International Linear Collider

Status i perspektywy po wyborze technologii

- Wprowadzenie
- Program fizyczny
- Projekty akceleratora
- Wybór technologii
- Koncepcje detektorów

A.F.Żarnecki

17.12.2004

Brief ILC History

- Late 1980s and 1990s:
  - Next Linear Collider:
    - SLAC/KEK warm RF designs
    - NLC detector group
  - TESLA:
    - European superconducting RF design
    - ECFA-DESY physics/detector studies →
      - 1st ECFA/DESY study: 1996/97
      - 2nd ECFA/DESY study: 1998/2000
      - Extended Joint ECFA/DESY study: 2001/2003
      - ECFA study: 2003/2005
    - \+ World-Wide Study of Physics & Detectors

→ **International Linear Collider Workshops organized starting 1991**

- 2000s:
  - Snowmass 2001
  - HEPAP recomendation 2002
  - **"Understanding Matter, Energy, Space and Time: The Case for the e+e- Linear Collider" 2003**

TESLA TDR: 2001

GLC Project Report: 2003

Physics motivation

Physics programme for the ILC depends on what appears at LHC but interesting scenarios can be considered in each case.

- *top measurements*
- *light "Higgs" measurements*
- *new particles (SUSY ?)*
- *precision measurements*

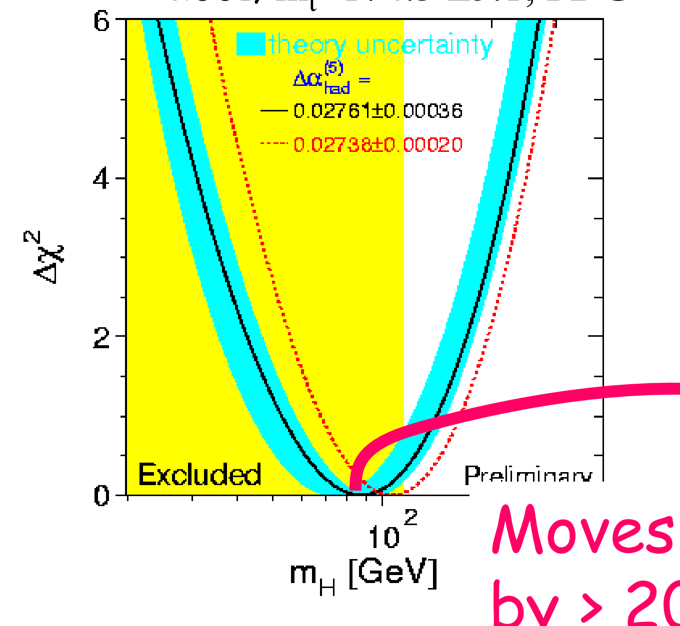
Should be found at LHC
studied at ILC

1. Definite job to be done. Measure m_t to $< \pm 100$ MeV

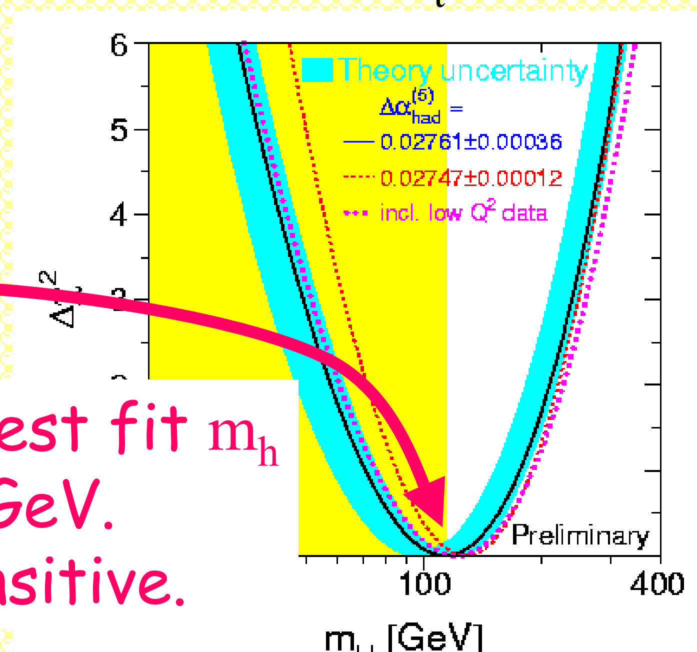
Why? Because precision on m_t limits current SM fit.

Recent illustration; D0's new m_t measurement

2001; m_t=174.3 ±5.1; PDG

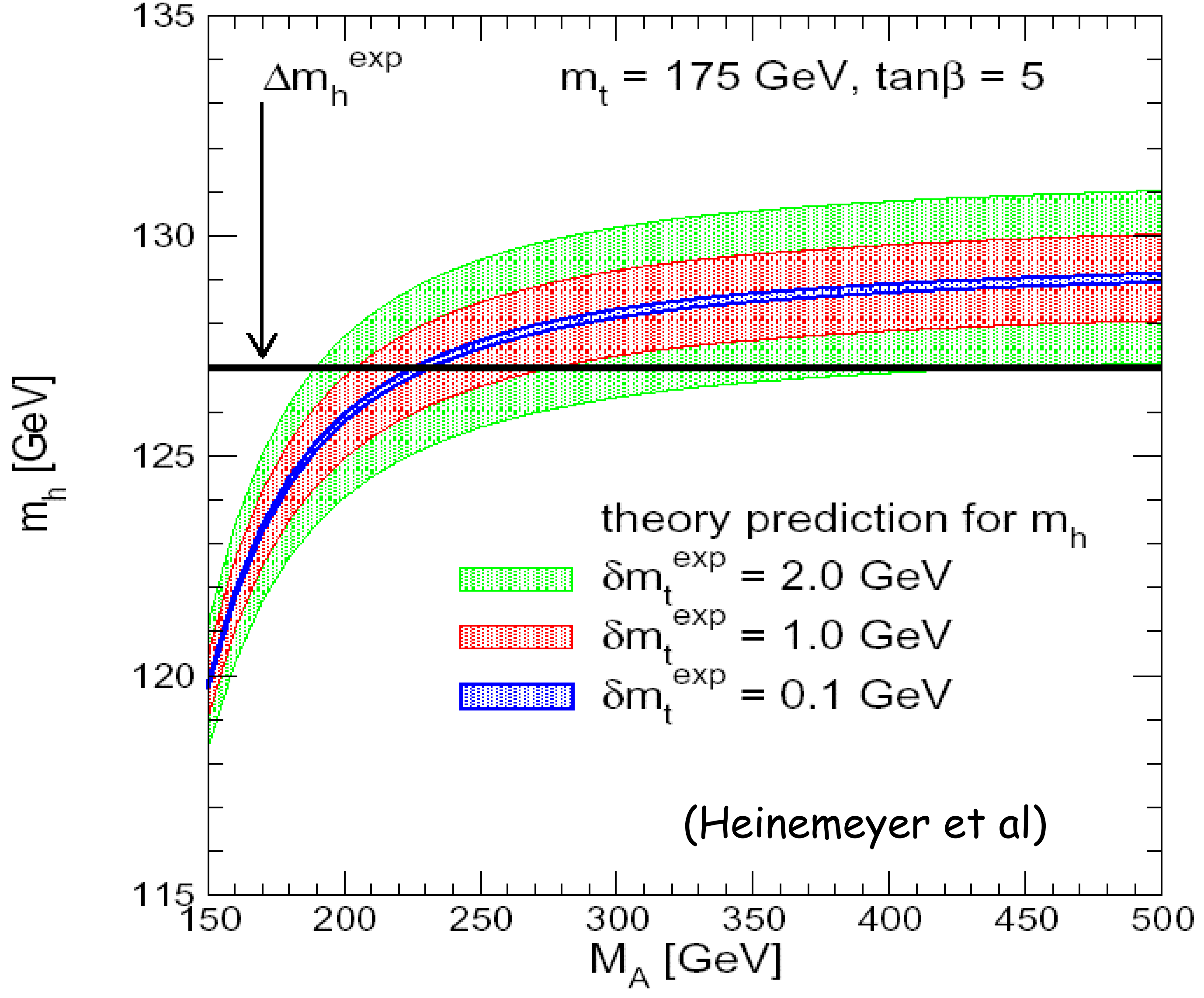


2004; m_t=178.0 ±4.3



Moves best fit m_h by > 20 GeV.
Very sensitive.

what precise m_t would do for MSSM



Higgs
Higgs
Higgs

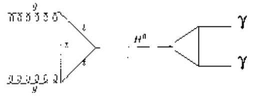
If there is a light Higgs of any kind, seen or unseen at LHC, ILC will:

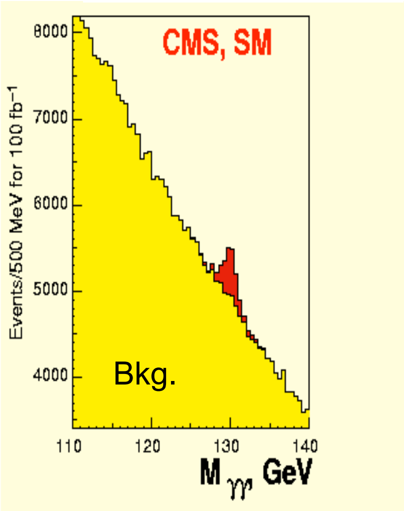
- see it,
- measure its precise mass,
- measure its total and partial widths (BRs), determine its couplings to other particles,
- measure its spin and parity,
- measure Higgs selfcoupling.

Many different scenarios have been investigated...

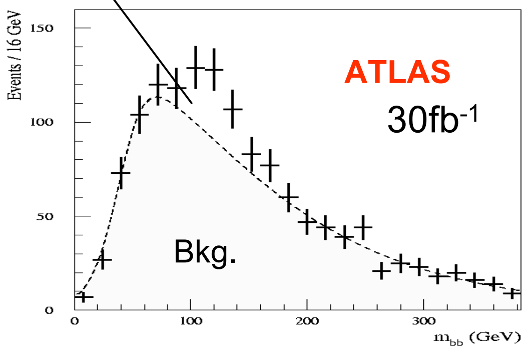
LHC Higgs signal

H→γγ

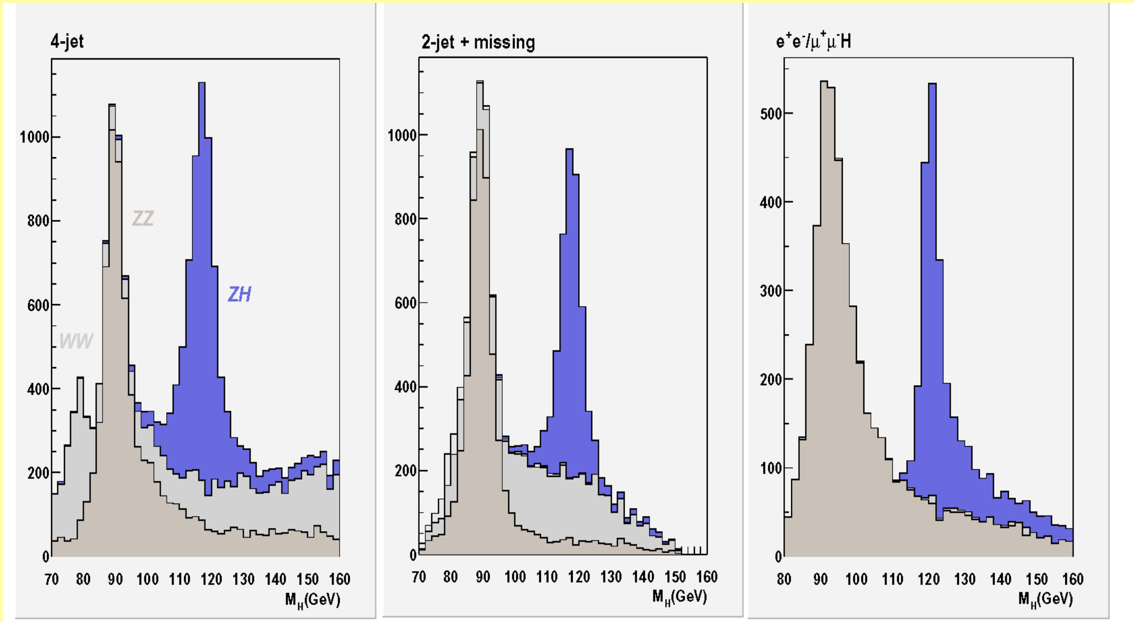


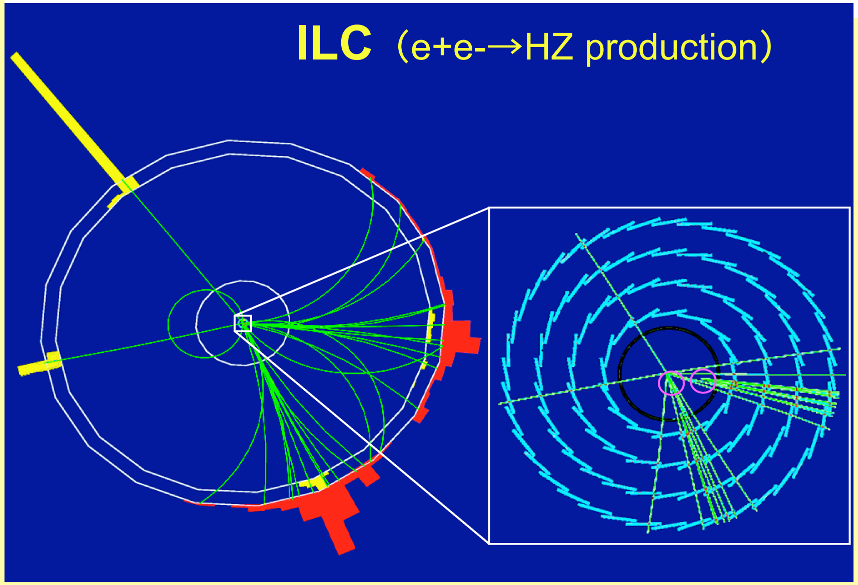


ttH→WbWbbb→*l*νjjbbbb



ILC Higgs signal





Typical numbers

Tagging efficiency ~ 30-50 %

S/N > 1

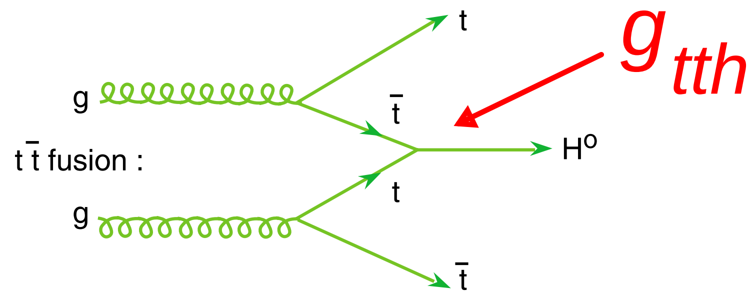
Satoru Yamashita, ACFA LCWS 7
Nov.9 2004

