# CERN and the Future of Particle Physics

Introduction

European Roadmap

- process
- results
- implementation

Outlook

→ a personal selection

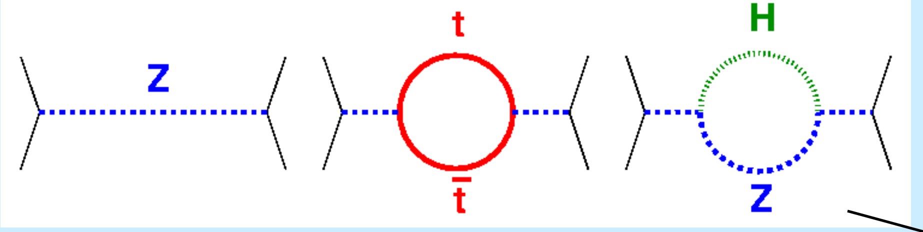
# Features of Particle Physics

Interplay and Synergy

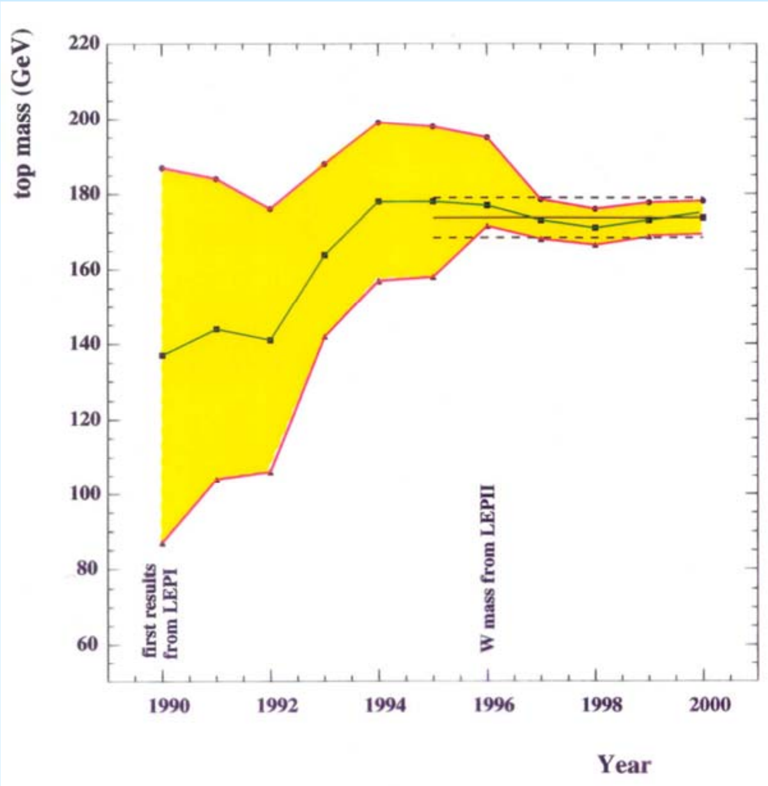
of different tools
(accelerators – cosmic rays – reactors . . .)

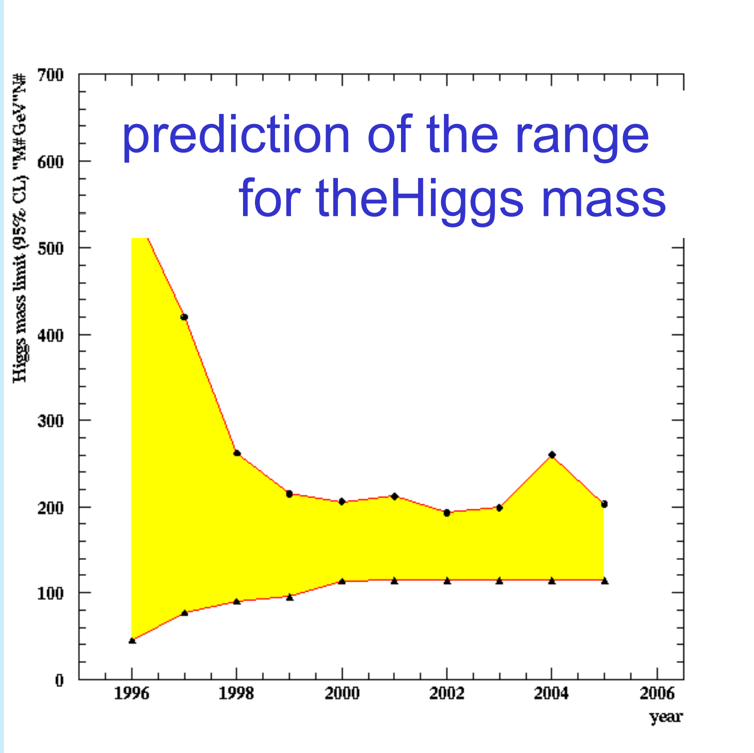
of different facilities
different initial states
lepton collider (electron-positron)
hadron collider (proton-proton)
lepton-hadron collider
at the energy frontier: high collision energy
and intensity frontier: high reaction rate

# Test of the SM at the Level of Quantum Fluctuations




indirect determination of the top mass



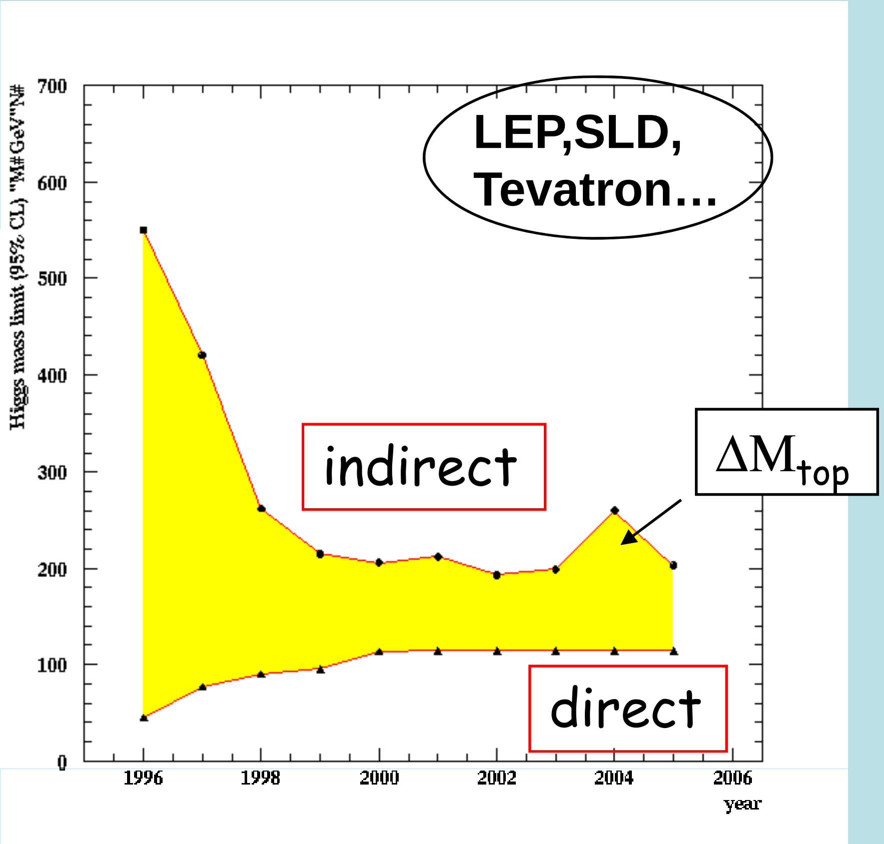

possible due to

- precision measurements
- known higher order electroweak corrections

$$\propto \left(\frac{\boxed{M_t}}{M_W}\right)^2, \ln\left(\frac{\boxed{M_h}}{M_W}\right)$$

Time evolution of experimental limits on the Higgs boson mass

## Synergy of colliders




knowledge obtained only through combination of results from different accelerator types

in particular:
**Lepton and Hadron Collider**

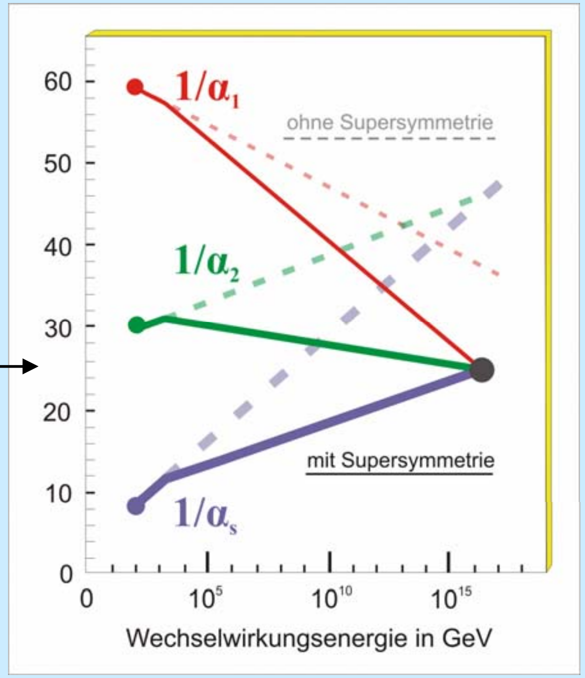
together with highly developed **theoretical calculations**

*$M_H$ between 114 and ~200 GeV*

# Key Questions of Particle Physics

origin of mass/matter or
origin of electroweak symmetry breaking

unification of forces



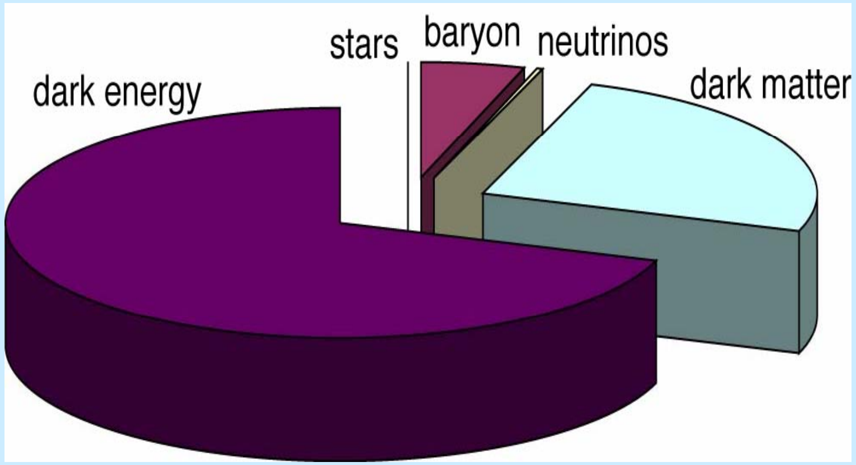

fundamental symmetry of forces and matter

unification of quantum physics and general relativity

number of space/time dimensions

what is dark matter

what is dark energy



# Features of Particle Physics

Duration of large particle physics projects:

decade(s)
from science case
via concept, R&D, and design
to realisation and exploitation

Excellent training grounds
in particle physics,
accelerator and detector technologies,
computing

# Duration of Projects



LEP Note 440

11.4.1983

PRELIMINARY PERFORMANCE ESTIMATES FOR A LEP PROTON COLLIDER

S. Myers and W. Schnell

1983

First LHC physics workshop 1984

LEP experiments: LoI 1982

1. Introduction

This analysis ... the United States where very large $p\bar{p}$ ... ively being studied at the moment. Inde... ic performance limitations of possible $p\bar{p}$ or ... nel seems overdue, however far off in the future a ... such a p-LEP project may yet be in time. What we shall ..., in fact, rather obvious, but such a discussion has, to the best ... our knowledge, not been presented so far.

