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EPS-HEP 99

Fermion pair production at LEP2 from 130 to 196 GeV

Marie-Noelle Minard

Laboratoire de Physique des Particules d'Annecy
France

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Outline

- Features of fermion pair production above the Z pole
  - Variable choice and definition
  - Test Standard Model extensions
    (see R.HARTMUT talk)

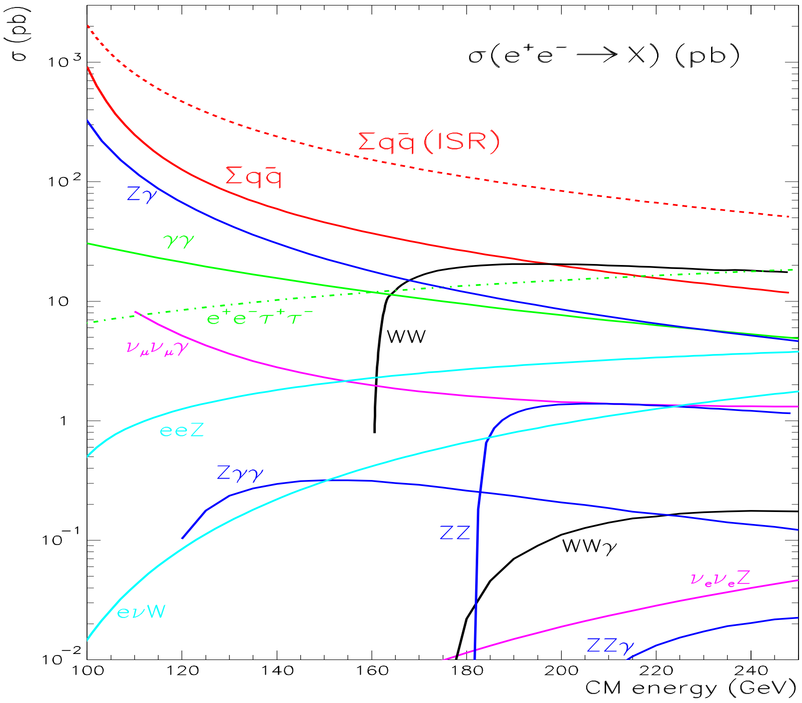
- Experimental aspects and results on $f\bar{f}$ production
  - Cross-section and asymmetry measurements (quark, μ,τ pairs)
  - Flavor tagged event cross-sections and asymmetries.
  - Asymmetries (leptons and quark pairs)

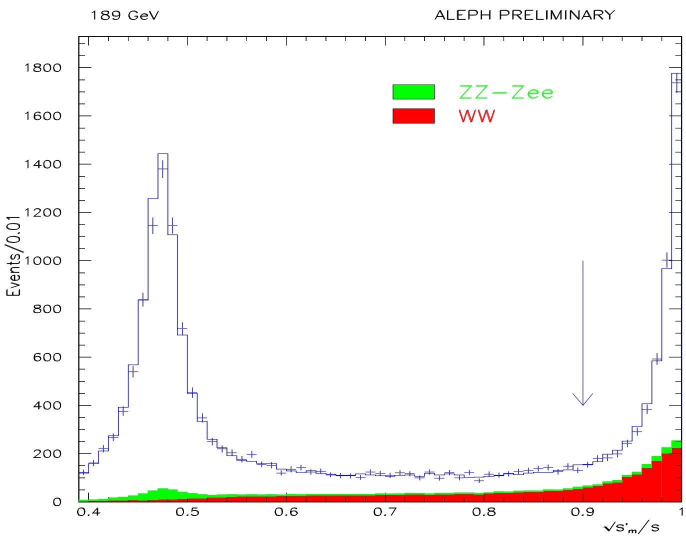
- Combined ADLO results (LEPWWG working group)

- Search for $e^+e^- \rightarrow$ t$\bar{c}(\bar{u})$

- Conclusion

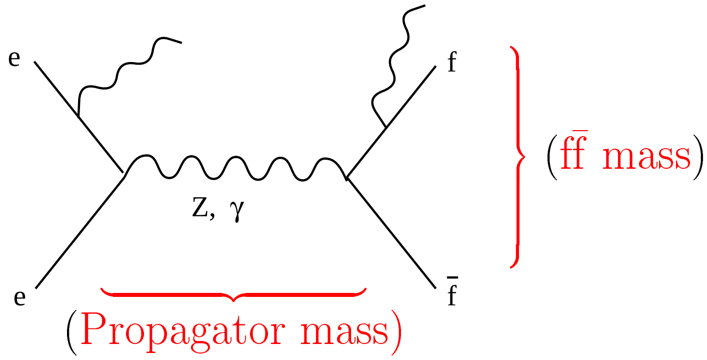
Standard Model Processes above the Z peak





- Cross-sections enhanced by $\sim$5 from QED
- Experiments cross-sections for 2 effective energy ranges
- $\sqrt{s'} > 0.85\sqrt{s}$ open new domain

- Generator level :

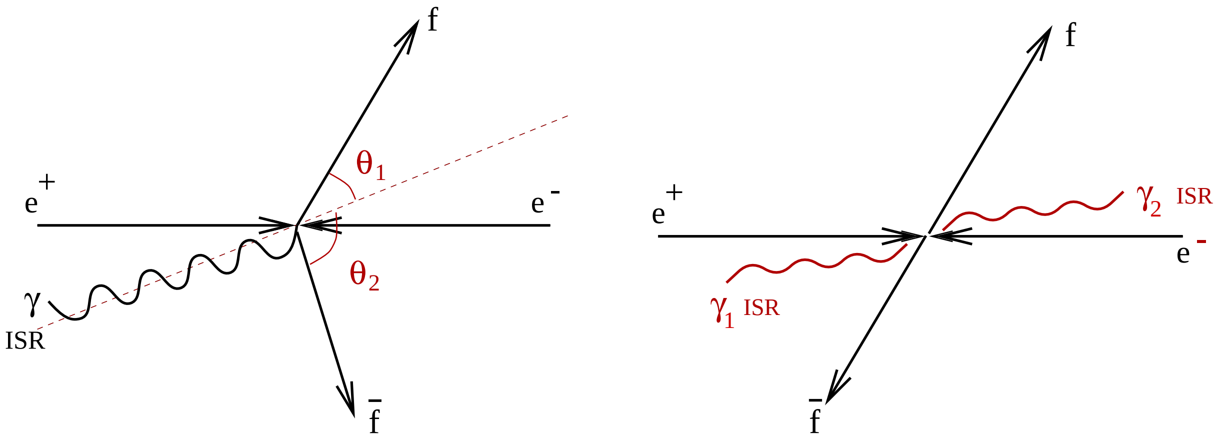


$$\sqrt{s'} = M_{f\bar{f}} \text{ or } M_{Z\gamma^*} \text{ ?}$$

- ISR/FSR interference ambiguous definition
- γ/gluon final state for quarks

- Experimental definition of s'_{meas} :

$$\Rightarrow s'_{meas} = \frac{\sin\theta_1 + \sin\theta_2 - |\sin(\theta_1+\theta_2)|}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1+\theta_2)|} \times \text{s}$$



- Jet/lepton angle direction
- Visible energy of fermion final state
  Kinematic fit .
- Identified hard photon detected.

Aleph, Delphi, L3, Opal

All results are preliminary

$\sqrt{s}$ **(GeV)**	130	136	161	172	183	189	192	196
Year	95/97	95/97	96	96	97	98	99	99
$\int \mathcal{L}$ dt **/exp (pb^{-1})**	6	6	10	10	55	175	25	20
ALEPH	P	P	P	P	P	C	C	C
DELPHI	P	P	P	P	C	C	C	C
L3	P	P	P	P	C	C	C	C
OPAL	P	P	P	P	P	C	C	C

P = Published C = conference contribution
C = Current data-taking

- Backgrounds (MC estimation)

  $\gamma\gamma \to f\ \bar{f}$, WW, Z$e^+e^-$, ZZ^*

- σ and A_{fb} quoted for two ranges

  - Inclusive measurements $\sqrt{s'/s} > 0.1$

    ♠ ZZ^* background

  - Exclusive measurements $\sqrt{s'/s} > 0.85 \sim 0.9$

    ♠ WW background (cut)

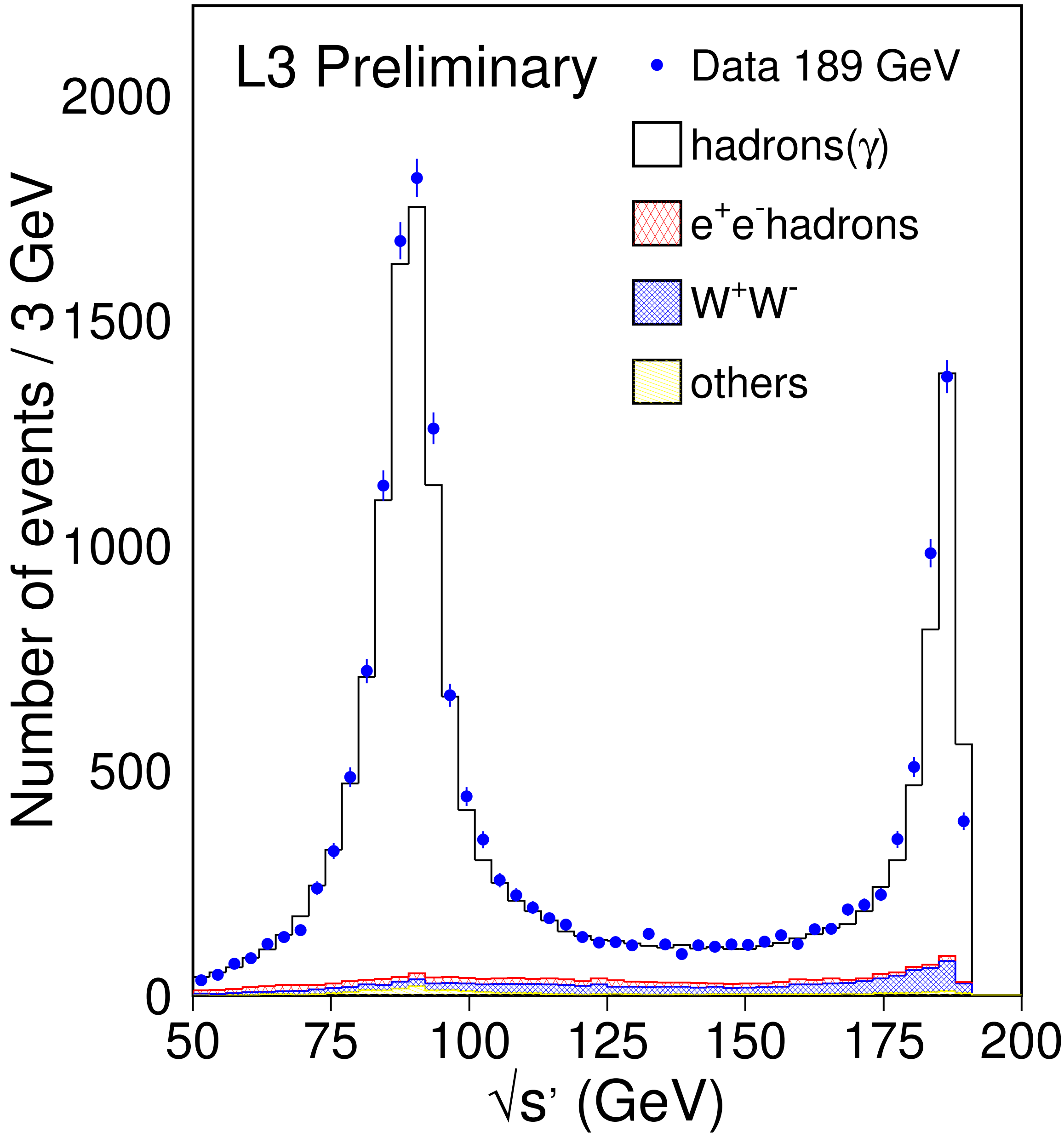
    ♠ Results quoted corrected for ISR/FSR interference from Zfitter (OPAL,L3)

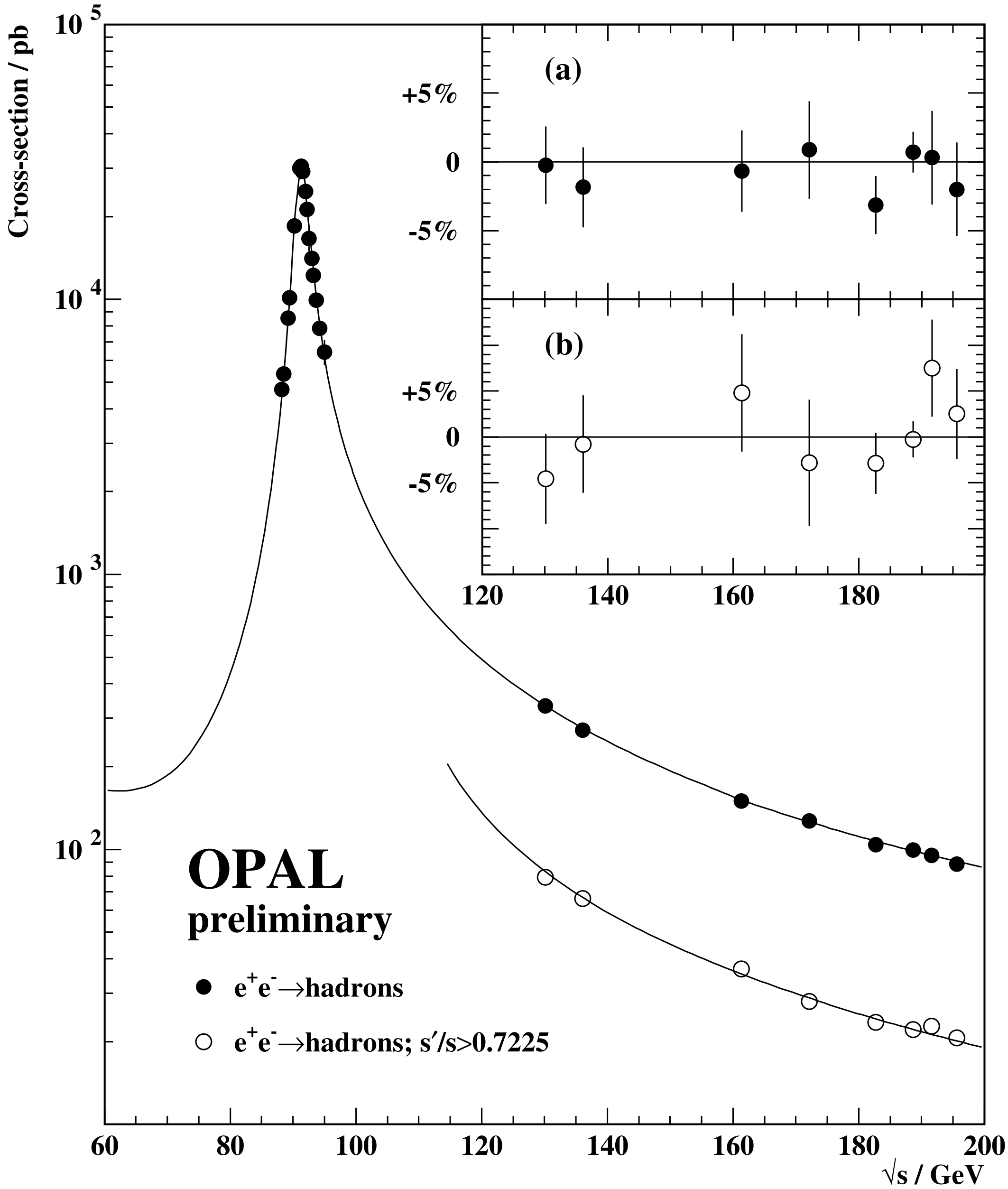
- Smallest error achieved for 189 GeV /exp. :

$\sqrt{s'}/\sqrt{s}$	flavor	ϵ %	Purity %	stat. %	sys. %
>0.1	$q\bar{q}$	85	87	0.5	$\sim$ 0.5
	$\mu^+\mu^-$	75	95	3	$\sim$ 1.5
	$\tau^+\tau^-$	43	85	4	$\sim$ 1.5
>0.85∼0.9	$q\bar{q}$	87	90	2	$\sim$ 0.5
	$\mu^+\mu^-$	90	98	5	$\sim$ 1.5
	$\tau^+\tau^-$	60	90	6	$\sim$ 1.5

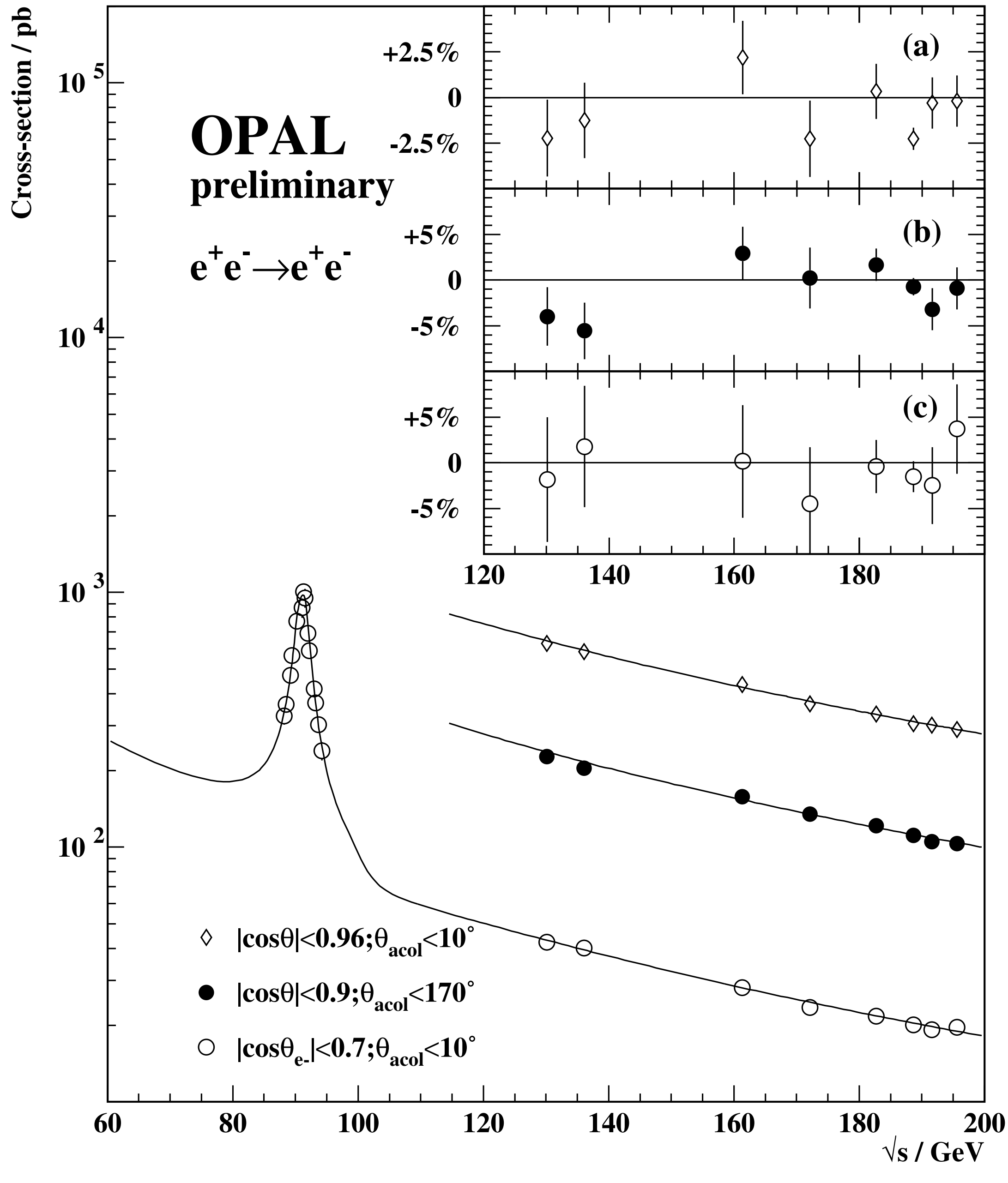
- Luminosity error ∼0.2% among which ∼0.12% from the theory (CERN-TH/99-07)

- Each experiment provides SM expectations corresponding to their selection procedure and extrapolation


L3 Preliminary
Data 189 GeV
hadrons(γ)
e⁺e⁻hadrons
W⁺W⁻
others
Number of events / 3 GeV
2000
1500
1000
500
0
50
75
100
125
150
175
200
√s' (GeV)

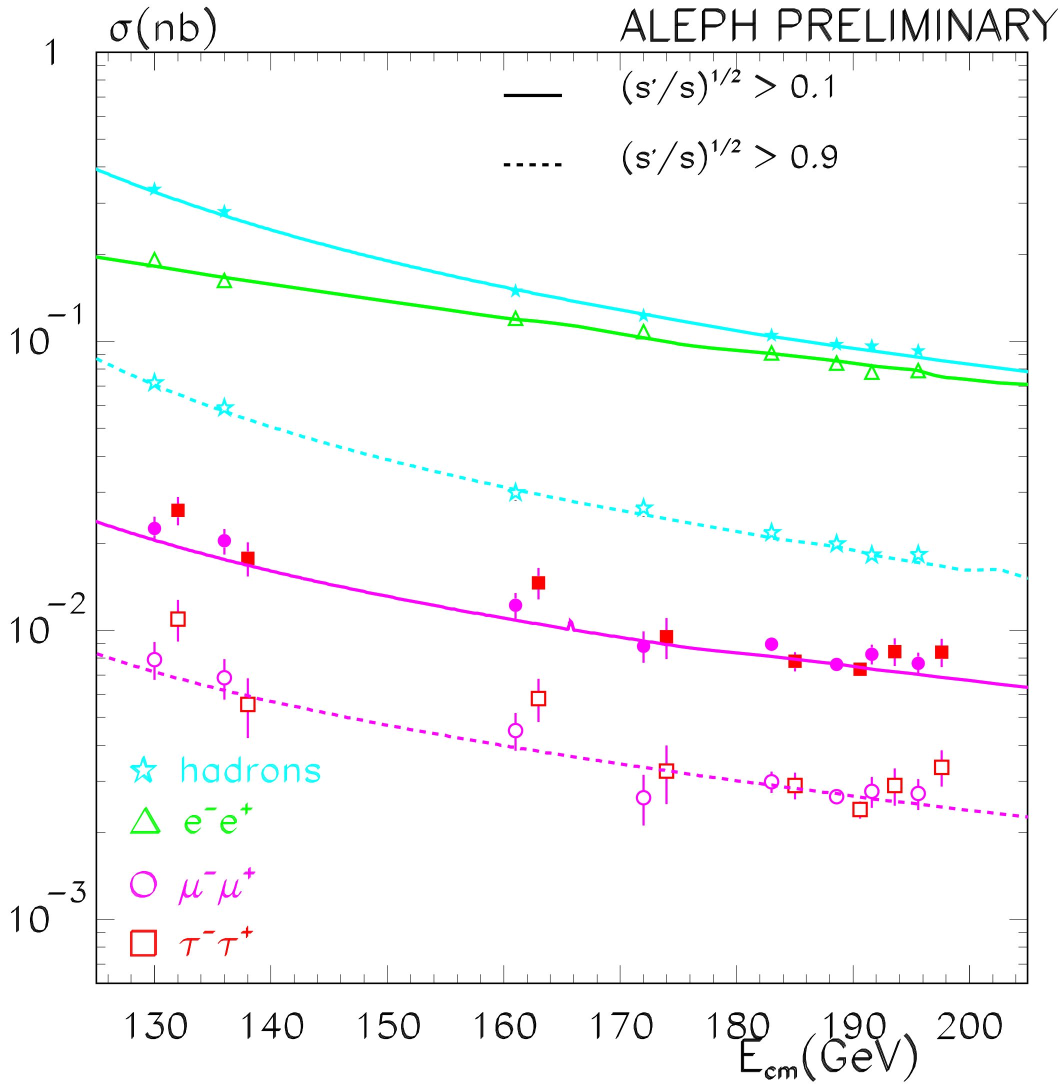


- Good agreement with SM



- Acollinearity replace $\sqrt{s'}$

- Results given for different $cos\theta$ ranges



- Good agreement with SM

- Major systematics to hadronic cross sections
  - ISR modelling (~0.5 %)
    KK2F, PYTHIA, KORALZ
  - Fragmentation (~0.3 %)
    JETSET/HERWIG
  - WW background (~0.4 %)
  - s' definition (~0.5 %)

- Major systematic to leptonic cross-section
  - Detector systematic effect (Tracking, E-scale)
  - 4-fermion contribution (Excalibur , Grace4f)

- Systematics quoted for the different channels

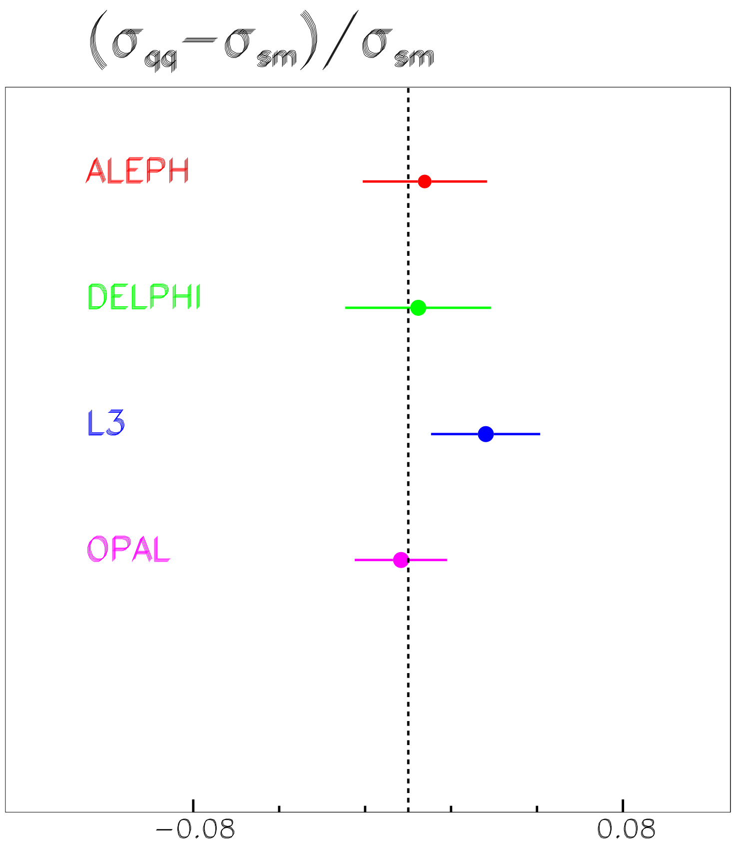
$\sqrt{s'}\,/\sqrt{s}$	> 0.1	> 0.9
$q\bar{q}$	0.5~1%	1%
$\mu^+\mu^-$	1.~2.%	1%
$\tau^+\tau^-$	3%	3%
e^+e^-	0.5~1%	0.5~1%

- Systematic at the level of statistic for $q\bar{q}$ channel

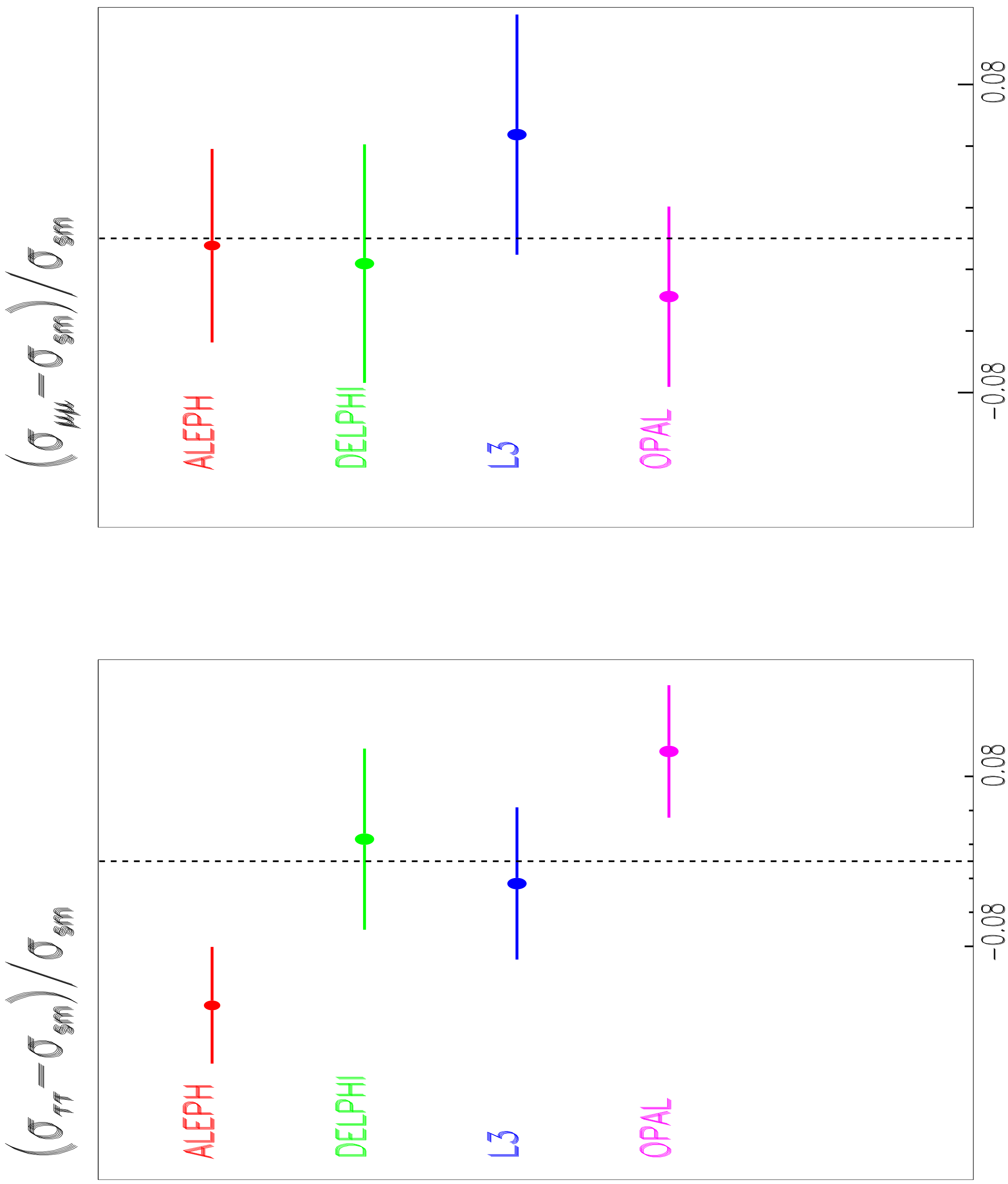
Good agreement with SM expectation

- $\int \mathcal{L}$ dt /expt $\sim$ 175 pb^{-1} $\sqrt{s}$=189 GeV
  $\sqrt{s'}$/s, >0.85 $\sim$ 0.9

  - Hadron precision $\sim$ 2 %
  - μ (τ) $\sim$ 5(6) %
  - Predictions from Zfitter 6.0

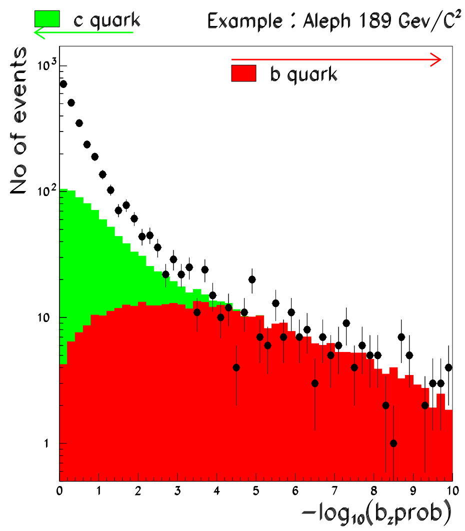


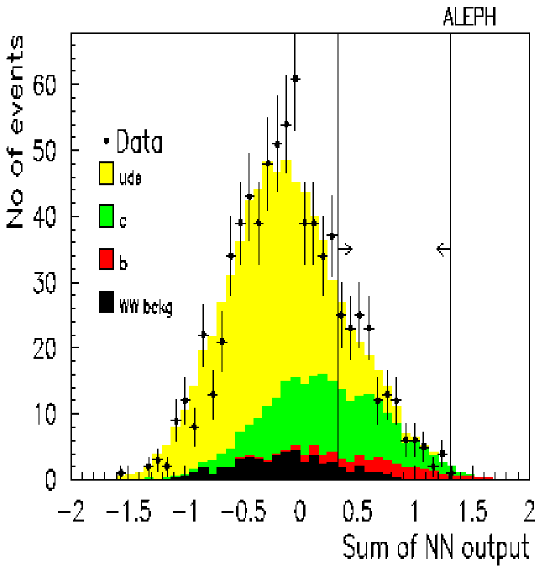
Good agreement with SM expectations



- Measurements on Flavour tagged quarks
  - ALEPH : R_b, R_c, A^b_{fb}, A^c_{fb}, Q^{udsc}
  - DELPHI : R_b, R_c,R_{uds}, A^b_{fb}, A^c_{fb}, A^{uds}_{fb}
  - L3 : R_b, A^b_{fb}
  - OPAL : R_b, A^b_{fb}, A^c_{fb}

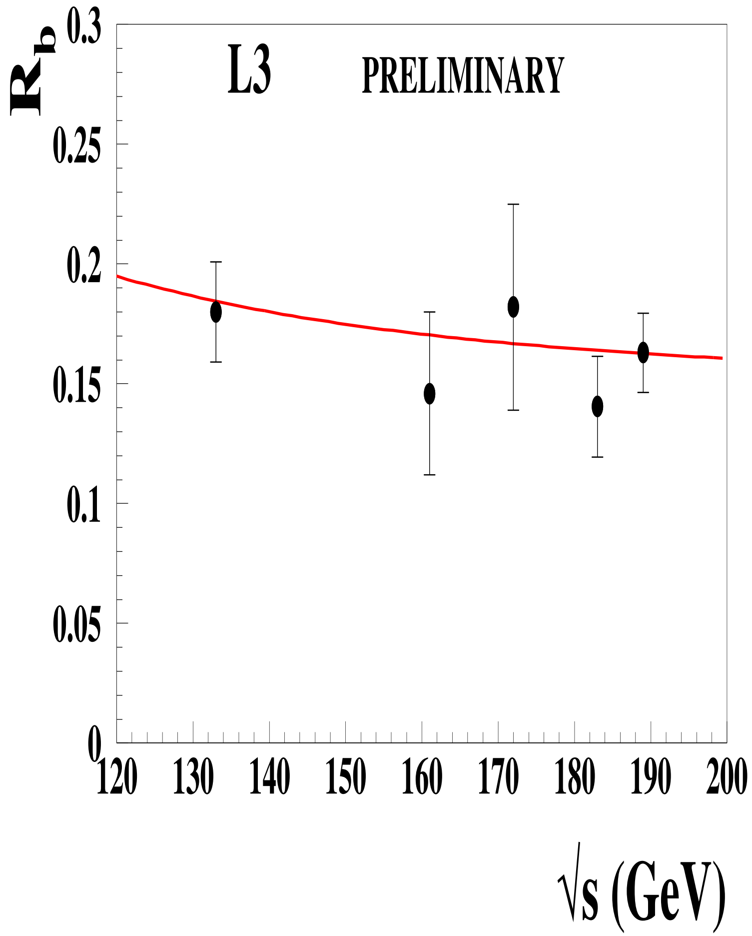
- Enriched b, c, uds samples

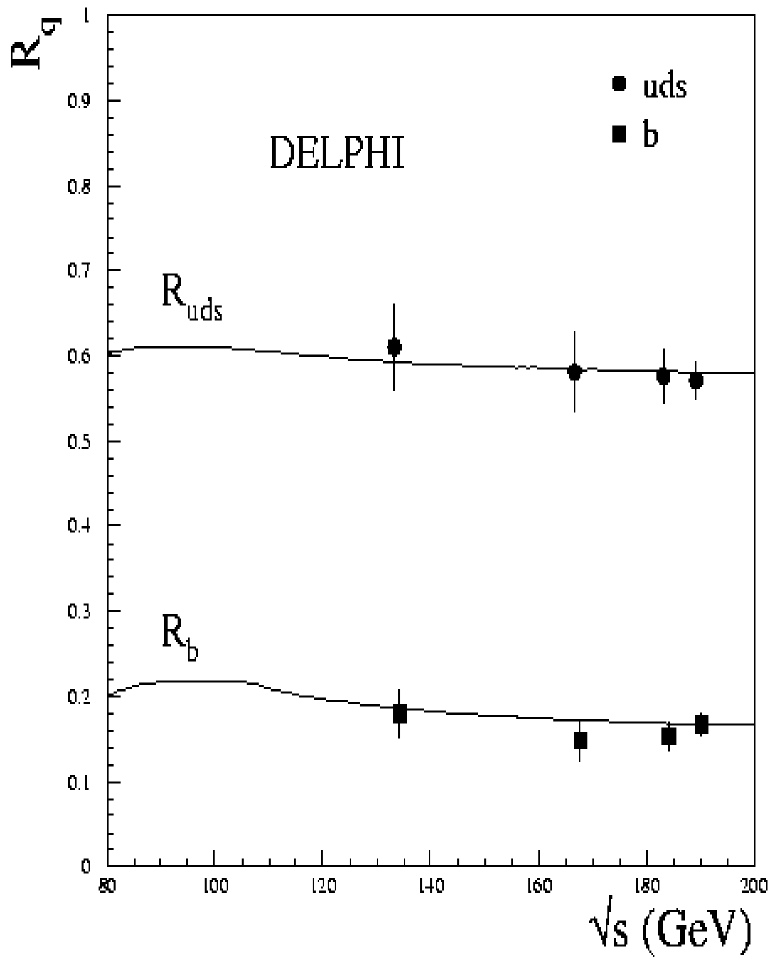


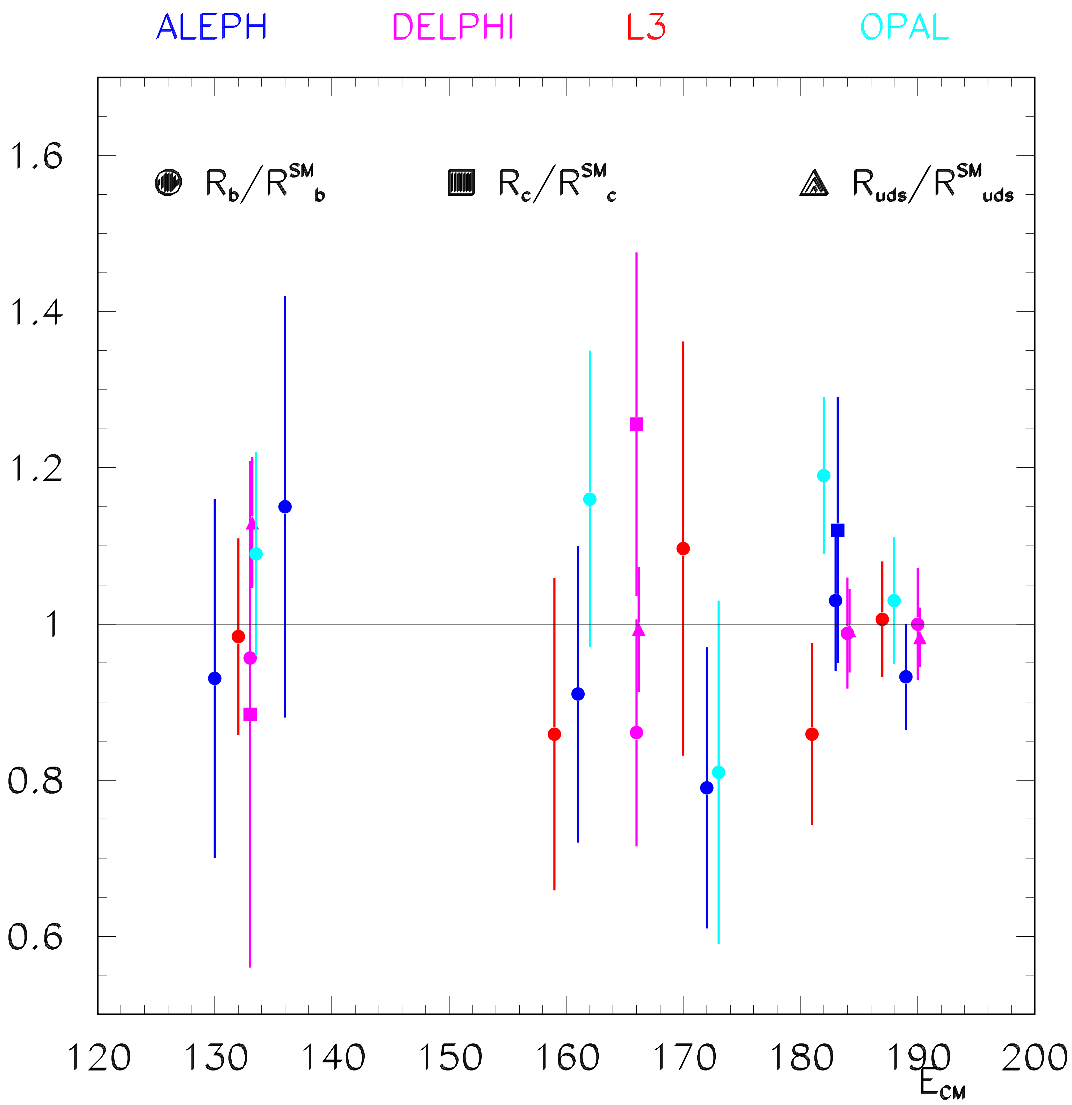


- B enriched Sample
- Lifetime tag
- Purity$\sim$ 60%
- $\epsilon \sim 70\%$,
  $\delta\sigma_b/\sigma_b \sim 10\%$

- C enriched Sample
- Anti B tag
- Neural net
  Impact parameter
  lepton tag
  Kinematic varables
- Purity$\sim$ 30%
- $\epsilon \sim 30\%$,
  $\delta\sigma_c/\sigma_c \sim 30\%$

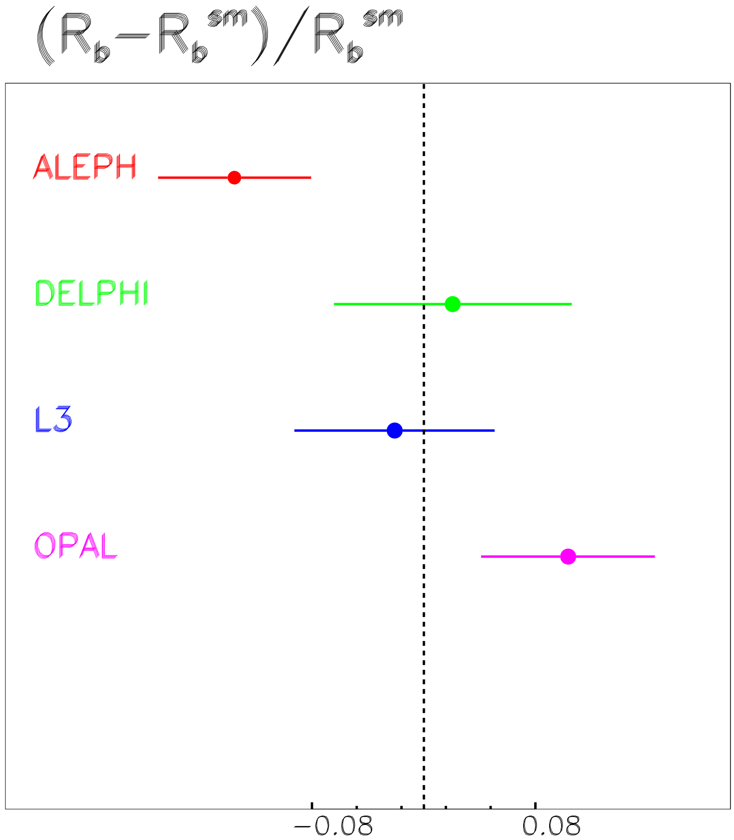

L3
PRELIMINARY
R_b
0.3
0.25
0.2
0.15
0.1
0.05
0
120
130
140
150
160
170
180
190
200
√s (GeV)


DELPHI
uds
b
R_q
R_{uds}
R_b
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
80
100
120
140
160
180
200
√s (GeV)



- Good agreement with SM expectations

- $R_b R_c$ averaged for $\sqrt{s}$=189GeV
- Statistical errors dominates
- Systematic due to flavor rate taken as fully correlated

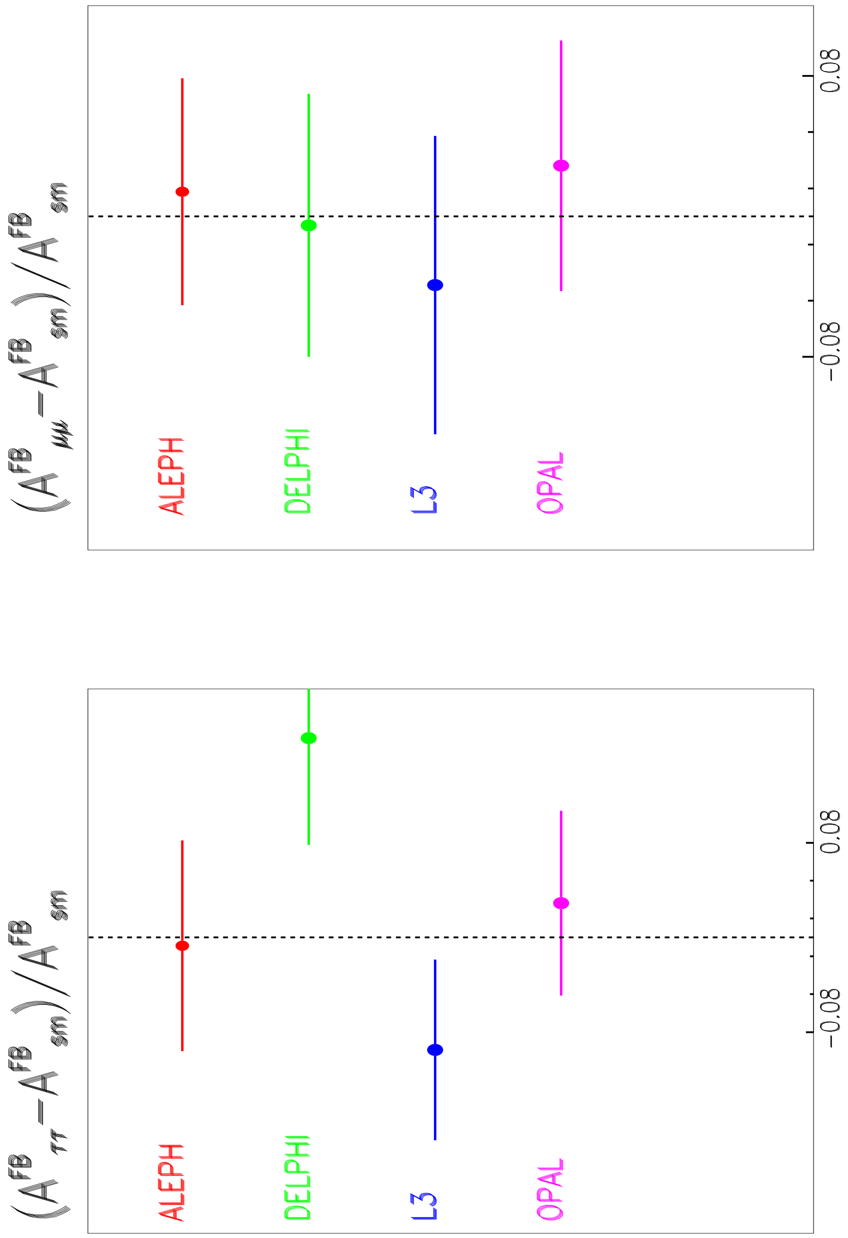


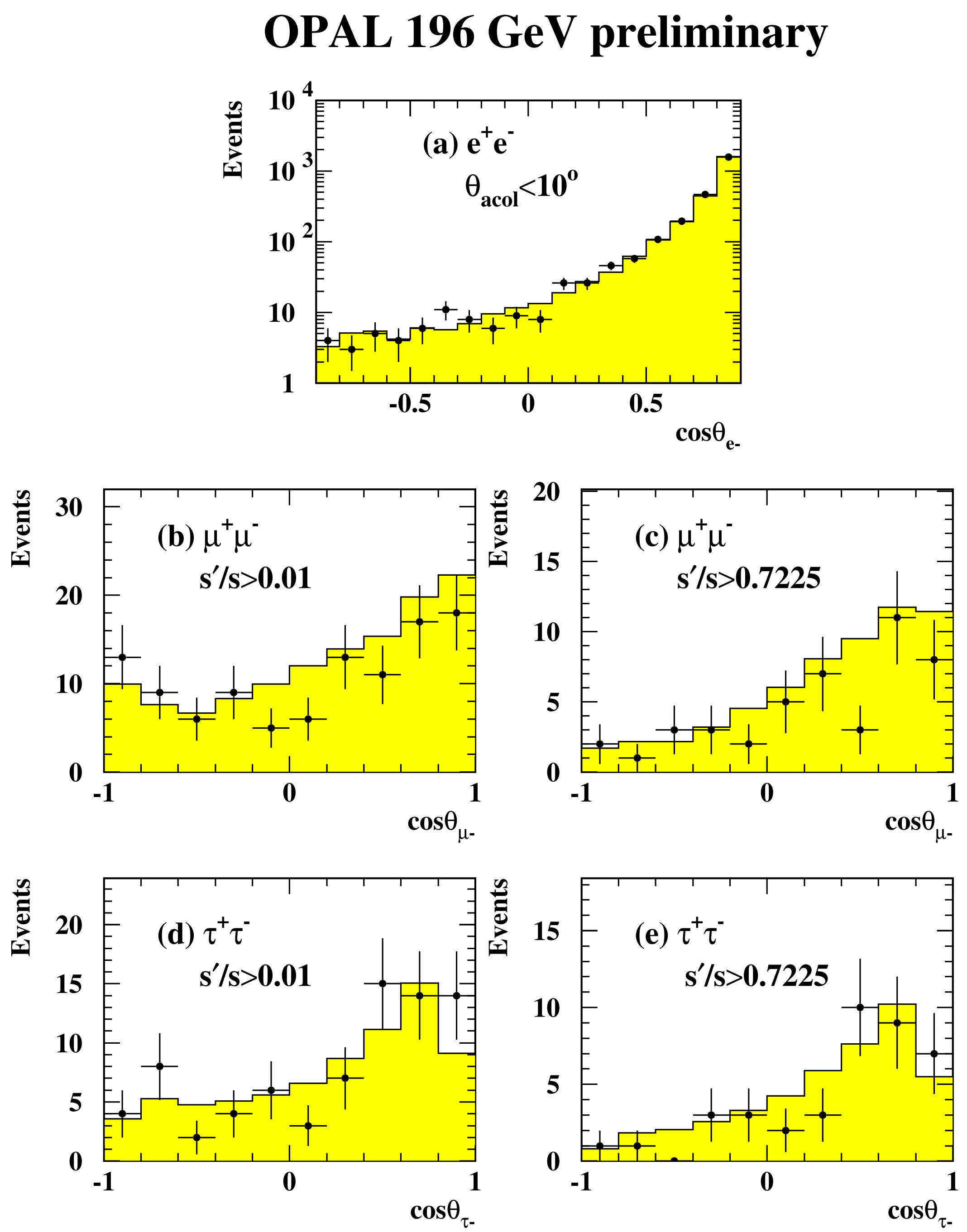
• At 189GeV $R_b = 0.162 \pm 0.0057$ •

(personal average)

SM 0.162

- At 189 GeV $\delta A^l_{FB} \sim 7\%$





- Angular distributions
- Sign of lepton from track charge

- Quark asymmetry

- Jet charge technique (uds,b)

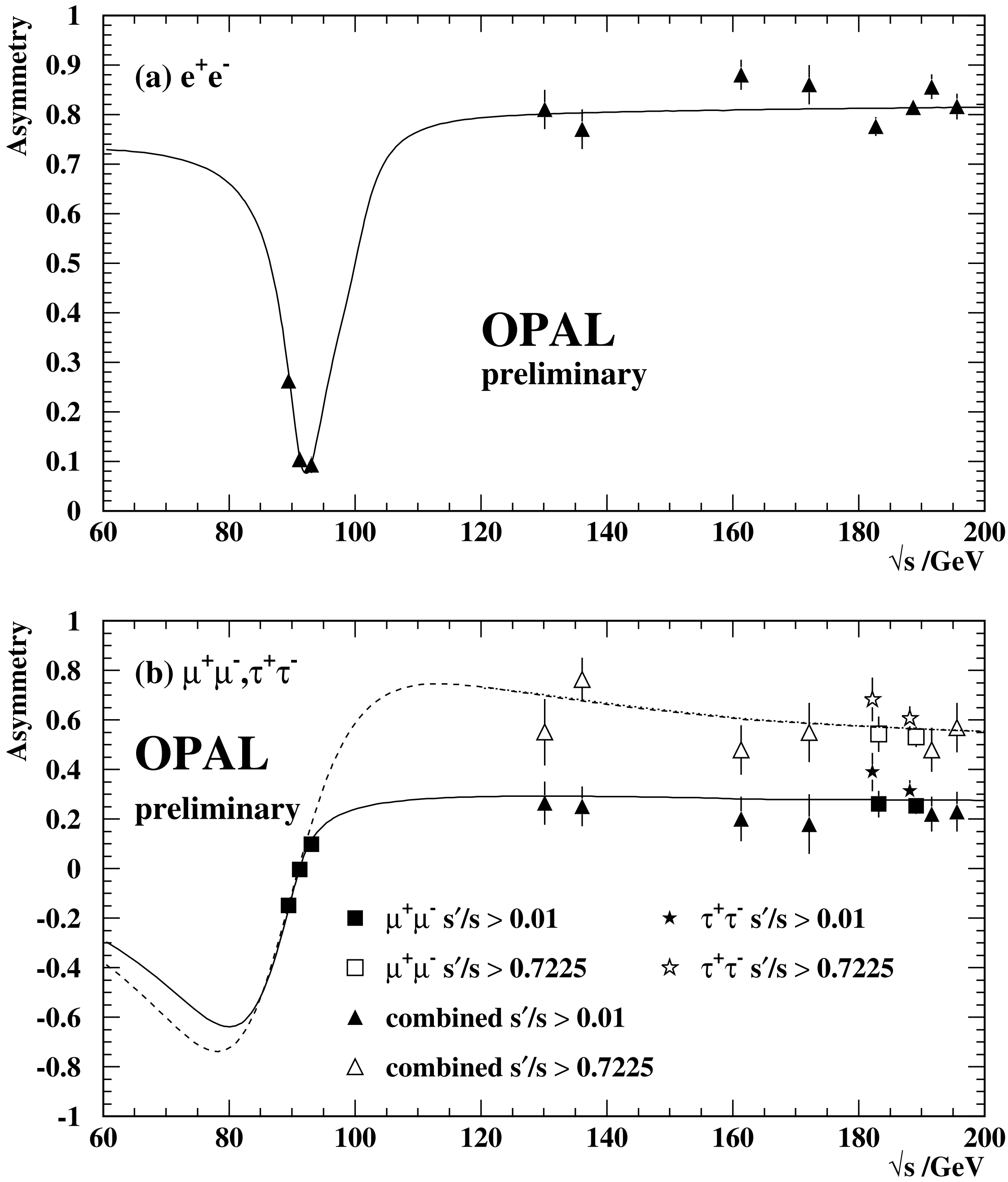
$$Q_{\text{jet}} = \sum_{i=1}^{\text{N}_{\text{track}}} p_{\parallel i}^{\kappa} Q_i \Big/ \sum_{i=1}^{\text{N}_{\text{track}}} p_{\parallel i}^{\kappa}$$

ALEPH,DELPHI,OPAL

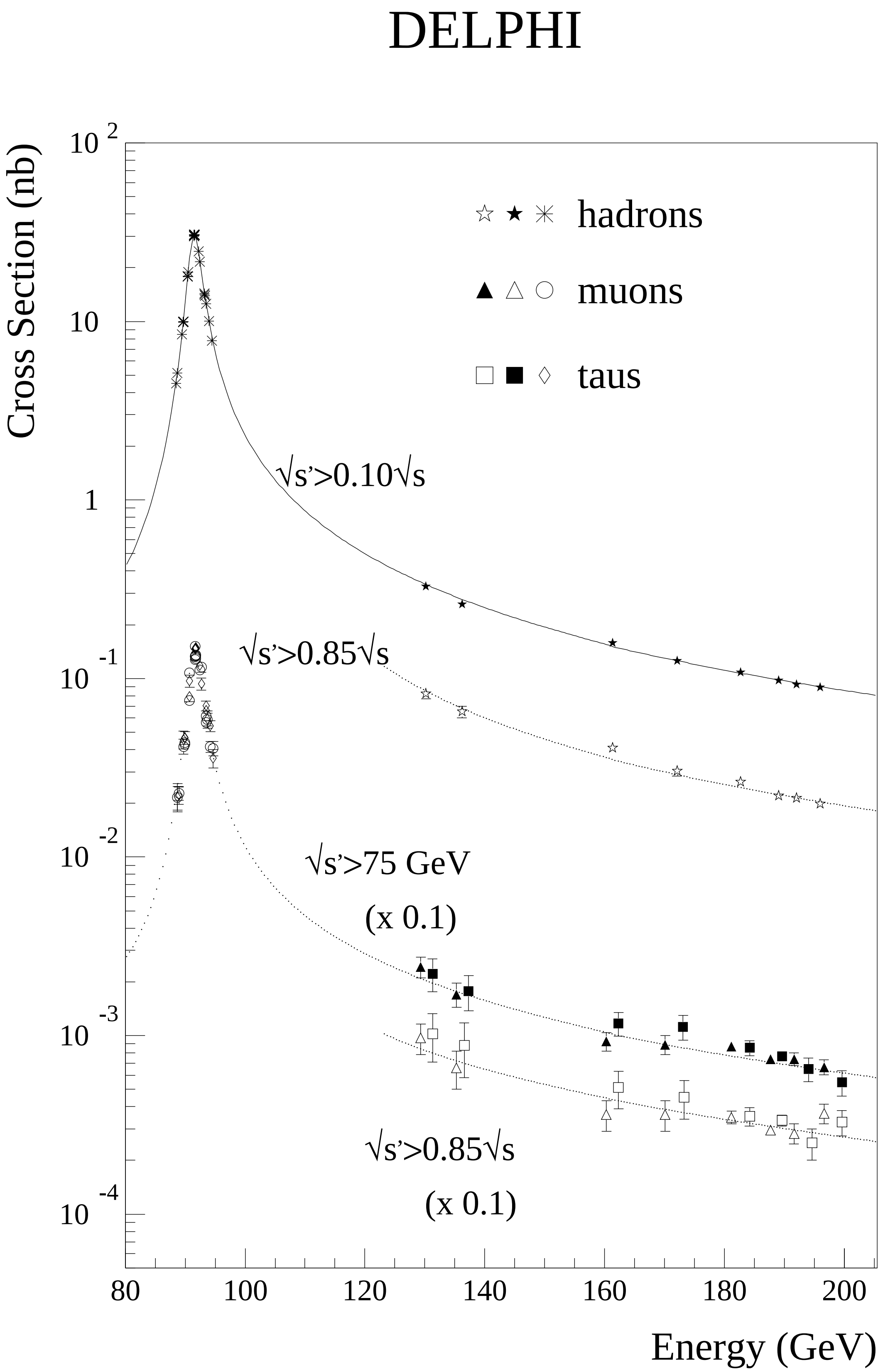
- Flavor tagged asymmetry

- Flavor tagging with
  - Signed lepton (L3 ,OPAL)
  - Leading track charge
  - secondary vertex charge
  - Slow pion tag (D^{*+}) for c (OPAL)
  - Neural net technique (ALEPH)

- Measurement from $Q_F - Q_B$
- $\delta A_{FB}^b / A_{FB}^b \sim 10\%$, • $\delta A_{FB}^c / A_{FB}^c \sim 30\%$



- 2 energy ranges
- γ/Z interference dominates
- QED dilutes asymmetry



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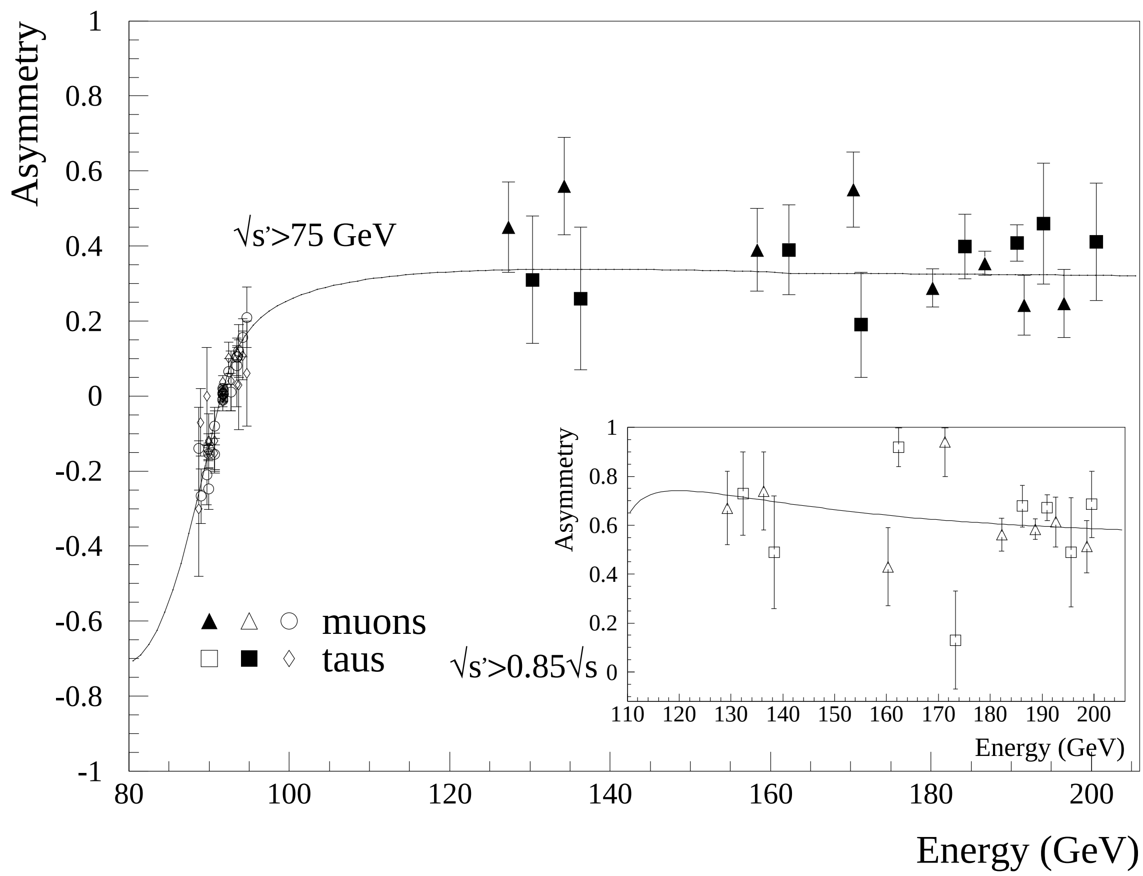
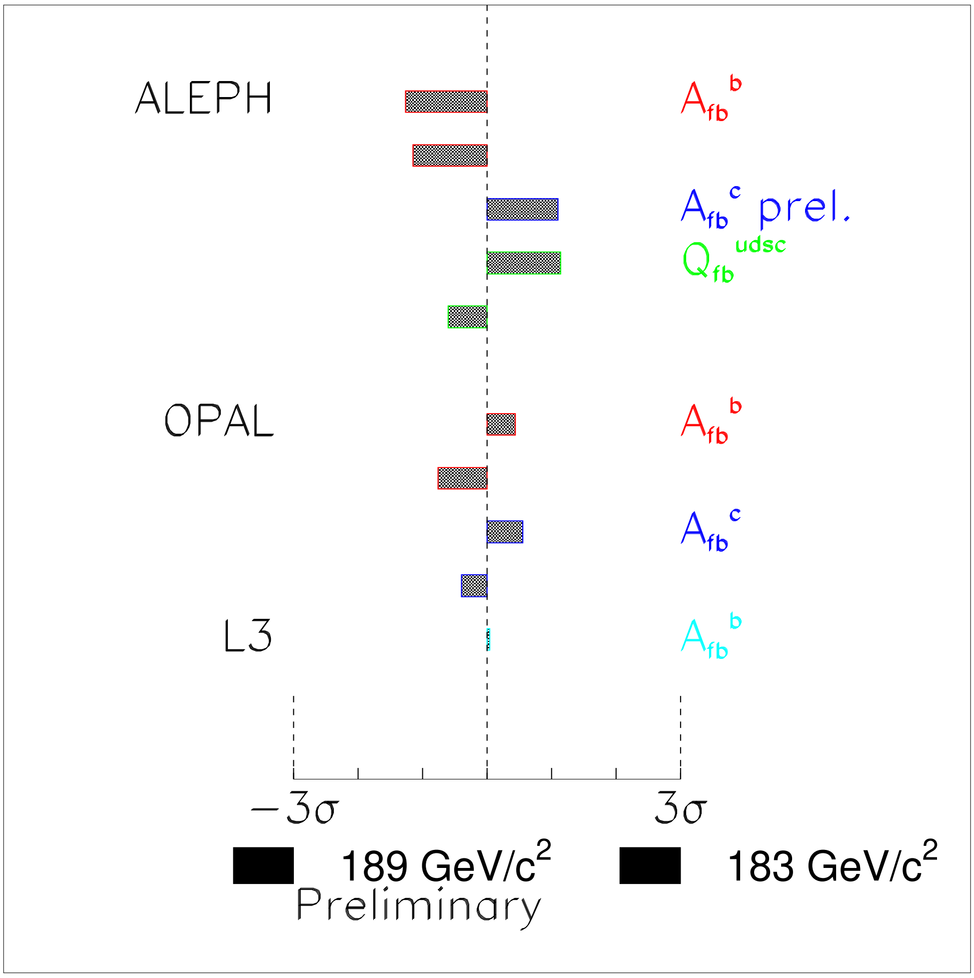
DELPHI

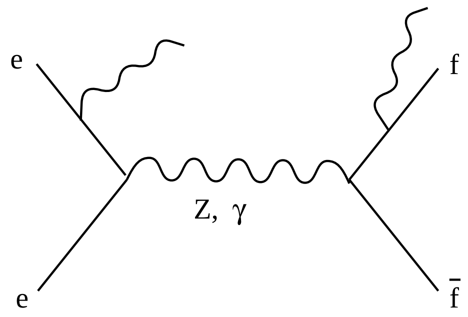


- 2 energy ranges
- γ/Z interference dominates

- All measurements agree with SM



Must choose common definition of $f\bar{f}$ signal

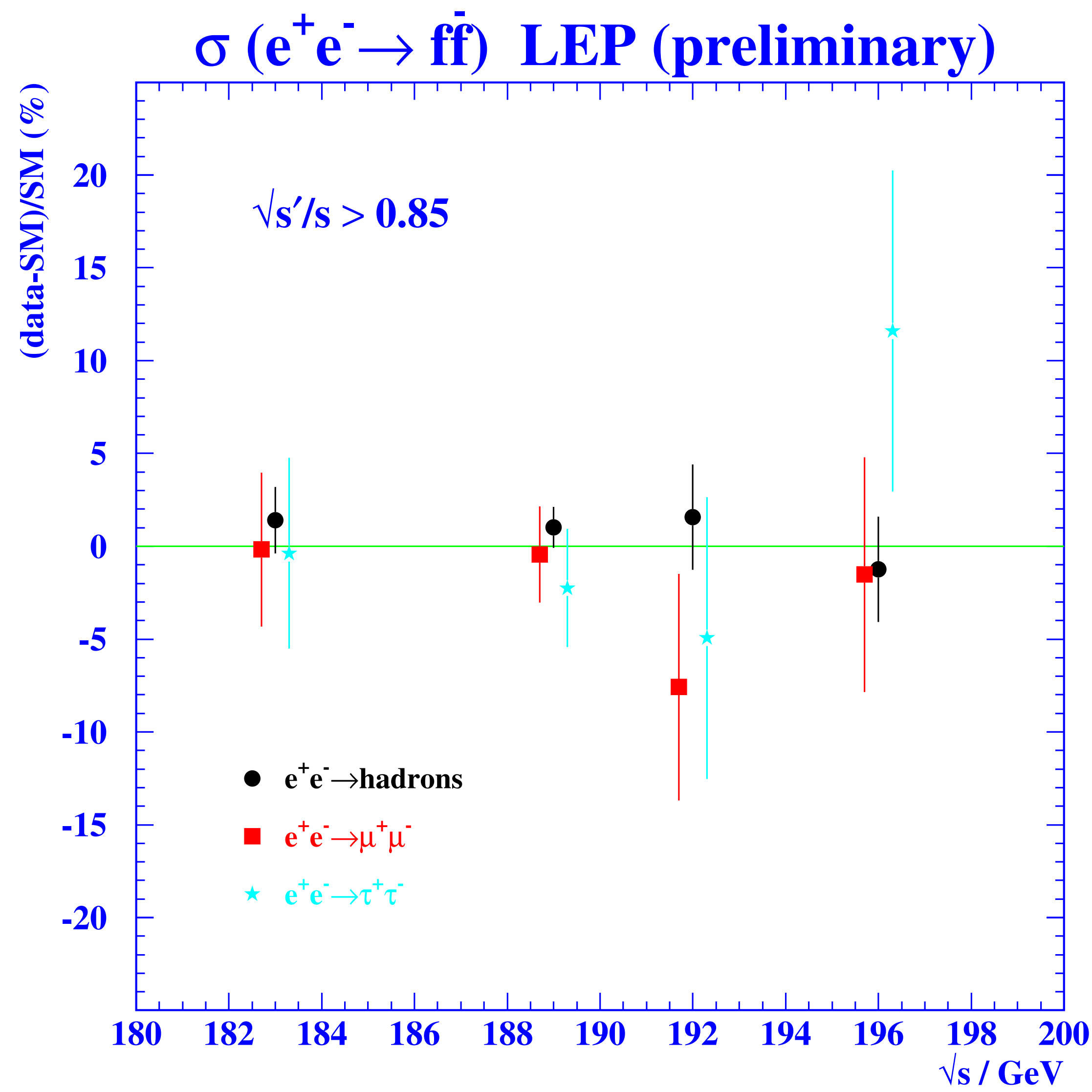


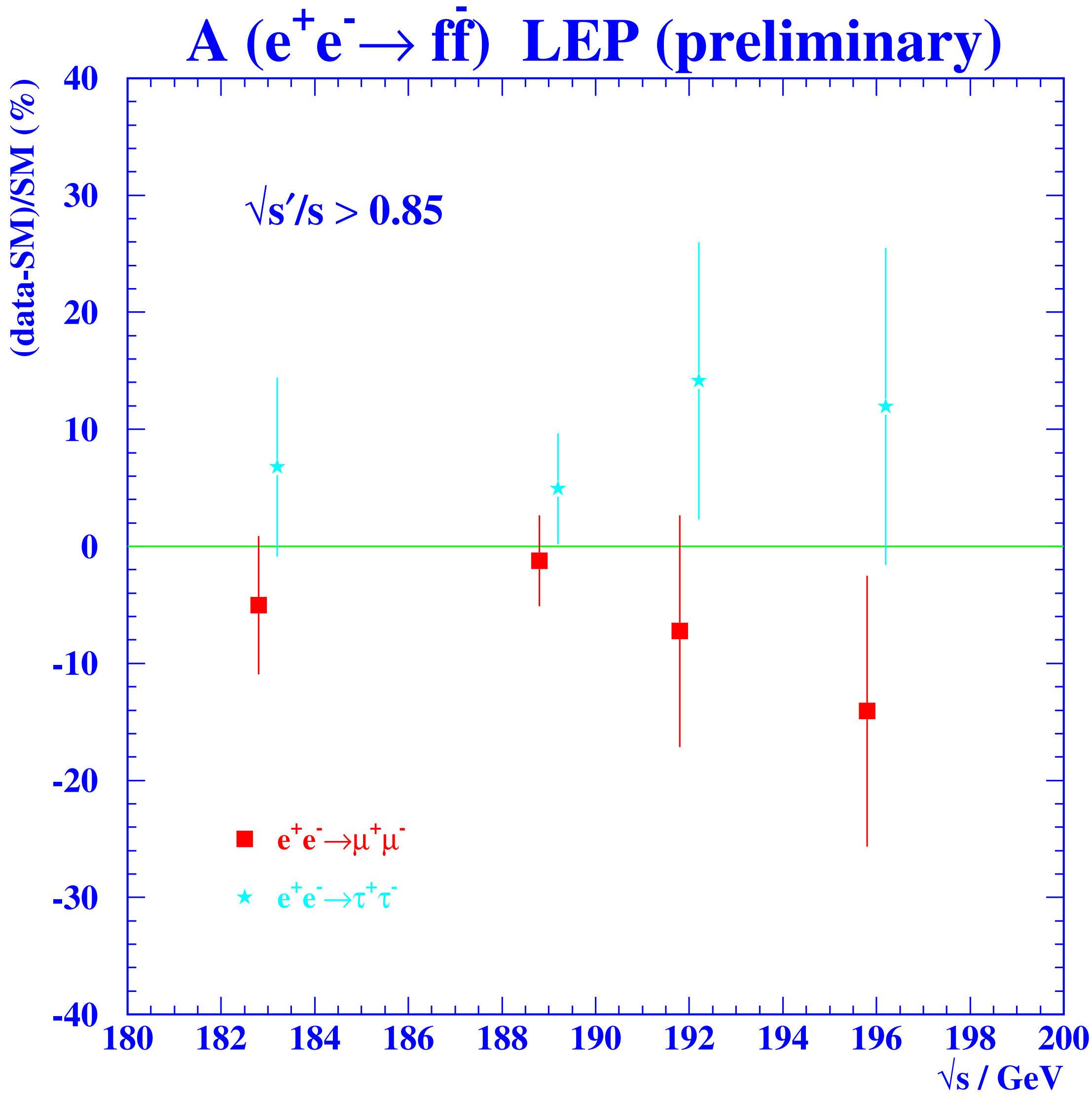
1. $\sqrt{s'/s} > 0.85$, where s' is propagator mass and ISR/FSR photon interference subtracted.
   (OPAL/L3)

2. $\sqrt{s'/s} > 0.85$, where s' is propagator mass for hadronic events and is dilepton mass for leptonic events. ISR/FSR photon interference is included.
   (ALEPH/DELPHI)

• Correct measurements of 4 experiments to common definition using ZFITTER v6.04.
- Take in account the different effective CM definition
- Acceptance range

• $\sigma_{q\bar{q}}$, $\sigma_{\mu^+\mu^-}$, $\sigma_{\tau^+\tau^-}$, $A_{FB}^{\mu^+\mu^-}$, $A_{FB}^{\tau^+\tau^-}$
E_{CM} = 183 - 189 - 192 - 196 GeV


σ (e+e- → ff̄) LEP (preliminary)
(data-SM)/SM (%)
√s′/s > 0.85
e+e-→hadrons
e+e-→μ+μ-
e+e-→τ+τ-
√s / GeV
180
182
184
186
188
190
192
194
196
198
200
20
15
10
5
0
-5
-10
-15
-20



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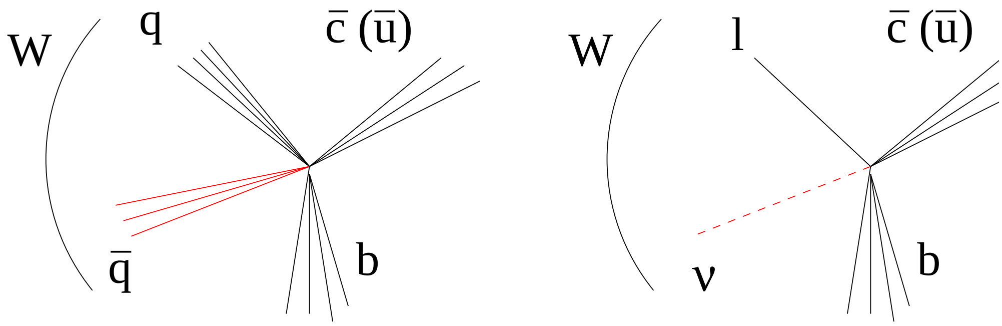
- Current limits
  - In SM only via loops $\sigma, <, 10^{-9} pb^{-1}$
  - Possible extension
  - CDF search for t $\rightarrow \gamma$c(u), t $\rightarrow$ Zc(u)
    BR(t $\rightarrow$ cγ) + BR(t $\rightarrow$ uγ) $<$ 3.2% 95%CL
    BR(t $\rightarrow$ cZ) + BR(t $\rightarrow$ uZ) $<$ 33%

- At LEP2 $\rightarrow \sigma$ $<$ 0.4 pb

- Look for the following topologies

  - $e^+e^-\rightarrow$ t$\bar{c}(\bar{u})$, t$\rightarrow$W b, W$\rightarrow$q$\bar{\text{q}}$ or lν



- Analysis uses :

  - Kinematics features
    E_{b-jet},M_{qq},$M_{l\nu}$
  - B tagging
  - Combined in a discriminant analysis

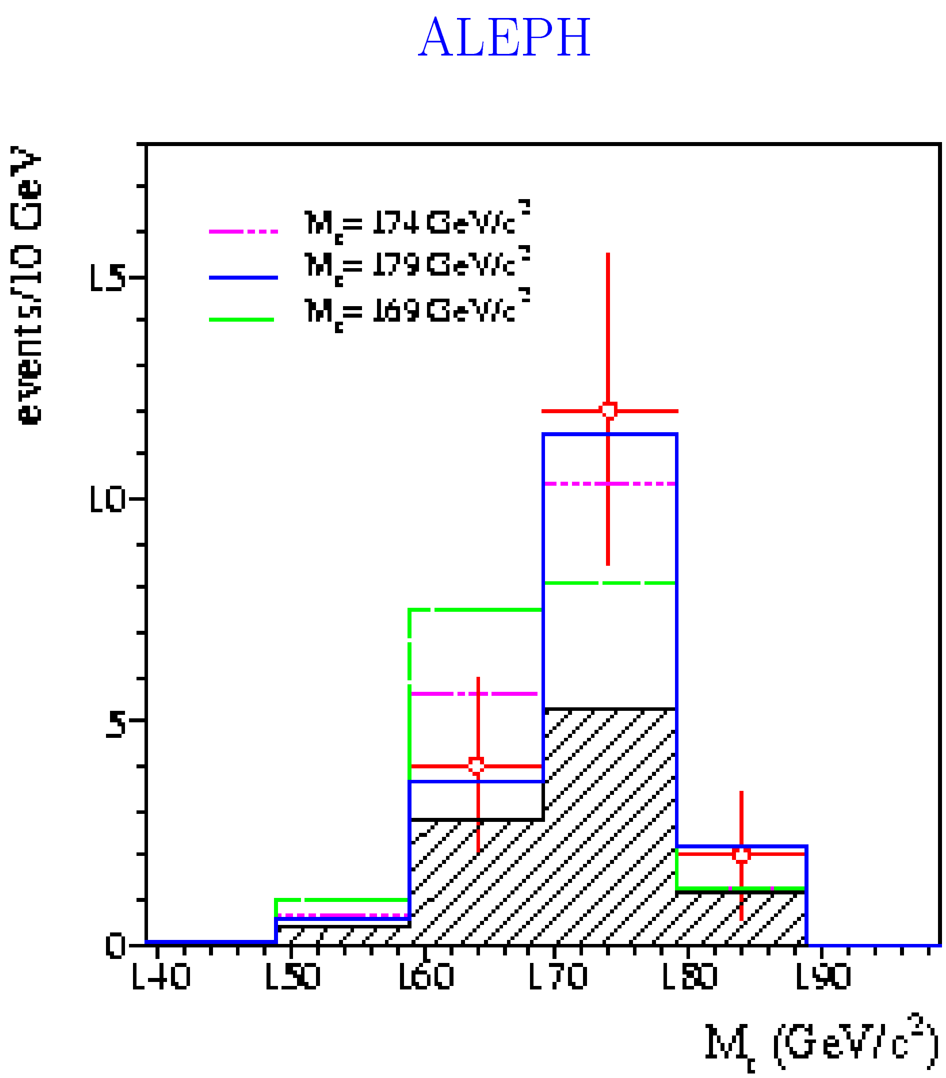
Selected sample (ALEPH)

	Hadronic W	Leptonic W	Combined
Background source:			
W^+W^-	1.54	0.95	2.48
Zee			
ZZ	0.59	0.01	0.60
$q\bar{q}$	6.43		6.43
Total	8.55	0.96	9.51
$\varepsilon(m_t = 174\,\mathrm{GeV})$	12.25%	5.35%	17.6%
σ_{95} pb	0.373	0.446	0.27
Observed	16	2	18

Selected sample (DELPHI)

	Leptonic W	Error
Background source:		
W^+W^-	0.59	0.42
Zee	0.19	0.11
$\tau\tau$	0.12	0.12
Weν	0.11	0.06
Total exp.	1.00	0.45
$\varepsilon(m_t = 175\,\mathrm{GeV})$	6.62%	0.57%
Observed	0	

- ALEPH : σ $<$ 0.6 pb at 95% CL
  Fluctuation probability $\sim$ 4.5%
- DELPHI : σ $<$ 0.3 pb at 95% CL


ALEPH
events/10 GeV
M_t= 174 GeV/c²
M_t= 179 GeV/c²
M_t= 169 GeV/c²
1.5
1.0
.5
0
140
150
160
170
180
190
M_t (GeV/c²)

Results for e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ and $q\bar{q}$: cross-section and asymmetry, including the 99 high energy run

R_b, R_c, R_{uds}

Good agreement with the Standard Model expectations

- Systematics at the level of statistic for $q\bar{q}$
- ADLO precision reached $\sim 1\%$ for $q\bar{q}$,$\sim 3.5\%$ on R_b
- Theoretical predictions more precise (MC LEP2 workshop)
- End of LEP2 expect $\sim 0.4\%$

Will allow one to constraint physics beyond the Standard Model