Future Linear Colliders

From physics requirements to today's projects

UiO student visit to CERN

April 8, 2010

Erik Adli, Department of Physics, University of Oslo

Linear colliders for high-energy particle physics

Stanford Linear Collider

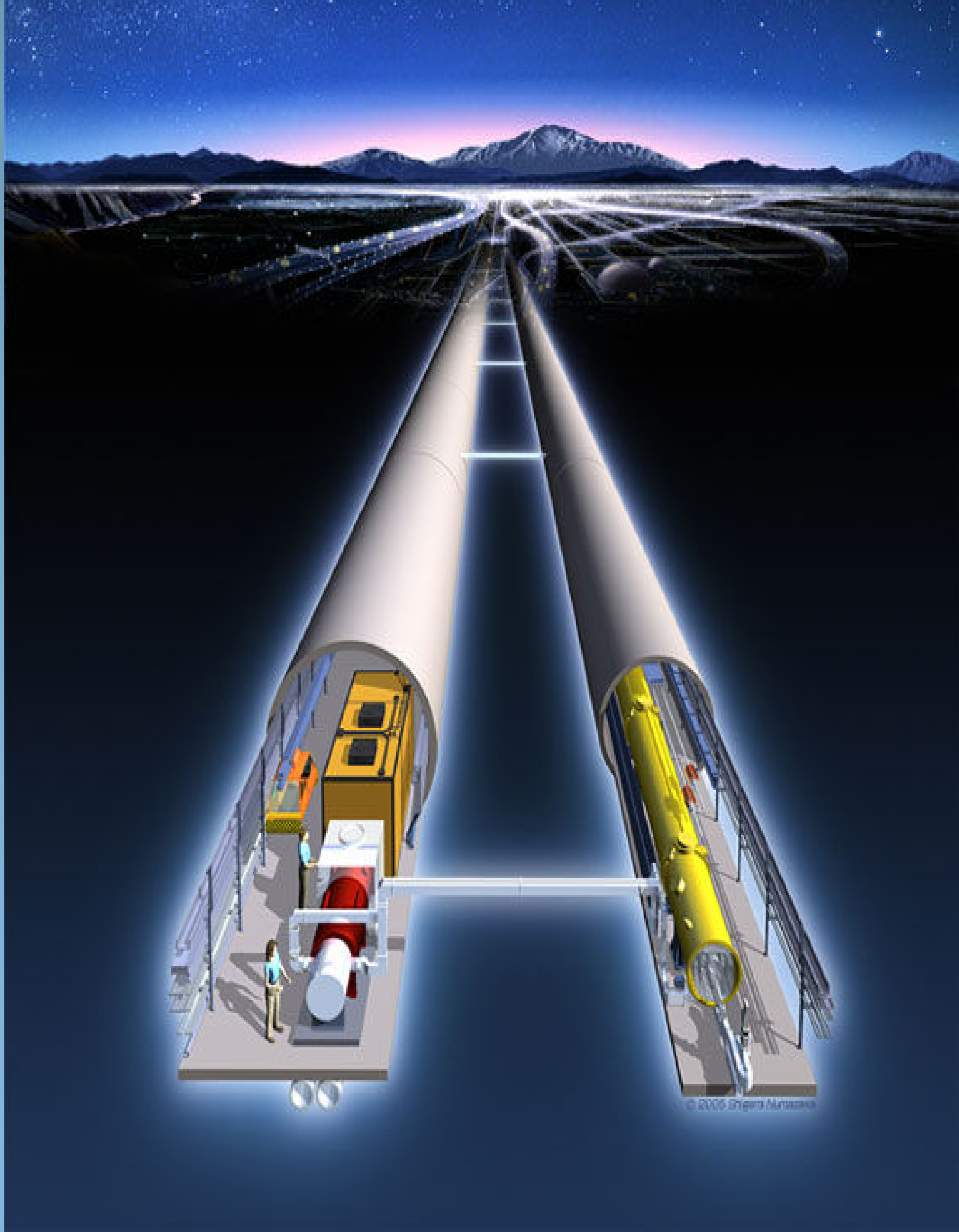
International Linear Collider

TESLA

NLC/GLC

CLIC

Novel schemes



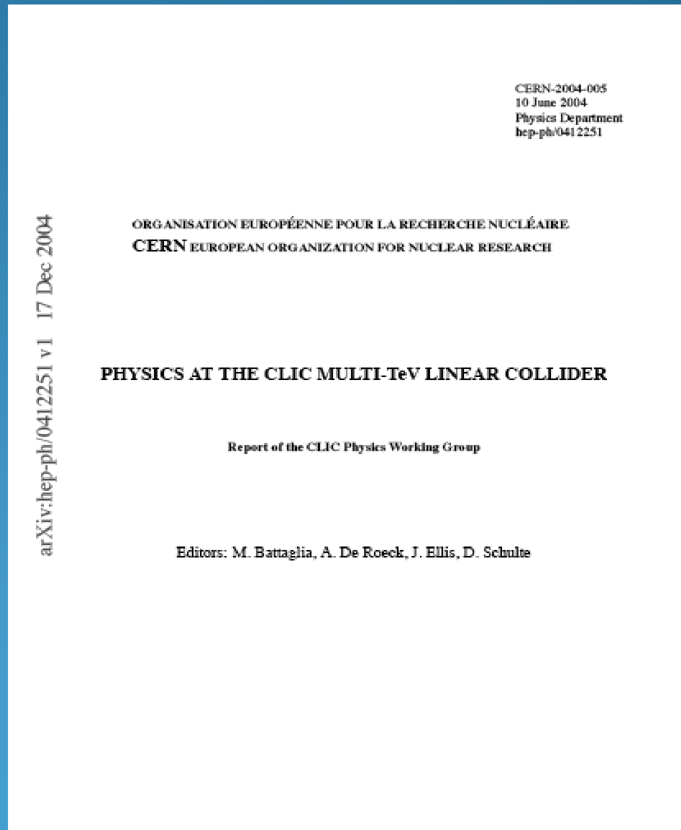
Outline

- Physics motivation
- Linear collider challenges
- Current projects: ILC and CLIC
- CLIC research at CERN/UiO
- Novel schemes
- Conclusions

Physics motivation

International Linear Collider, RDR, 2007

e^+e^- physics from ~ 200 GeV to ~ 1 TeV CM



CERN-2004-005
10 June 2004
Physics Department
hep-ph/0412251

arXiv:hep-ph/0412251 v1 17 Dec 2004

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

PHYSICS AT THE CLIC MULTI-TeV LINEAR COLLIDER

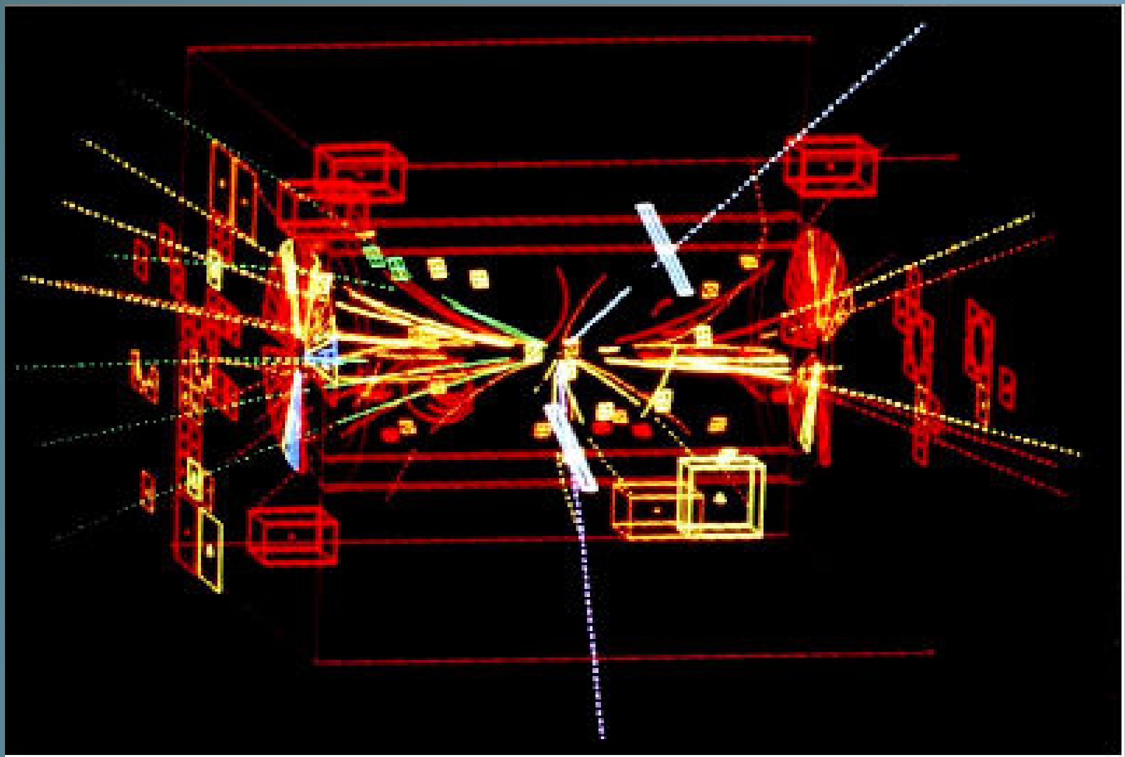
Report of the CLIC Physics Working Group

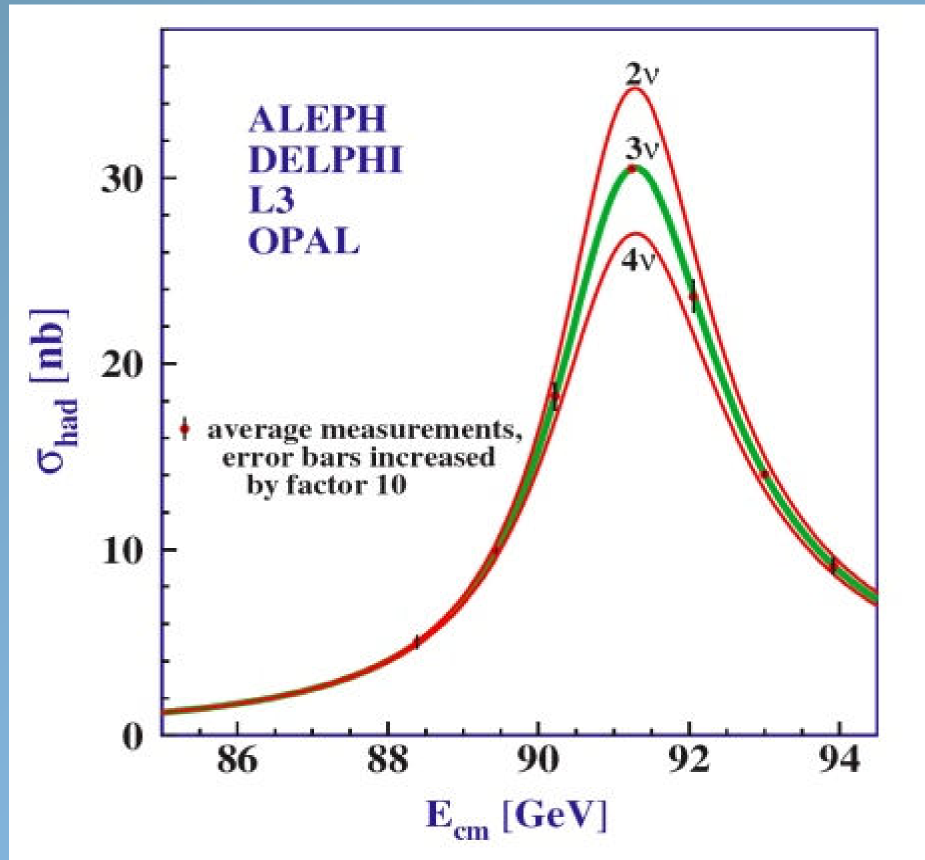
Editors: M. Battaglia, A. De Roeck, J. Ellis, D. Schulte

CLIC physics report, 2004,
arXiv:hep-ph/0412251

e^+e^- physics at Multi-TeV CM

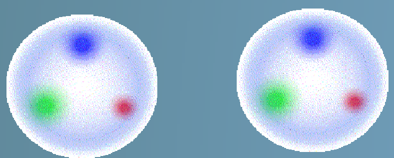
Hadron versus lepton colliders

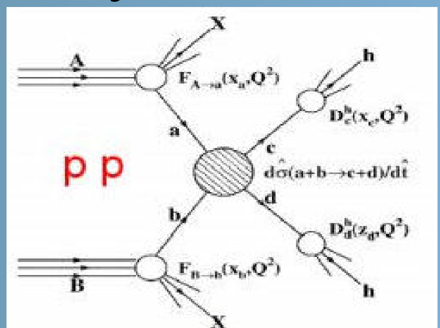


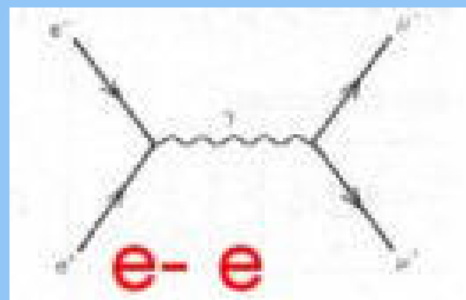


Hadron collider SppS, √s=540 GeV, $W^{+/-}$ and Z^0 discovery

Lepton collider LEP, $\sqrt{s}_{max}$=209 GeV, precision measurements of Z^0 decay width







LHC versus future colliders

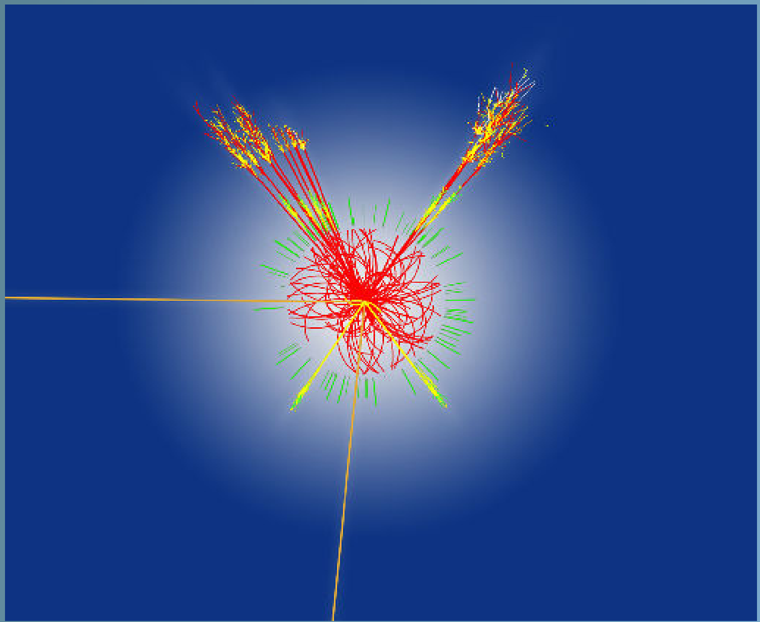
Example: Higgs physics

SM: assumes a very specific Higgs
-scalar spin-0 particle
-specific form of scalar potential