We shall not address any detailed design questions but shall give basic equations and make a few plausible assumptions for the purpose of illustration. Thus, we shall assume throughout that the maximum energy per beam is 8 TeV (corresponding to a little over 9 T bending field in very advanced superconducting magnets) and that injection is at 0.4 TeV. The ring circumference is, of course that of LEP, namely 26,659 m. It should be clear from this requirement of "Ten Tesla Magnets" alone that such a project is not for the near future and that it should not be attempted before the technology is ready.

driving technology

long term stability and strategy

# The European Strategy for particle physics

## *General issues*

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

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

## The European Strategy for particle physics

### The process:

CERN Council Strategy Group established

Open Symposium (Orsay, Jan 31/Feb 1, 2006)

Final Workshop (Zeuthen, May 2006)

Strategy Document approved unanimously
by Council July 14, 2006

# The European Strategy for particle physics

Unanimously approved by CERN Council July 14, 2006

LHC

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

$L \sim 10^{34}$

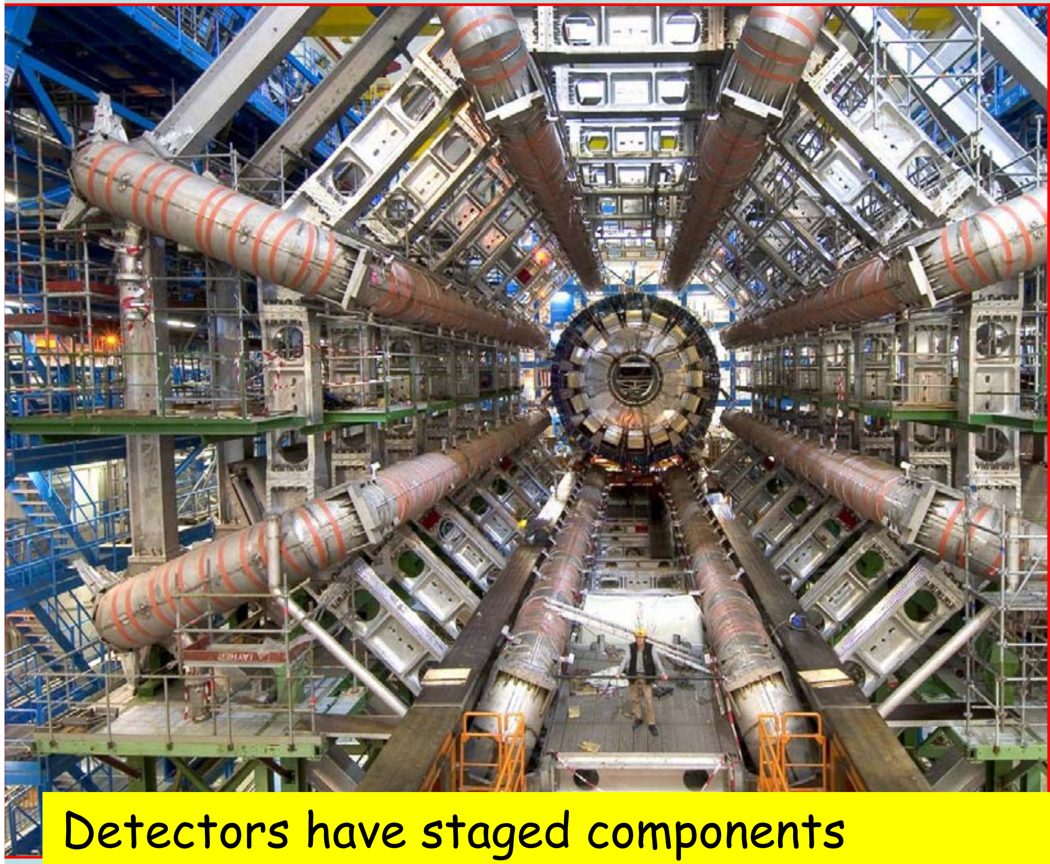

First beam around the ring September 10, 2008

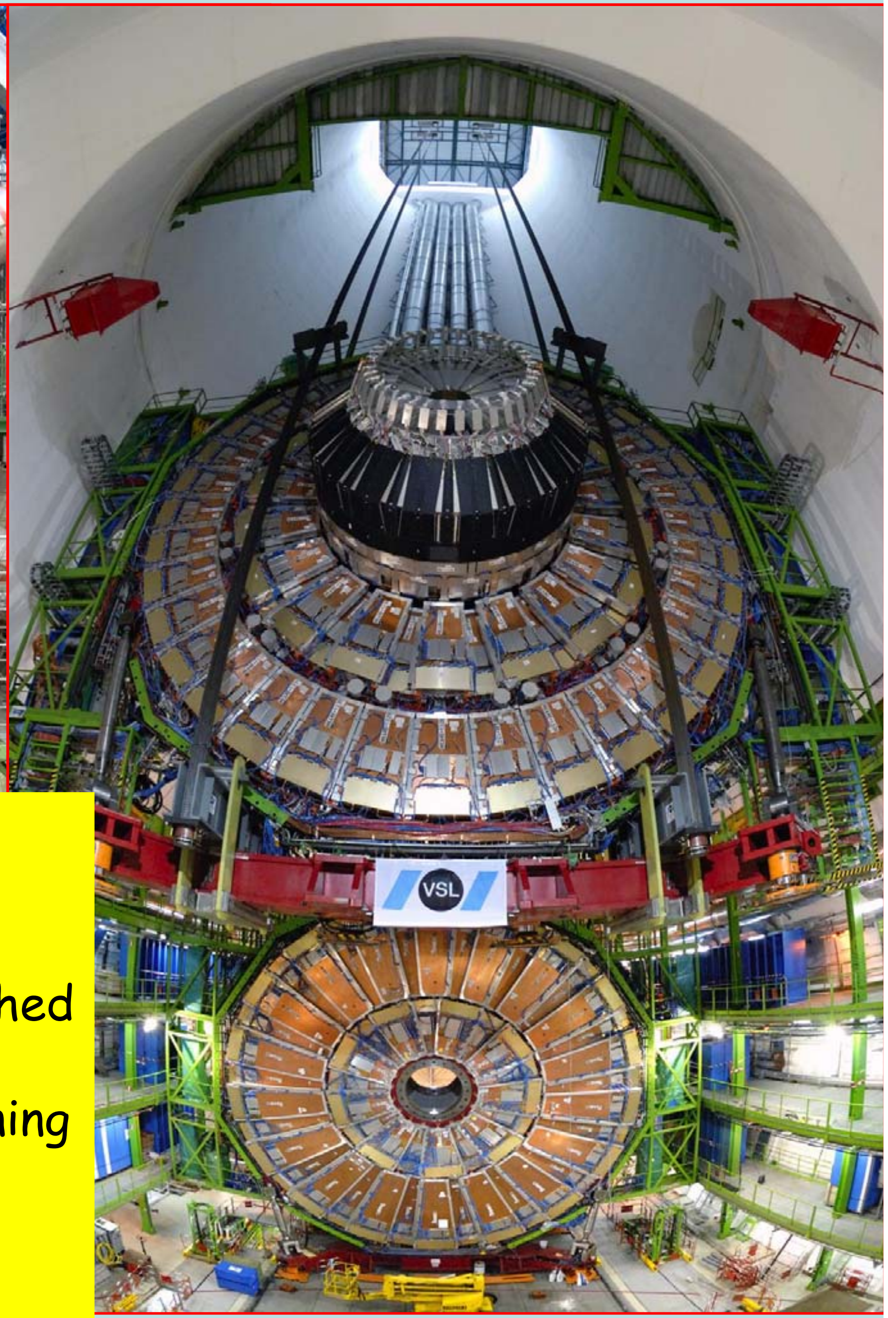
Incident Sector 3-4 on September 19, 2008

Inauguration October 21, 2008

First physics run summer 2009

Nominal luminosity $10^{34}$ needs continued effort
(LHC and injector chain)






Detectors have staged components

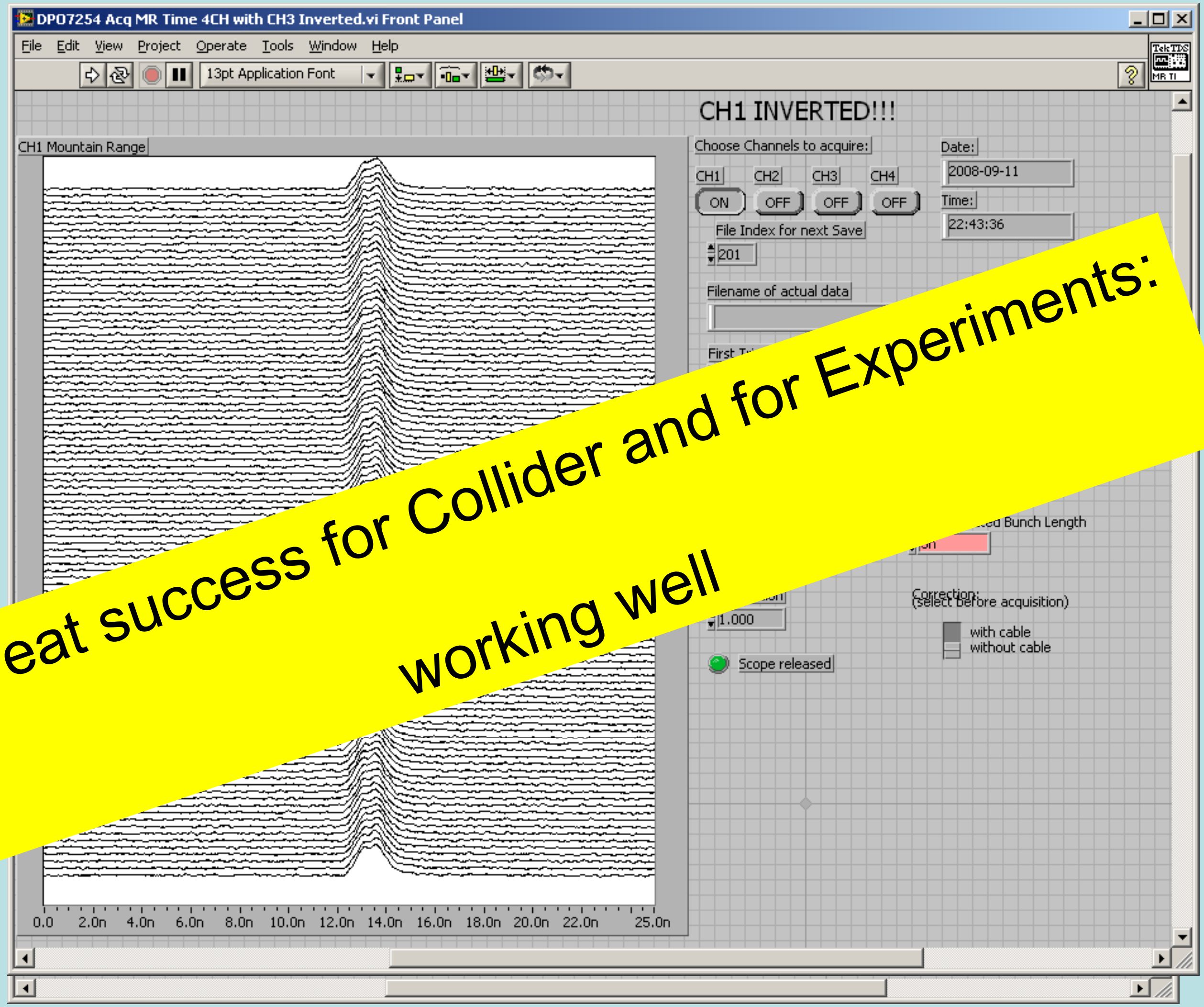
→ The initial phase (approved program) of LHC experiments is not yet fully established

