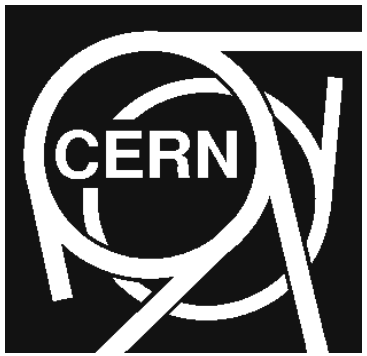
Search for Scalar Leptons at LEP



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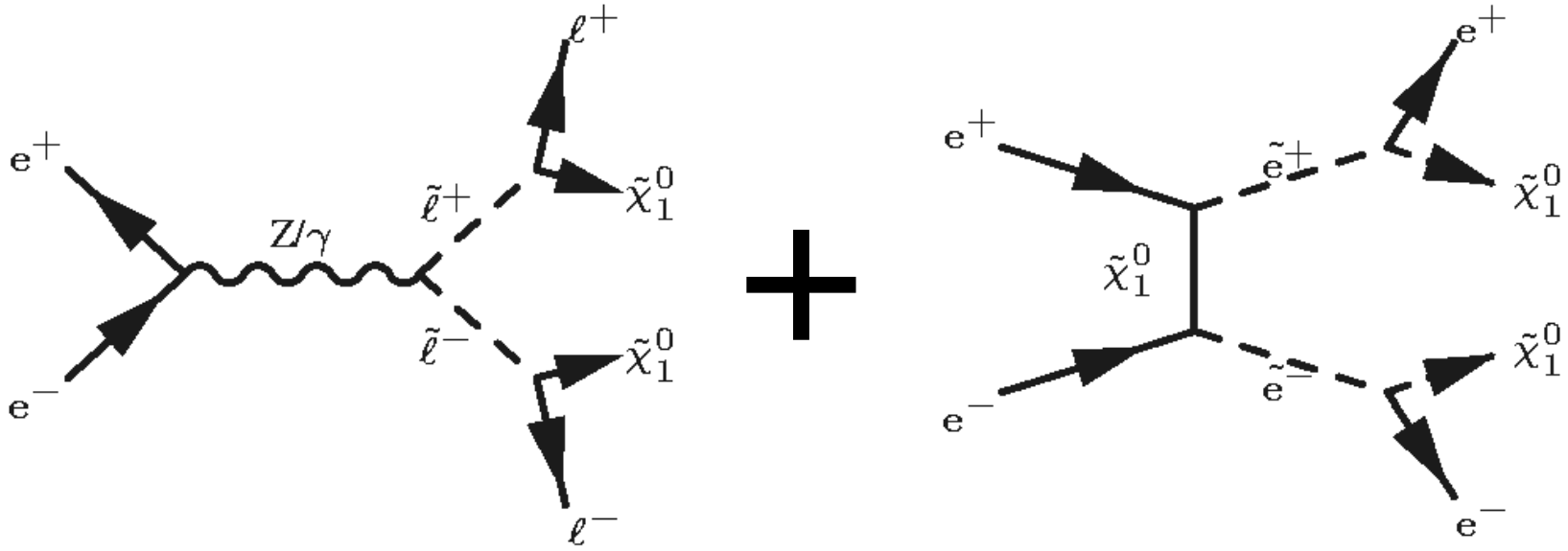
June 27th 2000
SUSY2k - CERN

S-leptons at LEP: quick introduction



- S-leptons$_R$ are expected to be the lightest scalars (if common m_0)
- S-taus might be the lightest in absolute through L-R state mixing (sizeable only for third generation $\propto \mathbf{m}_\tau$)

- Typical cross sections: $\sigma_{\tilde{\mu},\tilde{\tau}} \approx \mathbf{0.1pb}$ $\sigma_{\tilde{e}} \approx \mathbf{0.5\,pb}$
- Typical decay branching fractions: $\boldsymbol{Br}(\tilde{\ell} \to \tilde{\chi}_1^0 \ell) \approx \mathbf{100\%}$

Data Sample (1997-1999)

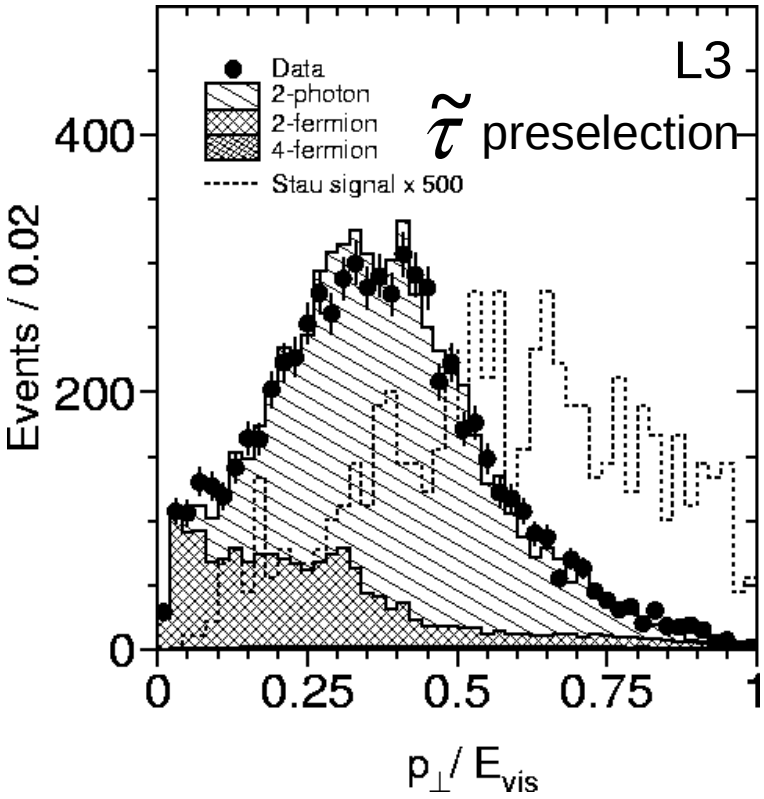
Most of the results do not include 183 GeV sample.
All results are preliminary.

Integrated Luminosities (pb^{-1}).

$\sqrt{s}$ (GeV)	Aleph	Delphi	L3	Opal
183	57.0	52.6	55.2	57.3
189	173.6	155.1	176.4	181.0
192	28.9	25.9	29.2	29.3
196	79.8	76.8	81.5	76.4
200	86.2	82.4	80.6	75.7
202	42.0	40.9	37.0	37.0
Total	467.5	433.7	459.9	456.7

How do experiments search for s-leptons?

- Two acoplanar leptons ⟹ missing energy and transverse momentum
- Elsewhere clean detector
- Electron and muon ID, hadronic tau decays as low multiplicity jets



Background:

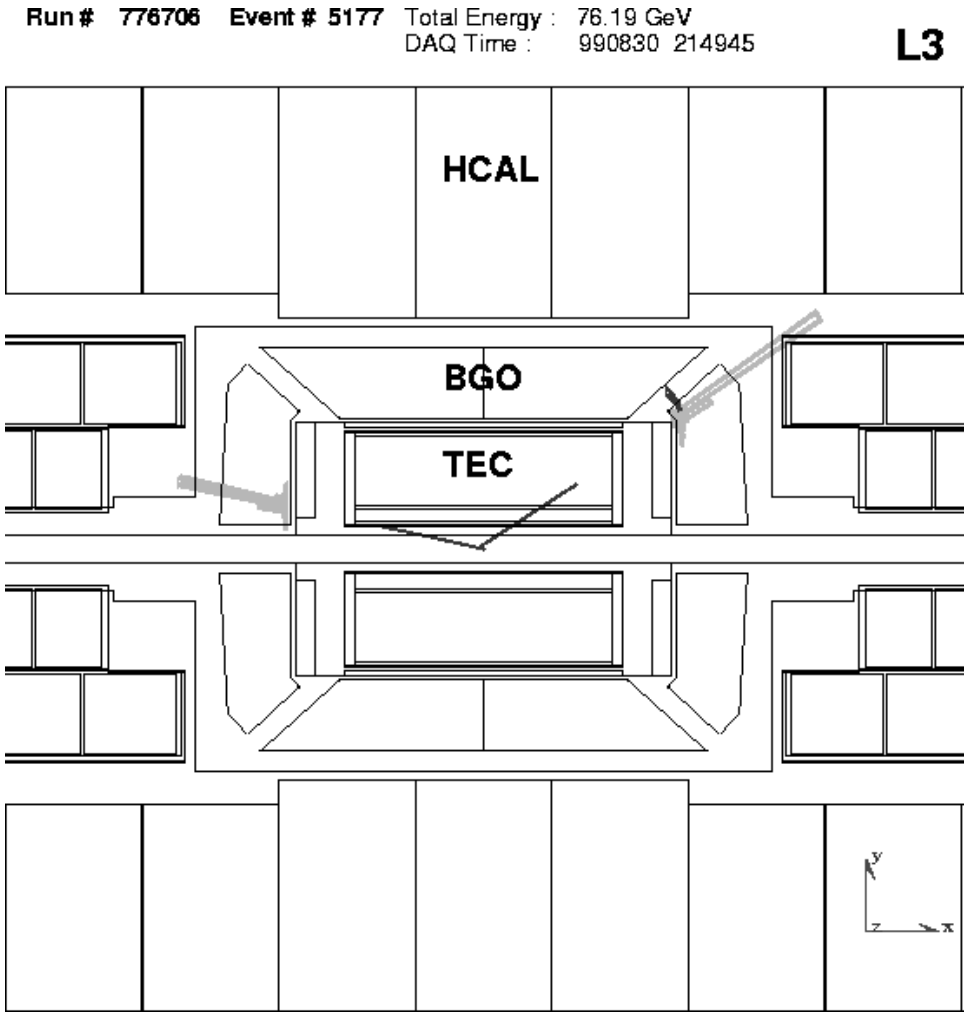
(large) $W^+ W^-$ and other 4f

$\Delta M = M_{\tilde{\ell}} - M_{\tilde{\chi}_1^0}$

(small) 2f (γ)

