Determination of Heavy Smuon and Selectron Mass at CLIC

Outline

- Physics motivation
- Mass measurement methods (Energy scan, End Point)
- Energy spread, ISR and Beamstrahlung
- Event selection, efficiency and S/B
- $\gamma\gamma \rightarrow h$ pile up and beam polarization
- Mass fit results
- Summary and Outlook

Work done at generator level, validated with full simulation and reconstruction using ILD software, Mokka and Marlin.

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Physics motivation

Scalar leptons are the supersymmetric partners of the right and left handed charged leptons. Their masses are ~ f (m0, m1/2, tanβ)

mo : the common squark, slepton and Higgs mass at Gut scale.

m1/2: the common gaugino mass at GUT scale.

tanβ : the ratio of Higss vacuum expectation values at Mz.

The main decay is: $\tilde{\ell}^{\pm}_{R} \rightarrow \tilde{\chi}^{0}_{1} + \ell^{\pm}$

Measuring $\tilde{\ell}^{\pm}_{R}$ and $\tilde{\chi}^{0}_{1}$ masses allows to constrain SUSY parameters.

The ^{o} is also a good dark matter candidate.

In the talk I focus on the smuon analysis wich is challenging due to its very low cross section. For the CLIC CDR studies, the final state with e-, e+ will be included; the cross section is larger; but at 3TeV the bremsstrahlung spoils the e-/e+ momentum measurement.

Signal and Background Cross Sections

Processes: $e^+ + e^- \to {}^{+} + {}^{-} \to {}^{o}\mu^+ + {}^{o}\mu^-$

$e^+ + e^- \to {}^{-} \to {}^{o}e^+ + {}^{o}e^-$

Generated with Isasugra, cMSSM parameters

$m_{1/2}$=1300, m_0=1001, tanβ=46, Sign(μ)<0

-> m = 1108.8 GeV m χ^0 = 554.3 GeV,

hadronization done with Pythia.

Process	Cross section x B.R(fb)
S: $e^+e^- \to {}^{+}\ {}^{-}$	0.7
S: $e^+e^- \to {}^{-}$	4.2
B: $e^+e^- \to$ Inclusive SUSY	0.1
B: $e^+e^- \to$ WW->lνlν	10.5
B: $e^+e^- \to$ ZZ ->ll νν	0.8
B: $e^+e^- \to \mu\nu_e\ \mu\nu_e$	135

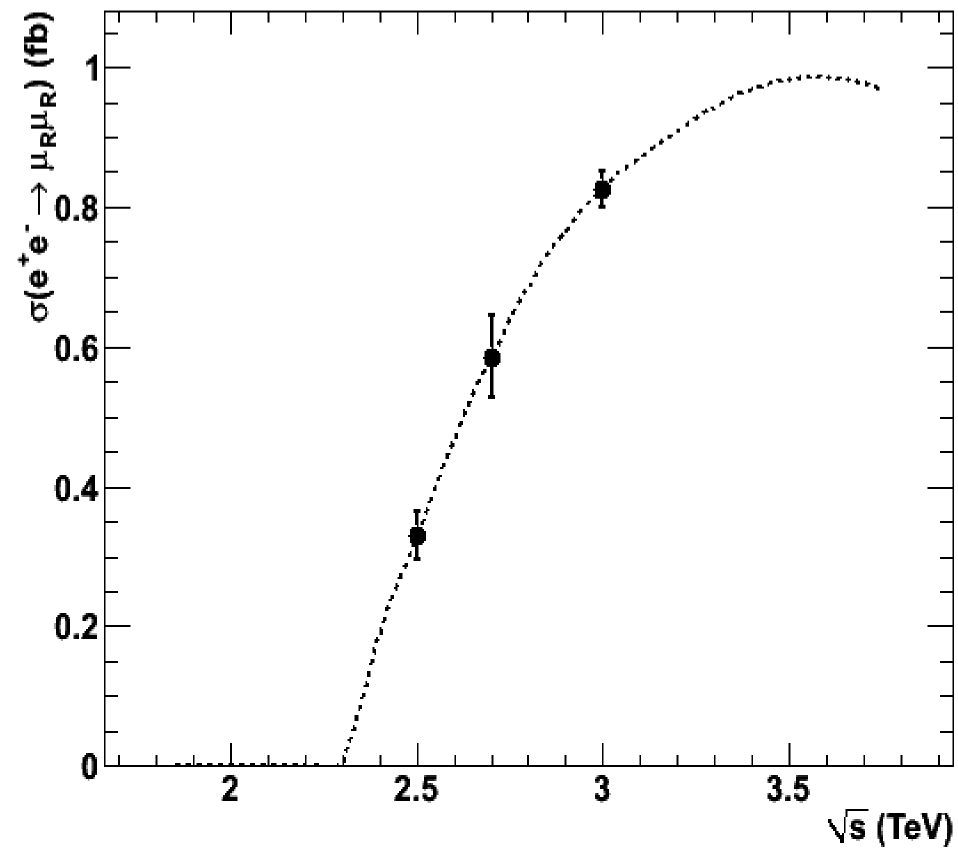
mass measurement
Energy Scan

$\sigma=\sigma(m\ \ ,\sqrt{S})$

Measuring the cross section at different C.M energies allows to derive the mass. δm determined at generator level, assuming:

- Selection efficiency =90%
- S/B=0.5

√S (TeV)	∫Lumi (ab^{-1})	σ (fb)
2.5	0.7	0.33±0.033
2.7	0.3	0.58±0.060
3.0	2	0.82±0.026



m =(1109.13 ± 6.40839) GeV (ISR)

m =(1108.38 ± 7.03864) GeV (ISR+BS)

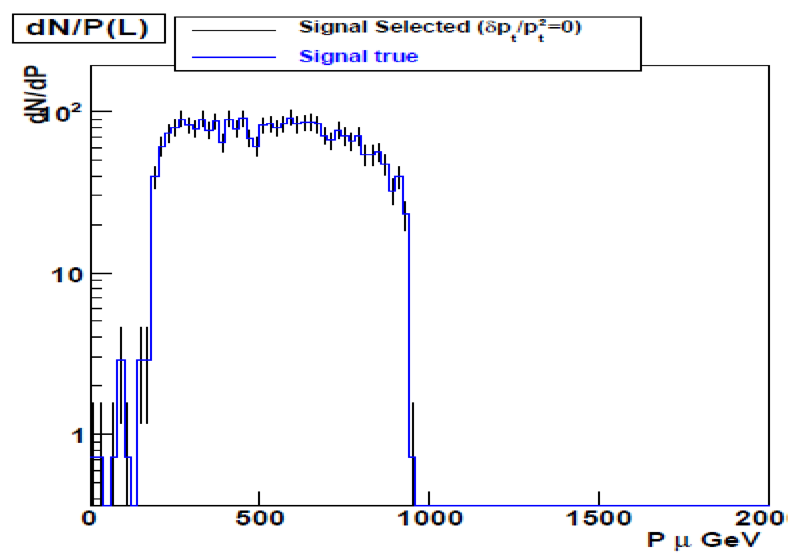
and χ⁰ mass measurements Momentum Spectrum End-point

