# The sensitivity of ILC to the $\chi$

## with a di-muon signature

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# Outlook

- The physics of the $\chi_2$
- Beam effects and polarization
- The identification of the di-muon channel
  - Description of the full background
  - Reduction of the SUSY background
- Future steps

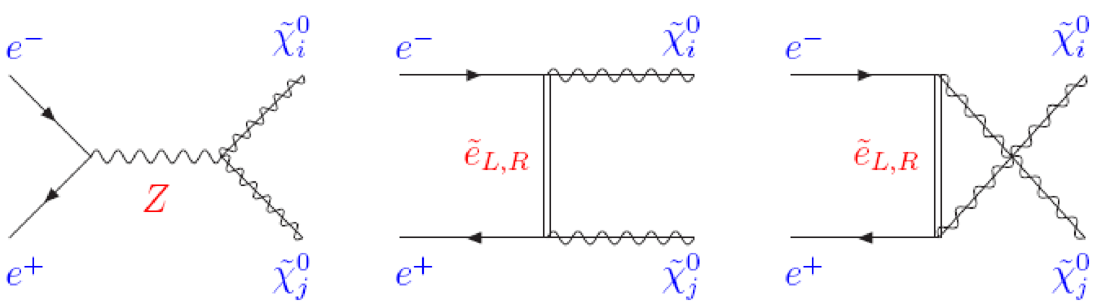
# The physics of the $\chi_2$

## The spin ½ susy partners of the electroweak gauge bosons (SU(2)xU(1)) are:

- B,W3,W+-
- The mass matrix of the neutral B,w3,H1,H2 (higgsinos) , after the Higgs mechanism is:

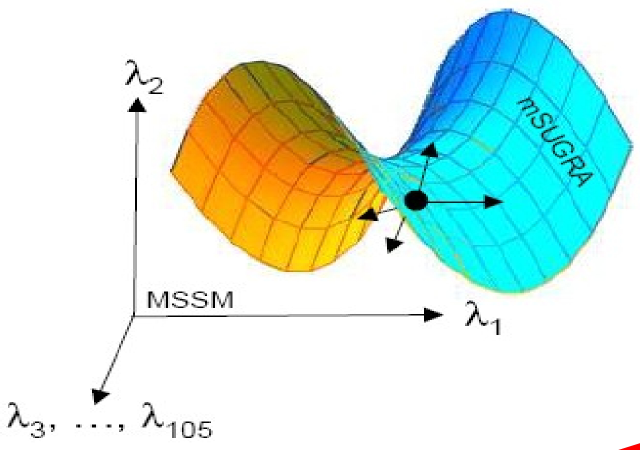
$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -m_Z c_\beta s_W & m_Z s_\beta s_W \\ 0 & M_2 & m_Z c_\beta c_W & -m_Z s_\beta c_W \\ -m_Z c_\beta s_W & m_Z c_\beta c_W & 0 & -\mu \\ m_Z s_\beta s_W & -m_Z s_\beta c_W & -\mu & 0 \end{pmatrix}$$

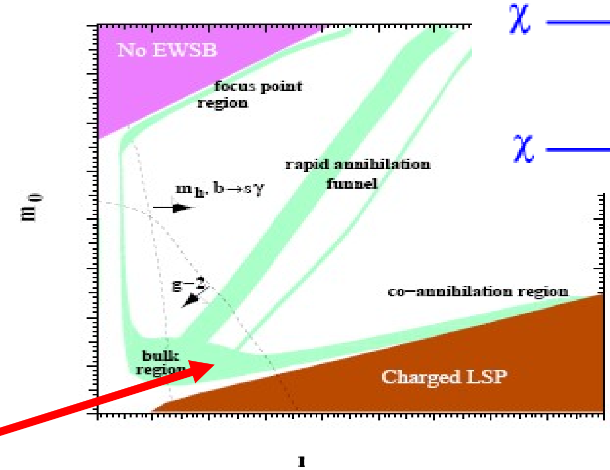
The diagonalization of the neutralino mass matrix yields 4 neutralino eigenstates.

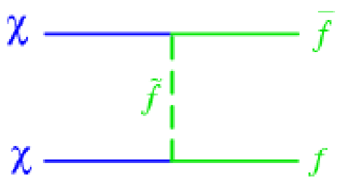



$$e^+e^- \rightarrow \tilde{\chi}_i^0\, \tilde{\chi}_j^0 \qquad (i,j = 1,2,3,4)$$

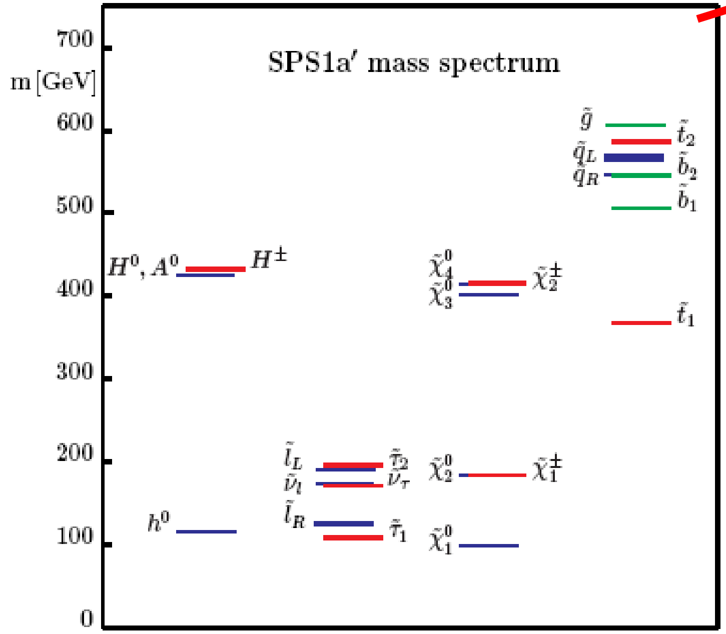
# The SUSY scenario considered in this analysis




| Process | Fraction |
|---|---|
| $\tilde\chi_1^0\tilde\chi_1^0 \to \ell^+\ell^-$ | 40% |
| $\tilde\chi_1^0\tilde\chi_1^0 \to \tau^+\tau^-$ | 28% |
| $\tilde\chi_1^0\tilde\chi_1^0 \to \nu\bar\nu$ | 3% |
| $\tilde\chi_1^0\tilde\tau_1 \to Z\tau$ | 4% |
| $\tilde\chi_1^0\tilde\tau_1 \to A\tau$ | 18% |
| $\tilde\tau_1\tilde\tau_1 \to \tau\tau$ | 2% |




In SPS1a':

- 7.00000000E+01 # m0
- 2.50000000E+02 # m12
- 1.03744295E+01 # tanb
- 1.00000000E+00 # Sign(mu)
- -3.00000000E+02 # A0

Mass spectrum:

$\chi_2$ 183 GeV

$\chi_1$ 97 GeV

$\mu_R$ 125 GeV

$\mu_L$ 189 GeV

...