(large) $\gamma\gamma \to \ell^+\ell^-$

S-electrons



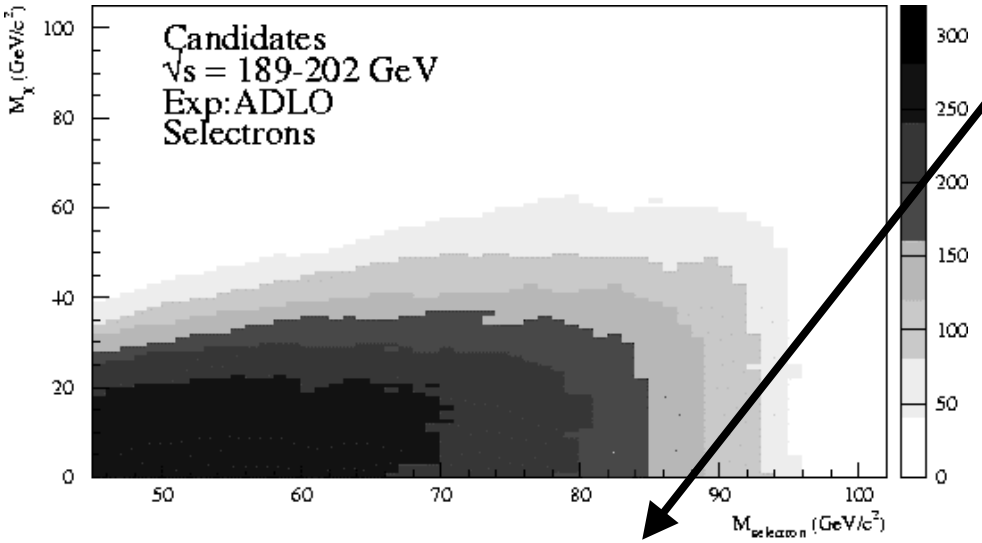
Selections are optimized for every point in the $M_{\tilde{\ell}} - M_{\tilde{\chi}_1^0}$ plane (1 GeV step).

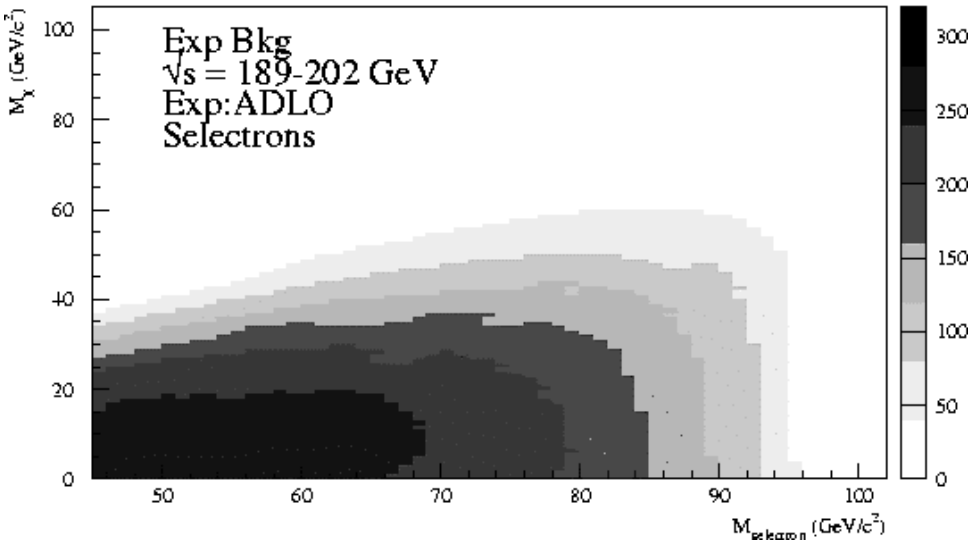
Example: selected candidates at 189-202 GeV for

$M_{\tilde{e}} = 90\ \text{GeV}, M_{\tilde{\chi}_1^0} = 30\ \text{GeV}$

	Data	Bg MC	P_b
Aleph	41	35.1	18.0%
Delphi	52	52.3	53.5%
L3	18	18.3	55.9%
Opal	22	27.7	88.4%

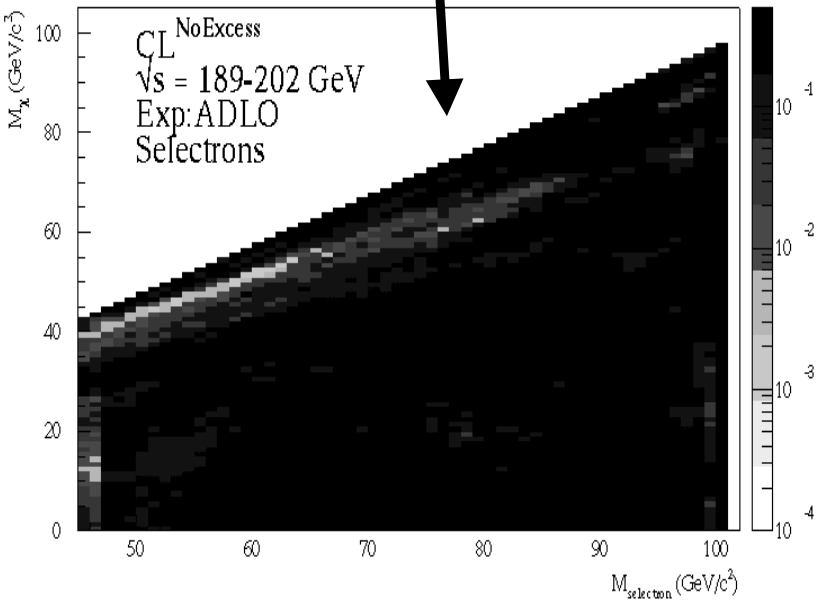
ADLO: 189-202 GeV results



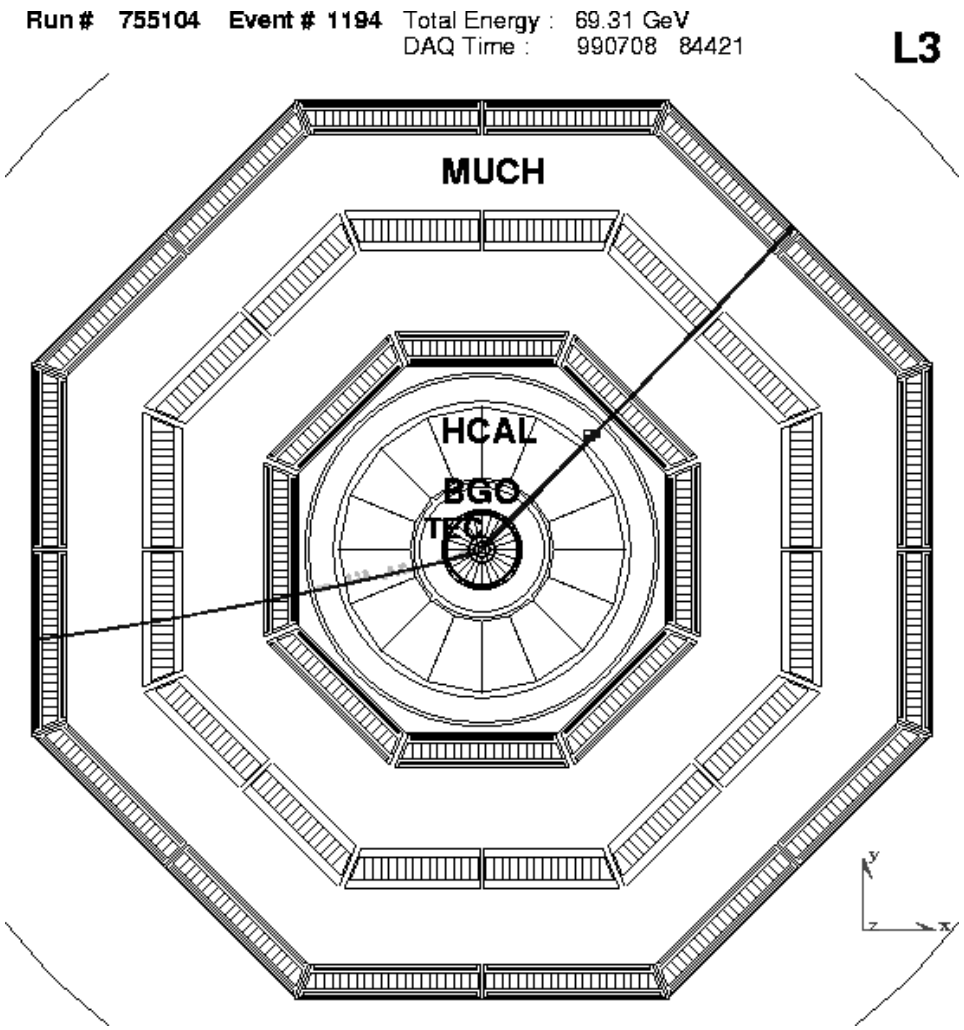


Data/Bg MC: perfect agreement.

