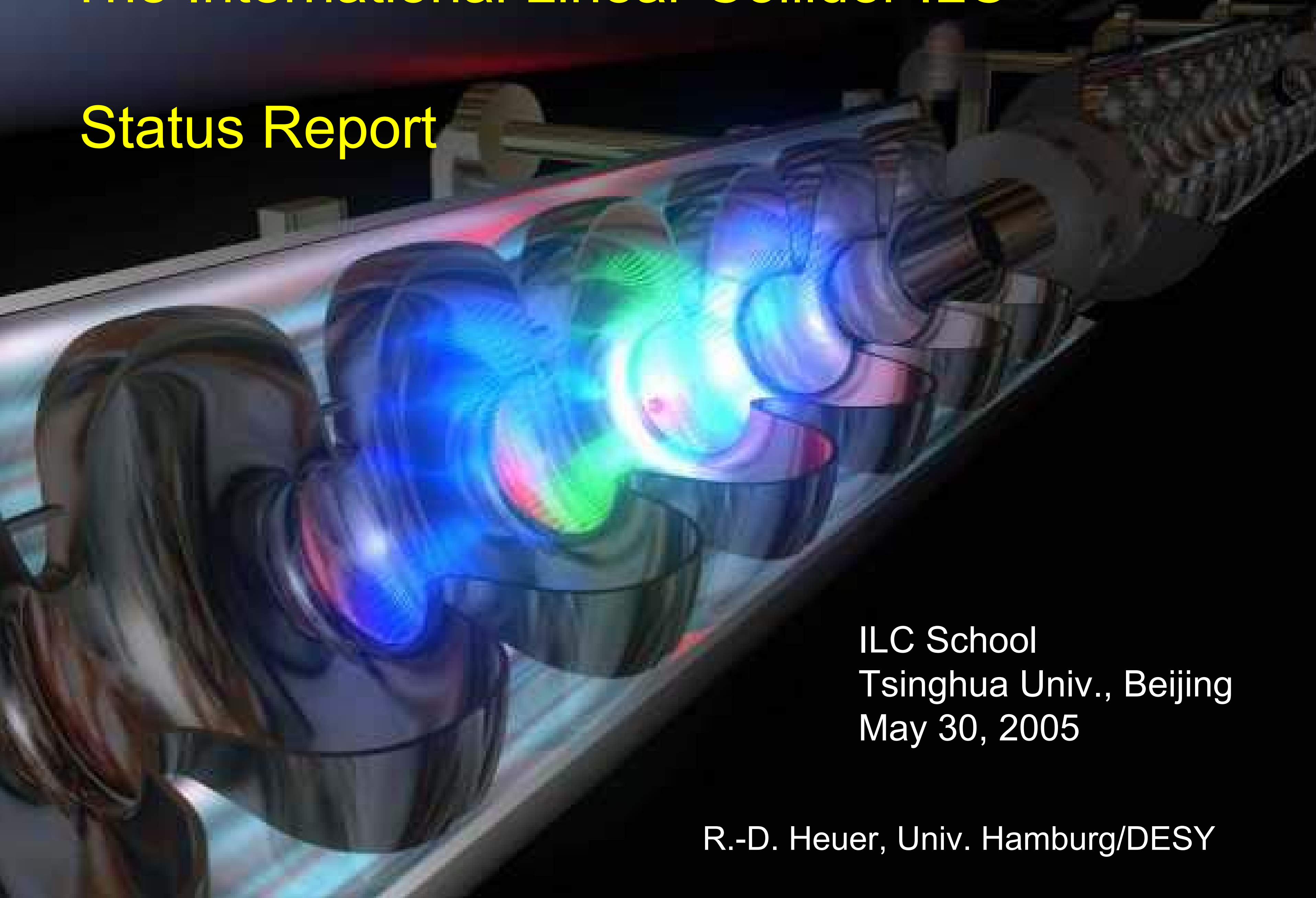
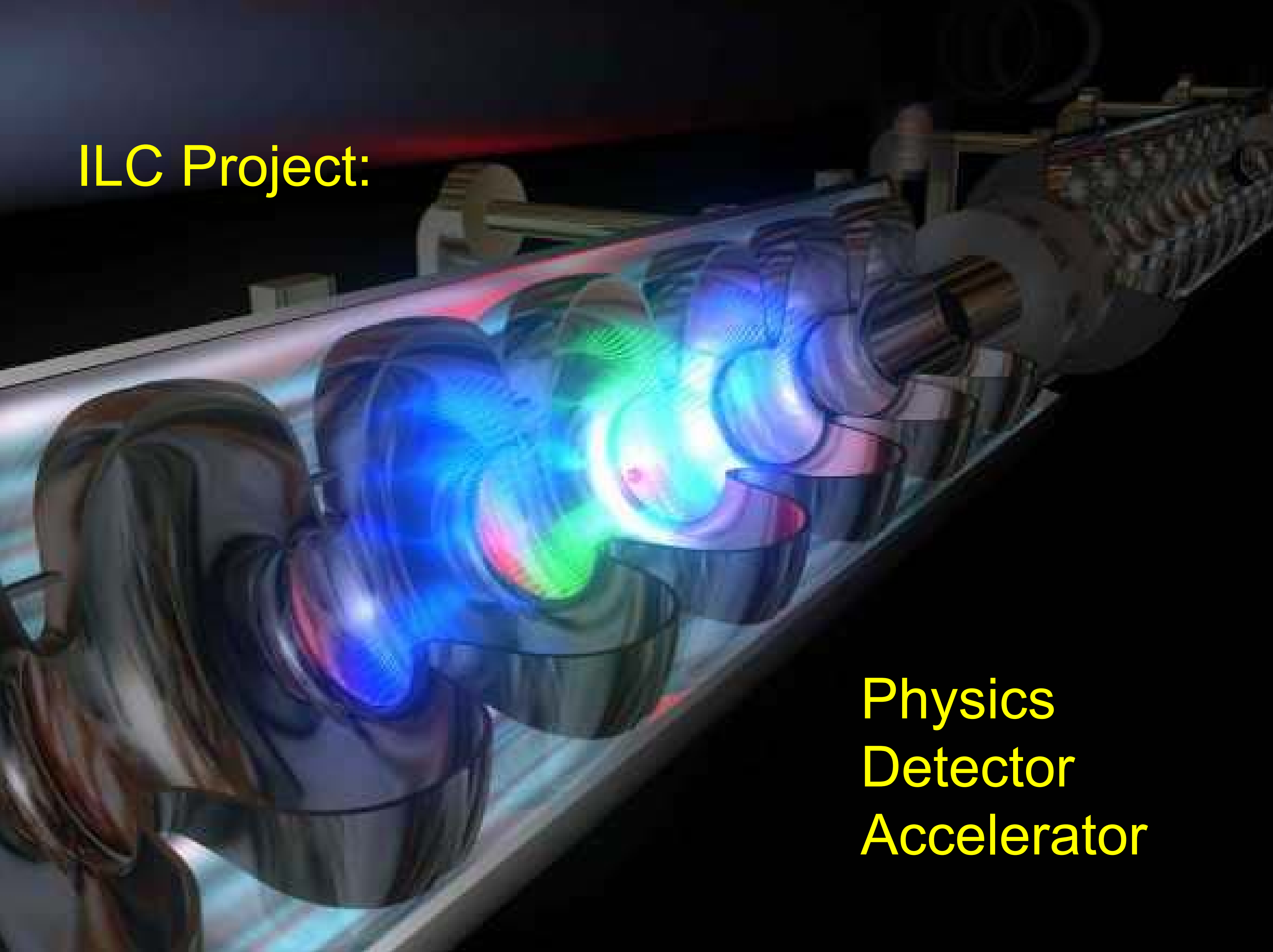
The International Linear Collider ILC

Status Report



ILC School
Tsinghua Univ., Beijing
May 30, 2005

R.-D. Heuer, Univ. Hamburg/DESY

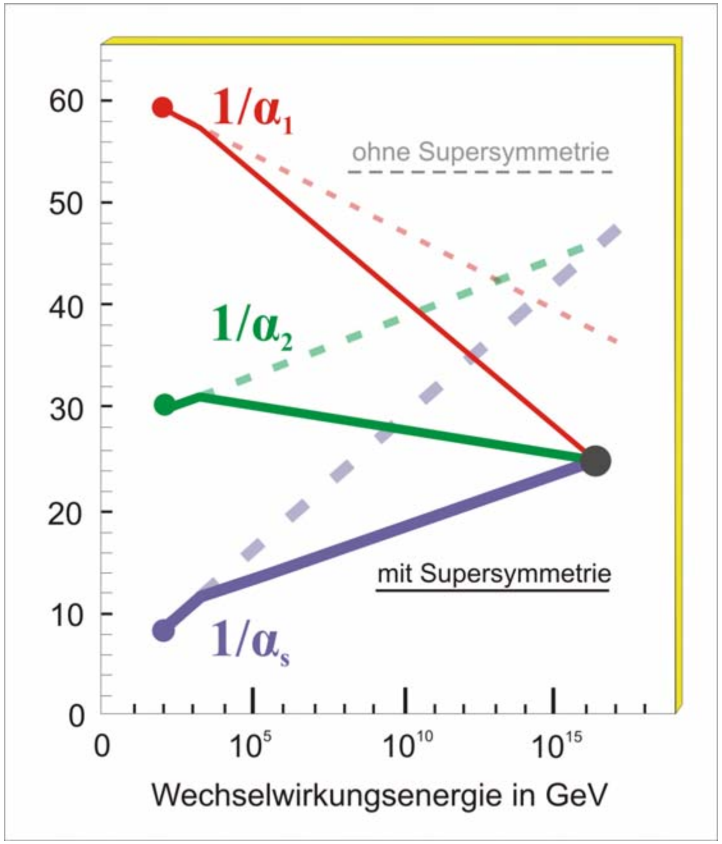

ILC Project:
Physics
Detector
Accelerator

Key Questions of Particle Physics

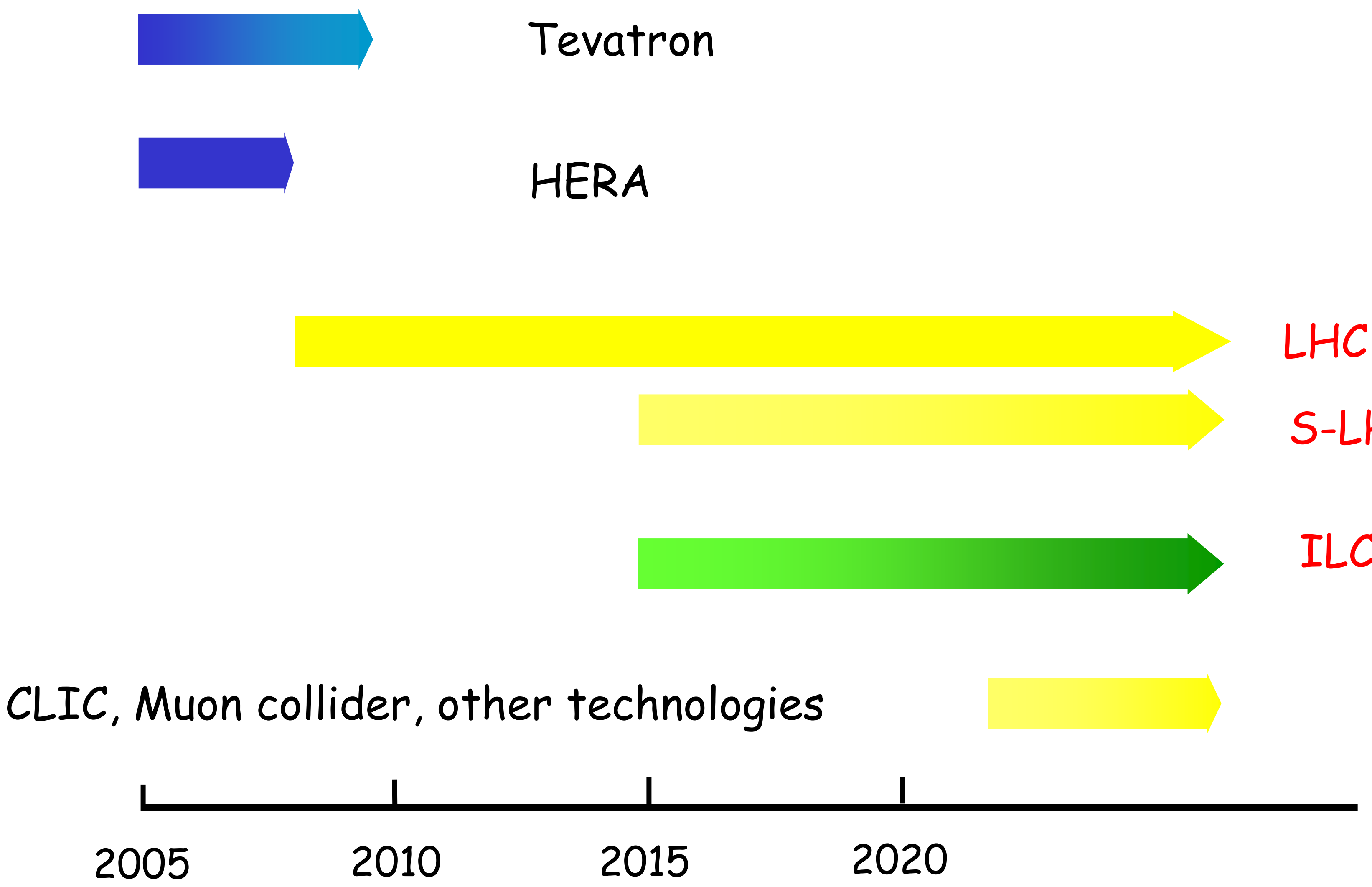
- What is mass/matter ?

