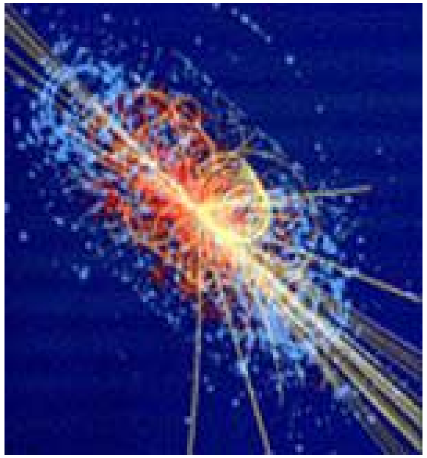
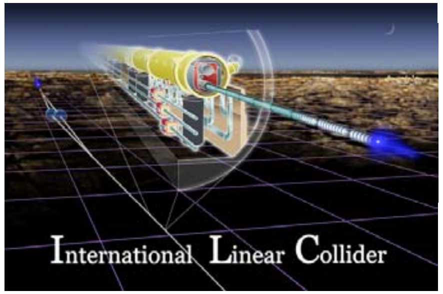
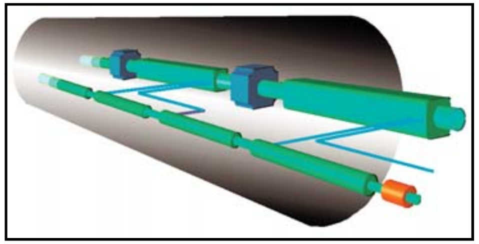
From LHC to SLHC & ILC and Beyond

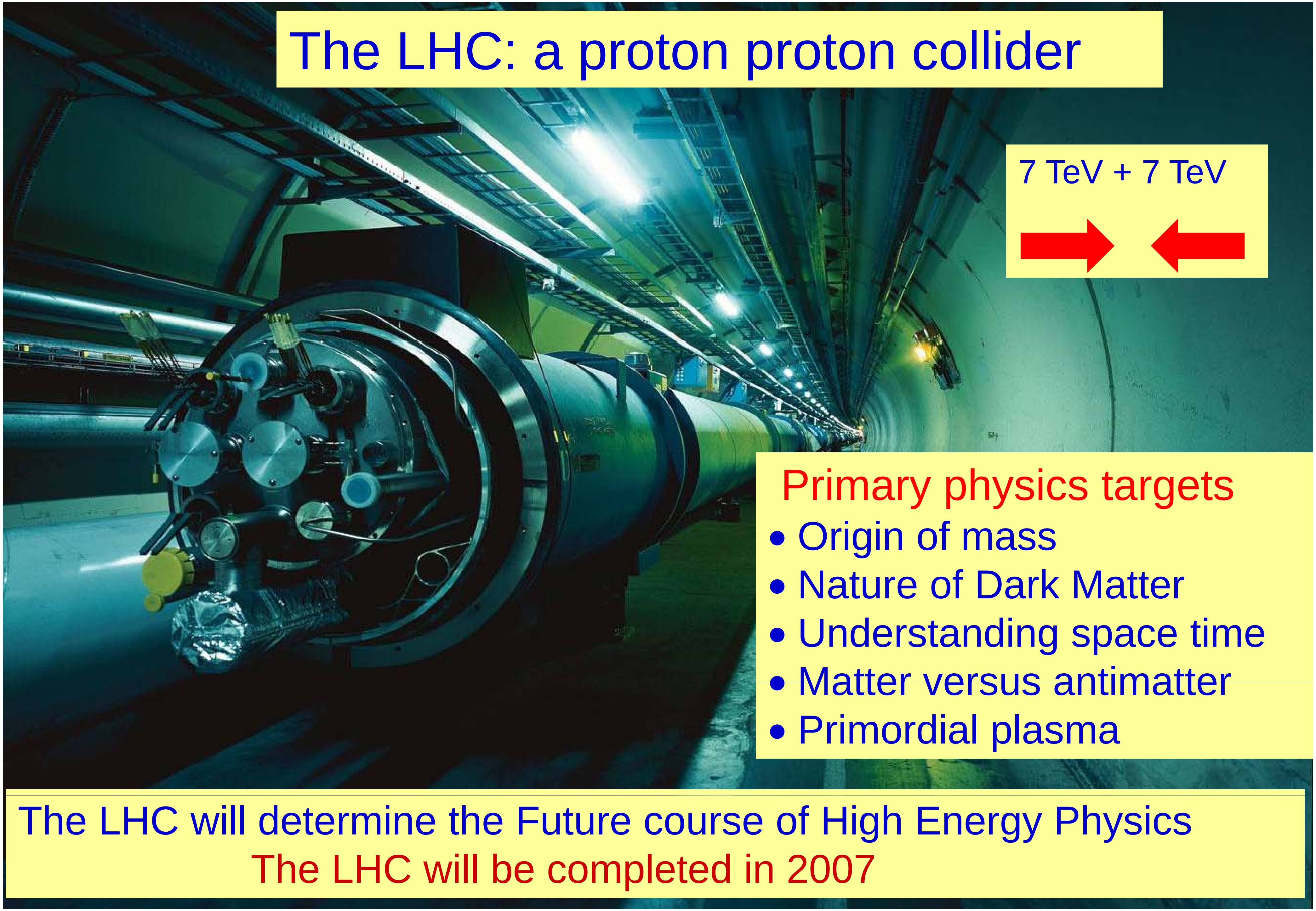
Albert De Roeck
CERN
and University of Antwerp
and the IPPP Durham







The LHC: a proton proton collider



7 TeV + 7 TeV

Primary physics targets

- Origin of mass
- Nature of Dark Matter
- Understanding space time
- Matter versus antimatter
- Primordial plasma

The LHC will determine the Future course of High Energy Physics

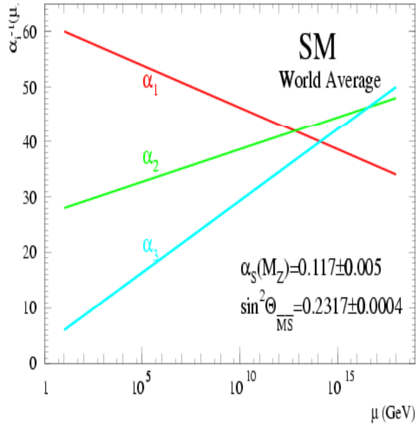
The LHC will be completed in 2007

Physics case for new High Energy Machines

Understand the mechanism Electroweak Symmetry Breaking

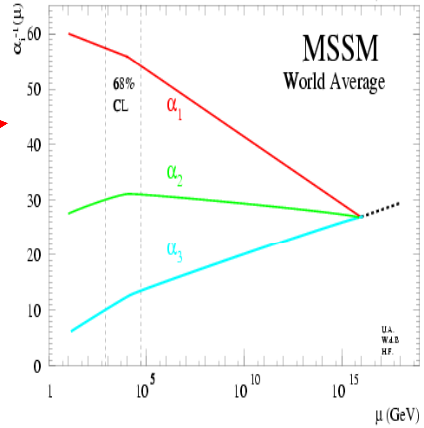
Discover physics beyond the Standard Model

Reminder: The Standard Model
- tells us how but not why (contains 19 parameters!)
  3 flavour families? Mass spectra? Hierarchy?
- needs fine tuning of parameters to level of 10^{-30} !
- has no connection with gravity
- no unification of the forces at high energy



Most popular extensions these days

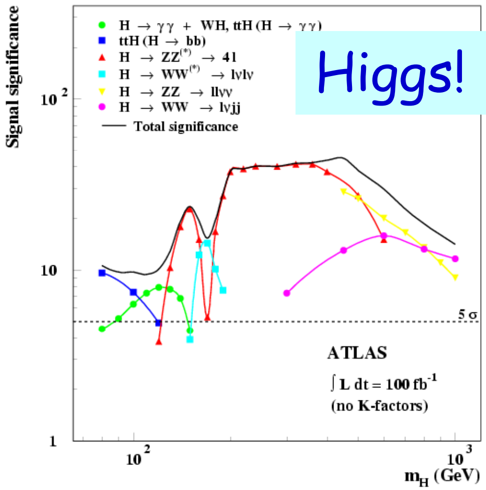
If a Higgs field exists:
- Supersymmetry
- Extra space dimensions



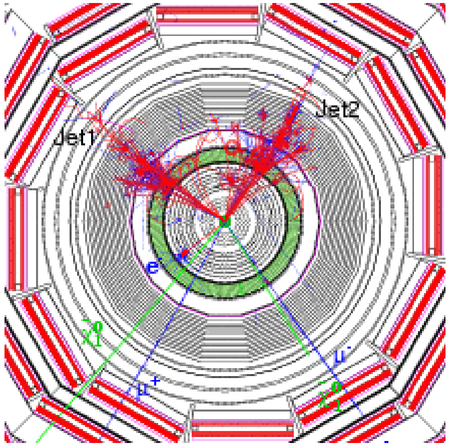
If there is no Higgs below ~ 700 GeV
- Strong electroweak symmetry breaking around 1 TeV

Other ideas: more gauge bosons/quark & lepton substructure, Little Higgs models…

Physics at the LHC: pp @ 14 TeV

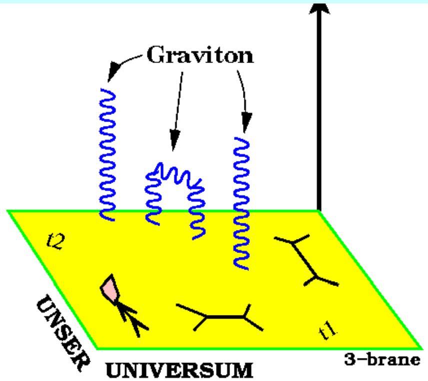


Higgs!

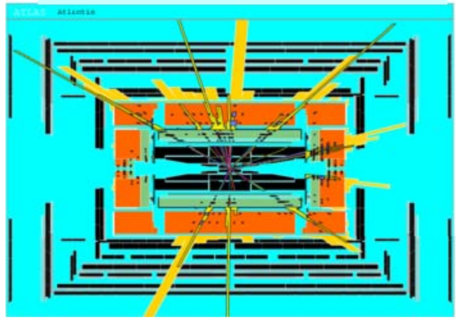


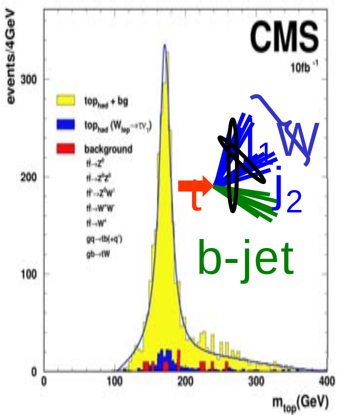
Supersymmetry?

Extra Dimensions?

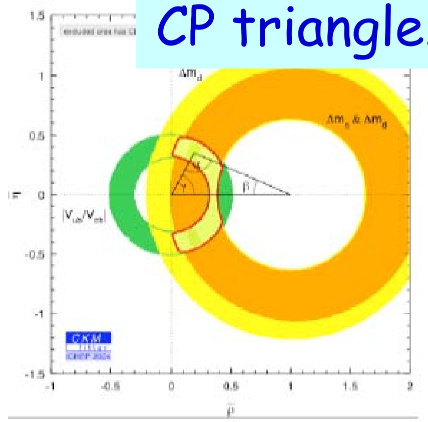


Black Holes???



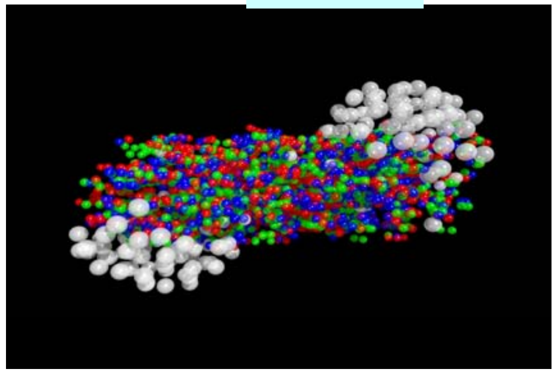


Precision measurements e.g top!



CP triangle!

QGP?



The LHC will be the new collider energy frontier

January 06 The Orsay Symposium : HEP in Europe

About 400 participants
47 documents submitted
⇒the European Strategy Document

Consequences for CERN

- consolidation of the LHC operation
- preparation for a luminosity upgrade of LHC and for new injection line (SPL, PS2), starting with Linac 4 construction
- enhancement of CLIC qualifying tests

Agenda and talks: http://council-strategygroup.web.cern.ch/council-strategygroup/

Webcast: http://webcast.in2p3.fr/OS2006/

Emerging Regional Strategies

P. Odone
Vancouver meeting
July 2006

EPP2010

- LHC
- ILC Global
- ILC Hosting
- Particle Astrophysics
- Global Neutrino Program
- Quark Flavour Physics

Panel to look at High Energy Particle Physics in the 21st century in the US

EUROPE

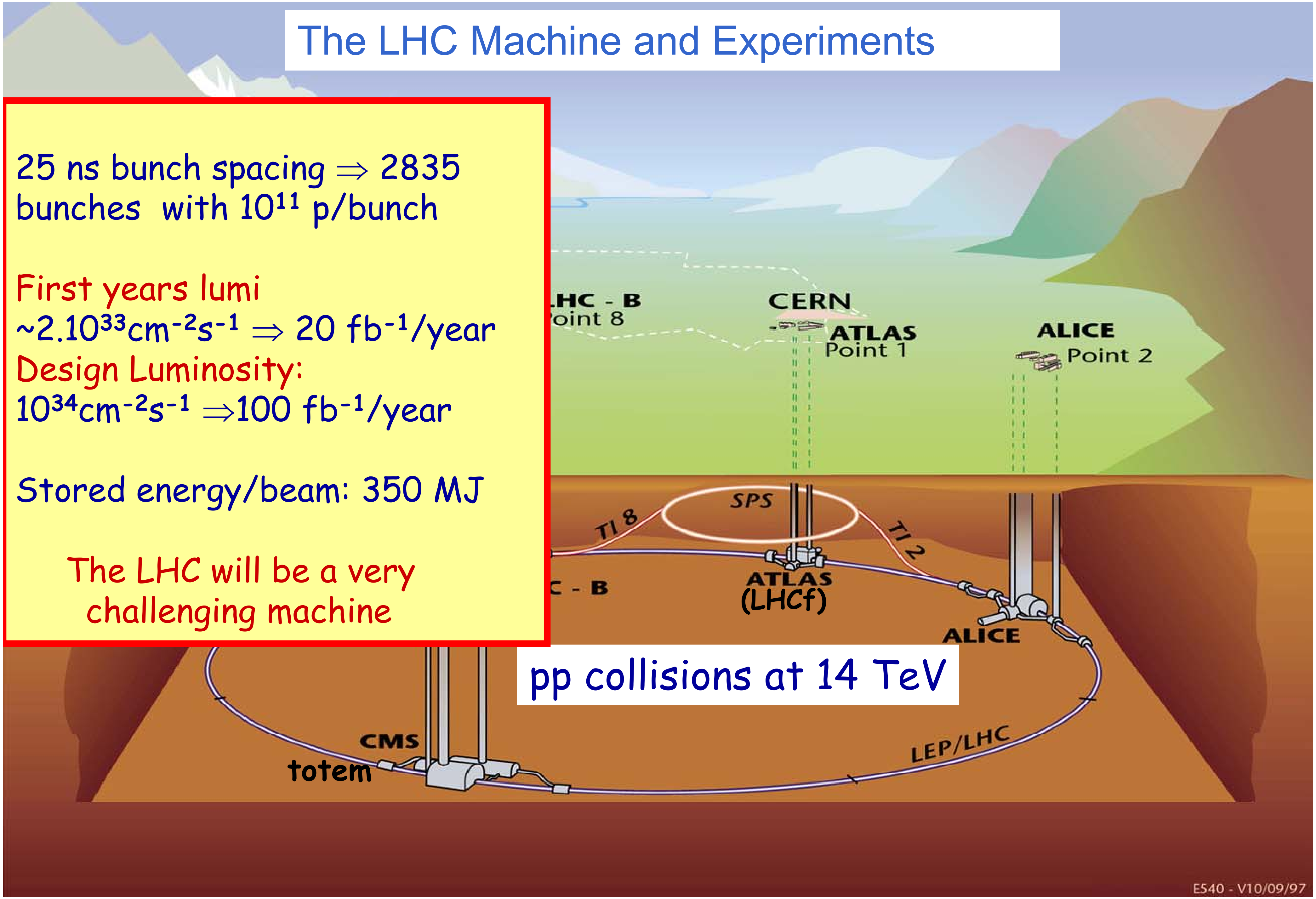
- LHC
- Accelerator R&D
- ILC
- Global Neutrino Program
- Astrophysics
- Flavour Physics
- Nuclear Physics

European Strategy group

The LHC

The Next High Energy Frontier Machine...

The LHC Machine and Experiments



25 ns bunch spacing ⇒ 2835 bunches with 10^{11} p/bunch

First years lumi
~2.10^{33} cm^{-2}s^{-1} ⇒ 20 fb^{-1}/year
Design Luminosity:
10^{34}cm^{-2}s^{-1} ⇒100 fb^{-1}/year

Stored energy/beam: 350 MJ

The LHC will be a very challenging machine

pp collisions at 14 TeV

Commissioning status

J. Wenninger

- Magnet production is completed.

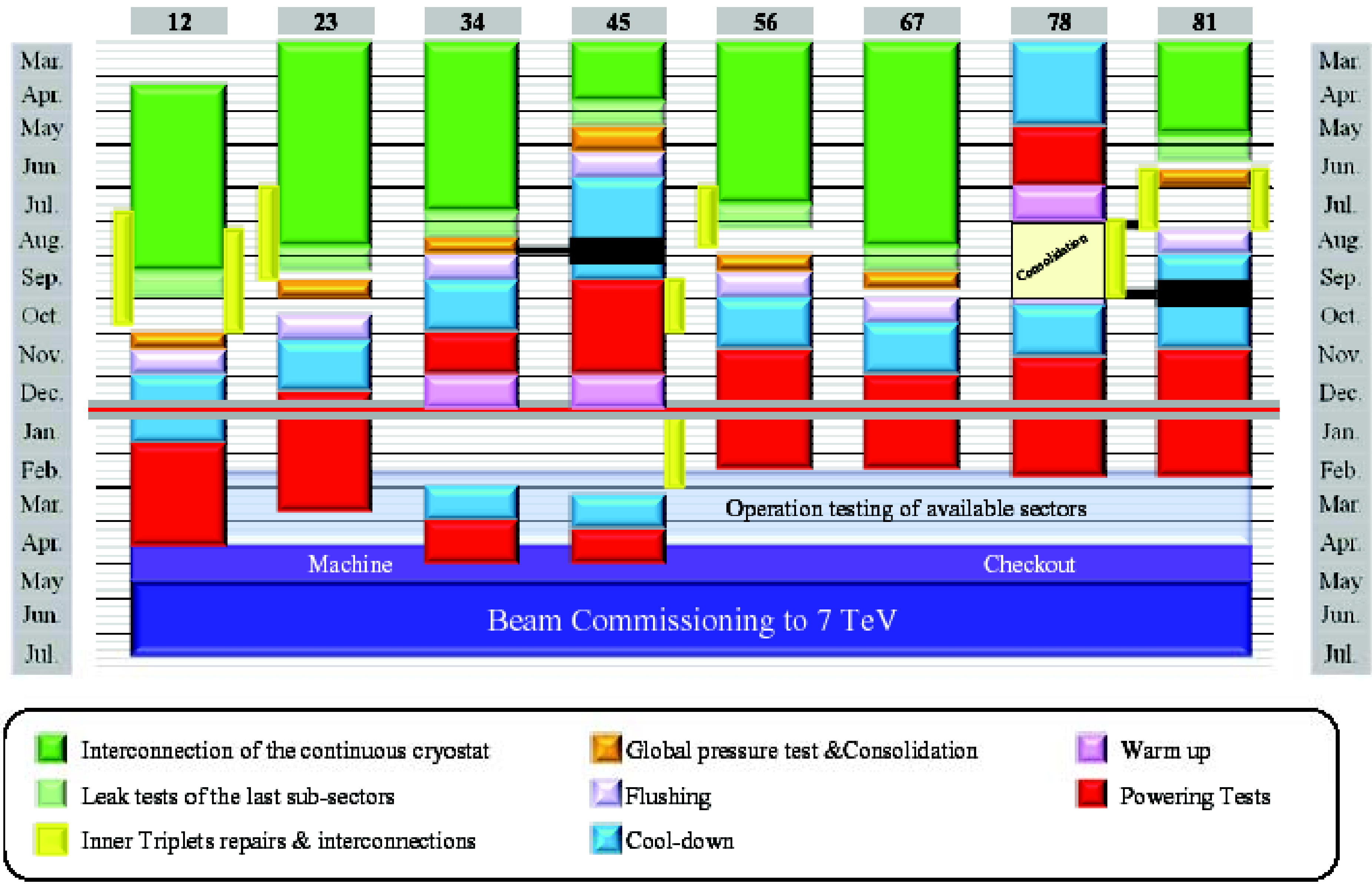
- Installation and interconnections in progress, few magnets still to be put in place.

