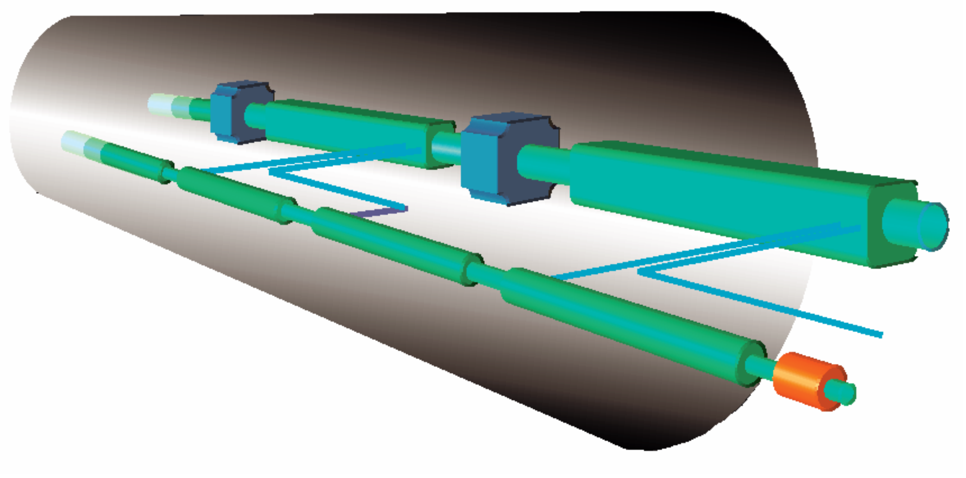
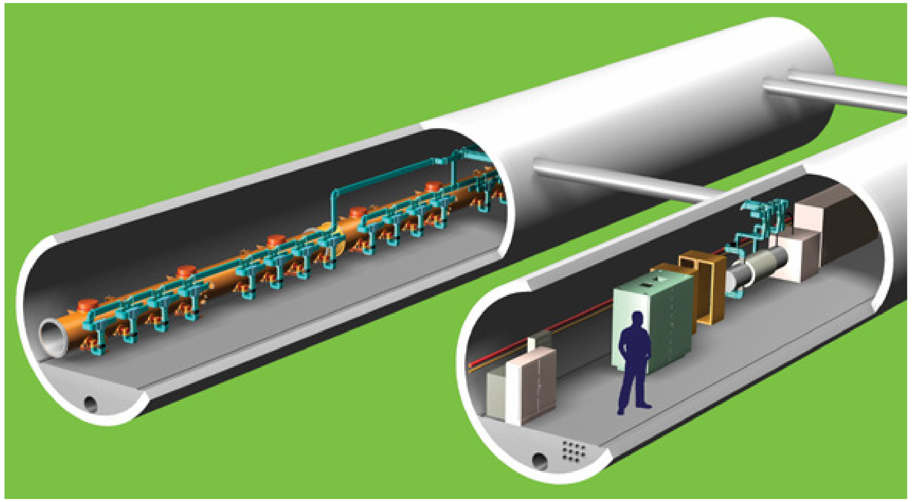
# *Future e+/e- Linear Colliders CLIC and ILC*





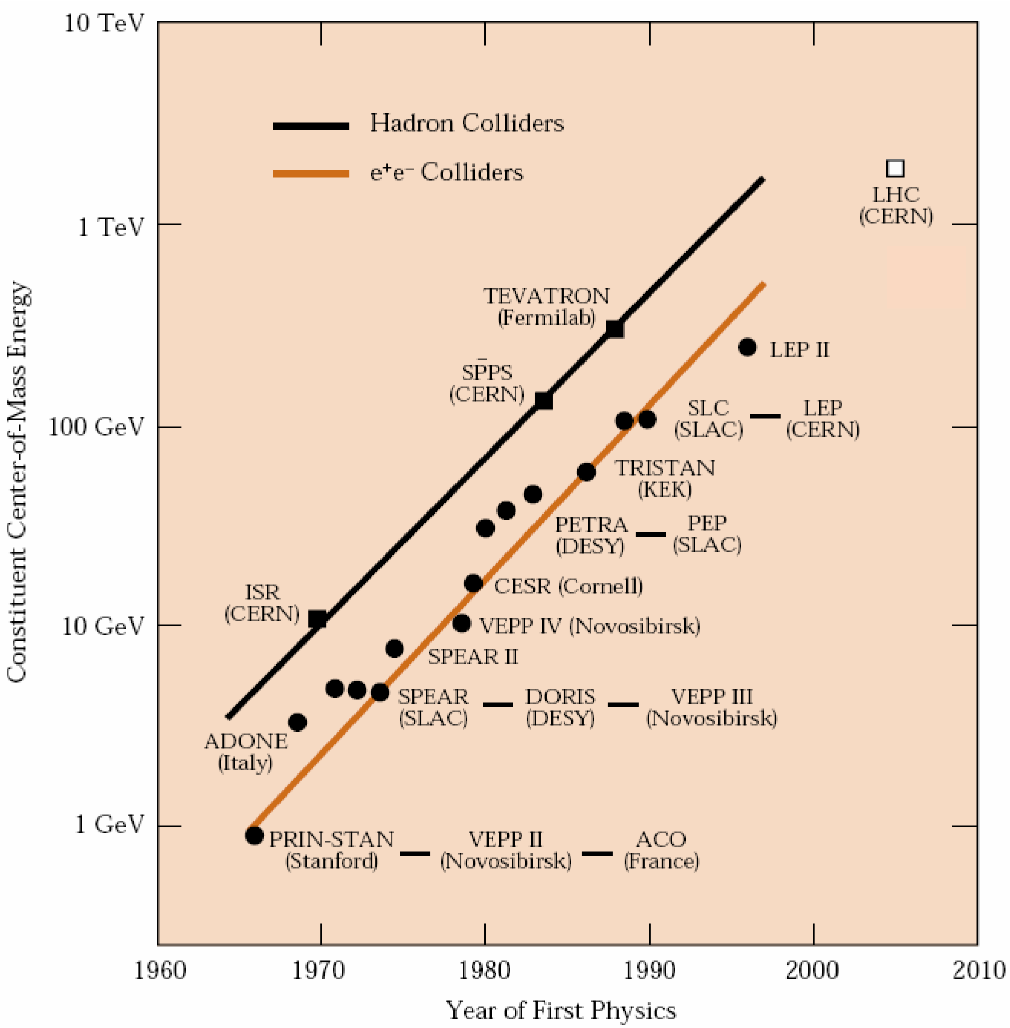
http://clic-study.web.cern.ch/CLIC-Study/

http://www.linearcollider.org/cms/

- **Linear Colliders in the HEP world-wide landscape**
- **The International Linear Collider (ILC)**
- **The Compact Linear Collider (CLIC)**
- **Status of R&D, plans and schedule for the future**
- **Synergies and Collaboration between CLIC and ILC**
- **Conclusion**

# *Lepton and Hadron facilities complementary for discovery and physics of new particles*

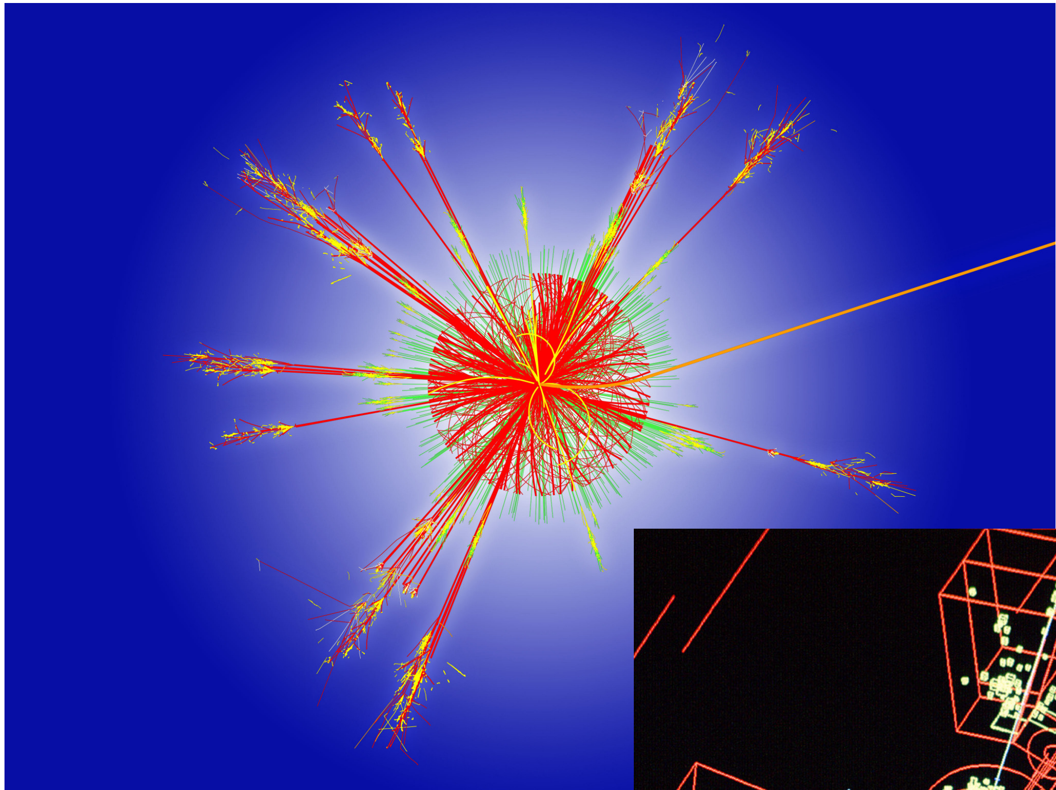
**Particle accelerators with colliding beams a long standing success story in particles discoveries and precision measurements**



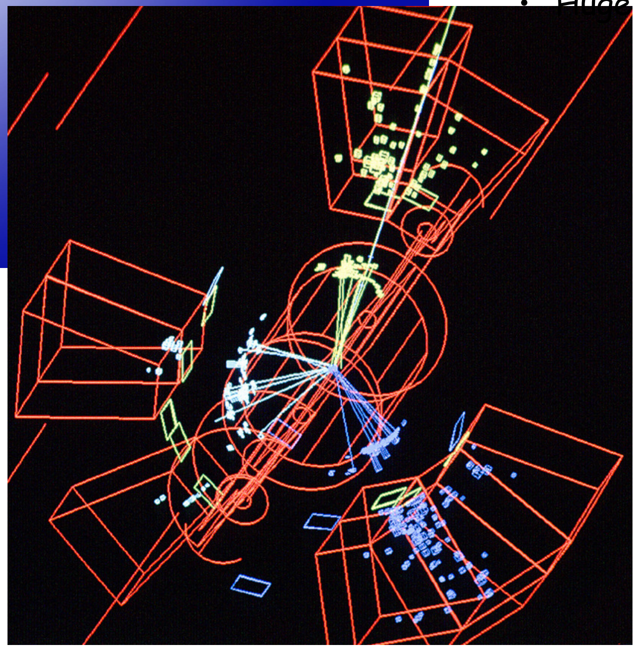

**Energy (<u>exponentially !</u>) increasing with time: a factor 10 every 8 years!**

- **Hadron Colliders** at the energy frontier as discovery facilities
- **Lepton Colliders** for precision physics
- **LHC** coming online from 2009
- Consensus for a future **lepton linear collider** to complement **LHC** physics

# Why e+/e- collisions



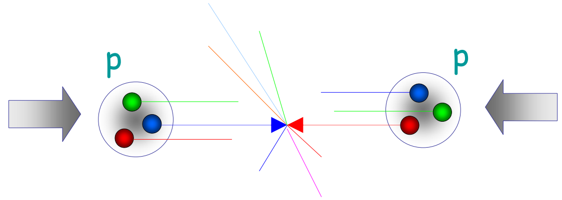
Simulated event of the collision of two protons in the ATLAS Experiment viewed along the beam pipe.



A 3-jet event probably originating from the decay of a Z0 into a quark and an antiquark together with a gluon as seen in the L3 detector

Hadron Colliders (p, ions):

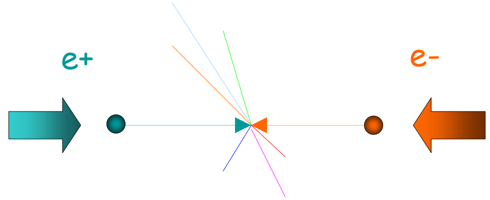
- Protons are composite objects




- Only part of proton energy available
- Can only use pt conservation
- Huge QCD background

Lepton Colliders:

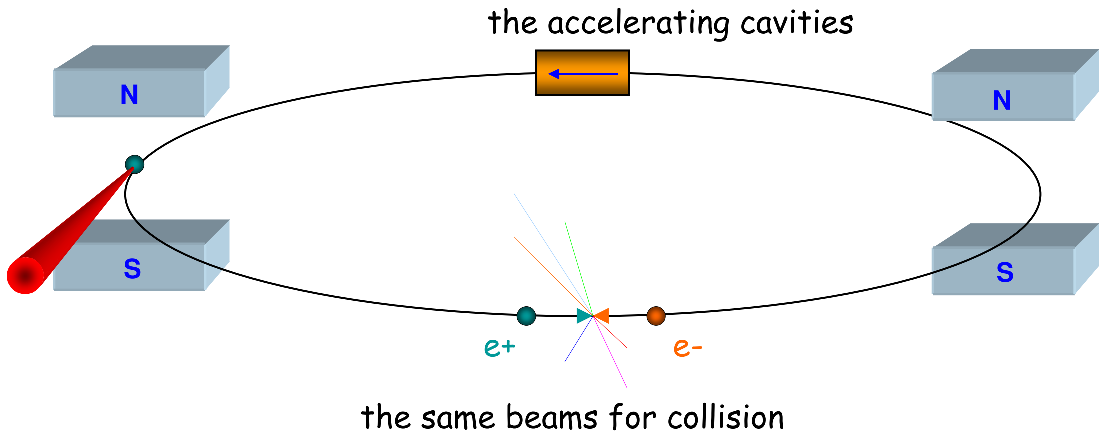
- Leptons are elementary particles




- Well defined initial state
- Momentum conservation eases decay product analysis
- Beam polarization

# Why a linear collider ?

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




However, charged particles emit synchrotron radiation in a magnetic field

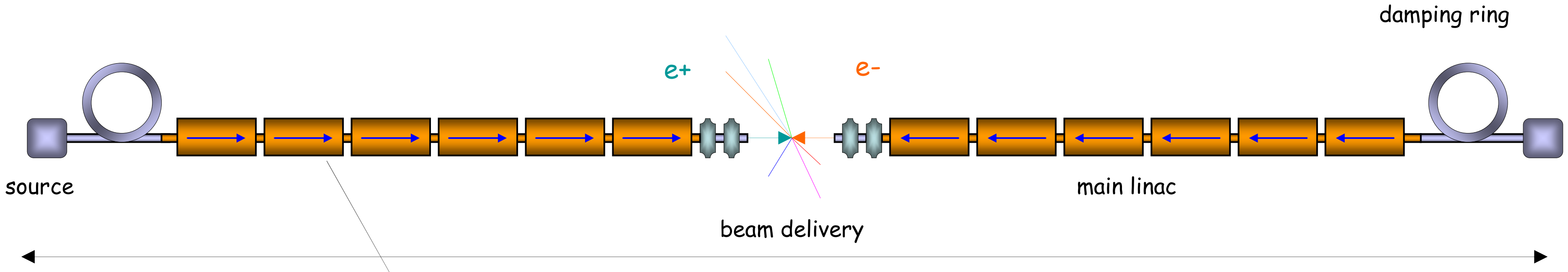
$$P = \frac{2}{3}\frac{r_e}{(m_o c^2)^3}\frac{E^4}{\rho^2} \Rightarrow \Delta E_{turn} = \frac{4}{3}\pi \frac{r_e}{(m_o c^2)^3}\frac{E^4}{\rho}$$

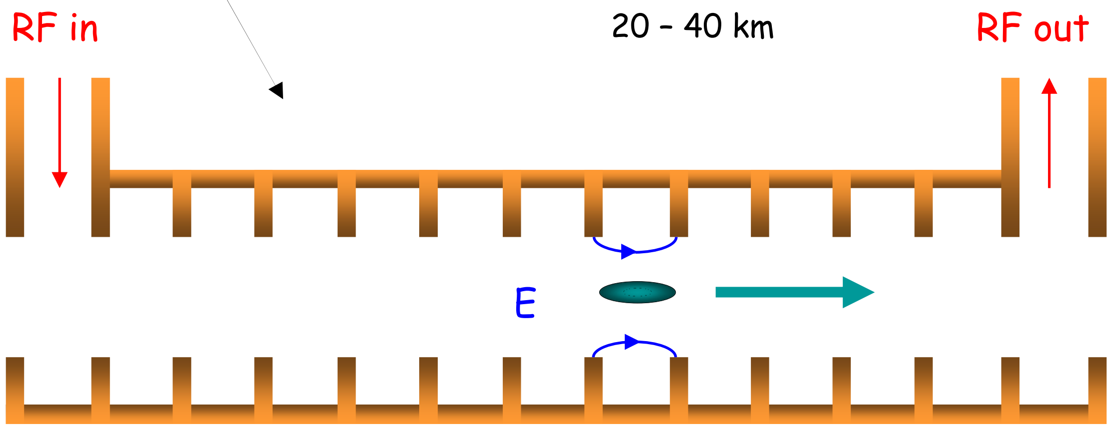
Much less important for heavy particles, like protons

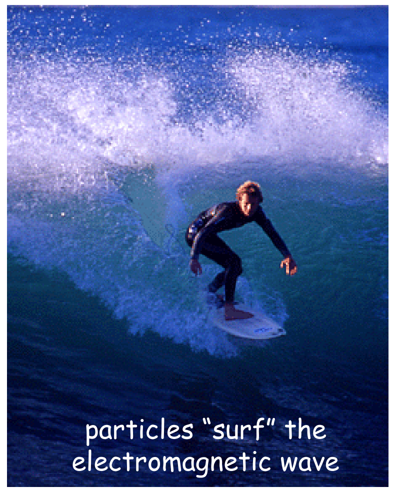
# LEP (27 km, 200 GeV $e^+ e^-$) @ CERN will probably remain the largest circular lepton collider ever built

# *A linear collider uses the accelerating cavities only once*

- Lots of them !
- Need a high accelerating gradient to reach the wanted energy in a "reasonable" length (total cost, cultural limit)





particles "surf" the electromagnetic wave

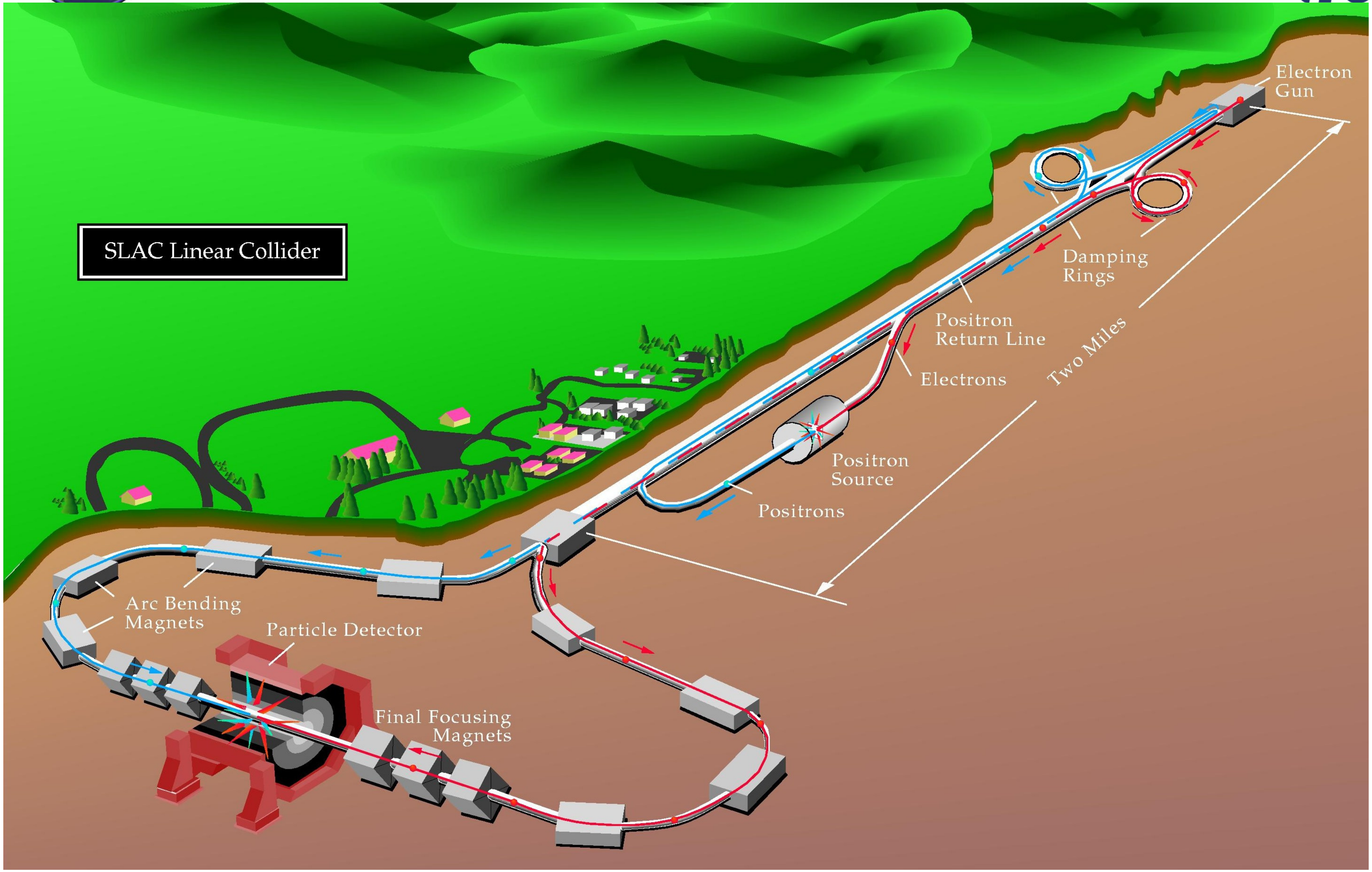
# What matters in a linear collider ?

Energy reach $$E_{cm} = 2 F_{fill} L_{linac} G_{RF}$$ → High gradient

Luminosity $$L = \frac{n_b N^2 f_{rep}}{4\pi\sigma^*_x\sigma^*_y} \times H_D \propto \frac{\eta^{AC}_{beam} P_{AC}}{\varepsilon_y^{1/2}} \frac{\delta_{BS}^{1/2}}{E_{cm}}$$ →

- **Beam acceleration:** MWatts of beam power with high gradient and high efficiency
- **Generation of small emittance:** Damping rings
- **Conservation of small emittance:** Wake-fields, alignment, stability
- **Extremely small beam sizes at Interaction Point:** Beam delivery system, stability

# The Linear Collider's father: SLC @ SLAC



# *Broad range exploration of technologies (1988 - 2004)*

| 500 GeV | TESLA | SBLC | JLC-S | JLC-C | JLC-X | NLC | VLEPP | CLIC |
|---|---|---|---|---|---|---|---|---|
| Techno. | Super Conduct | Norm Cond. | Norm. Cond. | Norm. Cond. | Norm. Cond. | Norm. Cond. | Norm. Cond. | Two Beams |
| $f$ [GHz] | 1.3 | 3.0 | 2.8 | 5.7 | 11.4 | 11.4 | 14.0 | 30.0 |
| $L\times10^{33}$ [$cm^{-2}s^{-1}$] | 6 | 4 | 4 | 9 | 5 | 7 | 9 | 1-5 |
| $P_{beam}$ [MW] | 16.5 | 7.3 | 1.3 | 4.3 | 3.2 | 4.2 | 2.4 | ~1-4 |
| $P_{AC}$ [MW] | 164 | 139 | 118 | 209 | 114 | 103 | 57 | 100 |
| $\gamma\varepsilon_y$ [$\times10^{-8}$m] | 100 | 50 | 4.8 | 4.8 | 4.8 | 5 | 7.5 | 15 |
| $\sigma_y^*$ [nm] | 64 | 28 | 3 | 3 | 3 | 3.2 | 4 | 7.4 |

# *World-wide consensus about a Linear Collider as the next HEP facility after LHC*

- **2001: ICFA recommendation of a world-wide collaboration to construct a high luminosity e+/e- Linear Collider with an energy range of 400 GeV/c upgradeable to at least 1 TeV**
- **2003: ILC-Technical Review Committee to assess the technical status of the 15 years of R&D on various technologies and designs of Linear Colliders**
- **2004: International Technology Recommendation Panel selected the Super-Conducting RF technology developed by the TESLA Collaboration for an International Linear Collider (ILC) in the TeV energy range**
- **2004: CERN council strong support for R&D addressing the feasibility of the CLIC technology to possibly extend Linear Colliders into the Multi-TeV energy range.**

# *CERN Council Strategy Group (Lisbon July 2006)*

## *The European strategy* *for particle physics*

*Particle physics stands on the threshold of a new and exciting era of discovery. The next generation of experiments will explore new domains and probe the deep structure of space-time. They will measure the properties of the elementary constituents of matter and their interactions with unprecedented accuracy, and they will uncover new phenomena such as the Higgs boson or new forms of matter. Long-standing puzzles such as the origin of mass, the matter-antimatter asymmetry of the Universe and the mysterious dark matter and energy that permeate the cosmos will soon benefit from the insights that new measurements will bring. Together, the results will have a profound impact on the way we see our Universe; European particle physics should thoroughly exploit its current exciting and diverse research programme. It should position itself to stand ready to address the challenges that will emerge from exploration of the new frontier, and it should participate fully in an increasingly global adventure.*

### *General issues*

1. European particle physics is founded on strong national institutes, universities and laboratories and the CERN Organization; *Europe should maintain and strengthen its central position in particle physics.*

2. Increased globalization, concentration and scale of particle physics make a well coordinated strategy in Europe paramount; *this strategy will be defined and updated by CERN Council as outlined below.*

### *Scientific activities*

3. The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; *the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.* A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; *to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.*

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.*

5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

6. Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; *Council will play an active role in promoting a coordinated European participation in a global neutrino programme.*

7. A range of very important non-accelerator experiments take place at the overlap between particle and astroparticle physics exploring otherwise inaccessible phenomena; *Council will seek to work with ApPEC to develop a coordinated strategy in these areas of mutual interest.*

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.*

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# Linear Collider Physics Goals
# (ICFA- ILCSC parameters study)

- $E_{cm}$ adjustable from 200 – 500 GeV
- Luminosity → $\int Ldt = 500\ fb^{-1}$ in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%
- The machine must be upgradeable to 1 TeV

**An ILC Reference Design Report has been published which meets the required Physics goals**

# ILC Reference Design Reports

- Reference Design Report (4 volumes)


Executive Summary

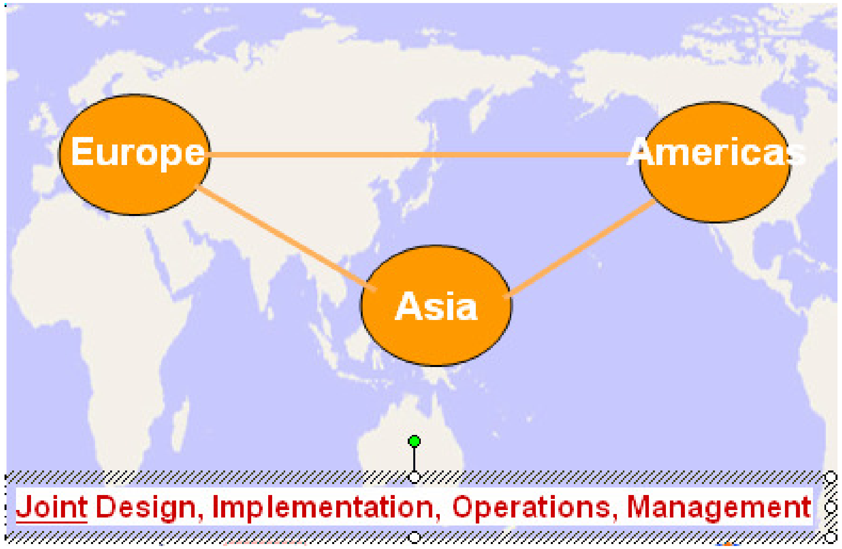

Physics at the ILC


Accelerator


Detectors

# *ILC Reference Design Report (RDR)*
# *A world-wide effort*

## ~700 Contributors from 84 Institutes



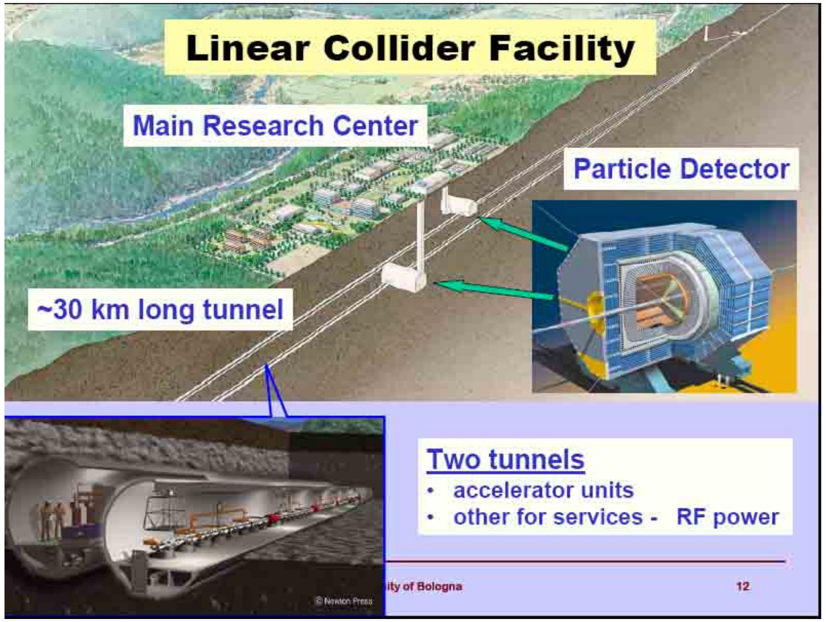


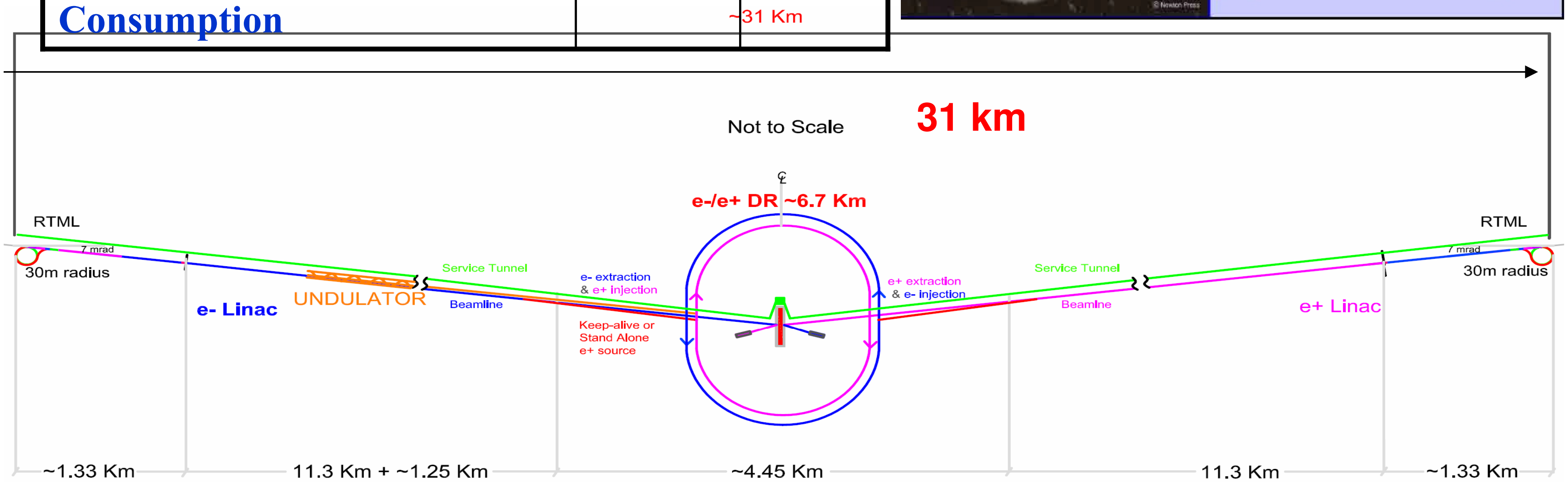

**Reference Design Report:** http://www.slac.stanford.edu/grp/ilc/positron/RDR-CD/
**Companion:** http://www.linearcollider.org/ilc_gatewayquantumuniverse_draft.pdf

# ILC @ 500 GeV

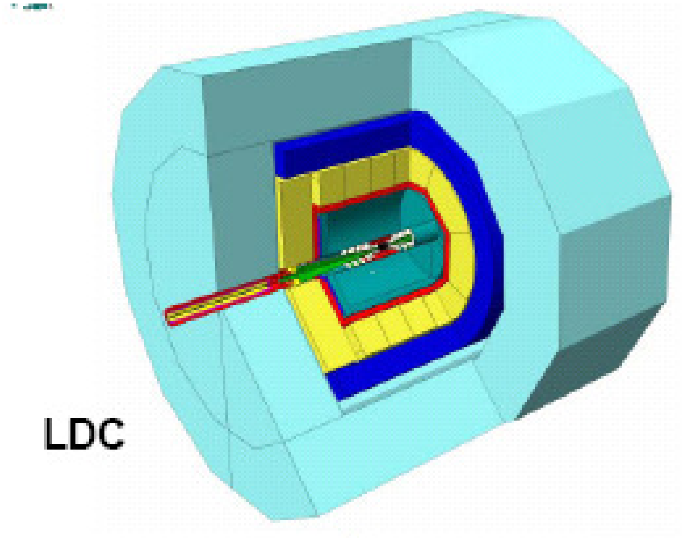
## ILC web site: http://www.linearcollider.org/cms/

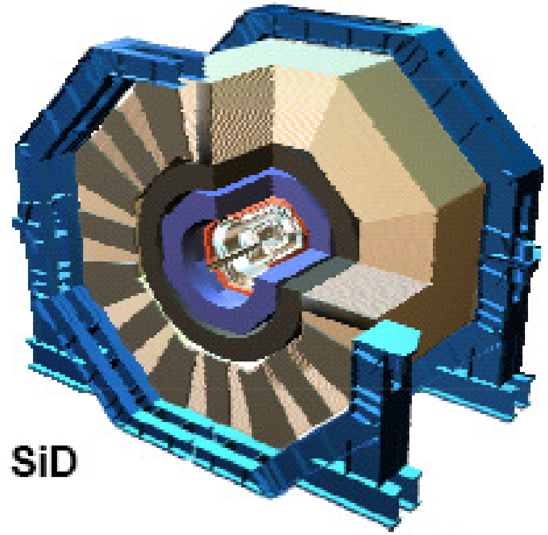
| | | |
|---|---|---|
| Max. Center-of-mass energy | 500 | GeV |
| Peak Luminosity | ~2x10$^{34}$ | cm$^{-2}$s$^{-1}$ |
| Beam Current | 9.0 | mA |
| Repetition rate | 5 | Hz |
| Average accelerating gradient | 31.5 | MV/m |
| Beam pulse length | 0.95 | ms |
| Total Site Length | 31 | km |
| Total AC Power Consumption | ~230 | MW |

