Selected ILD Analyses (full simulation)

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Helmholtz Alliance: *"Physics At The Terascale"*

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PHYSICS
AT THE
TERA
SCALE
Helmholtz Alliance

1 ILD Introduction

2 SM Analyses

- Higgs: cross section σ_{ZH} & mass m_H
- Tau Pairs: $\sigma_{\tau\tau}$ and A_{FB}
- Tau Pairs: Polarisation $\mathcal{P}_\tau$

3 SUSY Analyses

- Muon Signatures in SPS1a′
- Stau Pair Production in SPS1a′

4 Summary

ILC, ILD, and LoIs . . . what?

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  3 based on GLD & 3 on LDC simulation software
  (GLD, GLDPrime, GLD4LDC and LDC, LDCPrime, LDC4GLD)

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A lot of effort went into the ILD LoI document ($\approx$ 140 pages), mostly due to a detailed & realistic simulation of the entire ILD detector!

⇒ A year can be very short, but: **we made it!** . . . even on-time

http://www.ilcild.org/documents/ild-letter-of-intent/LOI.pdf

Disclaimer

The analyses were not done to show the ultimate ILC precision reach, but to help optimise the ILD detector using "real" physics observables !

SM: ZH-recoil ($\rightarrow m_H$, σ_{ZH}, and BRs), $t\bar{t} \rightarrow bq\bar{q}\,\bar{b}q\bar{q}$ (m_t and Γ_t), WW-scattering to study EWSB, $\tau\tau$-prod. ($\rightarrow \sigma_{\tau\tau}$, A_{FB}, $\mathcal{P}_\tau$), and ZHH production ($\rightarrow$ Higgs self coupling)

SP5: $\widetilde{\chi}_1^+\widetilde{\chi}_1^-(\widetilde{\chi}_2^0\,\widetilde{\chi}_2^0) \rightarrow W(Z)\widetilde{\chi}_1^0\,W(Z)\widetilde{\chi}_1^0$ (gaugino masses)

SPS1a′: $\widetilde{\mu}$ production ($\rightarrow m_{\widetilde{\chi}_1^0}$, $m_{\widetilde{\chi}_2^0}$ and $m_{\widetilde{\mu}_L}$),
$\widetilde{\tau}$ system ($m_{\widetilde{\tau}}$, $\mathcal{P}_\tau$ $\rightarrow$ τ-mixing & underlying model parameters)

Other: model indep. WIMP search, long-lived $\widetilde{\chi}^0$ in GMSB model, WW production ($\rightarrow$ beam pol $\mathcal{P}_{beam}$), and Littlest Higgs Model

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  background: $\int \mathcal{L}\, dt \gtrsim 250$ fb^{-1} (for most samples)
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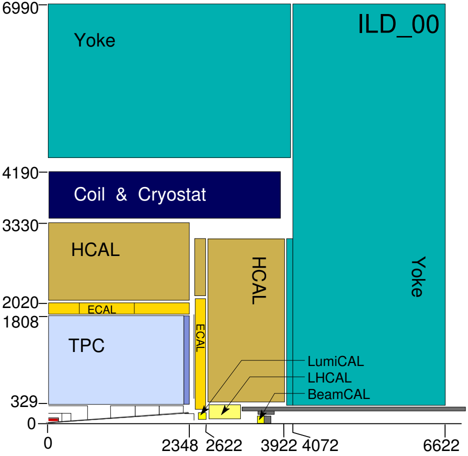
  a HUGE effort → production of 44 million events in total!
- Detailed detector simulation: for sim. events
  use reasonable geometries for all subdetectors; include accurate descriptions of dead regions, support structures & even cabling
  (MOKKA & MARLINRECO: geometry interface & event reconstruction)
- Full reconstruction for all events utilised in optimisation studies and/or physics analyses (no reference to MC truth information)

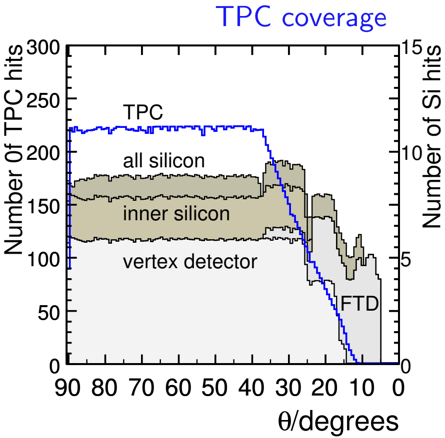
ILD Detector
“Basics”

ILD Detector

Quadrant view of the ILD detector as implemented in the simulation



Number of hits for sim. charged particle tracks versus $\cos\theta$



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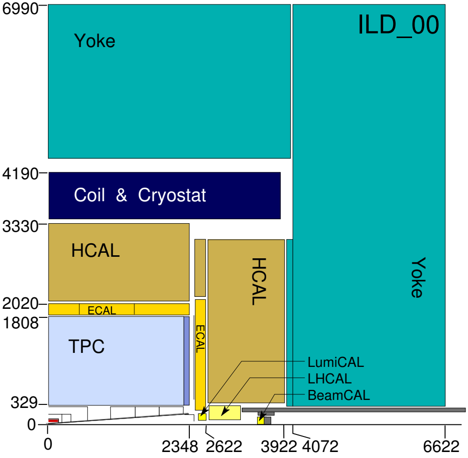
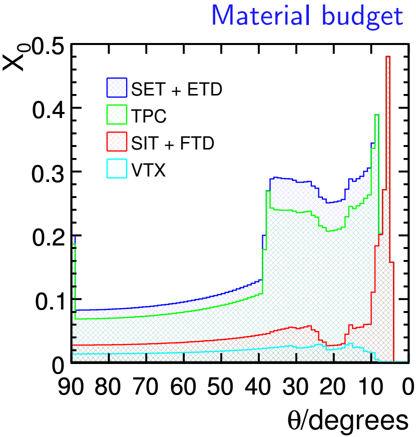


Rad. lengths λ_{I} of the material from all ILD tracking detectors



ILD Detector Characteristics

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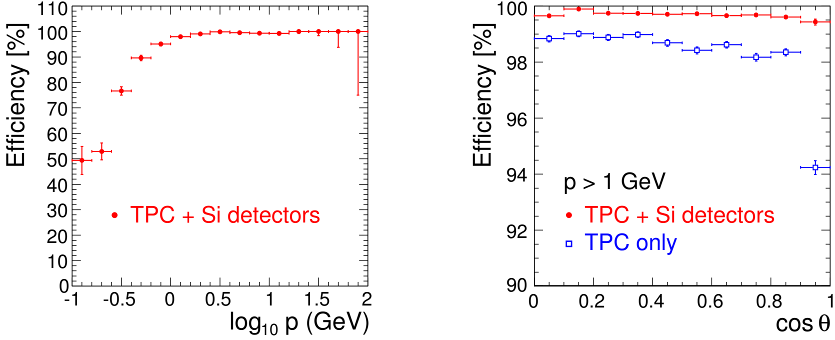
Tracking efficiency for simulated $t\bar{t} \rightarrow 6$ jet events at $\sqrt{s} = 500$ GeV



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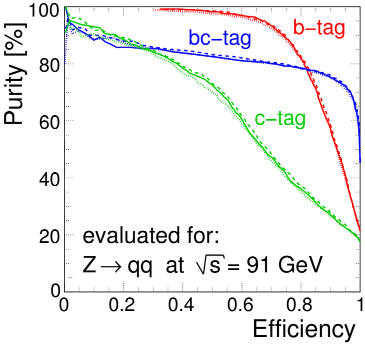
Flavour tagging:

b-tag: excellent b-jet recognition

c-tag: reasonable discrimination of c-jets vs light quark- & b-jets

bc-tag: very good b/c-jet separation



evaluated for:
$Z \rightarrow qq$ at $\sqrt{s} = 91$ GeV

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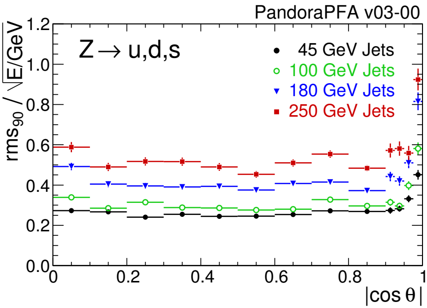

Jet energy resolution
constant $\delta E_j / E_j \approx 3.1\%$

E_{jet}	$\delta E_j / E_j$ [%]
45 GeV	$3.71 \pm 0.05\%$
100 GeV	$2.95 \pm 0.04\%$
180 GeV	$2.99 \pm 0.04\%$
250 GeV	$3.17 \pm 0.05\%$

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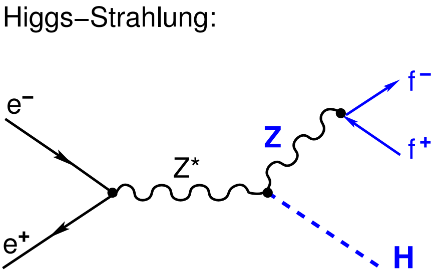
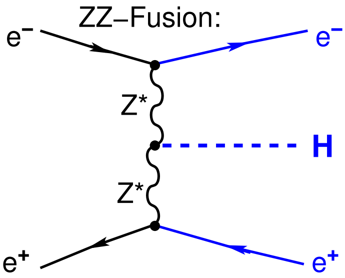
⇒ **All resolutions are implemented in the ILD detector simulation !**
(. . . material is also accounted for)

