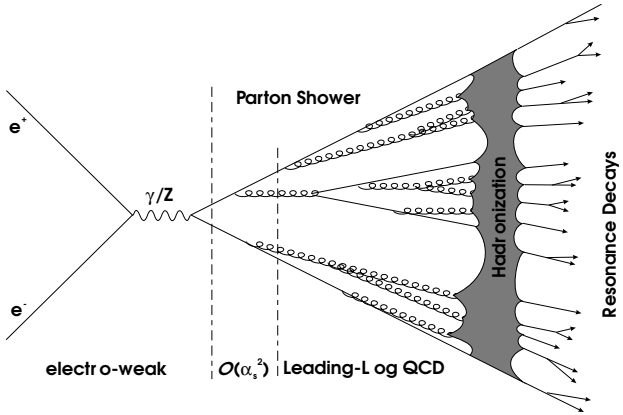
Spin Alignment in heavy and light flavour systems at OPAL

Simon Robins
The Technion, Israel

- Spin alignment of vector mesons in Z^0 decays
- Hyperon polarization in Z^0 decays.

Introduction

- $\sim$4M $Z^0 \rightarrow q\bar{q}$ events at each LEP experiment



- primary quarks highly polarized:
  - $P_d^L, P_s^L \sim$ -0.91
  - $P_u^L \sim$ -0.64

Source of spin alignment

- Vector mesons:
  - $q\bar{q}$: s=1, L=0
  - any spin alignment must arise (in part at least) from hadronization

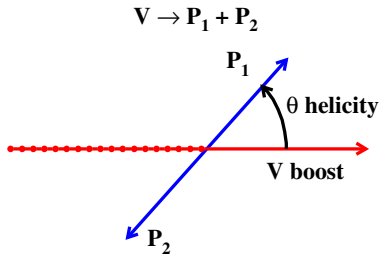
- Hyperons:
  - $Qq\bar{q}$
  - polarization of heavy quark is transferred directly to hyperon
  - any transverse polarization must come from hadronization.

Can the spin alignment of hadrons tell us about the relevance of particular hadronization models ?

Decay formalism

- Helicity density matrix:
  - ρ_{00}- probability to be in m=0 state
  - $\rho_{\pm1\pm1}$ - probability to be in m=$\pm$1 state
  - Off diagonal elements ρ_{1-1} measure coherence between helicity +1, -1 states.

- $\rho_{00} = \rho_{\pm1\pm1} = 1/3 \Rightarrow$ no spin alignment
- Work in the meson helicity rest frame:
  - θ_H is polar angle:



  - ϕ_H is azimuthal angle in helicity-beam frame

V →pseudoscalar + pseudoscalar

- Helicity density matrix elements ρ_{00}, ρ_{1-1} determined from decay angular distributions:

$$W(\cos\theta_H) = \frac{3}{4}[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta_H]$$

  - ρ_{00}= 0 $\Rightarrow N(\theta_H) \sim \sin^2\theta_H$
  - ρ_{00}= 1 $\Rightarrow N(\theta_H) \sim \cos^2\theta_H$
  - ρ_{00}= 1/3 $\Rightarrow N(\theta_H)$ isotropic in $\cos\theta_H$

$$W(|\alpha|) = (2/\pi)[1 + 2Re\rho_{1-1}\cos 2|\alpha|]$$

where $\alpha = |\phi_H| - \pi/2$

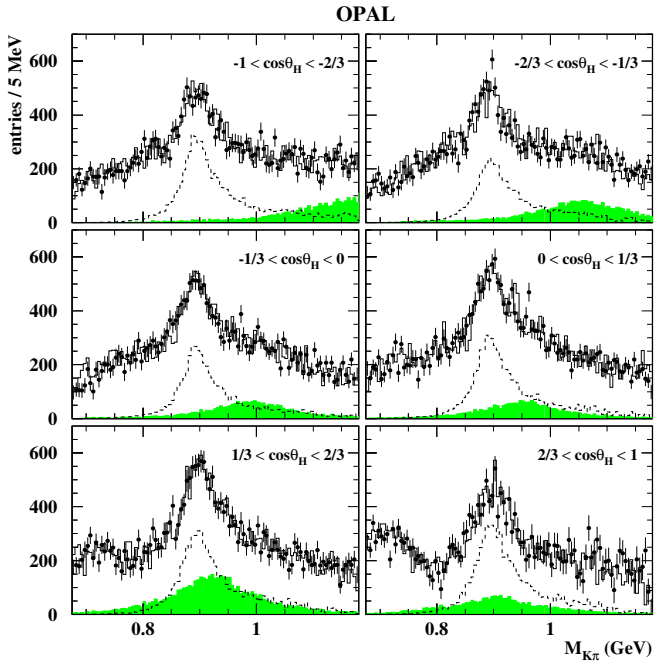
Hadronization - no detailed models: orientation of non-primary quarks expected to be random; no net polarization (ie: $\rho_{11} = \rho_{-1-1}$)

