Tests of the Electroweak Gauge Theory at LEP2

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OUTLINE

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- LEP and OPAL
- Testing the Standard Model at LEP2

Charm Production in W decays

- Introduction and Review
- W Boson Properties
  - WW Cross–Section and BR($\mathrm{W} \to \mathrm{hadrons}$)
- Direct Charm Tagging in W Decays
  - Measurement of $R_c^{\mathrm{W}} = \frac{\Gamma(\mathrm{W} \to cX)}{\Gamma(\mathrm{W} \to \mathrm{hadrons})}$

Single Top Production at LEP2

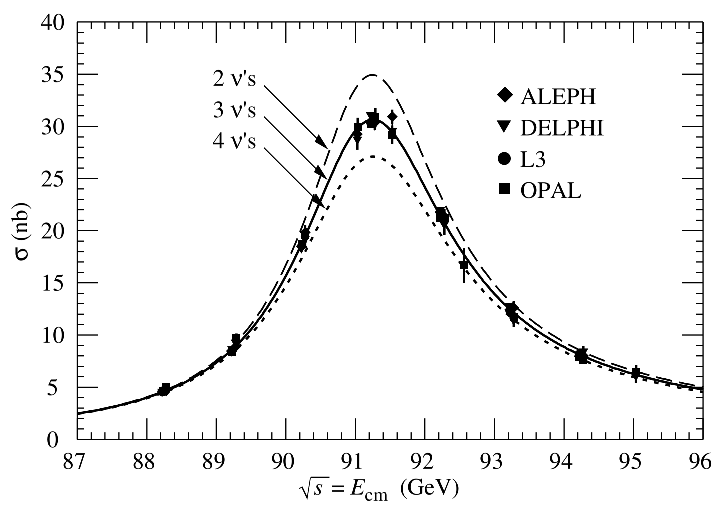
- Motivation and Strategy
- Limits on FCNC

Summary

Testing the Standard Model

- Success of the Standard Model over the last two decades has (perhaps) obscured the importance of thoroughly investigating the weak interaction.
- The situation 15 years ago looked like this[a]:
  - $\sin^2\theta_W = 0.217 \pm 0.014$
  - $M_W(\text{indirect}) = 83.0 \pm 2.8$ GeV
  - $M_Z(\text{indirect}) = 93.8 \pm 2.3$ GeV
- Today, we have *measured* $\Delta\sin^2\theta_W = 0.0002$, $\Delta M_Z = 0.002$ GeV, and $\Delta M_W = 0.05$ GeV !
  $\longrightarrow$ the SM success is so thorough, can only be wrong at the quantum loop level... and even then beyond leading order.

Nevertheless, measuring fundamental parameters of the SM and comparing them with the theoretical expectations is no less important today than it was 20 years ago. SM success just makes it more difficult.



[a]W.J.Marciano and A.Sirlin, Phys.Rev. **D29** (1984) 945.

Proposed Tests the SM

▷ **1-** Study the strength of the coupling at the W vertex for a quark transition $q \to \mathrm{W}q'$.

Weak Charged Current:

$$J_\mu^+ = (\bar{u}, \bar{c}, \bar{t})\, \frac{1}{2}\, \gamma_\mu\, (1 - \gamma^5) \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}$$

CKM Matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$\Longrightarrow$ **GOAL: Precise Determination of $|V_{\mathbf{cs}}|$!!!**

▷ **2-** Investigation of the neutral coupling at the Z or γ vertex for a FCNC transition $q \to \mathrm{Z}(\gamma)q'$.

Weak Neutral Current:

$$J_\mu^0 = \bar{q}\, \frac{1}{2}\, \gamma_\mu\, (g_V - g_A\gamma^5)\, q + \bar{q}\,'\, \frac{1}{2}\, \gamma_\mu\, (g_V - g_A\gamma^5)\, q'$$

with $\bar{q} = (\bar{u}, \bar{c}, \bar{t})$ and $\bar{q}\,' = (\bar{d}\,', \bar{s}\,', \bar{b}\,')$.

Allowed Quark Vertices:

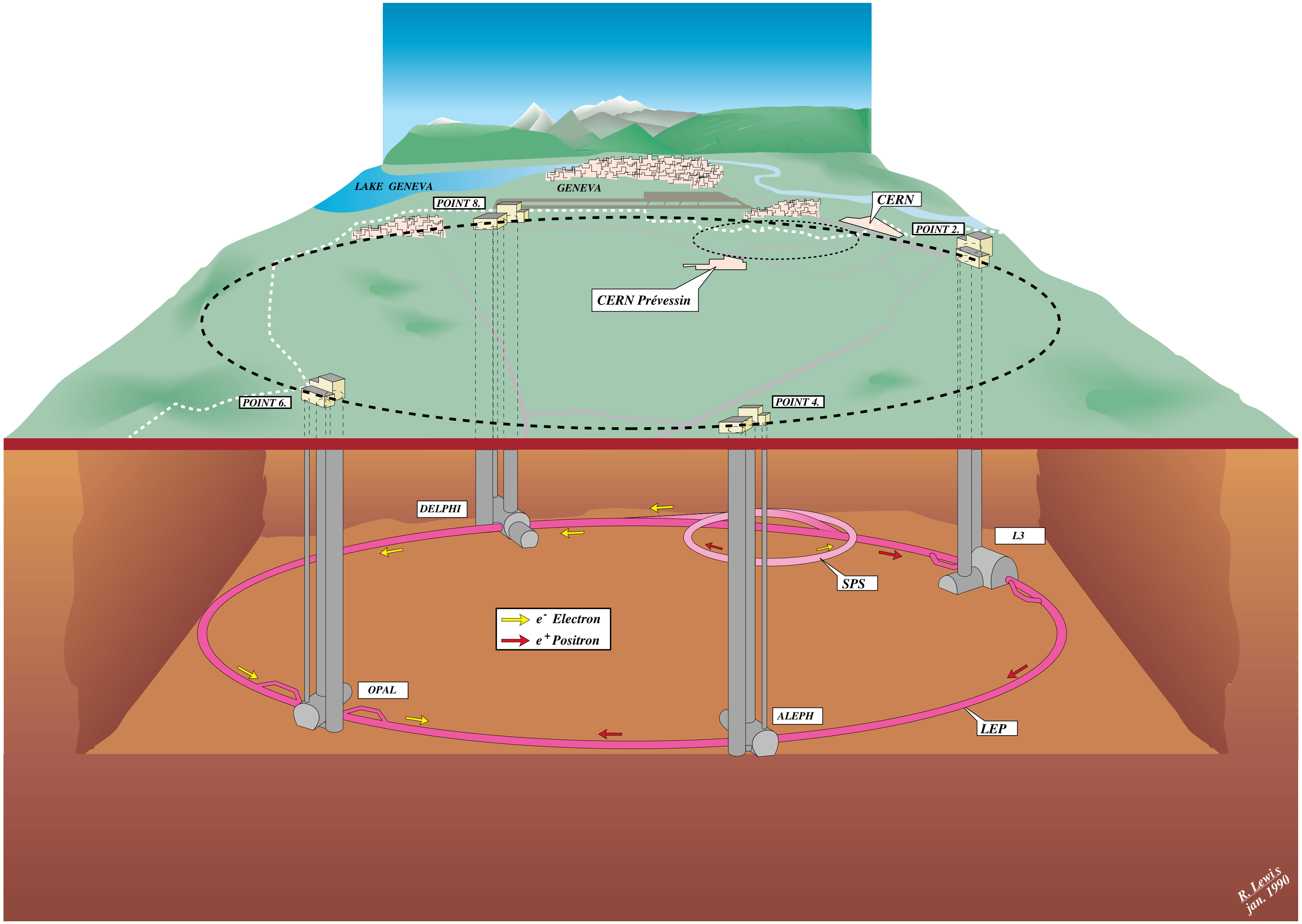
$$uu\mathrm{Z} - cc\mathrm{Z} - tt\mathrm{Z} - d'd'\mathrm{Z} - s's'\mathrm{Z} - b'b'\mathrm{Z}$$

$$\Downarrow$$

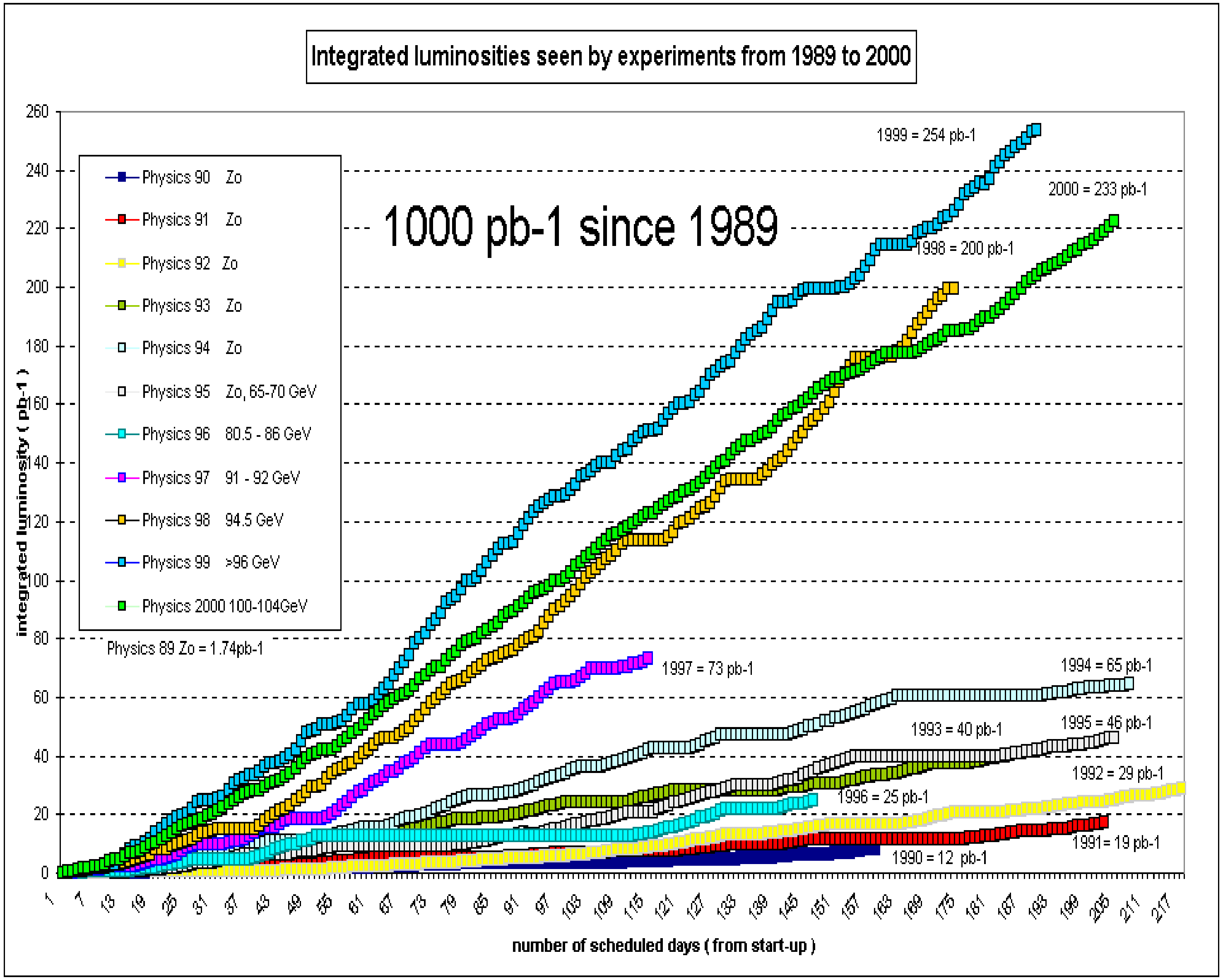
$$uu\mathrm{Z} - cc\mathrm{Z} - tt\mathrm{Z} - dd\mathrm{Z} - ss\mathrm{Z} - bb\mathrm{Z}$$

$\Longrightarrow$ **GOAL: Limits on Anomalous Couplings !!!**

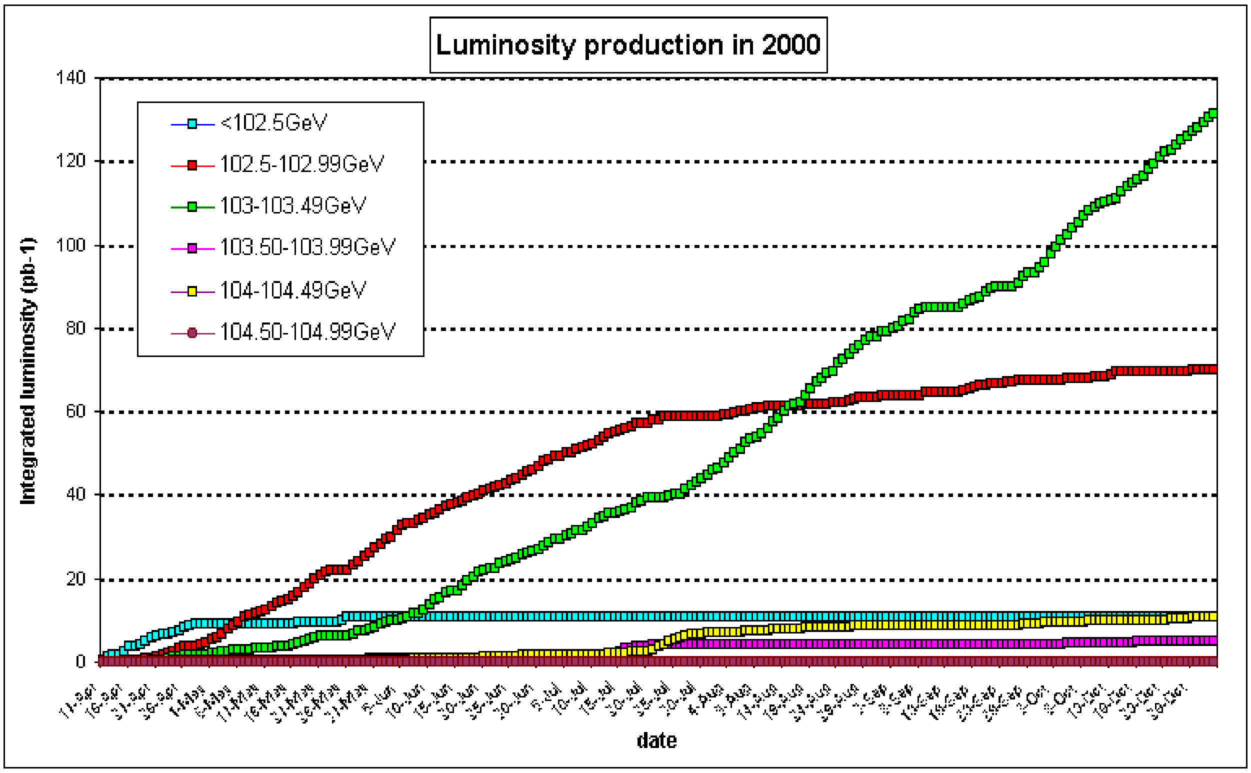
Experimental Apparatus: LEP



LEP Performance



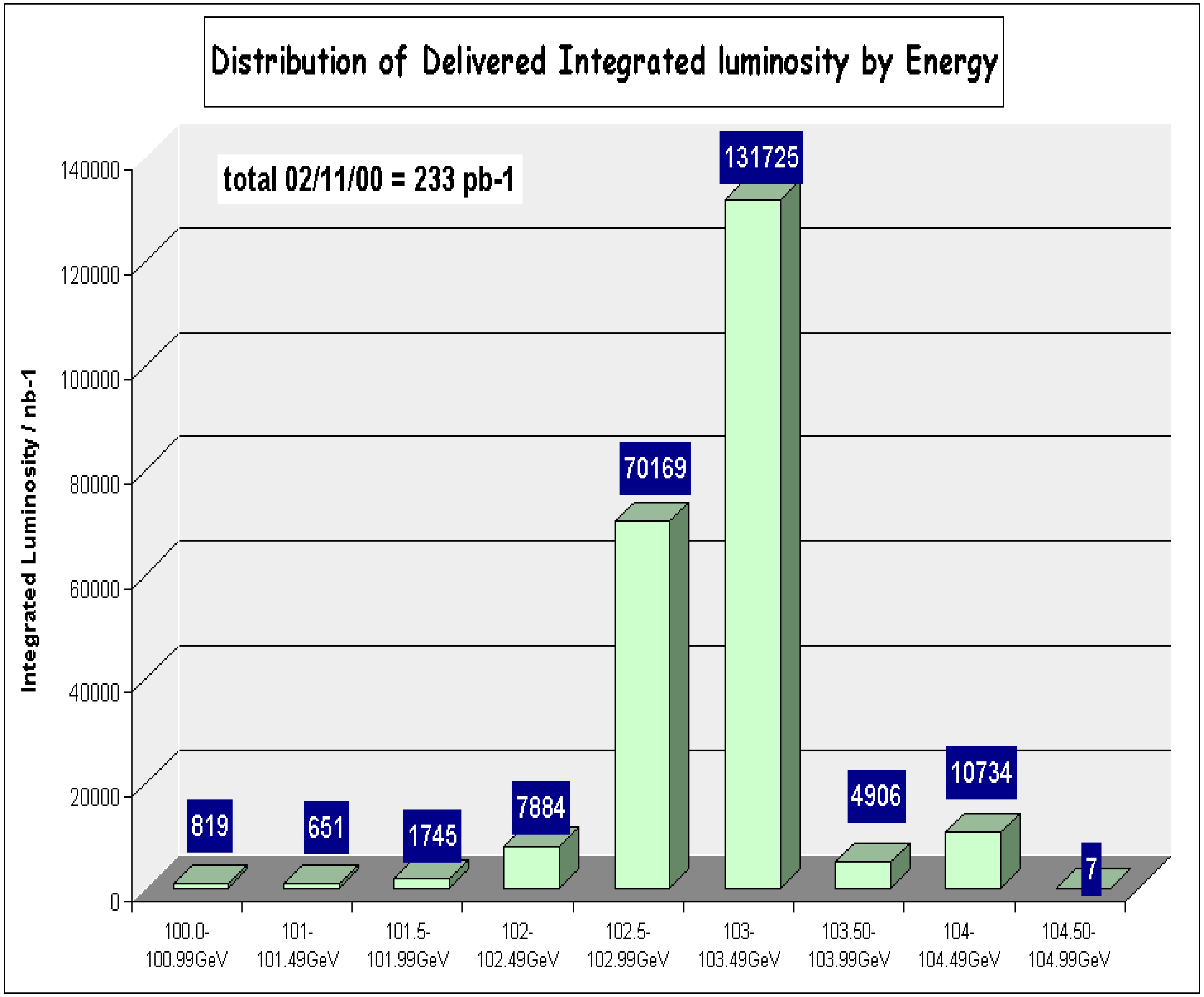
LEP Performance in 2000



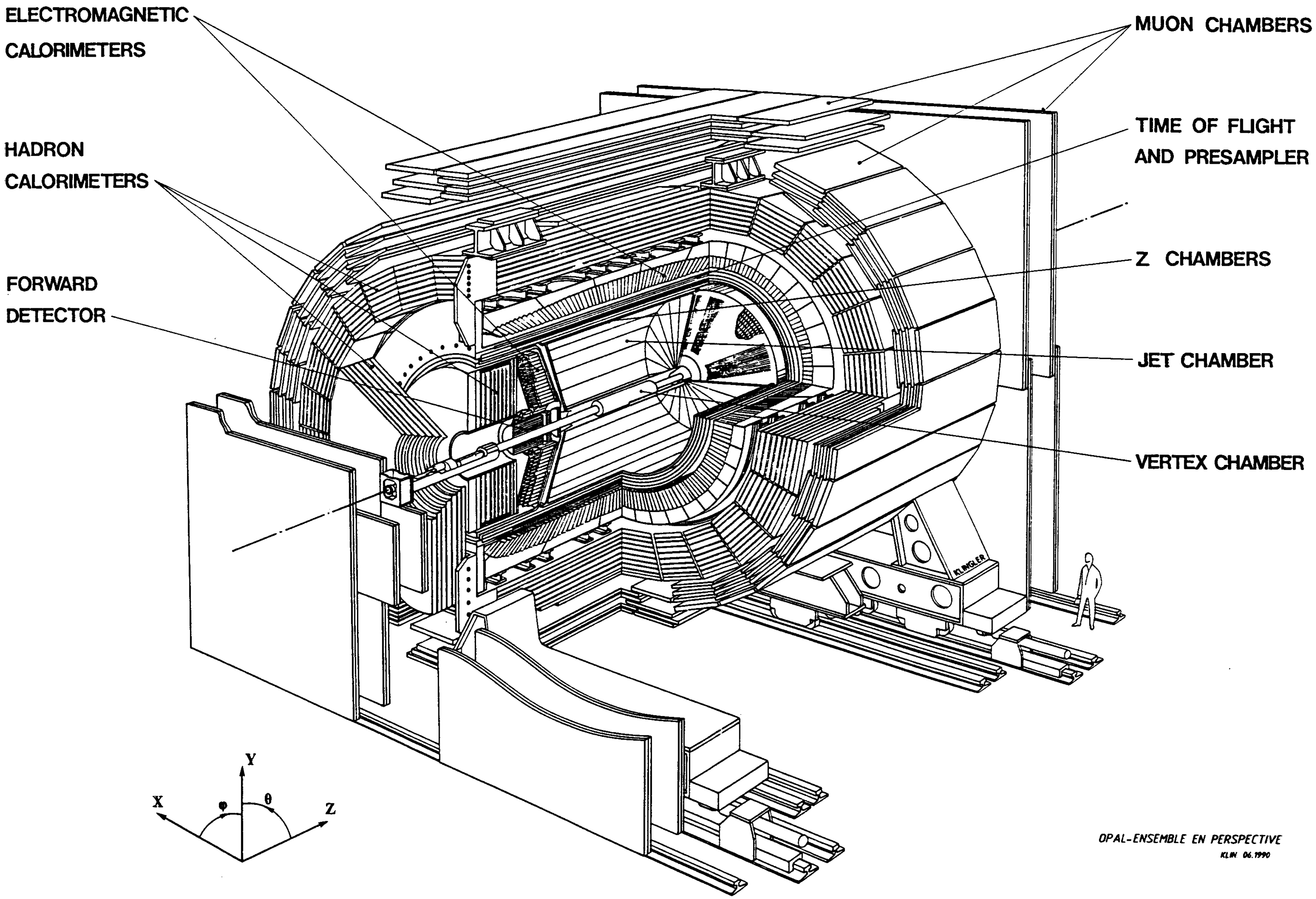
OPAL data samples used for the results presented here were collected between 1996-2000

$\sqrt{s}$ (GeV)	$\mathcal{L}_{\rm tot}$ ($\rm pb^{-1}$)
161	10
172	10
183	57
189	187
192-202	224
202-210	221
161-210	709

LEP Energies in 2000



Experimental Apparatus: OPAL



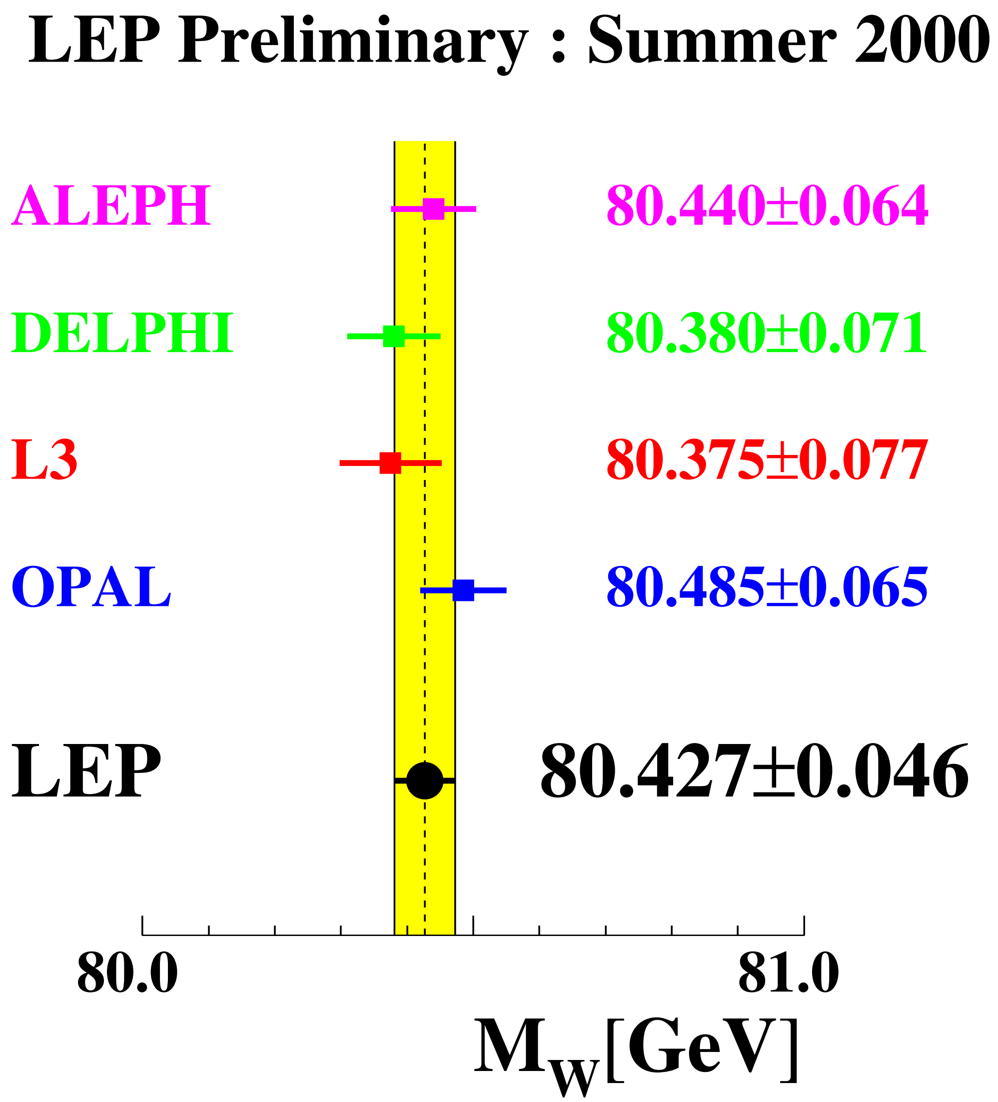
W Mass at LEP2

All LEP experiments ($\sqrt{s} = 161$ GeV):

$$M_{\rm W} = 80.40 \pm 0.20(\rm stat) \pm 0.08(\rm syst)\ \text{GeV}$$

All LEP experiments ($\sqrt{s} = 172 - 202$ GeV):

$$M_{\rm W}(\rm q\bar{q}\ell\bar{\nu}_\ell) = 80.427 \pm 0.038(\rm stat) \pm 0.035(\rm syst)\ \text{GeV}$$
$$M_{\rm W}(\rm q\bar{q}q\bar{q}) = 80.432 \pm 0.034(\rm stat) \pm 0.064(\rm syst)\ \text{GeV}$$
$$M_{\rm W}(\rm q\bar{q}q\bar{q}\text{-}q\bar{q}\ell\bar{\nu}_\ell) = (5 \pm 51)\ \text{MeV}$$
$$M_{\rm W} = 80.428 \pm 0.030(\rm stat) \pm 0.036(\rm syst)\ \text{GeV}$$



FUTURE: At the end of the LEP2 program with $710\,\text{pb}^{-1}$ per experiment $\Delta(M_{\rm W}) \approx 35$ MeV.