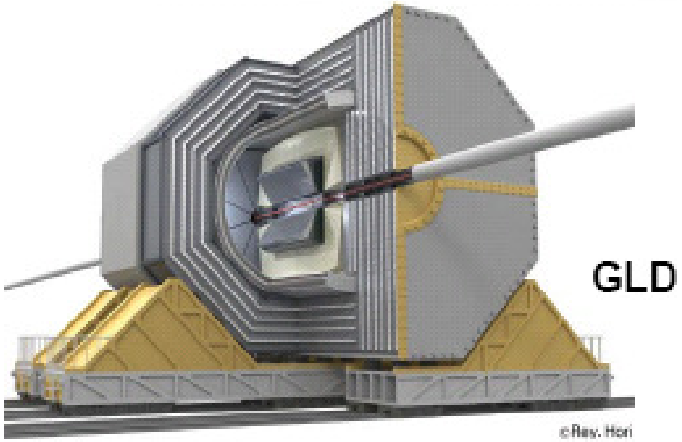


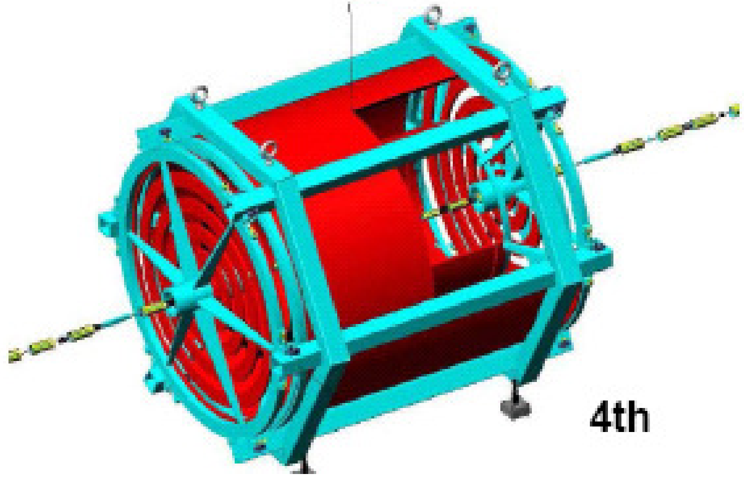



# Detector Concepts Report

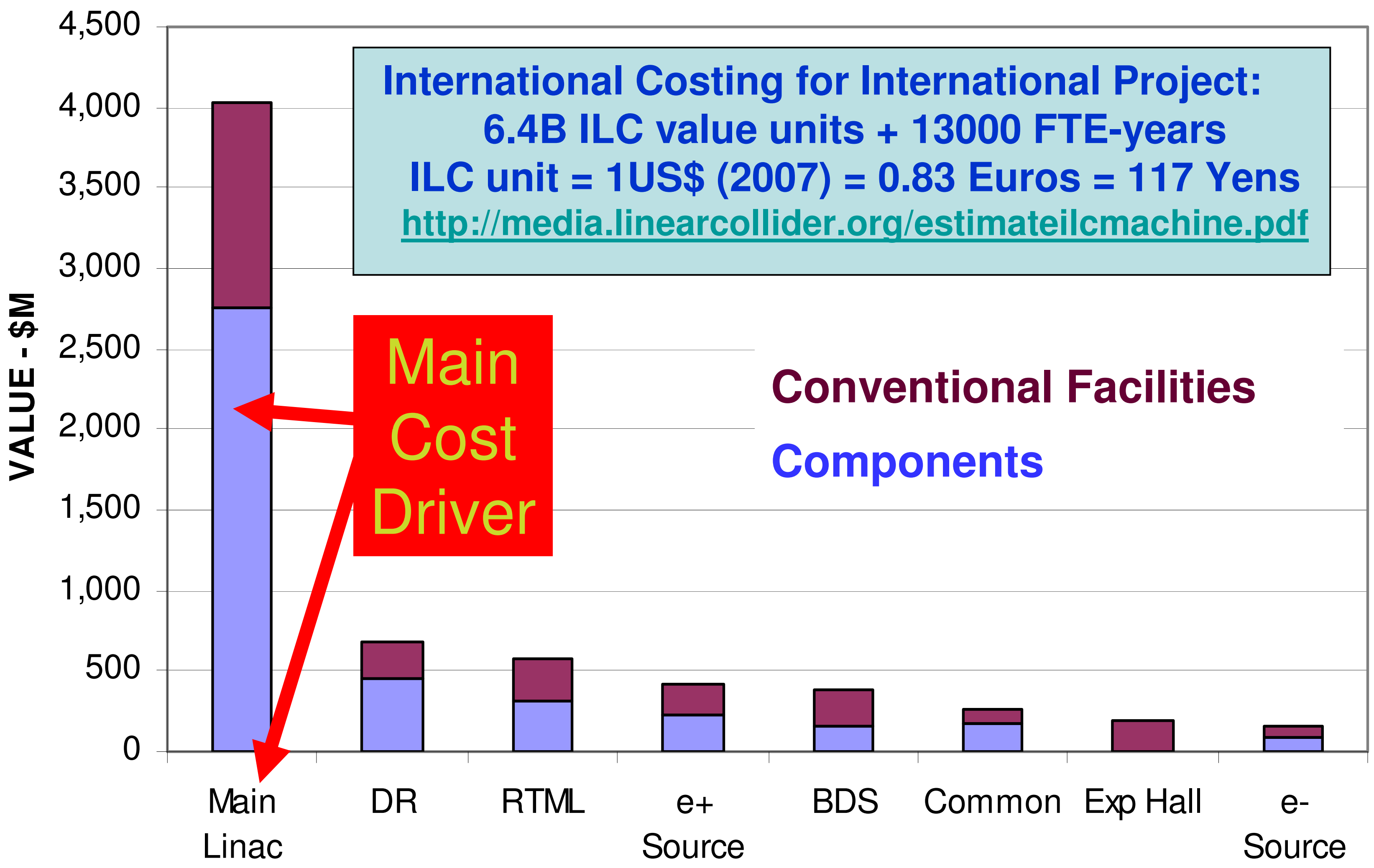


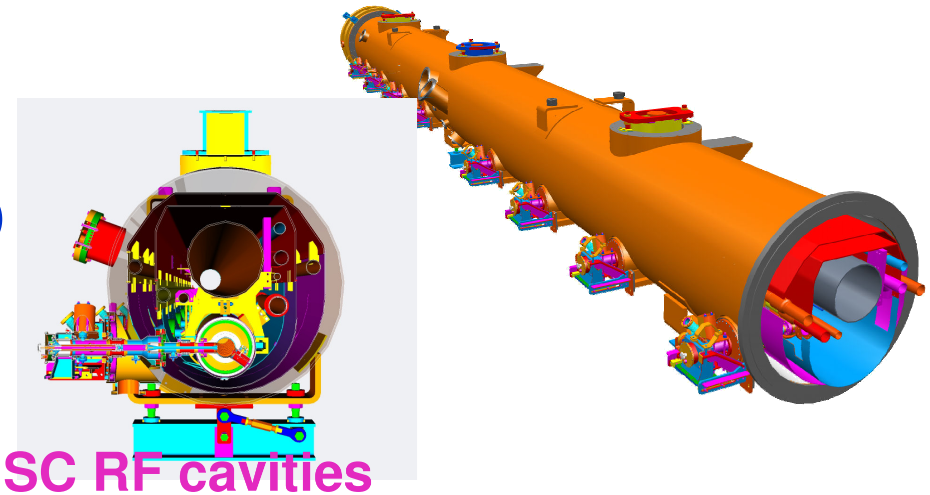
# ILC Value – by Area Systems



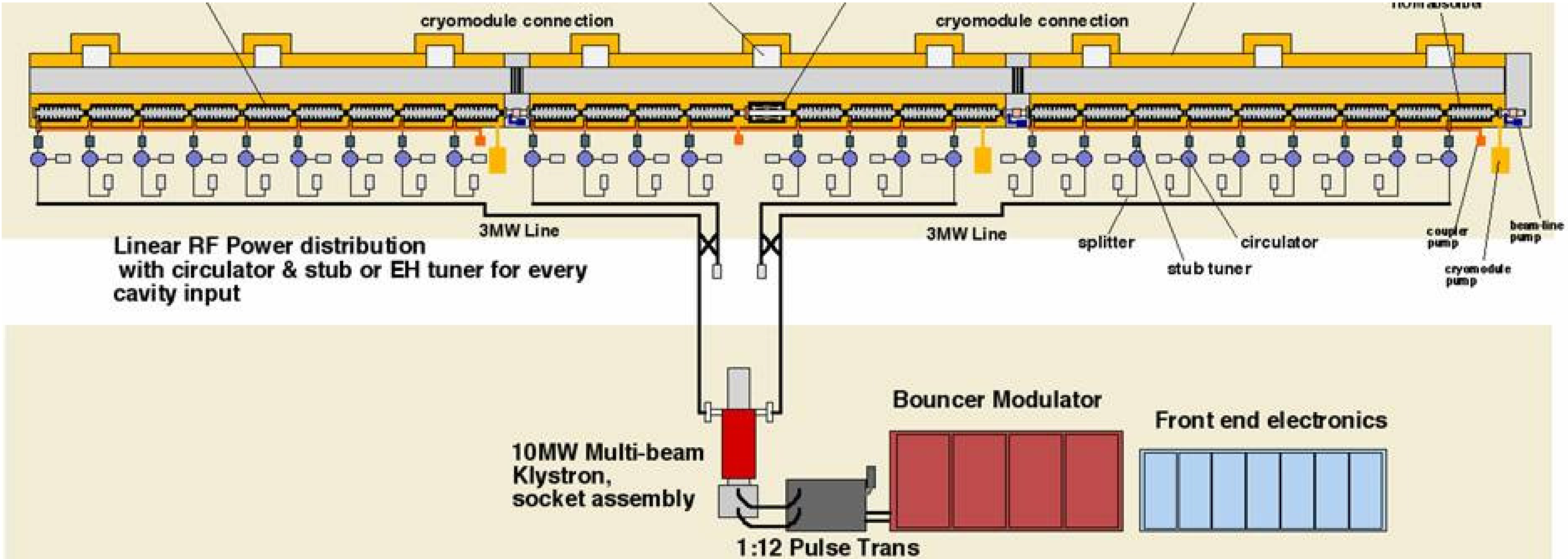
# *Main Linac RF Unit Overview*

**560 RF units each one composed of:**

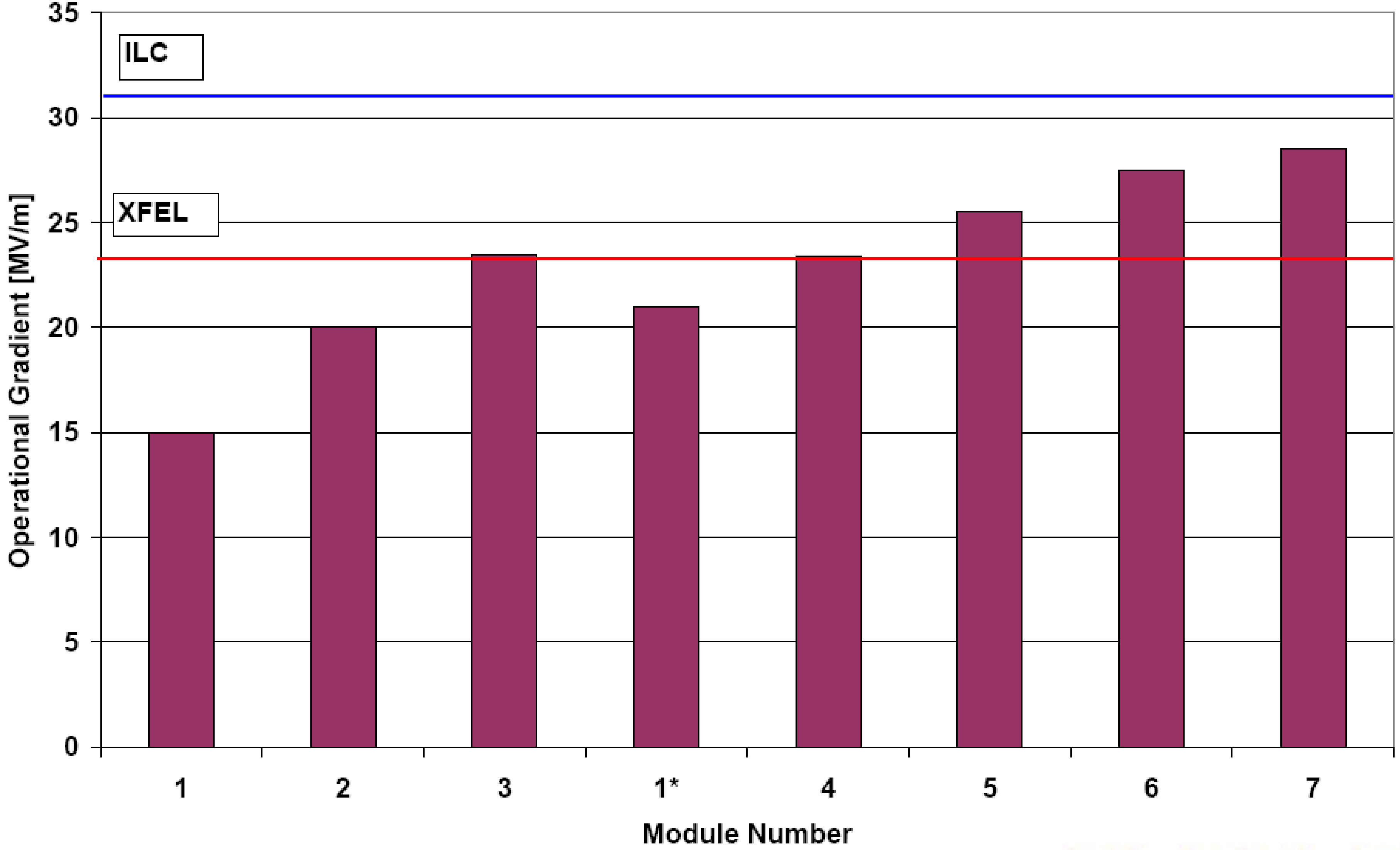
- **1 Bouncer type modulator**
- **1 Multibeam klystron (10 MW, 1.6 ms)**
- **3 Cryostats (9+8+9 = 26 cavities)**
- **1 Quadrupole at the center**



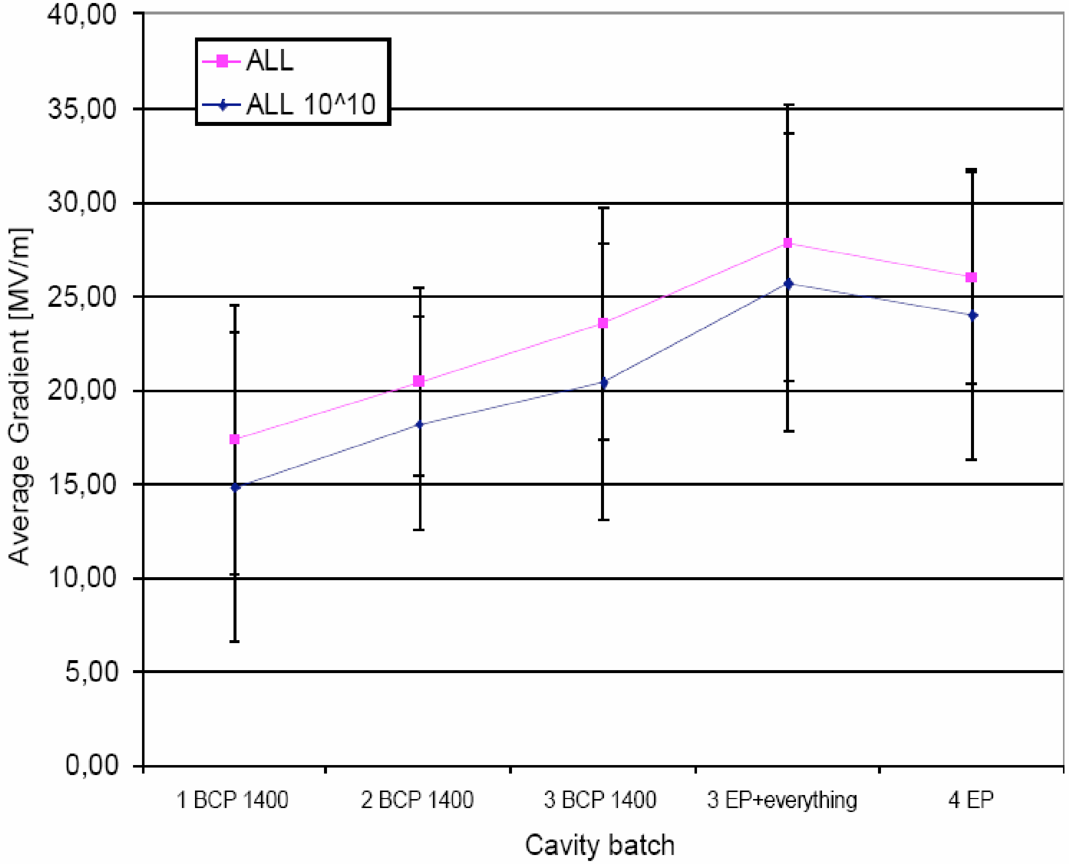
**Total of 1680 cryomodules and 14 560 SC RF cavities**

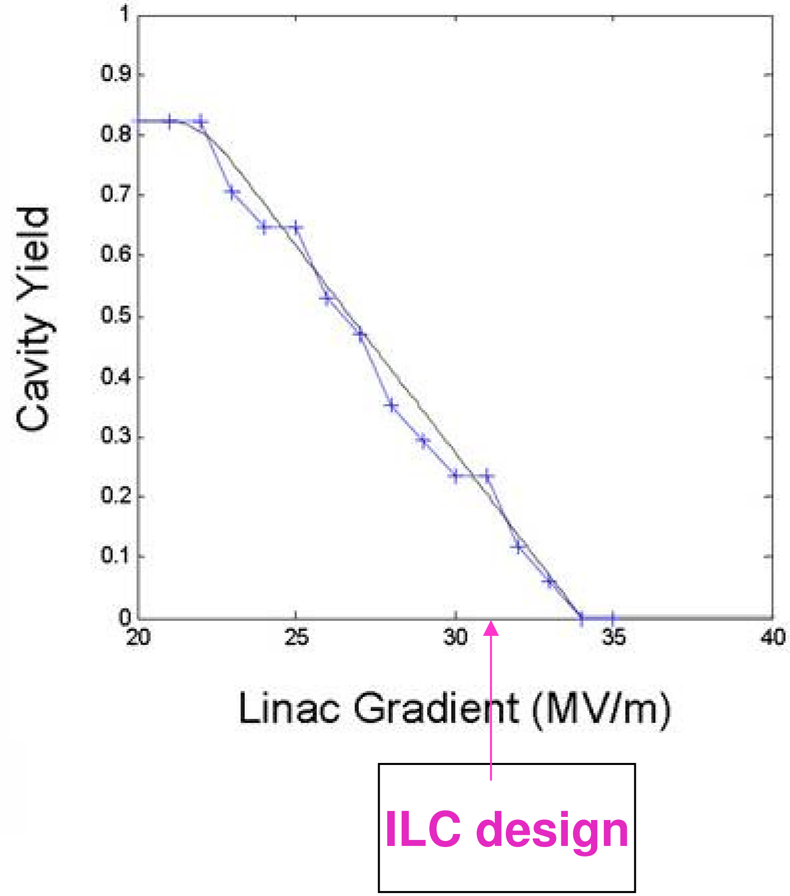


# TESLA Module Results



# *Major issue:*
# *Large spread of achieved accelerating gradients*

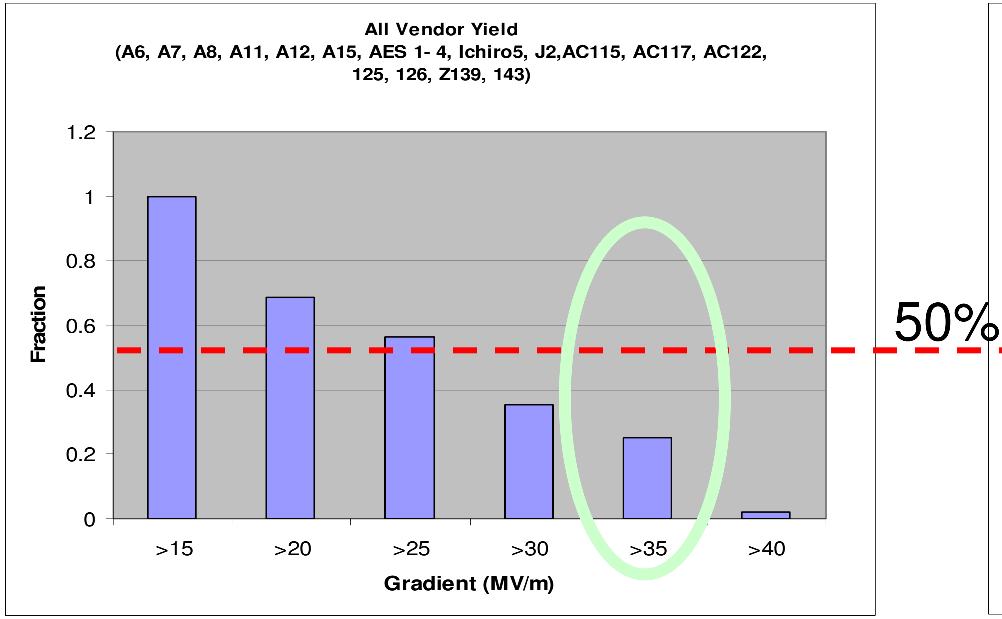


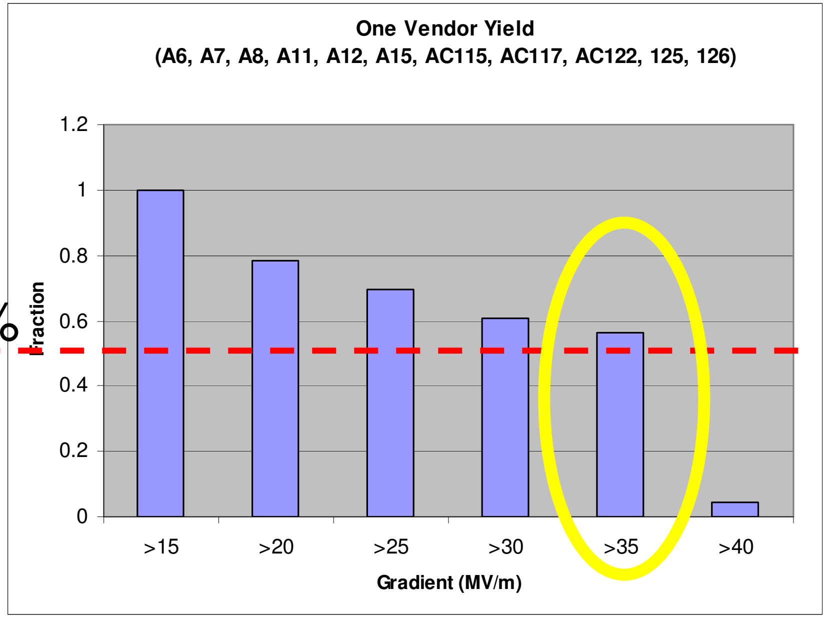




With the presently available technology **average 28 MV/m:**
**Cost increase ~7 %**

## *Combined Yield of Jlab and DESY Tests Reported at TTC (Delhi, Oct. 2008), summarized by H. Padamsee*

| 48 Tests, 19 cavities | 23 tests, 11 cavities |
|---|---|
| ACCEL, AES, Zanon, Ichiro, Jlab | One Vender |




Yield 50 % at 35 MV/m being achieved by cavities with a qualified vender !!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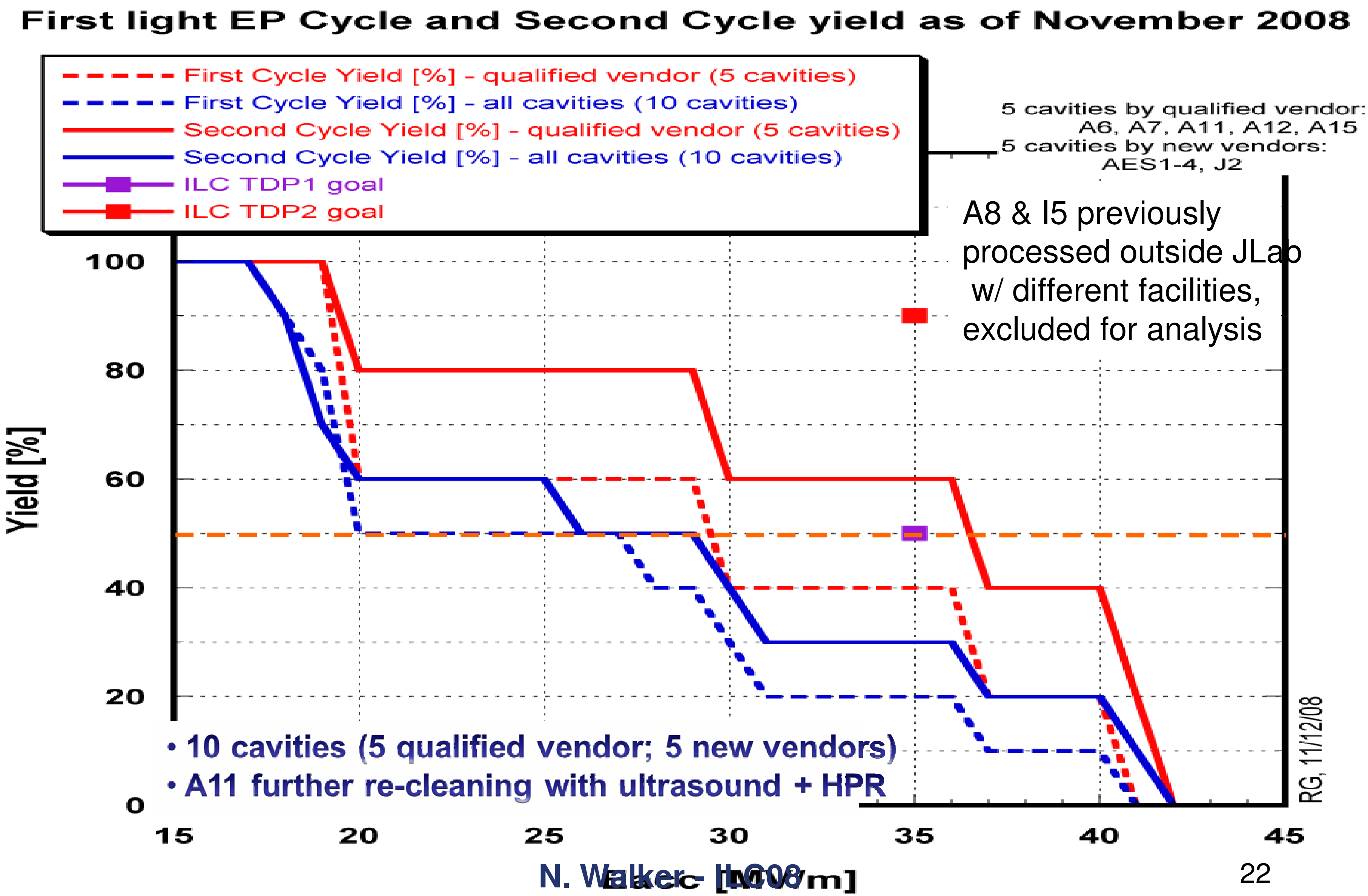
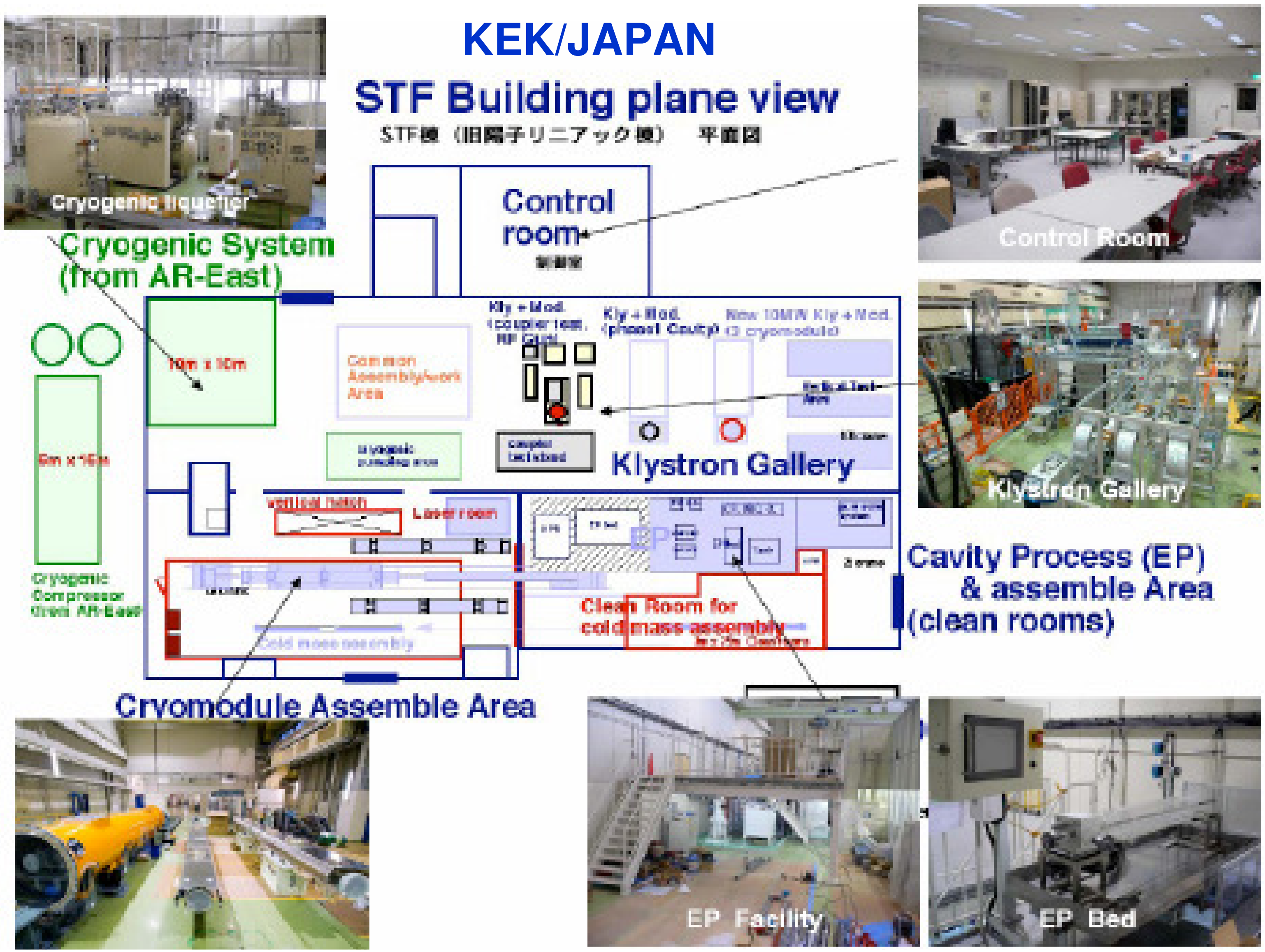
# *Yield Curve – 1st pass and 2nd pass*

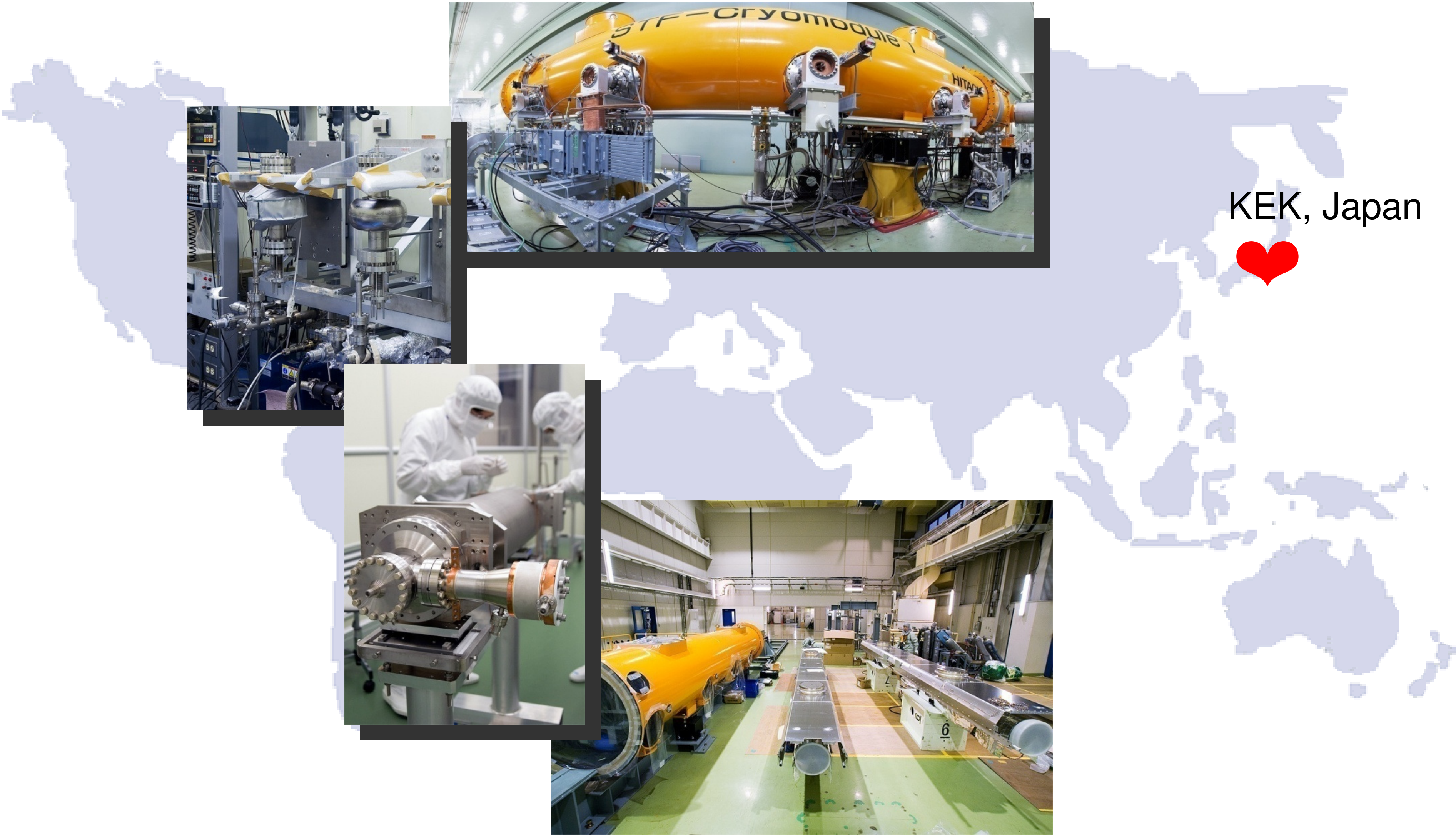
***summarized by R. Geng***



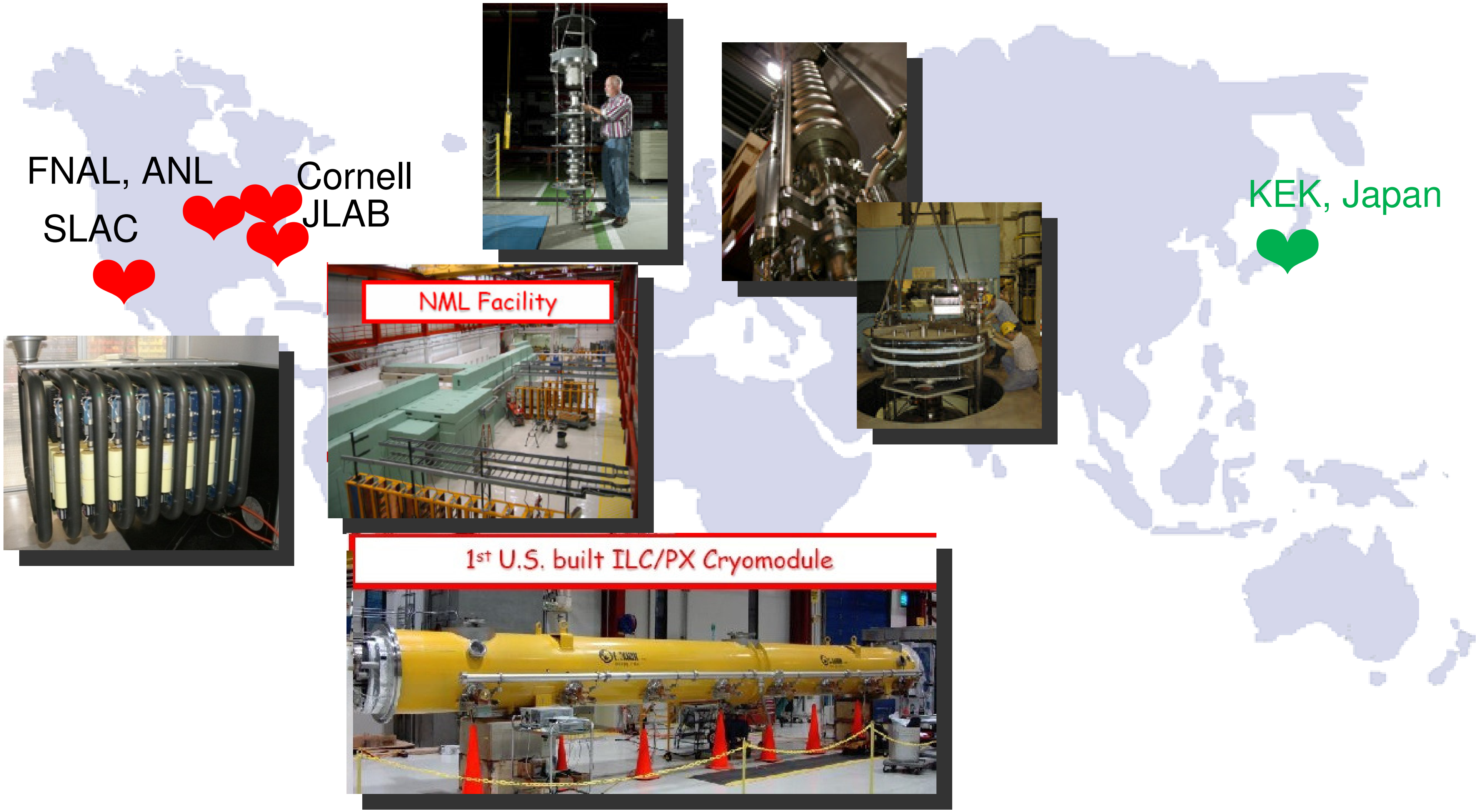
# *Ambitious SCRF test facilities in Asia, America and Europe*



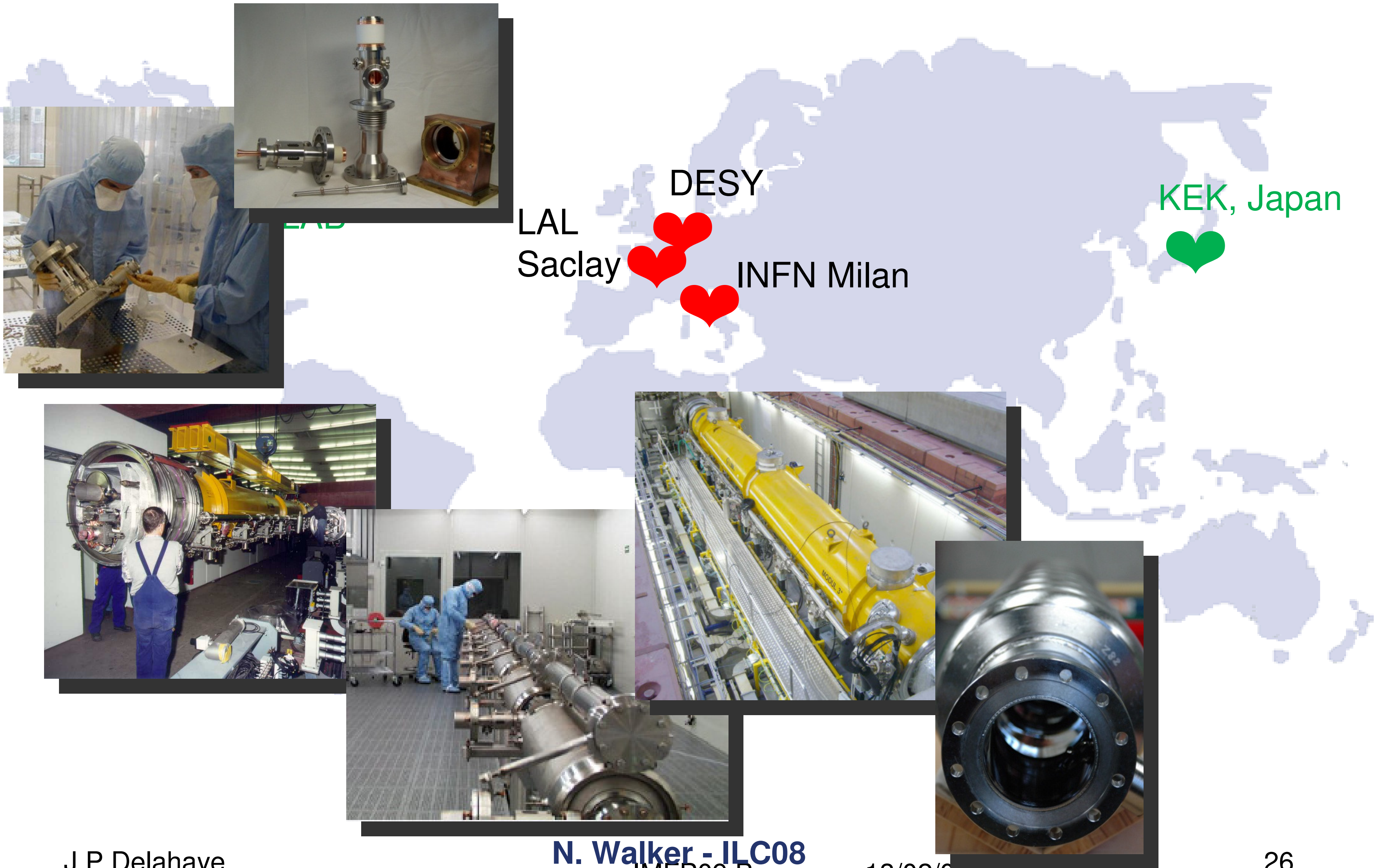
# Global SCRF Technology



# *Global SCRF Technology*



# Global SCRF Technology



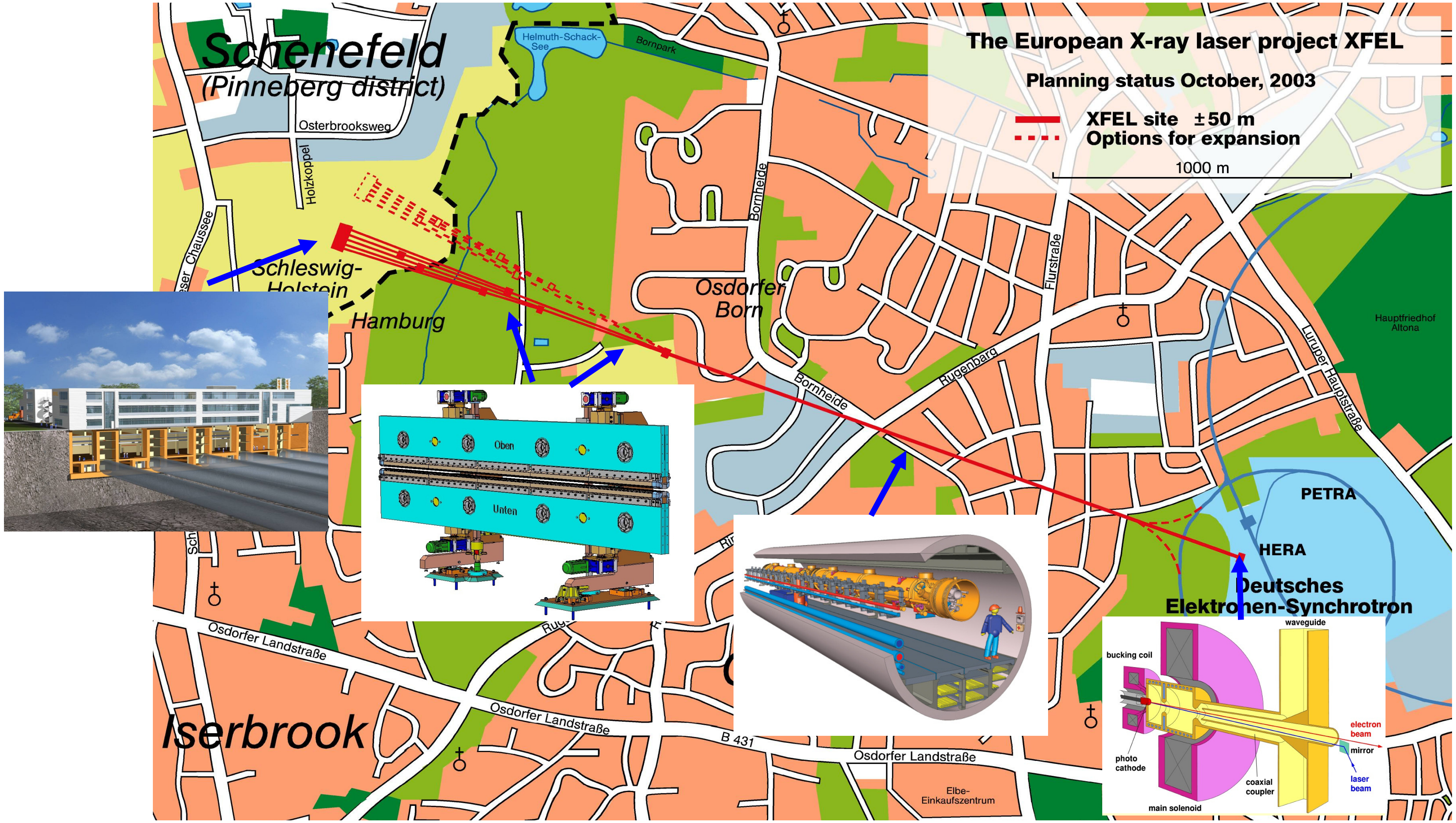

N. Walker - ILC08

# *Global SCRF Technology*


**Emerging SRF**

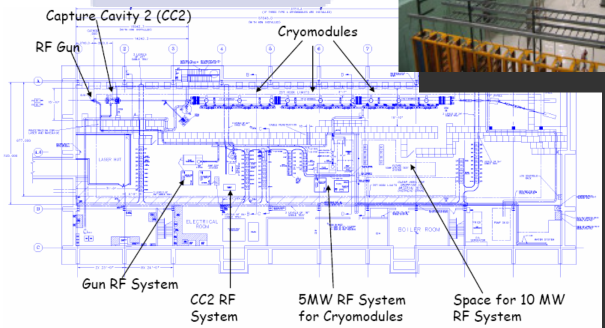
# X-FEL at DESY
# a 10% ILC and a GEuros Test Facility!

