



# Z boson pair production at DELPHI

Ivo van Vulpen

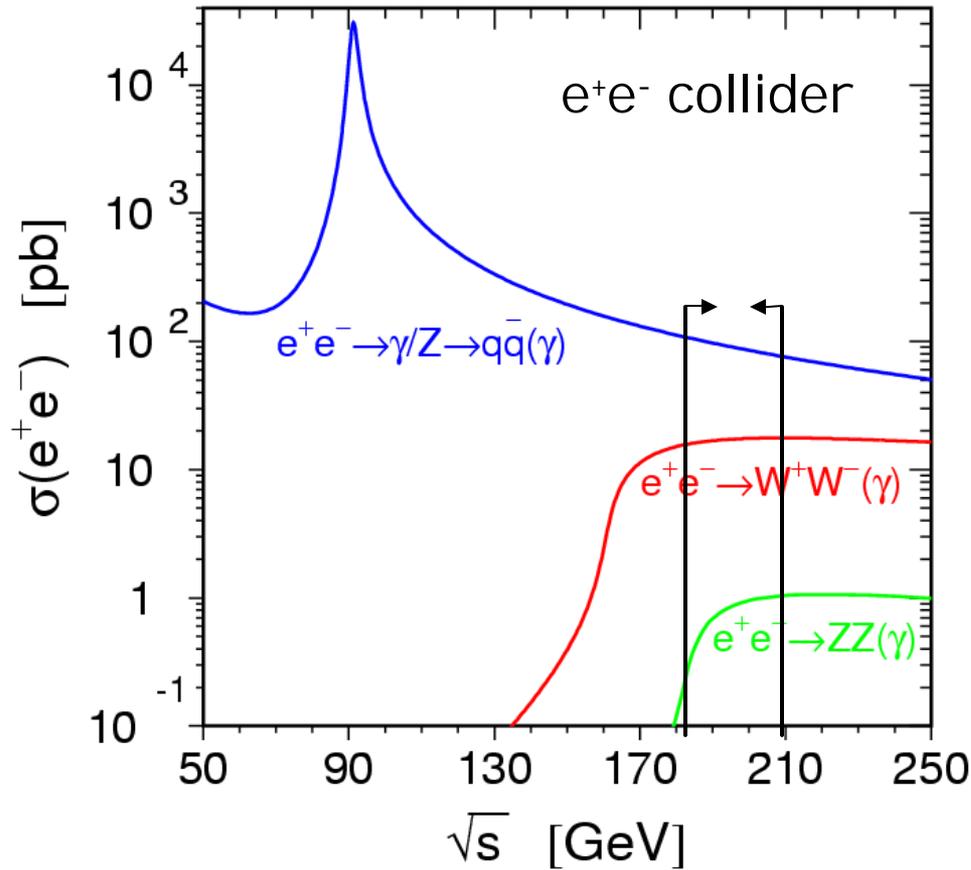
- Outline:
- LEP and its operation between 1997-2000
  - ZZ production & final states
  - Discussion of the various analyses
  - Combined results



# LEP2 data set



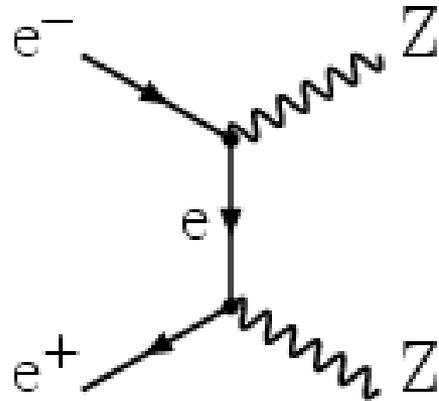
## Above ZZ threshold



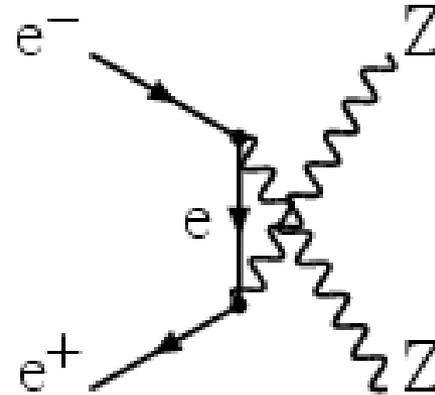
year	$\sqrt{s}$ [GeV]	Lum. [ $\text{pb}^{-1}$ ]
1997	183	54.7
1998	189	158.0
1999	192	25.9
	196	76.9
	200	84.3
	202	41.1
2000	<205.5	82.0
	>205.5	142.2
LEP2		665



# NC02 diagrams: on-shell ZZ production



NC02 diagrams



- Subset of all 4-fermion diagrams

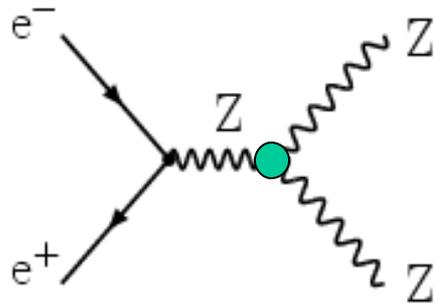
1) Define a 'ZZ signal' at generator level:

2) Measure  $\sigma_{ZZ}$

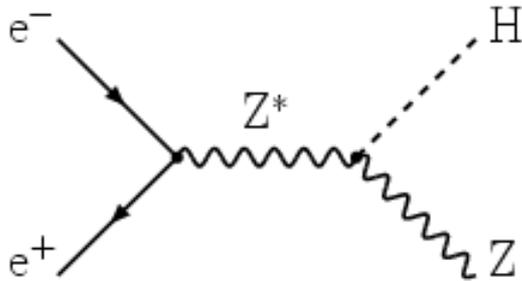
3) Translate  $\sigma_{ZZ}$  to a full NC02 cross section:  
(few % corrections)

$$'ZZ' \equiv \frac{M^2(\text{NC02})}{M^2(\text{all 4f})} > 0.5$$

$$\sigma_{ZZ} \dashrightarrow \sigma_{\text{NC02}}$$



- No ZZZ coupling in the SM  
--> constrain neutral TGCs



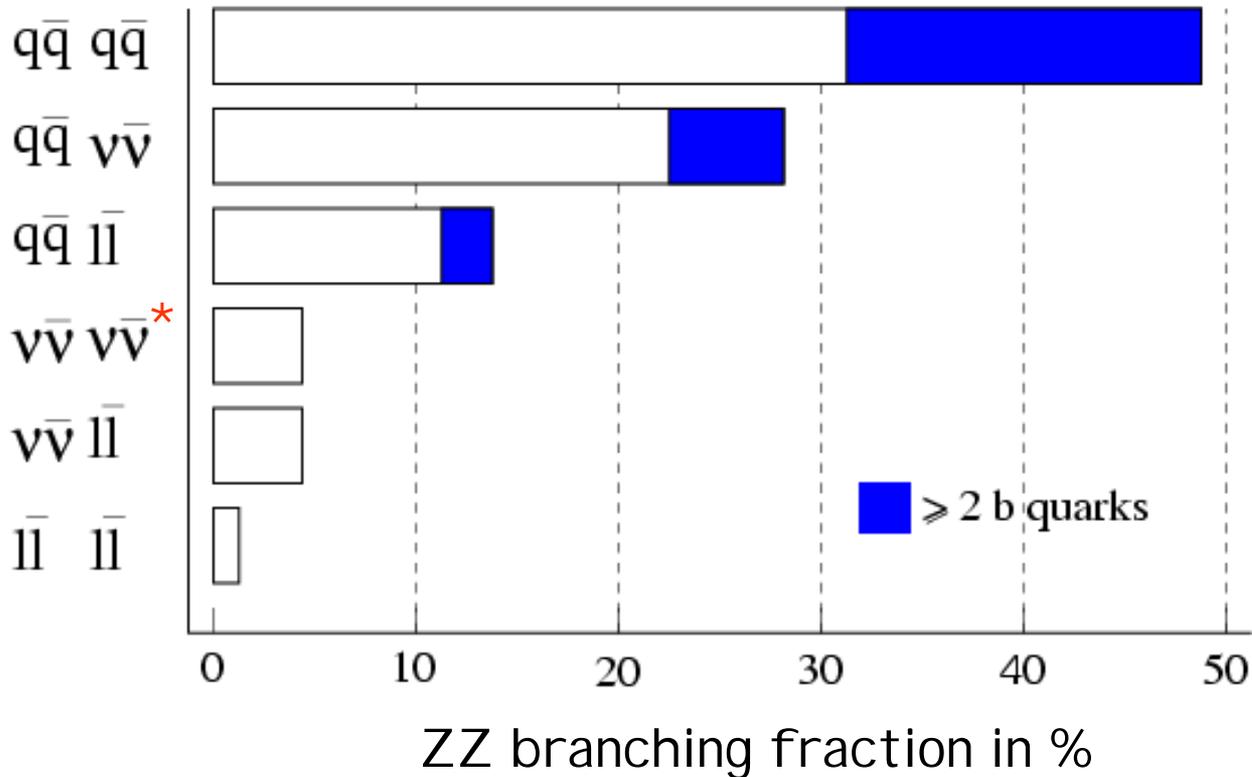
- Similar to Higgs production
  - \* experimental signature
  - \* cross section
- > test Higgs analyses
- > possible strong systematic effects

Most analyses are adapted Higgs analyses



# ZZ final states

LEP1:  $Z \rightarrow q\bar{q}$  (70%)     $Z \rightarrow \nu\bar{\nu}$  (20%)     $Z \rightarrow l^+l^-$  (10%)



