the future of the CERN accelerator complex

(emphasis on energy frontier)

Rolf-Dieter Heuer
CERN

From the PS to the LHC
50 Years of Nobel Memories in High-Energy Physics

CERN, 3 December 2009

"Discovery" of Standard Model

Through synergy of Colliders

hadron – hadron	(e.g. SPS Collider, Tevatron)
lepton – hadron	(HERA)
lepton – lepton	(e.g. LEP, SLC)

Key Questions in Particle Physics

origin of mass/matter or
origin of electroweak symmetry b

unification of forces

fundamental symmet and
matter

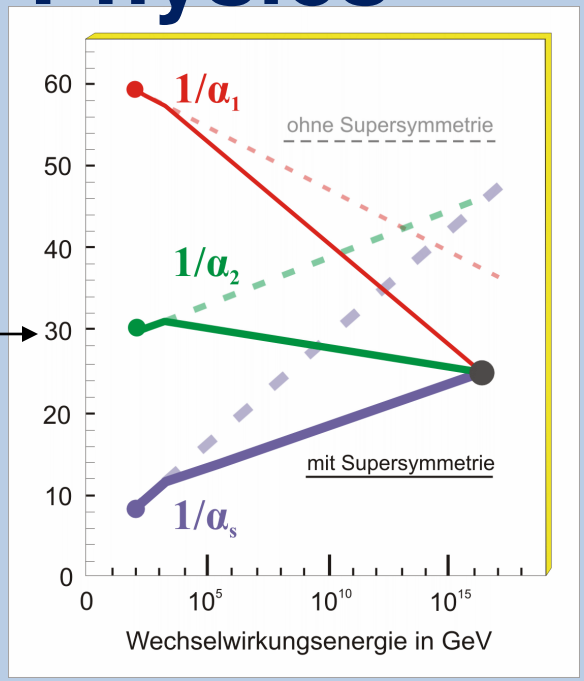
unification physics and
genera

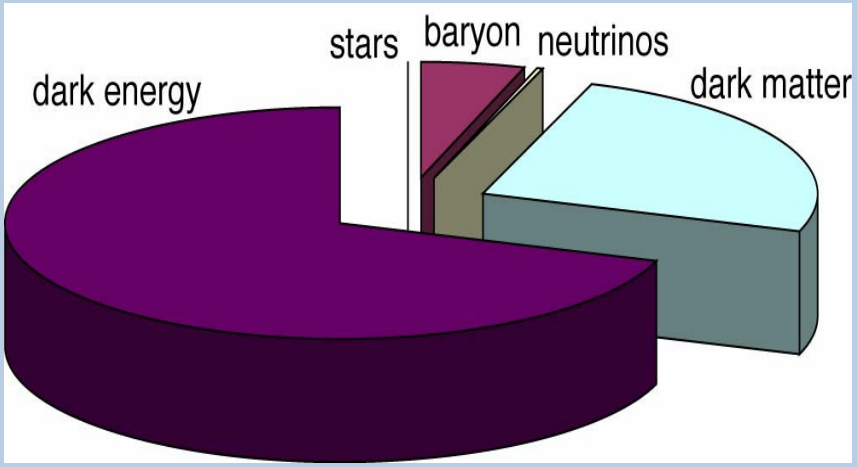
n ace/time dimensions

wh dark matter

what is dark energy

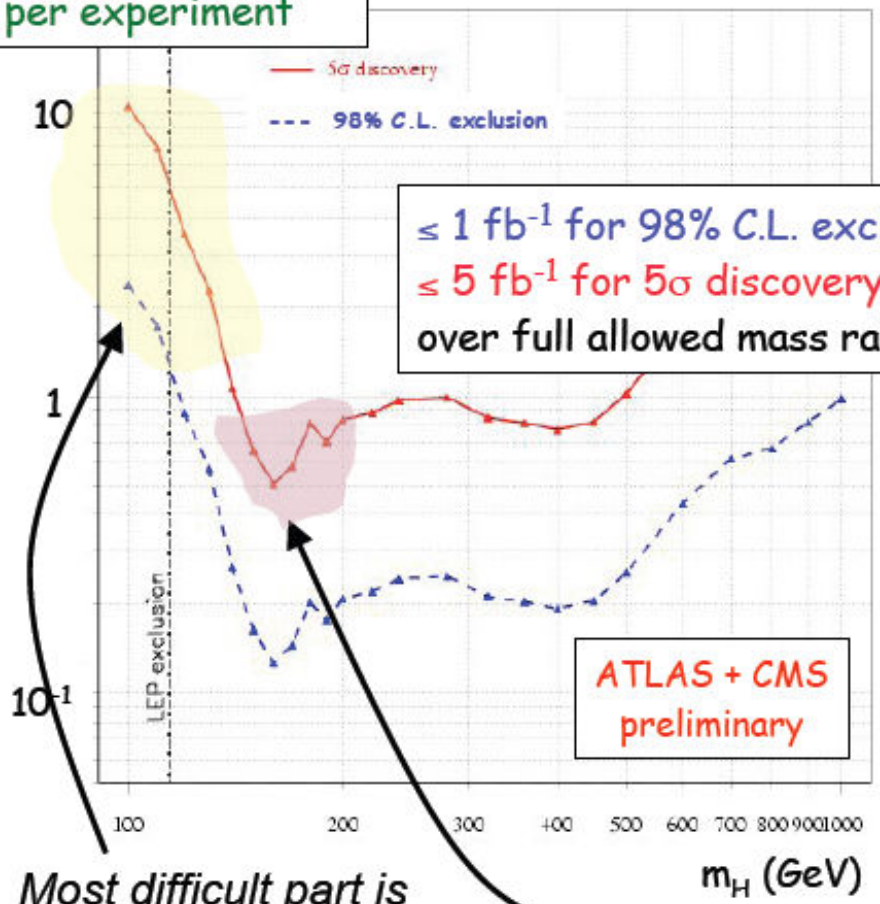
addressable at the energy frontier
first step: LHC





SM Higgs Reach

Needed $\int Ldt$ (fb^{-1}) per experiment

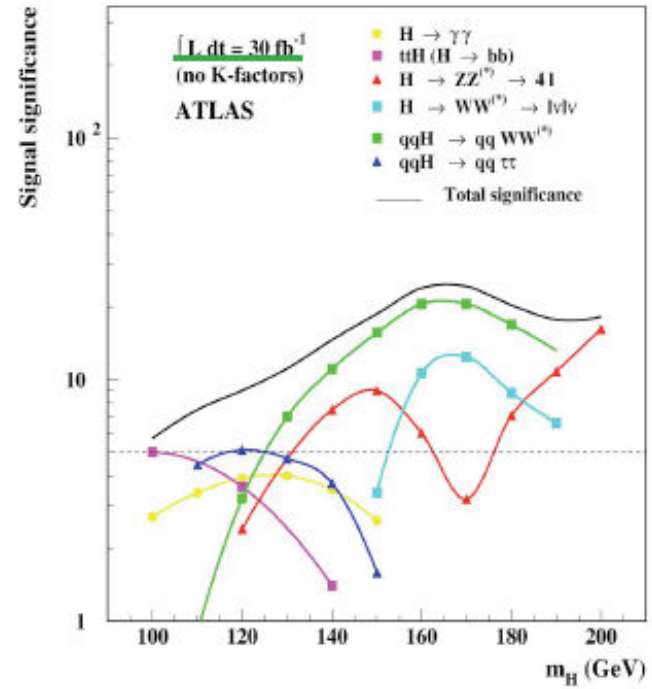


≤ 1 fb^{-1} for 98% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery
over full allowed mass range

ATLAS + CMS preliminary

Most difficult part is M_h~115 GeV

Early discovery already Possible with 1fb^{-1} $H \rightarrow WW^{(*)} \rightarrow 2l$



With 1fb^{-1} of understood data:

- *potential to exclude almost all m_h values*
- *potential to discover higgs with m_h~165 GeV*

LHC will give us an answer!

but it will take time. . .