SM Higgs Boson
Cross Section & Mass

Higgs Production @ ILC





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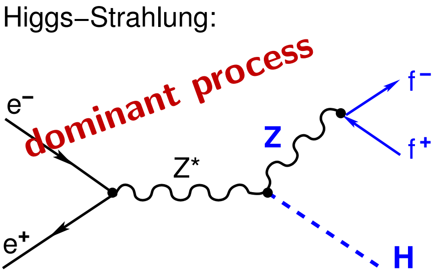

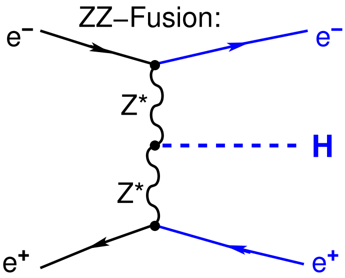

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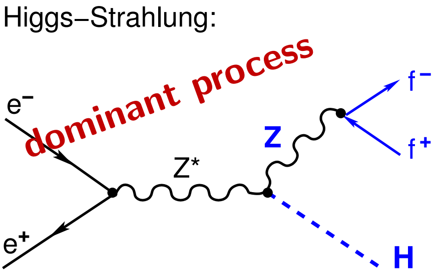

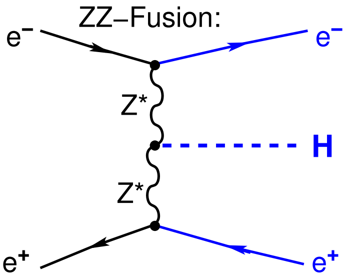

- assume a Higgs mass of $m_H = 120$ GeV (done @ $\sqrt{s} = 250$ GeV)
- well-known ILC initial state & clean e^+e^- environment
  $\longrightarrow$ ZH-recoil analysis of leptonic Z-decays

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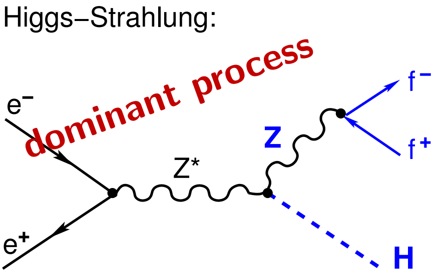

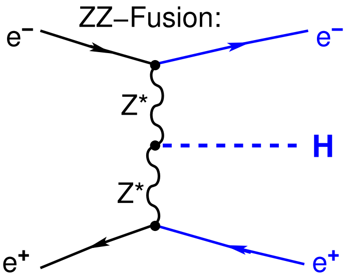

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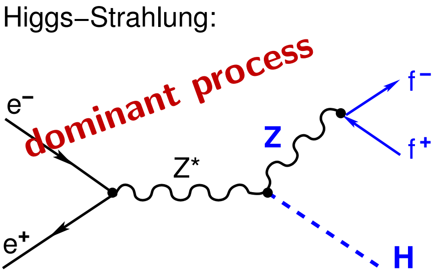

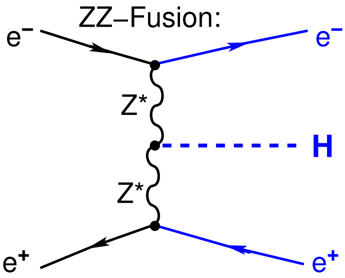

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Analysis optimised for Higgs-Strahlung process → latest results!

ZH Signal Selection

- Consider both polarisation modes $\mathcal{P}(e^-_L e^+_R)$ and $\mathcal{P}(e^-_R e^+_L)$, a beam energy spread of $E_b = 0.28\%_{(e^-)} \,/\, 0.18\%_{(e^+)}$ and beamstrahlung

Lepton identification & background suppression:

- discard lepton tracks with large uncert. δp on reco'd momentum p
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⇒ **Signal efficiencies:** $\boldsymbol{\varepsilon_{(e^+e^-X)} = 98.8\%}$, $\boldsymbol{\varepsilon_{(\mu^+\mu^-X)} = 95.4\%}$

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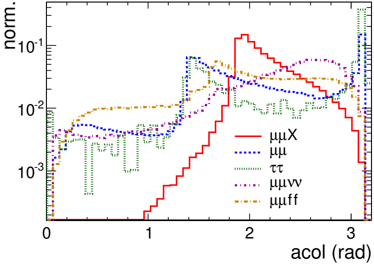
- transverse momentum balance: $\boldsymbol{p_T^{bal} = p_{T,\ell\ell} - p_T^{\gamma}}$
- and for events with at least 2 additional tracks: $|\Delta\theta_{tracks}|$

ZH Signal Selection, cont'd

Rejection of diboson bkgd. ZZ, WW:

- multi-variate likelihood analysis:

  acolinearity $Acol = \text{acos}\left(\frac{\vec{p}_{\ell+}+\vec{p}_{\ell-}}{|\vec{p}_{\ell+}||\vec{p}_{\ell-}|}\right)$



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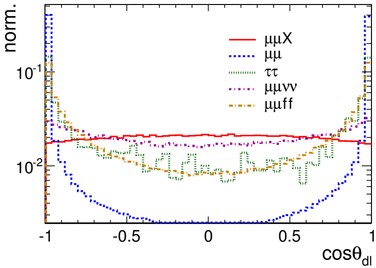

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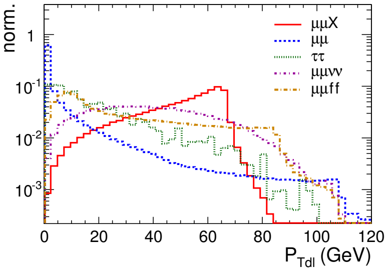

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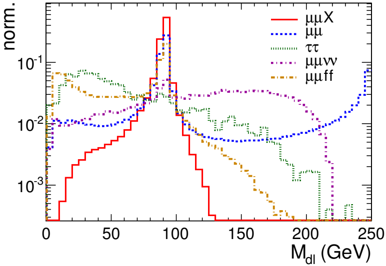

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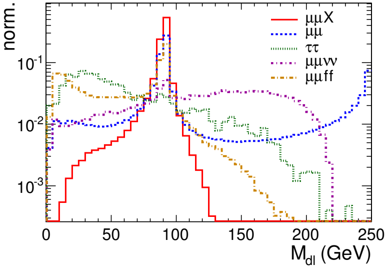

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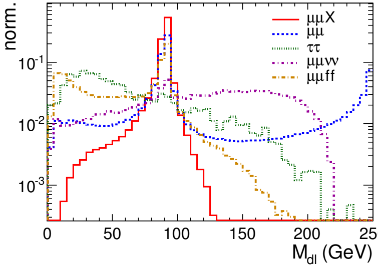

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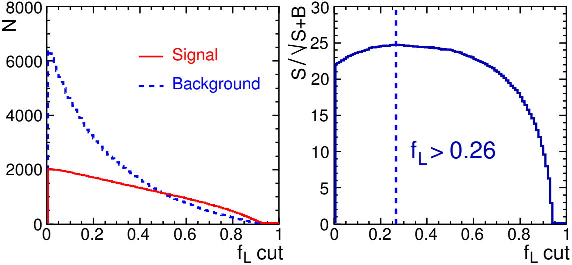

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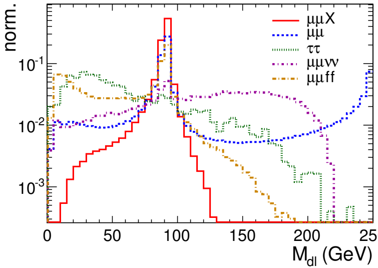

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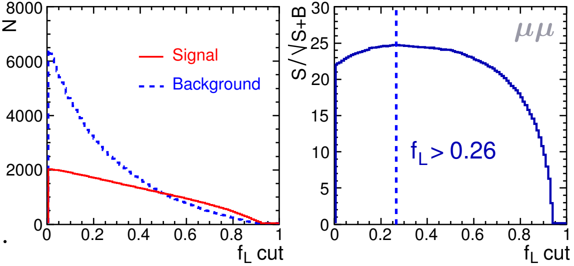
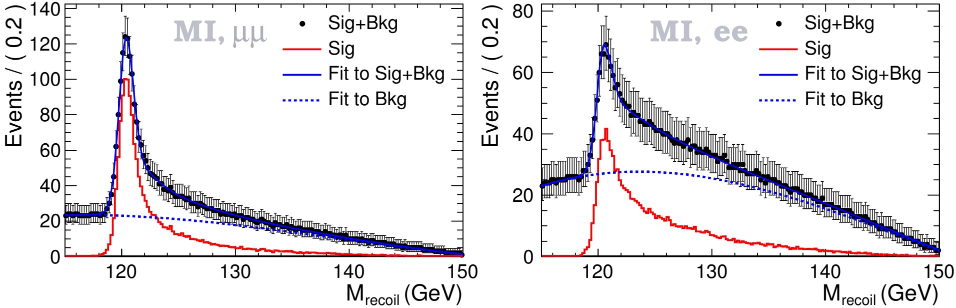
$\mathcal{P}(e^-_L e^+_R) = (-80, +30)\%$

- cut on f_L varies slightly depending on polarisation mode and analysis type . . .



