Particle Colliders at CERN

present and future

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References

- Bibliography:
  - CAS 1992, Fifth General Accelerator Physics Course, Proceedings, 7-18 September 1992
  - LHC Design Report [online]
  - K. Wille, The Physics of Particle Accelerators, 2000

- Other references
  - USPAS resource site, A. Chao, USPAS january 2007
  - CAS 2005, Proceedings (in-print), J. Le Duff, B, Holzer et al.
  - O. Brüning: CERN student summer lectures
  - N. Pichoff: Transverse Beam Dynamics in Accelerators, JUAS January 2004
  - U. Am aldi, presentation on Hadron therapy at CERN 2006
  - Various CLIC and ILC presentations
  - **Several figures in this presentation have been borrowed from the above references, thanks to all!**

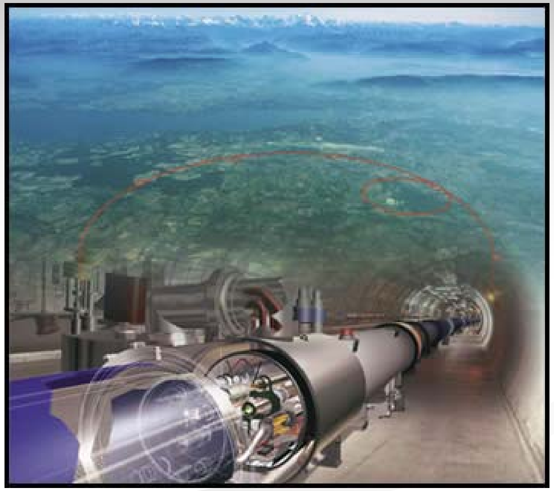
Part III

From LEP via LHC to CLIC

LEP, LHC and CLIC

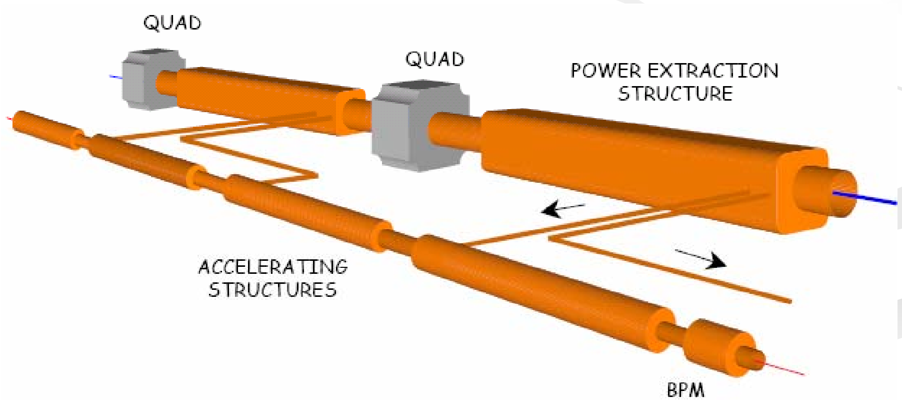
This decade: both LEP and LHC

LEP: 1989 - 2000



LHC: 2008 -

Next generation being studied:



CLIC: The future

Limitations LEP and LHC

- We want E_{cm} as high as possible for new particle accelerators
- circular colliders ⇒ particles bended ⇒ two limitations occurs:

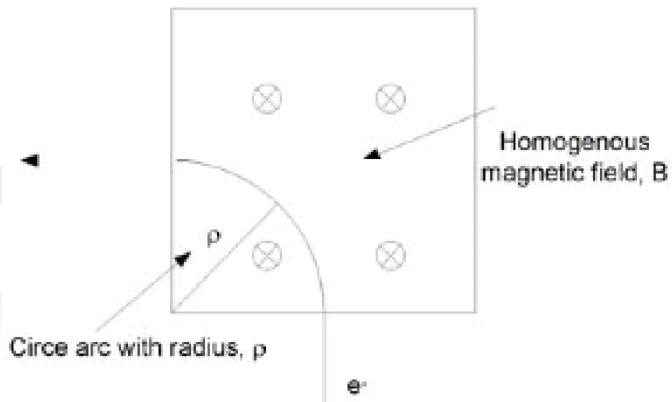
I) synchrotron radiation energy loss

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

$P \propto E^4$ ⇒ **Limited LEP to E_{cm}**=209 GeV (RF energy replenishment)
$P \propto m_0^{-4}$ ⇒ changing to p in **LHC** ⇒ **P no longer the limiting factor**

II) Magnetic rigidity

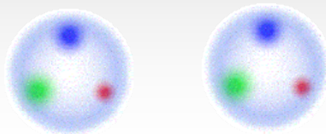
$$B\rho = \frac{p}{e}$$



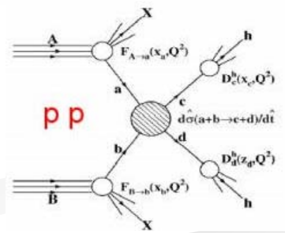
Technological limit of bending magnet field strength
⇒ **Limits LHC to E_{cm}=14 TeV** ($\propto$ B)
⇒ Superconducting magnets needed

