R_b,R_c Measurements at SLD/LEP-I

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The contributions

LEP: ALEPH, DELPHI, L3, OPAL
with ~ 4M Z^0 each
and double sided Si vertex detectors

SLC: SLD 550k Z^0
CCD pixel vertex detector and
very small & stable beam spot

Abstracts sent to this talk:

143 OPAL R_b (submitted publication)

667 L3 $R_b \times Br(b \to \ell)$ (submitted publication)

739 SLD R_b, R_c (New preliminary)
Improved reconstruction & b, c tagging
R_b update added last 150K Z^0

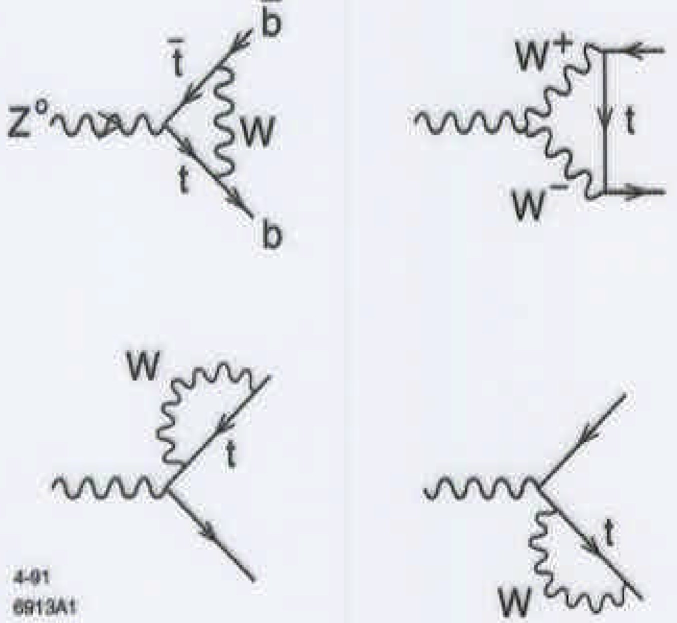
178 ALEPH R_c (charm counting) (submitted publication)

623 OPAL R_c (multiple tag) (not ready)

98 OPAL $g \to b\bar{b}$ $Z \to b\bar{b}b\bar{b}$ (prelim.)

LEP R_b, R_c results essentially unchanged from last year.

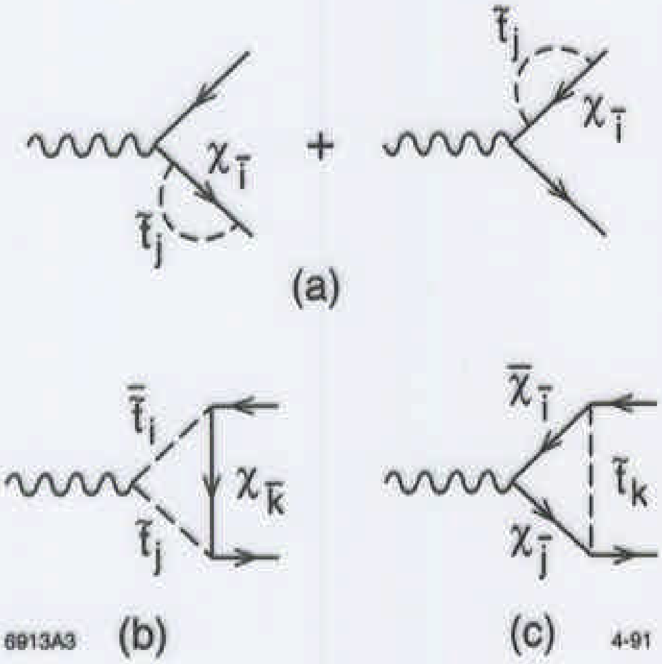
The Zb$\bar{b}$ coupling



Initial interest:

SM rad corr.
with large m_t
-> $\delta R_b \sim$ 1.2 %

As Precision Improves:



Could possible new physics emerge from the Zb$\bar{b}$ vertex ?