Extraction of σ_{ZH} and m_H



$$f(x) = N \begin{cases} e^{-\frac{(x-x_0)^2}{2\,\sigma^2}} & : \ \frac{x-x_0}{\sigma} \le k \\ \beta \cdot e^{-\frac{(x-x_0)^2}{2\,\sigma^2}} + (1-\beta)\cdot e^{-k\frac{x-x_0}{\sigma}} \ e^{\frac{k^2}{2}} & : \ \frac{x-x_0}{\sigma} > k \end{cases}$$

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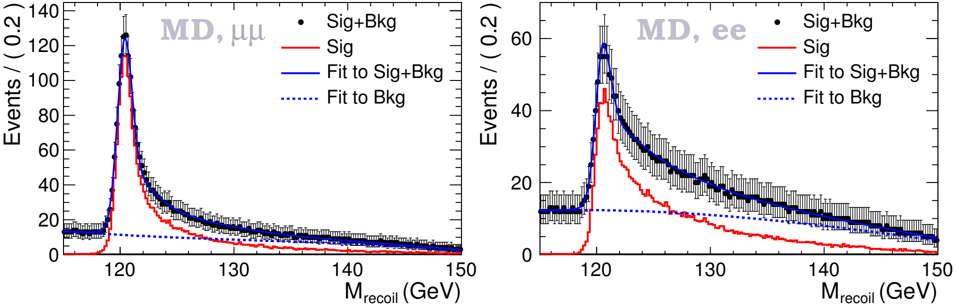

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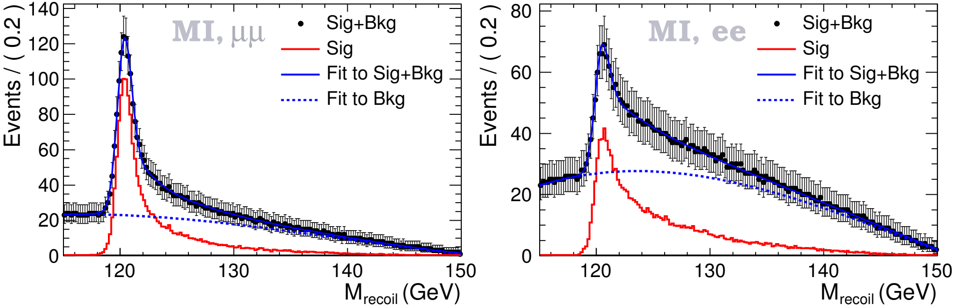
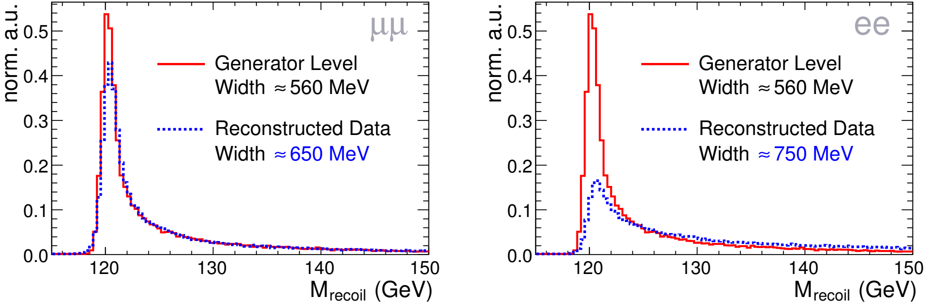
Extraction of σ_{ZH} and m_H



Model-indep. (MI) vs. model-dep. (MD) analysis, assuming SM decays & BRs for the Higgs → add. tracks & improved selection → further backgr. reduction

channel	$\delta(m_H)$	cross section stat. error $\delta(\sigma_{ZH})$	
$\mu\mu X$	37 / 31 MeV	±0.39 / ±0.32 fb	3.4% / 2.8%
eeX	87 / 66 MeV	±0.62 / ±0.45 fb	4.9% / 3.6%
$\boldsymbol{eeX \oplus \mu\mu X}$	34 / 28 MeV		2.8% / 2.2%

Machine & Detector Influences



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  ↘ depends on intrinsic E_{beam} spread & beamstrahlung for every $\sqrt{s}$

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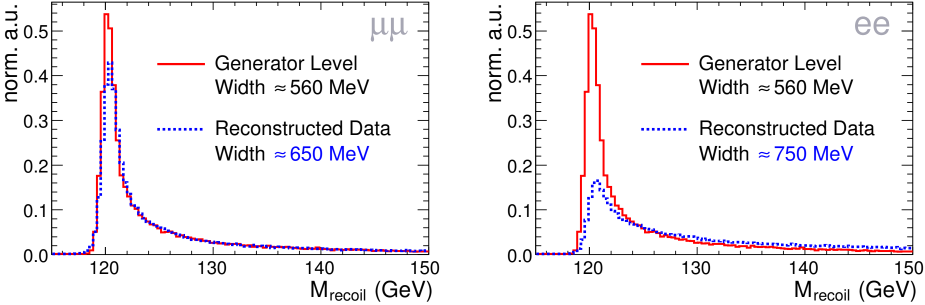

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- influence of detector response differs:

channel	δm_{total}	$\delta m_{\text{machine}}$	δm_{det}
$\mu\mu X$	650 MeV	560 MeV	330 MeV
eeX	750 MeV	560 MeV	500 MeV

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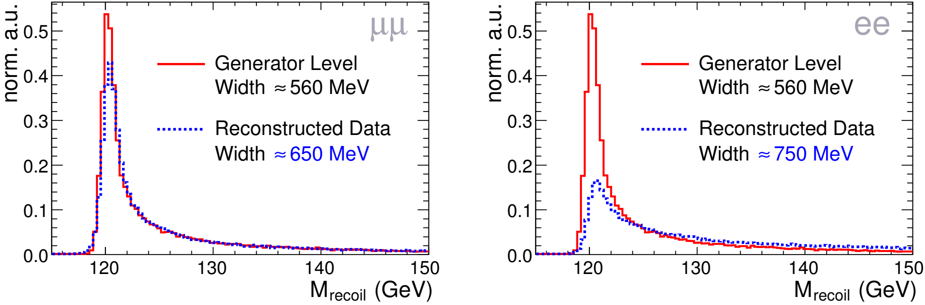

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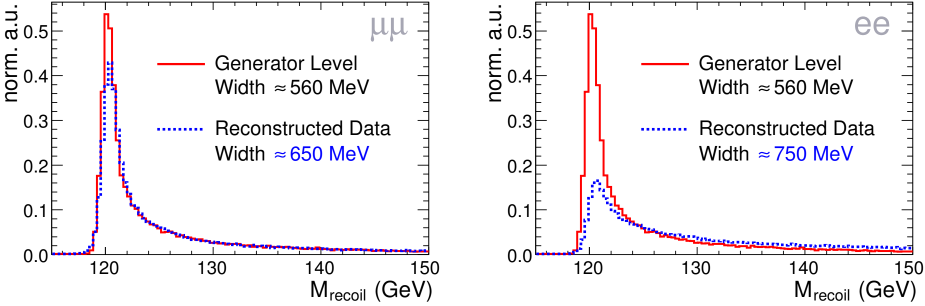

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- mass resolution is clearly machine-dominated in $\boldsymbol{\mu\mu X}$, while both (machine & detector) have about similar importance in $\boldsymbol{eeX}$

Tau Pairs

$\sigma_{\tau\tau}$ / $A_{\mathbf{FB}}$ / $\mathcal{P}_{\tau}$

Measuring τ-Pairs . . . ?

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- only select events with < 7 tracks and 2 opp. charged jets as $\tau^+\tau^-$ pairs (since about 99% of all τ-decays contain less than 3 charged particles)
- extremely small opening angle < 50 mrad of assumed τ-decay products, or: small opening angle < 1 rad and $m_{\rm inv} < 2$ GeV $(m_\tau = 1.777 \text{ GeV})$

Selection of $\tau\tau$ Pairs (background suppression)

Main backgrounds: $ee \rightarrow ee$ (Bhabha), $WW \rightarrow \ell\nu\,\ell\nu$, $\gamma\gamma(\rightarrow \tau\tau)$

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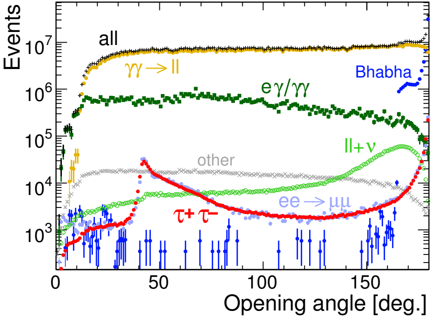

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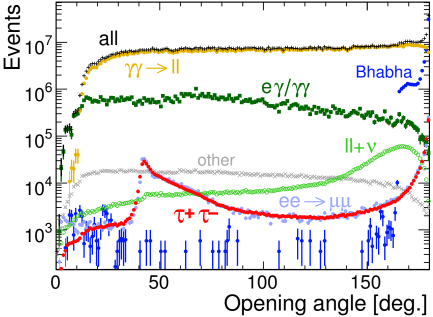

