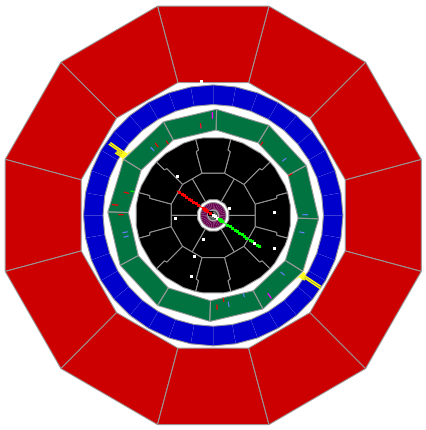
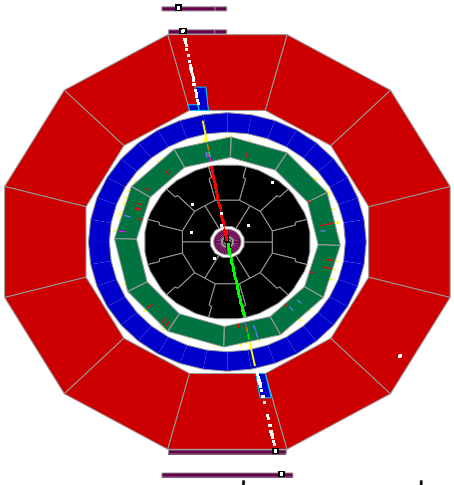


$e^+e^- \to e^+e^-$

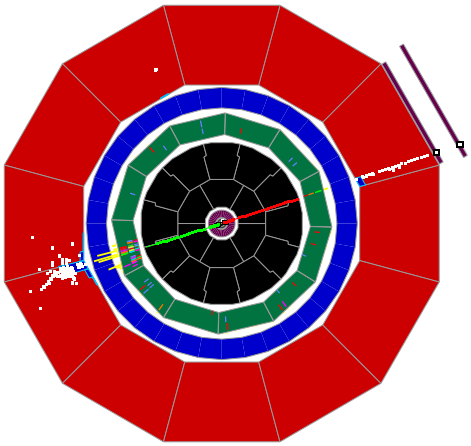


$e^+e^- \to \mu^+\mu^-$

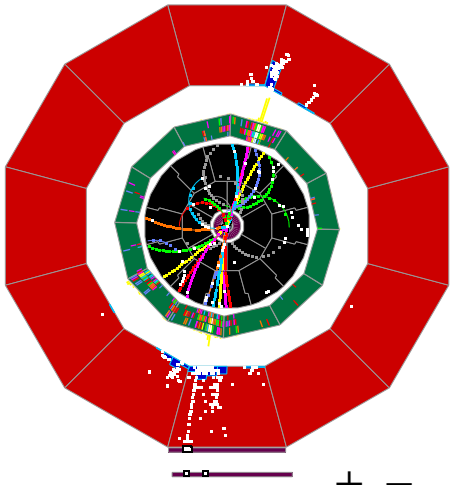
Fermion Pairs at LEP II

Corinne Goy - Lapp -Aleph

- Features of fermion pairs production above the Z peak
- Measurements : Cross sections
  Asymmetries
- Extensions of SM : Graviton
  Contact term
  Sneutrinos



$e^+e^- \to \tau^+\tau^-$

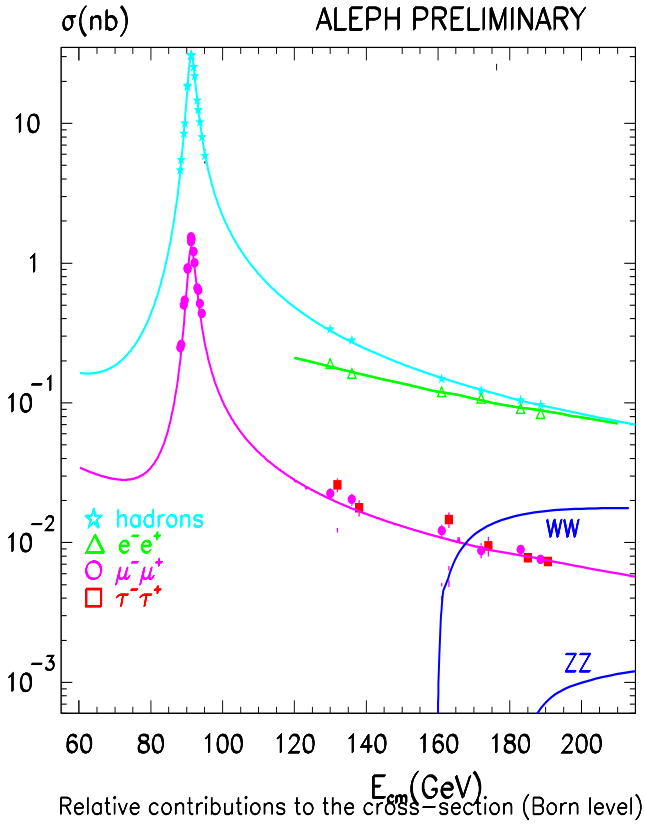


$e^+e^- \to q\bar{q}$

Introduction

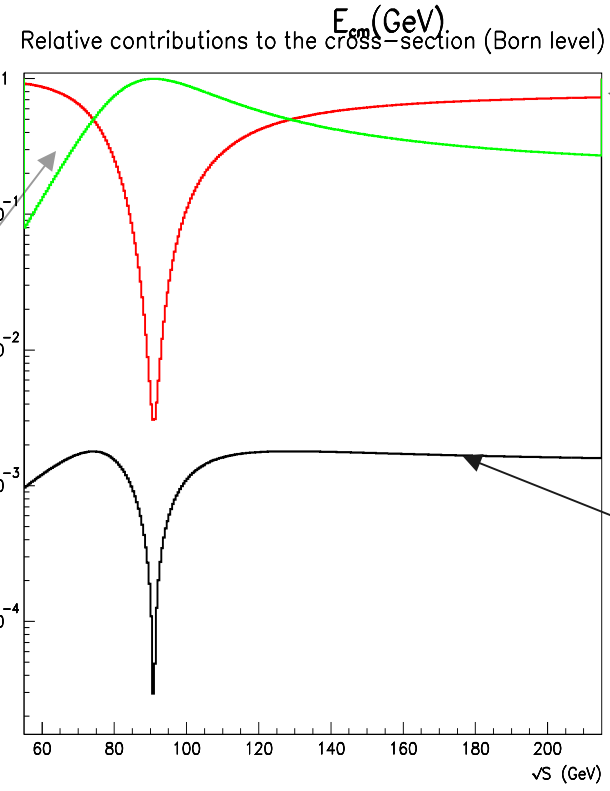
- LEP I : $\sqrt{S} \approx m_Z$ yr.:1990-95
  - Extensive test of the Z sector with 4.5 10^6 Z decays
    - M_z = 91.1885 ± 0.0031 gev/c^2
    - Γ_Z = 2.4951 ± 0.0043 gev/c^2
    - $N_{\nu \text{ light}}$ = 2.983 ± 0.013
  - Indirect constraints on M_w, M_t
  - Data support the Standard Model
- LEP II : $\sqrt{S} \geq 130\ \mathrm{GeV/c}^2$ yr.>1995
  - New energy domain each year
    - 161 gev/c^2 : WW pair production
    - 182 gev/ c^2 :ZZ pair production
  - Direct measurement of M_w : ± 50 mev
  - Other SM processes ee → ff further test the SM model and put limits on its extension
- 1999 : $\sqrt{S} = 196\mathrm{GeV/c}^2$