Hadron versus lepton collisions

- Colliding particles can be elementary particle (lepton) or composite object (hadron)
  - LEP: e^+e^- (lepton)
  - LHC: pp (hadron)

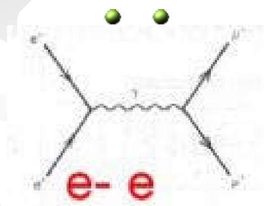


- Hadron collider:
  - Hadrons easier to accelerate to high energies



- Lepton collider (LC):
  - well-defined E_{CM}
  - well-defined polarization (potentially)

  $\rightarrow$ are better at **precision measurements**



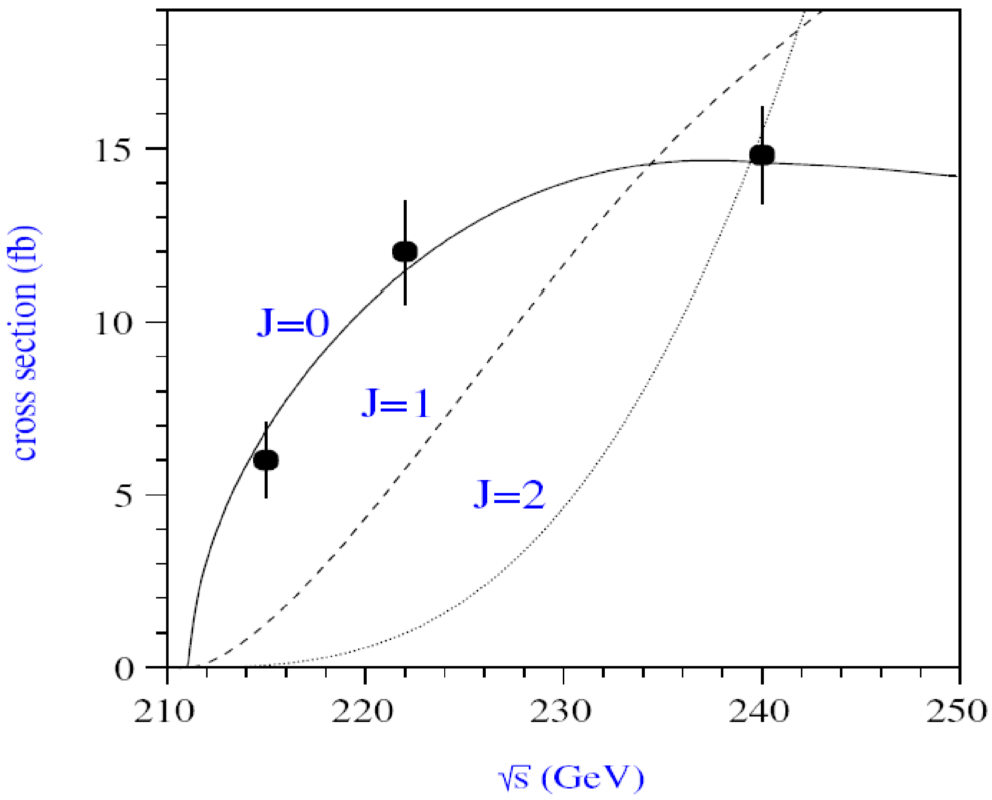
Example of LHC versus lepton colliders: Higgs

- LHC might discover one, or more, Higgs particles, with a certain mass
- However, discovery and mass are not enough
- Are we 100% sure it is really a SM/MSSM Higgs Boson?
  - What is its spin?
  - Exact coupling to fermions and gauge bosons?
  - What are its self-couplings?
- So, are these properties exactly compatible with the SM/MSSM Higgs?

Confidence requires a need for precision

Higgs: Spin Measurement

- The SM Higgs must have spin 0
- In a lepton collider we will know E_{cm}
- A lepton collider can measure the spin of any Higgs it can produce



$e^+e^- \rightarrow HZ$ (mH=120 GeV, 20 fb–1)

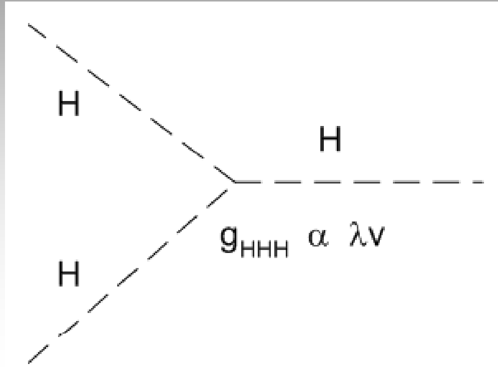
Slide: B. Barish

Higgs: self-couplings

The Higgs potential:

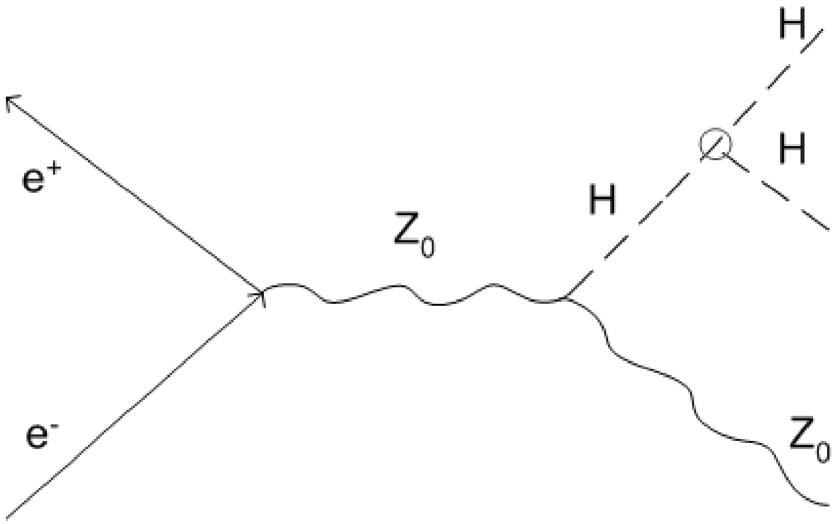
$$V(\sigma) = \frac{1}{2}m_H^2\sigma^2 + \lambda v\sigma^3 + \frac{1}{4}\lambda\sigma^4$$

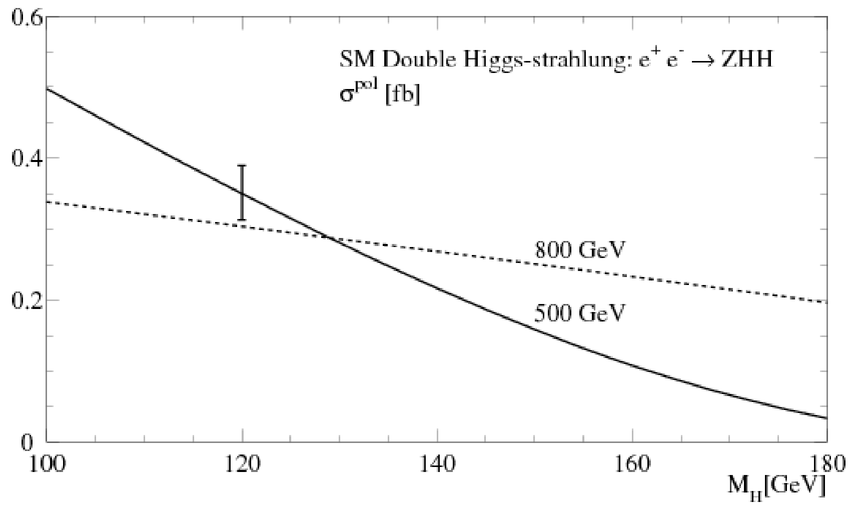
$$v = \sqrt{\frac{-\mu^2}{\lambda}} = \frac{m_H}{\sqrt{2\lambda}}$$



- SM predicts g_{HHH} α λ

- Best measured with polarized lepton collision via $e^+e^- \rightarrow HHZ$





(Graph: M.M.Mühlleitner)

The Chainsaw and the Scalpel

LHC

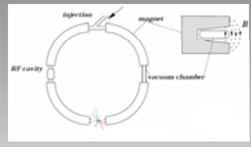
Lepton collider

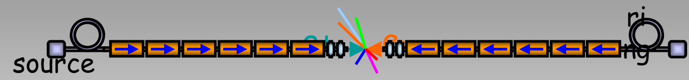
After LHC we need a linear lepton collider

Part IV

CLIC: the Compact Linear Collider

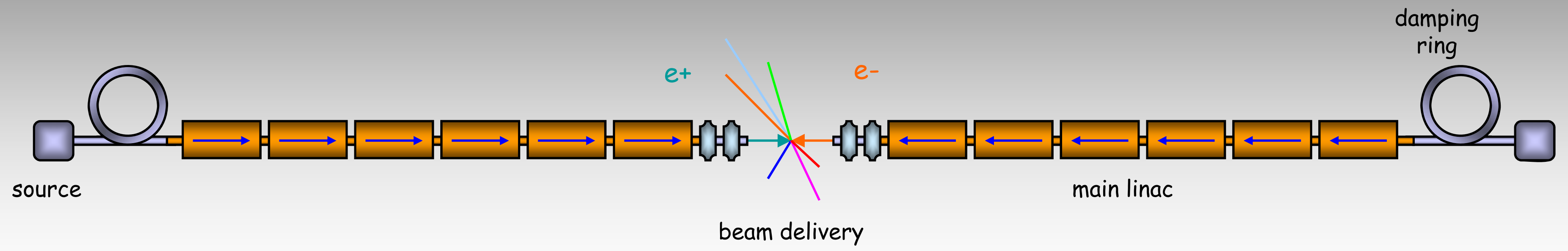
The three main parameters





	Rings	Linear colliders
Particle type(s)	ions, $p/\bar{p}$, $e^{+/-}$	ions, $p/\bar{p}$, $e^{+/-}$
Collision energy	accelerating cavities reused	accelerating cavities used once
Luminosity	▪ bunches collided many times ▪ several detectors simultaneously	▪ each bunch collide only once ▪ only one detector in use at a given time

What is a linear collider?



