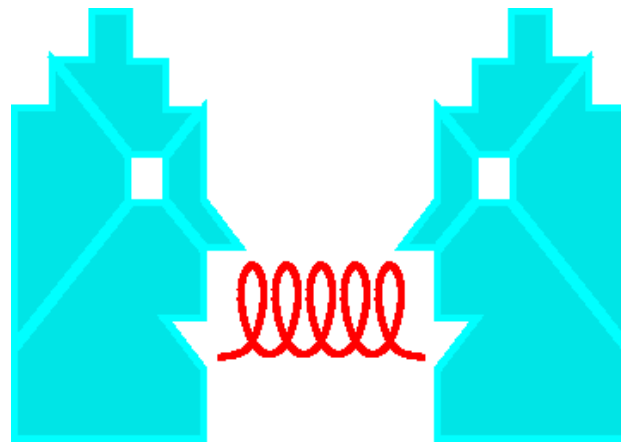


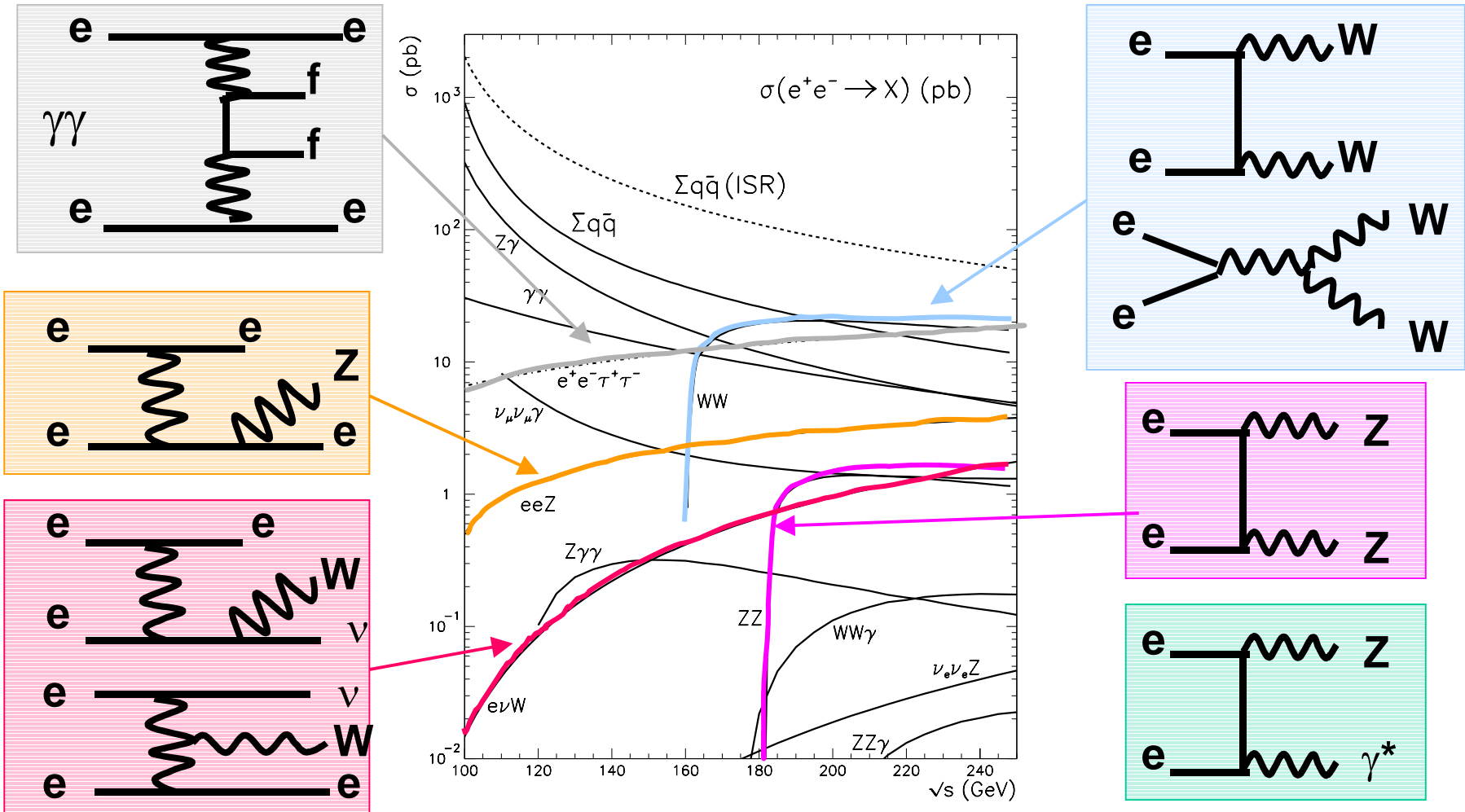
4-fermion production at LEP2



*Ernesto Migliore
TORINO Univ.& INFN
on behalf of LEP collaborations*

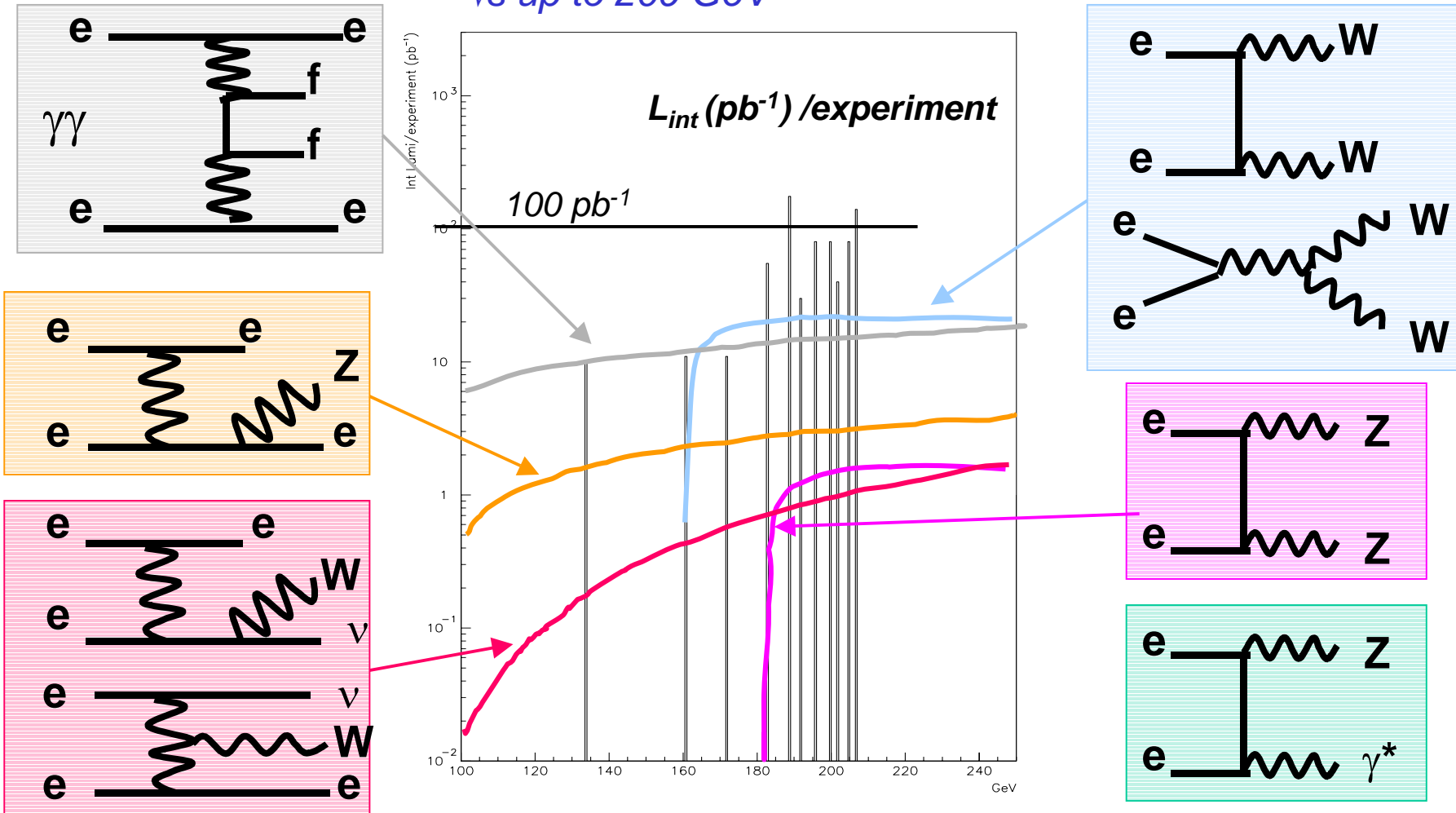
4f cross sections at LEP2

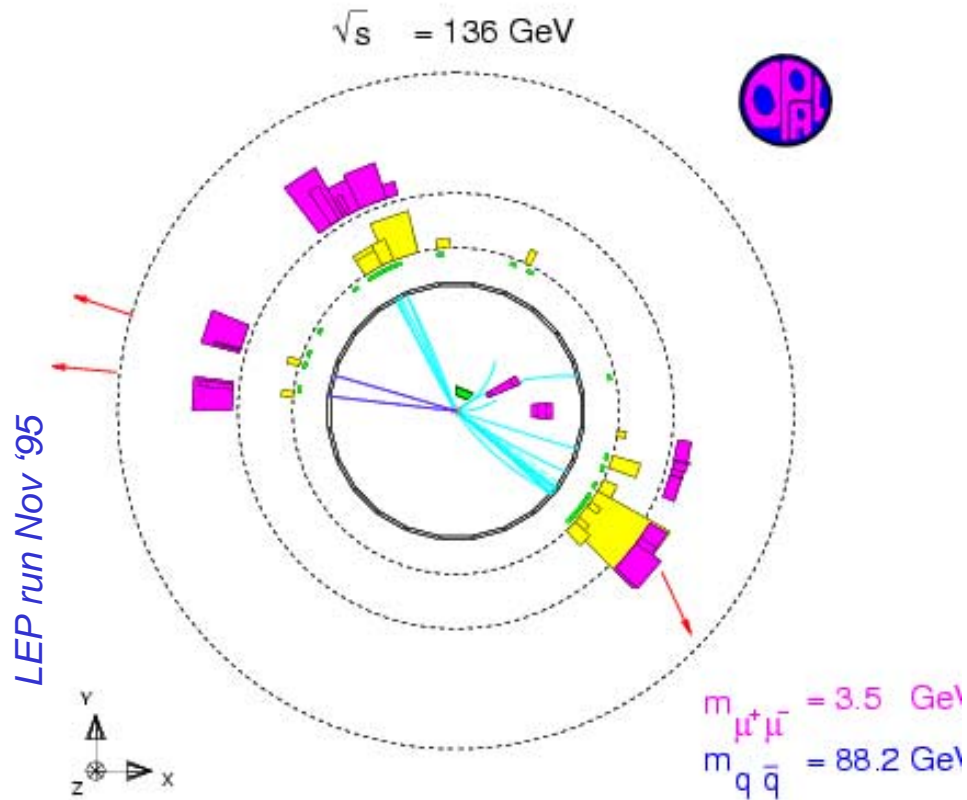
From the "PHYSICS AT LEP2" YR (1996)



LEP at high energy

- more than 600 pb^{-1} /experiment
- \sqrt{s} up to 209 GeV





From EPS97

		130-136 GeV			
		ALEPH	DELPHI	L3	OPAL
$q\bar{q}l\bar{l}$	exp. signal	4.41 ± 0.23	2.38 ± 0.14	2.10 ± 0.04	2.46 ± 0.21
	exp. backg.	$0.08^{+0.17}_{-0.04}$	0.32 ± 0.15	0.80 ± 0.30	$0.31^{+0.23}_{-0.15}$
	observed	2	2	2	7
$l\bar{l}l'\bar{l}'$	exp. signal	2.26 ± 0.12	0.27 ± 0.03		
	exp. backg.	$0.05^{+0.08}_{-0.02}$	0.27 ± 0.17		
	observed	3	0		

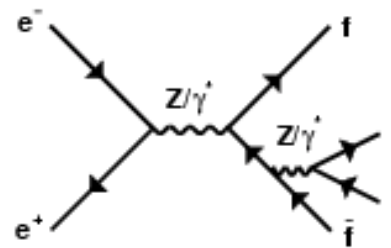
$Z\gamma^*$

