ECFA Study on

Physics and Detectors for a Linear Collider

A European Vision of the Futu
or
Par ysics in the next Decades

personal selection/view/vision

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

Warsaw, June 9, 2008

A European Vision of the Future
or
Particle Physics in the next Decades

Introduction

Roadmap

General Remarks

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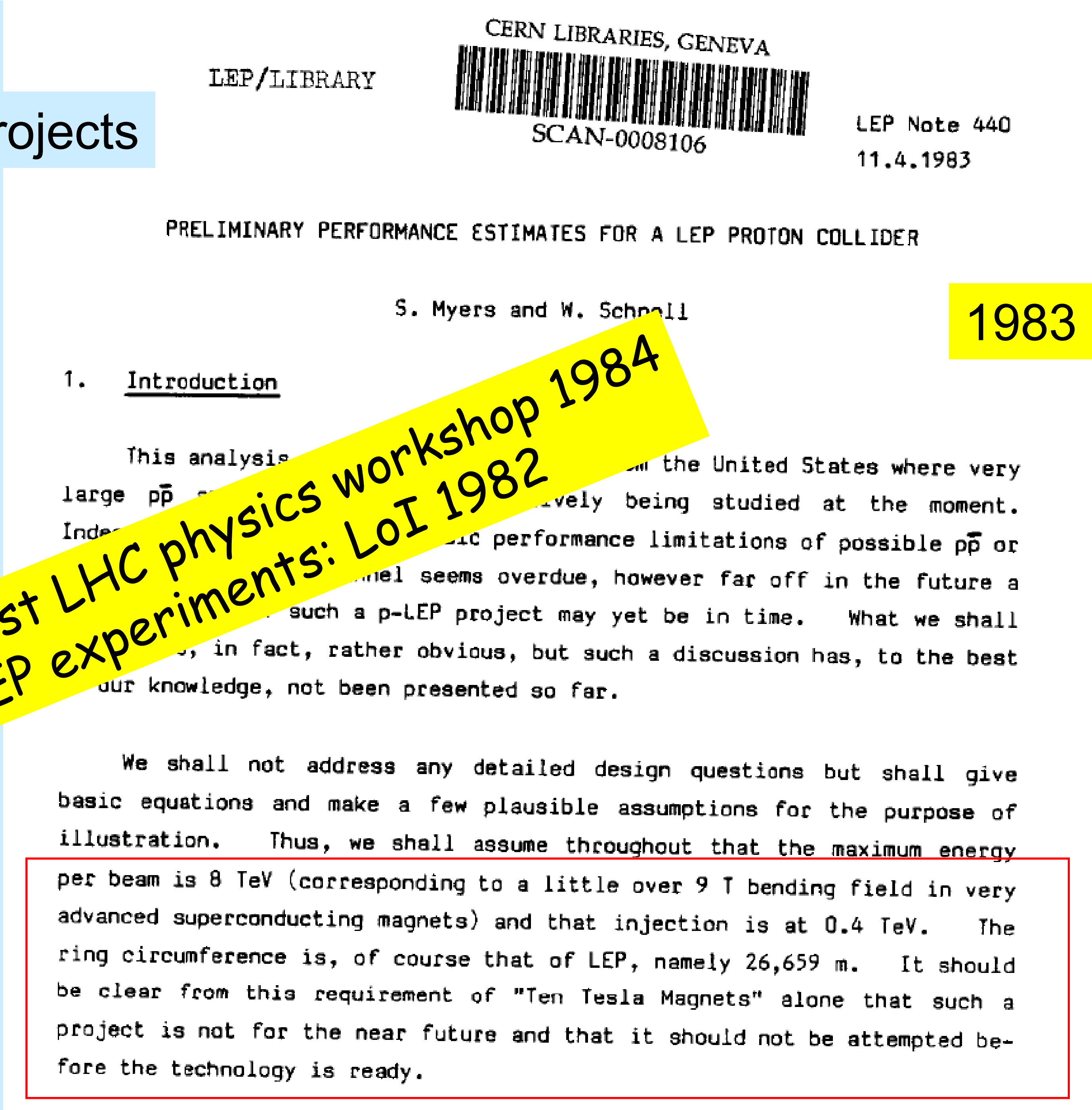
Duration of Projects



LEP/LIBRARY

LEP Note 440
11.4.1983

PRELIMINARY PERFORMANCE ESTIMATES FOR A LEP PROTON COLLIDER

S. Myers and W. Schnell

1. Introduction

This analysis … the United States where very
large pp̄ … ively being studied at the moment.
Inde… ic performance limitations of possible pp̄ 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.

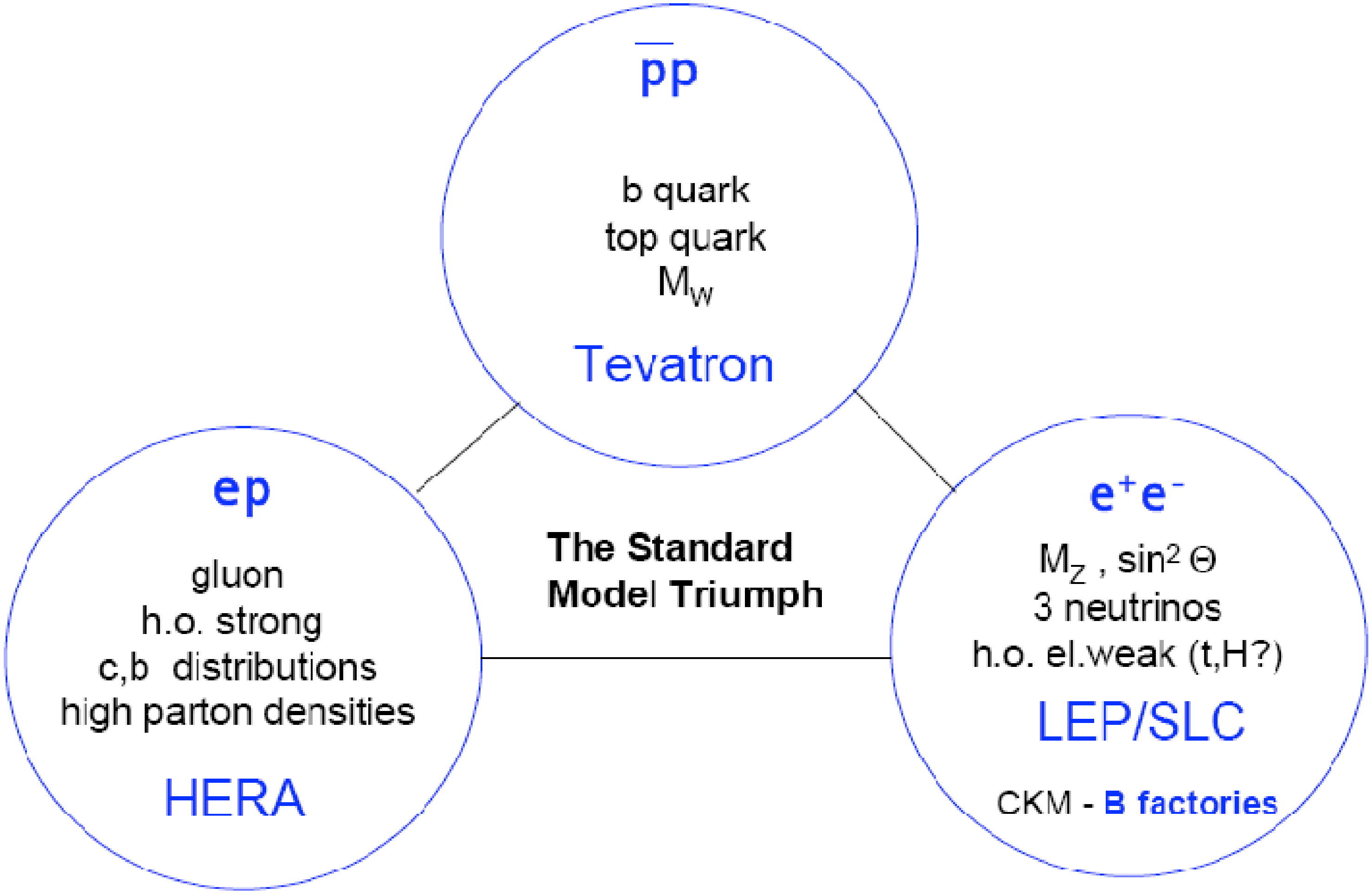
We shall not address any detailed design questions but shall give basic equations and make a few plausible assumptions for the purpose of illustration. Thus, we shall assume throughout that the maximum energy per beam is 8 TeV (corresponding to a little over 9 T bending field in very advanced superconducting 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.

1983

First LHC physics workshop 1984
LEP experiments: LoI 1982

Synergy of Colliders

The Fermi Scale [1985-2010]



$\bar{p}p$

b quark
top quark
M_W

Tevatron

ep

gluon
h.o. strong
c,b distributions
high parton densities

HERA

The Standard Model Triumph

e^+e^-

M_Z , $\sin^2 \Theta$
3 neutrinos
h.o. el.weak (t,H?)

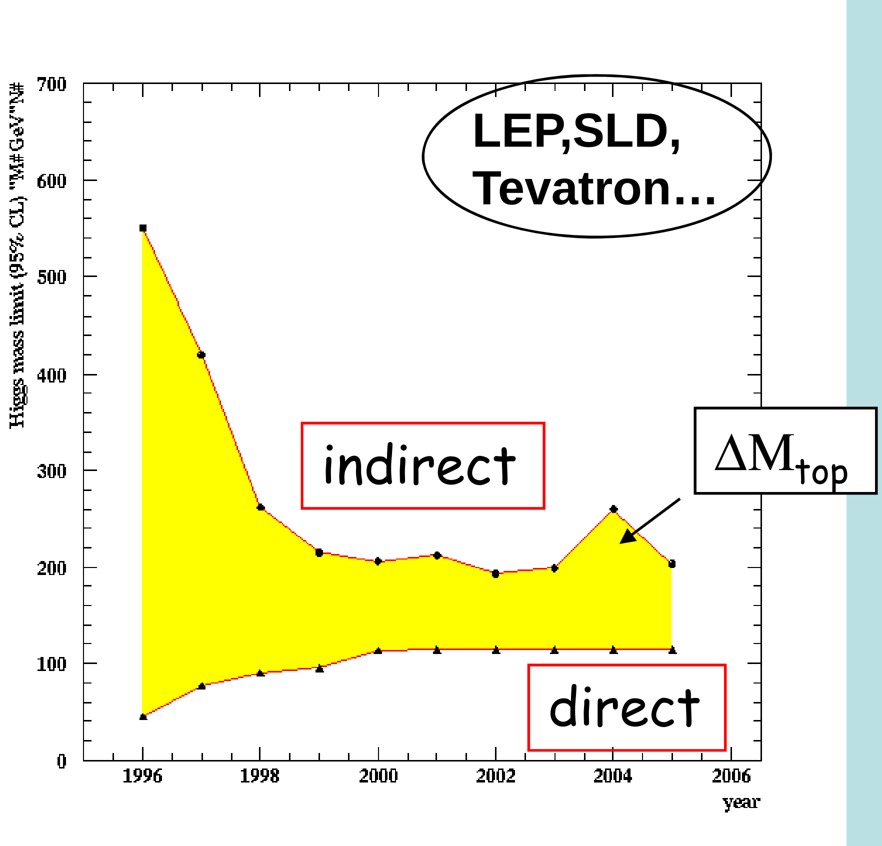
LEP/SLC

CKM - **B factories**

from M.Klein, ECFA meeting

Synergy of colliders

Time evolution of experimental limits on the Higgs boson mass



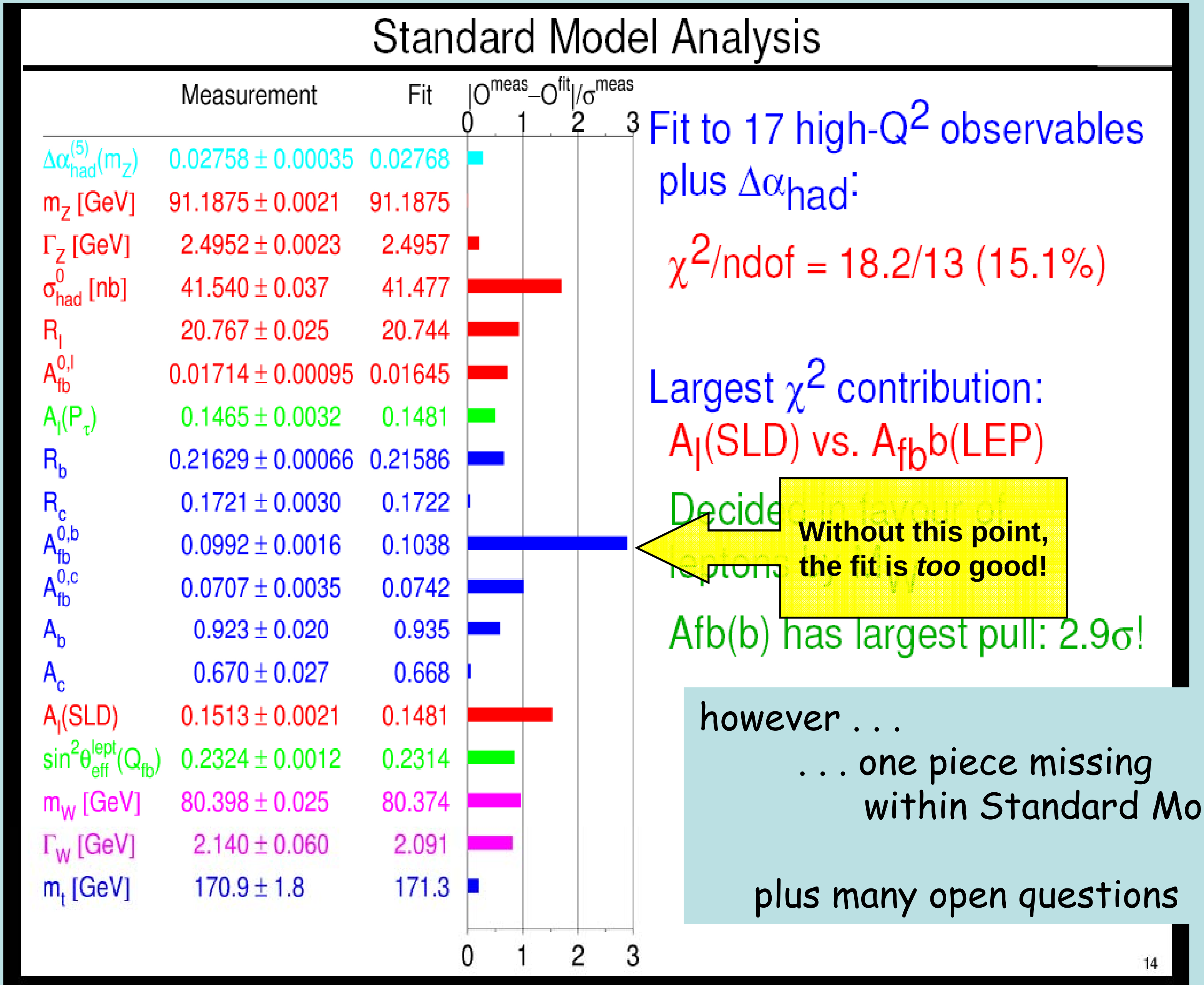
M_H between 114 and ~200 GeV

knowledge obtained only through combination of results from different accelerator types

in particular:
Lepton and Hadron Collider

together with highly developed theoretical calculations

Status Summer Conferences 2007



Standard Model Analysis

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
Γ_W [GeV]	2.140 ± 0.060	2.091
m_t [GeV]	170.9 ± 1.8	171.3

Fit to 17 high-Q^2 observables plus $\Delta\alpha_{had}$:

χ^2/ndof = 18.2/13 (15.1%)

Largest χ^2 contribution:

A_l(SLD) vs. $A_{fb}b$(LEP)

Decided in favour of leptons by M_W

Without this point, the fit is *too* good!

Afb(b) has largest pull: 2.9σ!