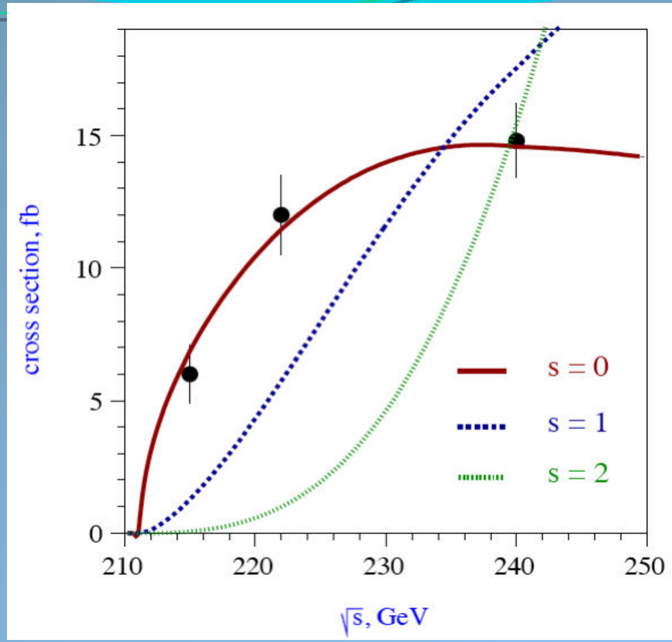
$$V(\eta) = \lambda v \eta^3 + \frac{1}{4}\lambda \eta^4$$

$$m_W = \frac{1}{2} g v$$

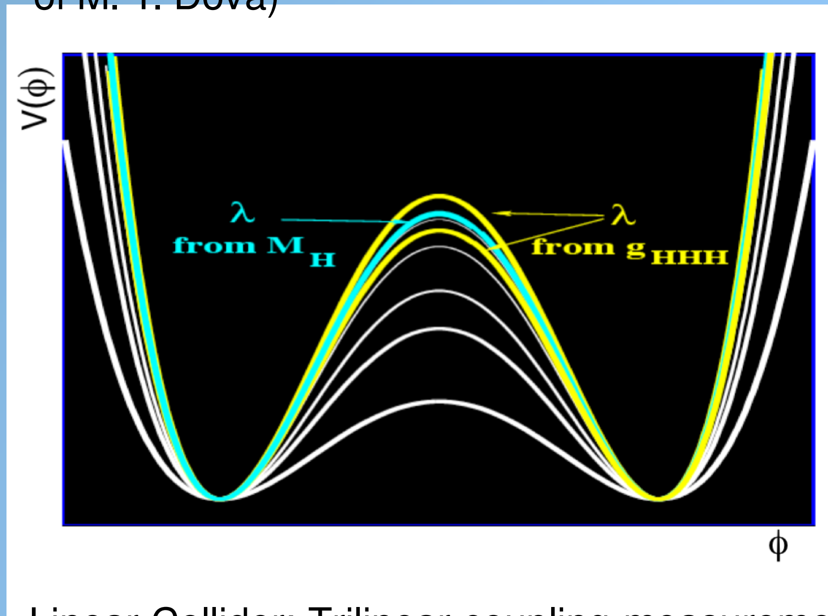
$$m_H = \sqrt{2\lambda v^2}$$



ATLAS@LHC, √s=14 TeV, promises discovery of Standard Model Higgs, and measurement of its mass with good precision (0.1% after 300 fb^{-1})

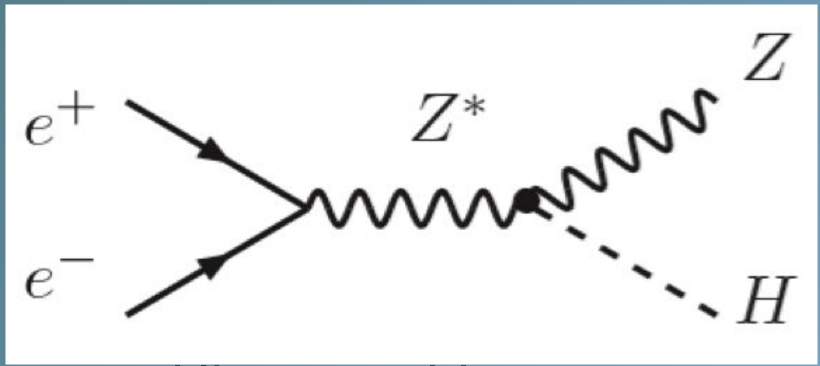


Linear Collider: Higgs spin measurments (Courtesy of M. T. Dova)

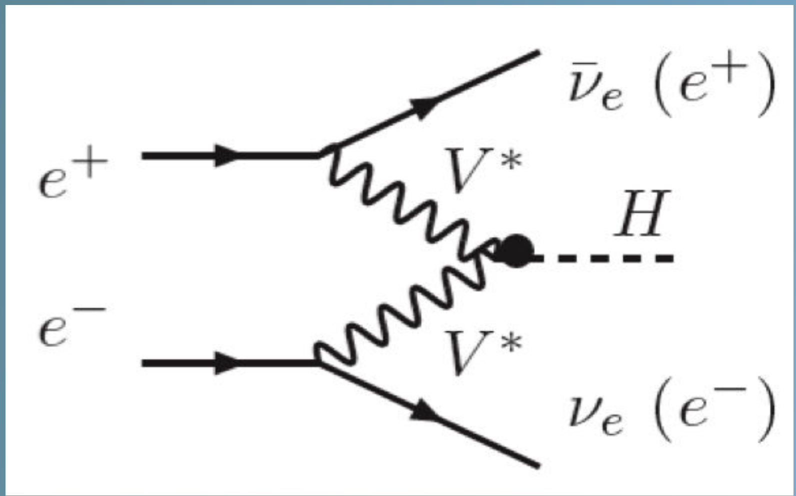


Linear Collider: Trilinear coupling measurements (Courtesy of M. Battaglia)

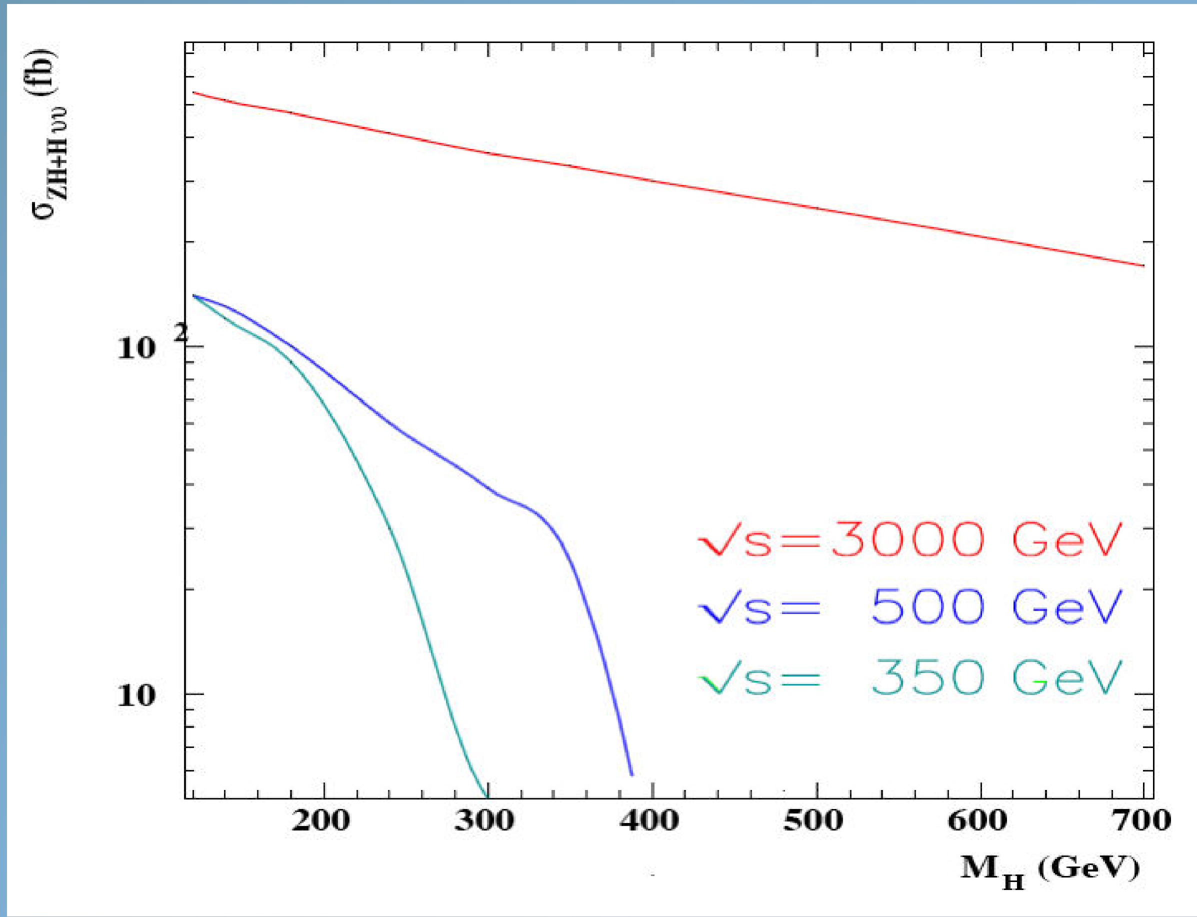
Higgs production at an e^+e^- collider



Higgs-strahlung

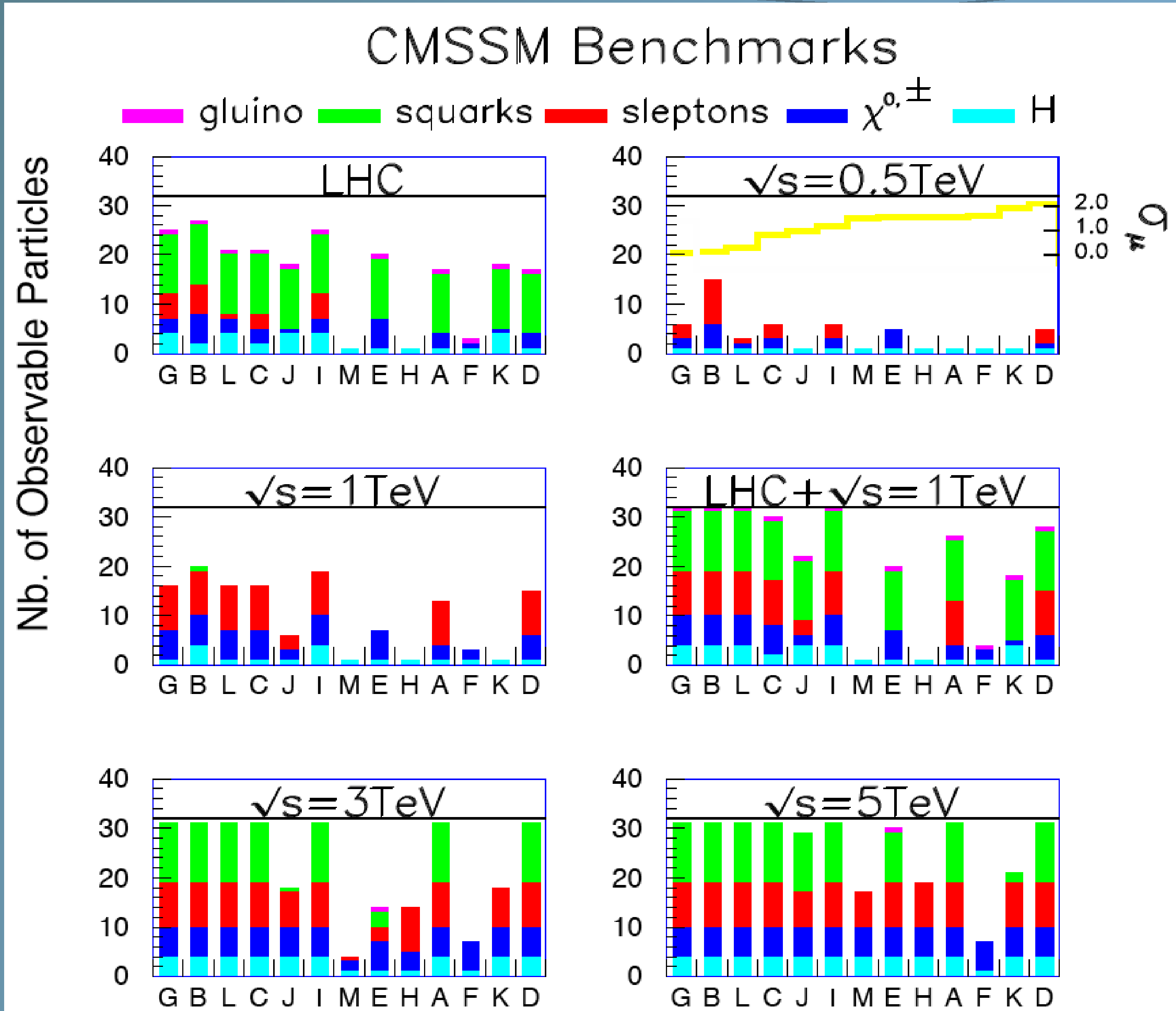


Vector boson fusion



Order of 10'000-100 '000 Higgs events needed to reach good precision for rare processes ➔ order of ab^{-1} integrated luminosity needed

Supersummetry benchmarks



From hep-ph/0412251

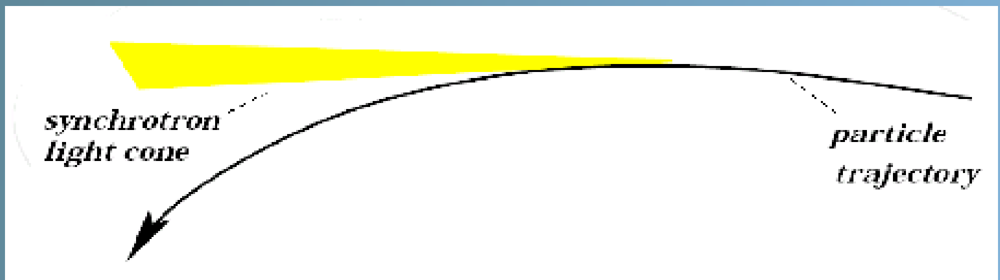
The next step in particle physics

Consensus in the HEPP community :

