International Linear Collider

Perspektiven der Teilchenphysik
KET Strategieworkshop 2010
Dortmund 25.10.2010

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Universität Bonn

Physics at the Terascale - what can we learn?

- Electroweak symmetry breaking + Higgs
- Hints for unification of forces
- Extra space dimensions
- Superspace
- Dark Matter
- New sources of CP violation
- The unknown

LHC entered the Terascale in 2010!

When new phenomena will appear at the LHC,

an Electron-Positron Collider will be needed

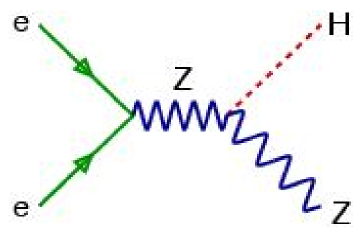
The ILC with 91 GeV < $\sqrt{s}$ < 1000 GeV is able to provide quantitative understanding complementary to the LHC

→ Examples

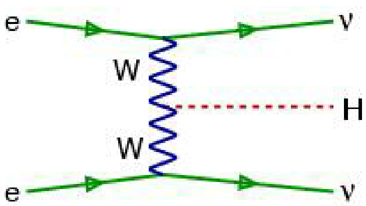
Higgs precision physics - model independent

Precision (%) profile of Higgs Boson:

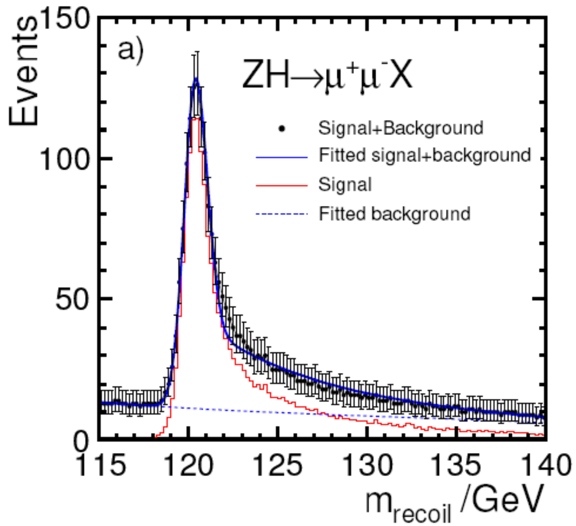
- mass
- quantum numbers J^{PC}
- model-independent ZH coupling
- Branching ratios + ttH → model independent Hff and HVV couplings
- WW→ H + H → WW → total width
- Higgs self coupling

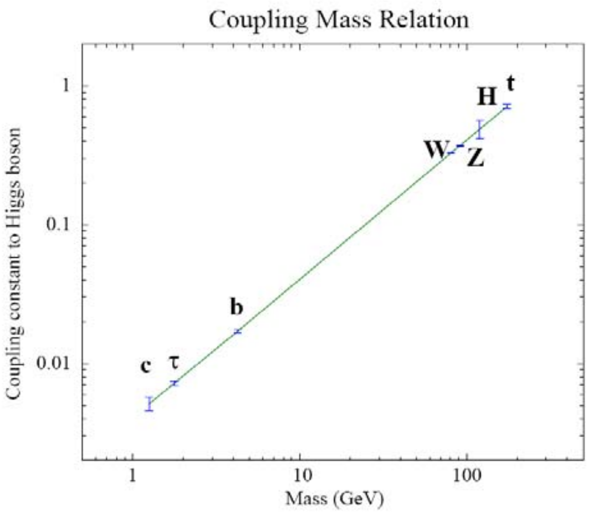


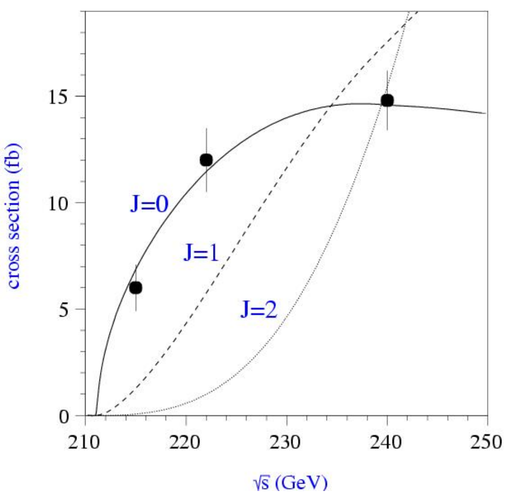
Higgsstrahlung



WW fusion



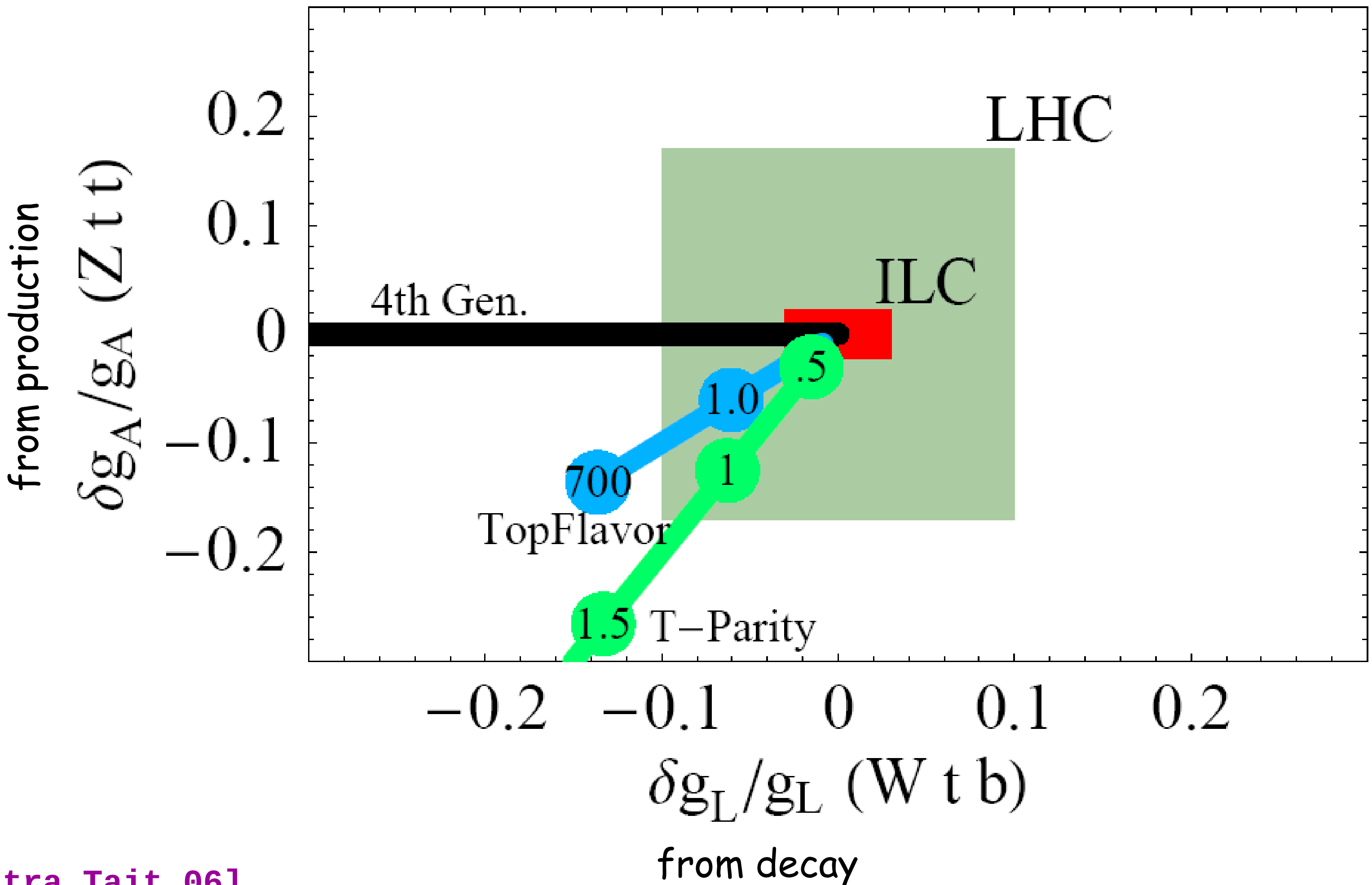




→ identify the underlying physics through precision

Top quark precision as window to BSM

Example: couplings to EW gauge bosons:

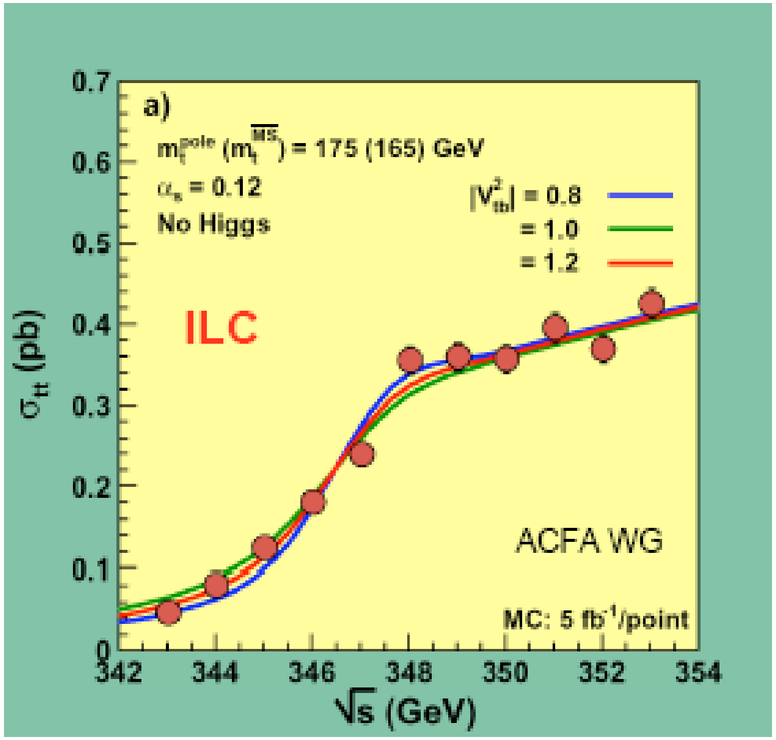


[Batra,Tait 06]

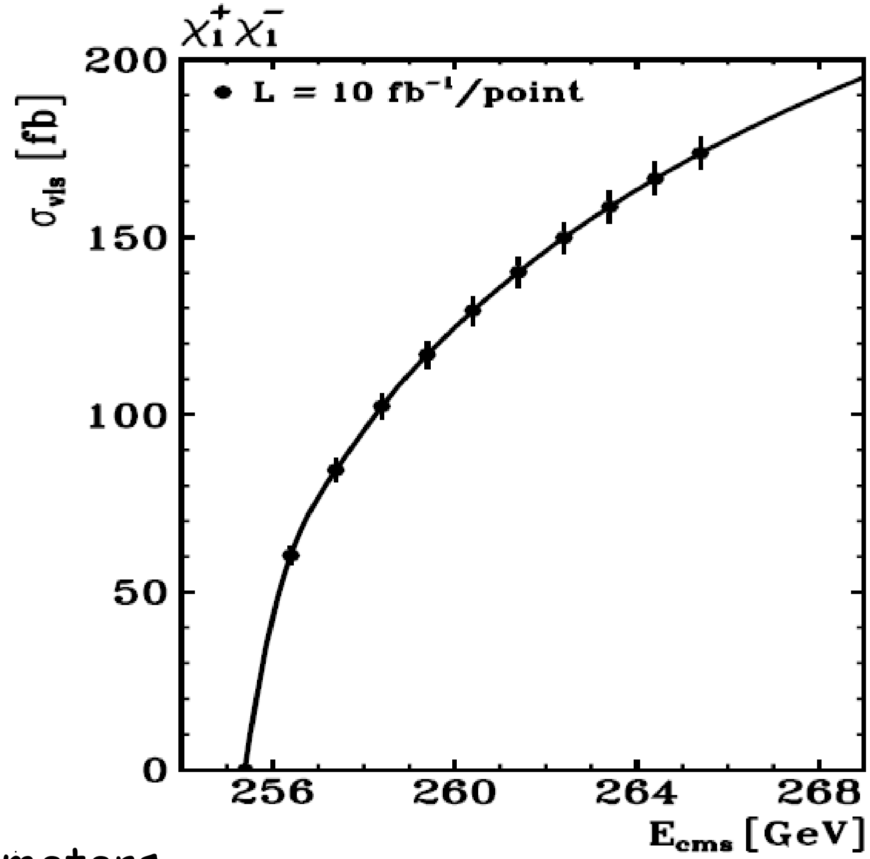
Threshold scans

Ultraprecise mass determinations

Top quark: ~100 MeV

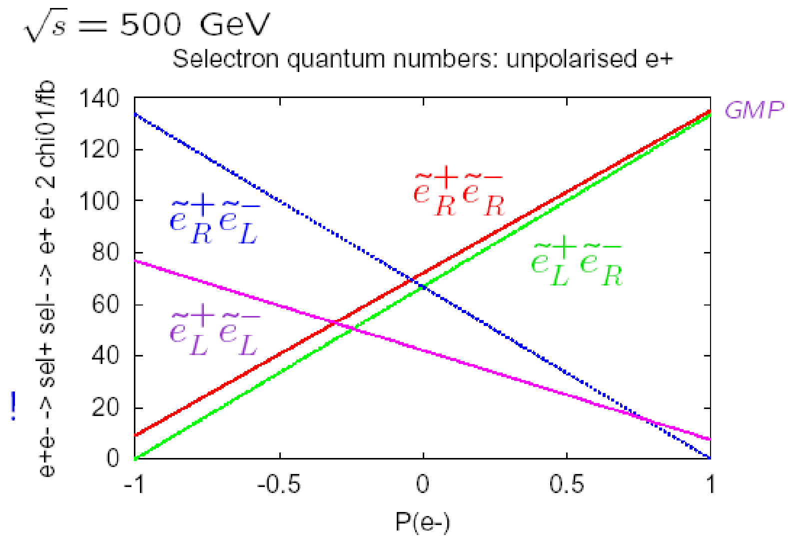


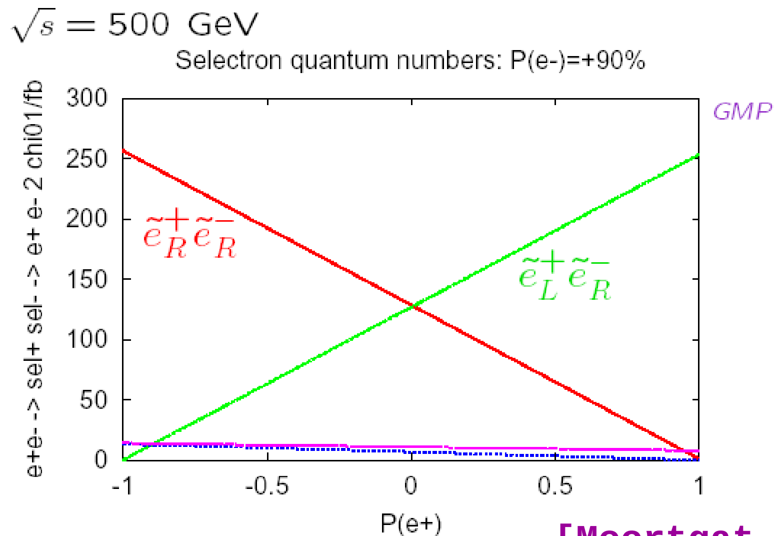
Colour-neutral SUSY particles, e.g.
Chargino: ~ 50 MeV



Needed to pin down BSM model parameters

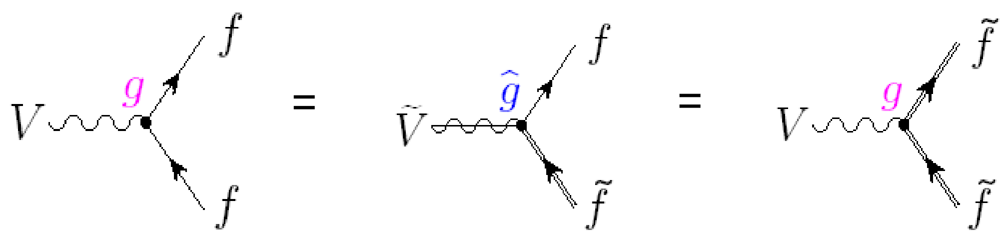
Disentangle chiral structure with polarization





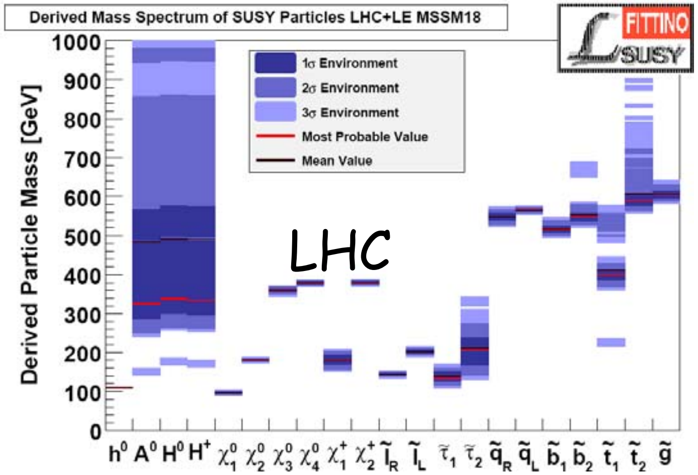
[Moortgat-Pick]