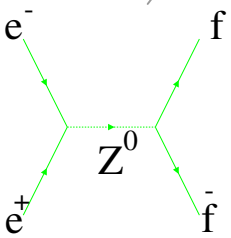
Production of Fermion Pairs at LEP II

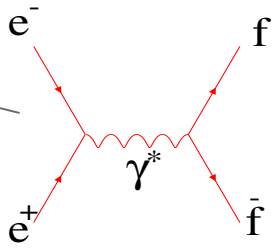


← 16.8 pb^{-1}

← 1.2 pb^{-1}





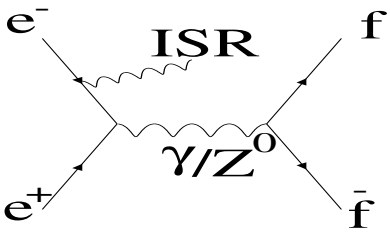


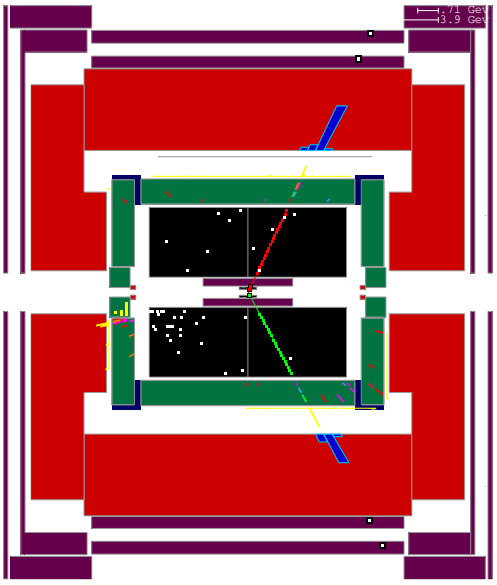
γ/Z interference responsible for Afb of about 0,6

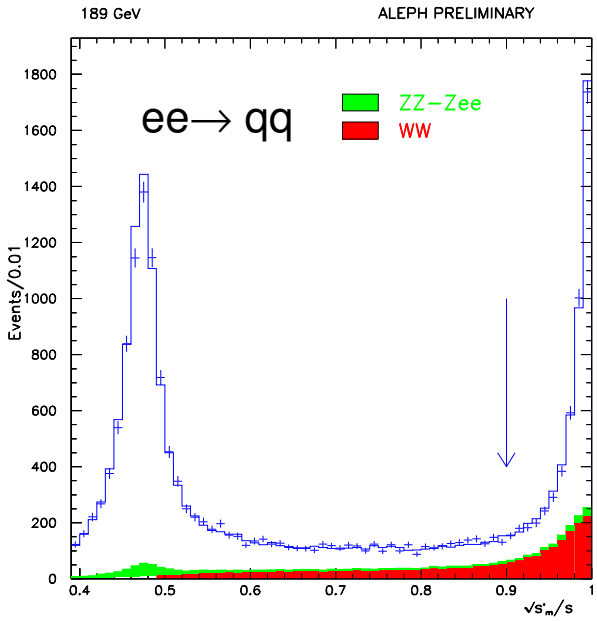
(0 at the Z)

Hard Initial State Radiation (ISR)

- S' : effective center of mass energy reduced







Acollinear fermions + 1 γ close/in the beam pipe

⇒ √S'/s > 0.1 (inclusive sample)

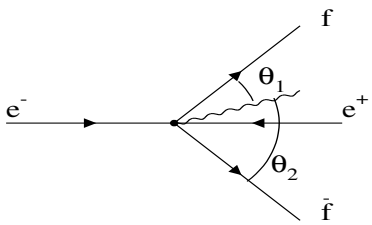
√s'/s > 0.85 -0.9 (exclusive sample)

open new energy domain

most sensitive to new physics

Experimentally $S' = S - 2E\gamma\sqrt{S} + E\gamma - P\gamma$

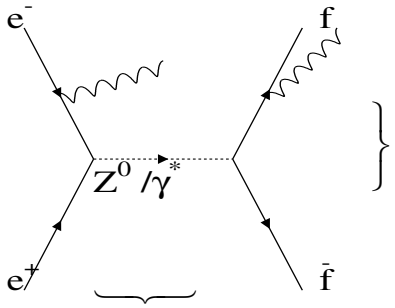
$$\frac{s'_{meas}}{s} = \frac{\sin\theta_1 + \sin\theta_2 - |\sin(\theta_1+\theta_2)|}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1+\theta_2)|}$$



- Exact formula if 1 ISRγ
- Approximate otherwise $\Rightarrow$ **Radiative background** (s'meas $\neq$ s' true)

NB : S' closely related to acollinearity of the out-going fermion pair - preferred in the case of $e^+ e^-$

Generator :



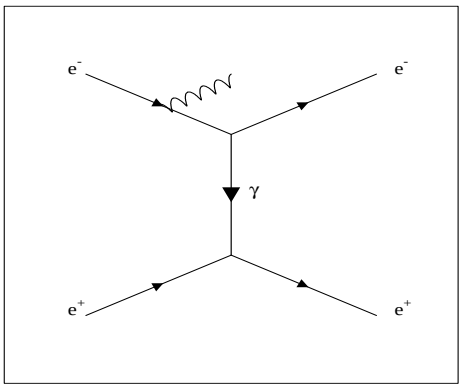
S' = M^2 of fermions after FSR

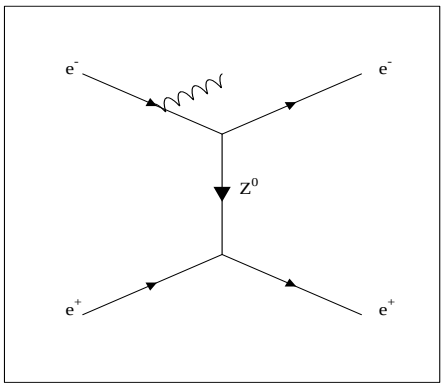
S' = M^2 of the propagator i.e. before FSR