- **Main part: two long linear accelerators (linacs), with as high accelerating gradient as possible**

- **The two beams are "shot" into the collision point, with a moderate repetion rate f_r ~ 10 Hz**

- **Damping rings needed to get the initial emittance, ε, as low as possible**

- **Beam Delivery System and final focus are needed to prepare the the beam for collisions (remember: very small beta function, $\beta(s)$, needed at the collision point)**

1^{st} challenge: E_{COM}

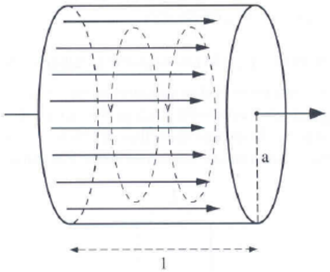
- Accelerating cavities used once

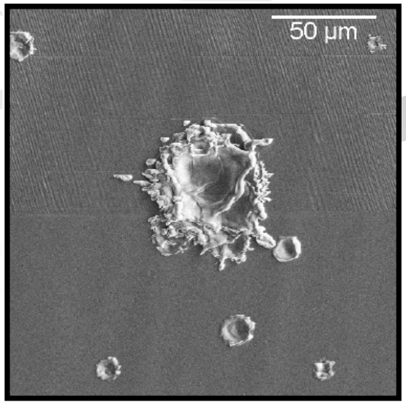
- The length of the linac is then given by
  1. E_{CM}
  2. Accelerating gradient [V/m]

- E.g. for E_e=0.5 TeV and an average gradient of g=100 MV/m we get: l=E[eV] / g[V/m] = 5 km
  - Needs two linacs (e^+ and e^-) and a long final focus section ~ 5 km ⇒ total length for this example 15 km

- ⇒ 1^{st} main challenge of future linacs: **maximize gradient** to keep collider short enough !

- Gradient limited by field break down





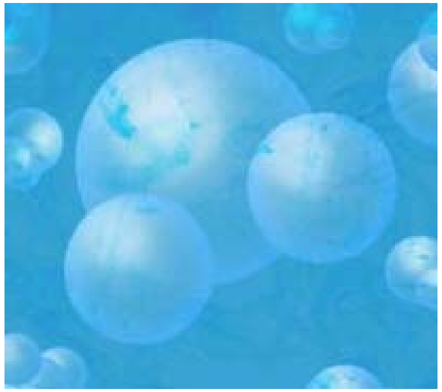
2nd challenge: $\mathcal{L}$

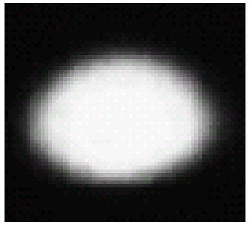
$$\mathcal{L} = f \frac{n_1 n_2}{4\pi\sigma_x\sigma_y}$$

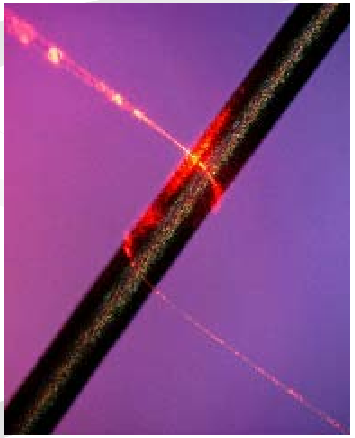
σ_x=60 nm, σ_y=0.7nm (!)

7Å ! Vertical bunch-width of a water molecule!

(LEP: width of a human hair)