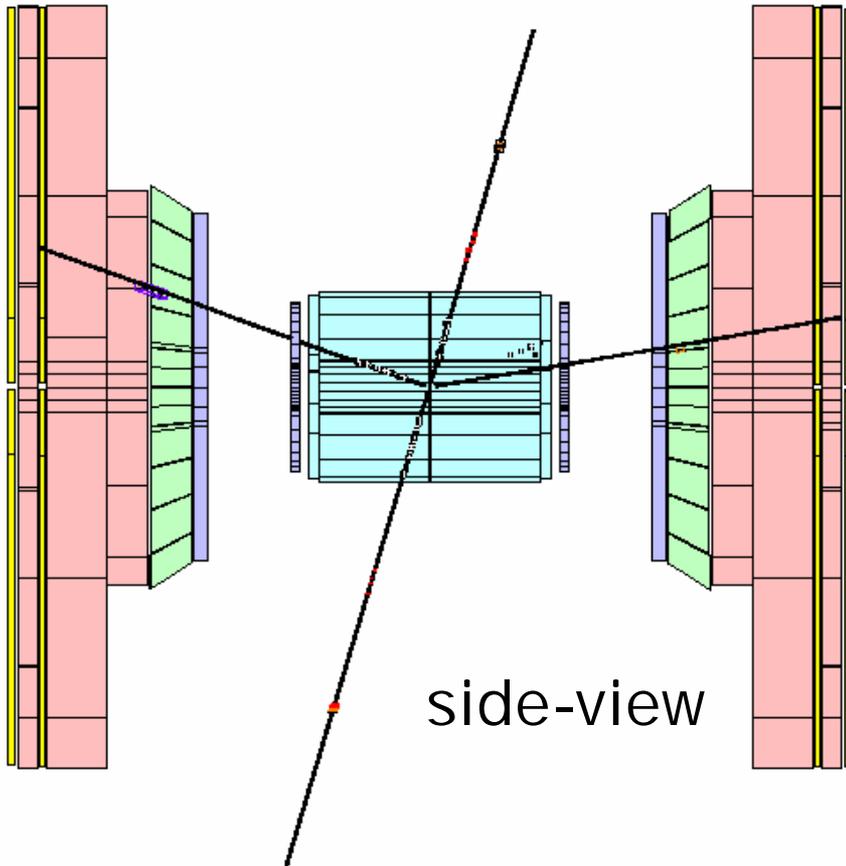
↑  
background

↑  
Except \* all final states covered (96%)



# four leptons

$ZZ \rightarrow 4 \text{ muons}$



"Rare beauties"

Branching ratio only 1 %

clean signal  
(very small background)



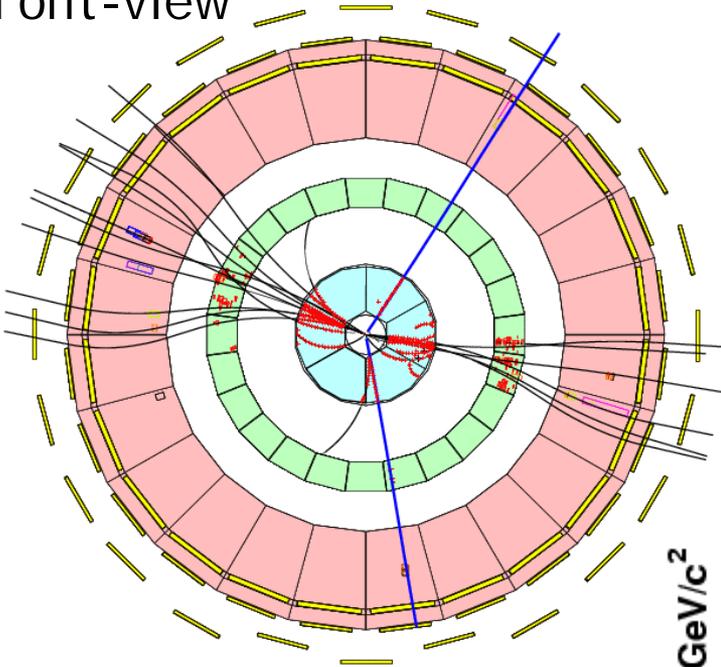
Unfortunately also a  
very small signal

--> One or two events per year <--



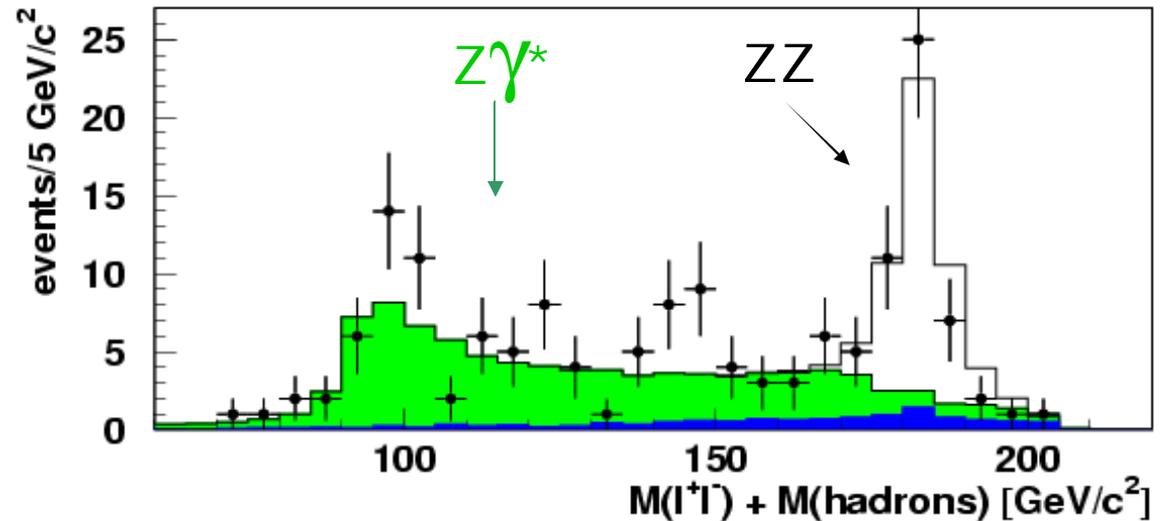
# $qq|l^+l^-$ (muons and electrons)