- *OPAL: $eeqq$ and $\mu\mu qq$ final states*

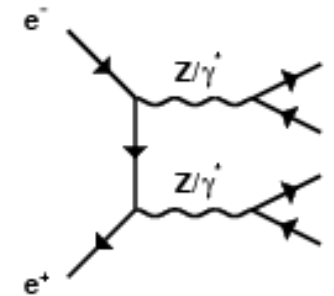
Signal definition:

- topology:
 - $|\cos\theta_\ell| < 0.95$ $\ell = e, \mu$
 - $m(qq) > 5 \text{ GeV}$
 - $m(ee) > 2 \text{ GeV}$; $m(\mu\mu)$ any
- diagram selection:
 - all but m.p.

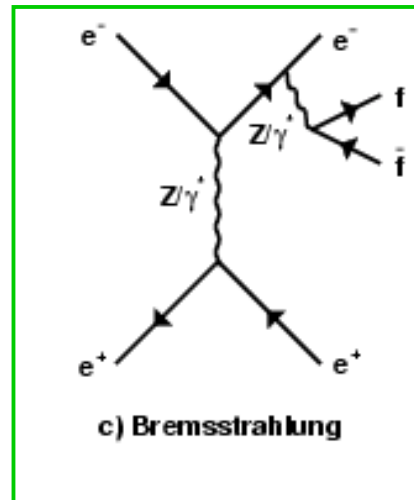
$$\sigma_{SM} = 150 \div 200 \text{ fb}$$



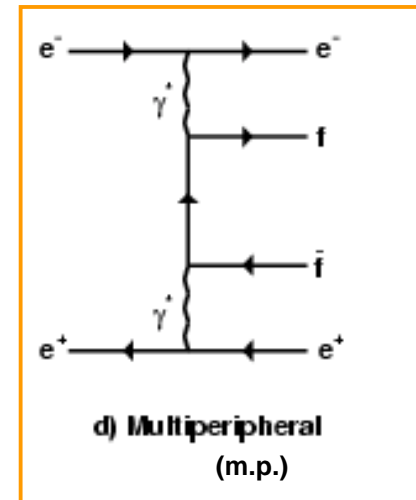
a) Annihilation



b) Conversion



c) Bremsstrahlung



d) Multiperipheral (m.p.)

eeqq only

background

Experimental Selection

1. hadronic presel + ℓ candidates
2. 4C fit
3. ℓ -ID
4. $p(\ell)$ cut
5. ℓ -isolation
6. $m(qq)$ and $m(\ell\ell)$
7. Anti-m.p. for $eeqq$: $|\cos\theta_e| < 0.7$

signal/(signal+bgd) rejection (650 pb^{-1}):

75 / 1380 \rightarrow 51 / 58 ($eeqq$)

72 / 4790 \rightarrow 49 / 52 ($\mu\mu qq$)