The -> μ + ⁰ is a two body decay;
The minimum and maximum muon momentun is given by (1). =>
m is f(√s, EL,EH) (2)
m ⁰ is f(m ,√s, EL,EH) (3)
EL and EH are the lower and uper edges of the muon momentum spectrum.
The and χ⁰ masses are determined from a 2 parameters fit to the muon momentum spectrum.
The spectrum is modeled according to eq (1). A smearing is applied to fold in iSR, Beamstrahlung and momentum resolution effects.

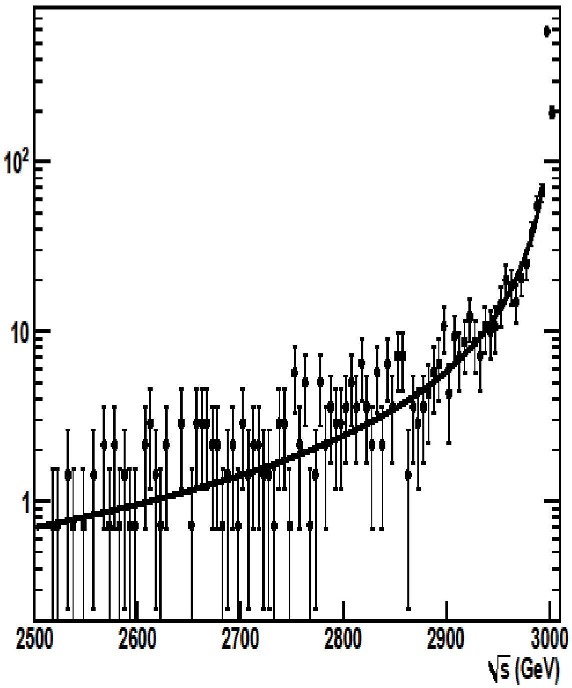
$$E_{L,H} = \frac{\sqrt{S}}{4}\left(1 - \frac{m^2_{\chi_1^0}}{m^2_{\mu_R^\pm}}\right)\left(1 \pm \sqrt{1 - 4\frac{m^2_{\mu_R^\pm}}{S}}\right)$$

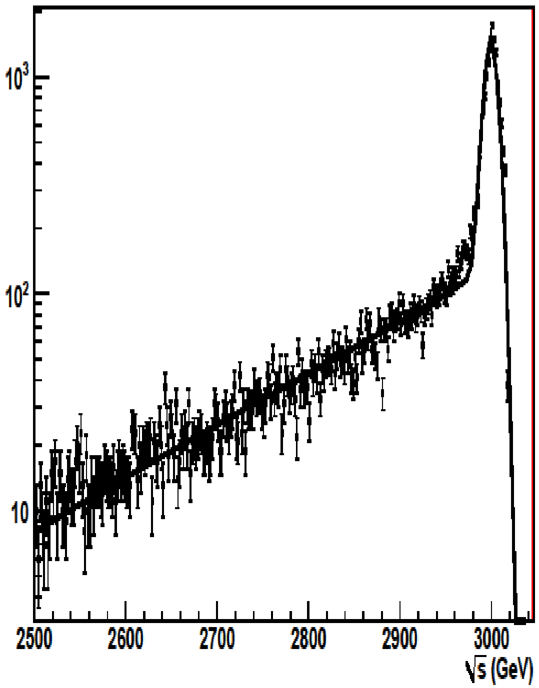
$$m_{\tilde{\mu}_R^\pm} = \frac{\sqrt{S}}{2}\left(1 - \frac{(E_H - E_L)^2}{(E_H + E_L)^2}\right)^{1/2} \quad (2)$$

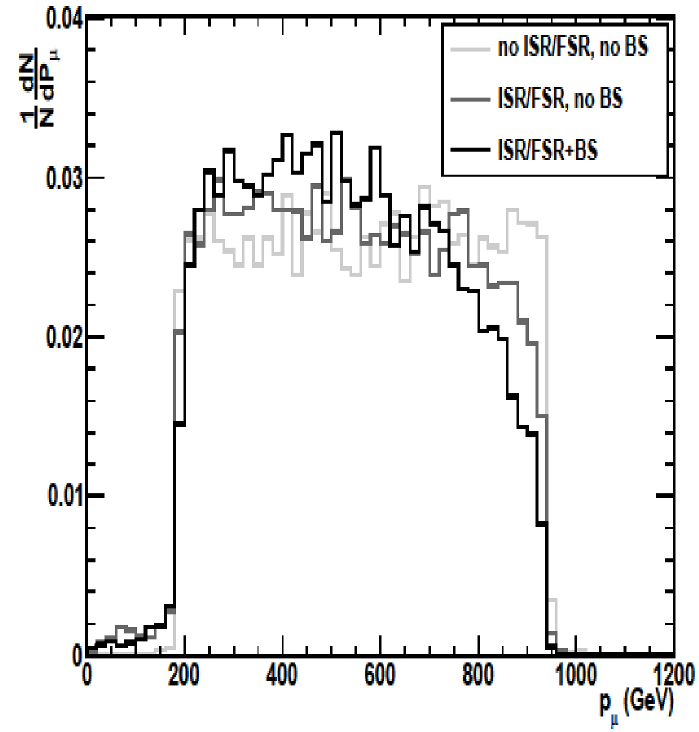
$$m_{\chi_1^0} = m_{\mu_R^\pm}\left(1 - \frac{2(E_H + E_L)}{\sqrt{S}}\right)^{1/2} \quad (3)$$



