

SM Background Contributions Revisited for SUSY DM Stau Analyses

Based on

1. P. Bambade, M. Berggren, F. Richard, Z. Zhang, hep-ph/0406010
2. Hans-Ulrich Martyn, hep-ph/0408226
3. Z. Zhang, contribution to ECFA06@Valencia
4. P. Bambade, V. Drugakov, W. Lohmann, physics/0610145

- Motivation
- Main results of previous studies
- SM background studies with realistic veto
- Summary

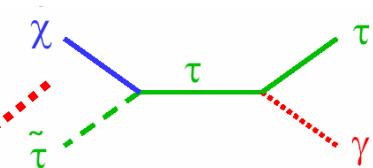
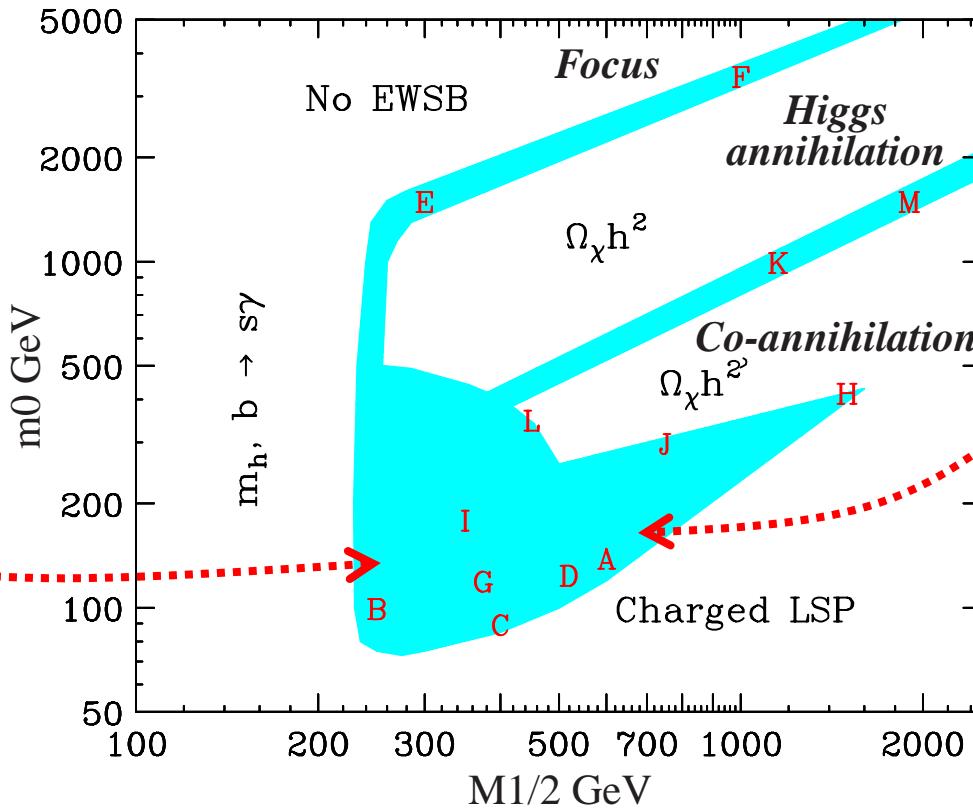
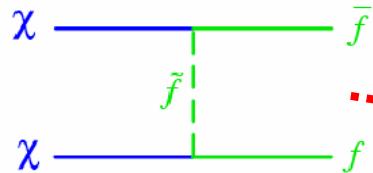
Motivation

- Dark Matter (DM) of ~25% established with good precision:
WMAP: 10% or in 2σ range: $0.094 < \Omega_{\text{DM}} h^2 < 0.129$
 - Strong constraint on (SUSY) parameter space
- Yet there are still many models and DM candidates
- Challenge for colliders:
 - What are these non-baryonic cold DM?
 - Any connection between DM and χ LSP in SUSY?
 - How precise can a LC measure DM relic density?