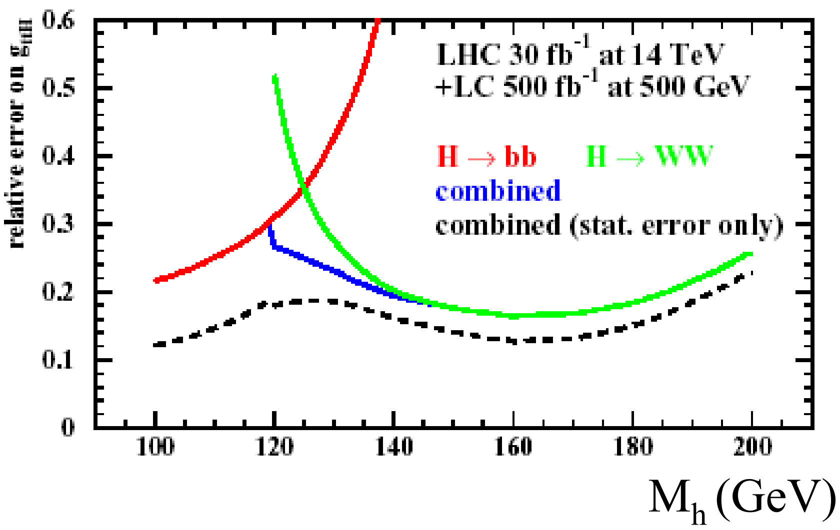
Measurement of top Yukawa coupling

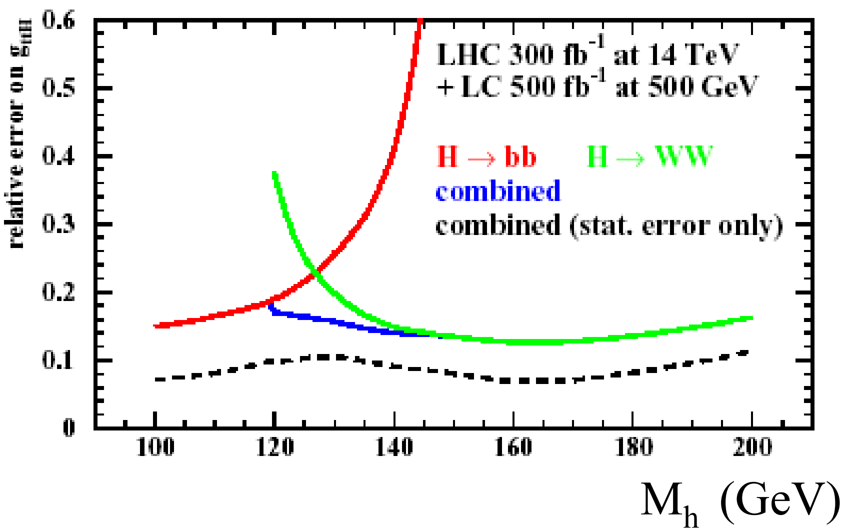
Dawson, Juste, Reina and Wackeroth, LHC/LC report.

Branching ratios and couplings from 500 GeV ILC + LHC rates

LHC:







Example of LHC-LC synergy:
without precise BR measurements at ILC, LHC measurements are model dependent

An Optimistic Conclusion: PDG 2016 ?

GAUGE AND HIGGS BOSONS

H

$J^{PC}=0^{++}$ [a]

Charge = 0

Mass m=120.0±0.040 GeV [b]

Full Width Γ =3.6 ±0.2 MeV[a]

H DECAY MODES[b]	Fraction
bb	(67.8 ±1.6) %
cc	(3.08 ± 0.25)%
ττ	(6.8 ±0.35)%
gg	(7.04 ± 0.5)%
γγ	(0.21 ±0.0 5)%
WW	(13.3 ± 1.3)%

SUMMARY TABLES OF PARTICLE PROPERTIES
Extracted from the Particle listings of the
Review of Particle Physics
Published in Eur. Jour. Phys **C3**, 1 (2014)
Available at http://www.eilamgross.com

Like the Z boson measurements at LEP

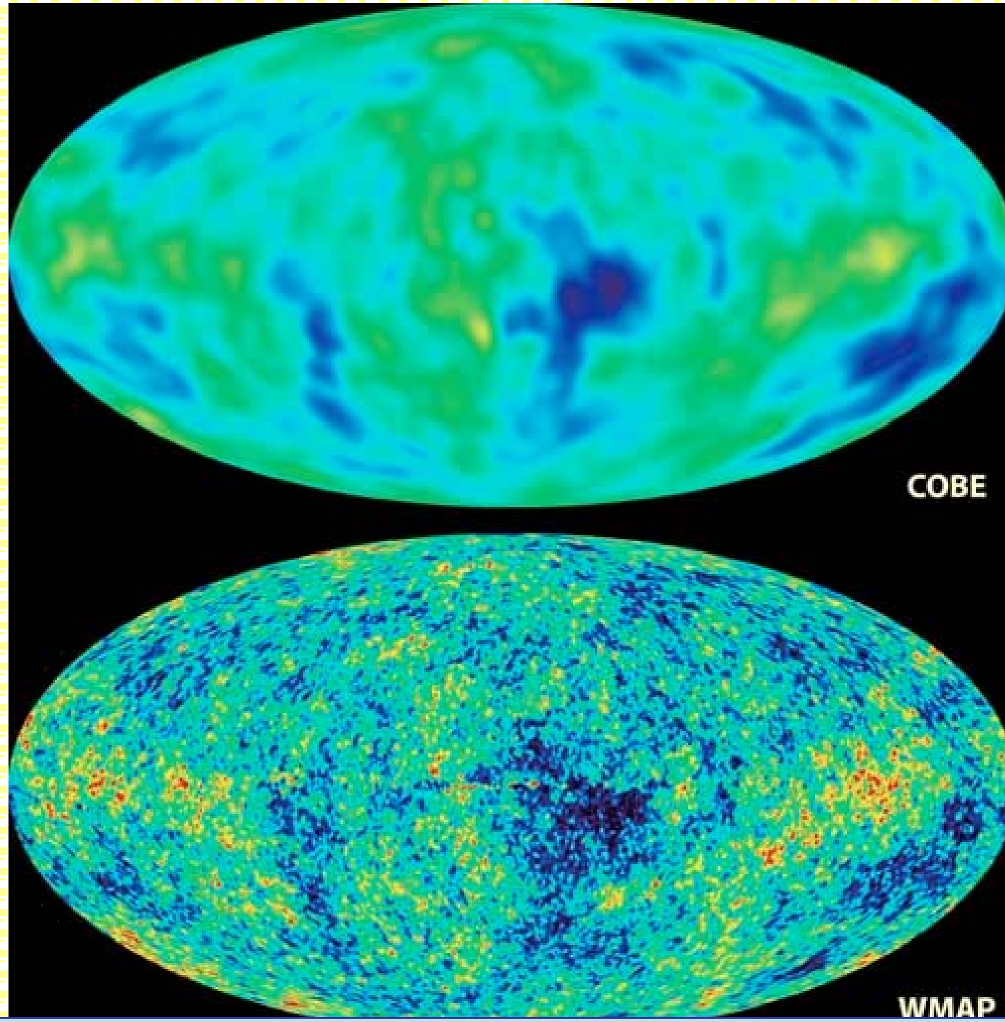
[a] LC, [b] LC/LHC

ICHEP'04 Aug.16-22,2004

Higher precision *can give discoveries.*

Then

Now



Cosmic Microwave Background

WMAP constrains $\Omega_{\Lambda} + \Omega_{M}$

Wouldn't know it's there from COBE

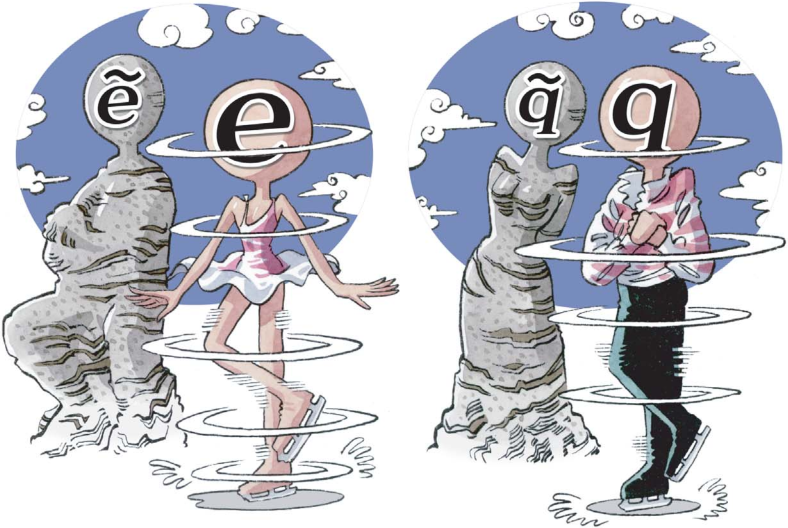
AND Planck is coming; more precise still

WITH

sation

If ILC measures the *wrong* Higgs mass (using S.M. fits with ILC value of m_t) ***it has discovered the new physics.*** LHC precision on m_h may not be enough to do this.

SUSY



3. If there is a light Higgs *and* extra particles

E.g. the Minimal Supersymmetric Standard Model*, then LHC expects to see squarks and gluinos.

ILC good for sleptons and especially for Lightest Supersymmetric Particle ($\tilde{\chi}_1^0$ LSP is favoured candidate for Dark Matter).

New studies at point SPS1a in LHC/LC report (Martyn).

LC at $\sqrt{s}$=400 GeV,

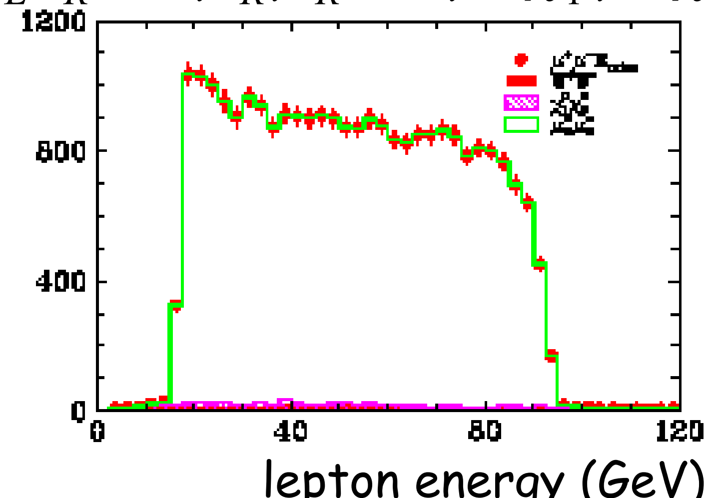
$\int \Lambda = 200\ \mathrm{fb}^{-1}$.

Clear endpoints give, for example,

$$\delta m_{\tilde{\mu}_R^+} \approx \delta m_{\tilde{\chi}_1^0} \approx 200\ MeV$$

(some others come from threshold scans).

$$e_L^+ e_R^- \to \tilde{\mu}_R^+ \tilde{\mu}_R^- \to \mu^+ \tilde{\chi}_1^0 \mu^- \tilde{\chi}_1^0$$

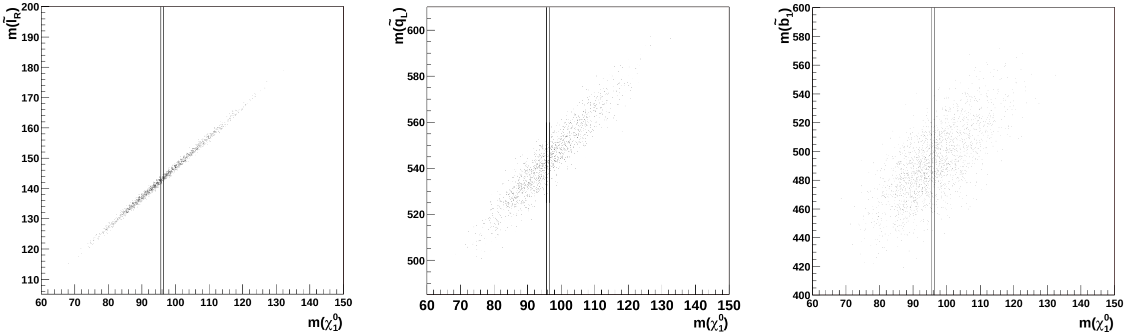


*(+ new work on NMSSM and others in LHC/LC report, at Victoria, here)

LHC - LC synergy

points - expected LHC measurement

vertical lines - LC measurement

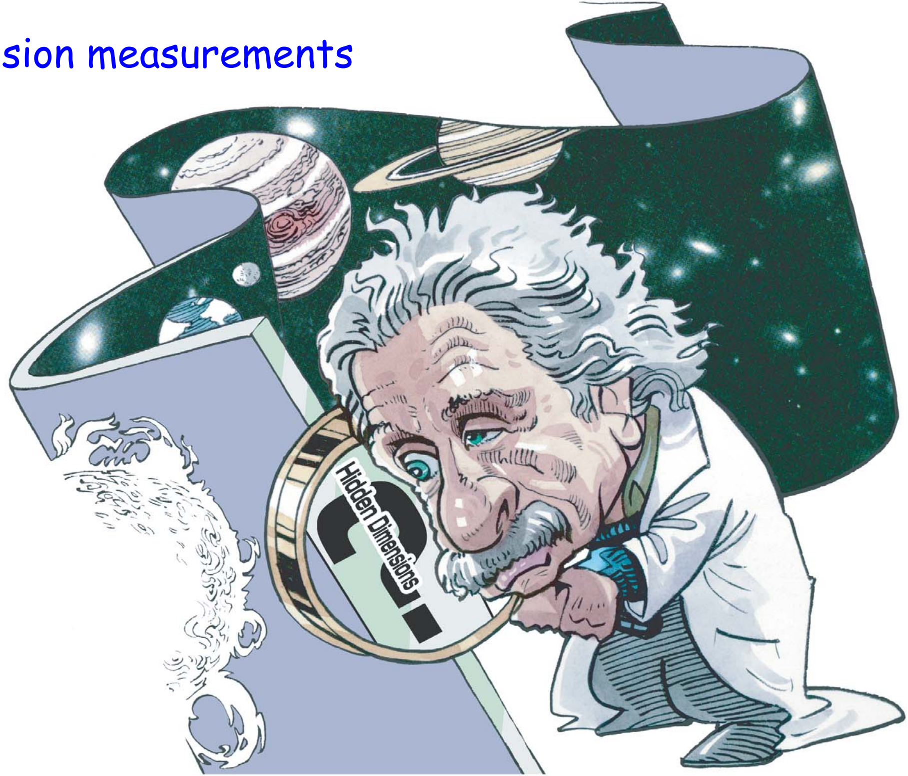


M.Chiorboli, et al., LHC/LC study

Very precise LSP mass measurement at ILC

will improve precision of other measurements at LHC

Precision measurements



Summary of the case for the TeV ILC

1. Definite; $\delta m_t < 100 MeV$

Vital constraint.
Increasingly sure
it can be done.

