L3 Measurements of Double and Single W Boson Production

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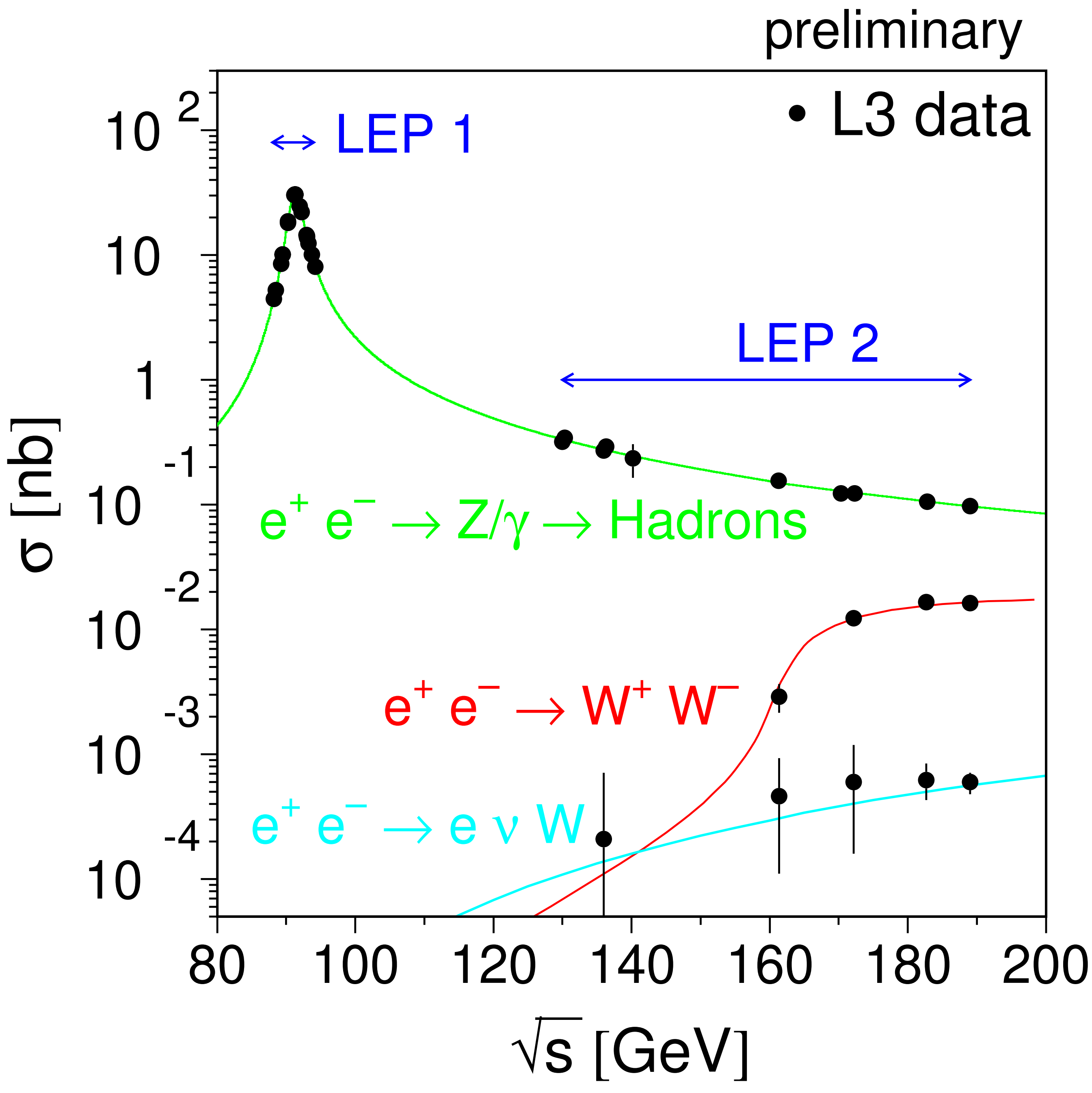
W production at LEP



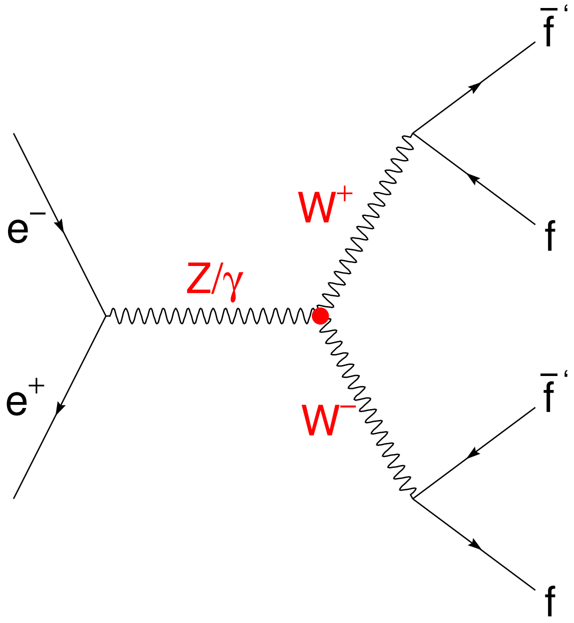
- LEP2: W^+W^- and single W production
- $265\,\mathrm{pb}^{-1}$ collected by L3 in energy range from 130 GeV to 189 GeV

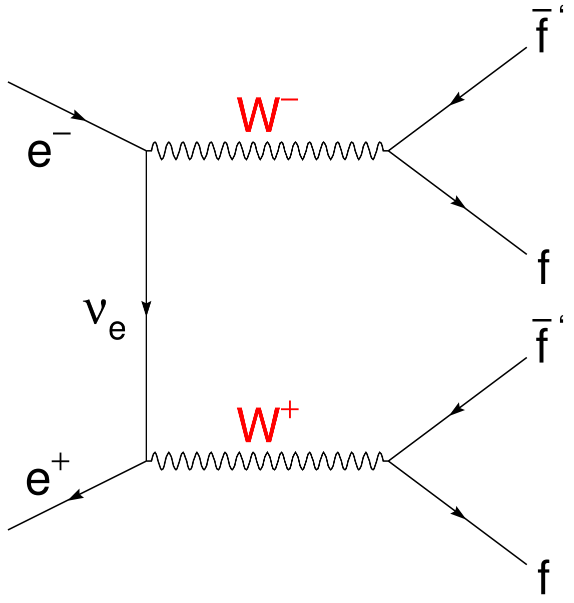
$\Rightarrow$ 3500 W^+W^- pairs and 130 single Ws

- results for energies up to 183 GeV and preliminary results for 189 GeV

W^+W^- pair production at LEP

- W^+W^- production at Born level (CC03):





- W^+W^- decay channels:

$$\begin{array}{llll} WW & \longrightarrow qqqq & & 45.6\ \% \\ WW & \longrightarrow qq\ell\nu & \left\{\begin{array}{l} qqe\nu \\ qq\mu\nu \\ qq\tau\nu \end{array}\right\} & 43.8\ \% \\ WW & \longrightarrow \ell\nu\ell\nu & & 10.6\ \% \end{array}$$

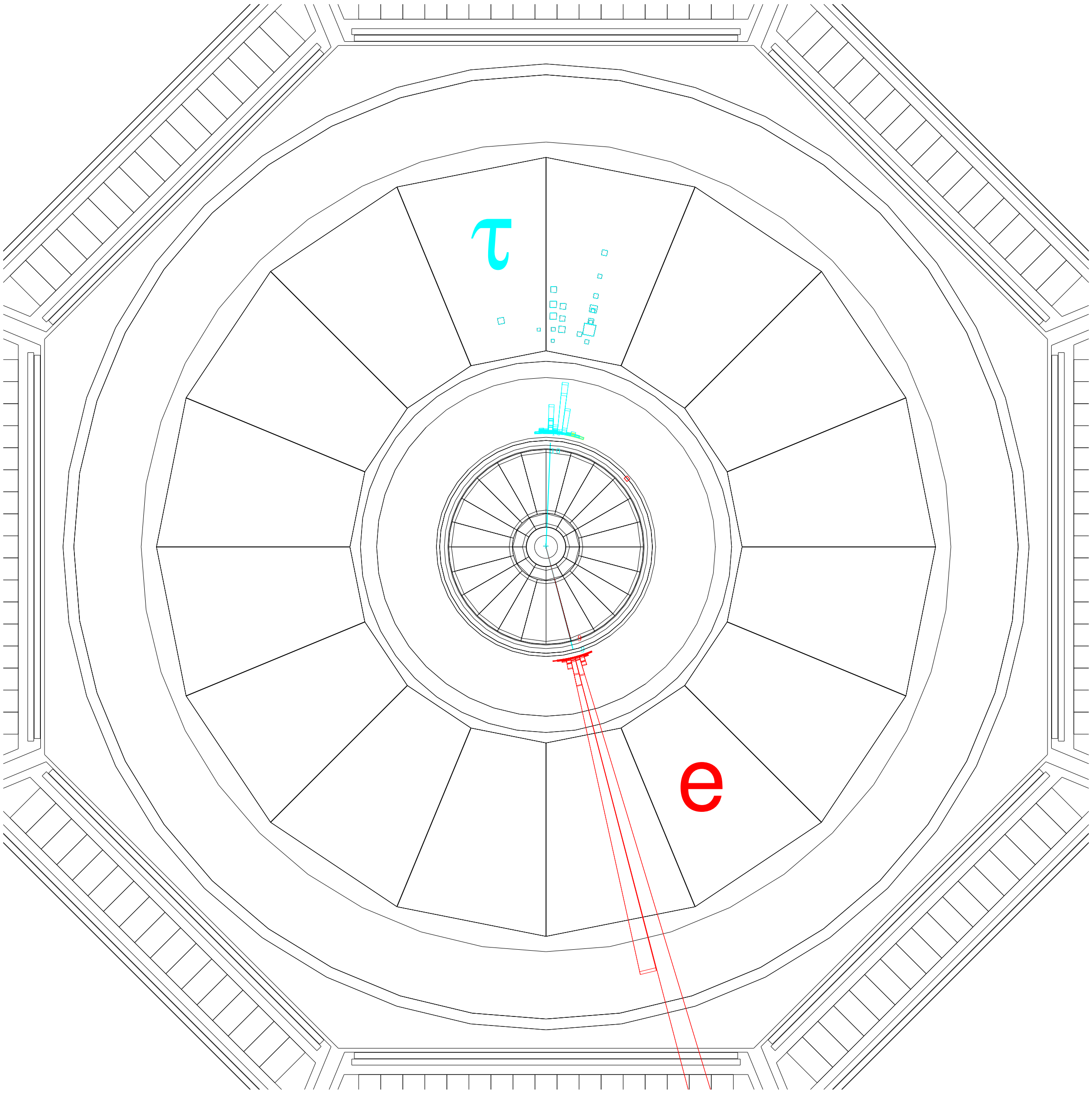
- depending on final state (in particular $e\nu f\bar{f}'$), many more diagrams contribute to 4-fermion production