The OPAL data samples

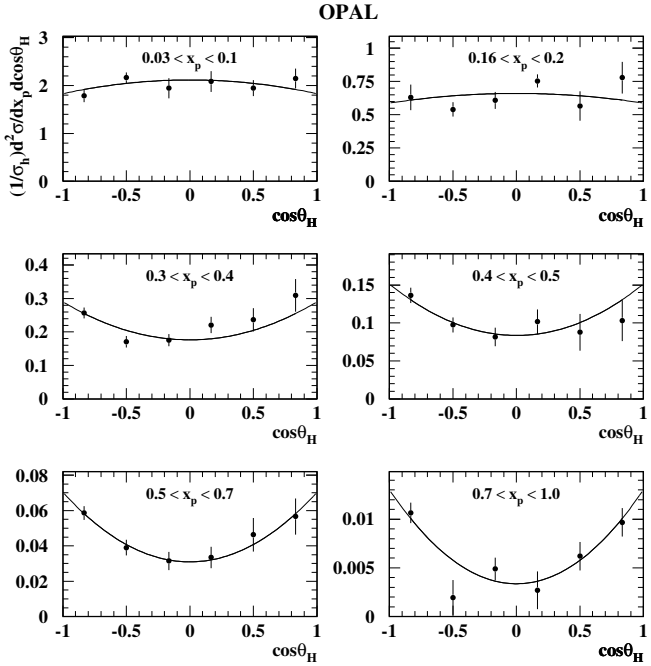
- OPAL - one of the four LEP experiments:
  - $e^+e^- \to Z^0 \to q\bar{q}$
  - Analysis of 4.3M hadronic Z^0 decays at LEP1, 1990-95:
- Reconstruct and measure helicity density matrix elements of:
  - $B^*, D^*, \phi(1020), K^*(892)^0$
  - Look at high $x_p = P_{meson}/P_{beam}$, in order to increase probability that we have a **leading** meson; *i.e.* containing primary q.
- Study both longitudinal and transverse polarization of Λ

Vector meson analyses

- Signal fitted in bins of $\cos\theta_H$
  - eg, $K^*(892)^0$:

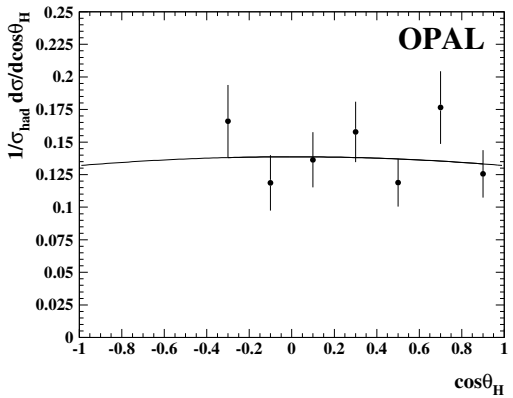


- Efficiency corrected distributions are fitted to extract ρ_{00}.
  - eg, also for $K^*(892)^0$, in bins of x_p:



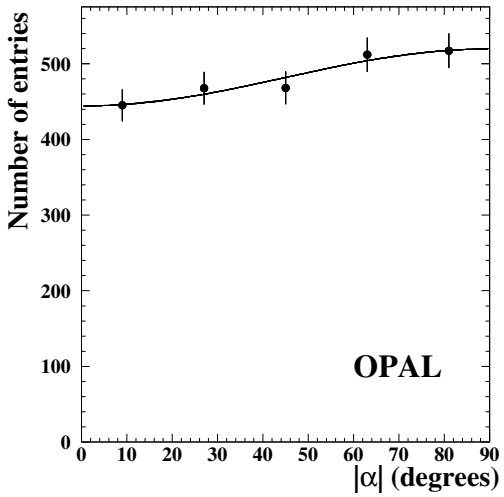
Vector meson analyses

- $B^* \rightarrow B\,\gamma$
  - Secondary vertex tag using microvertex information
  - Low energy photon ($E_\gamma < 800$ MeV) identified via conversion to e^+e^-
  - B mesons inclusively reconstructed



