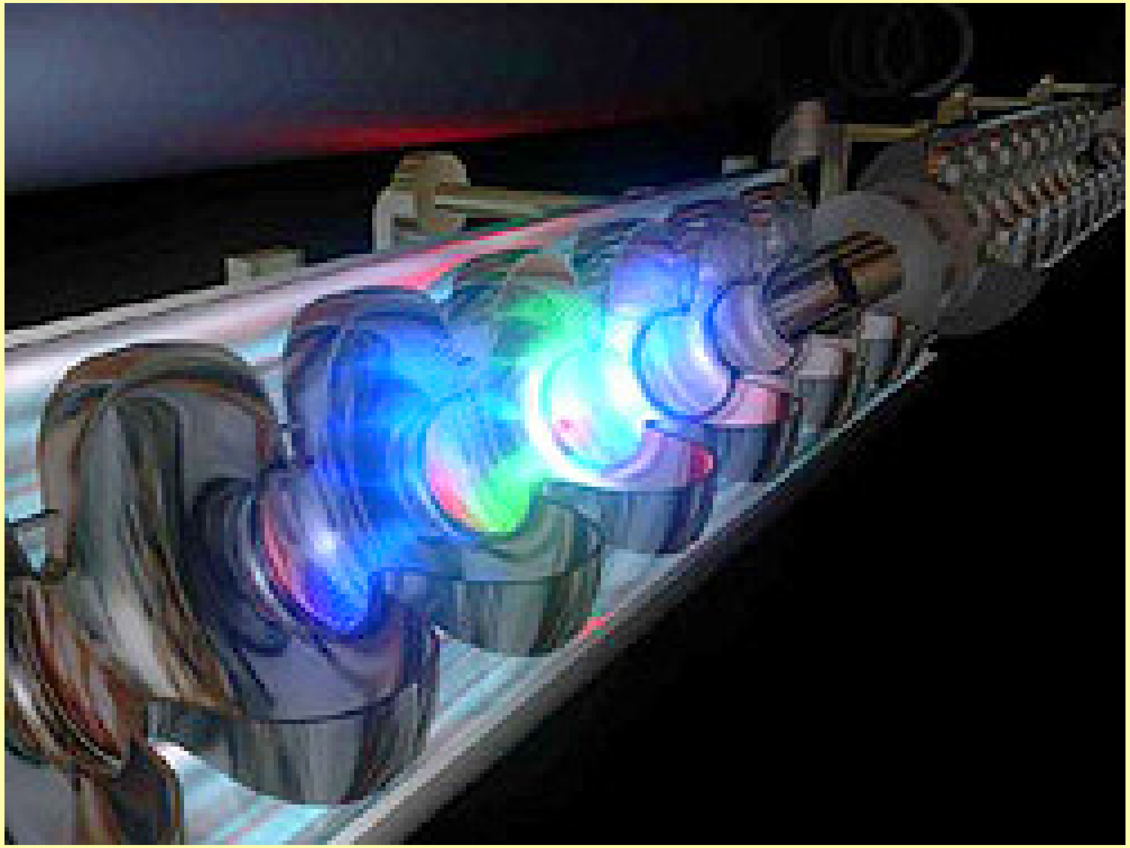
International Collaborations in High Energy Physics



Barry Barish

Edoardo Amaldi Conference

Rome

24-Oct-08

High Energy Physics
international collaboration from birth

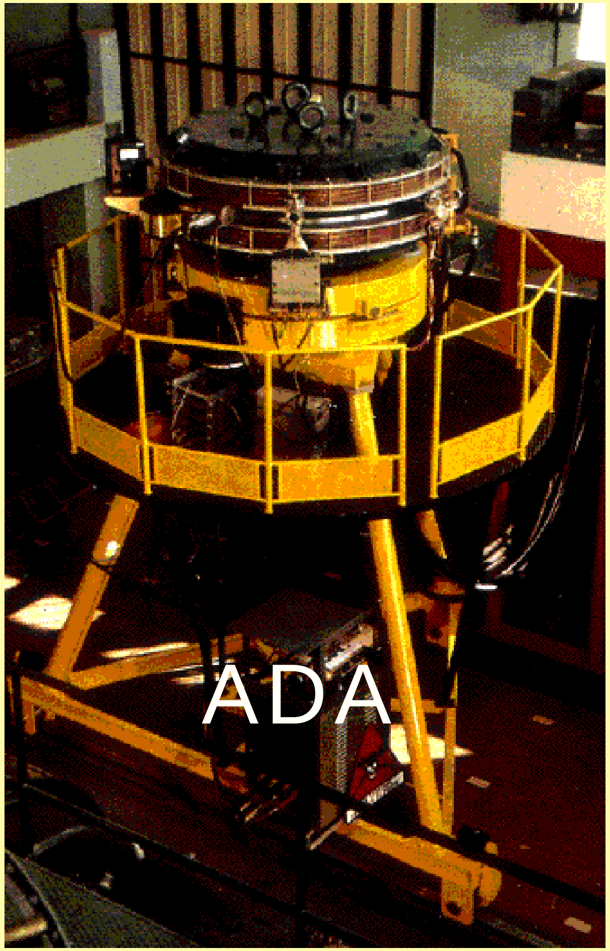
"The modern era in Particle Physics began in 1947 in Bristol and Manchester, with the discovery of the π-meson, of strange particles, and of muon catalysed fusion. The first paper that describes the strong interactions of a meson has only one author, but very quickly the advantages of international collaboration came to the fore. Within a year a American balloon (from Oppenheimer) was carrying a British emulsion (from Bristol) into the stratosphere to look for cosmic ray interactions." -D.H. Saxon

Evolution of Particle Physics

- To a large extent the long string of exciting discoveries and importance of particle physics followed from developing controlled particle beams at higher and higher energy --- (e.g. high energy particle accelerators)

- The field began and evolved to a large extent as an "observational field" (like astronomy) through several generations of opening new windows with new high energy accelerators. This frequently lead to unexpected (e.g. discovery of J/Ψ and charm particles), as well as planned new discoveries (Z^0 and W)

Electron-Positron Colliders



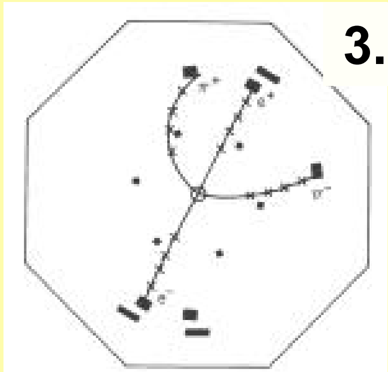
Bruno Touschek built the first succesful electron-positron collider at Frascati, Italy (1960)

Eventually, went up to 3 GeV

But, not quite high enough energy ….

SPEAR at SLAC

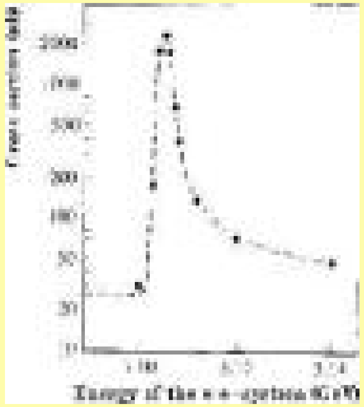
3.1 GeV



Burt Richter

and

Discovery
Of
Charm
Particles



Particle Physics has evolved into an *Inquiry Based Science*

1. **Are there undiscovered principles of nature:**
   New symmetries, new physical laws?
2. **How can we solve the mystery of dark energy?**
3. **Are there extra dimensions of space?**
4. **Do all the forces become one?**
5. **Why are there so many kinds of particles?**
6. **What is dark matter?**
   How can we make it in the laboratory?
7. **What are neutrinos telling us?**
8. **How did the universe come to be?**
9. **What happened to the antimatter?**

from the Quantum Universe

Answering the Questions
Three Complementary Probes

- **Neutrinos as a Probe**
  - **Particle physics and astrophysics using a weakly interacting probe**
- **High Energy Proton Proton Colliders**
  - **Opening up a new energy frontier (~ 1 TeV scale)**
- **High Energy Electron Positron Colliders**
  - **Precision Physics at the new energy frontier**

Exploring the Terascale
the tools

- **The LHC**
  - **It will lead the way and has large reach**
  - **Quark-quark, quark-gluon and gluon-gluon collisions at 0.5 - 5 TeV**
  - **Broadband initial state**
- **The ILC**
  - **A second view with high precision**
  - **Electron-positron collisions with fixed energies, adjustable between 0.1 and 1.0 TeV**
  - **Well defined initial state**
- **Together, these are our tools for the terascale**

CERN – A result of movement to international collaboration of HEP

Louis de Broglie first proposed the idea for a European research laboratory in 1949

"...Our attention has turned to the question of developing this new international unit, a laboratory or institution where it would be possible to carry out scientific work above and beyond the framework of the various nations taking part...This body could be endowed with greater resources than those available to the national laboratories and could then embark upon tasks whose magnitude and nature preclude them from being done by the latter on their own."

Rabi then stated at UNESCO meeting in 1950:

"the urgency of creating regional centres and laboratories in order to increase and make fruitful the international collaboration of scientists in fields where the effort of any one country is insufficient for the task."

CERN – The official beginning

The European Organization for Nuclear Research - CERN - came into being on 29 September 1954, when 12 Member States had ratified the Convention (a Treaty).

The Convention states:

“The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character.”

It also states that CERN shall organize and sponsor international co-operation in research, promoting contacts between scientists and interchange with other laboratories and institutes.

This includes dissemination of information, and the provision of advanced training for research workers, which continue to be reflected in the current programmes for technology transfer and for education & training at many levels.