$\Rightarrow$ corrections necessary to obtain σ(CC03)

$$\sigma^{CC03}_{meas}(e\nu f\bar{f}') = \sigma_{meas}(e\nu f\bar{f}') \cdot \frac{\sigma^{CC03}_{MC}}{\sigma^{4f}_{MC}}$$

Selection of $W^+W^- \to \ell\nu\ell\nu$

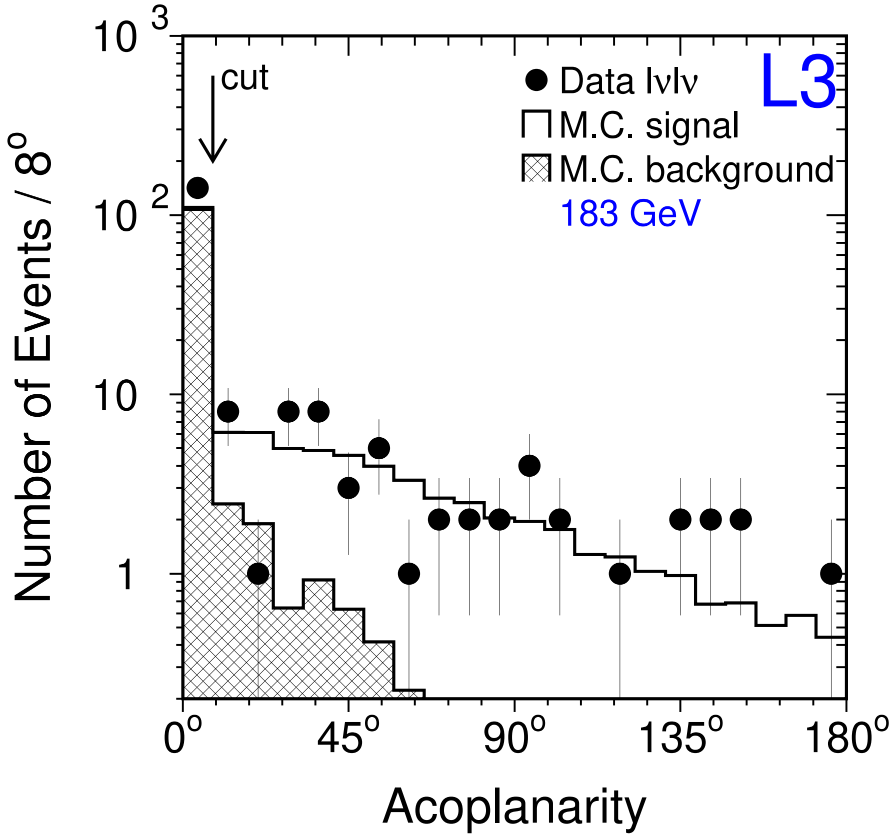
- 112 diagrams contribute to $\ell\nu\ell\nu$ final state

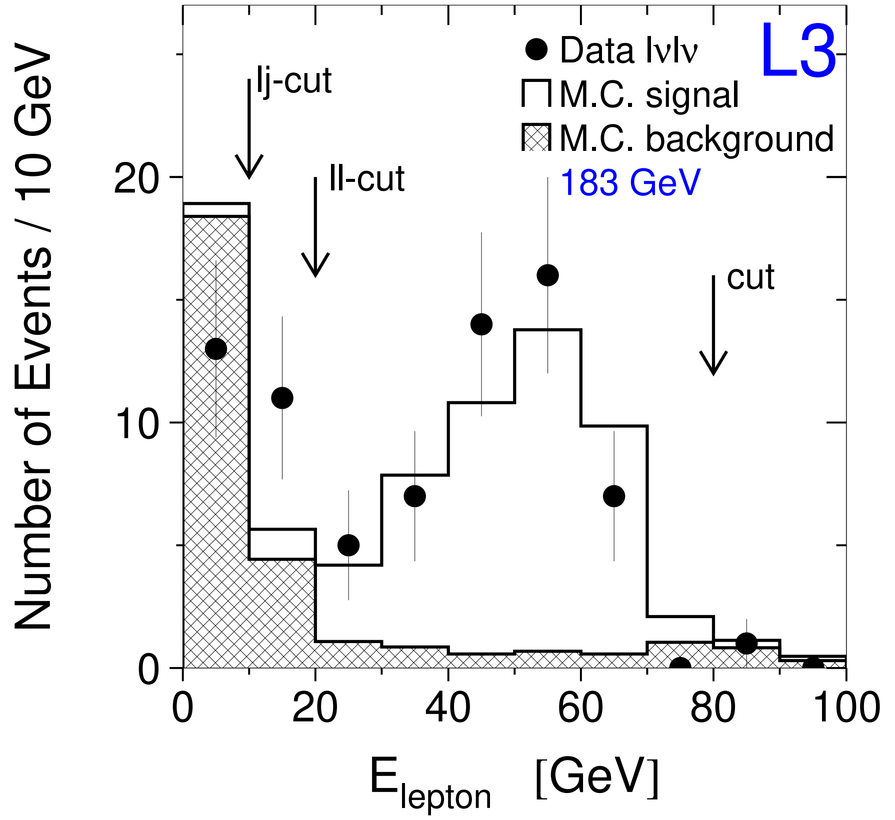


- 2 acoplanar, acollinear leptons (e, μ, τ-jet)
- missing transverse momentum from neutrinos
- high-energy leptons, but $E_\ell < 0.8 \cdot E_{beam}$

Background: ▷ fermion pair production
▷ Bhabha scattering
▷ $\gamma\gamma$-interactions

Selection of $W^+W^- \rightarrow \ell\nu\ell\nu$

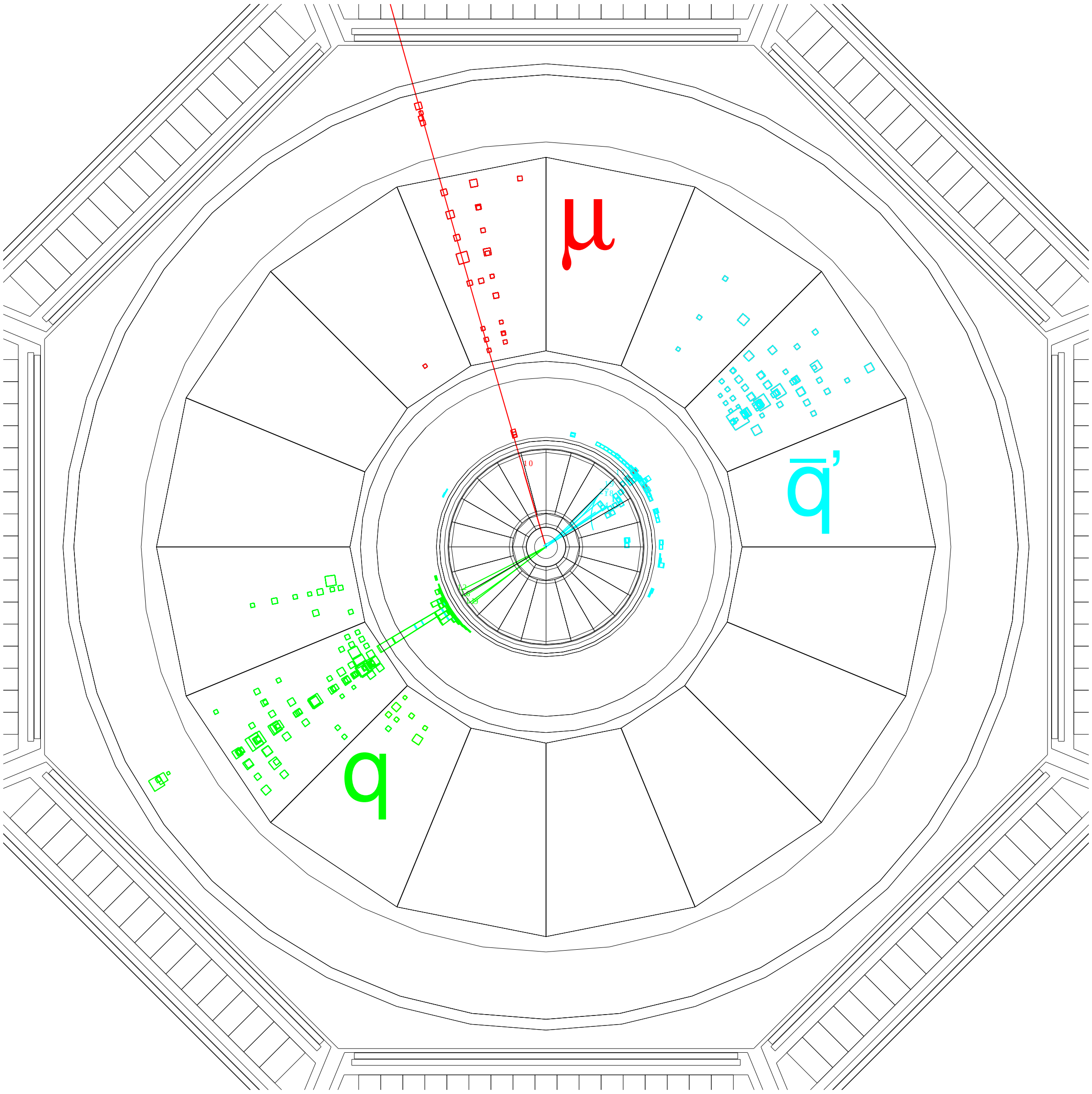




- efficiencies 20% ($\tau\nu\tau\nu$) to 60% ($e\nu e\nu$)
- background $\sim$ 15 %
- 169 events selected at 189 GeV

