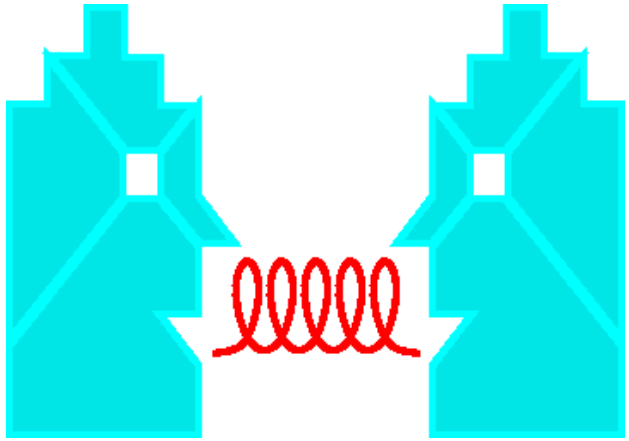
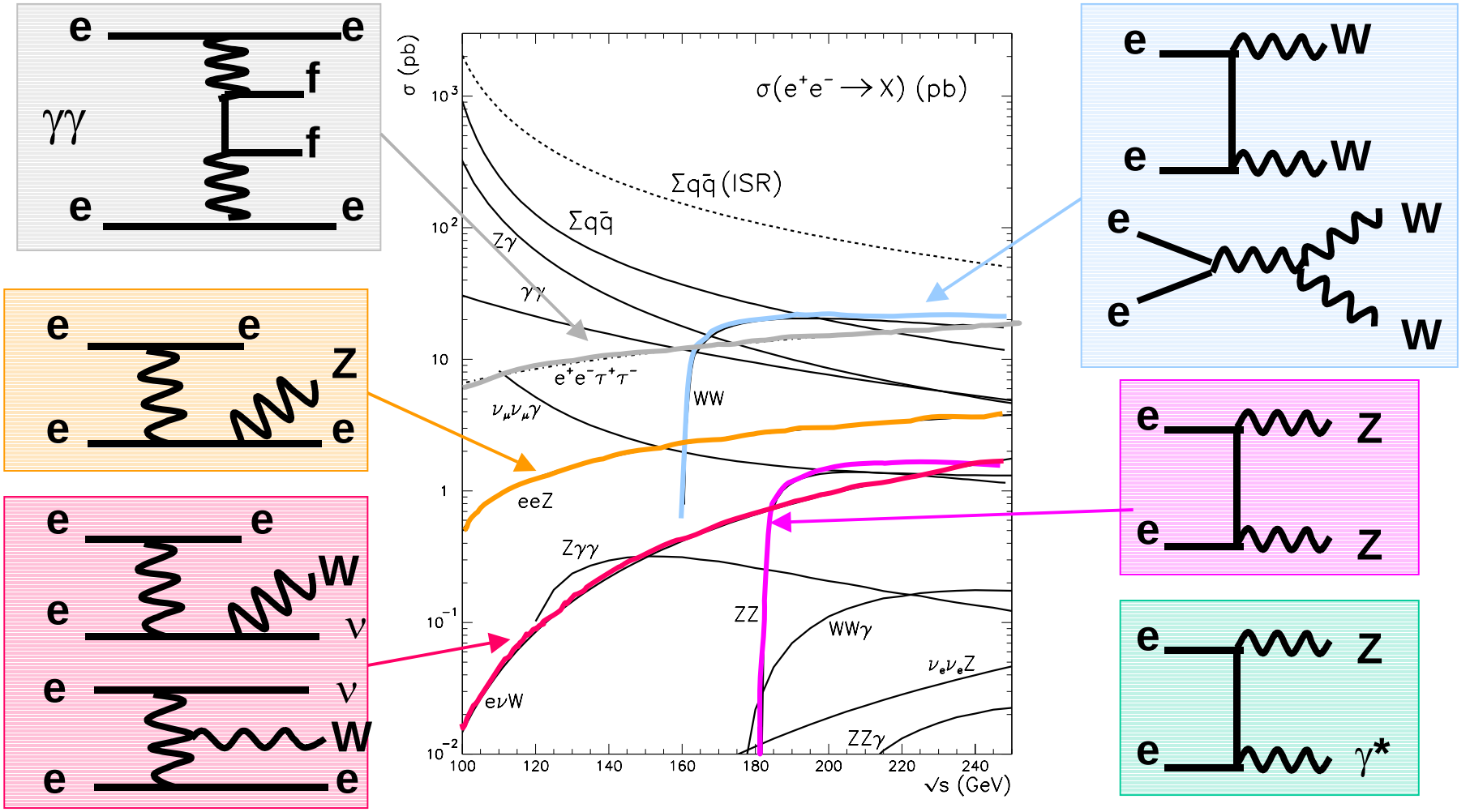
4-fermion production at LEP2