4. If LHC sees nothing new below ~ 500 GeV mass

ILC looks beyond LHC's direct reach

2. If there is a light Higgs

LHC probably sees.
ILC shows what it is.

Then LHC + ILC point to CLIC, and maybe superLHC

3. *and* extra particles

LHC and ILC needed to pin down model, identify DM(?), extrapolate to GUT scale.

Accelerator designs

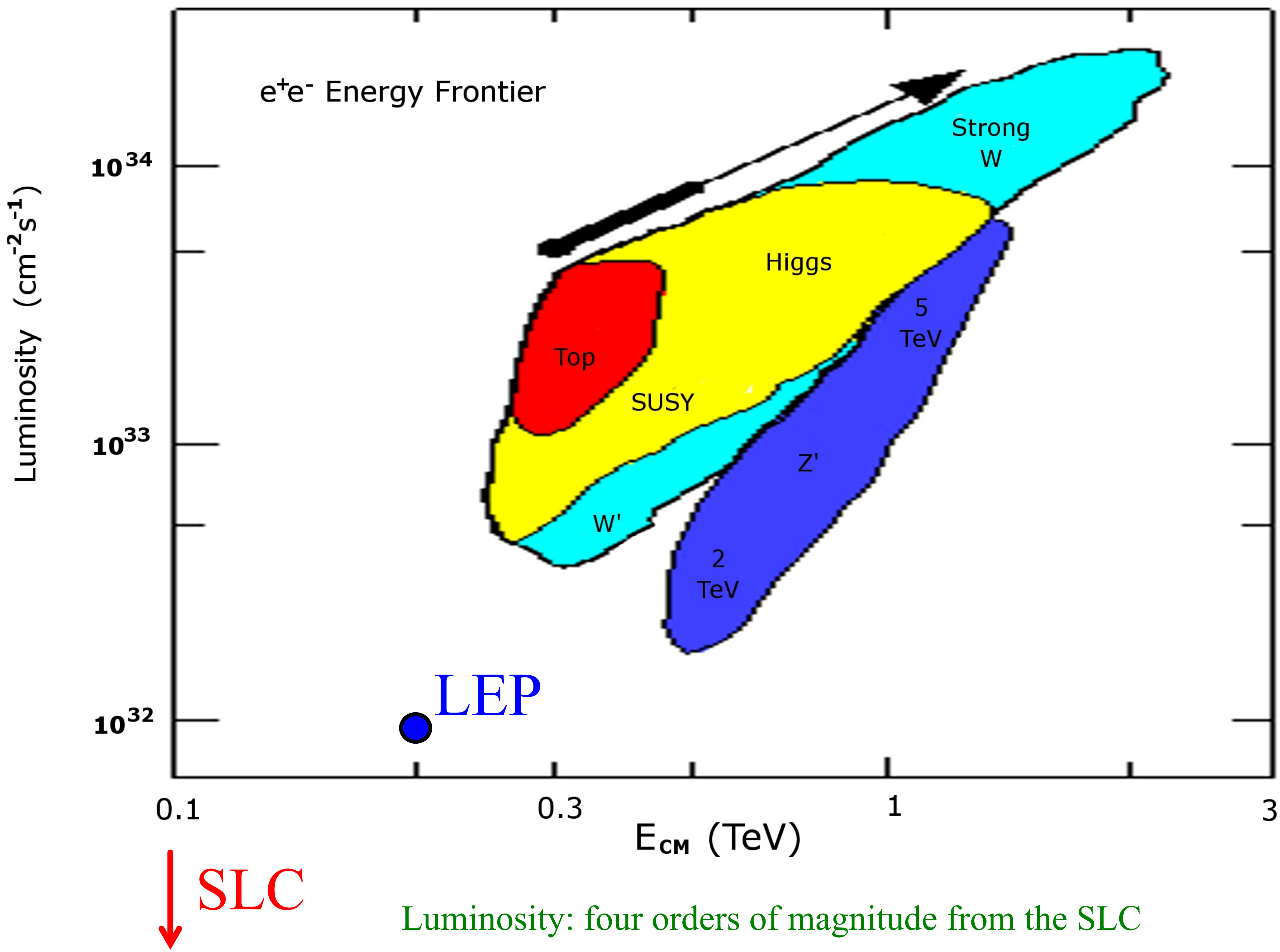
Parameters for the Linear Collider

September 30, 2003

- BASELINE MACHINE
  - E_{CM} of operation 200-500 GeV
  - Luminosity and reliability for 500 fb^{-1} in 4 years
  - Energy scan capability with <10% downtime
  - Beam energy precision and stability below about 0.1%
  - Electron polarization of > 80%
  - Two IRs with detectors
  - E_{CM} down to 90Gev for calibration
- UPGRADES
  - E_{CM} about 1 TeV
  - Allow for ~1 ab^{-1} in about 3-4 years
- OPTIONS
  - Extend to 1 ab^{-1} at 500 GeV in ~ 2 years
  - e^-e^-, $\gamma\gamma$, $e^-\gamma$, positron polarization
  - Giga-Z, WW threshold

http://www.fnal.gov/directorate/icfa/LC_parameters.pdf

The energy and luminosity challenges for a future e+e- linear collider:



Luminosity: four orders of magnitude from the SLC

High luminosity could be "easily" reached at the circular collider.

Ruled out by:

- construction costs
- power consumption

"LEP 1000"

2 TeV in Center-of-Mass

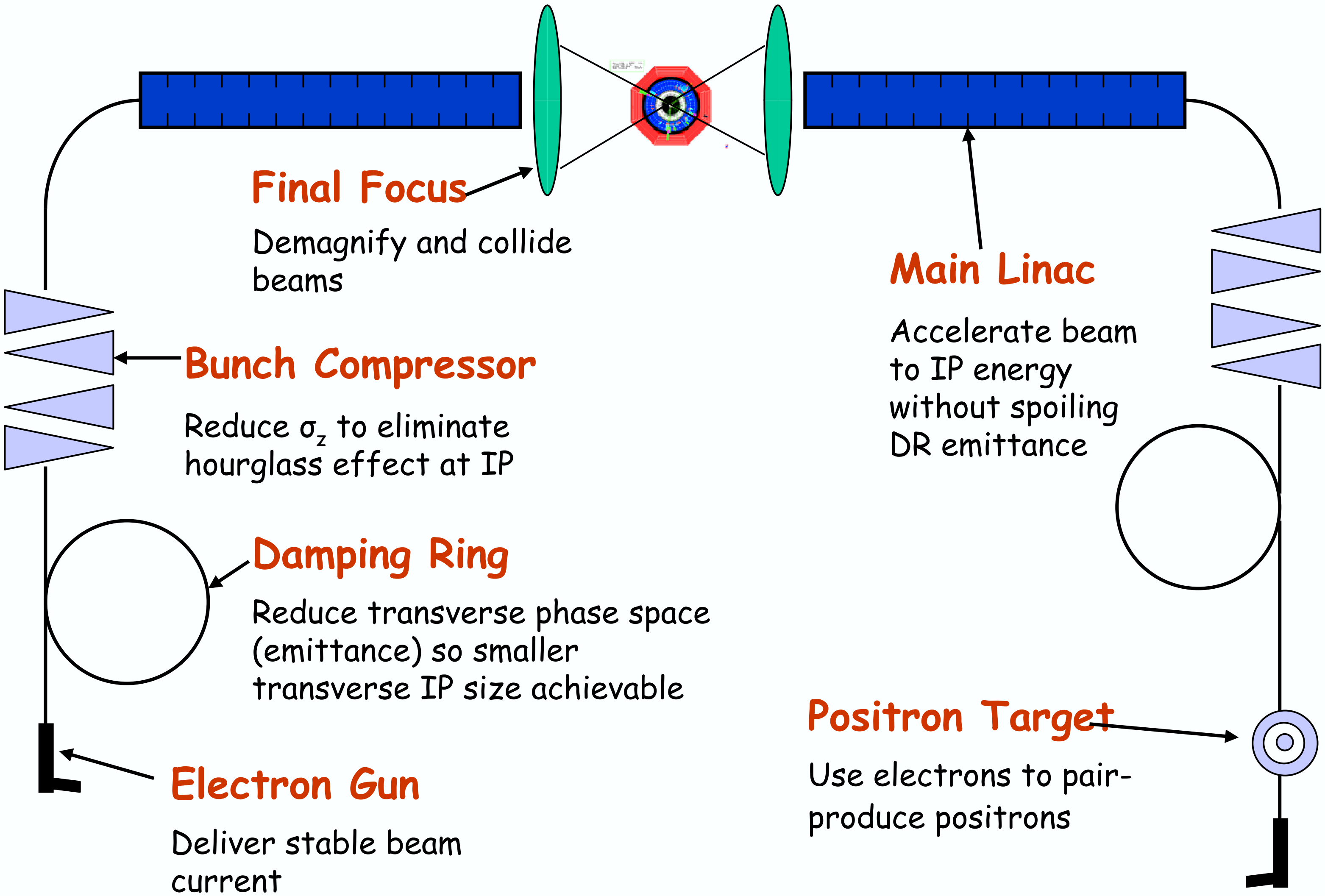
Diameter ≈ 900 km

Linear Collider at 50 MeV/m

Length = 40 km →–←

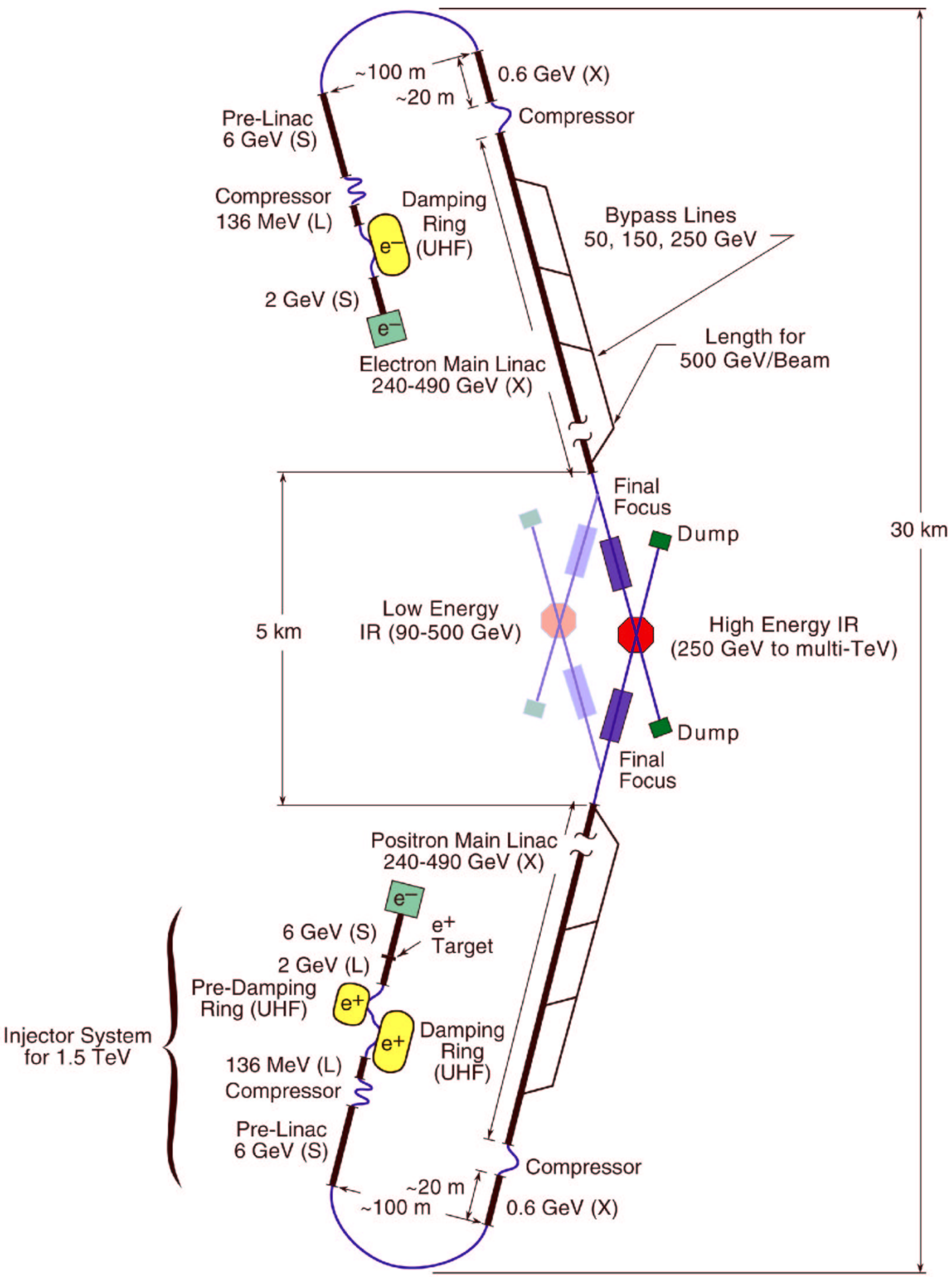
Why LEP 1000 gave way to the idea of linear colliders

