NLO simulations of chargino production at the International Linear Collider

Tania Robens

DESY

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1. Introduction and Motivation
   - Chargino and Neutralino sector in the MSSM
   - NLO results for $\sigma_{ee \to \tilde{\chi}\tilde{\chi}}$
2. NLO corrections in Whizard
   - Virtual corrections
   - Real photon contributions
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3. First results:
   - σ_{tot}
   - angular distributions
4. Summary and Outlook

Chargino and Neutralino sector in the MSSM

- Supersymmetric theories: New SUSY (breaking) parameters appear in the superpotential and the soft breaking terms
- Gaugino and higgsino sector of the MSSM:

  $\tan\beta$, μ (Higgs sector)
  M_1, M_2 (soft breaking terms)

- can be reconstructed from (Choi et al 1998, 2000,2001)

  masses of $\widetilde{\chi}_1^\pm$, $\widetilde{\chi}_2^\pm$, $\widetilde{\chi}_1^0$
  2 σ in the $\widetilde{\chi}^\pm$ sector

$\Rightarrow$ reconstruction of SUSY breaking scale parameters + mechanism

(Blair et al 2002)

- "experimental" and parameter fitting accuracy: % to ‰

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- First order virtual corrections for $\widetilde{\chi}\,\widetilde{\chi}$:
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σ_{corr} contributions and dependencies:

- σ_{born}
- virtual $\mathcal{O}(\alpha)$ corrections: $\sigma_{virt}(\lambda)$
- emission of 1 soft/ hard collinear/ hard non-collinear photon:

  $\sigma_{soft}(\Delta E, \lambda) + \sigma_{hc}(\Delta E, \Delta\theta) + \sigma_{2\to 3}(\Delta E, \Delta\theta)$
- higher order initial state radiation: $\sigma_{ISR} - \sigma_{ISR}^{\mathcal{O}(\alpha)}(Q)$

  λ: photon mass , ΔE: soft cut , $\Delta\theta$: collinear angle

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- experimental/ fitting routines errors on the % /‰ level
- loop corrections of equal size

⇒ need to include NLO results in Monte Carlo Generators ⇐

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- so far: analytic results for σ_{corr} for $2 \to 2(/3)$ process
- experiments: see final decay products

  e.g. $e^+ e^- \to \tilde\chi_1^+ \tilde\chi_1^- \to \tilde\tau_1^+ \tilde\tau_1^- \nu_\tau \bar\nu_\tau \, (\to \tau^+ \tau^- \nu_\tau \bar\nu_\tau \tilde\chi_1^0 \tilde\chi_1^0)$
- need to compare with simulated event samples
- also: important irreducible background effects
  (→ talk W. Kilian)

(also: angular distributions, ...)

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TECHNICALITIES: Virtual corrections

- Fritzsche et al: use FeynArts/ FormCalc to obtain

$$\mathcal{M}_{born},\ \mathcal{M}_{virt}(\lambda),\ f_s(\Delta E, \lambda)$$

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$$|\mathcal{M}^{W}_{eff}|^2(\Delta E) = (1 + f_s(\Delta E))\,|\mathcal{M}_{born}|^2 + 2\,Re(\mathcal{M}_{born}\,\mathcal{M}^*_{virt})$$

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Real photon contributions: standard method

- integrate
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- $+$ hard collinear photons: collinear approximation $(\mathcal{M}_{born})$
- $+$ hard non-collinear photons: explicit $e\,e \to \widetilde{\chi}\,\widetilde{\chi}\,\gamma$ process $(\mathcal{M}^{2\to 3}_{born})$

Drawback: $|\mathcal{M}_{eff}|^2 < 0$ for small values of $\frac{\Delta E}{\sqrt{s}}$; set $|\mathcal{M}_{eff}|^2 = 0$

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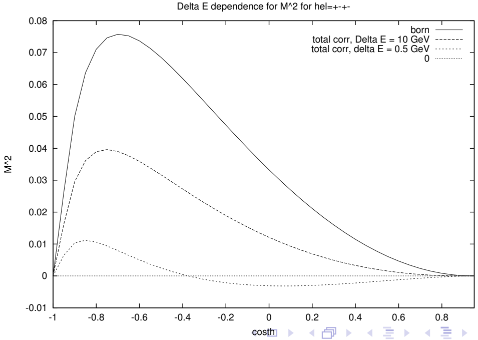

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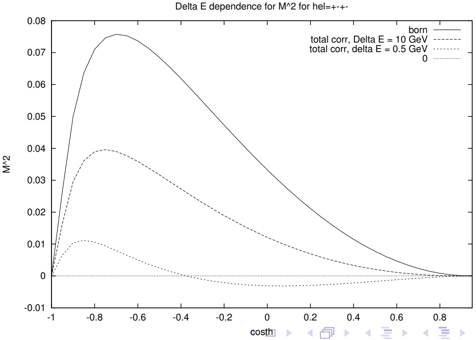

Alternative: subtraction method

- integrate over ΔE independent $|\mathcal{M}_{eff}|^2$:

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- fold this with ISR structure function (!! $\mathcal{M}_{born} + \mathcal{M}_{virt}$!!)
- all collinear photons described by ISR, hard non collinear: as before

more accurate description of $\sigma(x\,s)$ for $x \approx 1$ (soft region)

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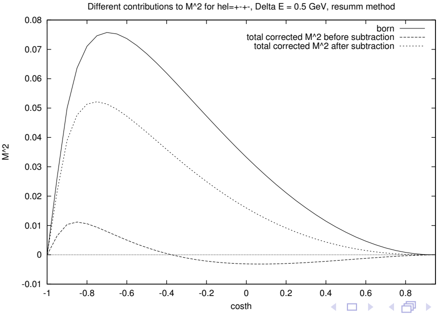

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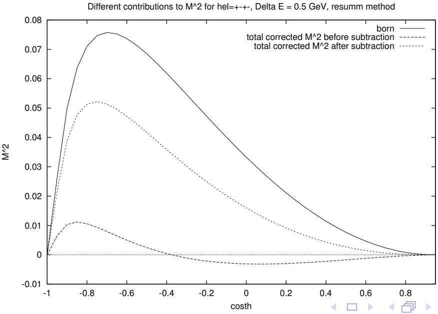

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σ_{corr} cut dependencies: ΔE

tests: soft photon approximation, negative $|\mathcal{M}|^2$ effects

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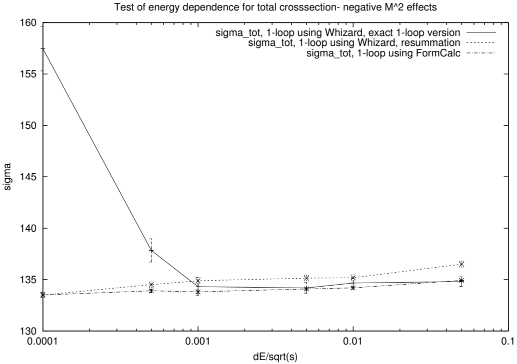

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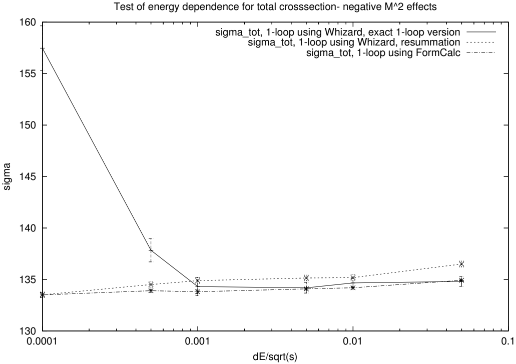

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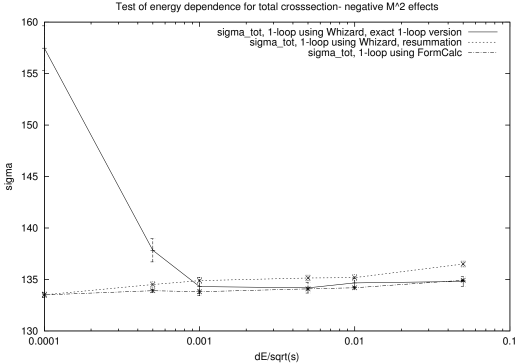

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σ_{corr} again larger for subtraction method

for higher angles: second order ISR effects ($\mathcal{O}$(‰))

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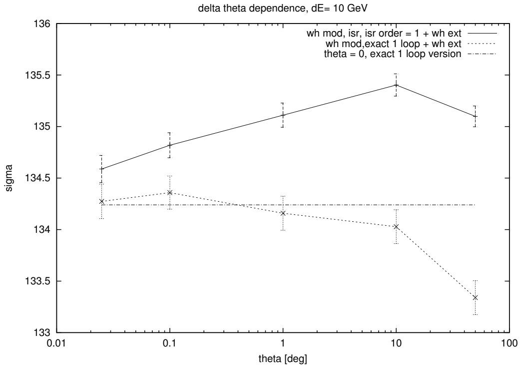

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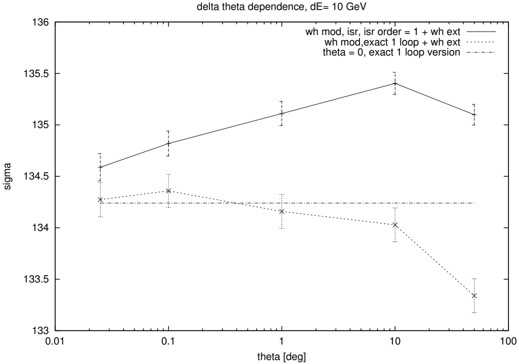

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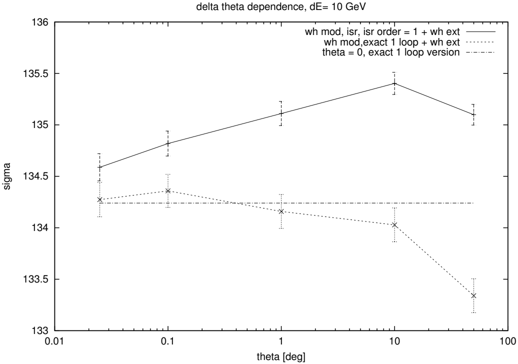

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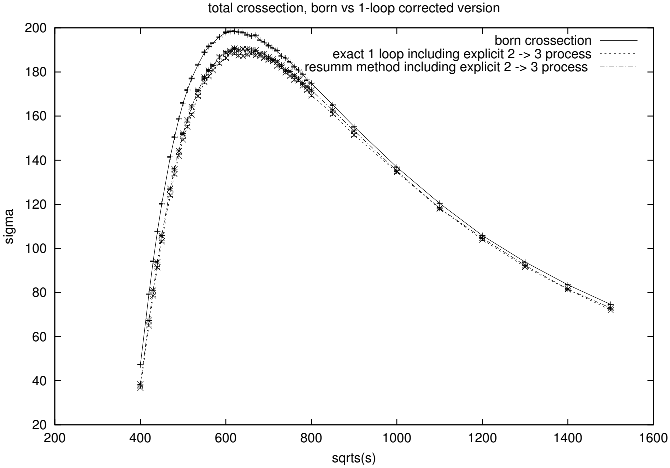

SPS1a'

agrees with results in the literature (Fritzsche et al, Öller et al)

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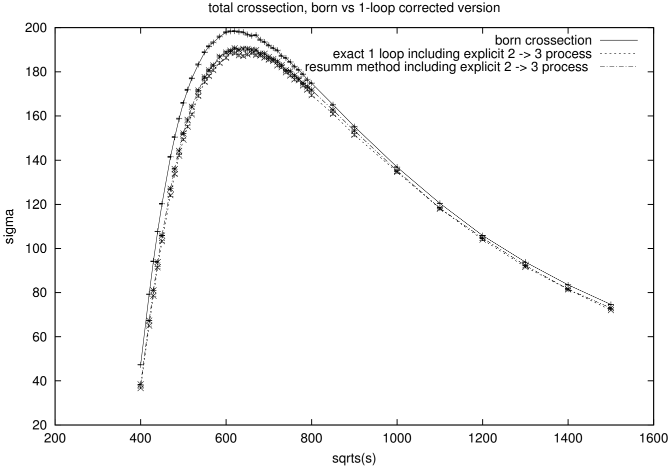

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simulation results: angular distributions

θ_{abs}: angle between $\widetilde{\chi}^-$ and e^+

!! more than 1 σ deviation !!
(nbins = 20)

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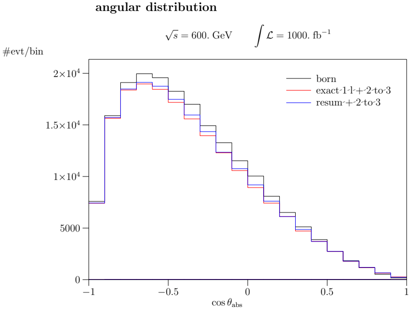

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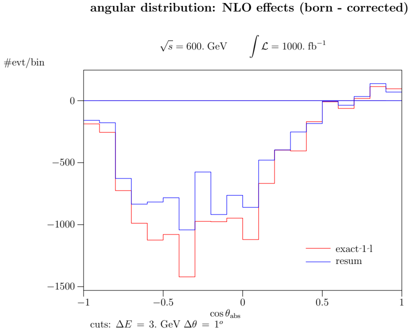
cuts: ΔE = 3 GeV $\Delta\theta$ = 1^o



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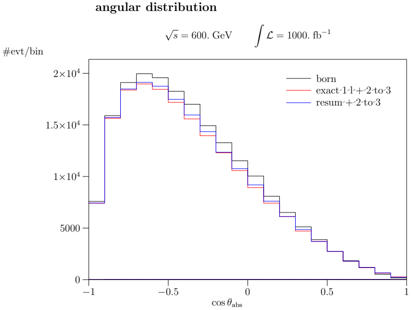

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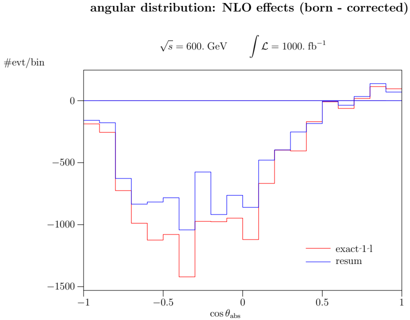

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Angular distribution: Do we see $|\mathcal{M}|^2 < 0$ effects ?? ($\checkmark$)

Reminder:
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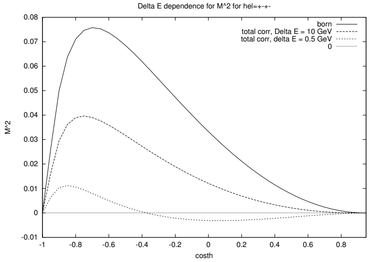

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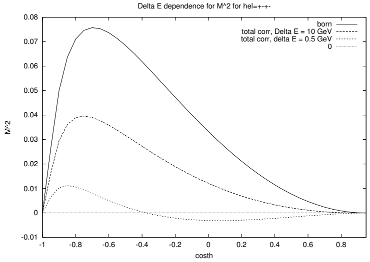

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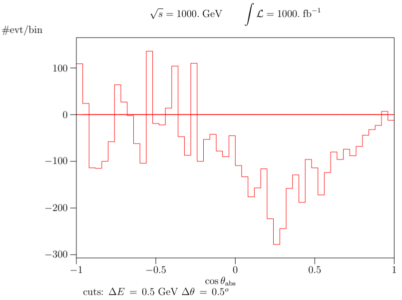

Summary

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  high precision in SUSY paramater analysis at EW scale
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ISR in its full beauty (Skrzypek et al, 1990)

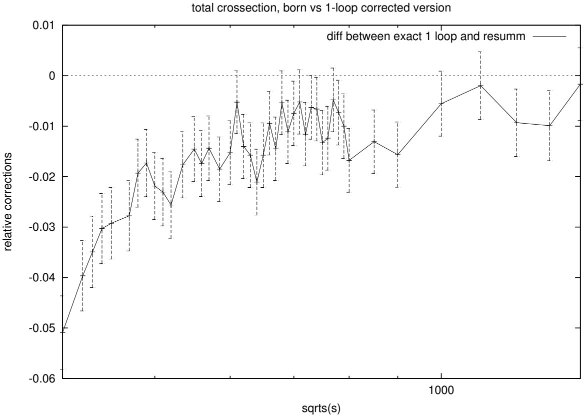
$$
\begin{aligned}
\Gamma_{ee}^{LL}(x, Q^2) = & \frac{\exp(-\frac{1}{2}\eta\gamma_E + \frac{3}{8}\eta)}{\Gamma(1+\frac{\eta}{2})}\frac{\eta}{2}(1-x)^{(\frac{\eta}{2}-1)} \\
- & \frac{\eta}{4}(1+x) + \frac{\eta^2}{16}\left(-2(1-x)\log(1-x) - \frac{2\log x}{1-x} + \frac{3}{2}(1+x)\log x\right. \\
- & \left.\frac{x}{2} - \frac{5}{2}\right) + \left(\frac{\eta}{2}\right)^3\left[-\frac{1}{2}(1+x)\left(\frac{9}{32} - \frac{\pi^2}{12} + \frac{3}{4}\log(1-x)\right.\right. \\
+ & \left.\frac{1}{2}\log^2(1-x) - \frac{1}{4}\log x\log(1-x) + \frac{1}{16}\log^2 x - \frac{1}{4}\mathrm{Li}_2(1-x)\right) \\
+ & \frac{1}{2}\frac{1+x^2}{1-x}\left(-\frac{3}{8}\log x + \frac{1}{12}\log^2 x - \frac{1}{2}\log x\log(1-x)\right) \\
- & \left.\frac{1}{4}(1-x)\left(\log(10x) + \frac{1}{4}\right) + \frac{1}{32}(5-3x)\log x\right]
\end{aligned}
$$

η, f_s, hard collinear approximation, $ISR^{\mathcal{O}(\alpha)}$

- $\eta = \frac{2\alpha}{\pi}\left(\log\left(\frac{Q^2}{m_e^2}\right) - 1\right)$ (Q = scale of process)
-
$$f_{soft}^{2\gamma} = \sum_{i,j=e^\pm} \int_{|\mathbf{k}|\leq \mathbf{\Delta E}} \frac{d^3k}{2\omega_k} \frac{2\,p_i\,p_j}{p_i\,k\,p_j\,k},$$
(Denner 1992)

$\omega_k = \sqrt{\mathbf{k^2} + \lambda^2}$, p_i initial/ final state momenta, k: γ momentum
- hard collinear factor (± helicity conserving/ flipping):
$$f^+(x) = \frac{\alpha}{2\,\pi}\frac{1+x^2}{(1-x)}\left(\ln\left(\frac{s\,(\Delta\theta)^2}{4\,m^2}\right) - 1\right), f^-(x) = \frac{\alpha}{2\,\pi}x.$$
(Dittmaier 1993)
- $ISR^{\mathcal{O}(\alpha)}$:
$$f_{soft,ISR} = \left[\int_{x_0}^1 P^{ee}(x)\,dx\right]_{\mathcal{O}(\alpha)} = \frac{\eta}{4}\left(2\ln(1-x_0) + x_0 + \frac{1}{2}x_0^2\right)$$

$\sigma_{corr}(\sqrt{s})$: differences between exact and resummation method



$\frac{\sigma_{exact} - \sigma_{resumm}}{\sigma_{exact}}$;

different descriptions in soft regime