Confronting Two Different Methods for Measuring SUSY Dark Matter in Co-annihilation Scenarios at ILC

Based on
1. P. Bambade, M. Berggren, F. Richard, Z. Zhang, hep-ph/040610
2. Hans-Ulrich Martyn, hep-ph/0408226
3. Recent development by M . Berggren, F. Richard, Z. Zhang

- Motivation
- Main results of hep-ph/040610 & hep-ph/0408226
- New recent development
- Summary

Motivation

- Current precision on Dark Matter from WMAP: 10%
  or in 2σ range: $0.094<\Omega_{DM}h^2<0.129$
- Future precision expected from Planck: 2%

➔ Questions for colliders:

What are these non-baryonic DM?

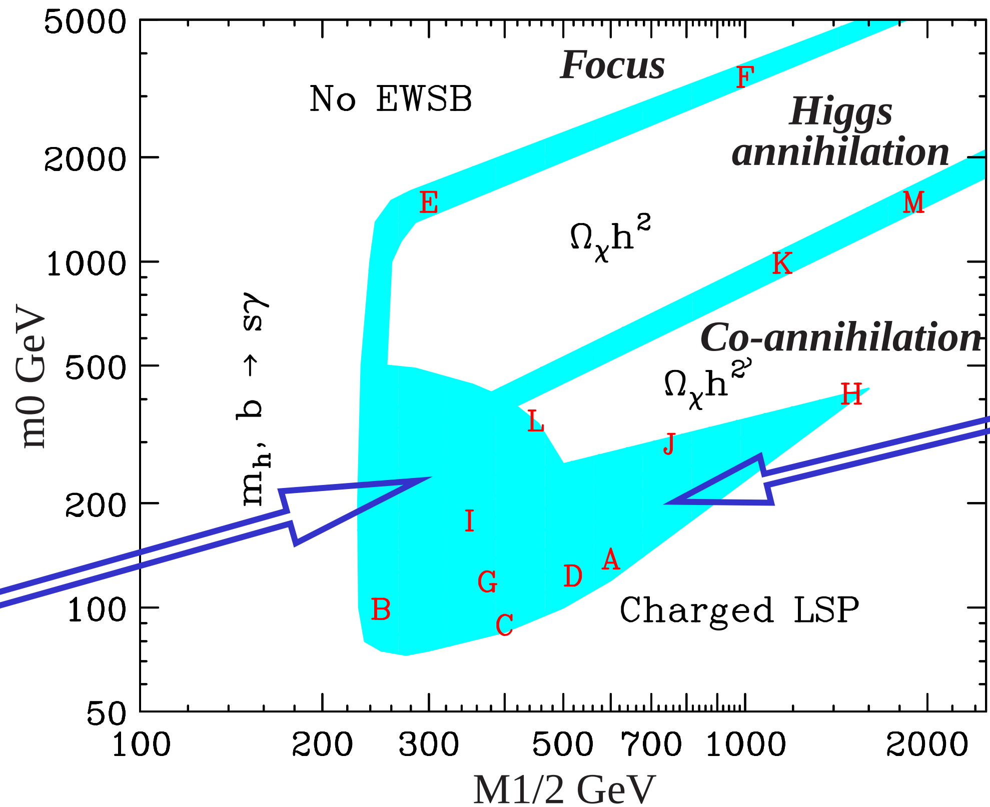
Any connection between DM and χ LSP in SUSY?

How precise can a LC measure DM relic density?

$$\Omega_{\tilde{\chi}_1^0}h^2 = m_{\tilde{\chi}_1^0} n_{\tilde{\chi}_1^0} \sim \int_0^{x_f} dx (\langle \sigma_{ann} v \rangle)^{-1}$$

DM vs. mSUGRA SUSY Model

Benchmark points:
Battaglia-De Roeck
Ellis-Gianatti-Olive
-Pape,
hep-ph/0306219



$\chi\chi$ pairs annihilation

χ stau ($s\tau$) annihilation

important when $\Delta M = m_{stau} - m_\chi$ is small

➔ The precision on SUSY DM prediction depends on ΔM & thus

δm_χ ➔ Needs smuon (or selectron) analysis
δm_{stau} ➔ Needs stau analysis

The Main Results of hep-ph/0406010

- **Smuon analysis:**
  - Benchmark point D: $\Delta M=224[m_{smuon}]-212[m_{\chi}]=12GeV$
  - Ecm=500GeV, $500fb^{-1}$, unpolarized beams, σ=7.2 fb
    - ➔ the smuon analysis fairly easy (w.r.t. the stau analysis)
    - ➔ m_{smuon} & m_{χ} can be precisely determined from the muon spectrum with the end point method

- **Stau analysis:**
  - Detailed analysis on D: $\Delta M=217[m_{stau}]-212[m_{\chi}]=5GeV$
  - The analysis also applied to other benchmark points: A (ΔM=7GeV), C(ΔM=9GeV), G(ΔM=9GeV), J(ΔM=3GeV)
  - Ecm=442GeV (←Optimal Ecm method), $500fb^{-1}$, unpolarized beams, σ=0.46fb
  - Challenge: background rejection
    - ➔ the stau analysis difficult but feasible
    - ➔ efficiency=5.7%, δm_{stau}=0.54GeV, $\delta\Omega_{DM}$=6.9%
    - ➔ ~25% efficiency loss if 20 mrad crossing angle

Why Optimal Ecm?