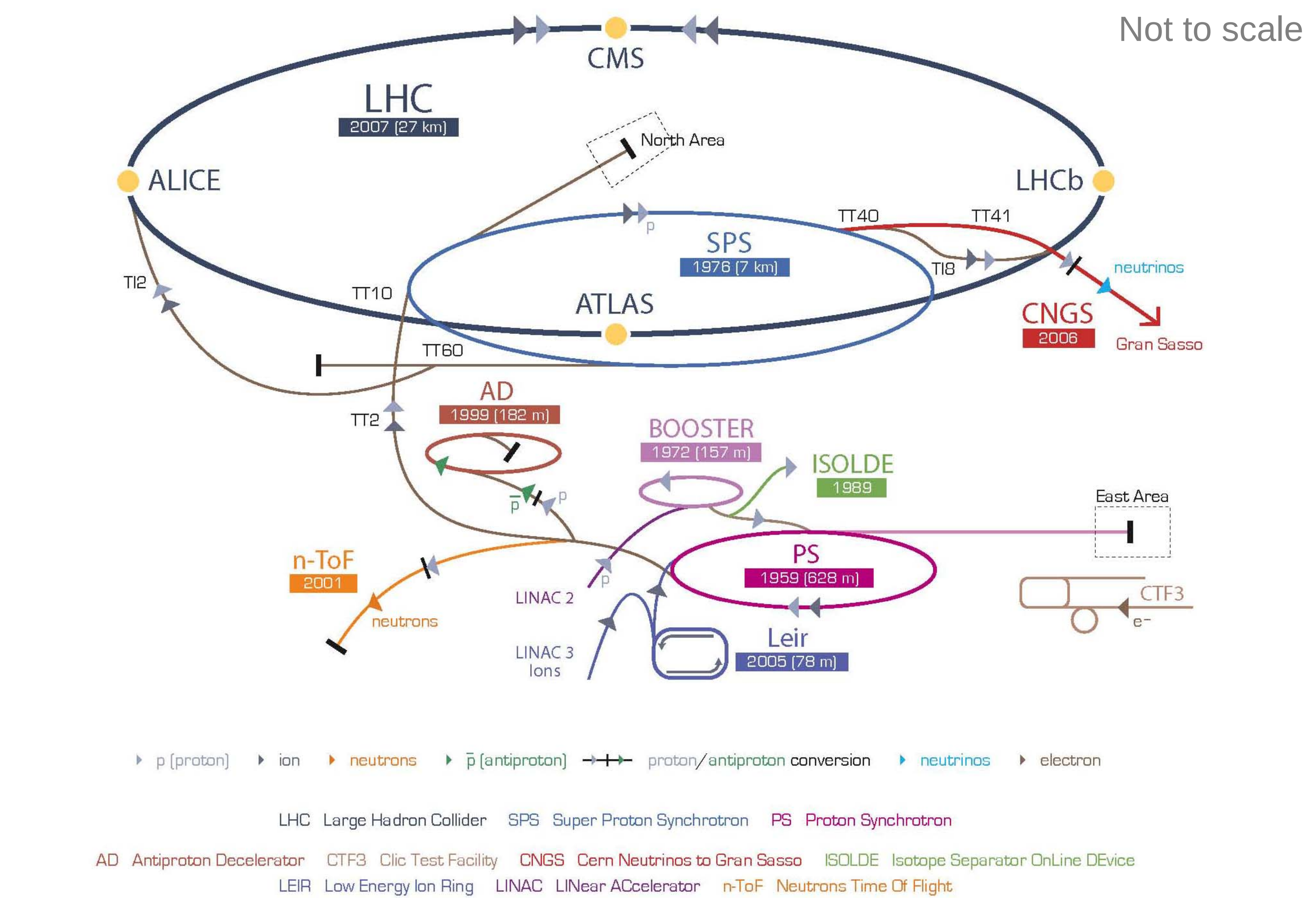
CERN today

- **Member States:** Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.
- **Observers to Council:** India, Israel, Japan, Russian Federation, Turkey, United States of America, European Commission and UNESCO

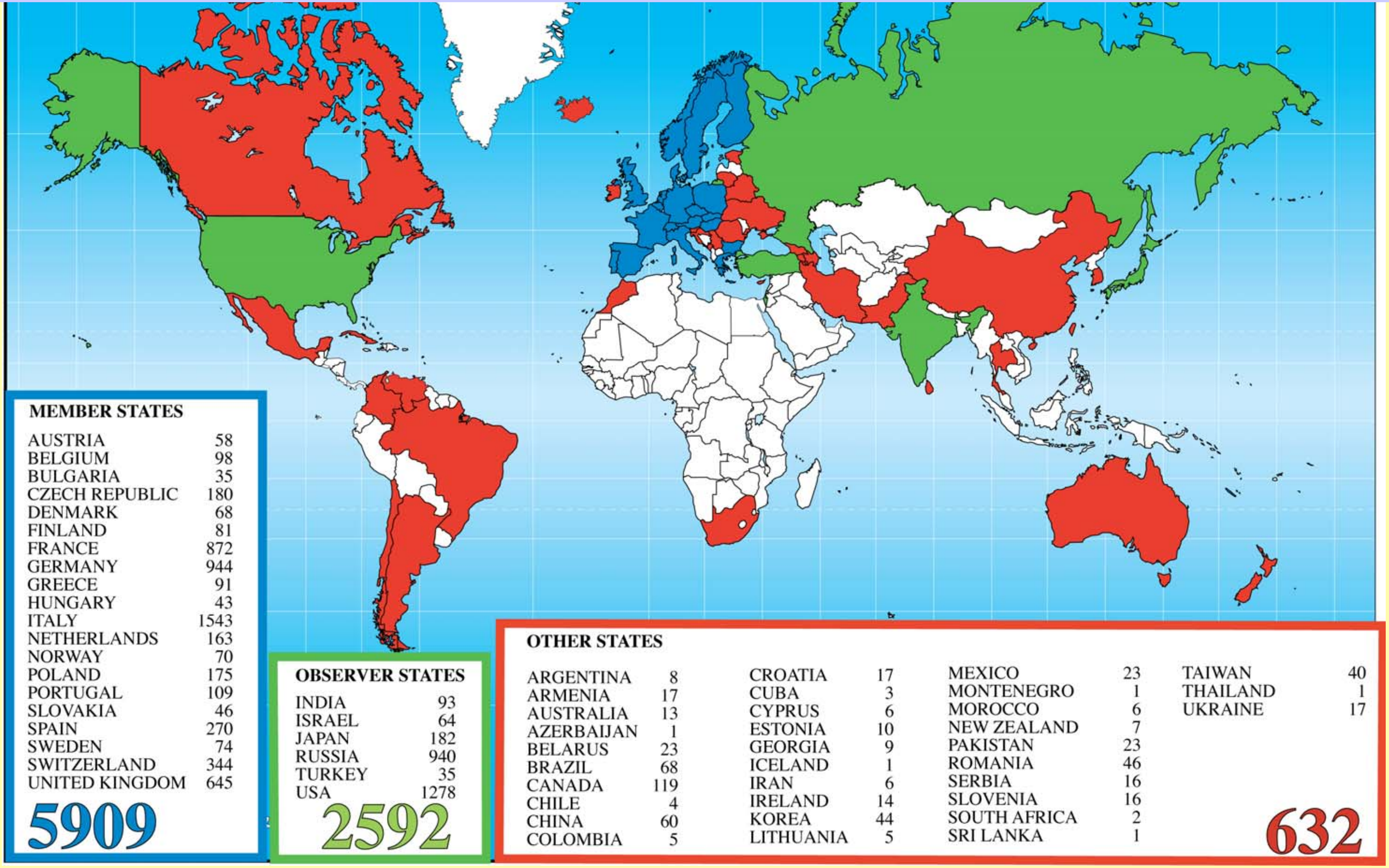
- 2415 staff*
- 730 Fellows and Associates*
- 9133 users*
- Budget (2007) 982 MCHF (610M Euro)

*5 February 2008

CERN Accelerator Complex



CERN users around the world



MEMBER STATES	
AUSTRIA	58
BELGIUM	98
BULGARIA	35
CZECH REPUBLIC	180
DENMARK	68
FINLAND	81
FRANCE	872
GERMANY	944
GREECE	91
HUNGARY	43
ITALY	1543
NETHERLANDS	163
NORWAY	70
POLAND	175
PORTUGAL	109
SLOVAKIA	46
SPAIN	270
SWEDEN	74
SWITZERLAND	344
UNITED KINGDOM	645

5909

OBSERVER STATES	
INDIA	93
ISRAEL	64
JAPAN	182
RUSSIA	940
TURKEY	35
USA	1278

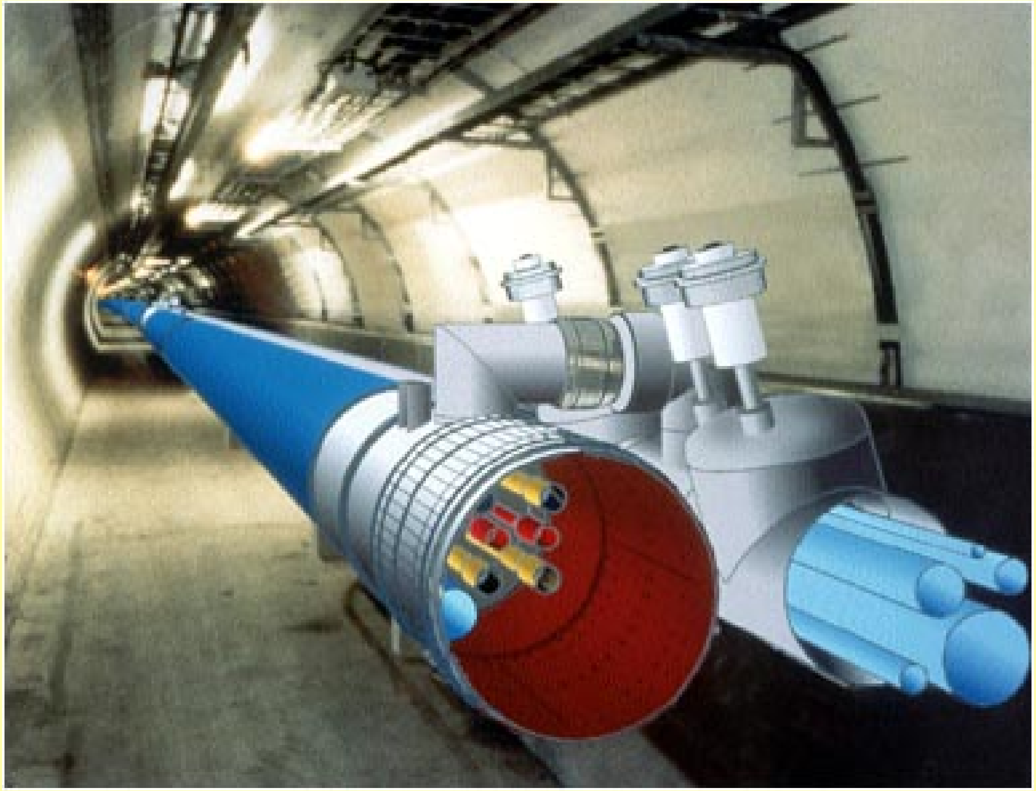
2592

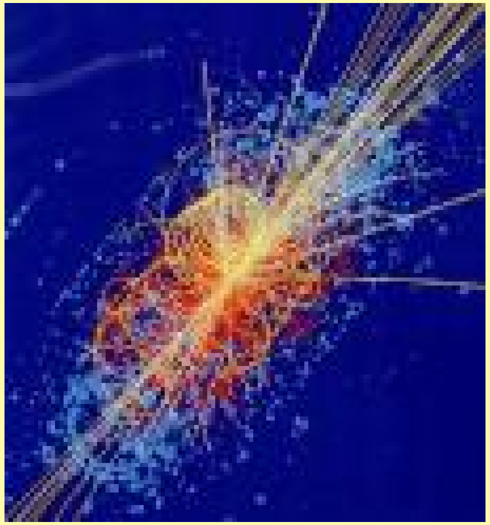
OTHER STATES	
ARGENTINA	8
ARMENIA	17
AUSTRALIA	13
AZERBAIJAN	1
BELARUS	23
BRAZIL	68
CANADA	119
CHILE	4
CHINA	60
COLOMBIA	5
CROATIA	17
CUBA	3
CYPRUS	6
ESTONIA	10
GEORGIA	9
ICELAND	1
IRAN	6
IRELAND	14
KOREA	44
LITHUANIA	5
MEXICO	23
MONTENEGRO	1
MOROCCO	6
NEW ZEALAND	7
PAKISTAN	23
ROMANIA	46
SERBIA	16
SLOVENIA	16
SOUTH AFRICA	2
SRI LANKA	1
TAIWAN	40
THAILAND	1
UKRAINE	17