Front-view



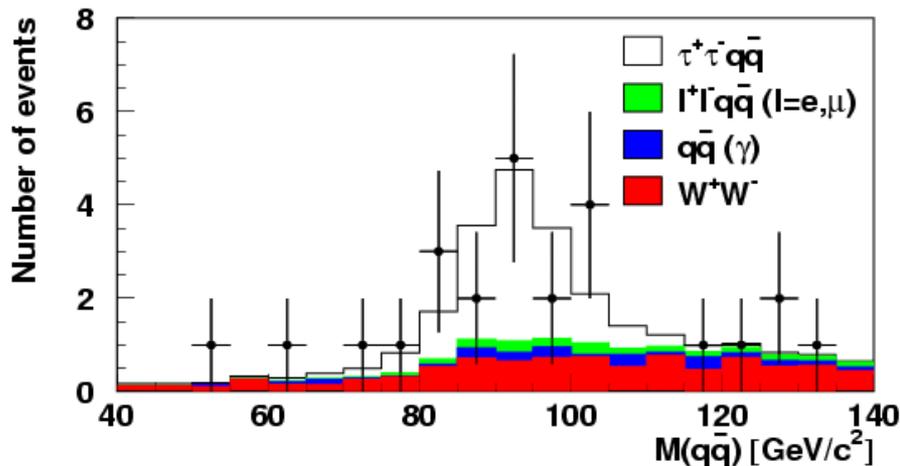
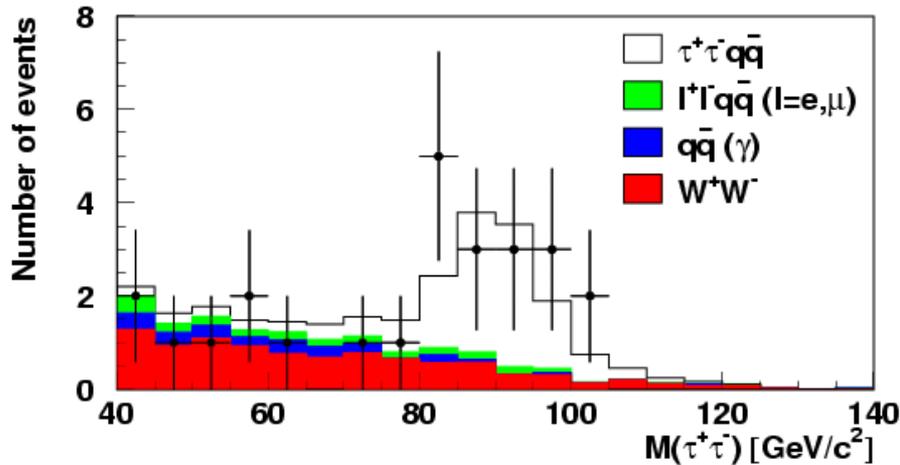
Branching ratio 9.4%

- Clean events (2 isolated leptons)  
Small backgrounds ( $Z\gamma^*$  and  $WW$ )
- Use invariant masses of leptonic and hadronic systems to select  $ZZ$
- Efficiencies 70 (85)% for  $e$  ( $\mu$ )'s





