Semileptonic branching fractions of b hadrons

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Outline

- Current situation with semileptonic branching ratios
- Results on the b baryon semileptonic BR
- Recent results on $\mathrm{BR}(\mathrm{b} \rightarrow \ell\mathrm{X})$ and $\mathrm{BR}(\mathrm{B}^{+} \rightarrow \ell\mathrm{X})$
- Outlook

Why measure $\mathrm{BR_{sl}}$?

Two problems at hand:

$\Rightarrow$ Differences observed in lifetimes for b hadrons

$\Rightarrow$ Experimental results from $\Upsilon(4S)$ and Z^0 for $\mathrm{BR(b \to \ell X)}$

$$(10.45 \pm 0.21)\% \neq (11.02 \pm 0.21)\% \text{ (Moriond)}$$

$\mathrm{BR_{sl}}$ and lifetime closely related: $\mathrm{BR_{sl}} = \frac{\Gamma_{\mathrm{sl}}}{\Gamma_{\mathrm{tot}}} = \tau\Gamma_{\mathrm{sl}}$

$\Rightarrow$ **Measure the b-baryon semileptonic branching fraction**

- Is $\tau_{\Lambda_\mathrm{b}}$ really $<<\tau_\mathrm{B}$? Is the technique biased?
- Are b-baryons causing the difference $\mathrm{BR_{sl}^{\Upsilon(4S)}} \neq \mathrm{BR_{sl}^{Z^0}}$

$\Rightarrow$ **Design new methods to measure $\mathrm{BR(b \to \ell X)}$ with higher precision and less model-dependence.**

- Is $\mathrm{BR_{sl}^{\Upsilon(4S)}} \neq \mathrm{BR_{sl}^{Z^0}}$ due to mismeasurement?
- Is it due to mismodelling of b decays?

$\Rightarrow$ $\mathrm{BR_{sl}}$ **are also important inputs for other analyses**

Measuring $\mathrm{BR}(\Lambda_\mathrm{b} \to \ell\mathrm{X})$ at LEP

- Measuring the inclusive BR($\Lambda_\mathrm{b} \to \ell$X) is very difficult
  $\Rightarrow$ Hard to get a pure Λ_b sample at the denominator

- Instead, measure closely related quantities:

OPAL

$$R_{\Lambda\ell} = \frac{\mathrm{BR}(\Lambda_b \to \Lambda\ell^- X)}{\mathrm{BR}(\Lambda_b \to \Lambda X)}$$

ALEPH

$$R_{p\ell} = \frac{\mathrm{BR}(\Lambda_\mathrm{b} \to \mathrm{p}\ell^- \bar{\nu}\mathrm{X})}{\mathrm{BR}(\Lambda_\mathrm{b} \to \mathrm{pX})}$$

$\Rightarrow$ ℓ for electrons and muons combined

$\Rightarrow$ Λ_b denotes generic b baryons

Since the decay $(\Lambda_\mathrm{b} \to \Lambda_\mathrm{c}\mathrm{X})$ is expected to dominate both for inclusive and semileptonic decays, then:

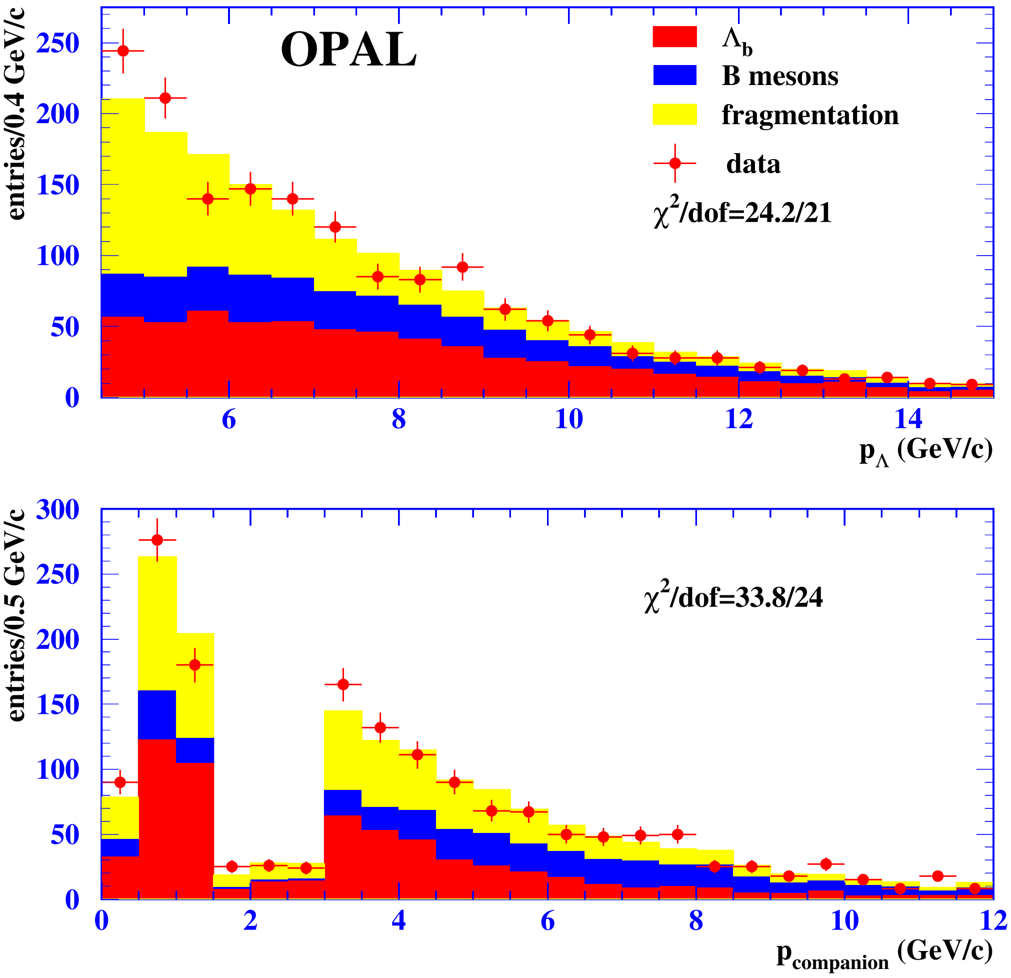
$$R_{\Lambda\ell} \sim R_{\mathrm{p}\ell} \sim \mathrm{BR}(\Lambda_\mathrm{b} \to \ell\mathrm{X})$$

(spectator model approximation)