632

Accelerators and the Energy Frontier

Large Hadron Collider
CERN – Geneva Switzerland

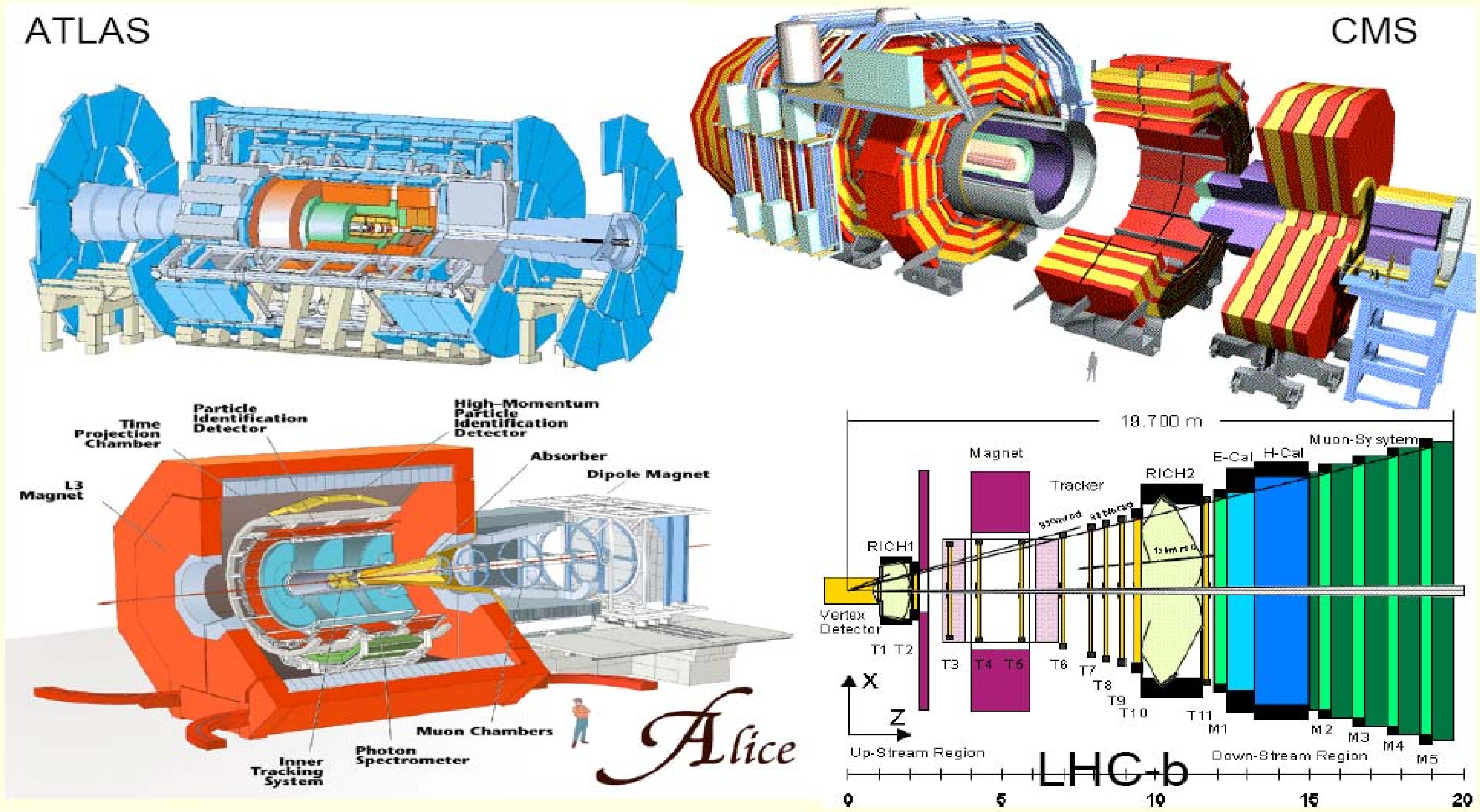




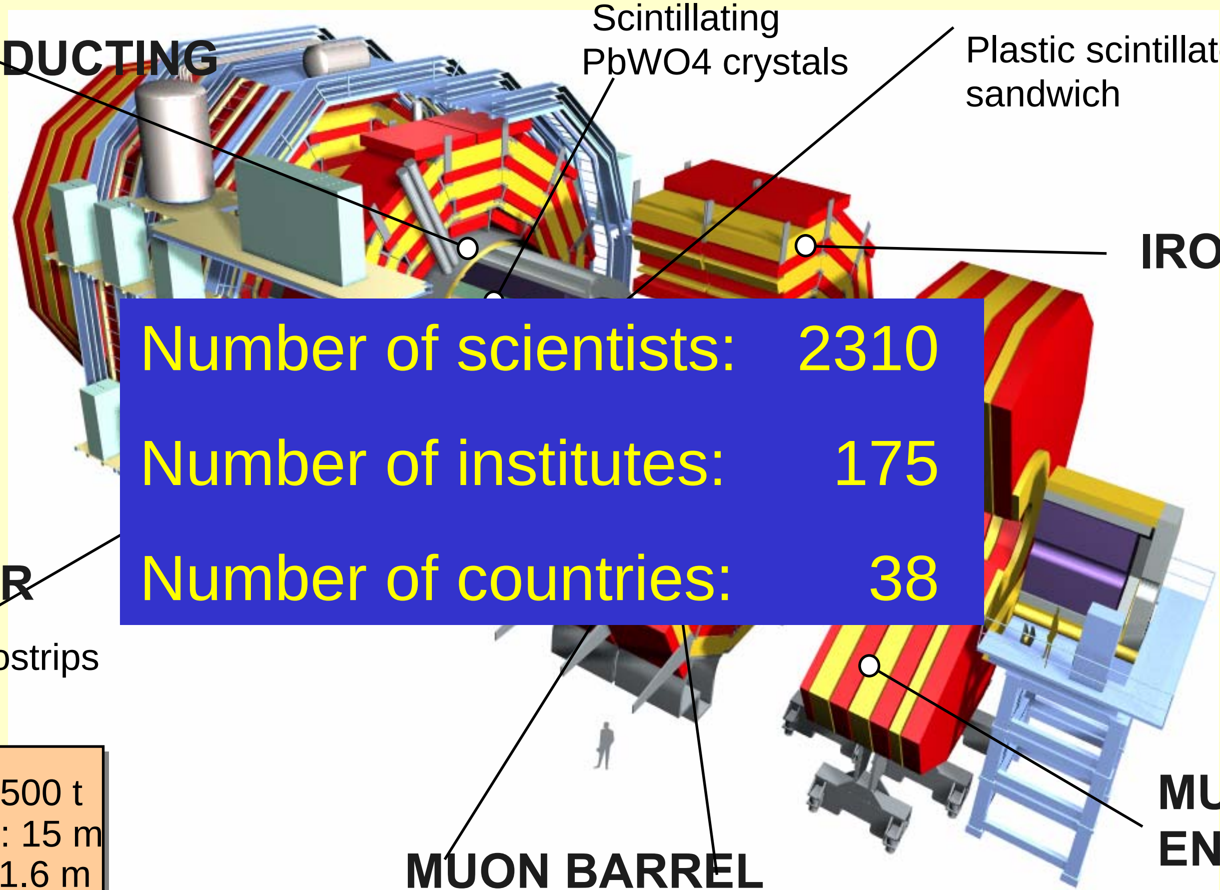
LHC Experiments

Ultimate in present day international collaboration

- Each experiment has its own independent management and governance structure
- CERN is a ~20% partner
- CERN steps in when contributor(s) fail to deliver (R. Aymar)



CMS – Compact Muon Solenoid



Number of scientists: 2310

Number of institutes: 175

Number of countries: 38

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

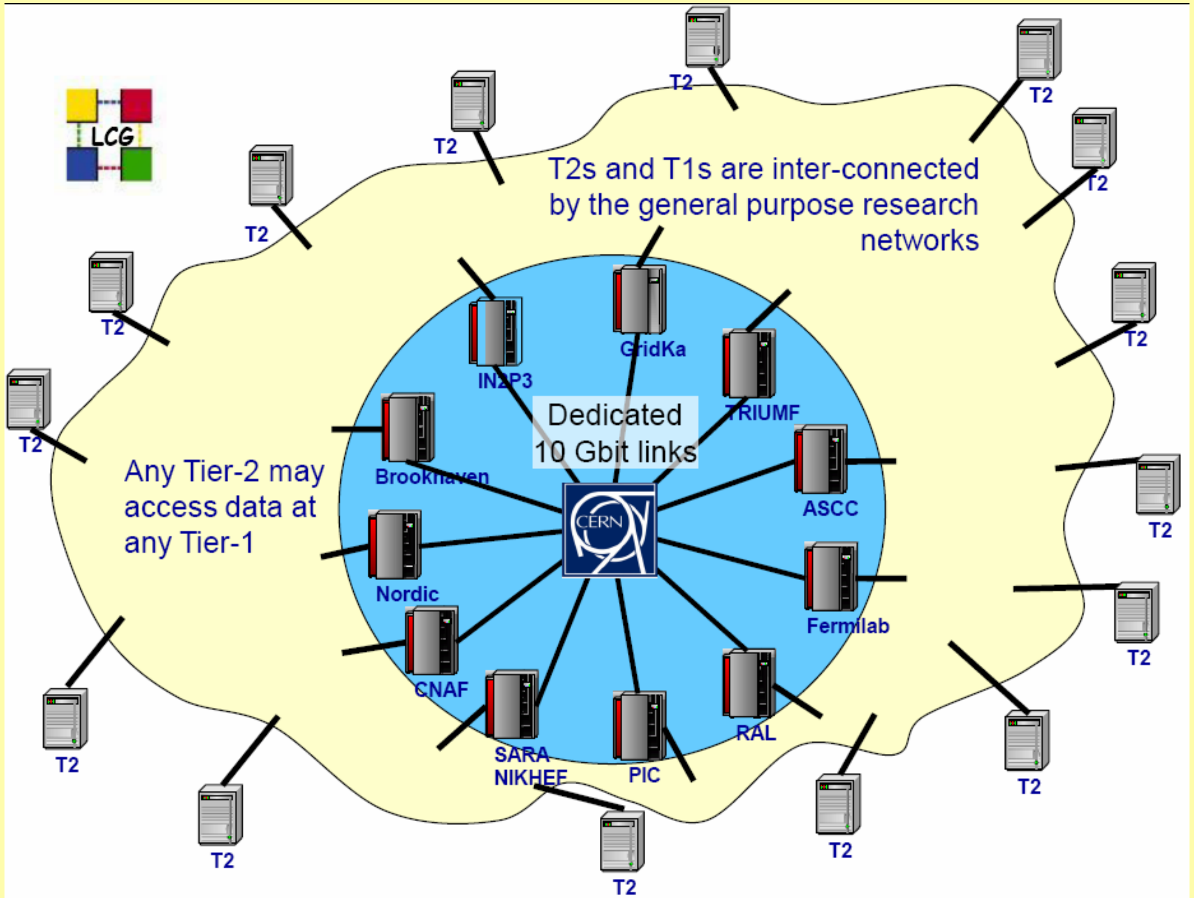
Enabling world-wide collaboration

- **LHC Grid – physics from your desktop**
- **The role of “open access” in HEP collaboration**
- **The future “open data”**

Collaborating from your desk

The World-wide LHC Computing Grid

The LHC produces 15 Million Gigabytes of data each year
Computing resources are distributed world-wide



