The International Linear Collider Project

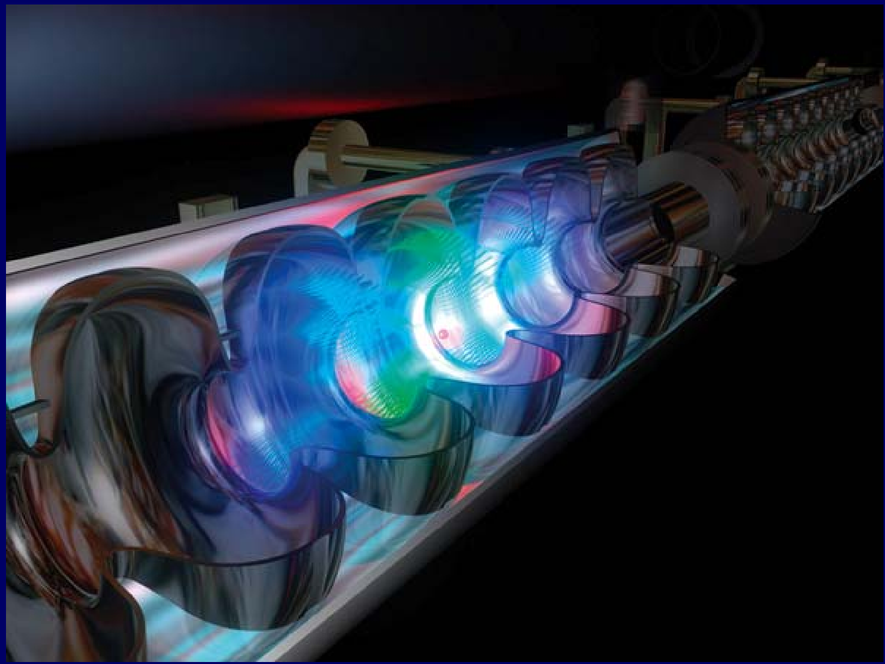
Outline:

1. Why? Physics

2. How? Accelerator

3. How? Detectors

4. When? Where? „Politics“



Klaus Desch
Universität Bonn

1. The next big project in particle physics

Long lead time of "big science" projects

HST: first plans 1971 – launch 1990

ITER: first plans 1988 – approval 2005 – start 2018?

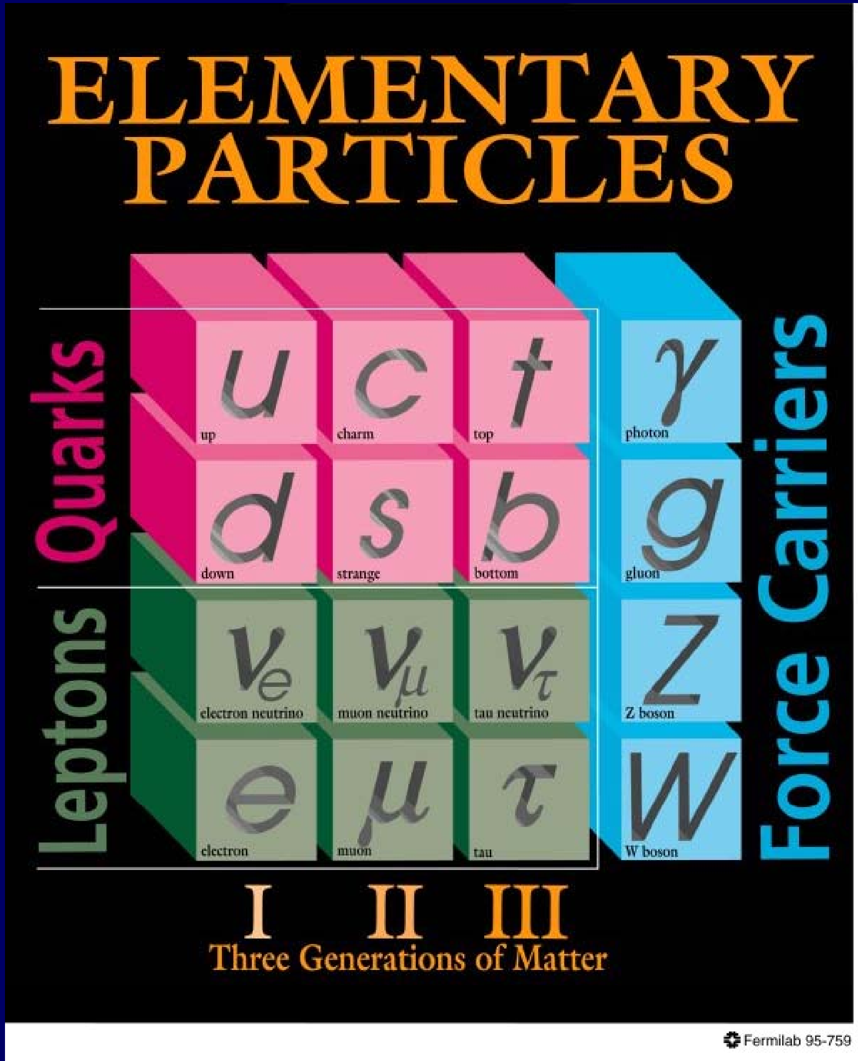
LHC: first workshop ~1984 – start 2008

International Linear Collider ILC first workshops ~1991 – start 20xx?

Temptation: technology for the ILC is +- at hands! (since ~2000)
Avoid to build something just because in can be built

Need for:
- a strong physics motivation
- a technical design (accelerator + detectors)
- a strong community

1. Physics First

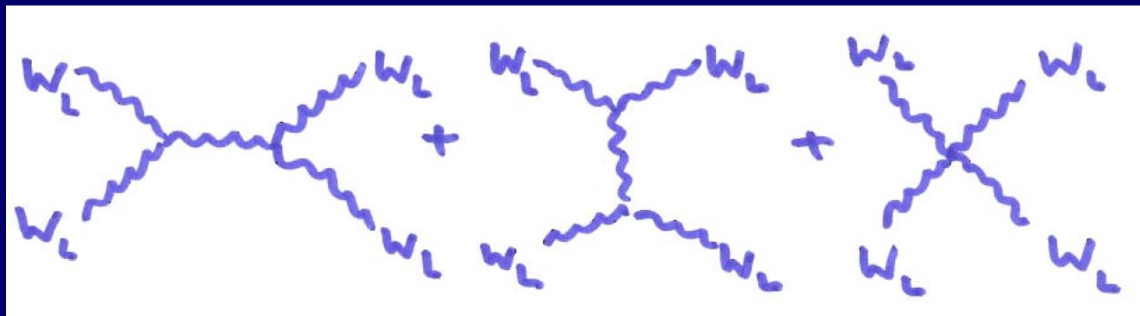


- tremendous progress in understanding the microscopic world since ~1974
- observation of a (could-be) complete set of matter particles and force carriers
- simple consistent theoretical framework to describe all interactions (except gravity) gauge principle
- theory and experiment consistent at the level of quantum corrections

1. A missing link (from theory)

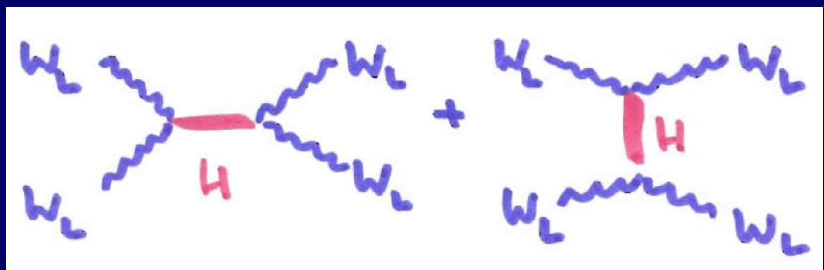
Polarization vector for longitundinal W bosons

$$\varepsilon^{\mu}_{long}(p) = \frac{1}{M_W}(E,0,0,p) \sim E$$



diverges for √s → ∞, violates unitarity at √s ≈ 1.2 TeV

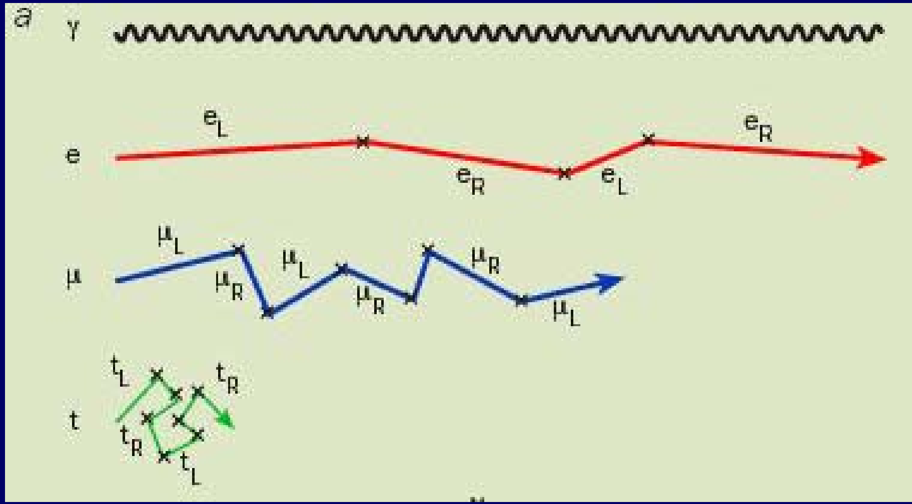
divergency can be compensated by new scalar particles with coupling ~ mass



The Higgs boson

1. A missing link (from theory)

Peter Higgs (1964!)



Is “mass” a property of a particle, or only the apparent result of a permanent external force???

We will get hints in a few years!

⇨ Large Hadron Collider LHC

If the Higgs mechanism comes to rescue the gauge principle it has to come with a Higgs boson mass <~ 1 TeV

Comparison of experiments and (quantum) theory point at a light Higgs: $m_H < 144$ GeV @ 95% C.L.

1. A missing link (from observation)

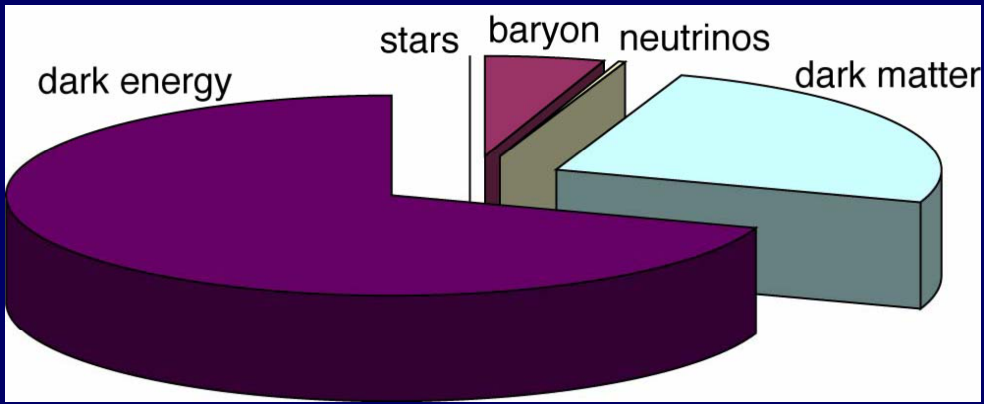
It seems very likely that the dark matter which makes up for a large part of our Universe consists of matter which is not quarks or leptons.

If true, this is physics beyond the Standard Model.

If true, we need to know what kind of matter this is.

Can it be produced (under controlled conditions) at accelerators on earth?

Several theoretical ideas (most prominent: SUSY) have good dark matter candidates which could be produced at LHC + ILC



The Universe in the ΛCDM model:

5% SM matter

25% dark matter

70% dark energy

1. A missing link (from esthetics?)

The Standard Model is an amazing theory of fundamental interactions.

However: it generates natural and fundamental questions:

Why 3 different forces (EW, strong, gravity) ?
Why is the proton sooooo stable ?

→ common origin of all forces? („Unification“)

Where has all the anti-matter gone ?

→ source of CP violation?

If the Higgs mechanism really is at work – why is the Higgs so „light“?
(naturally $m_H \sim m_{Planck}$)

→ protection mechanism for the hierarchy between M_{weak} and M_{Planck}

1. The Terascale "no lose" theorem

„Terascale"
o (TeV) energies

When a new energy regime is explored for the first time
nobody knows the new phenomena that will appear!

Good reason to explore the Terascale!
But the situation is even better:

Guaranteed: The mechanism for EW symmetry breaking
(Higgs or no Higgs!) will be decided here!

Likely: Insight into the mechanism which explains why the Higgs is so light,
if there is one.

Well possible (but speculation of course):

- Dark matter candidates
- Supersymmetry
- Extra spatial dimensions
- new gauge bosons
- something completely unexpected

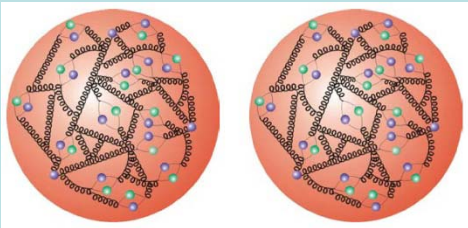
⇨ LHC will directly open the Terascale window for the first time
Why do we need to go beyond?

1. Complementarity of tools

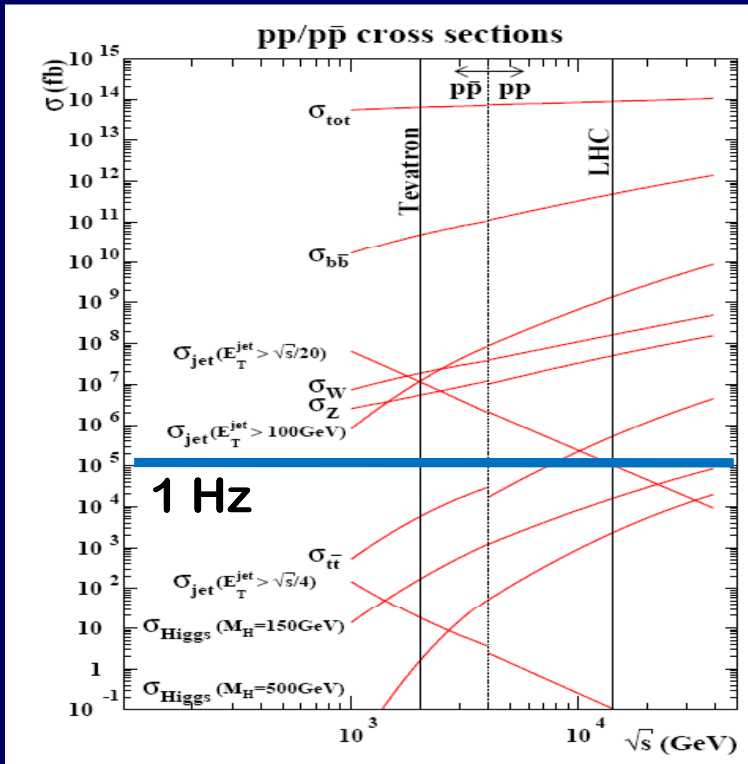
- p = composite particle:
  unknown energy of partons,
  unknown polarisation of partons,
  parasitic collisions
- e = pointlike particle:
  known and tunable energy of particles,
  polarisation of IS particles possible,
  kinematic contraints can be used
- p = strongly interacting:
  huge SM backgrounds,
  highly selective trigger needed,
  radiation hard detectors needed
- e = electroweakly interacting
  low SM backgrounds,
  no trigger needed,
  detector design driven by precision

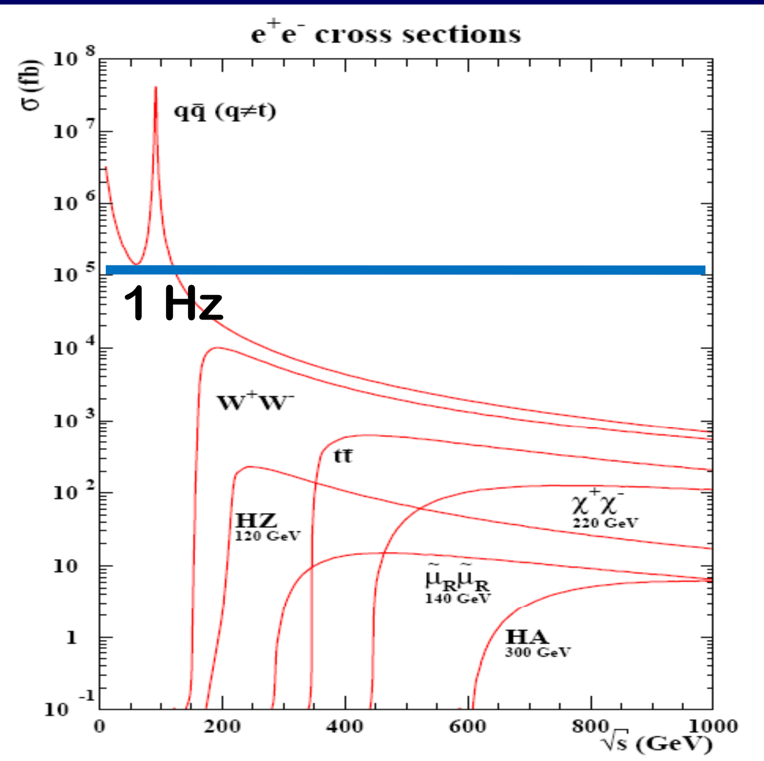
→ if they were equally easy to accelerate leptons were the choice!

1. Complementarity of tools

p  p

e^+ e^-





1. What is the ILC?

Linear electron positron collider using SC resonators for acceleration

High energy: 500 GeV upgradeable to 1 TeV.

High luminosity: > 500 fb^{-1} in 4 years

Flexible: energy tunable between 90 and 500 GeV

Polarized: electrons (90%) + positrons (60%)

Optional flexibility: e^-e^-, $\gamma\gamma$, $e\gamma$ collisions, Giga-Z (~100xLEP)

Some examples of physics potential:

- Higgs boson precision physics
- Supersymmetric particles
- Top Quark

1. Higgs discovery at the LHC

What the LHC can do:

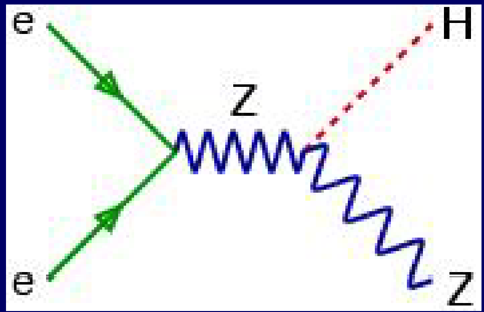
• discover a Standard-Model-like Higgs boson
• measure its mass
• observe few decay modes (not the dominant bb decay!)
• extract some coupling ratios

What the LHC probably cannot (but ILC can!)

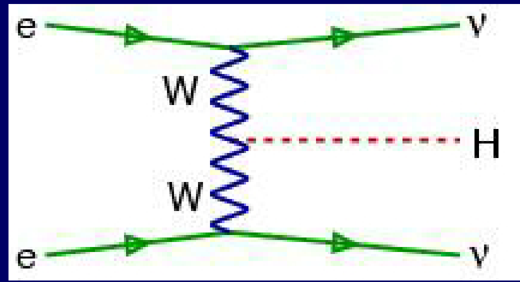
• observe a Higgs boson independent of its decay mode
• precisely measure all major decay modes
• measure unambigously its spin and CP quantum numbers
• measure the Higgs self coupling (Higgs-Higgs-interaction)!

→ in order to unambigously prove that the LHC-observed particle really is a Higgs boson, the ILC is needed
→ establish the Higgs mechanism as responsible for the EW symmetry breaking