  why are carriers of weak force so heavy while the photon is massless?

- Can the forces be unified?
- Fundamental symmetry of forces and building blocks?
- Can quantum physics and general relativity be united?
- Do we live in 4 dimensions?
- What happened in the very early universe ?
- Origin of dark matter



A Road Map for the Energy Frontier

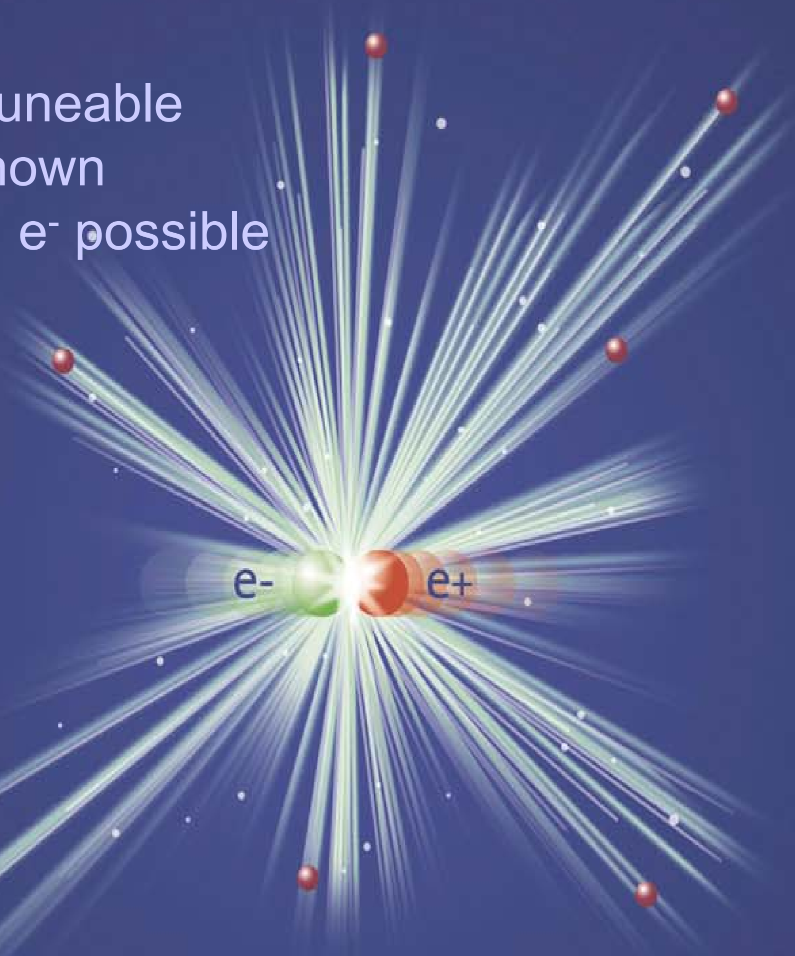


The power of an Electron-Positron Linear Collider

- well defined initial state
  - $\sqrt{s}$ well defined and tuneable
  - quantum numbers known
  - polarisation of e^+ and e^- possible

- clean environment
  - collision of pointlike particles
  - → low backgrounds

- precise knowledge of cross sections



options:
e^-e^-, $e\gamma$, $\gamma\gamma$

⇒ ILC = Machine for Discoveries and Precision Measurements

International Linear Collider Parameters
global consensus (Sept. 2003)

(1) baseline machine

200 GeV < $\sqrt{s}$ < 500 GeV

integrated luminosity ~ 500 fb^{-1} in 4 years

electron polarisation ~ 80%

(2) energy upgrade

to $\sqrt{s}$ ~ 1 TeV

integrated luminosity ~ 1 ab^{-1} in 3 years

(3) options

positron polarisation of ~ 50%

high luminosity running at M_Z and W-pair threshold

e^-e^-, $e\gamma$, $\gamma\gamma$ collisions

(4) concurrent running with LHC desired

! Times quoted for data taking cover only part of program !

The ILC Physics Case
or
Relation of Hadron Collider and Linear Collider

1. Since the ILC will start after the start of LHC, it must add significant amount of information. This is the case!
   (see e.g. TESLA TDR, Snowmass report, ACFA study etc.)

2. Neither ILC nor HC's can draw the whole picture alone. An ILC will
   - add new discoveries and
   - precision of ILC will be essential for a better understanding of the underlying physics

3. There are probably pieces which can only be explored by the LHC due to the higher mass reach. Joint interpretation of the results will improve the overall picture

4. Overlapping running of both machines will further increase the potential of both machines and might be mandatory, depending on the physics scenario realized

The Higgs: Key to Understanding Mass

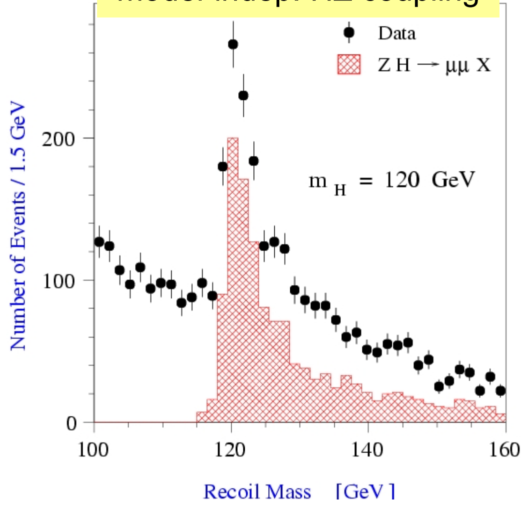
Only with ILC+LHC we can prove that the Higgs mechanism is at work!
(or maybe not…)

Higgs will become SM precision physics – look for deviations beyond SM

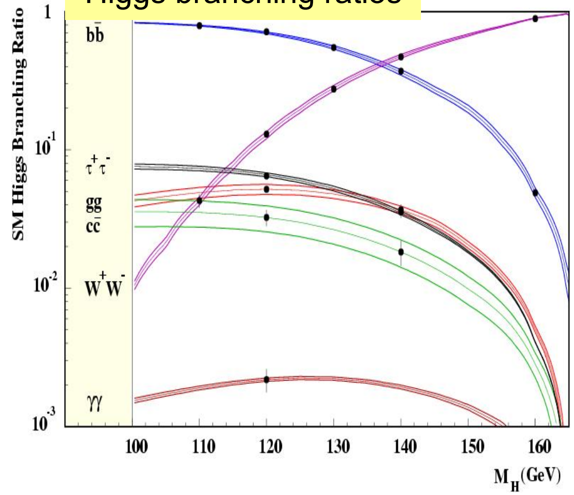
- structure of Higgs sector
- SUSY Higgs?
- Mixing with other scalars (Radions, …)