- For numerator: use baryon-lepton charge correlation

OPAL: Use Λ and companion baryon

- Look for Λ-baryon pairs in b-tagged events
- Extract fraction of Λ coming from Λ_b by fitting the momentum spectra of Λ-baryon pairs: (assumption free)

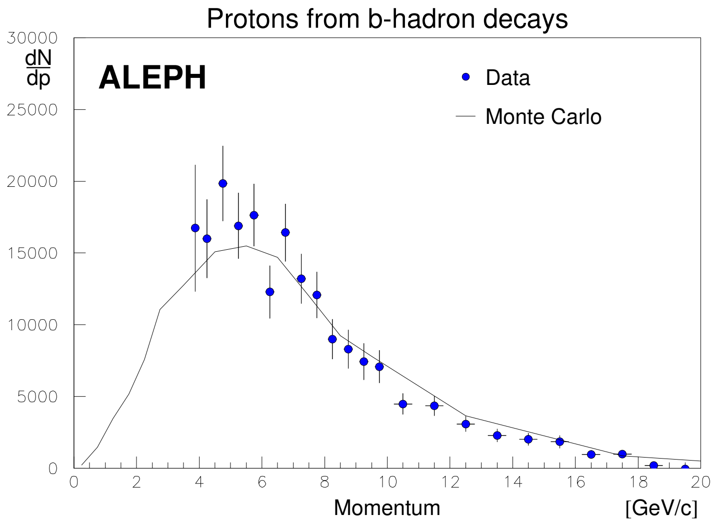


- For numerator, use Λ-ℓ correlations.
- Estimate $(\Lambda_b \to \Lambda \ell X)$ subtracting WS from RS events

$$\Rightarrow \frac{\mathrm{BR}(\Lambda_b \to \Lambda \ell X)}{\mathrm{BR}(\Lambda_b \to \Lambda X)} = (7.0 \pm 1.2 \pm 0.7)\% \Leftarrow$$

ALEPH: f_{Λ_b} from proton spectrum

- Use a lifetime b-tagging technique for flavour separation
- Use dE/dx info to separate p, K, π
- Fit p, K, π fractions in 50 momentum bins for b, c, and uds
- Use impact parameter and angle between proton and thrust axis to separate protons from b hadrons and fragmentation



$$N_p = (f_{\Lambda_b}\mathrm{BR}(\Lambda_\mathrm{b} \to \mathrm{pX}) + (1 - f_{\Lambda_b})\mathrm{BR}(\mathrm{B} \to \mathrm{pX}))N_b$$

f_{Λ_b}: fraction of b hadrons $\to \Lambda_\mathrm{b}$

N_b: # of b hadrons decays = $2R_b \cdot N_\mathrm{mh}$

N_p: # of protons in b hadron decays obtained from spectrum

Take $\mathrm{BR}(\mathrm{B} \to \mathrm{pX})$ from CLEO, $f_{\mathrm{B_s}}$ from PDG

Make assumptions for $\mathrm{BR}(\mathrm{B_s} \to \mathrm{pX}) = (8.0 \pm 4.0)\%$

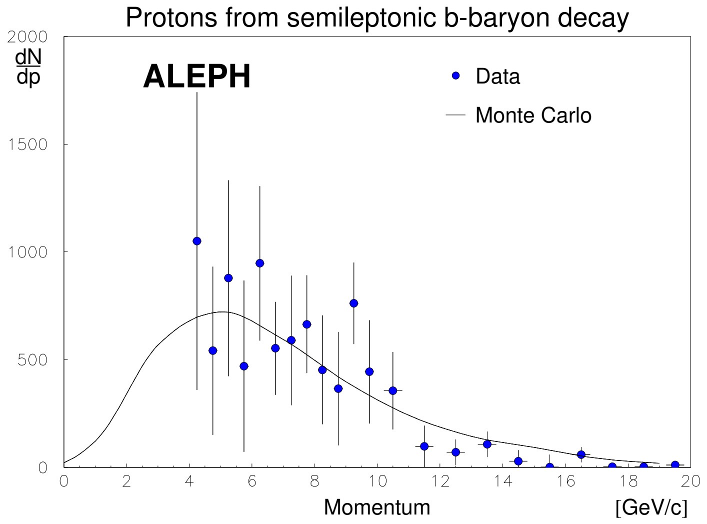
and $\mathrm{BR}(\Lambda_\mathrm{b} \to \mathrm{pX}) = (58 \pm 6)\%$

Get $f_{\Lambda_b} = (10.2 \pm 0.7 \pm 2.2 \pm 1.6\ (\mathrm{syst.\ BR}))\%$

PDG value: $f_{\Lambda_b} = (10.2^{+3.9}_{-3.1})\%$

ALEPH: $\mathrm{BR}(\Lambda_\mathrm{b} \to p\ell\bar{\nu}\mathrm{X})$

- Select proton-lepton pairs with proper charge correlation
- Require a high momentum lepton to enhance $\mathrm{b\bar{b}}$
- Use proton impact parameter to enhance $(b \to p)$
- Get $(\Lambda_\mathrm{b} \to p\ell\bar{\nu}\mathrm{X})$ from proton momentum spectrum



$f_{\Lambda_b}\mathrm{BR}(\Lambda_\mathrm{b} \to \mathrm{p}\ell\bar{\nu}\mathrm{X}) =$
$(4.72 \pm 0.66 \pm 0.44)\ 10^{-3}$

$$f_{\Lambda_b}\mathrm{BR}(\Lambda_\mathrm{b} \to \mathrm{pX}) = \frac{N_p}{N_b(1-f_{\Lambda_b})\mathrm{BR}(\mathrm{B}\to\mathrm{pX})}$$

with f_{Λ_b} from previous result from all b hadron decays

$$R_{p\ell} = \frac{\mathrm{BR}(\Lambda_\mathrm{b}\to\mathrm{p}\ell\mathrm{X})}{\mathrm{BR}(\Lambda_\mathrm{b}\to\mathrm{pX})} = (8.0 \pm 1.2 \pm 1.4)\%$$

Summary on b-baryon branching fraction

OPAL	$\frac{\mathrm{BR}(\Lambda_\mathrm{b}\to\Lambda\ell\mathrm{X})}{\mathrm{BR}(\Lambda_\mathrm{b}\to\Lambda\mathrm{X})}$	$= (7.0 \pm 1.2 \pm 0.7)\%$
ALEPH	$\frac{\mathrm{BR}(\Lambda_\mathrm{b}\to\mathrm{p}\ell\mathrm{X})}{\mathrm{BR}(\Lambda_\mathrm{b}\to\mathrm{pX})}$	$= (8.0 \pm 1.2 \pm 1.4)\%$
	$\mathrm{BR}_\mathrm{sl}^{\Lambda_\mathrm{b}} = (7.4 \pm 1.1)\%$	

