ETH Institute for Particle Physics

W Polarisation Studies with L3 at LEP

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PhD Students Seminar 2003

- Introduction
- W Polarisation, W Polarisation vs. cos θ_W
- WW Spin Correlations in Flight Direction
- WW Decay Plane Correlations

W Polarisations

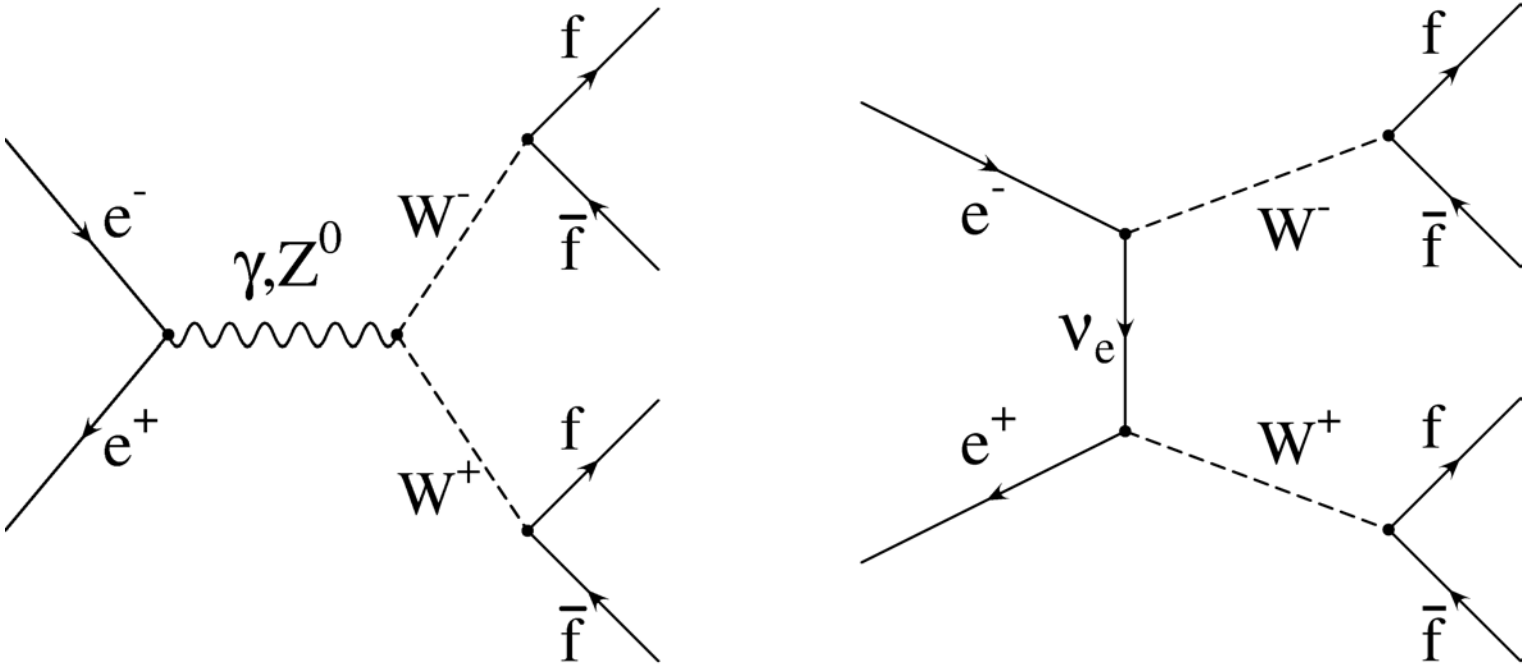
- **Mass 0 – photon**
  → helicities (–1), (+1)

- **Massive W boson**
  → helicities (-1), (+1) and (0)
  (-1),(+1): transverse polarisation, (0): longitudinal polarisation

- **Standard Model:**
  longitudinal d.o.f. from electroweak symmetry breaking mechanism

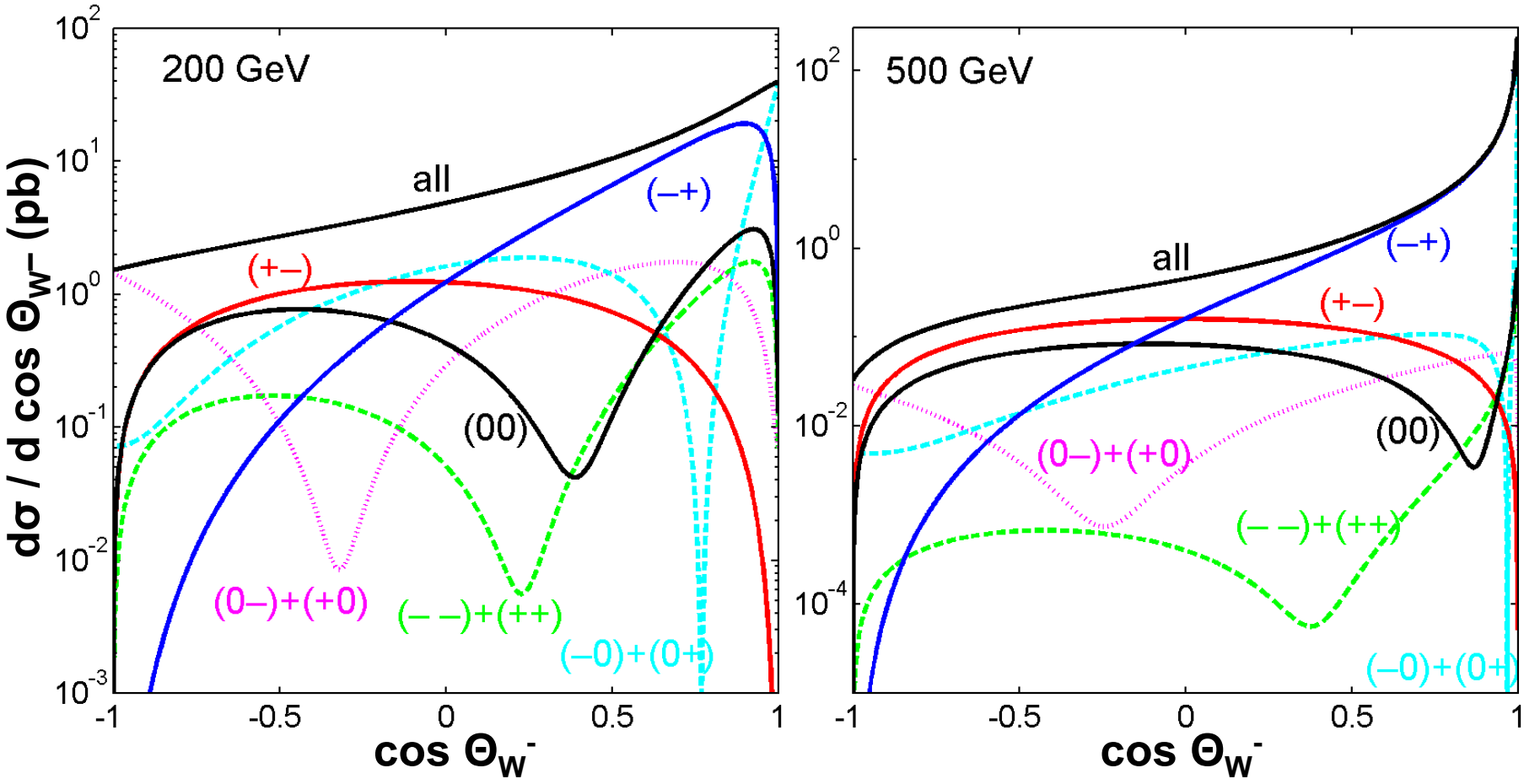
- **Equivalence theorem:**
  longitudinal gauge bosons ≈ Goldstone bosons