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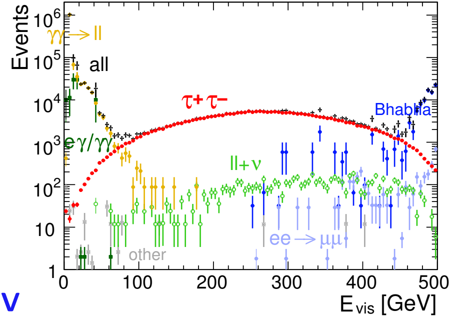

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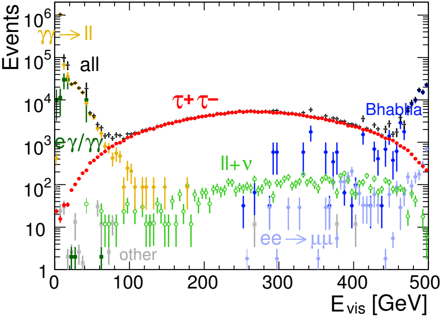

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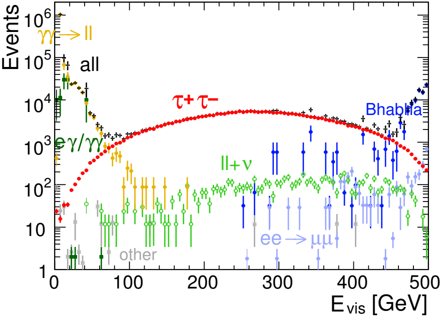

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$\Rightarrow$ **Background can be suppressed to $\approx$ 10% of the $\tau\tau$ signal !**

Cross Section $\sigma_{\tau\tau}$ & Asymmetry A_{FB}

Cross section can be determined with stat. precision of $\approx$ 0.30%

	p	ε	$N_S\,[10^3]$	$N_B\,[10^3]$	$\delta\,\sigma_{\tau\tau}$
$\mathcal{P}(e_L^- e_R^+)$	92.4%	15.8%	$\approx$ 125.4	$\approx$ 10.3	0.29%
$\mathcal{P}(e_R^- e_L^+)$	93.6%	16.3%	$\approx$ 103.2	$\approx$ 7.1	0.32%

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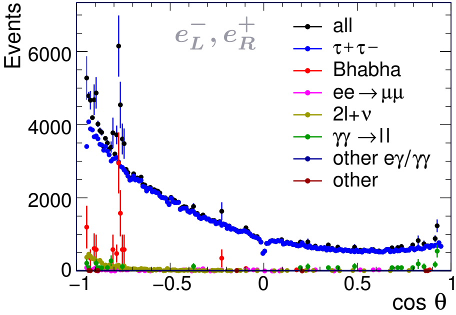

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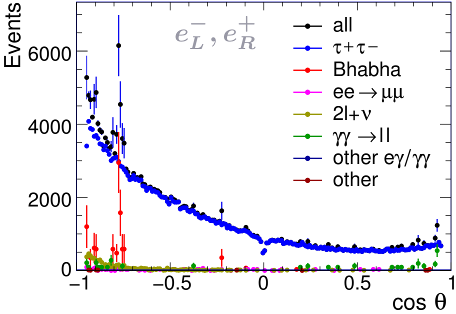
Shown for τ^+, but it looks exactly analogue for τ^- leptons due to the demand on the opening angle ($> 178°$)



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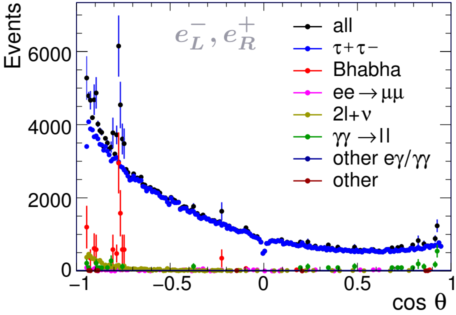

Decay Modes & Separation

Dominant τ^- decay modes, c.c. for τ^+:

$\tau^- \to e^- \bar{\nu}_e \, \nu_\tau$	17.9%	$\boldsymbol{\tau \to \pi\nu \, / \, \rho\nu}$
$\tau^- \to \mu^- \bar{\nu}_\mu \, \nu_\tau$	17.4%	highest sensitivity
$\boldsymbol{\tau^- \to \pi^- \nu_\tau}$	10.9%	to τ-polarisation $\mathcal{P}_\tau$
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The remaining modes (10.3%) include decays to kaons & multi-π decays.

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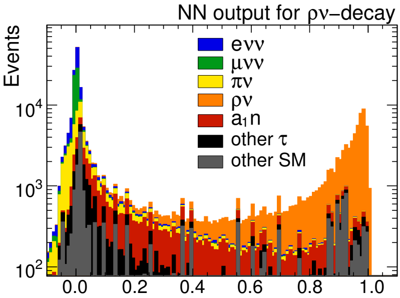
Much improved since LoI: NN-based selection instead of simple cuts:

- use **six diff. NNs**, one per decay mode



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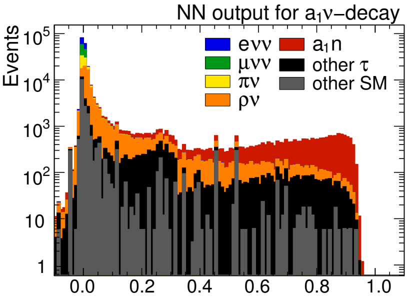

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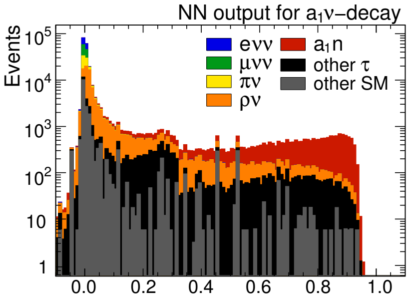

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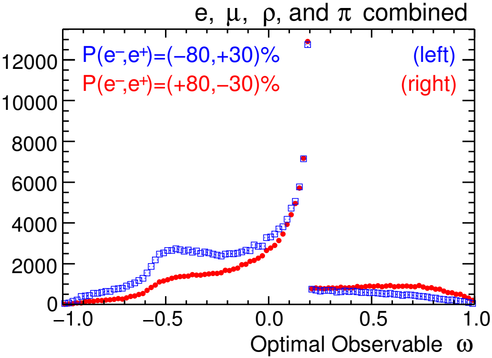
- combine all six decay modes and determine the $\boldsymbol{\tau}$ **polarisation**

decay mode	ε [%]	p [%]
$e\nu\nu$	98.9	93.2
$\mu\nu\nu$	98.8	89.7
$\pi\nu$	96.0	84.3
$\rho\nu$	91.6	83.0
$a_1\nu$, (1-pr.)	78.5	86.7
$a_1\nu$, (3-pr.)	91.1	86.7

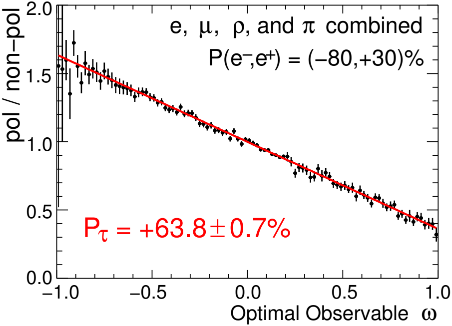
Polarisation $\mathcal{P}_\tau$

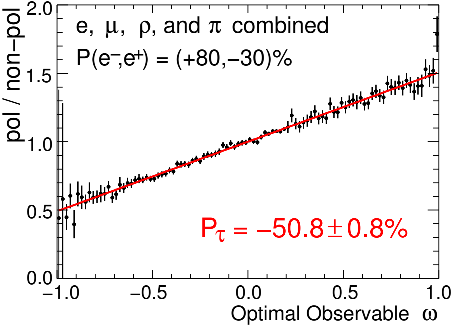
All τ-decay distr. have same analytic form: can be split into pol.-dep./-indep. parts → use optimal observables (one per mode)
→ then combine diff. optimal observables into one common ω



Polarisation $\mathcal{P}_\tau$

⇒ Extract the polarisation $\mathcal{P}_\tau$ from linear fits to the ratio of polarised to non-polarised sample in the ω distribution:





SUSY or rather:

SPS1a$'$

General SUSY and SPS1a′

SUSY could provide a rich spectrum & phenomenology of kinematically accessible particles @ ILC energies (up to $\sqrt{s} = 500$ GeV)

New Physics: complex mixture of dom. & sub-dom. processes/states (?) that might lead to the same visible final states anyway . . .

