The ILC Story

The technological and sociological challenges

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What is the ILC?

- A 0.5 - 1.0 TeV electron - positron linear collider
- Integrated luminosity of 500fb^{-1} @ 0.5TeV in 4 years and 1ab^{-1} @ 1 TeV in ~2years
- Funded and built by an international consortium
- Size; 30 -40 Km, Cost; 8+/-2 G$/€
- Major technology choice has been made
- Site to be chosen
- Not yet approved, aim to complete by middle of next decade

There has been much progress in the past few years:

- **In formulating the physics case**
- **In specifying the accelerator technology**
- **In establishing an organizational model**
- **In initiating contacts with government funding agencies**

The International Linear Collier is not only extremely complex technically, but poses unique socialogical, political and financial questions.

I hope in the next 3/4 hour to address some of these.

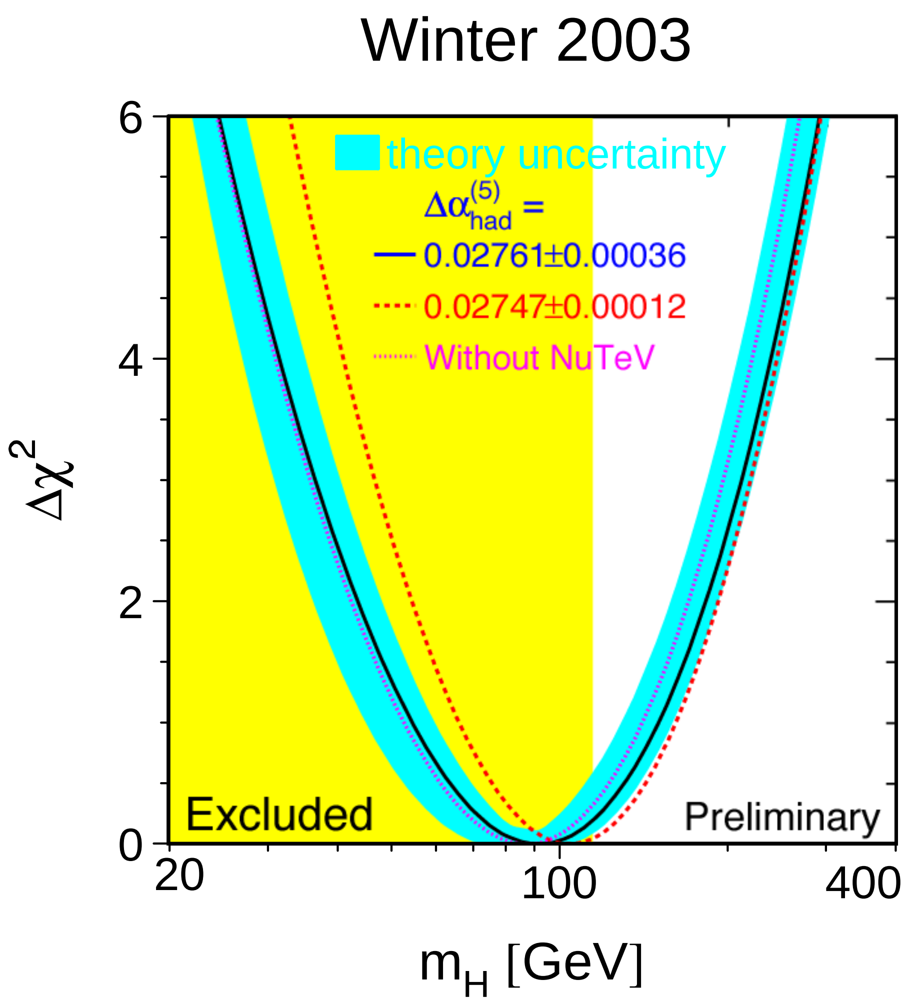
Because this is a huge subject I hope you will forgive me, if I miss out much detail. In particular I will not spend any appreciable time on the scientific justification. I assume that the lectures you have had have done this.

Main elements of the physics programme;

(see http://sbheput.physics.sunysb.edu/~grannis/ilcsc/lc_consensus.pdf)

- Precision measurements, complimentary to LHC.
- New phenomena, eg large extra dimensions
- The Higgs if it exists, will almost surely be discovered by the LHC but its properties must be determined; is it the SM Higgs or more complicated?
- The ILC will measure its mass, width, spin and parity, its coupling to all particles. SUSY Higgs couplings to fermions, WW (ZZ), differ from SM Higgs as SUSY parameters change.
- If SUSY exists, can measure masses, BR's and quantum numbers of accessible particles, with precision much greater than LHC.
- Eventually probably need to go higher than 1.0 TeV

Electroweak Precision Measurements



LEP results strongly point to a low mass Higgs and an energy scale for new physics < 1TeV