DM vs. mSUGRA SUSY Model

Benchmark points:

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



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

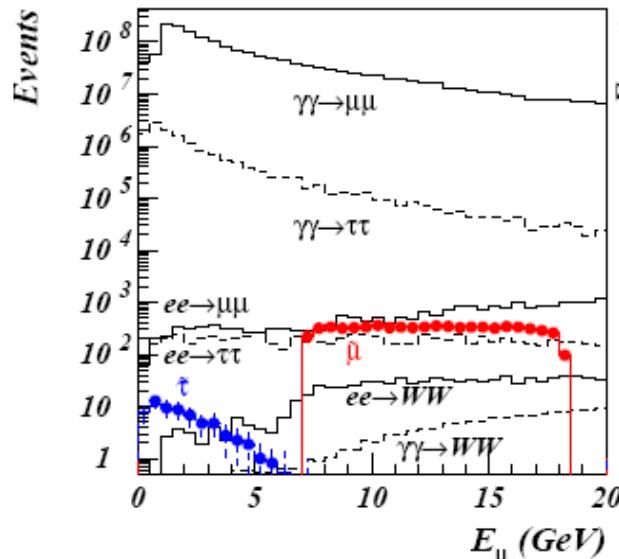
Method 1

□ Smuon analysis:

- Benchmark point D: $\Delta M = 224[m_{\text{smuon}}] - 212[m_\chi] = 12 \text{ GeV}$
- $E_{\text{cm}} = 500 \text{ GeV}$, 500 fb^{-1} , unpolarized beams, $\sigma = 7.2 \text{ fb}$
 - ➔ the smuon analysis fairly easy
 - ➔ m_{smuon} & m_χ can be precisely determined from the muon spectrum with the end point method

□ Stau analysis:

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



The Main Results of hep-ph/0408226

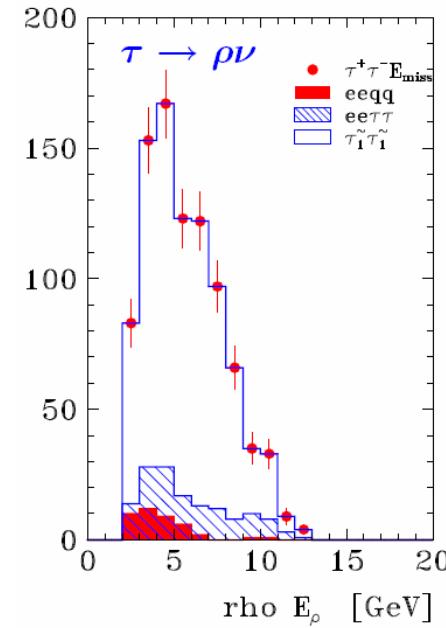
Method 2

□ Smuon analysis:

- Case study modified SPS 1a: $\Delta M = 143[m_{\text{smuon}}] - 135[m_\chi] = 8 \text{ GeV}$
- $E_{\text{cm}} = 400 \text{ GeV}, 200 \text{ fb}^{-1}$, polarized $e^-/(0.8)/e^+(0.6)$, $\sigma = 120 \text{ fb}$
 - ➔ $m_{\text{smuon}} = 143.00 \pm 0.18 \text{ GeV}, m_\chi = 135.00 \pm 0.17 \text{ GeV}$
 - ➔ Similarly: $m_{\text{selectron}} = 143.00 \pm 0.09 \text{ GeV}, m_\chi = 135.00 \pm 0.08 \text{ GeV}$

□ Stau analysis:

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



New Development for ECFA06@Valencia

Method 2

- 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 ($Ecm=600\text{GeV}$):