Model-independent measurements at %-level possible

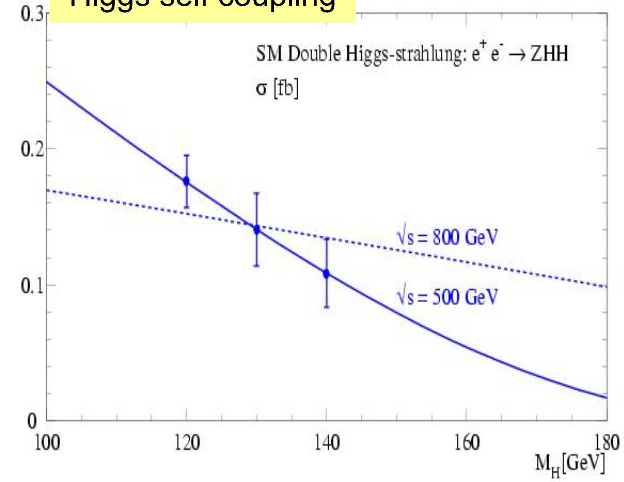
model-indep. HZ coupling



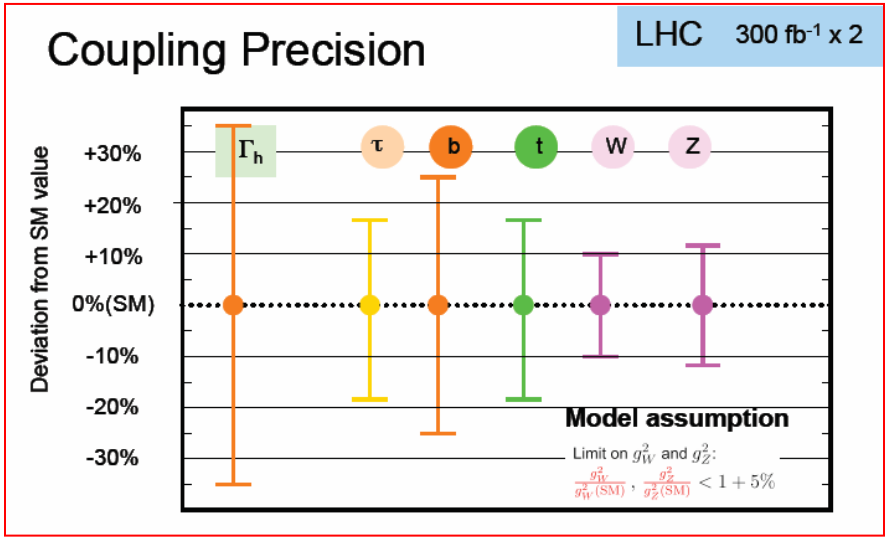
Higgs branching ratios

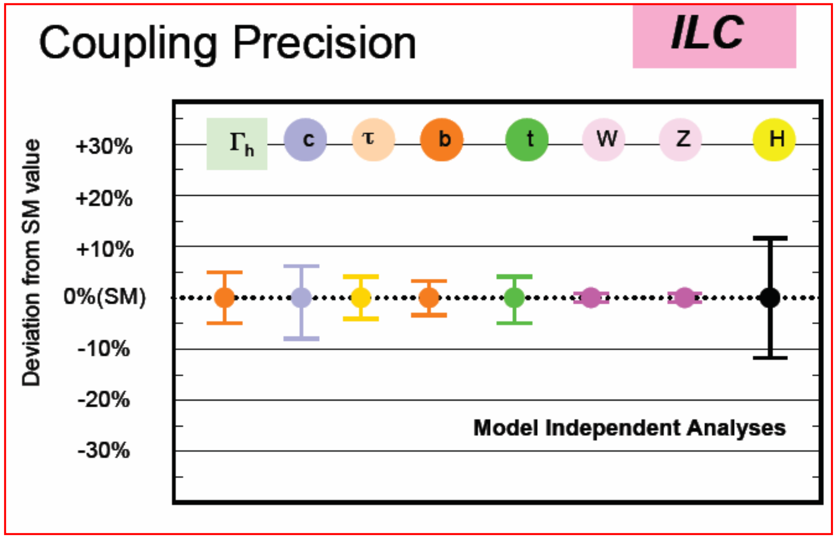


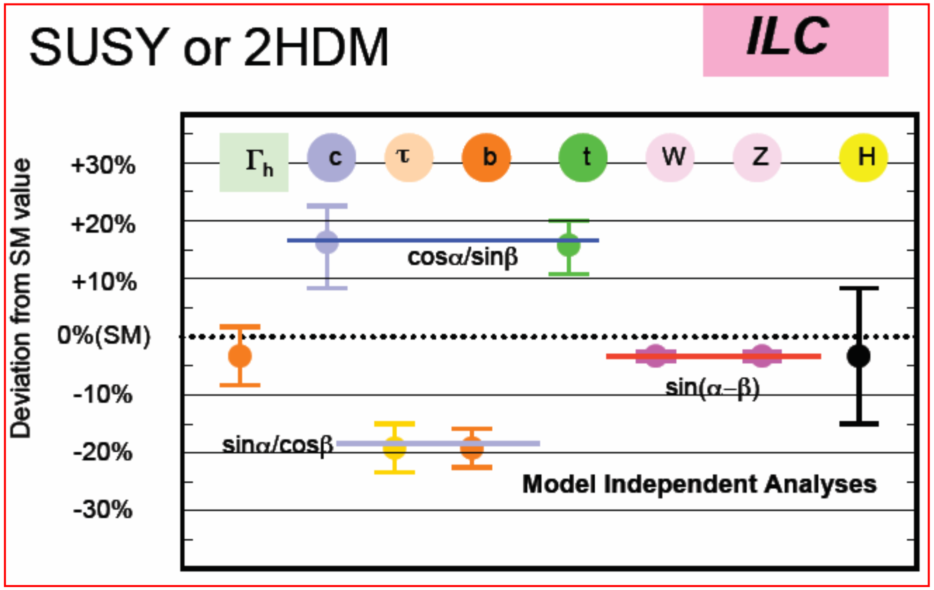
Higgs self coupling



Coupling Precision and New Physics

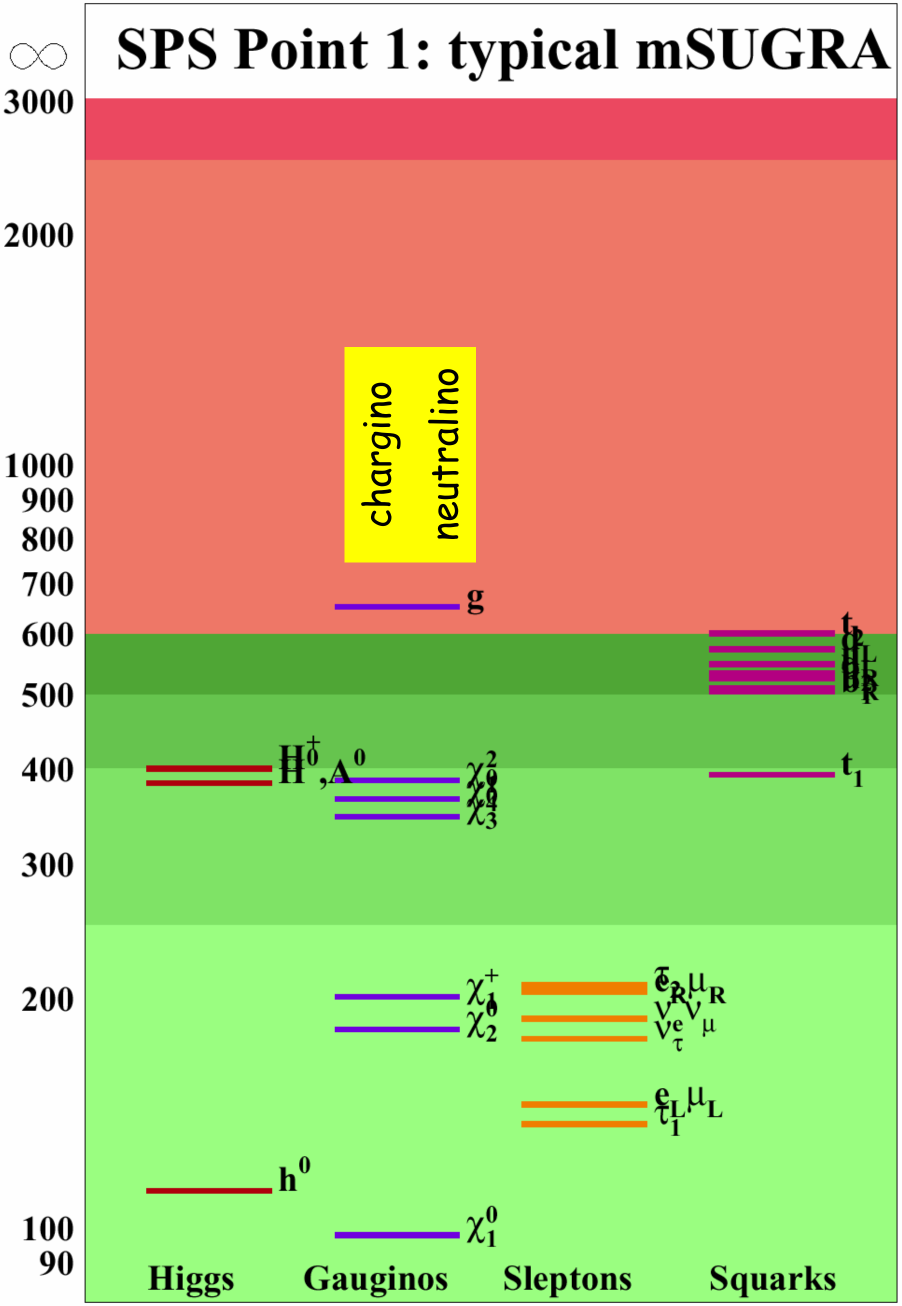






Yamashita

Discoveries beyond the SM: Supersymmetry



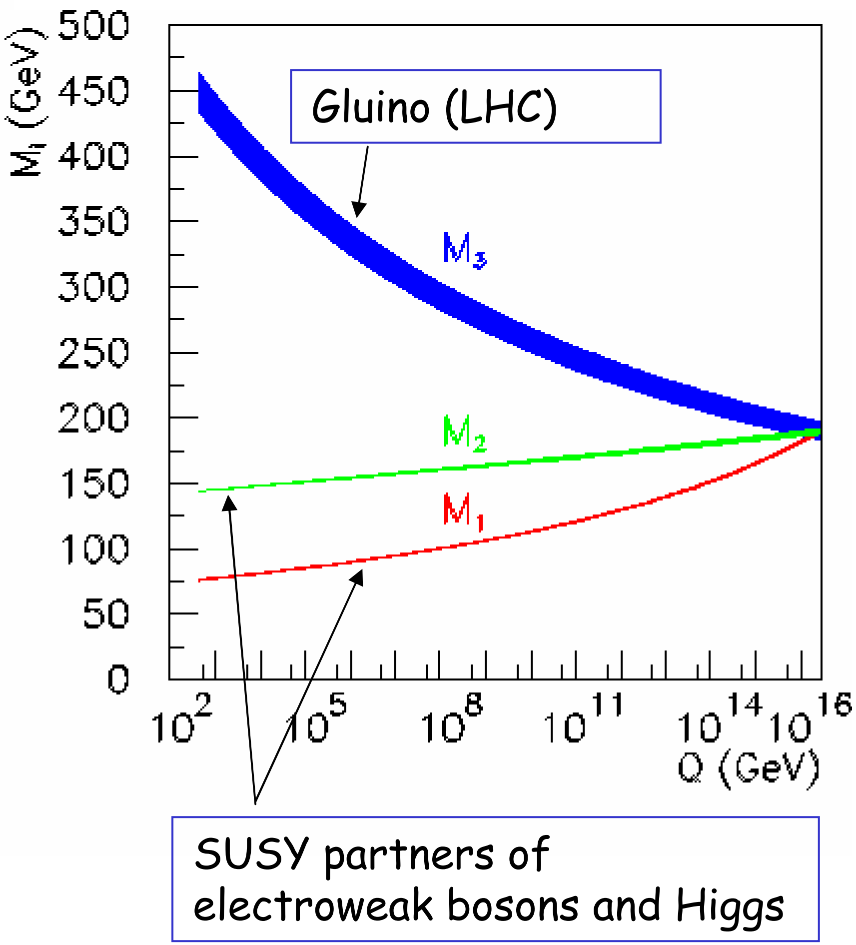
Mass spectra depend on choice of parameters...

Huge research area at **ILC:**

- measure sparticle properties (**masses,** cross sections, J^{PC} , **coupling strength, chirality, mixing**) with high precision
- use these + **LHC** to **determine underlying SUSY model** and **SUSY breaking mechanism**
- extrapolate to GUT scale using RGEs to determine **SUSY GUT mechanism**

Test of Unification

MSSM:
105 parameters: some from LHC, some from ILC



Extrapolation of SUSY parameters from weak to GUT scale (e.g. within mSUGRA)

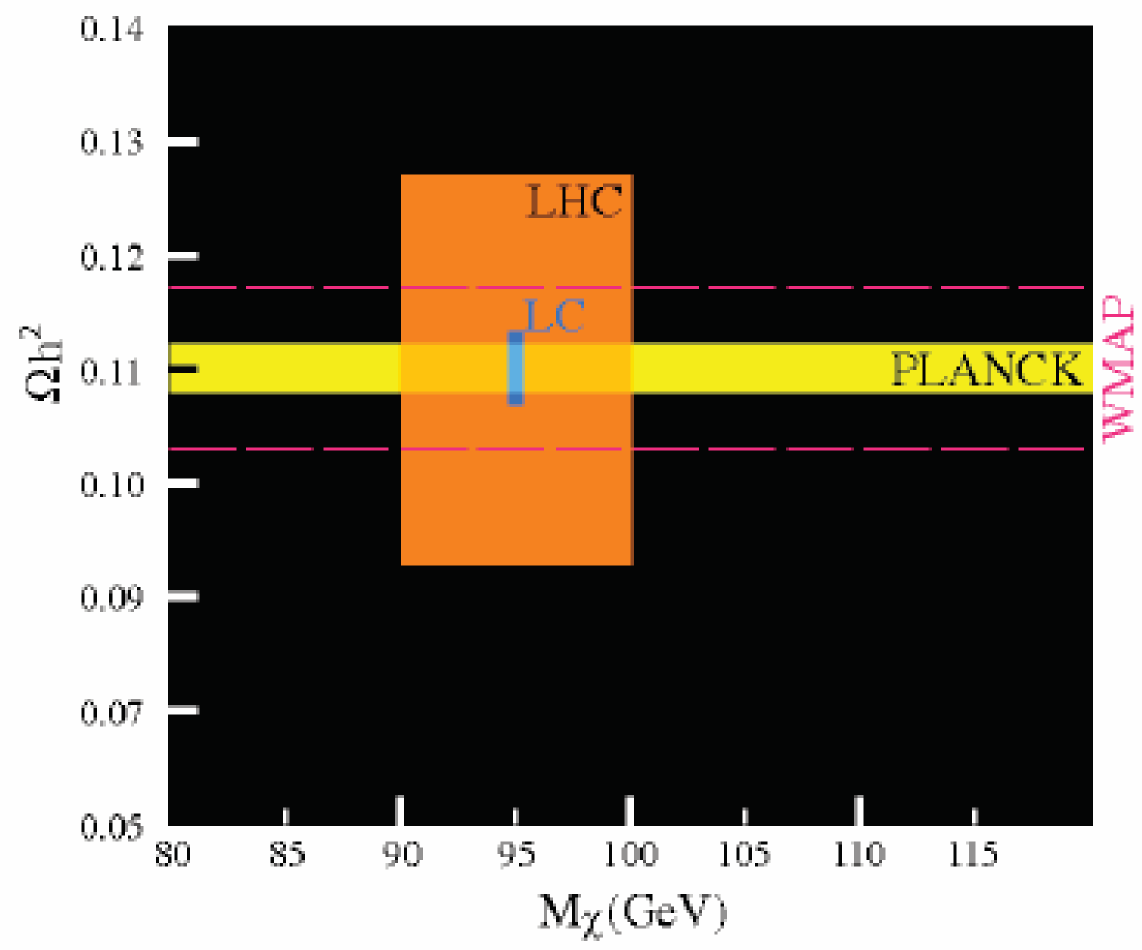
Gauge couplings unify at high energies,

Gaugino masses unify at same scale

Precision provided by ILC for sleptons, charginos and neutralinos will allow to test if masses unify at same scale as forces