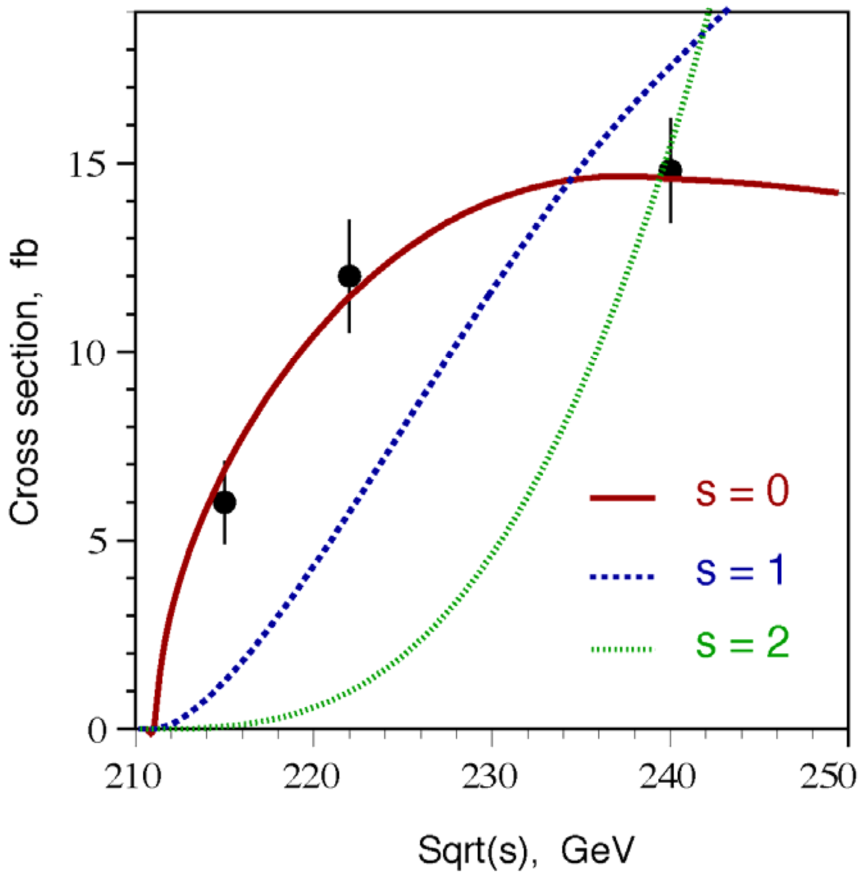
LHC/LC Complementarity

The 500 GeV Linear Collider Spin measurement

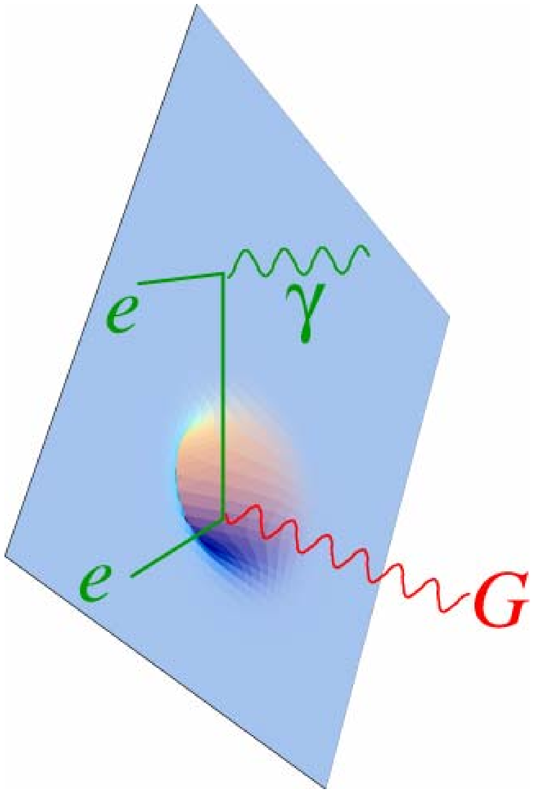
LHC should discover the Higgs
The linear collider will measure the spin of any Higgs it can produce.

The process $e^+e^- \rightarrow HZ$ can be used to measure the spin of a 120 GeV Higgs particle. The error bars are based on 20 fb^{-1} of luminosity at each point.

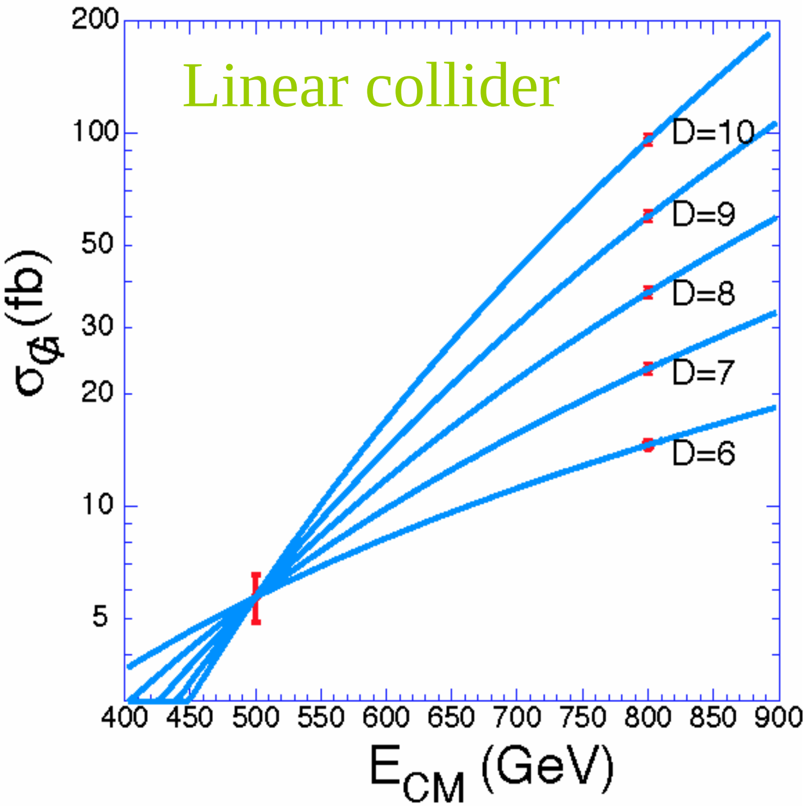
The Higgs must have spin zero



LHC/LC Complementarity



Extra Dimensions



New space-time dimensions can be mapped by studying the emission of gravitons into the extra dimensions, together with a photon or jets emitted into the normal dimensions.

- The high energy frontier has been the preserve of colliding beam machines for the past 25 years, starting with the ISR. Other examples are the ppbar collider, SLC, LEP and the Tevatron.

- The reason for this is easy to see, but brings technical complexity:
  - The cm energy of two equimass particles striking each other head on is just the sum of the two energies.
  - The cm energy in the case of a particle striking a fixed (stationary) target;

$$W^2(\text{cm energy}) = 2ME + M^2$$

So that when $E \gg M$, $W \sim E^{1/2}$

For example, for the LHC with $E_1 = E_2 = \mathbf{7}$ TeV

$W = 14$ TeV,

To get 14 TeV in the cm from a fixed target machine need beam energy;

$$E = (W^2/2M) - M/2$$

With $M \sim 1$ GeV (proton)

$E(\text{beam energy}) = (14^2 \times 10^6)/2 \text{ GeV} \sim \mathbf{10^5}$ TeV

- All previous colliders were circular machines except the SLC.
- It is energetically extremely unfavourable for high energy electron accelerators to be circular.
- When a charged particle changes its momentum, eg it is bent in a magnetic field, it radiates photons.

Radiated energy ~ $e^2\beta^2\gamma^4/\rho$

(Where e is the charge of the beam, β is the velocity in units of c (ie ~ 1), γ = p/m, where p is the momentum of the particle m its mass, and ρ is the radius of curvature.)

- For a fixed radius of curvature the radiated power goes as $(p/m)^4$

- For example; If we wished to run LEP at 0.5 TeV $(2.5)^4$ more power would be radiated than at 0.2 TeV

- But power radiated at 0.2 TeV is already ~15MW, so at 0.5 TeV it would be ~ 0.6 GW, and at 1 TeV it would be ~10 GW (about 2-3 nuclear power stations!)

(This assumes that the increase in luminosity needed, going from $\sim 10^{32}$ to $\sim 3\times10^{34}\ s^{-1}$ can be achieved without increase in circulating e+/e- current!)

So why International Linear Collider?

International: Cost, skilled manpower

Linear: Synchrotron radiation

Collider: Only way to reach high cm energies

What are the main technological Challenges?

- Studies started some 15 years ago in various parts of the world to define and solve the problems of building a high energy LC.

- The two critical parameters are high energy and high integrated luminosity

- An LC is a very complex device, but broadly consists of 3 sub-systems, a low energy injection and damping system, a main accelerating system and a beam delivery system.

- I will concentrate on the main accelerating system, although I will mention the beam delivery system.

- To build a machine of 1 TeV in a reasonable length, eg LEP tunnel length (27 Km) need accelerating gradients of > 35MV/m.
- No structures were available at the time to reach this gradient.
- This led to two developments:
  - Room temperature copper structures operating at 5.7 -> 11.4 GHz (X-band)
  - Super conducting niobium structures operating at ~2deg K and 1.3 GHz(L-band)
- In 1990, gradient available for SC cavities was 5MV/m

- By 2003, 35 MV/m SC cavities had been developed.

- In the case of copper, room temperature cavities, the accelerating field was also increased, reaching 50MV/m at 11.3GHz.

- Thus by 2003, the technology for the main linac was in place, but there were **2** possibilities!!

- A choice had to be made - the **ITRP** set up by ICFA.

- Reported in August 2004 - COLD!

