LC physics program demands precision calculations

- progress on higher-order corrections
  - 2-loop accuracy for $2 \to 2$ and $1 \to 3$ reactions
  - full 1-loop calculations for $2 \to 3, 4, ...$ processes
- progress on simulation tools
  - Monte Carlo generators for multi-particle final states

This talk: summary of developments (more topical than comprehensive)
achieved since spring 2001 (TESLA TDR) in

– the LoopVerein
(conveners: S. Dittmaier (replacing F. Jegerlehner), W. Hollik)

– the Event Generators Working Group
(conveners: M. Antonelli, S. Jadach, S. Moretti)

Theoretical Tools: S. Dittmaier

2.2 Recent results from the 2-loop frontier

Genuine 2-loop corrections to $2 \to 2$, $1 \to 3$ processes

- Algebraic reduction to master integrals — Anastasiou, Gehrmann, Glover, Laporta, Oleari, Remiddi, Smirnov, Tausk, Veretin '00

  by integration by parts, Lorentz invariance identities

  ↪ calculation of master integrals by Mellin–Barnes technique, — Anastasiou, Smirnov, Tausk, Tejeda-Yeomans '99-'02

  differential equations, numerical techniques

  Gehrmann, Remiddi '00, '01 — Binoth, Heinrich '00

- Direct reduction of full 2-loop amplitudes — Moch, Uwer, Weinzierl '02

  ↪ higher transcendental functions → nested harmonic sums

- Explicit algebraic results:
  - ◇ 2-loop amplitudes for massless $2 \to 2$ processes (Bhabha, QCD parton scattering, etc.) — Anastasiou, Bern, v.d.Bij, De Freitas, Dixon, Ghinculov, Glover, Oleari, Schmidt, Tejeda-Yeomans, Wong '01, '02
  - ◇ 2-loop QCD amplitudes for $e^+e^- \to 3$jets — Garland, Gehrmann, Glover, Koukoutsakis, Moch, Remiddi, Uwer Weinzierl '02

2.3 Multi-loop calculations in the MSSM

Precision observables in the MSSM

- known: – precision observables in 1-loop order since '94-'96
  – $\mathcal{O}(\alpha\alpha_s)$ corrections to $\Delta\rho$
  Djouadi, Gambino, Heinemeyer, Hollik, Jünger, Weiglein '97, '98
- new: corrections to $\Delta\rho$ of $\mathcal{O}(y_t^2)$, $\mathcal{O}(y_t y_b)$, $\mathcal{O}(y_b^2)$ Heinemeyer, Weiglein '02

  obtained with *FeynArts / TwoCalc*

  $\hookrightarrow$ induced corrections: $\Delta M_W \sim 2\,\mathrm{MeV}, \quad \Delta \sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}} \sim 0.00001$

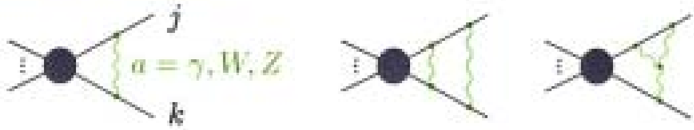
Precision calculations for MSSM Higgs masses and widths

- Higgs masses: progress in *FeynHiggs* Frank, Hahn, Heinemeyer, Hollik, Weiglein '98-'03
  - subleading 2-loop corrections
  - Δm_b resummation
  - new 1-loop renormalization (mainly $\tan\beta$)
- Higgs decays: progress in *HDECAY* (Djouadi, Kalinowski, Spira '97-'03) and *FeynHiggsDecay* (Heinemeyer, Hollik, Weiglein '00-'03)

  $\hookrightarrow$ Higgs and SUSY working groups

2.4 Electroweak radiative corrections at high energies

Sudakov logarithms induced by soft gauge-boson exchange



etc.

+ sub-leading logarithms from mass singularities

Typical impact on $2 \to 2$ reactions at $\sqrt{s} \sim 1\,\mathrm{TeV}$:

$$\delta_{\mathrm{LL}}^{1-\mathrm{loop}} \sim -\frac{\alpha}{\pi s_{\mathrm{W}}^2} \ln^2\left(\frac{s}{M_{\mathrm{W}}^2}\right) \simeq -26\%, \qquad \delta_{\mathrm{NLL}}^{1-\mathrm{loop}} \sim +\frac{3\alpha}{\pi s_{\mathrm{W}}^2} \ln\left(\frac{s}{M_{\mathrm{W}}^2}\right) \simeq 16\%$$

$$\delta_{\mathrm{LL}}^{2-\mathrm{loop}} \sim +\frac{\alpha^2}{2\pi^2 s_{\mathrm{W}}^4} \ln^4\left(\frac{s}{M_{\mathrm{W}}^2}\right) \simeq 3.5\%, \qquad \delta_{\mathrm{NLL}}^{2-\mathrm{loop}} \sim -\frac{3\alpha^2}{\pi^2 s_{\mathrm{W}}^4} \ln^3\left(\frac{s}{M_{\mathrm{W}}^2}\right) \simeq -4.2\%$$

⇒ Corrections still significant at 2-loop level

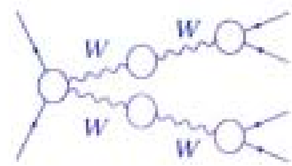
NOTE: differences to QED / QCD where Sudakov log's cancel

- massive gauge bosons W, Z can be reconstructed
  ↪ no need to add "real W, Z radiation"
- non-Abelian charges of W, Z are "open" → Bloch–Nordsieck theorem violated

⇒ Aim: universal prescription for improving (e.g. 1-loop) calculations

3 Radiative corrections to $2 \to 3, 4, \ldots$ processes

3.1 Progress on $e^+e^- \to 4f$ since TESLA TDR



W-pair production $e^+e^- \to WW \to 4f(+\gamma)$

- *RacoonWW* (Denner, S.D., Roth, Wackeroth)
  - anomalous triple and quartic gauge couplings
  - unweighting procedure and interface to *Pythia*
- *YFSWW* (Jadach, Placzek, Skrzypek, Ward)
  - combination with *KoralW* to concurrent MC code *KandY*
  - $\hookrightarrow$ cross-talk via FIFO files under UNIX/LINUX
- Reliable estimates of theoretical uncertainties (TU) for
  - M_W reconstruction (Jadach et al. '01) $\Delta M_W \lesssim 5\,\text{MeV}$
  - bounds on anomalous TGC λ (Brunelière et al. '02) $\Delta\lambda \lesssim 0.005$

$\hookrightarrow$ State-of-the-art generators include
- full lowest-order matrix elements for $e^+e^- \to 4f(+\gamma)$
- non-universal electroweak corrections in "double-pole approximation"
- improvements by leading higher-order corrections

3.2 Electroweak corrections to $e^+e^- \to \nu\bar{\nu}H$

- Fermion-loop corrections (+sfermion loops in MSSM)

  Ebert, Majerotto, Spanos '02; Hahn, Heinemeyer, Weiglein '02

- Full $\mathcal{O}(\alpha)$ corrections calculated by different groups

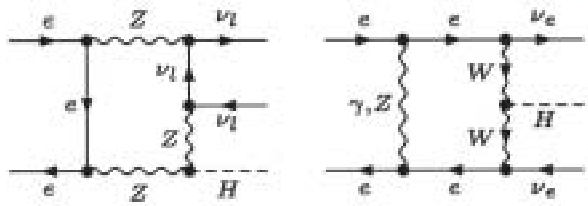
  Jegerlehner, Tarasov '02 (only virtual corrections, no numerics)
  – diagrams generated by DIANA and reduced with FORM/MAPLE

  Bélanger, Boudjema, Fujimoto, Ishikawa, Kaneko, Kato, Shimizu '02
  – diagrams generated and calculated with GRACE

  Denner, S.D., Roth, Weber '03
  – diagrams generated by FeynArts
  – two independent calculations in Mathematica (one partially with LoopTools)

  Hahn '98-'02

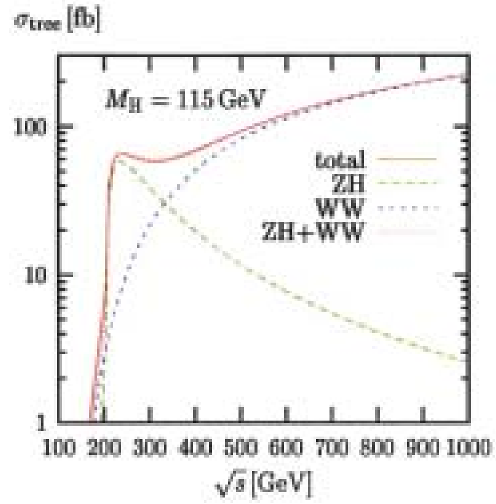
  Main complications: pentagon diagrams



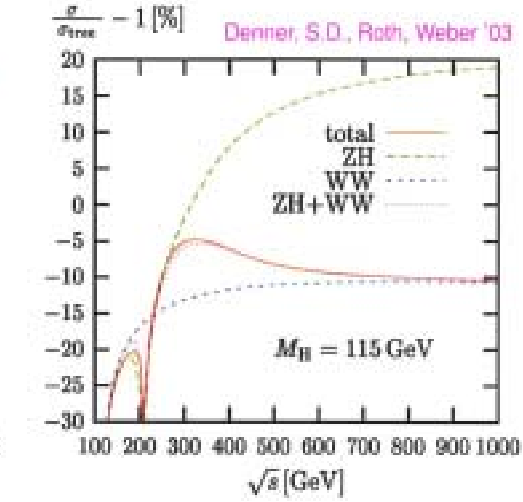
Calculational techniques improved

Total cross section for $e^+e^- \to \nu\bar{\nu}H$

Lowest order:



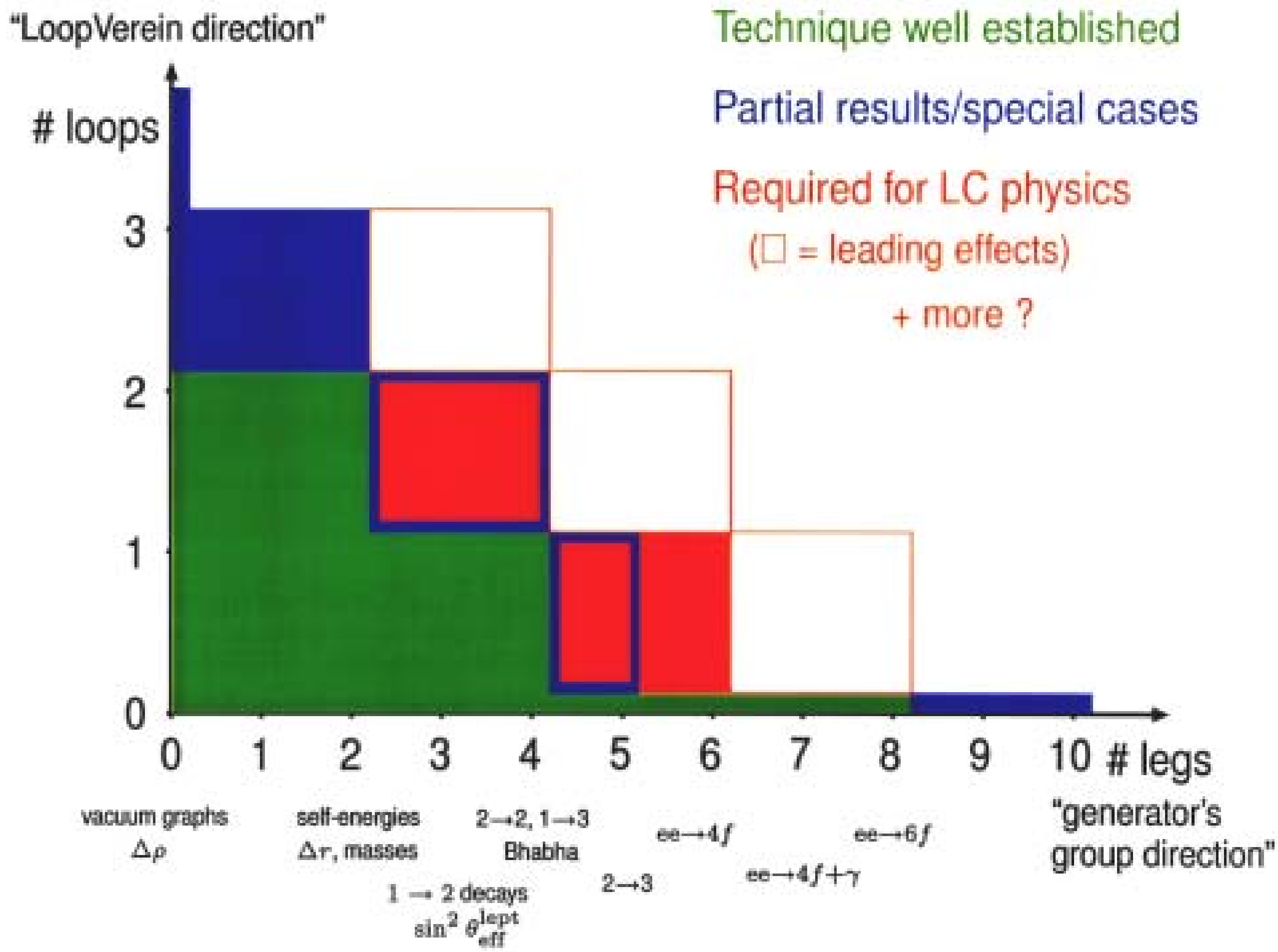
Relative corrections (G_μ scheme):



Comparison of results: ($\sqrt{s} = 500\,\text{GeV}$, $\alpha(0)$ scheme)

M_H [GeV]	σ_{tree} [fb]	σ [fb]	$\sigma/\sigma_{tree} - 1[\%]$	
150	61.074(7)	60.99(7)	−0.2	Bélanger et al.
	61.076(5)	60.80(2)	−0.44(3)	Denner et al.
300	10.758(1)	10.30(1)	−4.2	Bélanger et al.
	10.7552(7)	10.282(4)	−4.40(3)	Denner et al.

Agreement within $\mathcal{O}(0.2\%)$


"LoopVerein direction"
loops
Technique well established
Partial results/special cases
Required for LC physics
(□ = leading effects)
+ more ?
0
1
2
3
0 1 2 3 4 5 6 7 8 9 10 # legs
vacuum graphs
Δρ
self-energies
Δr, masses
2→2, 1→3
Bhabha
1 → 2 decays
sin² θ_eff^lept
2→3
ee→4f
ee→4f+γ
ee→6f
"generator's group direction"

4 Event generators for multi-particle final states

4.1 Generic generators for parton level

Basic idea: flexible event generator for a large set of final states

Existing programs:

- *AMEGIC++*
  Krauss, Kuhn, Schumann, Soff '01,'02
- *MadEvent + Madgraph*
  Maltoni, Stelzer '02; Stelzer, Long '94
- *Whizard + Omega/Madgraph/CompHEP*
  Kilian '01; Moretti, Ohl, Reuter '01 / Stelzer, Long '94 / Boos et al.'89-'02
- *GRACE*
  MINAMI-TATEYA group '92
- *PHEGAS + HELAC*
  Papadopoulos '00; Kanaki, Papadopoulos '00

Typical features – differences to process-specific generators:

- lowest-order predictions
  improved by universal corrections (parton shower, LL ISR, etc.)

+ many final states, uniform setup for different process classes, ideal for studying the physics potential of colliders

– long codes, improvements by radiative corrections problematic / limited
  ↪ usually not high-precision tools

4.3 "True" Monte Carlo event generators

PYTHIA (Sjostrand et al.), *HERWIG* (Corcella et al.), *ISAJET* (Baer et al.)

- Produce actual events as they appear in detector, by including parton shower, fragmentation/hadronization, hadron decays
- Mainly based on tree-level $2 \to 1$, $2 \to 2$ hard scatterings
- Matching of QCD matrix-elements (ME) for one-gluon real emission to parton shower (e.g., $t \to bW^+g$, $q\bar{q} \to Vg$ in HERWIG & PYTHIA)
- Recent developments (Extended Study) for LC physics:
  - complete $2 \to 2$ MSSM processes available (ALL)
  - $Q\bar{Q}^{(\prime)}$ + Higgs (SM and MSSM)
  - R-parity violating SUSY in HERWIG & cMSSM in PYTHIA
  - spin correlations $\oplus$ 3,4-body decay MEs (HERWIG)
- Future/current developments:
  - some NLO QCD processes (HERWIG, soon PYTHIA)
  - progress in C++: *HERWIG++* and *PYTHIA 7*

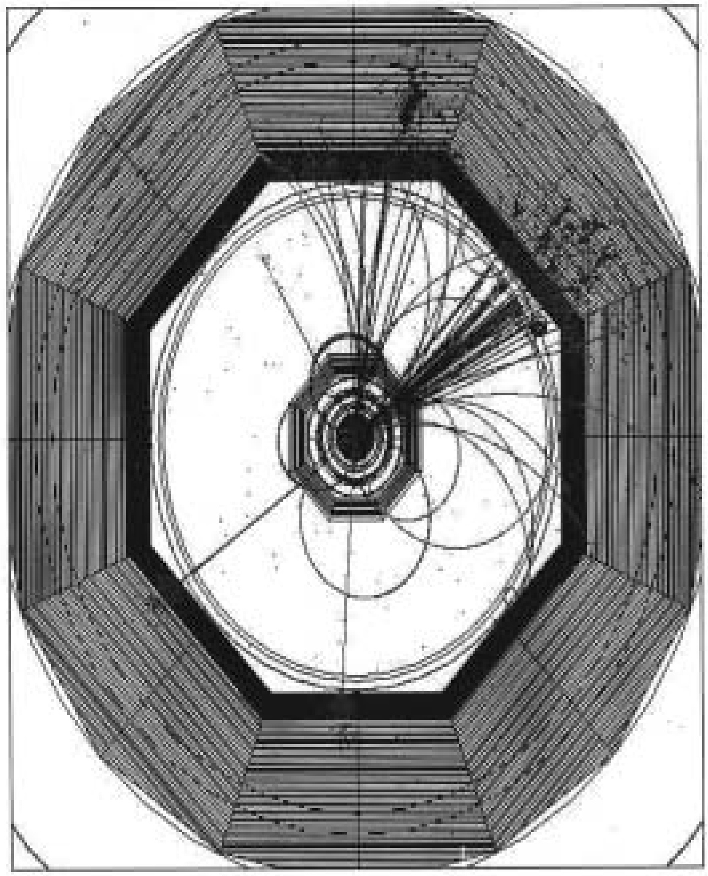
Many issues for the future:

- complete 2-loop calculations for $1 \to 2, 3$ and $2 \to 2$ reactions
  - ◇ Z line shape and Z-pole pseudo-observables ($\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$, etc.)
  - ◇ Bhabha scattering, $\mathrm{e^+e^-} \to 3\mathrm{jets}$, etc.
- complete 1-loop calculations for $\mathrm{e^+e^-} \to 4f$
- improvements in Monte Carlo generators
  - ◇ inclusion of radiative corrections
  - ◇ unweighting procedures
  - ◇ matching of matrix elements with parton showers in NLO
- general issues
  - ◇ resummation of leading higher-order corrections
  - ◇ treatment of unstable particles
  - ◇ parallelization / automatization / standardization

$\Rightarrow$ Many long-termed projects — continuous support needed !

Report from the Higgs Working Group

ECFA/DESY
LC workshop
NIKHEF,
Amsterdam
4/4/03



Fully simulated+reconstructed HZ event (BRAHMS)

Convenors:
M.Battaglia
K.Desch
A.Djouadi
E.Gross
B.Kniehl

Introduction

TDR conclusion: Higgs mechnanism can be established in all essential elements

→ extended study not essential??? No.

Goals:
- close remaining (but essential) corners
- keep up with new theoretical ideas
- further study relation to LHC
- further study $\gamma\gamma$ option (⇨A. deRoeck's talk)
- become more realistic in experimental simulation

Group was (and is) very active!
64 talks (35 exp/29 theo) in 4 workshops
(sorry, I cannot mention all of them...)

