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Critical Review of *b*-Asymmetry Measurements at LEP

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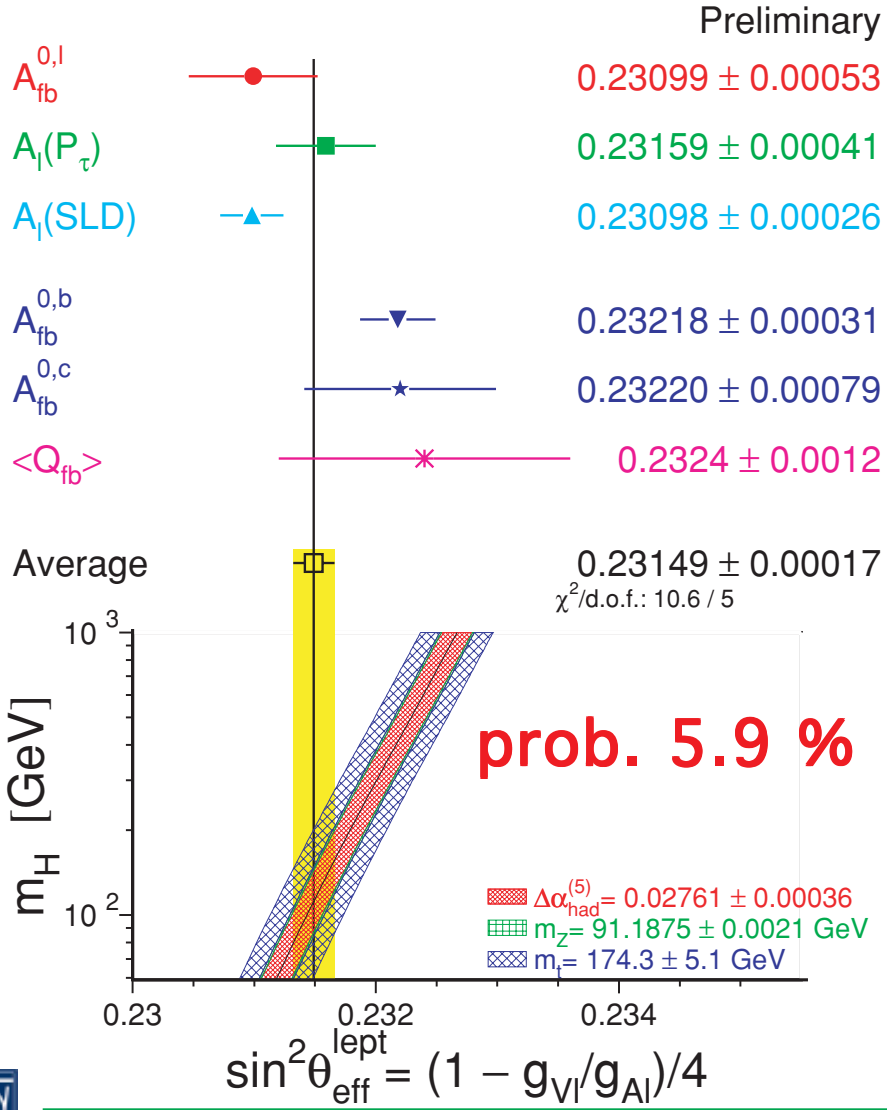
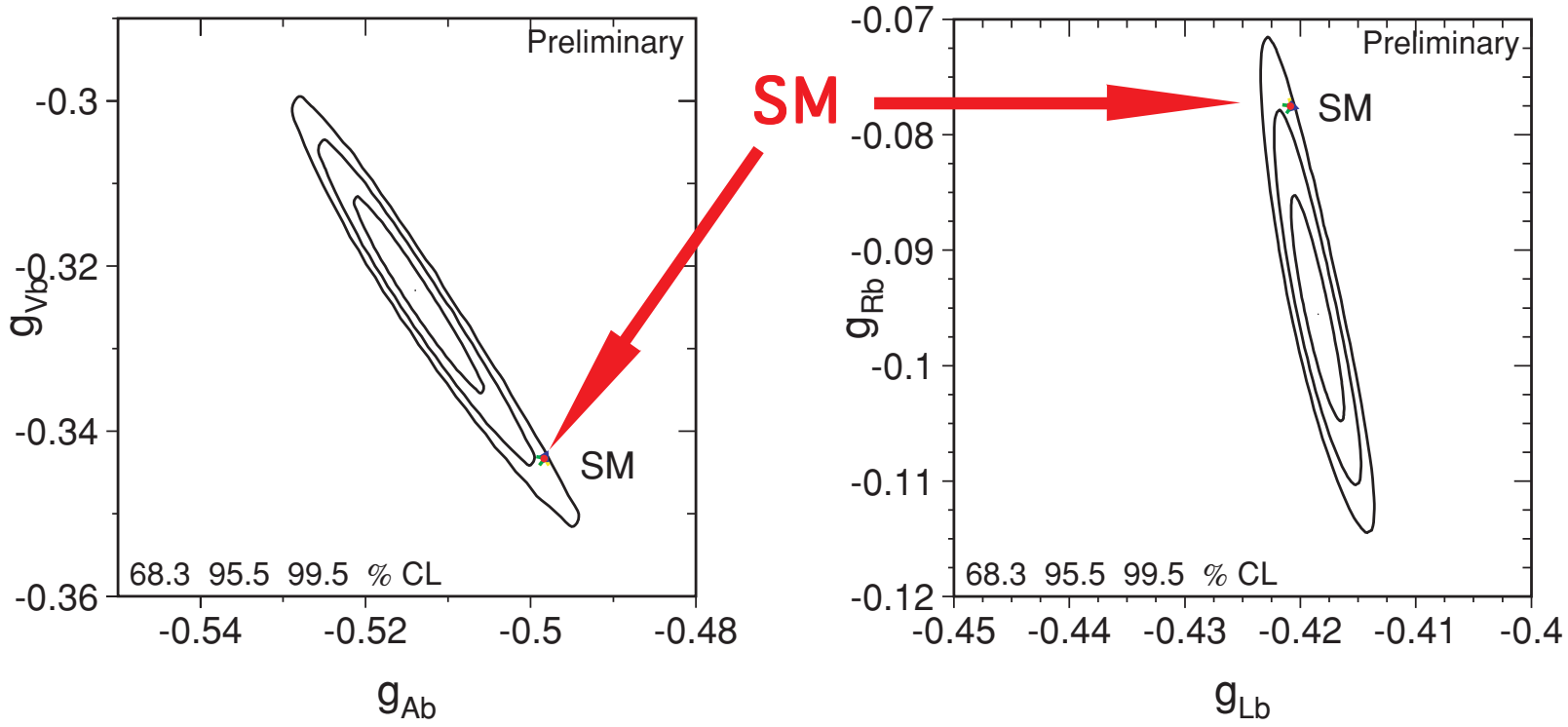
measurements of $sin^2\theta^{lept}_{eff}$