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

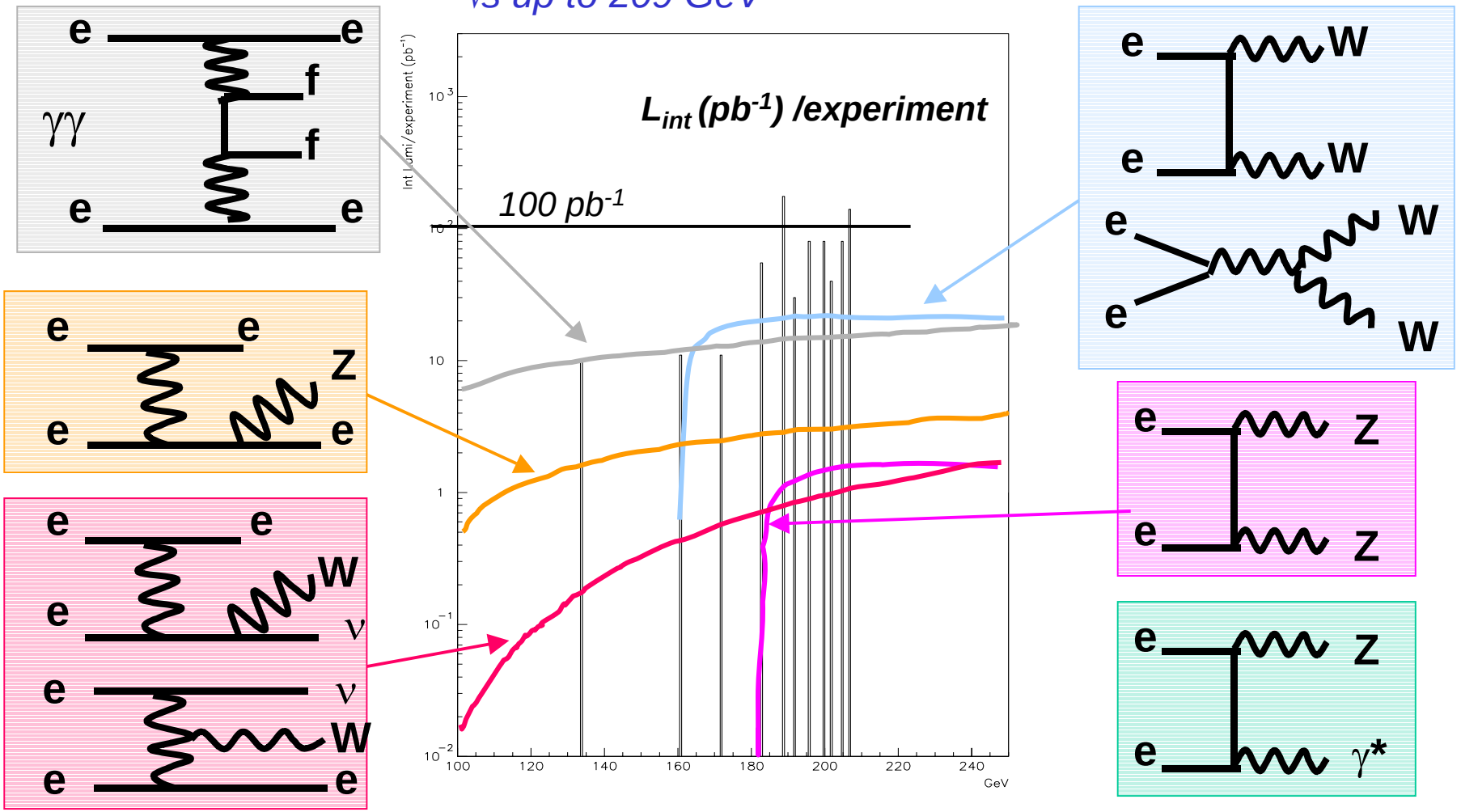
4f cross sections at LEP2

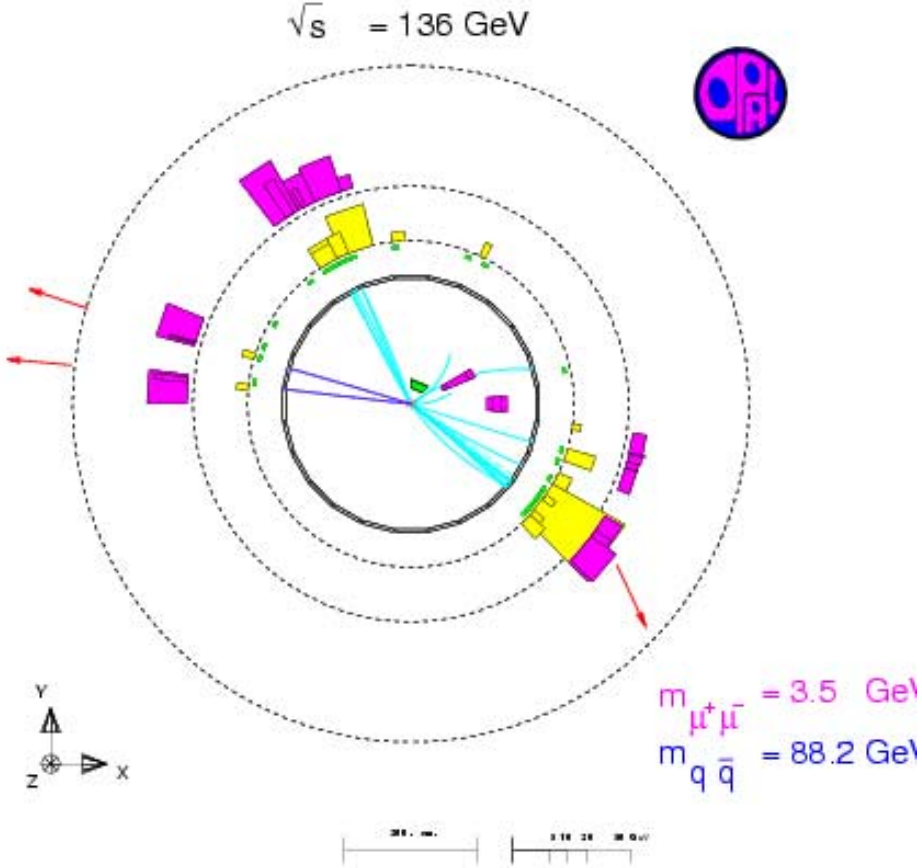
From the "PHYSICS AT LEP2" YR (1996)



LEP at high energy

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





LEP run Nov '95

From EPS97

		130-136 GeV			
		ALEPH	DELPHI	L3	OPAL
$q\bar{q}\ell\ell$	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	$0.31^{+0.23}_{-0.15}$
$\ell\bar{\ell}\ell'\bar{\ell}'$	observed	2	2	2	7
$ff\nu\bar{\nu}$	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:

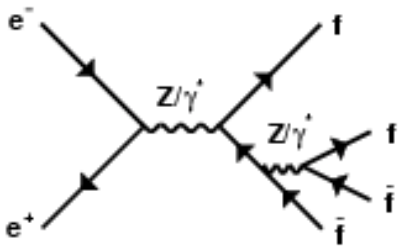
– *topology:*

- $|\cos\theta_\ell| < 0.95$ $\quad \ell = e,\mu$
- $m(qq) > 5$ GeV
- $m(ee) > 2$ GeV; $m(\mu\mu)$ any

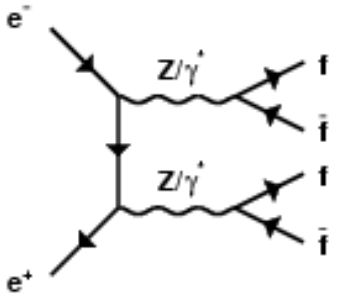
– *diagram selection:*

- all but m.p.

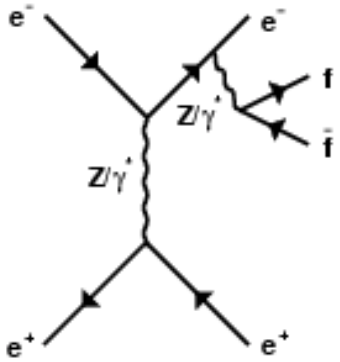
$\sigma_{SM} = 150 \div 200$ fb



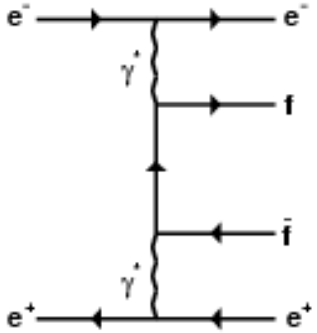
a) Annihilation



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(ℓ) cut*
5. *ℓ-isolation*
6. *m(qq) and m(ℓℓ)*
7. *Anti-m.p. for eeqq: $|\cos\theta_e| < 0.7$*

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

75 / 1380 → 51 / 58 (eeqq)

72 / 4790 → 49 / 52 (μμqq)

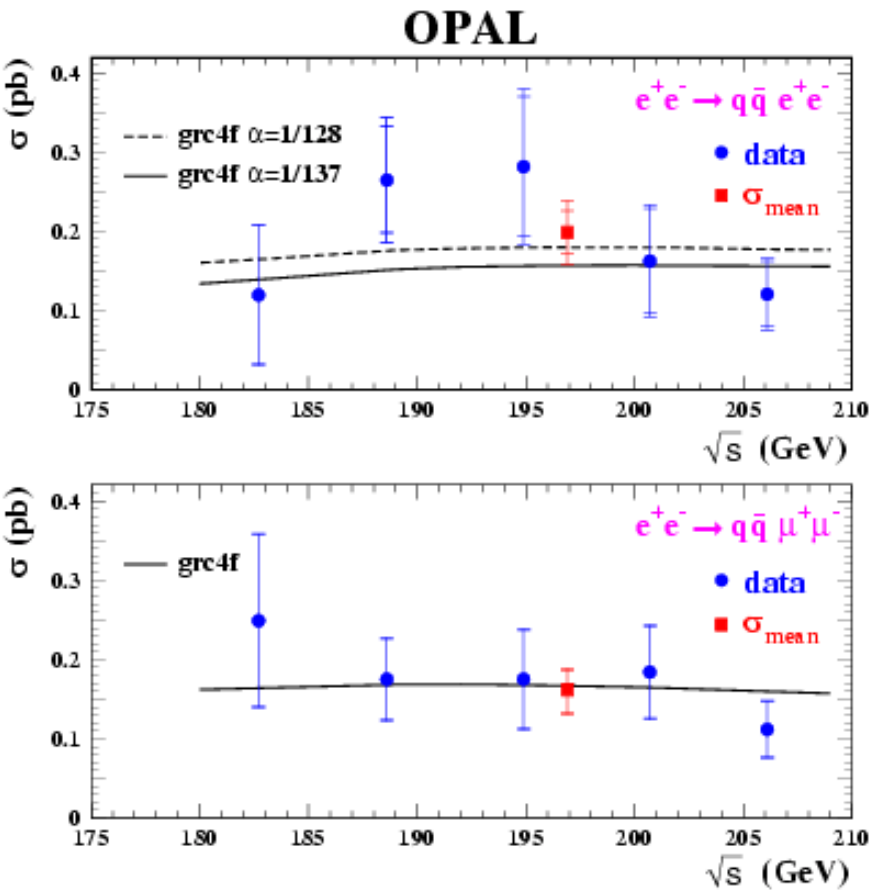
eeqq:

199 ± 27 ± 30 fb (SM: 180 fb)*

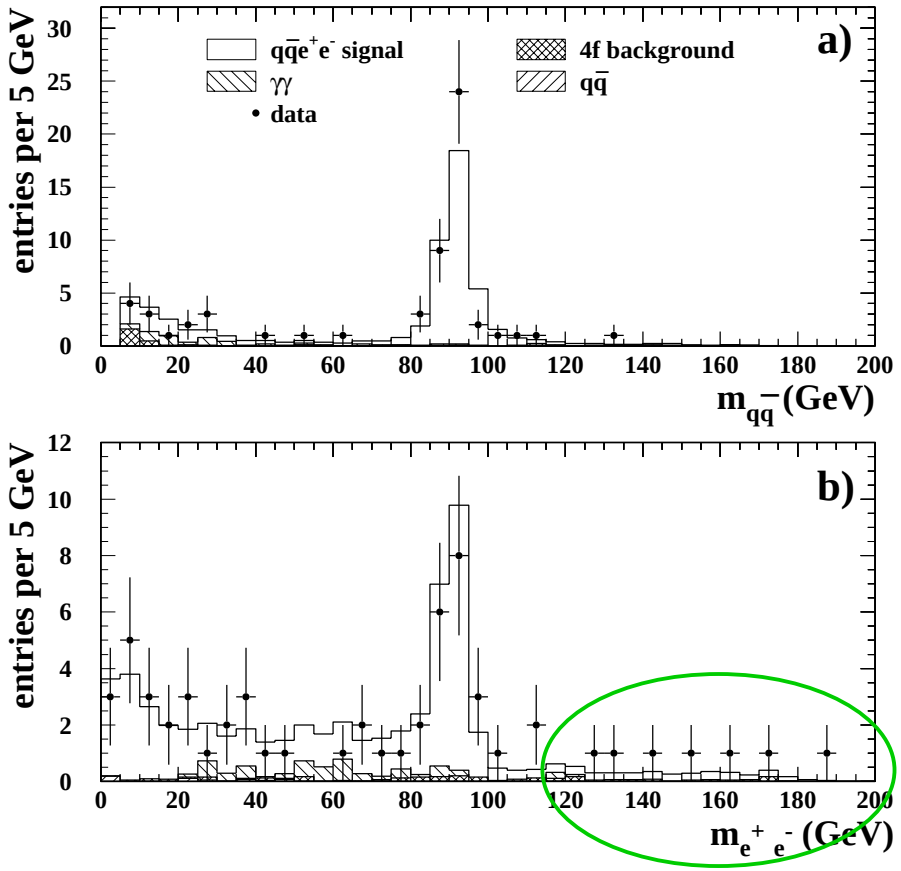
μμqq:

160 ± 26 ± 13 fb (SM: 165 fb)*

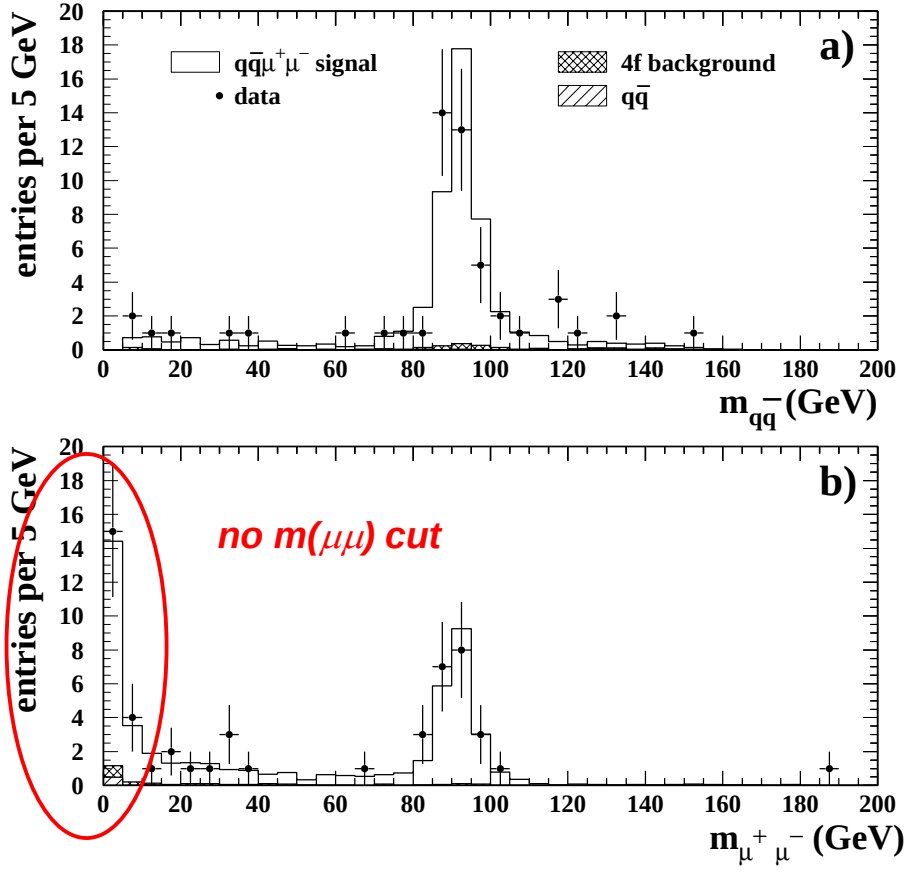
**grc4f with $1/\alpha = 128$*



eeqq

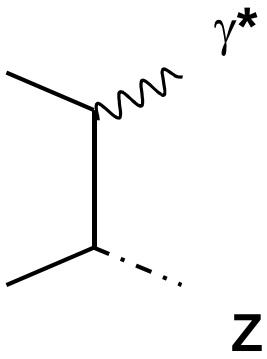

OPAL
a)
$q\bar{q}e^+e^-$ signal
$\gamma\gamma$
• data
4f background
$q\bar{q}$
entries per 5 GeV
$m_{q\bar{q}}$ (GeV)
b)
$m_{e^+e^-}$ (GeV)
bremsstrahlung

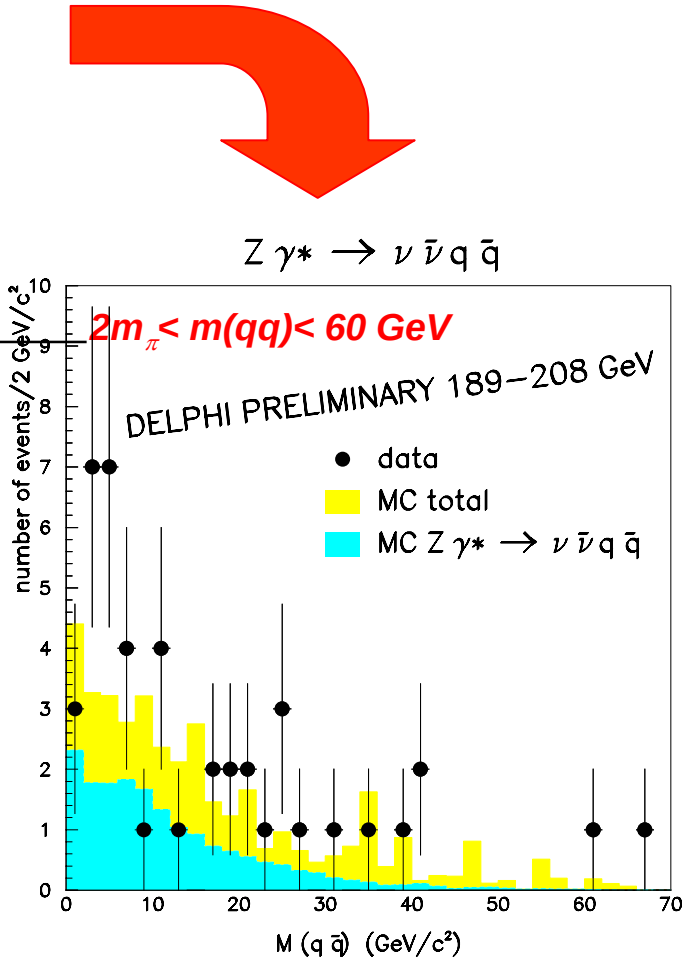
μμqq


OPAL
a)
$q\bar{q}\mu^+\mu^-$ signal
• data
4f background
$q\bar{q}$
entries per 5 GeV
$m_{q\bar{q}}$ (GeV)
b)
no m(μμ) cut
$m_{\mu^+\mu^-}$ (GeV)

• $Z\gamma^*$ DELPHI (650 pb^{-1})

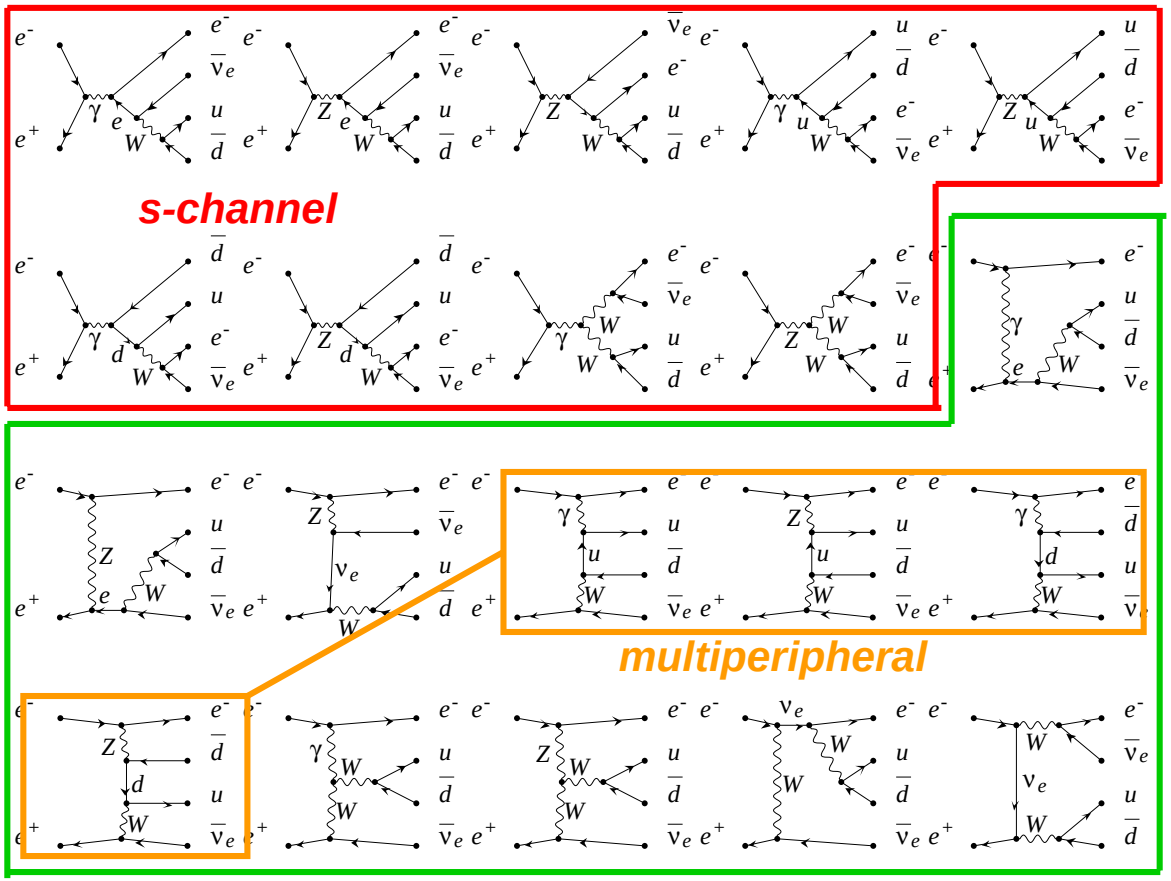
Final state	Signature	ε	$\sigma_{Z\gamma^*}$ (pb) (SM EXCALIBUR)
$\mu\mu qq$ $eeqq$	$Z\gamma^*$ dominating at low m(ll)	35%	0.129 $\pm$0.020$\pm$0.008 (0.098)
$\nu\nu qq$	monojet topology	31%	0.129 $\pm$0.035$\pm$0.015 (0.092)
$qqqq$	$qq\ \rho(\rightarrow\pi\pi)$	18%	0.071$\pm$0.042$\pm$0.015 (0.082)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





Weν

eνud



produced by GRACEFIG

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

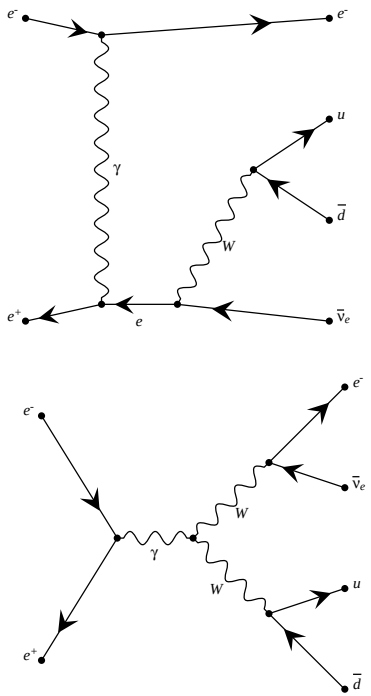
$e^- \nu_e$ qq' (CC20)	m(qq')> 45 GeV
$e^- \nu_e l^+ \nu_l$ (CC18)	E l^+>20 GeV
$e^- \nu_e e^+ \nu_e$ (Mix56)	E e^+>20 GeV $\|\cos\theta e^+\|$<0.95 $\|\cos\theta e^-\|$>0.95

σ_{SM} = 450÷600 fb ($e\nu_e$ qq')

σ_{SM} = 60÷90 fb ($e\nu_e l\nu_l$)

σ_{SM} = 30÷50 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 $\alpha(m^2_W)$
Exact Fermion Loop: gauge invariant treatment of finite W width → fixes properly the scale

$\Rightarrow$ *s-channel* $\alpha(m^2_W) \rightarrow$ *t-channel* $\alpha(0)$ $\quad \delta\sigma/\sigma \approx -5\%$

✓ *scale of QED radiation:*
Structure Function:
O(α) QED corrections required to fix q^2_i

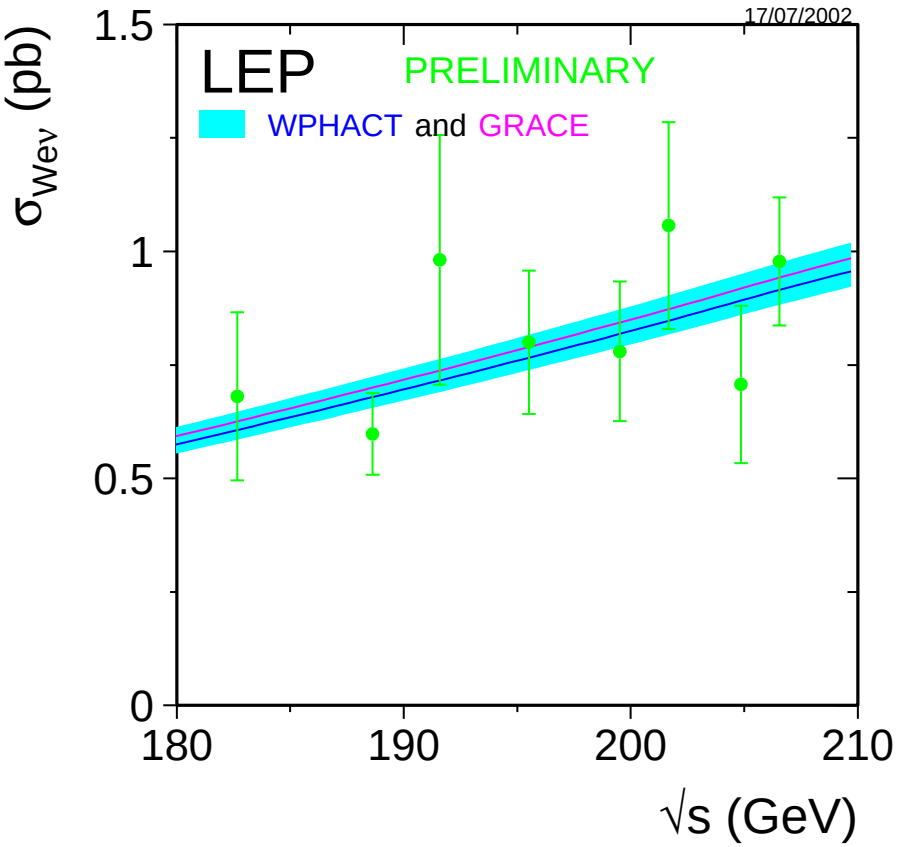
$$d\sigma = \prod_{i=e+,e-} \int dx_i \, D(q_i^2, x) d\sigma_0$$

$\Rightarrow SF(q^2=s) \rightarrow SF(q^2=t)$ $\quad \delta\sigma/\sigma \approx +8\%$

Status at ICHEP02:

***P**: preliminary*
***F**: final*

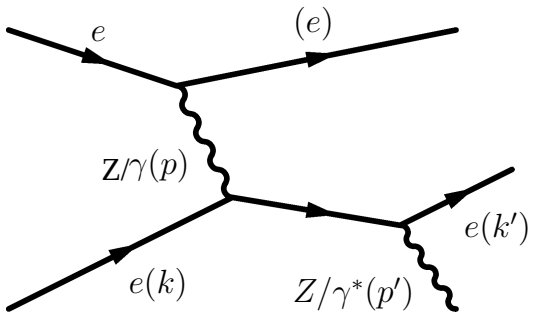
	A	***D***	***L***	***O***
183 GeV	*F*		*F*	
189 GeV	*P*	*P*	*F*	*F*
192-202 GeV	*P*	*P*	*P*	
205-207 GeV	*P*	*P*	*P*	



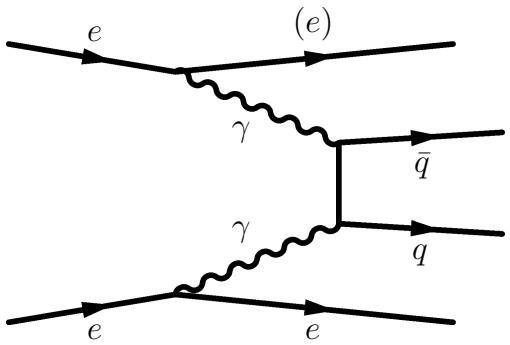
$$R_{ff'} = \sigma_{meas} / \sigma_{SM\ (WPHACT)} = 0.978 \pm 0.080$$

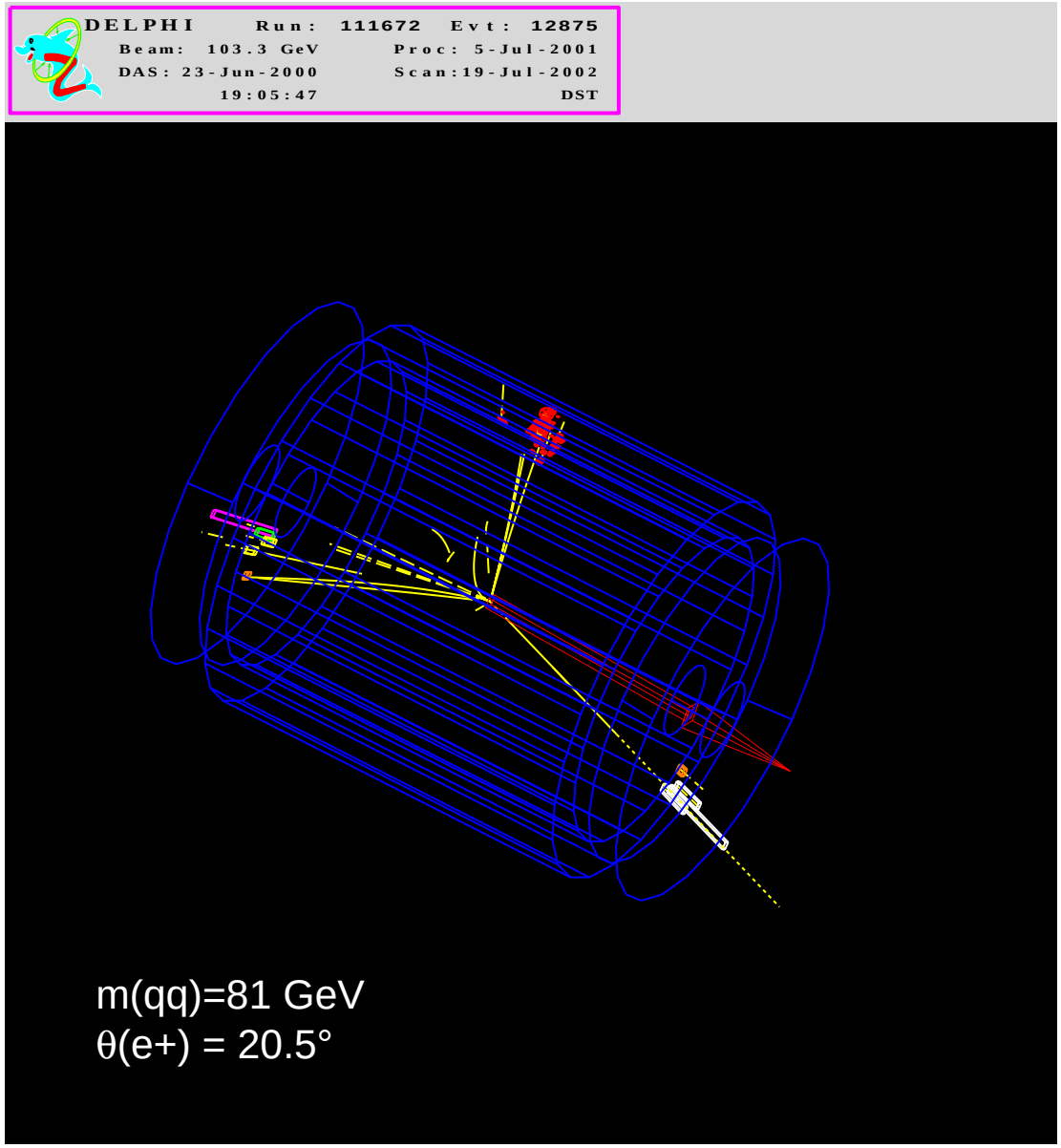
Zee

- *relevant diagrams:*

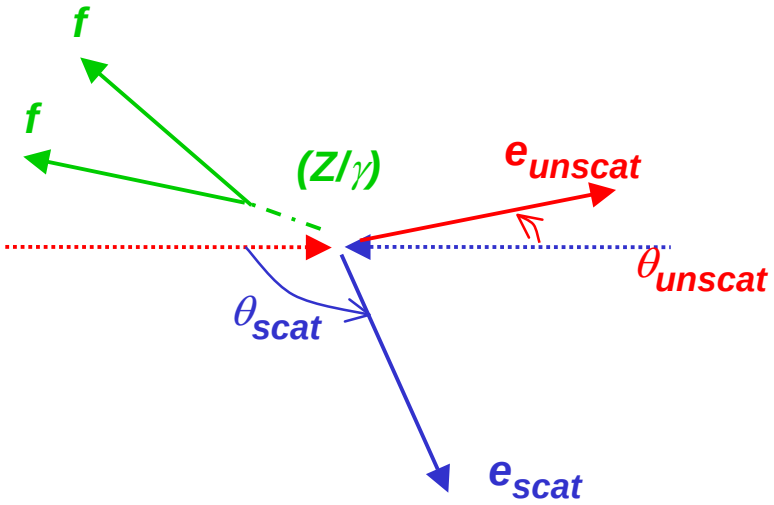


- *competing diagrams (multiperipherals):*





- *common LEP signal definition*



All diagrams (NC48)
+ phase space cuts:

$m(ff) > 60$ GeV

$\theta_{unscattered} < 12°$

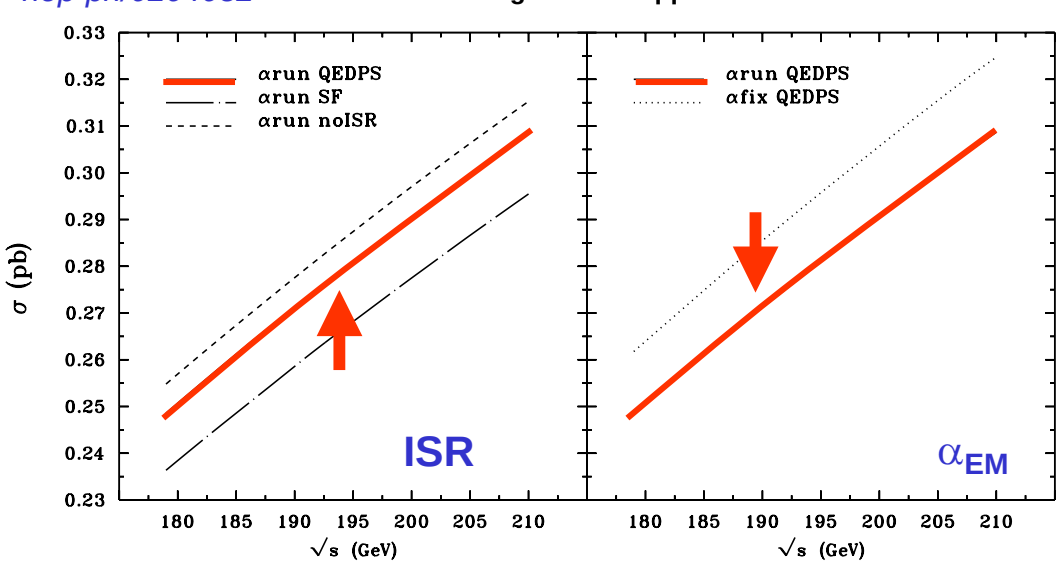
$60° < \theta_{scattered} < 168°$

$E_{scattered} > 3$ GeV

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

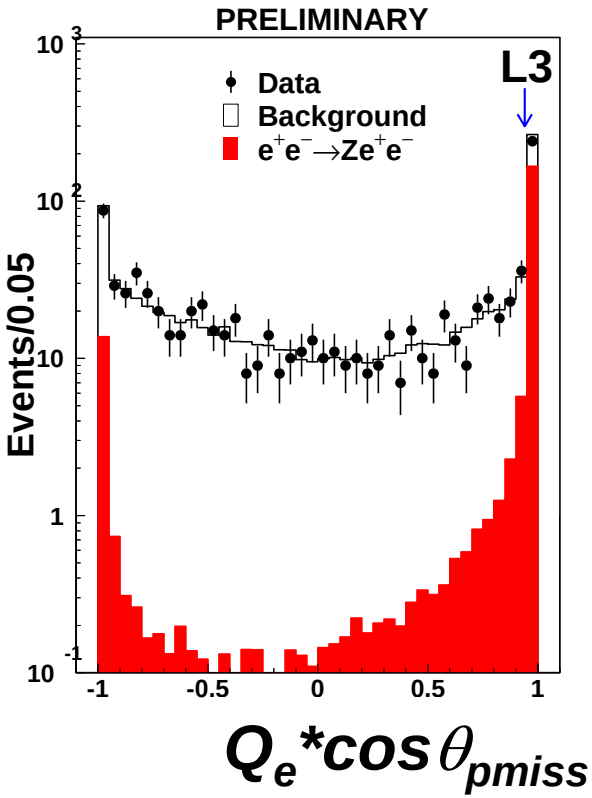
$\sigma_{SM} = 50$ fb (e)eμμ

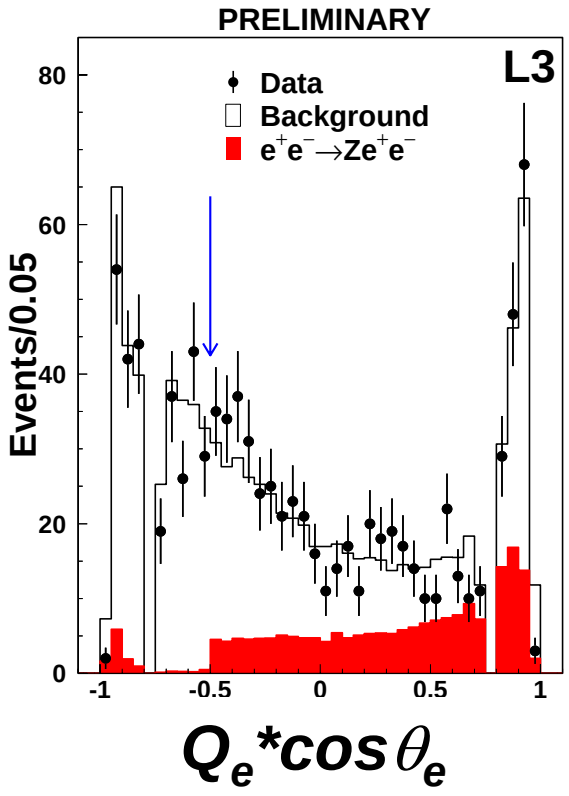
Accomando, Ballestrero & Maina, hep-ph/0204052



effects from energy scale similar as for We ν

- *Experimental selection:*
  - *jet pair*
  - *isolated electron*
  - *missing momentum along the beamline*
  - *e+/e- symmetric cuts using "signed" variables (Q_e*cosθ_e,Q_e*cosθ_{pmiss})*





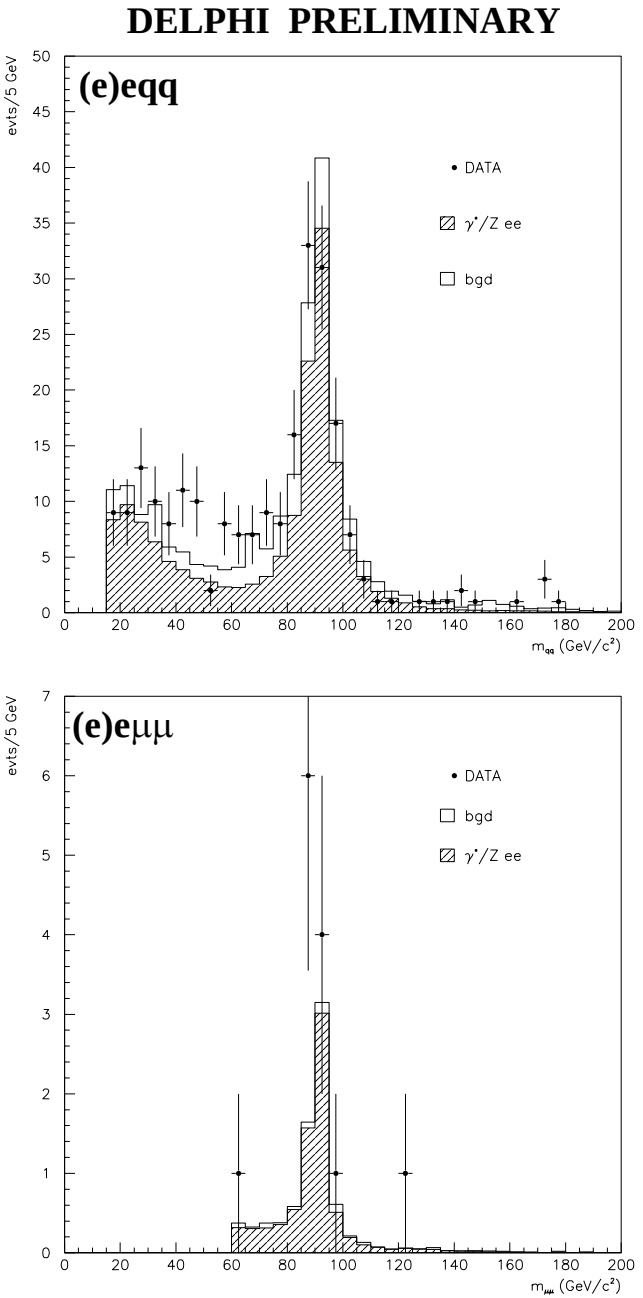
Final state	Signature	ε	bgd
(e)eqq	isolated e 2 acoplanar jets	30-40 %	$qq\gamma$ (15%)
(e)e$\mu\mu$	isolated e 2 identified μ	25 %	ee$\mu\mu$ (2%)

- *Experimental Systematics & Results*
  - *e-ID efficiency*
  - *qq(γ) fragmentation*

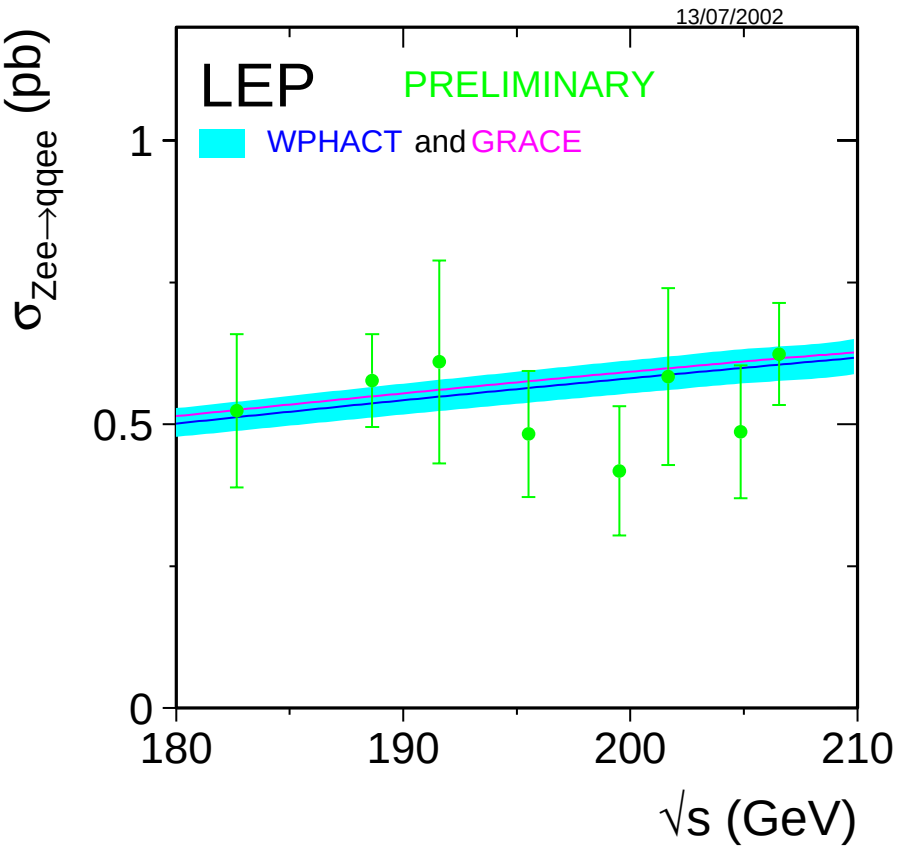
(e)eqq (189 GeV DELPHI+L3):

577± 77 ± 27 fb (SM: 538 fb)*

* *WPHACT with α_{run} QEDPS*



LEP combined results



Status at ICHEP02:

***P**: preliminary*
***F**: final*

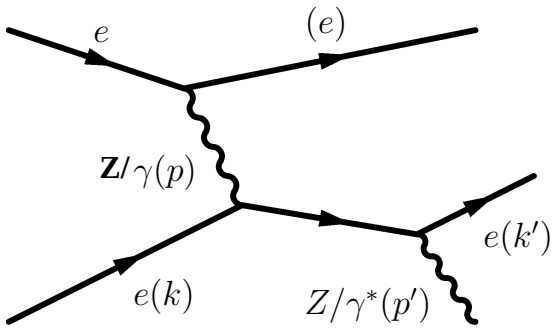
	A	*D*	*L*	*O*
(e)eqq		*P*	*P*	
(e)eμμ	*P*	*P*		

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

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

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

– *fermion level cuts on Lorentz invariants:*



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

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

- *Factorization*
- *modified EPA (Hagiwara et al.1991)*

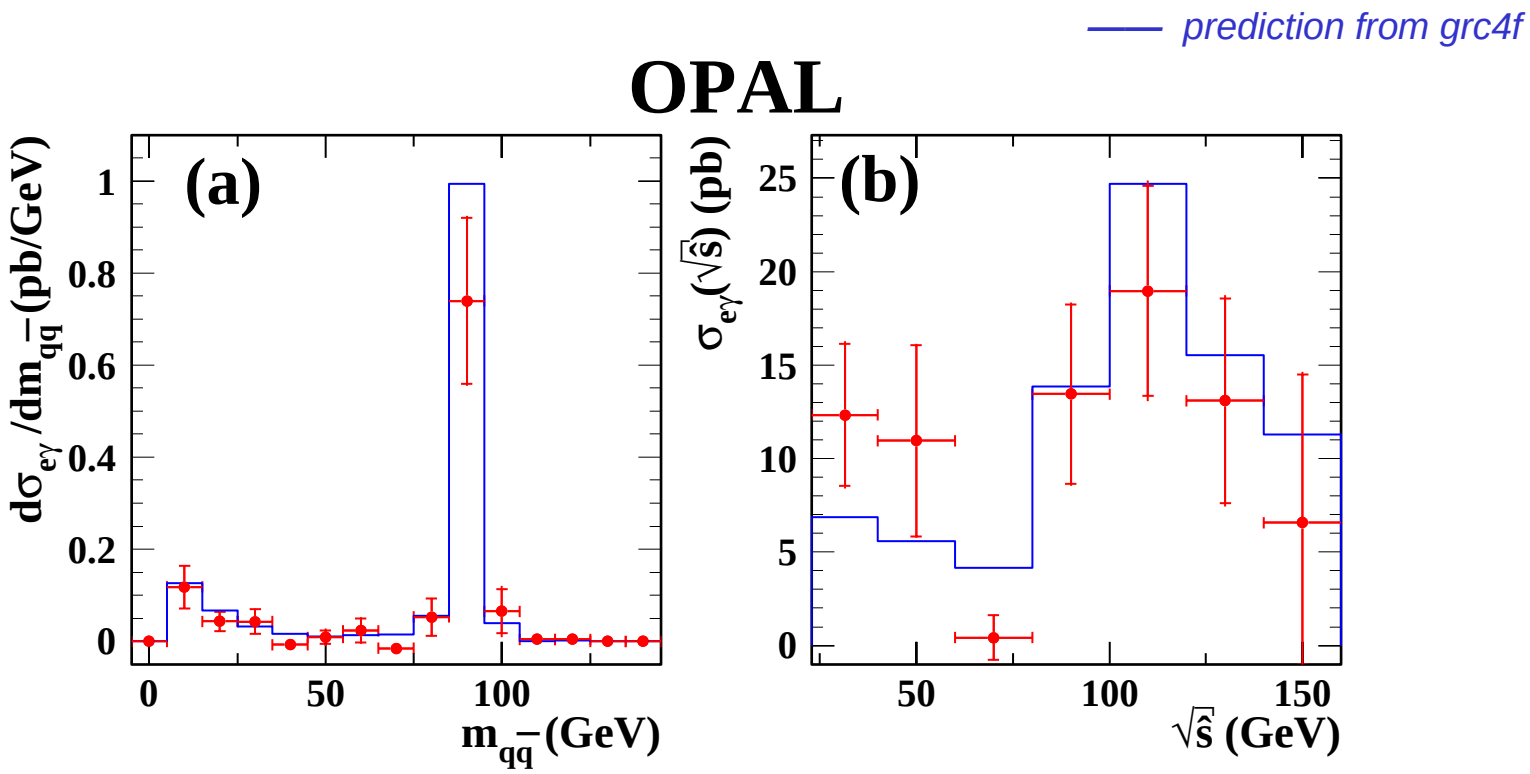
– *analysis at 189 GeV (175 pb^{-1})*

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

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

$t' + u' + s' = m^2_{qq}$

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



$e\gamma \to e\gamma^*/Z$ 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*

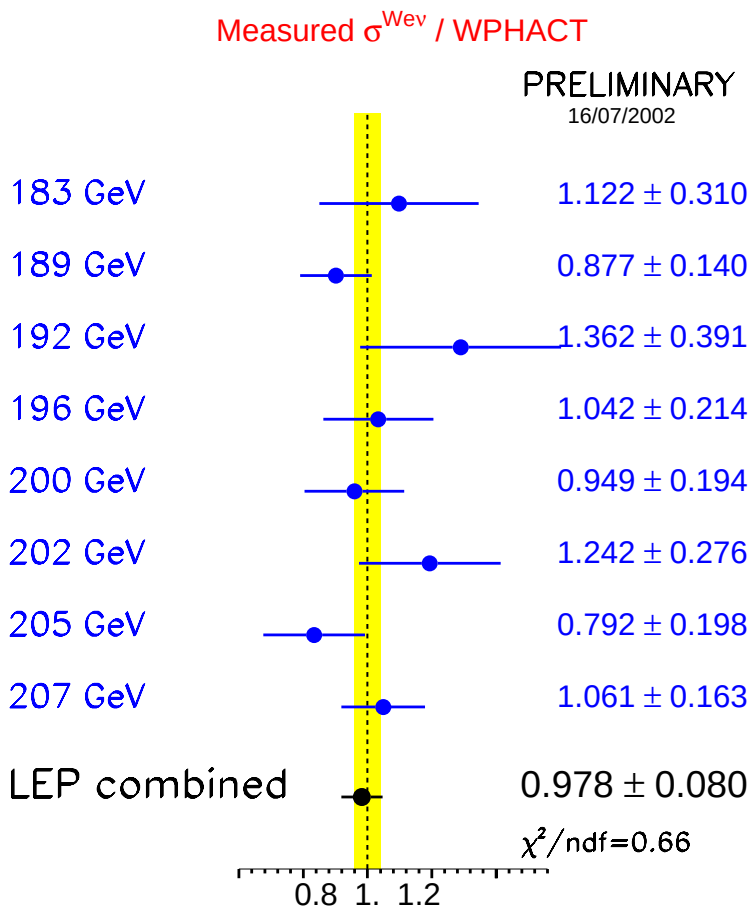
– *effort in tuning MC generators for the "final" LEP2 samples processing*

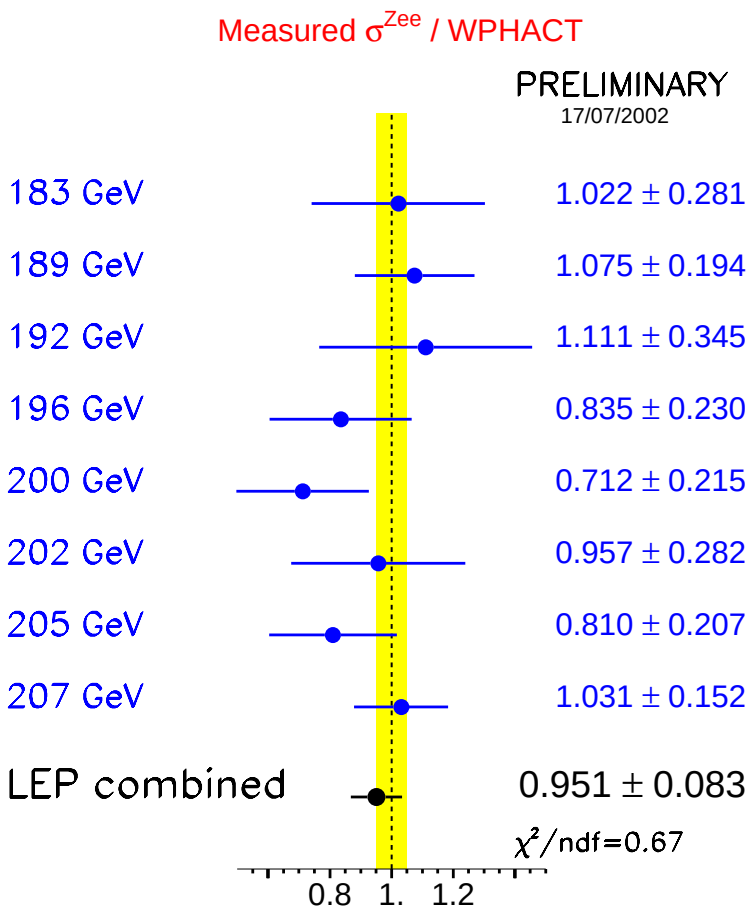
- *"Final" LEP2 accuracy:*

$We\nu \rightarrow \approx 7\%$

$Zee \rightarrow \approx 6.5\%$

$(cf.\ ZZ \rightarrow 5.7\%)$


Measured σ^Wev / WPHACT
PRELIMINARY
16/07/2002
183 GeV
189 GeV
192 GeV
196 GeV
200 GeV
202 GeV
205 GeV
207 GeV
LEP combined
1.122 ± 0.310
0.877 ± 0.140
1.362 ± 0.391
1.042 ± 0.214
0.949 ± 0.194
1.242 ± 0.276
0.792 ± 0.198
1.061 ± 0.163
0.978 ± 0.080
χ²/ndf=0.66
0.8
1.
1.2


Measured σ^Zee / WPHACT
PRELIMINARY
17/07/2002
183 GeV
189 GeV
192 GeV
196 GeV
200 GeV
202 GeV
205 GeV
207 GeV
LEP combined
1.022 ± 0.281
1.075 ± 0.194
1.111 ± 0.345
0.835 ± 0.230
0.712 ± 0.215
0.957 ± 0.282
0.810 ± 0.207
1.031 ± 0.152
0.951 ± 0.083
χ²/ndf=0.67
0.8
1.
1.2