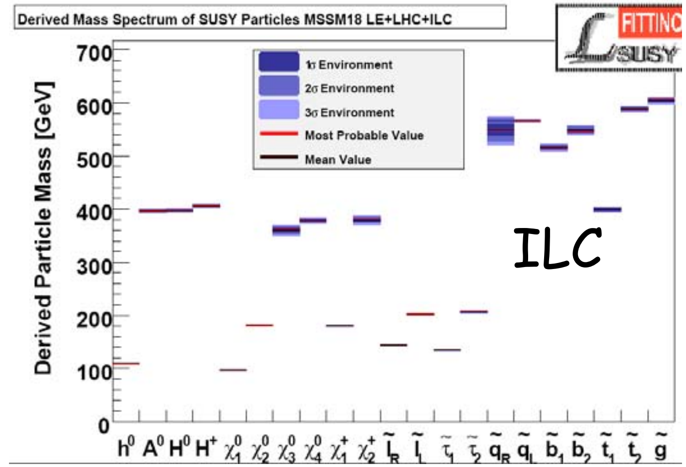
Test fundamental SUSY relations

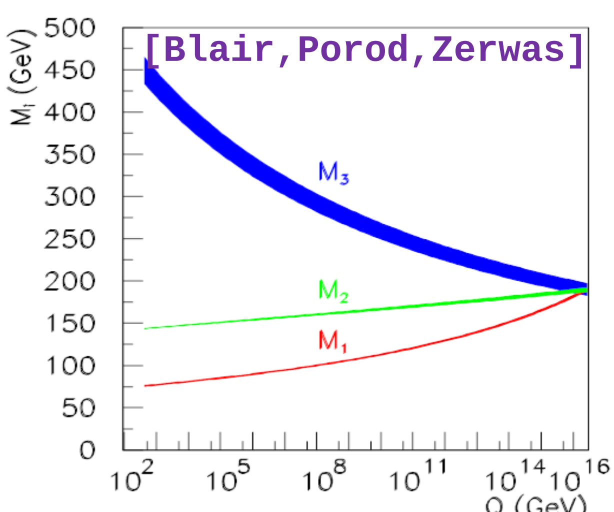


→ discriminate from other models, e.g. UED

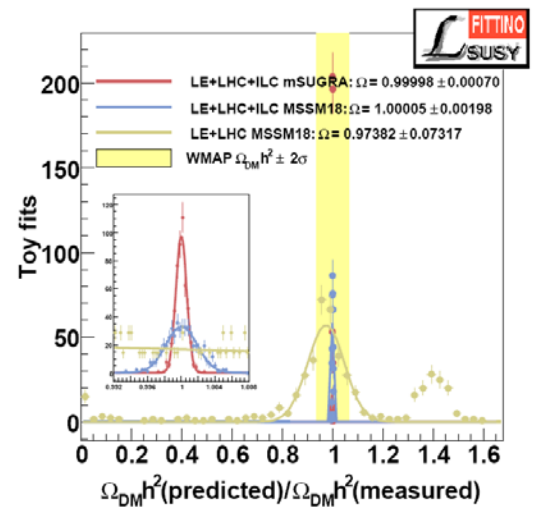
SUSY parameters, GUT models & Dark Matter







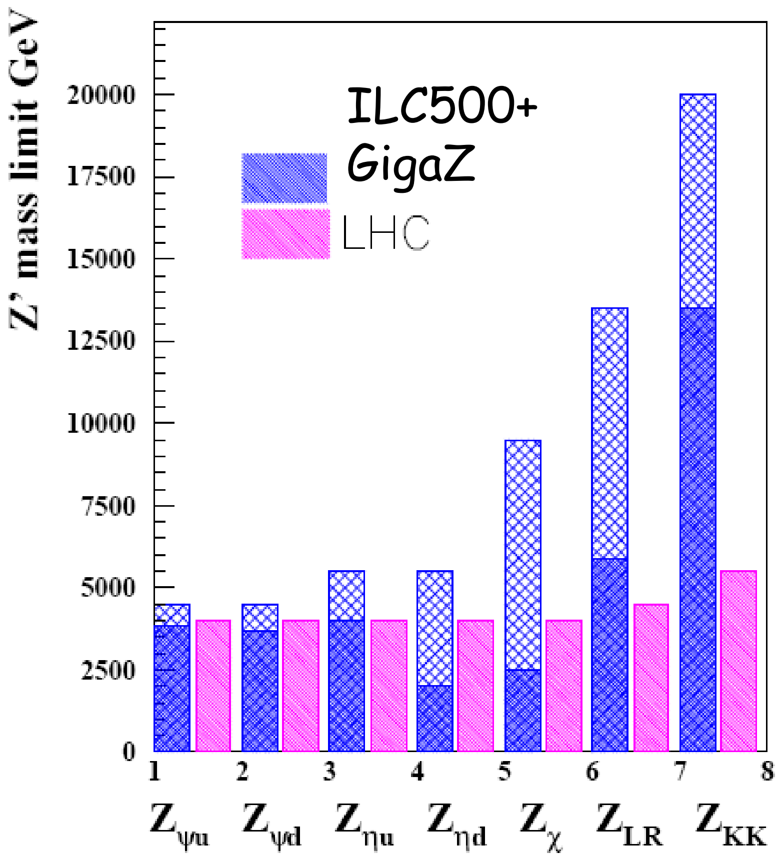
Decisive test of GUT unification and SUSY breaking

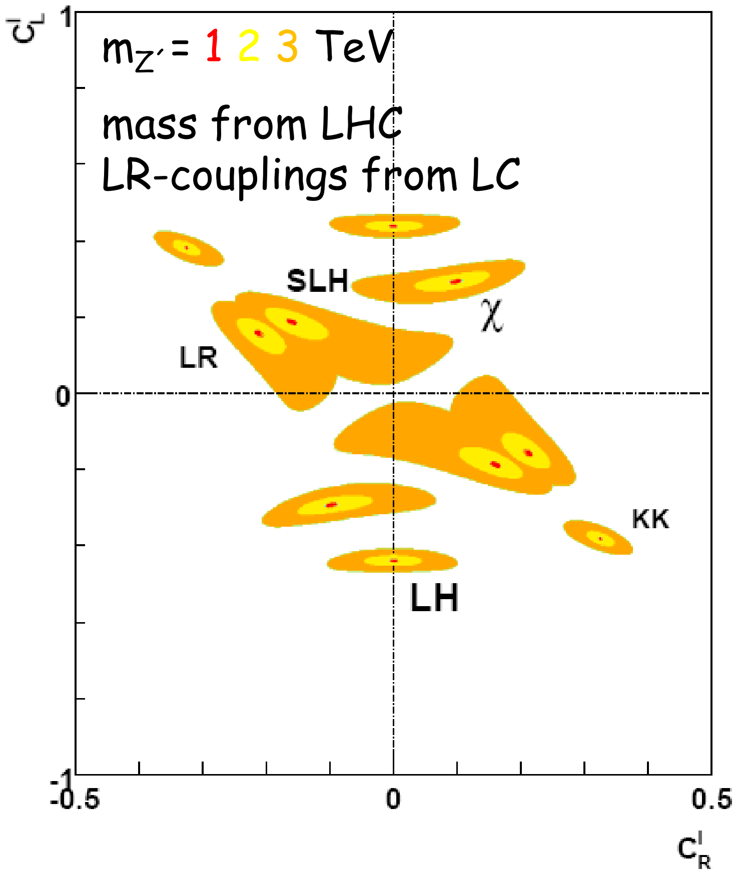


Match CMB precision in predicting CDM density

Sensitivity to Multi-TeV Bosons

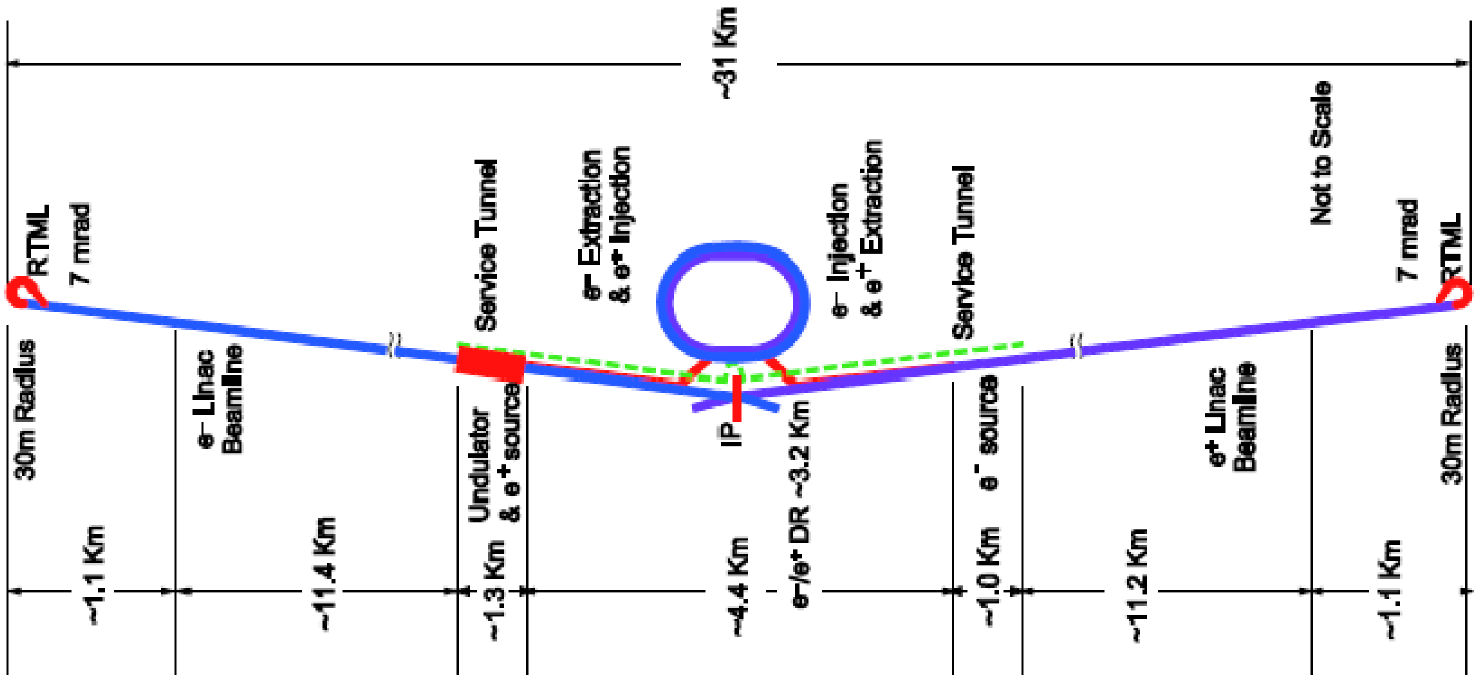
Examples: Z´ in $e^+e^- \rightarrow f\bar{f}$
from interference (at high $\sqrt{s}$) and mixing (at m_Z)





[S.Riemann; Richard; Godfrey et al]

The ILC



$\sqrt{s}$ = 91 to 500 GeV, upgradeable to 1 TeV, tunable energy

Luminosity: $2\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (500/1000fb^{-1} at 500/1000 GeV)

e^-/e^+ polarization 80%/30% (upgradeable)

<u>Option:</u>

- GigaZ (high luminosity running at M_Z and $2M_W$)

Progress/Timeline

Machine:

Since 2004 (after technology decision):

Global Design Effort (GDE) Barish, Foster (Europe)

Reference Design Report (Machine) 2007

Continue R&D on development critical issues: SCRF, eCloud, Conventional Facilities,...

Review of Machine Layout to contain cost in 2009/10 („SB2009")

Technical Design Report + Updated costs (XFEL experience) +
Project implementation plan in 2012 (~in time with update of European Strategy)

Physics and Detectors:

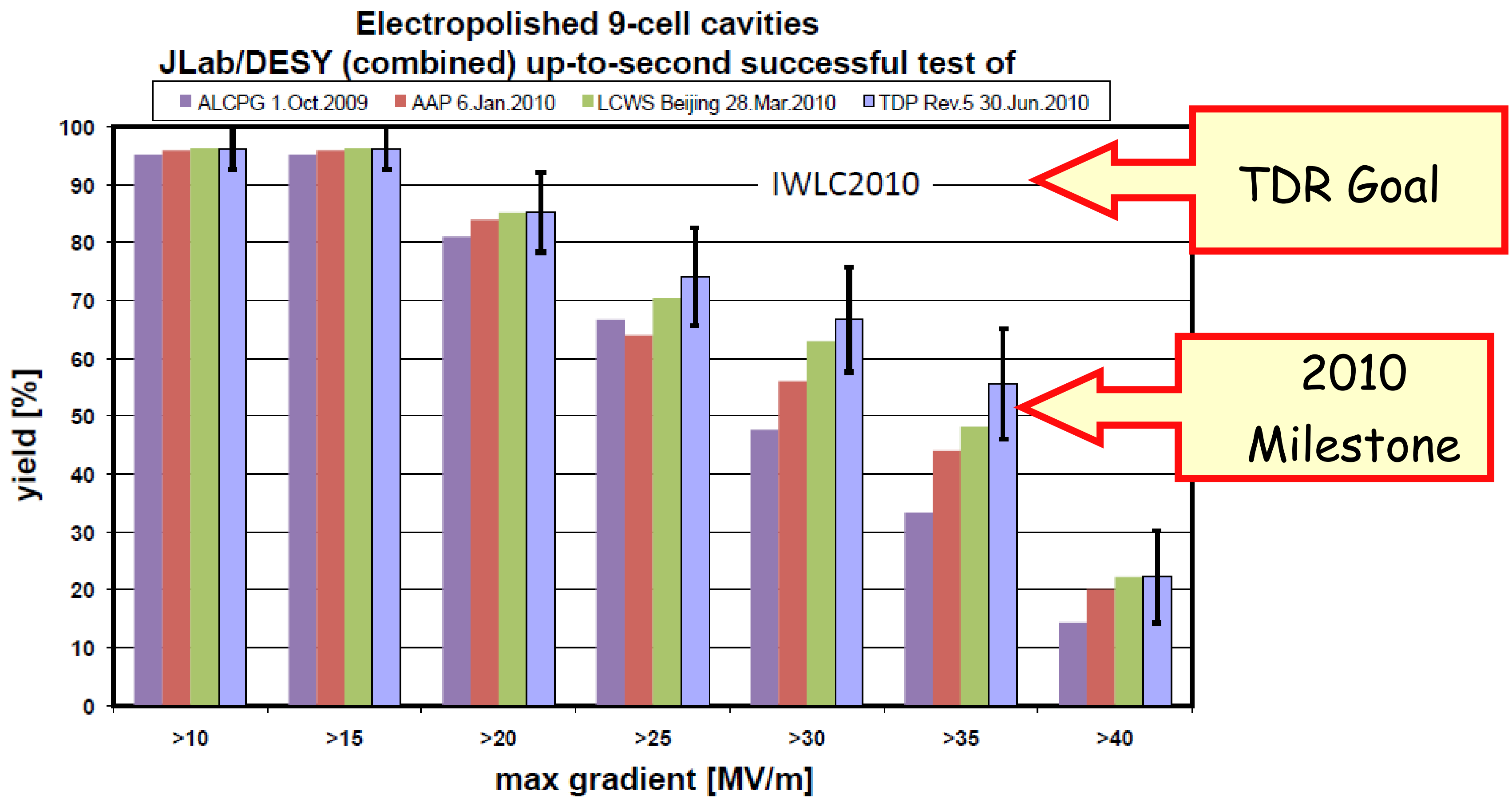
World-wide study, regional studies (Europe: ECFA study)

ILC Research Director (S. Yamada)

Letters of Intent (Detectors) 2009 (3 submitted, 2 „validated": ILD + SiD)