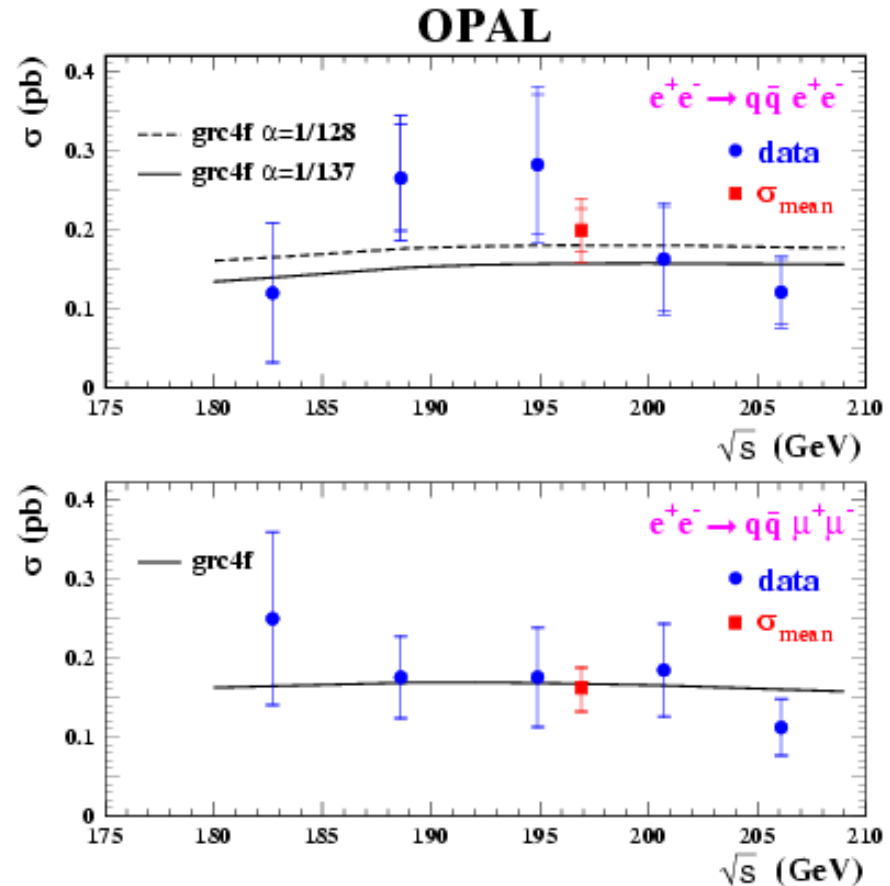
$eeqq$:

$199 \pm 27 \pm 30 \text{ fb}$ (SM^* : 180 fb)

$\mu\mu qq$:

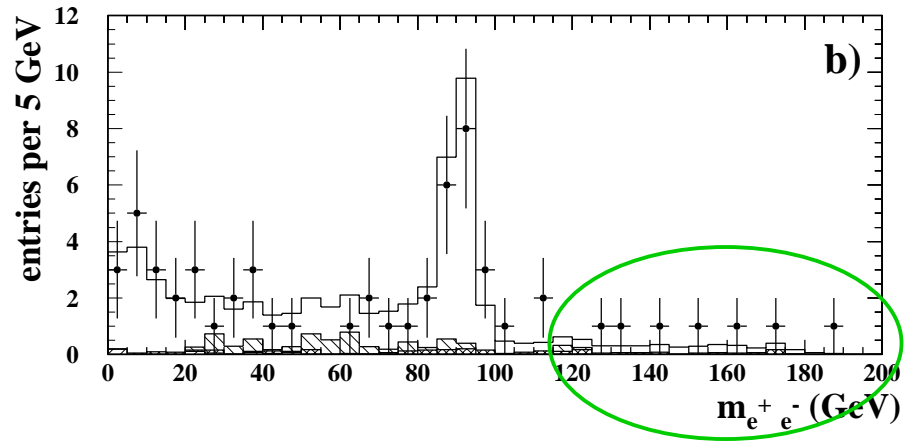
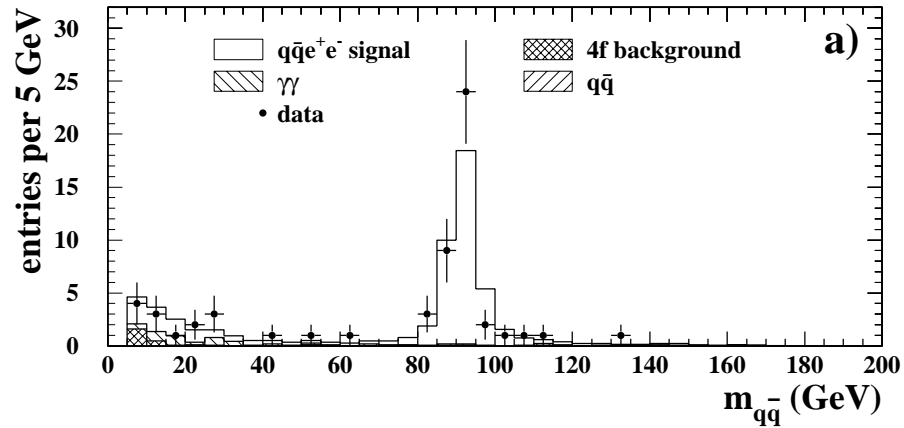
$160 \pm 26 \pm 13 \text{ fb}$ (SM^* : 165 fb)

*grc4f with $1/\alpha = 128$



eeqq

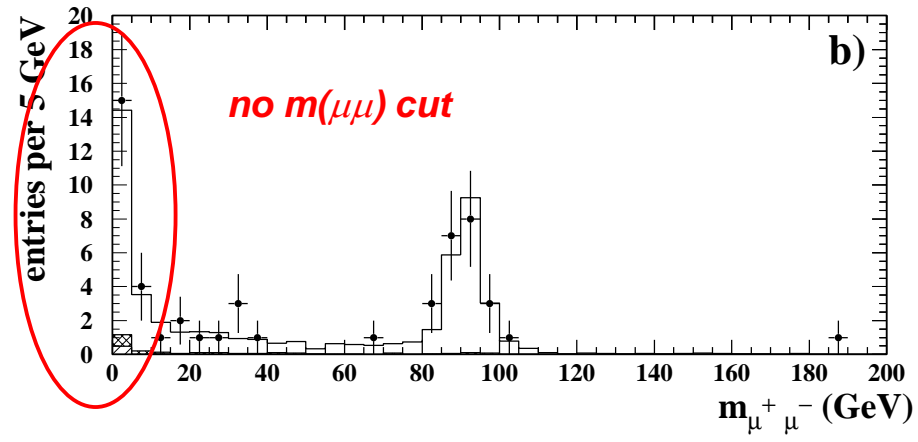
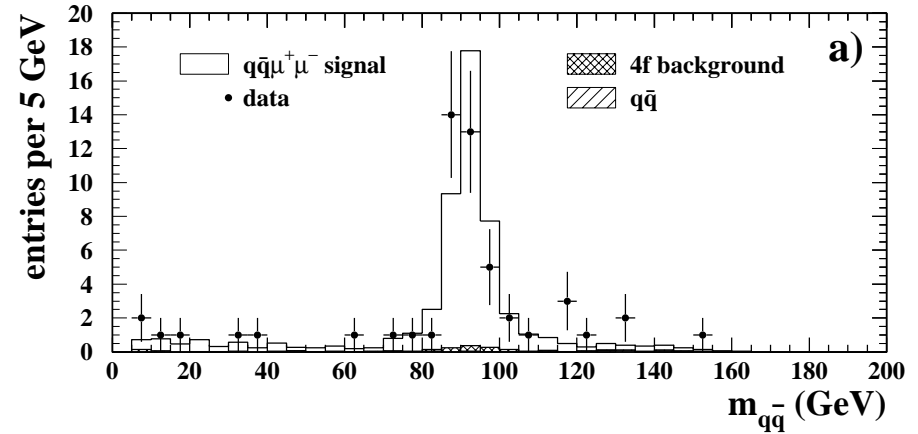
OPAL