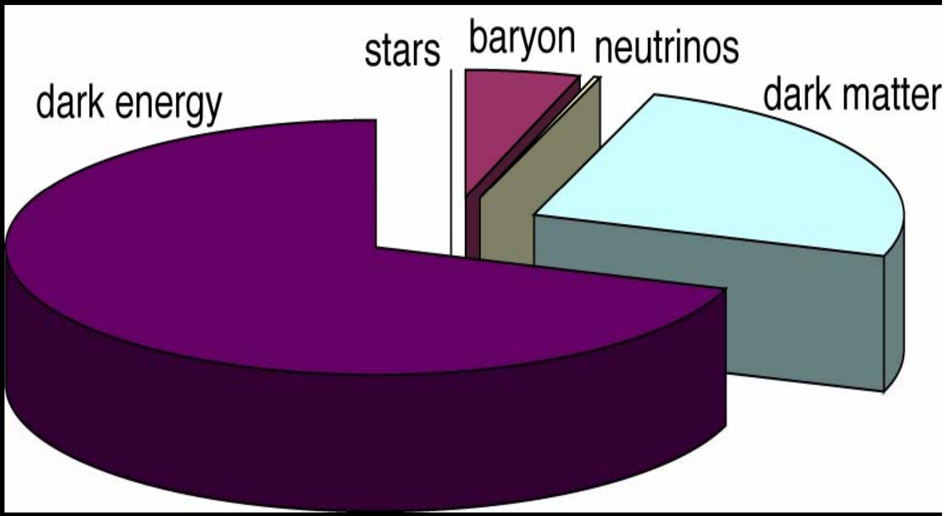
however . . .

. . . one piece missing within Standard Model

plus many open questions

in particular. . .

Standard Model



THE ENERGY DENSITY BUDGET

Ω_B BARYONS

Ω_{CDM} COLD DARK MATTER

Ω_ν NEUTRINOS

Ω_{DE} DARK ENERGY

$$\Omega_{TOT} = \Omega_B + \Omega_{CDM} + \Omega_\nu + \Omega_{DE}$$

→ we are now starting to explore the ’Dark Universe’

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Particle Physics in the next Decades

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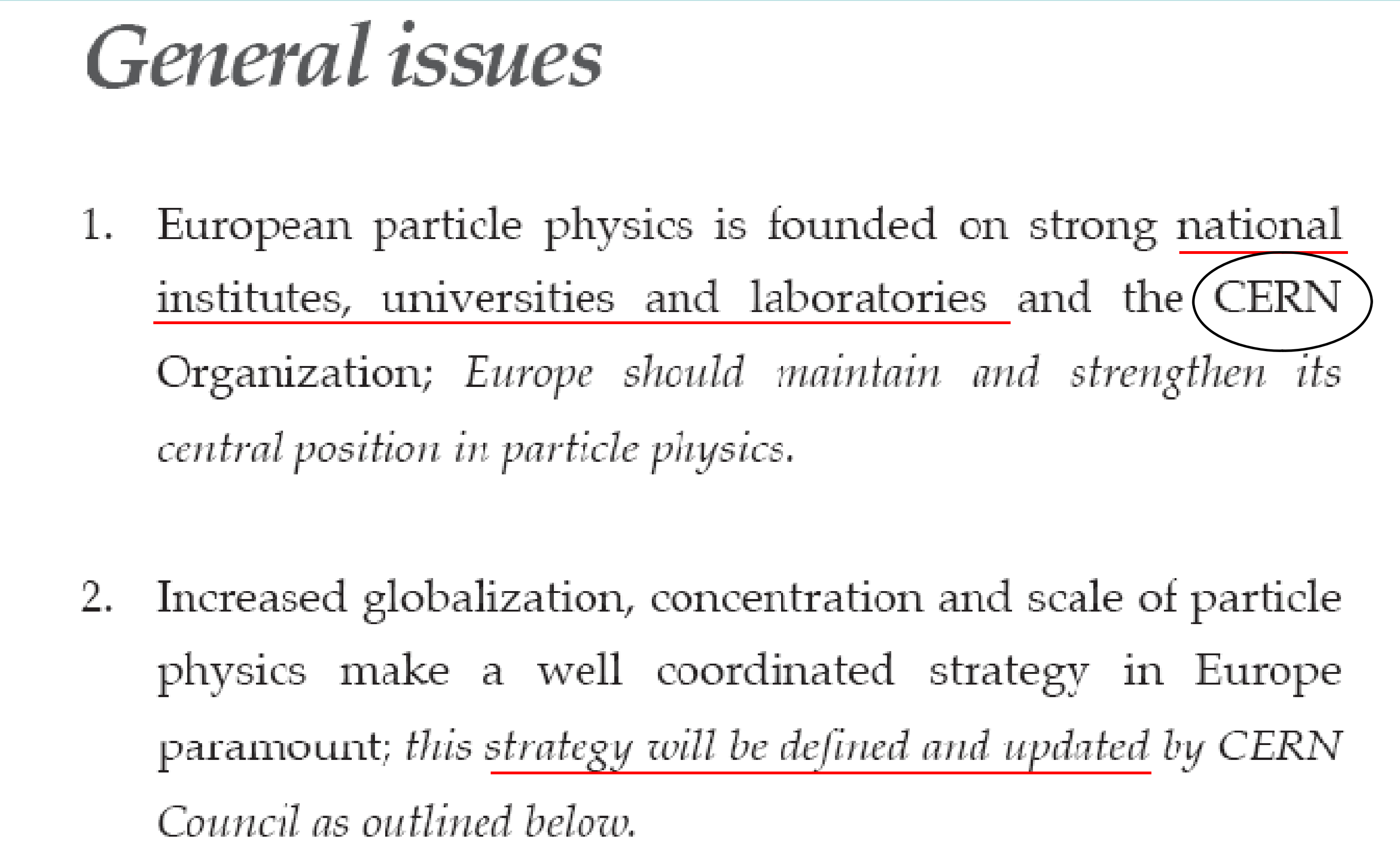
Roadmap

General Remarks

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)

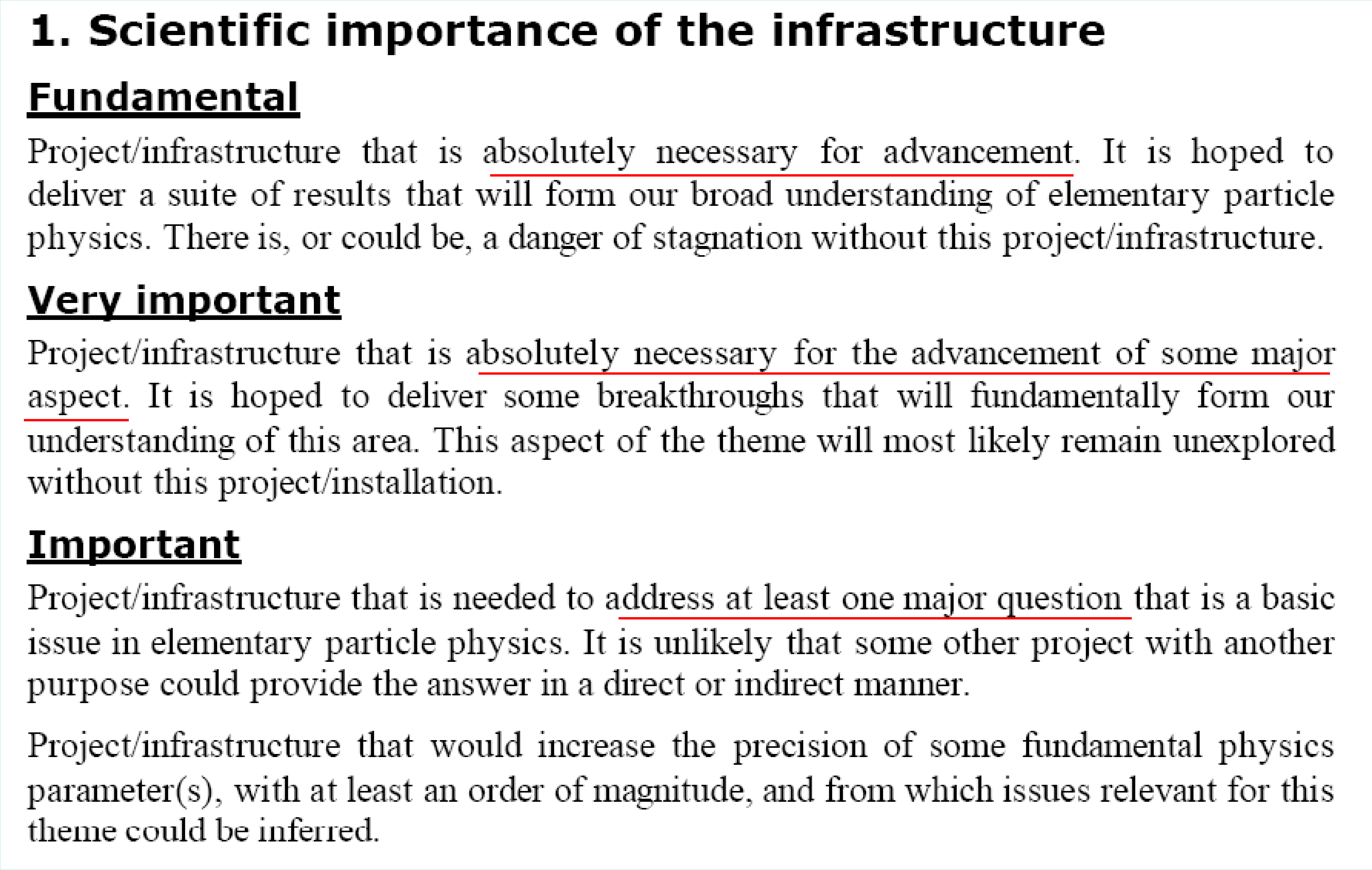
Final Workshop (Zeuthen, May 2006)

Strategy Document approved unanimously
by Council July 14, 2006

→ Next update: 2011

inbetween: regular European session of CERN Council

Vocabulary



1. Scientific importance of the infrastructure

Fundamental

Project/infrastructure that is absolutely necessary for advancement. It is hoped to deliver a suite of results that will form our broad understanding of elementary particle physics. There is, or could be, a danger of stagnation without this project/infrastructure.

Very important

Project/infrastructure that is absolutely necessary for the advancement of some major aspect. It is hoped to deliver some breakthroughs that will fundamentally form our understanding of this area. This aspect of the theme will most likely remain unexplored without this project/installation.

Important

Project/infrastructure that is needed to address at least one major question that is a basic issue in elementary particle physics. It is unlikely that some other project with another purpose could provide the answer in a direct or indirect manner.

Project/infrastructure that would increase the precision of some fundamental physics parameter(s), with at least an order of magnitude, and from which issues relevant for this theme could be inferred.

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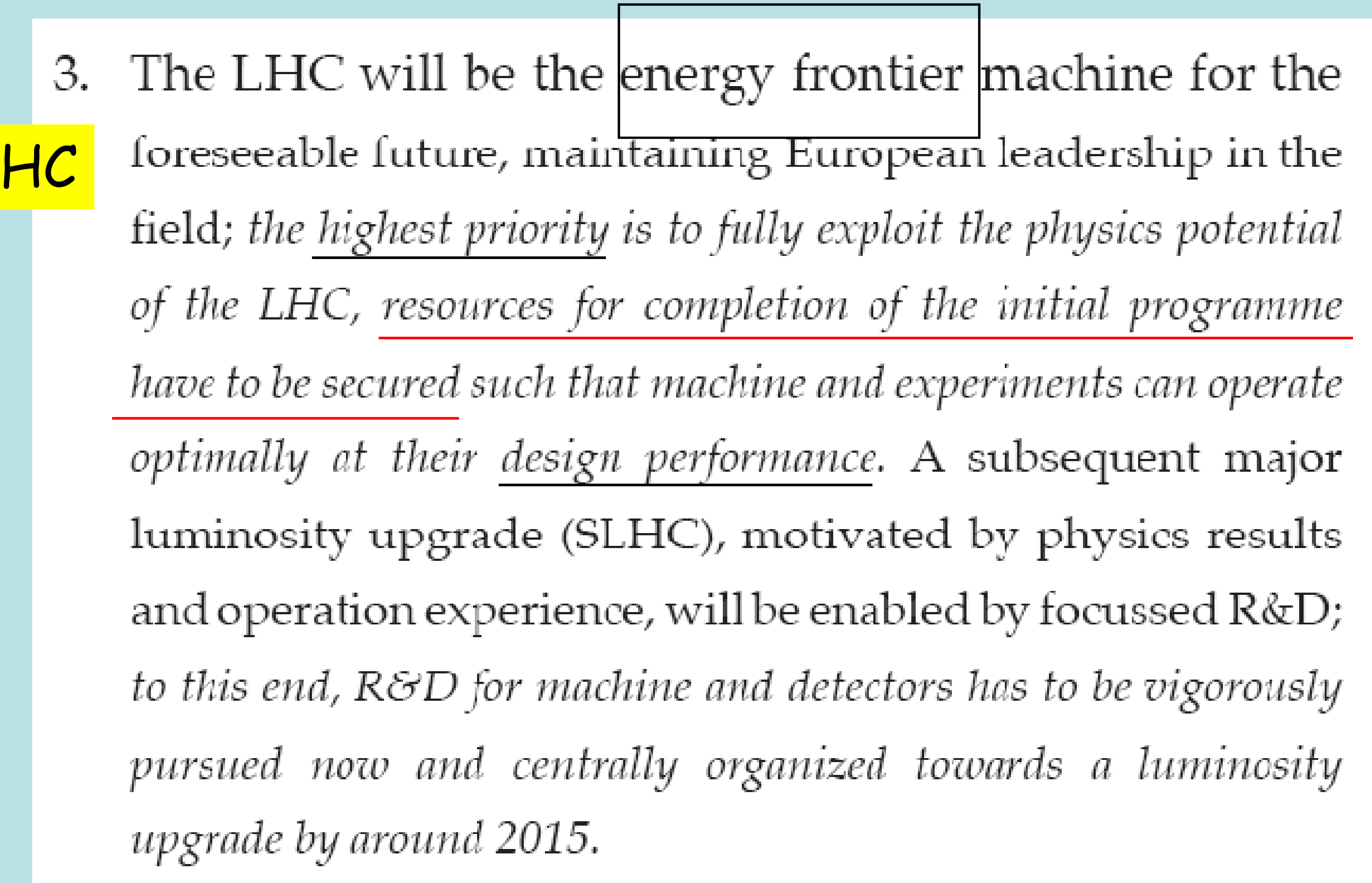
The European Strategy for particle physics

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.* 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.*

$L \sim 10^{34}$

Turn on of LHC
entering an exciting phase of particle physics
at the highest collision energies ever

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

Schedule:
- End July/ beginning August first injections
- after ~ 2 months first collisions at 10 TeV
- Pilot run at 10 TeV
- Shutdown incl. magnet training
- spring 2009 luminosity at 14 TeV

LHC is a collaborative effort and needs
sustained efforts from all partners to make it a success

- Detector (completing, running, maintaining)
- Data taking
- Analysis
- Preparations for necessary replacements
  detector modifications/upgrades

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

Possible ways beyond initial LHC at the ener r:

Luminosity increase (sLHC)
Doubling the energy (DLH
new machine, R eld magnets ongoing

Electron ider

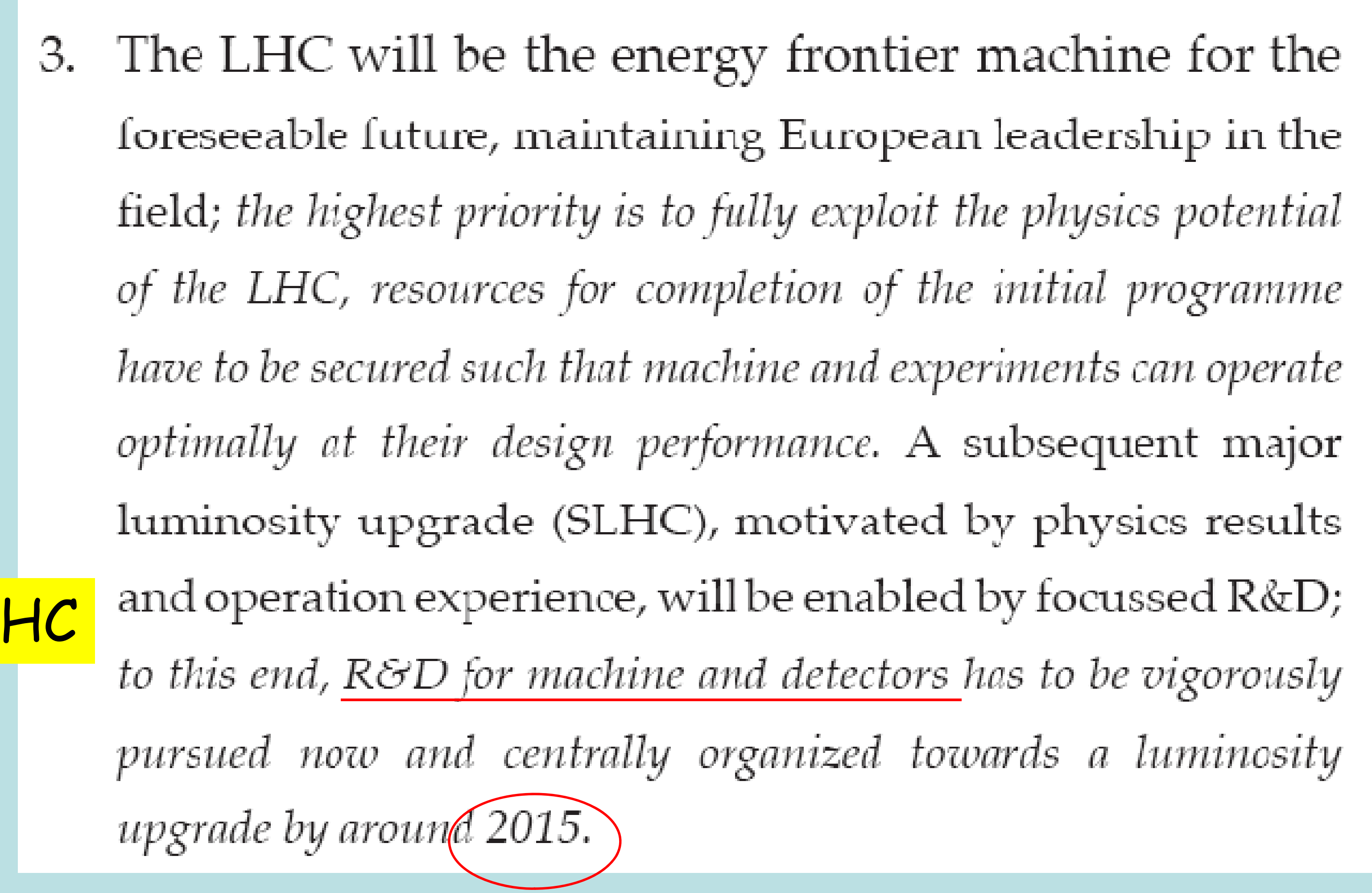
Expect
period for decision taking on next steps: 2010 to 2012