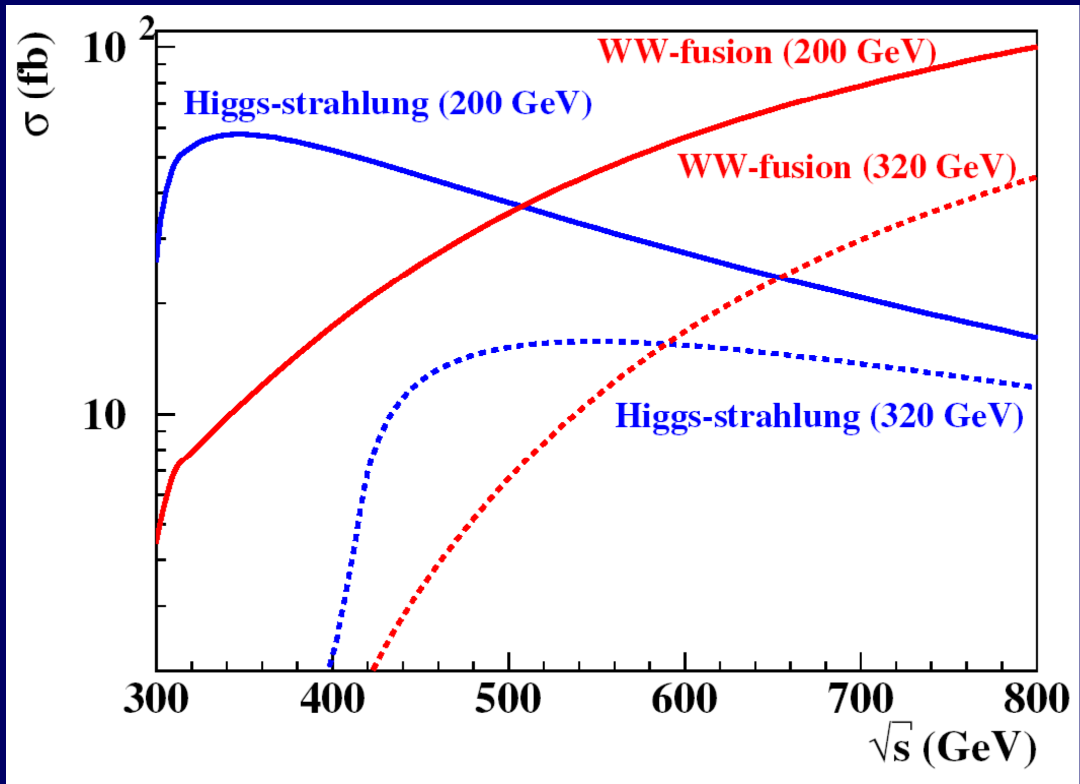
1. Higgs precision physics at ILC



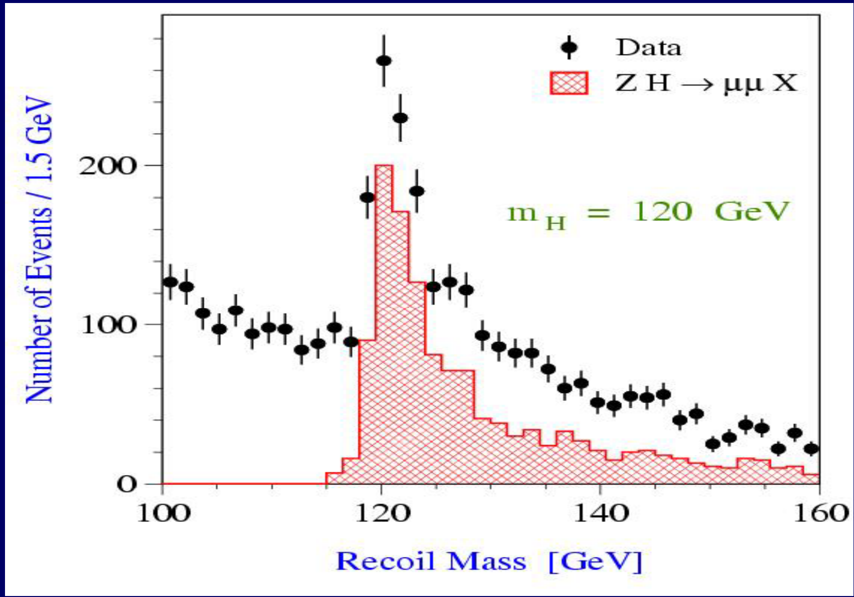
$\sigma \propto\sim 1/s$



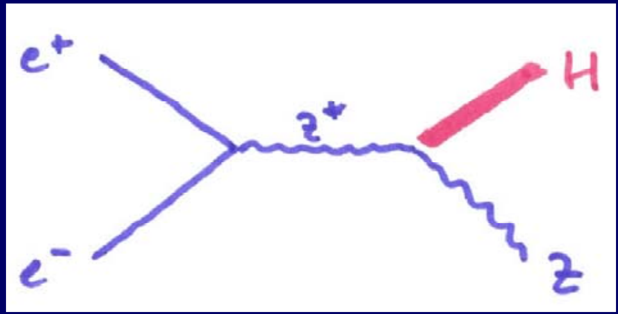
$\sigma \propto\sim \ln s$



1. Model-independent Higgs observation

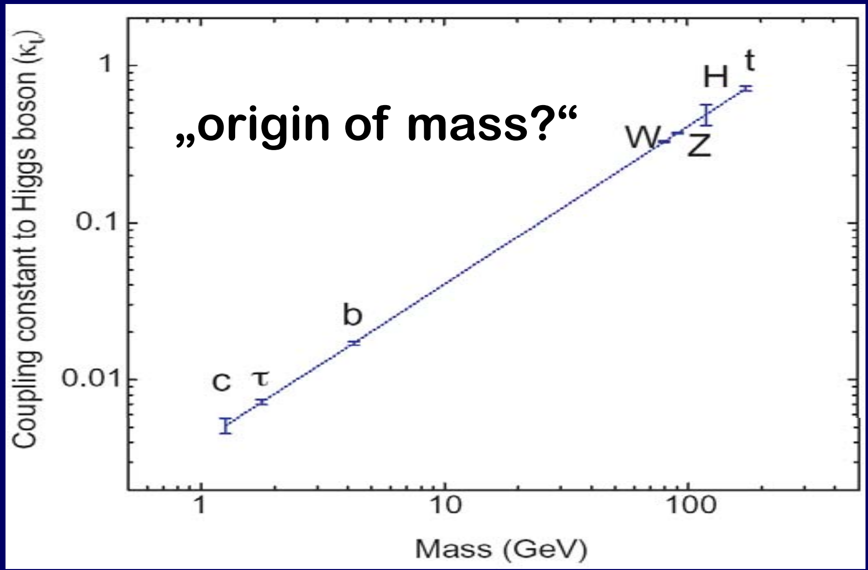


„seeing it without looking at it“



$$m_H^2 = (p_{\ell\ell} - p_{initial})^2$$

recoil mass



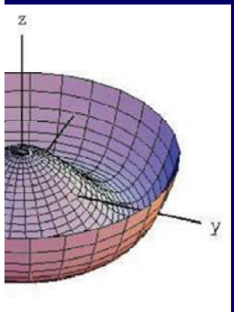
$\Delta\sigma/\sigma$ ~ 2%

$\Delta m/m$ ~ 50 MeV

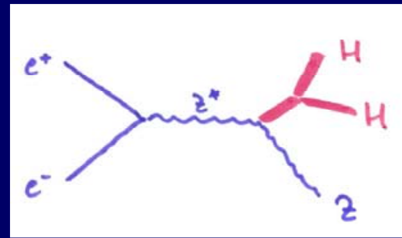
HZ coupling ~ 1%

Yukawa couplings ~ few%

1. Measurement of the Higgs self coupling

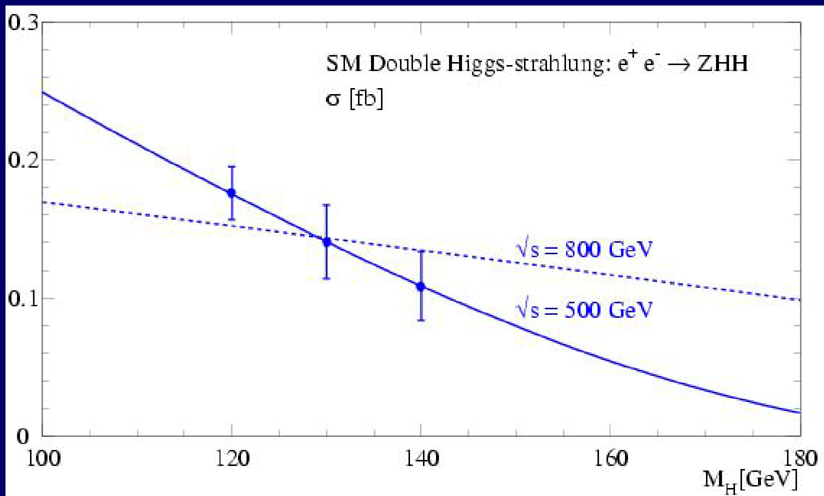


closely linked to shape to Higgs potential
→ most important test of spontaneous symmetry breaking

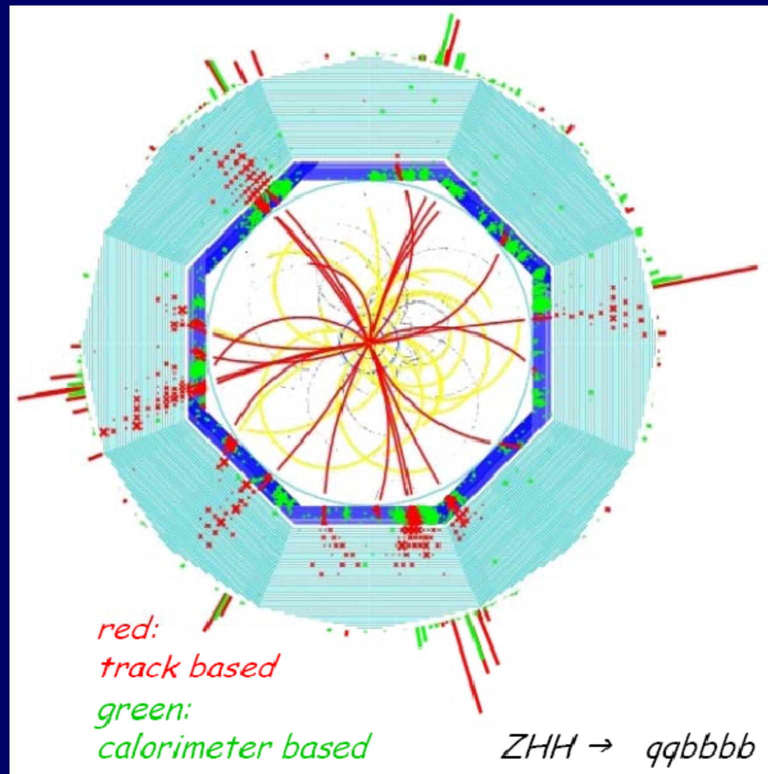


measurement at LHC seems impossible

ILC: double Higgs-Strahlung
challenge for detectors!

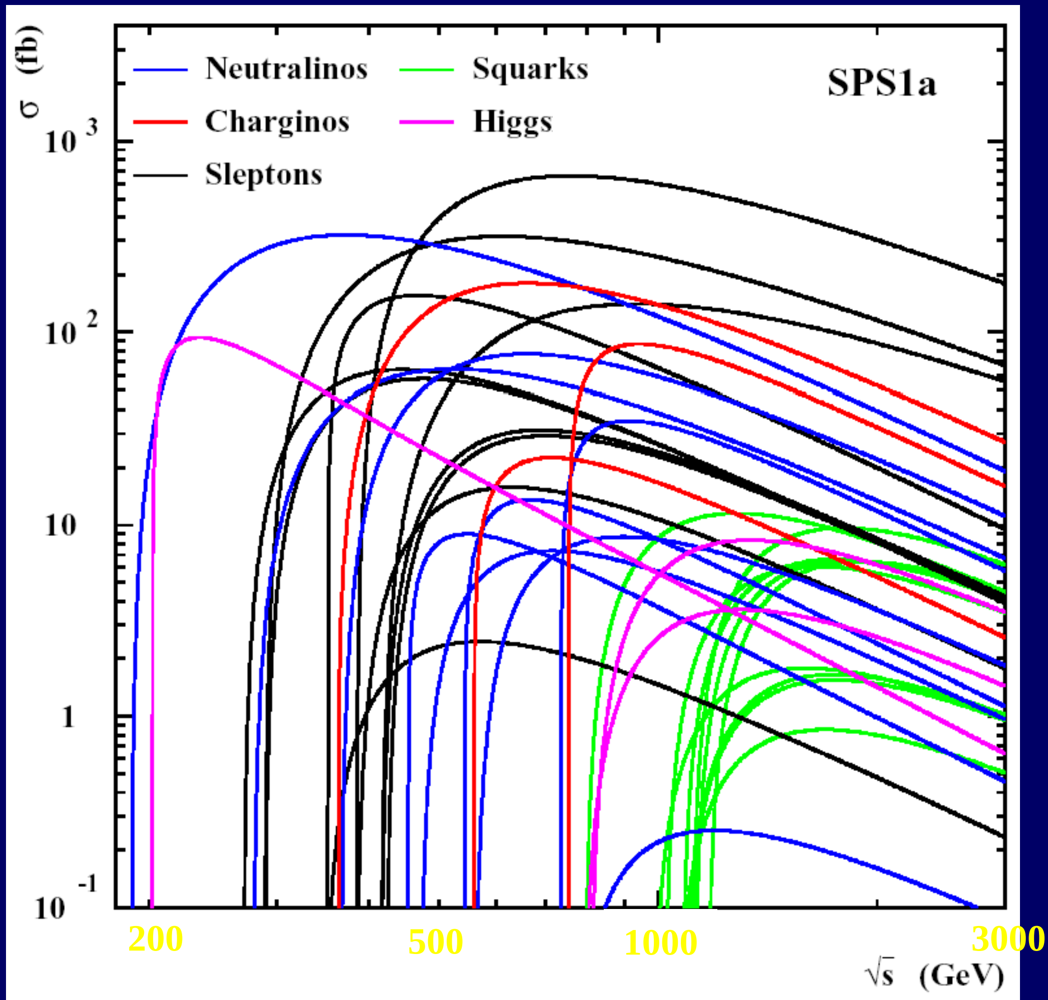


$\Delta\lambda/\lambda$ = 20% @ 500 GeV
12% @ 1 TeV (?)



1. Supersymmetric particles

A lot of fun…



cross sections 10 – 1000 fb (~ SM processes)

o(10^3 – 10^5) events

ILC options needed to disentangle this chaos

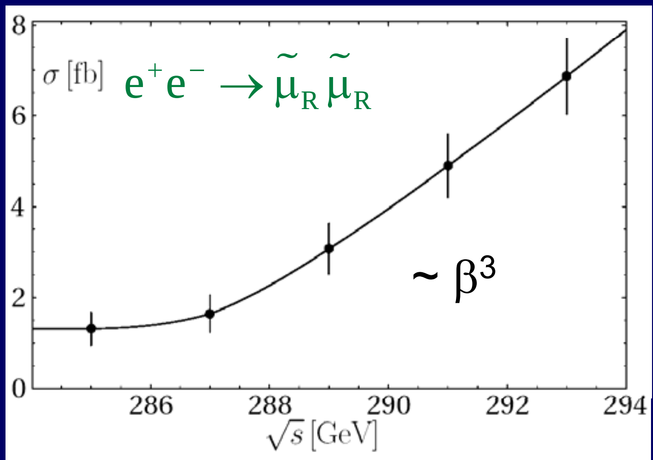
- variable √s
- beam polarisation

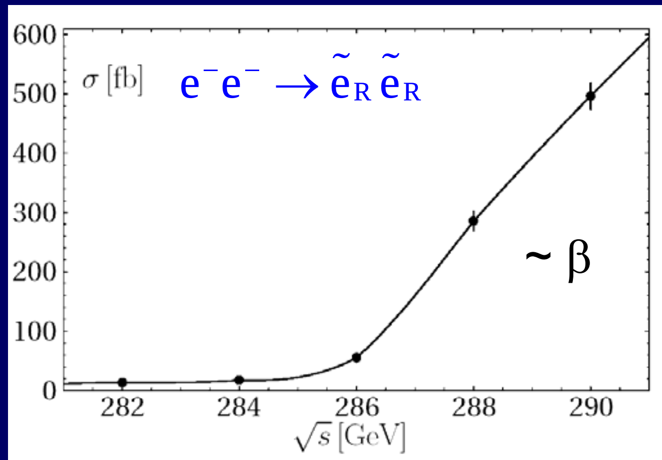
1. Supersymmetric particles

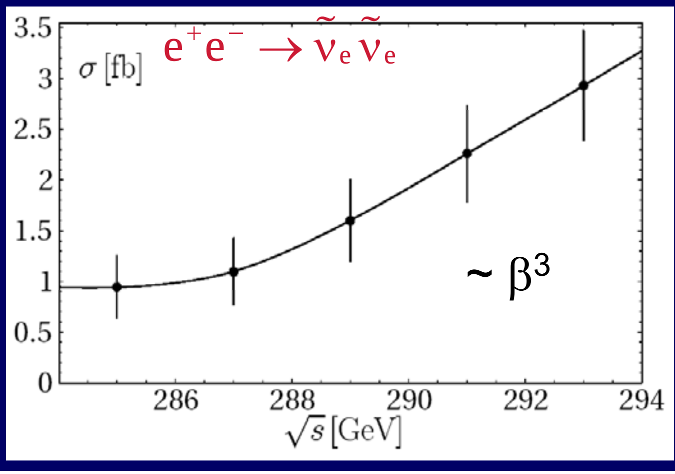
Threshold scans

→ most precise method to measure sparticle masses (50-500 MeV)

Example: superymmetric partners of leptons:

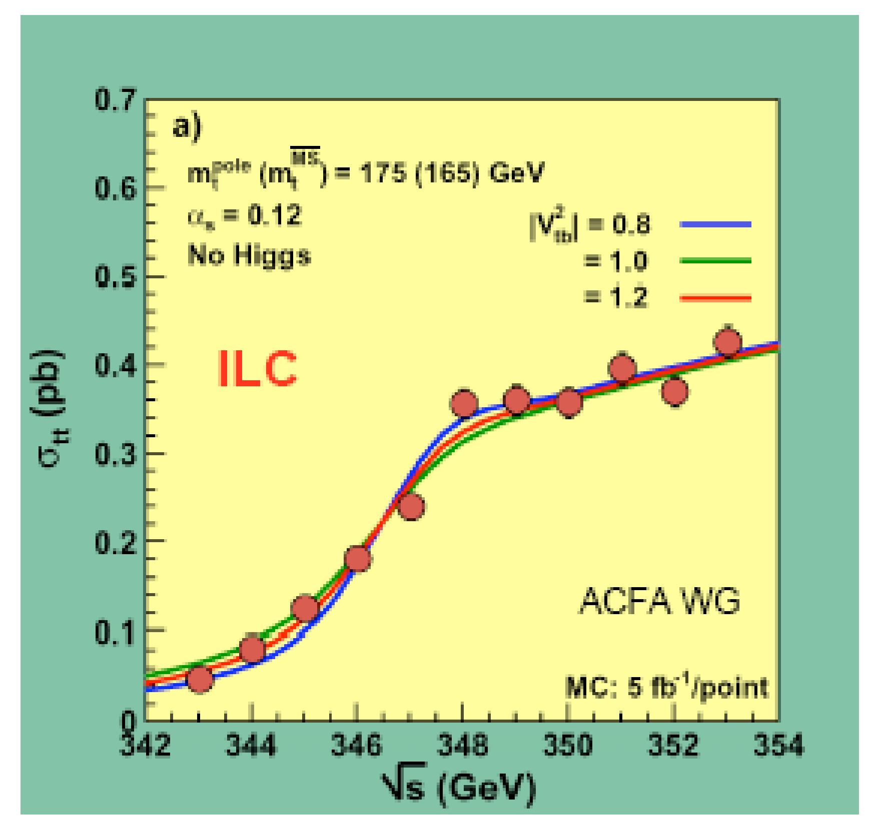






1. Top Quark

- top-quark could play a key role in the understanding of flavour physics
- m_{top} fundamental parameter
- Δm_{top} will limit many predictions (SM, SUSY-Higgs, Dark matter density,...)



requires precise determination of its properties

Energy scan of top-quark threshold:

$$\Delta M_{top} \approx 100 \text{ MeV}$$

10x better than LHC

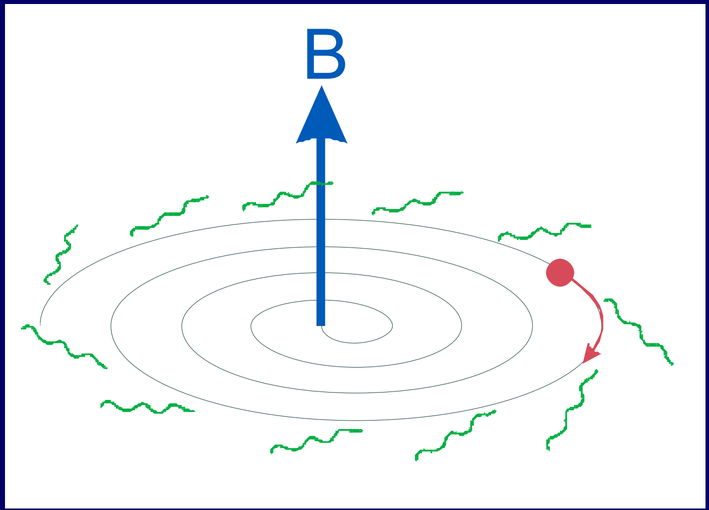
1. Summary: Physics motivation

- Electron positron collisions have clear advantages over pp collisions
- In order to fully understand the upcoming discoveries at the LHC the ILC is needed
- High precision and high energy is the key

→ How???

2. Accelerator

Electrons don´t like to move on circles…



Synchrotron radiation

radiated energy per turn:

$$P_\gamma \sim \frac{E^4}{m^4 R}$$

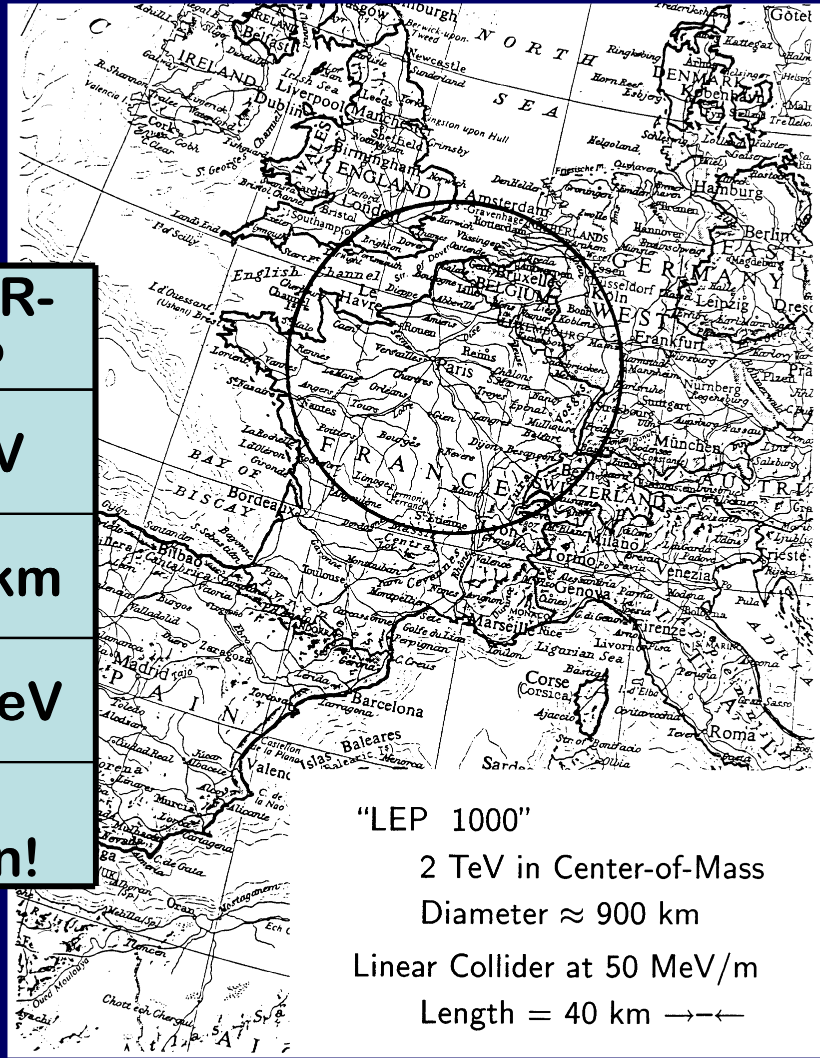
Cost scaling for circular accelerator:

linear costs (magnets, tunnel) ~ R
running costs (RF-energy) ~ E^4/R

cost optimum (for fixed E) ~ E^2

2. Accelerator

	LEP-II	Super-LEP	HYPER-LEP
E_{cm}	180 GeV	500 GeV	2 TeV
L	27 km	200 km	3200 km
ΔE	1.5 GeV	12 GeV	240 GeV
$€_{tot}$	2 billion	15 billion	240 billion!

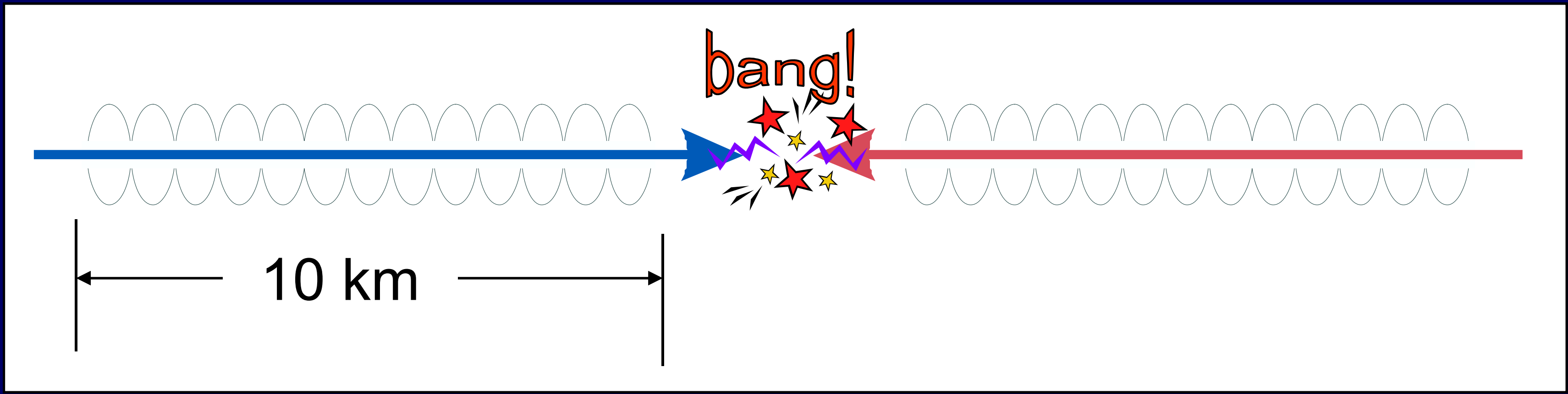


G.Loew

no go...

2. The future is linear

linear is simple



costs ~E (to first approximation)

but: - how to reach energy with reasonable length?
challenge: increase accelerating field (>30 MeV/m) !

- how to get luminosity?
challenge: squeeze beams at collision points to ~5nm (LEP: 120μm)

2. The ILC will not be the first LC

A Possible Apparatus for Electron-Clashing Experiments (*).