Many (but certainly not all) goals achieved – good progress

Higgs Profile: Quantum Numbers

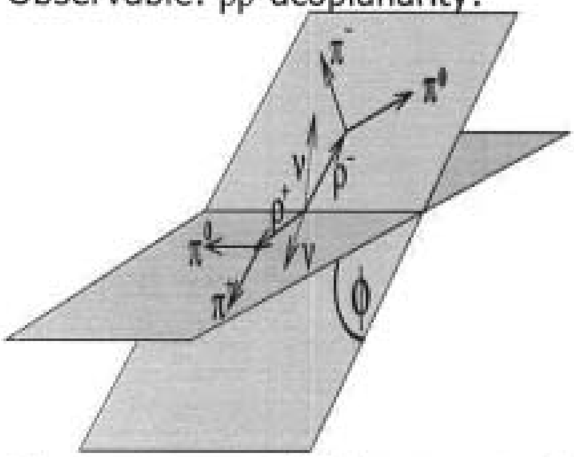
TDR: Spin from threshold scan

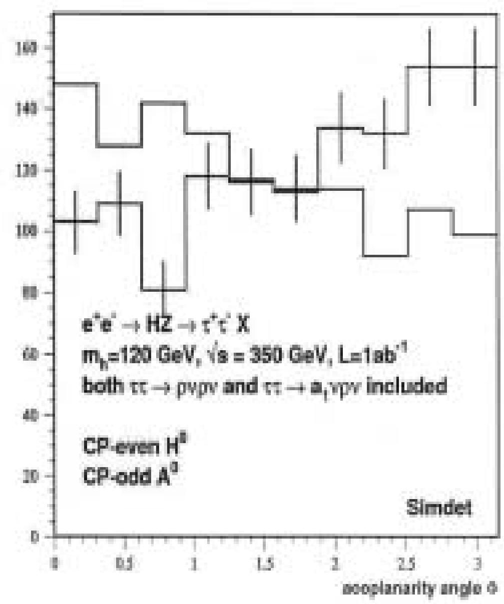
TDR: CP from angular distributions of ZH

New Ideas:Spin from $H \to ZZ$ **Miller et al**

CP from transverse polarisation correlations in $H \to \tau\tau$ **Was, Worek Bower Imhof, KD**

Observable: $\rho\rho$-acoplanarity:





First estimate with detector simulation:

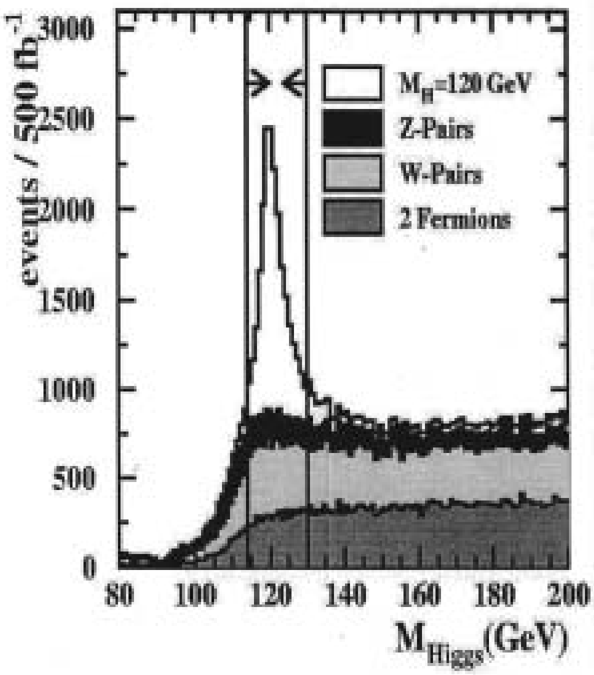
> 8σ separation between CP+ and CP- for 120 GeV Higgs (350GeV/1 ab^{-1})

Higgs Profile: Decay Modes

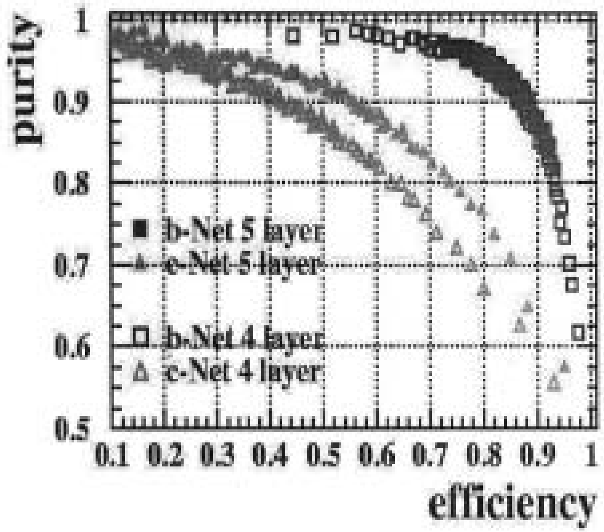
New analysis of hadronic BR's has started
using newest tools (ZVTOP, SIMDET4, kinematic fit)

T.Kuhl,KD

kinematic selection (Z→hadrons
and Z→leptons only) not yet optimal



study dependence on vtx layout



preliminary numbers seem to
~confirm TDR numbers

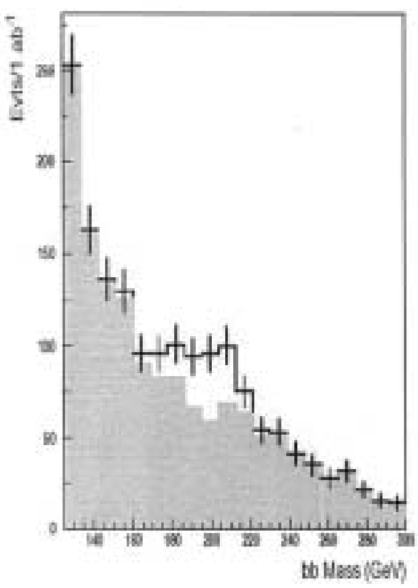
Higgs Profile: Rare Decay Modes

M.Battaglia

$H \to b\bar{b}$ as rare decay ($m_H > 160$ GeV)

Fusion(800GeV) preferred over Higgsstrahlung(350GeV)

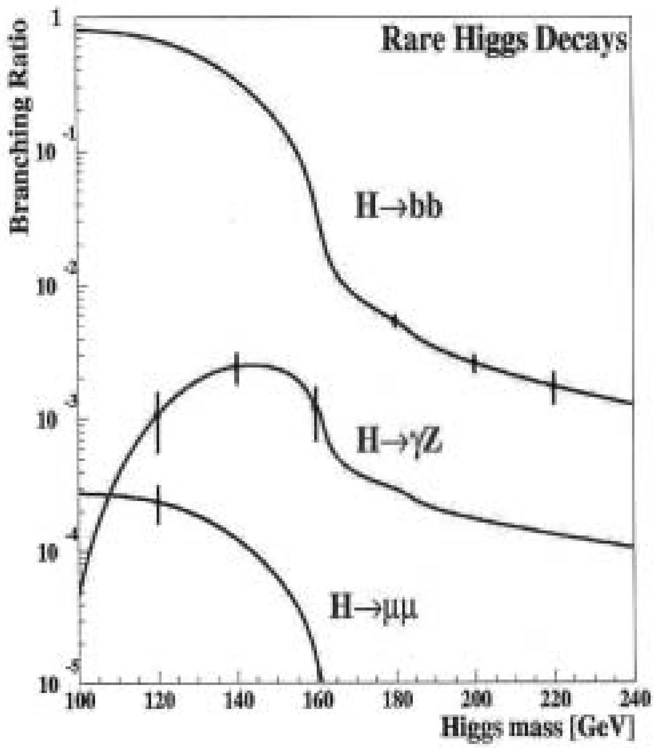
$M_H = 200$ GeV



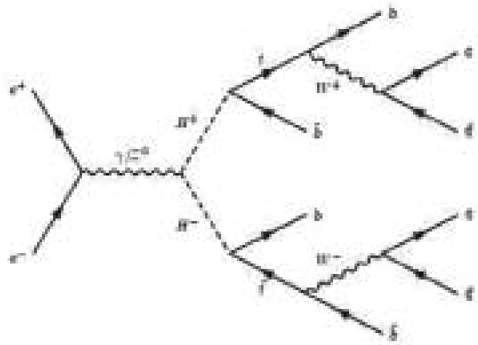
Results for 1ab⁻¹@800 GeV		
m_H(GeV)	S/sqrt(B)	ΔBR(bb)/BR(bb)
180	10.5	11.5%
200	7.5	16.5%
220	4.1	27.5%

Higgs Profile: Rare Decay Modes

Summary of rare decays:



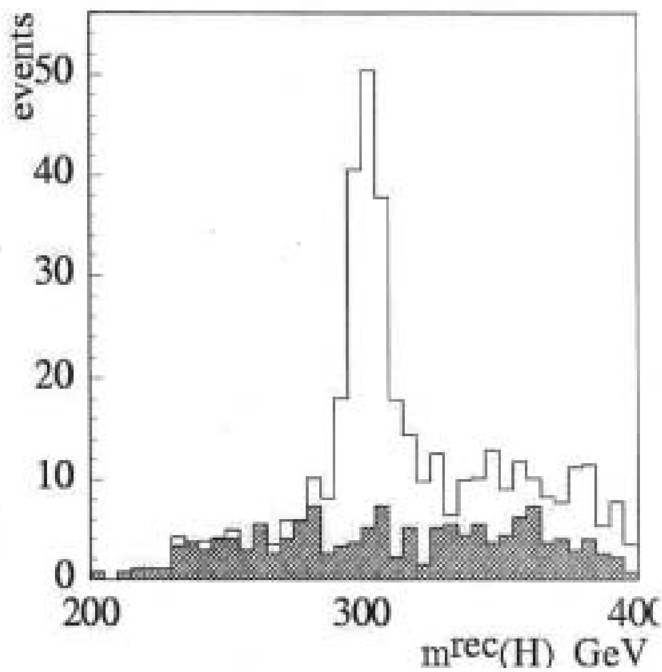
Charged Higgs



new: now with genuine
tbtb background

At 800 GeV:
5σ discovery up to m=350 GeV

Battaglia,Ferrari,Kiiskinen,Maki



Theory: new calculations to beat kinematic limit

Heavy SUSY Higgses: pair production dominant → mass reach limited
⇨ explore (supressed) single production modes

1. Charged Higgs:

$$e^+e^- \to t\bar{b}H^-$$
$$e^+e^- \to \tau^+\nu_\tau H^-$$
$$e^+e^- \to W^+H^-$$

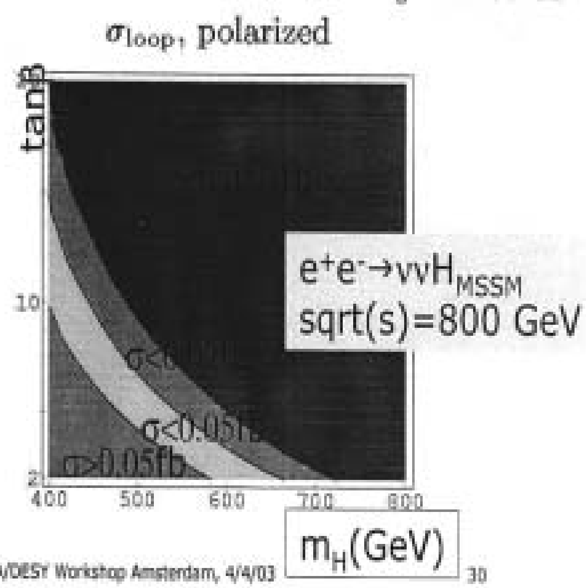
Kniehl et al
Moretti et al

2. Heavy neutral Higgses

Weiglein et al

couple ~$\cos(\beta-\alpha)$ in decoupling limit
→normally no WW-fusion cross section

Loop effects can enhance the cross section (a bit...)
→ (somewhat) higher mass reach than for pair production



Constraining the MSSM Higgs sector

Ultimate goal: extract the underlying SUSY parameters from Higgs sector measurements from a global fit

We're not there yet: difficult task since at higher orders, Higgs sectors depends on many parameters (stop mixing etc.)