Electron-Proton Collider
LHeC

Muon Collider

The European Strategy for particle physics

one possible way : luminosity upgrade



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sLHC

$L \sim 10^{35}$

LHC : towards increasing luminosity

- New inner triplet -> towards L~2*10^{34}
- New Linac (Linac4) -> towards L~5*10^{34}

  construction can/will start now → ~ 2012

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

  start ***design*** now, ready for decision ~ 2011
  aimed for L~10^{35} around 2016/17 if physics requires

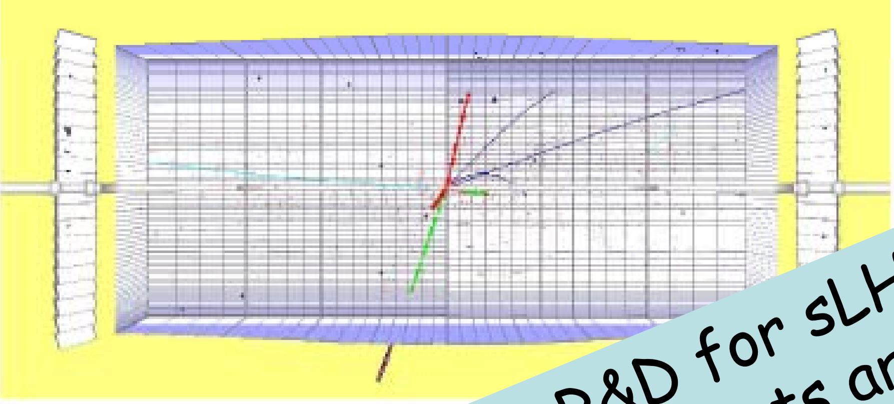
Times given: estimates for earliest installation/application
Criteria: Luminosity doubling time

Important: international collaboration

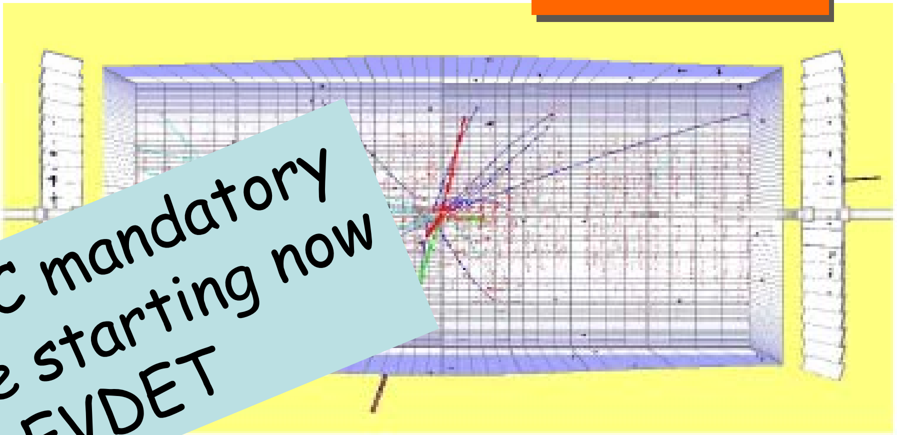
sLHC

The challenge: visually

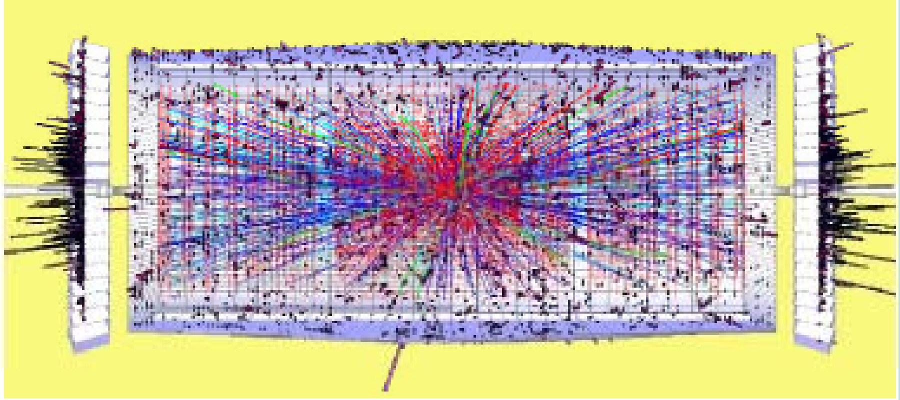
10^{32} cm^{-2} s^{-1}



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



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



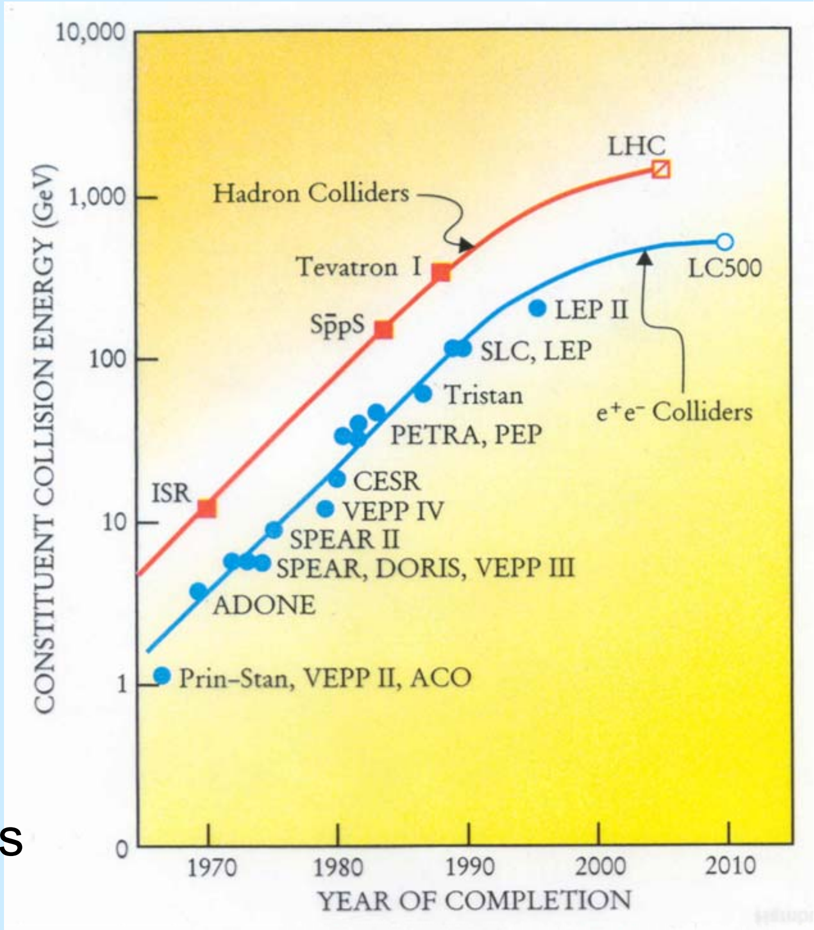
Detector R&D for sLHC mandatory
Concerted efforts are starting now
Proposal to EU FP7: DEVDET

Interplay of Hadron and Lepton Colliders

There are two distinct and complementary strategies for gaining new understanding of matter, space and time at future particle accelerators

HIGH ENERGY
direct discovery of new phenomena
i.e. accelerators operating at the energy scale of the new particle

HIGH PRECISION
Access to new physics at high energies through the precision
measurement of phenomena at lower scales



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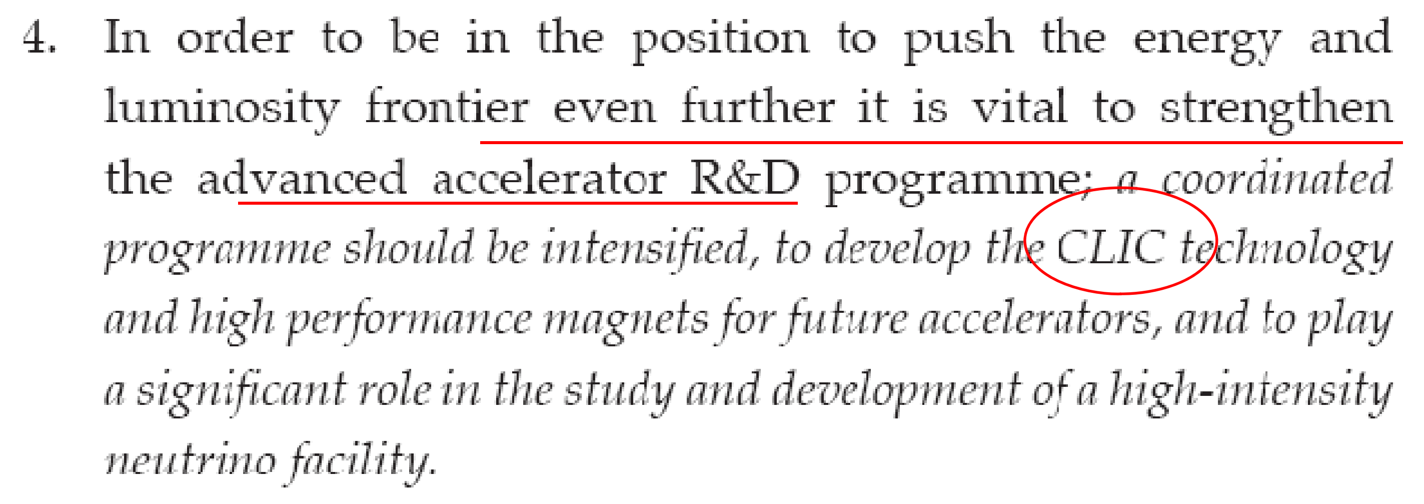
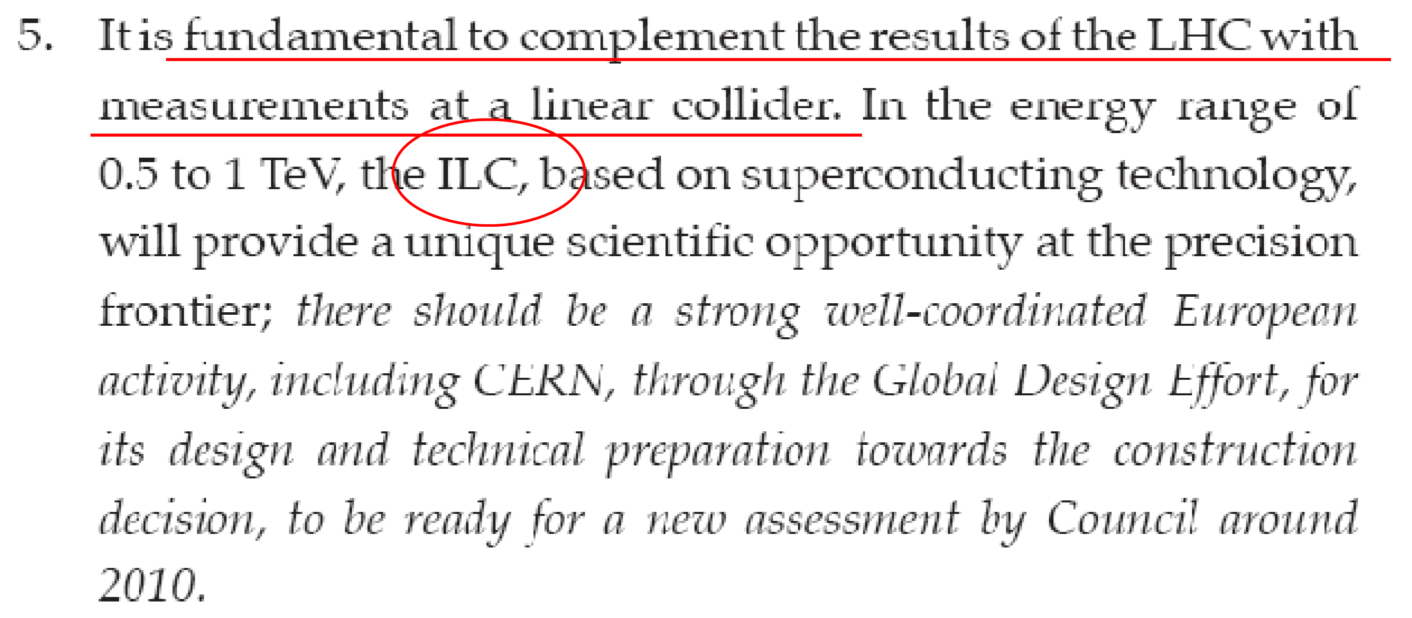
The European Strategy for particle physics



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.*

remember:

LCWS 2004 in Paris

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

ILC @ 500 GeV

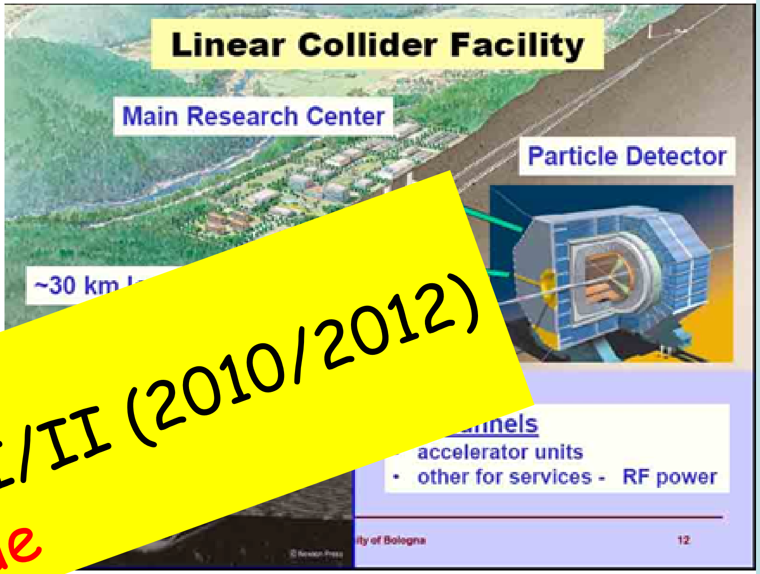
ILC web site: http://www.linearcollider.org/cms/

