L3 Results from the 189 GeV run

(Report to the LEPC)

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NIKHEF

24 March 1999

On behalf of the L3 collaboration

All results are preliminary

Papers for the winter conferences:
http://l3www.cern.ch/conferences/Moriond99

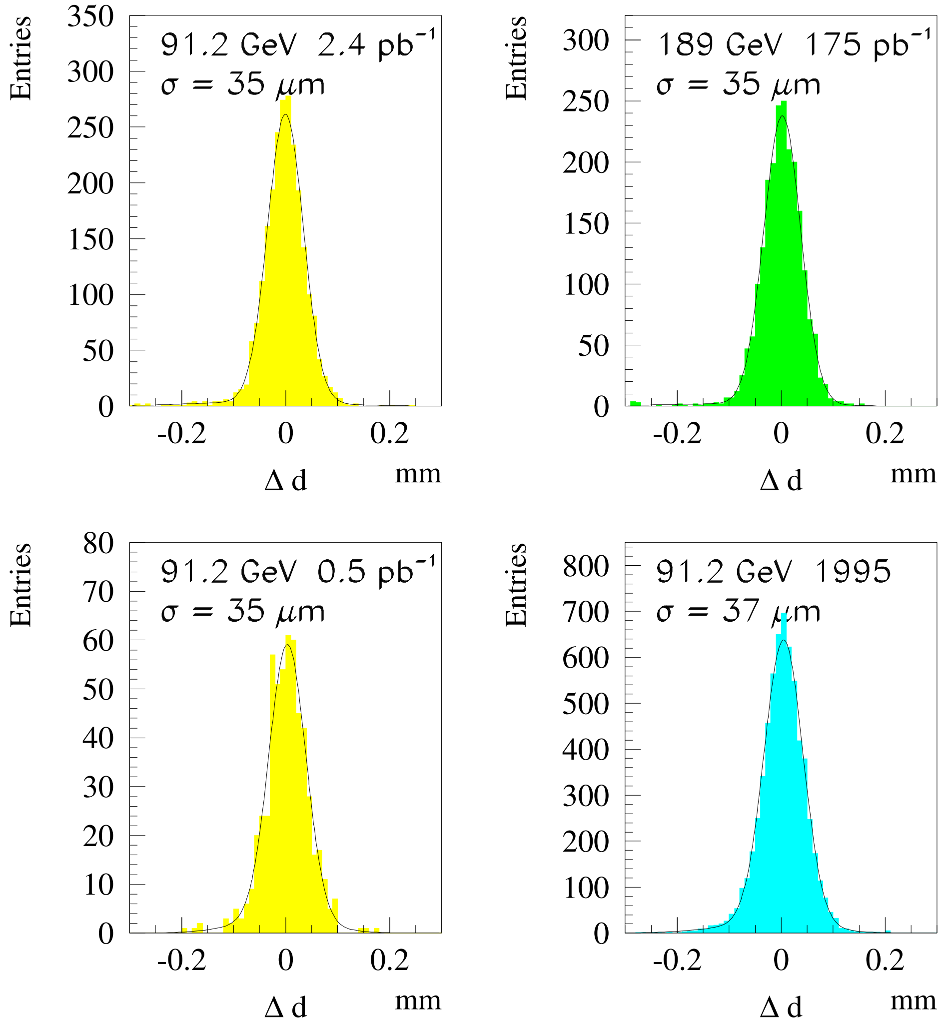
DCA resolution of TEC-SMD

Collected Luminosity in 1998:

- 91 GeV: 2.4 + 0.6 pb^{-1} at 92.0% efficiency
- 189 GeV: 176.4 pb^{-1} at 89.3%

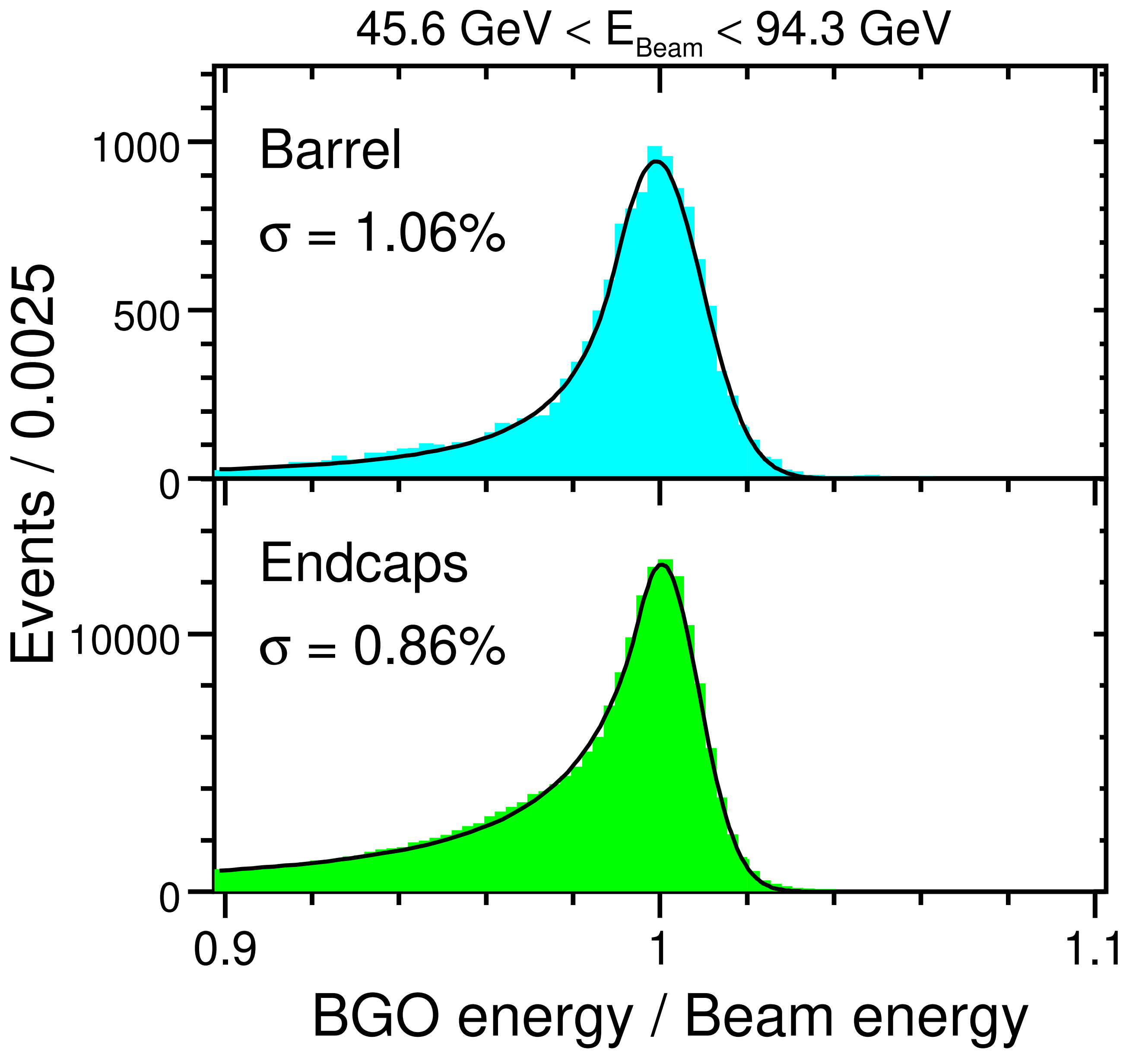
Total above the W^+W^- threshold: 253 pb^{-1}.

Performance of the TEC-SMD in 1998: DCA distributions of Bhabha and $\mu^+\mu^-$ events

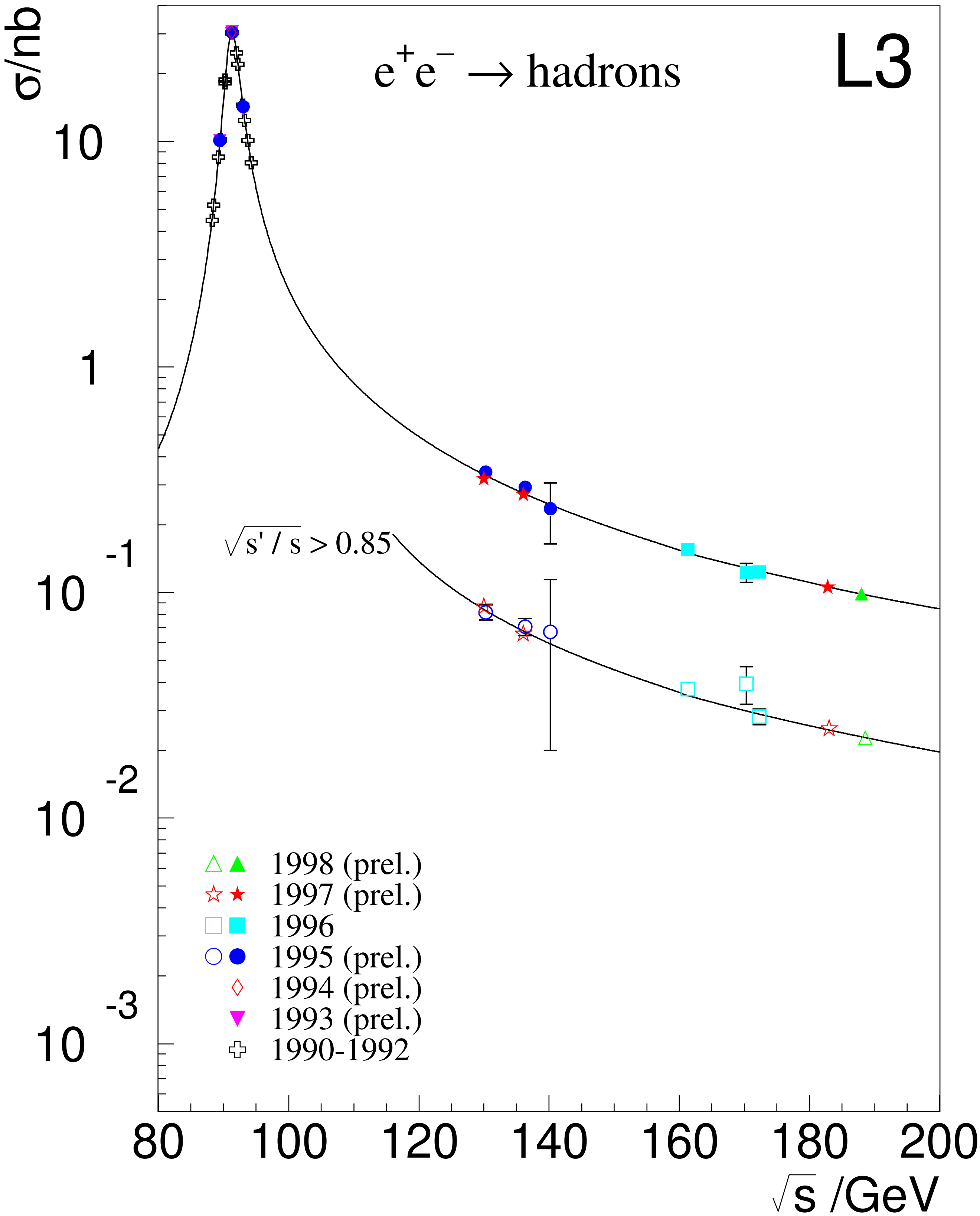


BGO Performance

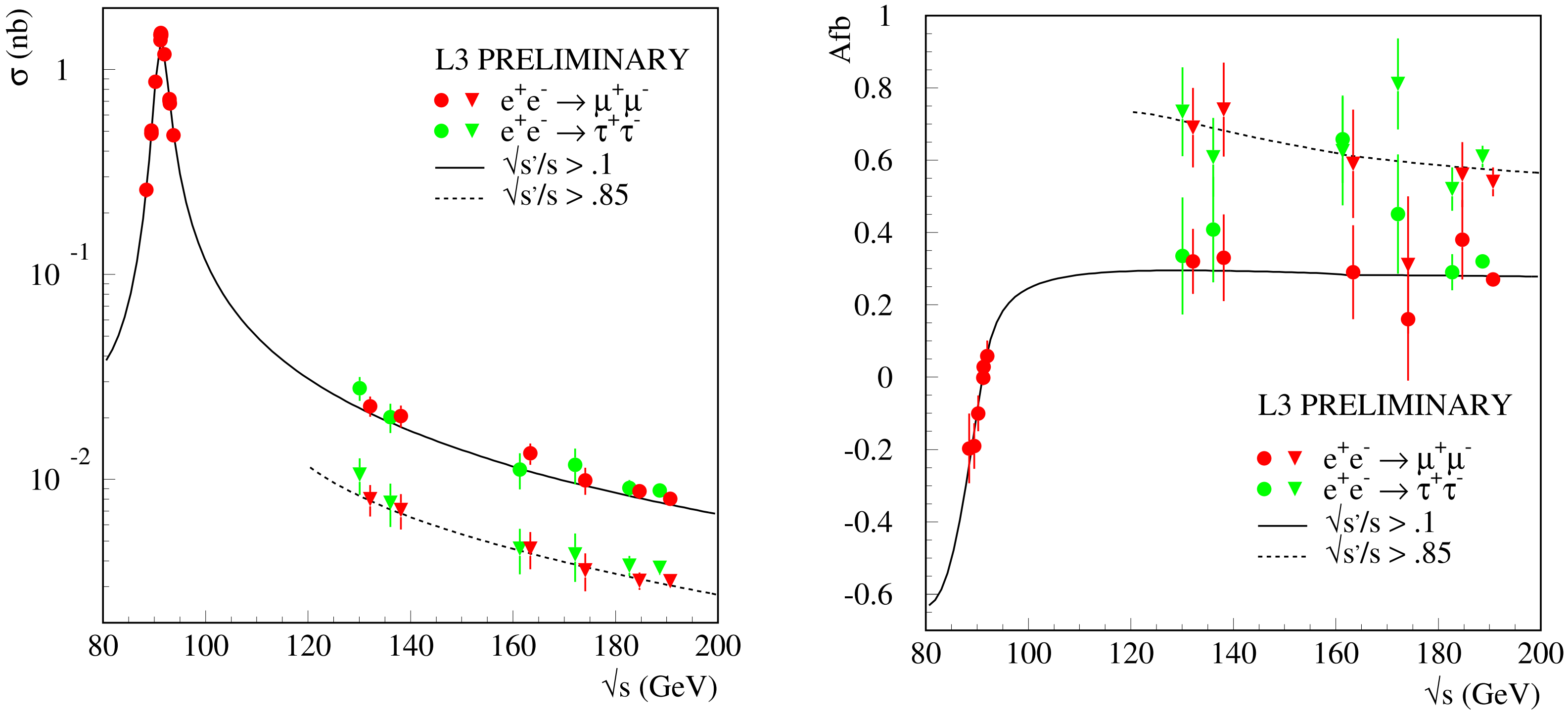
Performance of the BGO detector in 1998 (Bhabha events):



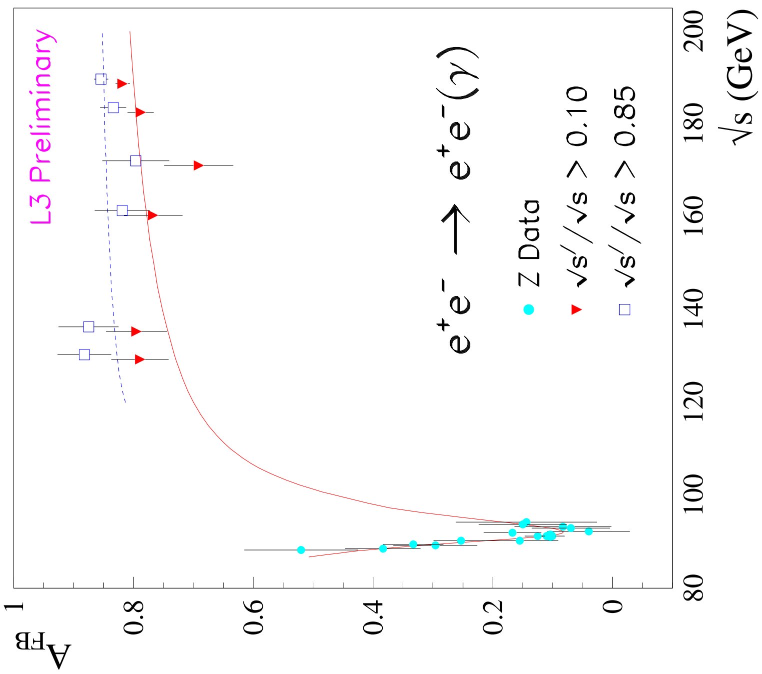
Fermion-Pair Production

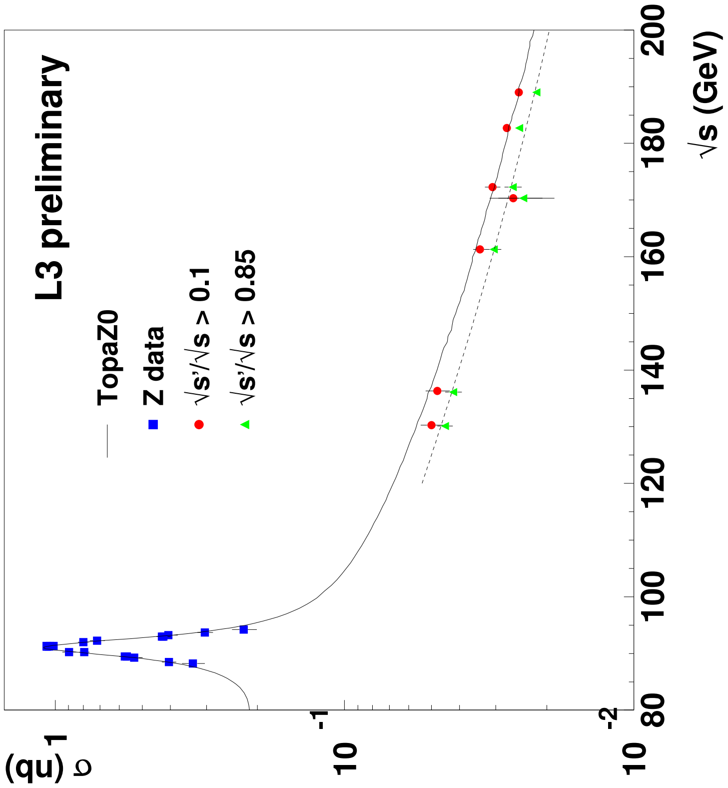


Fermion pairs

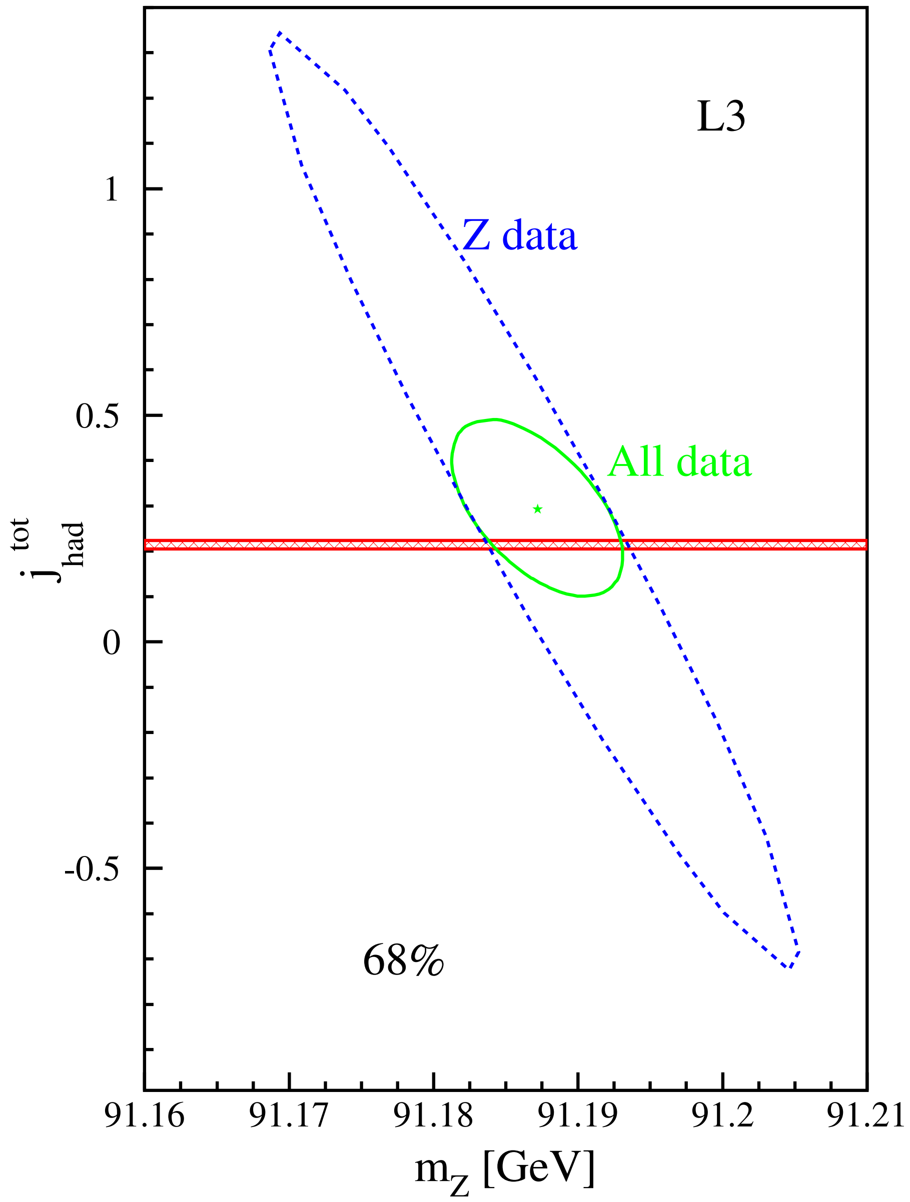


Fermion pairs





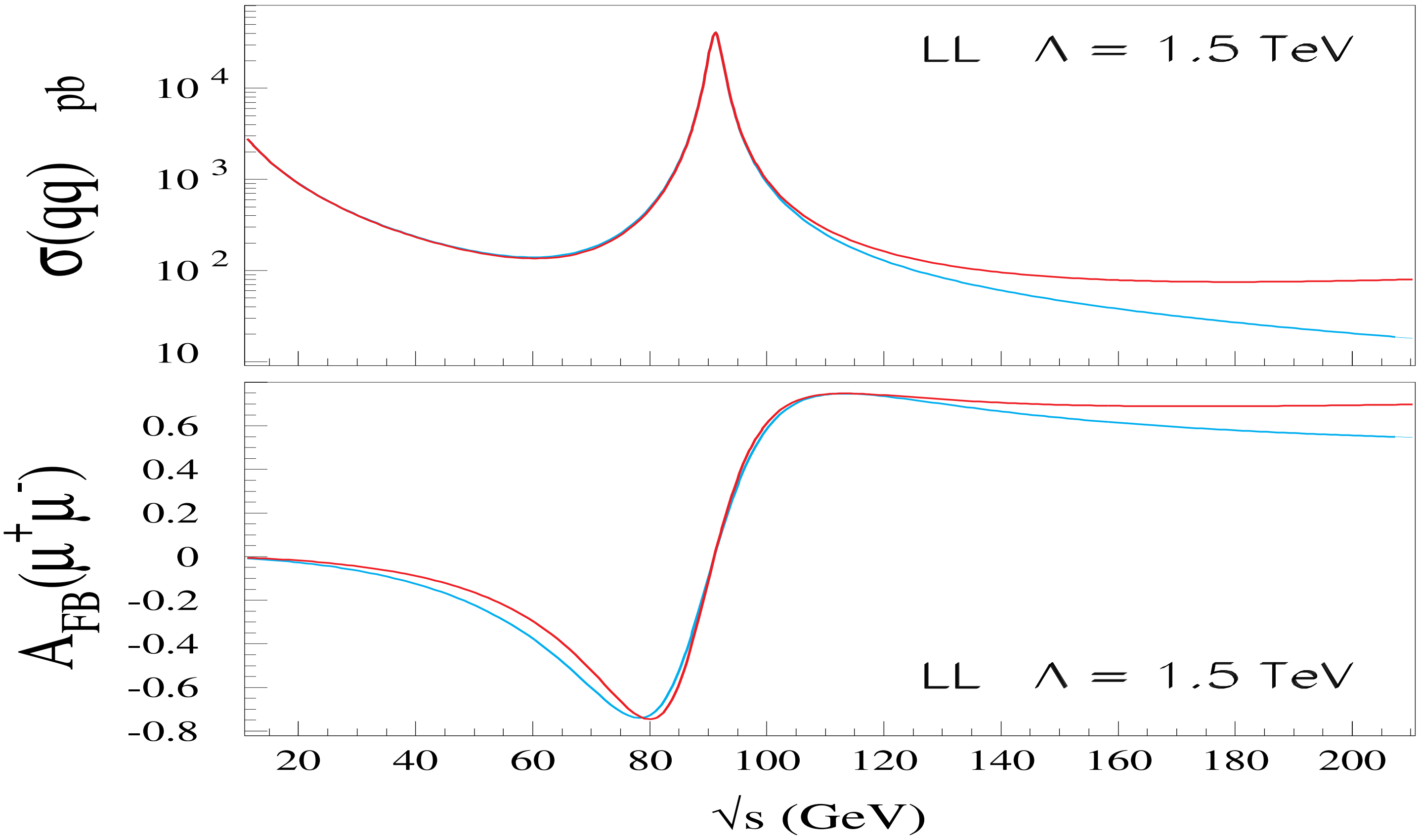
Hadronic γZ interference term:

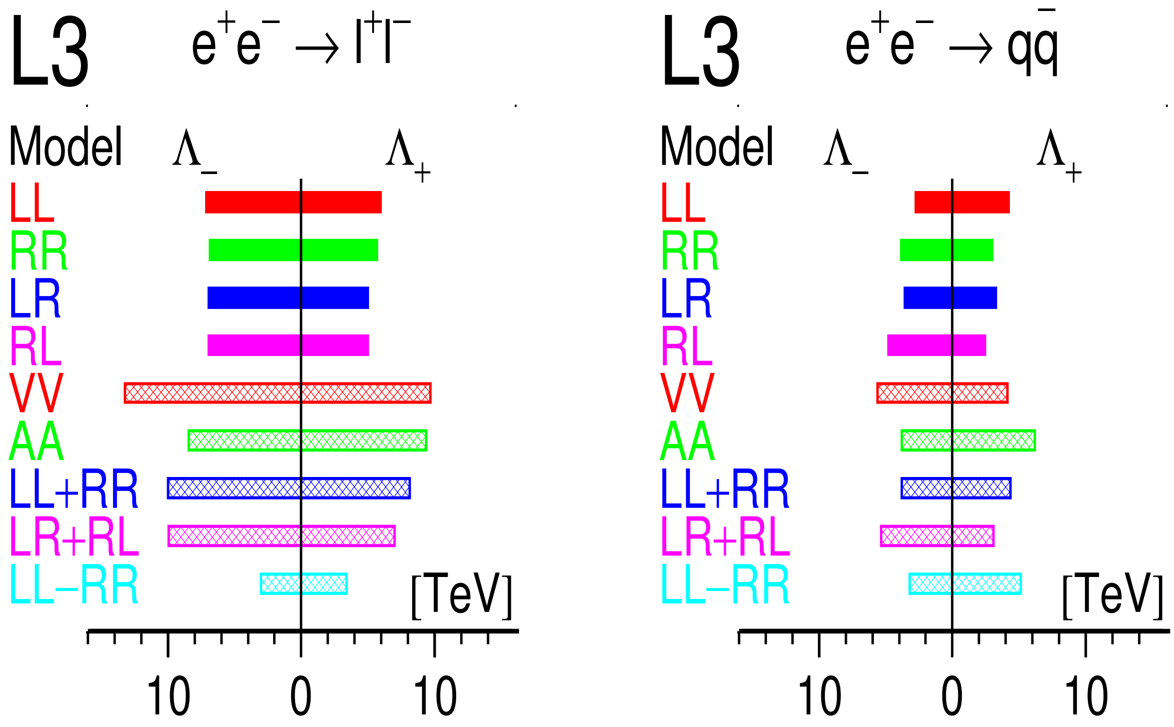


Fits in the S-matrix framework:

	j_{had}^{tot}	m_Z [MeV]
LEP I	0.18±0.73	91188 ±13
$\sqrt{s} \leq 189$ GeV	0.29±0.13	91187.2± 3.9
Standard Model	0.21	