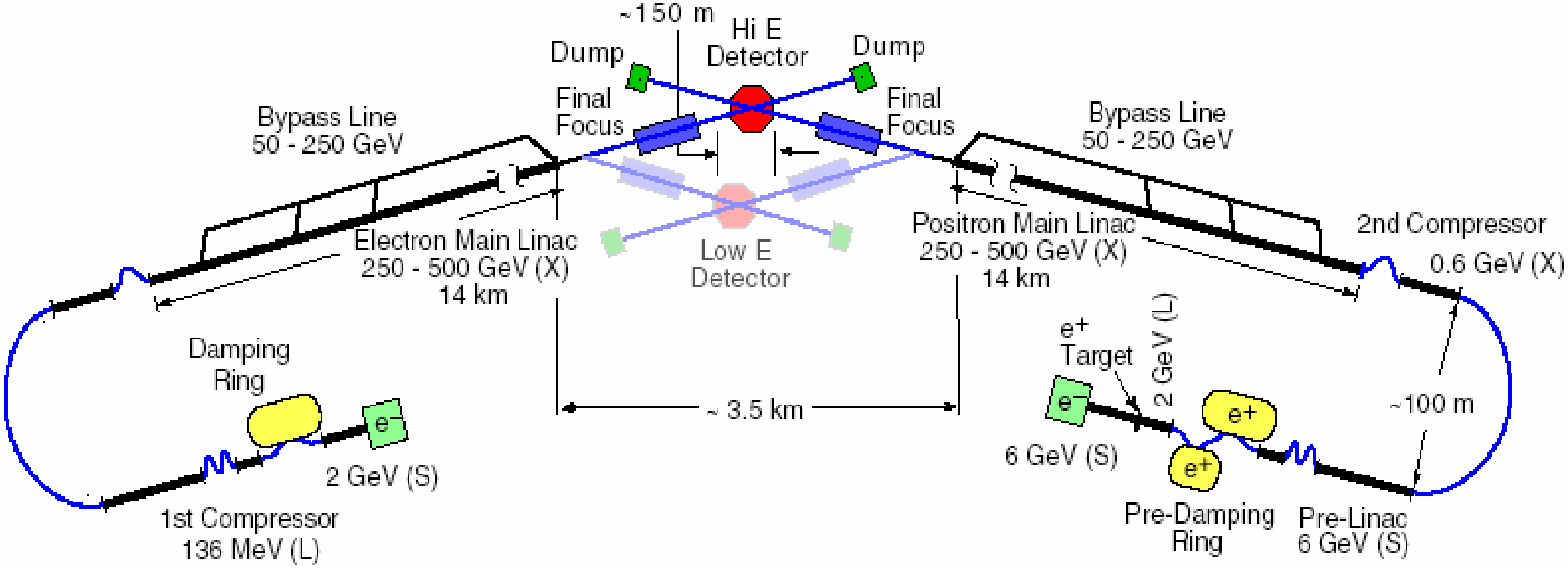
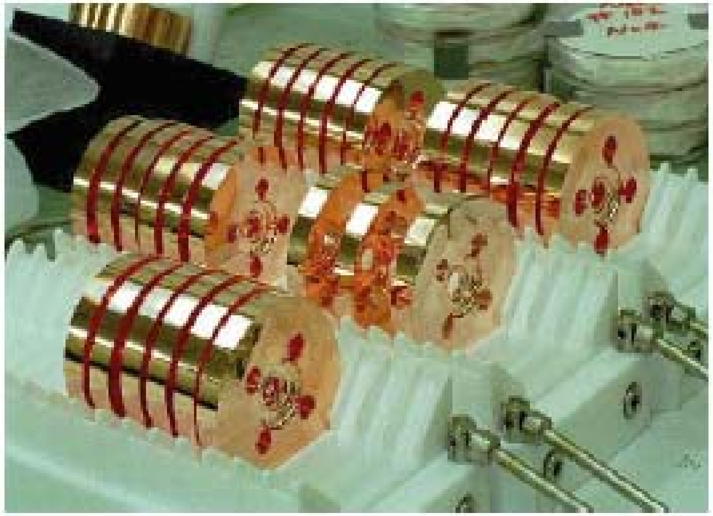


FIGURE 3.38. Schematic of the JLC-X/NLC.



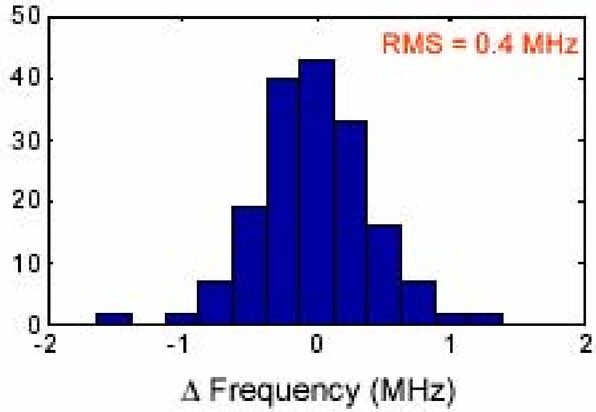
Cell Fabrication

Need to:

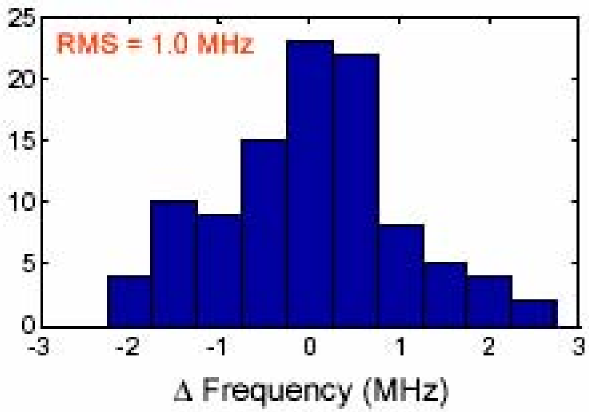
- Control fundamental frequency by tuning or feed-forward machining.
- Maintain smooth dipole frequency profile.