LHC results must be complemented by a ~ TeV, high luminosity, lepton collider in order to provide precision measurements

We need a few factors higher CM than LEP energy

LEP energy limited by synchrotron radiation loss

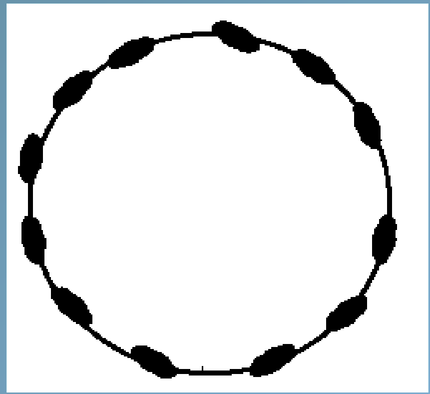


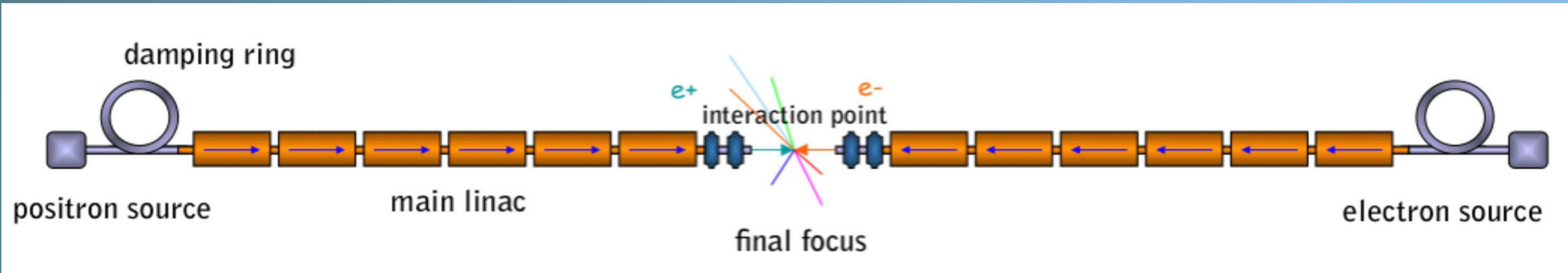
$$P_S = \frac{e^2 c}{6\pi\varepsilon_0} \frac{1}{(m_0 c^2)^4} \frac{E^4}{R^2}$$

A future electron-positron collider must be linear

Linear collider challenges

Rings versus linear colliders





We lose two advantages of ring colliders by going linear :

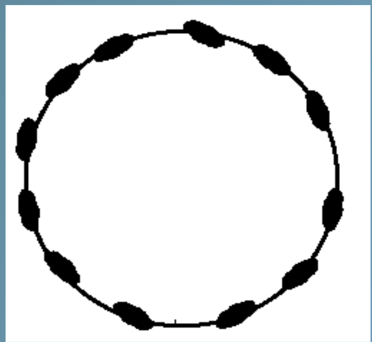
1)Each accelerating cavity can only be used once

2)Each bunch can only collide once

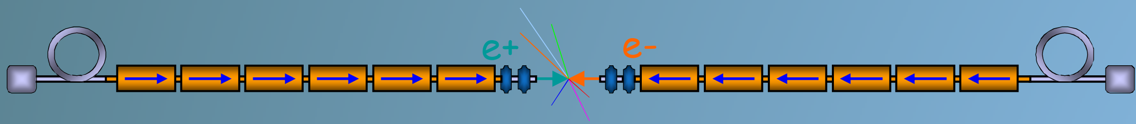
To reach both the centre of mass **energy** and the **luminosity** required by the particle physics, will be a challenge

Luminosity and power

One ab^{-1} integrated luminosity during 10^7 s ("one effective year") corresponds to collider luminosity of L = 10^{35} $cm^{-2}s^{-1}$



$$\mathcal{L} = f_{\text{bunch}} \frac{N^2}{4\pi\sigma_x\sigma_y}$$



$$\frac{\mathcal{L}}{P_{\text{machine}}} = \frac{N\eta}{4\pi\sigma_x\sigma_y E_{\text{CMS}}} H_D$$

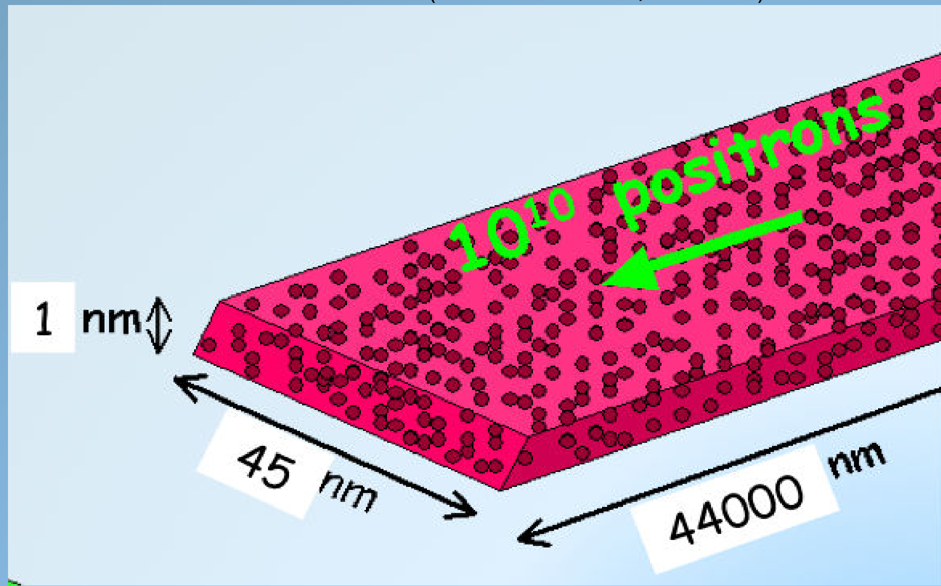
LHC: L = 10^{34} $cm^{-2}s^{-1}$ realized by f_{bunch} = 32 MHz and N=10^{11}.
LHC parameters for LC: ~ 1 TW continuous beam power.
LC: must compensate (factor ~ 10^5) by **very small beam sizes**, σ, and very good **wall-plug to beam power efficiency**, η.

Reaching small beam sizes

Luminosity needs drive beam size requirements at the interaction-point down to 1 nm

(picture from A. Seryi, ILC@SLAC)

(values for CLIC, 11/2008)

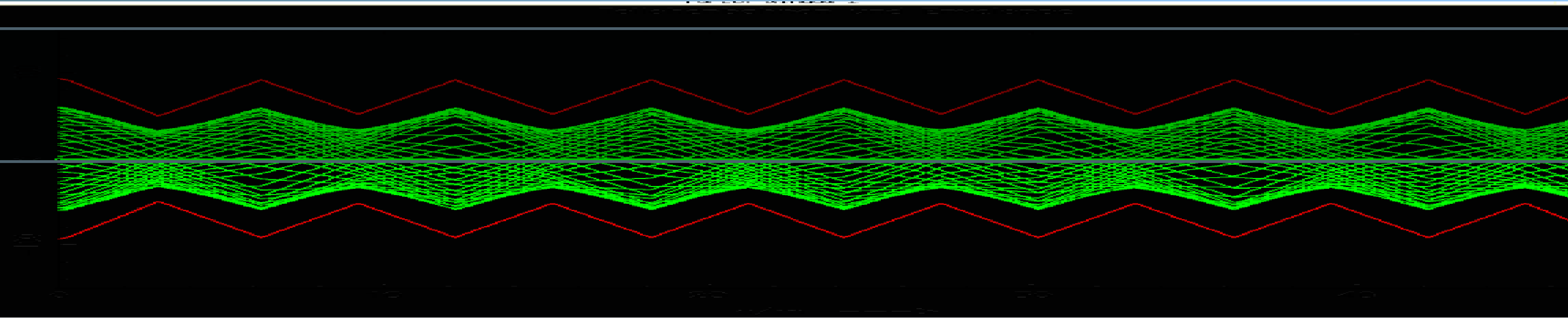


Beam size is give by :

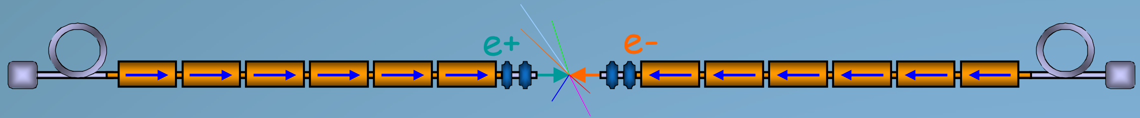
$$\sigma(s) = \sqrt{\varepsilon_{rms}\beta(s)}$$

Lattice

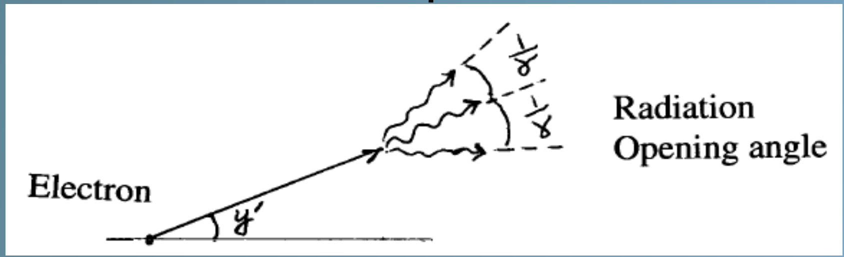
Beam quality

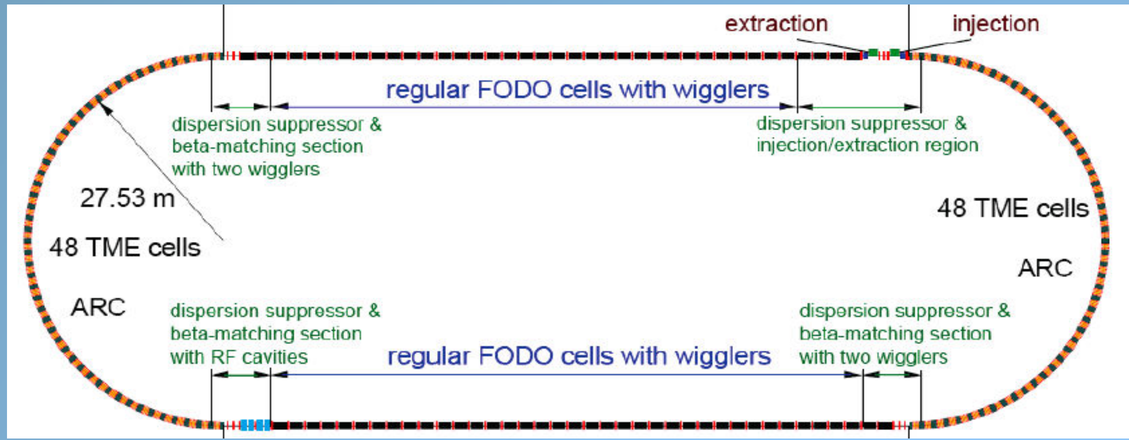


Reaching small beam sizes



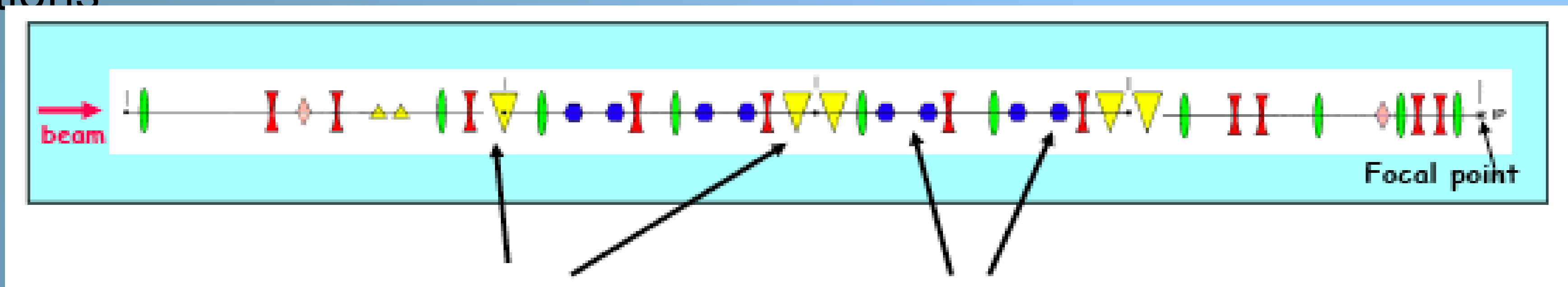
Damping rings (CLIC 365 m circ.) :
Mandatory for linear colliders emittances: use of damping rings to damp transverse oscillations resulting to minimum. Physics known from electron storage rings; performance must be improved for LC.