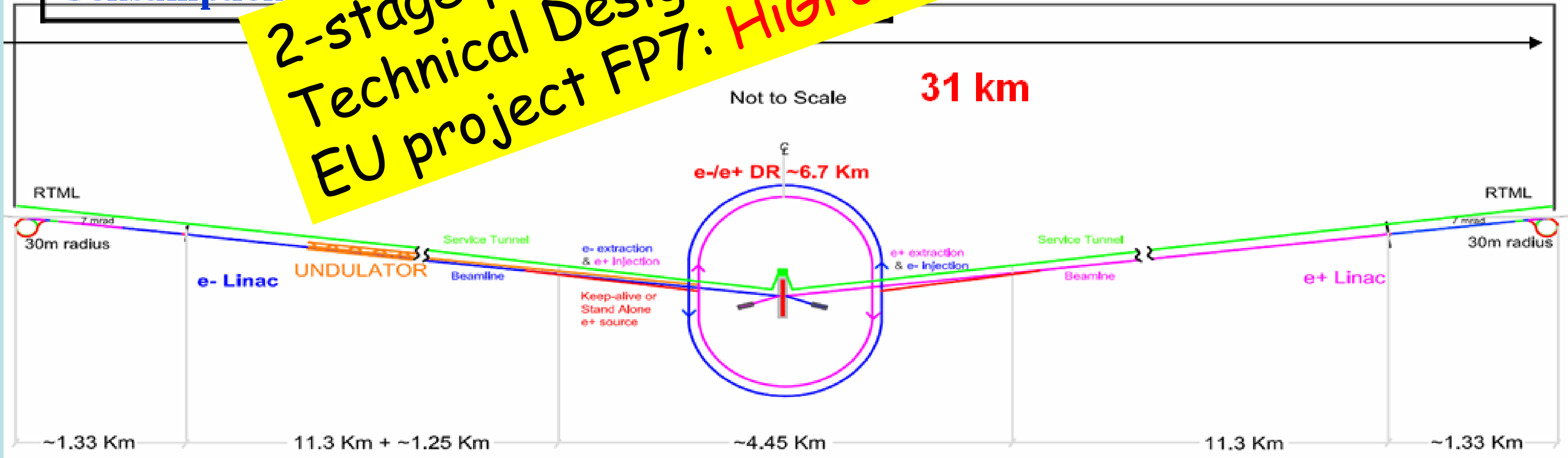
Max. Center-of-mass energy	500	GeV
Peak Luminosity	~2×10^{34}	$cm^{-2}s^{-1}$
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	m
Total Site Length		
Total AC Power Consumption		

2-stage process

Technical Design Phase I/II (2010/2012)

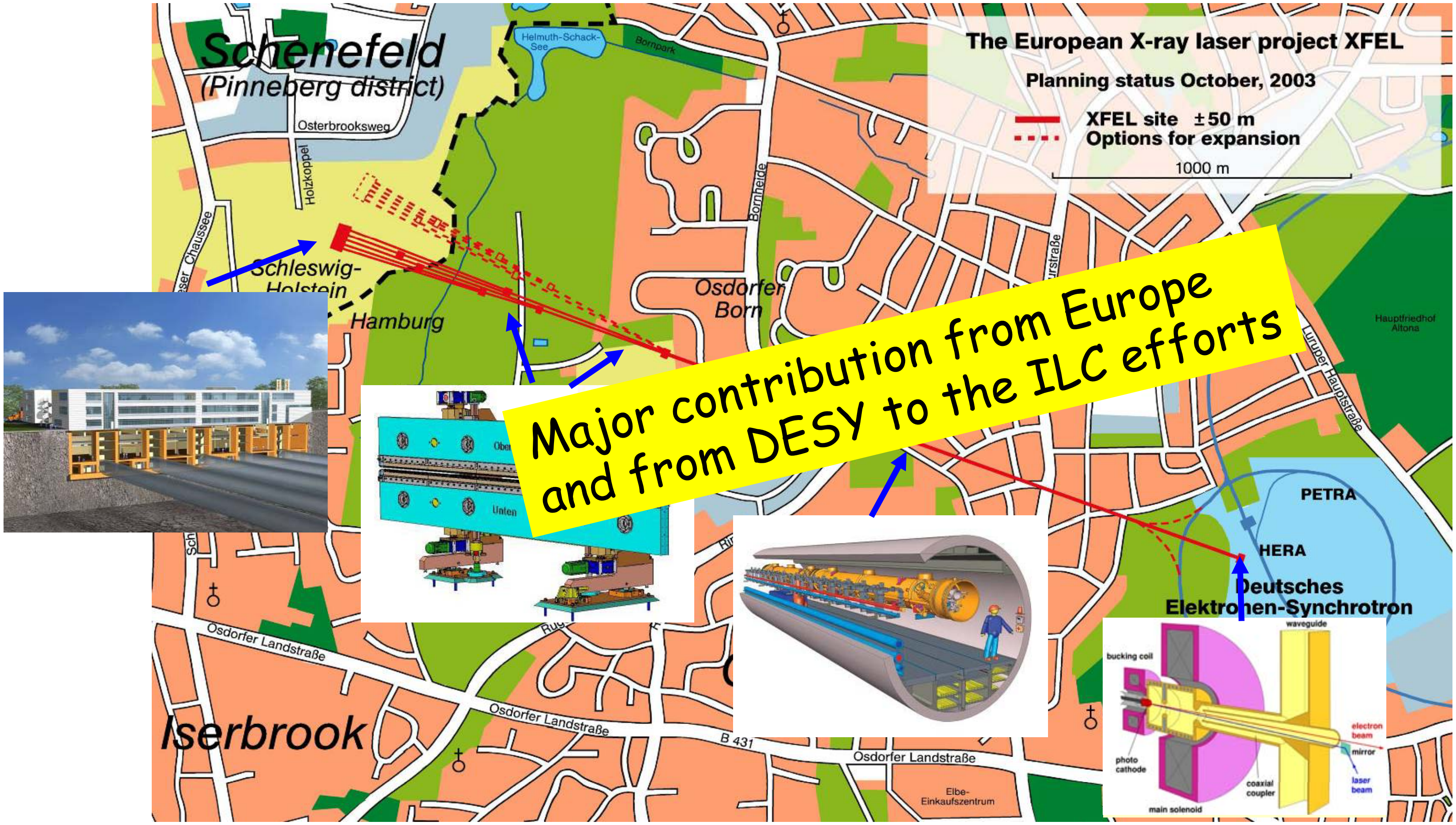
EU project FP7: HiGrade





X-FEL at DESY
a 10% ILC and 800 MEuros Test Facility!

3.4km



Major contribution from Europe and from DESY to the ILC efforts

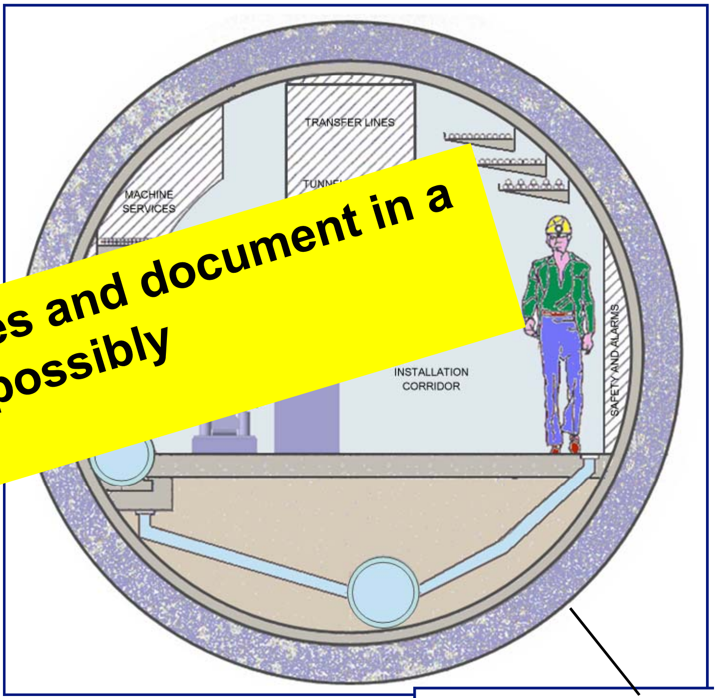
Technically ready, start construction soon for operation from 2012/13

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

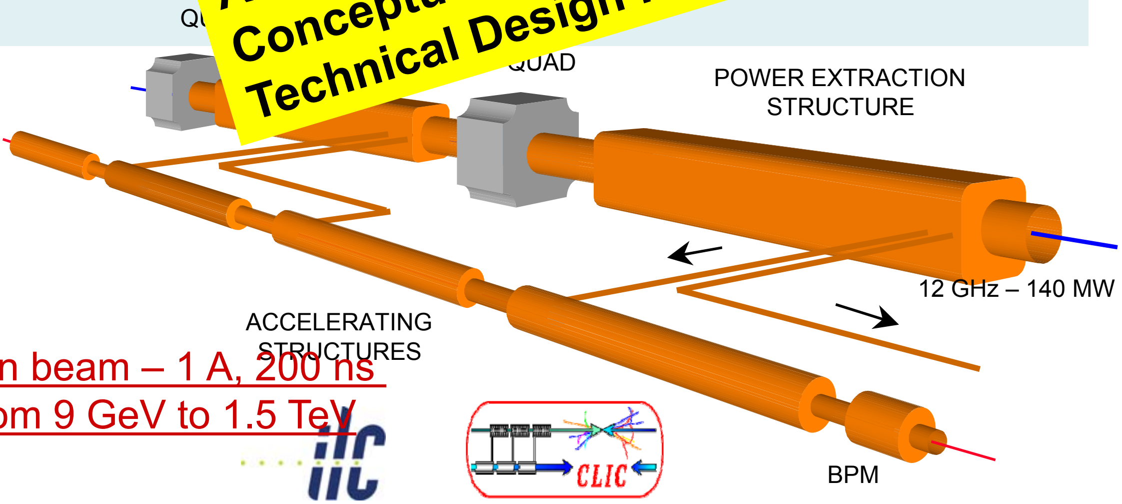
- **High acceleration gradient: ~ 100 MV/m**
  - **“Compact” collider – total length < 50 km at 3 TeV**
  - **Normal conducting acceleration structures at high frequency**
- **Novel Two-Beam Acceleration Scheme**
  - **Cost effective, reliable, efficient**
  - **Simple tunnel, no active**
  - **Modular,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



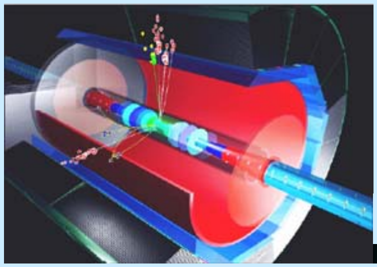
Drive beam - 95 A, 300 ns
from 2.4 GeV to 240 MeV

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

New CLIC main parameters

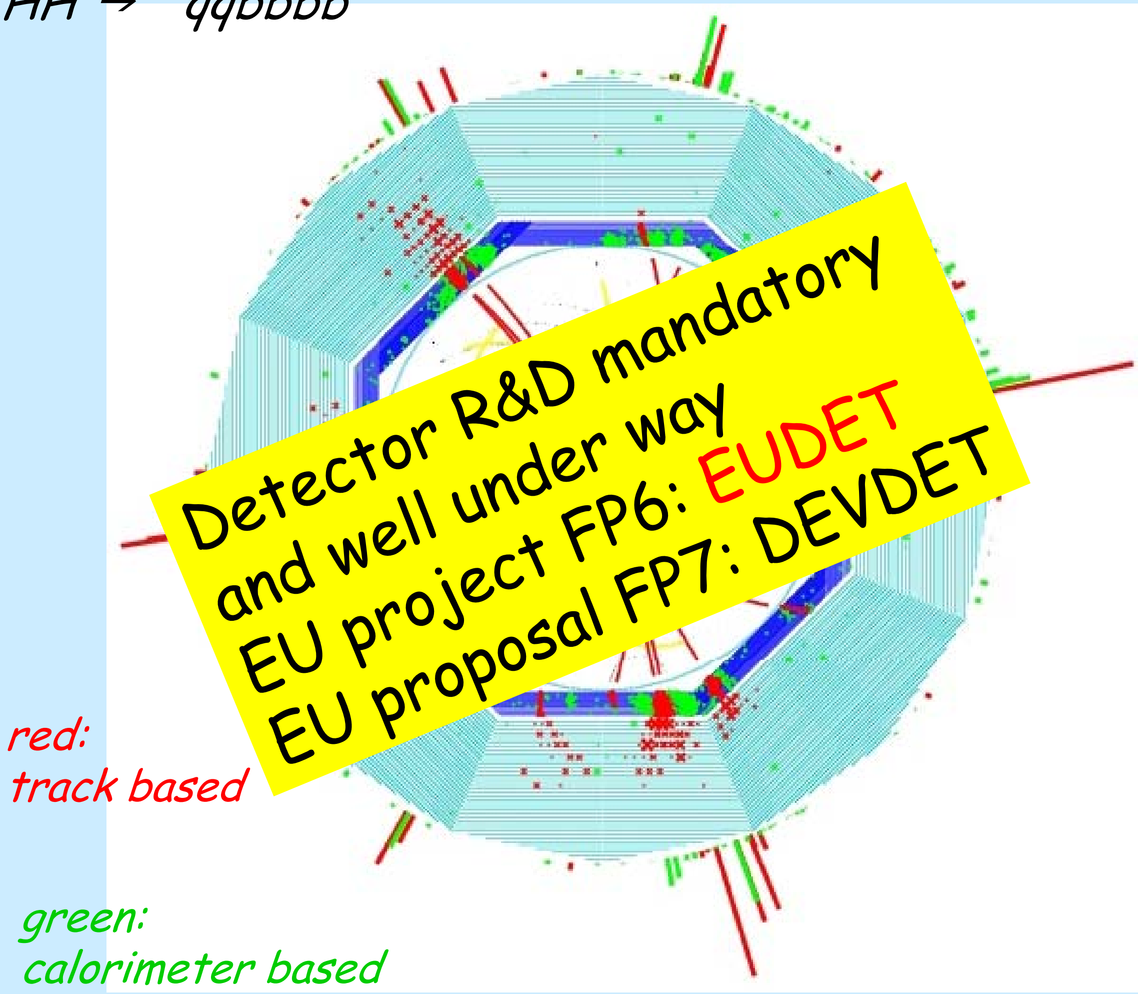
Center-of-mass energy	3 TeV
Peak Luminosity	$7 \cdot 10^{34}$ cm^{-2} s^{-1}
Peak luminosity (in 1% of energy)	$2 \cdot 10^{34}$ cm^{-2} s^{-1}
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	41.7 km
Bunch charge	$4 \cdot 10^{9}$
Beam pulse length	200 ns
Average current in pulse	1 A
Hor./vert. normalized emittance	660 / 20 nm rad
Hor./vert. IP beam size bef. pinch	53 / ~1 nm
Total site length	48.25 km
Total power consumption	390 MW

Provisional values



ILC Detector challenges: calorimeter

ZHH → qqbbbb



Detector R&D mandatory
and well under way
EU project FP6: EUDET
EU proposal FP7: DEVDET

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

Strategy to address LC key issues

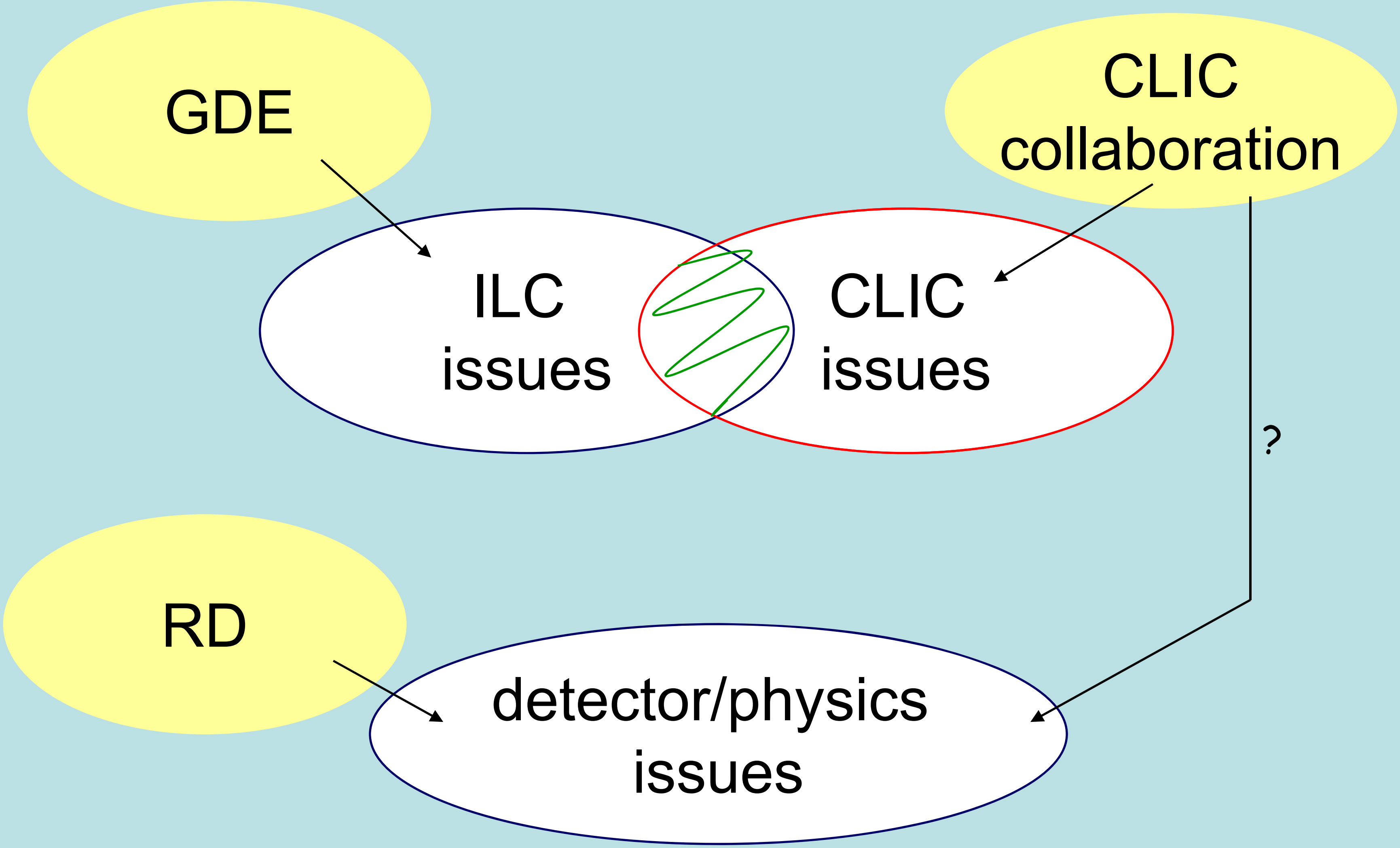
- Key issues common to all Linear Collider studies independently of the chosen technology in close collaboration between ILC and CLIC
  - The Accelerator Test Facility (ATF@KEK)
  - European Laboratories in the frame of the Coordinated Accelerator Research in Europe (CARE) and of a “Design Study” (EUROTeV) funded by EU Framework Programme (FP6)
  - New proposal submitted to the EU Framework Programme (FP7) comprising LC and LHC:

EUCARD

Strategy to address LC key issues

Recent progress: much closer collaboration

first meeting: February 08



GDE

CLIC collaboration

ILC issues

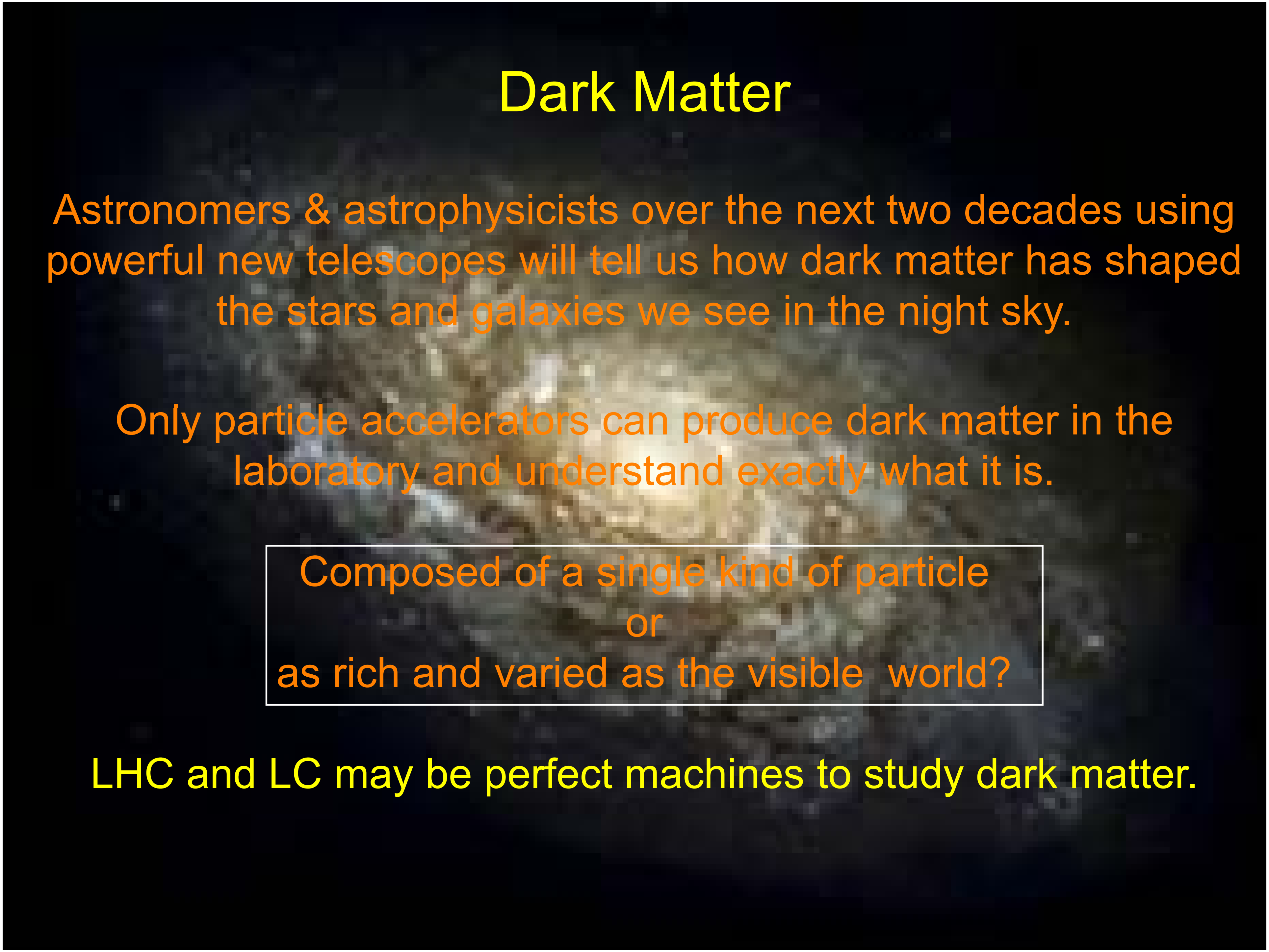
CLIC issues

?

RD

detector/physics issues

ready to explore the Dark Universe



Dark Matter

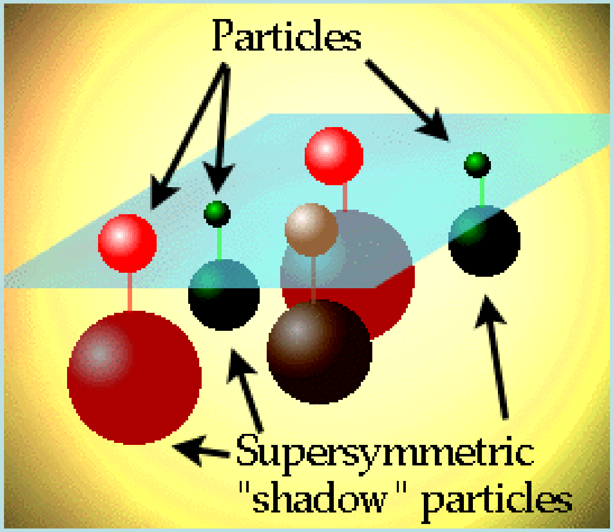
Astronomers & astrophysicists over the next two decades using powerful new telescopes will tell us how dark matter has shaped the stars and galaxies we see in the night sky.

Only particle accelerators can produce dark matter in the laboratory and understand exactly what it is.

Composed of a single kind of particle
or
as rich and varied as the visible world?

LHC and LC may be perfect machines to study dark matter.

Supersymmetry



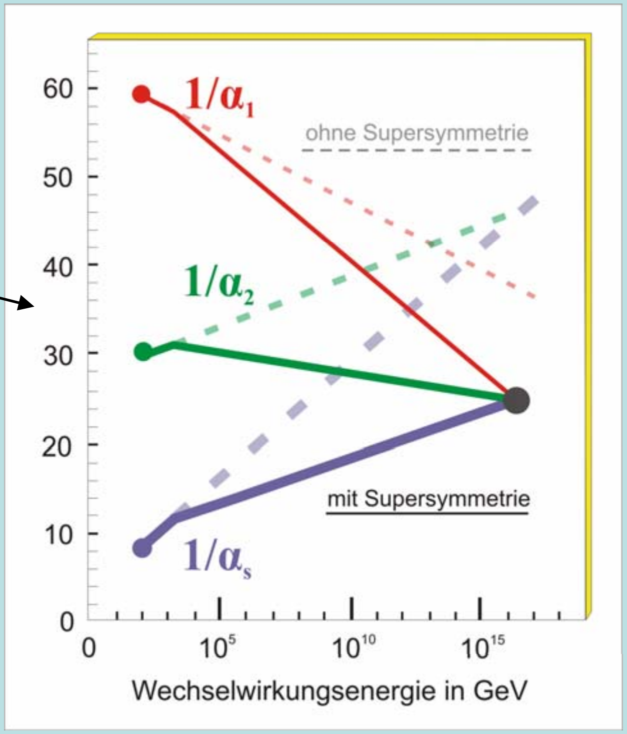
- unifies matter with forces

  for each particle a supersymmetric partner (*sparticle*) of opposite statistics is introduced

- allows to unify strong and electroweak forces

  $\sin^2\theta_W^{SUSY} = 0.2335(17)$

  $\sin^2\theta_W^{exp} = 0.2315(2)$

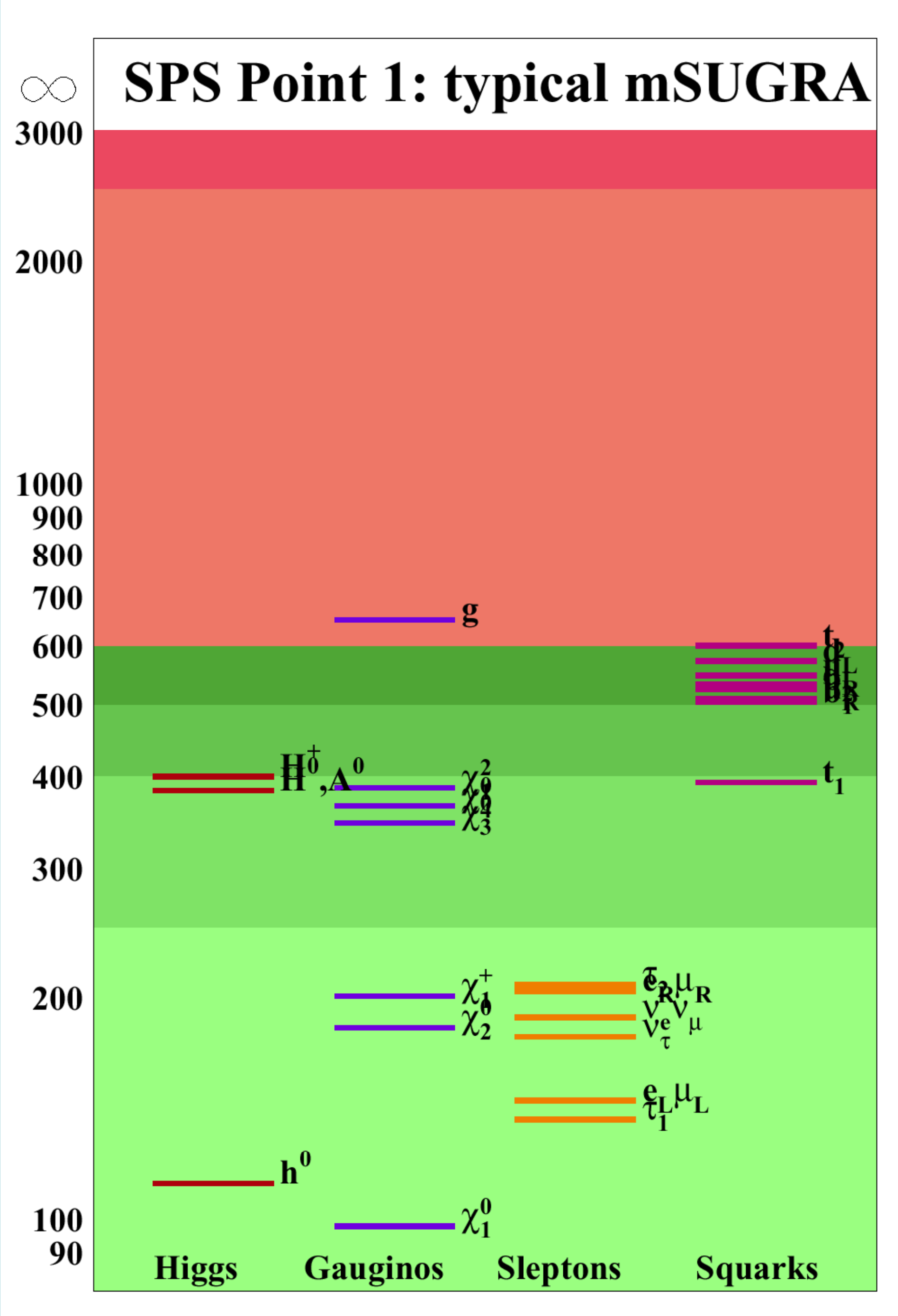


- provides link to string theories

- provides Dark Matter candidate

  (stable Lowest Supersymmetric Particle)

Supersymmetry

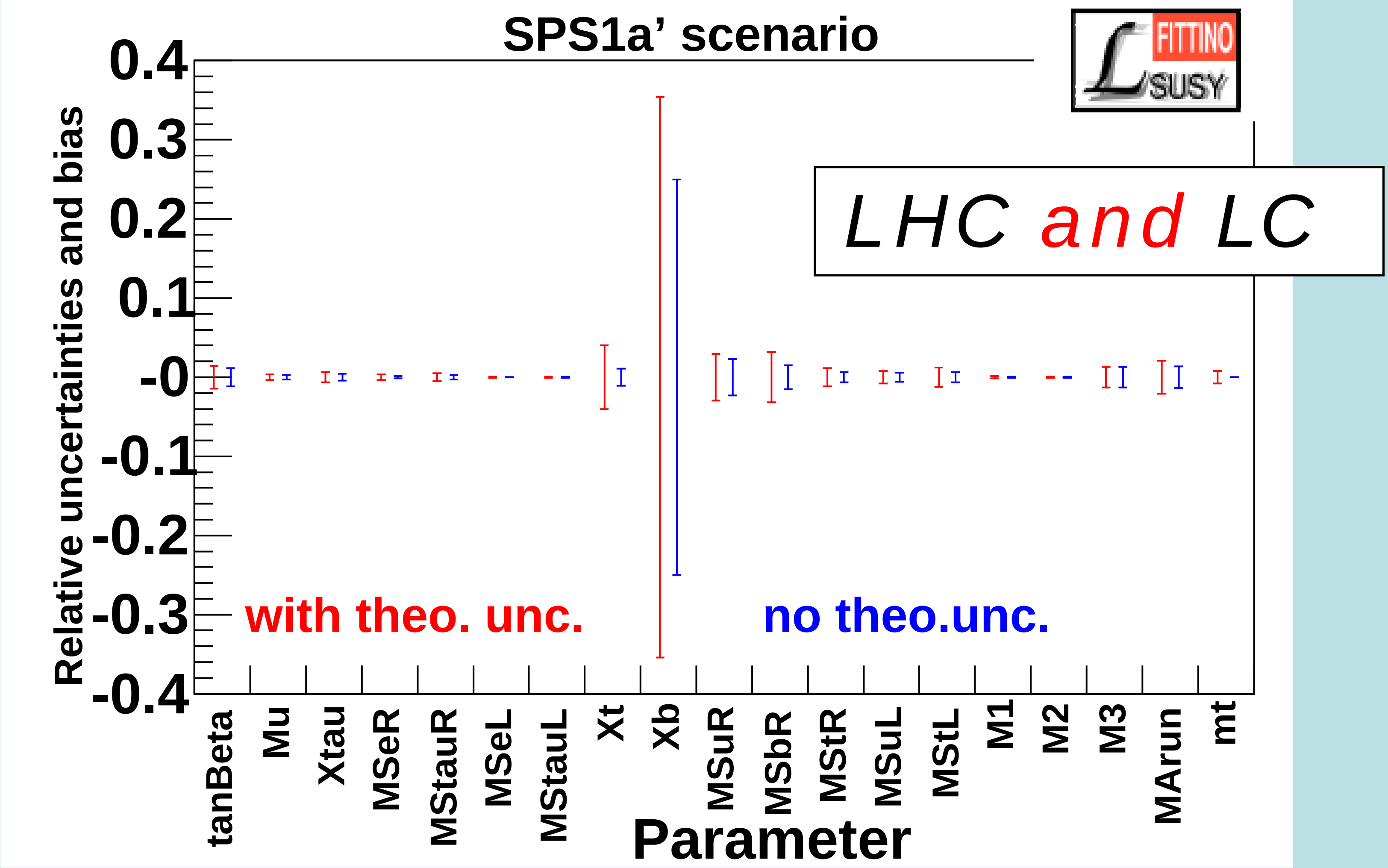


Mass spectra depend on choice of models and parameters...