Gluon/FSR radiation $\rightarrow$ quark

ISR/FSR interference accounted apart

NB : ee final state t-channel production

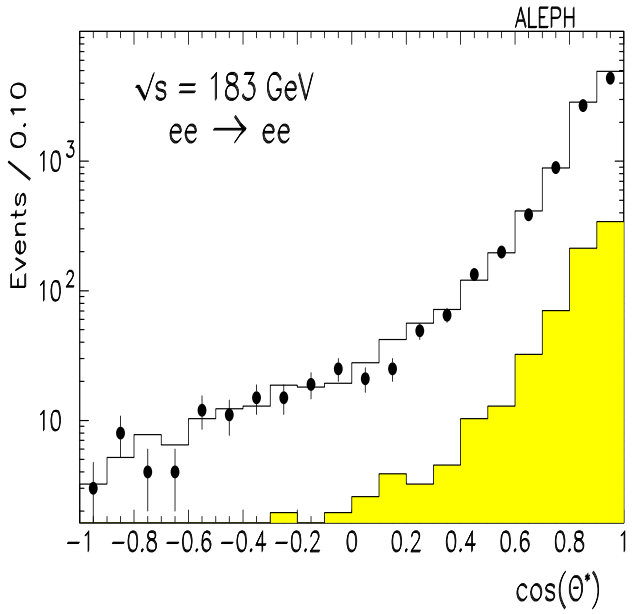


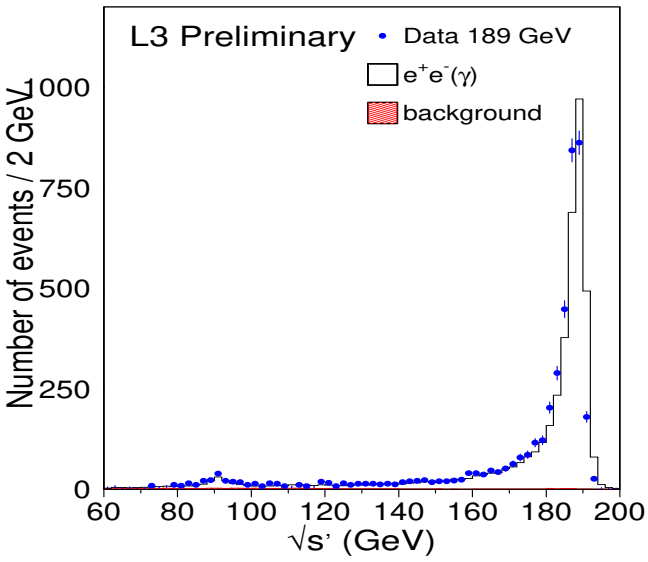


⇒ Event distribution peaked forward

⇒ Hardly no radiative return

Note the log scale





Precision of the SM predictions

ee: th. uncertainty 3% (yellow report 96-01)

- (Bhwide /alibhabha / topaz0)

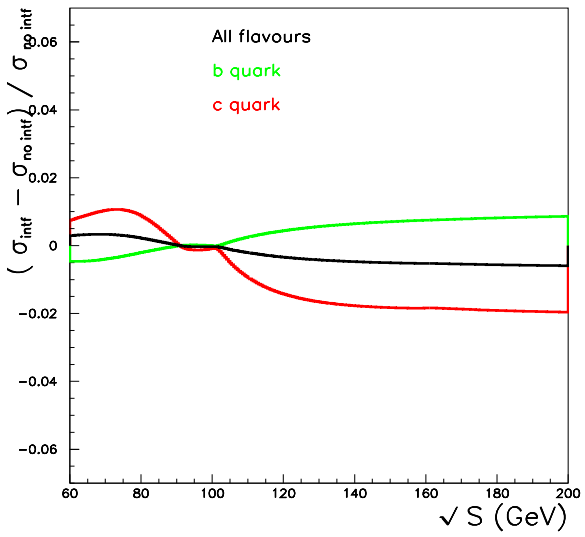
Other flavours:

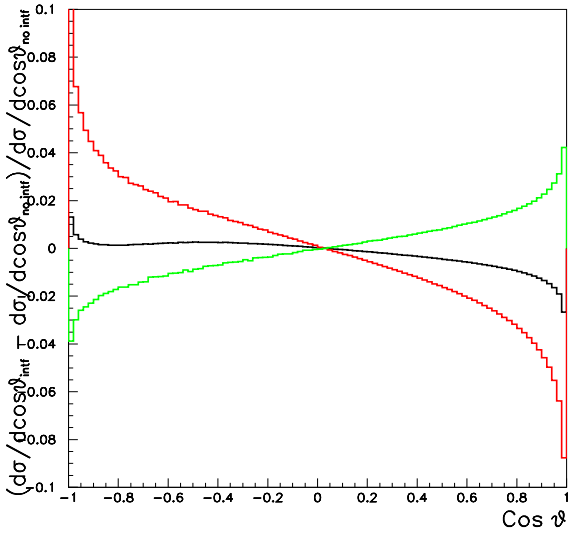
- Zfitter v5. ⇒ V6
- ISR/FSR interference, box diagram ….
- Maximum at low angle and large s'/s
- No higher orders terms

1.5 % full θ range :qq,ll

2 to 3 % for bb, cc

Relative contribution of interference term $\sqrt{\frac{s'}{s}} > 0.9$





Data analysis

Approximate integrated luminosity per experiment :

130/136 Gev/c^2	12 pb^{-1}
160/172 Gev/c^2	20 pb^{-1}
183 Gev/c^2	57 pb^{-1}
189 Gev/c^2	173 pb^{-1}

Measurements performed :

	Stat. Precision (189 Gev Exclusive**)**	**Background** (Aleph)
Leptons		
σ	e : 2% μ ,τ : 5%	e : 2 % μ : 4 % τ : 15 %
Afb	0.04 – 0.05	
Hadrons		
σ	2 %	10 %
Rb – Rc	10-15 %	5-50 %
Afb	0.10 – 0.15	

Background:

- From MC simulation
- Radiative background
  - Affects only exclusive measurements
- Other physical background
  - $\gamma\gamma$: Inclusive measurement and measurements related to leptons
  - WW : mainly hadronic cross-section
    - σ = 16. 83 pb
  - ZZ* : small but flavours tagged selections
    - σ = 2. 78 pb
  - Other 4f small ..

