Measurement of W Polarisation with L3 at LEP

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L3 Collaboration

- *Introduction*
- *Direct W Polarisation Measurement*
- *Test of CP Invariance*
- *W Polarisation vs. cos* Θ_{W^-}
- *WW Spin Correlations*
- *Summary*

W Polarisation

- Mass 0 – photon → helicities (–1), (+1)
- Massive W boson → helicities (-1), (+1) and (0)
- SM: W and Z masses from Higgs-mechanism
- Equivalence theorem:
  longitudinal gauge bosons ≈ Goldstone bosons

- Study W pair events with $W_1 \rightarrow \ell\nu$ and $W_2 \rightarrow qq$

$e^+e^- \rightarrow WW$ in terms of helicities

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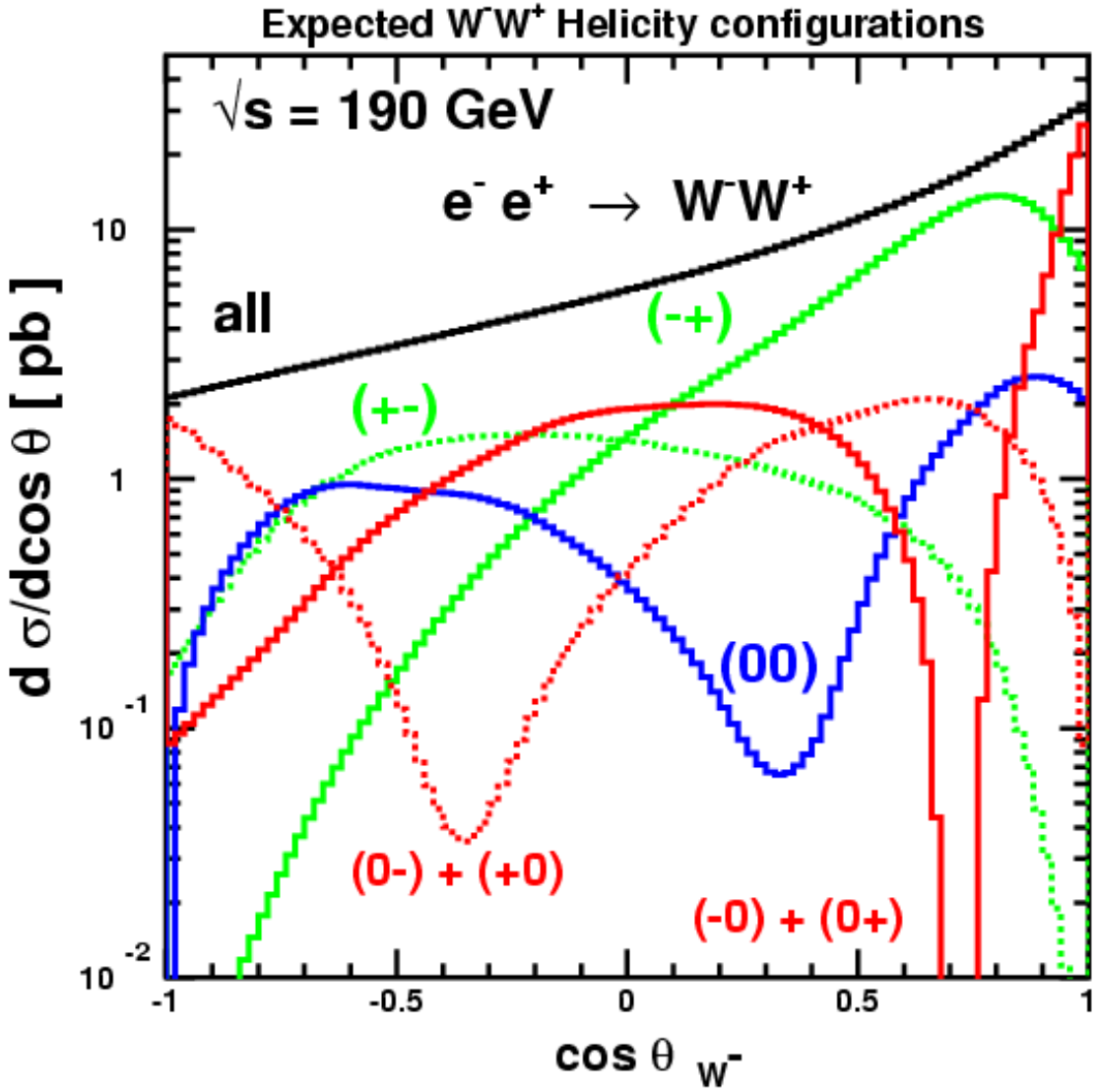

(–+) dominant

(00) smaller than transverse amplitudes

How to extract the helicities

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From the fermion polar decay angle θ* in the W rest frame.