- → $sin^2\theta^{lept}_{eff}$ from only :
  - leptons 0.23113±0.00021
  - hadrons 0.23220±0.00029
- → either :
  - statistical fluctuation
  - unknown sources of systematic errors
  - evidence for new physics
- → <u>note :</u>
  only average $\sin^2\theta^{lept}_{eff}$ consistent with m_H of O(100 GeV)

g_{Vb} vs g_{Ab} and g_{Rb} vs g_{Lb}

→ using R_b, A_b and A_{FB}^b , assuming lepton universality

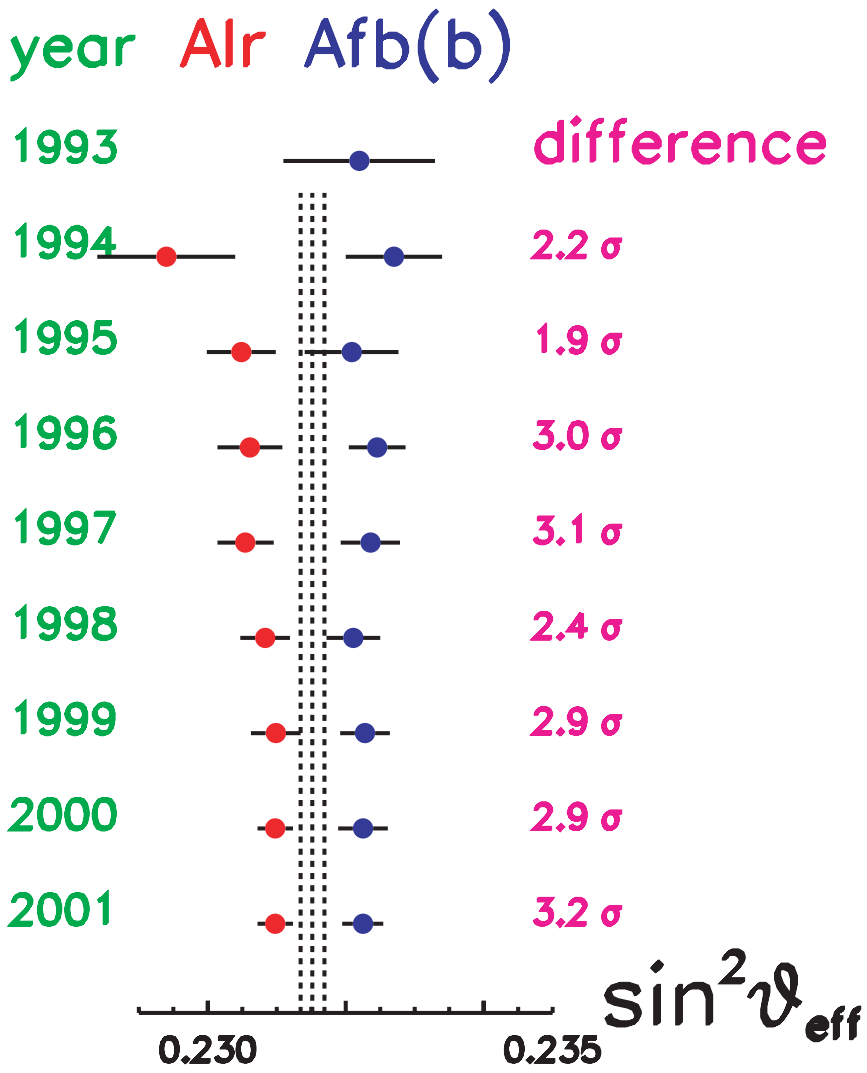


→ strong anti-correlation of g_{Vb} and g_{Ab}

- constraint on sum of squares from precise R_b

→ deviation from *SM* mainly for g_{Rb} ?

difference between A_{LR} and $A_{FB}^{0,b}$



- current difference : 3.0 σ !
- $\sigma(A_{FB}^{0,b})$ significantly reduced over years :
  - new analysis techniques
  - latest data reprocessings
- latest shift in LEP average :
  - new ALEPH lepton $A_{FB}^{0,b}$, $A_{FB}^{0,c}$ and $\overline{\chi}$ — see talk V.Ciulli
  - $\delta A_{FB}^{0,c} = +0.6\sigma$, $\delta\overline{\chi} = -0.25\sigma$

b-asymmetry using lepton tagging

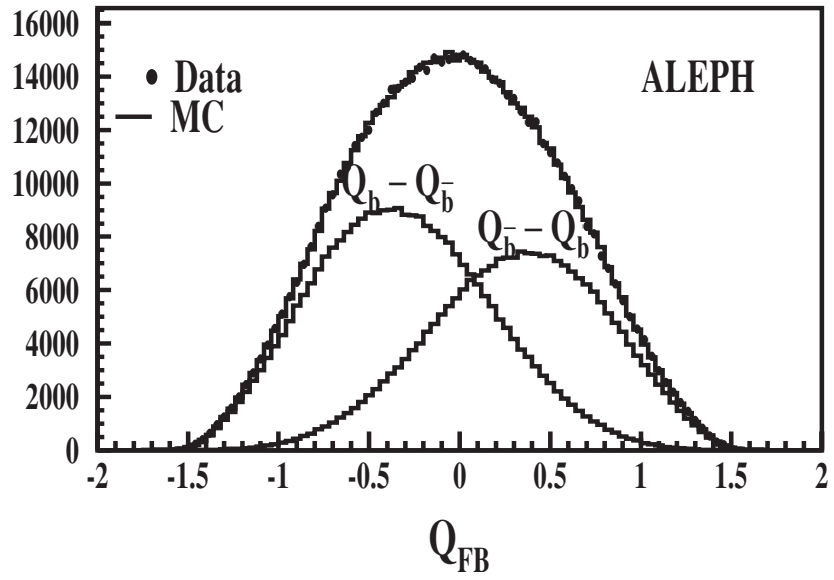
- V.Ciulli talk - details of new ALEPH result
- lepton gives clean tag of *b*(*c*) events and of charge
  - classical analysis - p,p_t mainly sensitive to $b \to l$
- new techniques gain sensitivity to $A_{FB}^{0,b}$, $A_{FB}^{0,c}$ and $\overline{\chi}$ separating better $b \to l$, $b \to c \to l$ and $c \to l$ by combining :
  - lifetime information (ADO)
  - kinematic information from rest of *b*-jet (AO)
  - opposite side jet-charge (D)
- indirect cross-check, compare $A_{FB}^{0,c}$ results :

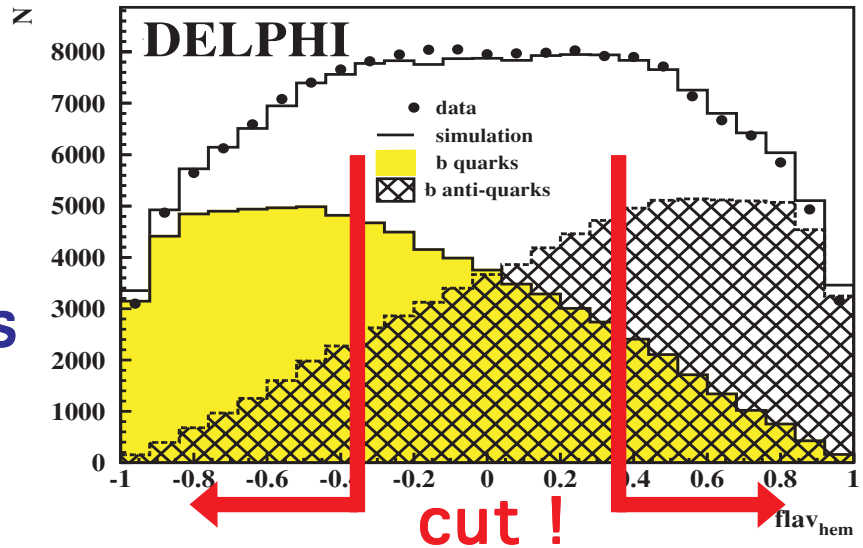
  leptons: 0.0700 ± 0.0034 *D**: 0.0711 ± 0.0057

  agree within 0.2 σ !