ISR and Beamstrahlung effects

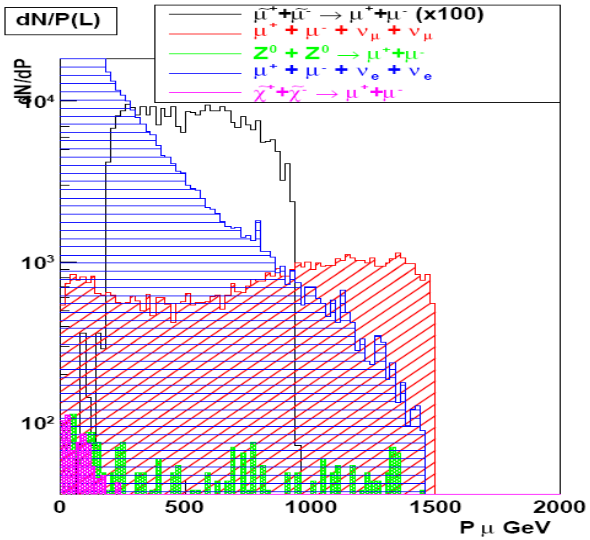


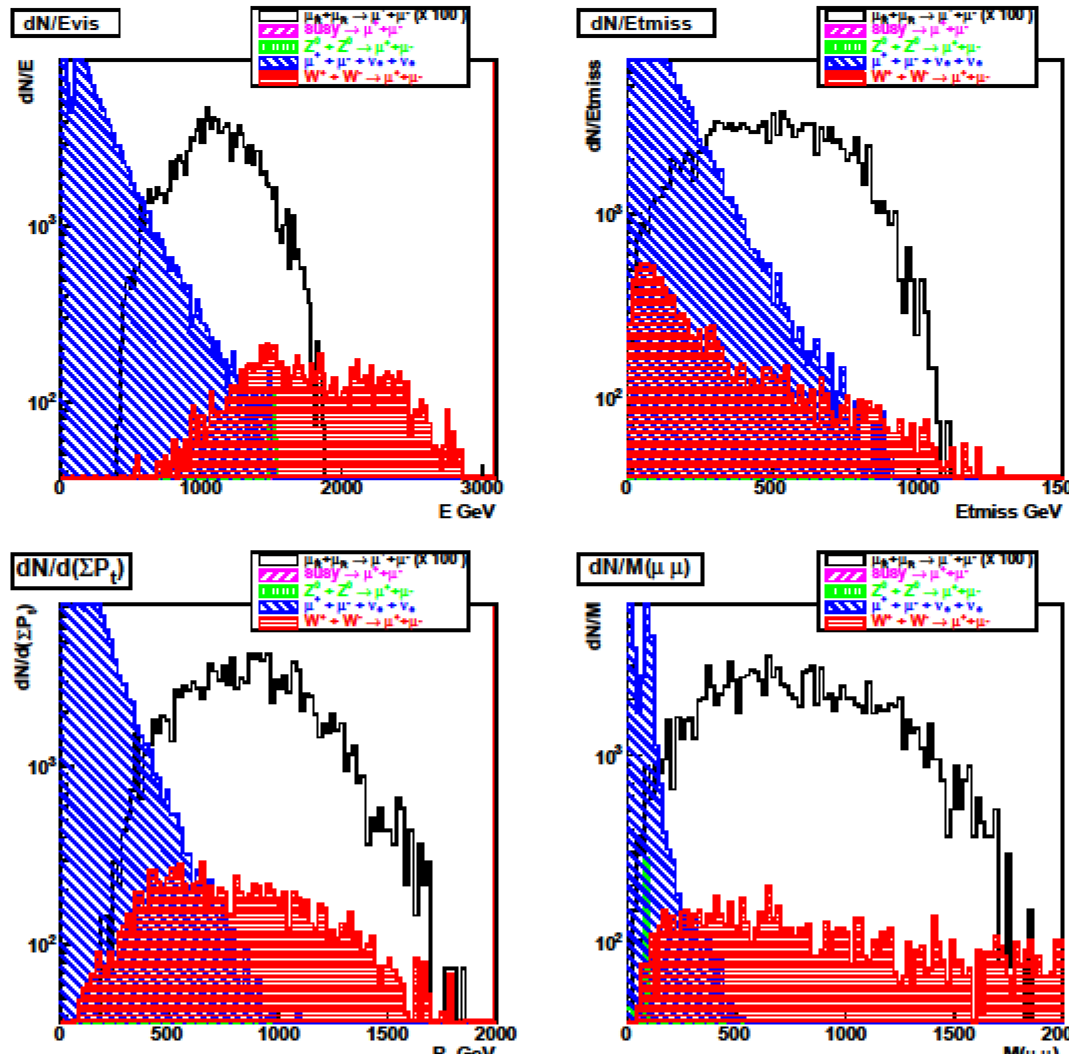




In both methods m ~ f(√S)
Left: Contribution to the C.M energy spread: ISR. Middle: ISR + Beam spread
This distribution is used to fold in the energy spread in the fit.
Right: Muon momentum distribution; No ISR/FSR no BS; with ISR/FSR, no BS; ISR/FSR+B.S; the higher end of the distribution is most affected.

S, B Discriminating variables





dN/dPμ (for fit)
dN/dEvis, dN/dEtmiss,
dn/d(∑Pt) and dN/dM(μμ)
distribution for Signal and
backgrounds after a pre-
selection requiring two muons
having |cos θ | < 0.985

Discriminating variables

- Visible energy E_{vis}
- Missing transverse energy E_{tmiss}
- Acollinearity and acoplanarity
- Sum of transverse momentum of muons Σp_t
- Polar angle of the missing energy vector θ_{miss}
- Invariant mass of the two muons $M_{\mu\mu}$
- unbalance of the muons momenta Δ
- Missing mass M_{miss}

With:

$$\Delta = \left(1 - \frac{(P_{\mu 1} - P_{\mu 2})^2}{(P_{\mu 1} + P_{\mu 2})^2} \right)^{1/2}$$