W^- helicities

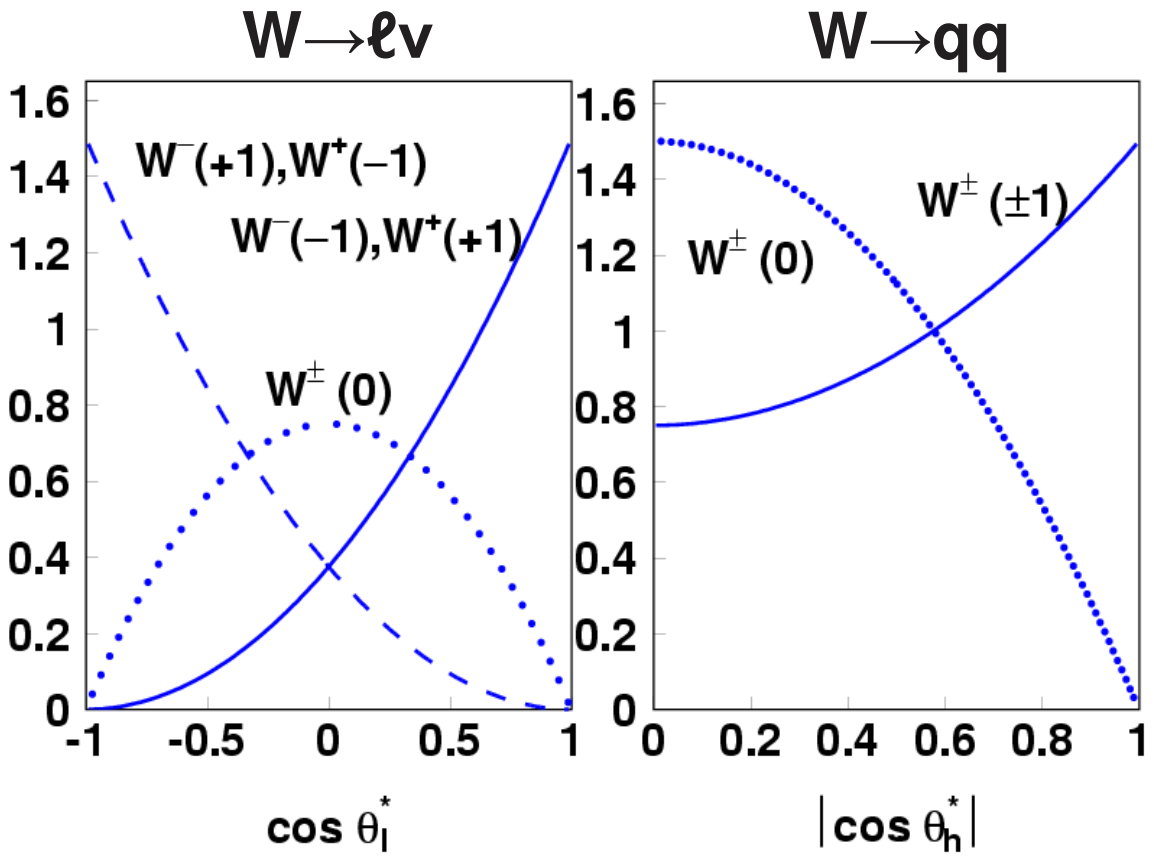
(–1) ~ $(1+\cos\theta^*)^2$

(+1) ~ $(1-\cos\theta^*)^2$

(0) ~ $\sin^2\theta^*$

Fit with

Σ fractions = 1



Some Characteristics

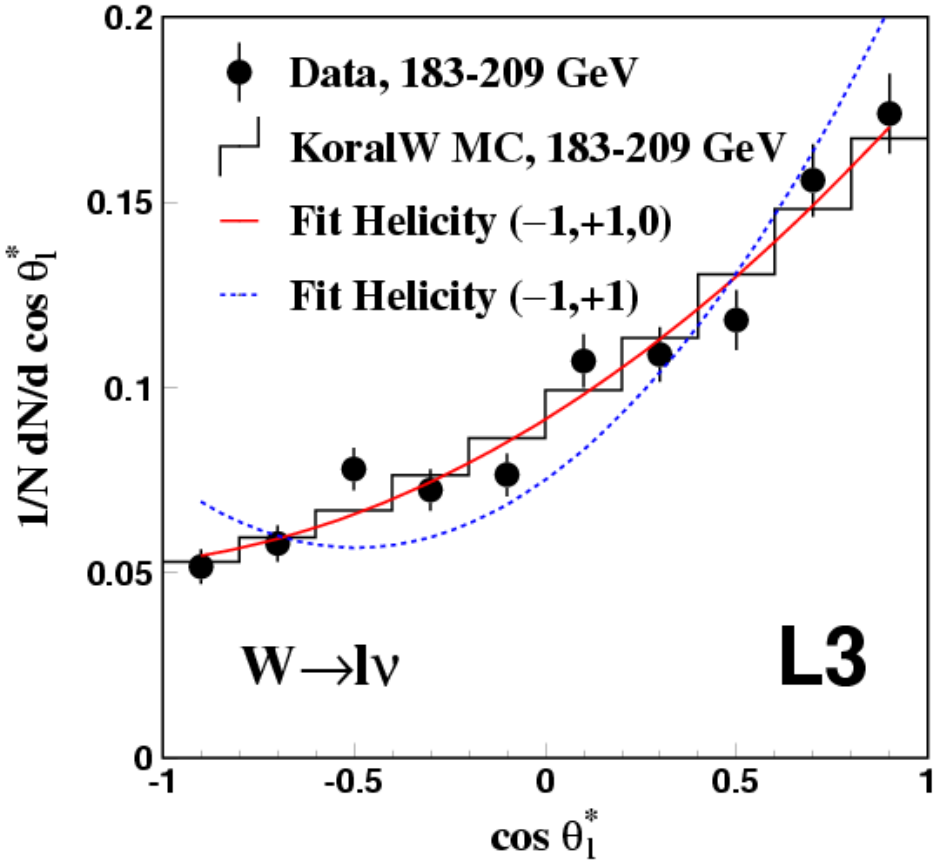
- **analyse semileptonic decays WW→ℓνqq, ℓ=e,μ**