M. Tigner

Laboratory of Nuclear Studies. Cornell University - Ithaca, N.Y.

Nuovo Cim.37:1228-1231,1965

a working example
SLAC SLC
– the first linear collider

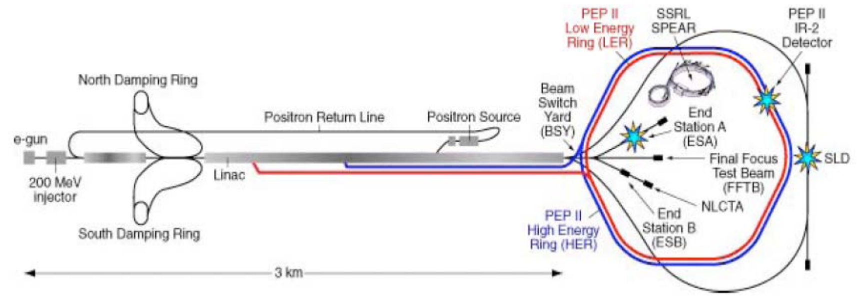
The ILC needs:

factor 5-10 higher energy
factor 10^4 higher luminosity
factor 100 smaller beams (5nm!)

$L = 10^{30}\ cm^{-2}\ s^{-1}$

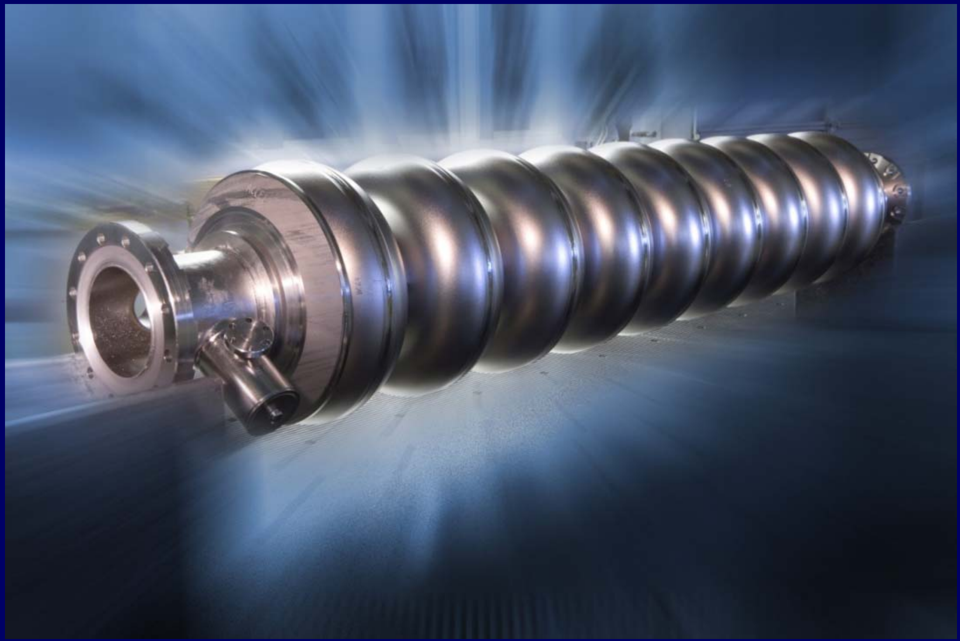
$E_{cms} = 100$ GeV

$\sigma_y = 600$ nm



2. Accelerator: Luminosity

Key: Superconducting technology



advantages:

SC:
→ good power efficiency
→ long pulses possible

rather low frequency (1.4 GHz):
→ small wakefield effects
→ larger tolerances

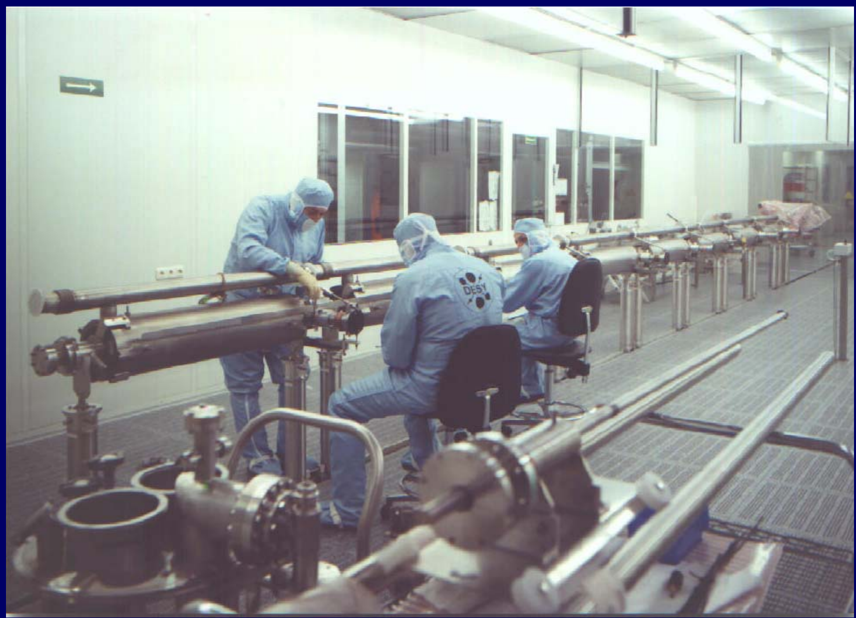
the challenge: how to achieve high accelerating field gradient?

SC cavities in LEP: ~ 7 MV/m (→ 70 km for 500 GeV!)
Fundamental limit /breakdown of SC at ~ 45-53 MV/m
(freqency dependent, RF surface resistance of superconductors)
How close can one get to this limit?

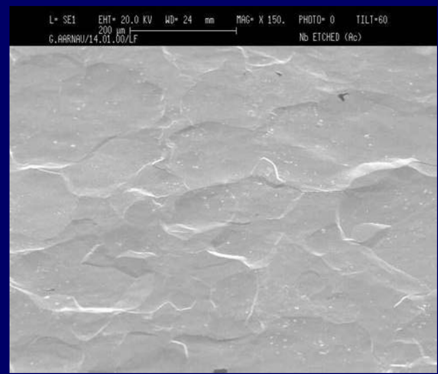
2. SC cavities

Goal of the TESLA collaboration (led by DESY, since 1992 (B.Wiik)): reach highest possible gradients in SC cavities

Key: niobium selection, cleanroom handling, surface treatment



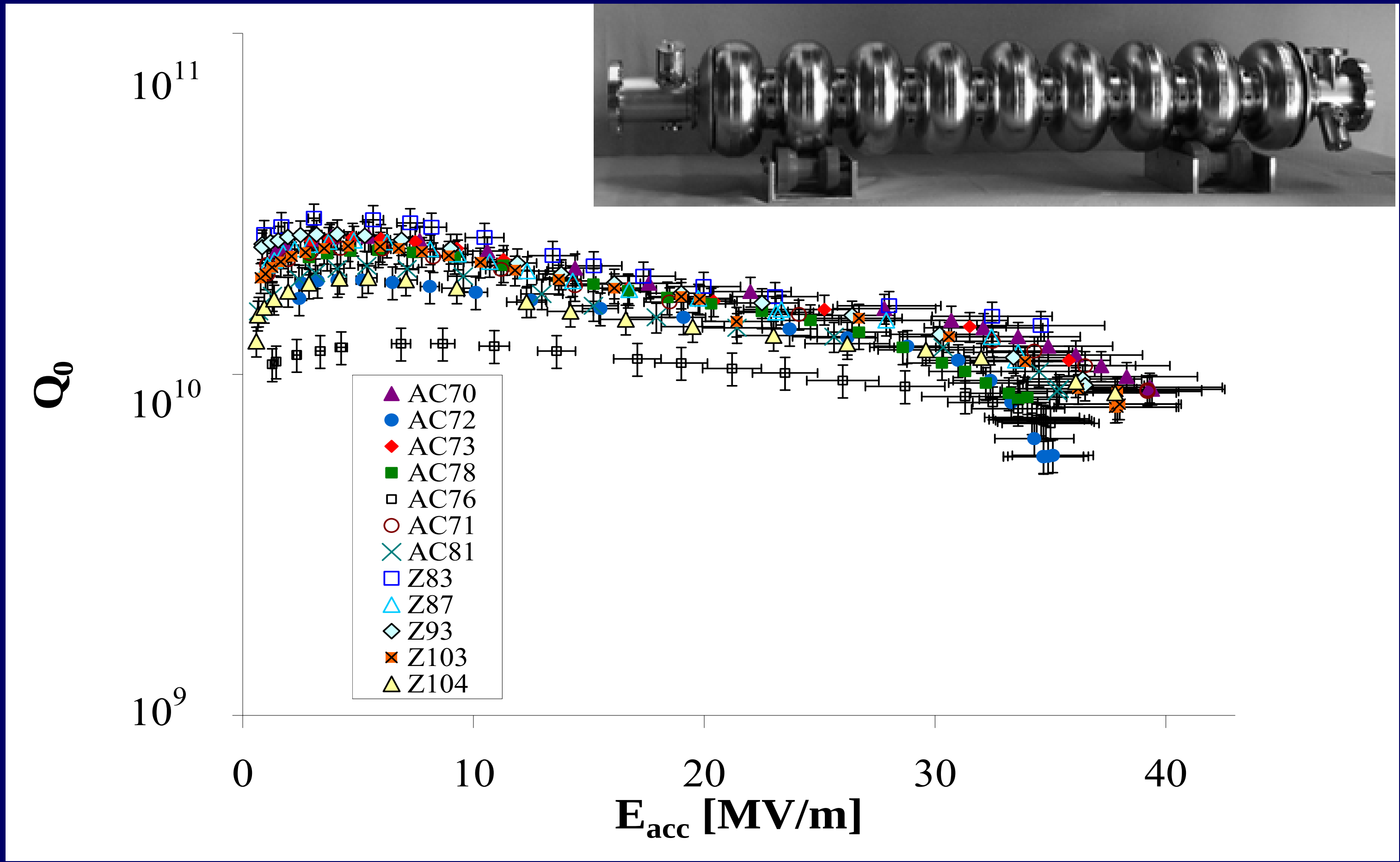
clean room assembly



etching

electro-polishing

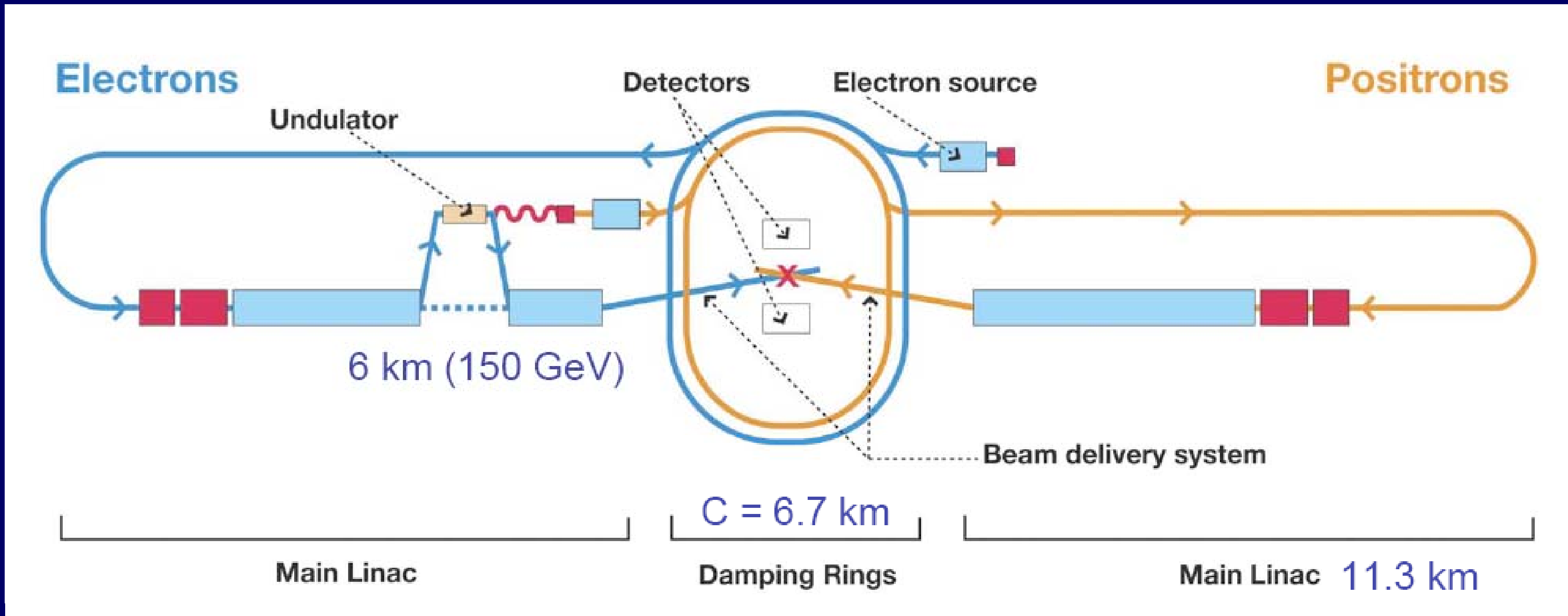
2. SC cavities



Several nine-cell cavities have reached ILC specifications
928 ILC-type cavities used for DESY-XFEL!

2. The ILC Reference Design

- The linear collider is more than just SC-RF!
- Complete technical design carried out in an international effort (GDE) led by Barry Barish (Caltech)



Several changes from TESLA design (DESY,2001)

- central damping rings + electron source
- 2 tunnels
- only one interaction region (push-pull for 2 detectors)

2. The ILC reference design

Max. Center-of-mass energy	500	GeV
Peak Luminosity	$\sim 2 \times 10^{34}$	$cm^{-2}s^{-1}$
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	ms
Total Site Length	31	km
Total AC Power Consumption	~230	MW

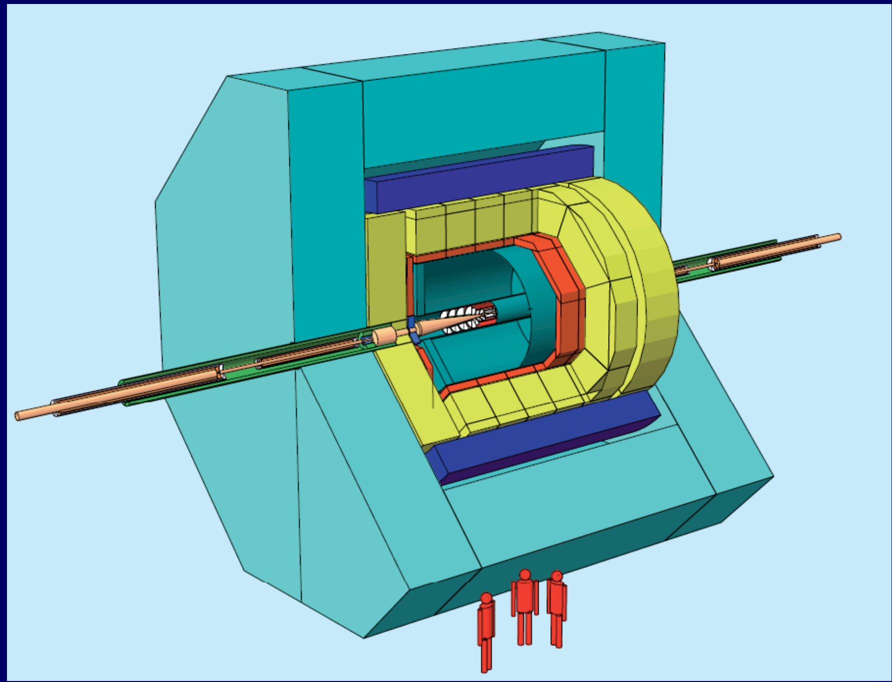
2. Summary on accelerator

- Only a linear collider allows to reach e^+e^- energy above ~200 GeV
- SC technology sufficiently advanced to plan the ILC
- Technical design of the ILC developed (RDR)
- Next step: detailed engineering design by ~2010
- DESY-XFEL serves as large-scale (10%) prototype!

3. Detectors

Focus on:

- highest possible precision
- robustness
- low material budget
- triggerless operation



Central paradigm: most exclusive reconstruction of the complete final state

→„particle flow“ approach

needs
- highly granular calorimeter
- robust and precise charged particle tracking
- low-material, fast vertex detector

rather different from LHC detectors (ATLAS, CMS)

3. Detectors for the ILC

Why are detectors so different?

Charged particle tracking goals (momentum resolution):

LHC (ATLAS): $\Delta p/p = 0.4\ p$ [TeV]
ILC (LDC): $\Delta p/p = 0.05\ p$ [TeV]

Calorimetry (jet energy resolution):

LHC (ATLAS) $\Delta E/E = 50\%/\sqrt{E[\mathrm{GeV}]} + 3\%$
ILC (LDC) $\Delta E/E = 30\%/\sqrt{E[\mathrm{GeV}]} + 1\%$

Radiation levels:

LHC (1st pixel layer) $o(10^{14}\ /\mathrm{cm}^2\ \mathrm{a})$
ILC (1st pixel layer) $o(10^{10}\ /\mathrm{cm}^2\ \mathrm{a})$

3. Detector Challenges

Jet energy resolution:

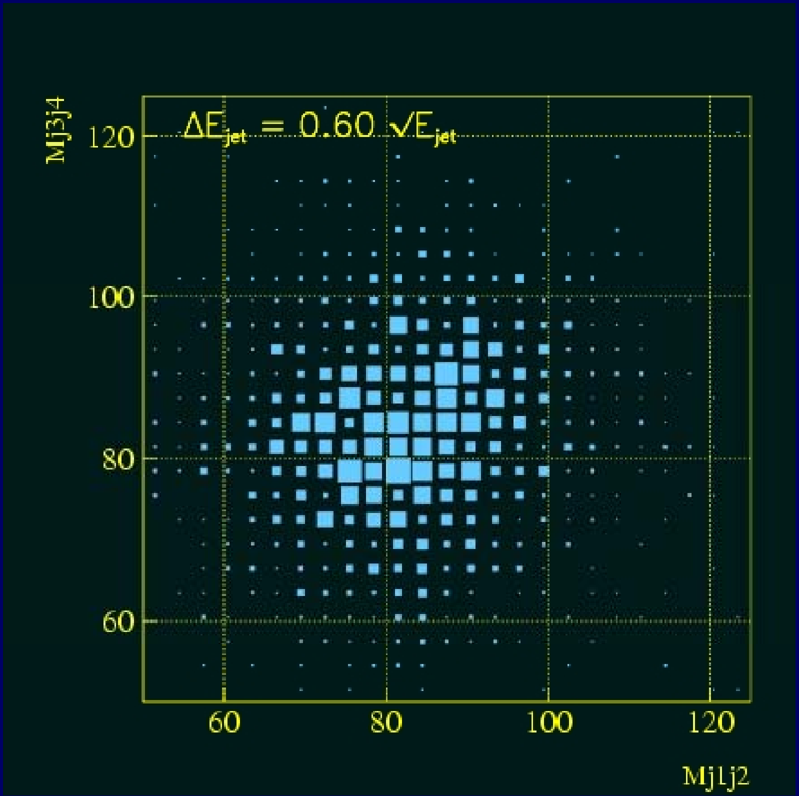
Best at LEP (ALEPH):

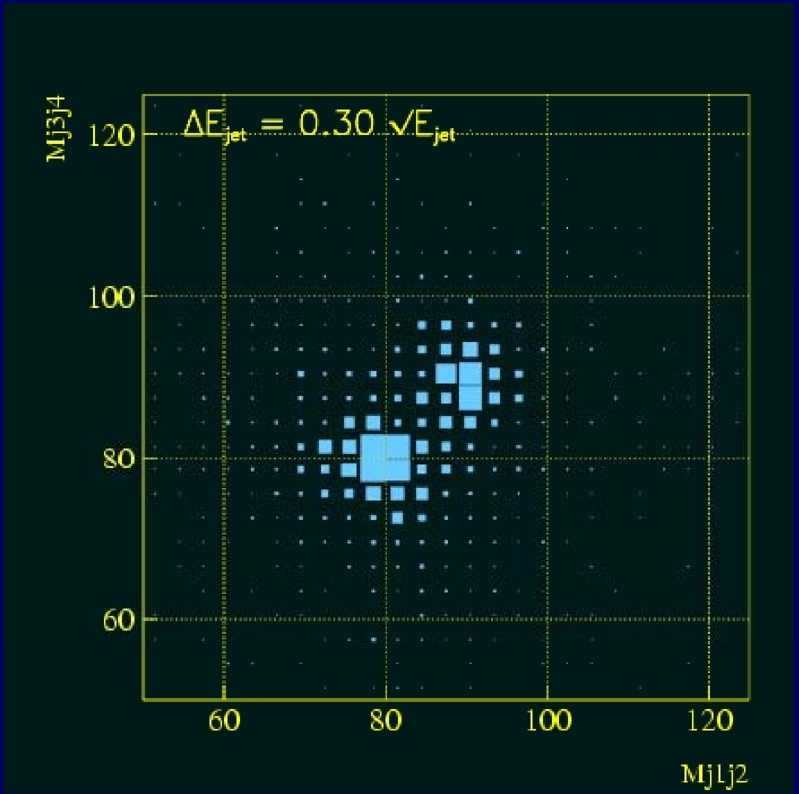
$\sigma_E/E = 0.6\,(1 + |\cos\theta_{jet}|) / \sqrt{E(GeV)}$

Goal at the ILC:

$\sigma_E/E = 0.3 / \sqrt{E(GeV)}$

Example: WW and ZZ dijet mass separation:

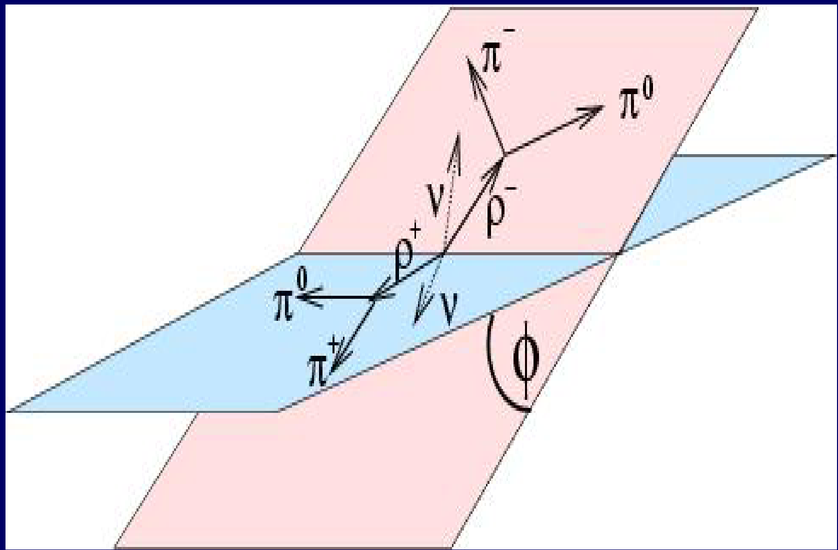


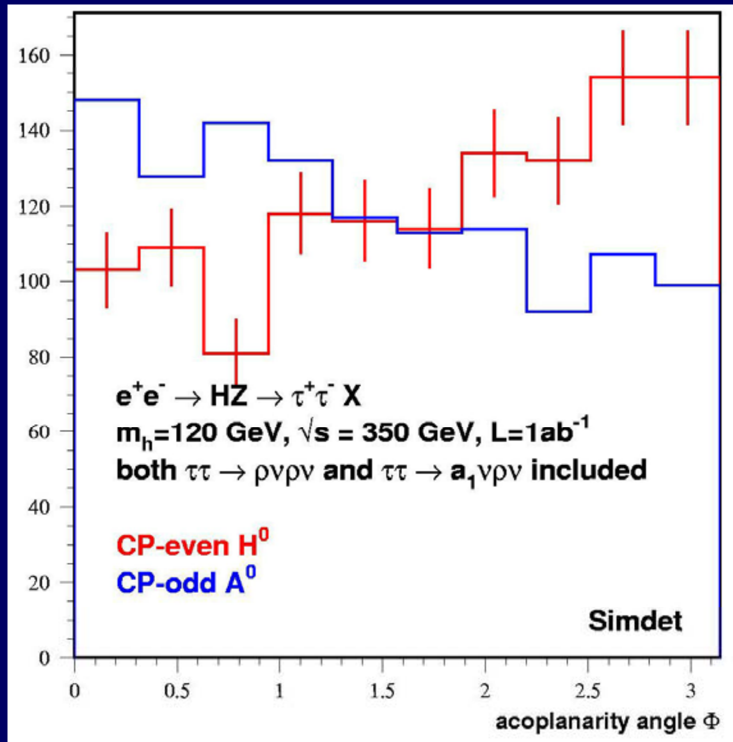


3. Detector Challenges

Exclusive particle reconstruction, e.g. τ leptons:

CP from transverse polarization correlations in $H \to \tau\tau$





Needs exclusive reconstruction
$\tau \to \rho\nu$ and $\tau \to a_1\nu$ decay modes

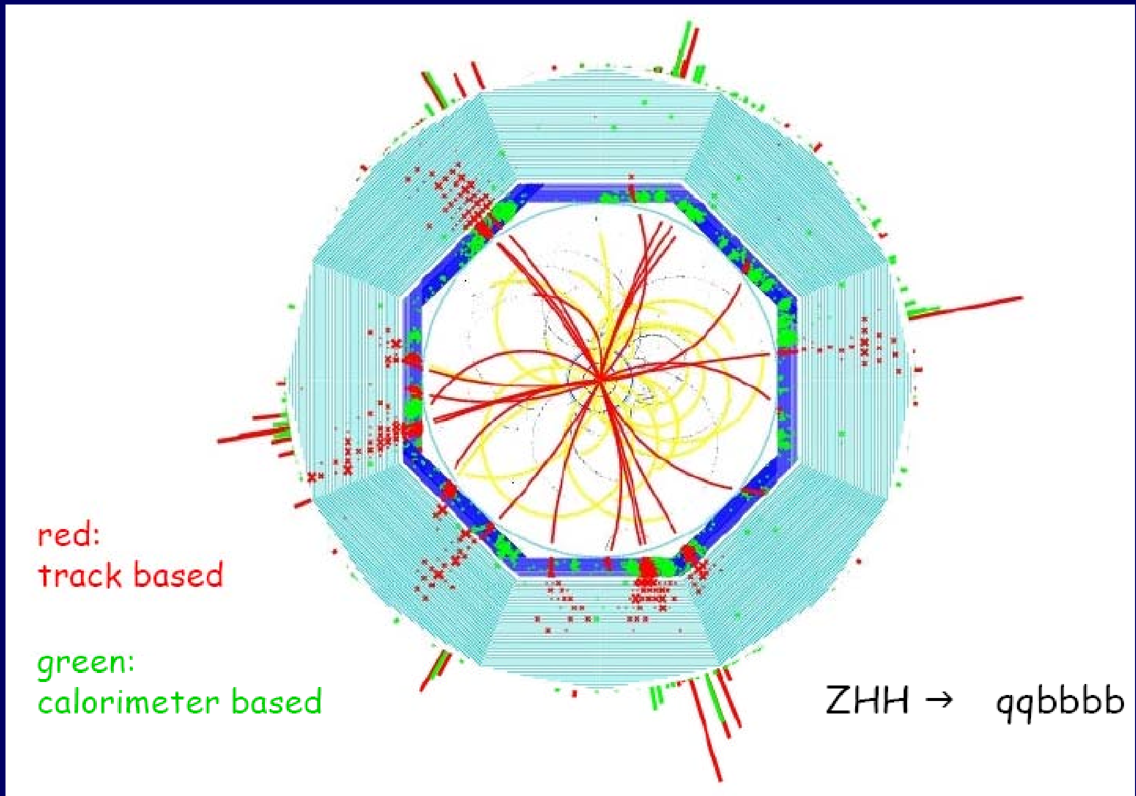
3. The particle flow concept

Measure (p,E) of each particle with the detector which can do it best

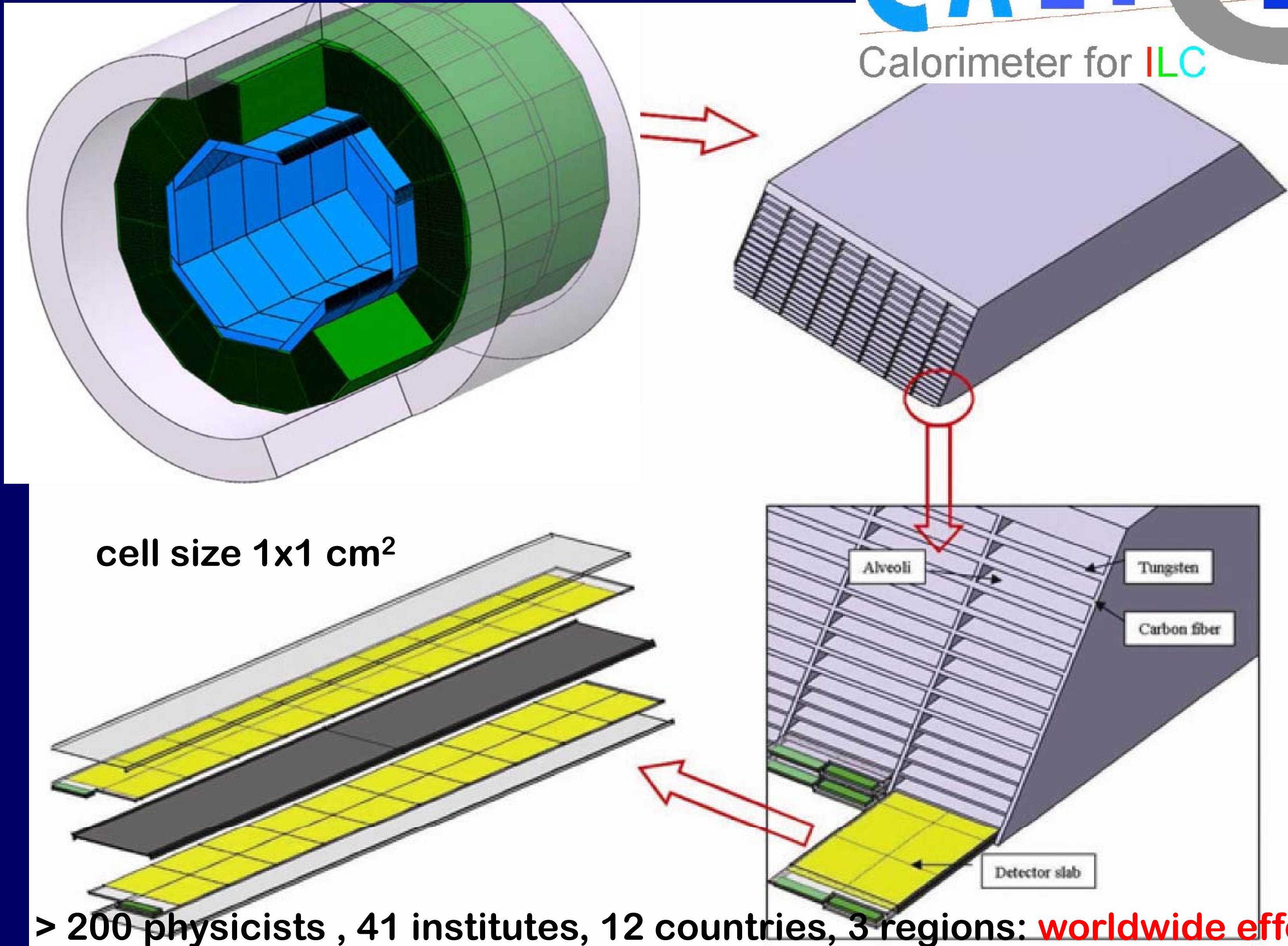
- Electrons → tracker+ECAL
- Photons → ECAL
- Charged hadrons → tracker
- Neutral „stable“ hadrons → HCAL
- Muons →tracker

challenge:
identifiy + seperate them in a dense jet

→ high granularity



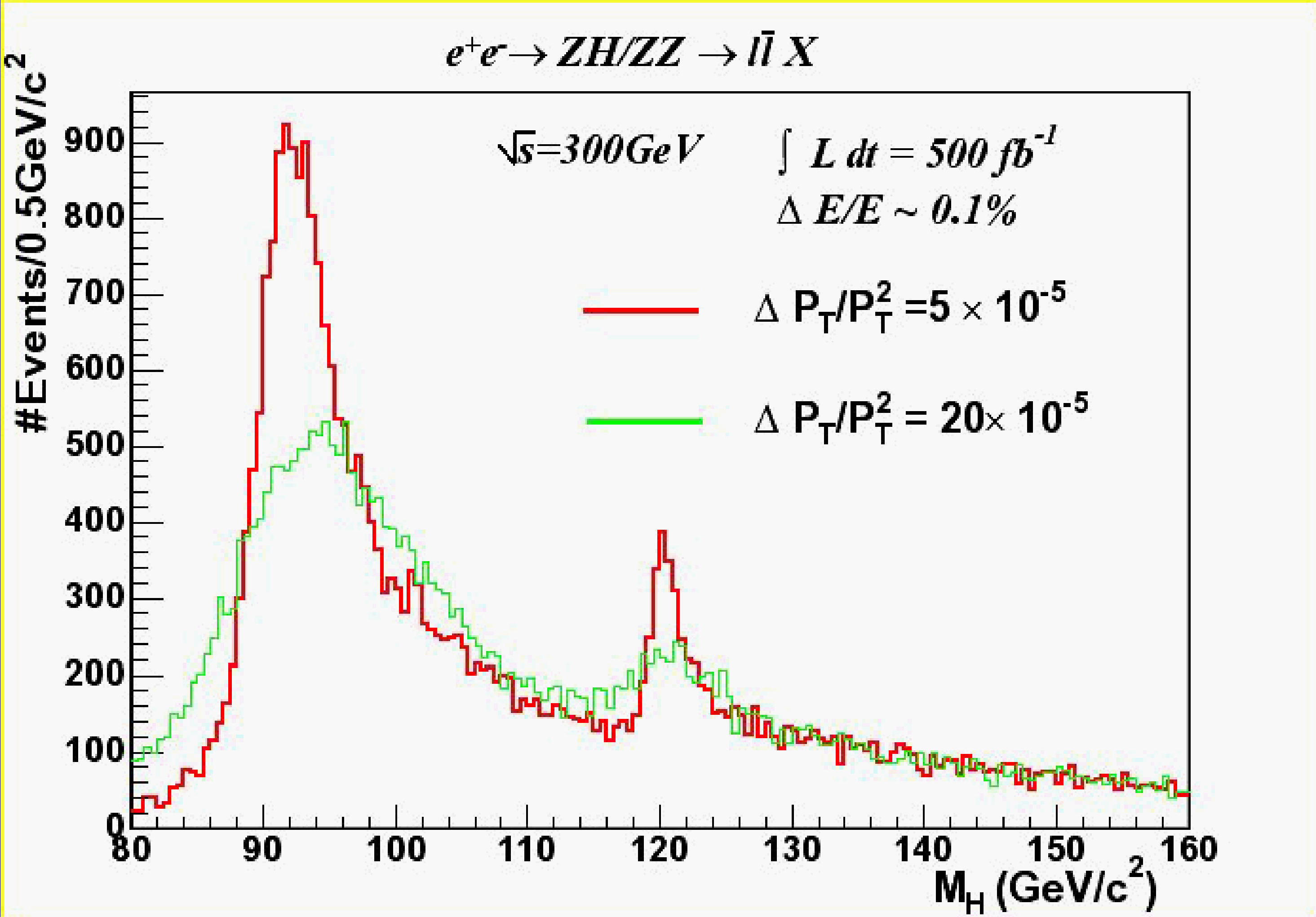
3. Si-W Calorimeter



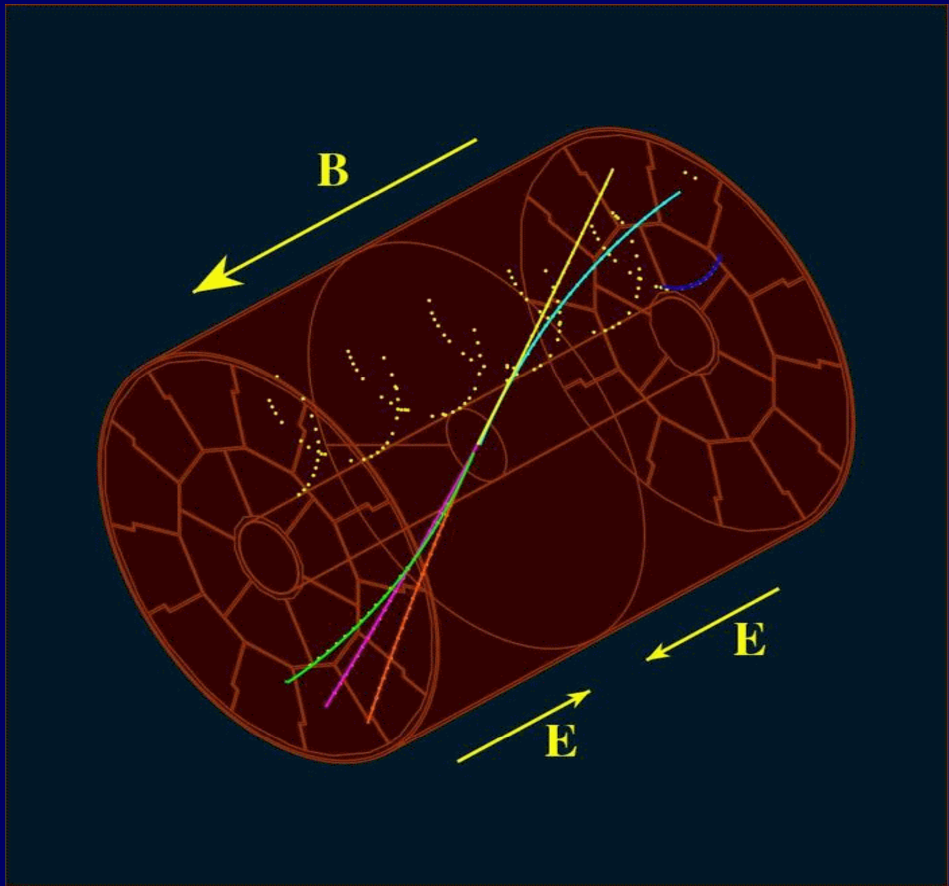
> 200 physicists , 41 institutes, 12 countries, 3 regions: worldwide effort

3. Charged particle tracking

Momentum resolution counts!



3. A Time Projection Chamber for the ILC



Challenges:

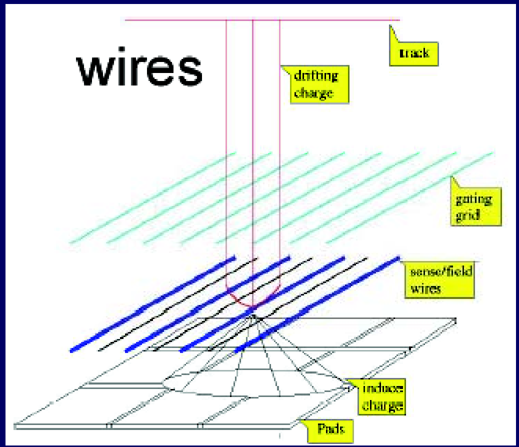
Minimize material in endplate

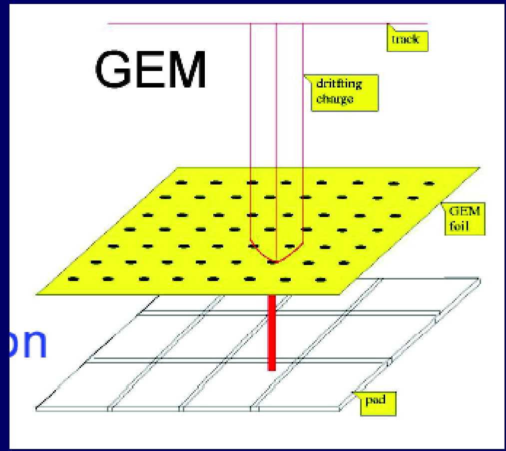
Maximize spatial resolution

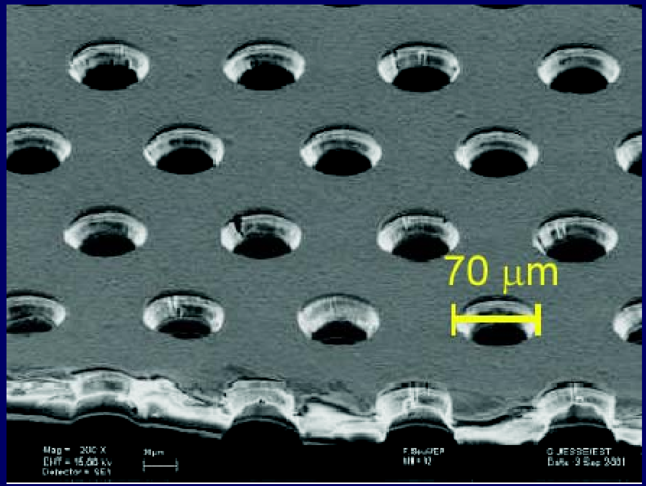
Maximize robustness
+ redundancy

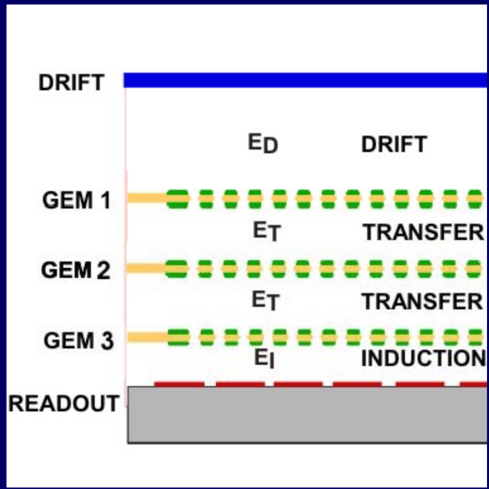
3. New gas amplification technologies

Use Micro Pattern Gas Detectors (GEMs, MicroMegas) for gas amplification and micro-pads (pixelized electronics)