Deviations of Cell Dipole Mode Frequencies: Require < 3 MHz RMS

Single-Crystal Diamond Turning

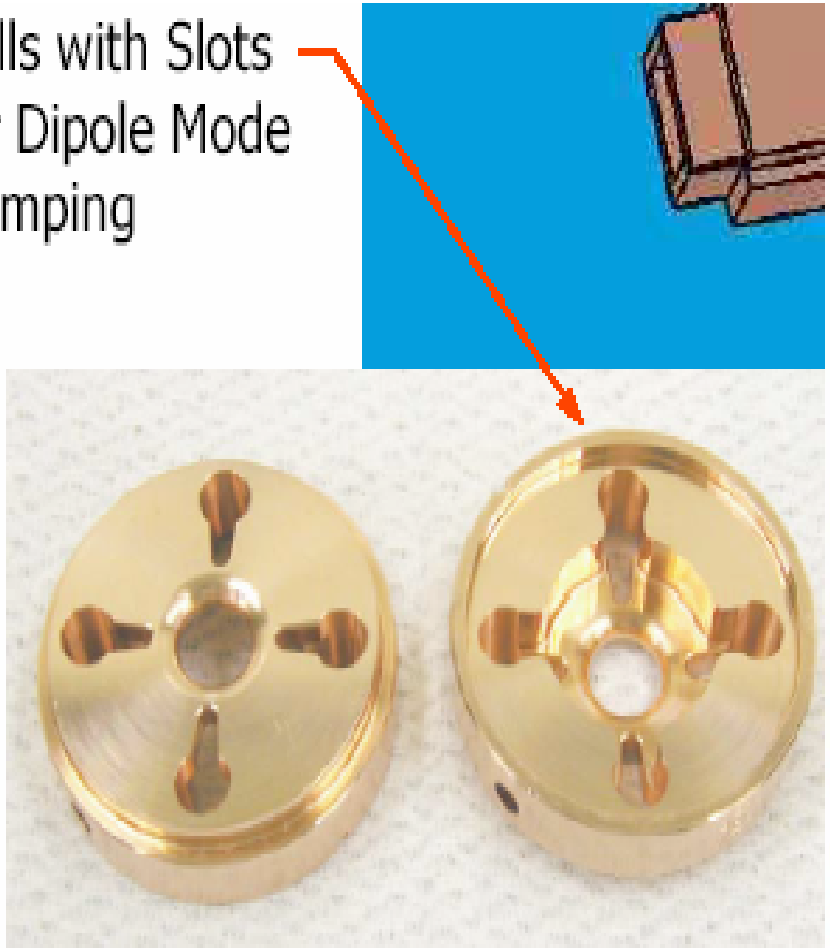


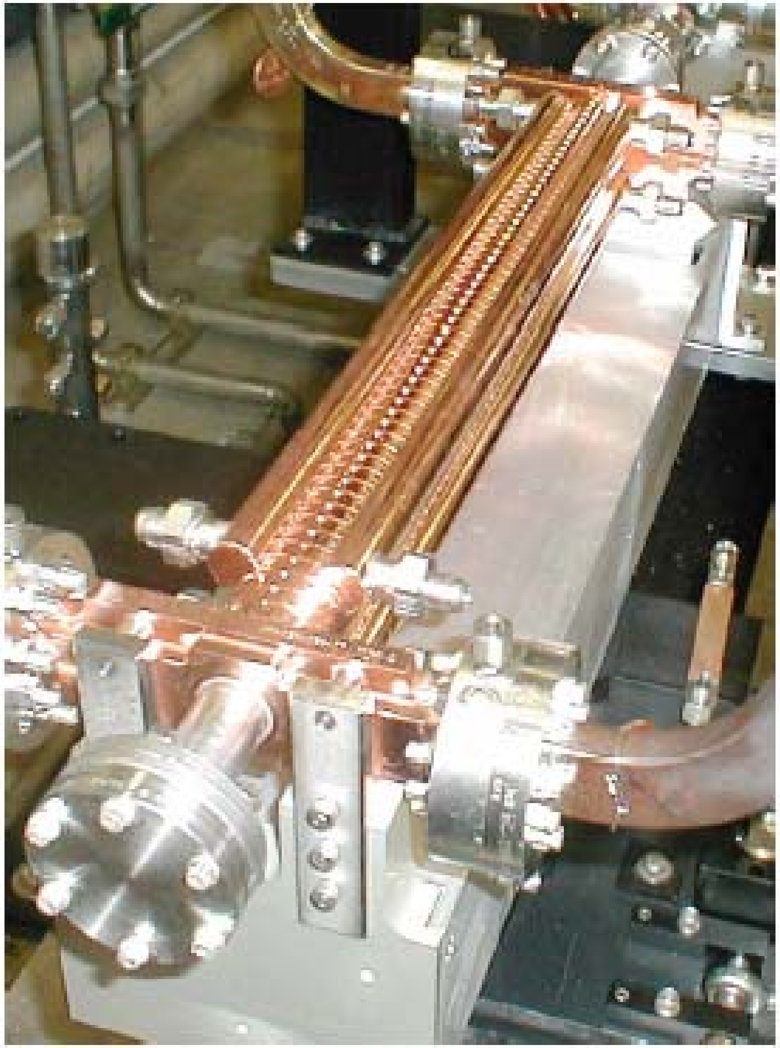
Poly-Crystal Diamond Turning



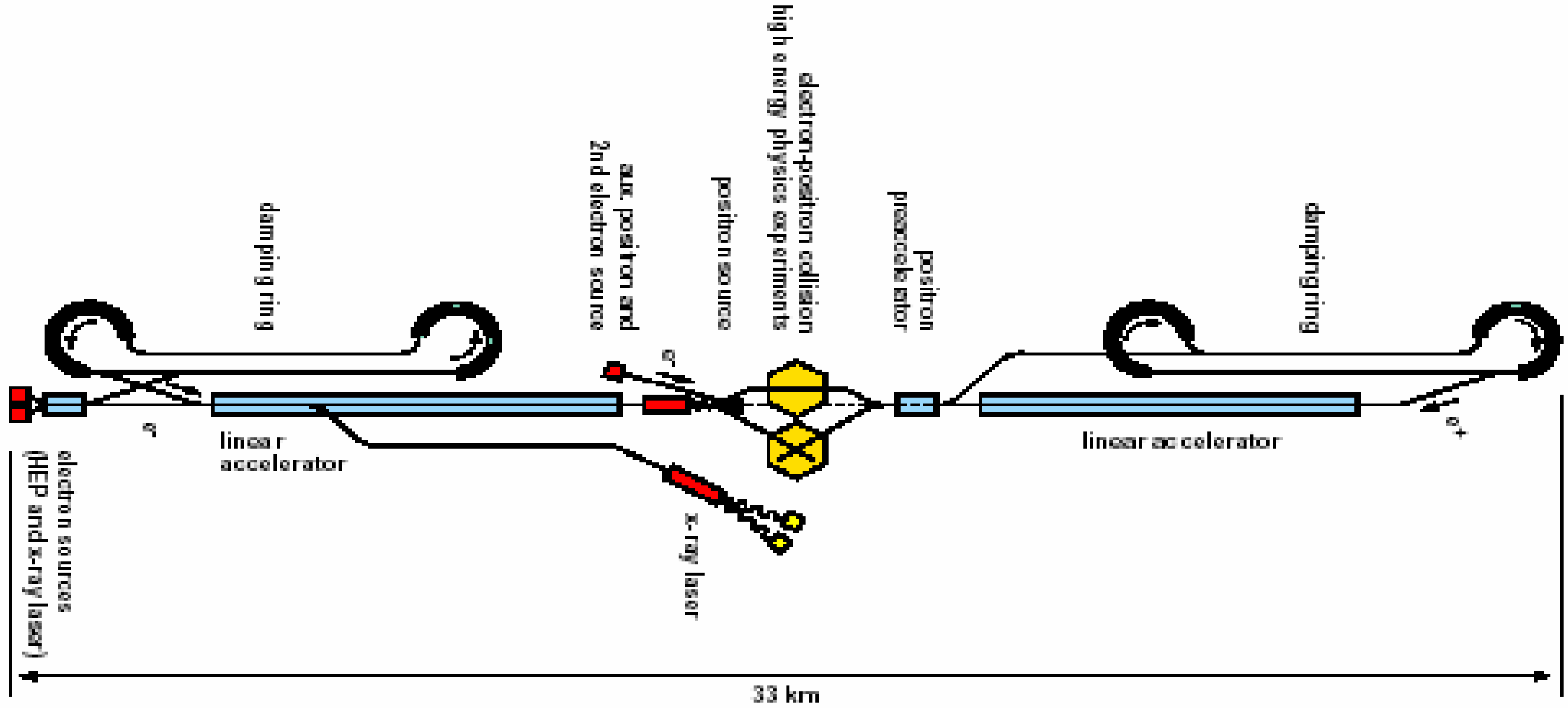
Traveling-Wave Structure

Cells with Slots for Dipole Mode Damping

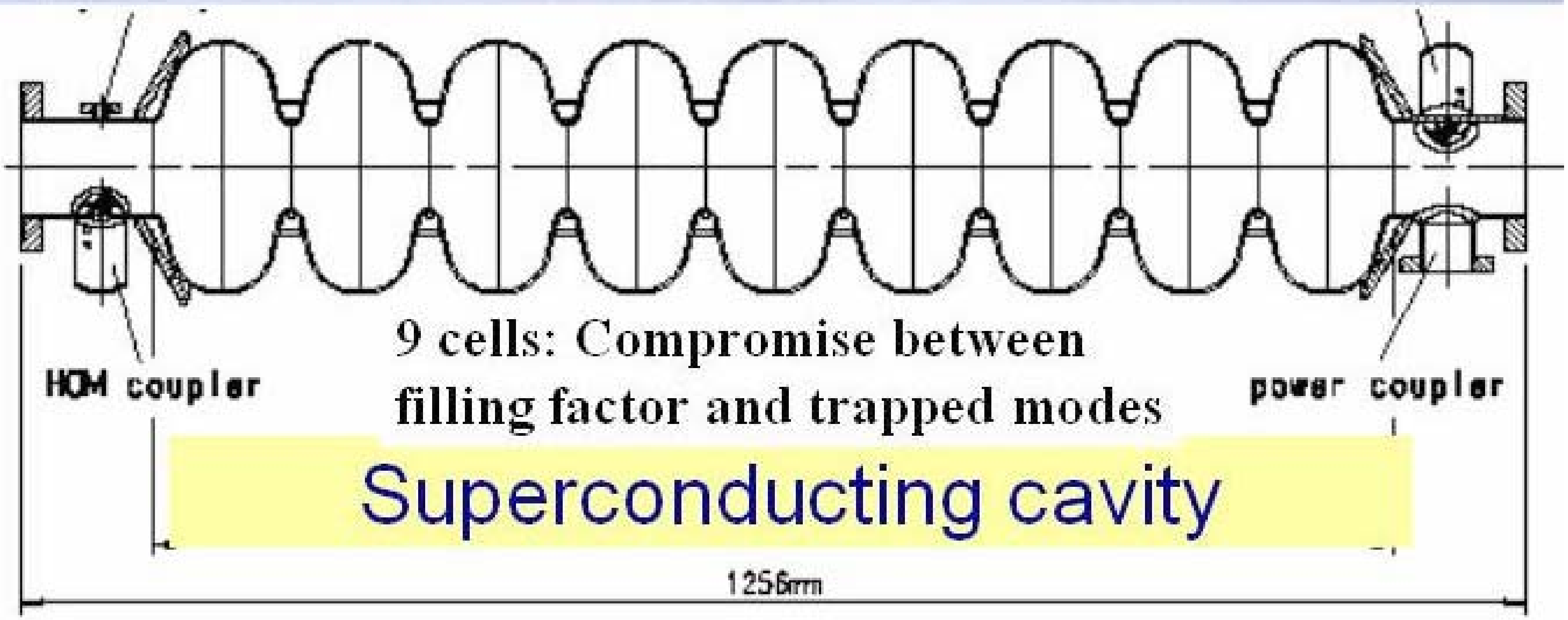




Schematic of TESLA




TDR Budget
1.3 GHz
Operating temperature 2K
24 kg/cavity Nb
Niob RRR 300
Deepdrawn from sheet
Welding by electronbeam


HOM coupler
9 cells: Compromise between
filling factor and trapped modes
power coupler
Superconducting cavity
1256mm