With negligible background and given
the integrated luminosity: L
the efficiency: ε
Signal cross section: $\sigma = A\beta^3$ (neglect ISR correction)
with $A \sim 100$, $\beta = (1-4m^2/s)^{1/2}$

➔ Observed events: $N = LA\beta^3\varepsilon$

QED correction: Large but known
Coulomb correction: Known & small
Width effect: small $[\Gamma/M \sim \alpha(\Delta M/M)^2]$

One can easily derive
the relative stau mass precision:

$$dm/m = s/12m^2\,[\beta/LA\varepsilon]^{1/2}$$

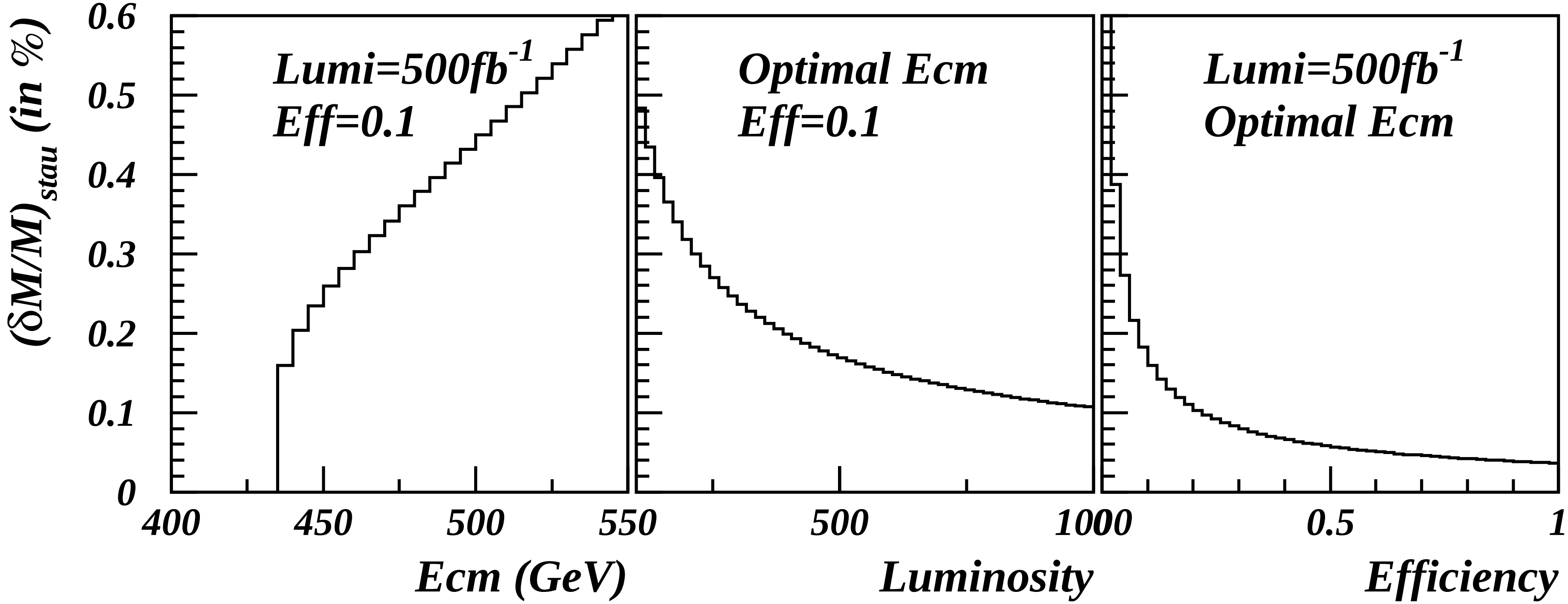
the optimal center of mass energy:

$$Ecm = s^{1/2} = 2m\,/\,[1-(N/LA\varepsilon)^{2/3}]^{1/2}$$

Note: This differs from a threshold scan measurement,
➔ Little sensitivity to the σ shape & corrections @ threshold

