STAU SEARCHES @ CLIC

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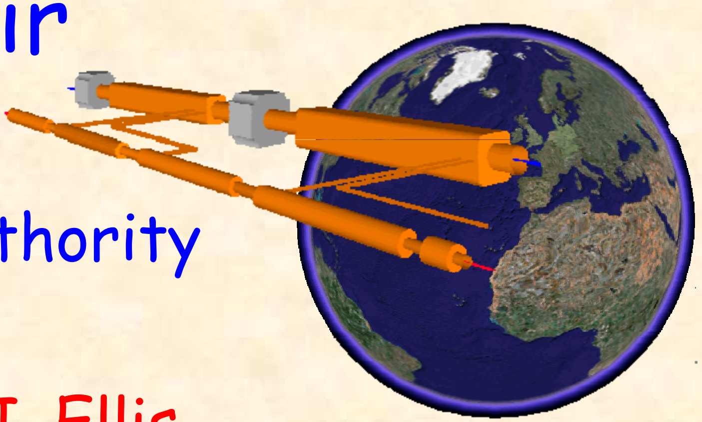


CLIC WORKSHOP
CERN, 16-18 October 2007

Outline

- LSP and NLSP in SUSY
- mSUGRA points + point θ
- production cross sections
  - optimization for the threshold
- relevant SUSY processes
- detection of stau
- conclusion

Supersymmetry (SUSY)

- most interesting possibility offered by quantum field theory
  - relating to fermions to bosons
    - unification with gravity
    - unification of gauge couplings
    - solution of the hierarchy problem
    - dark matter in the Universe
    - ...

SUGRA Model

- GraMSB: gravity-mediation
  - SUSY breaking scale ~ 10^{11} GeV
  - sparticle masses ~ (GeV-TeV)
  - CMSSM & GUT unification → mSUGRA

mSUGRA parameters:

$m_{1/2}$ = common gaugino mass
m_0 = common scalar mass
A_0= trilinear coupling
tan β = ratio of VEVs
sign(μ) = sign of Higgs mixing parameter

Most interesting:
gravitino LSP, stau NLSP

Experimental constraint on
NLSP stau: $m_{\tilde{\tau}_1}$ > 87.6 GeV
(pair production) –Abbiendi 04

- GMSB: gauge-mediated
  - SUSY breaking scale ~ 10^5 GeV
  - LSP = Gravitino mass (~ eV-GeV)

mSUGRA Benchmark Points

- consistent with present data from particle physics and BBN constraints
-astrophysics and cosmology constrain metastable particles such as staus
-comparison between calculated and observed abundance of light elements
- NLSP stau has long lifetime ~ $10^4 - 10^6$ s
- LSP gravitino, $m_G \sim m_0$ or $m_G \sim 0.2\ m_0$

Points:

ε - low m_0, low $m_{1/2}$, low tanβ
ζ - high m_0, high $m_{1/2}$, high tanβ
η - low m_0, high $m_{1/2}$, high tanβ

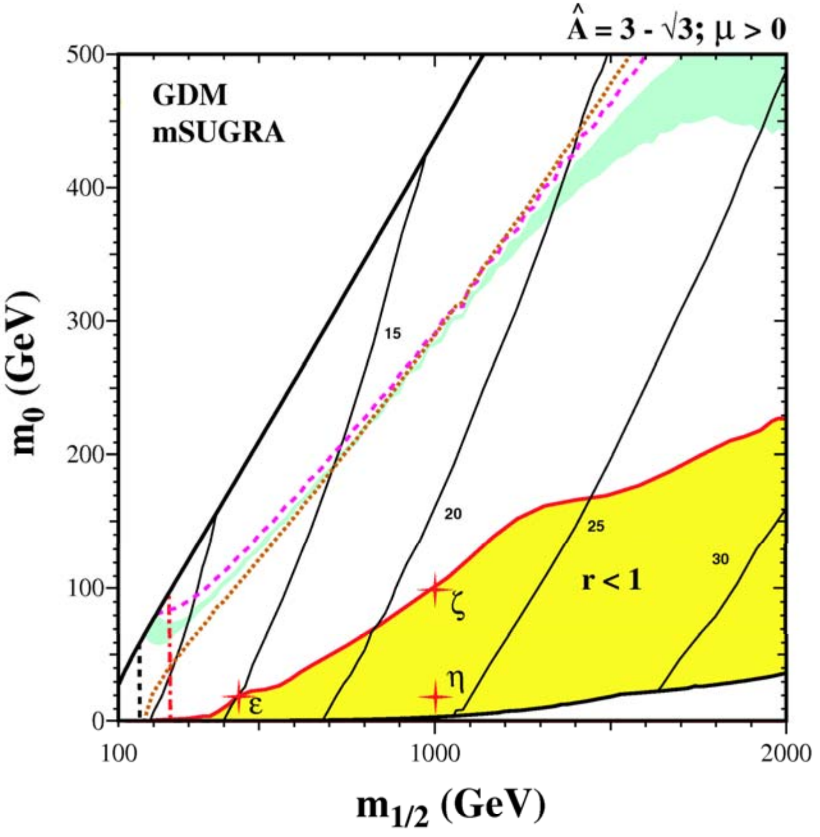
A. De Roeck *et al.* 05

θ - high m_0, high $m_{1/2}$, low tanβ

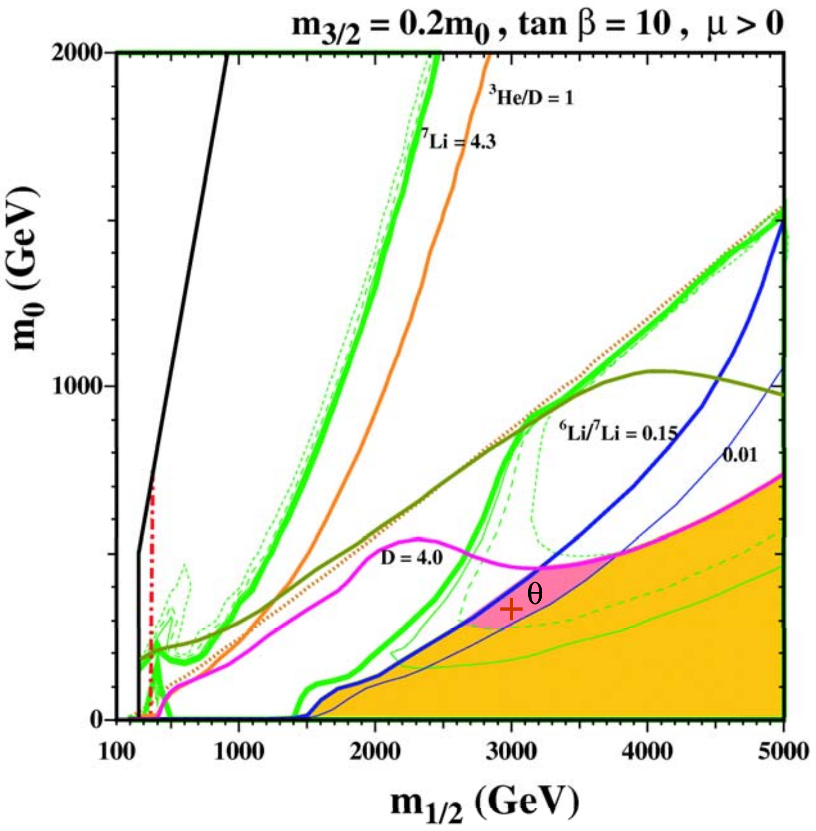
O. Cakir *et al.* 07

in some certain parameter space of mSUGRA, good agreement between BBN calculations and observed ^{6,7}Li abundances

mSUGRA with gravitino LSP and stau NLSP: benchmark points ε, ζ, η and the point θ



Three benchmark points with astrophysical constraints



Agreement between BBN calculations and the observed Li abundances

In large regions of mSUGRA parameters space, the lighter stau is the NLSP ending with an LSP $\tilde{\tau} \to \tau \tilde{G}$

The lighter (heavier) stau mass eigenstate is a linear combination of left and right-handed eigenstates