well measureable at LHC

precise spectroscopy
at ILC or CLIC

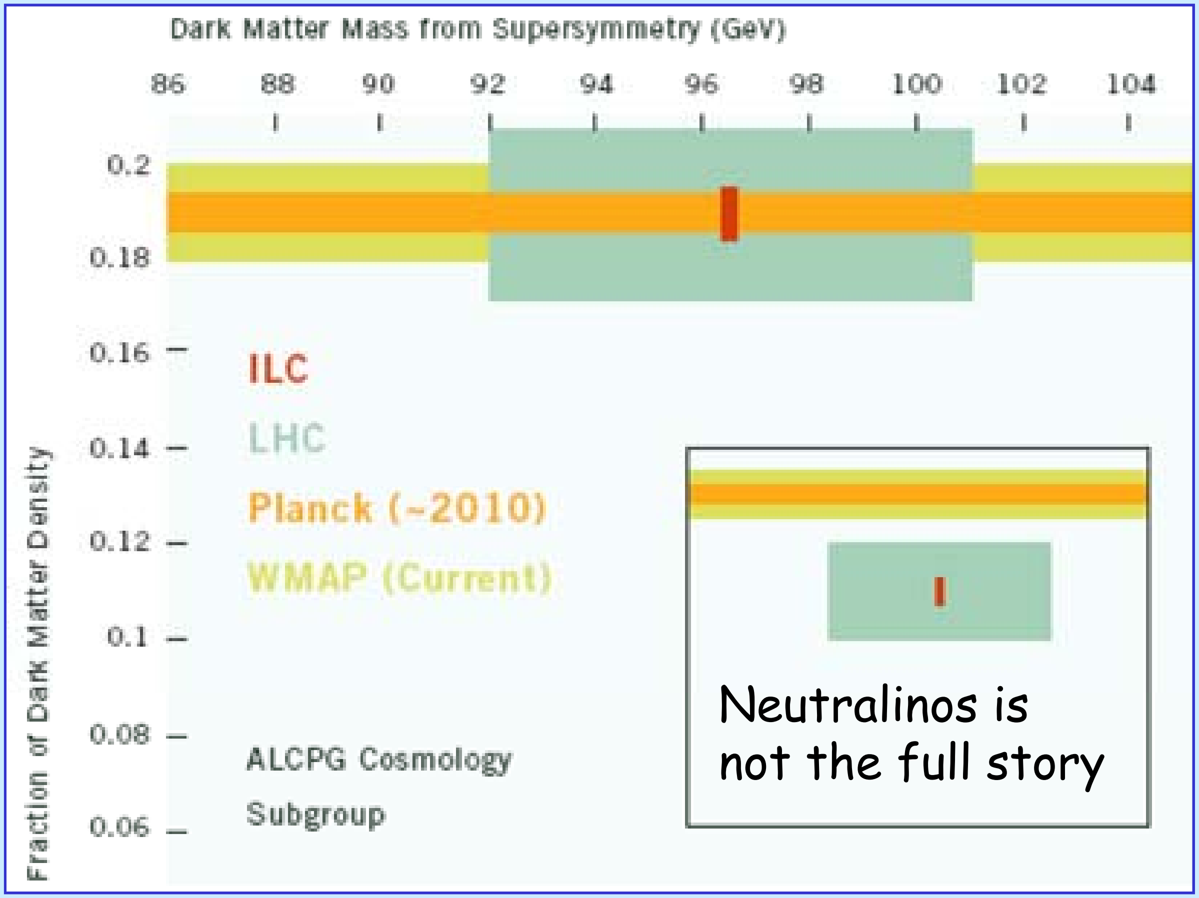
MSSM parameters from global fit



→ only possible with information from BOTH colliders

Dark Matter and SUSY

- Is dark matter linked to the Lightest Supersymmetric Particle?



Neutralinos is not the full story

LHC, LC and satellite data (WMAP and Planck):

complementary views of dark matter.

LC and LHC: identify DM particle, measures its mass;

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

Together they establish the nature of dark matter.

LHC and LC results should allow,
together with dedicated dark matter searches,
first discoveries in the dark universe

~ around 73% of the Universe is in some
mysterious “dark energy”. It is evenly
spread, as if it were an intrinsic property
of space. It exerts negative pressure.

Challenge:
get first hints about the world of
dark energy in the laboratory

The Higgs is Different!

All the matter particles are spin-1/2 fermions.
All the force carriers are spin-1 bosons.

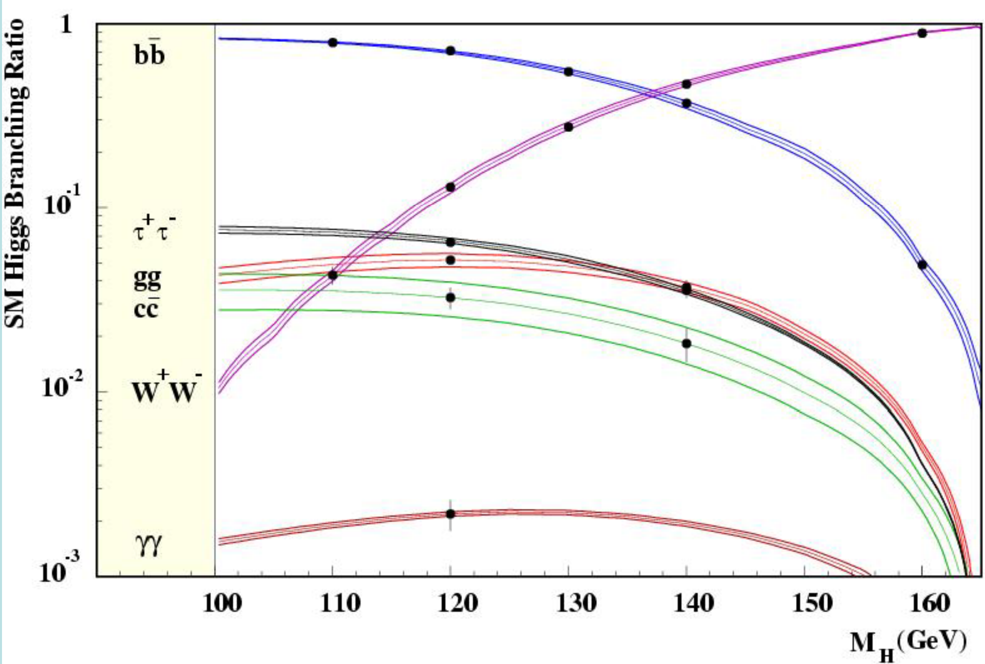
Higgs particles are spin-0 bosons.
The Higgs is neither matter nor force;
The Higgs is just different.
This would be the first fundamental scalar ever discovered.

The Higgs field is thought to fill the entire universe.
Could give some handle of dark energy(scalar field)?

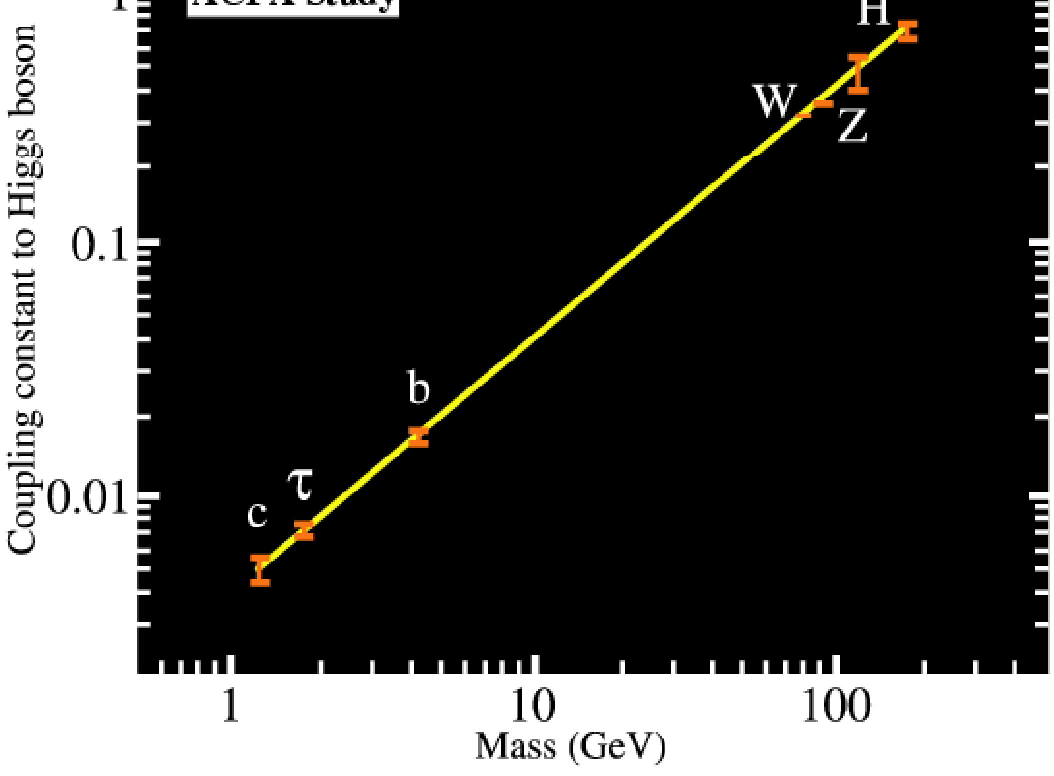
Many modern theories predict other scalar particles like the Higgs.
Why, after all, should the Higgs be the only one of its kind?

LHC and LC can search for new scalars with precision.

Precision Higgs physics



Coupling-Mass Relation



Determination of absolute coupling values with high precision

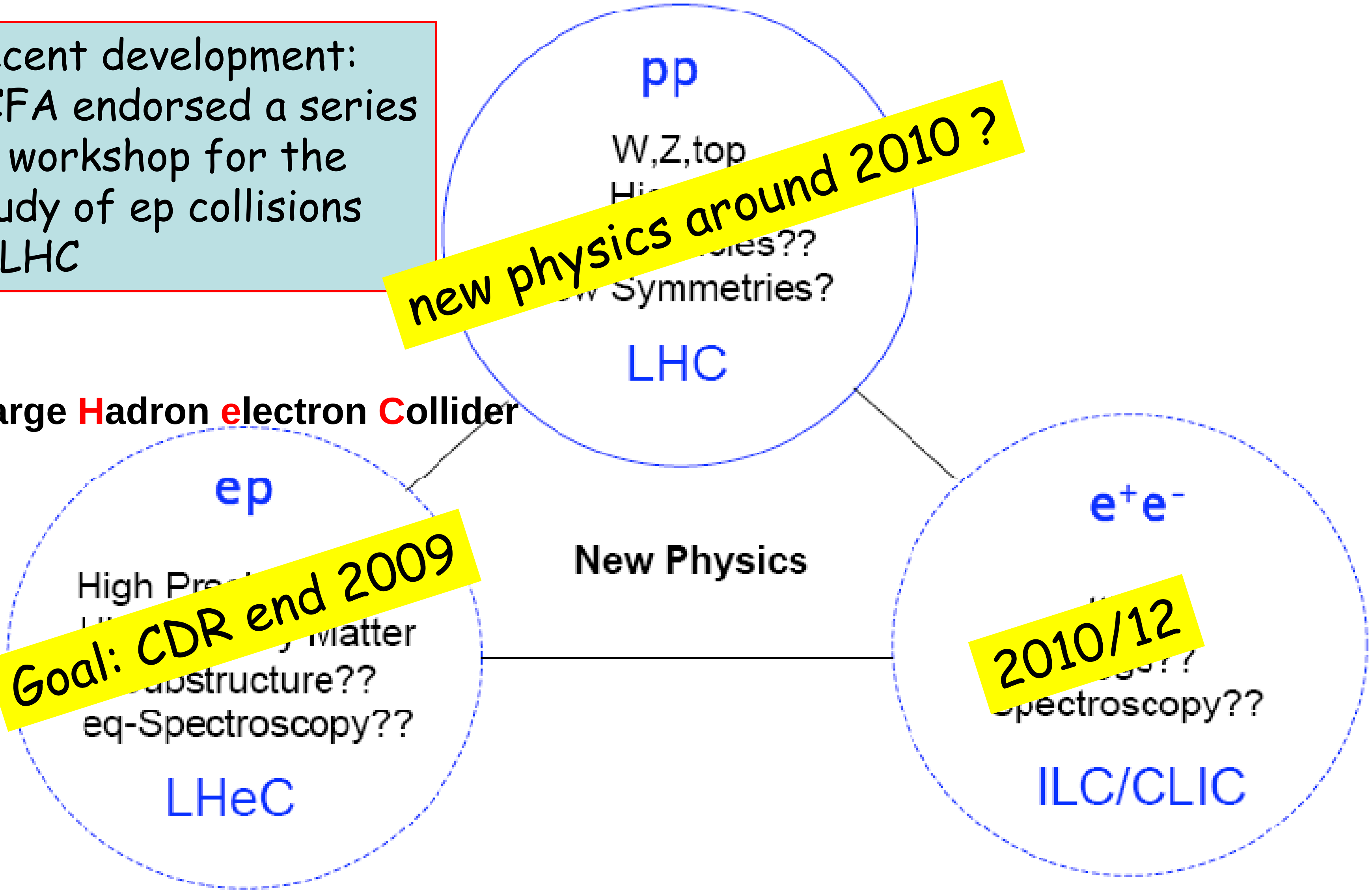
LHC and LC results will allow
to study the Higgs mechanism in detail and
to reveal the character of the Higgs boson

This would be the first investigation
of a scalar field

This could be the very first step to
understanding dark energy

The TeV Scale [2008-2033..]

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



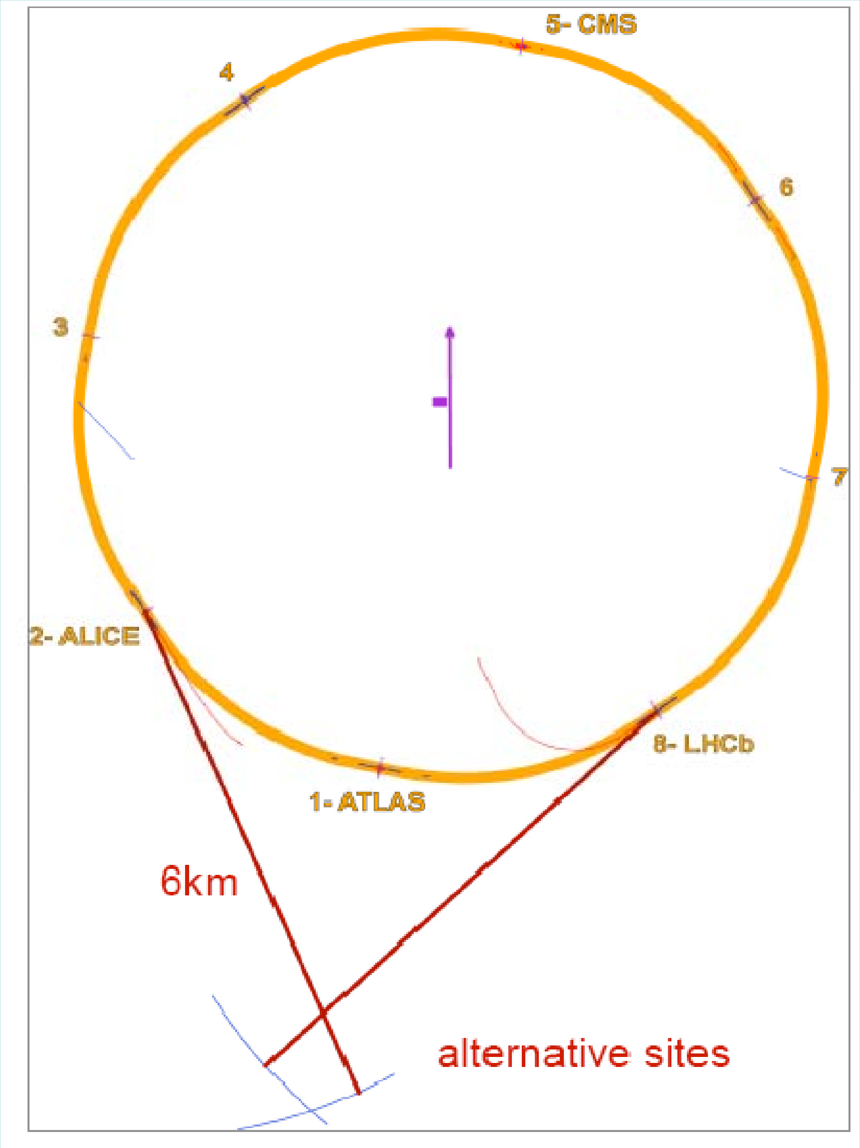
Large Hadron electron Collider

new physics around 2010 ?