Experiments need manpower for commissioning

→ The initial phase of LHC still needs sustained international collaboration

# Capture with optimum injection phasing, correct reference

September 10, 2008



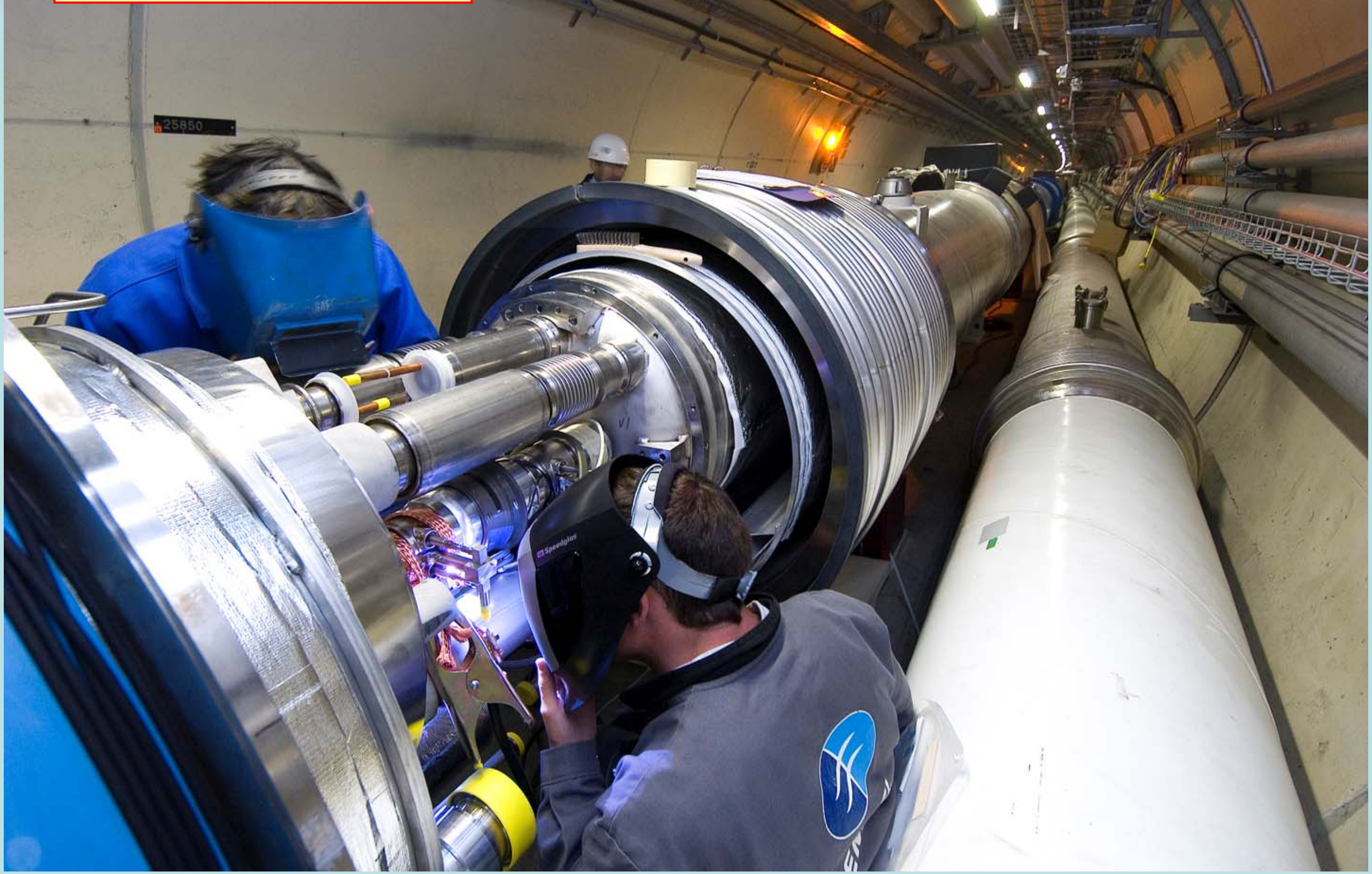

Great success for Collider and for Experiments:

working well

Courtesy E. Ciapala

# Interconnects

September 19, 2008



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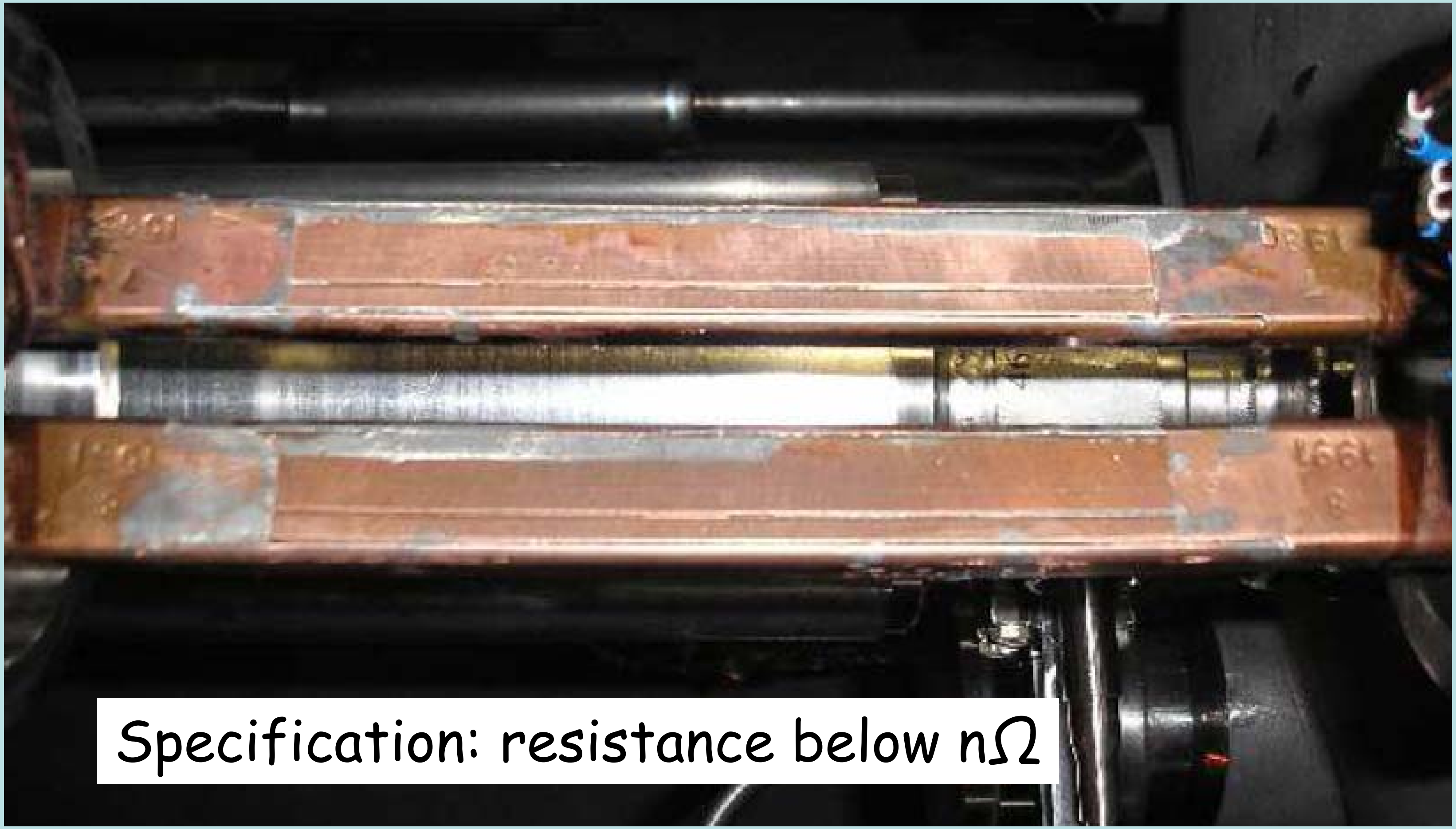

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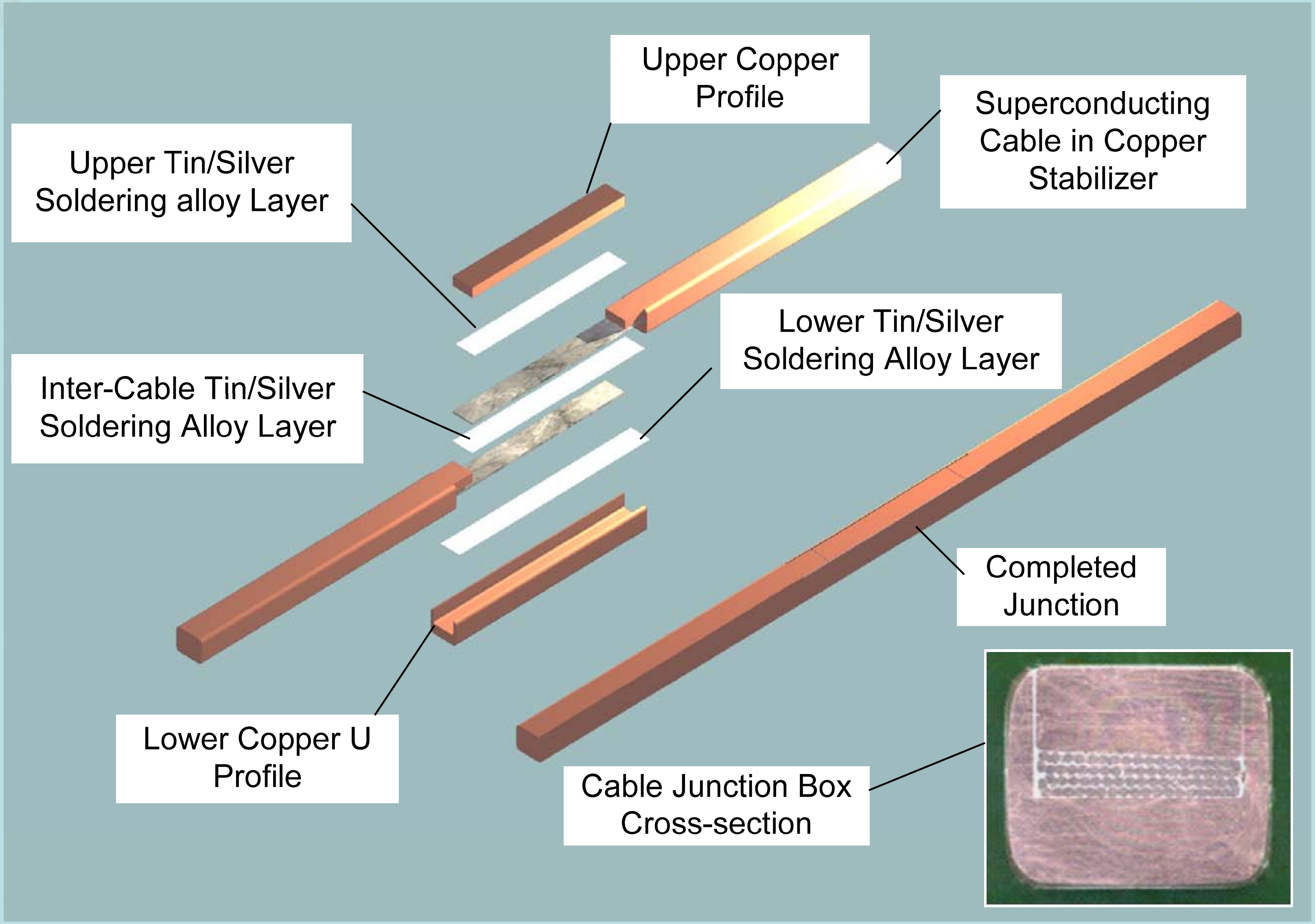


# Commissioning: A Real Challenge

The commissioning of LHC machine and detectors
of unprecedented complexity, technology and performance
will be one of the biggest challenges in the next year!
Only with fully commissioned experiments we will be able
to open the door to the new physics world!