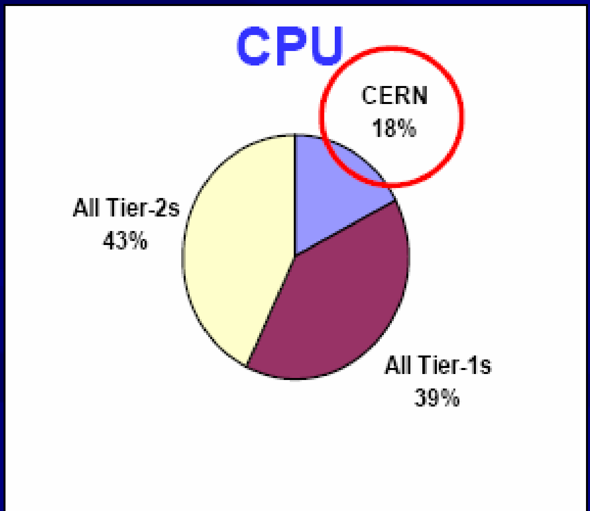
Collaborating from your desk

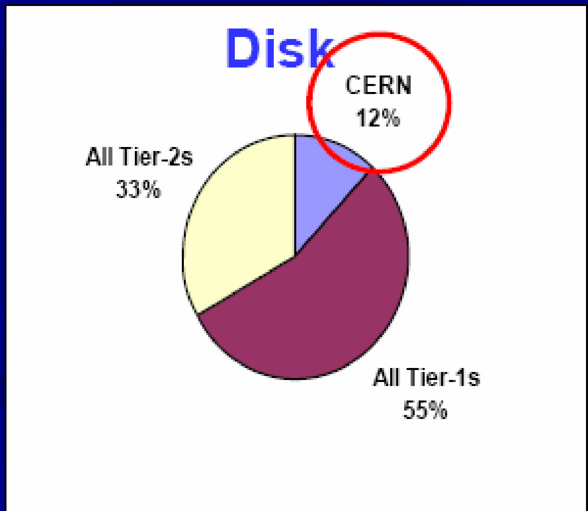
Summary of Computing Resource Requirements

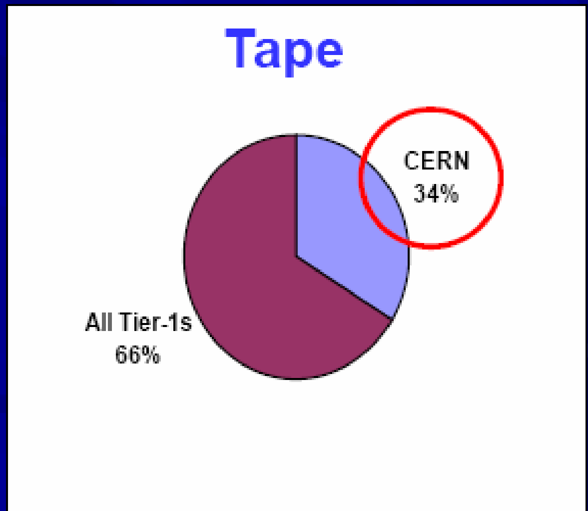
All experiments - 2008

From LCG TDR - June 2005

	CERN	*All Tier-1s*	*All Tier-2s*	*Total*
CPU (MSPECint2000s)	25	56	61	142
Disk (PetaBytes)	7	31	19	57
Tape (PetaBytes)	18	35		53







Open Access to Scientific Research

- **History**
  - **HEP developed a "preprint culture," to cut the time to see new research results (1960s)**
  - **Preprints became the standard way to communicate new research results with elaborate systems in HEP labs to archive, search, distribute (e.g. SPIRES at SLAC)**
  - **The rise of the bulletin board through the internet - arXiv (full-text server) by Paul Ginsparg at LANL (1990s)**
  - **The web to post / access / communicate / collaborate scientific data (CERN)**

- **SPIRES now contains metadata for >750 000 HEP articles, adding ~4500 records every month**
- **arXiv has about 450 000 full-texts, adding ~5000 new articles every month**

Open Access to Scientific Research

SCOAP^3 in one sentence

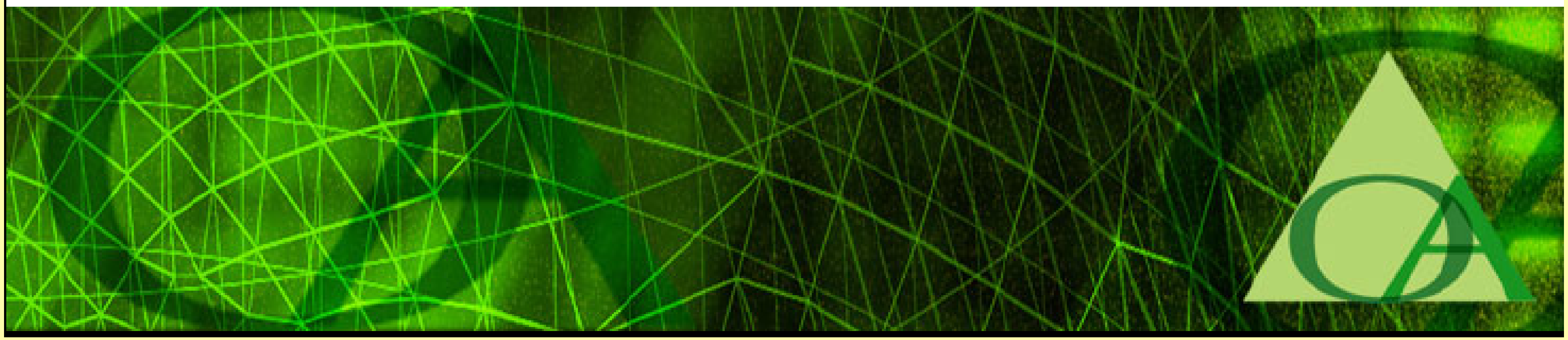
A consortium sponsors HEP publications and makes them OA by re-directing subscription money.

Today: (funding bodies through) libraries buy journal subscriptions to support the peer-review service and to allow their patrons to read articles.

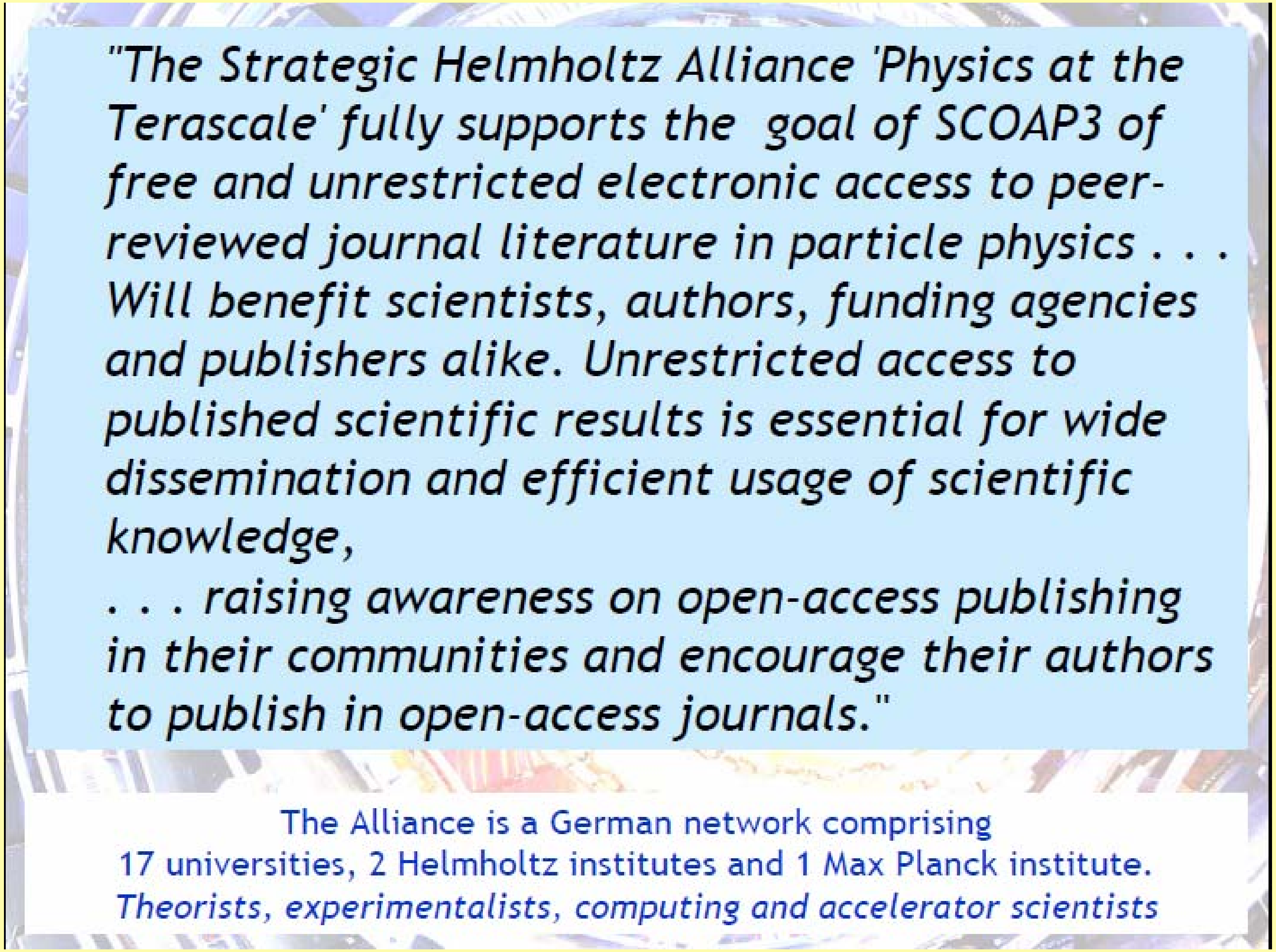
Tomorrow: funding bodies and libraries contribute to the consortium, which pays centrally for the peer-review service. Articles free to read for everyone.