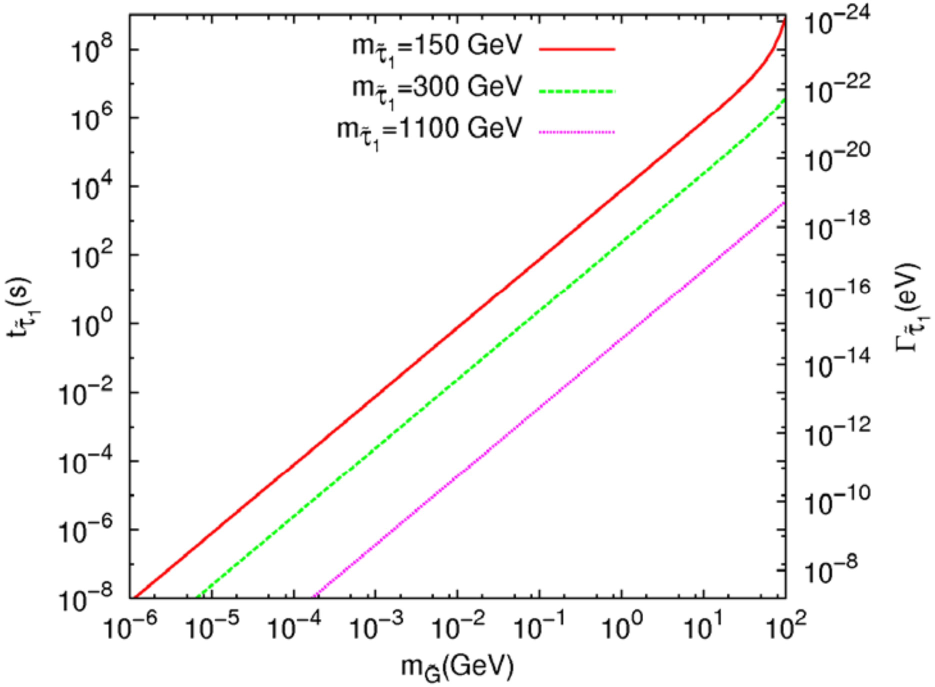
$$\widetilde{\tau}_1 = \widetilde{\tau}_L \cos\theta_{\tilde{\tau}} + \widetilde{\tau}_R \sin\theta_{\tilde{\tau}},$$

$$\widetilde{\tau}_2 = -\widetilde{\tau}_L \sin\theta_{\tilde{\tau}} + \widetilde{\tau}_R \cos\theta_{\tilde{\tau}},$$

Stau decay rate is given by

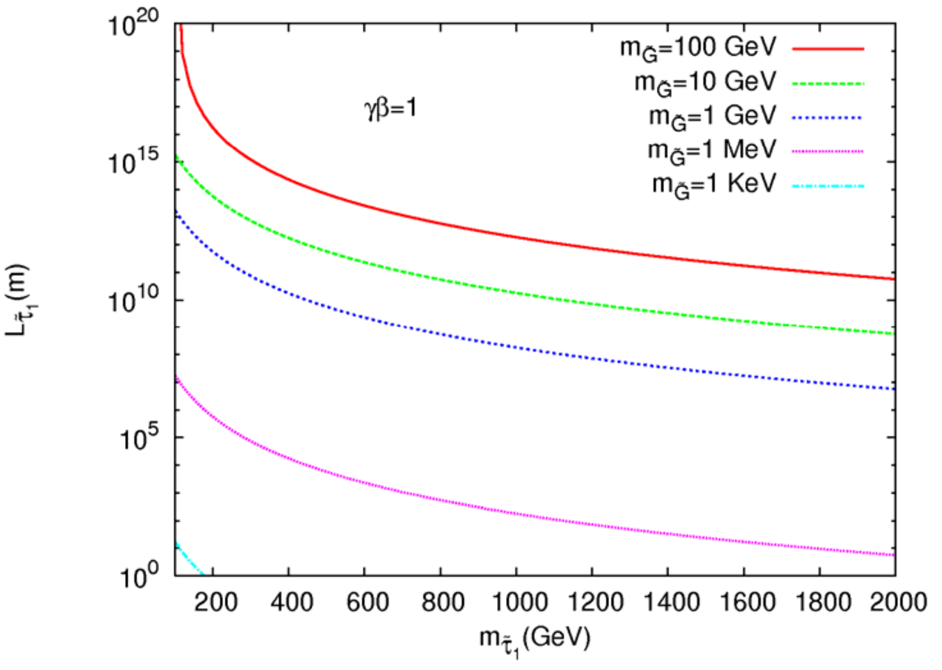
$$\Gamma_{\widetilde{\tau}_1} = \frac{(m^2_{\widetilde{\tau}_1} - m^2_{\widetilde{G}} - m^2_{\tau})^4}{48\pi M_p^2 m^2_{\widetilde{G}} m^3_{\widetilde{\tau}_1}} \left(1 - \frac{4 m^2_{\widetilde{G}} m^2_{\tau}}{(m^2_{\widetilde{\tau}_1} - m^2_{\widetilde{G}} - m^2_{\tau})^2}\right)^{3/2}$$

stau NLSP life-time, decay width, lenght



$t \cong 6.58\times10^{-25}s/\Gamma(GeV)$

$L \cong 1.97\times10^{-16} m/\Gamma(GeV)$



The benchmark points of mSUGRA

Point ε:

t=2.9x10^{6}s = 33.7 day

This point could be probed at LHC, ILC and CLIC

Point ζ:

t=1.7x10^{6}s = 19.4 day

Point η:

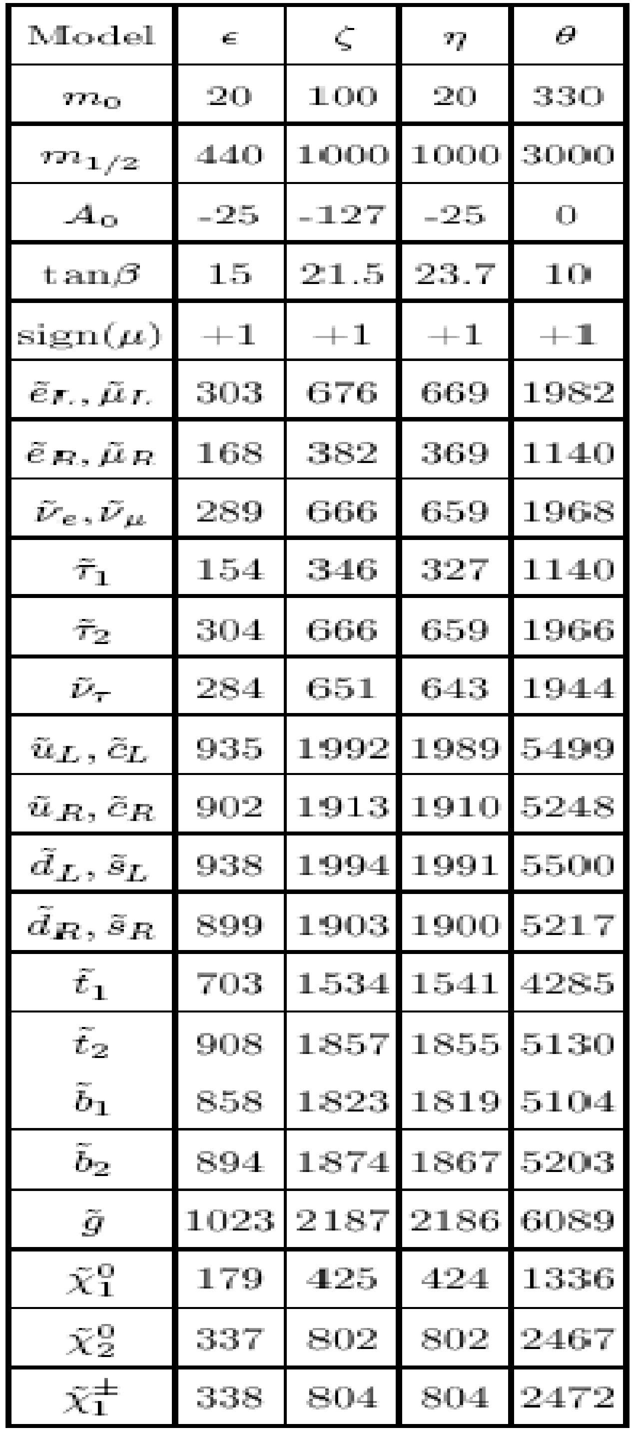
t=6.4x10^{4}s =0.7 day

These points could be probed at LHC and CLIC

Point θ:

t=1.35x10^{3}s

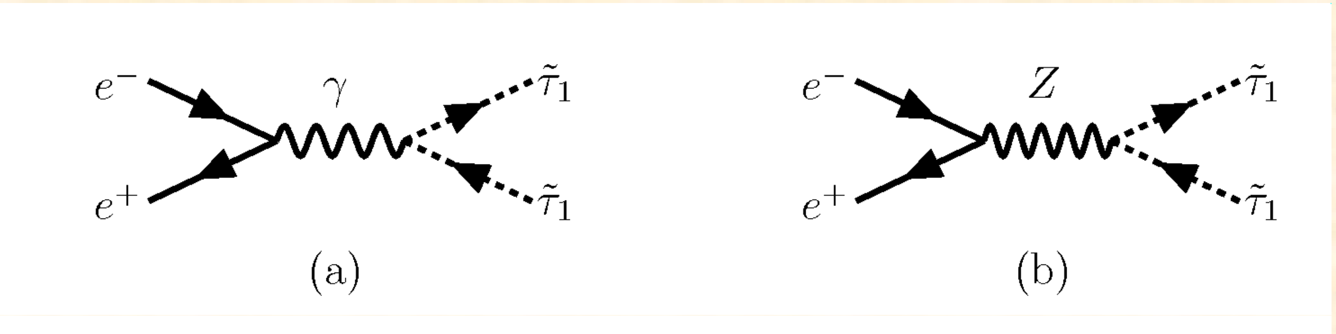
This point could be probed only at CLIC



Model	ϵ	ζ	η	θ
m_0	20	100	20	330
$m_{1/2}$	440	1000	1000	3000
A_0	-25	-127	-25	0
$\tan\beta$	15	21.5	23.7	10
sign(μ)	+1	+1	+1	+1
$\tilde{e}_L, \tilde{\mu}_L$	303	676	669	1982
$\tilde{e}_R, \tilde{\mu}_R$	168	382	369	1140
$\tilde{\nu}_e, \tilde{\nu}_\mu$	289	666	659	1968
$\tilde{\tau}_1$	154	346	327	1140
$\tilde{\tau}_2$	304	666	659	1966
$\tilde{\nu}_\tau$	284	651	643	1944
$\tilde{u}_L, \tilde{c}_L$	935	1992	1989	5499
$\tilde{u}_R, \tilde{c}_R$	902	1913	1910	5248
$\tilde{d}_L, \tilde{s}_L$	938	1994	1991	5500
$\tilde{d}_R, \tilde{s}_R$	899	1903	1900	5217
$\tilde{t}_1$	703	1534	1541	4285
$\tilde{t}_2$	908	1857	1855	5130
$\tilde{b}_1$	858	1823	1819	5104
$\tilde{b}_2$	894	1874	1867	5203
$\tilde{g}$	1023	2187	2186	6089
$\tilde{\chi}_1^0$	179	425	424	1336
$\tilde{\chi}_2^0$	337	802	802	2467
$\tilde{\chi}_1^\pm$	338	804	804	2472

Stau pair production

SUSY R-parity conservation → pair production at colliders



(a) (b)

