Completing the Sparticle Spectrum at a multi-TeV collider?

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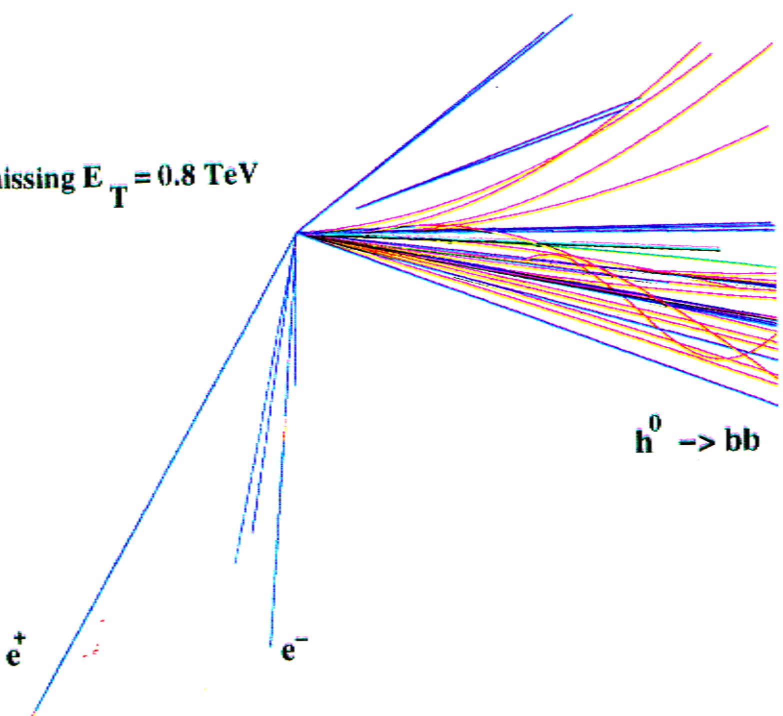
LCWS2000, 26 October

CLIC 3 TeV

$e^+ e^- \rightarrow \tilde{e}_L \tilde{e}_R$



$m_{\tilde{e}} = 1050$ GeV

$m_{h^0} = 115$ GeV

$\tilde{e}_L \rightarrow e \tilde{\chi}^0_2$

$\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 h$

$h \rightarrow b\bar{b}$

$\tilde{e}_R \rightarrow e \tilde{\chi}^0_1$

Introduction

- Role of a multi-TeV e+e- collider for SUSY?
  - Case I. No indications from LHC/LC
    - Continue the search to higher energies
      - Presumably most theorists would not bet too much on this (at least for now !)
    - or give up and look for other things at high energy
  - Case II. Discovered by LHC/LC
    - Pick up the left-overs from LHC/LC ?
    - Or, identify, understand and measure all the states predicted by the model
      - Challenging program to do a comprehensive job on the whole sparticle spectrum (gluino not feasible*) * (if $m_{\tilde{g}} > m_{\tilde{q}}$)
      - Illustrate with some examples

Case II

Questions to address

- Did LHC discover squarks or gluinos ?
  - Which squarks ? How did they decay ?
  - Which mass difference did LHC measure ?
- How many sparticles are there ?
  - Are there really just left-handed sneutrinos ?
    - are there ones for e, mu and tau ?
- Can the branching ratios, widths, masses and couplings be understood ?

Model framework

- Select simplified SUSY model à la LHC studies.
- Choose relatively heavy SUGRA model with
  - $m_{1/2}$=400 GeV, m0=400 GeV, tanb=35, A=-400 GeV, $\mu < 0$. (MODEL 1)
  - Chargino, neutralino, slepton and squark mass spectra are somewhat degenerate
    - big mass differences, so high missing pT and detectable
    - sparticles difficult to distinguish
  - Example has 1 TeV squarks detectable at LHC
    - but not much else.
  - C,N lightest sparticles (LC), sleptons heavier.
- NB this is for illustration only. Many other ways in which sparticles could be realised. K Matchev's talk suggests studying much heavier m0.

($m_{1/2} = 300$, $m_0 = 1450$, $\tan\beta = 10$, $A = 0$, $\mu > 0$) (high m_0 model)

Tools

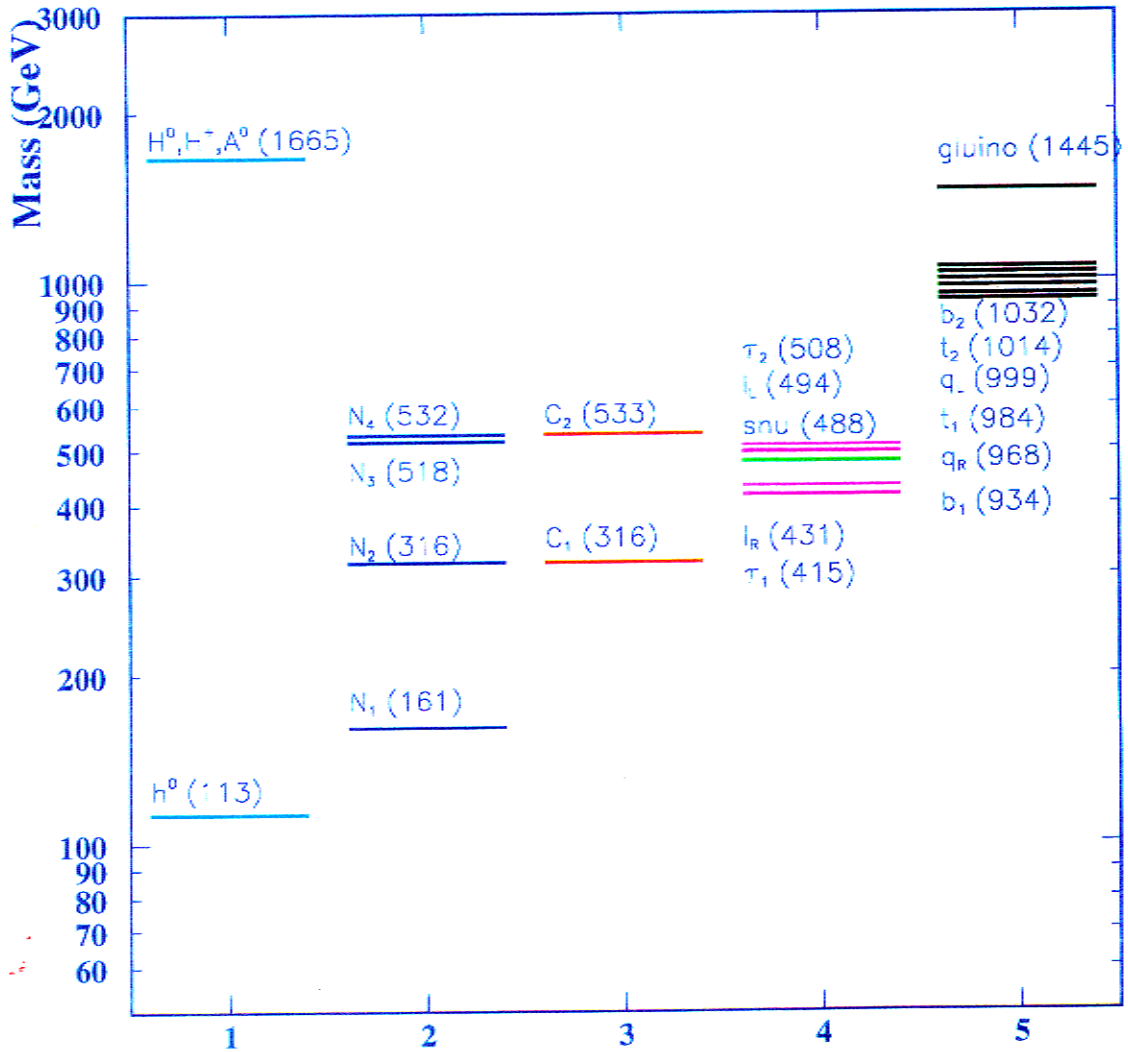
- SUSYGEN3 for cross-sections, BRs, masses and widths.
- SPYTHIA for inclusive SUSY production
  - NB doesn't seem to produce squarks other than stop and sbottom in e+e-.
  - Interfaced to CALYPSO for CLIC beamstrahlung and SIMDET for detector smearing

Schulte
Battaglia
De Roeck,
Schreiber,
Pohl

- Remark: width effects, IP, beamstrahlung, model, user ntuples, scanning.

