Measurement of the Average Polarization of *b*-baryons in Hadronic Z^0 Decays

(abstract #320)

OUTLINE

- Motivation
- Method
- Data sample
- Systematics
- Result, comparisons, summary

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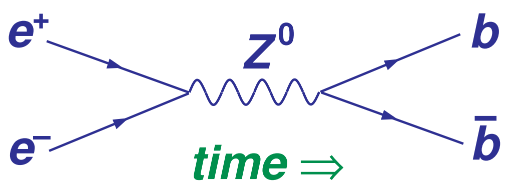
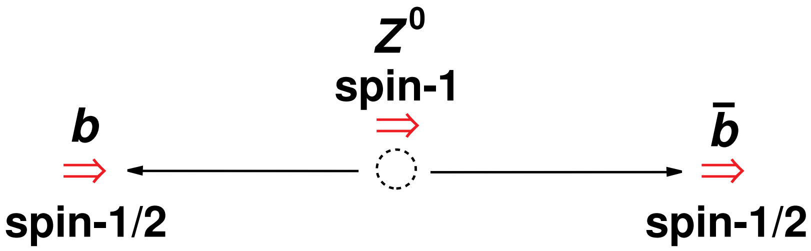
Parallel Session 8: Heavy Hadrons (talk823)
ICHEP '98, Vancouver, Canada

24 July 1998

b Quark Polarization





- According to the Standard Model, b quarks are produced with high longitudinal polarization

$$P_L^b = \frac{2v_b a_b \beta(1+\cos^2\theta) + 2r_e(v_b^2 + a_b^2\beta)\cos\theta}{(v_b^2 + a_b^2)\beta^2(1+\cos^2\theta) + v_b^2(1-\beta^2) + 4r_e v_b a_b \beta^2\cos\theta}$$

$$r_e = (4x_w - 1)(8x_w^2 - 4x_w + 1)$$

$$x_w = \sin^2\theta_w$$

- Depends only weakly on θ

$$\langle P_L^b \rangle = \frac{\sigma(b_R) - \sigma(b_L)}{\sigma(b_R) + \sigma(b_L)} = -0.94 \quad (\sin^2\theta_w = 0.23)$$

- Compare to tau lepton polarization: $\langle P_L^\tau \rangle = -0.16!$

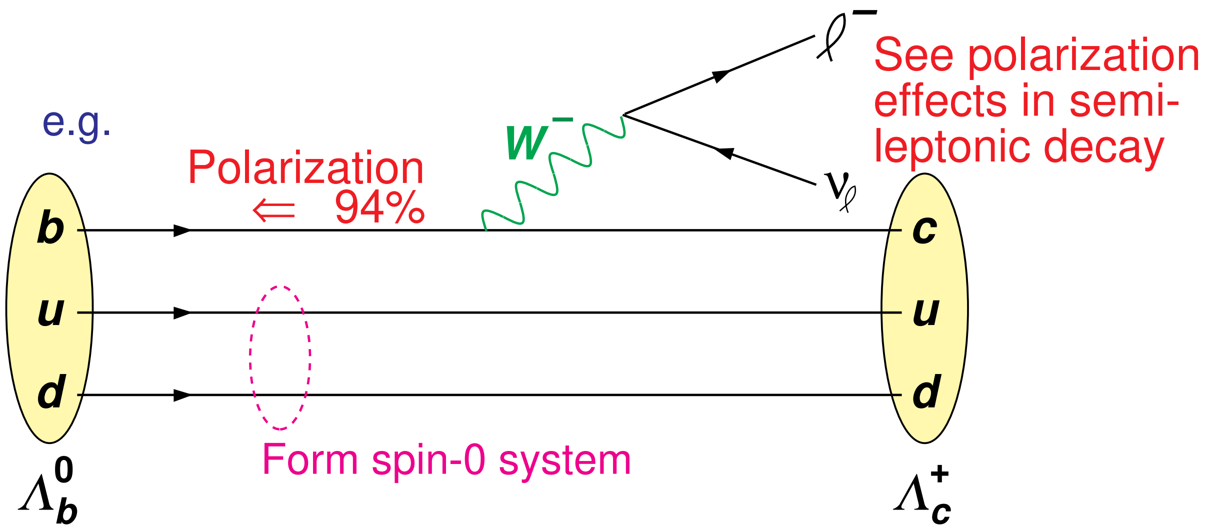
b Baryon Polarization

- Polarization destroyed in hadronization to spin-0 and spin-1 B mesons

  BUT

  predicted to be partially retained in spin-1/2 b baryons

e.g.



As $m_Q \to \infty$, 100% of polarization retained.

- Higher mass states?