Main Linacs

TESLA:

- Uses pure niobium cavities cooled by superfluid helium at 2K.
- Max. gradient 35MV/m
- Two 9-cell cavities standing wave structures coupled together make up the basic acceleration module (superstructure, 2.39m long)
- Each superstructure has a power coupler, 2 tuners and 3 HOM couplers.

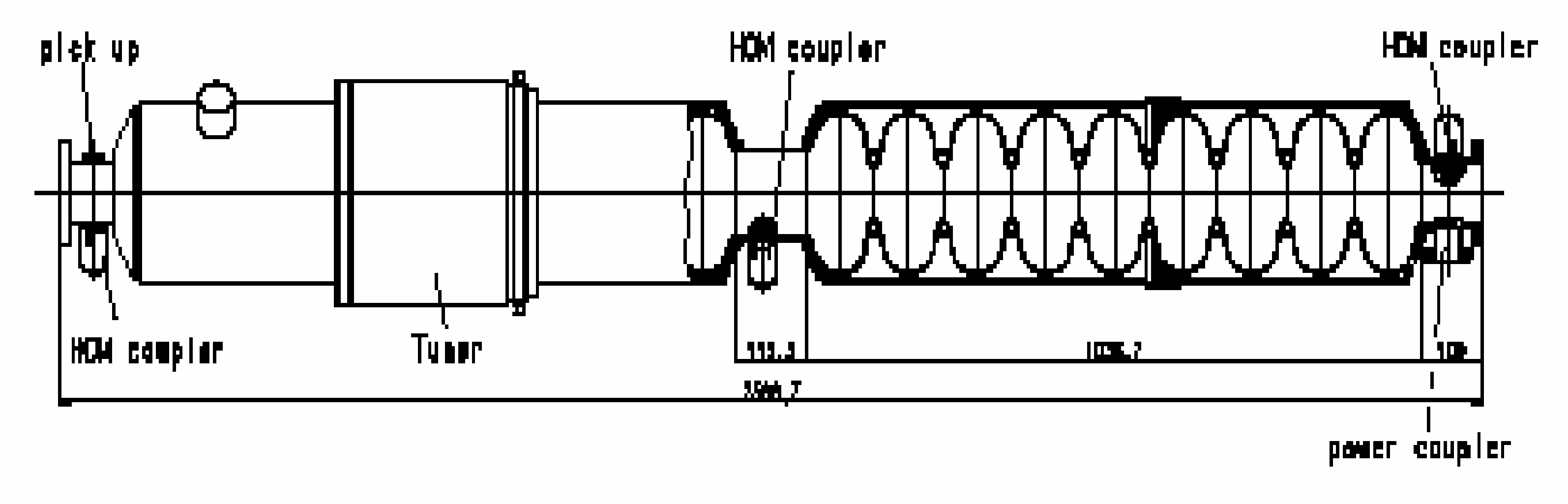
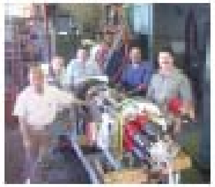
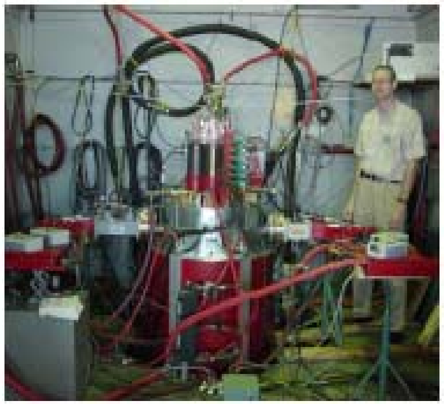


Photo gallery of the VKL-8301 MBK






R Budget
Complete Module

TESLA Single Tunnel Layout

- The TESLA cavities are supplied with rf power in groups of 36 by 572 10 MW klystrons and modulators.