R_b measurement

The standard double tag technique:

Apply b-tag to 2 hemispheres separately

Measure: 1) Single hemisphere tag rate

2) Event double tag rate

Derive: R_b, ε_b

Assume: MC ε_{uds}, ε_c, C_b **(correlation) and SM** R_c

The key is high efficiency, high purity b-tag:

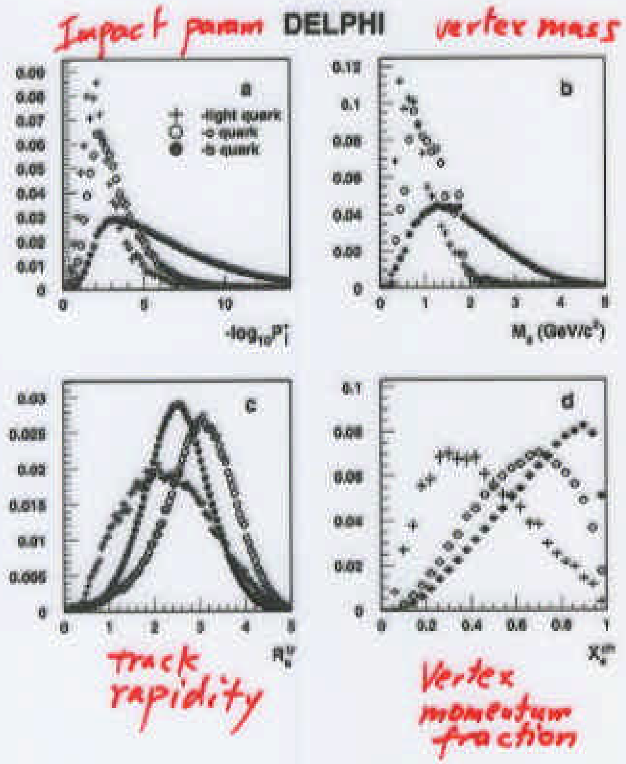
Statistics: $\delta R_b \sim 1/\varepsilon_b$ ($N_{event} \sim 1/\varepsilon_b^2$)

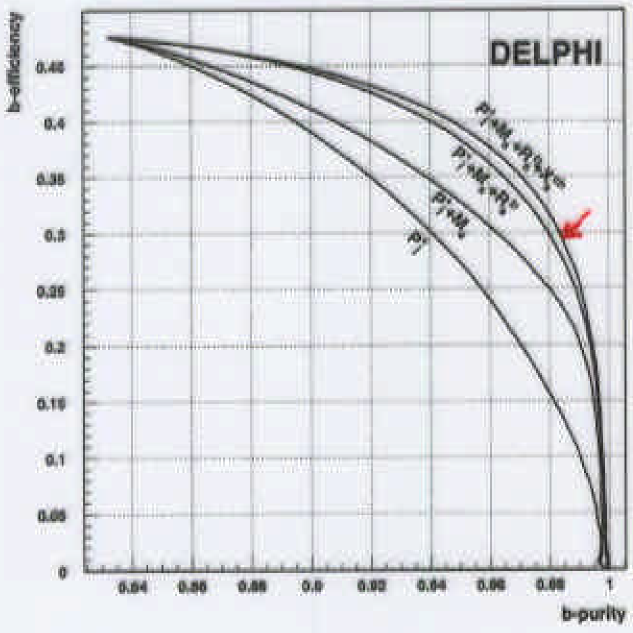
Systematics: also has $\sim 1/\varepsilon_b$ dependence

Multi-tag Analyses:

Use tags with different purities. The high purity tags can calibrate looser tag efficiencies – to reach additional 30-40% statistics from the looser tags.

DELPHI's `Improved Impact parameter tag'