Selection of $W^+W^- \longrightarrow qq\ell\nu$

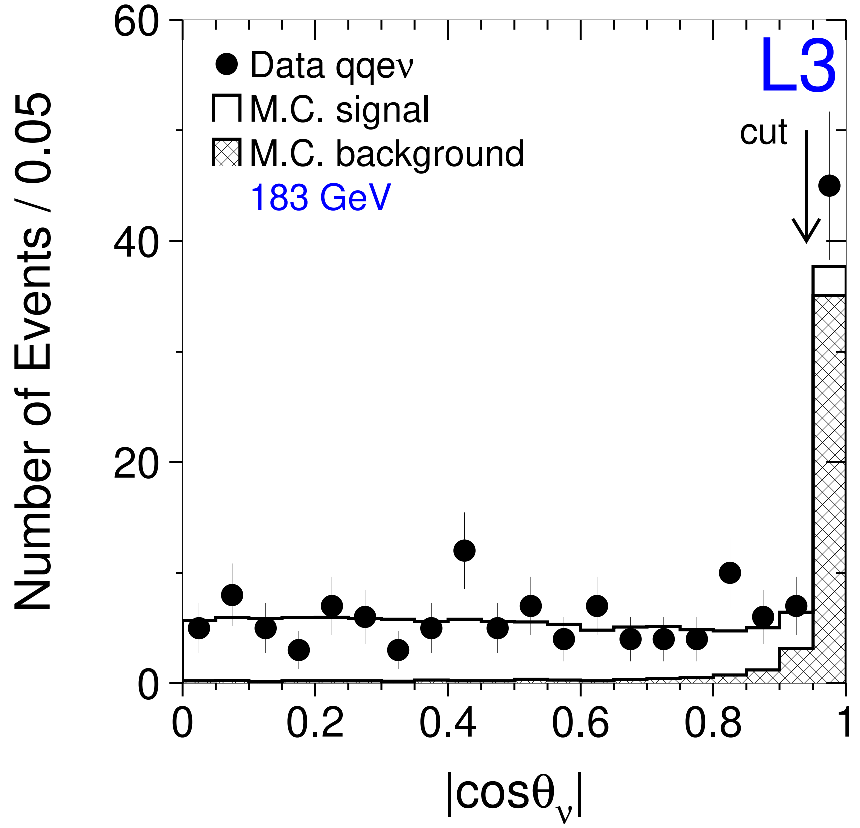
- $qq\mu\nu$-event in the L3 detector

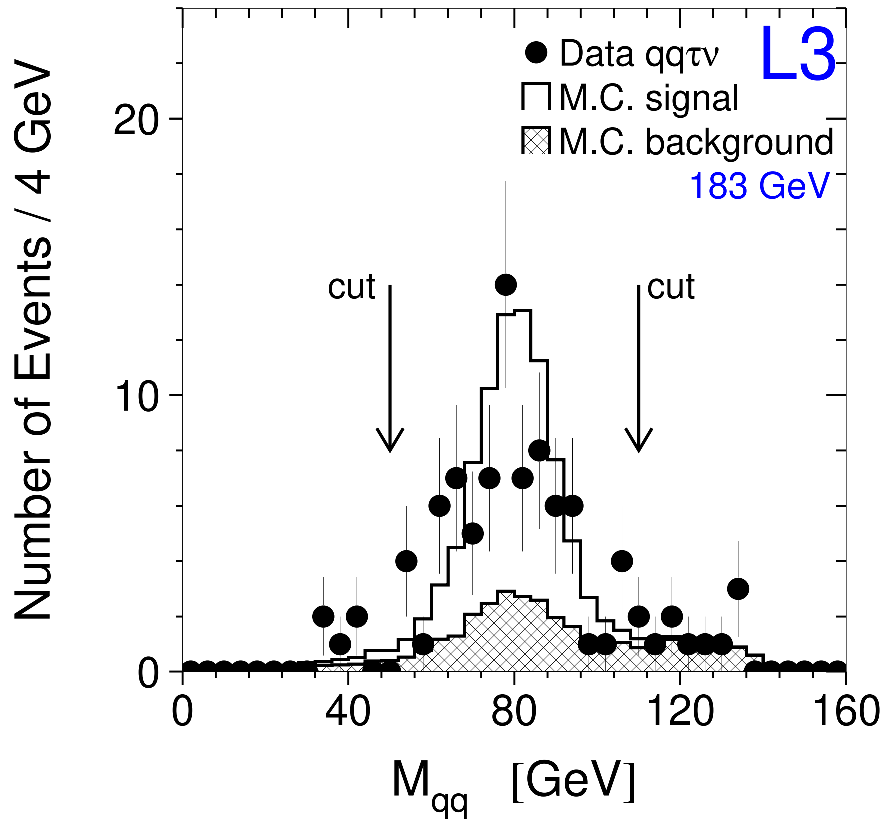


- 2 hadronic jets + 1 lepton (e, μ, τ-jet)
- lepton separated from hadronic jets
- missing transverse momentum from neutrino
- invariant masses M_{qq} and $M_{\ell\nu}$ in window around M_W

Background: ▷ mainly $e^+e^- \longrightarrow q\bar{q}(\gamma)$ (initial state radiation)

Selection of $W^+W^- \longrightarrow qq\ell\nu$

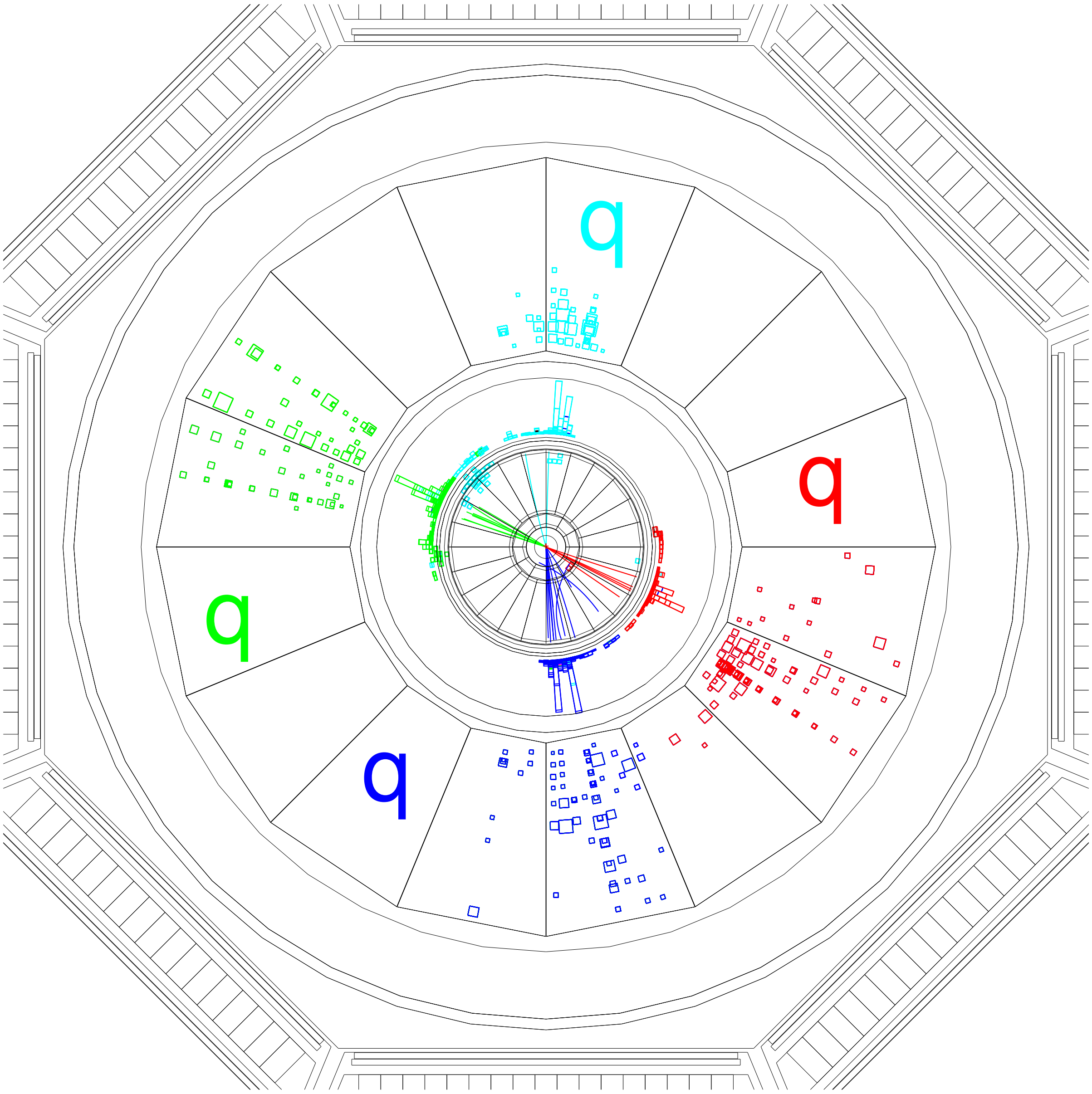




- efficiencies 50% ($qq\tau\nu$) to 80% ($qqe\nu$)
- background 13% ($qq\tau\nu$) to 3% ($qq\mu\nu$)
- 1013 events selected at 189 GeV