Sparticle Mass Spectrum

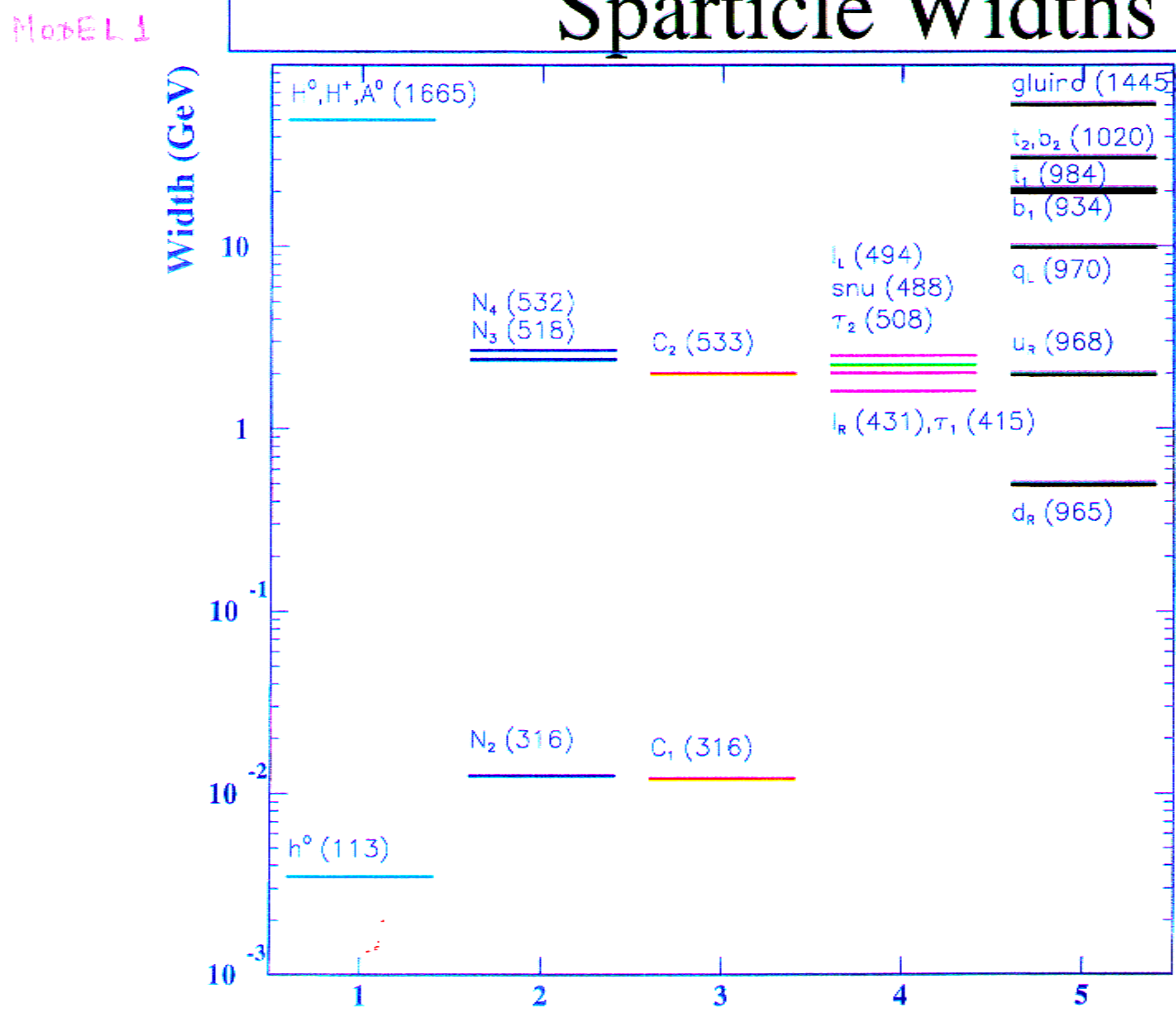
MODEL 1



Mass spectrum is clumped

Using $N_i = \tilde{\chi}^0_i$, $C_j = \tilde{\chi}^\pm_j$ notation.

Sparticle Widths

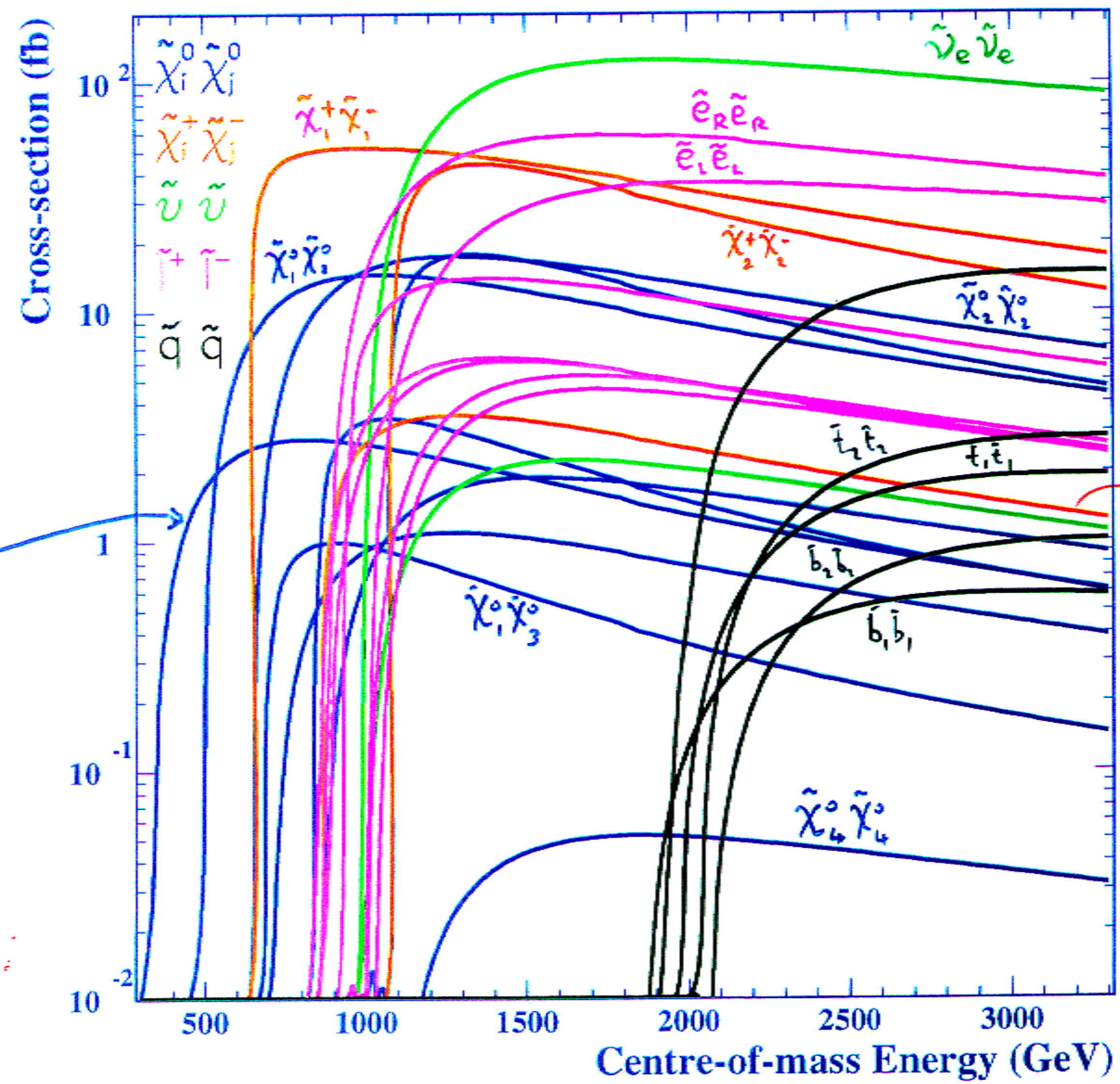


Heavier states are quite wide

Therefore, beam quality less of an issue at higher ECM.

Sparticle Cross-sections

MODEL 1



SB $\tilde{\nu}$ highest Xs

VERY BUSY.

→ many cross-section turn on at once...