W Pair Production



- **$e^+e^- \rightarrow W^+W^- \rightarrow ffff$**
- **ffff = e/$\mu\nu$qq – 29.2%**
  ffff = qqqq – 45.6%

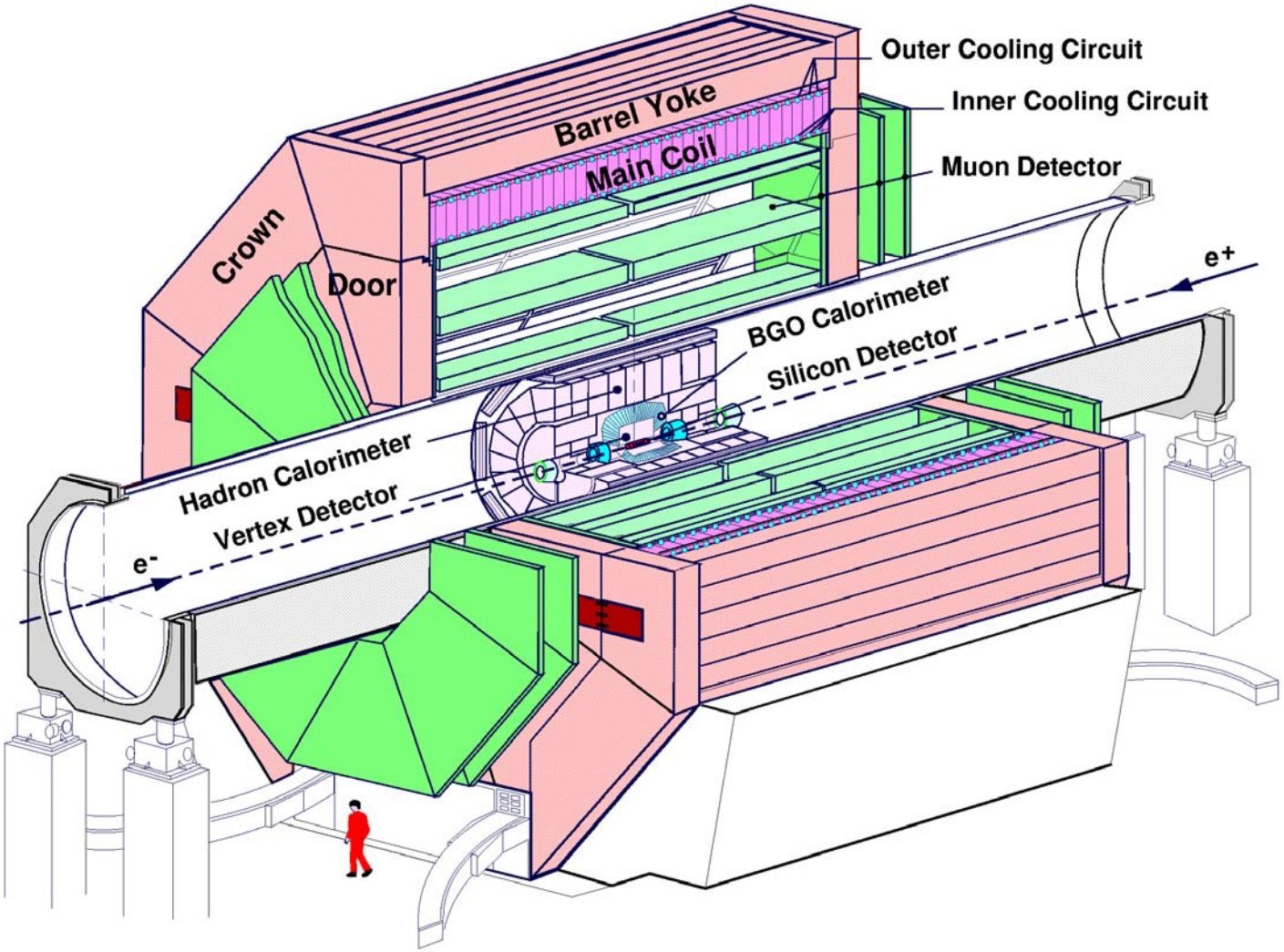
W Pair Production



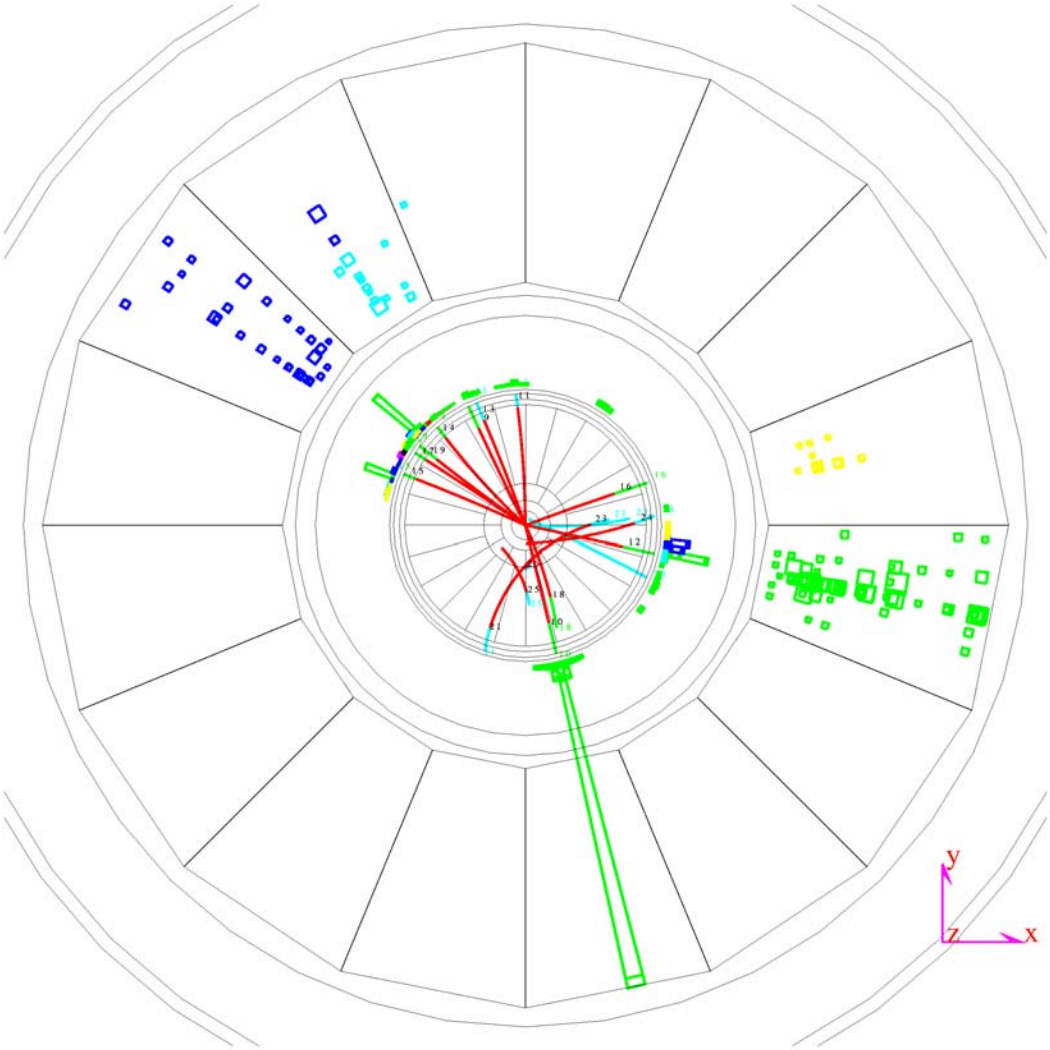
- **Analytical calculation: polarised W-pairs with helicities (λ_{W^-},λ_{W^+})**

  [Hagiwara et al, Nucl. Phys. B282 (1987)]

L3 Detector at LEP (RIP)