  - **low background**
  - **hadronic and leptonic W decays well separated**
  - **charge assignment from lepton**

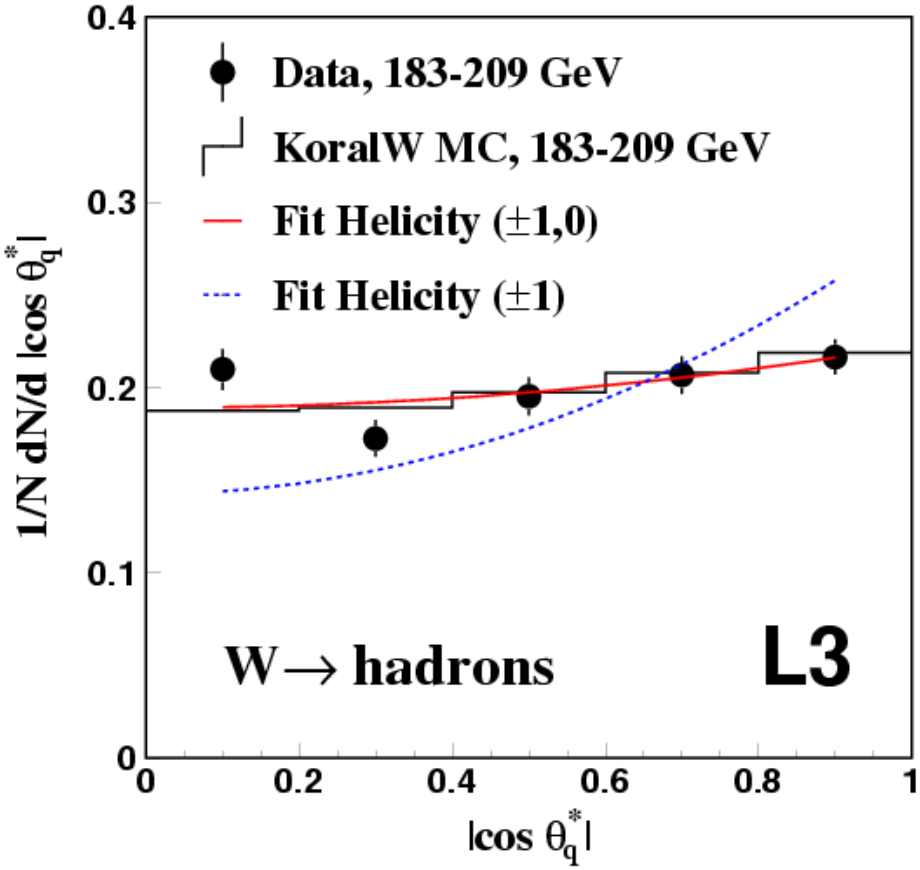
- **685 pb^{-1} at $\sqrt{s}$=183-209 GeV**
- **SM expectation slightly energy dependent**