  $\Sigma_b^+ = [\,(uu)_1 b\,]_{1/2}$ $\qquad$ $\Sigma_b^{(*)} \to \Lambda_b \pi$

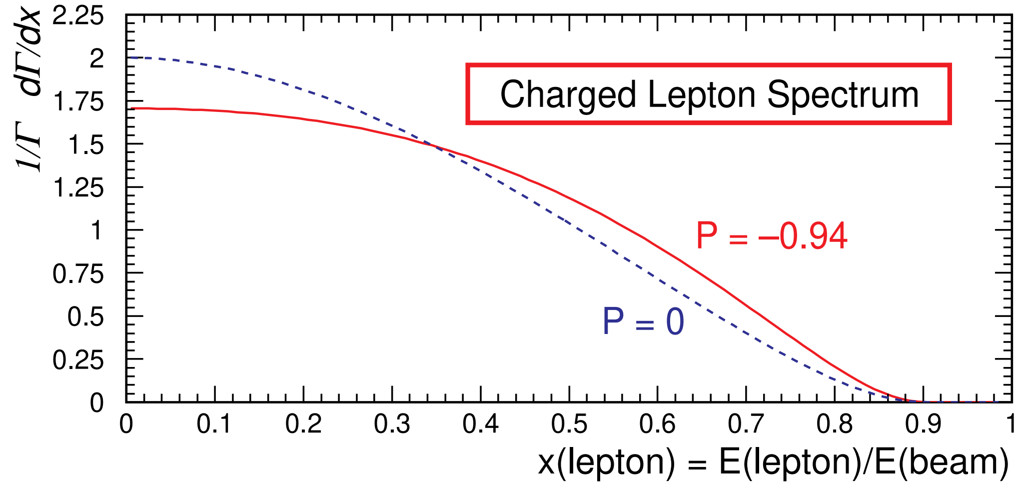
  $\Sigma_b^{+*} = [\,(uu)_1 b\,]_{3/2}$ $\qquad$ Strong decay $\Rightarrow$ depolarization?

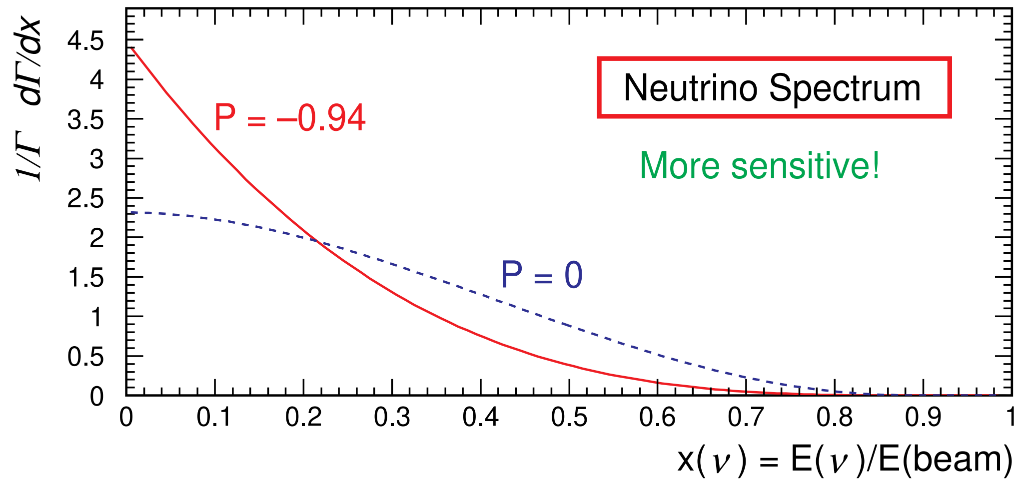
- Valuable information for HQET inputs, heavy quark expansion form factors, fragmentation parameters, spin transfer in fragmentation

Lab Frame Spectra

$\Lambda_b^0 \rightarrow \Lambda_c \ell^- \nu_\ell$

(see Korner, Schuler, Mele, Mannel, Altarelli, Rosner, Wise, Manohar...)





- However, spectra very sensitive to modelling

(quark masses, fragmentation, form factors, QCD corrections)

- *Ratio* of the two energies much less sensitive to these systematic effects, plus anti-correlation makes ratio ~4 times more sensitive statistically

(Bonvicini & Randall (1994), Jezabek (1994))

The Players

$\Lambda_b^0 = [\,(ud)_0 b\,]_{1/2}$ $\quad M = 5624 \pm 9$ MeV

$\Sigma_b^0 = [\,(ud)_1 b\,]_{1/2}$ $\quad \Sigma_b^0 \to \Lambda_b^0 \gamma$

$\Sigma_b^+ = [\,(uu)_1 b\,]_{1/2}$ $\quad \Delta M = 191 \pm 2$ MeV

$\Sigma_b^{*+} = [\,(uu)_1 b\,]_{3/2}$ $\quad \Delta M = 216 \pm 4$ MeV

(DELPHI, prelim.)

Strong decays $\quad \Sigma_b^{(*)+} \to \Lambda_b^0 \pi^+$

$\Xi_b^0 = [\,(us)_1 b\,]_{1/2}$

"Seen"

$\Xi_b^- = [\,(ds)_1 b\,]_{1/2}$

$\Omega_b^- = [\,(ss)_1 b\,]_{1/2}$

Study polarization averaged over all weakly-decaying (i.e. semileptonic decays) b baryons

Method

- Keep statistics high, "semi-inclusive" sample, reconstruct only a Λ baryon in the presence of a high momentum, ($p > 4$ GeV, $p_t > 0.7$ GeV) high-p_t (with respect to jet) electron or muon (e.g. used for *b* baryon lifetimes, production, etc.)

$$\Lambda_b^0 \to X_c\, \ell^- \nu_\ell$$

$$\quad\hookrightarrow \Lambda X$$

$$\qquad\hookrightarrow p\pi^-$$

look for "right-sign" correlations

- Wrong-sign correlations, $\bar{\Lambda}\,\ell^-$ or $\Lambda\,\ell^+$, give indication of background level and shape of background.