W Pairs in L3

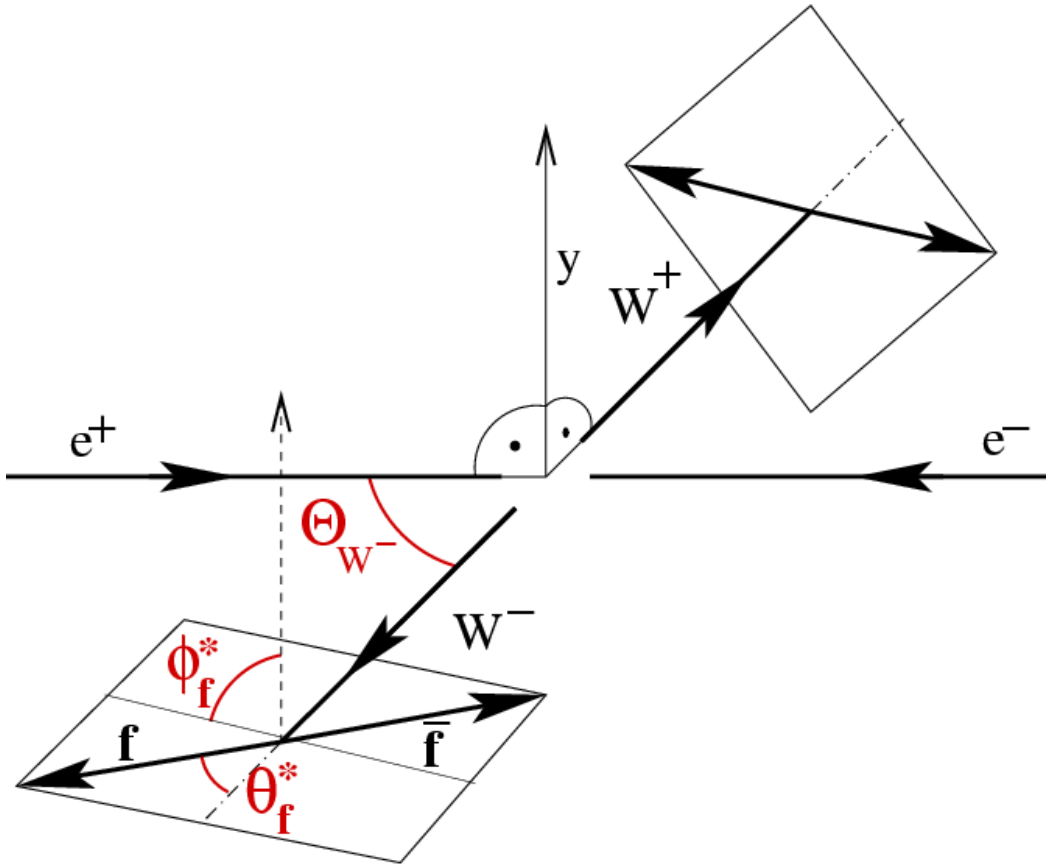


- **example:**

  WW→eνqq event in L3

W Pairs

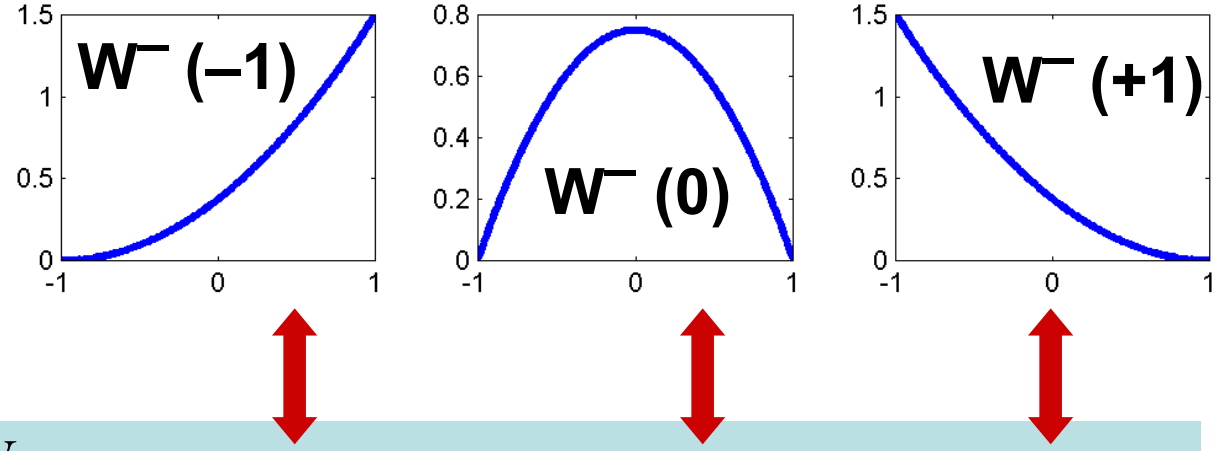
- Straightforward selection for WW→e/$\mu\nu$qq, ensures well measured angles.
- 2010 selected events, 3.7% background from WW→$\tau\nu$qq and ee→qq(γ),
- efficiency 65.7%



Inclusive Measurement

Polar decay angle in W rest frame

cos θ_f^*



W→ℓν:

$$\frac{1}{N}\cdot\frac{dN}{d\cos\theta_f^*} = f_-\cdot\tfrac{3}{8}(1+\cos\theta_f^*)^2 + f_0\cdot\tfrac{3}{4}(\sin^2\theta_f^*) + f_+\cdot\tfrac{3}{8}(1-\cos\theta_f^*)^2$$