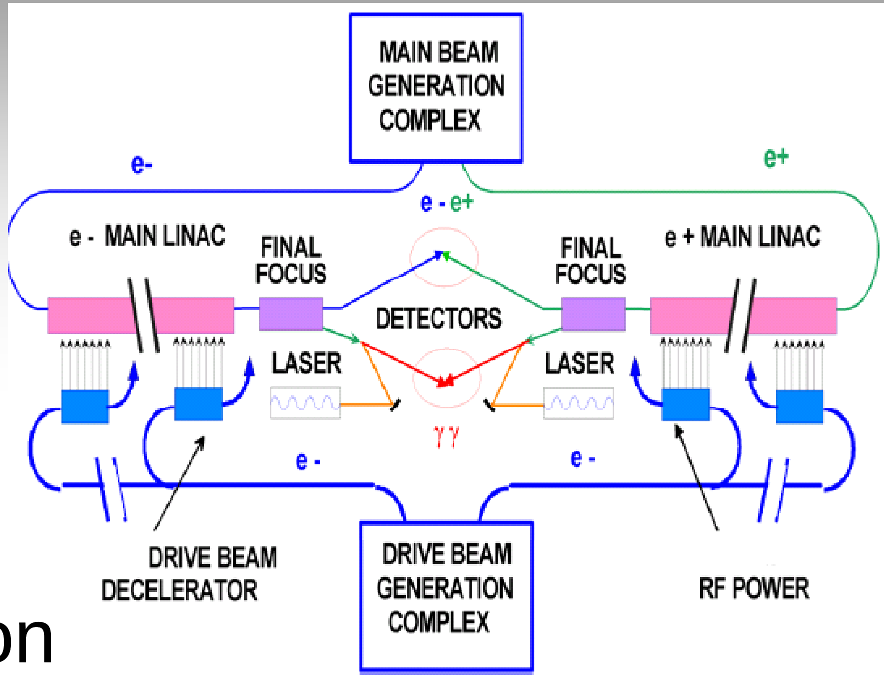
- Future linear colliders: truly **nanobeams**

The CLIC collaboration

- CLIC:

Compact Linear Collider

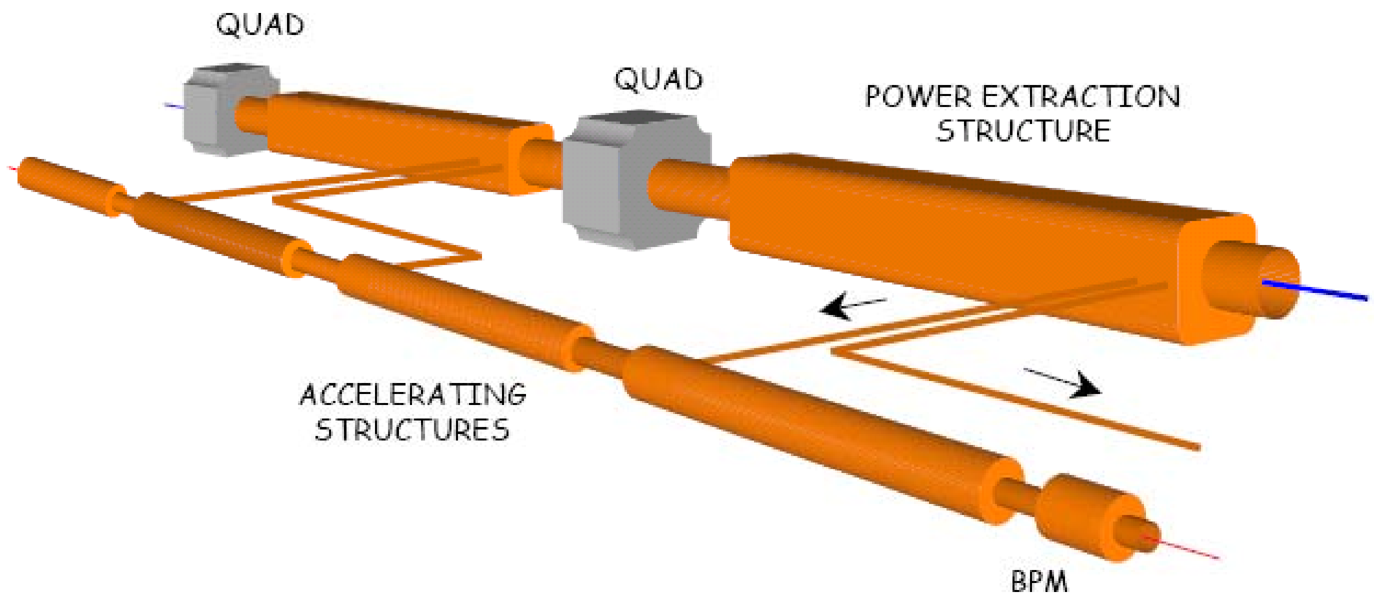
- Normal conducting cavities
- Gradient 100 MV/m
  - Limited by breakdown