LC conceptual scheme

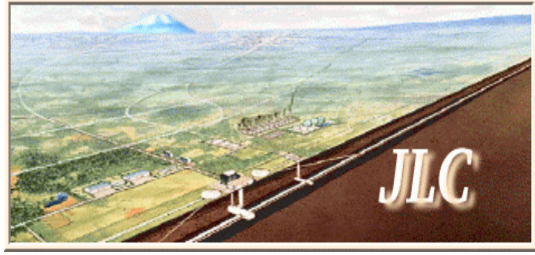


NLC

NLC design

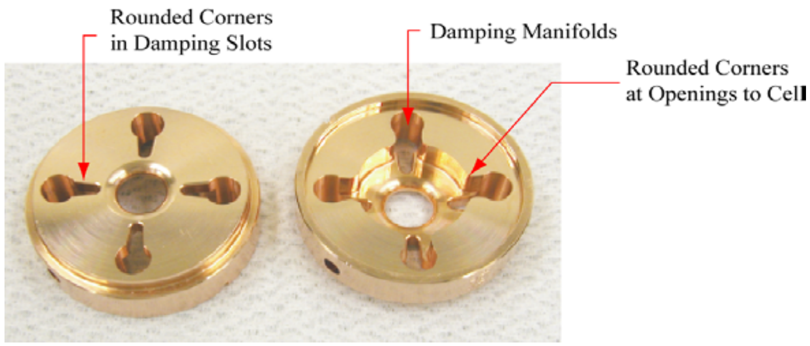


NLC

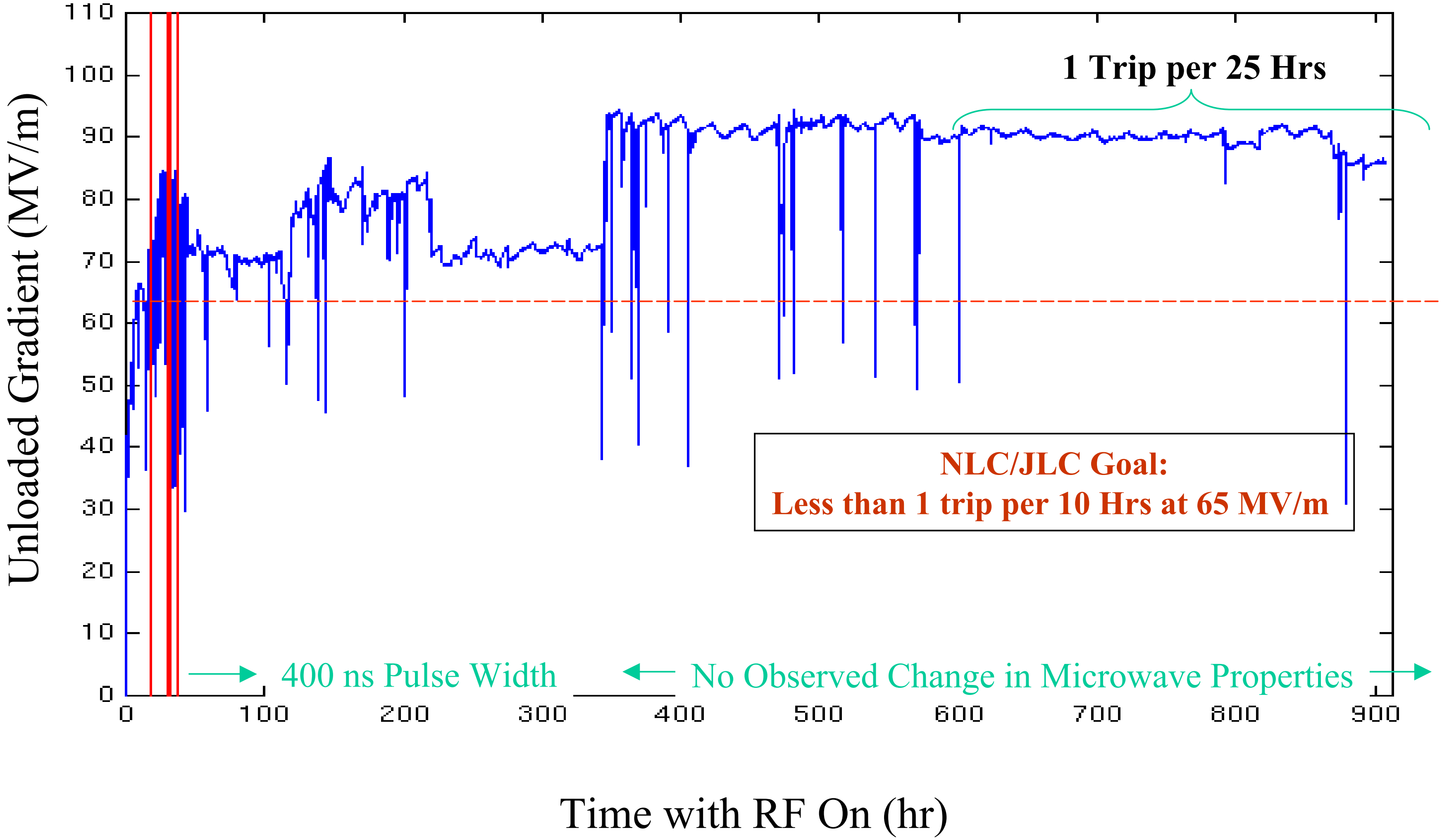


X-band technology (SLAC/KEK & coll. Inst.)

SLC-like 20MV/m, 3 GHz → 50MV/m (65 unloaded), 11.4GHz



Test Structure Run History
(T-Series 2003, not final version for linac)



500 *(→ 800)* GeV e+e- Linear Collider

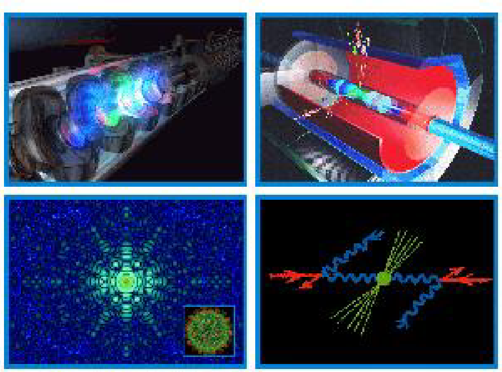
Based on superconducting linac technology

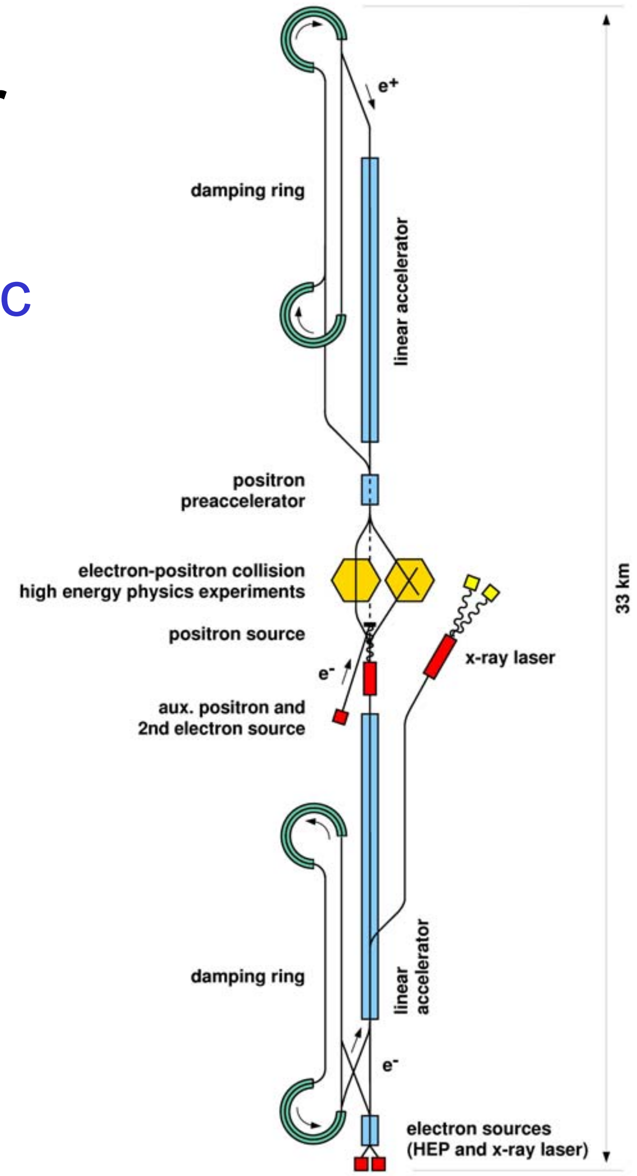
TESLA

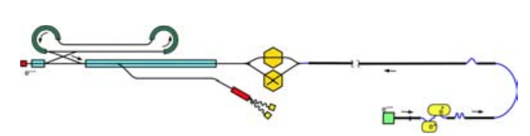
The Superconducting Electron-Positron Linear Collider

with an Integrated X-Ray Laser Laboratory

Technical Design Report







Why superconducting?

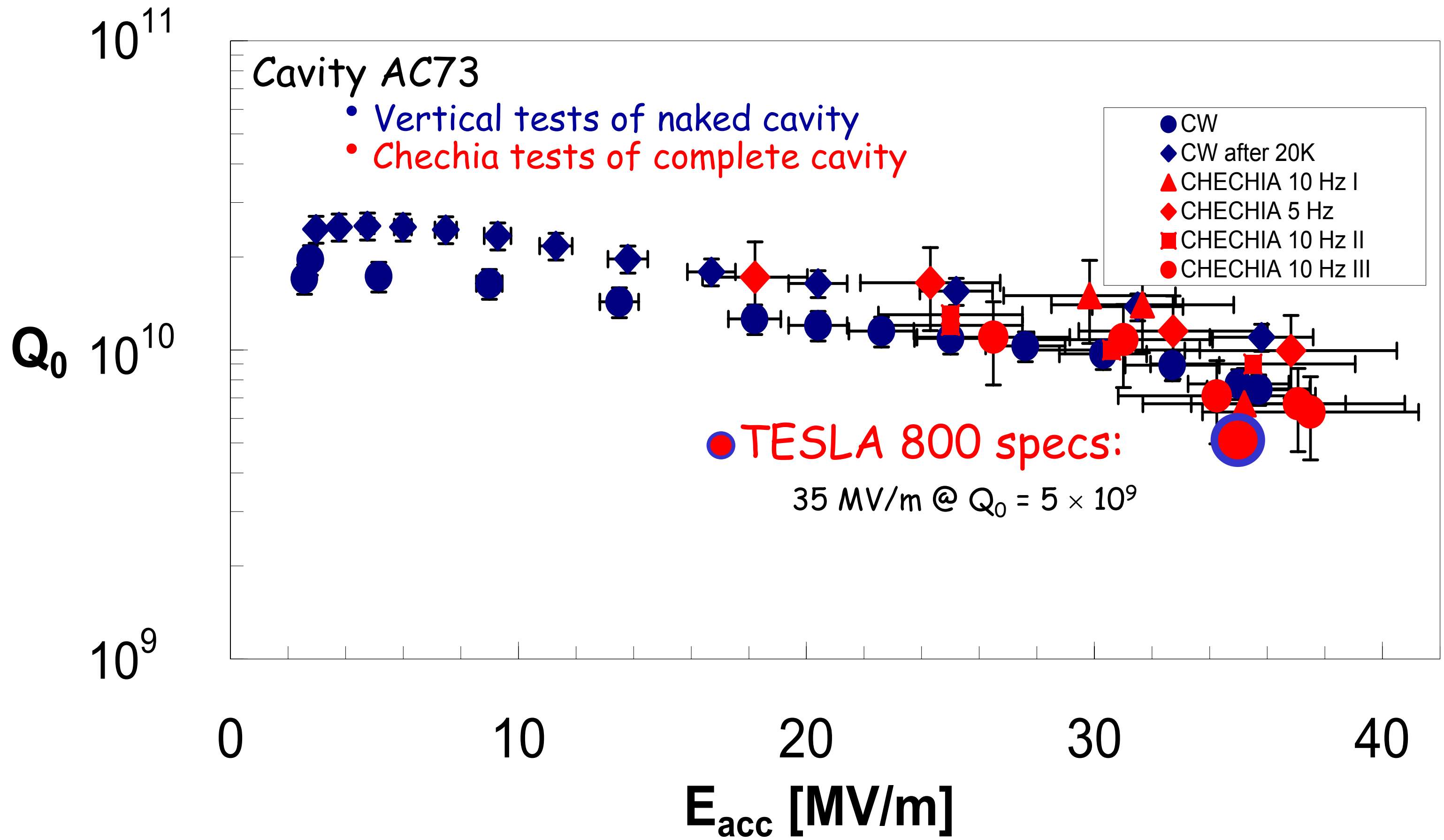
- High efficiency AC→beam (>20%, ~10% normal c.)