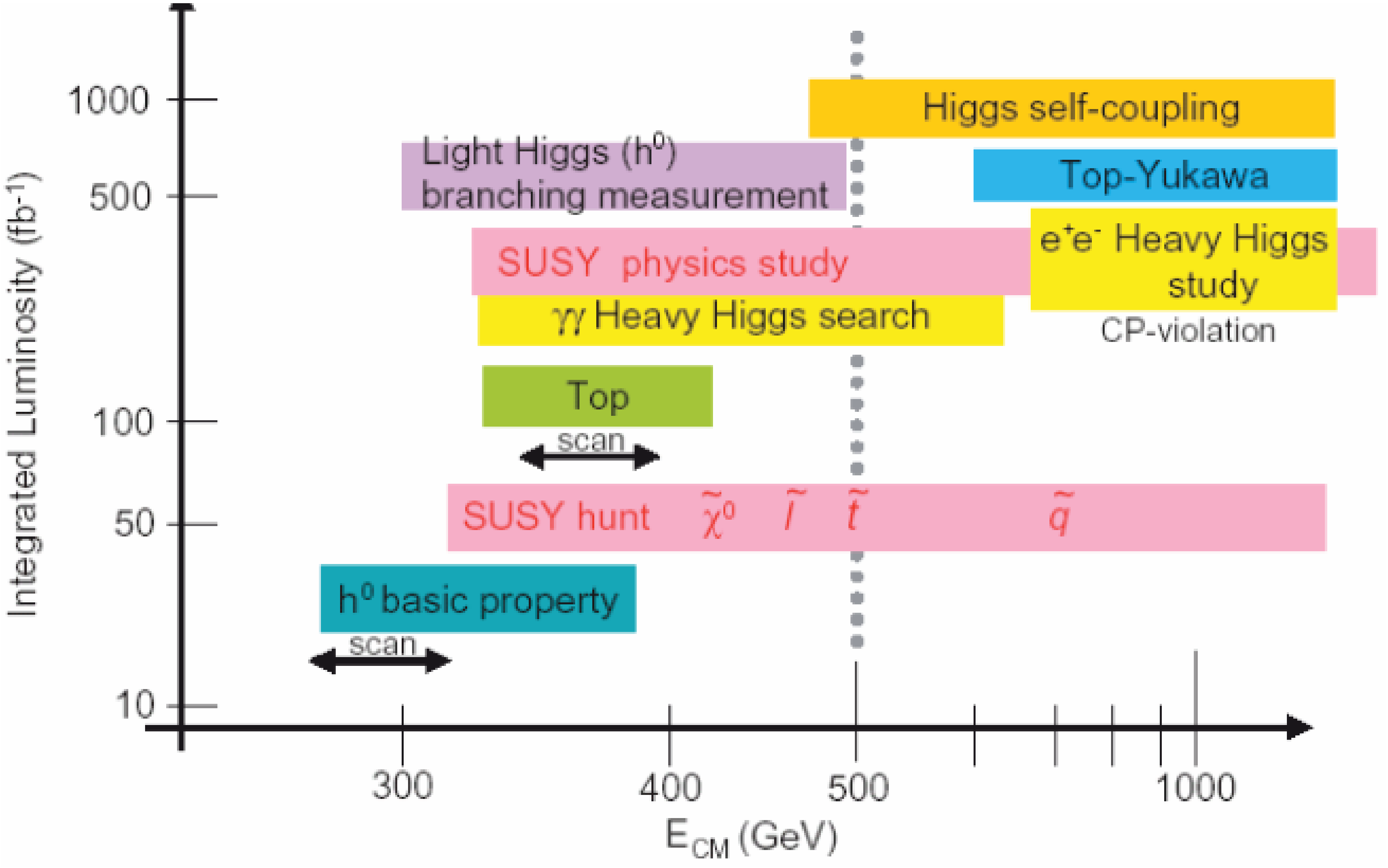
Dark Matter and SUSY

If SUSY LSP responsible for Cold Dark Matter, need accelerators to show that its properties are consistent with CMB data

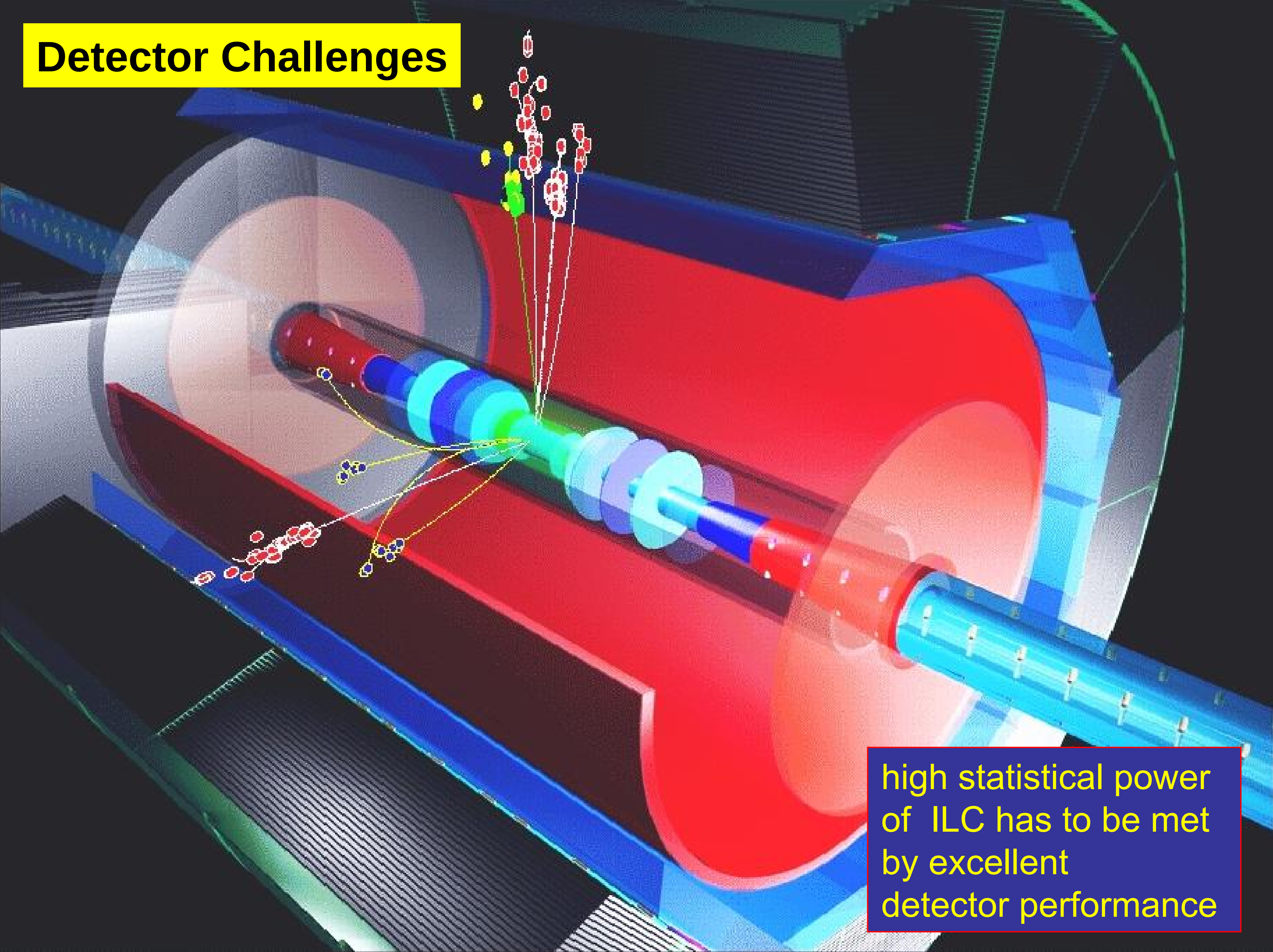


'WMAP'	7 %
LHC	~15 %
'Planck'	~2 %
ILC	~3 %

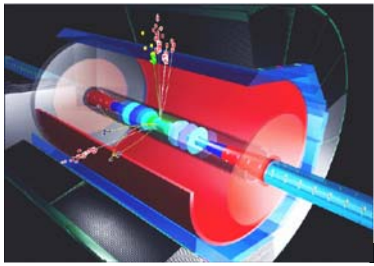
Intermezzo: ILC Physics Reach



Detector Challenges

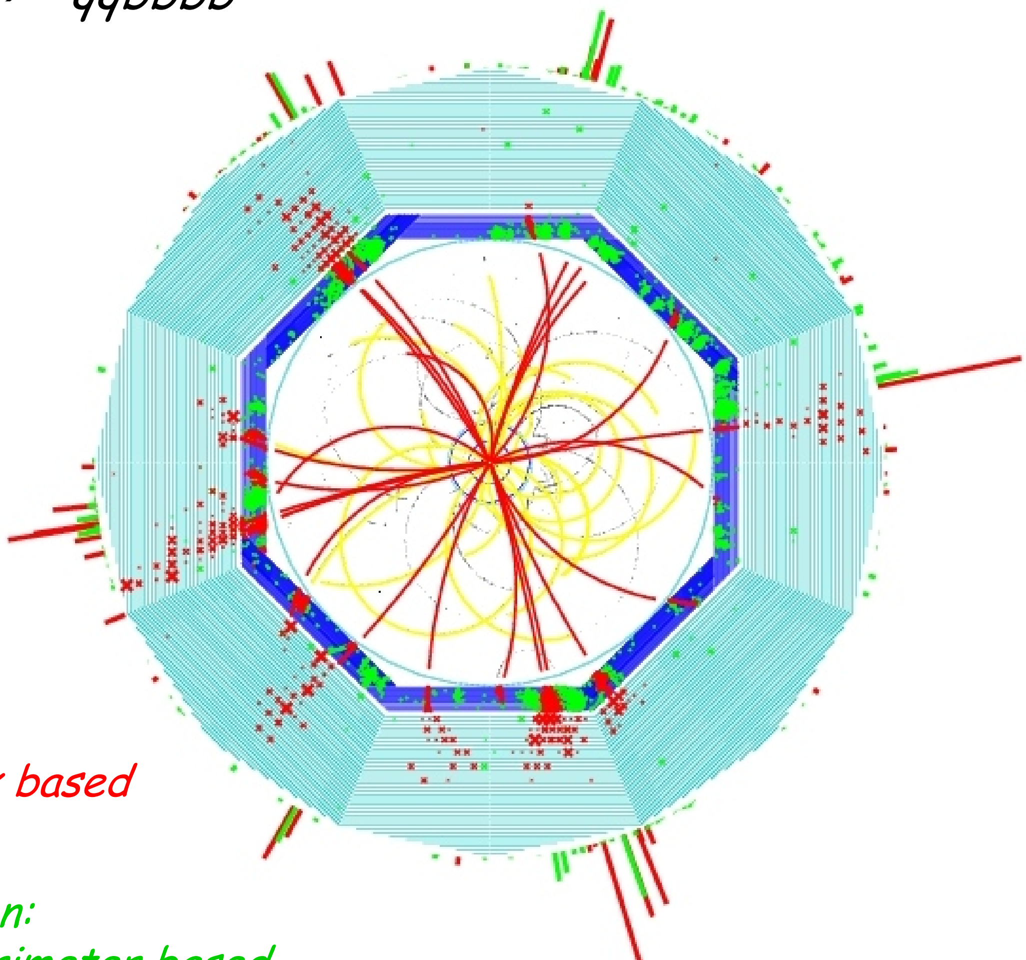


high statistical power of ILC has to be met by excellent detector performance



Detector challenges: calorimeter

ZHH → qqbbbb



red: track based

green: calorimeter based

High precision measurements demand new approach to the reconstruction:

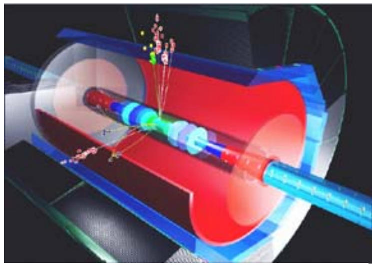
- particle flow (i.e. reconstruction of ALL individual particles)

this requires

- unprecedented granularity

in three dimensions

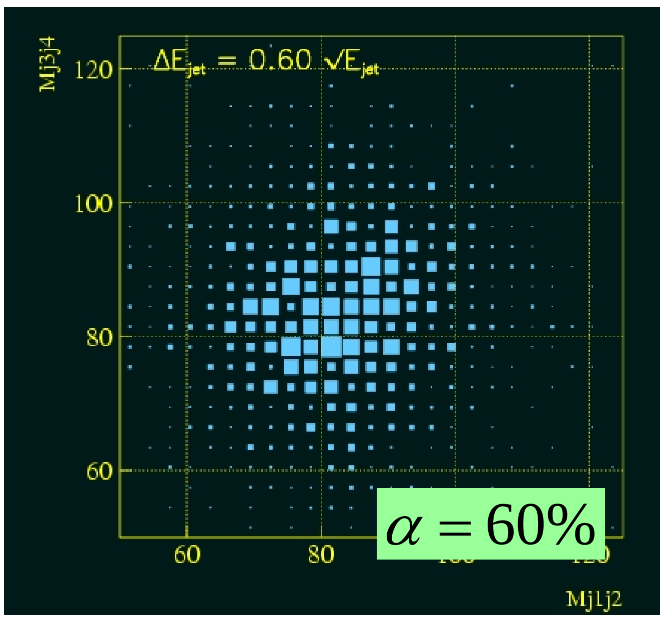
R&D needed now for key components



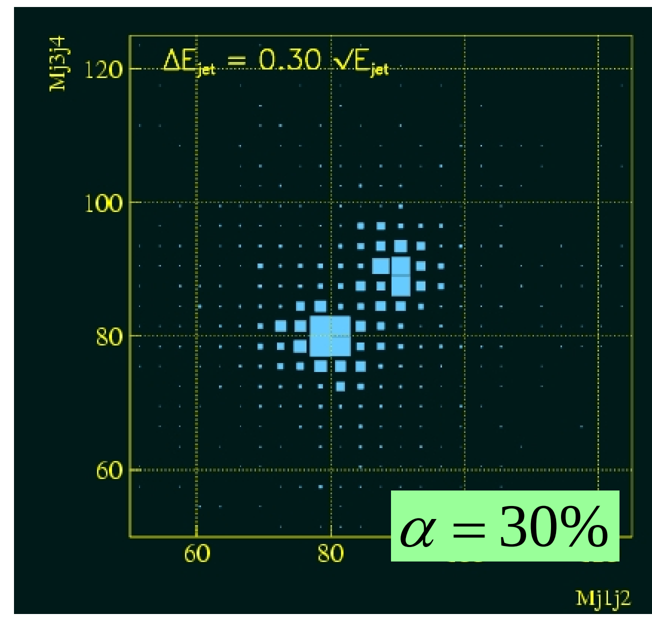
Jet energy resolution

- Dijet masses in WWvv, ZZvv events (no kinematic fit possible):
- Challenge: separate W and Z in their hadronic decay mode

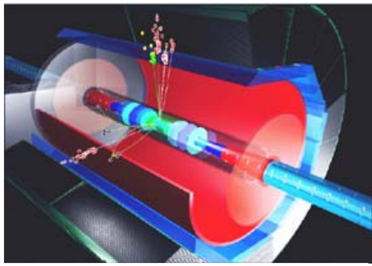
LEP-like detector



LC design goal

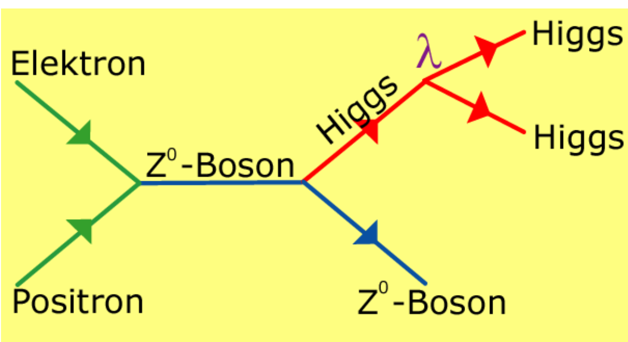


→ equivalent to some 40% luminosity gain



Higgs potential / self coupling

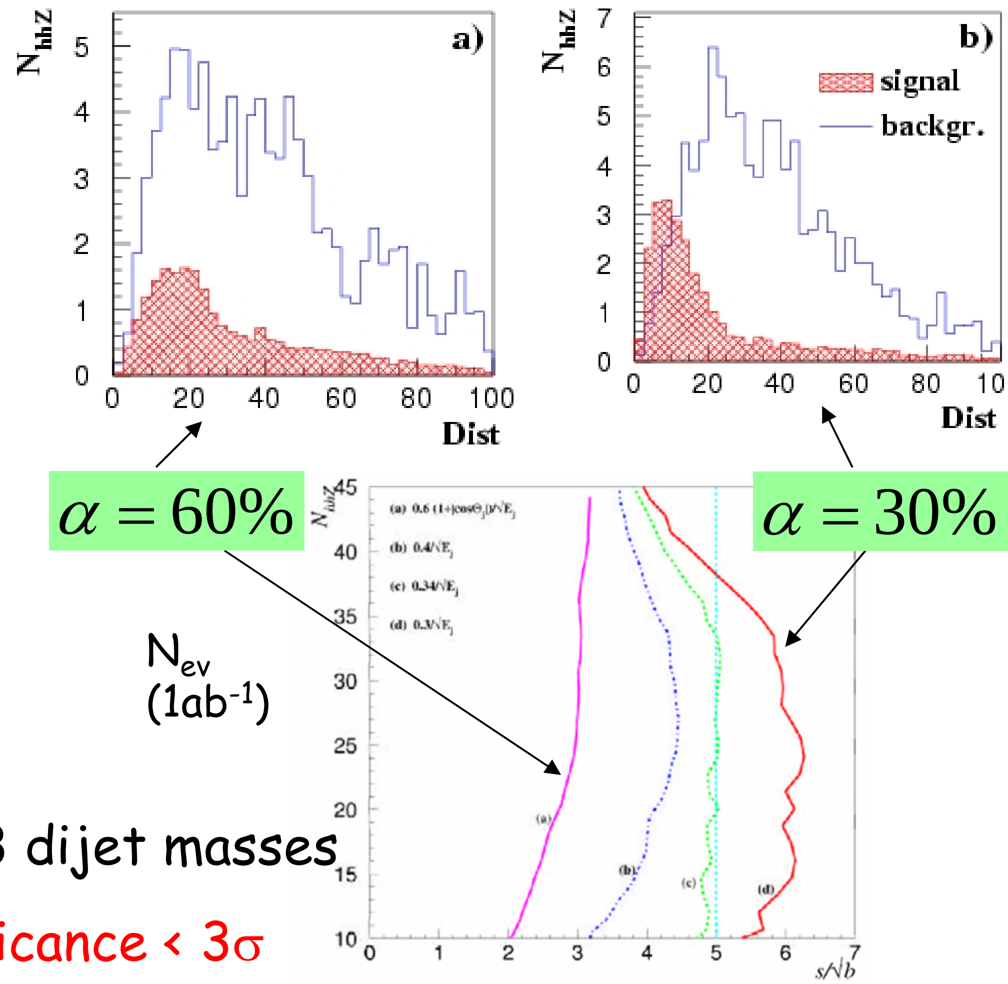
- **Is** the Higgs the Higgs?
- Check $\lambda = M^2_H/2v^2$

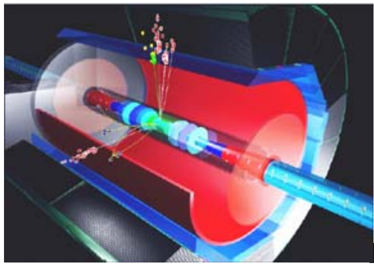


ee→ ZHH → 6 jets

- few tens of events
- reconstruct observable from 3 dijet masses

➔with LEP-like detector significance < 3σ





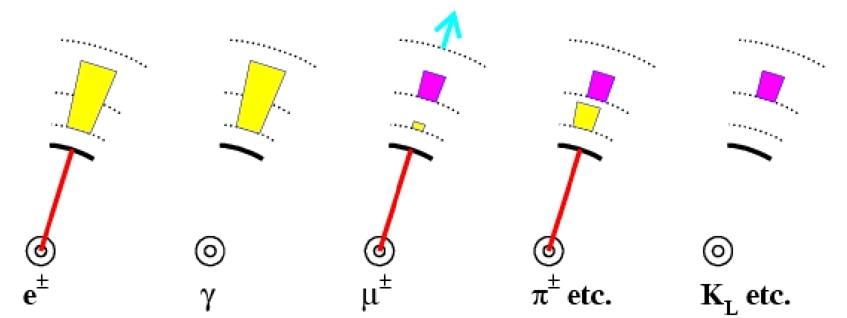
Particle Flow Method (ideal)

First measure charged particles (62%):

-momenta measured with tracking chambers

-merge track to calorimeter clusters

-substitute calorimeter energy with momentum

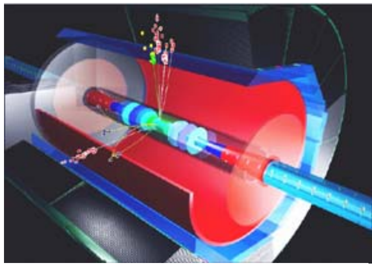


The rest of energy in the calorimeter is assigned to neutral clusters:

photons (26%):

neutral hadrons (10%)