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

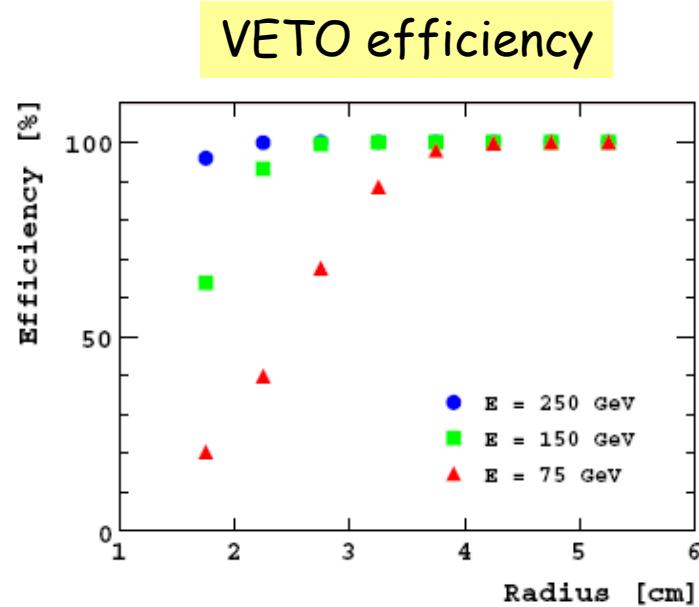
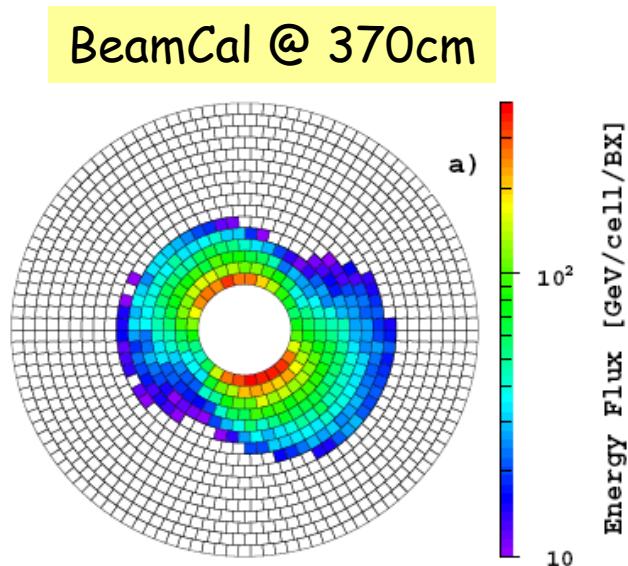
- New analyses under different beam conditions:

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

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

VETO SM Background Contributions

- (Many) orders of magnitude larger than the stau signals
- Ideal VETO (hep-ph/0408226):
 - Efficient veto assumed for all $\gamma\gamma$ background with $E_e, E_\gamma > 5\text{GeV}$ at $\theta < 0.125\text{rad}$
- Realistic VETO (physics/0610145):
 - Fine granularity tungsten/diamond sample calorimeter @ 370cm from IP
 - Identify energetic spectator e from $\gamma\gamma$ events out of huge low energy e^+e^- pairs from beamstrahlung

