CERN Academic Training Lectures
12-16 June 2006
Geneva, Switzerland

Technological challenges of CLIC
Alignment and Stabilization Issues

Hélène Mainaud-Durand - TS Department
and
Stefano Redaelli - AB Department

Outline

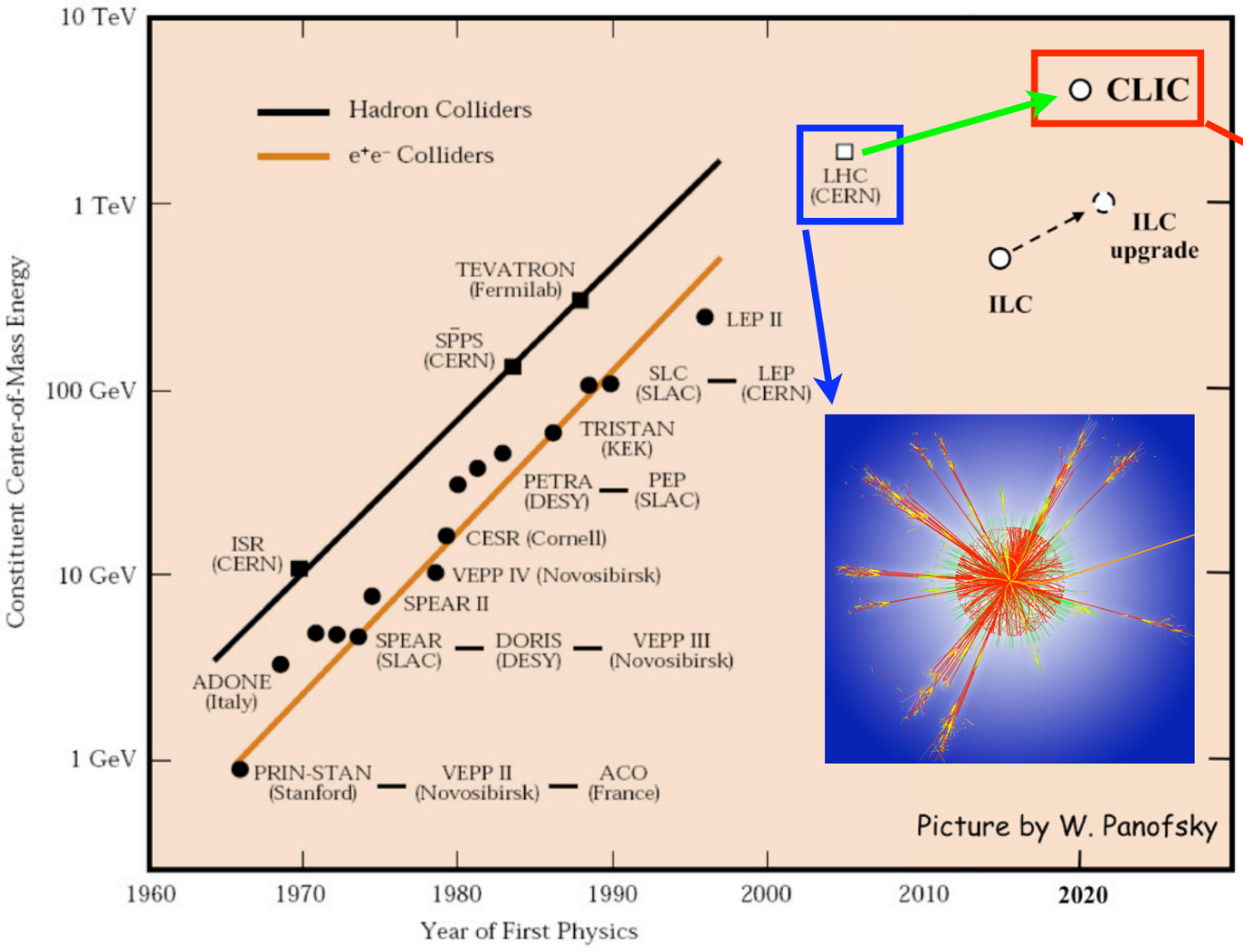
- **Introduction**
  - Review of CLIC complex
  - Alignment and stability requirements
  - References
- **Pre-alignment of LINAC components**
  - Measurement tools for alignment
  - Alignment system and perturbing effect
  - Towards a solution for CLIC
- **Sub-nanometre stabilization of magnets**
  - Luminosity performance in a linear collider
  - The CLIC stability
  - Achieved magnet stability
  - Outlook

Introduction

Challenge for accelerator physicists: build machines that produce higher energy beams and deliver higher luminosities!