Sparticle Cross-sections

high m_0 model

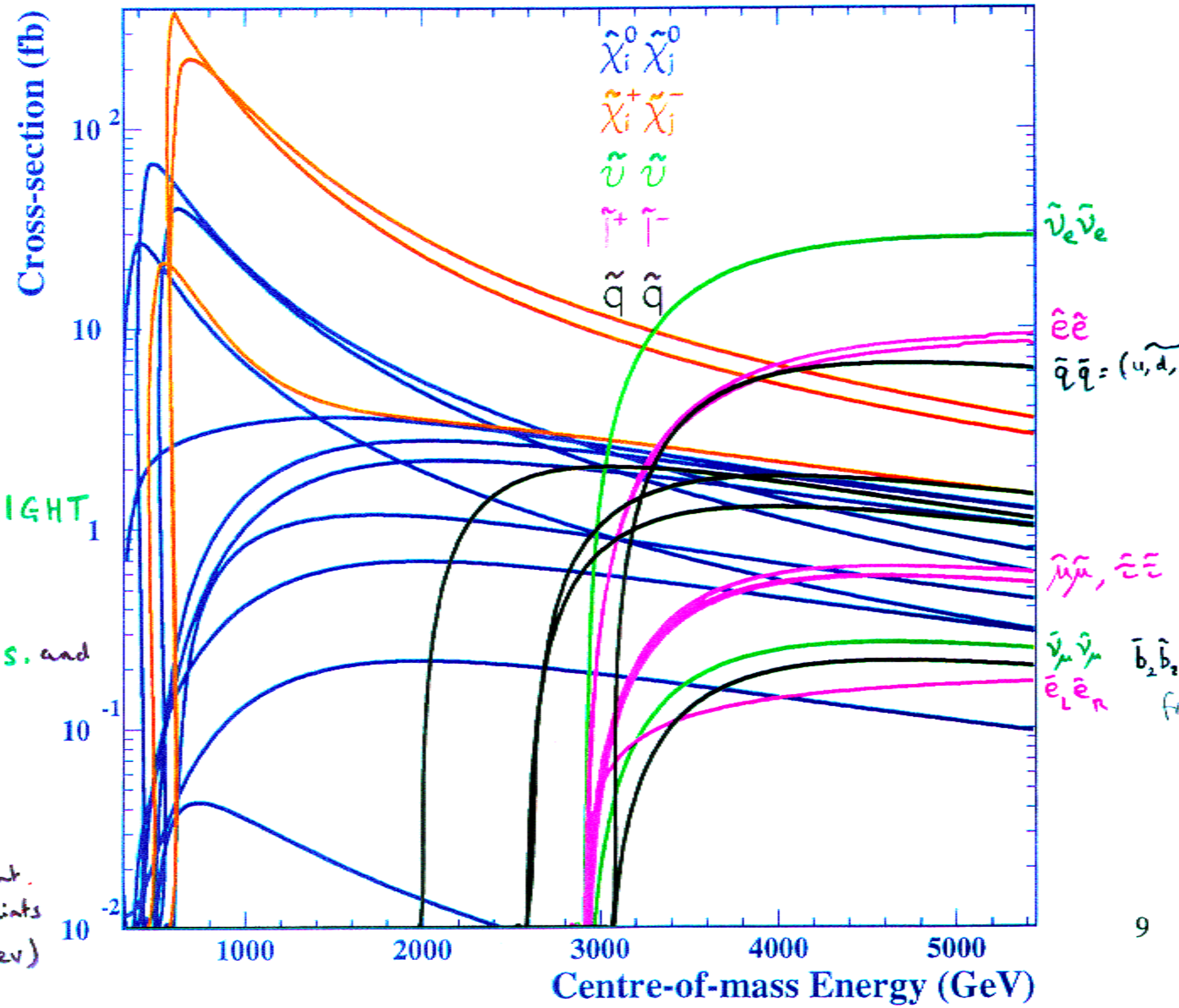
$m_{1/2}$ = 300 GeV

m_0 = 1450 GeV

neutralinos and charginos are LIGHT

sleptons, sneutrinos, and squarks are HEAVY

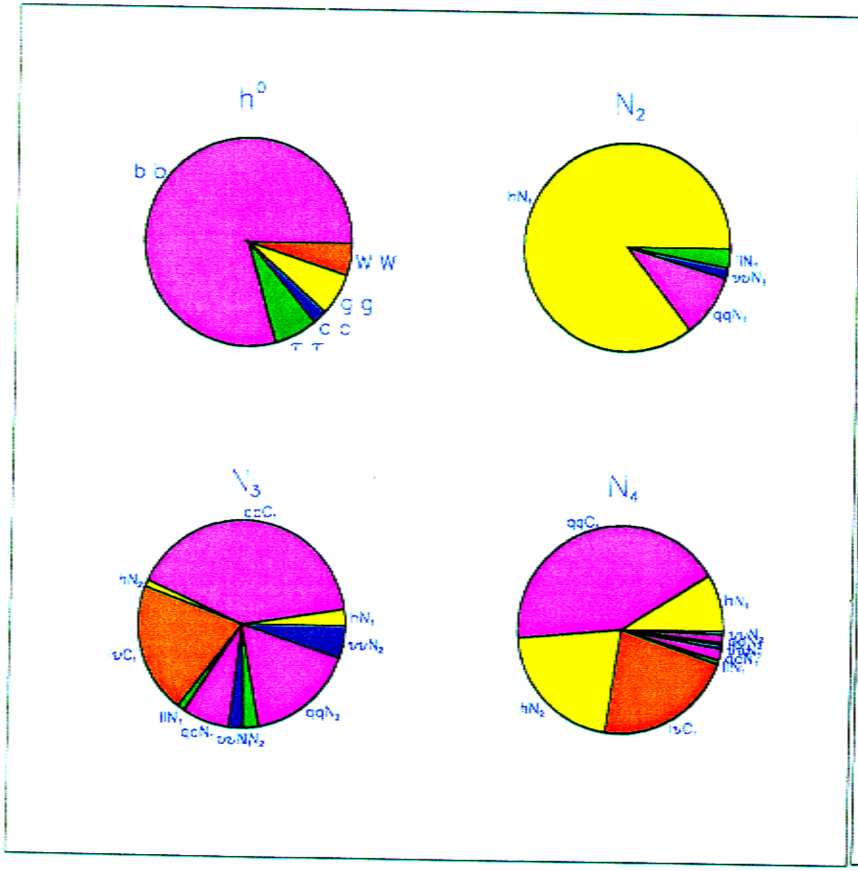
parameters consistent with CDM constraints (Matchev)