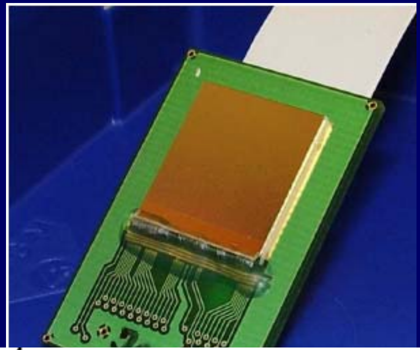


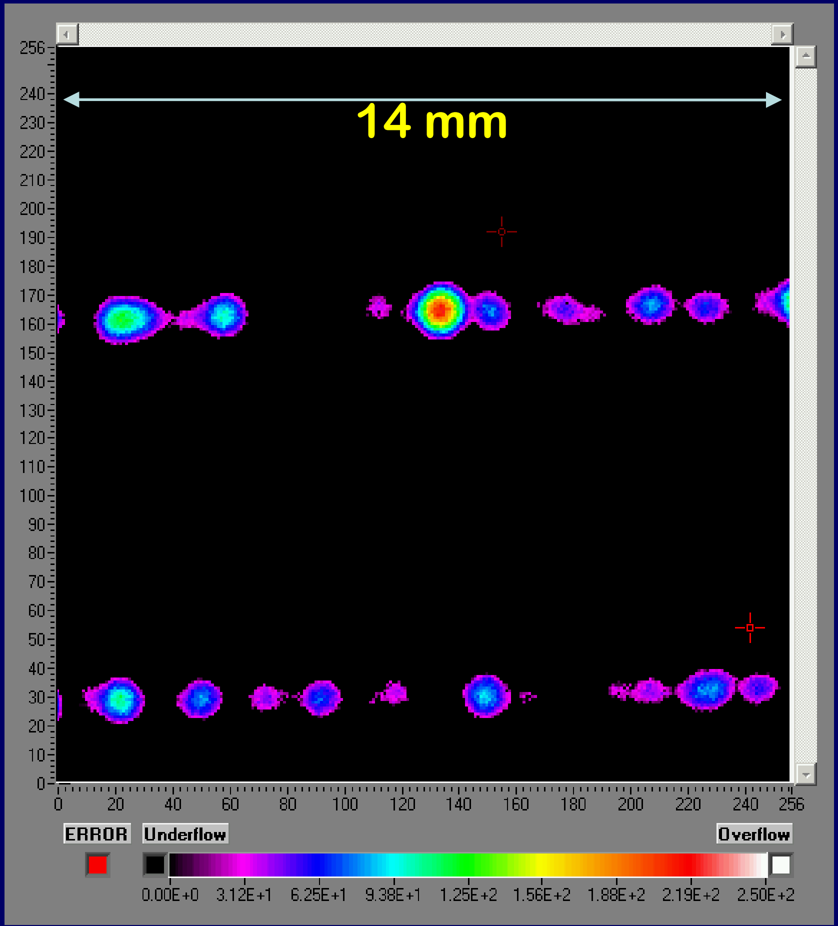




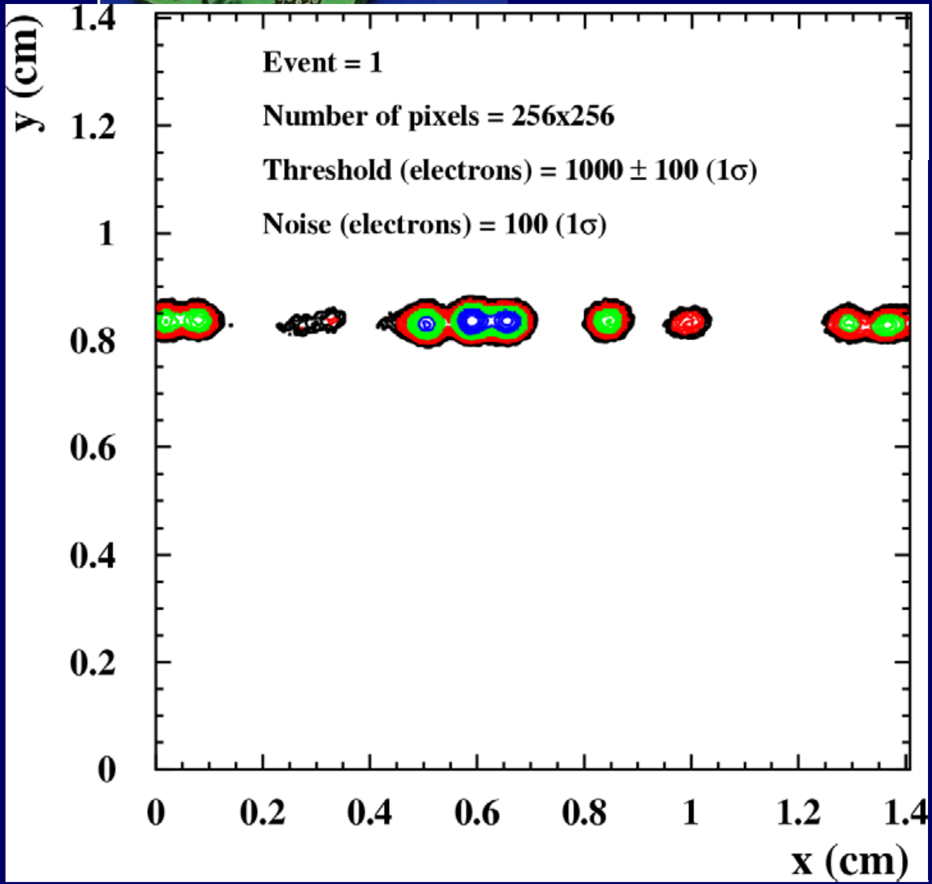
3. TimePix Chip

towards a „digital bubble chamber“





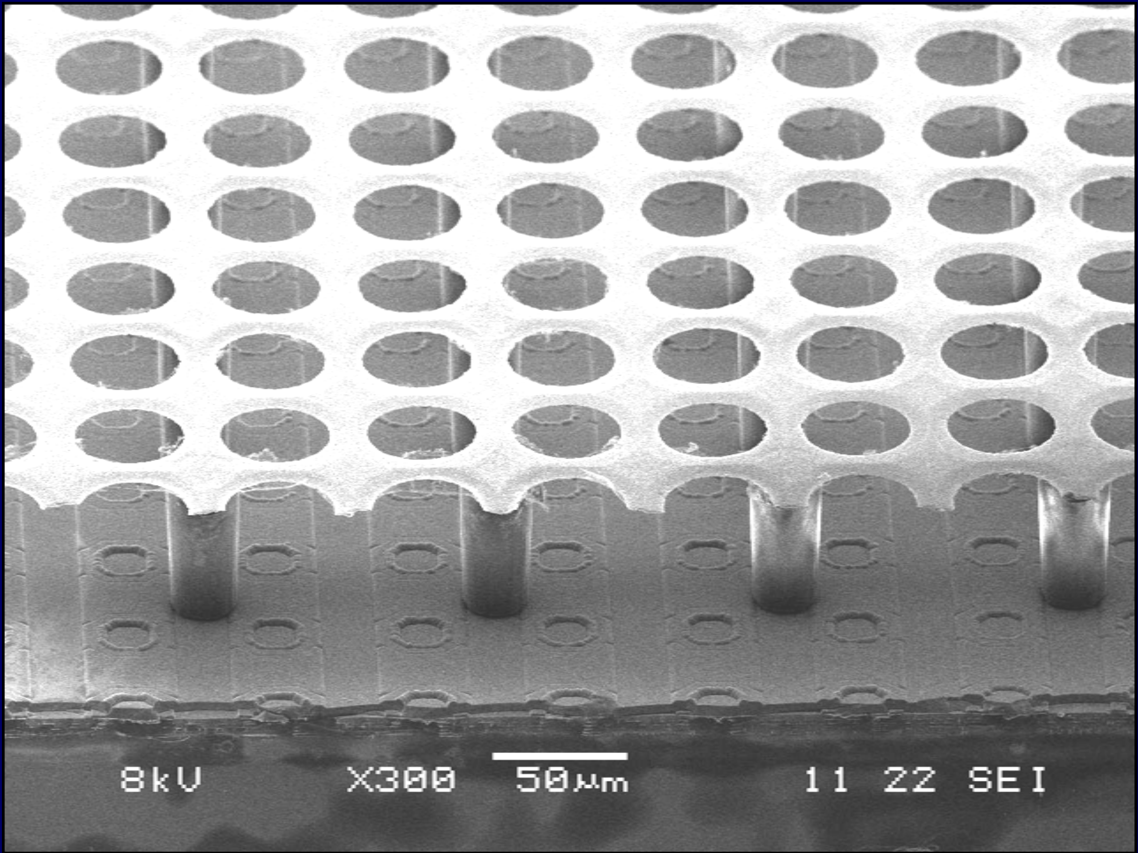
Freiburg/Bonn prototype in DESYelectron test beam



Simulation

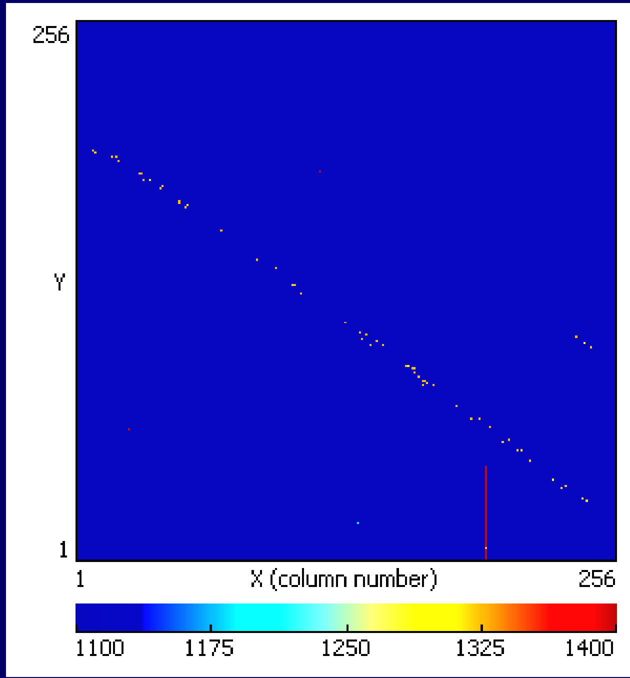
3. InGrid

integrate gas amplification grid onto a TimePix readout chips
„on-chip gas detector“



NIKHEF
Univ. Twente

cosmic track



3. Summary on detectors

- ILC detectors are a challenge different to LHC detectors
- Strive for best possible precision and large robustness
- R&D is ongoing on an international scale (R&D collaborations)

4. “Politics”: How to get there?

- Rather strong consensus in particle physics community that the ILC is to be the next major project in accelerator-based particle physics

- High priority project on many „Roadmaps“
  - US 20 year plan: highest priority of „midterm“ projects

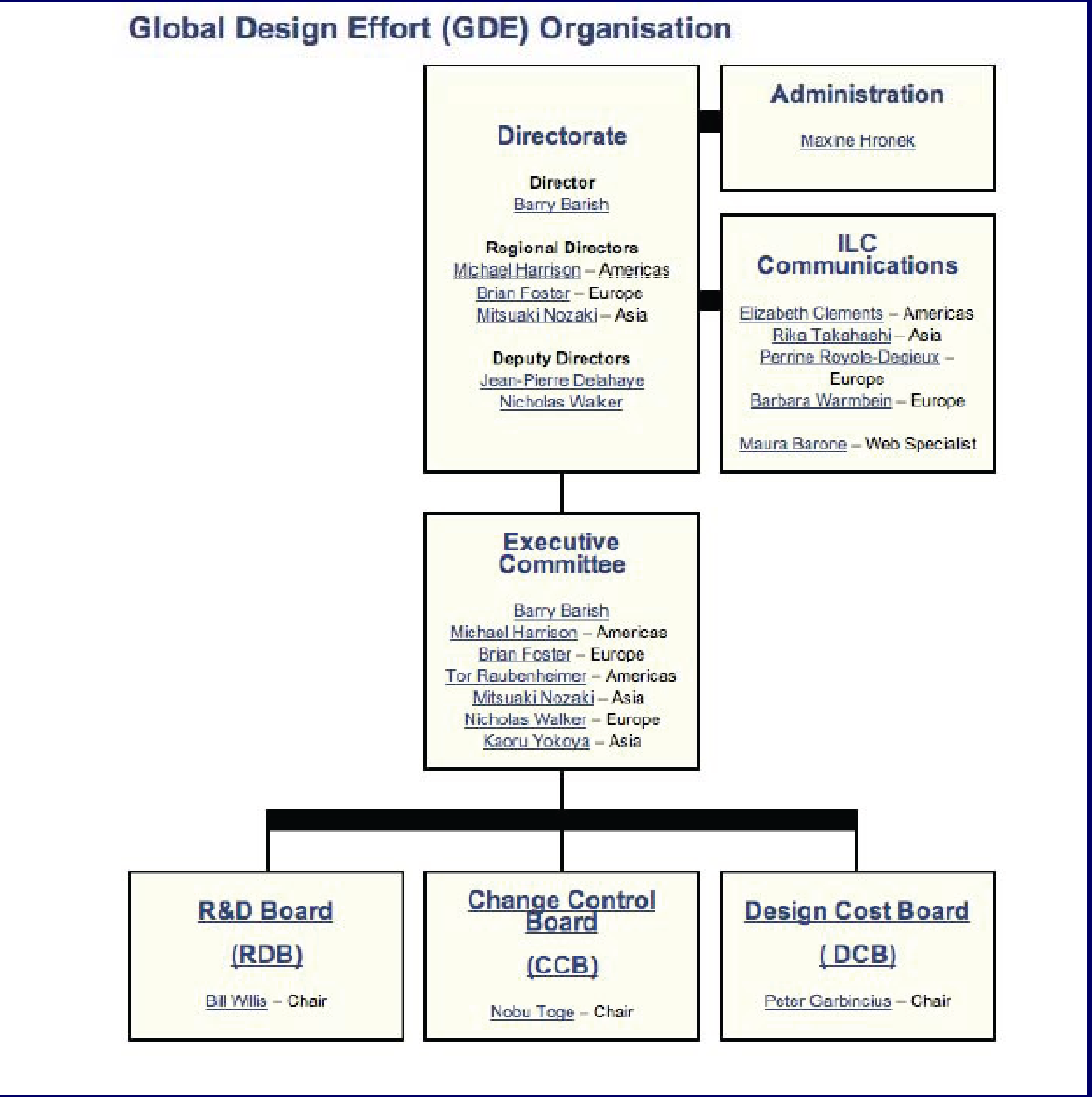
  - Europe: ESFRI roadmap/CERN council strategy document:

“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”

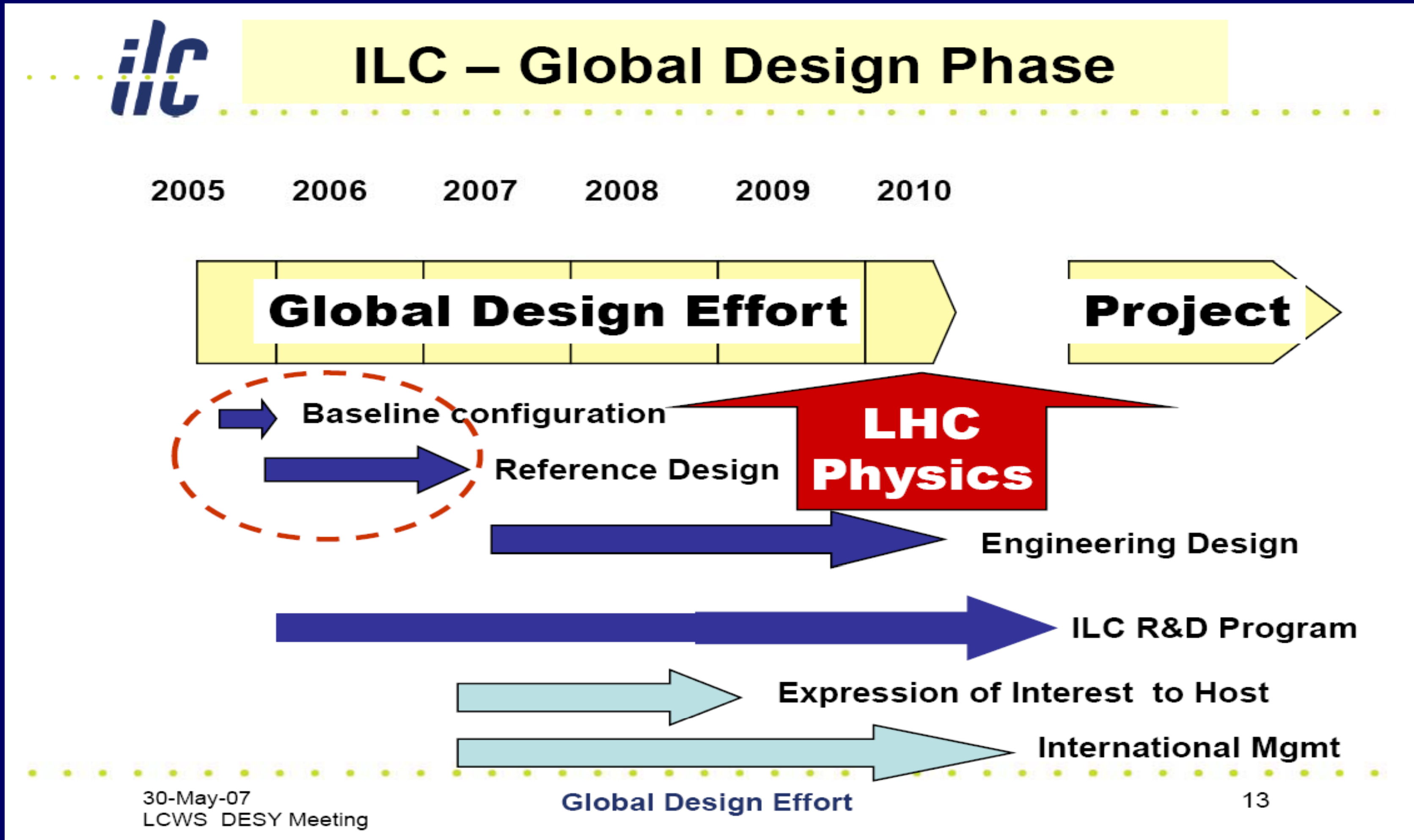
- Truly international effort (i.e. no single lab leading the effort)

- Internationally organized via ICFA: „Global Design Effort“ GDE

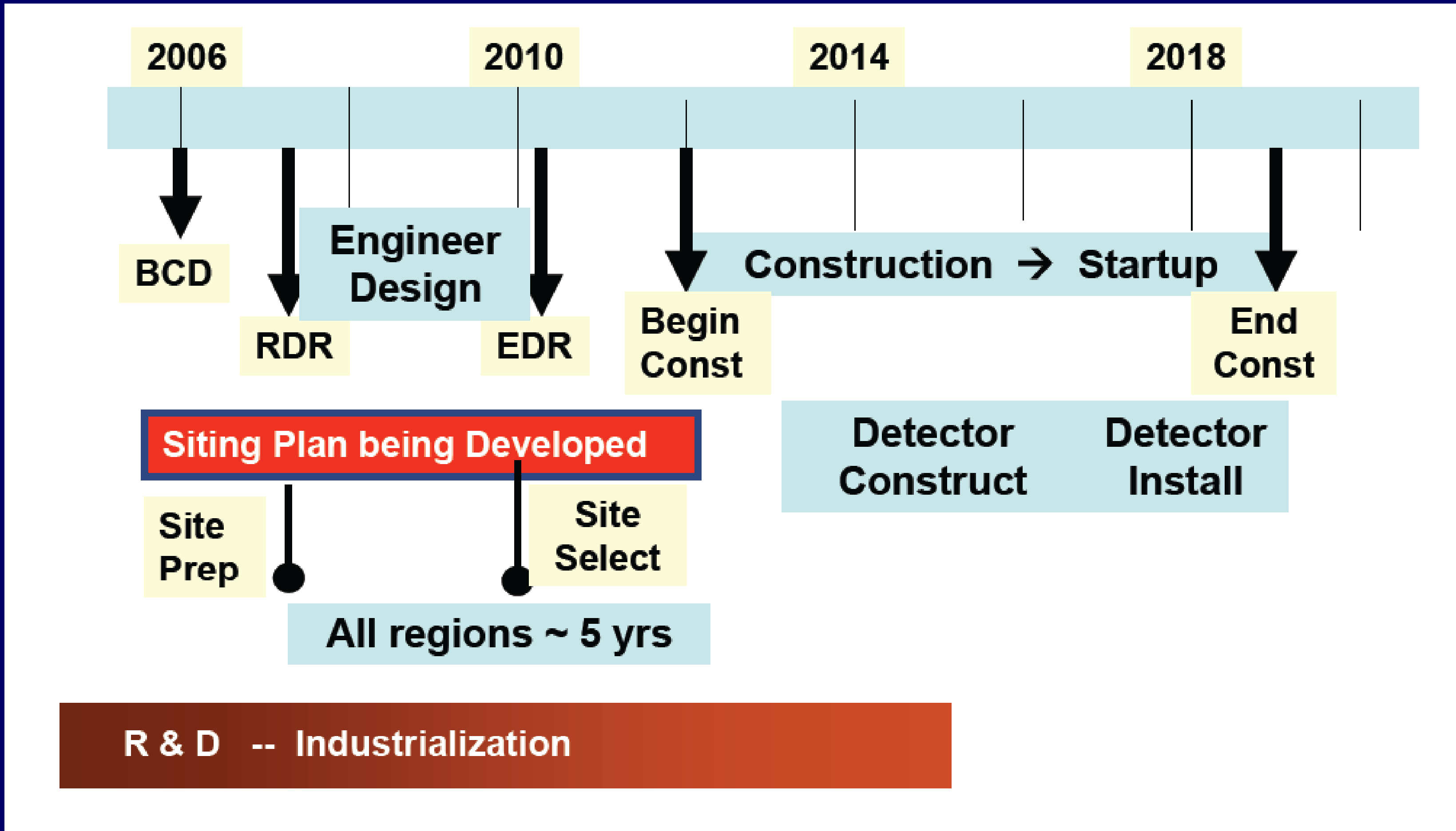
4. Global Design Effort



4. Timeline


ILC – Global Design Phase
2005
2006
2007
2008
2009
2010
Global Design Effort
Project
Baseline configuration
Reference Design
LHC Physics
Engineering Design
ILC R&D Program
Expression of Interest to Host
International Mgmt
30-May-07
LCWS DESY Meeting
Global Design Effort
13

4. Technically driven schedule

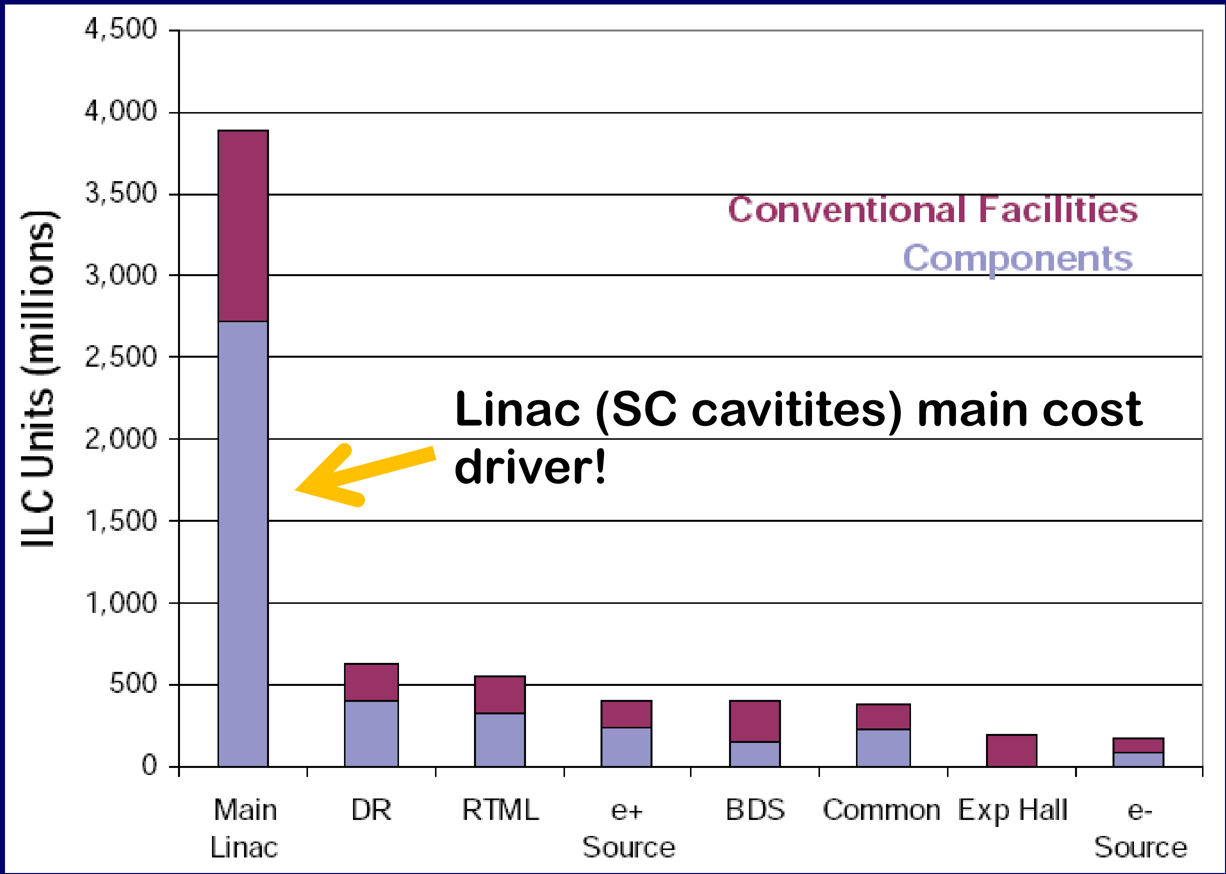


In a politically ideal situation, ILC can come into operation before 2020!

4. Cost estimate for Reference Design

6.6 ± (1.0-1.4) billion ILC units
+ 14 000 person-years

1 ILC unit = 1 US$ (2007)



but remember: construction time 7-8 years, to be shared among three regions

"6 billion bucks! What's this *thing* for?"

Summary

- International Linear Collider is the next large project particle physics at accelerators
- Strong physics motivation
- Technology is challenging but at hands
- Interesting R&D projects for Detector + Accelerator
- LHC startup will be important for next steps
- Technologically driven timescale: start before 2020

ENDE

4. How can universities take part?

- Detector R&D
- Accelerator R&D
- Physics case / theory

interesting for university research + education!!

has to be done now!