- Semileptonic BR much smaller for Λ_b than B mesons in agreement with a much shorter Λ_b lifetime

$$\mathrm{BR}_\mathrm{sl}^\mathrm{B} = (10.45 \pm 0.21)\%$$

$$\mathrm{BR}_\mathrm{sl}^\mathrm{b} = (10.89 \pm 0.24)\% \text{ (new LEP)}$$

- Support similar semileptonic widths for all b hadrons

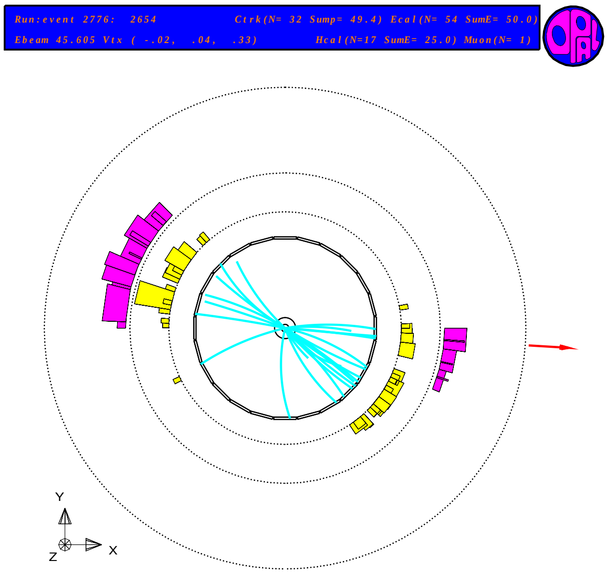
With $\mathrm{BR}_\mathrm{sl} = \tau\Gamma_\mathrm{sl}$:

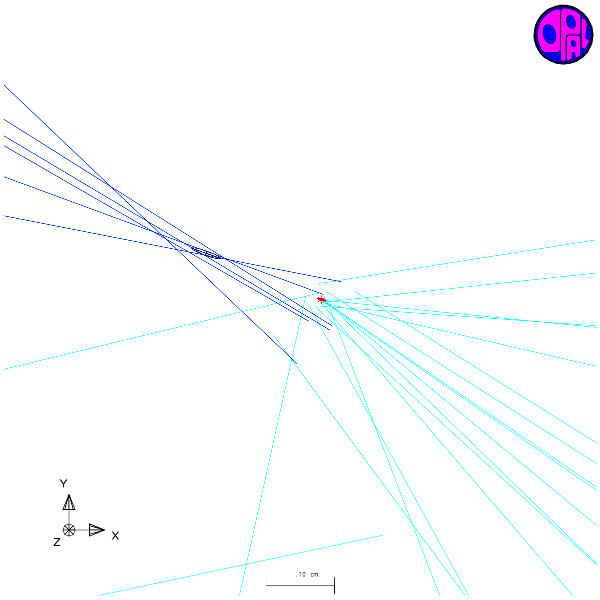
$$\frac{\mathrm{BR}_\mathrm{sl}^{\Lambda_\mathrm{b}}}{\mathrm{BR}_\mathrm{sl}^\mathrm{B}} = 0.71 \pm 0.11 \text{ and } \frac{\tau_{\Lambda_\mathrm{b}}}{\tau_\mathrm{B}} = 0.75 \pm 0.05$$

$$\frac{\mathrm{BR}_\mathrm{sl}^{\Lambda_\mathrm{b}}}{\mathrm{BR}_\mathrm{sl}^\mathrm{b}} = 0.68 \pm 0.10 \text{ and } \frac{\tau_{\Lambda_\mathrm{b}}}{\tau_\mathrm{b}} = 0.77 \pm 0.05$$

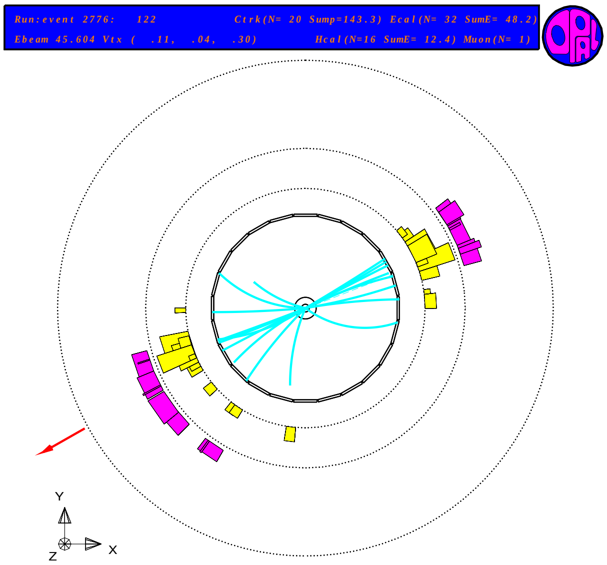
Separating $(b \to \ell)$ from $(b \to c \to \ell)$