# Motivation for the di-muon channel

$e^+ e^- \to \chi_1 \chi_2$ 188.1 fb

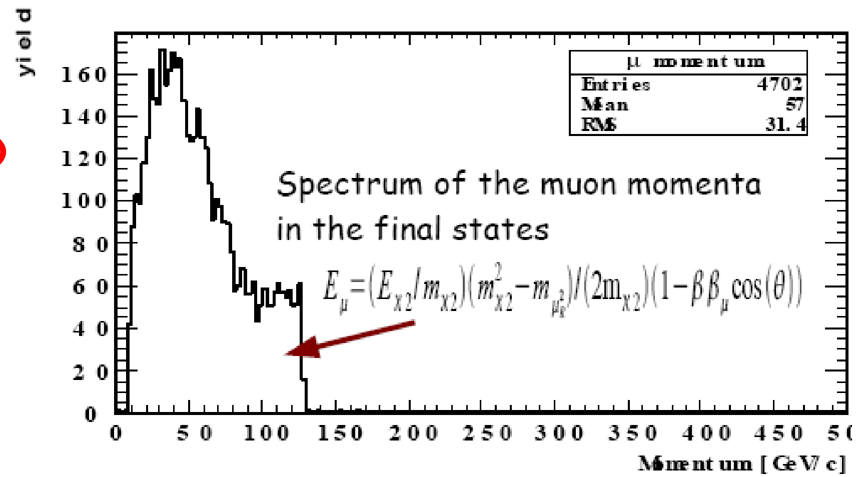
$\chi_2 \to \mu_R \mu$ , $e_R e$ 2.5% B.R.

$\chi_2 \to \tau_1 \tau$ 58% B.R.

2351 events expected at $500 fb^{-1}$

$$E_{\chi_2^0} = \frac{E_{cm}}{2} + \frac{m^2_{\chi_2^0} - m^2_{\chi_1^0}}{2 \cdot E_{cm}}$$

Polarization (-0.8,0.6)
Luminosity 500 fb-1



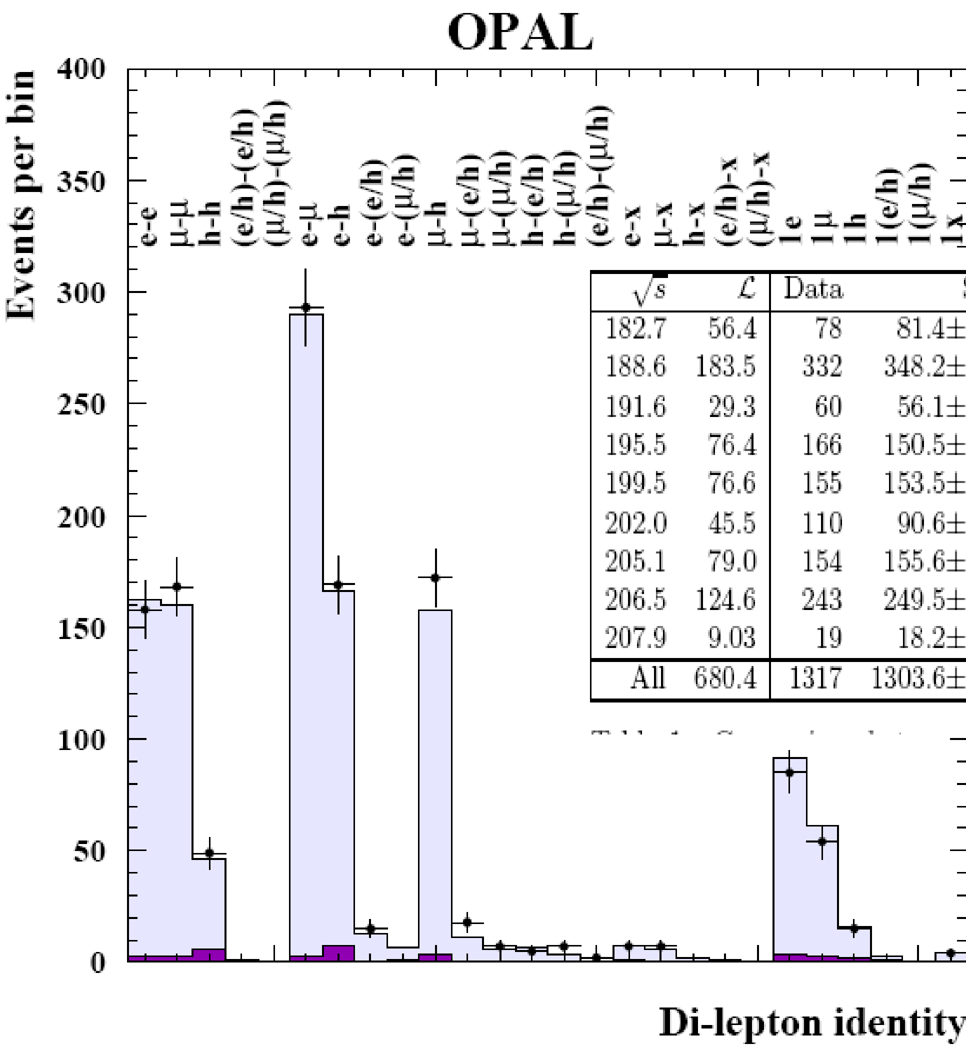

$$E^*_{\tilde{\mu}} = \frac{m_{\chi_2^0}}{2} + \frac{m^2_{\tilde{\mu}} - m^2_{\mu}}{2 \cdot m_{\chi_2^0}}$$

$$E^*_{\mu} = \frac{m_{\chi_2^0}}{2} - \frac{m^2_{\tilde{\mu}} - m^2_{\mu}}{2 \cdot m_{\chi_2^0}}$$

$$E_\mu = \gamma E^*_\mu \left(1 - \beta^2 \cos(\theta)\right) = \frac{E_{\chi_2^0}}{m_{\chi_2^0} c^2} \frac{m^2_{\chi_2^0} + m^2_{\tilde{\mu}}}{2 m_{\chi_2^0}} \left(1 - \beta \beta_\mu \cos(\theta)\right) \qquad (1.3)$$

The two body decay of the neutralino2 generates sharp edges dependent on its mass.
The individuation of the edge is the technique of mass measurement.
**The di-muon signature is clean and easy to detect in the ILC environment**

# Historical motivations




| $\sqrt{s}$ | $\mathcal{L}$ | Data | SM | $\ell^+\nu\,\ell^-\bar{\nu}$ | $e^+e^-\ell^+\ell^-$ | $\ell\ell q\bar{q}$ | $\ell^+\ell^-(\gamma)$ | $\nu\bar{\nu}\gamma(\gamma)$ |
|---|---|---|---|---|---|---|---|---|
| 182.7 | 56.4 | 78 | 81.4±0.8 | 77.5±0.7 | 3.4±0.5 | 0.07±0.03 | 0.31±0.04 | 0.06±0.03 |
| 188.6 | 183.5 | 332 | 348.2±1.9 | 337.2±1.7 | 3.6±0.7 | 1.6±0.1 | 4.6±0.3 | 1.1±0.2 |
| 191.6 | 29.3 | 60 | 56.1±0.6 | 54.2±0.6 | 0.6±0.1 | 0.2±0.04 | 0.9±0.2 | 0.10±0.04 |
| 195.5 | 76.4 | 166 | 150.5±1.2 | 144.7±1.0 | 2.7±0.4 | 0.6±0.06 | 2.1±0.4 | 0.42±0.05 |
| 199.5 | 76.6 | 155 | 153.5±0.9 | 148.7±0.7 | 1.8±0.3 | 0.7±0.06 | 1.8±0.2 | 0.45±0.05 |
| 202.0 | 45.5 | 110 | 90.6±0.7 | 87.6±0.6 | 1.4±0.2 | 0.4±0.04 | 1.0±0.1 | 0.19±0.04 |
| 205.1 | 79.0 | 154 | 155.6±1.2 | 150.8±1.1 | 1.8±0.3 | 0.6±0.07 | 2.0±0.3 | 0.38±0.07 |
| 206.5 | 124.6 | 243 | 249.5±1.4 | 241.4±1.2 | 3.9±0.6 | 1.1±0.1 | 2.3±0.3 | 0.64±0.08 |
| 207.9 | 9.03 | 19 | 18.2±0.2 | 17.7±0.2 | 0.20±0.04 | 0.08±0.01 | 0.18±0.03 | 0.06±0.01 |
| All | 680.4 | 1317 | 1303.6±3.3 | 1259.8±2.9 | 19.6±1.2 | 5.4±0.2 | 15.2±0.7 | 3.4±0.2 |

hep-ex/0309014

Exclution of right handed smuons with masses below 94 GeV at 95 % C.L.