1) **ENERGY (E_b)** Discovery reach of the accelerator → $E = mc^2$

2) **LUMINOSITY (L)** Event rate of new particles' production → $N_{\mathrm{Event}} = \sigma \times \mathcal{L}$



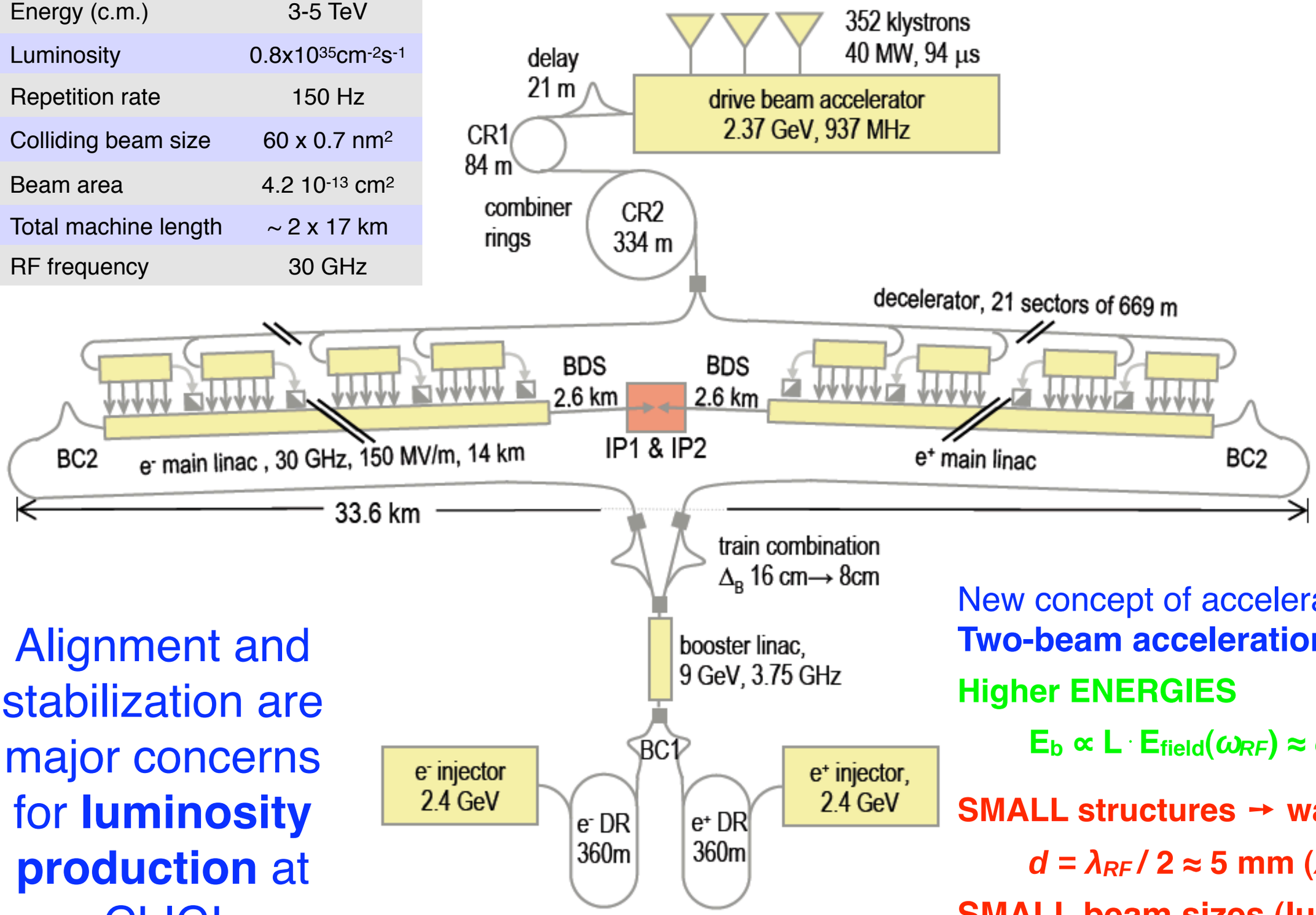
The Compact LInear Collider (CLIC) can make our dreams true!