Classical example: estimate m_A from BR-measurement

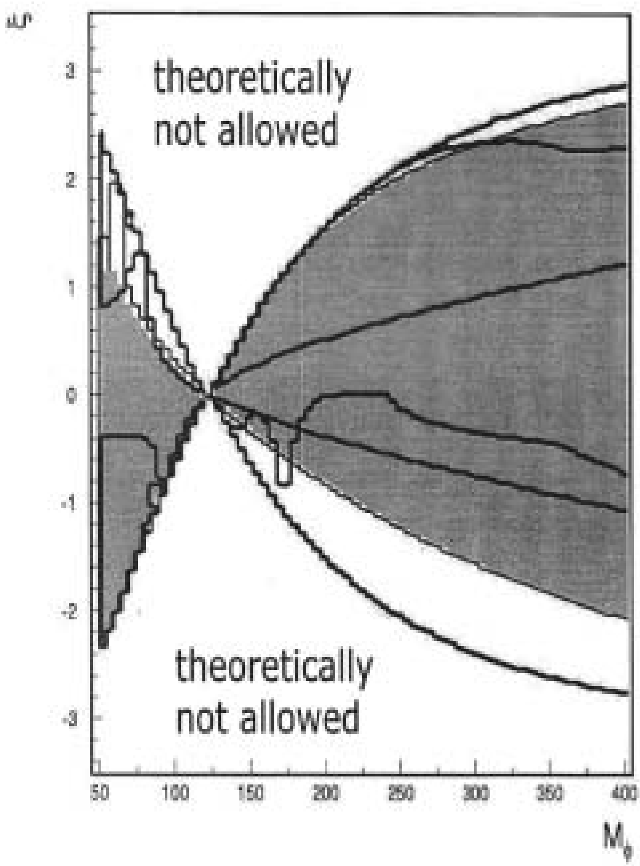
Yes! But, BR's also depend on $\tan\beta, m_{\tilde{t}}, m_t, A_t, \ldots, \Delta m_b (SUSY-QCD)$

We should try to bring the bits and pieces together!

Extended Models: XD effects on Higgs sector

Dominici,
Battaglia,
Gunion

LC ability of precise BR measurements allows to distingiush SM Higgs from mixed state (even if Radion itself is too heavy)



Red contours: deviation of $H \to bb$ BR > 2.5σ

Cyan Region: LHC H discovery Ensured

Blue contours: LHC Radion observation in $\Phi \to ZZ$

LC regions complementary to LHC reach

Thoughts About The Future

What are the goals for a Higgs working group in the next 2 years??

Experimental:

- Physics studies as crucial input to detector R&D

- Reexamine influence of machine parameters (Luminosity, Energy, Time structure, Backgrounds) on physics performance

- Become more realistic in simulation of our benchmark processes (recoil mass, BR's, ZHH)

- Continue quantitative evaluation of the running options in $\gamma\gamma$, $e\gamma$, e^-e^- modes (mass reach, light Higgs couplings, ...)

Thoughts About The Future

Facing Experimental Reality:

- full simulation (BRAHMS/MOKKA) is now really possible for physics studies `see e.g. V.Saveliev`

- development of appropriate analysis tools might take more time than the actual physics study (Kin.Fitting, Lepton-ID (esp. t) algorithms, ISR/BS photon ID, B-tagging, etc. etc.) – but it's worth the effort!

- Study the dependency of physics observables as a function of detector/machine parameters (First examples are arriving, we clearly need more) `see e.g. T.Kuhl`

Thoughts About The Future

Theory:

- match experimental and theoretical precision. Identify, where particular effort is needed
- Watch new theoretical ideas (models with modified H coupling now easy to explore → general survey?)

General:

- International connections – exchange of ideas, codes, common projects etc can still improve!
- PhD theses on detector R&D are much nicer if accompanied by a physics applicability study (improve possibilities for publications of results?)

ECFA DESY

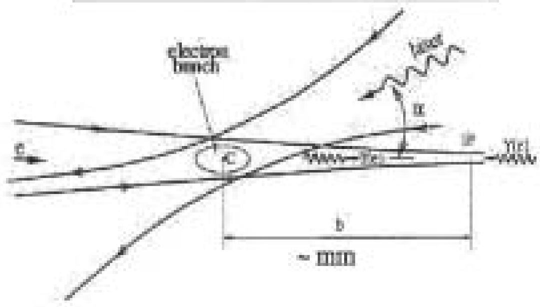
Linear Collider Workshop

e-e-, gamma-gamma and e-gamma options for a Linear Collider

A.De Roeck

CERN

Amsterdam, April 2003



In this study

- Gamma-gamma and e-gamma option
  - Working group on gamma-gamma/e-gamma collider technology
    K. Moenig and V. Telnov
  - Working group on gamma-gamma physics
    M. Kraemer, M. Krawczyk, S. Maxfield, ADR, (S. Soldner-Rembold)
    - 4+2 meetings during this study
    - During ECFA/DESY, integrated with other physics groups/ worked well!
    - Many new results
- e-e- option
  - No new studies in the context of this workshop/ 2 meetings St Malo/Amsterdam C. Heusch
    - Will remind some key issues based on Snowmass/Jeju reports

Golden Processes

hep-ph/0103090

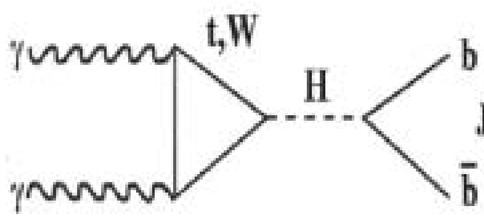
	Reaction	Remarks	
✪	$\gamma\gamma \to h^0 \to b\bar{b}$	$\mathcal{SM}$ or $\mathcal{MSSM}$ Higgs, $M_{h^0} < 160$ GeV	Higgs
✪	$\gamma\gamma \to h^0 \to WW(WW^*)$	$\mathcal{SM}$ Higgs, 140 GeV $< M_{h^0} <$ 190 GeV	
✪	$\gamma\gamma \to h^0 \to ZZ(ZZ^*)$	$\mathcal{SM}$ Higgs, 180 GeV $< M_{h^0} <$ 350 GeV	
✪	$\gamma\gamma \to H, A \to b\bar{b}$	$\mathcal{MSSM}$ heavy Higgs, for intermediate $\tan\beta$	SUSY
✪	$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-,\ H^+H^-$	large cross sections, possible observations of FCNC	
	$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium	
✪	$\gamma e \to \tilde{e}^- \tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$	
✪	$\gamma\gamma \to W^+W^-$	anomalous W interactions, extra dimensions	Tril/quart.
✪	$\gamma e^- \to W^- \nu_e$	anomalous W couplings	
✪	$\gamma\gamma \to WWWW, WWZZ$	strong WW scatt., quartic anomalous W, Z couplings	
✪	$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions	Top
	$\gamma e^- \to \bar{t} b \nu_e$	anomalous Wtb coupling	
✪	$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section	QCD
✪	$\gamma e^- \to e^- X$ and $\nu_e X$	$\mathcal{NC}$ and $\mathcal{CC}$ structure functions (polarized and unpolarized)	
✪	$\gamma g \to q\bar{q},\ c\bar{c}$	gluon distribution in the photon	
✪	$\gamma\gamma \to J/\psi\, J/\psi$	QCD Pomeron	

NOW

- ✪ Being done or ready: should be ready for the writeup
- ✪ promised

Higgs

Production Mechanism for Neutral Higgs Bosons



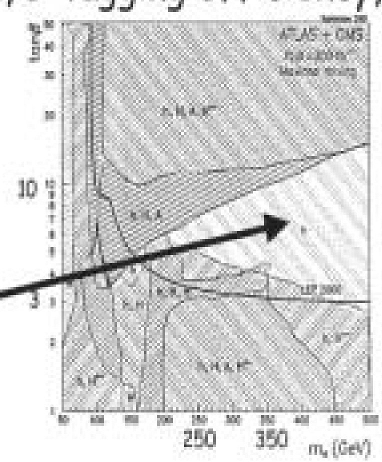
Landau-Yang $J^{PC}=0^{-+},0^{++},2^{++}$

Heralded as THE key measurement for the gamma-gamma option

- From the TDR (Jikia, Soldner-Rembold)

$$\frac{\Delta[\Gamma(h\to\gamma\gamma)\mathrm{BR}(h\to b\bar{b})]}{[\Gamma(h\to\gamma\gamma)\mathrm{BR}(h\to b\bar{b})]}\approx 2\%$$

- This workshop
  - Study H→ bb, with realistic spectra, background, B-tagging efficiency,...
  - Study H→ WW,ZZ
  - Study model separation power
  - Study spin of Higgs in H→ WW,ZZ
  - Study CP properties of the Higgs
  - Study MSSM Higgs (H,A): extend e+e- reach
  - Study of the Charged Higgs (US)



Golden Processes

Added at/since the Krakow meeting:

- Non-commutative QED
- $e\gamma$ for ED's
  - Light gravitinos
  - Radions
  - Gluino production
- $H \to \gamma\gamma$ (US groups)
- $H \to H^+H^-$ (US groups)
  - *CP* analyses in the Higgs sector

More (as yet uncovered/lower priority at present)

- $e\gamma \to e^*$
- Leptoquarks
- Strong WW scattering
- $e\gamma \to eH$

As always: still room for volunteers (next workshop)

SUPERSYMMETRY
STATUS REPORT

Jan Kalinowski
Warsaw University

ECFA/DESY Workshop, Amsterdam 2003

SUSY group very active:

14 talks in Cracow, 17 in St. Malo, 11 in Prague, 15 here

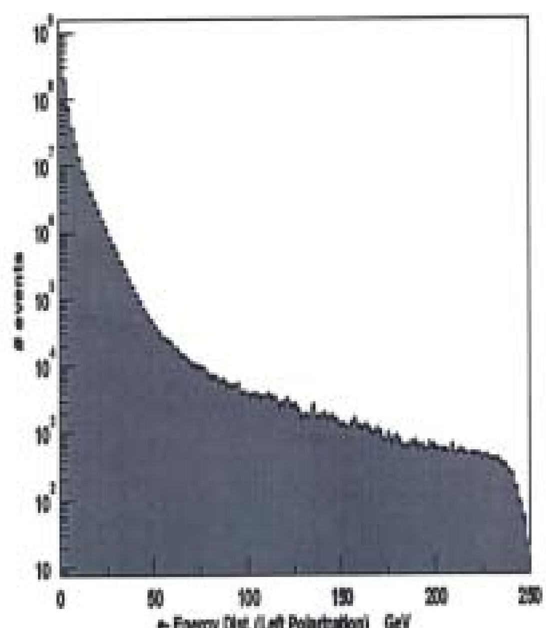
- more refined analyses
- effects of CP- violating phases
- radiative corrections
- R_p and/or lepton-flavour violating scenarios
- LHC/LC essentiality

Selectron Spectrum

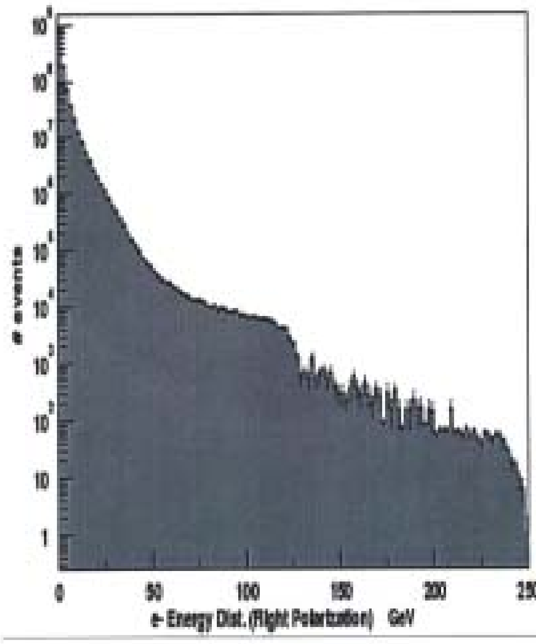
NLC - The Next Linear Collider Project

Electron Energy Spectrum

$$\mathrm{SUSY} + W\,W + \gamma^*\gamma^* \to e^+e^- + \tau\tau(e^+e^-)$$



80% L



80% R

Colorado Univ. - Boulder

$\tilde{\tau}$ **very interesting object**

- $\tilde{\tau}$ production and decay different from $\tilde{e}$ and $\tilde{\mu}$ because of
  - ◇ $\tilde{\tau}_R$–$\tilde{\tau}_L$ mixing $\sim \tan\beta$
  - ◇ non-negligible τ Yukawa coupling

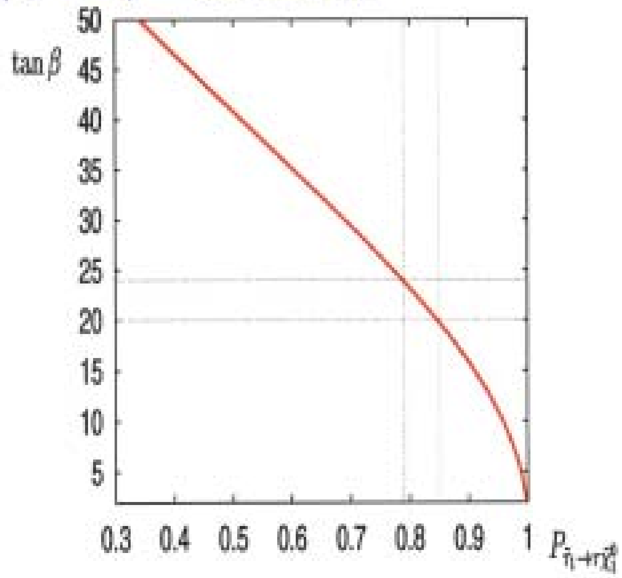
  - ◇ coupling sensitive to neutralino composition
- the τ polarization in $\tilde{\tau} \to \tilde{\chi}^0 \tau$ decay measurable
- τ polarization – a sensitive function of $\tilde{\tau}$ mixing, neutralino mixing and $\tan\beta$

[Nojiri '96, Boos et al., '02]

Study of staus

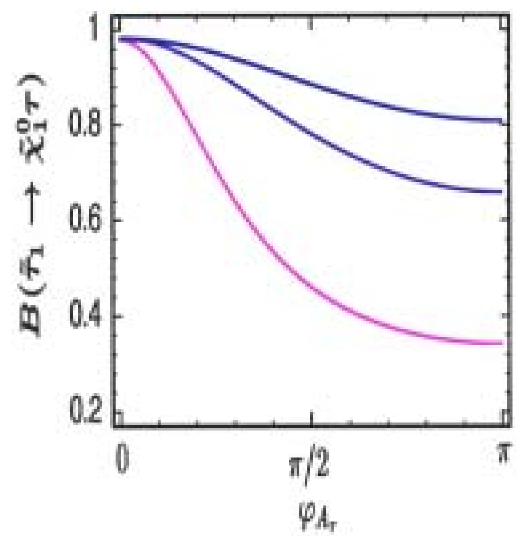
Example: $m_{\tilde{\tau}_1} = 155$ GeV, $m_{\tilde{\tau}_2} = 305$ GeV, $\mu = 140$ GeV, $\tan\beta = 20$, $A_\tau = -254$ GeV

- Assuming $\sqrt{s} = 500$ GeV, $\mathcal{L} = 250$ fb^{-1}, $\mathcal{P}_{e^-} = +0.8$, $\mathcal{P}_{e^+} = -0.6$
- expected precision: $m_{\tilde{\tau}_1} = 155 \pm 0.8$ GeV, $\cos 2\theta_\tau = -0.987 \pm 0.08$, $\mathcal{P}(\tilde{\tau}_1 \to \tau) = 0.82 \pm 0.03$



$\Longrightarrow$ $\tan\beta = 20 \pm 2$ [Moortgat-Pick et al., '03] moreover

- verify SU(2)xU(1) quantum numbers of $\tilde{f}_R$ by measuring σ_{tot} with different beam polarization [Blöchinger et al., '02]
- verify SUSY relations between Yukawa and gauge couplings [Freitas et al., '02]
- check (in)equality of $\tilde{e}_R$ and $\tilde{\mu}_R$ masses
- total and differential cross section for $e^+e^- \to \tilde{e}_R^+\tilde{e}_R^-$ sensitive to M_1 [Blöchinger et al., '00-'02]
- complex CP phases [Bartl et al., '01]

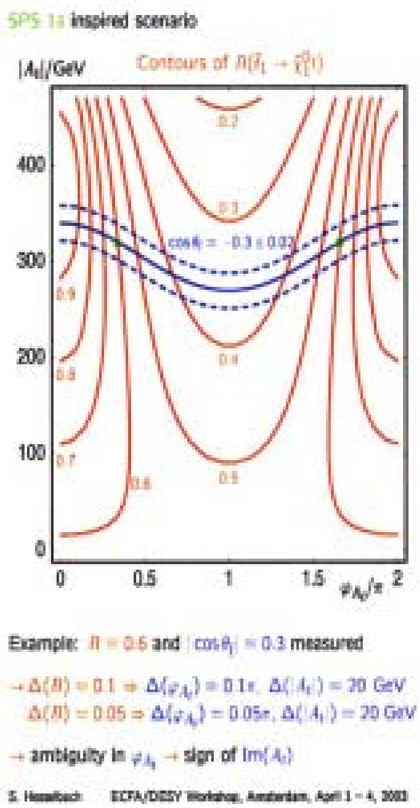


- if CP phases non-zero

◇ BR($\tilde{t}$) sensitive

to CP phases

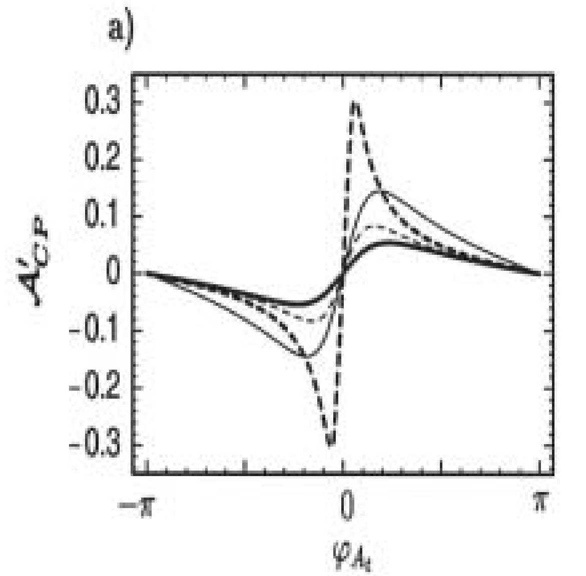
[Hesselbach et al., 03]