The data were found consistent with the S.M. predictions: di-lepton events mainly dominated by **W semi-leptonic decay.**

# Simulation tools

- Events generator : whizard version 1.51
  - Full beam properties (beamstrahlung, ISR, FSR) as implemented in SLAC
  - Fragmentation of the events with PYTHIA
- PHYTIA is used for the generation of the event, without beam properties

# The signal process and the main backgrounds

| Process | Cross Section× B.R. (fb) | Events |
|---|---|---|
| $e^+e^- \rightarrow \chi_2^0\chi_1^0 \rightarrow \tilde{\mu}_R^\pm\mu^\mp\chi_1^0 \rightarrow \mu^\pm\mu^\mp\chi_1^0\chi_1^0$ | 4.3 | 2150 |
| $e^+e^- \rightarrow \chi_2^0\chi_1^0 \rightarrow \tilde{\tau}_1^\pm\tau^\mp\chi_1^0 \rightarrow \mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\chi_1^0\chi_1^0$ | 3.19 | 1595 |
| $e^+e^- \rightarrow \tilde{\mu}_L^\pm\tilde{\mu}_L^\mp \rightarrow \mu^\pm\mu^\mp\chi_1^0\chi_1^0$ | 68.21 | 34105 |
| $e^+e^- \rightarrow \tilde{\mu}_R^\pm\tilde{\mu}_R^\mp \rightarrow \mu^\pm\mu^\mp\chi_1^0\chi_1^0$ | 42.80 | 21400 |
| $e^+e^- \rightarrow \tilde{\tau}_1^\pm\tilde{\tau}_1^\mp \rightarrow \mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\chi_1^0\chi_1^0$ | 1.71 | 855 |
| $e^+e^- \rightarrow \tilde{\tau}_2^\pm\tilde{\tau}_2^\mp \rightarrow \mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\chi_1^0\chi_1^0$ | 1.36 | 680 |
| $e^+e^- \rightarrow \tilde{\chi}_1^\pm\tilde{\chi}_1^\mp \rightarrow \mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\chi_1^0\chi_1^0$ | | |
| $e^+e^- \rightarrow \tilde{\chi}_1^\pm\tilde{\chi}_1^\mp \rightarrow \mu^\pm\mu^\mp\nu_\mu\nu_\mu\chi_1^0\chi_1^0$ | | |
| $e^+e^- \rightarrow W^\pm W^\mp \rightarrow \mu^\pm\mu^\mp\nu_\mu\nu_\mu$ | 528.5 | 264250 |
| $e^+e^- \rightarrow W^\pm W^\mp \rightarrow \mu^\pm\mu^\mp\nu_\mu\nu_\mu\nu_\tau\nu_\tau$ | 15.27 | 7635 |
| $e^+e^- \rightarrow Z^0 \rightarrow \mu^\pm\mu^\mp$ | 803 | 401500 |
| $e^+e^- \rightarrow Z^0Z^0 \rightarrow \mu^\pm\mu^\mp E$ | 11.39 | 5695 |
| $e^+e^- \rightarrow e^+e^+\mu^\pm\mu^\mp E$ | $3.6 \cdot 10^5$ | $180 \cdot 10^5$ |

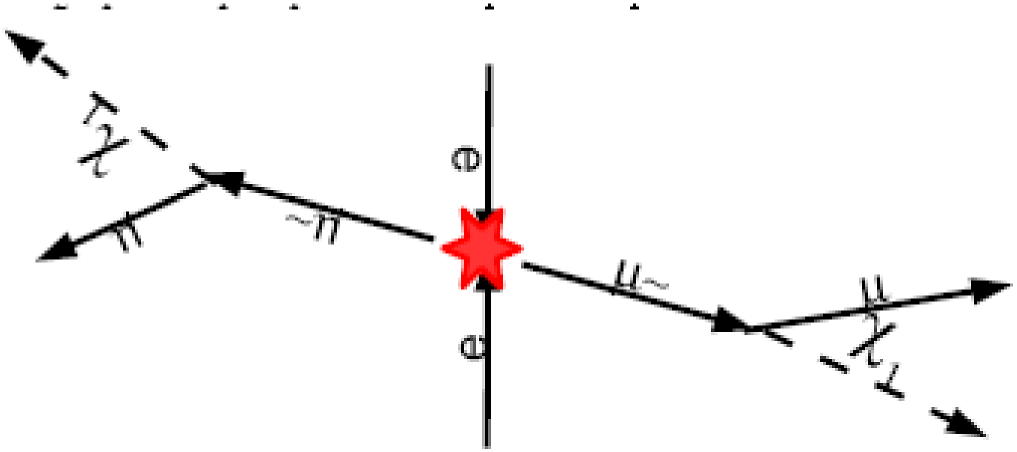
Polarization (-0.8,0.6)
Luminosity 500 fb-1

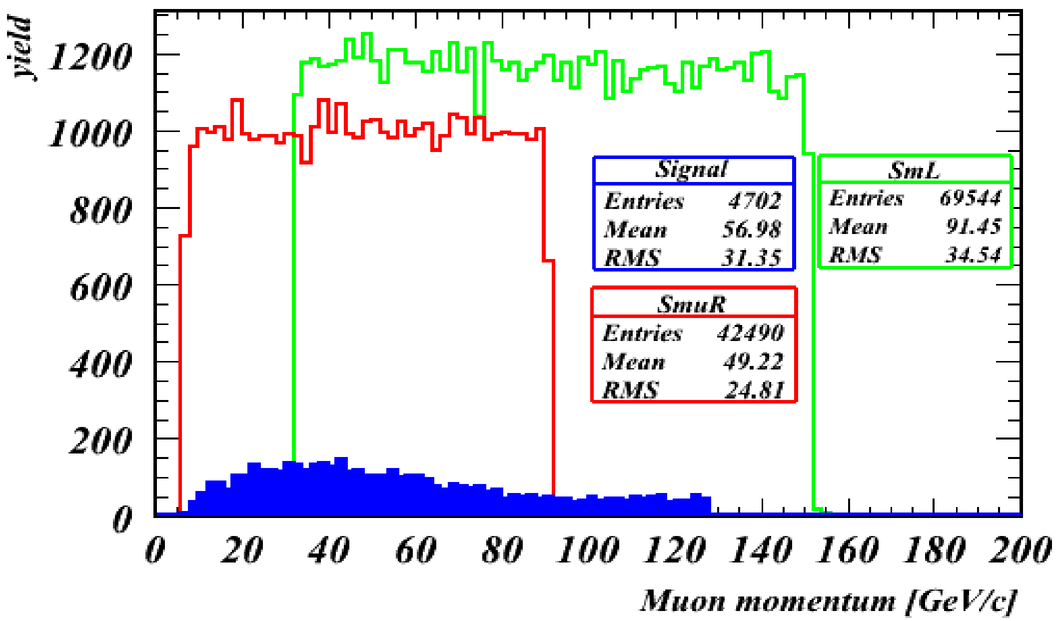
**The identification of a good signature for the neutralino sector is very important !**