3.4km



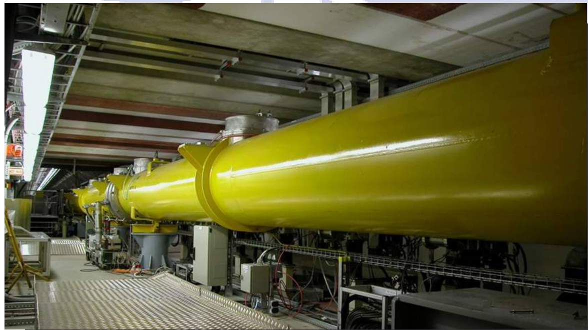
# SRF Test Facilities

FNAL

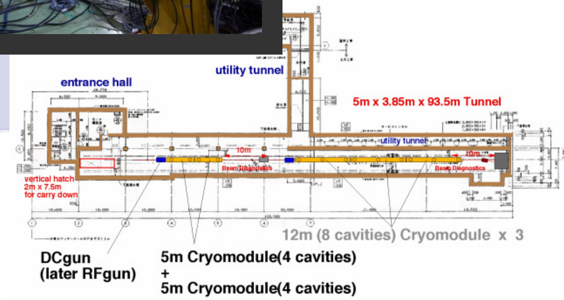

NML facility
Under construction
first beam 2010
ILC RF unit test

DESY



TTF/FLASH
~1 GeV
ILC-like beam
ILC RF unit
(* lower gradient)

KEK, Japan

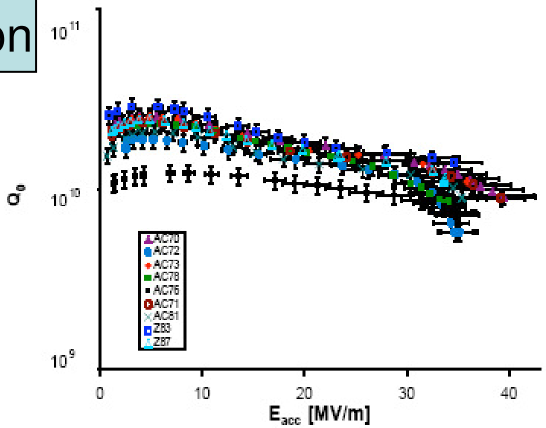



STF (phase I & II)
Under construction
first beam 2011
ILC RF unit test

# Impressive R&D and progress of SCRF cavities performances

Derived From TESLA Collaboration

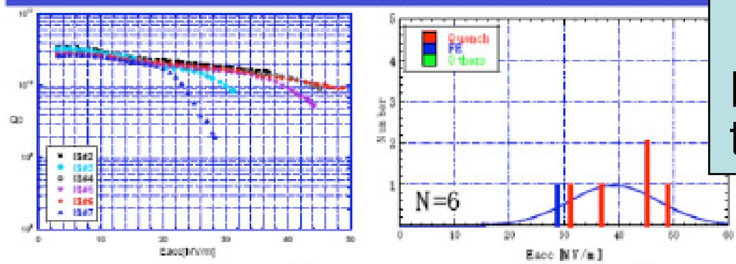
TESLA Nine-Cells: (Proof-of-Principle)
Best tests of 9 best Cavities (Vertical Test Results)




60mm-Aperture Re-Entrant Cavity, 58 MV/m!

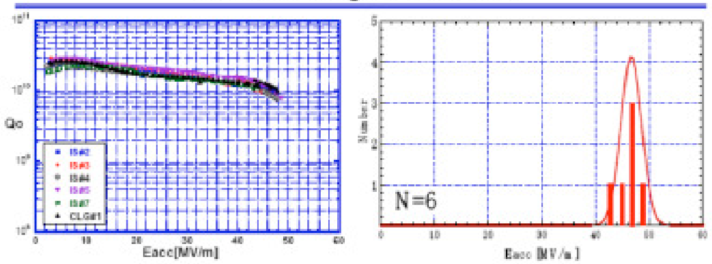
KEK/Cornell Collaboration

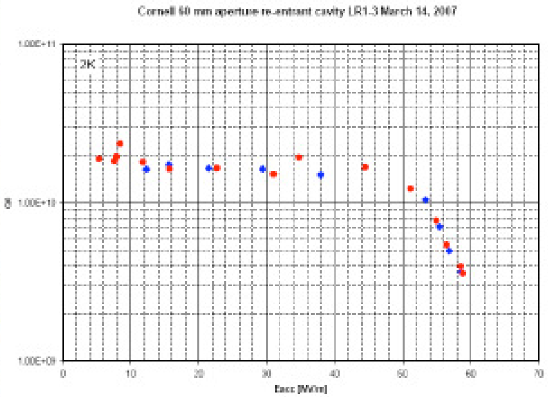
(A) CBP+CP+Anneal+EP(80μm) +HPR+Baking(120C*48hrs) K. Saito et al.



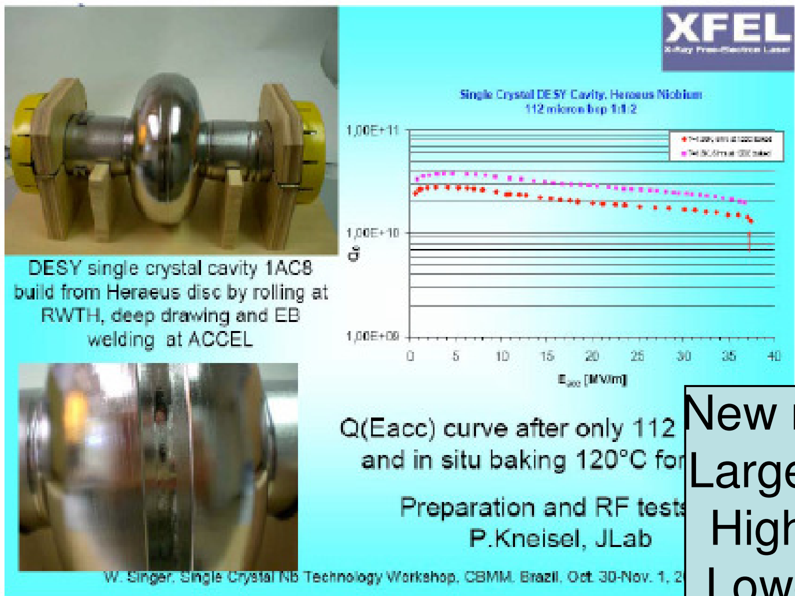

New preparation techniques

(D) +EP(20μm)+EP(3μm, fresh, closed) +HPR+Baking (120C*48hrs) K. Saito et al.



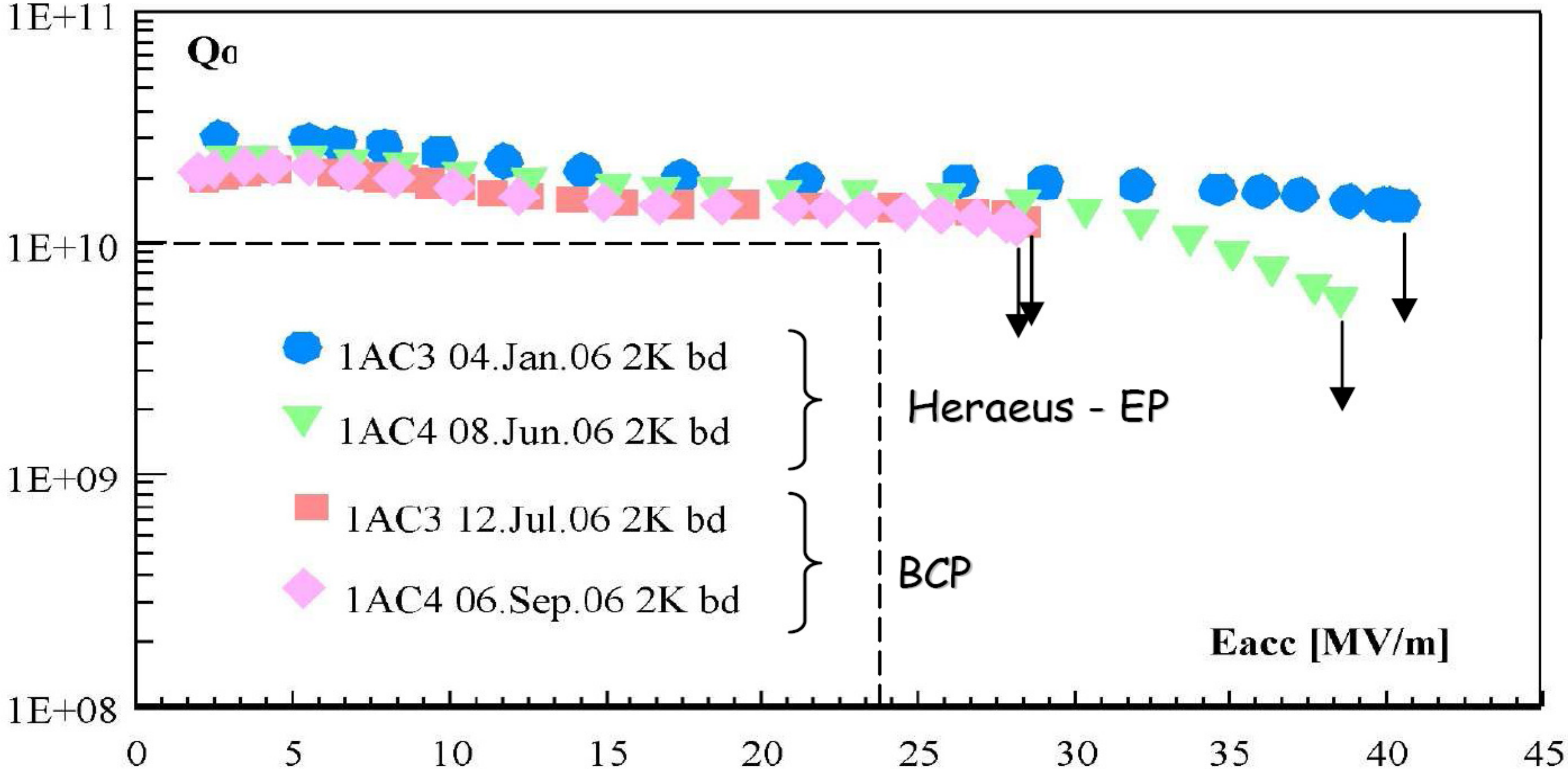




New cavity shapes




New material
Large grains
Higher perf
Lower cost

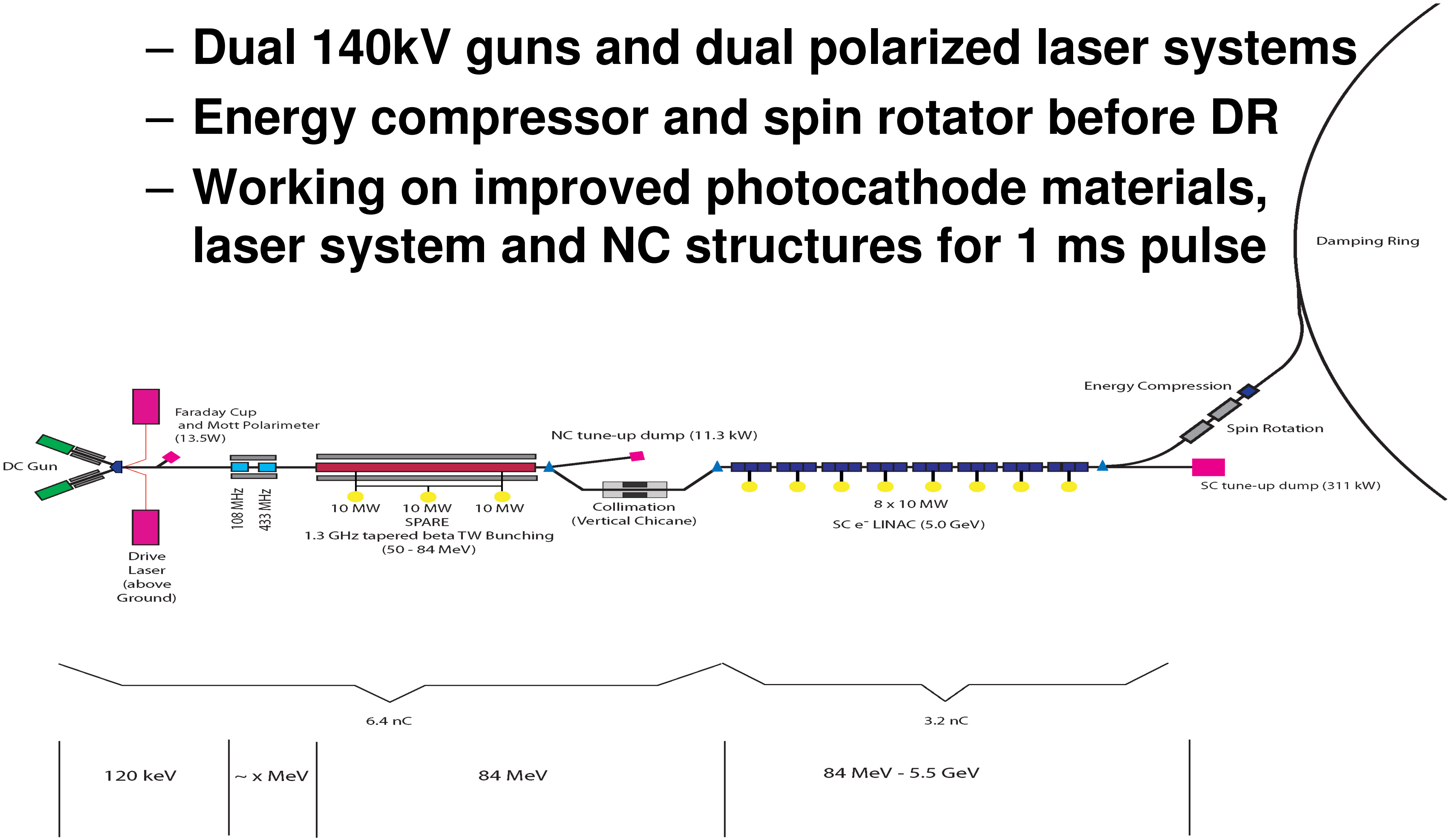
# *Large Grain Material: EP and BCP*




D. Reschke et al.

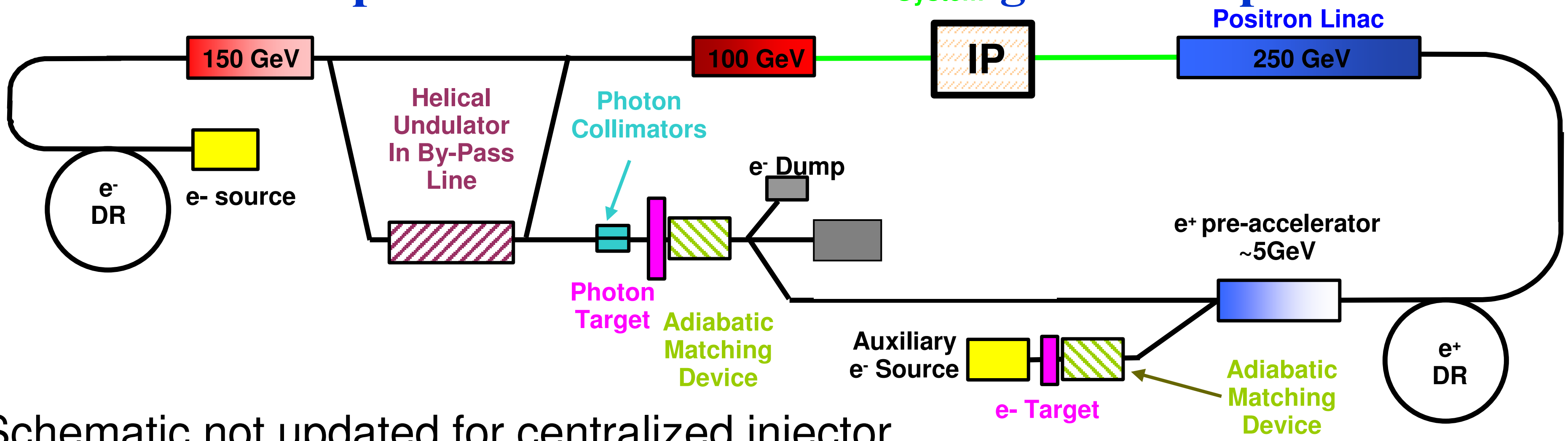
# ILC Polarized Electron Source

– Dual 140kV guns and dual polarized laser systems
– Energy compressor and spin rotator before DR
– Working on improved photocathode materials, laser system and NC structures for 1 ms pulse



# Positron Source

- **Undulator-based positron source**
  - ~150 meter undulator with K = 0.9; $\lambda$ = 1.2 cm; 6mm aperture
  - Easy upgrade to produce polarized positrons
- **Undulator located at 150 GeV in electron linac**
  - Eases operational issues when changing IP energy
- **Two e+ production stations including 10% keep alive**




Schematic not updated for centralized injector

# Damping Ring

Generation of ultra-low emittances

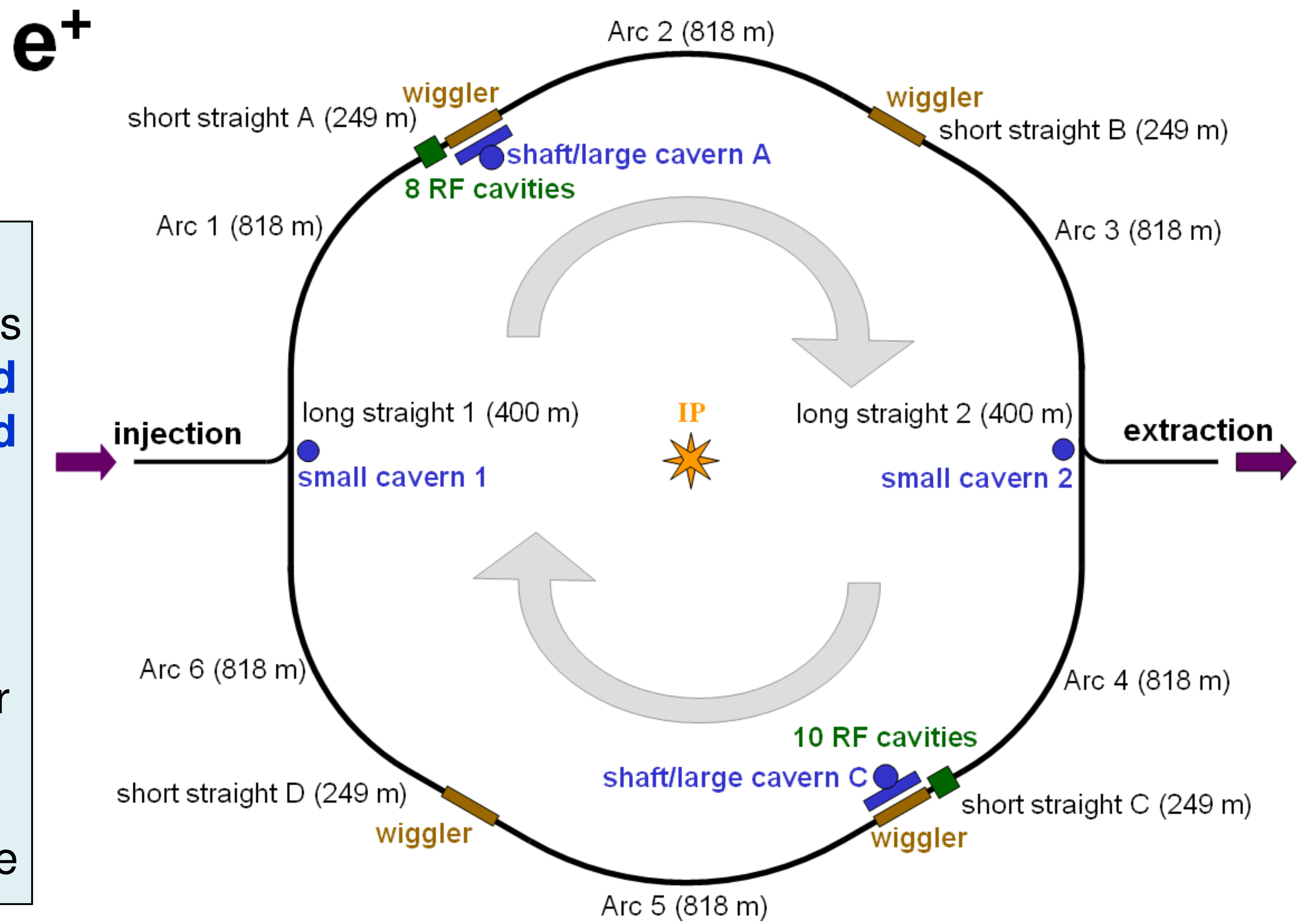
$\varepsilon_x = 8 \times 10\text{-}6$ m-rad

$\varepsilon_y = 2 \times 10\text{-}8$ m-rad

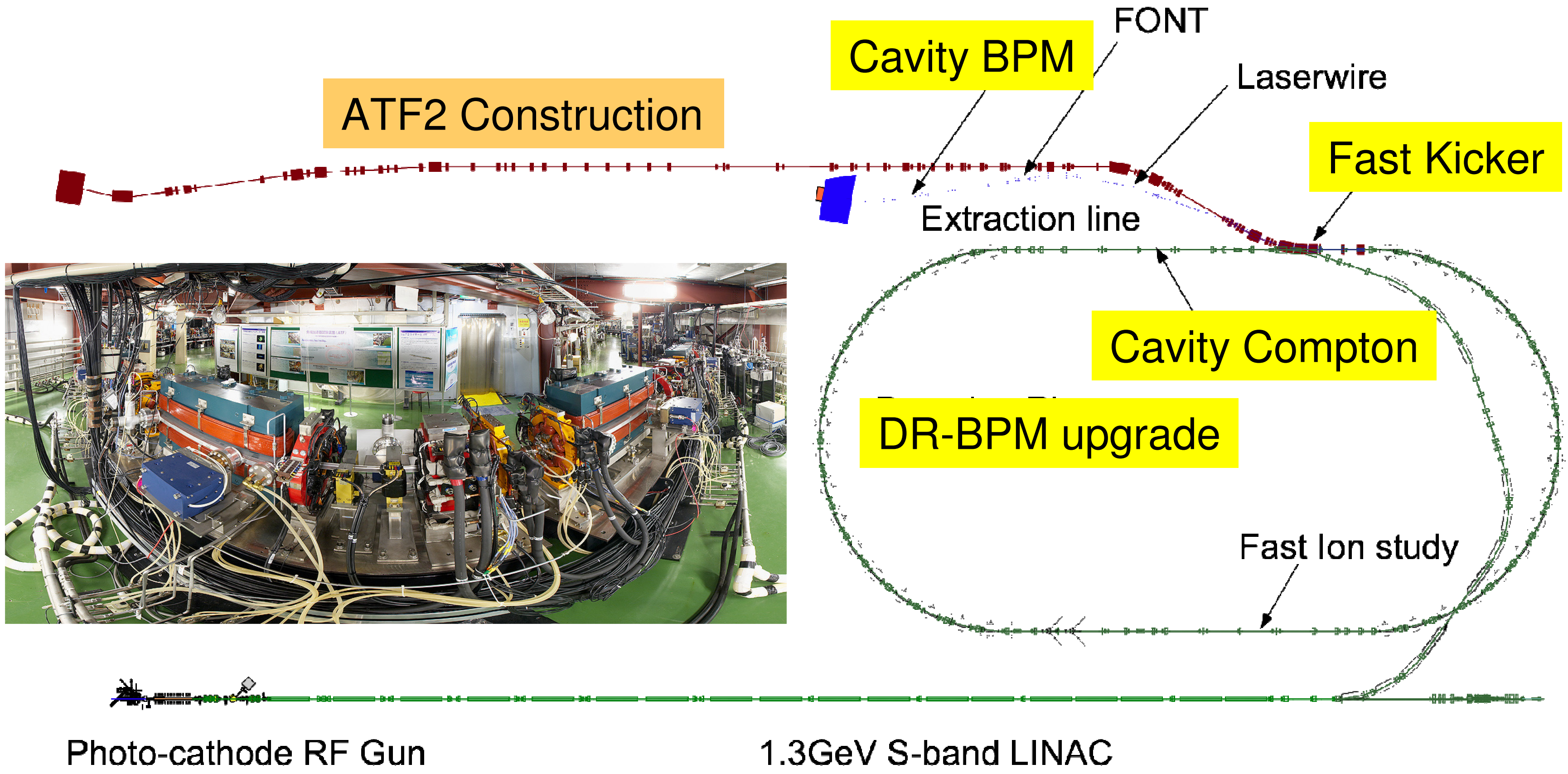
Large number of bunches

Short Inj/Ext kicker risetime

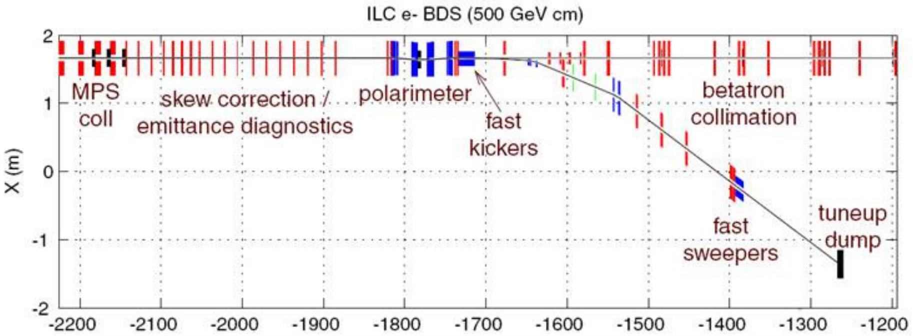
6 km circumference

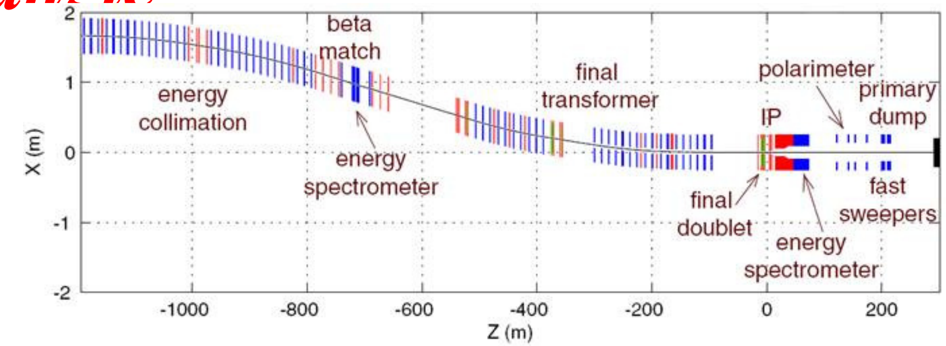


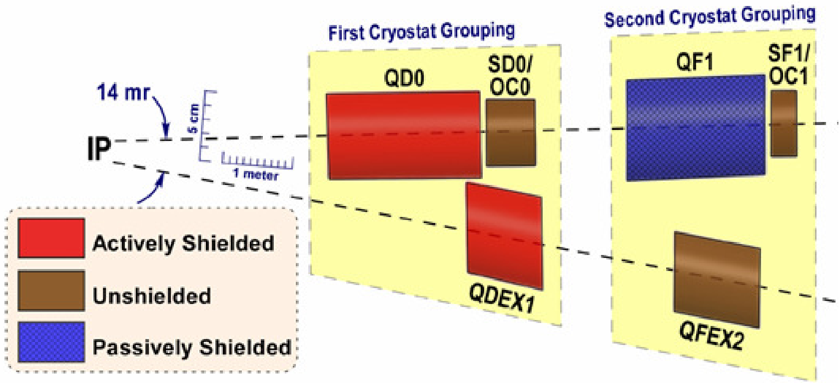
# KEK ATF - Layout

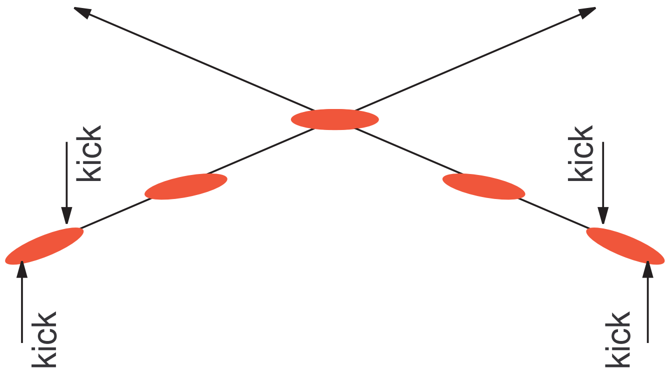


# *2.5 km Beam Delivery System with single Interaction Region and 14 mrad crossing angle*




**Focusing to very small beam sizes:**

**Sx, Sy = 640, 5.7 nm**

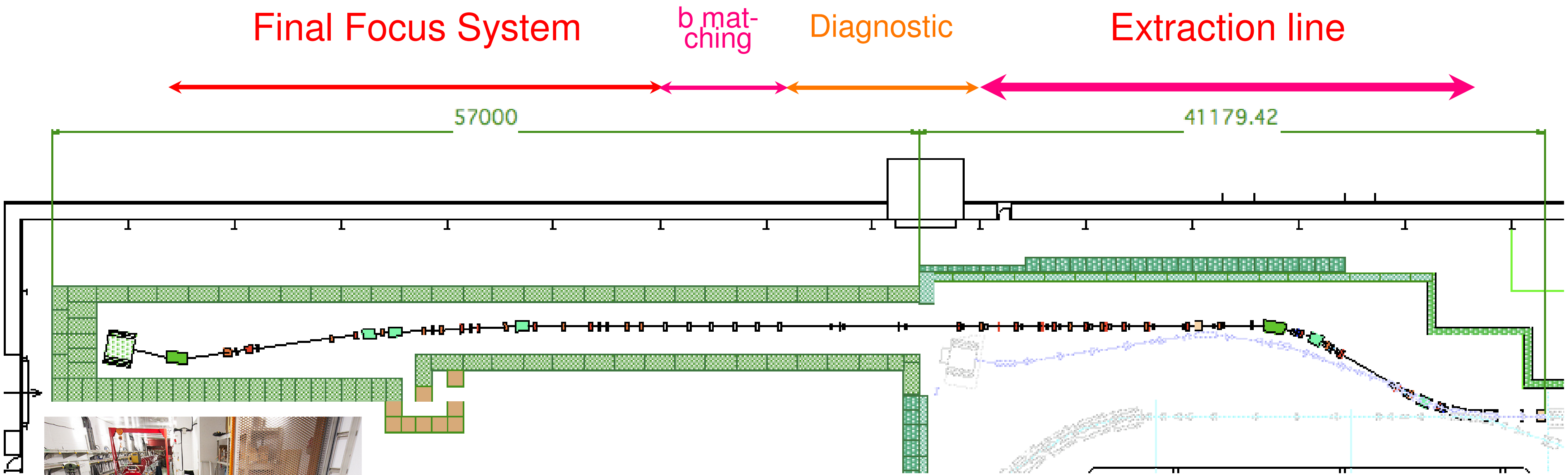
**Final quadrupole magnets**

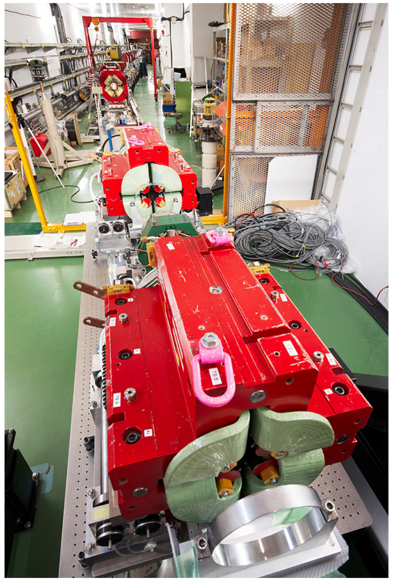
**Superconducting (QD0 in detector magnetic field)**

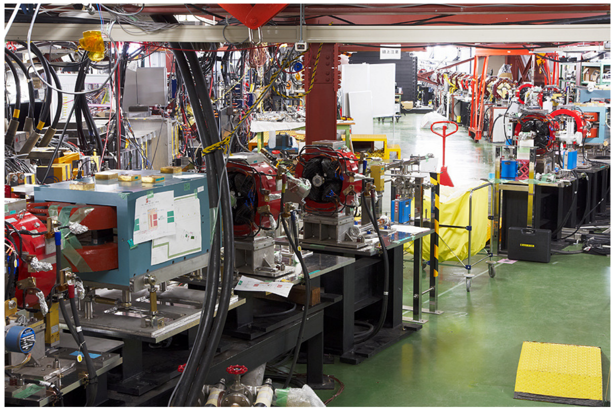
**Crab Crossing**

**deflect head and tail oppositely for head collisions**

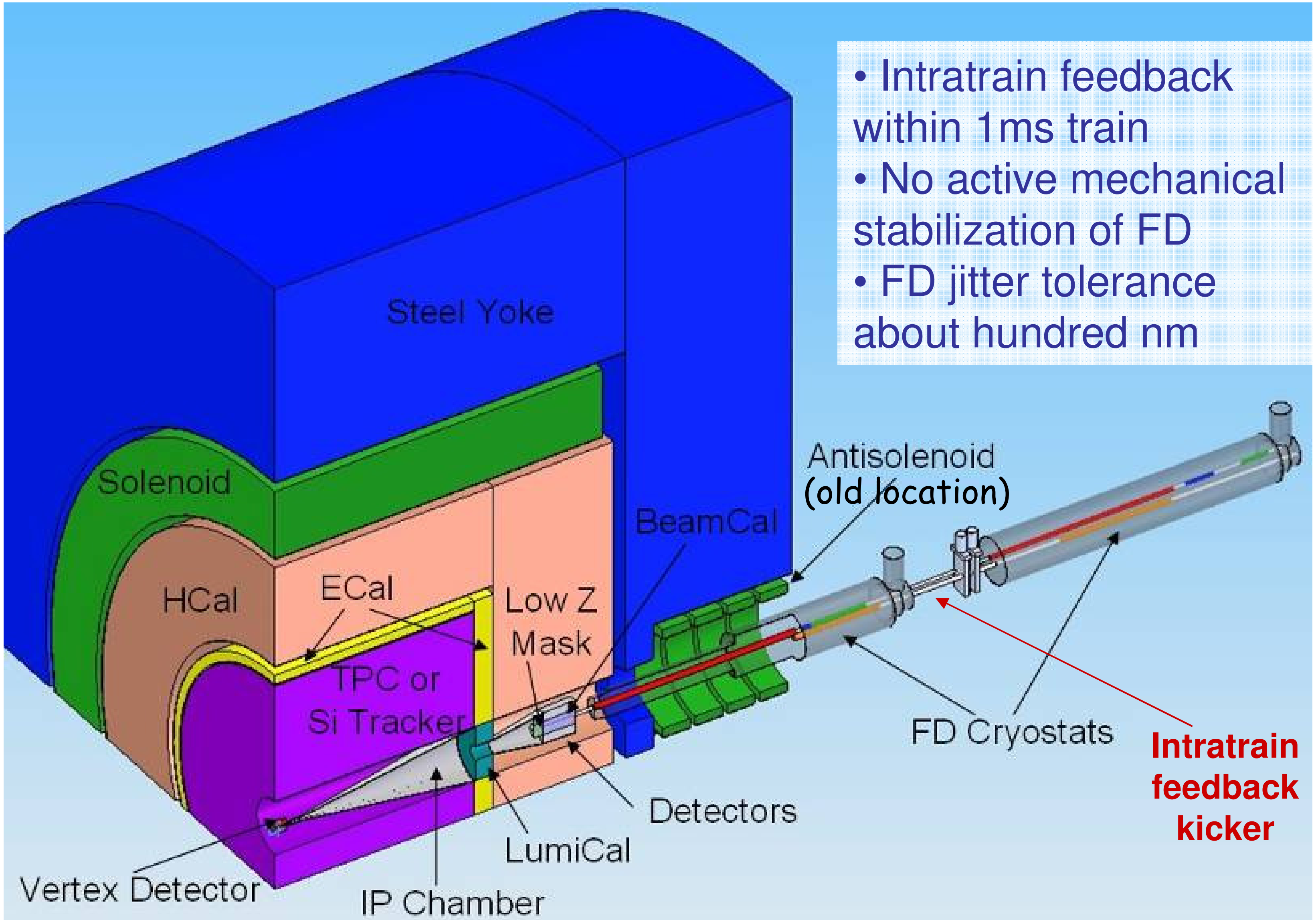
# KEK ATF2 Layout



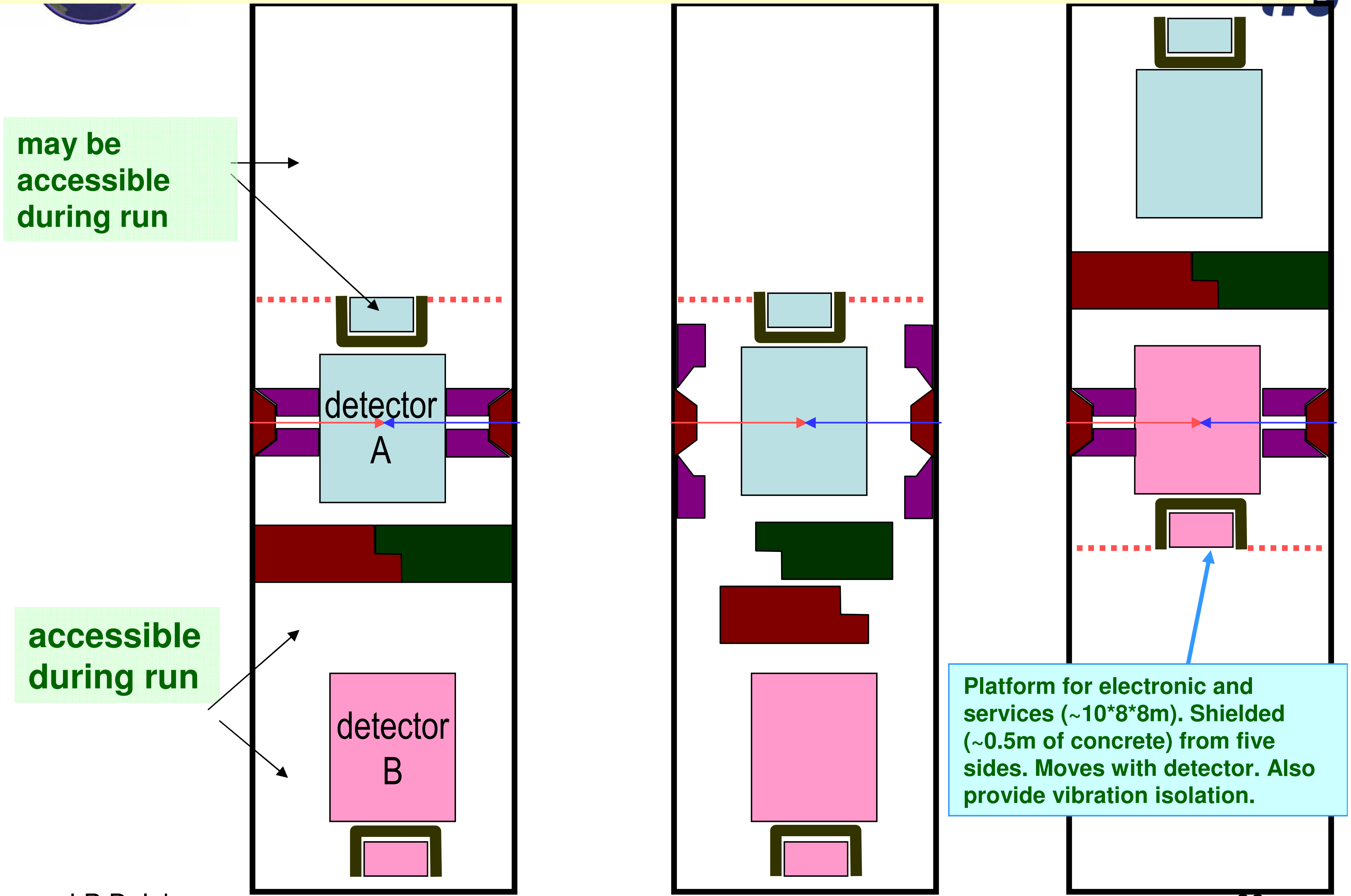


# *ILC IR configuration & stability*

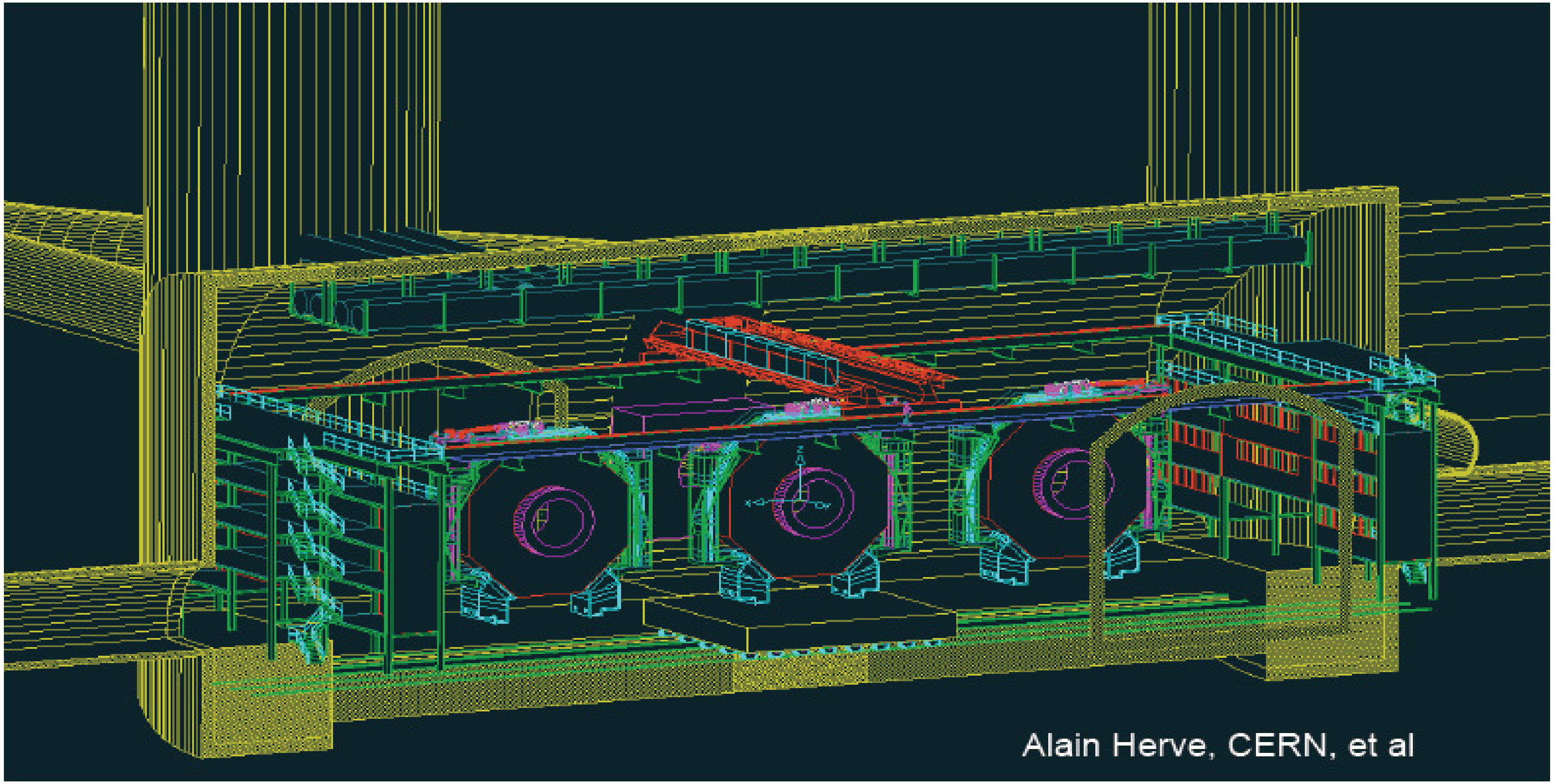



- Intratrain feedback within 1ms train
- No active mechanical stabilization of FD
- FD jitter tolerance about hundred nm