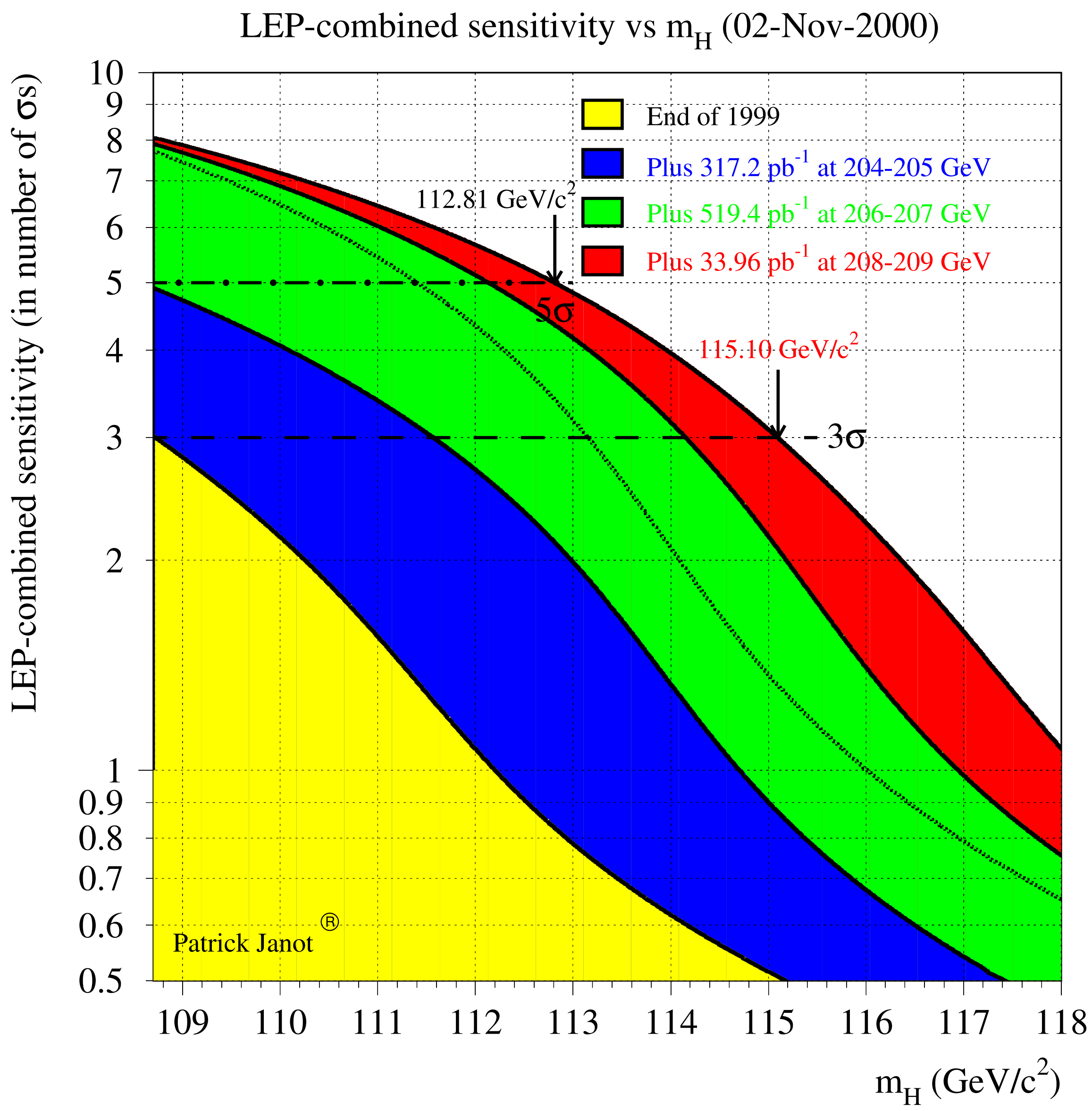
SM Higgs Search

PRELIMINARY Limit on the SM Higgs mass with data collected at $\sqrt{s} = 161 - 210$ GeV:

At the end of 00 run experiments reported preliminary limits up to:

$$m_H > 113.5 \text{ GeV } (95\% \text{ CL})$$

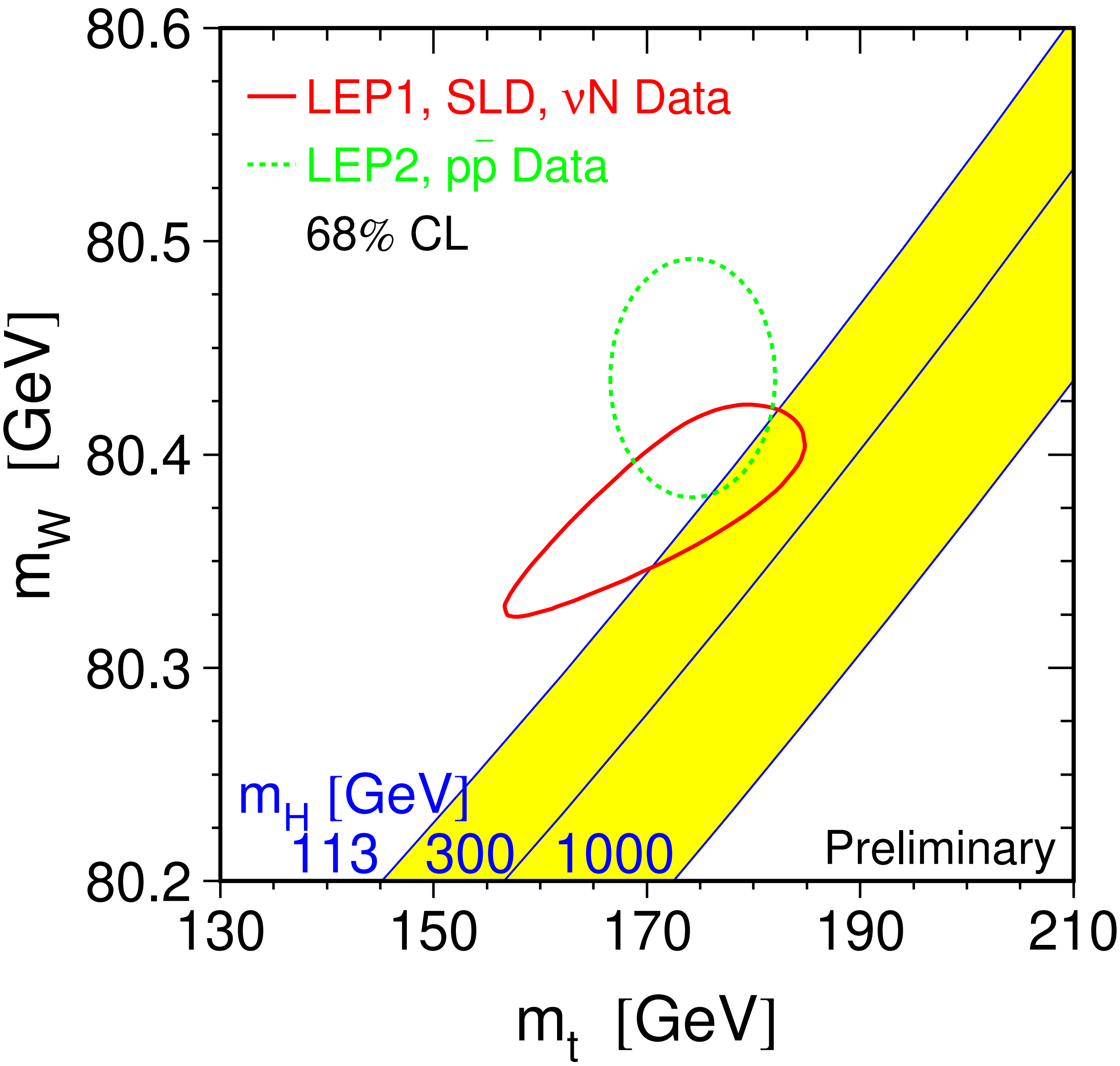
Expected limit $m_H > 115.3$ GeV (95% CL)



SM Higgs is light!

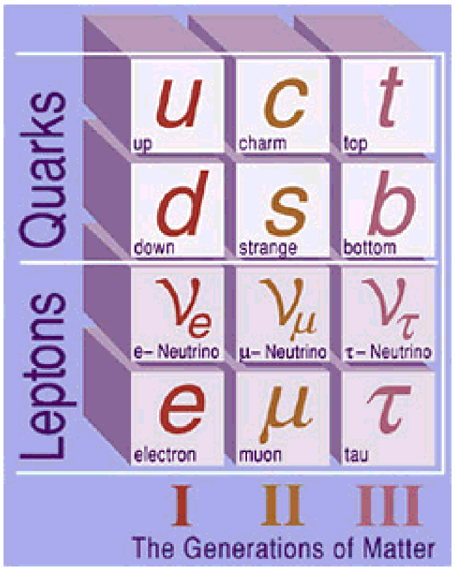
PRELIMINARY: Direct and indirect measurement of $\mathrm{m_{top}}$ and M_W for different $\mathrm{m_{Higgs}}$:

$m_H < 188$ GeV (95% CL)



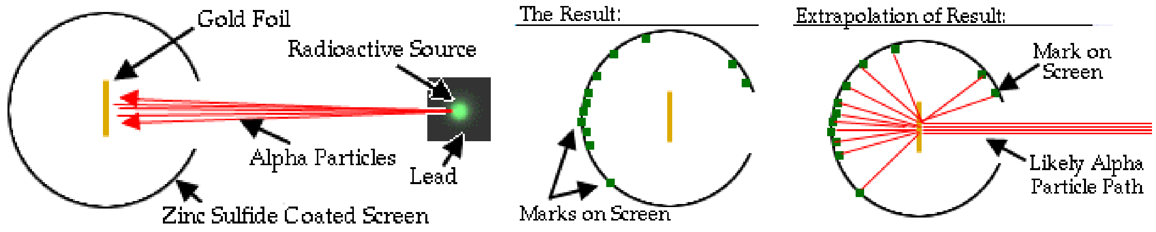
Standard Model parameter relations confirmed at quantum level that small Higgs masses are preferred.

Testing the Standard Model



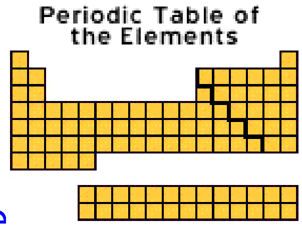
Probing the Matter

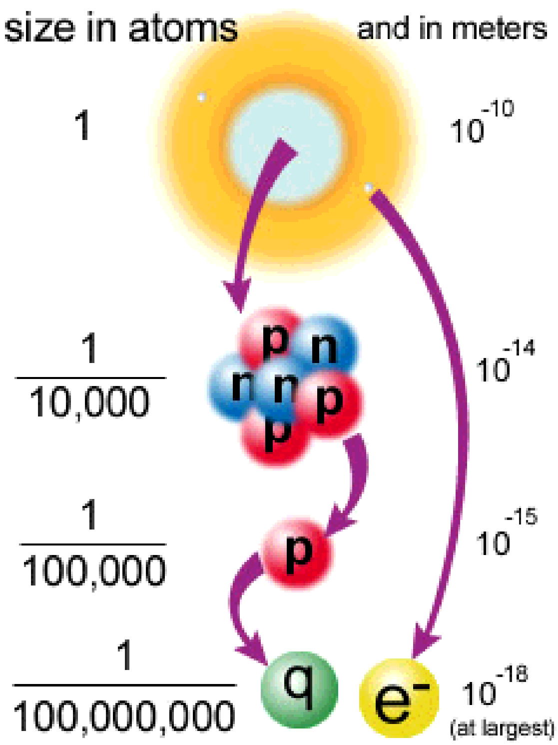
Rutherford (1911):



The Search for the Fundamental:

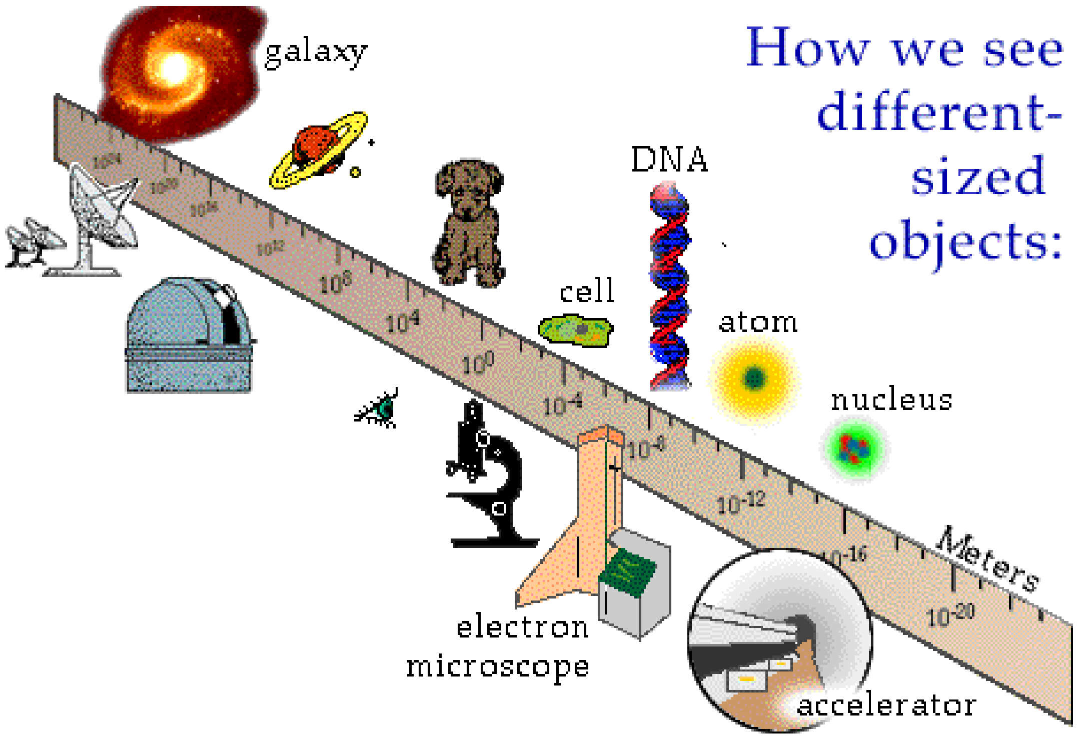
Scientists realized that they could categorise atoms into groups that shared similar **chemical properties**. This indicated that atoms were made up of simpler building blocks, and that it was these simpler **building blocks** in different combinations that determined which atoms had which chemical properties.





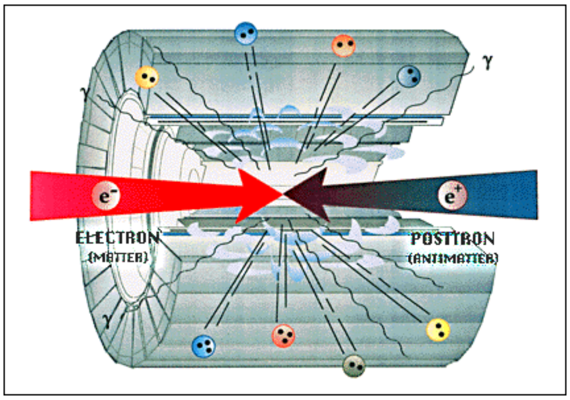
Subatomic Physics

Scale:



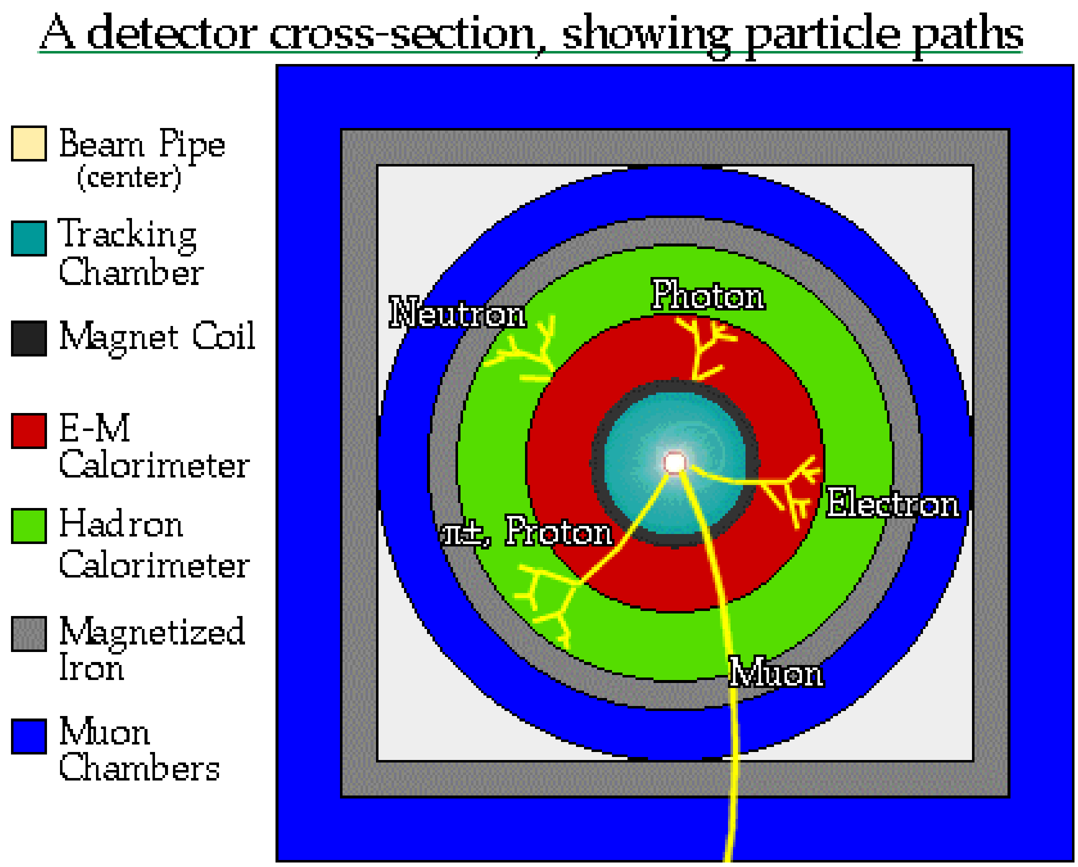
Modern Technique:

When a physicist wants to produce exotic particles, he puts the stable particles into an **accelerator**, give them a lot of kinetic energy, and then **collide** them together.



During this collision, the particle's kinetic energy is converted into the formation of new massive particles. It is through this process that we can create **new massive unstable particles** and study their properties.

Particle Detector

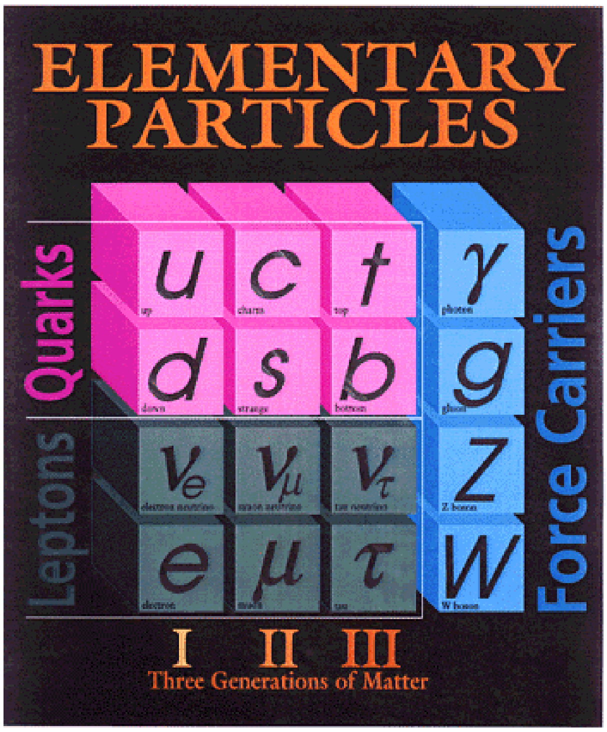


To look for these various particles and decay products, physicists have designed **multi-layer detectors** that test different aspects of an event.

Each component of a modern detector is used for **measuring** particle charges, energies and momenta, and/or distinguishing different particle types.

When all these components work together to detect an event, individual particles can be singled out for **data analysis** and check whether these particle processes agree with the **theory** they are testing.

The Standard Model



The SM provides a general description of the physics physics currently accessible with modern particle accelerators. The minimal SM postulates that matter is composed of fundamental spin-$\frac{1}{2}$ **quarks** and spin-$\frac{1}{2}$ **leptons** interacting via spin one **gauge bosons**.