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A_0	-300
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particle masses	
$m(\widetilde{\chi}_1^0)$	97.7 GeV
$m(\widetilde{\chi}_2^0)$	183.9 GeV
$m(\widetilde{\mu}_R)$	125.3 GeV
$m(\widetilde{\mu}_L)$	189.9 GeV
$m(\widetilde{\tau}_1)$	107.9 GeV

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SUSY parameters	
M_0	70 GeV
$M_{1/2}$	250 GeV
A_0	-300
sign(μ)	$+1$
tanβ	10

particle masses	
$m(\widetilde{\chi}_1^0)$	97.7 GeV
$m(\widetilde{\chi}_2^0)$	183.9 GeV
$m(\widetilde{\mu}_R)$	125.3 GeV
$m(\widetilde{\mu}_L)$	189.9 GeV
$m(\widetilde{\tau}_1)$	107.9 GeV

$\Rightarrow$ **Consider diff. final states, either with $\mu\mu\,\not{E}_T$, or with $\tau\tau\,\not{E}_T$!**

SUSY SPS1a$'$

$\mu\mu\,\not{E}_T$ Signatures

SPS1a$'$: pure mSUGRA model → conserved R-parity & CP
features light mass spectrum in the gaugino/slepton sector

Dimuon Signatures $\mu\mu \not{E}_T$

Concentrate on sub-dominant processes with $\mu\mu \not{E}_T$ final states!

(i.e. scenarios with large SUSY background due to suppressed $\mu\mu$ decay modes)

Measure $m_{\widetilde{\chi}_1^0}$, $m_{\widetilde{\chi}_2^0}$, and $\widetilde{\mu}_L$ using the two processes:

- $\boldsymbol{e^+e^- \to \widetilde{\chi}_2^0\widetilde{\chi}_1^0 \to \mu\widetilde{\chi}_1^0\,\mu\widetilde{\chi}_1^0}$ with $\sigma \approx 4.1$ fb
- $\boldsymbol{e^+e^- \to \widetilde{\mu}_L\widetilde{\mu}_L \to \mu\widetilde{\chi}_1^0\,\mu\widetilde{\chi}_1^0}$ with $\sigma \approx 54$ fb

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Both signals feature: 2 high energetic μ's and (quite a lot) $\not{E}_T$

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Identification & background rejection:

- tracking + HCAL info. + outer μ-chambers → μ-ID: $\varepsilon \approx$ 95%
- define two signal samples: $\widetilde{\mu}_L\widetilde{\mu}_L \rightarrow \mu\mu \not{E}_T$ and $\widetilde{\chi}_2^0\widetilde{\chi}_1^0 \rightarrow \mu\mu \not{E}_T$

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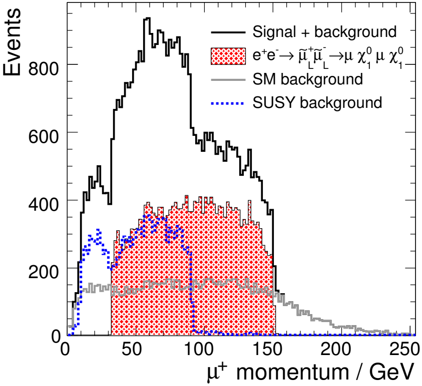
- selection requirements use:
  $\not\!\!E_T$, $m_{inv}(\mu\mu)$ and m_{recoil}, the transverse momentum p_T, and the direction & speed of the $\mu\mu$-system in the laboratory frame

Measuring $\widetilde{\chi}_1^0$ and $\widetilde{\mu}_L$ Masses

Use $\widetilde{\mu}_L\widetilde{\mu}_L$ production to measure these masses from the position of the kinematic edges in the μ^+ momentum distribution:



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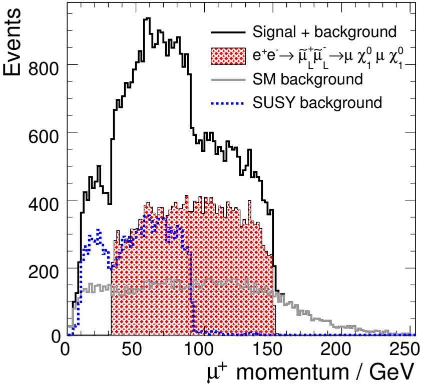
Fit signal edges at ≈32 GeV and ≈151 GeV with a step function → statistical uncert. of:

$$\delta m_{\widetilde{\chi}_1^0} = 1.40\%$$
$$\delta m_{\widetilde{\mu}_L} = 0.27\%$$



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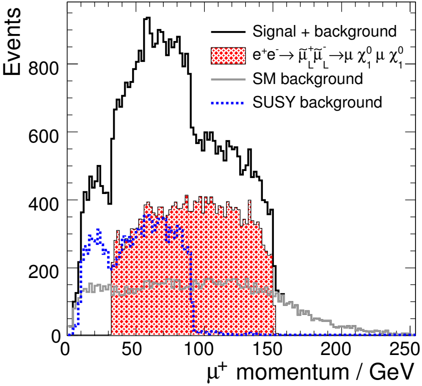

Measuring $\tilde{\chi}_1^0$ and $\tilde{\mu}_L$ Masses

Use $\tilde{\mu}_L\tilde{\mu}_L$ production to measure these masses from the position of the kinematic edges in the μ^+ momentum distribution:

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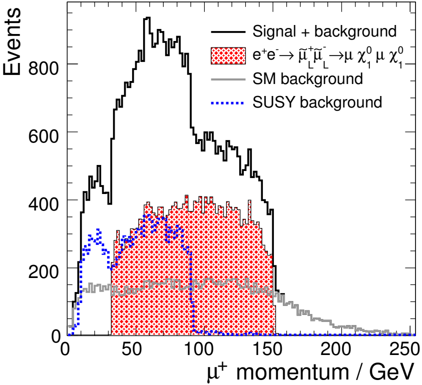
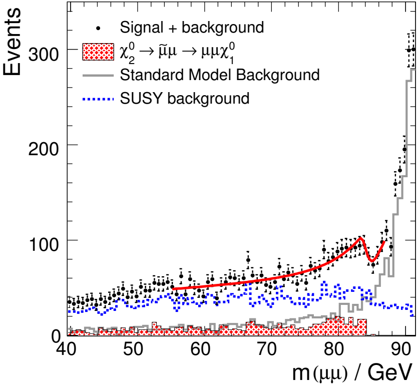


Definedness of the kinematic edges (→ mass measurement) is not so much limited by track or mom. resolution, **but rather by beam-strahlung !**

(For the ILC "low power" option $\delta m_{\tilde{\chi}_1^0}$ could be up to a factor ≈ 2 worse . . .)

Measuring the $\widetilde{\chi}_2^0$ Mass

Use $\boldsymbol{\widetilde{\chi}_2^0\widetilde{\chi}_1^0}$ production to measure the $\widetilde{\chi}_2^0$ mass from the position of the kinematic edge in the $\mu\mu$ mass distribution:



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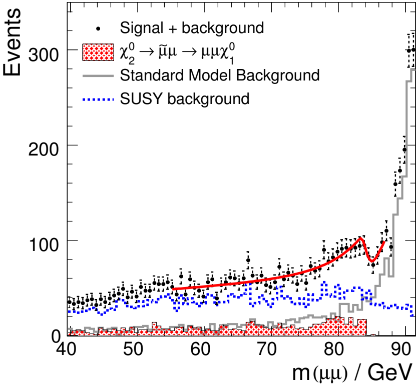
Edge just visible below the Z-peak!
Fit in: 40 GeV $< m_{\mu\mu} <$ 85 GeV
→ statistical uncert. of:

$$\boldsymbol{\delta m_{\widetilde{\chi}_2^0} = 1.41\%}$$

The statistical significance of excess in this region corresponds to about 9 standard deviations



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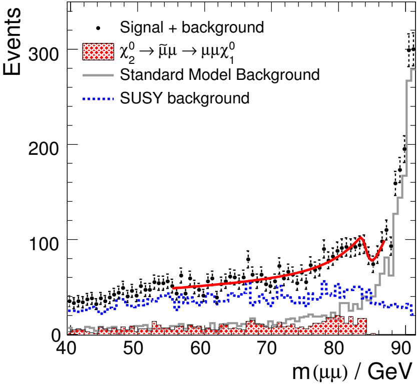

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$\widetilde{\chi}_2^0\widetilde{\chi}_1^0$ prod. would increase by ≈ 50%
(with only a small increase in background)
if ILC would operate with **60% positron polarisation** instead of 30% !

SUSY SPS1a$'$
$\widetilde{\tau}\widetilde{\tau}$ Prod. & Decay

SPS1a$'$: pure mSUGRA model → conserved R-parity & CP
features light mass spectrum in the gaugino/slepton sector

Why the $\widetilde{\tau}$ System?

Main objectives w.r.t. detector optimisation:

- what are ILD's capabilities for processes particularly sensitive to (machine induced) beam-beam background?
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- SPS1a′(in particular the $\widetilde{\tau}$ system) provides a rich phenomenology → underlining advantages of an e^+e^- collider tunable not only in beam energy E_b, but also in beam polarisation $\mathcal{P}_b$!