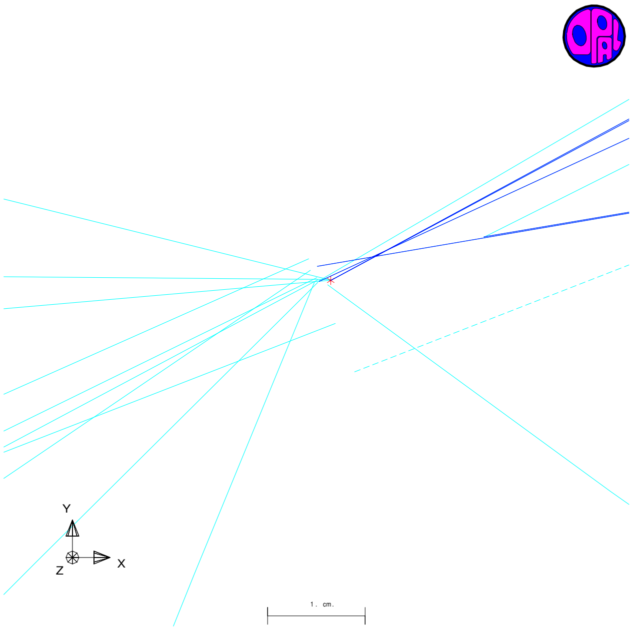
Typical $(b \to \mu)$ MC event in OPAL



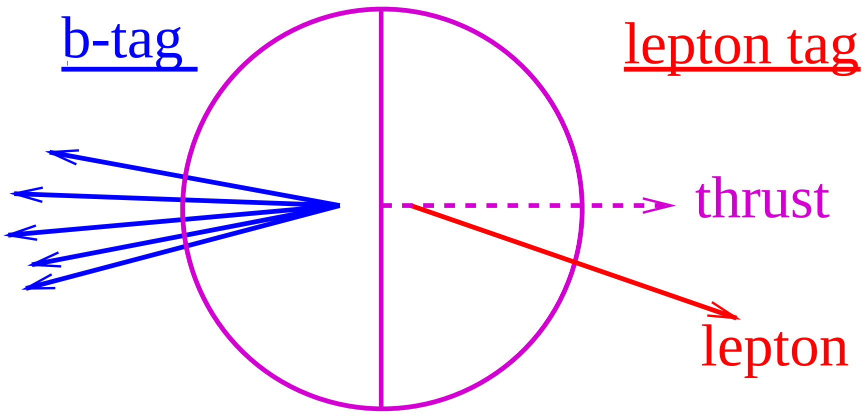


Typical $(b \to c \to \mu)$ MC event in OPAL





DELPHI: Updated result for $\mathrm{BR}(\mathrm{b} \to \ell \mathrm{X})$



- Select $\mathrm{b\bar{b}}$ events using a lifetime b-tagging technique
- Search hemisphere opposite a b-tag for prompt leptons
- Fit shape of combined momentum $p_c = \sqrt{p_T^2 + p^2/100}$ to MC shape for $(\mathrm{b} \to \ell)$, $(\mathrm{b} \to \mathrm{c} \to \ell)$ and others $((\mathrm{b} \to \bar{\mathrm{c}} \to \ell)$, fakes, $(\mathrm{c} \to \ell)$, $(\mathrm{b} \to \mathrm{J}/\Psi \to \ell^+\ell^-))$
- Four free fit parameters: $f(\mathrm{b} \to \ell)$, $f(\mathrm{b} \to \mathrm{c} \to \ell)$, $< x_{\mathrm{E}} >$ and $\bar{\chi}_{\mathrm{b}}$ (other fractions fixed)
- Search b-tagged events for leptons in both hemispheres. Add this constrain in the max. $\mathcal{L}$ fit to single leptons

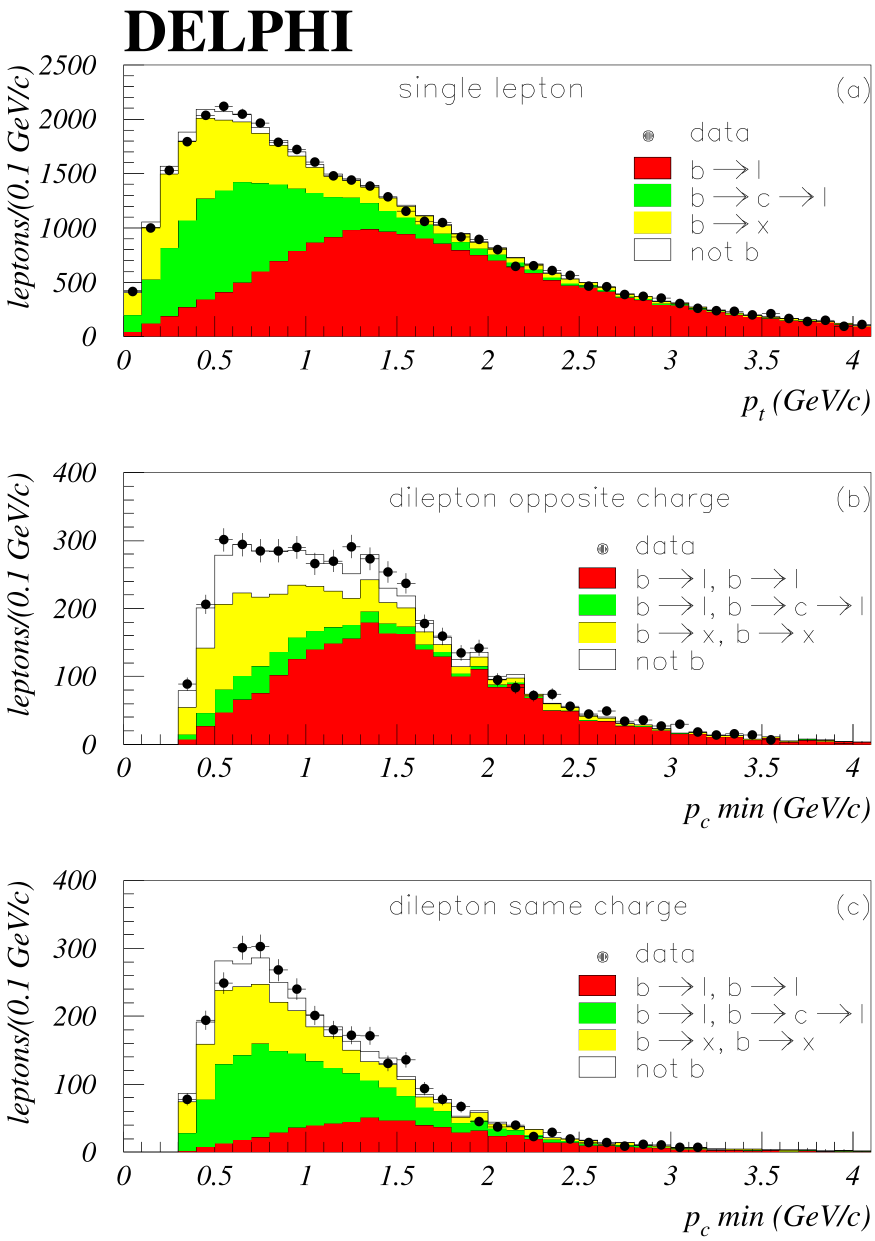
DELPHI: Lepton p_T spectrum

Preliminary (1994-95 data)