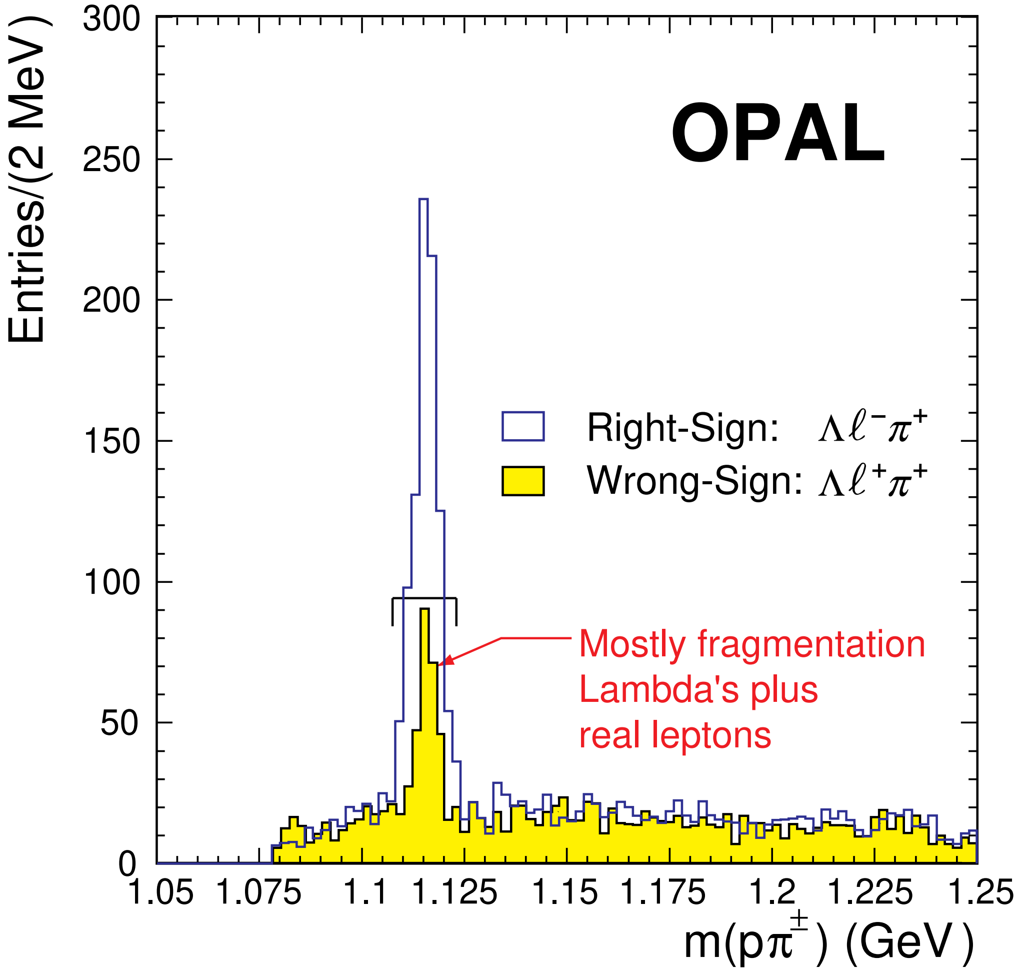
- Exploit Λ–π^+ correlations from:

$$\Lambda_b^0 \to \Lambda_c^+ \to \Lambda\,\pi^+ X$$

to improve signal-to-purity ratio

Signal Sample

- Start with 4.3 million hadronic Z^0 decays collected from 1990 to 1995



Right-sign	912
Wrong-sign	316
Excess	596

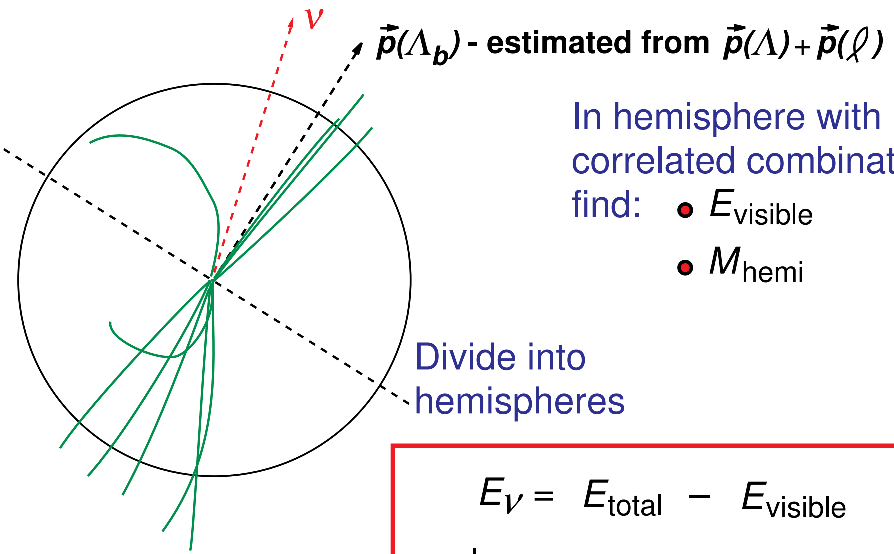
Background Estimate

From Monte Carlo:

Background Source	Right-Sign (of 912)	Wrong-Sign (of 316)
Fragmentation Λ plus:		
ℓ from B meson	94 ± 9	77 ± 8
ℓ from c baryon	9 ± 3	3 ± 2
ℓ from b baryon	5 ± 4	66 ± 6
ℓ from c meson	32 ± 6	43 ± 7
	RS-WS Imbalance "known"	
Exclusive Backgrounds:	32 ± 7	27 ± 6
Combinatorials and Fakes:	111 ± 8	100 ± 8
	RS-WS should balance	

Added "bonus" - use this fraction as signal too!!

Neutrino Energies



In hemisphere with correlated combination, find:
- E_{visible}
- M_{hemi}

Divide into hemispheres

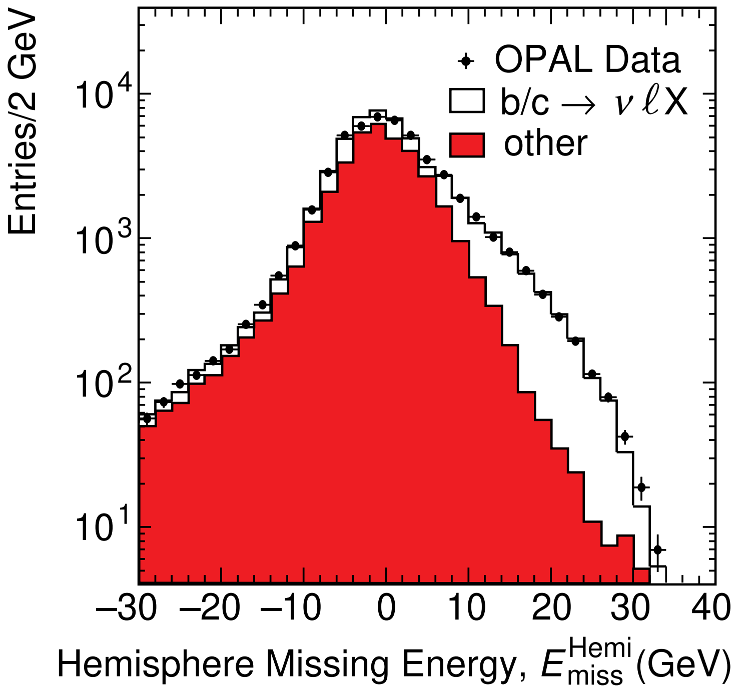
Find
- M_{recoil}

in this hemisphere

$$E_\nu = E_{\mathrm{total}} - E_{\mathrm{visible}}$$

where

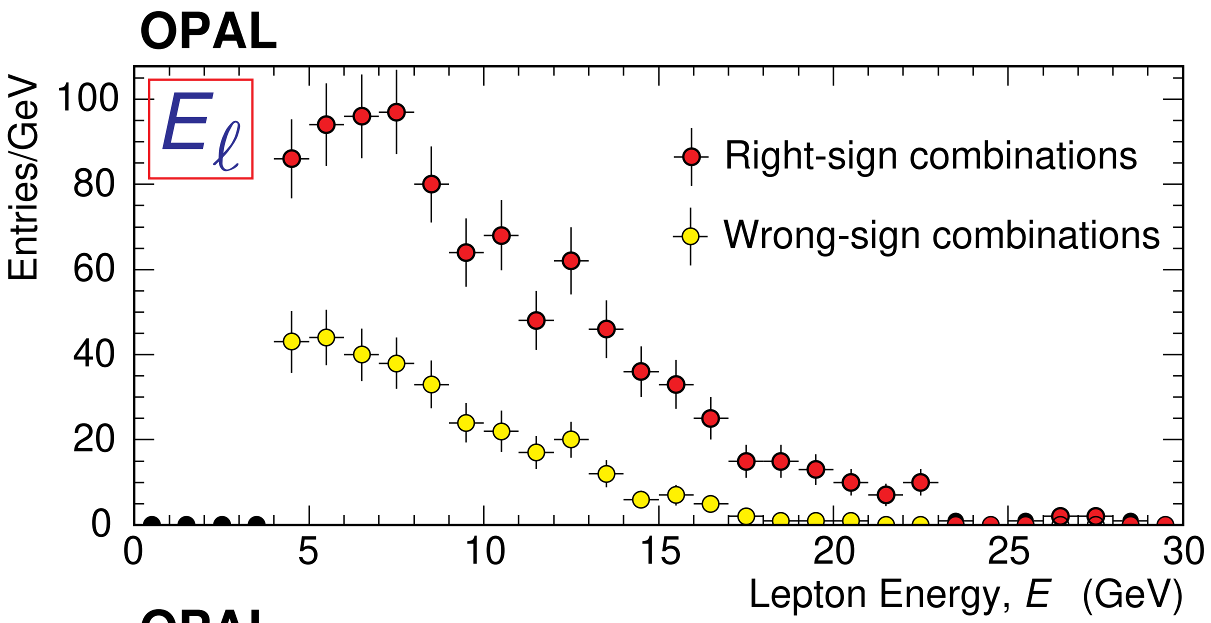
$$\underbrace{E_{\mathrm{total}} = E_{\mathrm{beam}}}_{\text{"Z into two bodies"}} + \frac{M^2_{\mathrm{hemi}} - M^2_{\mathrm{recoil}}}{4E_{\mathrm{beam}}}$$