# *Concept of IR hall with two detectors in Push-Pull*

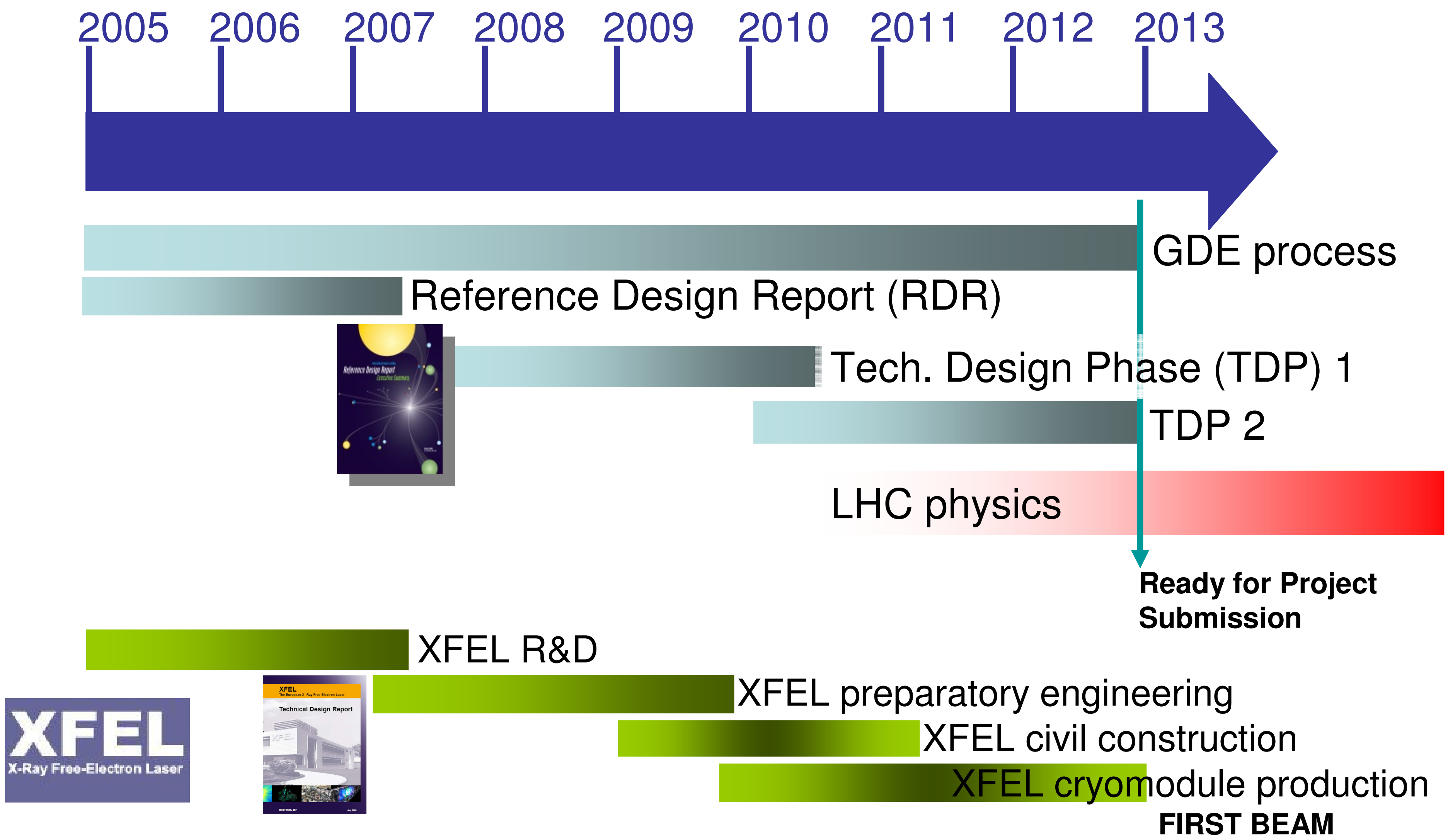


# Push-Pull studies for two detectors



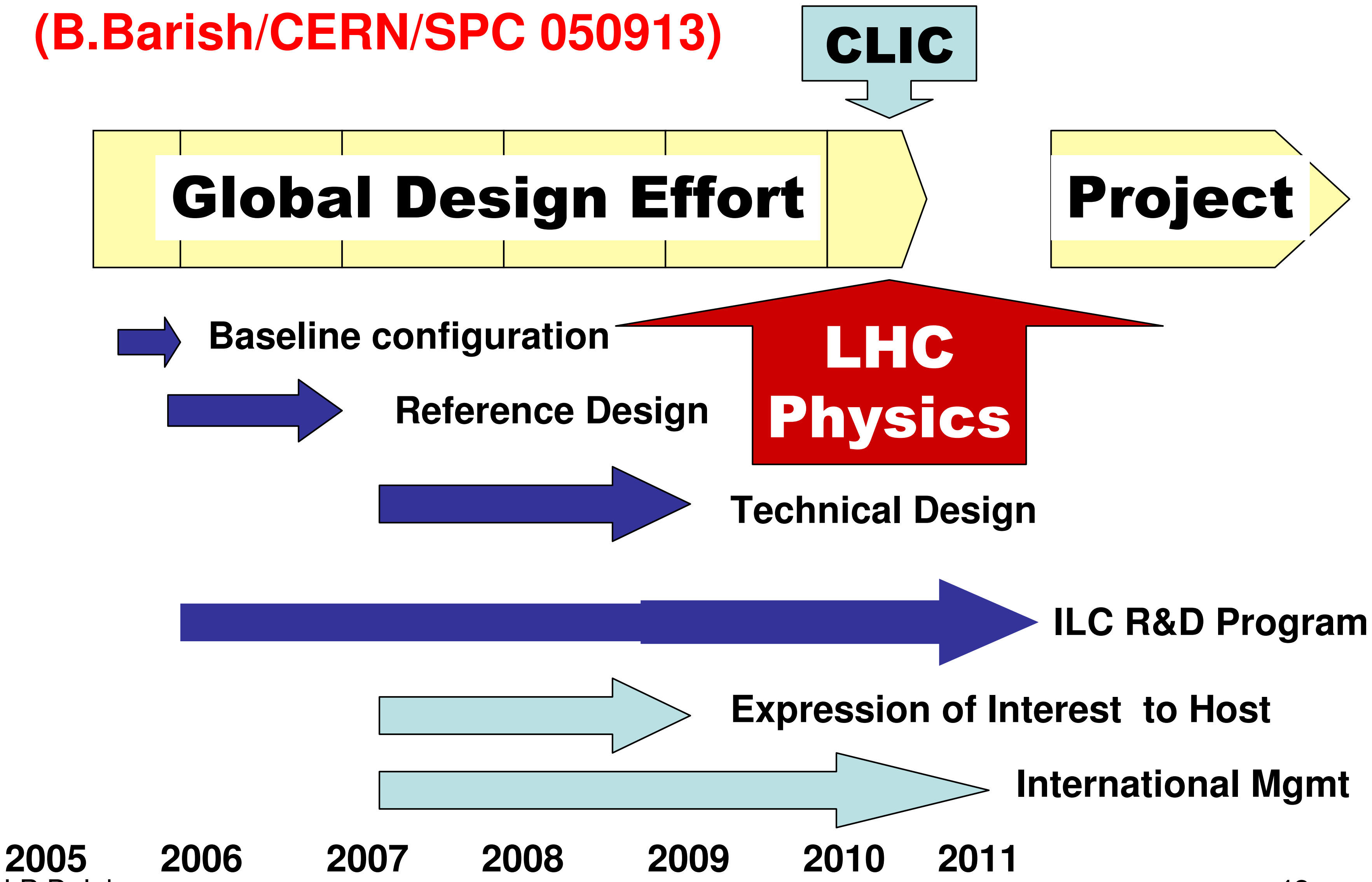

30

# ILC & XFEL Timelines



# The ILC Plan and Schedule

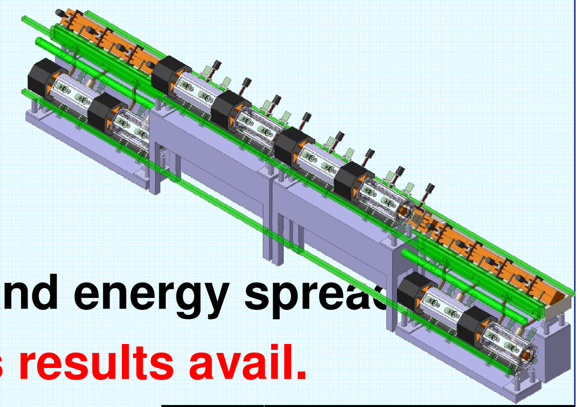
(B.Barish/CERN/SPC 050913)



# THE COMPACT LINEAR COLLIDER (CLIC) STUDY

## Aim: develop technology to extend e-/e+ linear colliders into the Multi-TeV energy range:

http://clic-study.web.cern.ch/CLIC-Study/

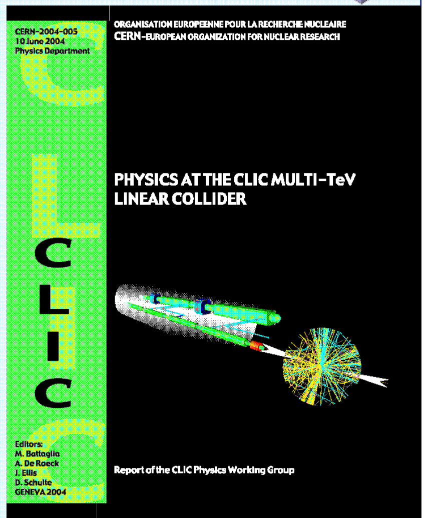


- ✓ $E_{CM}$ energy range from ILC to LHC maximum reach and beyond => $E_{CM}$ = 0.5- 3 TeV
- ✓ $L$ > few $10^{34}$ $cm^{-2}$ with acceptable background and energy spread
  - ⇒ $E_{CM}$ and $L$ to be reviewed when LHC physics results avail.
- ✓ Affordable cost and power consumption

## Physics motivation:

http://clicphysics.web.cern.ch/CLICphysics/

"Physics at the CLIC Multi-TeV Linear Collider: by the CLIC Physics Working Group:CERN 2004-5




## Present goal:

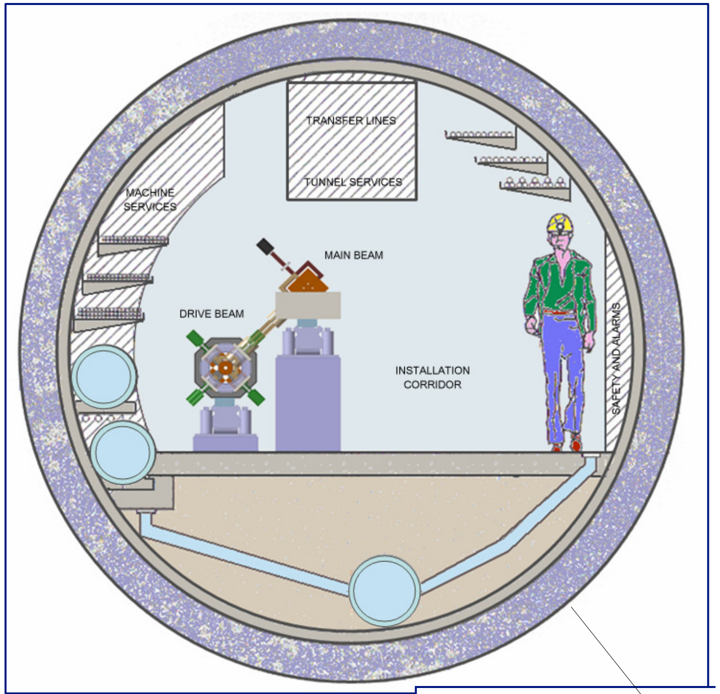
Demonstrate all key feasibility issues and document in a Conceptual Design Report by 2010 and possibly Technical Design Report by 2015

# *CLIC – basic features*

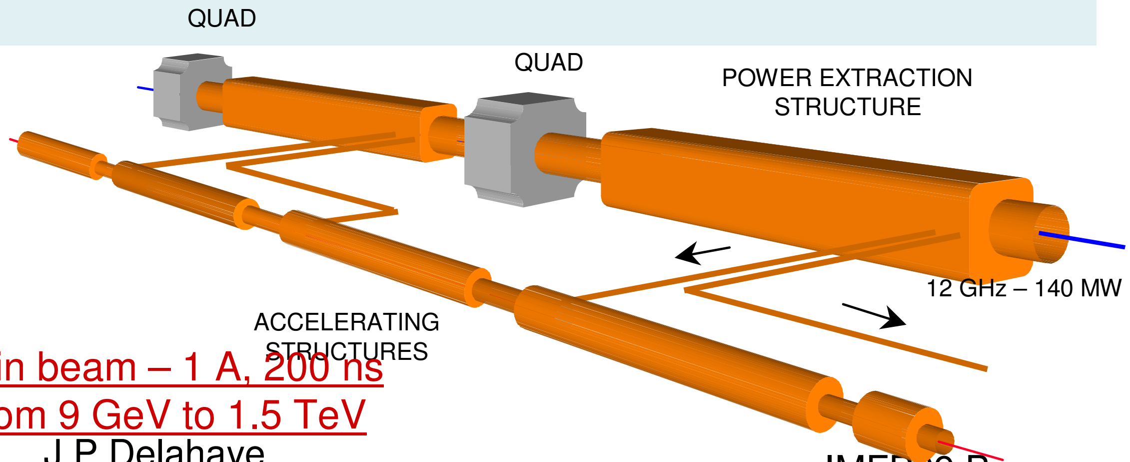
CLIC TUNNEL CROSS-SECTION

- **High acceleration gradient: > 100 MV/m**
  - **"Compact" collider – total length < 50 km at 3 TeV**
  - **Normal conducting acceleration structures at high frequency**

- **Novel Two-Beam Acceleration Scheme**
  - **Cost effective, reliable, efficient**
  - **Simple tunnel, no active elements**
  - **Modular, easy energy upgrade in stages**

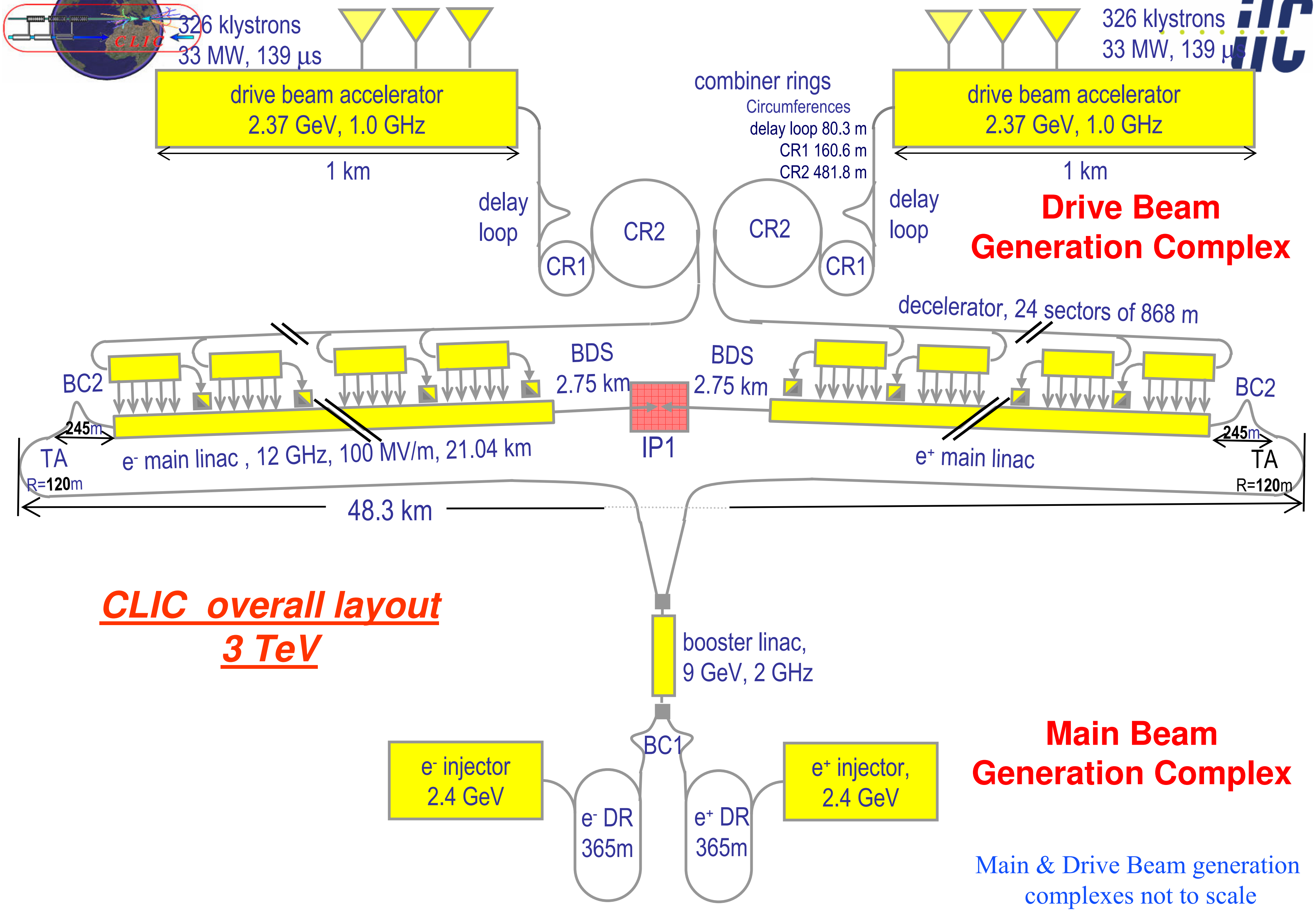



4.5 m diameter



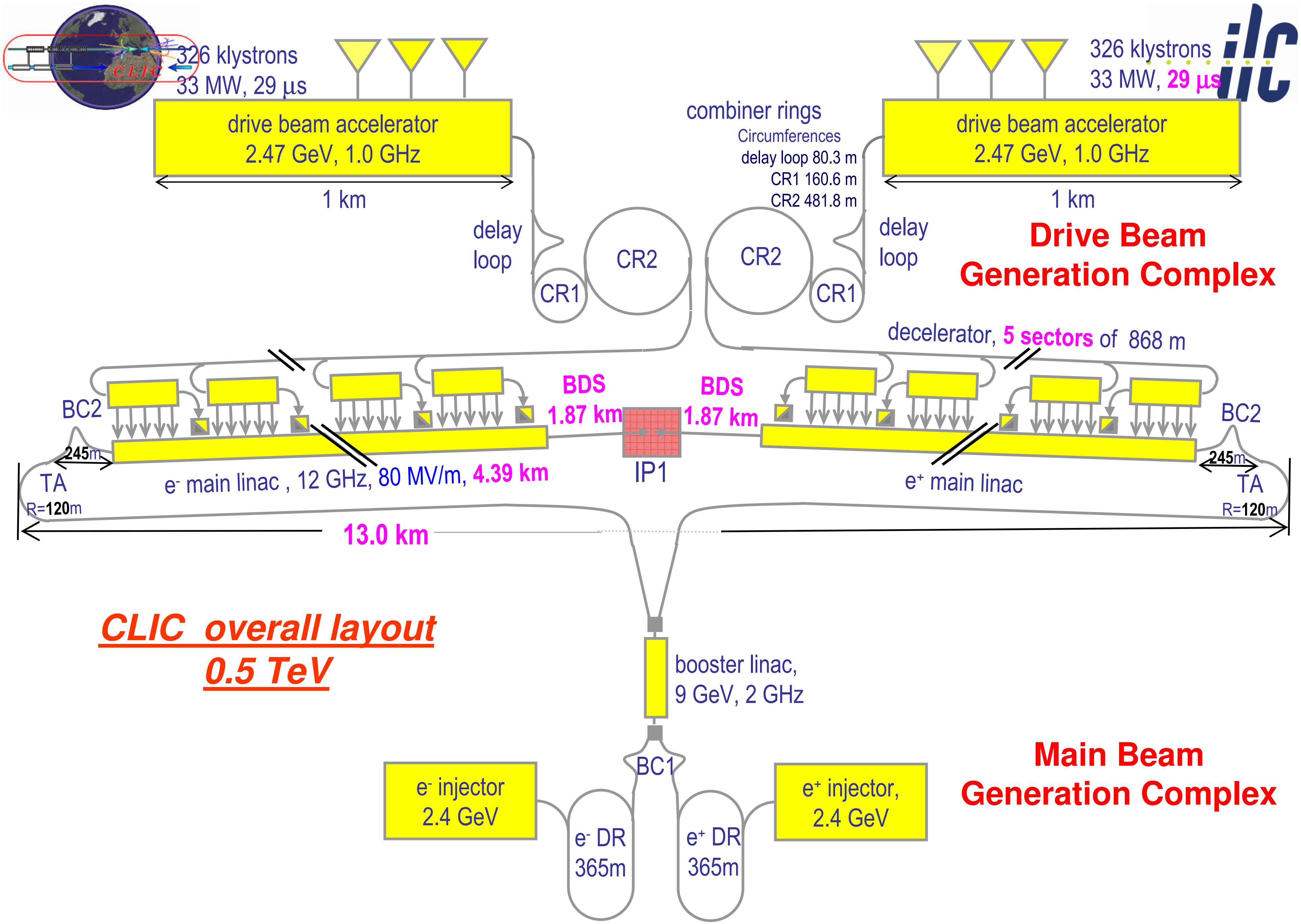

Drive beam - 95 A, 300 ns from 2.4 GeV to 240 MeV

Main beam – 1 A, 200 ns from 9 GeV to 1.5 TeV




# ***CLIC overall layout***
# ***3 TeV***

Main & Drive Beam generation complexes not to scale




# CLIC overall layout 0.5 TeV

# World-wide CLIC / CTF3 collaboration

http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm

*24 members representing 27 institutes involving 17 funding agencies of 15 countries*

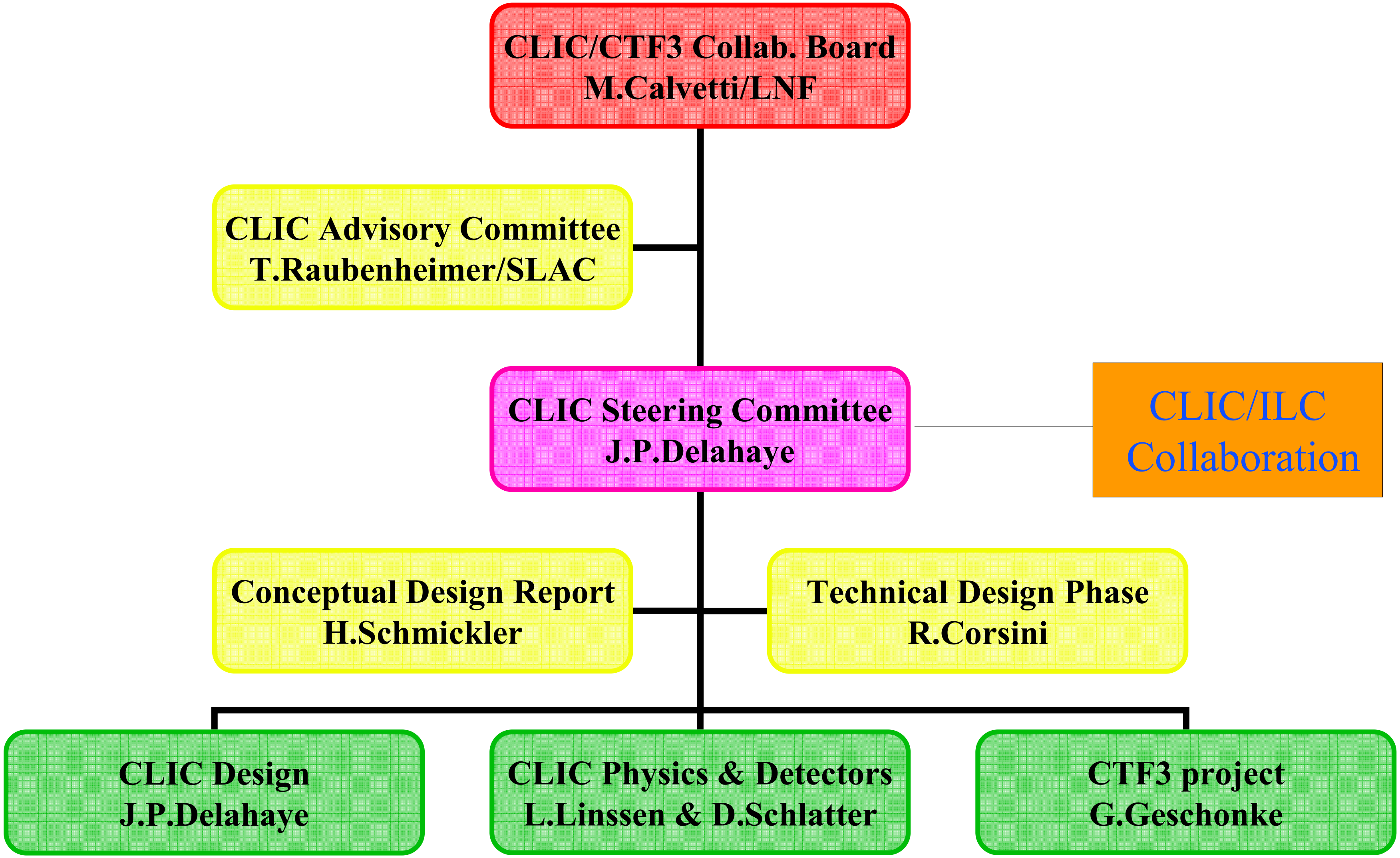

Ankara University (Turkey)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
Gazi Universities (Turkey)
IRFU/Saclay (France)

Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
Instituto de Fisica Corpuscular (Spain)
INFN / LNF (Italy)
J.Adams Institute, (UK)

JINR (Russia)
JLAB (USA)
KEK (Japan)
LAL/Orsay (France)
LAPP/ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)

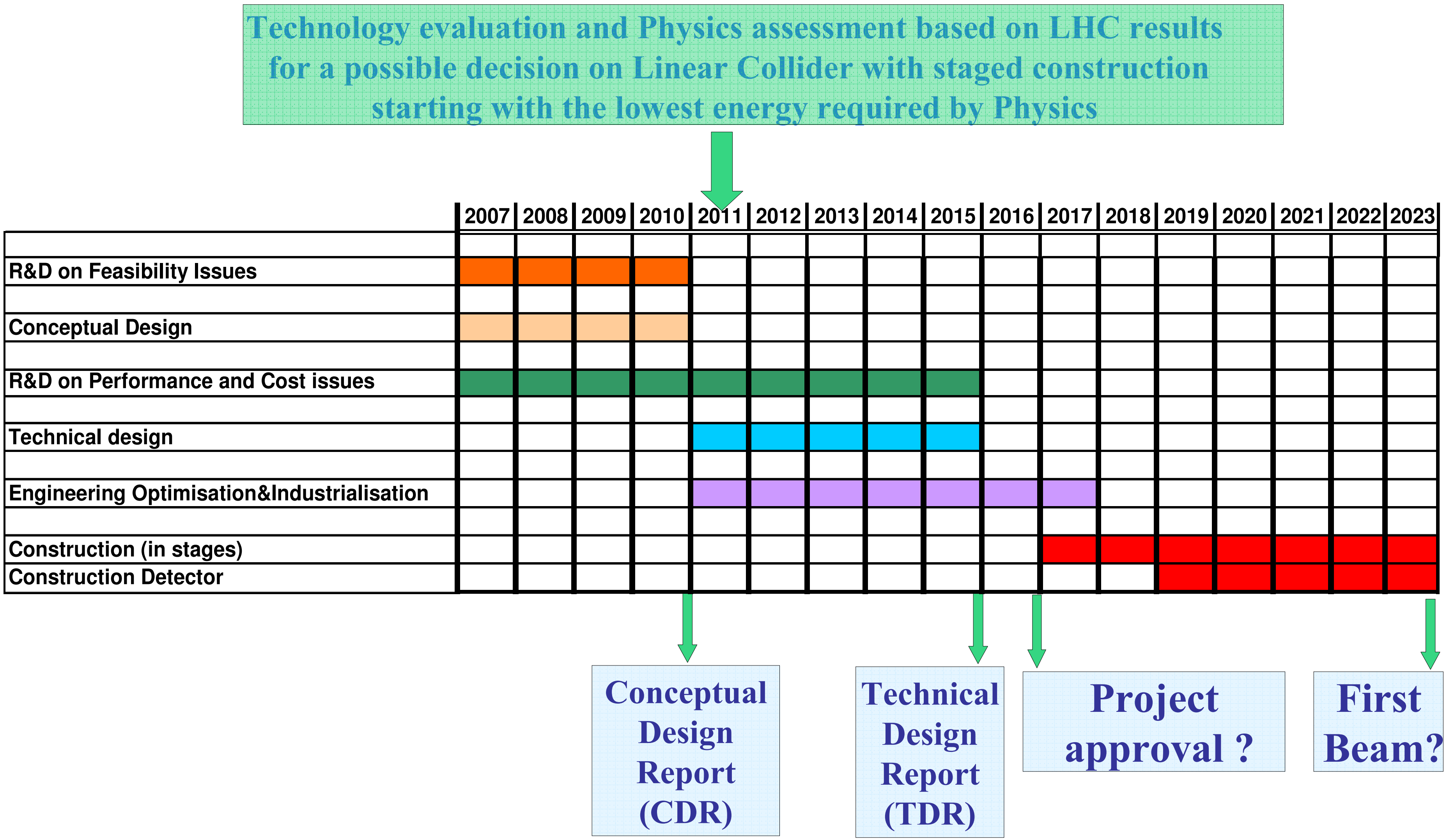
University of Oslo (Norway)
PSI (Switzerland),
Polytech. University of Catalonia (Spain)
RRCAT-Indore (India)
Royal Holloway, Univ. London, (UK)
SLAC (USA)
Uppsala University (Sweden)

# CLIC Chart 09



# *Tentative long-term CLIC scenario*

## *Shortest, Success Oriented, Technically Limited Schedule*



# *CLIC major activities and milestones up to 2010*

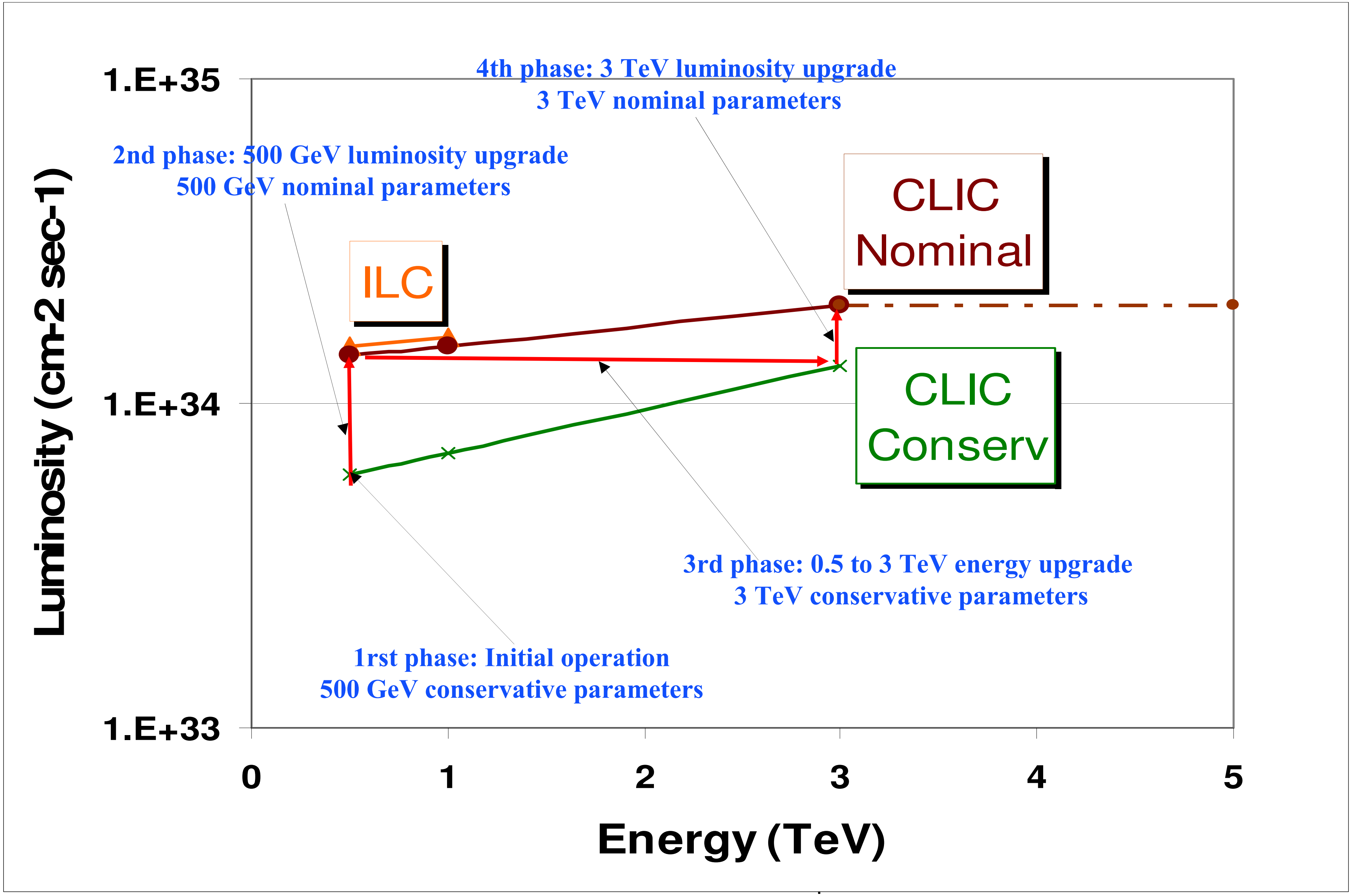
- **Demonstrate feasibility of CLIC technology**
  - **Address all feasibility issues**
- **Design of a linear Collider based on CLIC technology**

  http://clic-study.web.cern.ch/CLIC-Study/Design.htm
- **Estimation of its cost (capital investment & operation)**
- **CLIC Physics study and detector development:**