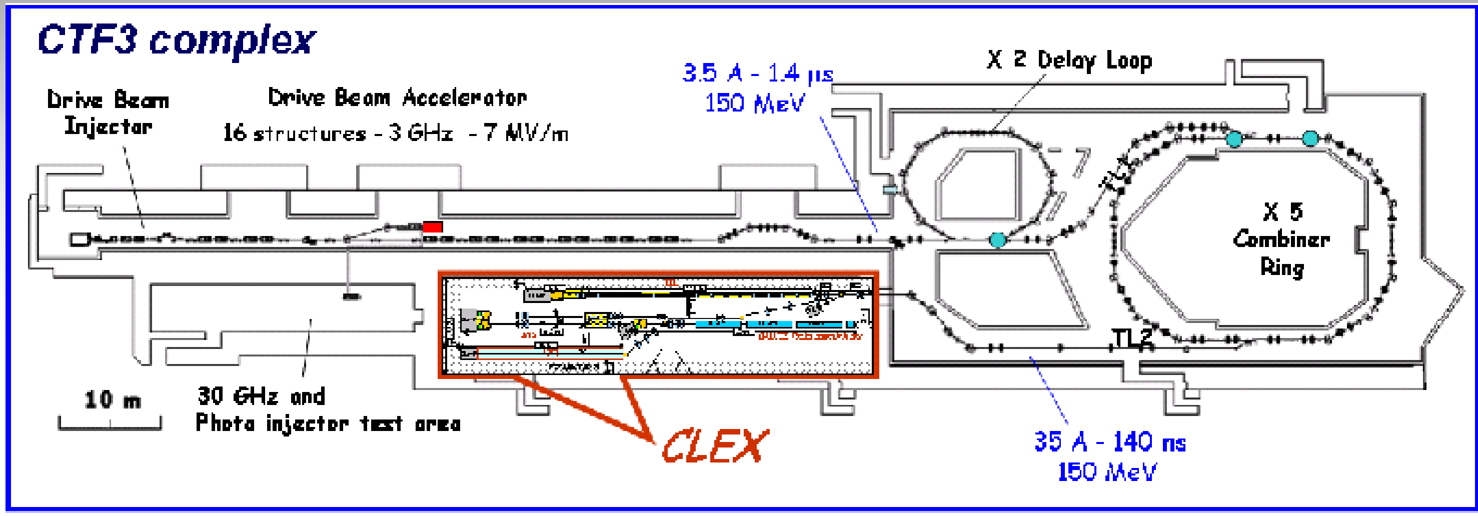
- Two-beam based acceleration
  - Instead of Klystrons use an e^- drive beam to generate power
  - For high-energy: klystrons (> 10000 needed) will be more costly, and must be extremely fail-safe
  - Power is easier to handle in form of beam ⇒ short pulses easier
  - Depending on final CLIC parameters klystrons might not even be feasible (too high POWER wrt. RF)

Two-beam accelerator scheme

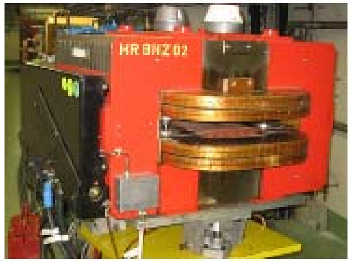
- Power extracted from one beam (the drive beam) to provide power main beam
- Special Power Extraction Transfer Structure (PETS) technology
- Particles generate wake fields ↔ leaves behind energy

