Detector and simulation issues in SUSY searches at ILC

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Introduction

✧ SUSY decay processes put significant challenges on detector response;

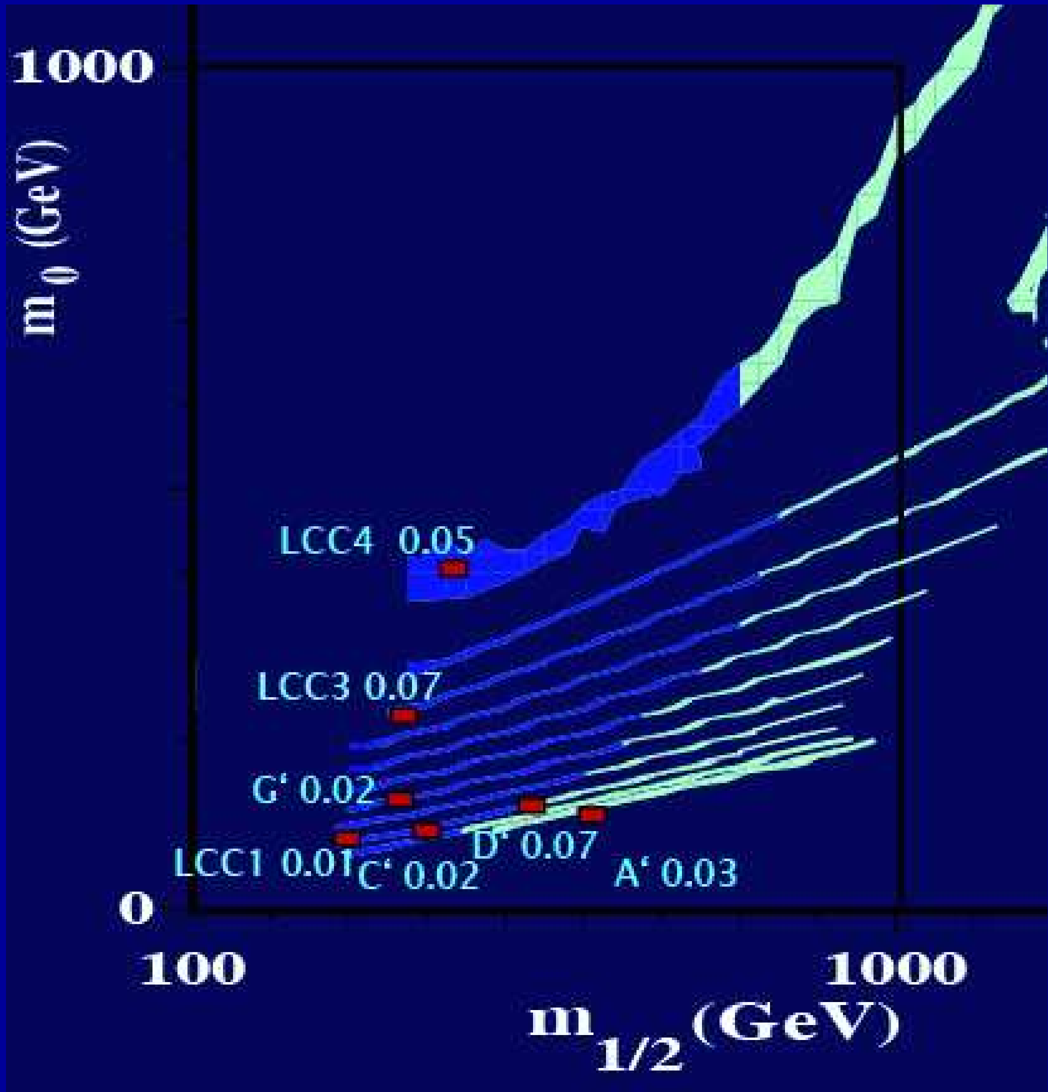
✧ Topologies vary from two low-momentum leptons in $e^+e^- \to \tilde{\ell}\tilde{\ell}$ to eight jets $e^+e^- \to H^+H^- \to tbtb$;

✧ Cosmology-motivated portions of (c)MSSM parameter space point to regions with characteristics mass relations (M_A/M_χ, $M_{\tilde{\tau}} - M_\chi$, ...) which need to be studied in great details and high accuracy;

✧ Review here some of these signatures in relation to detector response:

1. Low-Momentum Leptons
2. Lepton Id.
3. Lepton Momentum Resolution
4. Jet Energy Resolution
5. Di-Jet Mass Resolution
6. Very Forward Tagging

✧ based on results by Barklow, Dutta, Kamon, Bambade, M.B. *et al.*

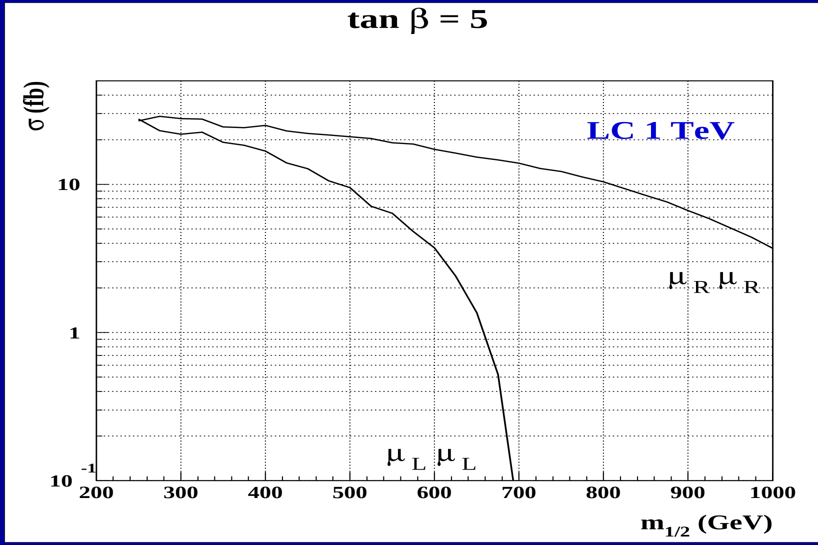

1000
m_0 (GeV)
LCC4 0.05
LCC3 0.07
G' 0.02
LCC1 0.01
C' 0.02
D' 0.07
A' 0.03
0
100
1000
$m_{1/2}$ (GeV)