$E = 3 \rightarrow 5$ TeV

$\mathcal{L} = 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

The CLIC complex

Energy (c.m.)	3-5 TeV
Luminosity	$0.8 \times 10^{35} cm^{-2} s^{-1}$
Repetition rate	150 Hz
Colliding beam size	60 x 0.7 nm^2
Beam area	$4.2\ 10^{-13}\ cm^2$
Total machine length	~ 2 x 17 km
RF frequency	30 GHz



Alignment and stabilization are major concerns for **luminosity production** at CLIC!

New concept of acceleration at 30 GHz:
Two-beam acceleration scheme

Higher ENERGIES

$$E_b \propto L \cdot E_{field}(\omega_{RF}) \approx \omega_{RF} \text{ !!}$$

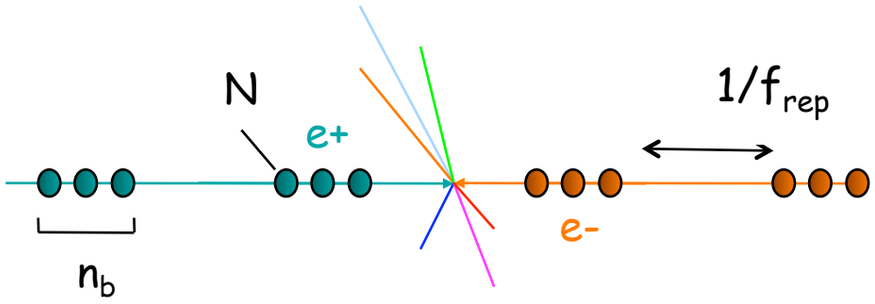
SMALL structures → wake fields

$$d = \lambda_{RF} / 2 \approx 5 \text{ mm } (\lambda \cdot f_{RF} = c)$$

SMALL beam sizes (luminosity)

Luminosity production in CLIC

$$N_{\mathrm{Event}} = \sigma_{\mathrm{interesting}} \times L$$



$$L = \frac{n_b N^2 f_{rep}}{4\pi\sigma_x^*\sigma_y^*} \times H_D$$

Depends on machine parameters

$$L \propto \frac{P_{\mathrm{beam}}}{A_{\mathrm{beam}}}$$

Beam power - *limited by cost: 30-40 MW*

Transfer beam area at the interaction point
Where are we limited?

Promise of future linear colliders
Collide beam of nanometre spot size (*nanobeams*)!

CLIC design values: σ_x = 60 nm - **σ_y = 0.7 nm** !!!

Feasibility must be assessed early on, before machine approval!

What has been achieved so far?

Human hair

↓

Water molecule!!