Final focus system (CLIC 2 x 2.7 km, incl. collimation and diagnostic) :
Mandatory for linear colliders focusing: dedicated final focus, reduction of the beta-function by many orders of magnitude, non-linear magnetic lenses to compensate chromatic aberrations

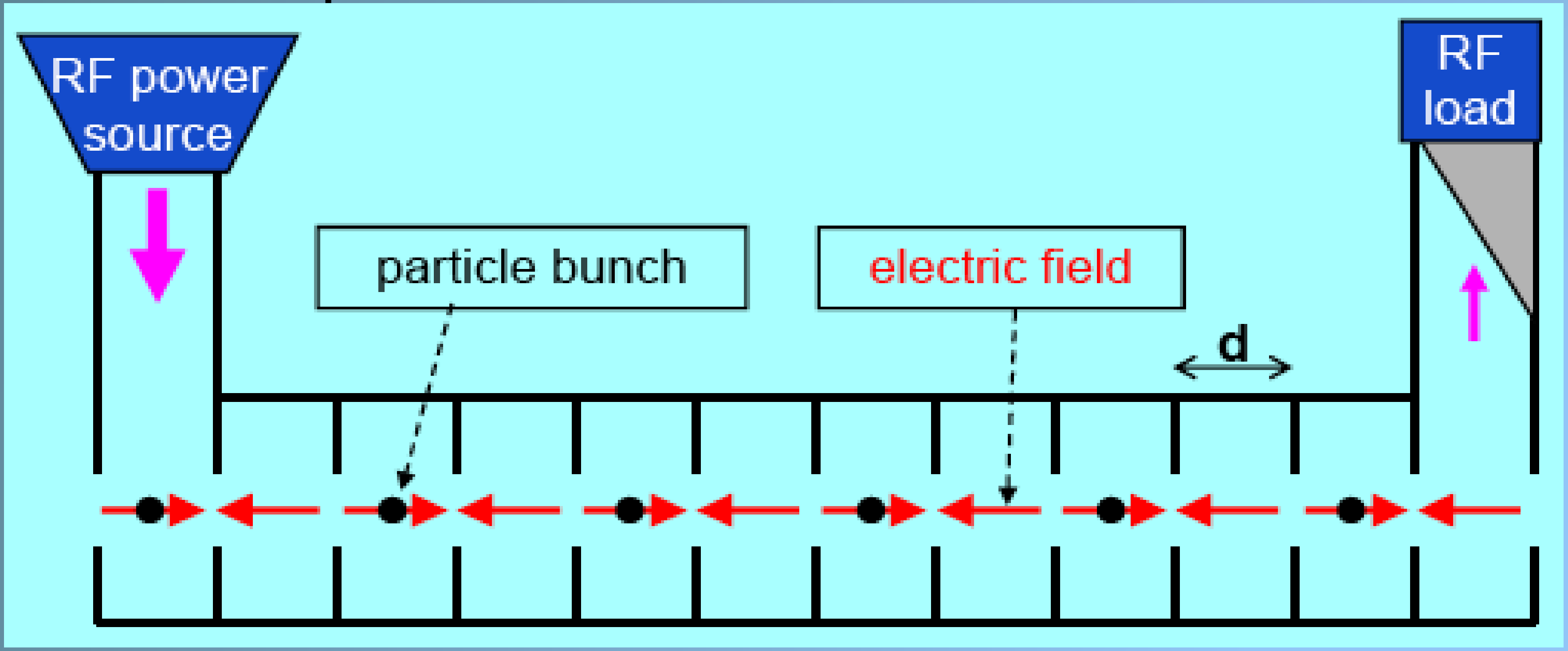
Example : FFTB at SLAC



Microwave based acceleration

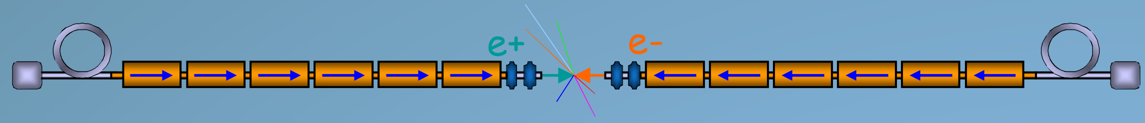
Conventional high-energy accelerators : radio-frequency microwaves (rf) are used to accelerate particles (conventional approach)

Both standing-wave or travelling-wave (v_ϕ=c) rf structures possible



Accelerating gradient has been limited to ~ 10 MV/m due to **rf breakdown** in structures

Reaching high energy *efficiently*



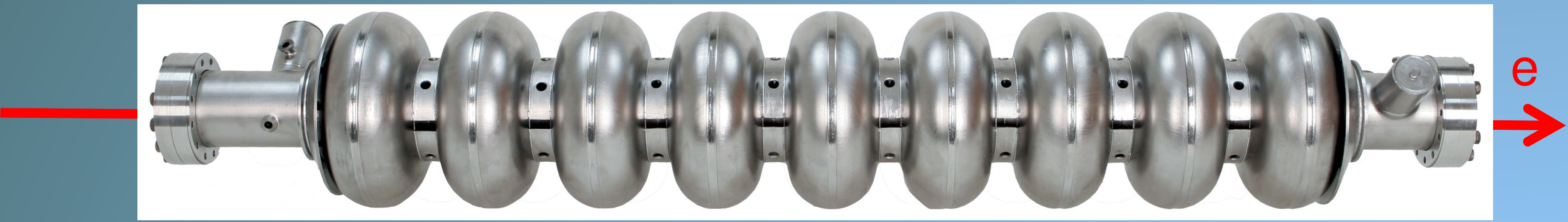
- Example: Stanford Linear Collider accelerating structures: 17 MeV/m
- Reaching √s = 1 TeV with these structures: almost 100 km site length is needed

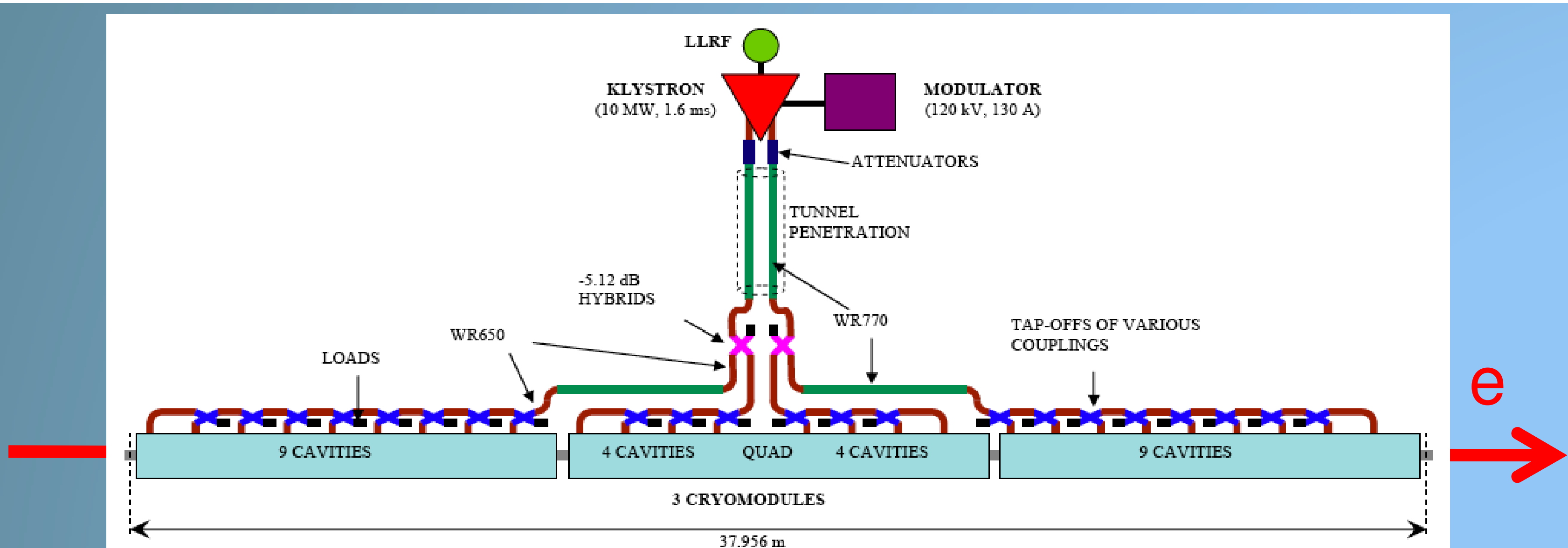
- Today : two on-going linear collider studies with two different approaches how to reach higher gradients in the main linac in an efficient way :
  - The **International Linear Collider** global design effort
    - Merge TESLA and NLC/GLC (2004). TESLA technology chosen for the main linear accelerators
  - The Compact LIneary Collider study (**CLIC**), an alternative high-energy scheme proposed by CERN

Current projects: ILC and CLIC

International Linear Collider

23 km of main linacs with **superconducting** standing-wave Niobium accelerating structures operating at 1.3 GHz
Rf field fed by pulses klystrons ("traditional approach")

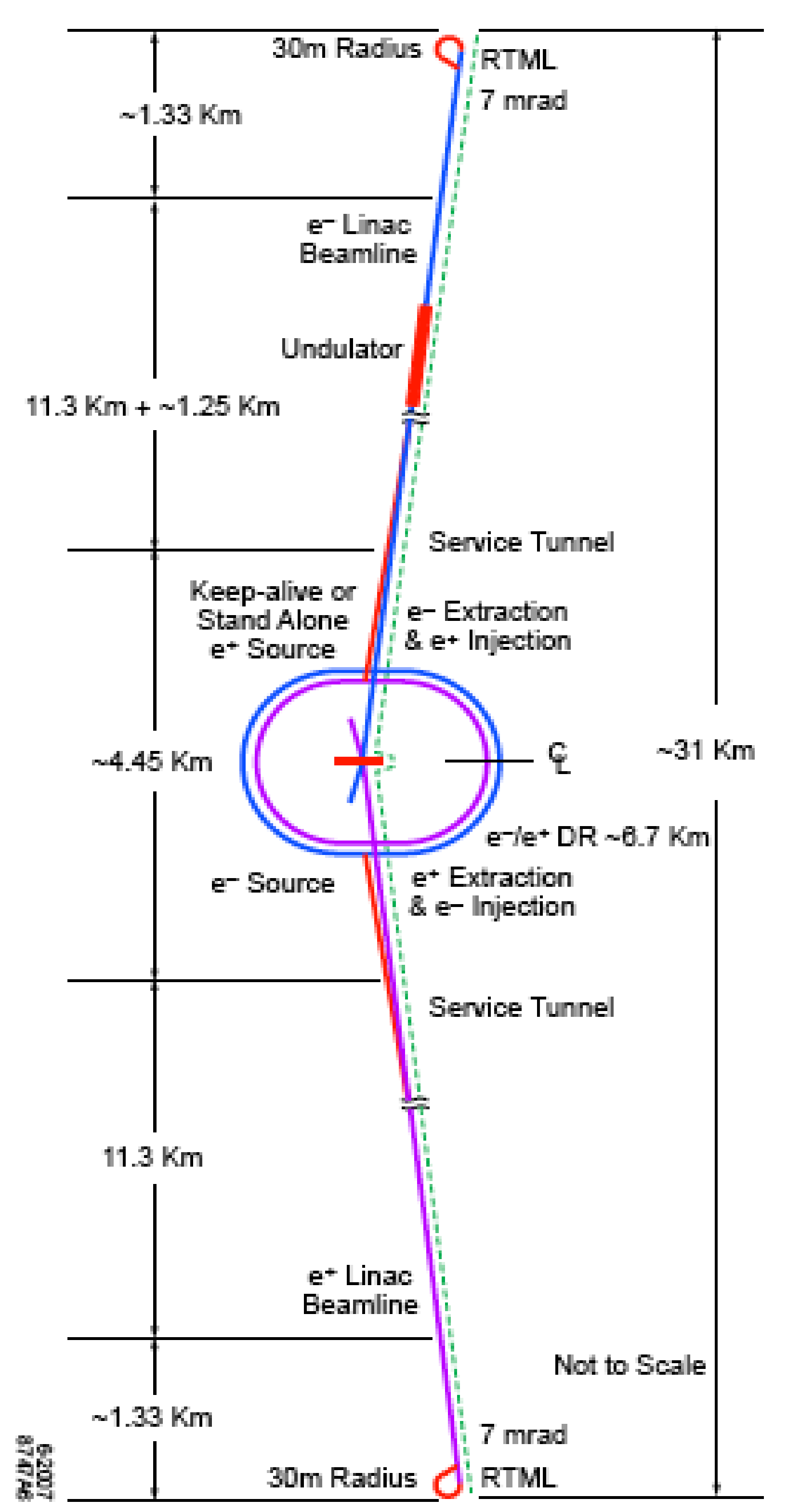




Advantage: power efficient **(9% wall-plug to beam efficiency)**

Disadvantage: gradient limited by superconductivity ->31.5 MV/m baseline

ILC baseline



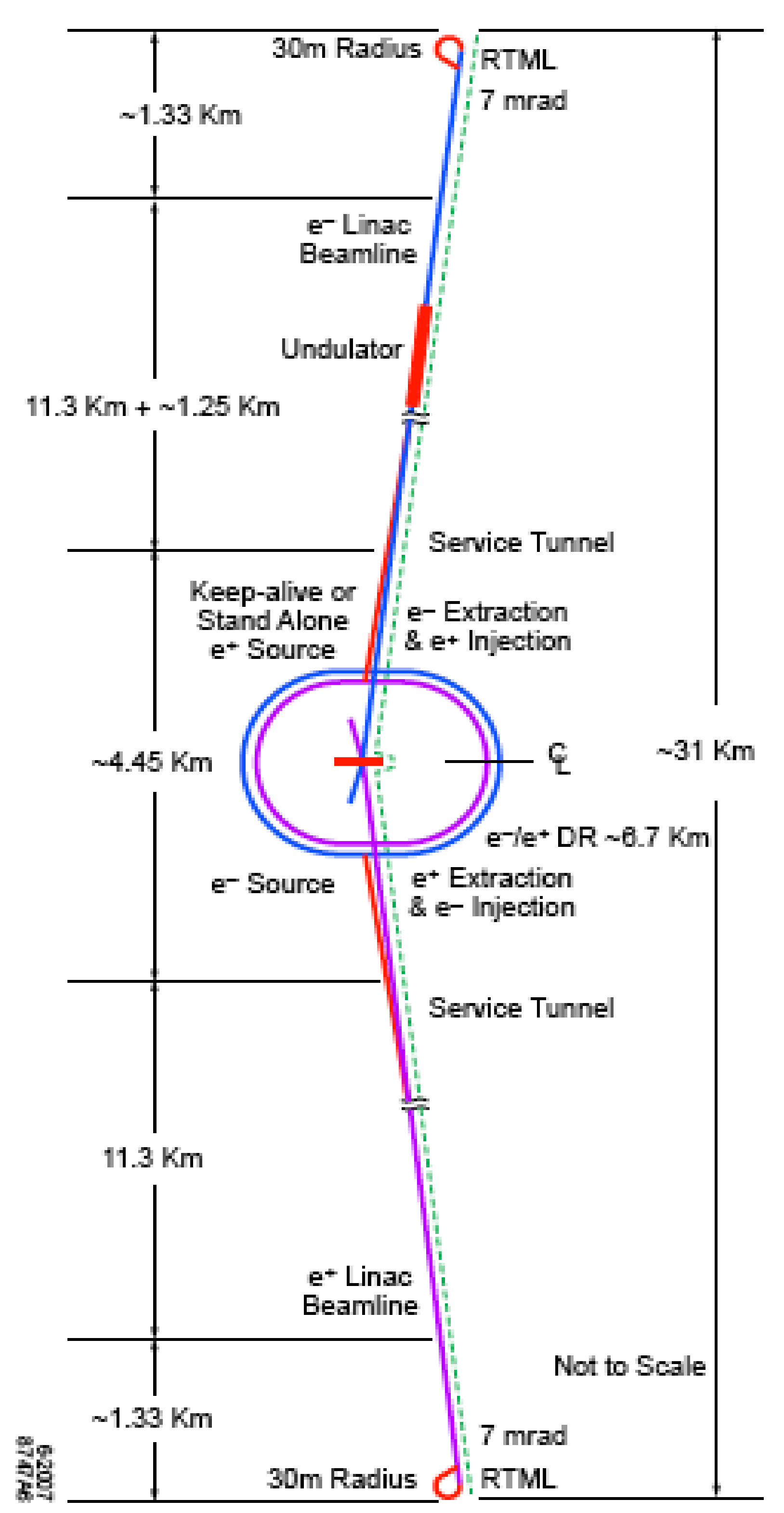
$\sqrt{s}$ = 500 GeV

Site length 31 km

L = $2 \times 10^{34}\ cm^{-2}s^{-1}$

Option to for $\sqrt{s}$ = 1 TeV (~53 km)

- not clear upgrade path



Status ILC

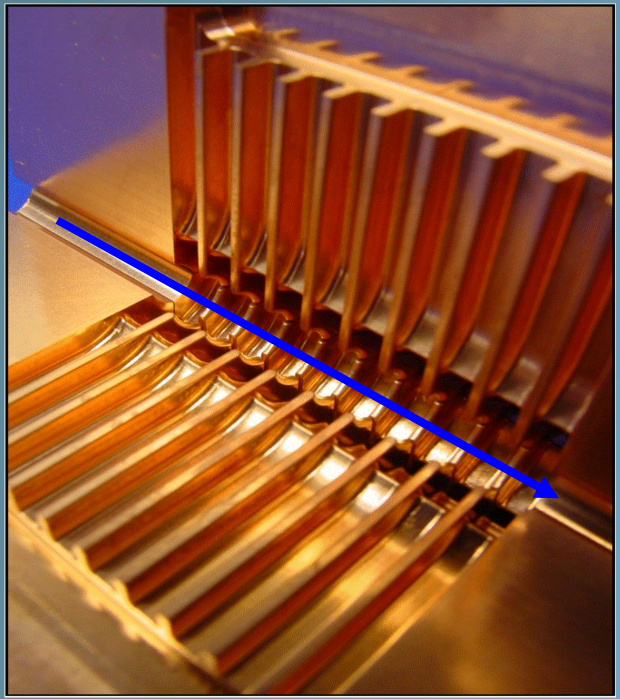
International collaboration: joint effort of previous TESLA and NLC/GLC collaborations, with superconducting TESLA-type adopted for the main linac (ITRP decision in 2004). Managed by a **truly global team**, not centered around one lab (ILC Global Design Effort). Emphasize on equal share Europe, Asia and the Americas.