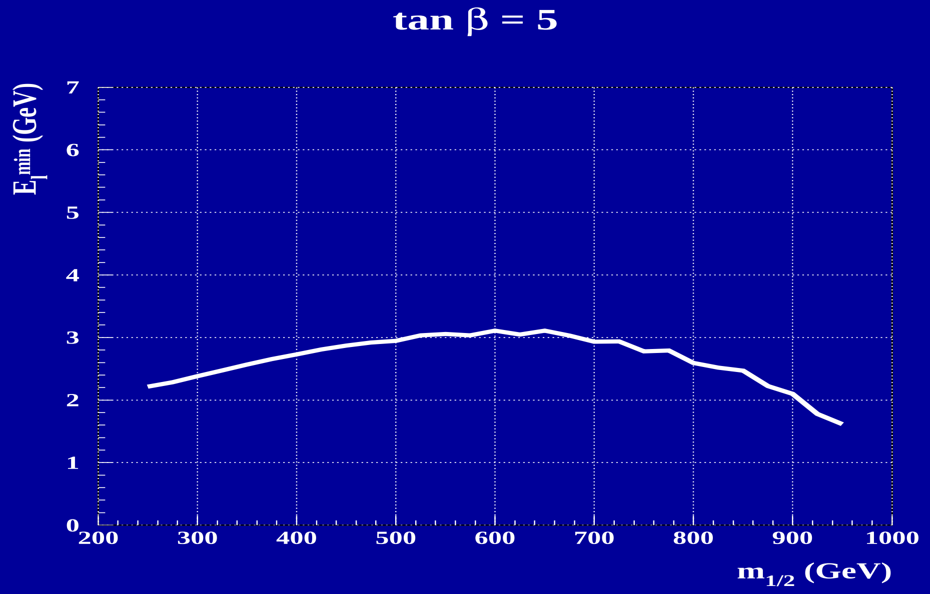
Slepton Signatures at low p_{lepton}

✧ Highest reach in $m_{1/2}$ from $e^+e^- \to \tilde{\ell}^+_R \tilde{\ell}^-_R$: ILC at $\sqrt{s}$=1 TeV covers upper limit in $m_{1/2}$ for $\tan\beta$ = 5 - 10 with $\sigma(e^+e^- \to \tilde{\ell}^+\tilde{\ell}^-) = \mathcal{O}$(1-10 fb);

✧ along WMAP line $\tilde{\ell}_R$ becomes nearly degenerate with χ^0_1: tuning E_{beam} for sizeable σ softens E^{min}_ℓ:

$$E^{min}_\ell = \frac{1}{2} M_{\tilde{\ell}} \left(1 - \frac{M^2_{\tilde{\chi}^0_1}}{M^2_{\tilde{\ell}}}\right) \gamma\left(1 - \sqrt{1 - \frac{M^2_\ell}{E^2_{beam}}}\right);$$





Slepton Signatures at low p_{lepton}

✧ Lepton id. critical at lower endpoint due to:

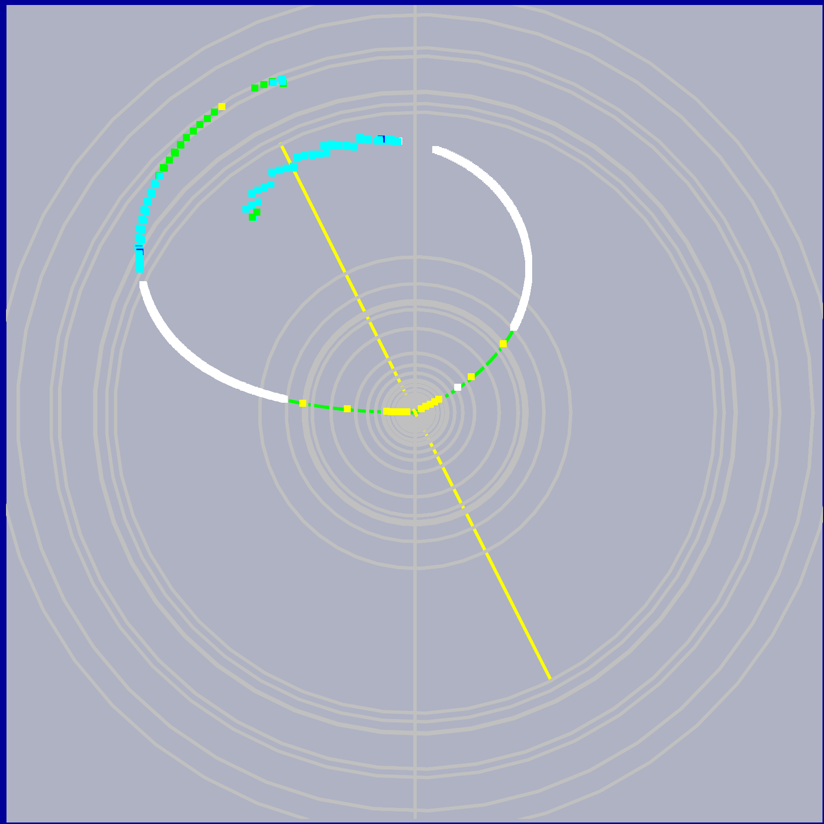
1. Intrinsic Momentum Cut-off
2. $\gamma\gamma \rightarrow$ hadrons Background

✧ Momentum cut-off p_t^{min} defined by radius R_{det} of ECal, HCal and Muon Chambers and solenoidal field B:

$$p_t^{min}[\mathrm{GeV}] = \frac{R_{det}[\mathrm{m}]}{0.3B[\mathrm{Tesla}]}$$

✧ $\gamma\gamma \rightarrow$ hadrons bkg becomes relevant if only one lepton can be tagged

WIRED DISPLAY OF $e^+e^- \rightarrow \tilde{\mu}_R^+\tilde{\mu}_R^-$ AT 1 TEV AT LOWER ENDPOINT
$\tan\beta = 5,\ m_{1/2} = 600,\ m_0 = 118$

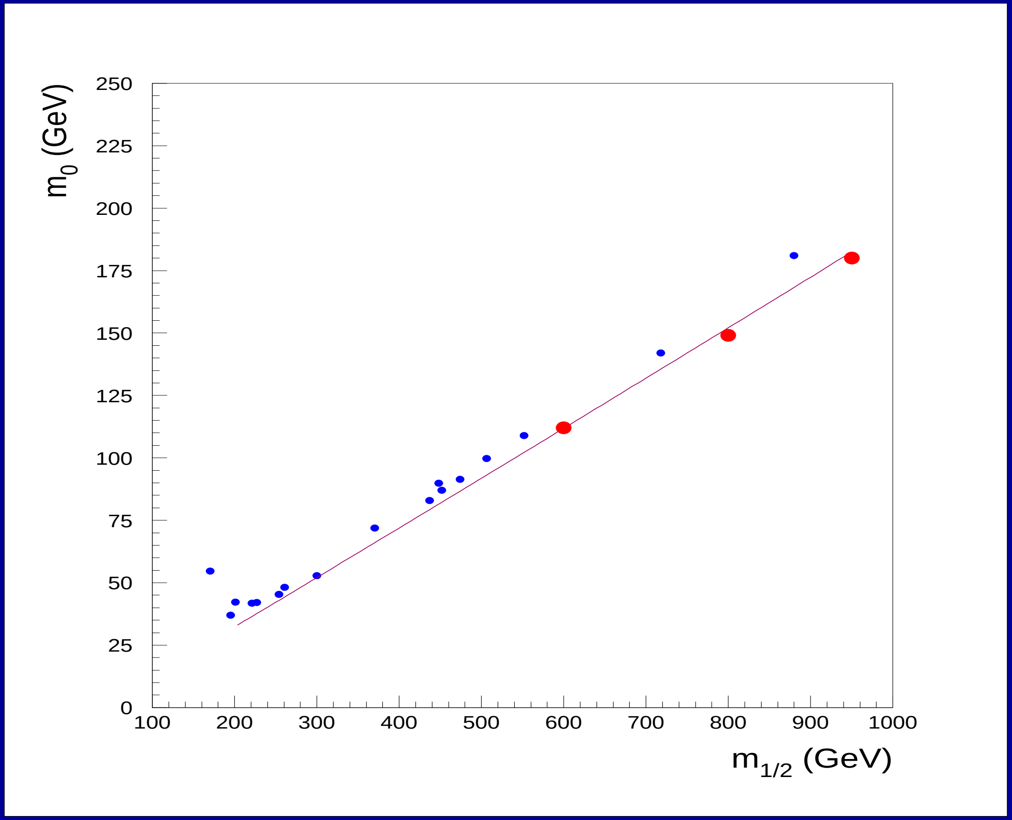


Benchmarking the co-Annihilation Tail

- Study co-annihilation tail with Micromegas and SSARD;
- define 3 study points at $\tan\beta = 5$ to track the slepton phenomenology at 1 TeV ILC;