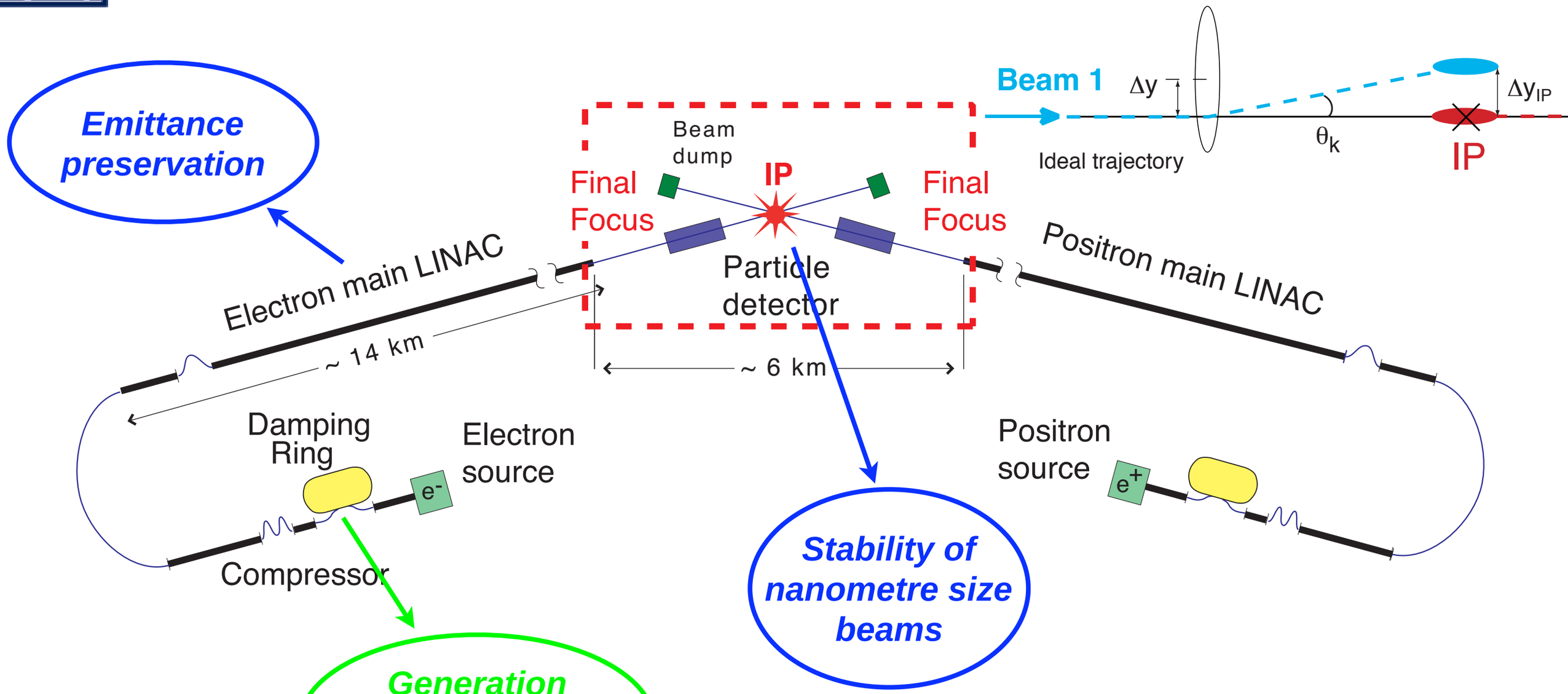
Machine	σ_x^* [nm]	σ_y^* [nm]	Tolerance [nm]	
LEP	300000	3000	~ 1000	*Achieved (colliding)*
SLC	1700	900	~ 300	
FFTB	~1000	70	- -	*Achieved (single beam)*
CLIC	**60**	**0.7**	**0.2**	*CLIC goal*
ATF2	3700	37	- -	*ATF2 goal (KEK)*

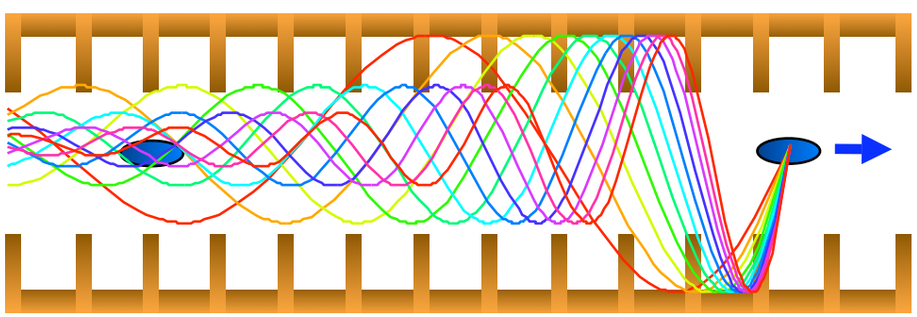
CLIC design goal → 1000 times smaller that the state-of-the-art of e^+e^- colliders

Stability tolerances are 1000 times more challenging!