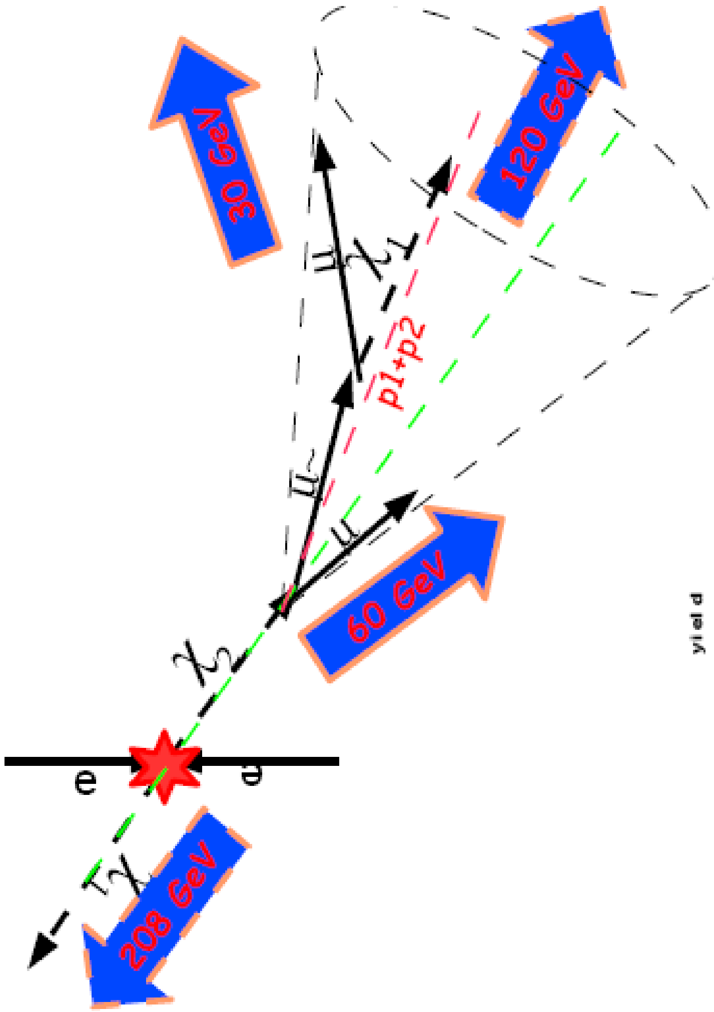
# The impact of the polarization

| Process | (0,0) | (-0.8,0) | (0.8,0) | (-0.8,0.6) | (0.8,-0.6) | (0.8,0.6) | (-0.8,-0.6) |
|---|---|---|---|---|---|---|---|
| $e^+e^+ \to \chi_2^0 \chi_1^0$ | 1.59 | 2.6 | 0.48 | 4.3 | 0.4 | 0.55 | 1.11 |
| $e^+e^+ \to \chi_2^0 \chi_1^0$ | 40.85 | 69.41 | 12.12 | 110.5 | 10.29 | 13.98 | 28.37 |
| $e^+e^+ \to \tilde{\mu}_L^\pm \tilde{\mu}_L^\mp$ | 28.34 | 43.35 | 13.33 | 68.21 | 15.48 | 10.98 | 18.49 |
| $e^+e^+ \to \tilde{\mu}_R^\pm \tilde{\mu}_R^\mp$ | 69.42 | 35.17 | 103.73 | 42.80 | 162.7 | 44.66 | 27.54 |
| $e^+e^+ \to \tilde{\tau}_1^\pm \tilde{\tau}_1^\mp$ | 75.60 | 45.35 | 105.7 | 59.29 | 164.5 | 46.83 | 31.80 |
| $e^+e^+ \to \tilde{\tau}_2^\pm \tilde{\tau}_2^\mp$ | 20.80 | 30.13 | 11.48 | 47.12 | 14.47 | 8.48 | 13.15 |
| $e^+e^+ \to W^\pm W^\mp$ | 368.4 | 660.4 | 761.4 | 1057 | 33.03 | 118.3 | 265.1 |
| $e^+e^+ \to Z^0 Z^0$ | 4.6 | 5.75 | 3.49 | 8.78 | 4.83 | | |

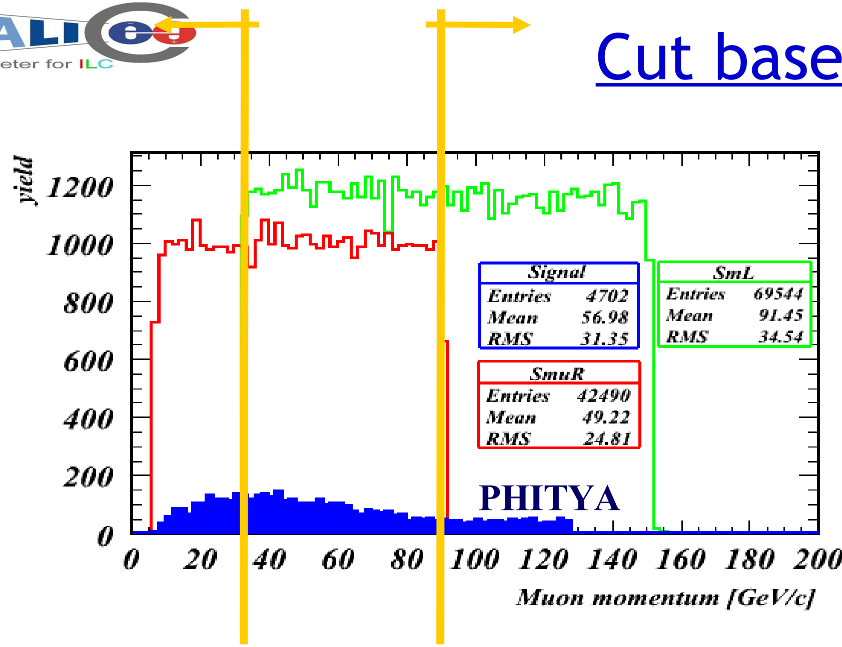
# SUSY Background and signal

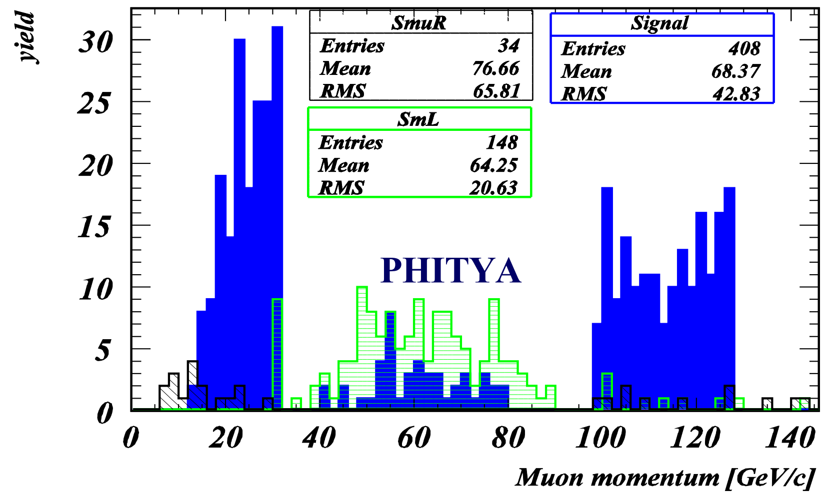




# Cut based approach




- The main SUSY contribution to the di-muon background is the production of smuons.
  - A crude cut can be defined as follows:

CUT A

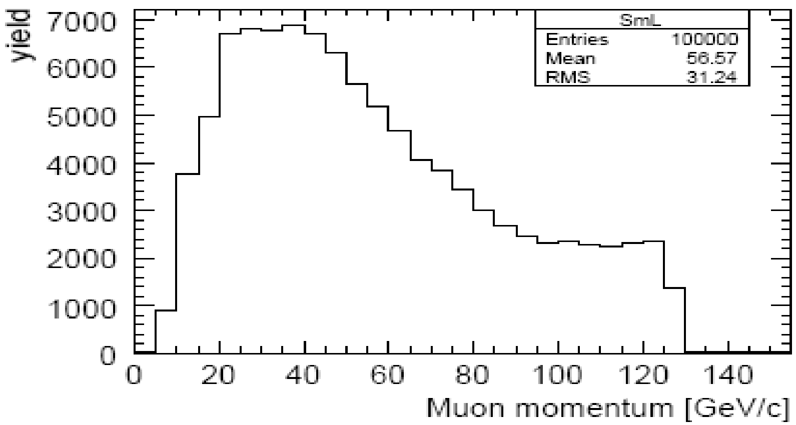
4. The muon with maximum momentum >90 GeV
5. One muon with minimum momentum<35 GeV
6. Complement of the angle between the two muons, in the plane perpendicular to the beam, (**acoplanarity**) > 0.5 $\pi$

CUT B

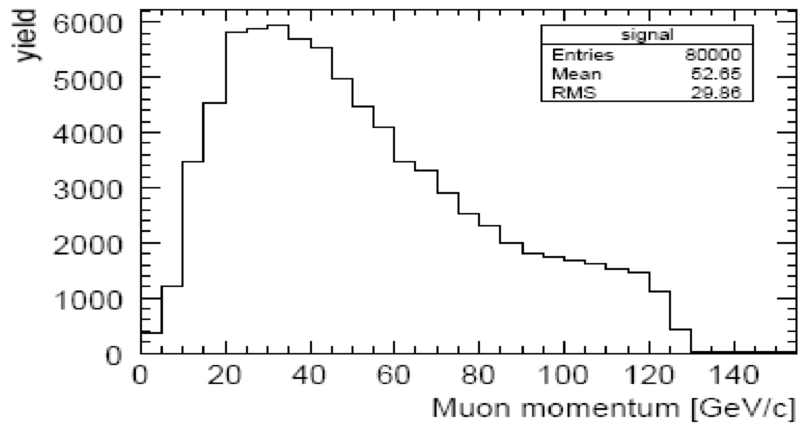
- The muon with maximum momentum <=90 GeV
- One muon with minumum momentum >=35
- **Acoplanarity >** 0.5 $\pi$
- Complement of the 3-d angle between the muons (**acollinearity**) > 0.5 $\pi$
- Angle between the maximum and minimum momentum muon and total momentum direction (Tmin,max) >0.16 $\pi$