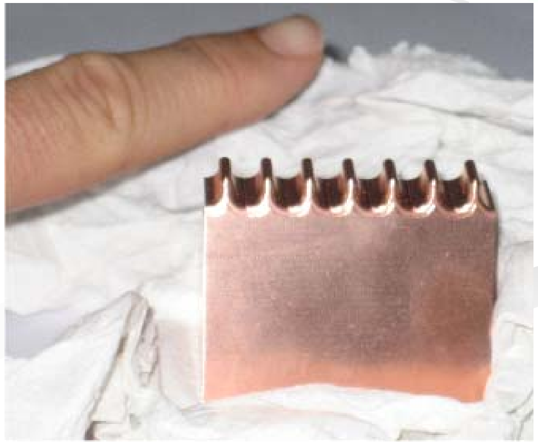


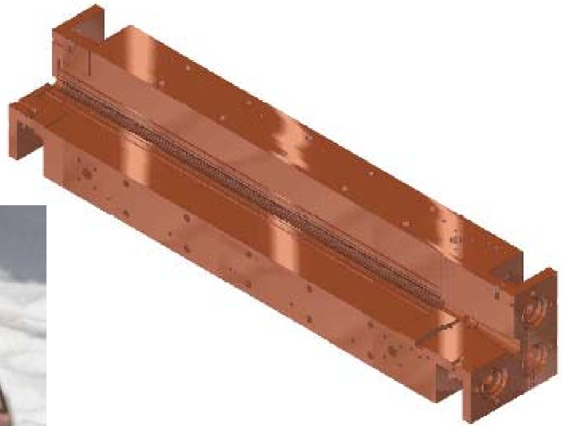
CTF3 – CLIC Test Facility 3



Lattice components







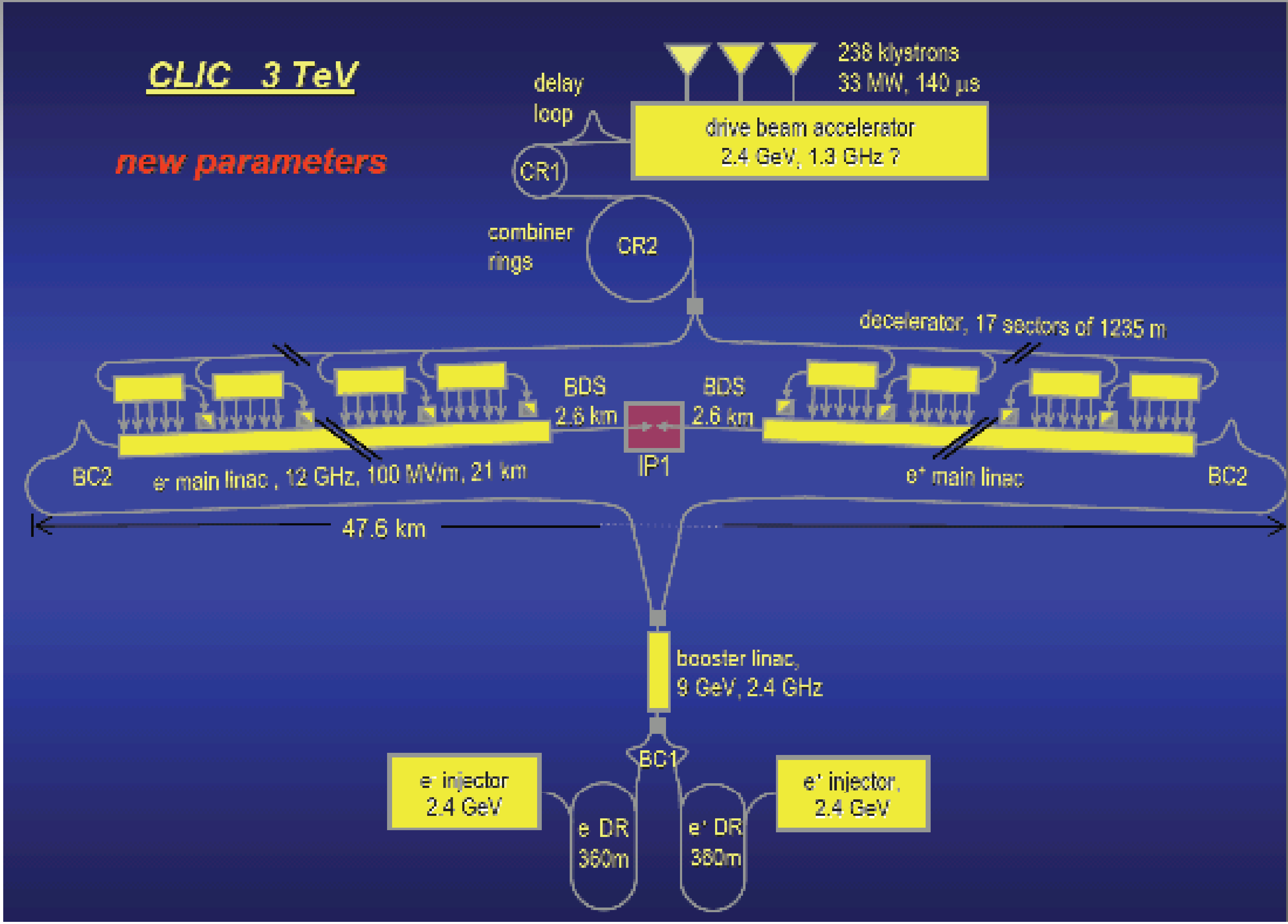
PETS

The European strategy *for particle physics*

- CLIC strongly supported by the CERN Council and management, as well as in the European strategy for particle physics:

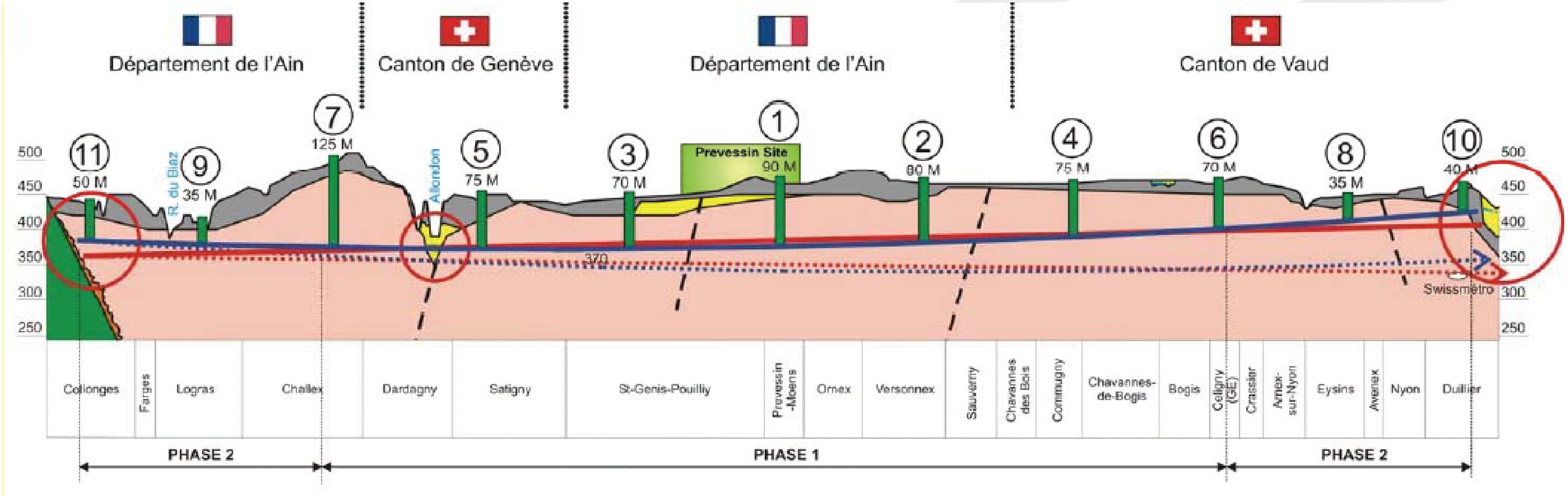
> 4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