Rather well organized (proto-)collaborations

Recently funded german network „Helmholtz-Alliance“ provides infrastructure and networking for German universities

ILC parameters

defined by ICFA parameter group – recently confirmed in RDR process

Baseline:

e^+e^- LC operating from 200 to 500 GeV, tunable energy
at least 80% e^- polarization
at least 500 fb^{-1} in the first 4 years
beam energy precision 0.1% or better

Upgrade path: to ~ 1 TeV 500 fb^{-1} /year

Options :
- 60% positron polarisation
- GigaZ (high luminosity running at M_Z)
- $\gamma\gamma$, $e\gamma$, e^-e^- collisions

Choice of options depends on LHC+ILC results

ILC Reference Design Report (RDR) meets these parameters

ILC physics case

Significant advance w.r.t. LHC in understanding of Terascale physics through high precision at high energy

Recent summary (to appear very soon): Physics part of the RDR

July 6, 2007

The Physics Case for the International Linear Collider

Edtors: Abdelhak Djouadi[1], Joe Lykken[2], Klaus Mönig[3], Yasuhiro Okada[4], Mark Oreglia [5], Satoru Yamashita[6]

no change in conclusions from TESLA TDR, Snowmass report, ACFA study (~2001) ⇨ ILC physics is rock solid ☺

Physics case: Highlights

Higgs precision physics

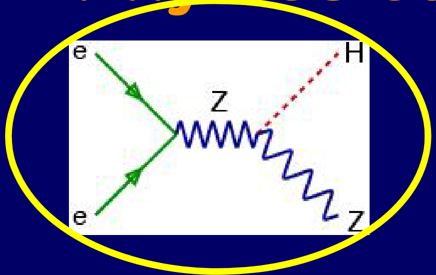
Gauge Bosons („SM probes of BSM physics“)

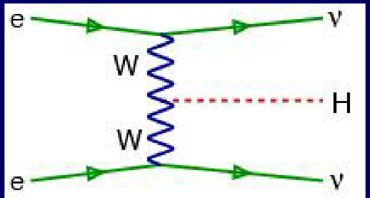
Top Quark

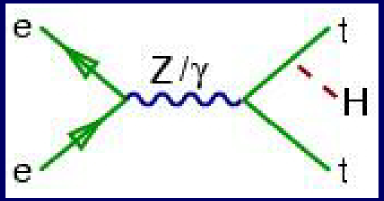
Supersymmetry

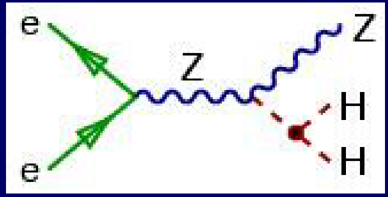
Large extra dimensions

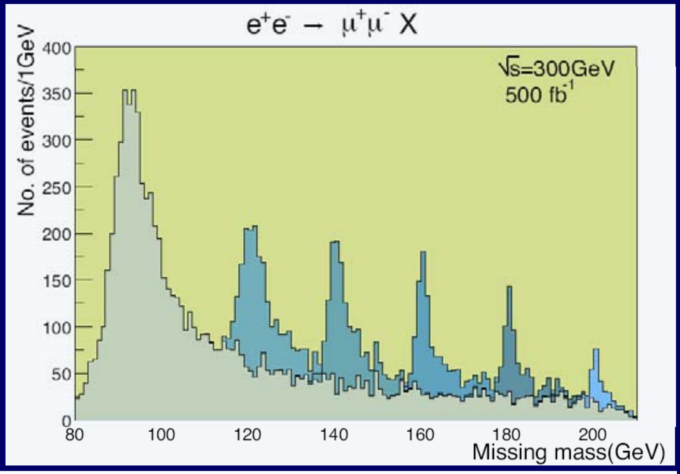
Physics case: Higgs

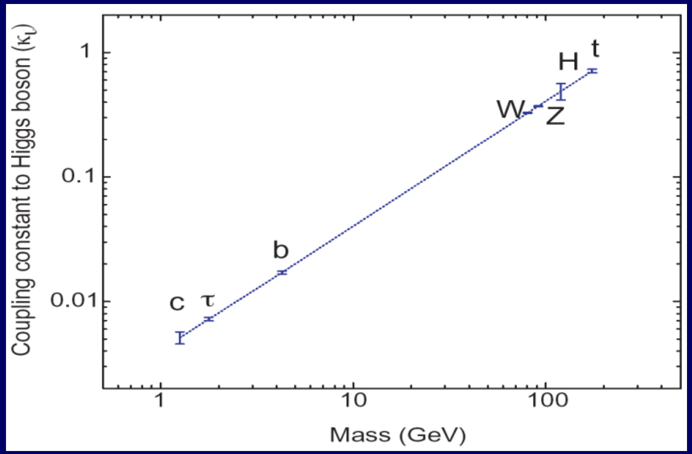








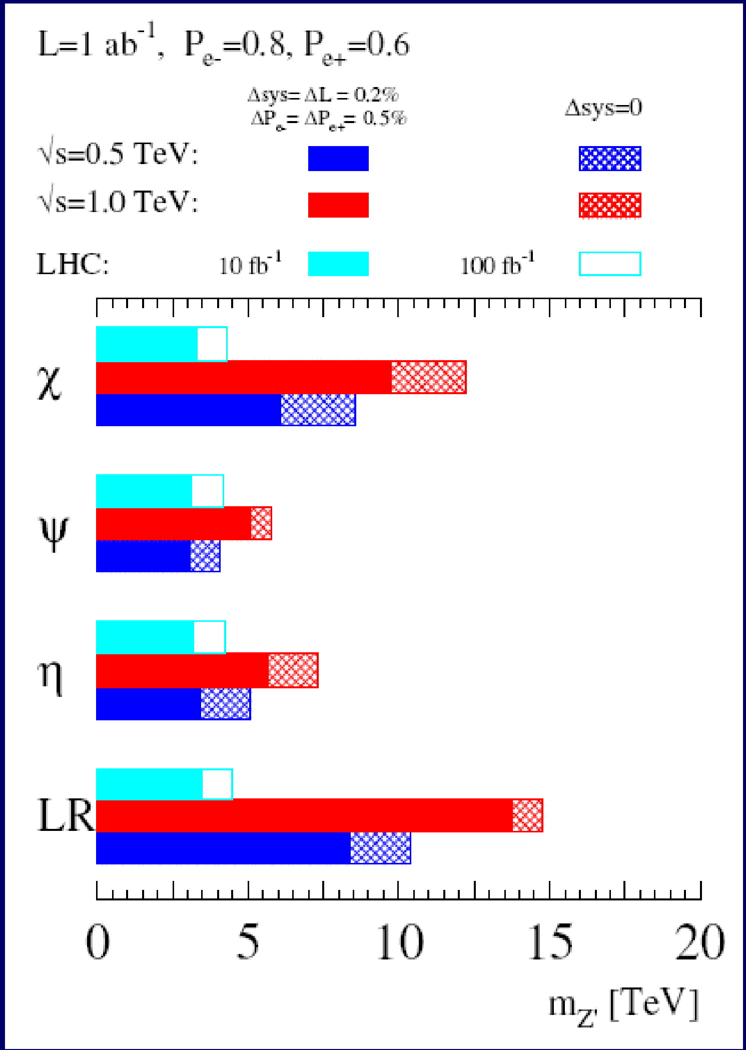


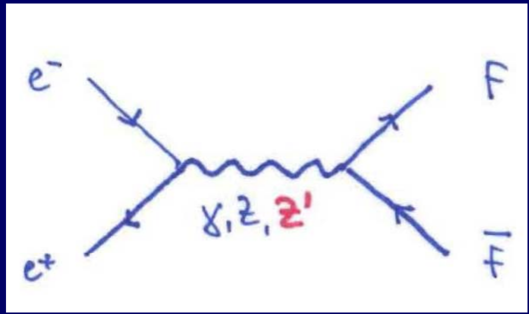


- decay-mode-independent observation
- mass (50 MeV)
- absolute couplings (Z,W,t,b,c,τ) (1-5%)
- total width (model-independent)
- spin, CP
- top Yukawa coupling (~5%)
- self coupling (~20%, 120-140 GeV)
- $\Gamma_{\gamma\gamma}$ at photon collider (2%)

fully establish Higgs mechanism!

Physics case: Gauge Bosons





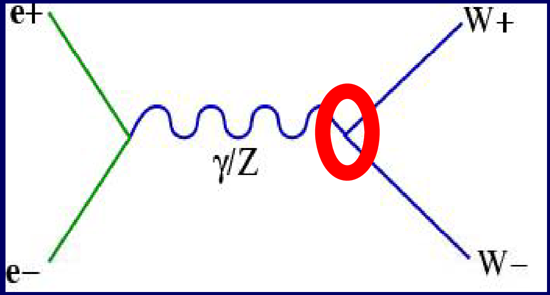
precision measurement of SM processes ($e^+e^- \to ff$)

higher mass reach for new Z´-like particles than direct search at LHC

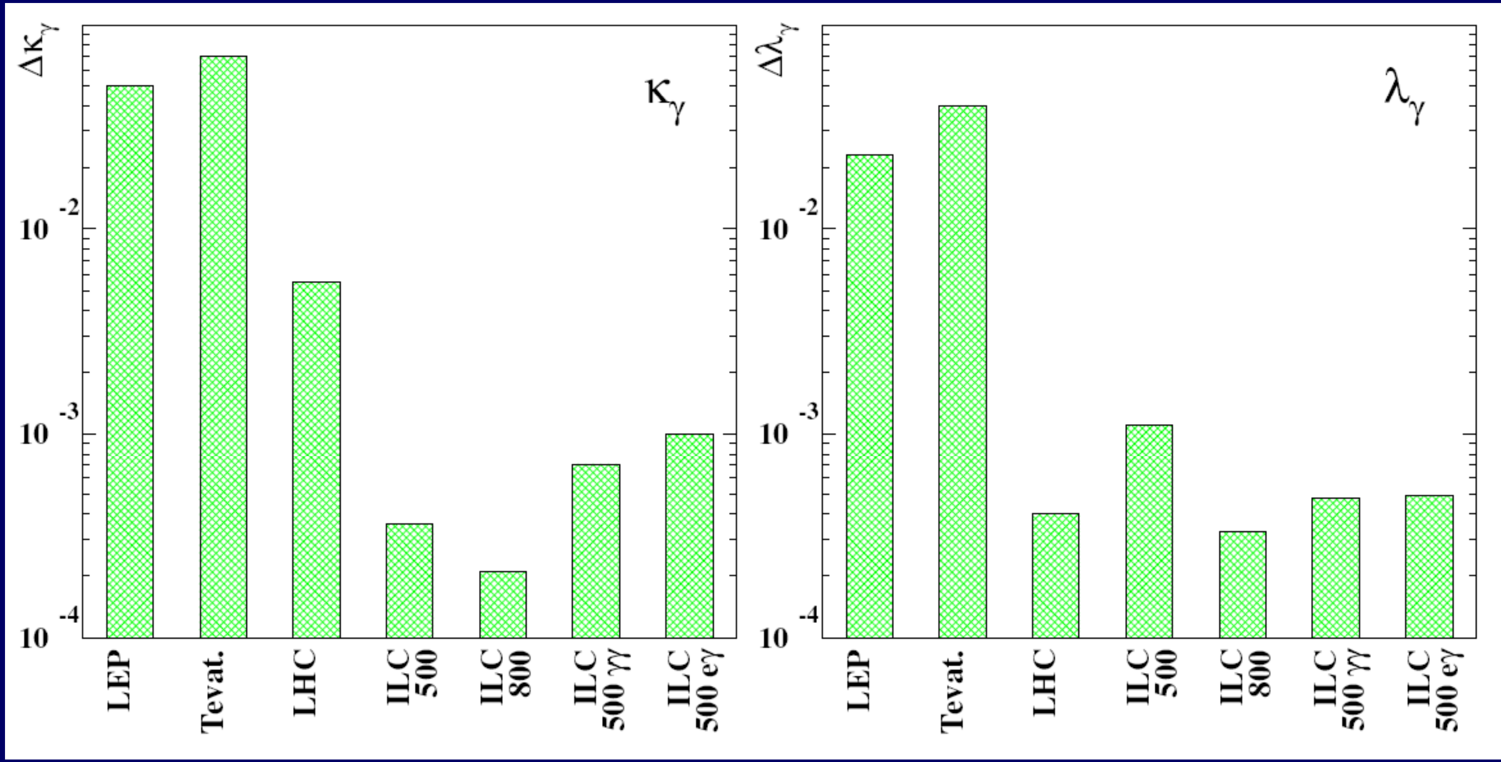
expect effects for large classes of new physics (Little Higgs, Higgsless, ...)

Physics case: Gauge Bosons

Anomalous Triple Gauge Boson couplings:

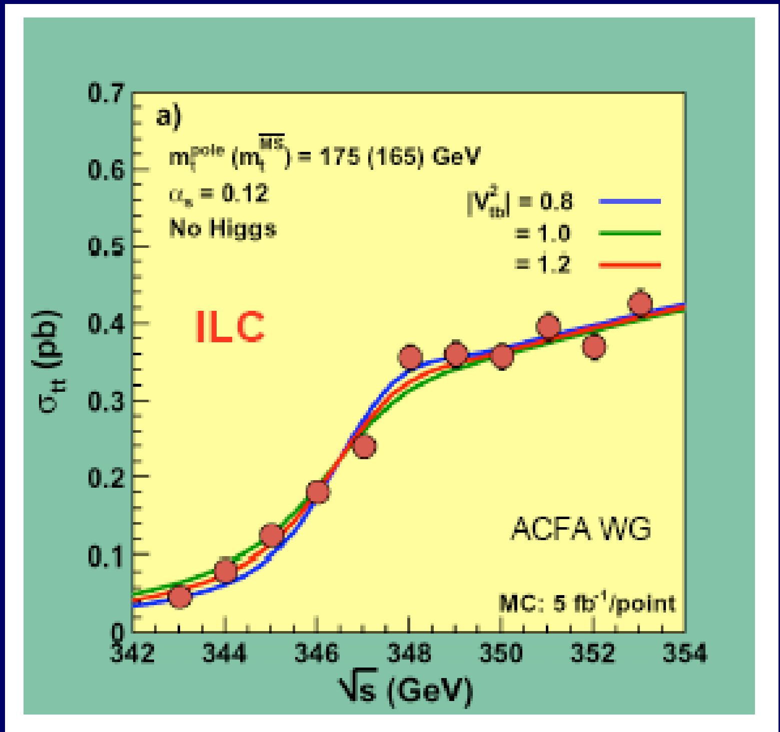


higher sensitivity than LHC for some couplings
beam polarisation (both beams)
important e.g. for Higgsless models



Physics case: Top Quark

- m_{top} fundamental parameter
- Δm_{top} will limit many predictions, e.g.
  - prediction of SM parameters ($\sin\theta_W$, m_W)
  - prediction of m_h in MSSM
  - prediction of relic DM density in MSSM

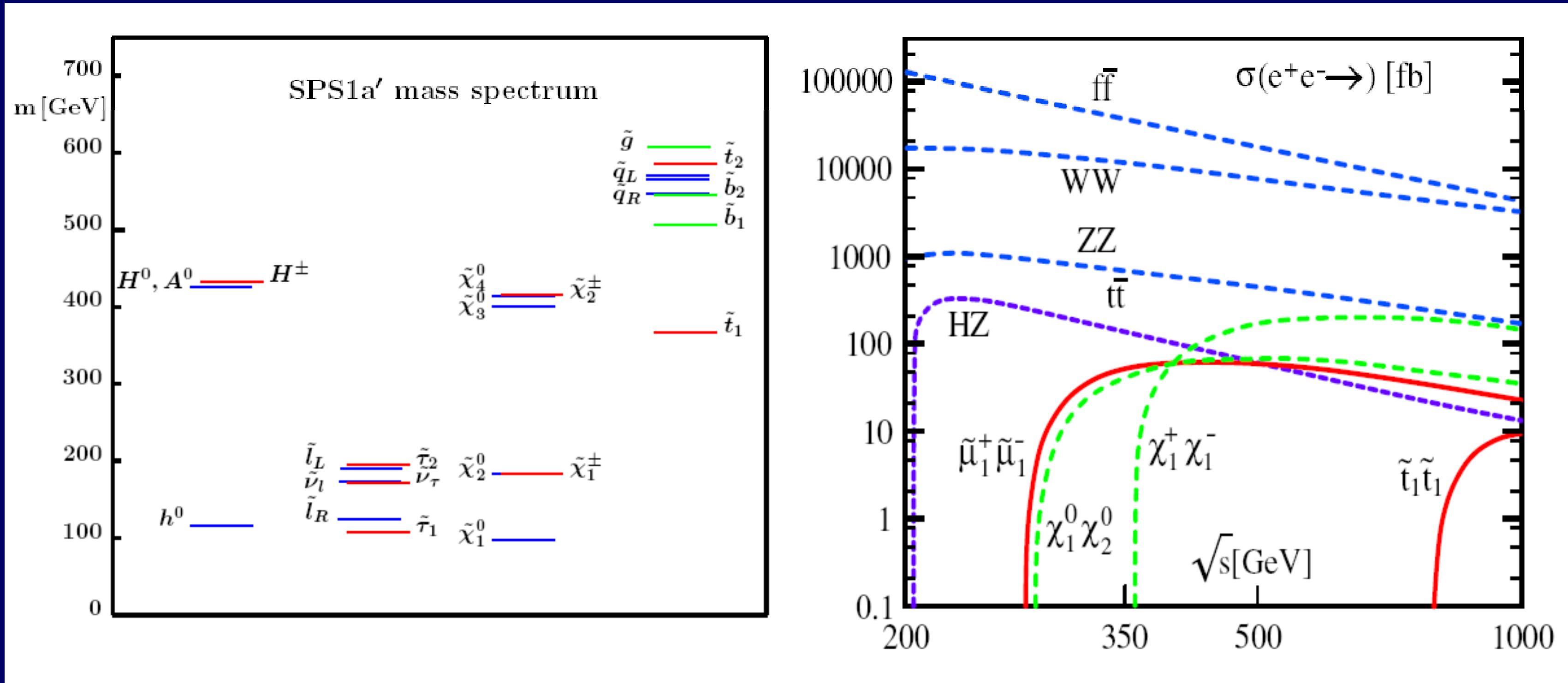


Energy scan of
top-quark threshold:

$\Delta M_{top} \approx 100$ MeV

(dominated by theory error)

Physics case: Supersymmetry

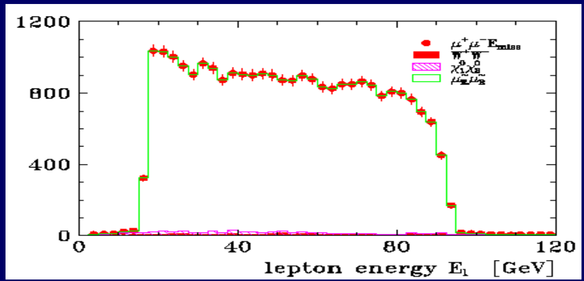


If colourless part of SUSY spectrum within ILC mass reach, ILC is the place to study the properties of these sparticles

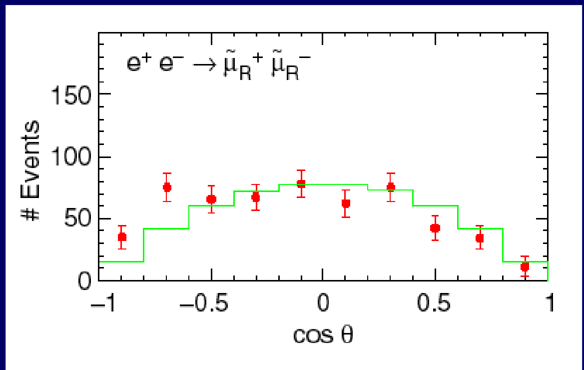
beam constraint allows for much improved kinematic reconstruction compared to LHC

⇨ expeditious test of SUSY predictions

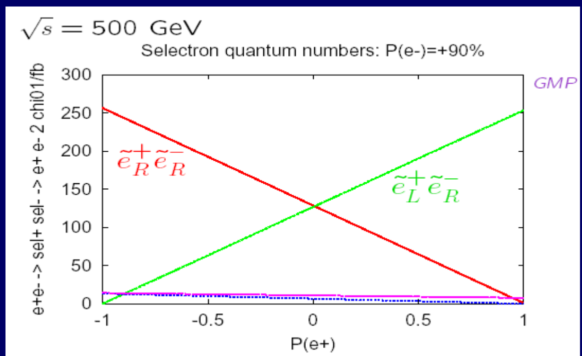
Physics case: Supersymmetry



precise masses of color-neutral states (50 MeV to 1 GeV)



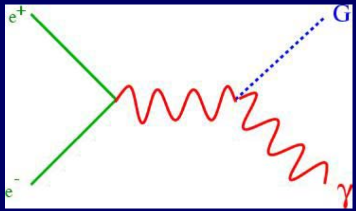
spins (angular distributions)



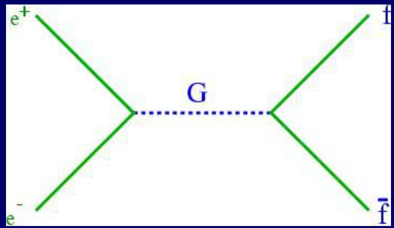
chiral quantum numbers (polarisation!)

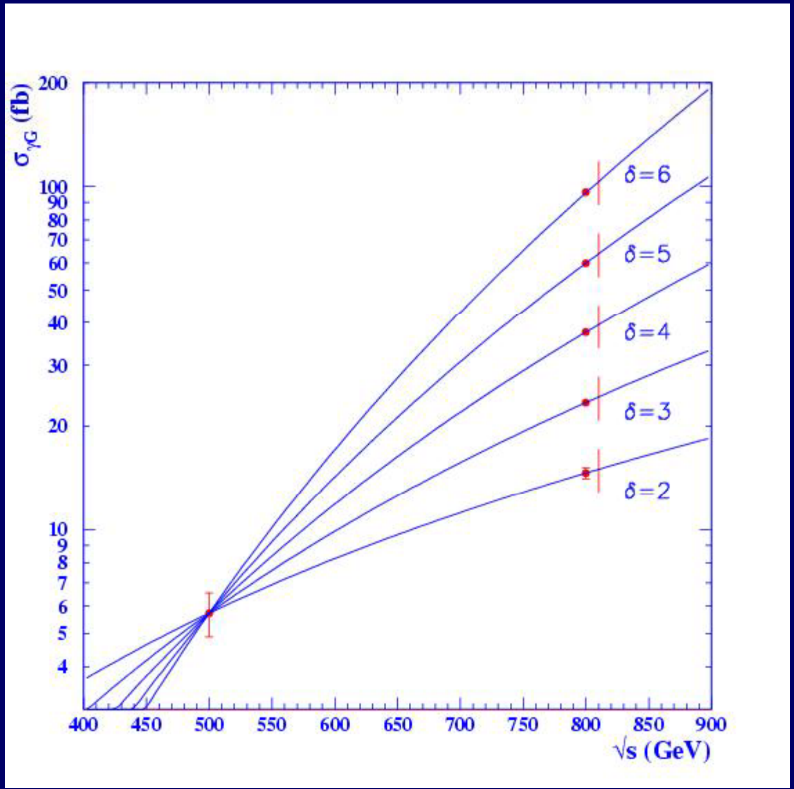
→ prove that it is SUSY
→ no model assumptions
→ learn about SUSY breaking

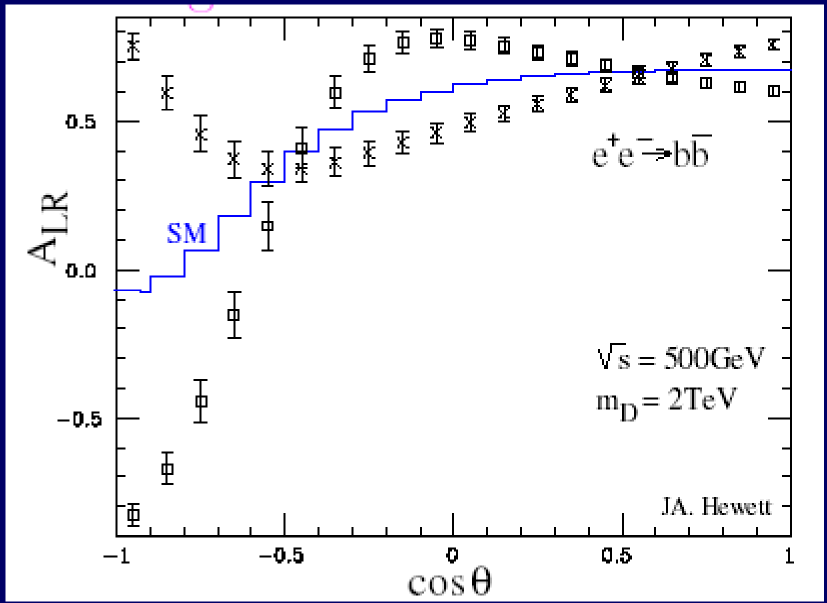
Physics case: Large Extra Dimensions



can determine Spin=2
number of XD's







Interplay and Synergy

LHC/ILC Study group,
Weiglein et al.