Selection of $W^+W^- \longrightarrow$ qqqq

- qqqq-event in the L3 detector

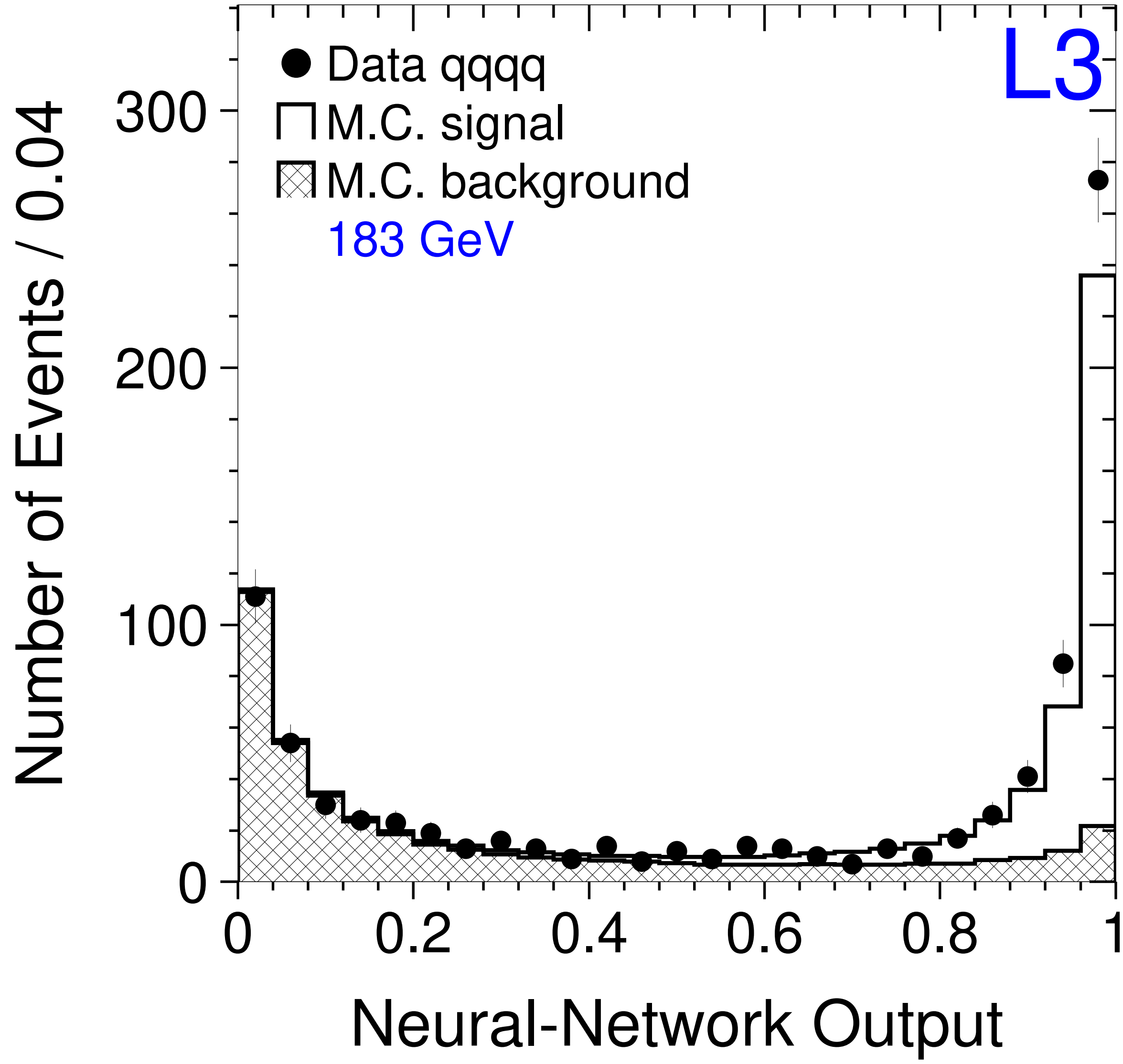


- event with 4-jet topology
- high multiplicity, no missing energy

Background: ▷ mainly $e^+e^- \longrightarrow q\bar{q}(\gamma)$
(gluon radiation)

Selection of $W^+W^- \longrightarrow qqqq$

- Neural-Network is trained to distinguish between W^+W^- and QCD background
- 8 input nodes to NN, most discriminating:
  - ▷ jet-resolution parameter
  - ▷ minimal jet-jet angle
  - ▷ minimal / maximal jet energy



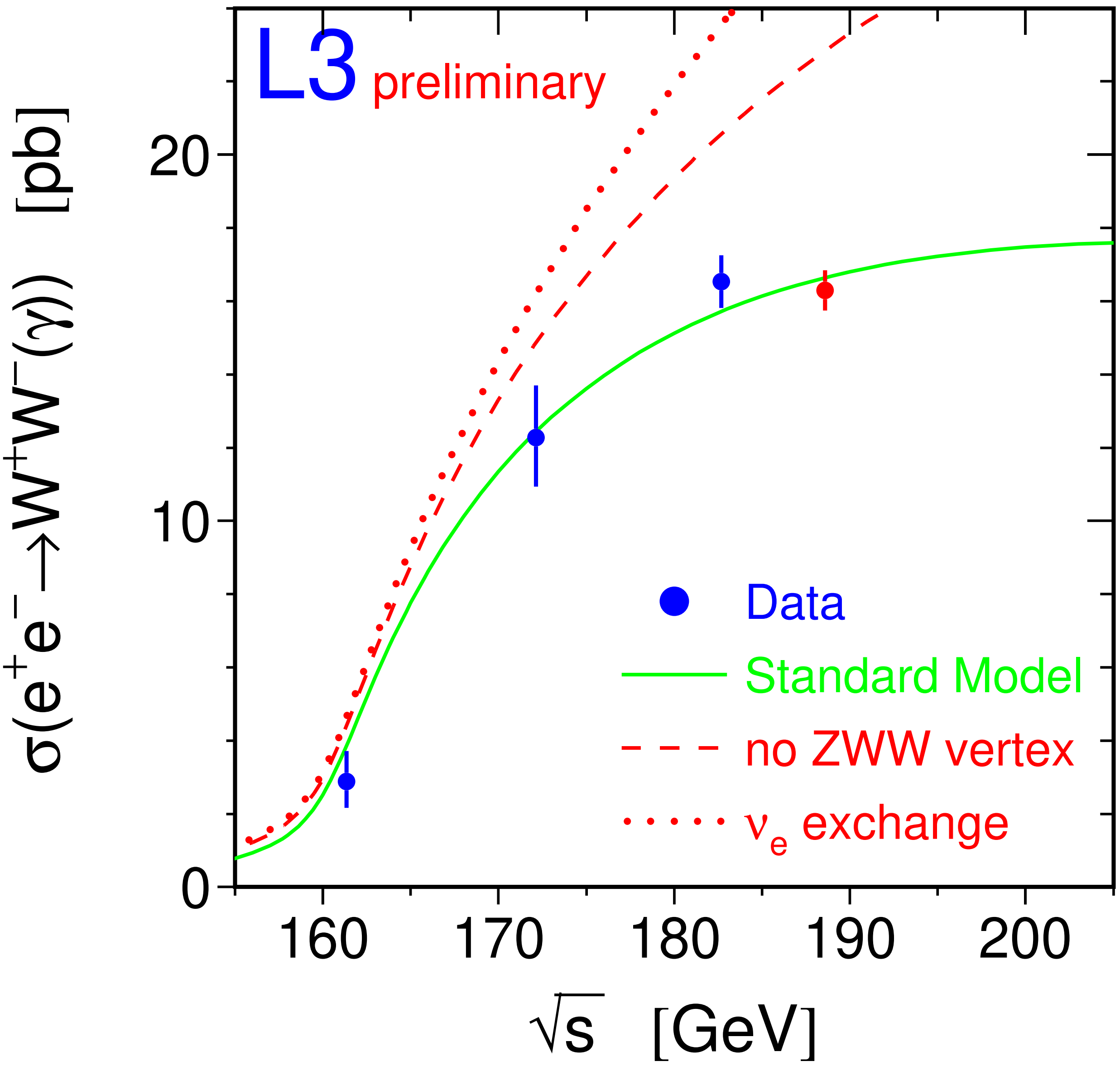
$\Rightarrow$ determine cross section for W^+W^- production by a binned log-likelihood fit to the Neural-Network Output

W^+W^- pairs: Cross section

- preliminary results from 189 GeV:

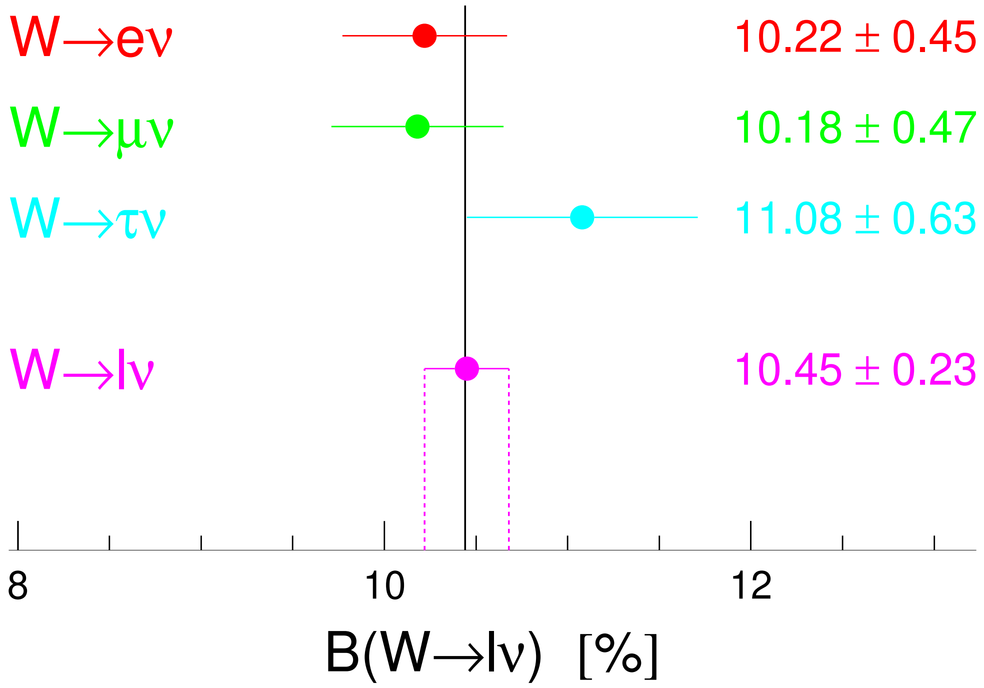
Channel	σ [pb]	σ_{SM} [pb]
$e^+e^- \to \ell\nu\ell\nu$	1.62 ± 0.15	1.76
$e^+e^- \to qqe\nu$	2.29 ± 0.14	2.43
$e^+e^- \to qq\mu\nu$	2.33 ± 0.14	2.43
$e^+e^- \to qq\tau\nu$	2.55 ± 0.20	2.43
$e^+e^- \to qqqq$	7.52 ± 0.26	7.59

$$\Rightarrow \sigma_{WW} = 16.29 \pm 0.38\,\text{pb}$$



W^+W^- pairs: Branching Fractions

- preliminary results from 189 GeV:



- Branching Fractions with lepton universality:

$$B(W \to \ell\nu) = 10.45 \pm 0.23\ \% \text{ (SM 10.8 \%)}$$
$$B(W \to qq) = 68.66 \pm 0.69\ \% \text{ (SM 67.5 \%)}$$

- CKM matrix element V_{cs} from $B(W \to qq)$:

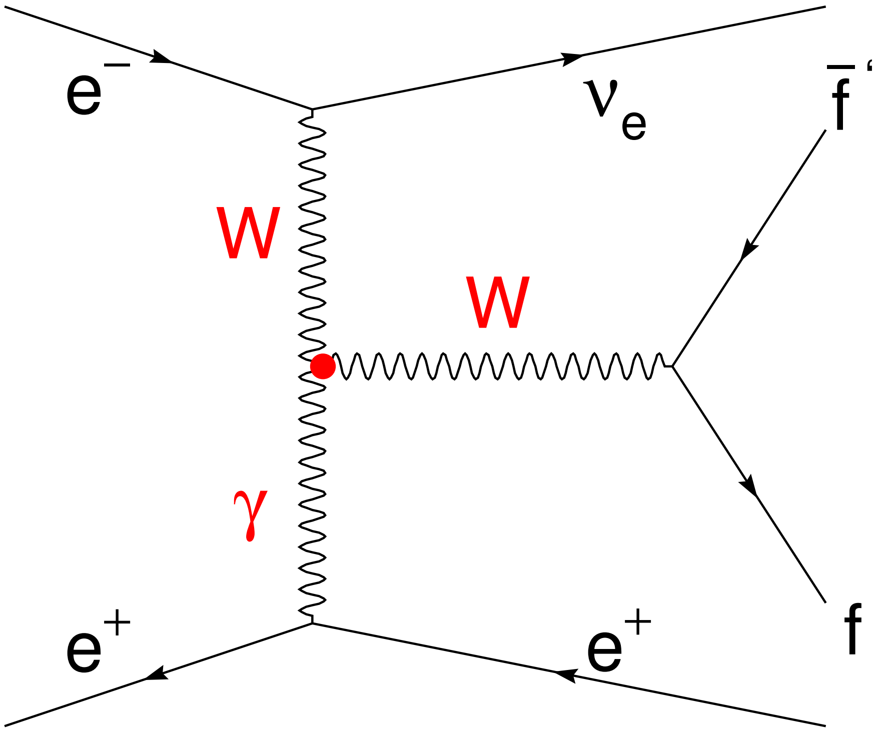
$$\frac{B(W \to qq)}{1 - B(W \to qq)} = \left(1 + \frac{\alpha_s}{\pi}\right) \Sigma \left|V_{ij}^{CKM}\right|^2$$

$\Rightarrow \Sigma \left|V_{ij}^{CKM}\right|^2 = 2.11 \pm 0.07$ (Unitarity $\equiv 2$)

$\Rightarrow$ fixing other CKM matrix elements:

$$V_{cs} = 1.03 \pm 0.03$$

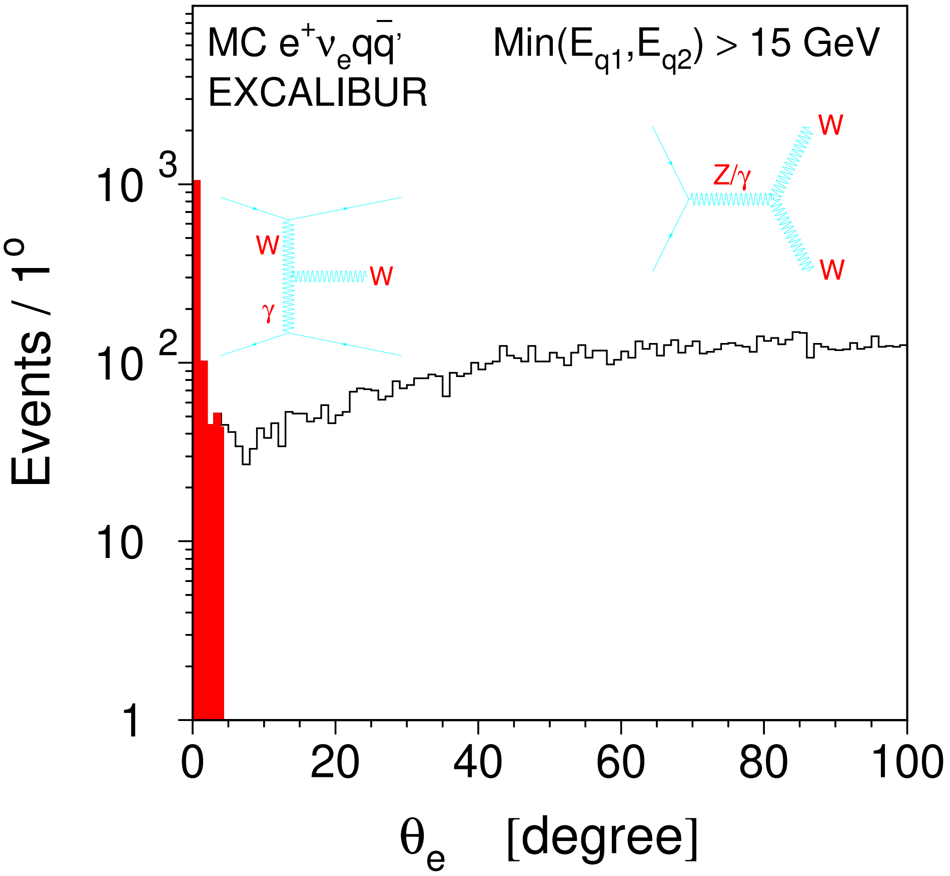
Single W production at LEP

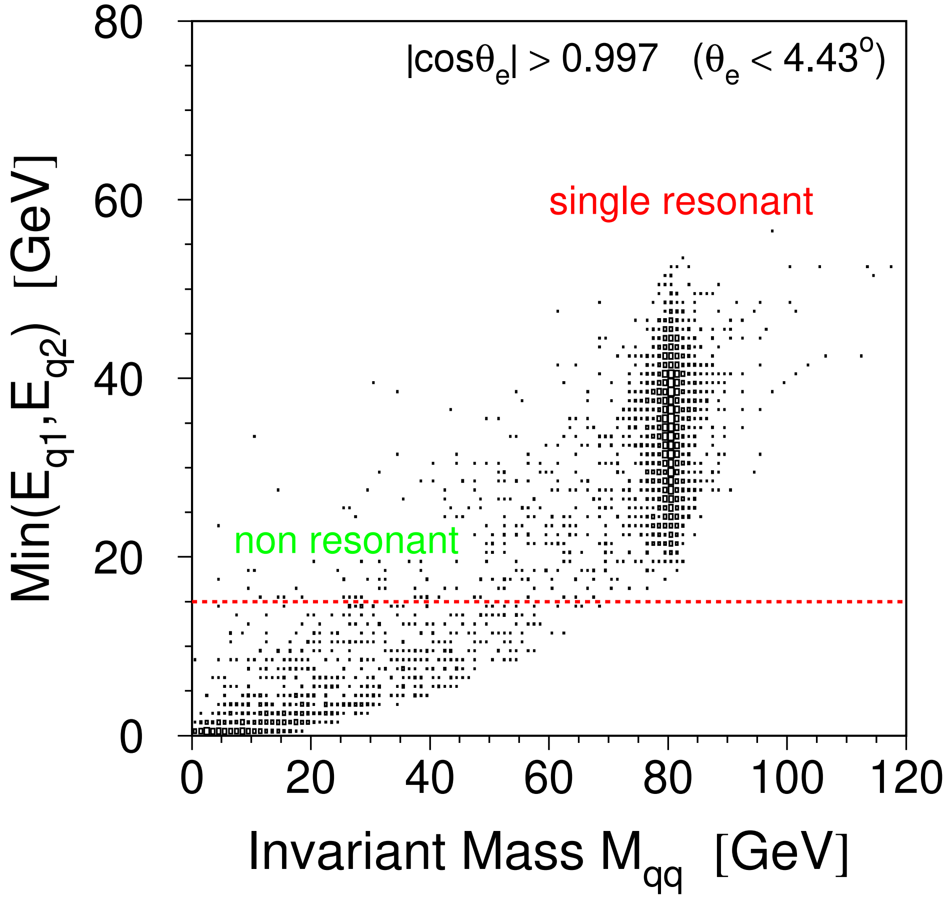


- sensitive to γWW vertex
- interesting SM process (t-channel)
- background to "new physics"

$\Rightarrow$ define phase space to separate single W process from other graphs contributing to $e\nu f\bar{f}'$ final state:
- $\triangleright$ non-resonant
- $\triangleright$ double-resonant WW

Single W production: Signal definition





Single W production: Signal definition

Phase space cuts for $e^+\nu_e f \bar{f}'$:

- $|\cos\theta_{e^+}| > 0.997$
- $\mathrm{Min}(E_f, E_{f'}) > 15$ GeV
- $|\cos\theta_{e^-}| < 0.75$ for $e^+\nu_e e^-\bar{\nu}_e$ only

$\Rightarrow$ reject $e^+e^-Z \to e^+e^-\nu_e\bar{\nu}_e$ contribution

$\Rightarrow$ purity of single resonant contribution accounts for 90% (75% for $e^+e^-\nu_e\bar{\nu}_e$)

SM expectation for $\sqrt{s} = 189$ GeV:

$\sigma_{e\nu\ell\nu}$ = 0.16 pb ~ 28 events

$\sigma_{e\nu q\bar{q}'}$ = 0.39 pb ~ 70 events

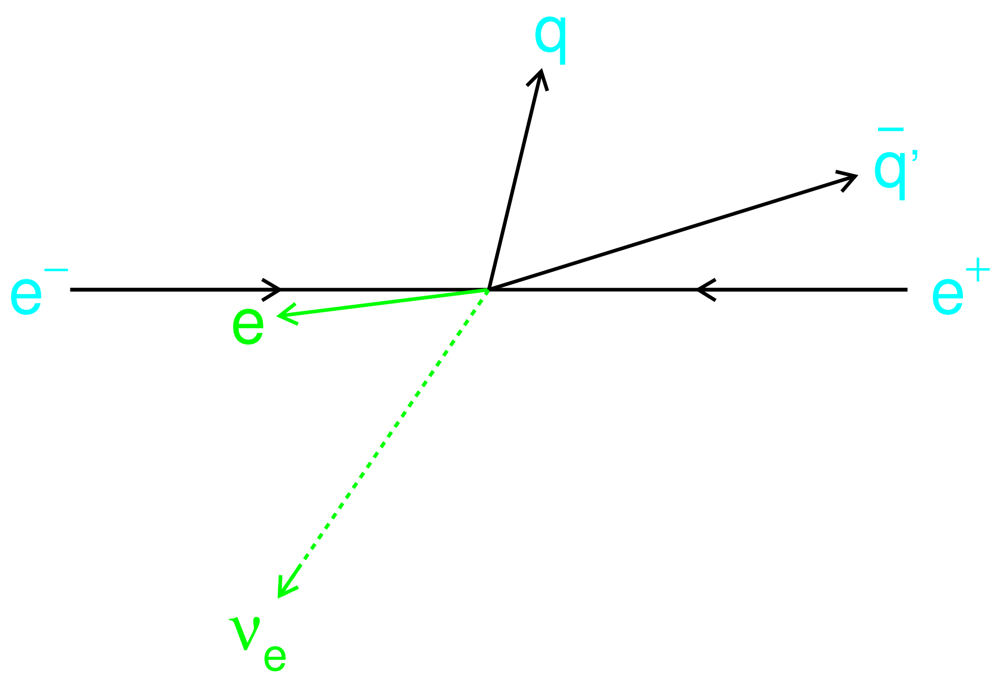
$\sigma_{\tau\tau}$ = 8.4 pb ~ 1500 events