W→qq:

$$\frac{1}{N}\cdot\frac{dN}{d\left|\cos\theta_f^*\right|} = f_\pm\cdot\tfrac{3}{4}(1+\left|\cos\theta_f^*\right|^2) + f_0\cdot\tfrac{3}{2}\left|\sin\theta_f^*\right|^2$$

Helicity fractions extracted by fit of corrected cos θ* distributions with $\Sigma f_i = 1$

Inclusive W Polarisation

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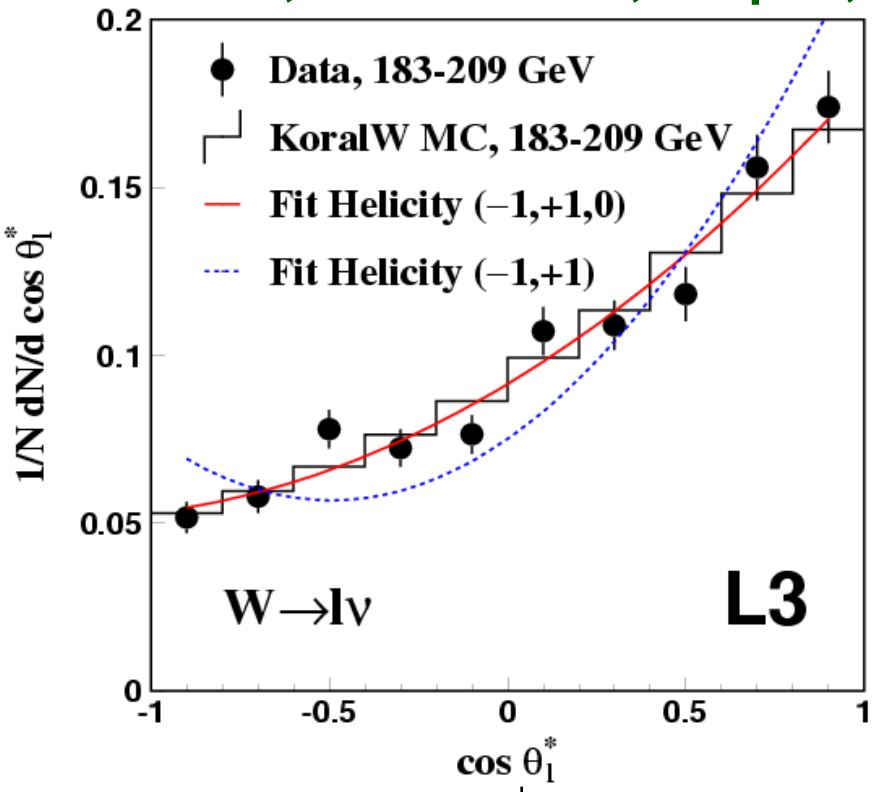
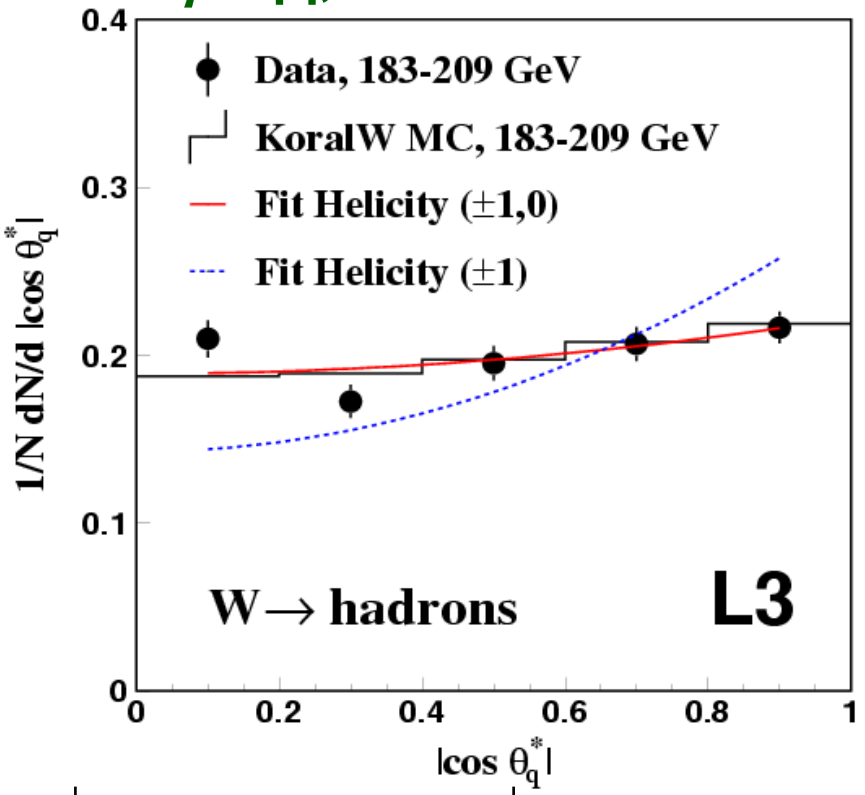
L3, 183-209 GeV, 685pb^{-1}, WW→e/$\mu\nu$qq, corrected