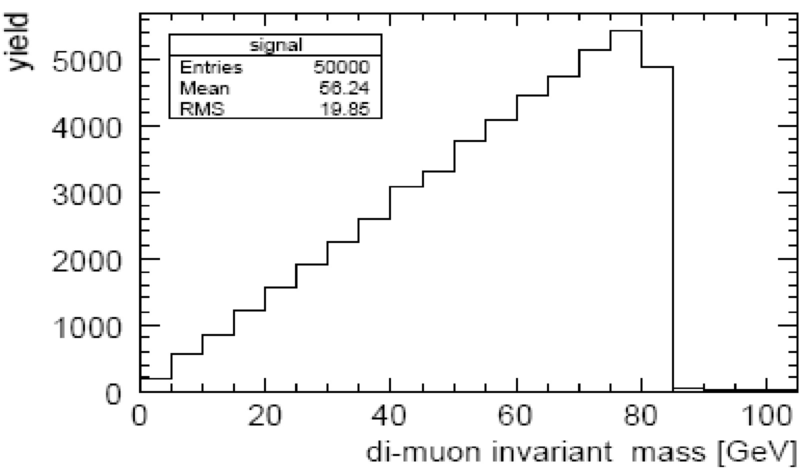
# Effects of the beam to the signal

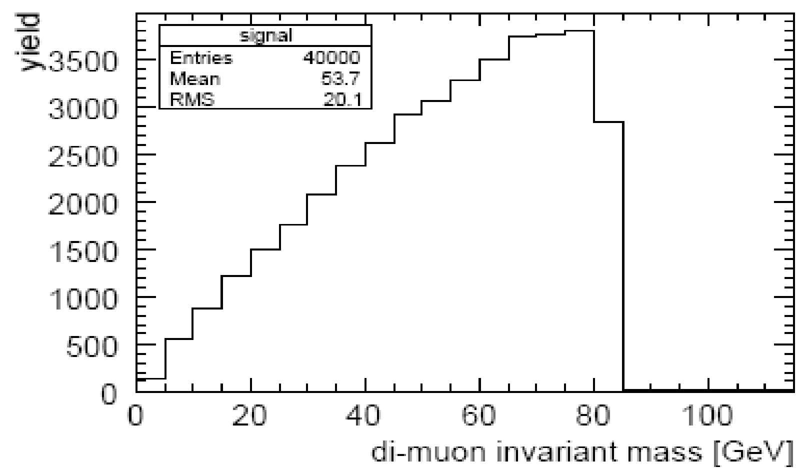
**PURE signal**




**With ISR,FSR,beam properties**



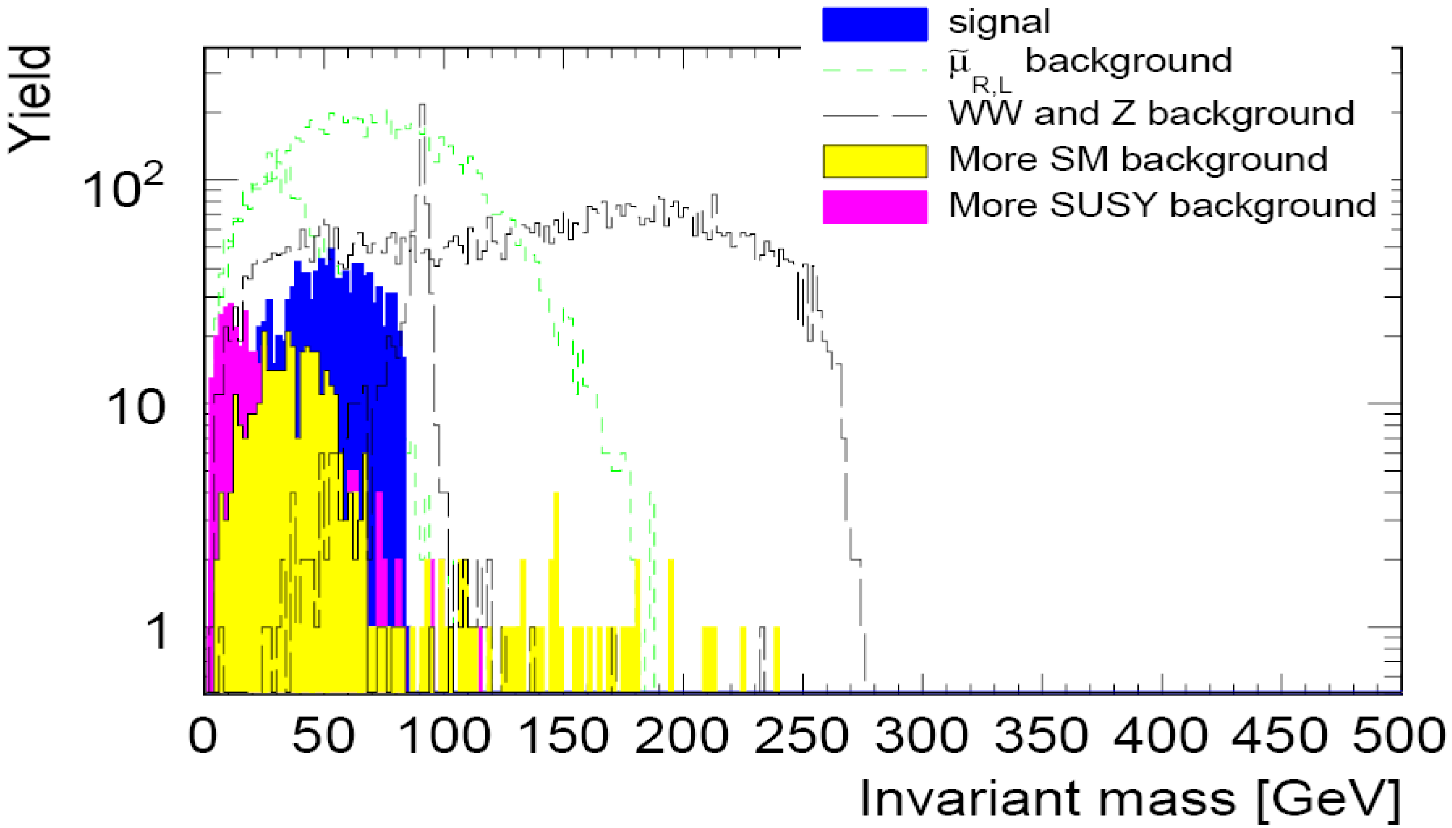




**The beam properties affect the momentum of the muons**

**Any sharp cut on the momentum is not efficient.**

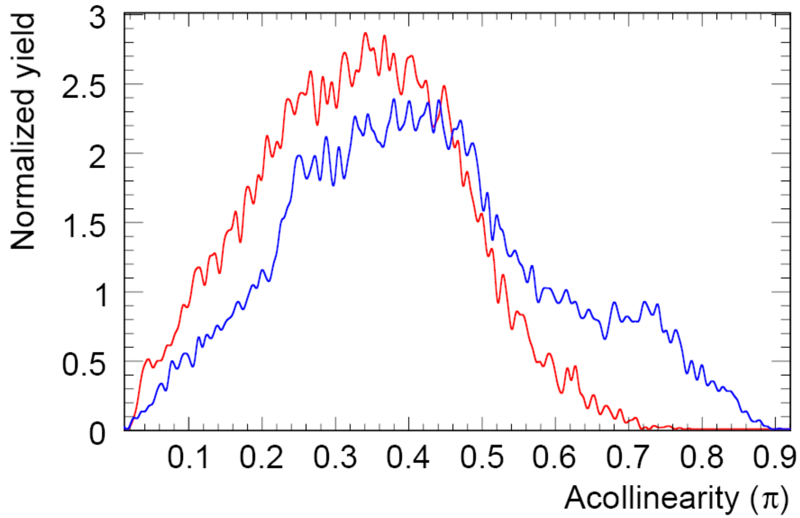
# More realistic pre-selection cuts

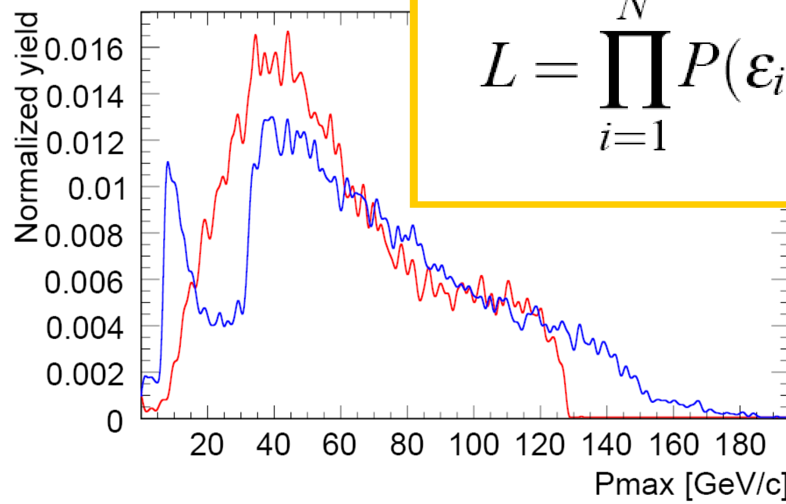



**Two isolated muons with:**

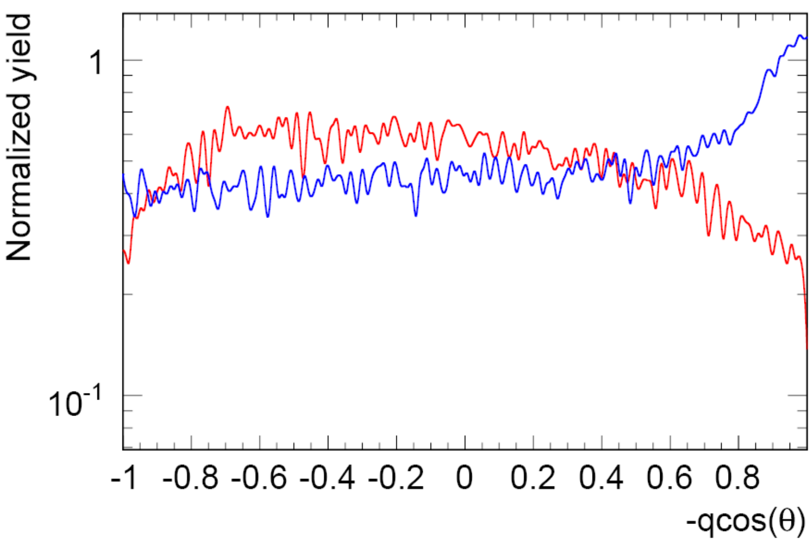
- Missing energy >300 GeV
- Transversal momentum > 40 GeV
- Acoplanarity > $0.5\ \pi$