Open Access to Scientific Research

After preprints, arXiv and the web,
Open Access journals
are the natural evolution of
HEP scholarly communication



Open Access to Scientific Research



Open Access to Scientific Research

The 2832nd EU Competitiveness Council

http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/intm/97236.pdf

"[The EU Council] recognizes the **strategic importance** for Europe's scientific development of current initiatives to develop **sustainable models for open access** [...]" and "underlines the **importance of effective collaboration between different actors, including funding agencies, researchers, research institutions and scientific publishers**, in relation to access [... to], scientific publications [...]". It **"invites Member States to enhance the co-ordination between Member States, large research institutions and funding bodies** on access [...] policies and practices"

These principles are precisely the pillars of the SCOAP^3 model

Vision for future HEP Open Access

May'07: HEP Information Summit @ SLAC
May'08: next Summit @ DESY

kick-off and brain-storming of all concerned parties to

1. Build a complete HEP information platform
2. Enable text- and data-mining applications
3. Demonstrate and deploy Web2.0 applications
4. Preservation and re-use of research data

Preservation and reuse of research data

- The same researchers who took the data, after the closure of the facility (~1 year, ~10 years)
- Researchers working at similar experiments at the same time (~1 day, week, month, year)
- Researchers of future experiments (~20 years)
- Theoretical physicists who may want to re-interpret the data (~1 month, ~1 year, ~10 years)
- Theoretical physicists who may want to test future ideas (~1 year, ~10 years, ~20 years)

Preservation and reuse of research data

- The HEP data model is highly complex. Data are traditionally not re-used as in Astronomy or Climate science.
- Raw data → calibrated data → skimmed data → high-level objects → physics analyses → results.
- All of the above needs duplication for *in-silico* experiments, necessary to interpret the highly-complex data.
- Final results depend on the grey literature on calibration constants, human knowledge and algorithms needed for each pass...oral tradition!
- Years of training for a successful analysis

The Future
Complete Global Collaboration
"from Concept to Science"

- **CASE EXAMPLE:** ***The International Linear Collider (ILC)***
  - **International collaboraton in the concept and R&D phase**
  - **The role of the International Committee for Future Accelerators (ICFA)**
  - **International collaboration in making technical decisions and performing the design**
  - **Issues and realities of a global project.**

The ILC and the Energy Frontier

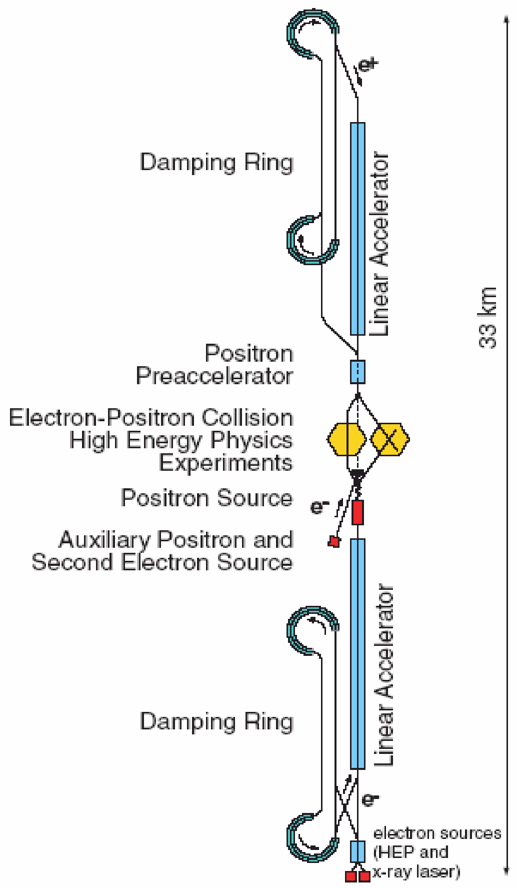
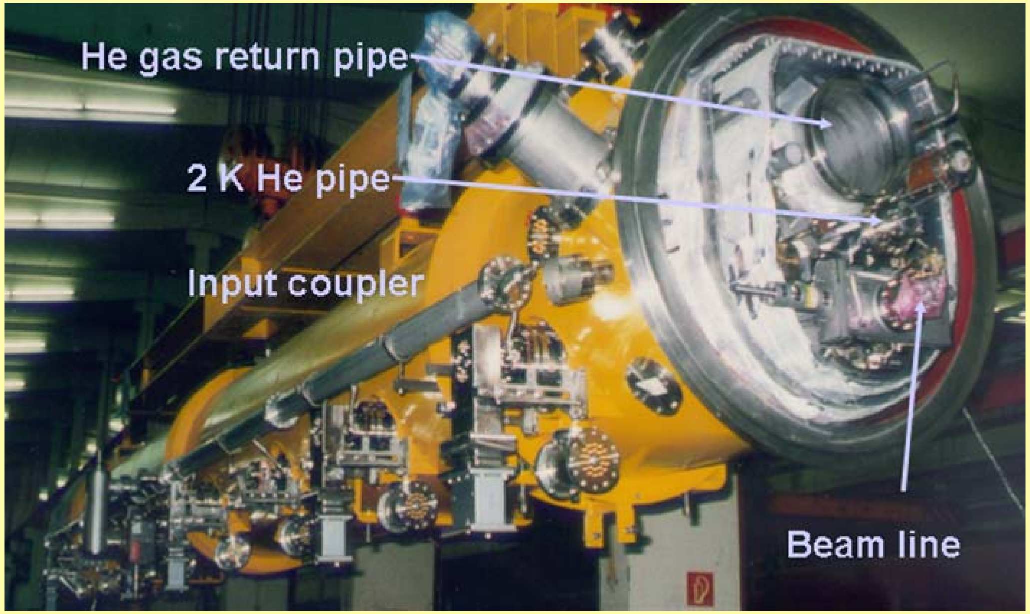


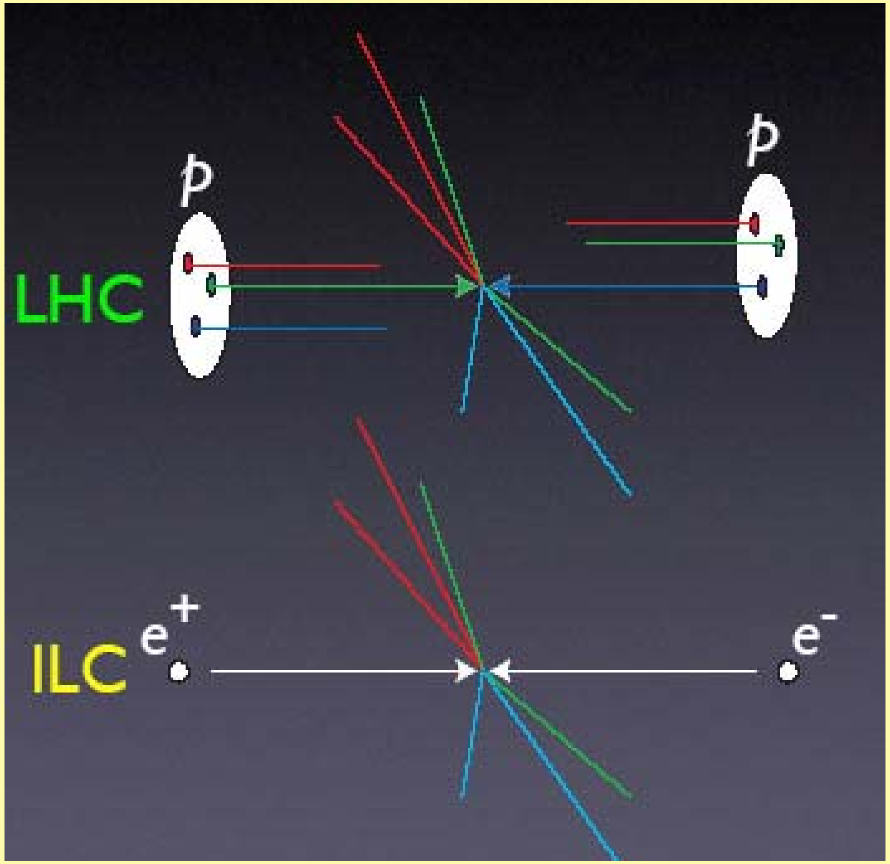
FIGURE 1. TESLA layout

International Linear Collider

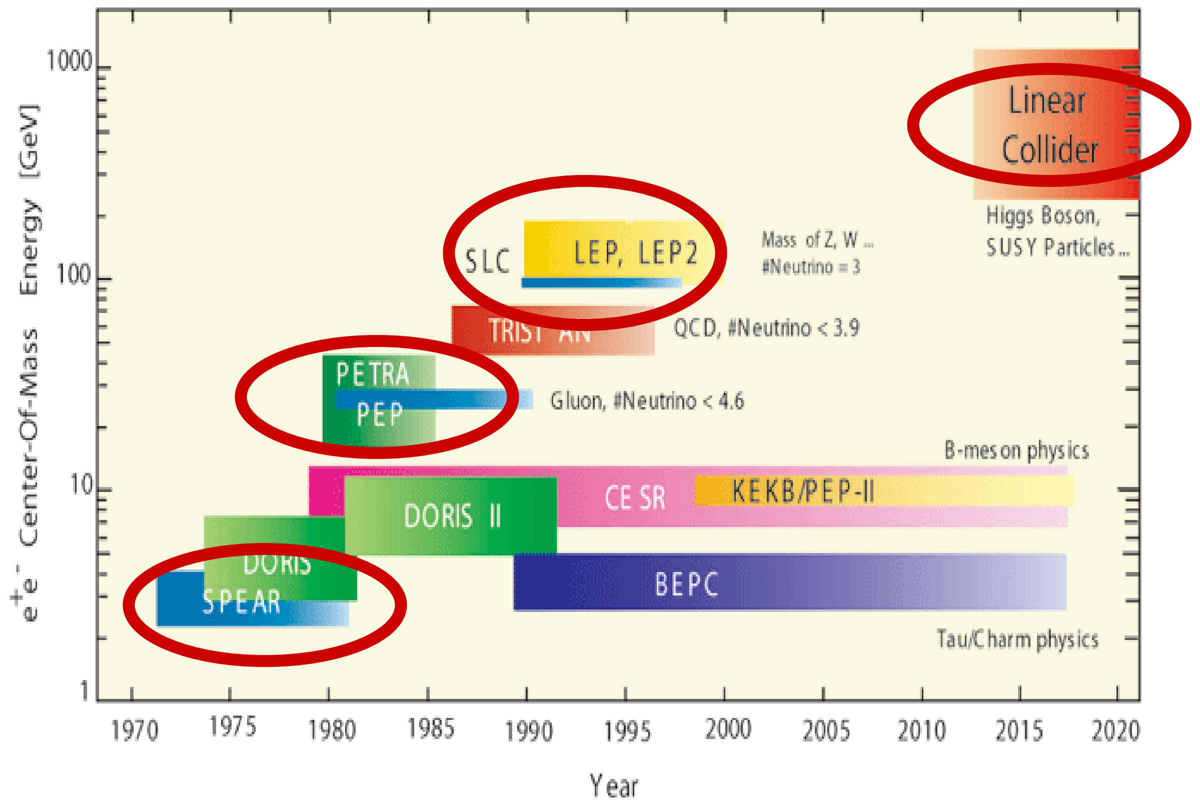


Why e^+e^- Collisions ?

