSAINVÄLINEN CLIC YHTEISTYÖ

Yli 30 valtiota – yli 70 instituuttia

Accelerator collaboration

Detector collaboration

Accelerator + Detector collaboration

CLIC roadmap

Goal for next strategy update: Present a CLIC project that is a “credible” option for CERN beyond LHC, a Project Implementation Plan.

Guidelines used internally:

- Adapt to physics results – LHC mostly – taking into account LHC at 13-14 TeV as results become available (be flexible)
- Physics no later than 2035, solid luminosities from Higgs/top at 380 GeV to 3 TeV (staging)
- Initial costs compatible with earlier projects (order LHC+50%) (staging)
- Upgradable in 2-3 stages over a 20-30y period, without major (max 3-4 years) operational breaks, and with upgrade costs also in reasonable agreement with current budget level.
- Cover accelerator, detector, physics

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)

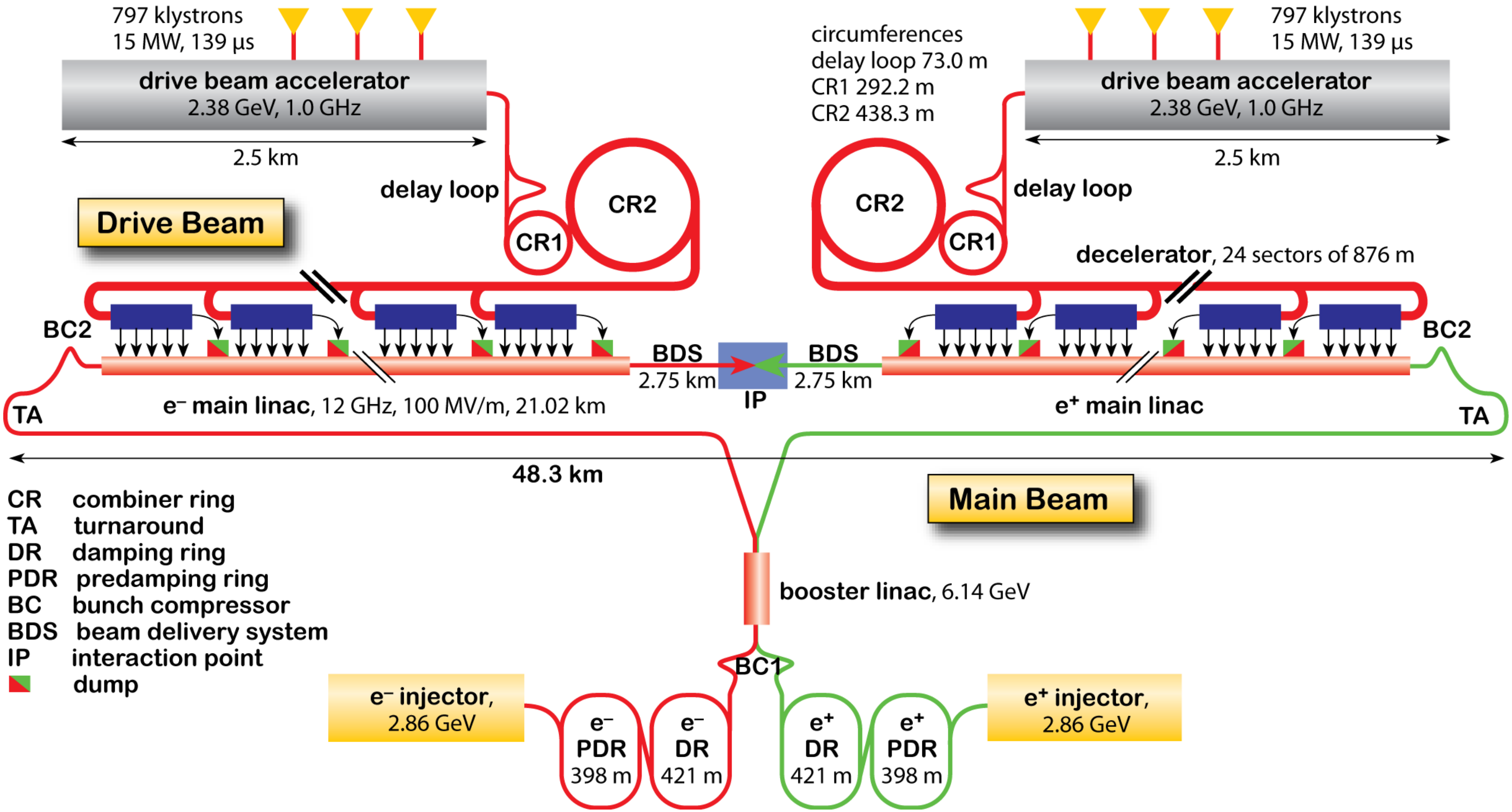
2025 Construction Start

Ready for construction; start of excavations

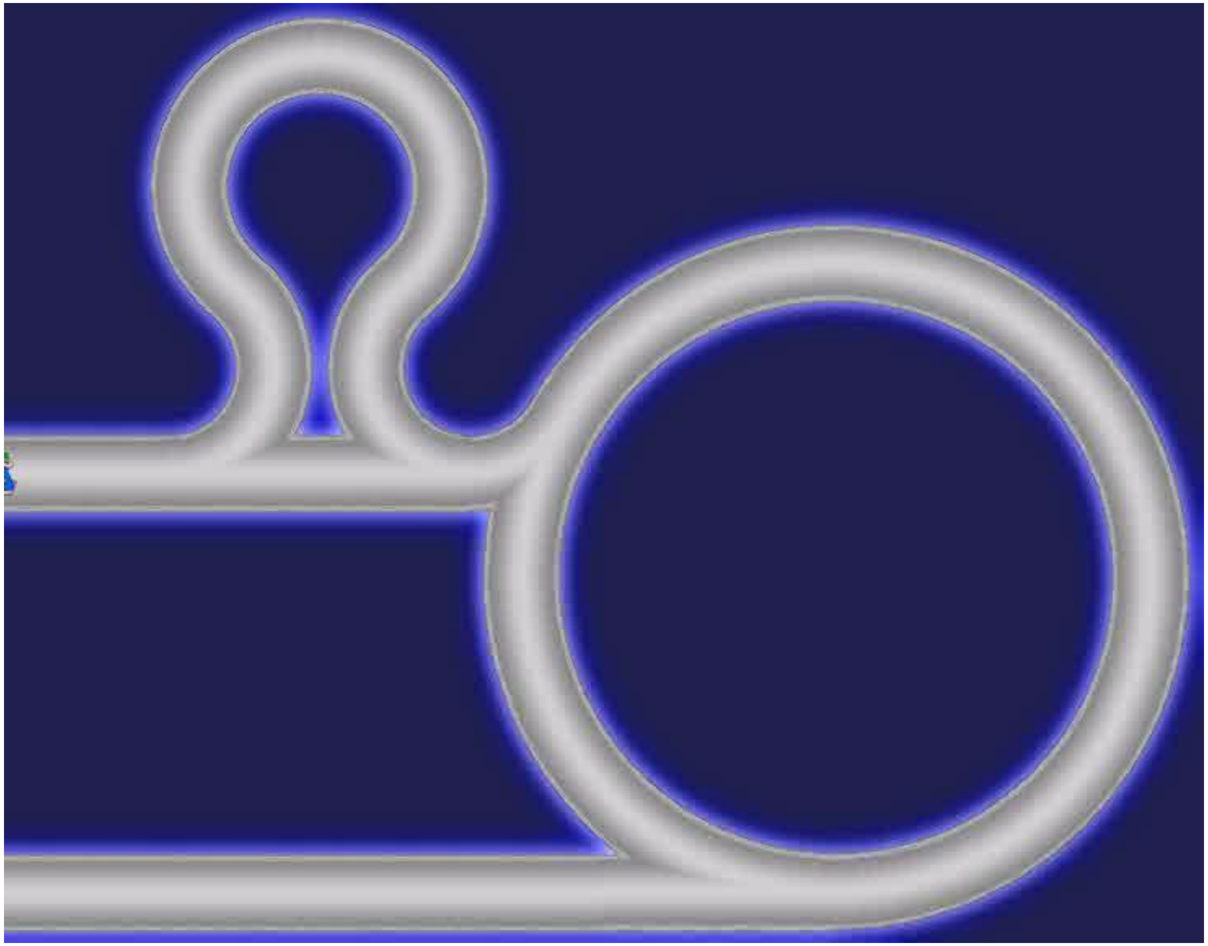
2035 First Beams

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