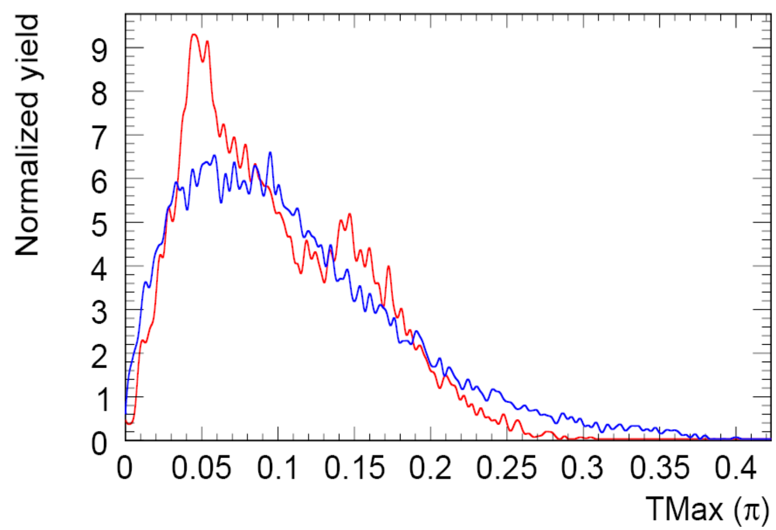
# Likelihood method for the identification of the signal