189 gev results are preliminary

ALEPH : extrapolates down to $|\cos\theta| < 0.95$

DELPHI /L3 : extrapolate to full θ range

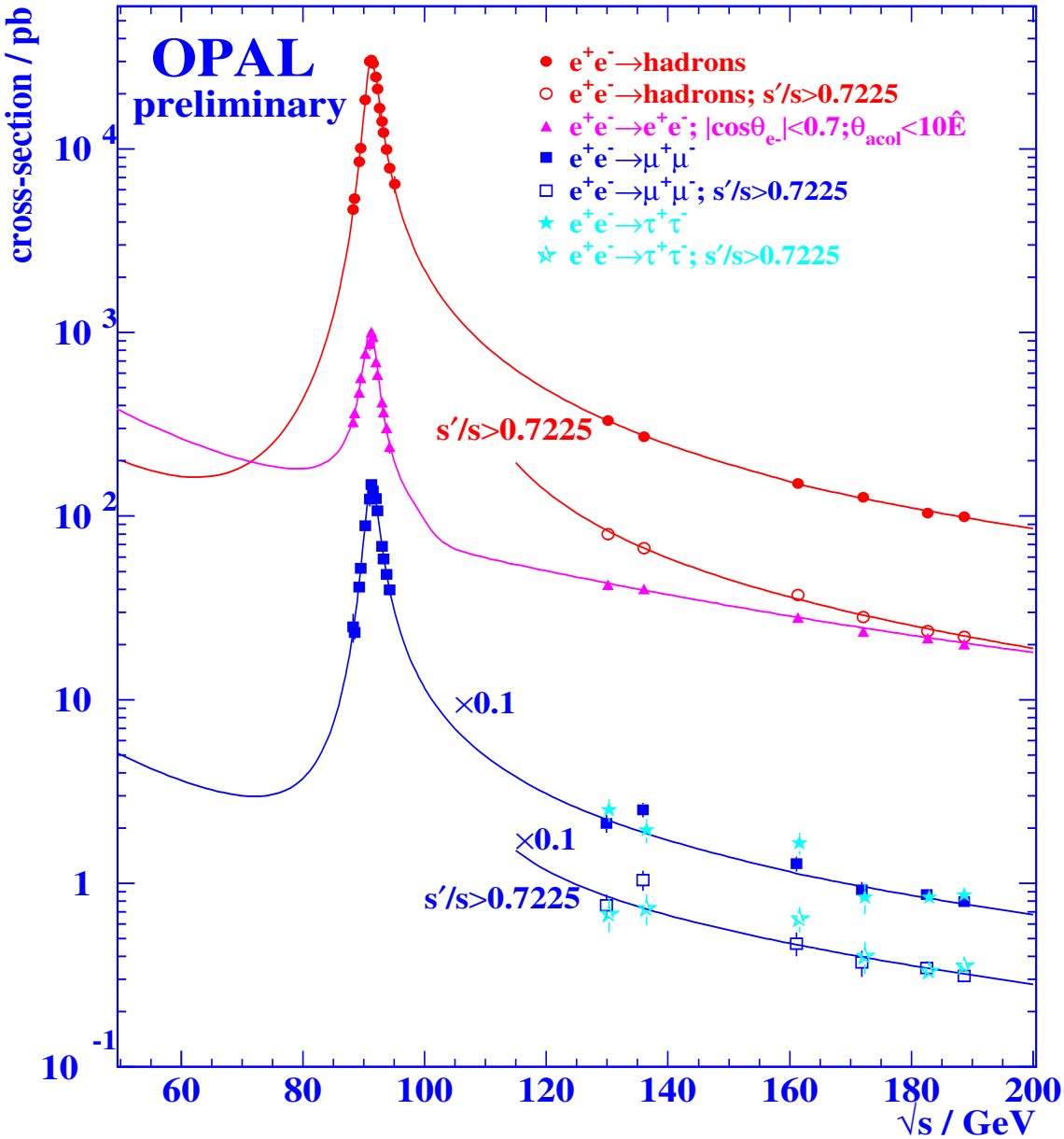
OPAL : subtracts contributions of ISR/FSR

(from Zfitter v 5)

Bhabha cross-sections : different definitions

combination on its way

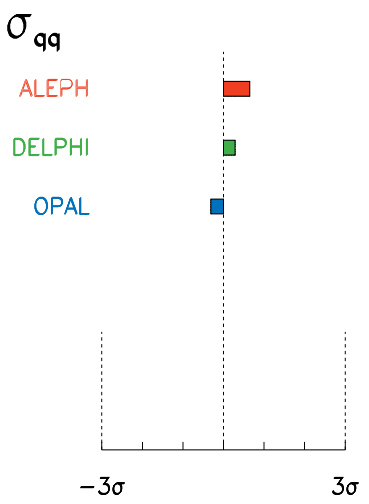
Cross-sections

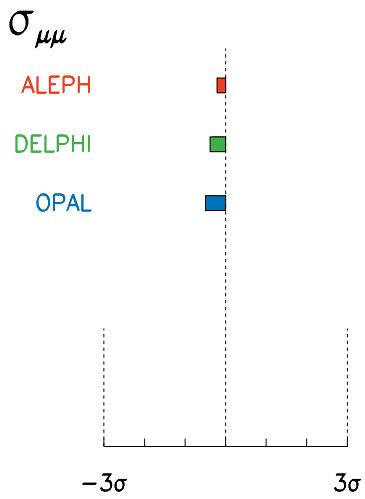


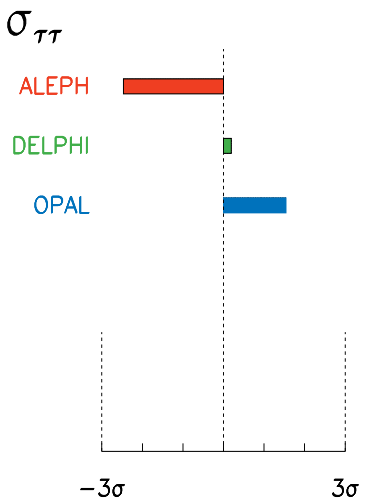
Deviation from SM

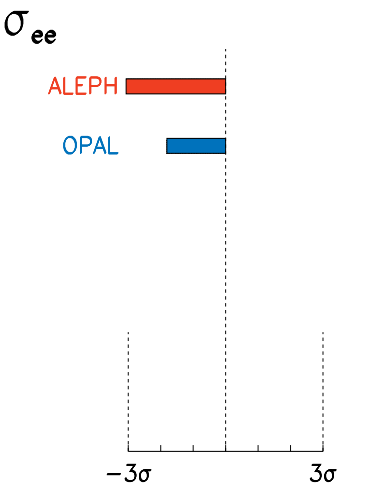
$L = 173\ pb^{-1}, \quad \sqrt{s} = 189\ GeV/c^2$

Exclusive sample, preliminary





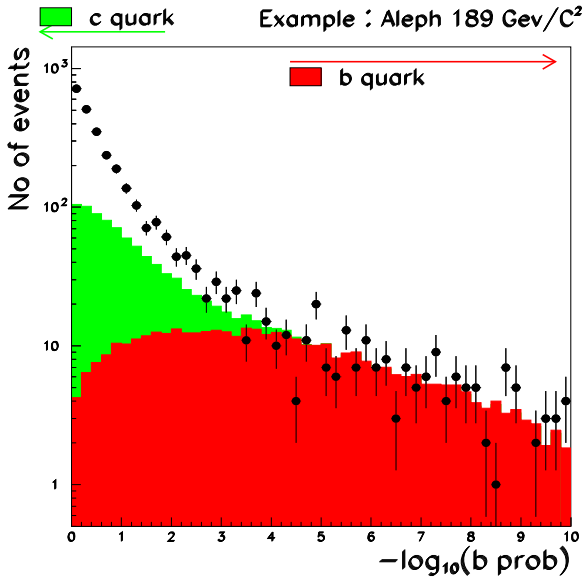




Rb, Rc, Ruds $(= \sigma_{fl}/\sigma_{qq}\sqrt{s'/s} > 0.9)$

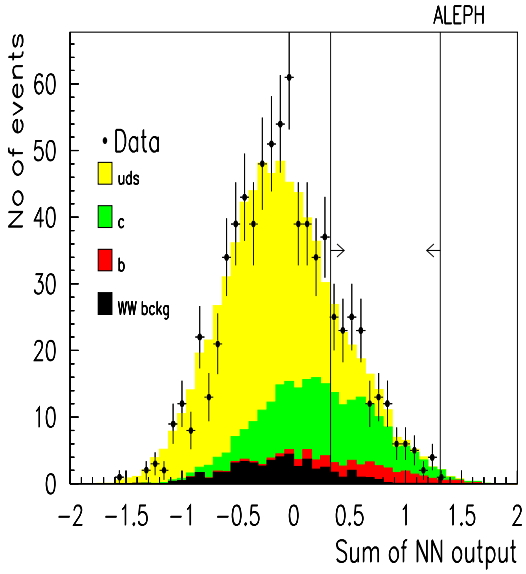
B selection:

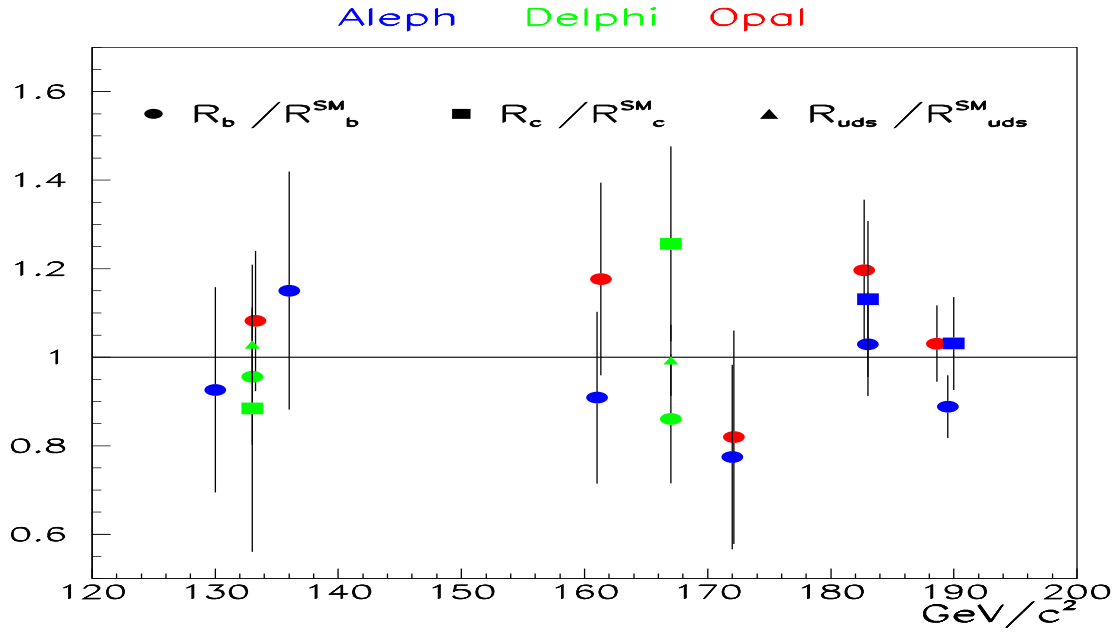
Based on lifetime tag
(impact parameter)



C selection :

IP+rapidity, lepton, energy variables





Asymmetries

Fermions charge :

- Leptons : sign of the track
- Quarks :

from jet charge $Q = \frac{\sum_i q_i X_i^{\kappa}}{\sum_i X_i^{\kappa}}$ with $X = P_L$ *or* η

complemented for b or c flavour with

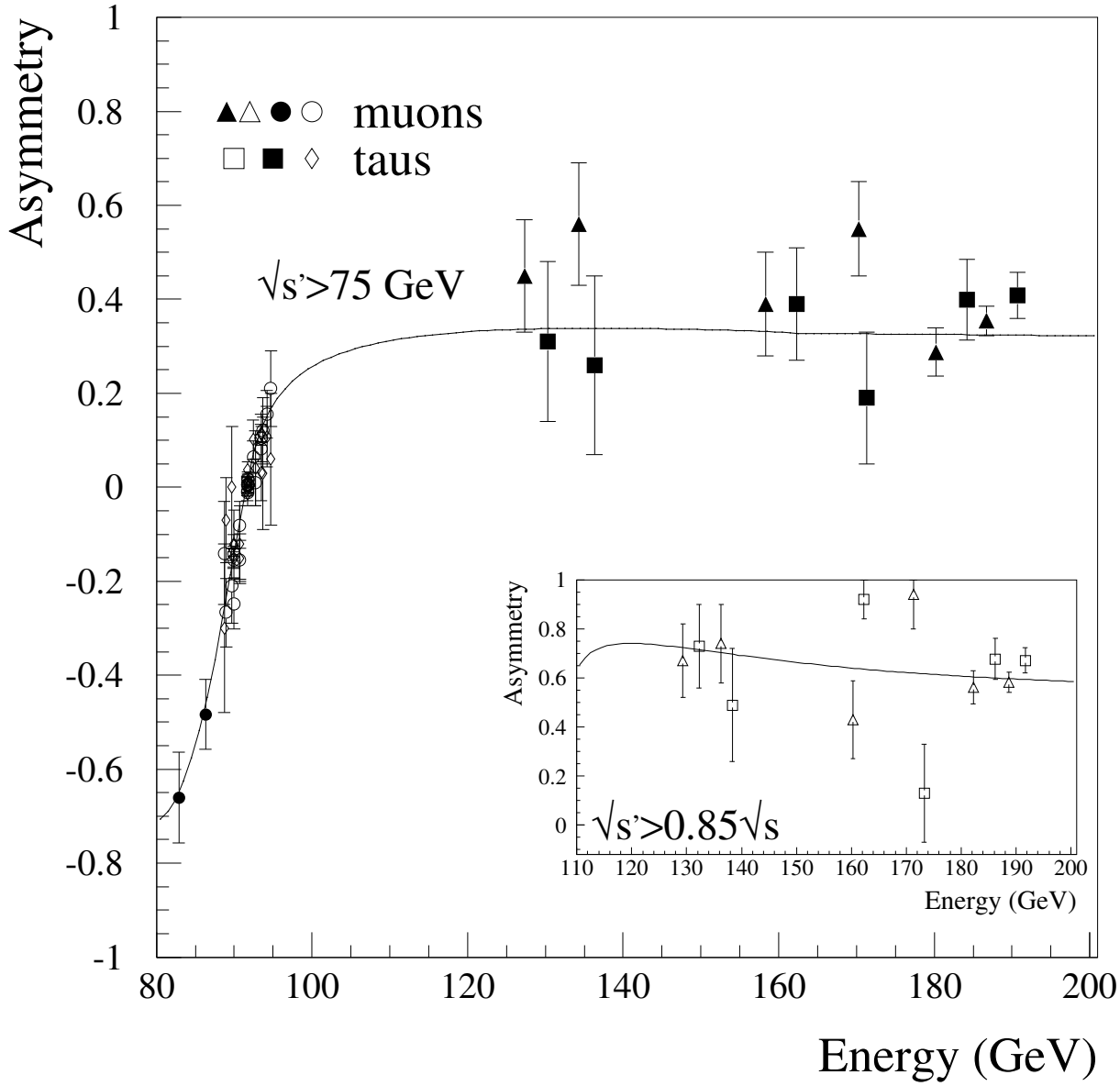
- lepton,kaon sign
- $D^{*\pm}$
- 2nd vertex charge
- Leading track charge

Measurement obtained from :

- counting method : $N_F - N_B / N_F + N_B$
- fit of cos θ^* distribution
- Charge asymmetry : $\langle Q_F - Q_B \rangle$