1. Is there a Higgs?
2. What is the Higgs mass?
3. Is the Higgs a SM-like weak ...
4. Is the Higgs element...
5. Is the stability ... by a symmetry or dynami...
6. I... ...ective at the weak scale?
7. ...er DM at the LHC?
8. ...re extra dimensions? Are there new strong ...rces?
9. Are there totally unexpected phenomena?
10. What is the mechanism of EW breaking?

Initial phase of LHC will tell
which way nature wants us to go

Standard

Nearly Standard

Not at all Standard

# Initial phase of LHC will tell which way nature wants us to go

Possible ways beyond initial LHC:

Luminosity upgrade (sLHC)

„Tomorrow“

Doubling the energy (DLHC)

new machine, R&D on high field magnets ongoing

Electron-Positron Collider

ILC

CLIC

„Beyond“

*Electron-Proton Collider*

*LHeC*

# The European Strategy for particle physics

one possible way : luminosity upgrade

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

sLHC

L~$10^{35}$

CERN 2008 – 2011: 240 MSFr additional funding

will partly be used to gradually increase performance of LHC, i.e. towards luminosity upgrade ($L \sim 10^{35}$) sLHC :

- New inner triplet -> towards $L \sim 2*10^{34}$
- New Linac (Linac4) -> towards $L \sim 4*10^{34}$

  ***construction*** can/will start now → earliest implementation~ 2012

- New PS (PS2 with double circumference)
- Superconducting Proton Linac (SPL)

  start ***design*** now, ready for decision ~ 2011

  aimed for $L \sim 10^{35}$ around (earliest) 2016/17 if physics requires

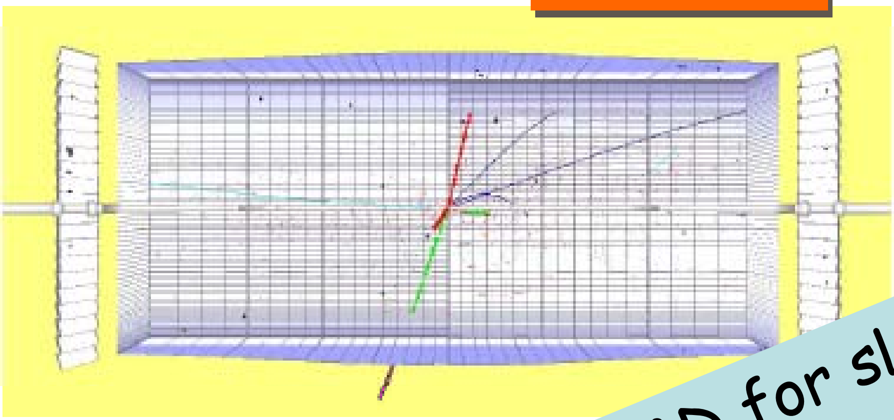
- Detector R&D (seed money)

Important: international collaboration

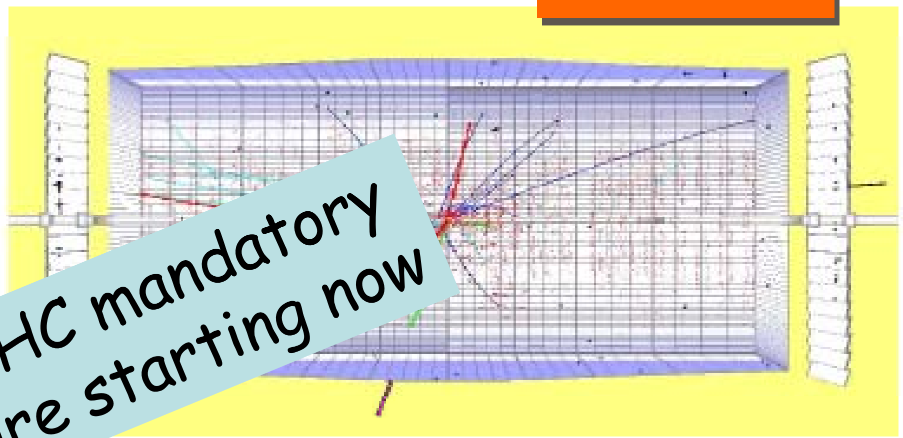
sLHC

# The challenge: visually

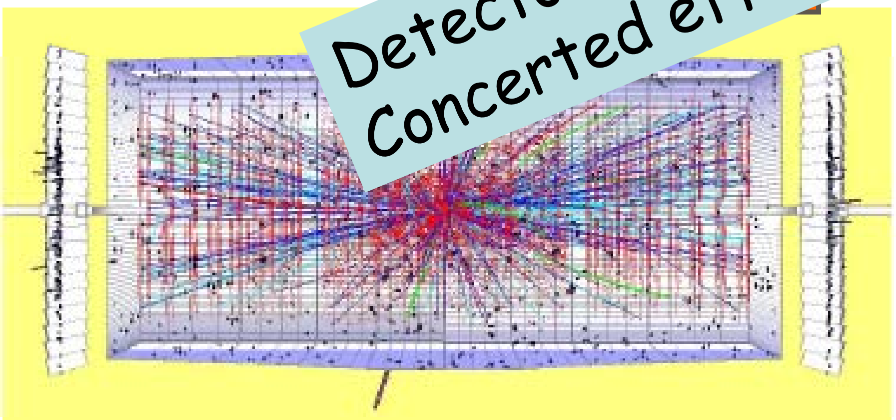
$10^{32}\ cm^{-2}\ s^{-1}$



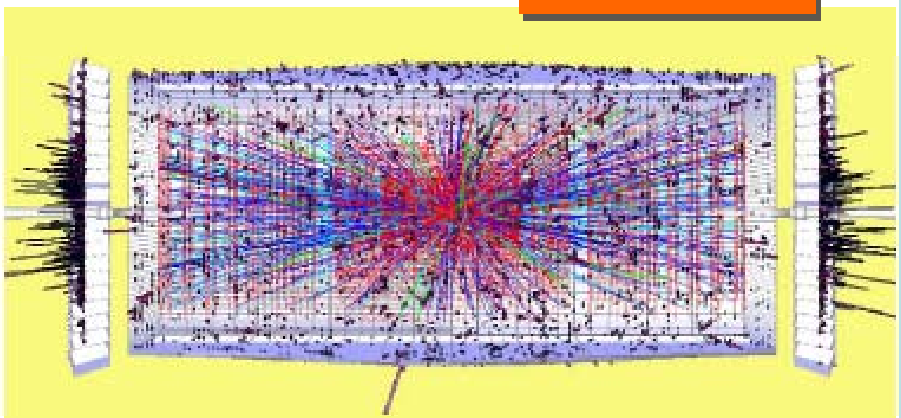
$10^{33}\ cm^{-2}\ s^{-1}$



Detector R&D for sLHC mandatory
Concerted efforts are starting now



$10^{35}\ cm^{-2}\ s^{-1}$



# Initial phase of LHC will tell which way nature wants us to go

Possible ways beyond initial LHC:

Luminosity upgrade (sLHC) „Tomorrow"

Doubling the energy (DLHC)
new machine, R&D on high field magnets ongoing

Electron-Positron Collider
ILC
CLIC

„Beyond"

*Electron-Proton Collider*
*LHeC*

# The European Strategy for particle physics

4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

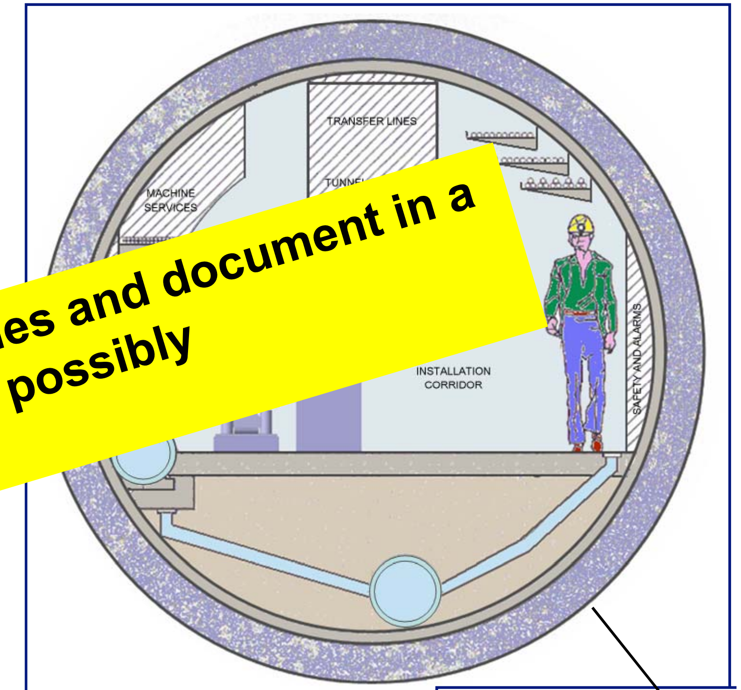
5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European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