Goal: CDR end 2009

2010/12

Large Hadron electron Collider: possible layouts



40 - 140 GeV
on
1 - 7 TeV

ring-ring solution:
$L \leq 10^{33}$

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

Would be the successor of HERA at higher cms

Past decades saw precision studies of 5 % of our Universe → Discovery of the Standard Model

The LHC will soon deliver data

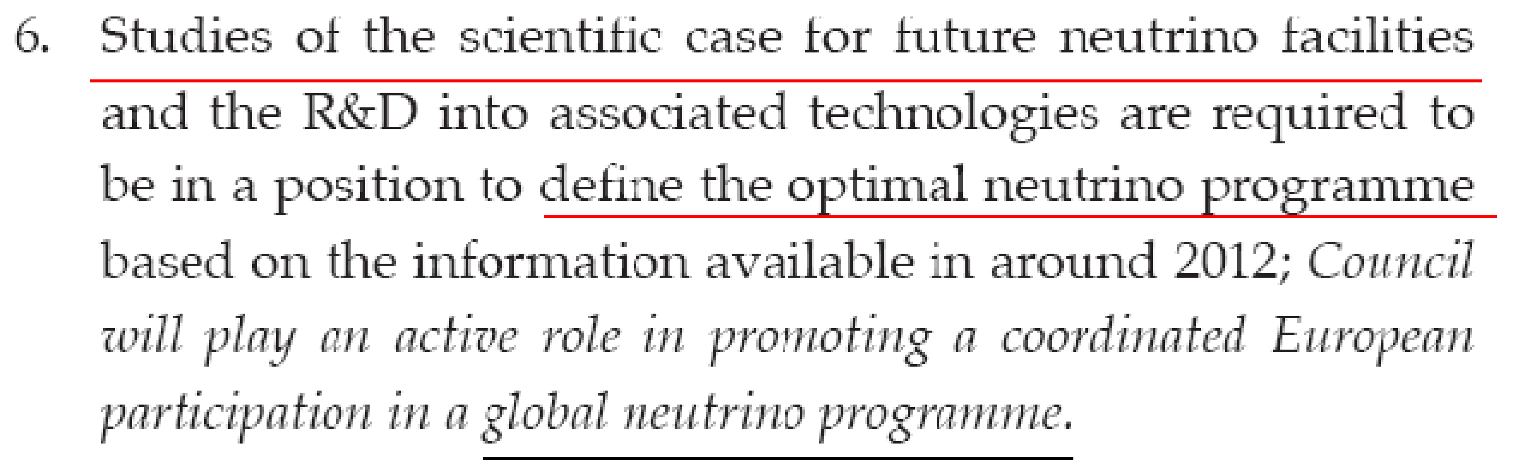
Preparations for the ILC as a global project are under way, R&D for CLIC well progressing

The next decades look very exciting:

We are just at the beginning of exploring
95 % of the Universe

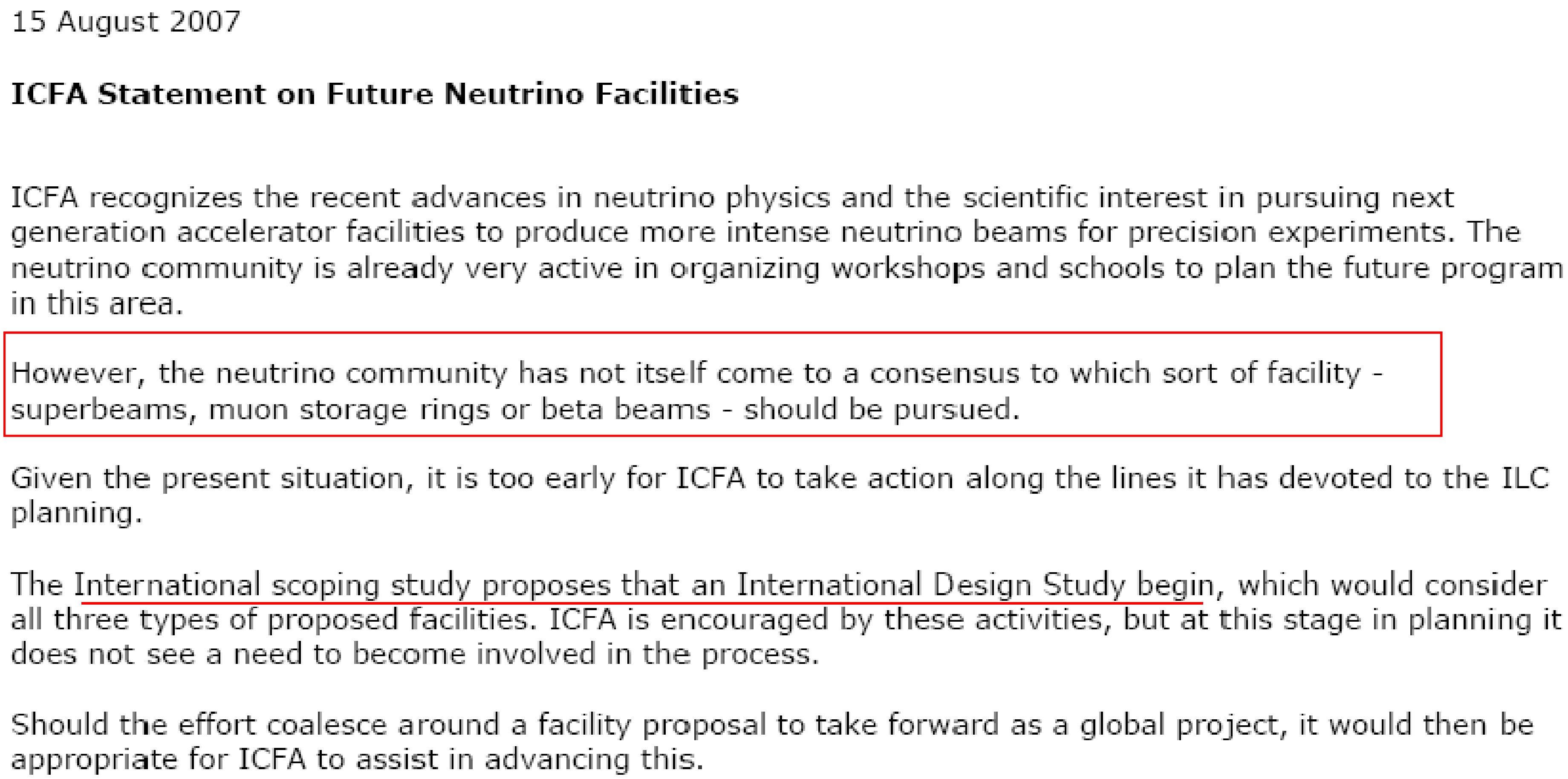
neutrino sector

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.*

ICFA



15 August 2007

ICFA Statement on Future Neutrino Facilities

ICFA recognizes the recent advances in neutrino physics and the scientific interest in pursuing next generation accelerator facilities to produce more intense neutrino beams for precision experiments. The neutrino community is already very active in organizing workshops and schools to plan the future program in this area.

However, the neutrino community has not itself come to a consensus to which sort of facility - superbeams, muon storage rings or beta beams - should be pursued.

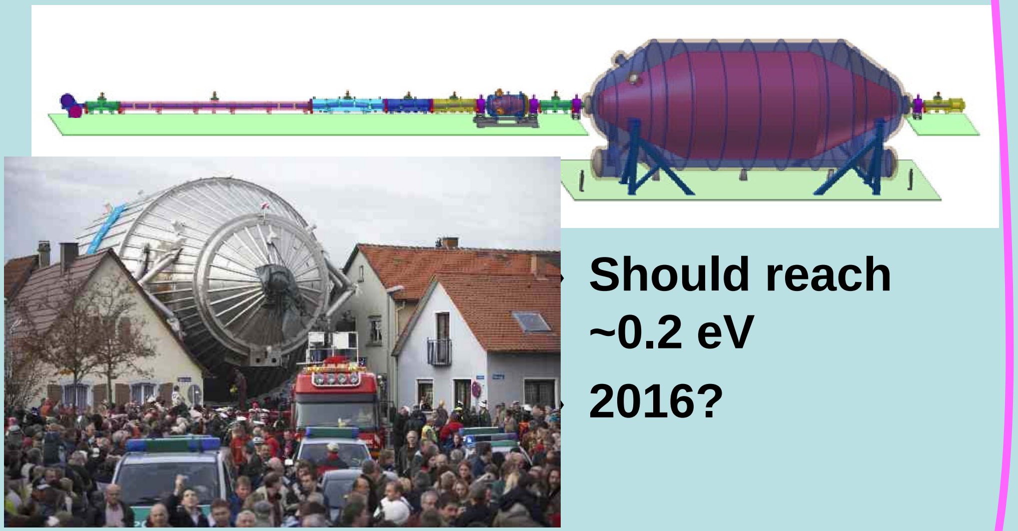
Given the present situation, it is too early for ICFA to take action along the lines it has devoted to the ILC planning.

The International scoping study proposes that an International Design Study begin, which would consider all three types of proposed facilities. ICFA is encouraged by these activities, but at this stage in planning it does not see a need to become involved in the process.

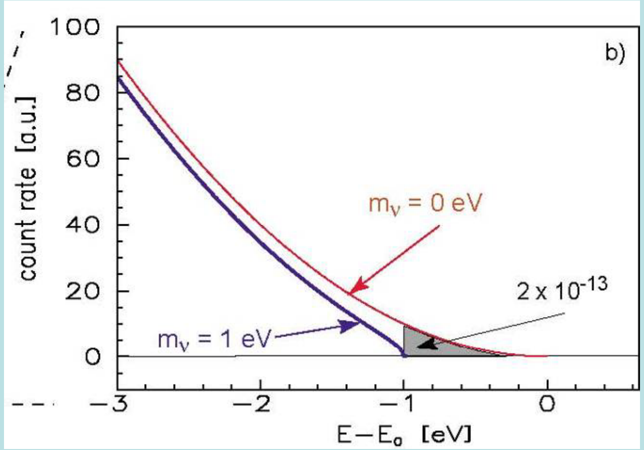
Should the effort coalesce around a facility proposal to take forward as a global project, it would then be appropriate for ICFA to assist in advancing this.

Absolute neutrino mass scale

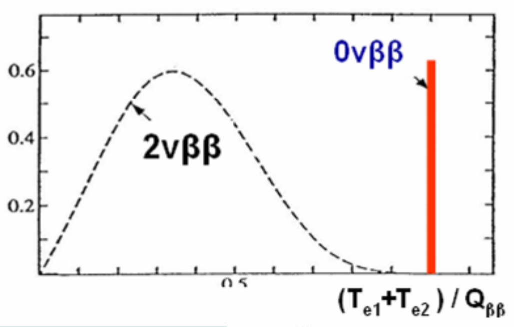
- Direct measurement
  - KATRIN

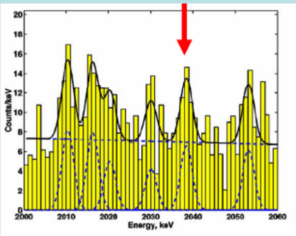


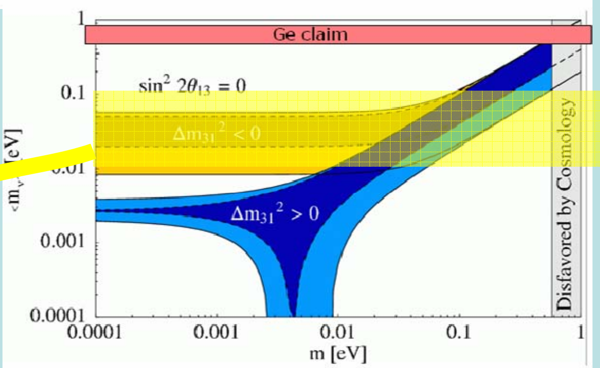
- Should reach ~0.2 eV
- 2016?

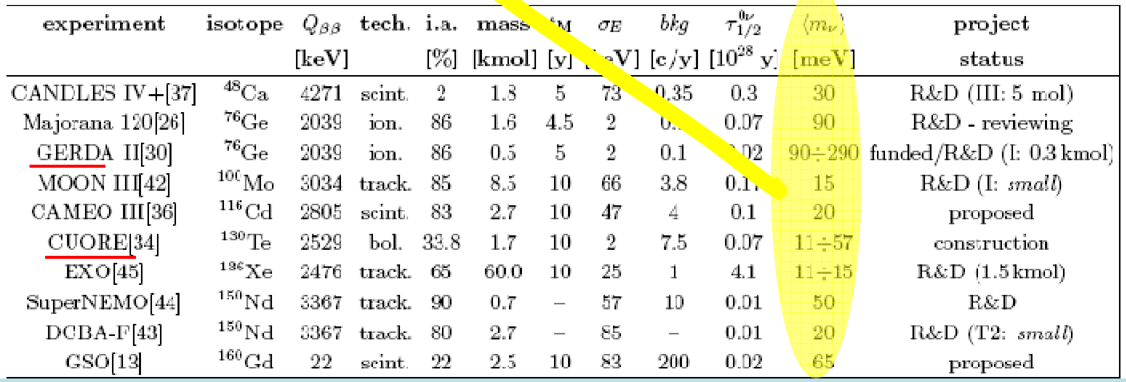


- Indirect measurement
  - 0νββ









experiment	isotope	$Q_{\beta\beta}$ [keV]	tech.	i.a. [%]	mass [kmol]	t_M [y]	σ_E [keV]	bkg [c/y]	$\tau^{0\nu}_{1/2}$ [10^{28} y]	$\langle m_\nu \rangle$ [meV]	project status
CANDLES IV+[37]	^{48}Ca	4271	scint.	2	1.3	5	73	0.35	0.3	30	R&D (III: 5 mol)
Majorana 120[26]	^{76}Ge	2039	ion.	86	1.6	4.5	2	0.[illegible]	0.07	90	R&D - reviewing
GERDA II[30]	^{76}Ge	2039	ion.	86	0.5	5	2	0.1	0.02	90÷290	funded/R&D (I: 0.3 kmol)
MOON III[42]	^{100}Mo	3034	track.	85	8.5	10	66	3.8	0.1	15	R&D (I: *small*)
CAMEO III[36]	^{116}Cd	2805	scint.	83	2.7	10	47	4	0.1	20	proposed
CUORE[34]	^{130}Te	2529	bol.	33.8	1.7	10	2	7.5	0.07	11÷57	construction
EXO[45]	^{136}Xe	2476	track.	65	60.0	10	25	1	4.1	11÷15	R&D (1.5 kmol)
SuperNEMO[44]	^{150}Nd	3367	track.	90	0.7	–	57	10	0.01	50	R&D
DCBA-F[43]	^{150}Nd	3367	track.	80	2.7	–	85	–	0.01	20	R&D (T2: *small*)
GSO[13]	^{160}Gd	22	scint.	22	2.5	10	83	200	0.02	65	proposed

Neutrino beam CERN -> Gran Sasso

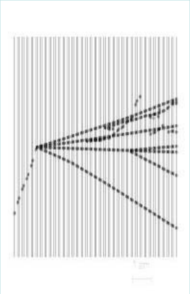
tau-neutrino appearance

OPERA

A hybrid emulsion and tracking detector

Goal: Verify that the ν_μ are oscillating into ν_τ

5 yrs
data taking



Pb target 1.8 kton

CNGS:
Beam $\langle E_\nu \rangle \approx$ 17 GeV
Baseline 732 km

Expected event rate:
~3600 ν NC+CC /kton/year
~16 ν_τ CC /kton/year

(for $\sin^2 2\theta_{23}=1$, $\Delta m_{32}^2=2.5\text{x}10^{-3}$ eV^2)