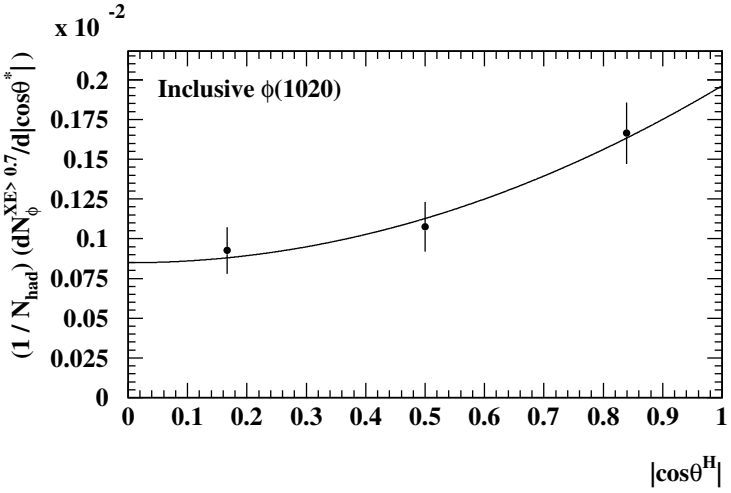
  - ρ_{00} = 0.36 $\pm$ 0.09

- $D^{*+} \rightarrow D^0\pi^+$
  - reconstruct $D^0 \rightarrow K^-\pi^+$
  - look for $D^{*+} \rightarrow \pi_s^+$
  - Result determined independently for those D^* from charm, with $x_E > 0.2$
  - ρ_{00} = 0.40 $\pm$ 0.02



  - ρ_{1-1} = -0.039 $\pm$ 0.14

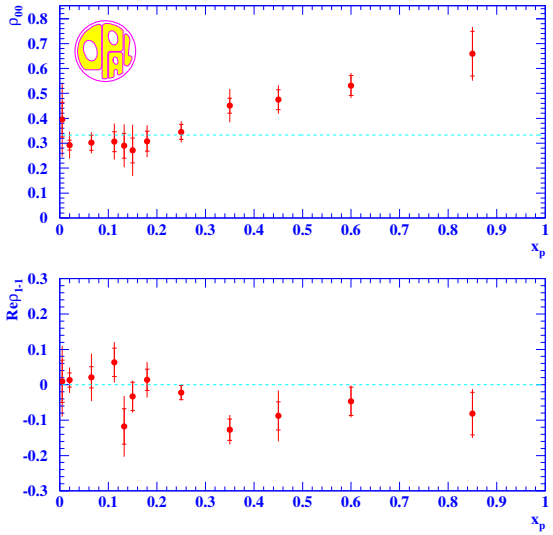
- $\phi(1020) \rightarrow K^+K^-$
  - select $K^{\pm}$ using energy loss information
  - Measured for $x_p > 0.7$



  - ρ_{00} = 0.54 $\pm$ 0.08
  - ρ_{1-1} = -0.11 $\pm$ 0.07

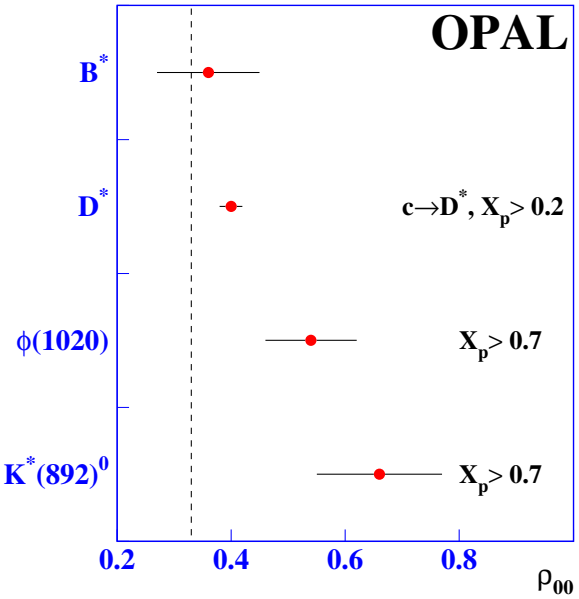
$K^*(892)^0 \rightarrow K^{\pm}\pi^{\mp}$

- Form $K^{\pm}\pi^{\mp}$ inclusive mass spectra
- High statistics enable measurement as function of x_p:



- Clear deviations from ρ_{00} = 1/3, and $Re\rho_{1-1}$ = 0 at large momentum, where leading K^* lie.

Vector mesons - ρ_{00}



- All mesons apart from B^* have $\rho_{00} > 1/3$
- Deviation larger for lighter mesons

Vector mesons - ρ_{1-1}

- $\rho_{1-1} \neq 0 \Rightarrow$ coherent fragmentation.
  - OPAL data at high x_P appears to support this

- Prediction exists that for K^{*0} at LEP [Anselmino *et al.*]:

$$Re\rho_{1-1}/(1-\rho_{00}) \sim -0.10$$

This assumes:

  - final state $q\bar{q}$ interactions
  - Standard Model couplings in the $e^+e^- \rightarrow q\bar{q}$ interaction
  - meson production at low p_T to parent jet

- OPAL measures:

$$Re\rho_{1-1}/(1-\rho_{00}) \sim -0.19 \pm 0.05$$

$\Lambda \rightarrow$p π

- To measure longitudinal polarization, P_L, of Λ:

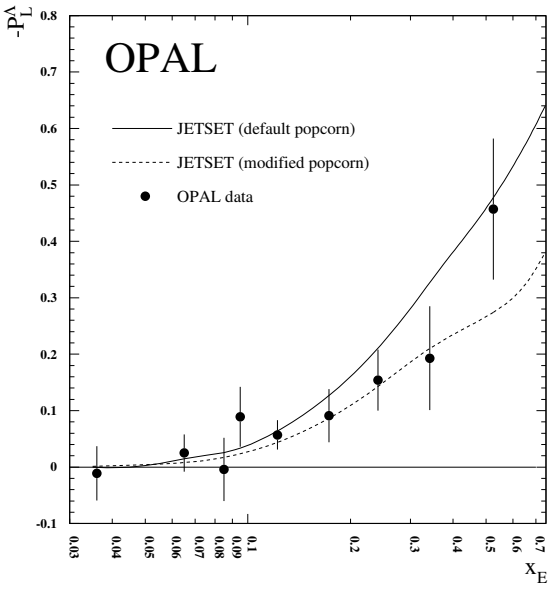
$$W(\cos\theta^*) \sim 1 + \alpha_\Lambda P_L \cos\theta^*$$

where $\cos\theta^*$ is the $\Lambda - p$ angle in the CM frame

- For transverse polarization, P_T, fit same distribution to $\cos\phi_p$, angle to the plane of the Λ and the thrust axis

Polarization of Λ hyperons

- $\Lambda \rightarrow$pπ reconstructed
- for longitudinal polarization fit straight line to $\cos\theta^*$ distributions in bins of x_E
- extract P_L^Λ



Polarization of Λ hyperons

- Comparison is with default JETSET and 'modified popcorn scheme' of Gustafson and Hakkinen.

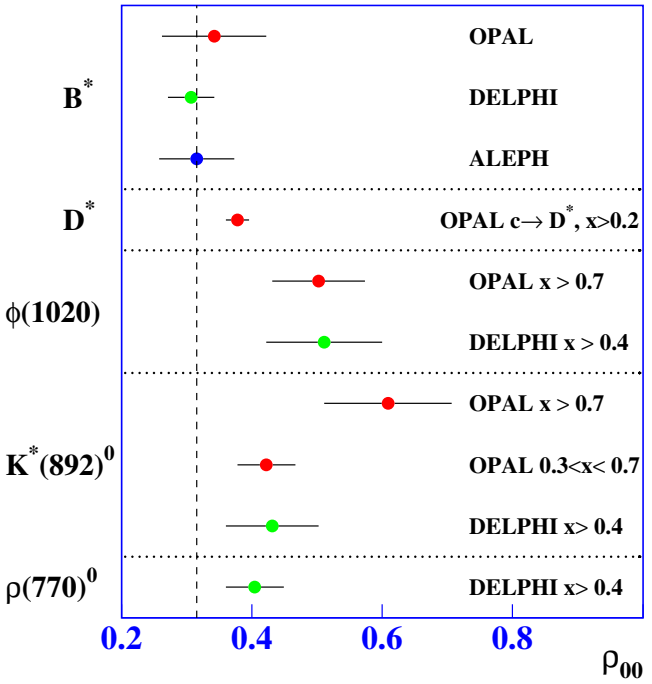
- For transverse polarization fit straight line - as for P_L - to $\cos\phi_p$ distributions as function of p_T
  - No transverse polarization observed

- OPAL results
  - for $X_E > 0.3$, P_L^Λ = -32.9 $\pm$ 7.6%
  - for $p_T > 0.3$ GeV/c, P_T^Λ = 0.9 $\pm$ 0.9%

Conclusions

Vector mesons:

• Leading light vector mesons are spin aligned, $\rho_{00} > 1/3$.



Vector mesons: ρ_{00}

- No model fully describes this behaviour:
  - Spin counting: 0< ρ_{00} <1/2
  - HQET - P/V=1/3 $\Rightarrow$ ρ_{00} = 1/3
  - QCD inspired: soft gluon emission, ρ_{00} = 0
  - production via q$\rightarrow$qV, ρ_{00} = 1
  - string model (LUND) and cluster model (HERWIG): ρ_{00} = 1/3, no spin alignment
- Whilst QCD models successfully describe much LEP1 data, the spin alignment results await theoretical interpretation !

Vector mesons: ρ_{1-1}

- Non-zero non-diagonal helicity matrix elements, ρ_{1-1}, imply coherent $q\bar{q}$ production and fragmentation.
- For K^{*0} a recent SM-based model agrees with OPAL results.

Λ polarization

- LEP results are consistent with a simple constituent model, where final state hyperon carries all primary quark polarization.