Utilize kinematic information in addition to impact parameters

Best tagging performance at LEP

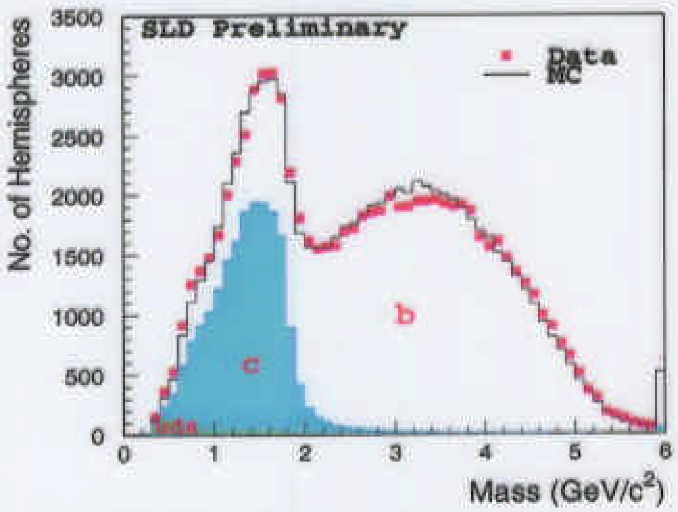
ε_b=29.6%,

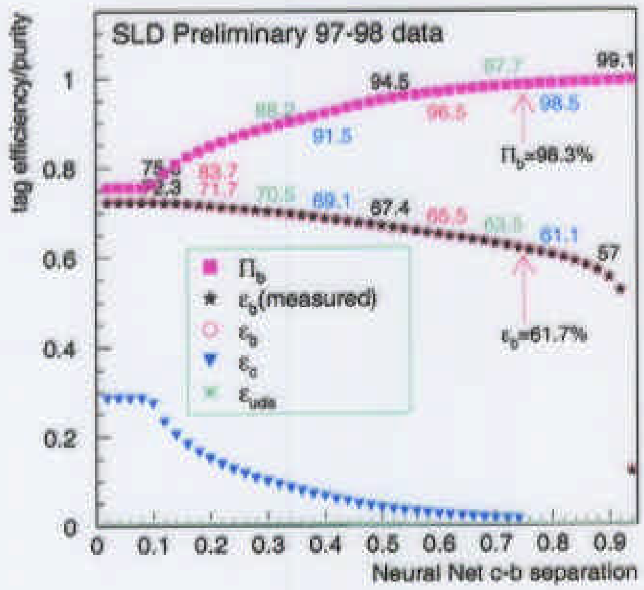
Π_b=98.5%

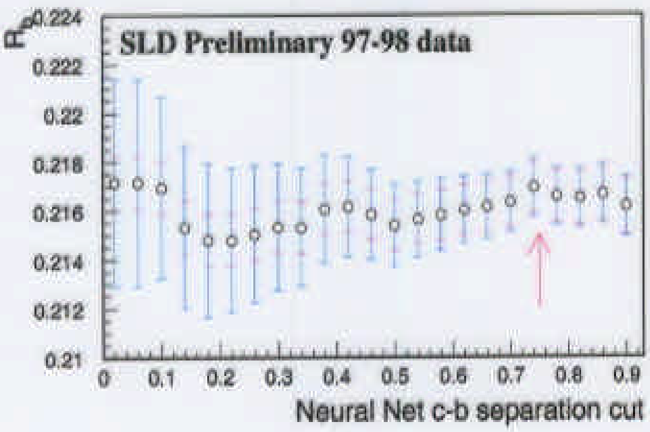
Most precise Single R_b measurement (~ ±0.4% !)

E.phys.J. C10 (1999) 415.

SLD Vtxmass &NeuralNet Tag







Track-Vertex Association NeuralNet:

Track 3D impact, Position and angle w.r.t. secondary vertex.

c-b separation NeuralNet:

Vertex mass, decay length, multiplicity and momentum.

ε_b =61.7%,

Π_b=98.3%

$\Rightarrow R_b = 0.21669$
$\pm 0.00094_{stat}$
$\pm 0.00101_{sys}$

ICHEP-739

New summer-2000 preliminary

g->$c\bar{c}$, g->$b\bar{b}$

- **g->$c\bar{c}$**

  mainly from OPAL measurements averaging g->$c\bar{c}$ = 3.19 $\pm$ 0.46 %

  ALEPH: 3.23 $\pm$ 0.48 $\pm$ 0.53% *(ICHEP-178)*

- **g->$b\bar{b}$**

  Now have a few measurements done in various ways:

ALEPH:	**2.77 $\pm$ 0.42 $\pm$ 0.57**	**x10^{-3}**	
DELPHI:	**2.1 $\pm$ 1.0 $\pm$ 0.9**	**x10^{-3}**	
OPAL:	**3.07 $\pm$ 0.53 $\pm$ 0.97**	**x10^{-3}**	**a)**
SLD:	**2.84 $\pm$ 0.61 $\pm$ 0.59**	**x10^{-3}**	**b)**