Relative Stau Mass Precision

Example with benchmark point D



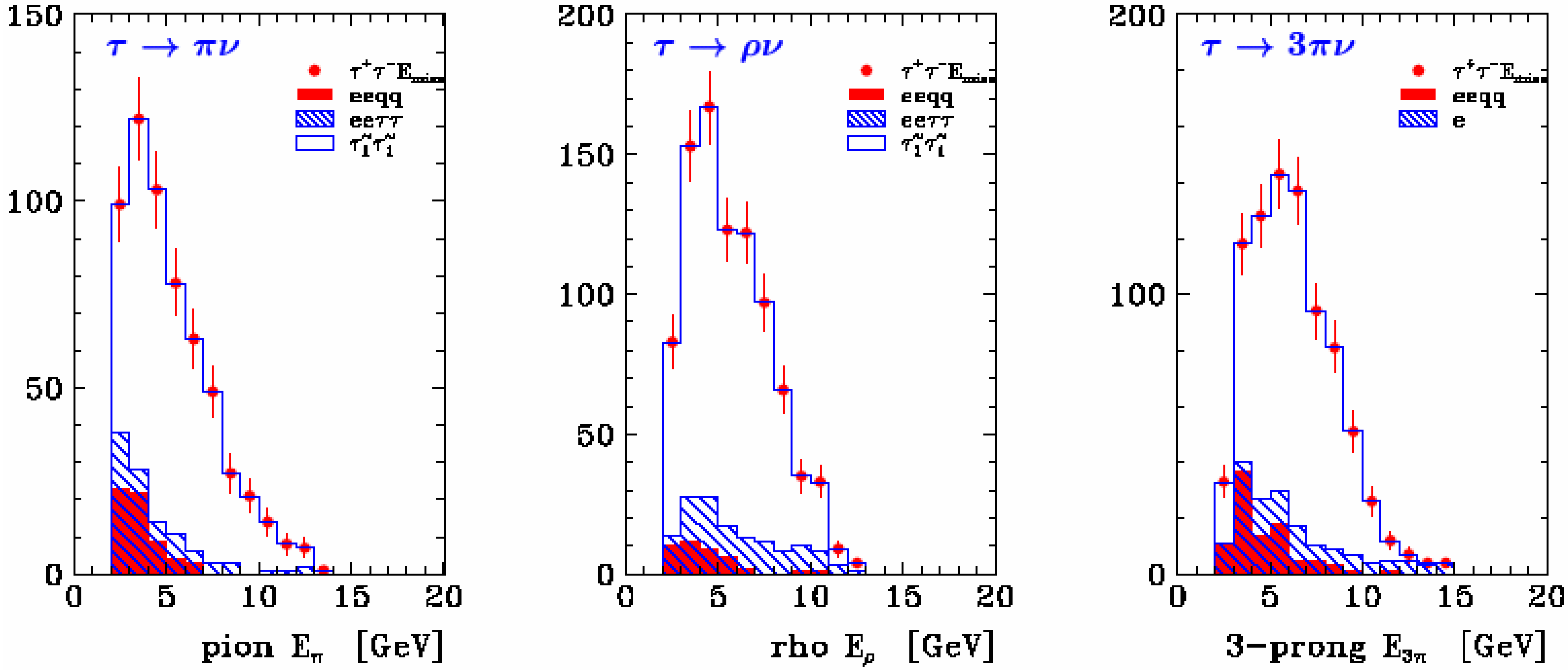
➔ Best sensitivity achieved with Ecm~2m_{stau}: δm_{stau}~0.4GeV
➔ Higher Ecm does not help
➔ Higher integrated luminosity and efficiency do

The Main Results of hep-ph/0408226

- **Smuon analysis:**
  - Case study modified SPS 1a: $\Delta M=143[m_{smuon}]-135[m_{\chi}]=8GeV$
  - Ecm=400GeV, $200fb^{-1}$, polarized e-(0.8)/e+(0.6), σ=120 fb
    ➔ $m_{smuon}=143.00\pm0.18$ GeV, $m_{\chi}=135.00\pm0.17$ GeV
    ➔ Similarly: $m_{selectron}=143.00\pm0.09$ GeV, $m_{\chi}=135.00\pm0.08$ GeV

- **Stau analysis:**
  - Case study modified SPS 1a: $\Delta M=133.2[m_{stau}]-125.2[m_{\chi}]=8GeV$
  - Ecm=400GeV, $200fb^{-1}$, polarized e-(0.8)/e+(0.6), σ=140 fb
    ➔ δm_{stau}=0.14GeV (based on π, ρ and 3π tau decay channels)
    ➔ extrapolation to ΔM=5GeV: δm_{stau}=0.22GeV
    ΔM=3GeV: δm_{stau}=0.28 GeV
  - Another case study D: $\Delta M=217.5[m_{stau}]-212.4[m_{\chi}]=5.1GeV$
  - Ecm=600GeV, $300fb^{-1}$, polarized e-(0.8)/e+(0.6), σ=50fb
    ➔ δm_{stau}=0.15GeV (based on π, ρ and 3π tau decay channels)