The <u>probability</u> for the <u>data to come from Bg only</u> is calculated for all the mass points.



S-muons



Again results are mass dependent.

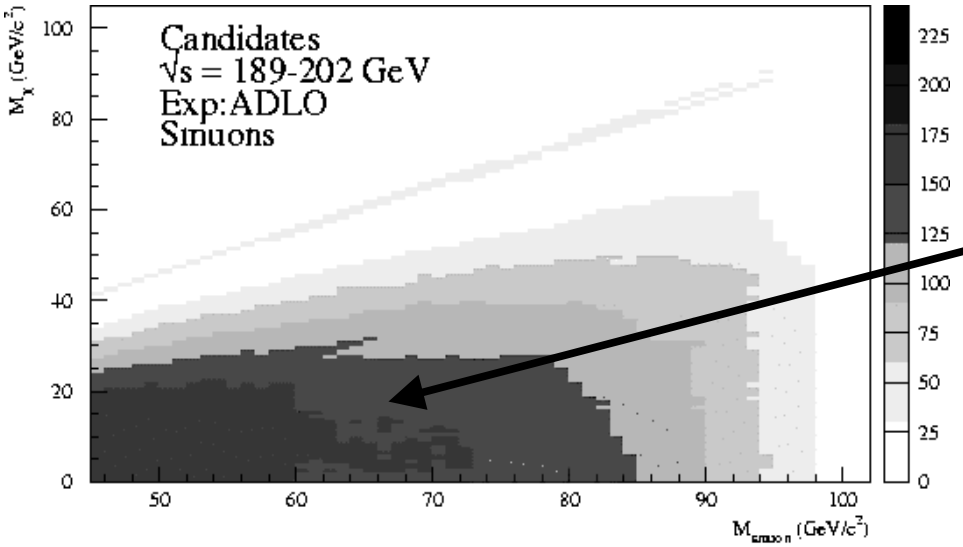
Optimization in steps of 1 GeV in the $M_{\tilde{\ell}} - M_{\tilde{\chi}_1^0}$ plane.

Example: selected candidates at 189-202 GeV for

$$M_{\tilde{\mu}} = 90\ \text{GeV},\ M_{\tilde{\chi}_1^0} = 30\ \text{GeV}$$

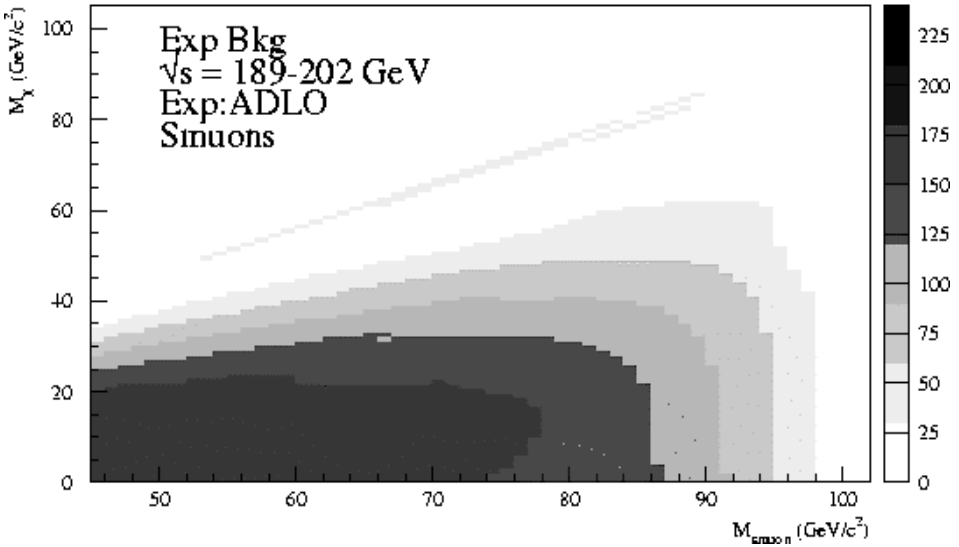
	Data	Bg MC	P_b
Aleph	25	22.4	31.9%
Delphi	12	19.0	96.5%
L3	39	39.2	53.4%
Opal	9	13.8	93.2%

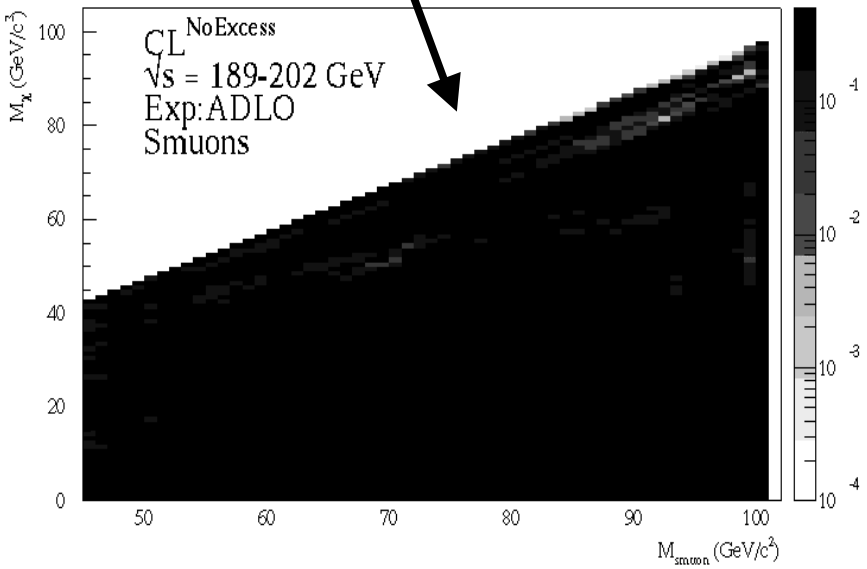
ADLO: S-muons



Data/Bg MC: slight deficit of data.

The probability for the data to come from Bg only shows no excess.