σ_{WW} = 16.7 pb ~ 3000 events

$\sigma_{q\bar{q}(\gamma)}$ = 98.1 pb ~ 17300 events

($\mathcal{L} = 176.4\,\mathrm{pb}^{-1}$)

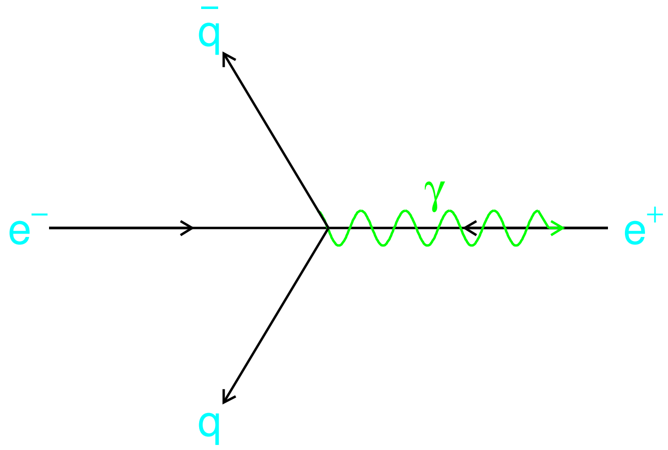
Hadronic single W: Experimental Signature



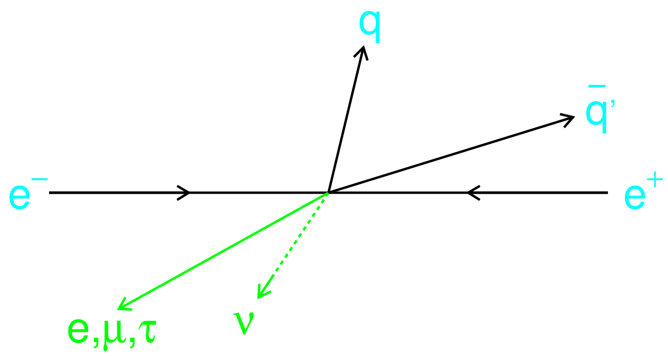
e in forward direction
ν within the detector
= not detected

$\Rightarrow$ 2 hadronic jets + missing momentum

$$e^+e^- \longrightarrow q\bar{q}(\gamma)$$

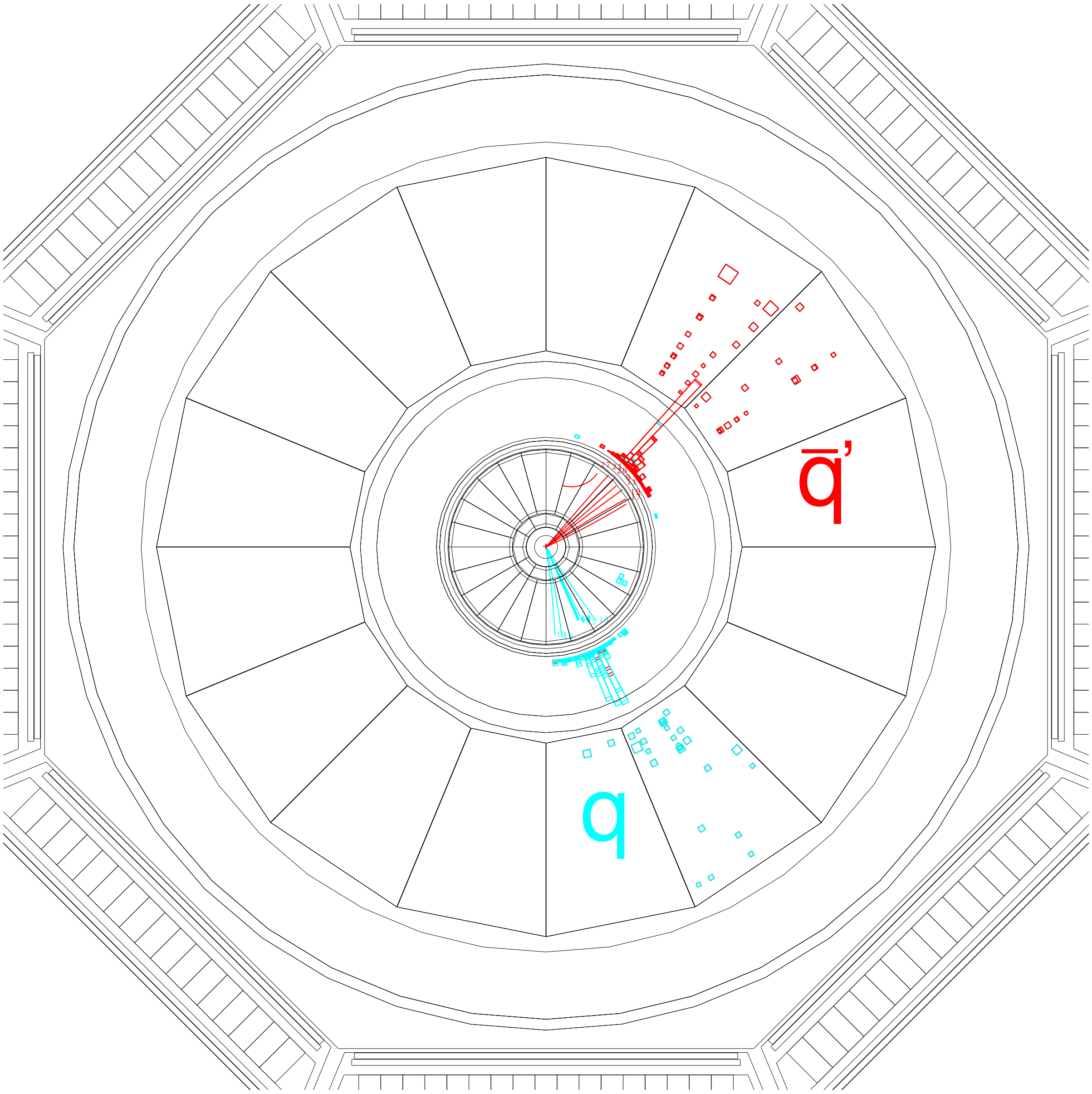


$$e^+e^- \longrightarrow W^+W^-$$



Hadronic single W: Preselection

$\sqrt{s} = 189$ GeV E_{tot} = 95.4 GeV M_{jj} = 74.0 GeV



⇒ background to "new physics": $e^+e^- \longrightarrow ZH \longrightarrow \nu\bar{\nu}q\bar{q}$

Preselection:

- 2 acoplanar jets
- suppressing events with identified leptons
- missing transverse momentum

⇒ select signal with efficiency of 60%

⇒ Signal / Background ≈ 1/6

Hadronic single W: NN analysis

Input nodes to NN:

- spherocity
- visible mass M_{vis}
- p_{mis}/E_{vis}

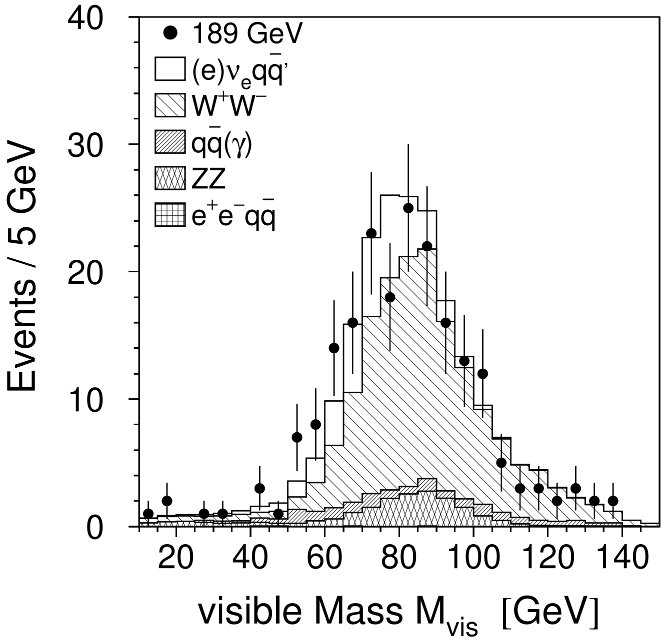
} global event variables

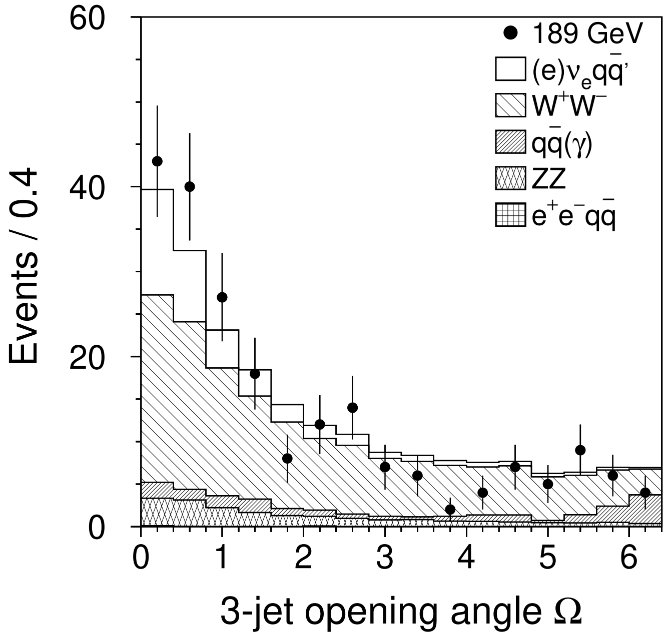
- $M_{jet1} + M_{jet2}$
- Max $\left(\Sigma_i \frac{\vec{p}_i \cdot \vec{p}_{jet}}{|\vec{p}_{jet}| \cdot E_{jet}}\right)$
- y_{23}

} 2-jet topology

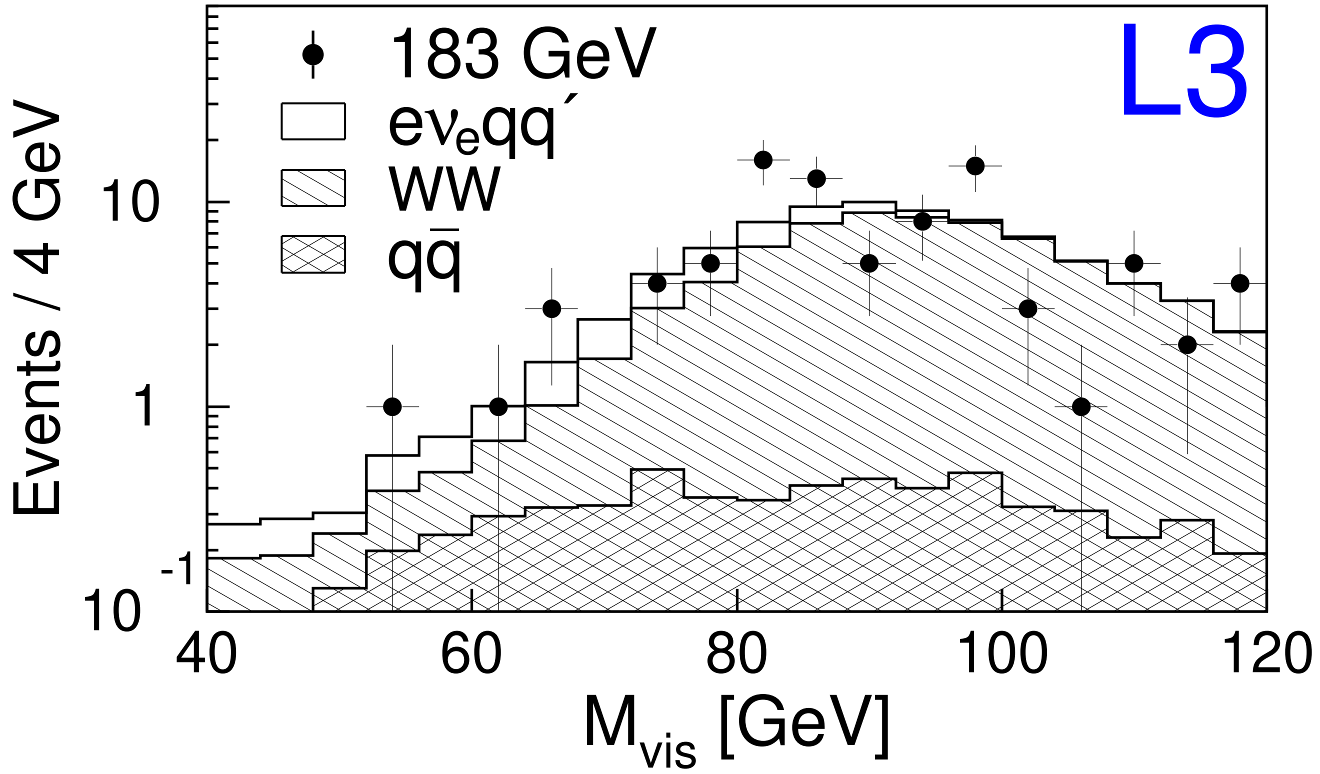
- y_{34}
- 3-jet opening angle Ω
- M_{jet3}/E_{jet3}

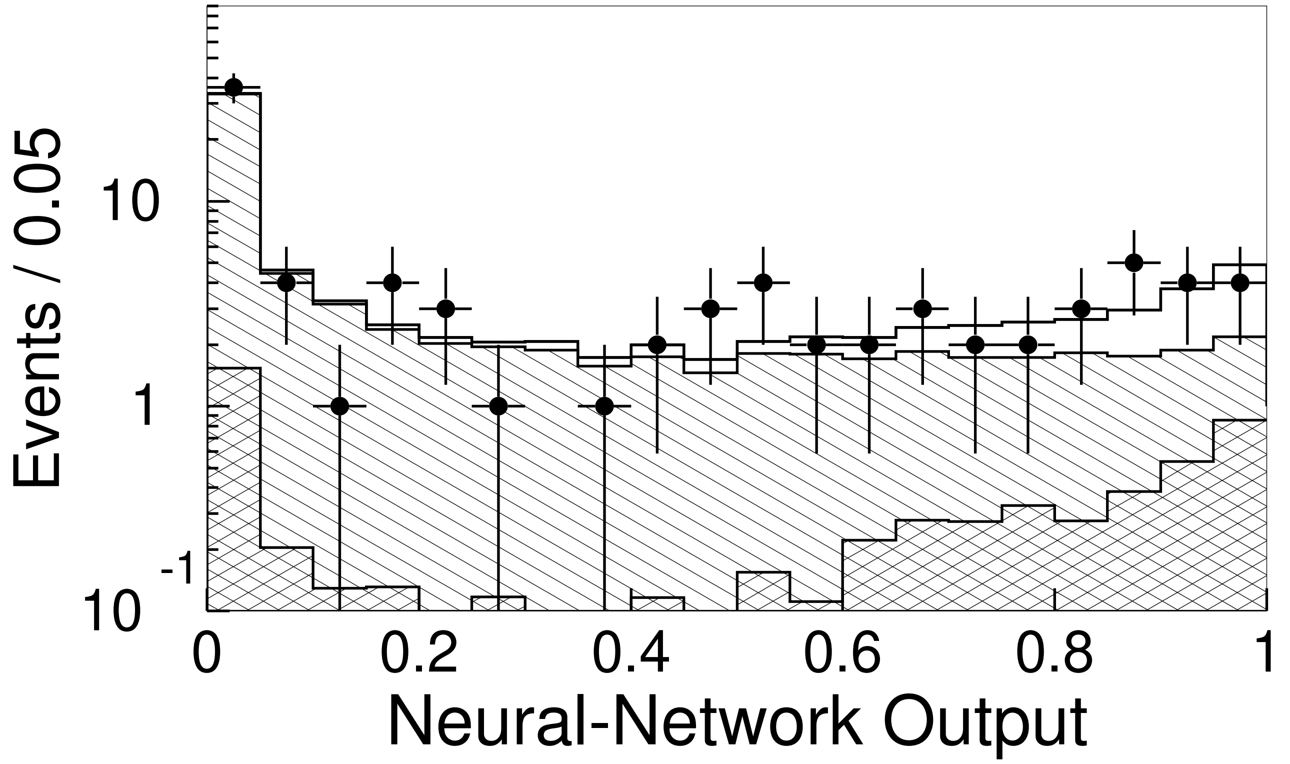
} 3-jet topology





Hadronic single W: NN analysis

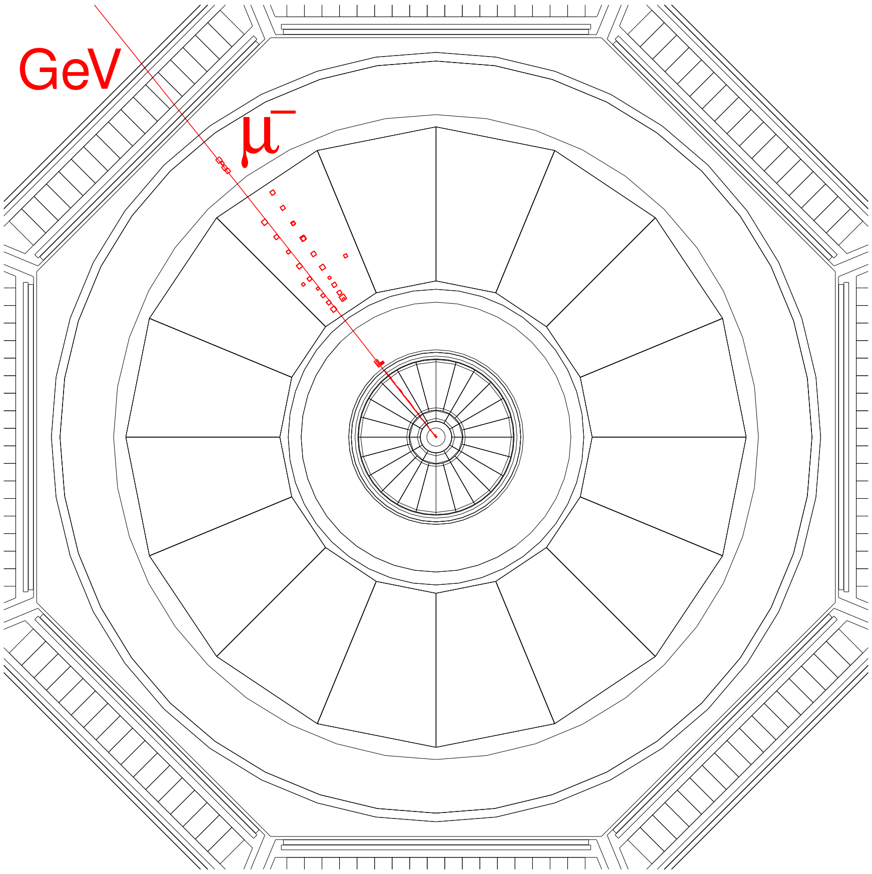




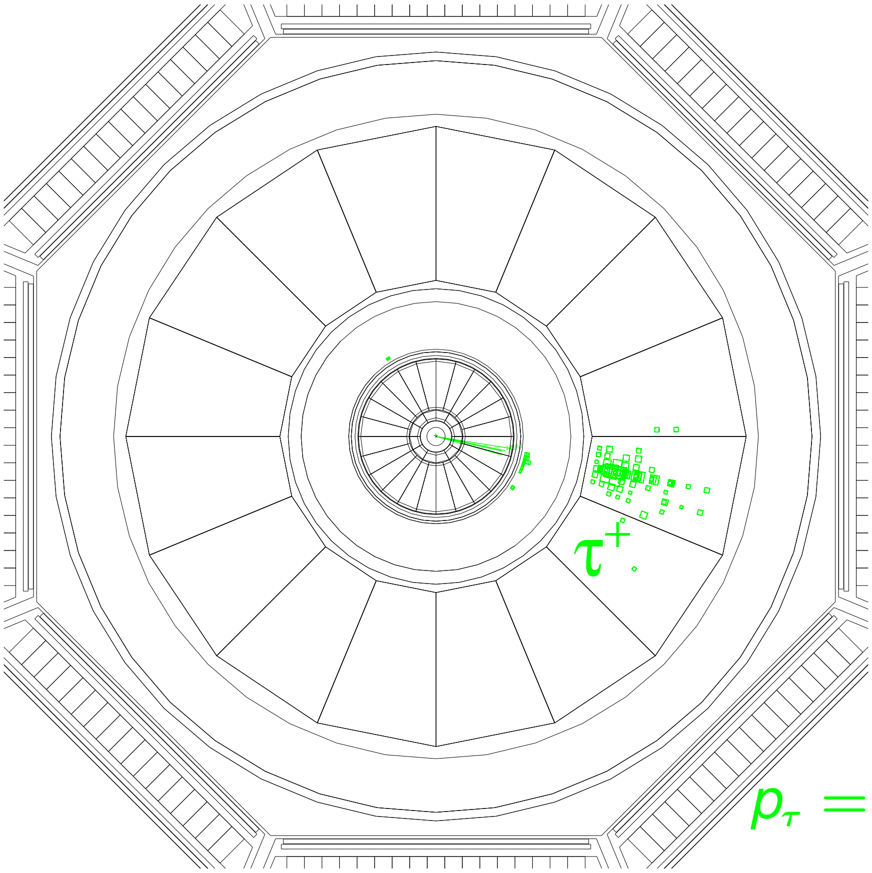
⇒ determine cross section for single W production by a binned log-likelihood fit to the Neural-Network Output