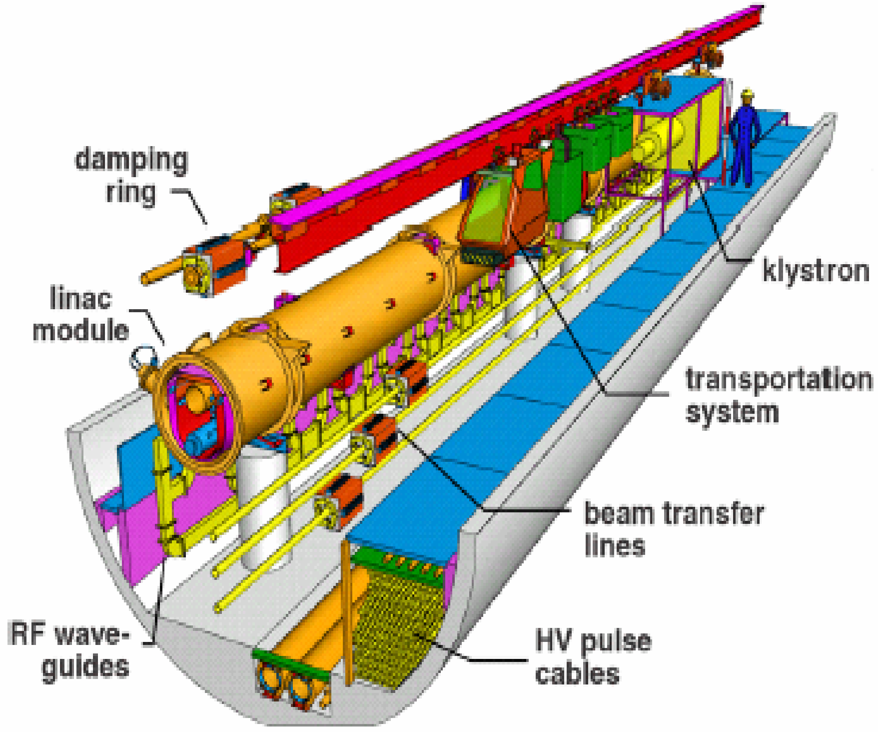


FIGURE 2. Sketch of the 5 m diameter TESLA linac tunnel

Usefull Linac Parameters
(500 GeV)

	TESLA	NLC
RF Frequency (GHz)	1.3	11.4
Design Luminosity (10**33)	34	25
Linac Rep. Rate (Hz)	5	120
No. of Particles/bunch at IP (10**10)	2	0.75
No. of bunches/pulse	2820	192
Bunch separation (nsec)	337	1.4
Bunch train length (microsec)	950	0.267
No. of Accelerating structures	18096	18080
No. of Klystrons	603	4520
Peak Power RF power/klystron (MW)	10	75
Peak RF power/ structure (MW)	0.276	56
Unloaded/loaded gradient (MV/m)	23.8/23.8 or 35/35	65/50
Linac AC power (MW)	132	207
Beam size at IP (H/V) (nm)	554/5.0	243/3.0

- I have said something about the need for high energy, but just as importantly high integrated luminosity is essential.

- In order to achieve this the two beams have to intersect reliably pulse after pulse.

Note: beam size is (h/v) 550/5 (or 243/3) nm (cf w/l of light ~ 500nm)!.

- High and consistent luminosity is enormously challenging for the alignment of the components of the linacs, the ground stability, the control systems as well as the beam delivery system. Accuracy, monitoring and control of the linac components has to be ~micron.

- It was largely this aspect which swung the decision to Cold

- Transverse wakefields are related to structure size and are a factor of ~1000 lower for SC.

- Apart from the huge technical problems, there was the question of cost, not just the construction cost but the "Lifetime" cost.
- As you might guess, it was extremely difficult, indeed impossible to get a believable cost estimate of the two machines, infact even a relative cost was difficult.
- However, the lifetime costs of the two machines, was felt to be the same within errors. However, the power consumption of the cold machine was much lower.
- Difference of 75MW at 500 GeV and more than 100 MW at 1TeV. (at $0.05/kwh, ~ $25M/year and energy costs are rising much faster than inflation)

- A Global Design Effort, under the leadership of Barry Barish has been set up and its first task is to design and cost the machine.

- Its second task is to convince the funding authorities and ministers of the particle physics community to participate. Eg CERN member states, USA, Russia, Japan, China, Korea, Canada, Australia, India, …………………

Economic, Political and Sociological considerations:

- The scale of the project, both financial and technical are such that any one country, with the possible exception of the USA, would find it impossible.

- It is clear that there will only be one machine of this type built in the world and it will be used by the global community, so it should be built by the global community.

- Apart from this there are ideological reasons, based perhaps on CERN's success, for making it global.

This is new territory!!

- There are very few truly global organizations, and even fewer (~0), successful ones.

- There are therefore no precedents to copy.

- What about the very successful example of CERN?

- It was born in a very different time, when Europe was regrouping after the war and was reacting to the dominance of the USA in our branch of physics. These considerations don't apply now.

- Let me briefly recall how accelerators have been built in the past. A single laboratory has specified, designed and constructed the machine on its own site.
- This meant that there was central control of all aspects of the machine; technical, financial and manpower.
- This meant that project leader not only had the responsibility for the project, but also the authority.
- This would appear to be good practice for a large and complex undertaking.
- However, although it worked at CERN, it was clear it would not work on a global scale, since it would mean shipping large sums of money from continent to continent
- Therefore other models were needed!

- Unlike a space craft, an accelerator has a site and the location of the site breaks any symmetry between the partners, conferring an advantage, financially, technically and culturally on the host nation.
- Are there any models on how to organise such an enterprise?
- Infact, within our own community there is one, and that is the way in which we design, build and even operate large detectors. eg DELPHI, ZEUS, ATLAS.
- But on a much smaller (>1/10) scale and with an ultimate authority, (the host laboratory)

- In 2002, ECFA set up a group to advise it on how to organise, such an international enterprise. I was asked to chair it. At the same time groups were set up in the USA and Asia to look at the same problem.

- I will briefly outline what our key recommendations were.

- For those interested I can point you to our report[(1)].

- I must emphasise that this is at this time a proposal, and has not been endorsed by funding agencies, let alone governments. But, we believed it is the best way forward.