- Cryogenic system : one sector (IR8→IR7) is cooled down to 1.9 K.

- Powering system: commissioning started
  - Power converters commissioning ~ 80% done.
  - Commissioning of the first complete circuits (converter and magnet) has started in IR8. The first quadrupoles have been tested to full current.
  - Tests of the main dipole circuits in the cold sector are expected to start THIS week.

- Other systems (RF, beam injection and extraction, beam instrumentation, collimation, interlocks, etc) are essentially on schedule for first beam in 2007/8.

Schedule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Jul.
Consolidation
Operation testing of available sectors
Machine
Checkout
Beam Commissioning to 7 TeV
Interconnection of the continuous cryostat
Leak tests of the last sub-sectors
Inner Triplets repairs & interconnections
Global pressure test &Consolidation
Flushing
Cool-down
Warm up
Powering Tests

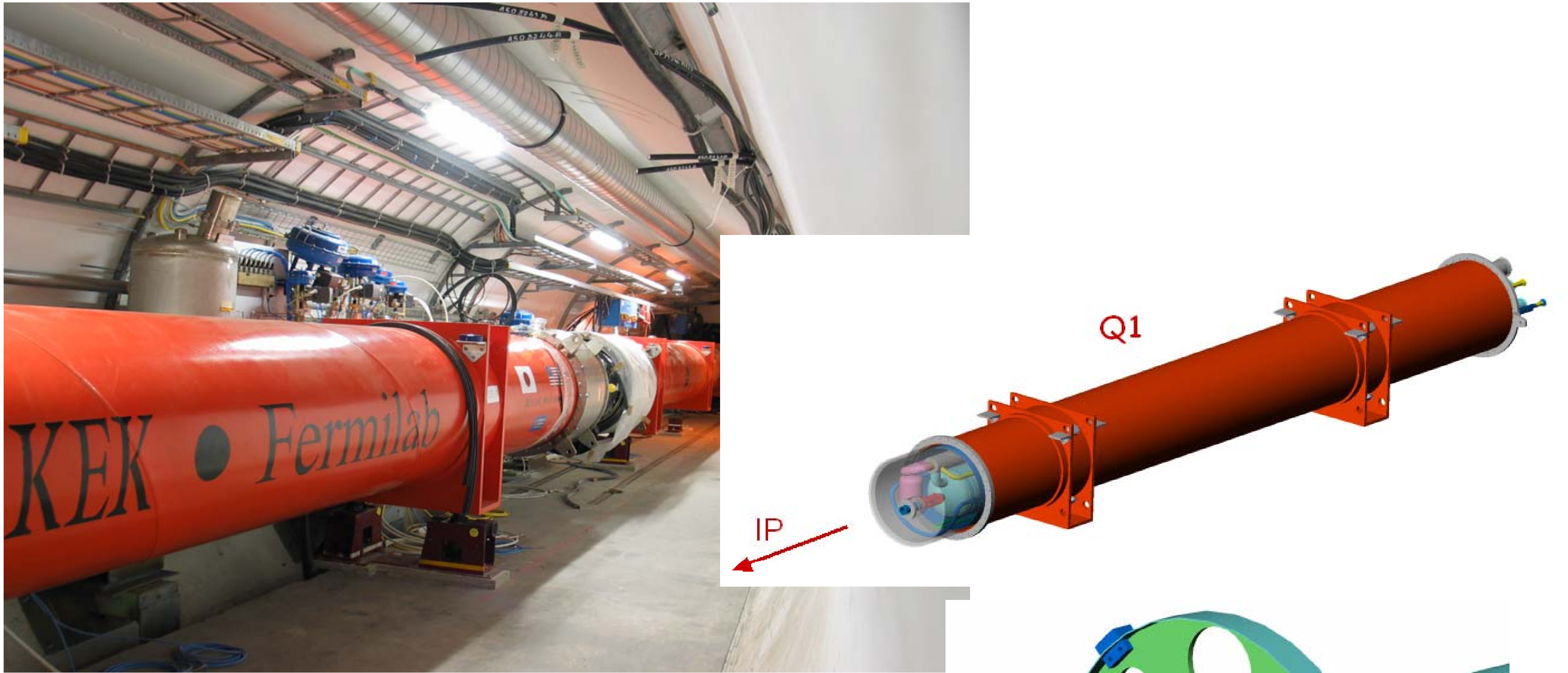
Towards beam

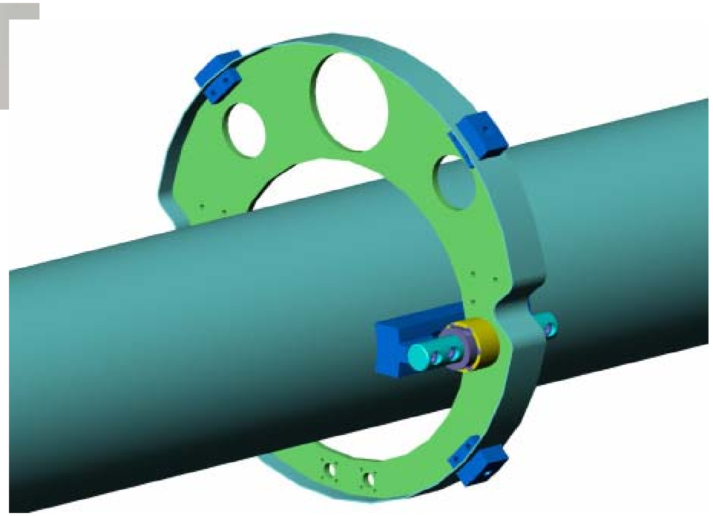
- Commissioning is progressing smoothly, maybe a bit more slowly than 'planned'.

- Problems discovered so far:
  - In the sector 7-8 that is cooled down to 1.9 K, a re-analysis of test data has revealed the presence of a dipole with a potentially damaged coil (inter-turn short). This sector must be warmed up in the summer and the magnet replaced.
  - The triplet magnets provided by FNAL suffer from a design problem of the support structure that must be repaired (in situ for all magnets except the one that was damaged).

- A new schedule has been released end of May:
  - Beam commissioning should start in the spring/early summer of 2008.
  - *A test of one sector with beam has been scheduled for December 2007. This will take beam from IR8 through LHCb to IR7 where the beam is dumped on a collimator.*

Inner Triplet at Point 5





Pressure test of Fermilab triplet in 5L

March 27
"Routine test"

April 24/25:
⇒Repair method proposed
Next pressure test in Summer

Lyn Evans RRB meeting at CERN 23/4/07

- Before the IT problem, we were about 5 weeks behind schedule.

- Once the full extent of the damage is known and the in-situ repair validated, we will publish a new schedule. It now looks unlikely that the engineering run can occur at the end of the year but all effort will be made to maintain a physics run in 2008 as foreseen.

⇒ We know now that it will take some time!!

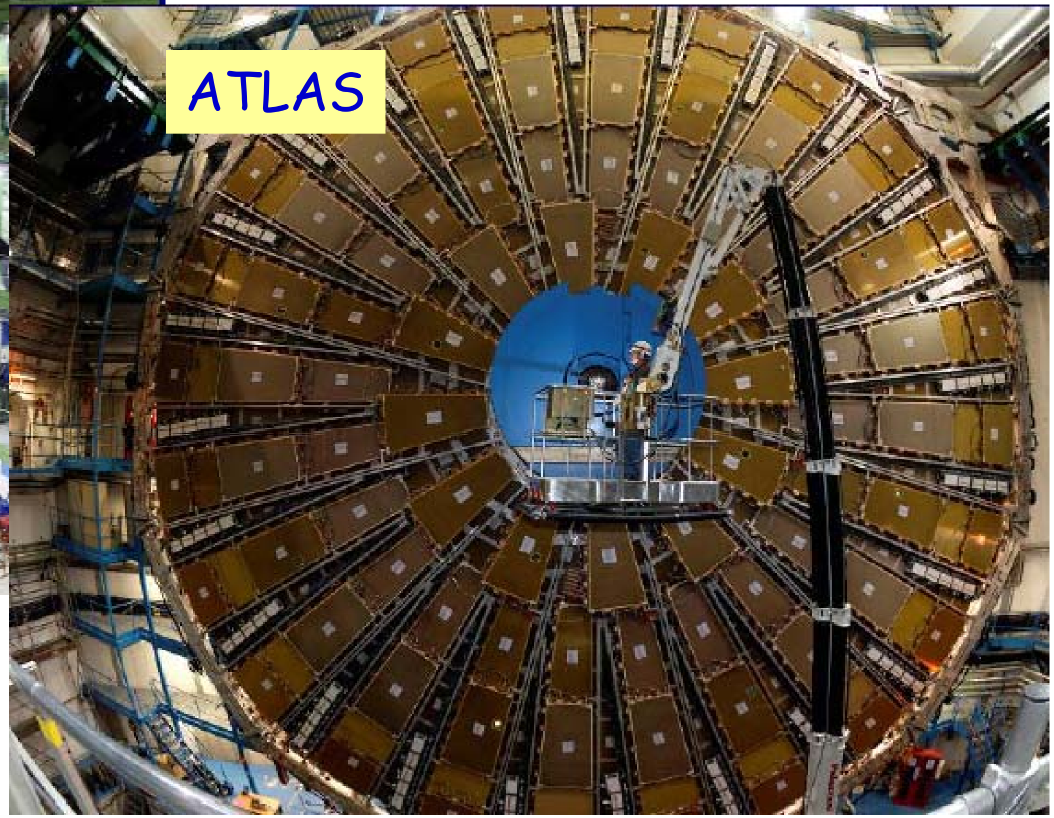
General Schedule

- Engineering run originally foreseen at end 2007 now precluded by delays in installation and equipment commissioning.
- 450 GeV operation now part of normal setting up procedure for beam commissioning to high-energy
- General schedule being reassessed, accounting for inner triplet repairs and their impact on sector commissioning
  - **All technical systems commissioned to 7 TeV operation, and machine closed April 2008**
  - **Beam commissioning starts May 2008**
  - **First collisions at 14 TeV com July 2008**
  - **Pilot run pushed to 156 bunches for reaching 10^{32} $cm^{-2}s^{-1}$ by end 2008**
- No provision in success-oriented schedule for major mishaps, e.g. additional warm-up/cool-down of sector

Total integrated luminosity in 2008 ~ 100 pb^{-1}?
Total integrated luminosity in 2008 ~ 1-10 fb^{-1}?

Detectors are well on track!

~100M channels/detector
Unprecedented complexity!!



Expect detectors to be essentially completed by March/April 2008

Media Interest

CORRIERE DELLA SERA

Data 26-03-2007
Pagina 23
Foglio 1 / 2

Un superacceleratore al Cern di Ginevra per catturare il bosone di Higgs

E ora i fisici cercano la «particella di Dio»

NEWS

OPEN The News in 2 minutes

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Last Updated: Wednesday, 28 February 2007, 13:49 GMT

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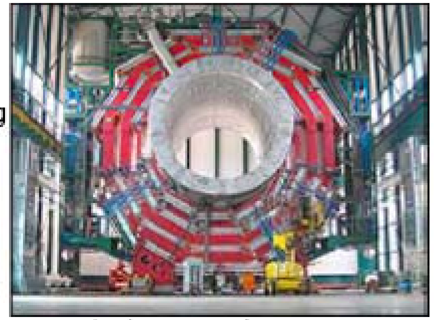
'It's like stepping on to a film set'

Construction of the Large Hadron Collidor, a giant underground particle accelerator, is reaching a major milestone as a key piece of machinery is lowered into the ground. BBC News Science Correspondent David Shukman reports from the scene.

It's like stepping onto the set of a James Bond film.

Or possibly something involving Austin Powers.



YB0 is the biggest and most impressive element of the CMS

Everything here is on a vast scale; many tens of thousands of cables woven together, silicon sensors by the thousand, towering shapes of steel, impossibly complicated engineering and science.

La tension monte au CERN dans la course au boson de Higgs

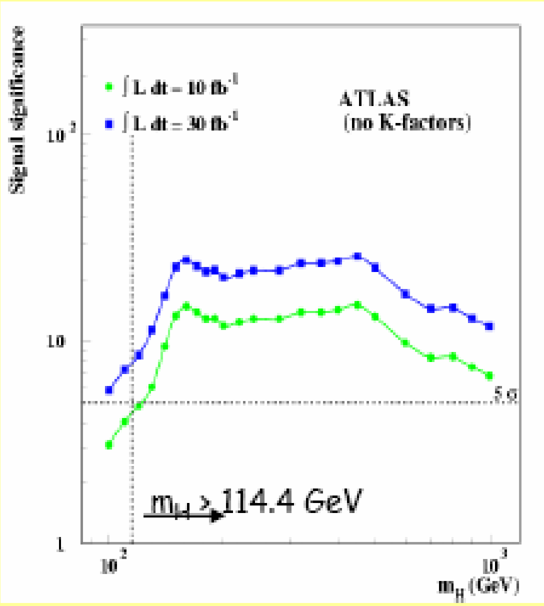
LE MONDE | 23.03.07 | 17h39 • Mis à jour le 23.03.07 | 17h39
CESSY (AIN) ENVOYÉ SPÉCIAL

Les solennités ne s'éternisent pas au CERN (Organisation européenne pour la recherche nucléaire). En deux petites heures arrachées de haute lutte au planning du chantier, des discours calibrés, des visites chronométrées ont rendu hommage, jeudi 22 mars, à l'élégance compacte et aux performances hors du commun de CMS. ….

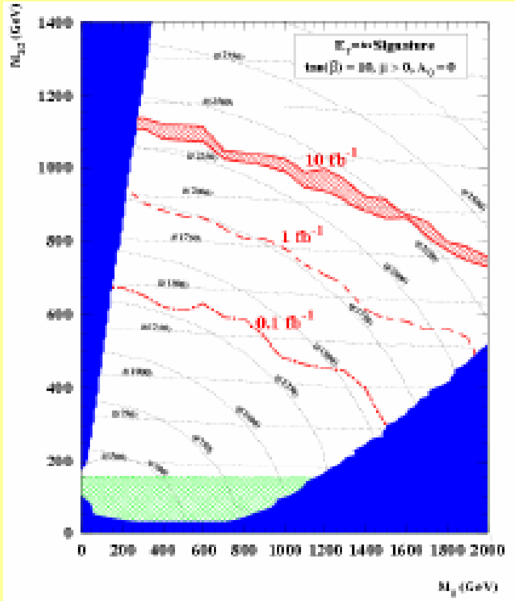
What can we expect in 2010 with 10 fb^{-1}?

"Early discoveries" at LHC

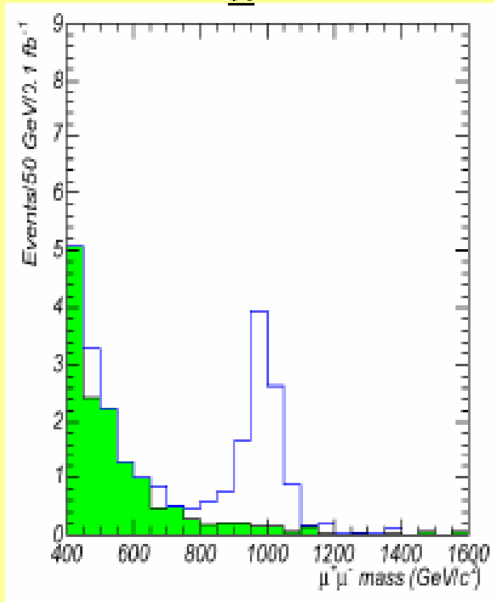
SM/MSSM Higgs



inclusive SUSY



di-lepton resonance (Z′,RS,Z_H,…)



with 10 fb^{-1}:

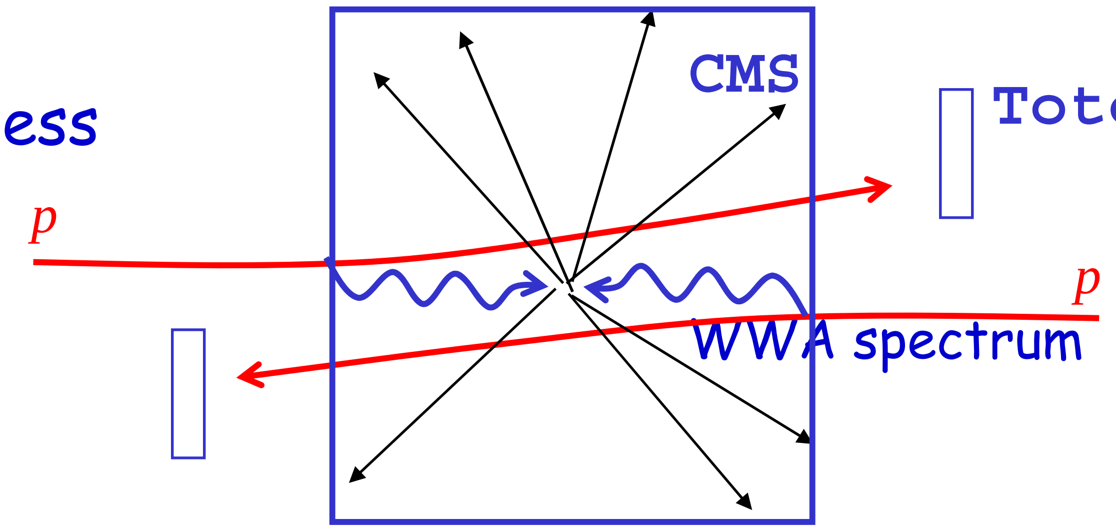
full range

$m_{sq,gl}$<2-2.5 TeV in mSugra

m<~3 TeV dep. on model

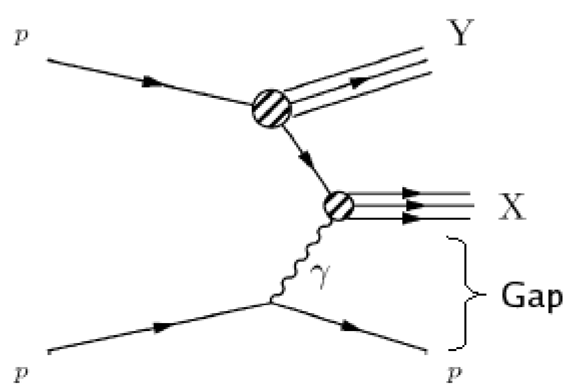
Photon-photon and photon-proton @ LHC

Process



This conference:

- γγ at the LHC — T. Pierzchala
- γp at the LHC — S. Ovyn
- Photoproduction in HI at LHC — D. D'Enterria
- γγ and more at the Tevatron — J. Pinfold
- UPC in heavy ion at the LHC — V. Pozdniakov



An interesting photon program lies ahead…

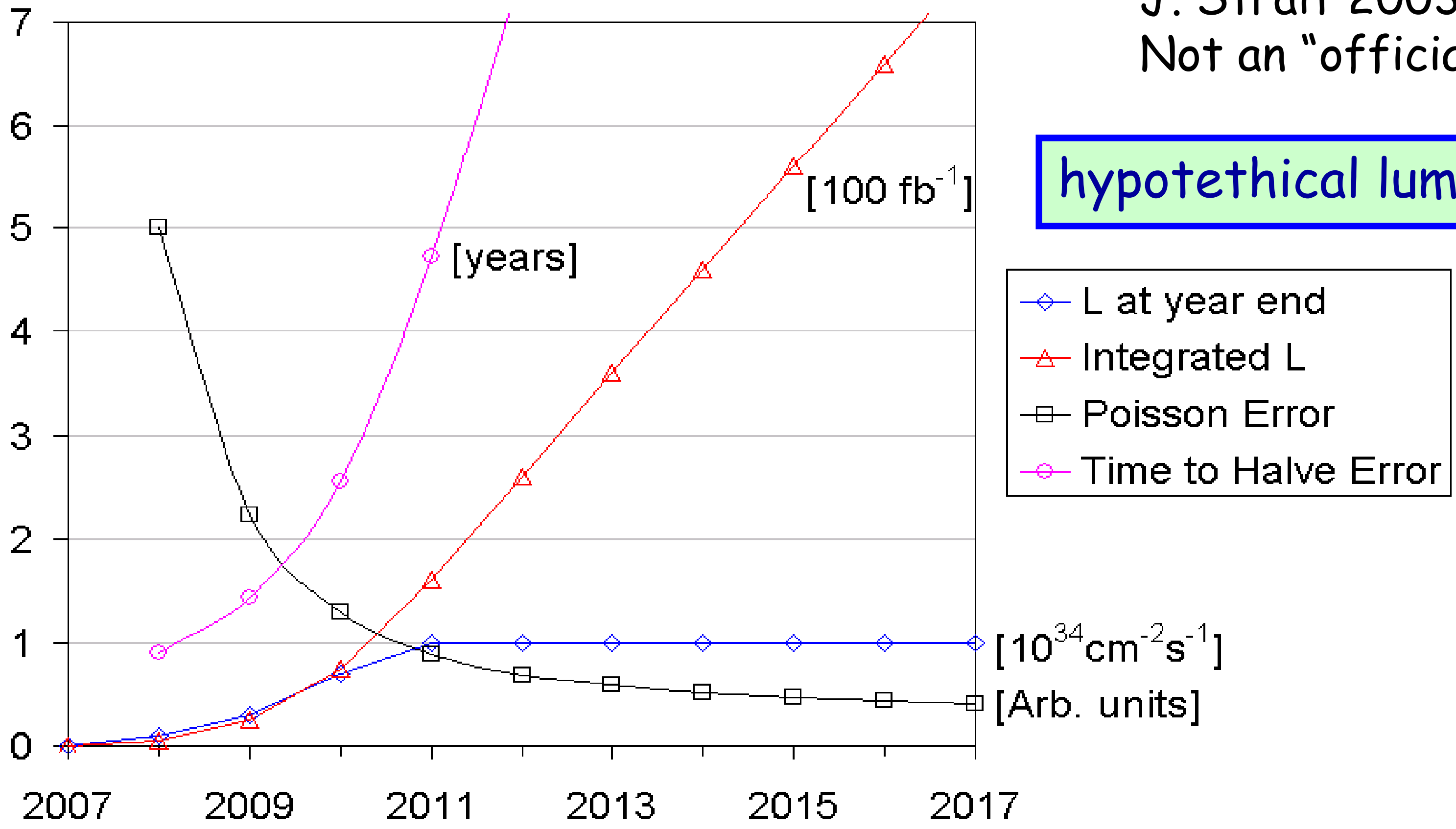
The LHC Upgrade

Making the most of the LHC…

Upgrades of the LHC

J. Strait 2003:
Not an "official" LHC plot

hypotethical lumi scenario



If startup is as optimistic as assumed here (10^{34} $cm^{-2}s^{-1}$ in 2011 already)
⇒After ~3 years the simple continuation becomes less exciting
⇒Time for an upgrade?