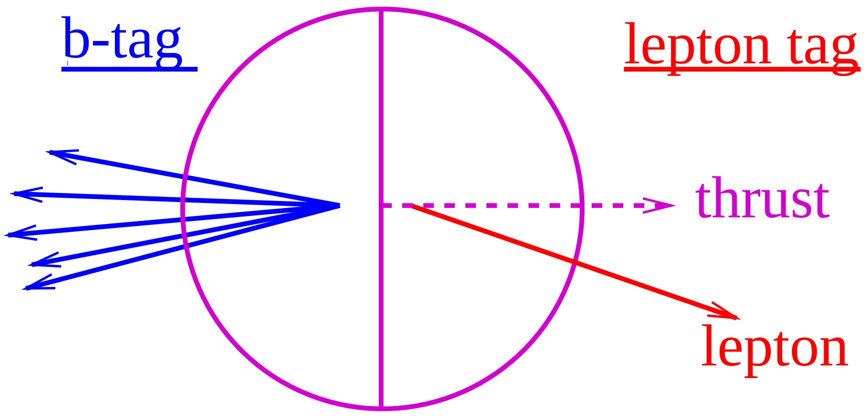
$$\mathrm{BR}(\mathrm{b} \to \ell X) = (10.65 \pm 0.11 \pm 0.23^{+0.43}_{-0.27}\ (\mathrm{model}))\%$$

$$\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \ell X) = (7.91 \pm 0.23 \pm 0.40^{+0.52}_{-0.65}\ (\mathrm{model}))\%$$

$$\bar{\chi}_{\mathrm{b}} = (0.128 \pm 0.013 \pm 0.003^{+0.007}_{-0.006}\ (\mathrm{model}))\%$$



OPAL: New method for $\mathrm{BR}(\mathrm{b} \to \ell \mathrm{X})$



- Select $\mathrm{b\bar{b}}$ events using a lifetime b-tagging technique
- Search hemisphere opposite a b-tag for prompt leptons
- Use a neural network to separate $(\mathrm{b} \to \mu)$ from $(\mathrm{b} \to \mathrm{c} \to \mu)$ events (use info from p, p_t and jet shape)
- Fit to shape of NN output variable to get fractions of $(\mathrm{b} \to \mu)$, $(\mathrm{b} \to \mathrm{c} \to \mu)$ and other backgrounds.

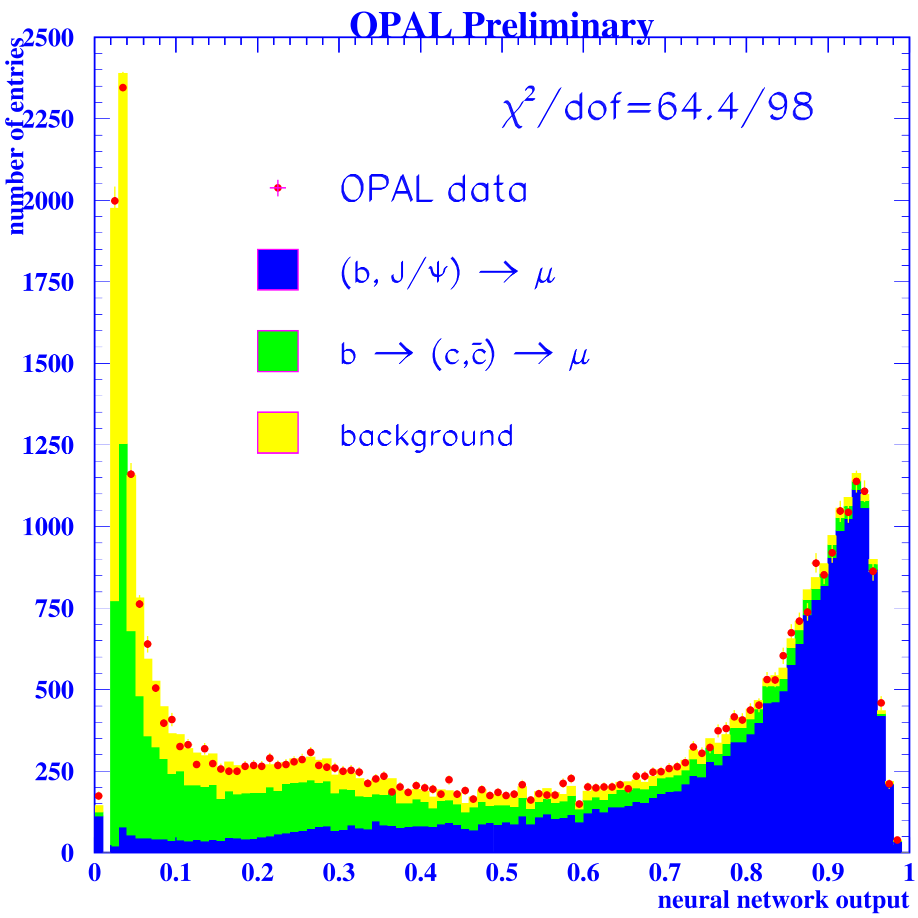
$\Rightarrow$ Preliminary result with muons only

$\Rightarrow$ Electrons will be included in upcoming final publication

NN output: data vs MC

- Use binned χ^2 to fit the data against the shape of NN output for the three Monte Carlo samples
- Fit has 2 free parameters: $f([\mathrm{b},\ \mathrm{J}/\Psi] \to \mu)$ and $f(\mathrm{b} \to [\mathrm{c}, \bar{\mathrm{c}}] \to \mu)$

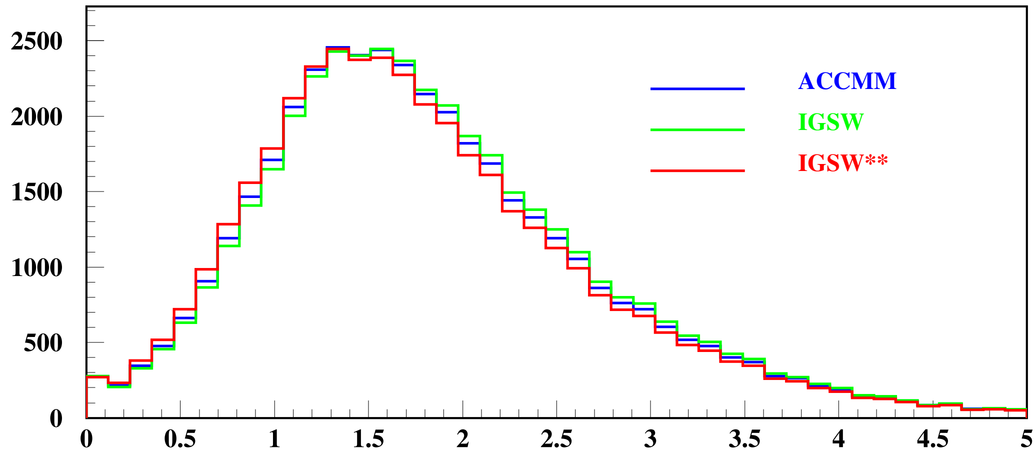
From the fit to $\sim 40\,000$ muons from 1992-95:



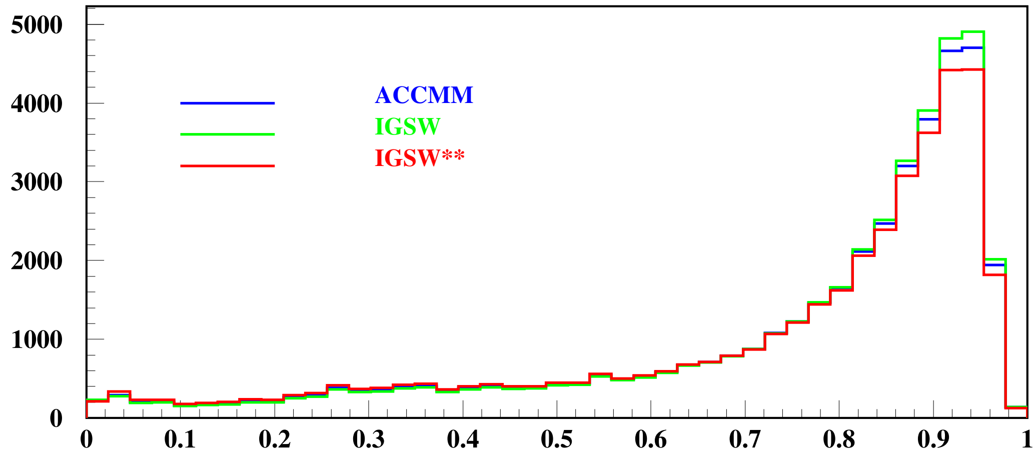
$$\mathrm{BR}(\mathrm{b} \to \mu\mathrm{X}) = (10.86 \pm 0.08 \pm 0.22^{+0.46}_{-0.31}\ (\mathrm{model}))\%$$

Lepton spectrum models

central value	ACCMM	$p_f = 298$ MeV, $m_c = 1673$ MeV/c^2
$+1\sigma$	IGSW	with 11% D^{**} (calculation)
-1σ	IGSW**	with 32% D^{**} (CLEO fit)



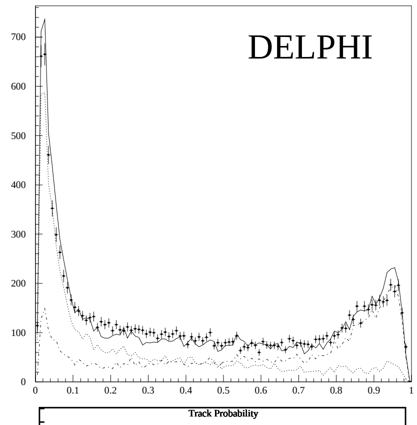
lepton p_T for $b \to \mu$



NN output for $b \to \mu$

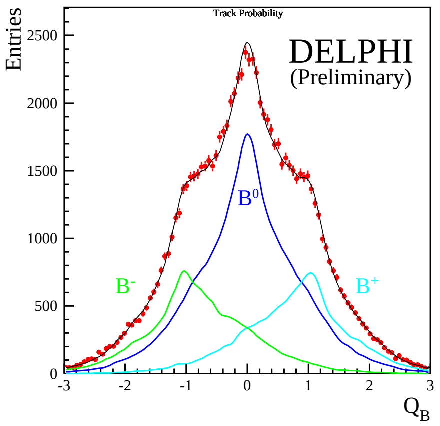
DELPHI: New method based on 3 neural networks

Separate tracks coming from b decays and fragmentation



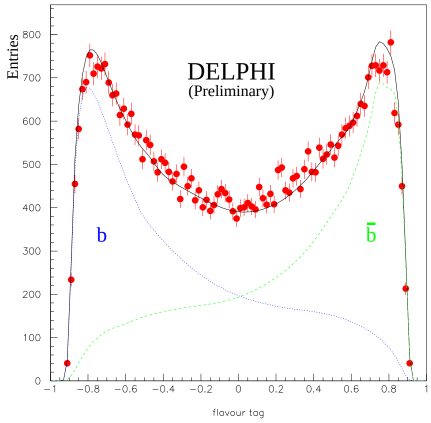
Secondary vertex charge

$Q_B = \sum Q_i p_i$



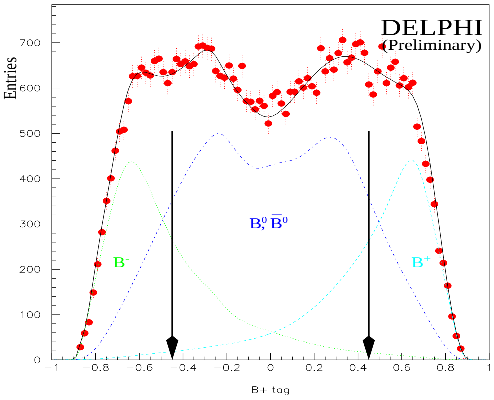
Separate b from $\bar{b}$ jets

$\rightarrow$ Kaon from B



B^+ enrichment

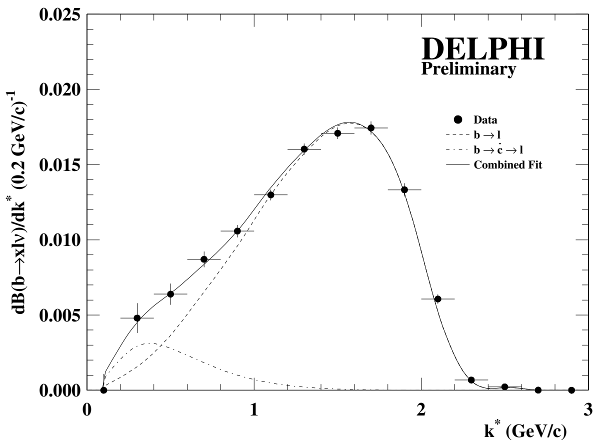
$\rightarrow Q_B$ and b jet NN output



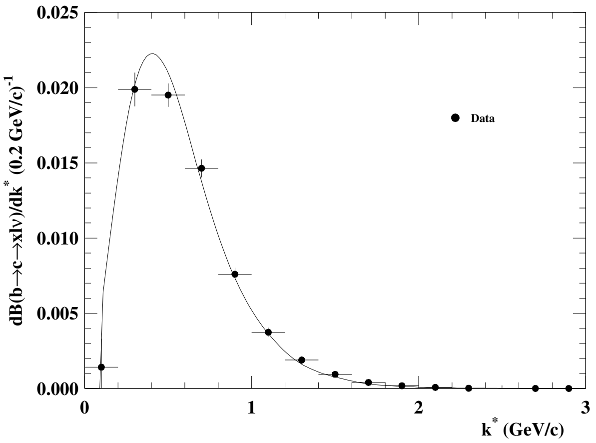
DELPHI: $\mathrm{BR}(\mathrm{b} \to \ell X)$ and $\mathrm{BR}(\mathrm{B}^+ \to \ell X)$