Phys. Rept. 426 (2006) 47

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Physics interplay of the LHC and the ILC☆

The LHC/ILC Study Group

G. Weiglein[a,*], T. Barklow[b], E. Boos[c], A. De Roeck[d], K. Desch[e], F. Gianotti[d], R. Godbole[f], J.F. Gunion[g], H.E. Haber[h], S. Heinemeyer[d], J.L. Hewett[b], K. Kawagoe[i], K. Mönig[j], M.M. Nojiri[k], G. Polesello[d,1], F. Richard[m], S. Riemann[j], W.J. Stirling[a], A.G. Akeroyd[n], B.C. Allanach[o], D. Asner[p], S. Asztalos[q], H. Baer[r], M. Battaglia[s], U. Baur[t], P. Bechtle[e], G. Bélanger[u], A. Belyaev[r], E.L. Berger[v], T. Binoth[w], G.A. Blair[x], S. Boogert[y], F. Boudjema[u], D. Bourilkov[z], W. Buchmüller[aa], V. Bunichev[c], G. Cerminara[ab], M. Chiorboli[ac], H. Davoudiasl[ad], S. Dawson[ae], S. De Curtis[af], F. Deppisch[w], M.A. Díaz[ag], M. Dittmar[ah], A. Djouadi[ai], D. Dominici[af], U. Ellwanger[aj], J.L. Feng[ak], I.F. Ginzburg[al], A. Giolo-Nicollerat[ah], B.K. Gjelsten[am], S. Godfrey[an], D. Grellscheid[ao], J. Gronberg[q], E. Gross[ap], J. Guasch[aq], K. Hamaguchi[aa], T. Han[ar], J. Hisano[as], W. Hollik[at], C. Hugonie[au], T. Hurth[b,d], J. Jiang[v], A. Juste[av], J. Kalinowski[aw], W. Kilian[aa], R. Kinnunen[ax], S. Kraml[d,ay], M. Krawczyk[aw], A. Krokhotine[az], T. Krupovnickas[r], R. Lafaye[aaa], S. Lehti[ax], H.E. Logan[ar], E. Lytken[aab], V. Martin[aac], H.-U. Martyn[aad], D.J. Miller[aac,aae], S. Moretti[aaf], F. Moortgat[d], G. Moortgat-Pick[a,d], M. Mühlleitner[aq], P. Nieżurawski[aag], A. Nikitenko[az,aah], L.H. Orr[aai], P. Osland[aaj], A.F. Osorio[aak], H. Päs[w], T. Plehn[d], W. Porod[au,aal], A. Pukhov[c], F. Quevedo[o], D. Rainwater[aai], M. Ratz[aa], A. Redelbach[w], L. Reina[r], T. Rizzo[b], R. Rückl[w], H.J. Schreiber[j], M. Schumacher[ap], A. Sherstnev[c], S. Slabospitsky[aam], J. Solà[aan,aao], A. Sopczak[aap], M. Spira[aq], M. Spiropulu[d], Z. Sullivan[av], M. Szleper[aaq], T.M.P. Tait[av], X. Tata[aar], D.R. Tovey[aas], authorA. Tricomi[ac], M. Velasco[aaq], D. Wackeroth[t], C.E.M. Wagner[v,aat], S. Weinzierl[aau], P. Wienemann[aa], T. Yanagida[aav,aaw], A.F. Żarnecki[aag], D. Zerwas[m], P.M. Zerwas[aa], L. Živković[ap]

Main questions:
How can our view of the Terascale be improved if results from both tools, LHC ⊕ ILC are interpreted simultaneously?

(also: are there cases which justify a simltuneous running of LHC and ILC?

became somewhat less important ☹)

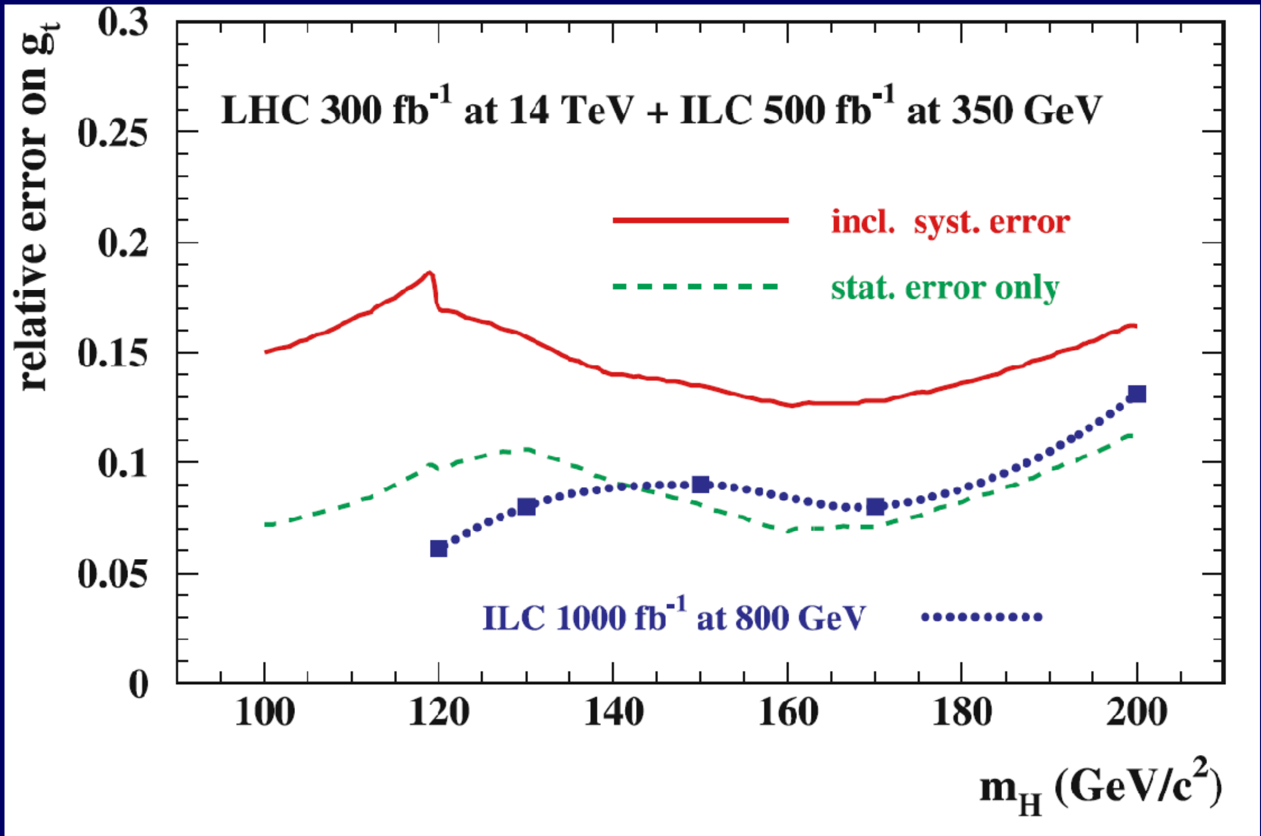
LHC⊕ILC example: Top Yukawa Coupling

LHC: measures

σ_{tth} x BR(H→bb)
σ_{tth} x BR(H→WW)
→ g_t^2 x BR(H→xx)

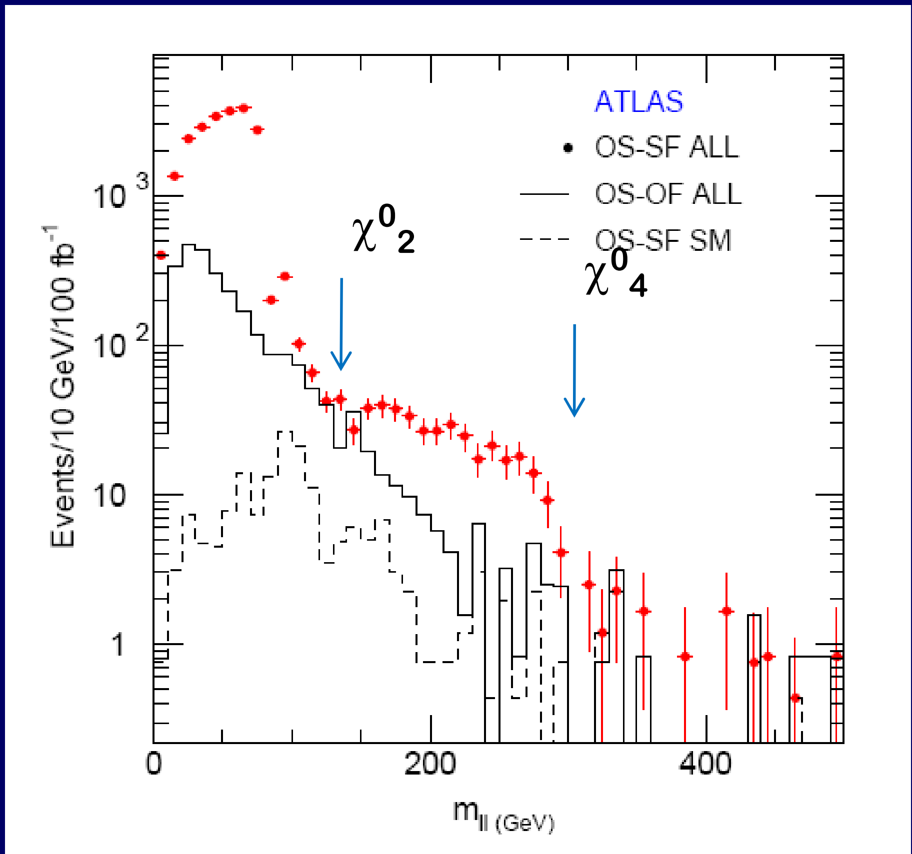
ILC(500): measures BRs

BR(H→bb)
BR(H→WW)



LHC⊕ILC: identification of LHC signals

SPS1a example:
from measurements of $\chi^+\chi^-$ and $\chi^0_1\ \chi^0_2$ production, neutralino+chargino sector can be fully reconstructed ⇨ prediction of all masses, couplings e.g. m(χ^0_4) = 378.3 ± 8.8 GeV



LHC⊕ILC: global parameter determination

Ultimate goal in study of SUSY: learn about SUSY breaking and GUT unification ⇨ need to be „unbiased“ in interpretation of data

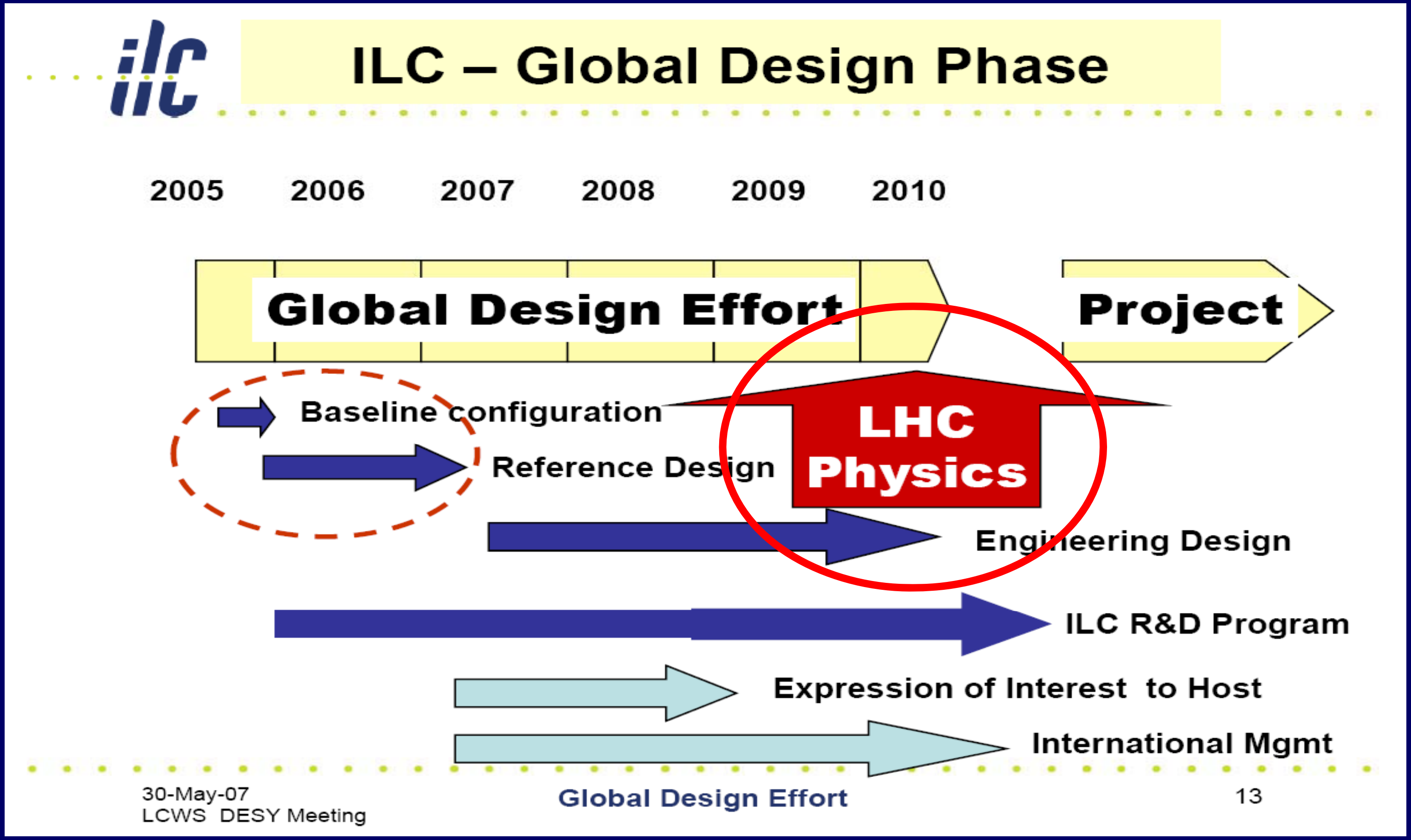
(exp observables) ⇨ (EW scale model parameters (e.g. MSSM(24))) ⇨ RGE evolution

global fit of all accessible observables from LHC and ILC needed:

TABLE 5.3-3
Results for the MSSM parameter determination in SPS1a [215] and SPS1a' [188] using the mass measurements at the ILC and the LHC [193] after a global fit. The central values are approximately reproduced.

	ΔLHC	ΔILC	ΔLHC+ILC	SPS1a	ΔLHC+ILC	SPS1a'
$\tan\beta$	±9.1	±0.3	±0.2	10	±0.3	10
μ	±7.3	±2.3	±1.0	344.3	±1.1	396
M_A	fixed 500	±0.9	±0.8	399.1	±0.8	372
A_t	±91	±2.7	±3.3	−504.9	±24.6	−565.1
M_1	±5.3	±0.1	±0.1	102.2	±0.1	103.3
M_2	±7.3	±0.7	±0.2	191.8	±0.1	193.2
M_3	±15	fixed 500	±11	589.4	±7.8	571.7
$M_{\tilde{\tau}_L}$	fixed 500	±1.2	±1.1	197.8	±1.2	179.3
$M_{\tilde{e}_L}$	±5.1	±0.2	±0.2	198.7	±0.2	181.0
$M_{\tilde{e}_R}$	±5.0	±0.05	±0.05	138.2	±0.4	115.7
$M_{\tilde{Q}3_L}$	±110	±4.4	±39	501.3	±4.9	471.4
$M_{\tilde{Q}1_L}$	±13	fixed 500	±6.5	553.7	±5.2	525.8
$M_{\tilde{d}_R}$	±20	fixed 500	±15	529.3	±17.3	505.7

Implications of first LHC data on ILC



Barish

With first collisions at 14 TeV next year, it is obvious that we have to start understanding implications of LHC discoveries for the ILC in much more detail

Implications of first LHC data on ILC

First workshop on this topic held at Fermilab, April 07

Next workshop: January 08 (?), SLAC

The LHC Early Phase for the ILC
Workshop charge

What could be the impact of early LHC results on the choice of the ultimate ILC energy range and the ILC upgrade path?

Could there be issues that would need to be implemented into the ILC machine and detectors design from the start?

Could there be cases that would change the consensus about the physics case for an ILC with an energy of about 500 GeV?

What are the prospects for LHC/ILC interplay based on early LHC data?

Strategy

Largely signal-driven (not so much model driven) scenarios

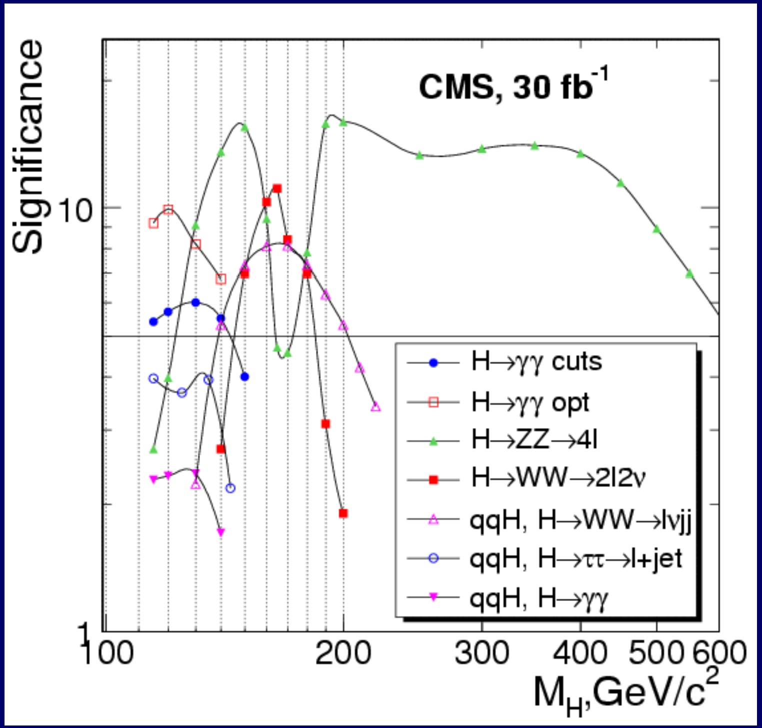
1. The detection of only one state with properties that are compatible with those of a Higgs boson

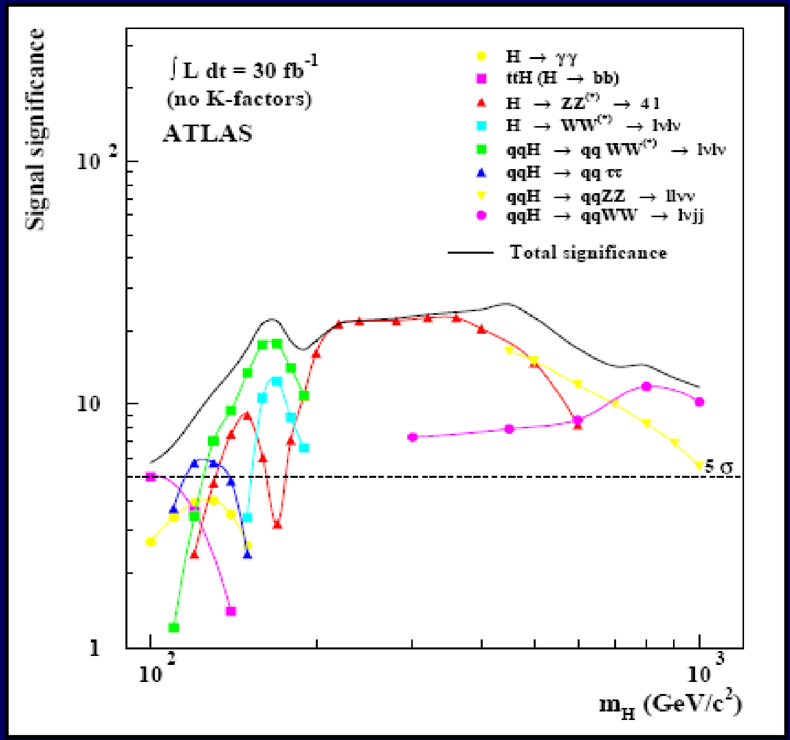
2. No experimental evidence for a Higgs boson at the early stage of LHC

3. The detection of new states of physics beyond the Standard Model.

    a. Missing Energy (+nothing, leptons, jets) signals
    b. Leptonic resonances
    c. Multi-Gauge-Boson signals
    d. Everything else.

Scenario 1: early Higgs at LHC





SM Higgs discovery with ~10 fb^{-1} over full mass range if nothing goes wrong

- rather easy (and fast) for m_H > 140 GeV
- more involved for light Higgs m_H < 140 GeV

Scenario 1: ILC implications

Depends (somewhat) on m_H

- Optimal $\sqrt{s}$ for HZ $\cong m_Z + m_H$ + 50 GeV ⇨ baseline ILC ok if m_H < ~ 350 GeV
- Yukawa couplings directly accessible at ILC up to 220 (bb), ~150 (cc,$\tau\tau$)
- HHH coupling studied up to 140 GeV so far

But not all possibilities for m_H> 160 GeV studied yet
More work necessary for the ILC!

for m_H > 160 GeV:

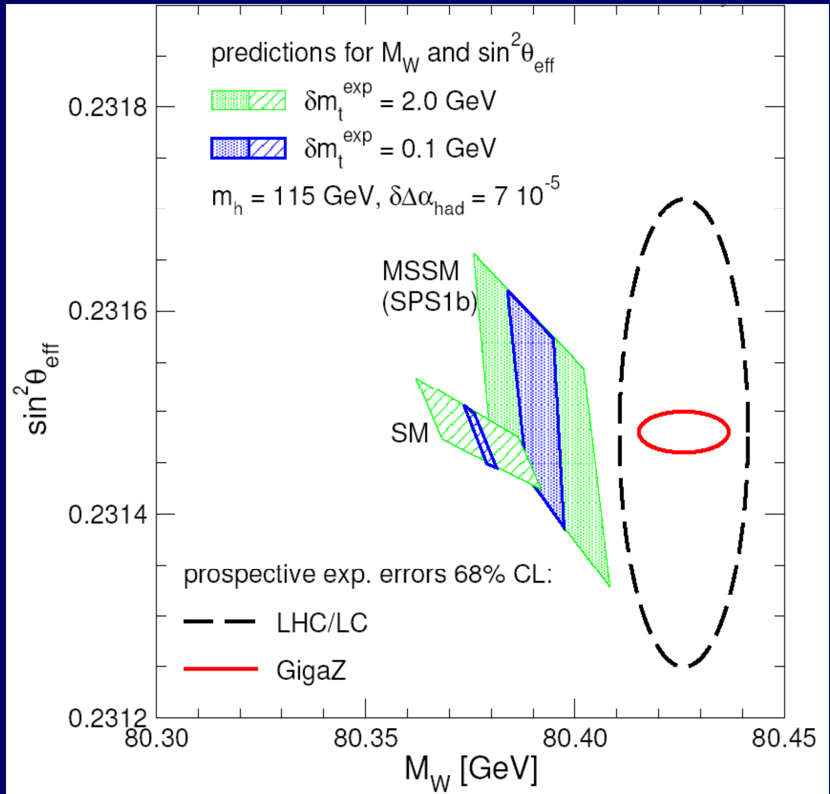
- couplings to WW, ZZ still measurable (but how much better than LHC?)
  $\rightarrow$ improve precision (include hadronic Z?, more luminosity?)
- fully explore WW-Fusion
- improvements for Yukawa couplings (H$\rightarrow$bb above 220 GeV, ttH, H $\rightarrow$tt*)
- explore total width measurement from WW$\rightarrow$H$\rightarrow$WW!
- total width from threshold scan?
- self coupling from $\nu\nu$HH$\rightarrow\nu\nu$WWWW (energy, luminosity)?

Scenario 1: m_H>>160 GeV ILC implications

If there is a heavy (>200 GeV?) SM-like Higgs we need precision measurements to test quantum structure
→ indication for new physics close-by.