The Next Decades

Initial Phase of LHC will tell the way to go

Possible ways beyond LHC

hadron - hadron collider (sLHC / DLHC)

lepton - lepton collider (ILC / CLIC)

lepton - hadron collider (LHeC)

The European Strategy for Particle Physics (2006)

One option: 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.*

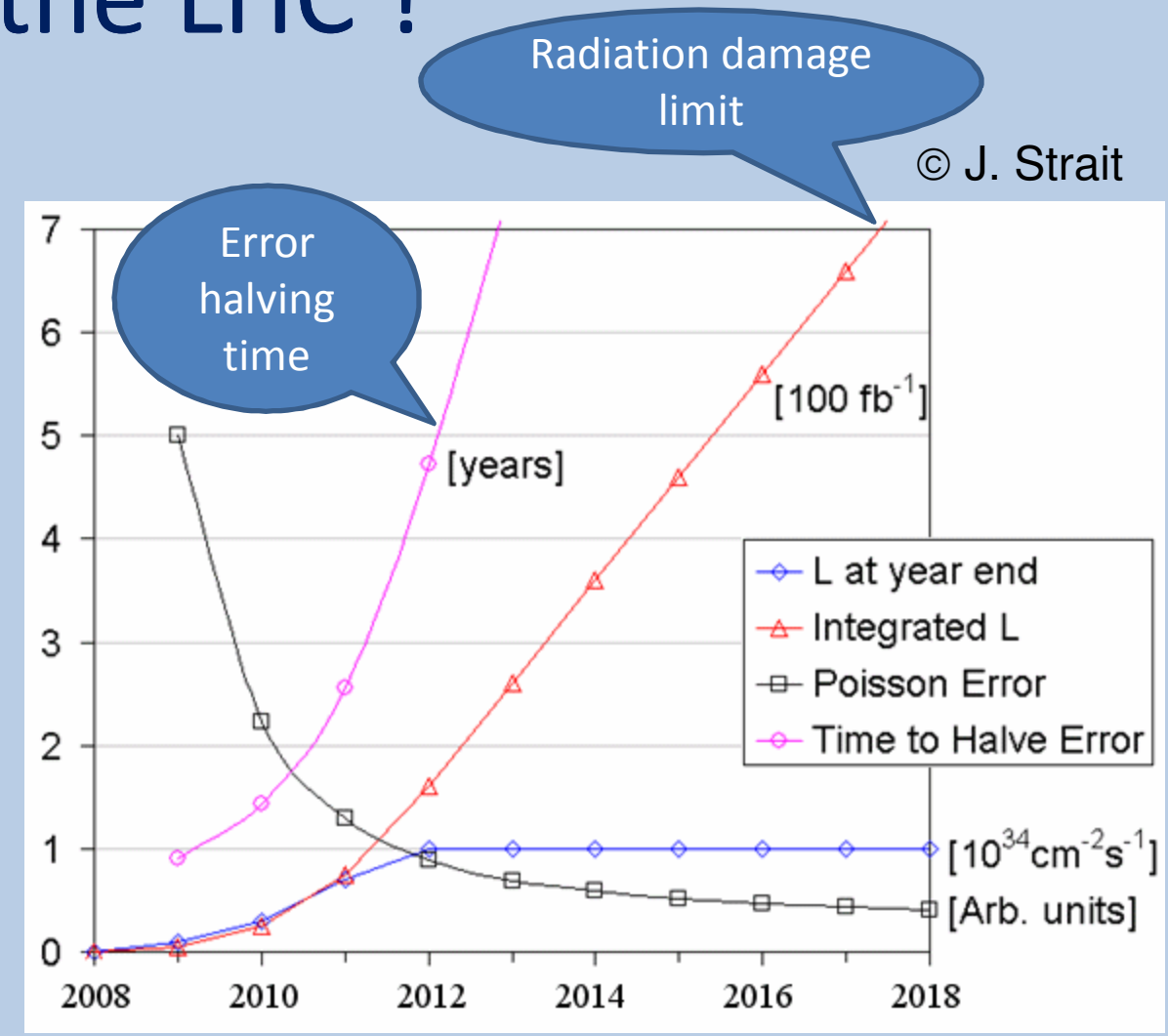
sLHC

Why Upgrade the LHC ?

- Hardware ageing

- Foreseeable luminosity evolution

⇒ **Need for a major luminosity upgrade (sLHC)**



sLHC

Extending the Physics Potential of the LHC

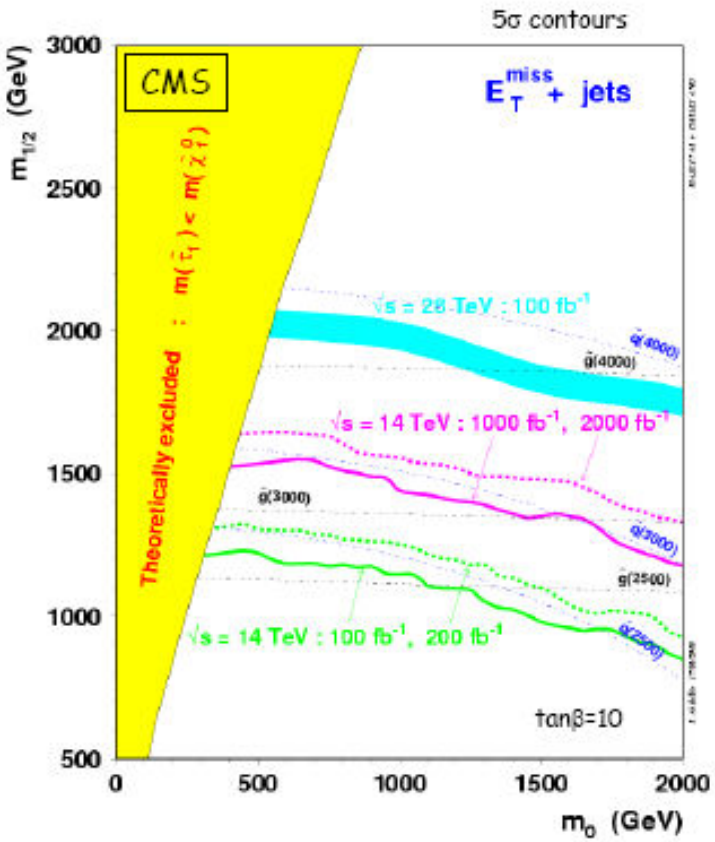
- Electroweak Physics
  - Production of multiple gauge bosons (nv3)
    - Triple & quartic gauge boson couplings
  - Top quarks / rare decays
- Higgs Physics
  - Rare decay modes
  - Higgs couplings to fermions & bosons
  - Higgs self-couplings
  - Heavy Higgs bosons of the MSSM
- Supersymmetry
- Extra Dimensions
  - Direct graviton production in ADD models
  - Resonance production in Randall-Sundrum models TeV-1 scale models
  - Black hole production
- Quark substructure
- Strongly-coupled vector boson system
  - $W_L Z_L g$, $W_L Z_L$, $Z_L Z_L$ scalar resonance, $W^+_L W^+_L$
- New gauge bosons

see CERN-TH/2002-078
hep-ph/0204087
April 1, 2002

Supersymmetry

Impact of the SLHC
Extending the discovery region by roughly 0.5 TeV i.e. from
~2.5 TeV → 3 TeV

This extension involved high E_T jets/leptons and missing E_T
⇒ Not compromised by increased pile-up at SLHC



LHC Luminosity (upgrade)