[(1)] (http://committees.web.cern.ch/Committees/ECFA/CERN03KalmusReport.pdf)

Recommendations :

a) ***The LC should be an international legal entity established through intergovernmental agreement as a time limited "Project" located at or near an established laboratory. (Global Linear Collider Project, (GLCP))***

b) ***The Project should be fully international from the outset, with a well-defined relationship with the nearby Host Laboratory which should provide services and infrastructure.***

c) ***Governance of the GLCP should be organised on a regional basis, namely three regions, "Americas", "Asia" and "Europe", each with its own Regional Board.***

f) ***States should participate in the governance of the GLCP through their Regional Board.***

Recommendations :

k) ***An appropriate structure should be devised for the GLCP giving the Project Leader the responsibility and resources to bring the Project to a successful conclusion. The structure should include an oversight and monitoring system which will ensure that the status of the GLCP is transparent to the Member States at all times.***

n) For "Europe" we consider there are two options:

- ***All CERN member states participate in the GLCP as part of the basic programme of CERN, with association/cooperation agreements to allow non-CERN "European" states to participate. In this case the "European" Regional Board would be the CERN Council. This role for the CERN Council will require it to take a strategic overview of European particle physics and modify its working practices. We note that such a role is fully consistent with the mandate of CERN as given in the CERN convention.***

or:

- **"European" contributions are made outside the CERN programme. In this case consideration should be given to using a super- or sub-set of the CERN Council**

Recommendations :

GLCP Contributions

o) ***The fairest and most justified financial model would involve the Host State paying a premium of about 25% of the construction cost (herein after referred to as the Host State Premium), and the balance being divided according to the GDP of the Member States including the Host State.***

p) ***The contributions of the Member States should be organised on a regional basis under the control of the Regional Boards, which would monitor and adjust the contributions within the region as necessary. In-kind contributions should be by value according to a common costing model.***

q) ***The minimum contribution of each member should be proportional to its GDP.*** **Contributions above the GDP share by interested states that wish to enhance the role of their institutes or industry should be encouraged.**

Recommendations:

r) ***Members should make cash and in-kind contributions. They may choose to make their contributions wholly in cash.***

s) ***The majority of the components should be provided as in-kind contributions valued according to a common costing model***

t) ***A significant cash element will be required to allow the Project Leader the flexibility needed to bring the project to a successful and timely conclusion.***

u) ***These in-kind contributions cover the design, manufacture and long-term technical responsibility for major components of the project. Competent institutes,(Lead Laboratories) of the Member States should take the responsibility for these contributions. These Lead Laboratories would be the key players in the realisation of the GLCP. This distribution of responsibility for major components is one of the basic concepts of the Global Accelerator Network (GAN)***

Recommendations :

Next Steps

v) ***A political and financial group at high level drawn from all regions should be formed as soon as possible to take forward the important questions of site choice, funding of the detailed design, cost sharing and form of the global project including governance. We recommend that "Europe" take the initiative to form this group.***

y) ***Once the technology and site have been chosen a group should be set up to prepare the detailed technical design and cost. This design group would most likely contain many of the same people as the ILCSC international design team which would then be dissolved.***