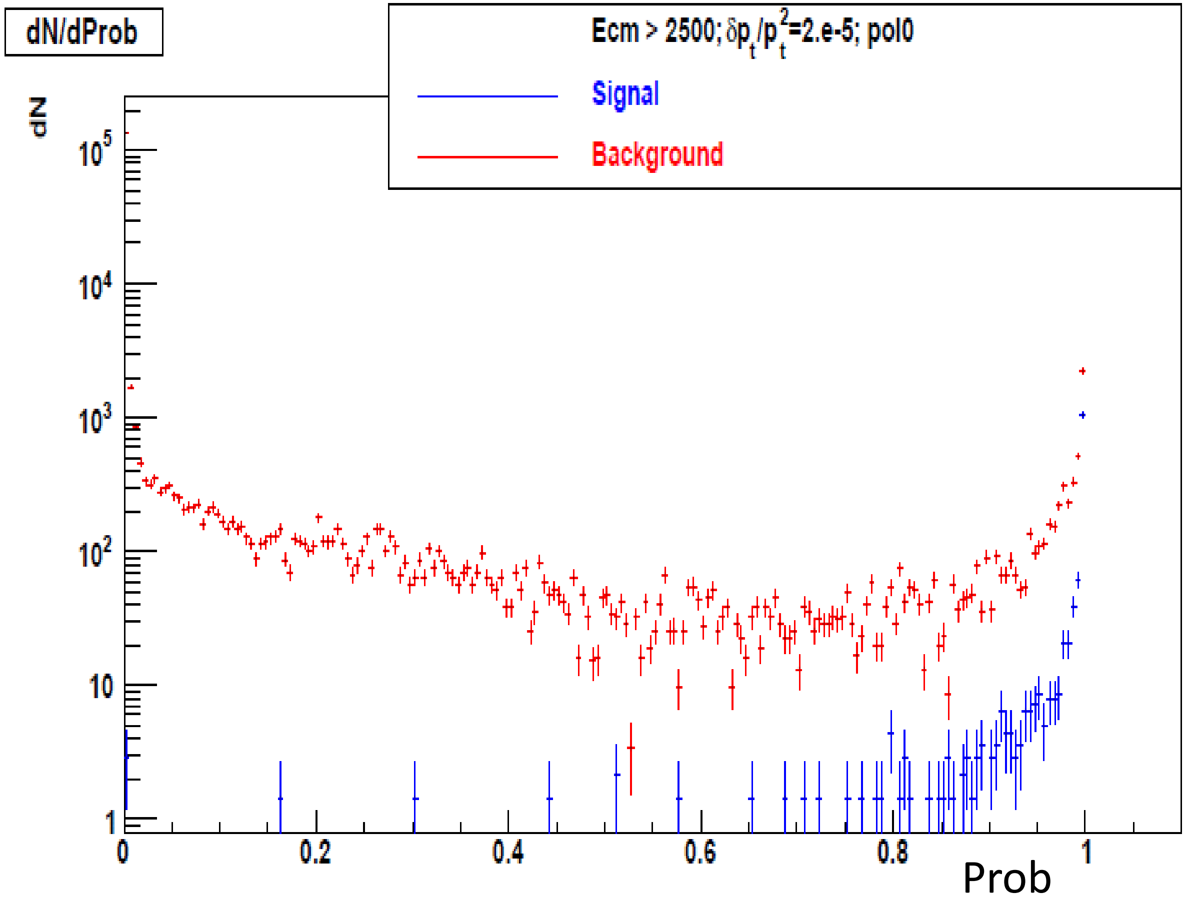
$$M_{miss} = (S + M_{VIS}^2 - 2E_{VIS}\sqrt{S})^{1/2}$$

$$M_{Vis}^2 = E_{Vis}^2 - P_{Cis}^2$$

Combined Probability

After a preselection requiring two muons having |cos θ | < 0.985, the normalized S/B values is computed for each variable and combined into a total probability used for the final selection.

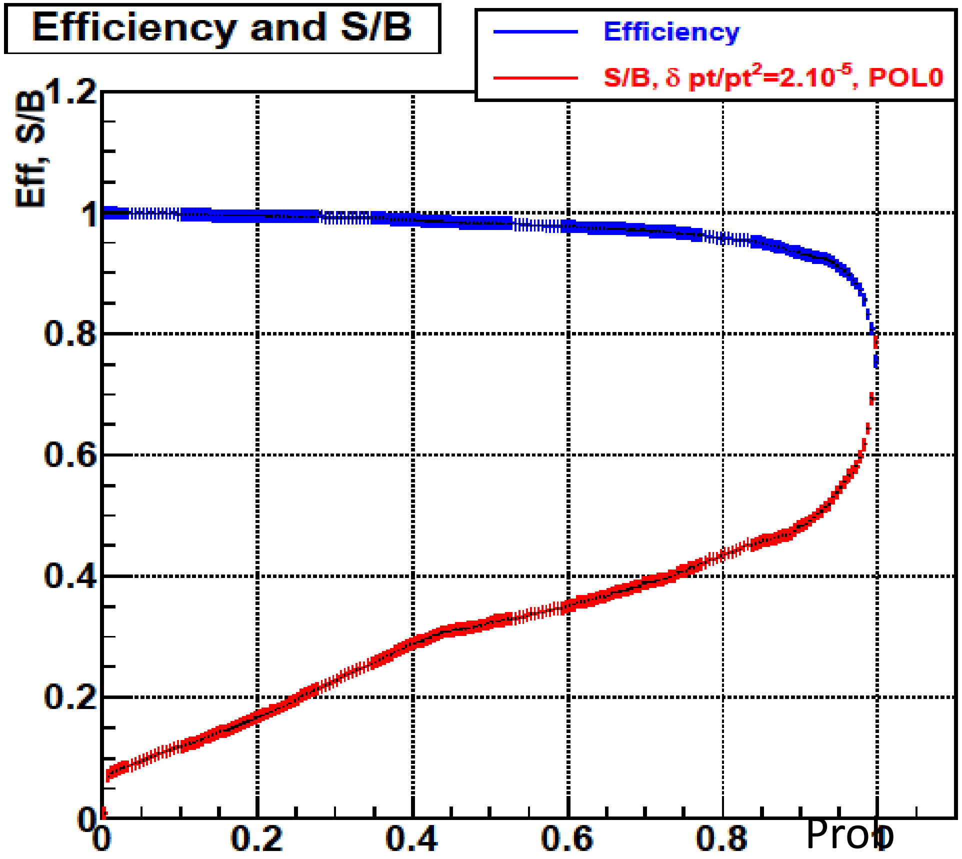
dN/dProb for signal (blue), and background (red); δPt/Pt²=2.10⁻⁵