- Low frequency:
  - Long pulses with low RF peak power
  - Small beam perturbations from wakefields
  - Intra-train feedback on beam orbit, energy, luminosity…

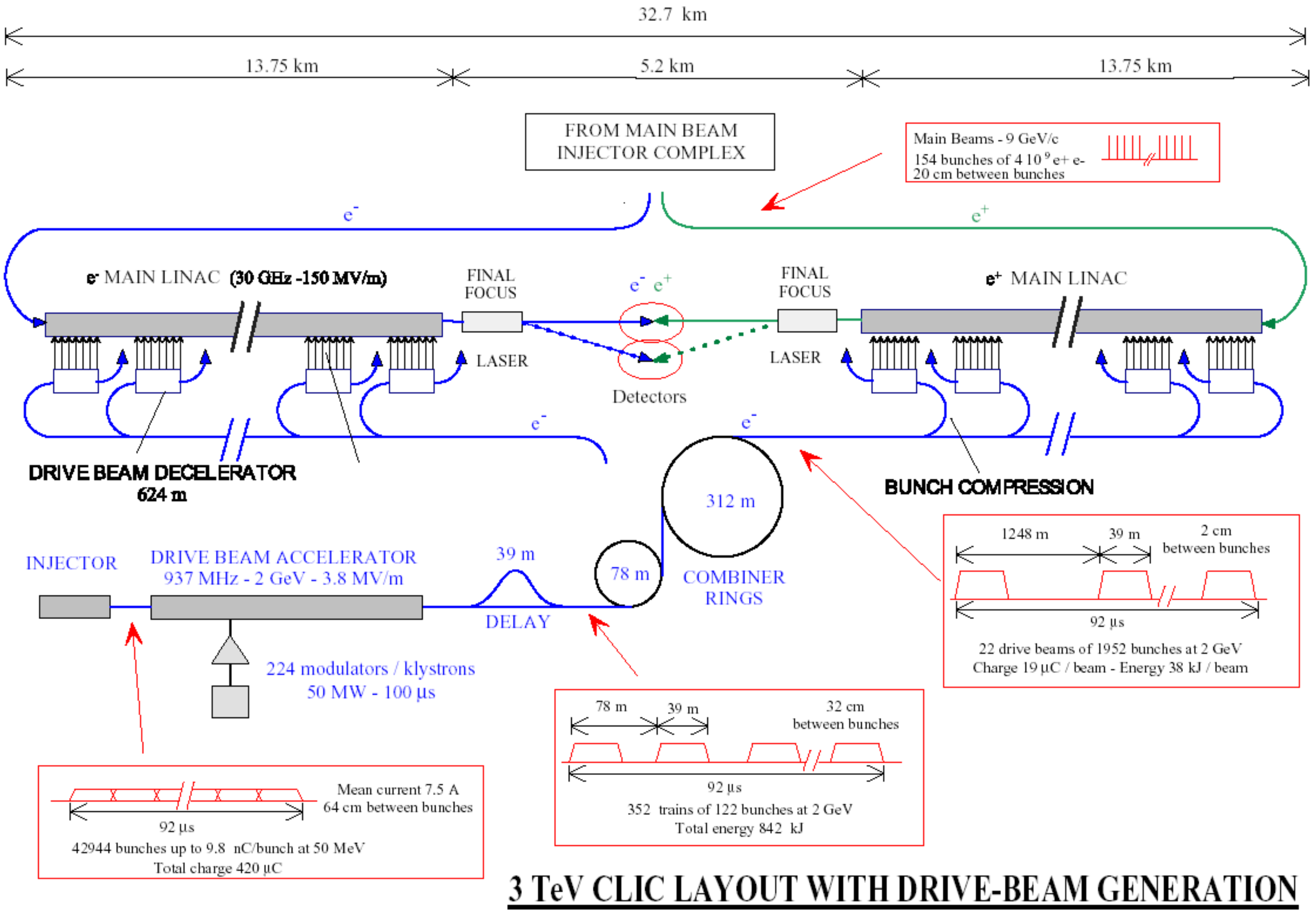
- First proposed in 1960s (M. Tigner)… show stopper was too low acc. Gradient, too high cost

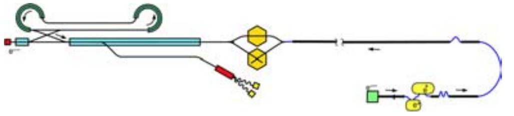
TESLA 800 in "Chechia"

- Long Term (> 1000 h) Horizontal Test
- In Chechia the cavity has all its ancillaries
- Chechia behaves as 1/8th (1/12th) of a TESLA cryomodule



CLIC two-beam accelerator approach
CERN & coll. Inst.

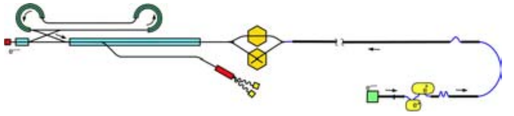




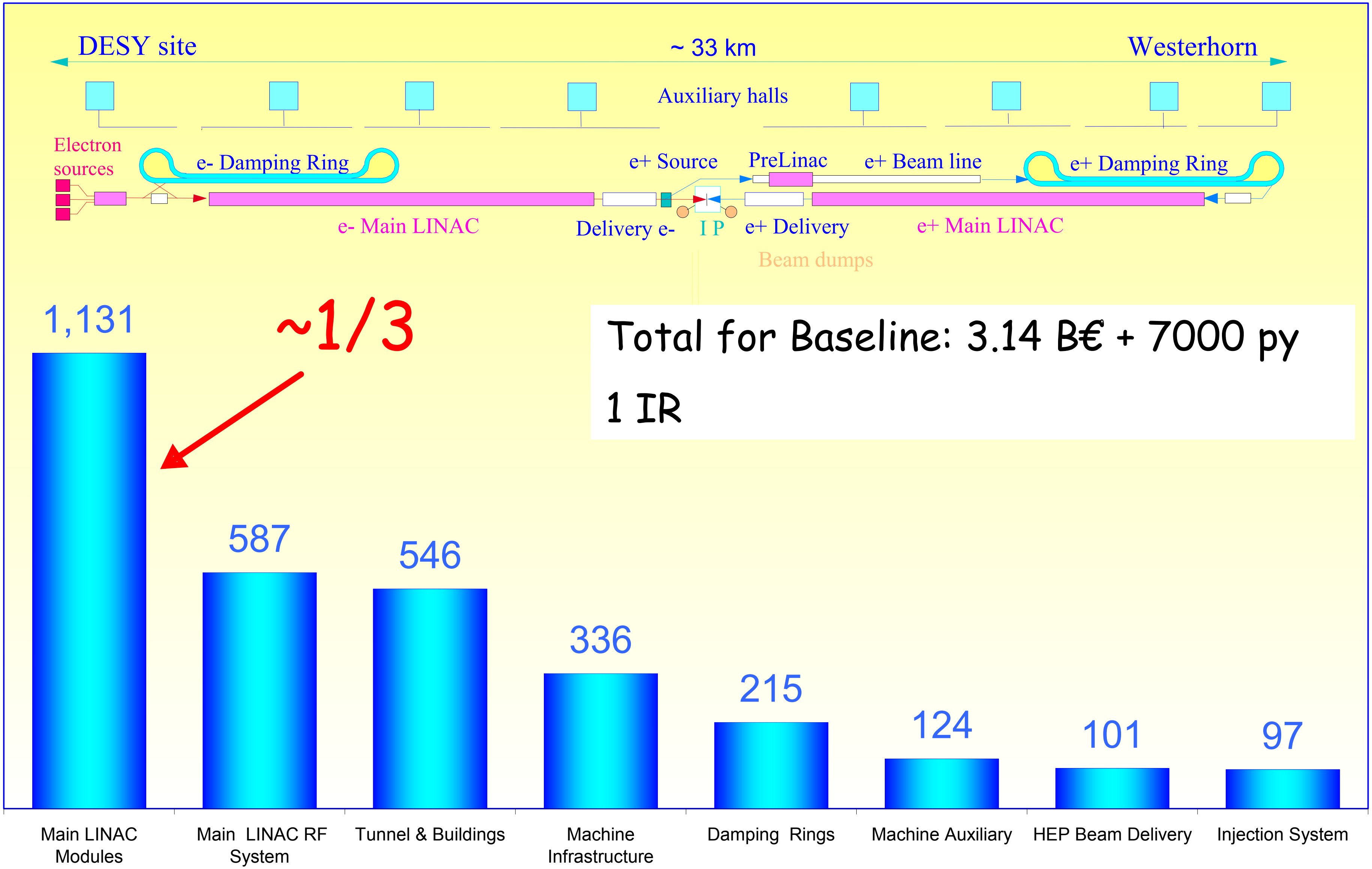
Linear Collider Parameter Overview

	NLC/JLC	TESLA	CLIC	SLC
f / GHz	11.4	1.3	30	2.9
E-cms / GeV	500 – 1000	500 – 800	3000 – 5000	100
g / MV/m	50	23 – 35	150	~20
Lumi / 10^{34}	2 – 3	3.4 – 5.8	~10	.0003
Power p. beam / MW	6.9 – 13.8	11.2 – 17	~15	0.04
σ_y at IP / nm	2.7 – 2.1	5 – 2.8	1	500
Beamstrahlung δB / %	3.2 – 4.3	3.4 – 7.5	21	<0.1
Site length / km	30	33	~35	3.5
Site power / MW	195 – 350	140 – 200	~400	
Cost[§] (stage-I)	~3.5B$	3.14B€+7k p.y.		?

§ numbers quoted at Snowmass 2001, no pre-operation, escalation and contingency included



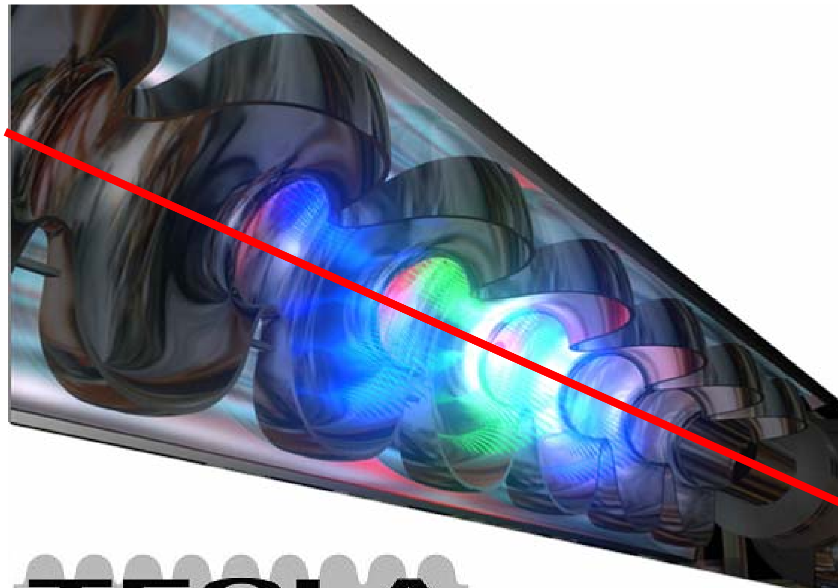
TESLA Cost Distribution



Total for Baseline: 3.14 B€ + 7000 py

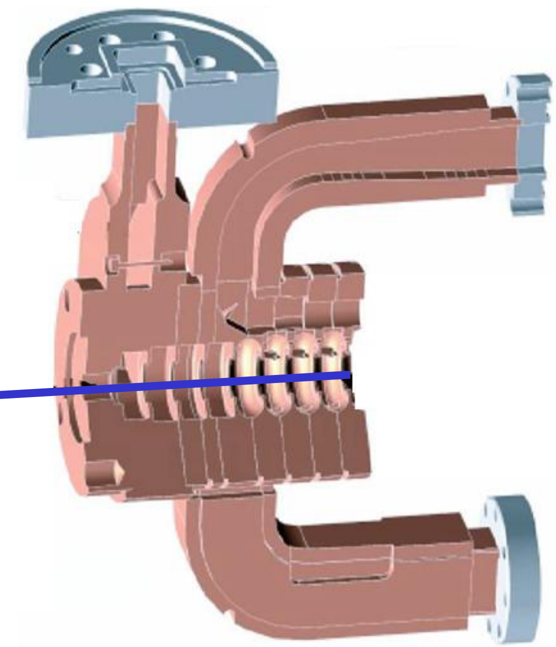
1 IR

Competing technologies



TESLA

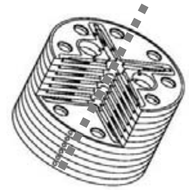
1.3 GHz - Cold



NLC

JLC

11.4 GHz - Warm



CLIC

30 GHz-Warm

Why Decide Technology Now?

- We have an embarrassment of riches !!!!
  - Two alternate designs -- “warm” and “cold” have come to the stage where the show stoppers have been eliminated and the concepts are well understood.
  - R & D is very expensive (especially D) and to move to the “next step” (being ready to construct such a machine within about 5 years) will require more money and a concentration of resources, organization and a worldwide effort.
  - It is too expensive and too wasteful to try to do this for both technologies.
  - A major step toward a decision to construct a new machine will be enabled by uniting behind one technology, followed by a making a final global design based on the recommended technology.
  - The final construction decision in ~5 years will be able to fully take into account early LHC and other physics developments.

The ITRP Members

Jean-Eudes Augustin (FRANCE)

Jonathan Bagger (USA)

Barry Barish (USA) - Chair

Giorgio Bellettini (ITALY)

Paul Grannis (USA)

Norbert Holtkamp (USA)

George Kalmus (UK)

Gyung-Su Lee (KOREA)

Akira Masaike (JAPAN)

Katsunobu Oide (JAPAN)

Volker Soergel (GERMANY)

Hirotaka Sugawara (JAPAN)

David Plane - Scientific Secretary

The Charge to the International Technology Recommendation Panel

General Considerations

The International Technology Recommendation Panel (the Panel) should recommend a Linear Collider (LC) technology to the International Linear Collider Steering Committee (ILCSC).

On the assumption that a linear collider construction commences before 2010 and given the assessment by the ITRC that both TESLA and JLC-X/NLC have rather mature conceptual designs, the choice should be between these two designs. If necessary, a solution incorporating C-band technology should be evaluated.