# *High Energy Colliders: CLIC (E$_{cm}$ up to ~ 3TeV)*

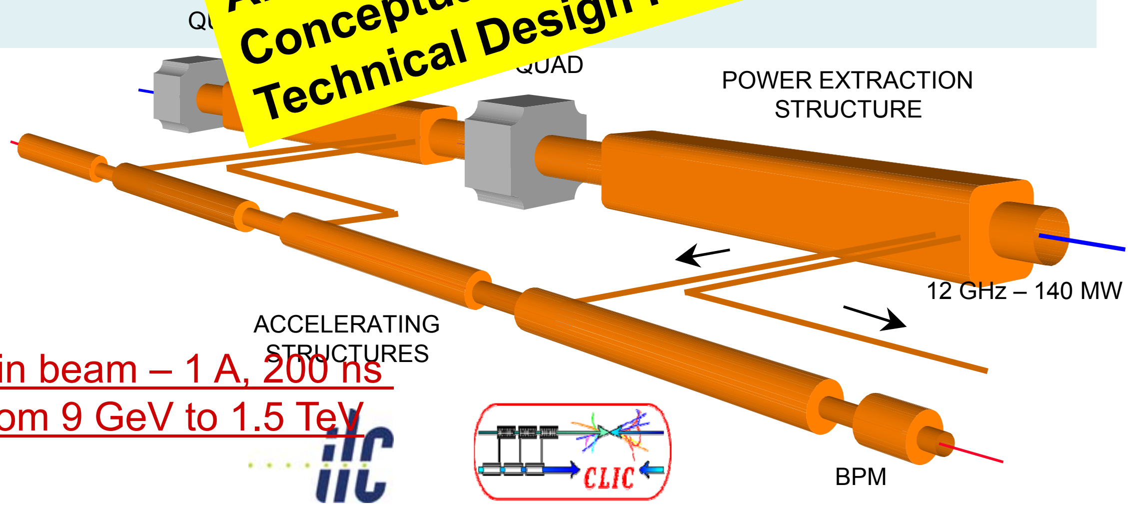
- **High acceleration gradient: ~ 100 MV/m**
  - **"Compact" collider – total length < 50 km at 3 TeV**
  - **Normal conducting acceleration structures at high frequency**
- **Novel Two-Beam Acceleration Scheme**
  - **Cost effective, reliable, efficient**
  - **Simple tunnel, no active ...**
  - **Modular, easy ... stages**

**Aim: Demonstrate all key feasibility issues and document in a Conceptual Design Report by 2010 and possibly Technical Design Report by 2015 + ?**

CLIC TUNNEL CROSS-SECTION




4.5 m diameter




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

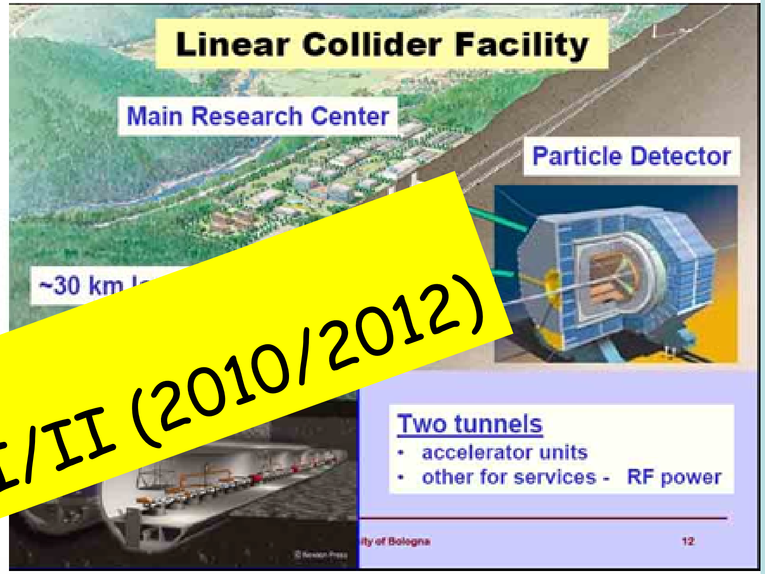
Main beam – 1 A, 200 ns from 9 GeV to 1.5 TeV

# High Energy Colliders: ILC ($E_{cm}$ up to ~ 1TeV)

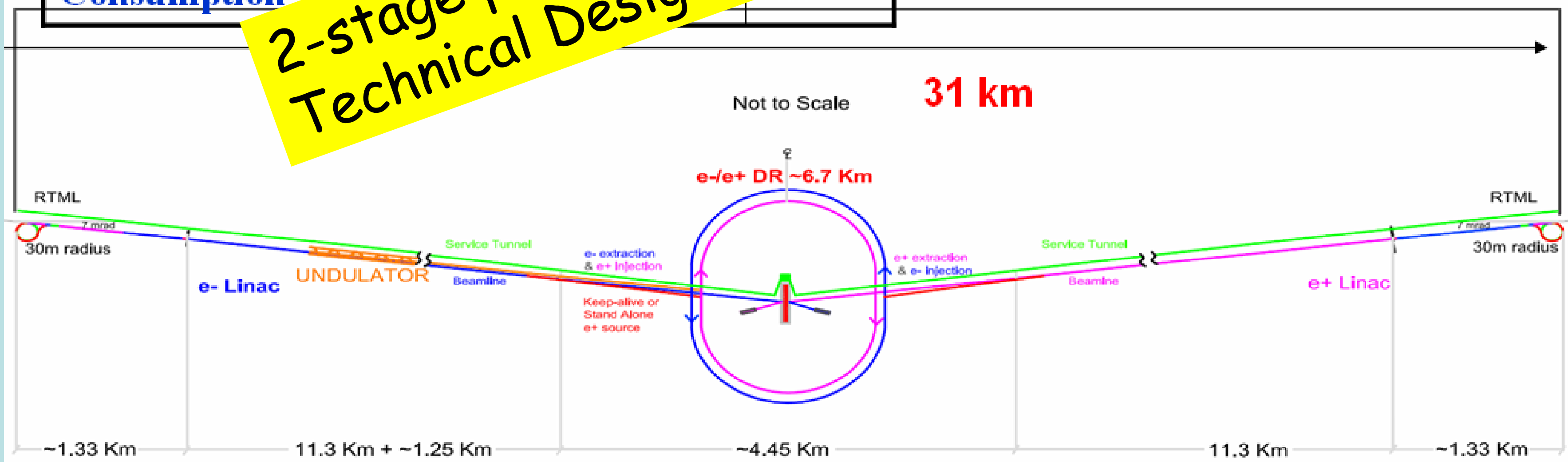
## *ILC @ 500 GeV*

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

| | | |
|---|---|---|
| Max. Center-of-mass energy | 500 | GeV |
| Peak Luminosity | $\sim 2 \times 10^{34}$ | $cm^{-2}s^{-1}$ |
| Beam Current | 9.0 | mA |
| Repetition rate | 5 | Hz |
| Average accelerating gradient | 31.5 | MV/m |
| Beam pulse length | 0.95 | [illegible] |
| Total Site Length | [illegible] | |
| Total AC Power Consumption | | [illegible] |



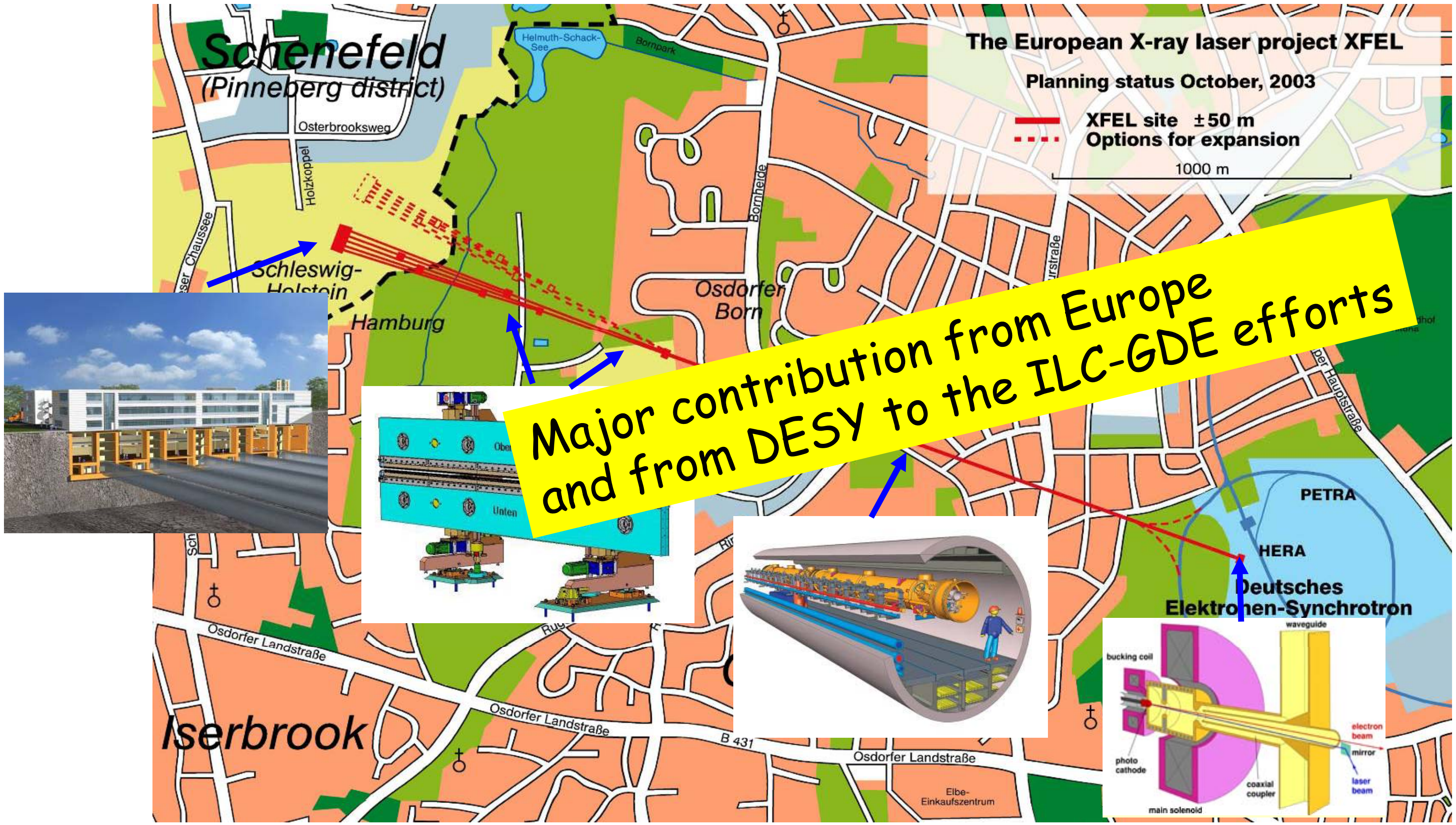

2-stage process
Technical Design Phase I/II (2010/2012)