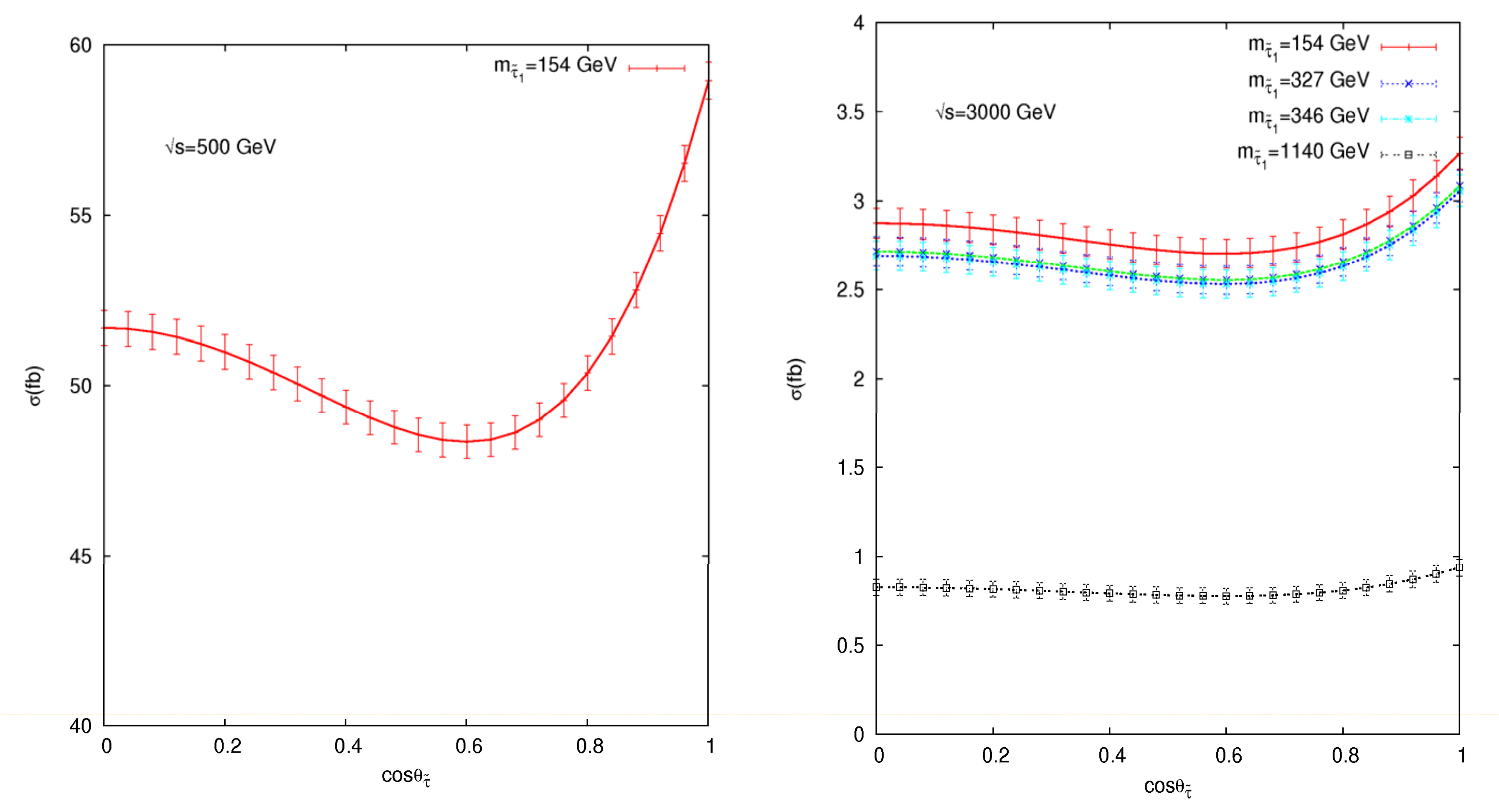
S. Kraml

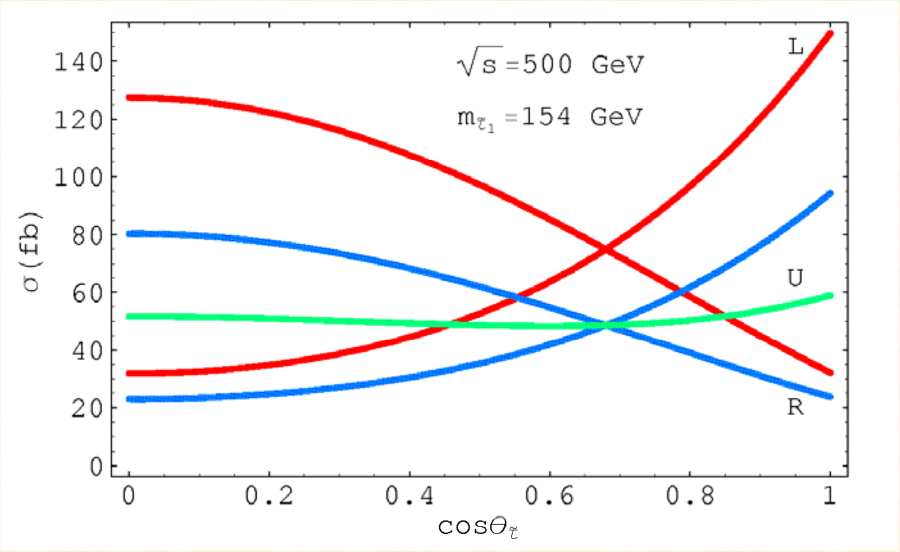
hep-ph/9903257

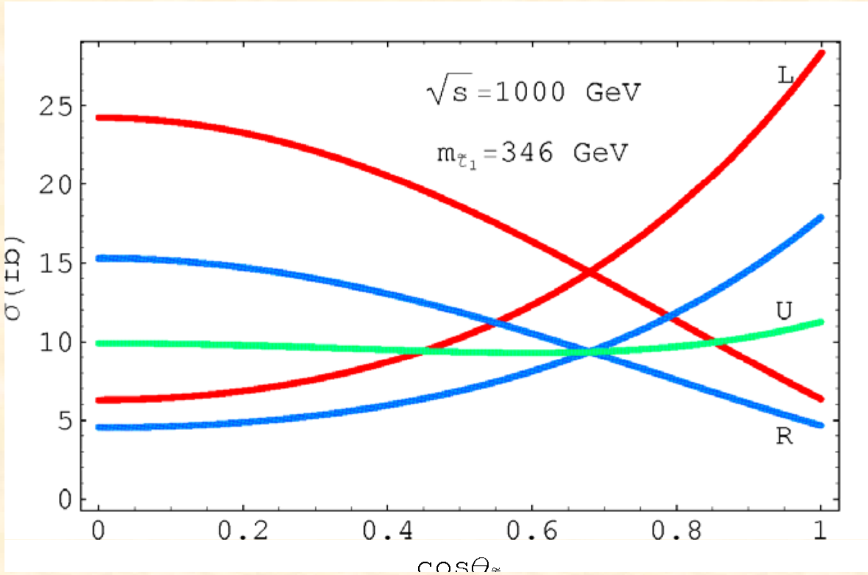
$$\begin{aligned}\sigma &= \frac{\pi\alpha^2\beta^3}{3s}\Bigg[(1-P_-P_+) + \frac{I_3\cos^2\theta_{\tilde{\tau}} + \sin^2\theta_W}{2\cos^2\theta_W\sin^2\theta_W}[v_e(1-P_-P_+) - a_e(P_- - P_+)]P_{\gamma Z} \\ &+ \frac{(I_3\cos^2\theta_{\tilde{\tau}} + \sin^2\theta_W)^2}{16\cos^4\theta_W\sin^4\theta_W}[(v_e^2+a_e^2)(1-P_-P_+) - 2v_e a_e(P_- - P_+)]P_{ZZ}\Bigg]\end{aligned}$$

$$P_{ZZ} = \frac{s^2}{(s-m_Z^2)^2 + m_Z^2\Gamma_Z^2} \quad , \qquad P_{\gamma Z} = \frac{s(s-m_Z^2)}{(s-m_Z^2)^2 + m_Z^2\Gamma_Z^2}$$

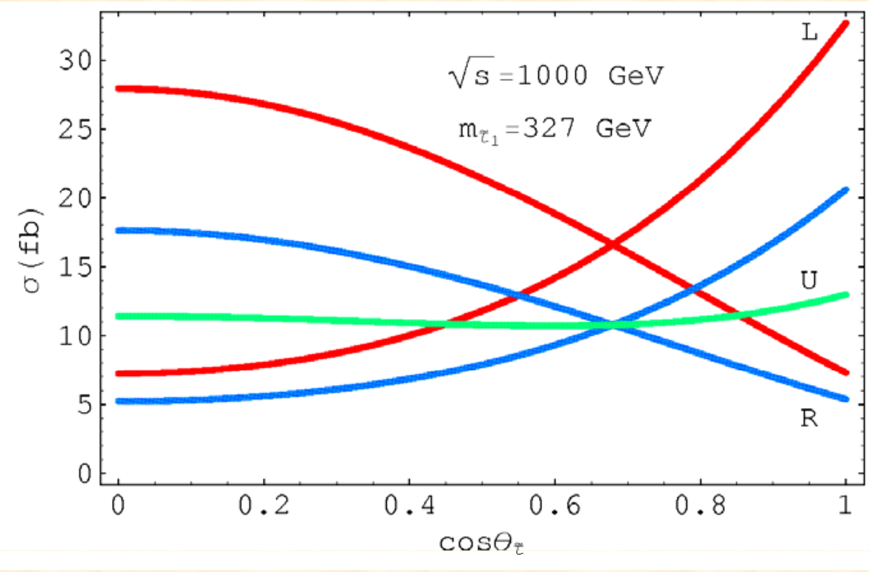
unpolarized cross-sections with statistical errors

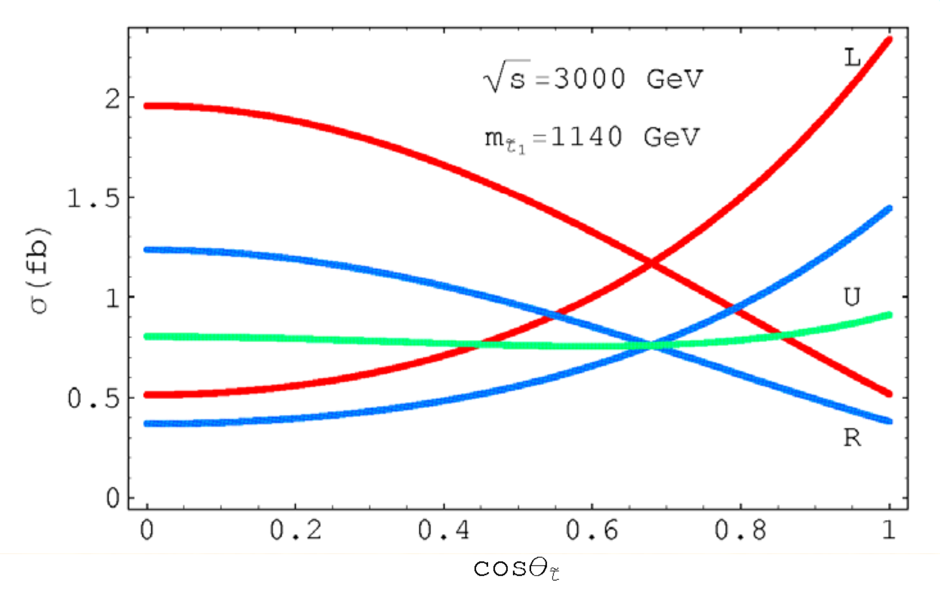




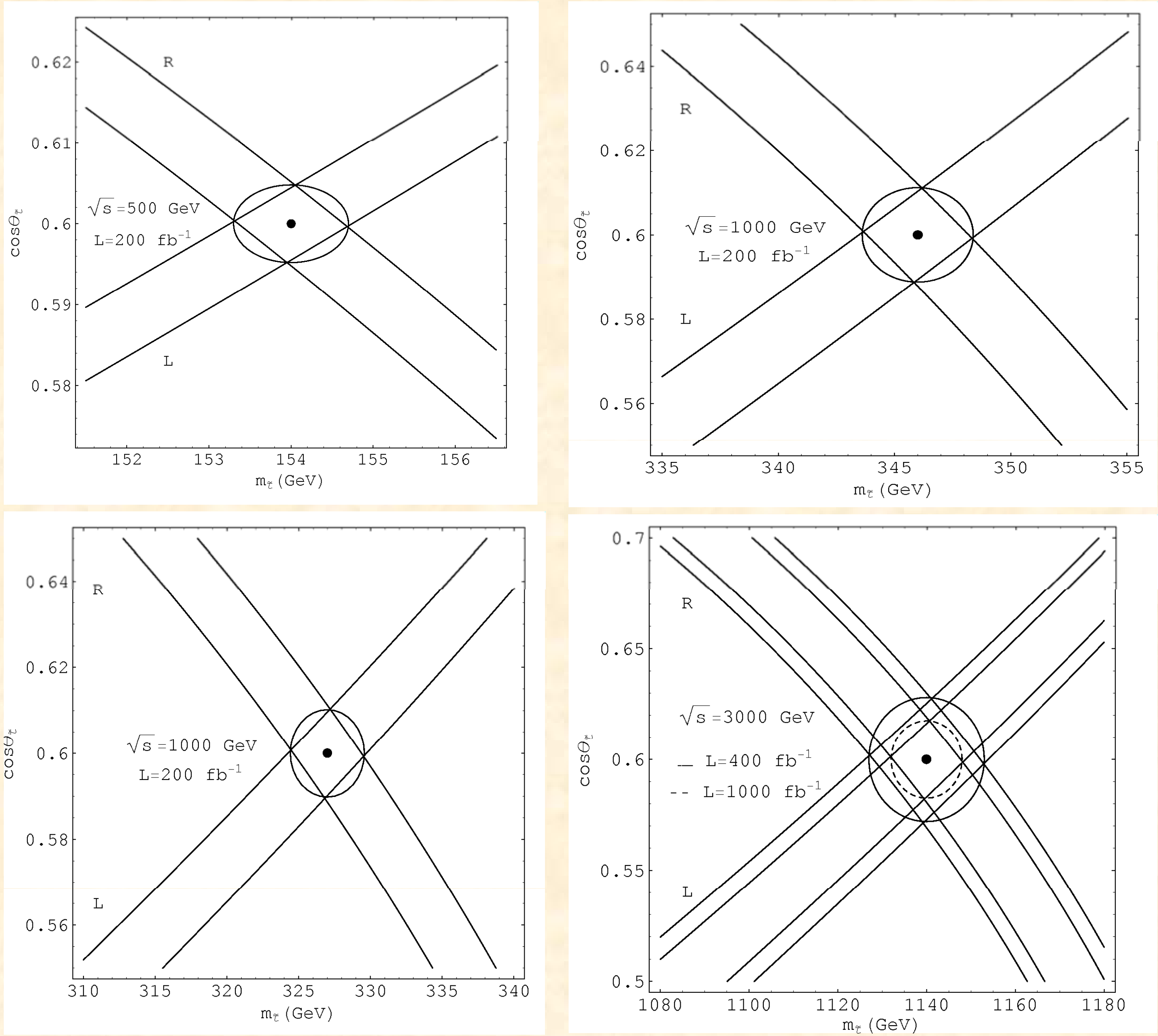


polarized cross-sections





Red: e- (%90), e+ (%60) ; blue: e- (%90); green: unpolarized



Polarization

e- %90

e+ %60

accuracies on the measurements:

$$(\Delta m_{\tilde{\tau}_1}, \Delta\cos\theta_{\tilde{\tau}})$$

(0.7, 0.005) for ε

(2.4, 0.01) for ζ, η

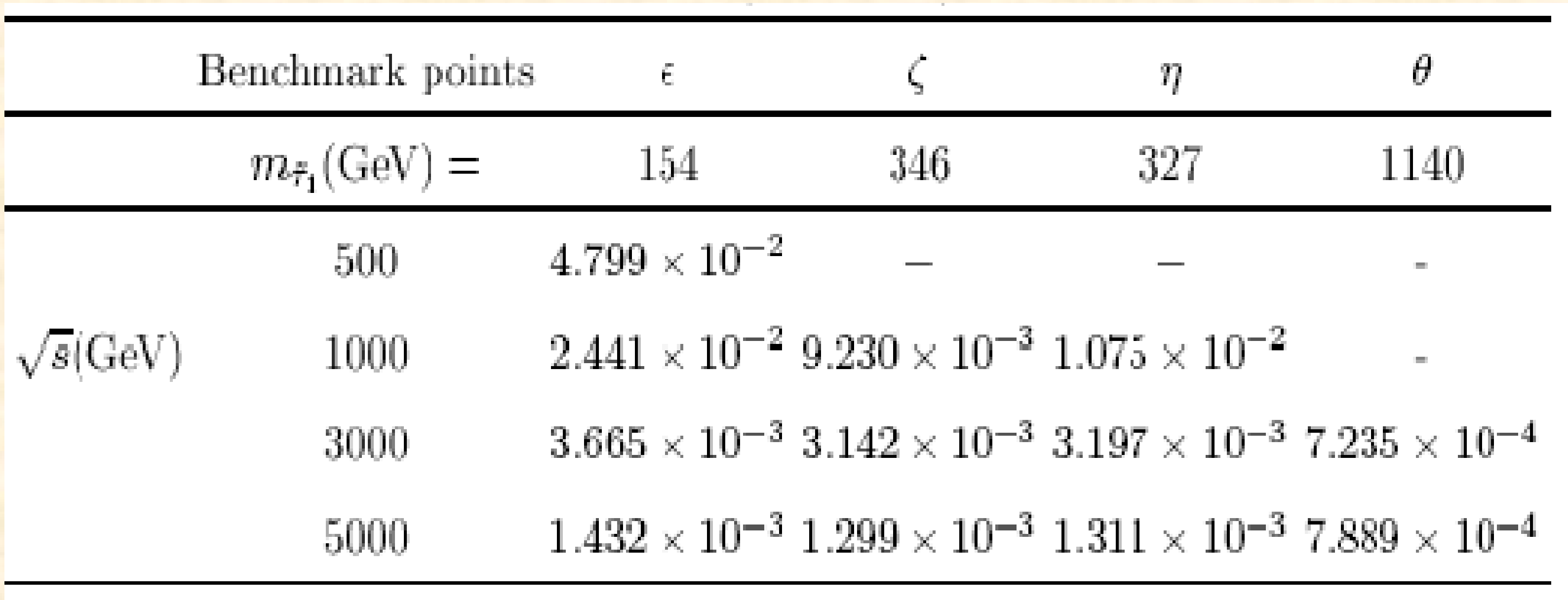
at Ecm=1000 GeV;

(8, 0.02) for θ

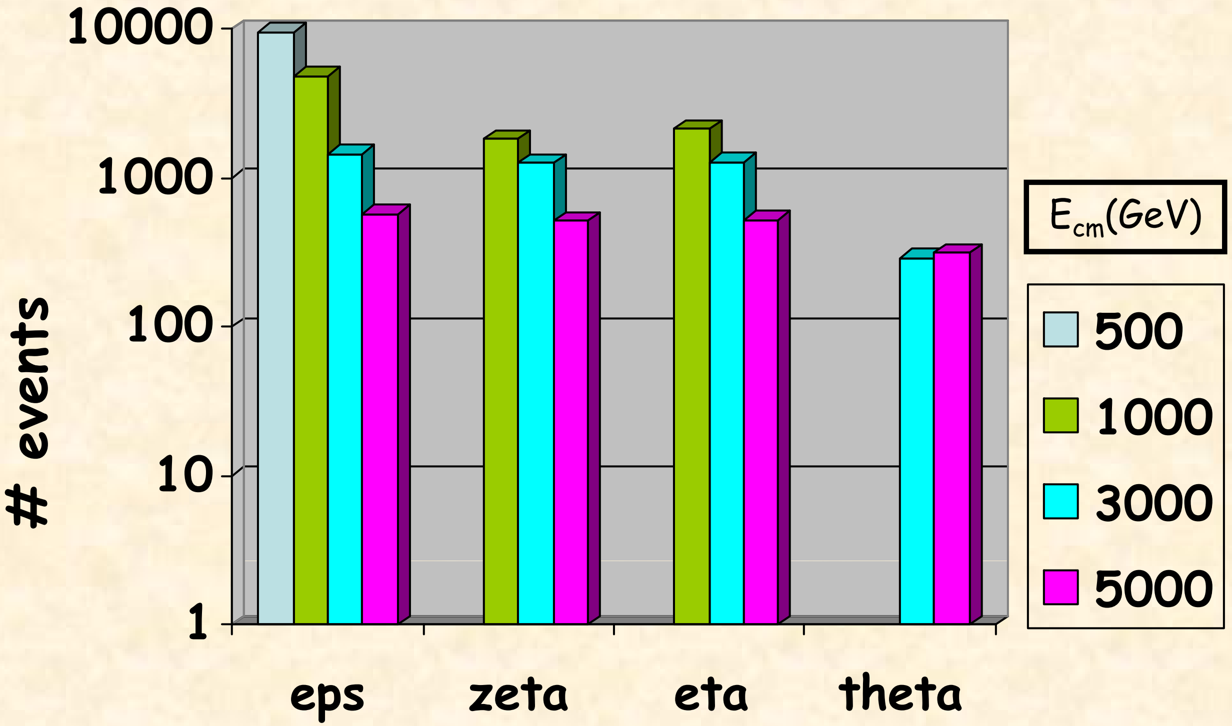
at Ecm=3000 GeV

Errors on the mixing (cosθ~0.6) and stau mass (m_τ)

The total cross section in pb calculated using PYTHIA with the full ISASUGRA spectrum [Baer *et al.* 00], including both initial and final state radiation (ISR+FSR)



	Benchmark points	ϵ	ζ	η	θ
	$m_{\tilde{\tau}_1}(\mathrm{GeV}) =$	154	346	327	1140
$\sqrt{s}(\mathrm{GeV})$	500	4.799×10^{-2}	–	–	-
	1000	2.441×10^{-2}	9.230×10^{-3}	1.075×10^{-2}	-
	3000	3.665×10^{-3}	3.142×10^{-3}	3.197×10^{-3}	7.235×10^{-4}
	5000	1.432×10^{-3}	1.299×10^{-3}	1.311×10^{-3}	7.889×10^{-4}