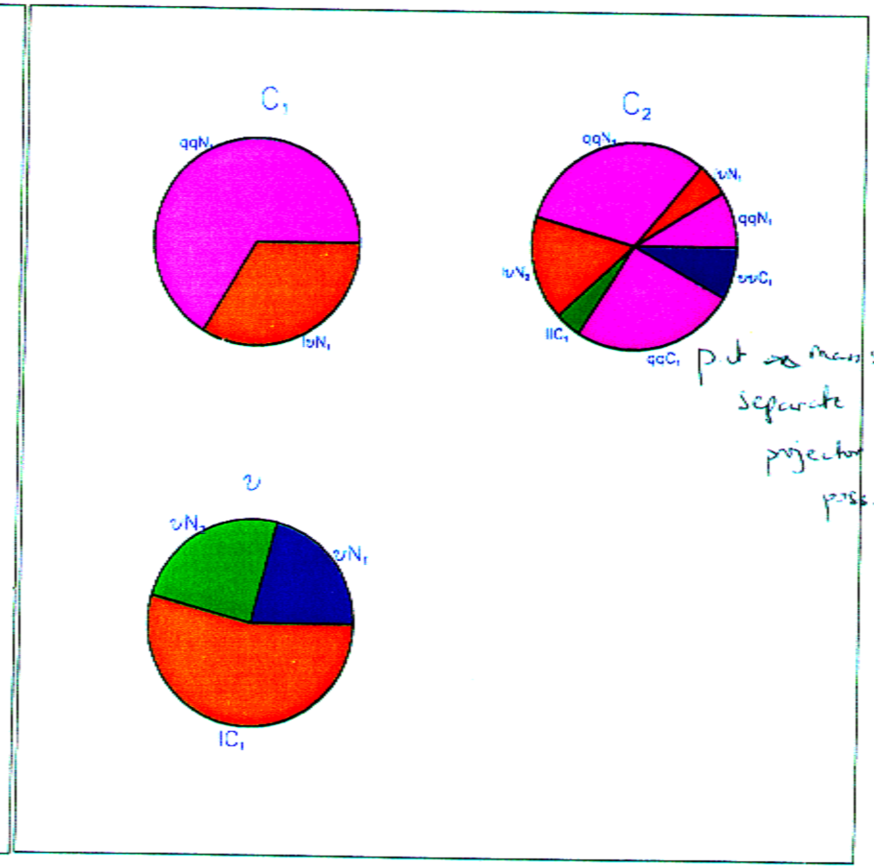


fraction of ... at 5 TeV

Sparticle Branching Ratios

MODEL 1



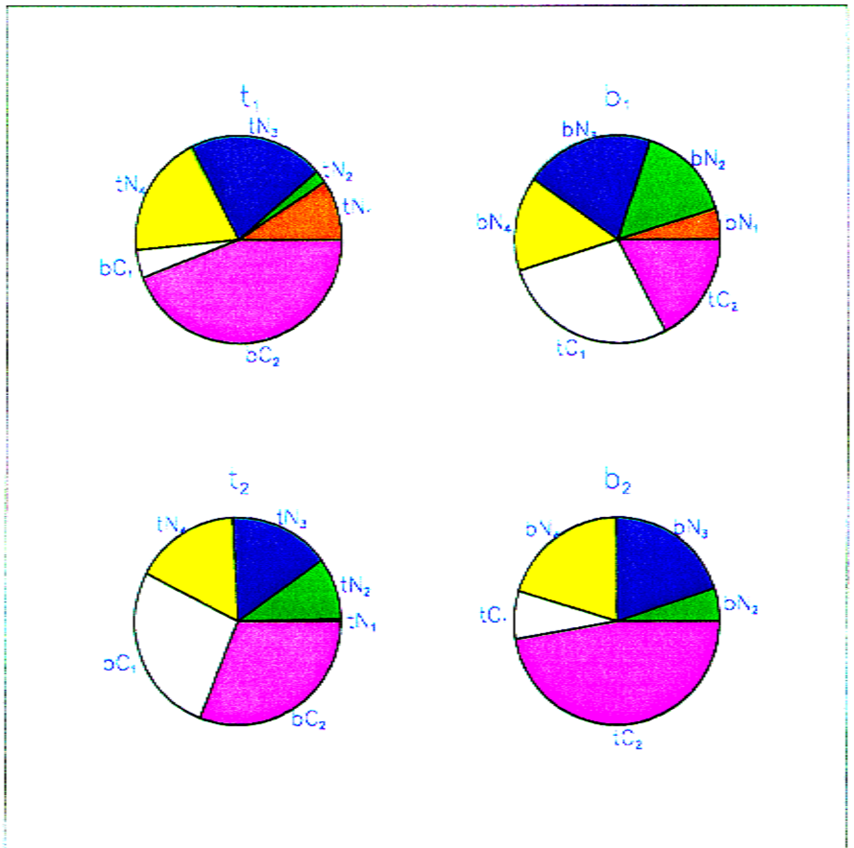


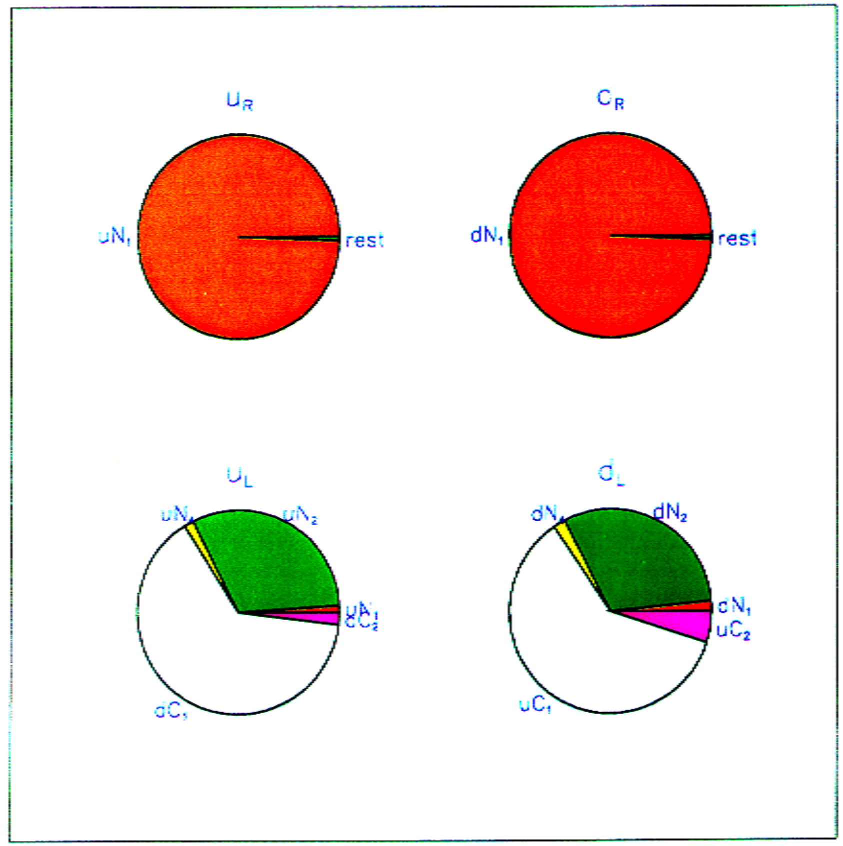
put on main screen. separate projector if possible

Using $C_i = \tilde{\chi}_i^{\pm}$, $N_j = \tilde{\chi}_j^{0}$ shorthand.

Sparticle Branching Ratios

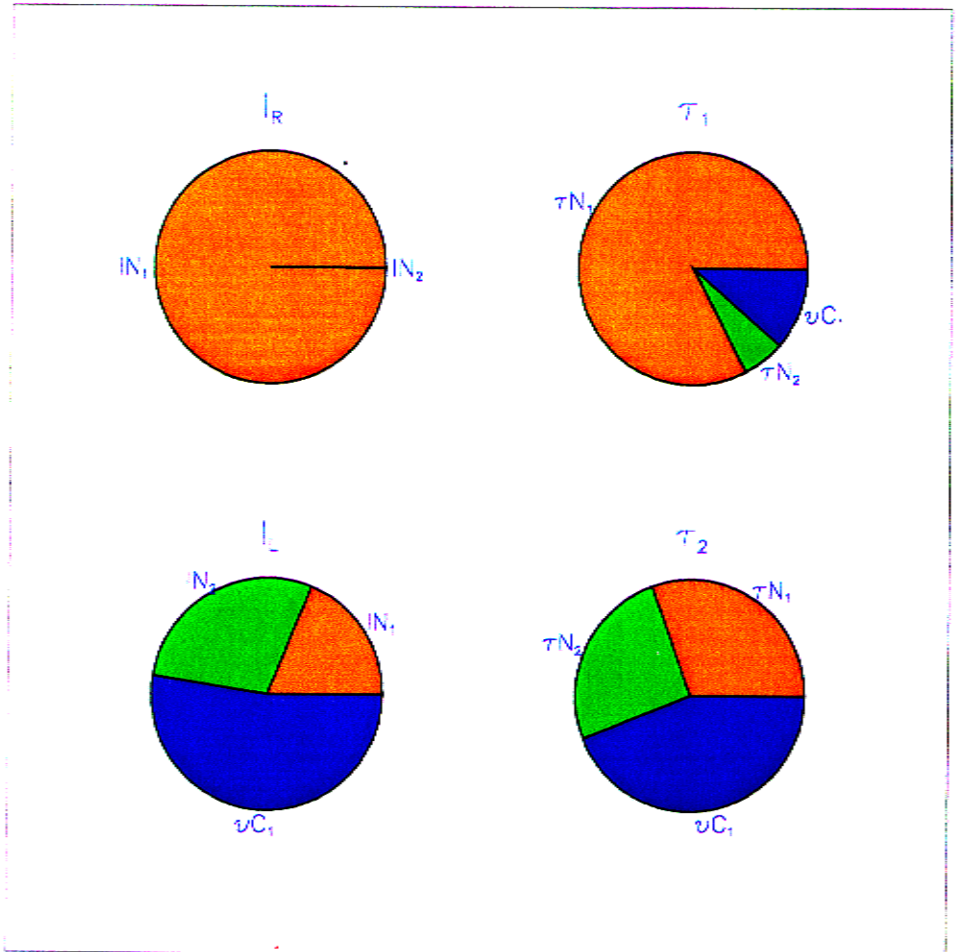
MODEL 1





MODEL 1

Sparticle Branching Ratios



only $\tilde{l}_R \; \tilde{u}_R \; \tilde{d}_R$

have characteristic simple decay modes.

Other sparticles can and usually do have multiple cascade decays. (⇒ small BR's for clean channels)

With two LSPs plus possible neutrinos for each decay chain, mass reconstruction is generally DIFFICULT, and sparticle ID AMBIGUOUS.

Threshold scans may be most appropriate if sparticle ID is clear-cut.

topology remarks...

Case Study

- ECM = 3 TeV, 140 inv fb (50k SUSY events)
- Focus on sneutrino pair production
  - highest cross-section at high energy (t-channel chargino exchange for snue). (MD $\leftrightarrow$ threshold scan)
  - Primary lepton flavour in CC decay gives sneutrino flavour. $\tilde{\nu}_\ell \rightarrow \ell \, \tilde{\chi}_1^+$
- Generate inclusive SUSY events and try to identify sneutrino masses from lepton energy spectra.
- So far have not used polarisation info (not in SPYTHIA)
- so far have neglected non SUSY backgrounds.