bremsstrahlung

$\mu\mu qq$

OPAL



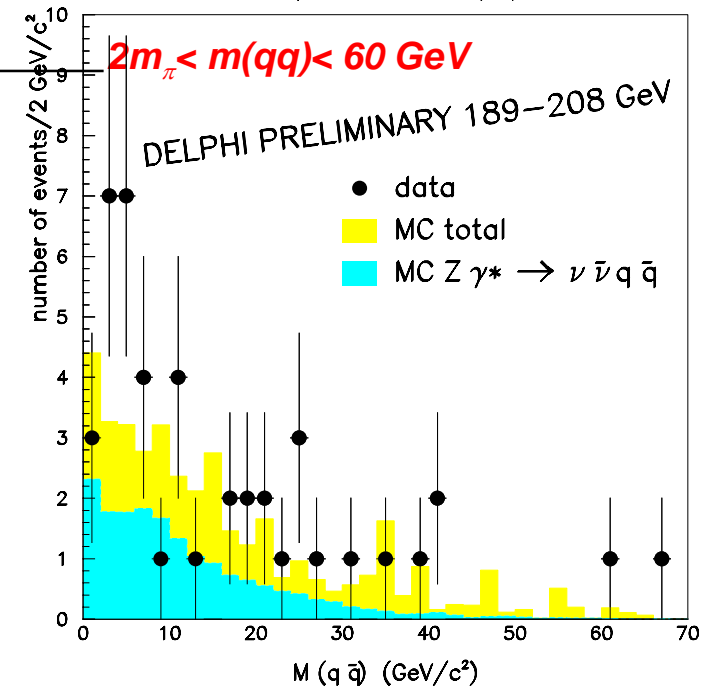
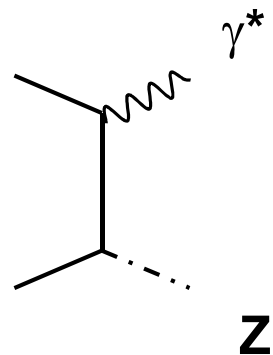
no $m(\mu\mu)$ cut

• $Z\gamma^*$ DELPHI (650 pb^{-1})

Final state	Signature	ϵ	$\sigma_{Z\gamma^*}$ (pb) (SM EXCALIBUR)
$\mu\mu qq$ $eeqq$	$Z\gamma^*$ dominating at low $m(\text{ll})$	35%	$0.129 \pm 0.020 \pm 0.008$ (0.098)
$\nu\nu qq$	monojet topology	31%	$0.129 \pm 0.035 \pm 0.015$ (0.092)
$qqqq$	$qq \rho(\rightarrow \pi\pi)$	18%	$0.071 \pm 0.042 \pm 0.015$ (0.082)
$llll$	$ee\mu\mu$ mainly	15%	0.052 ± 0.016 (0.033)

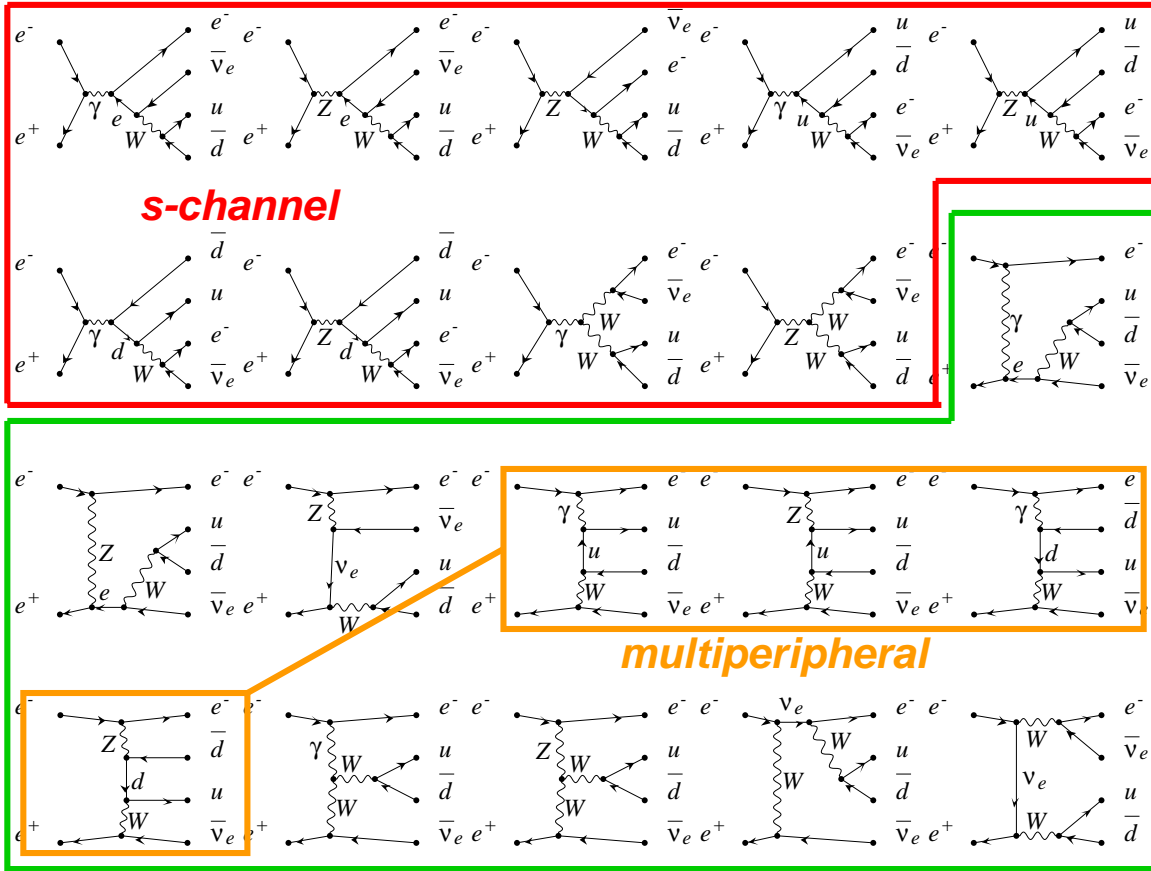


$Z\gamma^* \rightarrow \nu \bar{\nu} q \bar{q}$



Weν

evud



LEP common definition of the cross-section:
all (gauge invariance) and only
t-channel graphs
+ phase space cuts for m.p. rejection

$e^- \nu_e qq'$ (CC20)	$m(qq') > 45 \text{ GeV}$
$e^- \nu_e l^+ \nu_l$ (CC18)	$E l^+ > 20 \text{ GeV}$
$e^- \nu_e e^+ \nu_e$ (Mix56)	$E e^+ > 20 \text{ GeV}$ $ \cos\theta e^+ < 0.95$ $ \cos\theta e^- > 0.95$

produced by GRACEFIG

t-channel

$$\sigma_{SM} = 450 \div 600 \text{ fb } (e \nu_e qq')$$

$$\sigma_{SM} = 60 \div 90 \text{ fb } (e \nu_e l \nu_l)$$

$$\sigma_{SM} = 30 \div 50 \text{ fb } (e \nu_e e \nu_e)$$

- TGC but also...
- ... test of SM calculations (forthcoming LC)
 - Technical: process fwd peaked collinear singularity
→ full massive calculation needed