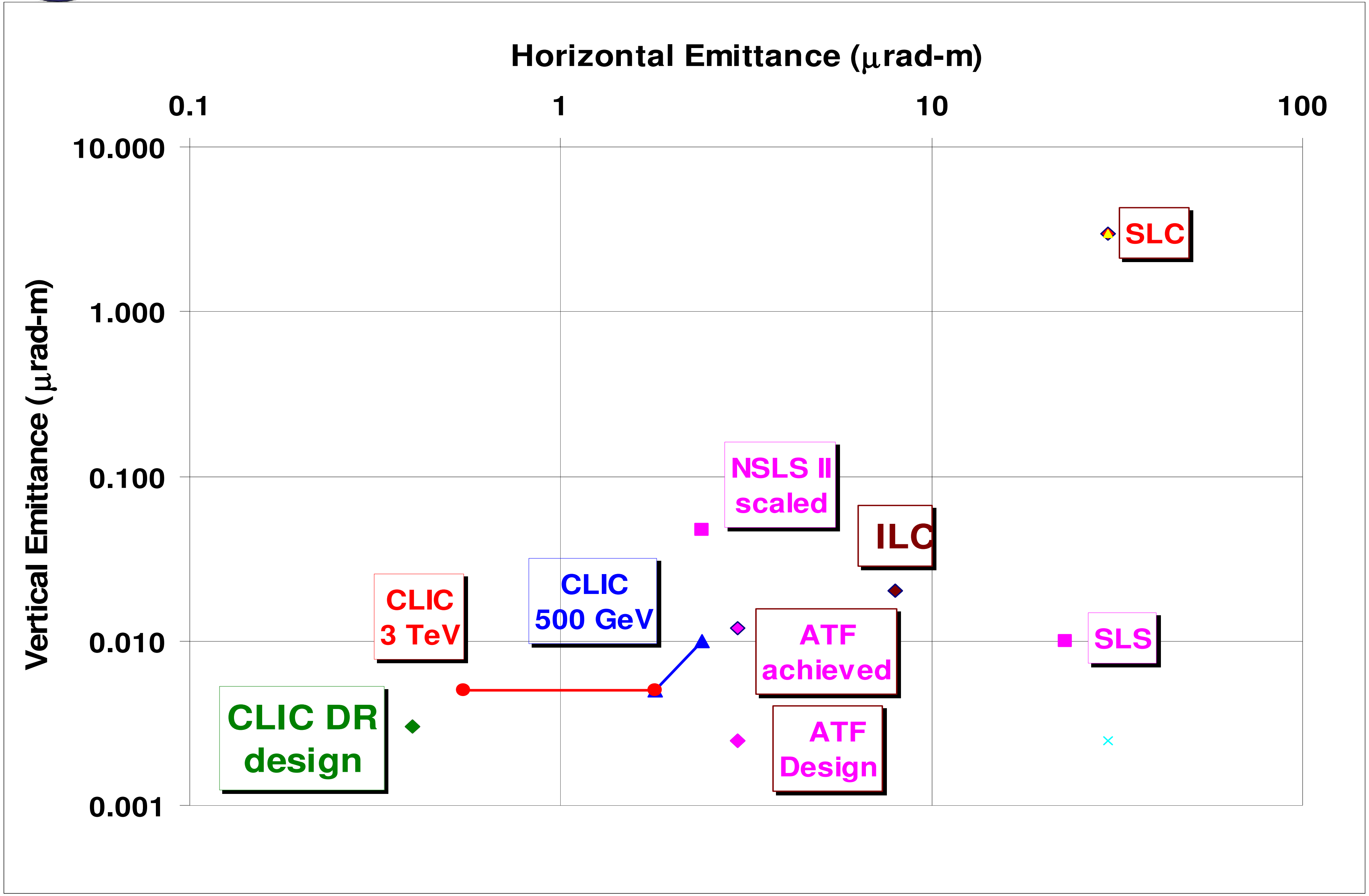
  http://clic-meeting.web.cern.ch/clic-meeting/CLIC_Phy_Study_Website/default.html
- **Conceptual Design Report to be published in 2010 including**
  - **Physics, Accelerator and Detectors**
  - **R&D on critical issues and results of feasibility study,**
  - **Preliminary performance and cost estimation**

# *CLIC Parameters and upgrade scenario*

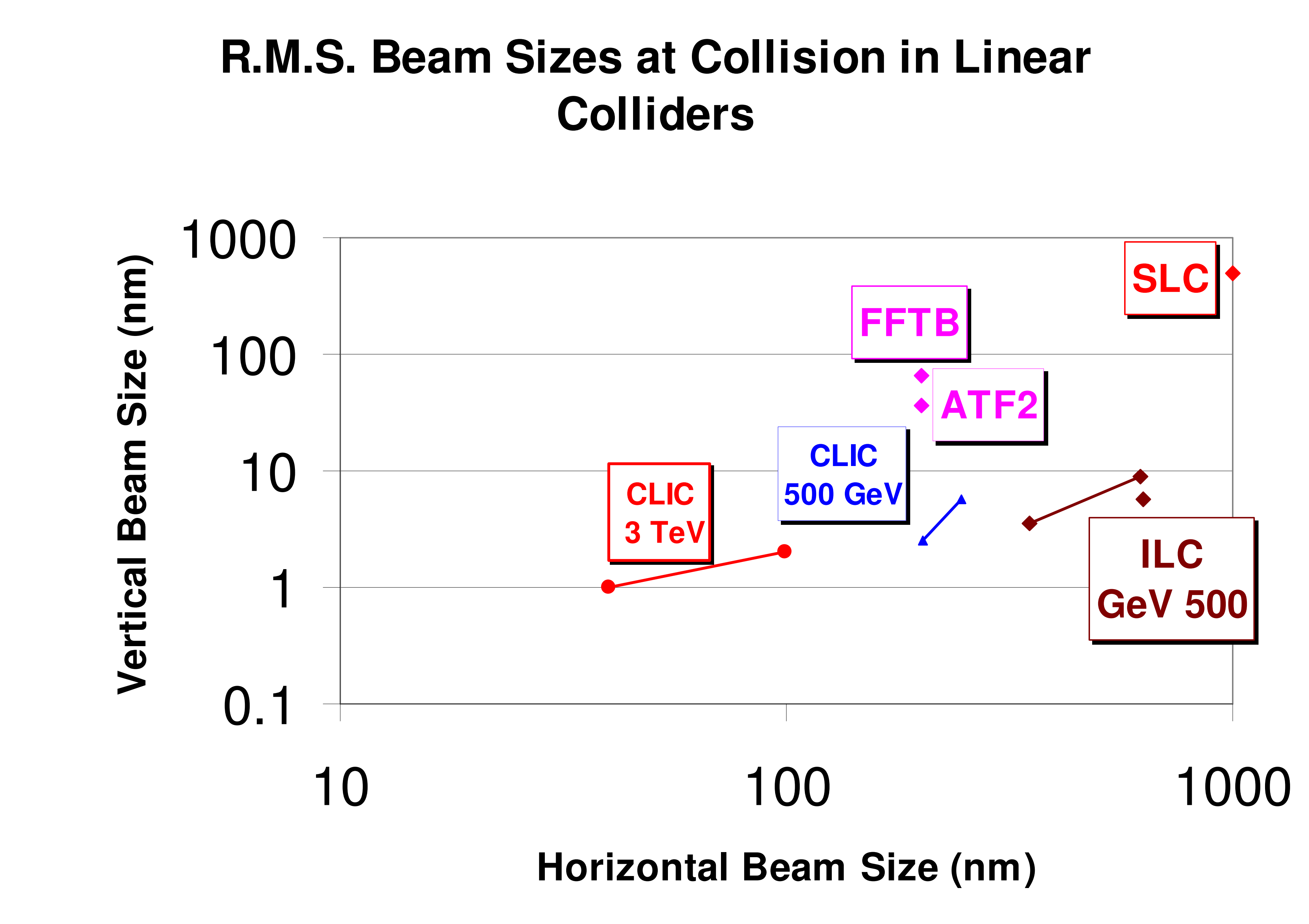
*http://cdsweb.cern.ch/record/1132079/files/CERN-OPEN-2008-021.pdf*



# Beam emittances at Damping Rings



# *Beam sizes at Collisions*



# CLIC main parameters

http://cdsweb.cern.ch/record/1132079?ln=fr http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html

| Center-of-mass energy | CLIC 500 G | | CLIC 3 TeV | |
|---|---|---|---|---|
| Beam parameters | Conservative | Nominal | Conservative | Nominal |
| Accelerating structure | 502 | | G | |
| Total (Peak 1%) luminosity | $0.9(0.6)\cdot10^{34}$ | $2.3(1.4)10^{34}$ | $1.5(0.73)10^{34}$ | $5.9(2.0)\cdot10^{34}$ |
| Repetition rate (Hz) | 50 | | | |
| Loaded accel. gradient MV/m | 80 | | 100 | |
| Main linac RF frequency GHz | 12 | | | |
| Bunch charge$10^9$ | 6.8 | | 3.72 | |
| Bunch separation (ns) | 0.5 | | | |
| Beam pulse duration (ns) | 177 | | 156 | |
| Beam power/beam (MWatts) | 4.9 | | 14 | |
| Hor./vert. norm. emitt ($10^{-6}$/$10^{-9}$) | 3/40 | 2.4/25 | 2.4/20 | 0.66/20 |
| Hor/Vert FF focusing (mm) | 10/0.4 | 8 / 0.1 | 8 / 0.3 | 4 / 0.07 |
| Hor./vert. IP beam size (nm) | 248 / 5.7 | 202 / 2.3 | 83 / 2.0 | 40 / 1.0 |
| Hadronic events/crossing at IP | 0.07 | 0.19 | 0.57 | 2.7 |
| Coherent pairs at IP | 10 | 100 | $5\ 10^7$ | $3.8\ 10^8$ |
| BDS length (km) | 1.87 | | 2.75 | |
| Total site length km | 13.0 | | 48.3 | |

# LC 500 GeV Main parameters

| Center-of-mass energy | ILC | CLIC conserv. | CLIC Nominal |
|---|---|---|---|
| Total (Peak 1%) luminosity | $2.0(1.5)\cdot10^{34}$ | $0.9(0.6)\cdot10^{34}$ | $2.3(1.4)\cdot10^{34}$ |
| Repetition rate (Hz) | 5 | 50 | |
| Loaded accel. gradient MV/m | 33.5 | 80 | |
| Main linac RF frequency GHz | 1.3 (SC) | 12 (NC) | |
| Bunch charge$10^9$ | 20 | 6.8 | |
| Bunch separation ns | 176 | 0.5 | |
| Beam pulse duration (ns) | 1000 | 177 | |
| Beam power/linac (MWatts) | 10.2 | 4.9 | |
| Hor./vert. norm. emitt ($10^{-6}/10^{-9}$) | 10/40 | 3 / 40 | 2.4 / 25 |
| Hor/Vert FF focusing (mm) | 20/0.4 | 10/0.4 | 8/0.1 |
| Hor./vert. IP beam size (nm) | 640/5.7 | 248 / 5.7 | 202/ 2.3 |
| Soft Hadronic event at IP | 0.12 | 0.07 | 0.19 |
| Coherent pairs/crossing at IP | 10? | 10 | 100 |
| BDS length (km) | 2.23 (1 TeV) | 1.87 | |
| Total site length (km) | 31 | 13.0 | |
| Wall plug to beam transfer eff. | 9.4% | 7.5% | |
| Total power consumption MW | 216 | 129.4 | |

# *Strategy to address key issues*

- **Key issues common to all Linear Collider studies independently of the chosen technology in close collaboration with International Linear Collider (ILC) study**
  - **The Accelerator Test Facility (ATF@KEK)**
  - **European Laboratories in the frame of:**
    - **the Coordinated Accelerator Research in Europe (CARE) and of a "Design Study" (EUROTeV) funded by EU Programme (FP6)**
    - **The European Coordination of Accerator R&D funded by EU FP7**
- **Key issues specific to CLIC technology:**
  - **Focus of the CLIC study**
  - **All R1 (feasibility) and R2 (design finalisation) key issues addressed in test facilities: CTF@CERN**

# *CLIC critical issues R&D strategy and schedule*

**Updated from the Technical Review Committee (TRC) (2003)**

**Overall list available under: https://edms.cern.ch/document/918791**

**Issues classified in three categories:**

- **critical for CLIC design and technology feasibility**

  **Fully addressed by 2010 by specific R&D with results in Conceptual Design Report (CDR) with Preliminary Performance & Cost**

- **critical for performance**
- **critical for cost**

  **Both being addressed now by specific R&D to be completed before 2015 with results in Technical Design Report (TDR) with Consolidated Performance & Cost**

# *CLIC feasibility issues*

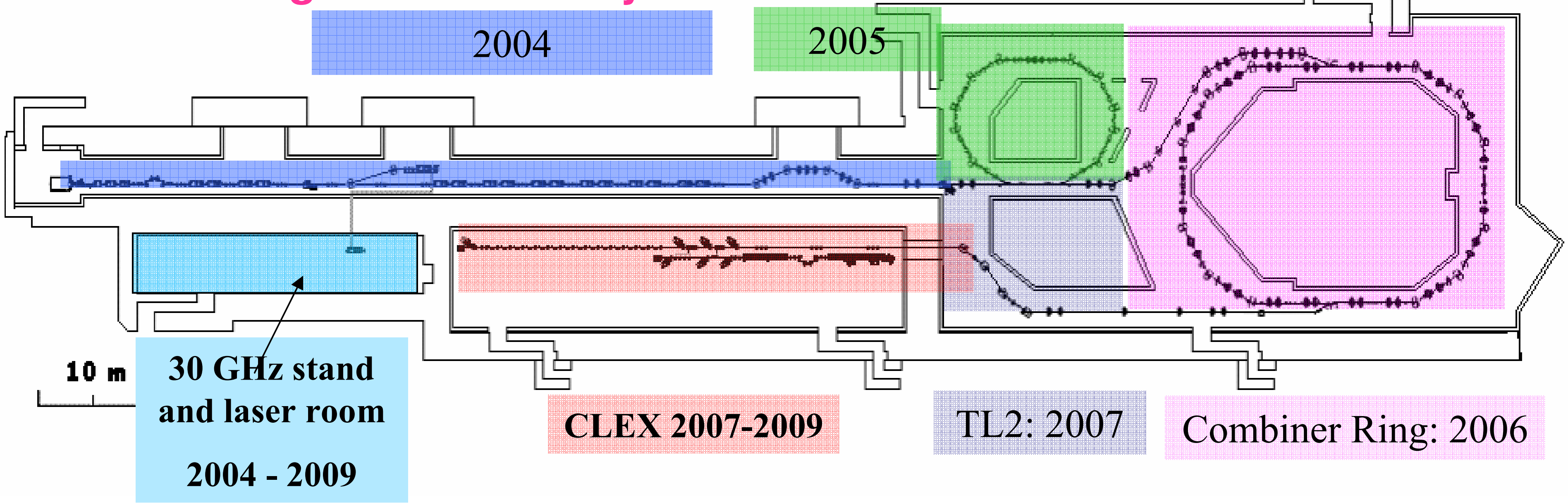
| SYSTEMS (level n) | | Critical parameters | Feasibility issue | Performance issue | Cost issue |
|---|---|---|---|---|---|
| Structures | **Main beam acceleration structures**<br>Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate . | 100 MV/m<br>240 ns<br>3·10-7 BR/(pulse*m) | X | X | X |
| | **Decelerator structures**<br>Demonstrate nominal PETS with damping features at design power, with design pulse length, breakdown rate on/off capability | 136 MW<br>240 ns | X | | X |
| Drive Beam | **Validation of drive Beam**<br>- production<br>- phase stability , potential feedbacks<br>- MPS appropriate for beam power | 0.2 degrees phase stability at 12 GHz | X | X | |
| Two Beam | Test of a relevant linac sub-unit with both beams | NA | X | | |
| Beam Physics | - Preservation of low emittances (main linac + RTML) | Absolute blow-up<br>Hor: 160nradm<br>Vert: 15 nradm | X | X | |
| Stabilization | Main Linac and BDS Stabilization | Main Linac : 1 nm vert (>1 Hz)<br>BDS: 0.15…1 nm vert (>4 Hz)<br>depending on implementation of final doublet girder | X | X | X |
| Operation and reliability | Commissioning strategy<br>Staging of commissioning and construction<br>MTBF, MTTR<br>Machine protection | Handling of drive beam power of 72 MW | X | X | X |

# *CLIC & ILC common Test Facilities (identified in red)*

| | CLIC critical issues SYSTEMS (level n) | Critical parameters | Crucial design choice or fesibility | Performance issue | Cost issue | Relevant Facilities (also valid for ILC) |
|---|---|---|---|---|---|---|
| Structures | Main beam acceleration structures<br>Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate . | 100 MV/m<br>240 ns<br>3·10-7 BR/(pulse*m) | X | X | X | CTF2&3 (2005-2010)<br>Test Stand (2009-2010)<br>SLAC/NLCTA<br>SLAC/ASTA<br>KEK/NEXTEF |
| Structures | Decelerator structures<br>Demonstrate nominal PETS with damping features at design power, with design pulse length, breakdown rate on/off capability | 136 MW<br>240 ns | X | | X | CTF3 (2005-2010)<br>CTF3/TBTS (2008-2010)<br>CTF3/TBL (2009-2010)<br>SLAC ASTA |
| Drive Beam | Validation of drive Beam<br>- production<br>- phase stability , potential feedbacks<br>- MPS appropriate for beam power | 0.2 degrees phase stability at 12 GHz | X | X | | CTF3 (2005-2010)<br>CTF3/TBL (2009-2010)<br>X-FEL<br>LCLS |
| Two Beam | Test of a relevant linac sub-unit with both beams | NA | X | | | CTF3/TBTS (2008-2010) |
| Beam physics | Ultra-low emittances<br>- Generation of low-emittances (damping rings) | Hor:500 nradm<br>Vert: 5 nradm | | X | | ATF (2008-10): 3000/12<br>CESRTA:Electron Cloud<br>NSLSII: Hor 2000nradm<br>SLS: Vert 10nm |
| Beam physics | - Preservation of low emittances (main linac + RTML) | Absolute blow-up<br>Hor: 160nradm<br>Vert: 15 nradm | X | X | | Beam simulations<br>LCLS<br>SCSS |
| Beam physics | - Beam focusing to small dimensions (BDS) | Hor: 40 nm<br>Vert: 1 nm | | X | | ATF2 (2006-2012)<br>Hor: 200 nm<br>Vert: 36 (20) nm |

# *Addressing all major CLIC technology key issues in CLIC Test Facility (CTF3)*

**Multi-lateral Collaboration of 27 volunteer institutes organized as a Physics Detector Collaboration**




**Key issues**

*From 2005: Accelerating structures (bi-metallic) Development& Tests (R2.1)*

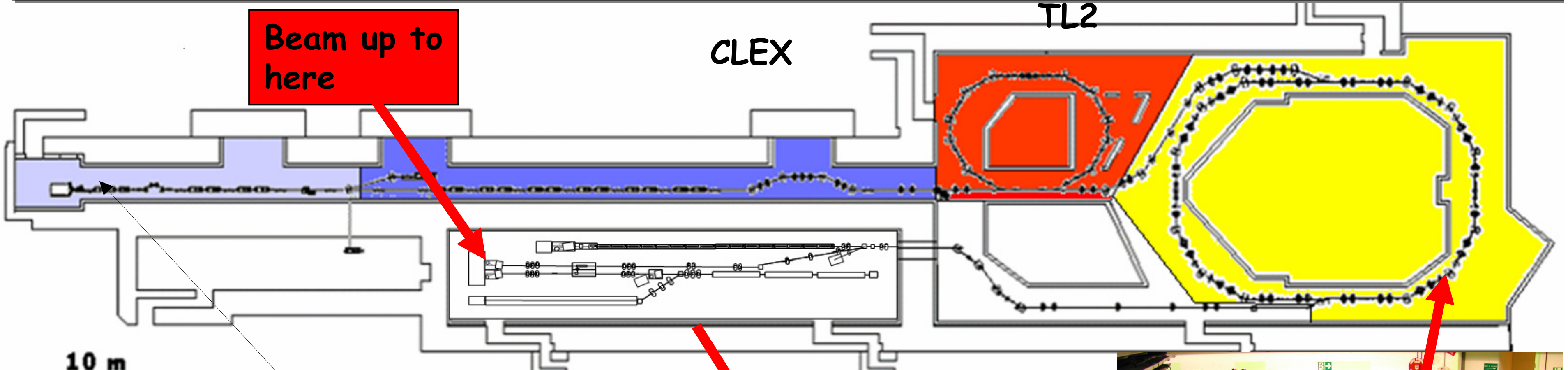
*2007- 2008: Drive beam generation scheme (R1.2)*

*2008- 2009: Damped accelerating structure with nominal parameters (R1.1)*
*ON/OFF Power Extraction Structure (R1.3)*
*Drive beam stability bench marking (R2.2)*
*CLIC sub-unit (R2.3)*

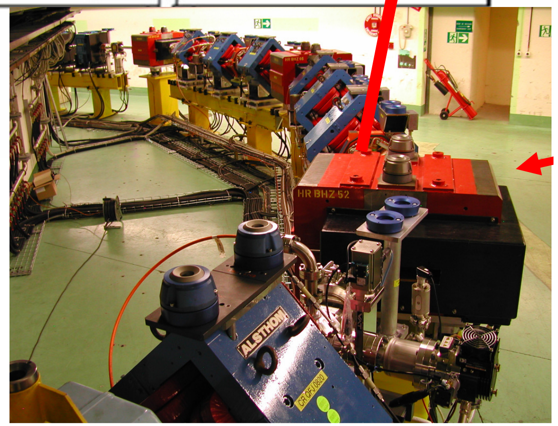
# CTF3 Continuous Operation (10months/year)

## HW & Beam Commisioning and RF power production for structure tests

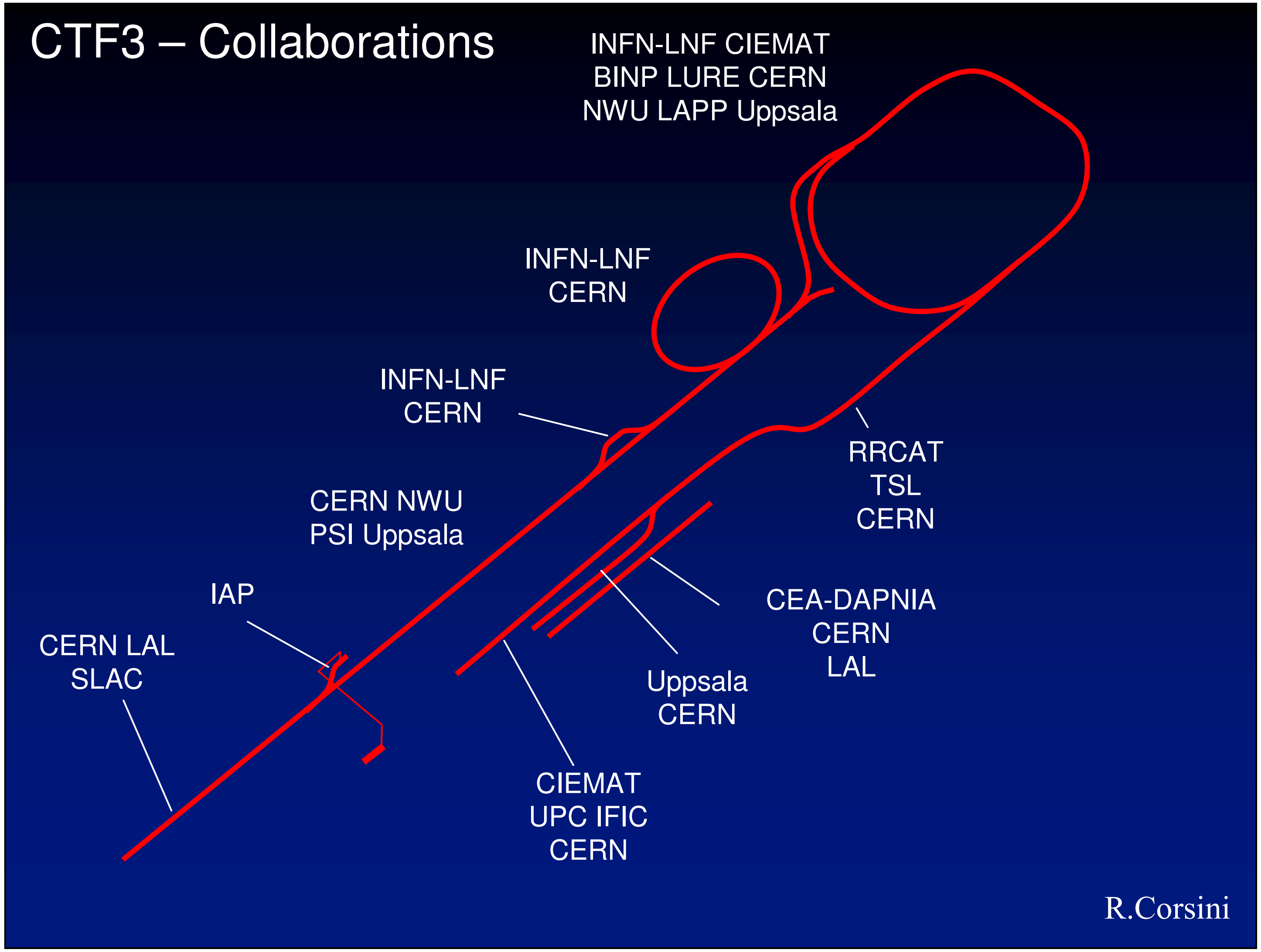
- Demonstrate Drive Beam generation
  (fully loaded acceleration, beam intensity and bunch frequency multiplication x8)
- Demonstrate RF Power Production and test Power Structures
- Demonstrate Two Beam Acceleration and test Accelerating Structures





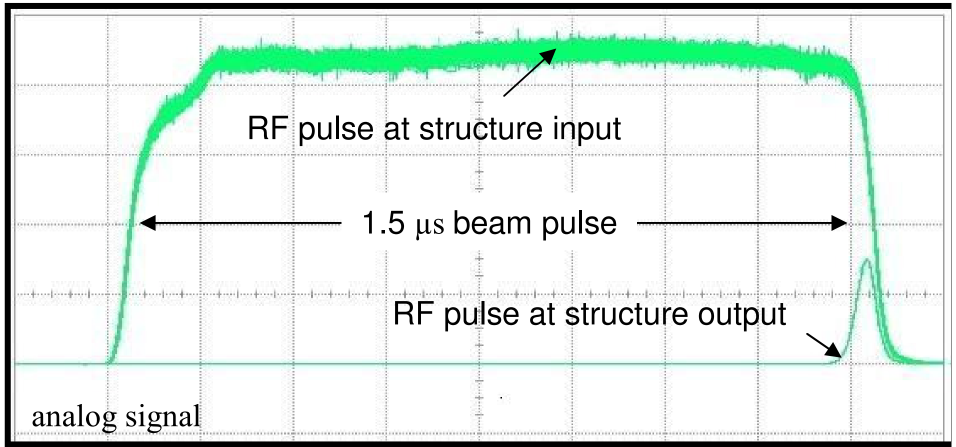


# CTF3 Collaboration

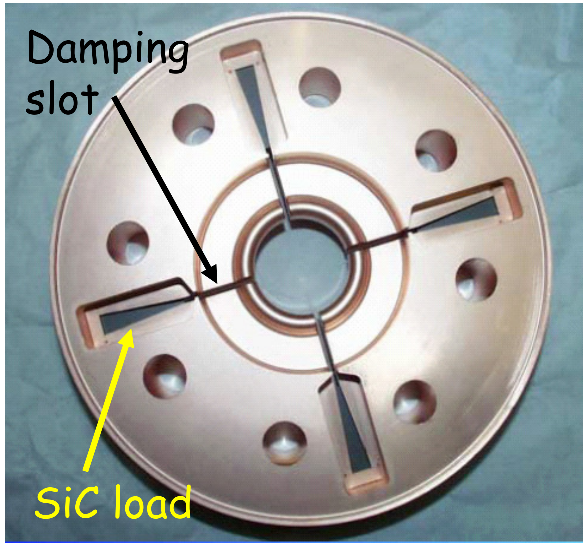


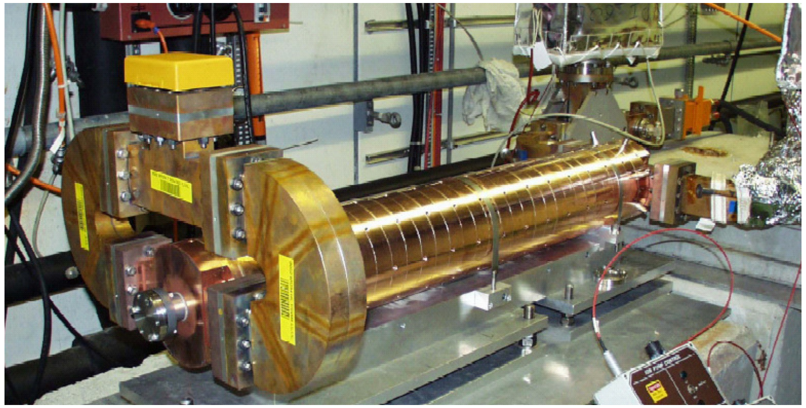
# *Drive beam generation with full beam-loading acceleration in CTF3 linac*

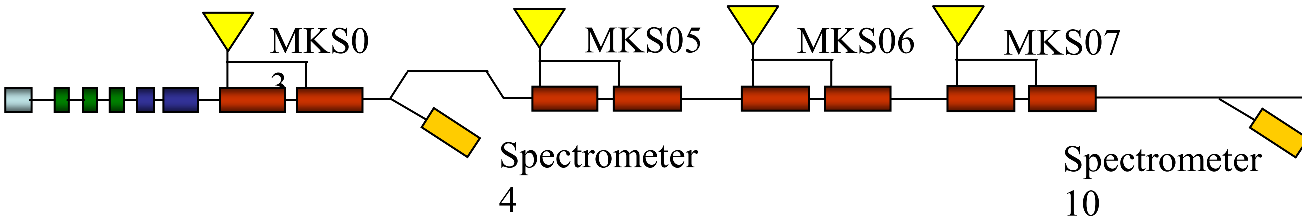
- **Measured RF-to-beam efficiency 95.3%**
- **Theory 96%**
  **(~ 4 % ohmic losses)**




Dipole modes suppressed by slotted iris damping (first dipole's Q factor < 20) and HOM frequency detuning

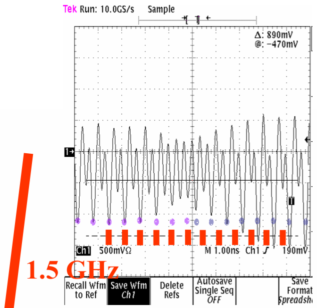


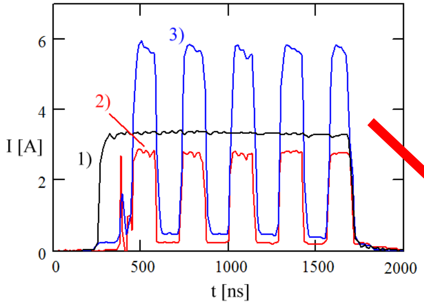





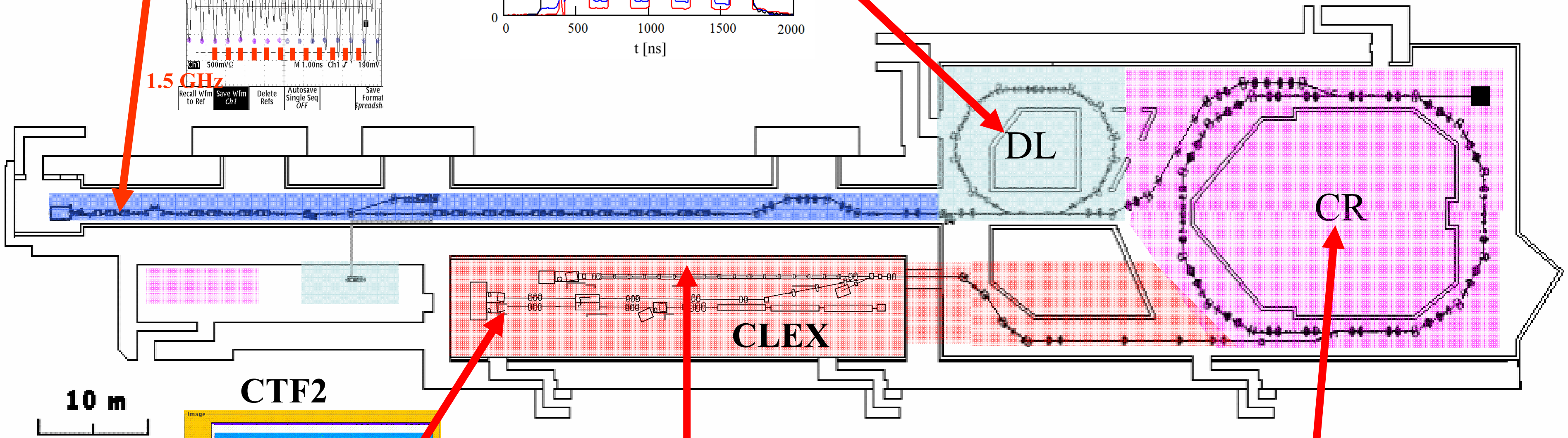
# *CTF3 HW & Beam Commissioning*

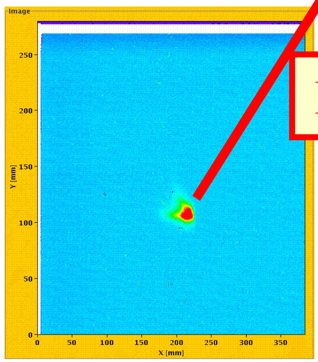
Phase coding



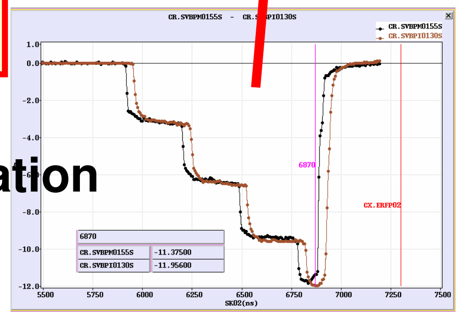

**Intensity and frequency multiplication by 2 in Delay Loop**



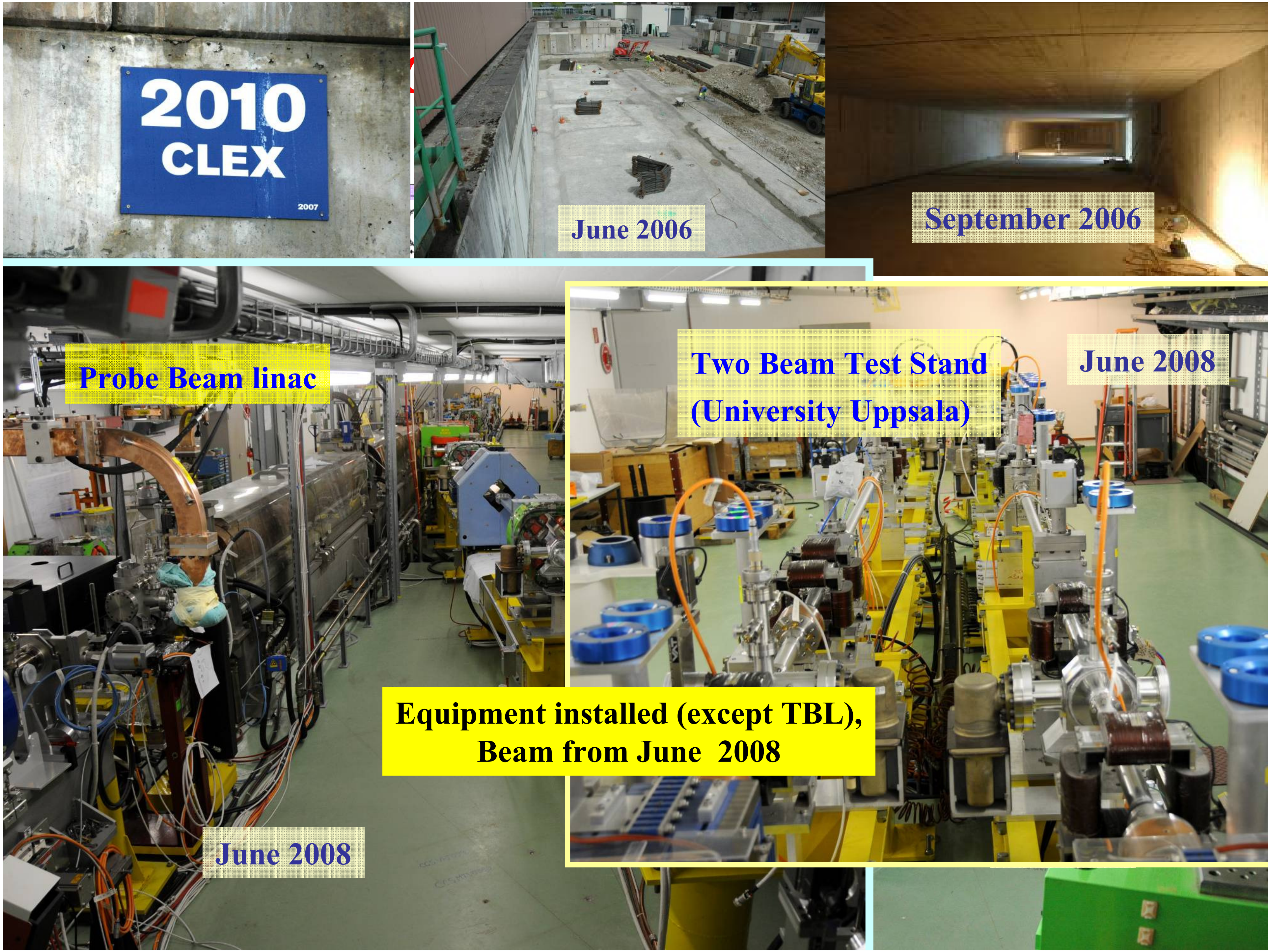



**Installation complete apart from TBL**

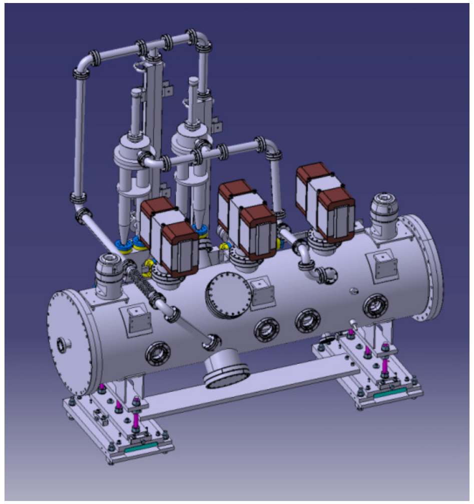
**Intensity and frequency multiplication by 4 in Combiner Ring**

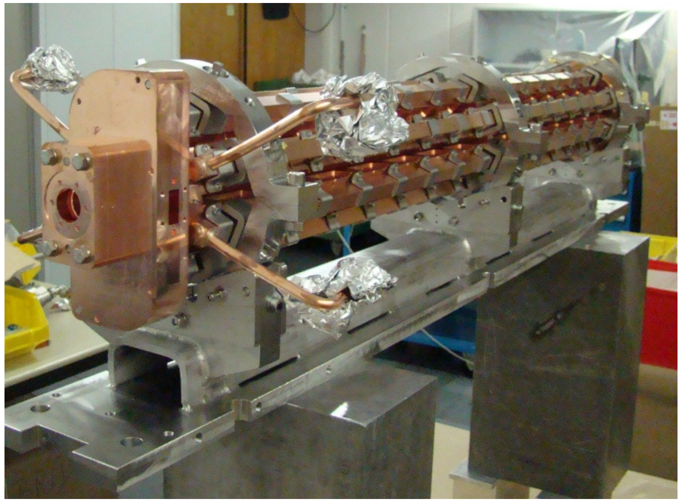


**Beam all the way through CLEX**


2010
CLEX
2007
June 2006
September 2006
Probe Beam linac
Two Beam Test Stand
(University Uppsala)
June 2008
Equipment installed (except TBL),
Beam from June 2008
June 2008

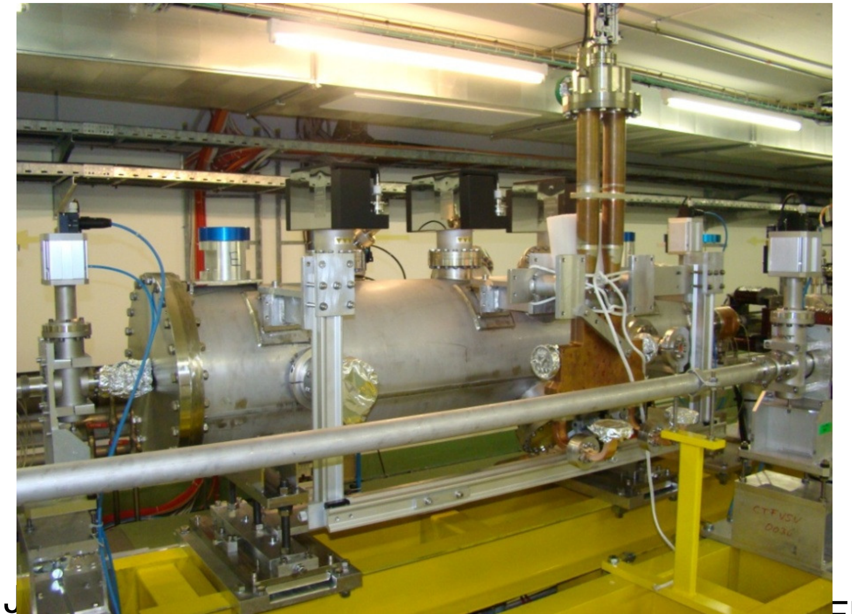
# *Power Extraction Structure test (PETS) in CTF3*