Can we really achieve this goal?
Which are the implications of colliding nanobeams?

Path of the nano-beams in CLIC





- Correctly align 35 km of components
- Generate small emittance beams
- Preserve the small emittance along 2x15 km
- Reliably collide as small as a water molecule

How do we bring the beams in collision?

1. We pre-align the machine sufficiently well to send a pilot beam

CLIC requirement: **Static relative alignment of 10 µm** over distances of 100-200m

Then: Information from beam measurements can be used to optimize the position of quadrupoles and RF's!

2. We use a beam-based alignment procedure to align the various components to the optimum beam trajectory

Then: Start the optimization of the CLIC performance!

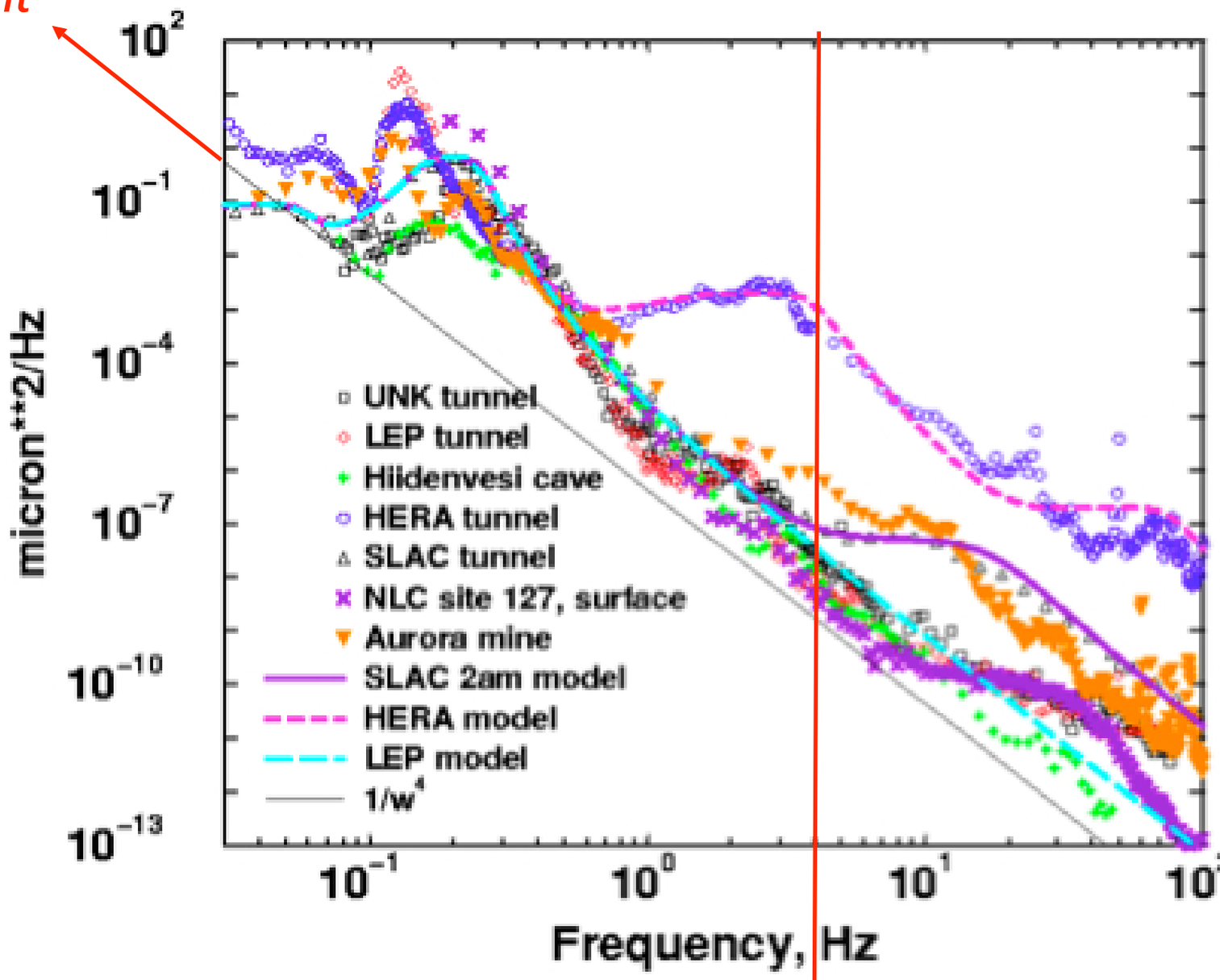
3. We optimize the luminosity performance with beam-based feedbacks with mechanical stabilization of components