# qq|<sup>+</sup>l<sup>-</sup> (with taus)



## Dedicated tau analysis

Branching ratio 4.7%

- Main background WW

- probabilistic analysis

\* Isolation of  $\tau$  candidates

\*  $\chi^2$  of kinematic fit

$$M_{\tau^+\tau^-} = M_{qq} = M_Z$$

- Efficiency:  $\sim 40\%$

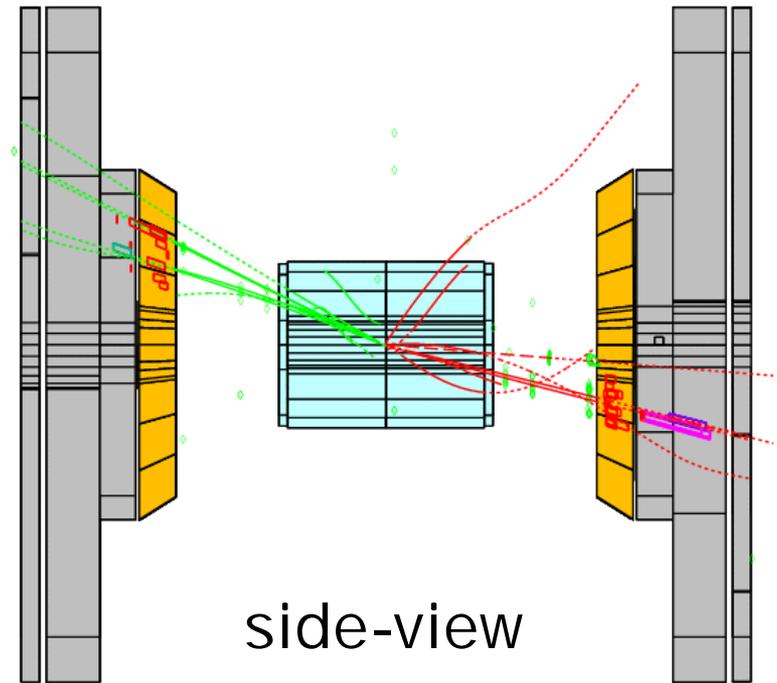
Purity:  $\sim 80\%$



## 2 jets + missing energy

Branching ratio 28.0 %

- Large background from:
  - \*  $WW$  &  $qq \tau\nu$  final state
  - \*  $qq(\gamma)$  & photon lost
  - \*  $W\text{ev}$  & electron lost
- Mass cuts in pre-selection
- 2 analyses in DELPHI
  - \* Likelihood ratio
  - \* Iterative Discriminant Analysis

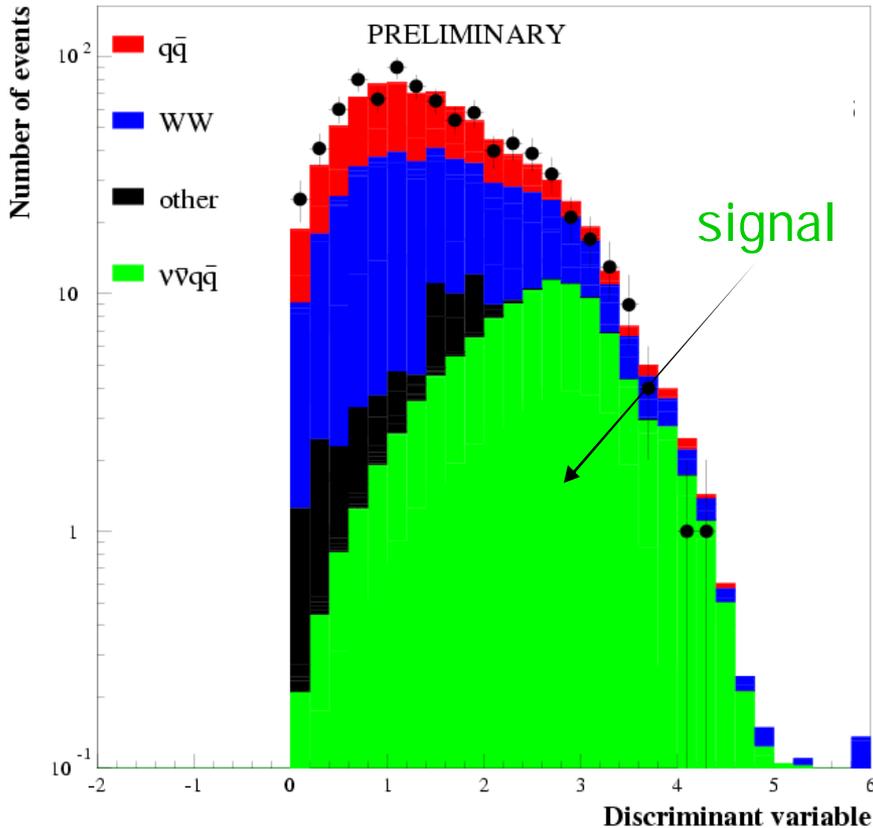




# qqvv (I DA analysis)



LEP2 combined



'Iterative' Discriminant Analysis

- \* Visible mass
- \* Visible energy
- \* Recoil mass
- \* Acoplanarity
- \* Acollinearity
- \* etc etc.



Compute correlations (NN like)