# *X-FEL at DESY*

# *a 10% ILC and 800 MEuros Test Facility!*

**3.4km**

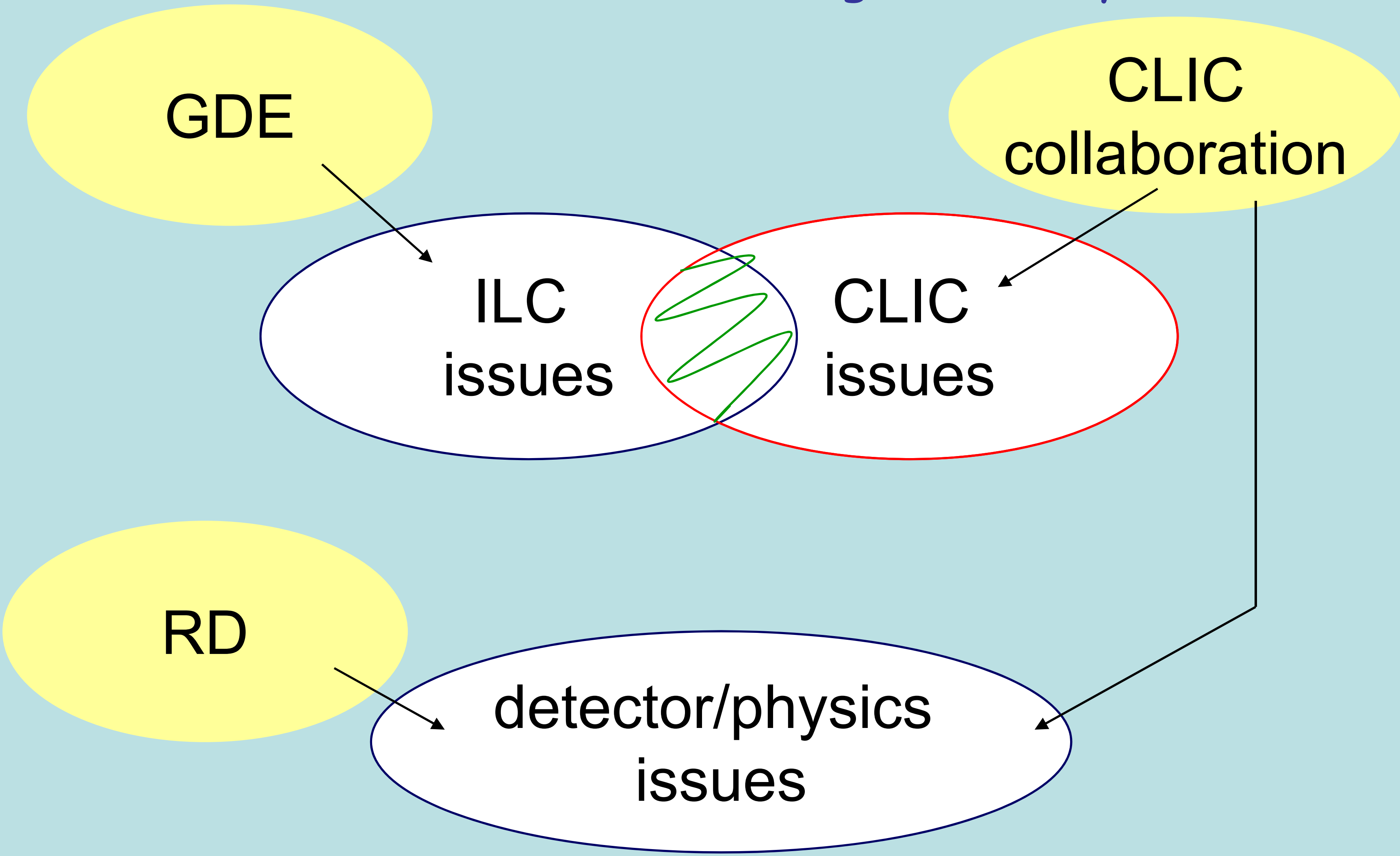



Major contribution from Europe
and from DESY to the ILC-GDE efforts

Technically ready, start construction soon for operation from 2013

# Strategy to address LC key issues

Recent progress: much closer collaboration
first meeting: February 08

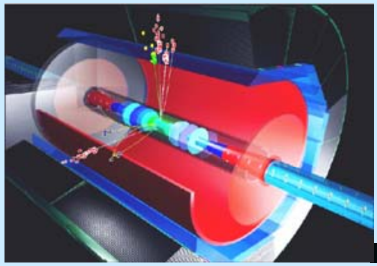


# Strategy to address LC key issues

- Key issues common to all Linear Collider studies independently of the chosen technology in close collaboration between ILC and CLIC

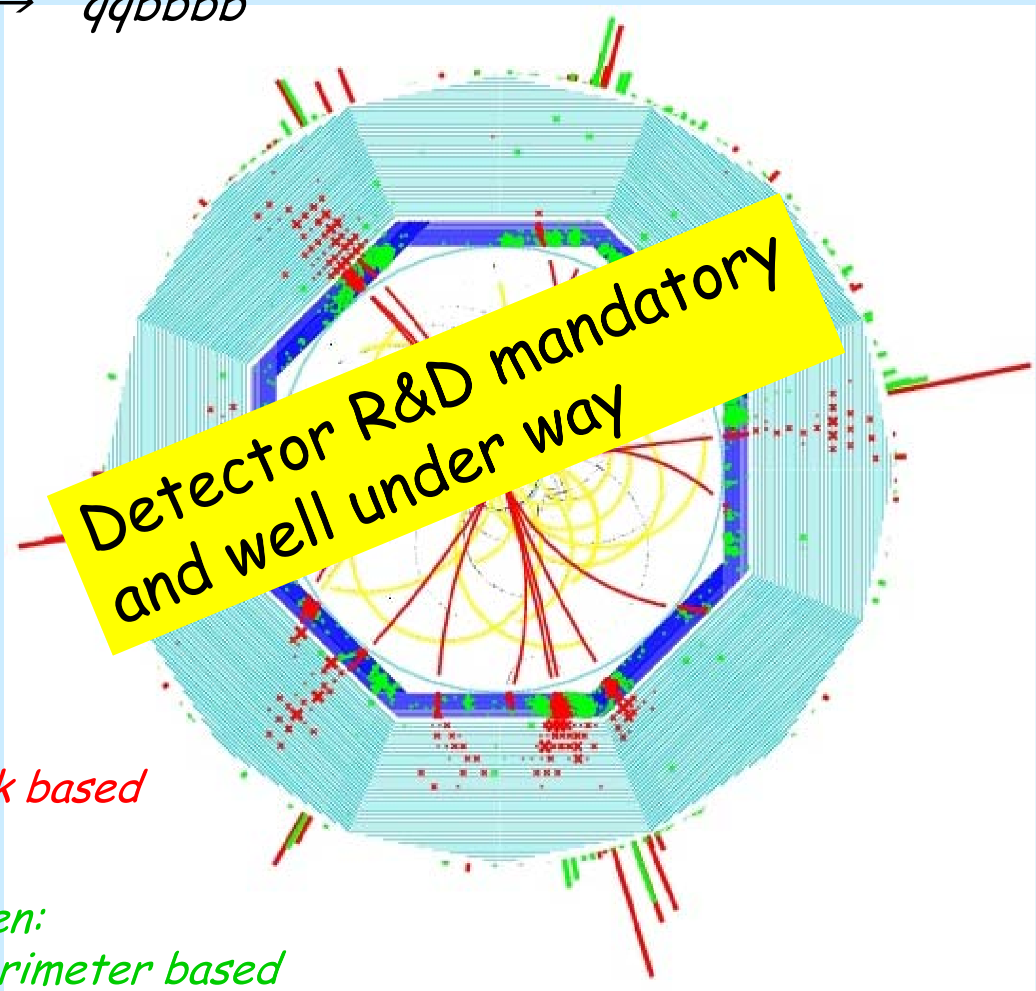
  – The Accelerator Test Facility (ATF@KEK)
  – European Laboratories in the frame of the Coordinated Accelerator Research in Europe (CARE) and of a “Design Study” (EUROTeV) funded by EU Framework Programme (FP6)

  – New proposal approved within the EU Framework Programme (FP7) comprising LC and LHC and more
  – HiGrade approved within FP7



# ILC Detector challenges: calorimeter

$ZHH \rightarrow qqbbbb$




red:
track based

green:
calorimeter based

High precision measurements demand new approach to the reconstruction:

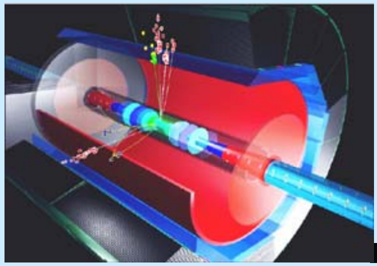
particle flow (i.e. reconstruction of ALL individual particles)

this requires

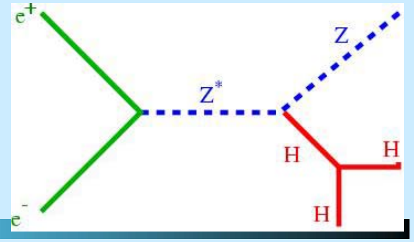
unprecedented granularity

in three dimensions

R&D needed now for key components

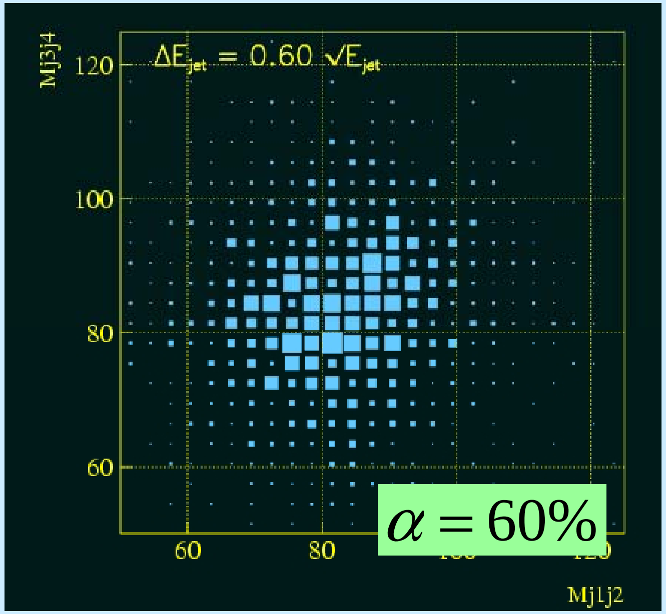


# Jet energy resolution

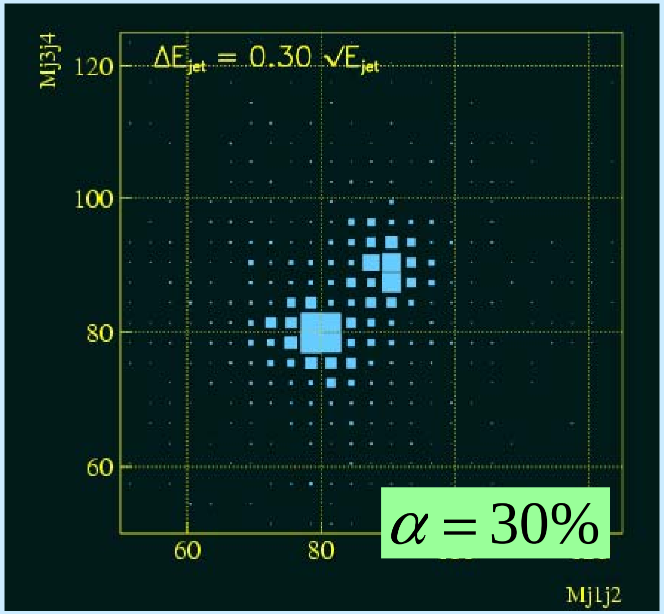



- Dijet masses in WWvv, ZZvv events (no kinematic fit possible):
- Challenge: separate W and Z in their hadronic decay mode