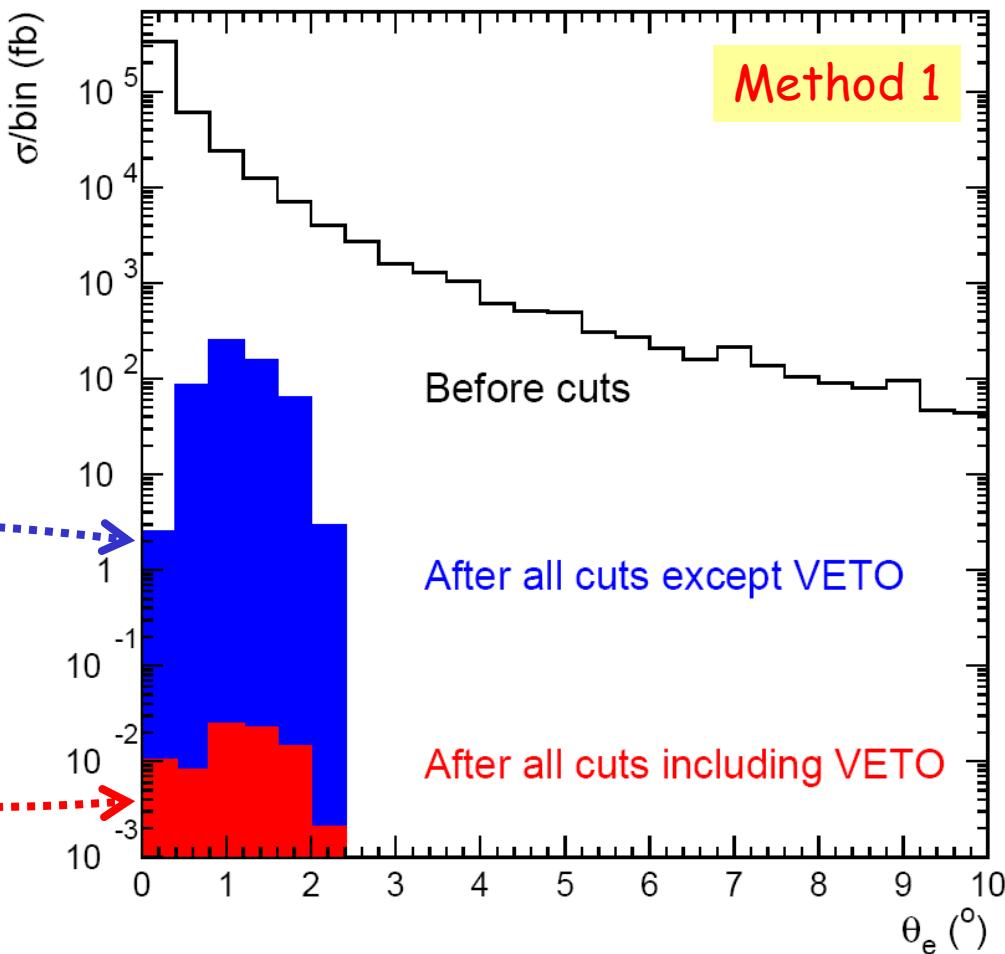


Example: SM Background $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$

Spectator e^\pm &
its angular distribution

SM background $\gamma\gamma \rightarrow \tau\tau$ generated
at Ecm of 500GeV

Method	1	2
$\sigma_{\text{signal}} [\text{fb}] * \varepsilon_{\text{eff}}$	$0.456 * 5.7\%$	$25 * 6.4\%$
$\sigma_{\text{bkg}} [\text{fb}]$ (w/o VETO)	561	168
$\sigma_{\text{bkg}} [\text{fb}]$ (+VETO)	0.08	0.26
S/B	~ 0.3	~ 6