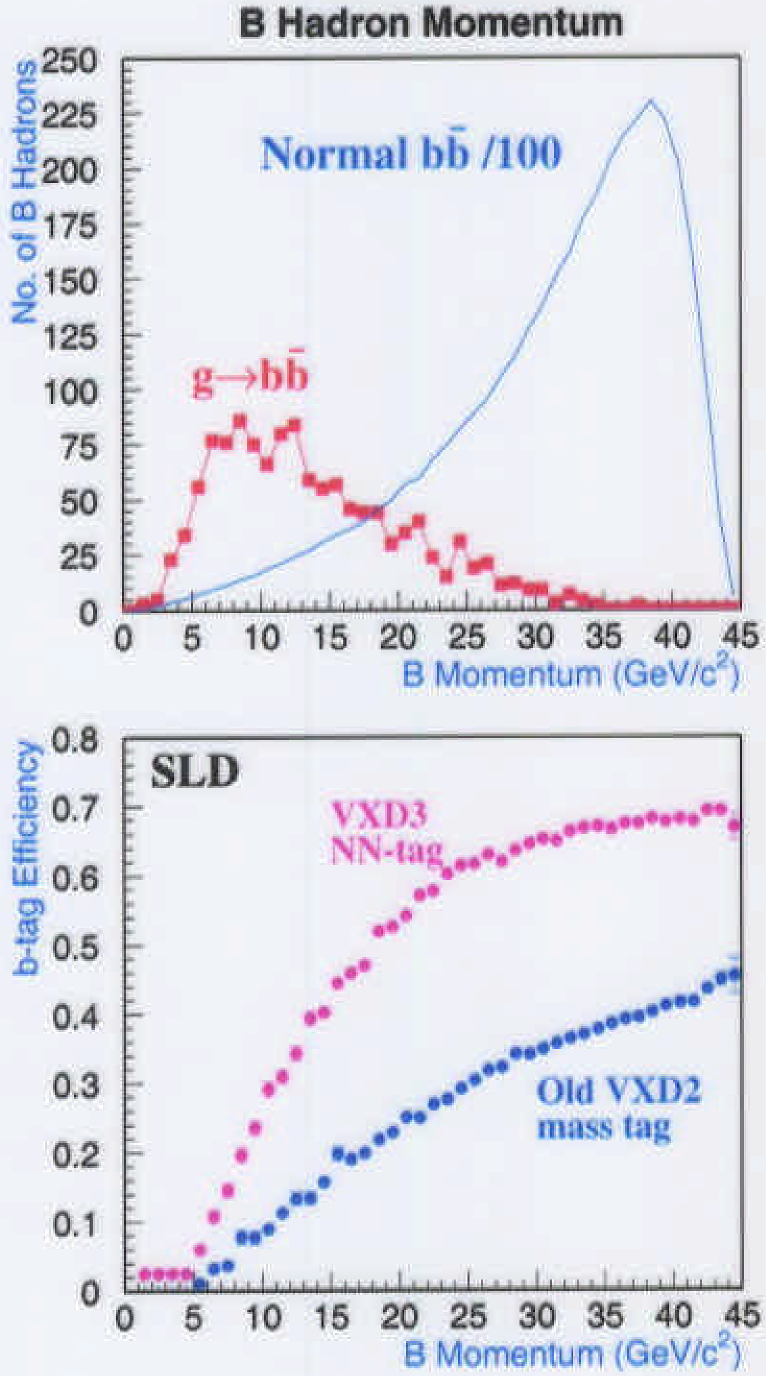
  Good consistency with the LEPEWWG averaging g->$b\bar{b}$ = 2.51 $\pm$ 0.63 x10^{-3}

but anything to say about spectrum shape ?

a) ICHEP-98
b) ICHEP-691

MC simulation g→$c\bar{c}$, $b\bar{b}$ is typically only ~$\frac{1}{2}$ of measured from data.

g->b$\bar{b}$, g->c$\bar{c}$



δR_b(g->c$\bar{c}$)

A: 0.00022

D: 0.00007

L: 0.00013

O: 0.00017

S: 0.00018

δR_b(g->b$\bar{b}$)