- elementary particles
- well-defined
  - energy,
  - angular momentum
- uses full COM energy
- produces particles democratically
- can mostly fully reconstruct events



Electron Positron Colliders
The Energy Frontier



ICFA

- **ICFA, the International Committee for Future Accelerators, was created to facilitate international collaboration in the construction and use of accelerators for high energy physics. It was created in 1976 by the International Union of Pure and Applied Physics. Its purposes, as stated in 1985, are as follows:**
  - **To promote international collaboration in all phases of the construction and exploitation of very high energy accelerators.**
  - **To organize regularly world-inclusive meetings for the exchange of information on future plans for regional facilities and for the formulation of advice on joint studies and uses.**
  - **To organize workshops for the study of problems related to super high-energy accelerator complexes and their international exploitation and to foster research and development of necessary technology.**
  - **The Committee has sixteen members, selected primarily from the regions most deeply involved in high energy physics.**

How the physics defines the ILC

Parameters for the Linear Collider

September 30, 2003

Parameters for the ILC

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 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%

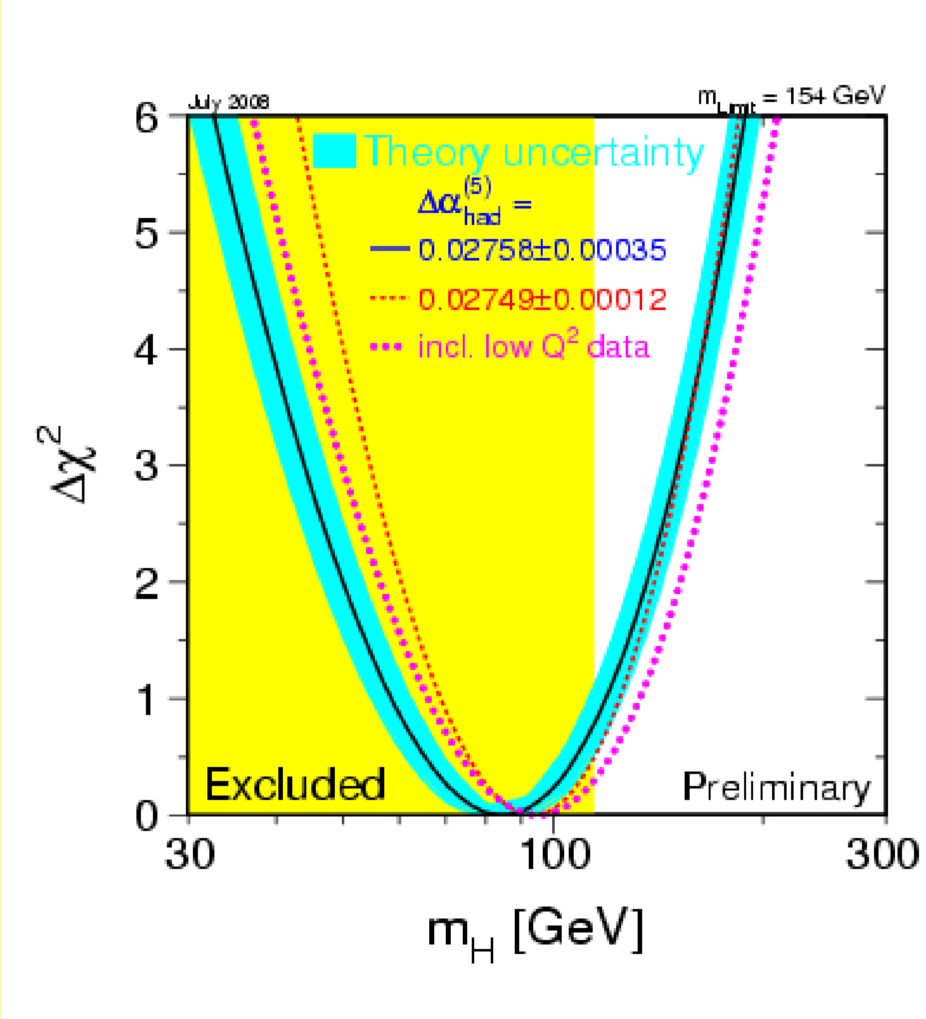
- The machine must be upgradeable to 1 TeV

LHC Results and GDE Program?

- We are presently planning a Technical Design Phase program, where we will be ready to propose the project in 2012

- The science guidance for a linear collider has not changed. **We have strong reason to anticipate that the energy reach and luminosity of the SCRF ILC will be well matched to the goals.**

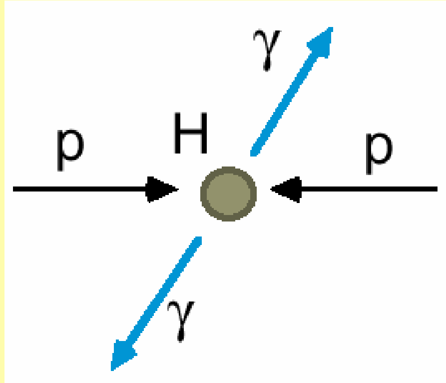
- Nevertheless, the GDE program and linear collider proposal must be informed by LHC timescale and results.

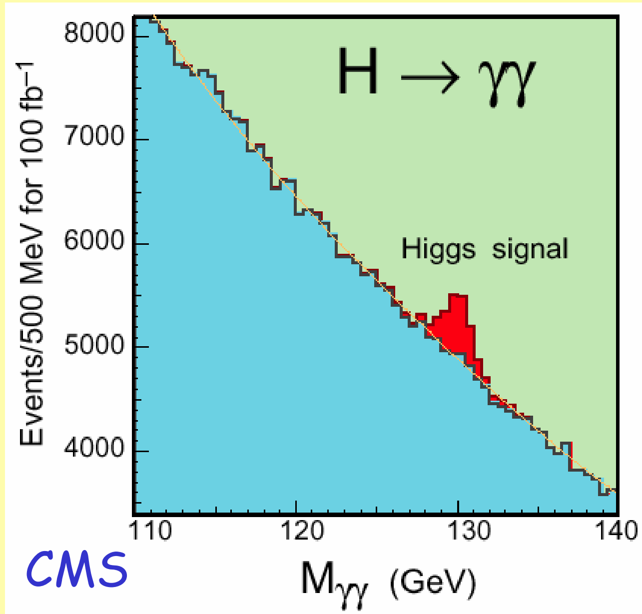


LHC: Low mass Higgs

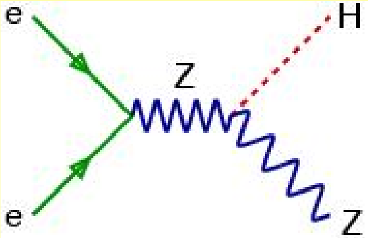
$H \rightarrow \gamma\gamma$ $M_{\mathcal{H}} < 150$ GeV/c^2

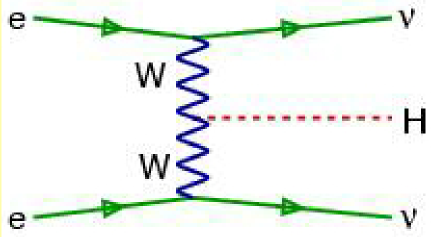
- **Rare decay channel: BR ~ 10^{-3}**
- **Requires excellent electromagnetic calorimeter performance**
  - **acceptance, energy and angle resolution,**
  - **γ/jet and γ/π^0 separation**
  - **Motivation for LAr/$PbWO_4$ calorimeters for CMS**
- **Resolution at 100 GeV: $\sigma \approx 1$ GeV**
- **Background large: S/B $\approx$ 1:20, but can estimate from non signal areas**

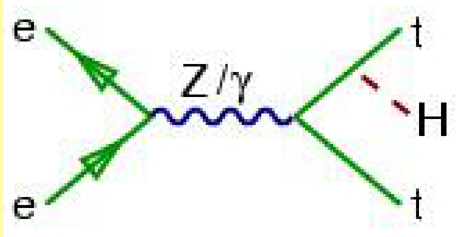


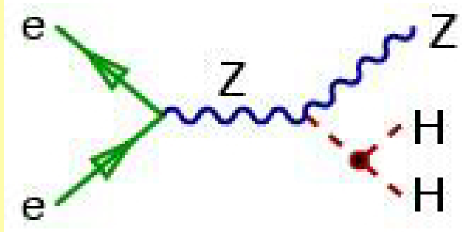


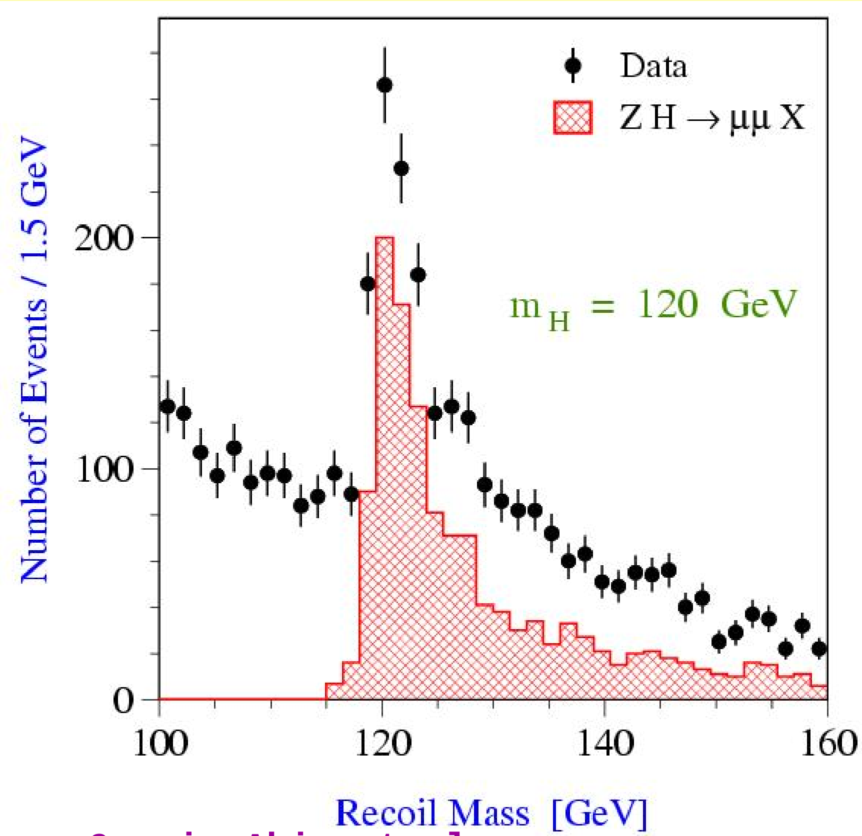
ILC: Precision Higgs physics







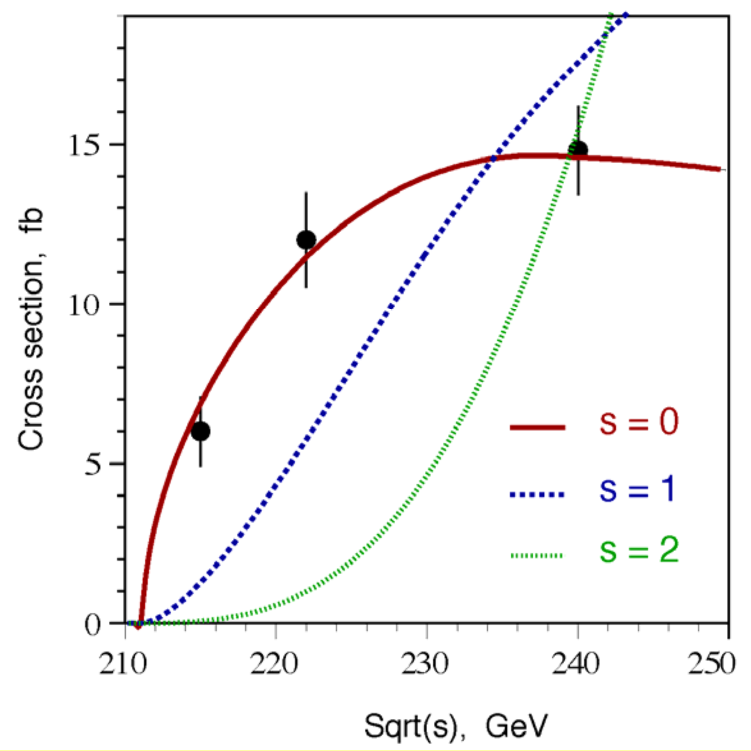




Garcia-Abia et al

- **Model-independent Studies**
  - **mass**
  - **absolute branching ratios**
  - **total width**
  - **spin**
  - **top Yukawa coupling**
  - **self coupling**
- **Precision Measurements**

How do you know you have discovered the Higgs ?