CLIC


CLIC 3 TeV
new parameters
delay loop
238 klystrons
33 MW, 140 μs
drive beam accelerator
2.4 GeV, 1.3 GHz ?
CR1
combiner rings
CR2
decelerator, 17 sectors of 1235 m
BDS 2.6 km
BDS 2.6 km
IP1
BC2
e⁻ main linac , 12 GHz, 100 MV/m, 21 km
e⁺ main linac
BC2
47.6 km
booster linac,
9 GeV, 2.4 GHz
BC1
e⁻ injector
2.4 GeV
e⁻ DR
360m
e⁺ DR
360m
e⁺ injector,
2.4 GeV

Potential site at CERN

- Global project → interests in Europe, USA, Asia
- In fact two different designs being studied CLIC and the ILC
- Which design, and where, depends on many factors, including the results of LHC physics
- CERN: advantage of quite nice stable ground



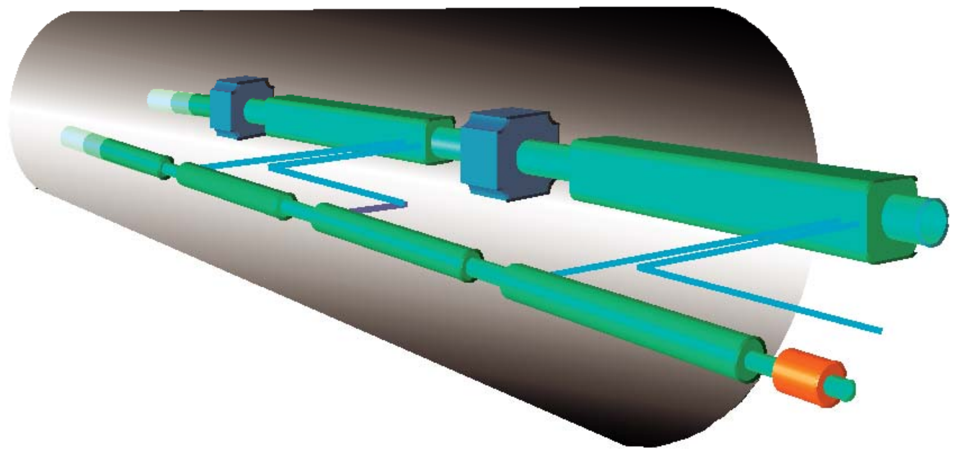
CLIC Main Parameters (3/2007)

- **Particle type: e^- and e^+**

- **E_{cm} = 3 TeV**
- Gradient: 100 MV/m
- Length: 47.6 km

- **Luminosity: $3 \times 10^{34}\ cm^{-2}s^{-1}$**
- Particles per bunch: 3×10^9
- Pulse repetition rate: (100 – 250) Hz
- Beam size at IP: σ_x = 60 nm , σ_y = 0.7 nm

- Cost: not yet established
- Site: not yet established

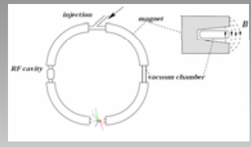


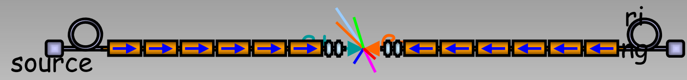
CLIC

Novel two-beam acceleration: the future of linear accelerators?

(NB: all parameters might be subject to change)

Grand summary: LHC and CLIC





	LHC	**CLIC**
Collider type	Ring	Linear, 100 MV/m
Length	27 km circumference	48 km linear length
Particle type(s)	p/p, ions	$e^{+/-}$
Collision energy	**14 TeV** per proton (max. of a few TeV per parton)	**3 TeV**
Luminosity	■ ~ 10^{11} protons per bunch ■ f_r = 40 MHz ■ $\sigma_{ip} \approx 17\ \mu m$ **L ~ 10^{34} cm^{-2}s^{-1}**	■ ~ 10^9 $e^{+/-}$ per bunch ■ f_r ~ 10 Hz ■ $\sigma_{y,ip}$ ~ 1 nm **L ~ 10^{34} cm^{-2}s^{-1}**

References

- Bibliography:
  - CAS 1992, Fifth General Accelerator Physics Course, Proceedings, 7-18 September 1992
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