CHANNELS

MODEL 1

SIGNAL

$$\tilde{\nu}_e \tilde{\nu}_e \ (488) \longrightarrow e^+ \tilde{\chi}_1^- \ e^- \tilde{\chi}_1^+ \ (316)$$

BACKGROUND

$$\tilde{e}_L \ \tilde{e}_L \ (494) \longrightarrow e^+ \tilde{\chi}_2^0 \ e^- \tilde{\chi}_2^0 \ (316)$$

$$\tilde{e}_R \ \tilde{e}_R \ (431) \longrightarrow e^+ \tilde{\chi}_1^0 \ e^- \tilde{\chi}_1^0 \ (161)$$

$$\tilde{e}_L^+ \ \tilde{e}_R^- \longrightarrow e^+ \tilde{\chi}_2^0 \ e^- \tilde{\chi}_1^0$$

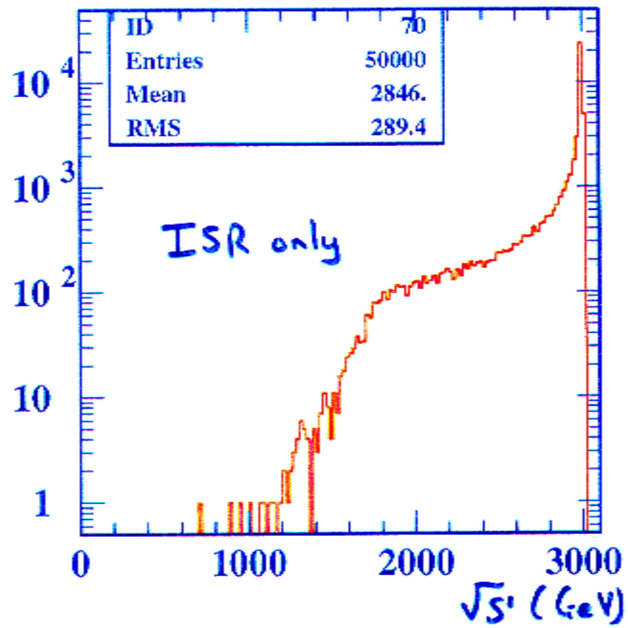
$$\tilde{\chi}_2^+ \tilde{\chi}_2^- \ (533) \longrightarrow e\nu \tilde{\chi}_2^0 \ e\nu \tilde{\chi}_2^0$$

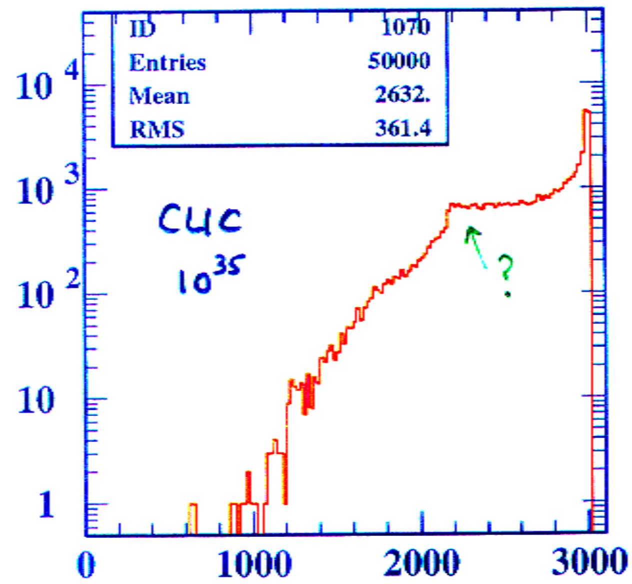
$$ee \tilde{\chi}_1^+ \ \nu\bar{\nu} \ \tilde{\chi}_1^-$$

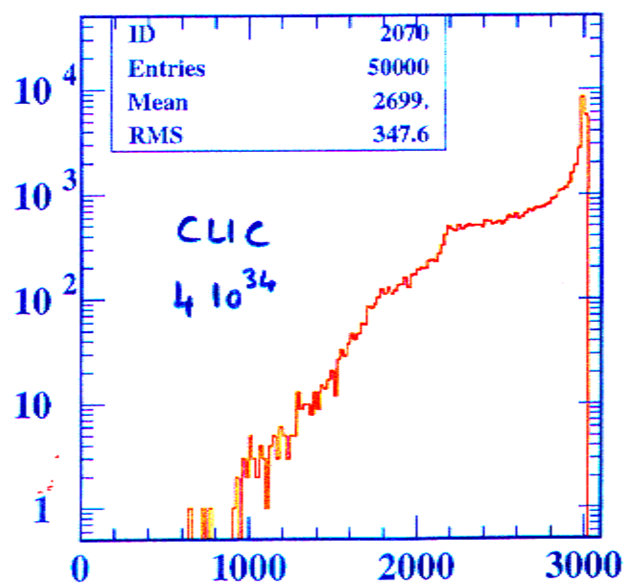
etc

etc.

Reduced $\sqrt{s}$ after ISR + BS + BEAMSTRAHLUNG for inclusive SUSY.







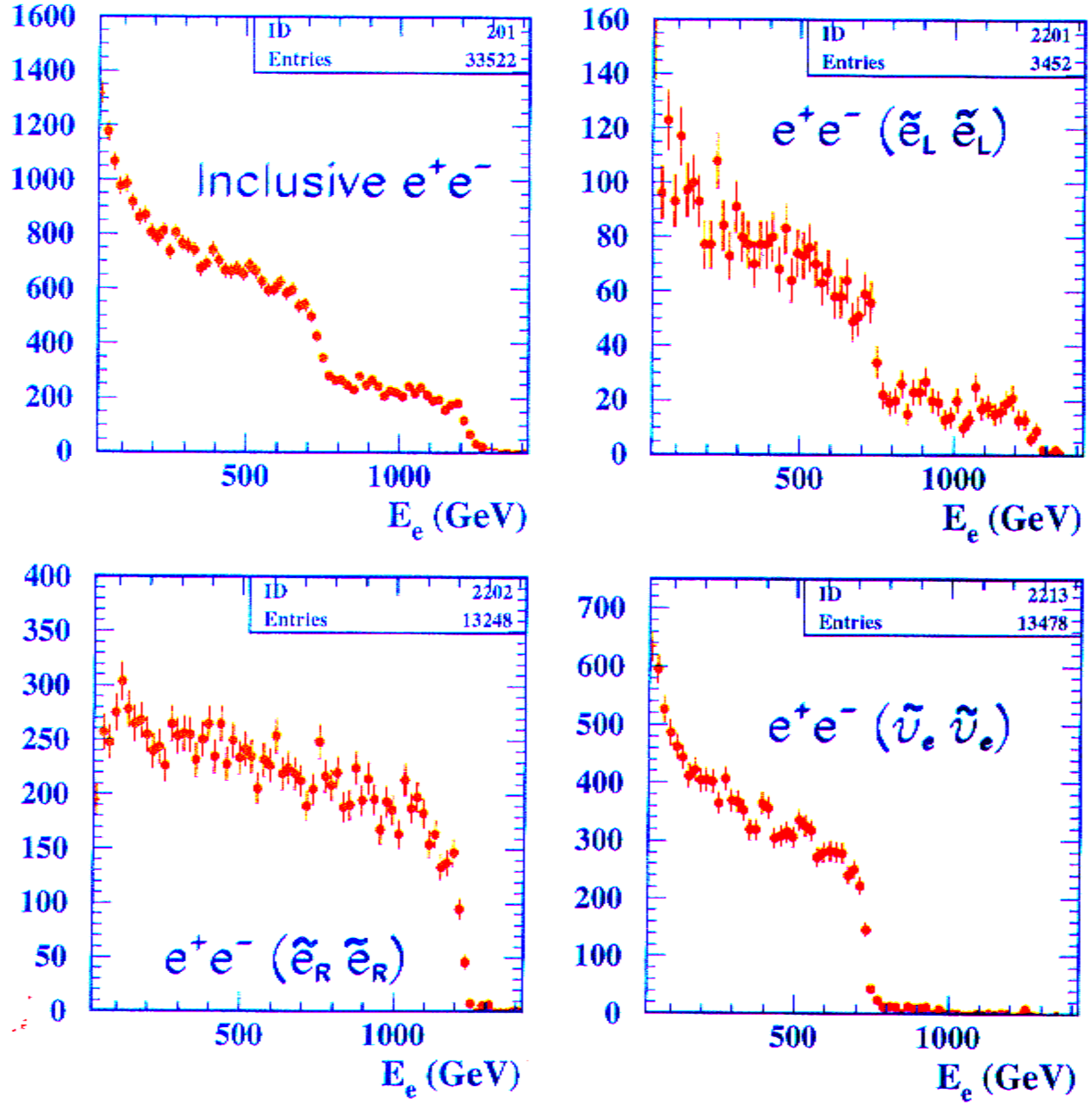
Select

$e^+e^- \to e^+e^- X \not{E}_T$

includes ECAL response of SIMDET.