„Detailed Baseline Document" in late 2012

Cavity development

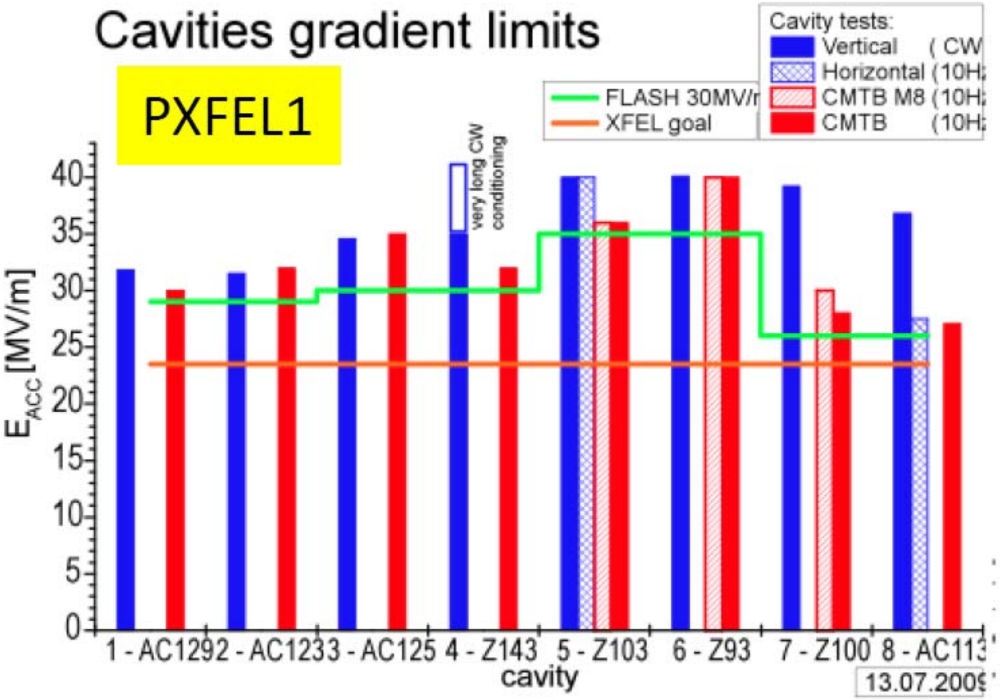


XFEL=eXperience For E+e- Linear collider

~ 10% prototype of ILC

extremely valuable for many aspects of ILC: engineering, industrialization, cost, …

XFEL=eXperience For E+e- Linear collider



First pre-series XFEL module almost reaching ILC specs (31.5 MV/m)

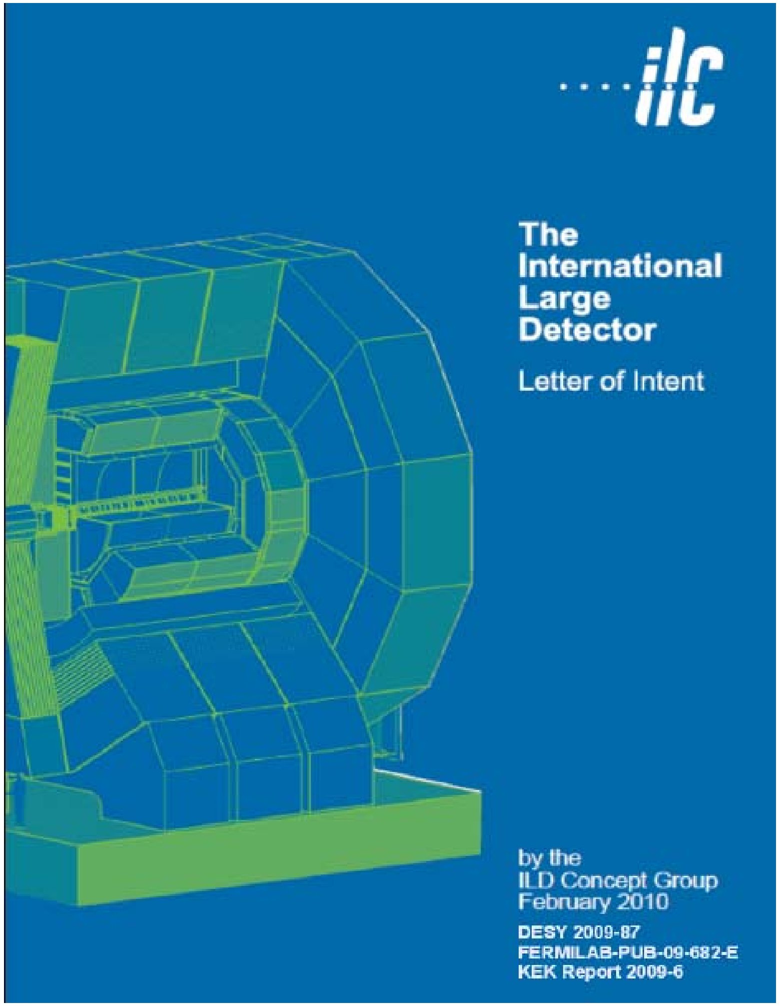
> 30 MV/m in module with beam! (2 cavities reach 35 MV/m with beam)

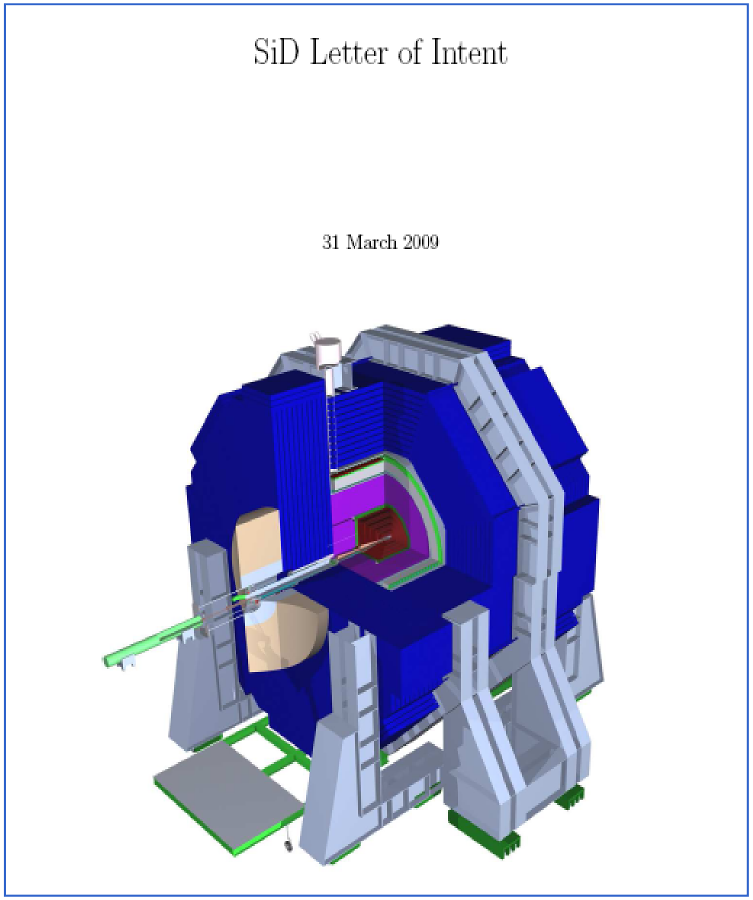
Goal achieved before mass production starts

Summary: Machine

- ILC on track for technical readiness for construction of ILC in 2012
- Merging physics and development efforts for CLIC and ILC where applicable
- „Waiting" for guidance from LHC
  - ILC technically ready
  - CLIC considerably later → Hauschild

ILC Detector concepts, software, physics study





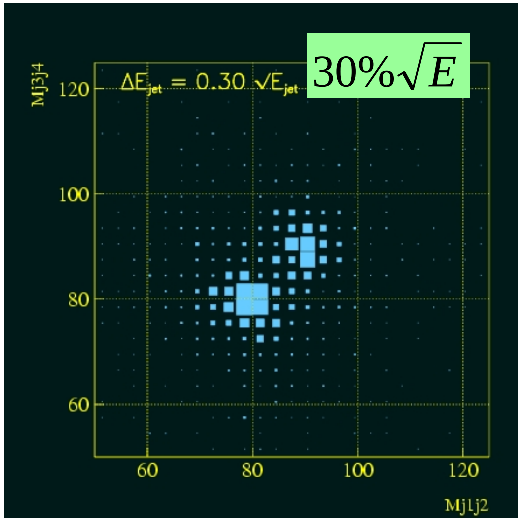
ILD: Major contributions (design and component R&D) in D

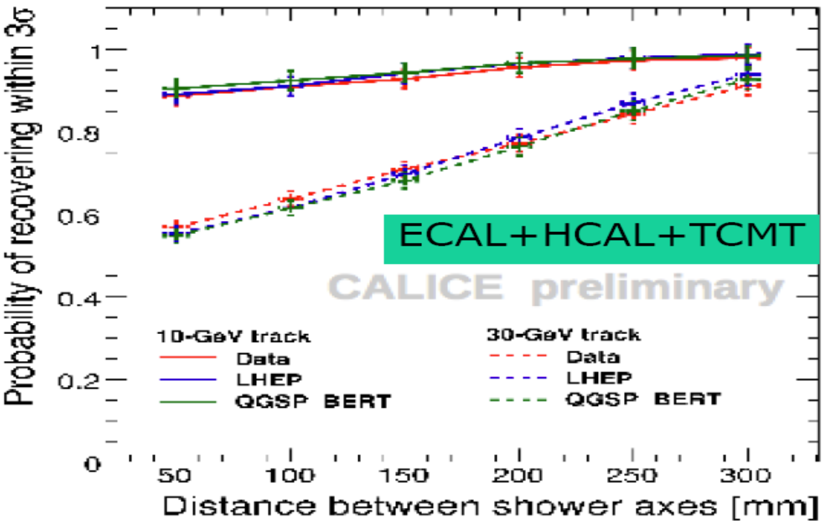
ILC Detectors in D: Imaging Calorimeter + FCAL

Why?

CALICE: particle flow now verified experimenatlly

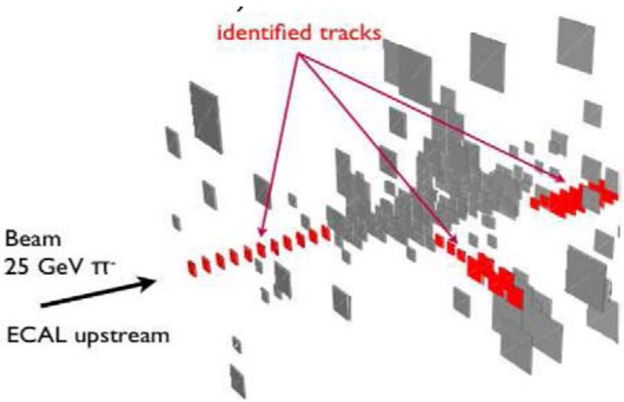
double track resolution of calorimeter!:





tell hadronic W from Z!

mips in a hadronic shower:
(data, not MC)



Contributions from D: DESY, HD, WU, MPI-M, DD

ILC Detectors in D: Imaging Calorimeter + FCAL

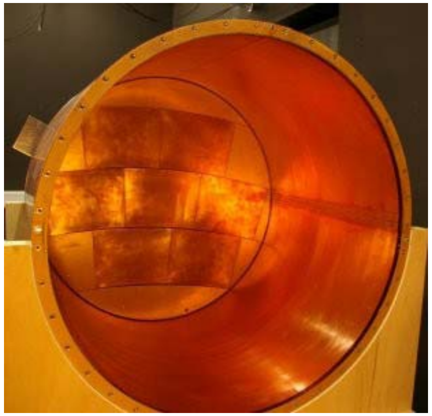
Next:

CALICE prototype at CERN for CLIC test with Tungsten absorbers in HCAL

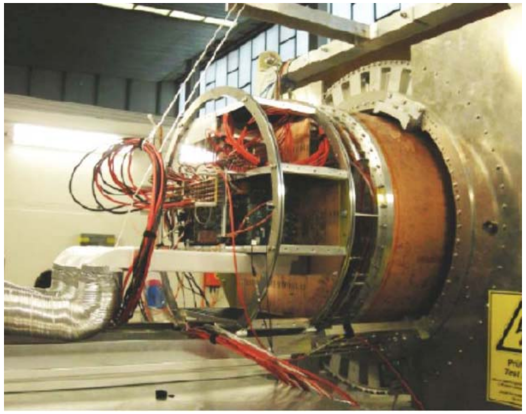
ILC Detectors in D: Gaseous tracking

LCTPC: develop a large TPC based on MPGD (GEM/Micromegas) amplification

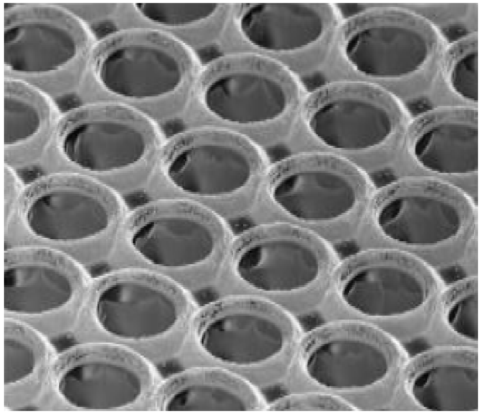
Significant progress through EUDET and Alliance



Large Prototype field cage



LP in 1T solenoid at DESY



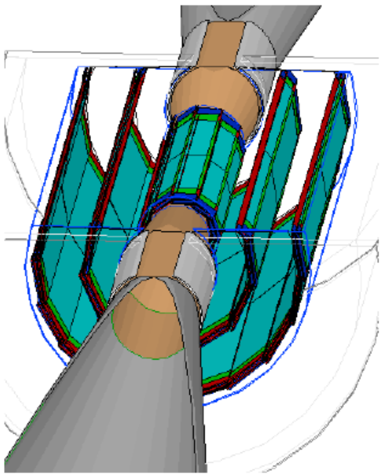
GEMGrid from IZM Berlin

Resolution of <100μm at 2m drift in 3.5T is in sight

Focus now: endplate design (10% X_0), readout electronics, cooling
also: pixelized readout

Contributions from D: AC, BN, DESY, FR, HH, KA, MZ, HRO, SI

ILC Detectors in D: Vertex Detectors



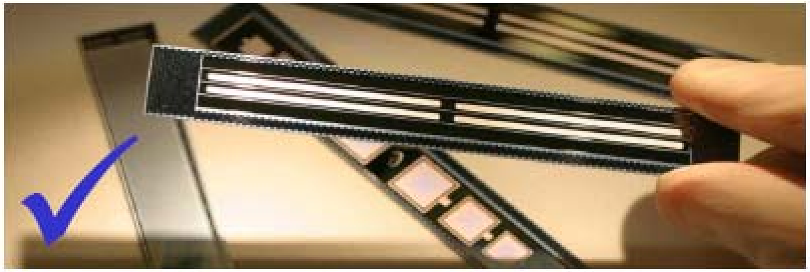
Pixel-Vertexdetector: provide bottom and charm tagging

with high efficiency and minimal material budget

- R&D on various technologies (DEPFET, MAPS, …)

Significant progress on

- pixel technologies
- thinning
- readout ASICs
- point resolution of 1 μm



Thinned DEPFET sensor

Contributions from D: DEPFET: MPI-M, BN, HD,… MAPS: DESY, HH, …

LC technology in use!

DEPFET
→ Belle-2

MAPS
→ EUDET Telescope
→ RHIC

SiPM
→ PET
→ fibre tracker

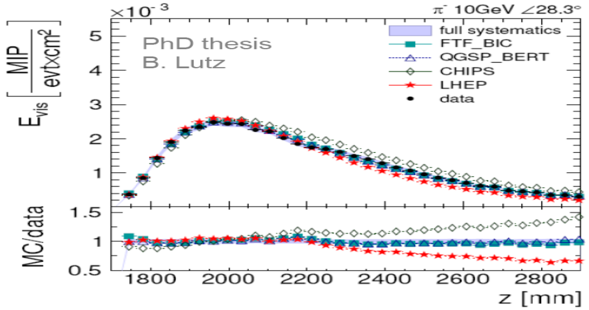
CALICE
→ Geant 4 improvements

LC-FCAL
→ CMS BCM

Gaseous Detectors (MPGDs)
→ T2K
→ RD51

mockup of Belle-2 PXD


EUDET telescope



Long. shower profile: CALICE data vs. G4 models

The ILC project in Europe and Germany

- CERN plays an active role in promoting a Linear Collider → Heuer
- CERN prepares to bid for hosting the LC
  (or participate elsewhere)
- CERN & DESY play an active role in defining LC governance
- Germany has been a leading player in the ILC since > 10 years
- Strong synergy with XFEL
- Strong detector R&D ongoing at universitites, MPI-M, DESY
  (supported by Helmholtz-Alliance, generic R&D by BMBF)
- Theory for LC traditionally strong in D (e.g. loops, SUSY, …)
- DESY acts as a major hub for ILC

Conclusion

- Physics case for the ILC is as strong as ever
- Expect confirmation from LHC soon
- Only new HE collider with technical readiness by 2012 (in time for EU strategy) [Bertolucci]
- My view: D should continue to play a leading role for ILC

IWLC10 (CERN)

BACKUP...

Summary

Key features of e^+e^- ("what does not work with hadron collisions")

- precisely defined and known centre-of-mass energy of hard process
  (machine requirement: low beam energy spread, low beamstrahlung)
- tunable centre-of-mass energy
  (machine requirement: flexibility, high luminosity)
- polarized beams
  (machine requirement: do it! – detectors: measure it!)
- clean, fully reconstructable events (also hadronic f.s.)
  (detector requirement: jet (flavour), lepton reconstruction, full hermeticity)
- moderate backgrounds → no trigger → unbiased physics
  (detector requirement)

Why e^+e^- ?