Fit to k^* spectrum: lepton momentum in b hadron rest frame

right sign



wrong sign

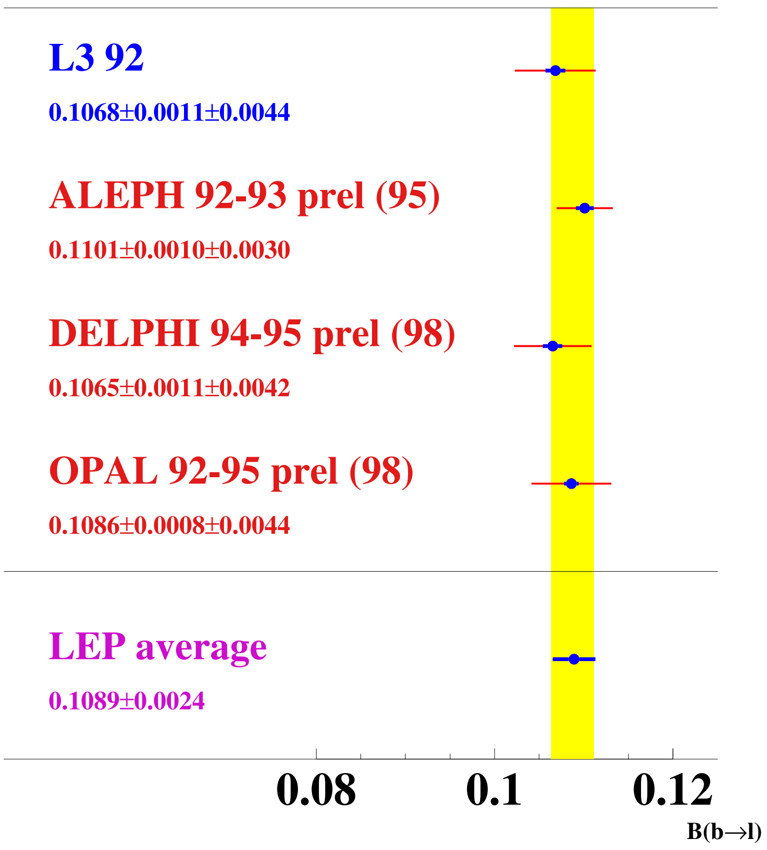


Still preliminary work: not all systematics studies done yet

(based on 1994-95 data)

$\mathrm{BR}(\mathrm{b} \to \ell X)$	$(10.32 \pm 0.12 \pm 0.24^{-0.21}_{+0.31}\%)$
$\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \ell X)$	$(0.94 \pm 0.16 \pm 0.27^{-0.50}_{+0.33}\%)$
$\mathrm{BR}(\mathrm{b} \to \bar{\mathrm{c}} \to \ell X)$	$(7.43 \pm 0.16 \pm 0.28^{-0.24}_{+0.18}\%)$
$\mathrm{BR}(\mathrm{B}^+ \to \ell X)$	$(9.89 \pm 0.28 \pm 0.24^{-0.21}_{+0.31}\%)$
$\mathrm{BR}(\mathrm{B}^+ \to \mathrm{c} \to \ell X)$	$(1.33 \pm 0.35 \pm 0.27^{-0.50}_{+0.33}\%)$
$\mathrm{BR}(\mathrm{B}^+ \to \bar{\mathrm{c}} \to \ell X)$	$(5.98 \pm 0.31 \pm 0.28^{-0.24}_{+0.18}\%)$

New LEP average for $\mathrm{BR}(\mathrm{b} \to \ell \mathrm{X})$



- New average does not include old lepton fits
  $\to N_{\mathrm{lepton}} = (\mathrm{BR}(\mathrm{b} \to \ell \mathrm{X}) \cdot R_{\mathrm{b}})/\epsilon_\ell$
  $\to -0.95$ correlation between $\mathrm{BR}(\mathrm{b} \to \ell \mathrm{X})$ and R_{b}

- Include only b-tagged measurements in global EW fit

- Constraint from A_{fb} reduces modelling error
  $\to \pm 0.13 \to \pm 0.18$ without A_{fb} in fit

New LEP average: $\mathrm{BR}(\mathrm{b} \to \ell \mathrm{X}) = (10.89 \pm 0.24)\%$

Outlook for $(\mathrm{b} \rightarrow \ell)$

- $\mathrm{BR}_{\mathrm{sl}}^{\mathrm{Z}^0}$ average is reduced with new b-tagged methods