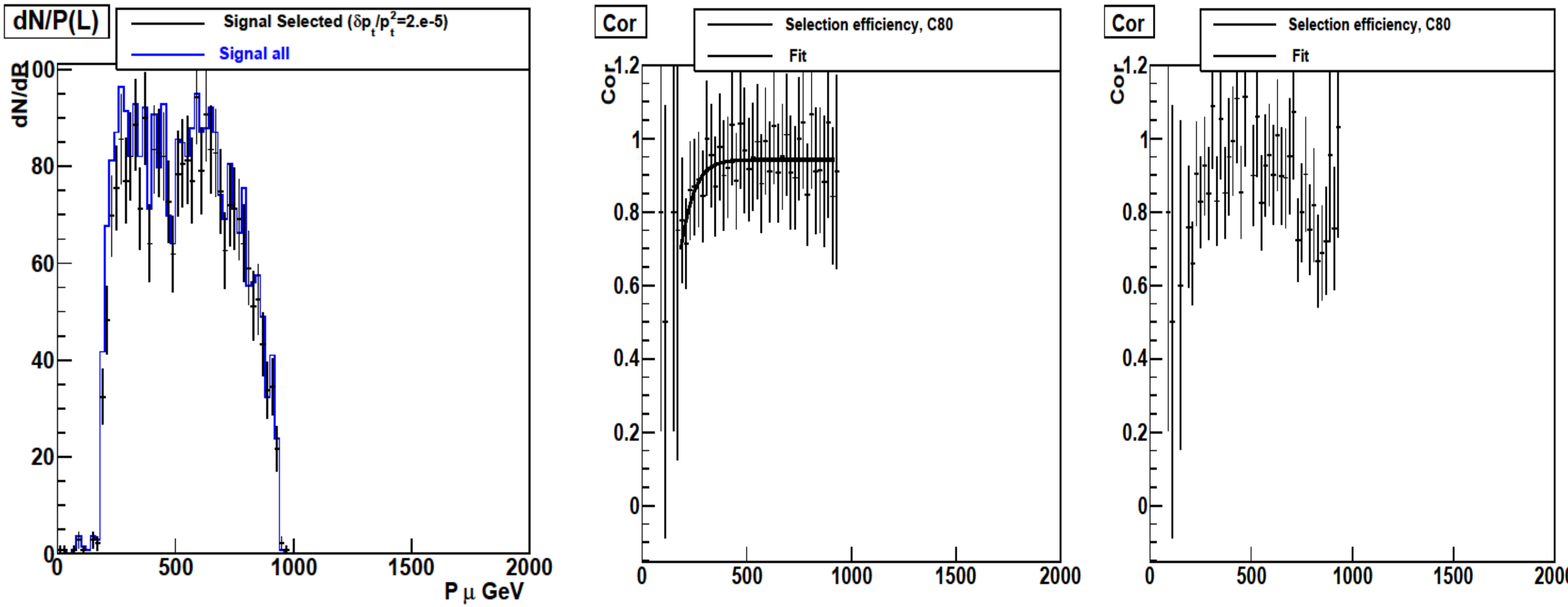
Selection Efficiency and S/B

Selection efficiency (blue) S/B ratio (red) for $\delta Pt/Pt^2 = 2.10^{-5}$ and muon identification efficiency = 100%.

For Prob > 0.8, the selection efficiency is 93 % and S/B ~ 40%;



Selection efficiency



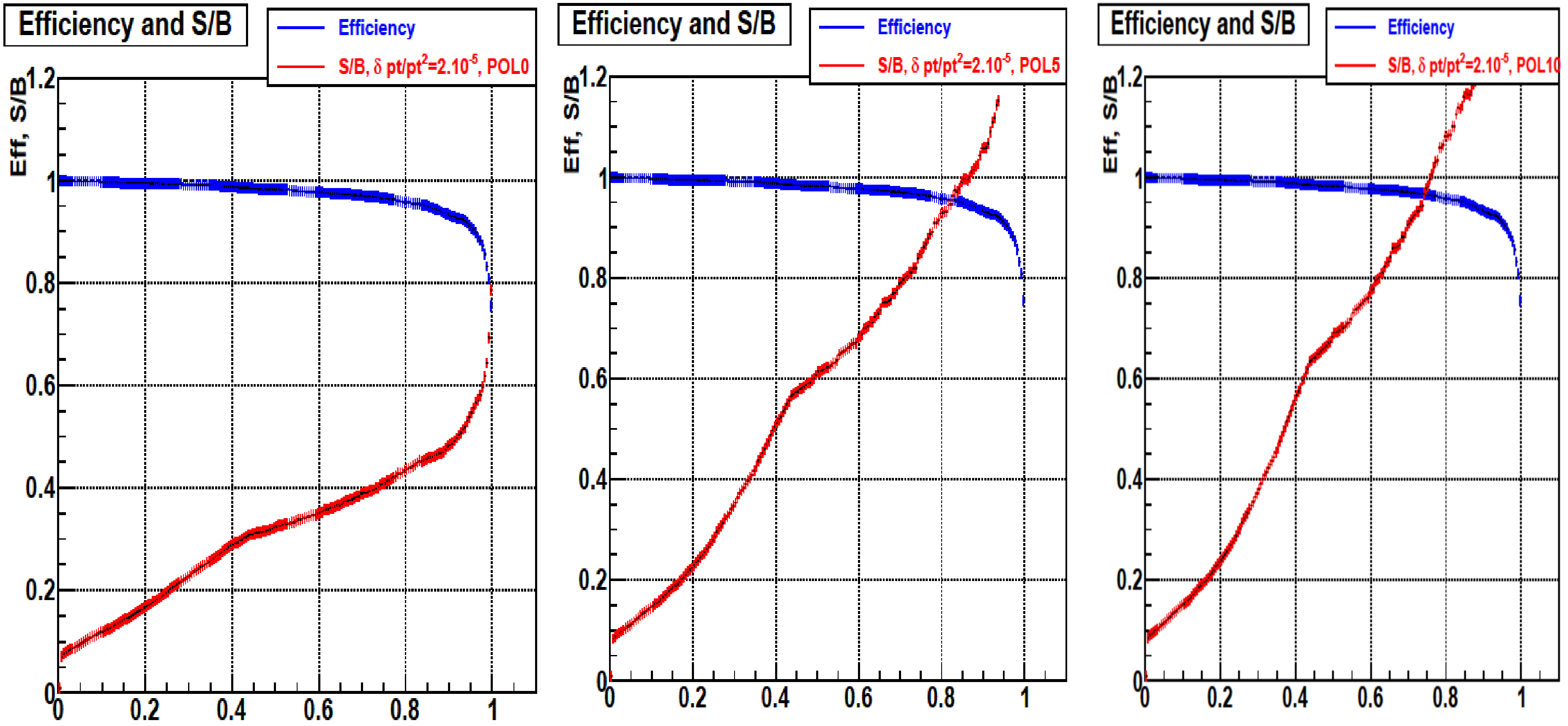
Left: Muon momentum distribution, $\delta Pt/Pt^2=2.10^{-5}$, no selection and for Prob>0.8

Middle:efficiency for Prob>0.8, $\delta Pt/Pt^2=2.10^{-5}$. E ~ 93 % and S/B ~ 40%;

Right : efficiency for Prob>0.8 $\delta Pt/Pt^2=2.10^{-4}$. E ~ 91 % S/B decreases to 33%