Two distinct and complementary strategies for advancing in particle physics with the help of colliders:

High Energy

direct discovery of new phenomena

High Precision

quantum effects of new physics at high energies through precise measurements of phenomena at lower scales

Both strategies have worked well together

→ much more complete understanding than from either one alone

(see LEP+SLC / Tevatron)

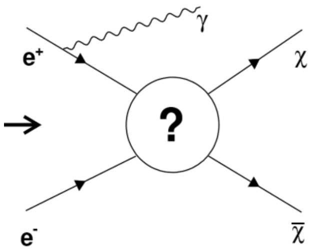
Things we'll never do with a hadron machine:

Reconstruct the invisible

Model-independent WIMP reconstruction:

$$M^2_{recoil} = s - 2\sqrt{s}E_\gamma$$

→



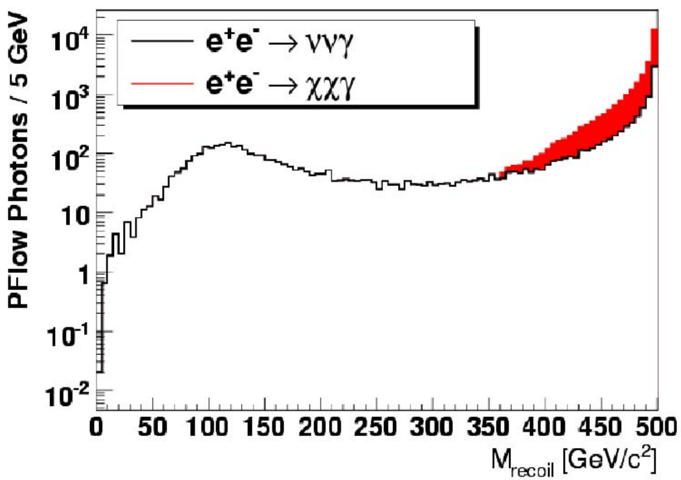
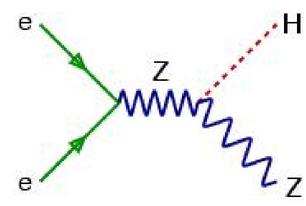


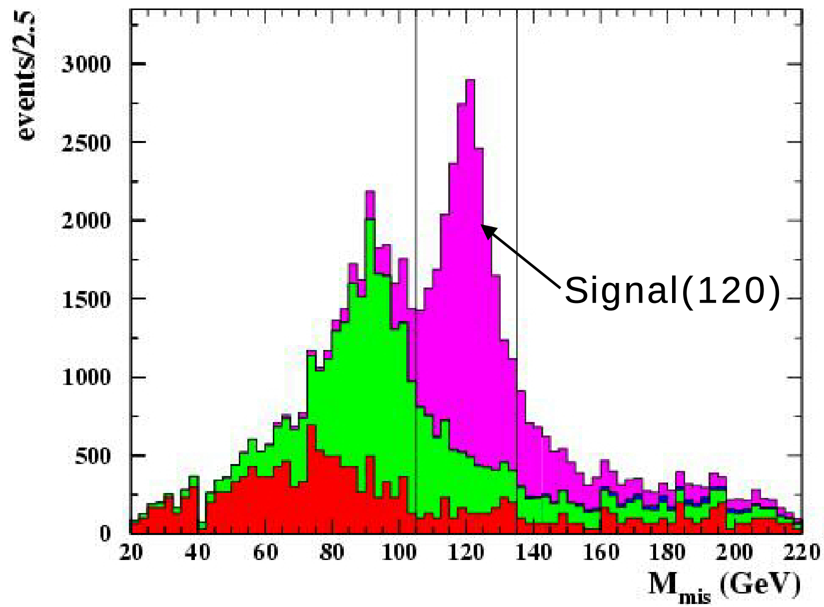
Figure 4: Recoil mass distribution for a 180 GeV Spin-1 WIMP.

[List et al, Birkedal et al]

Mass reconstruction of invisible Higgs:

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

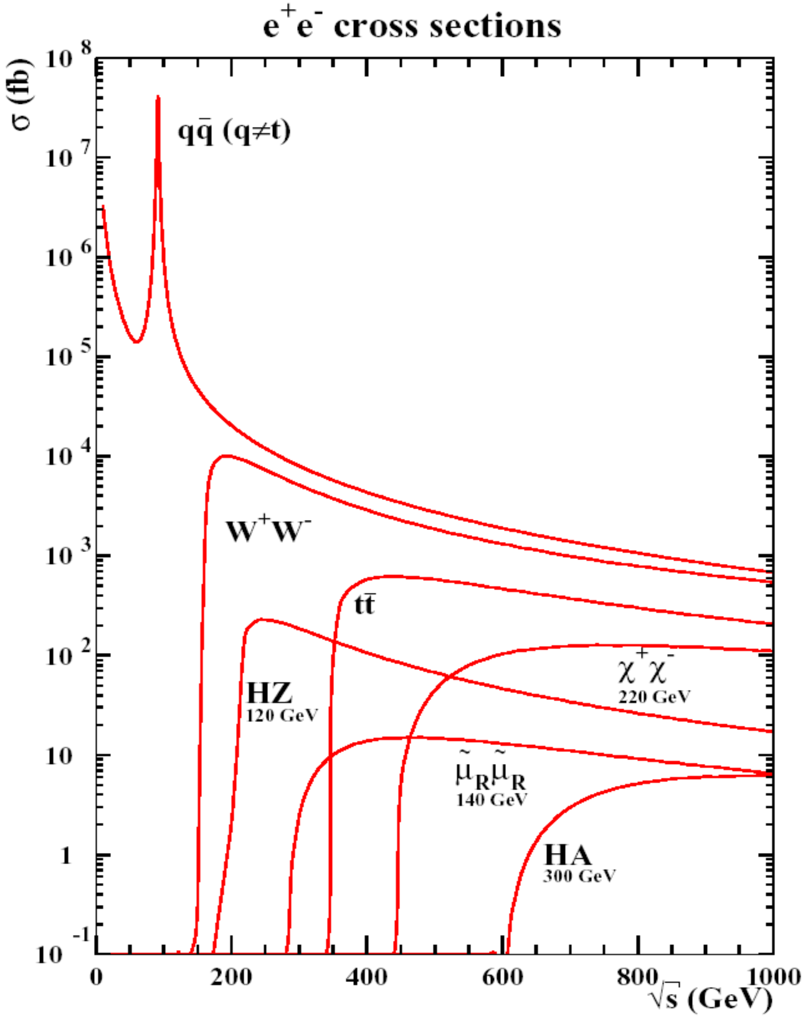




[Schumacher]

LC specs – What any LC needs to fulfil

$$\sigma(e^+e^- \to \gamma^* \to \mu^+\mu^-) = (\hbar c)^2 \frac{4\pi\alpha^2}{3s} = \frac{87\text{ nb}}{s\,(\text{GeV}^2)} = 87\text{ fb at 1 TeV}$$



<u>Remark:</u>

e^+e^- cross section at $\sqrt{s}$ > 500 GeV are small o (10-100 fb), multi-fermion processes smaller

500 fb^{-1} at 500 GeV are „only"

- 40000 HZ events
- 2500 HZ, Z→ll events
- 5000 smoun (m=140) pairs
- 200 HHZ events

By far most measurements at LC will be statistics-limited

Possibly have many thresholds to scan

→ Luminosity requirement of 2×10^{34} is a lower limit!

Higgs physics

LHC trigger:

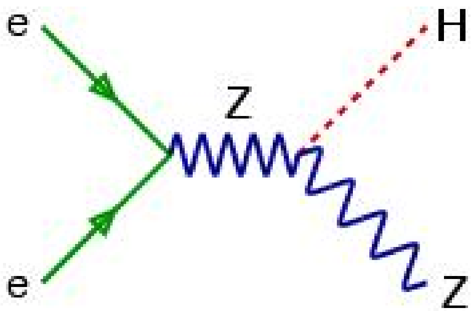
- any discovery of a Higgs-like state
- or absence of Higgs and absence of strong WW interactions (missed it?)

LC objective:

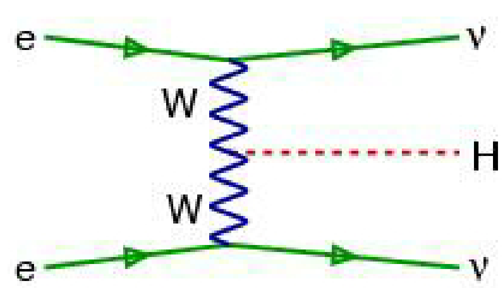
- precise and model-independent measurement of Higgs properties
- discrimination of different Higgs models
- consistency of visible Higgs sector with electro-weak precision measurements (→ Giga-Z + ...)

Higgs physics

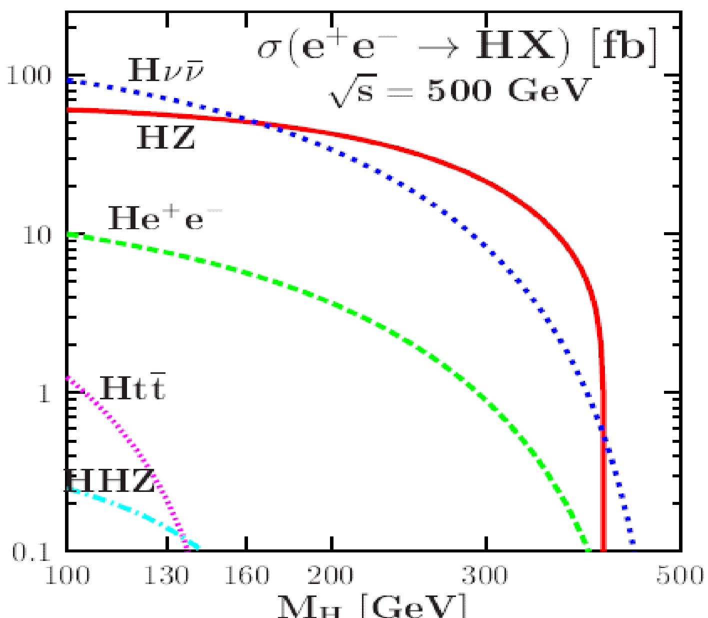
Dominant production processes at LC:

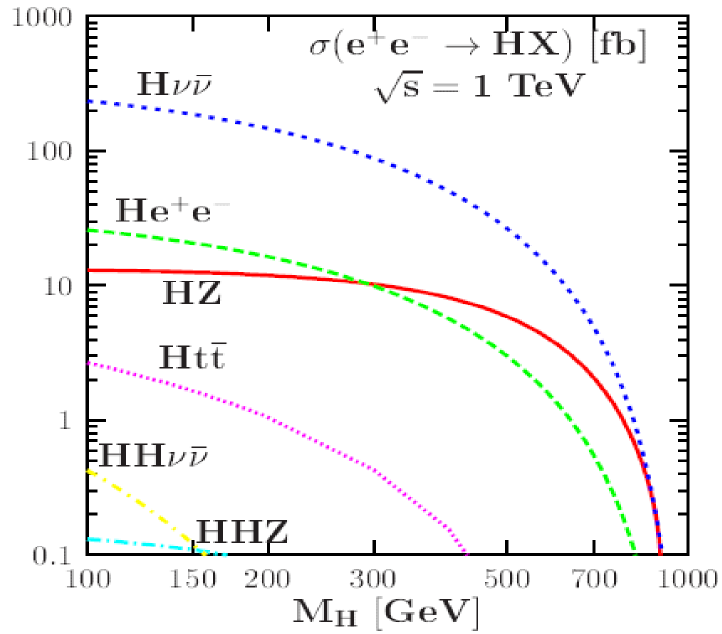


Higgs-strahlung



WW fusion



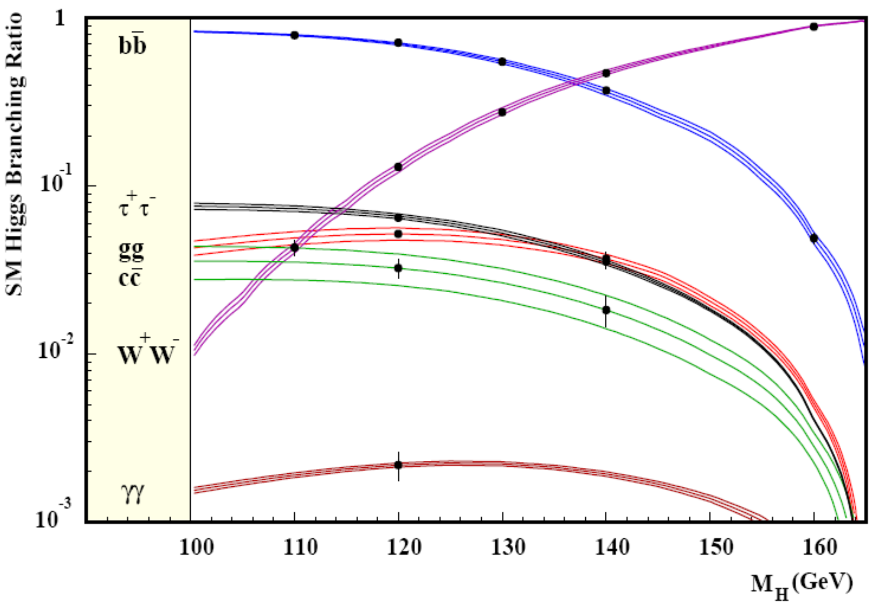


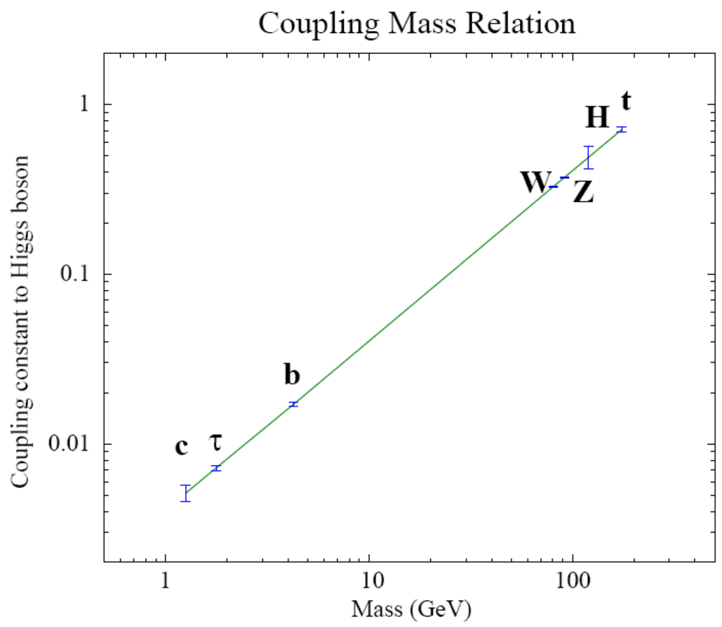
[Djouadi;…]

Higgs physics – the light Higgs case (m <160 GeV)

precise measurements of

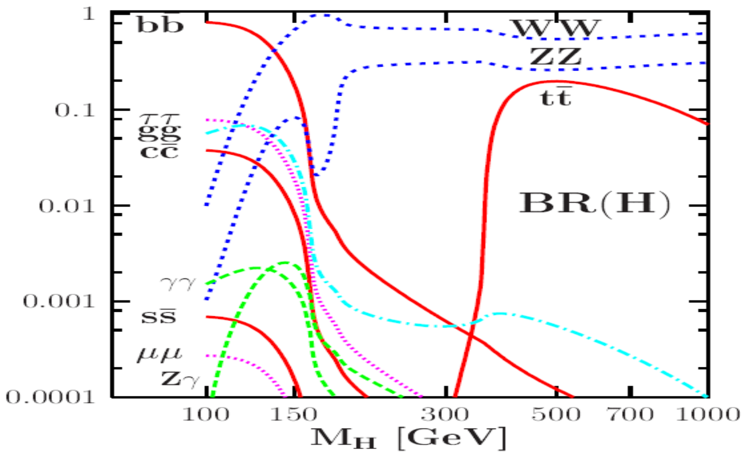
- couplings to bosons, up- and down-type fermions
- mass, total width
- quantum numbers J^{PC} (incl. sensitivity to CP violation)
- (not so precise but only) measurement of λ_{HHH}





[Battaglia]