◇ measure transverse τ polarization

in $\tilde{t}_1 \to b\tilde{\chi}_1^0 \nu_\tau \tau$

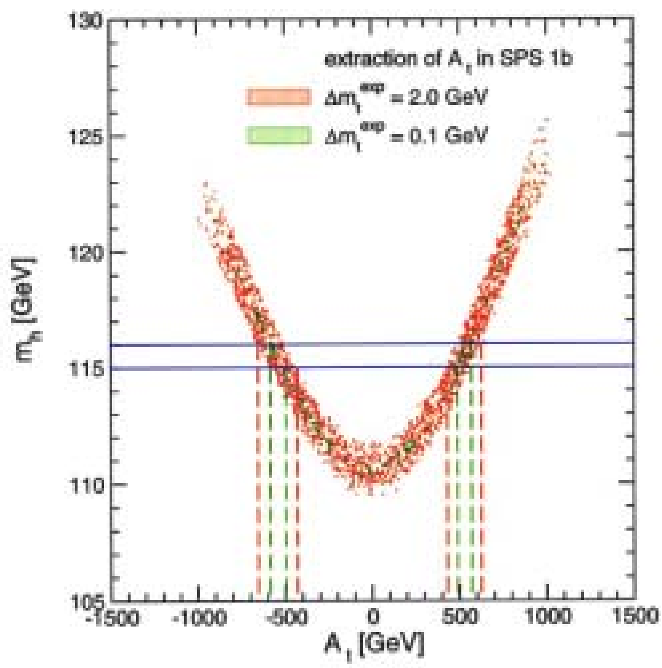
[Bartl et al., '02]



If the scalar top too heavy for the LC

Heinemeyer et al., '02]

Combine m_h, m_t (LC) and $m_{\tilde{t}}, m_{\tilde{b}}$ (LHC) :



⇒ $|A_t|$ indirectly measurable

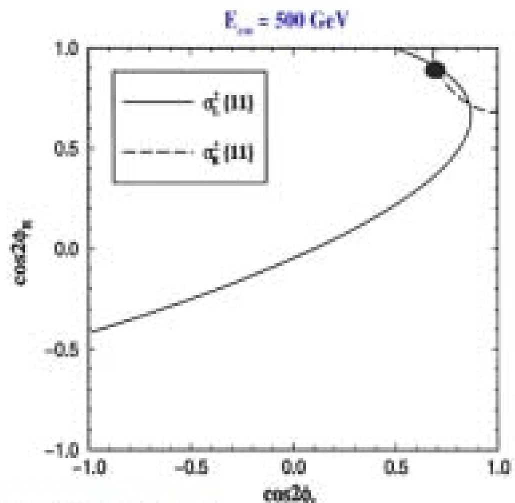
(sign unclear)

Question: Can we invert without knowing heavy chargino mass?

Early stage of the LC, only $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ [Choi et al., '01]

Measure $m_{\tilde{\chi}_1^\pm}$ and σ_L, σ_R

twofold ambiguity (assuming $m_{\tilde{\nu}}$ known)
for $\{\cos 2\phi_L, \cos 2\phi_R\}$



With the mass of $\tilde{\chi}_2^\pm$ still unknown:

- in CP–conserving case $\Longrightarrow$ two solutions for $\tan\beta,\ M_2,\ \mu$
  can be resolved using **transverse** beam polarization or info from other sectors: Higgs, neutralino etc.
- in CP–violating case $\Rightarrow$ two trajectories in $\{\tan\beta, M_2, \mu\}$ space parameterized by unknown $m_{\tilde{\chi}_2^\pm}$

$\Longrightarrow$ exploit neutralinos $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0,\ \tilde{\chi}_2^0\tilde{\chi}_2^0$

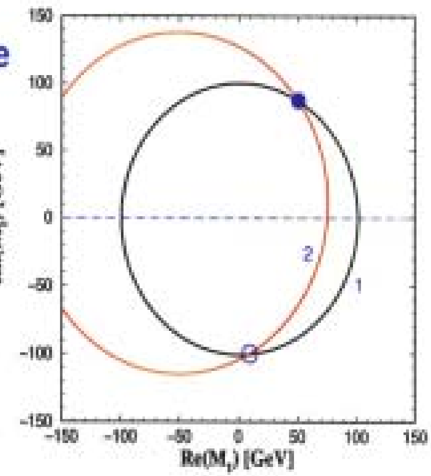
- neutralino masses satisfy the characteristic equation

$$m^8_{\tilde{\chi}^0_i} - a\, m^6_{\tilde{\chi}^0_i} + b\, m^4_{\tilde{\chi}^0_i} - c\, m^2_{\tilde{\chi}^0_i} + d = 0$$

a, b, c and d are binomials of $\Re e M_1$ and $\Im m M_1$

- equation for each $m^2_{\tilde{\chi}^0_i}$ has the form

$$(\Re e M_1)^2 + (\Im m M_1)^2 + u_i\, \Re e M_1 + v_i\, \Im m M_1 = w_i$$

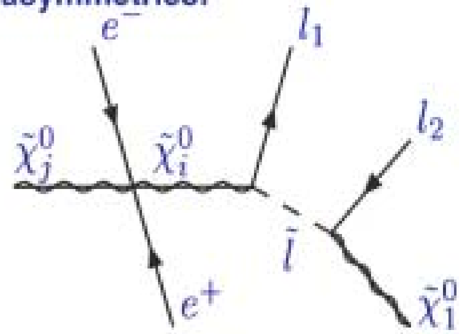


- each $m_{\tilde{\chi}^0_i}$ defines a circle in $\{\Re e M_1, \Im m M_1\}$ plane
- for $\tilde{\chi}^0_1$ and $\tilde{\chi}^0_2$: two crossing points
- crossing points will migrate with $m_{\tilde{\chi}^\pm_2}$
- use the measured cross section for $\tilde{\chi}^0_1\tilde{\chi}^0_2$ to select a unique solution for M_1 and predict the heavy chargino mass
- if LC runs concurrently with LHC, ask LHC friends to look for $\tilde{\chi}^\pm_2$

CP in the gaugino sector

CP-phases $\Longrightarrow$ masses, cross sections, decay rates,.. [Gaissmaier et al., '03]

best to measure CP-odd asymmetries: [Bartl et al., '03]



Define

$$T_I = \vec{p}(e^-) \times \vec{p}(\tilde{\chi}_i^0) \cdot \vec{p}(l_1)$$
$$T_{II} = \vec{p}(e^-) \times \vec{p}(l_1) \cdot \vec{p}(l_2)$$

and CP-odd asymmetry

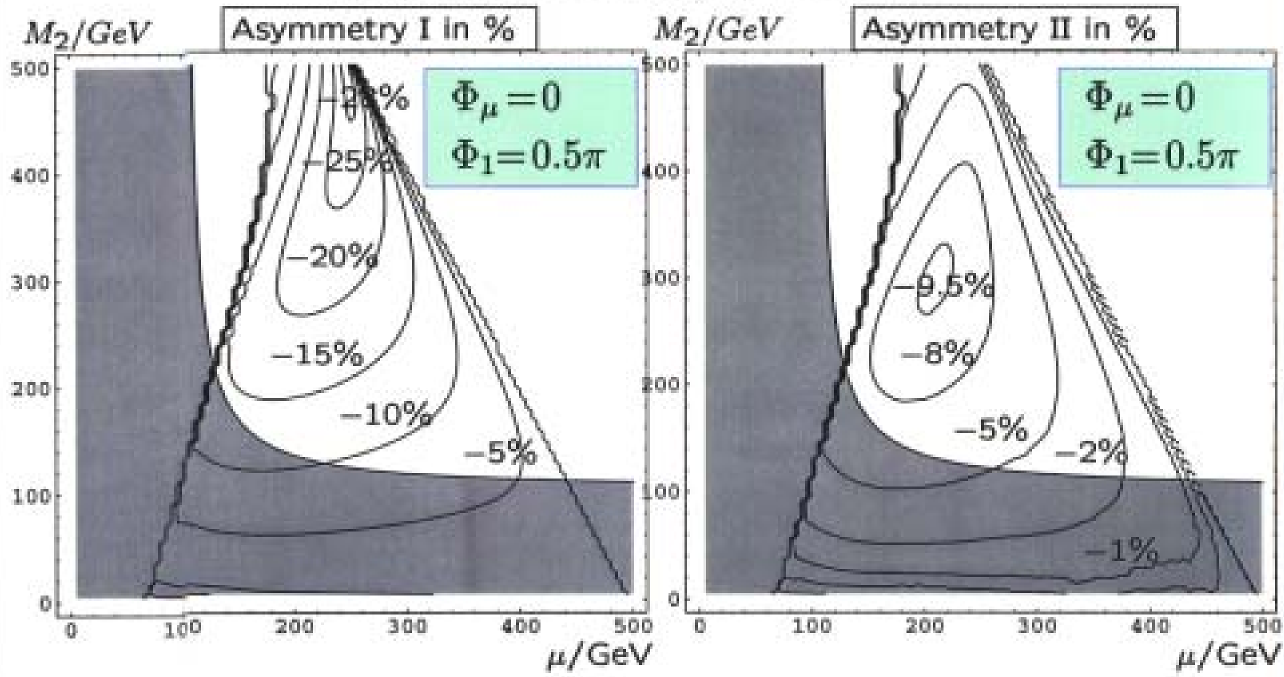
$$\mathcal{A} = \frac{\sigma(T > 0) - \sigma(T < 0)}{\sigma(T > 0) + \sigma(T < 0)}$$

CP in the gaugino sector

Asymmetries for $e^+e^- \longrightarrow \tilde{\chi}_1^0\tilde{\chi}_3^0$; $\tilde{\chi}_3^0 \longrightarrow \tilde{\ell}_R\ell$ *at* $\sqrt{s} = 500$ *GeV;*

$\tan\beta = 10$; $m_0 = 100$ *GeV*; $P(e^-) = 80\%$; $P(e^+) = -60\%$

grey shaded area: $M(\tilde{\chi}_1) < 104$ GeV



Electroweak Precision Tests and very little Alternative Theories

Klaus Mönig

DESY-Zeuthen

News since the TDR: on Triple Gauge Couplings

Optimal observables study for triple gauge couplings in e^+e^-

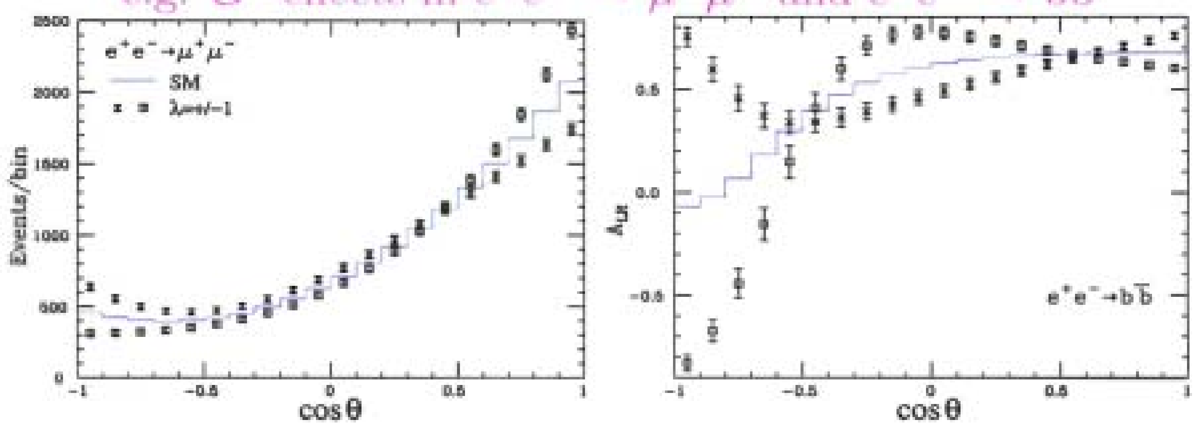
- study up to now only on parton level
- using optimal observables additional couplings (e.g. imaginary parts) can be included without a loss in precision
- precision on imaginary parts similar to real parts
- one combination ($\mathrm{Im}(g_1^R + \kappa_R)$) can only be measured with transverse polarization

Extra space dimensions

LC (and LHC) is sensitive to effects from KK graviton excitations (G^*)

- TDR status: visible effects from $e^+e^- \to \gamma G^*$ and $e^+e^- \to G^* \to f\bar{f}$ for $M_D < 8\,\mathrm{TeV}$ ($\sqrt{s} = 800\,\mathrm{GeV}$), similar to LHC

e.g. G^*-effects in $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to b\bar{b}$



- recent development: how can one distinguish extra dimensions from e.g. Z'?
- key: G^* has spin 2
- define moments $< P_n >= \int dz \frac{1}{\sigma}\frac{d\sigma}{dz} P_n(z)$ (P_n = Legendre polynomials)
- $s \leq 1$ exchange: $< P_n >= 0$ for $n > 2$
- $s = 2$ exchange: $< P_{3,4} > \neq 0$

➡ unique identification of $s = 2$ up to $4 - 5\,\mathrm{TeV}$

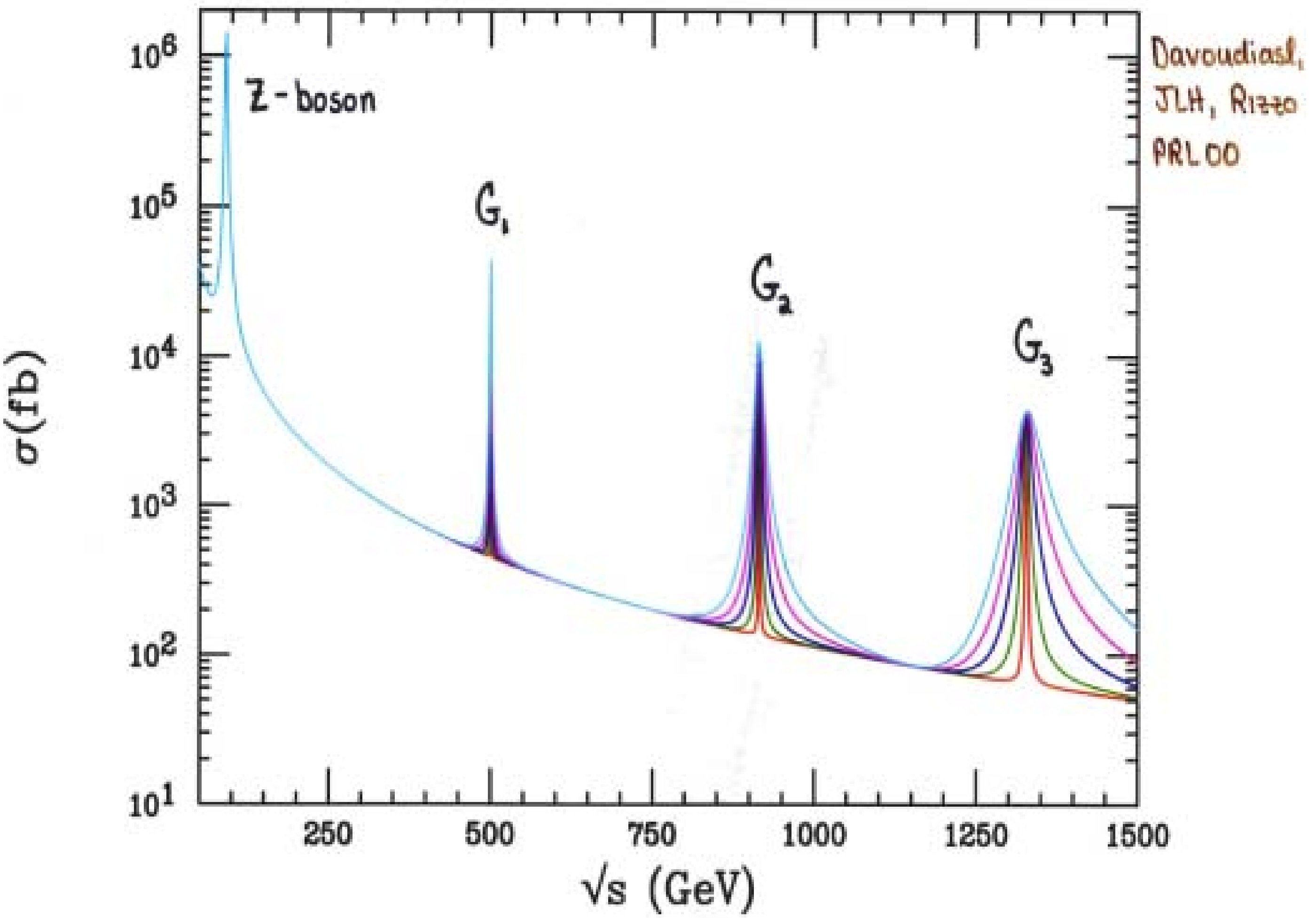
Additional possibility: transverse polarization

- with transverse beam polarization there exists an azimuthal asymmetry depending on $\cos\theta$ → plot
- this asymmetry is symmetric in $\cos\theta$ for vector or scalar particle exchange
- for tensor exchange (gravitons) it receives an asymmetric component

➡ Graviton and Z' exchange can be distinguished up to $M < 10\sqrt{s}$

- extra dimensions can be excluded up to $M_D <$ 10(22) TeV for $\sqrt{s} = 0.5(1)$ TeV
  (highest reach at next generation colliders)

$e^+e^- \to \mu^+\mu^-$ Line Shape

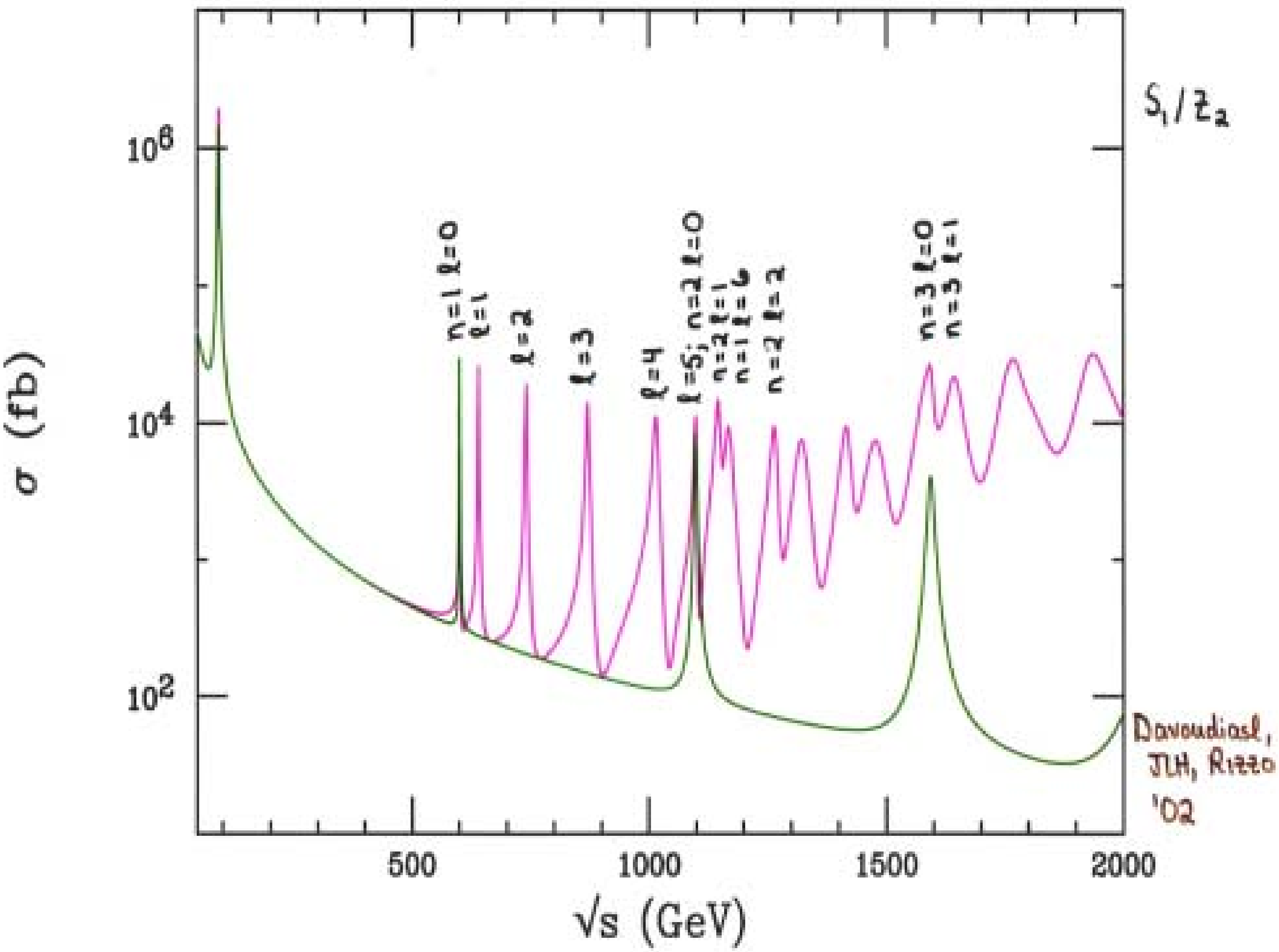


LC becomes a Graviton Factory!

Warped Geometry + Fat Brane

KR = 1
$K/\overline{M}_{Pl} = 0.03$

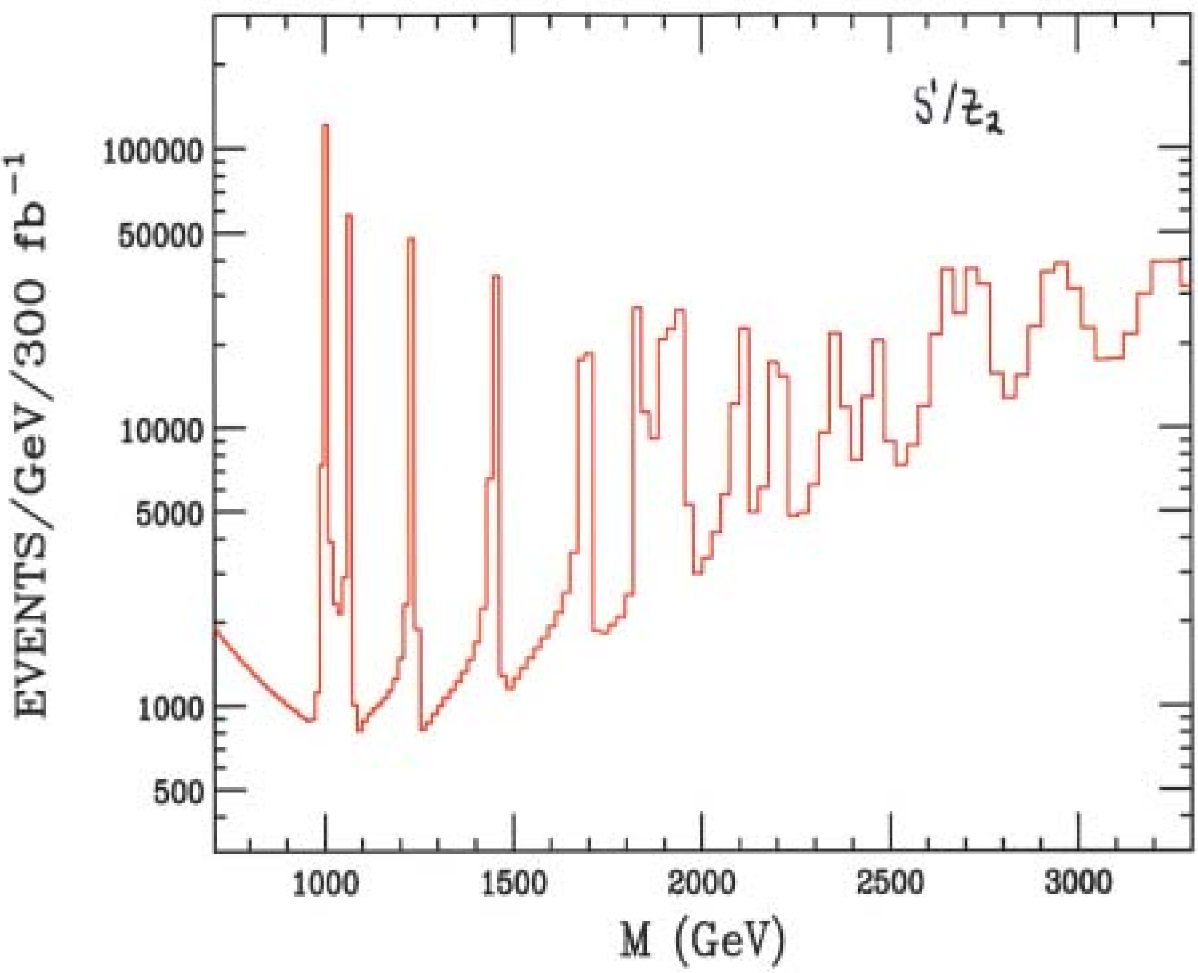
Graviton resonances in $e^+e^- \to \mu^+\mu^-$



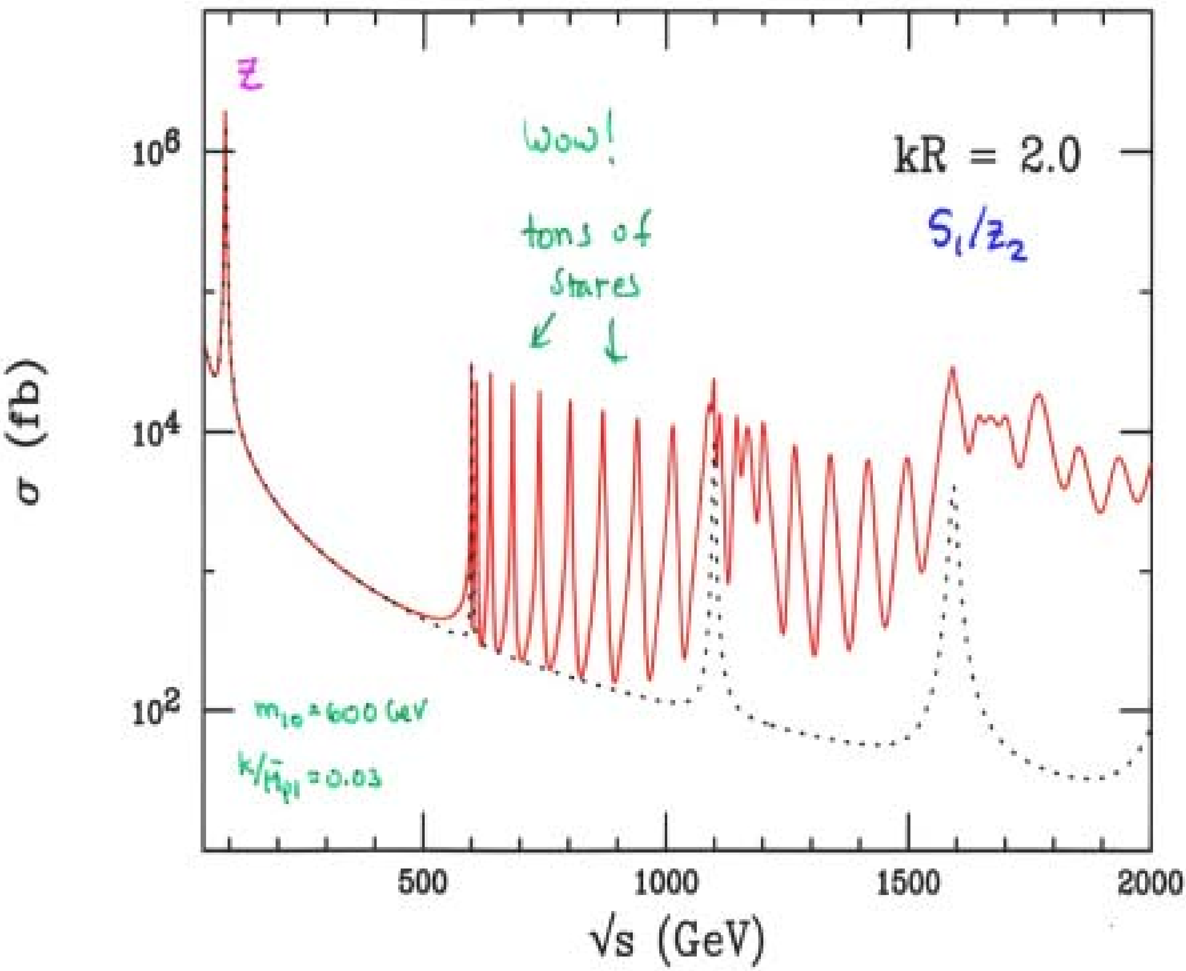
$$m_{n\ell} \simeq \left[x_n^2 + \frac{\ell^2}{(KR_c)^2} \right]^{1/2} K\, e^{-K\pi r_c}$$

Graviton Spectroscopy

Drell-Yan at LHC w/ smearing



increasing kR we get a denser forest ...



Outline for LHC / LC Study Group Working Document

The persons in charge of editing the different parts of the document are indicated in red. Please get in touch with them regarding your contribution.

The abstracts received for the different sections are linked below.

If an abstract is missing or if you would like to have something changed, please write to *Georg.Weiglein@durham.ac.uk*

1. Introduction

Physics case for LHC and LC
Different virtues of LHC and LC physics
Summary of further experimental aspects: detector capabilities at LHC and LC, etc.
---> *Heidi Schellman, Fabiola Gianotti, Daniel Denegri, Francois Richard*

LHC / LC interplay in the context of overlaps between particle physics and cosmology
---> *Heidi Schellman*

Aim of Study Group, summary of main results,
---> *All*

2. Electroweak Symmetry Breaking (Weakly)

2.1. Scenario where LHC sees a relatively light SM-like Higgs

Abstracts:

M. Battaglia, J. Hewett, T. Rizzo: Radion - Higgs mixing

Battaglia, Dominici, De Curtis, Gunion: Radion-Higgs search

A. Aranda, C. Bal\'azs, J.L. D\'\i az-Cruz: Hidden Higgs bosons

2.2. Scenario where Higgs mass found at LHC is considerably above indirect bound from precision data

2.1.-2.2. (include Radion physics, 'Little Higgs'):
---> *Albert De Roeck*

2.3. SUSY Higgs physics: scenario where only a light SM-like Higgs is found at the LHC

2.4. SUSY Higgs physics: scenario where also heavy Higgs states are seen at the LHC

Abstracts:

Desch, Heinemeyer, Moortgat, Weiglein: Higgs BR's direct and indirect, tan beta determination

2.5. SUSY Higgs physics: Influence of the χ^0_1 mass precision on the $H \to \chi^0_2\chi^0_2$ decay reconstruction

Abstracts:

F. Moortgat: Heavy MSSM Higgs Decays

2.3.--2.5.:
---> *Georg Weiglein*

2.6. Flavor-independent Higgs searches

Abstracts:

E. Berger et al: Higgs decay into hadronic jets

2.7. LC input to Higgs coupling measurements at the LHC