Electroweak Lagrangian:

$$\mathcal{L} = \mathcal{L}(\text{weak CC}) + \mathcal{L}(\text{weak NC}) + \mathcal{L}(\text{em NC})$$

$$\mathcal{L}(\text{weak CC}) = \frac{g}{\sqrt{2}} (J_\mu^- W_\mu^+ + J_\mu^+ W_\mu^-)$$

$$\mathcal{L}(\text{weak NC}) = \frac{g}{\cos\theta_W} (J_\mu^0 - \sin^2\theta_W J_\mu^{\text{em}}) Z_\mu$$

$$\mathcal{L}(\text{em NC}) = e J_\mu^{\text{em}} A_\mu$$

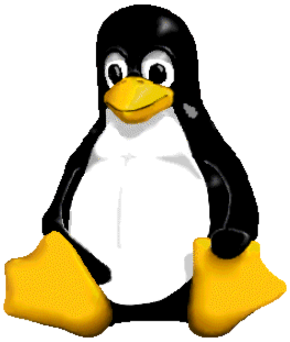
Proposed Tests of the SM

▷ **1**- Study the strength of the coupling at the W vertex for a quark transition $q \to \mathrm{W}q'$.

▷ **2**- Investigation of the neutral coupling at the Z or γ vertex for a FCNC transition $q \to \mathrm{Z}(\gamma)q'$.

Analysis

TOOLS



UL Calculation

The Poisson upper limit N on the number of signal events expected can be adjusted such that:

$$1 - CL = \frac{e^{\mu_B + N} \sum_{n=0}^{n_0} \frac{(\mu_B + N)^n}{n!}}{e^{\mu_B} \sum_{n=0}^{n_0} \frac{(\mu_B)^n}{n!}} = 0.05$$

μ_B: MC background (SM expectation),
n_0: Observed Data events,
N: Max. number of signal events.

$$\Longrightarrow \sigma_{95} = \frac{N/\epsilon}{\mathcal{L}}$$

with signal efficiency ϵ and integrated luminosity $\mathcal{L}$.

Consider μ_B and ϵ with errors (syst. & stat.) σ_B and σ_ϵ, the limit can be calculated with a hybrid frequentist/Bayes technique:

$$1 - CL =$$

$$\frac{\int_0^\infty dx\, G(x, \mu_B, \sigma_B) \int_0^\infty dy\, G(y, N, \sigma_S N)\, e^{-(x+y)} \sum_{n=0}^{n_0} \frac{(x+y)^n}{n!}}{\int_0^\infty dx G(x, \mu_B, \sigma_B)\, e^{-x} \sum_{n=0}^{n_0} \frac{x^n}{n!}}$$

Likelihood Function

HEP offers challenging data analyses. The likelihood selection method has become quite popular at LEP. It is a general purpose **multivariate** selection technique that is easy to understand and apply. The likelihood selection method is an alternative to standard multi-dimensional cut base methods and it is in general much more powerful.

Likelihood Selection:

Decision is made to classify an event as a signal or background candidate using a vector of measurements $\vec{x}$ on the basis of a single quantity:

$$\mathcal{L} = \frac{\mathcal{P}_{\rm signal}(\vec{x})}{\mathcal{P}_{\rm signal}(\vec{x}) + \mathcal{P}_{\rm back}(\vec{x})}$$

$\mathcal{P}_{\rm signal}$: PDF for signal events,
$\mathcal{P}_{\rm back}$: PDF for background events.

In the standard likelihood selection method, the PDF $\mathcal{P}(\vec{x})$ is determined from the product of MC 1D distribution functions:

$$\mathcal{P}(\vec{x}) = \prod_i p(x_i).$$

By construction signal events tend to have $\mathcal{L} \approx 1$, whereas background events $\mathcal{L} \approx 0$.

Neural Networks

Standard Procedure for Data Analysis:

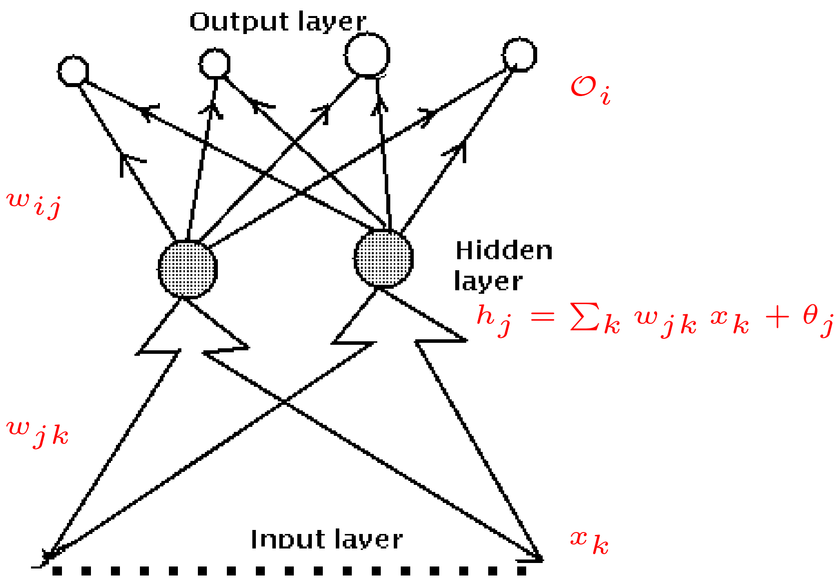
Specific selection cuts on various kinematic variables $\vec{x}$ lead to a particular set of **feature functions**: $\mathcal{O}_i = F_i(\vec{x})$.

Feed-forward ANN:

Automated **optimal** choice of the feature functions:

$$\mathcal{O}_i = F_i(\vec{x}) = g[\sum_j w_{ij}\; g(\sum_k w_{jk}\, x_k + \theta_j) + \theta_i]$$

k: Index for the number of input variables,
j: Index for the number of hidden layers,
w_{ij} and w_{jk}: Weights to be fitted to the data,
g: Activation Function $= \frac{1}{1+\exp(-\kappa x)}$.



The weights are determined by minimising with iterative methods:

$$E(\vec{w}) = \frac{1}{2\,N_p} \sum_{p=1}^{N_p} \sum_i (\mathcal{O}_i^p - t_i^p)^2$$

N_p: Number of training pattern,
t_i: Target (feature value).

Charm Production
in
W Decays

Introduction: Why $|V_{cs}|$?

Today, the SM provides a general description of the physics currently accessible with modern particle accelerators. However, many predictions of the SM still have to be verified:

- We are still searching for the Higgs boson.
- We are still seeking a better understanding of the electroweak properties of the neutral and charged mediators of the weak interaction.

The first concerns the origin of mass generation in the electroweak sector via the Higgs mechanism. The other deals with the origin of quark mixing and CP violation.

Quark Mixing

$$J_\mu^+ = (\bar{u}, \bar{c}, \bar{t})\,\frac{1}{2}\,\gamma_\mu\,(1-\gamma^5)\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}$$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}\begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM Matrix

CKM matrix element	Value(PDG00)
$\|V_{\mathrm{ud}}\|$	0.9735 ± 0.0008
$\|V_{\mathrm{us}}\|$	0.2196 ± 0.0023
$\|V_{\mathrm{cd}}\|$	0.224 ± 0.016
$\|V_{\mathrm{cs}}\|$	1.04 ± 0.16
$\|V_{\mathrm{ub}}\|/\|V_{\mathrm{cb}}\|$	0.090 ± 0.025
$\|V_{\mathrm{cb}}\|$	0.0402 ± 0.0019

⇒So far direct measurements of $|V_{\mathrm{cs}}|$ have limited precision compared to its CKM partners $|V_{\mathrm{ud}}|$, $|V_{\mathrm{us}}|$, and $|V_{\mathrm{cd}}|$.

$$V \simeq \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

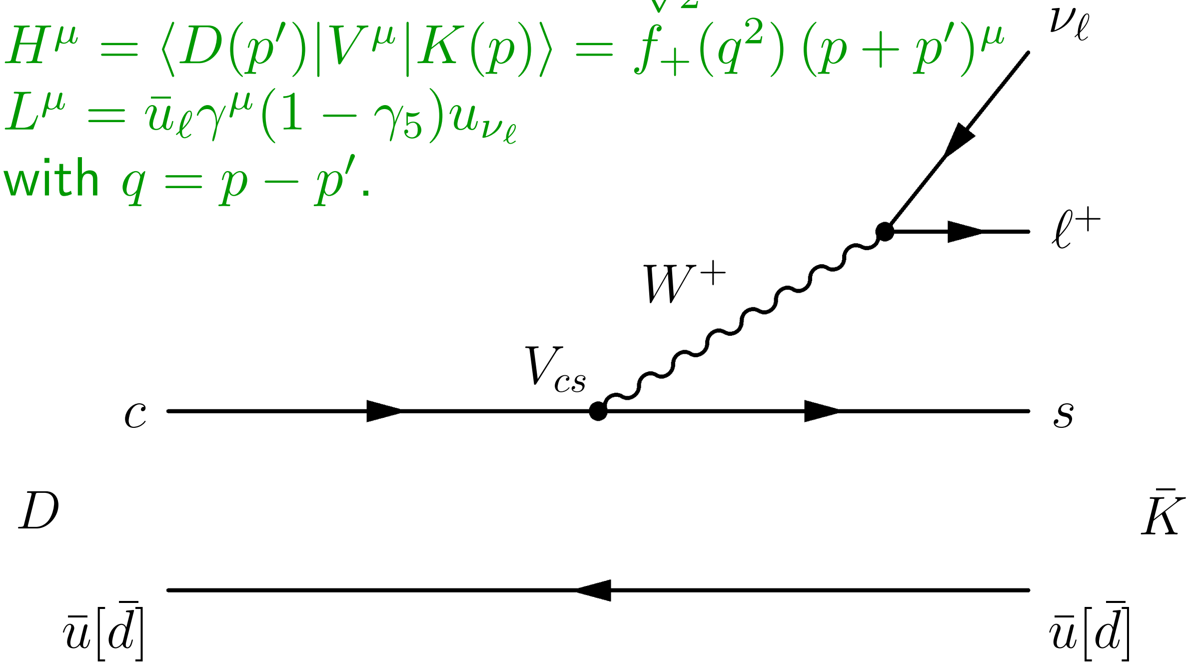
with the Cabibbo angle $\lambda \simeq 0.22$.

Using the measured values of the CKM matrix elements together with unitarity, and assuming ONLY 3 generations, the 90% CL on $|\mathrm{V}_{ij}|$ are:

$$\begin{pmatrix} 0.9742-0.9757 & 0.219-0.226 & 0.002-0.005 \\ 0.219-0.225 & 0.9734-0.9749 & 0.037-0.043 \\ 0.004-0.014 & 0.035-0.043 & 0.9990-0.9993 \end{pmatrix}$$

$|V_{cs}|$: $D \rightarrow \bar{K}\ell^{+}\nu_{\ell}$

Decay Amplitude: $\mathcal{M} = -i\frac{G_F}{\sqrt{2}}|V_{cs}|L^{\mu}H_{\mu}$ where
$H^{\mu} = \langle D(p')|V^{\mu}|K(p)\rangle = f_{+}(q^2)\,(p+p')^{\mu}$
$L^{\mu} = \bar{u}_{\ell}\gamma^{\mu}(1-\gamma_5)u_{\nu_{\ell}}$
with $q = p - p'$.



Most commonly assumed *forms* for the form factor are:

$f_{+}(q^2) = f_{+}(0)\,e^{\alpha q^2}$ and $f_{+}(q^2) = \frac{f_{+}(0)}{(1-q^2/M^2_{\rm pole})}$

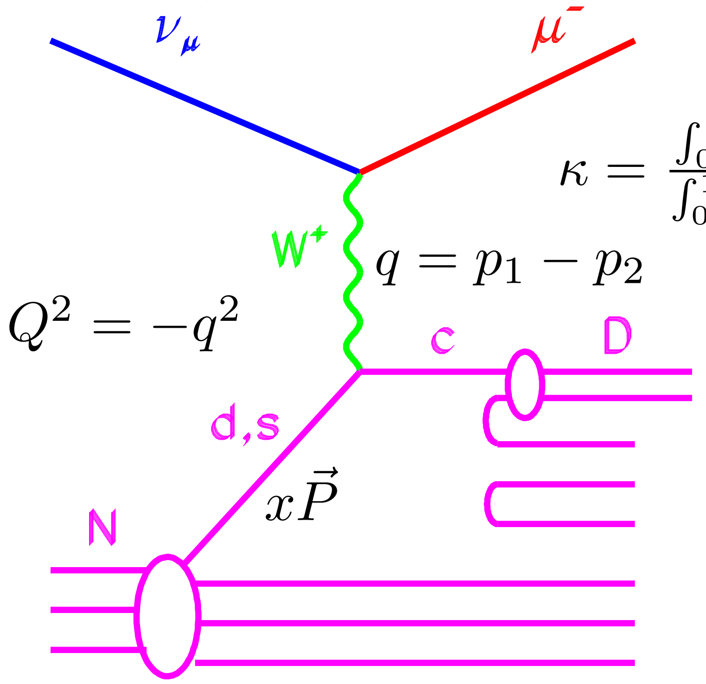
Normally $M_{\rm pole} = 2.1$ GeV is used. Then

$$\frac{d\,\Gamma(D \rightarrow \bar{K}\ell\nu_{\ell})}{d\,q^2} = \frac{G_F^2\,|V_{cs}|^2\,p_D^3}{24\,\pi^3}\,|f_{+}(q^2)|^2$$

$\Gamma(D \rightarrow \bar{K}\ell\nu_{\ell}) = |f_{+}(0)|^2|V_{cs}|^2\,(1.54 \times 10^{11}\ s^{-1})$.

$$\boxed{|V_{cs}| = 1.04 \pm 0.16}$$

$|V_{cs}|$: NuTeV



$$\kappa = \frac{\int_0^1 [xs(x,Q^2)+x\bar{s}(x,Q^2)]\,dx}{\int_0^1 [x\bar{u}(x,Q^2)+x\bar{d}(x,Q^2)]\,dx}$$

Value of $|V_{cs}|$ from neutrino beam depends on the strange quark density in the parton sea.

From di-muon sample: $\nu_\mu + N \rightarrow c + \mu^- + X$
$\hookrightarrow s + \mu^- + \nu_\mu$

$$\Rightarrow \frac{\kappa}{\kappa+2}|V_{cs}|^2 = 0.200 \pm 0.015$$

from CCFR using runs E744 and E770 collected in 1985 and 1987, respectively.

Recently, inclusive $\nu - N$ interaction studies provide and independent measurement of kappa:

$$\kappa = 0.453 \pm 0.106^{+0.028}_{-0.096}$$

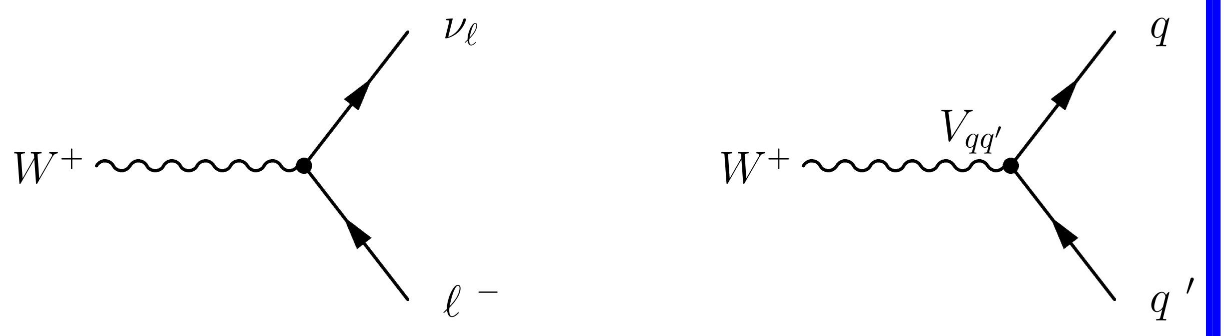
Leading to a preliminary result of

$$\boxed{|V_{cs}| = 1.05 \pm 0.10^{+0.07}_{-0.11}}$$

$|V_{cs}|$: OPAL at LEP

Since 1997 the LEP e^+e^- collider was operated at energies well above the threshold for on-shell W pair production. This offers a unique opportunity to study the hadronic decays of W bosons in a clean environment and to investigate the coupling strength of W bosons to different quark flavours.

Direct Production of W's



Data Samples recorded in 97 & 98 by OPAL:

The integrated luminosity used for the analyses described here amounts to $180.2\,\mathrm{pb}^{-1}$ ($56.5\,\mathrm{pb}^{-1}$) at a luminosity-weighted mean energy of 188.6 GeV (182.7 GeV).

Data Samples recorded in 99 & 00 by OPAL:

An additional $445\,\mathrm{pb}^{-1}$ was collected at $\sqrt{s} =$ 192-210 GeV: brief look and update.

Motivation

WW Production rate: $\mathrm{Br}(\mathrm{W} \to \mathrm{q\bar{q}})$

$$\frac{\mathrm{Br}(\mathrm{q\bar{q}})}{\mathrm{Br}(\ell\bar{\nu}_\ell)} = \frac{\mathrm{Br}(\mathrm{q\bar{q}})}{1-\mathrm{Br}(\mathrm{q\bar{q}})} = \left(1+\frac{\alpha_s(M_\mathrm{W})}{\pi}\right) \sum_{\substack{i=\mathrm{u,c}\\ j=\mathrm{d,s,b}}} |\mathrm{V}_{ij}|^2$$

Charm Tagging:
$R_\mathrm{c}^\mathrm{W} \equiv \Gamma(\mathrm{W} \to cX)/\Gamma(\mathrm{W} \to \mathrm{q\bar{q}})$

$$R_\mathrm{c}^\mathrm{W} = \frac{|V_\mathrm{cd}|^2+|V_\mathrm{cs}|^2+|V_\mathrm{cb}|^2}{|V_\mathrm{ud}|^2+|V_\mathrm{us}|^2+|V_\mathrm{ub}|^2+|V_\mathrm{cd}|^2+|V_\mathrm{cs}|^2+|V_\mathrm{cb}|^2}$$

$\Longrightarrow$ A measurement of R_c^W allows a direct **test of unitarity** of the CKM matrix in three generations within the framework of the Standard Model.

$\Longrightarrow$ $\mathrm{Br}(\mathrm{W} \to \mathrm{q\bar{q}})$ and R_c^W lead to a measurement of $|V_\mathrm{cs}|$ using the measured values of the other CKM matrix elements.

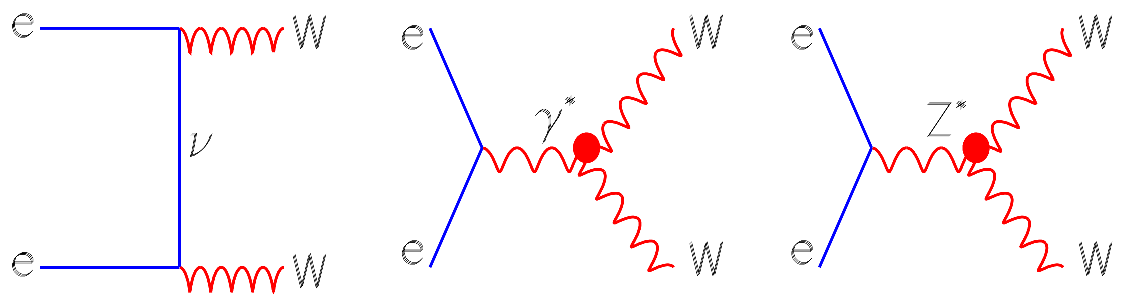
At LEP2, the determination of $|V_\mathrm{cs}|$ with the OPAL data at $\sqrt{s} \simeq 183$ GeV and 189 GeV will be more accurate than the current world average.

W Bosons Properties

WW Cross–Section and BR(W $\longrightarrow q\bar{q}$)

Signal Process

$e^+e^- \rightarrow W^+W^-$ dominated by:



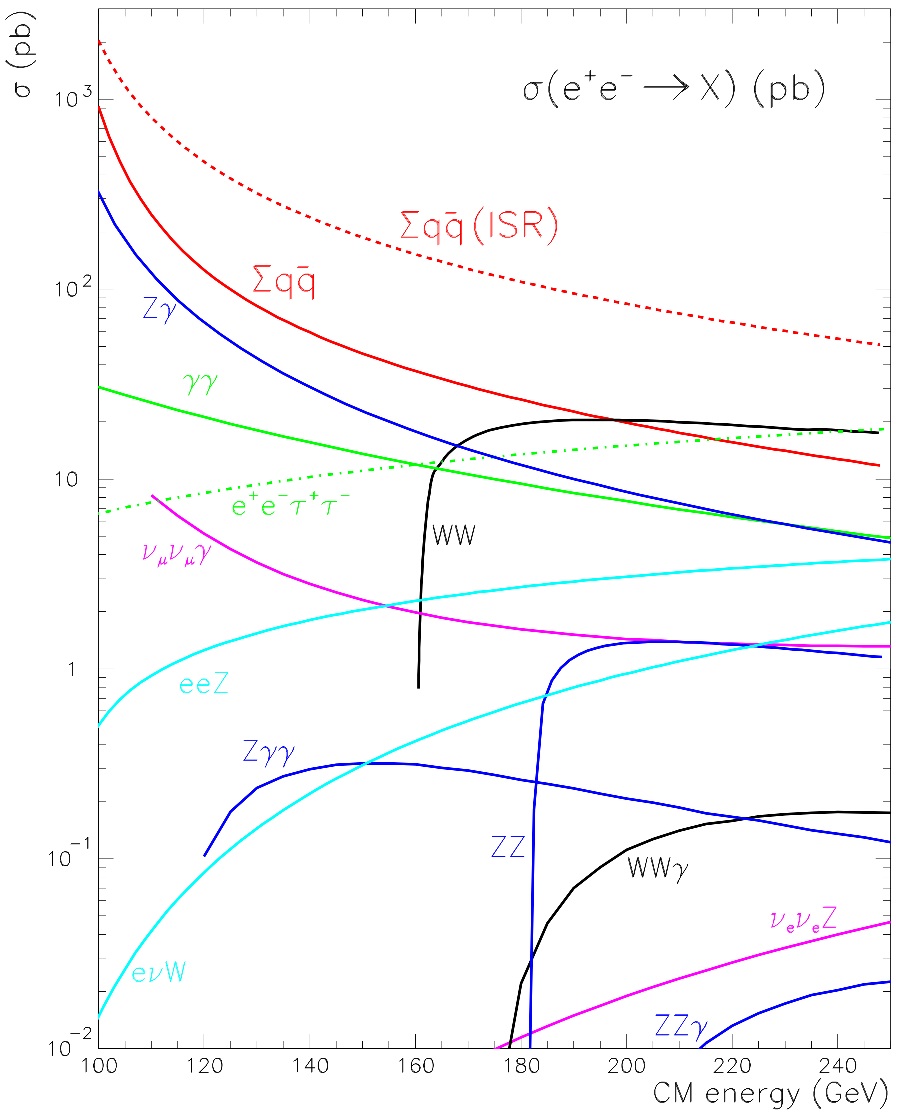
Each $W^{\pm}$ decays to $f\bar{f}$ pair. The $f\bar{f}f\bar{f}$ final states:

final state	BR
$q\bar{q}q\bar{q}$	45%
$q\bar{q}\ell\bar{\nu}_\ell$	44%
$\ell\bar{\nu}_\ell\ell\bar{\nu}_\ell$	11%

The expected production cross–sections are:

$\sqrt{s}$	$\sigma(e^+e^- \rightarrow WW)$
161 GeV	3.6 pb
172 GeV	12.4 pb
183 GeV	15.7 pb
189 GeV	16.7 pb

Background Processes



background	$\sigma(\sqrt{s} = 183\,\mathrm{GeV})$
$e^+e^- \to Z/\gamma \to q\bar{q}$	107 pb
$e^+e^- \to Ze^+e^-$	2.8 pb
$e^+e^- \to (Z/\gamma)^*(Z/\gamma)^*$	0.6 pb
$e^+e^- \to We\nu$	0.6 pb

Remark: The background $e^+e^- \to Z/\gamma \to q\bar{q}$ is labelled "QCD" background and the rest "4-fermion" background.