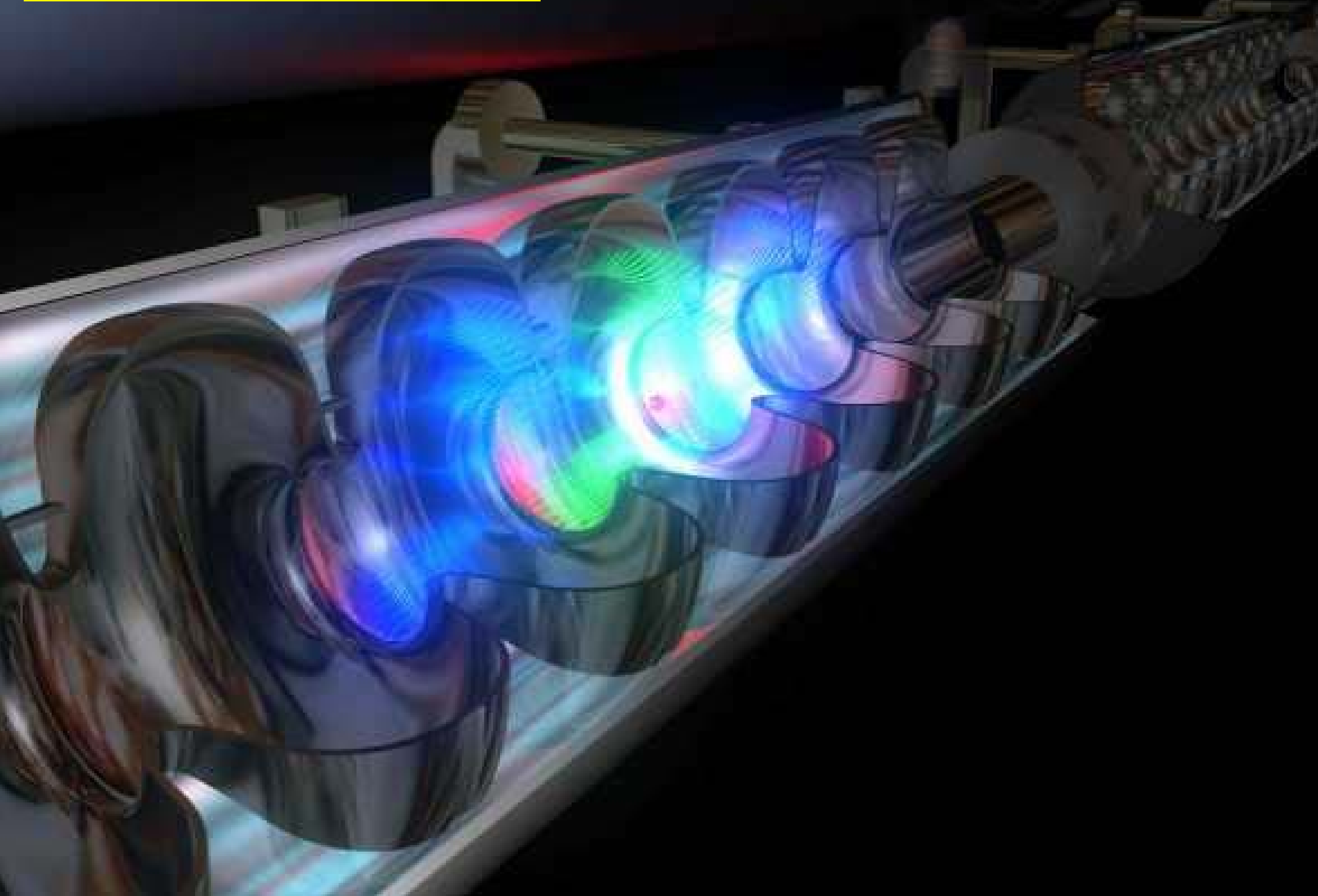
➔ This method requires extremely high granularity



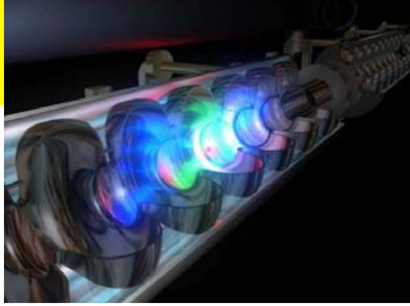
P-flow implications on calorimetry

Traditional Standards		P-Flow Modification
Hermeticity Uniformity Compensation Single Particle E measurement	→	Hermeticity Optimize ECAL/HCAL separately Longitudinal Segmentation Particle shower reconstruction
Optimized for best single particle E resolution		*Optimized for best particle shower separation/reconstruction*

Accelerator Challenges



Accelerator Challenges



Luminosity:
- high charge density (10^{10}), > 10,000 bunches/s
- very small vertical emittance (damping rings, linac)
- tiny beam size (5*500 nm) (final foc.)

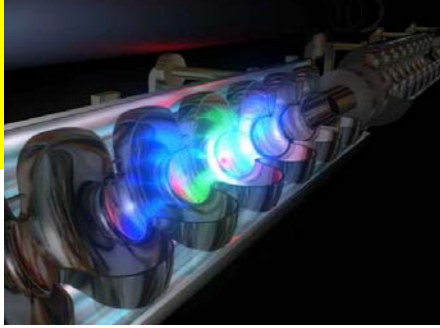
Energy:
- high accelerating gradient

Technology:
- normal vs superconducting rf technology

In comparision to SLC the ILC has the following properties:

	SLC	ILC		factor
Energy E_{cm}	100	500 ($\rightarrow$ ~1000)	GeV	5-10
Beam Power	0.04	~10	MW	250
Spot size IP	500	~5	nm	100
Luminosity	$3 \cdot 10^{-4}$	3	10^{34} cm^{-2} s^{-1}	10,000

Developments towards the International Linear Collider

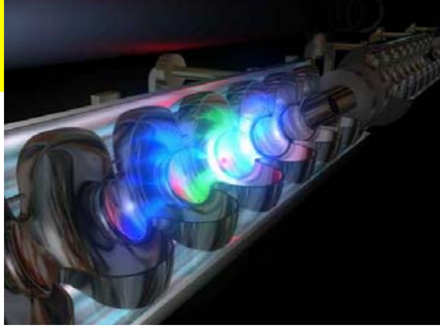


- Evaluation of scientific potential of the ILC by Global Science Forum of the OECD and its roadmap
  -> in 2004 OECD Ministerial support for ILC

- Two competing technologies:
  normal conducting vs supraconducting accelerating cavities

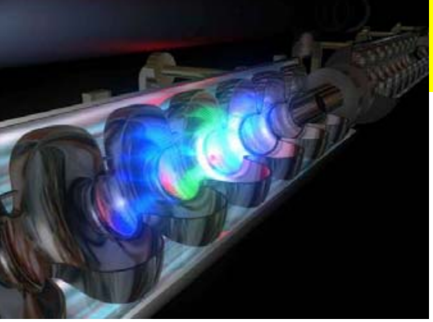
- Particle Physics Community established mechanism for Technology decision: International Technology Recommendation Panel
  (chair: B. Barish, CalTech)
  August 2004 Recommendation to use SC RF technology.
  - unanimously accepted by ICFA
  - created large momentum in all laboratories

The Technology Recommendation



- ITRP recommended that the linear collider be based on
  superconducting rf technology
- This recommendation is made with the understanding that the recommendation concerns the technology, not the design.

  - 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.



The Improvement of SC Cavities

SC RF structures for accelerators were developed in many countries

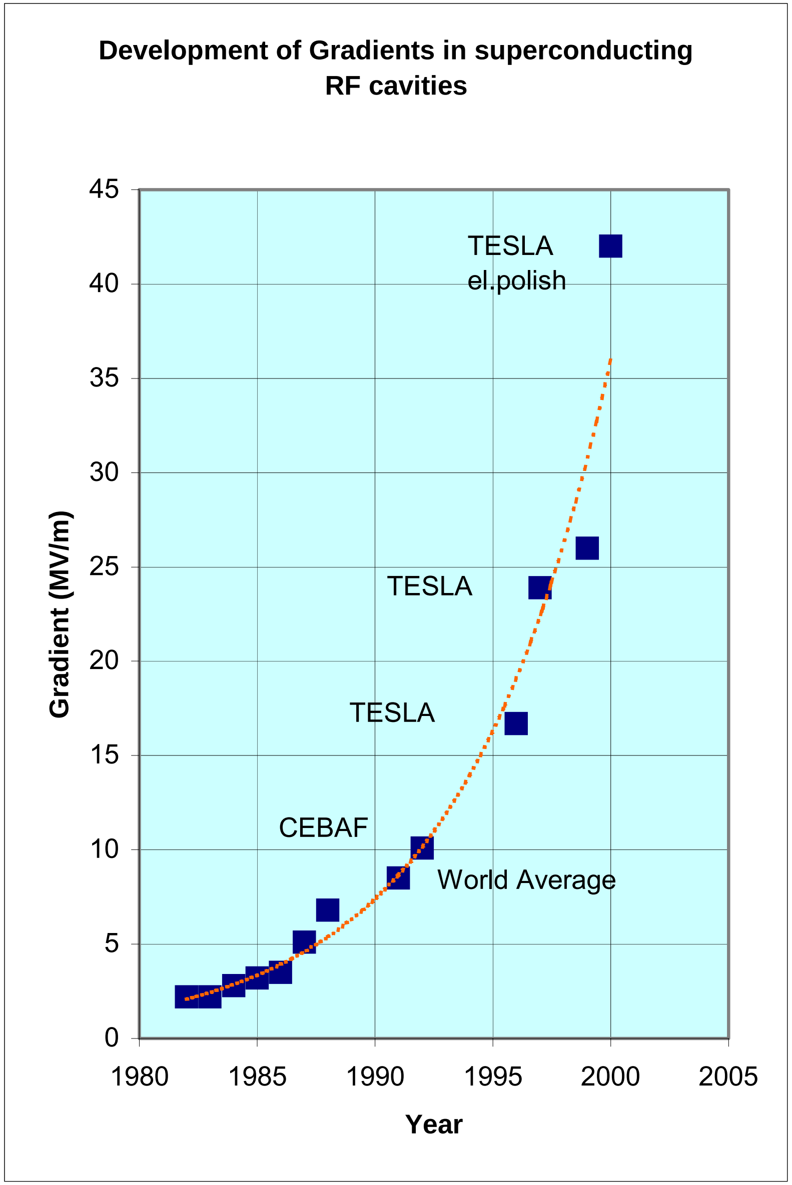
The TESLA collaboration (55 institutes in 12 countries), centred at DESY achieved major progress:

>25-fold improvement in performance/cost in 10 years

Major impact on next generation light sources (XFEL, ERL) , proton accelerators etc

Now: TESLA Technology Collaboration

New members: KEK, SLAC, . . .