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- $\widetilde{\tau}_1$ is NLSP $\rightarrow$ $\Delta m(\widetilde{\tau}_1, \widetilde{\chi}^0_1) = 10.2$ GeV
- achievable stat. precision on $m_{\widetilde{\tau}_1}$, $\sigma_{\widetilde{\tau}_1\widetilde{\tau}_1}$, and $\mathcal{P}_\tau$? ($\widetilde{\tau}^+_1\widetilde{\tau}^-_1 \rightarrow \tau^+\widetilde{\chi}^0_1\,\tau^-\widetilde{\chi}^0_1$) and on $m_{\widetilde{\tau}_2}$, and $\sigma_{\widetilde{\tau}_2\widetilde{\tau}_2}$? (using $\widetilde{\tau}^+_2\widetilde{\tau}^-_2 \rightarrow \tau^+\widetilde{\chi}^0_1\,\tau^-\widetilde{\chi}^0_1$)

Key Characteristics & Backgrounds

$e^+e^- \to \widetilde{\tau}_1^+\widetilde{\tau}_1^-$ and $e^+e^- \to \widetilde{\tau}_2^+\widetilde{\tau}_2^-$ production:

- two acollinear τ leptons in final state with $E_{\tau,max} \lesssim$ 43 GeV
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$m_{\tilde{\tau}}$: SUSY bkgd. less important; $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp/\tilde{\chi}_2^0\tilde{\chi}_2^0$ production dominate
kinematic limits well below $\tilde{\tau}_1/\tilde{\tau}_2$ prod. → little influence on endpoint
$\mathcal{P}_\tau$: need entire spectrum → SUSY bkgd. gains importance
(need slightly different selection criteria for diff. analyses)

Some Selection Requirements

Topological selection ($\widetilde{\tau}_1$ & $\widetilde{\tau}_2$) and $\gamma\gamma$ bkgd. rejection:

- exactly 2 low-multiplicity τ-jets with opp. charge & $m_{jet} <$ 2.5 GeV
- total $E_{vis} <$ 300 GeV, but $m_{miss} >$ 250 GeV (due to $\widetilde{\chi}^0_1$'s and ν's)

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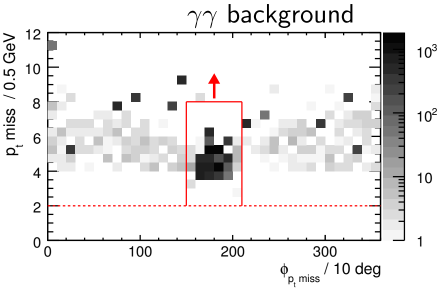

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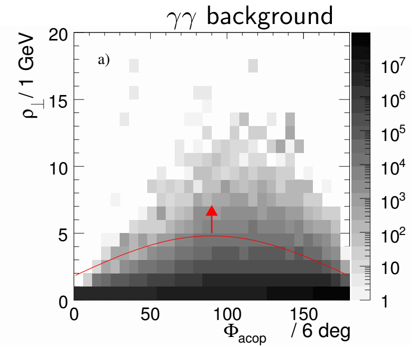

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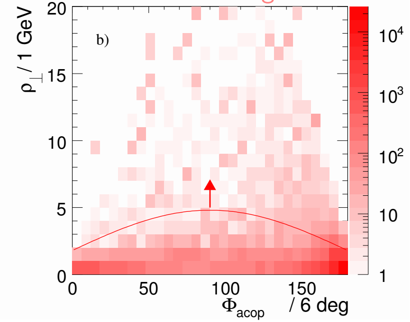
other SM background



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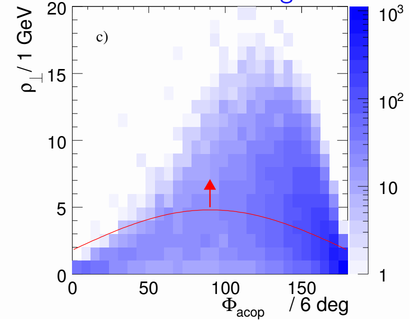
$\widetilde{\tau}\widetilde{\tau}$ signal



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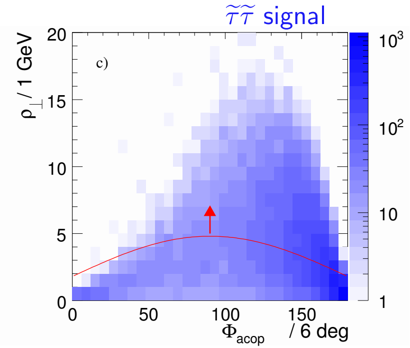
- more requirements depending on the analysis goal: $\boldsymbol{\sigma_{\tilde{\tau}\tilde{\tau}}}$, $\boldsymbol{m_{\tilde{\tau}_{1,2}}}$, or $\boldsymbol{\mathcal{P}_{\tau}}$



Endpoint Fit $\longrightarrow$ $m_{\widetilde{\tau}_1}$

- SPS1a′: has sizable co-annihilation contribution to DM relic density
  $\longrightarrow$ makes $m_{\widetilde{\tau}_1}$ an especially important quantity!
- measure upper endpoint of $\widetilde{\tau}_1$ energy spectrum: $E_{\tau,max}$
  SUSY will be a major source of bkgd due to NLSP-$\widetilde{\tau}_1$ $\rightarrow$ cascade decays

  (Measure $E_{\tau,min}$ in add. $\rightarrow m_{\widetilde{\chi}_1^0}$, but $E_{\tau,min} < 3$ GeV: overwhelming $\gamma\gamma$ bkgd! Easier in $\widetilde{\tau}_2$ decays where $E_{\tau,min} \approx 35$ GeV: $\gamma\gamma$ bkgd less severe, but more $WW \rightarrow \ell\nu\,\ell\nu$)

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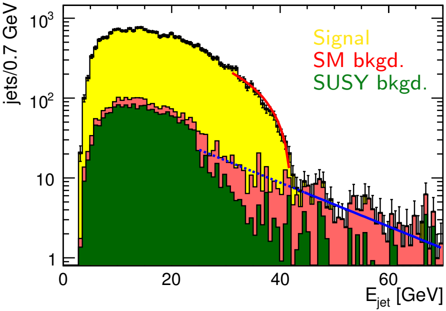
& extrapolate into signal region



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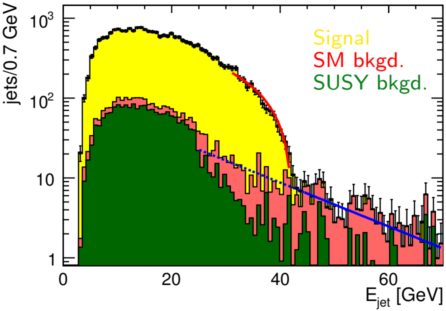
straight-line fit to total sample ($30 < E < 41.5$ GeV) → endpoint defined at crossover of both fits



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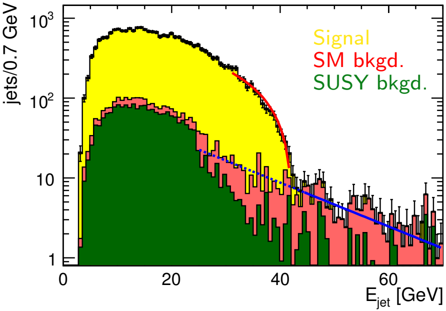

- $m_{\widetilde{\tau}_1} = 107.69^{+0.03}_{-0.06}$ GeV $\pm 1.1 \cdot \delta m_{\widetilde{\chi}^0_1}$
  $m_{\widetilde{\tau}_1} = 107.9$ GeV (nom. value)

Statistical uncertainty on $m_{\widetilde{\tau}}$ is entirely dominated by neutralino mass error!

Determination of $\mathcal{P}_\tau$

τ polarisation ↔ key observable in characterising the $\widetilde{\tau}$ system:

- depends on: mixing angle of $\widetilde{\tau}$ chiral & mass eigenstates ($\theta_{\widetilde{\tau}}$), and on the Higgsino & gaugino components of the $\widetilde{\chi}_1^0$-LSP

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- 2 ways to $\theta_{\widetilde{\tau}}$: cross sections & endpoints of E_τ-spectra (4 meas.) or from mixed $\widetilde{\tau}_1\widetilde{\tau}_2$ production → more sensitive!
  $\Rightarrow$ ILC needs to run between thresholds for $\widetilde{\tau}_1\widetilde{\tau}_1$ / $\widetilde{\tau}_2\widetilde{\tau}_2$ production
  for SPS1a′ @ $\sqrt{s} = 303..390$ GeV, but study done @ 500 GeV $\rightarrow \theta_{\widetilde{\tau}}$ not determined!