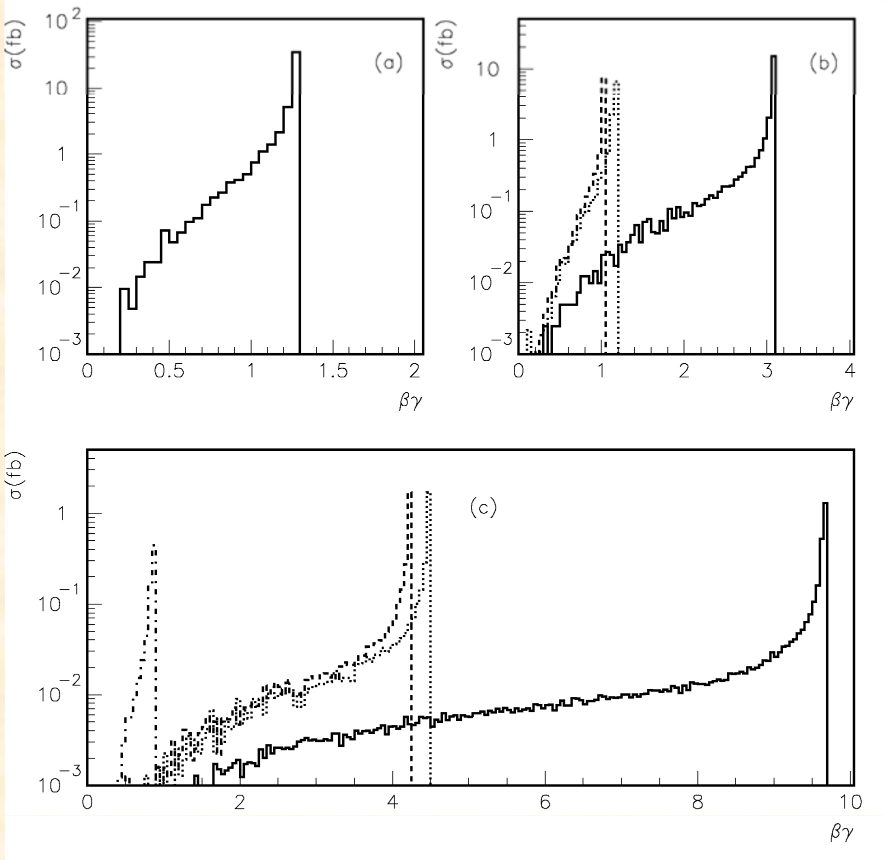


Number of stau pairs produced at:

E_{cm} = 500, 1000 GeV with L=200 fb^{-1}

E_{cm} = 3000, 5000 GeV with L=400 fb^{-1}

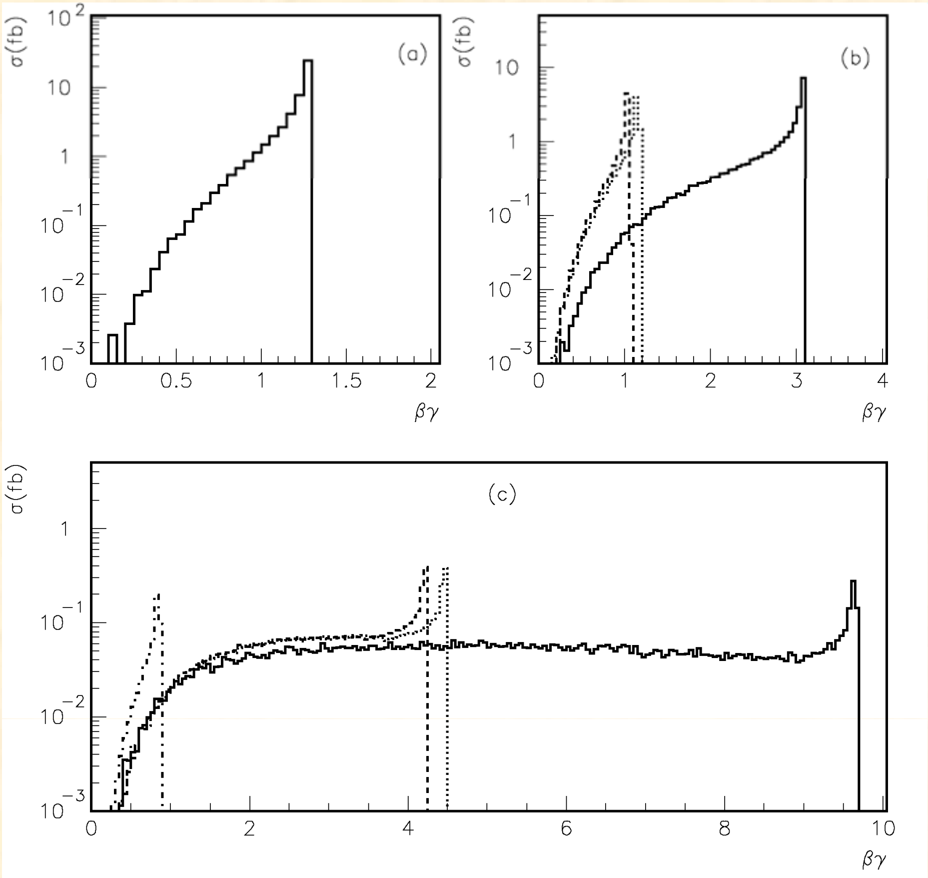
βγ distribution



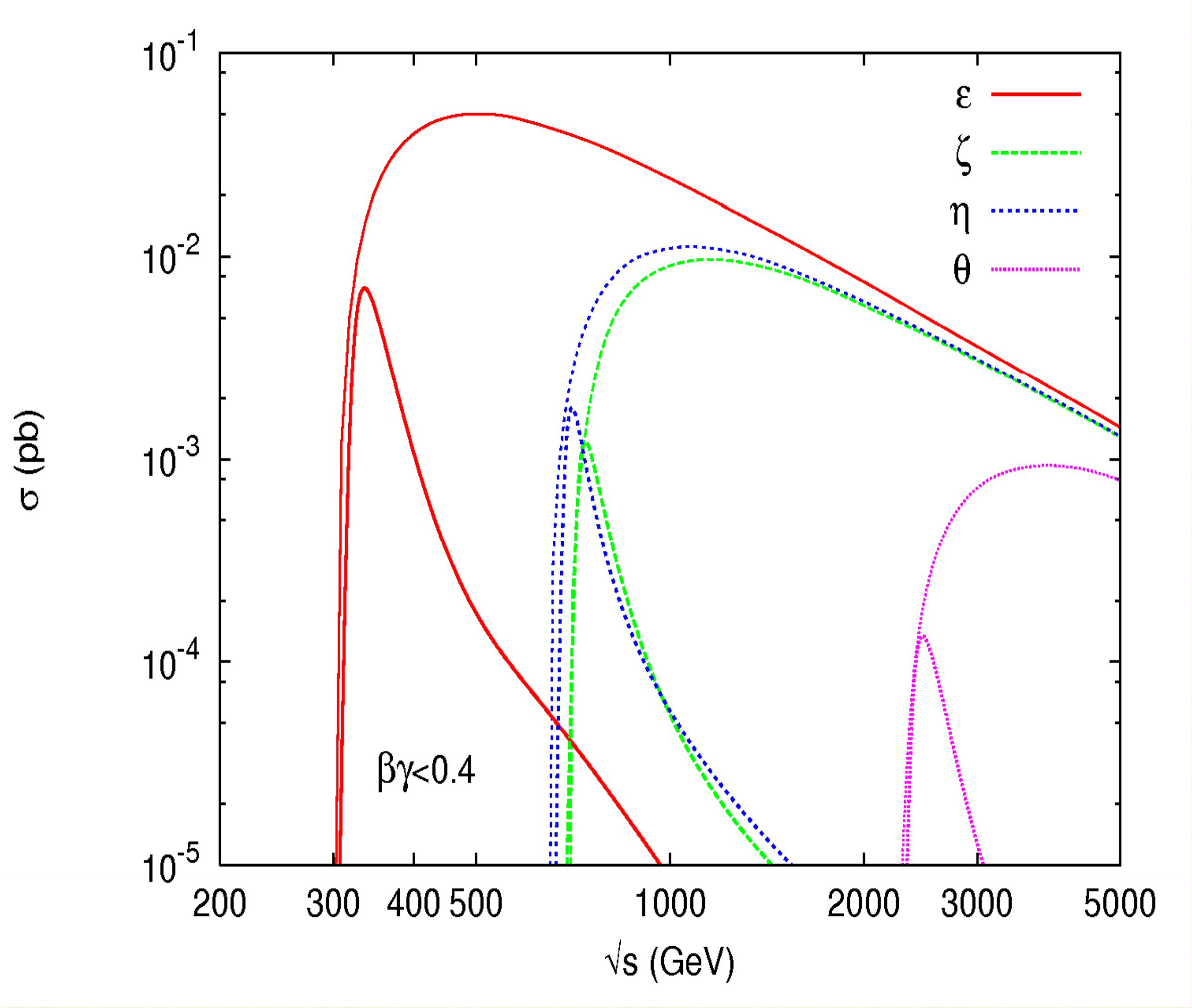
with simulated CLIC

energy spectrum →

(optimize total luminosity)



Stau pair production at benchmark points and optimal energies for slow-staus with βγ<0.4



optimal center of mass energies for the constraint βγ<0.4 :