inclusive charge techniques

- two main ingredients
  - select pure *b* sample : enhanced impact parameter *b*-tagging
  - improved inclusive charge tag combining :
    * jet-charge
    * vertex-charge
    * identified particles
- double hemisphere self calibration (like R_b)
  - ALEPH: charge flow analysis
  - DELPHI: cut based analysis prel. (require vertex in hem.)





extracting the *b*-asymmetry

➡ ALEPH analyses charge flow Q_{FB} as function of $\cos\theta$:

$$\langle Q_{FB} \rangle = \langle Q_F - Q_B \rangle = \sum_{f=u,d,s,c,b} P_f \, \delta_f \, A_{FB}^f \, \frac{8}{3} \, \frac{\cos\theta}{1+\cos^2\theta}$$

with P_f ~ purity δ_f ~ charge separation

➡ DELPHI is using differential asymmetry :

$$\frac{N^+ - N^-}{N^+ + N^-} = \sum_{f=u,d,s,c,b} P_f \, (2\omega_f - 1) \, A_{FB}^f \, \frac{8}{3} \, \frac{\cos\theta}{1+\cos^2\theta}$$

with P_f ~ purity ω_f ~ charge tagging probability

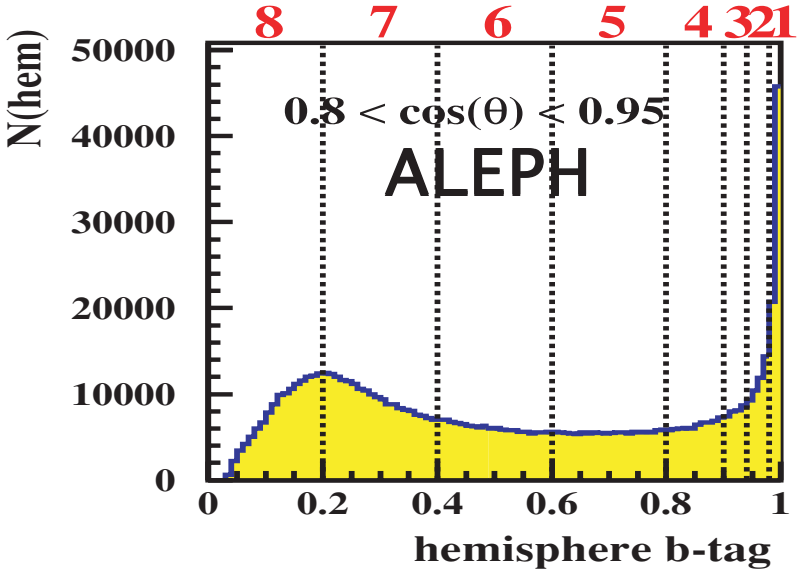
$N^{+/-}$ ~ double (single) hem. forward/backward events

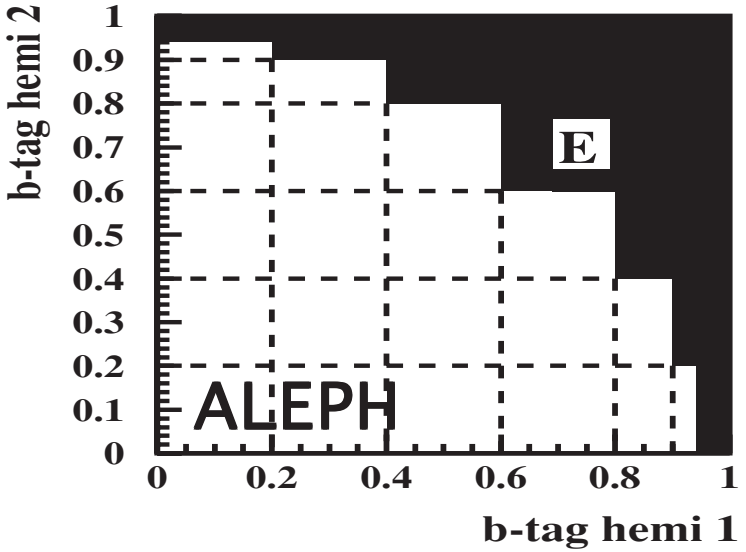
➡ critial issues are :

- *b*-purity and charm background efficiency
- calibration of charge tagging for *b* and charm
- hemisphere correlations for double tagging

b-purity and charm background efficiency

- ALEPH: ε_b and ε_c from data
  - hem. double tagging (R_b)
  - 8 *b*-tag bins per hem.
  - hem. correlations and ratio of $\varepsilon^1_{uds}/\varepsilon^2_{uds}$ from MC
  - R_b and R_c from LEP
  - fit ε_f^{bin} in all hem. bins
- average *b*-purity in "E"-region is 88%
- DELPHI works at 96% purity
  - study ε_b and ε_c using hem. double tagging
  - ±20% (prel.) systematics on ε_c





charge separation

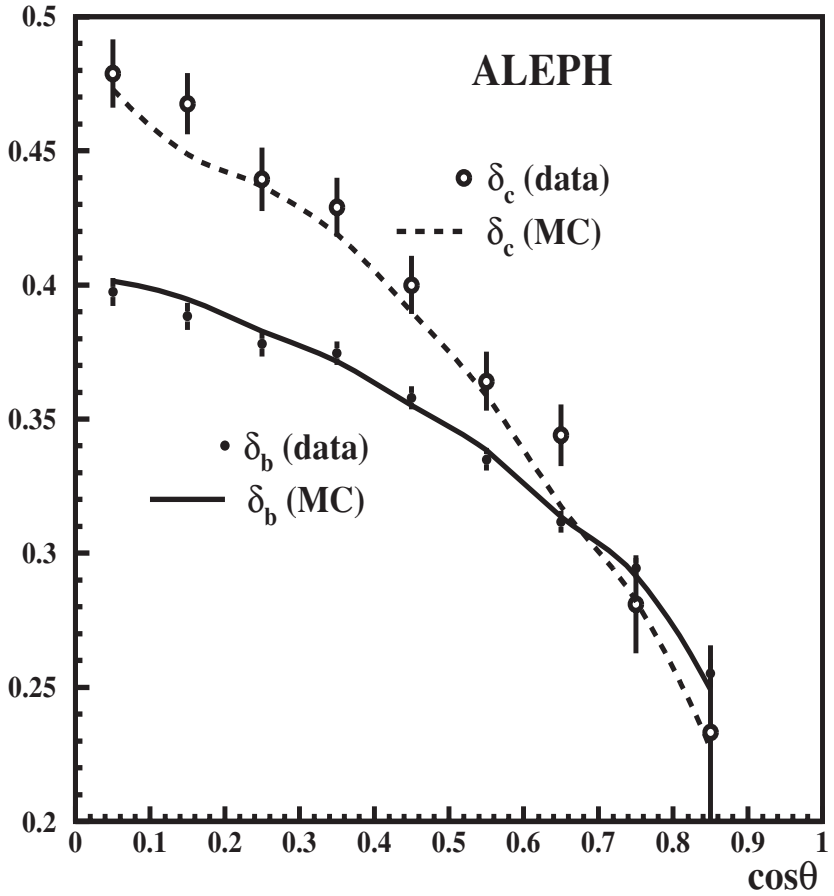
- ALEPH measures simultaneously δ_f for *b*, *c* and *uds* :

$$\overline{\delta}^2 = \sigma^2(Q_{FB}) - \sigma^2(Q_{TOT}) \approx \sum_f P_f \delta_f$$