Second order discriminant function

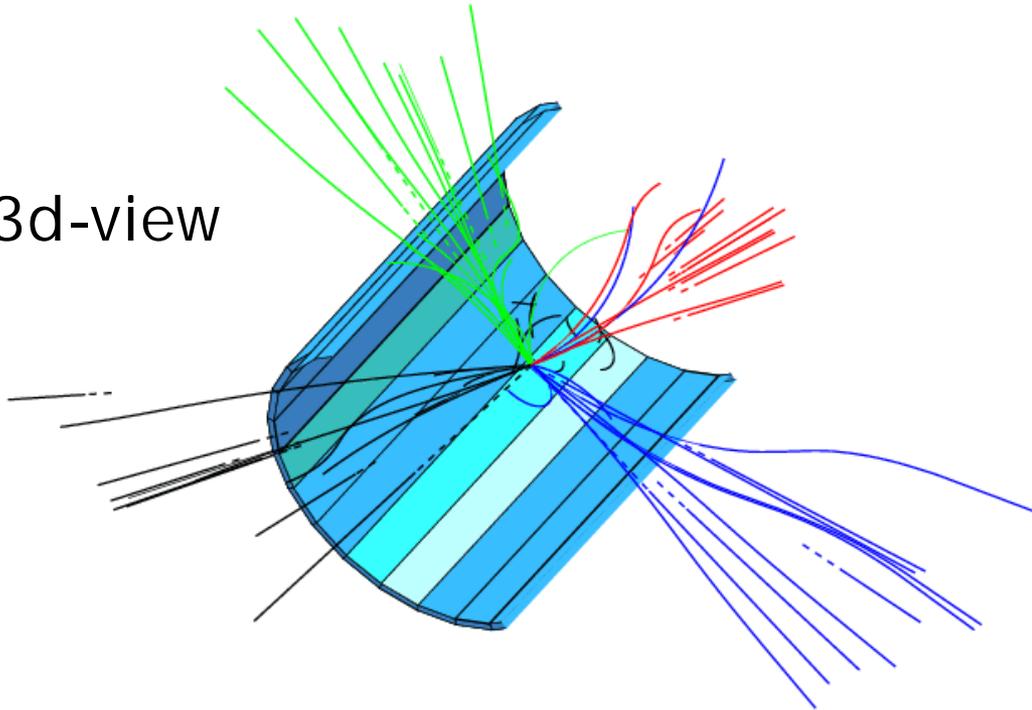


Likelihood fit to I DA distribution



# 4 quarks

3d-view



4 (or more) jets:  
Branching ratio 48.6%

- Large backgrounds
  - \* WW: 17 x ZZ signal
  - \* qq( $\gamma$ ) with gluon radiation
    - 5 x ZZ signal
- Pairing ambiguities
  - \* 4 jets --> 3 pairings
  - \* 5 jets --> 10 pairings

- DELPHI: 5 jets treated as 5 jets and all pairings used



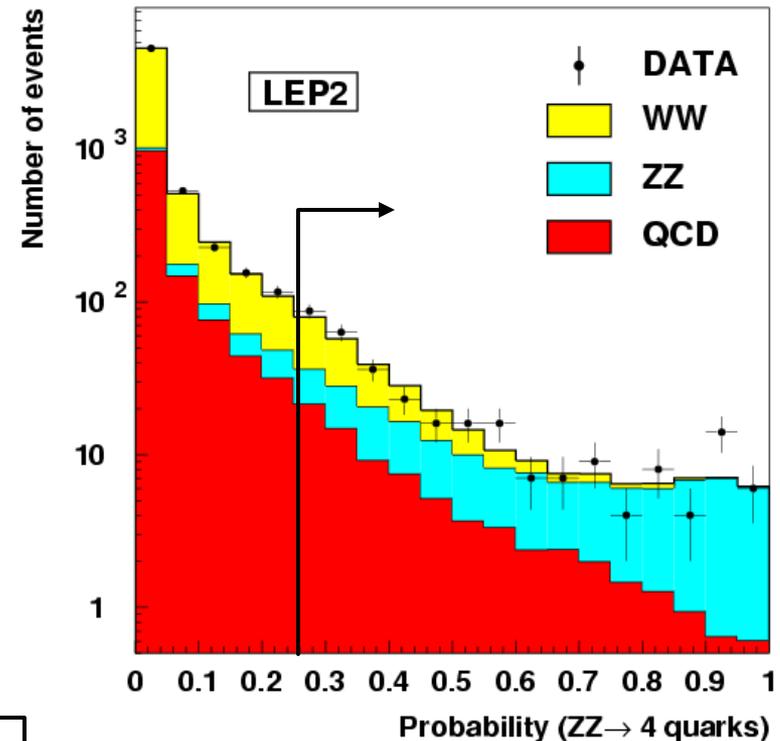
# qqqq probability distribution

## Likelihood ratio analysis

- b-tag information (per jet) --> reject WW
- Mass information (per pairing)
- Topological info. (per event) --> reject qq( $\gamma$ )