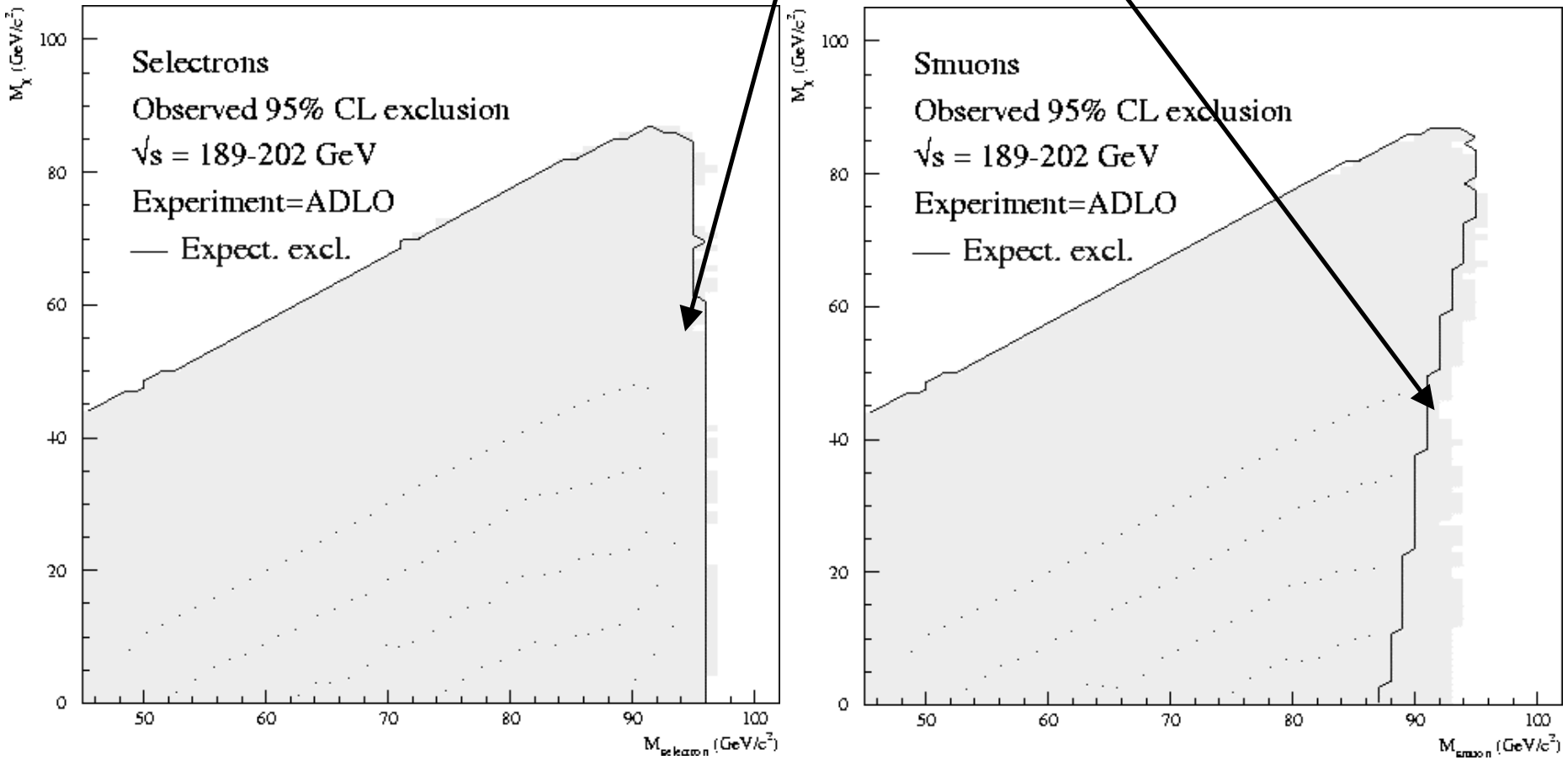




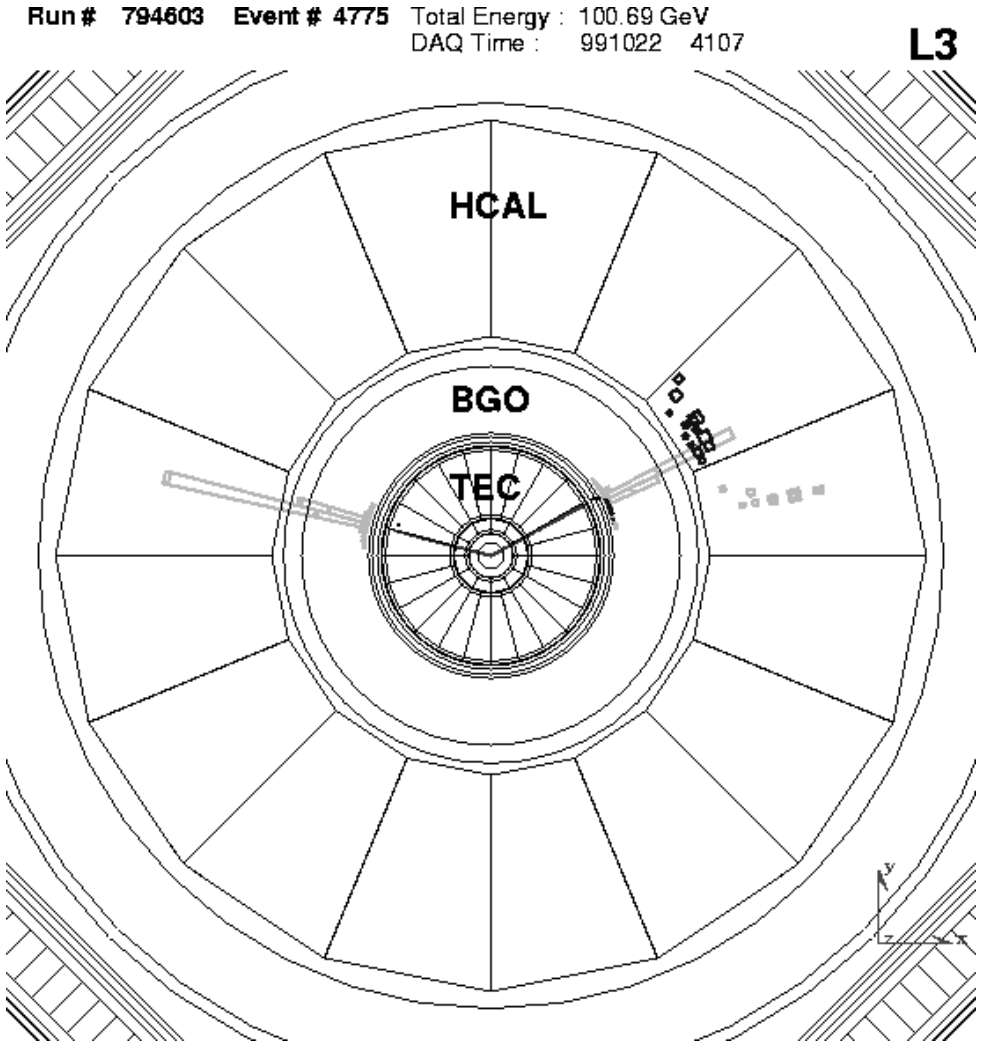
ADLO: mass limits in the MSSM

s-electrons excluded (95% C.L.) up to 95 GeV if $\Delta m > 10$ GeV

s-muons excluded (95% C.L.) up to 92 GeV if $\Delta m > 10$ GeV



What is different with s-taus ?



- Much more missing energy:

$$2\tilde{\chi}_1^0 + 2\nu_\tau \ (+\nu_{\mu,e})$$

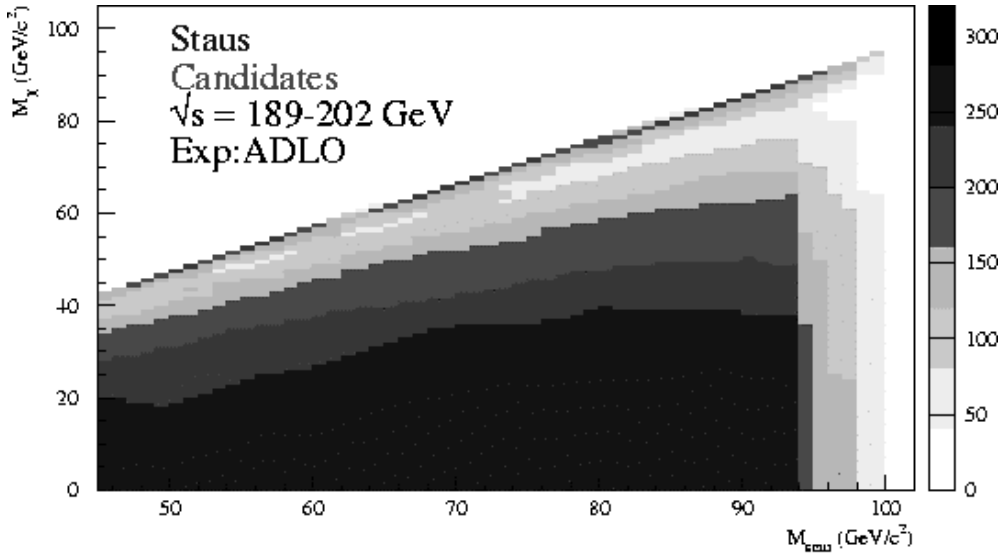
- Almost no trace of the $\tilde{\tau}$ mass is left

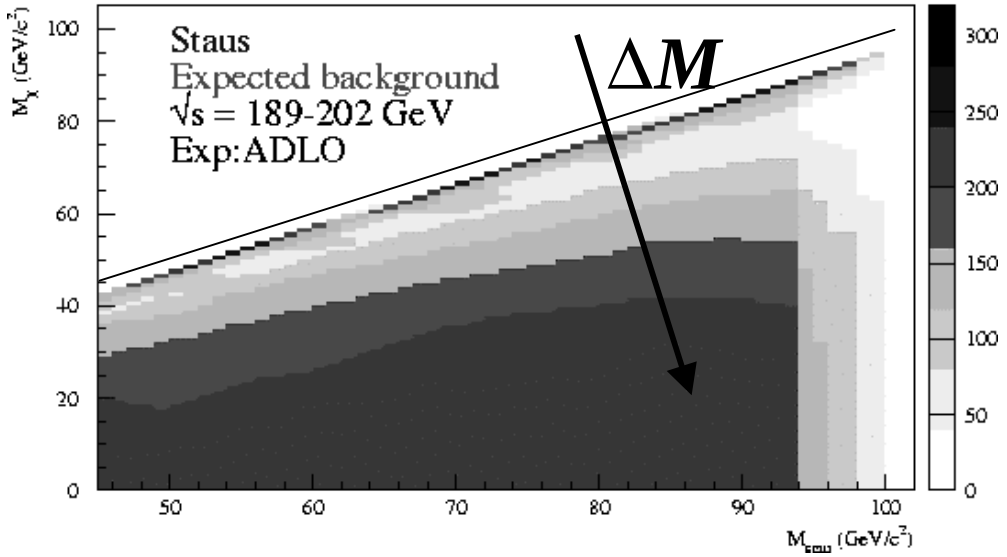
Example: selected candidates at 189-202 GeV for

$$M_{\tilde{\tau}} = 85\ \text{GeV},\ M_{\tilde{\chi}_1^0} = 22\ \text{GeV}$$

	Data	Bg MC	P_b
Aleph	50	38.0	3.5%
Delphi	82	71.4	11.8%
L3	70	55.3	3.2%
Opal	66	57.7	15.2%

ADLO: $\tilde{\tau}$ is that true ?