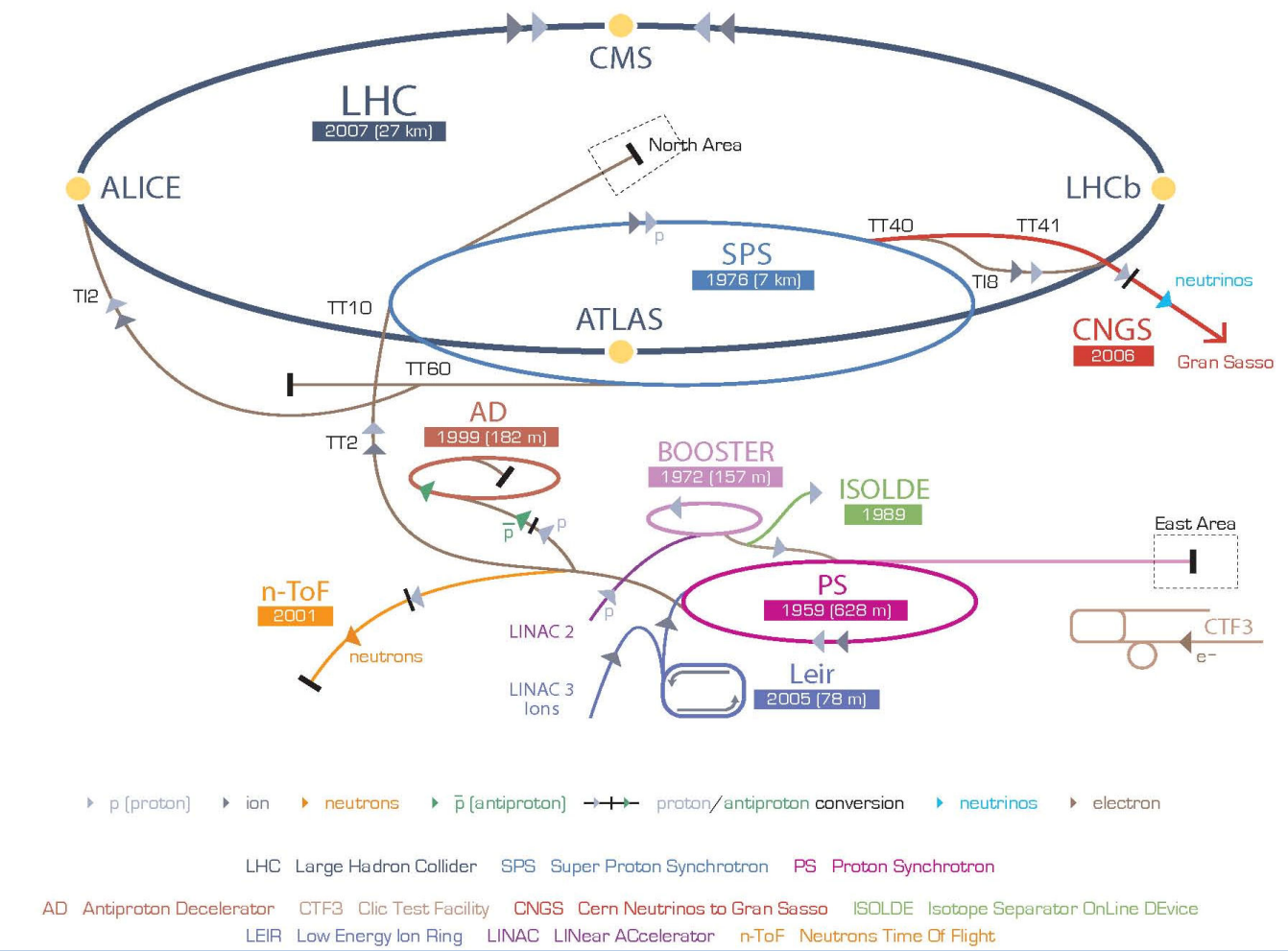
Goal: Maximize useable integrated luminosity for physics
key parameters: instantaneous luminosity, luminosity lifetime, efficiency, data quality (pile-up, radiation). . .

Steps:

1) Optimize running times vs shutdown times

2) Upgrade in several phases
Phase1: approved
Phase2[sLHC]: R&D
Study several options
in particular: consolidation and improvement program for the whole injector chain (Linac, Booster, PS, SPS) plus changes to the interaction region

The CERN Accelerator Complex



LHC Beam Route

LINAC2
BOOSTER
PS
SPS

Phase-I Status

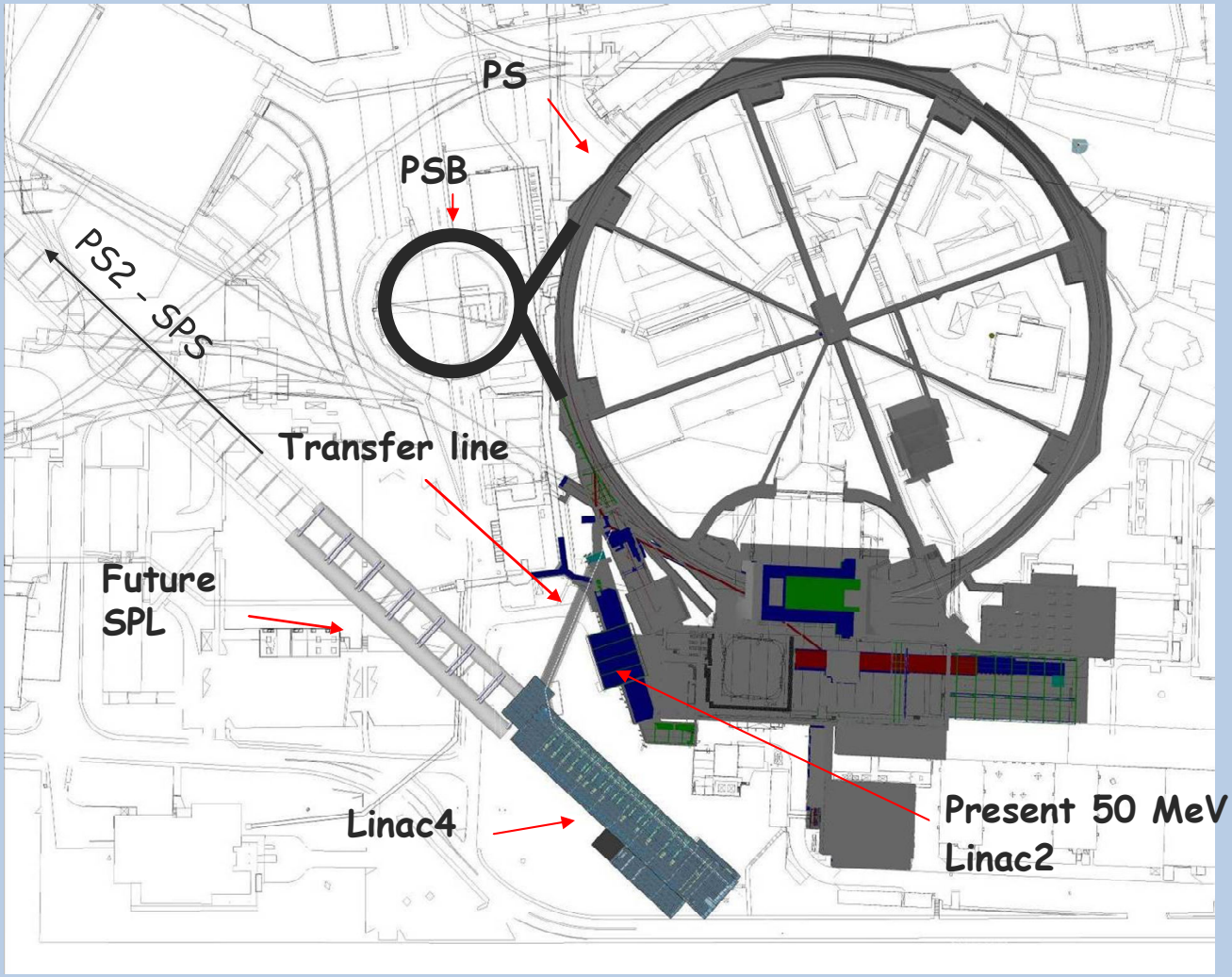
- Conceptual quadrupole design available
- Modifications for matching section under study
- Magnet model work advancing
- LINAC 4 under construction
- ready for earliest installation 2014/2015
- For “full” Phase-I upgrade needs long shutdown
  → coordination with experiments’ plans needed

IR mod (inner Triplet)

Linac4

Linac4 because the 4th linear accelerator to be built at CERN, replacing the present Linac2 as proton injector for the CERN accelerator complex.

Civil engineering works have started in one of the last free locations on the CERN site, in a position offering a simple connection to the present machines and the option of a future extension to the high-energy SPL linac.