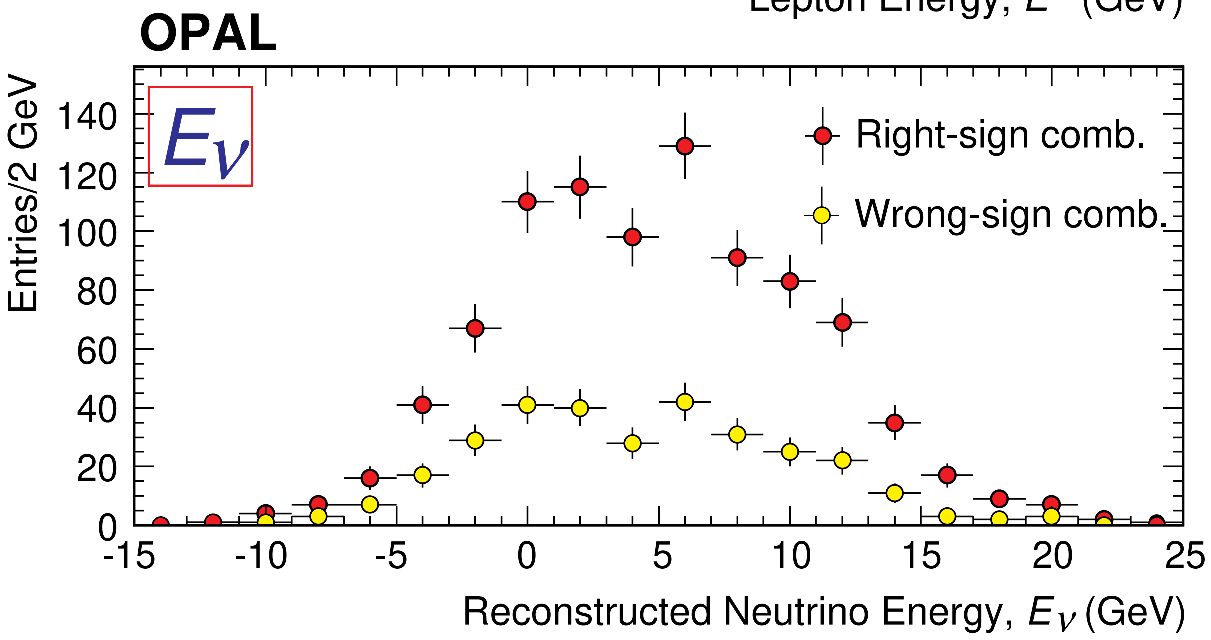


Use missing energy as an estimate of neutrino energy

For signal, average resolution is:

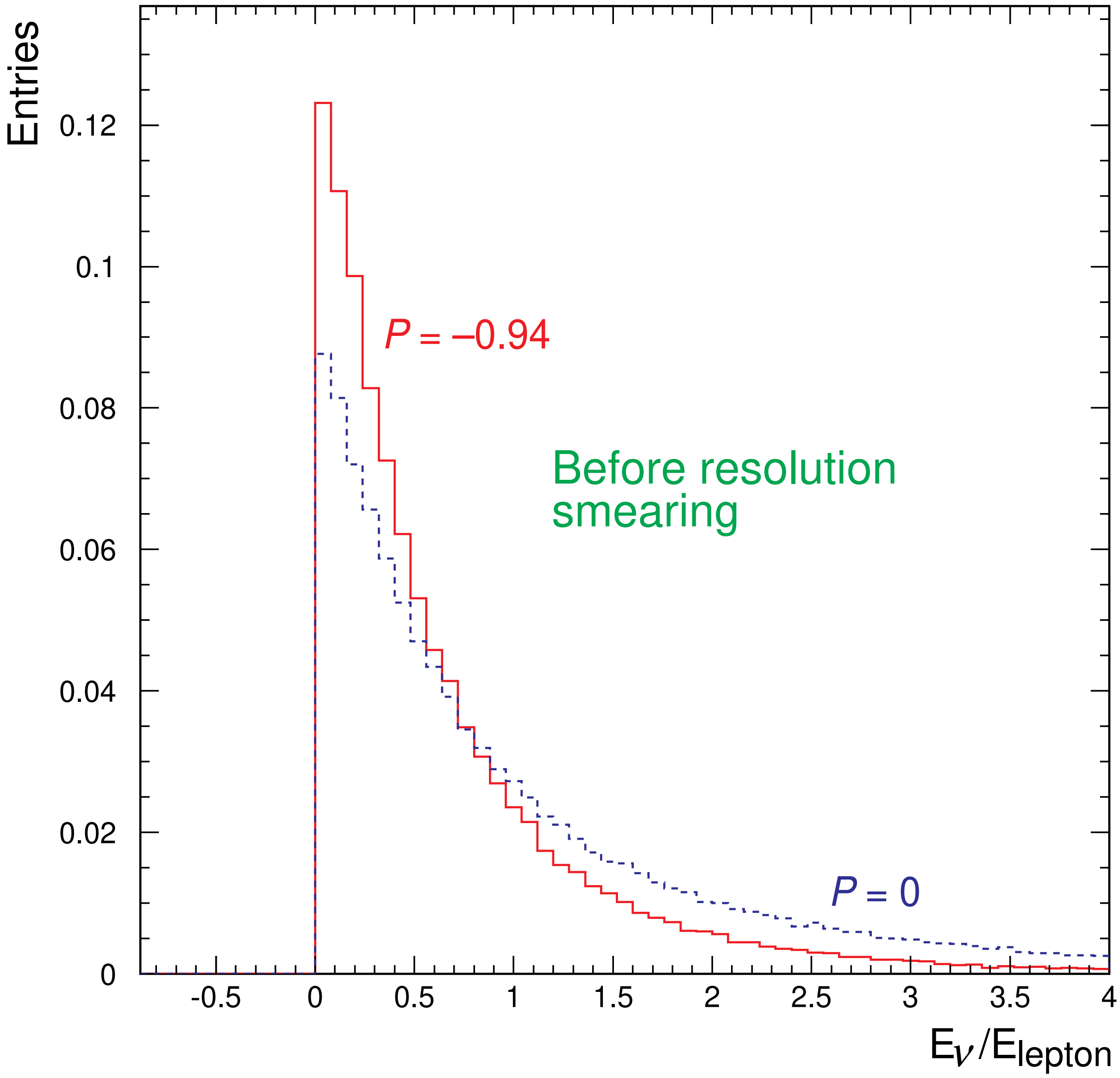
$$\sigma(E_\nu) = 3.5 \text{ GeV}$$





- Ratio of energies is less prone to systematics...
- Find E_ν / E_ℓ for each candidate, fit to distribution of the ratio

Event-by-Event Ratio of Energies



- Smeared out by neutrino energy resolution (and much less so by lepton energy resolution)
- Use dedicated signal samples of fully simulated MC at 12 steps in polarization as "templates"

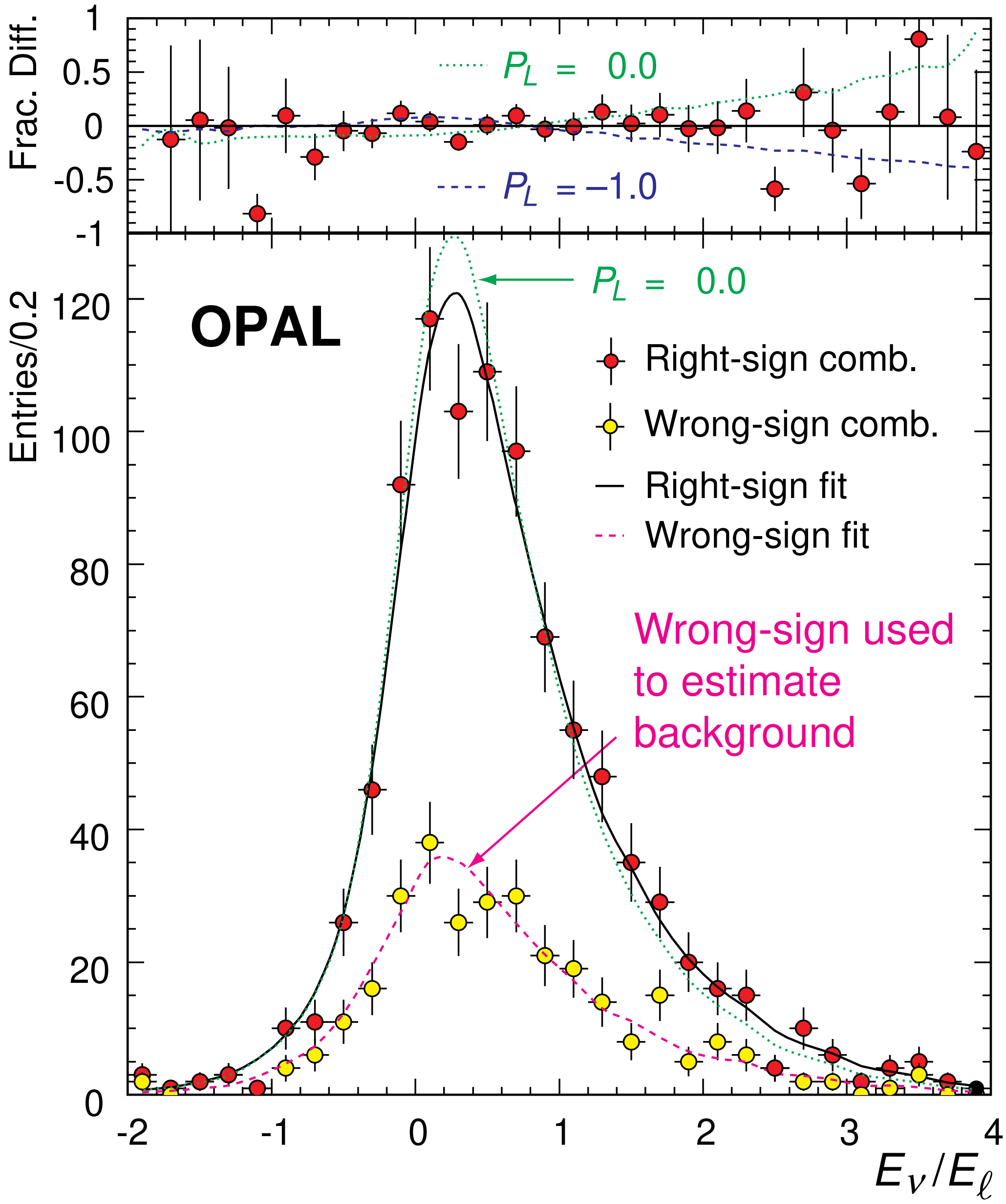
Binned Likelihood fit to E_ν/E_ℓ distribution:

from MC, varying P_{Λ_b}

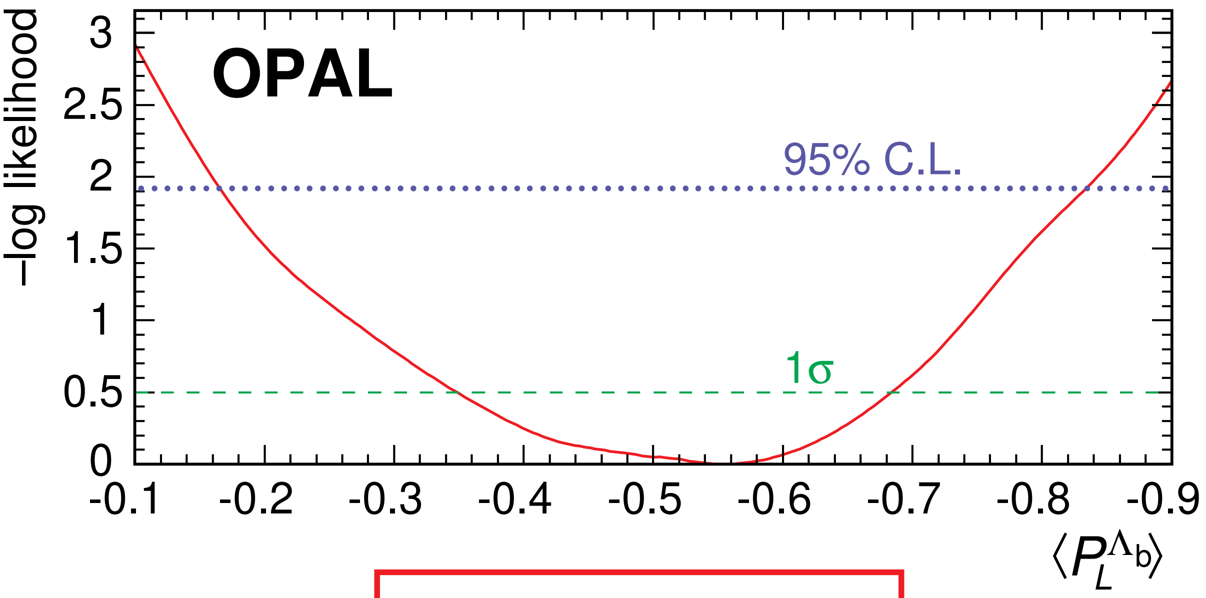
$$\mathrm{PDF_{RS}} = (1 - f_{\mathrm{back}})\,\mathrm{PDF_{sig}} + f_{\mathrm{back}}\,\mathrm{PDF_{back}}$$

constrained by $N_{\mathrm{RS}}/N_{\mathrm{WS}}$ + small MC corrections

wrong-sign dist.



Fit Result



$$\langle P_L^{\Lambda_b} \rangle = -0.56^{+0.20}_{-0.13}$$

Zero polarization excluded at > 95% CL (first)