The LHC upgrade

Already time to think of upgrading the machine if wanted in ~10 years

Two options presently discussed/studied

- Higher luminosity ~10^{35}cm^{-2} s^{-1} (SLHC)
  - Needs changes of the machine and particularly of the detectors
  - ⇒ Start change to SLHC mode some time 2014-2016
  - ⇒ Collect ~3000 fb^{-1}/experiment in 3-4 years data taking.

- Higher energy? (DLHC)
  - LHC can reach $\sqrt{s}$ = 15 TeV with present magnets (9T field)
  - $\sqrt{s}$ of 28 (25) TeV needs ~17 (15) T magnets ⇒ R&D needed!
  - Even some ideas on increasing the energy by factor 3 (P. McIntyre)

	Run I $\sqrt{s}$	Run II $\sqrt{s}$	Int Lumi (run I)	Int. Lumi (expected/runII)
Tevatron	1.8 TeV	1.96 TeV	100 pb	~4-8fb
HERA	300 GeV	320 GeV	100 pb	~500 pb

SLHC Machine Parameters

parameter	symbol	25 ns, small *	50 ns, long
transverse emittance	ε [μm]	3.75	3.75
protons per bunch	N_b [10^{11}]	1.7	4.9
bunch spacing	Δt [ns]	25	50
beam current	I [A]	0.86	1.22
longitudinal profile		Gauss	Flat
rms bunch length	σ_z [cm]	7.55	11.8
beta* at IP1&5	β* [m]	0.08	0.25
full crossing angle	θ_c [μrad]	0	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0	2.0
hourglass reduction		0.86	0.99
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	15.5	10.7
peak events per crossing		294	403
initial lumi lifetime	τ_L [h]	2.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	2.4	2.5
	$T_{run,opt}$ [h]	6.6	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	3.6	3.5
	$T_{run,opt}$ [h]	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.25	0.36
image current heat	P_{IC} [W/m]	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_l [cm]	3.7	5.3
comment		D0 + crab (+ Q0)	wire comp.

New upgrade scenarios

challenges

injector upgrade

Crossing with large Piwinski angle

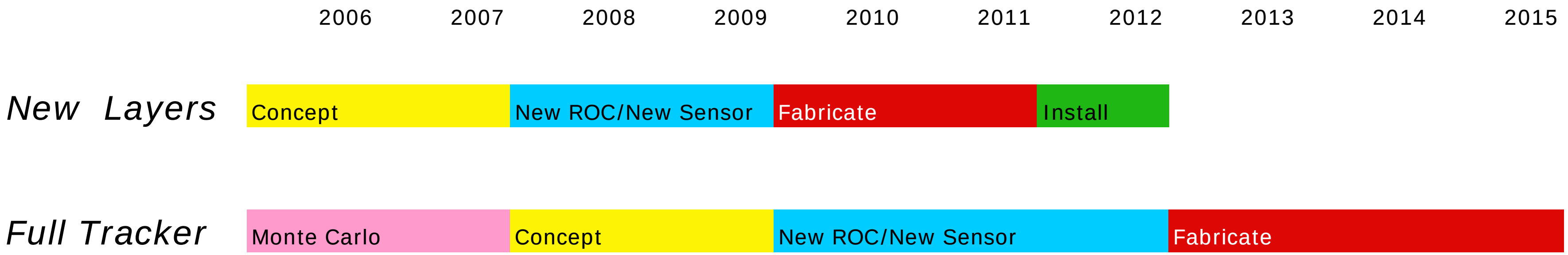
aggressive triplet

compromises between
# of pile up events
and
heat load

W. Scandale
HCP07

Upgrades of the detectors are required!

Tracker detector of both CMS & ATLAS will need to be replaced
Higher granularity at small radii. Tracker in the L1 trigger?



- Within 5 years of LHC start
  - New layers within the volume of the current Pixel tracker which incorporate some tracking information for Level 1 Trigger
    - Room within the current envelope for additional layers
    - Possibly replace existing layers
  - "Pathfinder" for full tracking trigger
    - Proof of principle, prototype for larger system
  - Elements of new Level 1 trigger
    - Utilize the new tracking information
    - Correlation between systems
- Upgrade to full new tracker system by SLHC (8-10 years from LHC Startup)
  - Includes full upgrade to trigger system

⇒one has to start now..

Extending the Physics Potential of LHC

- Electroweak Physics
  - Production of multiple gauge bosons ($n_V \geq 3$)
    - triple and quartic gauge boson couplings
  - Top quarks/rare decays
- Higgs physics
  - Rare decay modes
  - Higgs couplings to fermions and bosons
  - Higgs self-couplings
  - Heavy Higgs bosons of the MSSM
- Supersymmetry (up to masses of 3 TeV)
- 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

Examples studied in some detail

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

PHYSICS POTENTIAL AND EXPERIMENTAL CHALLENGES OF THE LHC LUMINOSITY UPGRADE

Conveners: F. Gianotti [1], M.L. Mangano [2], T. Virdee [1,3]
Contributors: S. Abdullin [4], G. Azuelos [5], A. Ball [1], D. Barberis [6], A. Belyaev [7], P. Bloch
Bosman [8], L. Casagrande [1], D. Cavalli [9], P. Chumney [10], S. Cittolin [1], S.Dasu [10], A. De Roeck
Ellis [1], P. Farthouat [1], D. Fournier [11], J.-B. Hansen [1], I. Hinchliffe [12], M. Hohlfeld [13], M. Huhtir
K. Jakobs [13], C. Joram [1], F. Mazzucato [14], G.Mikenberg [15], A. Miagkov[16], M. Moretti[17], S. Morett
T. Niinikoski [1], A. Nikitenko[3,†], A. Nisati [19], F. Paige[20], S. Palestini [1], C.G. Papadopoulos[21], F. Picc
R. Pittau[22], G. Polesello [23], E. Richter-Was[24], P. Sharp [1], S.R. Slabospitsky[16], W.H. Smith [10], S.
nes [25], G. Tonelli [26], E. Tsesmelis [1], Z. Usubov[27,28], L. Vacavant [12], J. van der Bij[29], A. Watsc
M. Wielers [31]

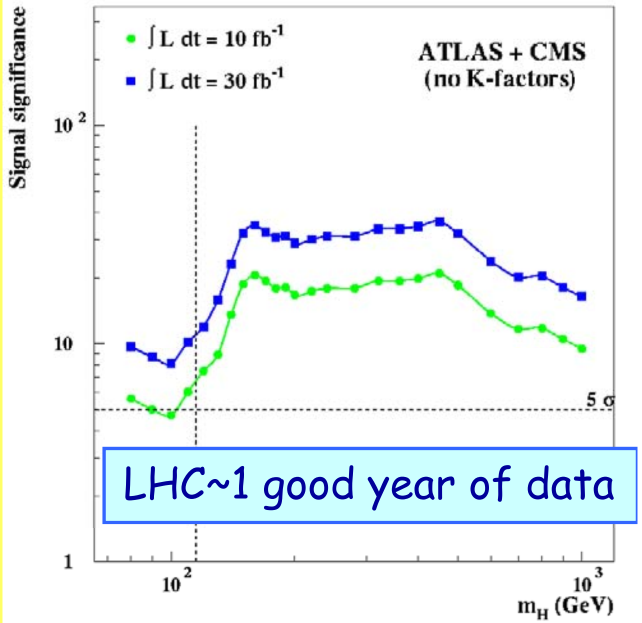
Include pile up, detector…

hep-ph/0204087

⇒ Extend discovery range by ~ 25% in mass

Example: The Higgs at the LHC

- First step
  - Discover a new Higgs-like particle at the LHC, or exclude its existence
- Second step
  - Measure properties of the new particle to prove it is the Higgs
    - Measure the Higgs mass
    - Measure the Higgs width
    - Measure cross sections x branching ratios
    - Ratios of couplings to particles ($\sim m_{particle}$)
    - Measure decays with low Branching ratios (e.g $H \rightarrow \mu\mu$)
    - Measure CP and spin quantum numbers (scalar particle?)
    - Measure the Higgs self-coupling ($H \rightarrow HH$), in order to reconstruct the Higgs potential



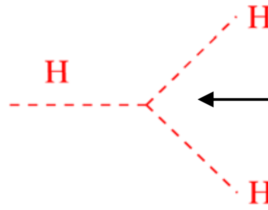
SLHC added value

Only then we can be sure it is the Higgs particle we were looking for

Higgs Self Coupling Measurements

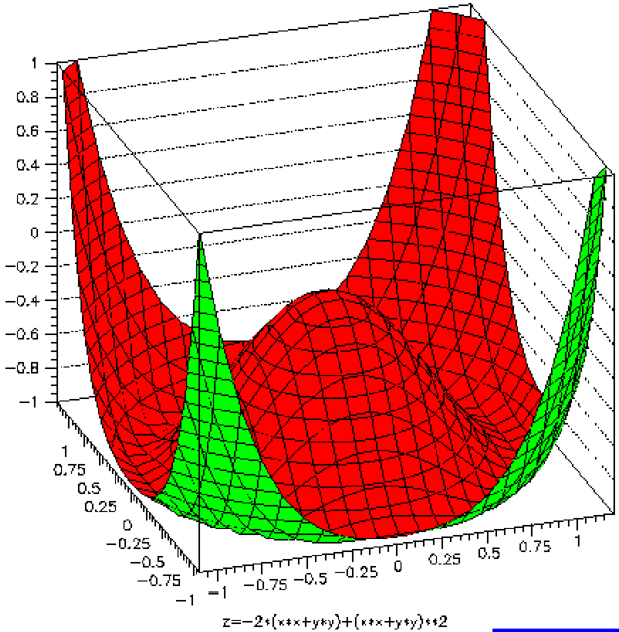
Once the Higgs particle is found, try to reconstruct the Higgs potential

$$V(\Phi) = -\lambda v^2(\Phi^\dagger\Phi) + \lambda(\Phi^\dagger\Phi)^2$$

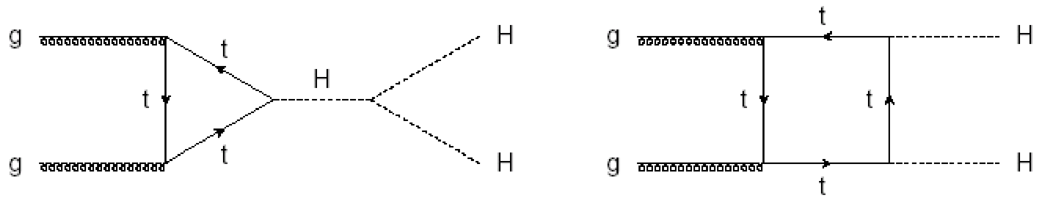


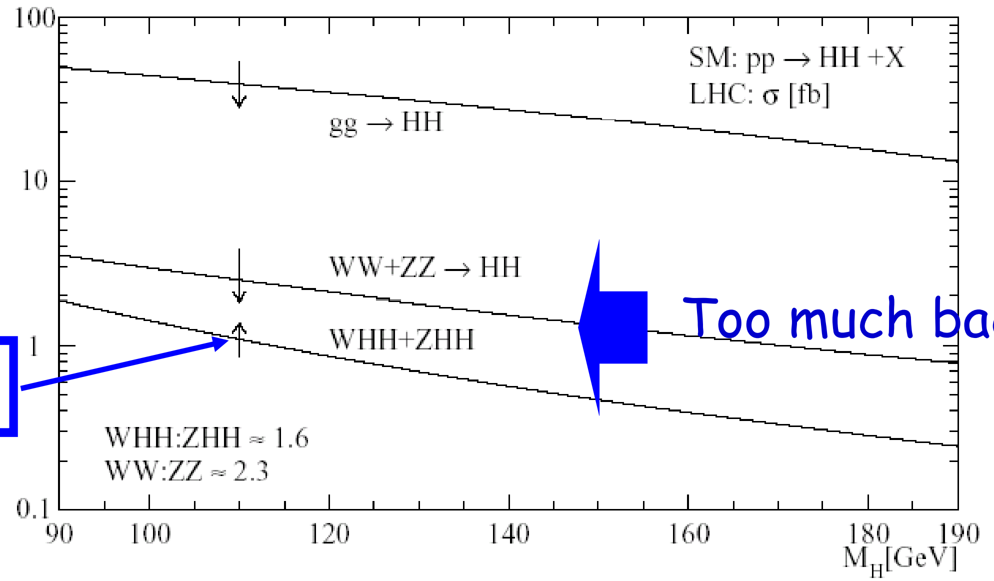
~ λv

$m_H^2 = 2\,\lambda\, v^2$



g g --> H H





Djouadi et al.

Dawson et al.

$\lambda/2 < \lambda < 3\lambda/2$

Too much backgr.

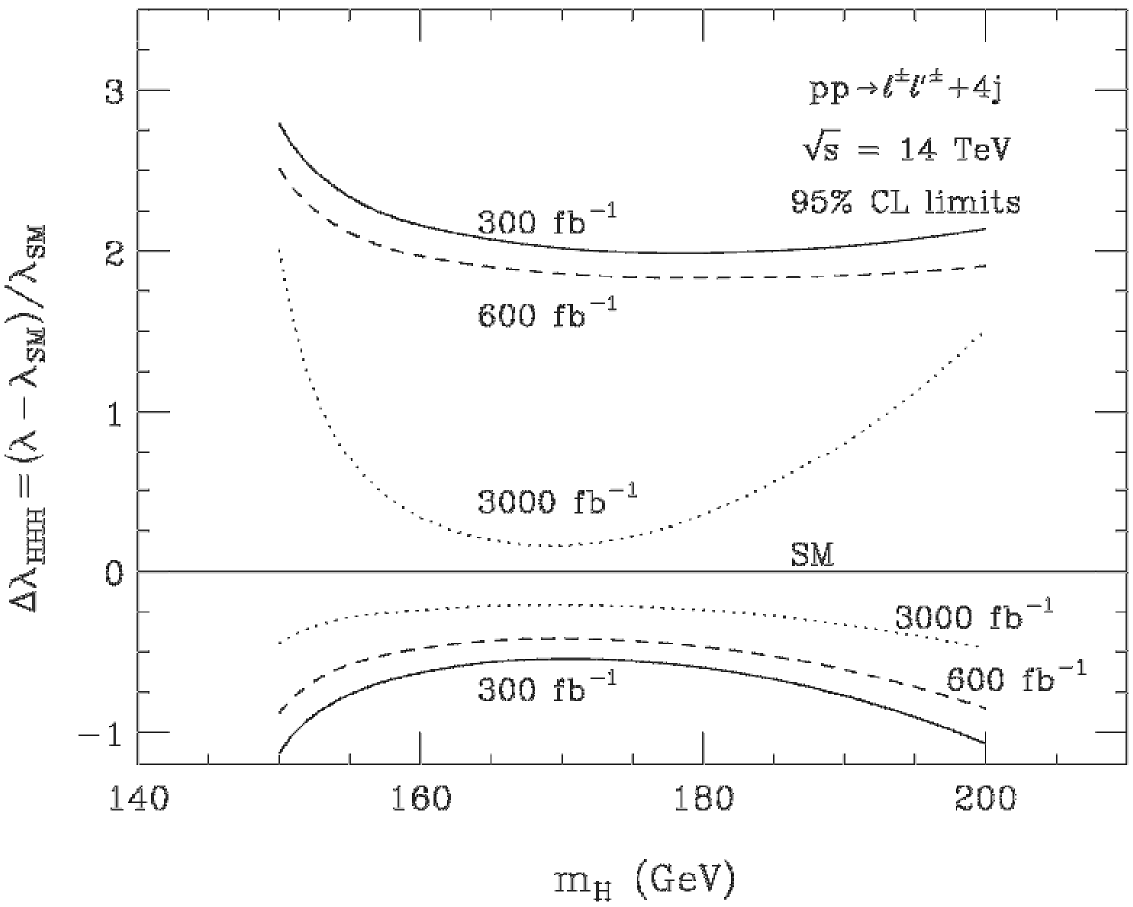
Difficult/impossible at the LHC

Higgs Self Coupling

Baur, Plehn, Rainwater

$HH \rightarrow W^+ W^- W^+ W^- \rightarrow \ell^{\pm} \nu jj \ \ \ell^{\pm} \nu jj$

Limits achievable at the 95% CL. for $\Delta\lambda=(\lambda-\lambda_{SM})/\lambda_{SM}$

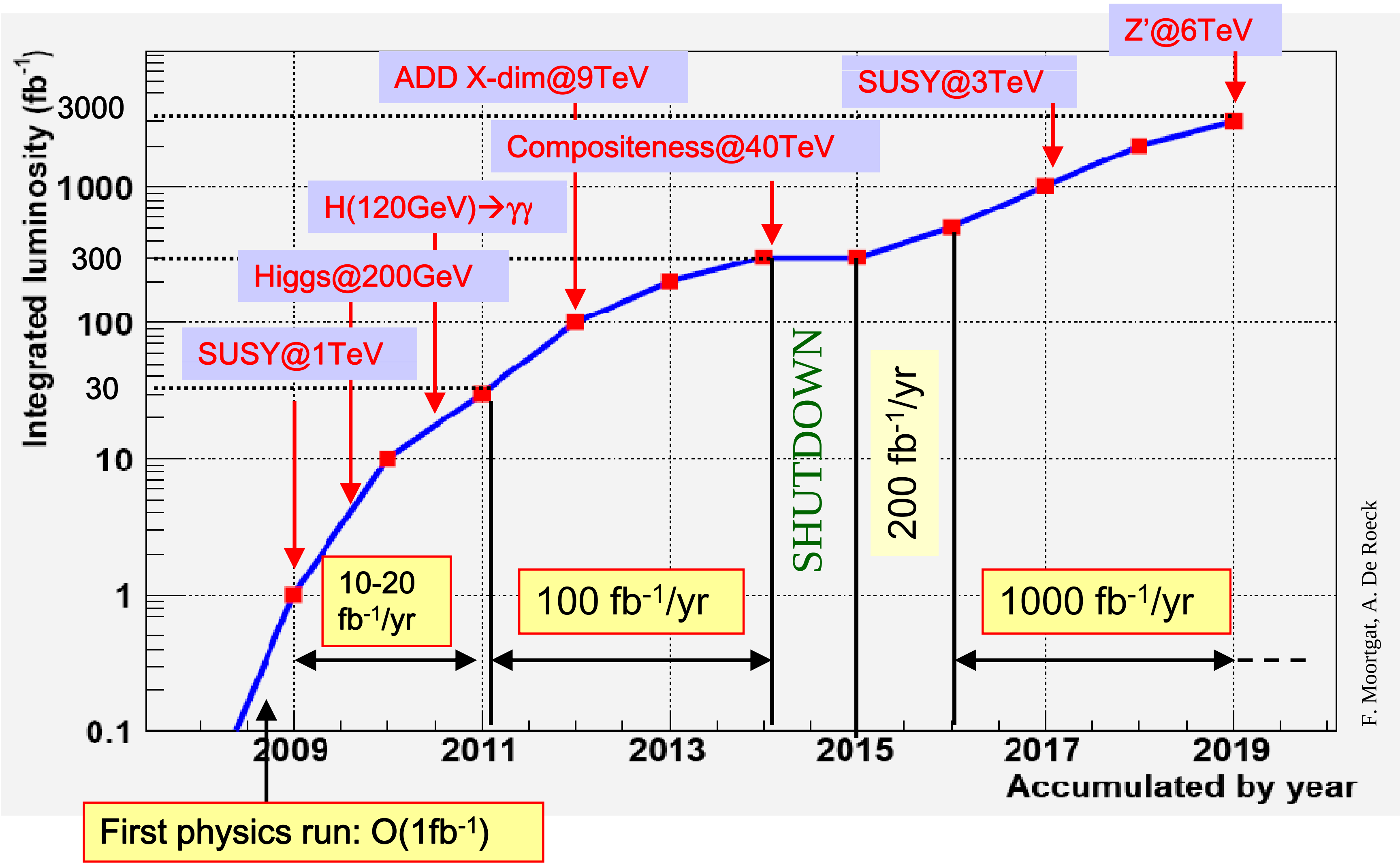


LHC: λ= 0 can be excluded at 95% CL.