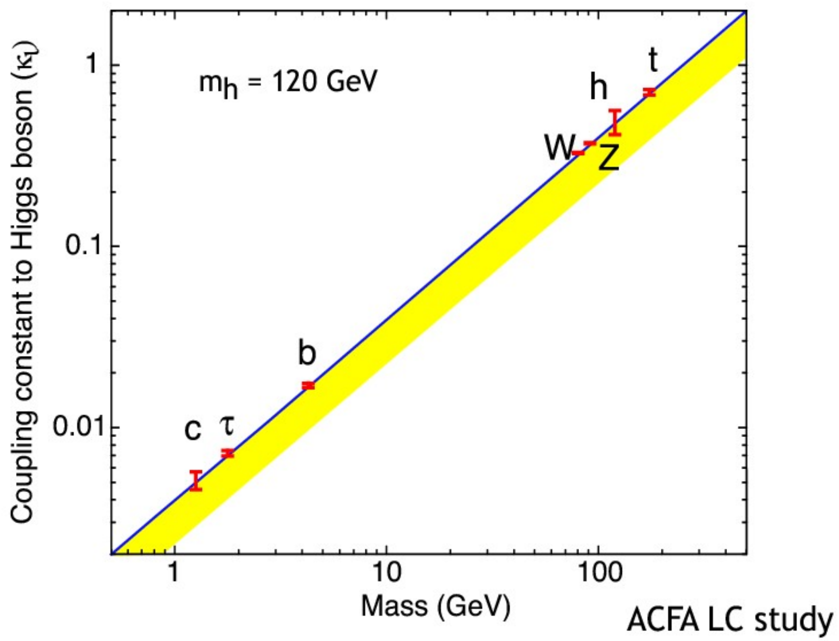


Measure the quantum numbers. The Higgs must have spin zero !

The linear collider will measure the spin of any Higgs it can produce by measuring the energy dependence from threshold

What can we learn from the Higgs?

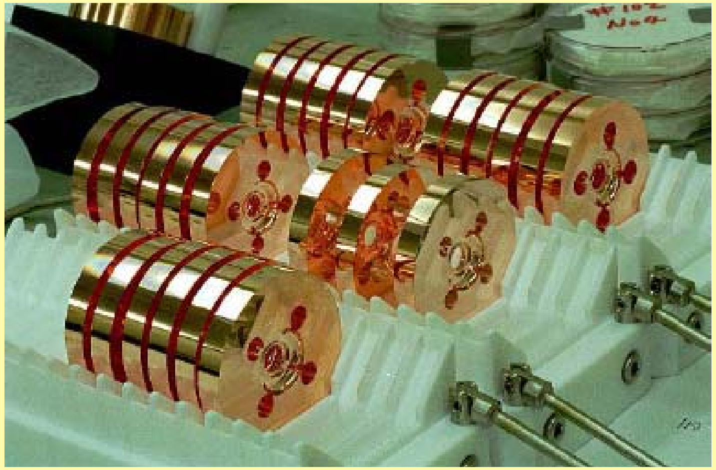
Precision measurements of Higgs coupling can reveal extra dimensions in nature



- Straight blue line gives the standard model predictions.
- Range of predictions in models with extra dimensions -- yellow band, (at most 30% below the Standard Model
- The red error bars indicate the level of precision attainable at the ILC for each particle

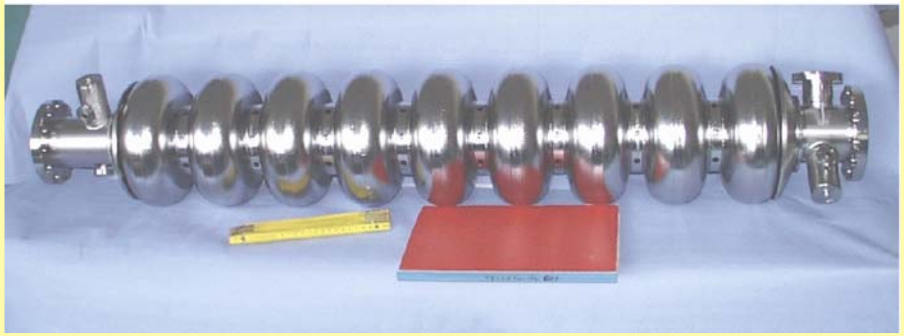
ILC – Underlying Technology

- **Room temperature copper structures**

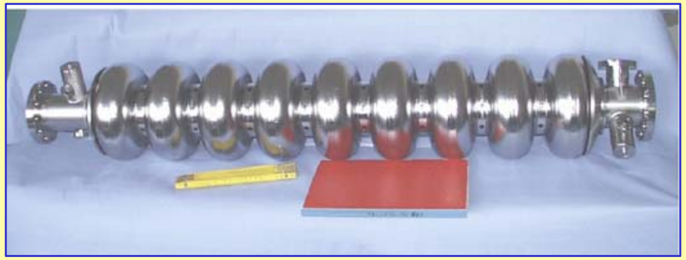


OR

- **Superconducting RF cavities**



ICFA: making a difficult technology decision globally

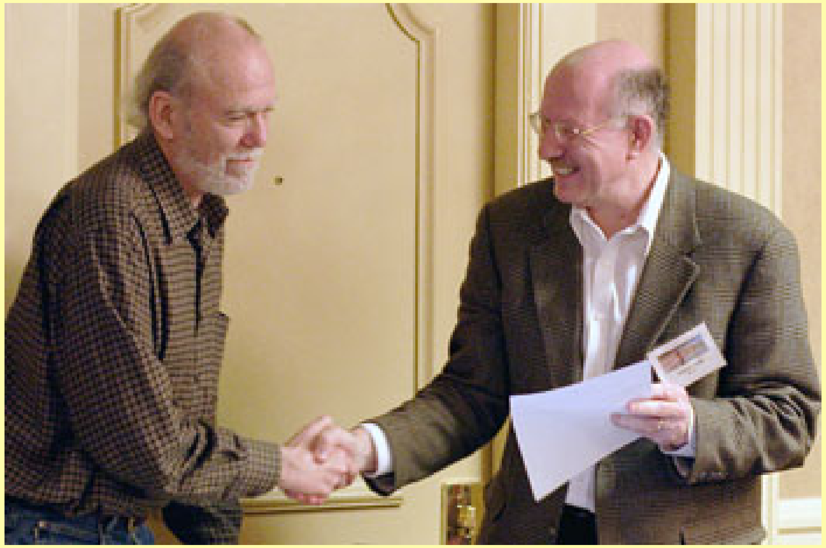


- **Forward looking technology for the next generation of particle accelerators: particle physics; nuclear physics; materials; medicine**

- **The ILC R&D is leading the way Superconducting RF technology**
  - **high gradients; low noise; precision optics**

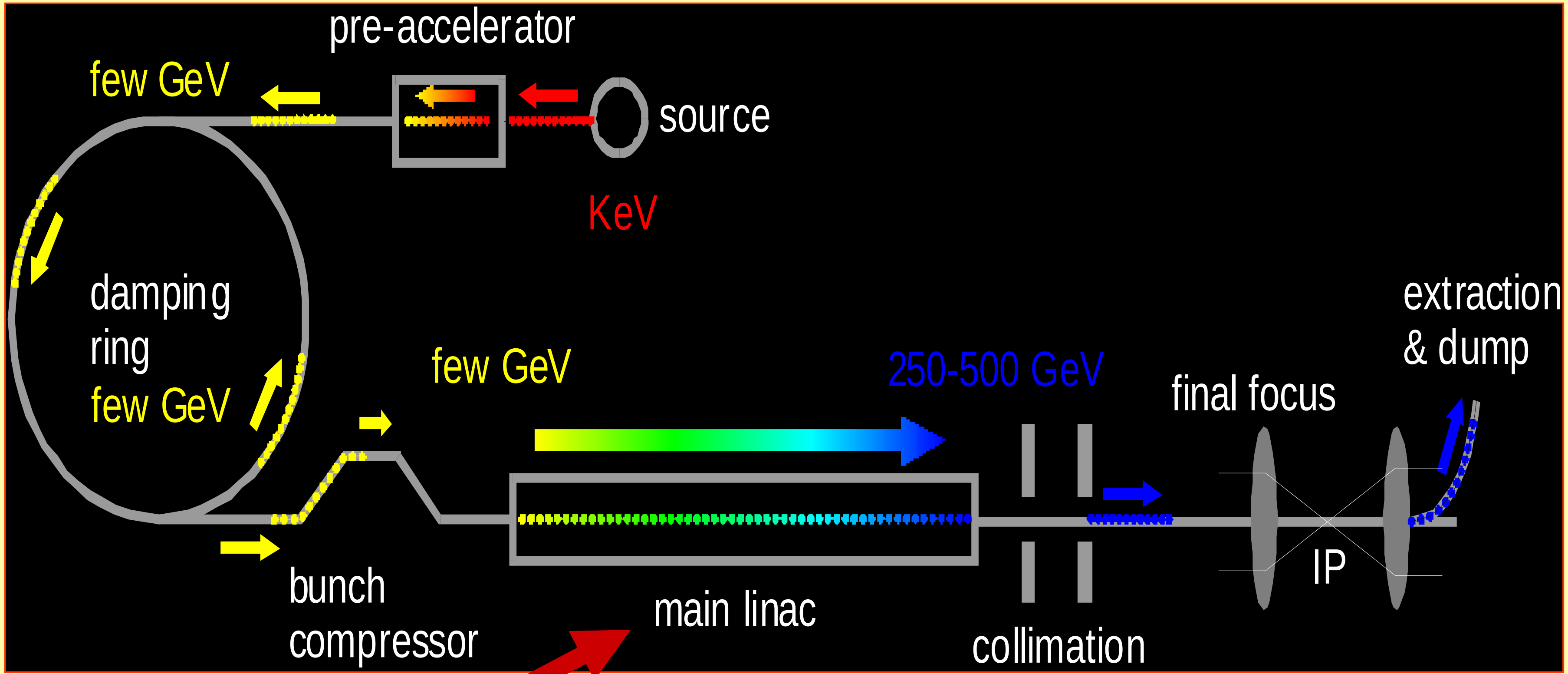
The ILC Global Design Effort

- **ICFA, through the International Linear Collider Steering Committee, I was appointed as Director of the Global Design Effort**
- **The mandate of our effort is to create a design through a true global effort for this future accelerator**
- **This process is well underway**

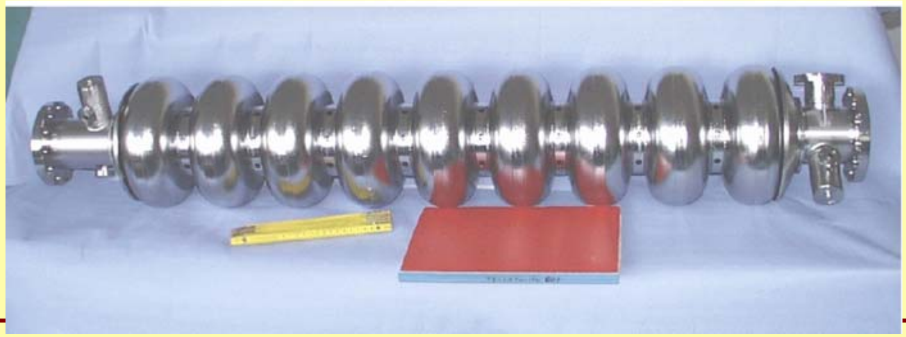


Global organization (GDE), global technical decision making, global ownership technical design and joint responsibility for the construction and science