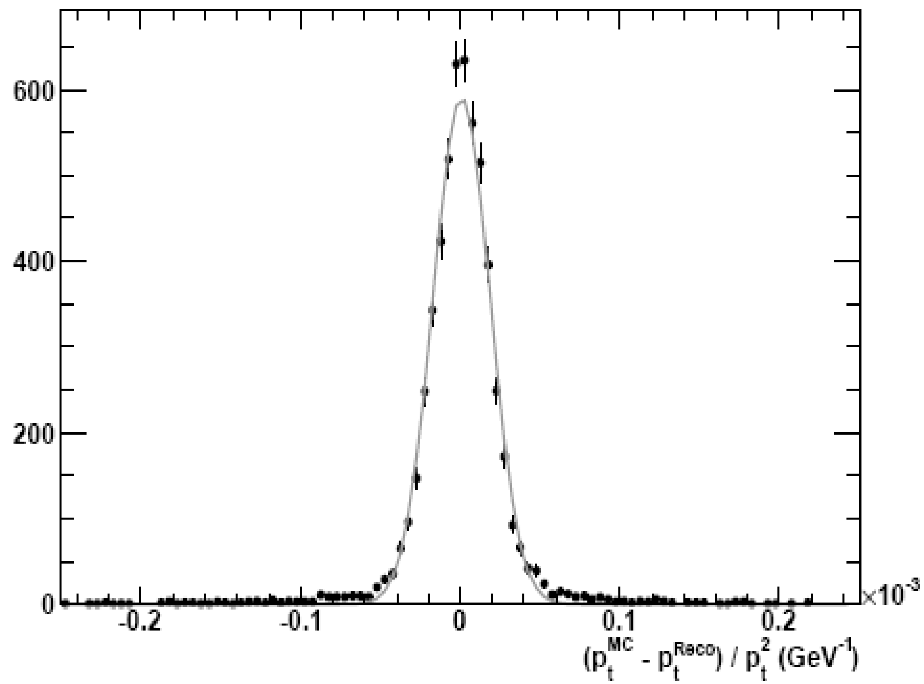
The degradation of the energy resolution distorts the shape of dN/dP

Efficiency and S/B, Beam Polarization

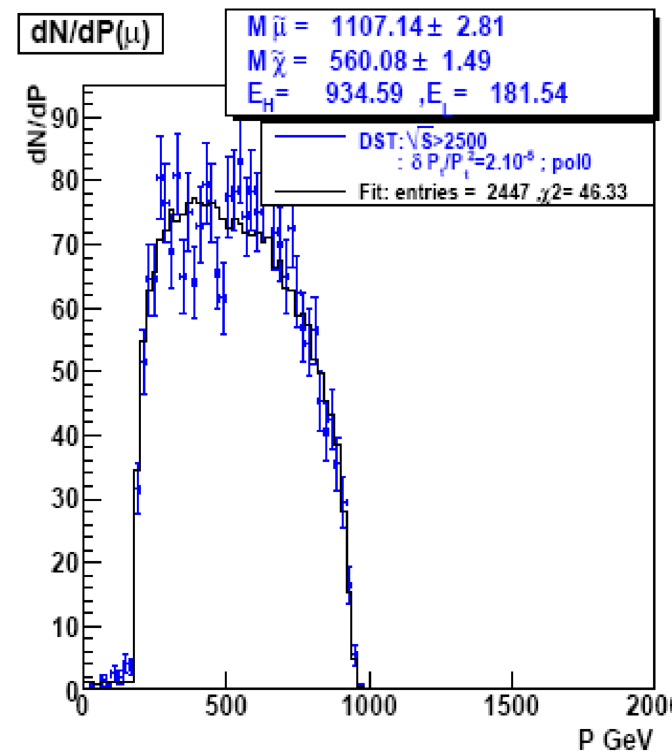


selection efficiency and S/B for $\delta Pt/Pt^2=2.10^{-5}$ and different polarization conditions
Left: pol (e^-/e^+) (0/0); S/B~0.4 Middle: (80/0); S/B~0.95 Right: (80/60); S/B~1.1

Signal (only) fit, no beam polarization no background



(a) $\delta p_\perp / p_\perp^2$ Resolution from Fully Simulated and Reconstructed Events



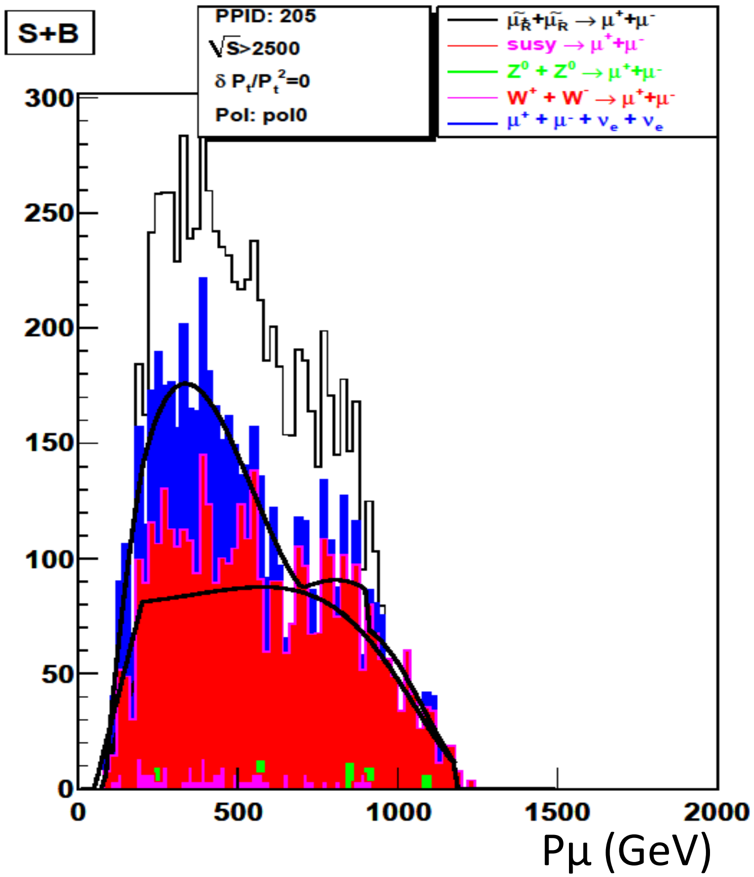
(b) Momentum Spectrum from Fully Simulated and Reconstructed Events