We will need:

- **precise m_{top} (100 MeV) from tt-threshold**
- **precise m_W (6 MeV) from WW threshold**
- **precise $\sin^2\Theta_W$ from Giga-Z**
- **$e^+e^- \to$ff, WW, …**



Heinemeyer,Kraml,Porod,Weiglein

Scenario 2: No Higgs at early LHC

assume SM Higgs and MSSM Higgs excluded at LHC
(can probably be achieved with < 30 fb^{-1})

$\rightarrow$ 2 choices:
A: there are Higgs-like states to which the LHC is insensitive
B: there is no Higgs mechanism at work

Can the LHC tell if A or B is true?

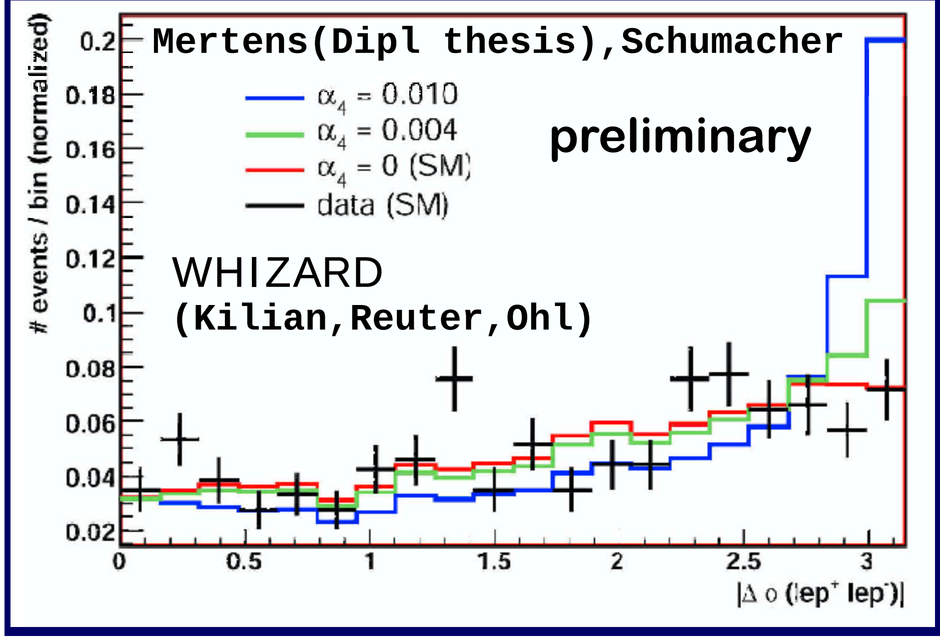
Since A is not testable by definition, B has to be tested!

Scenario 2: if no Higgs → look at strong EWSB

Rich field
- Measure TGCs in WW,WZ,ZZ
- Measure QGCs in WWZ, WWγ

Crucial test of EWSB: Weak boson fusion at high mass:
e.g. qq →jjWW→jjlνlν

Needs more attention at LHC (did I miss something?)
Important for ILC planning!



$$L_4 = \frac{\alpha_4}{16\pi^2} tr(V_\mu V_\nu) tr(V^\mu V^\nu)$$

$$L_5 = \frac{\alpha_5}{16\pi^2} tr(V_\mu V^\mu) tr(V_\nu V^\nu)$$

effective Lagrangian approach valid at m(WW)>1.2 TeV??

exclusion potential?

Scenario 2: Implications for ILC

if WW → WW remains weak

→ Higgs has been missed!

→ ILC to look for invisible, purely hadronic, exotic (e.g. singlet continuum) Higgses

if deviations in WW → WW found

→ is ILC the right machine?

- low energy precision program still interesting (GigaZ, ee→ff, TGC, QGC)
- but clearly the multi-TeV region comes into focus which tools? (CLIC, MUC, ???)

Scenario 3: MET signal at LHC

After observation of an excess: need estimate of thresholds at ILC

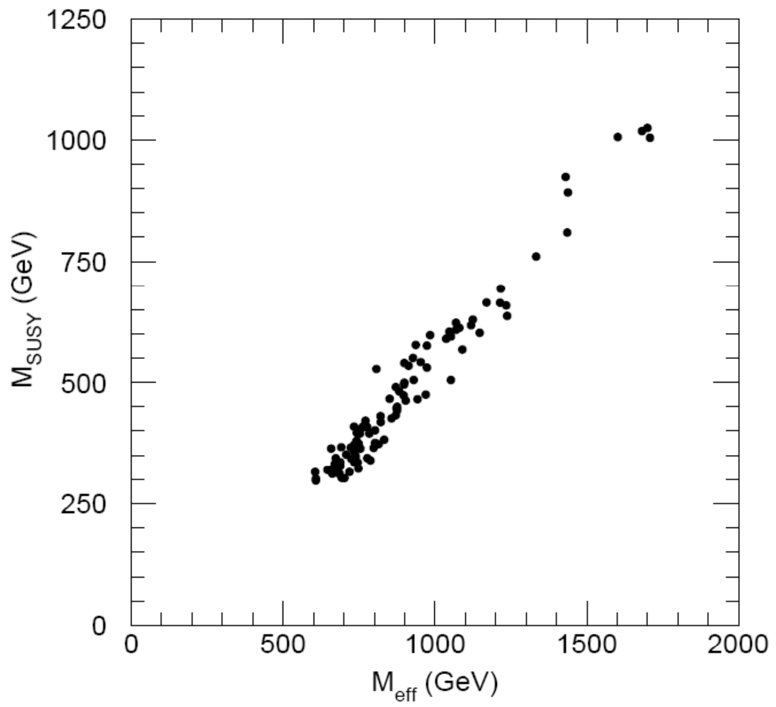
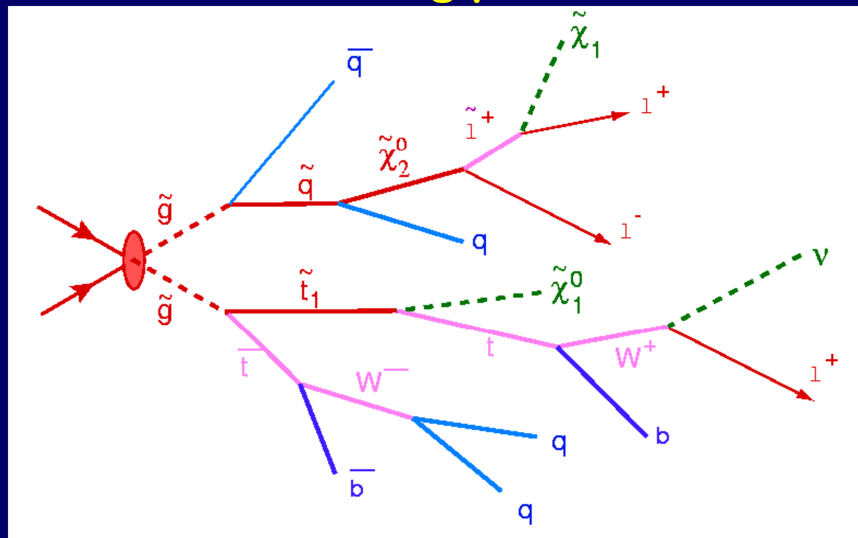


Figure 20-5 Peak of M_{eff} distribution as a function of. $M_{\mathrm{SUSY}} = \min(M_{\tilde{g}}, M_{\tilde{u}_R})$ for various models.

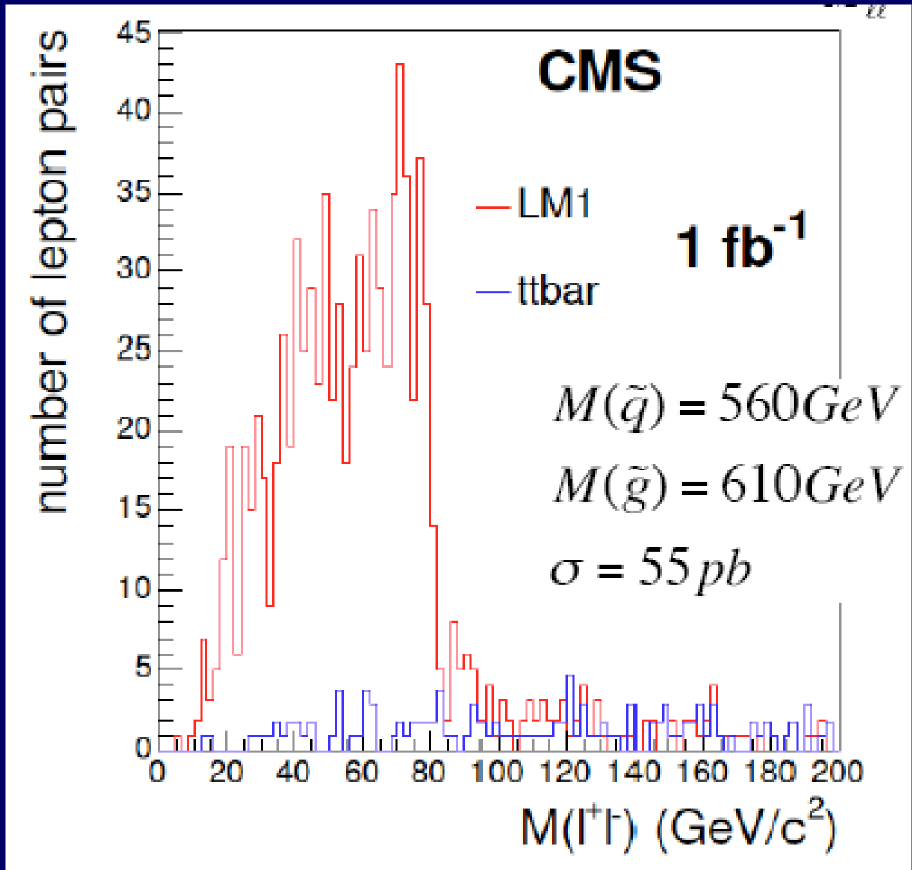
Fast estimate of m(gluino), m(squark) is not enough for ILC decision/optimization

need to get estimates of masses of the cascading particles!



Scenario 3: SUSY at LHC

Dileptons:



A sharp edge in the dilepton mass spectrum is a fast "go" for the ILC

$$M_{\ell\ell}^{\max} = m(\tilde{\chi}_2^0)\sqrt{1-\left(\frac{m(\tilde{\ell}_R^{\pm})}{m(\tilde{\chi}_2^0)}\right)^2}\sqrt{1-\left(\frac{m(\tilde{\chi}_1^0)}{m(\tilde{\ell}_R^{\pm})}\right)^2}$$

caveat:

could be (outside mSugra):

M^{edge} = 80 GeV
= 400 GeV – 320 GeV

excludable through LHC rates?

Scenario 3: MET signal at LHC

what we really need is a model-independent estimate
of the particle masses in cascade decays, which end in an
invisible massive particle (DM candidate)

Full kinematic reconstruction is tough
see e.g. Kawagoe,Nojiri,Polesello hep-ph/0410160

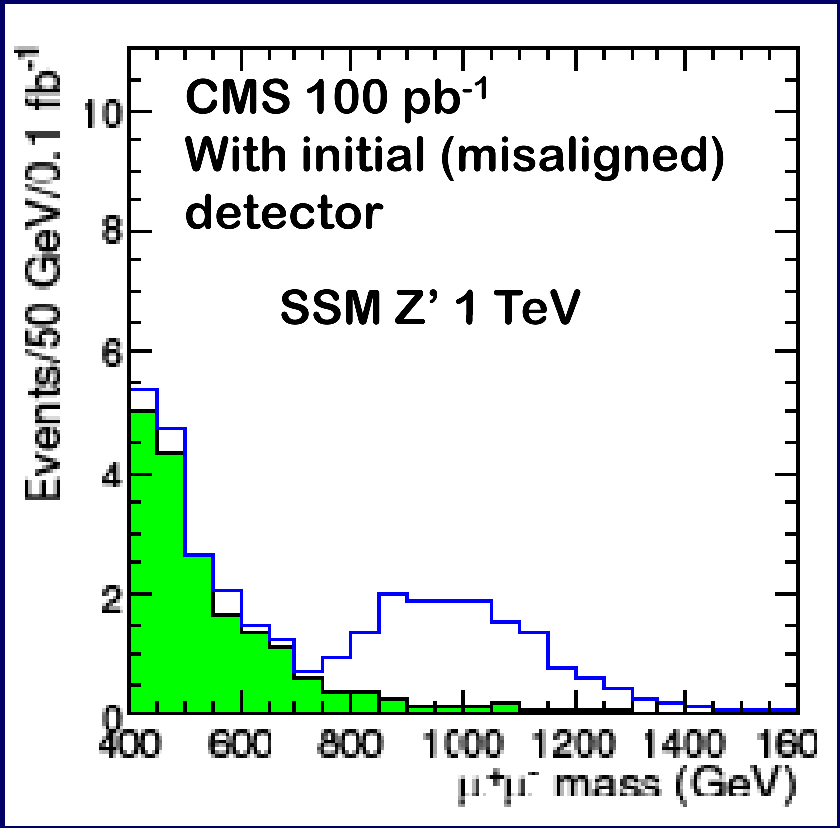
I don’t think, all tricks have been played yet..

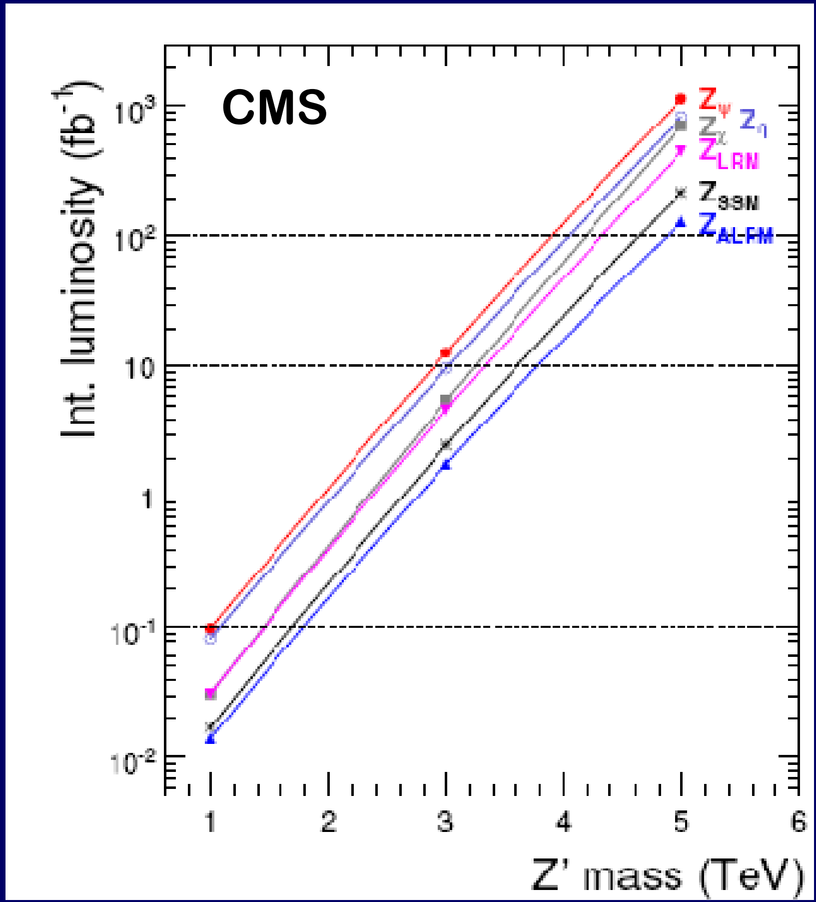
Fully exploit

- correlated p_T spectra of visible objects and MET
- invariant masses
- rates!

Scenario 3: Leptonic Resonances at LHC

can possibly be seen very early…





Discovery reach 3-4 TeV with 10 fb^{-1}

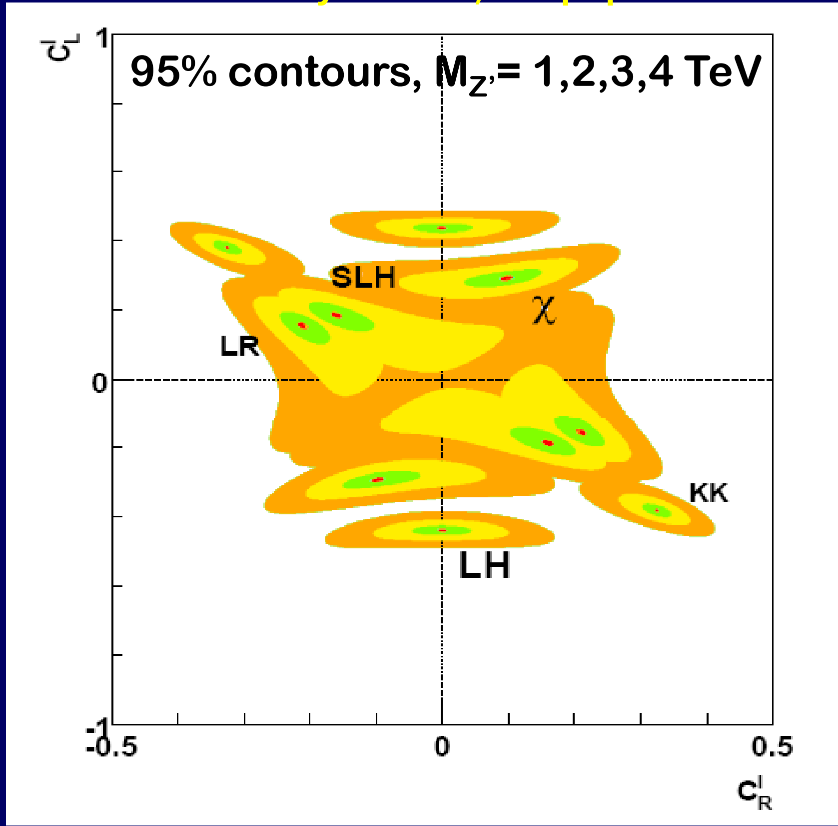
Scenario 3: Resonances: ILC consequences

- Not very likely, that a <500 GeV ll-Resonance appears (but ILC would of course study it in s-channel ☺☺)

- A resonance within the direct reach of an upgraded ILC would probably call for a fast upgrade path (still would like to do the precision Higgs (if there) and SM program)

- A resonance beyond the direct ILC reach: ILC+LHC can determine coupling structure from interference with γ/Z exchange to determine its nature

Godfrey et al, hep-ph/0511335



E6 χ model
LR symmetric
Littelest Higgs (LH)
Simplest Little Higgs (SLH)
KK excitations in ED

Conclusions

• ILC (as planned in the RDR) has a solid case for exploring the Terascale

• Joint interpretation of LHC and ILC data can yield additional information

• The LHC Early Phase will be exciting!
(first of all on its own – but also for the ILC…)

• We 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…)

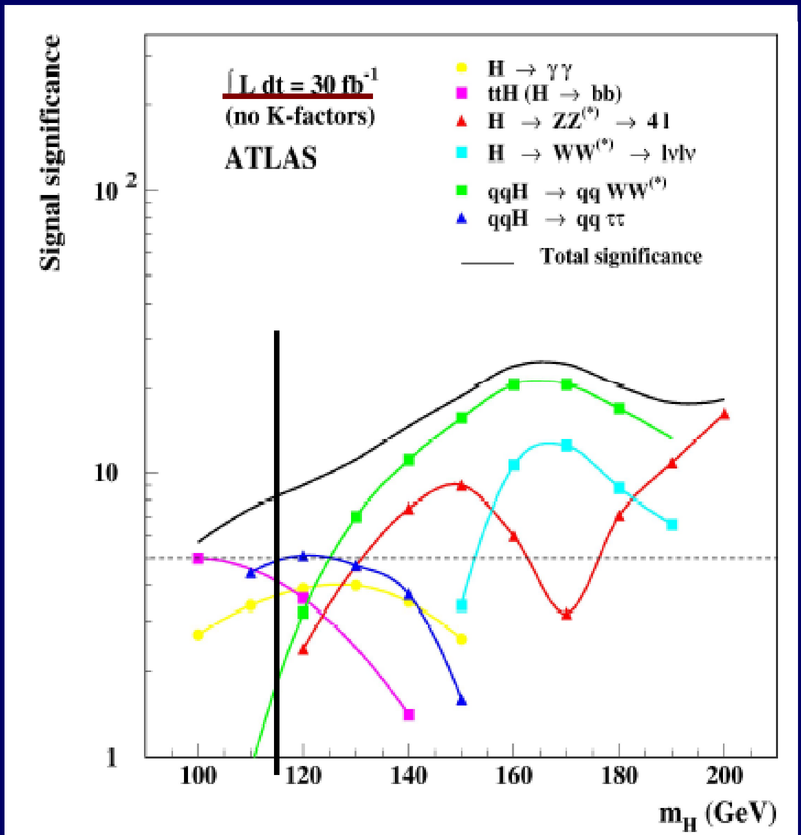
• Some possible signals at LHC (light Higgs, SUSY-like signals, leptonic resonances,…) are clear "go ahead" signs for ILC

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

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

LHC-ILC: Higgs boson decays

light (m_H<140 GeV) Higgs:
early discovery (10 fb^{-1}) through combination of 3 channels possible
(good or bad?)



m_H=115 GeV

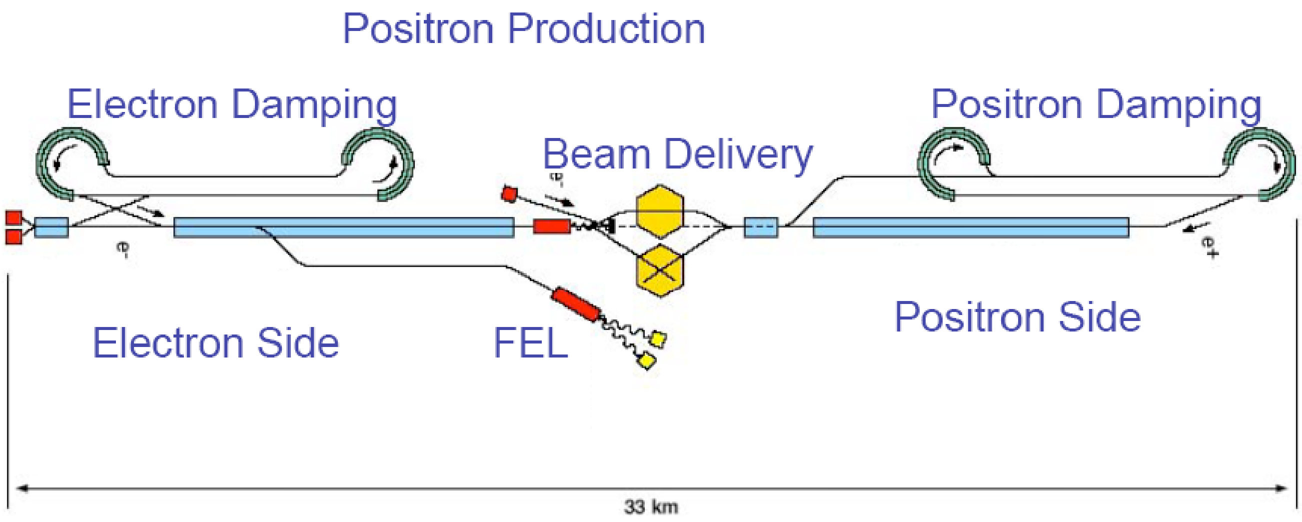
significance for 10fb^{-1}:

	S	B	$S/\sqrt{B}$
$H\to\gamma\gamma$	130	4300	2.0
ttH,$H\to bb$	15	45	2.7
qqH,$H\to\tau\tau$	10	10	2.7

combinied: ~4σ

2. Accelerator

$L = 3 \cdot 10^{34}\ cm^{-2}\ s^{-1}$ $E_{cms} = 500$ GeV $\sigma_y = 5$ nm



Key Technology taken from TESLA TDR to ILC :
SC Cavities at 1.3 GHz (L-Band)