Preliminary Results from the 161 GeV Run

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on behalf of the L3 collaboration

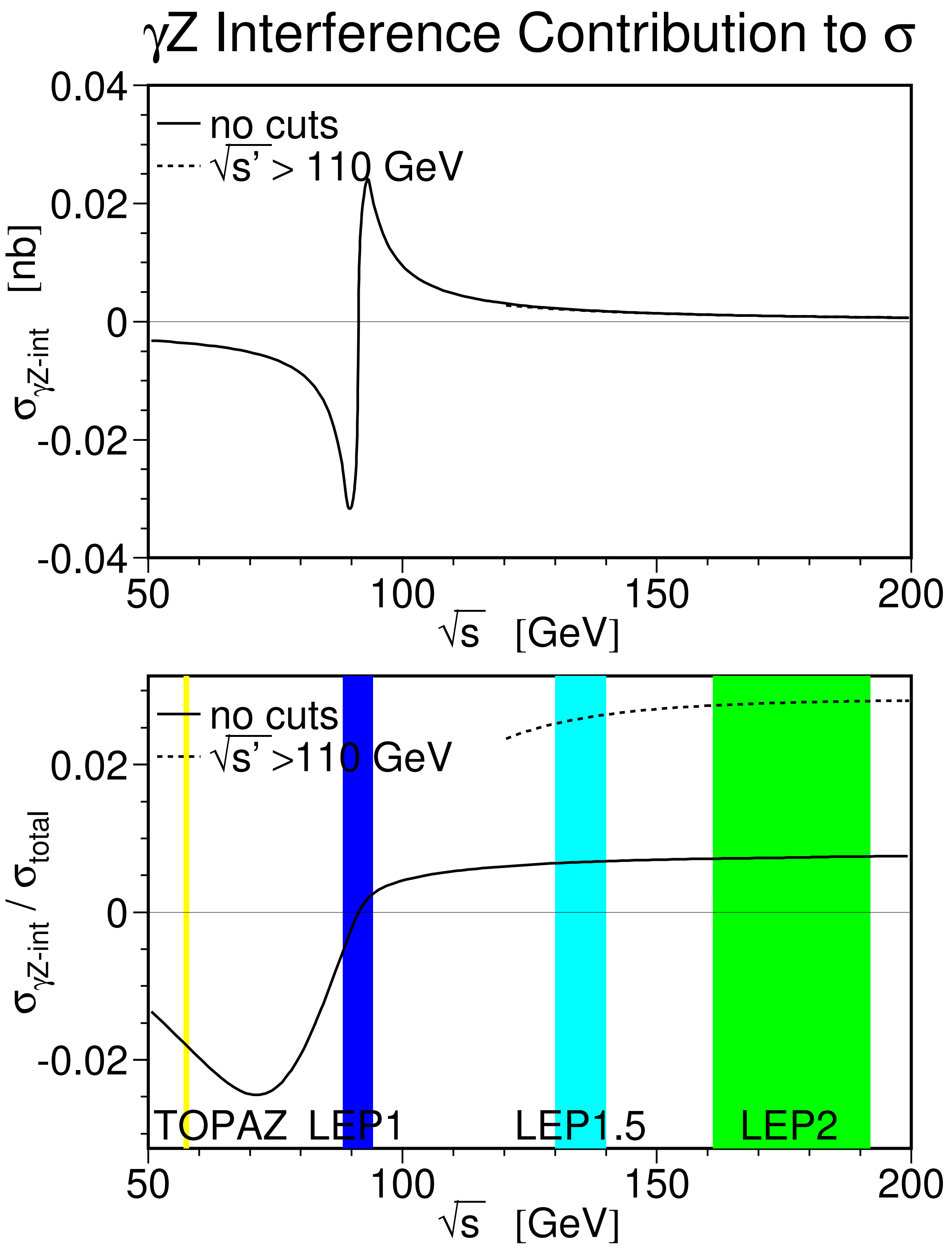
October 8, 1996

Outline

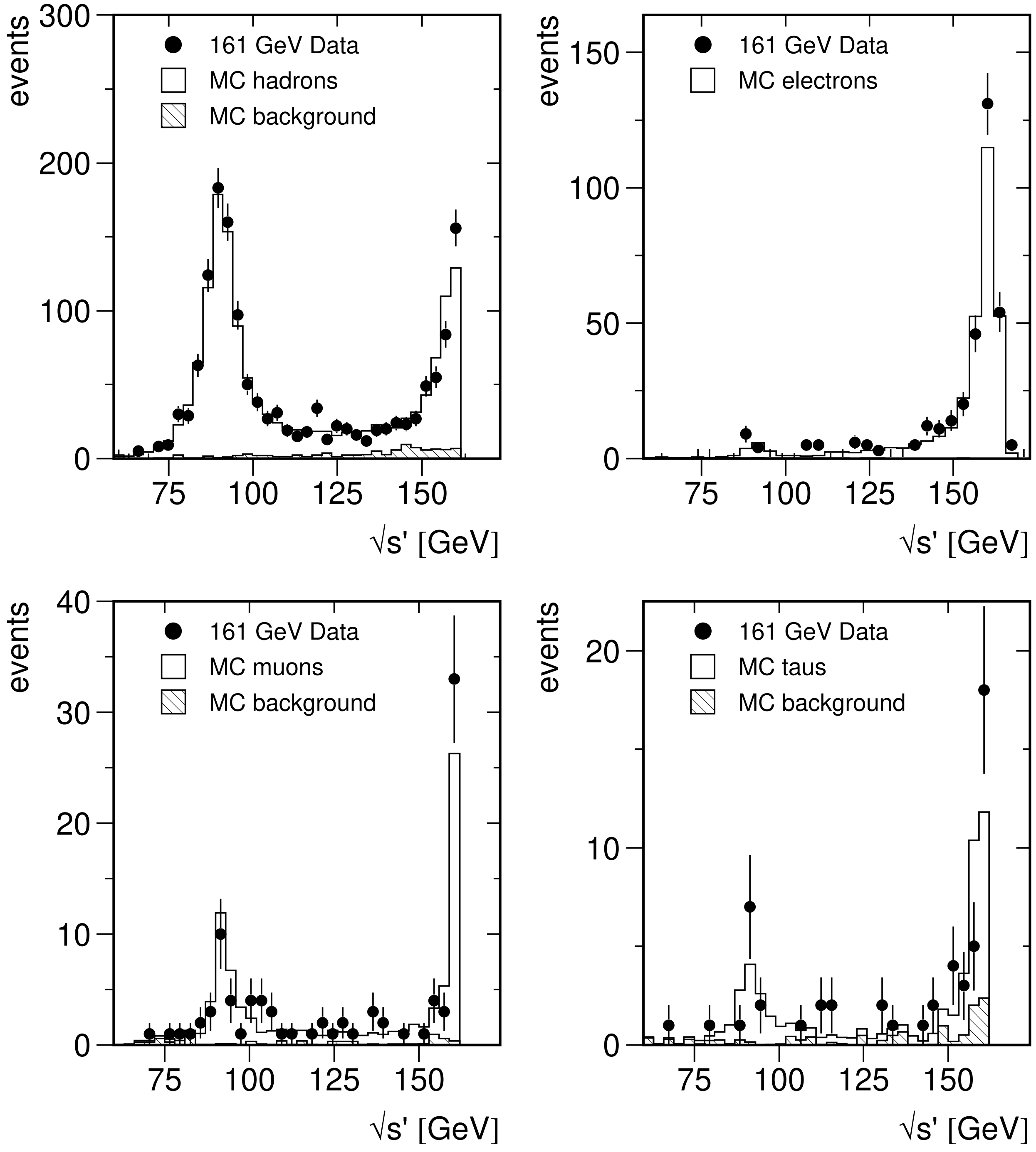
- **Fermion pair production** $e^+e^- \rightarrow f\bar{f}$
- **Four fermion production via** $e^+e^- \rightarrow W^+W^-$
- **Other four fermion production,** $e^+e^- \rightarrow f\bar{f}f'\bar{f}'$
- **Search for new particles, mainly SUSY**

L3's performance in 161 GeV run:
Delivered luminosity: 12.3 pb^{-1}
Recorded luminosity: 11.1 pb^{-1}
Data taking efficiency: 90.2%

All results preliminary


γZ Interference Contribution to σ
0.04
0.02
0
-0.02
-0.04
[nb]
σγZ-int
no cuts
√s' > 110 GeV
50
100
150
200
√s [GeV]
0.02
0
-0.02
σγZ-int / σtotal
no cuts
√s' >110 GeV
TOPAZ
LEP1
LEP1.5
LEP2
50
100
150
200
√s [GeV]

Effective Center of Mass Energy



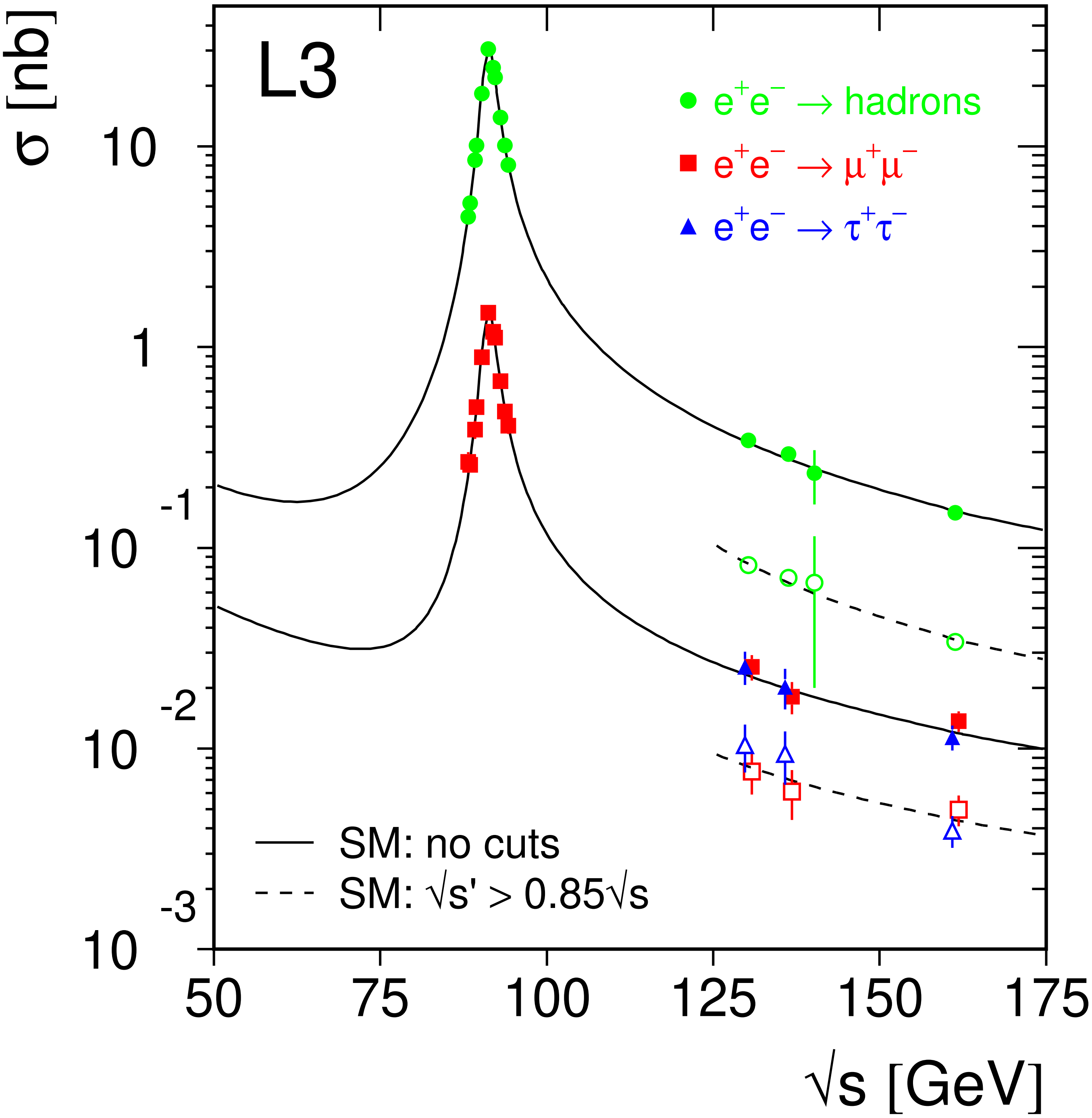
Fermion Pair Cross Sections at 161 GeV

Channel	$\mathcal{L}$ (pb^{-1})	Total		
		N_{ev}	σ (pb)	σ_{SM} (pb)
$q\bar{q}(\gamma)$	**10.7**	**1547**	**149 $\pm$ 4**	**152**
$\mu^+\mu^-(\gamma)$	**11.1**	**92**	**13.7 $\pm$ 1.6**	**12.0**
$\tau^+\tau^-(\gamma)$	**10.7**	**52**	**11.4 $\pm$ 1.6**	**12.0**
$\nu\bar{\nu}(\gamma)$	**11.1**	**58**	**70.6 $\pm$10.0**	**72.0**
$e^+e^-(\gamma)$	**10.6**	**364**	**35.6 $\pm$ 1.9**	**33.6**

For electron pairs: total cross section given inside
$44^\circ < \theta < 136^\circ$ **and** $\xi < 90^\circ$
For muon pairs: total cross section given for
$\sqrt{s'} > 2m_\tau$

Channel	$\mathcal{L}$ (pb^{-1})	$\sqrt{s'} > .85\sqrt{s}$		
		N_{ev}	σ (pb)	σ_{SM} (pb)
$q\bar{q}(\gamma)$	**10.7**	**447**	**34.0 $\pm$ 1.6**	**35.0**
$\mu^+\mu^-(\gamma)$	**11.1**	**45**	**5.0 $\pm$ 0.9**	**4.4**
$\tau^+\tau^-(\gamma)$	**10.7**	**32**	**3.9 $\pm$ 0.7**	**4.4**
$e^+e^-(\gamma)$	**10.6**	**297**	**30.3 $\pm$ 1.9**	**28.3**

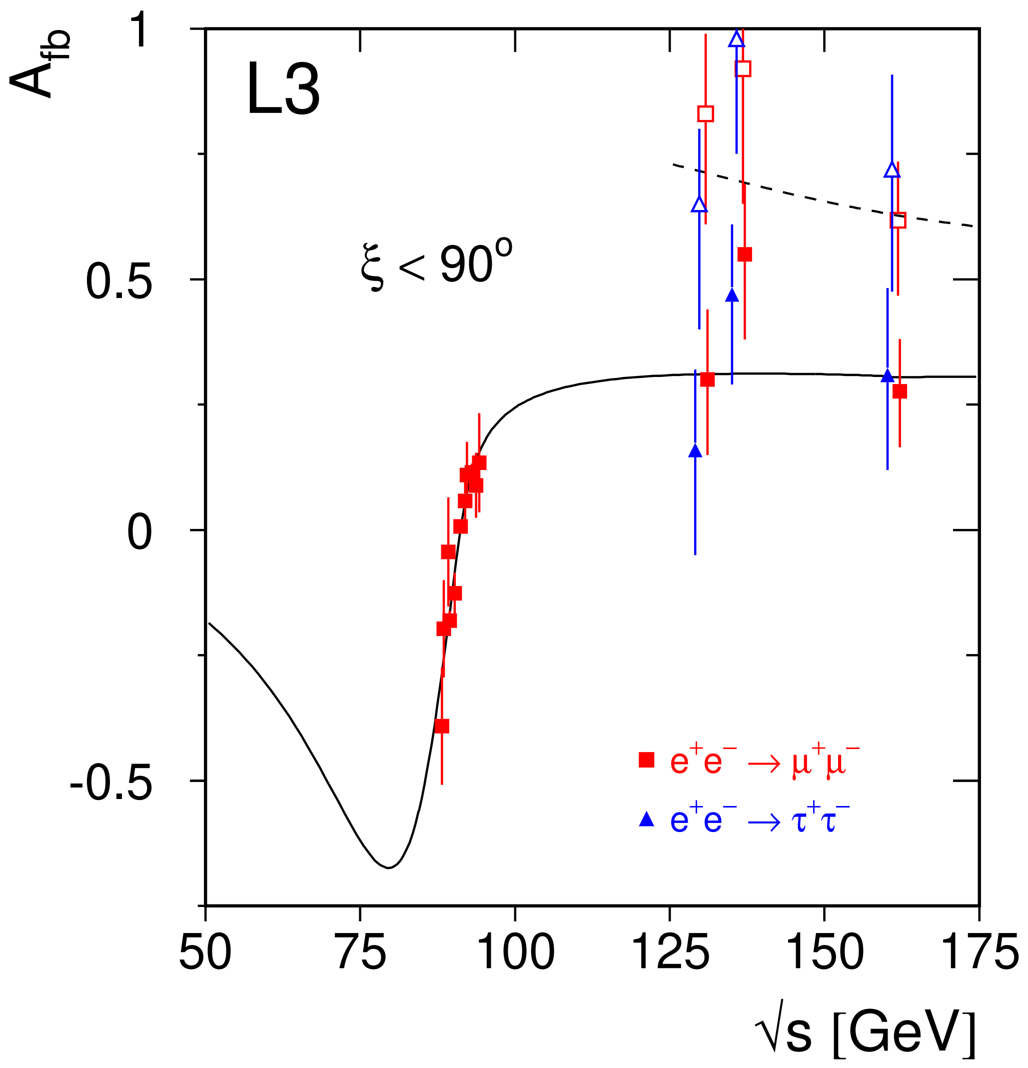
Fermion Pair Cross Sections



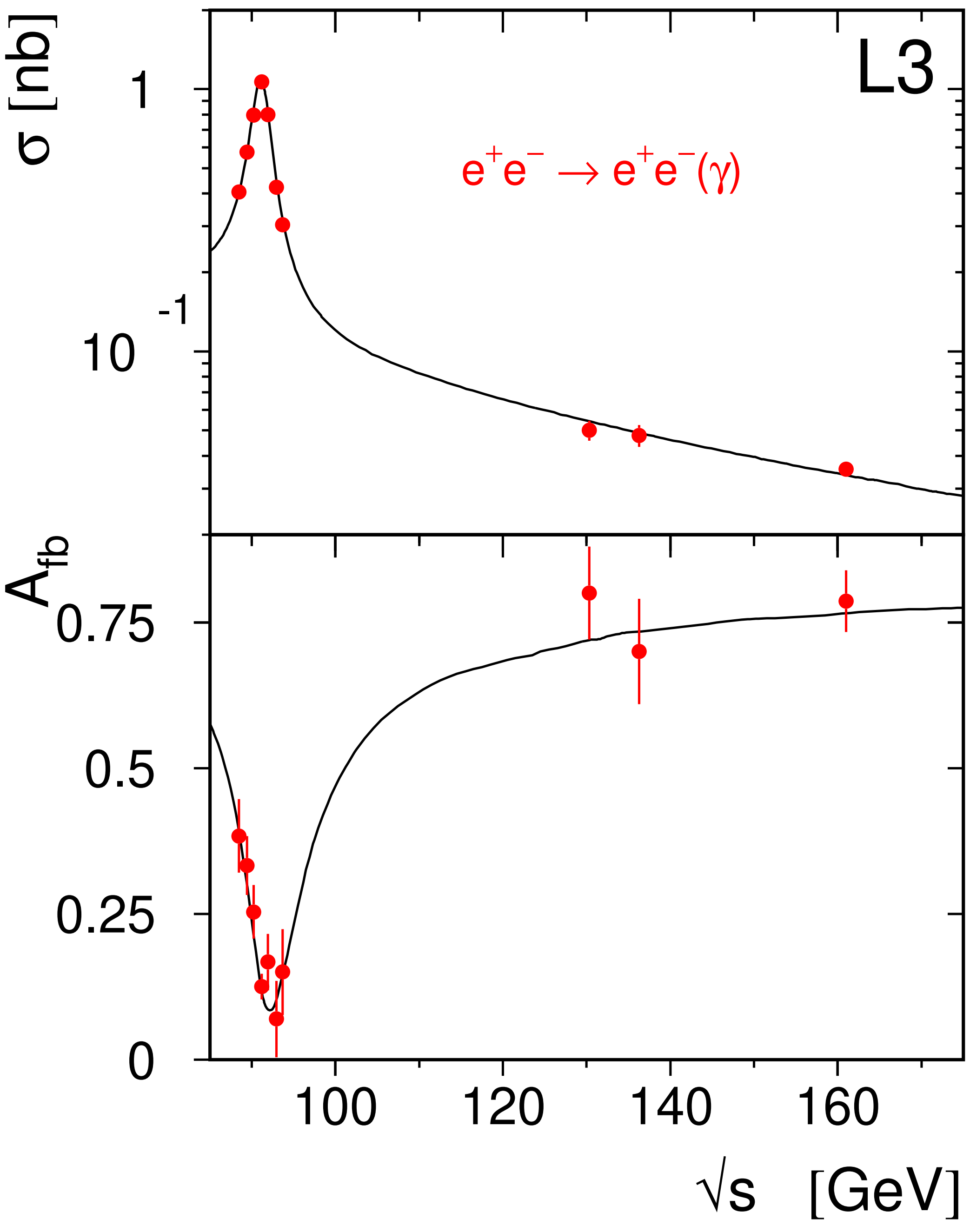
Fermion Pair Asymmetries at 161 GeV

Channel	Total A_{fb}	Total A_{fb}^{SM}	$\sqrt{s'} > 0.85\sqrt{s}$ A_{fb}	$\sqrt{s'} > 0.85\sqrt{s}$ A_{fb}^{SM}
$\mu^+\mu^-(\gamma)$	**0.28 $\pm$ 0.11**	**0.30**	**0.62 $\pm$ 0.14**	**0.63**
$\tau^+\tau^-(\gamma)$	**0.31 $\pm$ 0.18**	**0.30**	**0.72 $\pm$ 0.22**	**0.63**
$e^+e^-(\gamma)$	**0.79 $\pm$ 0.05**	**0.76**	**0.82 $\pm$ 0.05**	**0.81**