Comments on m_H = 160 … 200+ GeV



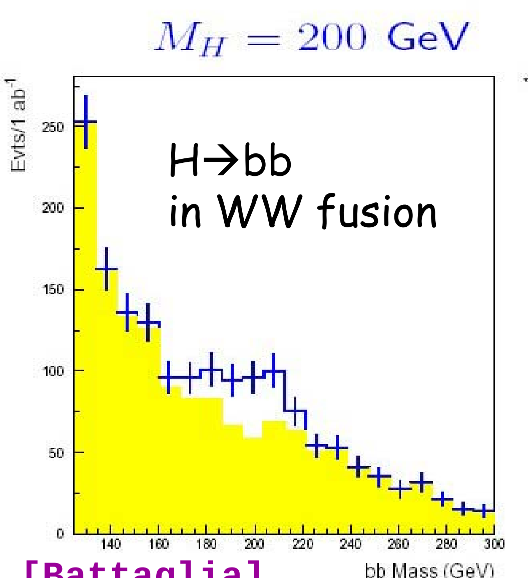
- Higgs phenomenology less rich
- Gauge boson couplings dominant
- LC vital to measure

b-Yukawa coupling from H->bb

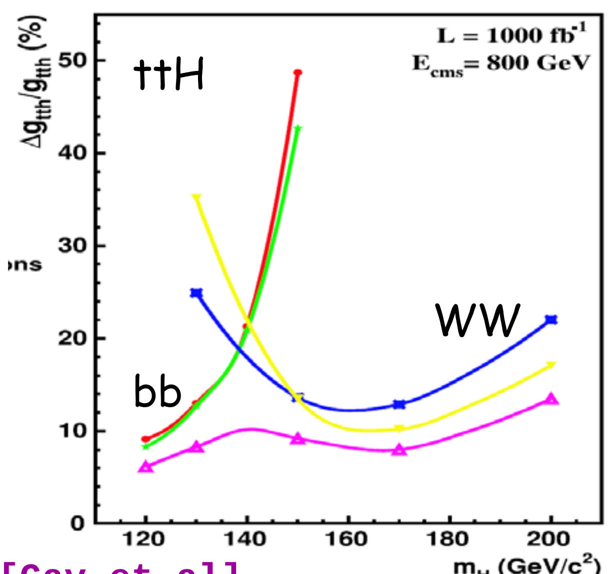
t-Yukawa coupling from ttH -> ttWW

total width from WW→H→WW + HZ→WWZ

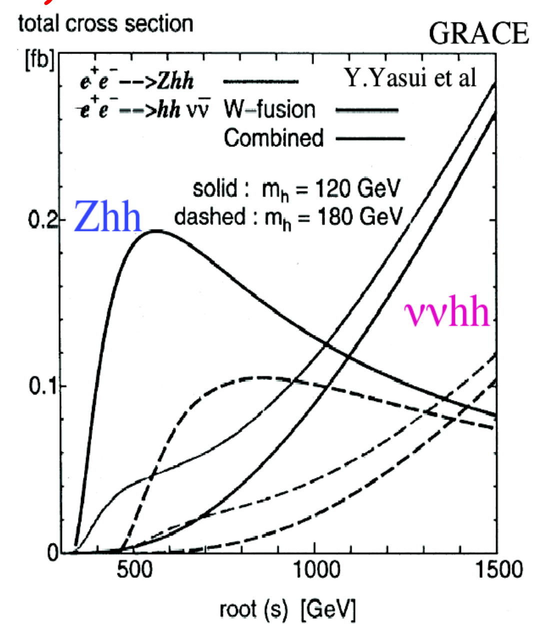
selfcoupling? (maybe…)



[Battaglia]



[Gay et al]



Higgs physics - what precision is good for

a very recent example: catalog of deviations from SM Higgs partial widths

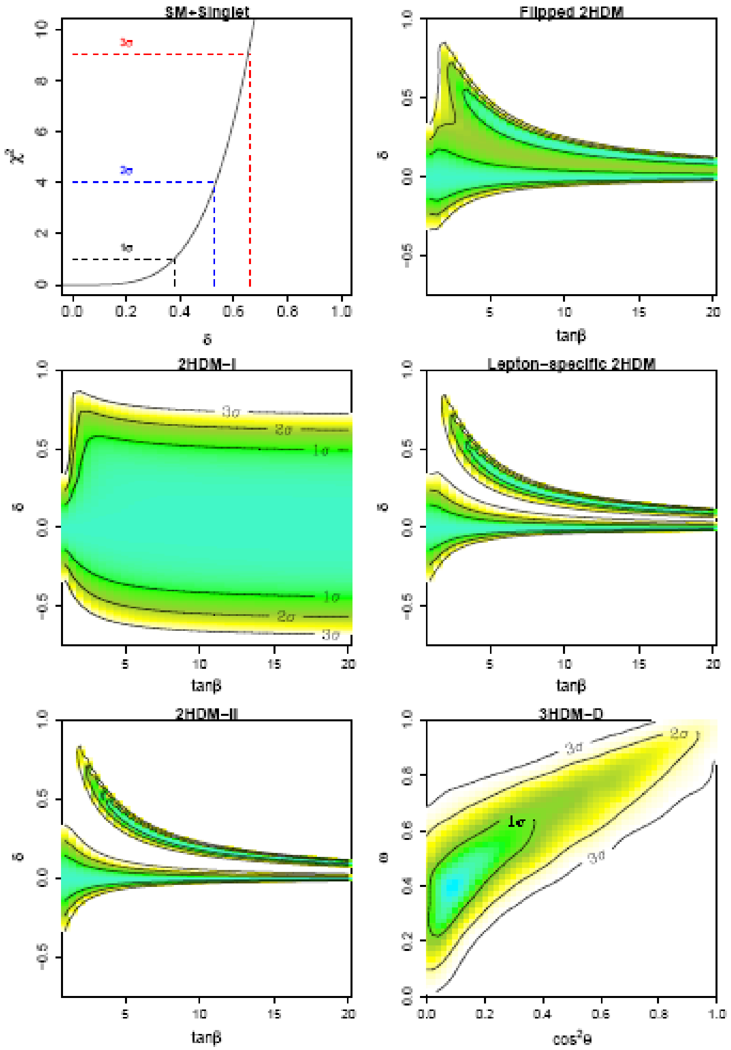
for various types of non-Standard Higgs sectors

Model	Γ_W^h/Γ_W^{SM}	Γ_d^h/Γ_d^{SM}	Γ_u^h/Γ_u^{SM}	$\Gamma_\ell^h/\Gamma_\ell^{SM}$
SM	1	1	1	1
SM+S	$1-\delta^2$	$1-\delta^2$	$1-\delta^2$	$1-\delta^2$
2HDM-I	$1-\delta^2$	$1+2\delta/t_\beta$	$1+2\delta/t_\beta$	$1+2\delta/t_\beta$
2HDM-II	$1-\delta^2$	$1-2t_\beta\delta$	$1+2\delta/t_\beta$	$1-2t_\beta\delta$
2HDM-II+S	$1-\delta^2-\epsilon^2$	$1-2t_\beta\delta-\epsilon^2$	$1+2\delta/t_\beta-\epsilon^2$	$1-2t_\beta\delta-\epsilon^2$
2HDM-II+D	$1-\delta^2$	$1-2\delta(s_\gamma t_\beta/c_\Omega+c_\gamma t_\Omega)$	$1+2\delta(s_\gamma/c_\Omega t_\beta-c_\gamma t_\Omega)$	$1-2\delta(s_\gamma t_\beta/c_\Omega+c_\gamma t_\Omega)$
Flipped 2HDM	$1-\delta^2$	$1-2t_\beta\delta$	$1+2\delta/t_\beta$	$1+2\delta/t_\beta$
Lepton-specific 2HDM	$1-\delta^2$	$1+2\delta/t_\beta$	$1+2\delta/t_\beta$	$1-2t_\beta\delta$
MSSM	$1-\delta^2$	$1-2t'_\beta\delta$	$1+2\delta/t_\beta$	$1-2t_\beta\delta$
3HDM-D	$1-\delta^2$	$1-2\delta(s_\gamma t_\beta/c_\Omega+c_\gamma t_\Omega)$	$1+2\delta(s_\gamma/c_\Omega t_\beta-c_\gamma t_\Omega)$	$1+2\delta c_\gamma/t_\Omega$

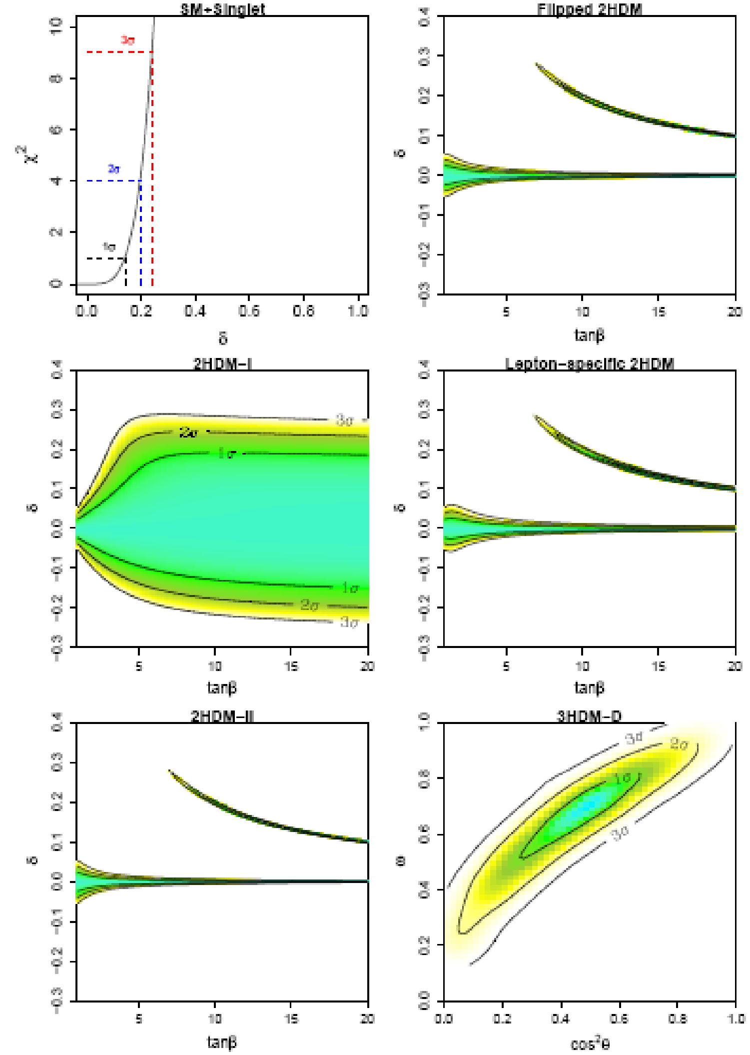
[Barger,Logan,Shaughnessy arXiv:0902.0170]

Higgs physics - what precision is good for

LHC



→ ILC



[Barger,Logan,Shaughnessy arXiv:0902.0170] note different scale on most plots

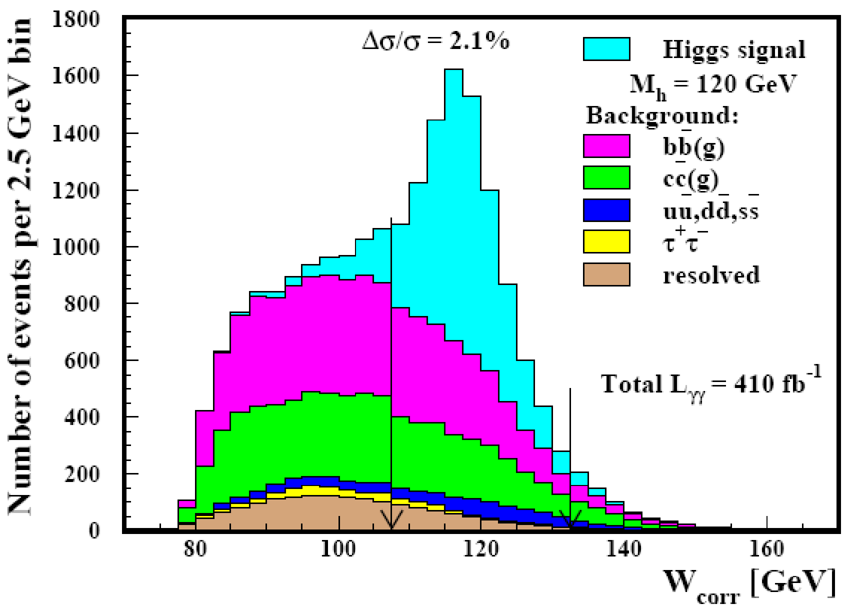
Higgs physics at a Photon Collider

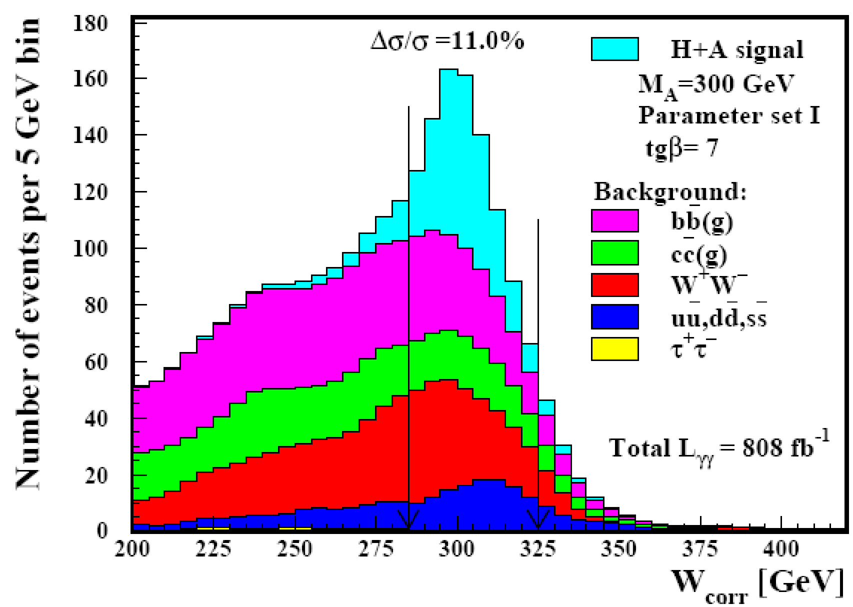
unique opportunity to measure the $H\gamma\gamma$ coupling

- sensitive to anything that´s charged and massive in the loop…

- adds to LC (e^+e^-) case, completes picture

- unique: single production of heavy H,A bosons + disentangle them





[Niezurawski,Zarnecki,Krawczyk]

Supersymmetry (+ related pheno)

<u>LHC trigger:</u>

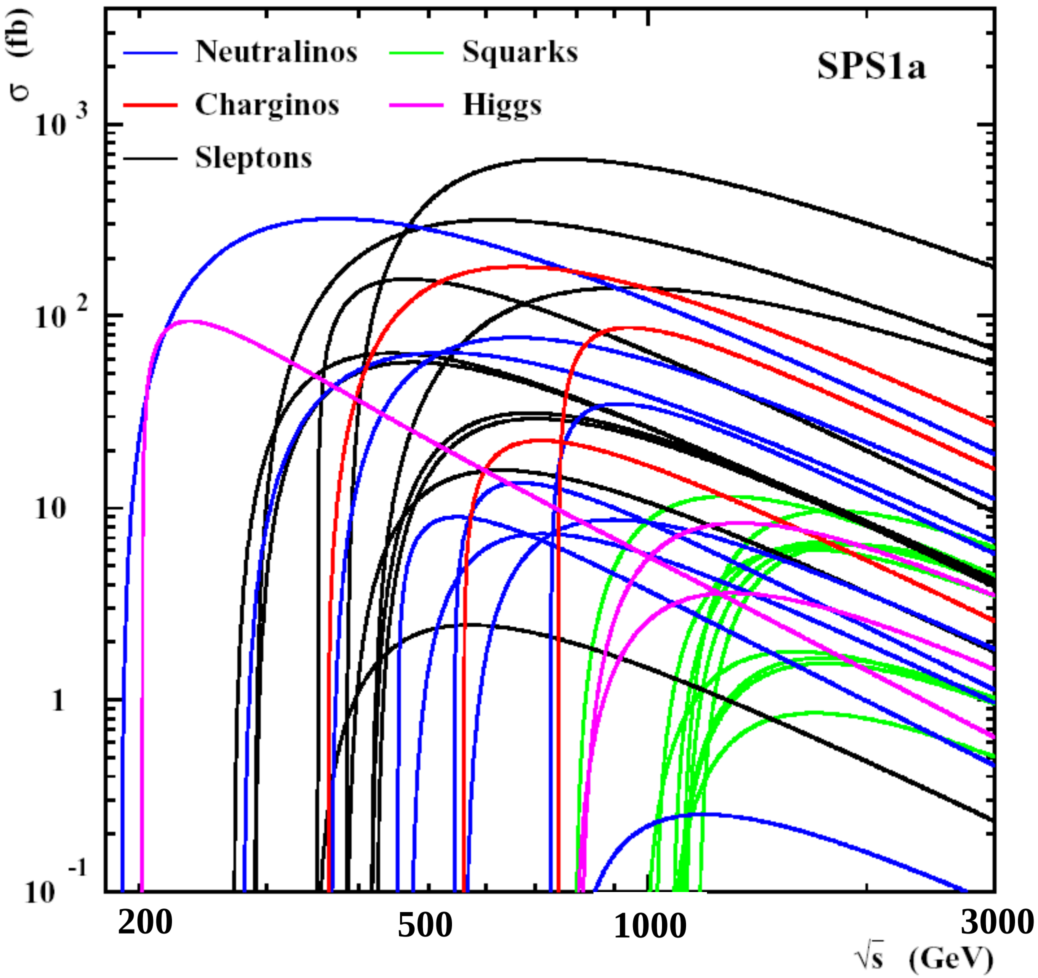
- evidence for excess of missing-E_T events consistent with existence of new $m \sim \sqrt{s_{LC}}/2$ particles
- or observation (mass reconstruction) of RPV SUSY particles at $m \sim \sqrt{s_{LC}}/2$

<u>LC objective:</u>

- precise and model-independent measurement of properties of kin. accessible sparticles
- test of fundamental SUSY relations
- together with LHC data pin-down model of SUSY breaking (determine pattern of high-scale unification)
- determine properties of dark matter candidate

Supersymmetry

may well be fun at LC in spite of all „Unkenrufe“



cross sections in the

10 – 1000 fb range

o(10^3 – 10^5) events

to disentangle this 'chaos'

the various LC options,

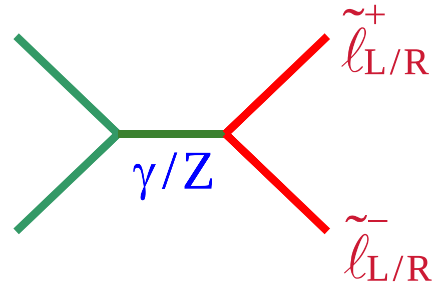
in particular are vital!

- tunable √s
- tunable beam polarisation
- high luminostiy!

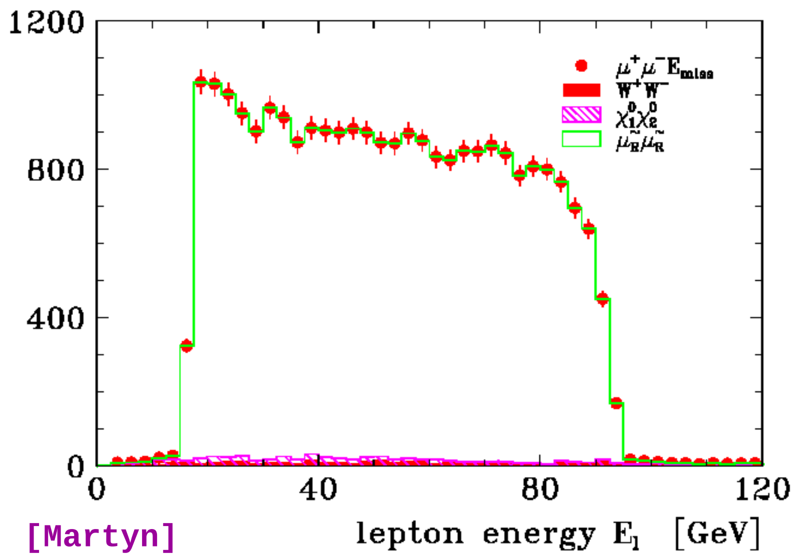
Supersymmetry - Sleptons

Pair-production

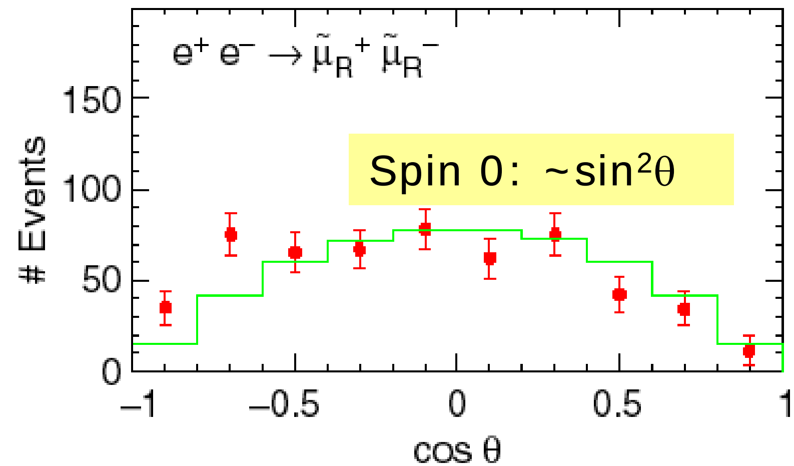
$$e^+e^- \rightarrow \tilde{e}_R\tilde{e}_R,\ \tilde{e}_L\tilde{e}_L,\ \tilde{e}_R\tilde{e}_L,\ \tilde{\nu}_e\bar{\tilde{\nu}}_e$$
$$e^+e^- \rightarrow \tilde{\mu}_R\tilde{\mu}_R,\ \tilde{\mu}_L\tilde{\mu}_L,\ \tilde{\nu}_\mu\bar{\tilde{\nu}}_\mu$$
$$e^+e^- \rightarrow \tilde{\tau}_1\tilde{\tau}_1,\ \tilde{\tau}_2\tilde{\tau}_2,\ \tilde{\tau}_1\tilde{\tau}_2,\ \tilde{\nu}_\tau\bar{\tilde{\nu}}_\tau$$



Examples:



[Martyn]



Easy spin measurement

Simple two-body kinematics and beam-constraint allow for mass measurement of both slepton and lightest neutralino

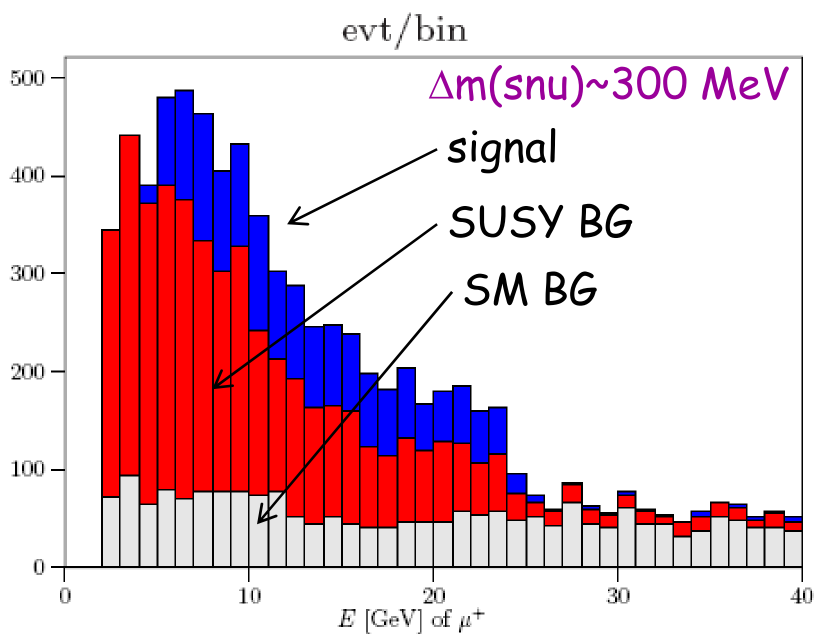
$$m_{\tilde{l}} = \frac{\sqrt{s}}{E_- + E_+}\sqrt{E_- E_+}$$
$$m_{\tilde{\chi}} = m_{\tilde{l}}\sqrt{1 - \frac{E_- + E_+}{\sqrt{s}/2}}$$

Supersymmetry

More difficult things are possible:

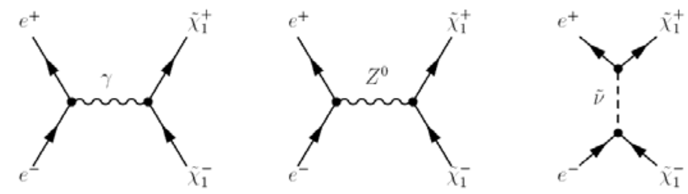
Example: Sneutrinos from Chargino decay

$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\nu}_e^* e^- \tilde{\nu}_\mu \mu^+ \rightarrow e^- \mu^+ \bar{\nu}_e \nu_\mu \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

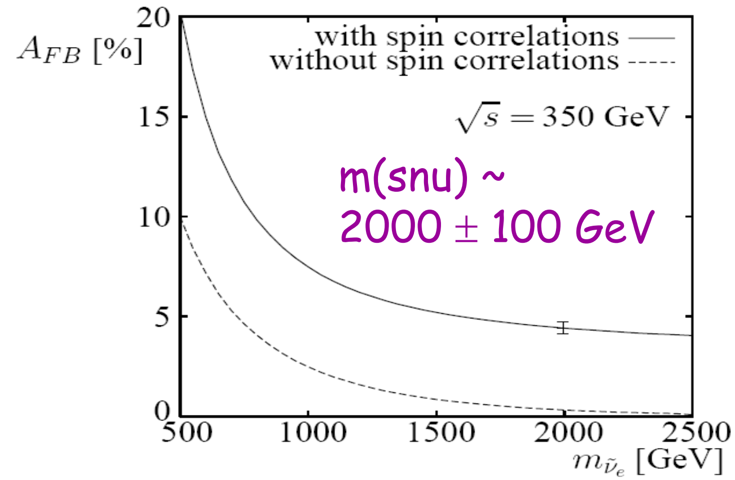


[Kalinowski,Kilian,Reuter,Robens,Rolbiecki 09]

Example: sensitivity to very heavy sneutrinos in t-channel exchange of chargino production



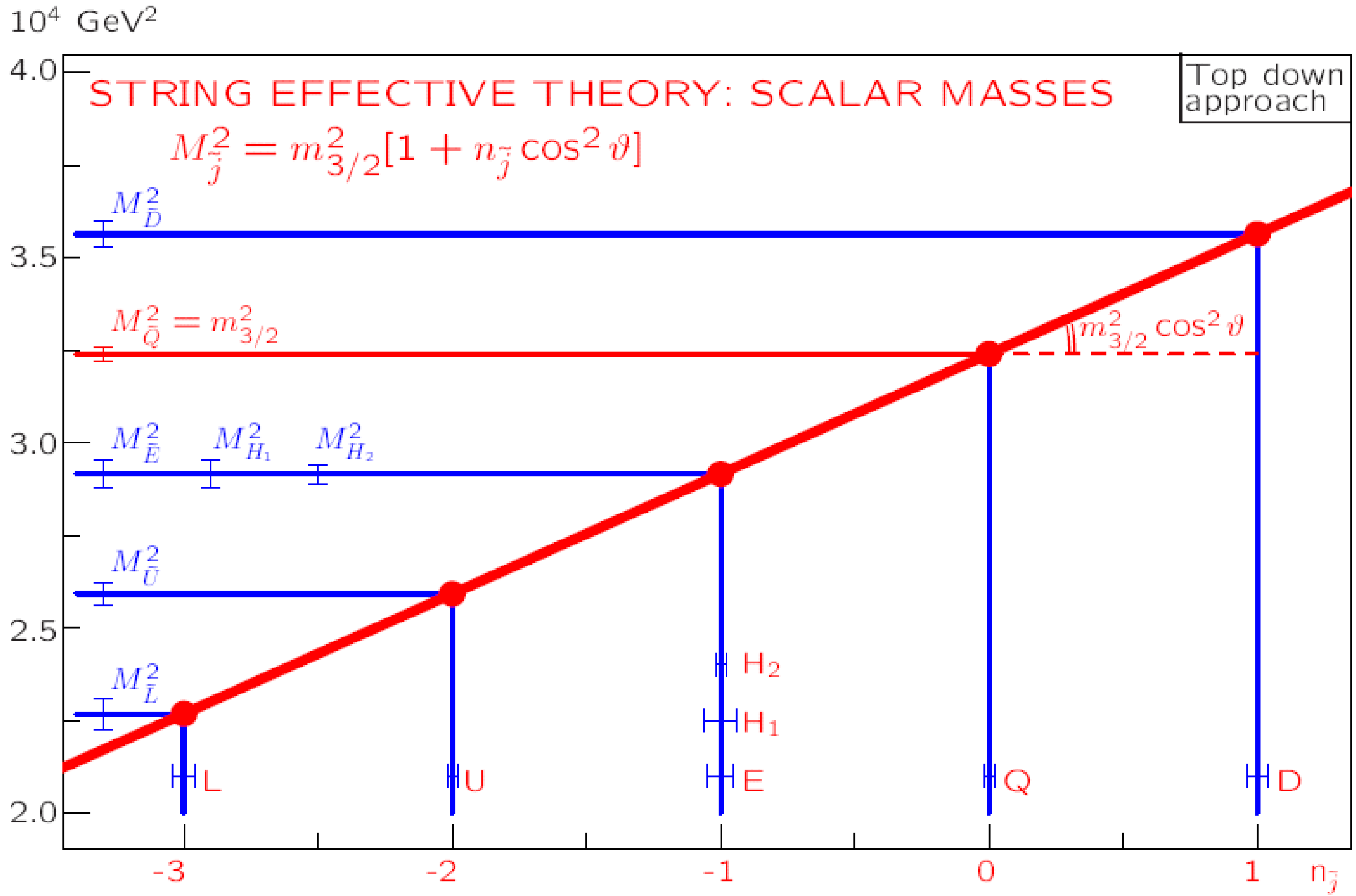
$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-,\ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \ell^- \bar{\nu}$$



[Kalinowski,Moorgat-Pick,Rolbiecki, Stirling,KD 06]

Supersymmetry - motivation for precision I

Example of distinct non-unification of mass parameters at high scale



[Blair, Porod, Zerwas]

Gauge Boson Couplings

LHC trigger:

- discovery of heavy gauge boson ($m \lesssim 5$ TeV)
- or absence of Higgs boson / evidence for strong WW interactions
- or most other „surprises“

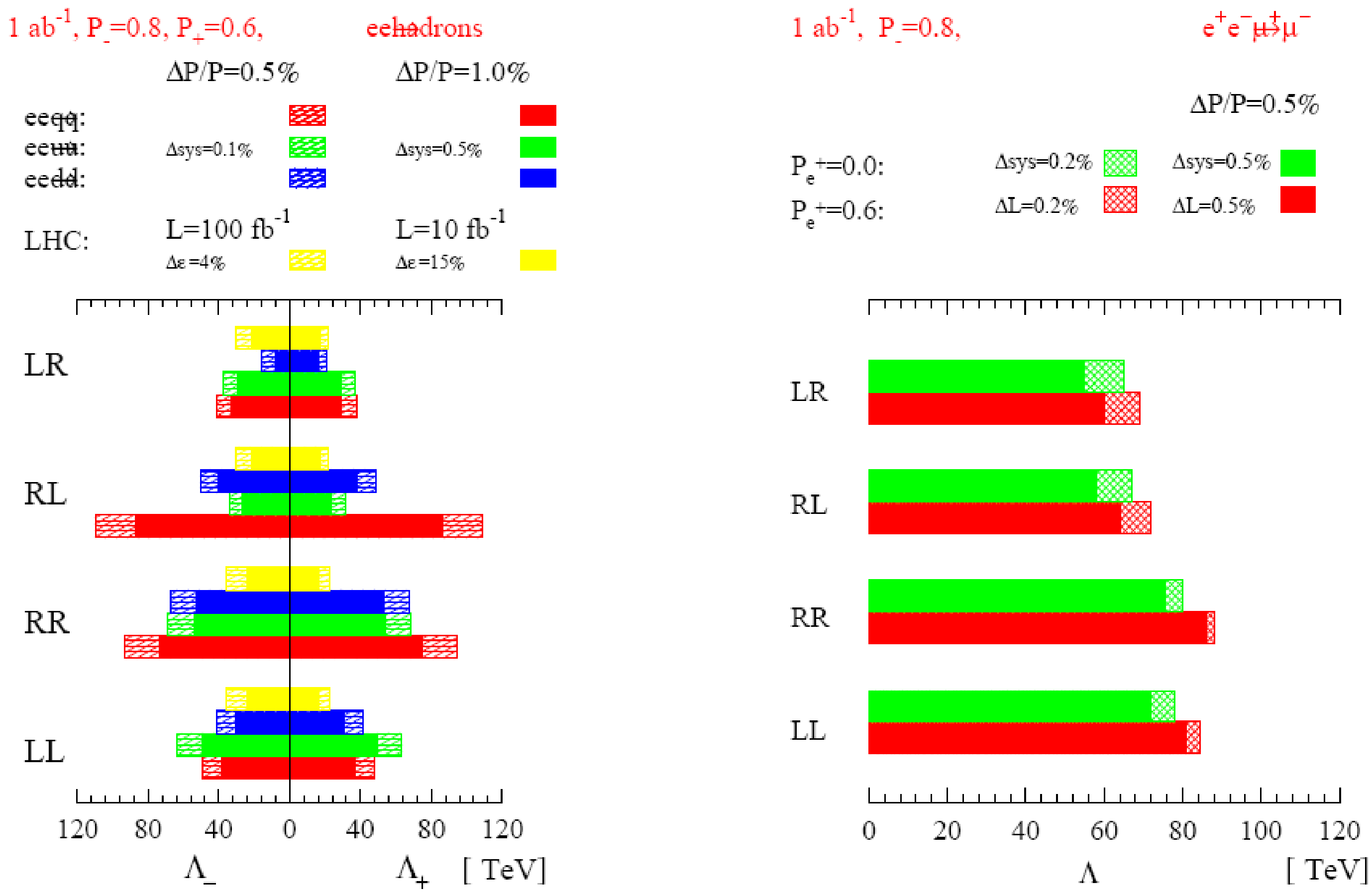
LC objective:

- (contribute to) determination of the properties of the new states / new physics through loop-level tests of SM processes

  at $\sqrt{s}_{max}$ and at $\sqrt{s} = M_Z$
- shine some light into the deep-multi-TeV region

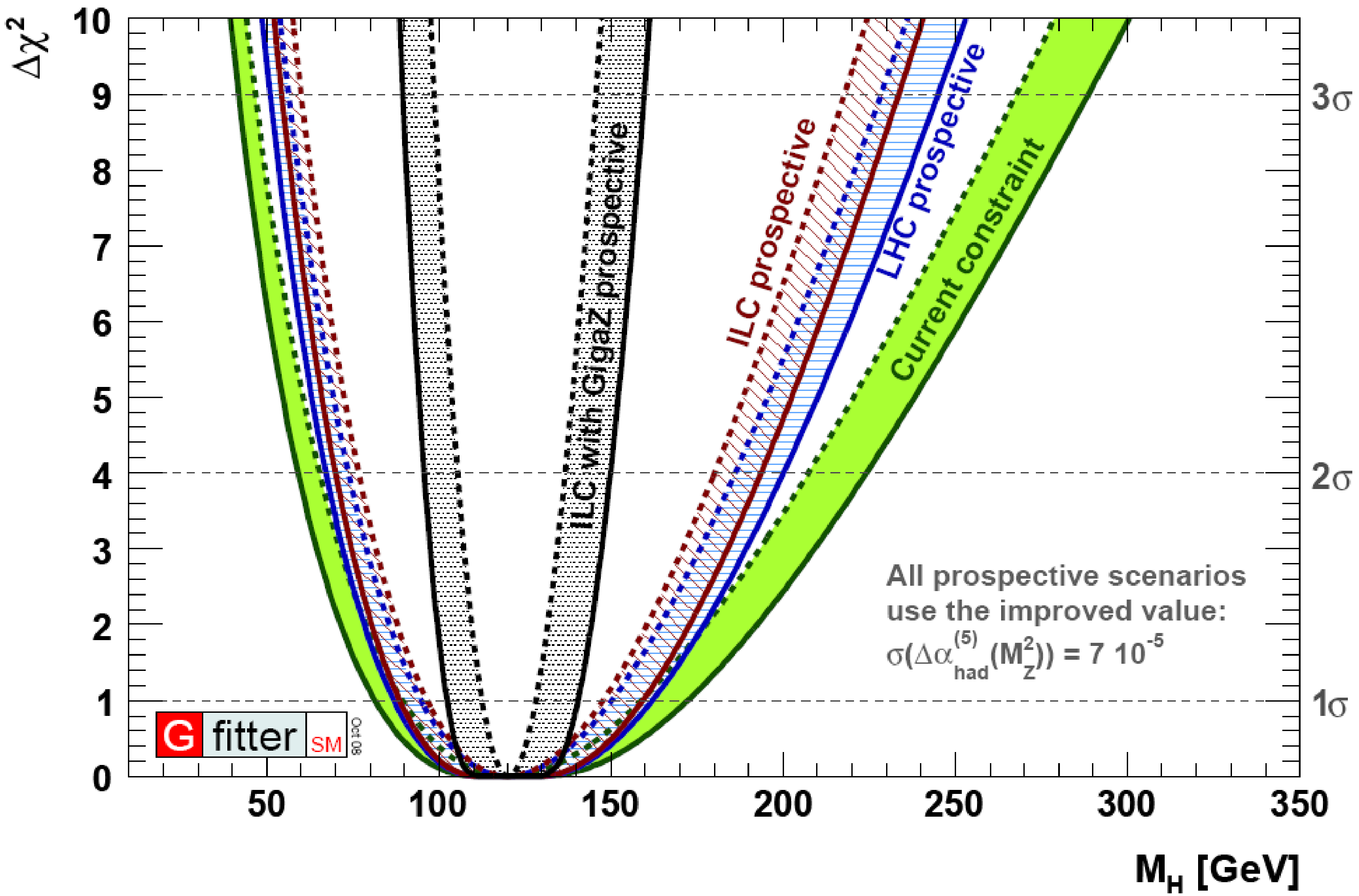
Gauge Boson - Fermion - Couplings

Example: Contact Interactions:



[S.Riemann]

Electro-weak fit with Giga-Z



[Flächer, Goebel, Haller, Höcker, Mönig, Stelzer 08]

Top Quark Physics

LHC trigger:

- none

LC objective:

- top mass determination factor 10 better than LHC/Tevatron (→ strong m_t dependence of many BSM predictions)
- electro-weak couplings of t (complementary to LHC)
- precise study of the ttg system (precise high-E QCD tests)

Alternatives

LHC trigger:

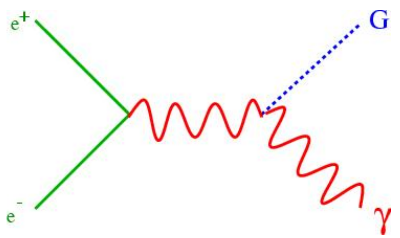
- signal of extra dimensions
- or signal of alternative EWSB (Little H, Higgsless, strong EWSB)
- or anything else (put your favourite discovery here...)

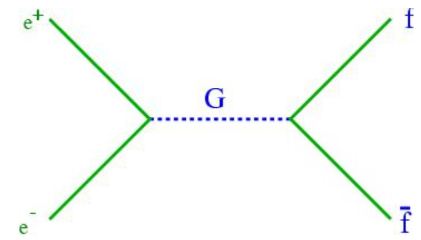
LC objective:

- study properties of new states if kinematically in reach
- study loop-effects on SM processes
  (indirect reach into deep-multi-TeV region)

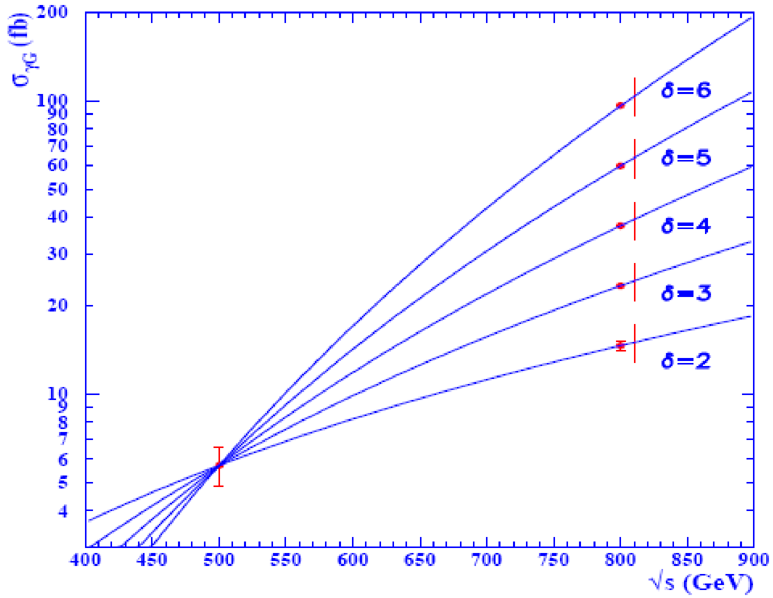
Alternatives

Example: Large Extra Dimensions (ADD)

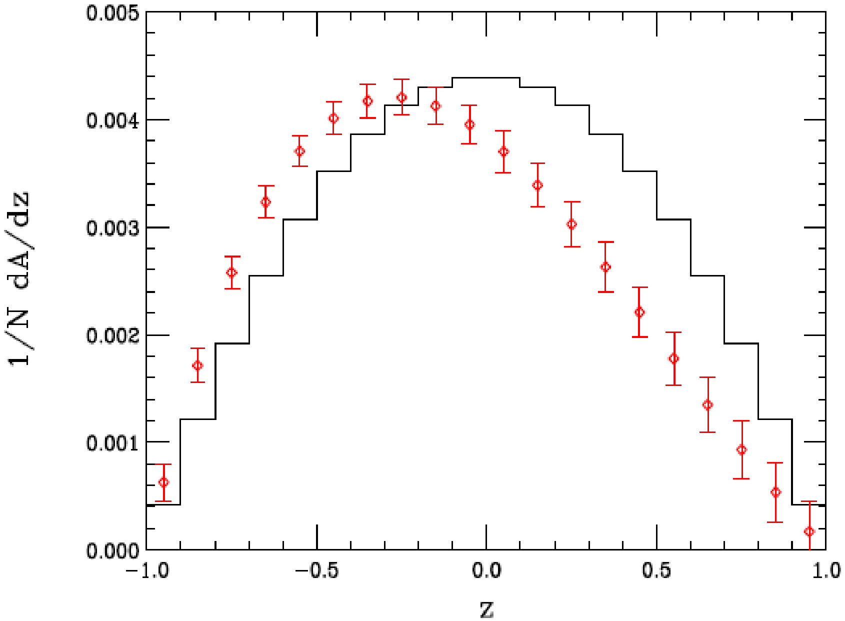




Real graviton emission



Azimuthal asymmetry with transverse polarization

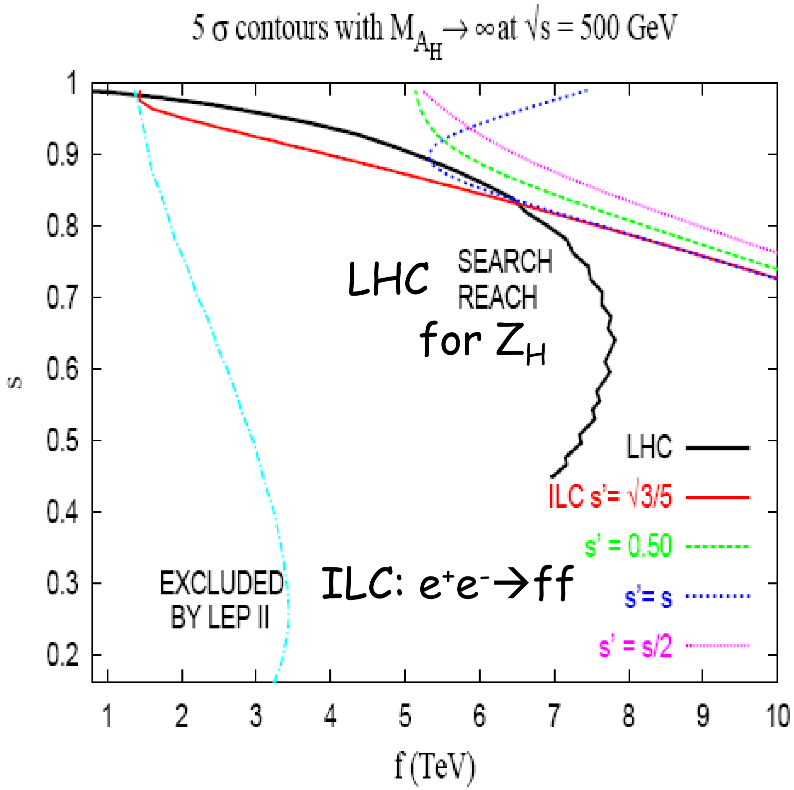


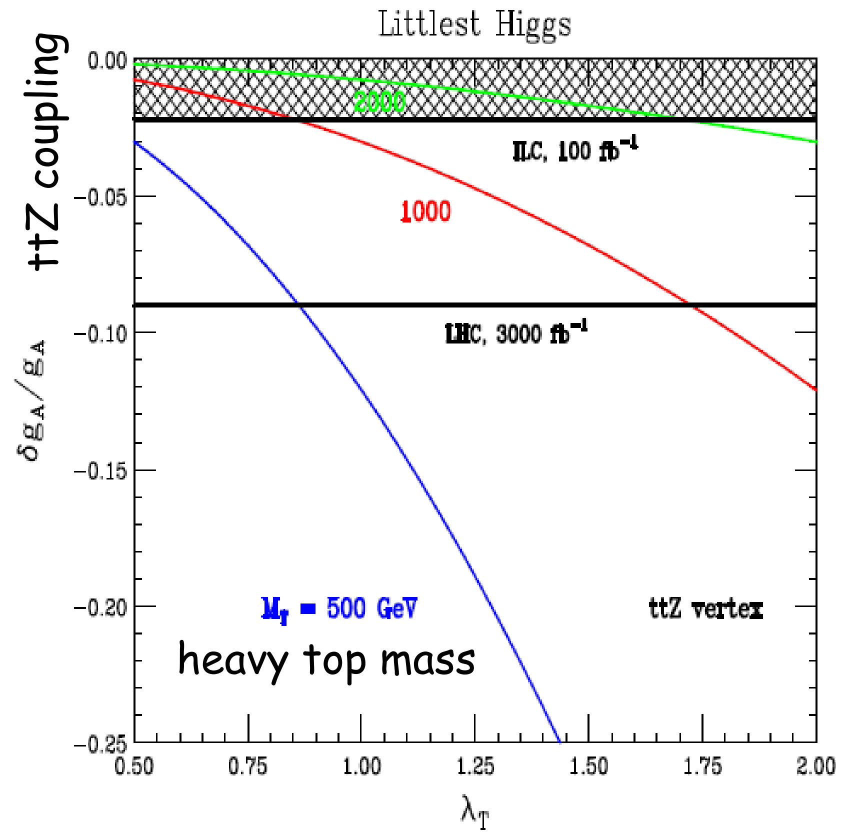
[Wilson; Rizzo]

[Rizzo]

Alternatives

Example: Little Higgs





$$m_T/f = (\lambda_t^2 + \lambda_T^2)/\lambda_T$$

f: scale of global symmetry breaking
s,s´ : mixing angles of gauge symmetry breaking

[Conley,Hewett,Le]

[Berger,Perelstein,Petriello]

Does LC Technology matter?

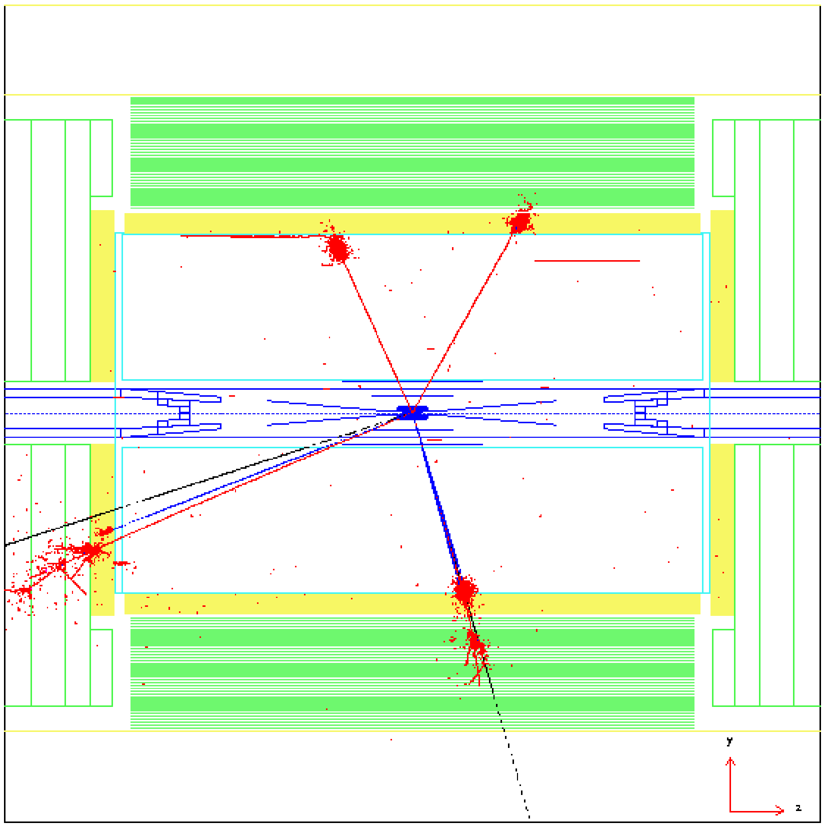
500 GeV comparison Table http://clic-meeting.web.cern.ch/clic-meeting/ComparisonTable.html

Center-of-mass energy	NLC 500 GeV	ILC 500 GeV	CLIC 500 GeV Conservative	CLIC 500 GeV Nominal
Total (Peak 1%) luminosity	$2.0(1.3)\cdot10^{34}$	$2.0(1.5)\cdot10^{34}$	$0.9(0.6)\cdot10^{34}$	$2.3(1.4)\cdot10^{34}$
Repetition rate (Hz)	120	5	50	
Loaded accel. gradient MV/m	50	33.5	80	
Main linac RF frequency GHz	11.4	1.3 (SC)	12	
Bunch charge 10^9	7.5	20	6.8	
Bunch separation ns	1.4	176	0.5	
Beam pulse duration (ns)	400	1000	177	
Beam power/linac (MWatts)	6.9	10.2	4.9	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	3.6/40	10/40	3 / 40	2.4 / 25
Hor/Vert FF focusing (mm)	8/0.11	20/0.4	10/0.4	8/0.1
Hor./vert. IP beam size (nm)	243/3	640/5.7	248 / 5.7	202/ 2.3
Soft Hadronic event at IP	0.10	0.12	0.07	0.19
Coherent pairs/crossing at IP	10?	10?	10	100
BDS length (km)	3.5 (1 TeV)	2.23 (1 TeV)	1.87	
Total site length (km)	18	31	13.0	
Wall plug to beam transfer eff.	7.1%	9.4%	7.5%	
Total power consumption MW	195	216	129.4	

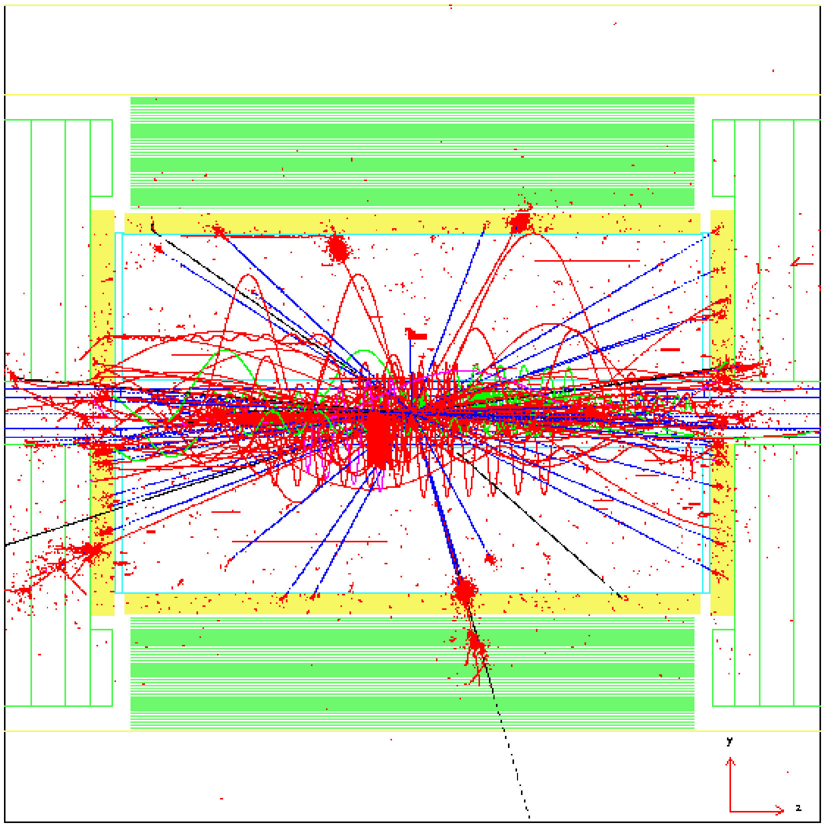
Does LC Technology matter?