  - 14 bins in *b*-tag
  - fix shapes of δ_f to MC
  - result: $\delta_b = -31.43 \pm 0.14\%$, $\delta_c = 37.33 \pm 0.39\%$

- DELPHI measures ω_b from :

$$\frac{N_{opp}}{N_{same}} \approx \frac{\omega_b^2 + (1-\omega_b)^2}{2\omega_b(1-\omega_b)}$$



92% (78%) for double (single) hemisphere tagged

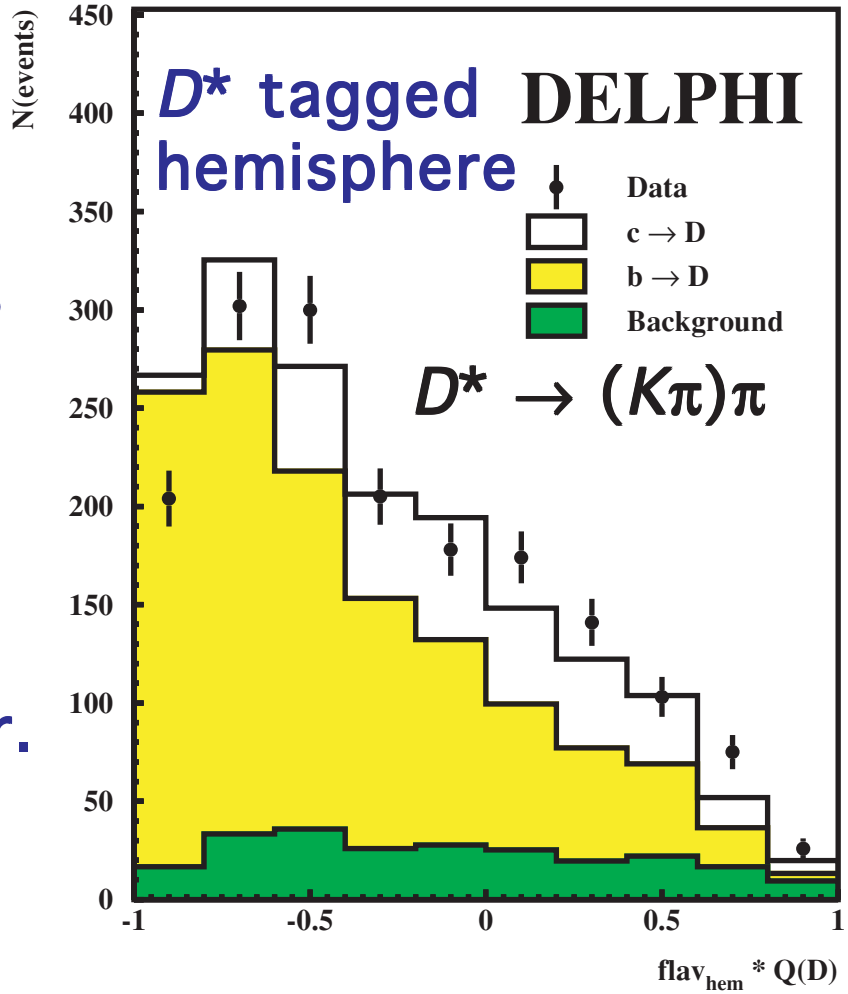
charge separation for charm

- DELPHI measures ω_c using D^* tagged events
  - 9 exclusive D^* decay modes
  - measure $flav_{hem}$ in opposite hemishpere
  - product of hem. charges :

    $-Q(D^*)\ \mathrm{sign}(flav_{hem})$
  - b/c separation, b mixing cor.
- difference of data and MC :

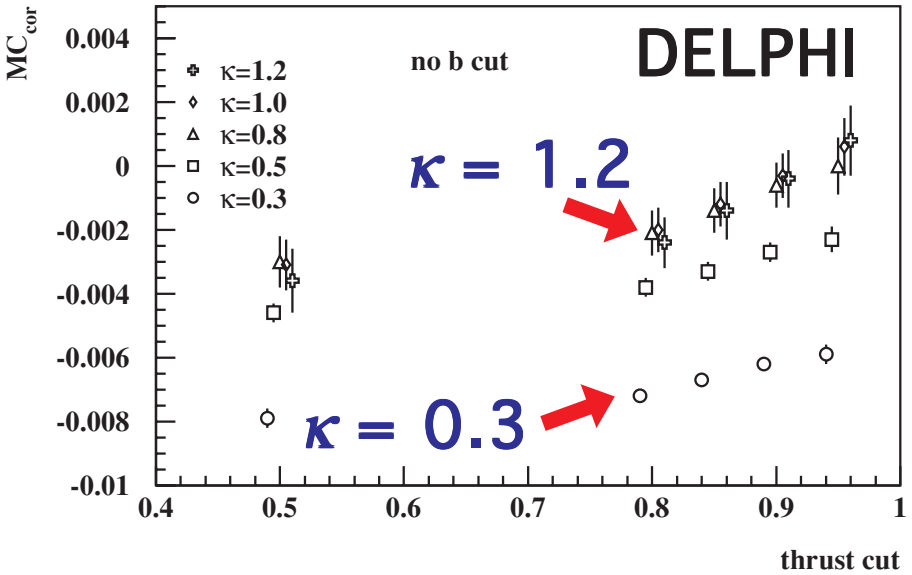
  $\delta\omega_c/\omega_c = -4.4 \pm 3.6\%$

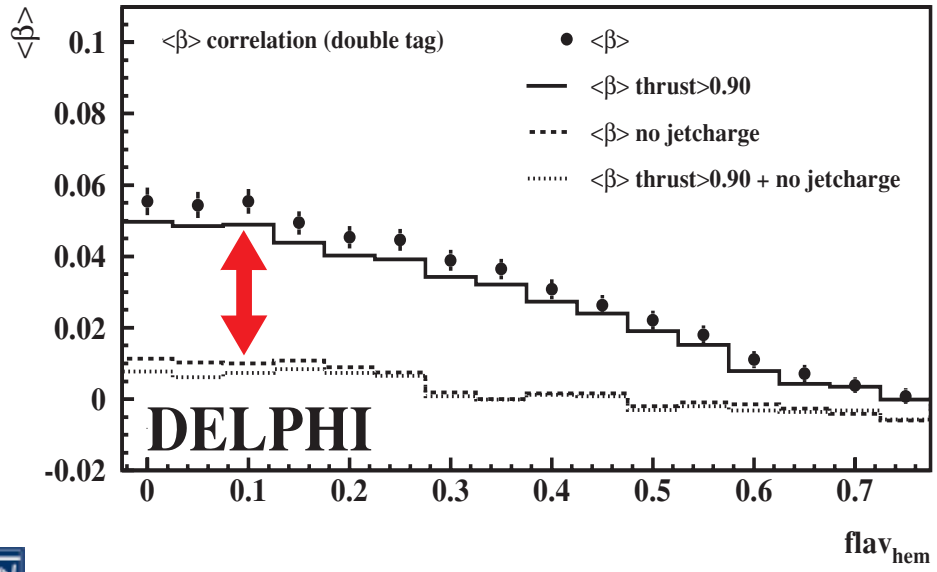
  covered by $\pm 10\%$ systematics



charge tagging hemisphere correlations

- jet-charge receives correlations from :
  - gluon radiation
  - charge conservation in event
- biggest contributions for small κ values