For electron pairs: asymmetries are given inside
$44^\circ < \theta < 136^\circ$ **and** $\xi < 90^\circ$



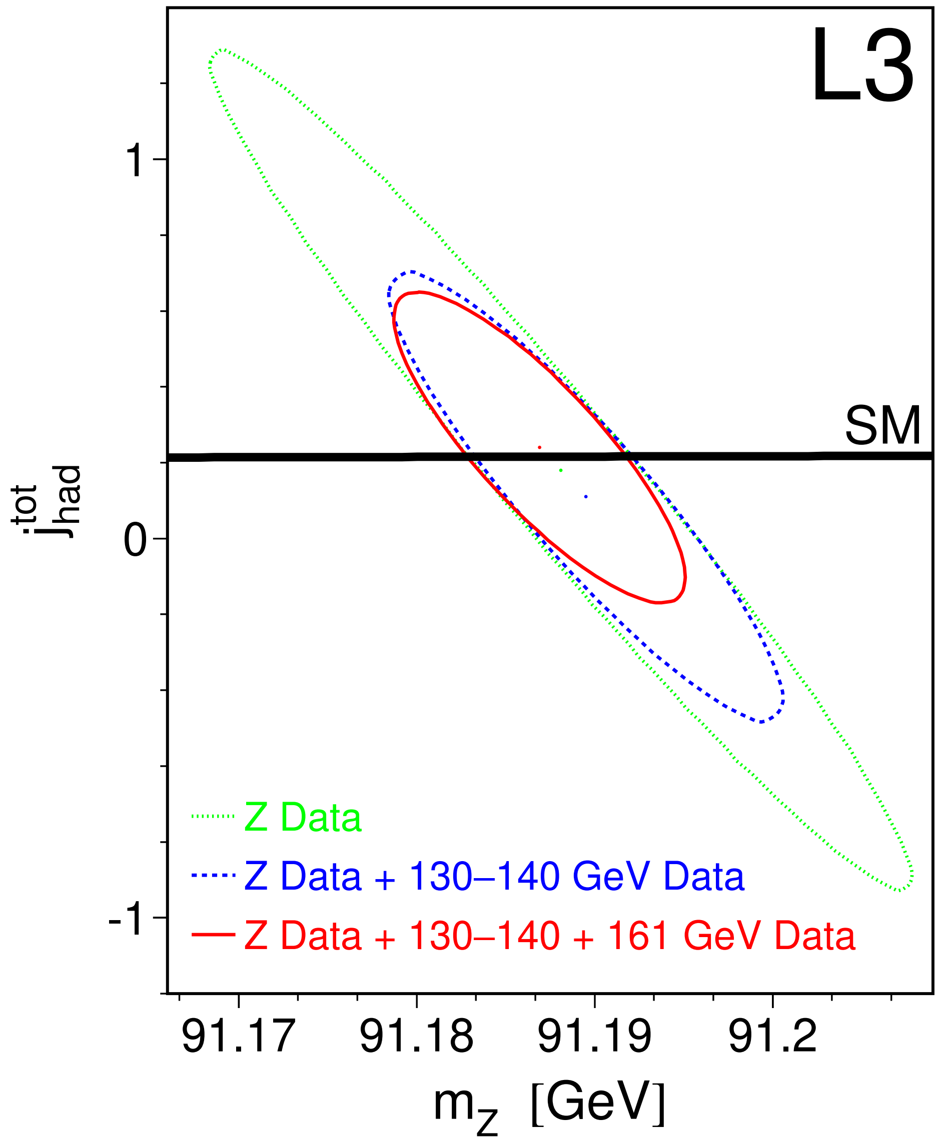
Electron Pair Production



Both leptons inside $44° < \theta < 136°, \xi < 90°$

No cut on $\sqrt{s'}$

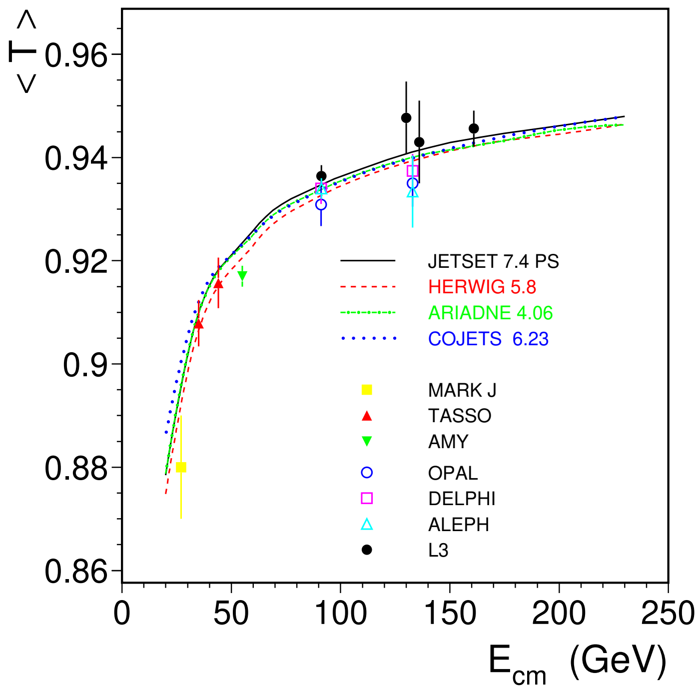
Hadronic Interference Term

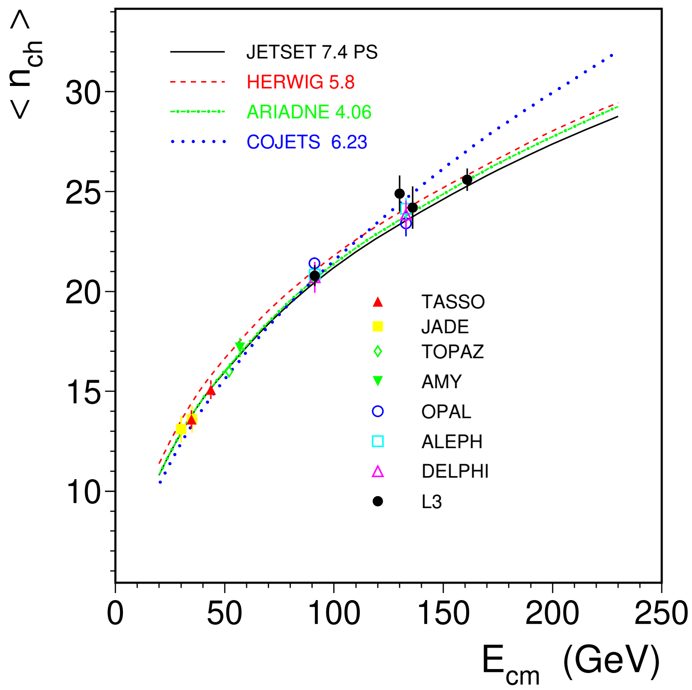


Data	j_{had}^{tot}	M_Z
LEP 1	0.18 ± 0.73	$91188. \pm 13.$
LEP 1 + 140	0.11 ± 0.39	91189.6 ± 7.3
LEP 1 + 140 + 160	0.24 ± 0.27	91187.0 ± 5.4

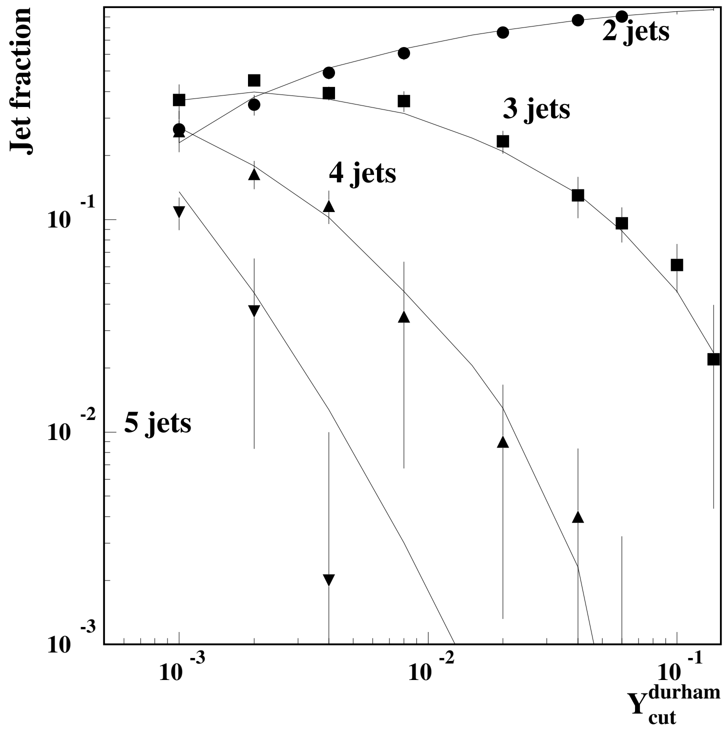
SM: **0.21**

Thrust, Multiplicity and Jet Rates



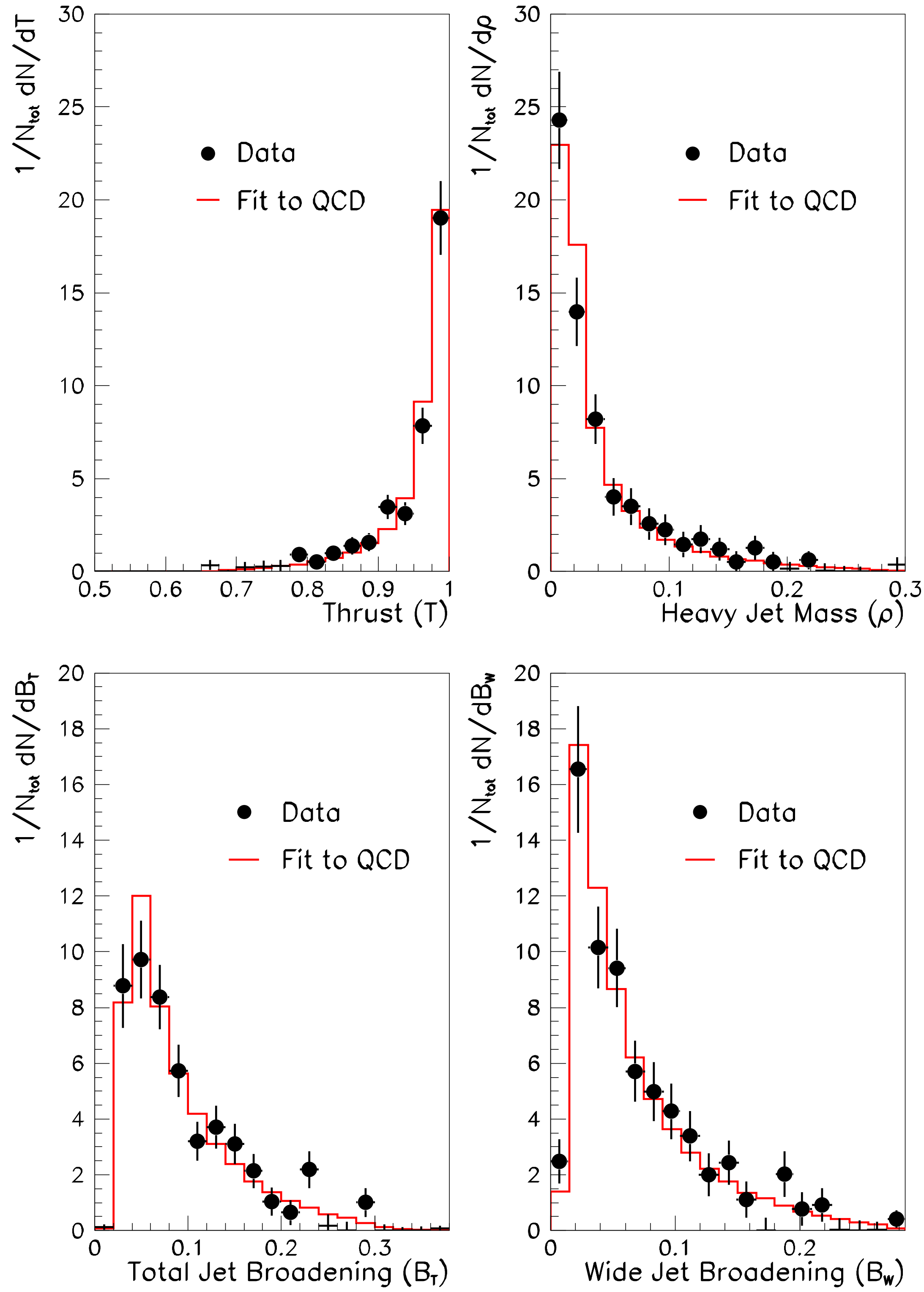


$$< T > = 0.946 \pm 0.003 \qquad < n_{ch} > = 25.6 \pm 0.6$$



Durham algorithm, corrected for bg and det. effects

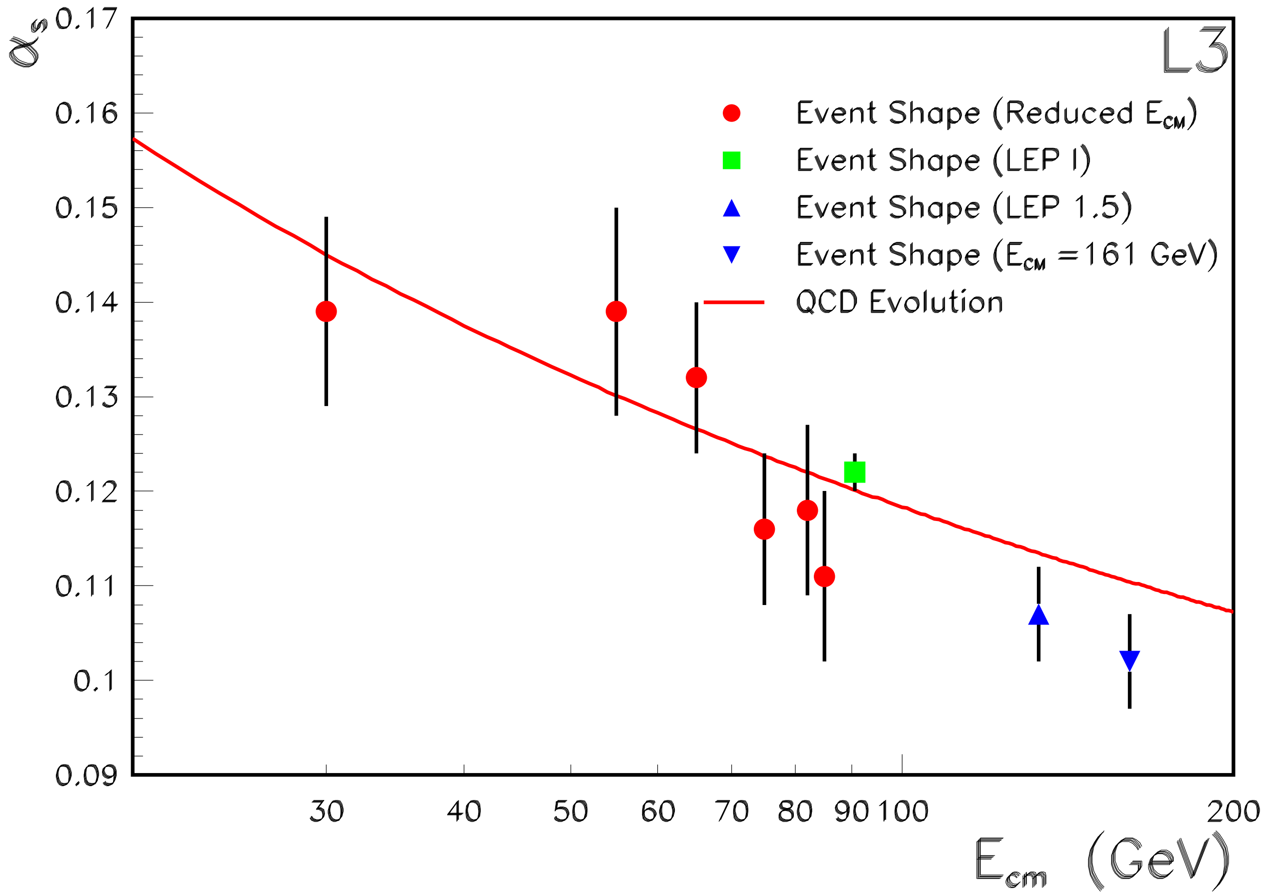
Event Shape Variables at 161 GeV



Strong Coupling Constant

	$(1-T)$	ρ	B_T	B_W
$\alpha_s(161\ \mathrm{GeV})$	**0.099**	**0.100**	**0.109**	**0.101**
Stat. error	$\pm$ **0.005**	$\pm$ **0.005**	$\pm$ **0.004**	$\pm$ **0.004**
Syst. error	$\pm$ **0.003**	$\pm$ **0.002**	$\pm$ **0.001**	$\pm$ **0.003**
Exp. error	$\pm$ **0.006**	$\pm$ **0.005**	$\pm$ **0.004**	$\pm$ **0.005**
Theo. error	$\pm$ **0.004**	$\pm$ **0.003**	$\pm$ **0.005**	$\pm$ **0.005**