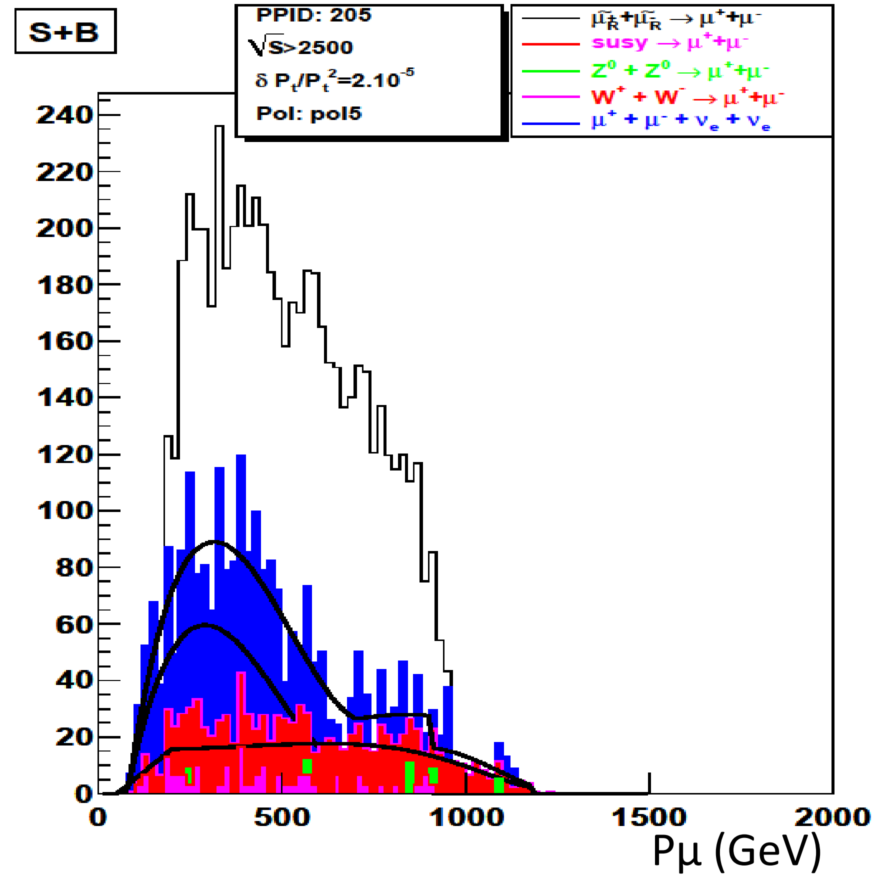
Left: muon momentum resolution; G4 simulation + reconstruction: $\delta pt/pt^2 \sim 2.10^{-5}$

Right: Momentum spectum fit, with ISR+B.S and $\delta pt^2/pt^2 \sim 2.10^{-5}$ modeling.

m =1107.1±2.8 GeV and m °=560.1 ± 1.5 GeV ; validation of fit and modeling

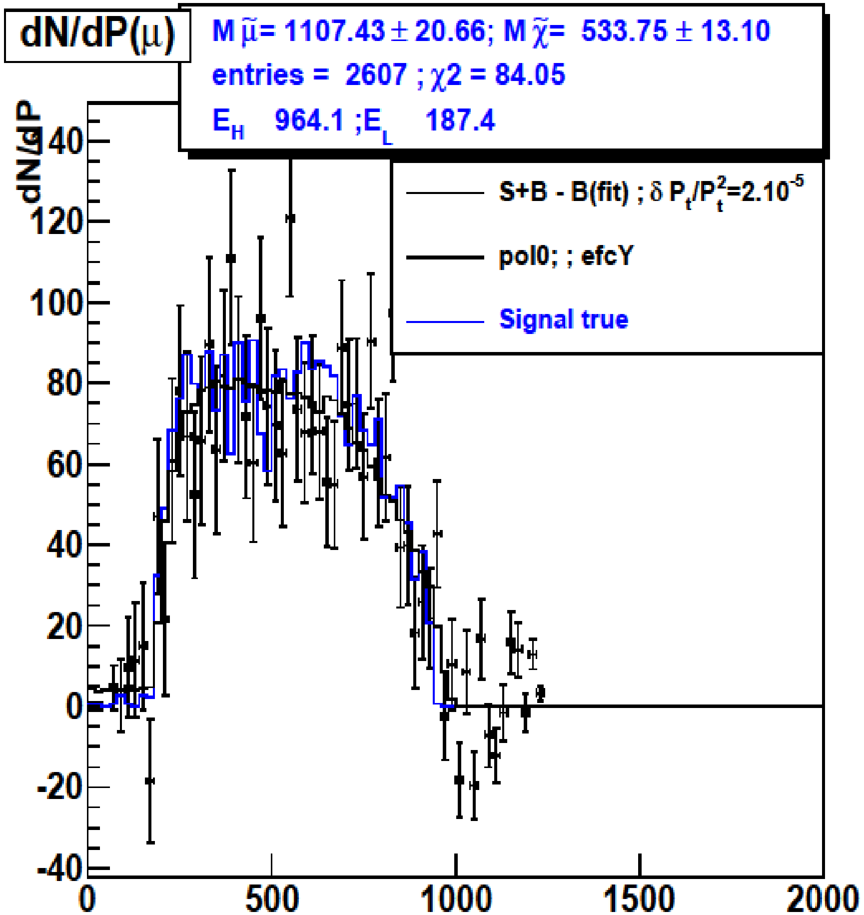
Stacked Signal + Background

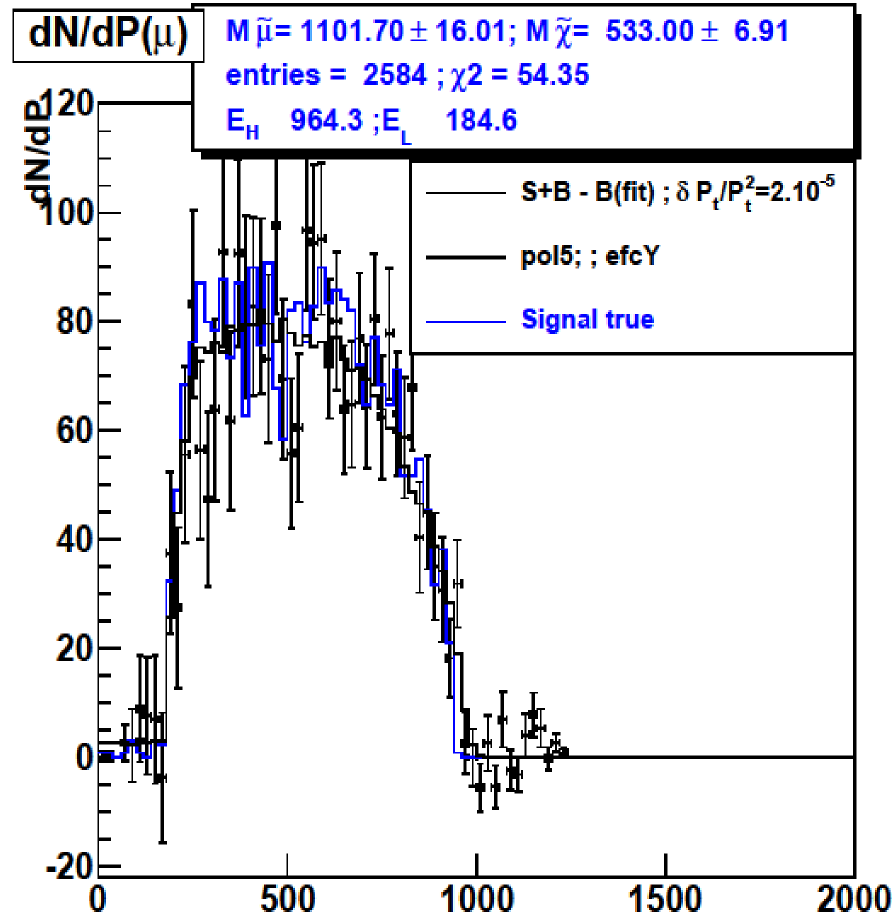




Left: Signal + backgrounds without polarization. Right: with (e^-80, e^+0) polarization; Signal x 1.8 and background x0.2; upper edge better preserved from WW bkg. Background modeled for background subtraction

S-B Fits after B subtraction





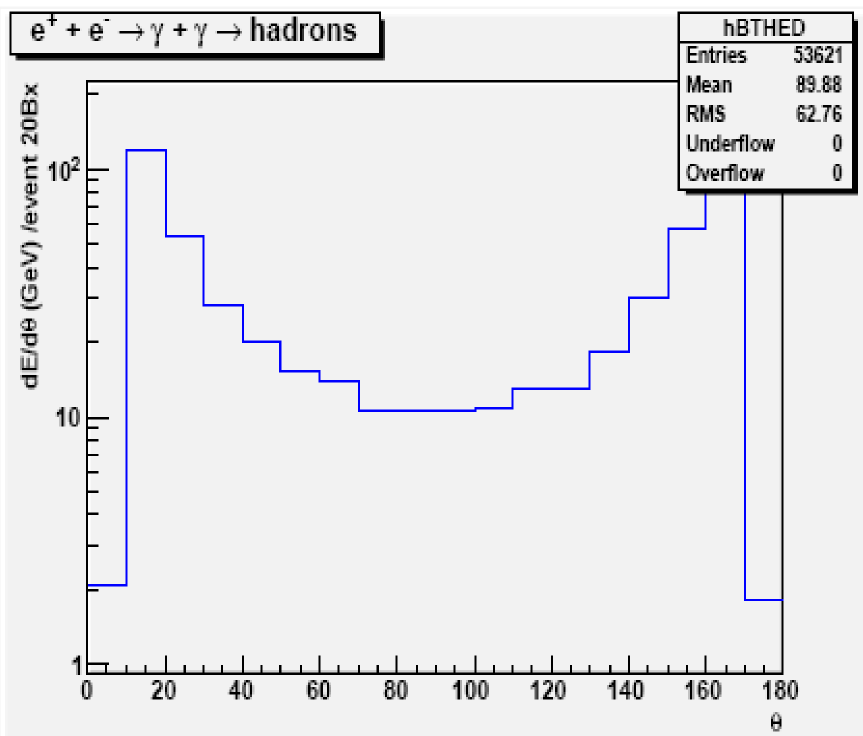
Momentum spectum fits, with ISR+B.S and $\delta pt/pt^2$ modeling and B subtraction.

Smuon : $\delta m/m$ ~ 2.0 % without polarization and 1.5 % with 80% e^- polarisation

Neutralino: $\delta m/m$ ~ 2.4 % without polarization and 1.2 % with 80% e^- polarisation

$e^+ + e^- \rightarrow \gamma\,\gamma \rightarrow$ hadrons

At 3 TeV ~ 3.3 $e^+ + e^- \rightarrow \gamma\,\gamma \rightarrow$ hadrons events / BX $\rightarrow$ ~ 13 particles/BX, 24 GeV/BX Per train (312 BX) ~ 7.5 Tev are dumped in the detector. Low E/Pt hadrons, but requires time stamping to preserve the energy resolution and the missing energy measurements necessary to discriminate Signal and background



Background peaked in F/B region.

Fig1: dE/dθ **for 20 Bx**

Energy deposit in a ±10 ° cone:

- ~ 2 Gev in barrel region
- ~ 20 Gev in F/B regions

For 5Bx (2.5 nsec) the selection efficiency Is unchanged ~ 93%, for 20 Bx (10 nsec) it decreases to 91 % .

The mass fits where done for 5 and 20 BX

Table of Results

Data Set	√S> (GeV)	$\delta pt/pt^2$ ($x10^{-5}$ GeV^{-1})	Polarization (e^- / e^+)	BX Capability	M (GeV)	M ^{o} (GeV)
S	2950	0	0/0	1	1106.3±2.9	558.8±1.3
S	2500	0	0/0	1	1098.8±2.6	555.4±1.2
S	2500	2	0/0	1	1104.6±2.9	560.0±1.7
S	2500	6	0/0	1	1098.8±3.1	559.1±3.6
S	2500	20	0/0	1	1107.5±4.2	575.7±5.3
S(G4+R)	2500	2	0/0	1	1107.2±2.8	560.1±2.2
S+B	2500	2	0/0	1	1107.4±20.2	533.8±13.1
S+B	2500	2	80/60	1	1101.7±13.5	536.7±5.5
S+B	2500	2	80/60	5	1102.4±12.9	548.9±7.1
S+B	2500	2	80/60	20	1104.6±12.8	551.1±7.1

When $\delta pt/pt^2$ increases, S/B decreases, δm increases; for $\delta pt/pt^2 > 10^{-4}$, efficiency corrections are large ,introducing significant systematic errors.

B modeling/subtraction increases δm; it can be improved using polarization.

γγ-> hadron decrease S/B; up to 20 BX time stamping (10 nsec); there is no significant δm degradation.

Summary and Outlook

^{0} masses can be obtained from energy scan and fit to the dN/dP.

^{0} masses are:

- The background estimation and subtraction.
- The luminosity spectrum modeling.
- The μ momentum resolution.

To reach a statistical accuracy $\delta m/m \sim 1\,\%$, with dN/dP fit method, requires:

- 2 ab^{-1} of integrated luminosity
- Electron beam polarization ~ 80% to increase the S/B ratio.
- Good control of the luminosity spectrum, ISR and beamstrahlung.
- Good muon ID and $\delta pt/pt^2 < 5.10^{-5}$ to minimize momentum spectrum efficiency correction
- Time stamping capability <=20 BX to preserve S/B from $\gamma\gamma \rightarrow h$ pile up.

the measurement method and the requirements are similar. The detector performances studies for will be done with full simulation and reconstruction for the CLIC CDR.