W^+W^- Events

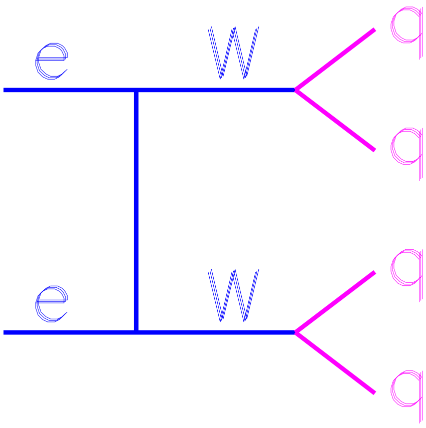
Event Characteristics:

- $W^+W^- \rightarrow \ell\bar{\nu}_\ell\ell\bar{\nu}_\ell$
  - Two acoplanar and energetic leptons.
  - A lot of missing energy
- $W^+W^- \rightarrow q\bar{q}\ell\bar{\nu}_\ell$
  - Two hadronic jets.
  - One isolated and energetic lepton.
  - Missing energy.
- $W^+W^- \rightarrow q\bar{q}q\bar{q}$
  - Four hadronic jets.
  - No missing energy.
  - Large QCD background.

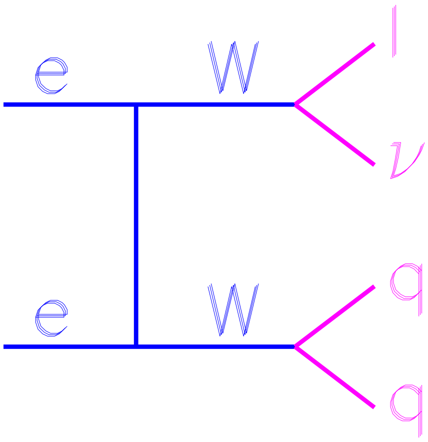
Events not selected as $W^+W^- \rightarrow \ell\bar{\nu}_\ell\ell\bar{\nu}_\ell$ are passed to the $W^+W^- \rightarrow q\bar{q}\ell\bar{\nu}_\ell$ selection procedure and may be classified as $q\bar{q}e\bar{\nu}$, $q\bar{q}\mu\bar{\nu}$, or $q\bar{q}\tau\bar{\nu}$. The $W^+W^- \rightarrow q\bar{q}q\bar{q}$ selection is applied to events that fail the preceding selections.

Event Selection

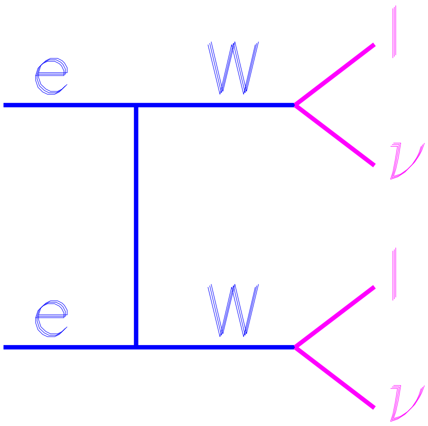
- Expected stat error: $\sim \frac{1}{\sqrt{\mathrm{N_{WW}}}} \cdot \frac{1}{\sqrt{\mathrm{Purity}}}$



$\mathrm{BR} \approx \mathbf{45\%}$
$\varepsilon = \mathbf{86\%}$
$\mathbf{P} = \mathbf{79\%}$



$\mathrm{BR} \approx \mathbf{44\%}$
$\varepsilon = \mathbf{87\%}$
$\mathbf{P} = \mathbf{90\%}$



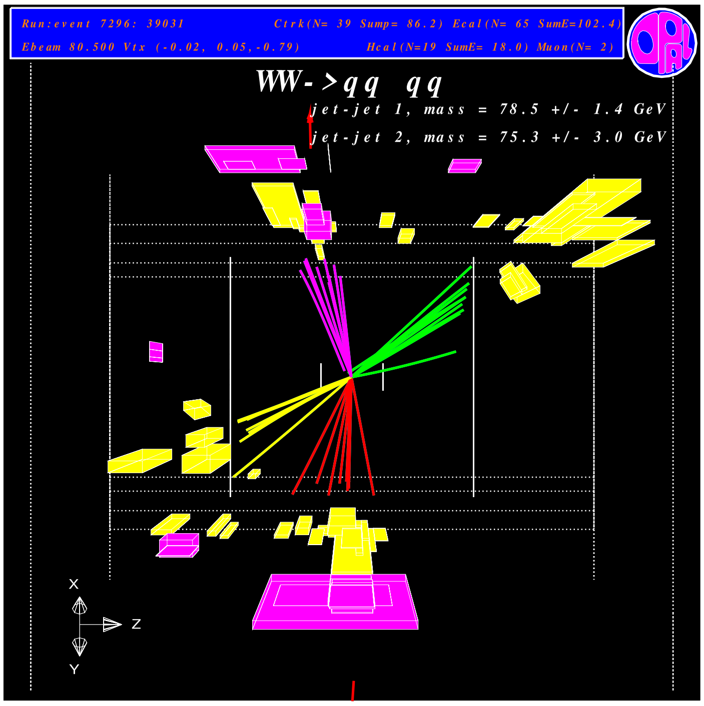
$\mathrm{BR} \approx \mathbf{11\%}$
$\varepsilon = \mathbf{82\%}$
$\mathbf{P} = \mathbf{90\%}$

For 1998 @ $\sqrt{s} = 189$ GeV this gives (excl. $\ell\bar{\nu}_\ell\ell\bar{\nu}_\ell$):

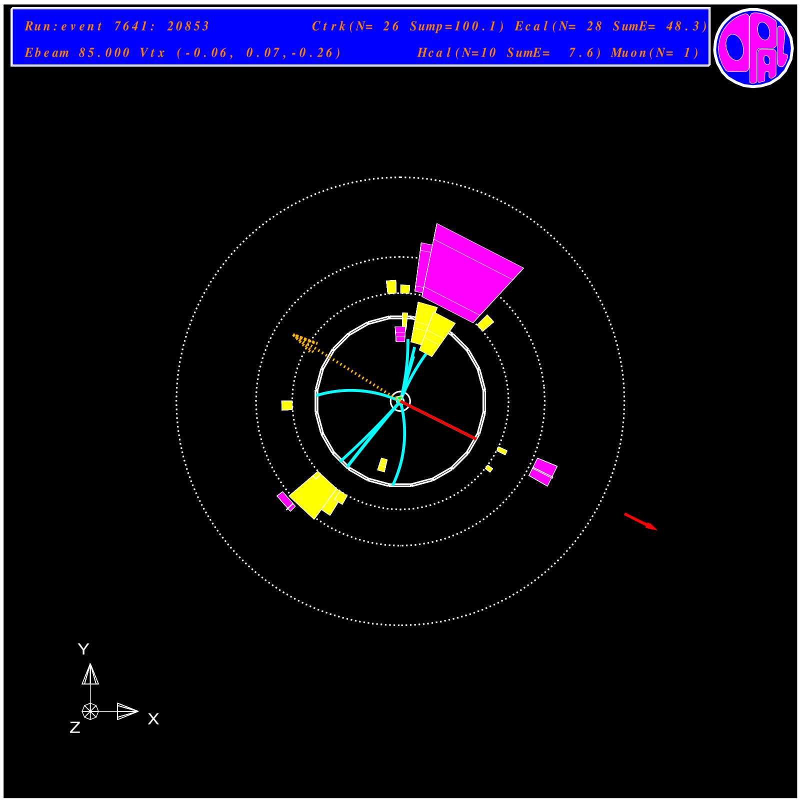
$\mathrm{N_{WW}} \approx 2800 \quad \mathrm{N_{bgd}} \approx 435$

Some Selected Events:

$\mathrm{WW} \rightarrow \mathrm{q\bar{q}q\bar{q}}$

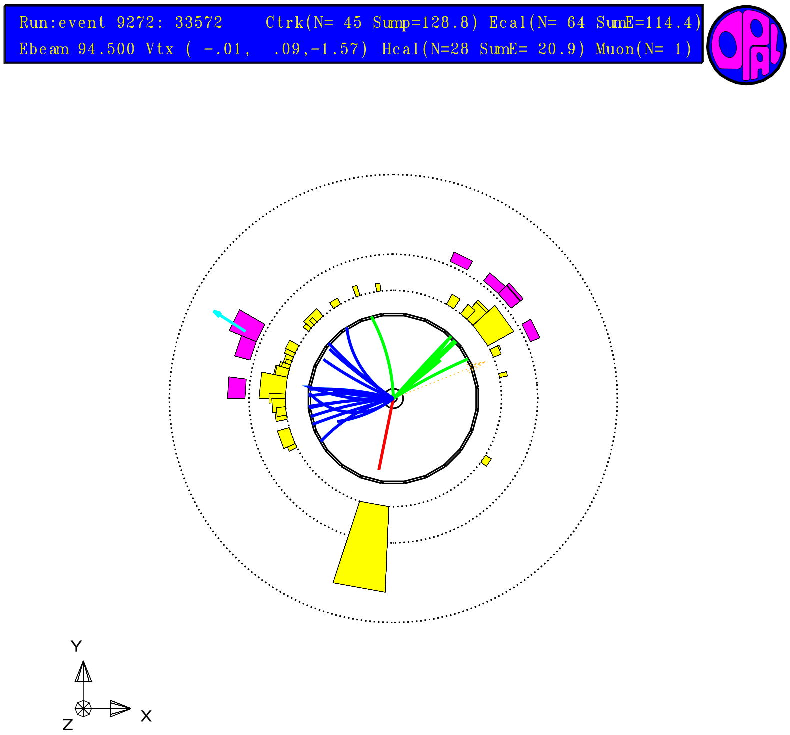


$\mathrm{WW} \rightarrow \mathrm{q\bar{q}}\mu\bar{\nu}$

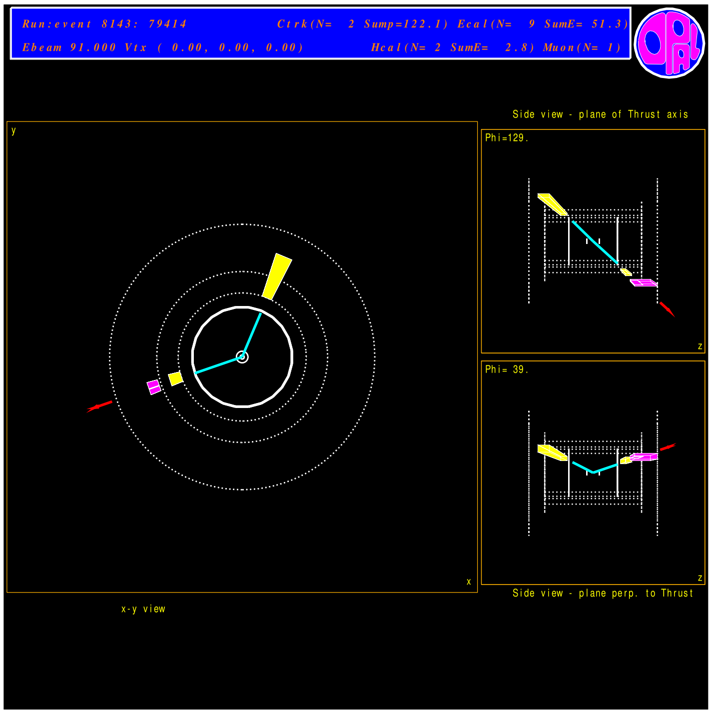


Some Selected Events:

$$WW \rightarrow q\bar{q}e\bar{\nu}$$

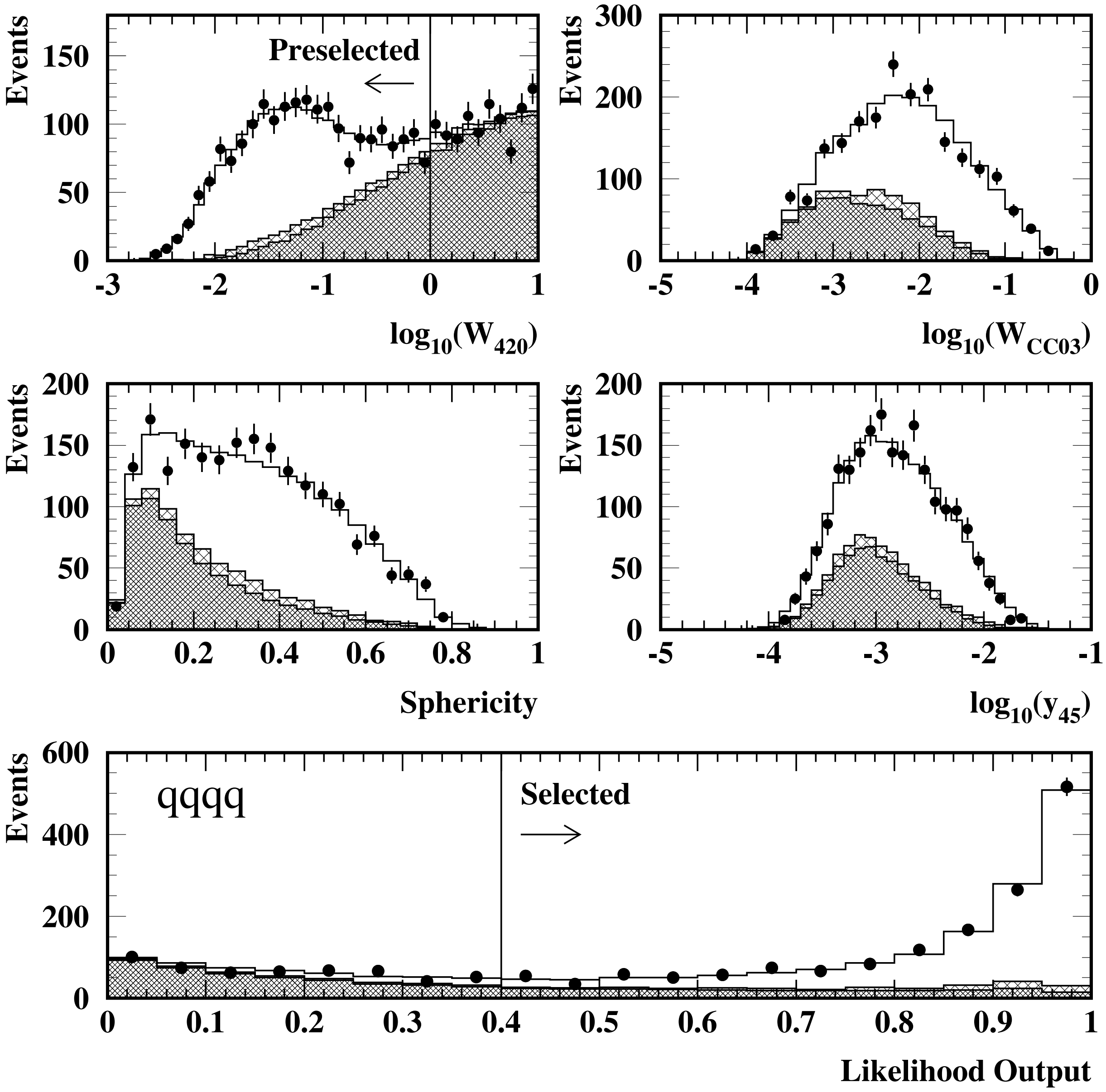


$$WW \rightarrow \ell\bar{\nu}_\ell\ell\bar{\nu}_\ell$$



$W^+W^- \rightarrow q\bar{q}q\bar{q}$ Selection:

OPAL $\sqrt{s}$=189 GeV

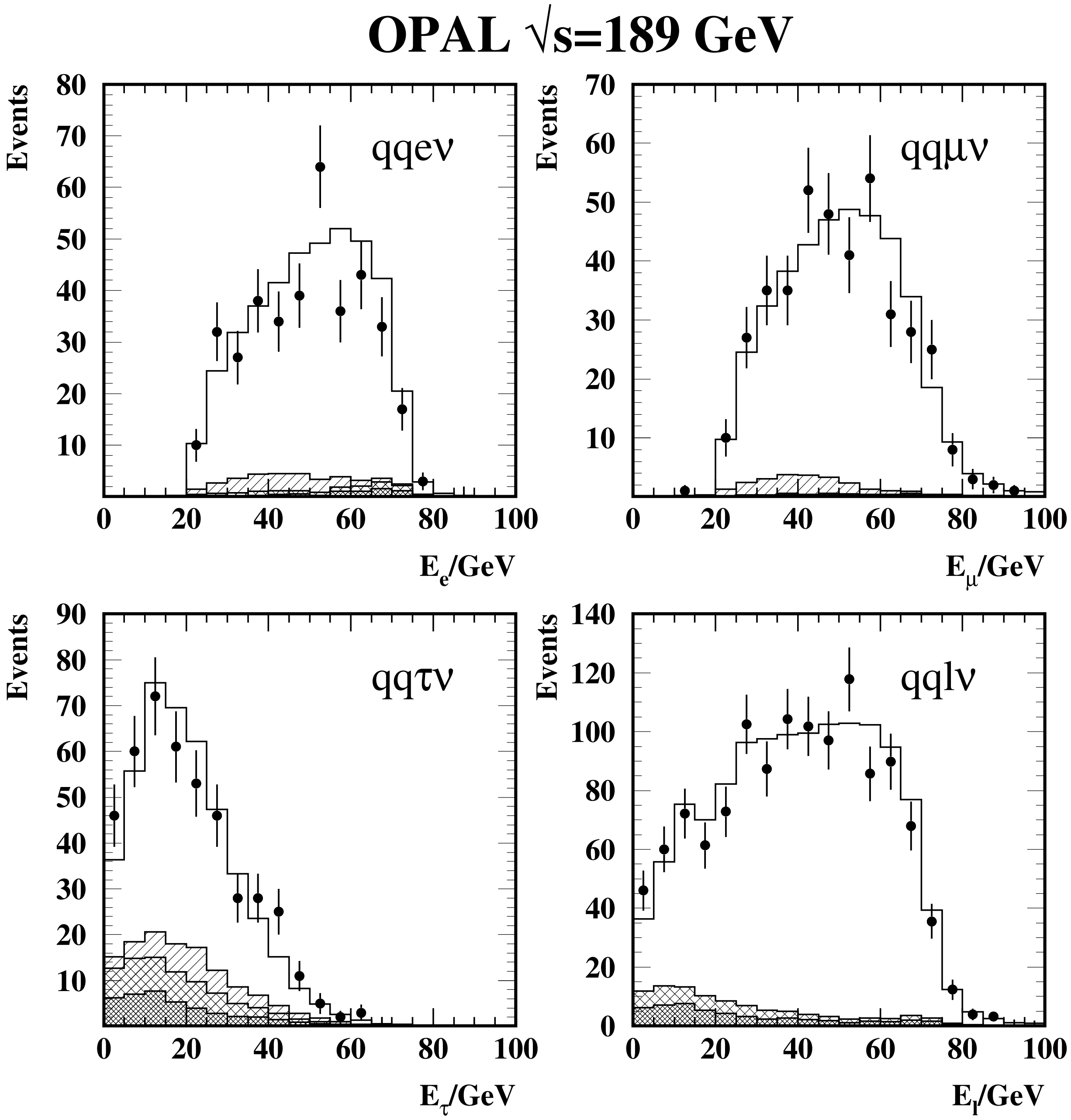


Likelihood Input Variables:

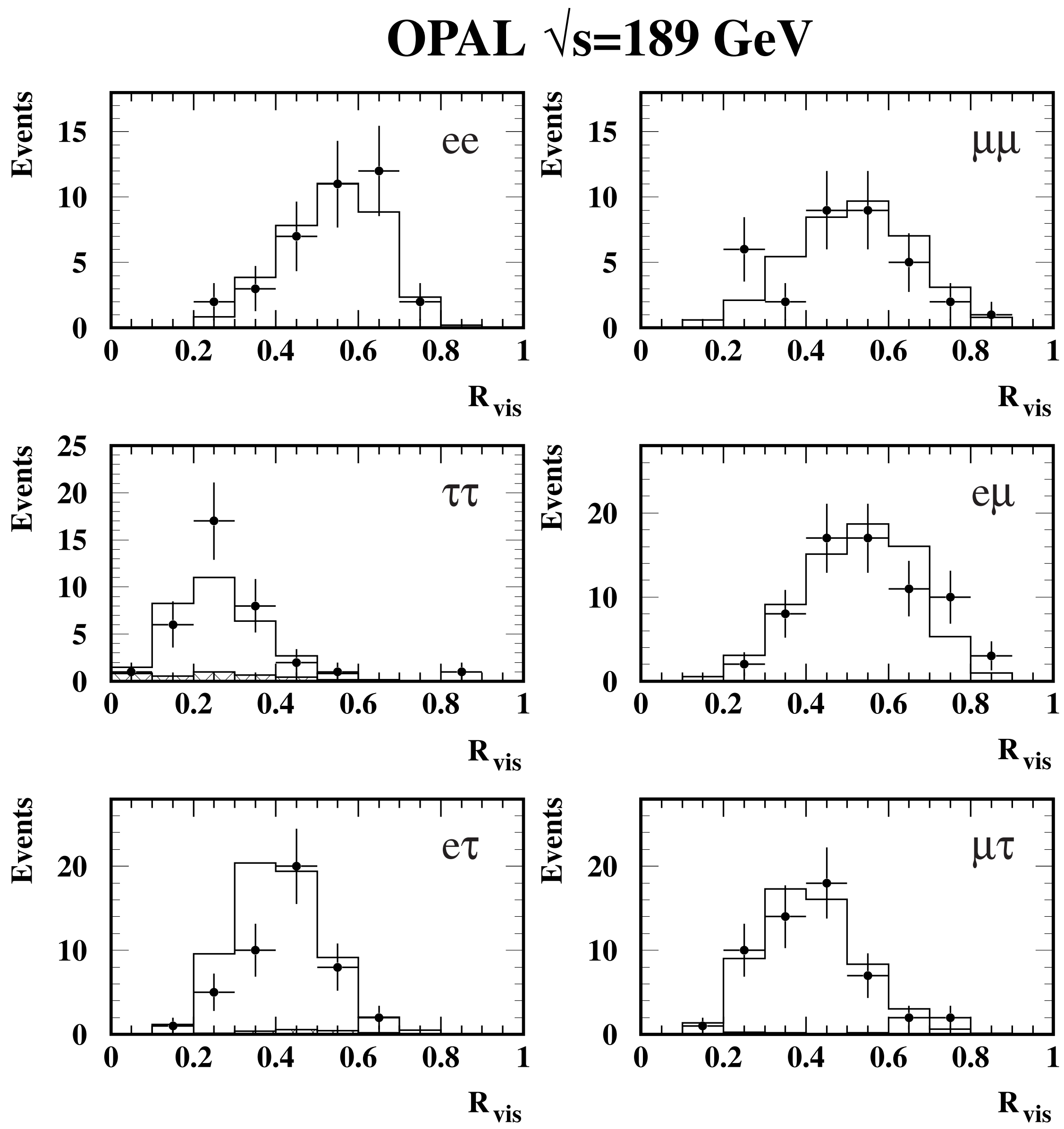
W_{420}: The QCD $\mathcal{M}$ $W_{\rm exe}$: The CC03 $\mathcal{M}$

Sphericity y_{45}: Durham 4 jets $\rightarrow$ 5 jets

$W^+W^- \rightarrow q\bar{q}\ell\bar{\nu}_\ell$ Candidates:



$W^+W^- \rightarrow \ell\bar{\nu}_\ell\ell\bar{\nu}_\ell$ Candidates:

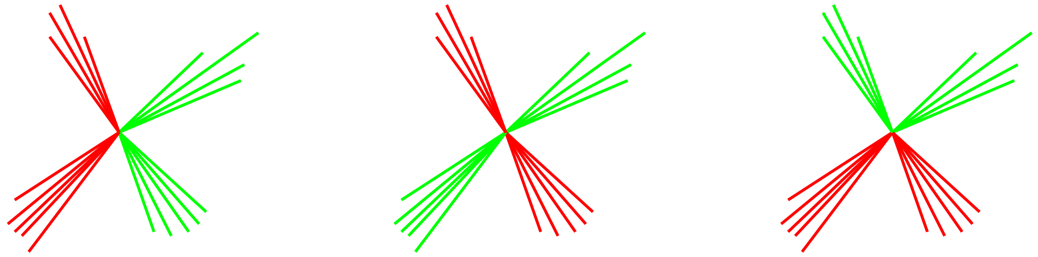


$$R_{\rm vis} = E_{\rm vis}/\sqrt{s}$$

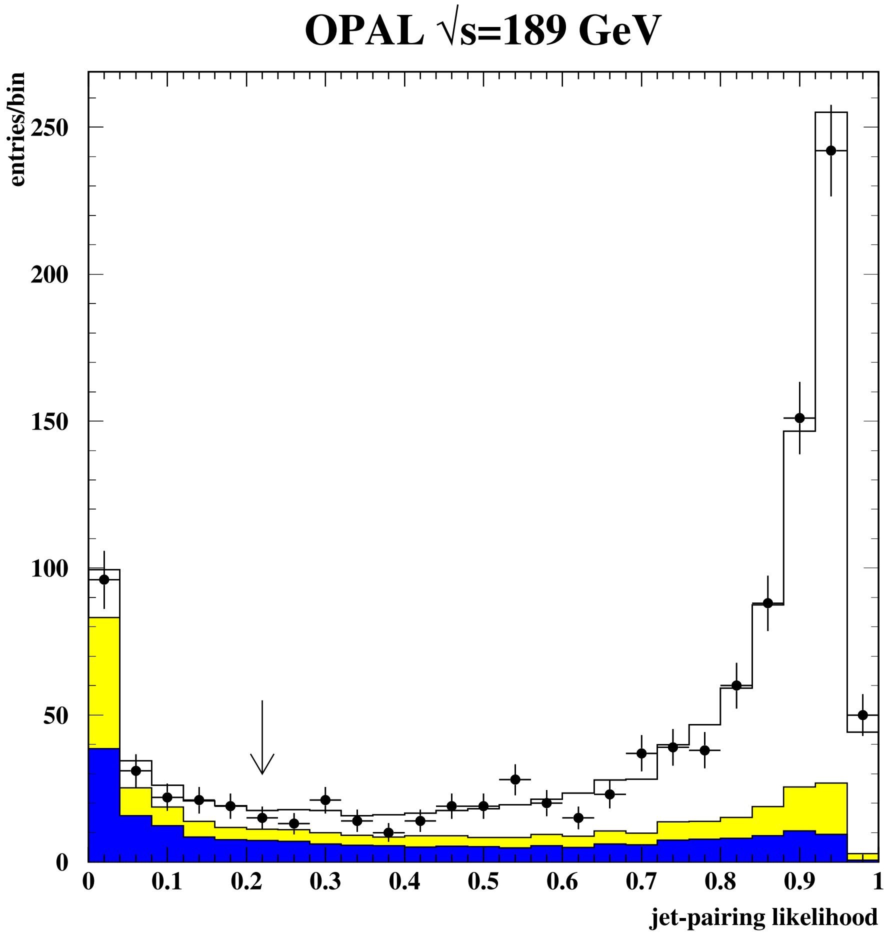
⇒ Data Quality is very good

WW $\rightarrow$ $q\bar{q}q\bar{q}$ Combinatorics

- 4-jets: jet pairing ambiguity yields 3 combinations:



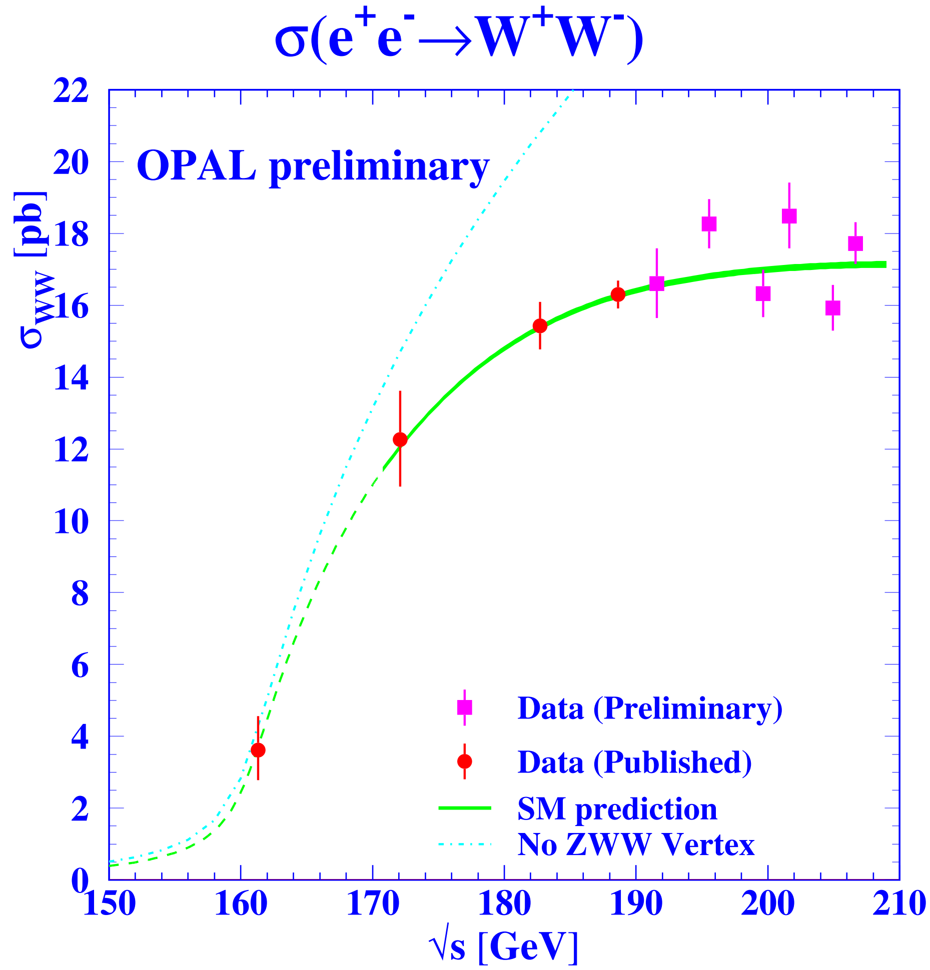
- only correct combination contains angular information
- use Δm_{rec}, $\sum \theta_{jj}$ and information from kinematic fit to choose best combination:



- choose correctly $\approx 87\%$

Cross–Section:

Final state	N_{exp}	N_{obs}
$W^+W^- \to \ell\bar{\nu}_\ell\ell\bar{\nu}_\ell$	287.2 ± 5.0	276
$W^+W^- \to q\bar{q}\ell\bar{\nu}_\ell$	1256.8 ± 16.1	1246
$W^+W^- \to q\bar{q}q\bar{q}$	1500.0 ± 25.2	1546
Combined (189 GeV)	3044.0 ± 32.1	3068



Assuming SM branching fractions (at 189 GeV):

$$\sigma_{WW} = 16.30 \pm 0.34(\mathrm{sta}) \pm 0.18(\mathrm{sys})\mathrm{pb}$$

Assuming lepton universality (161-210 GeV):

$$\mathrm{BR}(W \to q\bar{q}) = (67.93 \pm 0.61)\%$$

Selection Uncertainties

Signal Efficiency Error at 189 GeV (%)

Source of uncertainty	Event Selection WW → $q\bar{q}e\bar{\nu}$	$q\bar{q}\mu\bar{\nu}$	$q\bar{q}\tau\bar{\nu}$	$q\bar{q}q\bar{q}$
Statistical	0.18	0.17	0.27	0.06
Comp. of MC generators	0.24	0.51	0.78	0.21
M_W dependence	0.01	0.02	0.02	0.05
E_{beam} dependence	0.01	0.02	0.01	0.01
Fragmentation	0.40	0.40	0.60	0.72
Tracking losses	0.40	0.10	0.30	0.18
Data/MC preselection	0.29	0.24	0.58	–
Data/MC likelihood	0.36	0.34	0.72	0.12
Detector occupancy	0.02	0.02	0.02	–
Four-fermion rejection	0.30	0.10	0.30	–
Final-state interactions	–	–	–	0.36
Total	0.84	0.80	1.44	0.86

→ Dominant systematic uncertainty on selection efficiency from MC modelling.

Accepted background cross sections (fb)

Source	Event Selection WW → $q\bar{q}e\bar{\nu}$	$q\bar{q}\mu\bar{\nu}$	$q\bar{q}\tau\bar{\nu}$	$q\bar{q}q\bar{q}$
$q\bar{q}\ell\bar{\nu}_\ell$	54 ± 21	2 ± 1	74 ± 8	–
$q\bar{q}q\bar{q}$	0 ± 1	1 ± 1	13 ± 3	392 ± 67
$q\bar{q}\nu\bar{\nu}$	–	–	32 ± 3	–
$q\bar{q}ee$	30 ± 7	–	48 ± 12	22 ± 6
$q\bar{q}\ell\ell$	2 ± 1	28 ± 2	46 ± 4	26 ± 5
$eef\bar{f}$	7 ± 7	1 ± 1	7 ± 7	2 ± 2
$\ell^+\ell^-$	2 ± 1	1 ± 1	5 ± 1	–
$q\bar{q}$	40 ± 8	22 ± 4	192 ± 29	1337 ± 87
Total	135 ± 24	55 ± 6	417 ± 34	1777 ± 117

→ Dominant systematic uncertainty on accepted background from fragmentation uncertainties.

$|V_{cs}|$ from BR($W \rightarrow q\bar{q}$)

The hadronic branching fraction BR($W \rightarrow q\bar{q}$) can be interpreted as a measurement of $|V_{cs}|$ since:

$$\frac{\mathrm{Br}(q\bar{q})}{(1-\mathrm{Br}(q\bar{q}))} = \left(1+\frac{\alpha_s(M_W)}{\pi}\right)\sum_{\substack{i=u,c\\ j=d,s,b}} |V_{ij}|^2$$

- Under the assumption that the W couples with equal strength to quarks and leptons: BR($W \rightarrow q\bar{q}$)$= (67.93 \pm 0.61)\%$
- Using PDG00 for other $|V_{ij}|$.
- And $\alpha_s(M_W) = 0.120 \pm 0.005$.
- Without assuming unitarity of the CKM matrix.

OPAL Preliminary with $\sqrt{s}$=161-210 GeV data:

$$\boxed{|V_{cs}| = 0.996 \pm 0.017(\mathrm{stat}) \pm 0.023(\mathrm{syst})}$$

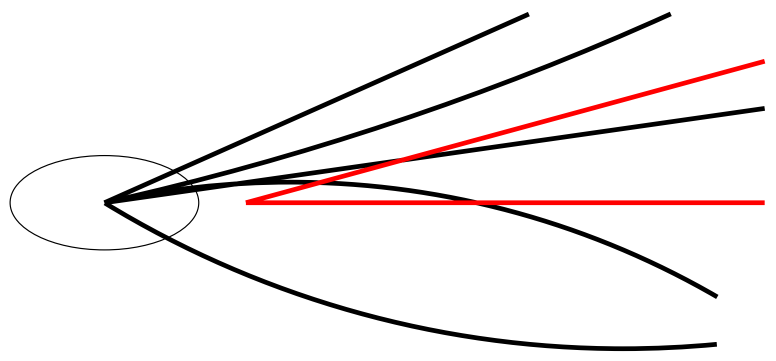
Remark: PDG00 from charm semielectronic decays is $|V_{cs}| = 1.04 \pm 0.16$.

Charm Tags and Direct Measurement of

$$R_{\mathrm{c}}^{\mathrm{W}} = \frac{\Gamma(\mathrm{W}\rightarrow cX)}{\Gamma(\mathrm{W}\rightarrow q\bar{q})}$$

Strategy

Reconstruction of the Sub-Jet



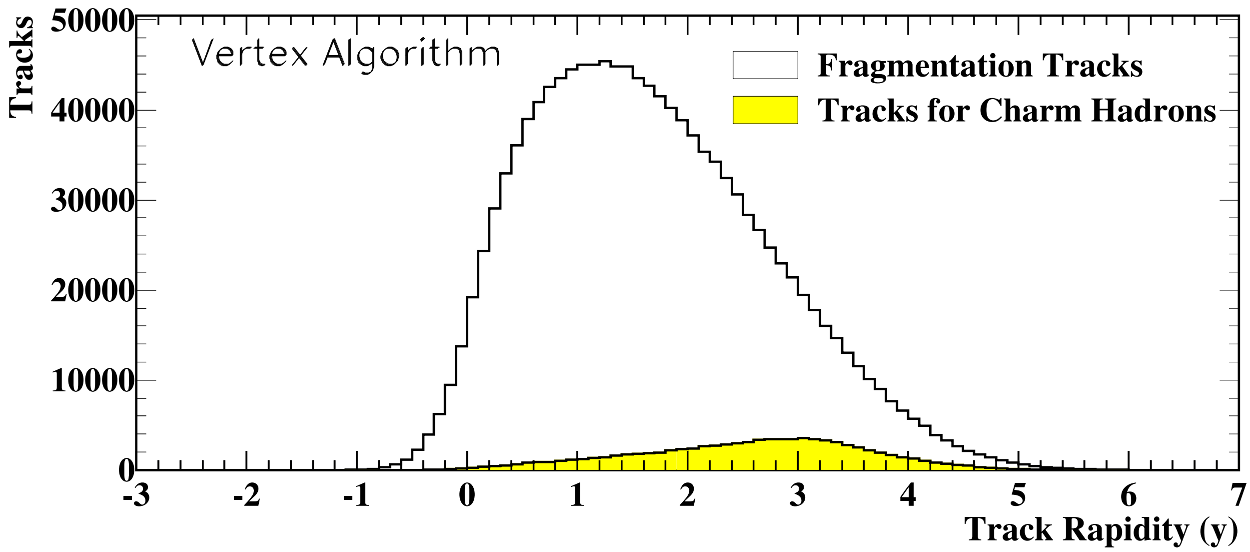
Tag the charm flavour with
- lifetime information
- lepton ID
- jet properties

- Inclusive JET BASED charm tag for a better statistical power
- Average charged multiplicity for charm hadron decays: 2-3
- $\tau_{\mathrm{charm}} \sim 1$ ps: large flight distance of about 1-2 mm
- Charm hadrons are a source of prompt leptons
- Charm quark heavier than uds-quarks: specific momentum distribution within the jet
- $|V_{\mathrm{ub}}|$ and $|V_{\mathrm{cb}}|$ are small

Vertex Tag: Selection

Charm Vertex Finding:

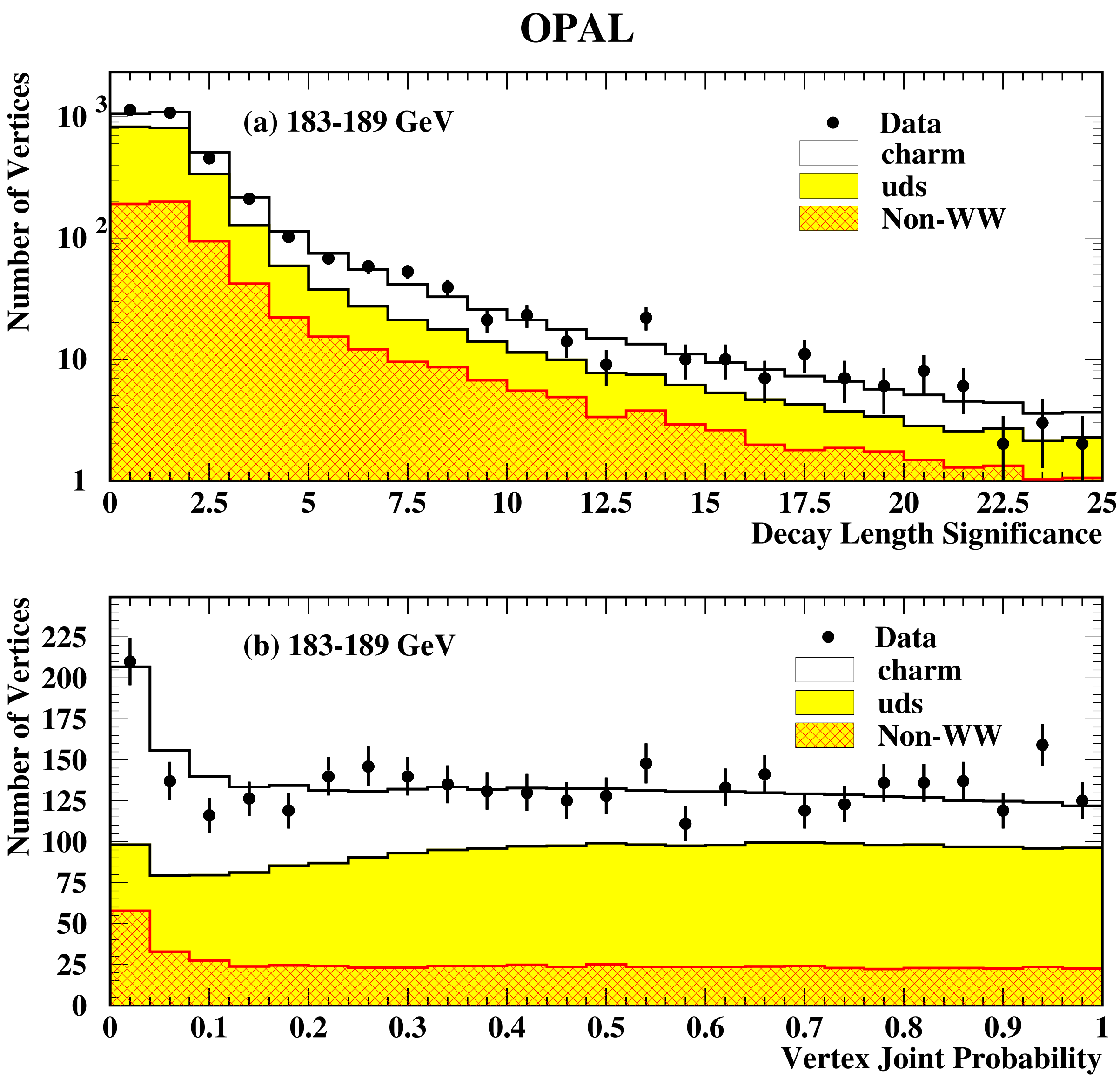
- Track preselections: $d_0 < 0.3\,\text{cm}$, $\sigma_{d_0} < 0.1\,\text{cm}$, $d_0/\sigma_{d_0} > 0$, and $p > 0.75\,\text{GeV}$.
- In Each Jet: the tracks or clusters with the lowest rapidity are removed until the charm mass is reached: $y = \frac{1}{2}\ln(\frac{E+p_\parallel}{E-p_\parallel})$.
- All tracks selected are fitted to a common vertex.
- Tracks which contribute more than 4 to the χ^2 of this fit are removed and the fit is repeated.



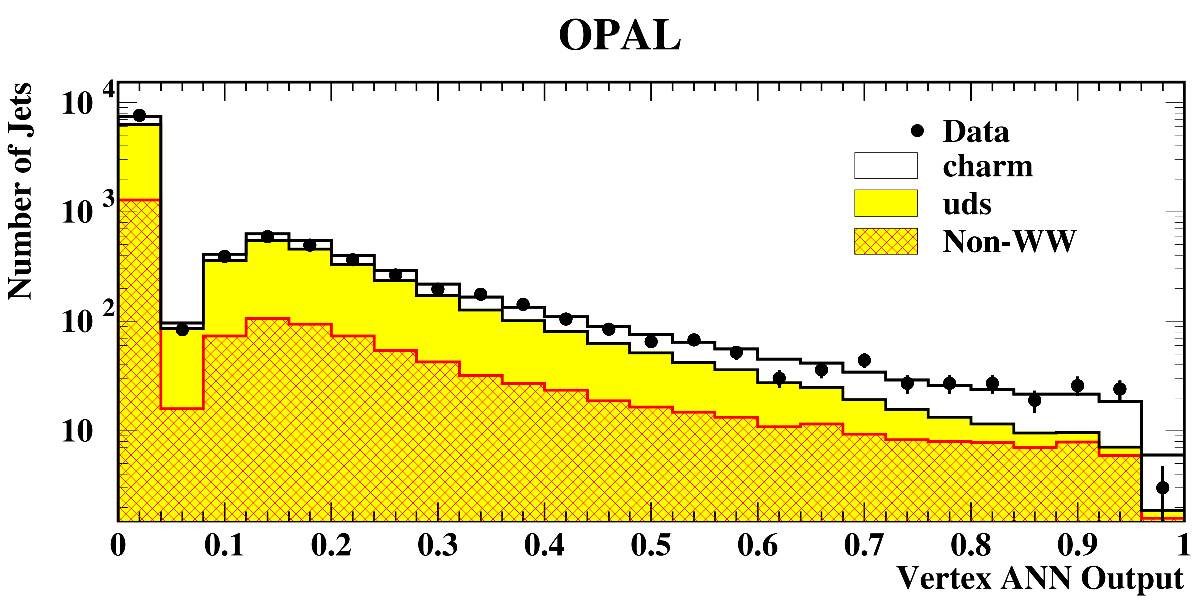
Vertex Tag: Inputs

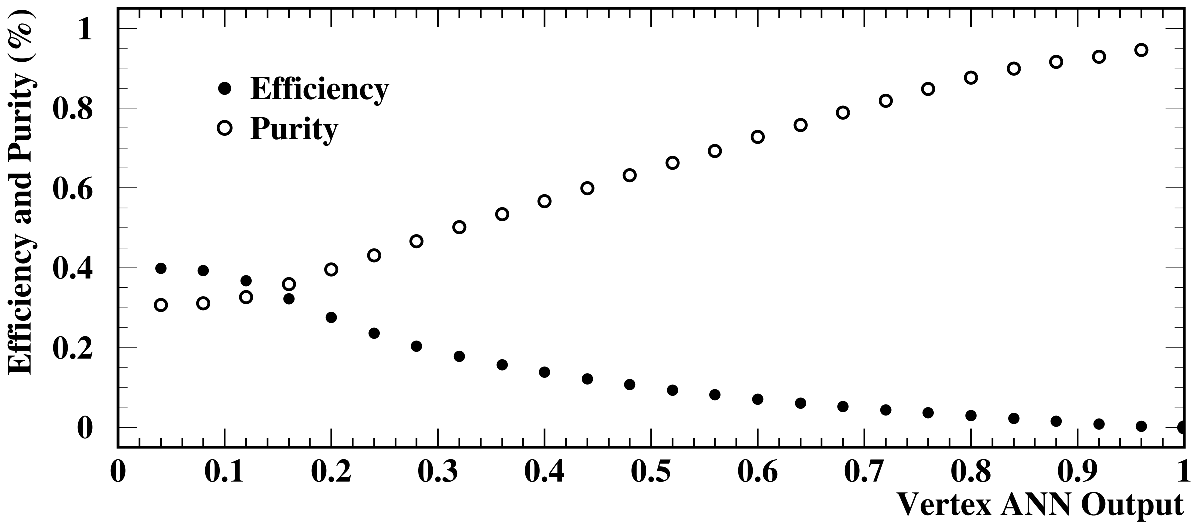
Inputs to the ANN:

- L/σ_L and Vertex joint probability
- $E_{\mathrm{vertex}}/E_{\mathrm{beam}}$ and M_{vertex}
- DCA_{vertex} and $\frac{\sum_{\mathrm{tracks}} d_0/\sigma_{d_0}^2}{\sum_{\mathrm{tracks}} 1/\sigma_{d_0}^2}$
- $Max(p_{\mathrm{track}})$
- Largest and second largest track d_0



Vertex Tag: Performance





Strategy: Tag charm hadron jets with the reconstruction of secondary vertices with respect to the primary vertices.

Goal: Discriminate charm and light flavoured jets!

Lepton Tag: Selection

Lepton Selection:

- $|\cos\theta_\ell| < 0.9$ and $p_\ell > 2.0$ GeV
- Electron: ID mainly based on E/p and dE/dx
- Muon: Match between tracking system, hadronic calorimeter, and the muon chambers
- Of these lepton candidates, the most energetic lepton of each jet, if any, is selected.

Lepton From Charm: Construction of a likelihood function to separate charm and uds jets.