W→ℓν, W→qq combined	f_- [%]	f_+ [%]	f_0 [%]
Data	59.2 ± 2.7 ± 1.6	19.0 ± 1.7 ± 1.5	21.8 ± 2.7 ± 1.6
SM MC	59.0 ± 0.3	16.9 ± 0.2	24.1 ± 0.3

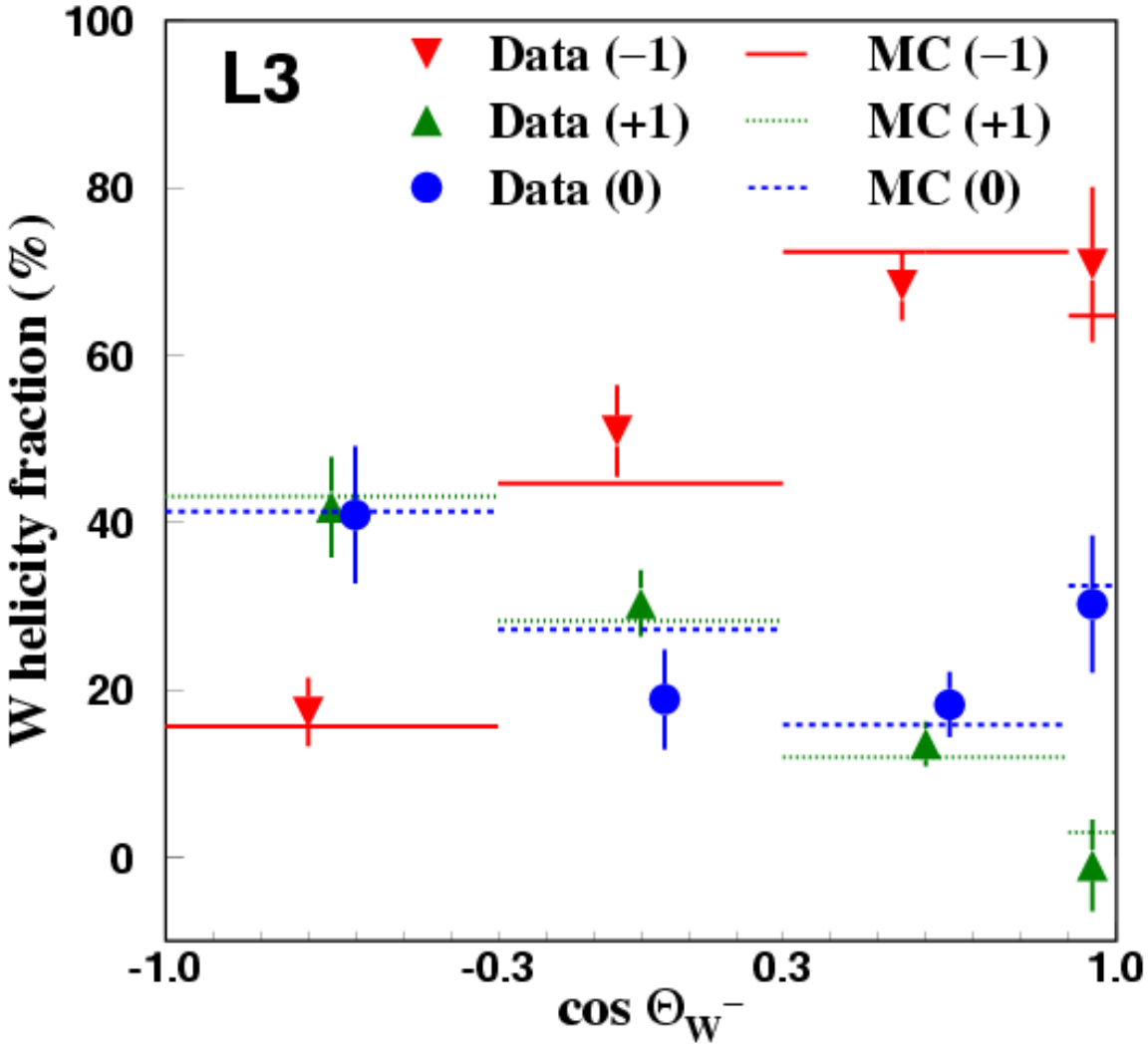
Longitudinal Polarisation at LEP

- DELPHI, OPAL:
  measure differential polarised cross-sections using Spin Density Matrix method, integrate over scattering angle, divide by total cross-section
- L3: inclusive measurement

	fraction of helicity (0) [%]
DELPHI 189-209GeV W→e/$\mu\nu$	**24.9 ± 3.3** (preliminary)
OPAL 183-209GeV W→e/μ/$\tau\nu$, W→qq	**23.8 ± 2.1 ± 1.4** (preliminary)
L3 183-209GeV W→e/$\mu\nu$, W→qq	**21.8 ± 2.7 ± 1.6** (published)
SM	**24.0**

Polarisation vs. cos Θ_W-

Direct measurement
183-209 GeV,
$W \to \ell\nu$ and $W \to qq$ combined



strong variations with W scattering angle,

in agreement with Standard Model

WW Spin Correlations

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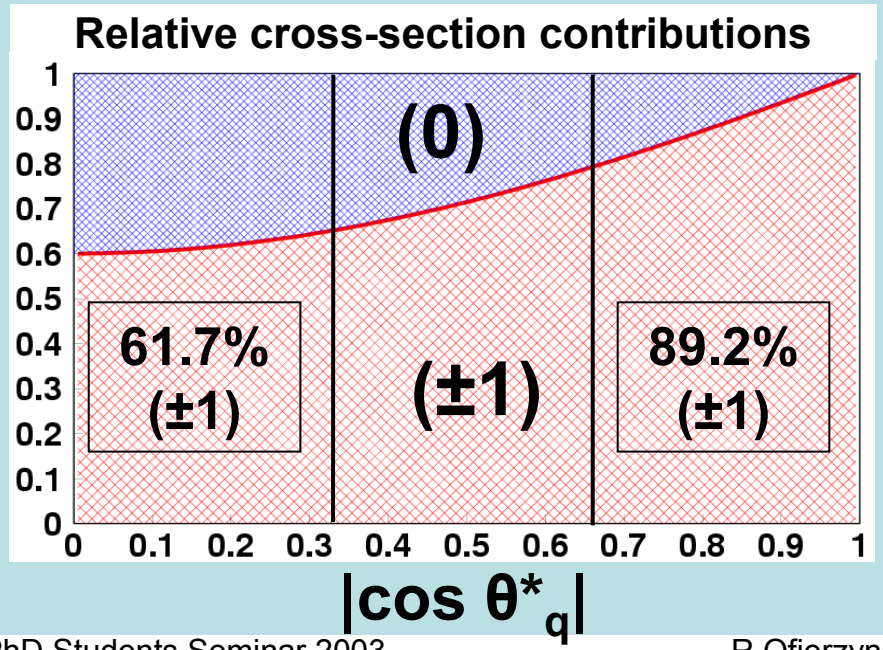
$W \to qq$