CLIC toimintaperiaate

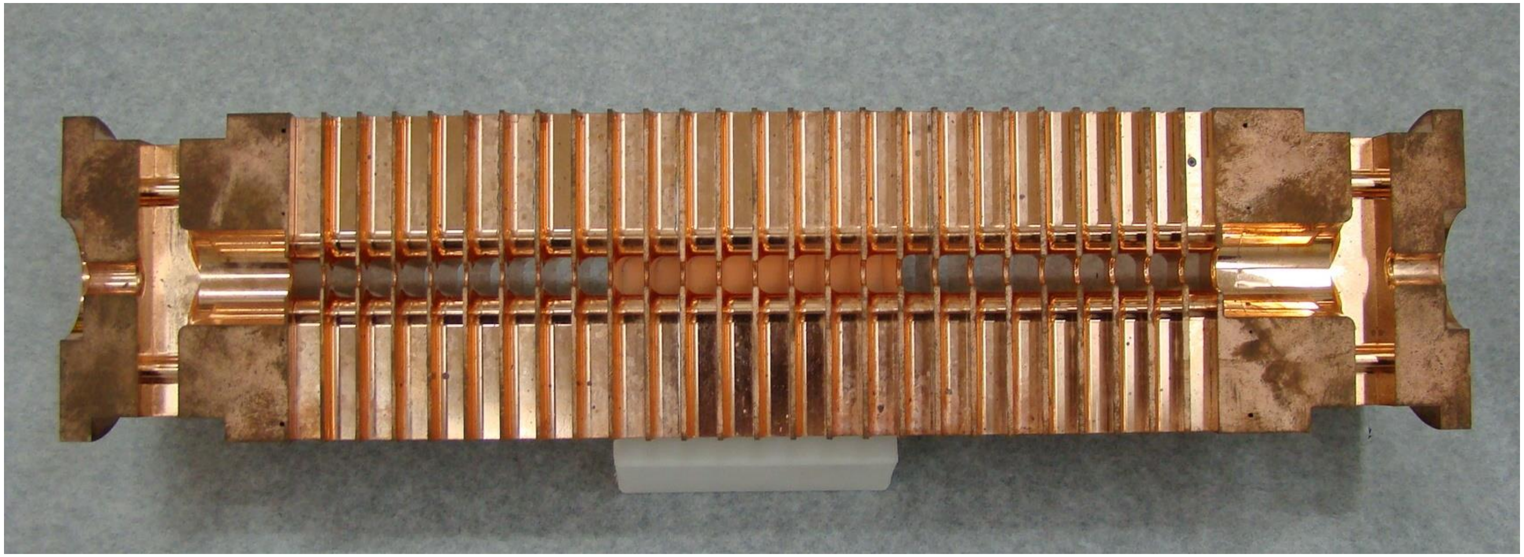


Delay loop & Combiner ring

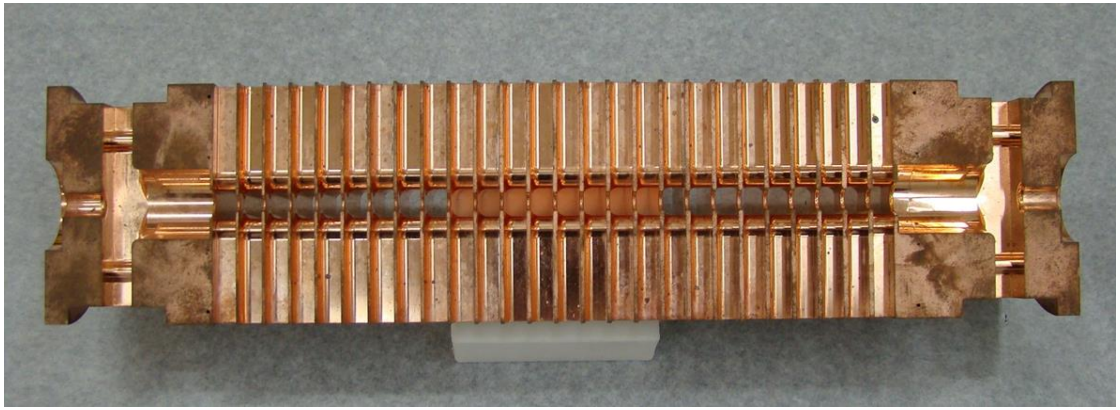


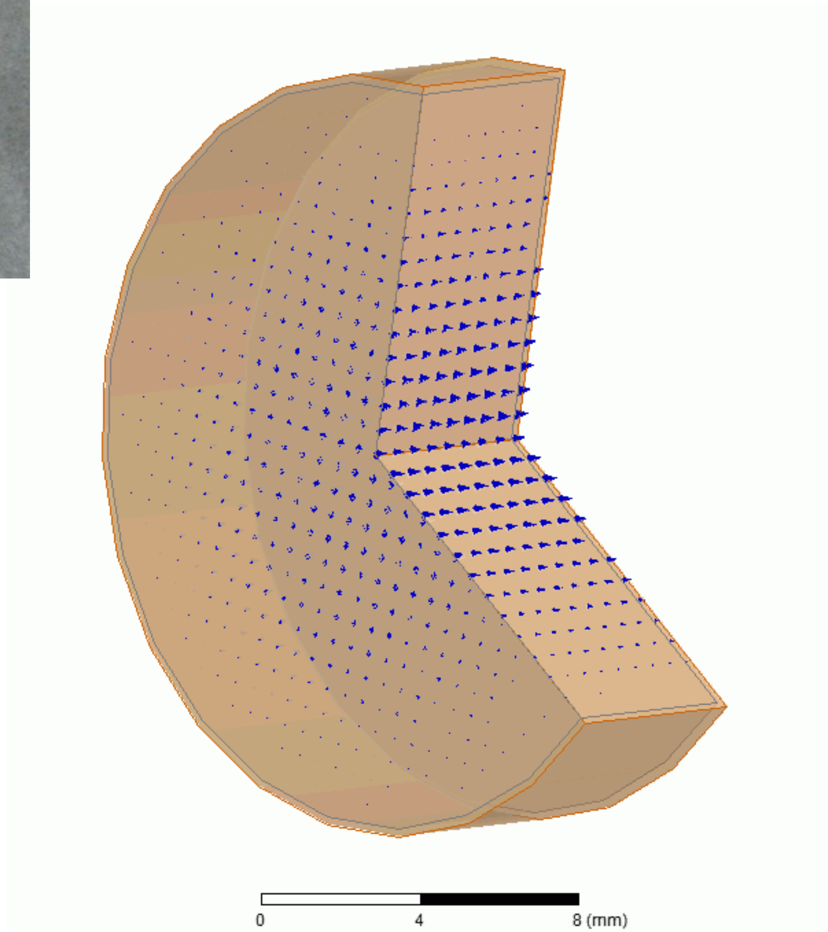
Courtesy of A. Andersson

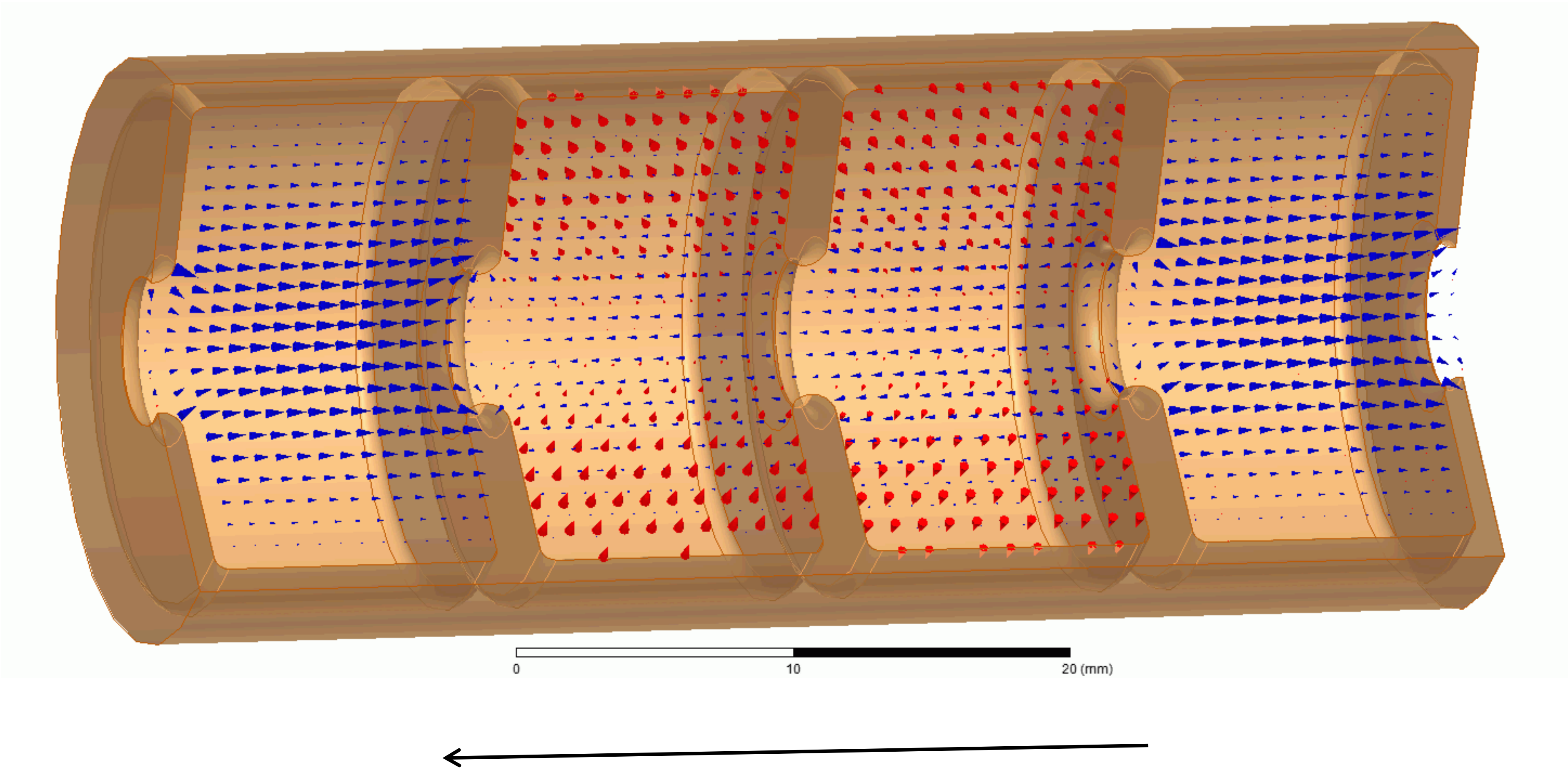
Kiihdytinrakenne



Sähkömagneettinen kenttä

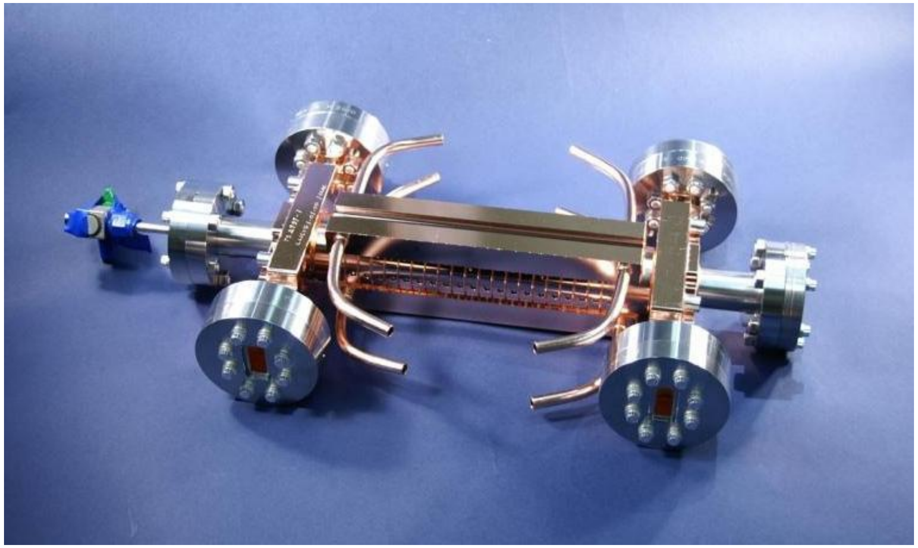


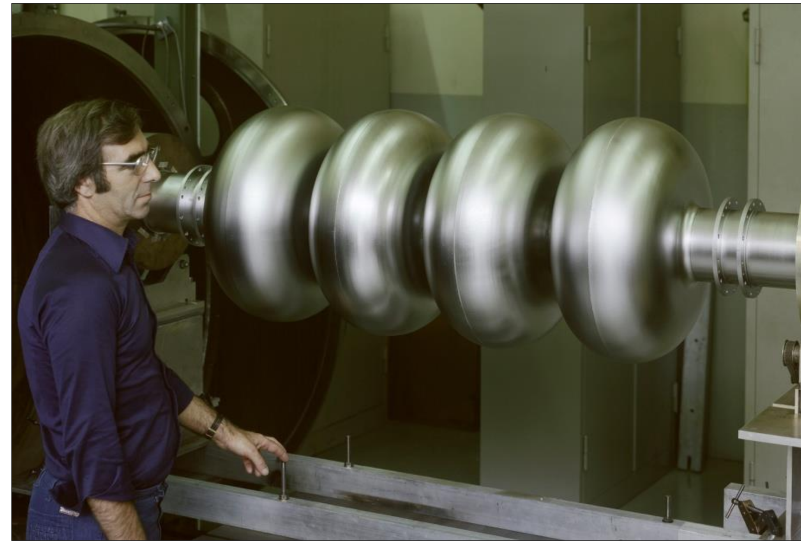




beam propagation direction

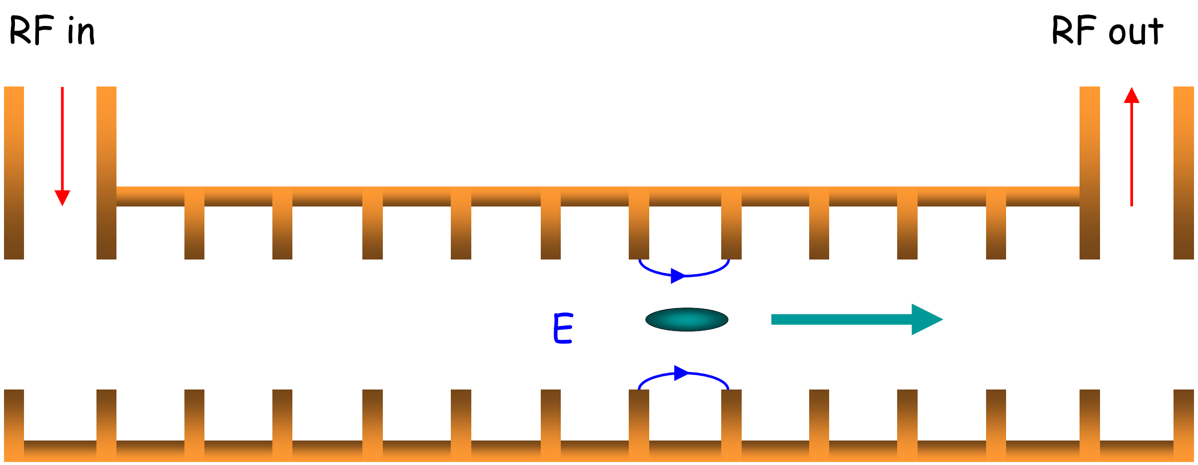
Korkea gradientti = kiihdytysteho





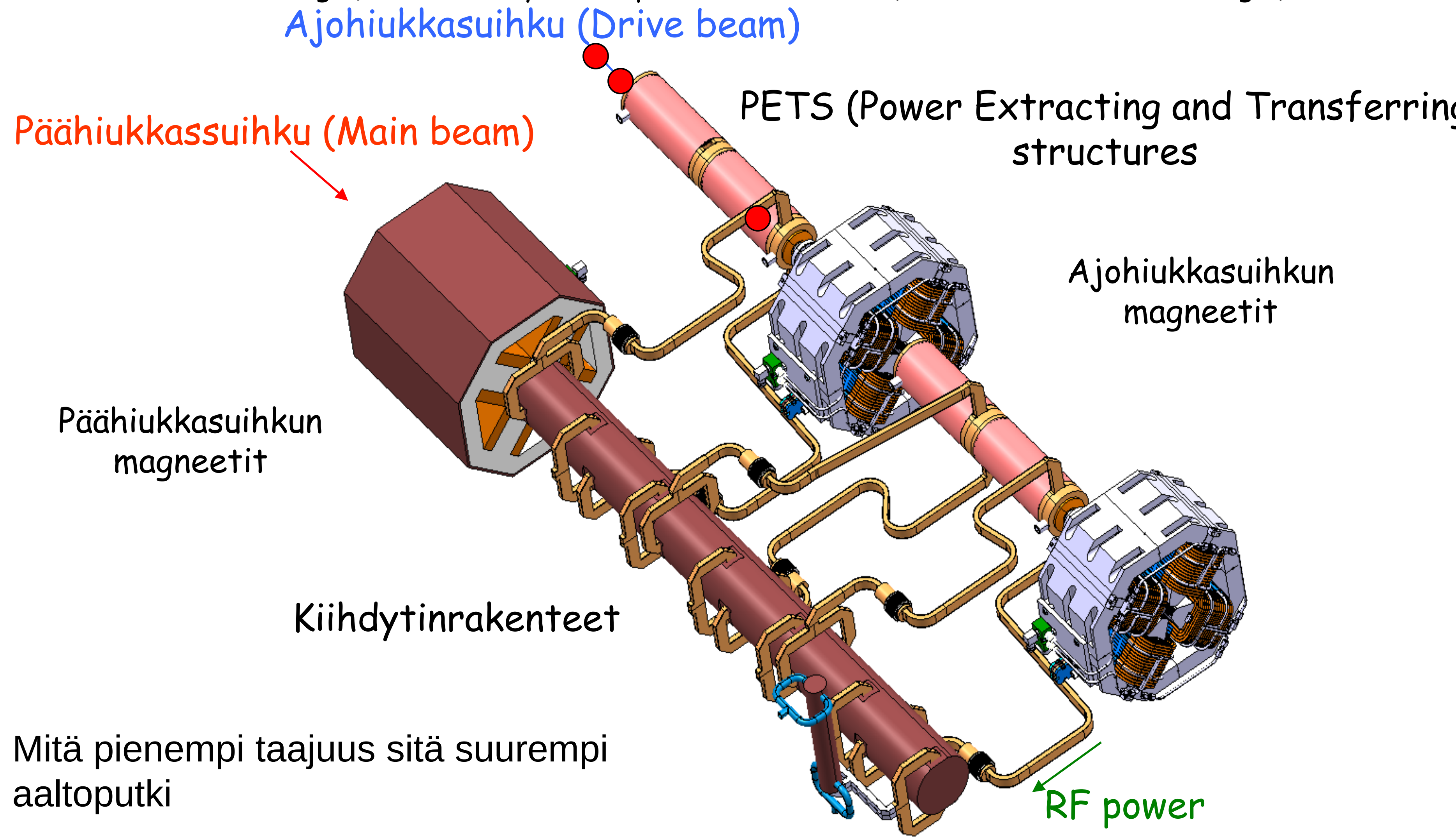
CLIC target gradient: 100 MV/m

LEP gradient ~ 5 MV/m



CLIC kahden hiukassuihkun kiihdytys

CLIC perustuu ns. kahden hiukkassuihkun kiihdytykseen, jossa ajohiukkassuihkun (korkea sähkövirta, matala energia) avulla kiihdytetään päähiukkassuihkua (matala virta, korkea energia).

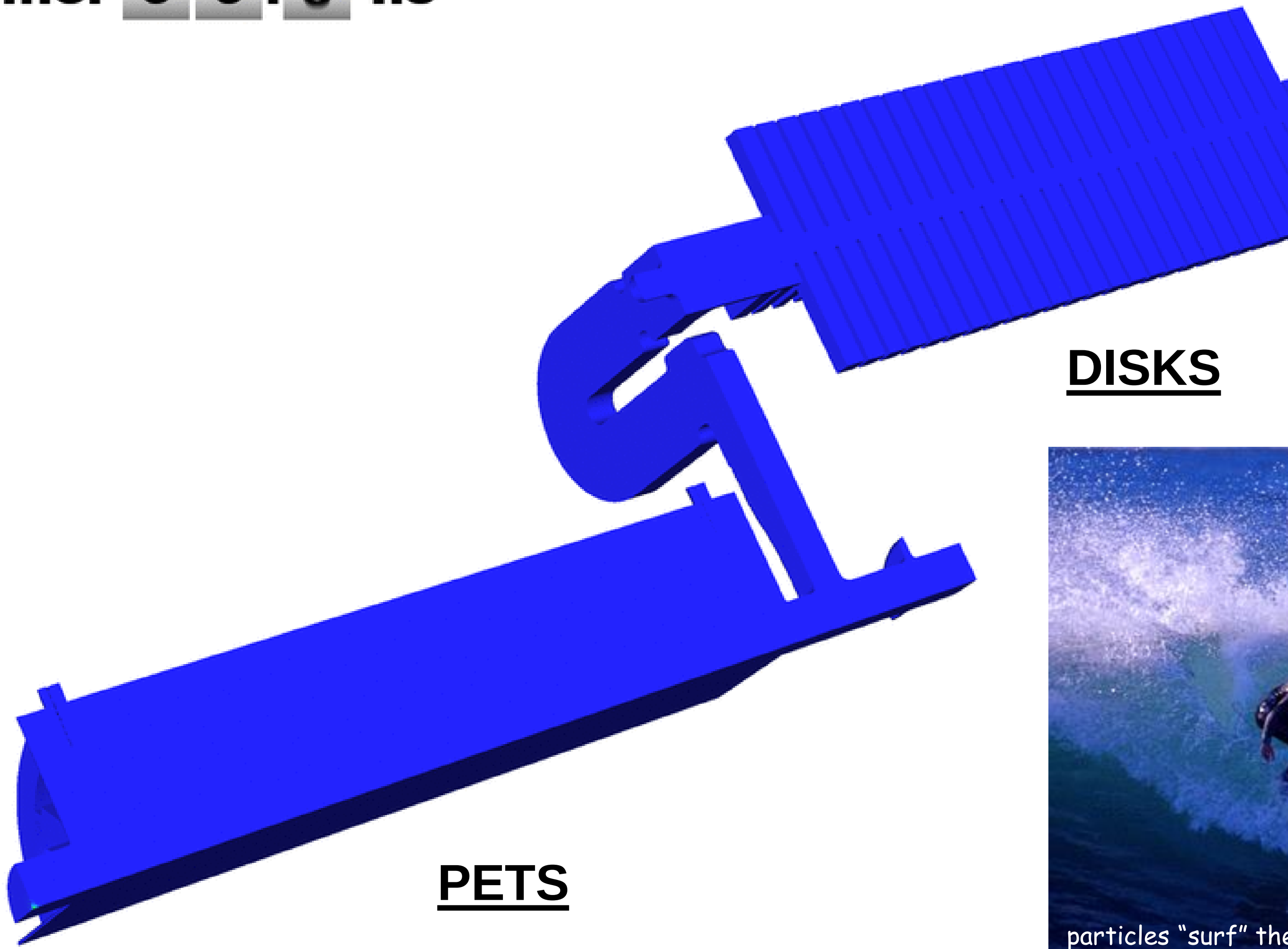


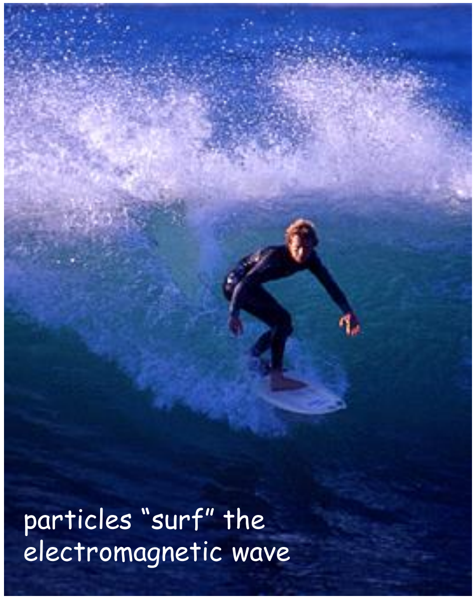
Mitä pienempi taajuus sitä suurempi aaltoputki

RF Power Transfer in Coupled Structure

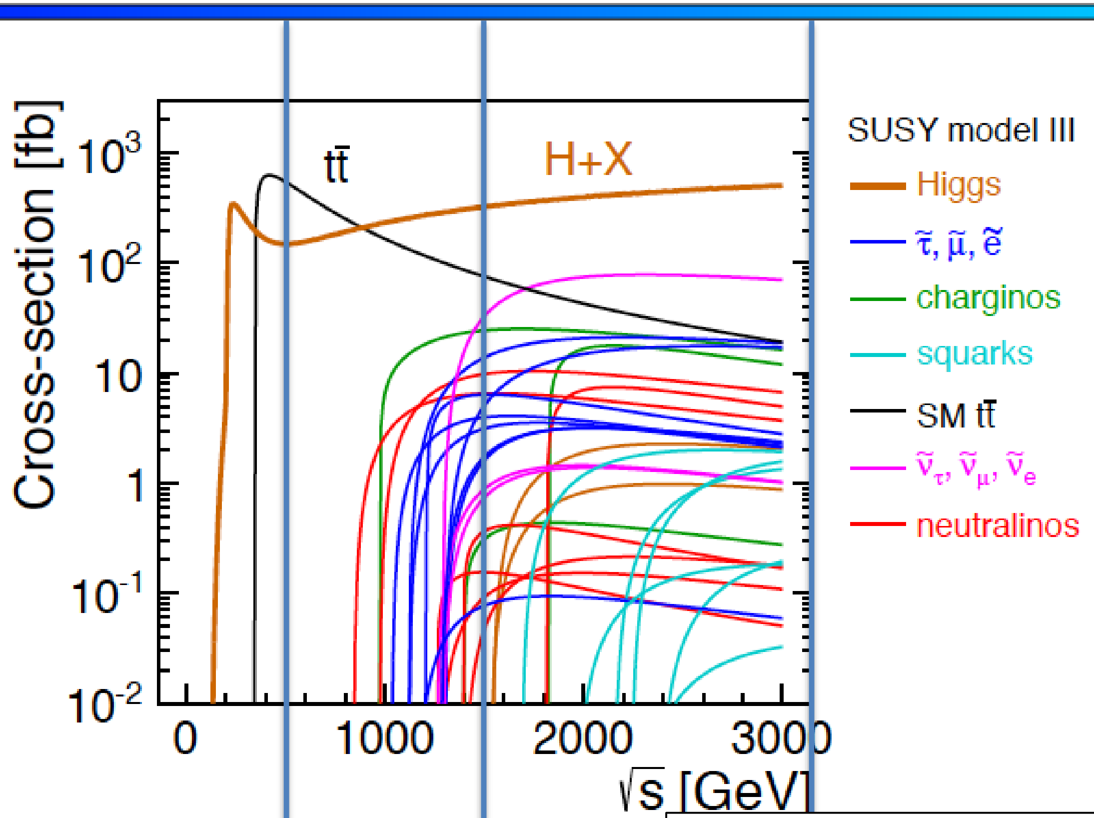
time: 0 0.0 ns

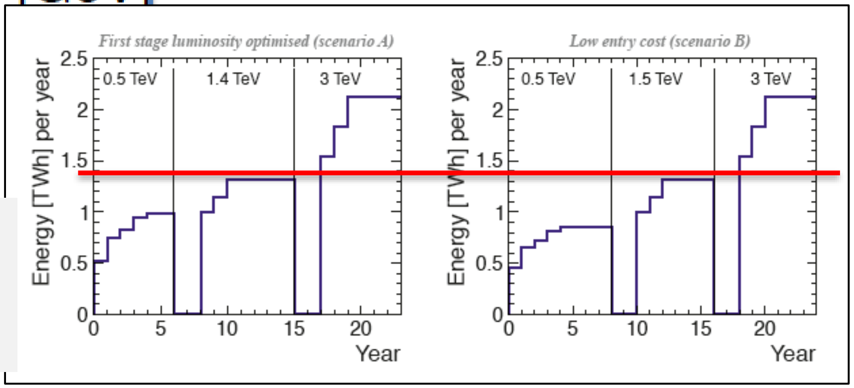
Slide courtesy of A. Candel (SLAC)