Masses at Study Points

$m_{1/2} = 600$	$m_0 = 114$
$M_{\tilde{\ell}_L} =$	428 GeV
$M_{\tilde{\ell}_R} =$	255 GeV
$M_{\chi^0_1} =$	243 GeV
$m_{1/2} = 800$	$m_0 = 149$
$M_{\tilde{\ell}_L} =$	564 GeV
$M_{\tilde{\ell}_R} =$	335 GeV
$M_{\chi^0_1} =$	329 GeV
$m_{1/2} = 950$	$m_0 = 182$
$M_{\tilde{\ell}_L} =$	668 GeV
$M_{\tilde{\ell}_R} =$	397 GeV
$M_{\chi^0_1} =$	394 GeV



Lepton Identification

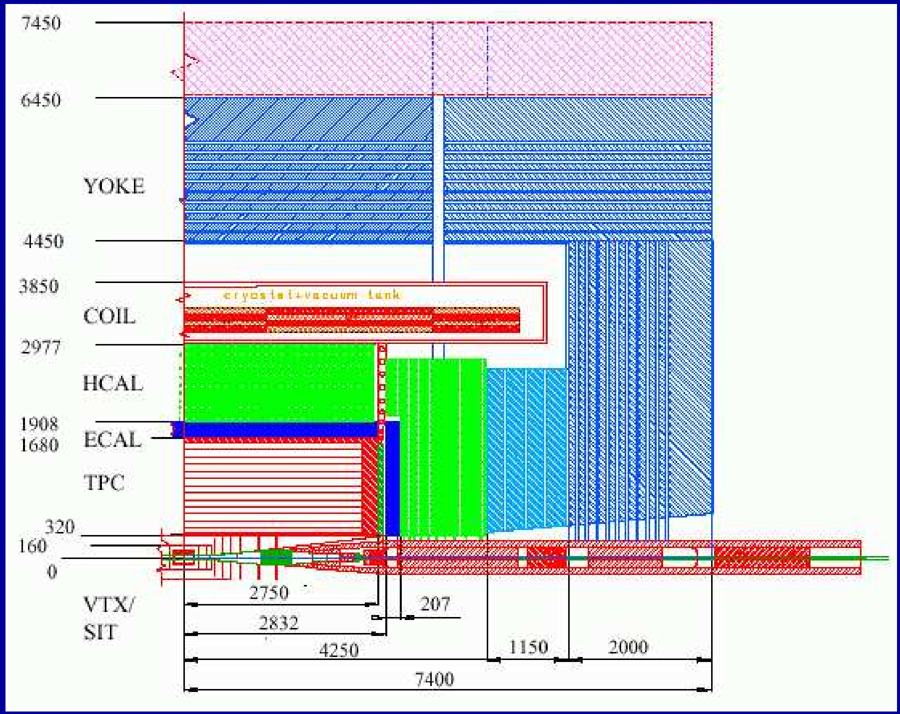
Muons

✧ Identify through hits in Muon Chambers and Energy deposited in HCAL

	Large Det
B [Tesla]	4
	p_t^{min} (GeV)
μ μCh	4.2
μ HCAL	2.0
e ECAL	1.5
e dE/dx	0.7

Electrons

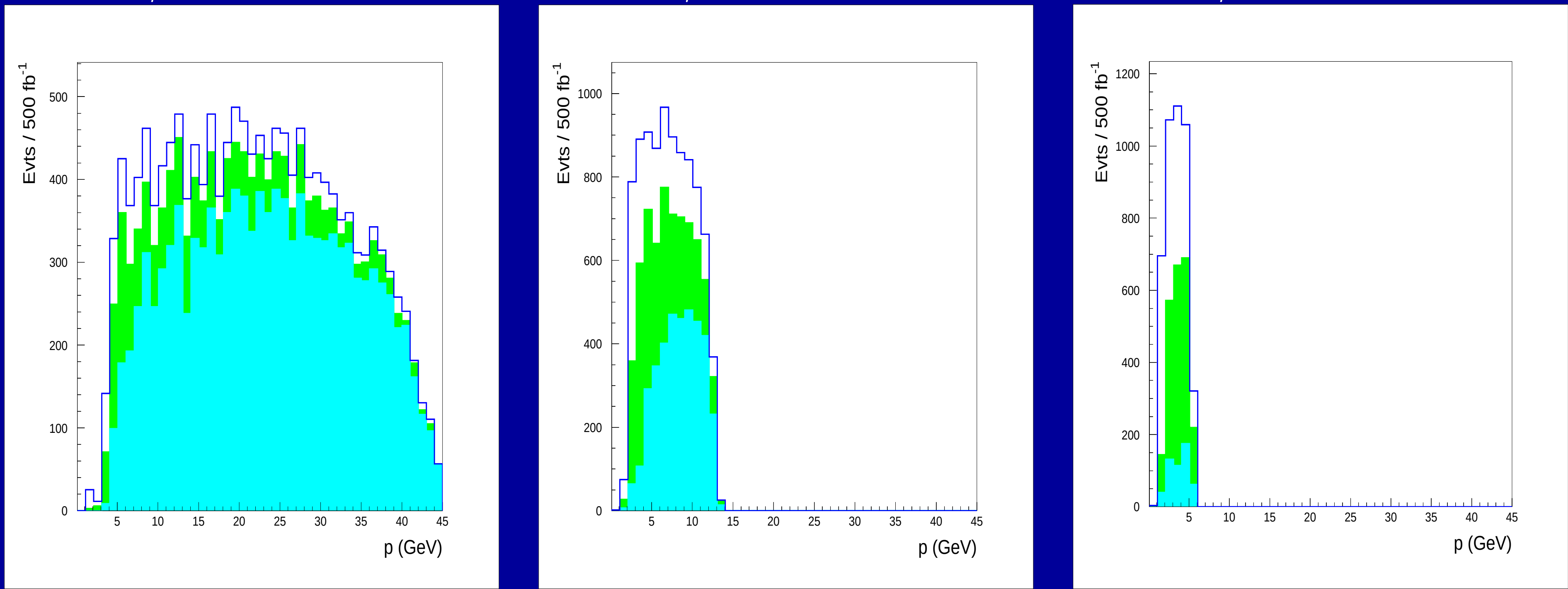
✧ Identify through shower in ECAL and dE/dx in Main Tracker



Lepton Momentum

Lepton Momentum Spectrum in
$e^+e^- \to \tilde{\ell}^+_R \tilde{\ell}^-_R \to \ell^+\chi^0_1 \ell^-\chi^0_1$ at 1 TeV for $\tan\beta = 5$ ($\ell = e, \mu$)

$m_{1/2} = 600$ GeV $\quad$ $m_{1/2} = 800$ GeV $\quad$ $m_{1/2} = 950$ GeV



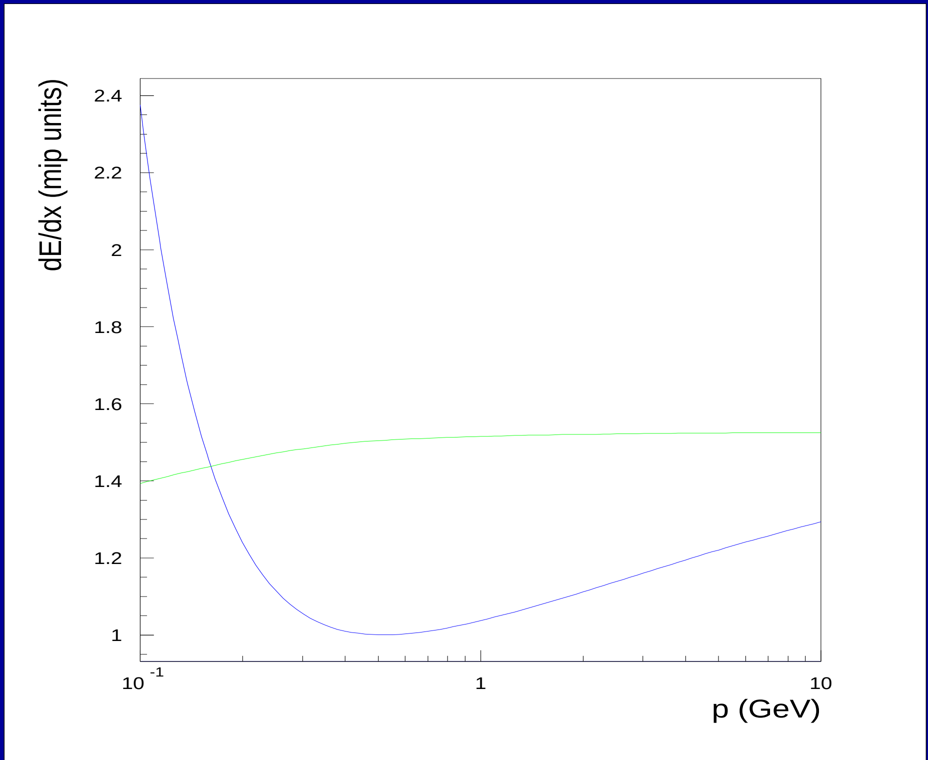
✧ Lepton Id momentum acceptance cuts into lower endpoint for $m_{1/2} > 500$ GeV.

Electron Id with dE/dx in TPC

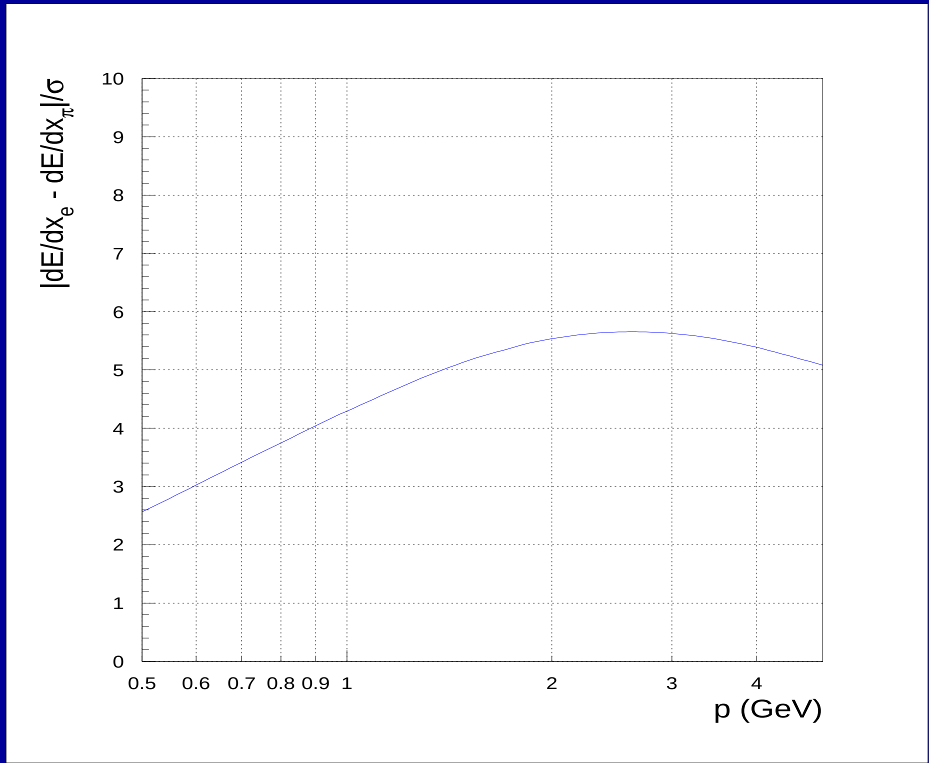
◇ dE/dx in TPC useful to recover low-momentum electrons:

$$\sigma(dE/dx) = 0.045 \times \sqrt{\frac{1.68[\mathrm{m}]}{0.3B[\mathrm{T}]p_t[\mathrm{GeV}]}}$$

dE/dx vs. p



$|dE/dx_e - dE/dx_\pi|/\sigma$

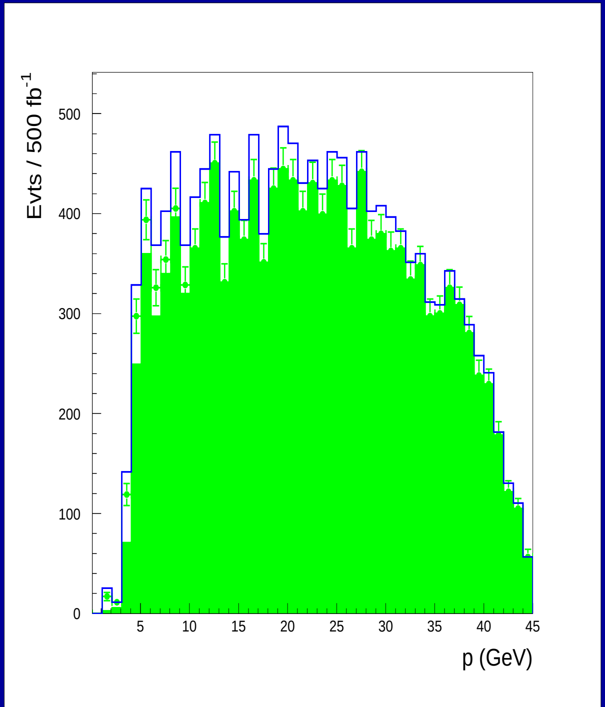


◇ TPC with 200 samplings and 4.5% resolution should ensure $> 4\sigma$ e/π separation over the interesting momentum window.

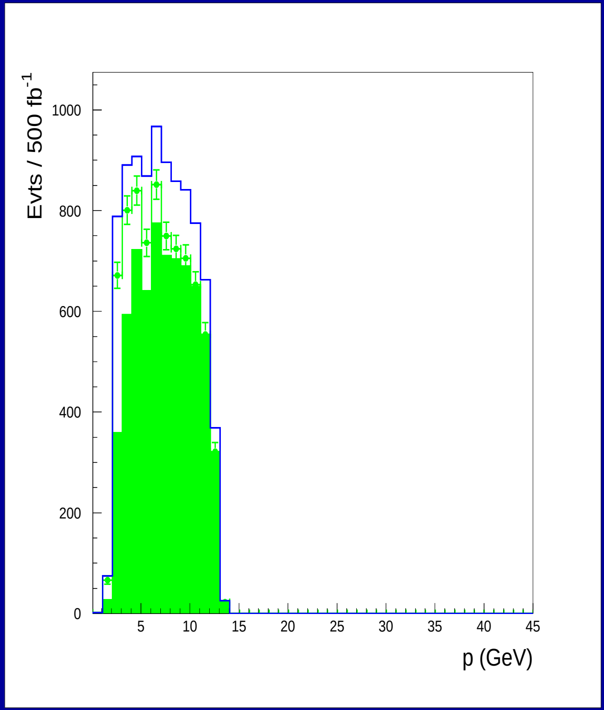
Electron Momentum

Electron Momentum Spectrum in
$e^+e^- \to \tilde{e}_R^+\tilde{e}_R^- \to e^+\chi_1^0 e^-\chi_1^0$ at 1 TeV for $\tan\beta = 5$ (with dE/dx Id)

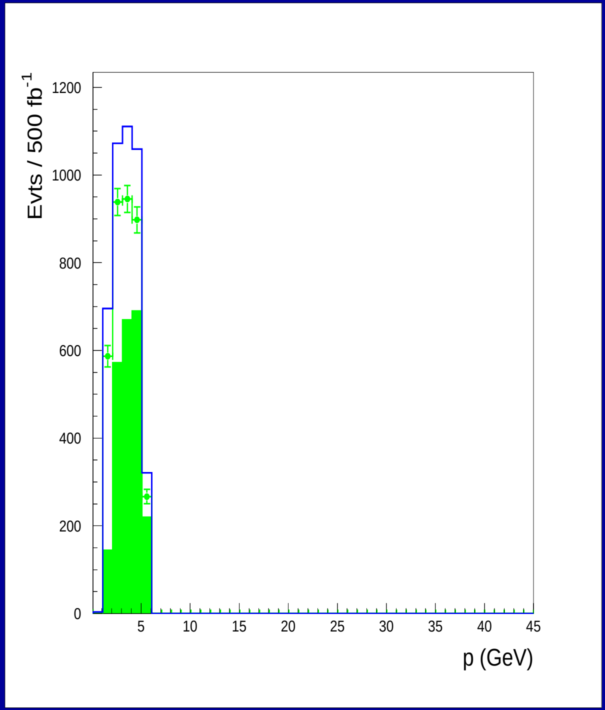
$m_{1/2} = 600$ GeV



$m_{1/2} = 800$ GeV



$m_{1/2} = 950$ GeV

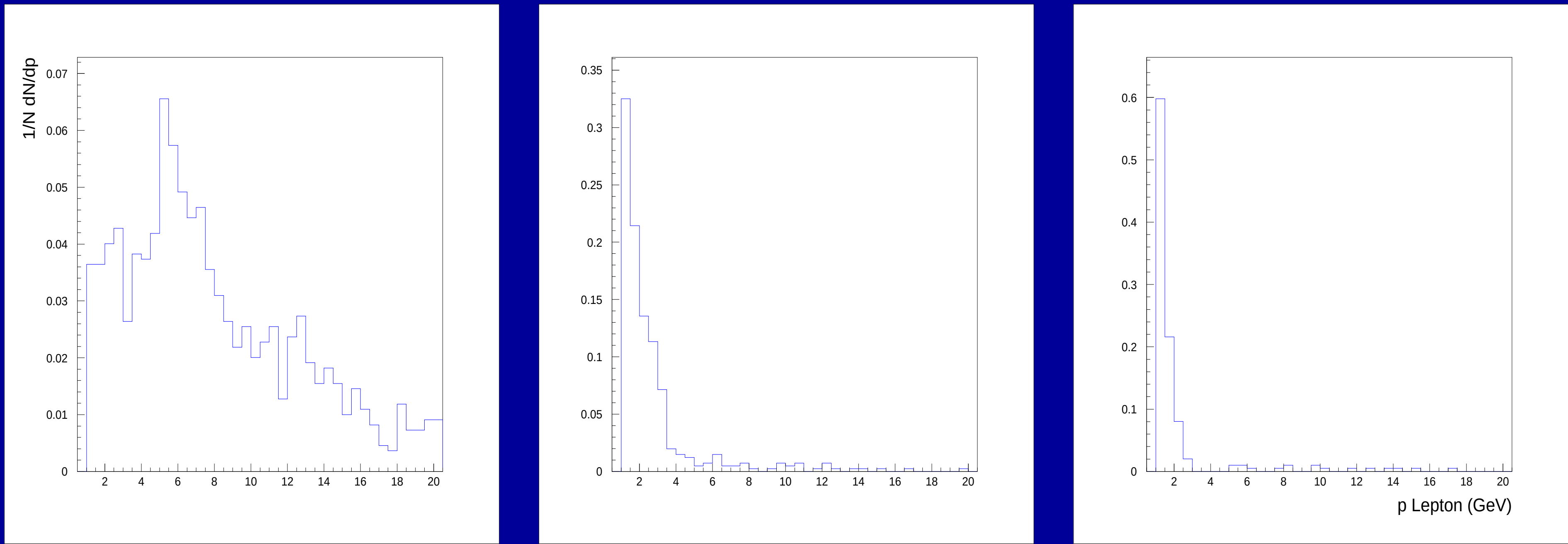


✧ Electron dE/dx Id recovers sensitivity to lower endpoint almost to upper $m_{1/2}$ edge.

✧ Soft lepton spectrum also affects reconstruction of stau decays;

LEPTON MOMENTUM SPECTRUM IN
$e^+e^- \to \tilde{\tau}^+\tilde{\tau}^- \to \ell^+ X \chi_1^0 \ell^- X \chi_1^0$ AT 1 TeV FOR $\tan\beta = 5$

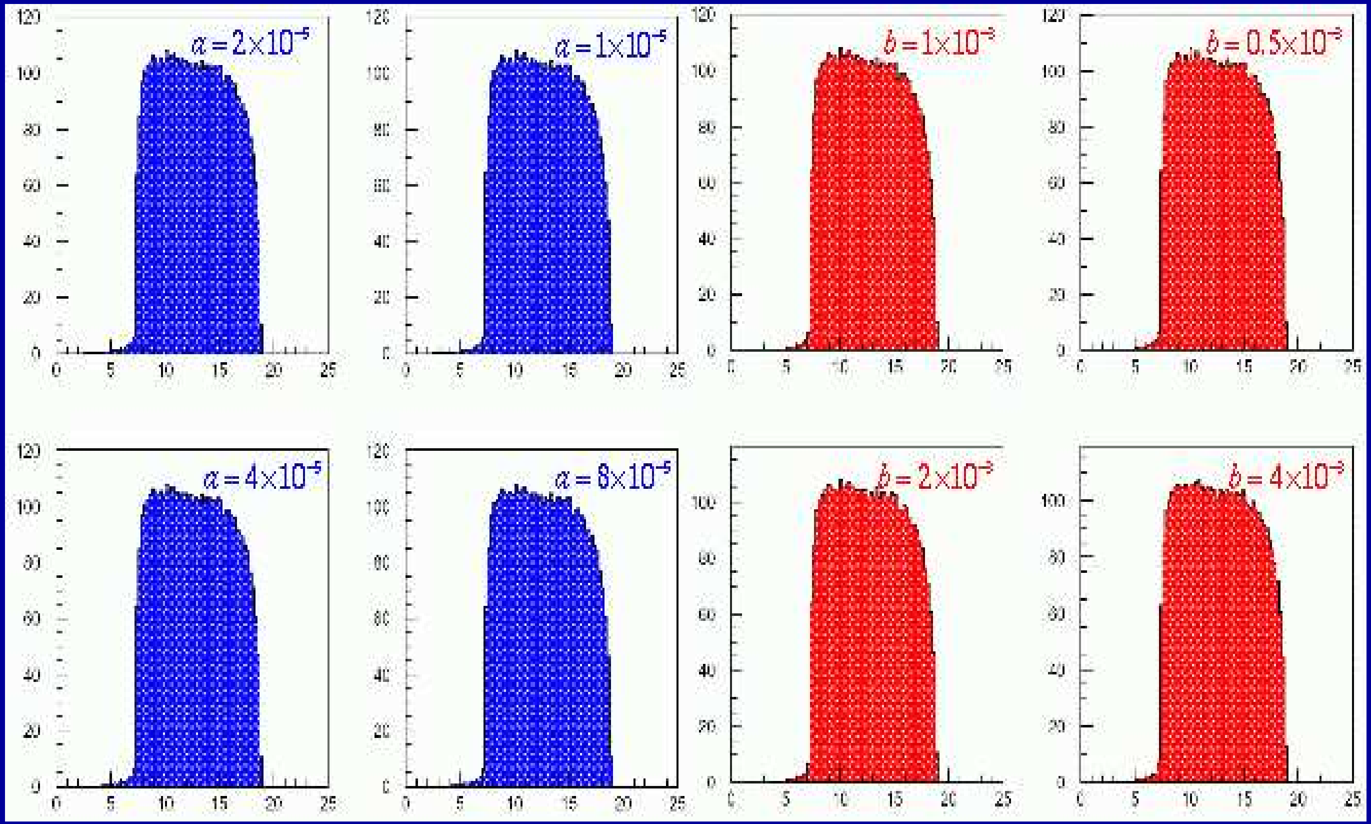
$m_{1/2} = 600$ GeV	$m_{1/2} = 800$ GeV	$m_{1/2} = 950$ GeV
$M_{\tilde{\tau}_1} = 253.6$ GeV	$M_{\tilde{\tau}_1} = 332.3$ GeV	$M_{\tilde{\tau}_1} = 396.8$ GeV
$M_{\tilde{\tau}_2} = 428.0$ GeV	$M_{\tilde{\tau}_2} = 563.7$ GeV	$M_{\tilde{\tau}_2} = 668.4$ GeV



Lepton Momentum Resolution

✧ Study $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\chi}^0_1\tilde{\chi}^0_1$, for $M_{\tilde{\mu}} = 224$ GeV, $\sqrt{s} = 0.5$ TeV;

✧ Parametrise $\delta p_t/p_t^2 = a \oplus \frac{b}{p_t sin\theta}$ with $1 \times 10^{-5} < a < 8 \times 10^{-5}$ and $0.5 \times 10^{-3} < b < 4 \times 10^{-3}$ and study the effect on the reconstructed smuon mass;

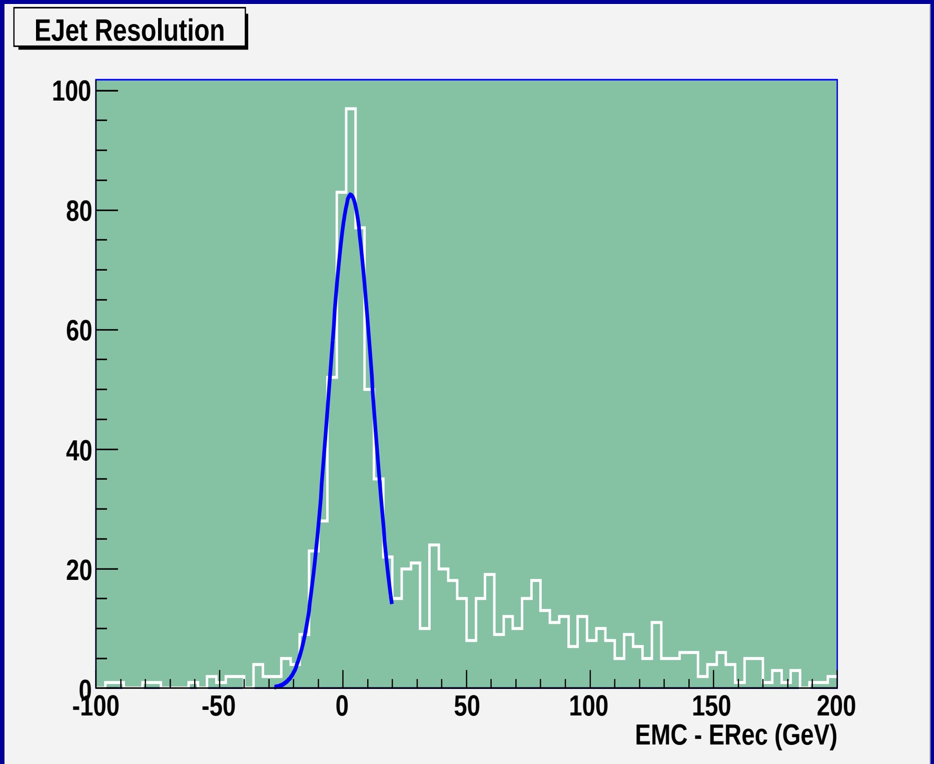


✧ No significant dependence of fit accuracy on a and b as the endpoint smearing is dominated by the ILC beamstrahlung spectrum;

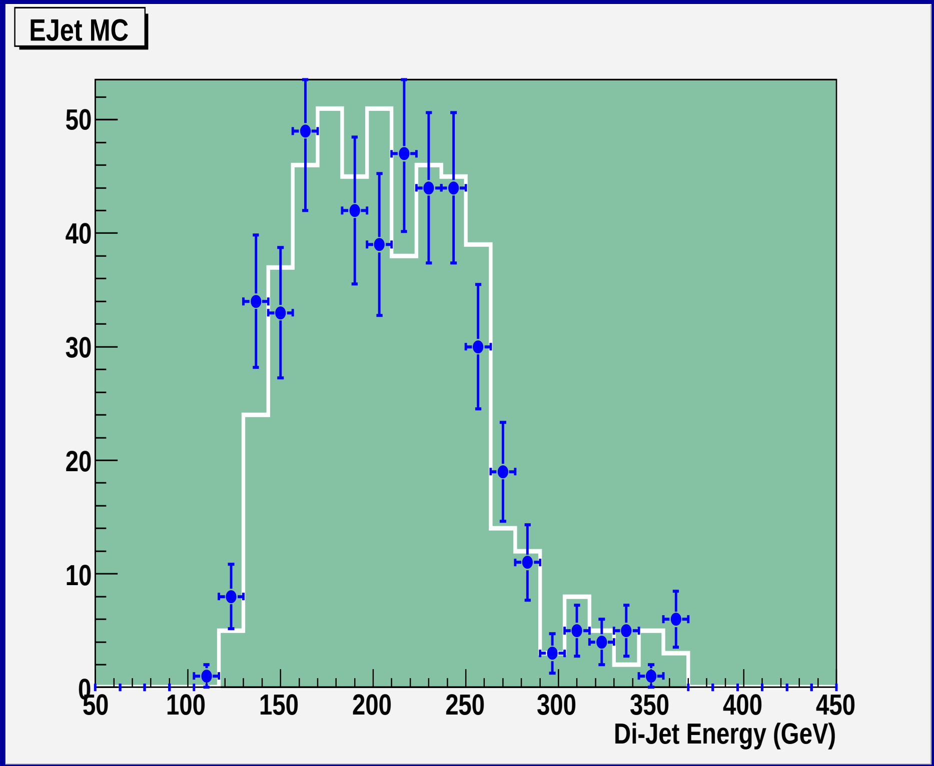
Jet Energy Resolution

- Study $\tilde{\chi}^0_{3,4} \rightarrow Z^0 \tilde{\chi}^0_1$ at LCC4 in funnel region;
- Significant decay branching fractions to real Z^0, requires reconstruction of E_{Z^0} to determine the χ_3 and χ_4 mass and the μ parameter, which is essential in the determination of $\Omega_\chi h^2$;
- Fast simulation of decays with $Z^0 q\bar{q}$, `Simdet 4.0` whith $\delta E_{jet}/E_{jet} = 30\%/\sqrt{E_jet}$;

Z^0 Di-jet Energy Resolution



$E_{Z^0 \rightarrow q\bar{q}}$ for Gaussian portion



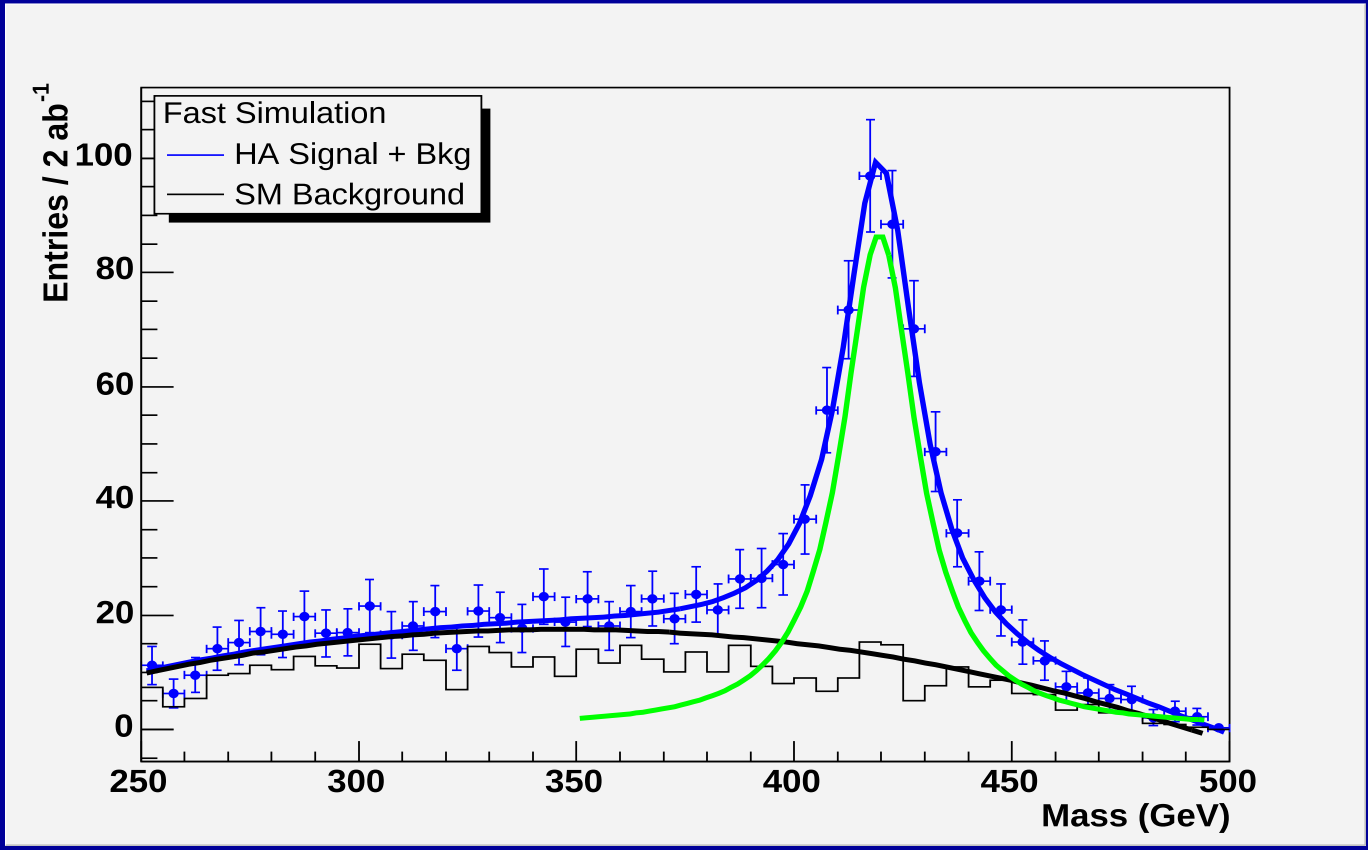
Di-Jet Mass Resolution

✧ In funnel region it is important not only to determine M_A but also Γ_A, which is sensitive to corrections to b-Yukawa couplings and thus to $\chi\chi \to b\bar{b}$ annihilation;

✧ Since A and H are almost degenerate, $M_A - M_H$ and Γ_A are highly correlated;

✧ Need high di-jet mass resolution to set constraints on Γ_A from $e^+e^- \to HA \to bbbb$:

```
14.11 5555        *    5555   66
13.64       44444444      55   6
13.18   44444      *4444    555
12.72 444          *    444   55
12.25      3333333333   444  55
11.79   3333        * 333   44  5
11.33 333        222*    333  44
10.86 3      2222 2222    33  44
 10.4       22      * 222   33  4
9.934      22    11111  22  3  44
9.471      2    11   *11   22 33  4
9.007      22   1    * 11   2   3  4
8.543 3****2**11*****1**22*33***
8.079 333  22   11 *   1    2   3
7.616   33  22   11*   1    2   3
7.152    333 222 11111     2   3
6.688 44    33   22 *       22   3
6.224  444  33   222       2    3
5.761    444 333  2222222    3
5.297 55     44  33 *          33
4.833   555   44   333         33
4.369     555 444   3333   333
3.906 66     55  44 *   3333      4
3.442  666   555 444              44
2.978    666   55   444        444
      I
       2.155         20.66
              11.41
```

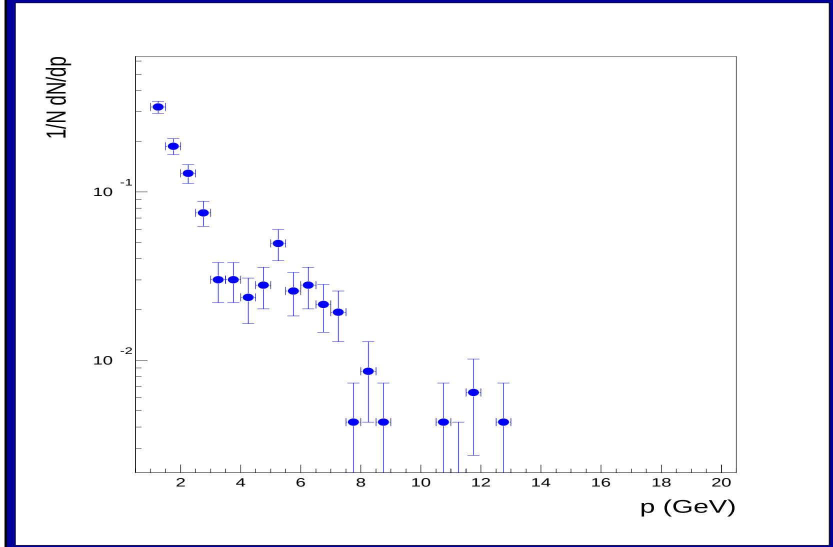


$\gamma\gamma \to$ hadrons **Background**

- Estimate rate from $\gamma\gamma \to$ hadrons background

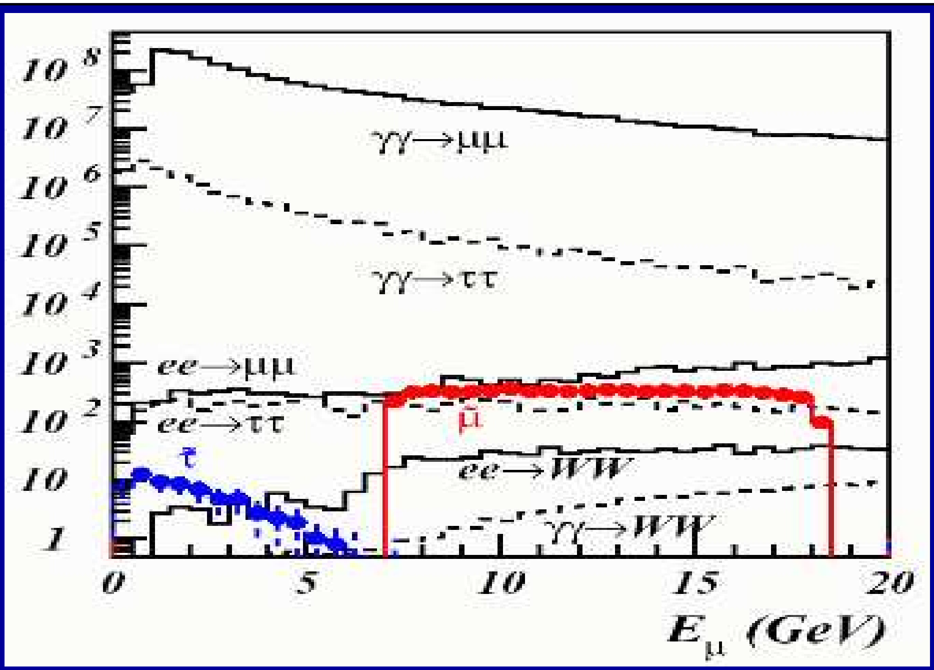
	TESLA 0.8 TeV
$\mathcal{L}$ (fb BX^{-1})	2.7×10^{-9}
$N_{\gamma\gamma}$ BX^{-1}	0.40
$N_{\gamma\gamma}$ 500 fb^{-1}	0.75×10^{11}

- Sample generated with GuineaPig + Pythia for TESLA at 800 GeV;
- Suppress $\gamma\gamma \to$ hadrons bkg using event shape and kinematical variables;
- Assume $\epsilon(\pi \to \ell) \simeq 0.10$ at low p (M. Piccolo)

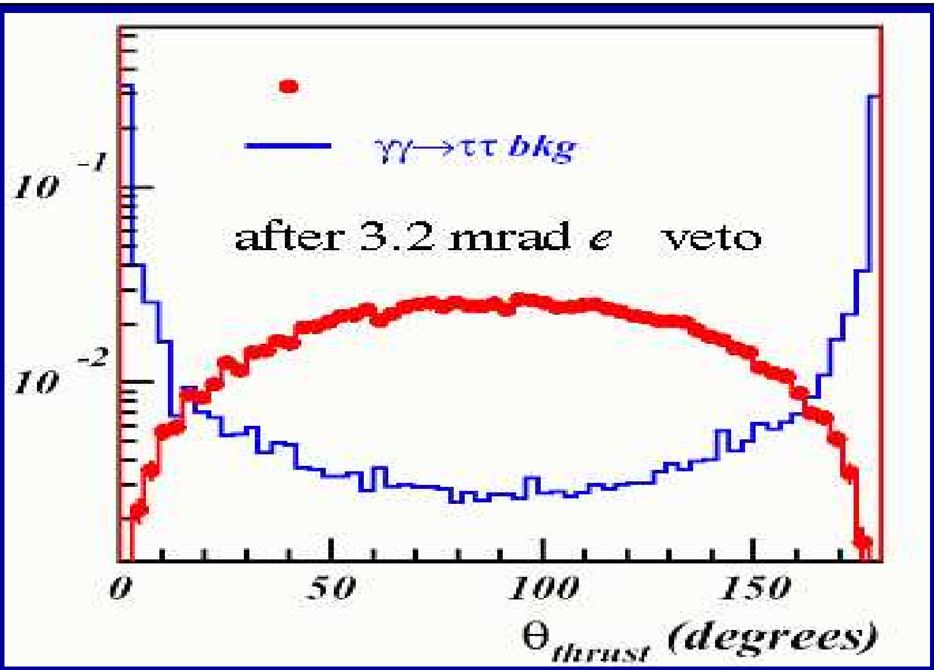


Evts/500 fb^{-1}	1.5 - 2.5 GeV	2.5 - 5 GeV
$2\ \ell\ +\ E_{miss}$	$\sim$ 22k	$\sim$ 7 k

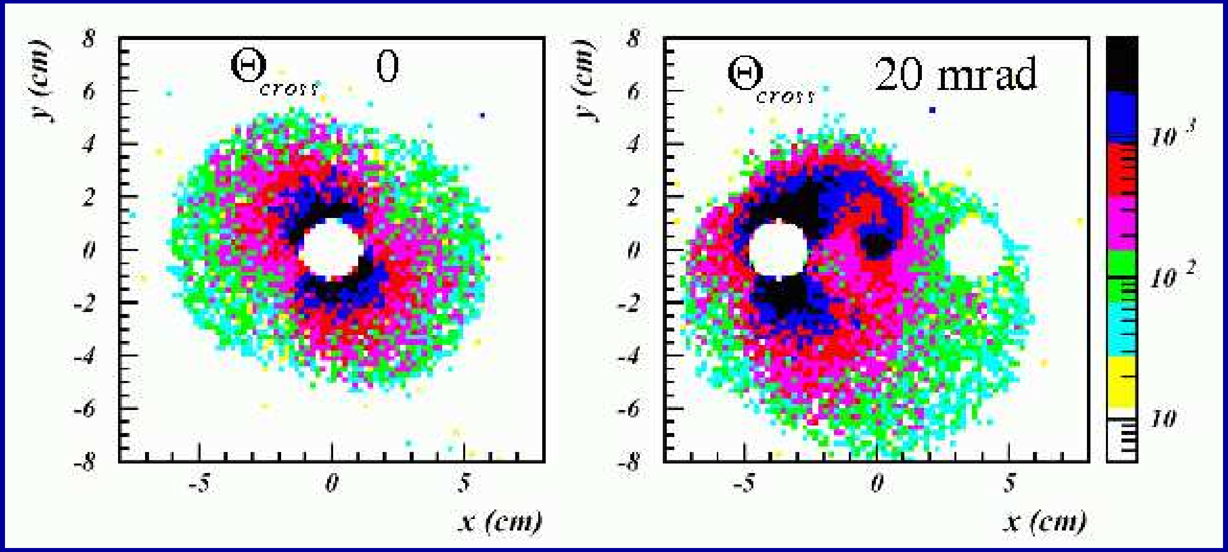
- Important to tag fwd electrons down to small angles to suppress $\gamma\gamma \to$ hadrons.



10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
γγ→μμ
γγ→ττ
ee→μμ
ee→ττ
ee→WW
γγ→WW
0
5
10
15
20
E_μ (GeV)



γγ→ττ bkg
after 3.2 mrad e veto
10^-1
10^-2
0
50
100
150
Θ_thrust (degrees)



Θ_cross 0
Θ_cross 20 mrad
y (cm)
x (cm)
10^3
10^2
10