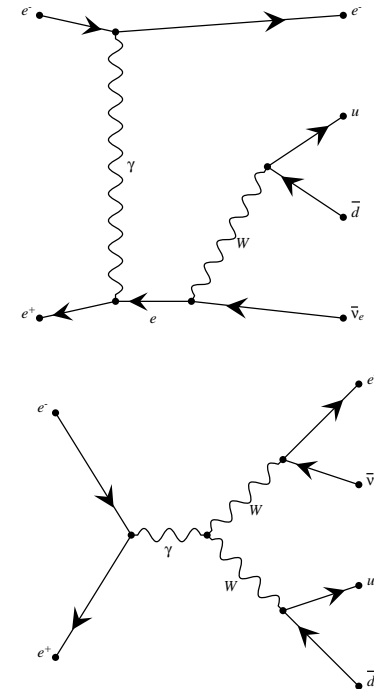
– Physics: different energy scales involved

- ✓ scale of the couplings:
i.e. t-channel $\alpha(0)$, s-channel $\alpha(m_W^2)$
Exact Fermion Loop: gauge invariant treatment of
finite W width → fixes properly the scale

⇒ s-channel $\alpha(m_W^2)$ → t-channel $\alpha(0)$ $\delta\sigma/\sigma \approx -5\%$

- ✓ scale of QED radiation:
Structure Function:
 $O(\alpha)$ QED corrections required to fix q_i^2

⇒ SF($q^2=s$) → SF($q^2=t$) $\delta\sigma/\sigma \approx +8\%$

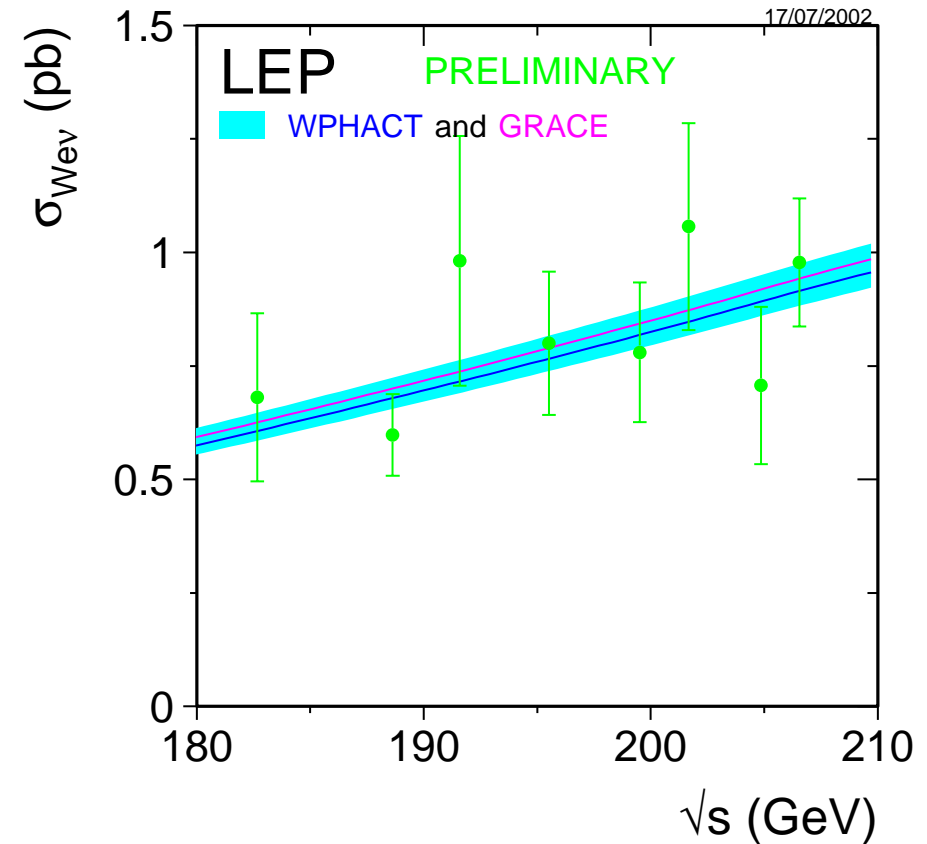


Status at ICHEP02:

P: preliminary

F: final

	A	D	L	O
183 GeV	F		F	
189 GeV	P	P	F	F
192-202 GeV	P	P	P	
205-207 GeV	P	P	P	

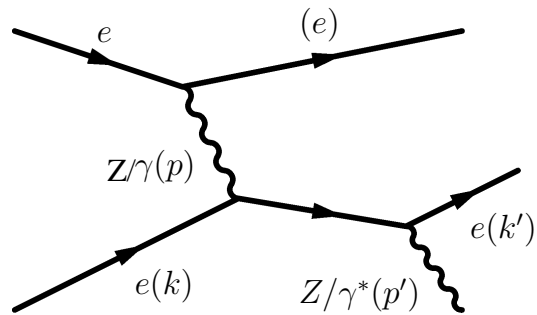


$$R_{\text{ff}'} = \sigma_{\text{meas}} / \sigma_{\text{SM (WPHACT)}} = 0.978 \pm 0.080$$

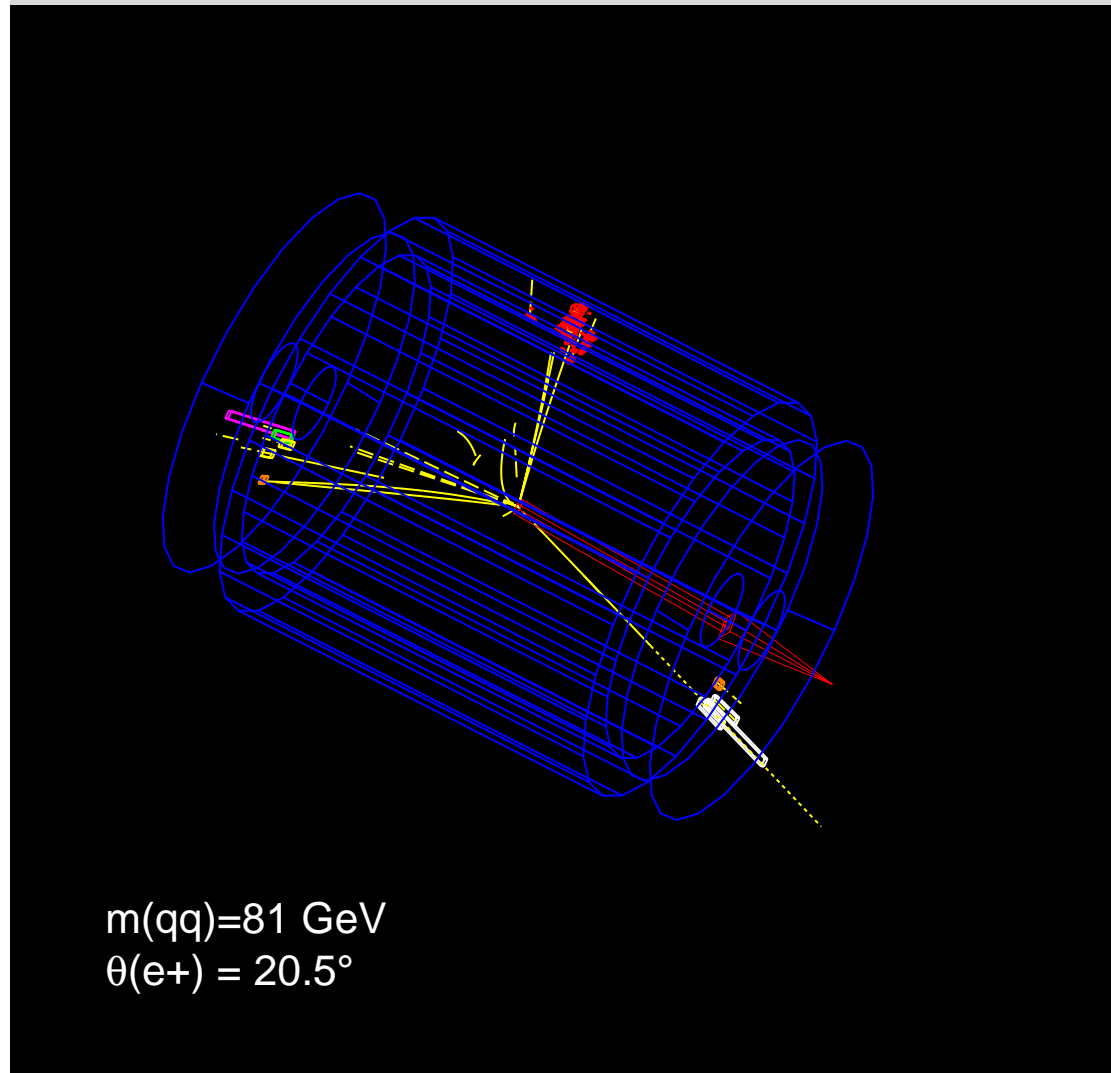
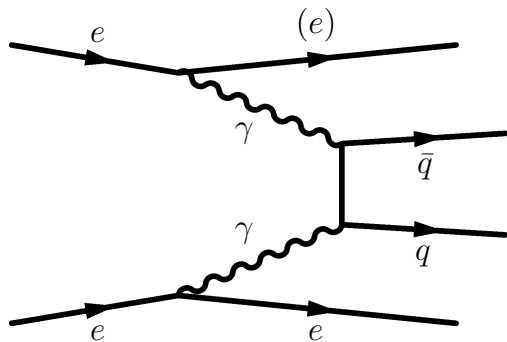
Zee