- **simple selection**
  - **1088 eνqq and 922 μνqq event candidates**

    (4% background from τνqq and qq(γ))

Direct Measurement





fit helicities (-1),(+1),(0): χ^2 = 12.7 (8 d.o.f.)
fit helicities (-1),(+1): χ^2 = 56.2 (9 d.o.f.)

fit helicities (±1),(0): χ^2 = 6.6 (4 d.o.f.)
helicities (±1): χ^2 = 59.1 (5 d.o.f.)

Direct Measurement Fit Results

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183 -209 GeV combined
Fractions combining leptonic and hadronic decays:

	(-1) [%]	**(+1) [%]**	**(0) [%]**
Data (stat.,syst.error)	59.2 ± 2.7 ± 1.6	19.0 ± 1.7 ± 1.5	21.8 ± 2.7 ± 1.6
SM	59.0	16.9	24.1

(biggest systematic uncertainties from selection criteria and binning effects)

SM expectation confirmed, sensitivity at level of 7σ

CP-Test

Standard Model: CP-Invariance

W^- helicity (-1), (+1), (0) fractions
equal
W^+ helicity (+1), (-1), (0) fractions

Test it by measuring helicity fractions in W^+ and W^- separately.

Charge assignment from lepton (e or μ):

select 1020 $W^+ \rightarrow \ell^+\nu$ and 990 $W^- \rightarrow \ell^-\nu$

CP-Test: W^- and W^+

	(-1) [%]	(+1) [%]	(0) [%]
W^- Data (stat.,syst.error)	55.5 ± 3.7 ± 1.6	20.0 ± 2.6 ± 1.5	24.5 ± 3.8 ±1.6
W^+ Data (stat.,syst.error)	63.4 ± 3.8 ± 1.6	18.1 ± 2.4 ± 1.5	18.5 ± 3.9 ± 1.6
SM	59.0	16.9	24.1

W scattering angle dependence

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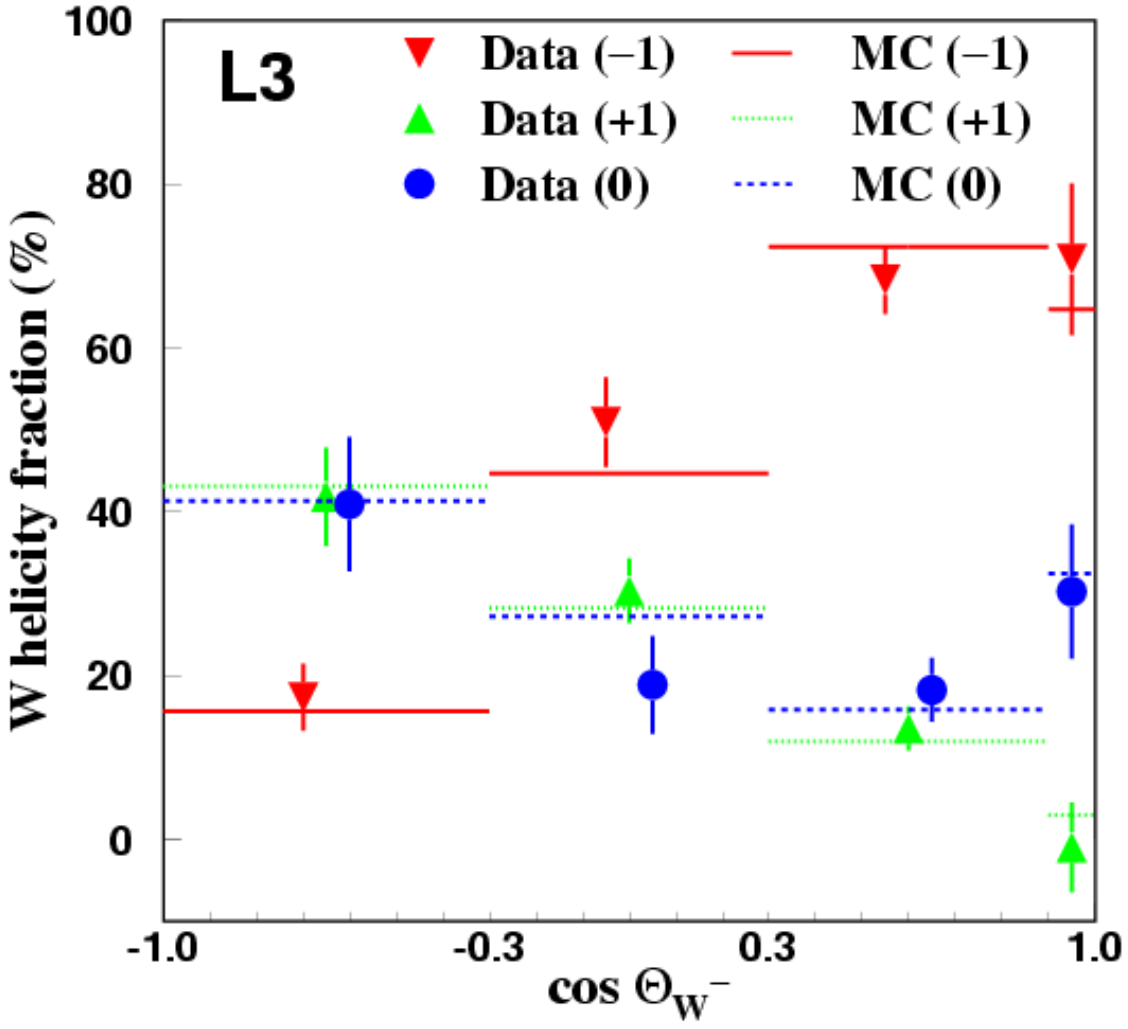
Fit results:

helicity fractions with stat. error:

(combining 183 – 209 GeV, $W \to \ell\nu$, $W \to qq$)



WW Spin Correlations Analysis w.r.t. W flight direction

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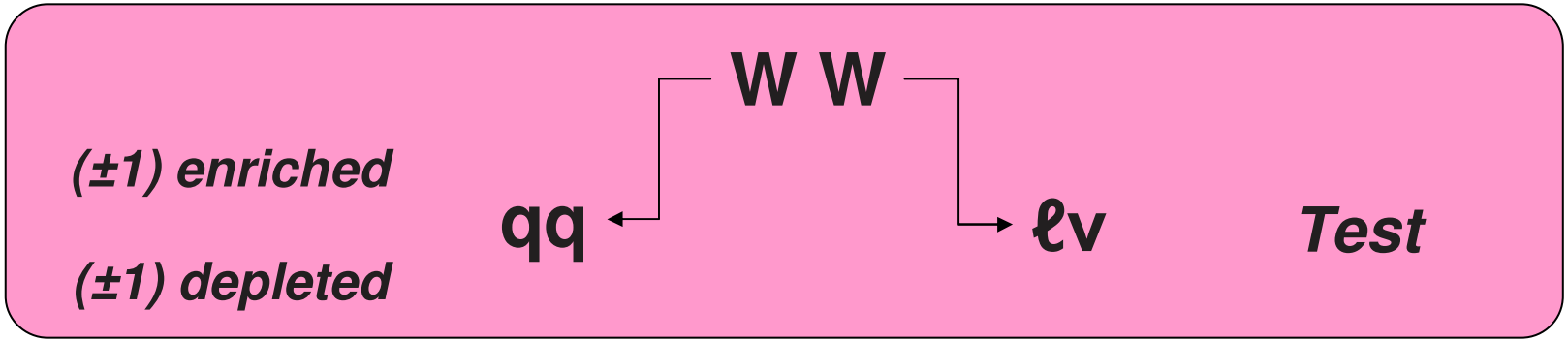