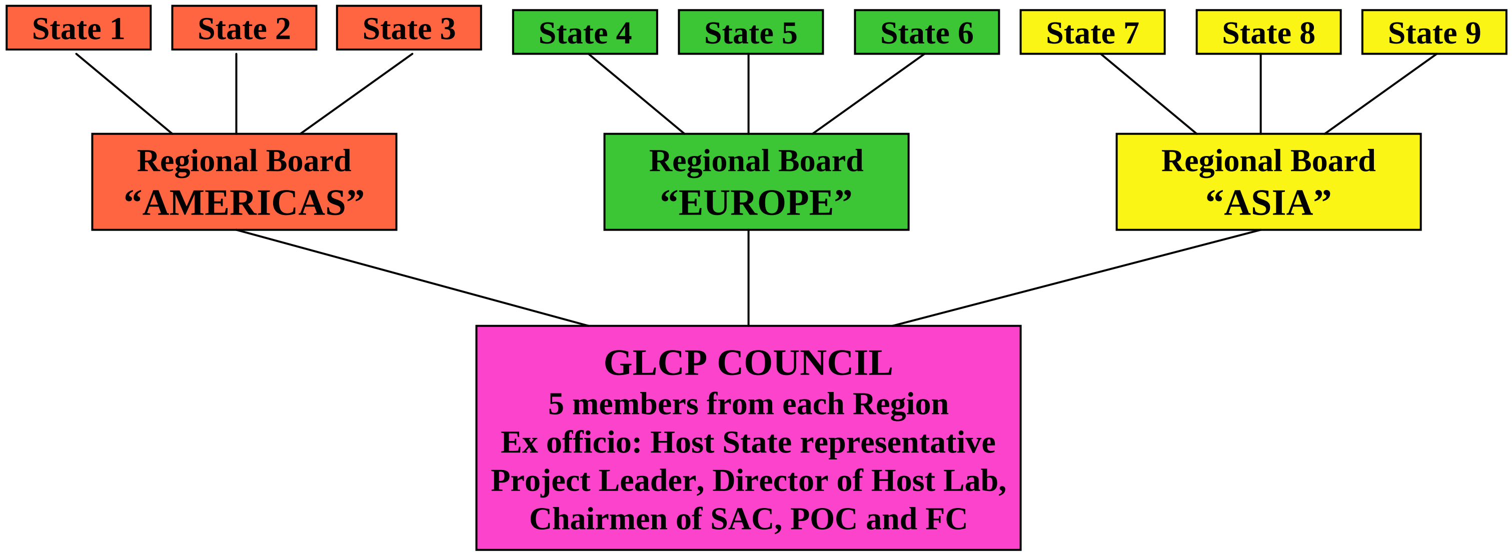


Fig. 1a Governance

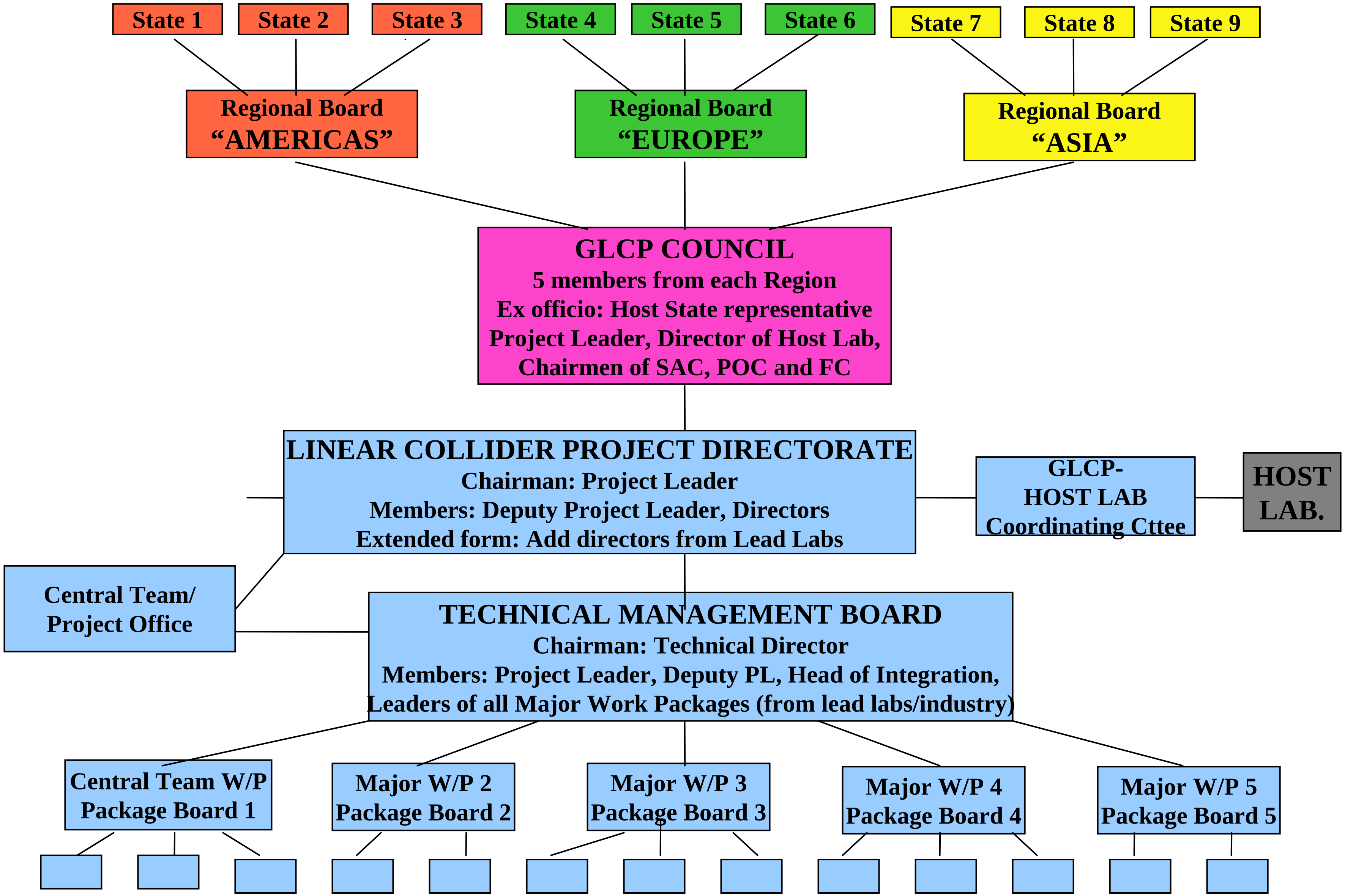


Fig. 1b Governance (GLCP Council and above), Management (Light blue boxes below GLPC Council)

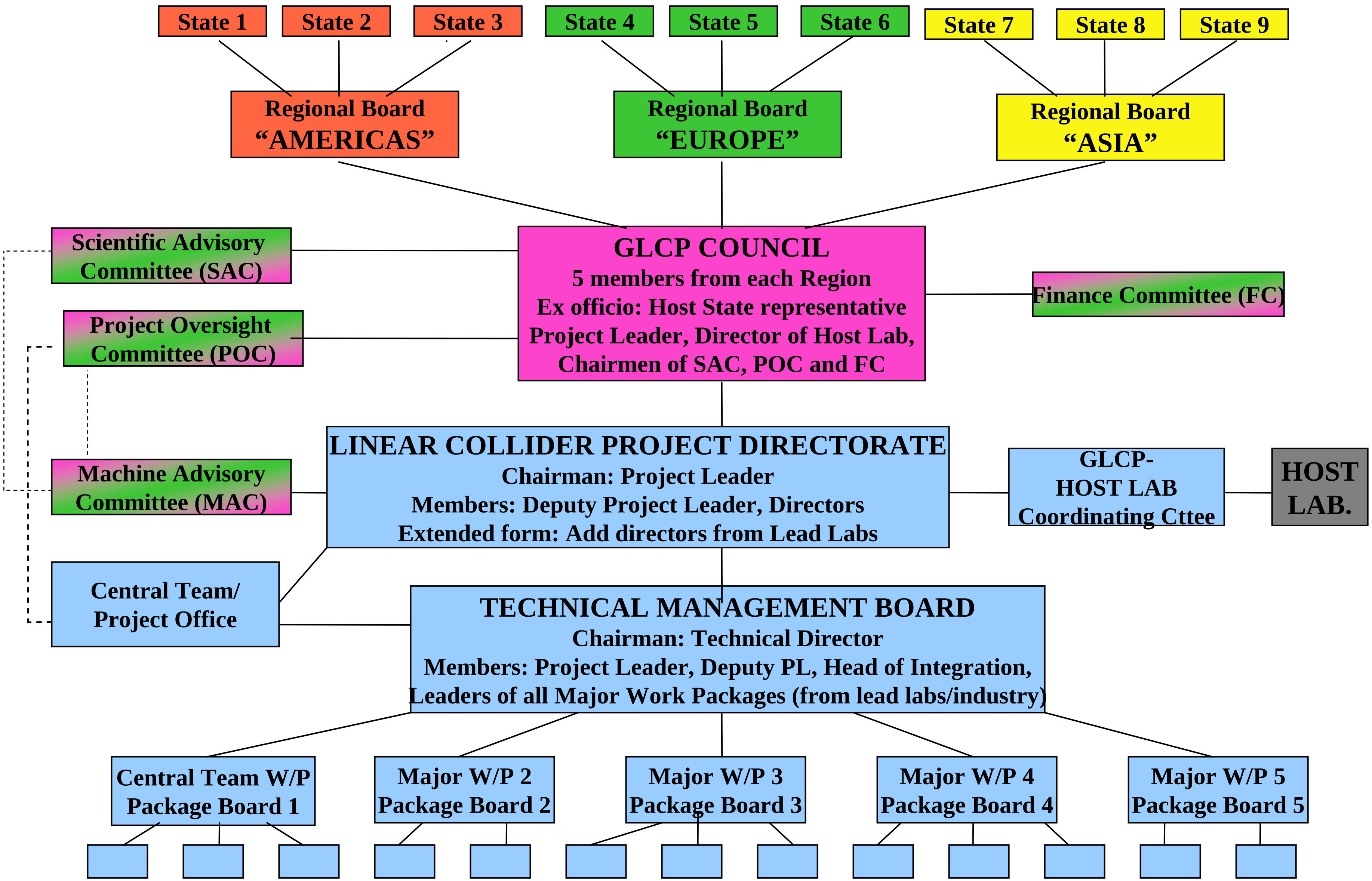


Fig. 1c Governance (GLCP Council and above), Management (Light blue boxes below GLPC Council) and Monitoring (Bi-coloured boxes) structure of the GLCP

Comparison of ALMA, ITER and GLCP

	ALMA	ITER	GLCP
Intergovernmental agreement	Yes	Yes	Yes
Separate legal entity	No	Yes	Yes
Time limited project	Yes	Yes?	Yes
Regional structure	Yes	No	Yes
Single Council appointed by Regions	Yes	No	Yes
Common costing-value model	Yes	Yes?	Yes
In-kind deliverables by value	Yes	Yes	Yes
Cash as well	Yes	Yes	Yes
Host State	No	Yes	Yes
Host Lab.	No	No?	Yes
Single central management	Yes	Yes	Yes
Central contingency	Yes	?	Yes

- The ILC is supported worldwide as the next major accelerator project.

- The linac technology has been chosen.

- Funding and organisational models have been proposed.

- A worldwide design team has been formed, its first task is to get an accurate costing.

- CERN Council has agreed that they are the body to coordinate PP in Europe

- The next steps are to agree on a site and the funding and organisational structure. **POLITICAL DECISION!**

Need high integrated luminosity.

- This means high instantaneous luminosity and high reliability!
- To obtain high instantaneous luminosity need very small bunches and the bunches have to fully intersect in the middle of the detector.
- They have to do this after each has traveled ~15 Km down separate accelerators.
- This poses *gigantic* problems associated with placing, surveying, monitoring and controlling the beams. Eg components in the linacs need to be placed with ~micron accuracy,and be stable, there needs to be monitoring and controlling at the same accuracy. Any vibrations, either ground motion or man-made must be tiny or be actively corrected.
- Even greater precision is needed in the beam delivery system.
- This stability must be maintained for long periods