- DELPHI tag uses small κ
  - at small $flav_{hem}$ correlations via jet-charge
  - at large $flav_{hem}$ vertex-charge dominates
- relative systematic error on jet-charge corr.: ±20%

charge tagging hemisphere correlations (II)

- ALEPH takes hemisphere correlation from MC
  - estimate systematic uncertainty using R_b technique
- projection along series of observables "v" :

$$(1+\rho_f)^2 = \frac{\int \{ Q^+_{same}(v)\, Q^-_{opp}(v) + Q^-_{same}(v)\, Q^+_{opp}(v) \}\, P(v)\, dv}{2 \langle Q^+ \rangle \langle Q^- \rangle}$$

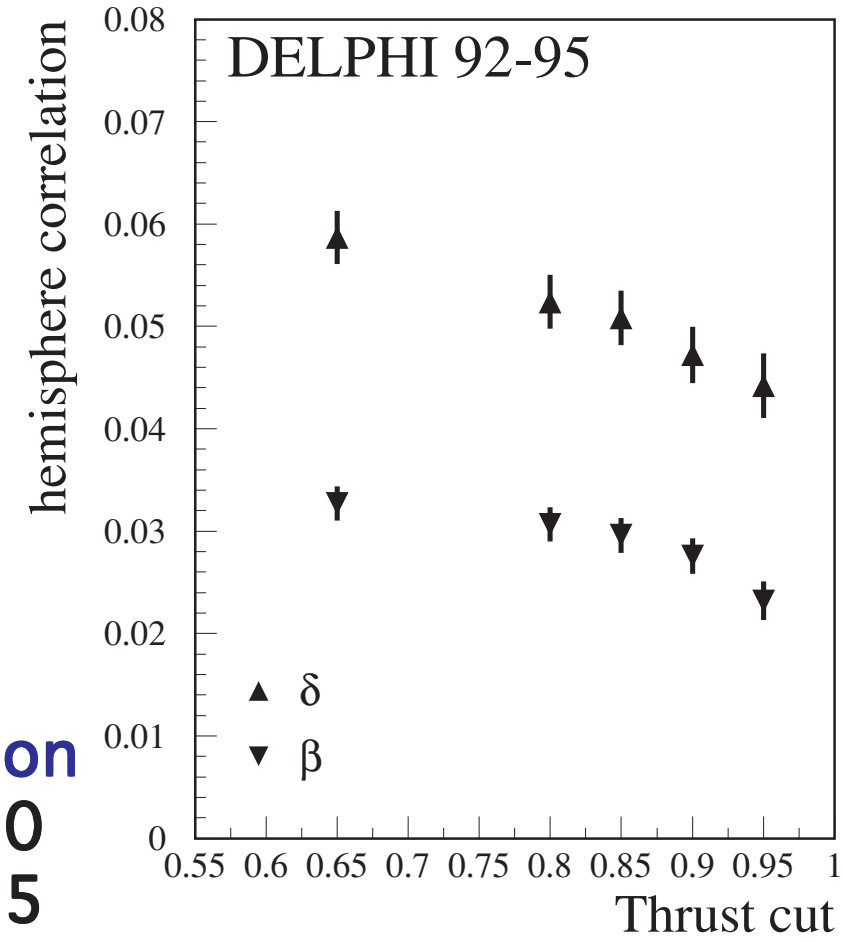
with v = thrust, *cos* θ, φ, P(*b*-hadr.), *b*-tag, jet/vtx/*K*-charge

  - assigning difference in data and MC as systematics yields : $(1+\rho_f) = 1.0920 \pm 0.0022$
- cross-check measuring $\delta'_b = -33.95 \pm 0.16\%$ in hemispheres opposite to lepton tag yields :

$$\frac{(1+\rho_f)}{(1+\rho_f)^{MC}} = \frac{\delta'_b}{\delta'^{MC}_b} \Big/ \frac{\delta_b}{\delta_b^{MC}} = 0.995 \pm 0.007$$

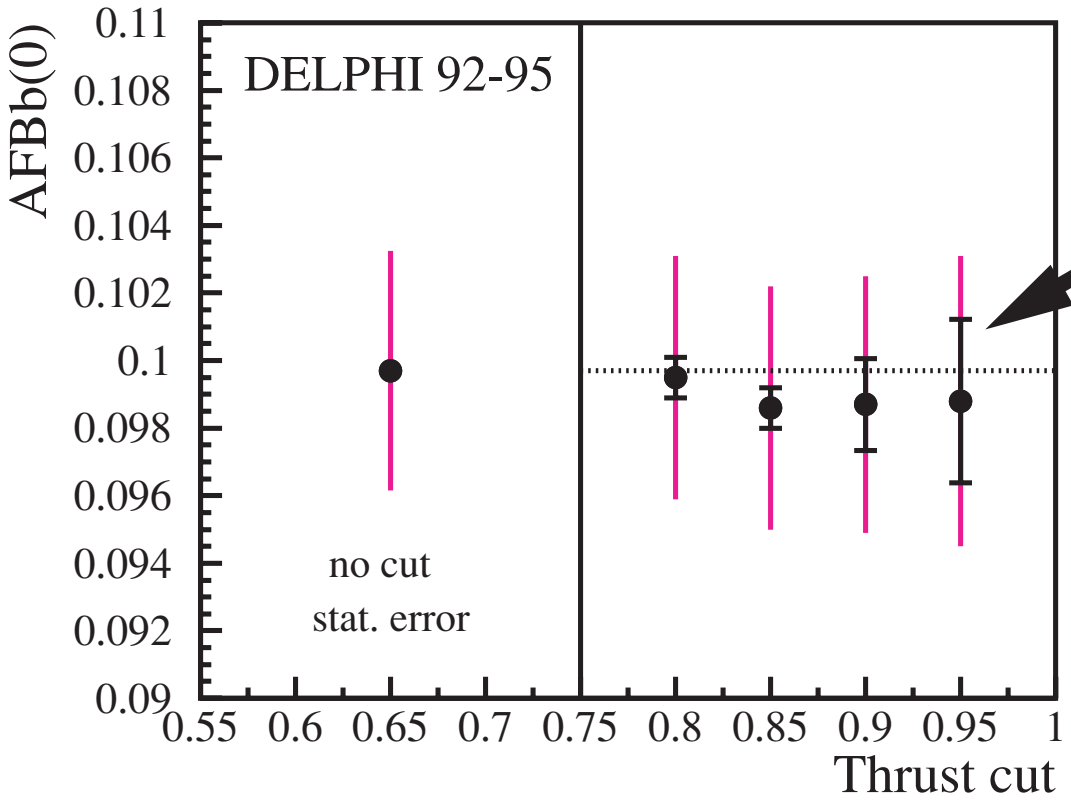
QCD correction

- QCD correction is
  $\Delta A_{FB}^{0,b} = (1.0354 \pm 0.0063) A_{FB}^{0,b}$
- current $\sigma(A_{FB}^{0,b})/A_{FB}^{0,b} = 1.7\%$
- selection biases sample
- on average 1/4 of QCD correction seen
- large part of QCD correction hidden in jet-charge hemisphere correlations
- add to error of QCD correction
  DELPHI: $\pm 0.00010 \rightarrow \pm 0.00040$
  ALEPH: $\pm 0.00005 \rightarrow \pm 0.00015$
- largest common systematic !