$$\mathrm{BR}_{\mathrm{sl}}^{\mathrm{Z}^0} = (10.89 \pm 0.24)\%$$

$$\mathrm{BR}_{\mathrm{sl}}^{\Upsilon(4\mathrm{S})} = (10.45 \pm 0.21)\%$$

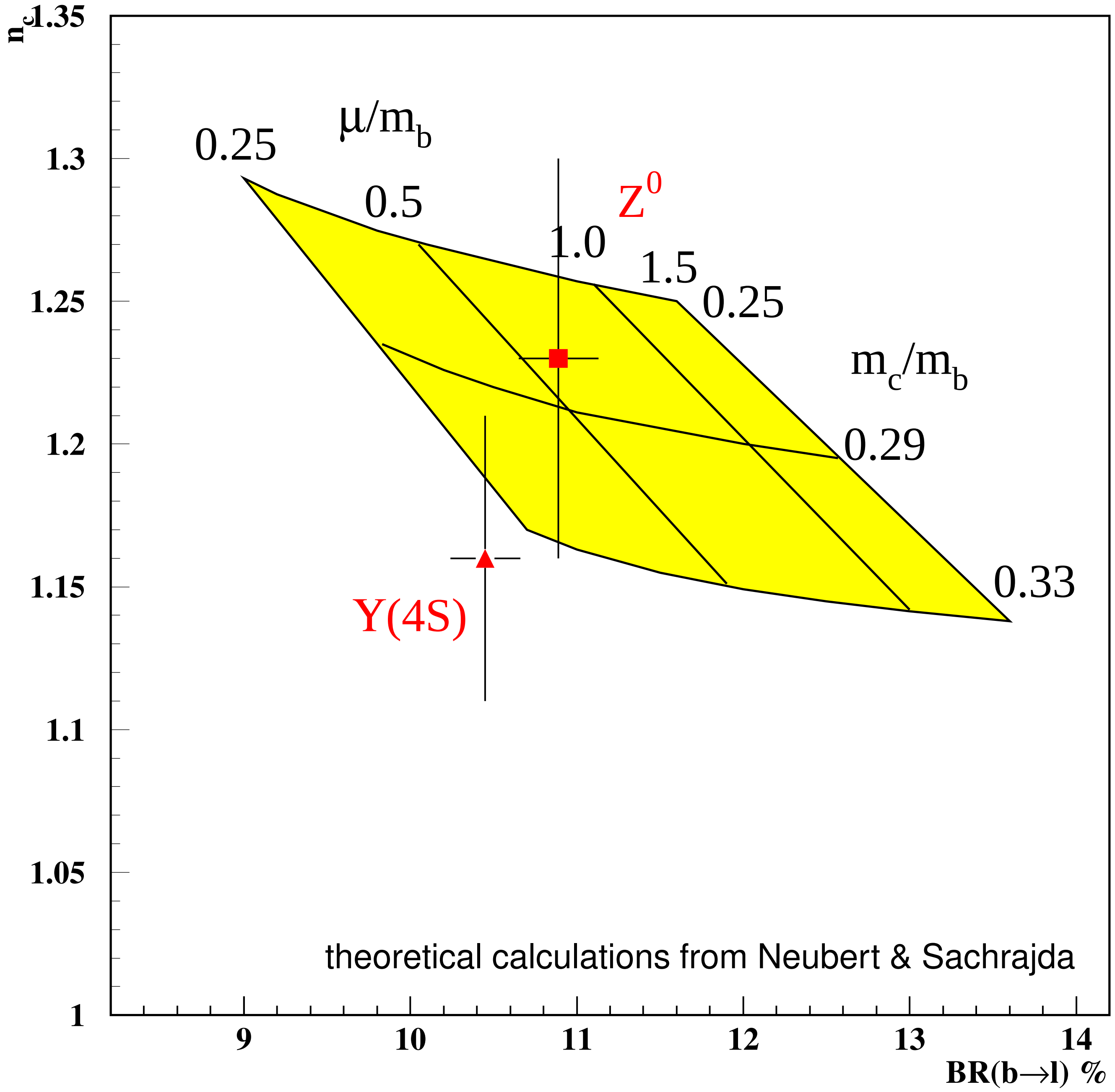
to correct for Λ_b and $\mathrm{B_s}$: multiply $\mathrm{BR}_{\mathrm{sl}}^{\mathrm{Z}^0}$ by

$$\tau_B/\tau_b = 1.020 \pm 0.024$$

- OPAL, Delphi and Aleph all working to finalise results
- New methods rely less on lepton spectrum modelling
- Model-dependence still the largest systematic error
- Updated theoretical models still greatly needed

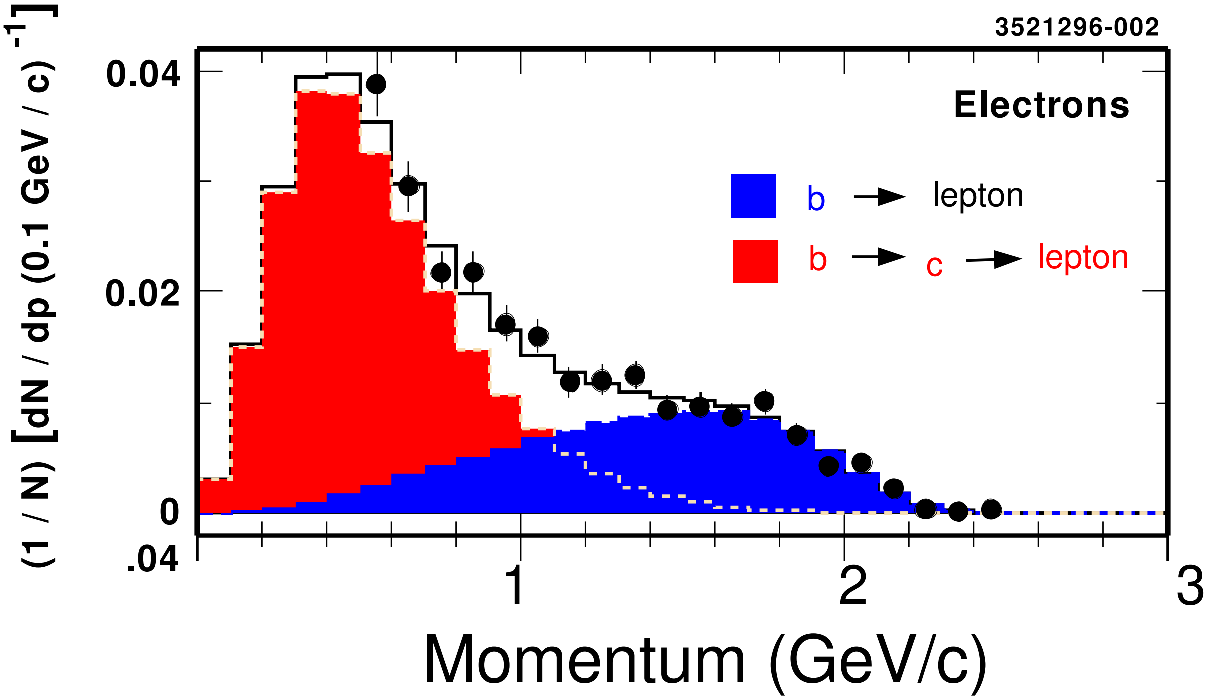
... this might be the end of the discrepancy between $\mathrm{BR}_{\mathrm{sl}}^{\Upsilon(4\mathrm{S})}$ and $\mathrm{BR}_{\mathrm{sl}}^{\mathrm{Z}^0}$

Theory versus results for $(\mathrm{b} \to \ell)$



n_c: number of charm hadrons per b hadron decay

Momentum spectrum from CLEO



Primary lepton momentum shape fitted to ISGW** model

- CLEO accepts electrons with 0.6 GeV/c
  $\rightarrow$ 95% of the full spectrum for $(\mathrm{b} \rightarrow \ell)$
- At LEP, limited at 2 GeV/c (85% of spectrum)