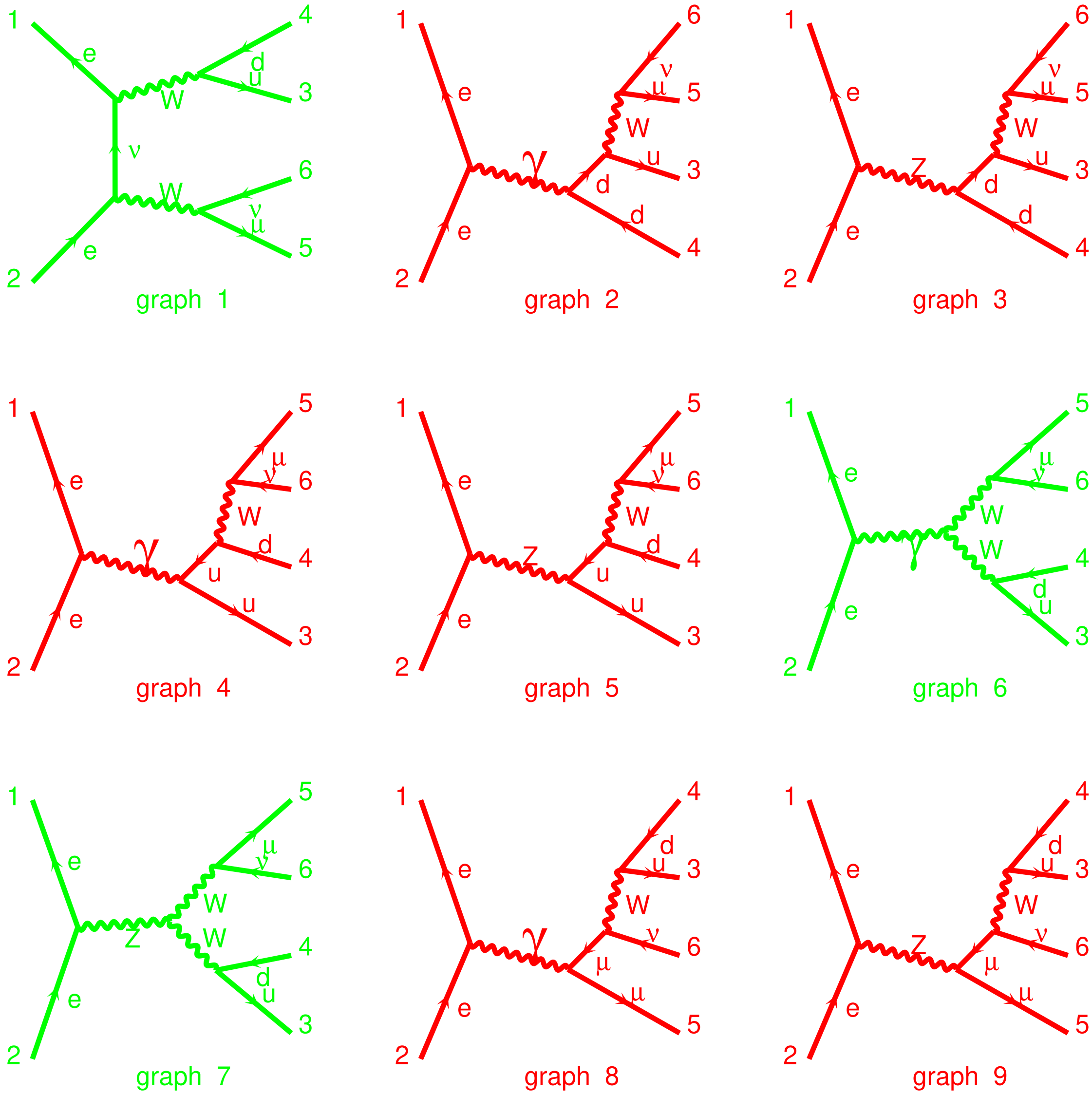
$$\alpha_s(161\,\mathbf{GeV}) = 0.102 \pm 0.005\ \mathbf{(exp)} \pm 0.005\ \mathbf{(theo)}$$

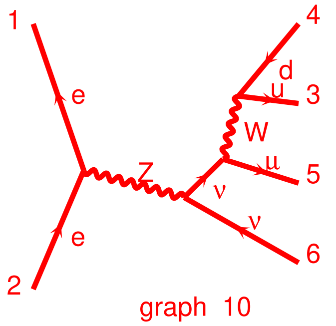


Experimental errors only

Four-Fermion Production

Diagrams by MadGraph





$e^+e^- \rightarrow u\bar{d}\boldsymbol{\mu}^-\bar{\boldsymbol{\nu}}_{\boldsymbol{\mu}}$

Non-resonant background:
small, reduced by M_{inv} **cuts**

$e^+e^- \to W^+W^- \to q\bar{q}'\ell\nu \to$ 2 Jets $+ \ell$

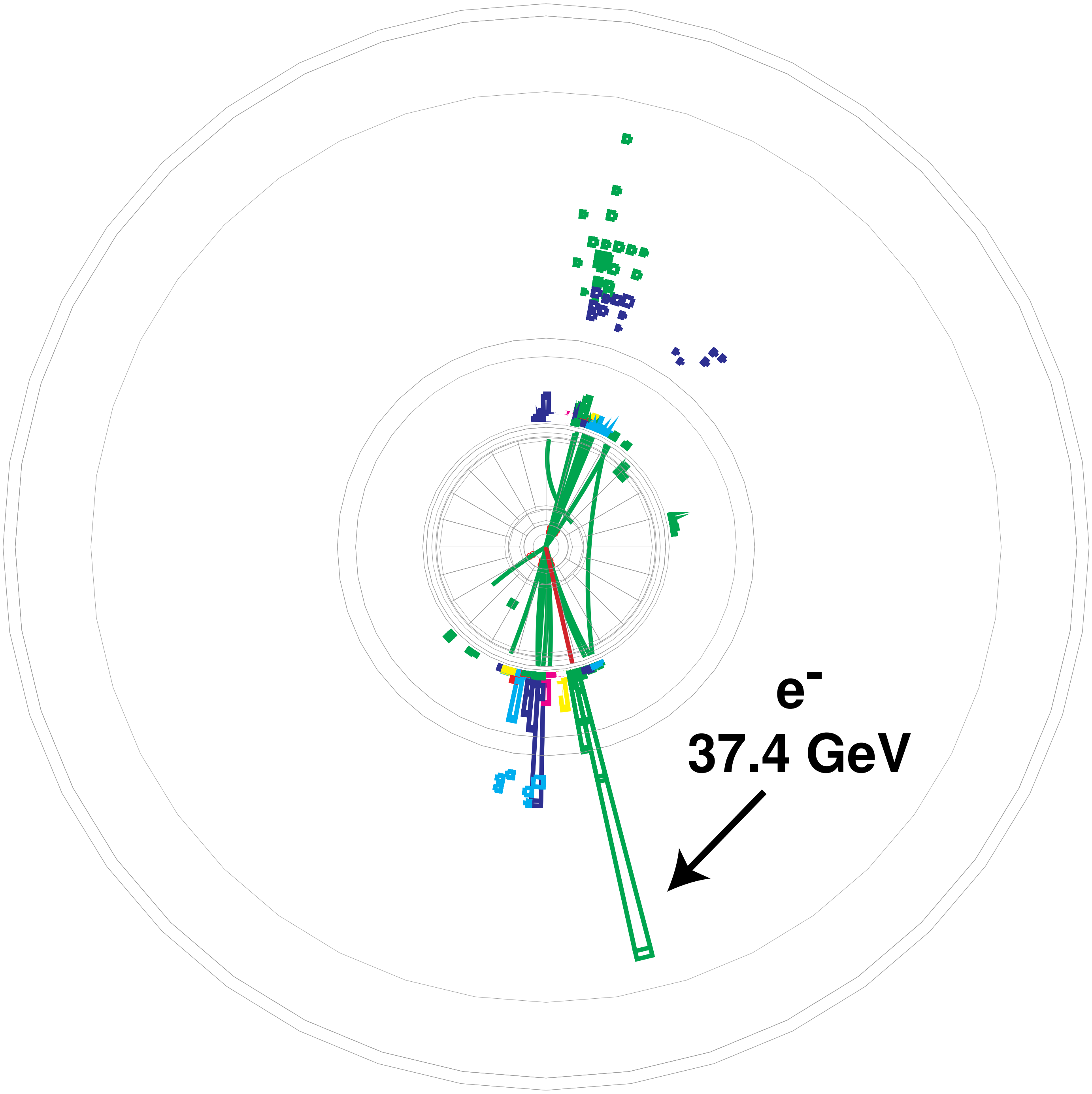
Selection strategy:

- **Identify isolated, high energy lepton** $(\vec{p}_l)$**:**
  - **electron: slim, short and symmetric shower in calorimeters**
  - **muon: track in muon spectrometer, MIP in calorimeters**
  - **tau: lower energy** l **or narrow, low multiplicity hadronic jet**
- **cluster remainder of event into two jets** $(\vec{p}_q, \vec{p}_{\bar{q}})$
- **determine missing momentum vector** $(\vec{p}_\nu)$
- **cut on kinematics of the four fermion system:**
  - **lepton and jet energies**
  - **direction and size of missing energy**
  - **angle between lepton and jets**
  - $M_{l\nu}$, $M_{q\bar{q}}$

$$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'e\nu$$

Efficiency: 57.4%

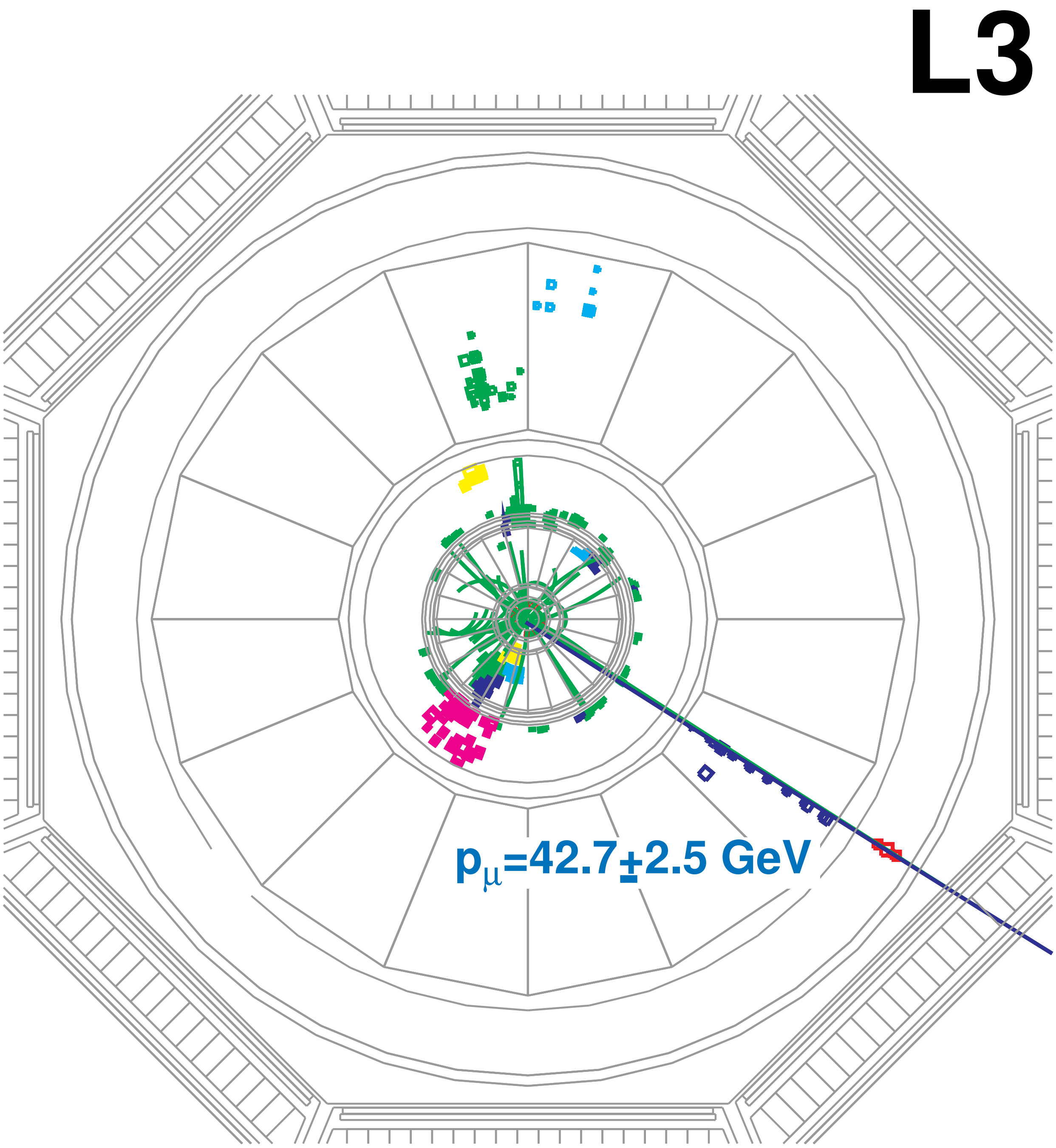
Background: 19 fb



Selected events: 4

$$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'\mu\nu$$

Efficiency: 66.7% **Background: 29 fb**

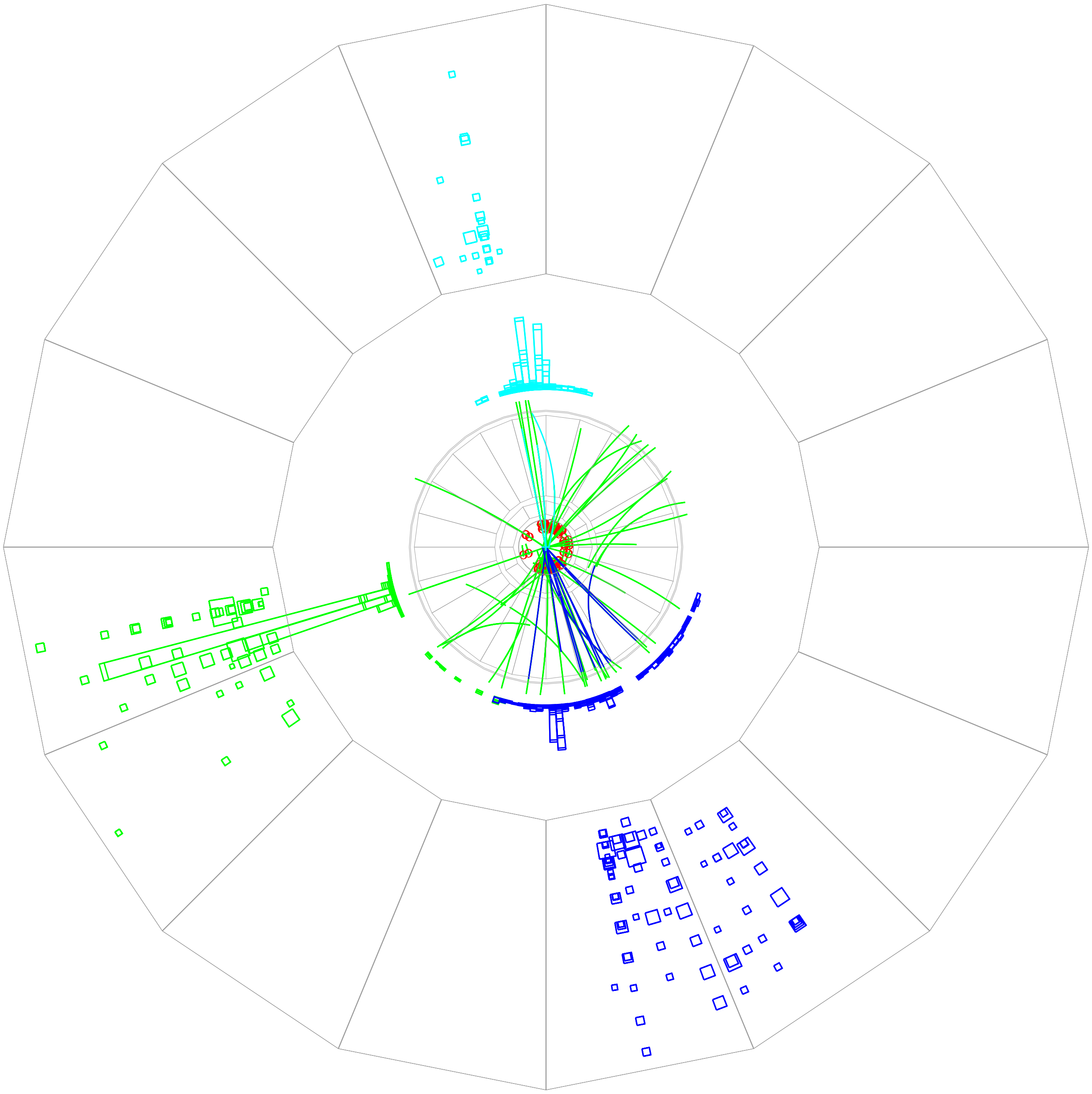


Selected events: 4

October 8, 1996 M. Pohl, ETHZ

$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'\tau\nu$

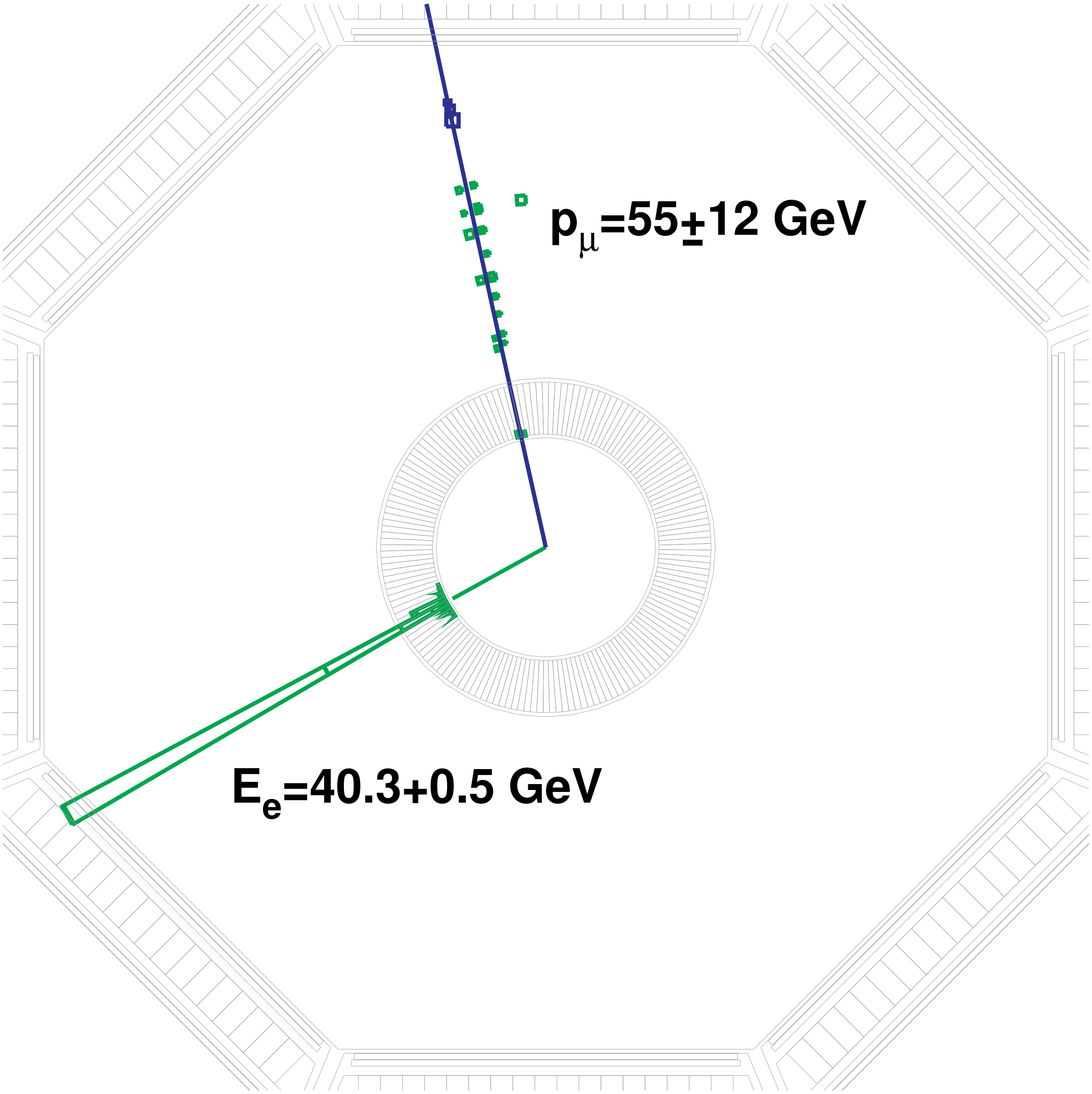
Efficiency: 39.6% **Background: 259 fb**