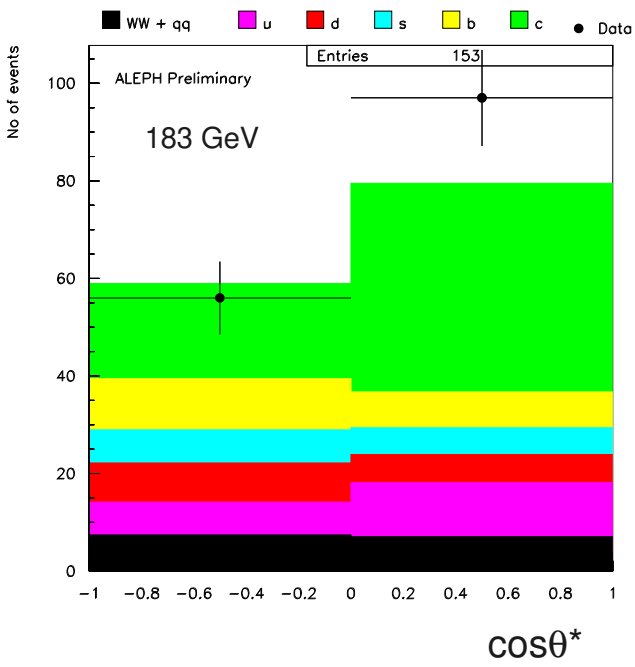
μ and τ asymmetries

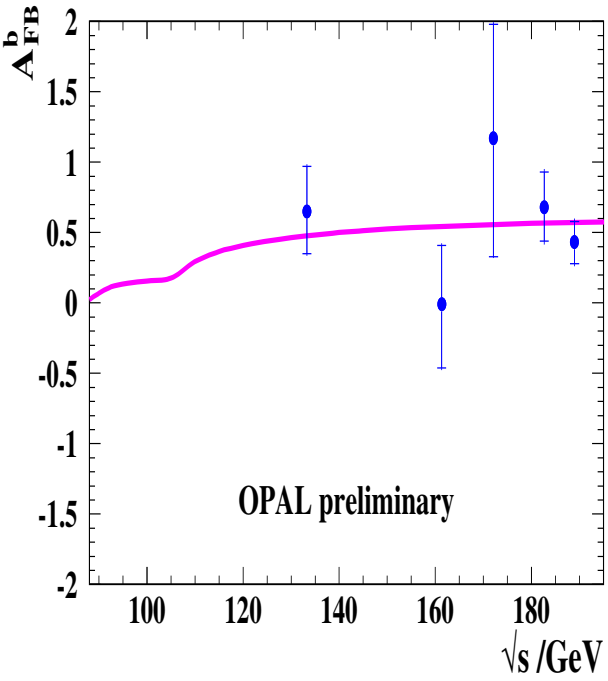
DELPHI



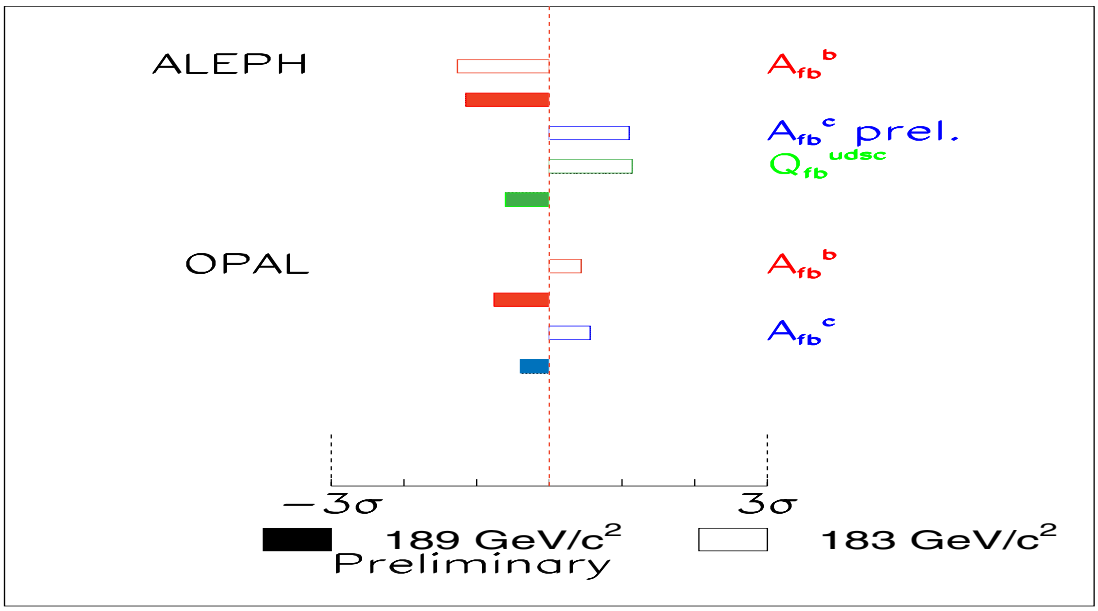
Flavour tagged quark asymmetries

A^c_{FB}

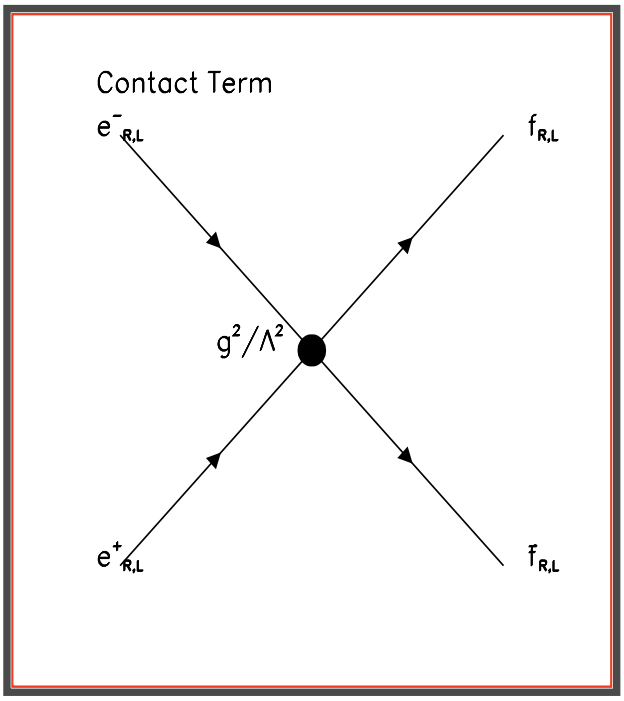


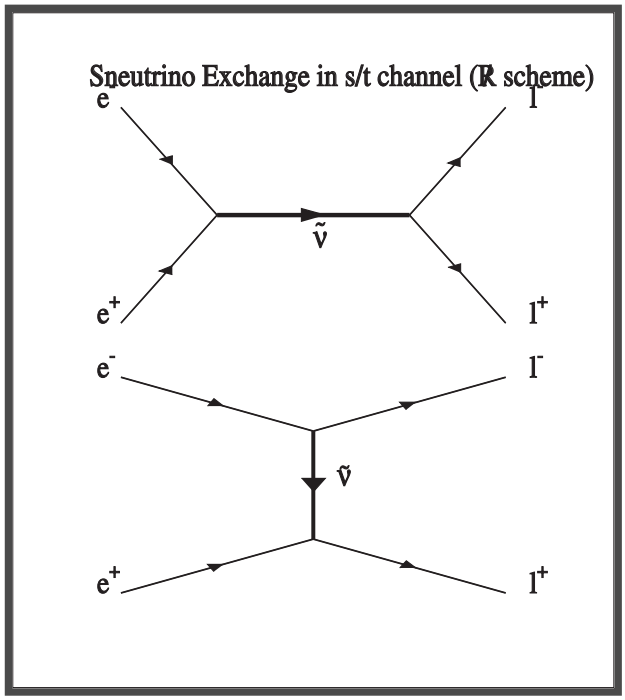


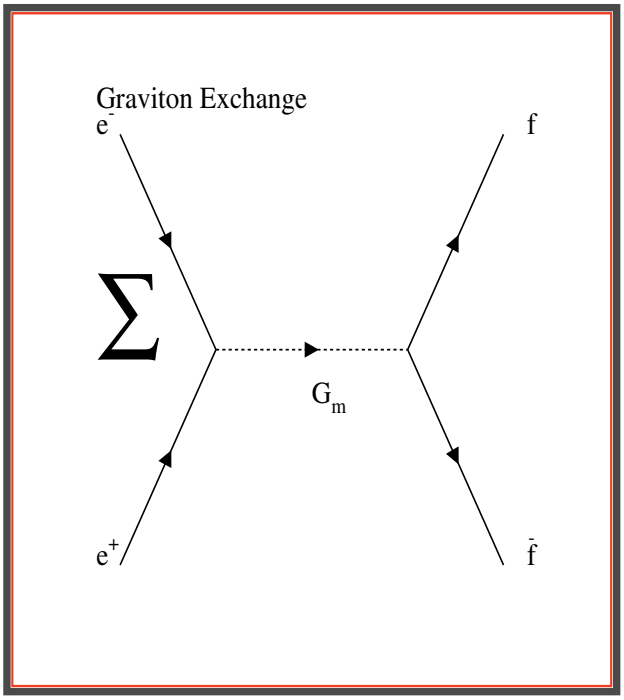
Deviation from SM predictions

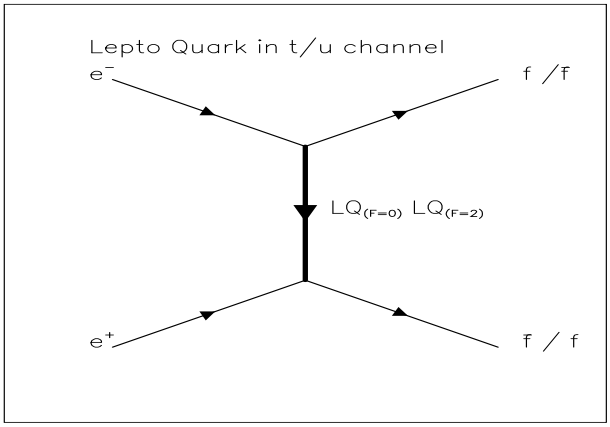


Extensions of SM









Z' boson can mix with SM Z

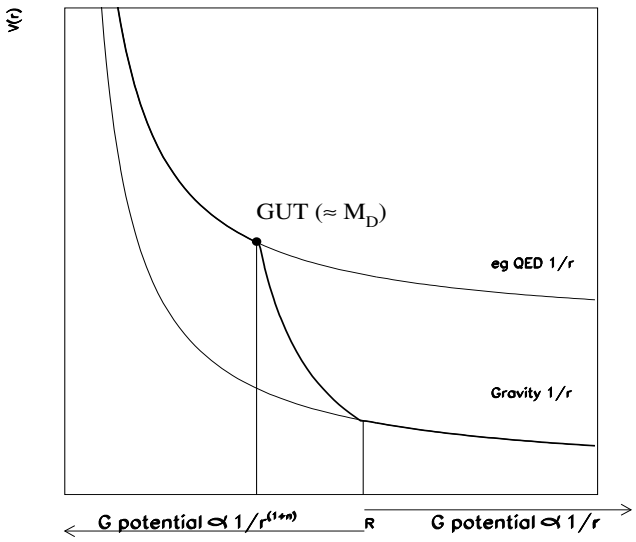
Graviton exchange

Motivation: hierarchy problem

$M_{Pl}\,(10^{19}\text{GeV}) >> M_{weak}(10^{3}\ \text{GeV})$

1/r dependence of gravity only tested to distances > 1mm

Rise at small distance, so that at M_D , gravity ≈ other forces