(±1) depleted

(±1) enriched



$W \to \ell\nu$

f_-, f_+, f_0

f_-, f_+, f_0

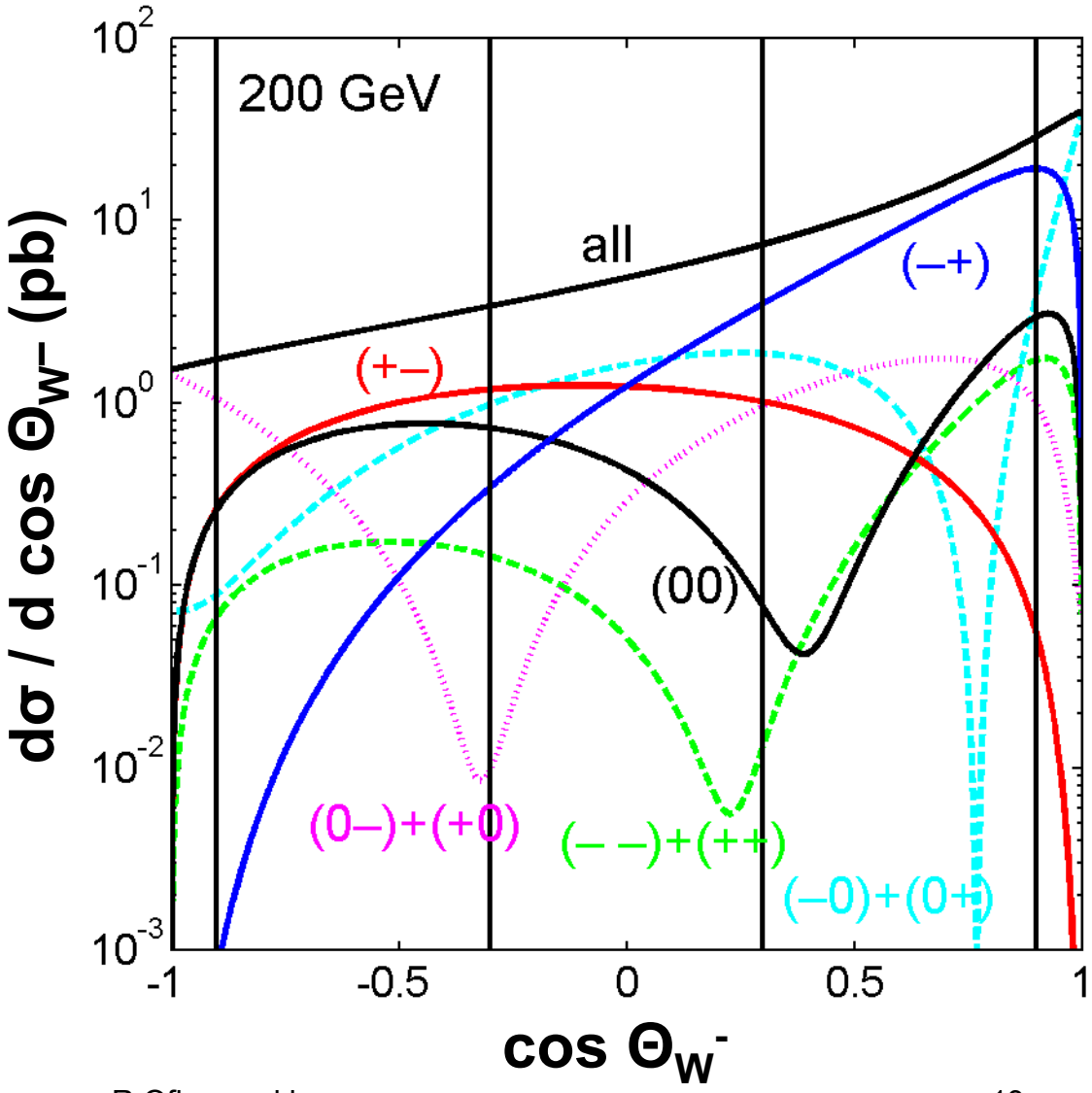
difference
=
indicator for
correlations

WW Spin Correlations cont.

Enlarge possible effects using W scattering angle

Forward bin:
$0.3 < \cos\Theta_{W^-} < 0.9$
$f(-+) \approx 63\%$
(average 43%)

Backward bin:
$-0.9 < \cos\Theta_{W^-} < -0.3$
$f(00) \approx 25\%$
(average 9%)