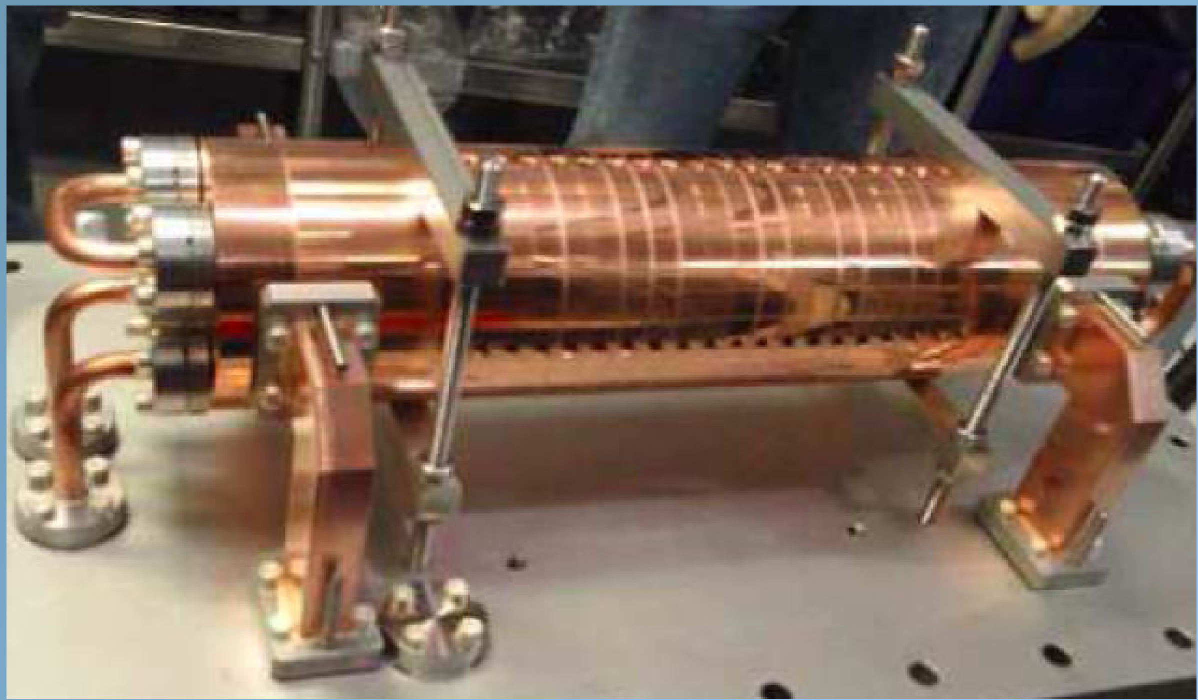
Study in an advanced state. Technology proven**. No major outstanding feasibility issues**. Reference Design Report published August 2004. Cost and performance still to be improved (cavity yield).

Currently in the technical design phase. Target: finalize technical design report in ~2012 (might be challenging with current resource level).

Compact Linear Collider - CLIC

42 km of main liancs with normal conducting traveling-wave copper structures operating at 12 GHz

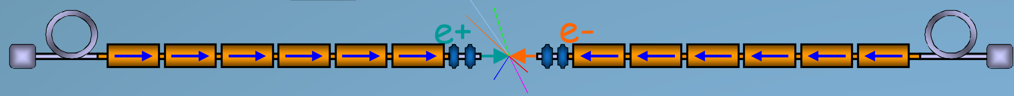


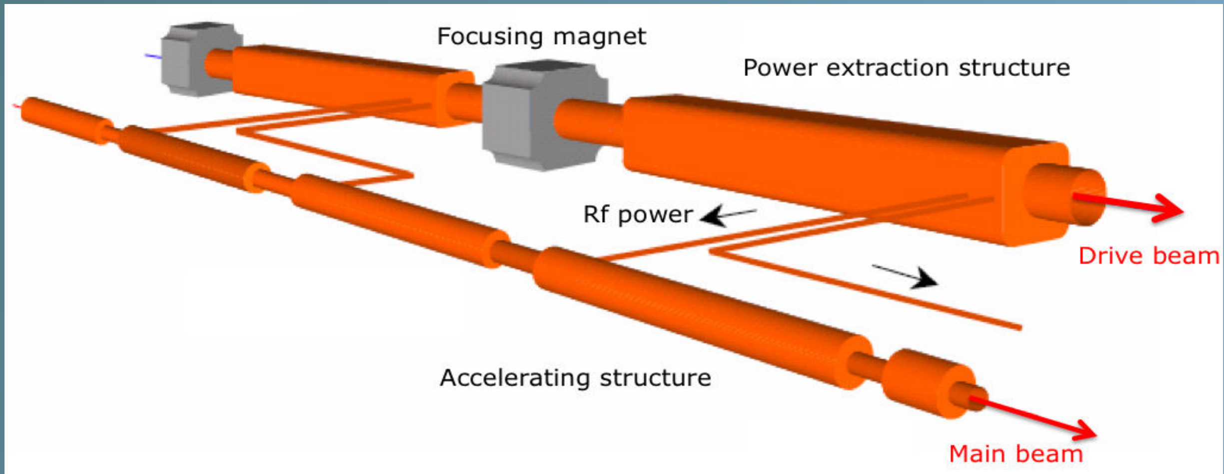


Advantage: high gradient -> 100 MV/m. Good efficiency maintained by novel **two-beam acceleration** scheme **(7% wall-plug to beam efficiency)**

Disadvantage: complex, novel technology, proof-of-principle needed

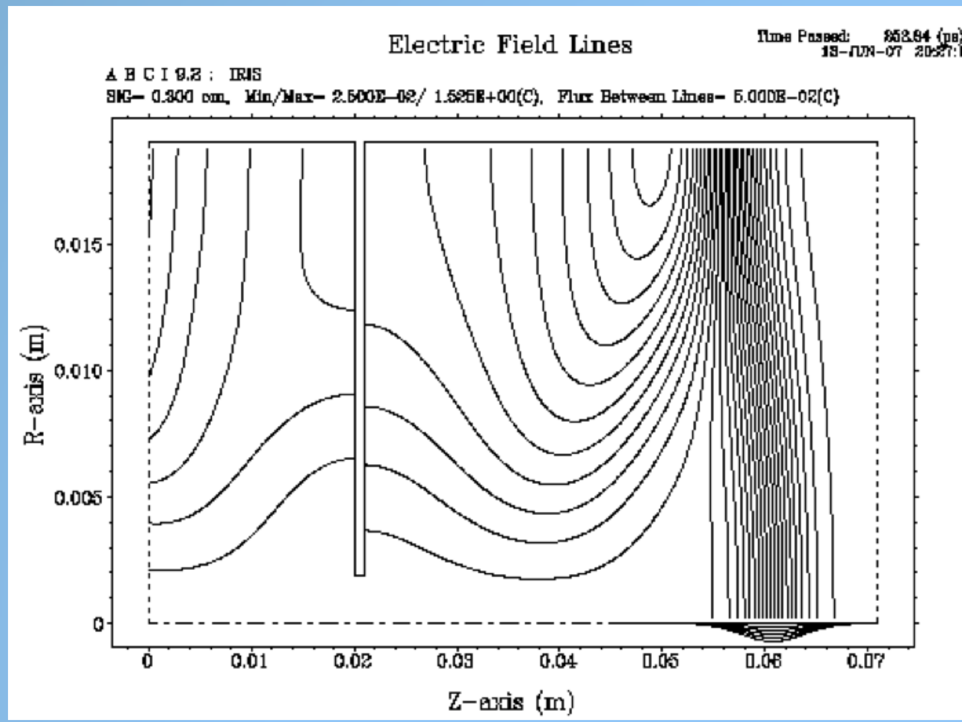
CLIC - two-beam acceleration





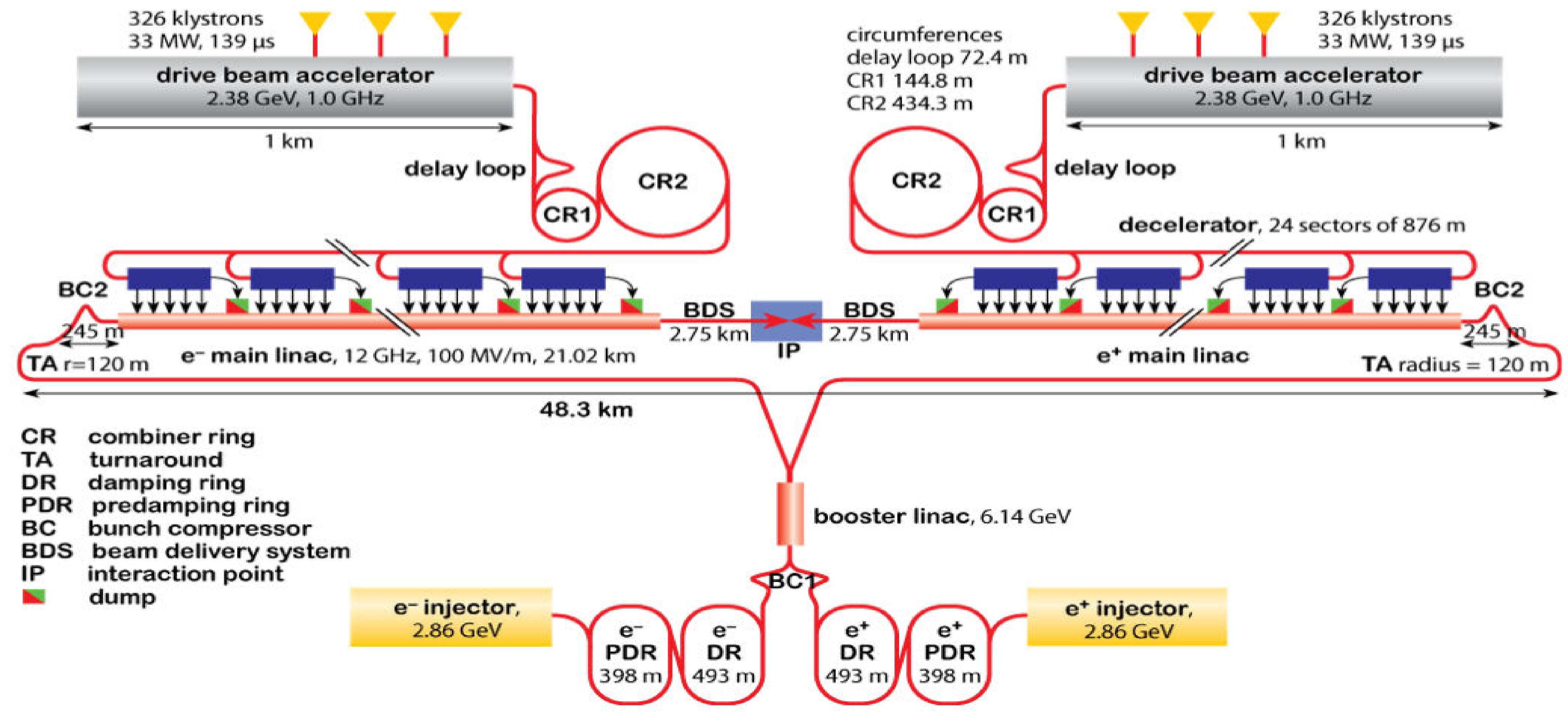
Novel approach CLIC: extract the accelerating rf energy from a 100A e⁻ drive beam, running in parallel with main beams. **No active RF components in tunnel**

Physical principle: energy in form of rf power is extraced by copper structures structures. e^- Lorentz-contracted "pancake field" cut off by irises, resonantely built up and transported out of the structure (high group velocity)



Transport of drive beam: practically loss free -> **highly energy efficient**

CLIC basline



$\sqrt{s}$ = 3 TeV

Site length 48 km

L = 6 x 10^{34} $cm^{-2}s^{-1}$ (2 x 10^{34} $cm^{-2}s^{-1}$ in top 1% of energy)

Option to start at $\sqrt{s}$ = 0.5 TeV (13 km)

Status CLIC

International collaboration, for the moment strongly centred at CERN (CLIC steering committee 100% CERN staff, formally taking input from the collaboration board, with repr. from the collaboration institutes)

Norway/University of Oslo official member of the CLIC collaboration since 2008 (S. Stapnes team leader, EA deputy)

Feasibility study on-going with the aim of delivering the conceptual design report, CDR, in end 2010 (should prove major feasibility issues)

Expected that CERN council will decide upon further research for CLIC summer 2011. CLIC strongly supported in European Strategy for PP