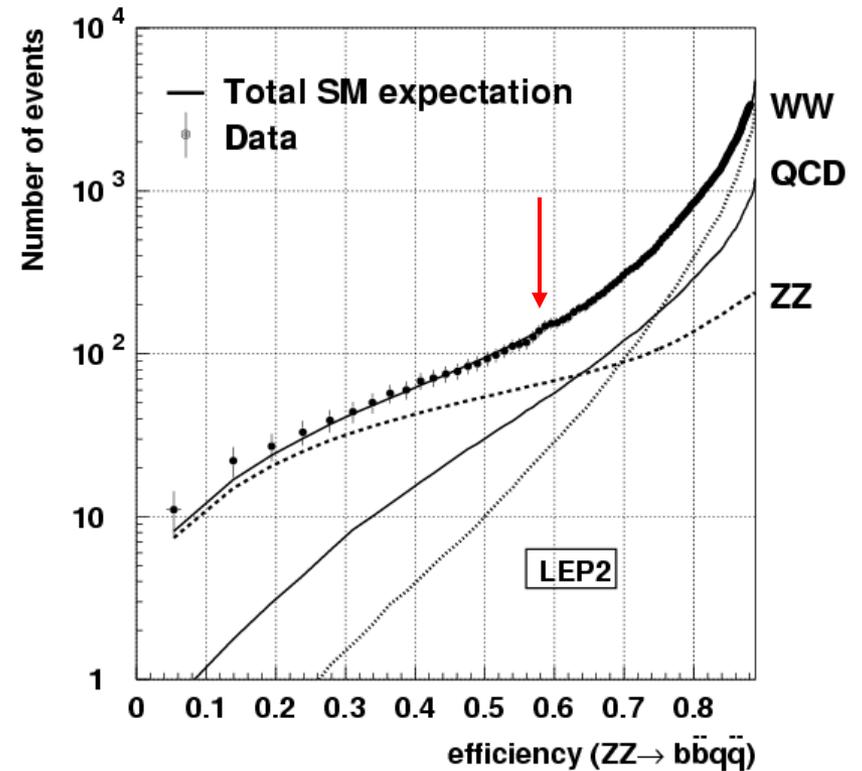
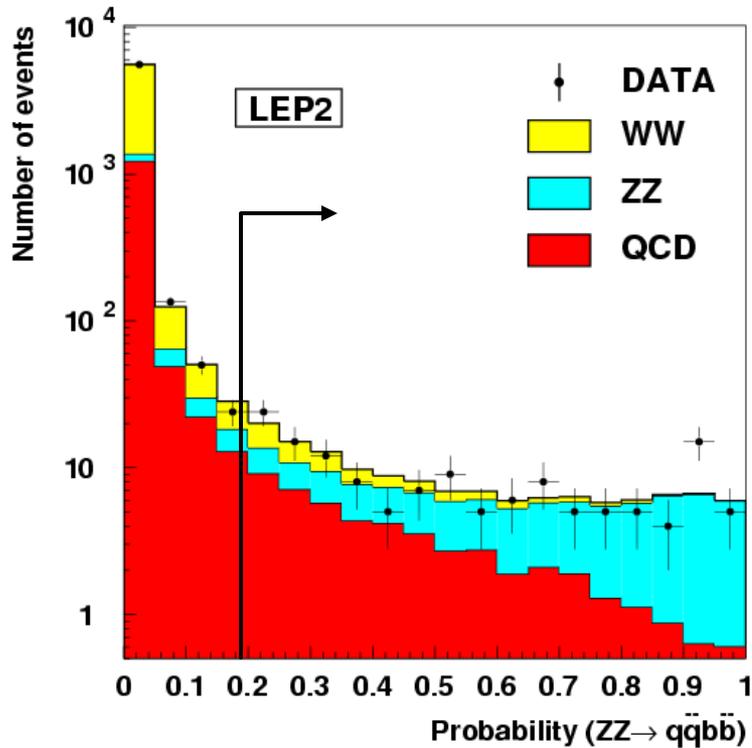
Event-by-event ZZ probability



Likelihood fit to ZZ prob. distr.: efficiency  $\approx$  42% , purity  $\approx$  35%