Both for electrons and for muons:

- OPAL lepton ID ANN output
- $\cos\theta_\ell$
- $|p_\ell|$

In $\mathrm{W^+W^-} \rightarrow \mathrm{q\bar{q}q\bar{q}}$ selected events:

- $Q_\ell \cdot \cos\theta_\mathrm{W}$

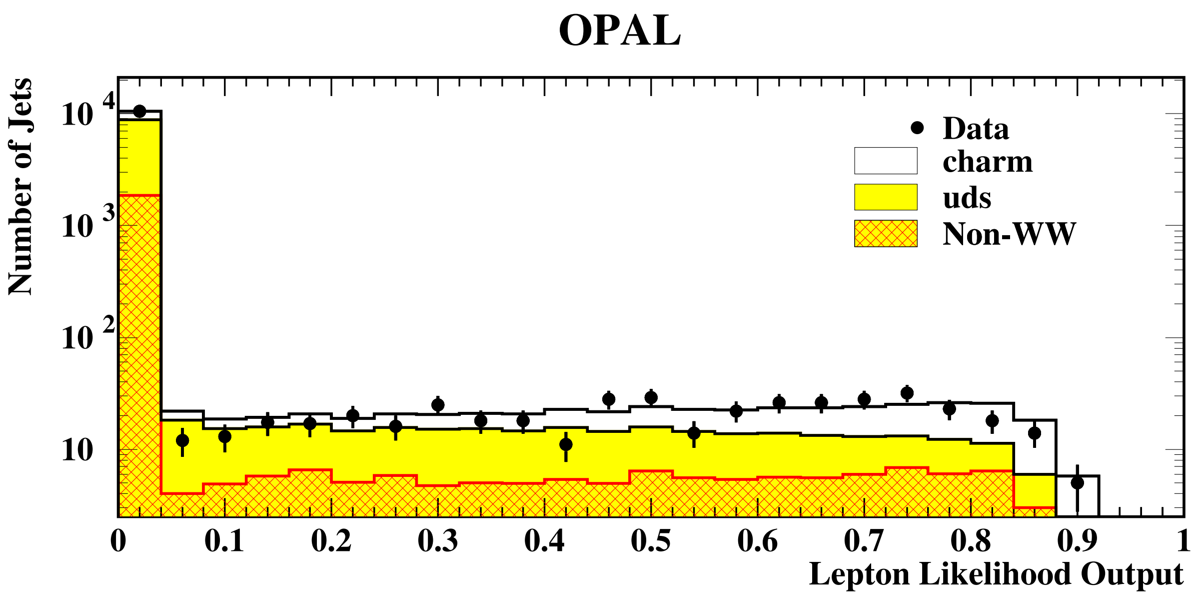
In $\mathrm{W^+W^-} \rightarrow \mathrm{q\bar{q}}\ell\bar{\nu}_\ell$ selected events:

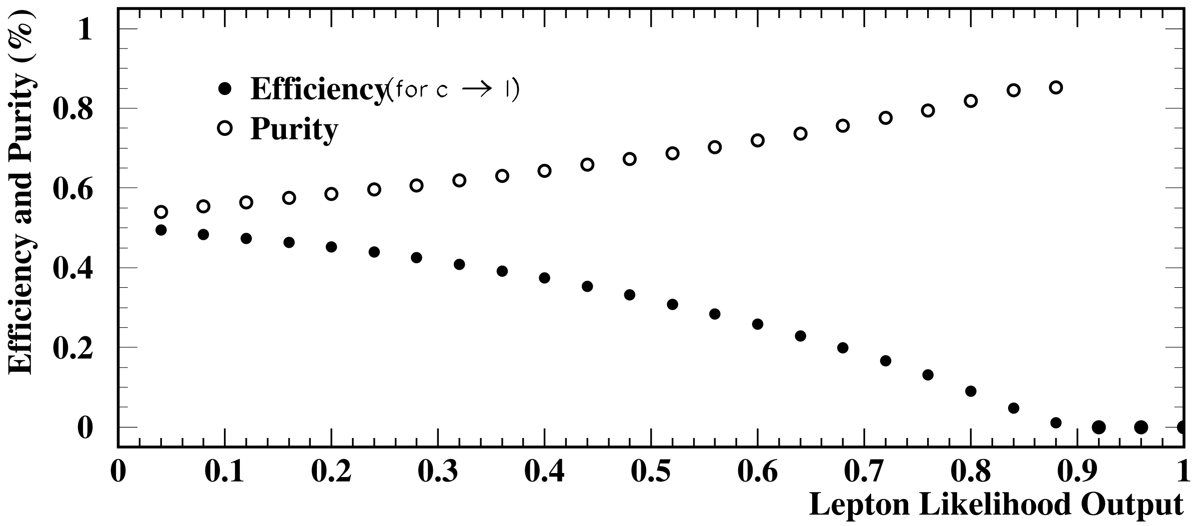
- $Q_\ell \cdot Q_{\mathrm{W}\rightarrow\ell\bar{\nu}_\ell}$

For electron only:

- OPAL conversion finder ANN output

Lepton Tag: Performance

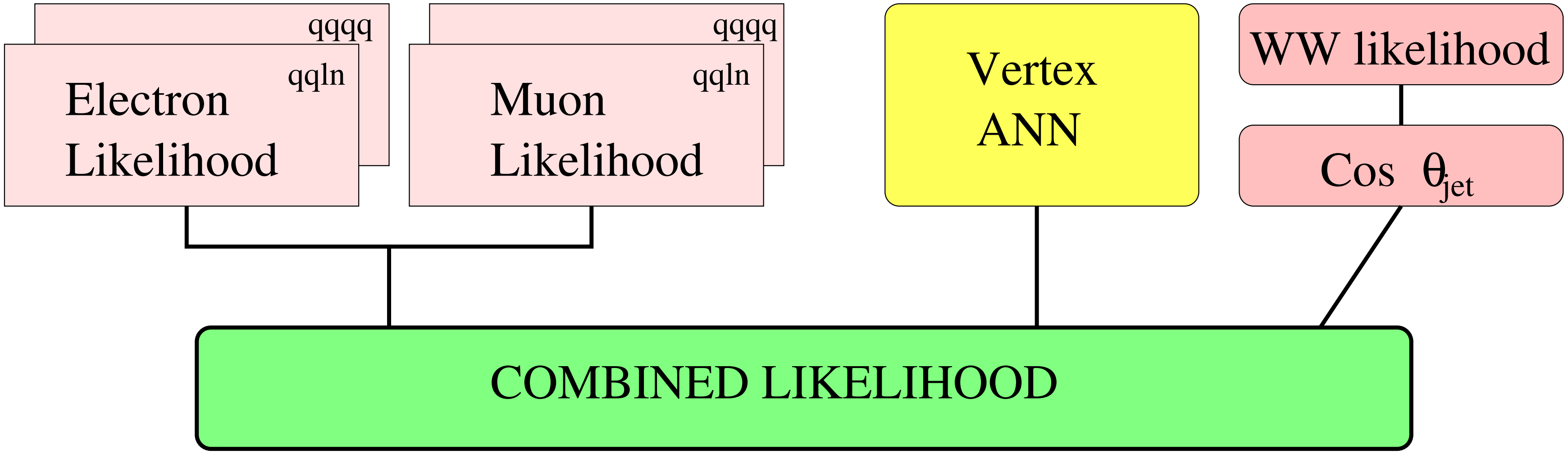




Strategy: Using the fact that BR$(c \to \ell) \simeq 20\%$ with $\ell = e$ or μ: Tag charm hadron jets with the identification of prompt leptons.

Goal: Separation of charm jets from other jets!

Combined Tag



- The jet angle in the W (*i.e.* di-jet) rest frame helps to discriminate jets originating from up–type quarks from down–type quarks due to the $V - A$ nature of the weak interaction.
- The likelihood output of the WW event selection suppresses false tags from background events, especially from $\mathrm{Z}^0/\gamma \rightarrow \mathrm{b\overline{b}}$ events.

Fit for R_c^W

Binned Maximum Likelihood Fit:

$$-\ln\mathcal{L} = -\sum_{i=1}^{N} n_i \ln\{(1-F_{\rm bkg})[F_c\mathcal{P}_c^i + (1-F_c)\mathcal{P}_{uds}^i] + F_{\rm bkg}\mathcal{P}_{\rm bkg}^i\}$$

with $R_c^W = 2\,F_c$ and

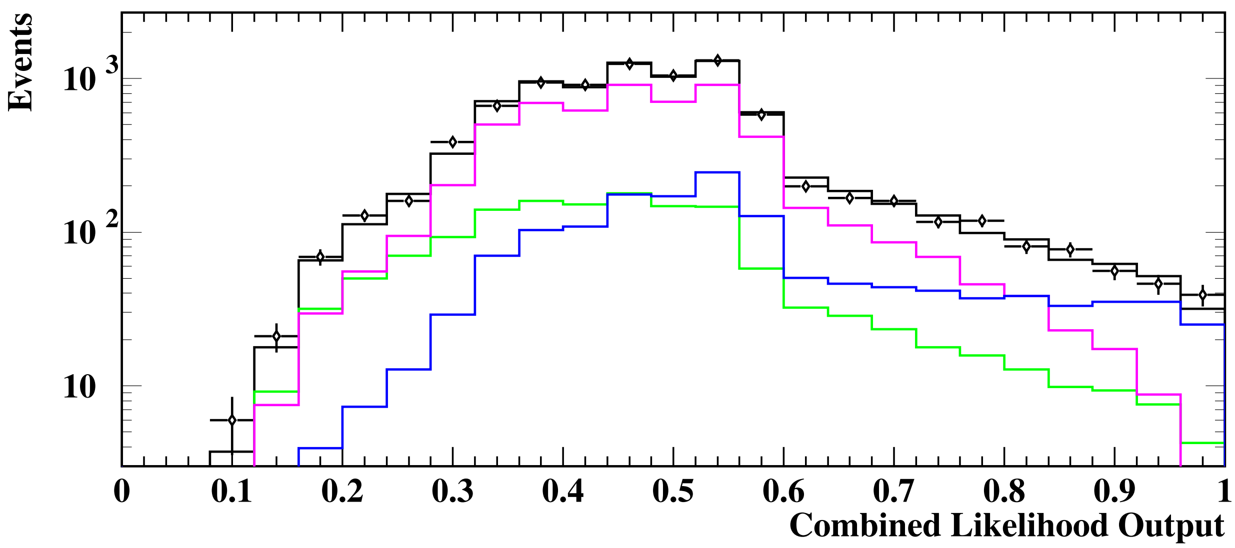
F_c: Fraction of charm jets (float)

$\mathcal{P}_c^i$: Probability to tag Charm in $i^{\rm th}$ bin

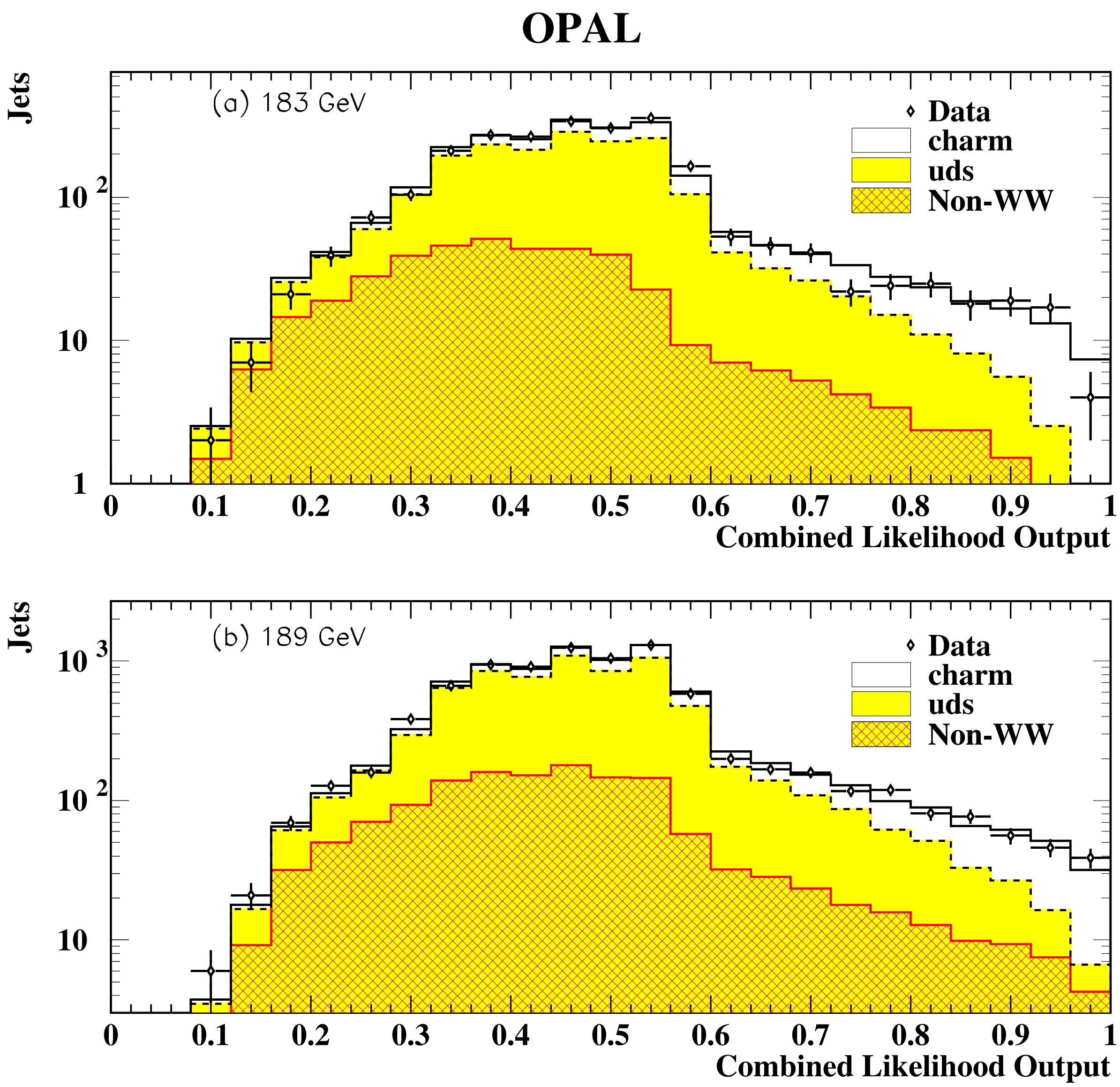
$\mathcal{P}_{uds}^i$: Probability to tag uds in $i^{\rm th}$ bin

$F_{\rm bkg}$: Fraction of background jets (float or fixed)

$\mathcal{P}_{\rm bkg}^i$: Probability to tag non-WW bkg in $i^{\rm th}$ bin



Fit Results for R_c^W



$\mathrm{R}_c^W = \mathbf{0.493 \pm 0.090}$ at 183 GeV $(\chi^2\mathrm{pdf} = 17.2/24)$

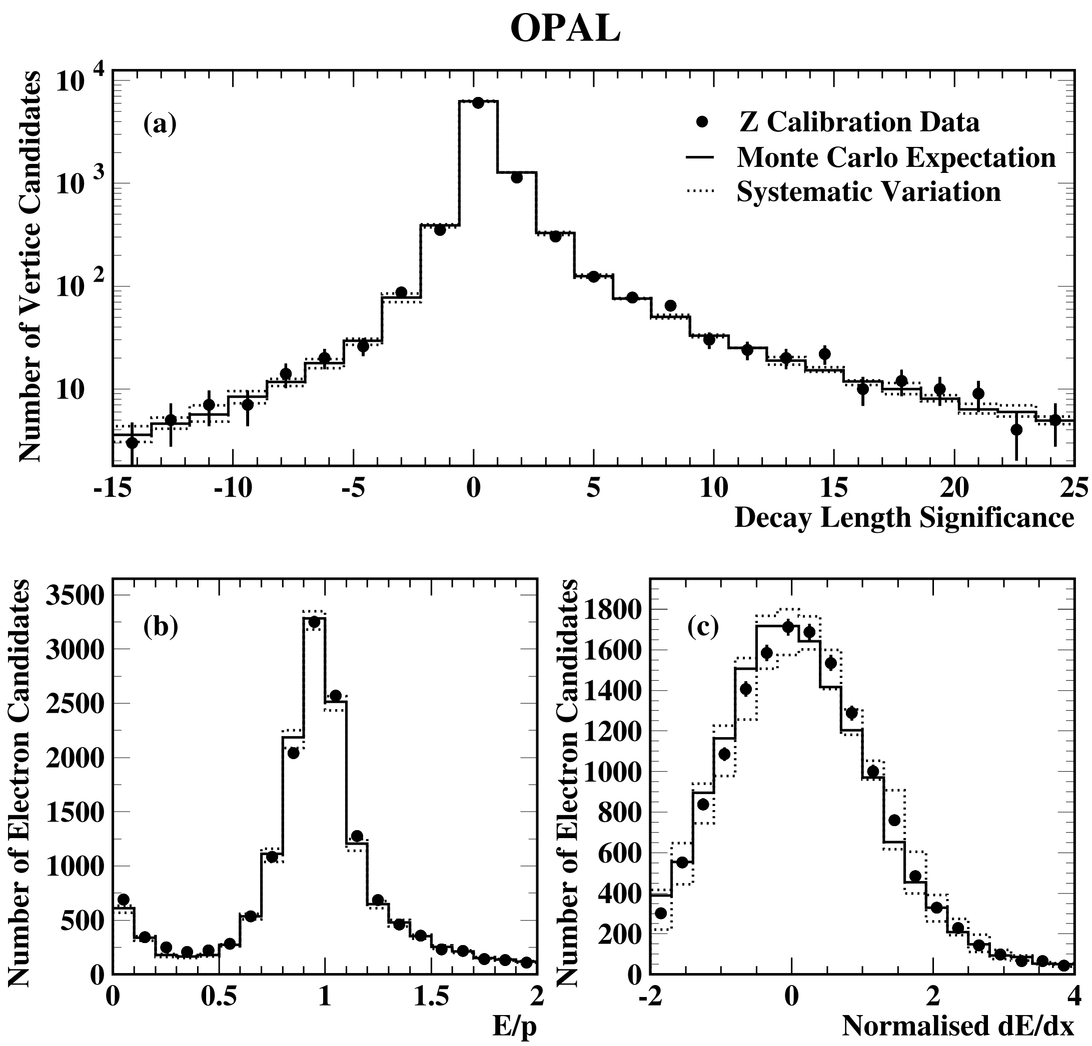
and

$\mathrm{R}_c^W = \mathbf{0.478 \pm 0.047}$ at 189 GeV $(\chi^2\mathrm{pdf} = 35.4/24)$

Systematic Uncertainties

Source of Systematic Error	$\Delta\ R_{\rm c}^{\rm W}$ 183 GeV	$\Delta\ R_{\rm c}^{\rm W}$ 189 GeV
Hadronisation Model	0.011	0.012
Centre–of–mass Energy	0.007	0.005
Mass of the W Boson	0.004	0.003
Charm Frag. Function	0.007	0.007
Back. Cross–Section	0.006	0.006
Back. Composition	0.010	0.009
Charm Hadron Fractions	0.006	0.007
Light Quark Composition	0.007	0.005
Vertex Reconstruction	0.016	0.017
Charm Hadron Lifetimes	0.003	0.002
Charm Decay Multiplicity	0.010	0.010
Lepton Identification	0.012	0.014
Lepton Spectrum	0.003	0.003
$\mathrm{Br}(\mathrm{c} \to \ell)$	0.006	0.006
Total systematic error	0.032	0.032
Statistical error	0.090	0.047
Value of $R_{\rm c}^{\rm W}$	0.493	0.478

Main Systematic Errors



⇒ The dominant systematic errors are those associated with the vertex reconstruction and lepton identification (*i.e.* detector response).

(a) The decay length significance L/σ_{L} for data and MC. The dotted line shows the effect of the $\pm 5\,\%$ variation on the tracking resolution used to assess the systematic uncertainty on the vertex tag.

(b-c) E/p and the norm. $\mathrm{d}E/\mathrm{d}x$ for electron candidates from data and MC. The dotted lines show how the variation of the detection (mis)identification and resolution.

Results (OPAL)

At $\sqrt{s} \simeq 183$ GeV:

$$R_c^W = 0.493 \pm 0.090(\mathrm{stat}) \pm 0.032(\mathrm{syst})$$

At $\sqrt{s} \simeq 189$ GeV:

$$R_c^W = 0.478 \pm 0.047(\mathrm{stat}) \pm 0.032(\mathrm{syst})$$

Combined value:

$$\boldsymbol{R_c^W = 0.481 \pm 0.042(\mathrm{stat}) \pm 0.032(\mathrm{syst})}$$

CKM matrix element	Value(PDG00)
$\lvert V_{ud}\rvert$	0.9735 ± 0.0008
$\lvert V_{us}\rvert$	0.2196 ± 0.0023
$\lvert V_{cd}\rvert$	0.224 ± 0.016
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	0.090 ± 0.025
$\lvert V_{cb}\rvert$	0.0402 ± 0.0019

$$|V_{cs}| = \sqrt{\frac{R_c^W(|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2)}{1 - R_c^W} - |V_{cd}|^2 - |V_{cb}|^2}$$

$$|V_{cs}| = 0.93 \pm 0.08(\mathrm{stat}) \pm 0.06(\mathrm{syst}) \pm 0.004(\mathrm{ckm})$$

Results (OPAL)

Based on a new and original idea, one can extract $|V_{cs}|$ from $\mathrm{Br}\,(\mathrm{W} \to \mathrm{hadrons})$ and $\Gamma^{\mathrm{W}}_{\mathrm{tot}}$. In the SM,

$$\Gamma\,(\mathrm{W} \to \mathrm{c\,X}) = \frac{C G_{\mathrm{F}} {M_{\mathrm{W}}}^3}{6\sqrt{2}\pi}(|V_{\mathrm{cd}}|^2 + |V_{\mathrm{cs}}|^2 + |V_{\mathrm{cb}}|^2)$$

with $$\frac{C G_{\mathrm{F}} {M_{\mathrm{W}}}^3}{6\sqrt{2}\pi} = (707 \pm 1)\mathrm{MeV}$$

Thus:

$$\mathbf{\Gamma\,(W \to c\,X) = \boldsymbol{R}^{W}_{c}\,Br\,(W \to q\overline{q})\,\Gamma^{W}_{tot}}$$

$\mathrm{BR}\,(\mathrm{W} \to \mathrm{q\overline{q}})$	$\Gamma^{\mathrm{W}}_{\mathrm{tot}}$ (GeV)
0.6848 ± 0.0059	2.12 ± 0.05

$$\boldsymbol{|V_{cs}| = 0.969 \pm 0.045 \pm 0.034 \pm 0.013 \pm 0.004}$$

– 1^{st} Error: Statistical,
– 2^{nd} Error: Experimental Systematic,
– 3^{rd} Error: External from $\mathrm{BR}\,(\mathrm{W} \to \mathrm{q\overline{q}})$ and $\Gamma^{\mathrm{W}}_{\mathrm{tot}}$,
– 4^{th} Error: Uncertainties on the other $|\mathrm{V}_{ij}|$ used.