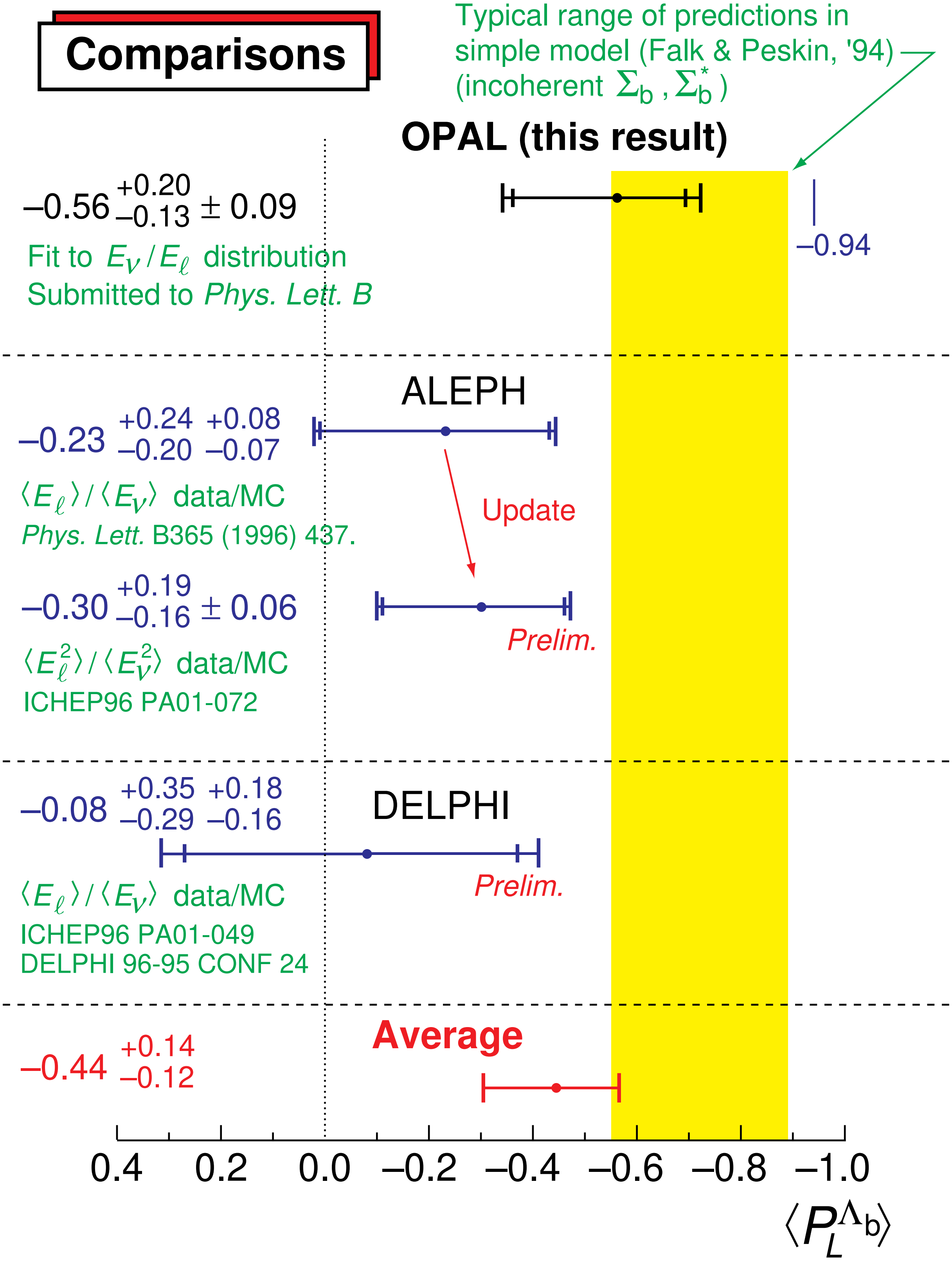
Further Checks in Data

- independent checks of remaining biases in data, ground-state B mesons should have *zero* polarization

  ⇒ Inclusive high-p, high-p_t lepton "control sample"

  ⇒ D^*– lepton correlations tagging B^0 (and $B^\pm$) for OPAL V_{cb}

  ⇒ Small polarization observed, consistent with zero


Comparisons
Typical range of predictions in simple model (Falk & Peskin, '94) (incoherent Σ_b , Σ_b^*)
OPAL (this result)
$-0.56^{+0.20}_{-0.13} \pm 0.09$
Fit to E_ν / E_ℓ distribution
Submitted to *Phys. Lett. B*
-0.94
ALEPH
$-0.23^{+0.24}_{-0.20}{}^{+0.08}_{-0.07}$
$\langle E_\ell \rangle / \langle E_\nu \rangle$ data/MC
Phys. Lett. B365 (1996) 437.
Update
$-0.30^{+0.19}_{-0.16} \pm 0.06$
Prelim.
$\langle E_\ell^2 \rangle / \langle E_\nu^2 \rangle$ data/MC
ICHEP96 PA01-072
$-0.08^{+0.35}_{-0.29}{}^{+0.18}_{-0.16}$
DELPHI
Prelim.
$\langle E_\ell \rangle / \langle E_\nu \rangle$ data/MC
ICHEP96 PA01-049
DELPHI 96-95 CONF 24
Average
$-0.44^{+0.14}_{-0.12}$
0.4
0.2
0.0
–0.2
–0.4
–0.6
–0.8
–1.0
$\langle P_L^{\Lambda_b} \rangle$

Summary

- longitudinal polarization of weakly-decaying b baryons extracted with new technique and measured to be:

$$\boxed{\langle P_L^{\Lambda_b}\rangle = -0.56\,^{+0.20}_{-0.13} \pm 0.09}$$

- $-0.13 \geq \langle P^{\Lambda_b}\rangle \geq -0.87$ at 95% CL

  ⇒ First exclusion of zero polarization at 95% CL

  ⇒ *b* quarks from *Z* decay are longitudinally polarized and transfer polarization to *b* baryons

  ⇒ some reduction of polarization does occur, consistent with typical model predictions

- valuable input to the ~15 theory papers past 3 years on this topic, consistent with HQET predictions

- need more inputs on e.g. fraction of $\Sigma_b^{(*)}$

- limits on right-handed coupling of the *b* quark??

  (previous assumed (V–A) coupling in charged current decay - admixture of (V+A)?)

  Amundson et al. 1993, Gronau 1994, Rizzo 1998

  (theoretical activity on trying to explain difference in SLD $\sin^2\theta_W$ from A_{LR}^{bb} and world)

  Field 1997