Linac4 Construction

- Schedule - Ready by 2013/2014
- Long shutdown needed to connect

Beyond 2015

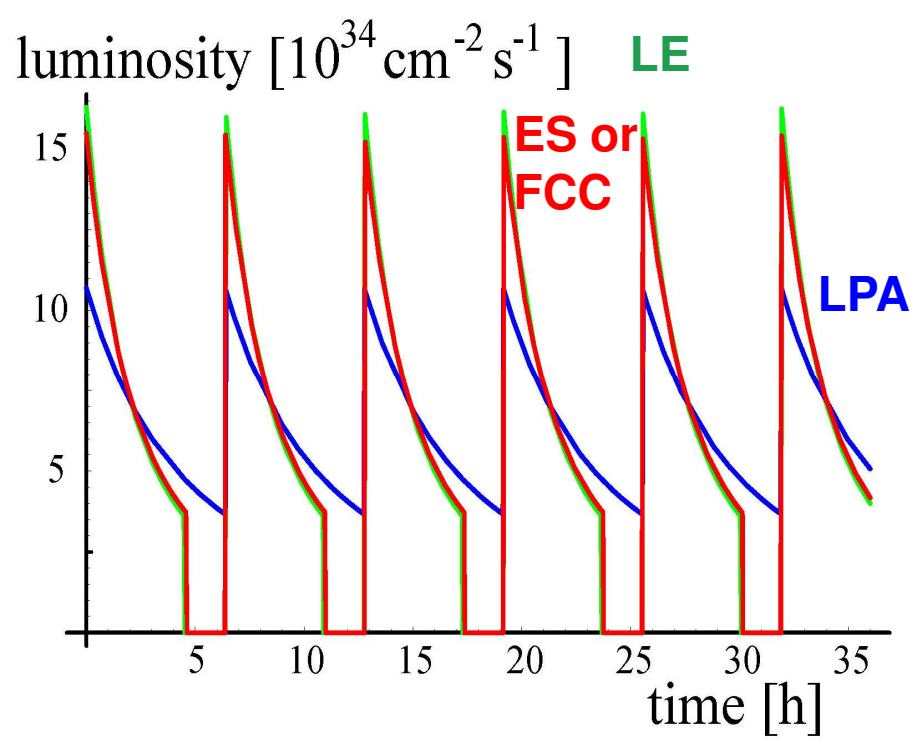
- Several LHC upgrade scenarios under discussion
  - **Injector chain**
    - Ageing accelerators operating far beyond original design
    - Main limitation is space charge at injection in PSB and PS
      - Higher injection energies and better beam quality through the chain
        - » LINAC4
        - » Superconducting Proton Linac (SPL)
        - » PS2
  - **Consolidation and improvement of existing injector chain (PSB, PS, SPS)**
  - **β* and Final Focusing**
    - IR upgrade in Point 1 (ATLAS) and Point 5 (CMS)
      - Allows to reach β* =0.3m from nominal β* =0.55m
  - **In addition**
    - Crab cavities
    - Luminosity leveling
    - Lower emittance (from injector upgrades)

Taking into account the non-LHC physics

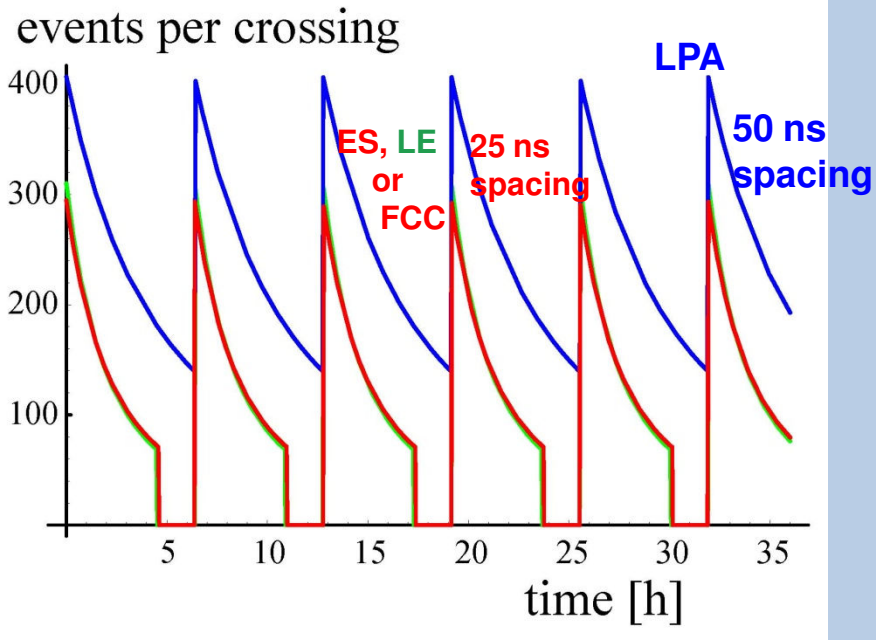
Peak vs Integrated Luminosity

- The experiments need to plan for a substantial increase of integrated luminosity.
  - 3000 fb^{-1} may be accumulated in the next 20 years
- A peak luminosity of 10^{35} cm^{-2} s^{-1} complicates the construction and operation of the detectors
  - Finer ID granularity, larger events to be acquired and to trigger on, more noise induced by neutrons, more stringent radiation hardness requirements, more complexity in the physics reconstruction!
- The experiments are embarking on a very complex upgrade road map, with material resources and 8-9 years of intense construction work.

Luminosity Life time



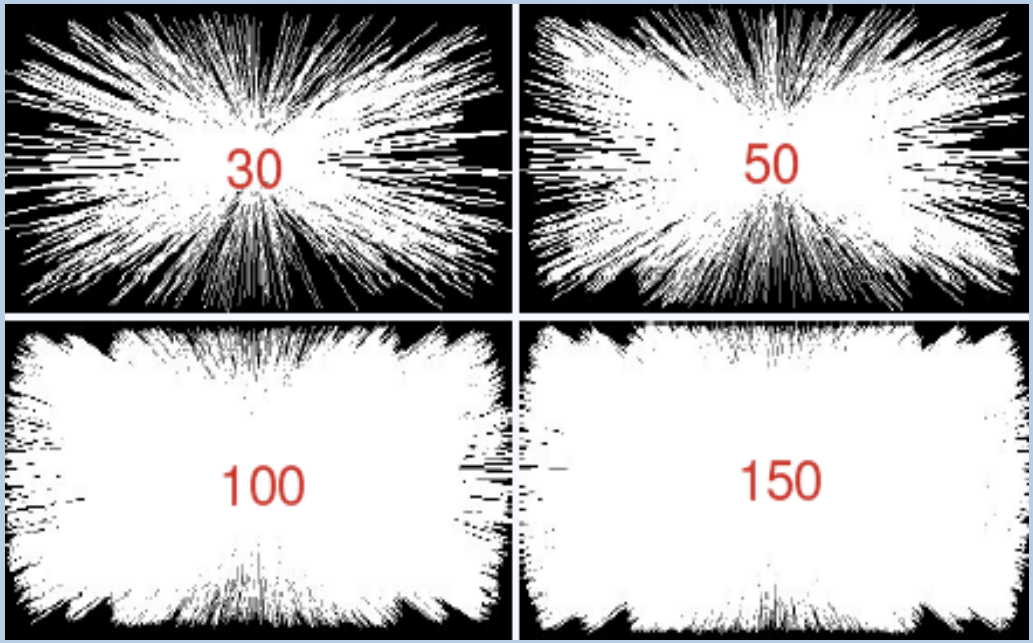
Very short beam lifetime, very difficult experimental environment at the beginning of the fill, short cycles (5-6 hours)

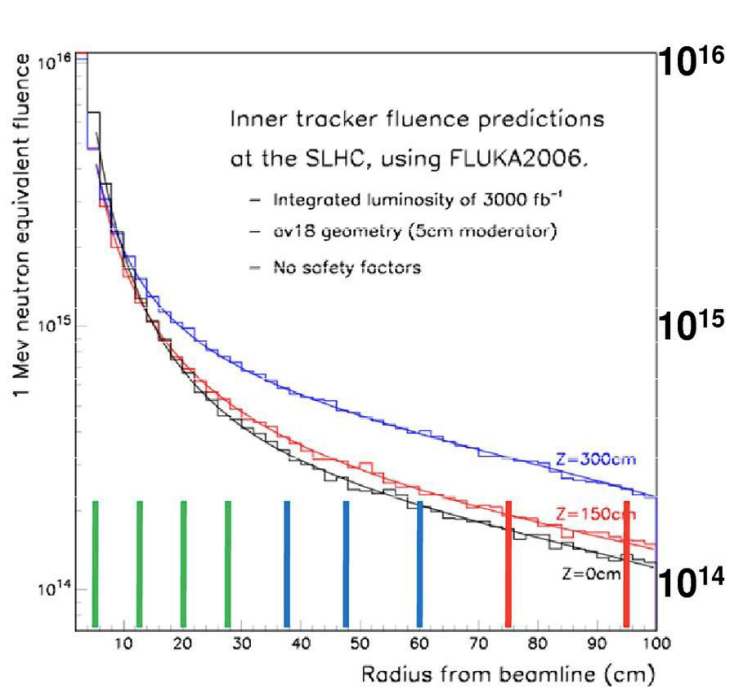


expected fast decay of luminosity (few hours) dominated by proton burn-off in collisions

$$\tau_{eff} = \frac{N_b n_b}{n_{IP} \hat{L} \sigma_{tot}}$$

Detector Environment & Requirements





*Minimum bias event **pile-up** dominated by the peak luminosity. sLHC scenarios define the value we have to assume in our design (today's worst case **300 to 400 pile-up events / bunch crossing**). Detector granularity, detector transparency and trigger strategy will need to be tuned to it.*