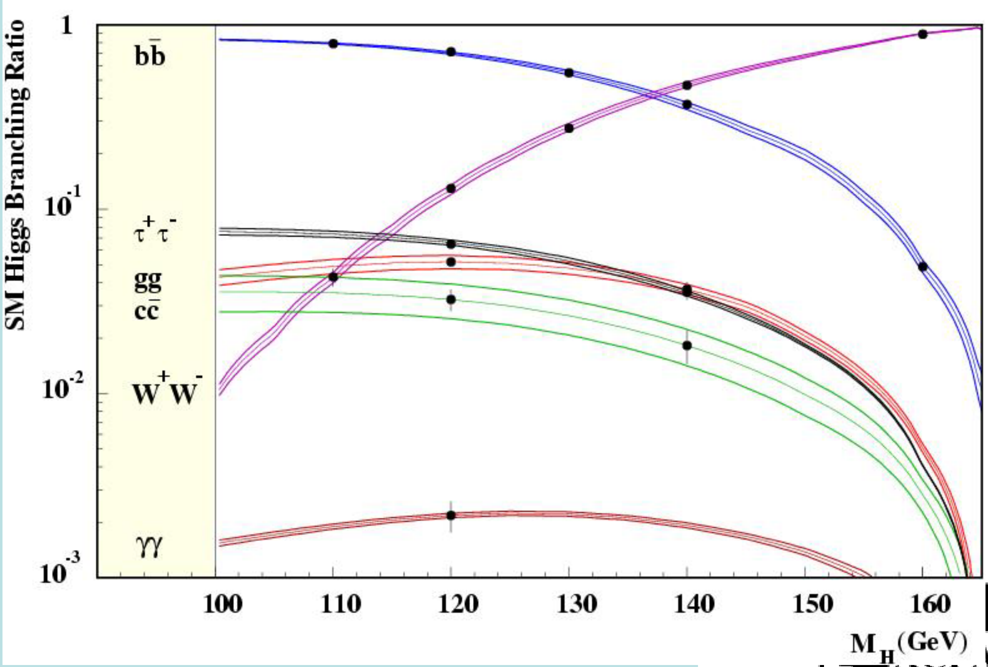
*LEP-like detector*

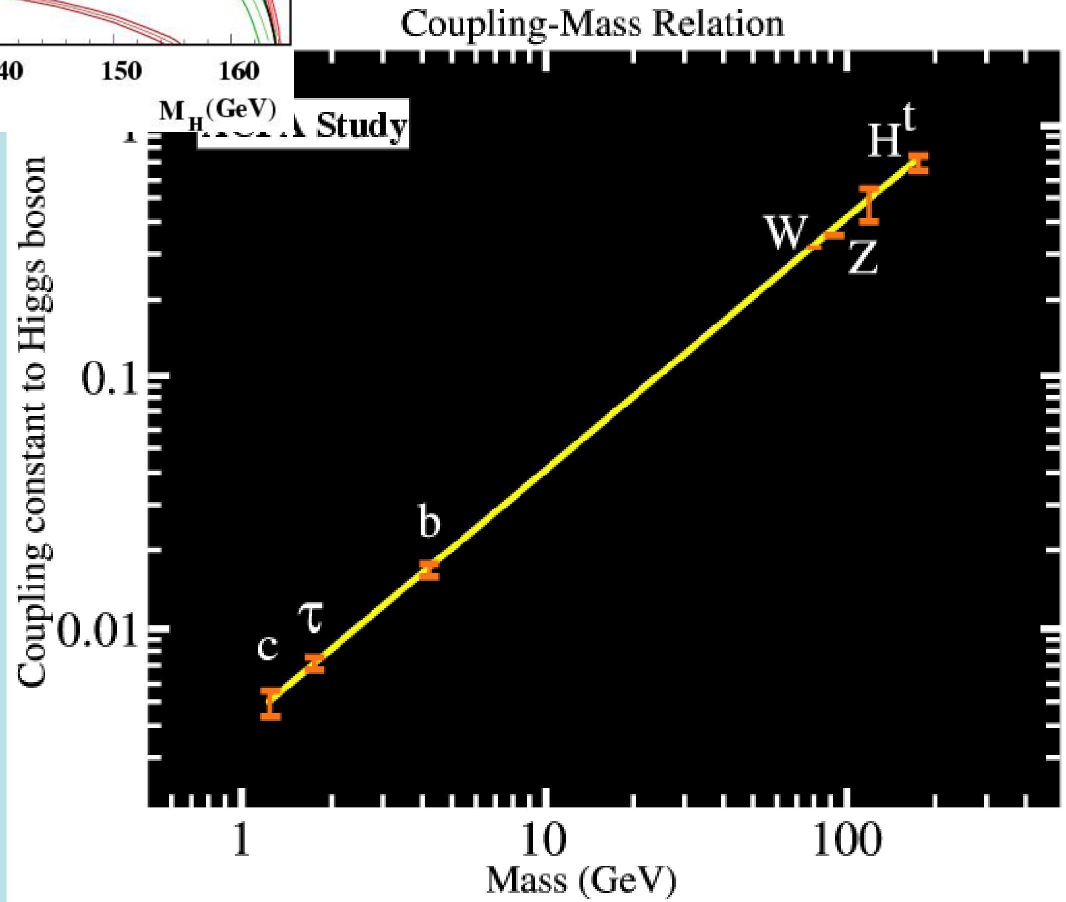



*LC design goal*



# Precision Higgs physics

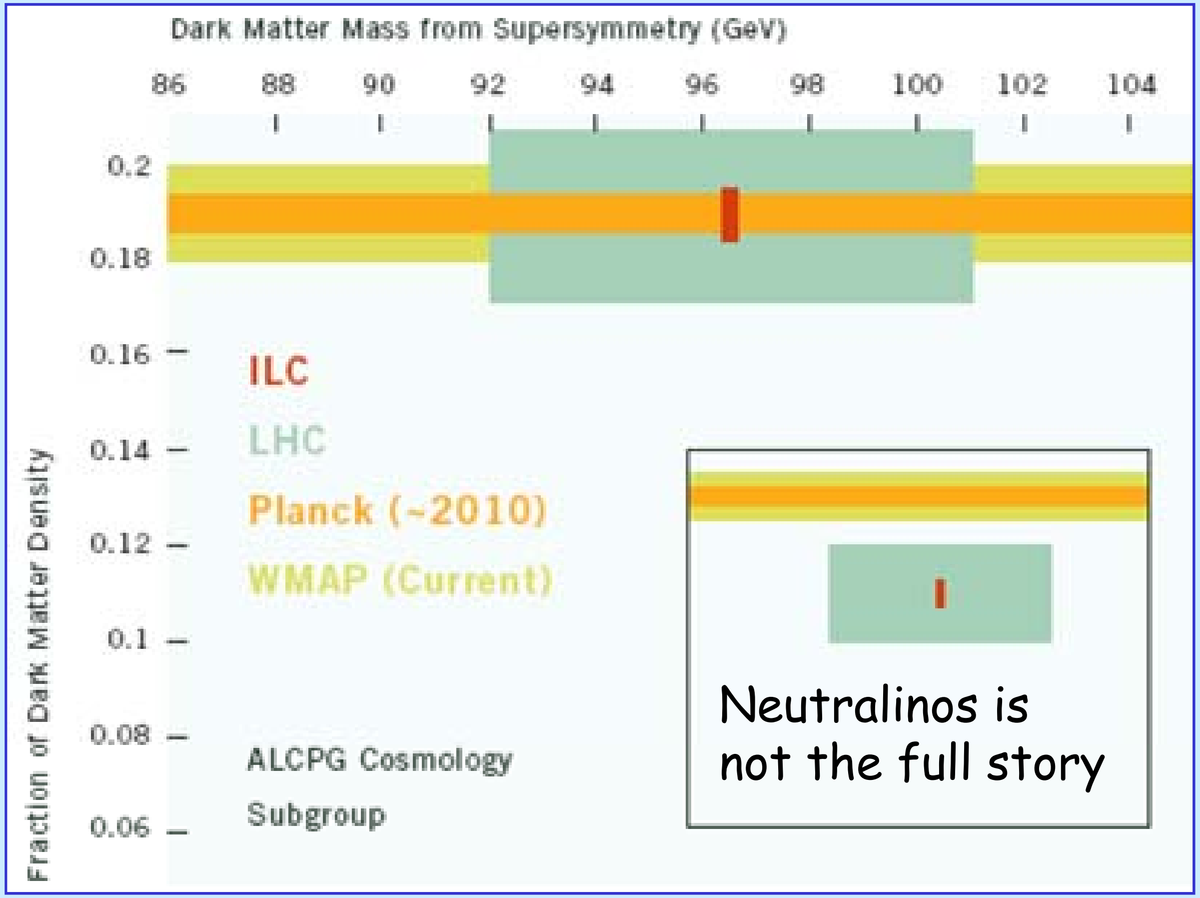



Determination of absolute coupling values with high precision

# Dark Matter and SUSY

- Is dark matter linked to the Lightest Supersymmetric Particle?




LC and satellite data (WMAP and Planck):

complementary views of dark matter.

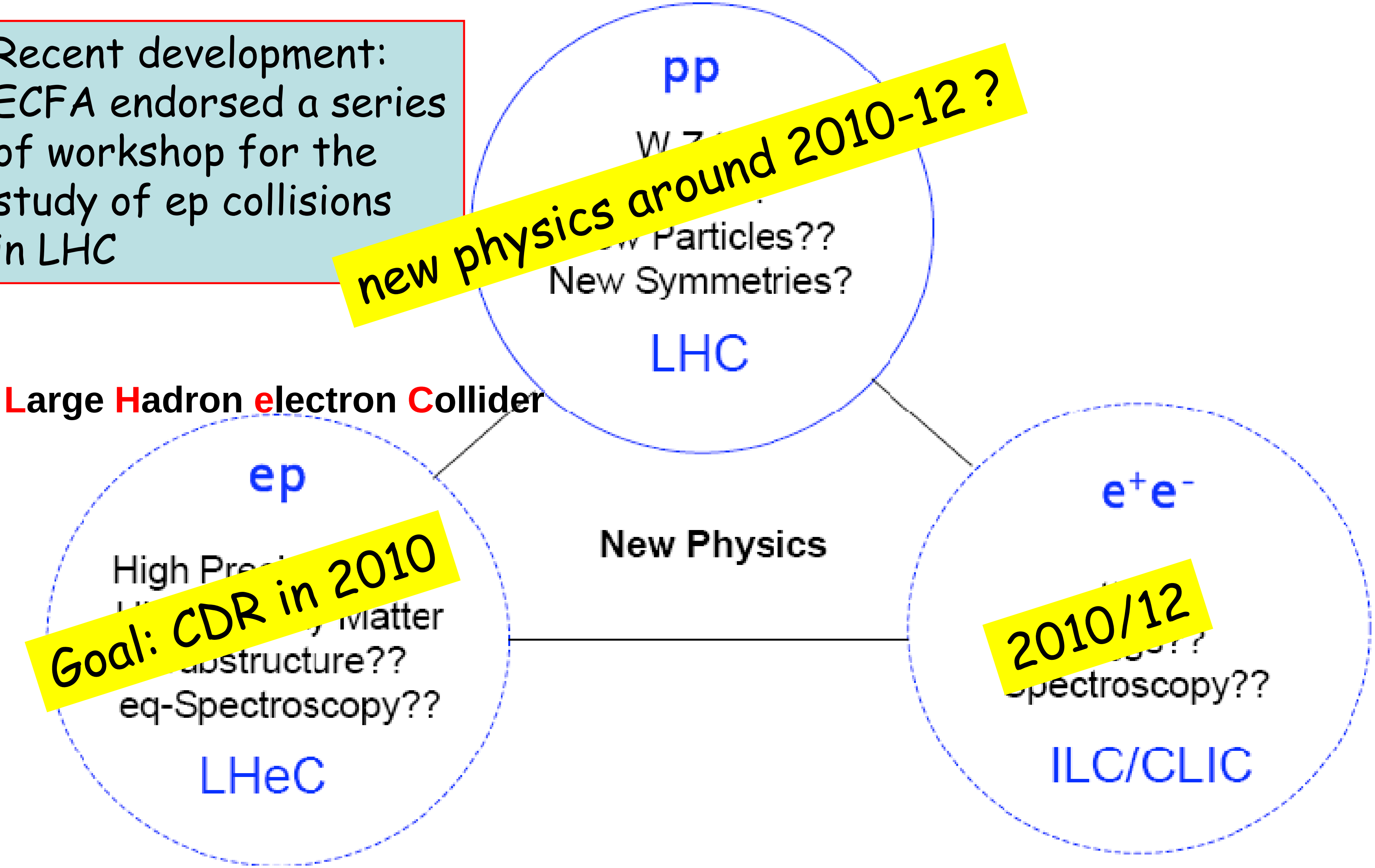
LC: identify DM particle, measures its mass;

WMAP/Planck: sensitive to total density of dark matter.