DELPHI Run: 111672 Evt: 12875
Beam: 103.3 GeV Proc: 5-Jul-2001
DAS: 23-Jun-2000 Scan: 19-Jul-2002
19:05:47 DST

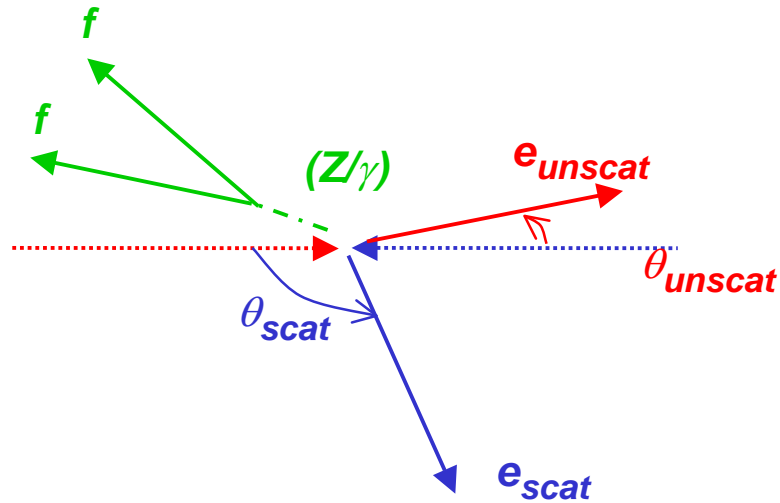
- relevant diagrams:



- competing diagrams (multiperipherals):



- common LEP signal definition



All diagrams (NC48)
+ phase space cuts:

$$m(ff) > 60 \text{ GeV}$$

$$\theta_{\text{unscattered}} < 12^\circ$$

$$60^\circ < \theta_{\text{scattered}} < 168^\circ$$

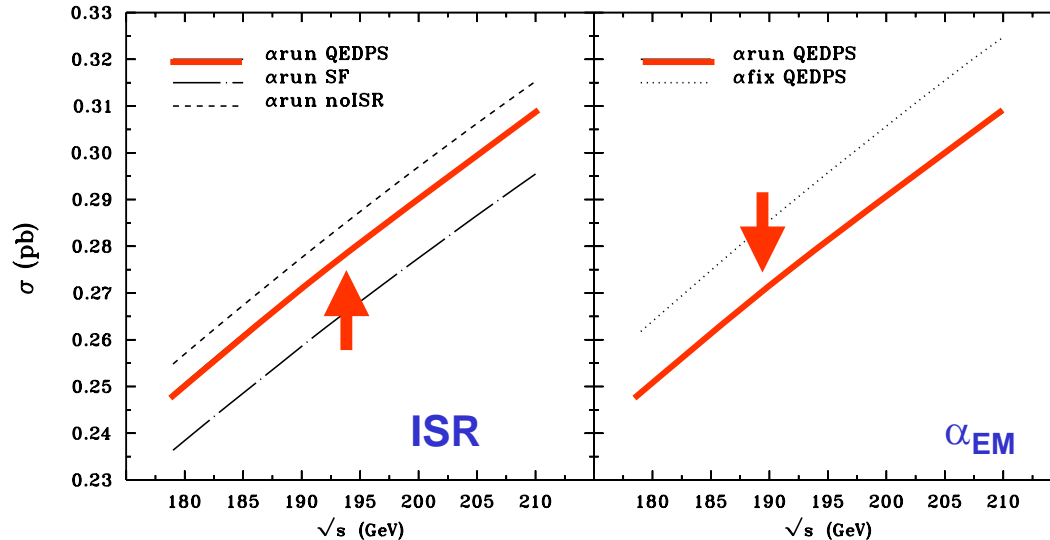
$$E_{\text{scattered}} > 3 \text{ GeV}$$

$$\sigma_{SM} = 500 \text{ fb} \quad (e)eqq$$

$$\sigma_{SM} = 50 \text{ fb} \quad (e)e\mu\mu$$

Accomando, Ballestrero & Maina,
hep-ph/0204052

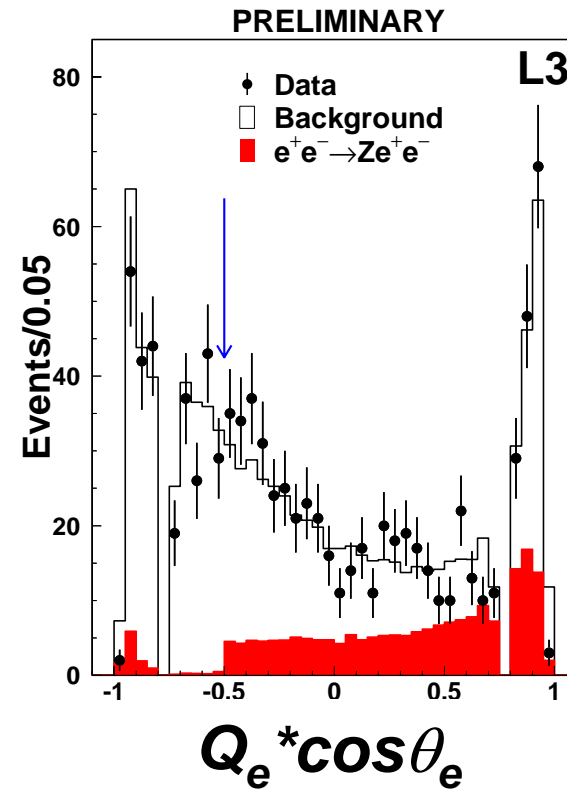
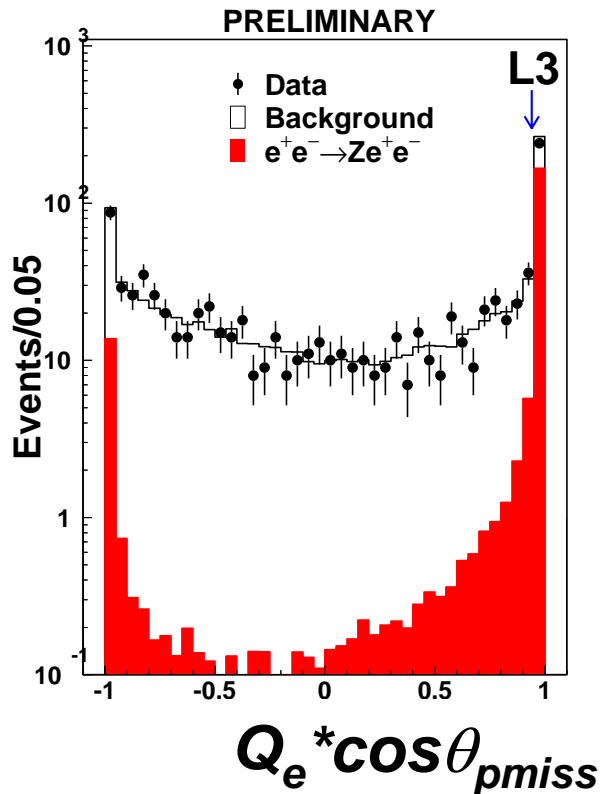
Single Z in eeqq