HZ → ττee event

Without soft hadronic events overlaid (=ILC)



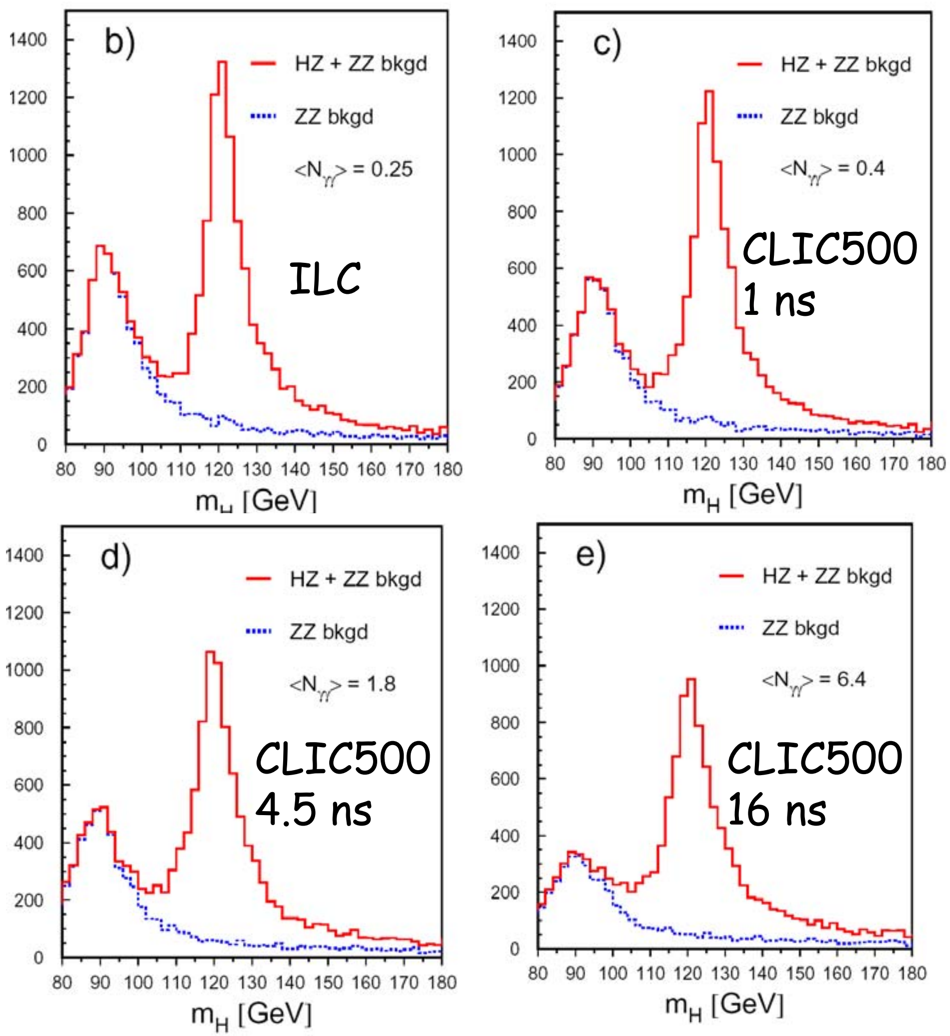
With 32 BX (=16 ns) „CLIC nominal 500“ overlaid



note: CLIC 3000 nominal has 14 times CLIC500 overlaid

Does LC Technology matter?

Higgs recoil mass



many LC precision measurements

depend on machine presicions

more than on detector precision

- threshold scans
- polarized cross sections

Needs careful consideration!

Average energy loss (beamstrahlung)

2.4% / 7% / 29%
ILC500/CLIC500/CLIC300

ref + Rohini+Manuel

Phys.Rev.Lett.67:1189-1192,1991

On staging

Various „natural" stages (ordered in $\sqrt{s}$) for an e^+e^- collider:

91.2 GeV -- Giga-Z

~ 250 GeV -- maximum of HZ cross section

344 GeV -- ttbar threshold

2 m(LSP,LKP,...) + X -- model independent WIMP measurements

2 m(NLSP) + X -- SUSY spectroscopy (part I)

~ 800 GeV -- maximum of ttH cross section, HH coupling

m (Z´)

2 m (squarks) + X

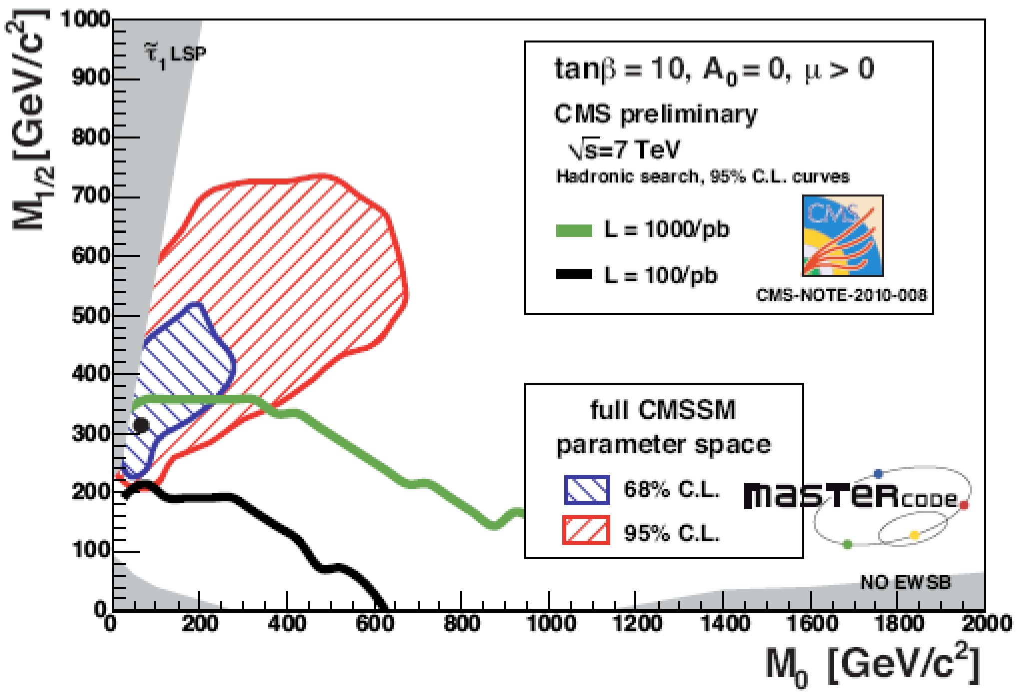
3 TeV

Different stages (and when to reach them) will (hopefully) be known from LHC data

SUSY Wheather forecast

Comparison: preferred region in the m_0–$m_{1/2}$ plane vs. CMS 95% C.L. reach for $0.1, 1\ \mathrm{fb}^{-1}$ at $7\ \mathrm{TeV}$

[*O. Buchmueller, R. Cavanaugh, A. De Roeck, J. Ellis, H. Flächer, S. Heinemeyer, G. Isidori, K. Olive, P. Paradisi, F. Ronga, G. W. '10*]



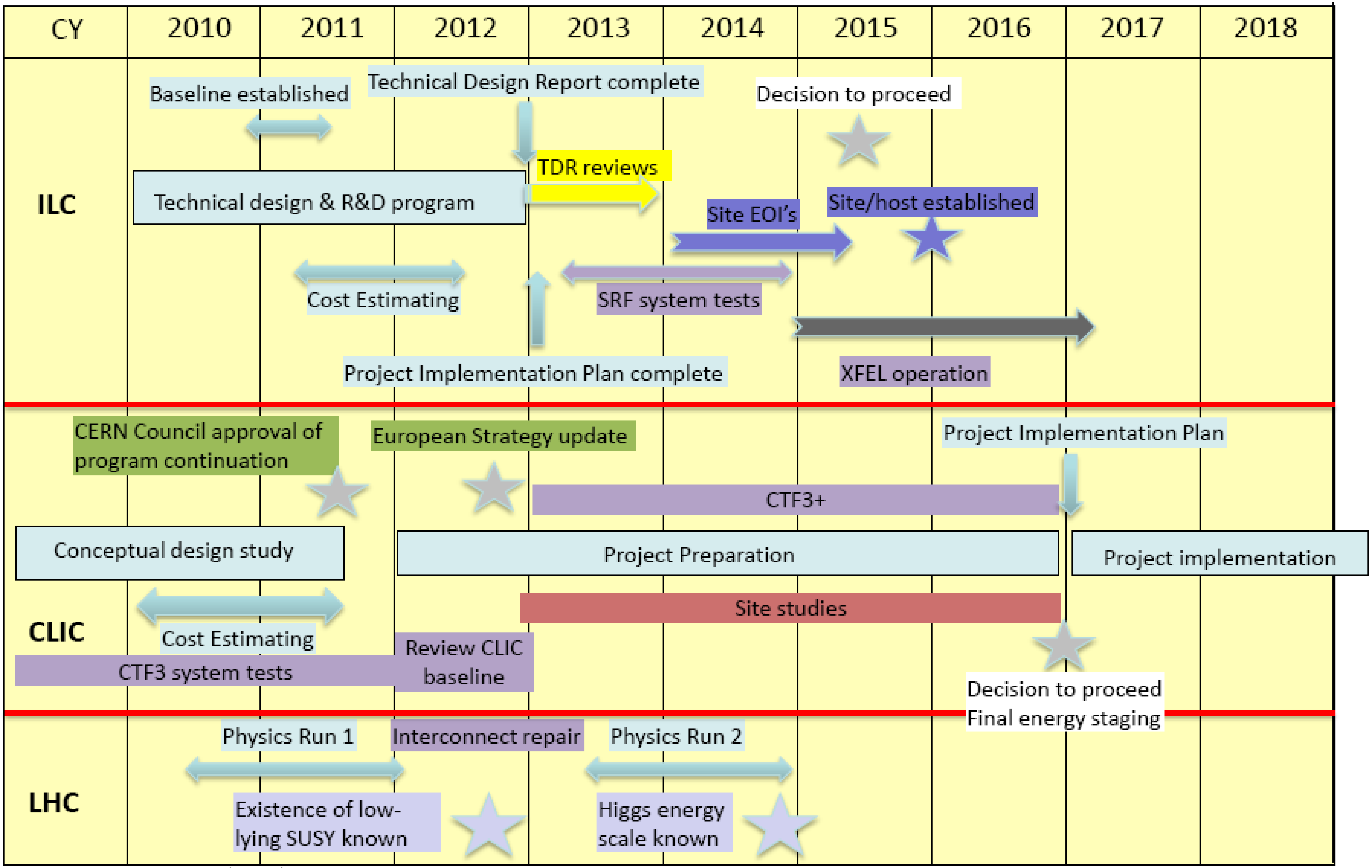
⇒ Good prospects for early discovery! Get hint in first run?

Summary

CLIC-ILC specialized WG

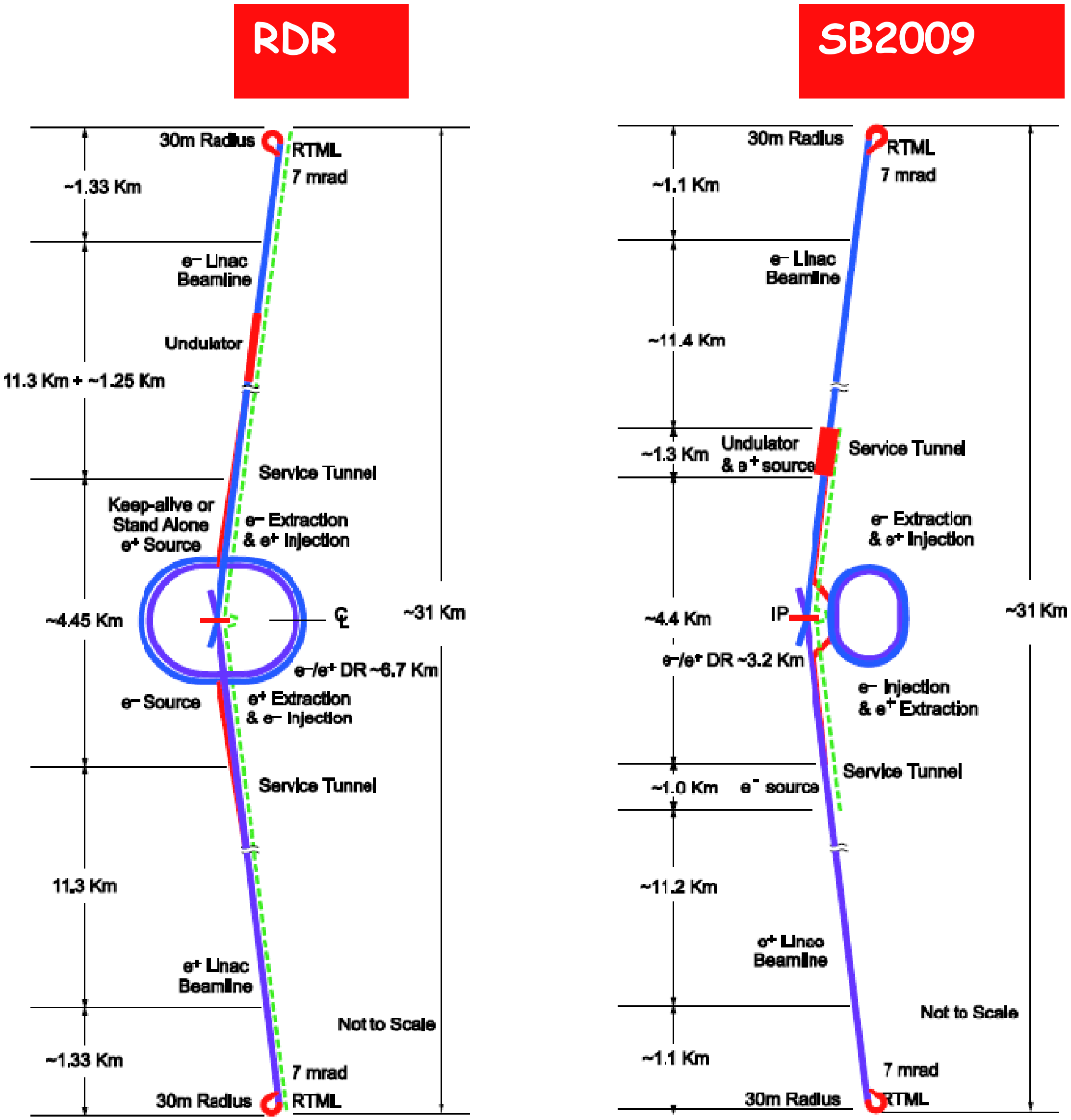
	CLIC	ILC
Physics & Detectors	L.Linssen, D.Schlatter	F.Richard, S.Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)	L.Gatignon D.Schulte, R.Tomas Garcia	B.Parker, A.Seriy
Civil Engineering & Conventional Facilities	C.Hauviller, J.Osborne.	J.Osborne, V.Kuchler
Positron Generation	L.Rinolfi	J.Clarke
Damping Rings	Y.Papaphilipou	M.Palmer
Beam Dynamics	D.Schulte	A.Latina, K.Kubo, N.Walker
Cost & Schedule	P.Lebrun, K.Foraz, G.Riddone	J.Carwardine, P.Garbincius, T.Shidara

CLIC & ILC roadmaps



P. Lebrun 22/10/10

ILC Layout



- Single Tunnel for main linac
- Move positron source to end of linac ***
- Reduce number of bunches factor of two (lower power) **
- Reduce size of damping rings (3.2km)
- Integrate central region
- Single stage bunch compressor