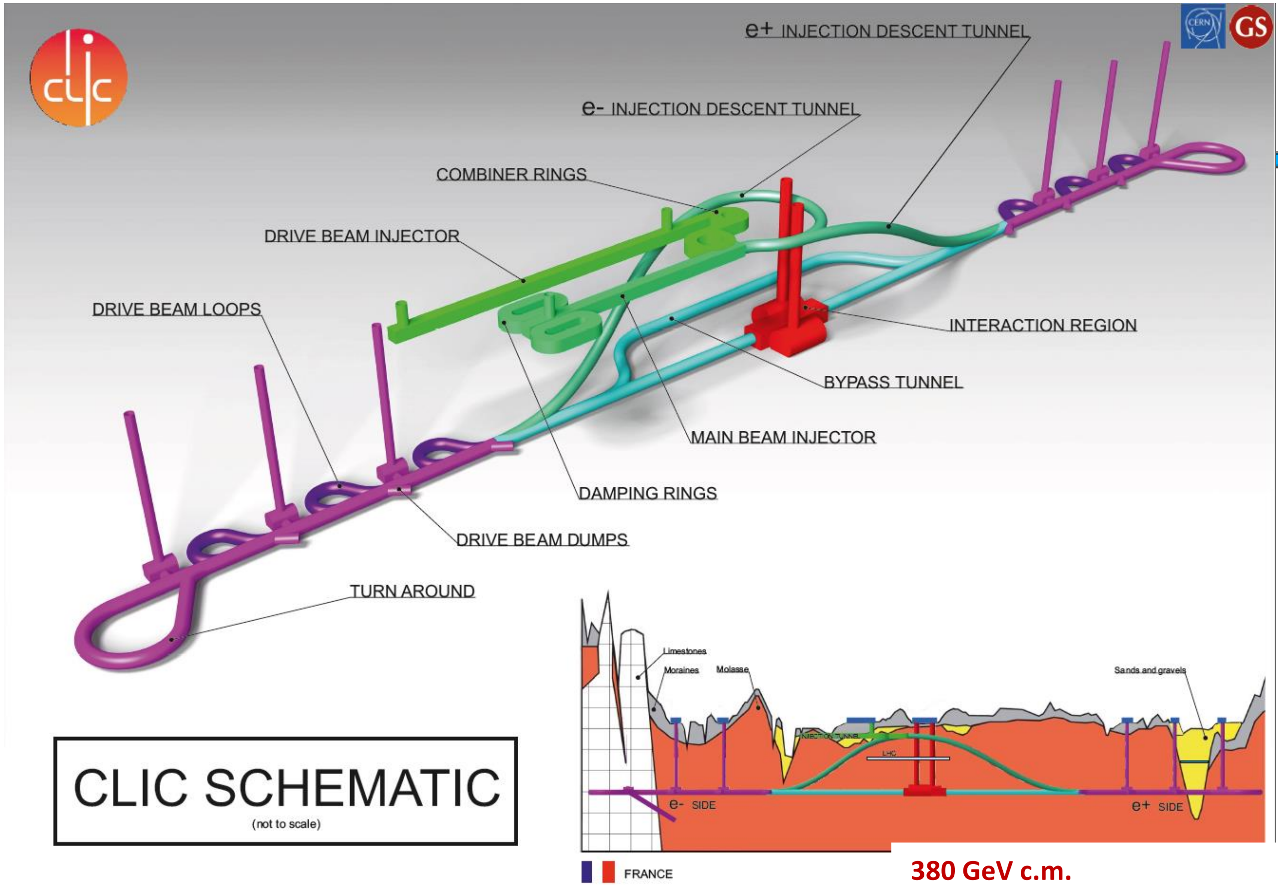
CLIC:n mahdollisuudet

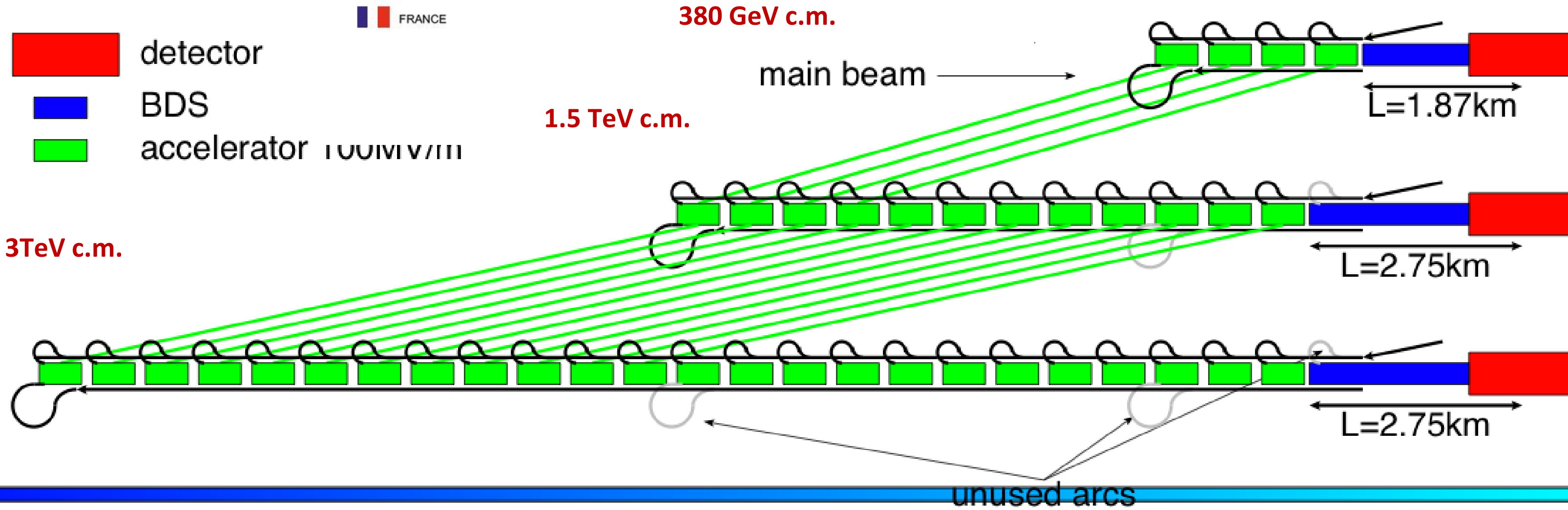




CERN energian kulutus vuonna 2012: 1.35 TWh

CLIC teho 582 MW

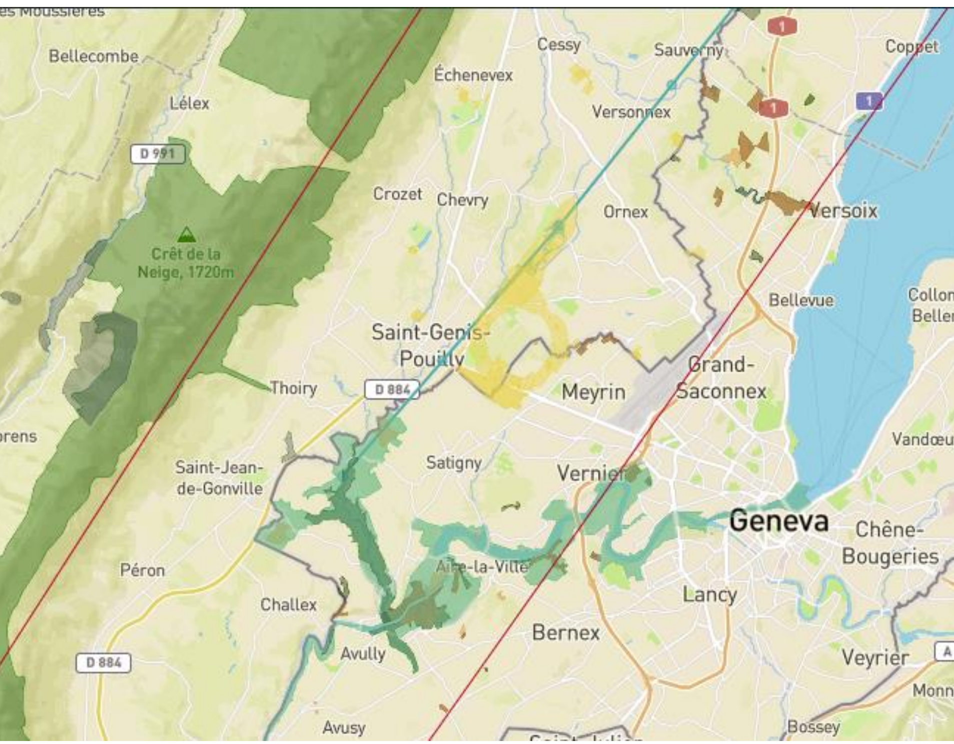

e+ INJECTION DESCENT TUNNEL
e- INJECTION DESCENT TUNNEL
COMBINER RINGS
DRIVE BEAM INJECTOR
DRIVE BEAM LOOPS
INTERACTION REGION
BYPASS TUNNEL
MAIN BEAM INJECTOR
DAMPING RINGS
DRIVE BEAM DUMPS
TURN AROUND
CLIC SCHEMATIC
(not to scale)
Limestones
Moraines
Molasse
Sands and gravels
e- SIDE
e+ SIDE
FRANCE

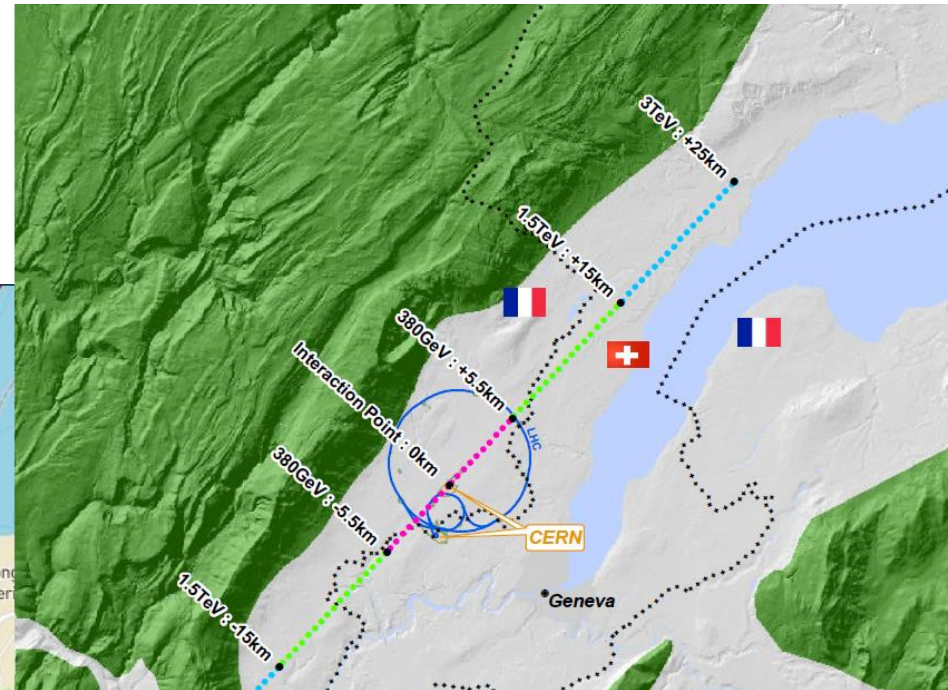

detector
BDS
accelerator
380 GeV c.m.
main beam
L=1.87km
1.5 TeV c.m.
L=2.75km
3TeV c.m.
L=2.75km
unused arcs

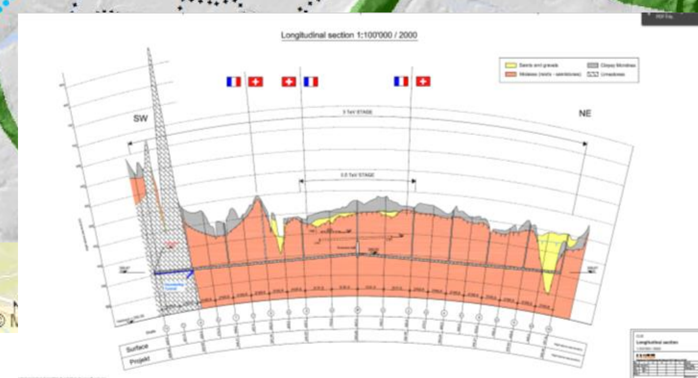
Esimerkki loppusijoituspaikasta

IP under CERN Prevessin site

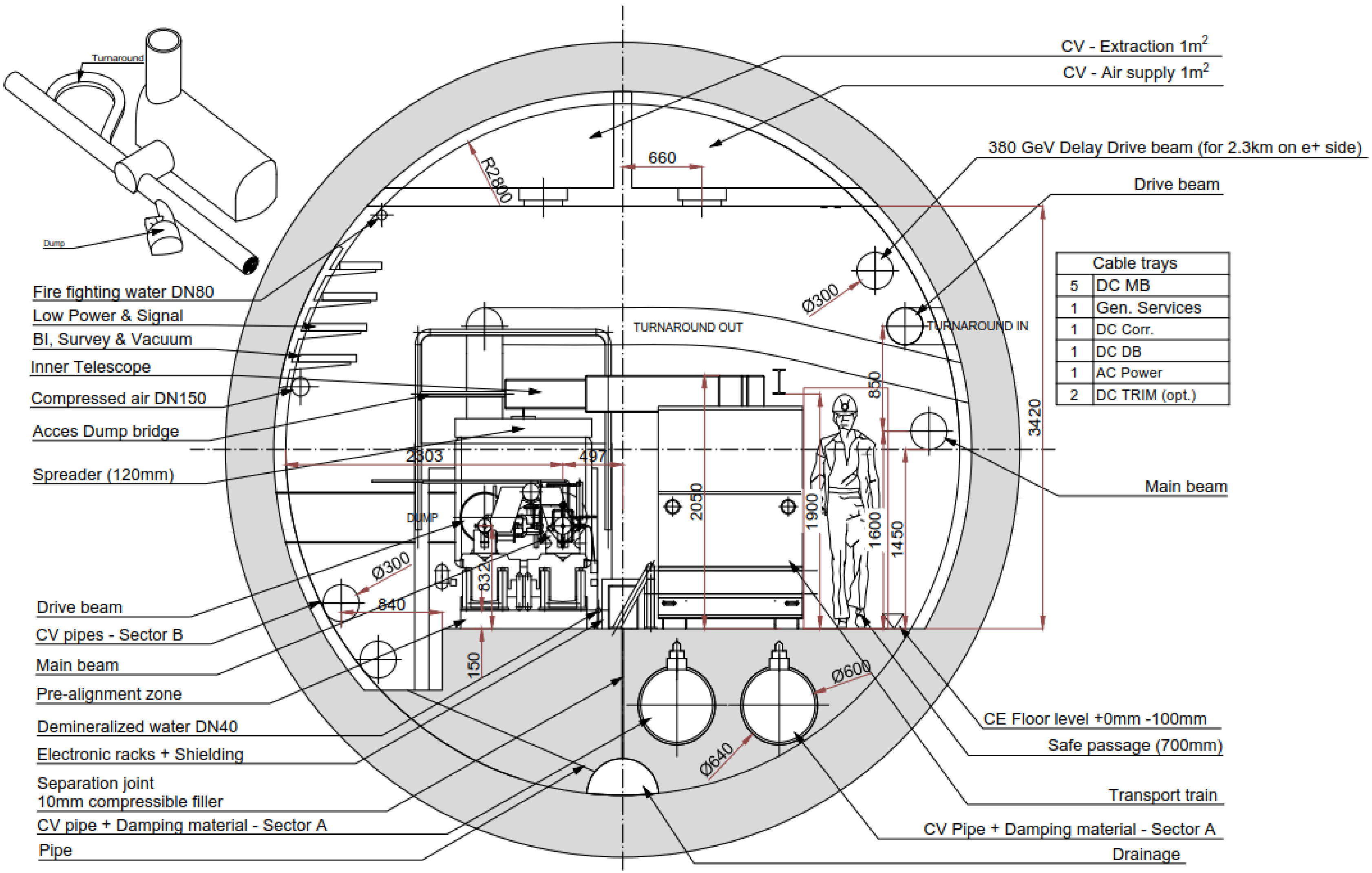
Vaihe 1: 380 GeV pituus 11 km, Vaihe 2: 1,5 TeV, Vaihe 3: 3 TeV pituus 48.5 km





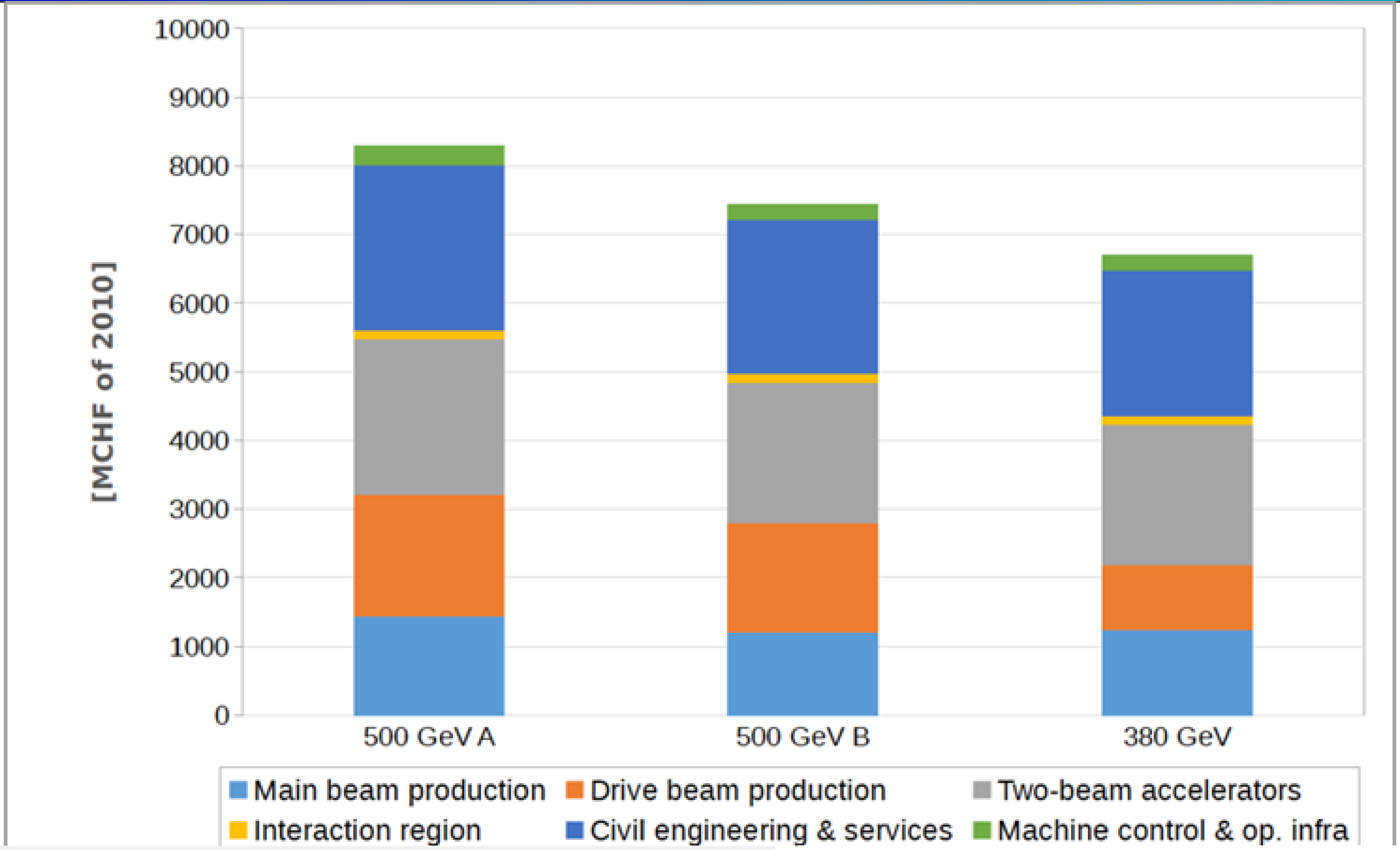


CLIC TUNNELI POIKKILEIKKAUS



Cable trays	
5	DC MB
1	Gen. Services
1	DC Corr.
1	DC DB
1	AC Power
2	DC TRIM (opt.)

Kustannusarvio



First to second stage: 4 MCHF/GeV (i.e. initial costs are very significant)

Caveats:

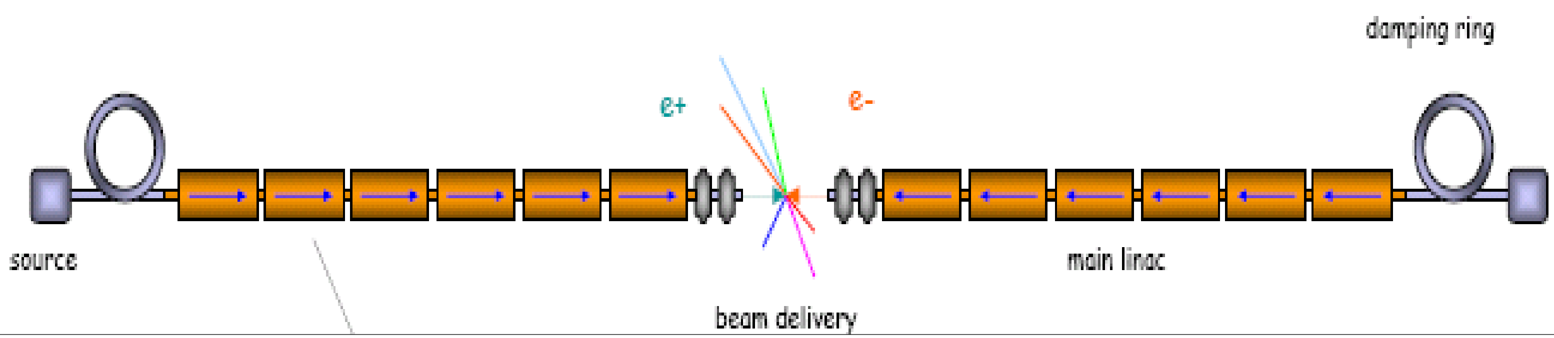
- Uncertainties 20-25%
- Possible savings around 10%
- However – first stage not optimised (work for next phase), parameters largely defined for 3 TeV final stage

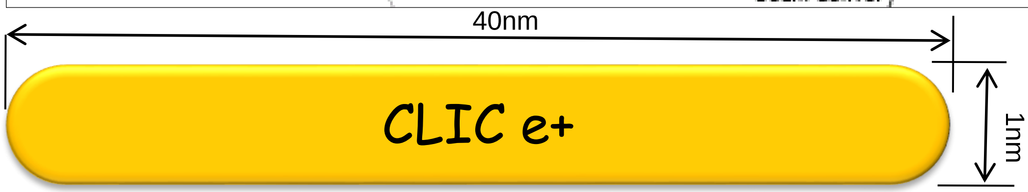
Table 11: Value estimate of CLIC at 380 GeV centre-of-mass energy.

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

CLIC Lineaaritörmäyttimen suurimmat tekniset haasteet:

1. Suuri kiihdyttävä gradientti törmäyttimen pituuden minimoimiseksi
2. Hiukkassuihkut nanometriluokkaa valmistustarkkuus, kohdistus, suoruus ja stabilointi
3. Kustannukset ja rahoitus





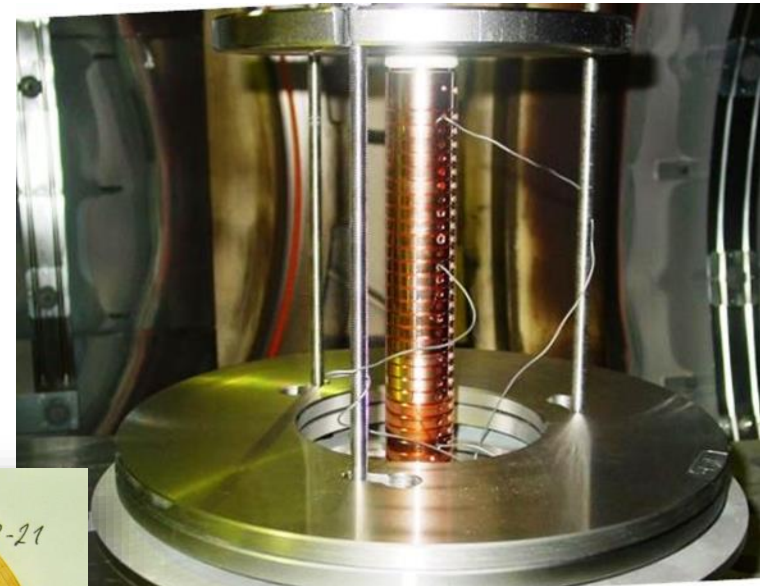
Hiuksen halkaisija noin 100 µm (100 000 nm)

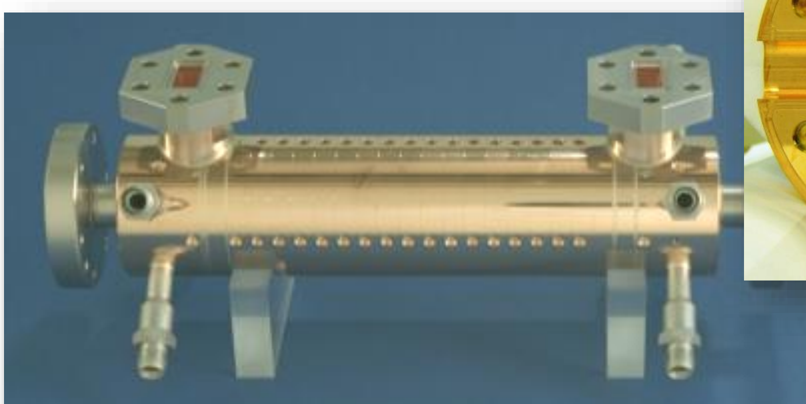
Keskeisiä teknisiä osa-alueita

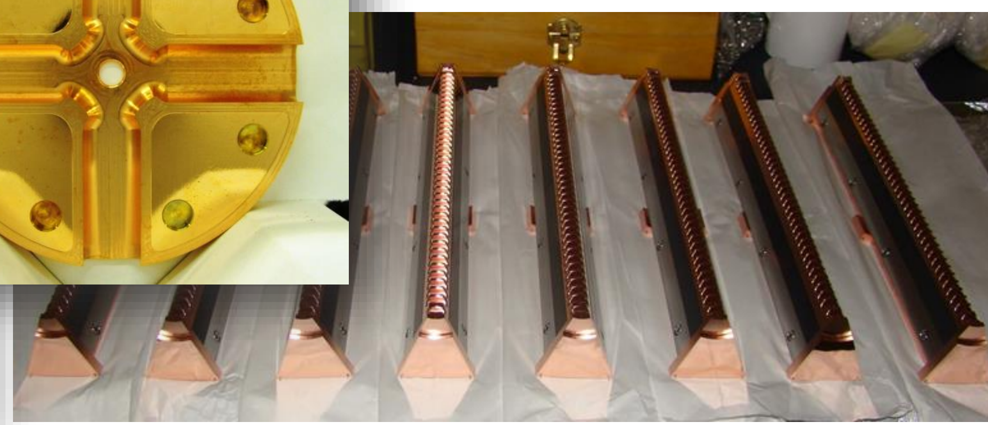
- Korkea kiihdyttävä gradientti: vahvat sähkö- ja magneettikentät RF-komponenteissa
  - Komponentit huoneenlämmössä, normaali sähkönjohtavuus
  - Kuparia käytetään RF-komponenteissa erinomaisen sähkönjohtavuutensa takia
- Vaadittava asemointitarkkuus mikrometriluokkaa
  - Suoruus, absoluuttinen tarkkuus, liukuva ikkuna -ajatus
  - Lisäksi aktiivinen asemointijärjestelmä
- Stabilointi
  - Magneetit kiihdyttimessä sekä fokusointi
- Lämmönhallinta
  - Tämän hetkinen suunnitelma on jäähdyttää moduleita vedellä
  - Törmäyttimen kokonaishyötysuhdetta optimoidaan *jatkuvasti*
- Tyhjiö UHV-luokassa (10^{-9} mbar)
- Hiukkassuihkut liikkuvat "lähes" valonnopeudella

Kiekkojen valmistus:

- *Cu OFE UNS C10100*
- *Muototarkkuus ± 2.5 µm*
- *Pinnankarheus Ra 0.025 µm*
- *Ø 80 mm*
- *Liittäminen diffuusiohitsaamalla*

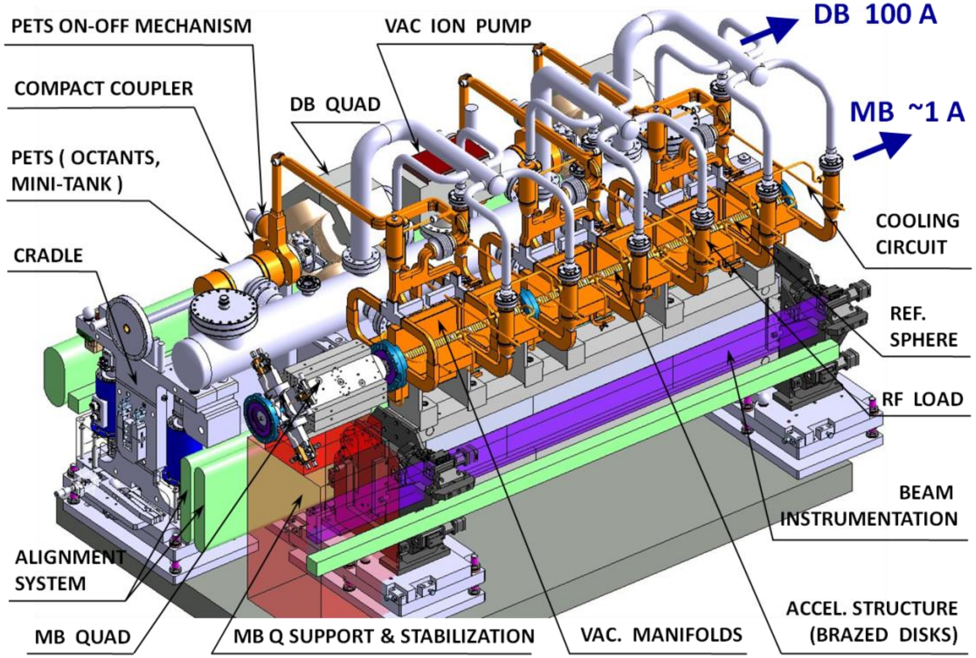


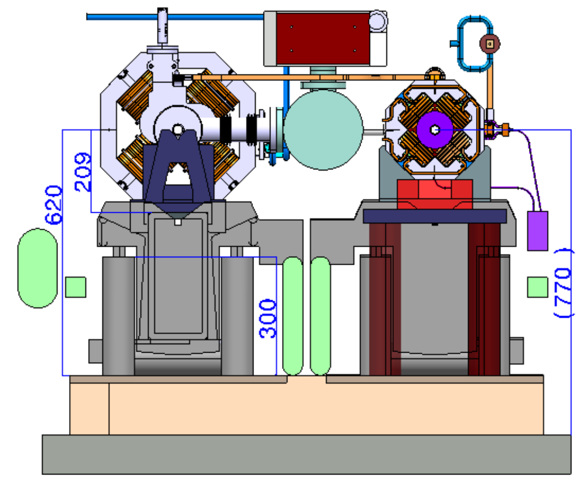




08.03.2018 L. Deparis

CLIC moduuli





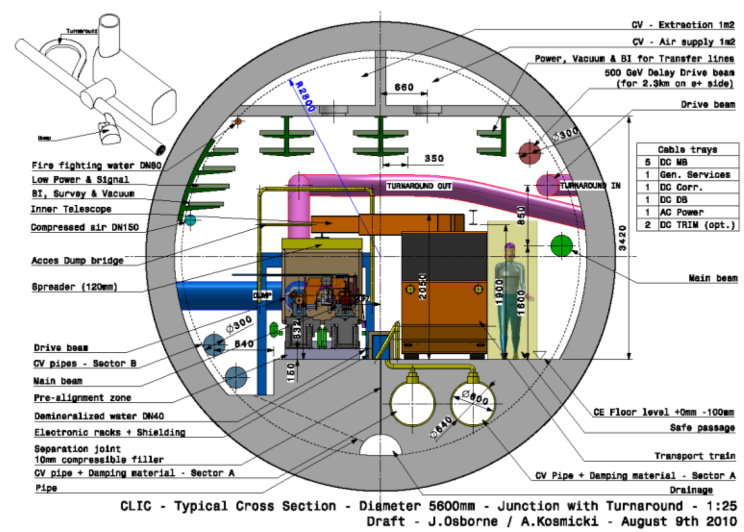
(Courtesy A. Samoshkin)

20760 moduulia/ (noin 2 metriä pitkiä)

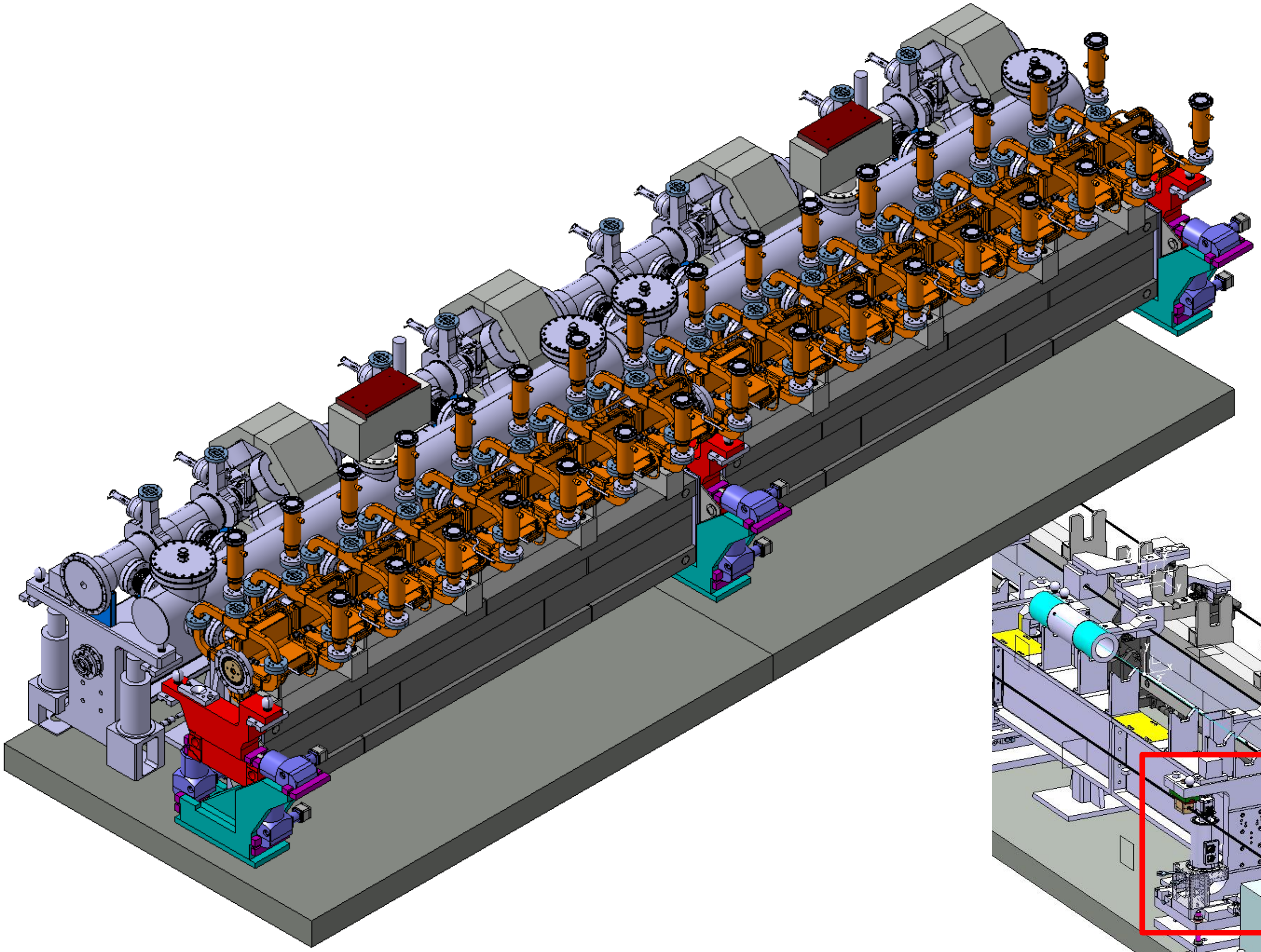
71460 voimansiirtoyksikköä PETS (drive beam)