*Detector **radiation** resistance requirement dominated by the delivered integrated luminosity. Here the detector radius and pseudorapidity (η) are the scaling factors. 10^{17} n/cm^2 will be the fluence at the front face of the forward calorimeters*

Luminosity Leveling

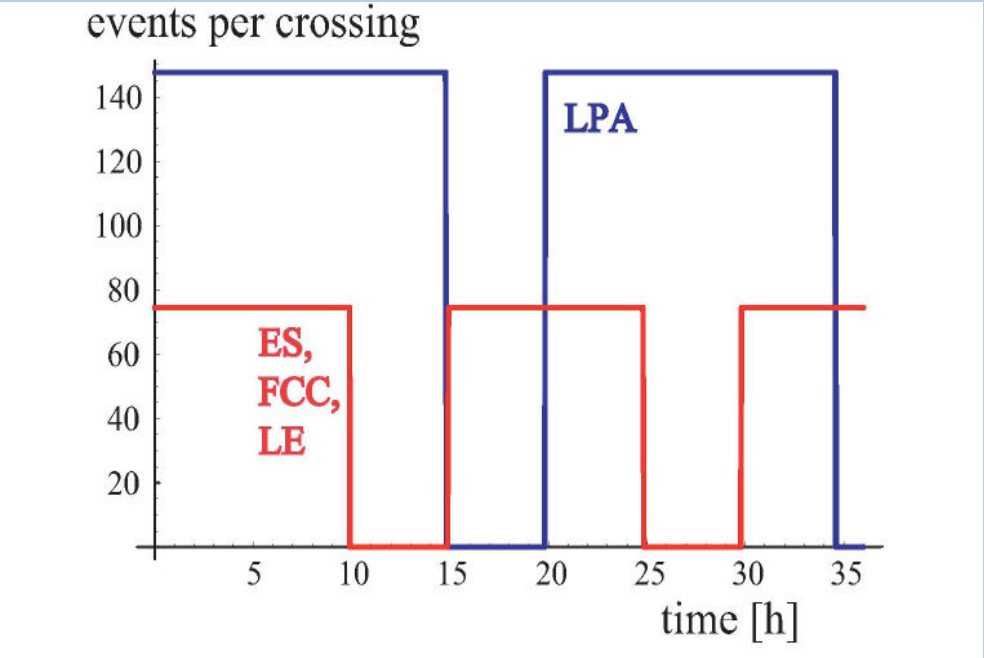
Luminosity leveling

(change dynamically θ_c , β^* or σ_z in store to keep luminosity constant) becomes a powerful strategy to reduce event pile up in the detector & peak power deposited in IR magnets

Leveling with crossing angle has distinct advantages

- increased average luminosity if beam current not limited
- operational simplicity

Natural option for early separation or crab cavities



Flat luminosity profile (~80 events per crossing, ~10 h fill lifetime for leveling with crossing angle)

Optimize Integrated Luminosity vs. Peak Luminosity

the Energy Frontier beyond LHC

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.*

Linear e+e- Colliders

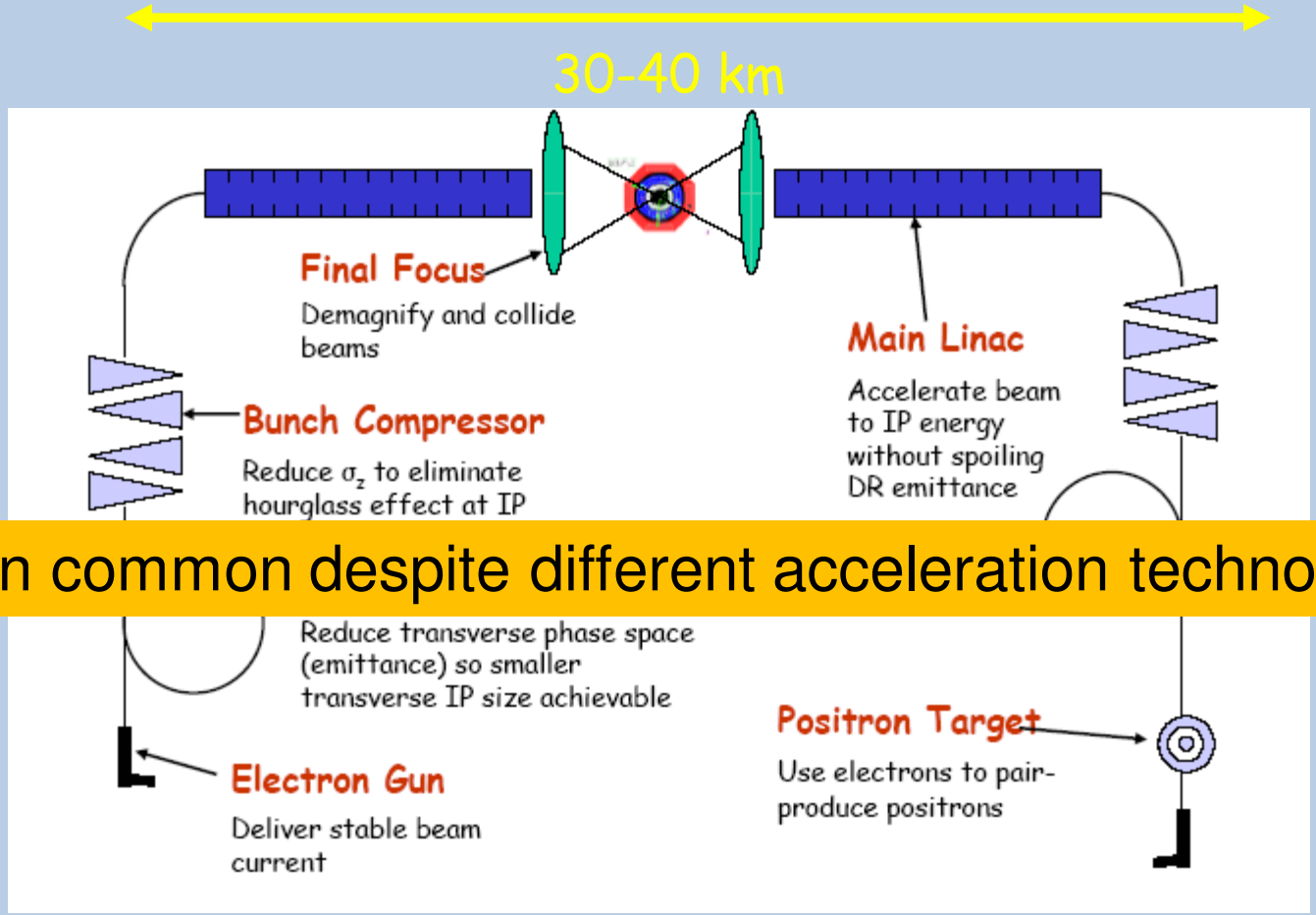
- The machine which will complement and extend the LHC best, and is closest to be realized, is a Linear e+e- Collider with a collision energy of at least 500 GeV.

PROJECTS:

⇒ TeV Colliders (CMS energy up to 1 TeV) → Technology ~ready
→ ILC with superconducting cavities

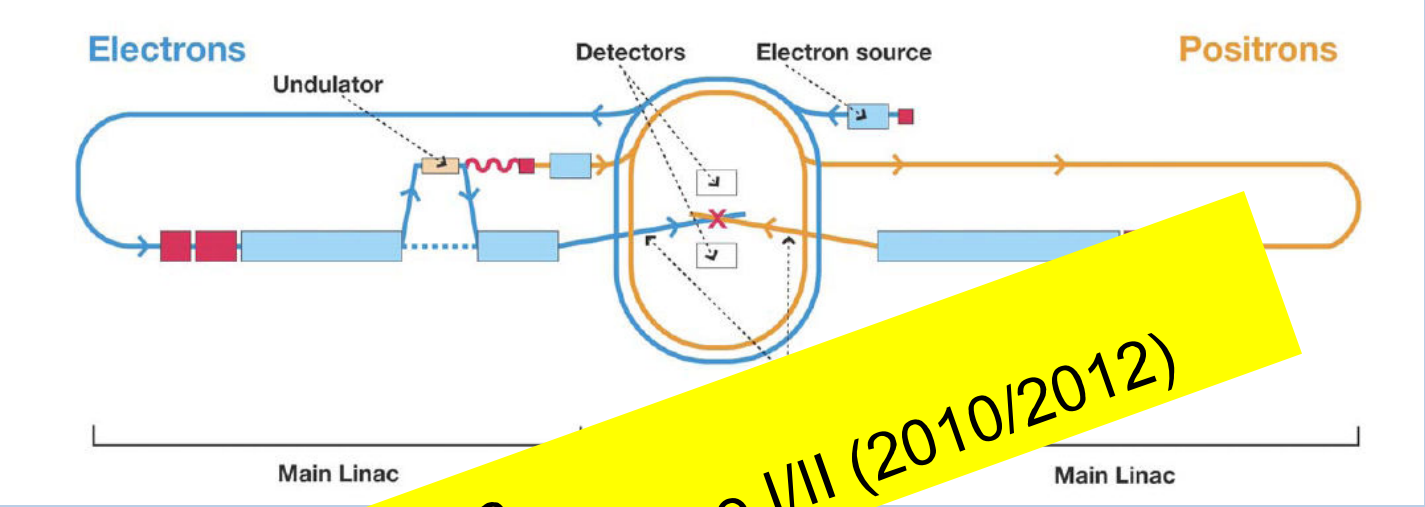
⇒ Multi-TeV Collider (CMS energy in multi-TeV range) → R&D
→ CLIC (Two Beam Acceleration)