a simple cross-check

➡ measure *b*-asymmetry using different thrust cuts



uncorrelated error

● only statistical errors shown

➡ no sign for additional QCD systematic error

external inputs

- modelling of heavy flavour production and decays necessary for the *b*-asymmetry measurements
  - valuable input from CLEO, MARKIII, DELCO, ...
  - continuous improvements from LEP data itself :

	1996		2002		
$\langle X_E(b) \rangle$	0.700±0.020		0.702±0.008		(Peterson et al.)
$\langle X_E(c) \rangle$	0.510±0.020		0.484±0.008		
$g \to bb$	0.160±0.080	%	0.254±0.051	%	
$g \to cc$	1.60 ±0.80	%	2.96 ±0.38	%	
$\langle N(b \to \text{ch}) \rangle$	5.500±0.500		4.955±0.062		
b-lifetime	1.550±0.050	ps	1.576±0.016	ps	
...	...		...		

- most important inputs are free parameters in fit :

	4 leptonic inputs	$b \to l$, $b \to c \to l$, $c \to l$, $\overline{\chi}$
	4 charm fractions	$f(D^0)$, $f(D_s)$, $f(\Lambda_c)$, $P(c \to D^*)$
plus	6 EW-observables	R_b, R_c, $A_{FB}^{0,b}$, $A_{FB}^{0,c}$, A_b, A_c

averaging the results

- correlations between results using different methods :
  - ALEPH: 26.4±3.9% lepton vs jet-charge
  - DELPHI:

DELPHI:	neural-net	jet-charge
lepton	30%	39%
neural-net		49%

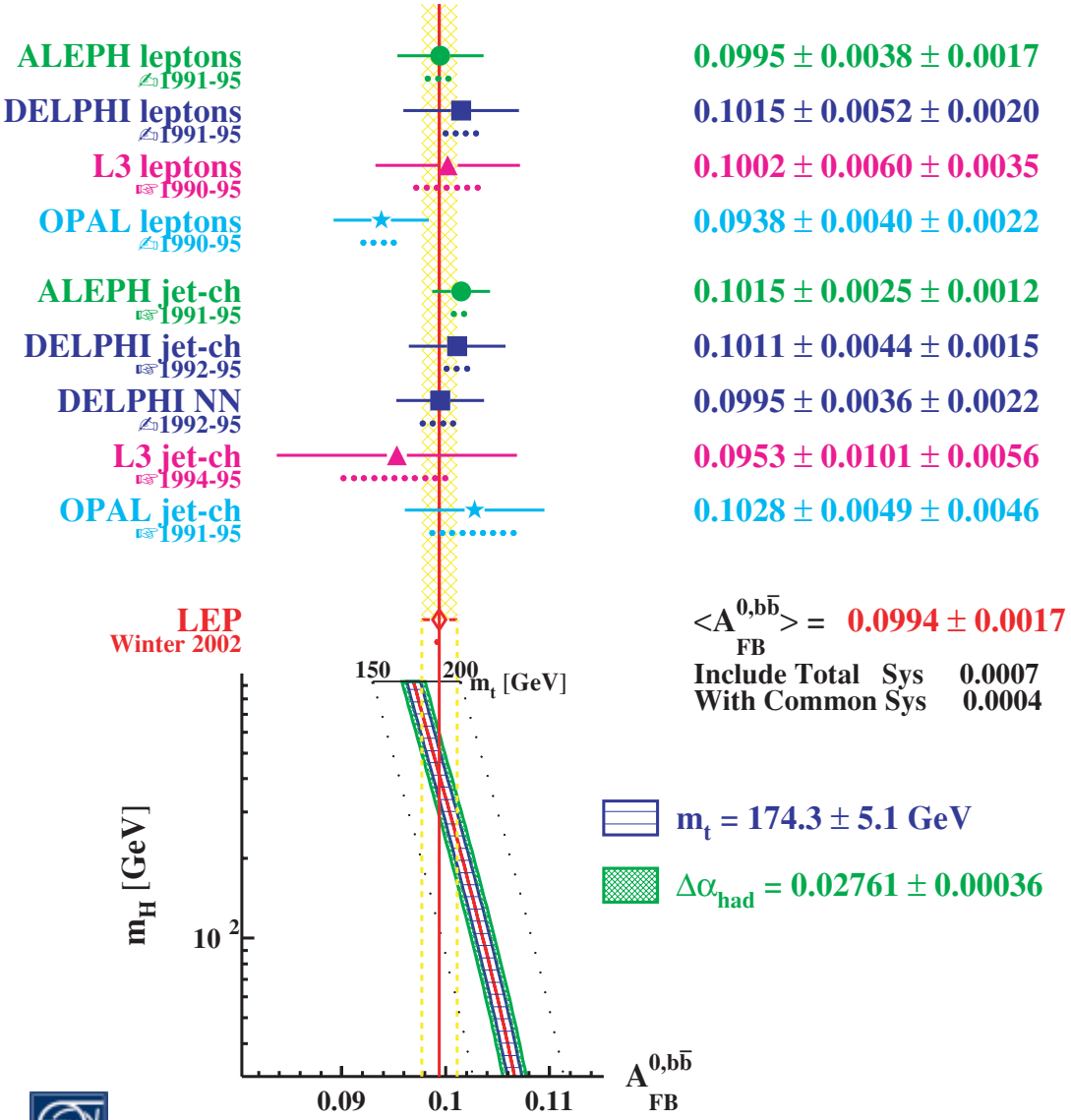
- heavy flavour fit : χ^2/NDF = 47/(105-14) = 0.52 !
- $A_{FB}^{0,b}$ error breakdown :

QCD correction largest common systematics

statistics	±0.00157
internal syst.	±0.00060
common syst.	±0.00039
total syst.	±0.00071

- correlations with $A_{FB}^{0,b}$ are small :
  16% with $A_{FB}^{0,c}$ 12% with $\overline{\chi}$
- using only statistical errors :
  $\delta A_{FB}^{0,b} = +0.1\sigma$ $\delta A_{FB}^{0,c} = \pm 0.0\sigma$