Designing a Linear Collider



Superconducting RF
Main Linac



Luminosity & Beam Size

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

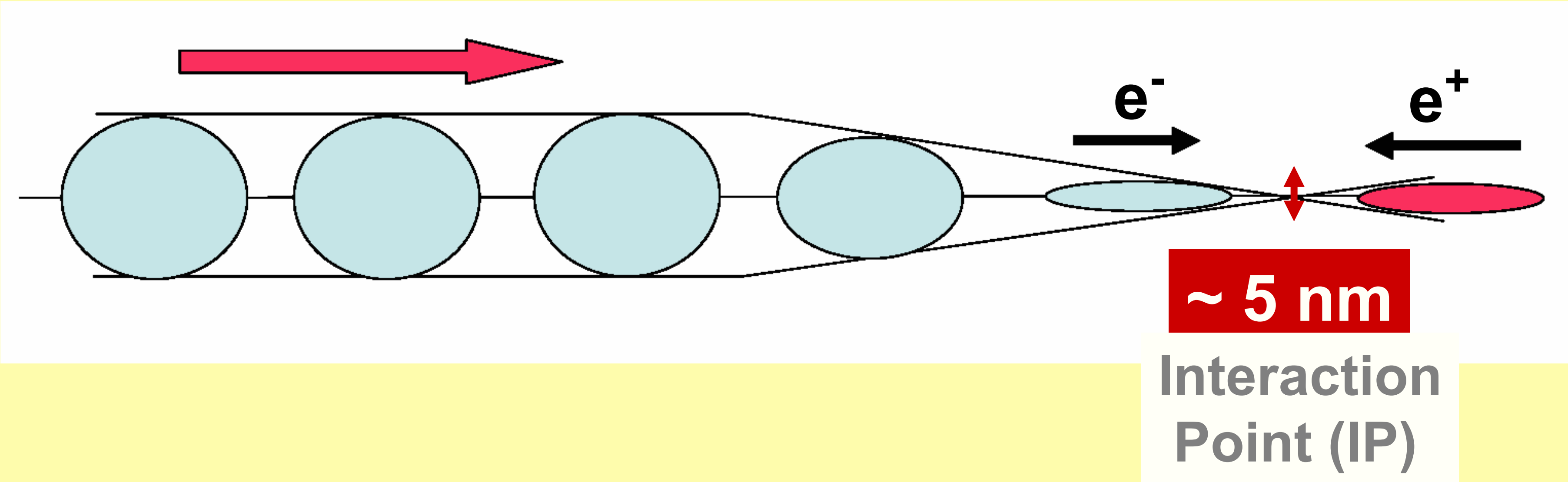
- **f_{rep} * n_b tends to be low in a linear collider**

	L	f_{rep} [Hz]	n_b	N [10^{10}]	σ_x [μm]	σy [μm]
ILC	2×10^{34}	5	3000	2	0.5	0.005
SLC	2×10^{30}	120	1	4	1.5	0.5
LEP2	5×10^{31}	10,000	8	30	240	4
PEP-II	1×10^{34}	140,000	1700	6	155	4

- **Achieve luminosity with spot size and bunch charge**

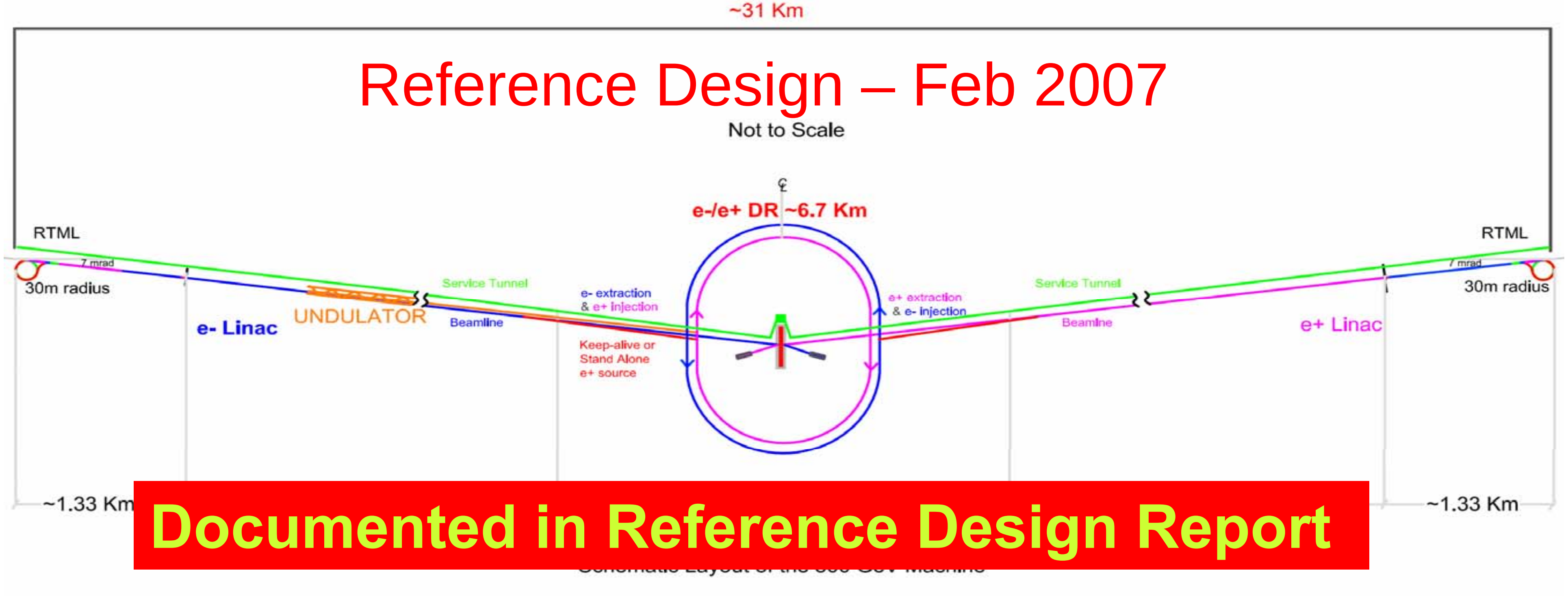
Achieving High Luminosity

- **Low emittance machine optics**
- **Contain emittance growth**
- **Squeeze the beam as small as possible**



ILC Reference Design

- **11km SC linacs operating at 31.5 MV/m for 500 GeV**
- **Centralized injector**
  - **Circular damping rings for electrons and positrons**
  - **Undulator-based positron source**
- **Single IR with 14 mrad crossing angle**
- **Dual tunnel configuration for safety and availability**



Documented in Reference Design Report

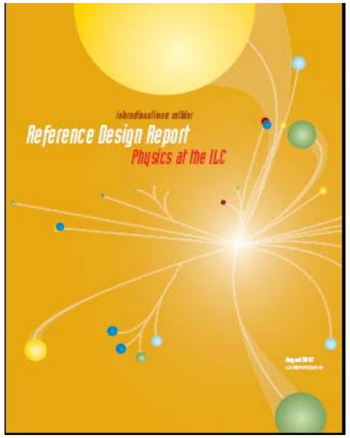
RDR Design Parameters

Max. Center-of-mass energy	500	GeV
Peak Luminosity	$\sim 2x10^{34}$	$1/cm^2s$
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

ILC Reference Design

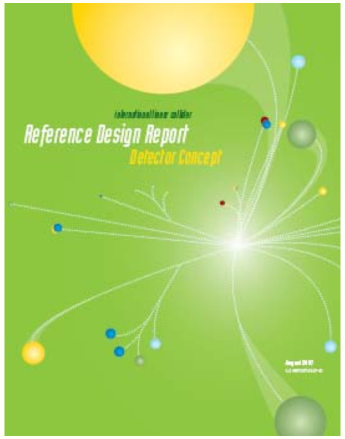
- Reference Design Report (4 volumes)

Executive Summary



Physics at the ILC

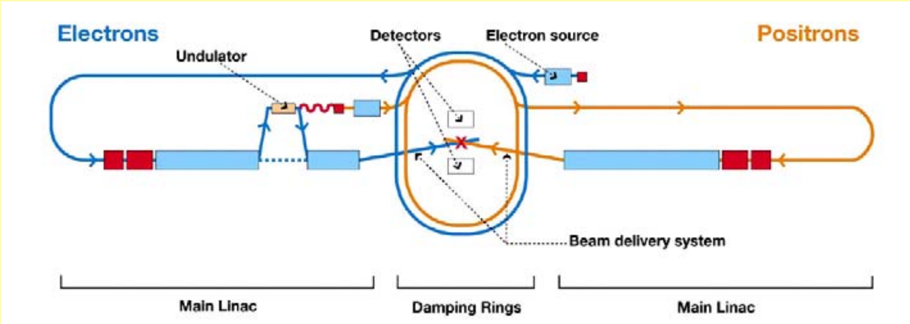
Accelerator



Detectors

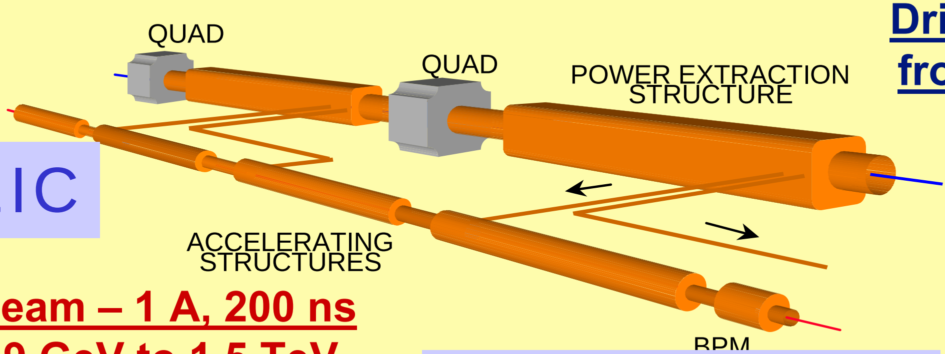
Alternative TeV Scale Lepton Colliders

ILC



ILC < 1 TeV
Technically possible
~ 2020 +

CLIC

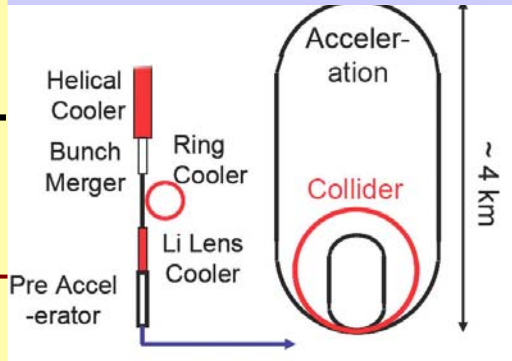


Drive beam - 95 A, 300 ns
from 2.4 GeV to 240 MeV

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

CLIC < 3 TeV
Feasibility?
Longer timescale

Muon Collider



Much R&D Needed
- **Neutrino Factory R&D +**
- **bunch merging**
- **much more cooling**
- **etc**

Muon Collider
< 4 TeV
FEASIBILITY??
Much longer timescale

Final Remarks

- **High Energy Physics has led and continues to lead the way to international collaboration in fundamental science**
- **International collaboration is at all levels: theoretical work; communicating results; open access to research.**
- **Large experimental collaborations (e.g. LHC) are our most advanced form of collaboration, including governance, financing, responsibility, etc.**
- **In the future, we can anticipate mechanisms for preservation and open access to data**
- **New large scale global collaboration is developing for the next generation of accelerators from concept to science (e.g. International Linear Collider)**