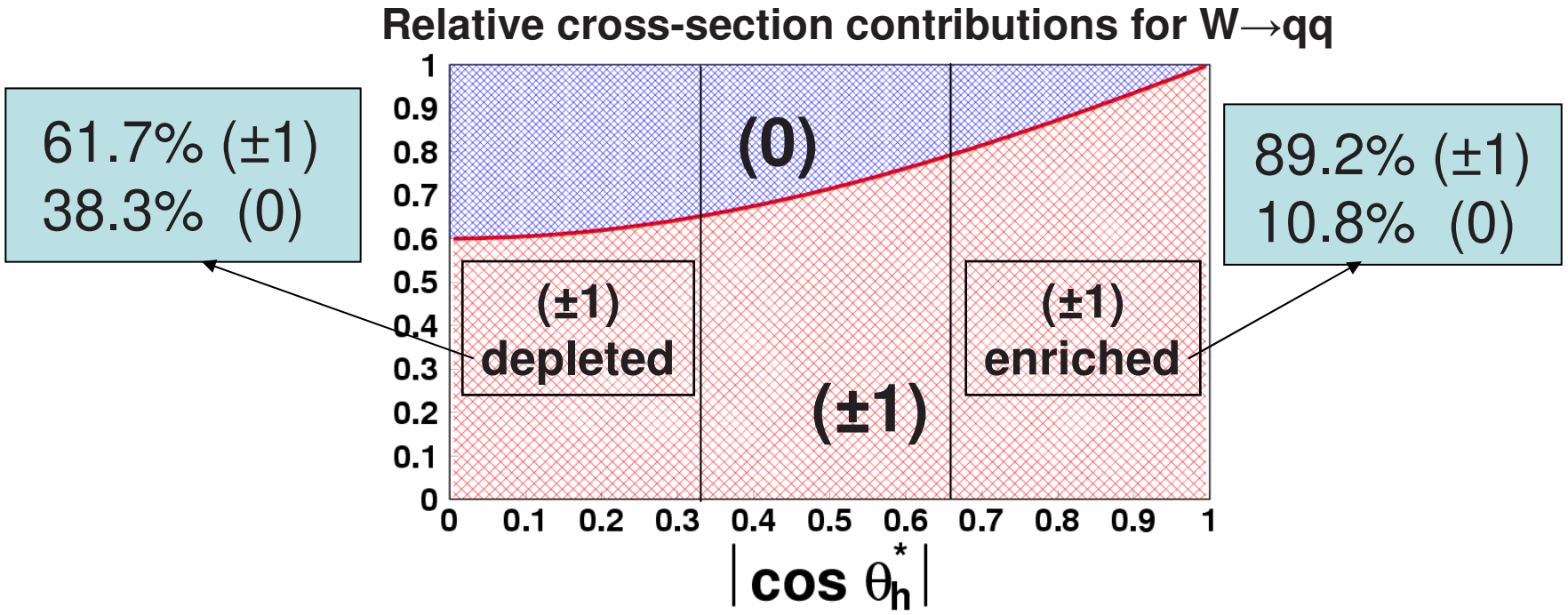

WW Spin Correlations cont.