compilation of b-asymmetry results



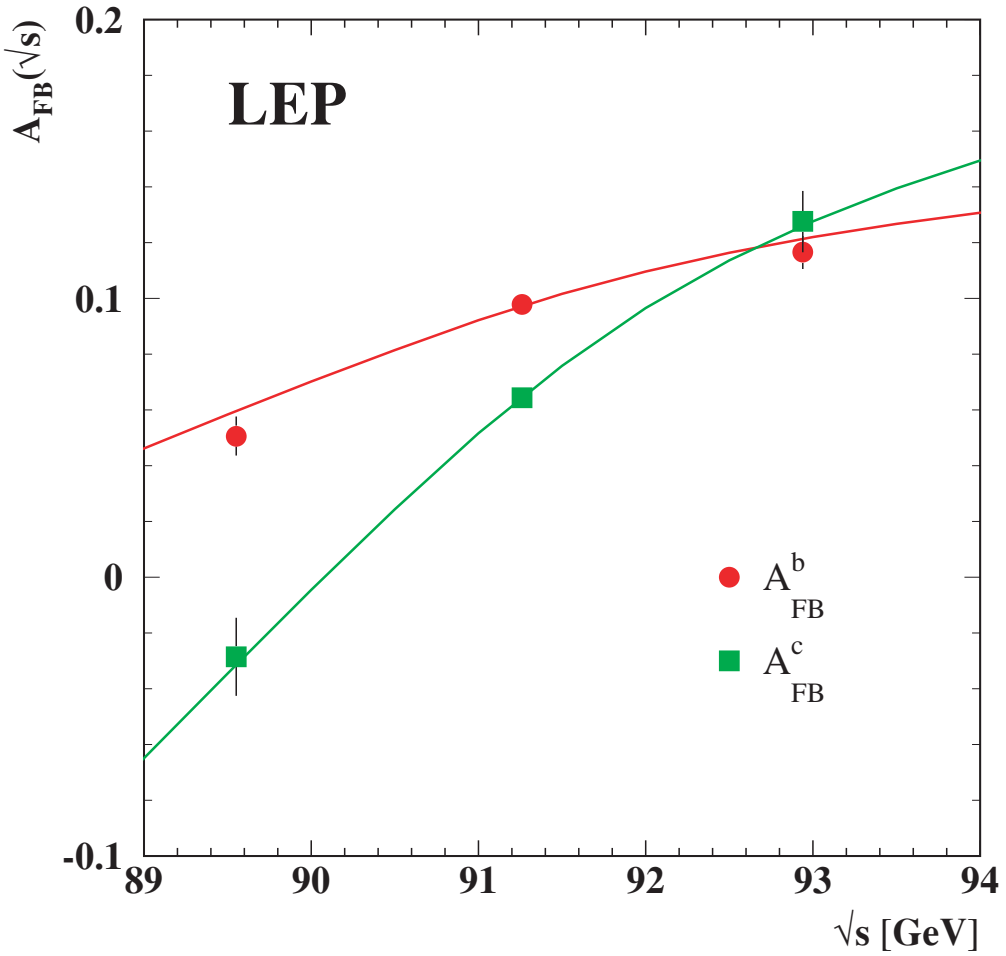
- only LEP quantity preferring high m_H
- not all results are final yet
- are LEP results consistent ?
- average only leptons :

  0.0975 ± 0.0025
- average only jet-charge :

  0.1009 ± 0.0020
- difference ~ 1.1 σ

energy dependence of b-asymmetry

- new ALEPH lepton off-peak results
- off-peak points tend to be low
  - peak only :
    0.1003 ± 0.0018
  - including off-peak :
    0.0994 ± 0.0017
- difference -0.5 σ
  (was -0.6 σ)



are LEP and SLD compatible ?

- compare results in terms of A_b :
- indirect (LEP only !) :

$$A_b = 0.893 \pm 0.022$$

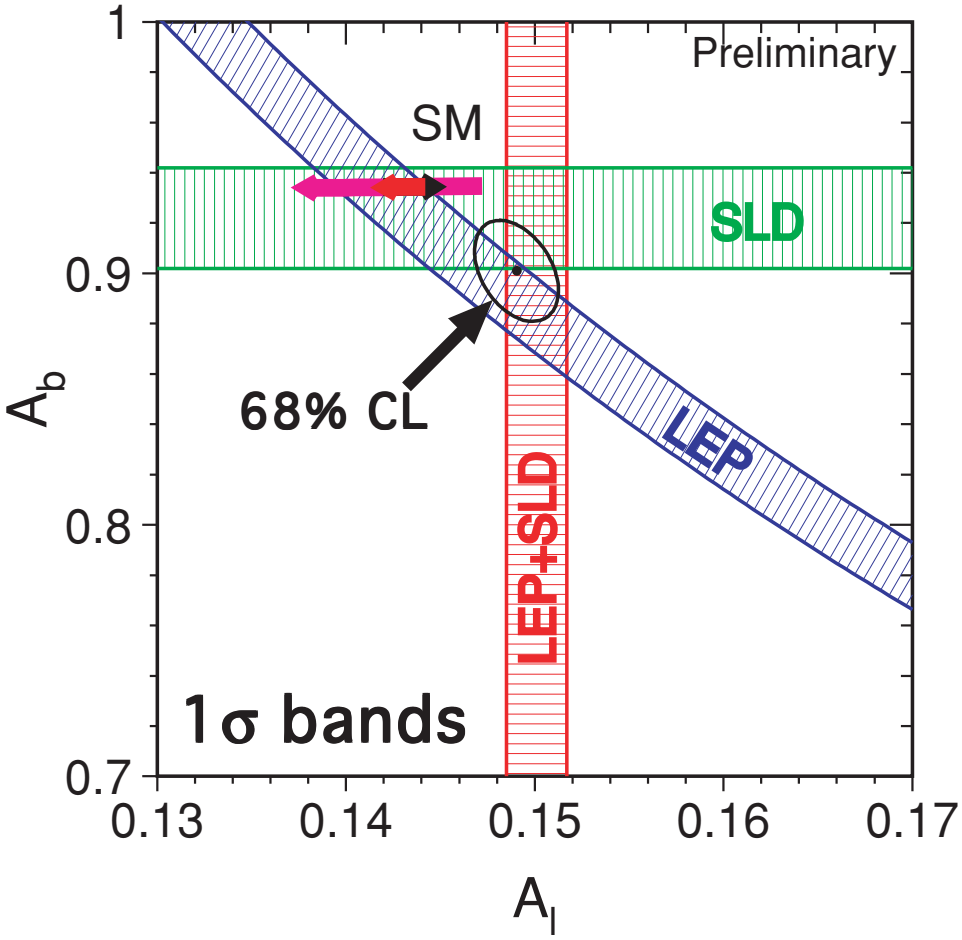
- and SLD :

$$A_b = 0.922 \pm 0.020$$

- agree within 1.0 σ !
- combined LEP+SLD :

$$A_b = 0.901 \pm 0.013$$

(0.935 *SM*)



$A_{FB}^{0,b} = 3/4\ A_e A_b$ $\quad A_{LR,FB}^{b} = 3/4\ A_b$

$A_l \sim \{A_{LR}\ ,\ A_{FB}^{0,l}\ ,\ \tau\text{-Pol.}\}$

summary

- status of *b*-asymmetry results from LEP :
  - new techniques boosted precision
  - as much as possible self calibration from data
  - analyses control key issues of the measurements
  - LEP + SLD average is consistent
  - still ongoing LEP *b*-asymmetry "workshop"
- one has to take the results seriously !!!
- still some room to improve LEP precision :
  - not all results are final yet
  - expect new jet-charge and lepton results from OPAL

so stay tuned !!!

error break-down of LEP average

Backup

→ general :

statistics	±0.00157
internal syst.	±0.00060
common syst.	±0.00039
total syst.	±0.00071