SLHC: λ can be determined to 20-30% (95% CL)

Note: Different conclusion from ATLAS study $\rightarrow$no sensitivity at LHC and smaller sensitivity at SLHC. Jury is still out

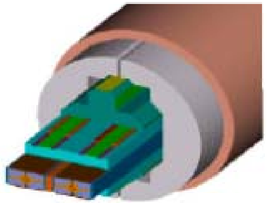
LHC Luminosity/Sensitivity with time

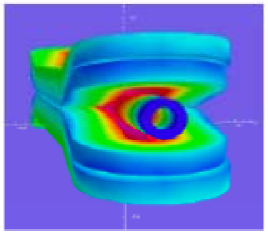


LHC energy doubler 14*14 TeV

- dipole field B_{nom} = 16.8 T, B_{design} = 18.5-19.3 T (10-15% margi
  - o superconductor - Nb_3Sn
  - o 10-13 T field demonstrated in several 1-m long Nb3Sn dipole models
  - o DLHC magnet parameters well above the demonstrated Nb3Sn magnet technology
- R&D and construction time and cost estimates
  - o 10+ years for magnet technology development and demonstration
  - o Magnet production by industry ~ 8-10 years
  - o High cost for R&D and construction (cost of dipoles > 3GCHF ?)

LHC Energy Upgrade





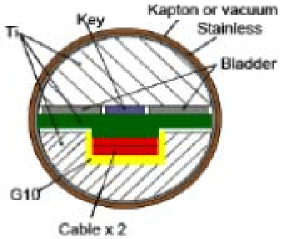
Design Features & Applications

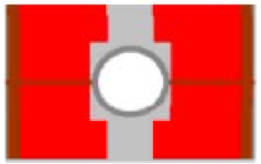
- Target field 15 Tesla
- Clear bore 36 mm
- Simple coil configuration
- Designed for high field quality
- Suitable for HF cable testing
- Compatible with HTS inserts

4.5 K Short Sample Parameters

Parameter	Unit	HD1	**HD2**
Clear bore	mm	8	**36**
Coil field	Tesla	16.1	**15.8**
Bore field	Tesla	16.7	**15.0**
Max current	kA	11.4	**17.3**
Stored Energy	MJ/m	0.66	**0.84**
F_x (quadrant, 1ap	MN/m	4.7	**5.6**
F_y (quadrant, 1ap	MN/m	-1.5	**-2.6**
Ave. stress (h)	MPa	150	**150**

High-field cable testing





2-layer winding without spacers in body or ends

W. Scandale
HCP07

LHC energy tripler 21*21 TeV

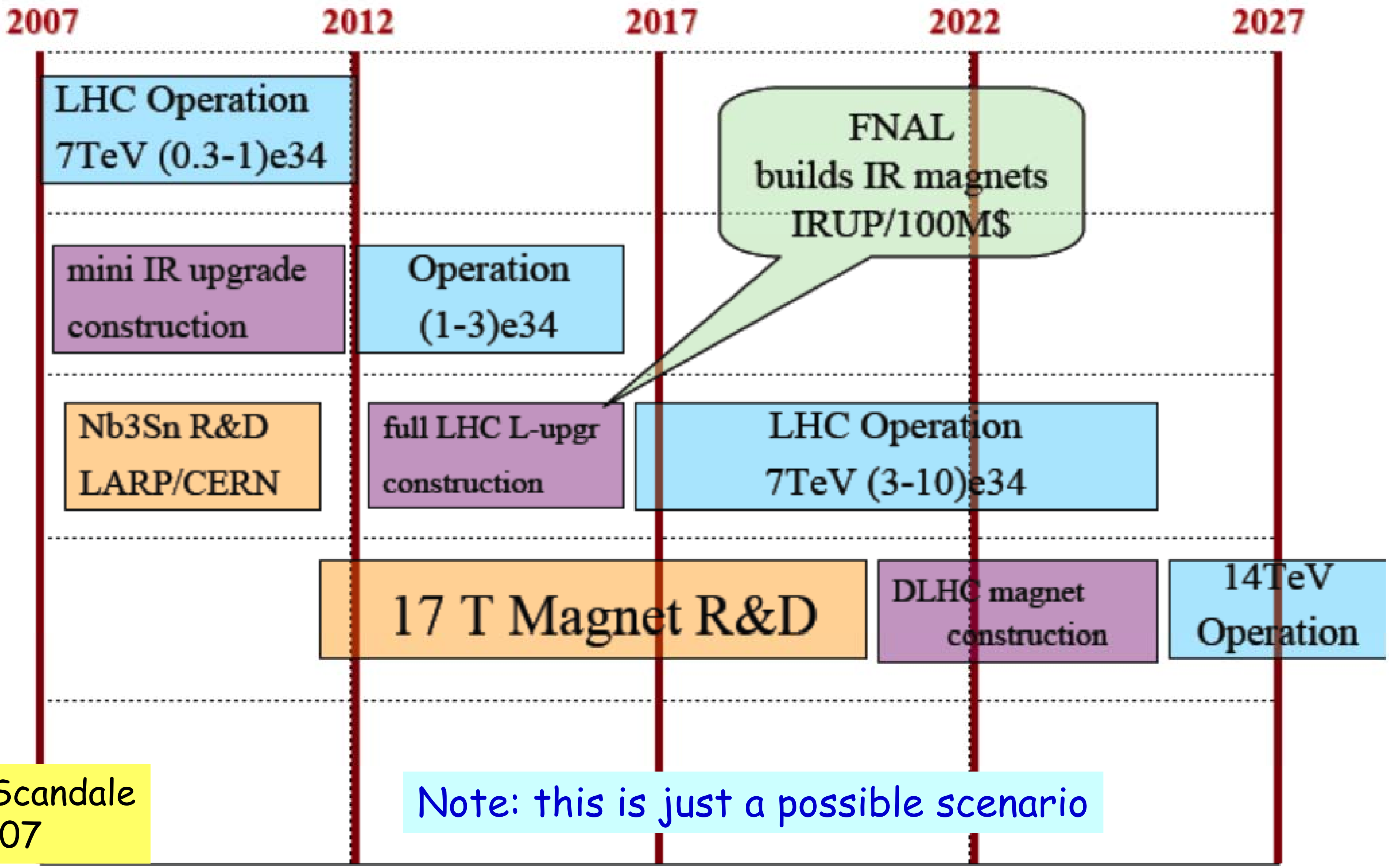
- dipole field B_{nom} = 25 T, B_{design} = 28-29 T (10-15% margin)
  - superconductor - HTS-BSCCO (low demand) or Nb_3Sn
  - Magnet technology to be fully demonstrated
  - DLHC magnet parameters well above the demonstrated Nb3Sn magnet technology
- Large aperture dipole to accommodate an efficient beam screen

- R&D and construction time and cost/risk estimates
  - 20++ years for magnet technology development and demonstration
  - Extremely high R&D and construction cost and risk
    - SC cable to be developed,
    - Magnetic coil stress requires innovative dipole cross section
  - Magnet production by industry (?) ?? years

W. Scandale
HCP07

The SSC in the LHC tunnel ? ☺

LHC, sLHC, DLHC perspective



W. Scandale
HCP07

Note: this is just a possible scenario

Present CERN Position

CERN DG 27/6/07

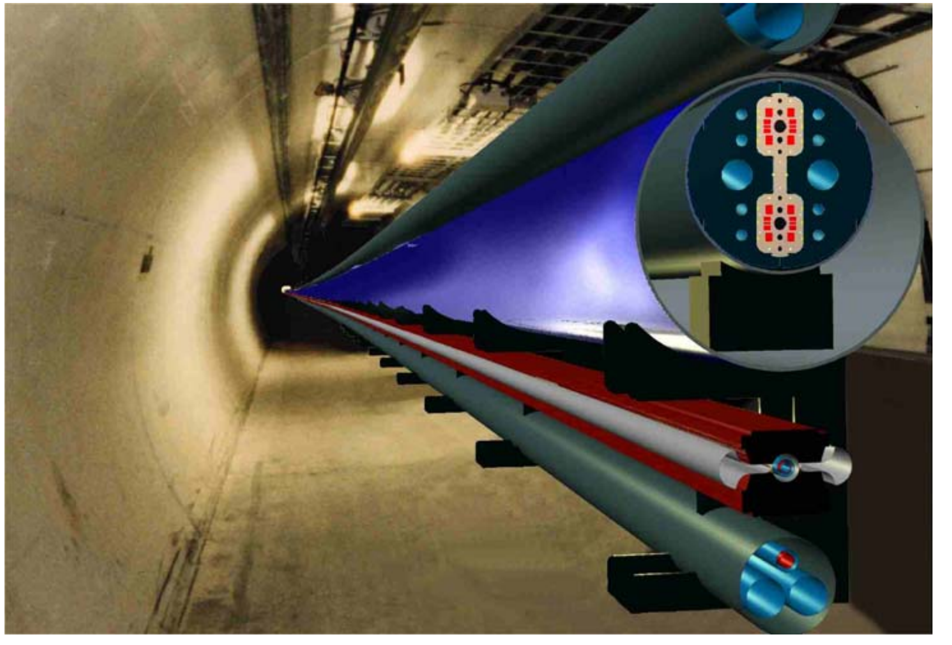
Prospects for scientific activities over the period 2012-2016

Results available from LHC operation during the period 2008-2011 and from the activities proposed above should allow the CERN Council in 2010-2011 to decide on the future of CERN for more than one decade.

- If results from the LHC, as is highly likely, suggest the need for an increase in luminosity allowing a more extensive exploration of the new territory opened by the LHC, **a decision on the luminosity increase** (new RF system, new magnets for IR, increased cooling, new tracking in detectors, etc.) **will entail a simultaneous decision to build a new injector (SPL and PS) since higher LHC performance cannot be achieved reliably enough without a new injection line.**

The total cost of the investment, which is assumed to be realized in 6 years (2011-2016), is within the range 1'000-1'200 MCHF and will require a staff of 200-300 per year, thus a total budget of about 200-250 MCHF per year.

VLHC: Very Large Hadron Collider



http://vlhc.org

Tunnel of 233 km (E.G could be somewhere near FNAL)
Stage 1: 40 TeV collider with "cheap" 2T field magnets $L=10^{34} cm^{-2} s^{-1}$
Stage 2: 200 TeV collider with superconducting magnets. $L=2.10^{34} cm^{-2} s^{-1}$

Magnet & Vacuum R&D required (and ongoing)
Detectors with good tracking up to 10 TeV (increase B,L), calorimeter coverage $|\eta|$ up to 6-7, good linearity up to 10 TeV, harsh forward radiation

Linear Colliders: The ILC

Linear e+e- Colliders

Since end of 2001 there seems to be a worldwide consensus in high energy physics (ECFA/HEPAP/Snowmass 2001…)

⬇

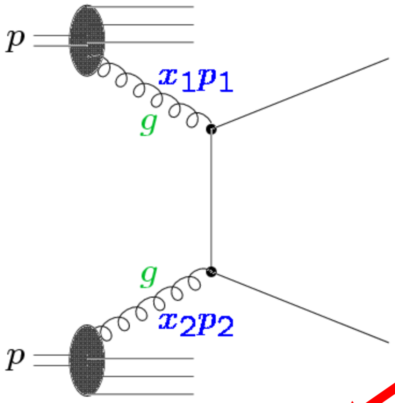
The machine which will complement and extend the LHC best, and is closest to be realized is a Linear e+e- Collider with a collision energy of at least 500 GeV

PROJECTS:

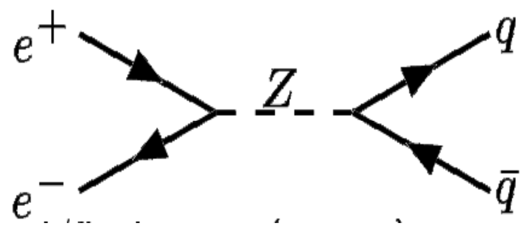
⇒ TeV Colliders (cms energy up to 1 TeV) → Technology ~ready
August'04 ITRP: NLC/GLC/TESLA→ ILC superconducting cavities

⇒ Multi-TeV Collider (cms energies in multi-TeV range) → R&D
CLIC (CERN + collaborators) → Two Beam Acceleration

LHC/e+e- colliders



Different characteristics of the two machines
⇒ Different virtues



LHC pp collisions $\sqrt{s}$ = at 14 TeV

⇒ Strong point: larger mass reach for direct discoveries

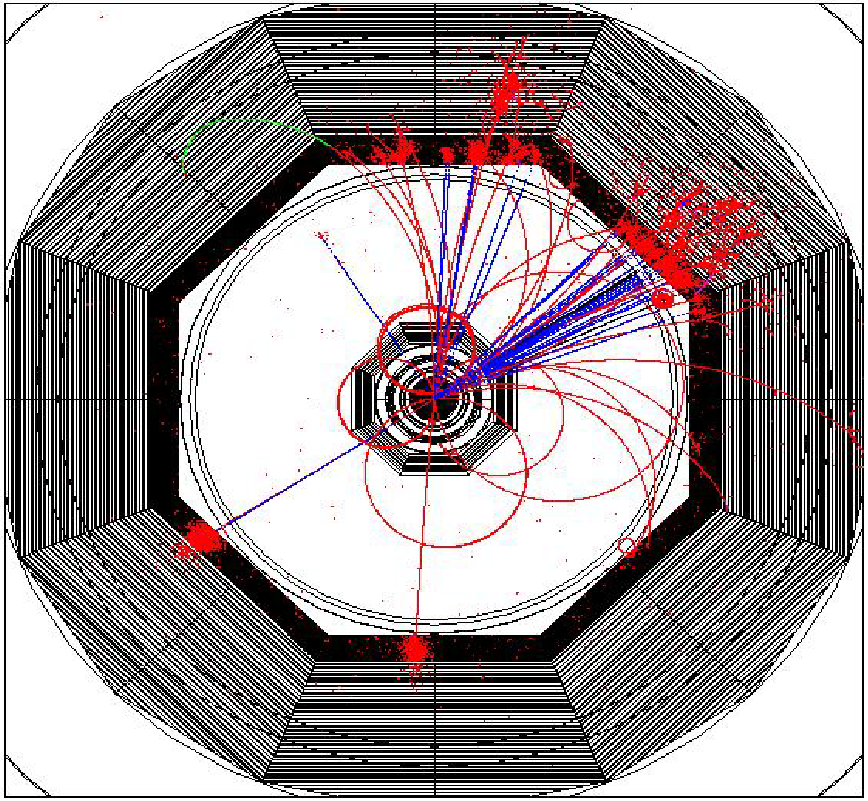
- Kinematics: can use conservation of p_T
- Composite nature of colliding protons
  ⇒underlying remant event
- $\sqrt{s}$ of the hard interaction not fixed
- Strongly interacting particles
  ⇒ huge QCD cross sec. (background)

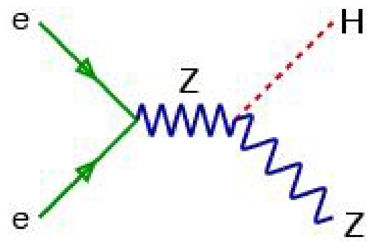
ILC: e+e- collisions $\sqrt{s}$ = 0.5-1.0 TeV

⇒Strong point: high precision physics

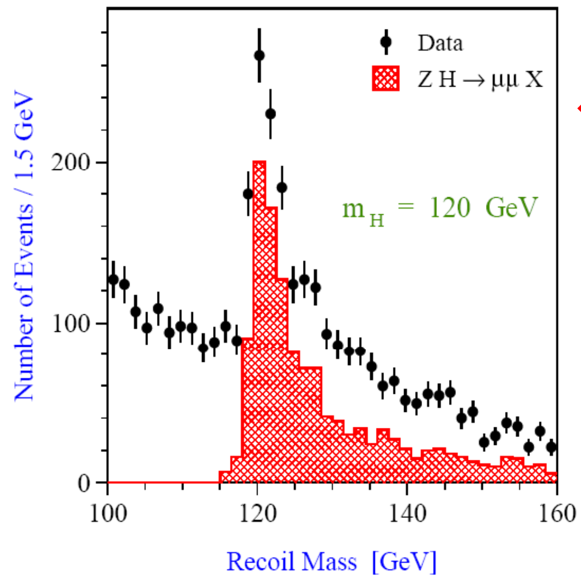
- Kinematics: mom. conservation used to analyze the decays,...
- Well defined initial state, beam polarization, $\sqrt{s}$,...
- Backgrounds smaller than LHC
- Options: $\gamma\gamma$, $e\gamma$, e-e- colliders.

Higgs studies at a e+e- linear Collider





Can detect the Higgs via the recoil to the Z



Fully simulated+reconstructed HZ event
Very clean compared to events at LHC

Precision measurements!

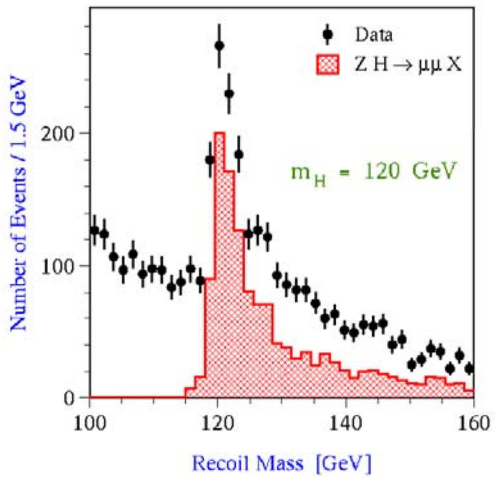
Observation of the Higgs independent of decay modes
Precise determination of couplings

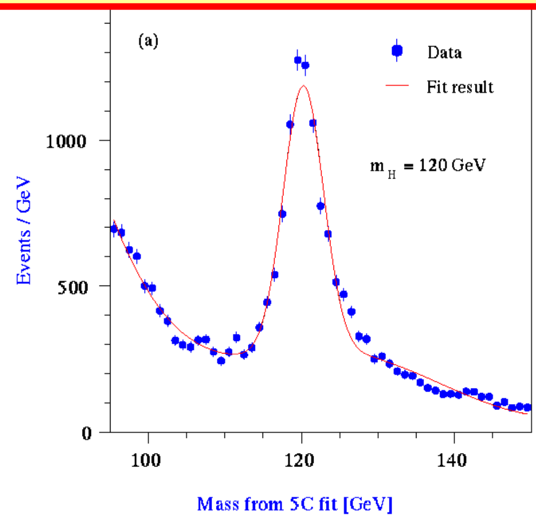
A LC is a Precision Instrument

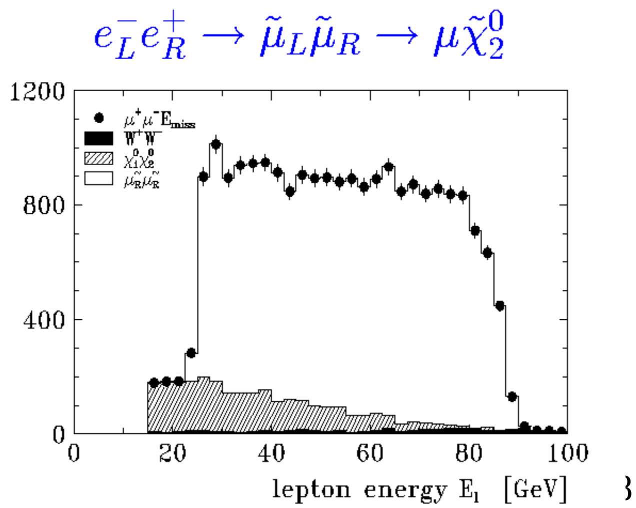
- Clean e+e- (polarized intial state, controllable √s for hard scattering)
- Detailed study of the properties of Higgs particles

  mass to 0.03%, couplings to 1-3%, spin & CP structure, total width (6%)
  factor 2-5 better than LHC/measure couplings in model indep. way
- Precision measurements of SUSY particles properties, i.e. slepton masses to better than 1%, if within reach
- Precision measurements a la LEP (TGC's, Top and W mass)
- Large indirect sensitivity to new phenomena (eg $W_L W_L$ scattering)

LC will very likely play important role to disentangle the underlying new theory







ILC: Few More Examples

⇒Understanding SUSY

High accuracy of sparticle mass measurements relevant for reconstruction of SUSY breaking mechanism

⇒ Dark Matter

LC will accurately measure $m\chi$ and couplings, i.e. Higgsino/Wino/Bino content

→ Essential input to cosmology & searches

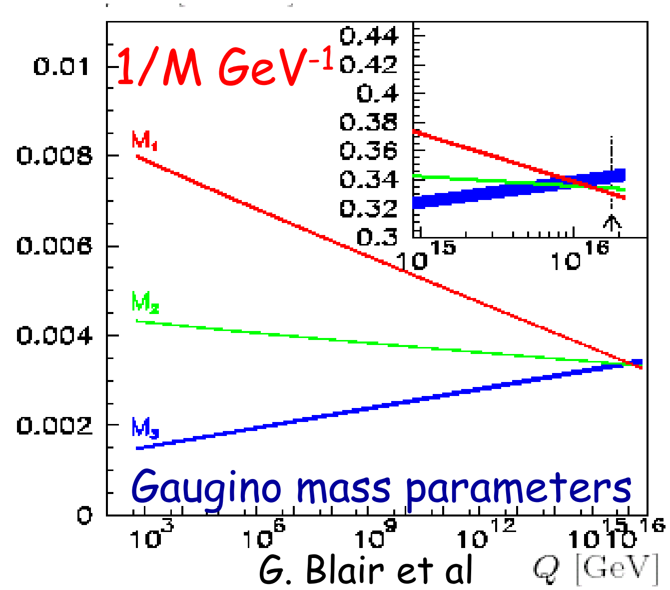
LC will make a prediction of $\Omega_{DM}h^2$ ~ 3% (SPS1a)

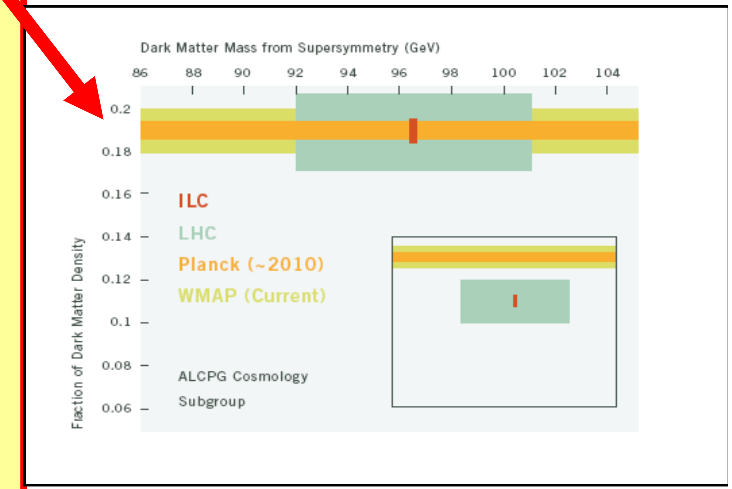
→A mismatch with WMAP/Planck would reveal extra sources of DM (Axions, heavy objects)

⇒ Quantum level consistency: M_H(direct)= M_H(indirect)?

$\Delta\sin^2\theta_W$~10^{-5} (GigaZ), ΔM_W ~ 6 MeV (+theory progress)

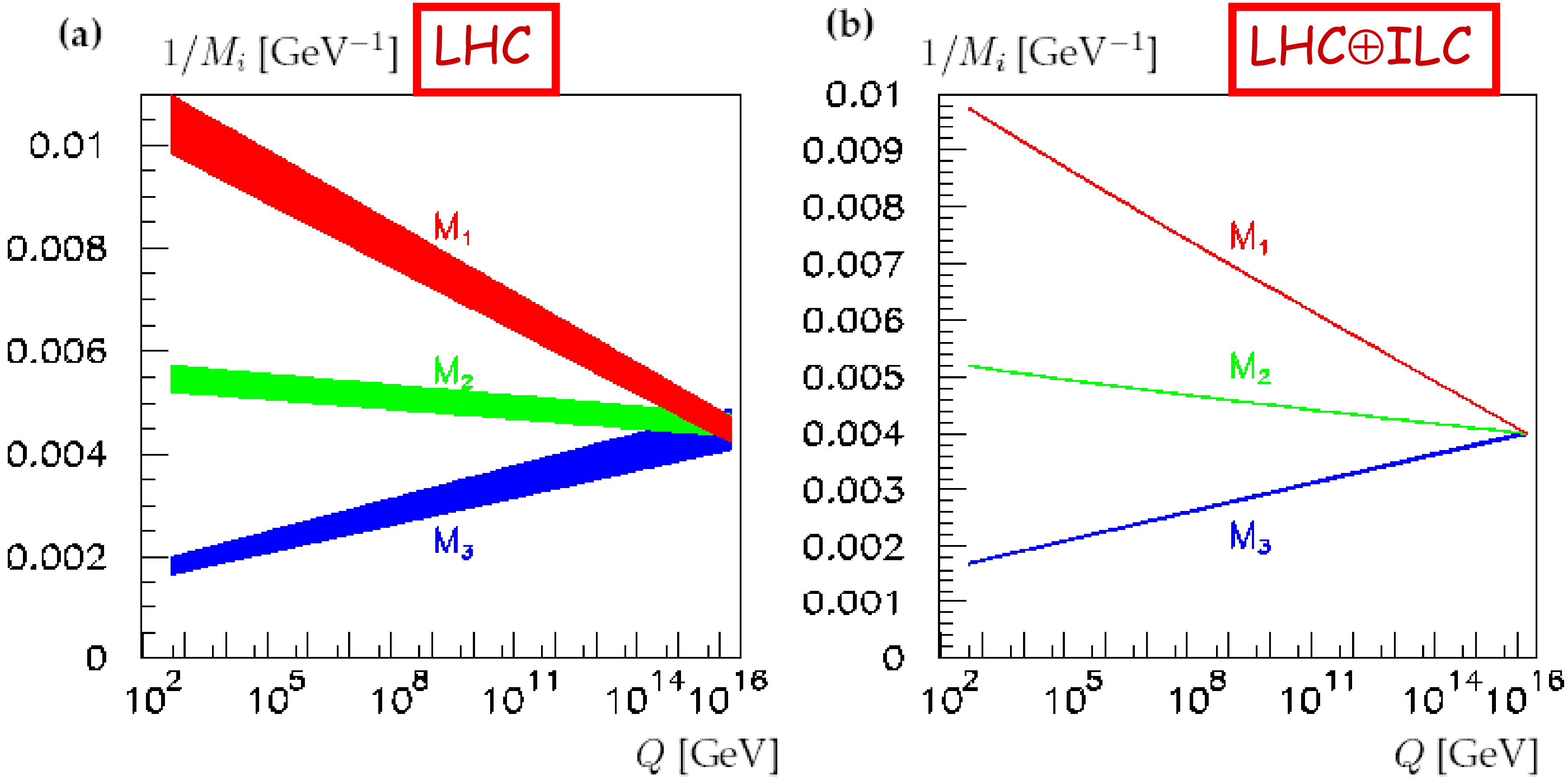
→ ΔM_H (indirect) ~ 5%





Extrapolation to physics at high scales

From a combination of LHC and ILC results, precise measurements of masses of SUSY particles, couplings: Evolution of gaugino mass parameters



Good case for LHC/ILC interplay, see G. Weiglein et al., hep-ph/0410364

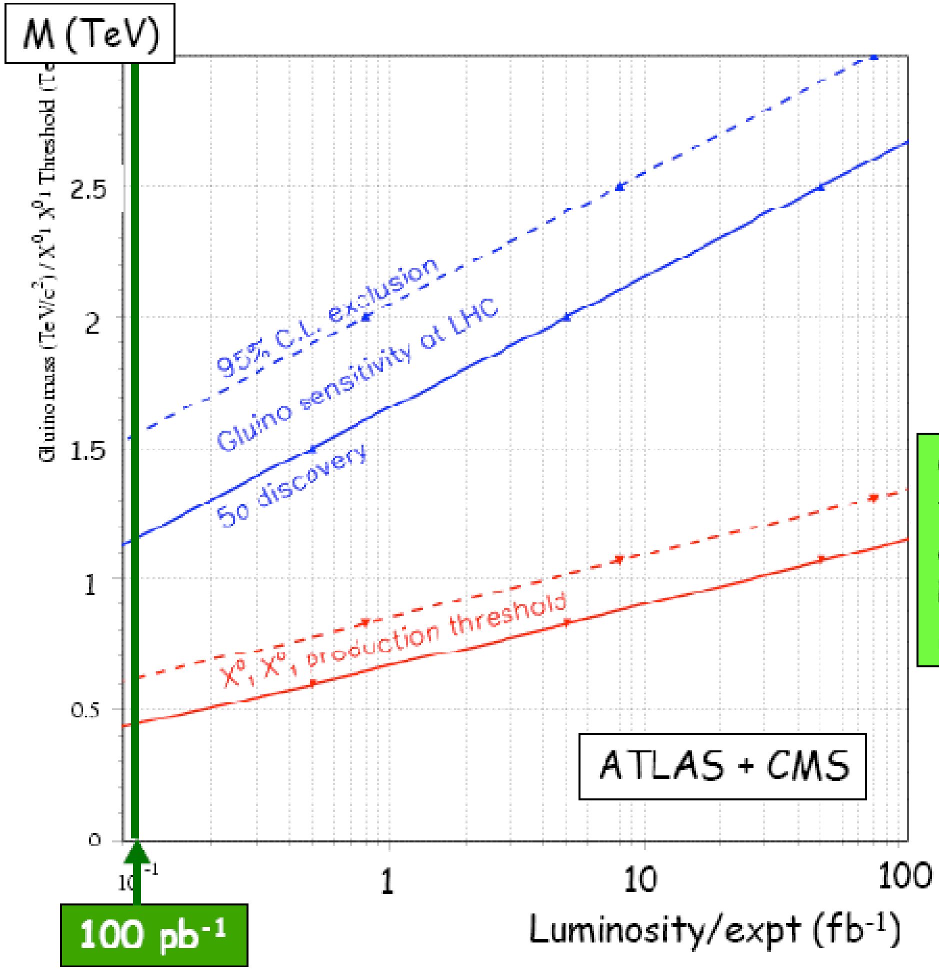
Input from the LHC for the LC…

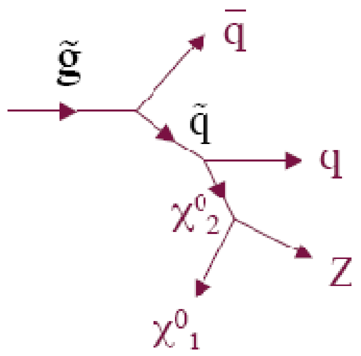
F. Gianotti, ADR et al.

Example of "early" discovery: Supersymmetry ?

If SUSY at TeV scale → could be found "quickly" …. thanks to:

- large $\tilde{q},\tilde{g}$ cross-section → ≈ 10 events/day at 10^{32} for $m(\tilde{q},\tilde{g}) \sim 1$ TeV
- spectacular signatures (many jets, leptons, missing E_T)





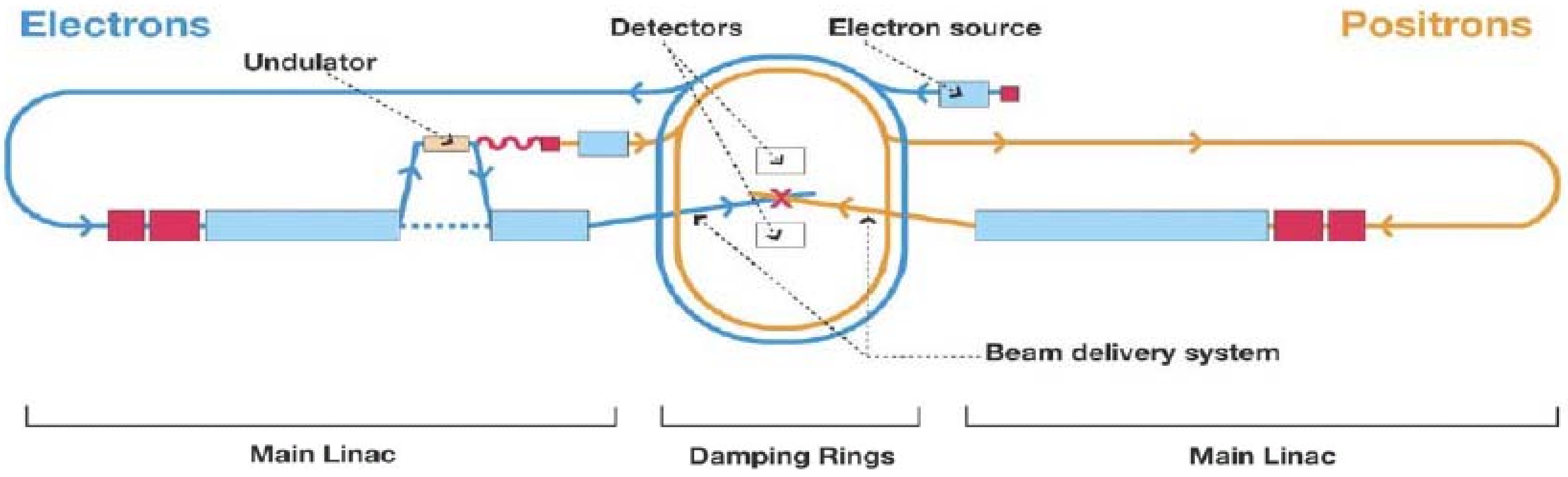
Something to watch for the ILC…
LHC/ILC workshop

Our field, and planning for future facilities, will benefit a lot from quick determination of scale of New Physics. E.g. with 100 (good) pb^{-1} LHC could say if SUSY accessible to a ≤1 TeV ILC

BUT: understanding E_T^{miss} spectrum (and tails from instrumental effects) is one of the most crucial and difficult experimental issue for SUSY searches at hadron colliders.

ILC Global Design Effort

~31 km (500 GeV)

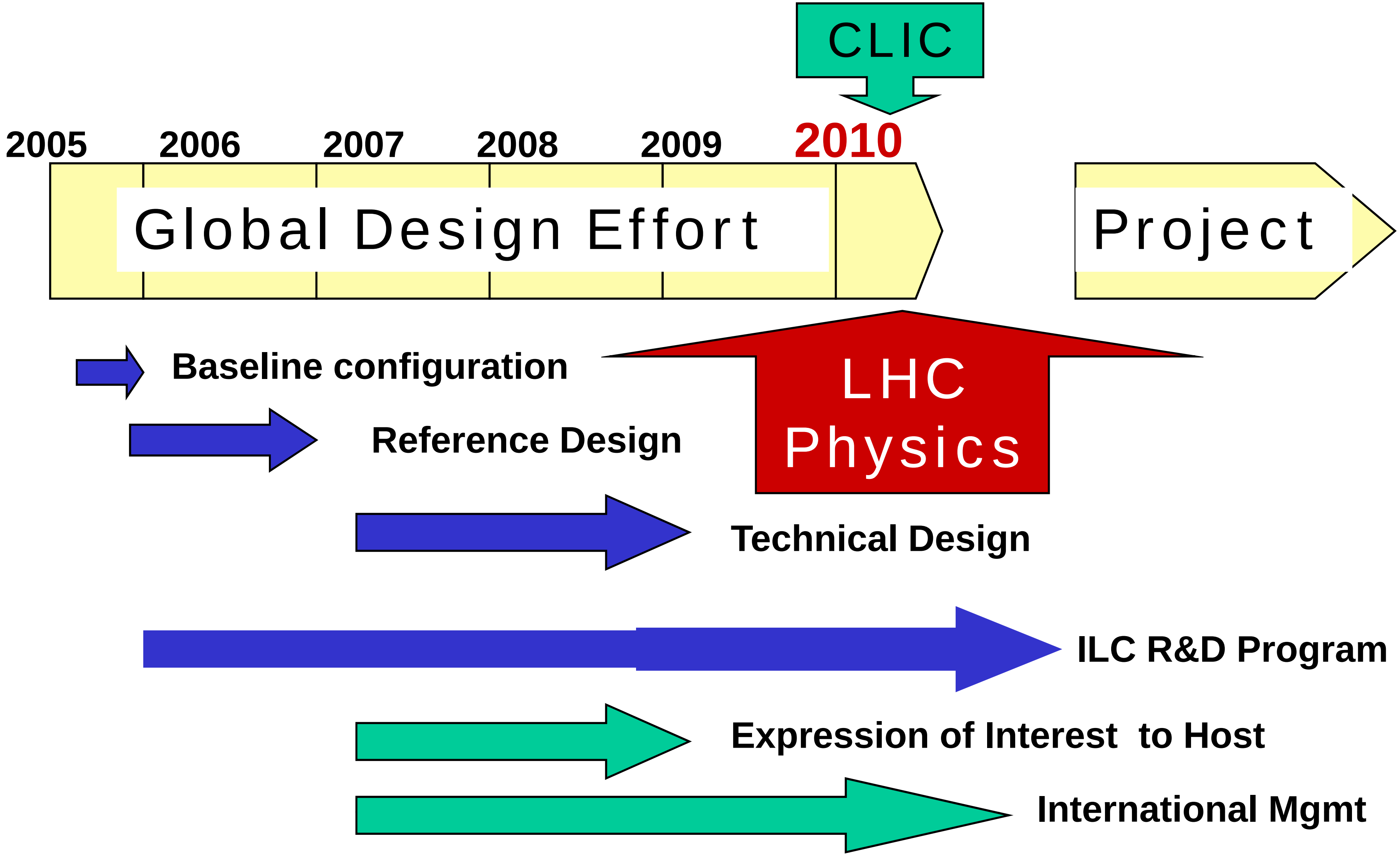


Luminosity
~ $2 \bullet 10^{34}$ $cm^{-2}s^{-1}$

Barry Barish
GDE
LCWS07 DESY

Active since
March 2005

The GDE Plan and Schedule for ILC



Costing made public in February 2007: 6.6 GUSD+ manpower

Baseline Configuration Document

- A structured electronic document
  - Documentation (reports, drawings etc)
  - Technical specifications.
  - Parameter tables

http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home

The International Linear Collider

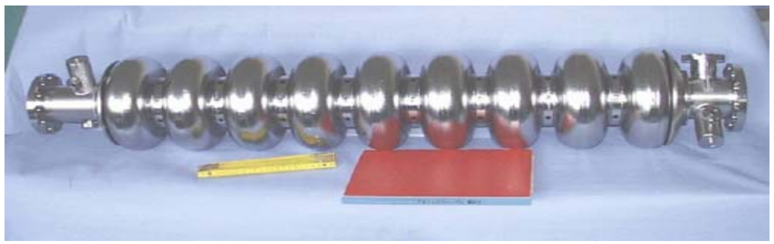
Global Design Effort

Baseline Configuration Document

		min	nominal		max
Bunch charge	N	1	2	2	$\times 10^{10}$
Number of bunches	n_b	1330	2820	**5640**	
Linac bunch interval	t_b	**154**	308	461	ns
Bunch length	σ_z	**150**	300	500	μm
Vertical emitance	$\gamma\varepsilon_y$	**0.03**	0.04	0.08	mm.mrad
IP beta (500GeV)	β_x	**10**	21	21	mm
	β_y	**0.2**	0.4	0.4	mm
IP beta (1TeV)	β_x	**10**	30	30	mm
	β_y	**0.2**	0.3	0.6	mm

Table 1.1 Baseline Parameter

Acceleration gradient of the cavities
31 MV/m (500 GeV) $\rightarrow$ 36MV/m (1 TeV)



Luminosity: 2 $\bullet 10^{34} cm^{-2} s^{-1}$

Nice, but what about Orbach?

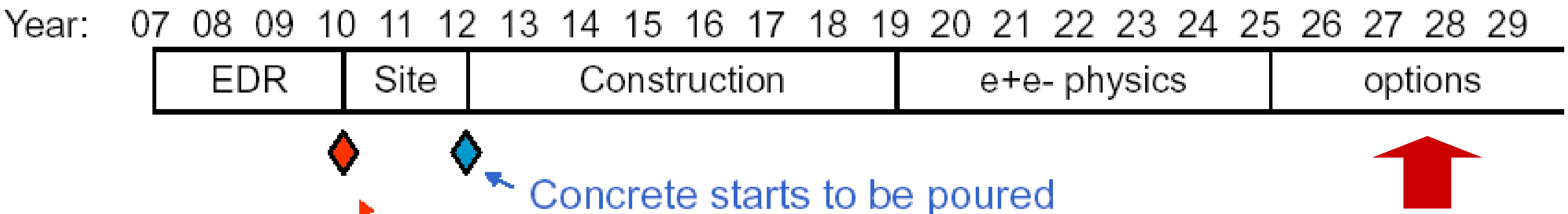
"Completing the R&D and engineering design, negotiating an international structure, selecting a site, obtaining firm financial commitments, and building a machine could take us well into the mid-2020s, if not later,"

- **Our technically driven time-scale is**
  - **Construction proposal in 2010**
  - **Construction start in 2012**
  - **Construction complete in 2019**
- **What do we need to do to achieve our schedule?**

B. Barish
LCWS07

⇒ Prepare to propose ILC construction

Timeline for ILC options?



Concrete starts to be poured
Decision are made that we will have to l

Photon collider?
Is the community in place?

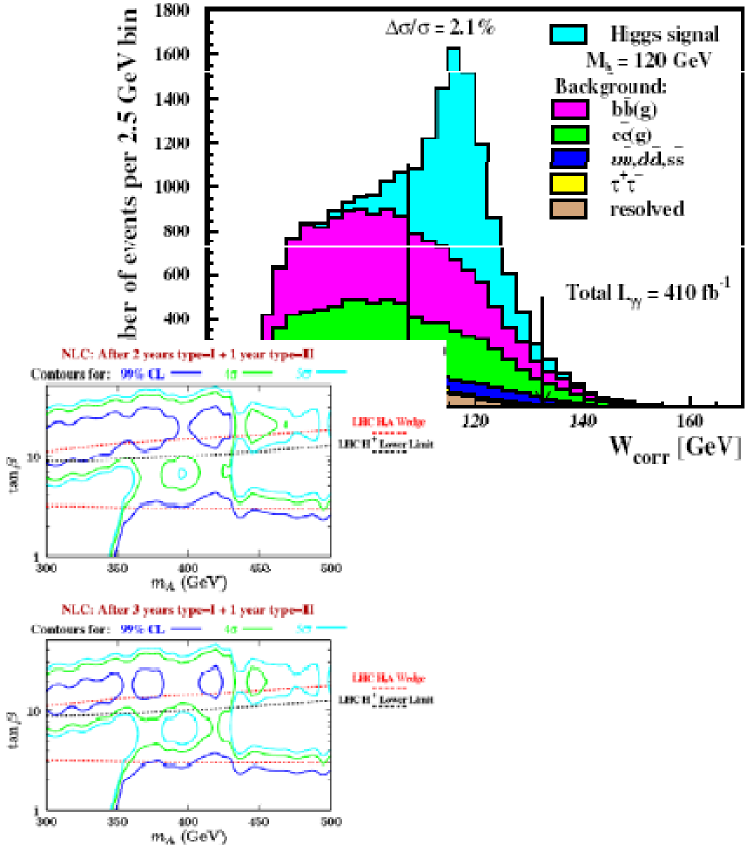
First Physics from LHC
Our view of what needs to be done will be refined, perhaps changed

We need to be ready to make decisions for the baseline machine to maximize it's physics potential for the long term.

J. Gronberg LCWS07

Photon Linear Collider physics is a valuable addition to the base program

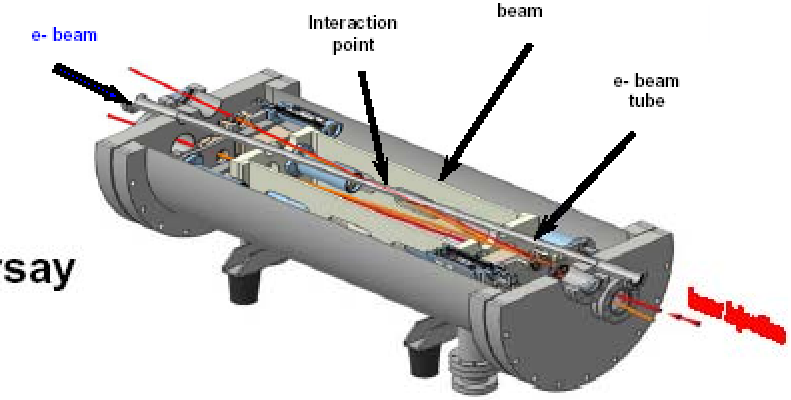
- PLC allows direct production neutral C=+ parity spin zero objects
  - Higgs
- Greater energy reach for SUSY H and A
  - Covers LHC wedge
- Linear polarization allows initial state of definite CP
- Double and single W production probes anomalous couplings
- Etc.



Physics case was reviewed at Jeju 2002 by the wider community
Photon Collider was determined to add real value to the physics program

Compton light sources are developing the laser technology

LAL - Orsay



- Resonant cavities are being developed for:
  - Polarized positron source
  - Laser wire
  - Beam diagnostics
  - Medical and industrial applications
  - Photon collider

KEK - Hiroshima

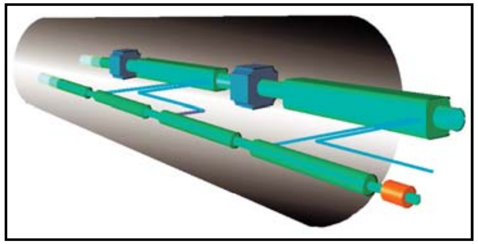
Laser development is being pushed by applications inside and outside of HEP

CERN contribution to ILC/GDE

- R&D on generic key issues independent of technology:
  - Participation in EUROTeV design study, CARE project and ELAN network
  - R&D on Beam diagnostics, Beam Delivery System (BDS), Beam dynamics...
  - Resources: 2.3 MEur. material, 25 staff-y, 20 fellows-y = 6.75 MEur. Total
- Tests with beam in CTF3 Test facility:
  - Beam instrumentation and beam simulations benchmarking
  - Beam combination for DR injection/extraction with RF Cavities
- Participation to R&D on Low Emittance generation at ATF/KEK
- Major participation in the establishment of costs for the RDR (Reference Design Report) for tunnel/civil engineering, infrastructure and cryogenic plants and cooling distribution and in the International Review of cost estimates for the ILC.
- In August 2007, a new phase for ILC: Engineering Design activities, will be launched and approval of construction assumed for 2010.

CERN DG 27/6/07

CLIC Compact LInear Collider



A multi-TeV e+e- collider
$\Rightarrow$High acceleration gradients

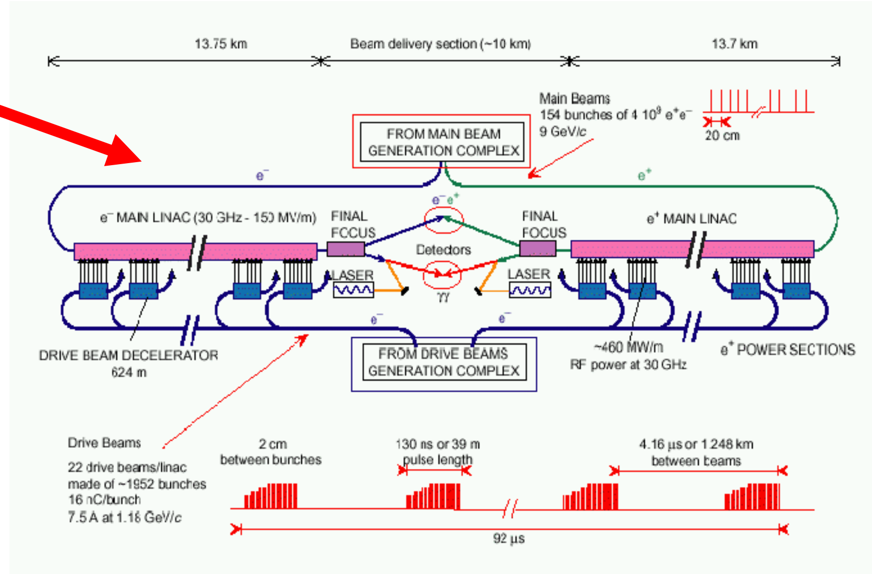
WORLD WIDE CLIC COLLABORATION

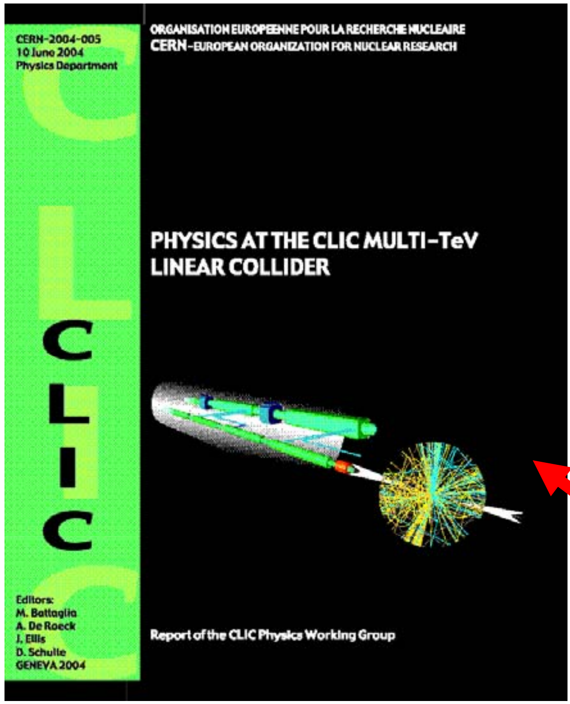
Ankara University (Turkey):	CTF3 beam studies & operation
Berlin Tech. University (Germany):	Structure simulations GdfidL
BINP (Russia):	CTF3 magnets development & construction
CERN:	Study coordination, structures devel., CTF3 construction/commissioning
CIEMAT (Spain):	CTF3 septa and kickers, correctors, power extraction structures
DAPNIA/Saclay (France):	CTF3 probe beam injector
Finnish Industry (Finland):	Sponsorship of mechanical engineer
INFN / LNF (Italy):	CTF3 delay loop, transfer lines & RF deflectors, ring vacuum chambers
JINR & IAP (Russia):	Surface heating tests of 30 GHz structures
KEK (Japan):	Low emittance beams in ATF
LAL/Orsay (France):	Electron guns and pre-buncher cavities for CTF3
LAPP/ESIA (France):	Stabilization studies, CTF3 beam position monitors
LLBL/LBL (USA):	Laser-wire studies
North-West. Univ. Illinois (USA):	Beam loss studies & CTF3 equipment
RAL (England):	Lasers for CTF3 and CLIC photo-injectors
SLAC (USA):	High Gradient Structure testing, structure design, CTF3 injector design
Uppsala University (Sweden):	Beam monitoring systems for CTF3

CLIC: a Multi-TeV Linear Collider

- Two beam acceleration presently only feasible way to reach multi-TeV region
- Principle demonstrated with CTF2
  More than 150 MV/m for short pulses
  …but 100 MV/m for long pulses?
- Present R&D ⇒ CTF3: drive beam

CLIC: 3 TeV (5 TeV) LC L=O(10^{35})$cm^{-2}s^{-1}$





⇒CERN: accelerate CLIC R&D support to evaluate the technology by 2009/2010

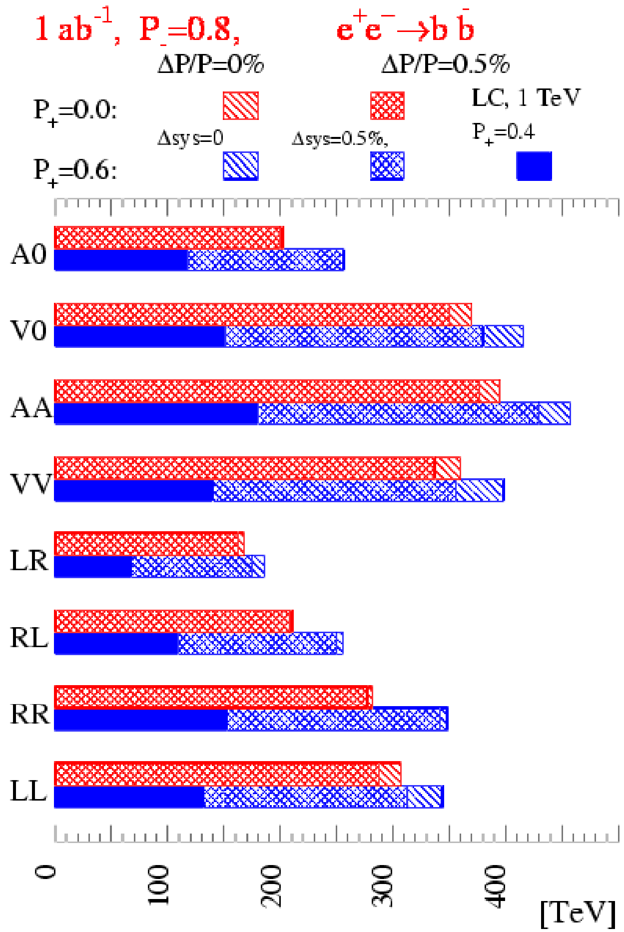
⇒CLIC collaboration.

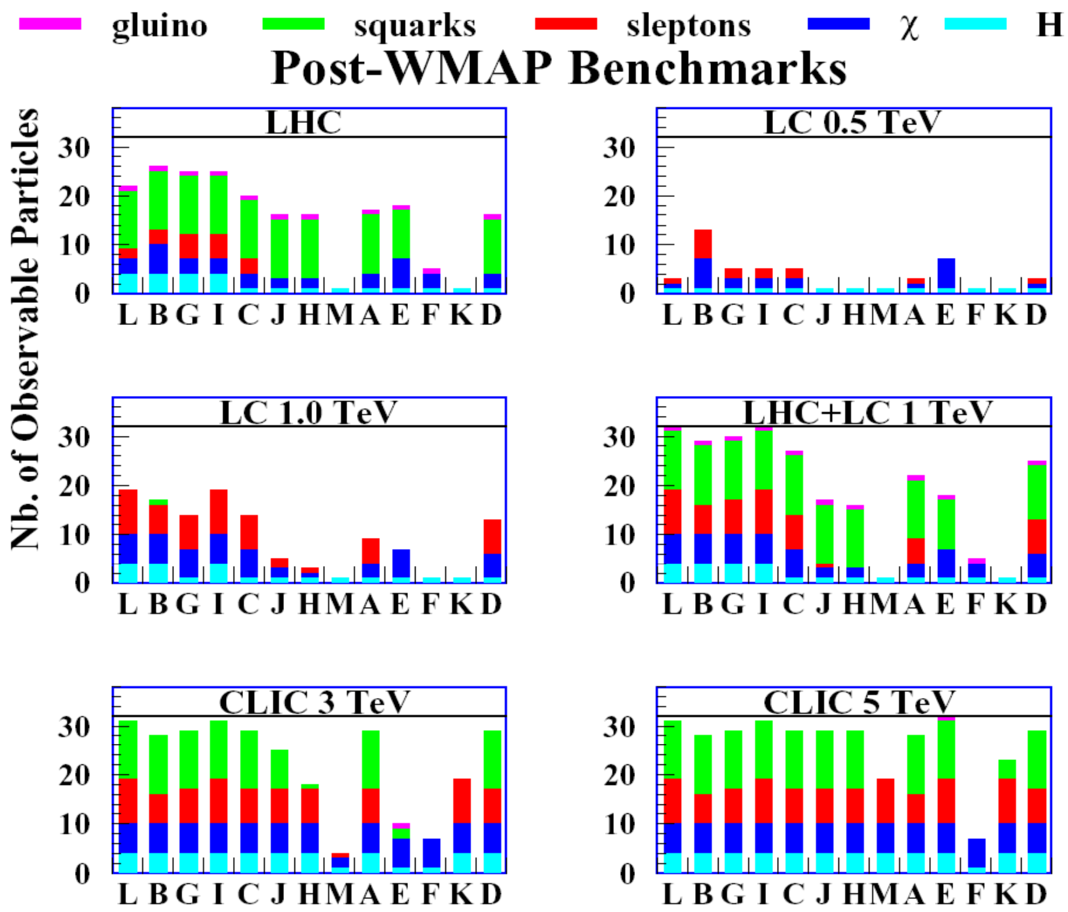
FAQs:

- CLIC technology O(5) years behind TeV class LCs
- CLIC can operate from 90 GeV→ 3 (5) TeV .

Physics case for CLIC documented in a CERN yellow report CERN-2004-005 (June)

CLIC: Examples of the Large Reach





Eur.Phys. J C33 273 (2004)

E.g.: Contact interactions:
Sensitivity to scales up to
100-800 TeV (few years of data)

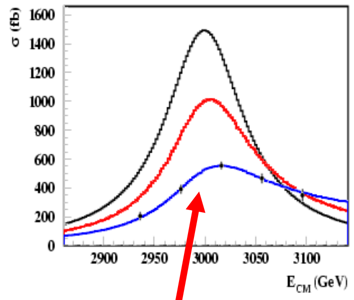
E.g. Supersymmetry
sparticles that can be detected
Expect higher precision at LC vs LHC

CLIC: Overview of Physics Reach

Measurements at CLIC (5 TeV / 1 ab^{-1})

Higgs (Light)	λ_{HHH} to $\sim 5-10\%$ (5 ab^{-1})
Higgs (Light)	$g_{H\mu\mu}$ to $\sim 3.5-10\%$ (5 ab^{-1})
Higgs (Heavy)	2.0 TeV (e^+e^-) 3.5 TeV ($\gamma\gamma$)
squarks	2.5 TeV
sleptons	2.5 TeV
Z' (direct)	5 TeV
Z' (indirect)	30 TeV
l^*, q^*	5 TeV
TGC (95%)	0.00008
Λ compos.	400 TeV
$W_L W_L$	>5 TeV
ED (ADD)	30 TeV (e^+e^-)
	55 TeV ($\gamma\gamma$)
ED (RS)	18 TeV (c=0.2)
ED (TeV^{-1})	80 TeV
Resonances	$\delta M/M, \delta\Gamma/\Gamma \sim 10^{-3}$
Black Holes	5 TeV

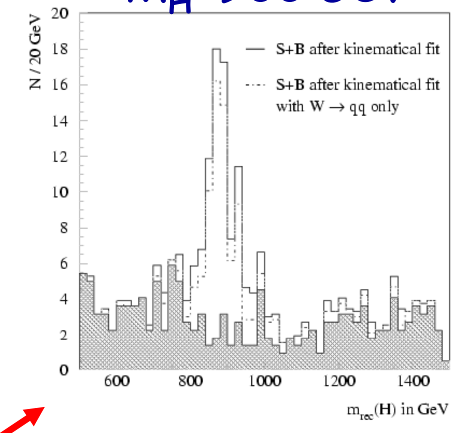
Assume $M_{Z'} = 3.0$ TeV and $\Gamma(Z')/M_{Z'} \simeq \Gamma(Z^0)/M_{Z^0}$



$\Rightarrow$ Fit Accuracy (1 ab^{-1})

$\delta M'_Z/M'_Z \sim 10^{-4}$ $\delta\Gamma'_Z/\Gamma'_Z \sim 3 \cdot 10^{-3}$

M_H=900 GeV

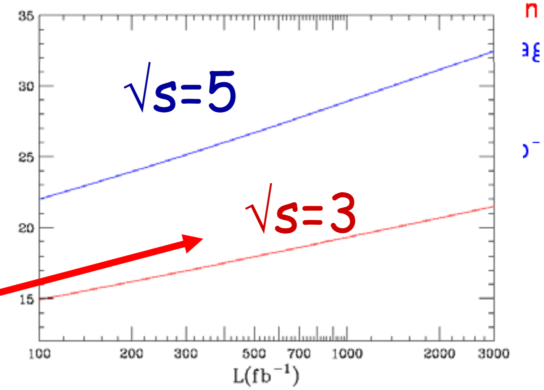


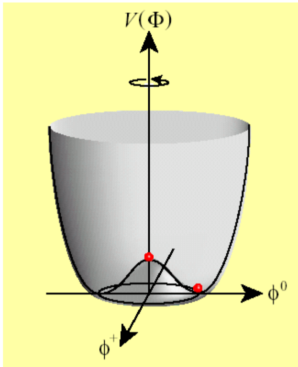
New Z' resonance

Heavy Higgs

ADD Extra Dimensions

Measuring the Higgs self coupling to 5-10%





M_H (GeV)	$\sigma_{HH\nu\bar{\nu}}$ Only	$\lvert\cos\theta^*\rvert$ Fit
120	$\pm$ 0.094 (stat)	$\pm$ 0.070 (stat)
180	$\pm$ 0.140 (stat)	$\pm$ 0.080 (stat)

Prospects for scientific activities over the period 2012-2016

- Assuming positive results in 2010 from the CLIC technology qualifying programme with CTF3, it will be appropriate **to prepare a Technical Design for implementing the CLIC programme after the LHC upgrade is achieved**.

- **The need for infrastructure consolidation** is evident and thus the Management proposes to enhance this activity to some 30 MCHF + 40 FTEs from 2011 onwards.

During the same period of 2011-2016, **effective participation of CERN in another large programme** (ILC or a neutrino factory) **will not be possible within the expected resources** if positive decisions are taken on the two programmes mentioned above (LHC upgrade and CLIC Technical Design). This situation could totally change *if none of the above programmes is approved* or if a new, more ambitious level of activities and support is envisaged in the European framework.

CERN DG 27/6/07

Indicative Physics Reach all Machines

Ellis, Gianotti, ADR
hep-ex/0112004+ few updates

Units are TeV (except $W_L W_L$ reach)
☞ $\int$Ldt correspond to <u>1 year of running</u> at nominal luminosity for <u>1 experiment</u>

PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	DLHC 28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	LC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
$W_L W_L$	2σ	4σ	4.5σ	7σ	18σ	6σ	90σ
Z'	5	6	8	11	35	8†	30†
Extra-dim (δ=2)	9	12	15	25	65	5-8.5†	30-55†
q*	6.5	7.5	9.5	13	75	0.8	5
Λcompositeness	30	40	40	50	100	100	400
TGC (λ_γ)	0.0014	0.0006	0.0008		0.0003	0.0004	0.00008

† indirect reach
(from precision measurements)

Approximate mass reach machines:
$\sqrt{s}$ = 14 TeV, L=10^{34} (LHC) : up to ≈ 6.5 TeV
$\sqrt{s}$ = 14 TeV, L=10^{35} (SLHC) : up to ≈ 8 TeV
$\sqrt{s}$ = 28 TeV, L=10^{34} (DLHC) : up to ≈ 10 TeV

Summary

The LHC luminosity upgrade to 10^{35} $cm^{-2}s^{-1}$

- Extend the LHC discovery mass range by 25-30% (SUSY,Z',EDs,…)
- Higgs self-coupling measurable with a precision of (20-30%)
- Rear decays accessible: $H\rightarrow\mu\mu$, γZ, top decays…
- Improved Higgs coupling ratios by a factor of 2,…
- TGC precision measurements…

Challenge for the experiments/ LHC at its limits/Later energy upgrade?

A high luminosity linear collider as the next HE frontier accelerator

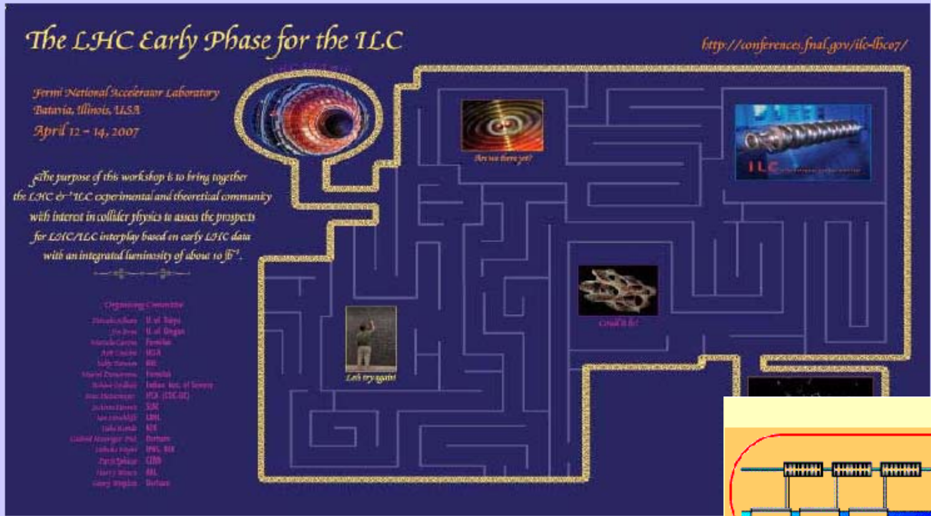
- ILC design very advanced and project has good momentum. CLIC still R&D
- LC: Precision measurements, eg improve by an order of magnitude on properties of particles, within its production reach/model independent $\Rightarrow$ unravel the underlying theory/model in detail.
- The exciting possibility for a Photon Collider!!
- Discovery of particles which are difficult to find in LHC pp collisions
- Optimal LC energy will be known better from the LHC results by 2010

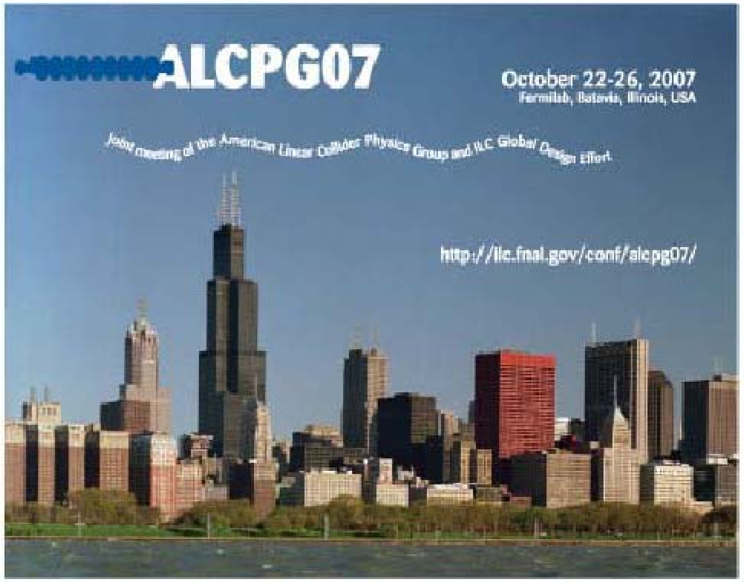
Some Upcoming Workshops

"… to assess the prospects for LHC/ILC interplay based on early LHC data with an integrated luminosity of about $10\ fb^{-1}$."

Next LHC/ILC Interplay Meeting:

SLAC, November 15-17, 2007





Next Regional Meeting is at Fermilab in October!

CLIC

CLIC Workshop

CERN, 16-18 October 2007

Local Organising Committee

H. H. Braun (chair)
R. Corsini
J.-P. Delahaye
J. Ellis
S. Fecnfire
G. Geschonke
A. de Roeck
W.D. Schlatter
D. Schulte
W. Wuensch

CLIC'07 provides a forum to review all aspects related to the Accelerator, Detector and Particle Physics of a Multi-TeV Linear Collider based on the CLIC technology.
It is open to any interested Accelerator and Physics expert already part or not of the CLIC/CTF3 collaboration.

The workshop will address in particular:

- Present status and future plans of the CLIC study
- CLIC physics case and detector issues
- The Test Facility CTF3 used to address major CLIC technology issues
- The ongoing CLIC R&D, future plans (including FP7 proposals) and open issues
- The CLIC related collaborative efforts

LC: Few More Examples

⇒ Understanding SUSY

High accuracy of sparticle mass measurements relevant for reconstruction of SUSY breaking mechanism

⇒ Dark Matter

LC will accurately measure m_χ and couplings, i.e. Higgsino/Wino/Bino content

→ Essential input to cosmology & searches

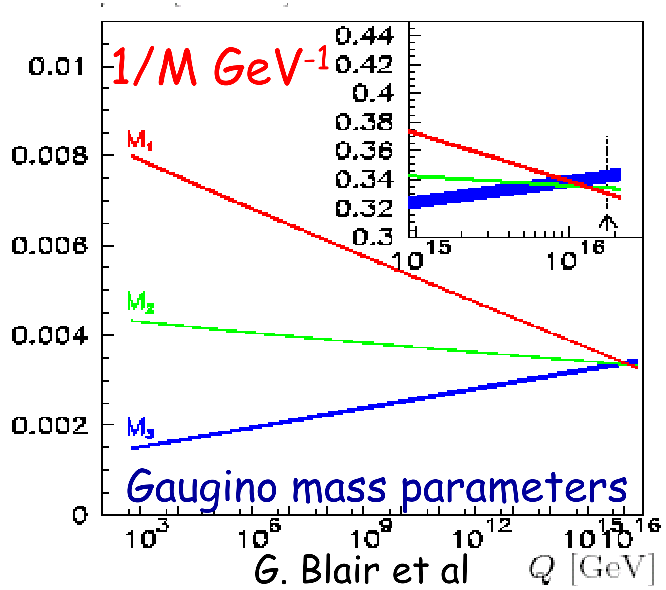
LC will make a prediction of $\Omega_{DM}h^2 \sim 3\%$ (SPS1a)

→ A mismatch with WMAP/Planck would reveal extra sources of DM (Axions, heavy objects)

⇒ Quantum level consistency: M_H(direct)= M_H(indirect)?

$\Delta\sin^2\theta_W \sim 10^{-5}$ (GigaZ), $\Delta M_W \sim 6$ MeV (+theory progress)

→ ΔM_H (indirect) ~ 5%



G. Blair et al

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

F. Richard/SPS1a

Baseline Configuration Document

- A structured electronic document
  - Documentation (reports, drawings etc)
  - Technical specs.
  - Parameter tables

http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home

The International Linear Collider

Global Design Effort

Baseline Configuration Document

		min	nominal		max
Bunch charge	N	1	2	2	$\times 10^{10}$
Number of bunches	n_b	1330	2820	**5640**	
Linac bunch interval	t_b	**154**	308	461	ns
Bunch length	σ_z	**150**	300	500	µm
Vertical emitance	$\gamma\varepsilon_y$	**0.03**	0.04	0.08	mm.mrad
IP beta (500GeV)	β_x	**10**	21	21	mm
	β_y	**0.2**	0.4	0.4	mm
IP beta (1TeV)	β_x	**10**	30	30	mm
	β_y	**0.2**	0.3	0.6	mm

Table 1.1 Baseline Parameter

Acceleration gradient of the cavities
31 MV/m (500 GeV) → 36MV/m (1 TeV)

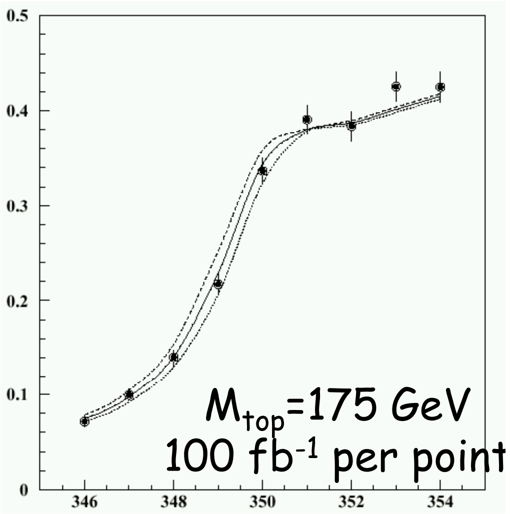
Luminosity: $2 \bullet 10^{34} cm^{-2} s^{-1}$

What if no new particles in LC range?

⇒Precision measurements of the top quark, e.g top mass!
Compare m_W and $\sin^2\theta_{eff}$ experimental accuracy with theoretical prediction ⇒ theoretical consistency!
Top mass uncertainty is a limiting factor

$$\delta m_t = 1\ \text{GeV} \quad \Rightarrow \quad \Delta M_W^{\text{para},m_t} \approx \pm 6\ \text{MeV}, \quad \Delta \sin^2\theta_{\text{eff}}^{\text{para},m_t} \approx \pm 3 \times 10^{-5}$$

$$\delta m_t = 0.1\ \text{GeV} \quad \Rightarrow \quad \Delta M_W^{\text{para},m_t} \approx \pm 1\ \text{MeV}, \quad \Delta \sin^2\theta_{\text{eff}}^{\text{para},m_t} \approx \pm 0.3 \times 10^{-5}$$

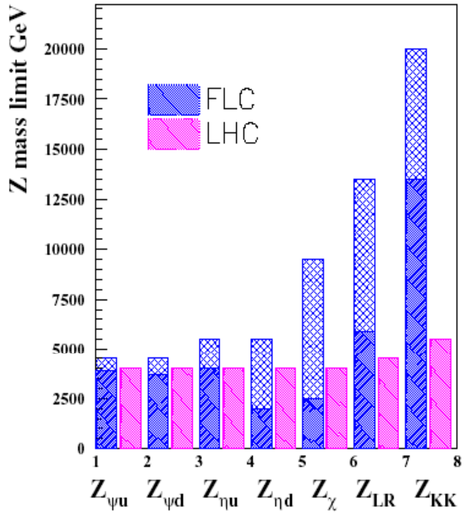


~ similar to theoretical HO uncertainties, 5x better than exp. precision

⇒Precision indirect measurements (TGCs, Z′, strong EWSB...)

LC has large reach for indirect measurements

e.g Compares indirect (LC) Z′ searches with direct LHC
Note: some indirect searches also possible at the LHC
e.g. Z_{KK} indirect sensitivity up to 15-20 TeV for SLHC



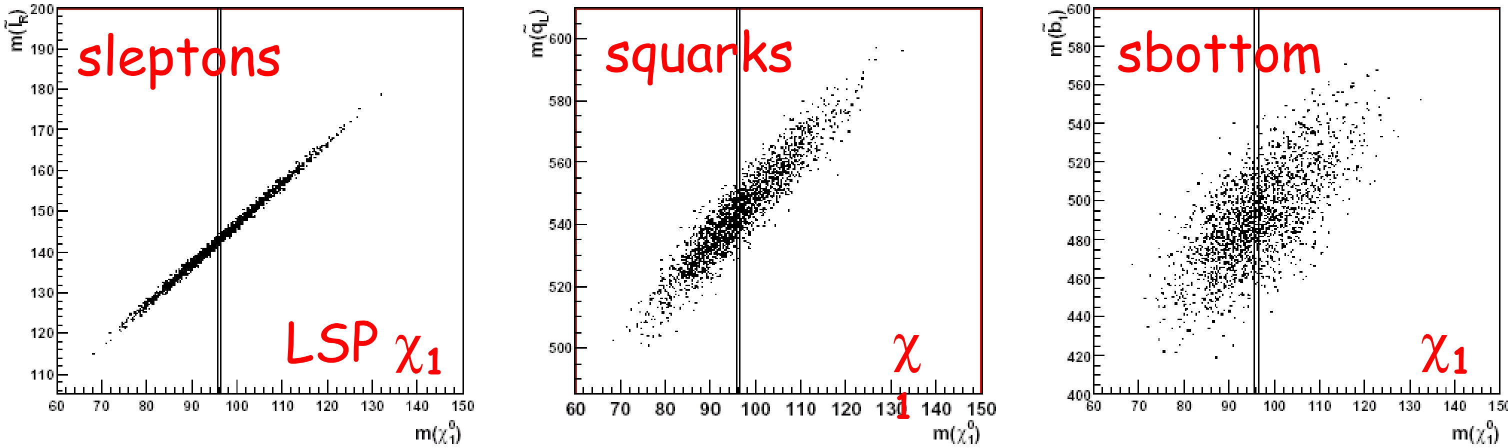
LHC/LC Complementarity

http://www.ipp.dur.ac.uk/~georg/lhclc/

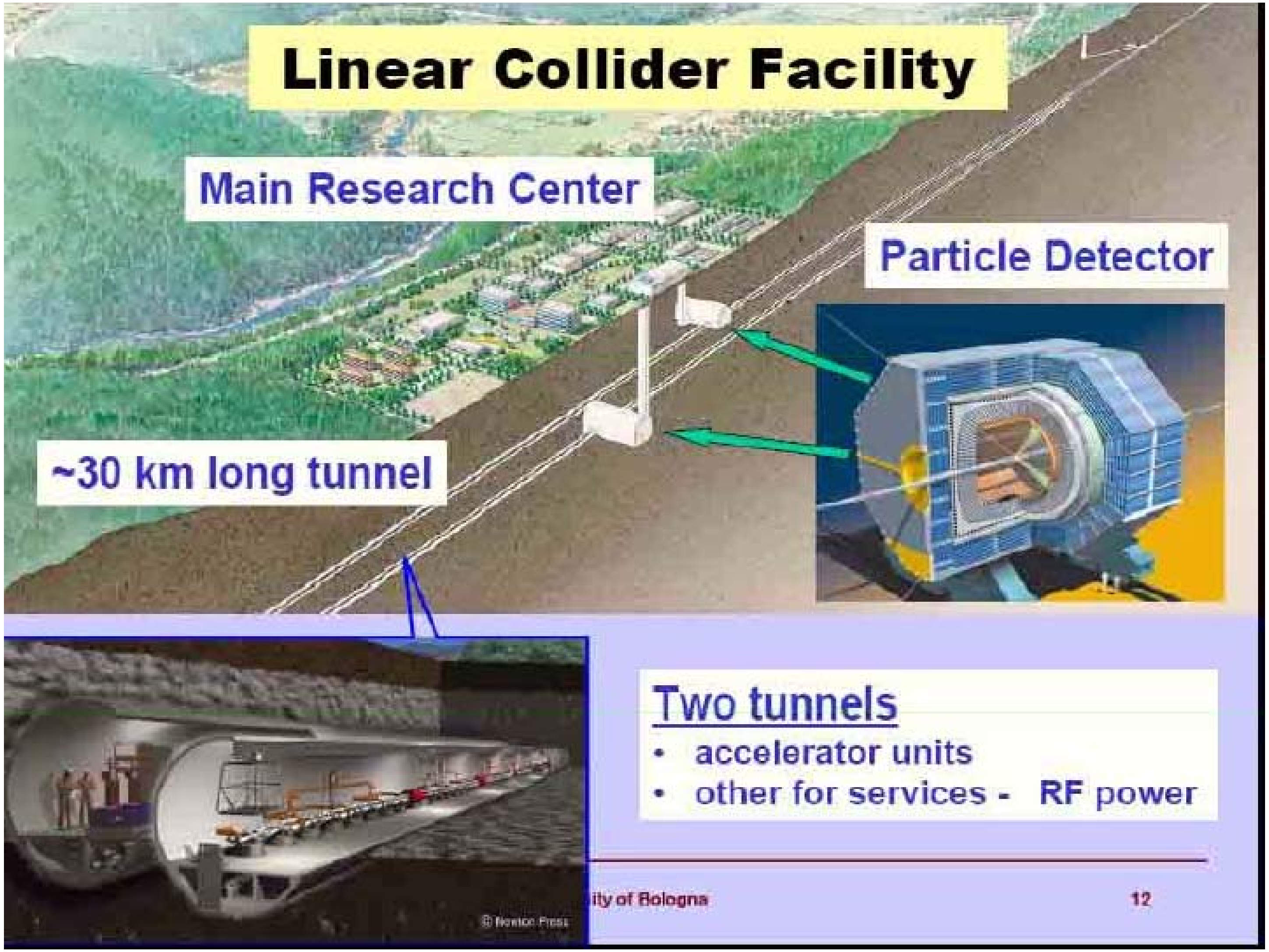
- The complementarity of the LHC and LC results has been studied by a working group and has produced a huge document
- Working group contains members from LHC and LC community + theorists

Conclusion: lot to gain for analysis of BOTH machines if there is a substantial overlap in running time.

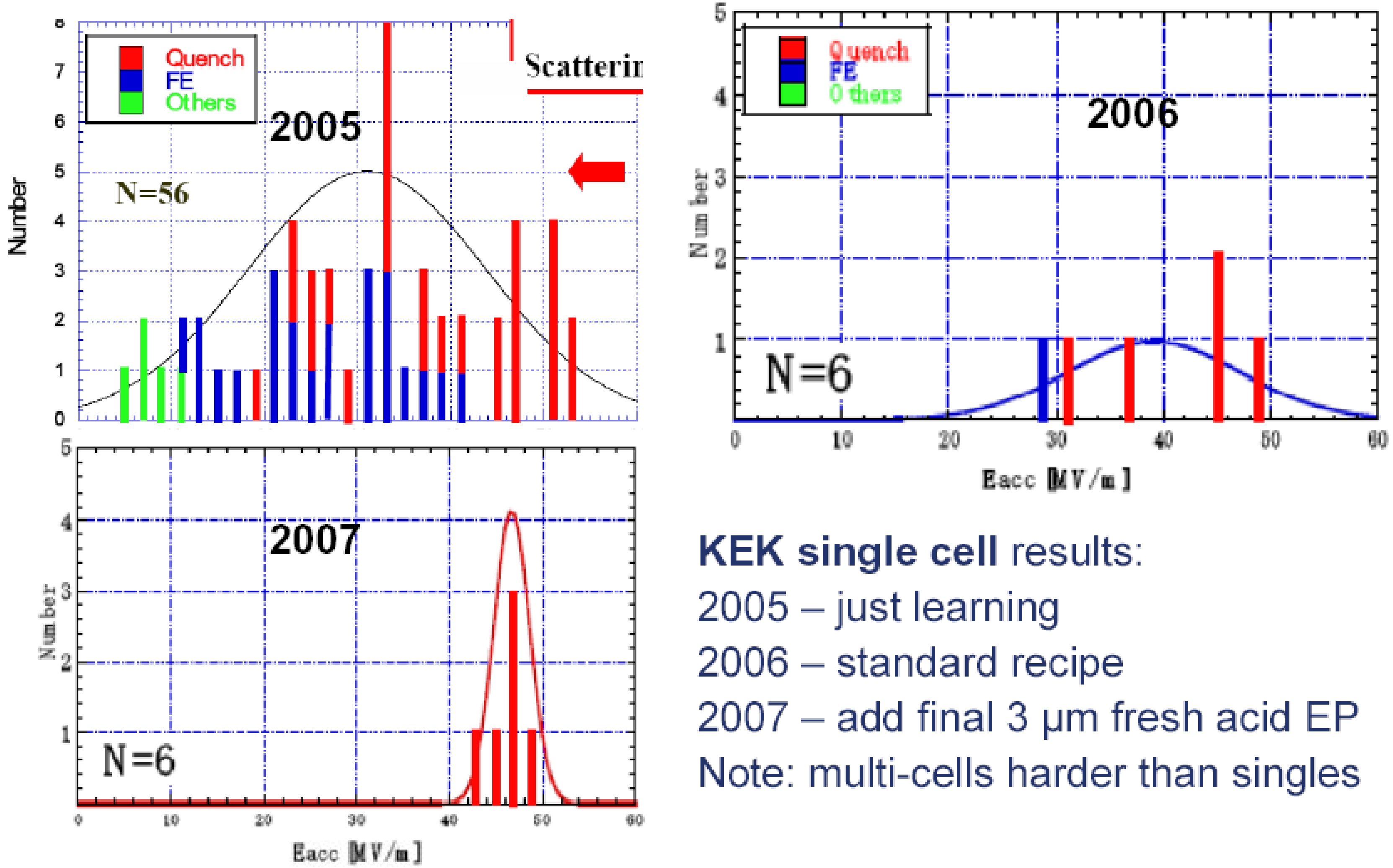
Example: at LHC masses of the measured particles are strongly correlated with the mass of the lightest neutralino



Largely improve LHC mass measurements when LC χ_1^0 value is used


Linear Collider Facility
Main Research Center
Particle Detector
~30 km long tunnel
Two tunnels
• accelerator units
• other for services - RF power
ity of Bologna
12