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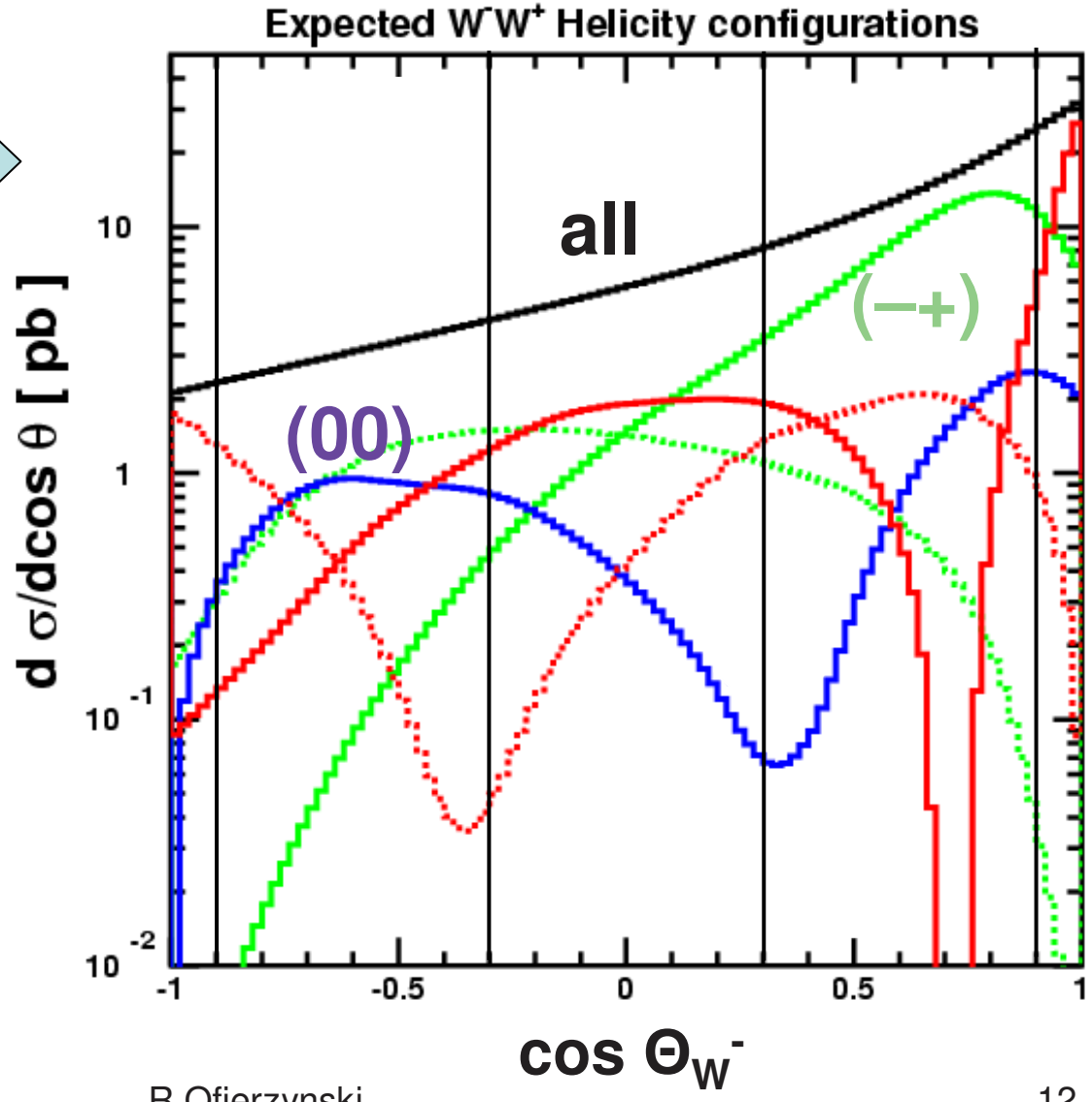
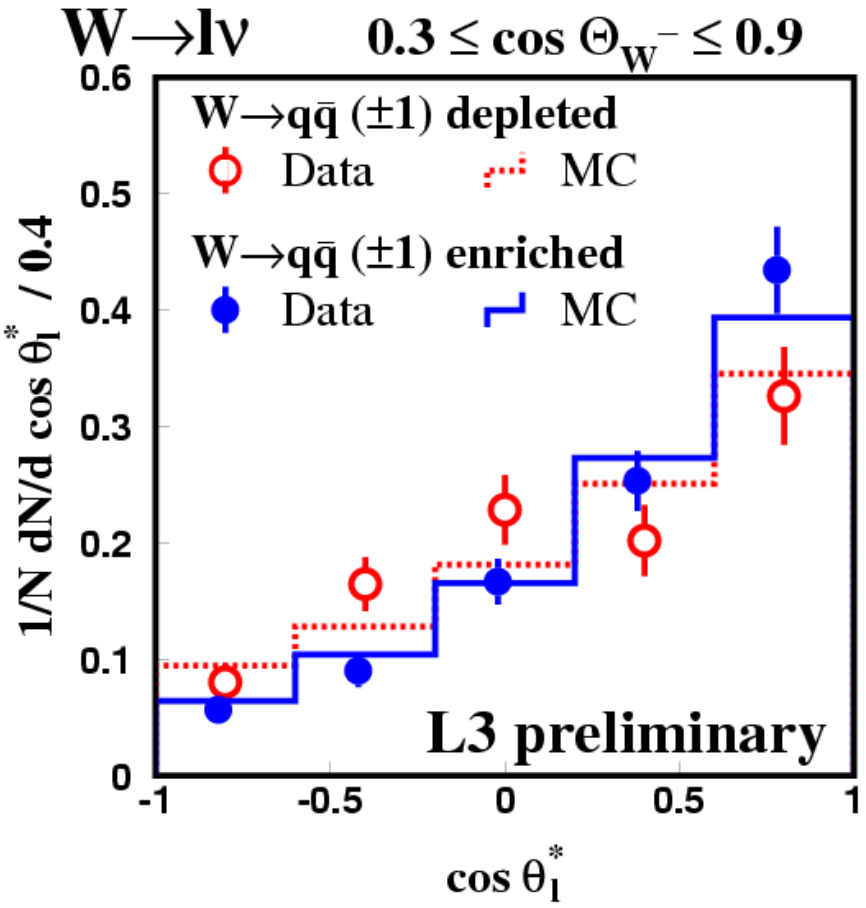
Enlarge possible effects using W scattering angle