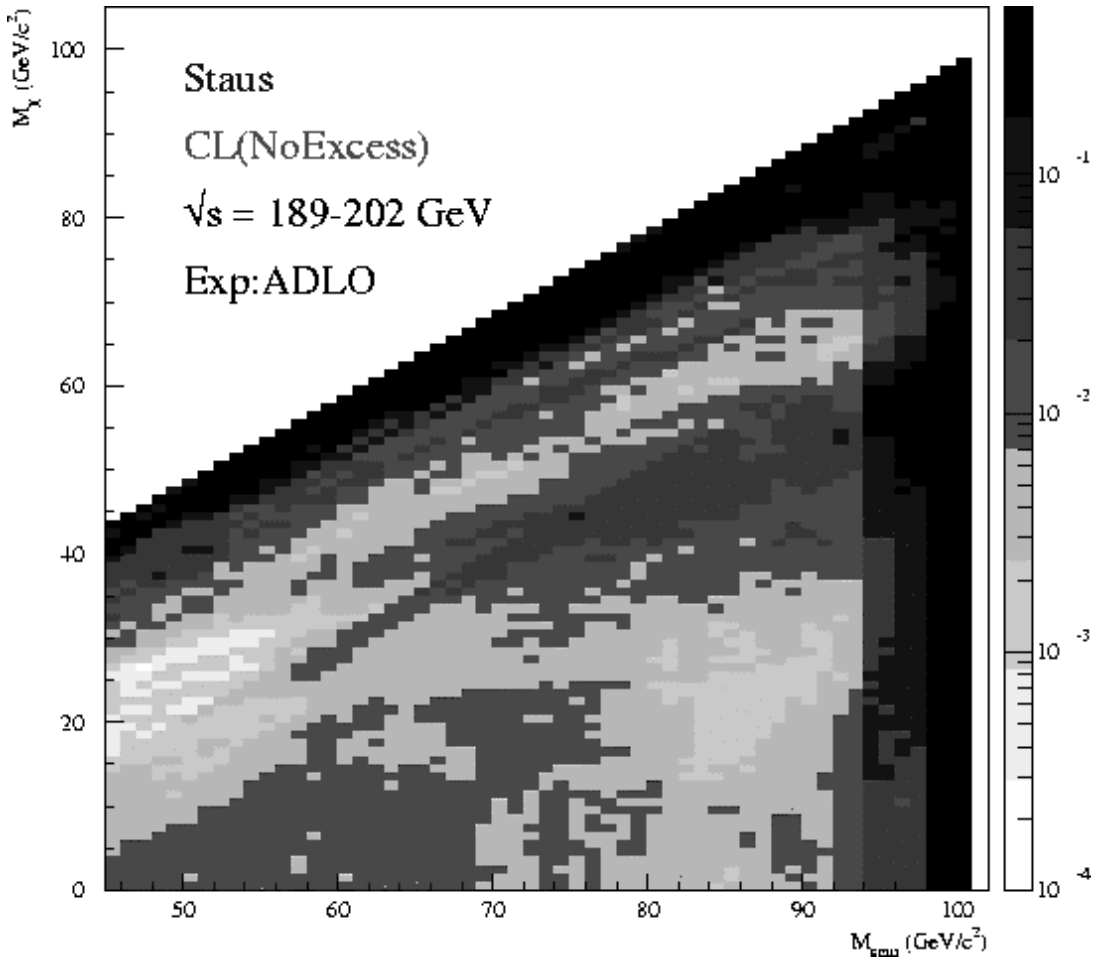




- For the first time in the SUSYwg an excess of data is observed coherently by the 4 LEP experiments
- A lot of work to understand:
  the systematics,
  the significance of the excess,
  the consistency with the $\tilde{\tau}$ hypothesis (very preliminary)
- No excess is observed for $\Delta M < 10$ GeV. The excess is in the large ΔM region (WW Bg):

~45 events (~3σ)

Data vs Bg: so inconsistent ?



- For every mass point in the plane the probability is calculated.
- The events selected in the different mass point are largely correlated.

$$M_{\tilde{\tau}} = 85\ \text{GeV},\ M_{\tilde{\chi}_1^0} = 22\ \text{GeV}$$

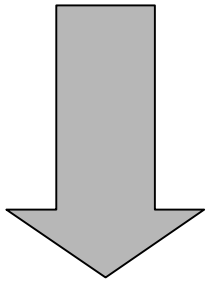
$\sqrt{s}$	Data	Bg MC	P_b
189	113	96.7	5.7%
192	26	17.2	2.9%
196	62	43.9	0.6%
200	50	42.5	14.3%
202	17	22.0	88.2%

Do we understand …….?

- The backgrounds:
  Use new RacoonWW / YFSWW
  Theoretical error on σ_{WW} <1%
  Large uncertainty on $\gamma\gamma$ processes but very small contribution

Process	Fraction
4 fermion (mainly WW)	80%
$\gamma\gamma$ leptonic	12%
$\gamma\gamma$ hadronic	2%
$\tau\tau(\gamma)$	5%
Other	1%

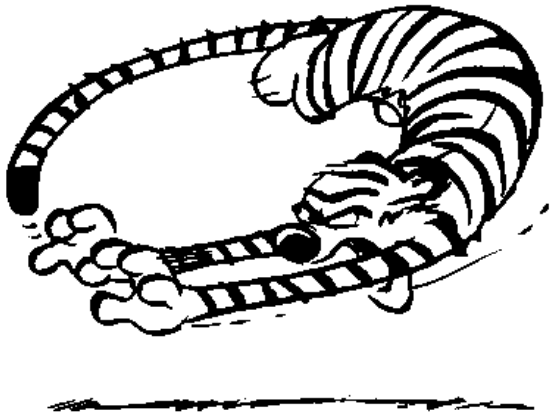
- The systematics:
  MC statistics $1.4\% - 3.9\%$
  Detector systematics (4f and 2f processes) $2\% - 3\%$
  Detector systematics ($\gamma\gamma$ processes) $10\% - 50\%$



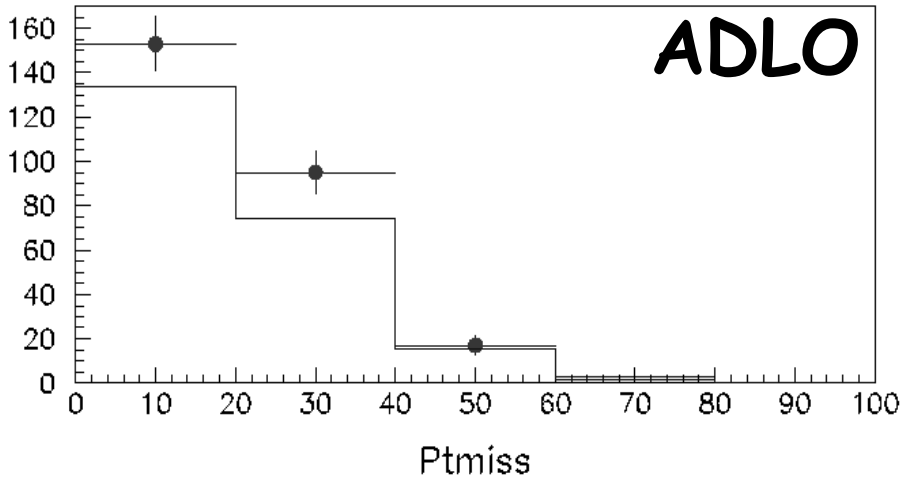
Total systematics < 4%

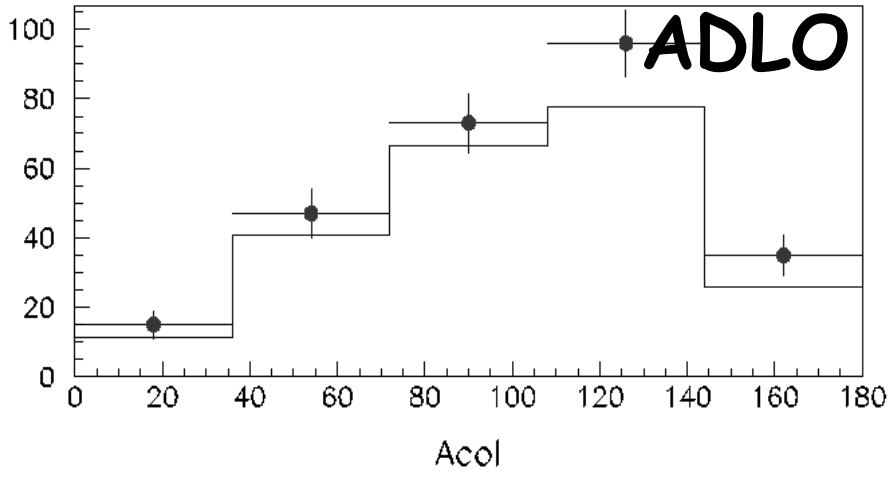
It can not explain such an excess (20%)