S0 : Cavity Gradient – Results



KEK single cell results:

2005 – just learning

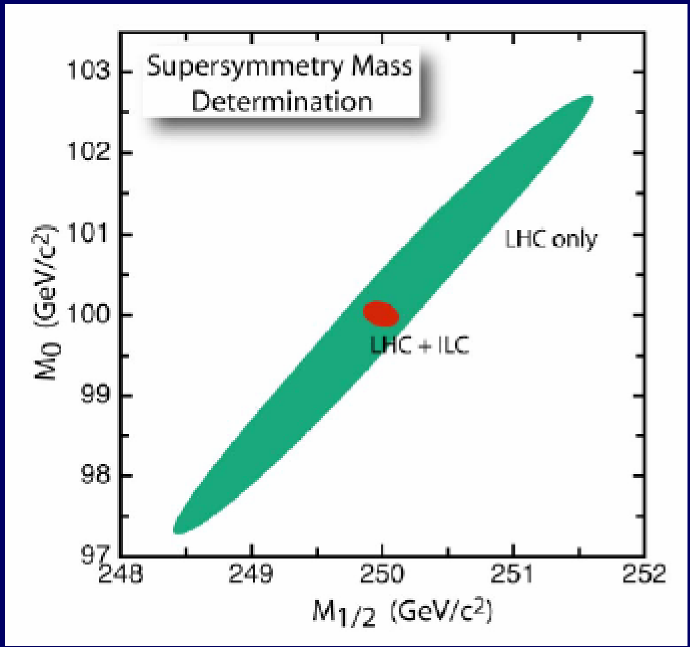
2006 – standard recipe

2007 – add final 3 μm fresh acid EP

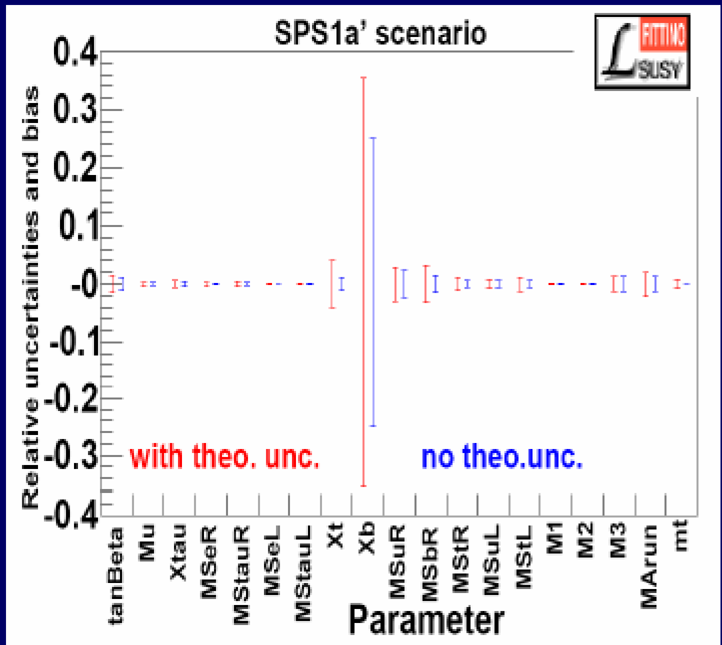
Note: multi-cells harder than singles

SUSY at ILC + LHC

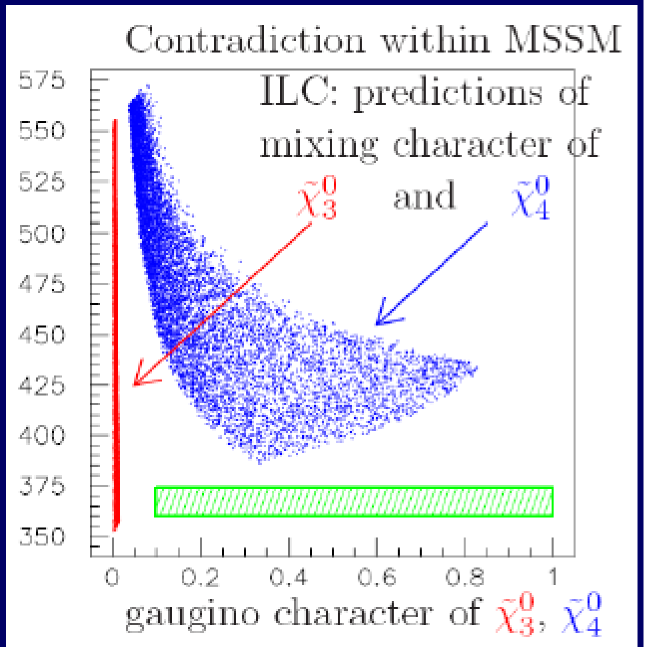
ILC and LHC together can likely measure precisely
- **the parameters of constrained models (mSugra...)**
- **determine the underlying SUSY parameters w/o model assumptions**
- **determine the properties of the LSP → dark matter density**
- **test more complex realisations (e.g. NMSSM)**



LHC-ILC report



Bechtle,KD,Wienemann
also SFITTER: Plehn ea



Hesselbach,Moortgat-Pick

Nothing yet…

With 10-30 fb^{-1} analysed at the LHC, many of our favourite scenarios can be excluded:

- SM Higgs
- MSSM Higgs
- MSSM indirect: absence of light Higgs, direct: up to ~1.5 TeV
- …

Major focus then: EWSB

1. has the LHC missed the Higgs(es)?
   (e.g. invisible, Higgs continuum, $H \rightarrow$jets, …)
   ILC can discover the Higgs in these scenarios.

2. there is really no Higgs
   Technicolor/Higgsless models
   Signals might show up with higher luminosity
   (WW scattering at high masses crucial)
   if this scenario can be excluded at LHC, revisit option 1.

Conclusions

The LHC Early Phase will be exciting!

The LHC Early Phase will confront our ideas about Terascale physics with real data

We will have to demonstrate that there is indeed a strong case for the ILC in the light of these data: that’s no free lunch!
(but I’m not nervous…)

Some possible signals at LHC (light Higgs, SUSY-like signals, leptonic resonances,…) are clear “go ahead” signs for ILC

Others (e.g. heavier Higgs) need more studies to assess the ILC physics potential within the various physics scenarios

Optimal ILC run plan and upgrade path have to be inferred from LHC data

Other options: an ep collider

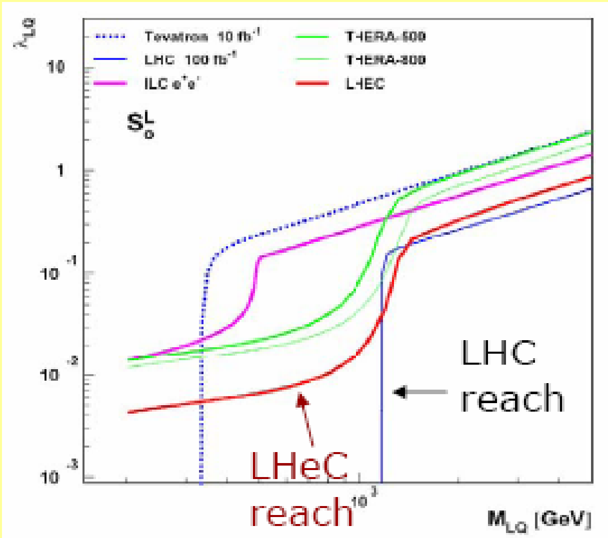
Electron-Proton Collider LHeC

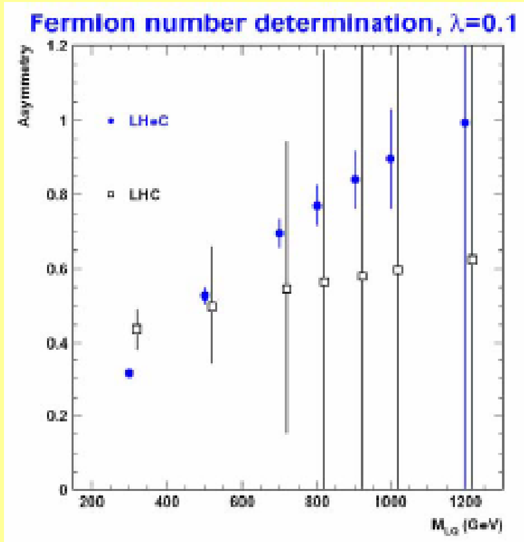
new proposal submitted to this meeting:
supplement LHC by 70 GeV e^-/e^+ storage ring

$\sqrt{s}$ = 1.4 TeV
L = 10^{33} $cm^{-2}s^{-1}$

machine design: → Raimondi
structure functions, low-x physics, QCD: → Butterworth

here: potential for new physics:
unique for eq-resonances, e.g. Leptoquarks, Squarks in RPV-SUSY,...
can provide precise analysis (F-number,spin,couplings...) of LQ's
within complete LHC discovery range





Other options: A muon collider

Physics at a Muon Collider

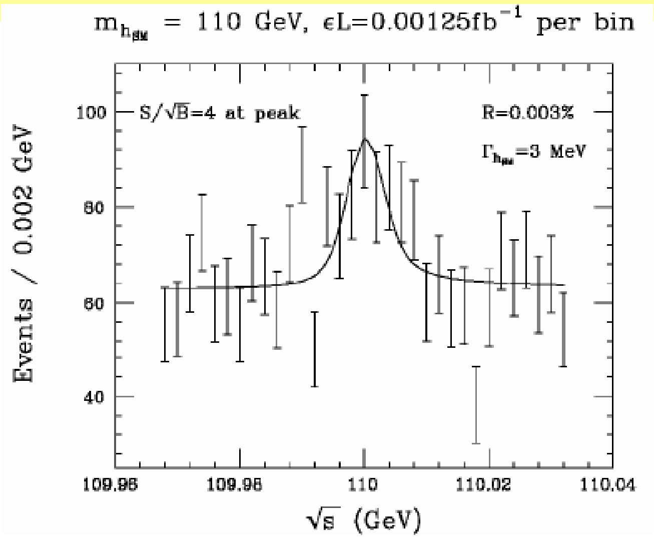
100 GeV → Multi-TeV $\mu^+\mu^-$ Collider could emerge as a (major) upgrade of a Neutrino factory →Raimondi

Multi-TeV μC could do same physics as multi-TeV e^+e^- if same luminosity can be achieved (seems hard→impossible)

advantage: no ISR, beamstrahlung → $\Delta E_b/E_b \sim 10^{-6}$?

disadvantage: huge backgrounds from μ decay

Unique Selling Point: s-channel Higgs production



Not an option for the near future…

Conclusion

- LHC will be the next high energy collider
  - It will reveal the EWSB mechanism
  - It will probe the TeV scale for new physics
- SHLC (luminosity upgrade) will give good return for a modest investment
- VLHC is still for the far future
- A LC collider is a precision instrument
  - It complements the LHC perfectly
  - ILC community has built up large momentum
  - CLIC (3 TeV) aims to demonstrate feasibility of the technology by 2009/2010
- Is a 500 (1000) GeV the right energy for a LC?
  - By 2010 the LHC will have the first answers: SM Higgs?, new physics with particles in the ILC range?
- 2010(+) will be an important year.

In any case: exciting times ahead !!

CERN Council position on the LC

8. SUMMARY OF CONCLUSIONS

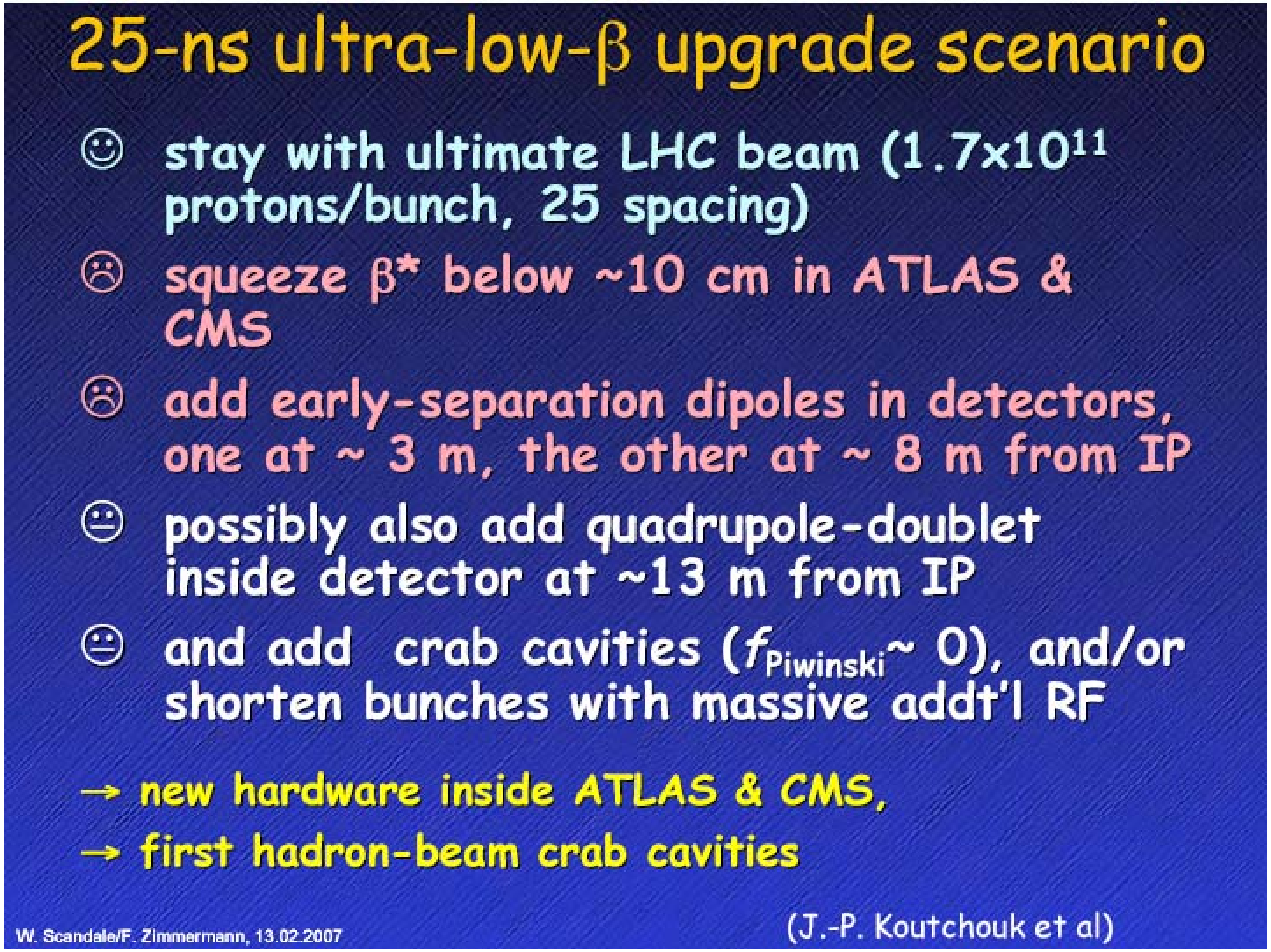
(Item 8 of the agenda)

The PRESIDENT presented a draft summary of conclusions, prepared by himself and the two Vice-Presidents of Council during the adjournment, and invited comments and amendments by the delegations. After extensive discussion, the Council agreed that it could go on record with the following statement:

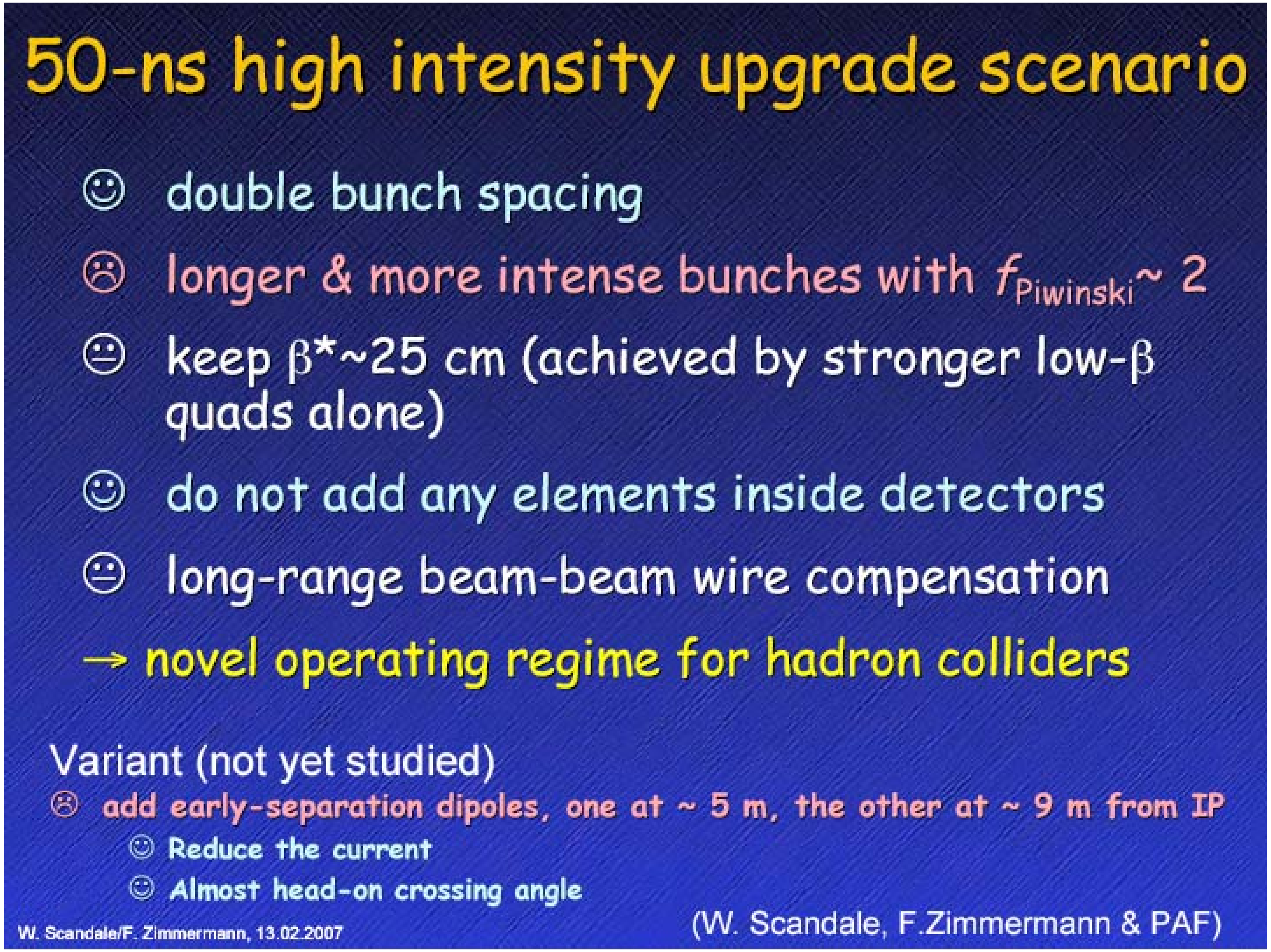
"The Council:

- Confirms that the first priority for the world particle physics community is to complete the LHC and its detectors in order to unveil, as soon as possible, the physics at the new energy frontier;
- Encourages the effort towards the design and development of a linear collider as a unique scientific opportunity at the precision frontier, complementary to the LHC;
- Confirms its endorsement of accelerated R&D activities for CLIC;
- Recognises the overall value for the world particle physics community of a decision to construct a TeV linear collider, and encourages the efforts of the leading players in that direction;
- Takes the view that, in the course of this process, it will be appropriate to take stock of the LHC and accelerator R&D results and produce a new assessment of the physics and the technology by 2010;
- Is of the opinion that, in the initial phase (2004-2007), the organisational structure of the global design initiative, in particular the Central Design Team, should be light."

Option 1


25-ns ultra-low-β upgrade scenario
☺ stay with ultimate LHC beam (1.7x10^11 protons/bunch, 25 spacing)
☹ squeeze β* below ~10 cm in ATLAS & CMS
☹ add early-separation dipoles in detectors, one at ~ 3 m, the other at ~ 8 m from IP
😐 possibly also add quadrupole-doublet inside detector at ~13 m from IP
😐 and add crab cavities (f_Piwinski ~ 0), and/or shorten bunches with massive addt'l RF
→ new hardware inside ATLAS & CMS,
→ first hadron-beam crab cavities
W. Scandale/F. Zimmermann, 13.02.2007
(J.-P. Koutchouk et al)

Option 2


50-ns high intensity upgrade scenario
☺ double bunch spacing
☹ longer & more intense bunches with $f_{Piwinski}$~ 2
😐 keep β*~25 cm (achieved by stronger low-β quads alone)
☺ do not add any elements inside detectors
😐 long-range beam-beam wire compensation
→ novel operating regime for hadron colliders
Variant (not yet studied)
☹ add early-separation dipoles, one at ~ 5 m, the other at ~ 9 m from IP
☺ Reduce the current
☺ Almost head-on crossing angle
W. Scandale/F. Zimmermann, 13.02.2007
(W. Scandale, F.Zimmermann & PAF)