CP effects in decay chains at LHC+ILC

-- work in progress --

Jenny Smillie, Jamie Tattersall, Gudrid Moortgat-Pick

(in collaboration with John Ellis, Filip Moortgat)

- **Triple product correlations and spin effects**
- **Effect of phases**
- **Numerical results for LHC and ILC**
- **Further studies**

SUSY introduction

- **105 new parameters in MSSM --> new sources of CP-violation**
  - **unravelling the underlying model requires precise determination of all parameters**
  - **constraints on parameters from e, n, Hg dipole moments, LEP, Tevatron, b -> sγ, g_μ-2, dark matter searches, etc....**

    Ibrahim ea '99, Barger ea '01, Abel ea'01, Belanger ea'04, Olive ea.'05

- **Determination of phases in two steps**
  - **observation of unique effects of CP-violation**
  - **disentangling and determination of corresponding phase parameter**
- **CP-even observables: masses, cross section**
  - **unique observation and determination needs CP-odd observables**

CP phases in SUSY

- **Use T_N-odd observable:**
  - CPT invariance: T-odd corresponds to CP-odd
  - ok under certain circumstances, tree-level etc. and as a kind of 'getting an estimate'
- **Dependence on phases:**
  - gaugino/higgsino sector: ϕ_{M1}, ϕ_μ
  - squarks/sleptons: ϕ_A
- **Usually always certain combinations of pases occur in observables**
  - disentangling quite tricky, already at tree-level
  - strategy for disentangling, beginning with processes at LHC

Present study

- **At LHC: qq,gg -> squarks -> gauginos -> leptons**
  - **quite common cascade decay chains, but very involved**
  - **often 2-body decays studies** *see eg Bartl ea '06,'07*
- **Specific process:**

$$gg \to \tilde{t}_i \tilde{t}_j \to \tilde{t}_i + \tilde{\chi}_k^0 t \to \tilde{t}_i + \tilde{\chi}_1^0 \ell^+ \ell^- + W^+ b$$

also studied by Langacker ea '07

  - **depends on** $\phi_{\mathrm{M1}}, \phi_\mu, \phi_{\mathrm{At}}$
- **Also corresponding processes via b and charginos and $\tilde{b}_i$**
- **Strategy: exploit spin correlations in decay chain**
  - **full analytic solution in lab system, including tricky phase space**
  - **Cross check with HERWIG successful (also vice versa !)**