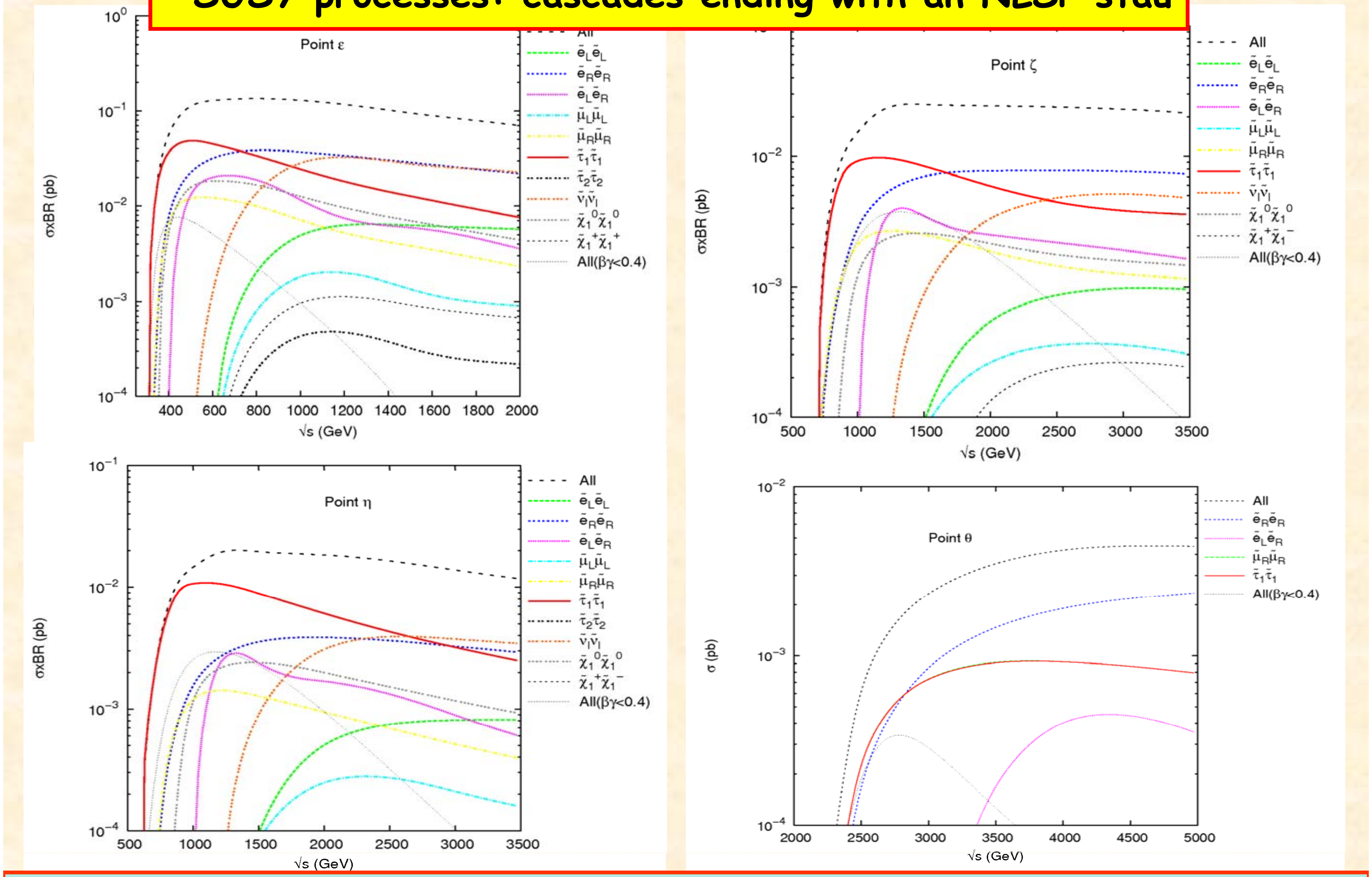
330 GeV for ε

730 GeV for ζ

700 GeV for η

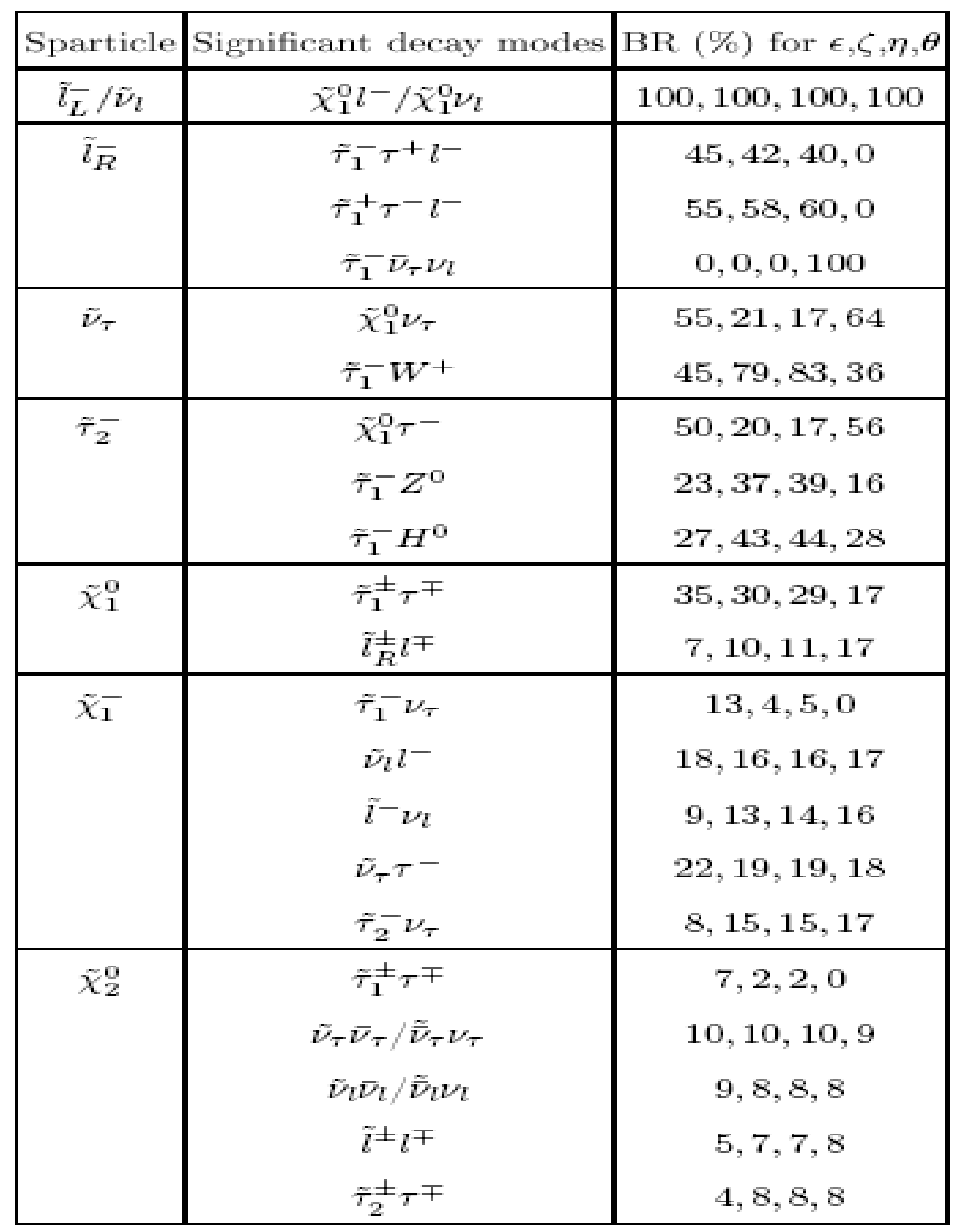
2500 GeV for θ

SUSY processes: cascades ending with an NLSP stau



The cross sections for pair-production of supersymmetric particles in the benchmark scenarios ε,ζ,η and θ, as functions of √s. $\sigma(e_R e_R)=8.5\times10^{-4}$ pb, $\sigma(\mu_R\mu_R)=7.3\times10^{-4}$pb at 3000 GeV for point θ