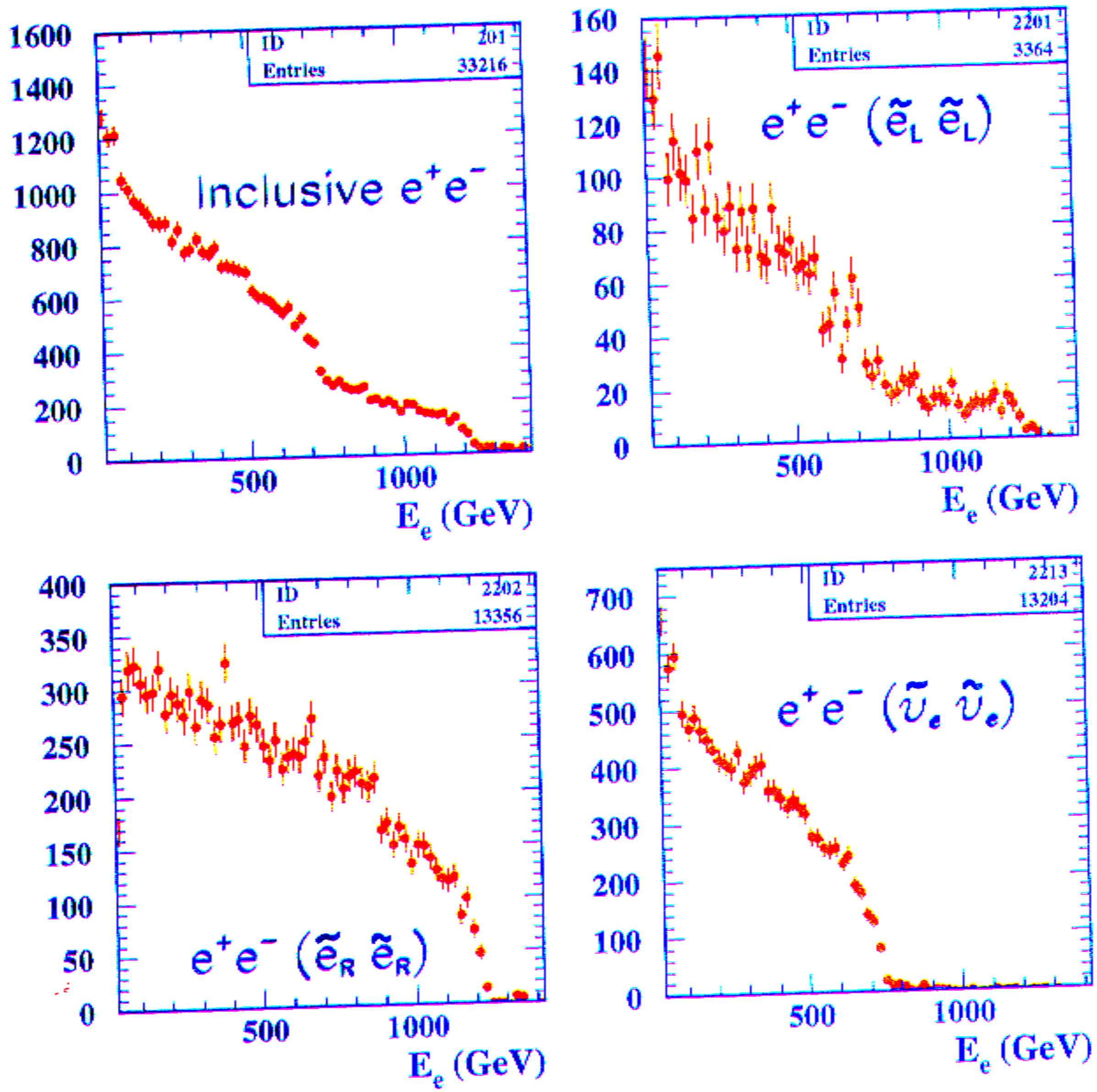
ISR only

MODEL 1



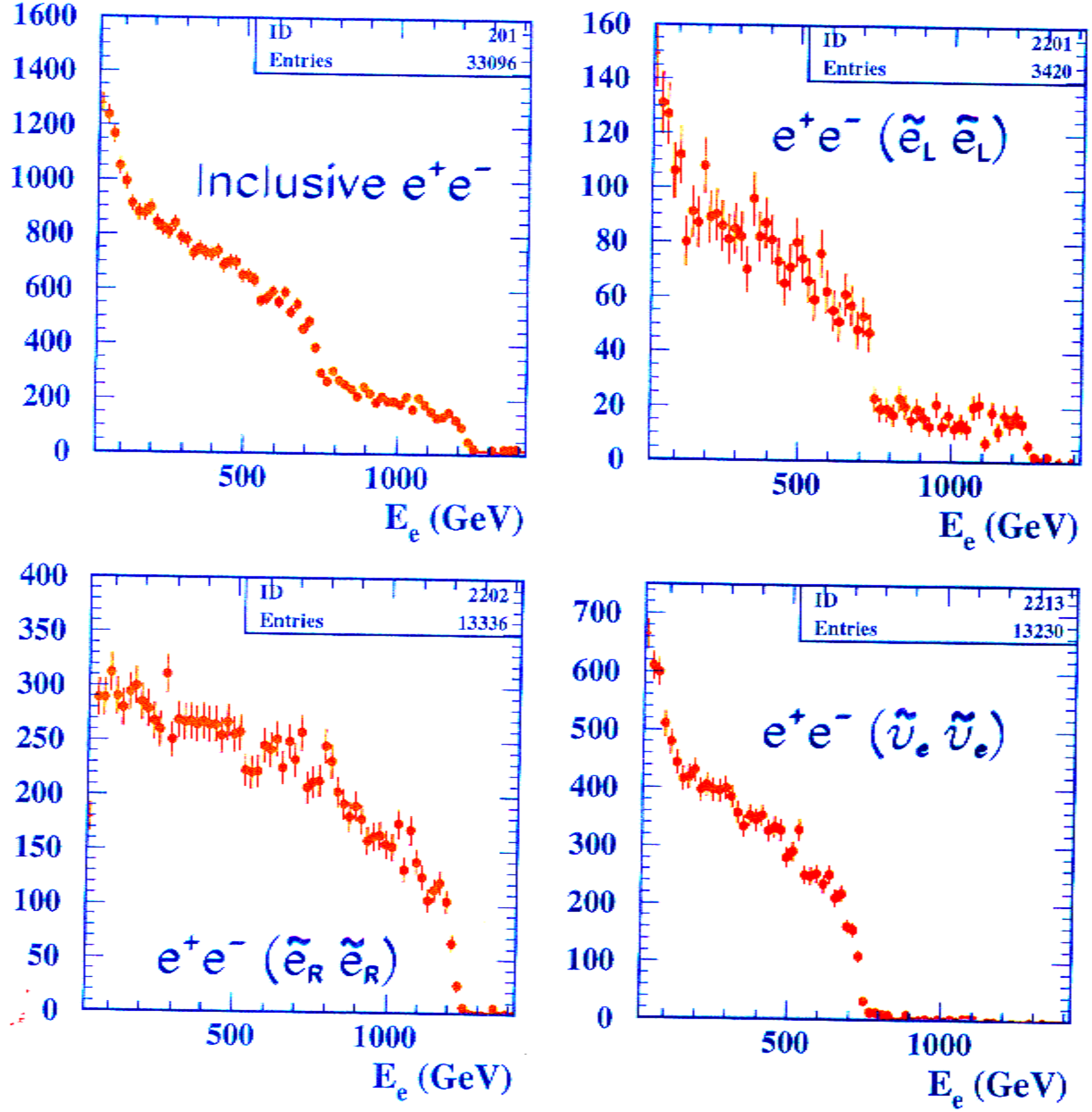
MODEL 1.

CLIC beamstrahlung (10^{35})



Model 1.