Selected events: 1

$e^+e^- \rightarrow W^+W^- \rightarrow \ell\nu\ell\nu$

Efficiency: 55.2% **Background: 63 fb**



Selected events: 2

$e^+e^- \to W^+W^- \to q\bar{q}'q\bar{q}'$

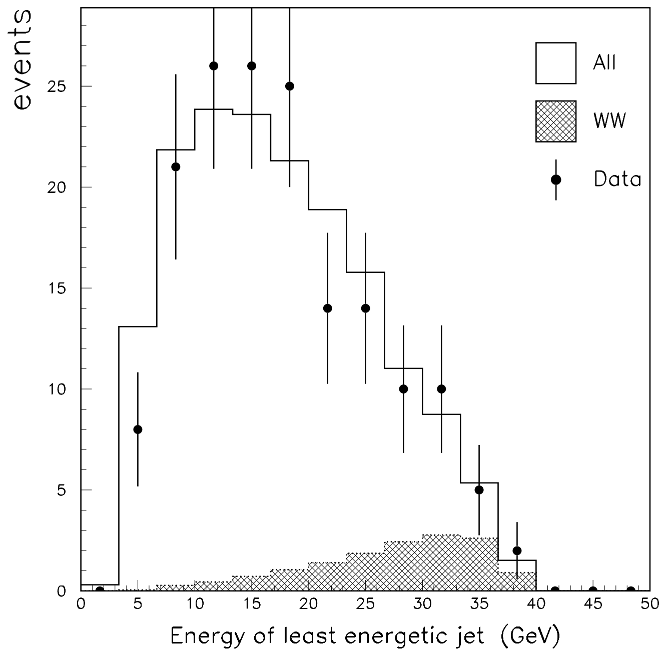
Characteristics:

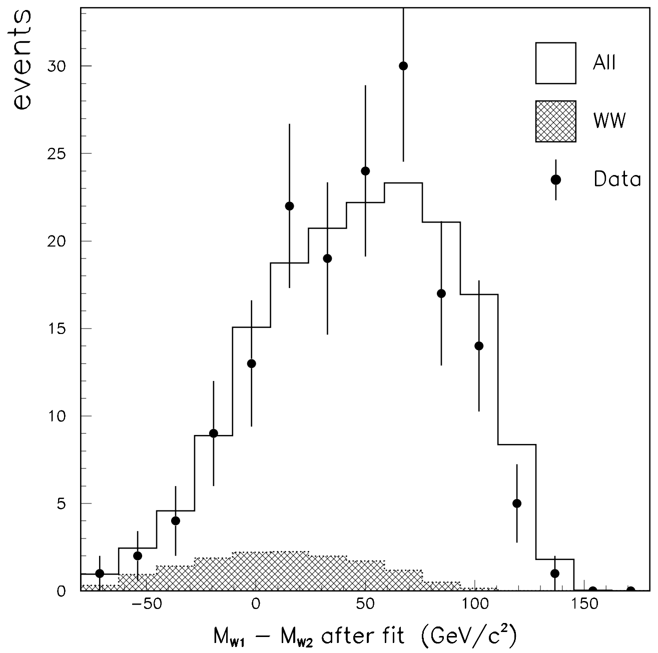
- **Signal:** $\sigma(e^+e^- \to W^+W^- \to q\bar{q}'q\bar{q}') \simeq 1.5$ pb
- **Main background:** $\sigma(e^+e^- \to q\bar{q}) \simeq 150$ pb
- **Four jet events from QCD not drastically different from signal at WW threshold**

Selection strategy:

- **Select high multiplicity events without missing energy**
- **Reject radiative return to Z**
- **Force events to four jets, using Durham clustering**
- **Improve energy resolution by 4C kinematic fit**
- **Use a neural network to distinguish WW events from background**

$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'q\bar{q}'$

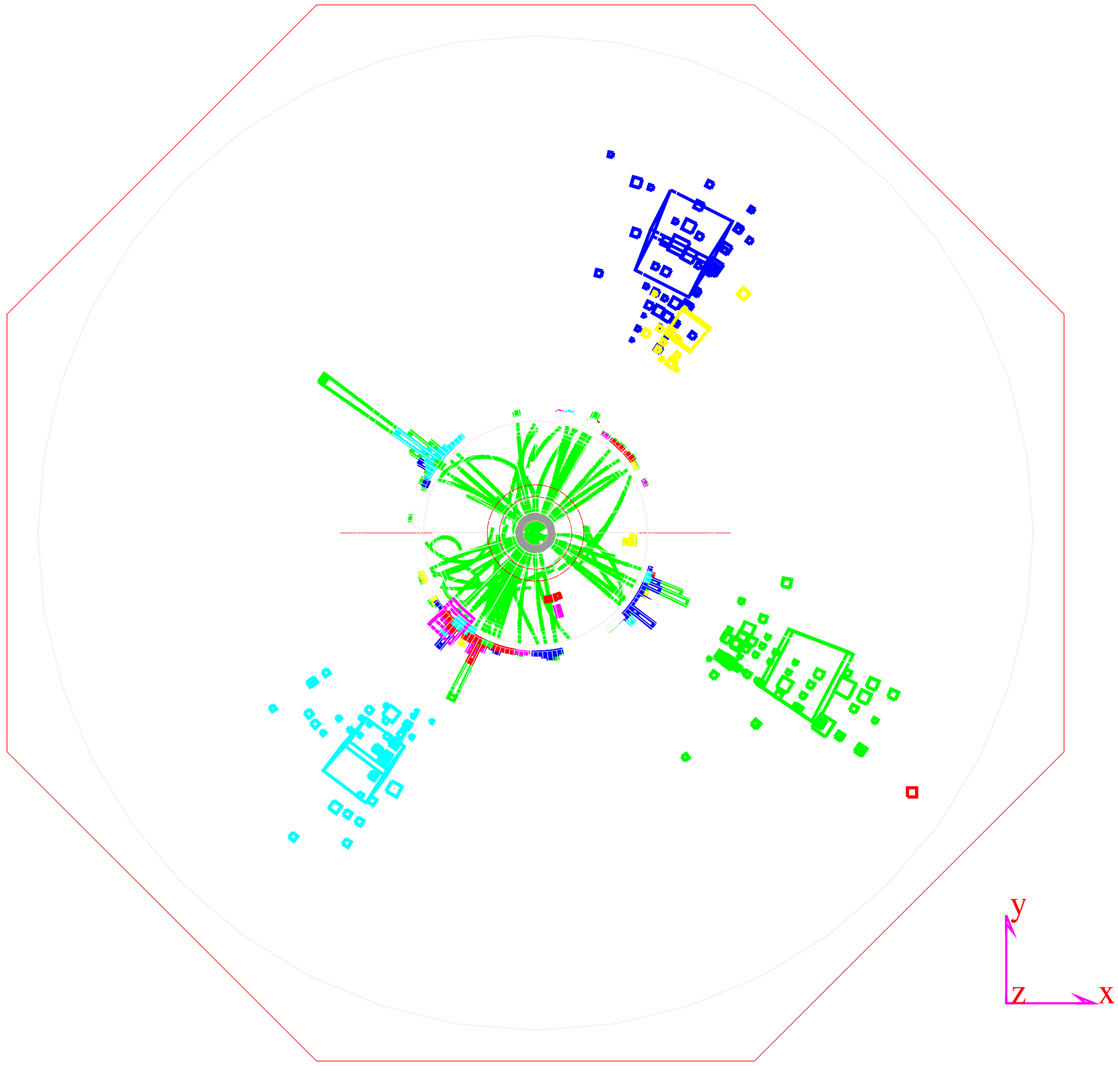




- **Neural network input variables:**
  - **Four jet topology (Y_{34}, sphericity, jet energy and multiplicity)**
  - **WW kinematics ($M_1 \pm M_2$, $\beta_{1/2}$, angle between jets)**
  - **Background topology (mass of jets when event forced to 2 jets)**
- **Fit signal and background cross sections from distribution of neural network output.**
- **Advantage: get signal cross sections and background normalisation from data.**

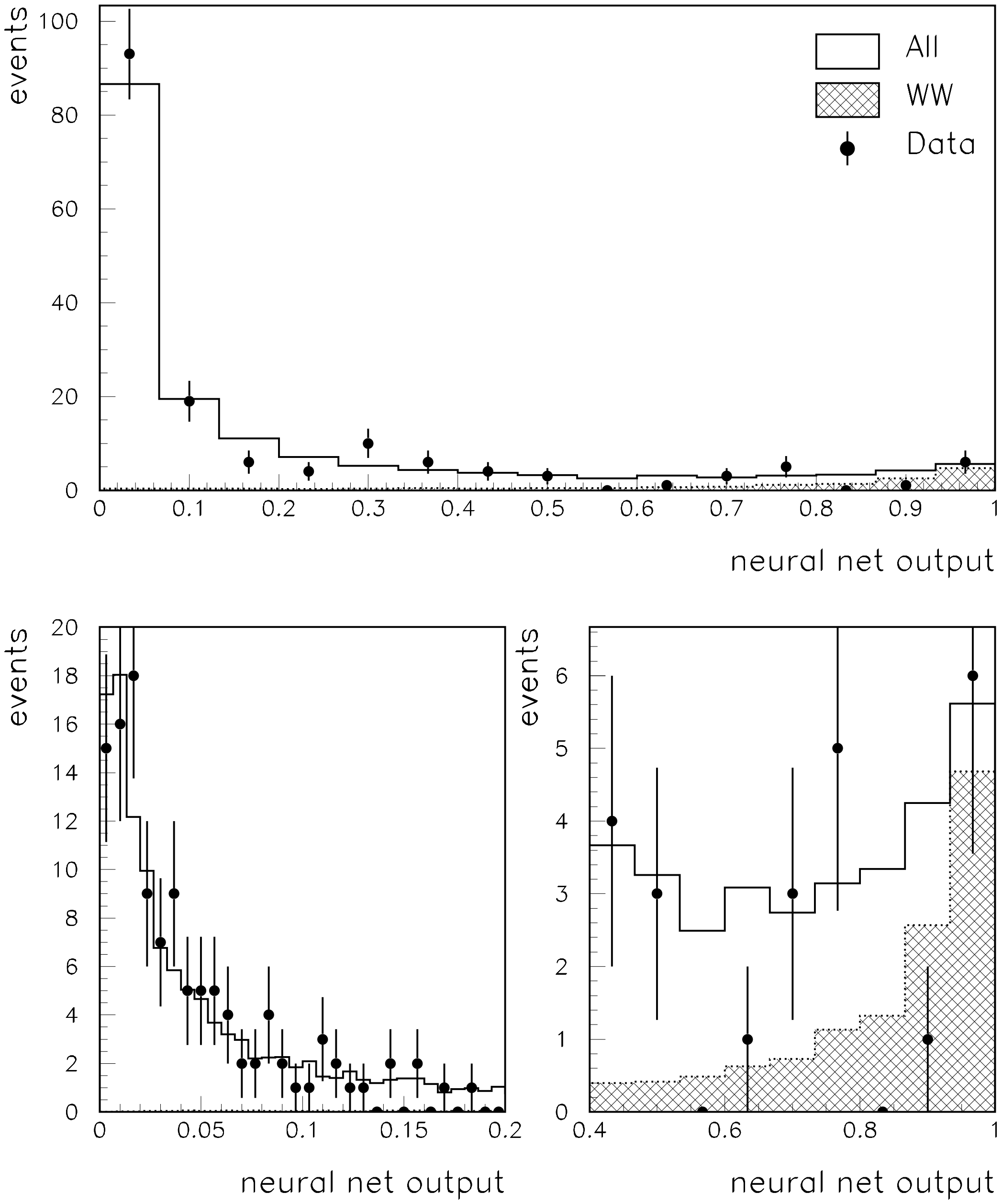
$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'q\bar{q}'$

Run # **658912** **Event #** **2968** Total Energy : 167.13 GeV



Transverse Imbalance :	.0265		**Longitudinal Imbalance :**	.0383
Thrust : .7515		**Major :** .6040		**Minor :** .0905
Event DAQ Time :	*960723 103616*			

$e^+e^- \to W^+W^- \to q\bar{q}'q\bar{q}'$



- $\boldsymbol{\sigma}(WW \to q\bar{q}'q\bar{q}') = 1.0^{+0.5}_{-0.4}$ **pb** **(SM: 1.7 pb)**
- $\boldsymbol{\sigma}_{bg} = 147 \pm 12$ **pb** **(SM: 152 pb)**

L3 WW Cross Section at 161 GeV

Channel	**Eff. (%)**	**Backgr. (fb)**	**Events**	$\sigma \times$ Br **(pb)**
$q\bar{q}'e\nu$	**57.4**	**19**	**4**	$0.63^{+0.39}_{-0.28}$
$q\bar{q}'\mu\nu$	**66.7**	**29**	**4**	$0.53^{+0.34}_{-0.24}$
$q\bar{q}'\tau\nu$	**39.6**	**259**	**1**	
$\ell\nu\ell\nu$	**55.2**	**63**	**2**	$0.23^{+0.31}_{-0.19}$
$q\bar{q}'q\bar{q}'$		**Neural Net**		$1.0^{+0.5}_{-0.4}$

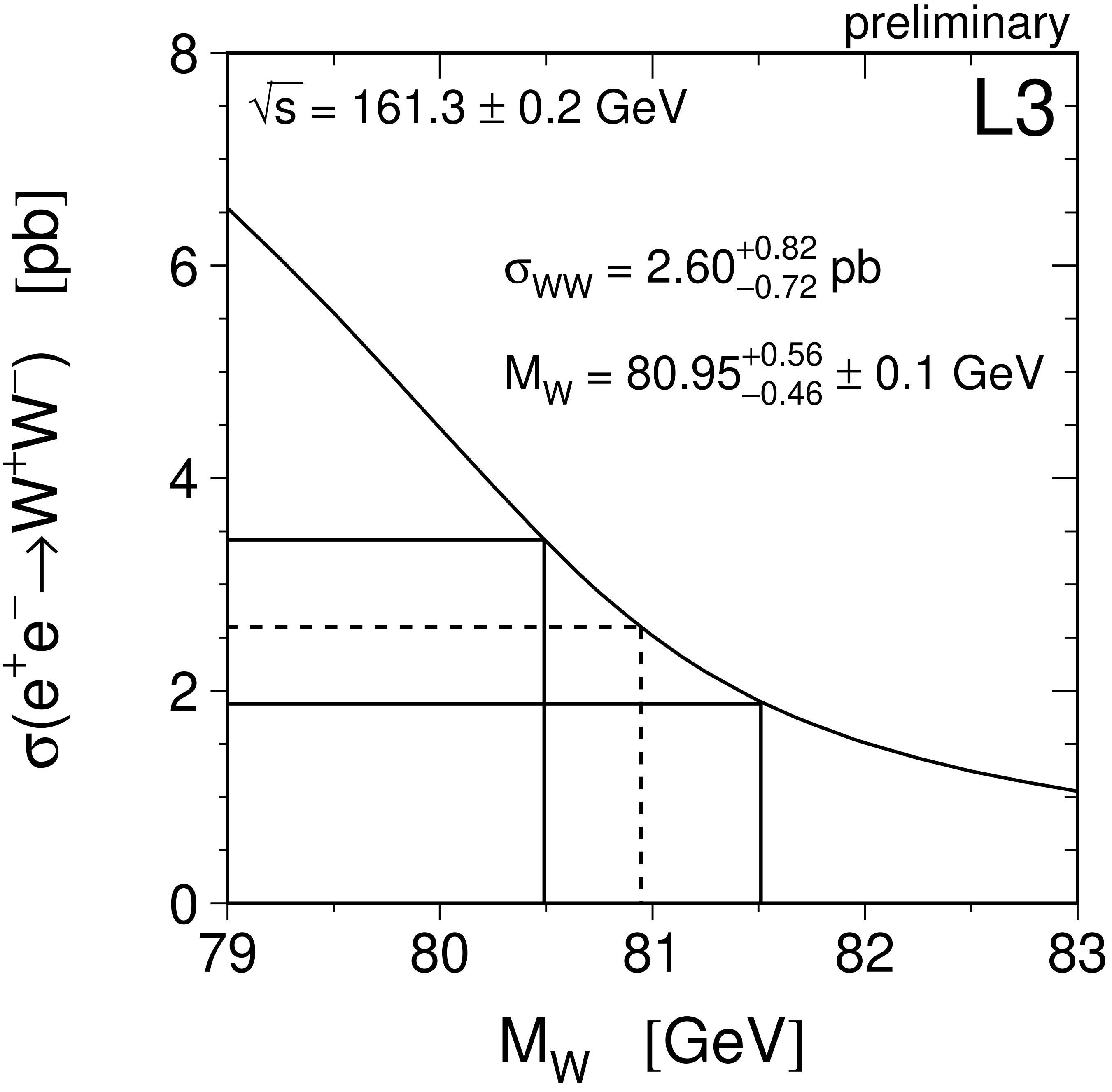
Integrated luminosity: 10.5 ± 0.1**pb**$^{-1}$
Statistical errors only

Maximum Likelihood fit for total cross section:

$$\sigma_{\text{tot}} = 2.60^{+0.82}_{-0.72}\,\mathbf{pb}$$

Statistical and (negligible) systematic error

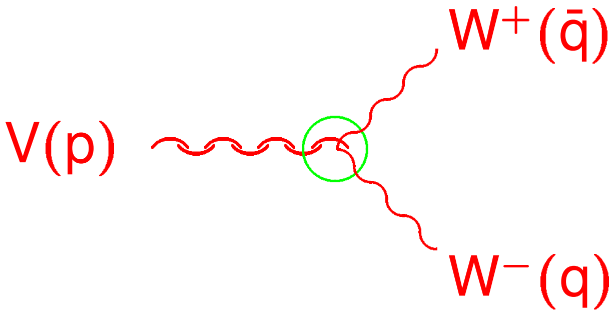
W Mass from SM Cross Section



Statistical and systematic errors

ZWW Couplings

General three-boson vertex function:

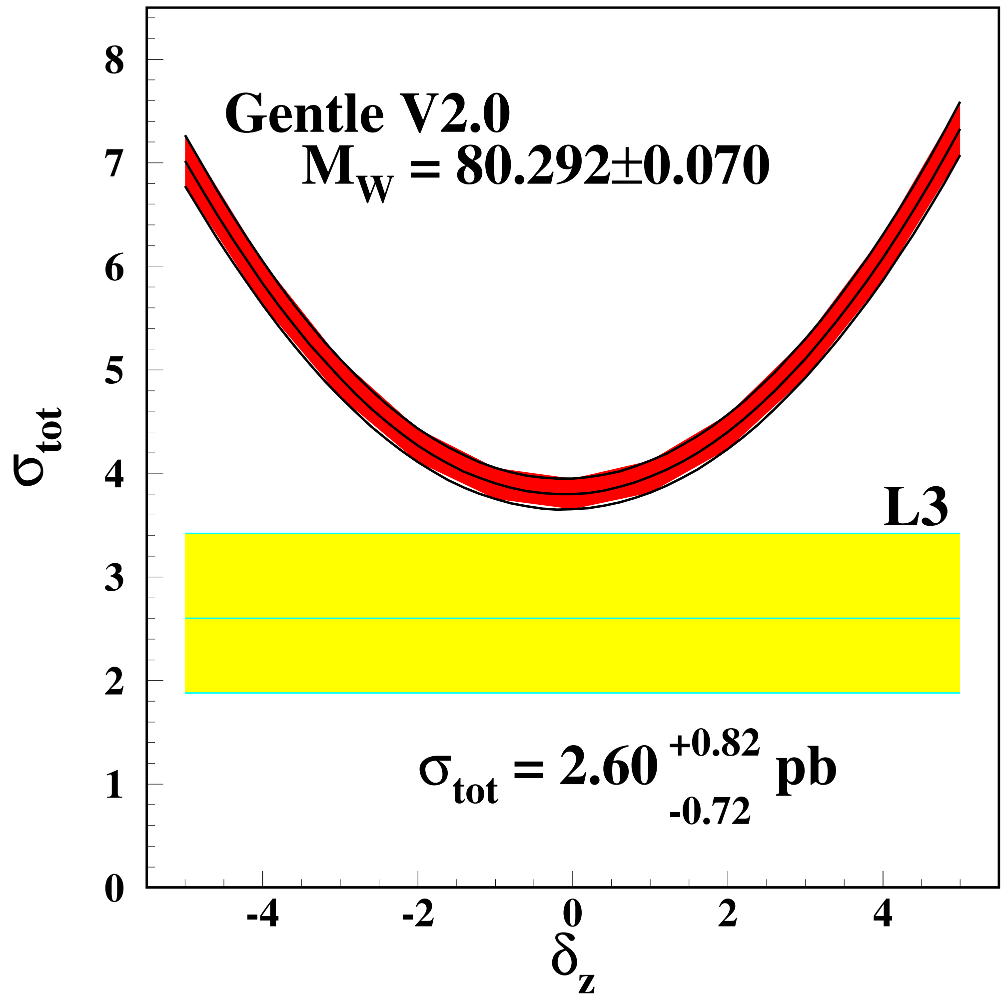


$$= -ieg_{VWW}\Gamma_V^{\alpha\beta\mu}(q,\bar{q},p)$$

$$g_{\gamma WW} = 1$$

$$g_{ZWW} = \cot\theta_W$$

$$\delta_Z = g_{ZWW} - \cot\theta_W$$

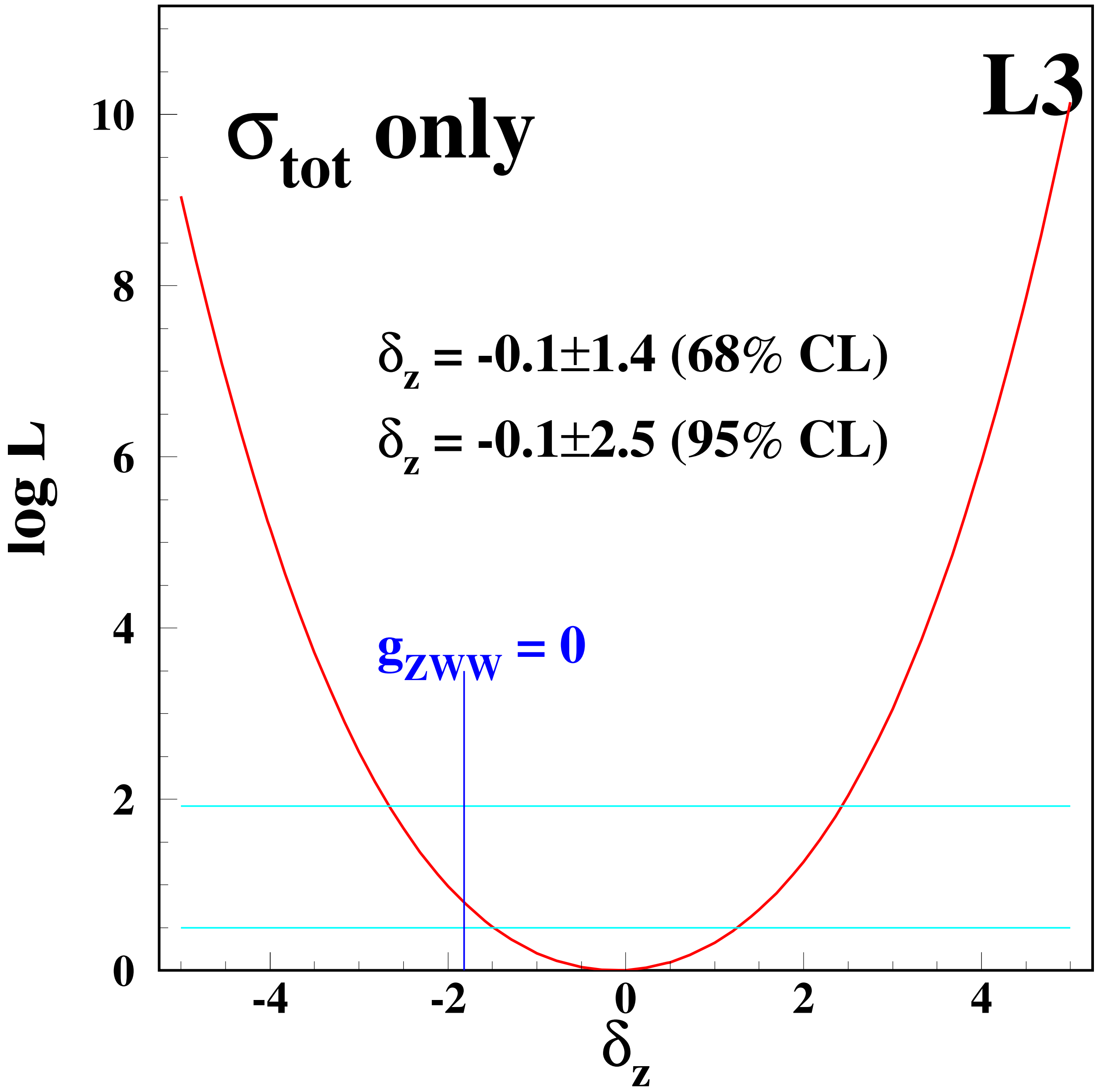


W mass from LEP I results and G_F

Syst. err. from W mass is small, syst. err. from W width is negligible

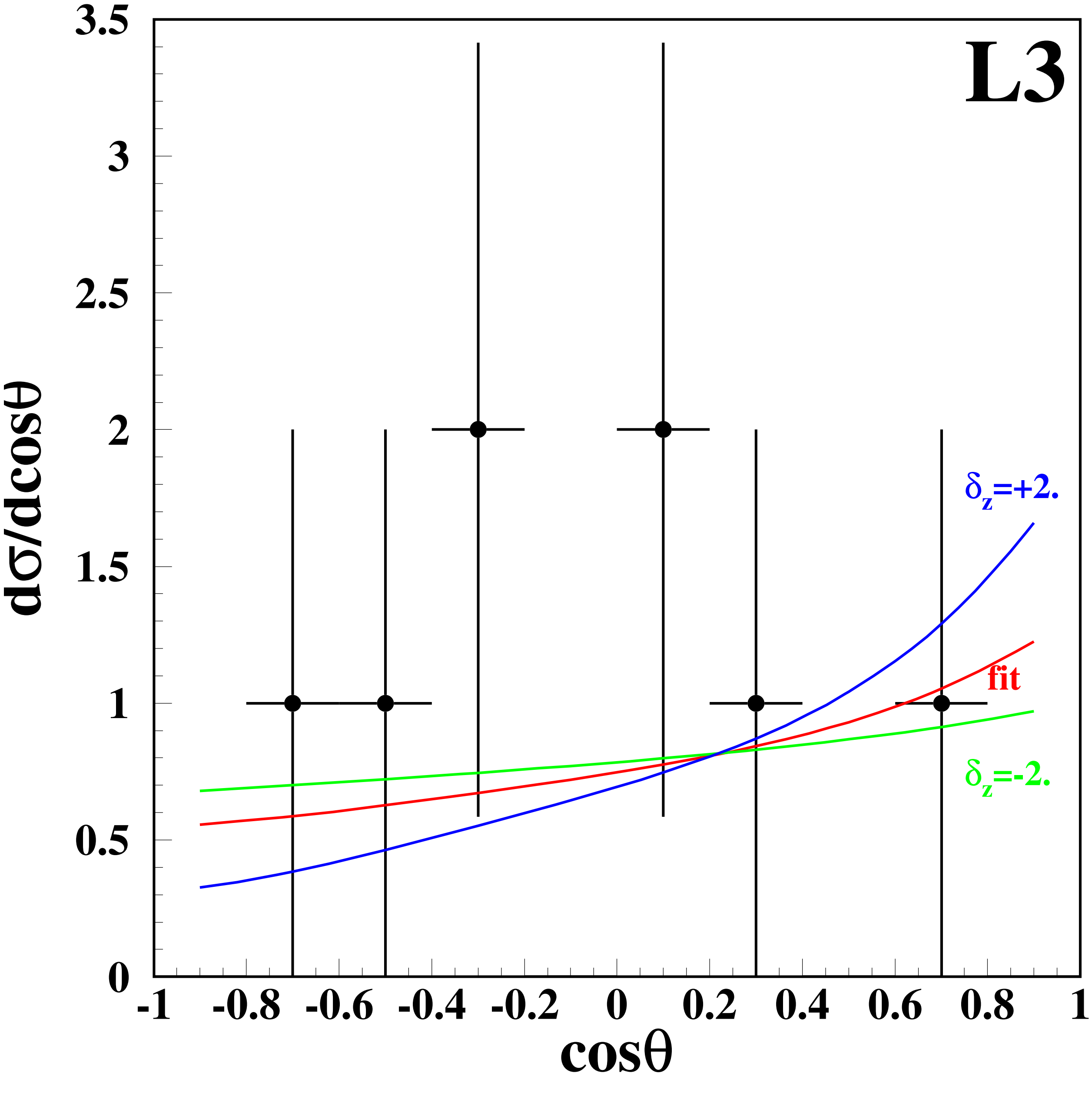
Likelihood Fit to Cross Section Alone

All other couplings fixed to SM values



Non existence of g_{ZWW}**:** $\delta_Z \simeq -2$

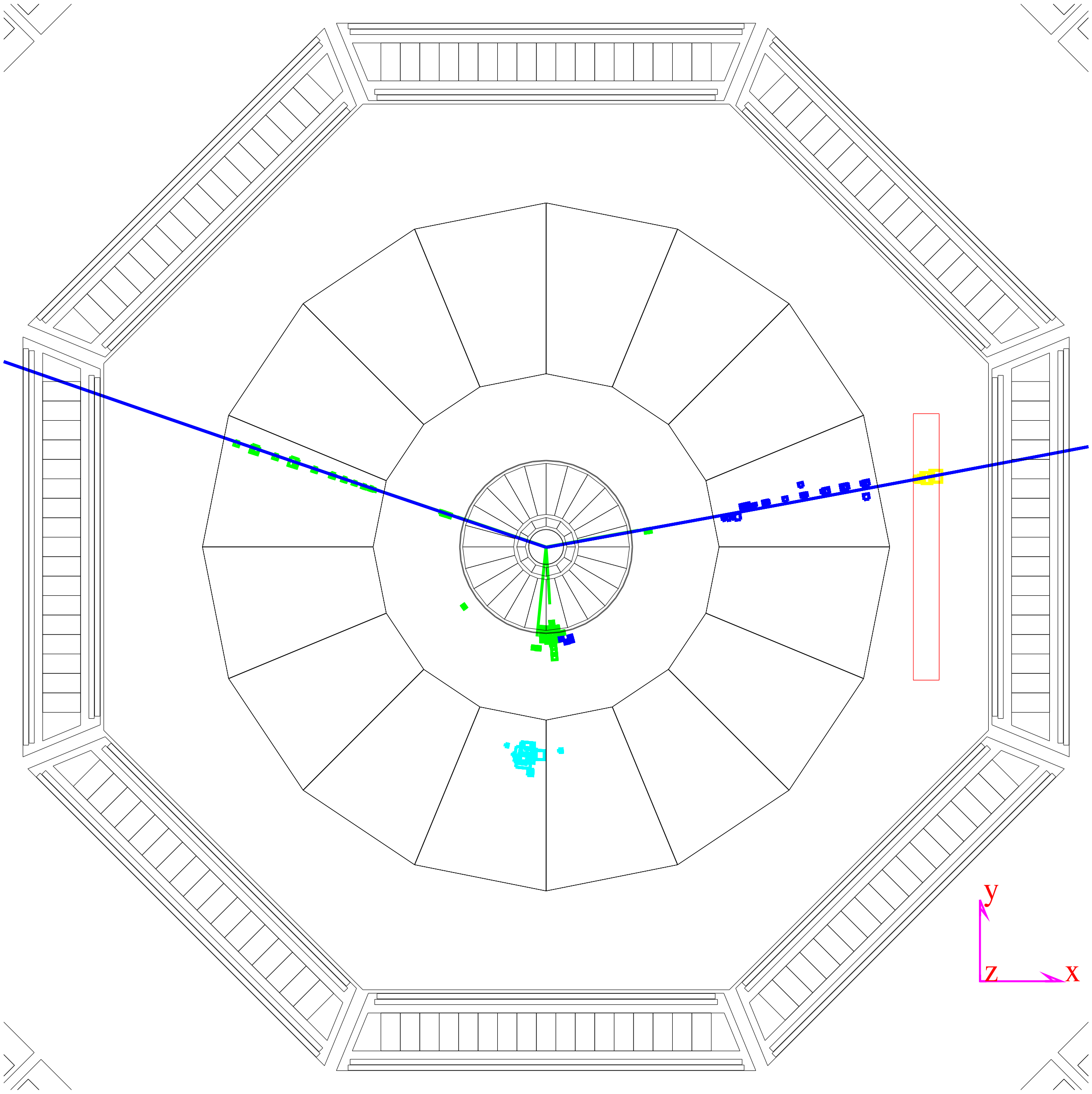
Distribution of W Production Angle



There is not much to be learned from normalised angular distribution

Other Four-Fermion Production Channels

- Below ZZ threshold: Cross section for $e^+e^- \to f\bar{f}\, f'\bar{f}'$ small, but observable
- Primary background for Higgs search



Other Four-Fermion Production Channels

	Expected Signal	Efficiency
$e^+e^-e^+e^-$	0.429 ± 0.035	0.084
$e^+e^-\mu^+\mu^-$	0.415 ± 0.043	0.049
$e^+e^-\tau^+\tau^-$	0.142 ± 0.025	0.017
$\mu^+\mu^-\mu^+\mu^-$	0.034 ± 0.002	0.200
$\mu^+\mu^-\tau^+\tau^-$	0.036 ± 0.002	0.095
$\tau^+\tau^-\tau^+\tau^-$	0.010 ± 0.001	0.059
$e^+e^-q\bar{q}$	1.278 ± 0.063	0.050
$\mu^+\mu^-q\bar{q}$	0.606 ± 0.015	0.206
$\tau^+\tau^-q\bar{q}$	0.040 ± 0.003	
Total signal	2.99 ± 0.09	
Total background	0.64 ± 0.22	

- **Total expected events: 3.63 ± 0.24**
- **Total observed events: 1 $e^+e^-q\bar{q}$, 1 $e^+e^-\mu^+\mu^-$**

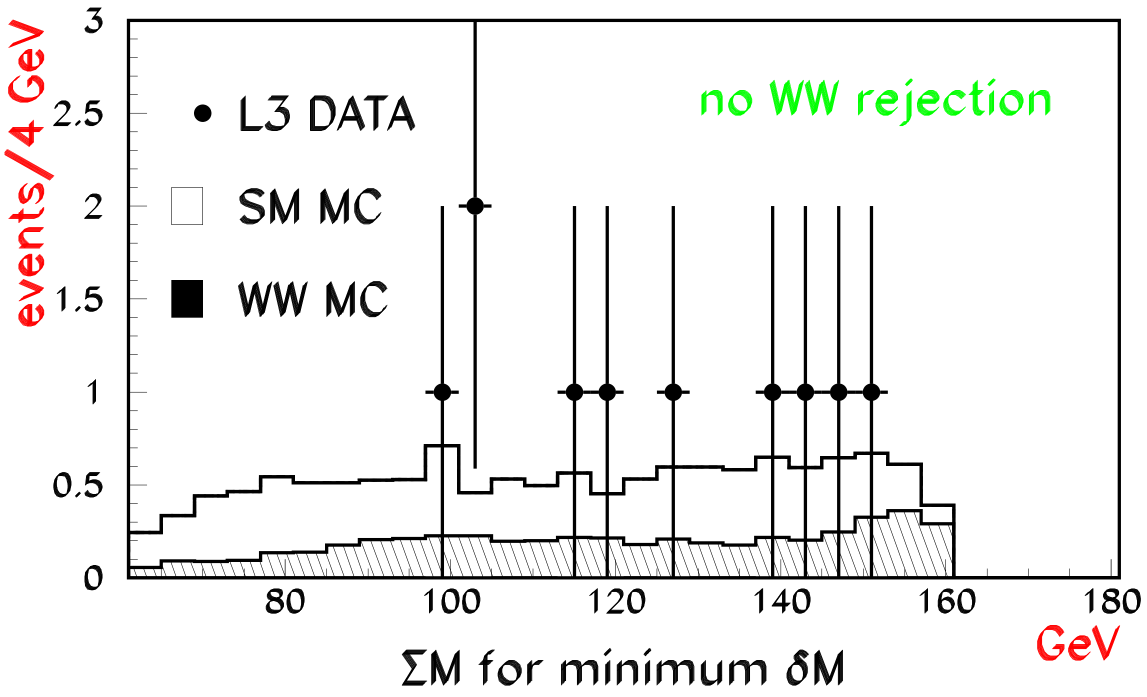
Four Jet Events Other than WW

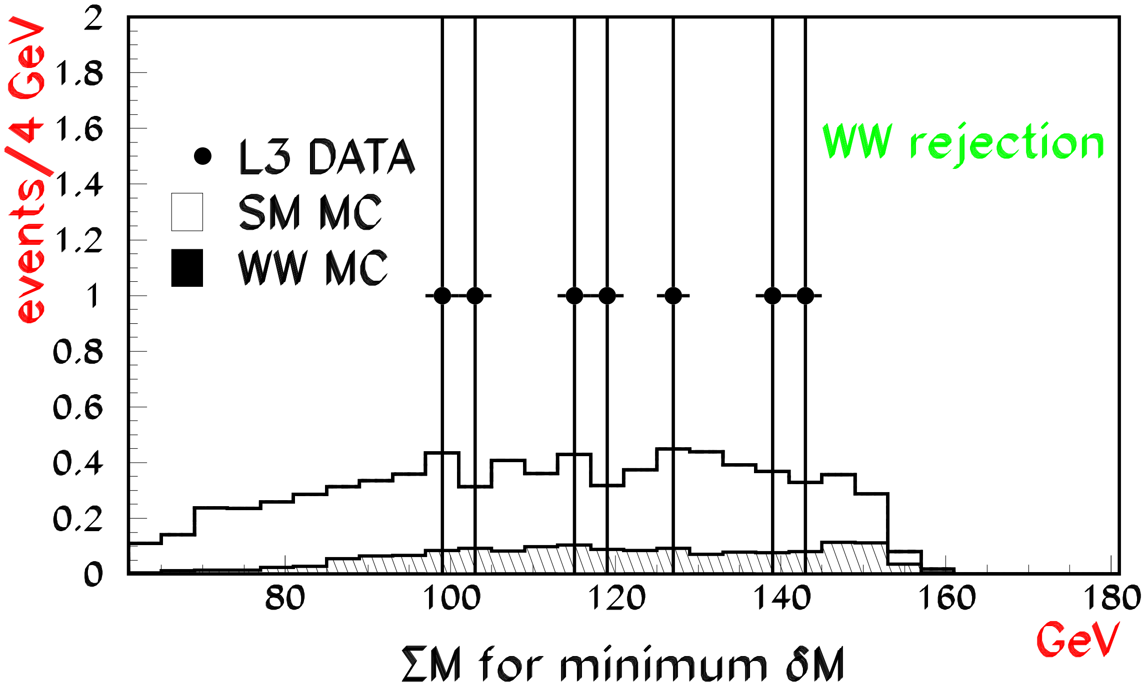
Try to carbon-copy Aleph analysis: compromise eff.

- **High mult./energy:** $>$ 20 **tracks,** $>$ 50 **clusters,** $0.7\sqrt{s} < E_{vis} < 1.3\sqrt{s}$, $\sqrt{s'/s} > 0.85$
- **Four jets: At least four jets (Durham y=0.008 or Jade y=0.02), none with** $>$ 50% **e.m. energy**
- **Jet quality: After rescaling: none with** $E < 0$.
- **Di-jet properties:** $M_i + M_j > 0.07\sqrt{s}$, $N_i^{tr} + N_j^{tr} > 9$, $M_{JJ} > 0.14\sqrt{s}$
- **WW rejection:** $\chi^2_{WW} > 15$

Requirement	Backgr. (WW)	Data	Eff. h^0A^0 (%)
High multiplicity/energy	253 (19)	275	95
Four jets	72 (13)	67	79
Jet quality	61 (11)	55	73
Di-jet properties	13.8 (5)	10	42
WW rejection	7.9 (1.6)	7	34

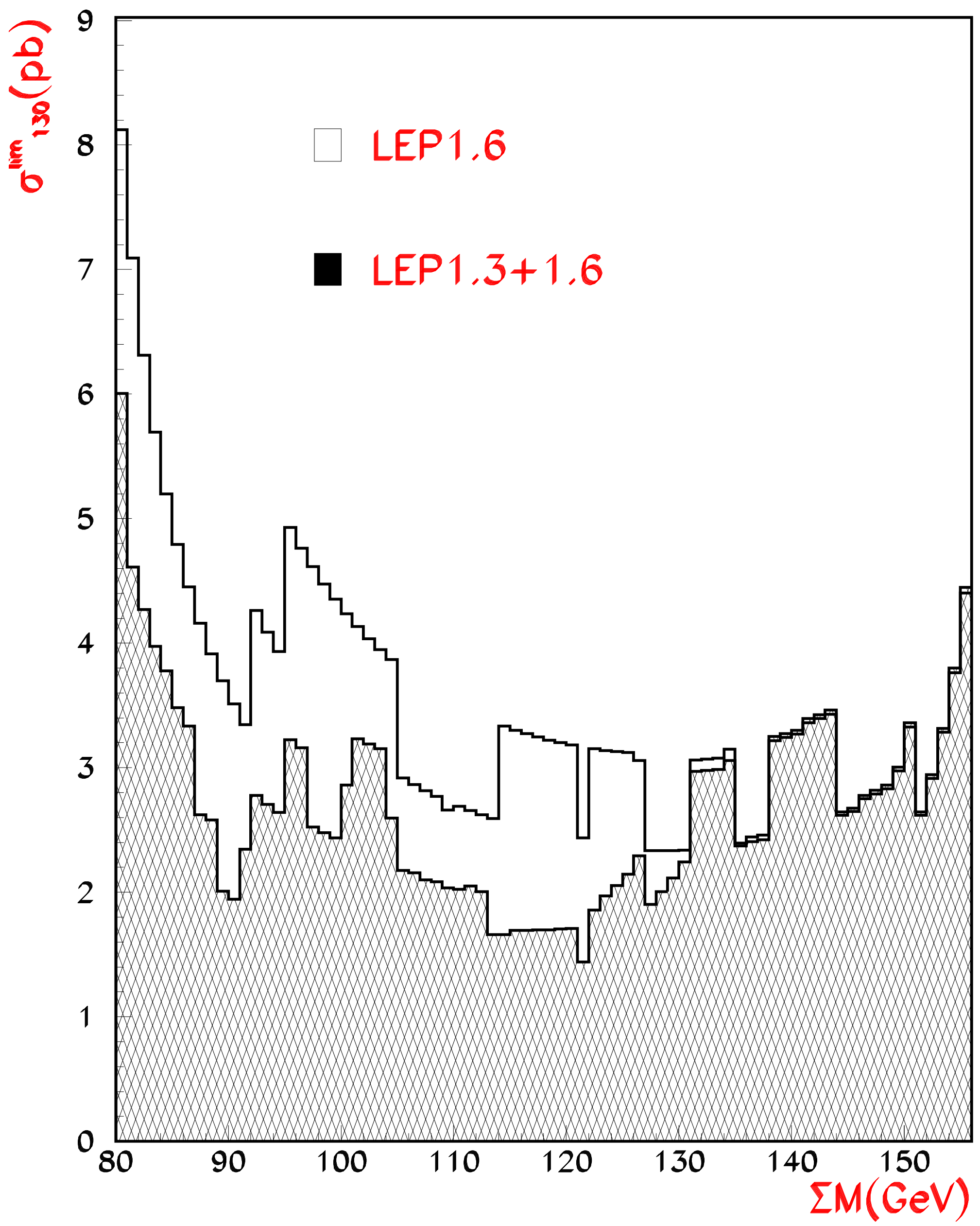
Four Jet events





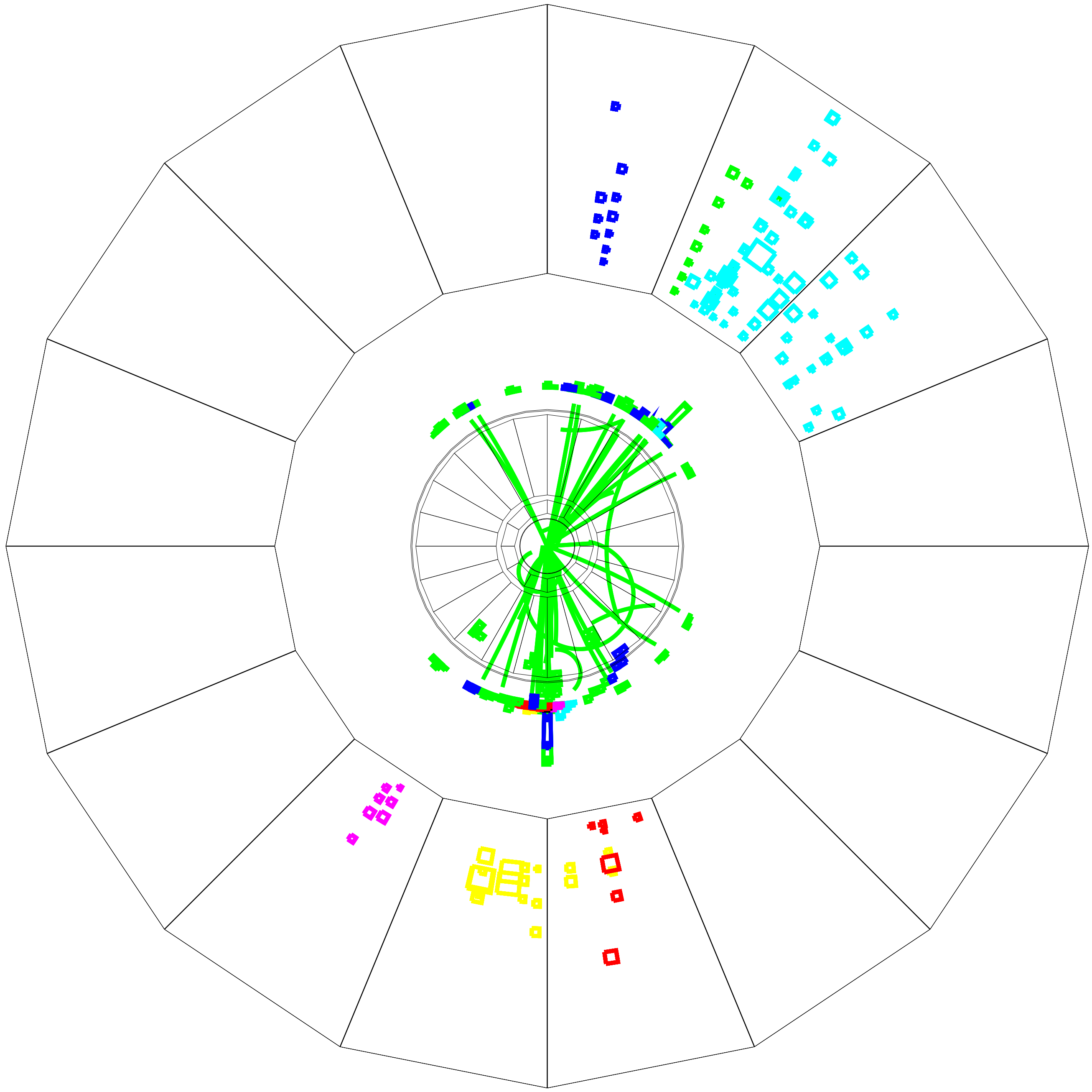
95% CL upper limit on cross section for h^0A^0 at 130 GeV, assume scaling like 1/s

L3



SM Higgs and Other Higgses

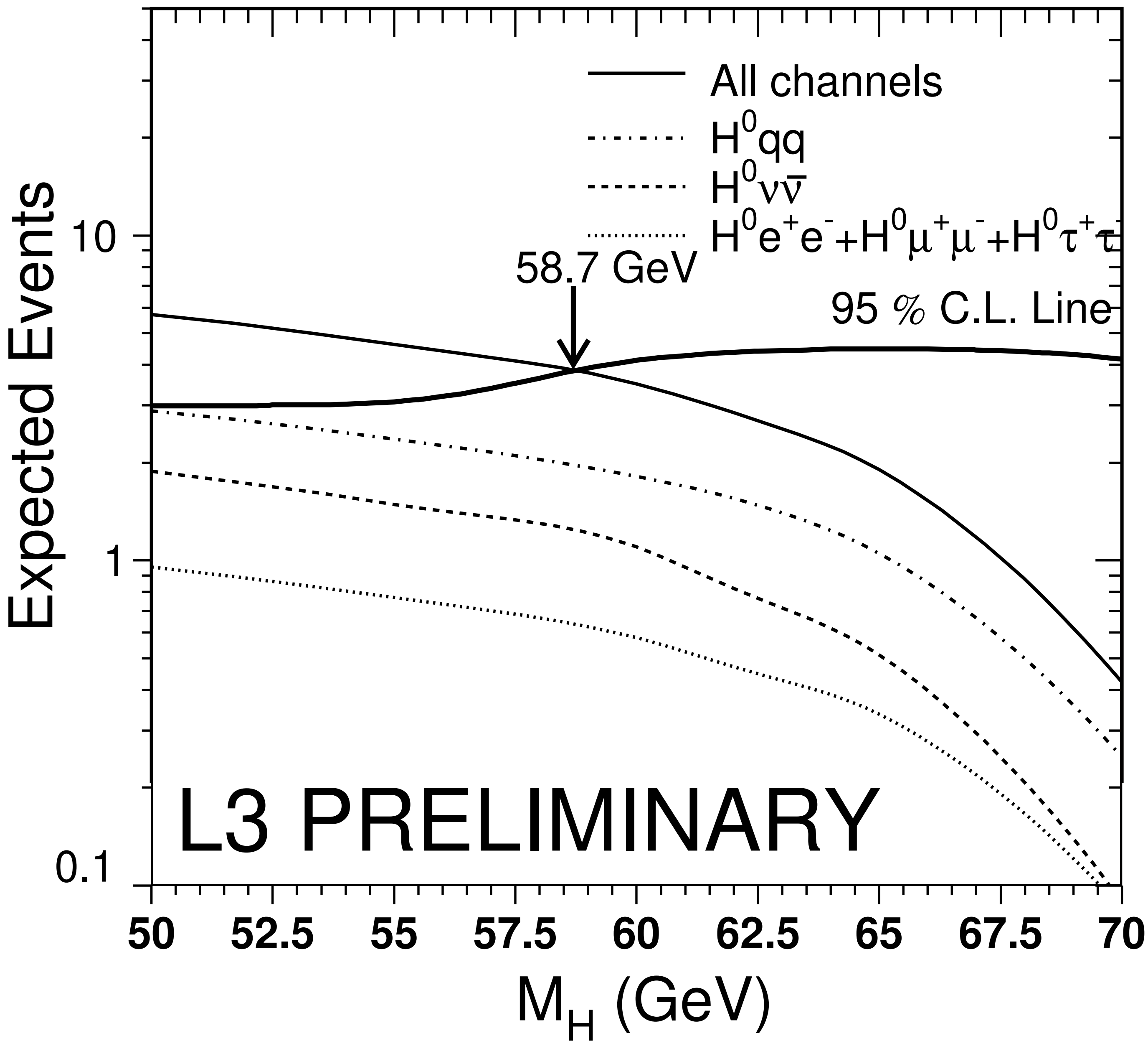
L3 candidate for $e^+e^- \rightarrow H\nu\nu$



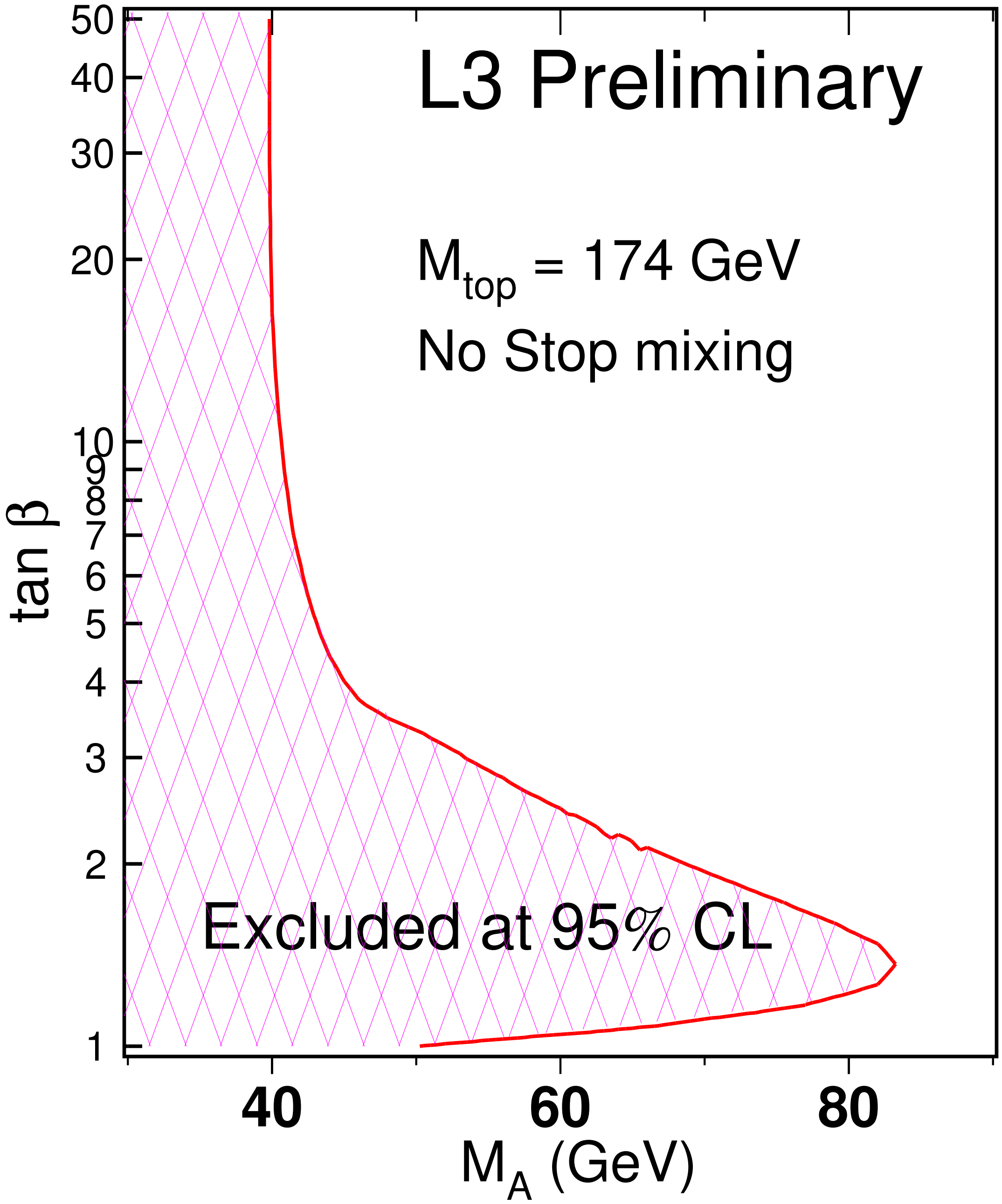
$E_{vis} = 78.4$**GeV,** $M_{vis} = 73.2 \pm 8$**GeV,** $M_{mis} = 78.1$**GeV**
$D_{btag} = 0.232$**, very unlikely to be a** $b\bar{b}$

Standard Model Higgs

Total expected background: 2.5 events
161 GeV data: 1 candidate, $M_H = 65.6 \pm 3.4$GeV
5% systematics subtracted from efficiency

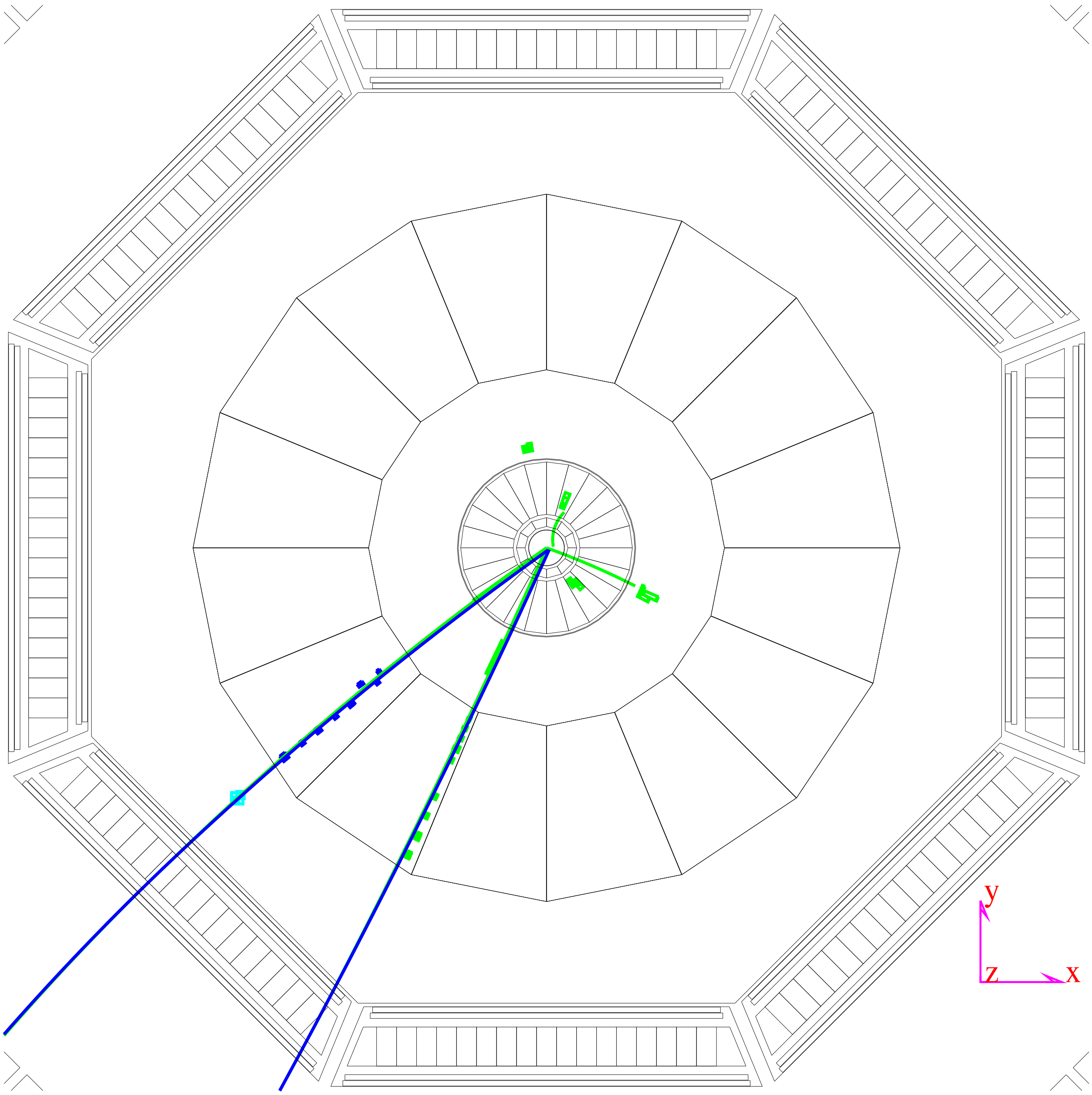


Search for $h^0A^0 \rightarrow b\bar{b}b\bar{b}, b\bar{b}\tau\bar{\tau}$
Total expected background: 1.5 events
161 GeV data: 0 candidates



Search for Supersymmetric Particles

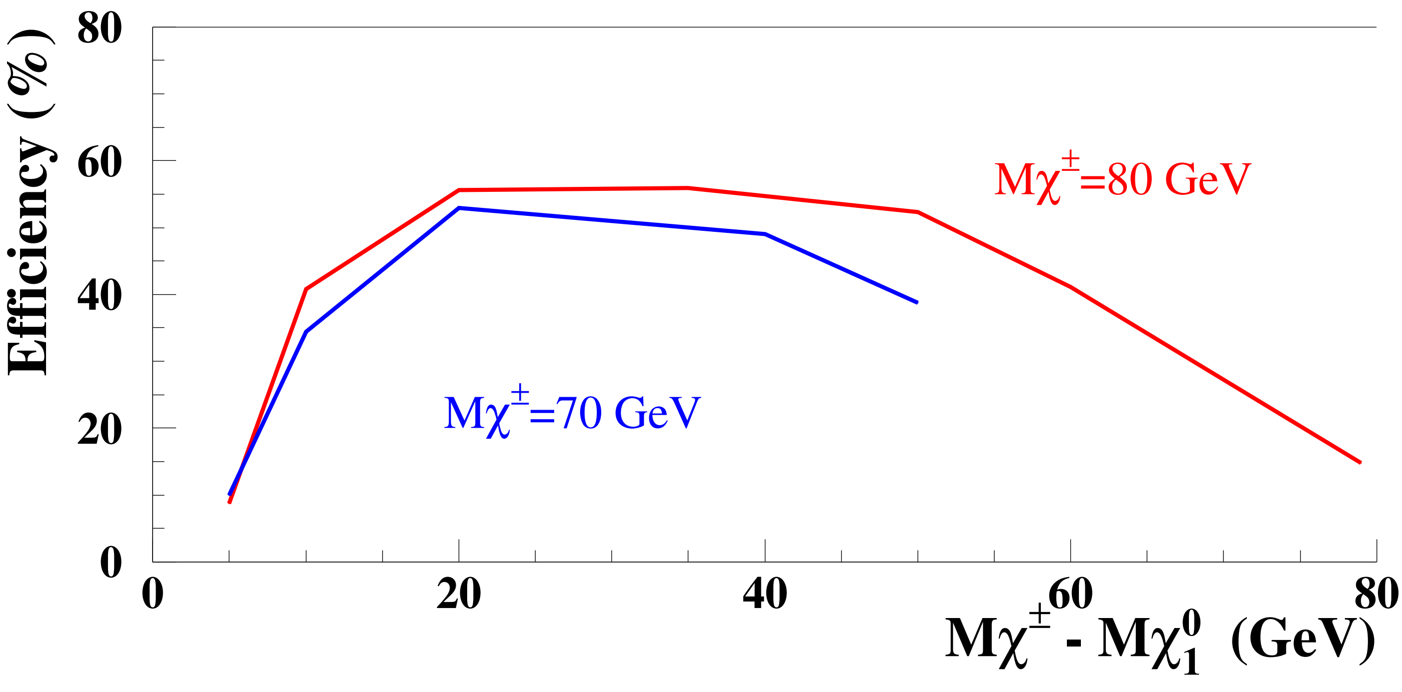
Candidate for Neutralino pair production (loose cuts)



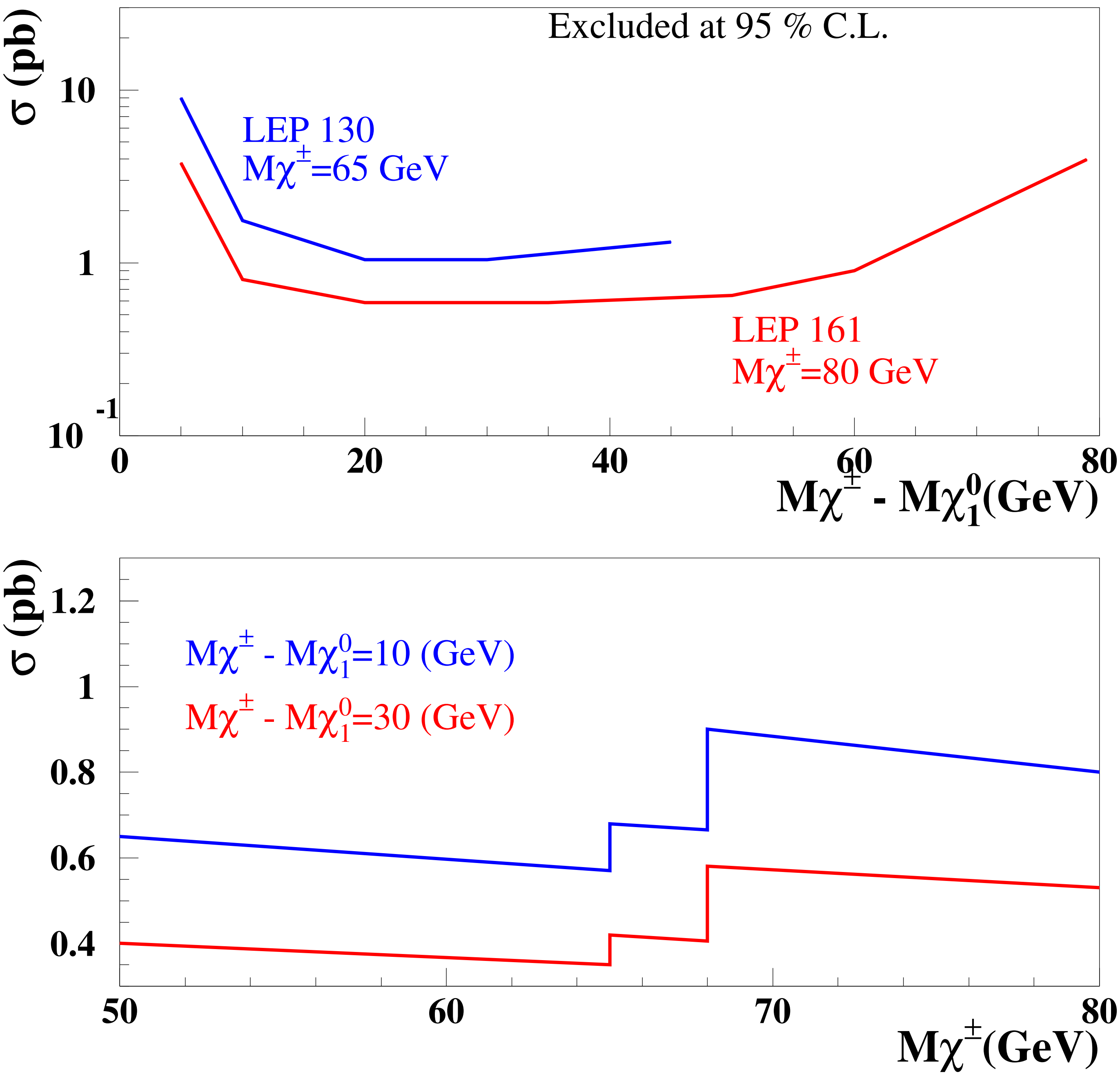
Charginos

Search for $e^+e^- \to \chi^+\chi^- \to \ell^+\ell^-\not{E}, \ell j\not{E}, jj\not{E}$

Total expected background: 1.2 events
161 GeV data: 0 candidates

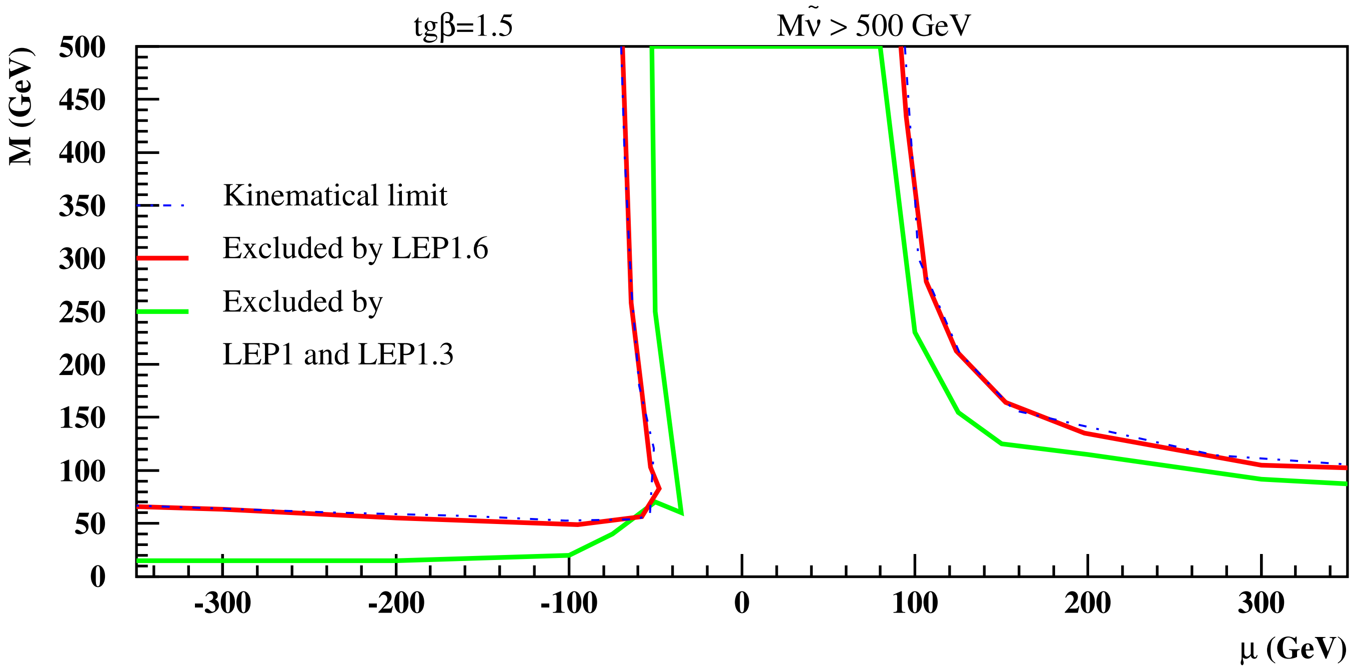


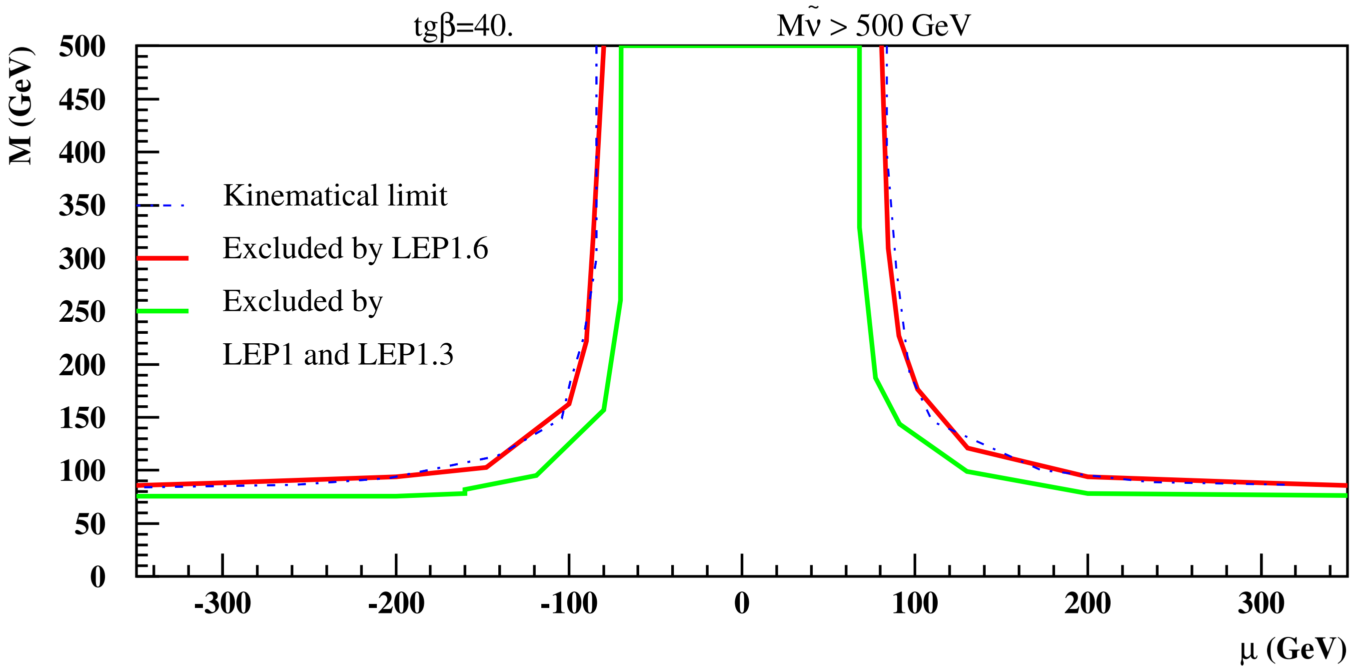
Upper Limit on Chargino Cross Section



MSSM Parameter Space

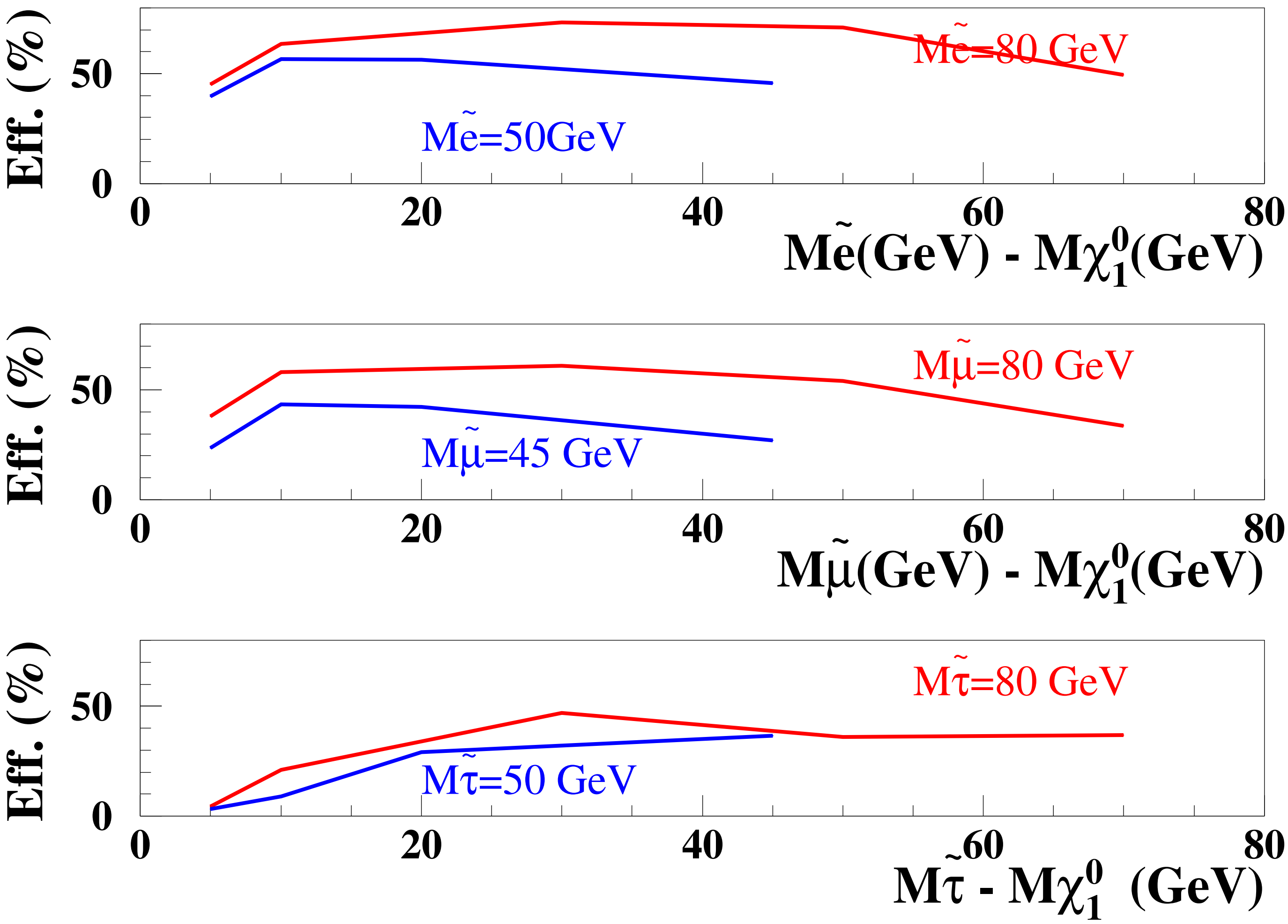
From chargino and neutralino search:



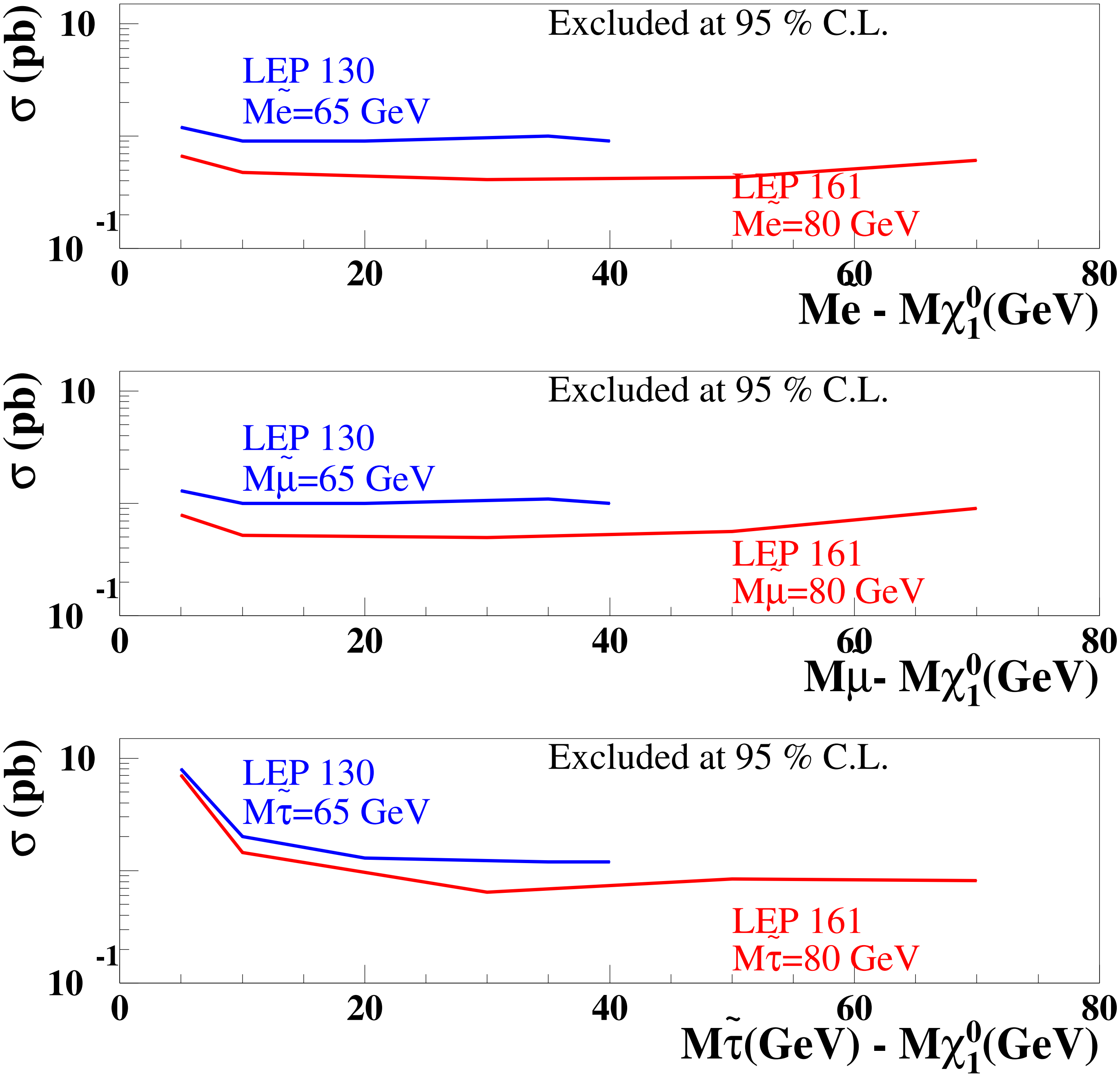


Sleptons

Total expected background: 1.2 events
161 GeV data: 0 candidates



Upper Limit on Slepton Cross Section

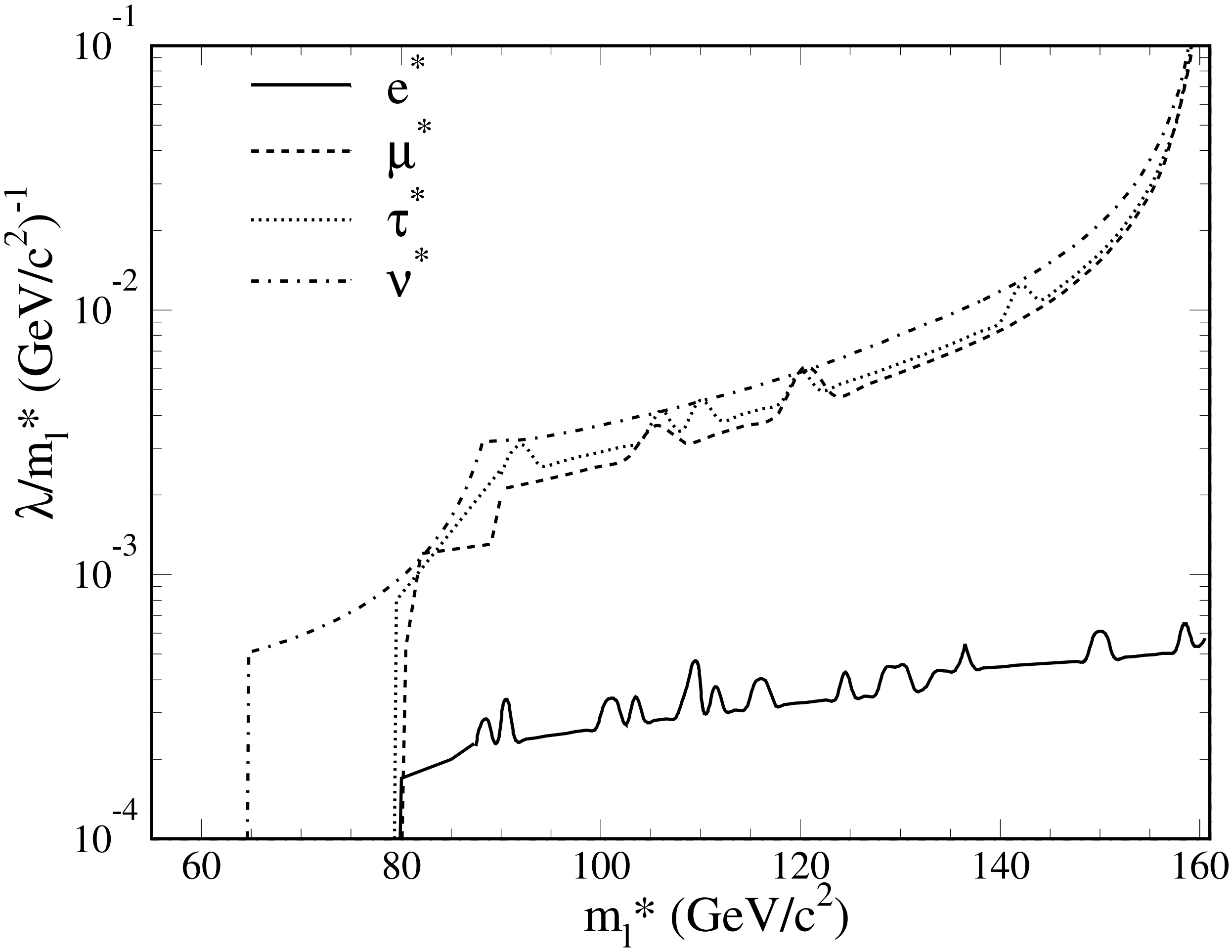


Excited Leptons

95% CL lower mass limits for pair production:

Excited Lepton	Limit from 161 GeV	(from LEP1.5)
e^*	**79.7**	**(64.7)**
μ^*	**79.9**	**(64.9)**
τ^*	**79.3**	**(64.2)**
$\nu^*, \nu^* \to \nu\gamma$	**71.3**	**(61.4)**
$\nu^*, \nu^* \to eW$	**64.6**	**(57.3)**

95% CL limits for associated production:



Charged and Neutral Heavy Leptons

95% CL lower mass limits:

Unstable neutral heavy lepton

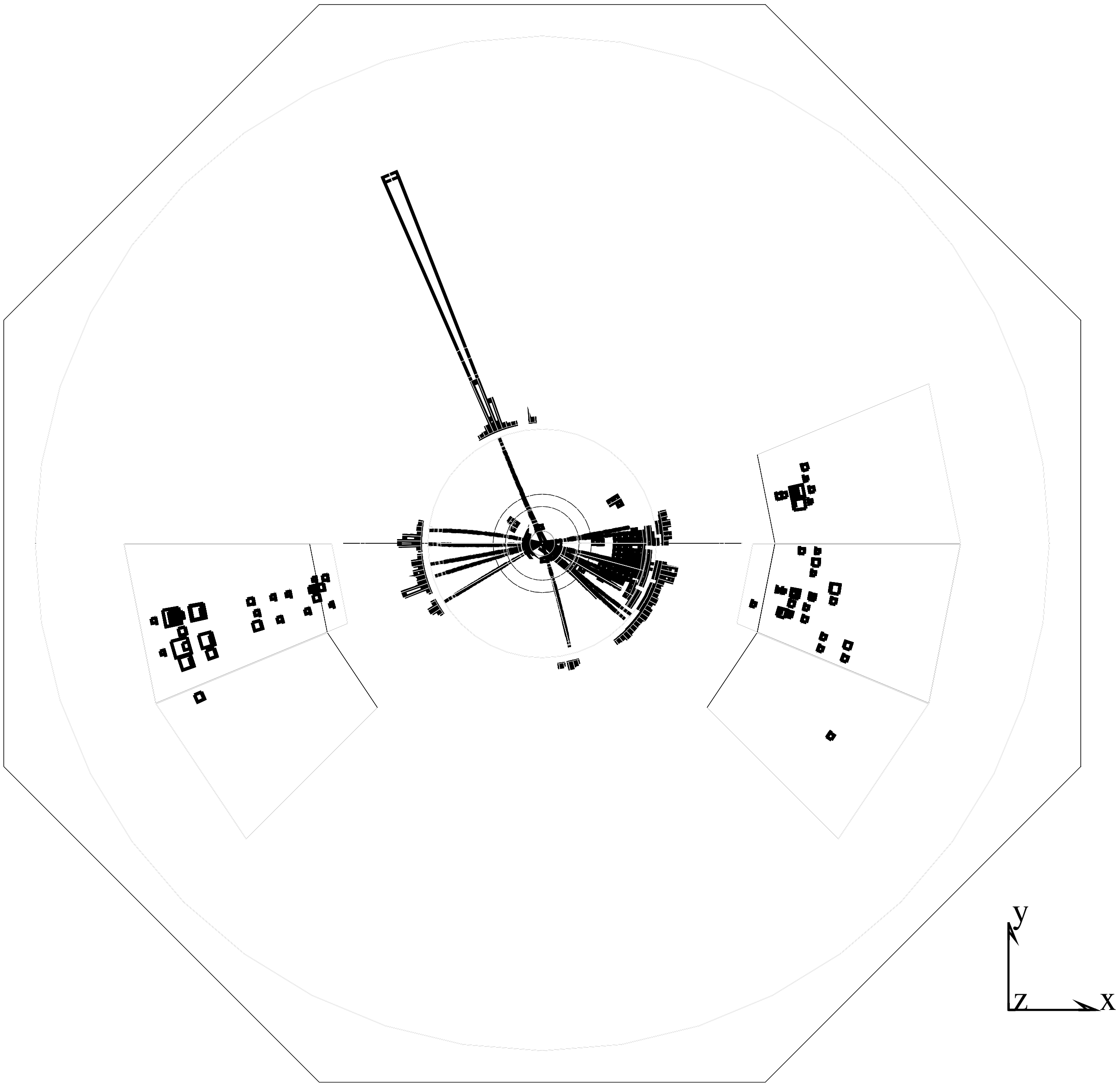
Decay mode	Events Data	Events . Backgr.	Mass Limit (GeV)
$L^0 \to e(\mu)W$	0	0.6	
Dirac L^0			72
Majorana L^0			58
$L^0 \to \tau W$	0	1.0	
Dirac L^0			65
Majorana L^0			53

Unstable charged heavy lepton

Decay mode	Events Data	Events . Backgr.	Mass Limit (GeV)
$L^\pm \to \nu W$	4	4.8	74

Charged Heavy Lepton Candidate

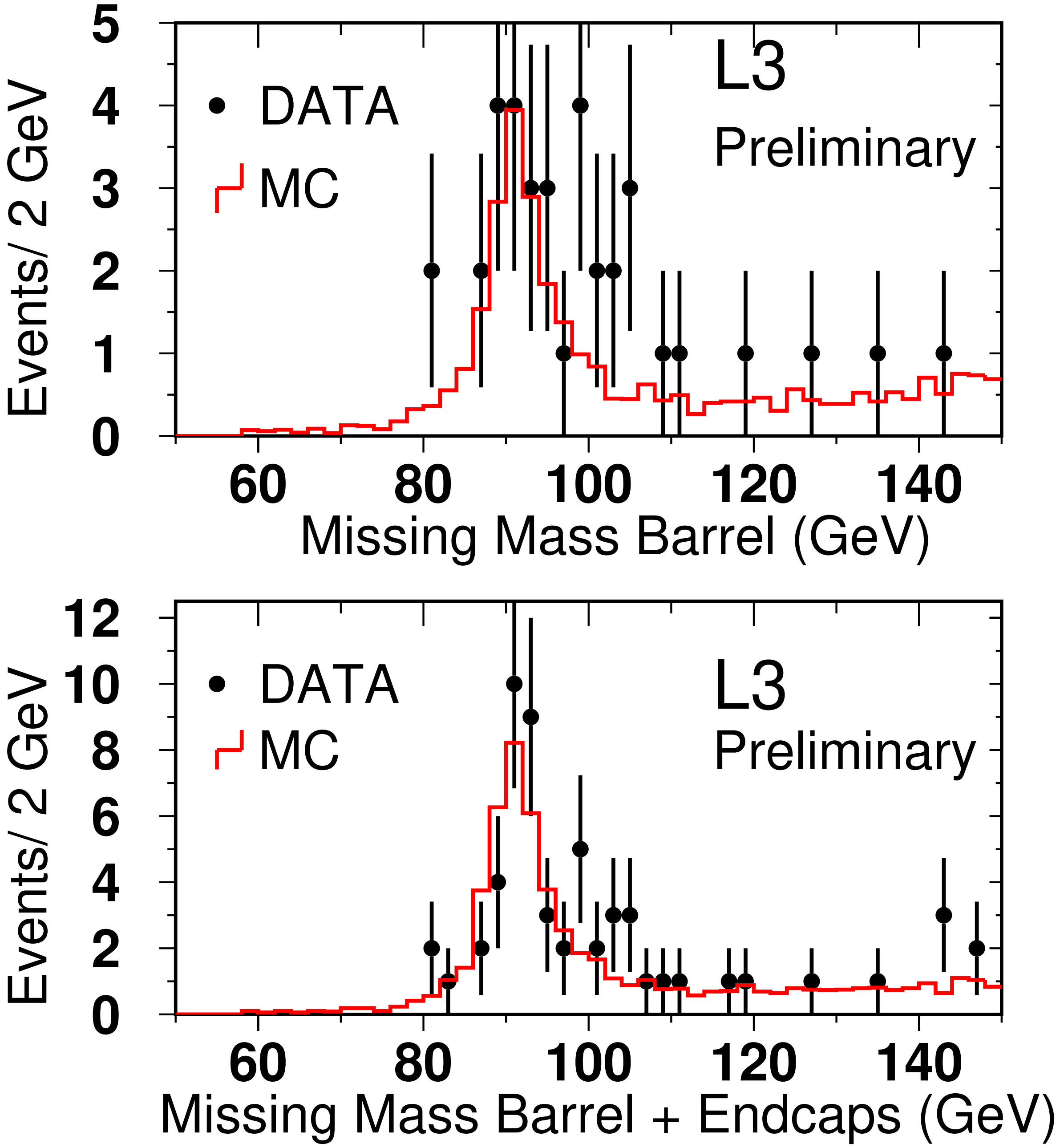
$E_{vis} = 89\mathbf{GeV}$



$E_e = 21\mathbf{GeV,}\ E_{j1} = 35.1\mathbf{GeV,}\ E_{j2} = 30.8\mathbf{GeV,}$
$M_{jj} = 64.5\mathbf{GeV}$

Single and Multiphoton Events

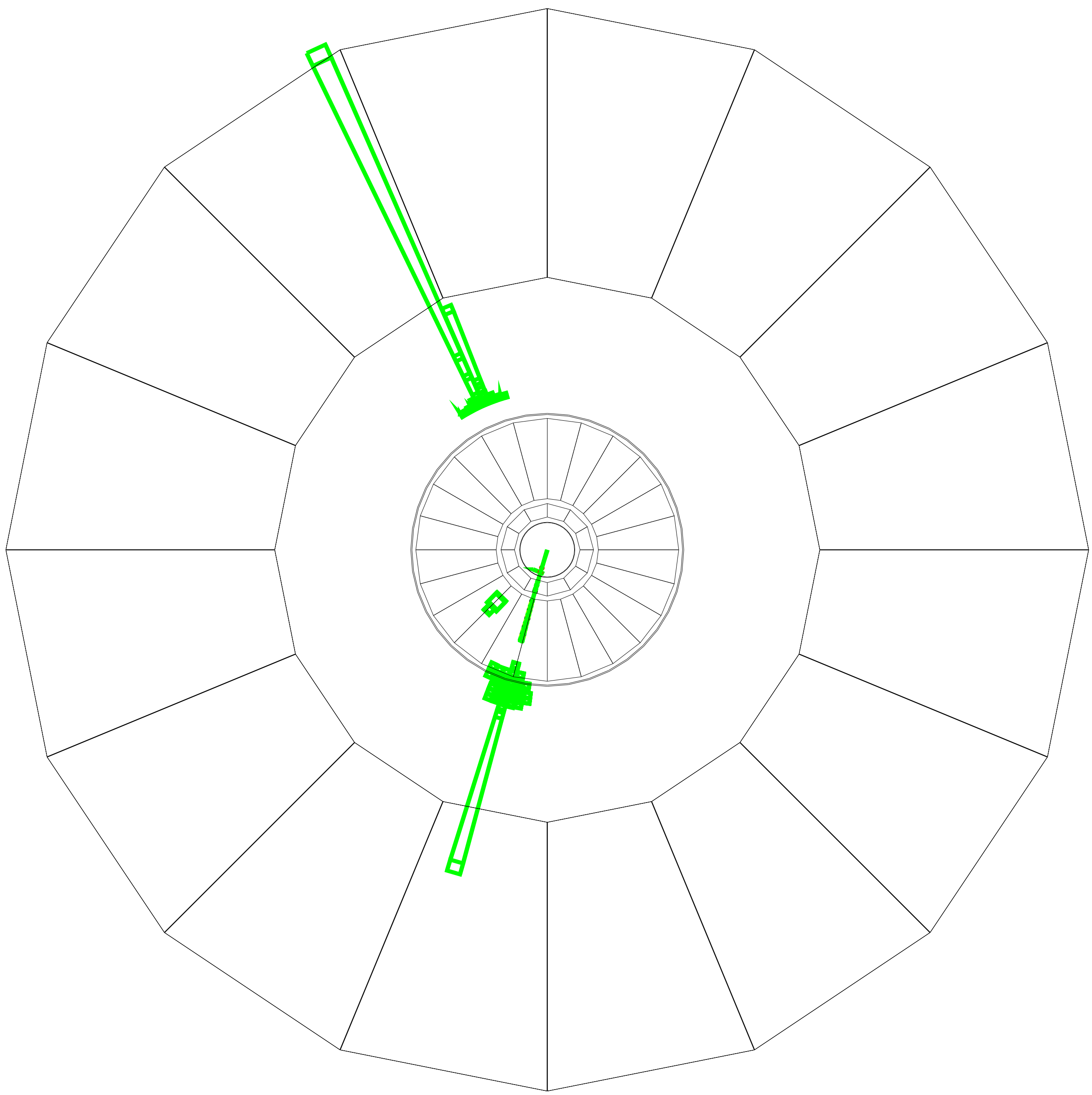
Expected events: 58.5 (30.7 in barrel, 27.7 in endcap)
Observed events: 58 (35 in barrel, 23 in endcap)



Multiphoton Events with Missing Energy

Might be a sign of supersymmetry (neutralinos)

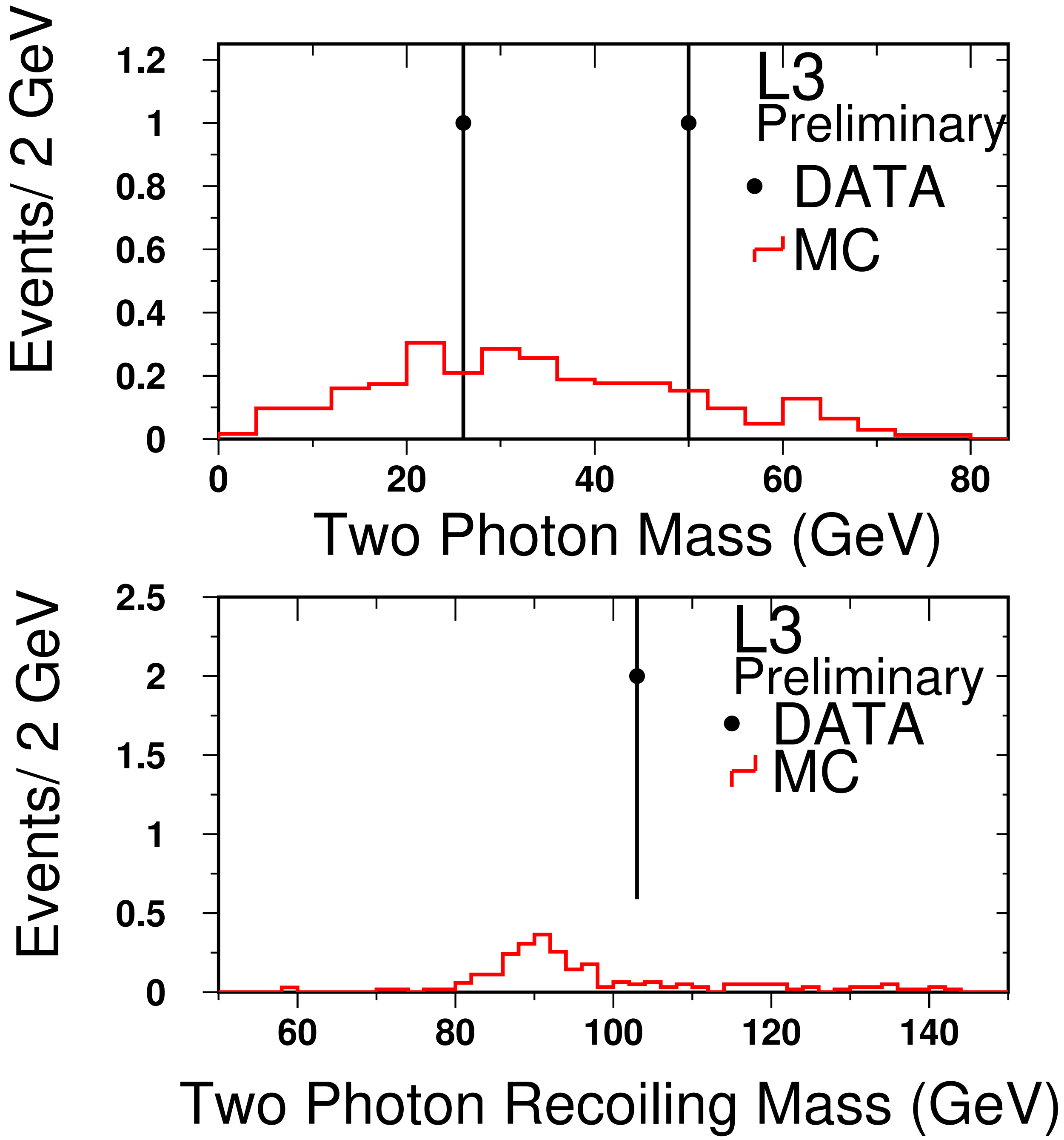
$E_{\gamma 1} = 36.2$ **GeV,** $E_{\gamma 2} = 19.8$ **GeV**



Multiphoton Events with Missing Energy

Expected events: 2.8
Observed events: 2

$10 < E_{\gamma 1} < 70$**GeV**
$E_{\gamma 2} > 5$**GeV**



Conclusions

- Cross sections and asymmetries for fermion pair production in agreement with SM expectation
- Hadronic $Z\gamma$ interference term better determined
- Characteristics of hadronic events in agreement with QCD evolution
- $\sim$21 WW events have been observed
- W mass is determined from WW cross section to be $M_W = 80.95^{+0.56}_{-0.46} \pm 0.1$ (LEP)
- ZWW coupling in agreement with SM expectations, for $M_W = 80.292$ (from LEP 1) we get $\delta_Z = -0.1 \pm 1.4$
- Other four fermion production rates in agreement with SM background, including four jet rate and mass distribution
- No sign of SM or other Higgses
- No sign of SUSY, upper limits on cross sections of order 0.5 pb
- No sign of excited leptons or further heavy leptons
- Single and multiphoton rates look normal

L3 is looking forward to running at higher energies