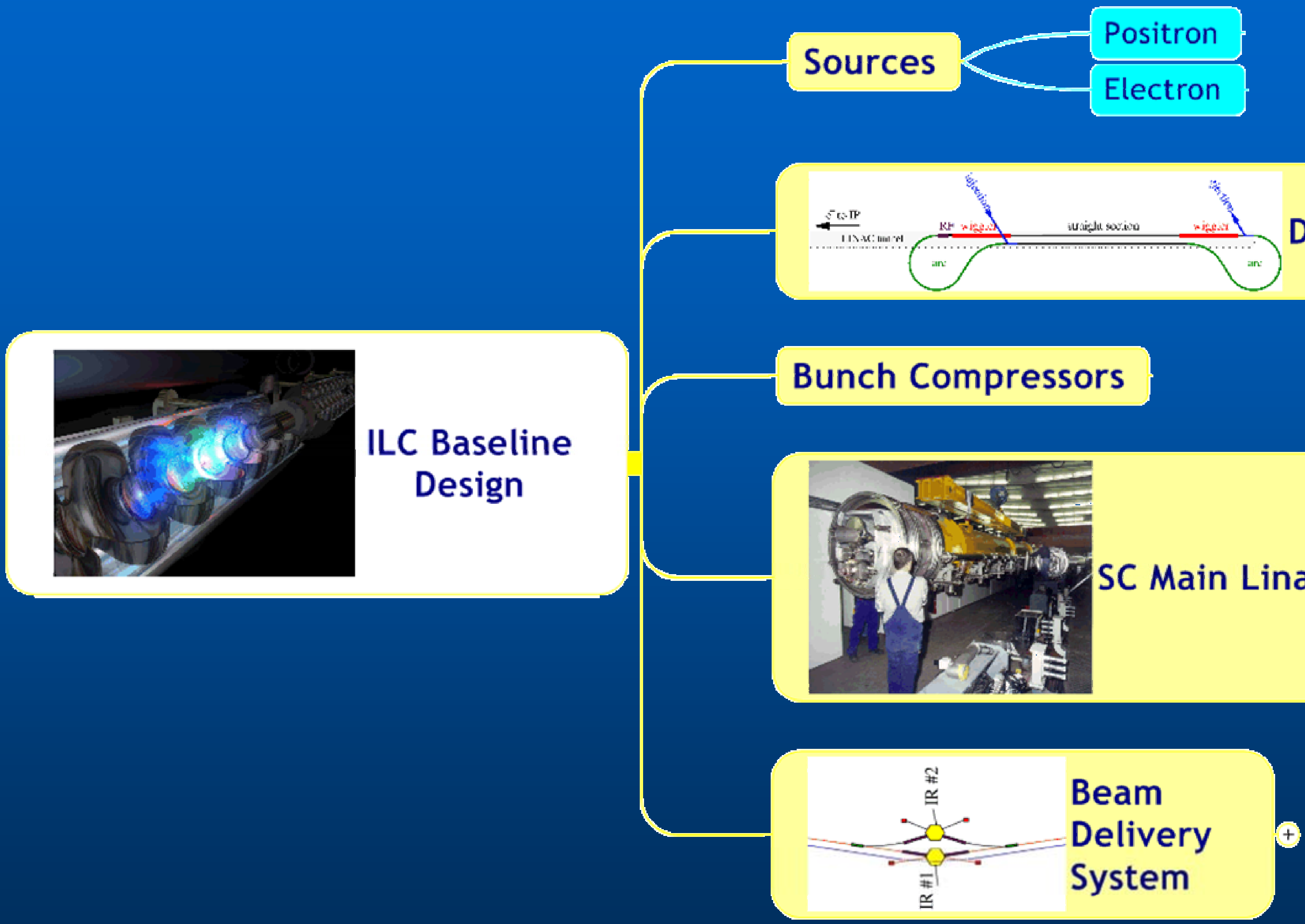
→ Start of the Global Design Effort

~ 220 participants from 3 regions, most of them accelerator experts

- A lot of enthusiasm, willingness to self-organise, and a strong sense of initiative
- Working Group structure was very effective
- Has helped to advance the global collaboration on well defined work packages

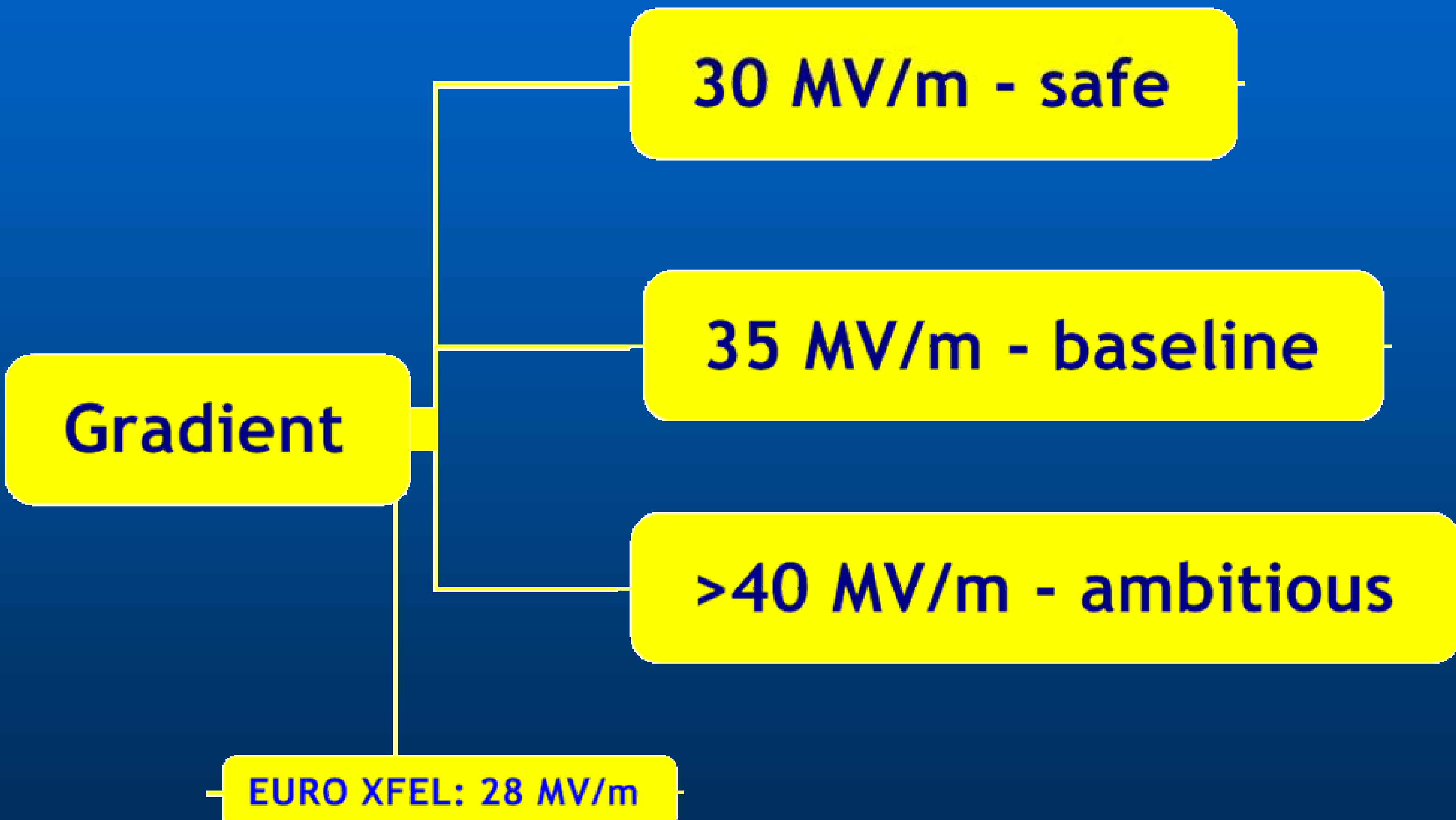
Convergence towards a common project

Towards the ILC Baseline Design



Decisions to be Made!

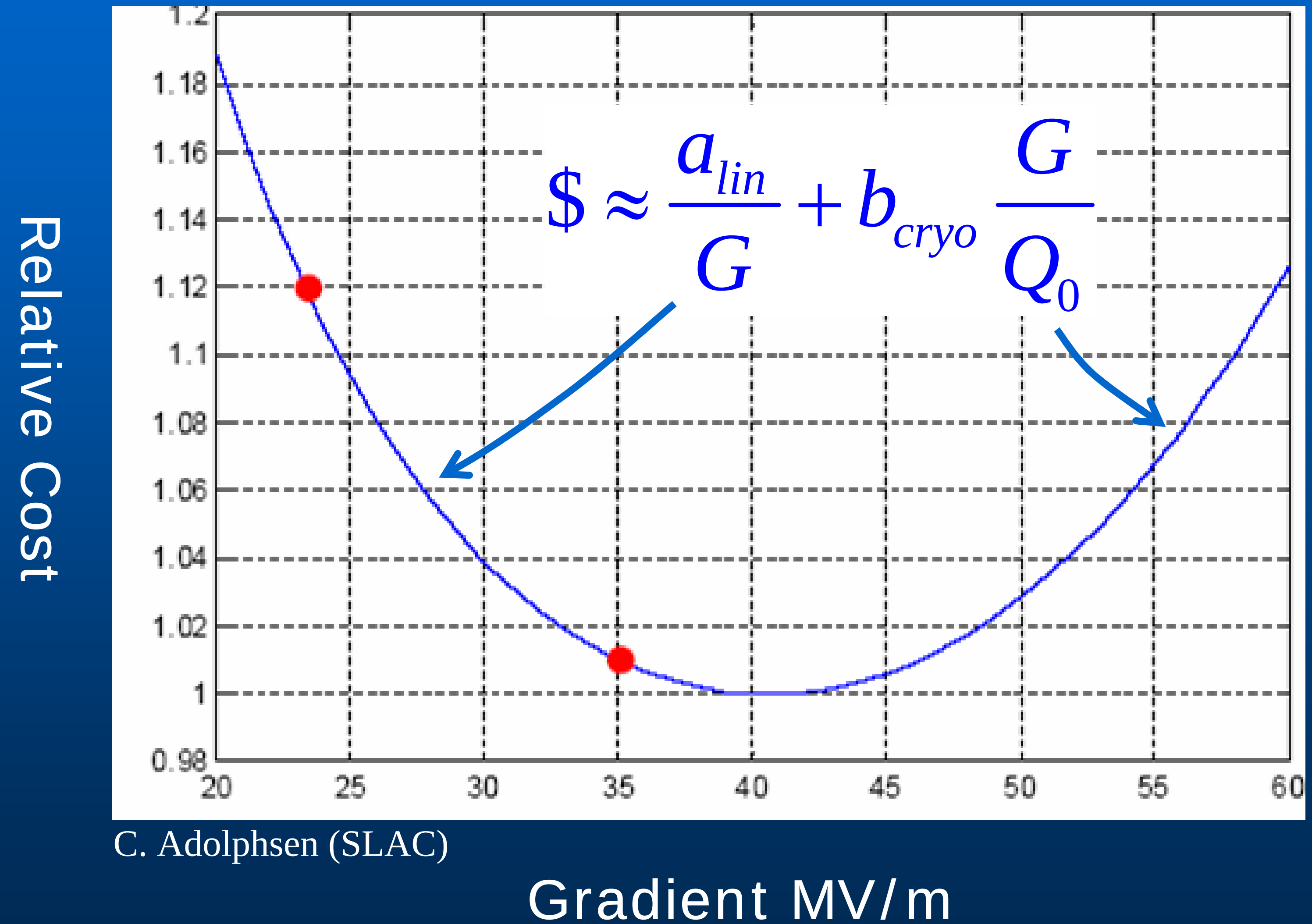
Gradient


Gradient
30 MV/m - safe
35 MV/m - baseline
>40 MV/m - ambitious
EURO XFEL: 28 MV/m

Gradient versus Length

- Higher gradient gives shorter linac ☺
  - cheaper tunnel / civil engineering
  - less cavities
  - (but still need same # klystrons)
- Higher gradient needs more refrigeration ☹
  - 'cryo-power' per unit length scales as G^2/Q_0
  - cost of cryoplants goes up!