CLIC requirement: Magnet stabilization at the **0.2 nanometre level**!!

This lecture addresses points 1 (Helène) and 2 (Stefano)

“Slow” and “fast” motions

Pre-alignment



Courtesy of A. Seryi

Correction with beam based feedbacks

Limited by f_{rep}

Slow motion

Fast motion

Mechanical stability of magnets

$$f_{cut} \approx f_{rep} / 25 = 4 \text{ Hz}$$

Conclusive remarks

- Luminosity production at CLIC will rely on colliding ***nanobeams***!

  σ_y = 0.7 nm *(size of a water molecule - 1000 smaller than state-of-the-art)*

- This imposes *unprecedented tolerances* on

  Machine alignment → **10 µm along 100-200 m**

  Component stability → **0.2 nm above 4 Hz**

- Beam-based feedbacks are used to correct "slow" perturbations
- "Fast" perturbations must be mechanically stabilized
- Beam repetition frequency (100-150 Hz) sets the scale

  → "Fast" motion: $f > f_{cut} \approx$ 4-6 Hz (based on experience)

- Alignment/stability issues are of interest for many machines

Some references

International workshops on these subjects

ICFA workshop at SLAC in 2000 (USA, CA).
ICFA-Nanobeam2002 workshop in Lausanne (Switzerland).
ICFA-Nanobeam2005 workshop in Tsukuba (Japan).
IWAA workshop series (8 editions from 1987 to 2004 - 9th this year at SLAC).

Overviews on vibration, measurement and alignment issues for accelerators

G. E. Fischer, “Ground Motion And Its Effects In Accelerator Design,” ***SLAC-PUB-3392-REV*** (1984).
J. Gervaise and E.J.N. Wilson, “High precision geodesy applied to CERN accelerators,” CAS school (1986).
M. Mayoud *et al.*, “Technological evolution of measurement tools. Dilemmas, illusions and realities,” IWAA1990 (1990).
G. E. Fischer, “Ground Motion - An Introduction for Accelerator Builders,” ***SLAC-PUB-5756*** (1992).

CLIC alignment studies

F. Becker, W. Coosemans, R. Pittin and I. Wilson, “An active pre-alignment system and metrology network for CLIC,” ***CLIC-NOTE-553*** (2003).
F. Becker *et al.*, “Consequences of perturbations of the gravity field on HLS measurements,” IWAA02 (2002).
H. Mainaud-Durand, “Micrometric alignment metrology: means, developments and applications”, **TS-2004-038** (2004).
H. Mainaud-Durand, “The CLIC alignment studies: past, present and future,” **TS-2005-028** (2005).

CLIC stabilization studies

S. Redaelli, “Stabilization of Nanometre-size particle beams in the final focus of the Compact LInear Collider (CLIC),” PhD thesis, UNIL Lausanne, CH (2003), also as ***CERN-AB-2004-026-ABP*** (2004).

Mathematical formulation for vibration analysis

Besides any book of spectral analysis:
“Zeroth-Order Design Report of the Next Linear Collider," Appendix C, ***SLAC-REPORT-474*** (2001).