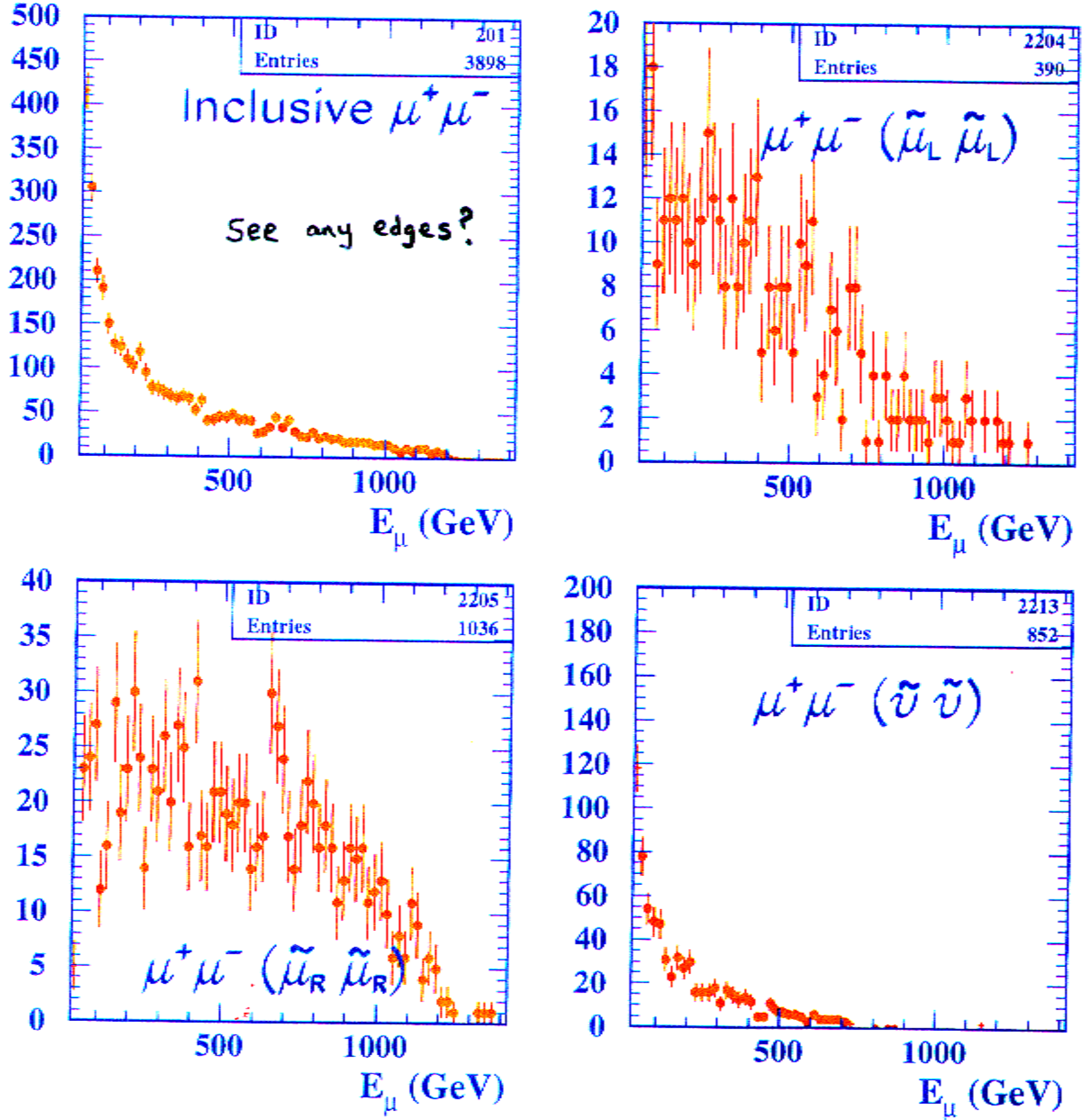
CLIC beamstrahlung (4 10^{34})



Model 1.

CLIC beamstrahlung (10^{35})

140 fb^{-1}



Select $e^+e^- \to \mu^+\mu^- X \not{E}_T$

Smuons and muon sneutrinos are much tougher.

Cross-sections not t-channel enhanced and p resolution worse ..

Staus and tau sneutrinos will be even tougher !

Threshold scans may save the day.

CLIC beamstrahlung (10^{35})

$\sqrt{s} = 3.5$ TeV

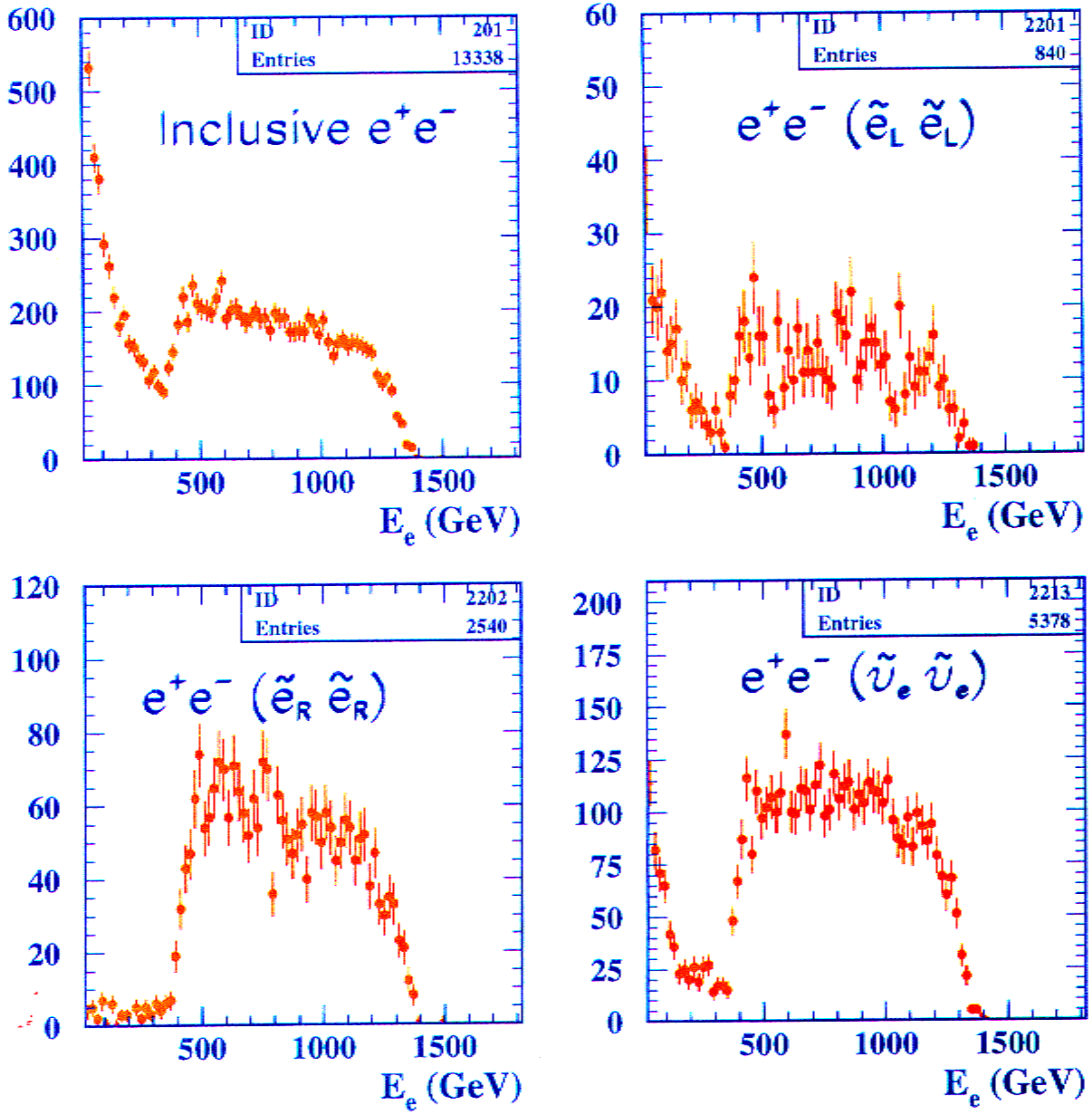
$\int \mathcal{L} dt = 650 fb^{-1}$

(high m_0 model)