# NC02 (qqbb) results: (all LEP2 data)



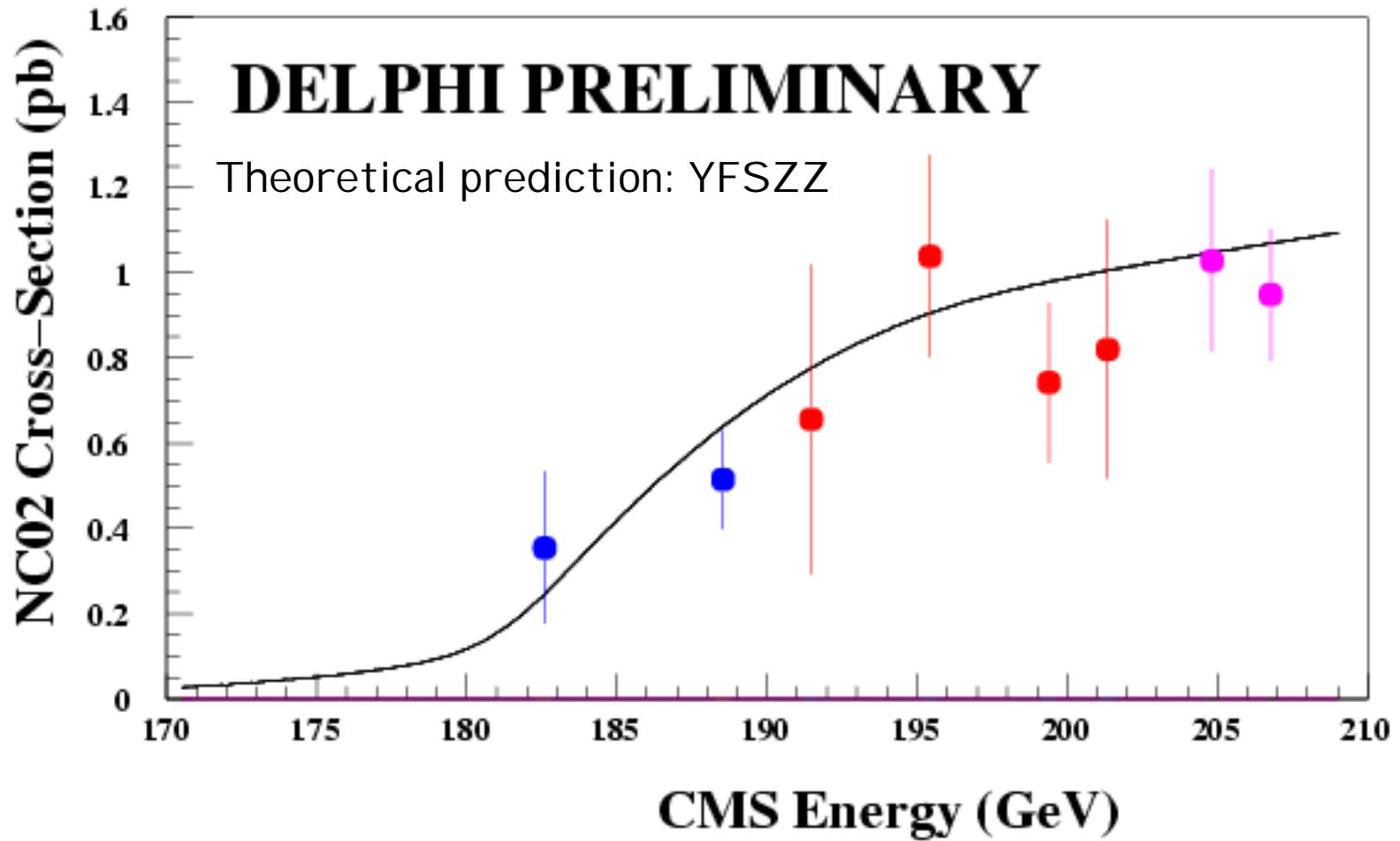
NC02 (qqbb):

$$\sigma^{\text{measured}} / \sigma^{\text{SM}} = 1.05^{+0.17}_{-0.15}$$

Eff = 60 %  
 Pur = 45 %

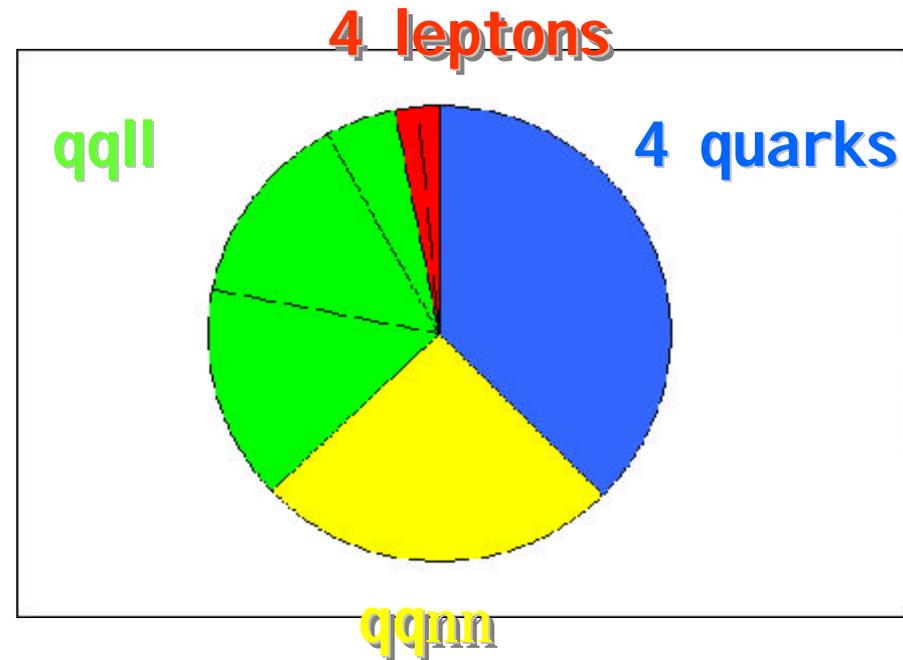


# Combined results (per energy)





- Expected contribution of individual channels to combined uncertainty



- LEP2 combined DELPHI result on NC02 cross section

$$\sigma^{\text{measured}} / \sigma^{\text{SM}} = 0.90 \pm 0.08 \text{ (stat.)} \pm 0.02 \text{ (syst.)}$$

**PRELIMINARY**



# Conclusions

- NC02 cross section in agreement with SM expectation  
96% of final states covered
- Irreducible background for Higgs searches under control
- Constrained neutral TGCs
- Statistics dominated  
(even the combined LEP result)