Chosen SUSY scenarios

- **Favourable LHC scenario**
- **Parameters and mass spectrum:**

M_1	109
M_2	240
μ	220
$\tan\beta$	10
A_t	-610

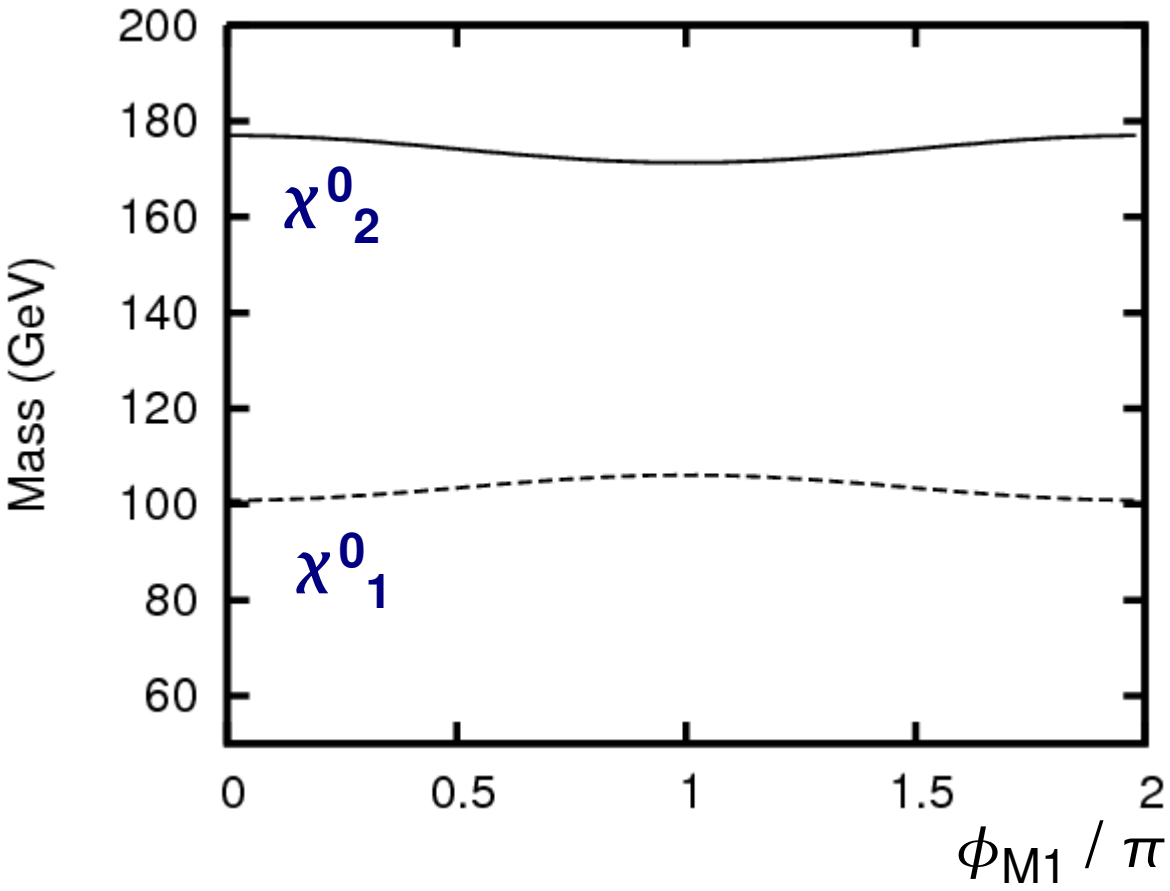
$M_{\tilde{t}_1}$	393.9
$M_{\tilde{t}_2}$	600
$M_{\tilde{\chi}_1^\pm}$	177
$M_{\tilde{\chi}_2^\pm}$	301.9
$m_{\tilde{\ell}_L}$	303.1
$m_{\tilde{\ell}_R}$	229.2

- **varying M_1: neutralino masses about 100 GeV and 170 GeV**
- **BR(stop -> t chi02) ~ 10%**
- **BR(chi02 -> chi01 l+ l-) ~ 6%**

CP-even: Masses

- **Dependence of neutralino masses on ϕ_{M1}**

  - **weak dependence**
  - **CP-even observable**



- **not suitable as unique 'hints' for CP violation**

Effects of spin correlations

- **Which further observable could be used?**
  - **CP-asymmetry of triple product momenta**
    - **(w.r.t. outgoing t and outgoing leptons)**
- **Dependent on spin correlations of decaying neutralino:**
  - **amplitude squared: $t_1 \to t\,\chi^0_2$ and $t \to W\,b$, $\chi^0_2 \to \chi^0_1\,l^+\,l^-$**

$$|T|^2 = |\Delta_{f_1}|^2 |\Delta_{f_2}|^2 \sum_{fin.sp.} \overbrace{(P^{\lambda_{f_1}\lambda_{f_2}} P^{*\lambda'_{f_1}\lambda'_{f_2}})}^{\text{spin-density matrix}} \times \overbrace{(Z_{\lambda_{f_1}} Z^*_{\lambda'_{f_1}})}^{\text{decay matrix}} \times \overbrace{(Z_{\lambda_{f_2}} Z^*_{\lambda'_{f_2}})}^{\text{decay matrix}}$$

$$\longrightarrow \quad |T|^2 \sim P D_i D_j + \Sigma^P_a \Sigma^D_a D_j + \Sigma^P_b \Sigma^D_b D_i + \Sigma^P_{ab} \Sigma^D_a \Sigma^D_b$$

cross section | **$A_{CP}(tl^+l^-)$** | **not needed** | **$A_{CP}(bl^+l^-)$**

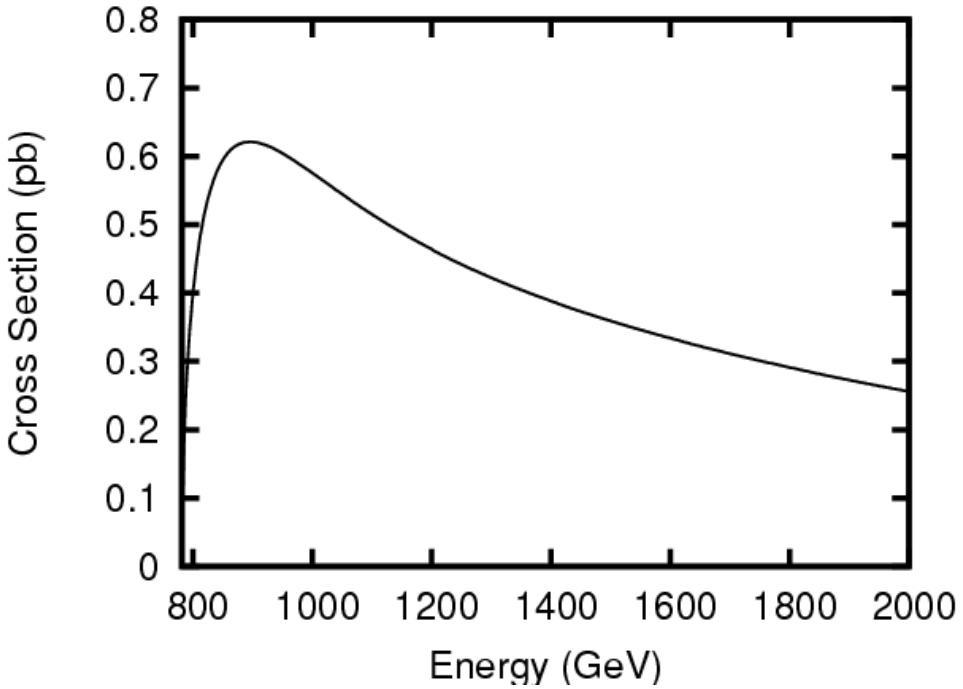
'new contributions'

Phase dependence

- If no phases: A_{CP} has to be exactly zero
- If spin correlations are neglected: A_{CP} is also zero
- Triple product correlations show different dependence on phases
  - $A_{CP}(t\, l^+l^-)$ depends only $\phi_{M1}\,(\,\phi_\mu)$ due to spin correlations
  - $A_{CP}(b\, l^+l^-)$ depends also on ϕ_{At} due to spin-spin correlations

LHC study : parton level

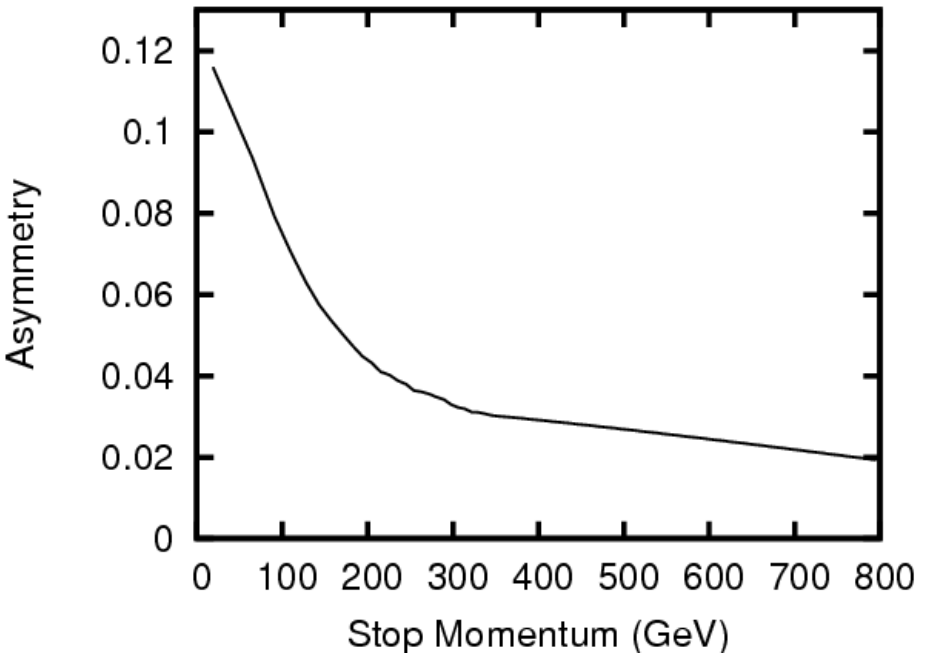
- **Stop production vs. energy:**



-> high cross section

-> up to 600 fb

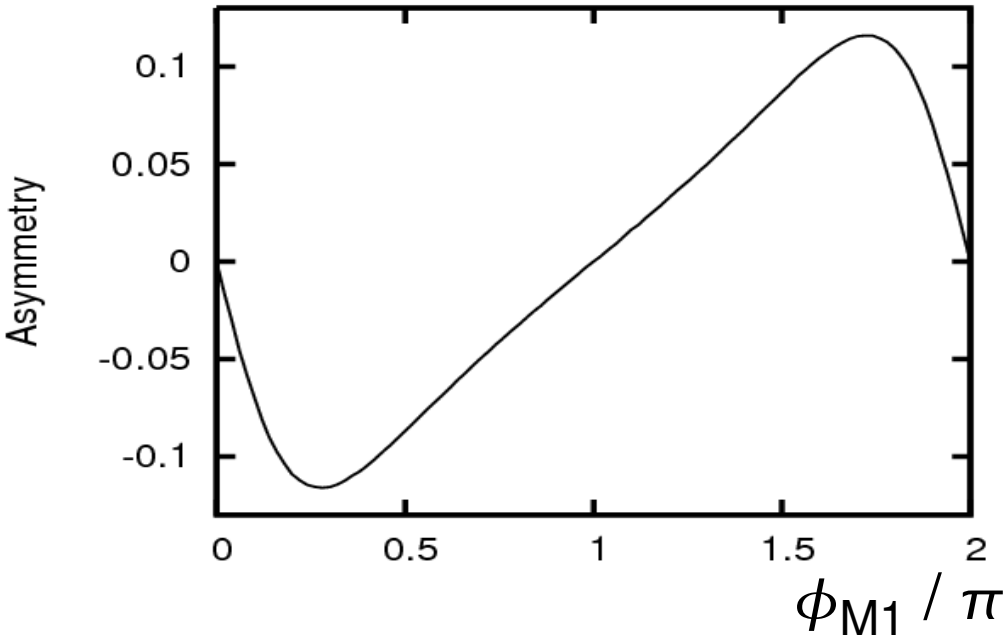
- **CP-asymmetry vs. energy**
  - **largest at threshold**
  - **due to spin effect**



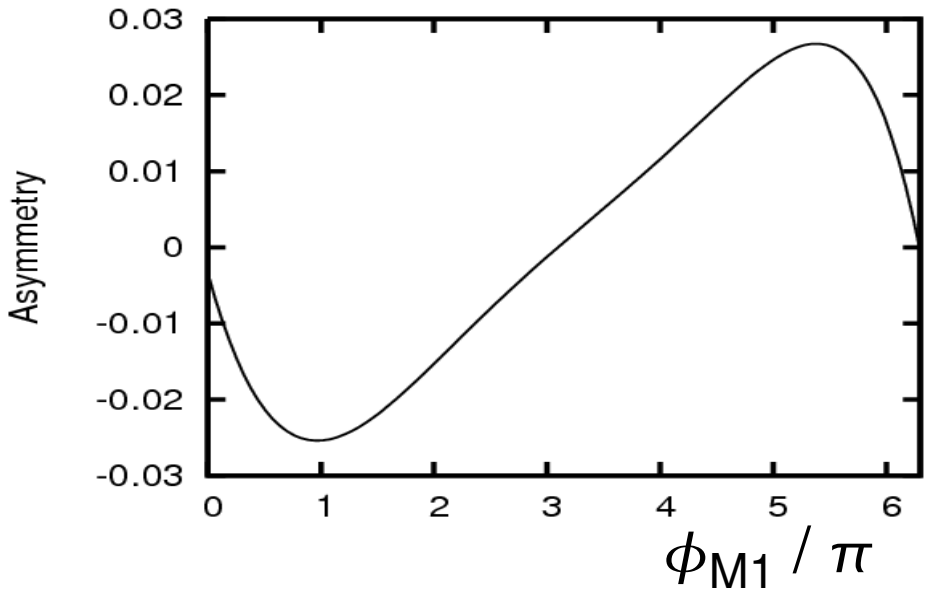
LHC CP-asymmetry

- **CP-asymmetry at parton level: up to 12% for small phases**

-> rather large effect



- **CP-asymmetry after PDF's: up to 3% achievable**

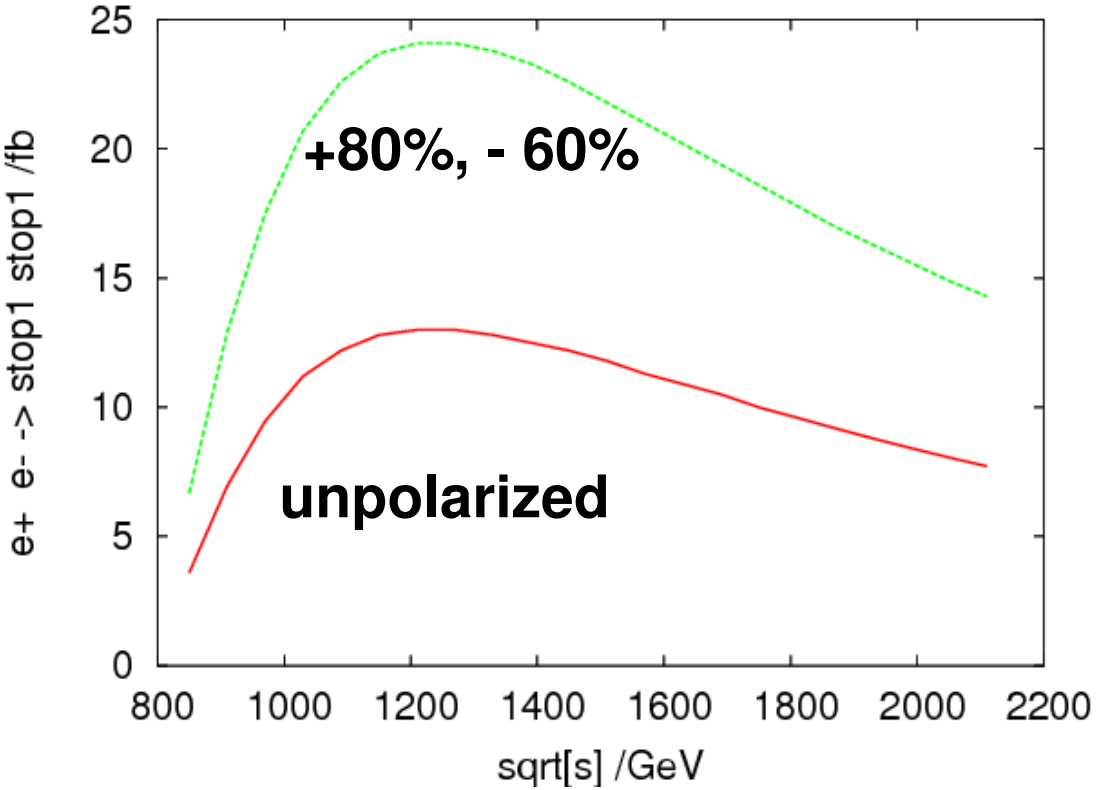


-> difficult to observe but still some hope

-> statistical error same order as signal after 100 fb^{-1}

ILC : cross section

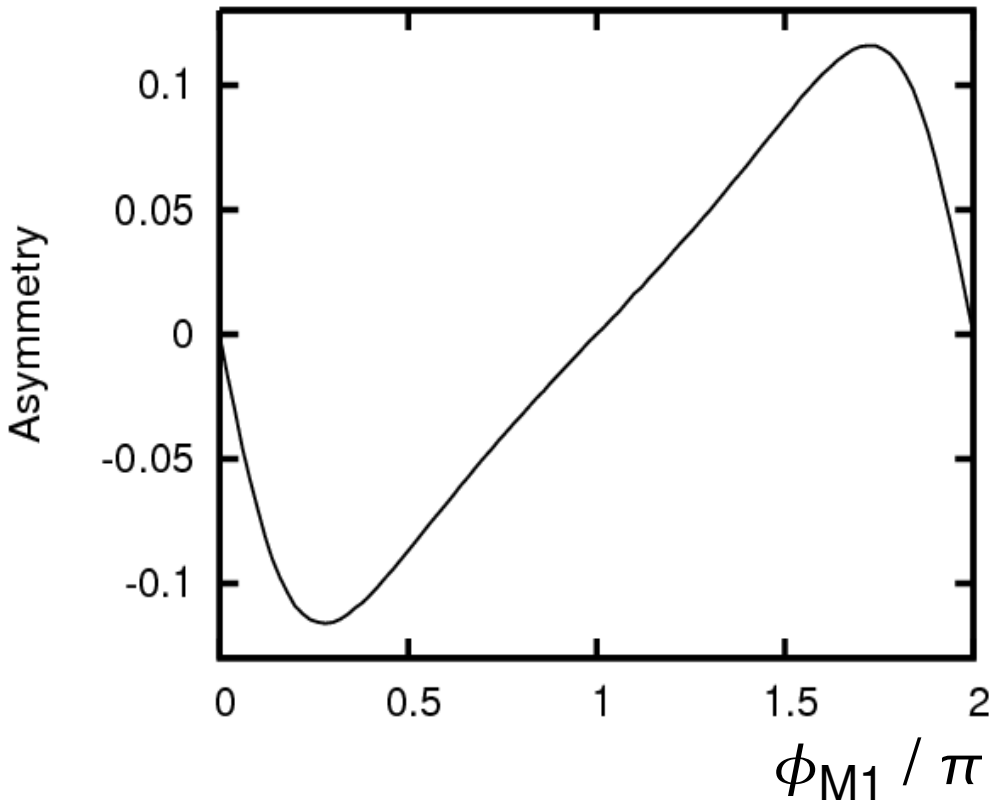
- **Cross section with polarized beams:**
  - low cross sections close to threshold
  - polarized beams important for enhancemennt



- **Callenging at ILC as well, but much cleaner signatures**
  - due to low cross sections: ~20 fb at 1000 GeV
  - high lumi needed!

ILC asymmetry

- **Maximum at threshold, but lowest statistics**
  - **up to 12 %**
  - **has to find optimal energy**



- **At 1000 GeV: only ~3 %**

Outlook

- Nice feature of phase 'disentangling' due to spin correlations
- In mSUGRA scenarios: usually smaller asymmetries
- At LHC: good statistics, but challenging because of t background
  - under study: 'up to which phase detectable?'
- At ILC: study other scenarios, e.g. coannihilation region
  - lighter stop
  - inclusion of other decay channels (via chargino)

- Prospective playground for LHC/ILC interplay
  - but small phases and disentangling remain challenging

High lumi required!