n extra dimensions $V \approx 1/r^{1+n}$

extra dimensions are compactified to a radius R: $r >> R$, $v \approx 1/r$

$$M_{Pl}^{2} \approx R^{n} M_{D}^{n+2}$$

eg : $M_D \approx 1\text{TeV}$

$n = 2 \Rightarrow R \approx 1\text{mm}$

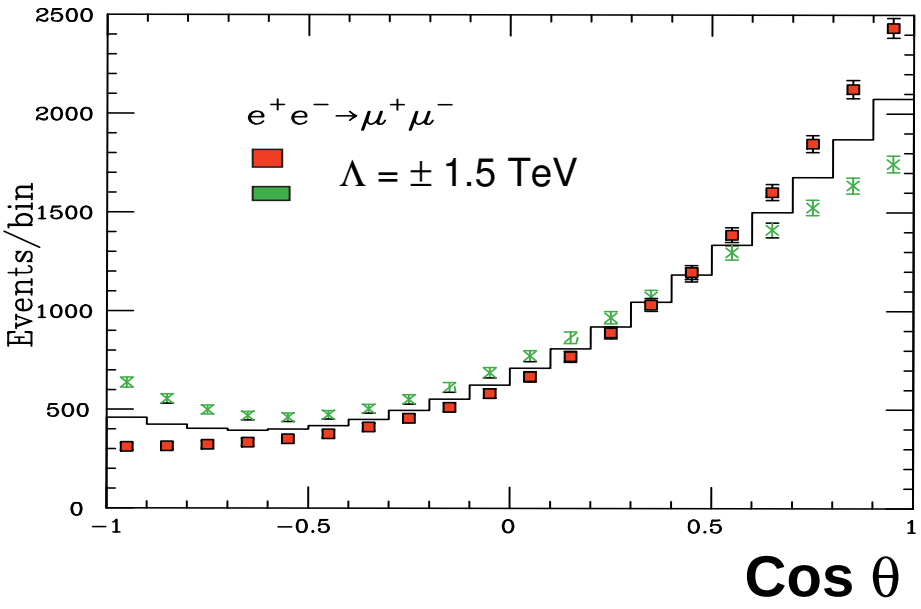
Graviton : spin 2 particle

Mass from momentum in extra dimensions

$$M^2 = \sum_{i=1}^{n} P_i^2$$

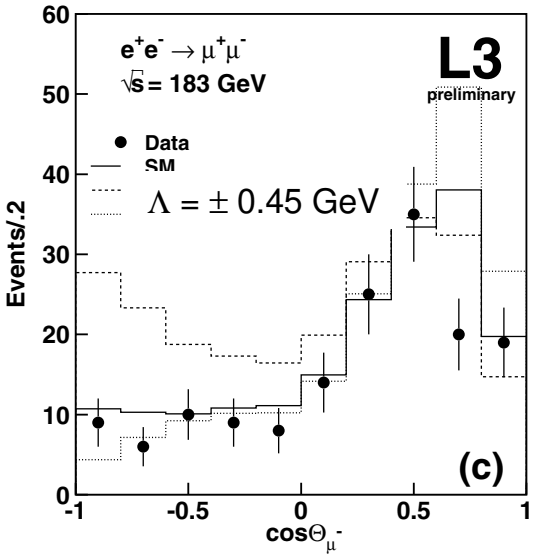
- R finite $\Rightarrow$ P quantized
- spectrum of mass state g_m
- coupling to energy-tensor weak
- ee $\rightarrow$ ff affected by the exchange of $\Sigma\, g_m$

- differential cross section parametrised by ultra violet cut-off Λ (= $O(M_D)$) at which the 4 forces are unified



Total cross-section unchanged : $+1/\Lambda^8$ (….)