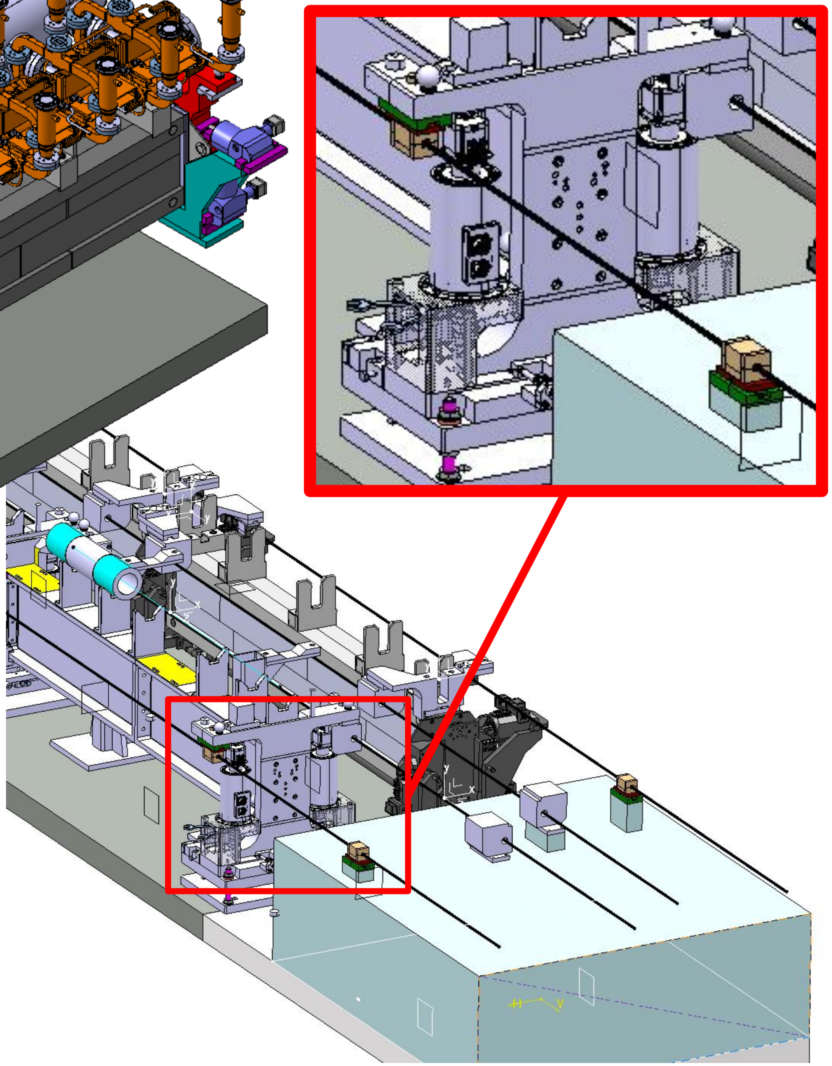
143010 kiihdytinrakennetta

(päähiukkassuihkulle)



(Courtesy J. Osborne)

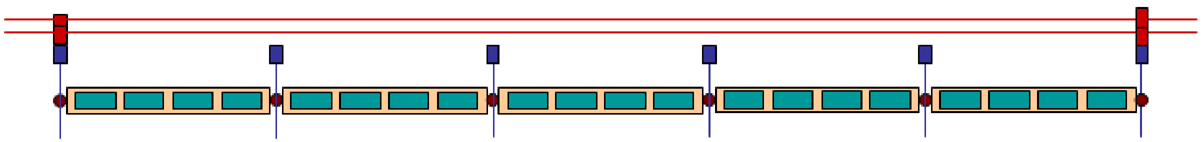


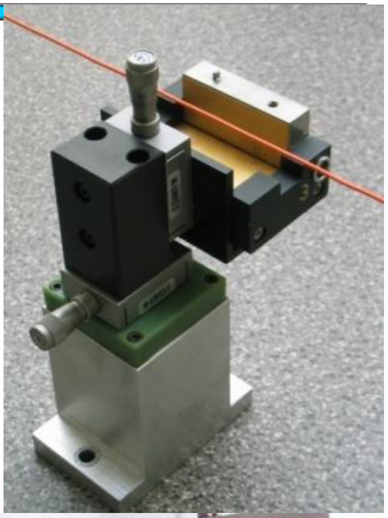


Aktiivinen asemointi

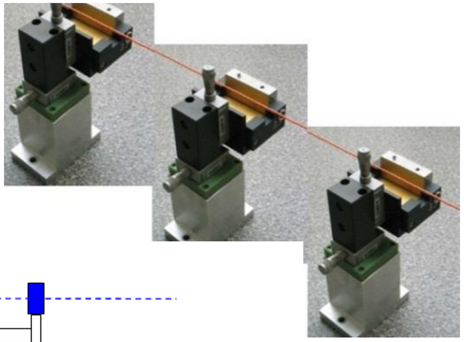
Determination of the position of the components

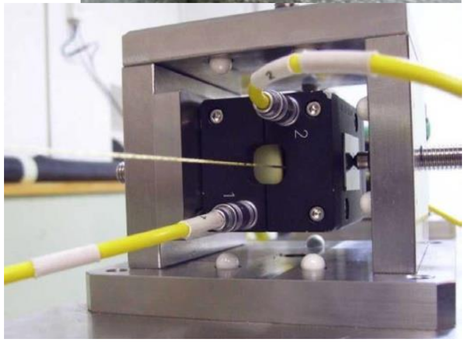
- Association of a propagation network every articulation point

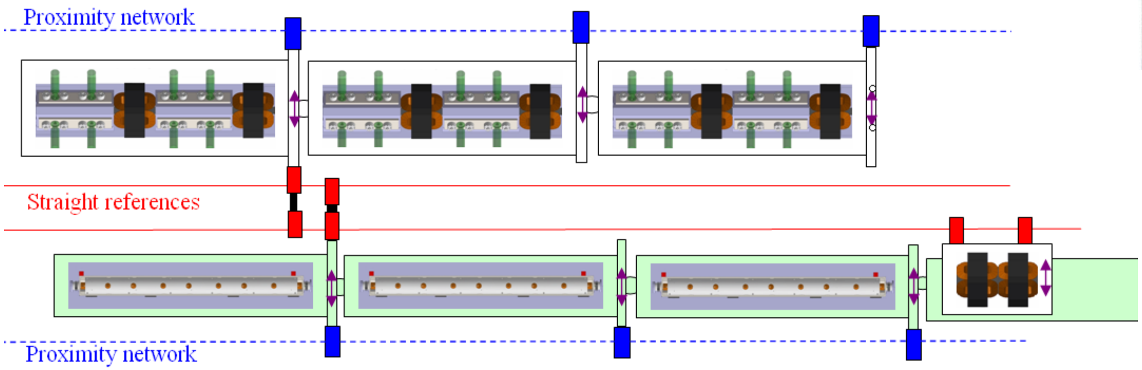




At the scale of the module:



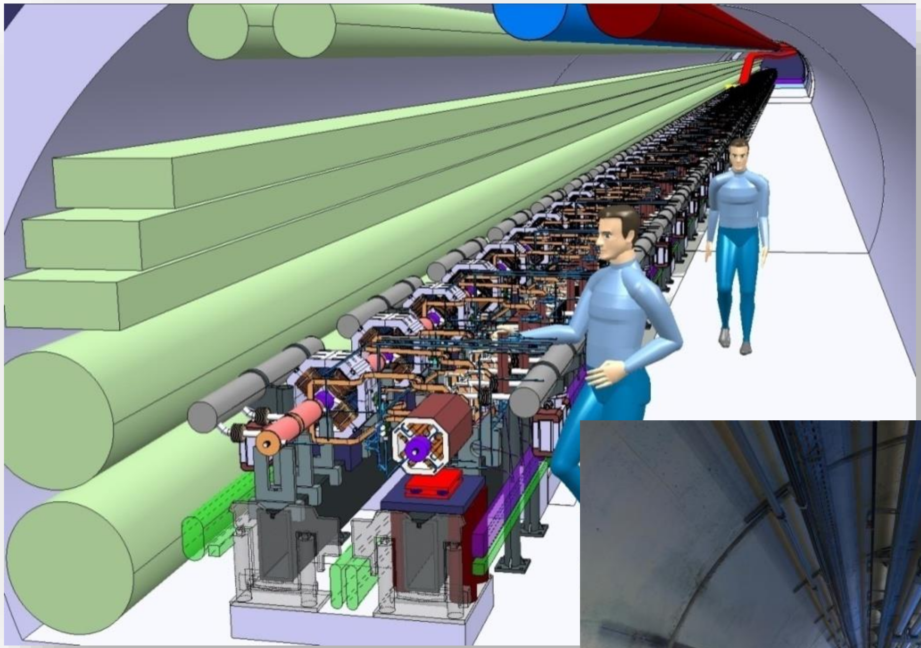


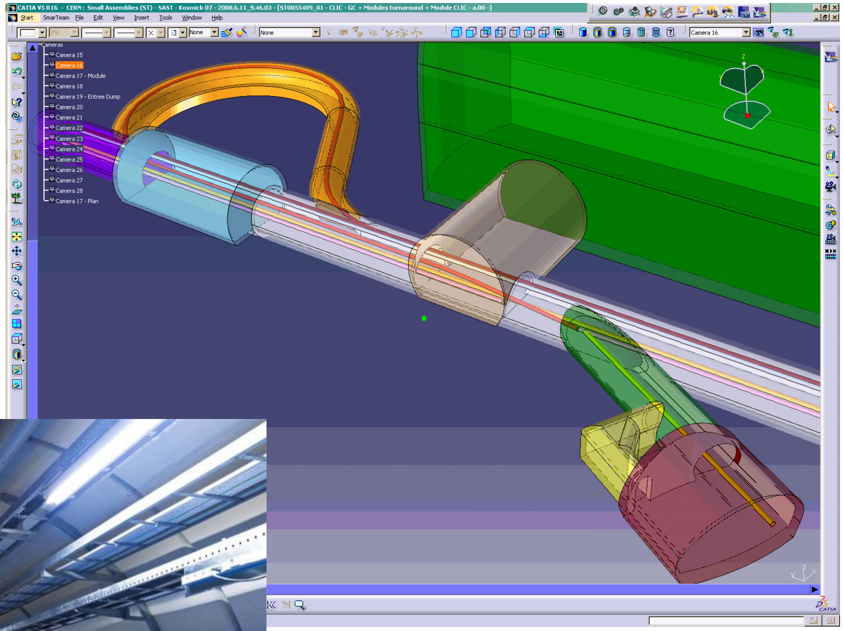


Drive beam (PETS + quad on the same girder)

Main beam (cavities on girder, quad independent)

Asennustunneli

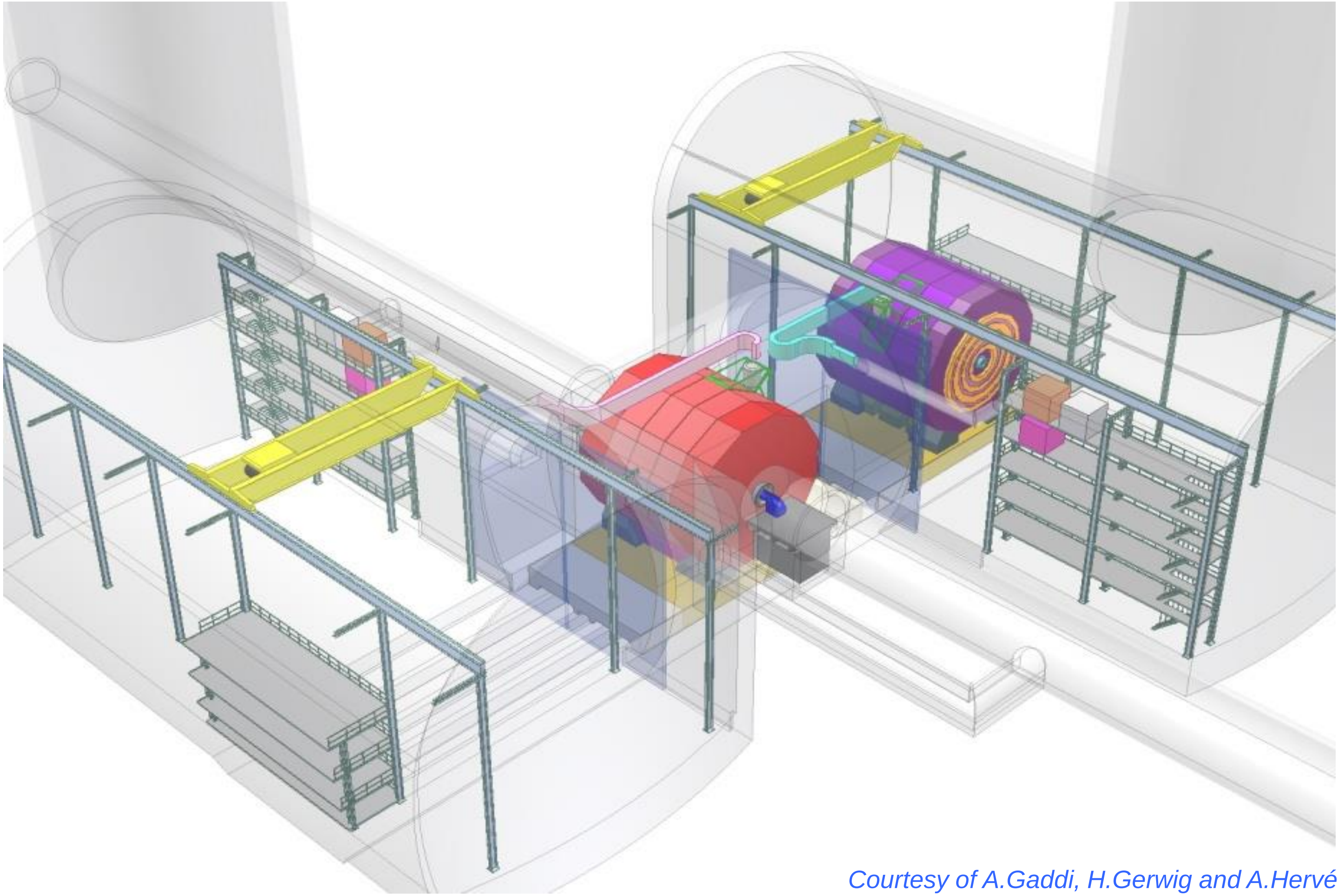




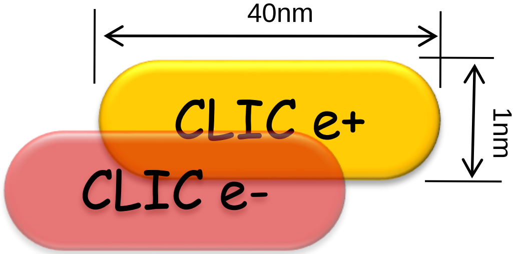
(Courtesy J. Osborne)

Standard tunnel with modules

CLIC yksi törmäyskohta, kaksi detektioria



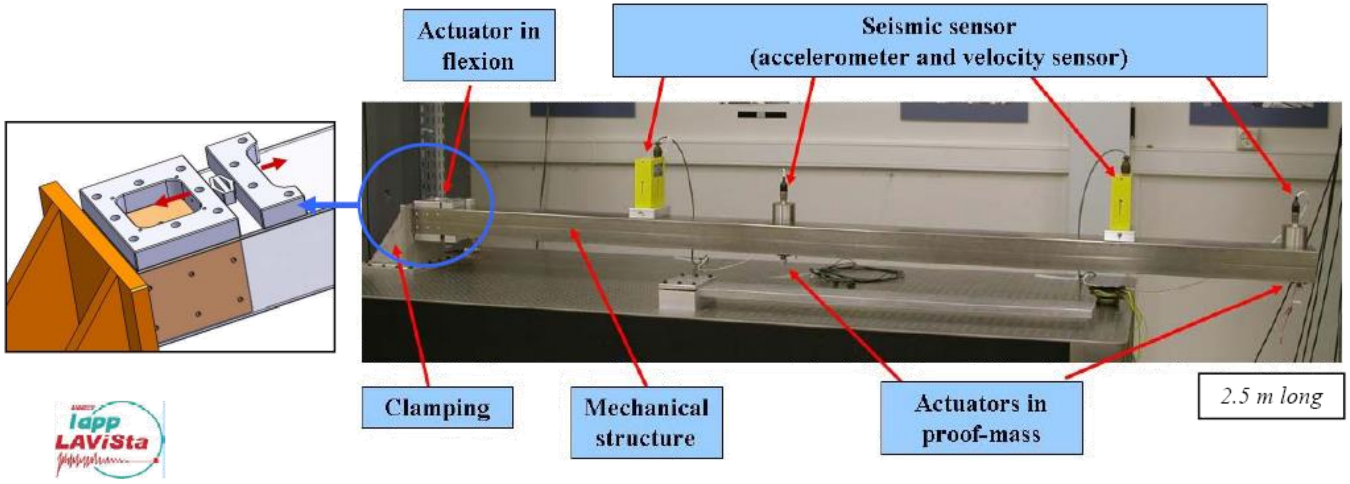
Courtesy of A.Gaddi, H.Gerwig and A.Hervé



Feedback

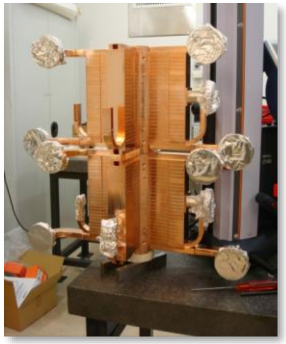
Active rejection of canteliver beam resonances: home-made

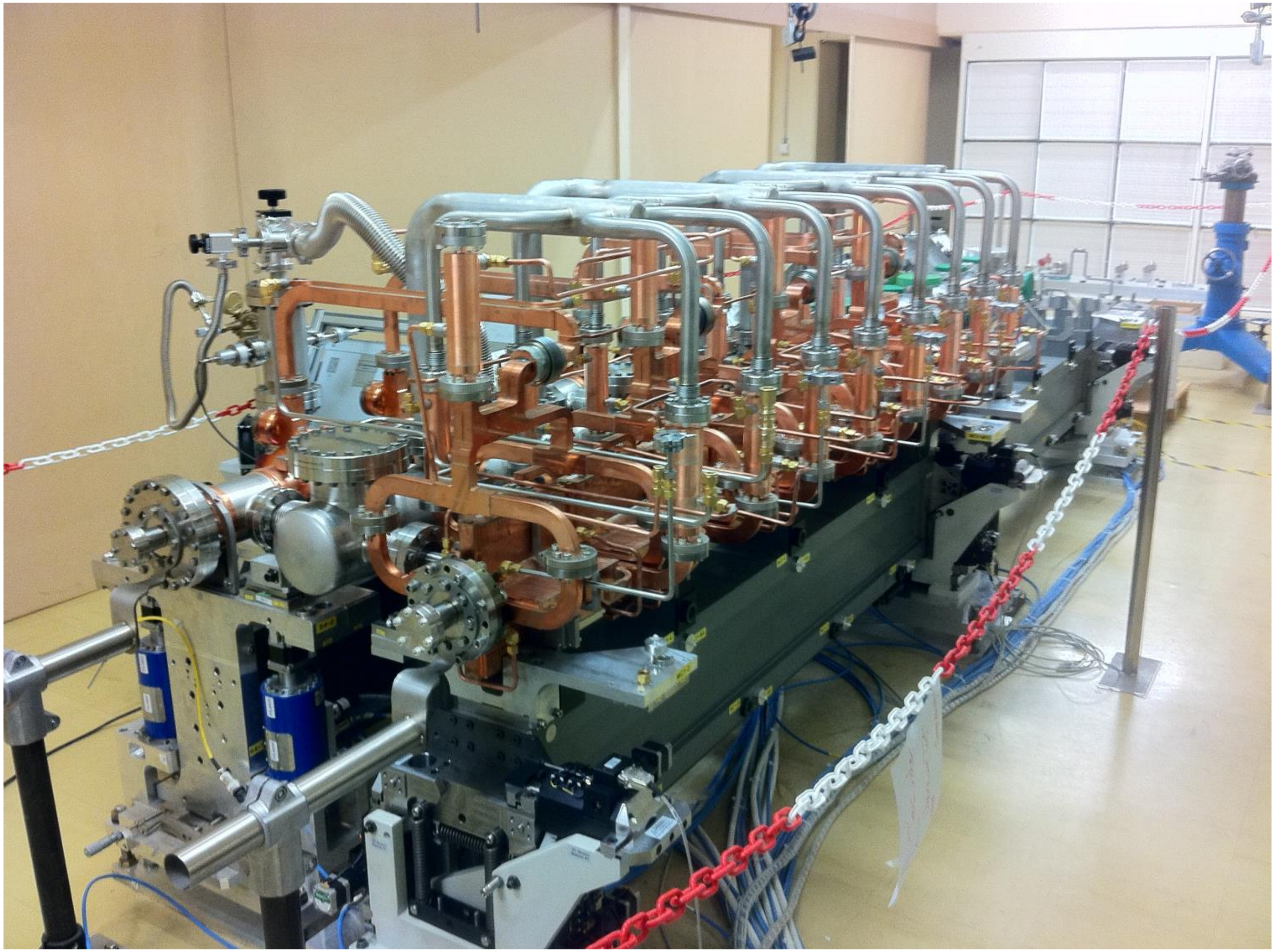
Mechanical structure and its instrumentation



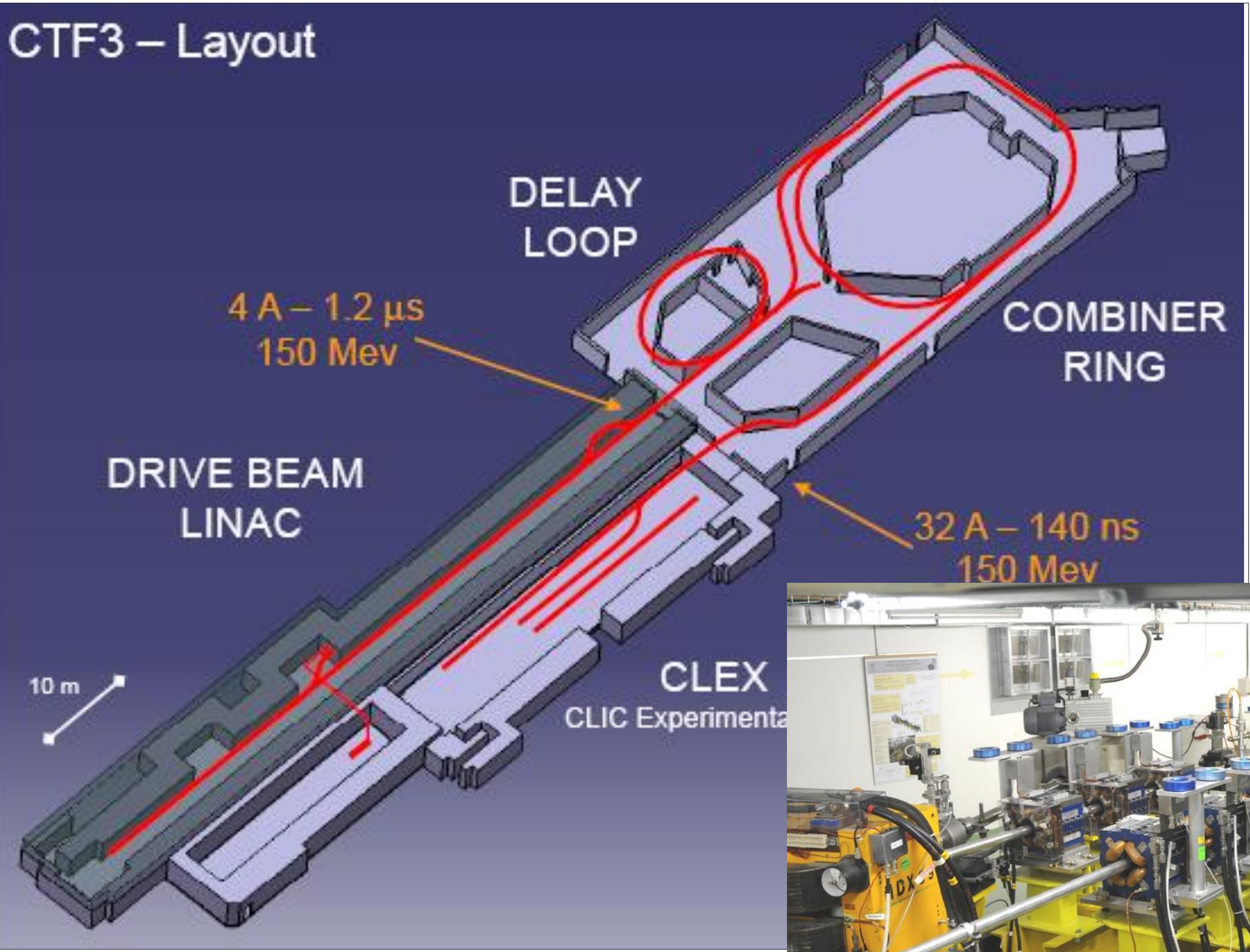
2008-05-30 C.Hauviller CLIC seminar

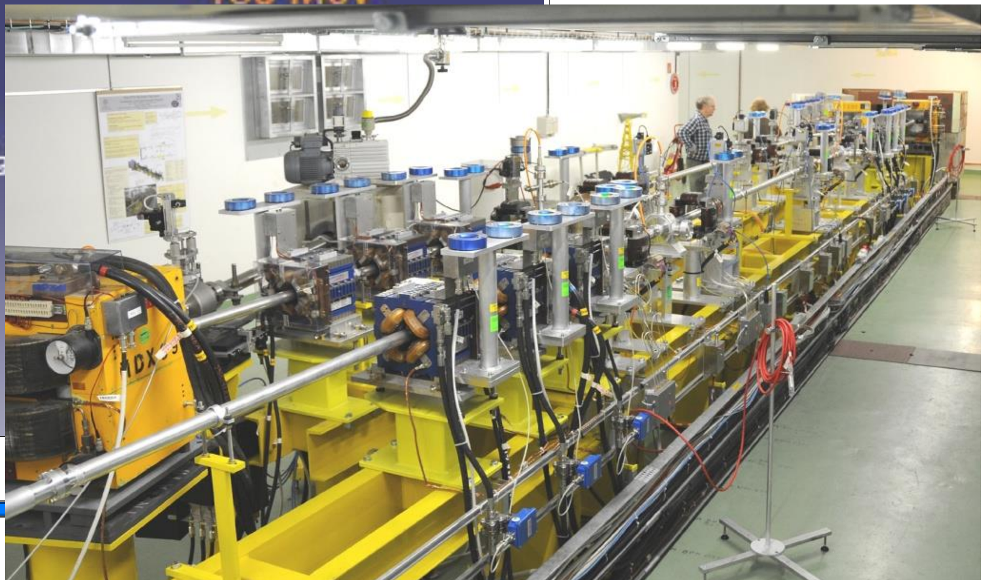
CLIC laboratoriomoduuli



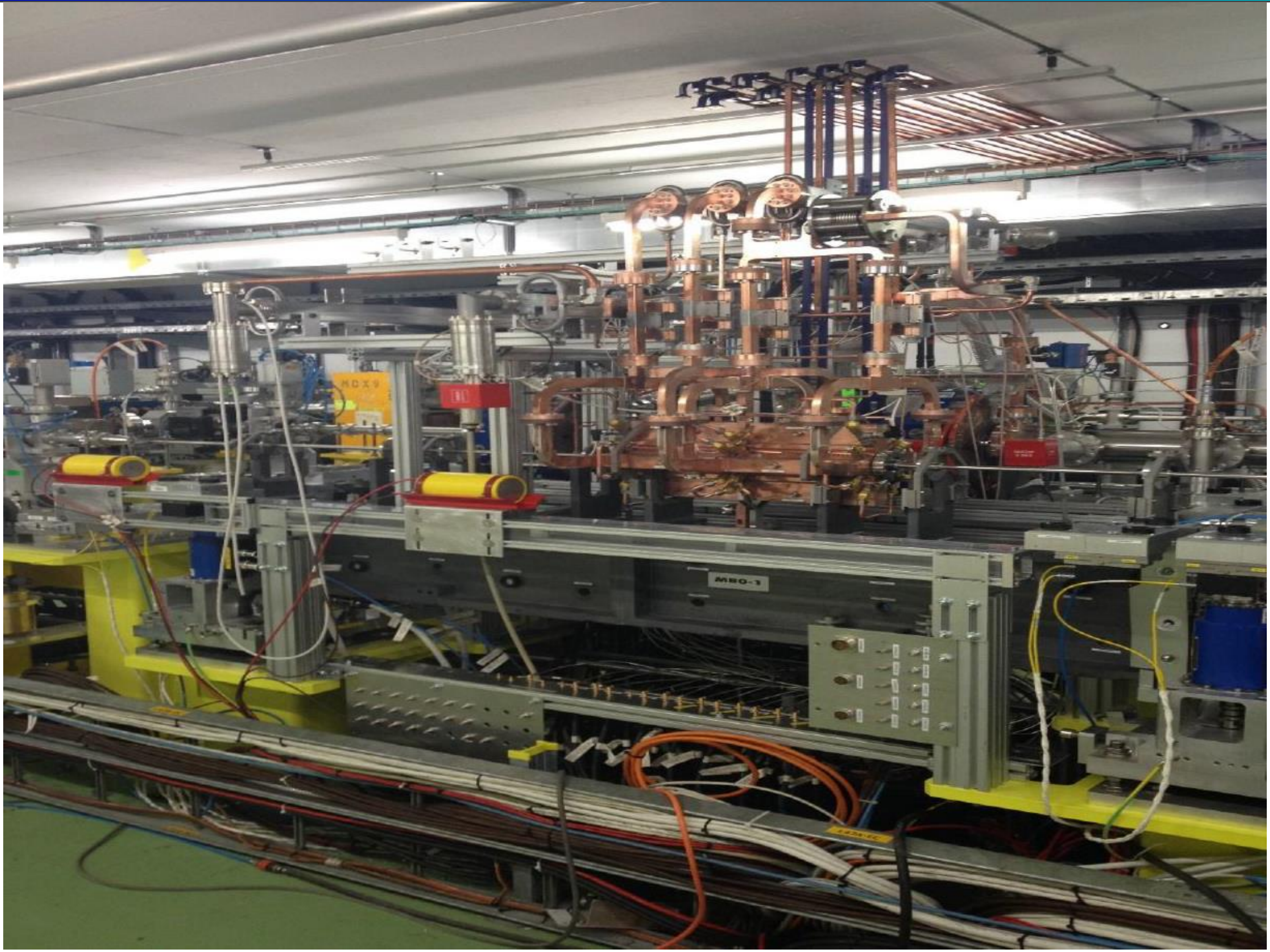


CTF3: CLIC Test Facility #3



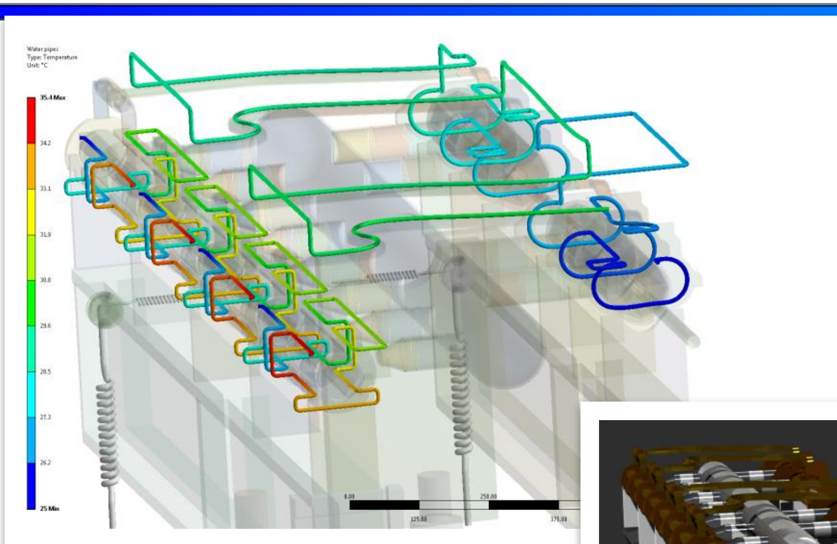


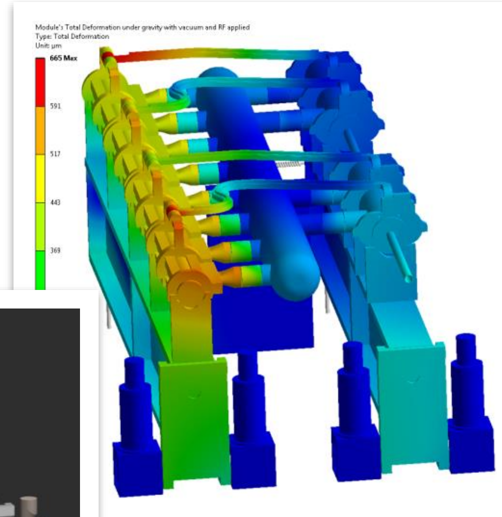
CTF3: CLIC Test Facility #3

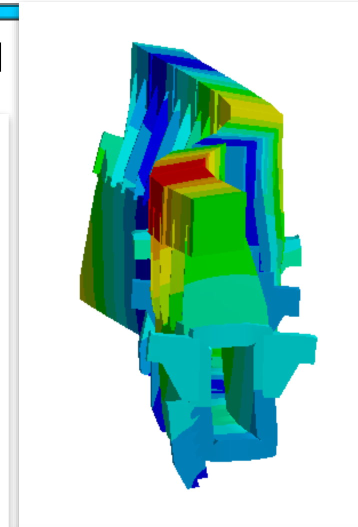


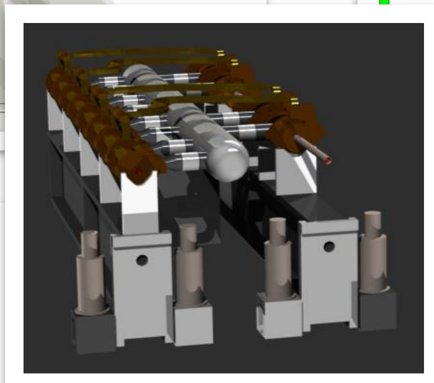
Termomekaaninen simulointi

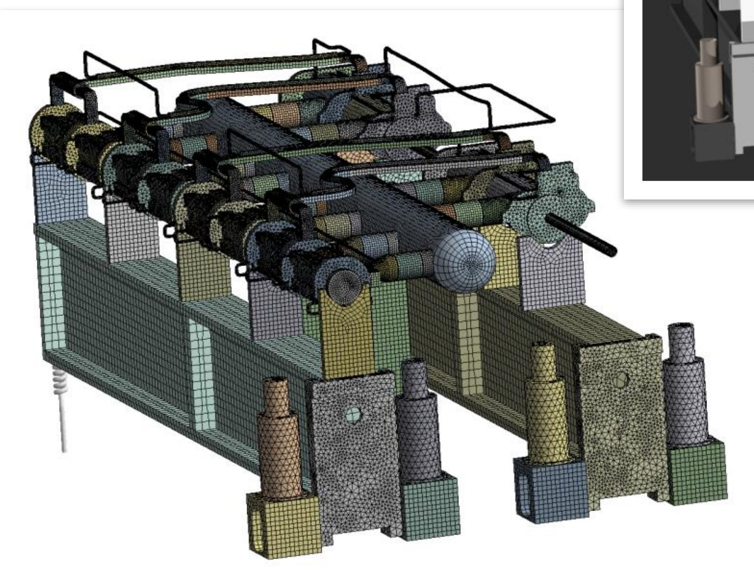
Numeerinen menetelmä, FEM

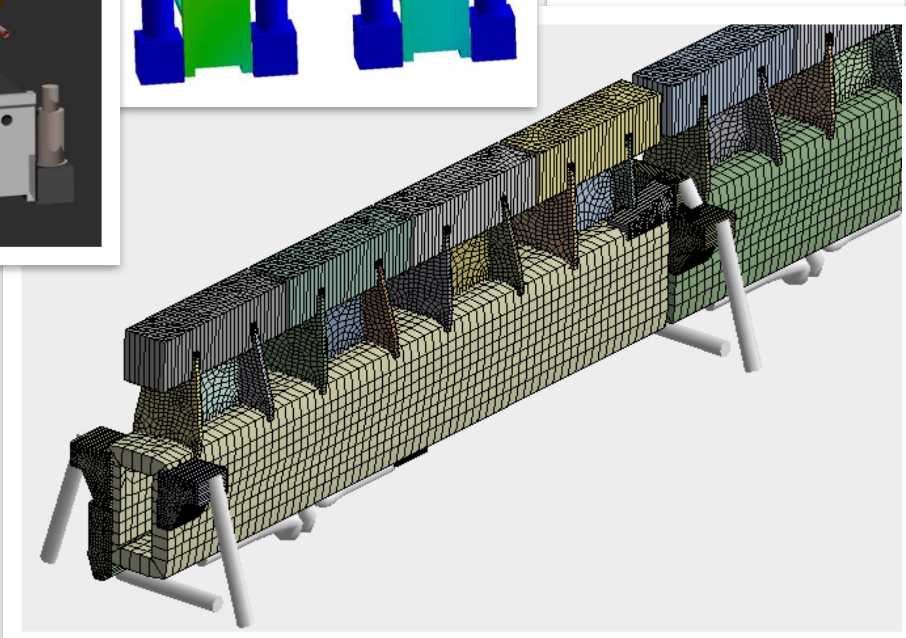






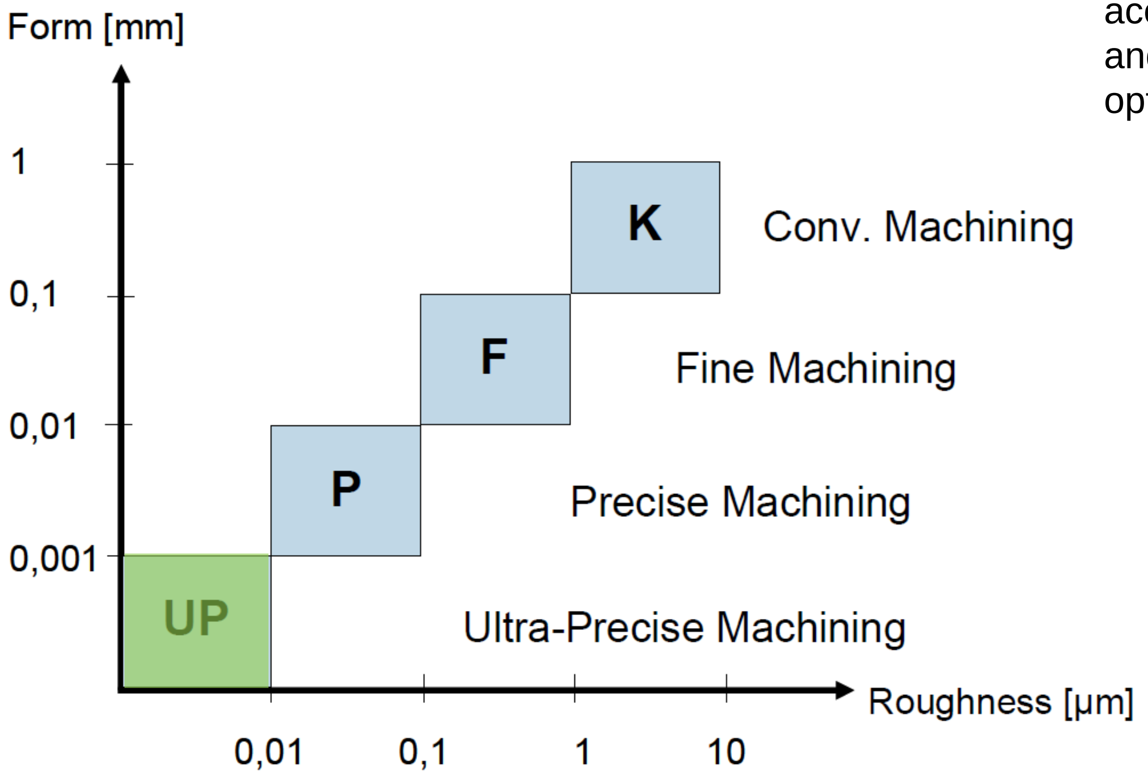






Courtesy of R. Nousiainen HIP/VTT

CLIC:n vaatimukset:
Muototarkkuus ± 2,5 µm
Pinnankarheus Ra 25 nm

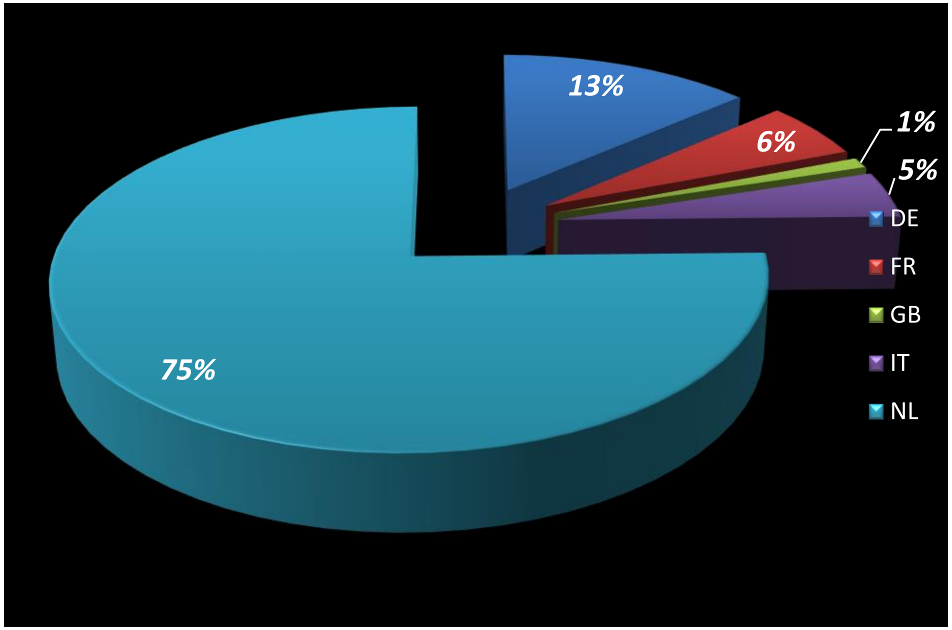


- key Technologies same as complex mechanical/optical key components
- often a combination of highly accurate 3d-form, positioning and roughness, as well as optical effects are required

08.03.2018 L. Deparis

CLIC alihankinta

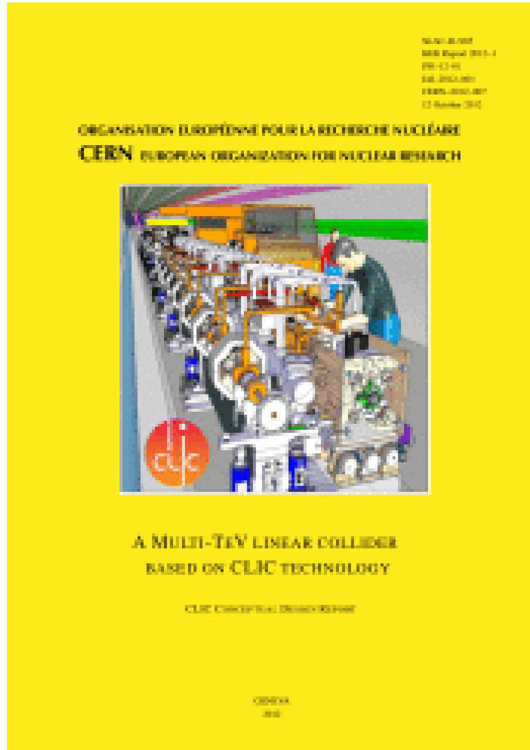
- Validointivaihe 1: komponentti/disk
- Validointivaihe 2: rakenne
- Hyväksytty partneri: osallistuminen tarjouskilpailuihin

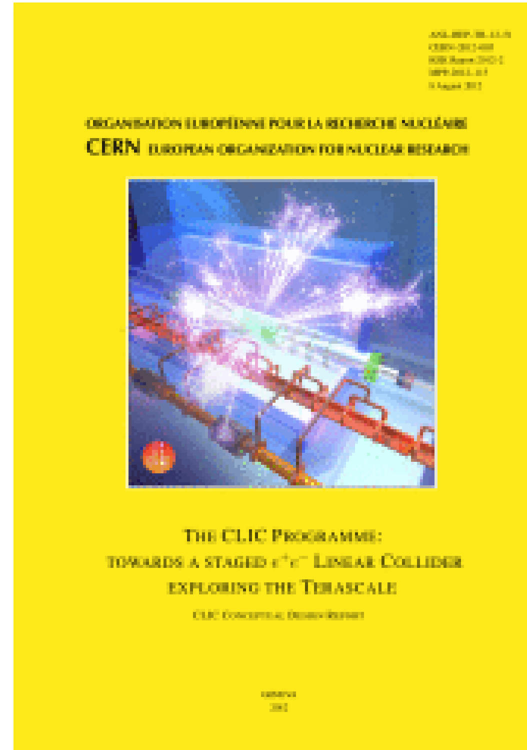


MeChanICs - Marie Curie Linking Industry to CERN

- 2010 -2014, henkilöliikkuvuusohjelma
- Cern, HY, Metso, Loval, Tarkmet, Mectalent, Lewel Group
- Yrityksistä 6-18 kuukautta Cernissä, Cernistä 2 kk yrityksissä
- 2 palkattua työntekijää 2 vuodeksi Cerniin

CLIC CDR (Conseptual Design Report) (2012)



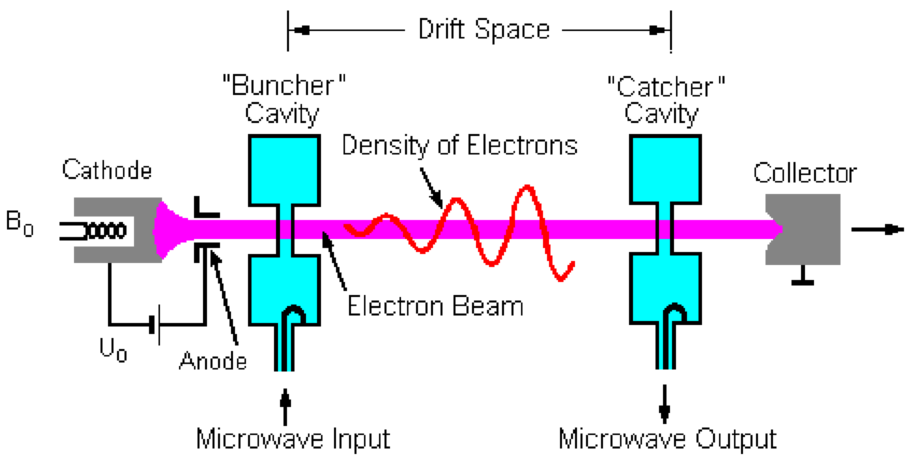


- Conseptual Desigh Report, CDR 2012
- 3 osaa: Fysiikka & detektorit, Kiihdytinrakenteet, Strategia, kustannukset & aikataulu
- Laajan kv-yhteistyöverkoston tulos: 40+ instituuttia osallisina, nyt jo yli 70
- Saatetaan käyttää mallina FCC CDR raportille

Lisätietoa:
http://clic-study.org/

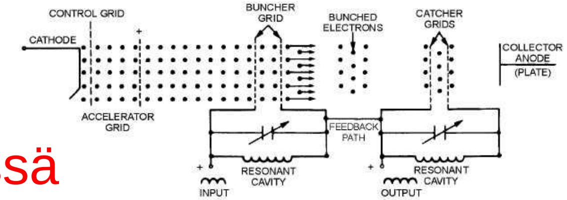
CONSEPTUAL DESIGN REPORT (CDR)
http://project-clic.cdr.web.cern.ch/project-CLIC-CDR

CLIC showroom

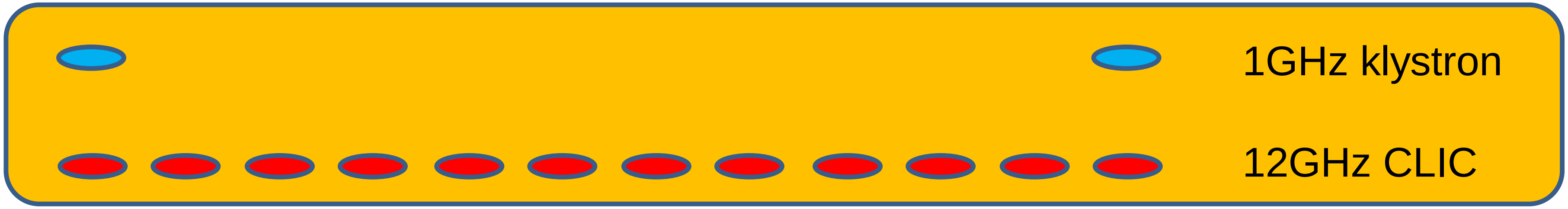


Klystronin toiminta:

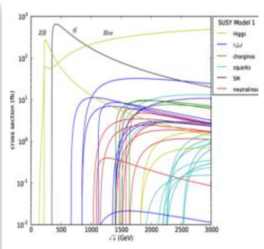
1. Tasavirta elektronilähde.
2. Buncher-cavity (modulate the velocities)
3. Drift (the electrons gather in bunches)
4. Catcher-cavity (extract the electromagnetic wave)



Korkea taajuus on hyödyllinen hiukkaskiidyttimessä

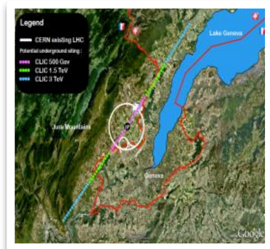


Toteutettavuus



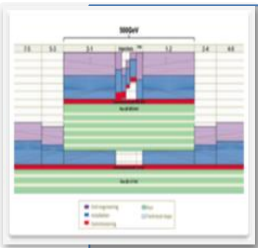
Physics - how do we build the optimal machine given a physics scenario (partly seen at LHC ?):

Understand the benefits of running close to thresholds versus at highest energy, and distribution of luminosities as function of energy



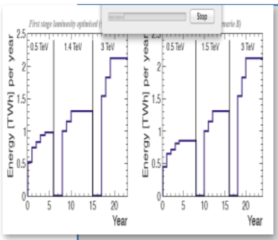
Construction scenario (and approval scenario):

Explore how we in practice will do the tunneling and productions/installation/movement of parts in a multistage approach ? Environmental impact study



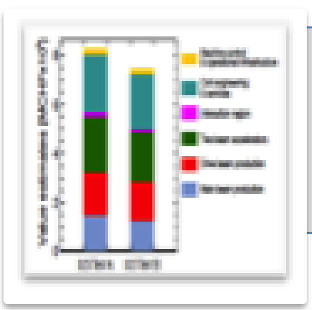
Timescale/lifecycle for project re-defined: Buildup of drive beam (CLIC zero), stage one – physics, more stages/extensions

Parameters: energy steps and scans, inst. and int. luminosities, commissioning and lum. ramp up times.



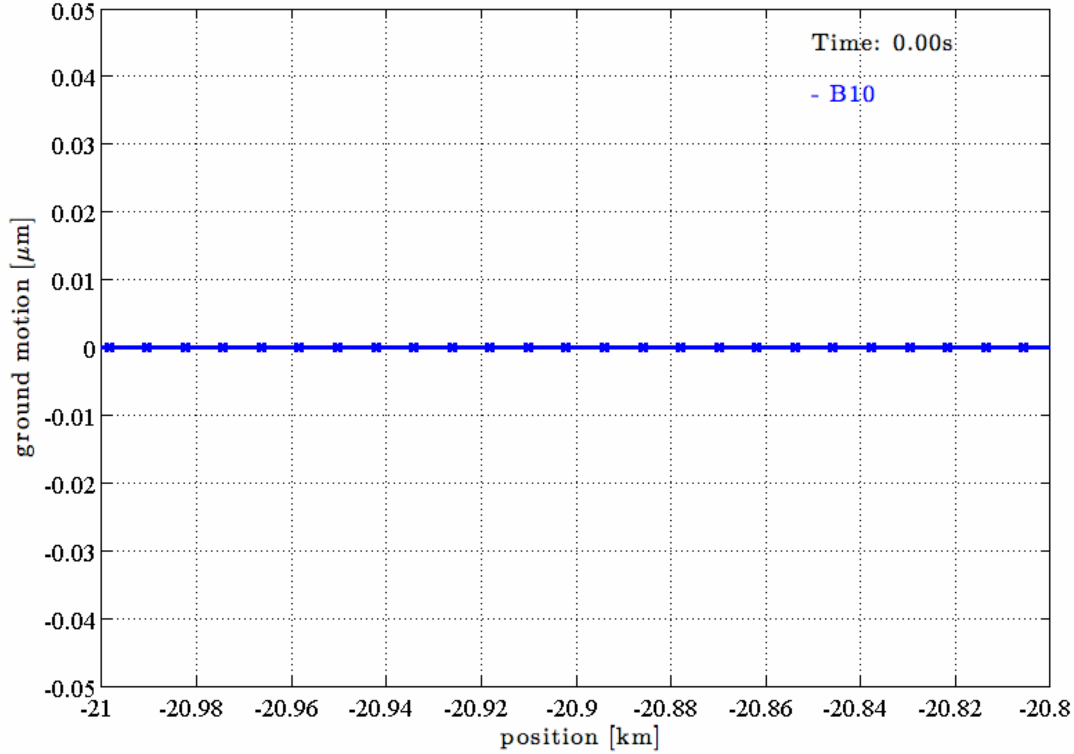
Power and energy development.

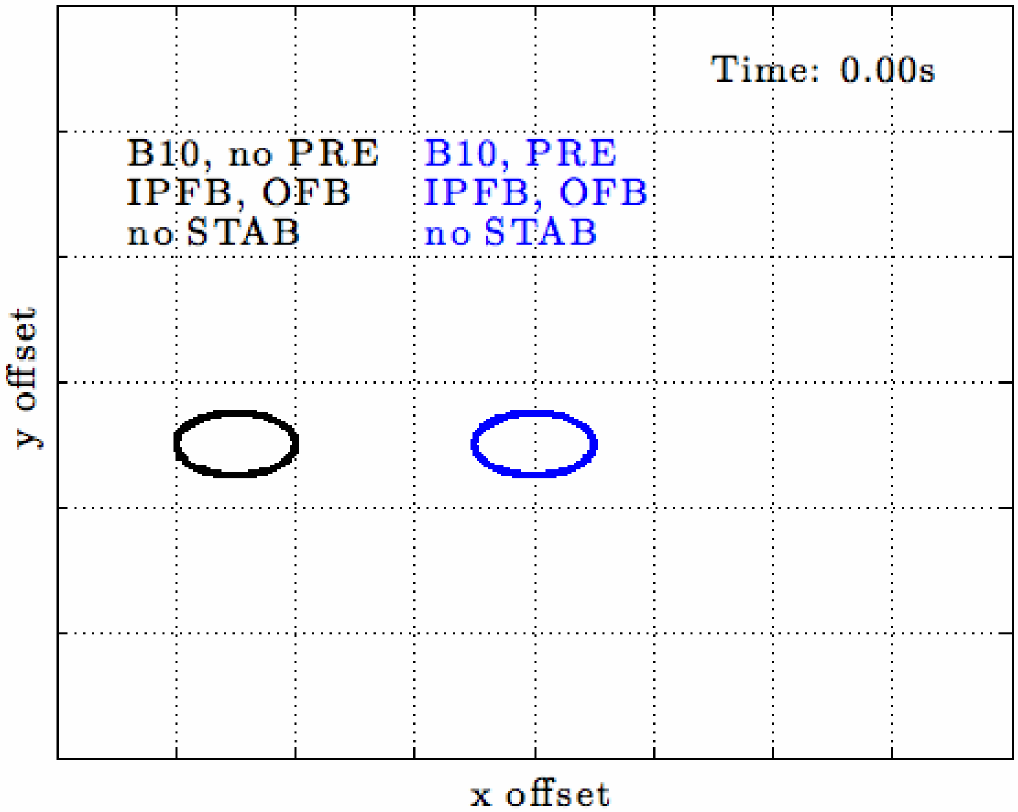
Have started to work on energy estimates (not only max power at max luminosity and the highest energy) based on running scenarios and power on/off/standby estimates



Costs - Initial machine plus energy upgrade: External cost review 21-22.2.2012, costs discussed in volume 3 of the CDR

Zoom on the ground movement

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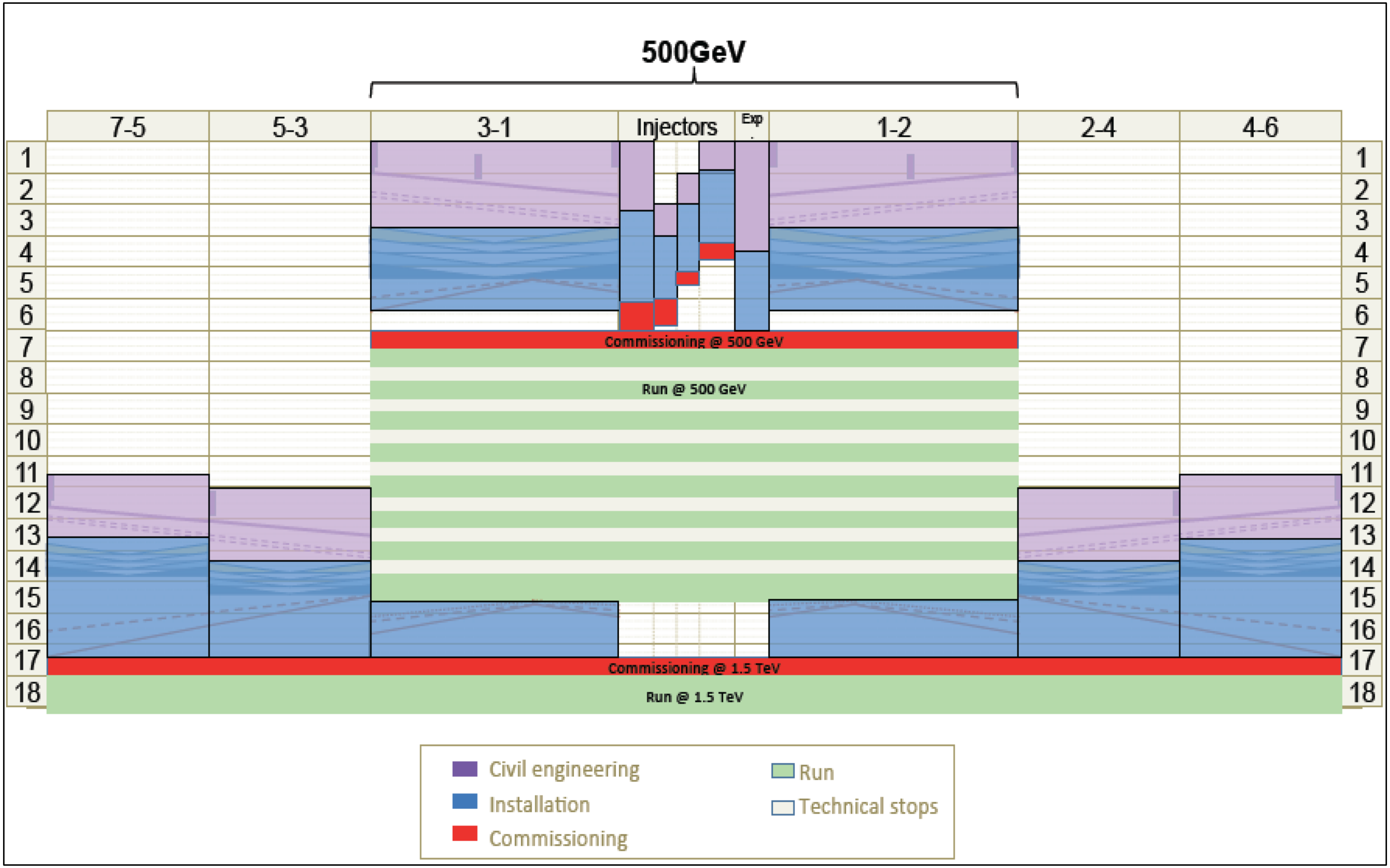
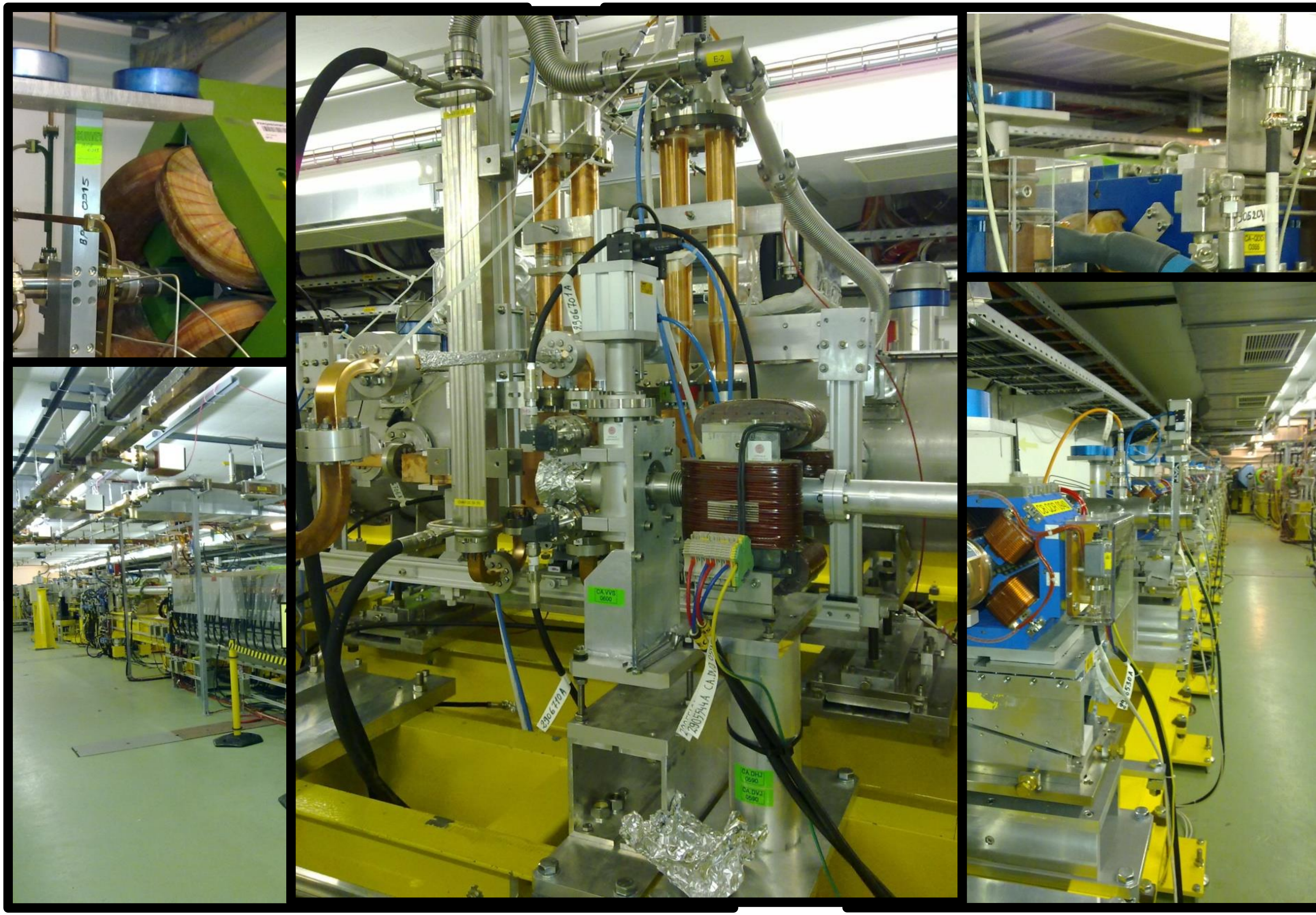
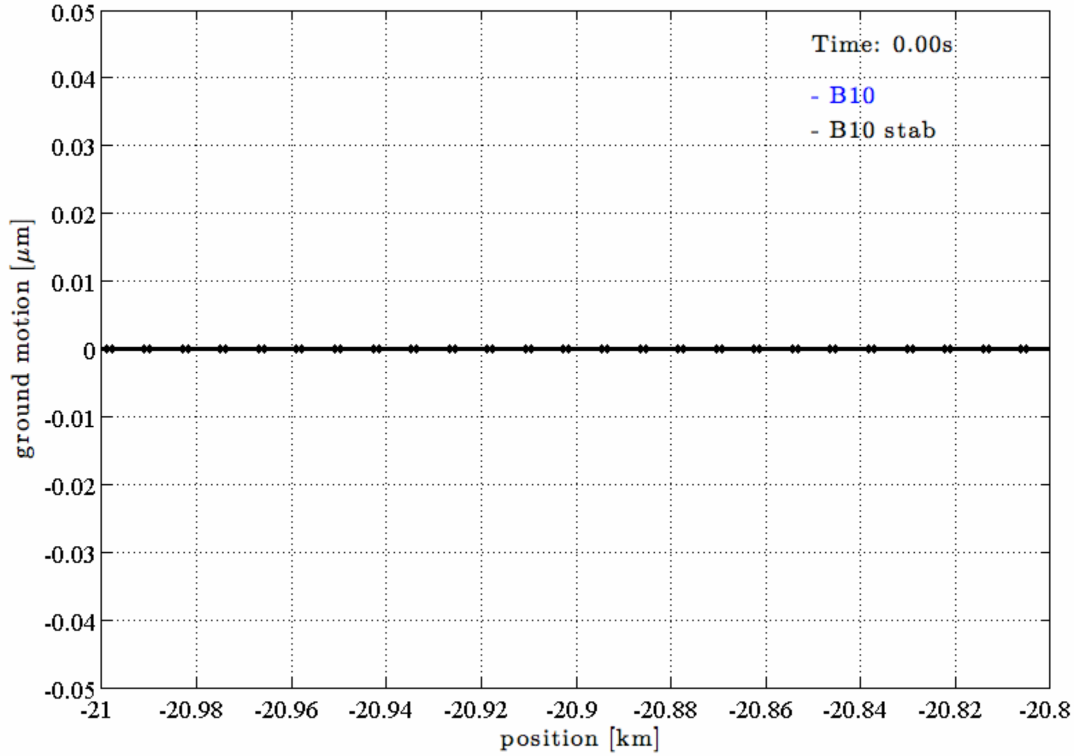
B10, no PRE
IPFB, OFB
no STAB
B10, PRE
IPFB, OFB
no STAB
y offset
x offset

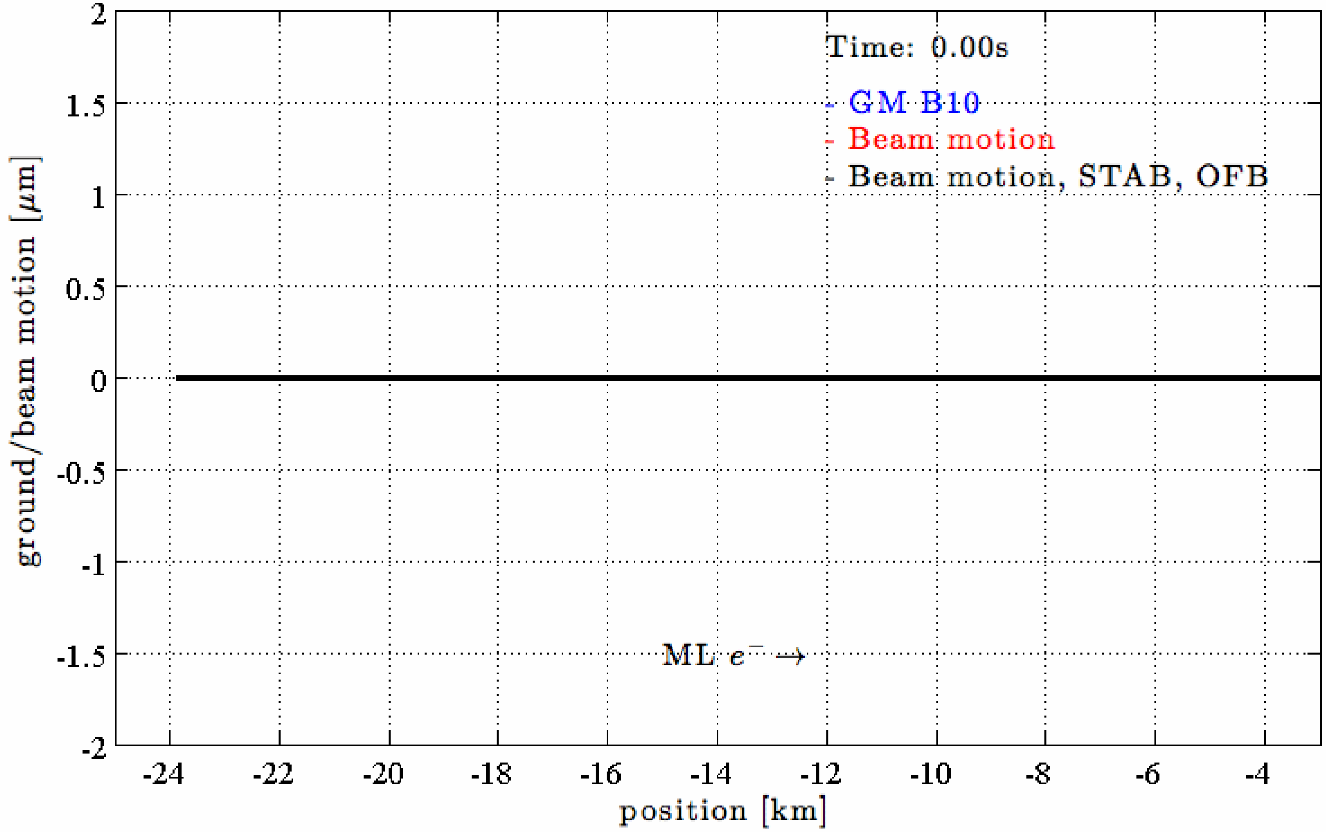

500GeV
7-5
5-3
3-1
Injectors
Exp
1-2
2-4
4-6
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Commissioning @ 500 GeV
Run @ 500 GeV
Commissioning @ 1.5 TeV
Run @ 1.5 TeV
Civil engineering
Installation
Commissioning
Run
Technical stops

CTF3

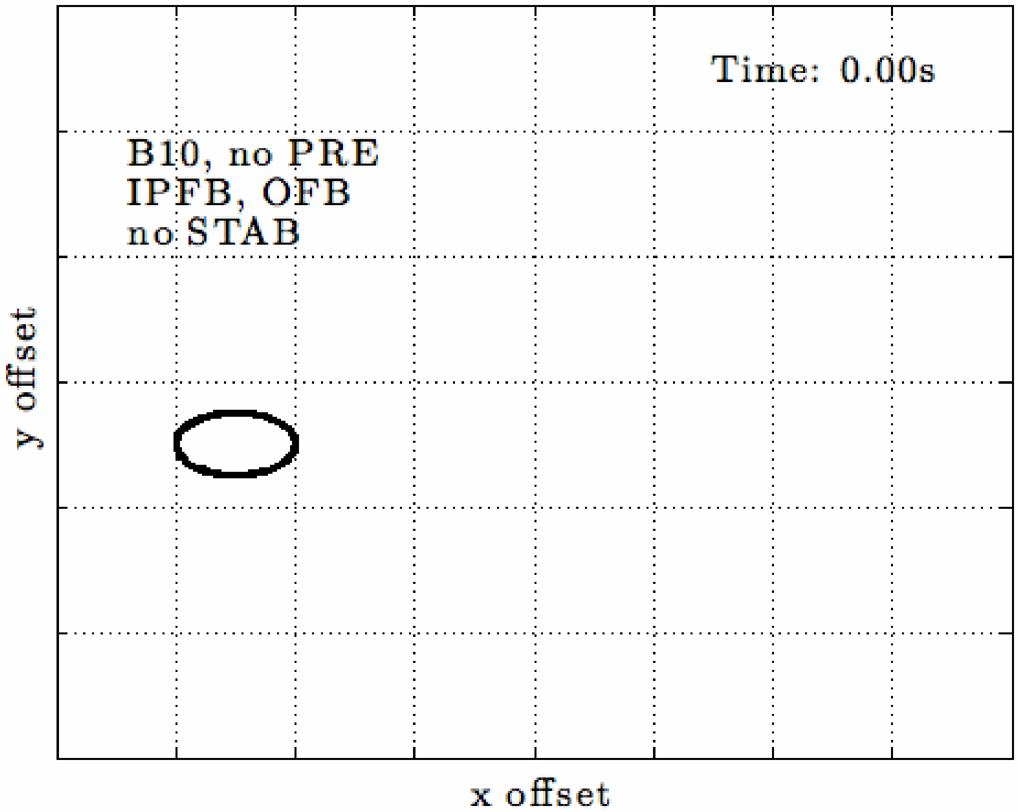


Stabiloitu maaperän liikkuminen





Time: 0.00s
GM B10
Beam motion
Beam motion, STAB, OFB
ground/beam motion [μm]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
ML e⁻ →
-24
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
position [km]


Time: 0.00s
B10, no PRE
IPFB, OFB
no STAB
y offset
x offset

Luminositeetti, esisuodatus, stablilointi