Summary: OPAL Charm Tag

Measurement of R_c^W

Data Collected at $\sqrt{s}$= 183 GeV and 189 GeV with the OPAL detector:

$$\boldsymbol{R_c^W = 0.481 \pm 0.042(\mathrm{stat}) \pm 0.032(\mathrm{syst})}$$

It leads to an indirect measurement of $|V_{cs}|$:

$$\boldsymbol{|V_{cs}| = 0.969 \pm 0.058}$$

D semileptonic decays (MARKIII & CLEO):

$$|V_{cs}| = 1.04 \pm 0.16$$

Neutrino experiments (CCFR):

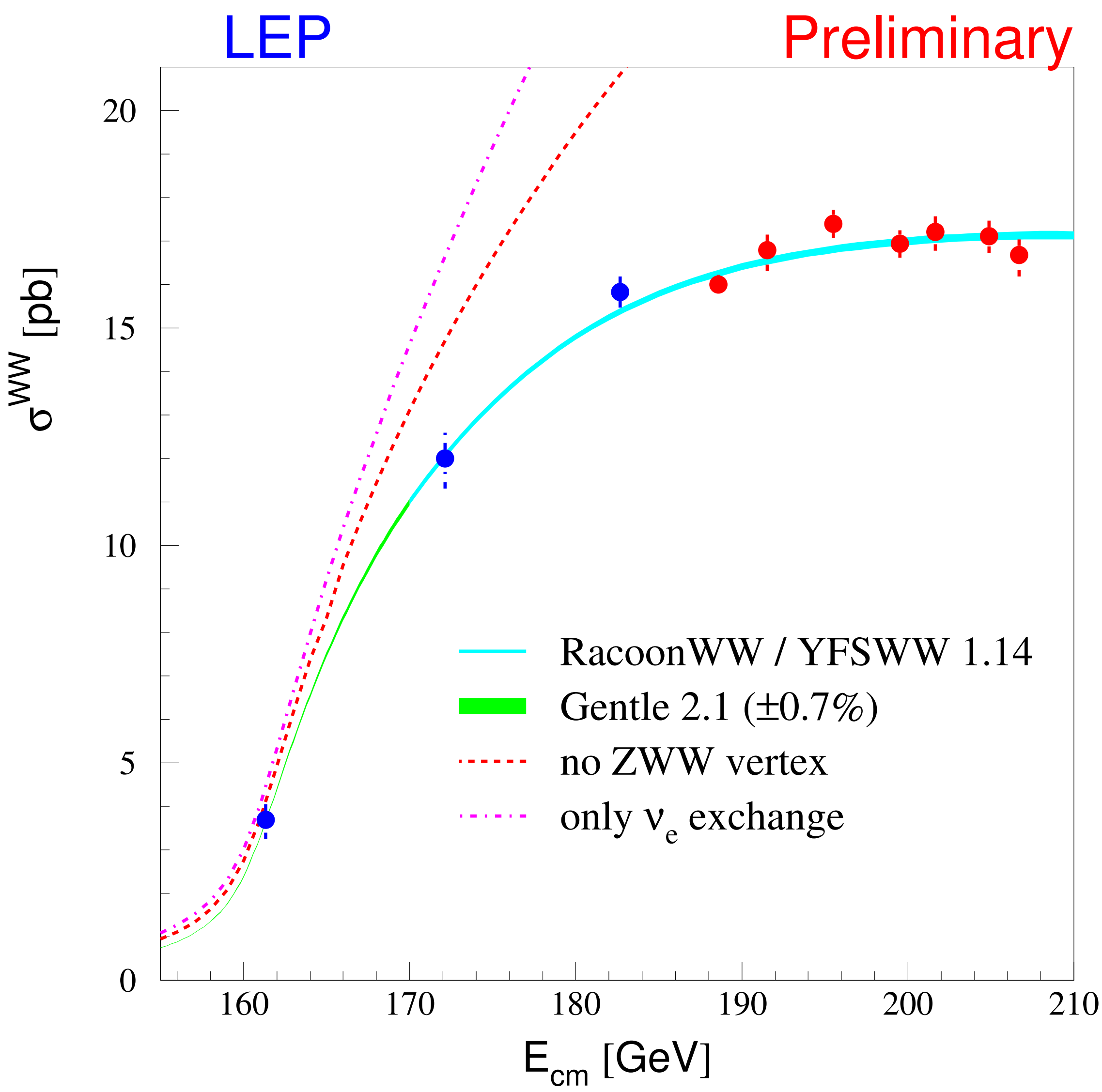
$$|V_{cs}| = 1.05^{+0.12}_{-0.15}$$

SUMMARY

$|V_{cs}|$ at LEP2

ALEPH DELPHI L3 OPAL

WW Cross–Section



Assuming lepton universality (data up to 210 GeV):

$\mathrm{BR}(\mathrm{W} \to \mathrm{q\bar{q}}) = (67.78 \pm 0.32)\%$

$$\boxed{|V_{cs}| = 0.989 \pm 0.016}$$

R_c^W and $|V_{cs}|$ at LEP2

Exp.	R_c^W
ALEPH	$0.510^{+0.050}_{-0.050}(\text{stat}) \pm 0.030(\text{syst})$
DELPHI	$0.520^{+0.070}_{-0.050}(\text{stat}) \pm 0.050(\text{syst})$
L3	$0.502^{+0.110}_{-0.110}(\text{stat}) \pm 0.035(\text{syst})$
OPAL	$0.481^{+0.042}_{-0.042}(\text{stat}) \pm 0.032(\text{syst})$
LEP	$\mathbf{0.499 \pm 0.027(stat) \pm 0.037(syst)}$

Data Samples:

- ALEPH: $\sqrt{s} = 172$ GeV & 183 GeV
- DELPHI: $\sqrt{s} = 161$ GeV, 172 GeV & 183 GeV
- L3: $\sqrt{s} = 183$ GeV
- OPAL: $\sqrt{s} = 183$ GeV & 189 GeV

Preliminary update of $|V_{cs}|$ from R_c^W at LEP2:

$$\boxed{|V_{cs}| = 0.987 \pm 0.050}$$

DELPHI provides a measurement of:

$$R_{cs} = \frac{\Gamma(W \to c\bar{s})}{\Gamma(W \to q\bar{q})} = 0.46^{+0.18}_{-0.14}(\text{stat}) \pm 0.07(\text{syst}),$$

which leads to

$$|V_{cs}| = 0.94^{+0.32}_{-0.26}(\text{stat}) \pm 0.13(\text{syst}).$$

Future Expectations

LEP2

R_c^W at OPAL

$$\Delta R_c^W(\mathrm{stat}) \simeq 0.020 \quad \text{and} \quad \Delta R_c^W(\mathrm{syst}) \simeq 0.030$$
$$\Delta R_c^W \simeq 0.036$$

$|V_{cs}|$ at LEP2

$$\Delta|V_{cs}|(\mathrm{stat}) \simeq 0.008 \quad \text{and} \quad \Delta|V_{cs}|(\mathrm{syst}) \simeq 0.011$$
$$\Delta|V_{cs}| \simeq 0.014$$

Remark: In the charm sector $U = \sum_j |V_{cj}|^2 = 1$, ΔU is dominated by $|V_{cs}|$ since $\Delta U \propto \sqrt{\sum_j [|V_{cj}|^2 (\Delta|V_{cj}|)^2]}$.

NLC

CKM at NLC ($\mathcal{L}_{HE} = 3 \times 10^{34}$ sec^{-1}cm^{-2})

CKM	Uncertainties Current	Projected	NLC
$\|V_{ud}\|$	± 0.0008	–	± 0.0028
$\|V_{us}\|$	± 0.0023	–	± 0.0124
$\|V_{ub}\|$	± 0.008	± 0.0004	± 0.011
$\|V_{cd}\|$	± 0.016	–	± 0.0072
$\|V_{cs}\|$	± 0.16	± 0.014	± 0.0017
$\|V_{cb}\|$	± 0.0019	± 0.0012	± 0.0011

Single Top Production at LEP2

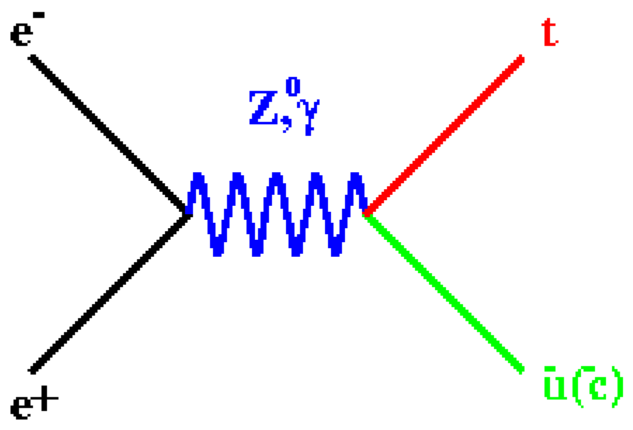
Introduction

Flavour-Changing-Neutral-Currents (FCNC) are known to be absent at tree level in the Standard Model. Neutral currents such as $e^+e^- \rightarrow t\bar{q}$ can be present at the one loop level, but the rates are severely suppressed.

In SM: Single Top Production is $\mathcal{O}(\frac{1}{10^9})$fb at LEP2 Energies

This opens the possibility of using the corresponding FCNC processes to probe for new physics !

PRODUCTION



Flavour changing vertices are present in many extensions of the SM which could enhance the production of the top quarks.

Remark: In the SM a single top can be produce via $e^+e^- \rightarrow t\bar{q}e\bar{\nu}$. The associated Xsection is $\mathcal{O}(10^{-4})$fb.

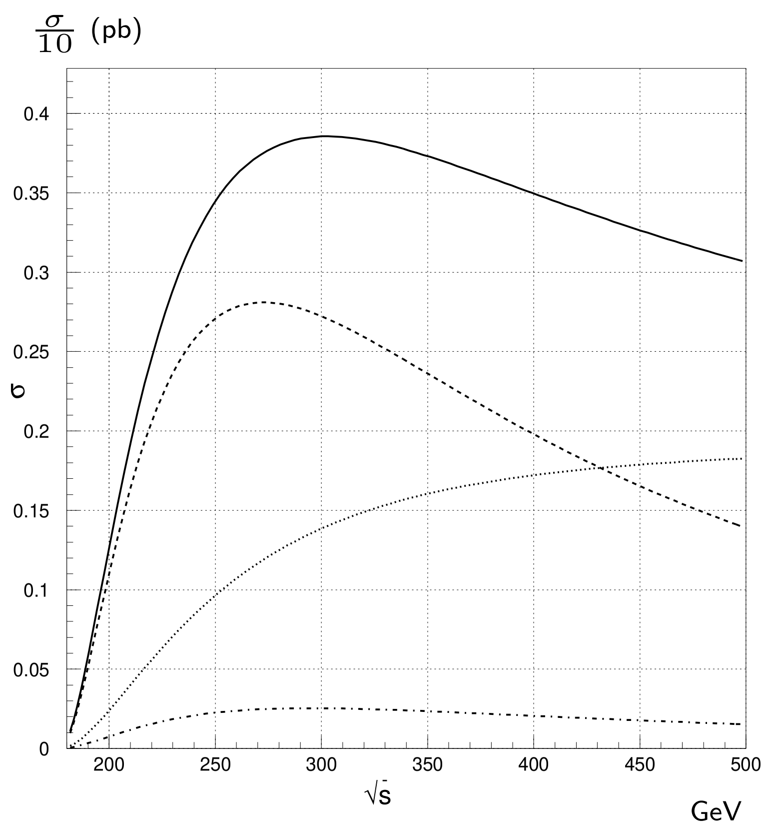
TeVatron

Limit from CDF:

$\mathrm{Br}(t \to \gamma q) < 3.2\%$
$\mathrm{Br}(t \to Zq) < 33\,\%$

$\Downarrow$

$\kappa_\gamma < 0.42$
$\kappa_Z < 0.73$



Cross-Section:

$$\sigma(e^+e^- \to t\bar{c}) = \frac{\pi\alpha^2}{s}\left(1 - \frac{m_t^2}{s}\right)^2 \left[\kappa_\gamma^2 \frac{m_t^2}{\Lambda^2} e_q^2 \frac{s}{m_t^2}\left(1 + \frac{2m_t^2}{s}\right)\right.$$

$$\left. + \frac{\kappa_z^2 (1 + a_w^2)(2 + \frac{m_t^2}{s})}{4\sin^4 2\vartheta_W (1 - \frac{M_Z^2}{s})^2} + 3\kappa_\gamma\kappa_z \left(\frac{m_t}{\Lambda}\right) \frac{a_w e_q (g_1 z_1 + g_2 z_2)}{\sin^2 2\vartheta_W (1 - \frac{M_Z^2}{s})}\right]$$

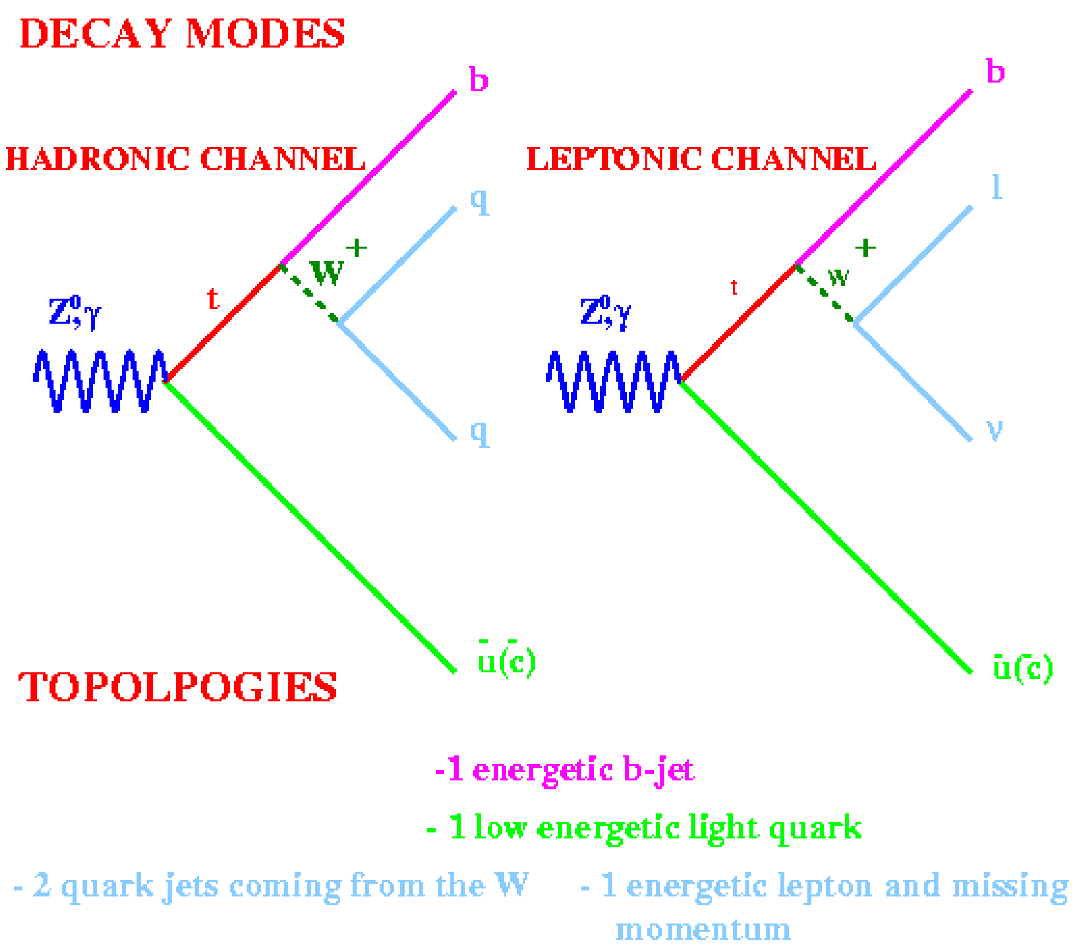
Branching Ratio:

$$\Gamma(t \to c\gamma) = \kappa_\gamma^2 \frac{\alpha e_q^2}{4}\left(\frac{m_t^2}{\Lambda^2}\right) m_t$$

$$\Gamma(t \to cZ) = \kappa_z^2 \frac{\alpha}{8\sin^2 2\vartheta_W\ M_Z^2} m_t^3 \left(1 - \frac{M_Z^2}{m_t^2}\right)^2 \left(1 + 2\frac{M_Z^2}{m_t^2}\right)$$

FCNC at OPAL

Selections developed to identify events from FCNC process $e^+e^- \rightarrow t\bar{q}$, where $q \equiv u$ or c:



Assumption: We assume $\mathrm{Br}(t \rightarrow bW) = 100\%$. When limits are derived, the reduction of $\mathrm{Br}(t \rightarrow bW)$ due to possible FCNC is taken into account.

Data Samples: The data used for this analysis was recorded by OPAL at $\sqrt{s}$ =189-210 GeV. The integrated luminosity used for this analysis amounts to $652\,\mathrm{pb}^{-1}$.

Motivation and Strategy

Motivation:

- Presently, LEP energy exceeds the top mass.
- The process $\mathrm{e^+e^-} \rightarrow \mathrm{t\bar{q}}$ is now kinematicly available.
- With a few $100\,\mathrm{pb}^{-1}$ of data at $\sqrt{s} > \mathrm{m_{top}}$: LEP should be able to improve some of the existing best direct limits obtained at the TeVatron.
- Search for FCNC and direct test of the NC in three generations within the framework of the SM.
- Yet an other test of the SM and look for new physics beyond the SM.

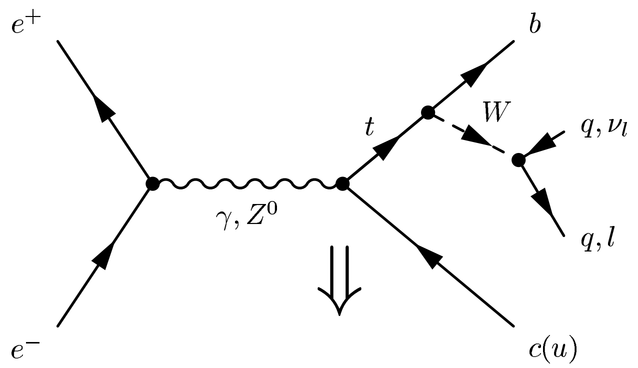
Strategy:

Search for Single Top Production

Hadronic Channel	Leptonic Channel
Large $\mathrm{q\bar{q}q\bar{q}}$ back.	Clean final state
$\frac{\mathrm{Br(W \rightarrow q\bar{q})}}{\mathrm{Br(W} \rightarrow \ell\bar{\nu})} \simeq 6.25$	No jet-jet comb.
$M(\mathrm{q\bar{q}}) = M_\mathrm{W}$	$M(\ell\bar{\nu}_\ell) = M_\mathrm{W}$
b Jet	b Jet
$M(\mathrm{bW}) = \mathrm{m_{top}}$	$M(\mathrm{bW}) = \mathrm{m_{top}}$

Single Top Production

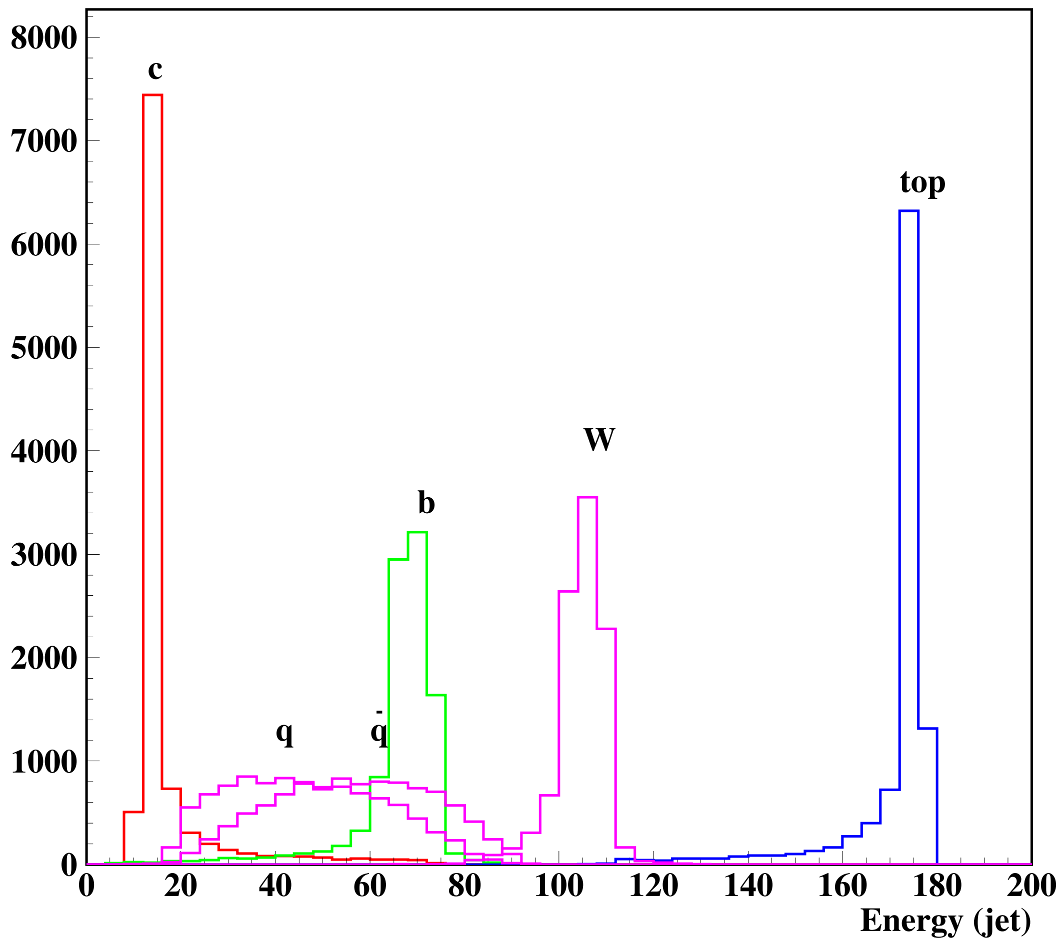
At $\sqrt{s} \simeq 189$ GeV:



$$E_t \simeq m_t$$
$$E_W \simeq \frac{m_t^2 + m_W^2 - m_b^2}{2m_t}$$
$$E_b \simeq \frac{m_t^2 - m_W^2 + m_b^2}{2m_t}$$
$$E_{c(u)} \simeq \sqrt{s} - m_t$$

Coupling Parameters κ_Z and κ_γ

Characteristic Kinematics



Event Properties

Btag: Lifetime, Prompt Lepton, Sub-Jet Shape.

Kinematic Fit: $\mathrm{e^+e^- \to t\bar{q} \to bW\bar{q}}$.

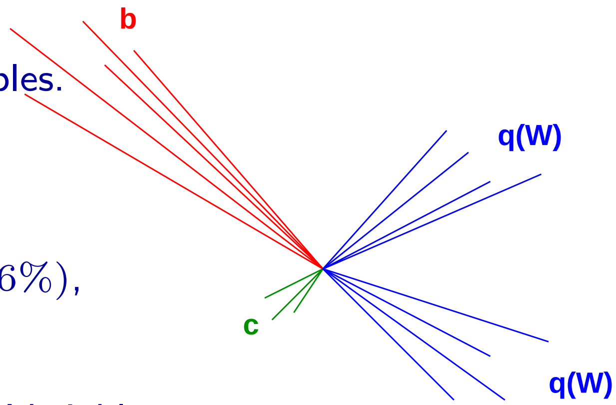
The kinematic properties are exploited by using kinematic fits to enforce energy and momentum conservation (4C Fit) and impose the appropriate mass constraint (6C Fit):

- $\sum \vec{p}_i = 0$ and $\sum E_i = \sqrt{s}$.
- $M(\mathrm{q\bar{q}})$ or $M(\ell\bar{\nu}_\ell) = M_\mathrm{W}$, and $M(\mathrm{bW}) = \mathrm{m_{top}}$.