Note -- We have interpreted our charge as being to recommend a technology, rather than choose a design

Evaluating the Criteria Matrix

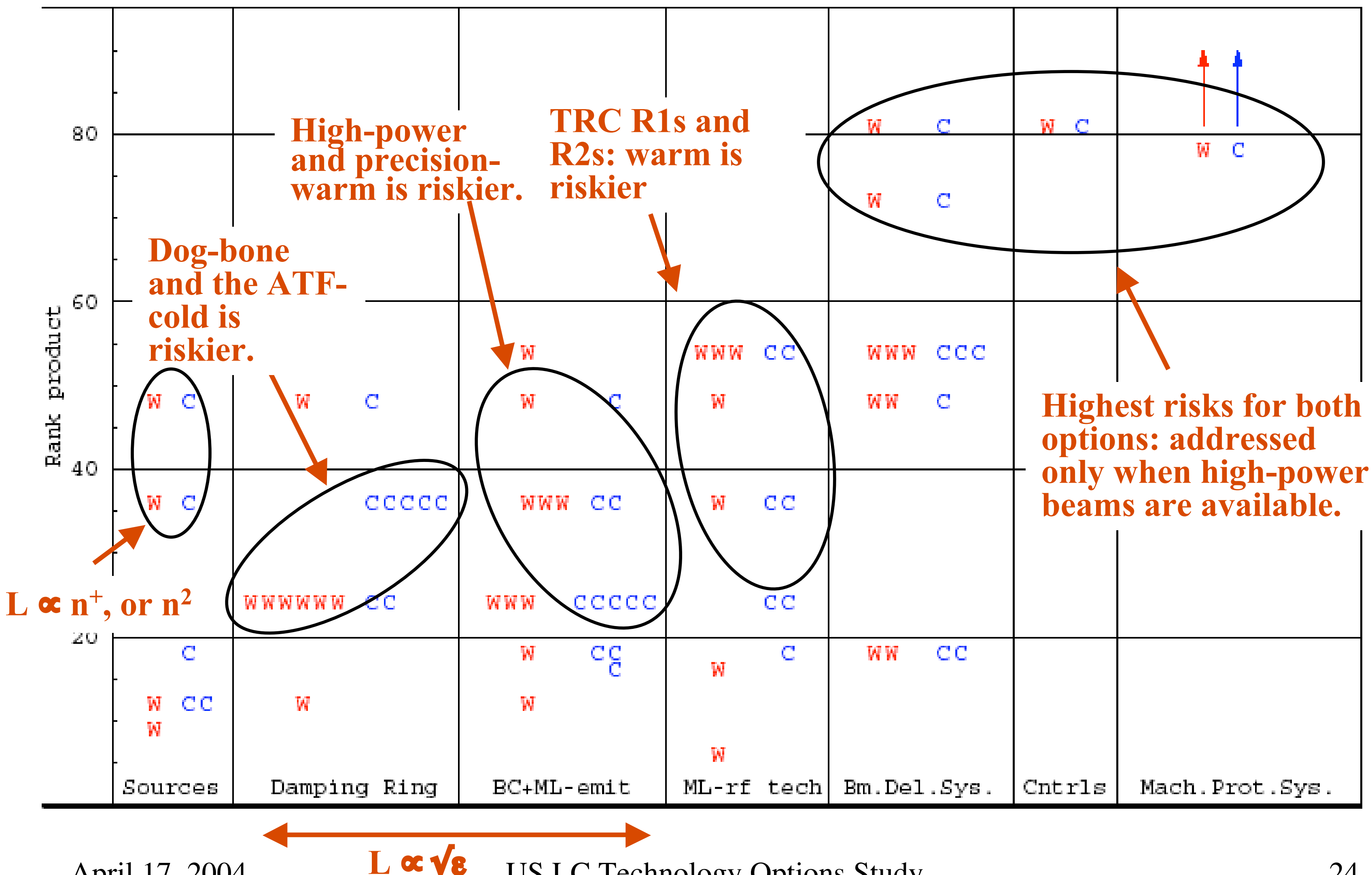
- We analyzed the technology choice through studying a matrix having six general categories with specific items under each:
  - the scope and parameters specified by the ILCSC;
  - technical issues;
  - cost issues;
  - schedule issues;
  - physics operation issues;
  - and more general considerations that reflect the impact of the LC on science, technology and society

- We evaluated each of these categories with the help of answers to our "questions to the proponents," internal assignments and reviews, plus our own discussions

ILC Technical Review Committee report (2003)

Still missing	TESLA		JLC-C	JLC-X/NLC		CLIC		Common
	500	800	500	500	1000	500	3000	
feasibility study	0	1	2	2	0	5	2	0
design	7	4	2	3	0	6	2	8
prototype tests	10	3	3	11	0	5	0	19
final optimization	1	0	1	2	2	0	0	8

Risk Assessment Rank Product Summary



The Recommendation

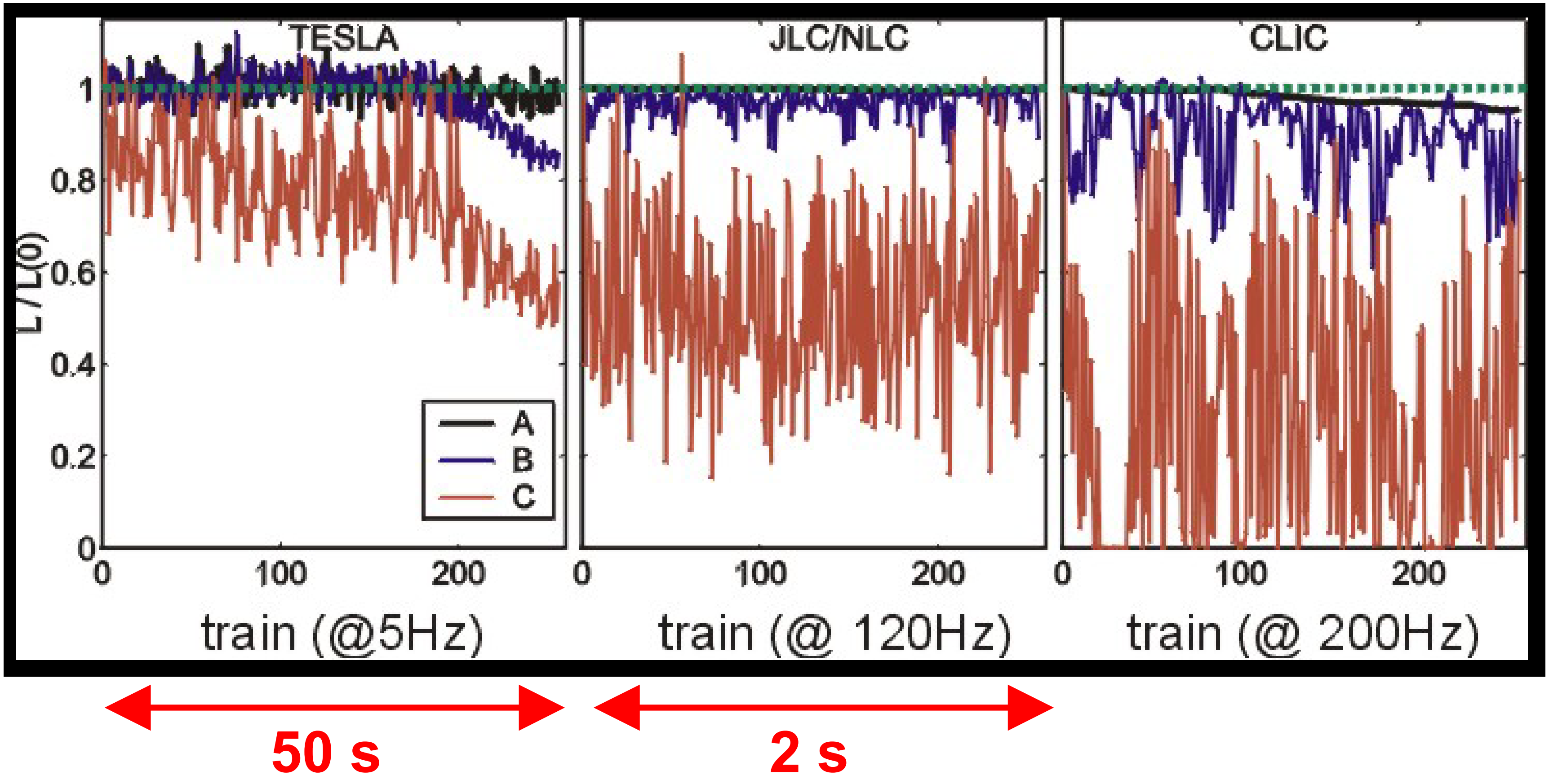
- **We recommend that the linear collider be based on superconducting rf technology (from Exec. Summary)**
  - **This recommendation is made with the understanding that we are recommending a technology, not a design. We expect the final design to be developed by a team drawn from the combined warm and cold linear collider communities, taking full advantage of the experience and expertise of both (from the Executive Summary).**
  - **We submit the Executive Summary today to ILCSC & ICFA**
  - **Details of the assessment will be presented in the body of the ITRP report to be published around mid September**
  - **The superconducting technology has features that tipped the balance in its favor. They follow in part from the low rf frequency.**

Some of the Features of SC Technology

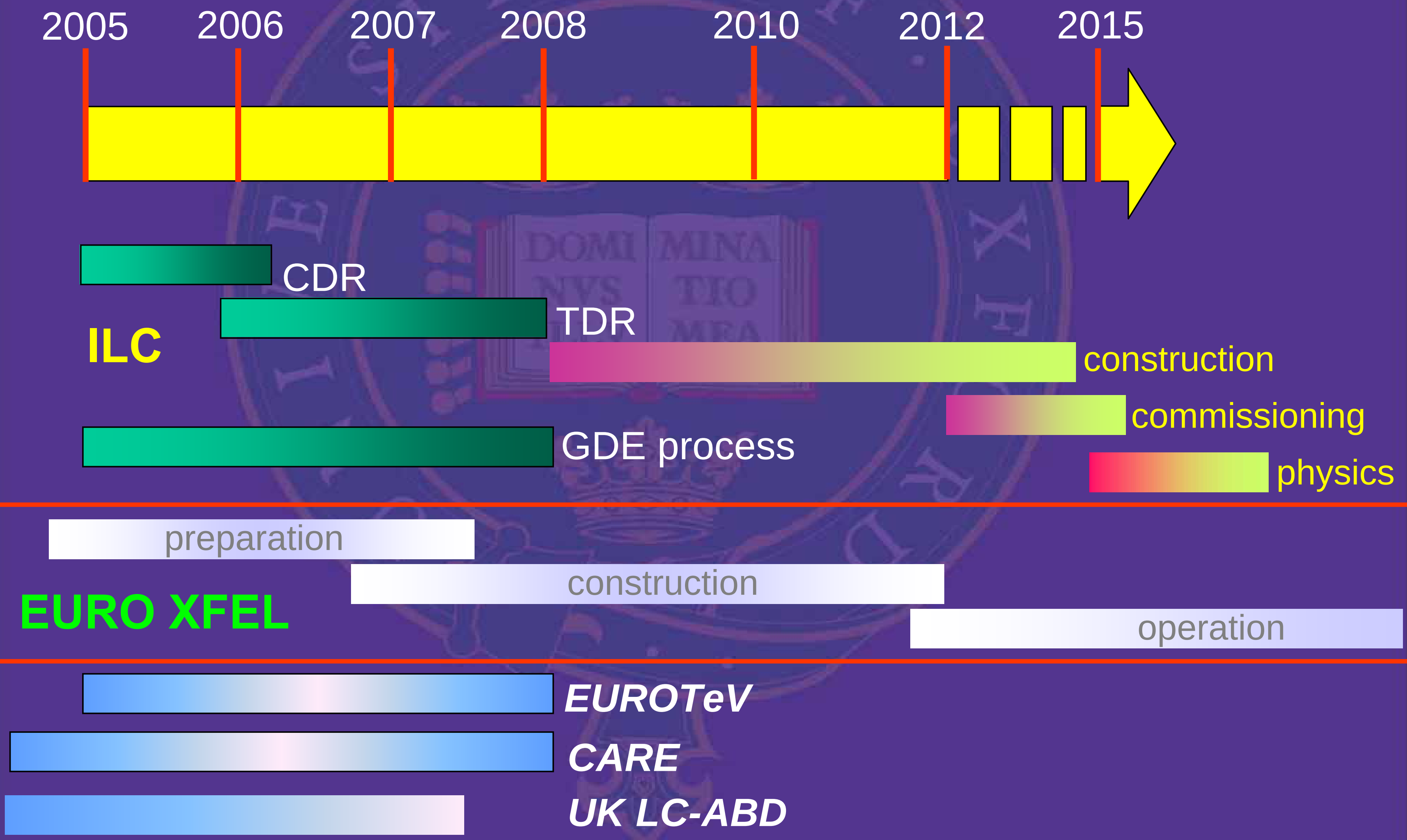
- **The large cavity aperture and long bunch interval reduce the complexity of operations, reduce the sensitivity to ground motion, permit inter-bunch feedback and may enable increased beam current.**
- **The main linac rf systems, the single largest technical cost elements, are of comparatively lower risk.**
- **The construction of the superconducting XFEL free electron laser will provide prototypes and test many aspects of the linac.**
- **The industrialization of most major components of the linac is underway.**
- **The use of superconducting cavities significantly reduces power consumption.**

Both technologies have wider impact beyond particle physics. The superconducting rf technology has applications in other fields of accelerator-based research, while the X-band rf technology has applications in medicine and other areas.

Luminosity stability: "Start-to-end" simulations, including ground motion



Project Timelines

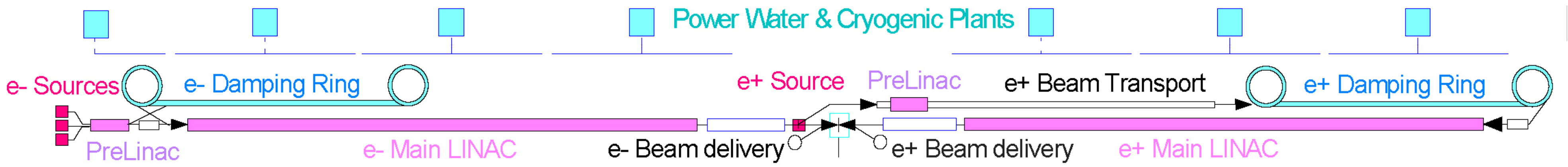


Note -- "We have interpreted our charge as being to recommend a technology, rather than choose a design..."

Can TESLA be the baseline?

Still many alternatives remain after the SC/NC decision

- Accelerating gradient: 35MV/m or higher ?
- Tunnel: Single or double (or triple) ?
- Damping ring: dogbone or small ?
- Positron production: undulator or conventional ?
- Crossing angle: zero or small or large ?

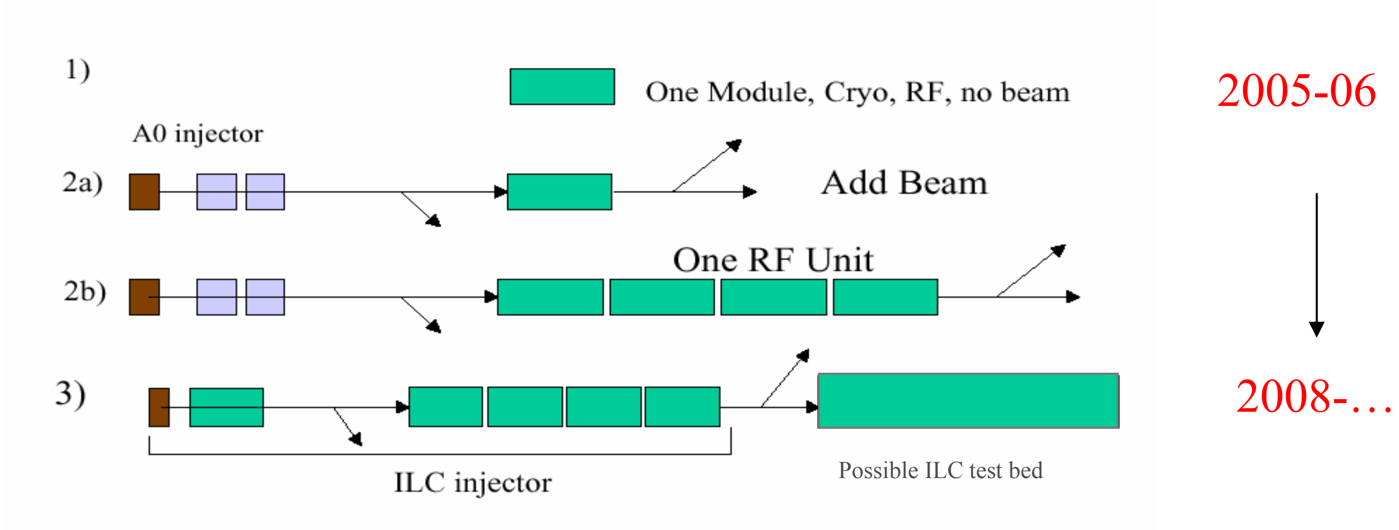


ILC Cryomodule Fabrication and SMTF

- **It is imperative to establish a US-based capability in the fabrication of high gradient superconducting accelerating structures.**
  - Assume the fabrication of ~20,000 ILC accelerating structures will be shared among the three regions.
  - Significant U.S. SCRF expertise at: Argonne, Cornell, Fermilab, Jefferson Lab, Los Alamos, Michigan State
  - Experience extends to both development and fabrication (e.g. SNS), but at gradients significantly below 35 MV/m
  - JLab has made an SRF proposal to DOE for ILC cryomodule fabrication and technology transfer.
- **The vehicle is the SMTF (Superconducting Module and Test Facility).**
  - "The goal is to strengthen U.S. capabilities in high gradient and high Q superconducting accelerating structures in support of the International Linear Collider (ILC) and other accelerator projects of interest to U.S. laboratories."
  - Collaboration of major DOE and NSF laboratories and universities, with international participation.
  - Incorporate ILC, $\beta<1$ (Proton Driver, RIA), and CW test areas.

ILC Cryomodule Fabrication and SMTF

- **Expression of Interest submitted to Fermilab Director.**
  - Based on commitment to play a leading role following the cold decision.
  - Provisional goal is fabrication and testing of three U.S. plus one European high gradient cryomodules by 2008. (in close coordination with the GDE).
  - Cryomodule test facility to be constructed at Fermilab
- **Interested partners:** ANL, BNL, Cornell, FNAL, JLab, LANL, LBNL, MIT, MSU, NIU, ORNL, Pennsylvania, SLAC (, DESY, INFN, KEK)
- **Concept of a possible evolution (ILC portion):**



Depressed?

Honestly yes, for a while, but

Quickly reforming ourselves

- Forming SCRF group
  - Fortunately we have rich manpower and experience for SCRF (Tristan, KEKB, J-Parc)
  - Planning a test facility
- ATF continues
  - The only ring that can create low emittance beam
  - May even create TESLA format beam
- Strengthening Asian collaboration (⇒ Kurokawa)
- Even more enthusiastic participation of industries

3rd ACFA Statement on e^+e^- Linear Collider in Nov. 2004 in Kolkata, India

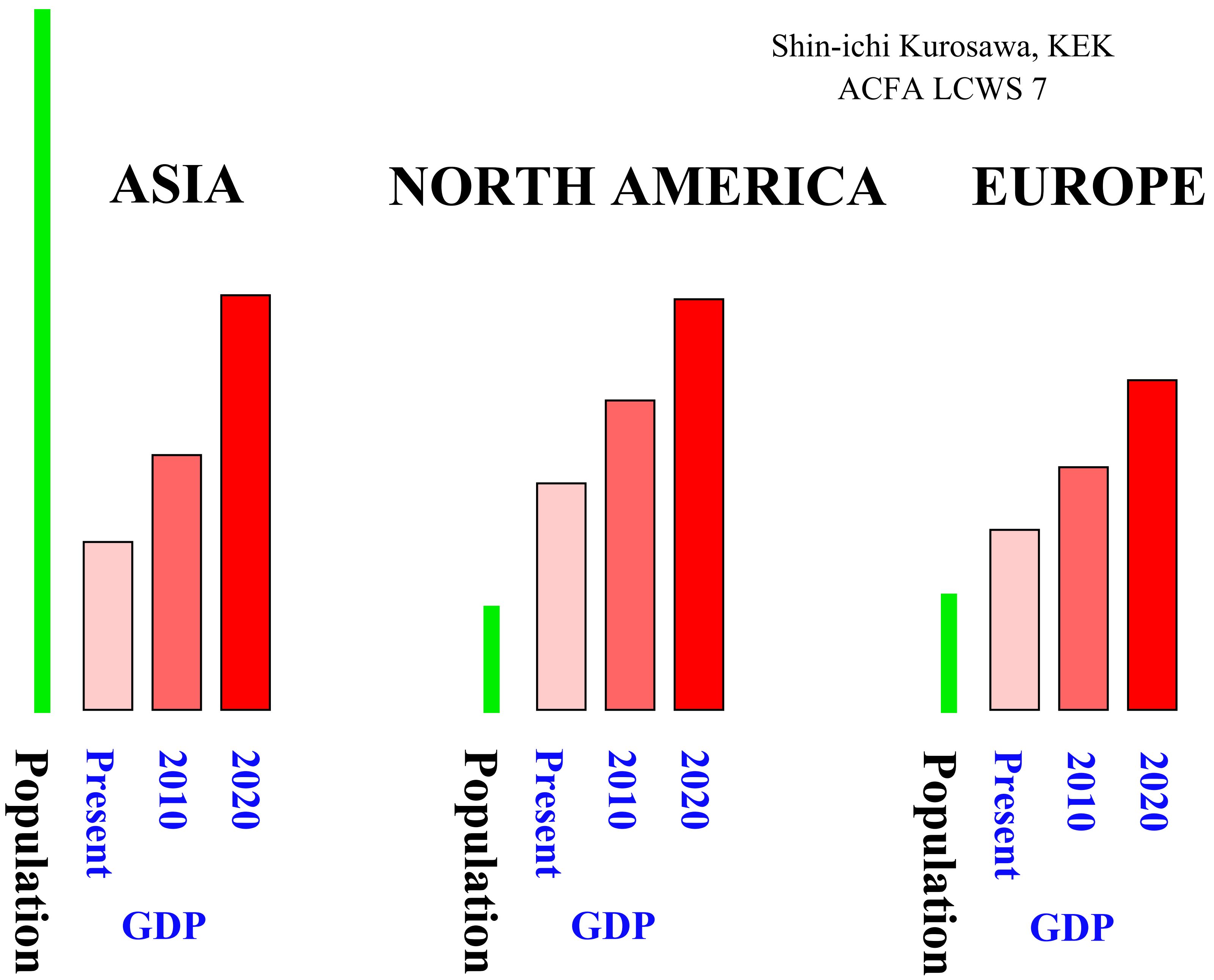
- ACFA welcomes the truly international nature of the decision on technology for the ILC (...)

(...)

- ACFA reconfirms the importance of hosting ILC in Asia, which will make high energy physics and accelerator science truly global.

(...)

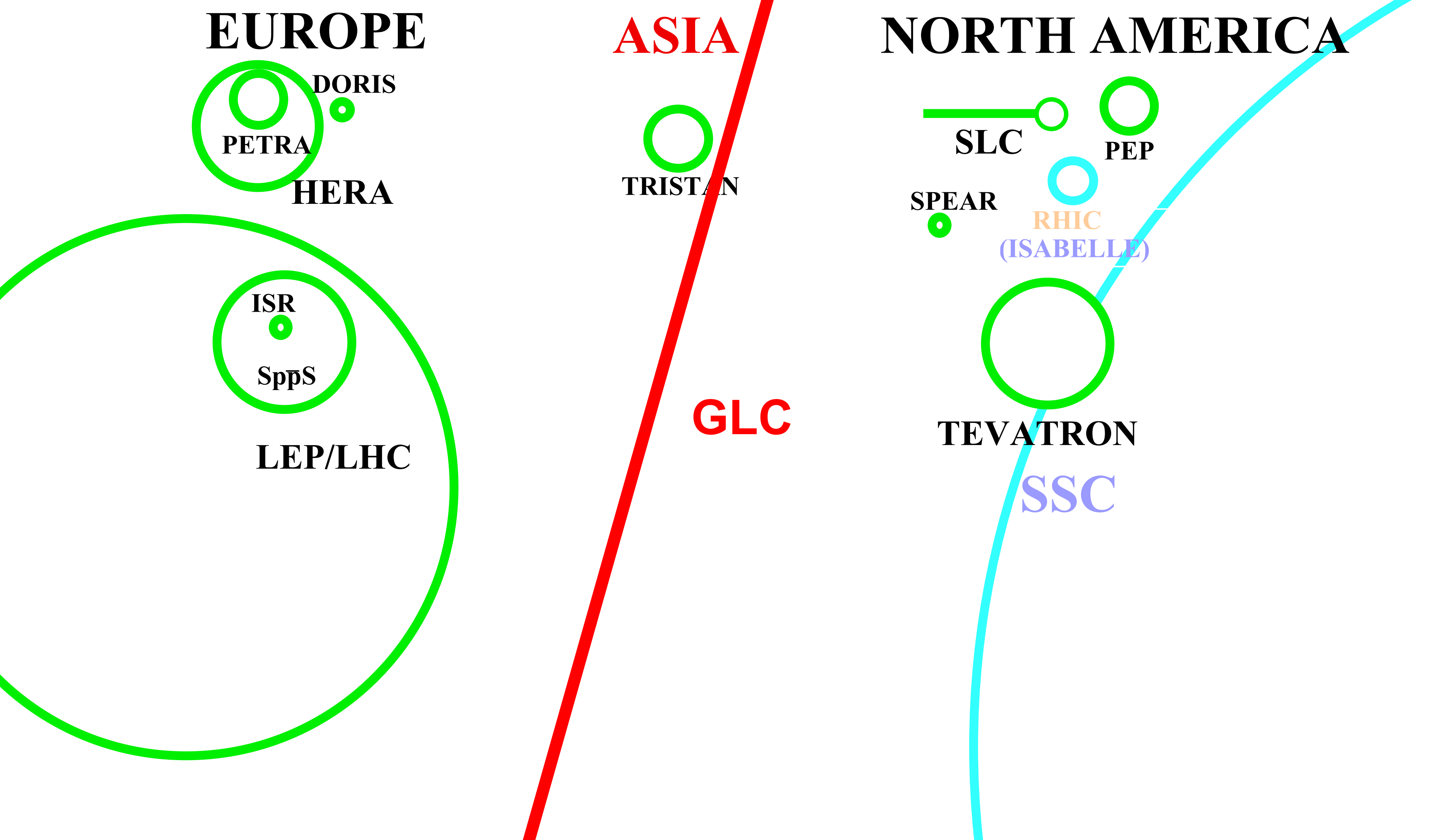
- ACFA reconfirms that KEK is the best suited institute for hosting the Central Team of GDI.



Shin-ichi Kurosawa, KEK
ACFA LCWS 7
ASIA
NORTH AMERICA
EUROPE
Population
Present
2010
2020
GDP
Population
Present
2010
2020
GDP
Population
Present
2010
2020
GDP

Asians Desperately Needs

A Major Energy-Frontier Machine



LC Detector Requirements

- Any design must be guided by these goals:
  - a) Two-jet mass resolution comparable to the natural widths of W and Z for an unambiguous identification of the final states.
  - b) Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks).
  - c) Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than beam-energy spread.
  - d) Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum.
  - e) Timing resolution capable of separating bunch-crossings to suppress overlapping of events.