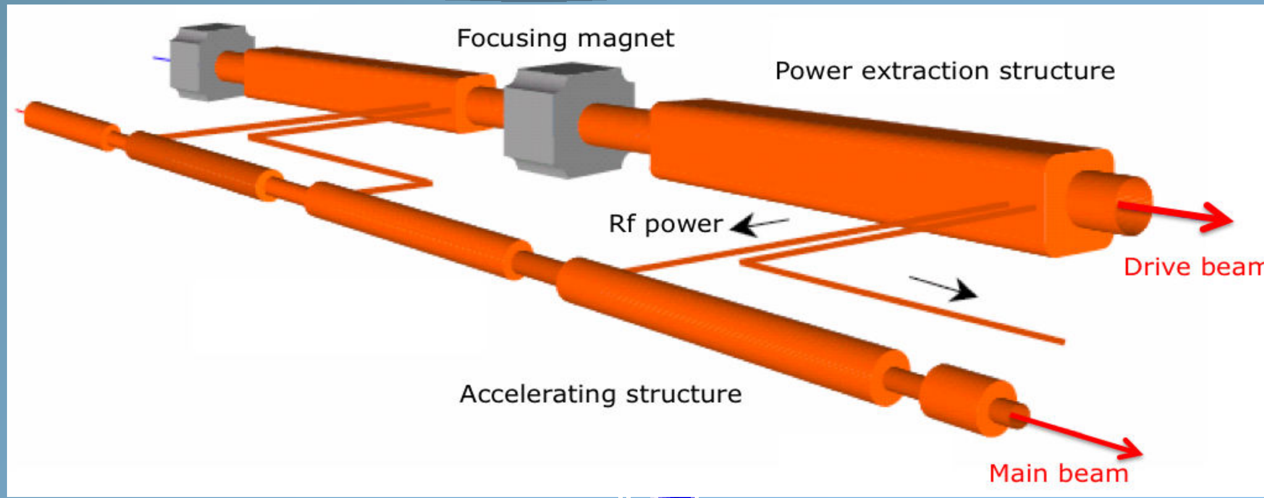
Possible scenario ILC/CLIC efforts: merged after LHC results become available

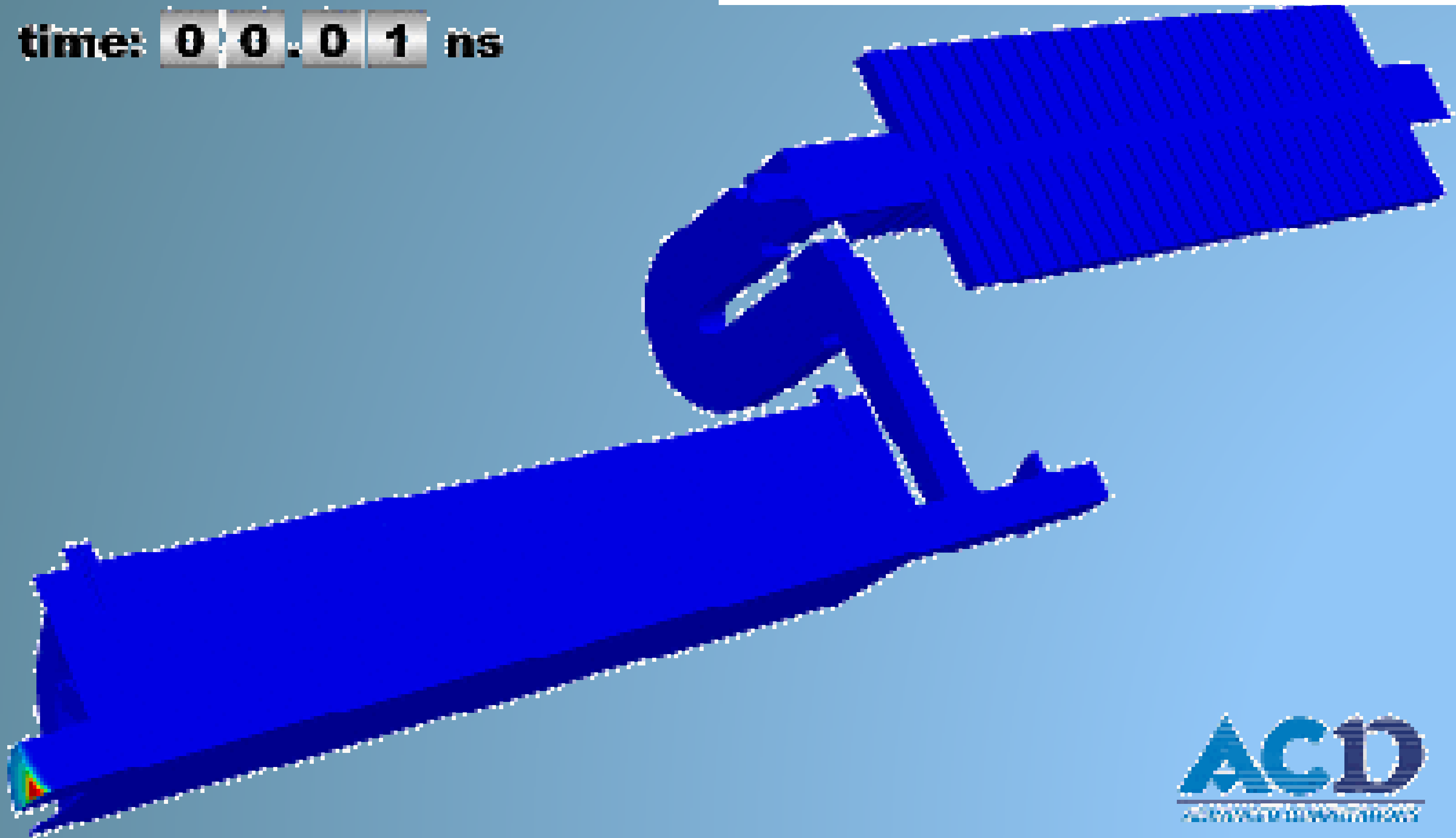
CLIC research at CERN/UiO

Particulary of CLIC: two-beam scheme

Two-beam acceleration:

- drive beam generation
- drive beam power extraction
- main beam acceleration

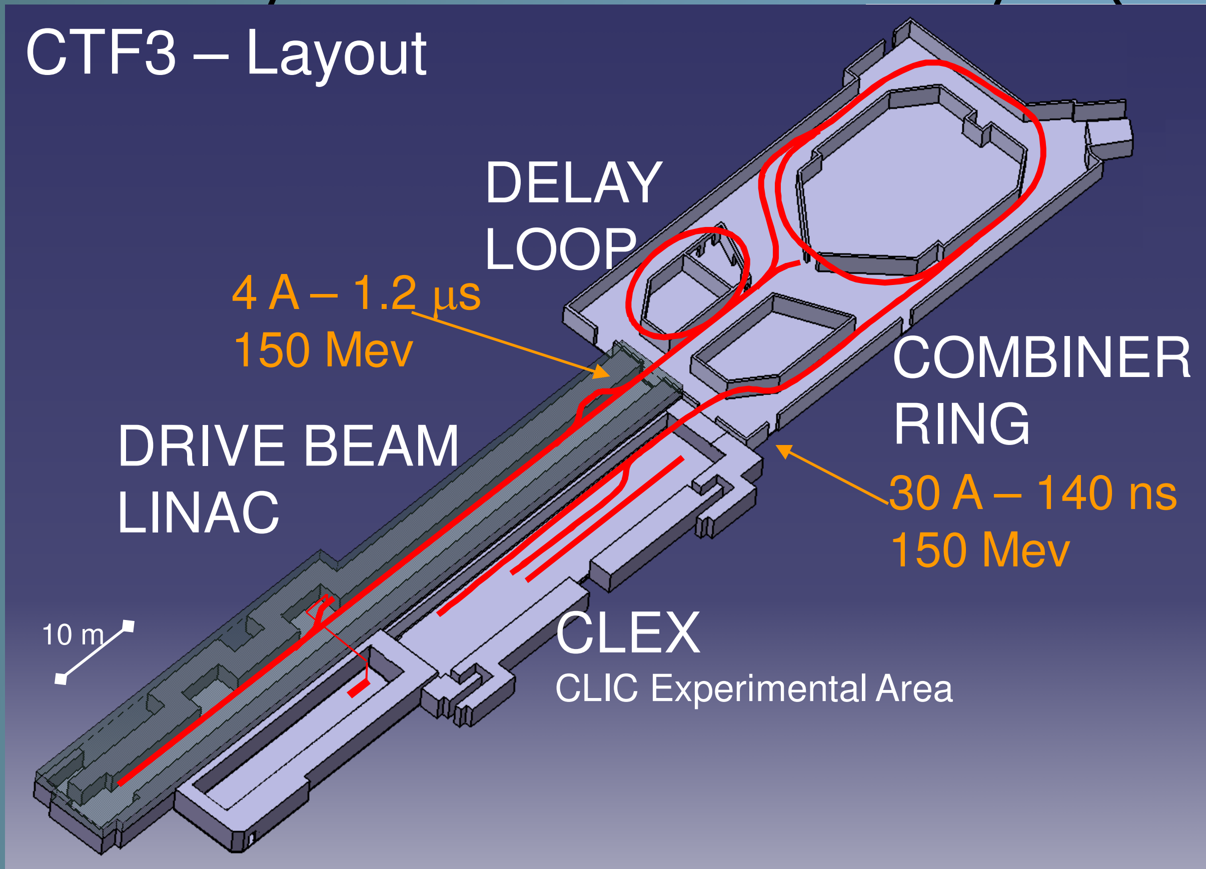


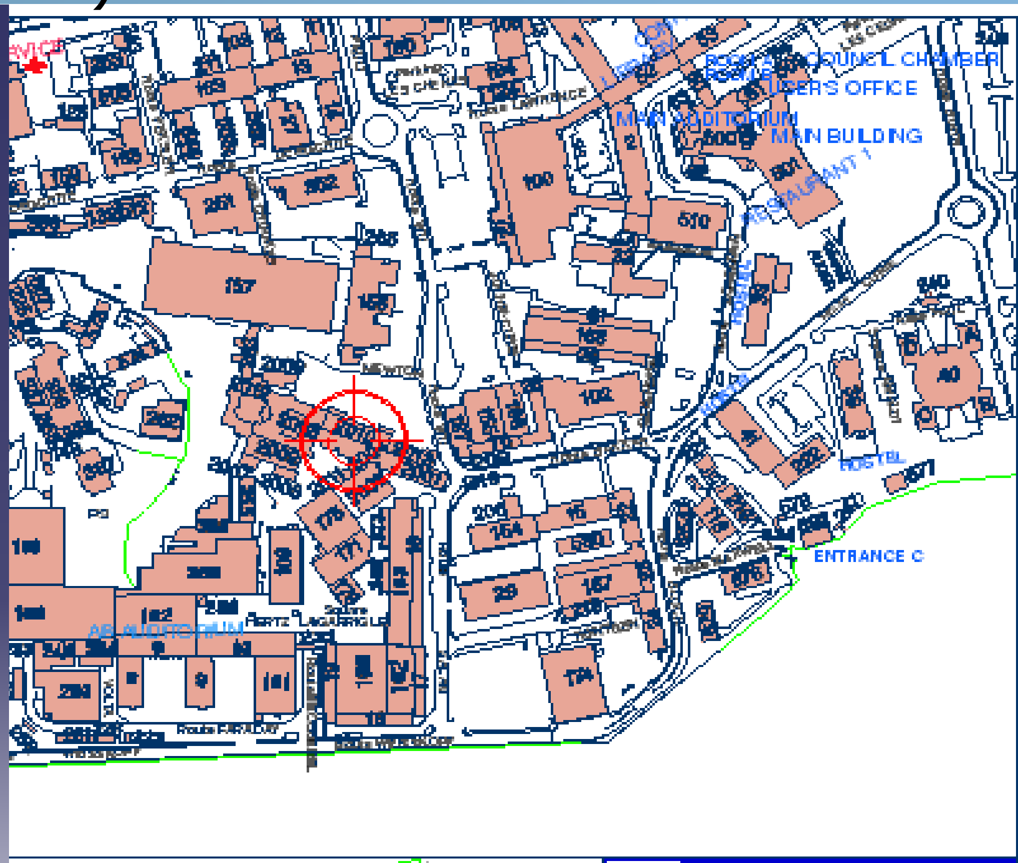


Animation courtesy
of A. Candel (SLAC)

Feasilbity of two-beam scheme

- Dedicated test-facilites for CLIC two-beam feasibility build up at CERN the last ~10 years, reaching their completion the coming few years : CLIC Test Facility 3 (CTF3)

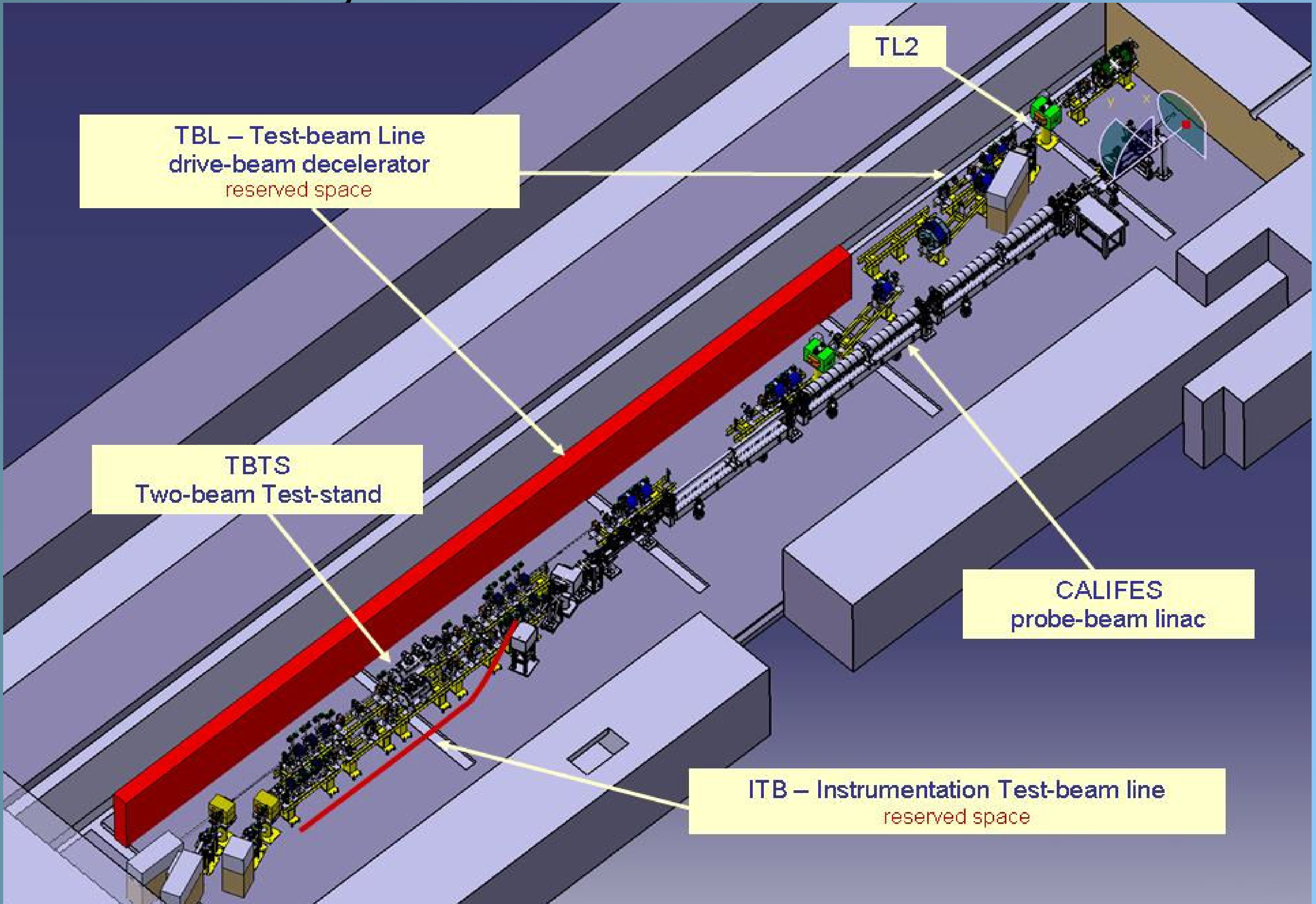




- Norway involved in core research in CLIC and CTF3 : electron deceleration, power structure design
- On-going efforts to establish a Nordic collaboration, presently