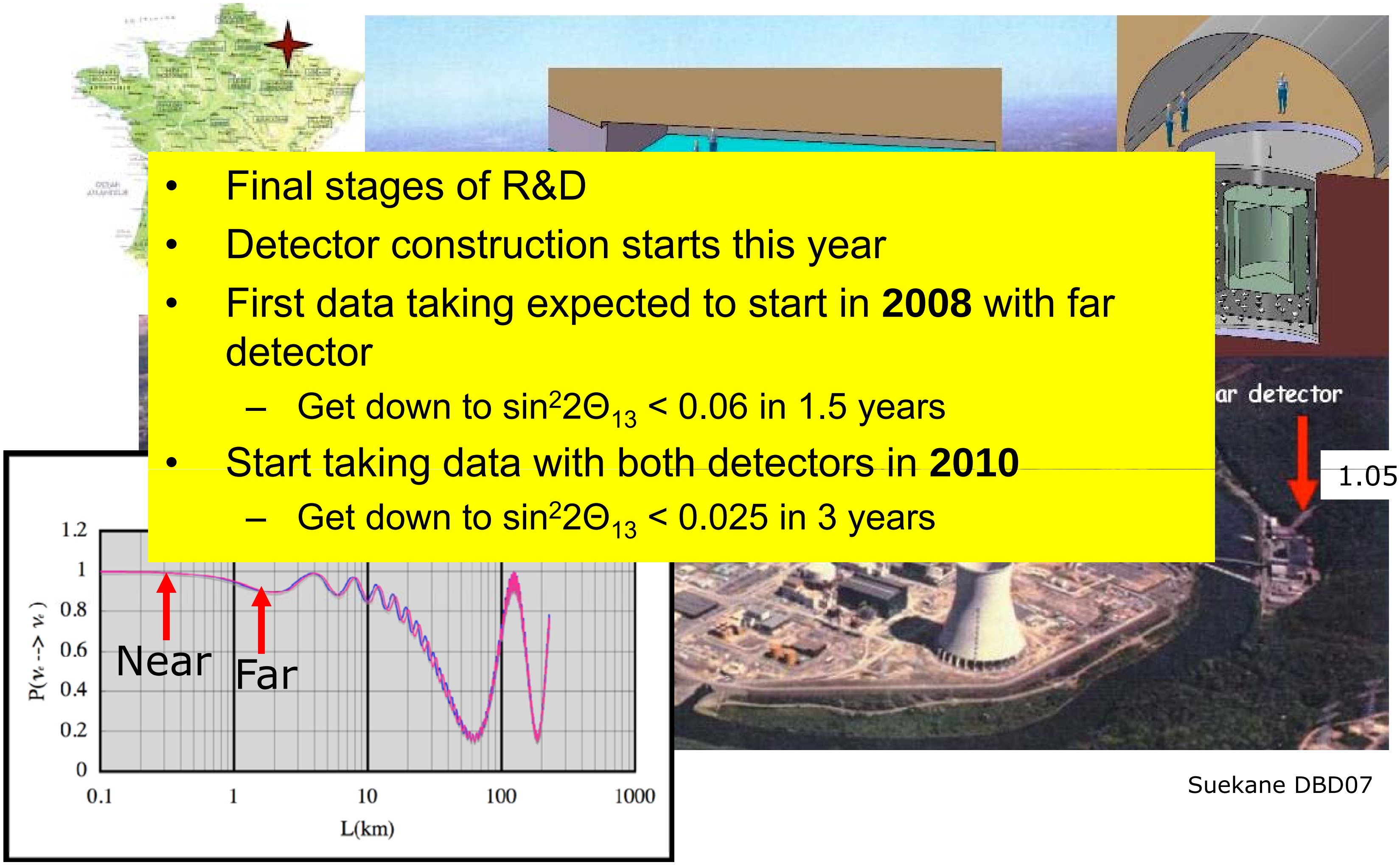
LAr detector

ICARUS

to demonstrate feasibility for future neutrino projects

Double Chooz

Θ_{13}



- Final stages of R&D
- Detector construction starts this year
- First data taking expected to start in **2008** with far detector
  - Get down to $\sin^2 2\Theta_{13} < 0.06$ in 1.5 years
- Start taking data with both detectors in **2010**
  - Get down to $\sin^2 2\Theta_{13} < 0.025$ in 3 years

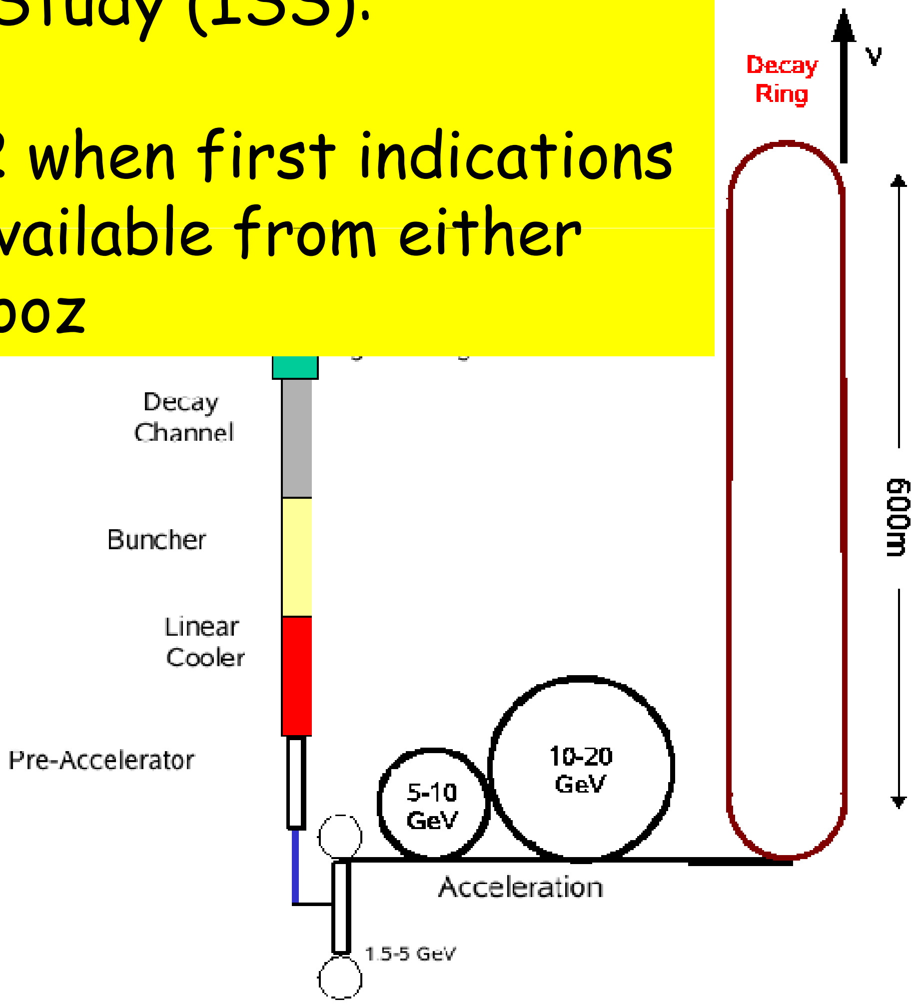
Suekane DBD07

Neutrino Factory

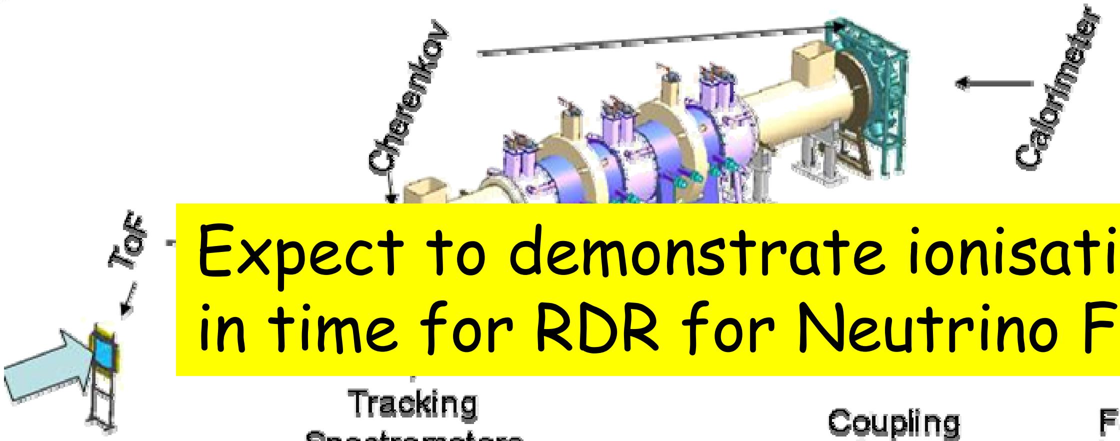
International Scoping Study (ISS):

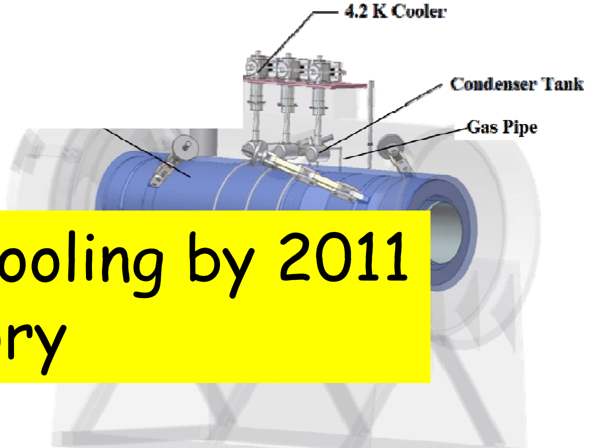
aim: have RDR by **2012** when first indications of Θ_{13} should be available from either T2K or Double-Chooz

- Pr
- Ta
- Cooling
  - Reduce transverse emittance
- Muon acceleration
  - ~130 MeV to 20-50 GeV
- Decay ring(s)
  - Store for ~500 turns
  - Long production straights

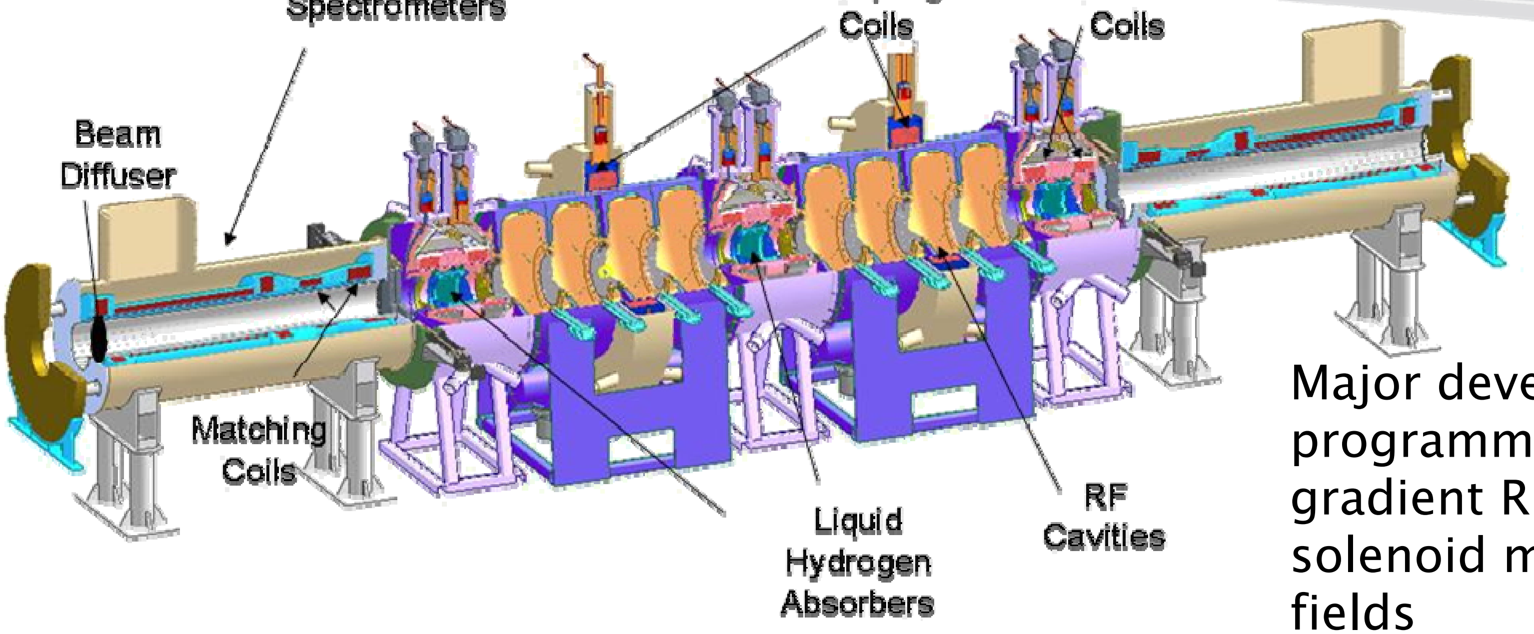


Muon Ionisation Cooling Experiment (MICE at RAL)





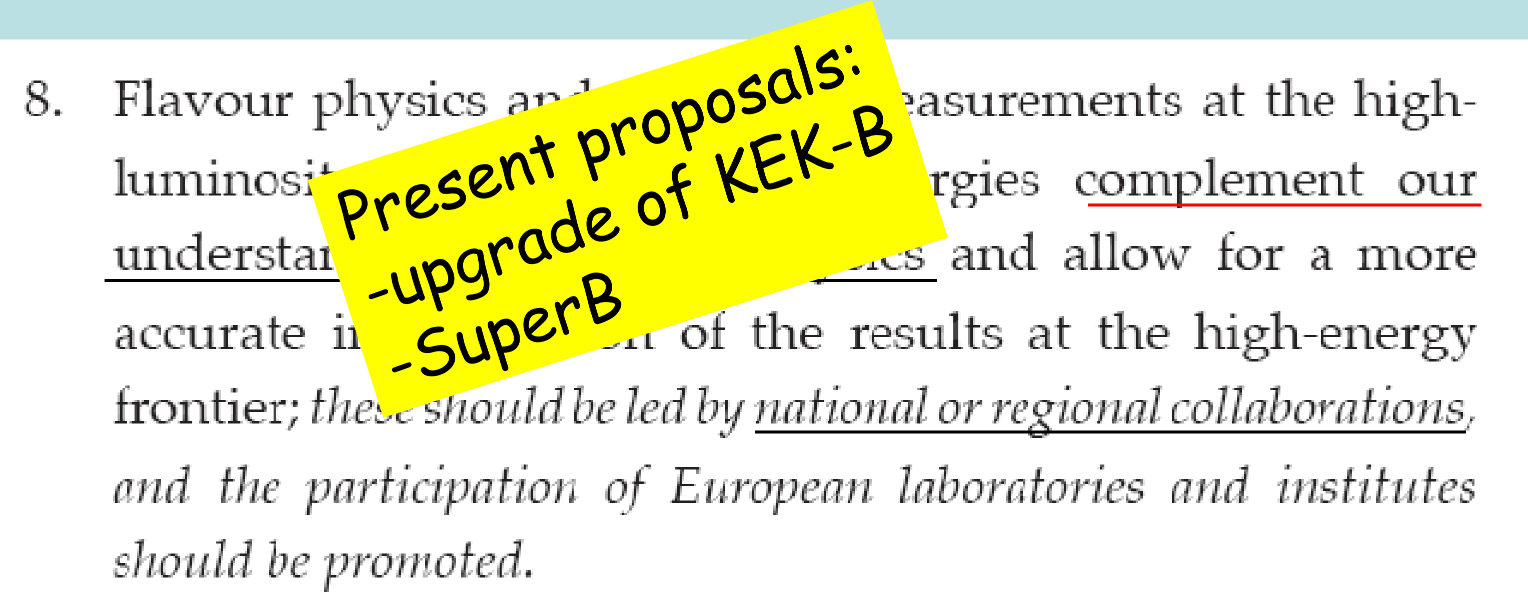
Expect to demonstrate ionisation cooling by 2011 in time for RDR for Neutrino Factory



Major development programme of high gradient RF cavities in solenoid magnetic fields

Flavour physics

The European Strategy for particle physics



8. Flavour physics an easurements at the high-luminosi rgies complement our understar ics and allow for a more accurate i n of the results at the high-energy frontier; *the should be led by national or regional collaborations, and the participation of European laboratories and institutes should be promoted.*

Present proposals:
-upgrade of KEK-B
-SuperB

A European Vision of the Future
or
Particle Physics in the next Decades

Introduction

Roadmap

General Remarks

General Remarks -1-

Turn on of LHC
entering an exciting phase of particle physics
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

But
LHC is a collaborative effort and needs
sustained efforts from all partners to make it a success

General Remarks -2-

Results from LHC will guide the way

Expect
- period for decision taking on next steps in 2010 to 2012

Need
- R&D and technical design work now to enable these decisions and is ongoing for several projects
- global collaboration and stability on long timescales (remember: first workshop on LHC was 1984)
- intensified efforts

How ?

General Remarks -3-

Collaboration in network of HEP laboratories/institutes
in Europe, Americas, Asia

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

Use the exciting times ahead to establish such a partnership