effects from energy
scale similar as for Wev



- *Experimental selection:*
 - *jet pair*
 - *isolated electron*
 - *missing momentum along the beamline*
 - *e+/e- symmetric cuts using “signed” variables*
 $(Q_e \cdot \cos\theta_e, Q_e \cdot \cos\theta_{pmiss})$



Final state	Signature	ε	<i>bgd</i>
(e)eqq	isolated e 2 acoplanar jets	30-40 %	qq γ (15%)
(e)e $\mu\mu$	isolated e 2 identified μ	25 %	e $e\mu\mu$ (2%)

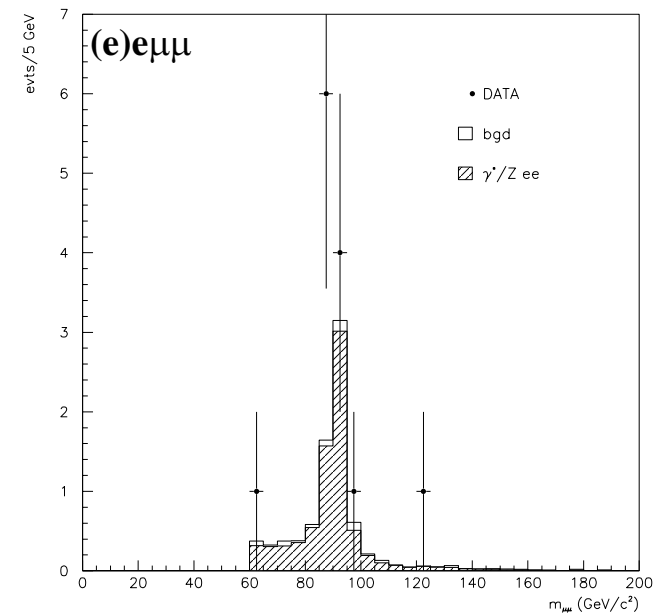
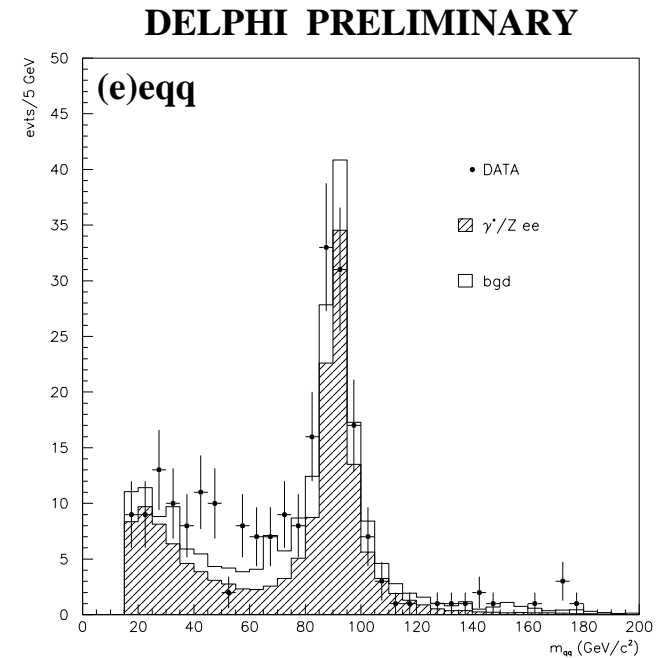
- Experimental Systematics & Results**

- e-ID efficiency
- qq(γ) fragmentation

(e)eqq (189 GeV DELPHI+L3):

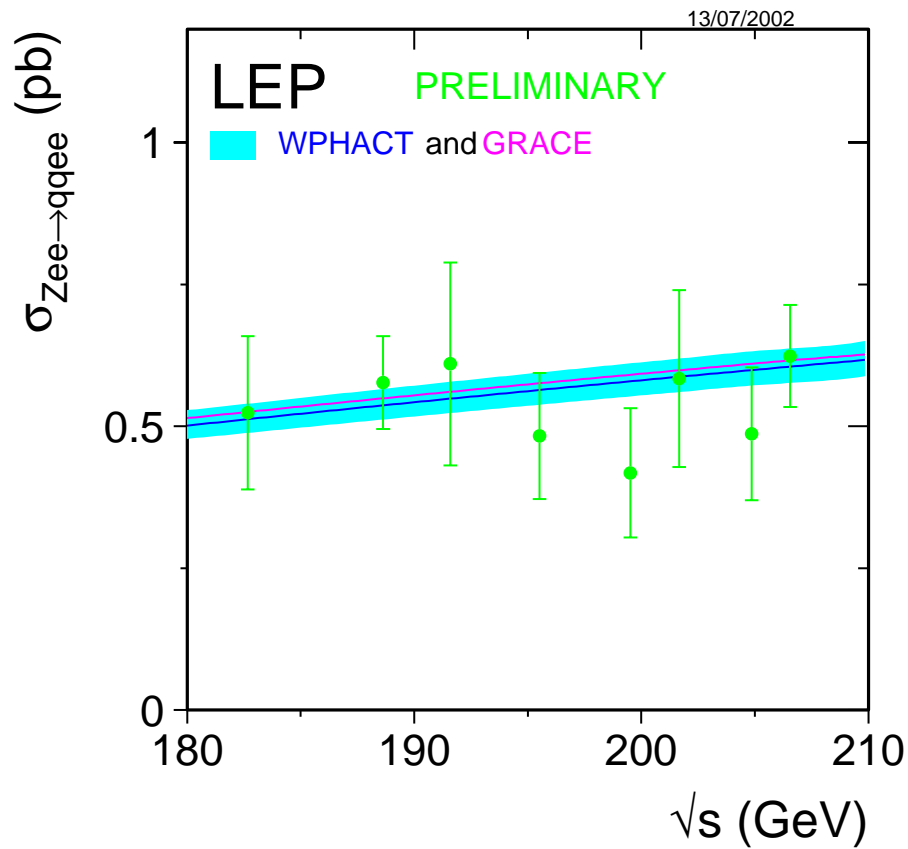
$577 \pm 77 \pm 27 \text{ fb}$ (SM*: 538 fb)

* WPHACT with α_{run} QEDPS



LEP combined results

Status at ICHEP02:



P: preliminary
F: final

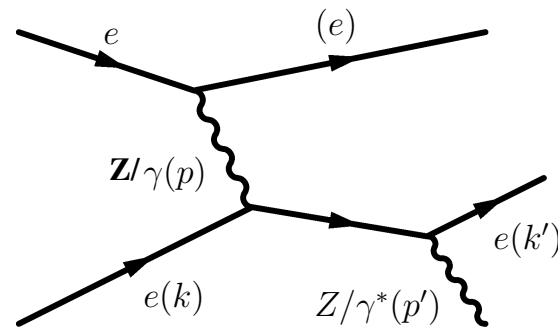
	A	D	L	O
(e)eqq		P	P	
(e)e $\mu\mu$	P	P		

$$R_{qq} = \sigma_{\text{meas}} / \sigma_{\text{SM (WPHACT)}} = 0.951 \pm 0.083$$

$$R_{\mu\mu} = \sigma_{\text{meas}} / \sigma_{\text{SM (WPHACT)}} = 1.42 \pm 0.26$$

$e\gamma \rightarrow e\gamma^*/Z$ (OPAL)

– fermion level cuts on Lorentz invariants:



- $|t'| = |(p' - p)^2| > 500 \text{ GeV}^2$
- $|p^2| < 10 \text{ GeV}^2$
- $|u'| = |(p' - k)^2| > 10 \text{ GeV}^2$
- $m(qq) > 5 \text{ GeV}$

$$\sigma_{Zee}(s) = \int_0^1 dz D_{ey}(z, s) d\hat{\sigma}_{ey}(s')$$

- Factorization

- modified EPA (Hagiwara et al. 1991)

– analysis at 189 GeV (175 pb^{-1})

– selection similar to standard Zee (2 jets + 1 isolated e)

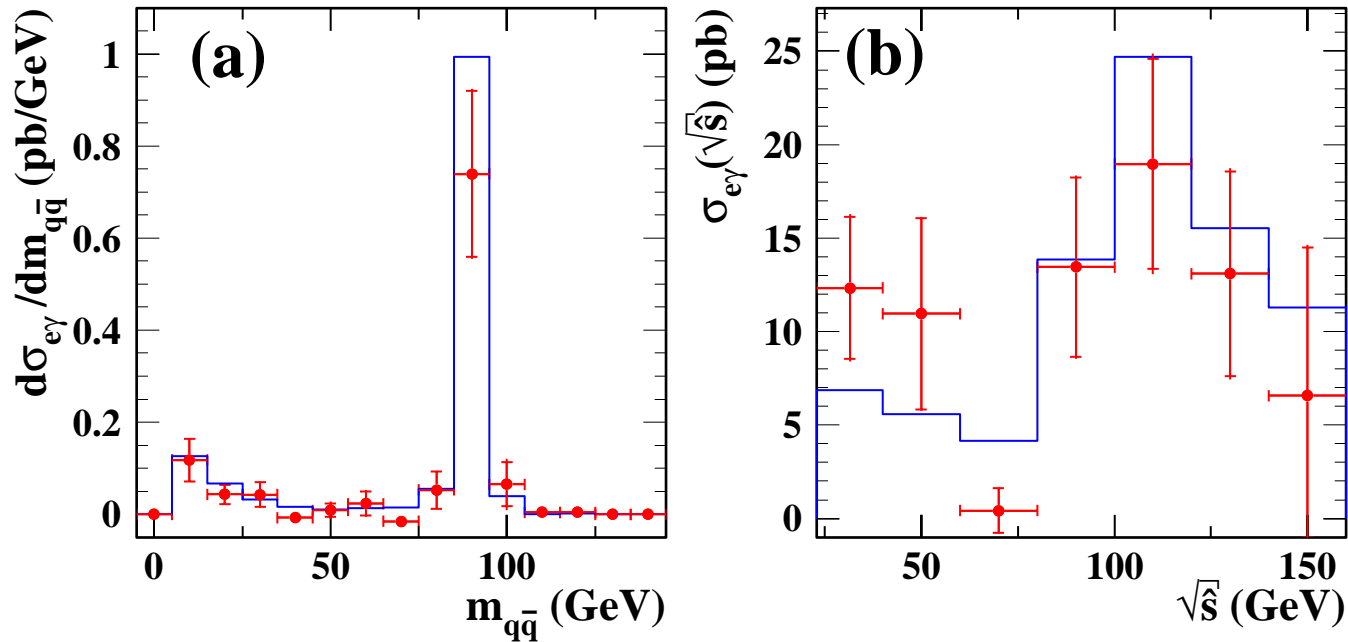
– t', u' determined from $E_{beam}, E_e, \cos\theta_e, E_{qq}, \cos\theta_{qq}$

$$t' + u' + \underbrace{s'} = m_{qq}^2$$

$$\sigma(e\gamma \rightarrow e\gamma^*/Z)$$

— prediction from grc4f

OPAL

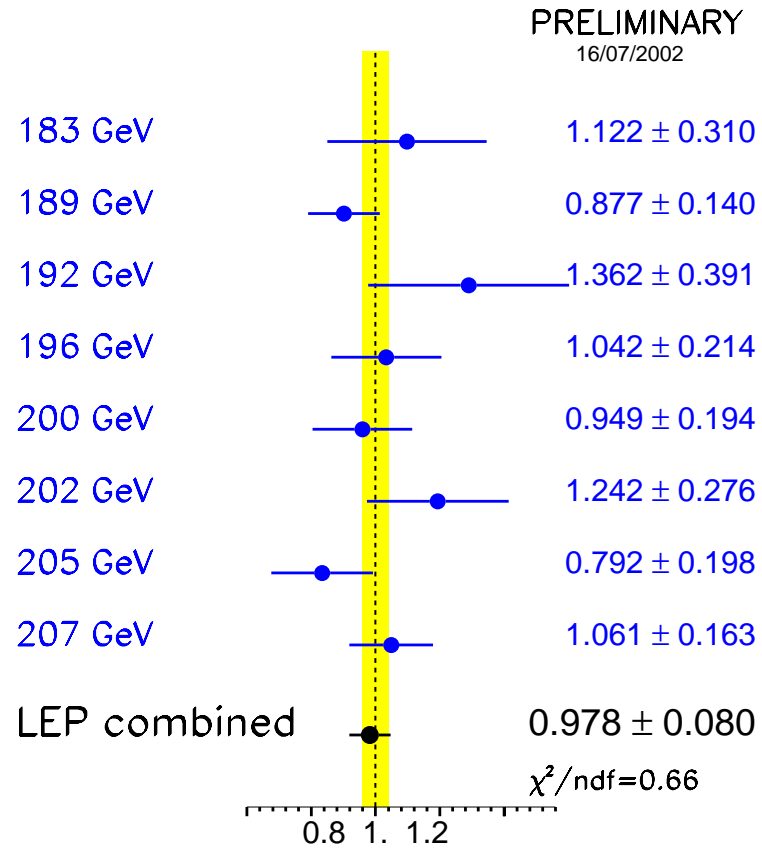


$e\gamma \rightarrow e\gamma^*/Z$ independent of $e+e^-$ c.m. energy
 can be compared with other experiments (HERA?)

Summary

- *measurement of non resonant $4f$ production challenging (both experimentally & theoretically)*
 - *unique opportunity to study the scale dependence of couplings and of the ISR treatment*
 - *effort in tuning MC generators for the “final” LEP2 samples processing*
- *“Final” LEP2 accuracy:*
 - $W_{e\nu} \rightarrow \approx 7\%$*
 - $Z_{ee} \rightarrow \approx 6.5\%$*
 - (cf. $ZZ \rightarrow 5.7\%$)*

Measured $\sigma^{W\text{ev}}$ / WPHACT



Measured $\sigma^{Z\text{ee}}$ / WPHACT