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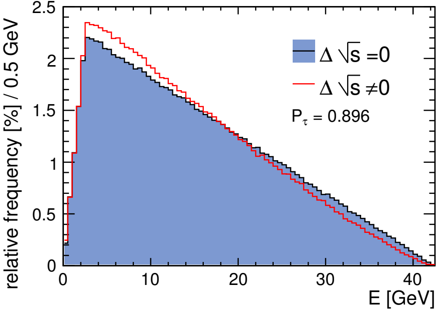
- depends on: mixing angle of $\widetilde{\tau}$ chiral & mass eigenstates ($\theta_{\widetilde{\tau}}$), and on the Higgsino & gaugino components of the $\widetilde{\chi}_1^0$-LSP

Use $\widetilde{\tau} \rightarrow \pi^\pm \nu_\tau$ decay:

- non-negl. beam spread & ISR effects $\rightarrow$ parametrise true E_π spectra for extreme polarisations ($\mathcal{P}_\tau = \pm 1$)
- expected true E_π spectra can then be calculated for any τ polarisation

E_π spectrum for $\widetilde{\tau}_1 \rightarrow \tau \rightarrow \pi\nu_\tau$

gen. w/o ILC beam spectrum & ISR



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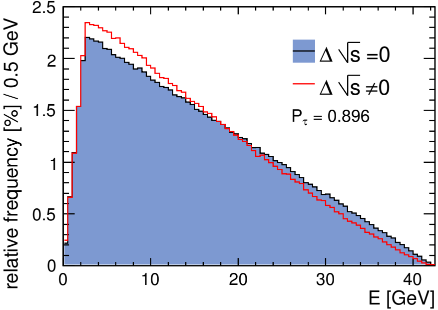

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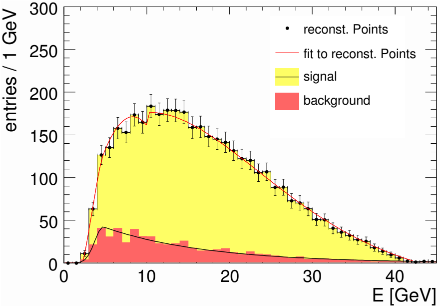
- fit resulting, eff. corrected spectrum with theoretical distr. and correct for ISR & ILC beam spread → extract:

$$\boldsymbol{\mathcal{P}_\tau^{obs} = 91 \pm 6 \pm 5\,(\text{bkg}) \pm 3\,(m_{SUSY})\%}$$

$\mathcal{P}_\tau^{exp} = 89.6\%$ for comparison

fit-"dent" @ 10 GeV: discontinuity in efficiency par. ↔ p.d.f change in PFA



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- do not use CAL-based PFlowObj.-ID (π^0 clusters close to tracks); use instead TPC dE/dx to reject $\tau \to e\nu\nu$ and $\tau \to K^\pm \pi\nu$, and $\boldsymbol{m_{jet}}$ around $\boldsymbol{\rho}$ mass
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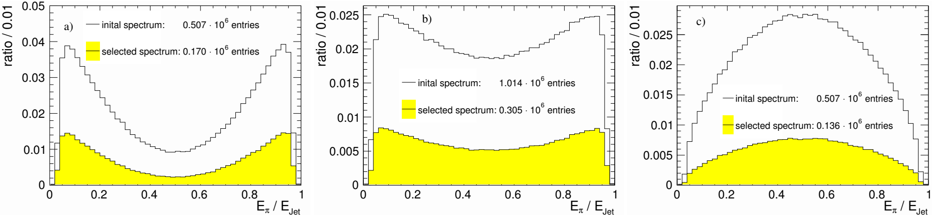

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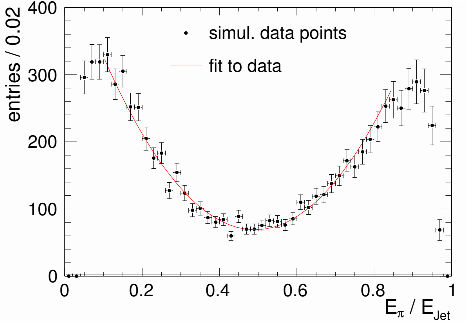
  both, in overall selection eff. and for low and high R efficiencies



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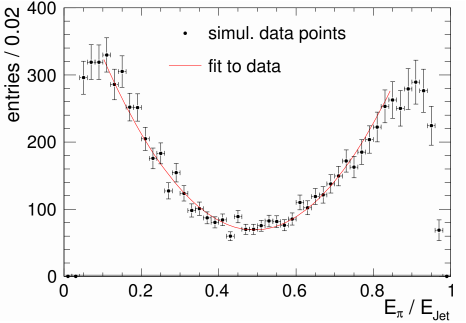

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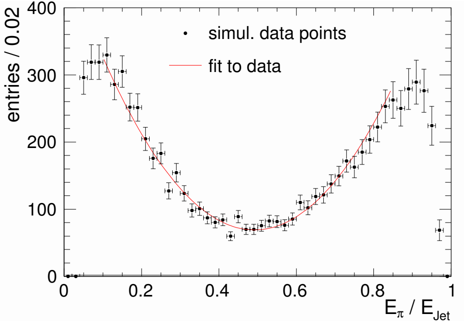

$\mathcal{P}_\tau^{obs} = \mathbf{87.0 \pm 3.4\%}$ 89.6% (exp)

only small imapct exp. from m_τ and $m_{\widetilde{\chi}^0_1}$

Conclusion and Outlook

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- some analyses ($ZHH \rightarrow$ Higgs self coupling) do not yet reach fast-sim. sensitivity, but: many issues already identified + some ideas!
- $\widetilde{\tau}$ system: achieved full-sim. precision okay! But, lesson learned: $\Rightarrow$ ILC operation @ 500 GeV is not optimal for in-depth $\widetilde{\tau}$ study!

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  ⇒ **the ILC (& ILD detector) are approved and being built!**

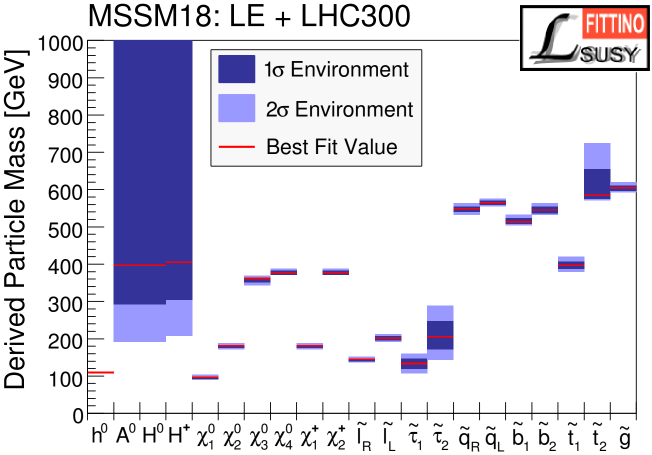
Thank You!

Some Advertisment for ILC

MSSM18: no assumptions on unification & breaking mechanisms!

MSSM18: gen. MSSM + mild assumptions:

- ▷ absent flavour-non-diagonal & CP-violating terms
- ▷ eff. universality of first two particle generation



LE: data from low-energy measurements

LHC300: expected LHC meas. for $\mathcal{L}^{int} = 300$ fb^{-1}

Some MSSM18 sparticle masses are not accessible @ LHC

⇒ uncertertainties large compared to constrained models

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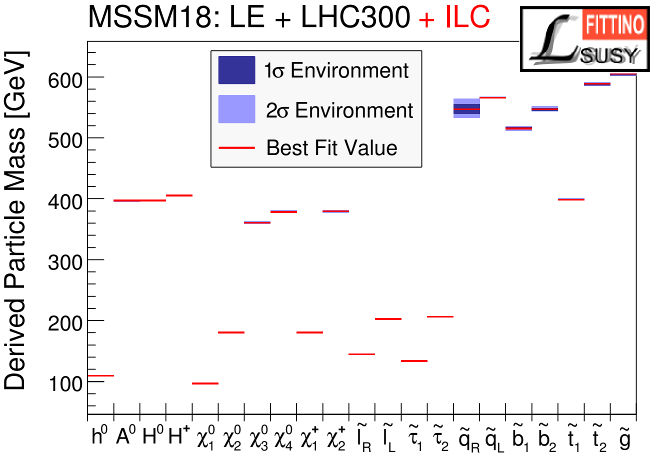

Increase in precision not limited to param's linked directly to observables @ tree level; strong decrease of correlations

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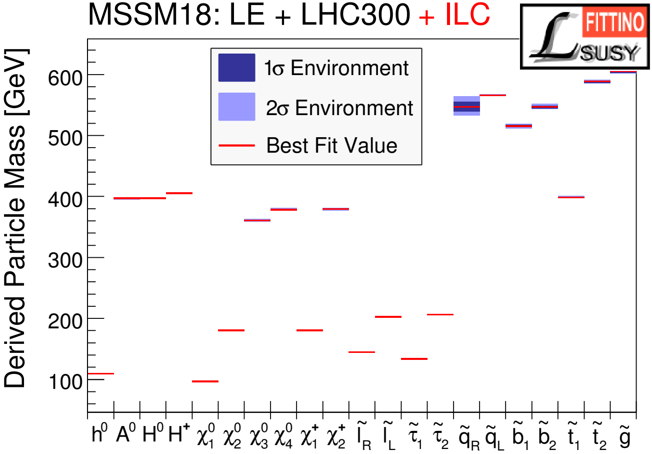

Fittino: arXiv:0907.2589v1 [hep-ph] July, 2009

ILC tremendously improves the theoretical understanding of ANY SUSY-scenario in agreement with cosmological & low-energy data!

BACKUP

SUSY Point 5: Gaugino Production

SP 5: includes non-universal soft breaking contributions to Higgs masses
$\widetilde{\chi}_1^{\pm}$ and $\widetilde{\chi}_2^0$ nearly mass degenerate: $m_{\widetilde{\chi}_1^{\pm}} = 216.5$ GeV, $m_{\widetilde{\chi}_2^0} = 216.7$ GeV

Gaugino Production in SUSY Point 5

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…separating W and Z hadronic decays:

- requires excellent jet energy resolution, and
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In addition, $\sigma(\widetilde{\chi}_2^0\widetilde{\chi}_2^0)$ only $\approx$ 10% of $\sigma(\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\mp)$ $\rightarrow$ complex analysis!