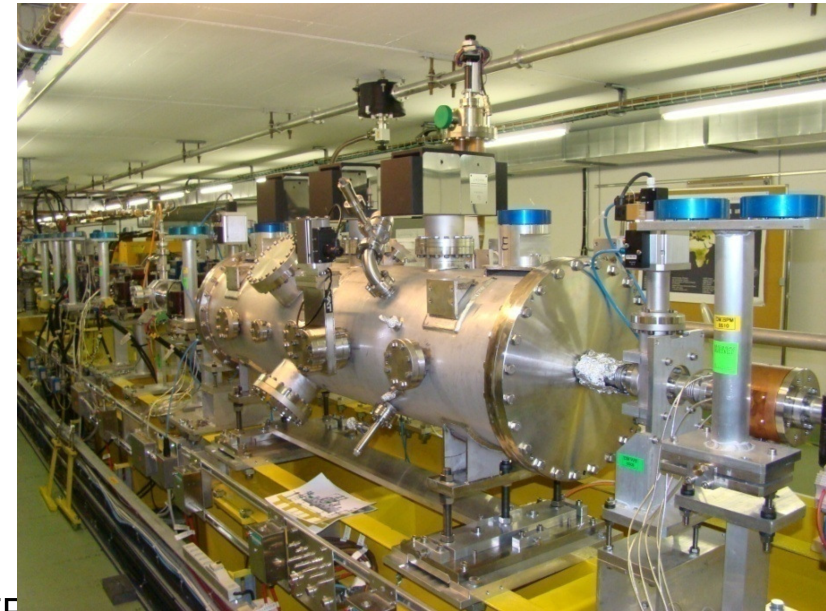




PETS installation in tank successful
(**collaboration with Pakistan – NPC Islamabad**)

PETS installation in CLEX under way

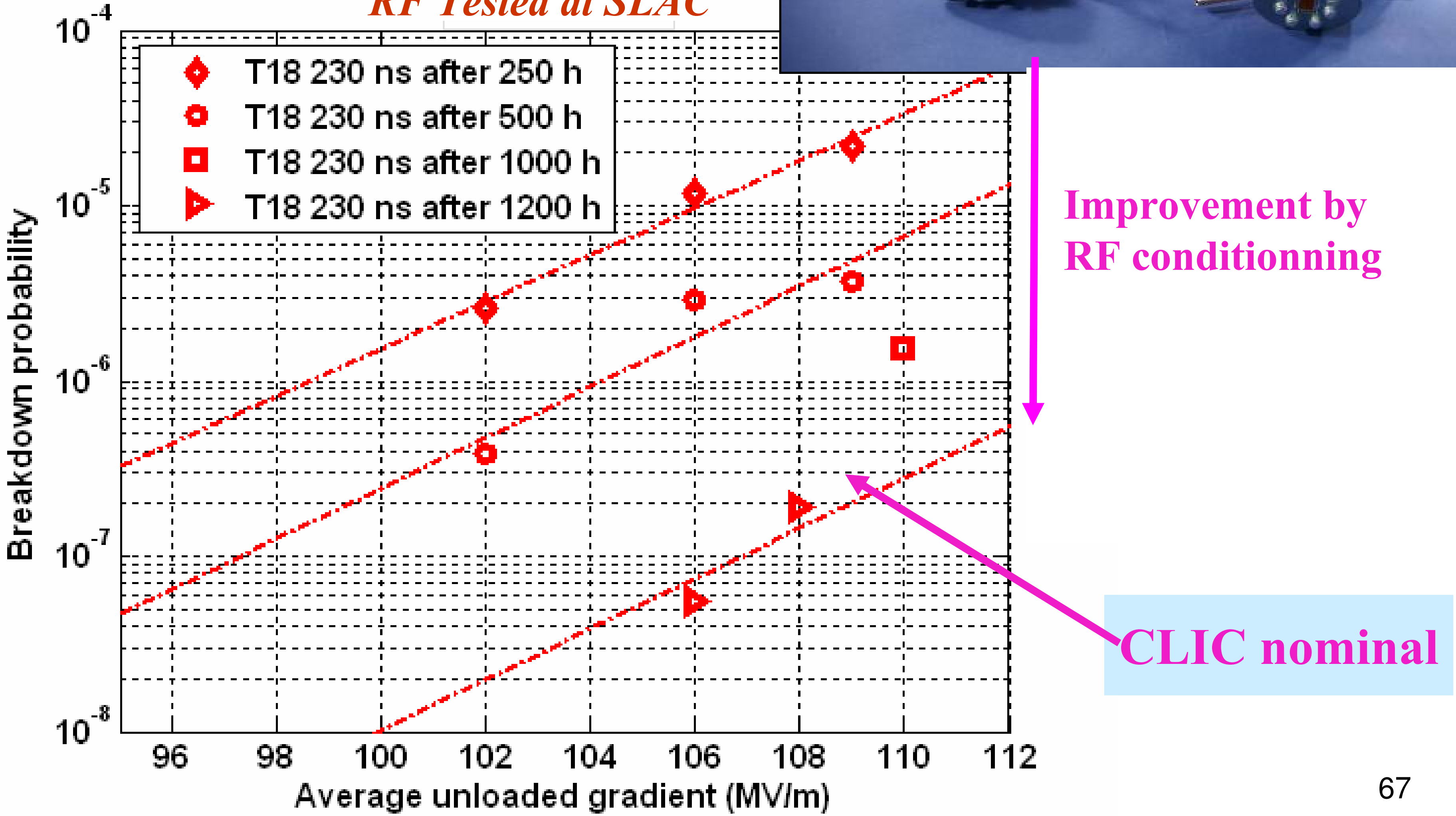




# Nominal CLIC Structure Performance demonstrated

*A shining example of fruitful collaboration:*

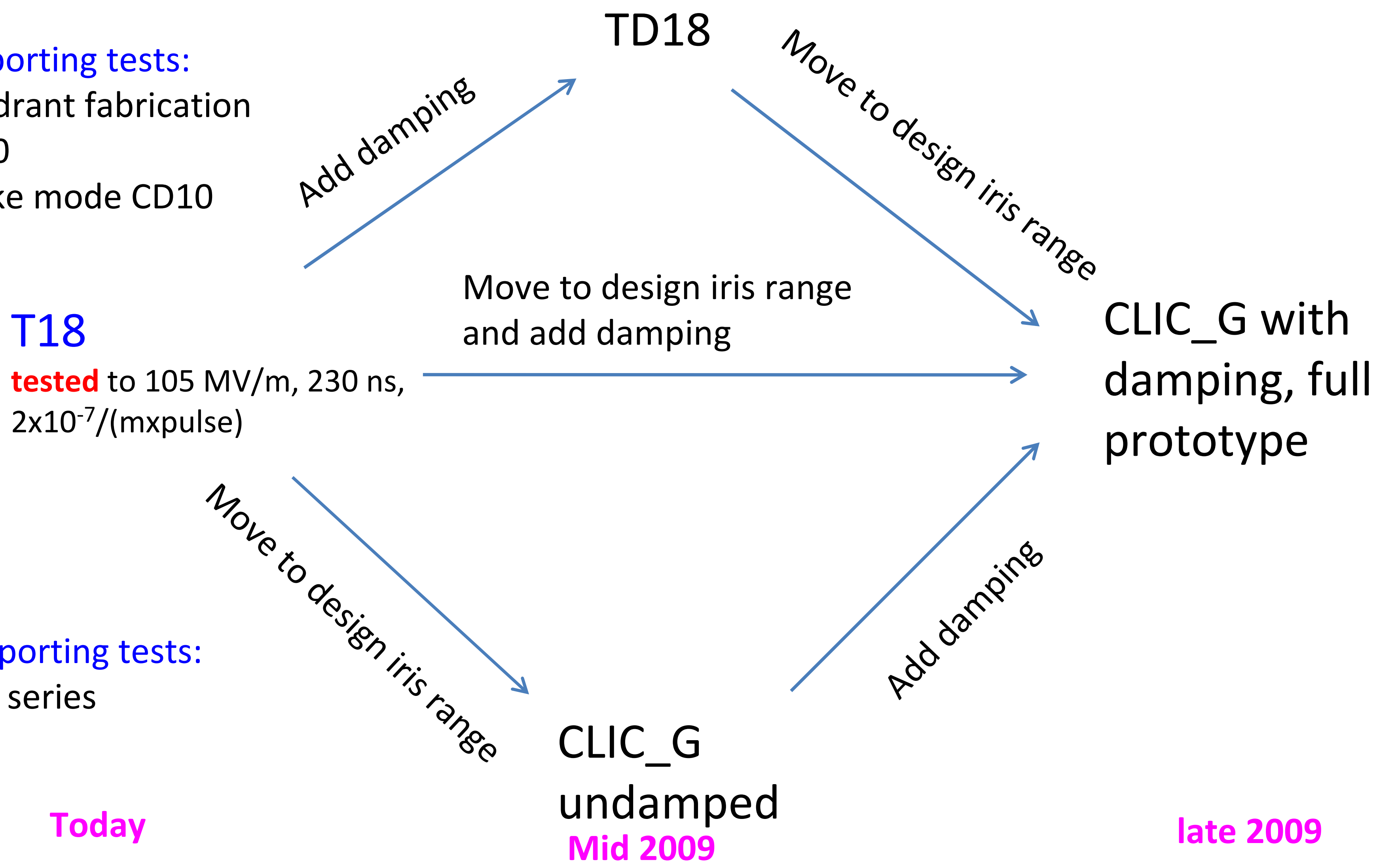
*T18_VG2.4_disk: (without damping)* — *Designed at CERN, Built at KEK, RF Tested at SLAC*



# *The path to the CLIC full-structure feasibility demonstration*

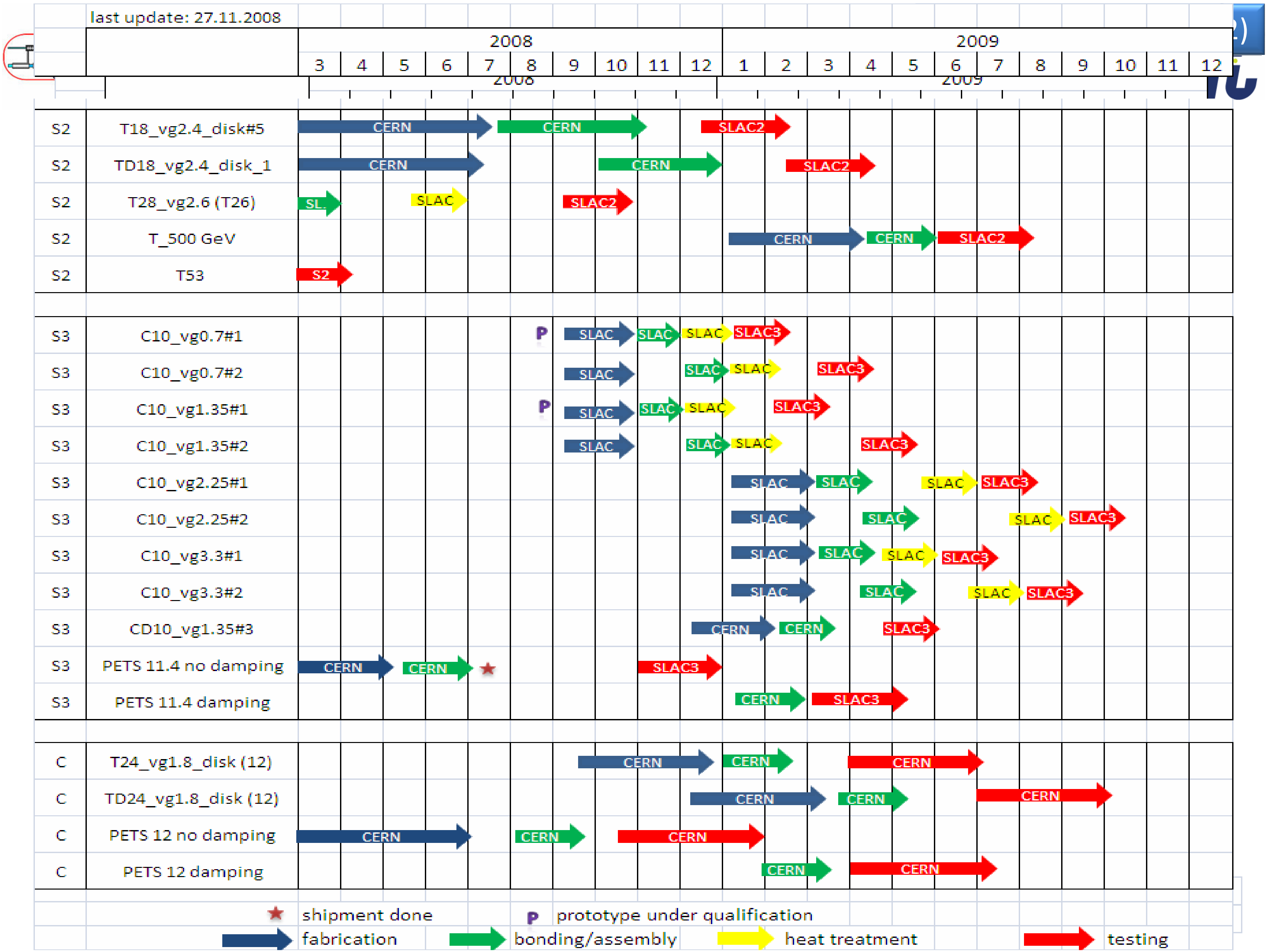
***Move from achieved result with simplified structure to fully equipped, higher efficiency structure***

Supporting tests:
Quadrant fabrication
CD10
Choke mode CD10




Supporting tests:
C10 series
T23

Today

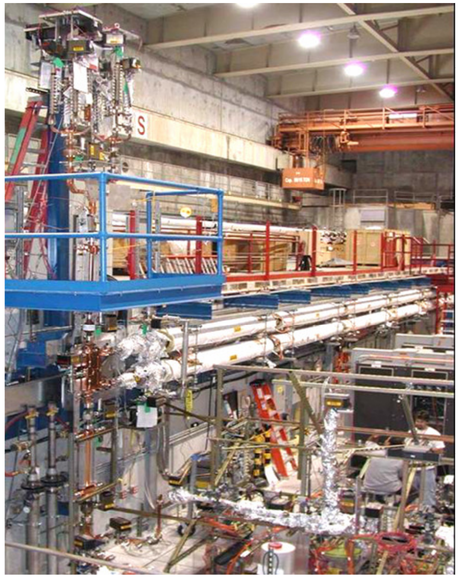


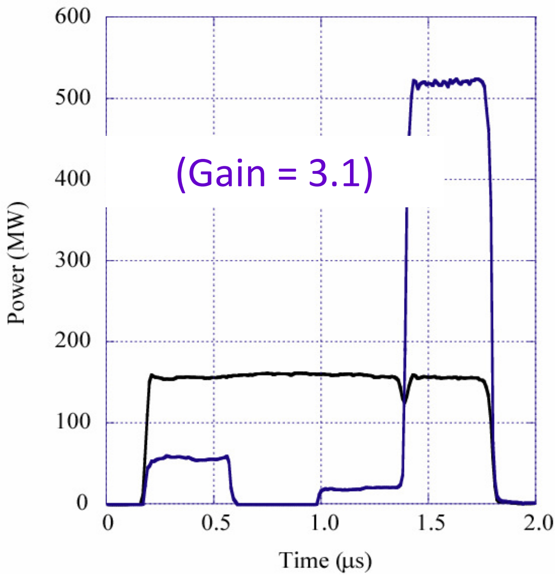
last update: 27.11.2008
2008
2009
3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
S2 T18_vg2.4_disk#5 CERN CERN SLAC2
S2 TD18_vg2.4_disk_1 CERN CERN SLAC2
S2 T28_vg2.6 (T26) SL SLAC SLAC2
S2 T_500 GeV CERN CERN SLAC2
S2 T53 S2
S3 C10_vg0.7#1 P SLAC SLAC SLAC SLAC3
S3 C10_vg0.7#2 SLAC SLAC SLAC SLAC3
S3 C10_vg1.35#1 P SLAC SLAC SLAC SLAC3
S3 C10_vg1.35#2 SLAC SLAC SLAC SLAC3
S3 C10_vg2.25#1 SLAC SLAC SLAC SLAC3
S3 C10_vg2.25#2 SLAC SLAC SLAC SLAC3
S3 C10_vg3.3#1 SLAC SLAC SLAC SLAC3
S3 C10_vg3.3#2 SLAC SLAC SLAC SLAC3
S3 CD10_vg1.35#3 CERN CERN SLAC3
S3 PETS 11.4 no damping CERN CERN SLAC3
S3 PETS 11.4 damping CERN SLAC3
C T24_vg1.8_disk (12) CERN CERN CERN
C TD24_vg1.8_disk (12) CERN CERN CERN
C PETS 12 no damping CERN CERN CERN
C PETS 12 damping CERN CERN
shipment done
P prototype under qualification
fabrication
bonding/assembly
heat treatment
testing

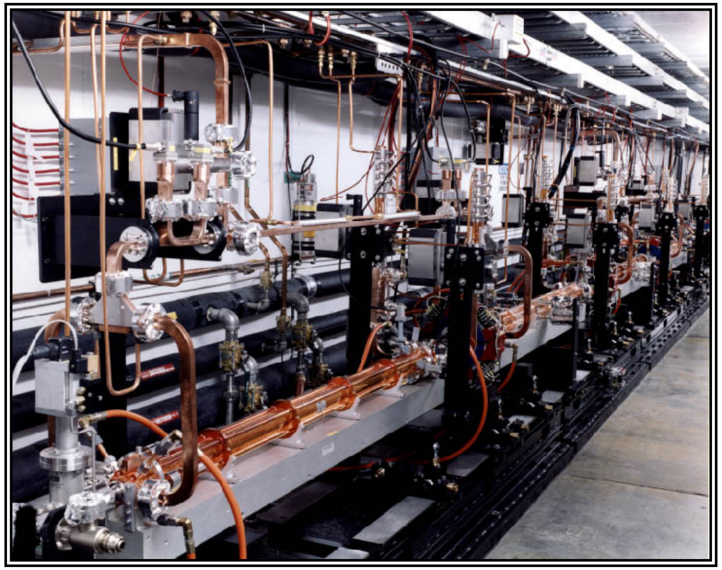
# SLAC/ NLCTA – Layout

- 3 x RF stations
  - 2 x pulse compressors (240ns - 300MW max), driven each by 2 x 50MW X-band klystrons
  - 1 x pulse compressors (400ns – 300MW /200ns – 500MW variable), driven by 2 x 50MW X-band klystrons.
- 1 x Injector: 65MeV, ~0.3 nC / bunch

- In the accelerator housing:
  - 2 x 2.5m slots for structures
- Shield Enclosure: suitable up to 1 GeV
- For operation:
  - Can run 24/7 using automated controls

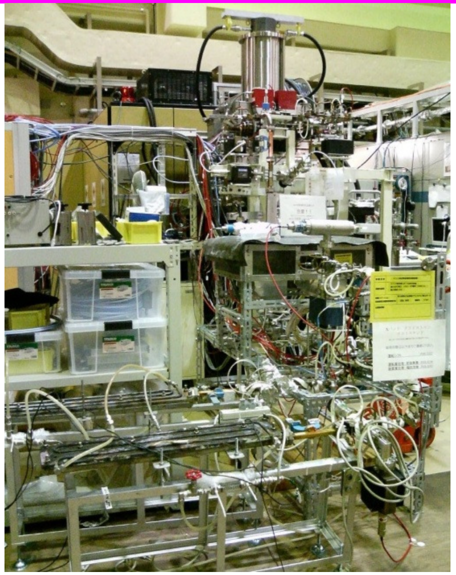




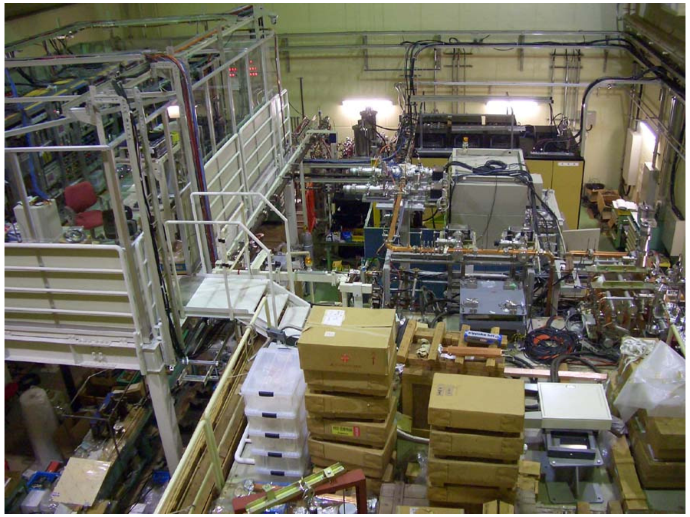



# KEK / NEXTEF - Layout

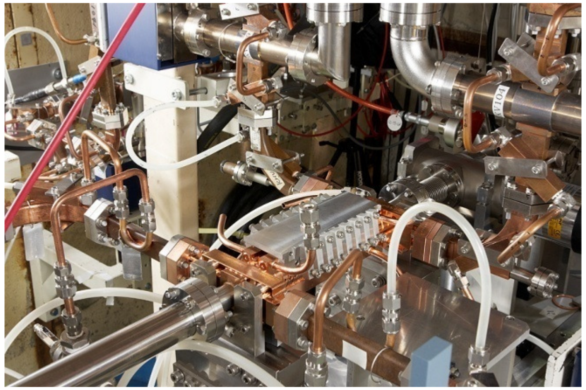
- Presently,
  - Two klystrons with a power combiner.
  - Max. 120MW/300ns, Typical. 100MW/300ns at comb.-out;
  - ~70MW/300ns at struc.-in
- Hoping to implement in 2010 (or later)
  - Pulse compression to make power of ~150MW available.



One klystron setup

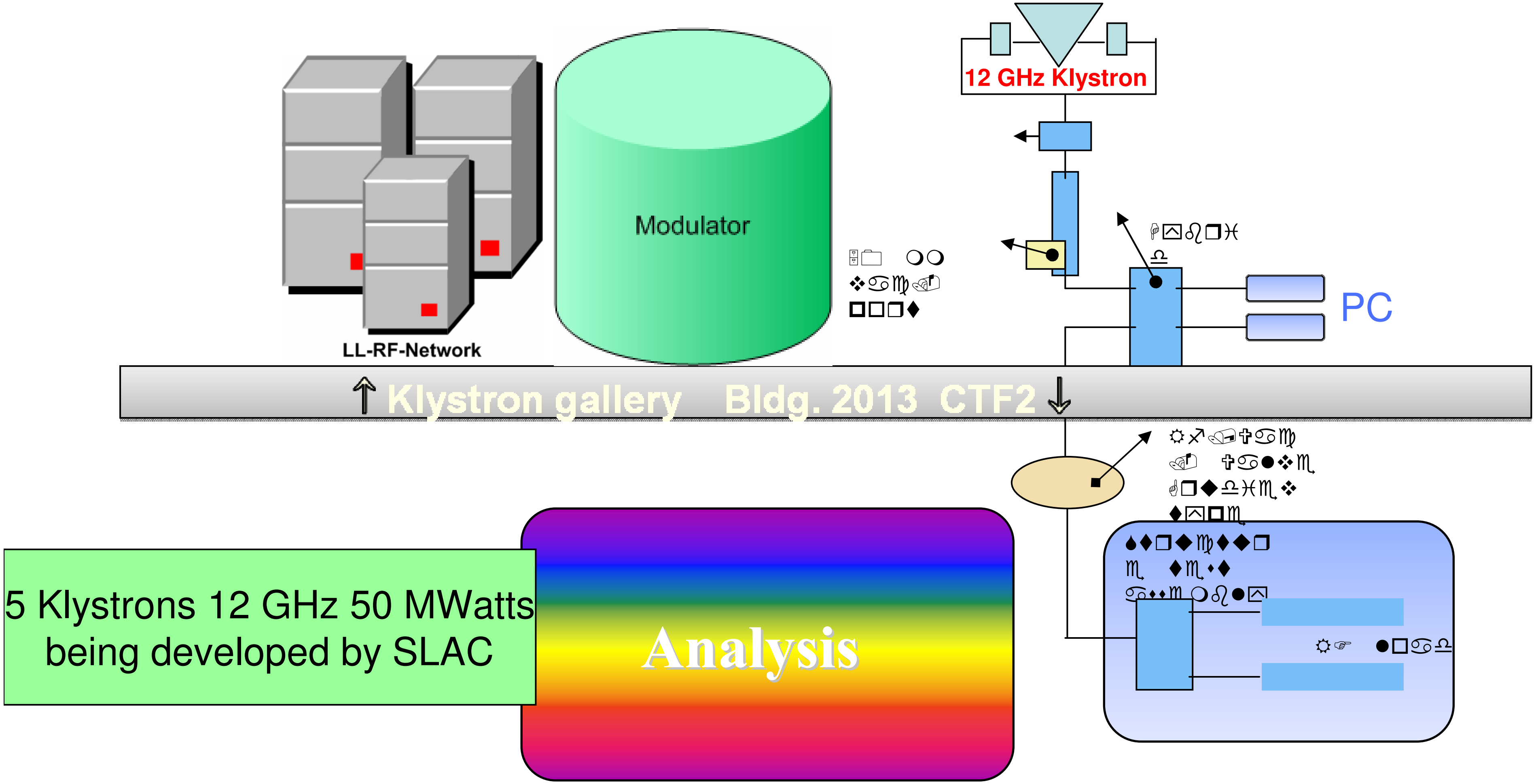


Two klystron facility



Inside shield room

# *12 GHz Klystron based RF power source*
# *X-b Structure Test-Stand at CERN (and later CEA)*
# *X-b Structure Operation at PSI and Trieste*



# X-Band structures for Linac based X-FEL at PSI and ELETTRA/TRIESTE

FEL-DM84-002-1

Date15.08.2008

## Collaboration framework for a common CLIC/PSI-XFEL X Band structure.

M.Dehler, J.-Y. Raguin, A. Citterio, A. Falone (PSI)

W. Wuensch, G. Riddone, A. Grudiev, R. Zennaro (CERN)

### *Motivation*

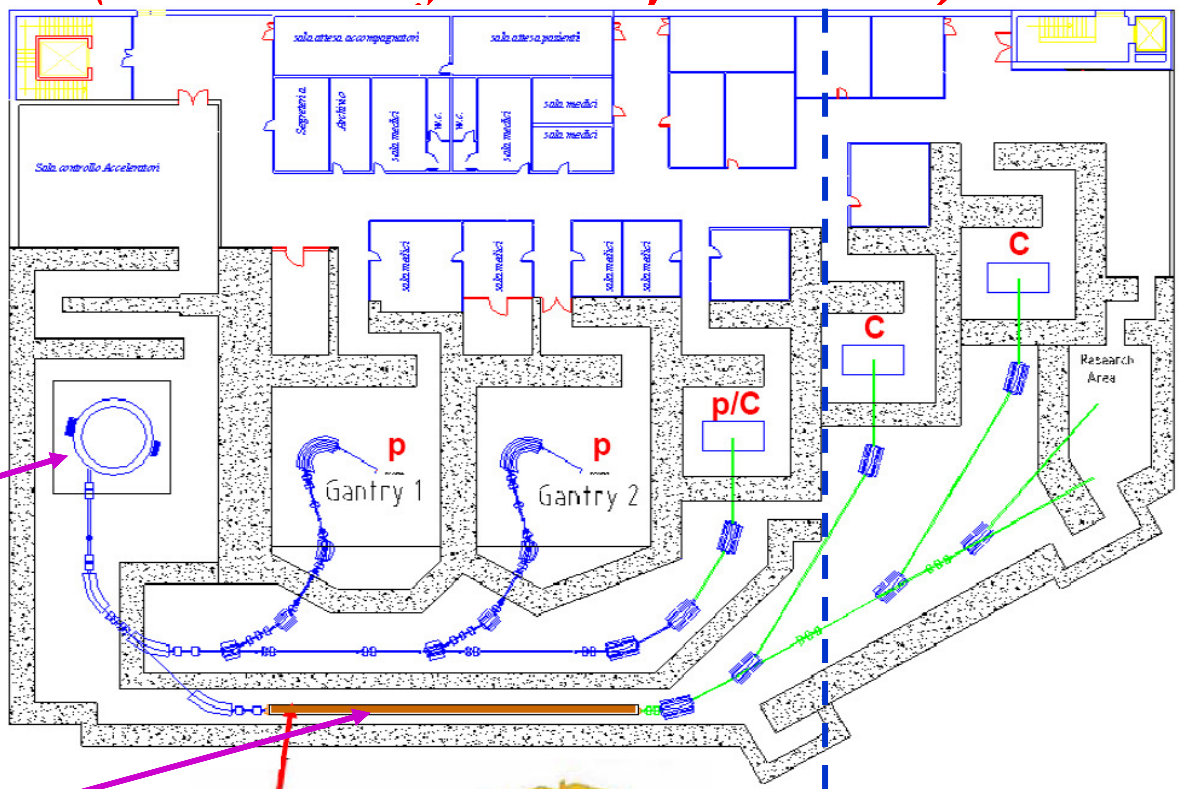
To compensate nonlinearities in the longitudinal phase space at the injector prototype of the PSI-XFEL, PSI requires a high frequency RF structure in the X band. At the same time CLIC is pursuing a program for producing and testing high gradient RF structures in the X band, exploring the effect of different geometries and materials on break down limits and rates.

Given that the PSI-XFEL has somewhat lower requirements in terms of gradient and efficiency, it may be interesting to share work and expense in designing and producing a common CLIC/XFEL structure. It would provide new data for the CLIC structure tests and be simultaneously a safe and low risk solution for the more relaxed operating gradient used at the PSI-XFEL. At the same time the prolonged operation of such a structure in the PSI FEL injector, albeit not at CLIC parameters, would constitute a good quality test for the procedure employed.

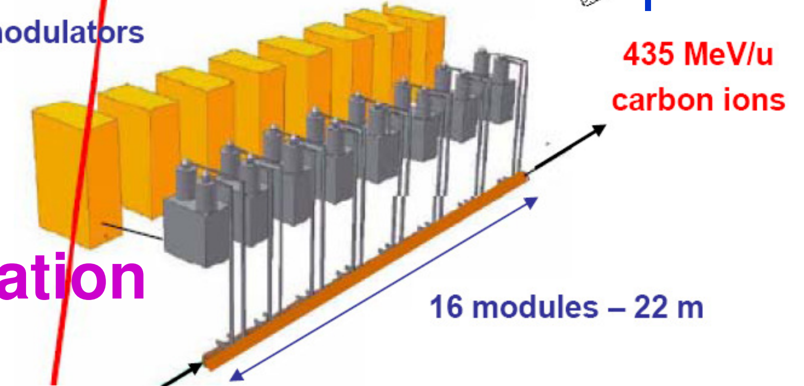
The collaboration covers the design, fabrication, tuning and low level testing of the X band structures. Two structures will produced, of which the first will go directly to PSI to be integrated into the 250 MeV injector. The second will undergo high power tests at the two beam test stand in CTF3. As soon as these are finished and the necessary data has been taken, this structure will serve as a spare at PSI.

# *CArbon BOoster Therapy in Oncology (CABOTO by TERA foundation)*

**TERA**




**SC cyclotron**




**12 GHz NC Linac**
**(power efficiency)**
**CLIC/TERA Collaboration**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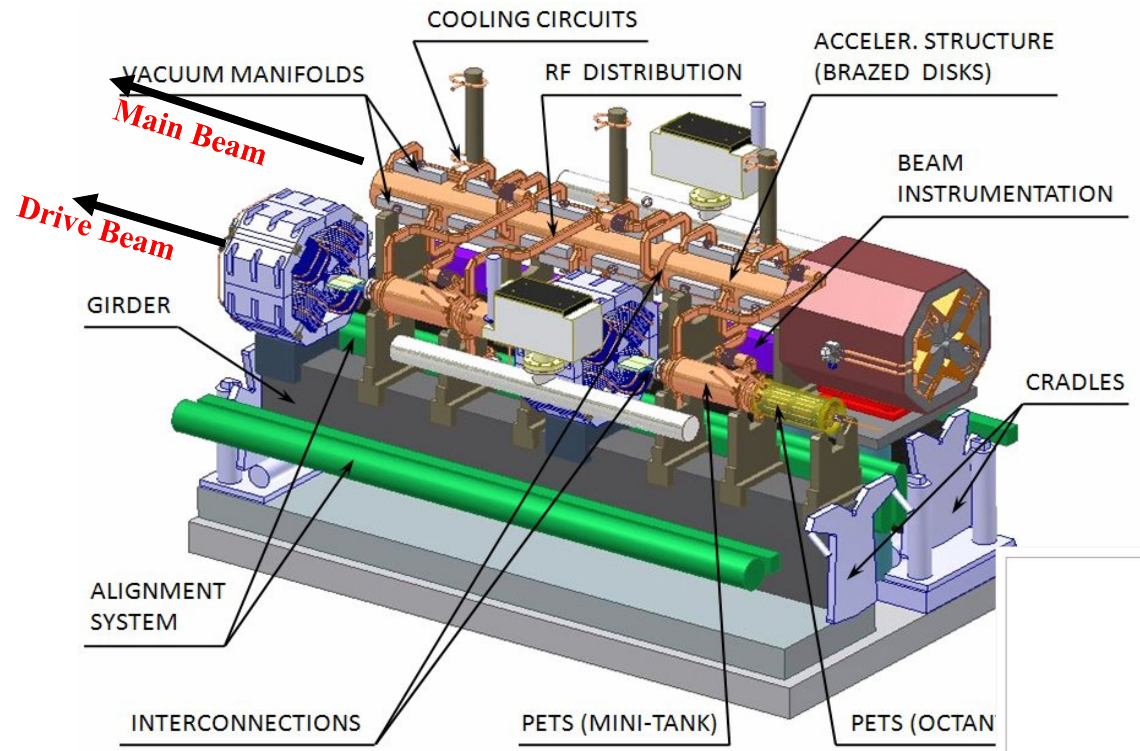
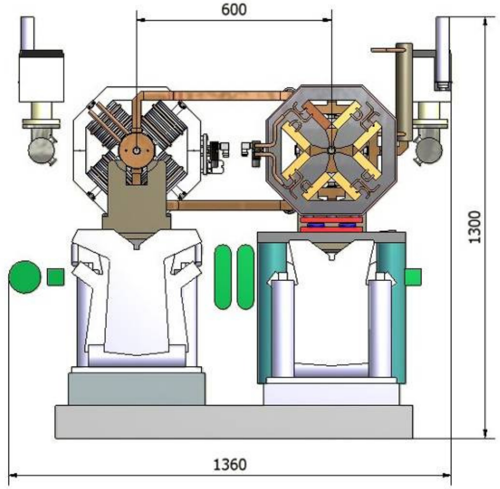
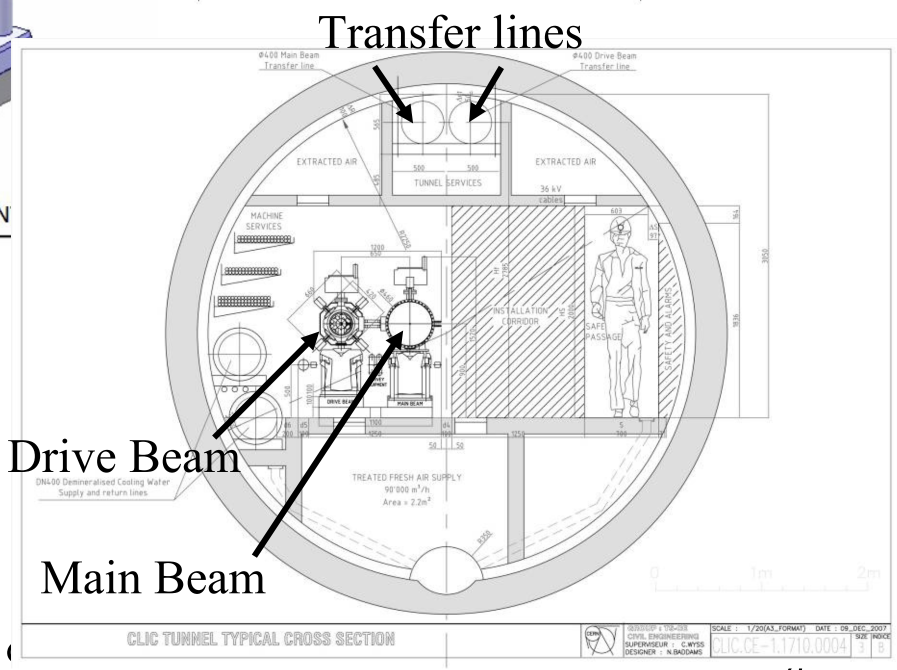
# CLIC Two Beam Module



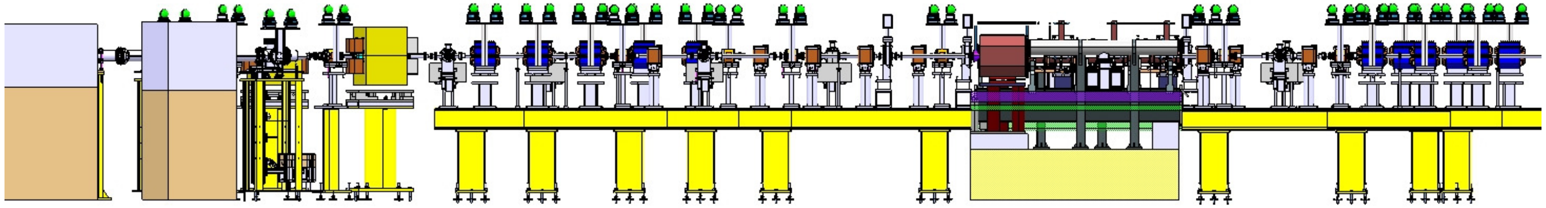

20760 modules (2 meters long)

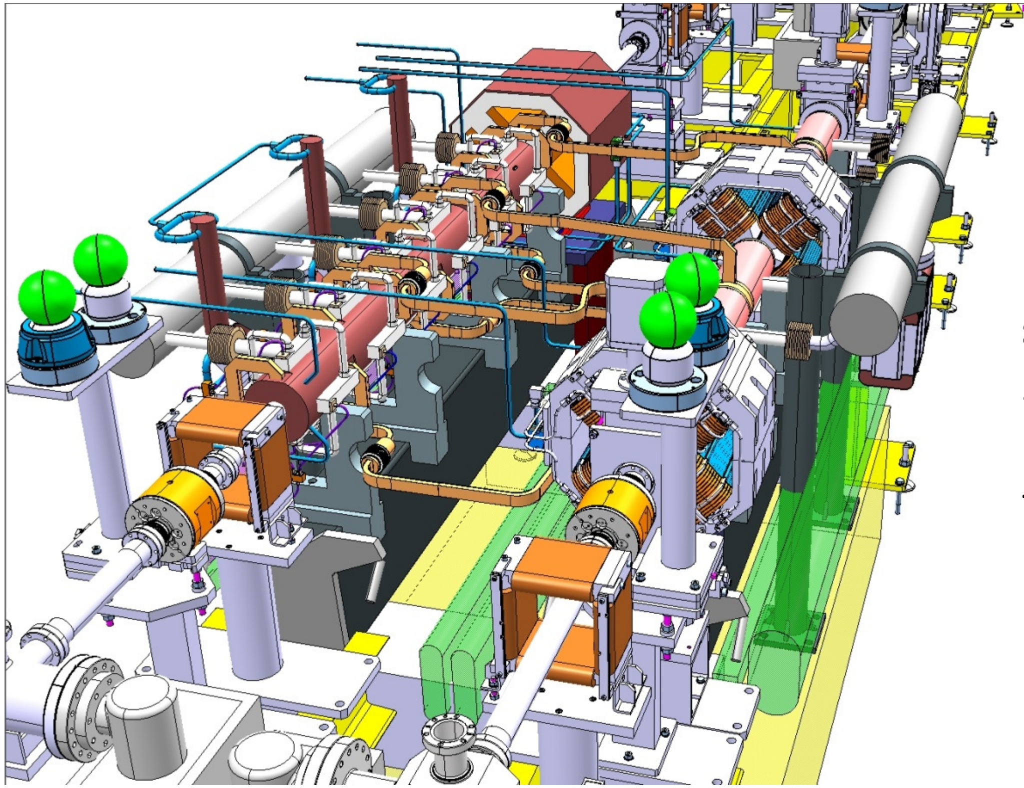
71460 power production structures PETS (drive beam)

143010 accelerating structures

(main beam)