Hunting for tails

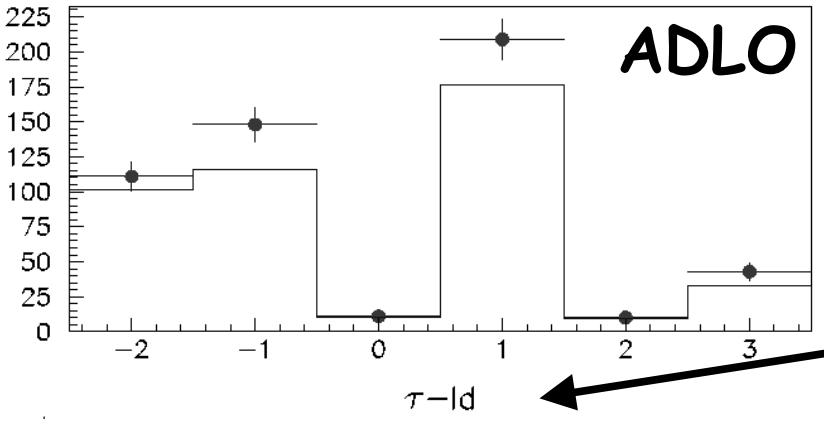


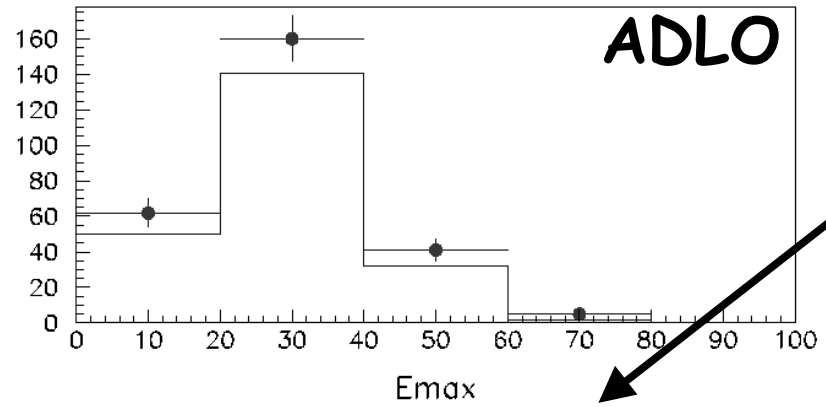
- ADLO provided the full set of selected data and Bg MC events.
- Check the most important distributions of the τ decay products.
- These distributions do not show any pathological behavior.
- The Kolmogorov test shows that the shape of distributions is in agreement with Bg MC. → Need signal MC samples from the 4 experiments.

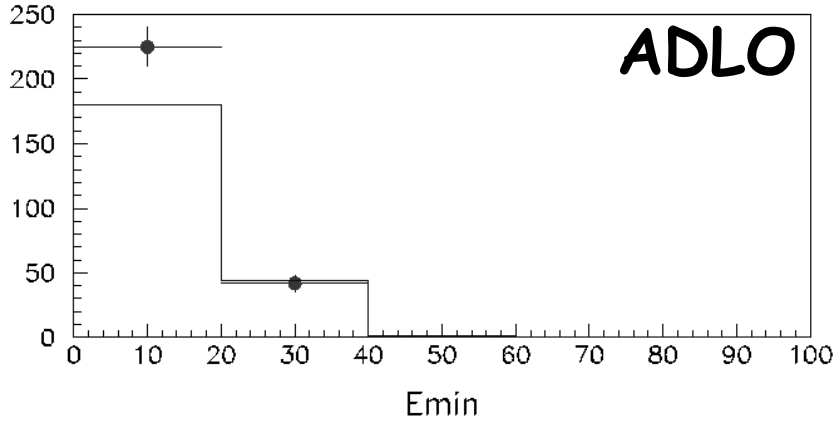




Hunting for tails: 2



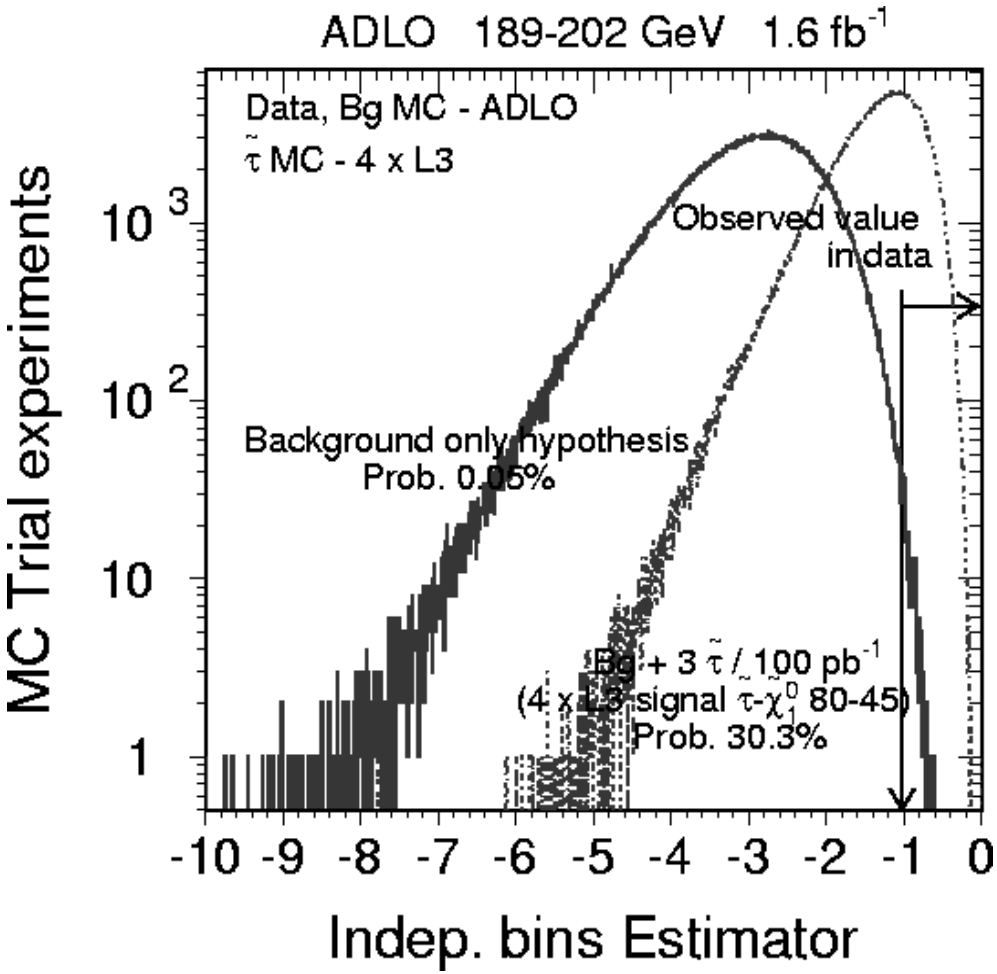




- τ decay products as expected (–2=muons; –1=electrons; 0–3 prongs in hadronic decays).
- Energy spectra for the τ decays also as expected.
- Signal distributions are very similar to the data and background ones (as expected in the final selected sample).
  No quantitative estimate of the Data/Signal consistency yet.

Is it so unlikely to observe such an excess?

- We observe an excess in the $\tilde{\tau} - \tilde{\chi}_1^0$ mass plane where the outcome of 56x101 selections is reported.
- The Data/MC yield from these selections is highly correlated.
- A statistical estimator which takes into account the yield of all the bins can not be built unless the huge correlation matrix is included.
- Try different estimators like:
  1) $\log(\prod_{i,j,k} \max(CL_{i,j,k}))$
  $i = mass, j = \exp., k = \sqrt{s}$
- Run MC experiments with Bg only and with Bg+signal (**this is only an exercise with 4xL3**) and estimate the Probability for the observed figure.