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 forward bin



W→qq	W→ℓν helicity (-1) [%]	(+1) [%]	(0) [%]
(±1) depleted	45.6 ±8.6±6.0	9.7 ±5.8±3.6	44.8 ±11.7±6.9
(±1) enriched	83.2 ±6.1±0.4	9.2 ±3.3±3.0	7.6 ±8.1±3.0
difference Data	-37.6 ±10.5 ±6.0	0.5 ±6.7 ±4.7	37.2 ±14.2 ±7.5
diff. SM	-12.0	4.8	7.2

2σ stronger than expected

WW Spin Correlations – Results backward bin

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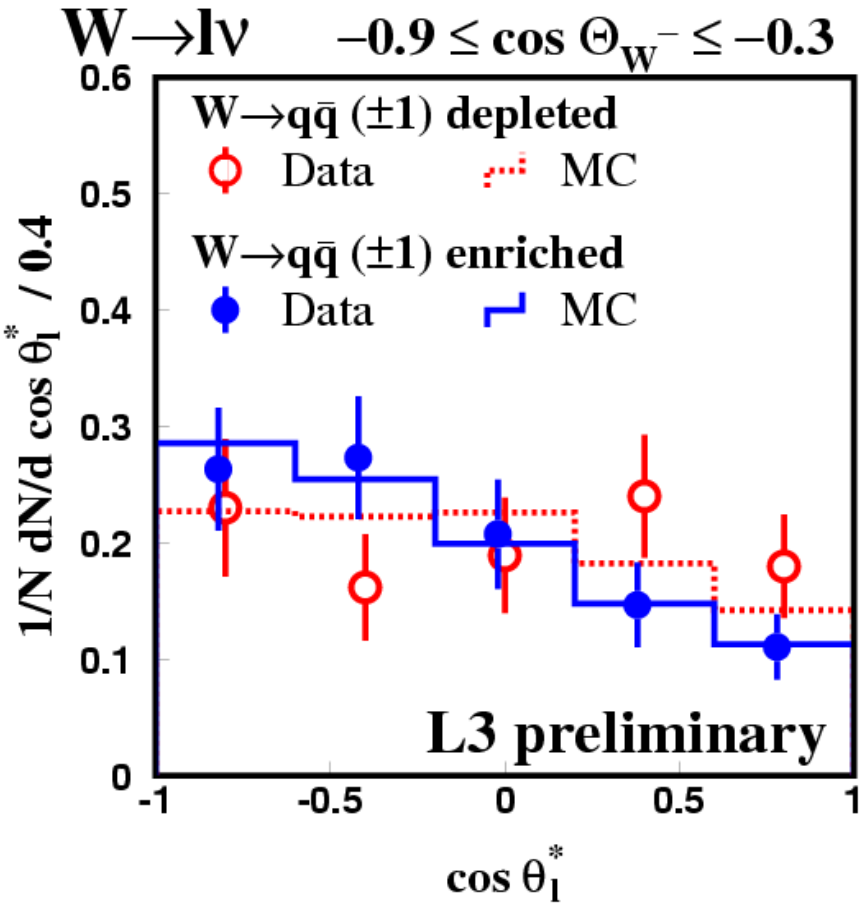

W→qq	W→ℓν helicity (-1) [%]	W→ℓν helicity (+1) [%]	W→ℓν helicity (0) [%]
(±1) depleted	32.7 ±11.2±8.9	29.6 ±11.2±7.6	37.7 ±25.9±11.2
(±1) enriched	13.4 ±7.5±7.5	47.2 ±10.7±10.4	39.4 ±19.7±13.6
difference Data	19.3 ±13.5 ±11.6	-17.6 ±15.5 ±12.9	-1.7 ±32.5 ±17.6
diff. SM	3.9	-16.3	12.4

not very strong …

Summary

W polarisation studies in the reaction $e^+e^- \rightarrow W^+W^- \rightarrow \ell\nu qq$:

- all three possible helicity states observed, in agreement with SM
- longitudinal polarisation observed with 7σ significance:
  21.8 ± 2.7 ± 1.6 % (in agreement with expectation of 24.1%)
- helicity fractions of W^+ and W^- in agreement with CP invariance
- helicity fractions vary with the W scattering angle, in agreement with SM
- hep-ex/0301027, “Measurement of W Polarisation at LEP”

- data show significant correlations between W^+ and W^- helicities, 2σ stronger than expected from SM