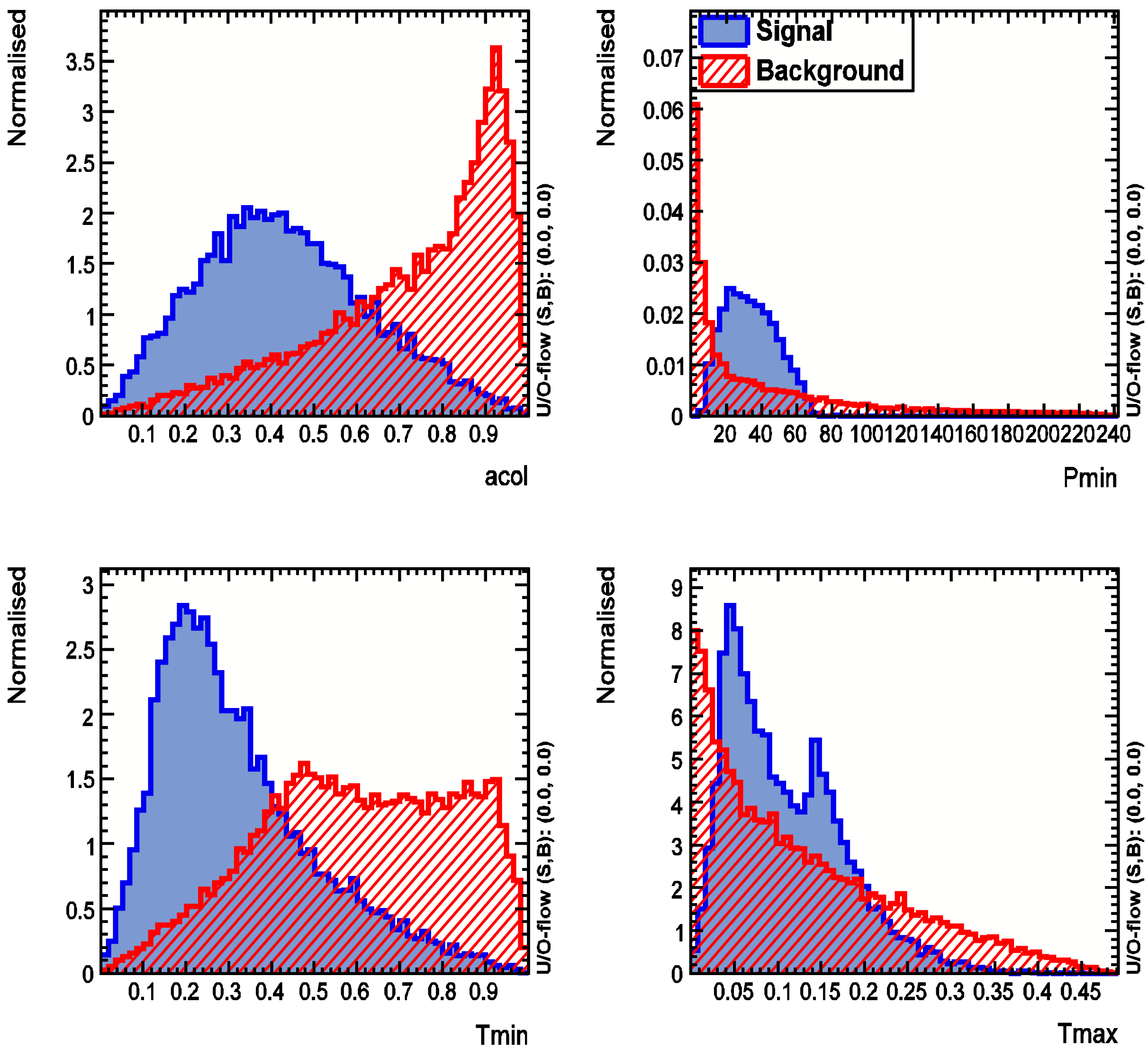




$$L = \prod_{i=1}^{N} P(\varepsilon_i)$$



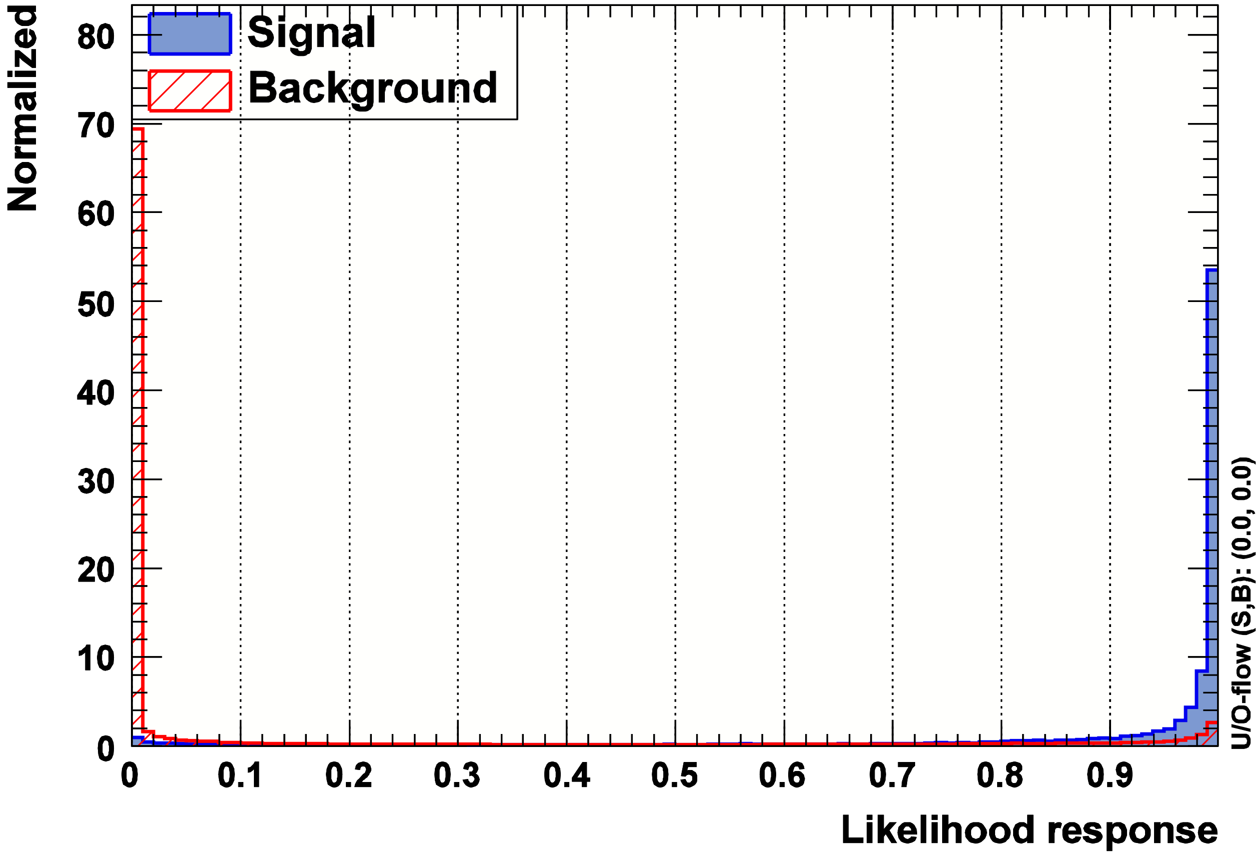



# Restriction to the SUSY background




**For the SUSY background –qcos(θ is not used...**

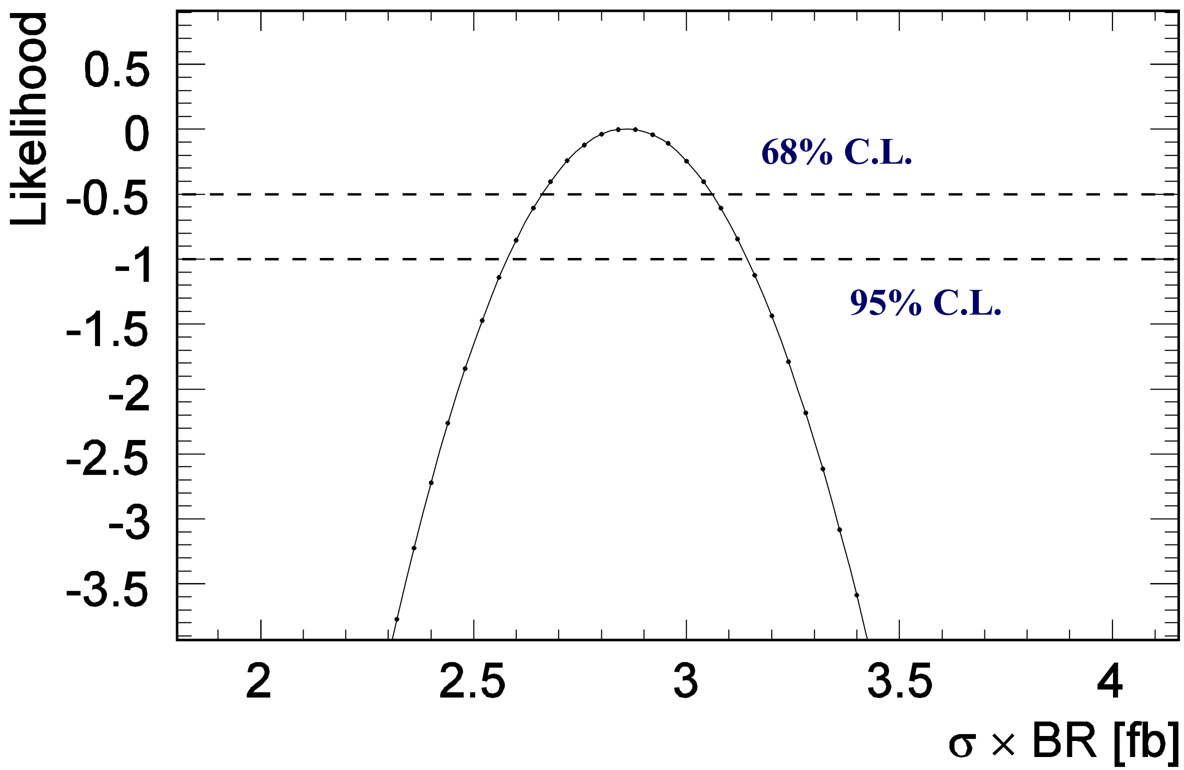
# Likelihood (only SUSY)




The likelihood is very powerful in the separation between the signal and the pure S.M.

# Extended likelihood : the determination of the cross section

$$L_{ext} = \frac{(N_B + \mathbf{L} \times \sigma_L)^{N_{obs}} e^{-N_{obs}}}{N_{obs}!} \prod_{i=1}^{N} (L_B(\varepsilon_i, \varepsilon_j, \ldots) \times N_B + L_S(\varepsilon_i, \varepsilon_j, \ldots) \times \sigma_L \times \mathbf{L})$$



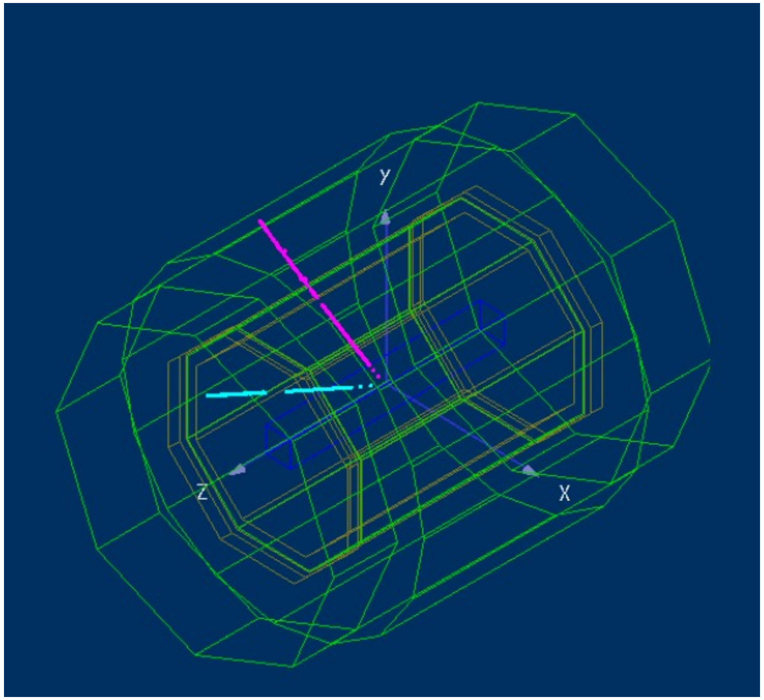

**Even at the not optimal polarization point (-0.8,0) the sensitivity to the signal is very good.**

**The BR x (cross section) can be measured as:**

**2.85+-0.2 at 68% CL**
**2.85+-0.3 at 95 % CL**

**This result can be achieved if the Standard Model is identified and only the SUSY background is dominant.**

# Next steps




The extended likelihood approach seems to be a promising technique in order to enhance the sensitivity of ILC to the small signals

**Next steps:**

- **Inclusion of the full S.M. Background and optimization of the cuts in order to reduce WW and ZZ contributions**

- **Full detector simulation (MOKKA) and event reconstruction**

- **This channel is now integrated in the mass production and it is currently beeing simulated**