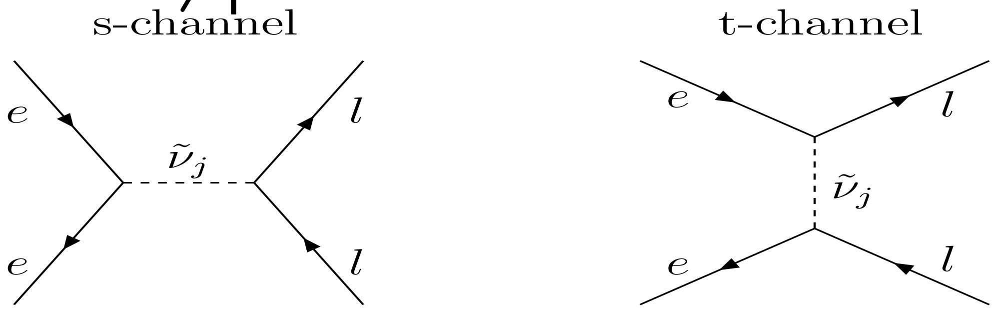
Contact Interactions



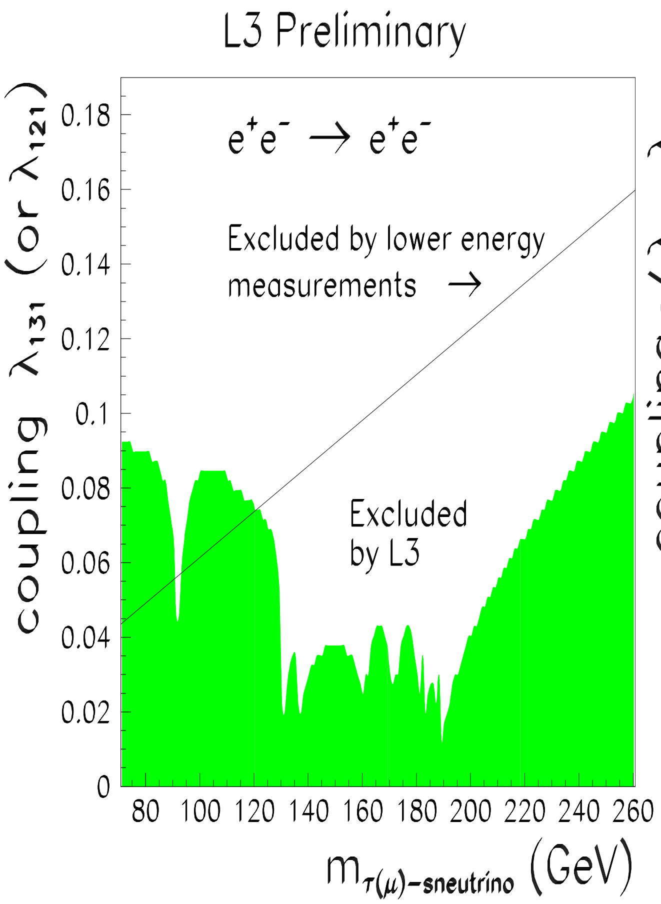


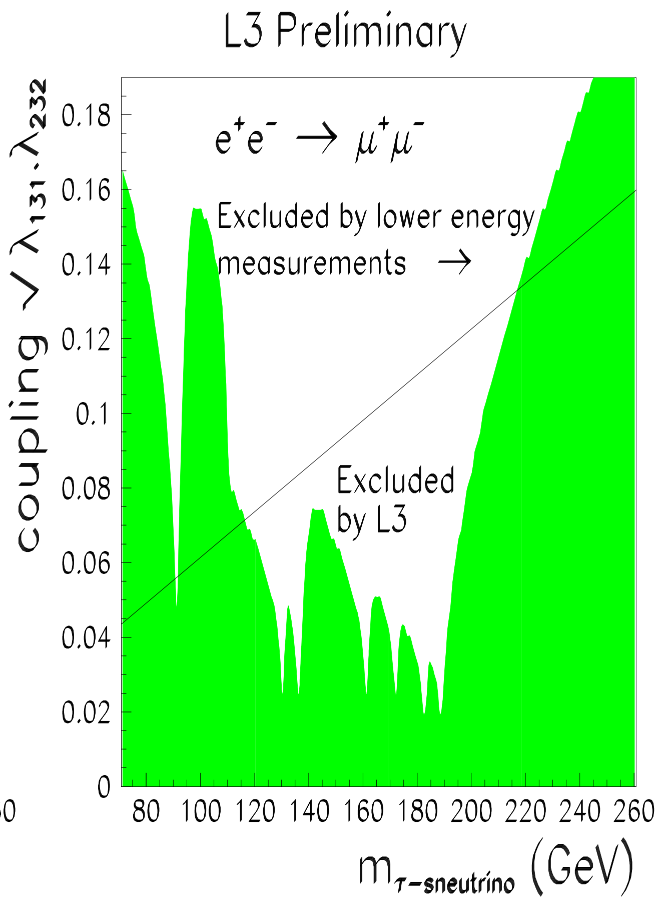
Contact Interactions

Resonance formation & t-channel exchange of single $\tilde{\nu}$ in $\not{R}_P$ theories



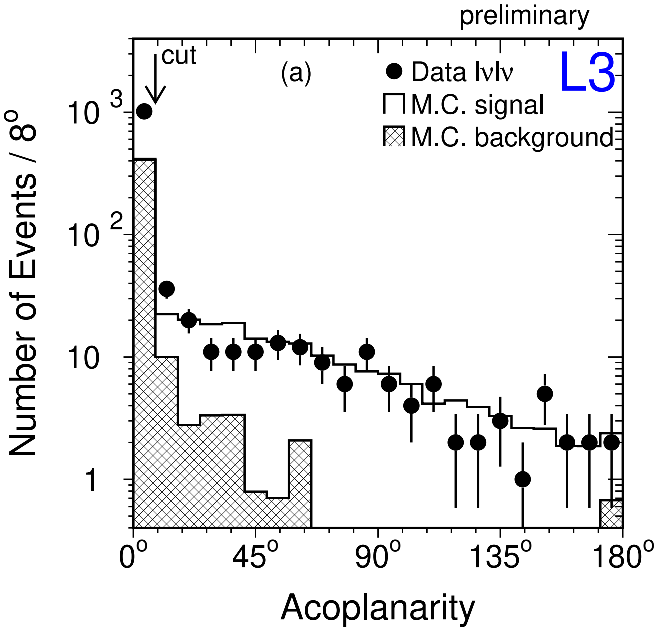
	s-channel	t/u-channel	Coupling
Amplitude	$\frac{1}{2} \cdot \frac{(\lambda_{1jk}/e)^2 \cdot s}{s - m_j^2 + i\Gamma_j m_j}$	$\frac{1}{2} \cdot \frac{(\lambda_{1jk}/e)^2 \cdot s}{t - m_j^2}$	$\frac{\lambda}{m_x} \simeq \frac{\sqrt{8\pi}}{\Lambda} \Rightarrow \lambda \simeq 5.01 \frac{m_x}{\Lambda}$



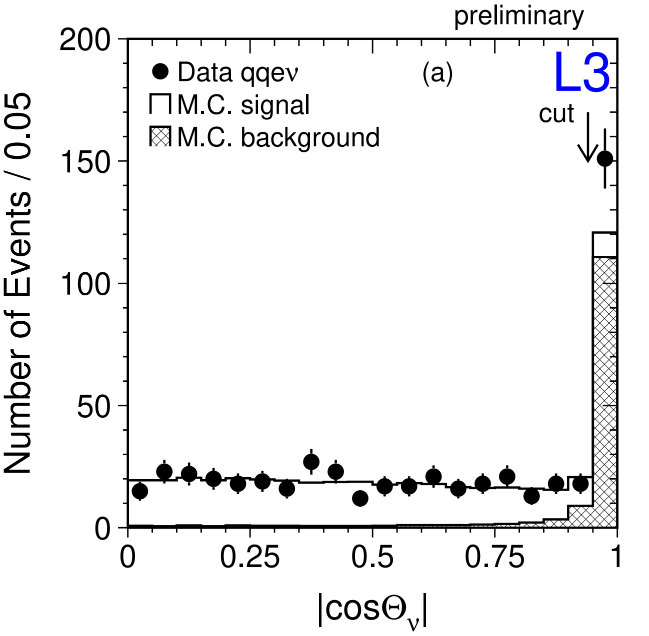


Boson Pair Production: $W^+ W^-$

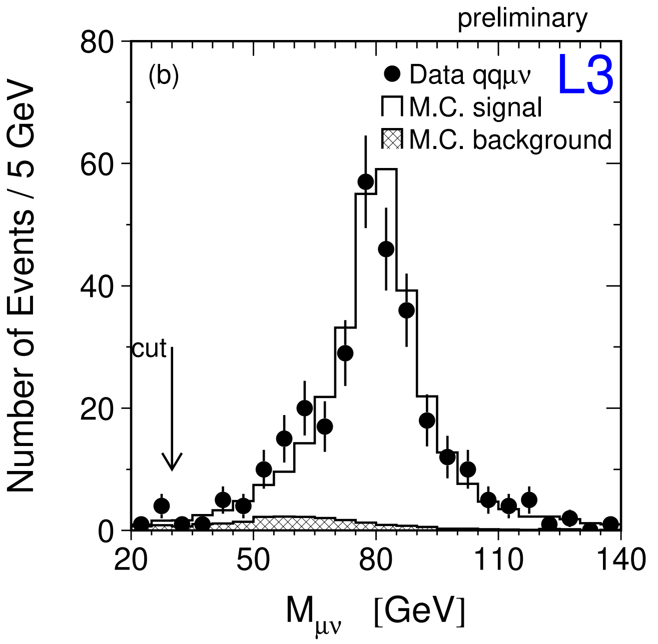
$l\nu l\nu$



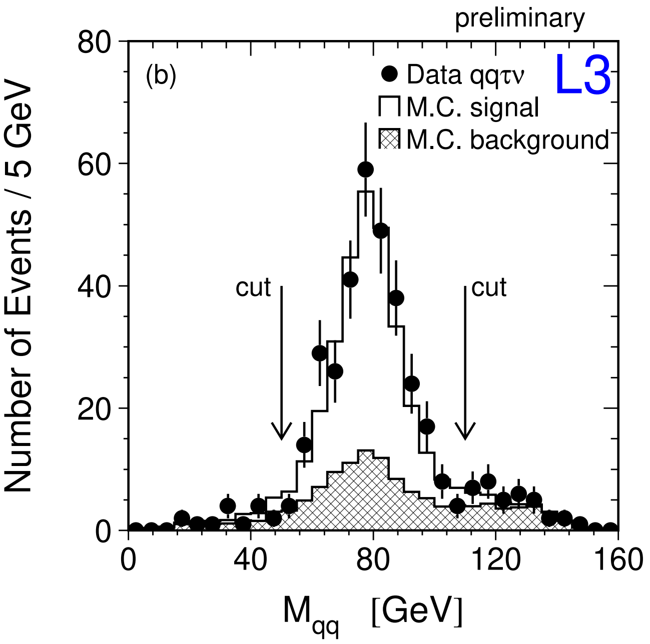
$qqe\nu$



$qq\mu\nu$



$qq\tau\nu$

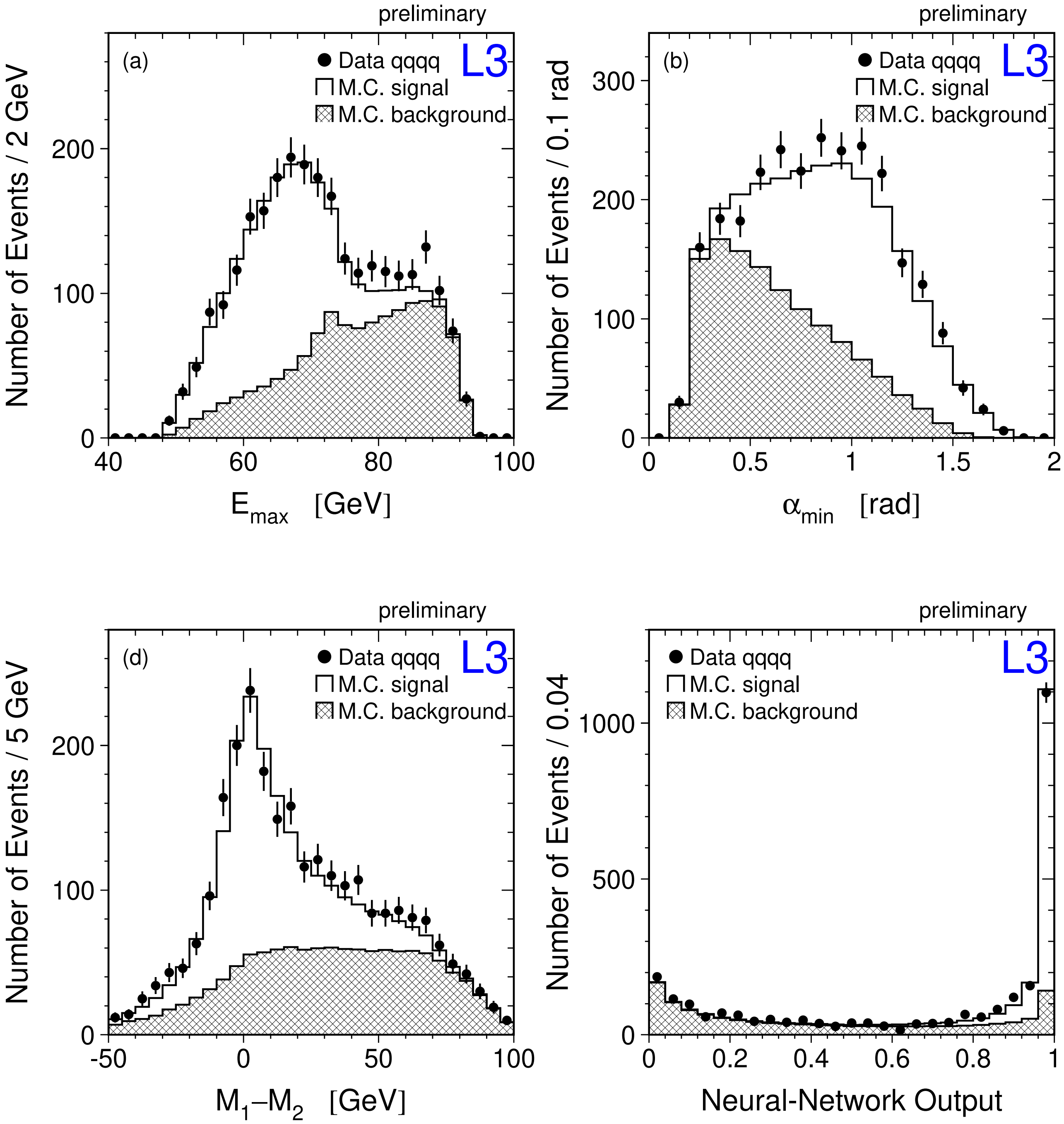


$\sigma_{\mathrm{qql}\nu} = 7.14 \pm 0.24(stat) \pm 0.09(syst)\mathrm{pb}$ $[\sigma_{\mathrm{SM}} = 7.29\ \mathrm{pb}]$

$\sigma_{\mathrm{l}\nu\mathrm{l}\nu} = 1.56 \pm 0.13(stat) \pm 0.04(syst)\mathrm{pb}$ $[\sigma_{\mathrm{SM}} = 1.77\ \mathrm{pb}]$

Selection of $e^+e^- \rightarrow W^+W^- \rightarrow qqqq$

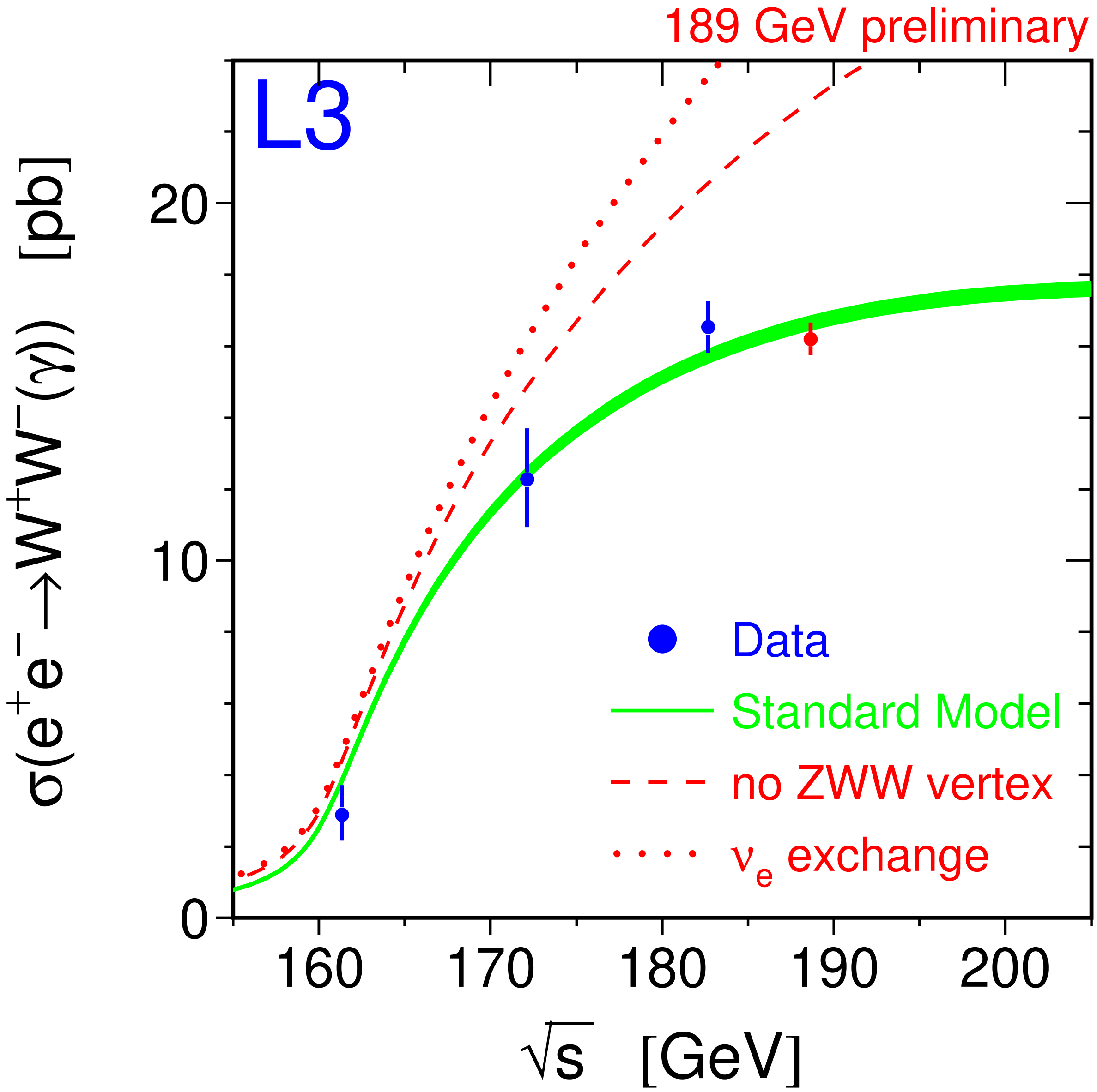
Neural-Network based on 8 input variables, e.g.:



Fit to NN output:

$\sigma_{\mathrm{qqqq}} = 7.46 \pm 0.25(stat) \pm 0.22(syst)$pb [$\sigma_{\mathrm{SM}}$ = 7.59 pb]

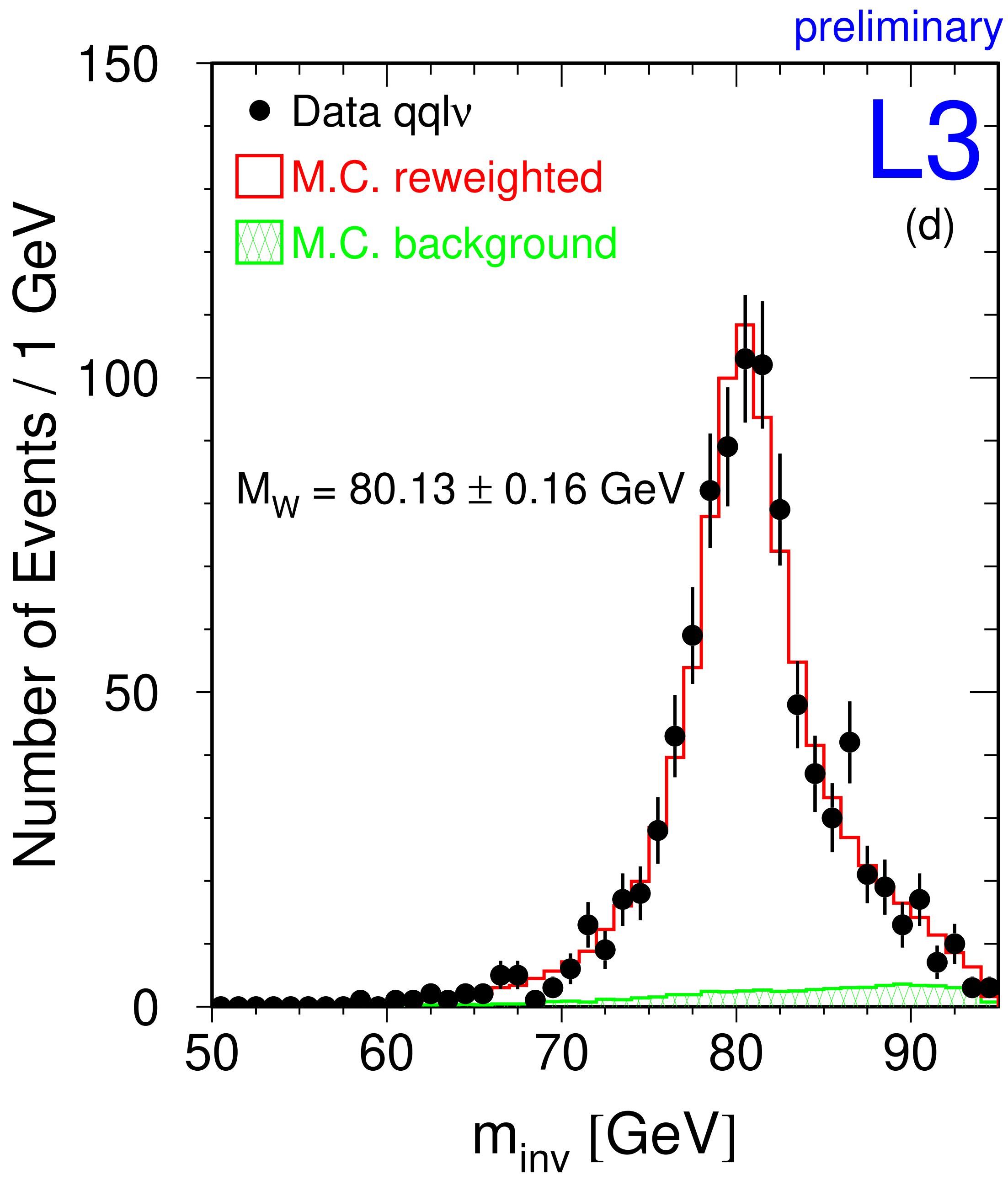
Boson Pair Production: $W^+ W^-$



channel	Branching Fraction (%)	SM (%)
$W \rightarrow e\nu$	$10.31 \pm 0.44 \pm 0.17$	10.83
$W \rightarrow \mu\nu$	$9.95 \pm 0.46 \pm 0.17$	10.83
$W \rightarrow \tau\nu$	$11.20 \pm 0.63 \pm 0.25$	10.83
$W \rightarrow q\bar{q}$	$68.54 \pm 0.69 \pm 0.39$	67.51