Leptonic single W: Experimental signature

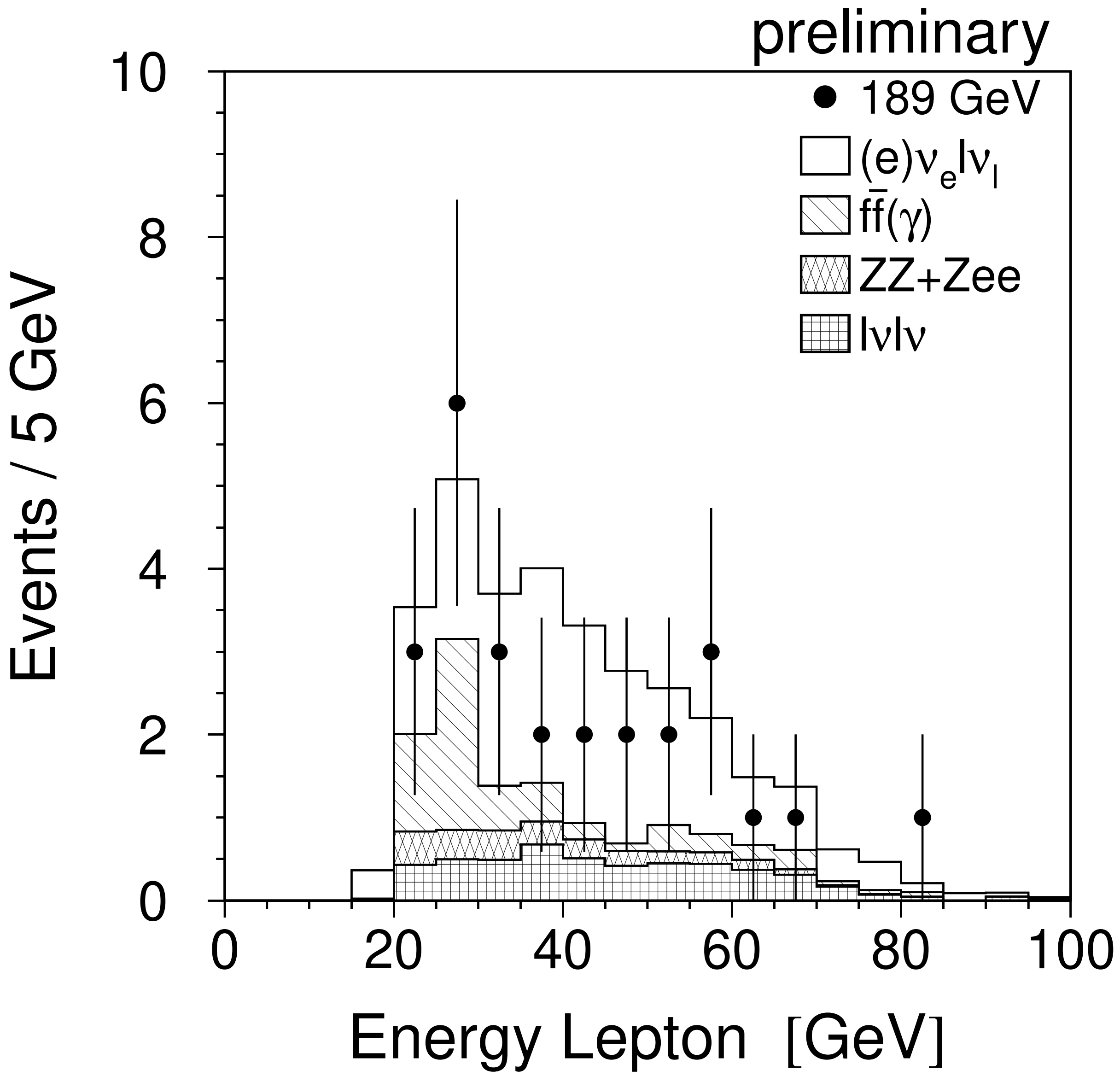
$$e^+e^- \longrightarrow e^+\nu_e\mu^-\bar{\nu}_\mu$$



$$e^+e^- \longrightarrow e^-\bar{\nu}_e\tau^+\nu_\tau$$



Leptonic single W: Selection



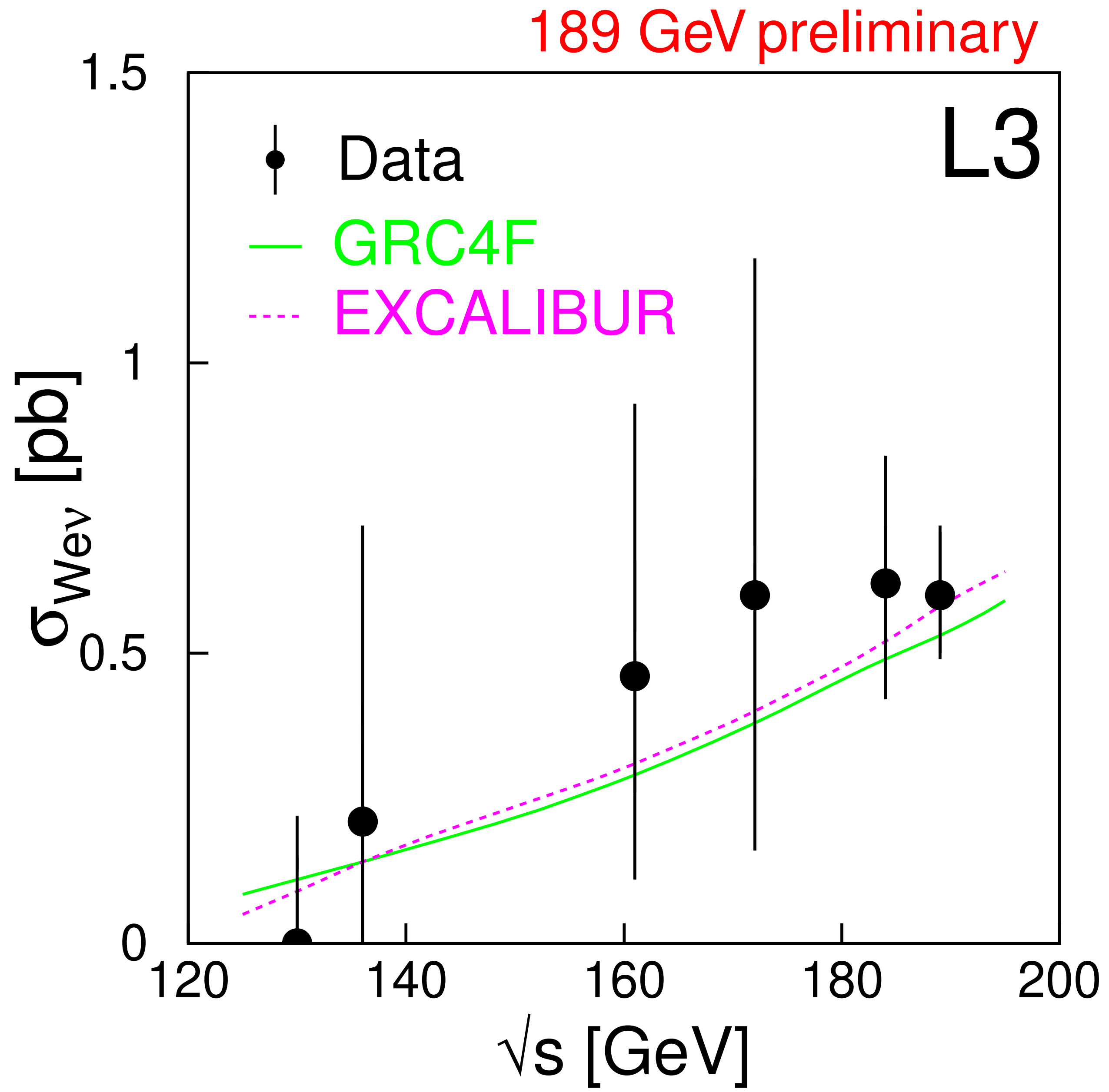
- signal characterized by one high-energy lepton from W-decay in the detector

$\Rightarrow$ exclude other significant activity

- signal purity typically $50 - 70\%$
- efficiency $\mathrm{W} \to \mu\nu$, $\mathrm{W} \to e\nu$: $65 - 70\%$
  efficiency $\mathrm{W} \to \tau\nu$: 25%

$\Rightarrow$ cross section determination by a binned log-likelihood fit to the energy spectrum

Single W: Cross section



$\sqrt{s}$ [GeV]	$\sigma_{e\nu W}$ [pb]	$\Delta\sigma_{stat}$ [pb]		$\Delta\sigma_{syst}$ [pb]
130	0.00	+0.22	–	$\pm$0.02
136	0.21	+0.50	–	$\pm$0.02
161	0.46	+0.47	−0.35	$\pm$0.04
172	0.60	+0.59	−0.44	$\pm$0.04
183	0.62	+0.22	−0.19	$\pm$0.04
189	0.60	+0.12	−0.11	$\pm$0.04

Conclusions and outlook

- W^+W^- production is measured at energies from 161 GeV to 189 GeV

$$\sigma_{WW}(189\ \mathrm{GeV}) = 16.29 \pm 0.38\ \mathrm{pb}$$

- W decay Branching Fractions:

$$B(W \to \ell\nu) = 10.45 \pm 0.23\%$$
$$B(W \to qq) = 68.66 \pm 0.69\%$$

- CKM matrix element $|V_{cs}|$:

$$V_{cs} = 1.03 \pm 0.03$$

- single W production is measured in the energy range 130 GeV to 189 GeV

$$\sigma_{e\nu W}(189\ \mathrm{GeV}) = 0.60^{+0.12}_{-0.11}\ \mathrm{pb}$$

▷ 1999: LEP will start at 192 GeV, aim is to run later at 200 GeV

▷ assuming the same excellent performance as in 1998, $150\ \mathrm{pb}^{-1}$ per experiment can be expected