- Benchmark D (below) studied in π,ρ,3π channels
- Main idea: $E_{max} \leftarrow\rightarrow E_{nu}=0$
  - ➔ $E_{max}=f(m_{stau}, m_{\chi}, m_{tau}, Ecm)$
  - ➔ $\delta m_{stau}=f(E_{max}, m_{\chi}, m_{tau}, Ecm)\delta E_{max} + \delta m_{\chi}$



New Recent Development

- Cross-checking Uli's result in the same condition:
  - ✓ use same cuts as Uli, we reproduce his τ-τ ε_{eff} of 7.6%
  - ✓ we have less selected events in π, ρ & 3π channels & our events consistent with the expectation
  - ✓ error propagation formula (Ecm=600GeV):

$$\delta m_{\tilde{\tau}} = 0.44\delta E_{\tau}^{\max} \oplus 1.03\delta m_{\chi} \oplus 0.15\delta m_{\tau} \qquad Ecm = 600GeV$$

- New analyses under different beam conditions:

Ecm (GeV)	Beam Pol.	σ (fb)
600	Unpol.	20
500	0.8(e-)/0.6(e+)	25
500	Unpol.	10

$$\delta m_{\tilde{\tau}} = 0.61\delta E_{\tau}^{\max} \oplus 1.05\delta m_{\chi} \oplus 0.12\delta m_{\tau} \qquad Ecm = 500GeV$$

Stau Mass Determination

Uli's results (rough & educated estimate):

600GeV, 300fb^{-1}, polarized beams:

π: δE_π=0.43 GeV ρ: δE_ρ=0.27 GeV 3π: $\delta E_{3\pi}$=0.32 GeV

Combined: δE_τ=0.25 GeV (assuming δm_χ=0.1 GeV) ➔ $\delta m_{s\tau}$=0.15 GeV

Our results (based on a polynomial fit (p2)):

600GeV, 300fb^{-1}, polarized beams:

π: δE_π=0.30 GeV ρ: δE_ρ=0.17 GeV 3π: $\delta E_{3\pi}$=0.17 GeV

Combined: δE_τ=0.10 GeV (assuming δm_χ=0.1 GeV) ➔ $\delta m_{s\tau}$=0.11-0.13 GeV

600GeV, 300fb^{-1}, unpolarized beams:

Combined: δE_τ=0.25 GeV (assuming δm_χ=0.1 GeV) ➔ $\delta m_{s\tau}$=0.14-0.17 GeV

500GeV, 300fb^{-1}, polarized beams:

Combined: δE_τ=0.16 GeV (assuming δm_χ=0.1 GeV) ➔ $\delta m_{s\tau}$=0.13-0.20 GeV

500GeV, 500fb-1, unpolarized beams:

Combined: δE_τ=0.18 GeV (assuming dmc=0.1 GeV) ➔ $\delta m_{s\tau}$=0.15 GeV

Results on the Stau Mass & Relic DM Density

Method one: ($L=500fb^{-1}$)

Scenario	A	C	D	G	J
ΔM (GeV)	7	9	5	9	3
Ecm (GeV)	505	337	442	316	700
σ (fb)	0.216	0.226	0.456	0.139	3.77
Efficiency (%)	10.4	14.3	5.7	14.4	<1.0
δm_{stau} (GeV)	0.49	0.16	0.54	0.13	>1.0
$\delta \Omega h^2$ (%)	3.4	1.8	6.9	1.6	>14*

Method two: ($L=$ $200fb^{-1}$ $300fb^{-1}$)

Scenario	Modified SPS 1a			D			
ΔM (GeV)	8	5	3	5			
Ecm (GeV)	400			600			500
Pol 0.8(e-)/0.6(e+)	yes	yes	yes	yes		no	yes
σ (fb)	140			50		20	25
Efficiency (%)	18.5			7.6		7.7	6.4
δm_{stau} (GeV)	0.14	0.22	0.28	0.15	0.11-0.13	0.14-0.17	0.13-0.20
$\delta \Omega h^2$ (%)	1.7*	4.1*	6.7*	1.9	1.4-1.7	1.8-2.2	1.7-2.6

Uli | This analysis

*: $\Omega h^2 < 0.094$ (WMAP lower limit)

micrOMEGAs

Summary

- LSP and smuon masses precisely measurable @ small ΔM
- Stau mass measurement @ small ΔM more challenging
  Two different methods confronted
- Depending on SUSY scenario, DM density precision @ LC can compete with expected precision from e.g. Planck