# *Two Beam Module tests in CTF3/CLEX*

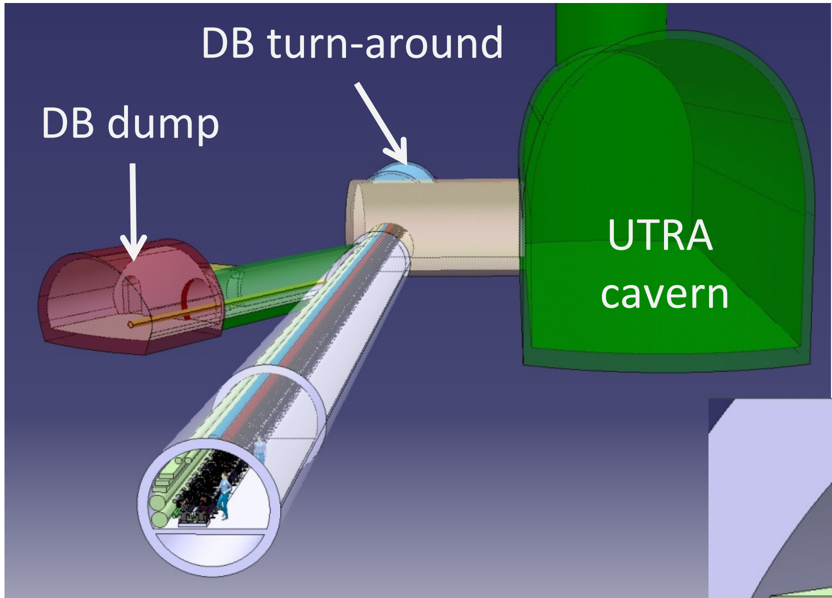


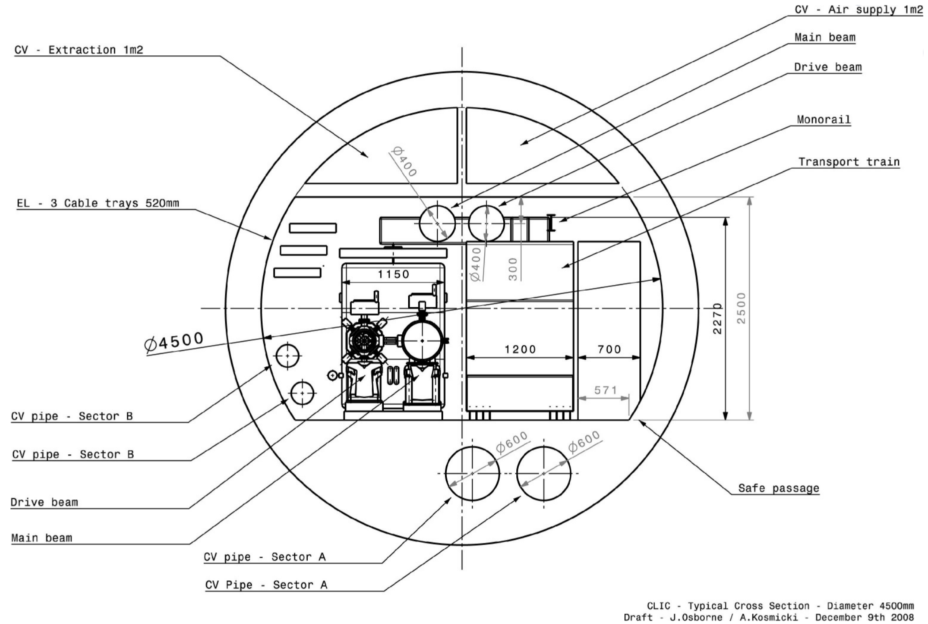


**Two Beam Test Stand: Contribution of Swedish Collaboration: Uppsala Univ.**

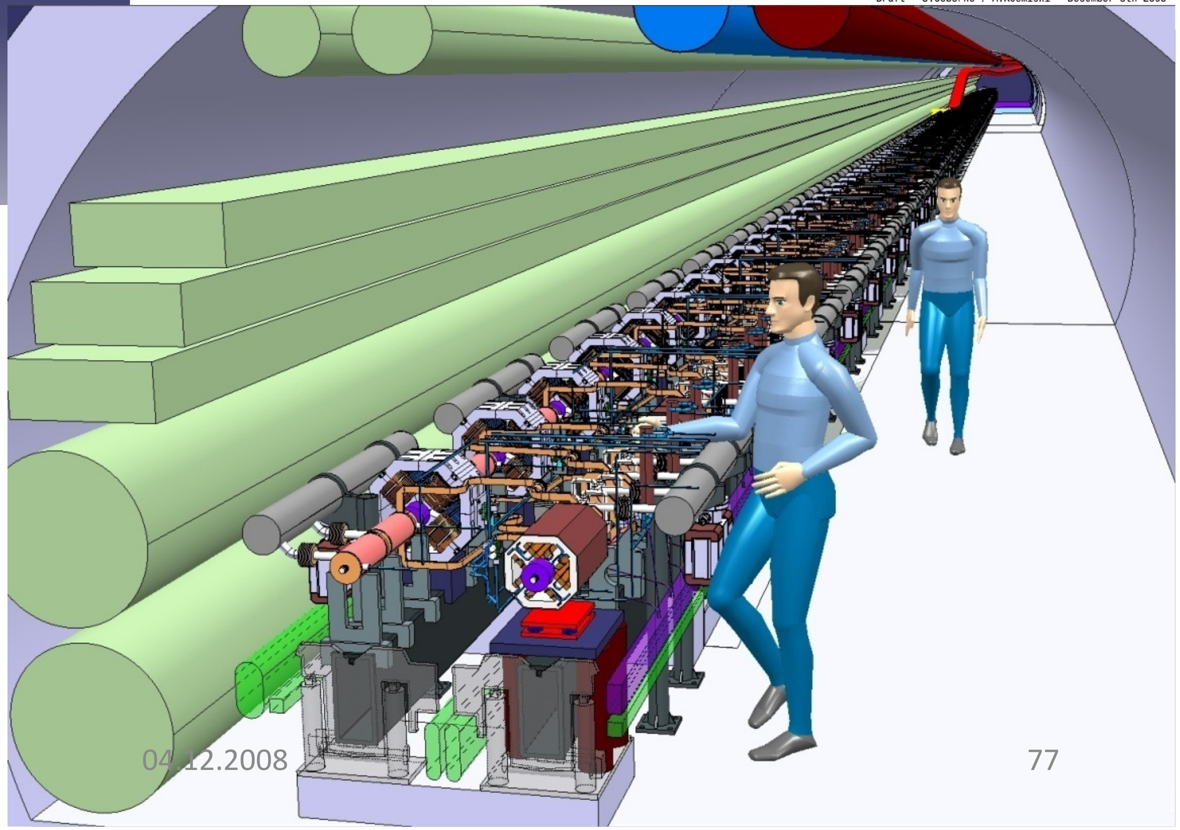
**Design and integration of different sub-systems**, i.e. to simultaneously satisfy requirements of highest possible gradient, power handling, tight mechanical tolerances and heavy HOM damping

# *Tunnel integration*

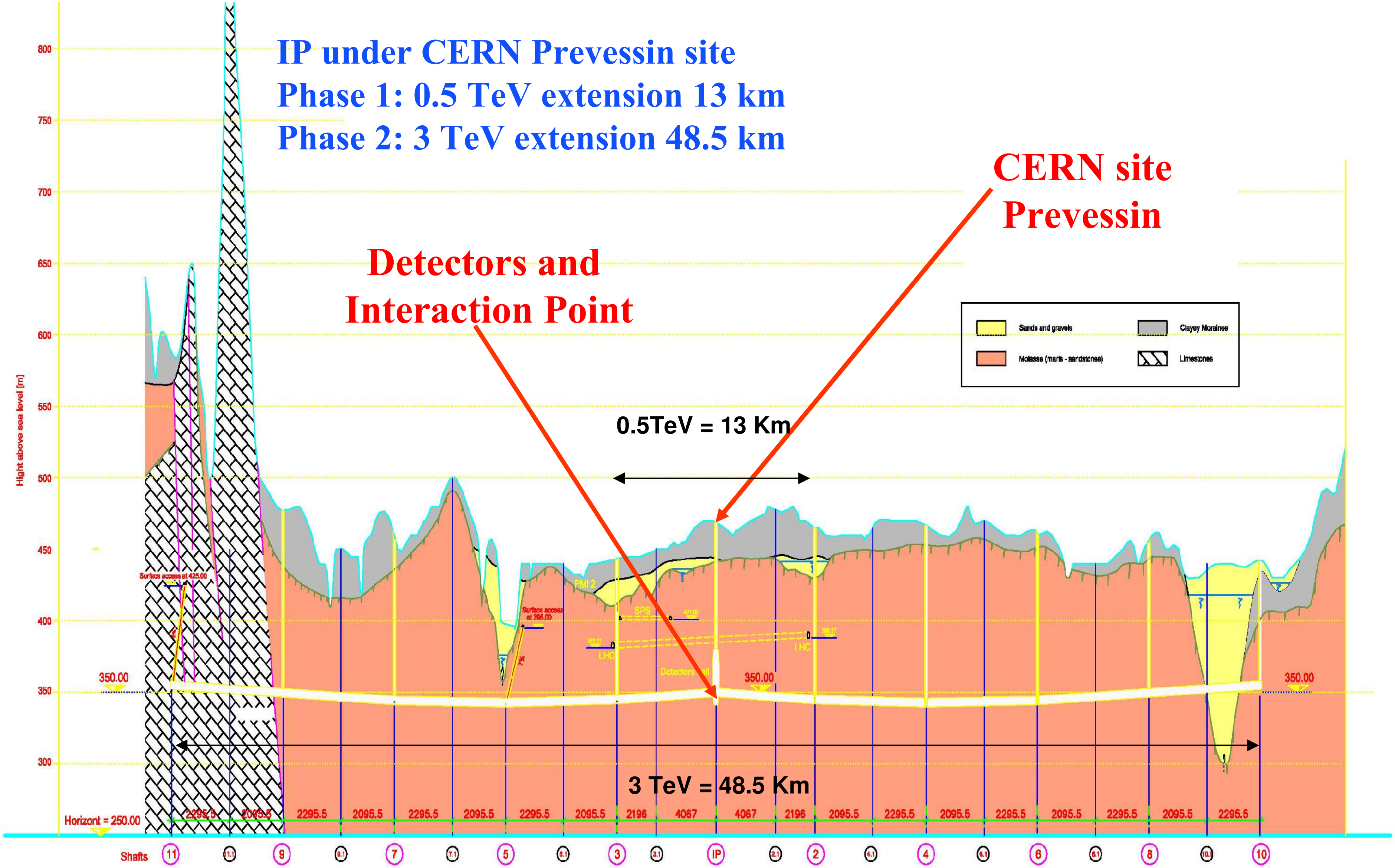


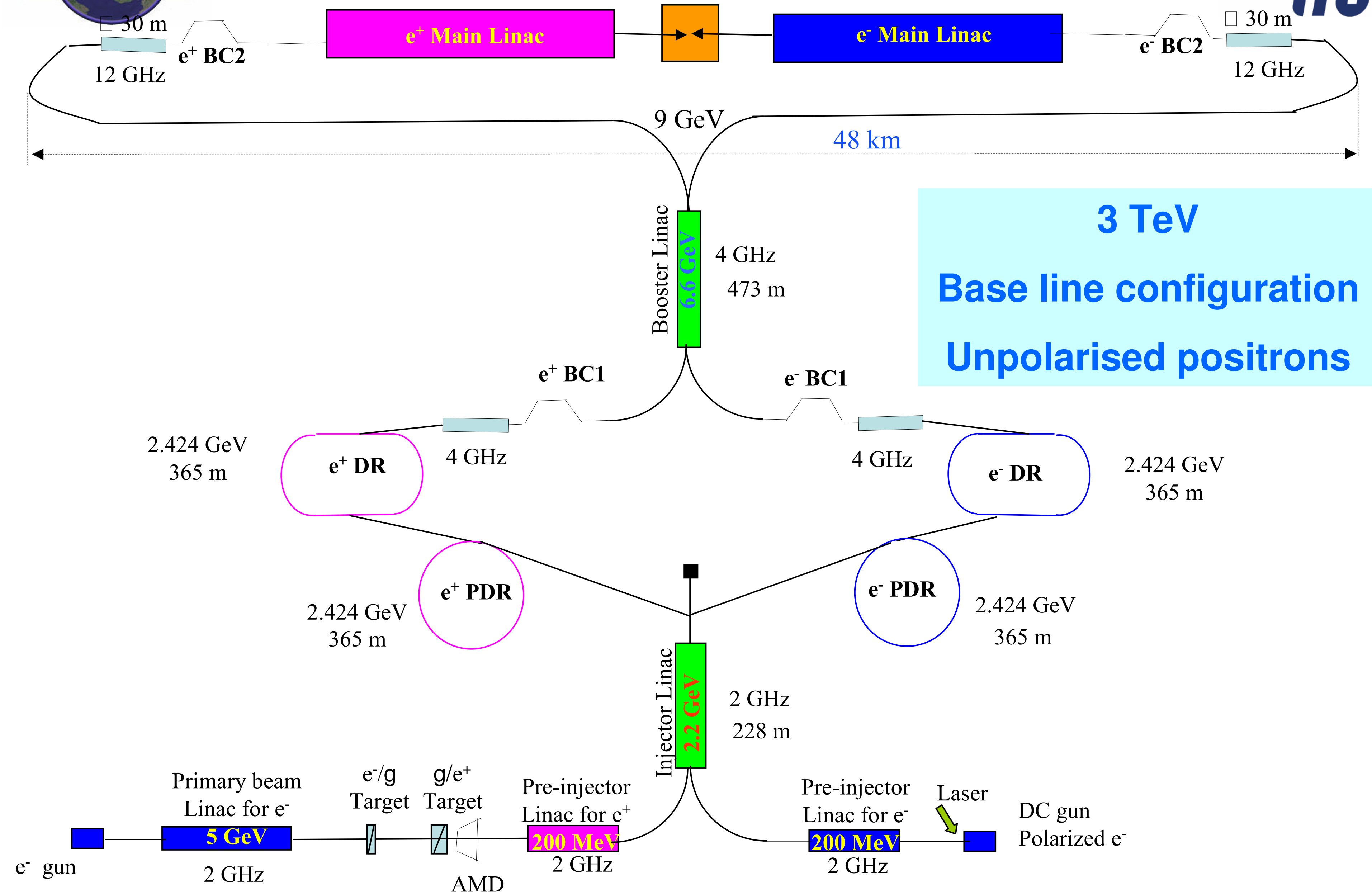

**Standard tunnel with modules**



# Longitudinal section of a laser straight Linear Collider on CERN site–



# The CLIC Injector complex in 2008

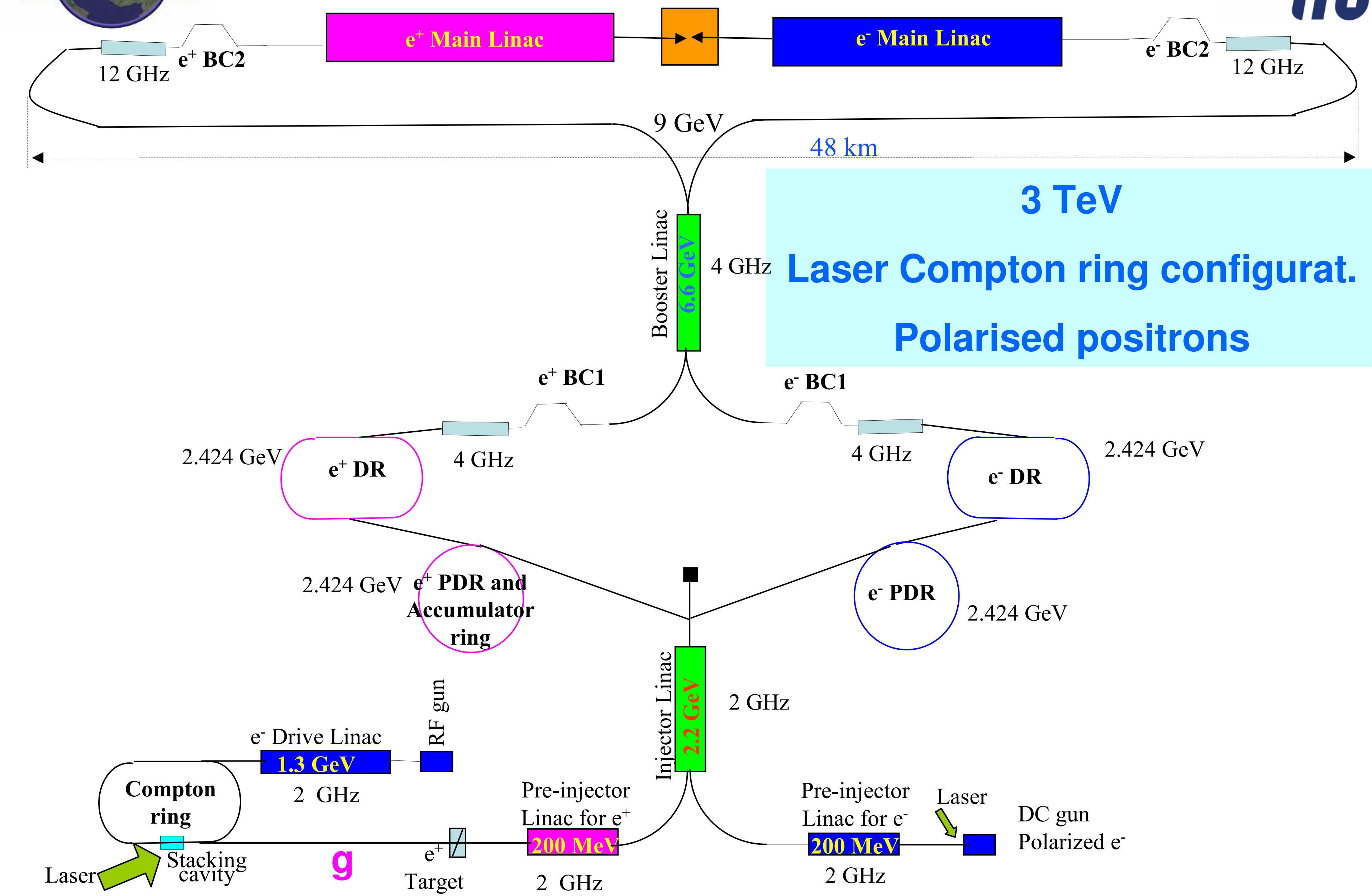



**3 TeV**

**Base line configuration**

**Unpolarised positrons**

# The CLIC Injector complex (Compton)

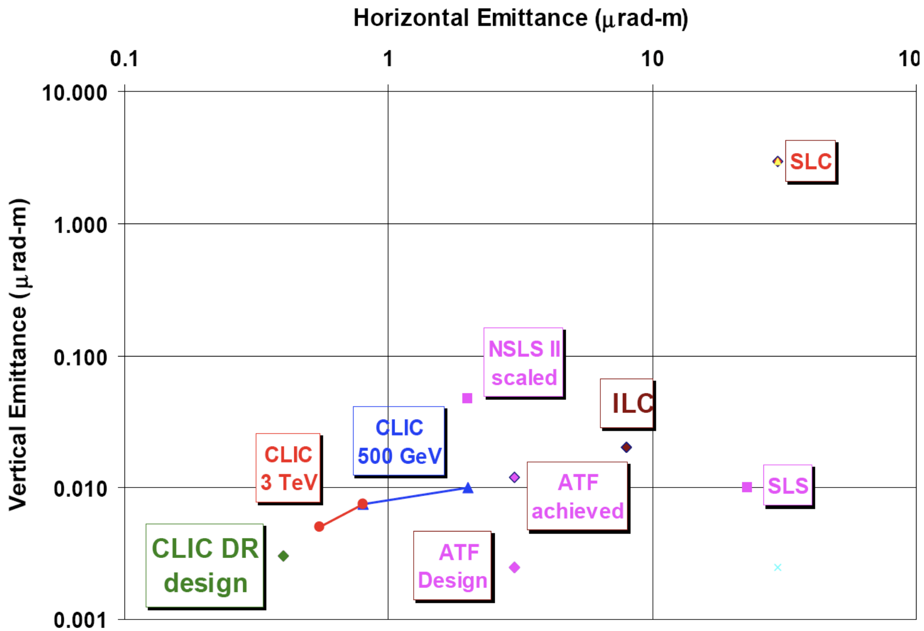



**3 TeV**

**Laser Compton ring configurat.**

**Polarised positrons**

# *Damping ring design*

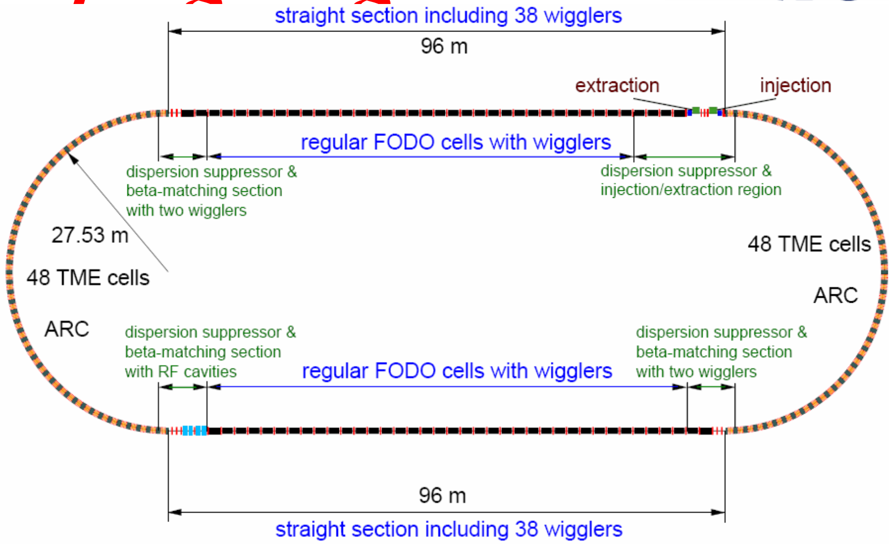



| PARAMETER | NLC | CLIC (3TeV) |
|---|---|---|
| bunch population ($10^9$) | 7.5 | 4.1 |
| bunch spacing [ns] | 1.4 | 0.5 |
| number of bunches/train | 192 | 316 |
| number of trains | 3 | 1 |
| Repetition rate [Hz] | 120 | 50 |
| Extracted hor. normalized emittance [nm] | 2370 | <550 |
| Extracted ver. normalized emittance [nm] | <30 | <5 |
| Extracted long. normalized emittance [keV.m] | 10.9 | <5 |
| Injected hor. normalized emittance [µm] | 150 | 63 |
| Injected ver. normalized emittance [µm] | 150 | 1.5 |
| Injected long. normalized emittance [keV.m] | 13.18 | 1240 |

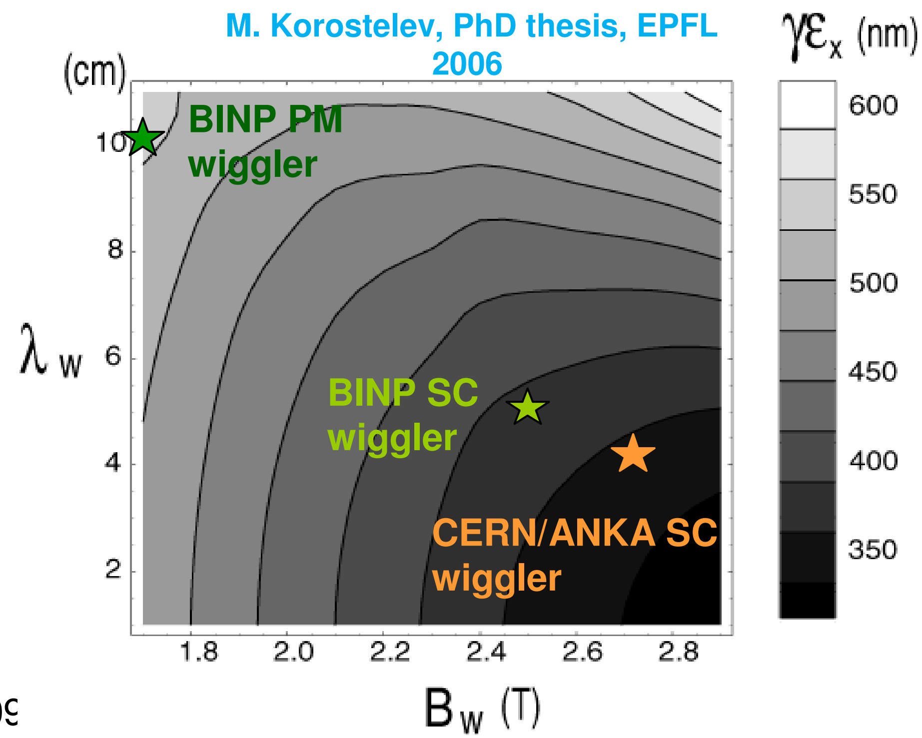
- **Present CLIC DR design for** 3TeV **achieves goals for transverse emittances with a 20%-30% margin (**380nm **horizontal and** 4.1nm **vertical)**
- **Conservative DR output emittances (**2.4µm **horizontal,** 10nm **vertical) for CLIC @** 500GeV **scaled from operational or approved light source projects (NSLSII, SLS)**
- **Route to lower emittances to be defined**

# *CLIC damping rings*

- Two **365.2m** long rings of racetrack shape @ **2.424GeV**
- Arcs filled with **TME cells** and straights with **2m-long superconducting** damping wigglers (**2.5T**, **5cm** period)
- Output emittance strongly dominated by **IBS**
- Issues to be addressed
    - Lattice optimization (magnet design, non-linear dynamics)
    - Superconducting wiggler design progress (NbTi/$Nb_3Sn$, radiation absorption)
    - Collective effects ($e^-$ cloud, IBS)
    - RF system considerations
    - ILC/CLIC DR common issues
    - Pre-damping ring design (positron stacking)




M. Korostelev, PhD thesis, EPFL 2006



# Beam emittance preservation
# Beam Dynamics, alignment and stability

**Emittance blow-up from Damping Ring to BDS limited:**
- **in Horizontal to 30% from 500 nrad**
- **in Vertical to 300% from 5 nrad**

Pre-alignment precision: 15 microns
Beam based alignement: 5-10 microns
Stability requirements (> 4 Hz)

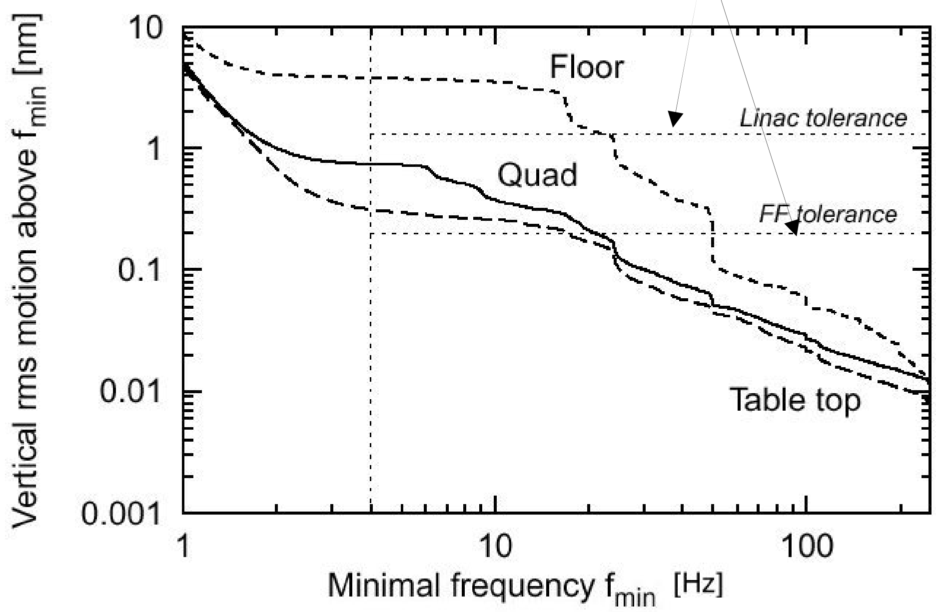
| Magnet | Horiz. | Vert. |
|---|---|---|
| Linac (2600 quads) | 14nm | 1.3 nm |
| Final Focus (2quads) | 4 nm | .15 to1 nm |

Need active damping of vibrations

**Achieved stability on CERN vibration test stand**

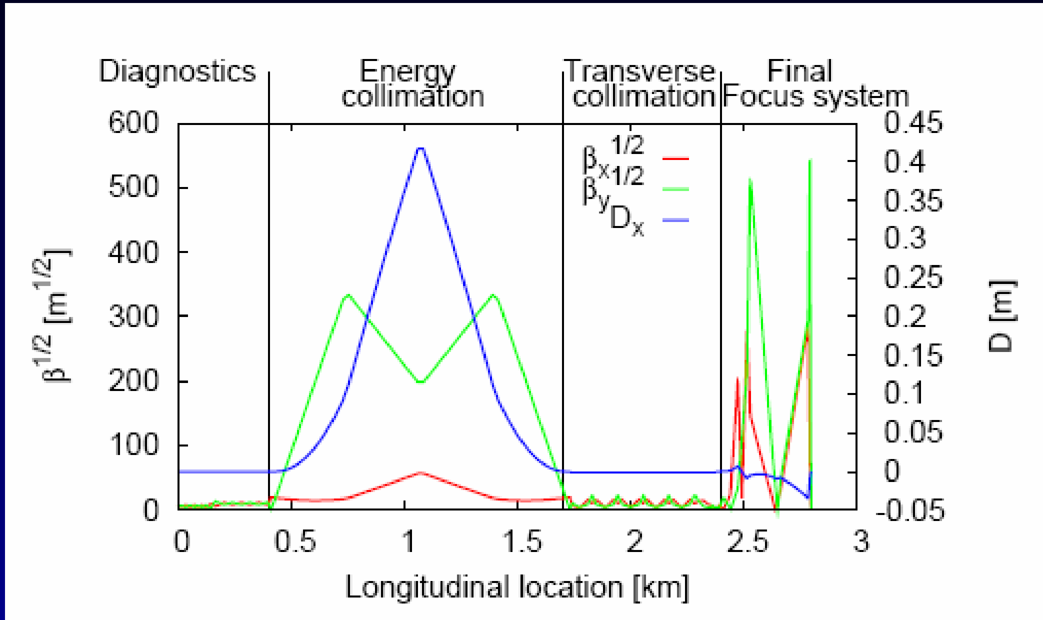
Test made in noisy environment, active damping reduced vibrations by a factor about 20, to rms residual amplitudes of:
Vert. 0.9 ± 0.1 nm
1.3 ± 0.2 nm with cooling water
Horiz. 0.4 ± 0.1 nm

CLIC tolerances

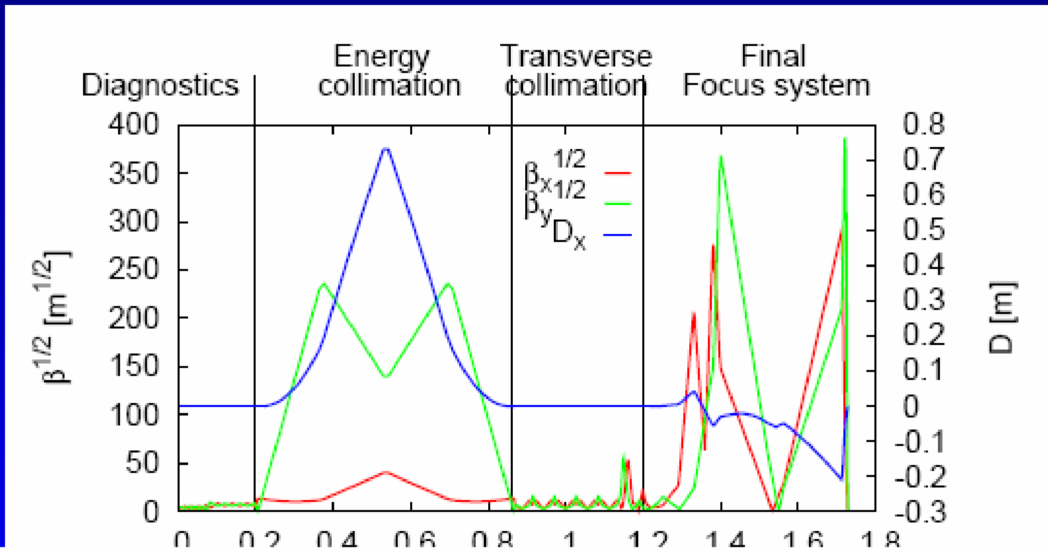


# The CLIC BDS

3 TeV

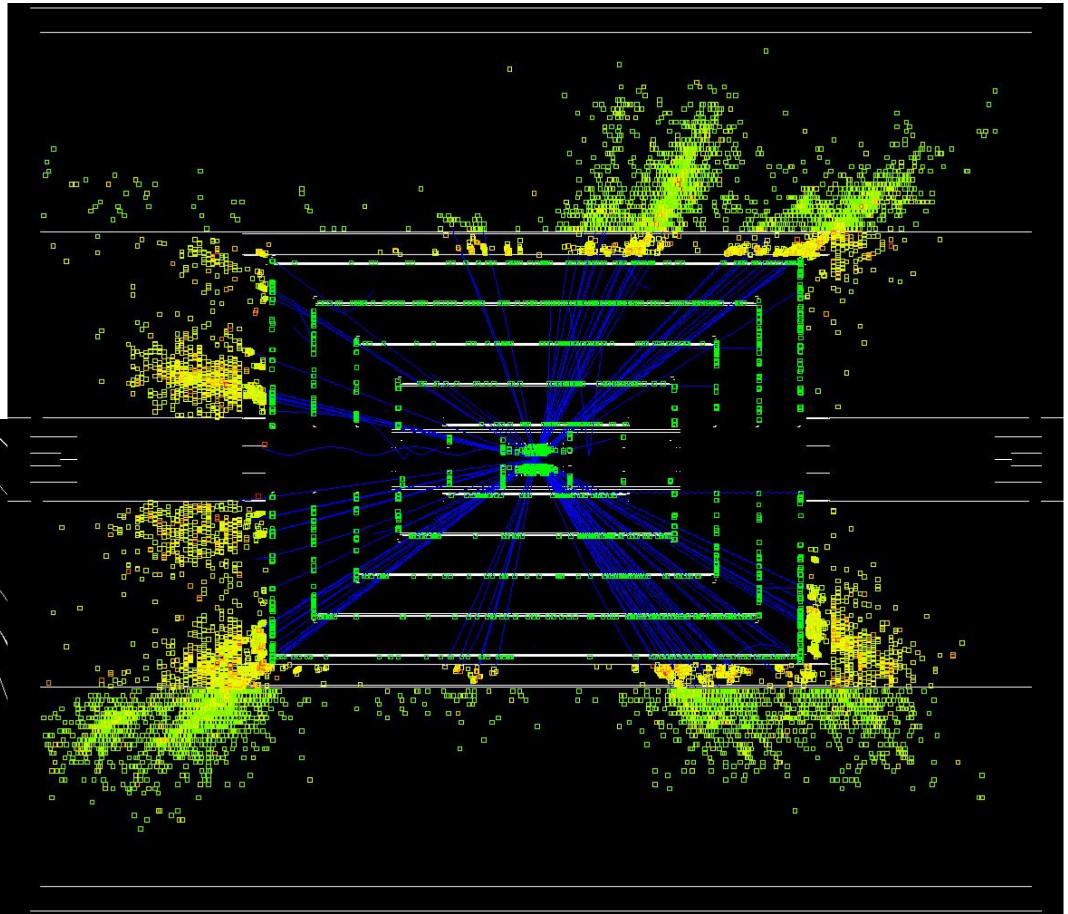


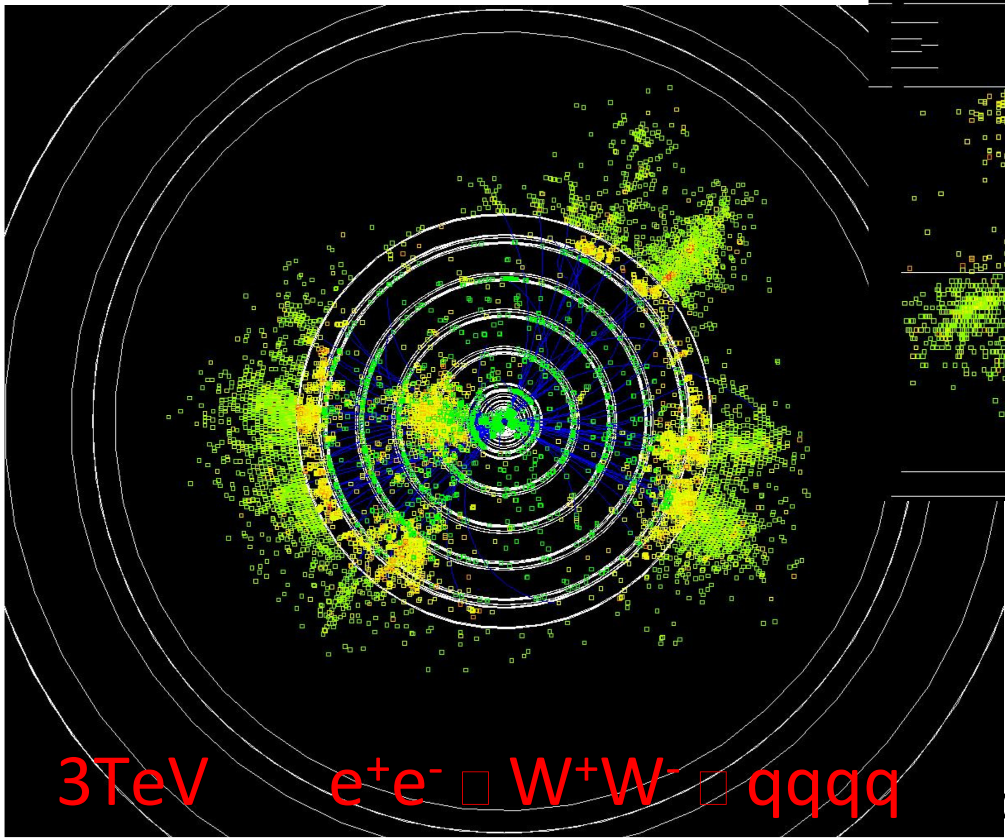

500 GeV



**In preparation for CLIC Conceptual Design Report (CDR) by 2010**

**In collaboration with ILC detector community**



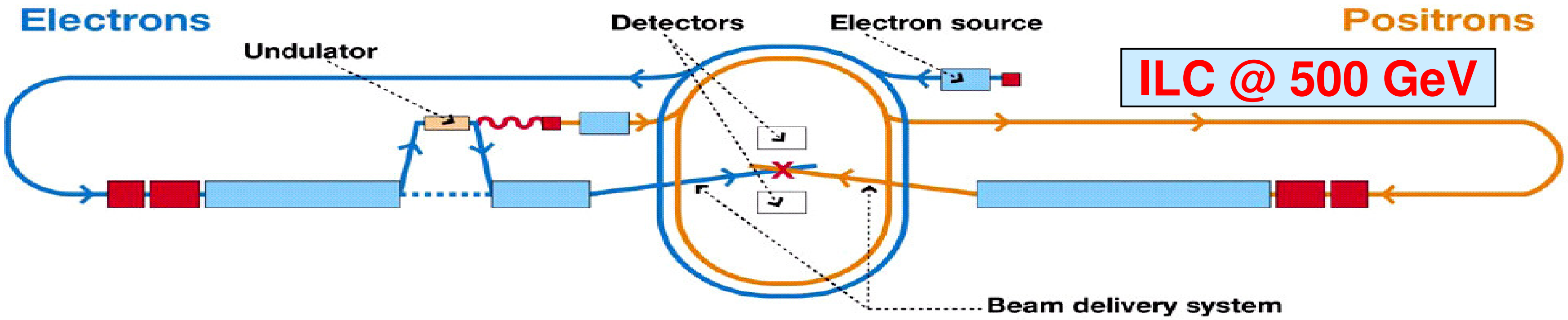


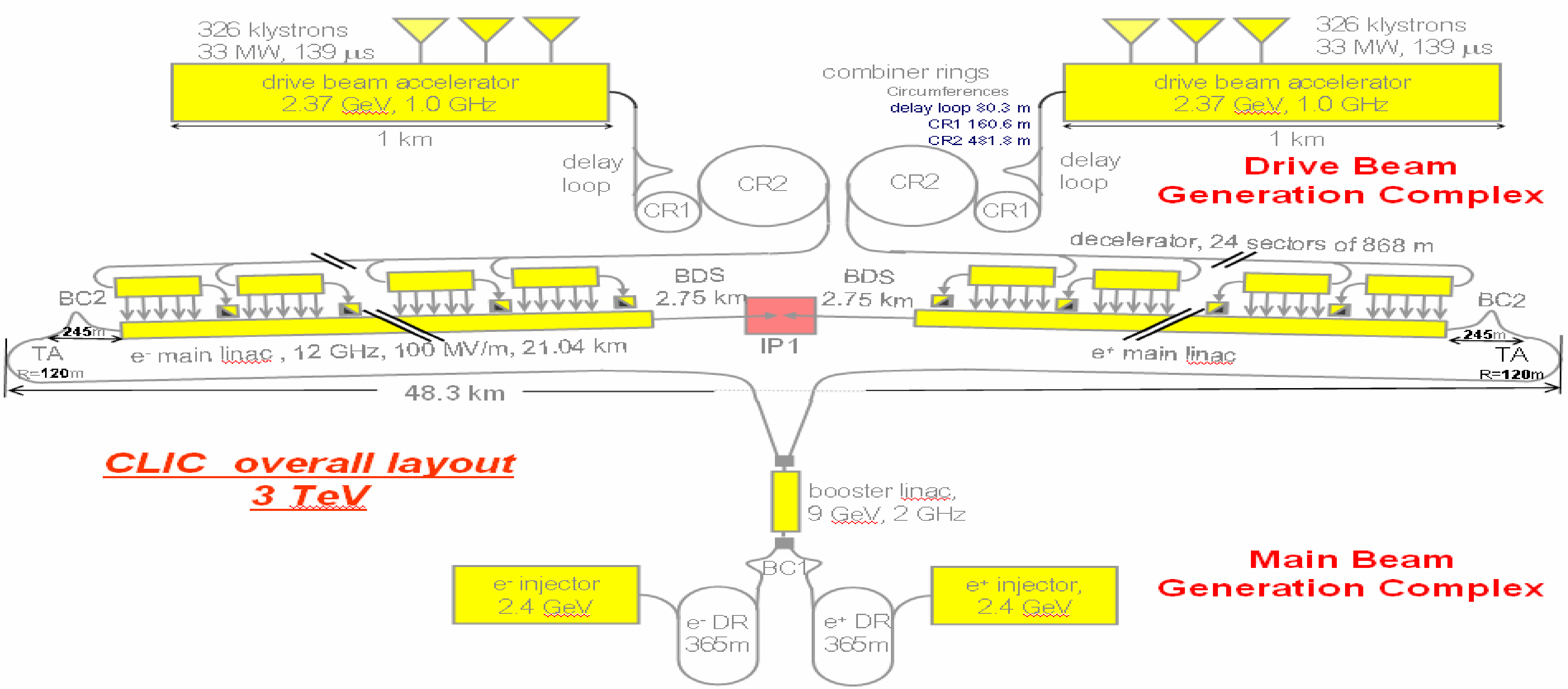
# *A necessary and beneficial CLIC /ILC Collaboration*

http://clic-study.web.cern.ch/CLIC-Study/CLIC_ILC_Collab_Mtg/Index.htm

- **Focusing on subjects with strong synergy between CLIC & ILC**
  - **making the best use of the available resources**
  - **adopting systems as similar as possible**
  - **identifying and understanding the differences due to technology and energy (technical, cost….)**
- **developing common knowledge of both designs and technologies on status, advantages, issues and prospects for the best use of future HEP**
- **preparing together by the Linear Collider Community made up of CLIC & ILC experts:**
  - **the future evaluation of the two technologies**
  - **proposal(s) best adapted to the (future) HEP requirements**

# CLIC and ILC layouts



# *Subjects with strong synergy Working Groups & Conveners*

| | CLIC | ILC |
|---|---|---|
| Physics & Detectors | L.Linssen, D.Schlatter | F.Richard, S.Yamada |
| Beam Delivery System (BDS) & Machine Detector Interface (MDI) | D.Schulte, R.Tomas Garcia E.Tsesmelis | B.Parker, A.Seriy |
| Civil Engineering & Conventional Facilities | C.Hauviller, J.Osborne. | J.Osborne, V.Kuchler |
| Positron Generation (new) | L.Rinolfi | J.Clarke |
| Damping Rings (new) | Y.Papaphilipou | M.Palmer |
| Beam Dynamics | D.Schulte | A.Latina, K.Kubo, N.Walker |
| Cost & Schedule | H.Braun (P.Lebrun), K.Foraz, G.Riddone | J.Carwardine, P.Garbincius, T.Shidara |

# Nature Editorial

- (November 27, 2008)

## Friendly rivalry

The spirit of collaboration in the race to define the LHC's successor sets an example for large projects.