Combined: Btag and 6C Fit information.

$$\mathcal{P}_{\text{b-tag, 6C}} = \frac{\mathcal{P}_{\text{6C}}\,\mathcal{P}_{\text{b-tag}}}{\mathcal{P}_{\text{6C}}\,\mathcal{P}_{\text{b-tag}} + (1-\mathcal{P}_{\text{6C}})\,(1-\mathcal{P}_{\text{b-tag}})}$$

Hadronic Channel

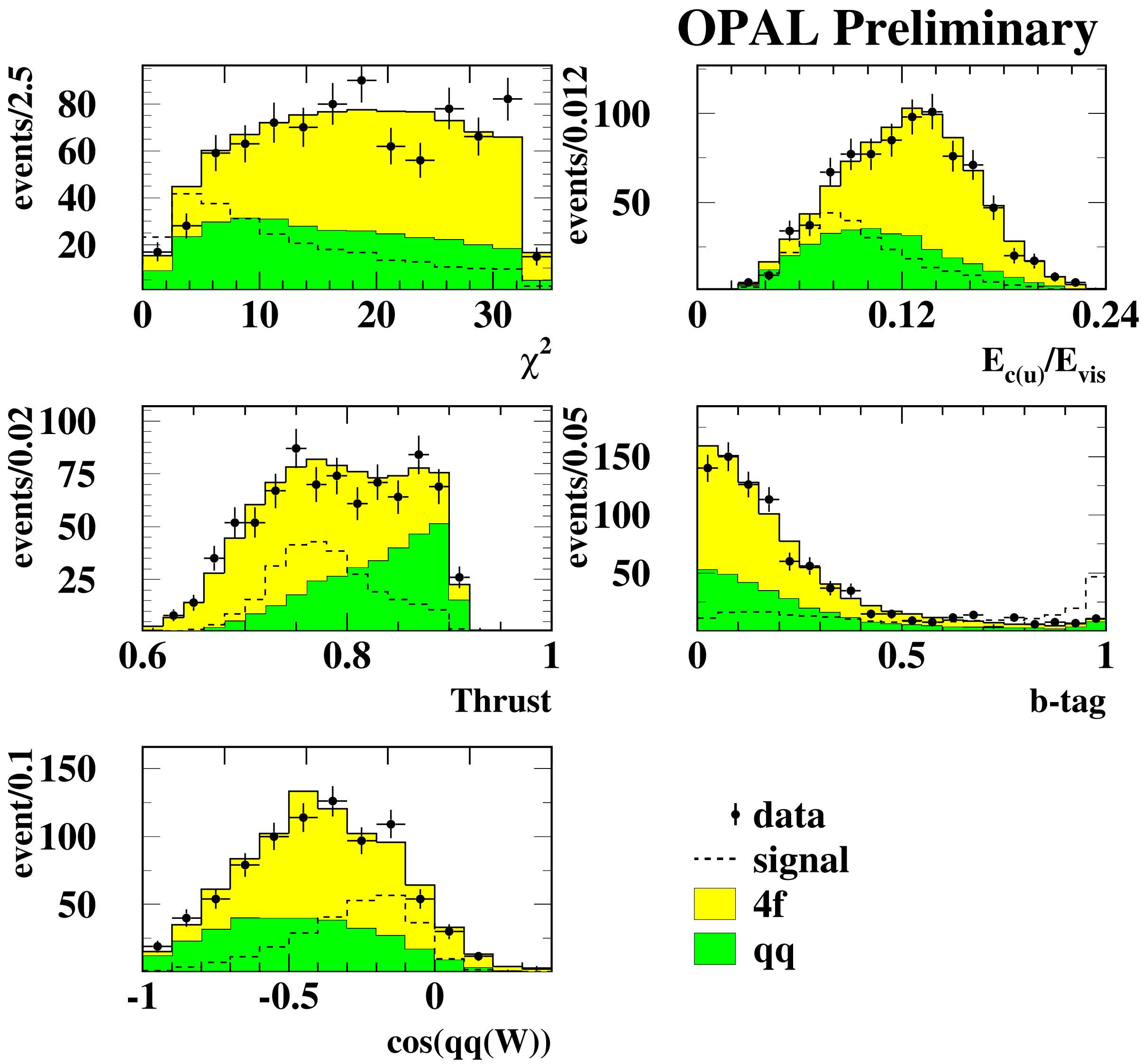


Preselection: Event Shape Variables.

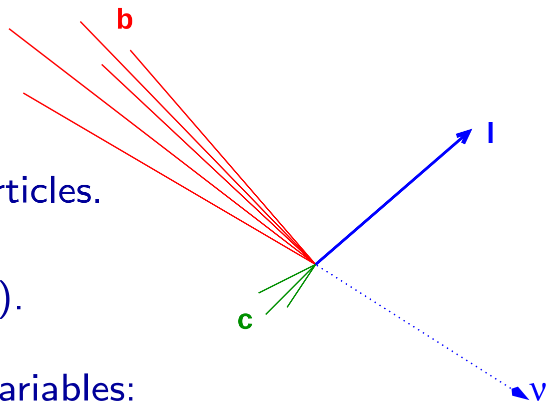
Jet Assignment: $\mathcal{P}_{\text{b-tag},\,6C}$.

Main bck: $W^+W^- \rightarrow q\bar{q}q\bar{q}$ (66%),
$Z^0/\gamma \rightarrow q\bar{q}$ (33%).

Likelihood Function: Five Inputs Variables:



Leptonic Channel

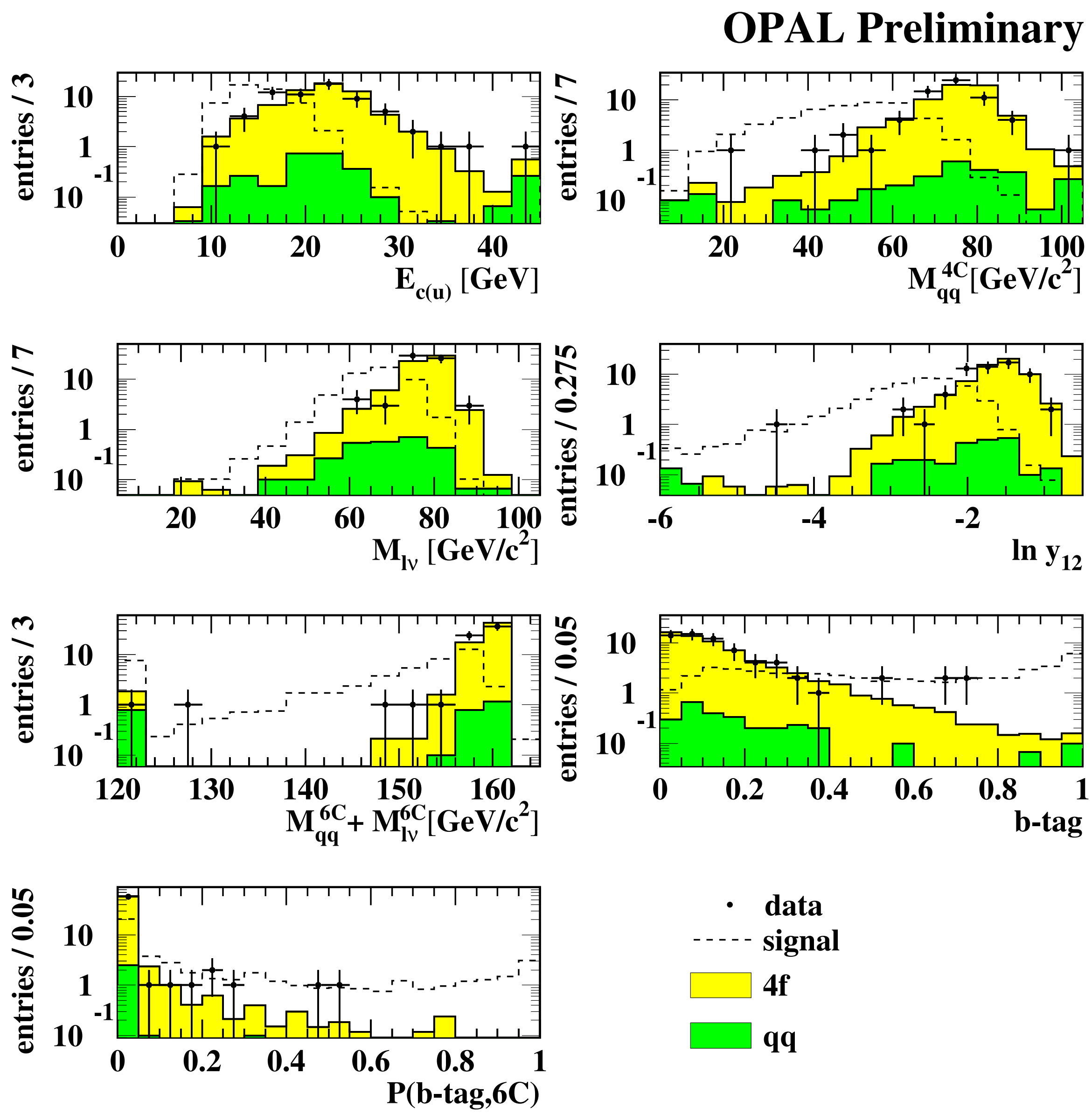


Preselection: Missing Energy.

Lepton ID ($e - \mu - \tau$): Isolated Particles.

Main bck: $W^+W^- \rightarrow q\bar{q}\ell\bar{\nu}_\ell$ (95%).

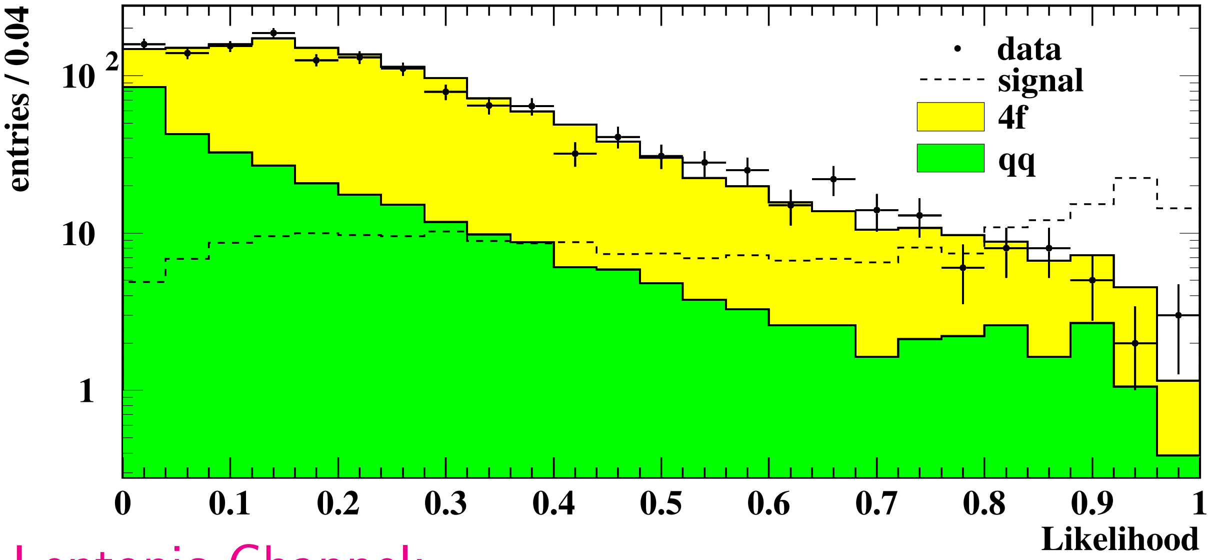
Likelihood Function: Seven Inputs Variables:



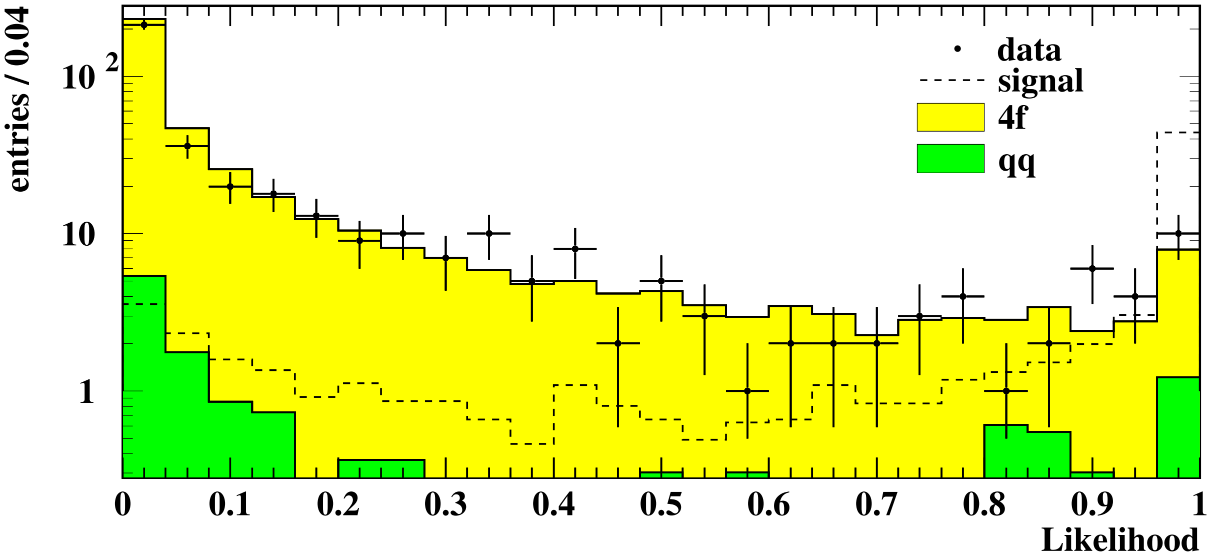
Likelihood Functions

OPAL Preliminary: Single Top (206 GeV)

Hadronic Channel:



Leptonic Channel:



The signal corresponds to an assumption of 3 pb for single top production cross-section.

No evidence for single top quark production is observed in the data.

Results (OPAL)

$\mathcal{L}$ (pb^{-1})	$\sqrt{s}$ (GeV)	ϵff	Data	SM	$\sigma_{95}^{\mathrm{exp.}}$ (pb)	$\sigma_{95}^{\mathrm{obs.}}$ (pb)
Hadronic Channel						
172.1	189	12.8%	13	11.6	0.41	0.45
28.9	192	18.0%	7	5.1	1.27	1.61
74.8	196	14.7%	6	6.4	0.65	0.59
77.2	200	16.0%	10	9.4	0.67	0.68
36.1	202	18.6%	8	7.5	1.13	1.15
209.4	206	15.7%	24	26.3	0.38	0.31
Leptonic Channel						
172.1	189	9.1%	3	4.0	0.39	0.32
28.9	192	9.5%	0	1.0	1.53	1.19
74.8	196	8.7%	1	2.9	0.85	0.56
77.2	200	7.9%	3	2.7	0.89	0.91
36.1	202	7.5%	2	1.2	1.61	1.95
209.4	206	6.6%	7	5.7	0.50	0.57

Systematic Uncertainties

Performed Systematic Uncertainty Studies for 189 GeV, 200 GeV, 206 GeV in Hadronic and Leptonic Channels (each year)

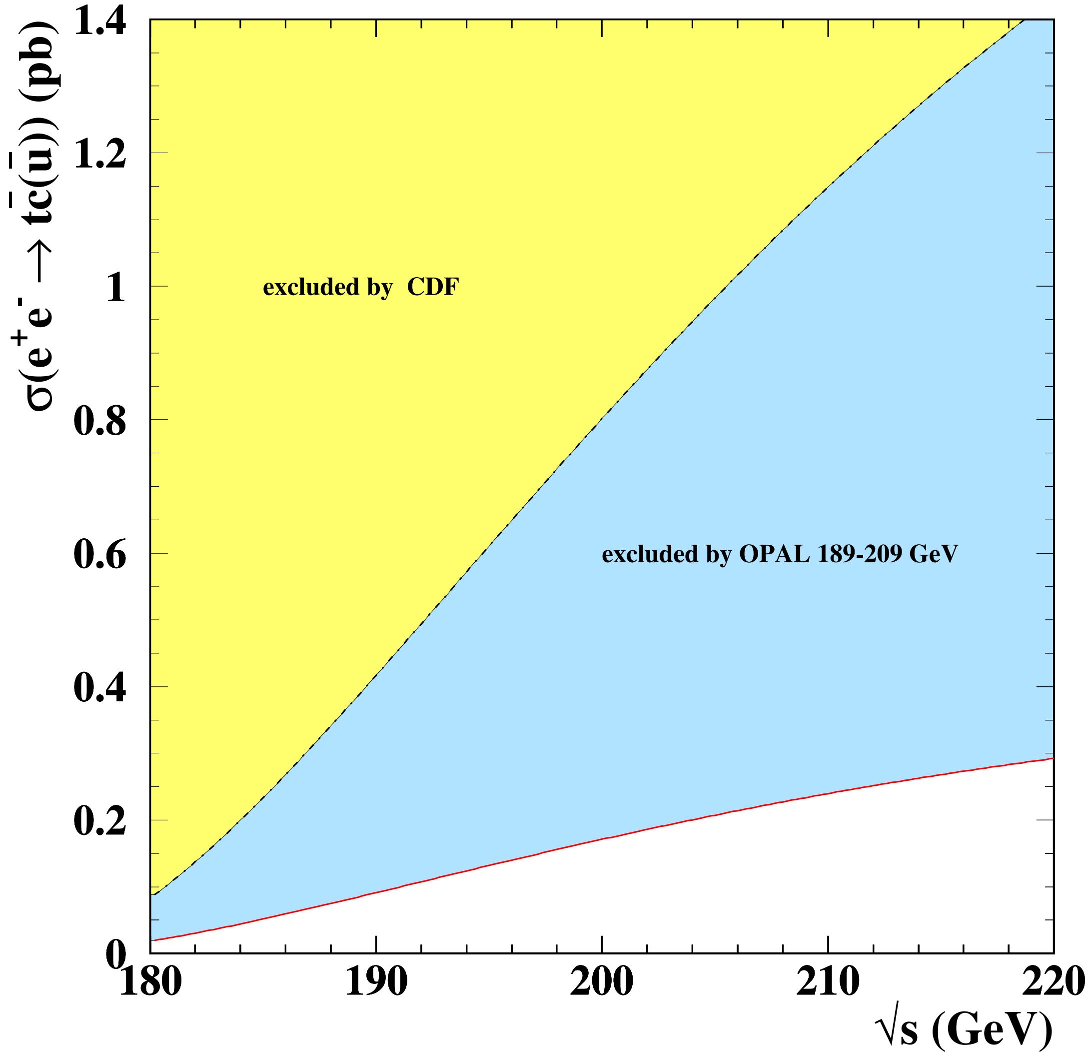
Source of Systematic Error	Hadronic Channel		Leptonic Channel	
	Δefficiency (in %)	Δback. (in %)	Δefficiency (in %)	Δback. (in %)
Preselection	1.0	3.2	1.0	2.0
$\sqrt{s}$	0.6	1.5	1.1	2.7
Background	-	5.0	-	6.8
b-tagging	3.8	6.9	4.2	7.8
Lepton ID	-	-	4.4	3.0
Reconstruction	0.6	1.0	1.0	1.4
MC Statistic	2.0	5.4	2.2	1.5
Total	4.5	10.7	6.7	11.4

Preliminary Results

Combine all centre–of–mass energy data points for the Leptonic and Hadronic Channels

Include Statistical Errors & Systematic Uncertainties

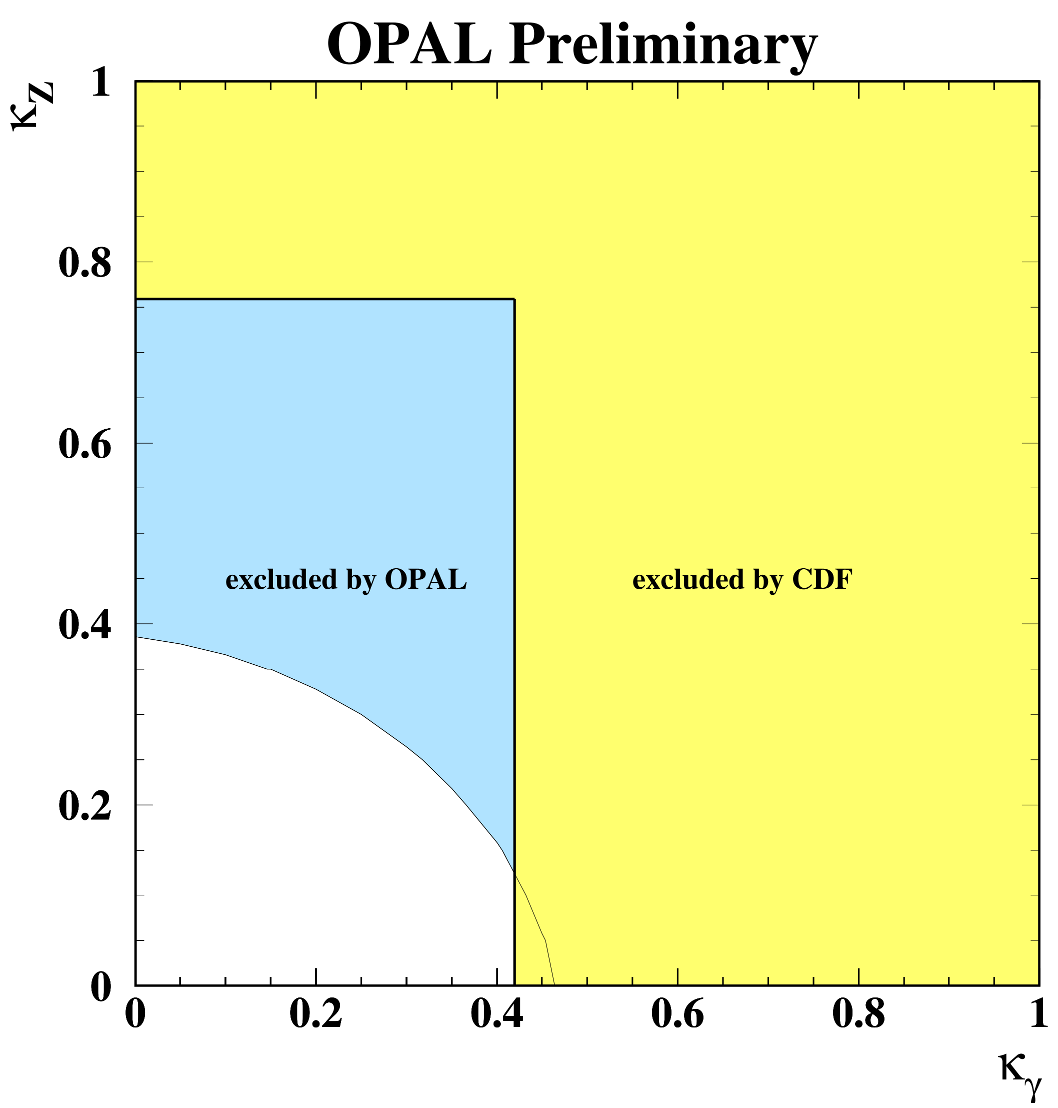
Upper Limit (95% CL) on Xsection for Single Top Production



Preliminary Results

Exclusion in the Plane of the Anomalous Coupling Parameters (189-210 GeV)

Limit at the 95% CL



Summary

- LEP2 provides a clean environment to investigate the coupling strength of the W boson to the charm quark.
- The extraction of $|V_{\rm cs}|$ from $\mathrm{Br}(\mathrm{W} \to \mathrm{q\overline{q}})$ and the direct measurements of the other CKM matrix elements is more accurate that the current best measurement.
- The measurement of $R_{\rm c}^{\rm W}$ assume neither $\mathrm{Br}(\mathrm{W} \to \mathrm{q\overline{q}}) + \mathrm{Br}(\mathrm{W} \to \ell\bar{\nu}) = 1$ nor lepton universality.
- Moreover, the extraction of $|V_{\rm cs}|$ from $R_{\rm c}^{\rm W}$ with the direct measurements of $|V_{\rm cd}|$, $|V_{\rm cb}|$, $\mathrm{Br}(\mathrm{W} \to \mathrm{q\overline{q}})$, and $\Gamma_{\rm tot}^{\rm W}$ is more accurate that the current(PDG00) best measurement.
- The LEP2 experiments offer a great variety of experimental probes for the study of the weak properties of the charged AND neutral mediators of the weak interaction.
- LEP2 is now providing data samples with which to make tests of the Standard Model and to search for new physics.
- LEP2 allows a direct search for single top production via FCNC.
- All LEP2 experiments provide the best limit on $\mathrm{Br}(t \to Zq)$ and $\mathrm{Br}(t \to \gamma q)$.

Last Slide

LEP $|V_{cs}|$ from the WW Cross-Section:

$$\mathrm{BR}(\mathrm{W} \to \mathrm{q\bar{q}}) = (67.78 \pm 0.32)\%$$
$$|V_{cs}| = 0.989 \pm 0.016$$

LEP R_c^W and $|V_{cs}|$:

$$R_c^W = 0.499 \pm 0.027(\mathrm{stat}) \pm 0.037(\mathrm{syst})$$
$$|V_{cs}| = 0.987 \pm 0.050$$

Standard Model expectation:

$$R_c^W = 0.5$$
$$\mathrm{BR}(\mathrm{W} \to \mathrm{q\bar{q}}) = 67.5\%$$

Consistent with a 3×3 Unitarity CKM Matrix

Single Top Production at OPAL: