Two-fermion Production at LEP(2)

measurements and interpretations

Paolo Checchia DELPHI Coll. & INFN PADOVA

Summary

Channel description and Physics motivations

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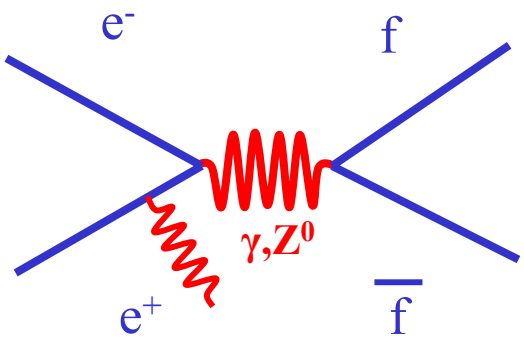
Excursus to two-photon production

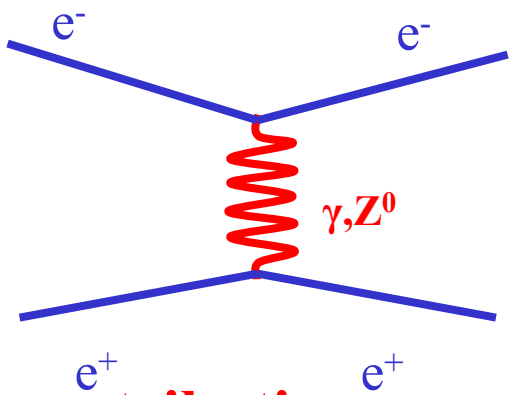
Interpretations

Conclusions

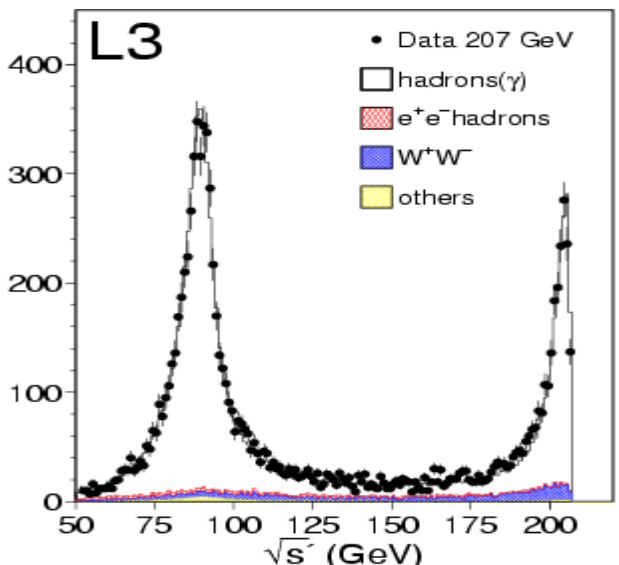
Channel description and Physics motivations

Standard Model production





but at LEP 2: **large ISR contribution**



'radiative return to Z^0'

Channel description and Physics motivations

$$e^+e^- \to f\bar{f}(\gamma)$$

- **Test of Standard Model :**
  - **-measured quantities (σ,$d\sigma/d\cos(\theta)$,A_{FB},…) compared with SM predictions**
  - **-check of the $Z\gamma$ interference (S-Matrix fit)**
- **Search for Physics Beyond the SM**
  - **- virtual effects⇒ well above kinematic limit (sensitivity from interf.)**
  - **- test of specific models**
  - **- largest sensitivity on non radiative events**

NB: ‘clean’ channel with signal much larger than expected backgrounds

Data analysis

LEP2 data set: ~700 pb^{-1} per experiment

$\sqrt{s}$ (GeV)	Year	$\sim\int\mathcal{L}dt$ (pb^{-1})
130	95/97	6
136	95/97	6
161	96	10
172	96	10
183	97	55
189	98	155
192	99	25
196	99	75
200	99	85
202	99	40
205	00	85
207	00	140
LEP2	**95-00**	**~700**

Final state measurements vs experiment

$q\bar{q}$	σ	ADLO
$\mu^+\mu^-,\tau^+\tau^-$	$\sigma, A_{FB}, d\sigma/d\cos\theta$	ADLO
e^+e^-	$\sigma, A_{FB}, d\sigma/d\cos\theta$	ADLO
$b\bar{b}, c\bar{c}$	R, A_{FB}	ADLO

with $A_{FB} = \dfrac{N_{\cos\theta>0} - N_{\cos\theta<0}}{N_{\cos\theta>0} + N_{\cos\theta<0}}$ $\quad R_{b,c} = \dfrac{\sigma_{b\bar{b},c\bar{c}}}{\sigma_{q\bar{q}}}$

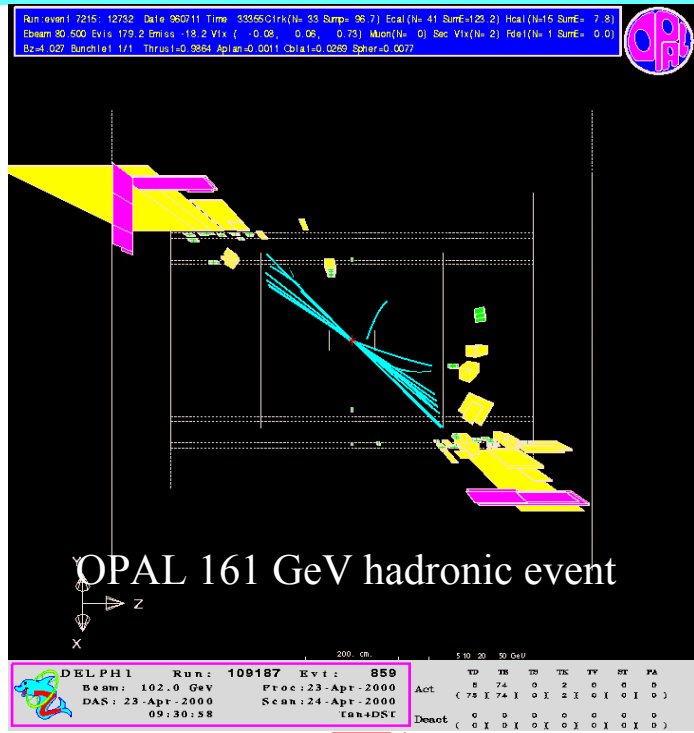
LEP ElectroWeak Working Group:
all measurements combined taking into account systematic effects and correlations

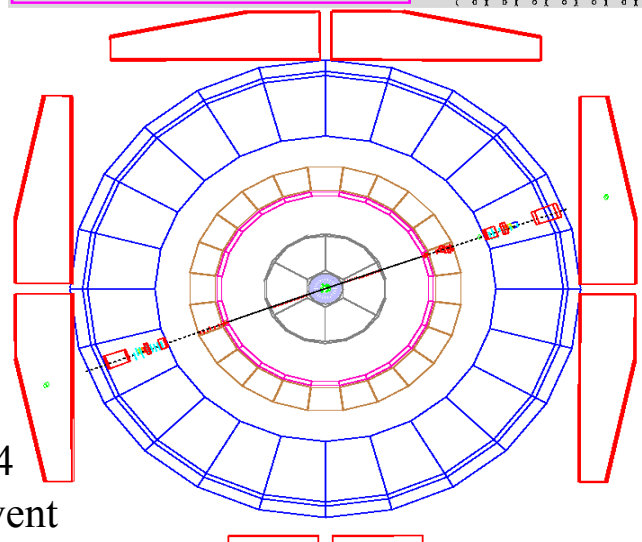
results are still preliminary

Data analysis

selection efficiencies and backgrounds given the clean topology and large signal:

$q\bar{q}$	**eff. ~90%**	**bckg. 10-50% (WW,ZZ rejection)**
$\mu^+\mu^-$	**eff. ~90%**	**bckg. 1-3%**
$\tau^+\tau^-$	**eff. ~50%**	**bckg ~10%**
e^+e^-	**eff. ~90%**	**bckg. <1%**





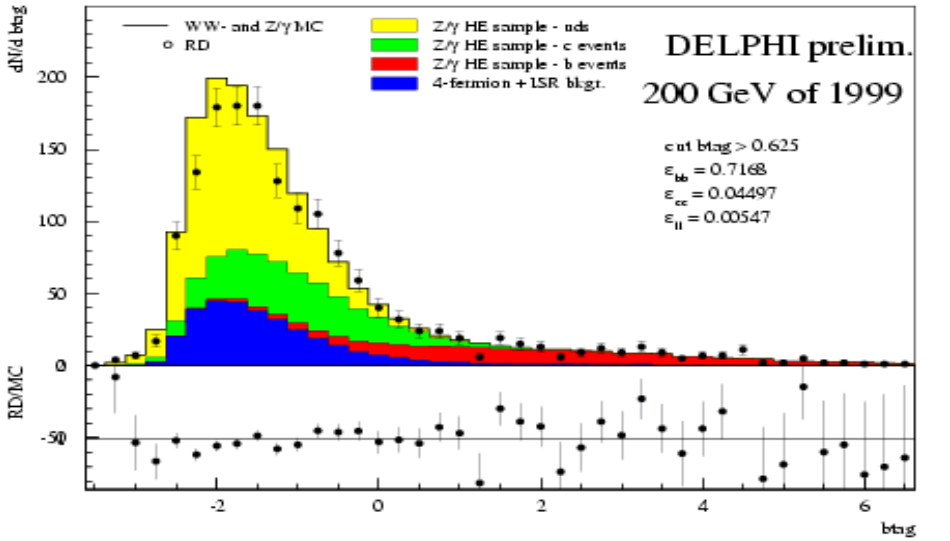
DELPHI 204 GeV $\mu^+\mu^-$ event

Data analysis

Flavour Tagging

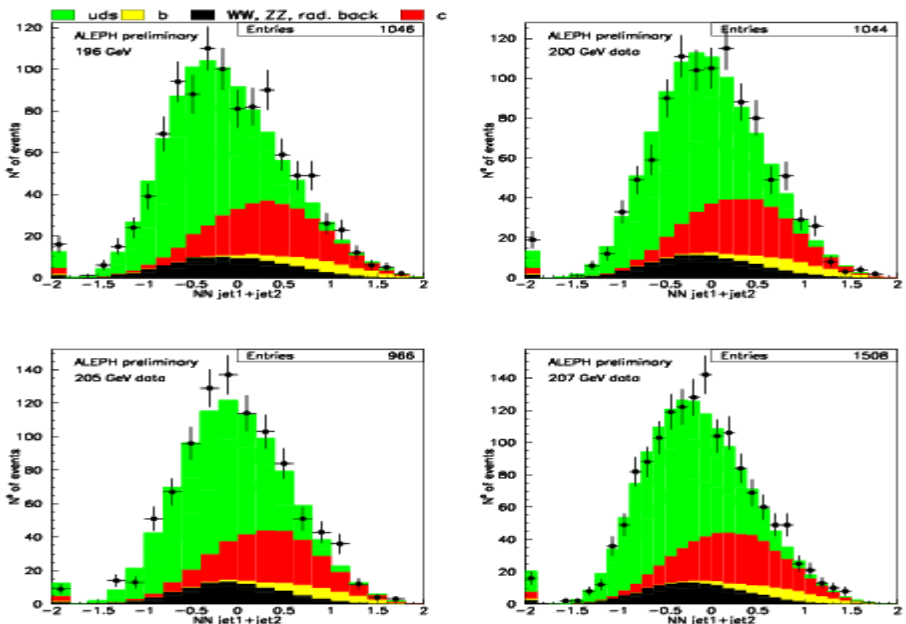
b

- lifetime variable
- mass of secondary vertex
- track rapidity
- jet, vertex charge



c (R_c:A)

- anti b tag
- multivariable NN to separate from light quarks
- NN+combined A_{fb} fit (O)



Data analysis

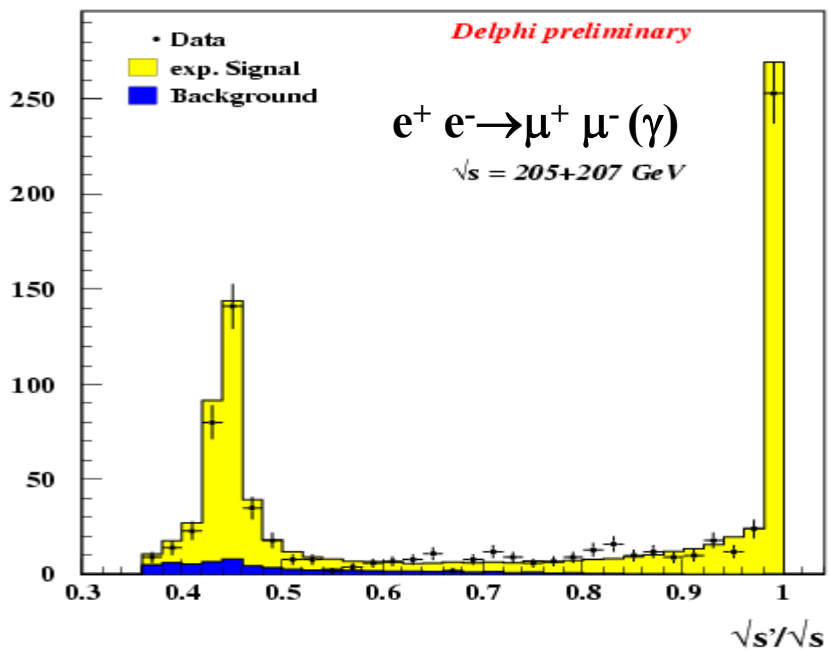
center of mass energy after initial state radiation ($\sqrt{s}'$)

in order to select high energy peak: $\sqrt{s}' \sim \sqrt{s}$:

- **jet/lepton angles**
- **γ detection**
- **Z^0 peak used as a cross check**

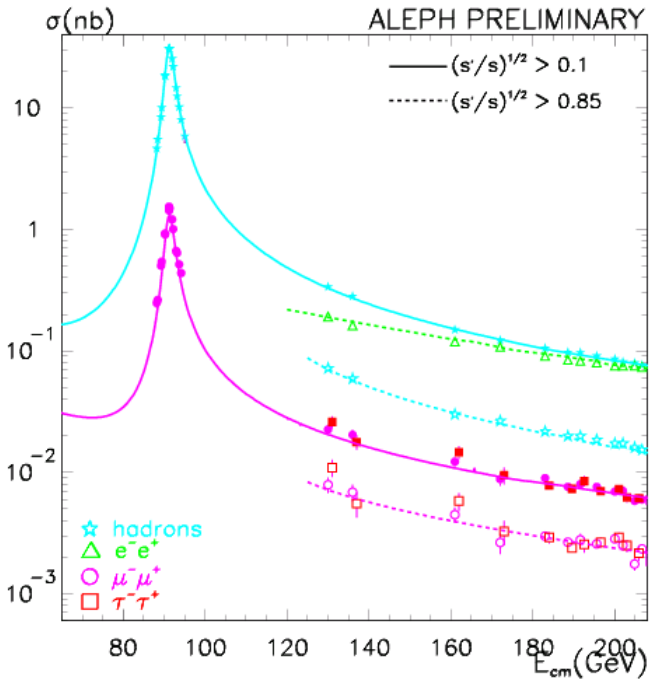
non radiative:

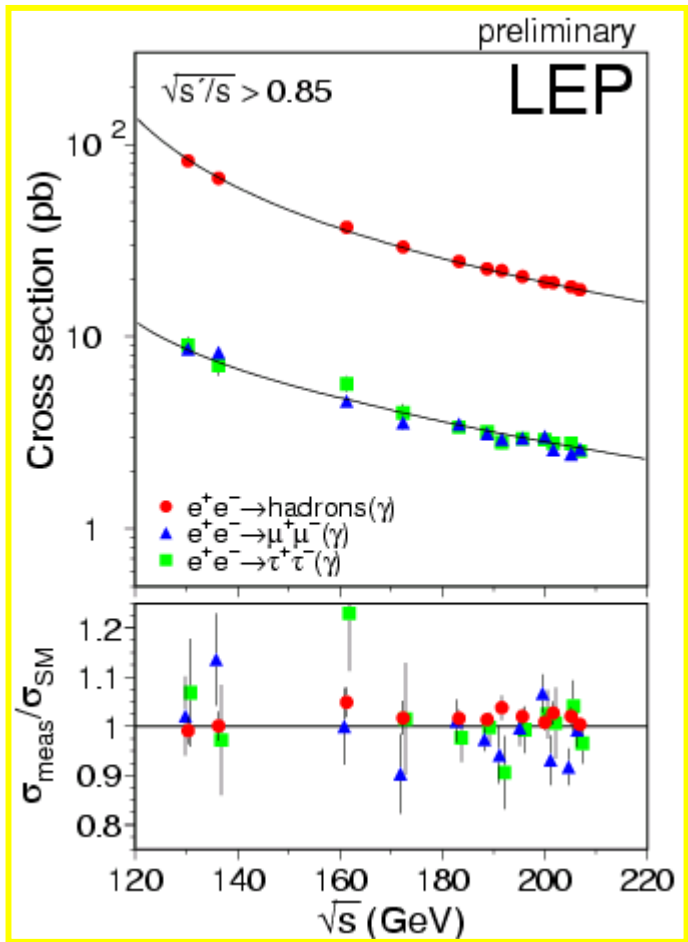
$\sqrt{s}'/\sqrt{s} > 0.85\text{-}0.90$
or (e^+e^-) acol$<20^o$



Results

Cross section and Asymmetries





Results

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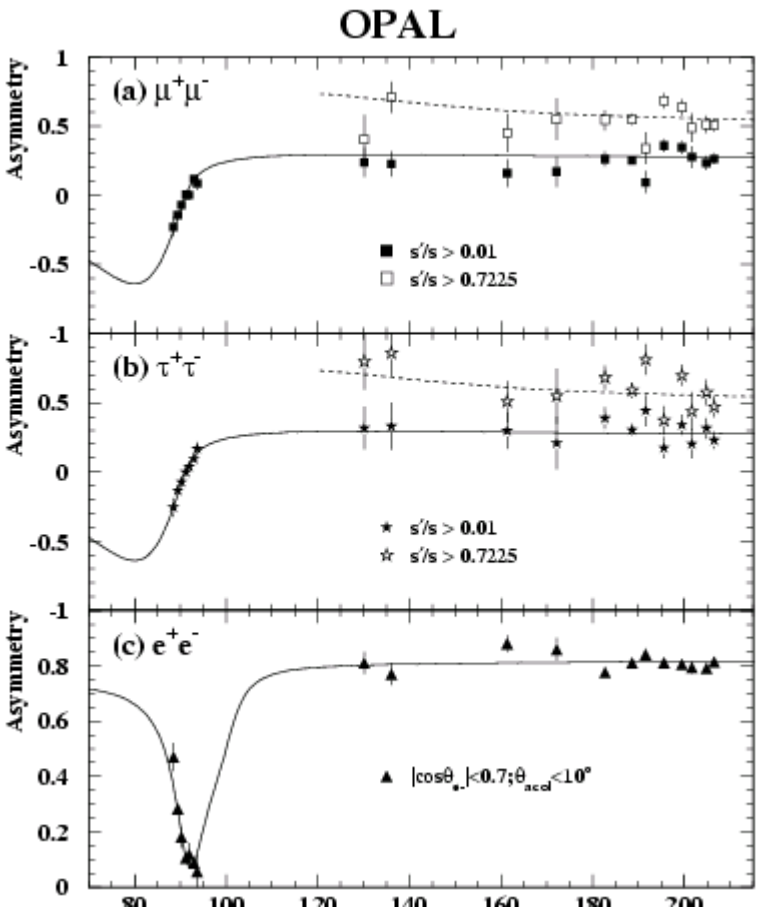
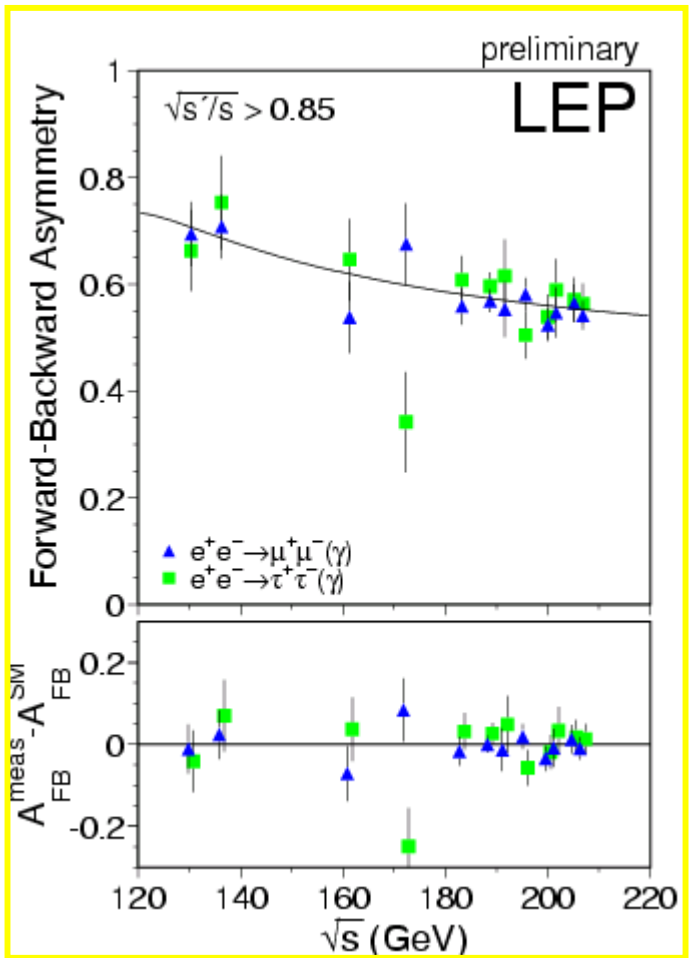
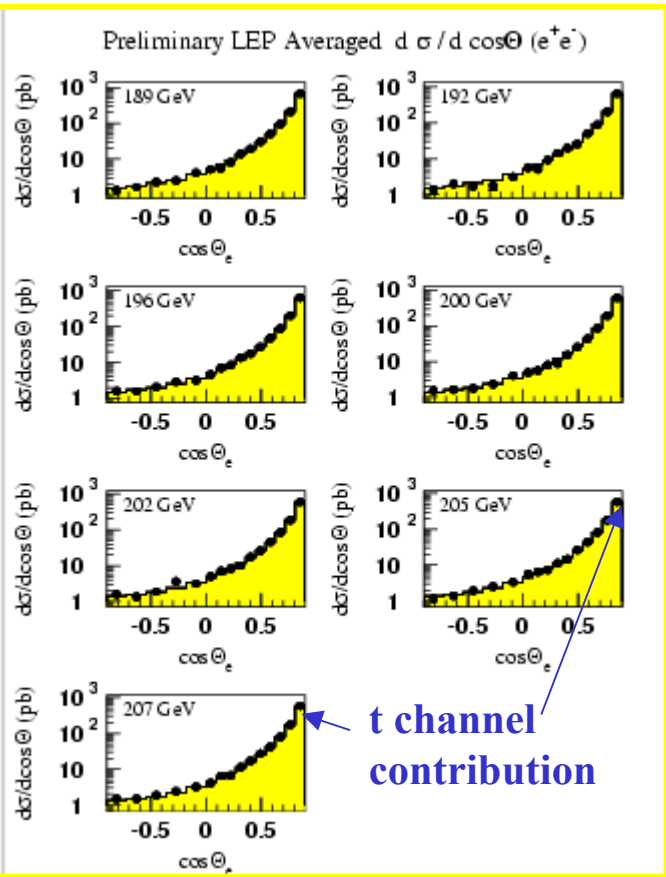
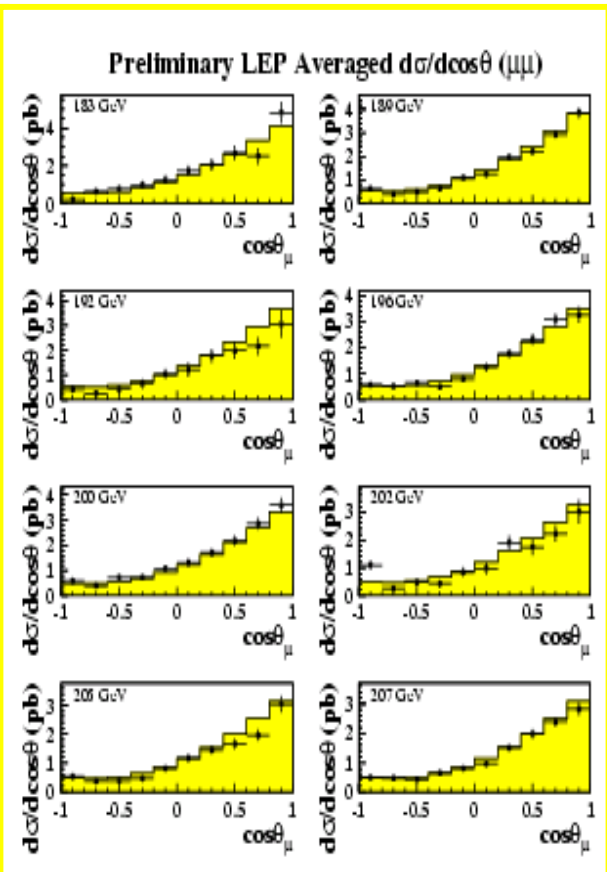


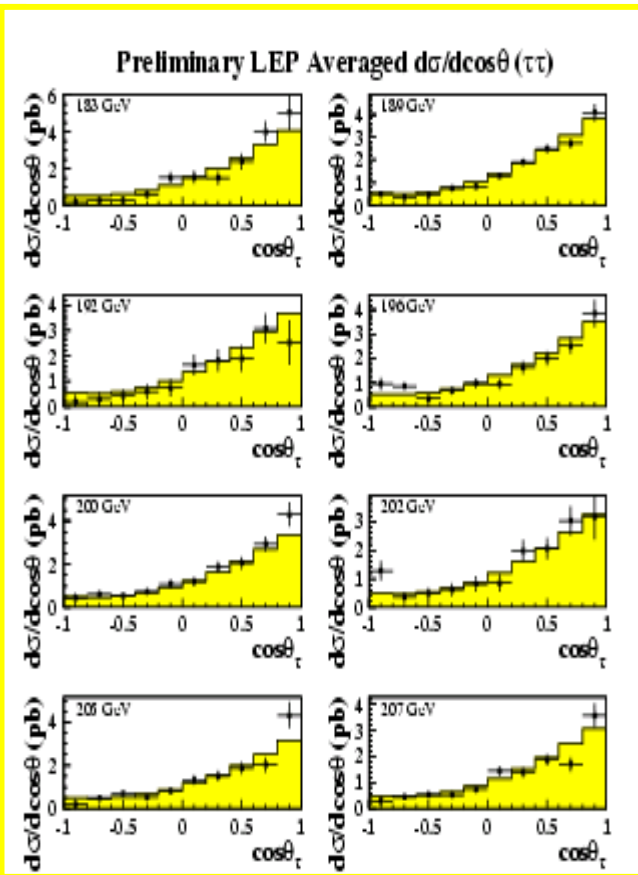


Results

Differential Cross section



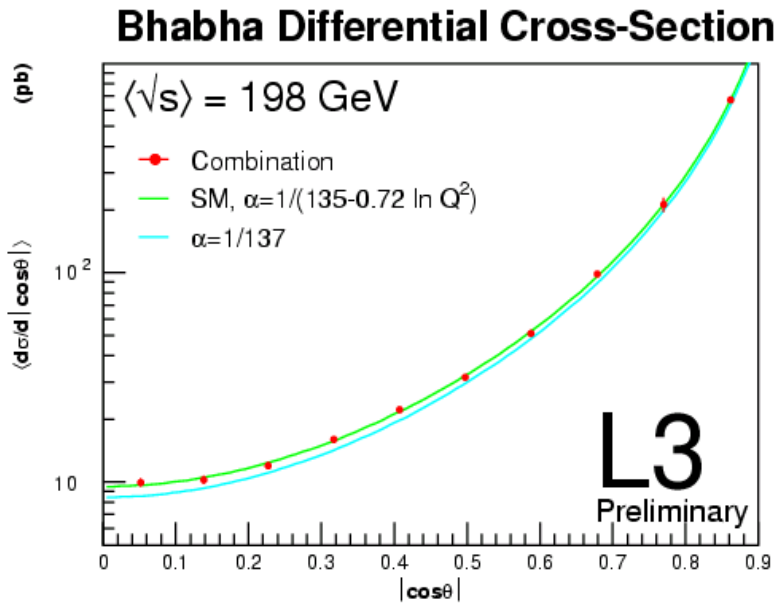




Good agreement with the S.M. expectations

Results

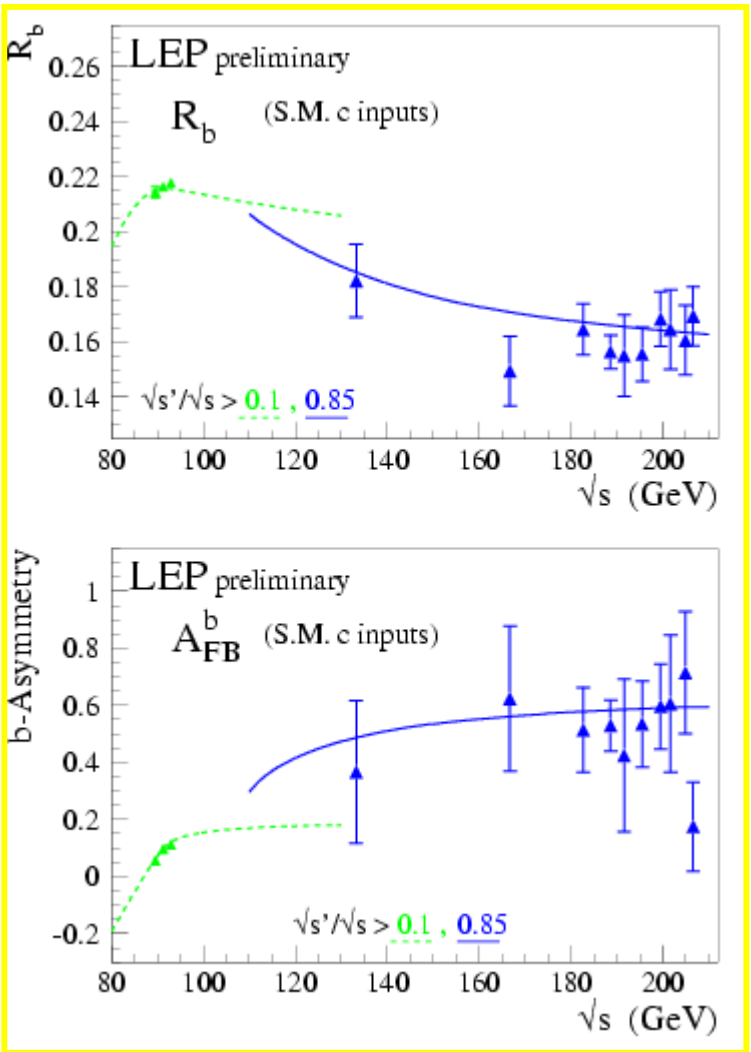
Differential Cross section

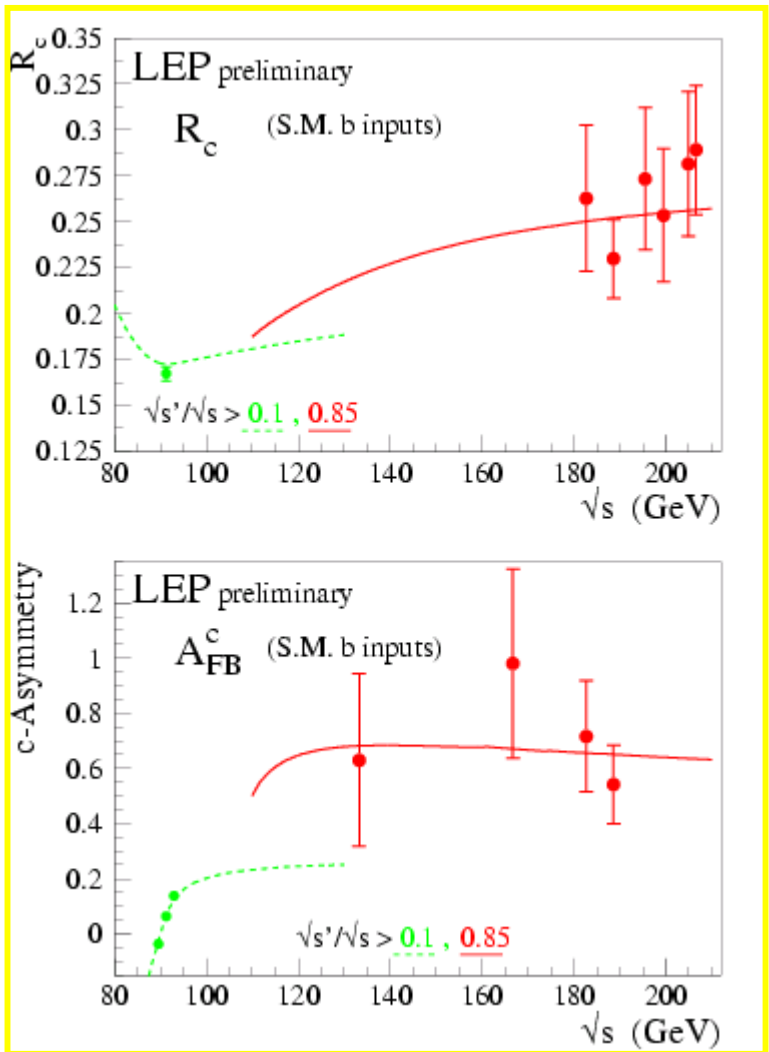


- No running ($\alpha = 1/137$): $\chi^2/\mathrm{ndof} = 173/80$ (CL=10^{-8})
- Consistency with the running of α: $\chi^2/\mathrm{ndof} = 81/80$

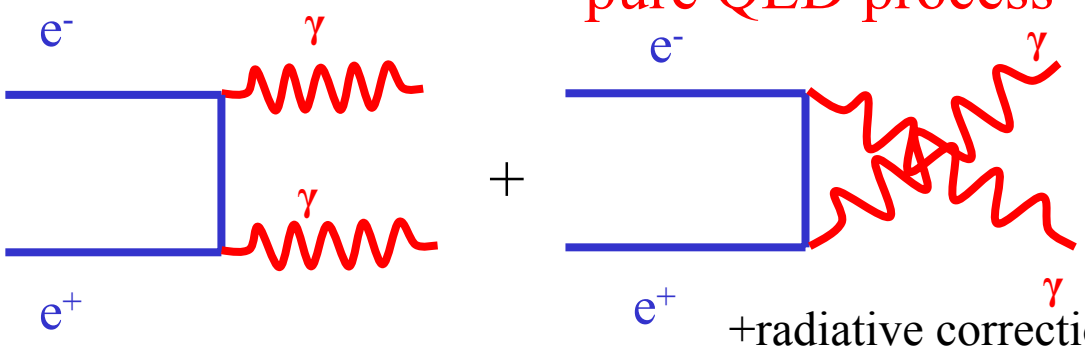
Results

Heavy quarks





Excursus to two-photon production



$$\frac{d\sigma}{d\Omega_{Born}} = \frac{\alpha^2}{s}\frac{1+\cos^2\theta}{\beta_e^{-2}-\cos^2\theta}$$

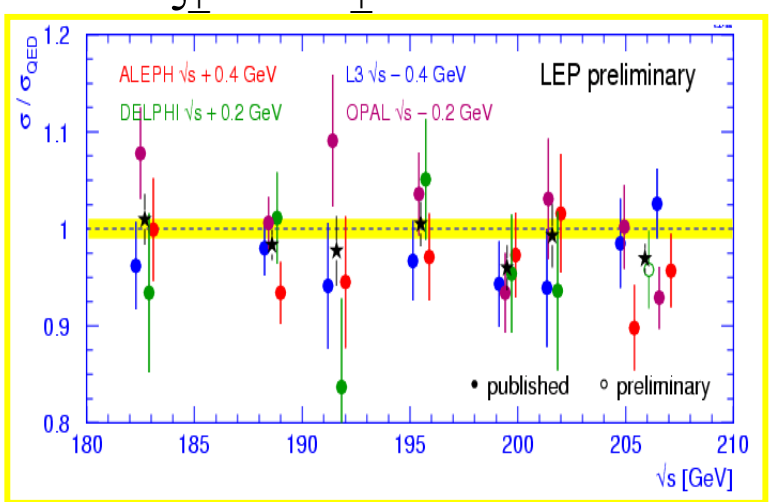
+radiative corrections: $\frac{d\sigma}{d\Omega_{QED}} = \frac{d\sigma}{d\Omega_{Born}}(1+\delta_{QED})$

deviations parametrised as: $\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_{Born}} \pm \frac{d\sigma}{d\Omega_D}$ and

$$\frac{d\sigma}{d\Omega_D} = s\xi(1+\cos^2\theta)$$

i.e. $\xi_{\pm} \propto 1/\Lambda_{\pm}^4$

high energies and high angles



$\sigma_{meas}/\sigma_{QED} = 0.982 \pm 0.01_{exp} \pm 0.01_{rad.\ corr}$

Interpretations

S-Matrix fit

LEP I 5 parameter fit to 2-fermion c.s. and asymm. provides a precise M_Z/Γ_Z determination but γ-Z interference as in SM. In S-Mat. formalism boson exchange and interference contributions can vary independently⇒ 9→16 parameters (5→8 lept. universality)

$$\sigma^0_{tot,f}(s) = \frac{4}{3}\pi\alpha^2\left(\frac{g^{tot}{}_f}{s} + \frac{j_f^{tot}(s-\overline{M}_Z^2) + r_f^{tot}\,s}{(s-\overline{M}_Z^2)^2 + \overline{M}_Z^2\overline{\Gamma}_Z^2}\right)$$

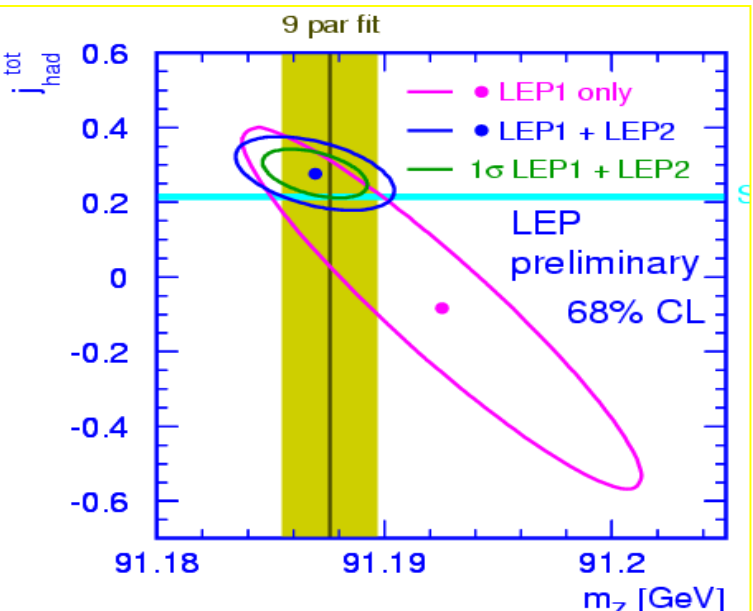
f=had,e,μ,τ or had,l

$$A^0_{fb,f}(s) = \frac{\pi\alpha^2}{\sigma^0_{tot,f}(s)}\left(\frac{g^{fb}{}_f}{s} + \frac{j_f^{fb}(s-\overline{M}_Z^2) + r_f^{fb}\,s}{(s-\overline{M}_Z^2)^2 + \overline{M}_Z^2\overline{\Gamma}_Z^2}\right)$$

f=e,μ,τ or l

LEP I: only 3 precise points in had c.s.⇒ large correlation $M_Z \leftrightarrow j^{tot}_{had}$

LEP II data constrain the interference contributions



data	M_Z (GeV)	j^{tot}_{had}	corr.	χ^2/d.o.f
LEP I only	91.1925 ±0.0059	-0.084 ±0.324	-0.935	62/48
LEPI + LEPII	91.1869* ±0.0023	0.277 ±0.065	-0.461	64/60

*91.1876±0.0021 9-par. fit

Interpretations

Effective Lagrangian

Contact Interactions*

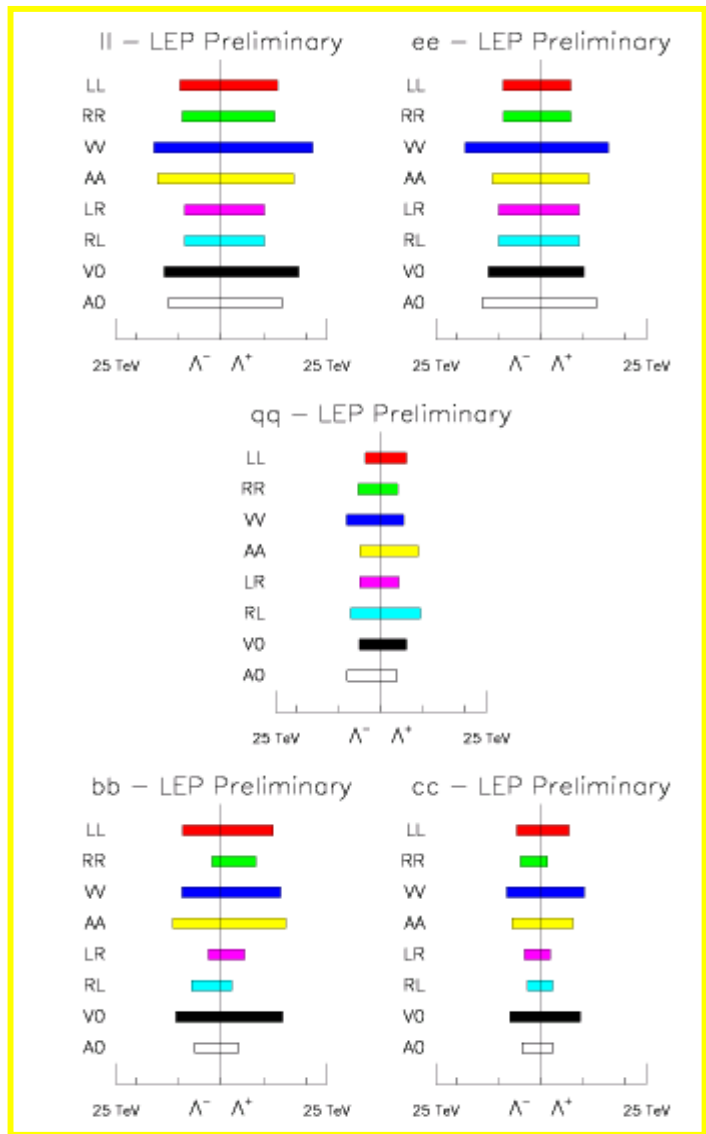
$$L_{eff} = \frac{g^2}{(1+\delta)\Lambda^2} \sum_{i,j=L,R} \eta_{ij} (\bar{e}_i \gamma e_i)(\bar{f}_j \gamma^\mu f_i)$$

Λ energy scale of contact interactions
g unknown coupling (usually $g^2=4\pi$)
δ =1 for e final state (0 elsewhere)
ηij =±1,0 chiral structure of each model

fit σ,A_{FB},$d\sigma/d\cos\theta$,$R_{b,c}$

For photons:

$\Lambda_{\pm}$ >392/364 GeV



* parametrization to describe deviations from SM

Interpretations

Z´ bosons

Several models:

- **GUT E6 models**(2 additional gauge groups; χ,ψ,η depending on mixed state Z´ **)**
- **L-R symmetric models** (Additional $SU(2)_R$; couplings to fermions$\leftrightarrow\alpha_{LR}$ **)**
- **Sequential S.M** (Z´ same couplings as Z **)**

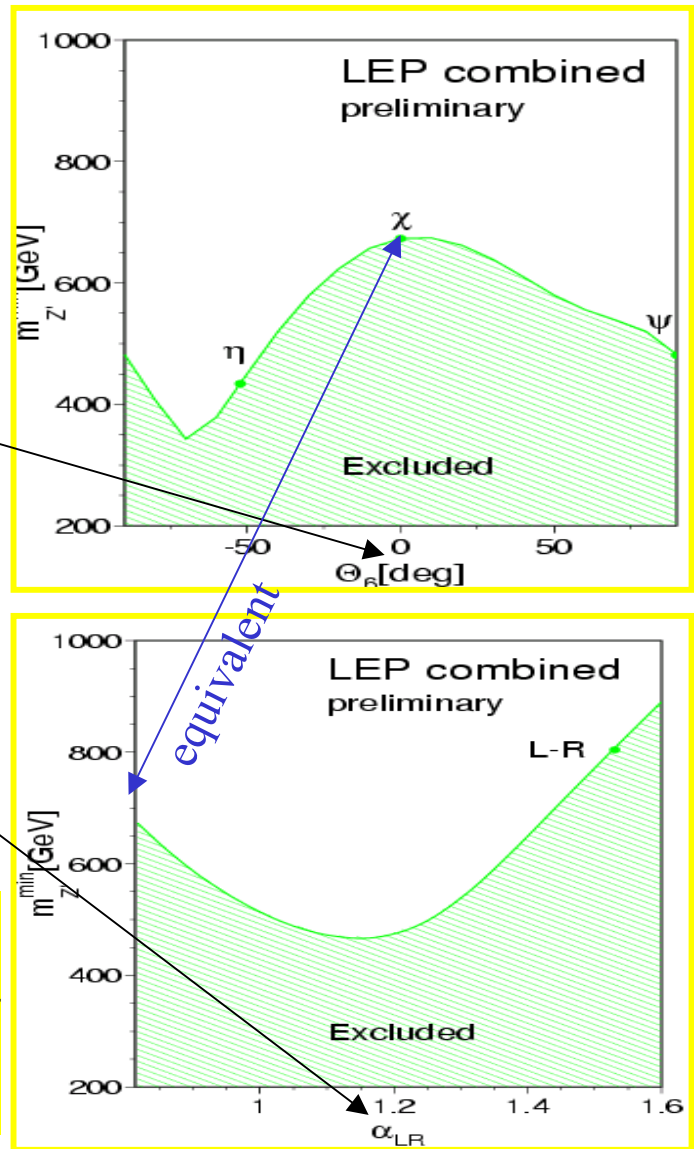
Free parameters:

- Mixing angle $\Theta_{ZZ'}$ (~0 from Lep I)
- **Z´ mass**

fit σ, A_{FB}

No Z´ evidence found, 95% C.L. $M_{Z'}$ limits :

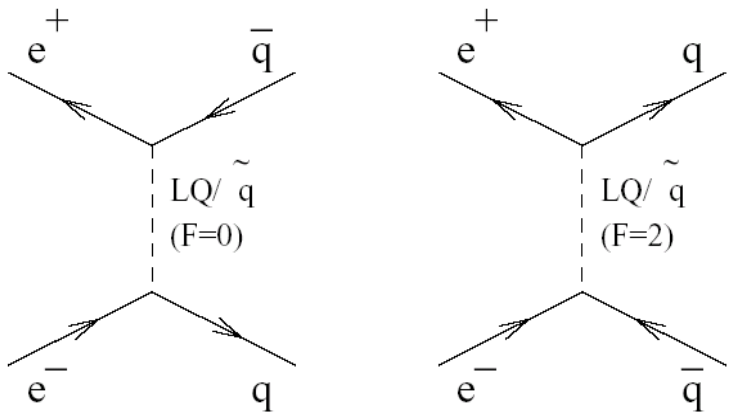
Model	χ	ψ	η	L-R	SSM
Limit (GeV)	673	481	434	804	1787



Interpretations

Leptoquarks

- quark-lepton transition: F=L+3B
- scalar S_I, vectors V_I, hypercharge(~)
- modify σ_{had} , A_{FB} and $R_{b,c}$
- limits on coupling to n^{th} q generation as function of M_{LQ}



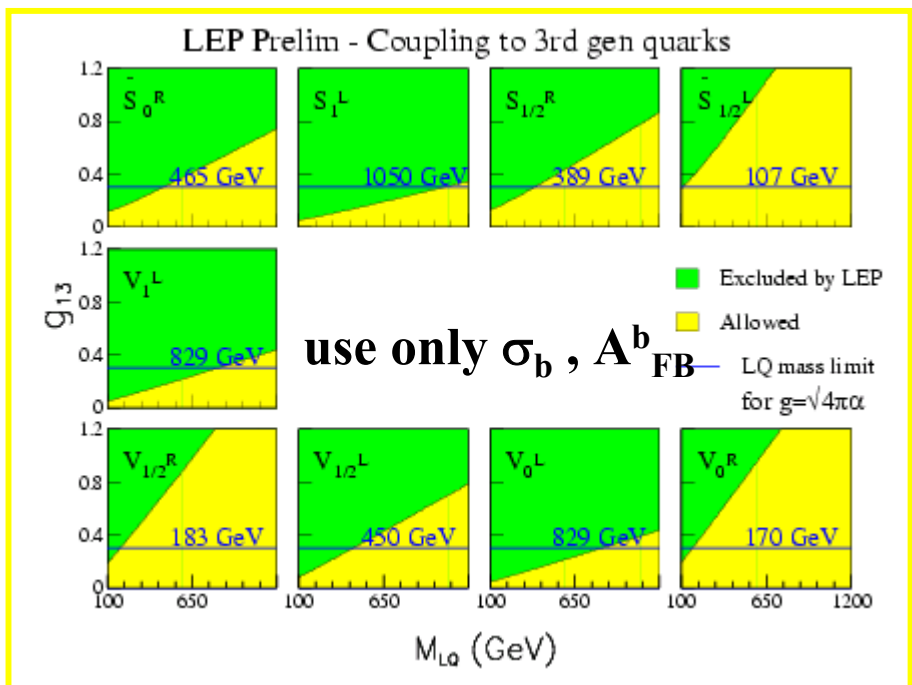
equivalent to R_p violating squarks

Limit on scalar LQ mass (GeV/c^2) $g=\sqrt{4\pi\alpha}$

	$S_0(L)$	$S_0(R)$	$\tilde{S}_0(R)$	$S_{\frac{1}{2}}(L)$	$S_{\frac{1}{2}}(R)$	$\tilde{S}_{\frac{1}{2}}(L)$	$S_1(L)$
LQ_{1st}	655	520	202	178	232	-	361
LQ_{2nd}	539	430	285	269	309	-	478
LQ_{3rd}	NA	NA	465	NA	389	107	1050

Limit on vector LQ mass (GeV/c^2)

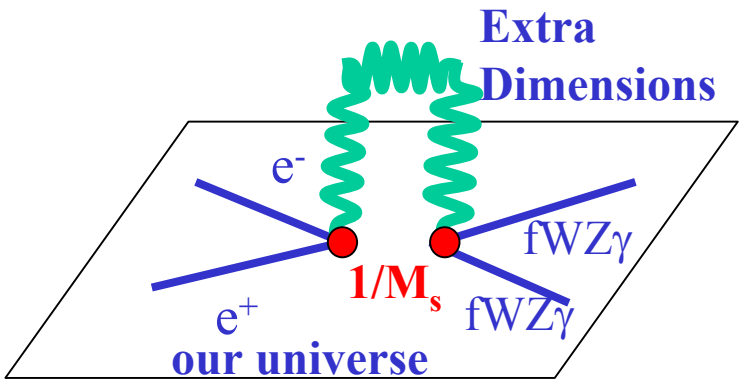
	$V_0(L)$	$V_0(R)$	$\tilde{V}_0(R)$	$V_{\frac{1}{2}}(L)$	$V_{\frac{1}{2}}(R)$	$\tilde{V}_{\frac{1}{2}}(L)$	$V_1(L)$
LQ_{1st}	917	165	489	303	227	176	659
LQ_{2nd}	692	183	630	357	256	187	873
LQ_{3rd}	829	170	NA	451	183	NA	829



use only σ_b , A^b_{FB}

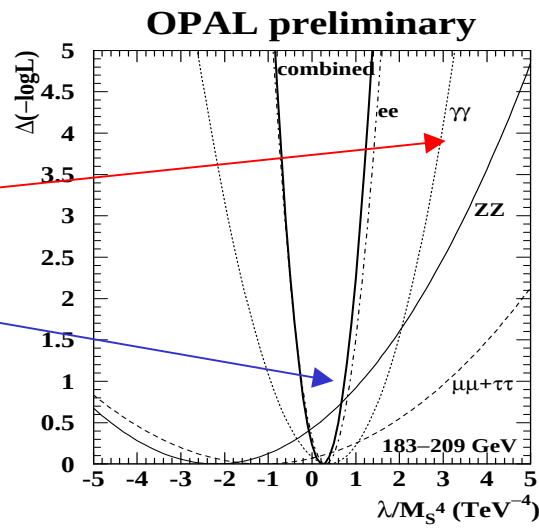
Interpretations

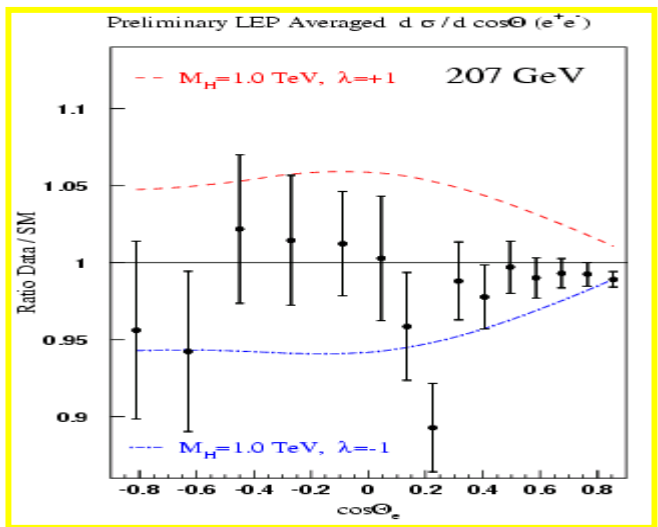
Quantum Gravity extra dimensions



contributions from virtual exchange of Kaluza Klein excitations of graviton

max sensitivity for $e^+e^-,\gamma\gamma$ angular distribution





LEP $e^+e^-\rightarrow e^+e^-$:
λ=+1: M_S> 1020 GeV
λ= -1: M_S> 1009 GeV

LEP $e^+e^-\rightarrow\gamma\gamma$:
λ=+1: M_S> 933 GeV
λ= -1: M_S> 1010 GeV

Conclusions

- **Fermion (and photon) pair production studied at LEP in the whole energy range from Z^0 to $\sqrt{s}$~208 GeV**
- **Good agreement with Standard Model both from the single experiments and the combined results**
- **S matrix fit ~ as precise as SM fit**
- **Limits on several models of Physics beyond Standard Model:**

  Contact Interactions, Z ′ , Leptoquarks, Quantum Gravity

Still preliminary but final results and combinations coming soon

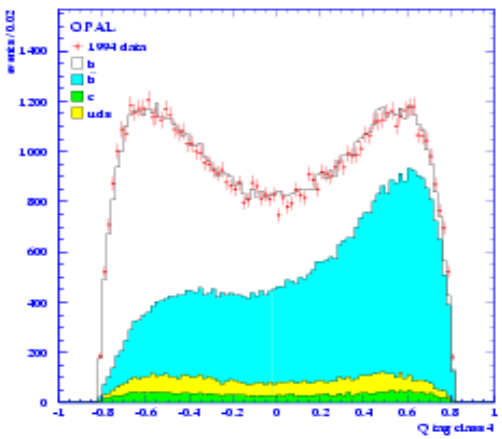
Results

LEP 1

$A_{FB}(b)$ at Z

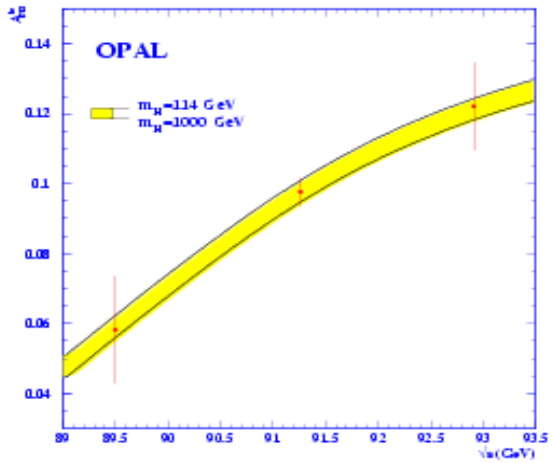
Combination of 4 charge tags

using jet, vertex, $K^{\pm}$



Sophisticated fitting procedure

$$A_{FB}^{b} = 0.0582 \pm 0.0153 \pm 0.0012 \quad pk-2$$
$$A_{FB}^{b} = 0.0977 \pm 0.0036 \pm 0.0018 \quad pk$$
$$A_{FB}^{b} = 0.1221 \pm 0.0123 \pm 0.0025 \quad pk+2$$



New OPAL result

$$A_{FB}^{0,b} = 0.1002 \pm 0.0034 \pm 0.0018$$
$$\sin^2\theta_{eff}^{e} = 0.23205 \pm 0.00068$$

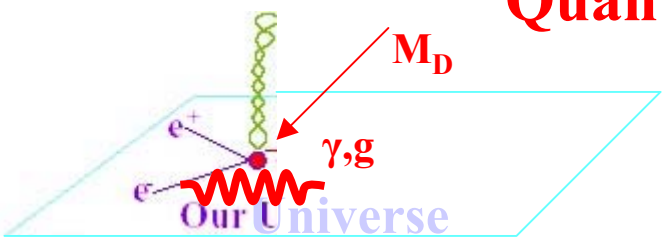
Previous OPAL result

$$A_{FB}^{0,b} = 0.1007 \pm 0.0055 \pm 0.0040$$

Final A_{FB}^{b} using leptons will follow soon.

Results

Quantum Gravity extra dimensions

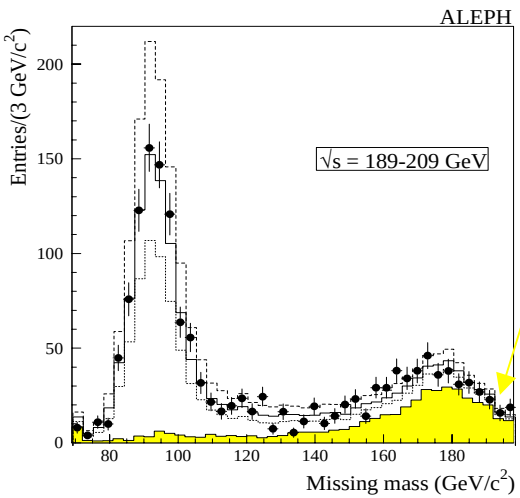


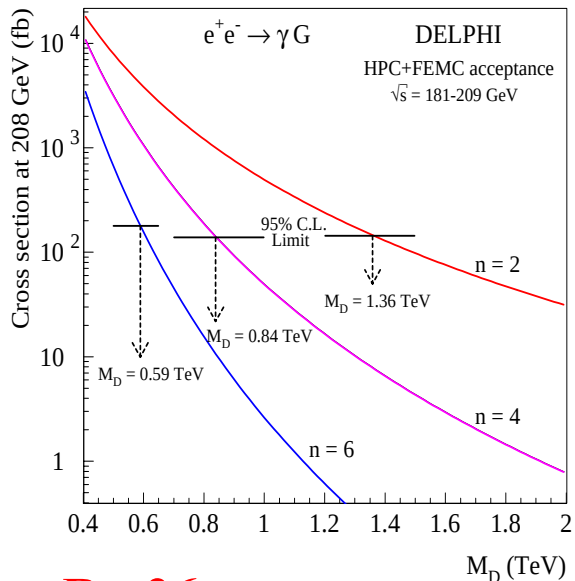
Direct Effects

$e^+e^- \rightarrow G\gamma$: single photon (see also superlight $\tilde{G}$)

Limits depend on the number of extra dimensions

Produzione centrale e a bassa E_γ





ADLO: limiti M_D>1÷1.35 TeV per n=2

M_D>.51÷.59TeV per n=6

⇒

R<.26mm

R<6x10^{-12} m