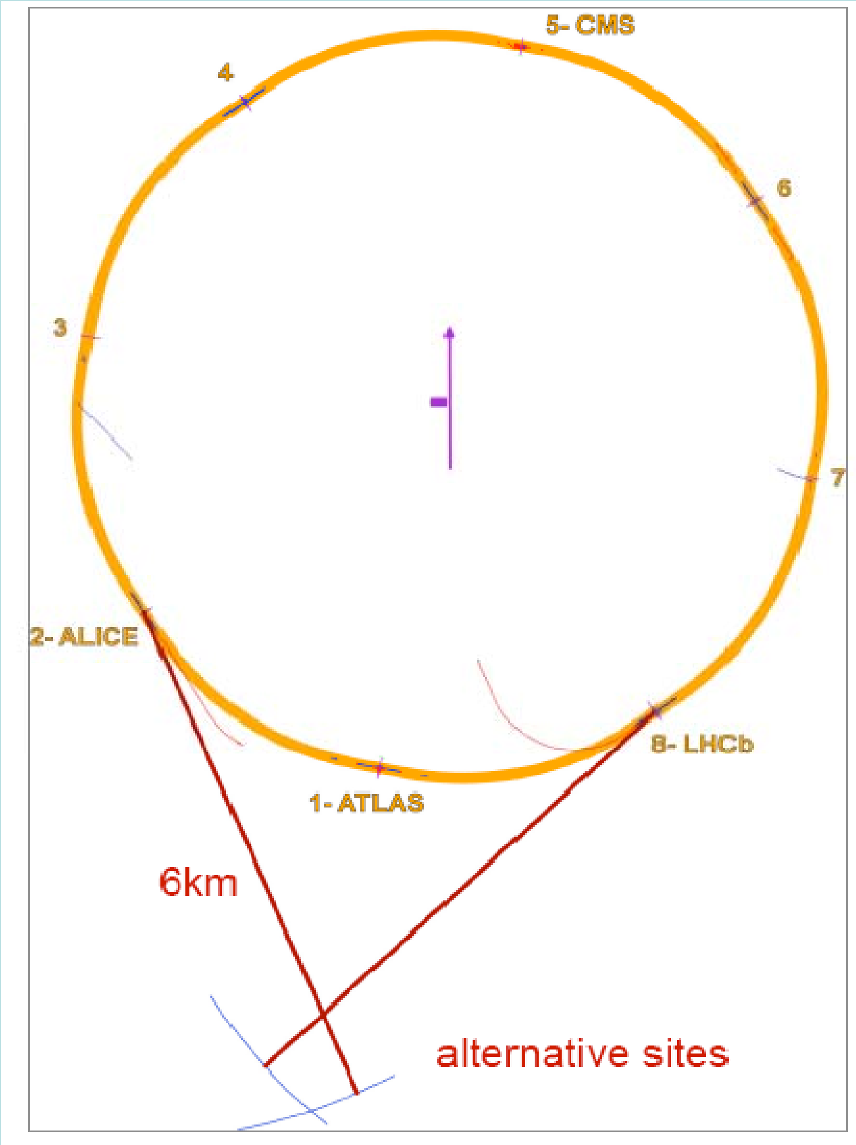
Together with LHC they establish the nature of dark matter.

# The TeV Scale [2008-2033..]

Recent development:
ECFA endorsed a series of workshop for the study of ep collisions in LHC



# Large Hadron electron Collider: possible layouts




40 - 140 GeV
on
1 - 7 TeV

ring-ring solution:
L ≤ $10^{33}$

linac-ring solution:
L few $10^{31}$

Would be the successor of HERA at higher cms

neutrino
sector

The European Strategy for particle physics

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

Neutrinos

# J-PARC and T2K

ex: $\Theta_{13}$


2012 first indications of $\Theta_{13}$ should be available from either T2K or Double-Chooz

Science & Technology Facilities Council
ASTeC

# Neutrino Factory

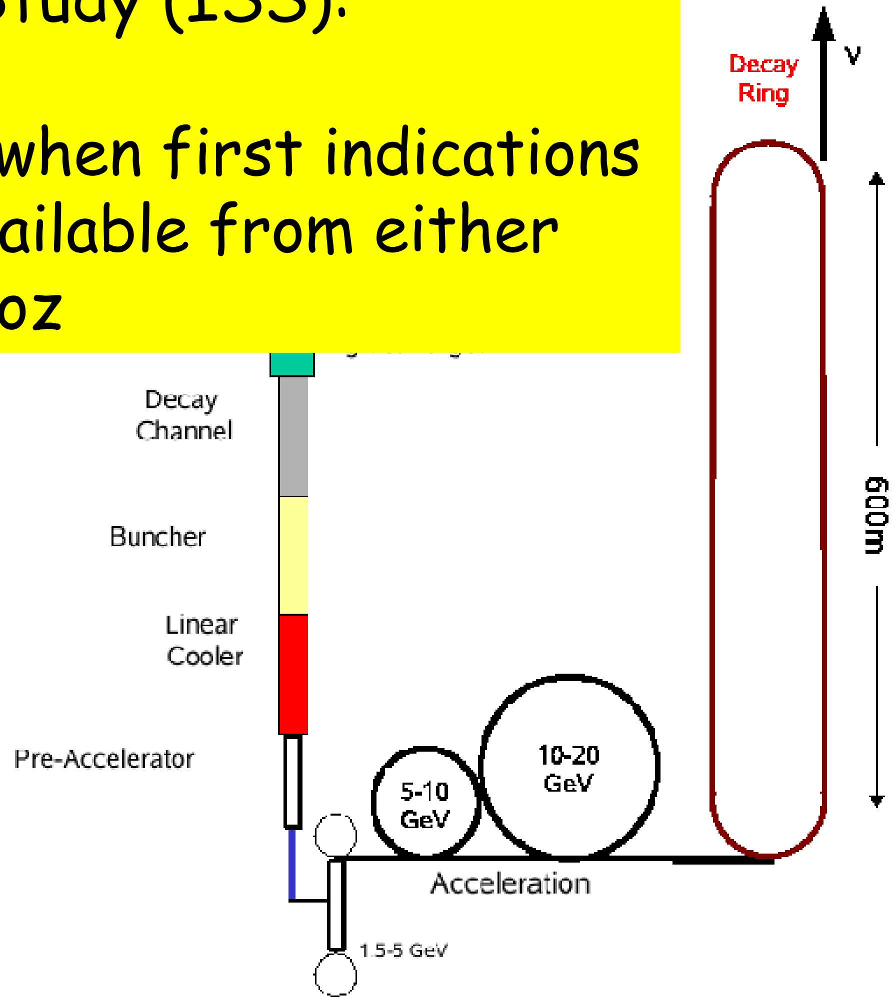
International Scoping Study (ISS):

aim: have RDR by 2012 when first indications of $\Theta_{13}$ should be available from either T2K or Double-Chooz

- Pro
  - 
- Ta
  - 
- Cooling
  - Reduce transverse emittance
- Muon acceleration
  - ~130 MeV to 20-50 GeV
- Decay ring(s)

  Store for ~500 turns

  Long production straights



IPMU

BERKELEY CENTER FOR THEORETICAL PHYSICS

# Bottom line: Synergy

- *Big questions = ambitious questions*
- *Need to clear the cloud of T...*
  *physics to obta...*
- *M... ...e*
  *to r...*
- *Har... , but conceivable*
- *No single experiment would achieve it, need a broad program*

Great opportunities ahead

Window of opportunity for decision on the way forward 2010-2012 (?)

## So…any changes needed for the future?

facilities for HEP (and other sciences) becoming larger and expensive

funding not increasing

fewer facilities realisable

time scales becoming longer

laboratories are changing missions

→ more coordination and more collaboration required

# Outlook: Enhancing World Collaboration

Key message

Future major facilities in Europe and elsewhere require collaborations on a global scale; *Council, drawing on the European experience in the successful construction and operation of large-scale facilities, will prepare a framework for Europe to engage with the other regions of the world with the goal of optimizing the particle physics output through the best shared use of resources while maintaining European capabilities.*

from CERN Council Strategy Document

We need

- to maintain expertise in all regions
- long term stability and support in all three regions
- to engage all countries with particle physics communities
- to integrate particle physics developing countries (regions)
- global view from funding agencies
- a closer linkage of (at least) particle physics and astroparticle physics

We need

- to maintain expertise in all regions

national – regional – global projects

- long term stability and support in all three regions

→ example: CERN Council

- to engage all countries with particle physics communities

→ CERN Council Working Group set up

and CERN Coordinator for External Relations established

- to integrate particle physics developing countries (regions)

CERN Council Working Group / ICFA

CERN Coordinator for External Relations

- global view from funding agencies

FALC (modified) as a first step ?

- a closer linkage of (at least) particle physics and astroparticle physics

Europe: CERN, CERN Council, ASPERA

ICFA ? . . . .

We are NOW entering a new exciting era of particle physics

Turn on of LHC
allows particle physics experiments
at the highest collision energies ever

Expect
- revolutionary advances in understanding the microcosm
- changes to our view of the early Universe

CERN
unique position as host for the LHC

Results from LHC will guide the way

Expect
- period for decision taking on next steps in 2010 to 2012
  (at least) concerning energy frontier
-(similar situation concerning neutrino sector $\Theta_{13}$)

We are NOW in a new exciting era of accelerator
planning-design-construction-running
and need
- intensified efforts on R&D and technical design work
  to enable these decisions
- global collaboration and stability on long time scales
  (reminder: first workshop on LHC was 1984)

We need to define the most appropriate organisational form
NOW and need to be open and inventive
(scientists, funding agencies, politicians. . .)

Mandatory to have accelerator laboratories in all regions
as partners in accelerator development / construction /
commissiong / exploitation

Planning and execution of HEP projects today need
global partnership for *global, regional and national* projects
in other words: for the whole program

Use the exciting times ahead to establish such a partnership

**Particle Physics can and should play its role as**

**spearhead in innovations as in the past**

**now and in future**