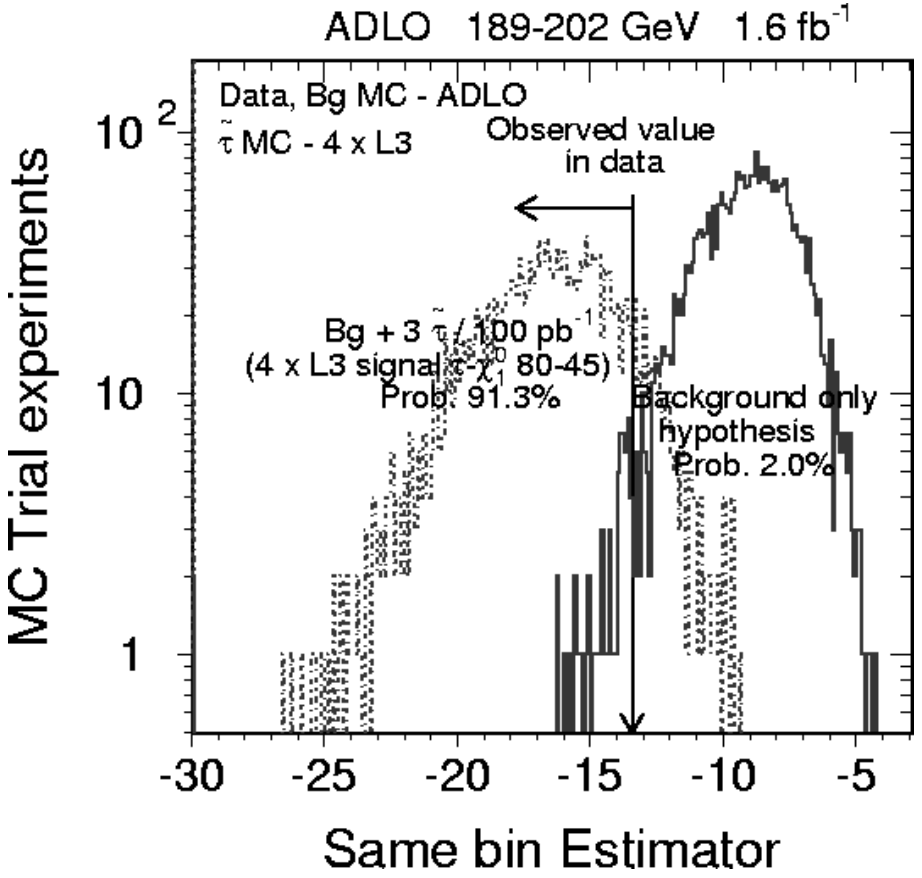


A better estimator

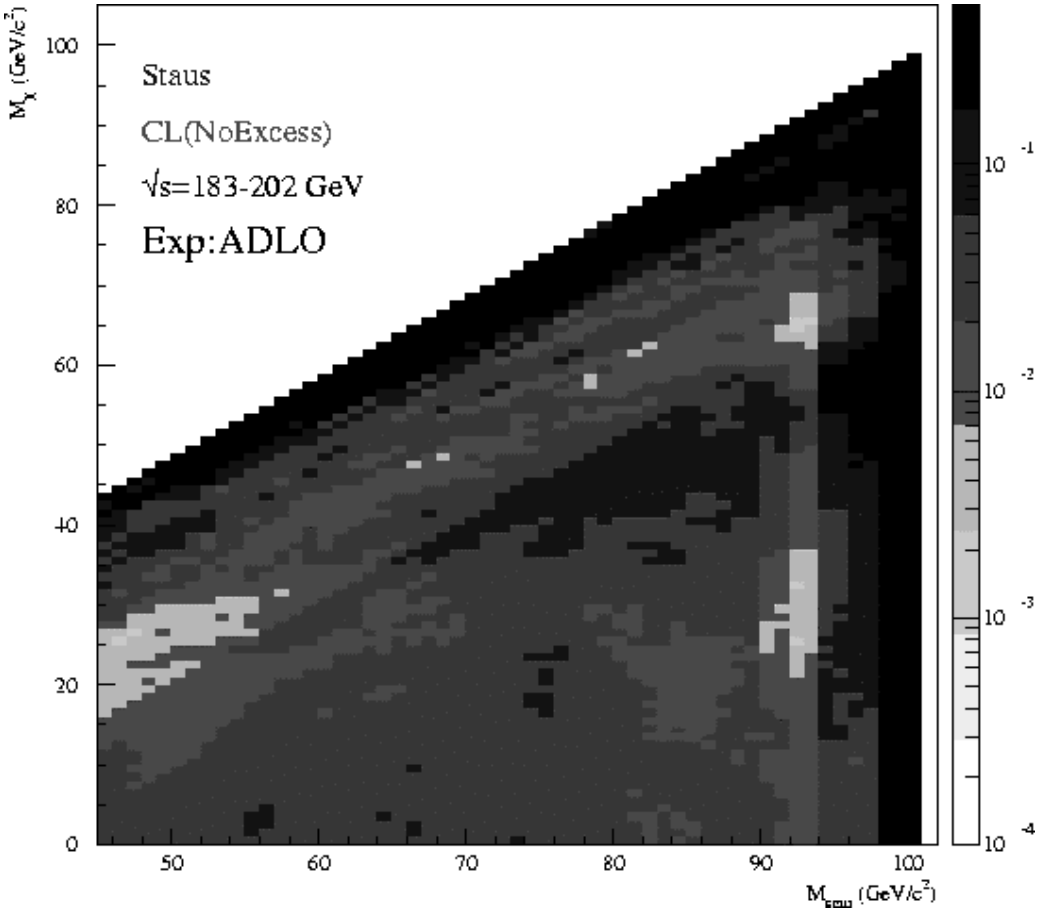
- Try also 2): $\log(\max(\prod_{i,j,k} CL_{i,j,k}))$

$$i = mass,\ j = \exp.,\ k = \sqrt{s}$$

- While Estimator 1) probes excesses appearing everywhere in the plane in an uncorrelated way among experiments and c.o.m. energies,
  Estimator 2) probes excesses which appear preferably in the same mass bin.
- Estimator 2) is much more sensitive to the presence of a signal as shown by the probabilities in the Bg+signal hypothesis.
- The probability to see a larger background fluctuation is 2.0%.



And in 183 GeV data ?



- Originally we abandoned 183 GeV data due to their reduced sensitivity to high $\tilde{\tau}$ masses (smaller $\sqrt{s}$ and luminosity).
- But if we deal with background statistical fluctuations why not including them.
- At 183 GeV there is a deficit of data ⟹ the significance of the excess is reduced. For example at:

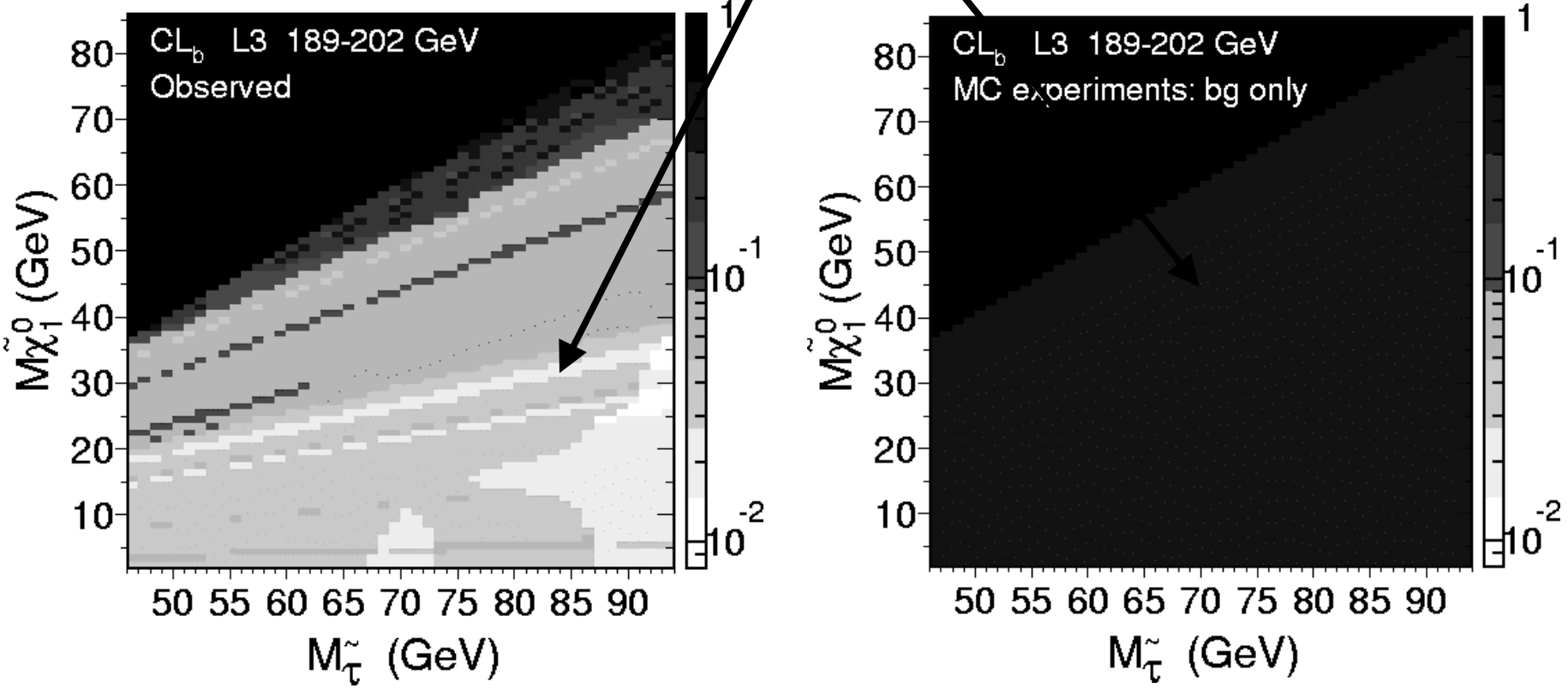
$$M_{\tilde{\tau}} = 85\ \text{GeV},\ M_{\tilde{\chi}_1^0} = 22\ \text{GeV}$$

from ~0.1% to ~1%.

- Warning: 189–202 GeV analyses thoroughly checked !! The same can not be said for 183 GeV analyses.