Results



L3 : up to 183 GeV

ee $\to$ $\mu\,\mu$, $\tau\tau$

Λ^+ **= 0.59 GeV**

Λ^- **= 0.51 GeV**

OPAL : up to 189 GeV

ee $\to$ $\mu\,\mu$, $\tau\tau$

Λ^+ **= 0.65 GeV**

Λ^- **= 0.64 GeV**

ALEPH : up to 189 GeV

ee $\to$ ee, $\mu\,\mu$, $\tau\tau$ and qq angular dist.

Λ^+ **= 1 TeV**

Λ^- **= 0.85 TeV**

These results can be complemented by

ee $\to\gamma\gamma$ (ZZ,WW ..) with graviton exchange

Opal (not combined): **0.75/0.60 GeV**

Aleph : **1.12/0.85 TeV**

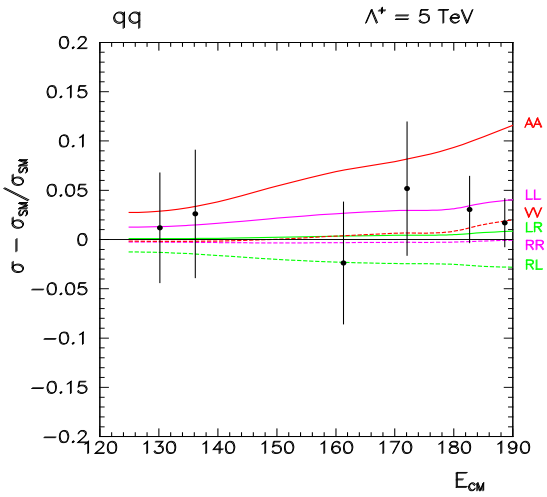
L3 : **0.77/0.63 TeV**

Contact Term

$$Leff = \frac{g^2}{2(1+\delta)\Lambda^2} \sum_{i,j=L,R} \eta_{ij} (e_i \gamma_\mu e_i)(\bar{f}_j \gamma^\mu f_j)$$

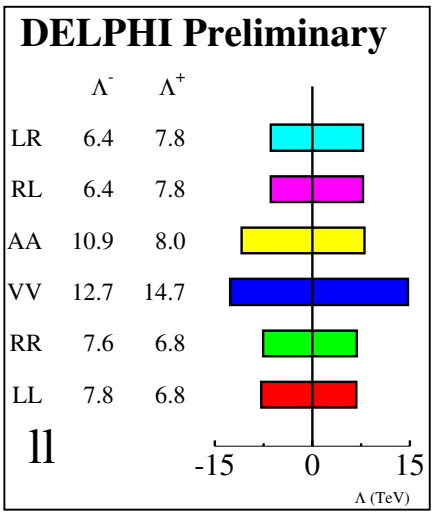
$$\delta : 1 = \text{electron} / 0 = \text{others}$$

$$\text{coupling}: \frac{g^2}{4\pi} = 1$$



Λ : energy scale of new physics

- Different behaviour depending on the allowed helicity of initial and final state fermions: LL,AA,VV
- Modifies Cross-section and Afb



189 GeV/c2

Up to 189 GeV

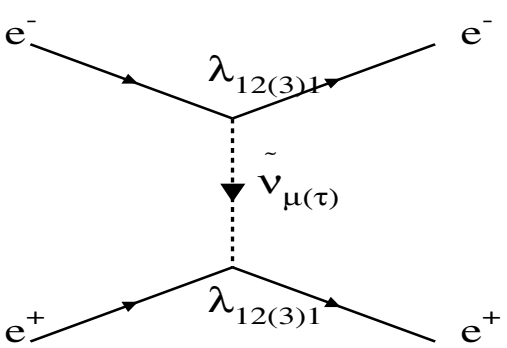
LR-RL : 6 GeV

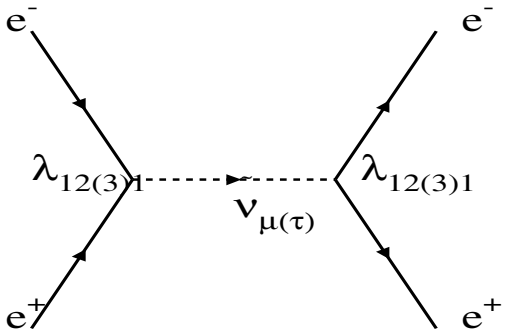
VV-AA : 15 GeV

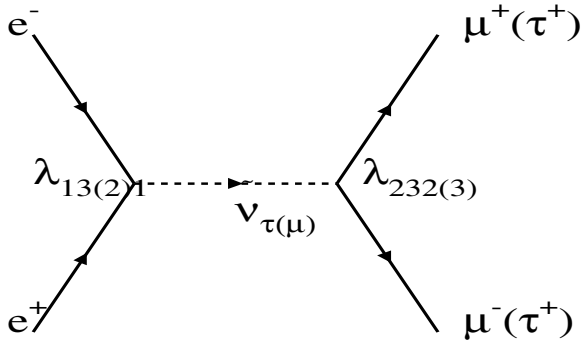
similar to all exp..

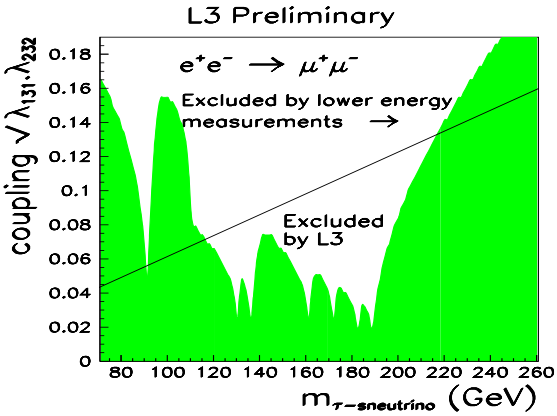
Existing limits : 15 GeV for RR, LL,RL,LR from atomic physics

RP violating sneutrinos









- Input : differential cross -section or leptonic asymmetries
- Similar results for μ sneutrinos
- Similar results from all experiments

- Existing limits from direct searches :

$$\tilde{\nu}\mu, \tilde{\nu}\tau \geq 49\,\mathrm{GeV/c^2}, \tilde{\nu}_e \geq 72\,\mathrm{GeV/c^2}$$

Conclusions

- Good agreement with SM over a wide range of energies and measurements
- Several extensions of SM can be tested and existing limits improved
- Statistical precision so far per experiment 2 to 10 %
- At the end of LEP2 (500 pb^{-1} , 4 exp.) (* LepII MC workshop)

qq	0.60%
ll	1.50%
Rb	2%
Rc	3%
Afb lepton	0.015
Afb b	0.04

- ≈ 50 % of the syst. corr. between exp.
- Theoretical predictions (* LepII MC workshop)
  - ee : 0.5 % (Bhwide improvement)
  - ll : 0.5 % (KK Jadach et al.)
  - other : at least an exact estimate of the theoretical errors.