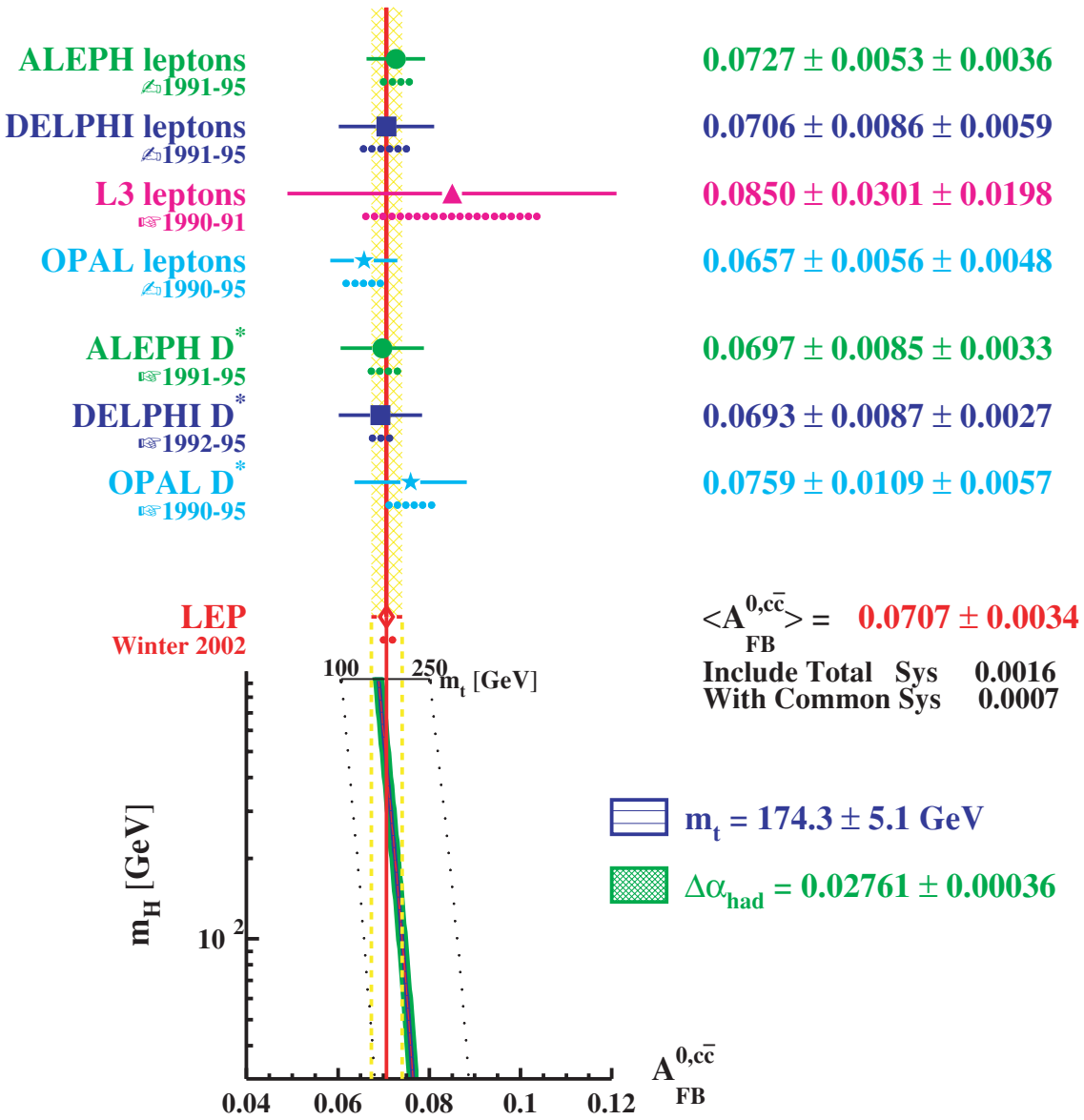
→ detector (if > 0.00010) :

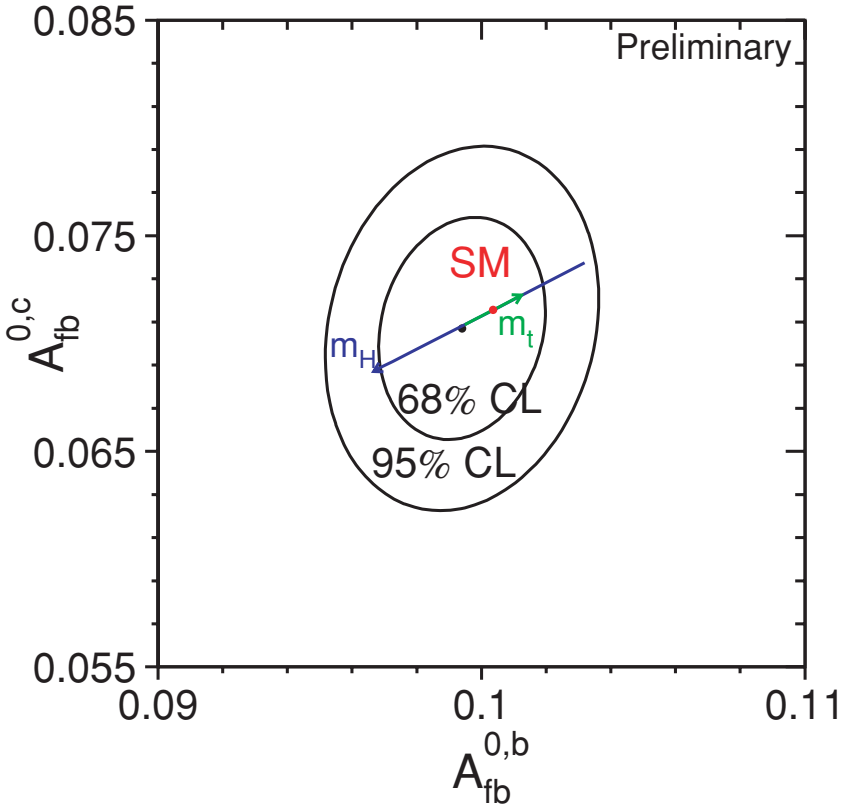
MC statistics	0.00012	
internal	0.00026	✗
A. - b-tag purities	0.00018	
A. - delta b	0.00024	✗
A. - c charge sep.	0.00013	
D. - track resolu.	0.00010	
O. - track resolu.	0.00018	
O. - jet char. int.	0.00015	
O. - theta dep.	0.00011	

→ physics (if > 0.00005) :

model c→l	0.00005	
b → D model	0.00008	
D decay multipl.	0.00005	
g → bb	0.00006	
AFB QCD corr.	0.00030	✗
light quark fragm.	0.00013	
effective χ	0.00008	
time dep. mixing	0.00006	

Backup


ALEPH leptons
1991-95
DELPHI leptons
1991-95
L3 leptons
1990-91
OPAL leptons
1990-95
ALEPH D*
1991-95
DELPHI D*
1992-95
OPAL D*
1990-95
LEP
Winter 2002
0.0727 ± 0.0053 ± 0.0036
0.0706 ± 0.0086 ± 0.0059
0.0850 ± 0.0301 ± 0.0198
0.0657 ± 0.0056 ± 0.0048
0.0697 ± 0.0085 ± 0.0033
0.0693 ± 0.0087 ± 0.0027
0.0759 ± 0.0109 ± 0.0057
<A^{0,cc̄}_{FB}> = 0.0707 ± 0.0034
Include Total Sys 0.0016
With Common Sys 0.0007
100
250
m_t [GeV]
m_H [GeV]
10^2
m_t = 174.3 ± 5.1 GeV
Δα_had = 0.02761 ± 0.00036
0.04
0.06
0.08
0.1
0.12
A^{0,cc̄}_{FB}


Preliminary
0.085
0.075
0.065
0.055
A^{0,c}_{fb}
SM
m_H
m_t
68% CL
95% CL
0.09
0.1
0.11
A^{0,b}_{fb}