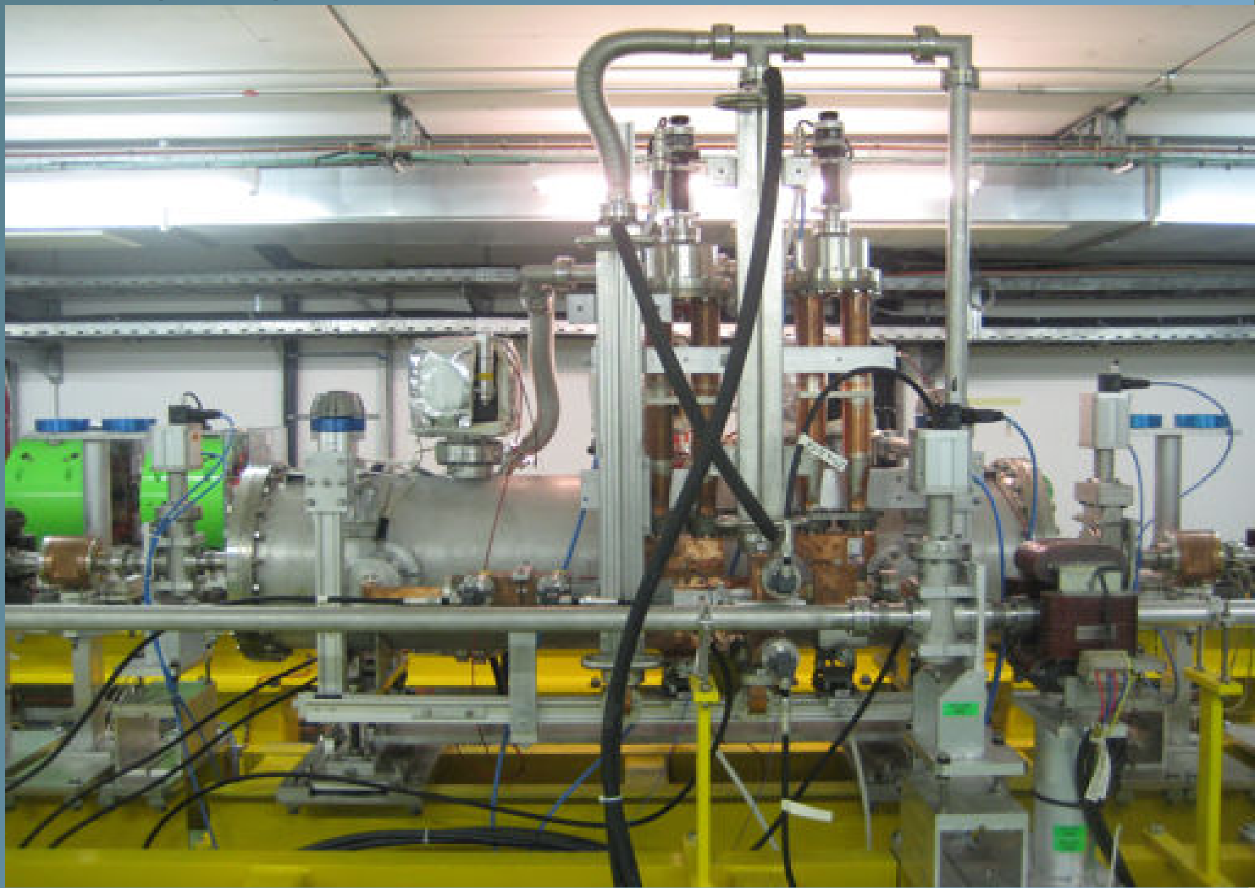
The CLIC Experimental Area

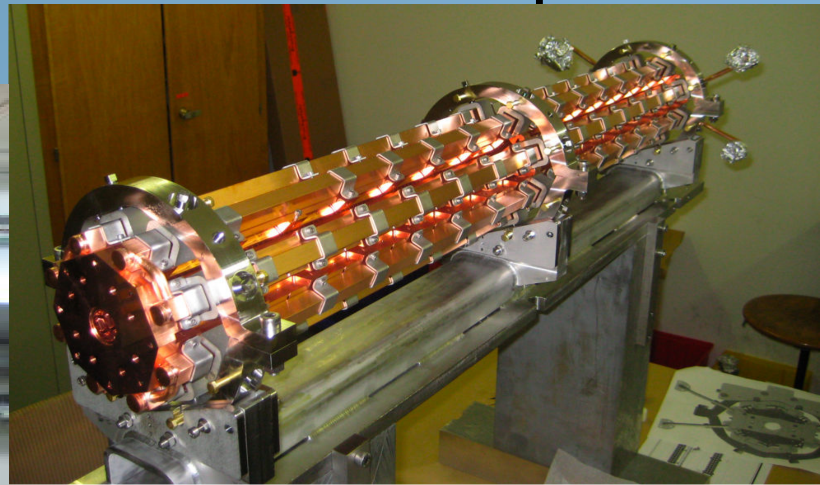
High-intensity electron beam is generated in CTF3 (target: 28A) and provided to the experimental area CLEX. Experiments Test Beam Line (UiO strong participation) and the Two-beam Test Stand (Uppsala) to extract energy and investigate beam stability.

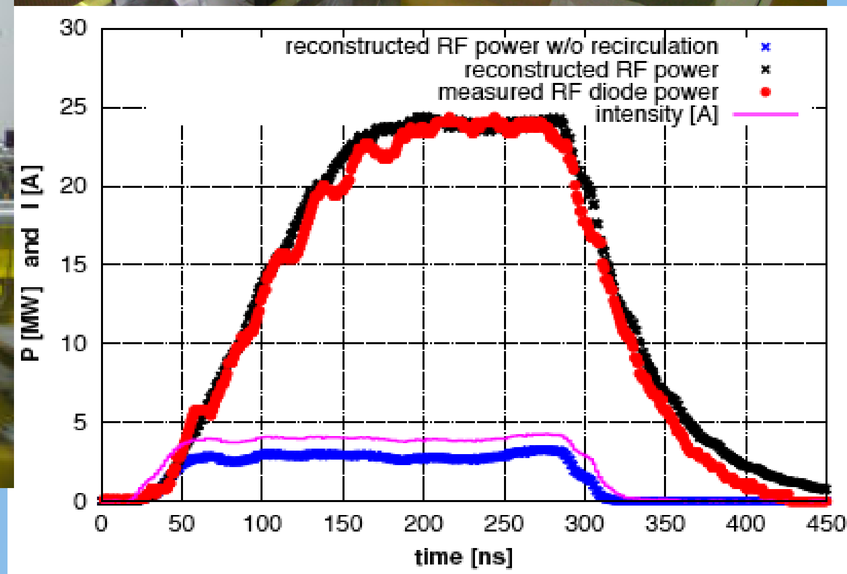


current research: energy extraction

- Last year: first beam tests of the CLIC baseline "power extractor"





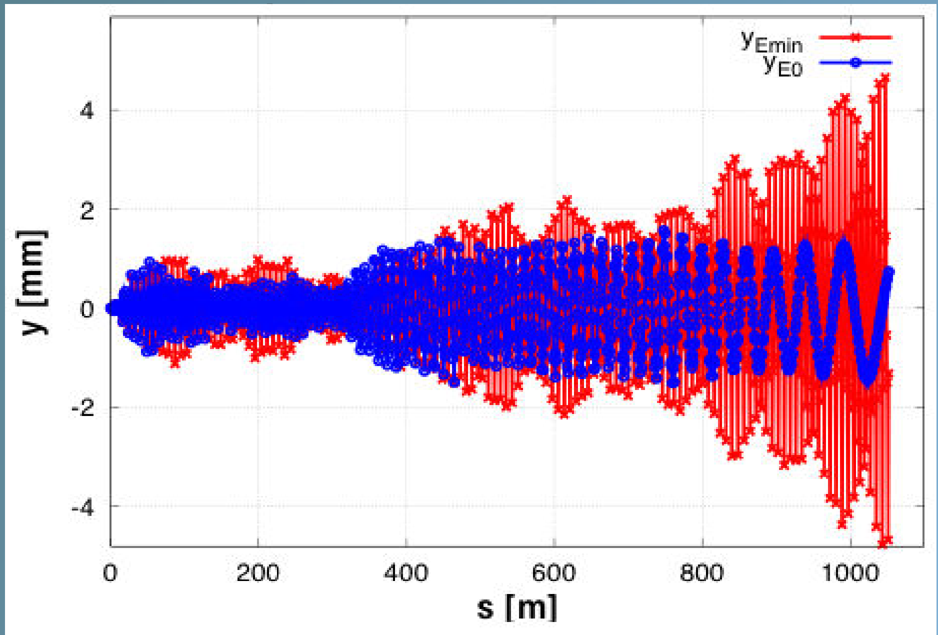


This year and next: demonstration of full two-beam acceleration scheme (TBTS, CERN/Uppsala U.) + research into **rf breakdown**

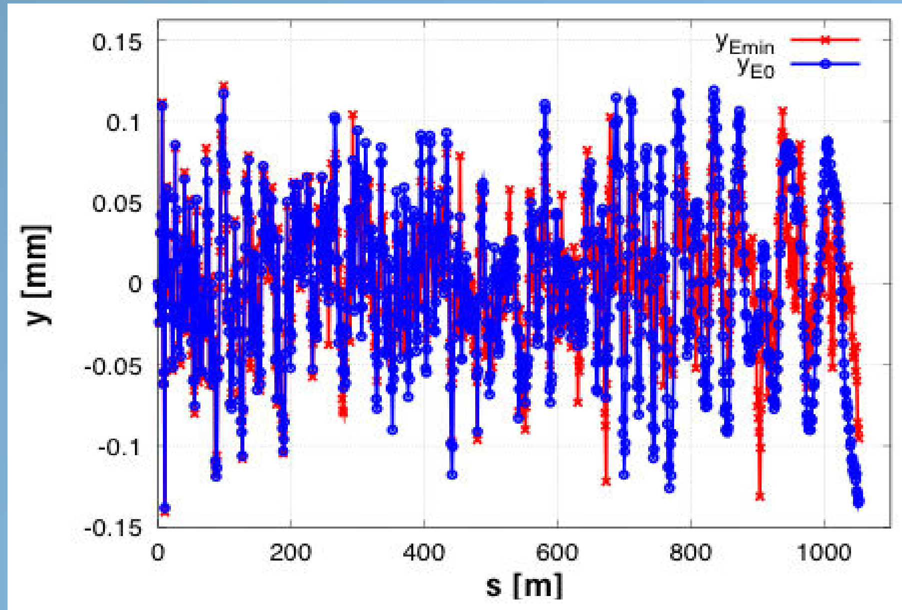
First test results (analyzed this year) show excellent performance, and agreement theory and measurements, for the CLIC power extractor (30 MW output power reached during first run)

current research: beam dynamics

CLIC beams must be transported through tens of km with limited transverse dilution and growth (extracted fields also deflects the beam transversally). This requires clever CLIC structure microwave design and clever beam steering and focusing

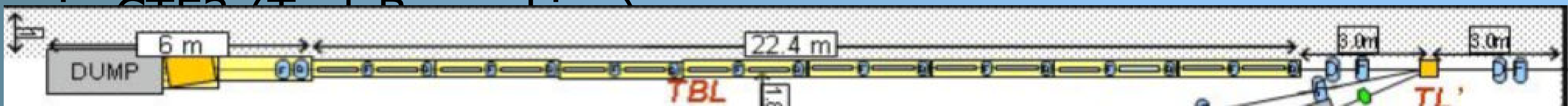


CLIC energy-extractor w/o correction

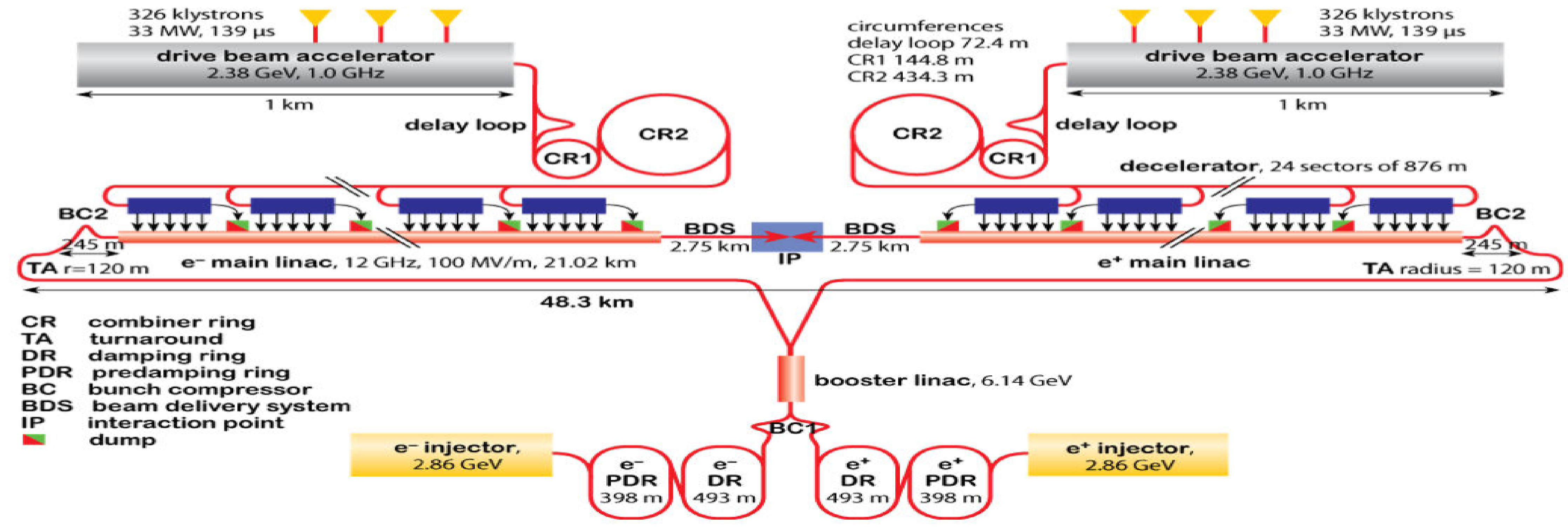


CLIC energy-extractor w/ correction

Stable beam transport of heavily decelerated beam will be shown in CTF3 (Test Beam Line)