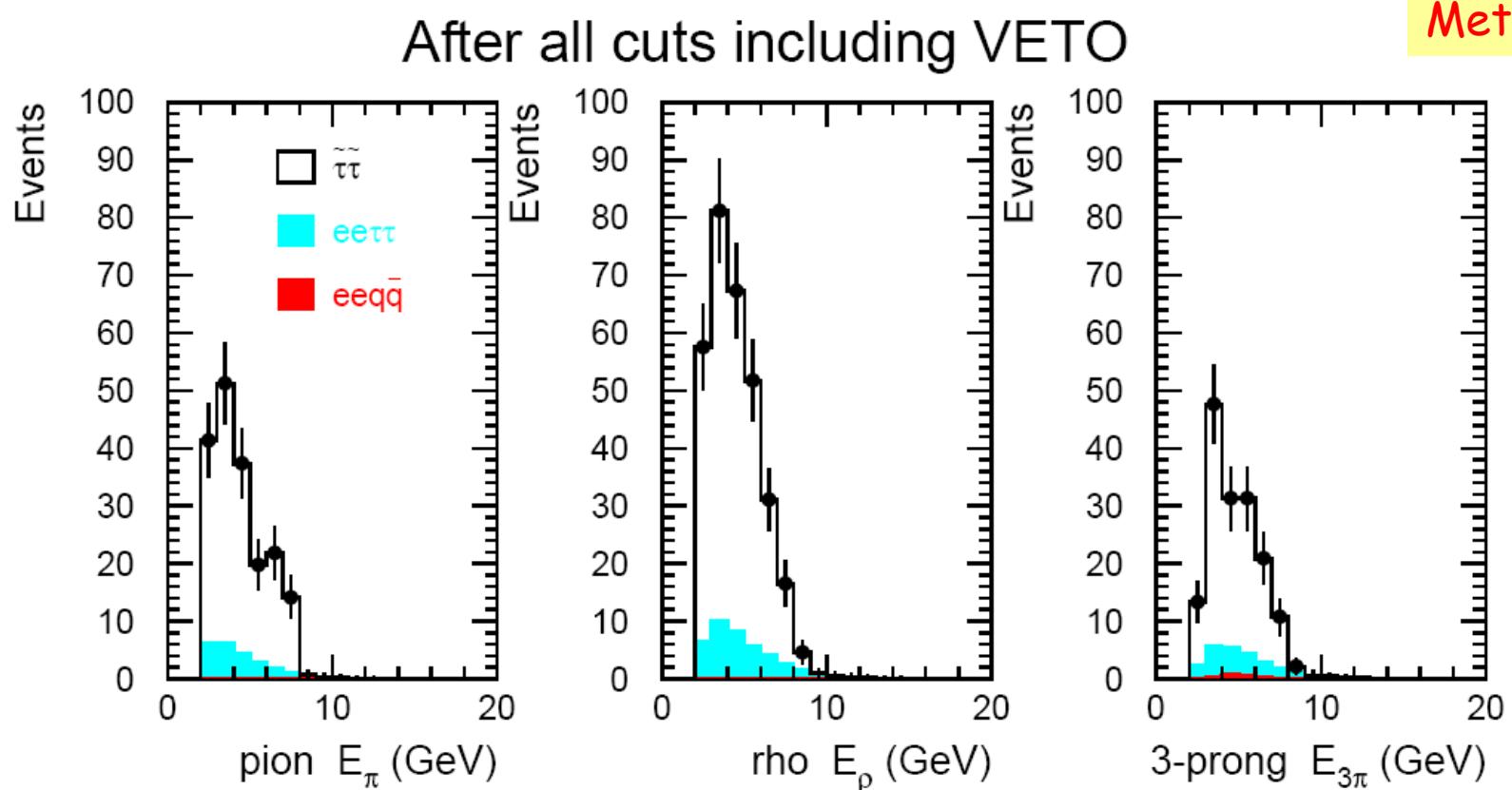


→ VETO eff. is pretty good for method 1 but needs improvement for method 2

Energy Spectrum with Realistic VETO

$E_{cm}=500\text{GeV}$, $L=300\text{fb}^{-1}$, Polarization: 80% (e^-), 60% (e^+)

Method 2



→ With realistic VETO efficiency, SM background contributions remain under control

Results on Relic DM Density

Results to
ECFA06@
Valencia &
remain valid

Method one:

Scenario	A	C	D	G	J
ΔM (GeV)	7	9	5	9	3
E_{cm} (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
$\delta m_{\tilde{\tau}}$ (GeV)	0.49	0.16	0.54	0.13	>1.0
$\delta \Omega h^2$ (%)	3.4	1.8	6.9	1.6	>14*

microMegas

Method two:

Scenario	(L= 200fb ⁻¹)			Modified SPS 1a (300fb ⁻¹)		
ΔM (GeV)	8	5	3			5
E_{cm} (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
$\delta m_{\tilde{\tau}}$ (GeV)	0.14	0.22	0.28	0.15	0.11-0.13	0.14-0.17
$\delta \Omega h^2$ (%)	1.7*	4.1*	6.7*	1.9	1.4-1.7	1.8-2.2

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

Uli

This analysis

Summary

- LSP and smuon masses precisely measurable @ small ΔM
- Stau mass measurement @ small ΔM more challenging
Two different methods confronted
- SM background contributions remain reasonably small with realistic VETO efficiency
- Depending on SUSY scenario, DM density precision @ ILC can compete with expected precision from e.g. Planck

Why Optimal Ecm?

hep-ph/0406010

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: $N = LA\beta^3\varepsilon$

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:

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

QED correction: Large but known

Coulomb correction: Known & small

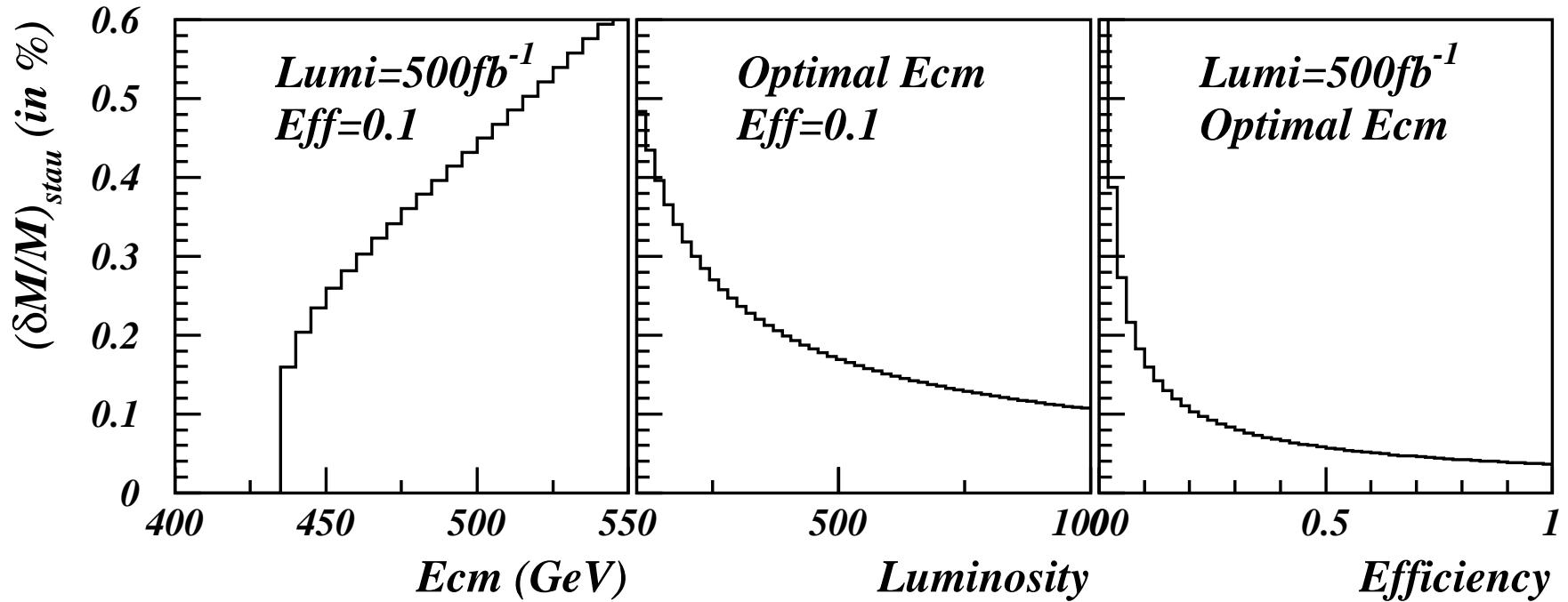
Width effect: small [$\Gamma/M \sim \alpha(\Delta M/M)^2$]

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

hep-ph/0406010

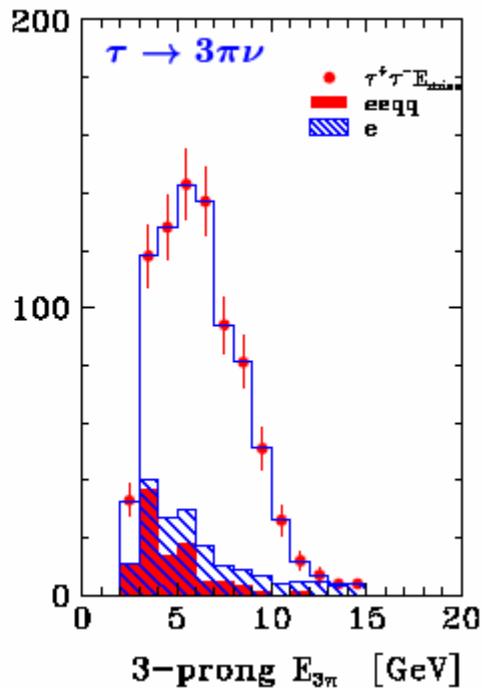
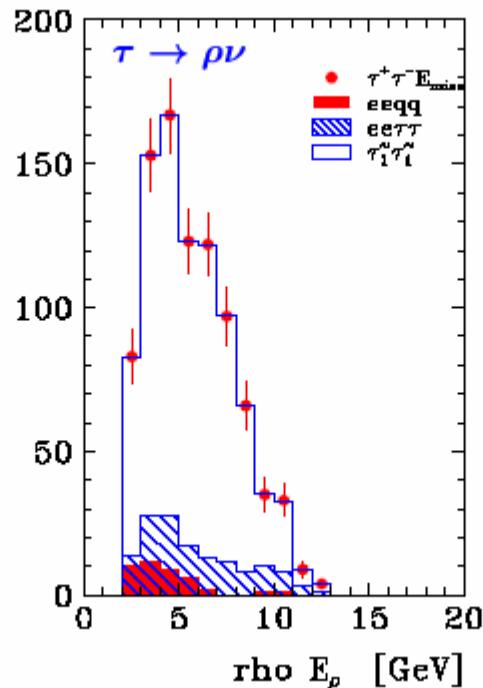
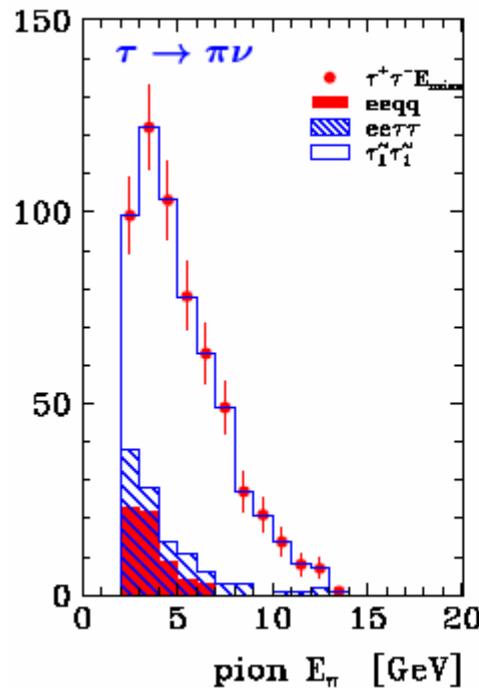