Challenge

In order to accomplish our physics goal at ILC

With respect to detectors at LHC:

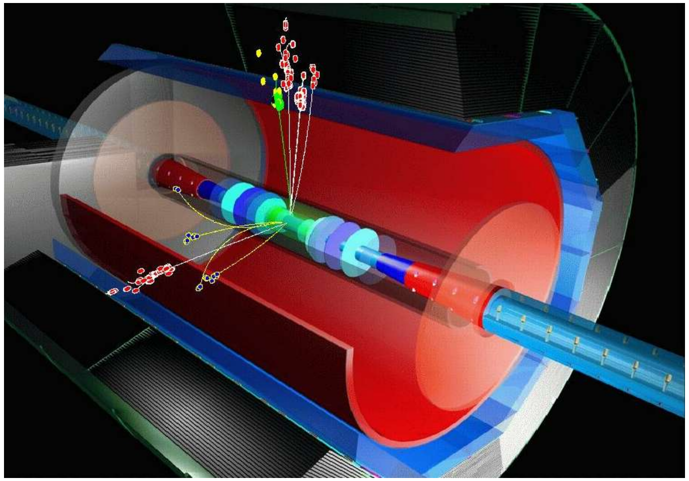
Inner VTX layer	**3--6 times closer to IP**
VTX pixel size	**1 / 30**
VTX materials	**1 / 30**
Materials in Tracker	**1 / 6**
Track mom. resolution	**1 / 10**
EM cal granularity	**1 / 200 !!**

A Medium Size Detector for the ILC

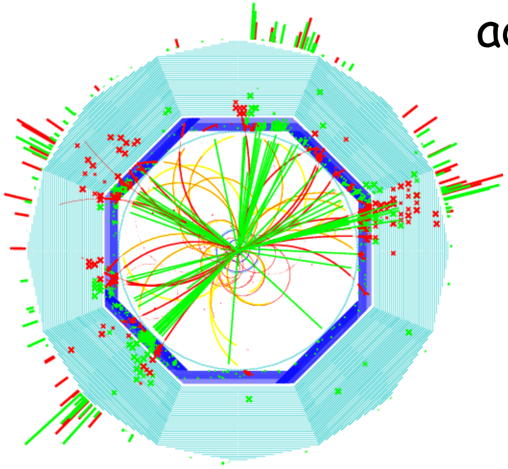
... what used to be the TESLA or LD detector concept

A medium size detector for the linear collider:

- precision tracking
- particle flow based event reconstruction



- high precision VTX
- large volume gaseous tracker
- medium precision SI tracker to join the two devices



advantages of a gaseous detector:

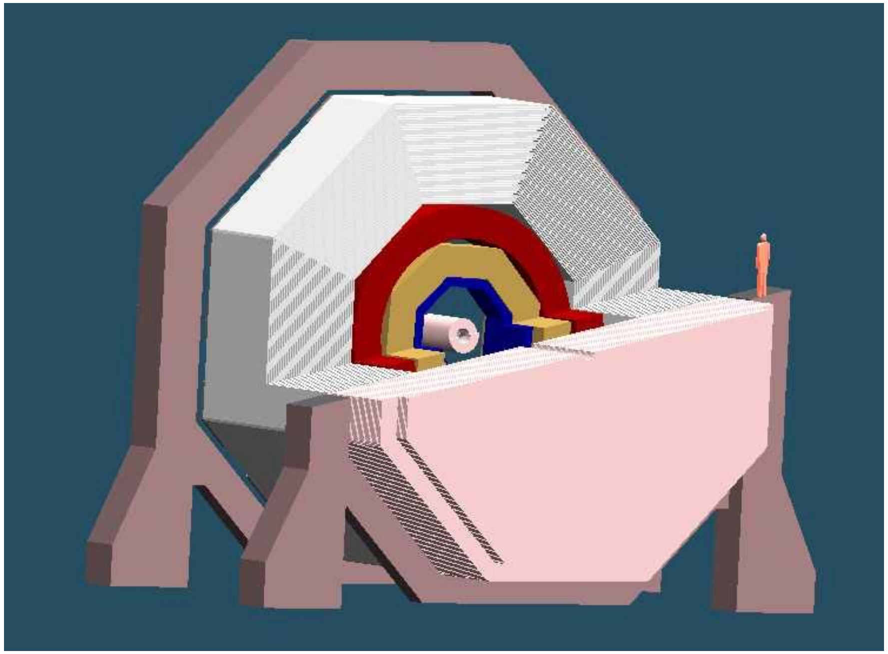
- many space points (200 for current design)
- good precision
- TPC is true 3D device: very robust against backgrounds
- long lived particles (new particles)
- Thin (little material)

H.Weerts

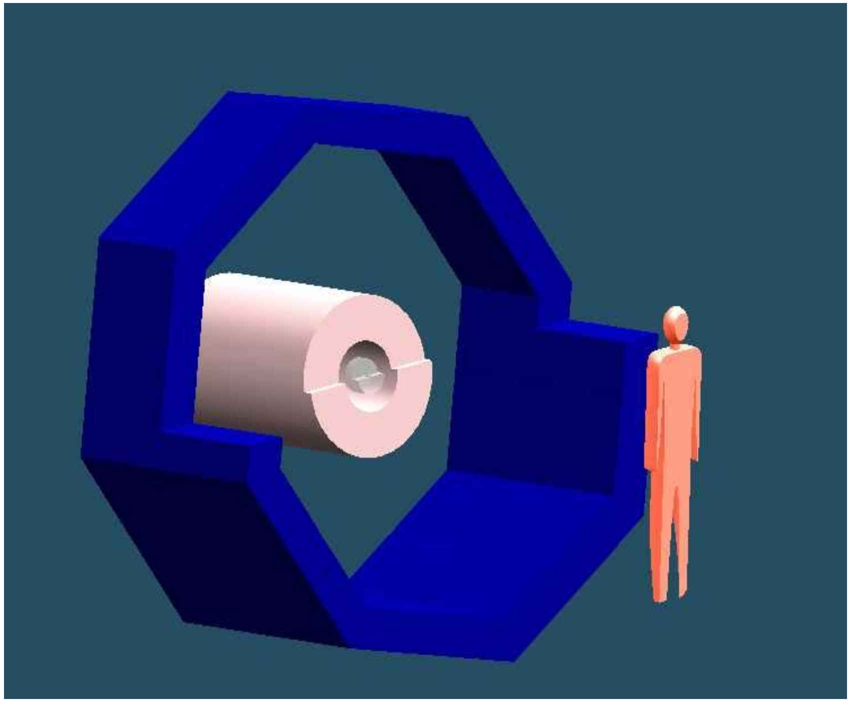
SiD starting assumptions…

particle flow calorimetry will deliver the best possible performance

Si/W is the right technology for the ECAL



Overall SiD



Size of VXD
outer cryostat
and EMCAL

(EMCAL inner radius larger than
Dzero EM cal radius)

Basic design concept

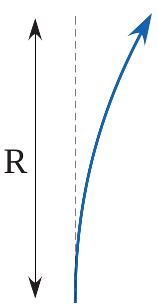
- Performance goal (common to all det. concepts)
  - Vertex Detector: $\delta(IP) \le 5 \oplus 10 / p \sin^{3/2}\theta$
  - Tracking: $\delta p_t / p_t^{\,2} \le 5 \times 10^{-5}$
  - Jet energy res.: $\delta E / E \le 0.3 / \sqrt{\ }$

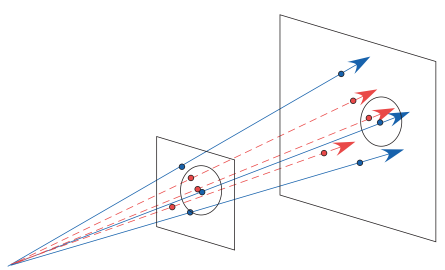
    ➔ Detector optimized for Particle Flow Algorithm (PFA)

- Figure of merit (ECAL):
  - Barrel: $B\, R_{in}^{2} / R_{m}^{effective}$
  - Endcap: $B\, Z^{2} / R_{m}^{effective}$

    R_{in} : Inner radius of Barrel ECAL

    Z : Z of EC ECAL front face

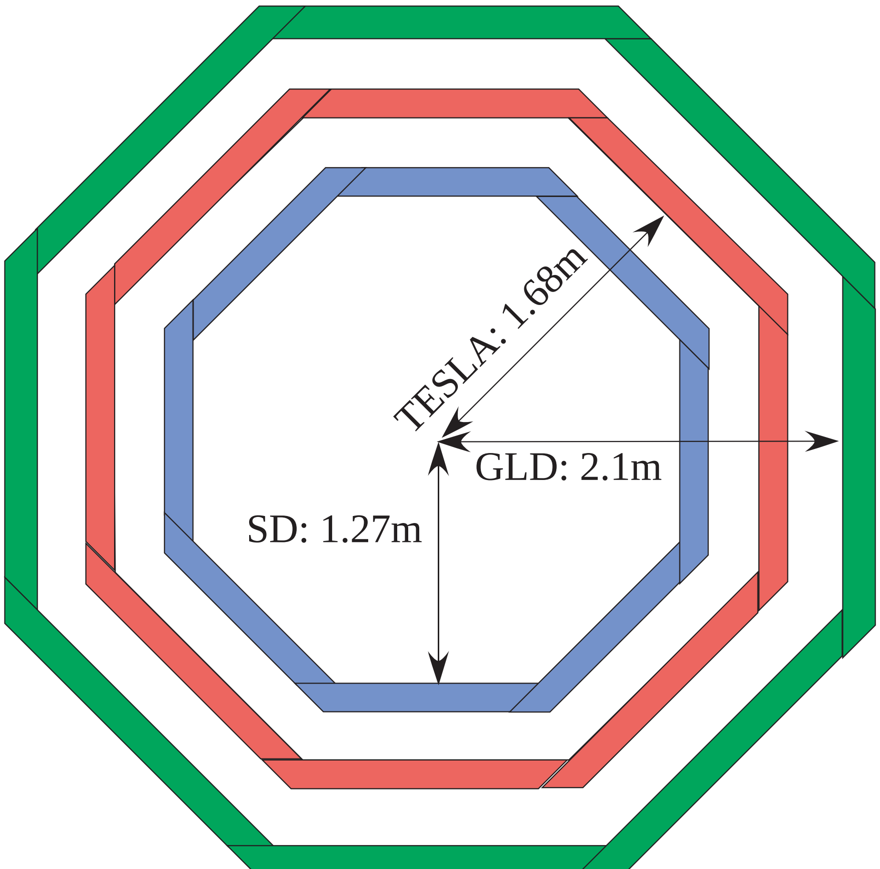




increase R and Z, keeping moderate B

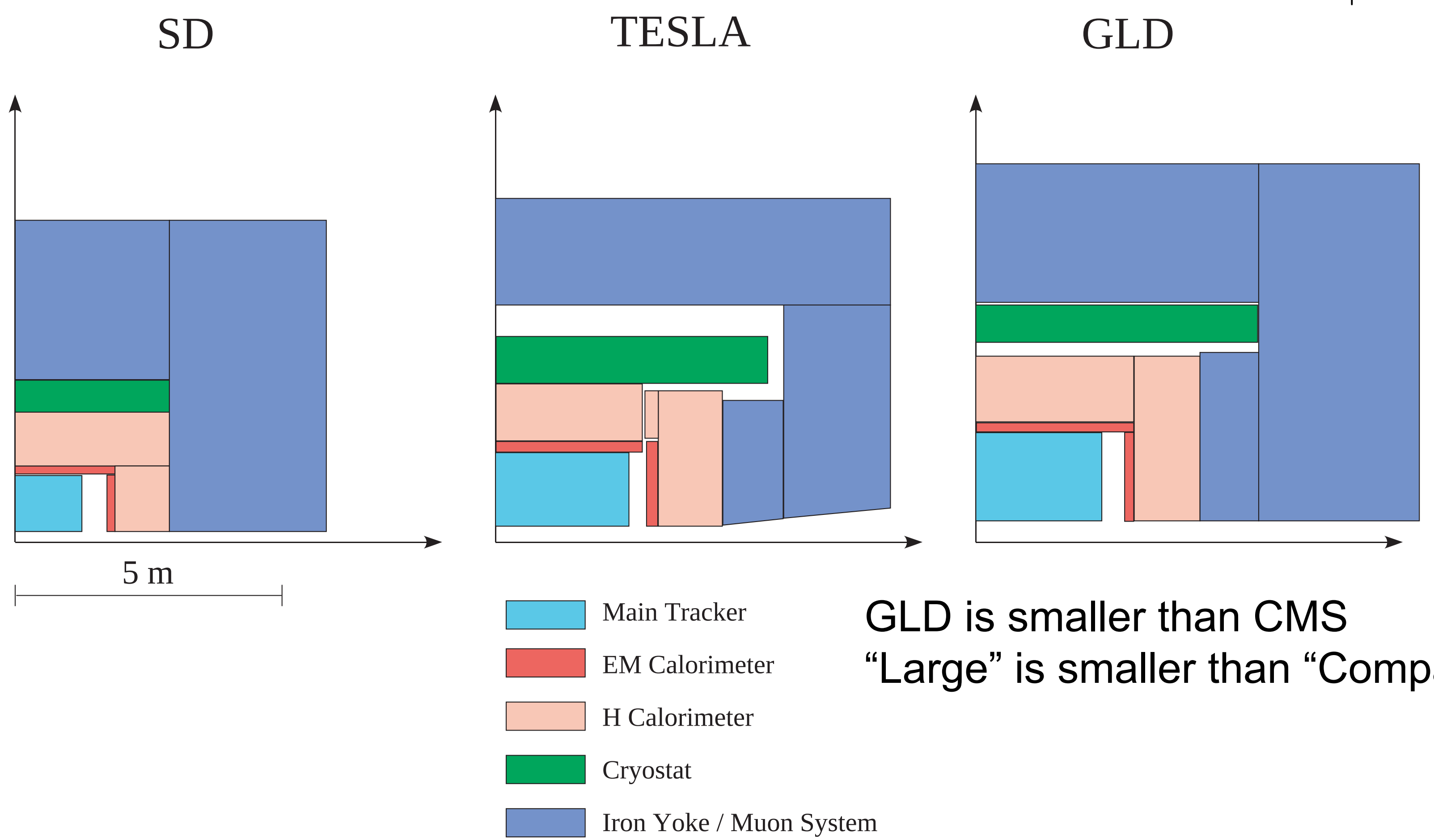
Detector size

- EM Calorimeter



- Area of EM CAL (Barrel + Endcap)
  - SiD: ~40 m^2 / layer
  - TESLA: ~80 m^2 / layer
  - GLD: ~ 100 m^2 / layer
  - (JLC: ~130 m^2 / layer)

Global geometry



GLD is smaller than CMS
“Large” is smaller than “Compact” ☺

Detector design timeline:

(2004) ITRP tech. recommendation	Set up 3 panels (costing, detector R&D, and MDI)
(2005) Accelerator CDR	Single preliminary-costing paper for >1 whole detector concepts
(2007) Accelerator TDR	WWS receives CDR from each detector concept team

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(2008) LC site selection	Collaborations form and submit LOIs for proposal to the global lab (or GDO?)
Site selection + 1yr	Global lab selects experiments.