CLIC – possibly the next big thing in HEP

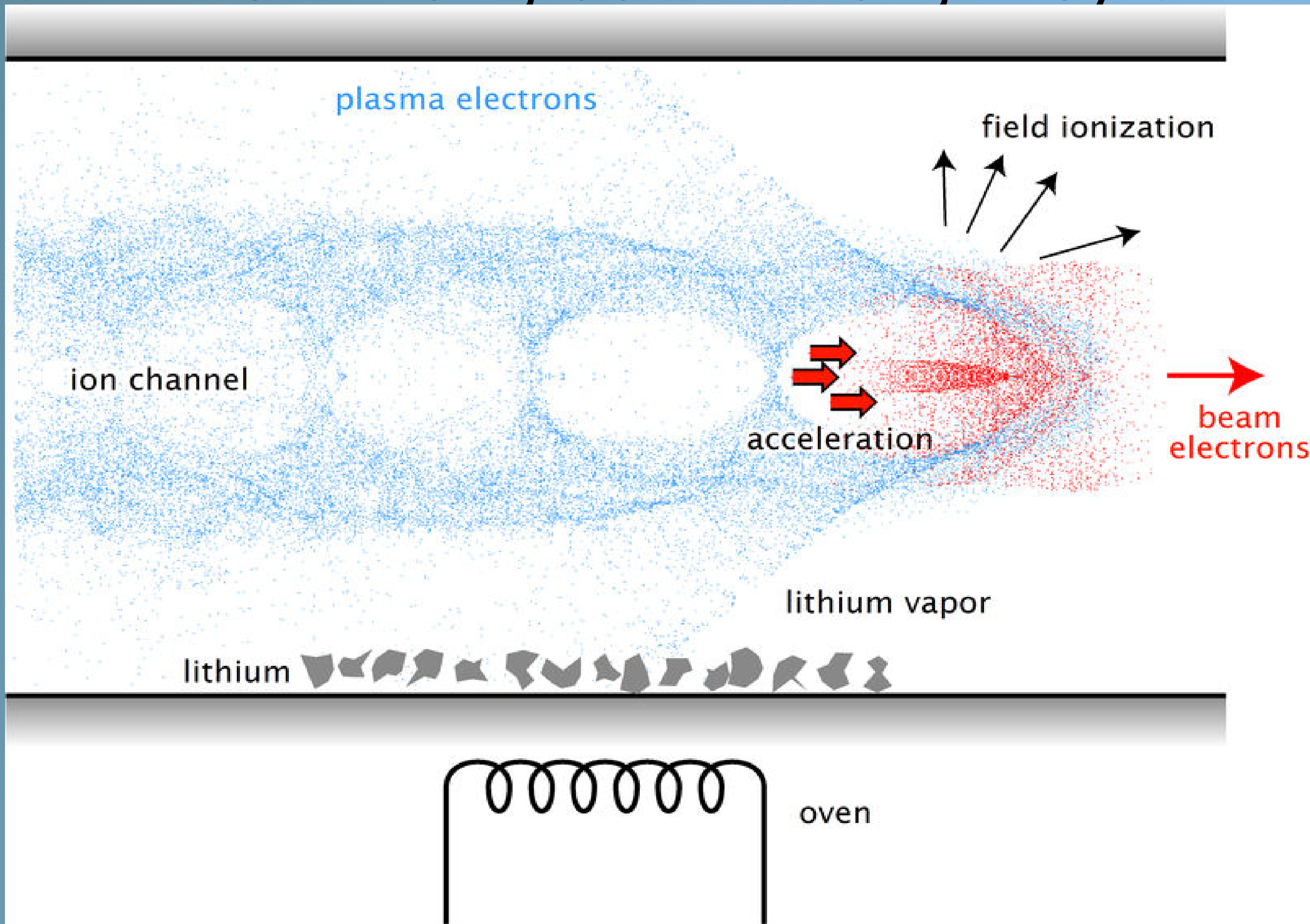


- LHC discoveries will give physics requirements (energy range) for next large HEPP project
- CLIC: the only option today for a Multi-TeV collider
- Possible large ramp-up in project size from 2011/2012
- The CLIC machine contains numerous accelerator physics and technology challenges (relatively larger fraction of cost/research into machine wrt. LHC)

Novel schemes

Novel acceleration: plasma

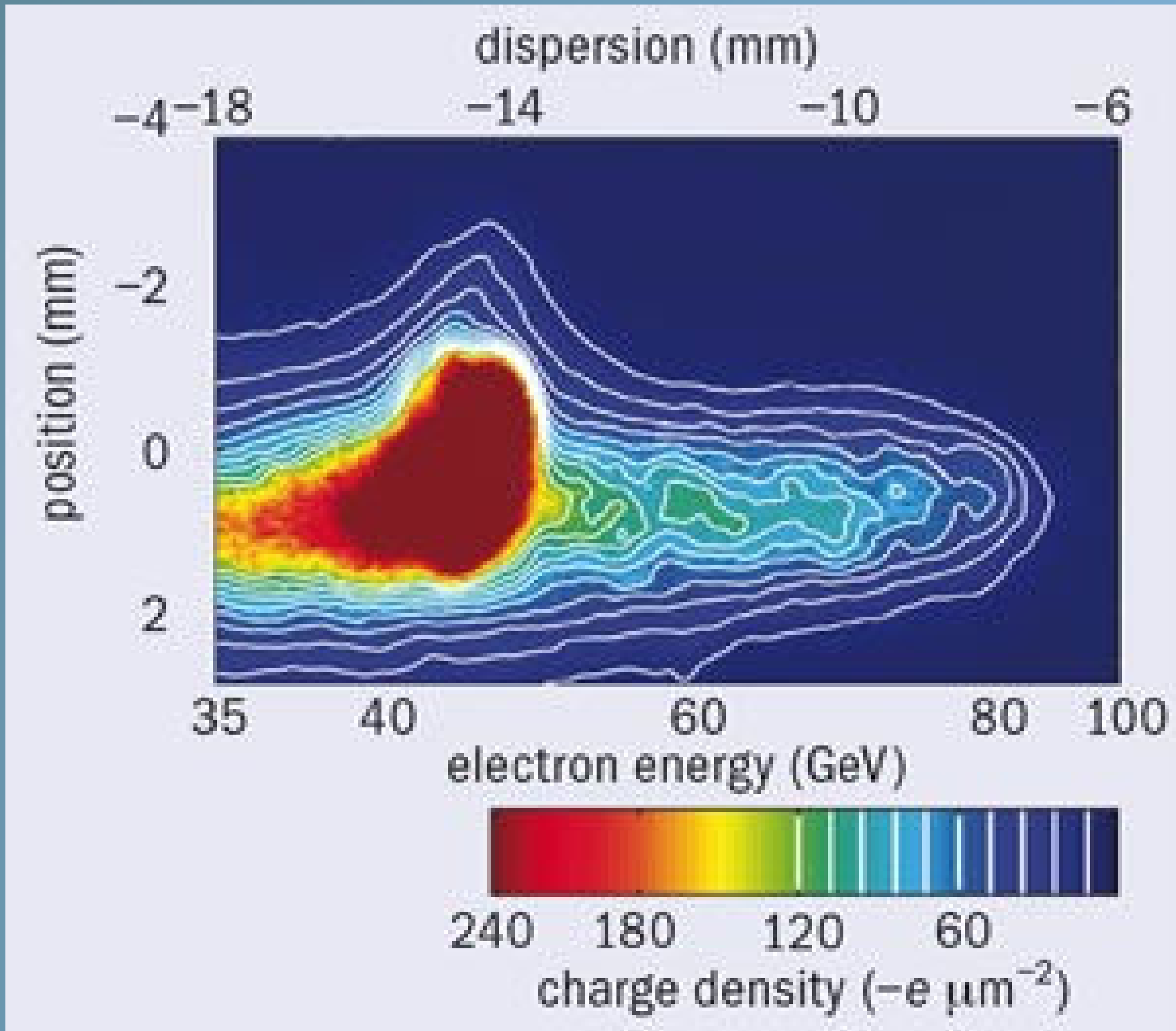
- Microwave structure-based acceleration gradient limited (highest today: CLIC 100 MV/m)
- Gradient limit can be overcome by acceleration in plasmas – theoretical gradients larger by several OM



R. Ischebeck (DESY)

Plasma: proof of principle

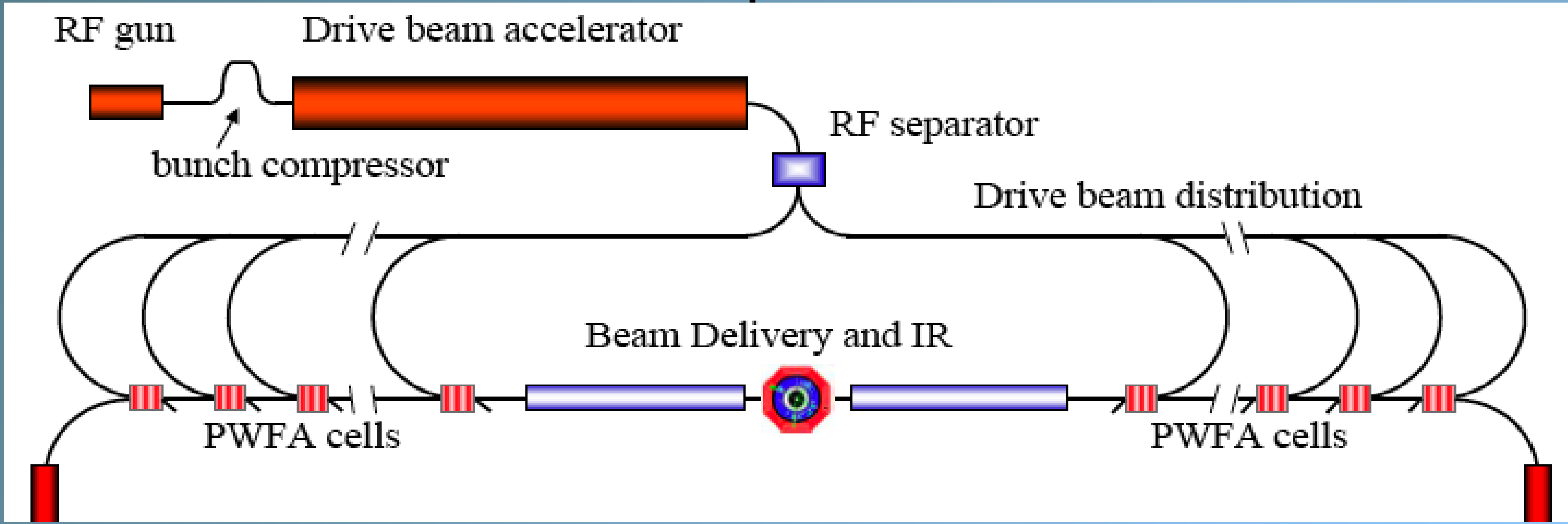
- SLAC: showed electron energy doubling (from 42 GeV to ~85 GeV) in 85 cm of lithium gas

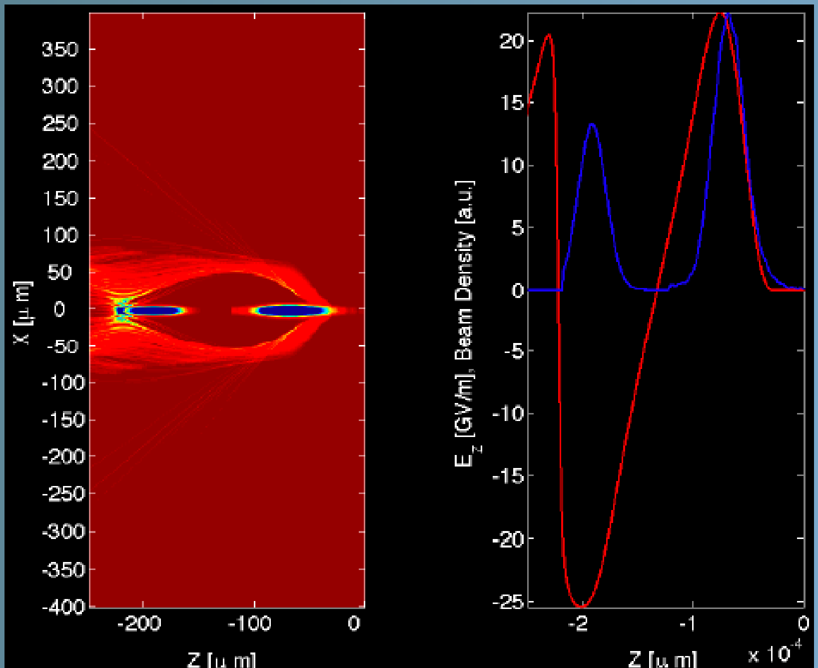


Nature ***445,*** *741-744 (2007)*

Plasma for linear colliders?

Novel ideas: beam-driven plasma for linear colliders:





ICFA / RHS Symposium, SLAC, 2009

SLAC currently constructing large test-facilites (FACET) for beam-driven plasma acceleration for first demonstration

- Efficiency gain not clear
- Path to LC luminosity target not clear
- **Long-term research**

Conclusions

Conclusions

- Consensus in community for linear e^+e^- collider as next step : essential to advance our field
- LHC will indicate physics requirements, and probably drive design choice for the next HEP collider
  - Sub-TeV option: ILC
  - Multi-TeV option: CLIC
  - Advanced acceleration schemes show promise, but has a long way to go to reach maturity
- CERN will play a major role in e^+e^- development (and bid for site), and a large part of CERN's R&D might go into e^+e^- colliders the coming years
- Important for Norway to be a part of it