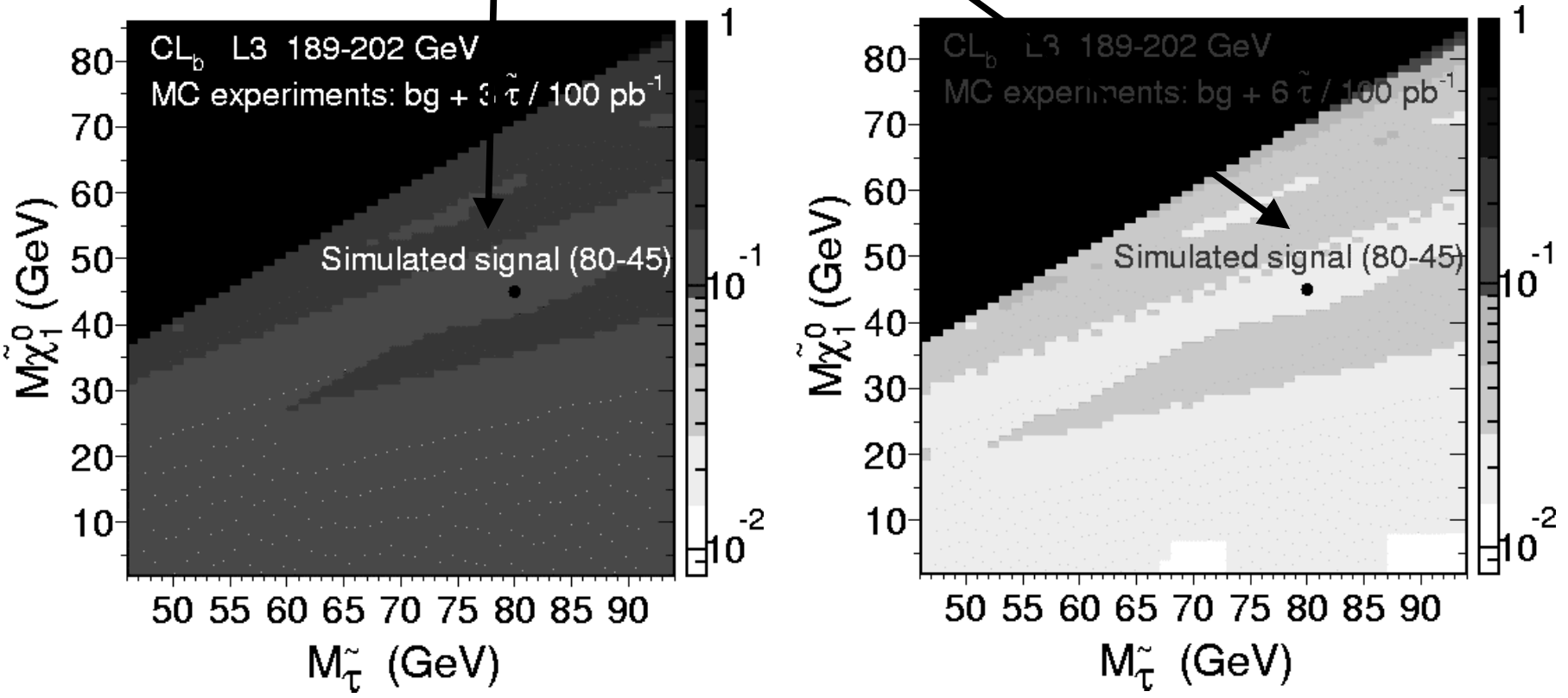
How a $\tilde{\tau}$ signal would look like ?

- Make the exercise using only L3 data and MC.
- Are we supposed to see such a structure in the $\tilde{\tau} - \tilde{\chi}_1^0$ mass plane if a signal of given mass is present ?
- Perform MC experiments with background only and also with signal.



$\tilde{\tau}$ signal simulation

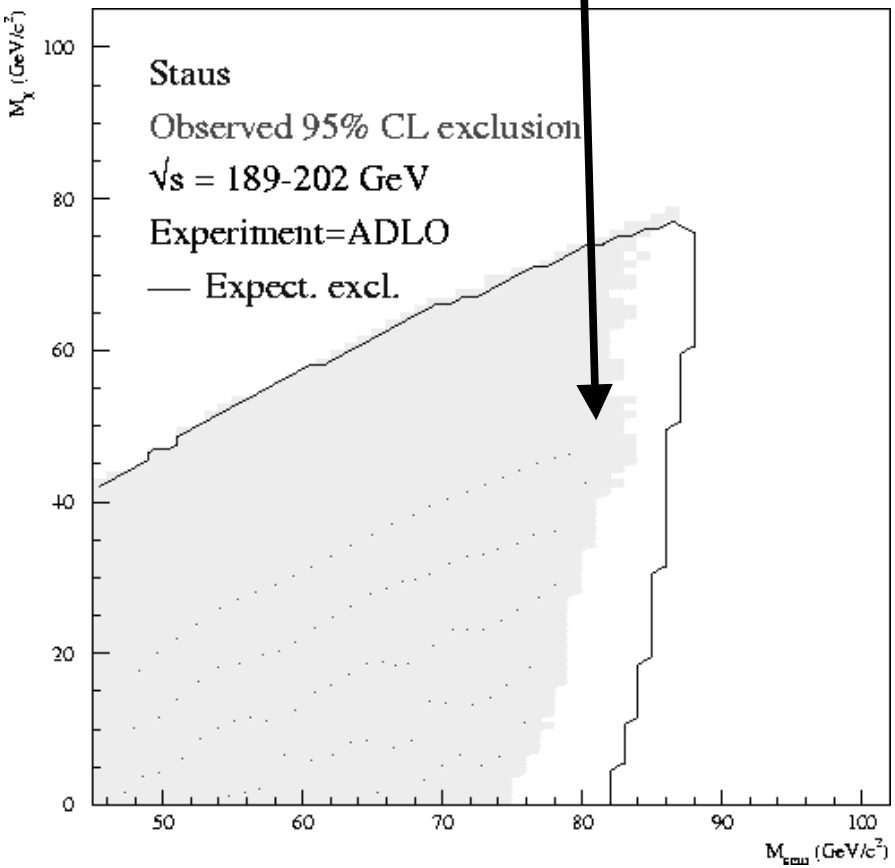
- Inject on average 12 or 24 $\tilde{\tau}$ events in the L3 sample.
- Similar structures to the one observed in data appear.
- As expected the large number of undetected particles washes out the mass information.

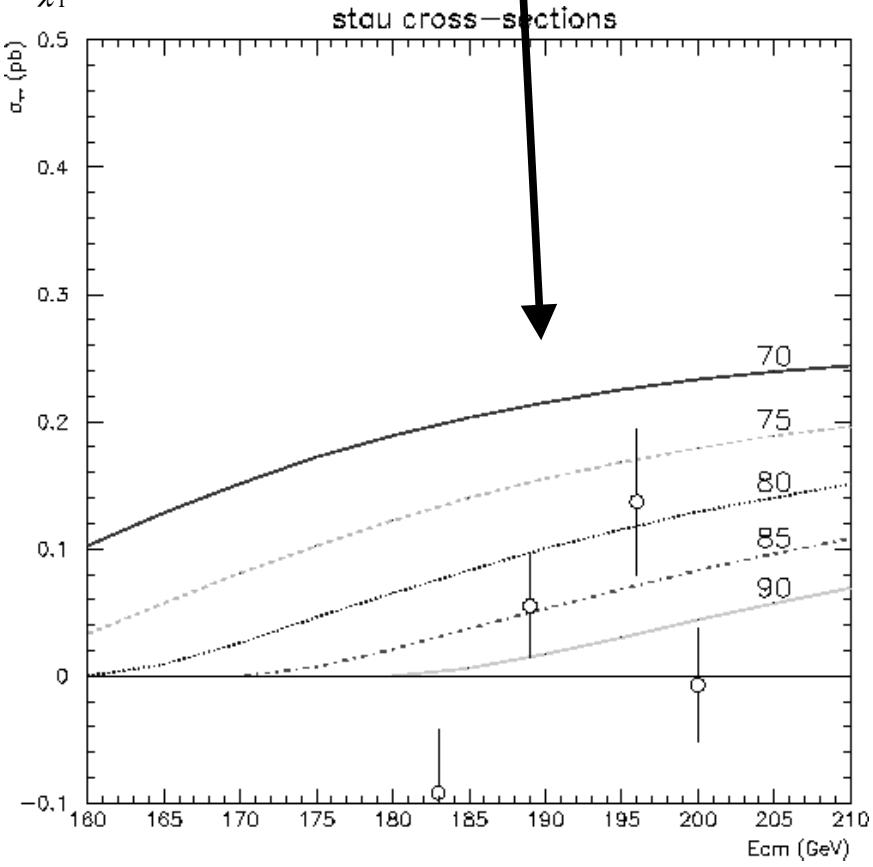


Interpretations in the MSSM

❶ It is just a statistical fluctuation of the background ⇒ derive exclusions and mass limits.

❷ This is a signal ⇒ measure the production cross section for instance assuming $M_{\tilde{\tau}} = 85\,\text{GeV}, M_{\tilde{\chi}_1^0} = 22\,\text{GeV}$ (stat errors only).





Conclusions

S-electrons and s-muons: no signals.

ADLO mass limits at 95 GeV and 92 GeV respectively.

At the end of 2000 they will reach ~ 100 GeV.

S-taus: ADLO see a ~3σ excess in the large ΔM region.

❶ Statistical fluctuation of the background ? $\Rightarrow$
2000 data may give a positive answer to this question.

❷ S-tau signal ? $\Rightarrow$ if it's there we'll chase it !!

Unfortunately the additional luminosity **will not** be enough for a definitive answer. From 1.6 fb^{-1} to ~2.3 fb^{-1}. Max significance ~4σ.