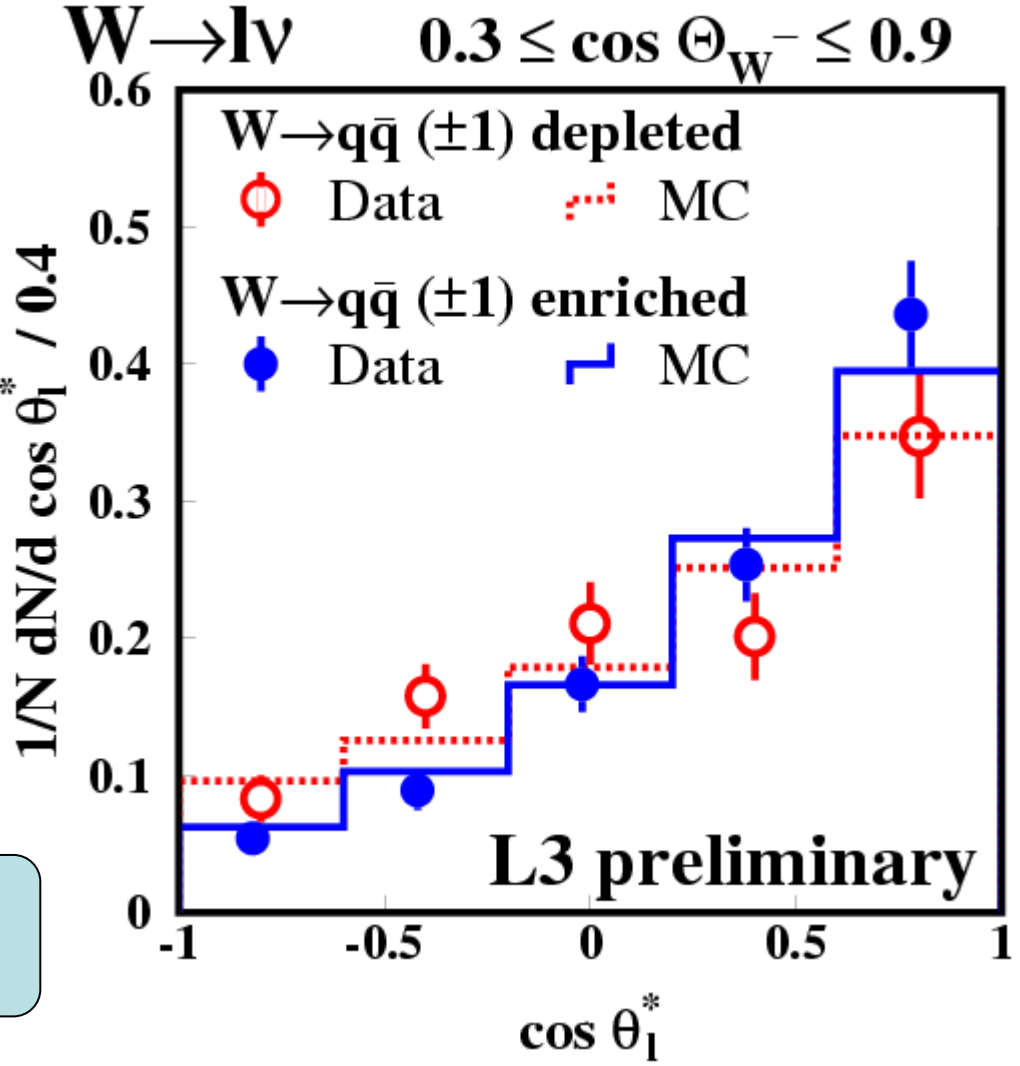


WW Spin Correlations Results

189-209 GeV, corrected $W \to \ell\nu$

$W \to \ell\nu$ helicity	$(f_{dep} - f_{enr})$ Data	$(f_{dep} - f_{enr})$ MC
(-1) [%]	-31.8 ±10.3±6.5	-11.1 ±1.1
(+1) [%]	3.4 ±6.7±5.2	5.7 ±0.7
(0) [%]	28.4 ±13.7±9.5	5.4 ±1.5

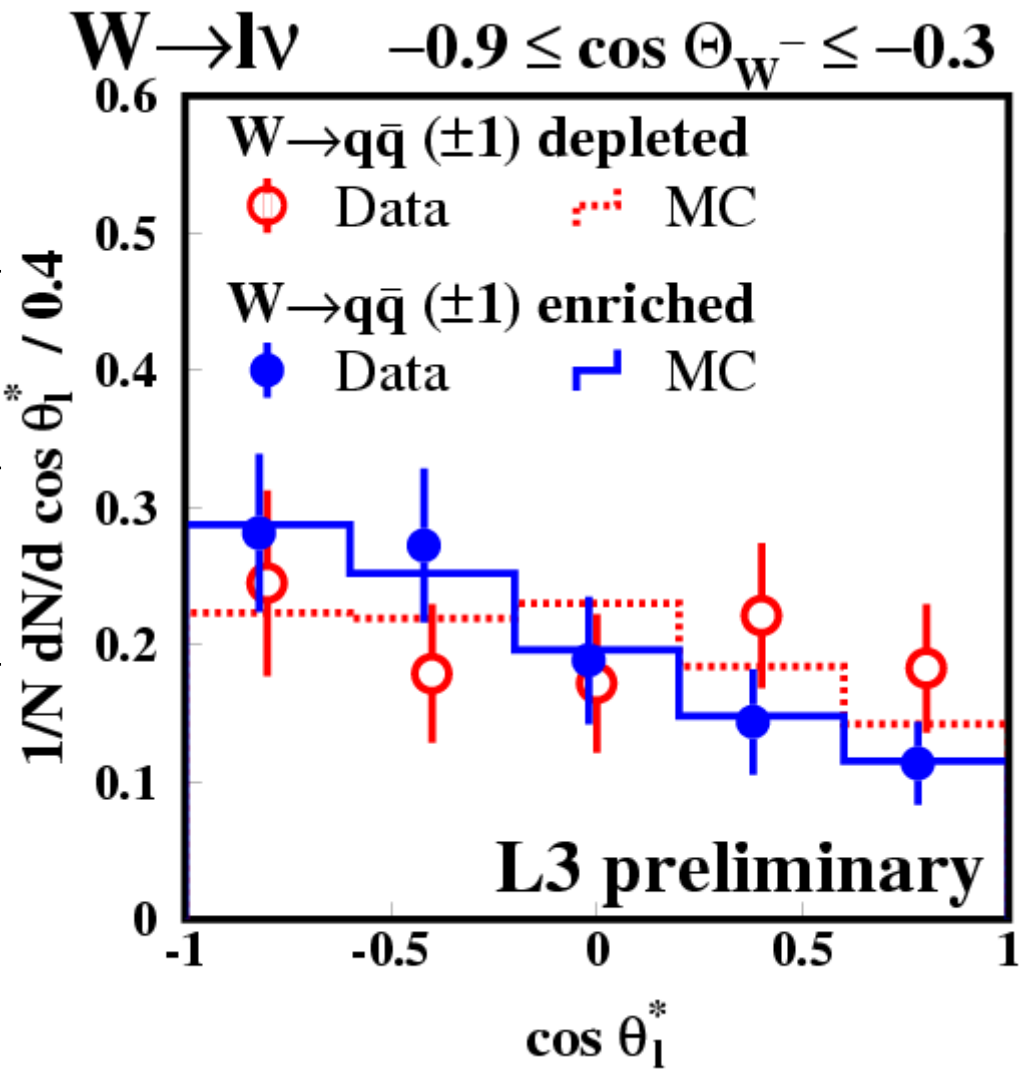
seen with 2.6σ,
somewhat stronger than in MC