- Best sensitivity achieved with $E_{\text{cm}} \sim 2m_{\text{stau}}$: $\delta m_{\text{stau}} \sim 0.4\text{GeV}$
- Higher E_{cm} does not help
- Higher integrated luminosity and efficiency do

Analyzing Energy Spectra for Stau Mass Determination

hep-ph/0408226

- Benchmark D (below) studied in $\pi, \rho, 3\pi$ channels
- Main idea: $E_{\max} \leftrightarrow E_{\nu} = 0$
 - $E_{\max} = f(m_{\text{stau}}, m_{\chi}, m_{\tau}, E_{\text{cm}})$
 - $\delta m_{\text{stau}} = f(E_{\max}, m_{\chi}, m_{\tau}, E_{\text{cm}}) \delta E_{\max} + \delta m_{\chi}$



Stau Mass Determination

ECFA06@Valencia

Uli's results (rough & educated estimate):

600GeV, 300fb⁻¹, polarized beams:

$$\pi: \delta E_\pi = 0.43 \text{ GeV} \quad \rho: \delta E_\rho = 0.27 \text{ GeV} \quad 3\pi: \delta E_{3\pi} = 0.32 \text{ GeV}$$

$$\text{Combined: } \delta E_\tau = 0.25 \text{ GeV} \text{ (assuming } \delta m_\chi = 0.1 \text{ GeV) } \rightarrow \delta m_{s\tau} = 0.15 \text{ GeV}$$

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

600GeV, 300fb⁻¹, polarized beams:

$$\pi: \delta E_\pi = 0.30 \text{ GeV} \quad \rho: \delta E_\rho = 0.17 \text{ GeV} \quad 3\pi: \delta E_{3\pi} = 0.17 \text{ GeV}$$

$$\text{Combined: } \delta E_\tau = 0.10 \text{ GeV} \text{ (assuming } \delta m_\chi = 0.1 \text{ GeV) } \rightarrow \delta m_{s\tau} = 0.11-0.13 \text{ GeV}$$

600GeV, 300fb⁻¹, unpolarized beams:

$$\text{Combined: } \delta E_\tau = 0.25 \text{ GeV} \text{ (assuming } \delta m_\chi = 0.1 \text{ GeV) } \rightarrow \delta m_{s\tau} = 0.14-0.17 \text{ GeV}$$

500GeV, 300fb⁻¹, polarized beams:

$$\text{Combined: } \delta E_\tau = 0.16 \text{ GeV} \text{ (assuming } \delta m_\chi = 0.1 \text{ GeV) } \rightarrow \delta m_{s\tau} = 0.13-0.20 \text{ GeV}$$

500GeV, 500fb⁻¹, unpolarized beams:

$$\text{Combined: } \delta E_\tau = 0.18 \text{ GeV} \text{ (assuming } \delta m_\chi = 0.1 \text{ GeV) } \rightarrow \delta m_{s\tau} = 0.15 \text{ GeV}$$