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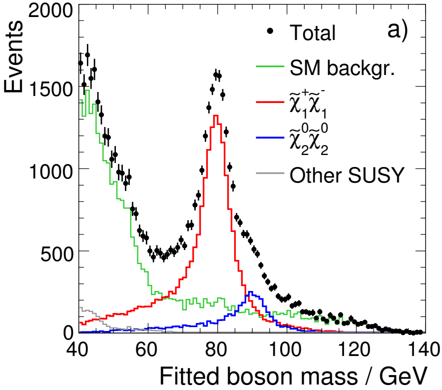

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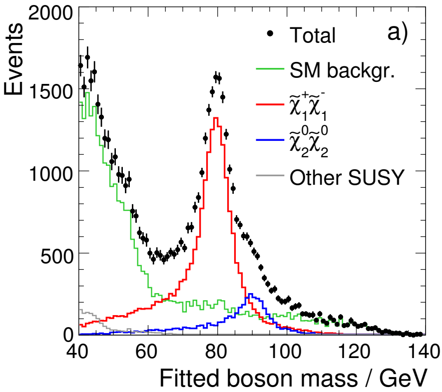

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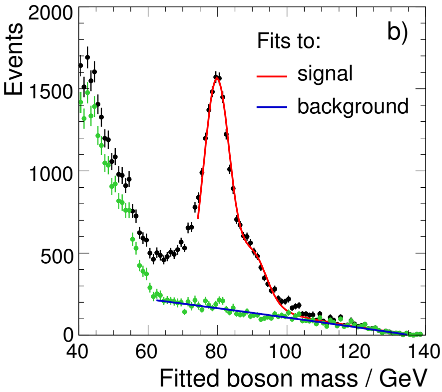

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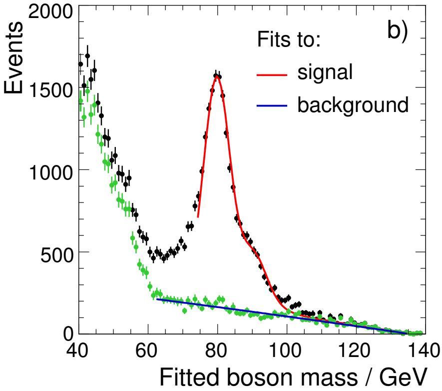

2nd strategy uses MC-templates to fit 2D m_{jj} distributions, leaving only normalisations of the two signal contrib's as free parameters . . .

Gaugino Mass Determination

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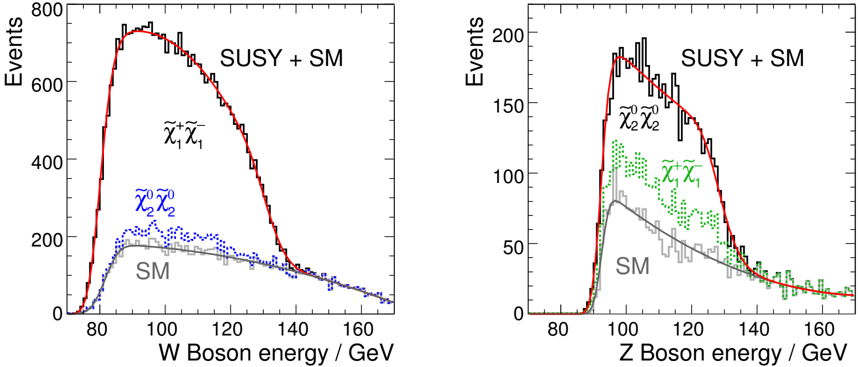

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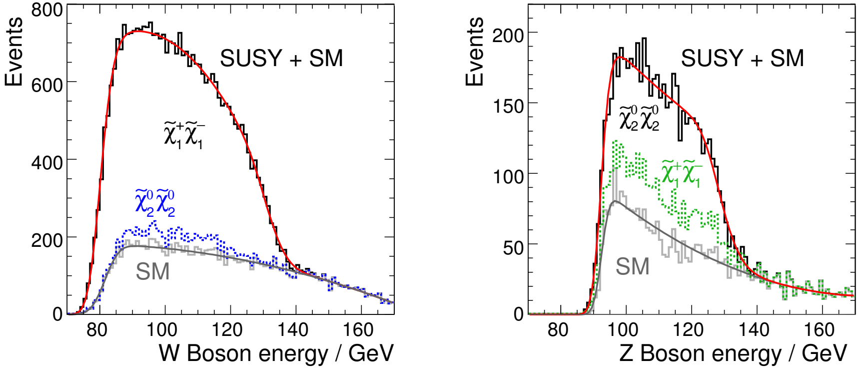

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Fit spectra using an empirical signal function + SM bkgd. parametrisation
→ upper/lower kinematic edges → determine gaugino mass
(both upper edges are rather sensitive to beam & luminosity spectrum!)

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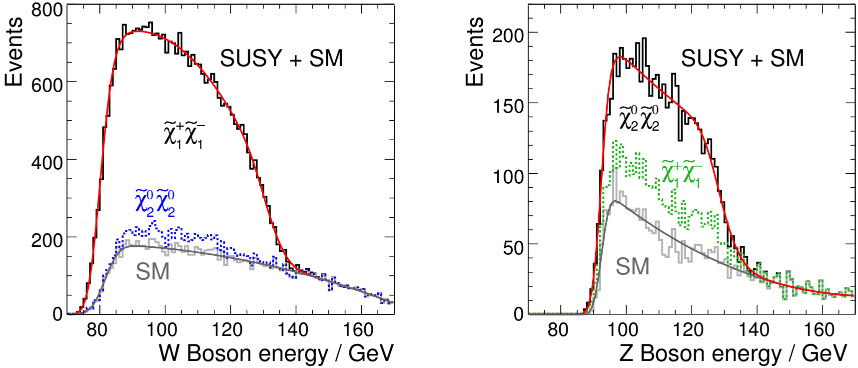

$$\left.\begin{array}{l} E_W : \pm 0.2 \,/ \pm 0.7 \text{ GeV} \\ E_Z : \pm 0.4 \,/ \pm 0.8 \text{ GeV} \end{array}\right\} \begin{array}{lll} \delta m_{\widetilde{\chi}_1^{\pm}} = 2.9 \text{ GeV} & 2.4 \text{ GeV} \\ \delta m_{\widetilde{\chi}_2^0} = 1.7 \text{ GeV} & 0.9 \text{ GeV} \\ \delta m_{\widetilde{\chi}_1^0} = 1.0 \text{ GeV} & 0.8 \text{ GeV} \end{array} \left\{ \begin{array}{l} \text{for 7C-fit, with:} \\ m_{jj} = m_W / m_Z \end{array}\right.$$

Uncert. on masses are larger due to strong correlation of gaugino masses!

SM Higgs Boson Branching Ratios

Higgs Branching Ratios (BR)

. . . allow a test of the SM-hypothesis: $\boldsymbol{H}$-coupling $\propto$ $\boldsymbol{m_{particle}}$
use again: $m_H = 120$ GeV

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- simultaneously determine stat. error on exclusive cross sections for each topology & combine each with the 5% uncert. on the total Higgs-Strahlung cross section σ_{ZH}

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- simultaneously determine stat. error on exclusive cross sections for each topology & combine each with the 5% uncert. on the total Higgs-Strahlung cross section σ_{ZH}

$\Rightarrow$ **extract BRs and their corresponding statistical uncertainties!**

Different Z-decay Topologies

$ZH \rightarrow \ell\ell\, q\bar{q}$: 2 high-$p_T$ leptons + 2 jets

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  $\Rightarrow$ completely independent of wether H decays into $b\bar{b}$, $c\bar{c}$, or gg !
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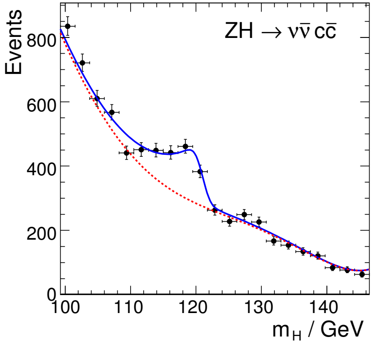
- use b-, c-, and bc-flavour tags!
  reconstruct m_{jj} & fit signal contrib.
  for b-/ c-tagged sample separately



Branching Ratios: Results

$ZH \to q\bar{q}\,c\bar{c}$: 4 jets, one m_{jj} compatible with m_Z

- 4j-events from $Z/\gamma^* \to q\bar{q}$ fragmentation, (mostly $q\bar{q}\,gg$ final state)
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The results mostly agree with earlier fast simulation analyses !

TESLA TDR: http://tesla.desy.de/new_pages/TDR_CD/PartIV/detect.html

Sensitivity to Higgs Self-Coupling

Study $e^+e^- \rightarrow ZHH \rightarrow q\bar{q}\, b\bar{b}\, b\bar{b}$ (only 34% of all ZHH-decays)

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Higgs trilinear coupling measurement will be very difficult . . .

Sensitivity does not yet approach that of earlier fast sim. studies!