A Generic Linear Collider

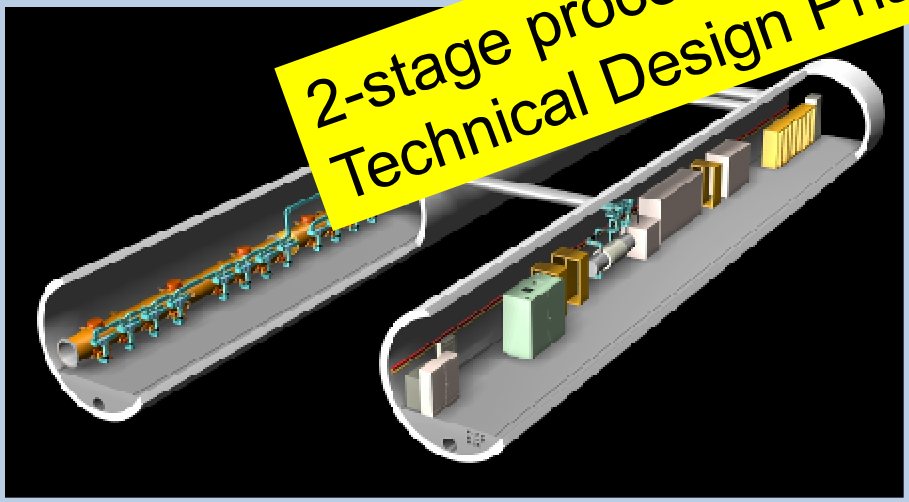


Much in common despite different acceleration technologies

The International Linear Collider

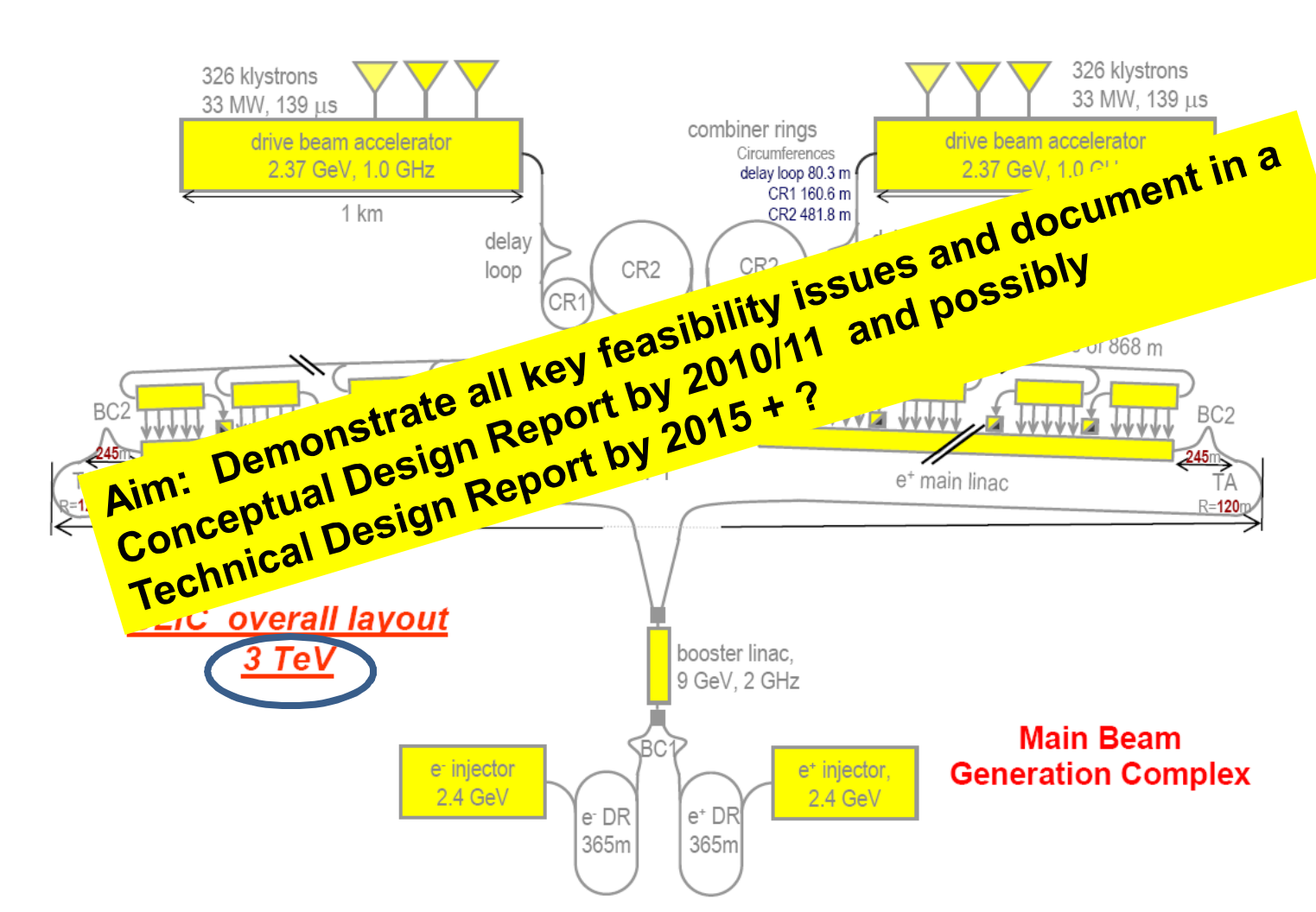


2-stage process
Technical Design Phase I/II (2010/2012)

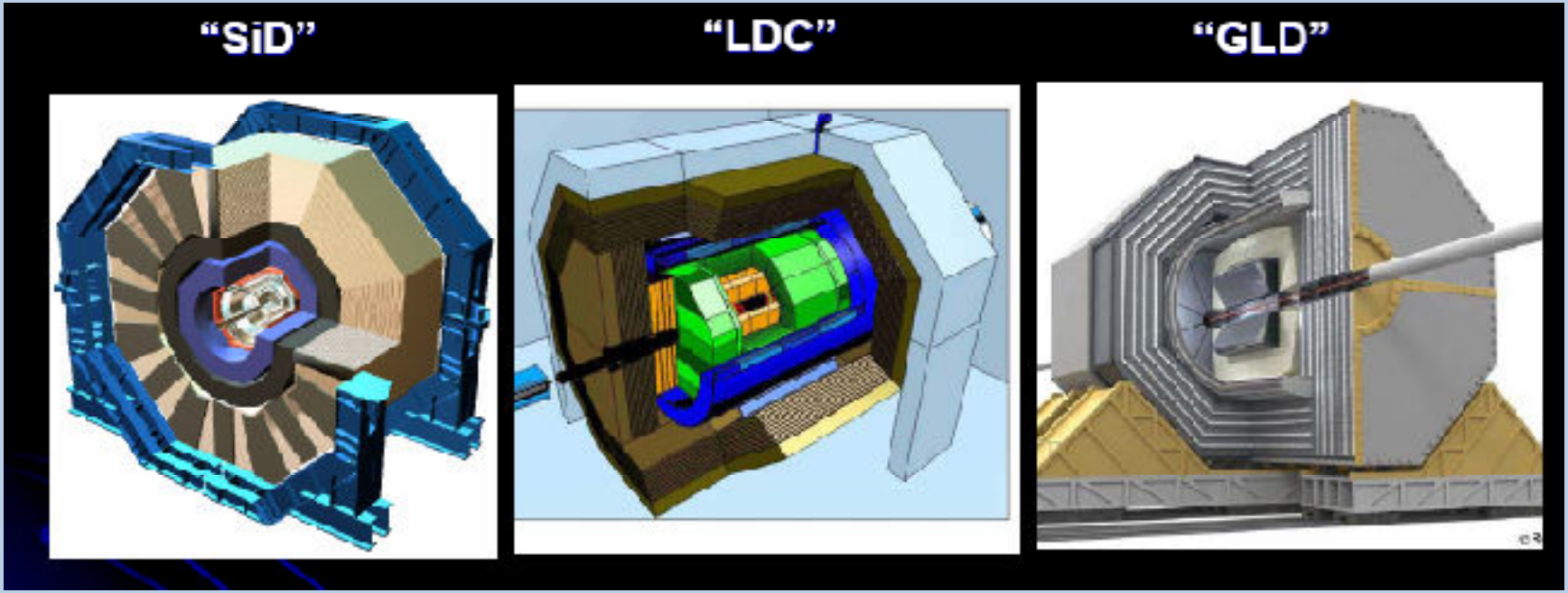


Energy	250 Gev x 250 GeV upgradable
# of RF Units	560
# of Cryomodules	1680
# of 9-cell Cavities	14560
Accelerating Gradient	31.5 MeV/m
Peak luminosity	2 10^{34} $cm^{-2}s^{-1}$
Rep. Rate	5 Hz
IP	σ_x 350 – 620 nm; σ_y 3.5 – 9.0 nm
Total Power	~230 MW
2 Detectors Push-pull	

CLIC Overall Lay-out

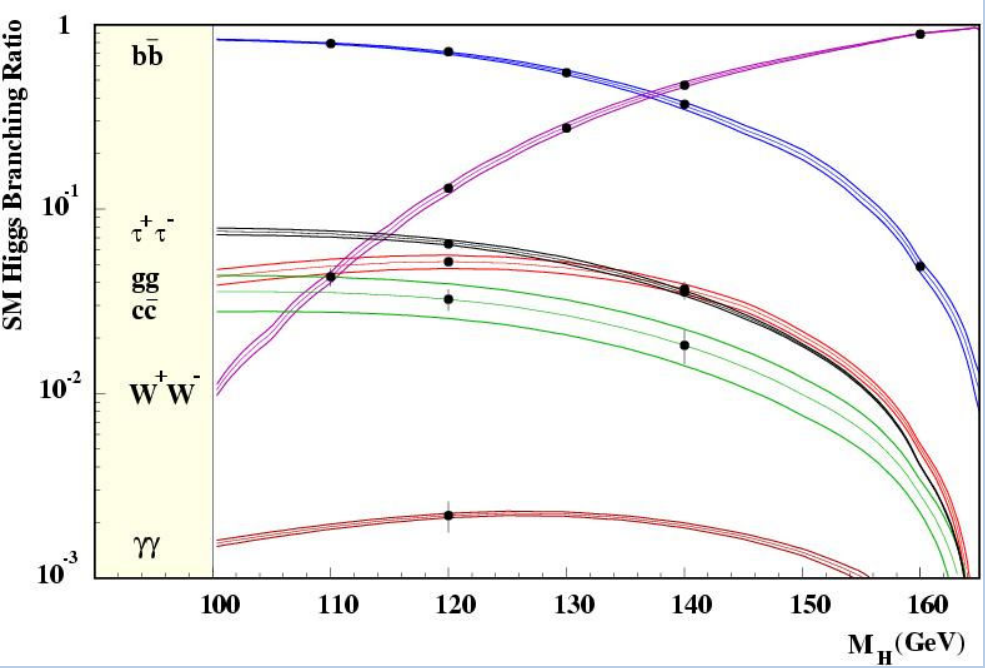


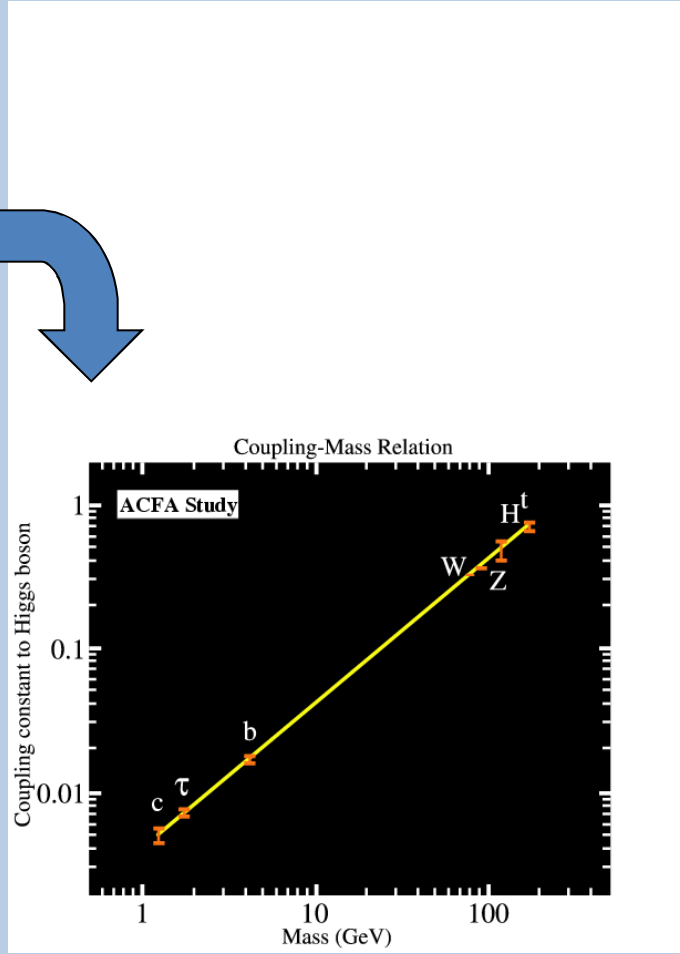
Generic Detector Concepts



A lot of R&D work on detectors is in progress: good tracking resolution, jet flavour tagging, energy flow, hermeticity,…

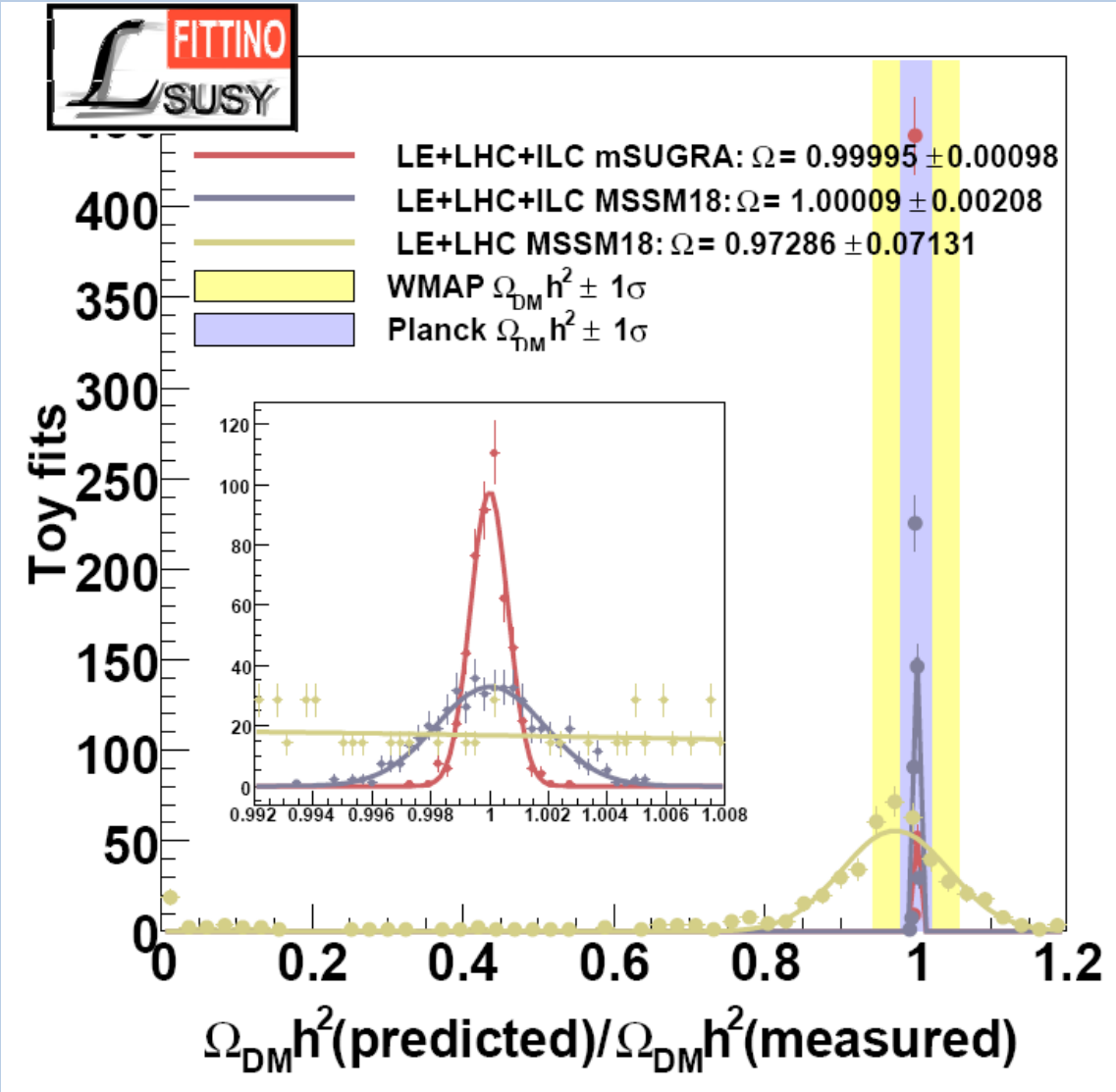
Precision Higgs Physics
LHC and Linear Collider



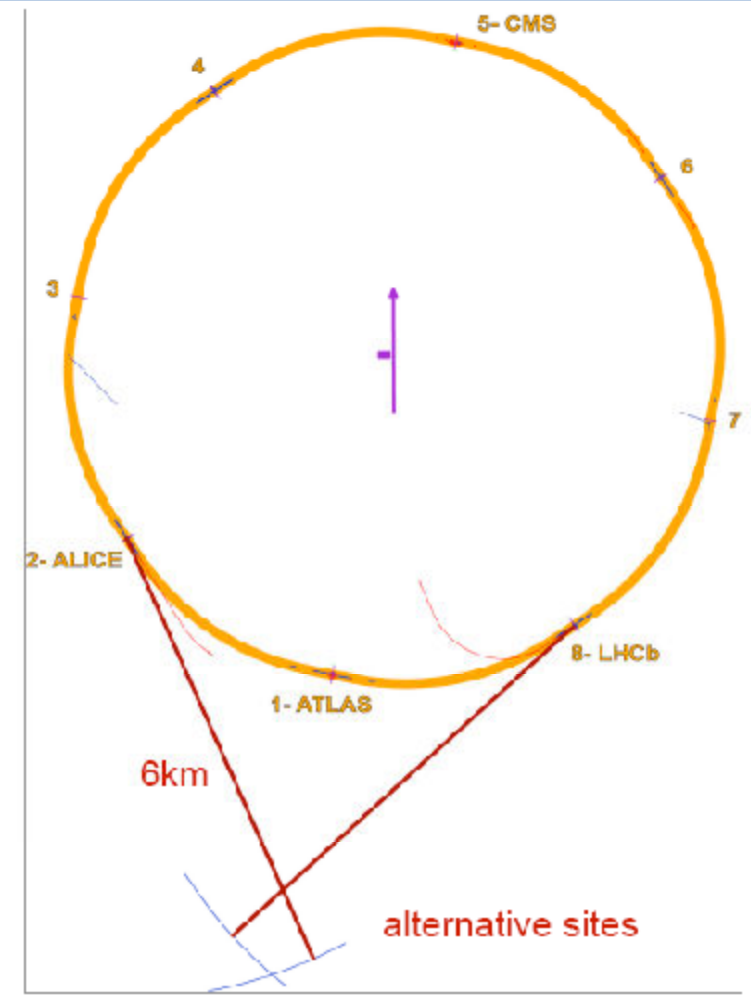


Determination of absolute coupling values with high precision

Dark Matter and SUSY



Large Hadron electron Collider



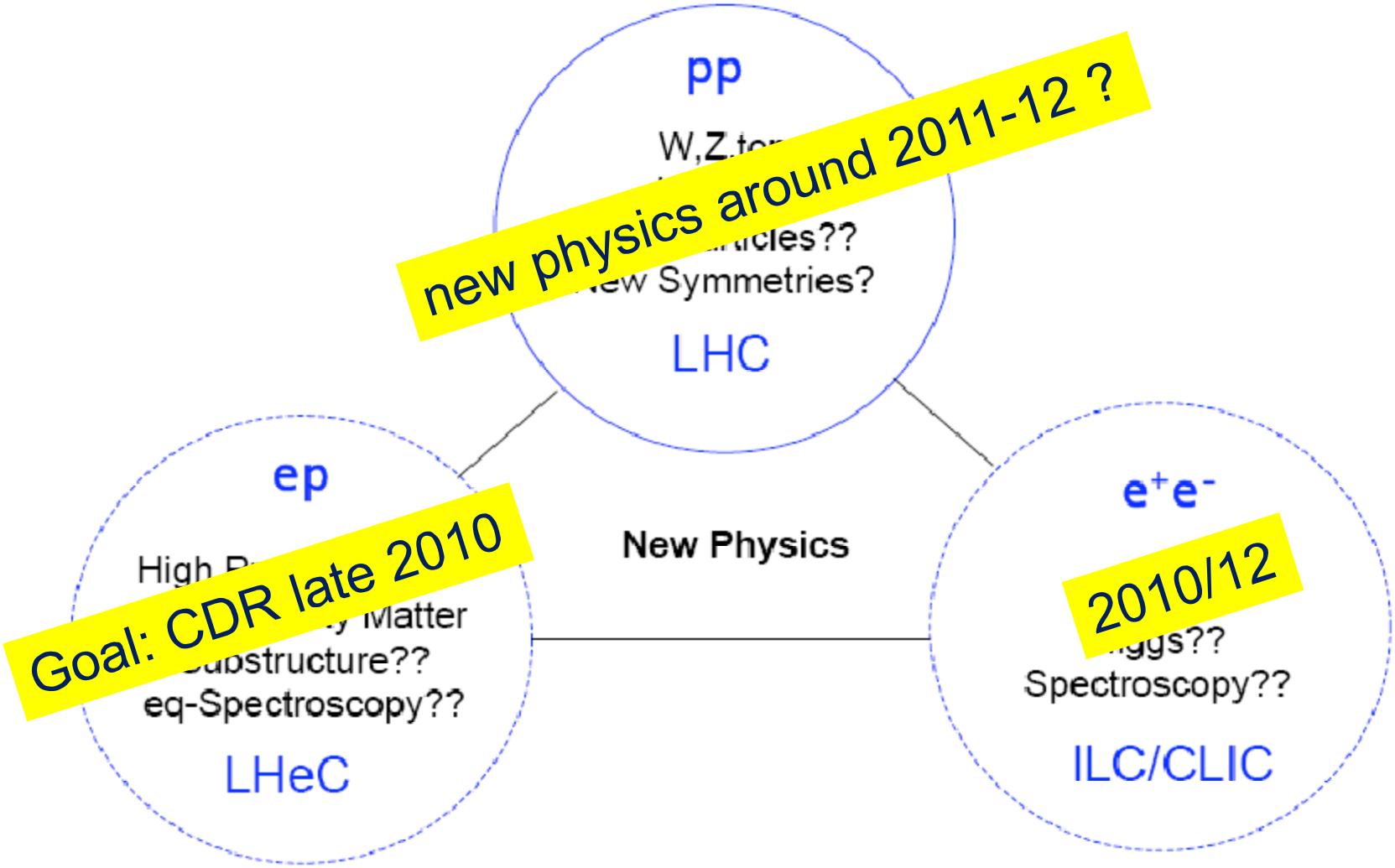
40 - 140 GeV
on
1 - 7 TeV

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

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

Would be the successor of HERA at higher centre-of-mass energy

The TeV Scale [2008-2033..]



Key Messages

- No clear cut case yet beyond LHC
- Synergy of Colliders (ee, ep, pp)
- sLHC serves dual purpose
    - Luminosity increase and rejuvenation of CERN accelerator complex
- Converge towards one Linear Collider project
  - ILC could be constructed now
  - CLIC more R&D needed
- Detector R&D mandatory for all projects
- LHC results decisive to guide the way forward

Great opportunities ahead at the TeV scale

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