Derived: $|V_{cs}| = 1.032 \pm 0.033(stat) \pm 0.018(syst)$

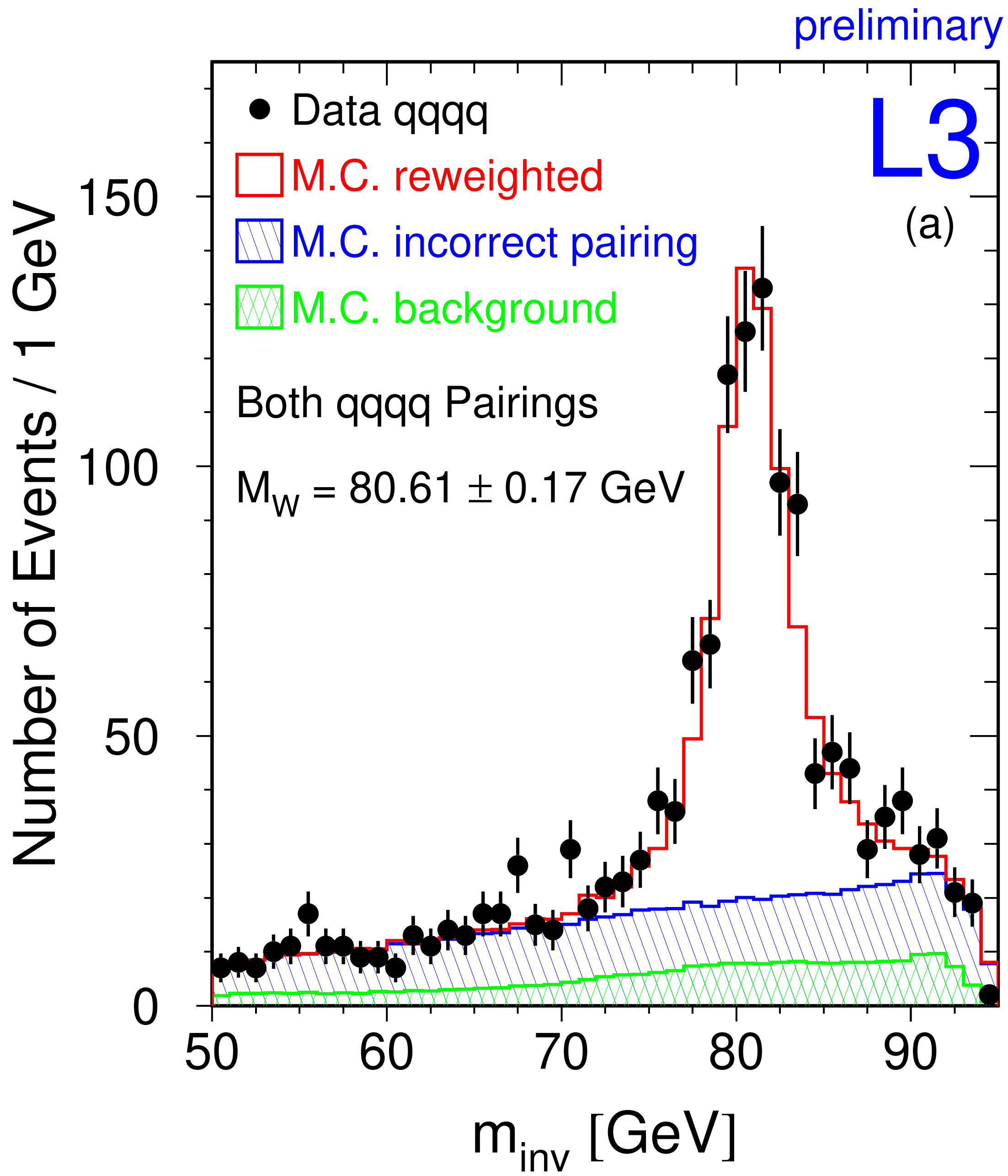
W mass $q\bar{q}\ell\nu$ events



Reconstructed W mass from $q\bar{q}\ell\nu$ events (including 172 and 183 GeV data):

$$m_{\mathrm{W}} = 80.22 \pm 0.12(stat) \pm 0.07(syst)\ \mathrm{GeV}$$

W mass $q\bar{q}q\bar{q}$ events

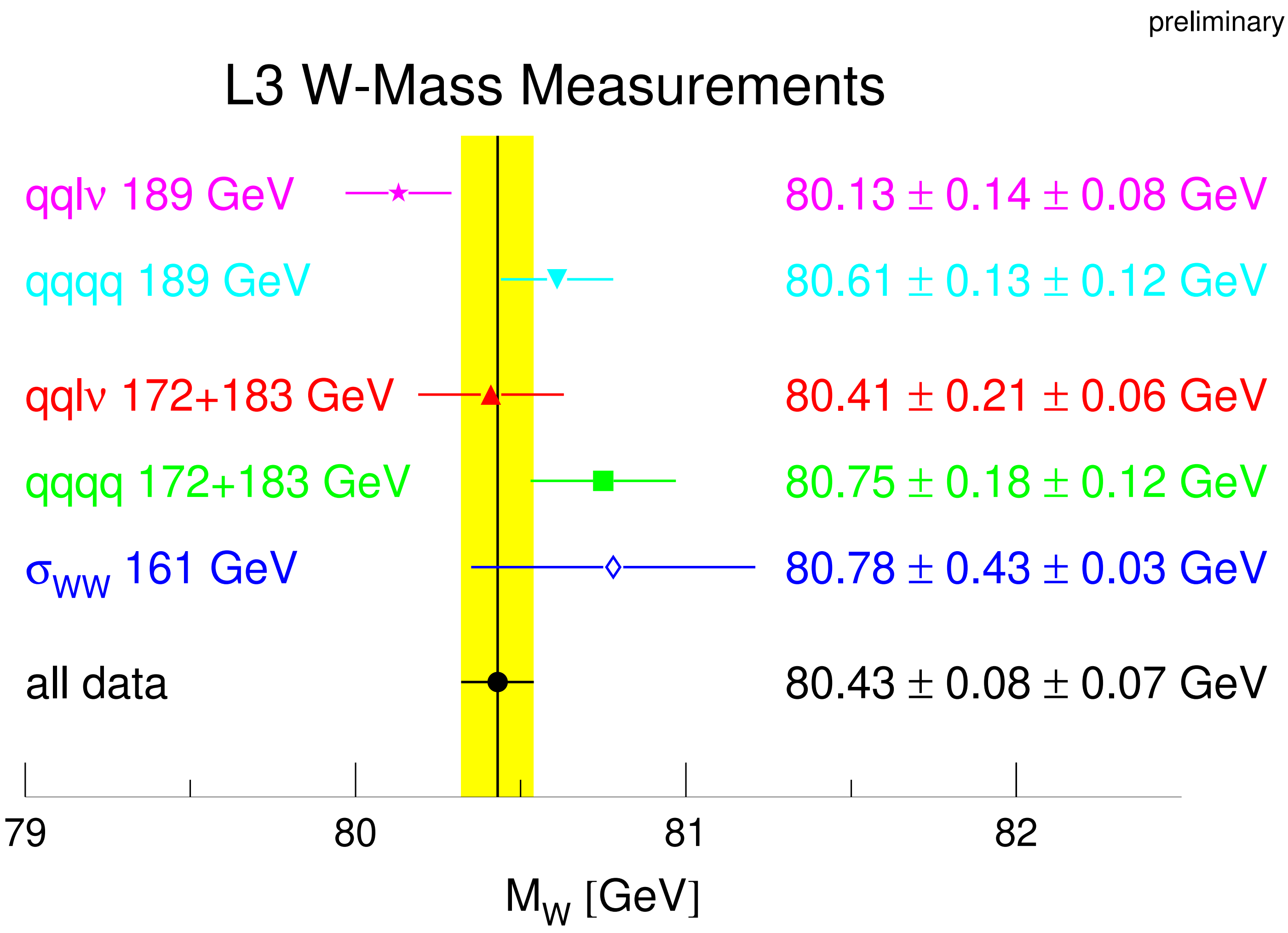


Reconstructed W mass from $q\bar{q}q\bar{q}$ events (including 172 and 183 GeV data):

$$m_W = 80.66 \pm 0.10(stat) \pm 0.12(syst) \text{ GeV}$$

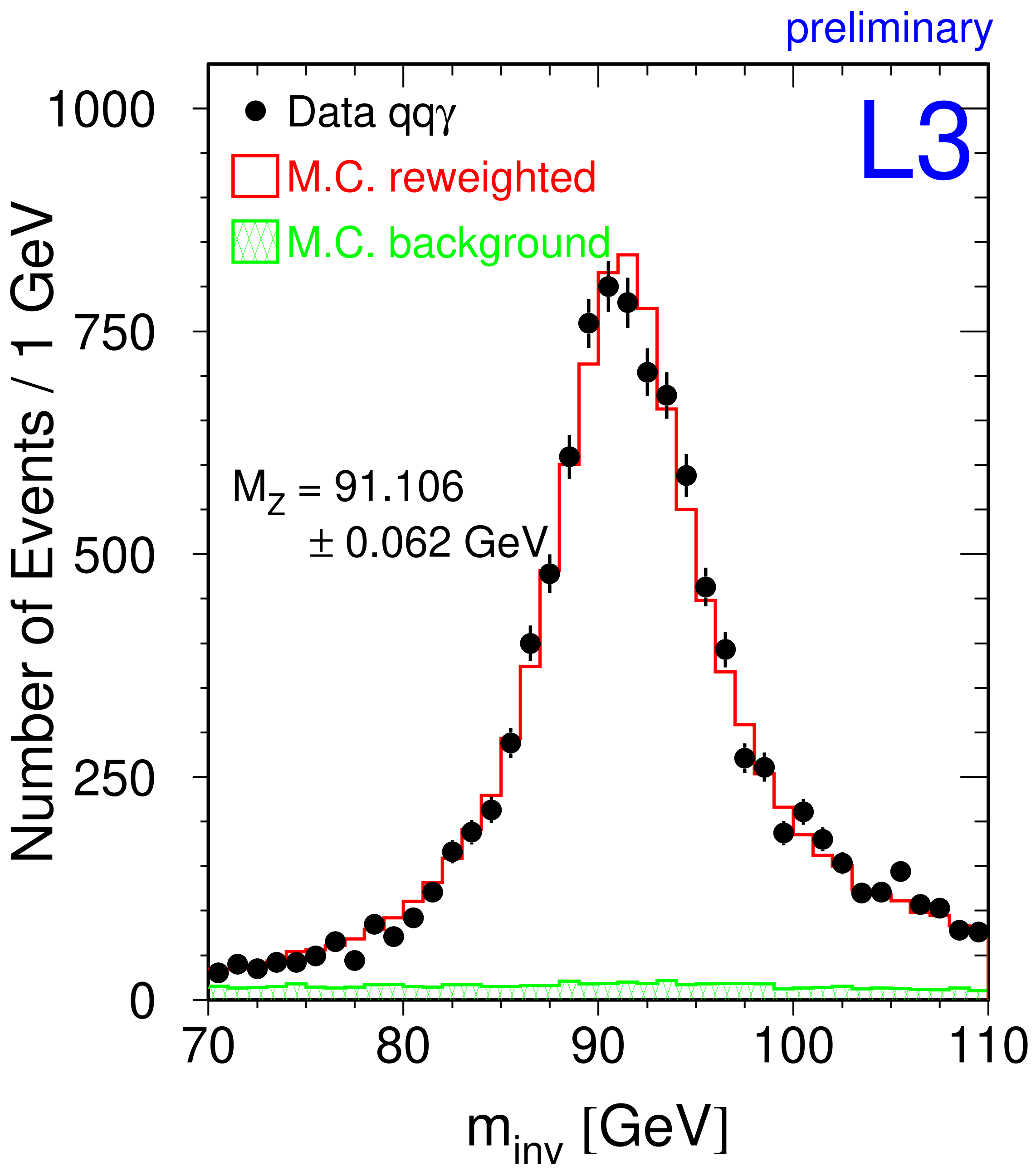
Systematic error dominated by Colour Reconnection and Bose-Einstein effects.

Combination of W mass measurements



CHECK: Return to Z events

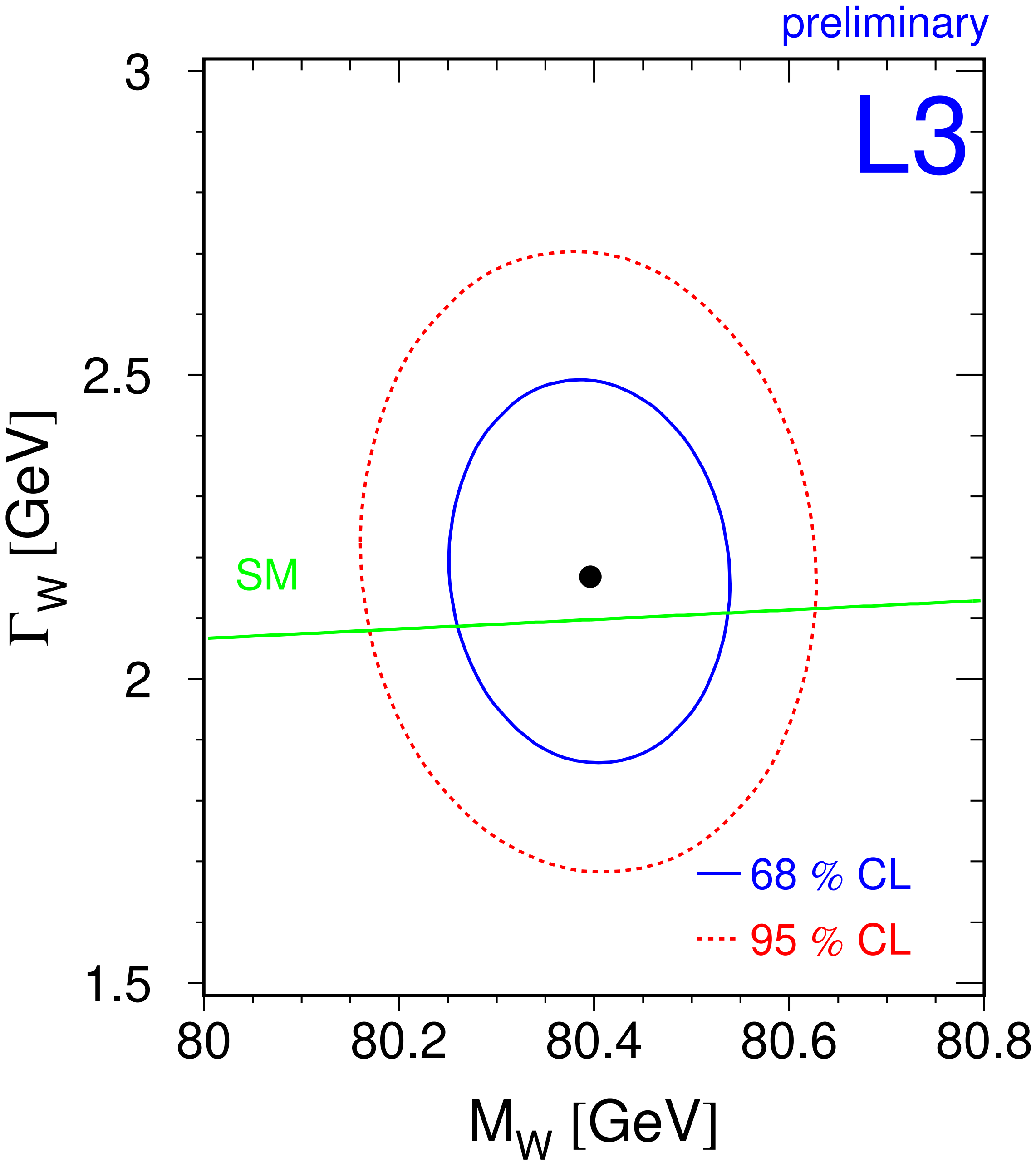
Cross check of W-mass analysis with radiative
$e^+e^- \to Z\gamma, Z \to q\bar{q}$ events



Good agreement with $m_Z = 91.188 \pm 0.003$ GeV
measured using the Z-lineshape data

W mass and width

Simultaneous fit for W mass and total width:

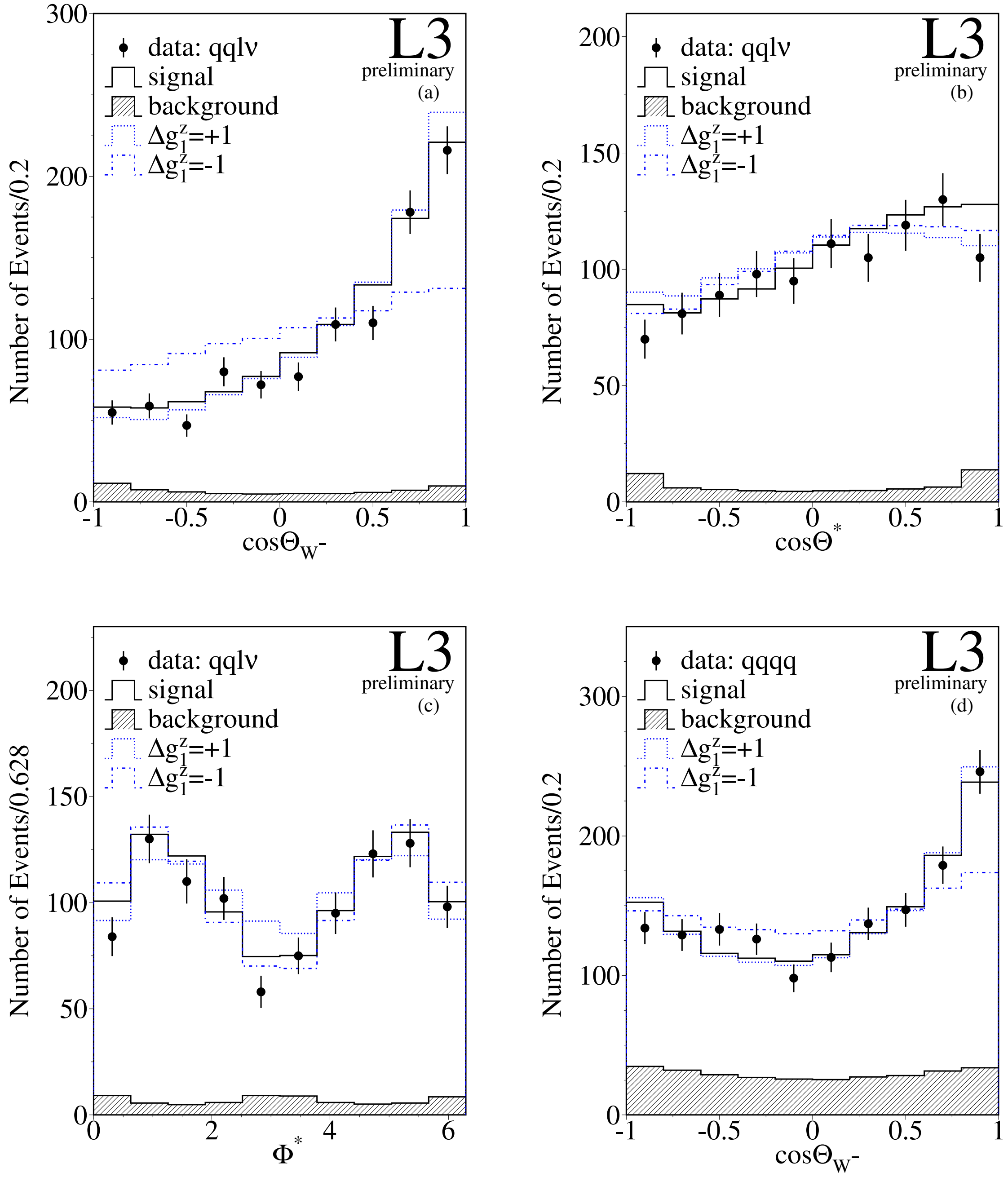


All data ($\sqrt{s}$ = 172 to $\sqrt{s}$ = 189 GeV):

$$\Gamma_W = 2.12 \pm 0.18(stat) \pm 0.18(syst) \text{ GeV}$$

Gauge Couplings of W

Affect: Total cross section, W production and polarisation



Results of 1-parameter fits : SM value

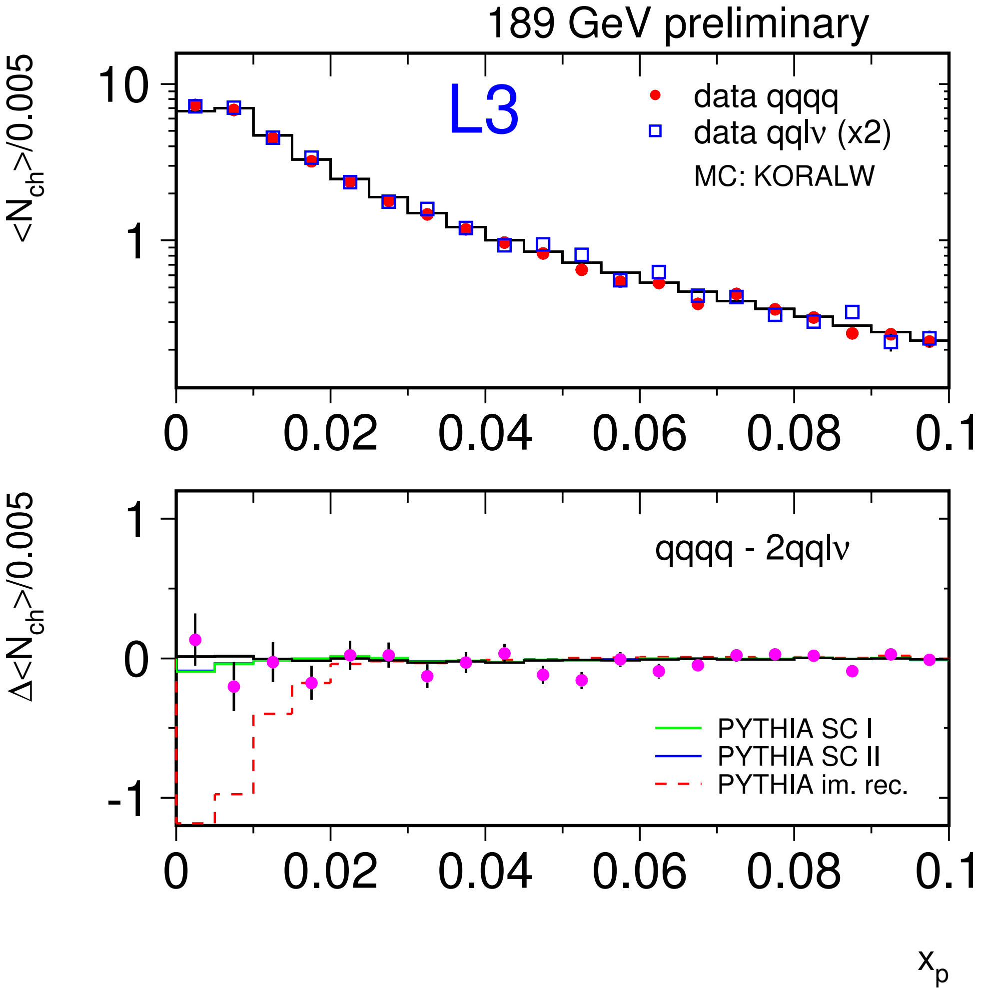
$$g_1^Z = 0.98 \pm 0.07 \pm 0.03 \qquad 1$$

$$\kappa_\gamma = 0.88^{+0.14}_{-0.12} \pm 0.08 \qquad 1$$

$$\lambda_\gamma = 0.00 \pm 0.07 \pm 0.03 \qquad 0$$

Charged multiplicity in W-pair events

$x_p = 2p/\sqrt{s}$ distribution of charged particles in WW events:



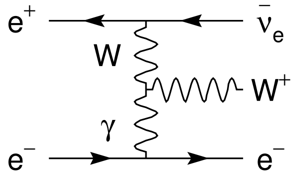
Average charged particle multiplicity:

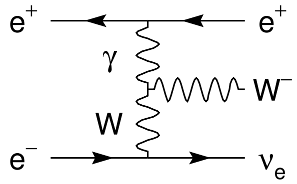
$$\Delta < N_{\mathrm{ch}}^{\mathrm{qqqq}} > (\mathrm{data} - \mathrm{MC}) \;=\; \mathbf{0.0 \pm 0.8}$$

$$\Delta < N_{\mathrm{ch}} > (\mathrm{qqqq} - 2\mathrm{qq}\ell\nu) \;=\; \mathbf{-0.3 \pm 0.6}$$

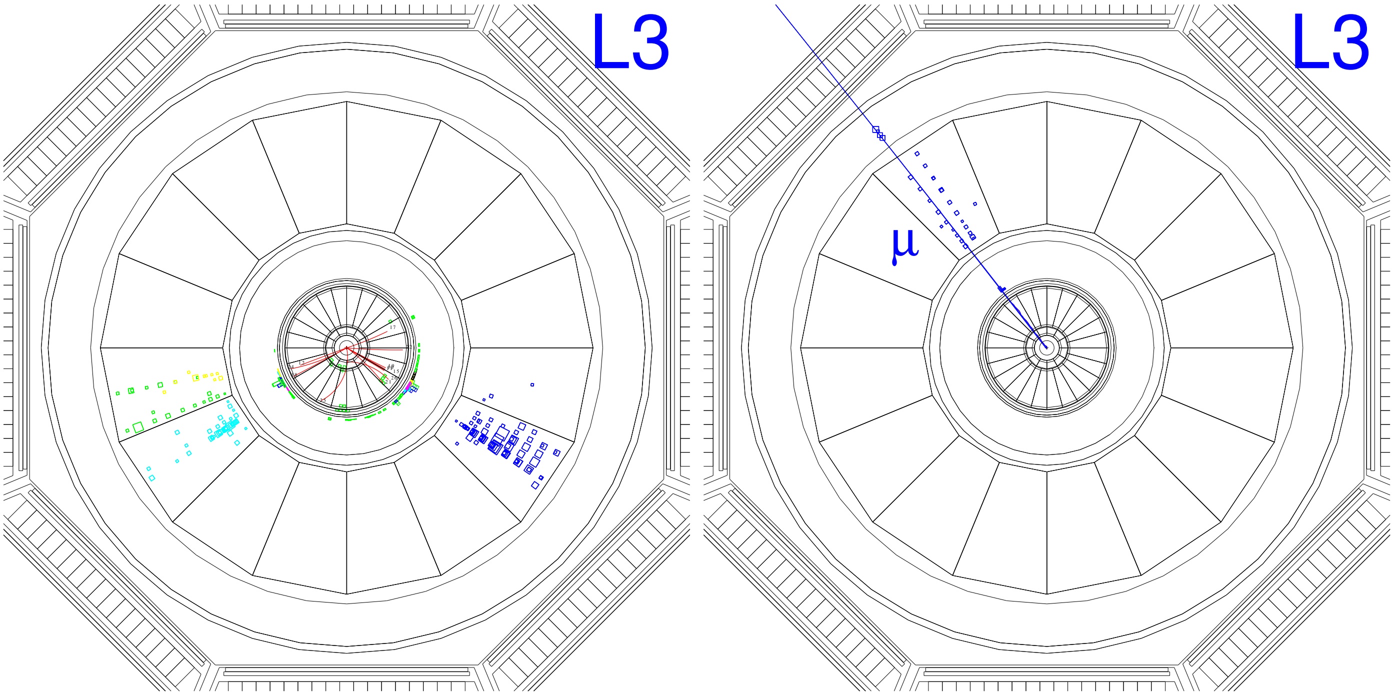
Consistent with 0 as well as with moderate colour reconnection models. Large effects on multiplicity in qqqq events are excluded.

Single W Production





∘ Electron is escaping along the beam pipe

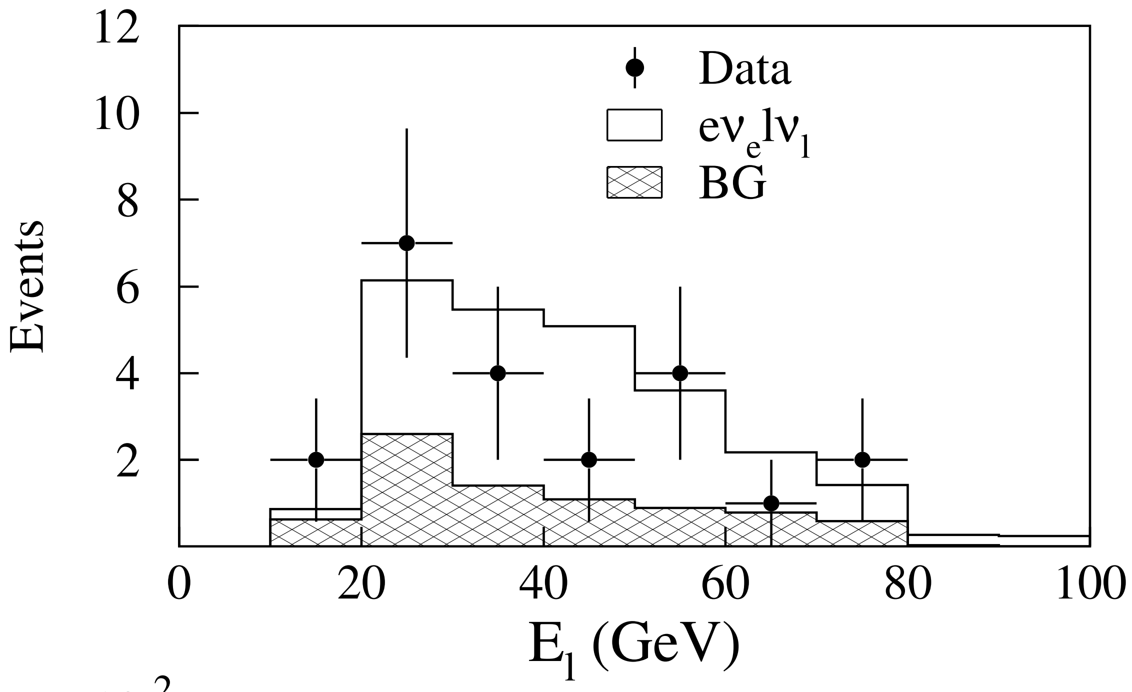


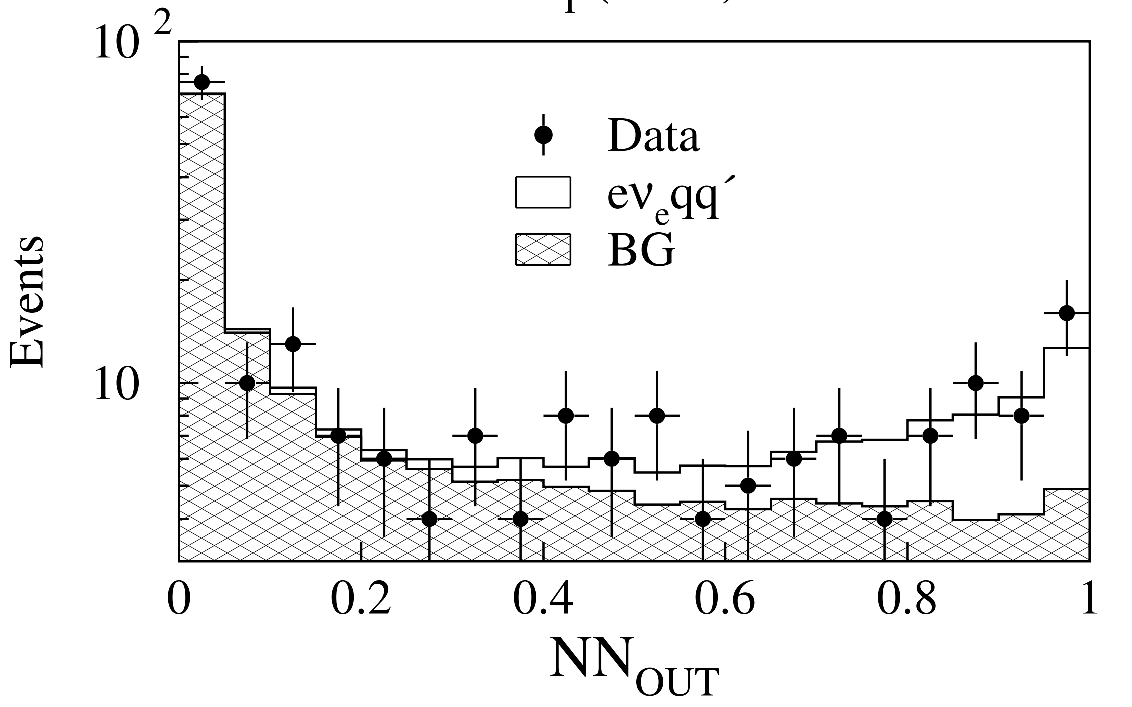
Sensitive to γWW couplings.

Signal definition:

$$
\begin{aligned}
|\cos\theta_{e^+}| &> 0.997 \\
\min(E_f, E_{\bar{f}'}) &> 15\ \text{GeV} \\
|\cos\theta_{e^-}| &< 0.75, \qquad \text{for } e^+\nu_e e^-\bar{\nu}_e \text{ events only}
\end{aligned}
$$

Single W Production





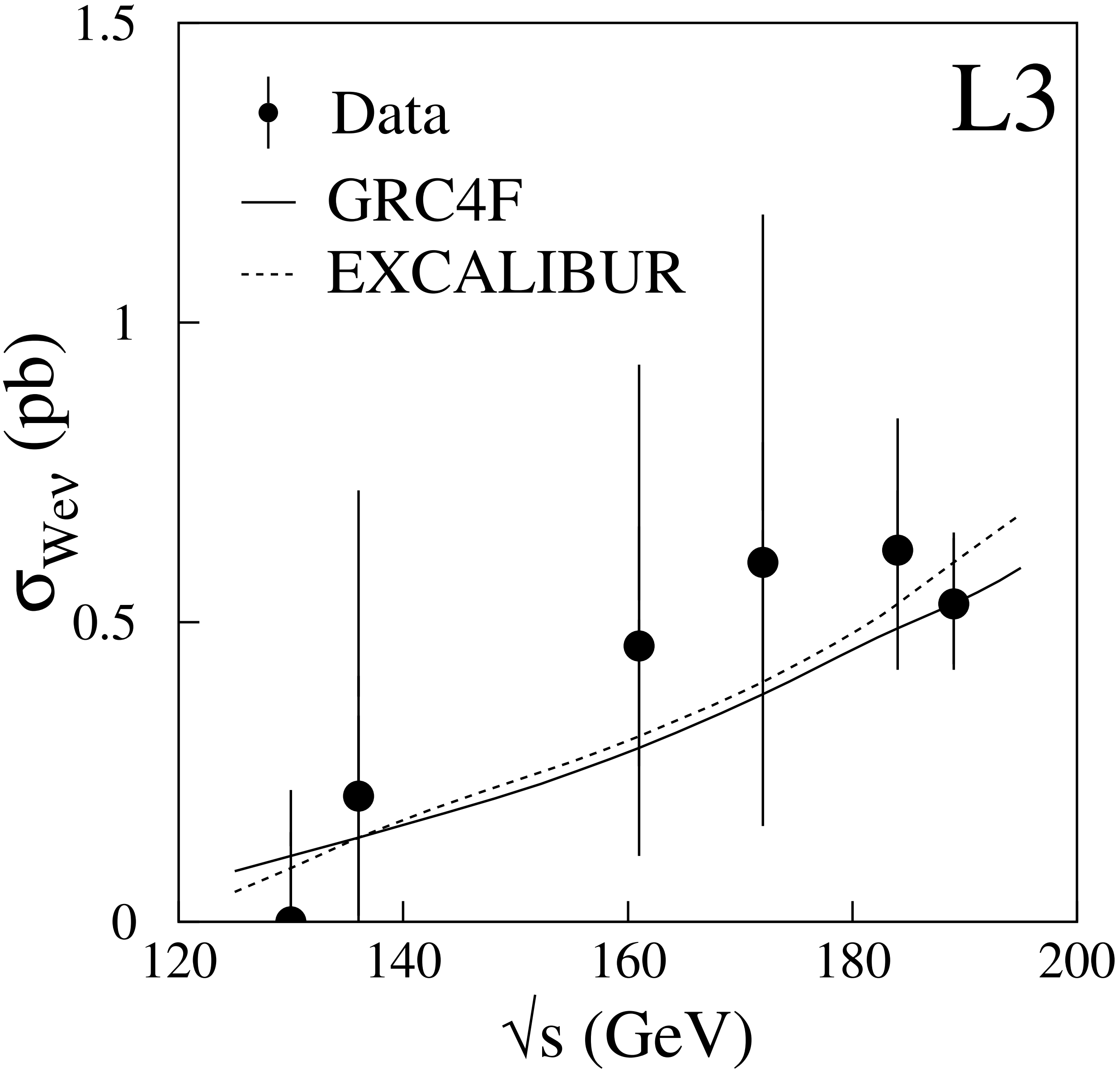
Leptonic W decays:
22 events found; expected 17.2 SM signal and 8.5 background

Hadronic W decays with NN $>$ 0.8:
41 events found; expected 20.1 signal and 17.5 background

Single W Production

Measured cross-section at 189 GeV: $\mathbf{0.53 \pm 0.12}$ pb

(SM calculations: 0.53 to 0.60 pb)

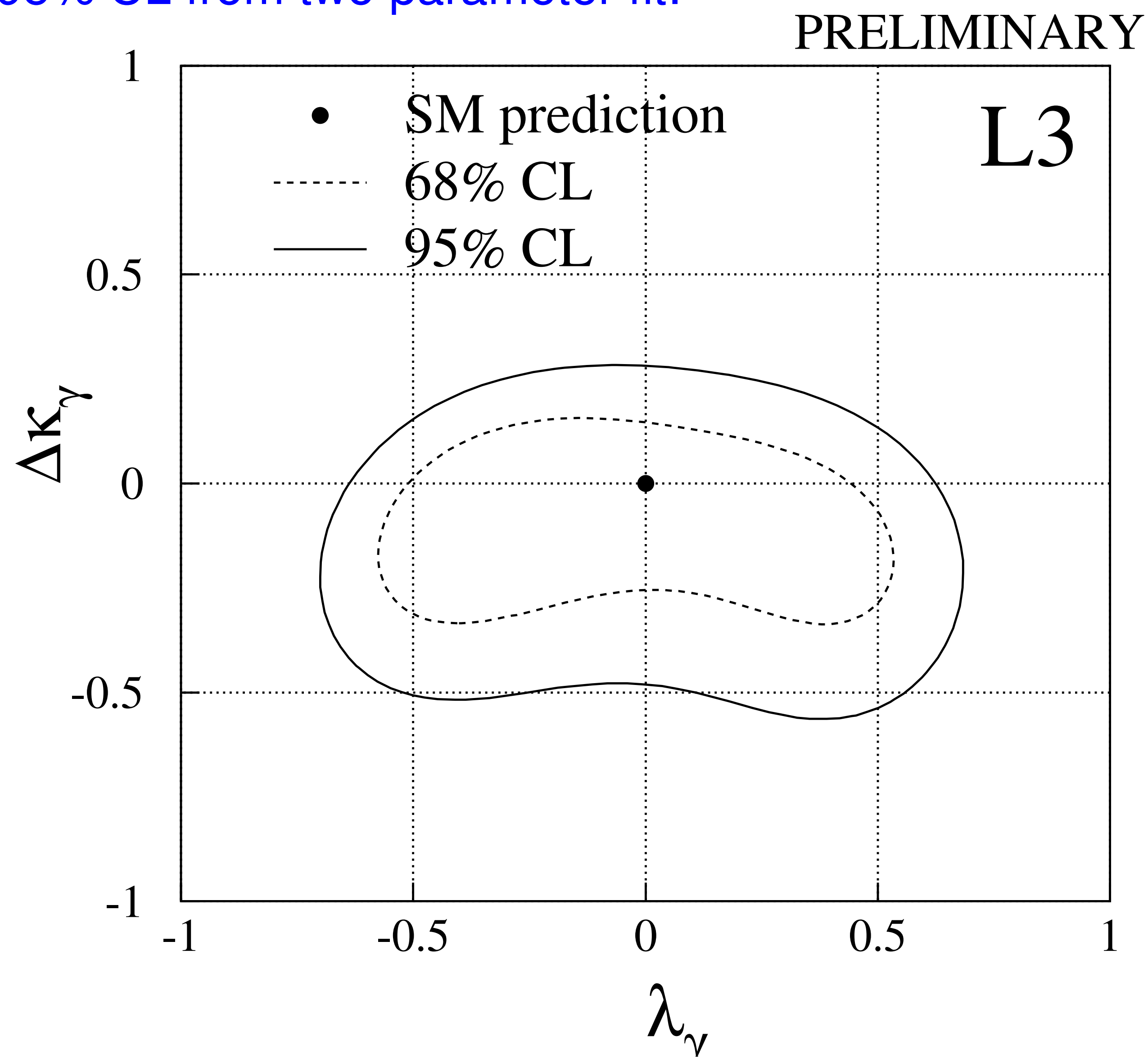


Single W:κ_γ

Results of 1-parameter fit:

$$\kappa_\gamma = 0.96^{+0.15}_{-0.17}$$
$$\lambda_\gamma = -0.26^{+0.53}_{-0.19}$$

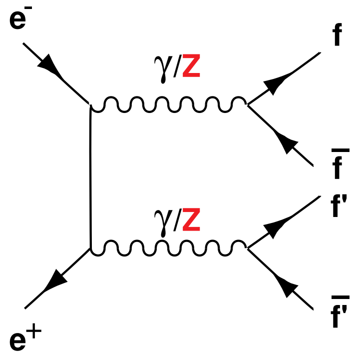
95% CL from two parameter fit:



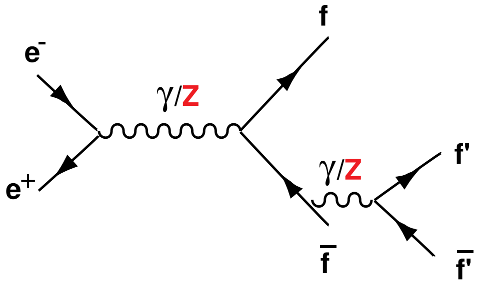
Precision of κ_γ measurement is comparable to that from W pairs.

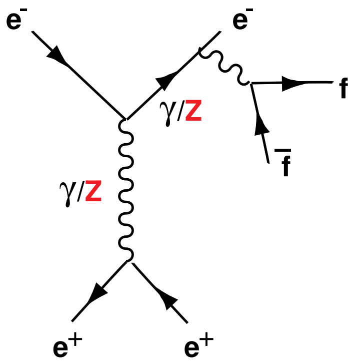
ZZ production

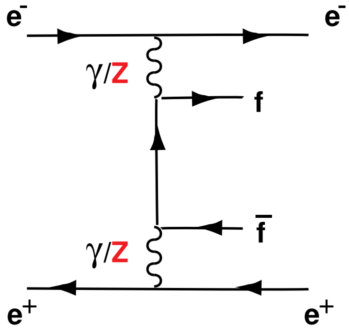
At $\sqrt{s} \geq 2 * M_Z$ the production of Z pairs is possible:



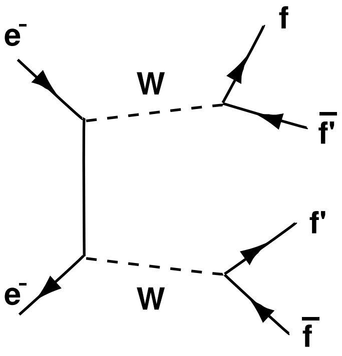
Some non resonant background diagrams:

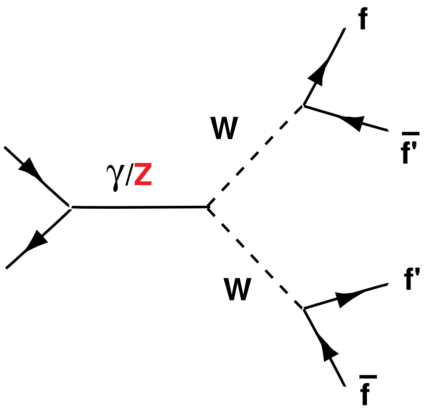






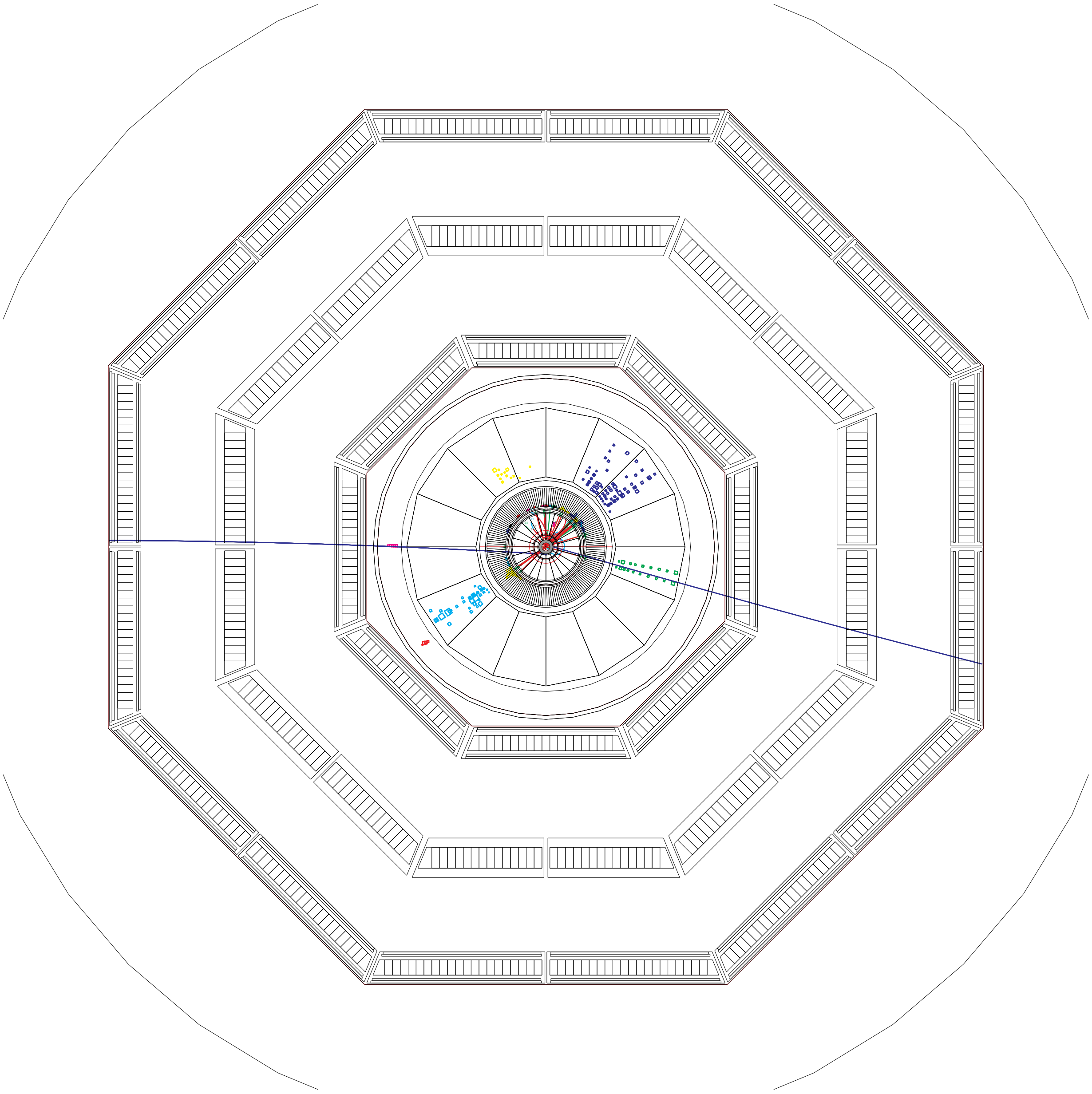
Also diagrams involving WW production are possible:





ZZ $\rightarrow \mu^+\mu^- q\bar{q}$ candidate at 189 GeV

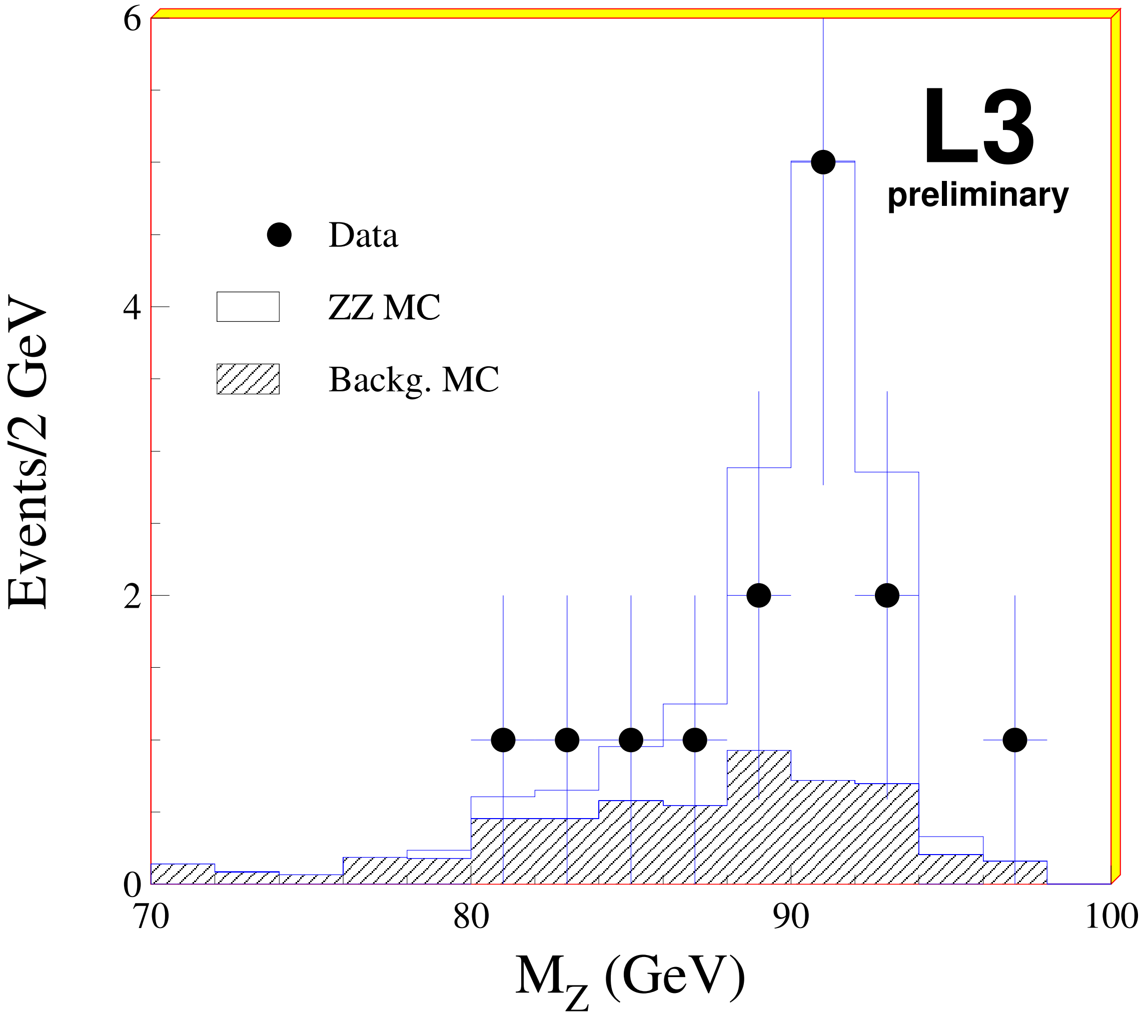
Run # 705301 Event # 24



$m_{\mu^+\mu^-} = m_{jet_1 jet_2} = 93$ GeV (5-C kinematic fit)

ZZ $\rightarrow \ell^+\ell^- q\bar{q}$

- High multiplicity events
- Two jets plus isolated leptons



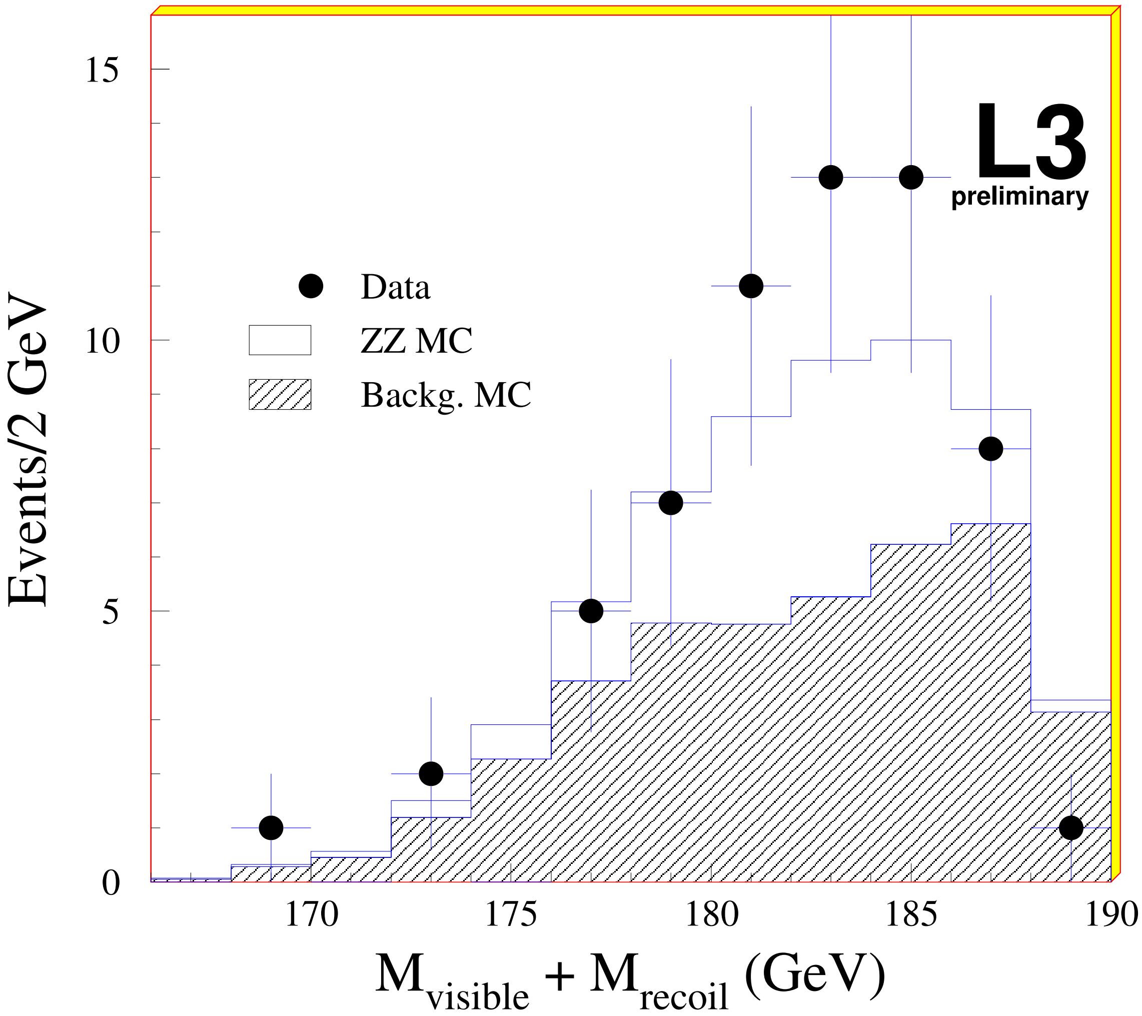
$N_{data} = 14 \qquad N^{SM}_{signal} = 10.0 \qquad N_{bkgd} = 5.4$

Efficiencies:

$e^+e^-q\bar{q}$=73% $\mu^+\mu^-q\bar{q}$= 55% $\tau^+\tau^-q\bar{q}$=28%

ZZ $\longrightarrow q\bar{q}\nu\bar{\nu}$

- High multiplicity events
- Large visible and recoil masses
- Neural network method

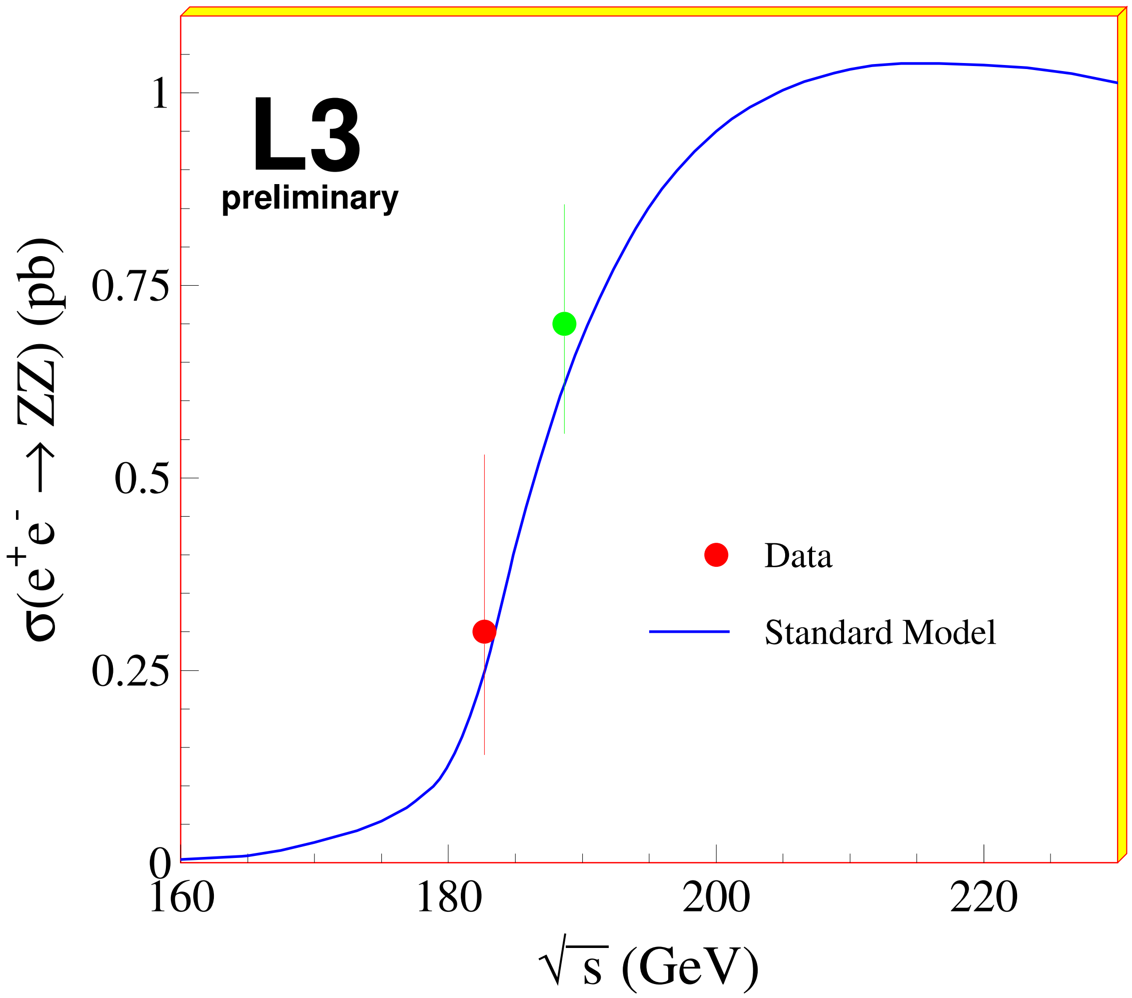


$N_{data} = 58$ $\quad N^{SM}_{signal} = 19.2$ $\quad N_{bkgd} = 38.8$

Efficiency : 61%

ZZ cross section

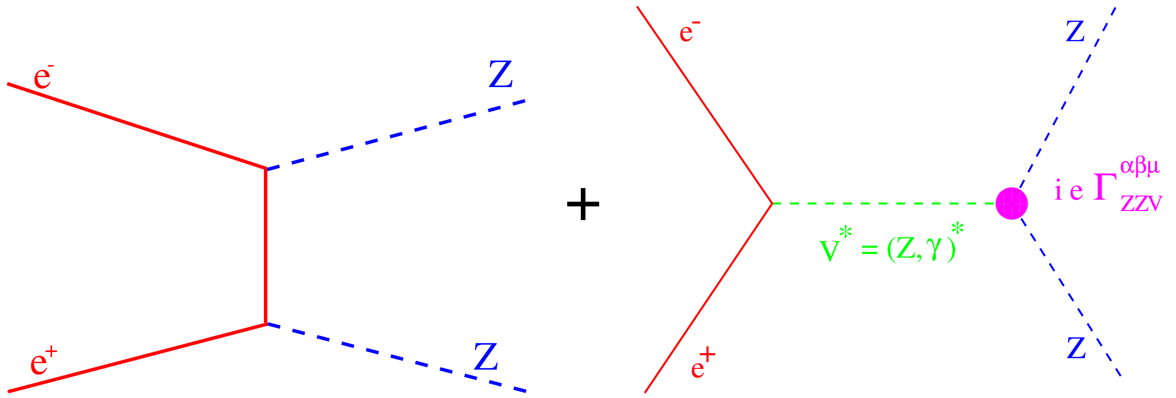
Standard Model Prediction : 4-fermion Monte Carlo with generator cuts:



$\sqrt{s}$	Measured $\sigma(ZZ)$	SM $\sigma(ZZ)$
183 GeV	$0.30^{+0.22+0.07}_{-0.16-0.03}$pb	0.25pb
189 GeV	$0.68^{+0.15}_{-0.14}$pb	0.62pb

Limits on ZZV anomalous Couplings

ZZ final states with non-SM couplings:



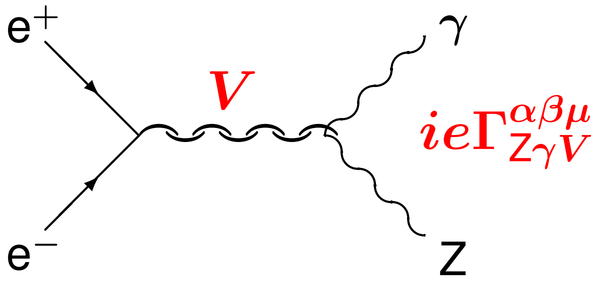
- Anomalous coupling of ZZZ, ZZγ :
  Vertex function $\Gamma^{\alpha\beta\mu}_{ZZV}$ has coupling $f_4^{Z,\gamma}$, $f_5^{Z,\gamma}$
  for CP-violating, conserving processes
  $f_4^{Z,\gamma}$, $f_5^{Z,\gamma}$=0 at SM tree level

- Signatures :
  deviations of σ_{ZZ} and
  angular distributions of the Z bosons
  with respect to SM predictions

At 95% C.L.:

$-1.7 < f_4^Z < 1.8$ $\quad -4.7 < f_5^Z < 4.7$
$-1.0 < f_4^\gamma < 1.1$ $\quad -2.8 < f_5^\gamma < 2.9$

Boson Pair Production: Zγ

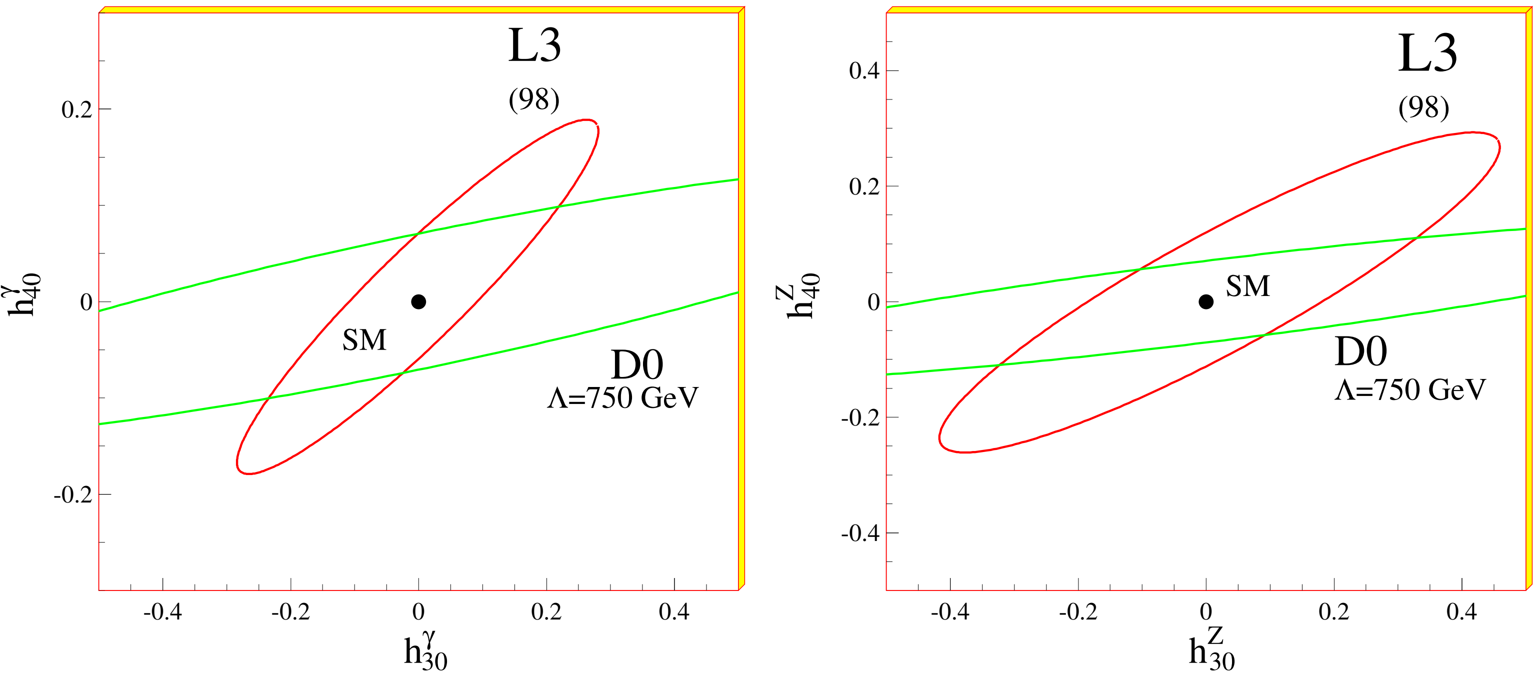


- 8 anomalous couplings h_i^V ($V = \mathrm{Z}, \gamma$)

$$h_i^V = \frac{h_{i0}^V}{(1+s/\Lambda^2)^n}; \quad n = 3 \text{ for } i = 1,3; \quad n = 4 \text{ for } i = 2,4$$

- Sensitivity increases with $\sqrt{s}$
- $e^+e^- \to$ hadrons $+\gamma$, $e^+e^- \to \nu\bar{\nu}\gamma$

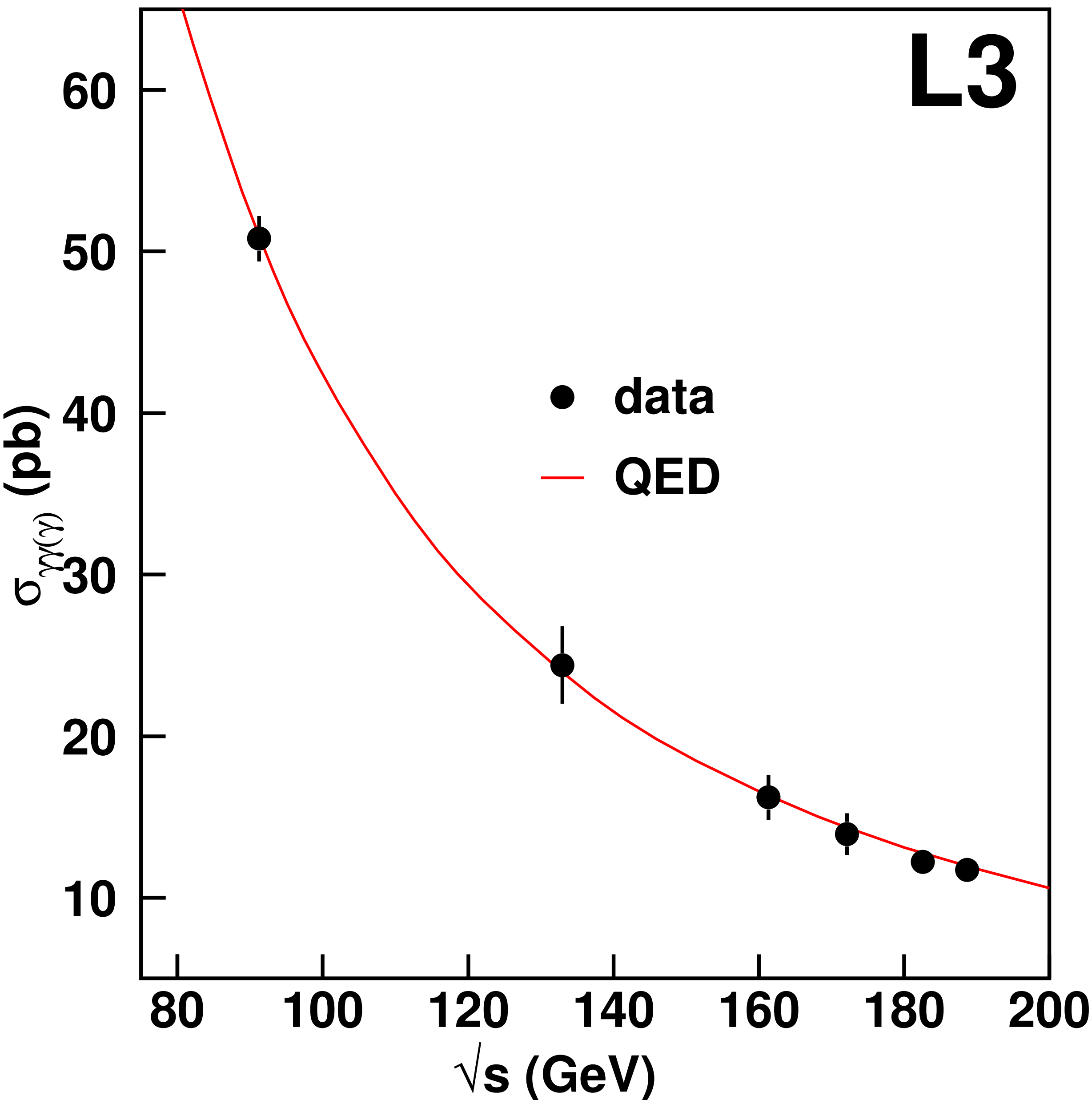
95% C.L. contours:



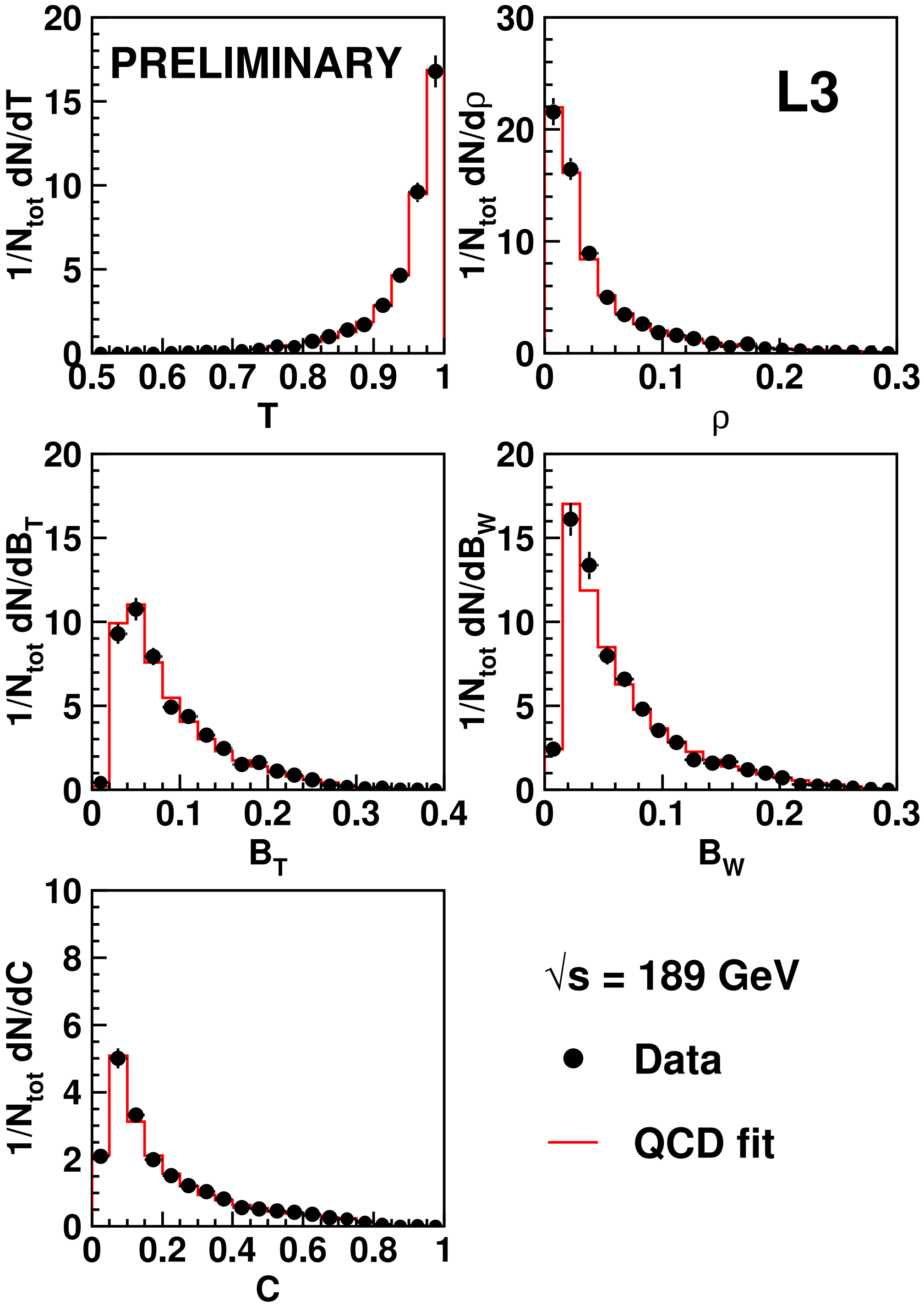
Results complementary to D0

Test of QED

Study of $e^+e^- \to n\,\gamma\ (n \geq 2)$ at LEPII

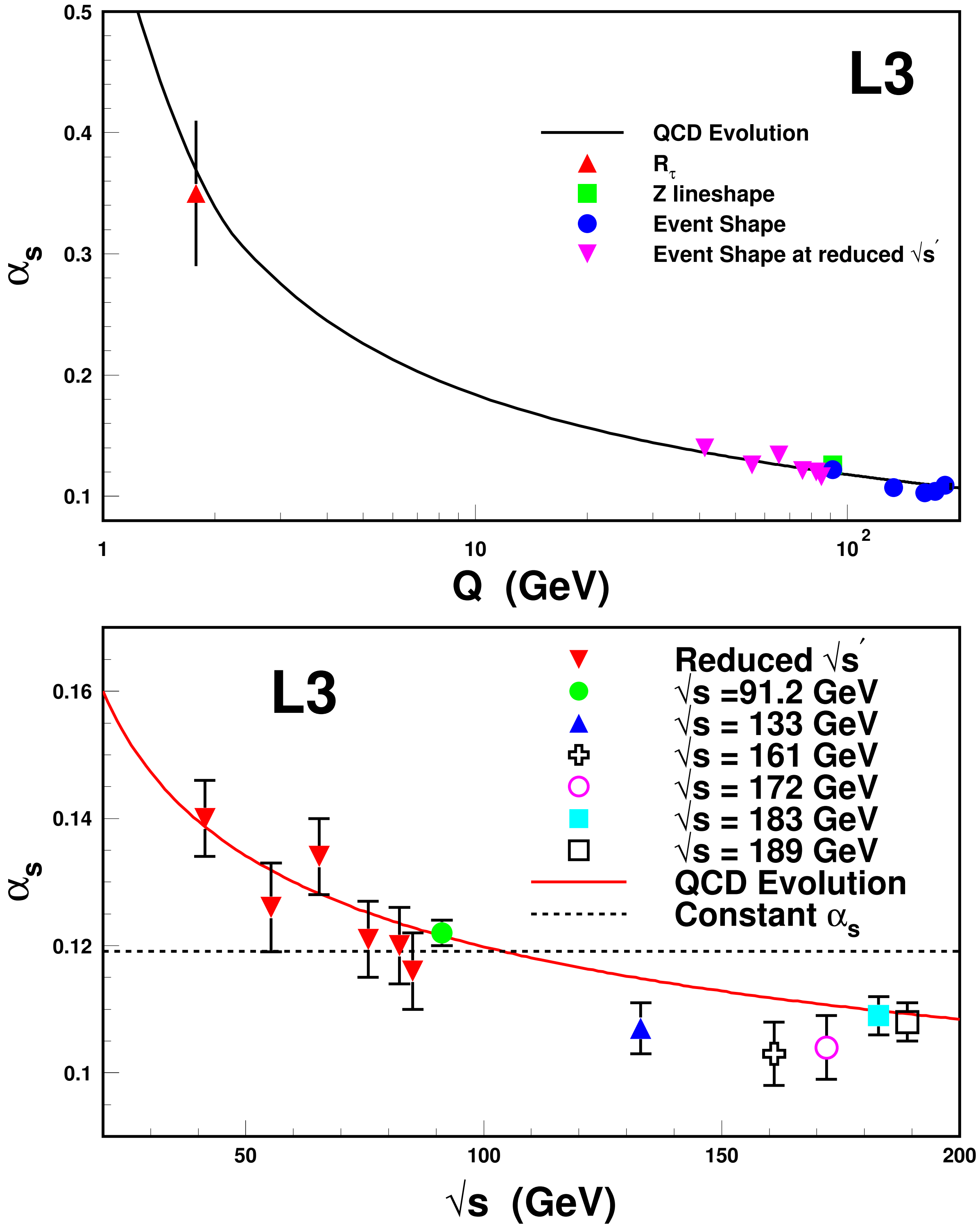


QCD–Event Shape Distributions

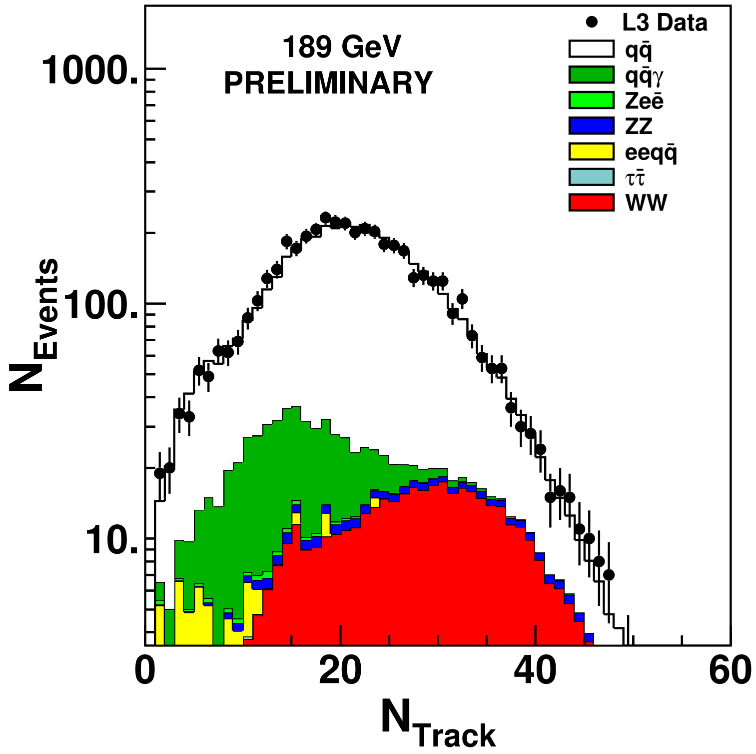


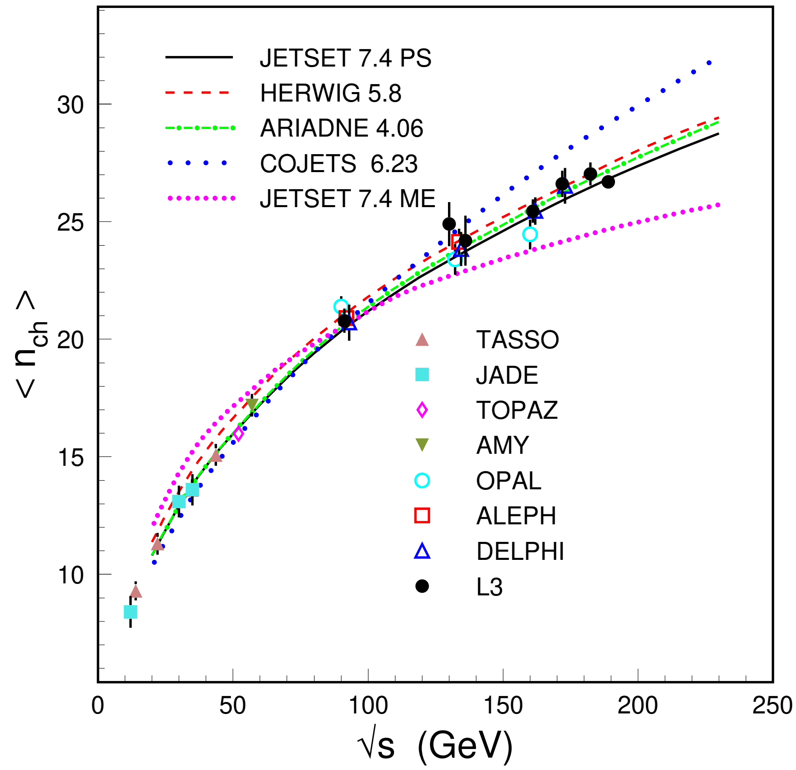
$$\alpha_s(189\ \text{GeV}) = 0.108 \pm 0.003\ (\text{exp}) \pm 0.005\ (\text{theo})$$

QCD–Running of α_s



QCD – Multiplicity distribution





Bose-Einstein Correlations in 3-D

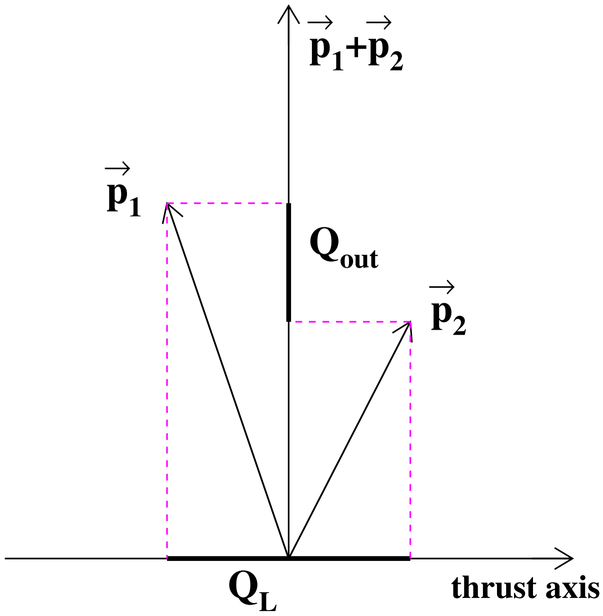
Using $\sim$1M Z events from 1994,
measure correlation function of $\pi^{\pm}\pi^{\pm}$

$$R_2 = \frac{\rho(p_1, p_2)}{\rho_0(p_1, p_2)}$$

ρ = 2-particle number density
ρ_0 = 2-particle number density if no BE – event mixing
$R_2 - 1$ is related to space-time structure of π source by a Fourier transform

Longitudinal CMS (LCMS):
boost each pair of $\pi^{\pm}\pi^{\pm}$ along thrust axis to

- $p_{\mathrm{L},1} + p_{\mathrm{L},2} = 0$
- out direction along $\vec{p}_1 + \vec{p}_2$
- side direction $\perp$ to (L,out)



In LCMS:

$$\begin{aligned} Q^2 &= Q_{\mathrm{L}}^2 + Q_{\mathrm{side}}^2 + Q_{\mathrm{out}}^2 - (\Delta E)^2 \\ &= Q_{\mathrm{L}}^2 + Q_{\mathrm{side}}^2 + Q_{\mathrm{out}}^2(1-\beta^2), \quad \beta \equiv \frac{p_{\mathrm{out}\,1} + p_{\mathrm{out}\,2}}{E_1 + E_2} \end{aligned}$$

Q_{L} and Q_{side} are independent of ΔE
and hence independent of emission time of π_1,π_2

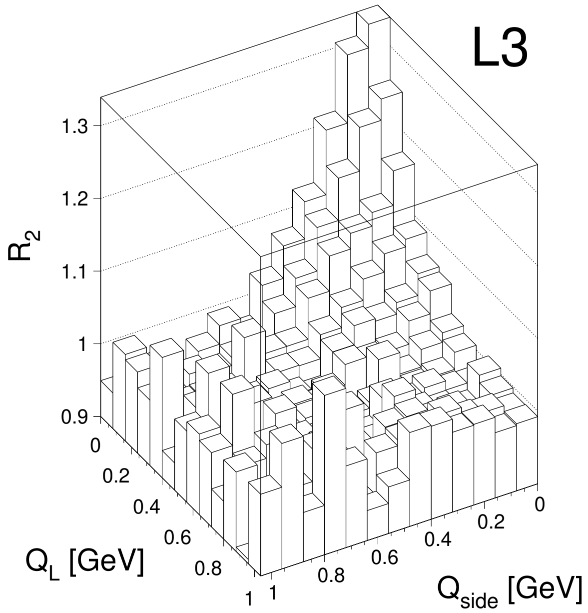
Bose-Einstein Correlations in 3-D

Assuming Gaussian shape of source
with azimuthal symmetry about thrust axis:

$$R_2(Q_\mathrm{L}, Q_\mathrm{out}, Q_\mathrm{side}) = \gamma\,(1 + \delta Q_\mathrm{L} + \varepsilon Q_\mathrm{out} + \xi Q_\mathrm{side}) \times$$
$$\left[1 + \lambda \exp\left(-R_\mathrm{L}^2 Q_\mathrm{L}^2 - R_\mathrm{out}^2 Q_\mathrm{out}^2 - R_\mathrm{side}^2 Q_\mathrm{side}^2 + 2\rho Q_\mathrm{L} Q_\mathrm{out}\right)\right.$$

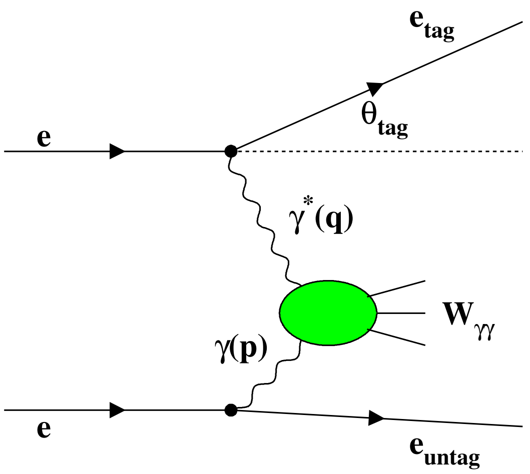
Results: $\rho \approx 0$ So fix to 0.

parameter	Gaussian
λ	$0.41 \pm 0.01^{+0.02}_{-0.19}$
R_L (fm) R_out(fm) R_side (fm)	$0.74 \pm 0.02^{+0.04}_{-0.03}$ $0.53 \pm 0.02^{+0.05}_{-0.06}$ $0.59 \pm 0.01^{+0.03}_{-0.13}$
$R_\mathrm{out}/R_\mathrm{L}$ $R_\mathrm{side}/R_\mathrm{L}$	$0.71 \pm 0.02^{+0.05}_{-0.08}$ $0.80 \pm 0.02^{+0.03}_{-0.18}$

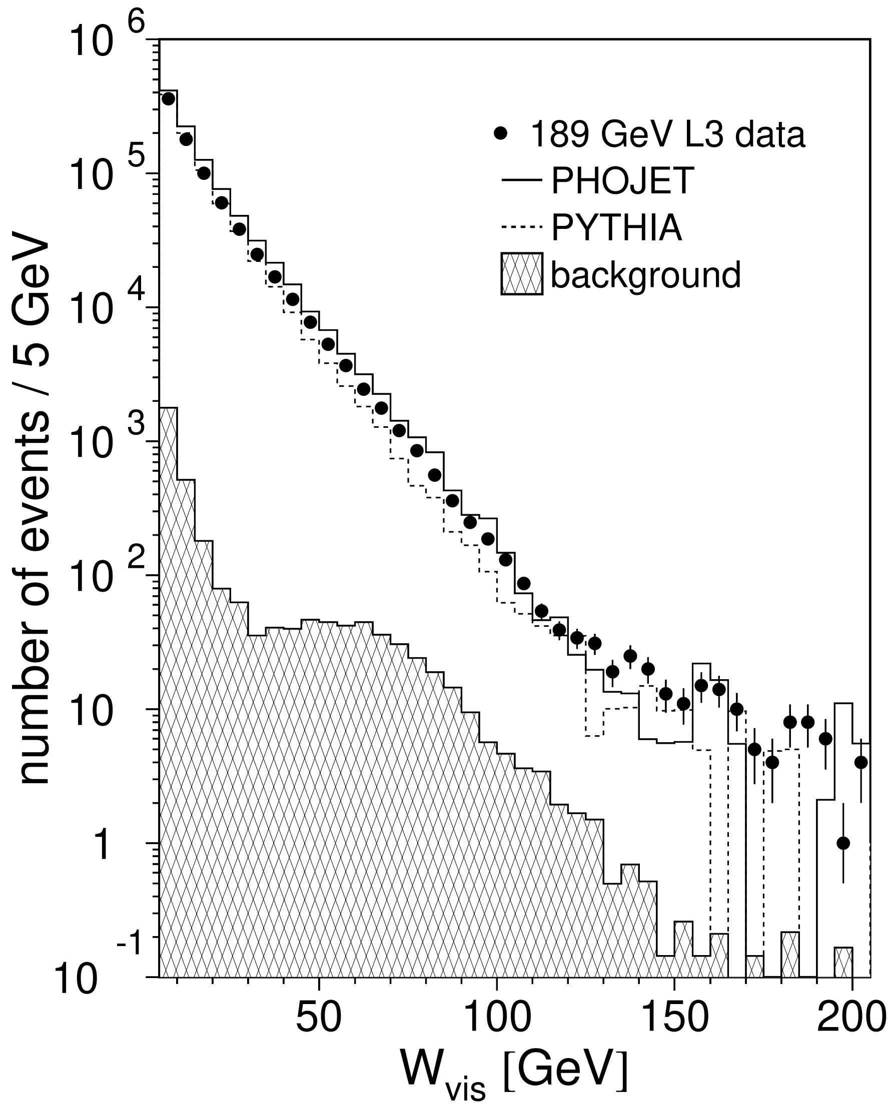


Conclusions:
π source is elongated along thrust axis
not reproduced by JETSET with LUBOEI
in contradiction to equal radii in present VNI
– (Geiger *et al.*, CERN-TH/98-345)

$\gamma\gamma \longrightarrow$ hadrons

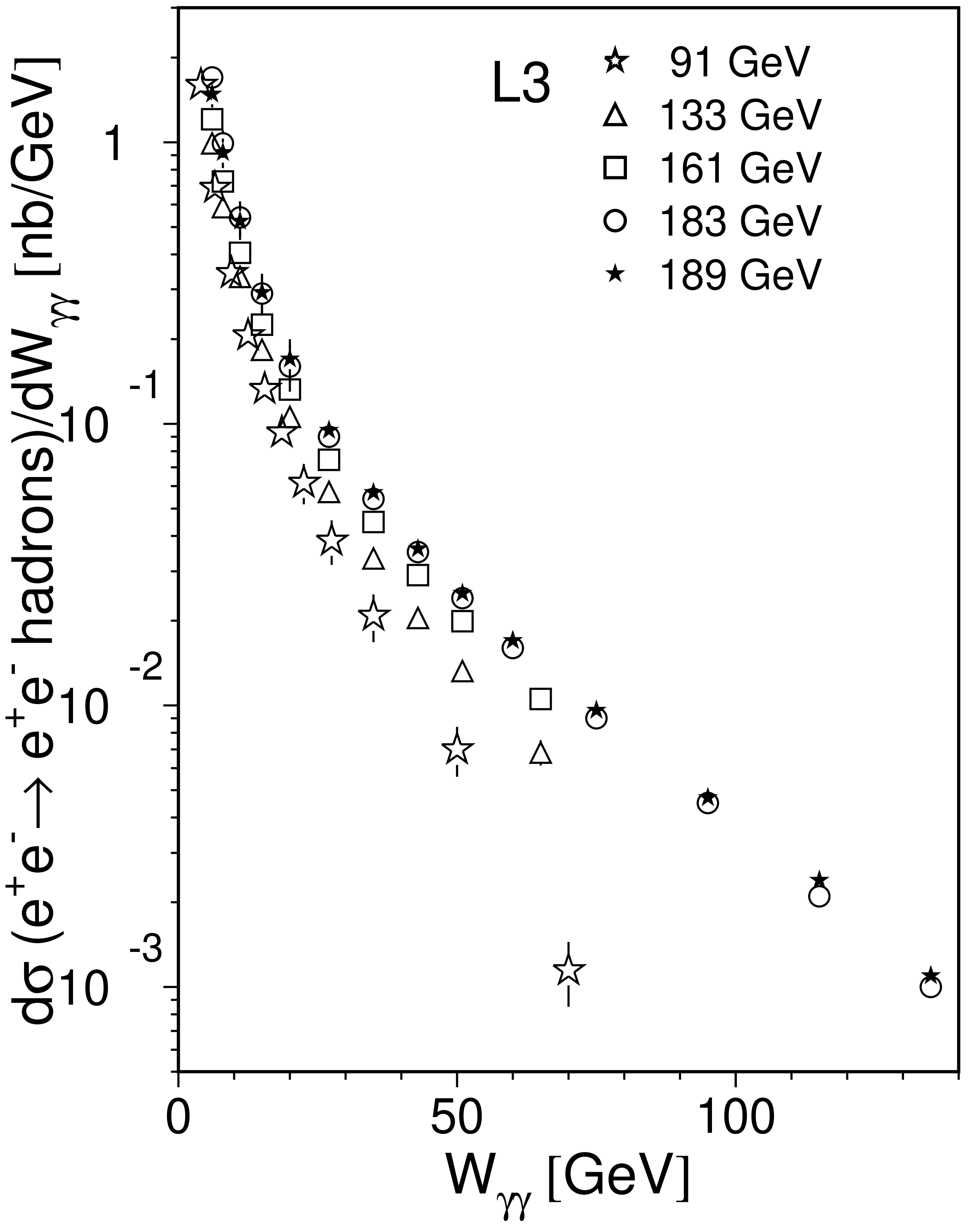


W_{vis} distribution for untagged events:



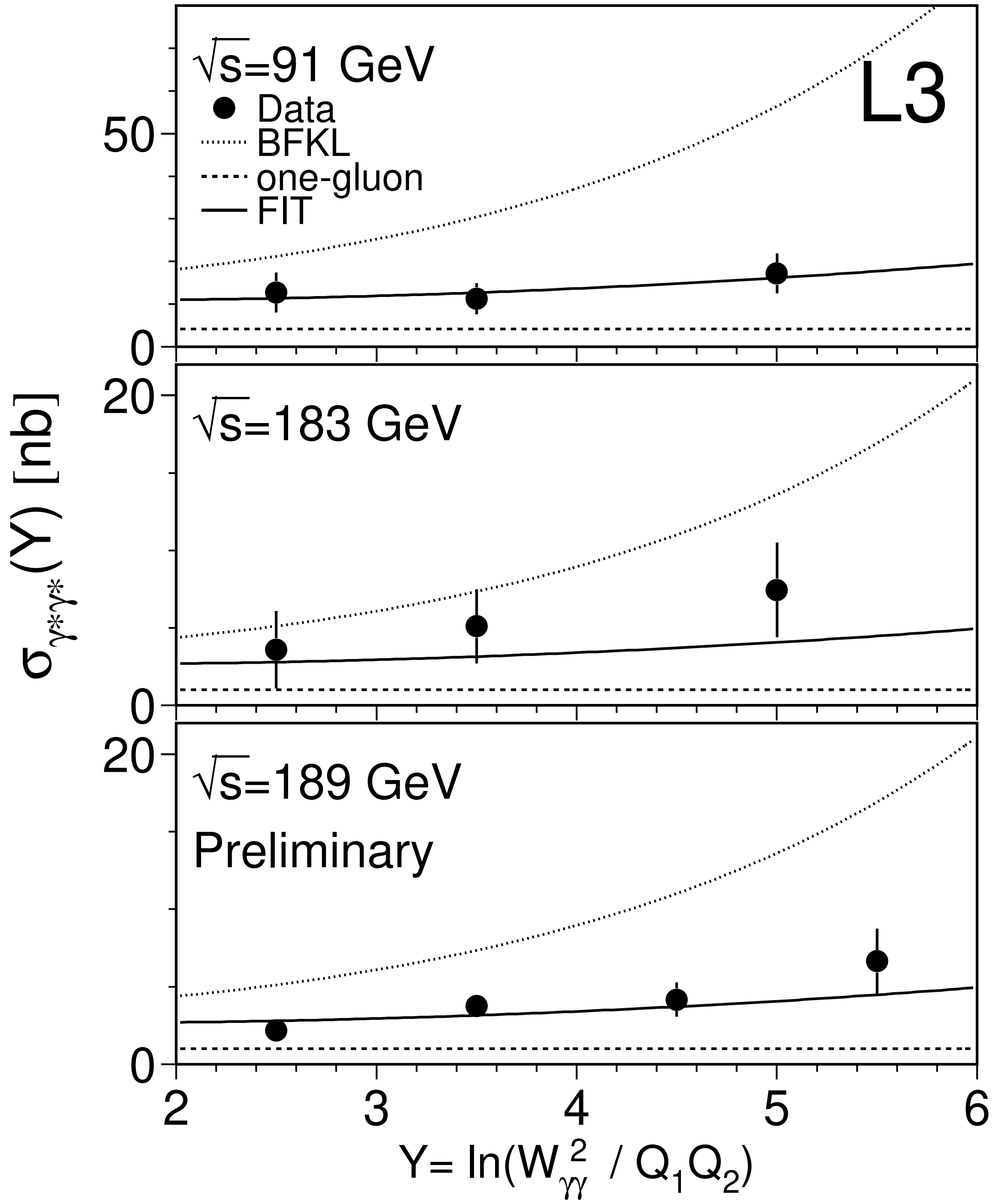
$\gamma\gamma \longrightarrow$ hadrons

Unfolding needed for $W_{vis} \longrightarrow W_{\gamma\gamma}$



$\gamma^*\gamma^* \longrightarrow$ hadrons

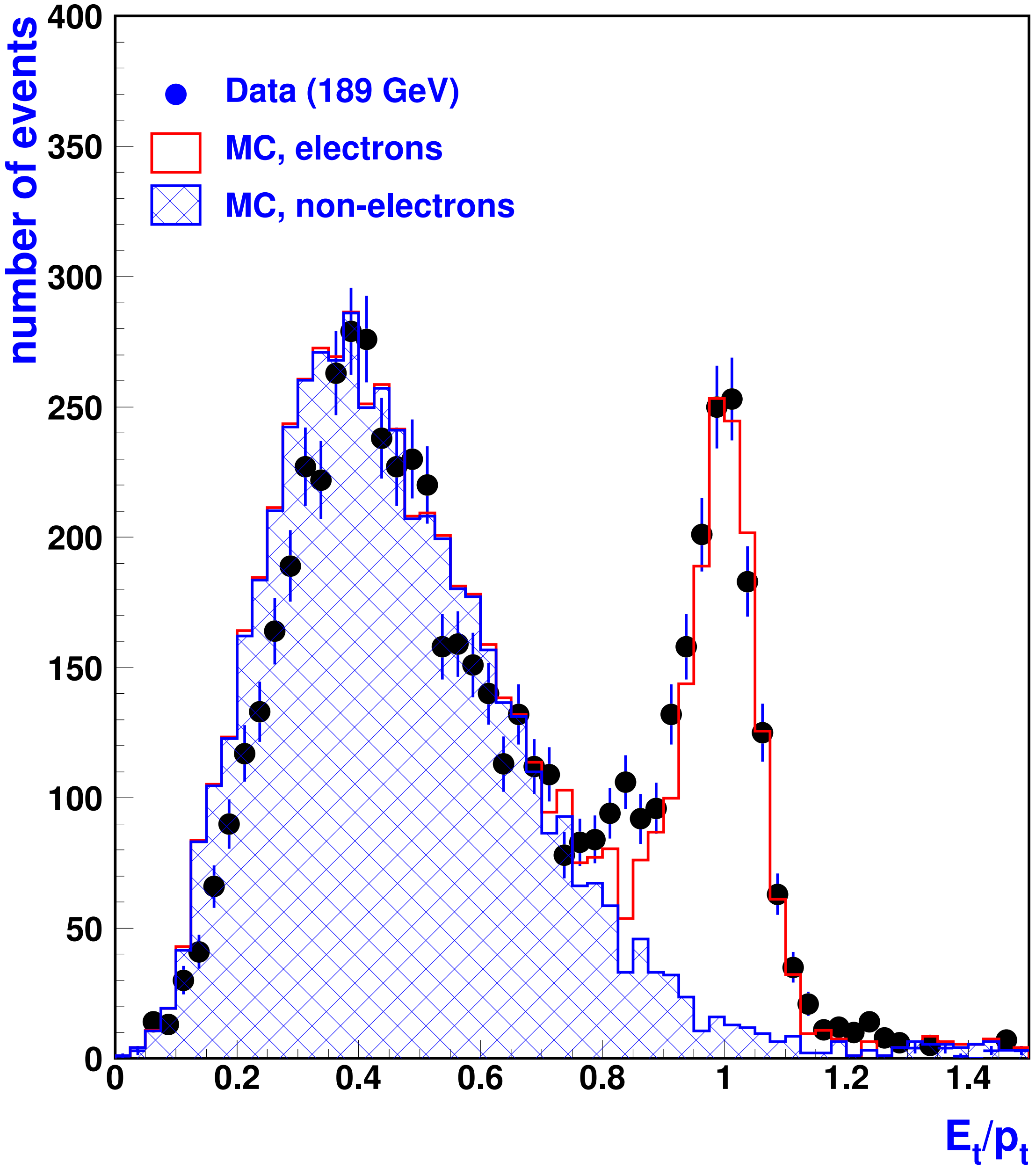
Cross section of double tagged events
(137 events at 91 GeV, 142 at $183 - 189$ GeV)



σ larger than one-gluon exchange
σ smaller than BFKL prediction

Charm production in $\gamma\gamma$

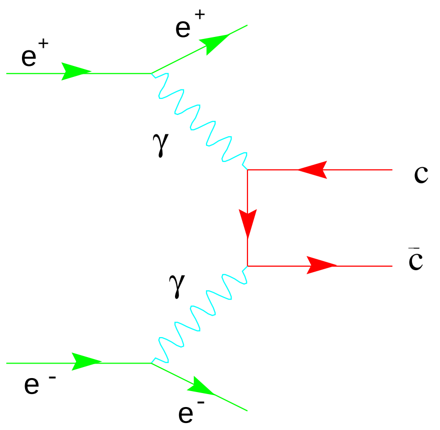
Charm tagged by semi-leptonic decays:



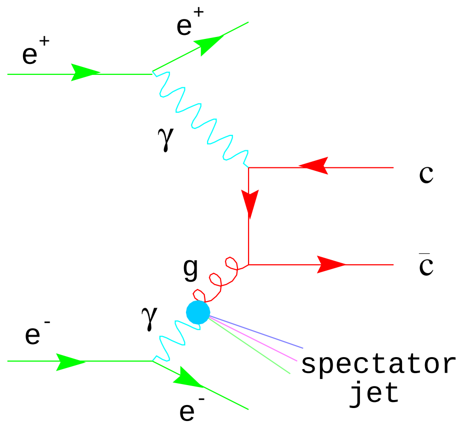
Electron energy: 0.5 – 7 GeV

$< E_e >$ = 1.1 GeV

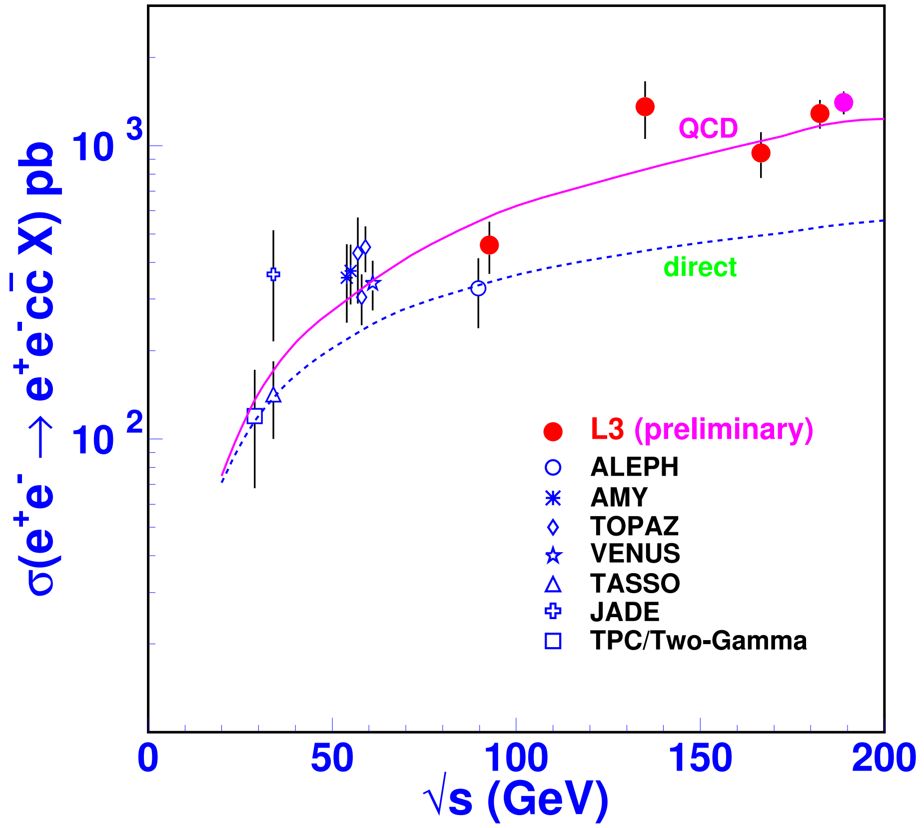
Charm production in $\gamma\gamma$



Direct



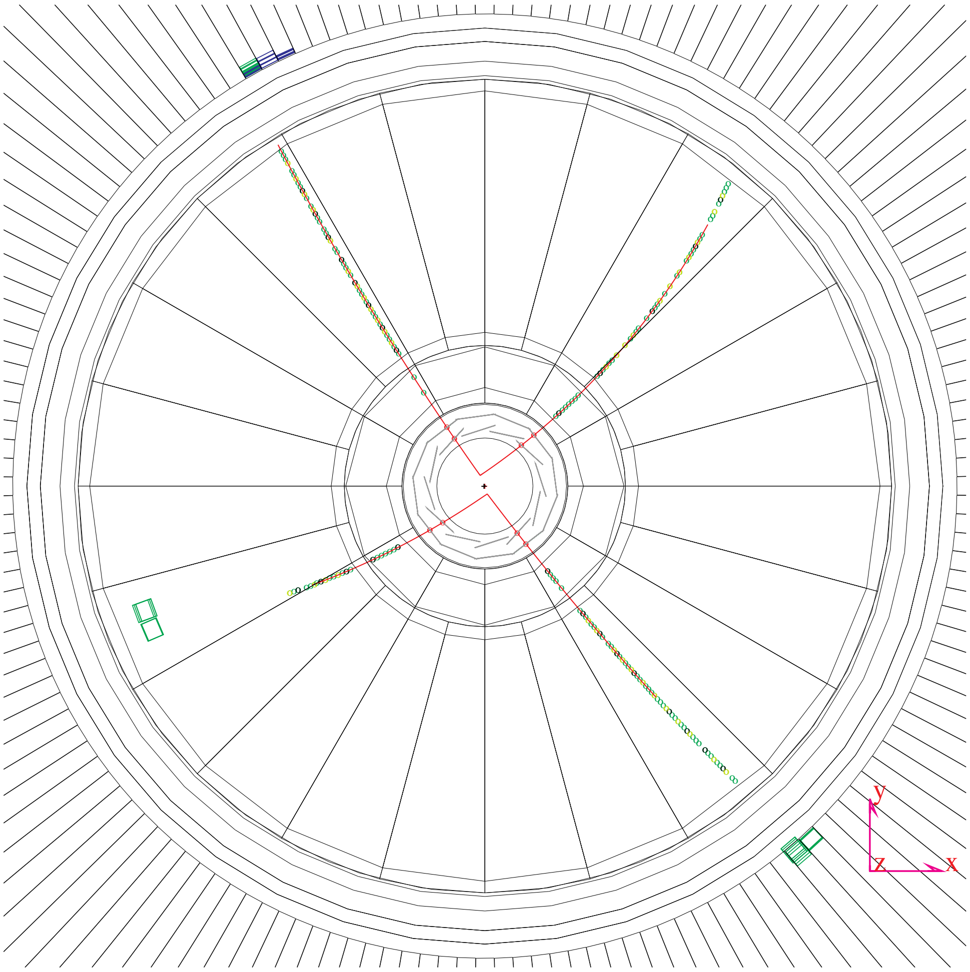
Single Resolved

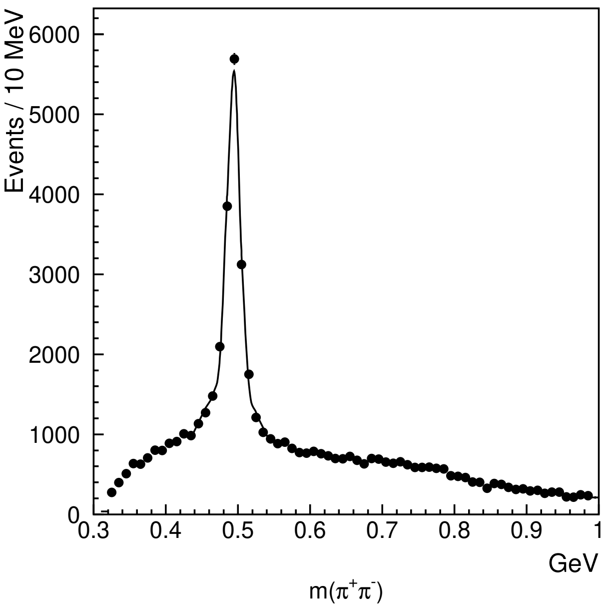


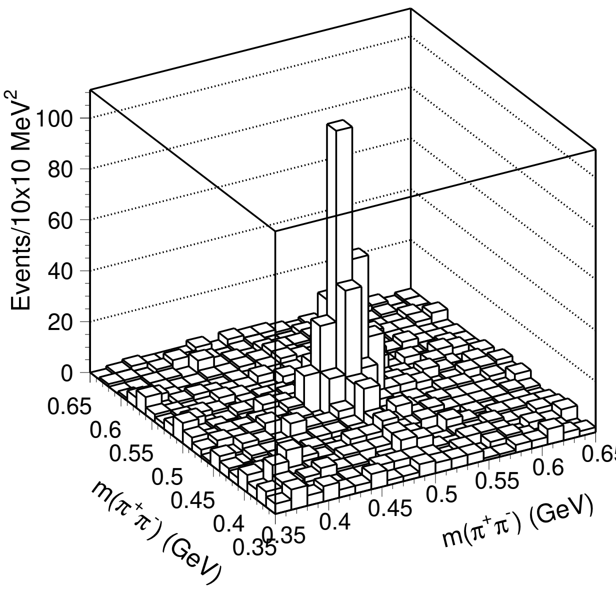
Clear evidence of gluon content of photon.

$\gamma\gamma \rightarrow K^0_S K^0_S$

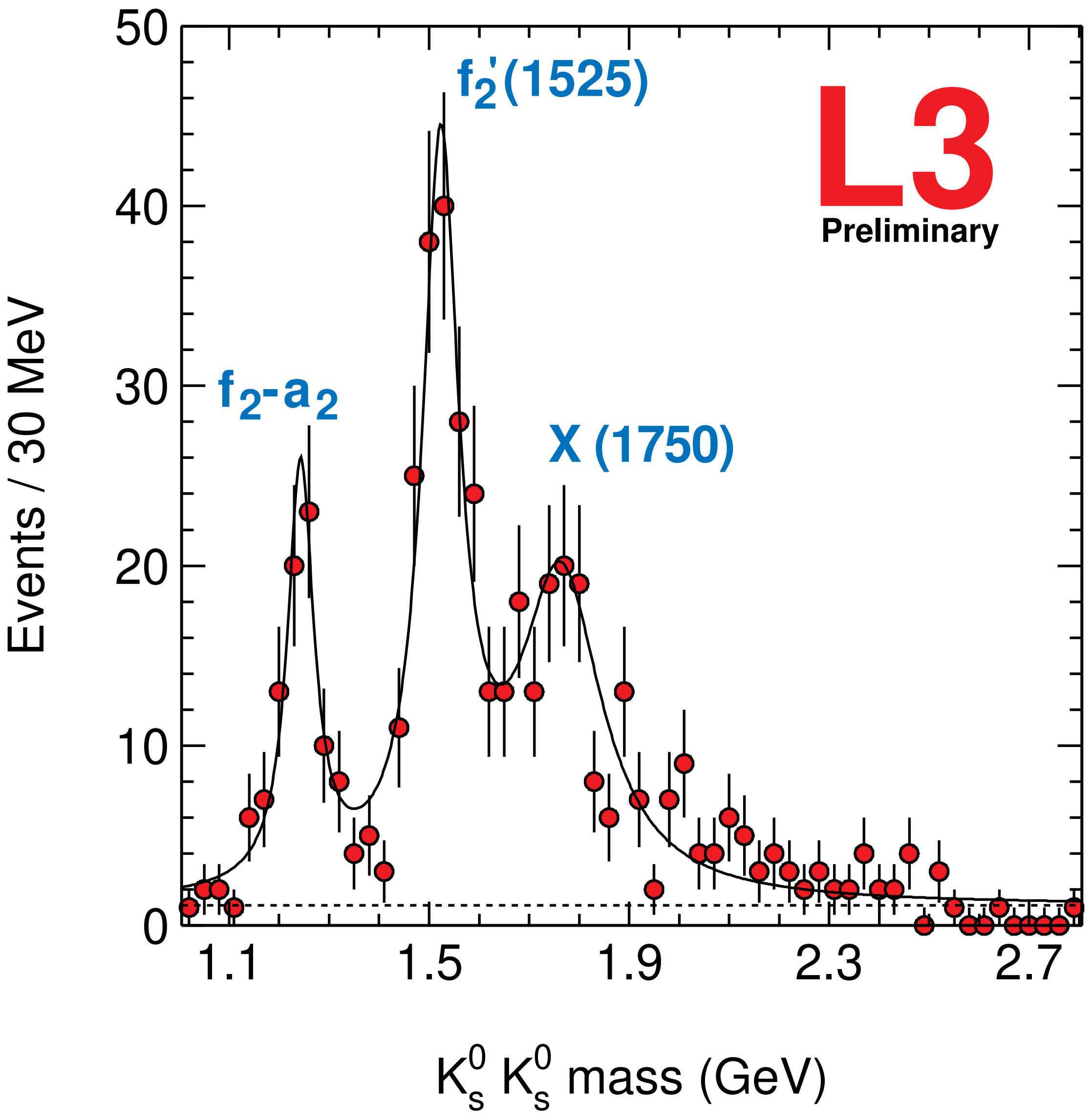
Run # **689002** **Event #** **287** Total Energy : .78 GeV







$K^0_S K^0_S$ Invariant Mass



Spin-parity of 1750 region under study:

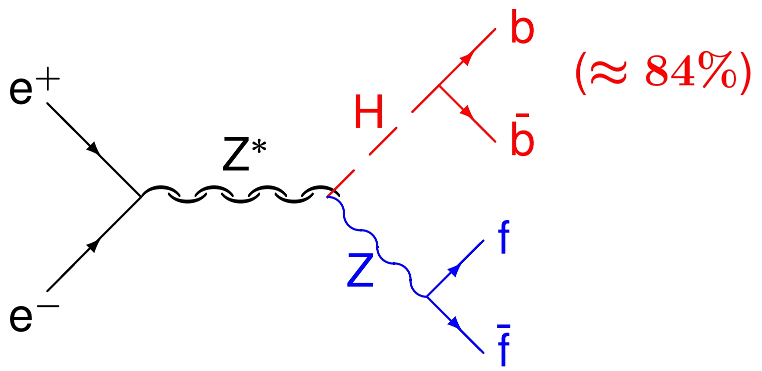
- 2^{++} (f_2' radial recurrence?)
- 0^{++} ($s\bar{s}$ state?)

No signal in $\xi(2230)$ region:

$$\Gamma(\xi \to \gamma\gamma) \times \mathrm{BR}(\xi \to K^0_S K^0_S) < 1.5 \text{ eV (95\% CL)}$$

Search for the SM Higgs boson

The Standard Model Higgs boson



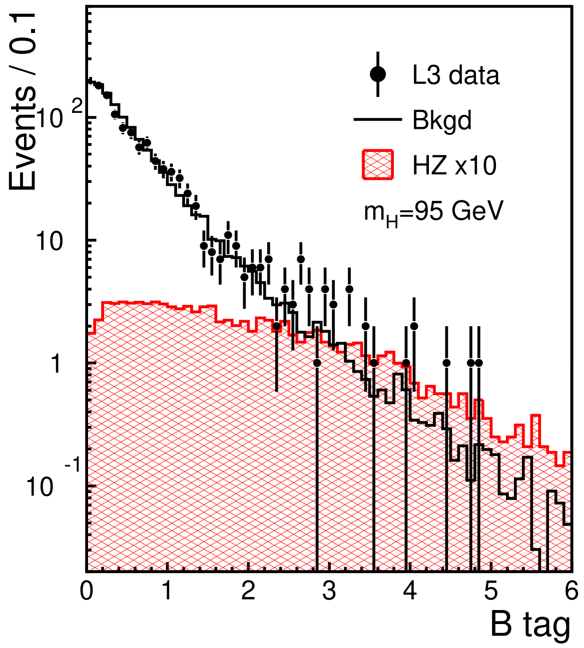
(+ small contribution from WW and ZZ fusion diagrams)

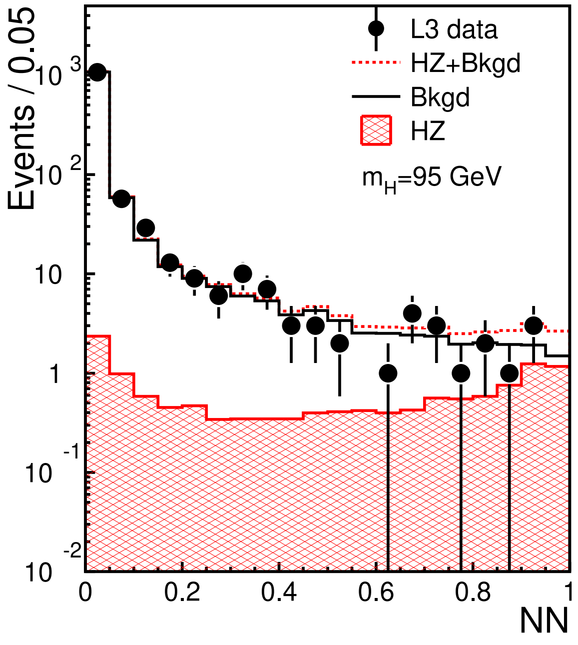
Dominant: HZ $\longrightarrow$ $b\bar{b}\,q\bar{q}$

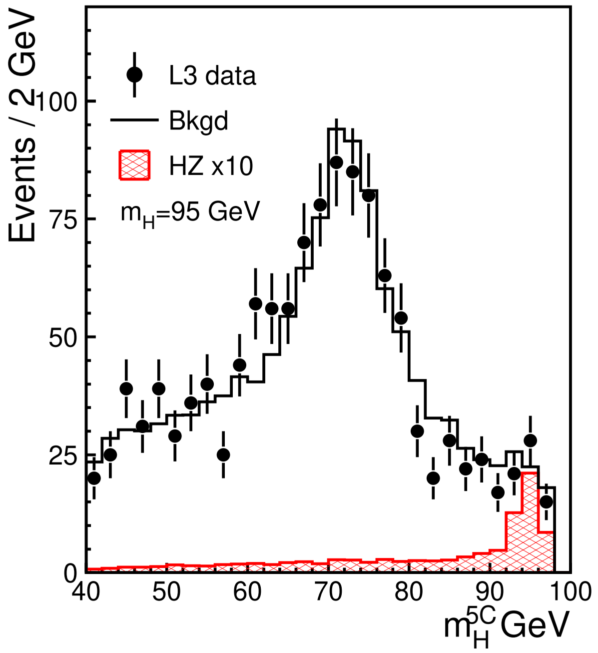
- loose preselection
- neural network, including B-tagging and kinematic variables
- mass reconstruction after kinematic fit using m_Z
  $\Rightarrow M^{H}_{rec}$
- Combine neural network output and reconstructed mass into the final discriminant variable (purity)

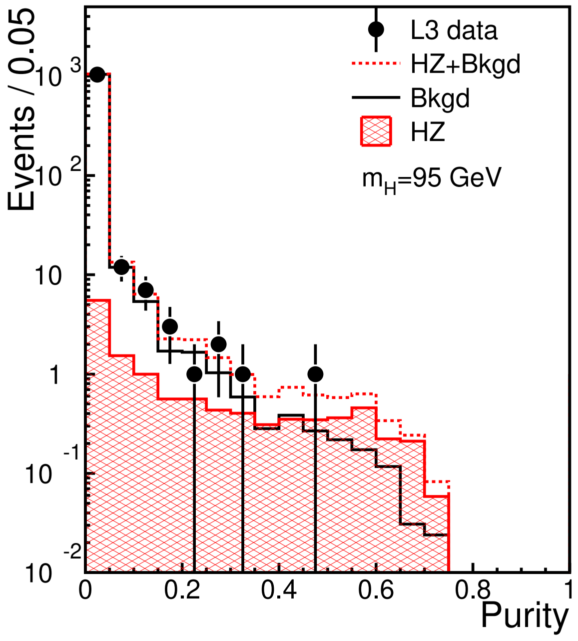
Search for the SM Higgs boson

Distributions for data, expected background and signal with $m_{\mathrm{H}} = 95$ GeV for HZ $\rightarrow$ b$\bar{\mathrm{b}}$ q$\bar{\mathrm{q}}$



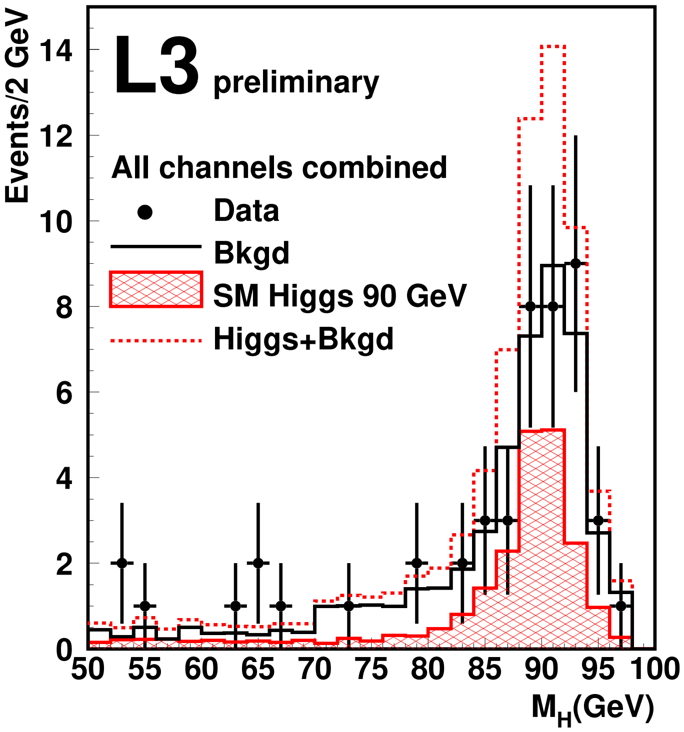




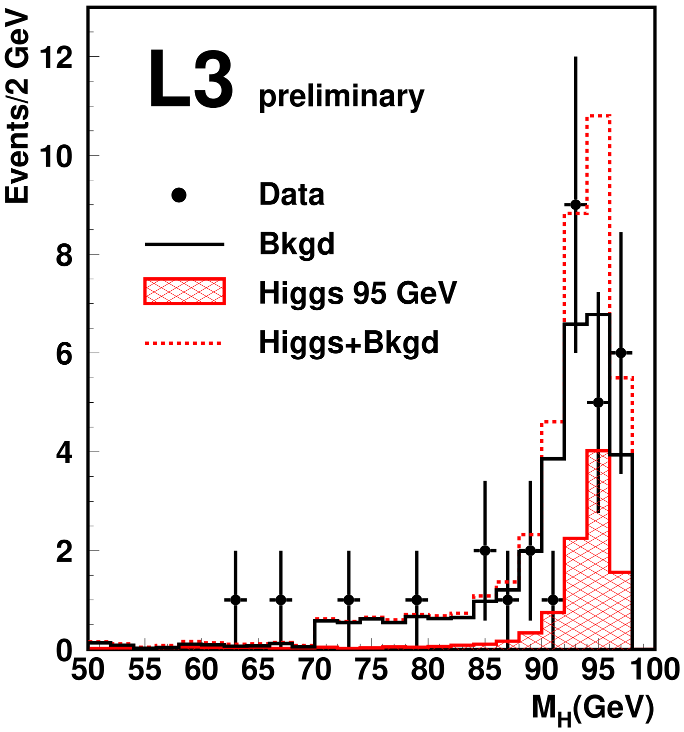


Search for the SM Higgs boson

Mass distribution of the most significant candidates for all channels combined

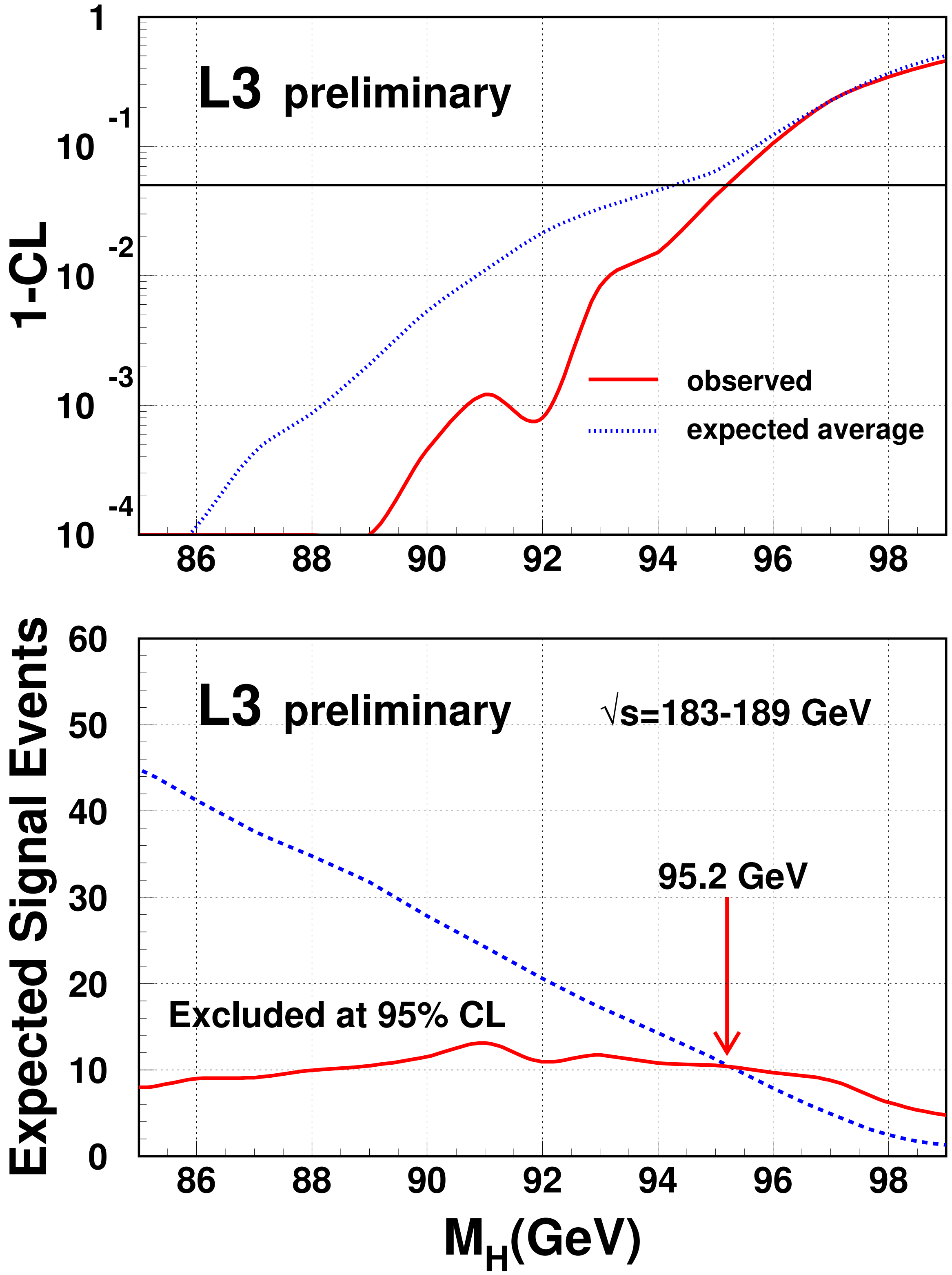


Observed	47
Expected bgkd	47.6
Higgs signal	22.0



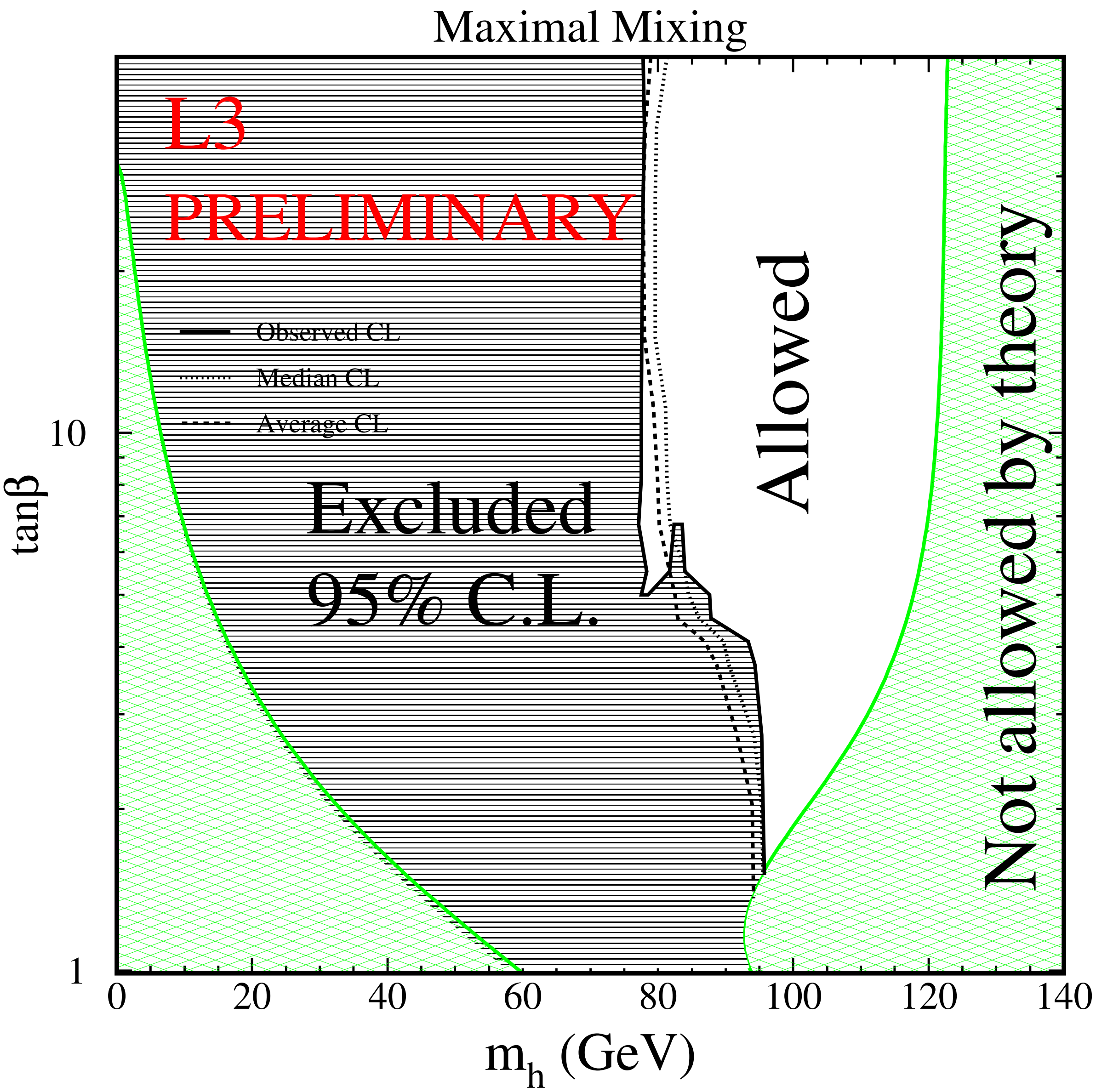
Observed	30
Expected bgkd	30.3
Higgs signal	9.9

Search for the SM Higgs boson



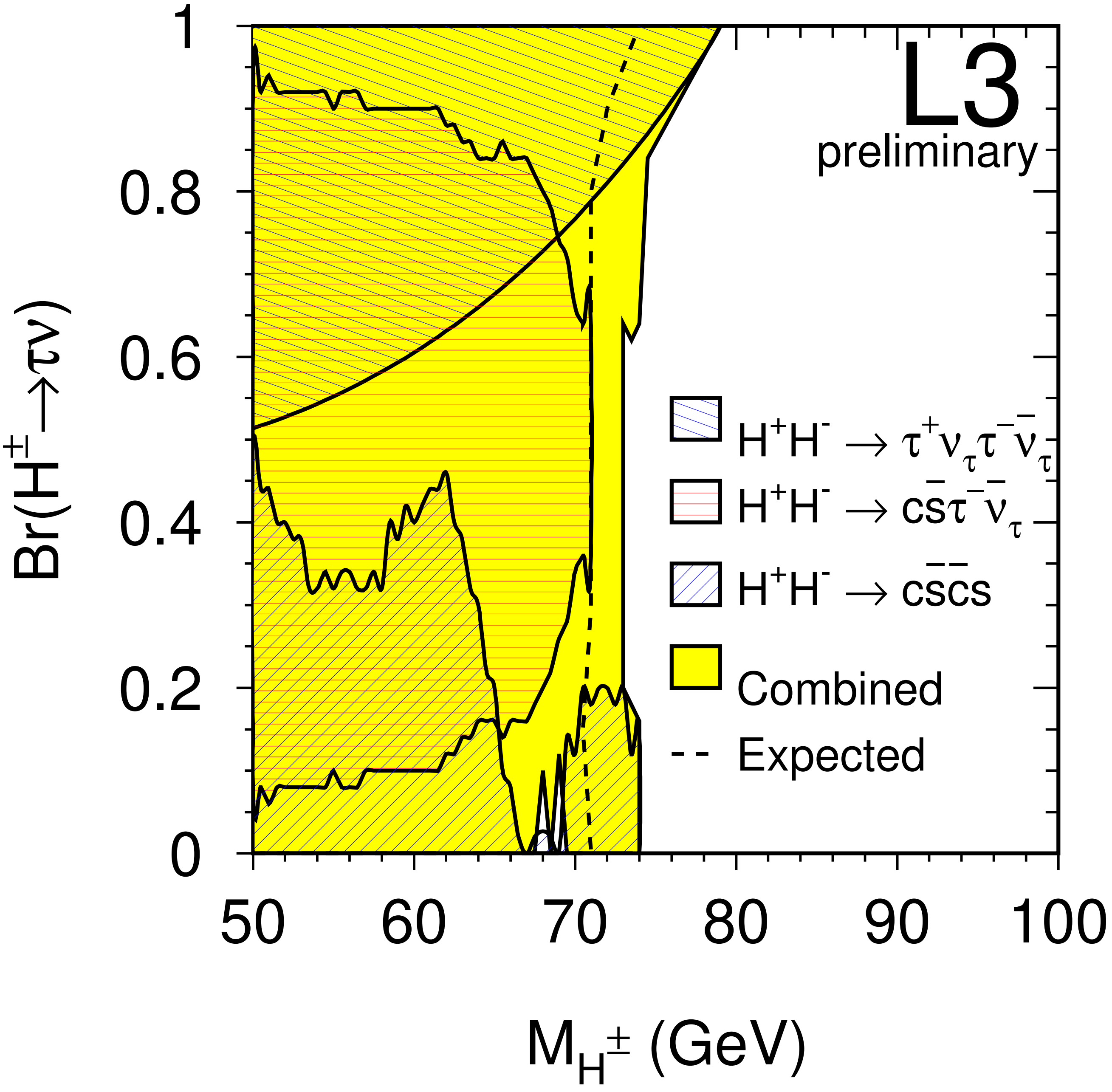
$m_H > 95.2$ GeV (95% CL)

Search for the MSSM Higgs bosons



$m_h > 77$ GeV, $m_A > 78$ GeV at 95% CL
independent of tanβ

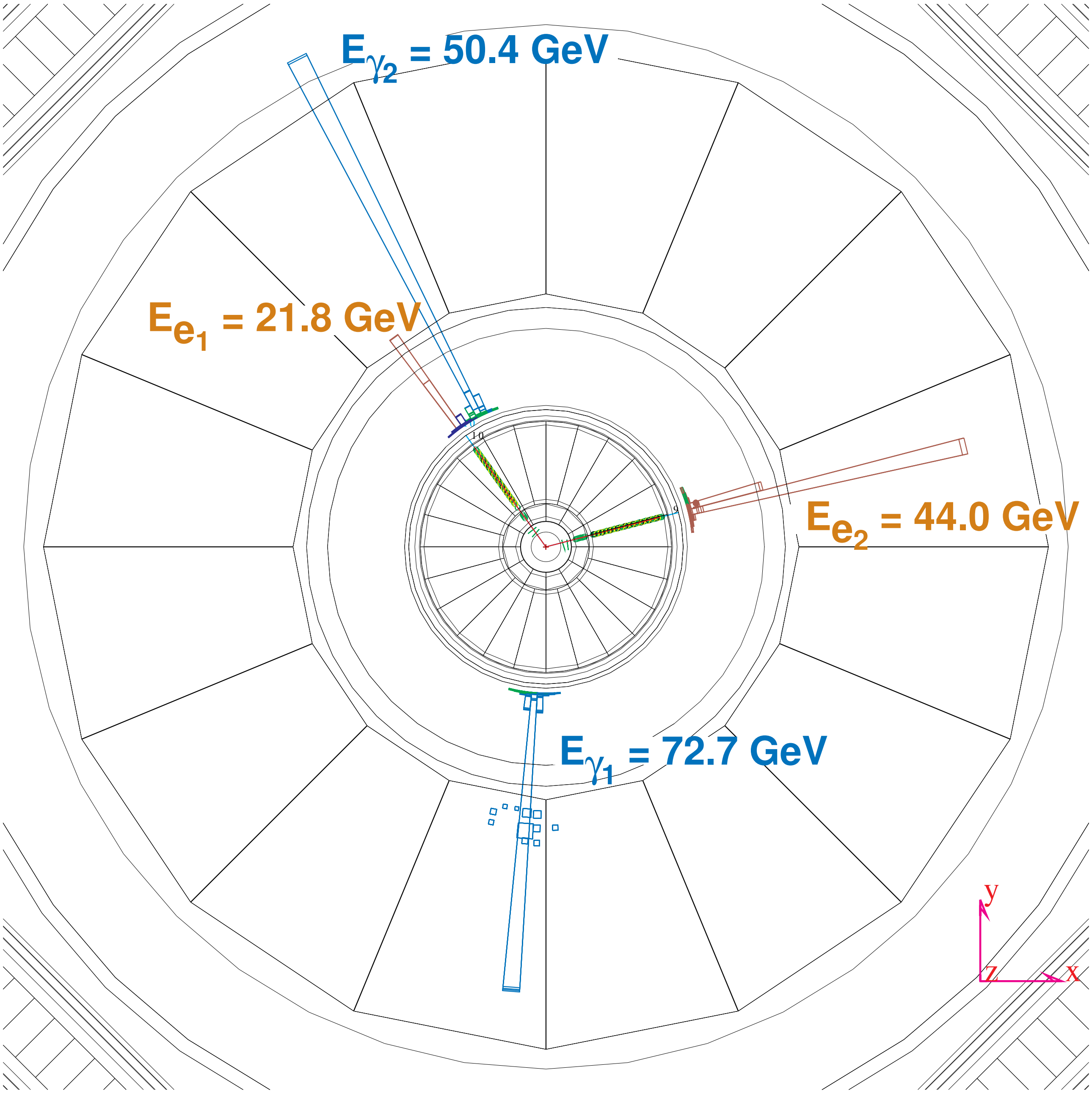
$1 \lesssim \tan\beta \lesssim 1.5$ excluded



$m_{\mathrm{H}^\pm} > 67.5$ GeV

e*e* Candidate Event

Run # 726808 Event # 3270



$m_{e_1\gamma_1} = 74.4$ GeV $m_{e_2\gamma_2} = 74.1$ GeV

0.6 event expected

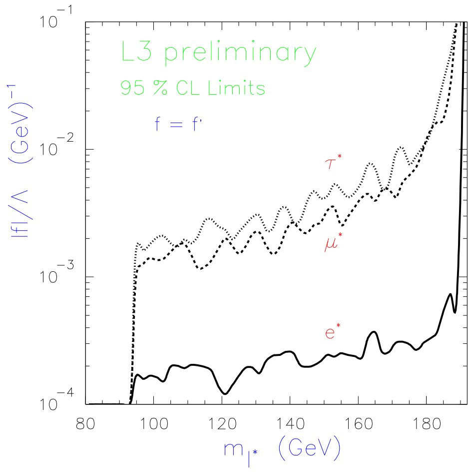
Excited Lepton Searches

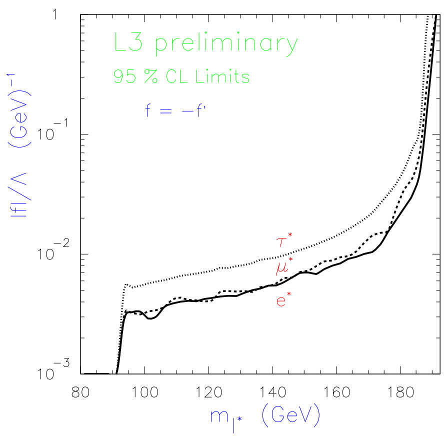
Pair production:

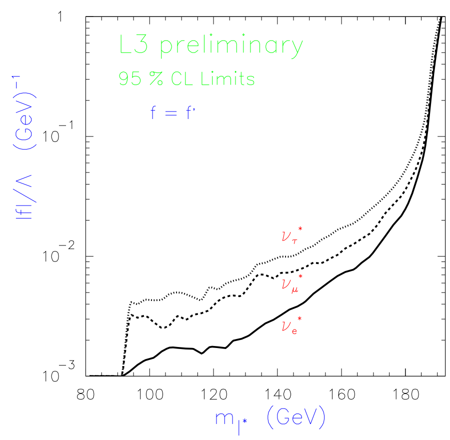
	$f = f'$	$f = -f'$
	$\ell^* \longrightarrow \ell\gamma$	$\ell^* \longrightarrow \nu\mathrm{W}$
$m_{\ell^*} >$	94.2 GeV	93.0 GeV

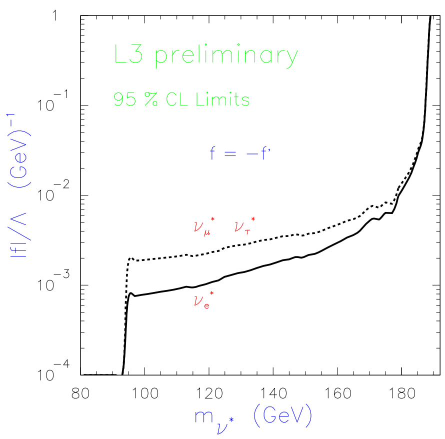
	$f = -f'$	$f = f'$
	$\nu^* \longrightarrow \nu\gamma$	$\nu^* \longrightarrow \ell\,\mathrm{W}$
$m_{\nu^*} >$	94.1 GeV	92.3 GeV

Single production:









New Heavy Leptons

Unstable Neutral Lepton

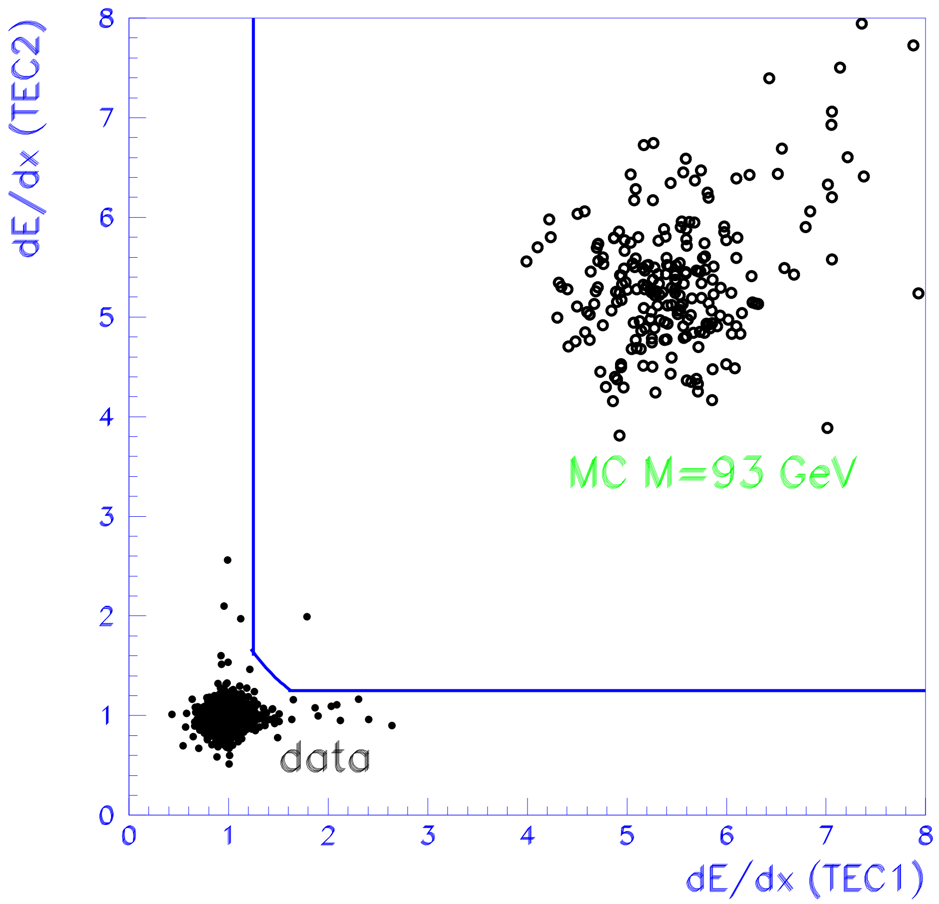
Decay mode		Dirac	Majorana
$L^0 \to eW$	$m >$	92.4 GeV	81.8 GeV
$L^0 \to \mu W$	$m >$	93.3 GeV	84.1 GeV
$L^0 \to \tau W$	$m >$	83.3 GeV	73.5 GeV

Unstable Charged Lepton

$L^\pm \to \nu W \quad m > 92.4$ GeV

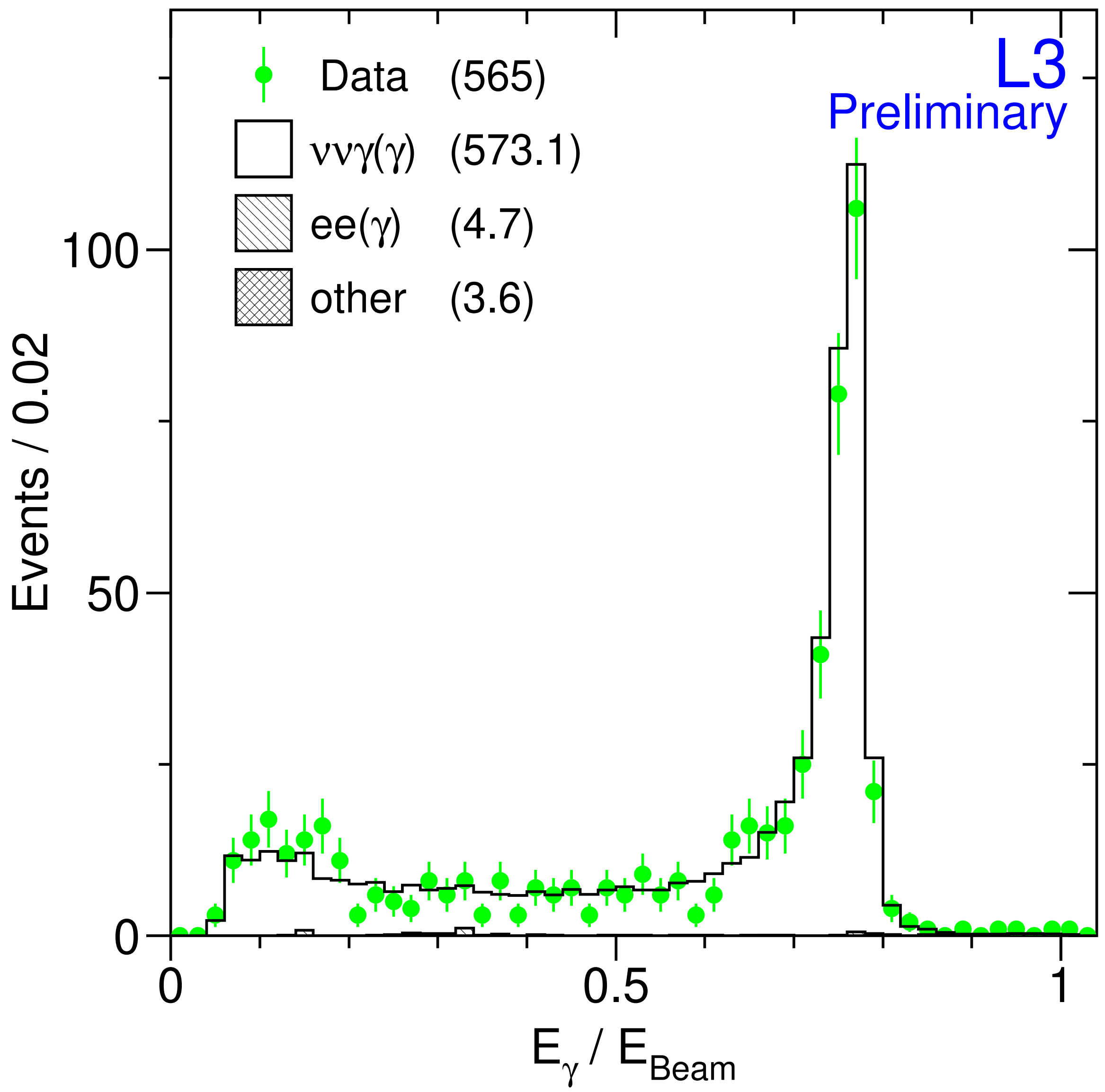
Stable Charged Lepton

Ecm = 189 GeV



$m > 93.5$ GeV

γ + missing energy



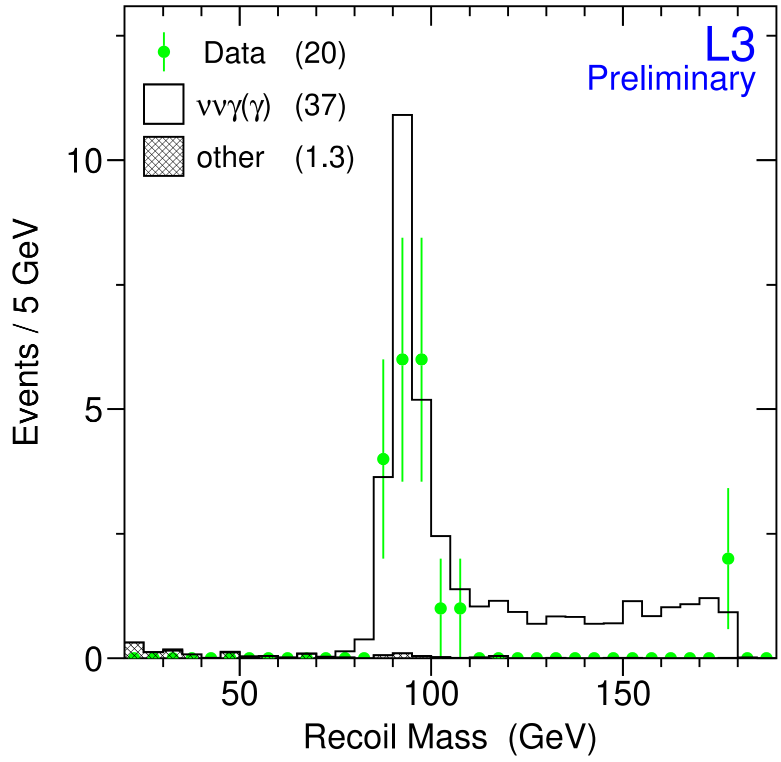
Measured cross section $e^+e^- \rightarrow \nu\bar{\nu}(\gamma)$:

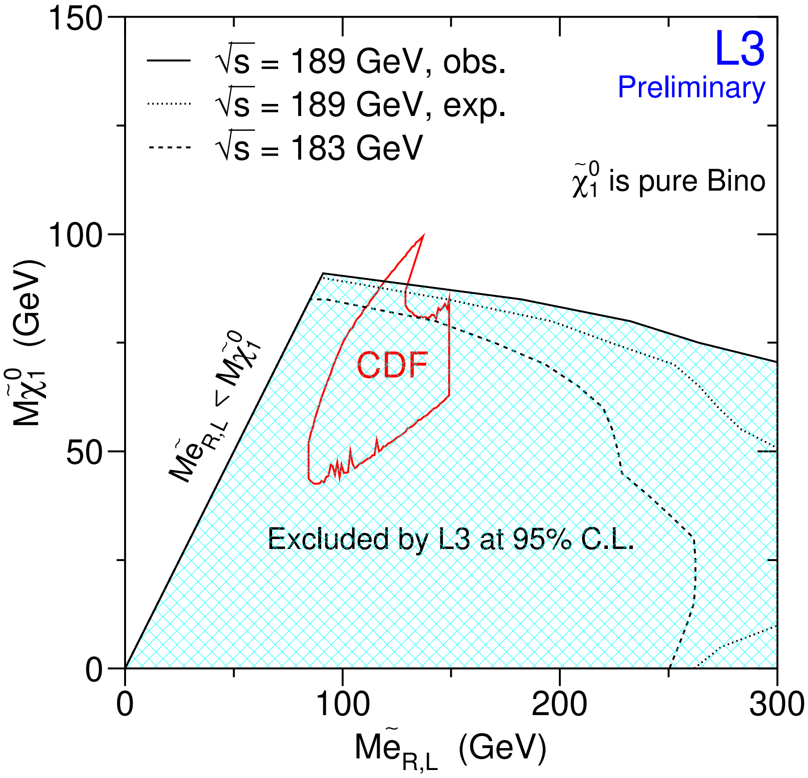
$$\sigma_{\nu\bar{\nu}} = 57.2 \pm 2.4(\text{stat})\ \text{pb} \qquad \sigma^{\text{SM}}_{\nu\bar{\nu}} = 58.4\ \text{pb}$$

GMSB: superlight gravitino scenario $e^+e^- \rightarrow \tilde{G}\tilde{G}(\gamma)$:

$$m_{\tilde{G}} > 9.8 \cdot 10^{-6}\ \text{eV} \quad \text{at 95\% C.L.}$$

$\gamma\gamma$ + missing energy





L3 limit $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{G}\tilde{G}\,\gamma\gamma$

Gravitino interpretation of CDF event almost ruled out

Standard SUSY searches

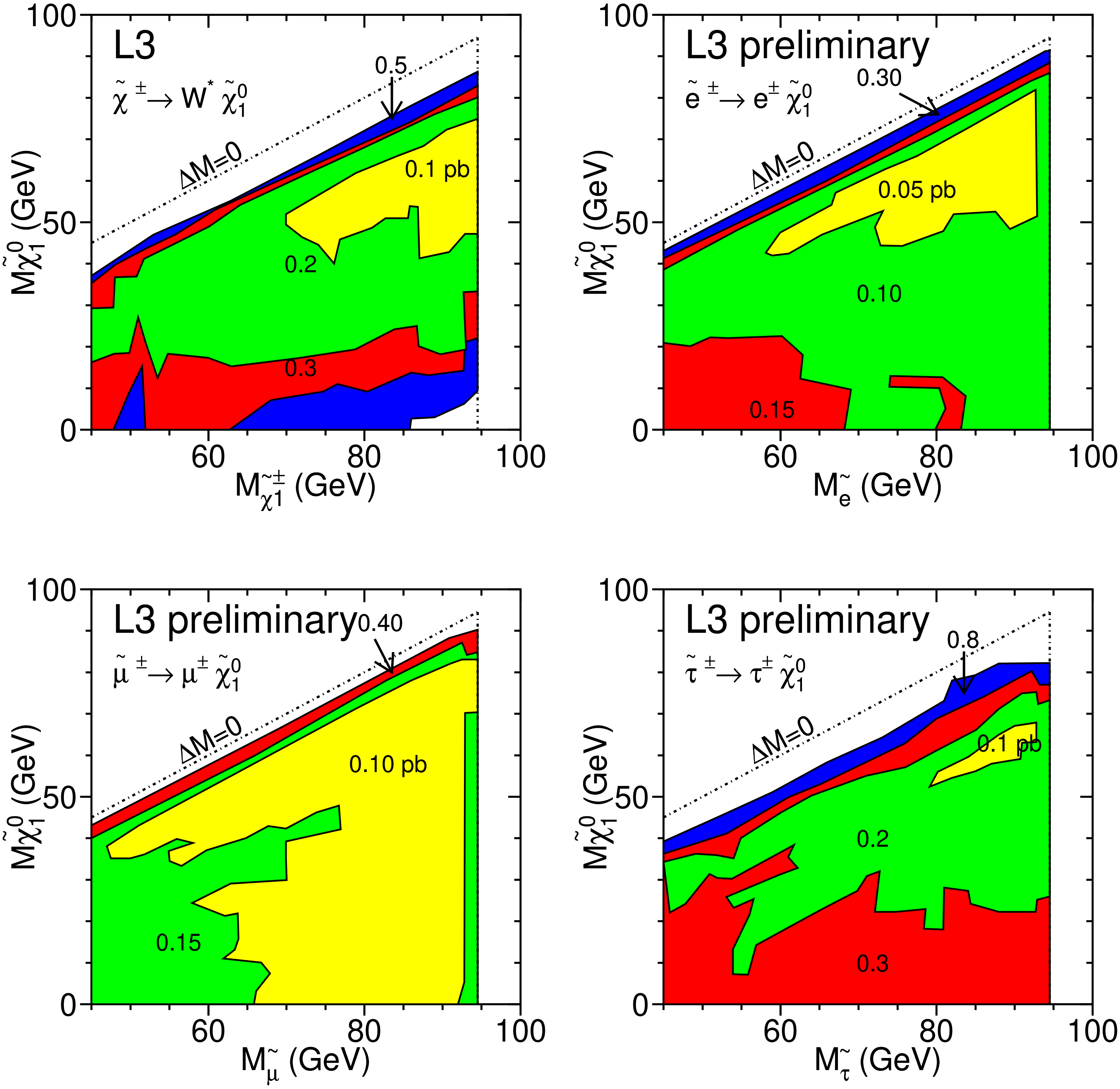
- Chargino selections
  - 4 jets and $\not{E}$
  - 1 e/μ, 2 jets and $\not{E}$
  - 1 τ, 2 jets and $\not{E}$
  - 2 e/μ and $\not{E}$
  - 2 τ and $\not{E}$
- selectron: 2 e and $\not{E}$
- smuon: 2 μ and $\not{E}$
- stau: 2 τ and $\not{E}$
- stop: jets, leptons, $\not{E}$

For each selection, 3 ΔM ranges.

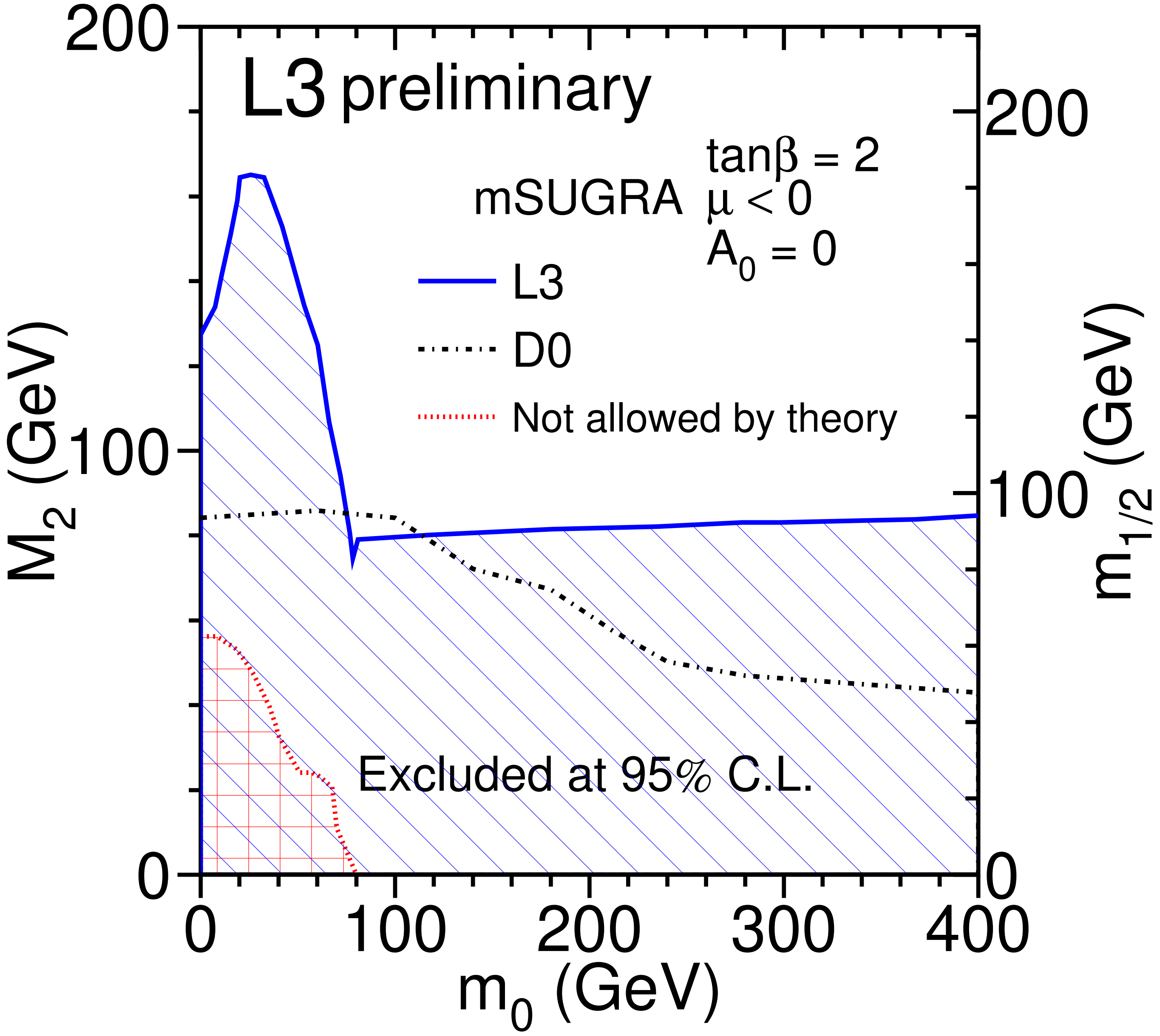
	Low ΔM		Medium ΔM		High ΔM		.OR.	
	N_{data}	N_{exp}	N_{data}	N_{exp}	N_{data}	N_{exp}	N_{data}	N_{exp}
$\tilde{\chi}^{\pm}$	11	8.51	7	3.69	7	11.1	24	22.1
$\tilde{\mathrm{e}}$	7	6.0	3	4.8	11	12.4	21	23.1
$\tilde{\mu}$	10	11.5	2	1.0	8	9.1	19	21.0
$\tilde{\tau}$	4	2.7	3	8.4	9	11.9	14	15.5
$\tilde{\mathrm{t}}_1 \longrightarrow \mathrm{c}\tilde{\chi}^0_1$	3	4.5	4	2.0	5	4.3	12	10.0
$\tilde{\mathrm{t}}_1 \longrightarrow \mathrm{b}\ell\tilde{\nu}$	2	4.6	1	0.95	5	5.0	8	9.7

No signal seen

Cross section Upper Limits

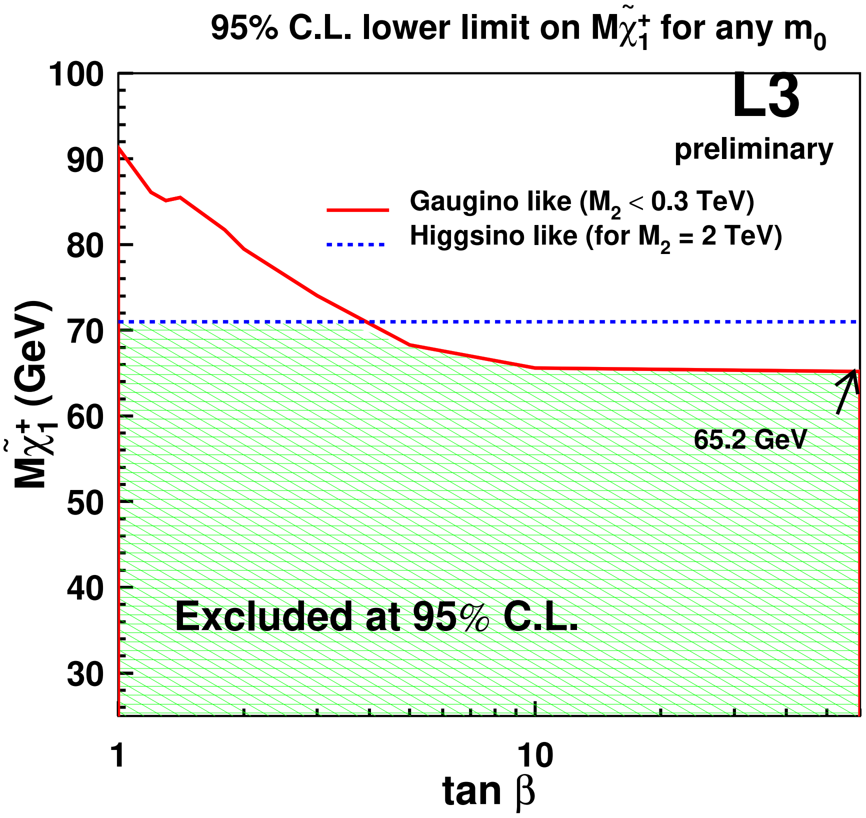


From scalar lepton and chargino searches exclusion in M_2, m_0 plane

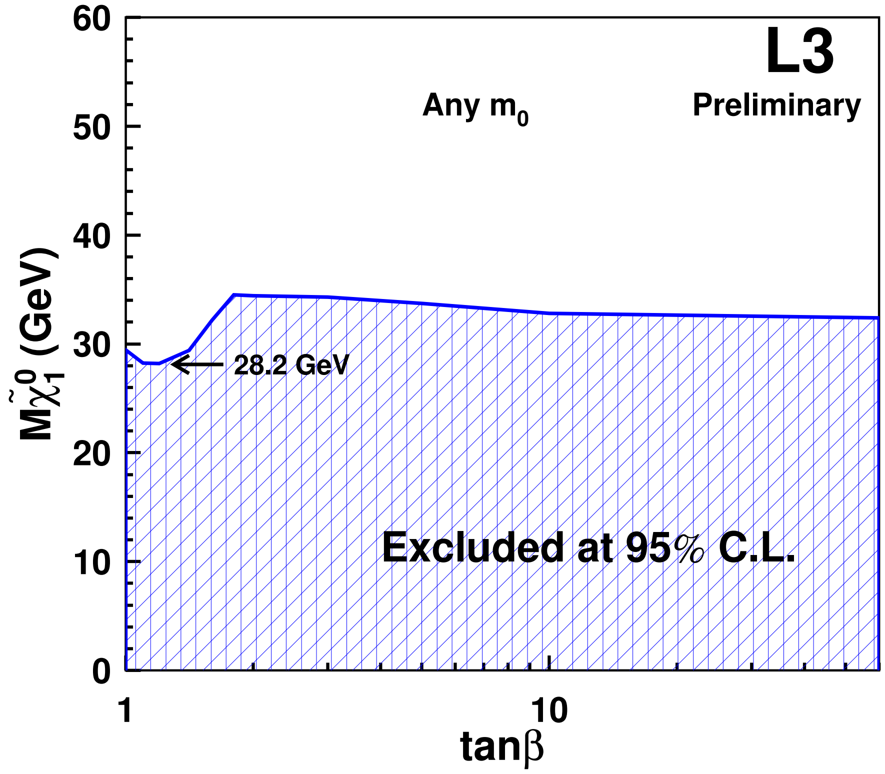


Chargino and Neutralino Limits

Limits $m_{\tilde{\chi}_1^\pm}$ and $m_{\tilde{\chi}_1^0}$ independent of MSSM parameters:



$$m_{\tilde{\chi}_1^+} > 65.2 \text{ GeV}$$



$$m_{\tilde{\chi}_1^0} > 28.2 \text{ GeV}$$

Summary and conclusions

- W pair cross section at 189 GeV:
  $$\sigma_{\mathrm{WW}} = 16.20 \pm 0.37 \pm 0.27 \text{ pb}$$
- W mass (All LEP II combined):
  $$m_{\mathrm{W}} = 80.43 \pm 0.08 \pm 0.07 \text{ GeV}$$
- W couplings measured
- single W, ZZ, Zγ, measured and limits on anomalous boson couplings derived.
- Measurements of fermion-pair production lead to improved limits on new physics.
- Studies of $\gamma\gamma$ scattering at high energies.
- Hadronic event shapes in agreement with QCD.
  $$\alpha_{\mathrm{s}}(189 \text{ GeV}) = 0.108 \pm 0.003\,(\text{exp}) \pm 0.005\,(\text{th})$$
- Searches for Higgs bosons result in improved mass limits:
  $$m_{\mathrm{H}} > 95.2 \text{ GeV}, m_{\mathrm{h}} > 77 \text{ GeV}, m_{\mathrm{A}} > 78 \text{ GeV}$$
- No sign for Supersymmetry
  $$m_{\tilde{\chi}_1^0} > 28.2 \text{ GeV}, m_{\tilde{\chi}_1^\pm} > 65.2 \text{ GeV}$$
  (for any of the five MSSM parameters)
- Thanks to the accelerator divisions for the excellent performance in 1998. L3 is looking forward to high luminosity at LEP200 and needs 2.5 pb^{-1} at the Z at the beginning of the run for TEC calibration.