Simple Cost Scaling



C. Adolphsen (SLAC)

general consensus that 35MV/m is close to optimum

Nonetheless people are still pushing for 40-45MV/m

Global SCRF Test Facilities

- TESLA Test Facility (TTF)
  currently unique in the world
  VUV-FEL user facility
  test-bed for both XFEL & ILC
- US proposed SMTF
  Cornell, JLab, ANL, FNAL, LBNL, LANL, MIT, MSU, SNS, UPenn, NIU, BNL, SLAC
  currently requesting funding
  TF for ILC, Proton Driver (and more)
- STF @ KEK
  aggressive schedule to produce high-gradient (~45MV/m) cavities / cryomodules

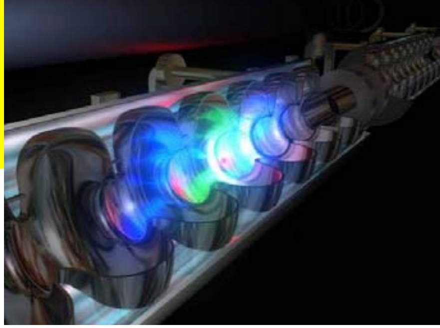
Summary at LCWS 2005

- The ILC is ambitious project which pushed the envelope in every subsystem:
  - Main SCRF linac — cost driver $$$
  - sources
  - damping rings
  - beam delivery

  (sources, damping rings, beam delivery) — *L* performance bottleneck

- Still many accelerator physics issues to deal with, but **reliability** and **cost issues** are probably the greater challenges
- Probably in excess of 3000 man-years already invested in design work.
  - but still plenty for you to do if you want to join us ☺

Developments towards the International Linear Collider



International coordination of work

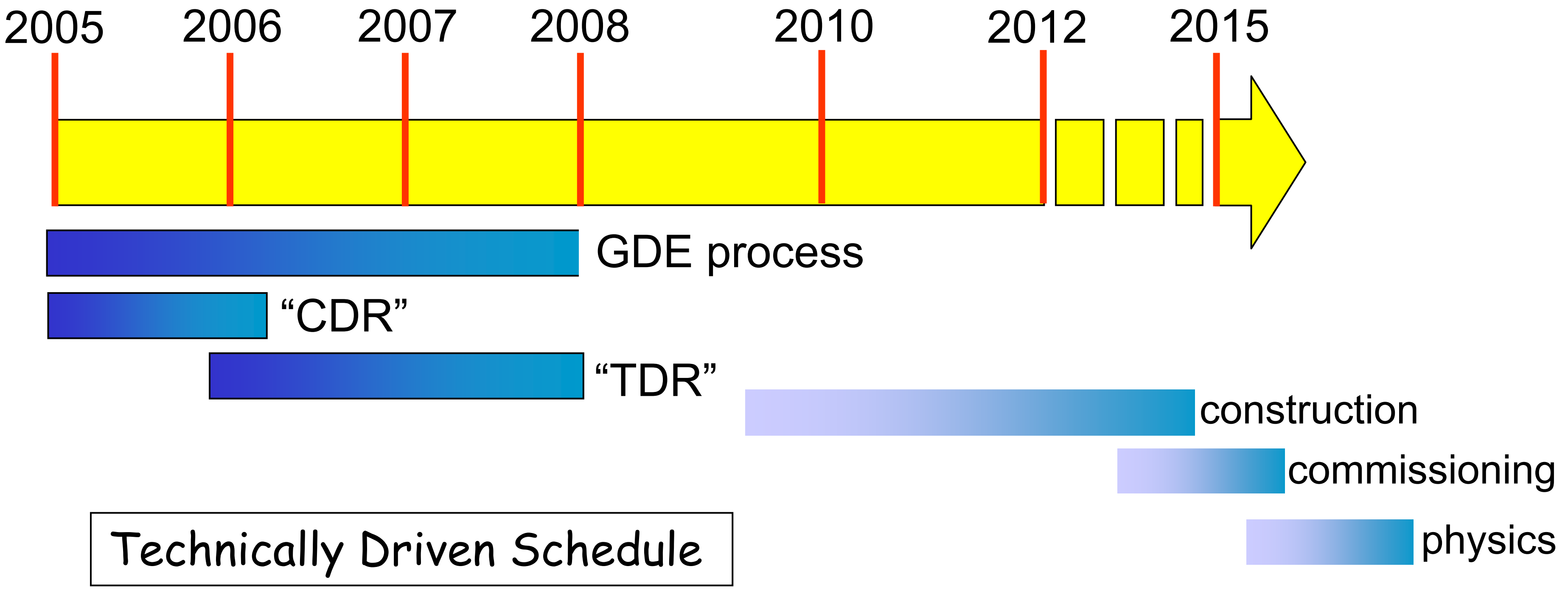
- Establish Global Design Effort (GDE) for the ILC
  → Director nominated March 2005: B. Barish
  regional team leaders nominated May 2005:
  B.Foster – G.Dugan – F.Takasaki
  → expected team size: some 20 FTE
  → virtual organisation (no specific GDE site)

- Next meeting of accelerator and detector/physics experts and GDE team: August 2005 at Snowmass

- Goal: prel. costed design report 2006
  „Technical Design Report“ 2008/9

- Regular meetings of funding agencies, which follow and support development. They have set up a working group on resource issues.

ILC Project Timeline



„CDR“ ≡ basis for TDR
baseline configuration established end 2005
introduce change control beginning 2006
include site specific studies (≥ one per region)
include detector concepts
include reliable cost estimate (emphasis on cost consciousness)

GDE – Near Term Plan

- **Staff the GDE**
  - **Administrative, Communications, Web staff**
  - **Regional Directors (each region)**
  - **Engineering/Costing Engineer (each region)**
  - **Civil Engineer (each region)**
  - **Key Experts for the GDE design staff from the world community (please give input)**
  - **Fill in missing skills (later)**

Total staff size about 20 FTE (2005-2006)

From Barry Barish

GDE – Near Term Plan

- **Schedule**
  - **Begin to define Configuration (Aug 05)**
  - **Baseline Configuration Document by end of 2005**

  - **Put Baseline under Configuration Control (Jan 06)**
  - **Develop Reference Design Report by end of 2006**

- **Three volumes -- 1) Reference Design Report; 2) Shorter glossy version for non-experts and policy makers ; 3) Detector Concept Report**

From Barry Barish

ILC Siting and Civil Construction

- **The design is intimately tied to the features of the site**
  - **1 tunnels or 2 tunnels?**
  - **Deep or shallow?**
  - **Laser straight linac or follow earth's curvature in segments?**
- **GDE ILC Design will be done to samples sites in the three regions**

  → not intended to select a potential site, but rather to understand from the beginning how the features of sites will effect the design, performance and cost

  European sample sites: DESY, CERN

From Barry Barish

GDE – Near Term Plan

- **Organize the ILC effort globally**
  - **First Step --- Appoint Regional Directors within the GDE who will serve as single points of contact for each region to coordinate the program in that region.**

    Make Website, coordinate meetings, coordinate R&D programs, etc

- **R&D Program**
  - **Coordinate worldwide R & D efforts, in order to demonstrate and improve the performance, reduce the costs, attain the required reliability, etc.**

From Barry Barish

European Funding for ILC R&D

Structured and integrated European area in the field of accelerator research and related R&D

3 Networking Activities and 4 Joint Research Activities.

(CERN and DESY participating).

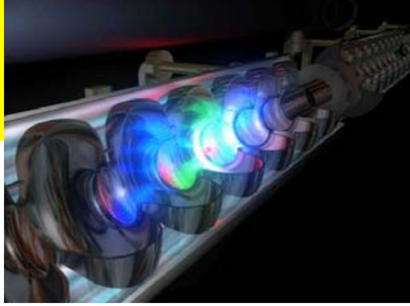
European Design Study

(27 institutions, including CERN and DESY)

With top marks (score: 4.8/5), EU funding: ~9 M€

Kick-off meeting 1.11.2004

ILC - XFEL Synergy

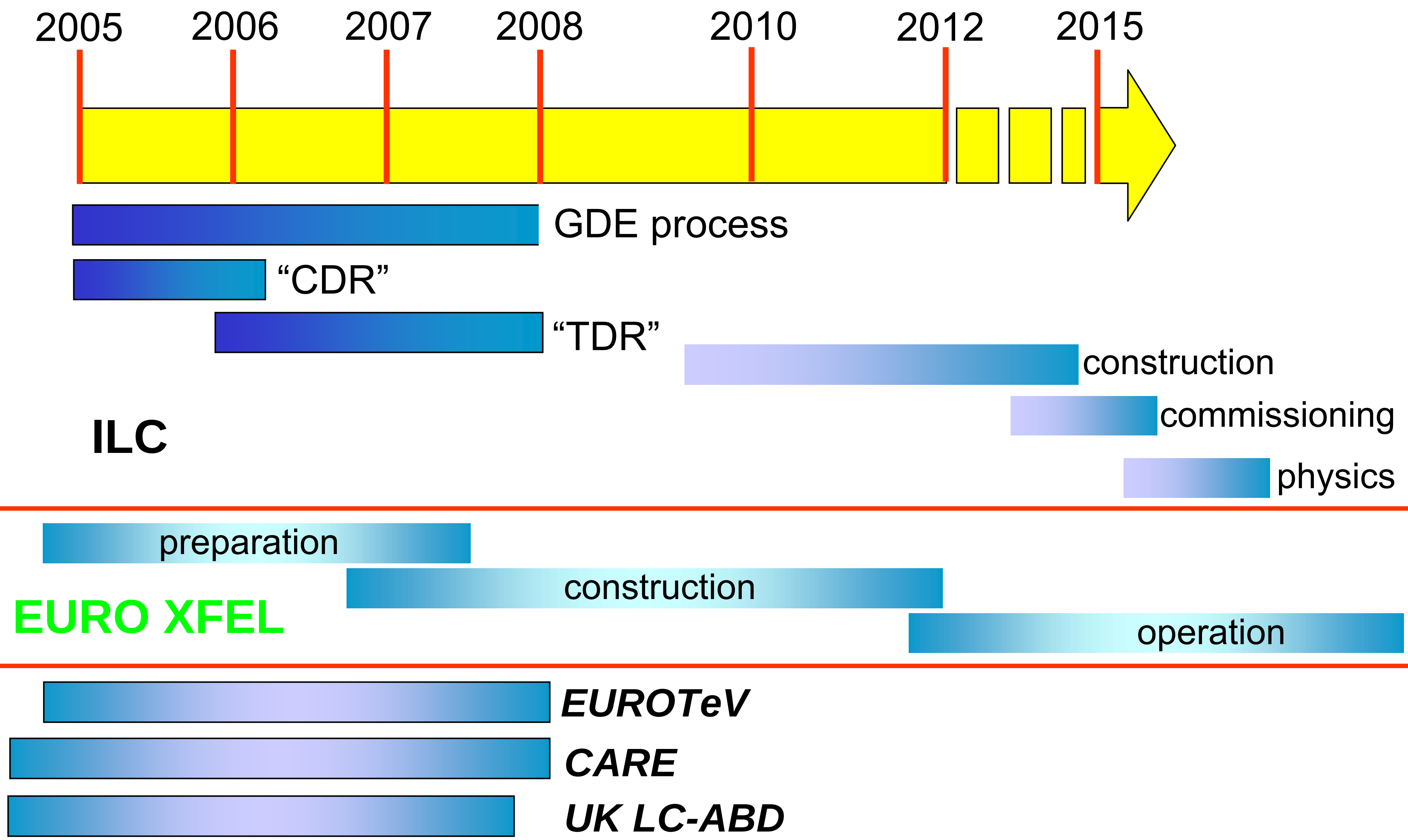


Some examples of ongoing work for the
XFEL at DESY (approved project) relevant to ILC:

- Qualification of vendors in all regions (Europe, US and Asia)
- Industrial studies & prototypes for klystrons
- Involve industry in string & module assembly: 3 industrial studies
- Industrial studies for RF coupler fabrication
- Further experience with cavity treatment, improve statistics for cavities
- Build up module test stand → end of 2005.

Further Synergy by operating VUV-FEL, XFEL commissioning etc

Project Timelines



Conclusions (I)

- The scientific case for a Linear Collider is strong and convincing, a world consensus exists on its importance and on its timing w.r.t. the LHC
- ILC and LHC offer a complementary view of Nature at the energy frontier
- Detector technologies to do the physics at the ILC are being developed
- The SC technology for the ILC is well developed
- 2015 is the target date for commissioning. To reach this we have to keep going at full speed. At present, community is keeping timeline. . .
- Politicians are following the process (technical decision, joint global design, self-organisation,..)

Conclusions (II) (Barry Barish at FNAL in June)

Remarkable progress in the past two years toward realizing an international linear collider:

- **important R&D on accelerator systems**
- **definition of parameters for physics**
- **choice of technology**
- **start the global design effort**
- **funding agencies are engaged**

Many major hurdles remain before the ILC becomes a reality (funding, site, international organization, detailed design, …), but there is increasing momentum toward the ultimate goal --- An International Linear Collider.