The future for high-energy physics is decidedly mixed. On the one hand, physicists are eagerly awaiting the insights into the Universe promised by the Large Hadron Collider (LHC) at CERN, the European particle-physics laboratory near Geneva. But as governments shift their priorities to societal problems, such as climate change, energy, health and the environment, the field as a whole must also face up to the fact that it will be increasingly difficult to secure funds for pure science.

**"Given this financial uncertainty, it is important that the high-energy physics community does all it can to reduce any internal divisions and to strengthen its external coherence. That is why a new collaboration over what should come after the LHC is to be greeted with enthusiasm."**

**"The potential for destructive rivalry was real. Yet late last month, leaders of the two efforts formally agreed to collaborate as much as is practicable."**

**"The two rivals are closer than they have ever been, and yet research and development on the two underlying accelerator technologies will continue apace with a healthy spirit of competition. "**

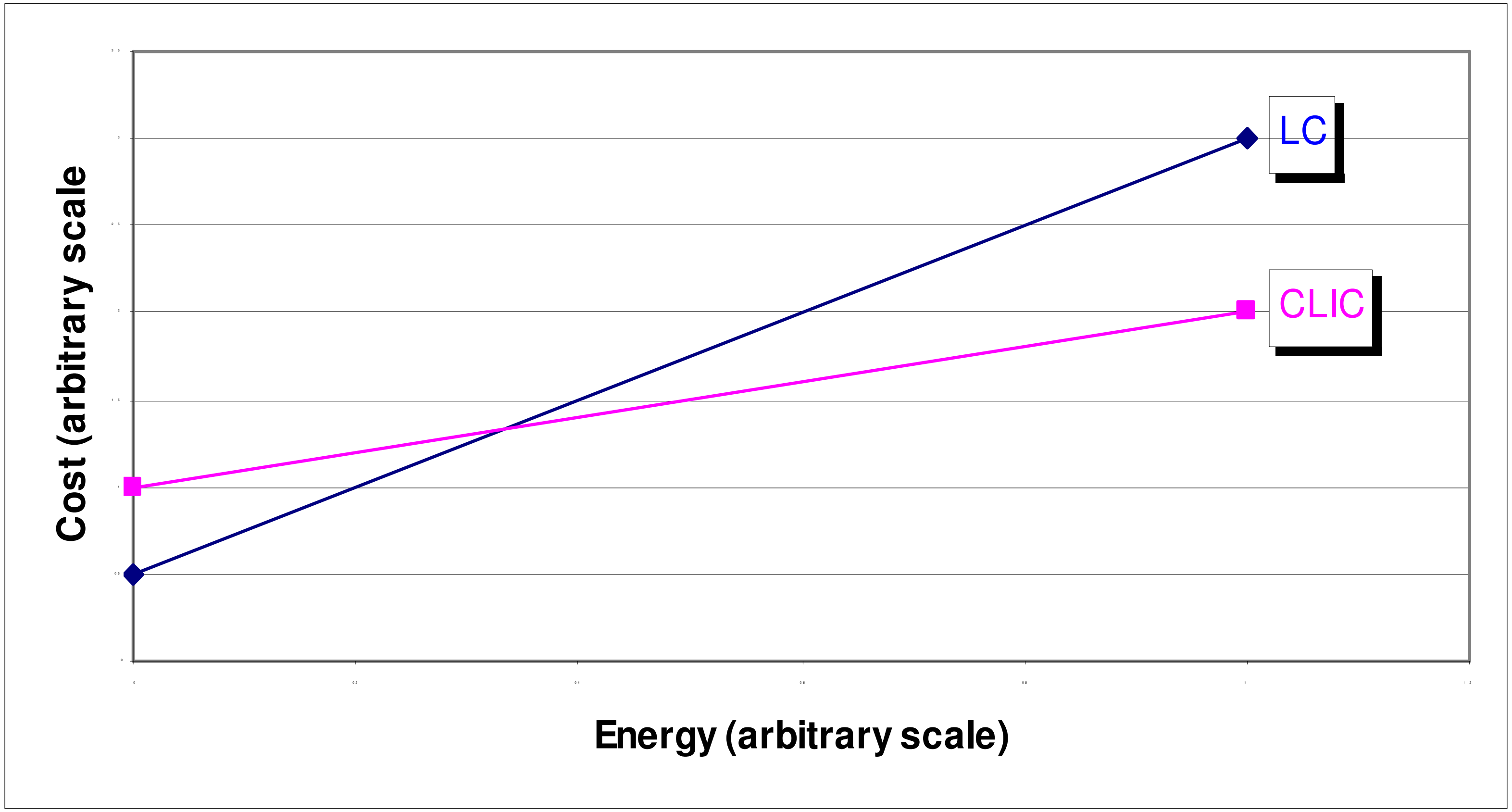
**"The result is that the ILC and CLIC are setting an example that other large scientific endeavours would do well to emulate."**

# Conclusion

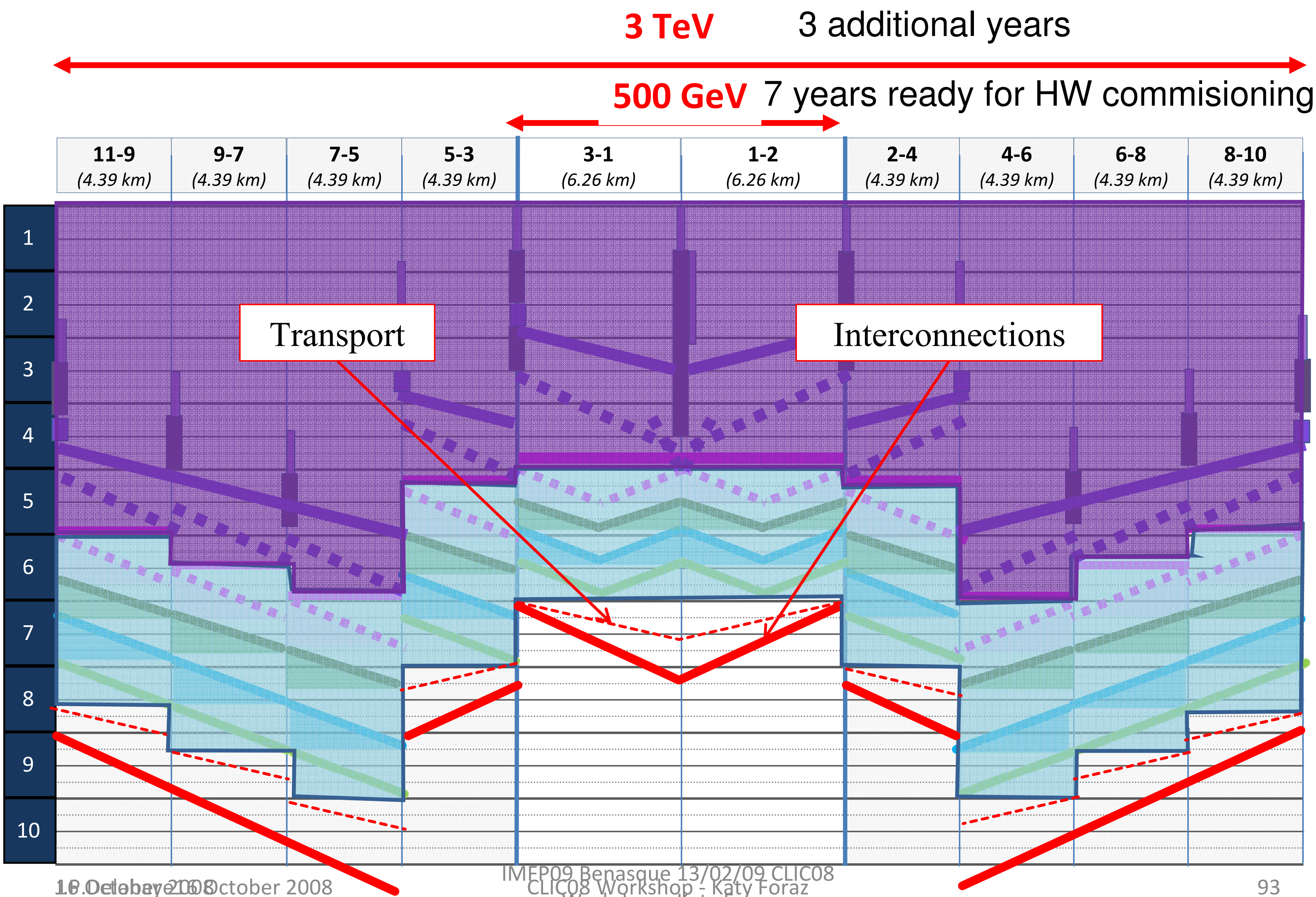
- World wide consensus on Linear Colliders favored facility to complement the LHC in the future.
- ILC based on pretty mature SCRF technology derived from TESLA Collaboration for a Linear Collider in the TeV range.
  - Conceptual Design Report including cost available, Technical Design Report by 2012
  - R&D to further improve performances and reduce cost
  - Taking advantage of strong synergy with X-FEL (industrialisation)
  - To be ready to be built as soon as interest for Physics in the TeV range confirmed by LHC Physics results and resources available
- CLIC technology based on novel TBA scheme to further extend energy reach of Linear Colliders into the Multi-TeV range
  - Promising performances with possible substantial cost savings
  - Novel scheme with challenging technology with feasibility to be demonstrated in CTF3 and published in Conceptual Design Report including preliminary performances and cost by 2010
  - Technical Design with consolidated design and cost by 2015
- CLIC/ILC Competitive-Collaboration preparing together proposal of the most appropriate facility and technology based on Physics results when available from the LHC in 2010-12
- Spanish contribution to present LC related R&D warmly appreciated and participation to the future LC facility construction & operation in a world-wide project strongly welcome.

# Spares

# Relative cost of Linear Colliders



# CLIC Machine installation

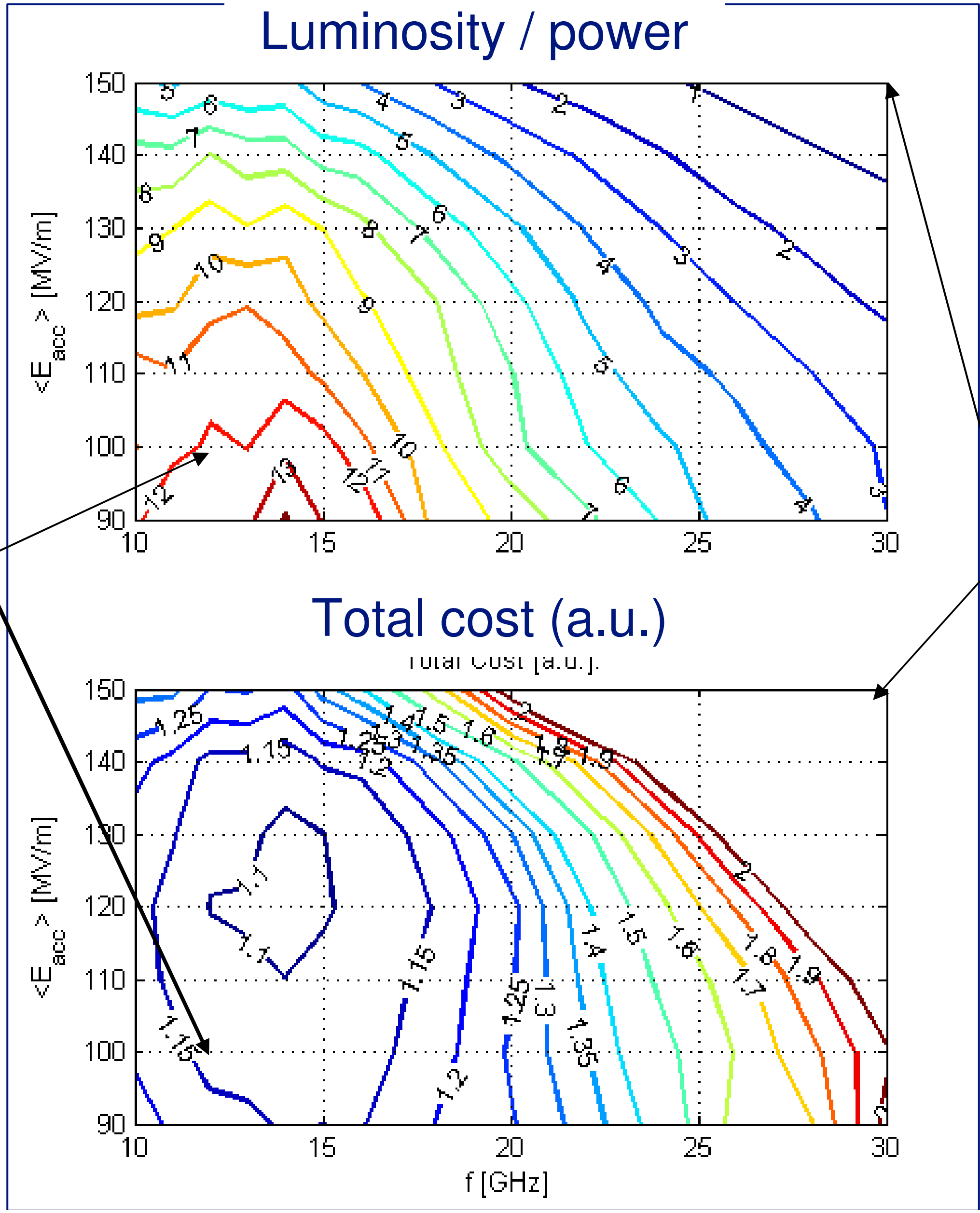


# CLIC Performance and Cost optimization

**CLIC**
**New parameters**

**Accelerating field = 100 MV/m**

**RF frequency = 12 GHz**



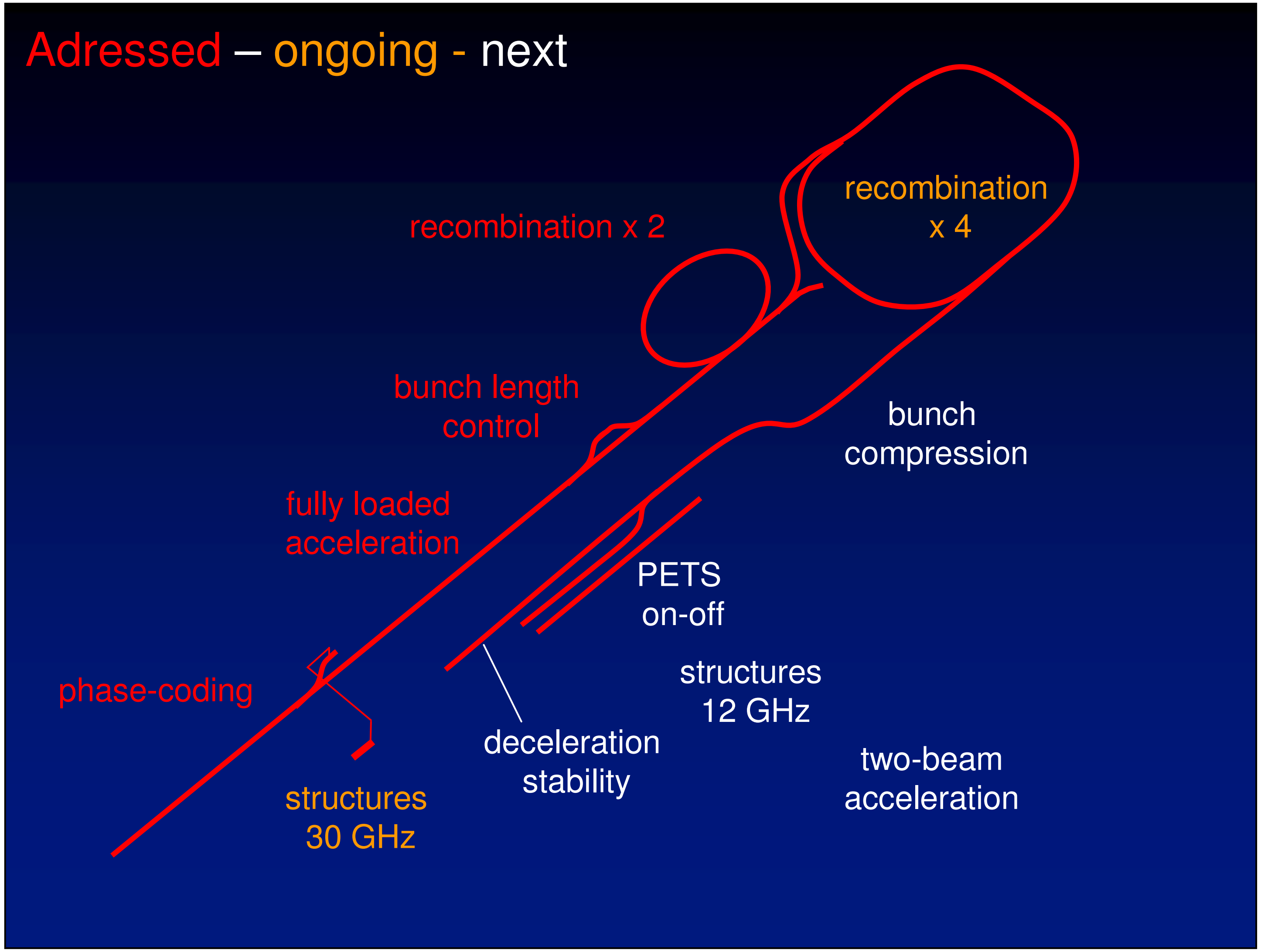

**CLIC**
**Old Parameters**

**Accelerating field = 150 MV/m**

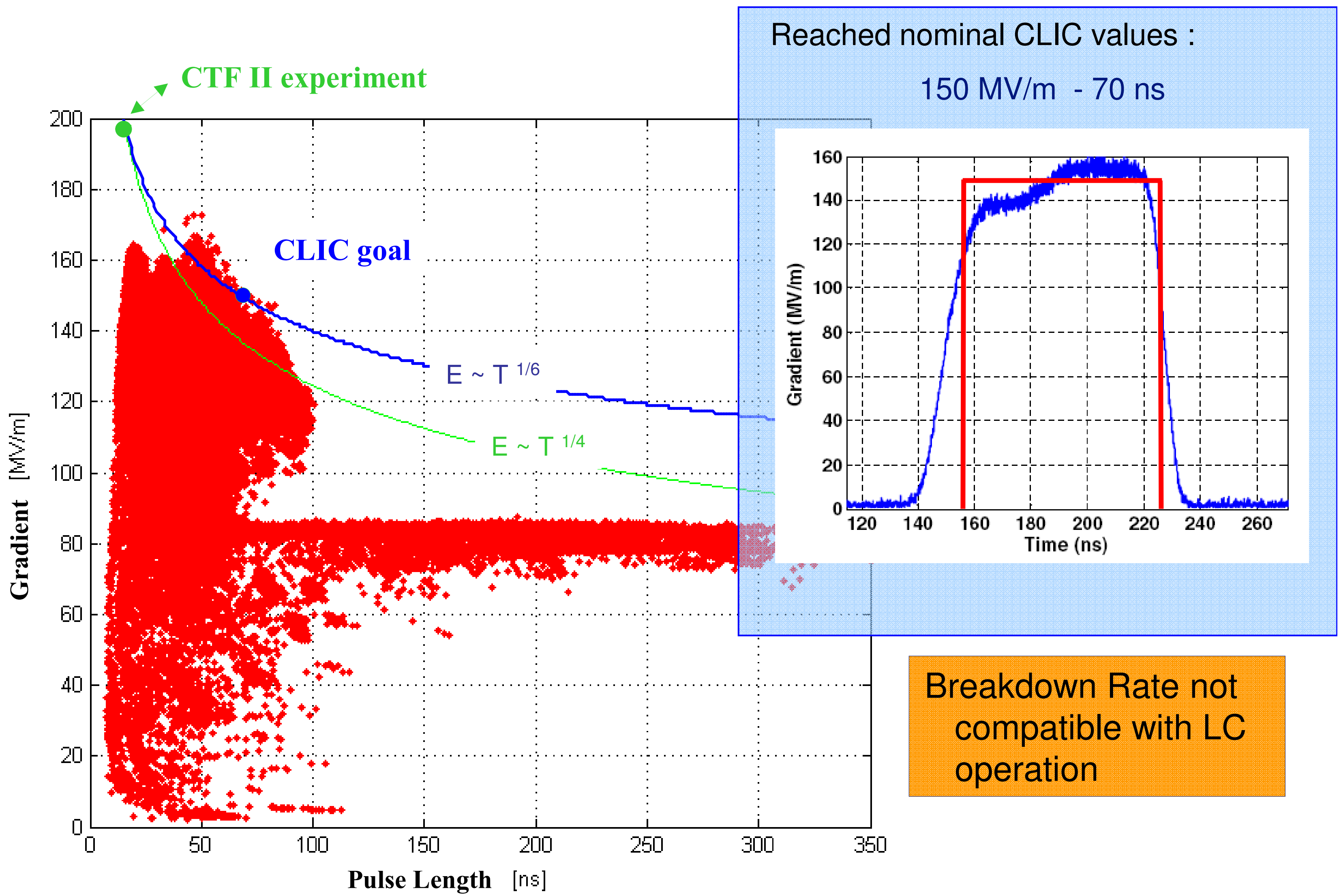
**RF frequency = 30 GHz**

*A. Grudiev* et al.
EPAC '06

# CTF3: R&D issues



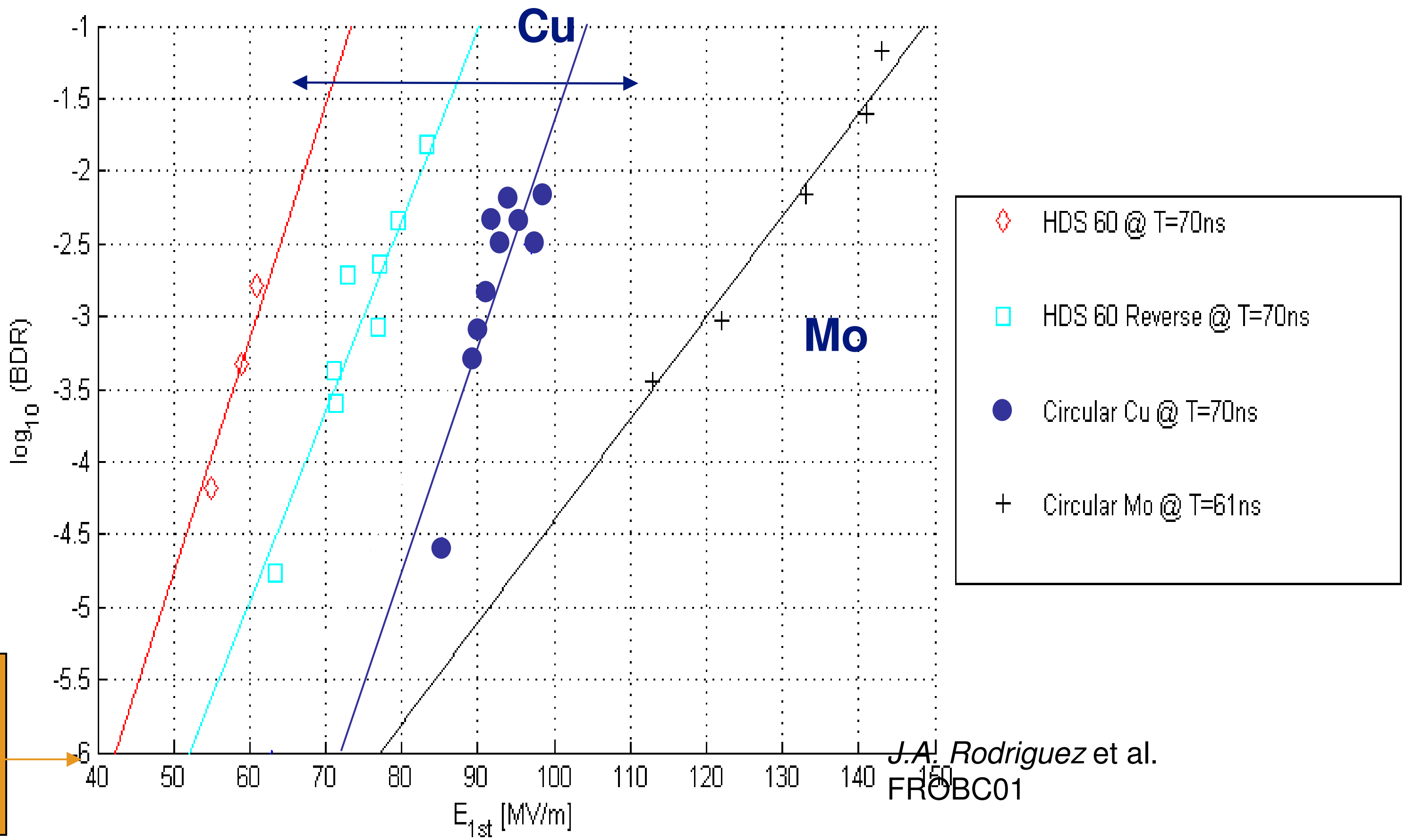
# CTF3 High-Power test results – 30 GHz




Breakdown Rate not compatible with LC operation

# CTF3 High-Power test results – 30 GHz

- Acceptable Breakdown Rate in linear collider operation not higher than 10-6
- Reduction of accelerating field by about 30 MV/m for low BR with Co



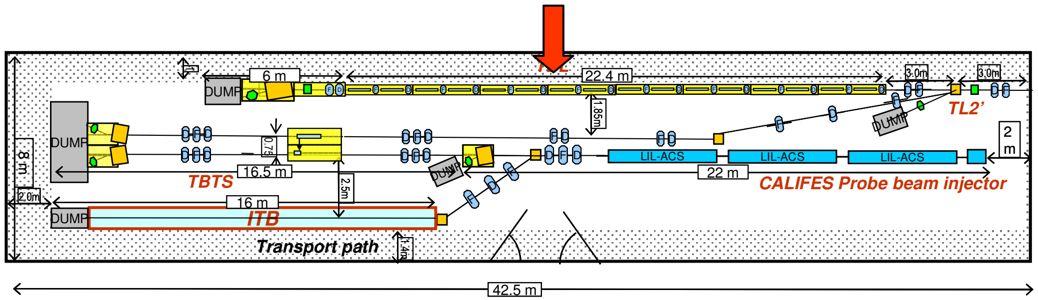

CLIC operational goal

*J.A. Rodriguez* et al.
FROBC01

# The CLIC BDS hot topics

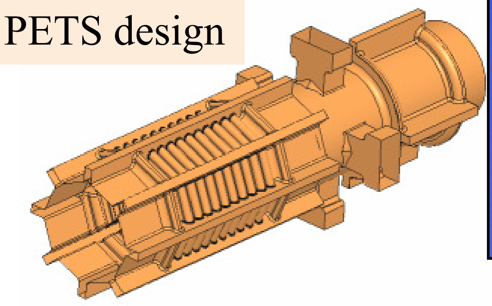
- Collimation: collimator survival, collimator wakefields, lattice design.
- BDS global alignment and stabilization
- FFS design and L*: 3.5m, 4.3m, ?
- FFS tuning strategies need improvement
- ATF2 ultra-low betas proposal to address CLIC-like chromaticities and tuning problems
- Polarization measurement inclusion and its impact in the lattice

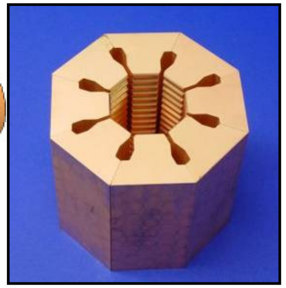
# Test Beam Line TBL




- High energy-spread beam transport
  decelerate to 50 % beam energy
- Drive Beam stability
- Stability of RF power extraction
  total power in 16 PETS: 2.5 GW
- Alignment procedures

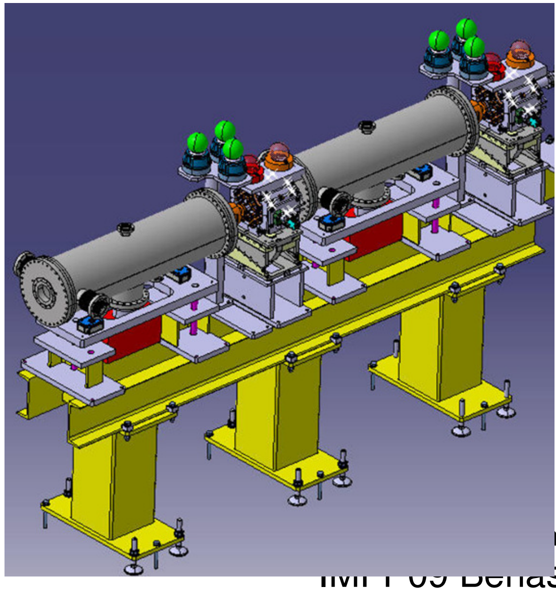
PETS design

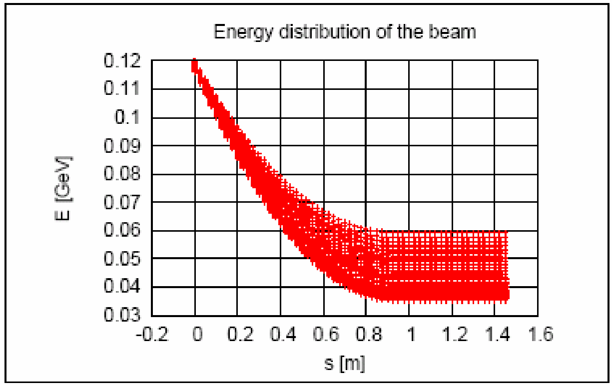




5 MV/m deceleration (35 A)

165 MV output Power





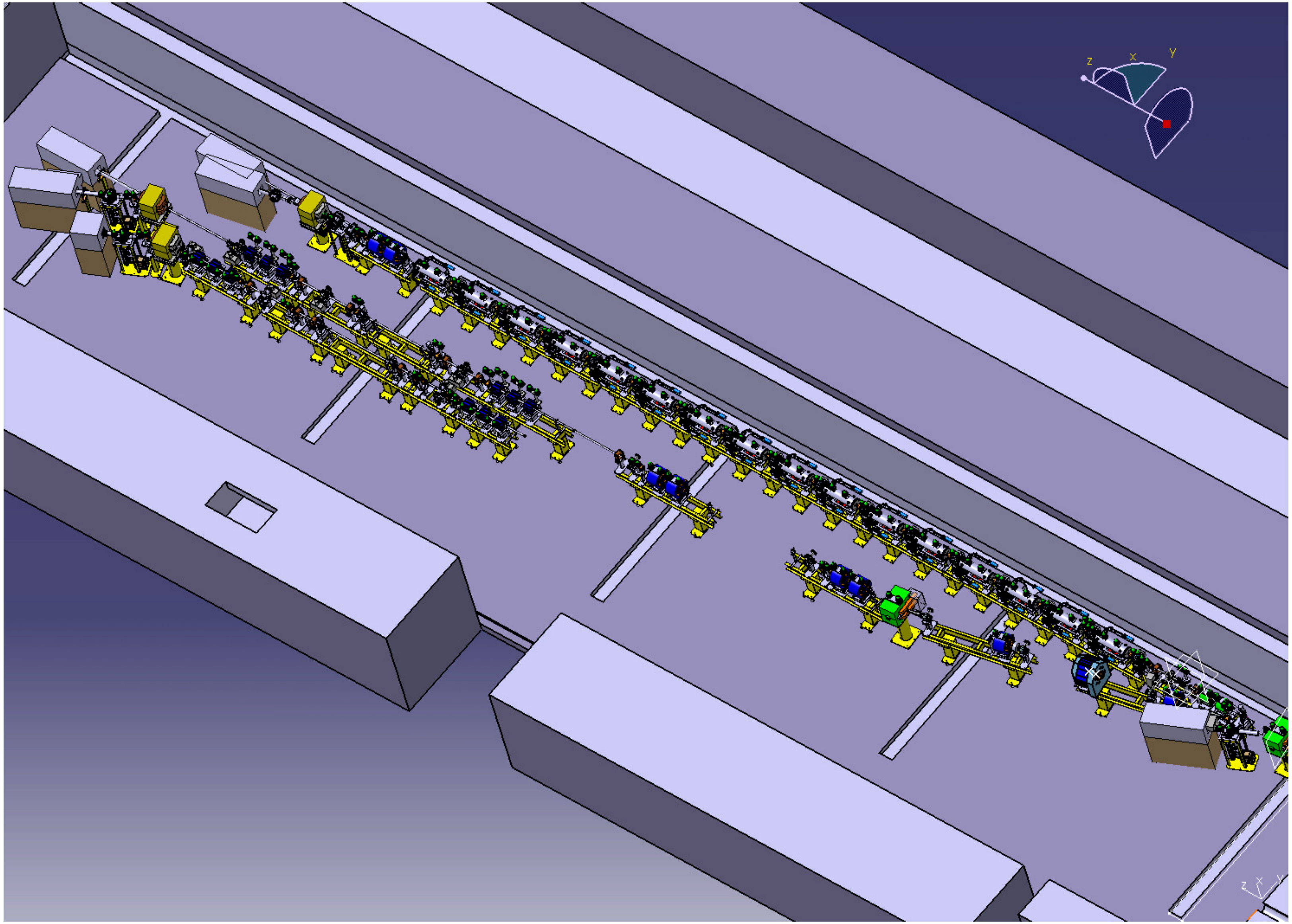

PETS development: CIEMAT

BPM: IFIC Valencia

and UPC Barcelona

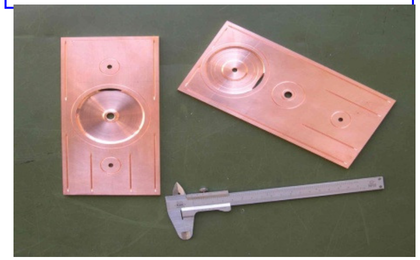
2 standard cells, 16 total

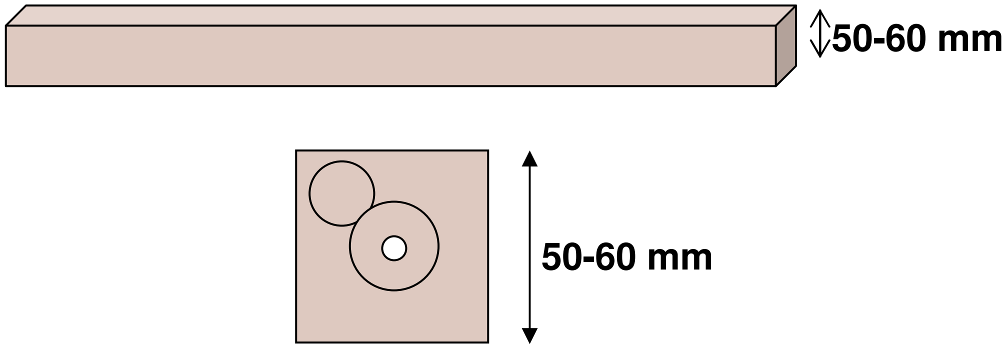
# TBL integration into CLEX



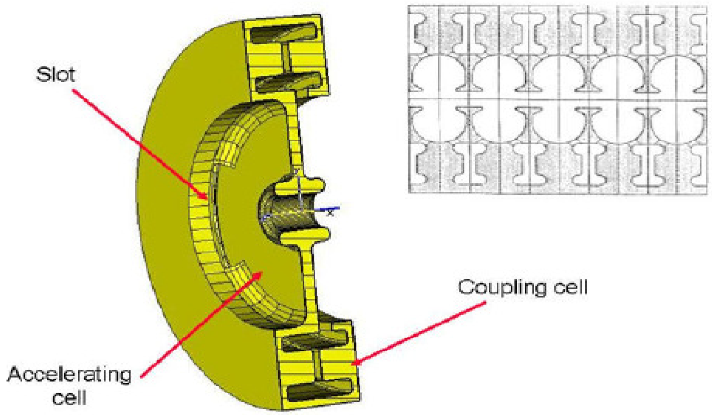
# *Design and construction/tests of 12 GHz accelerating structures Collaboration CLIC TERA*

**A. SCL**
**very similar to LIGHT for IDRA**






**B. ACS**
**studied by TERA**





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