closer to threshold

$\Rightarrow$ edges are sharper

BUT spectra are $\approx$ degenerate

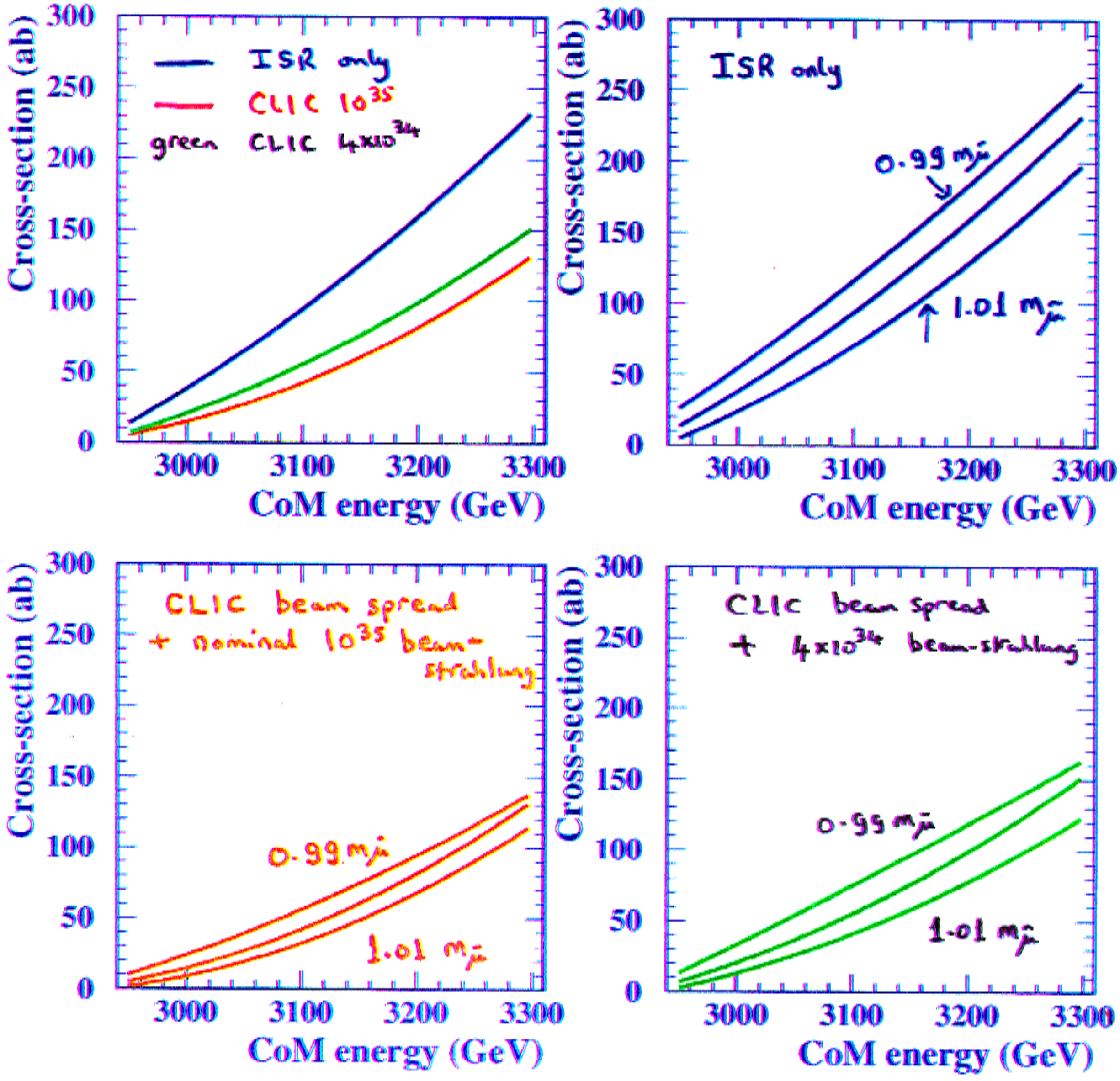


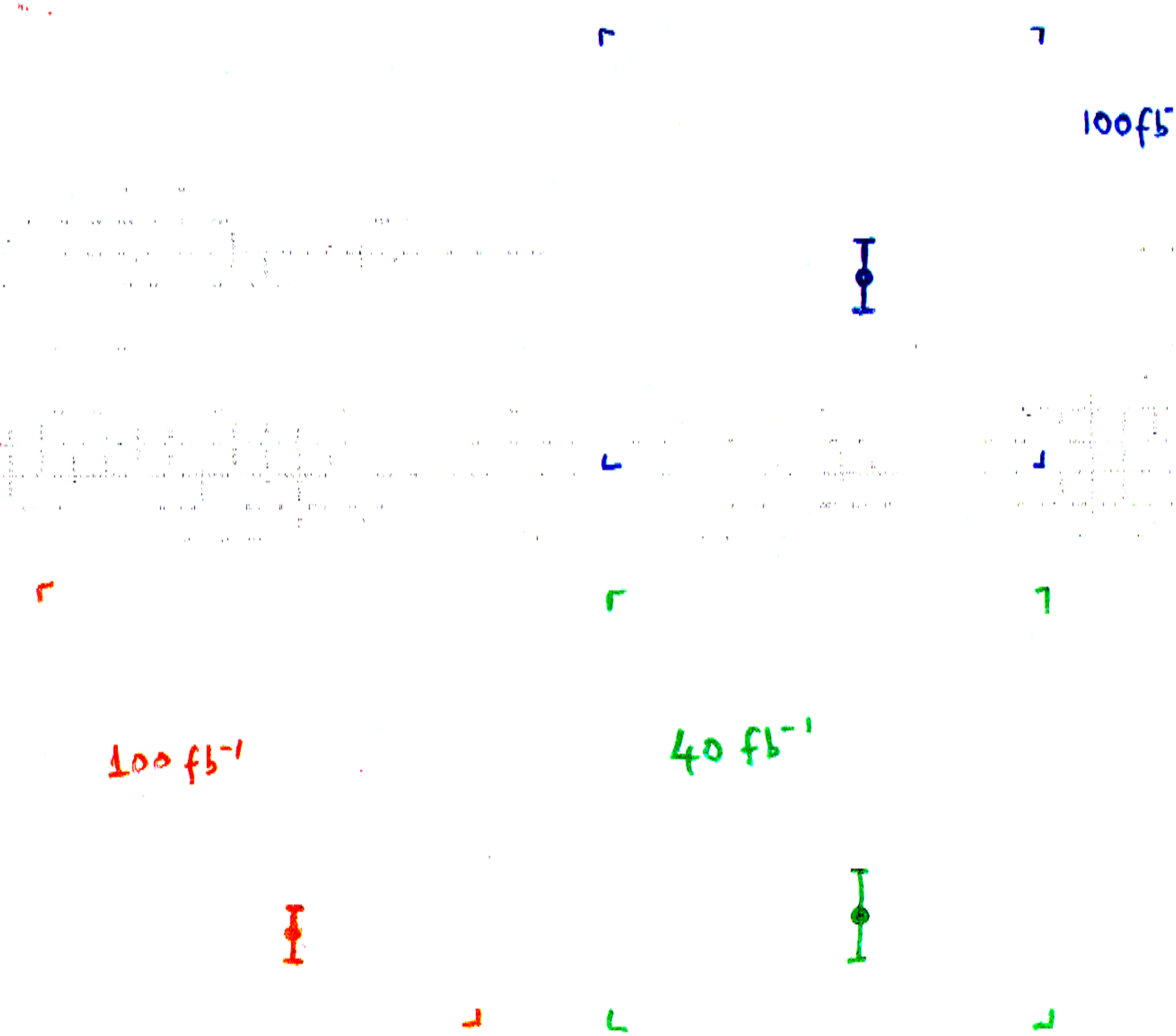
Example : $e^+e^- \to \tilde{\mu}_R \tilde{\mu}_R$ $m_{\tilde{\mu}_R} = 1452$ GeV.

$\Gamma = 7$ GeV (narrowest)

(high m_0 model)

Scalar threshold scan ..





$$\Delta M \sim \sqrt{\sigma}\ \left|\frac{d\sigma}{dM}\right|^{-1} \mathcal{L}^{-1/2}$$

OBSERVATIONS

IF BEAMSTRAHLUNG, ENERGY SPREAD
IS UNDERSTOOD,

MASS DETERMINATION FROM THRESHOLD SCANS
FOR HEAVY SCALARS
IS STILL FEASIBLE IN PRINCIPLE FOR
CLIC TYPE $\mathcal{L}$ SPECTRUM WITH
SOMEWHAT DEGRADED PRECISION. CF ISR ONLY.

$$\frac{\Delta m_{\tilde{\mu}}}{m_{\tilde{\mu}}} \rightarrow \mathcal{O}(1\%) \quad \text{in} \quad 10^6\,\text{s} \quad \begin{cases} \text{ALL DECAY MODES} \\ \text{ZERO BKGD} \\ \varepsilon = 100\% \end{cases}$$

IN PRACTICE
WOULD NEED A BACKGROUND-FREE
REGIME AT THE ATTOBARN LEVEL !
AND HIGH LUMINOSITY, KNOWN BRs,
KNOWN Γ / STRATEGY FOR Γ DETERMINATION.

$\Rightarrow$ A "CHALLENGE" !

Strategy for unscrambling SUSY

- Bottom-up
  - Go down in energy and turn off higher mass sparticle production
  - Build on solid foundations of masses and branching ratios of the lighter states.
  - Use polarisation to control background and identify couplings of each sparticle
- 3 TeV for 500 GeV sparticles ?
  - NO! need to study each near threshold.
- Is complete unscrambling feasible ?
  - Difficult to demonstrate for all possible scenarii!
  - I guess not - but experiment would not be interesting if we knew all the techniques in advance !

Conclusions

- IF SUSY is realised in nature, a future generation linear collider needs as many handles as possible to decipher unambiguously the masses, couplings, widths and BRs of the 32 new particles.
  - may lead to an understanding of the underlying physics.
- Beam polarisation, e-e-, high luminosity with energy RANGE, good beamstrahlung spectrum, low energy spread, all seem to be options to keep available., $\gamma\gamma$ too.