Significant decay modes and branching ratios of SUSY particles



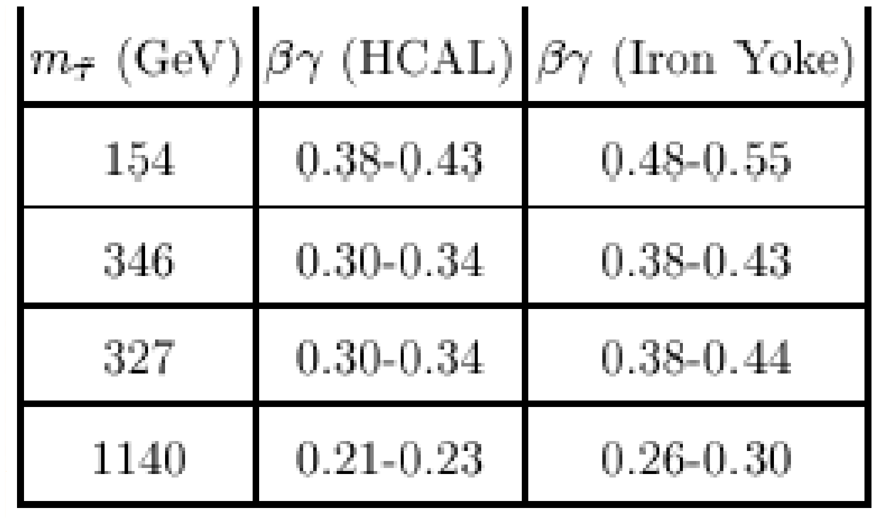
Sparticle	Significant decay modes	BR (%) for ϵ,ζ,η,θ
$\tilde{l}_L^-/\tilde{\nu}_l$	$\tilde{\chi}_1^0 l^-/\tilde{\chi}_1^0 \nu_l$	100, 100, 100, 100
$\tilde{l}_R^-$	$\tilde{\tau}_1^- \tau^+ l^-$	45, 42, 40, 0
	$\tilde{\tau}_1^+ \tau^- l^-$	55, 58, 60, 0
	$\tilde{\tau}_1^- \bar{\nu}_\tau \nu_l$	0, 0, 0, 100
$\tilde{\nu}_\tau$	$\tilde{\chi}_1^0 \nu_\tau$	55, 21, 17, 64
	$\tilde{\tau}_1^- W^+$	45, 79, 83, 36
$\tilde{\tau}_2^-$	$\tilde{\chi}_1^0 \tau^-$	50, 20, 17, 56
	$\tilde{\tau}_1^- Z^0$	23, 37, 39, 16
	$\tilde{\tau}_1^- H^0$	27, 43, 44, 28
$\tilde{\chi}_1^0$	$\tilde{\tau}_1^\pm \tau^\mp$	35, 30, 29, 17
	$\tilde{l}_R^\pm l^\mp$	7, 10, 11, 17
$\tilde{\chi}_1^-$	$\tilde{\tau}_1^- \nu_\tau$	13, 4, 5, 0
	$\tilde{\nu}_l l^-$	18, 16, 16, 17
	$\tilde{l}^- \nu_l$	9, 13, 14, 16
	$\tilde{\nu}_\tau \tau^-$	22, 19, 19, 18
	$\tilde{\tau}_2^- \nu_\tau$	8, 15, 15, 17
$\tilde{\chi}_2^0$	$\tilde{\tau}_1^\pm \tau^\mp$	7, 2, 2, 0
	$\tilde{\nu}_\tau \bar{\nu}_\tau/\bar{\tilde{\nu}}_\tau \nu_\tau$	10, 10, 10, 9
	$\tilde{\nu}_l \bar{\nu}_l/\bar{\tilde{\nu}}_l \nu_l$	9, 8, 8, 8
	$\tilde{l}^\pm l^\mp$	5, 7, 7, 8
	$\tilde{\tau}_2^\pm \tau^\mp$	4, 8, 8, 8

Detection of stau

$$log_{10}(\beta\gamma) = \frac{[log_{10}(R/m_{\tilde{\tau}_1}) - c_1]}{c_2}$$

c_1 = 2.087, c_2 = 3.22
for steel

Rossi, 52

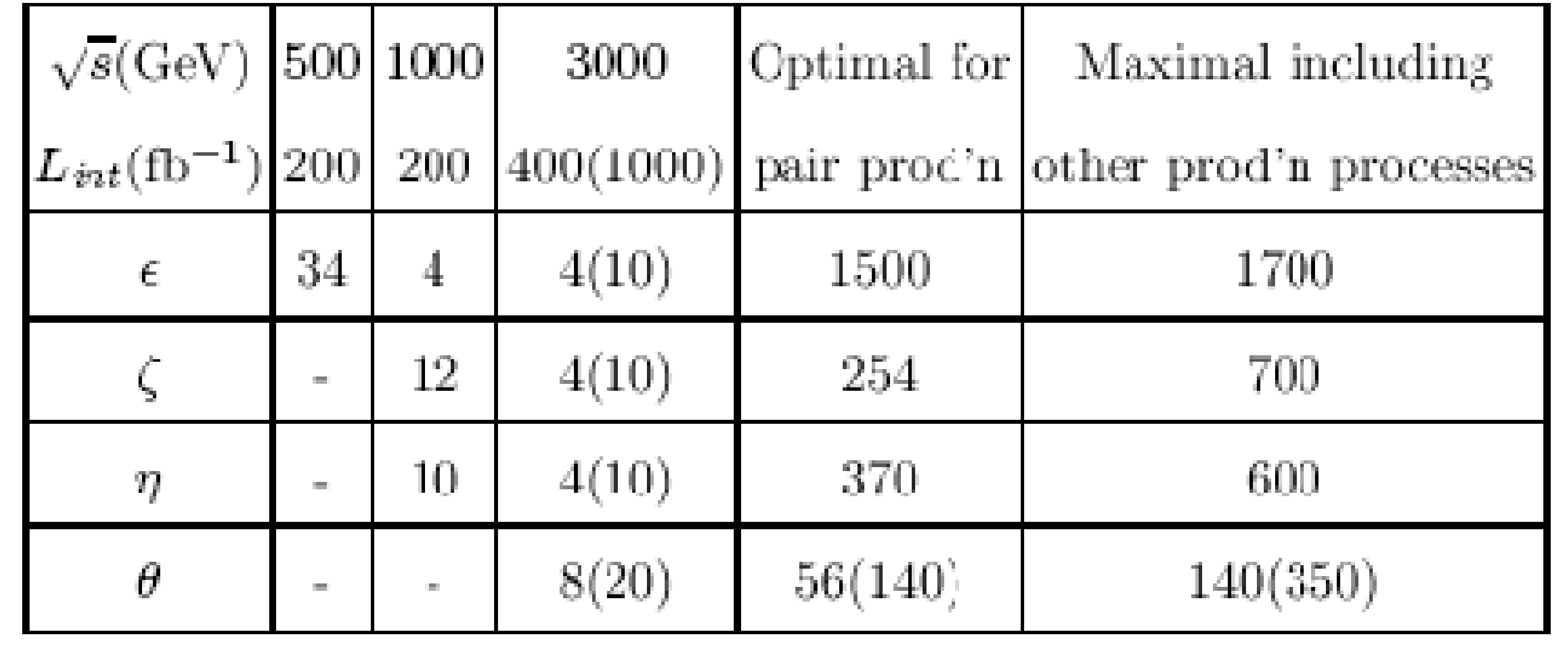


$m_{\tilde{\tau}}$ (GeV)	$\beta\gamma$ (HCAL)	$\beta\gamma$ (Iron Yoke)
154	0.38-0.43	0.48-0.55
346	0.30-0.34	0.38-0.43
327	0.30-0.34	0.38-0.44
1140	0.21-0.23	0.26-0.30

Martyn, 06

The coresponding values of βγ for staus stopping in different detector parts for the benchmark points ε, ζ, η and θ

The number of stau pairs with $\beta\gamma < 0.4$, stopped in GLCD



$\sqrt{s}$(GeV)	500	1000	3000	Optimal for	Maximal including
L_{int}(fb^{-1})	200	200	400(1000)	pair proc'n	other prod'n processes
ϵ	34	4	4(10)	1500	1700
ζ	-	12	4(10)	254	700
η	-	10	4(10)	370	600
θ	-	-	8(20)	56(140)	140(350)

CONCLUSIONS

- Discussed the choice of cm energy that would maximize the σ for prod. slow moving stau with $\beta\gamma < 0.4$ in a CLIC det.

- Presented metastable staus produced in the cascade decays of heavier sparticles, so that optimal cm energies for trapping staus higher than stau pair-prod. threshold

- If stau (for point ε,ζ,η) found by the LHC, one would know optimal energy and optimal number of stopping staus

- ^{6,7}Li friendly point θ features relatively heavy sparticles beyond the reach of either the LHC or the ILC, but within the kinematic reach of CLIC

- Even if there are some light sparticles, the heavier sparticles beyond the reach of LHC and ILC can be discovered and measured precisely at a high energy linear collider CLIC

Many “staus” at CLIC