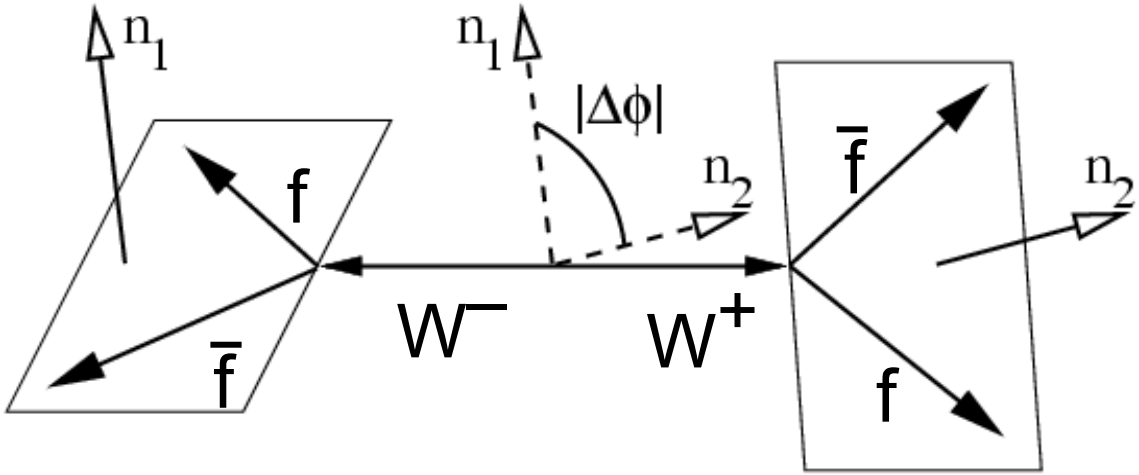
WW Spin Correlations Results

189-209 GeV, corrected $W \to \ell\nu$

$W \to \ell\nu$ helicity	$(f_{dep} - f_{enr})$ Data	$(f_{dep} - f_{enr})$ MC
(-1) [%]	23.5 ±15.9±13.4	2.8 ±2.0
(+1) [%]	-13.2 ±15.8±12.1	-18.1 ±2.3
(0) [%]	-10.3 ±38.2±19.4	15.3 ±3.5



Decay Plane Correlations



- determine angle between decay plane normal vectors
- fit with

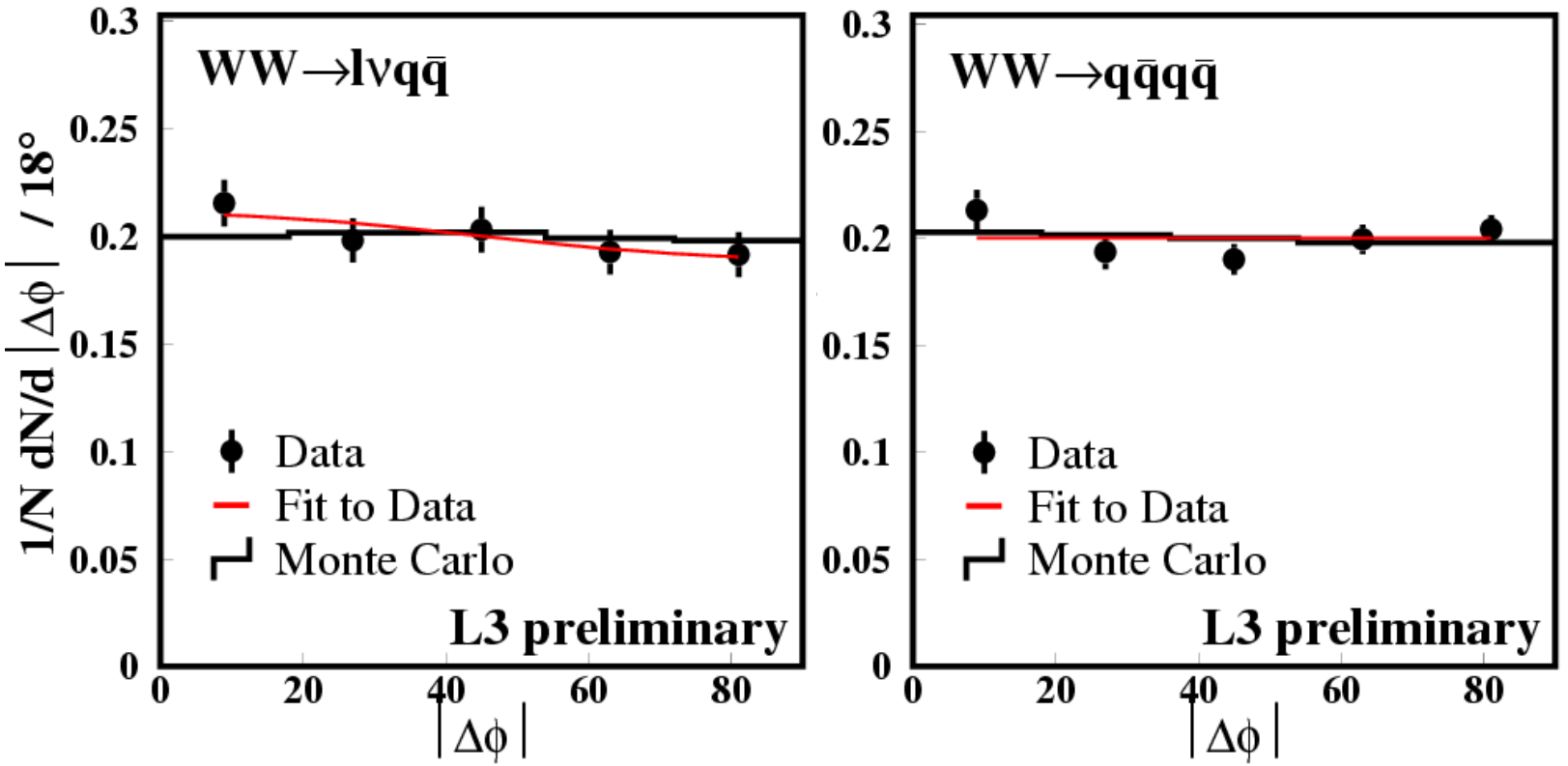
$$\frac{1}{N}\frac{dN}{d\,|\Delta\varphi|} = 1 + D\cdot\cos(2\cdot|\Delta\varphi|)$$

[Duncan,Kane,Repko, Nucl.Phys.B272(1986)]

D = correlation parameter, D > 0

- WW→e/$\mu\nu$qq and WW→qqqq, 189-209 GeV

Decay Plane Correlations Results



D = 0.051 ± 0.033 ± 0.020

D = 0.000 ± 0.024 ± 0.014

combined data: D = 0.017 ± 0.019 ± 0.011 (MC: D = 0.010 ± 0.002)

Conclusions

- **Inclusive measurement**
- **Fraction of longitudinal polarisation, variation with W scattering angle in agreement with SM**
- **WW spin correlations in flight direction observed with 2.6 standard deviations**
- **WW decay plane correlations very small, in agreement with SM**
- **Interested in more ?**

  Phys. Lett. B 557 (2003) 147,

  L3 note 2812 (contributed to EPS 2003)