A: 0.00038

D: 0.00025

L: 0.00011

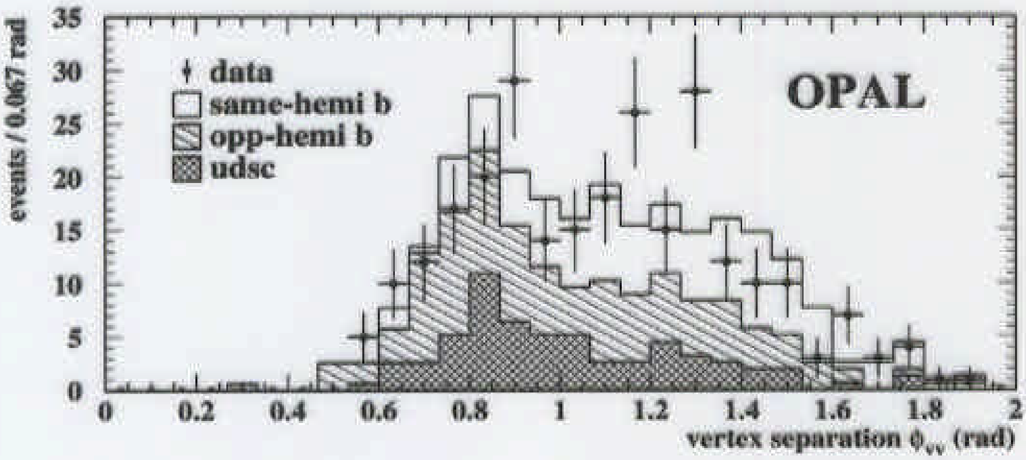
O: 0.00025

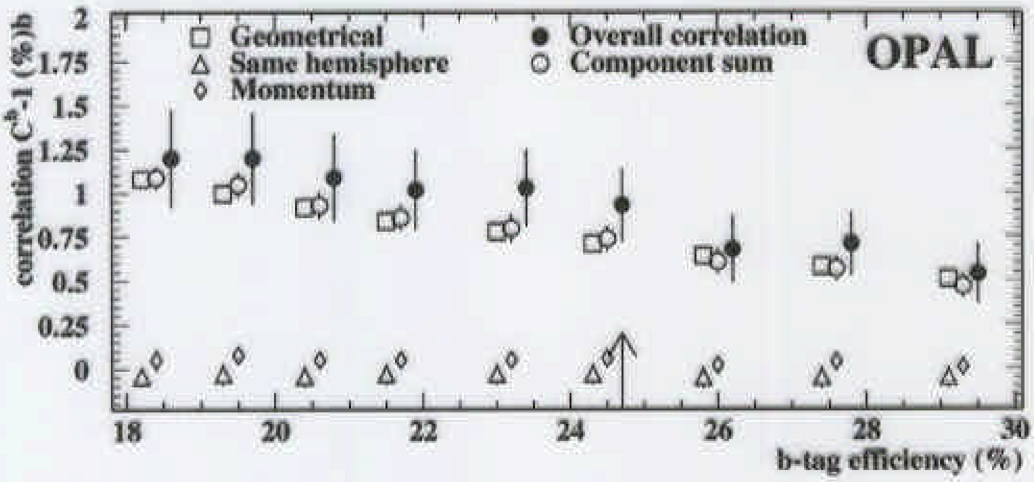
S: 0.00022

Effects Confined to 0.1-0.2%

but correction on R_b can be x2-3 larger.

Hemisphere Correlations





Some of the correlation studies are physics topics by themselves. Have we really looked at everything ? So far MC model is doing well.

Most extensive discussion:

OPAL E. Phys. J. C8 (1999) 217.

Event Selection b mass effect ?

In the SLD systematics :

Event selection running b mass effect	±0.00067
All other systematics	±0.00076
Total	±0.00101

Event selection $N_{jet} \leq 3$ removes ~ 8% events

According to JETSET this removes more udsc than b in fraction. How reliable is this prediction ?
(~ ½% on R_b)

Recent LO QCD calculation by Arndt Brandenburg et.al.

	$m_b = 0$	$m_b(z) = 3$	$m_b = 5$ GeV
$b\bar{b}$ 4 jet rate	4.27%	4.03%	3.65%

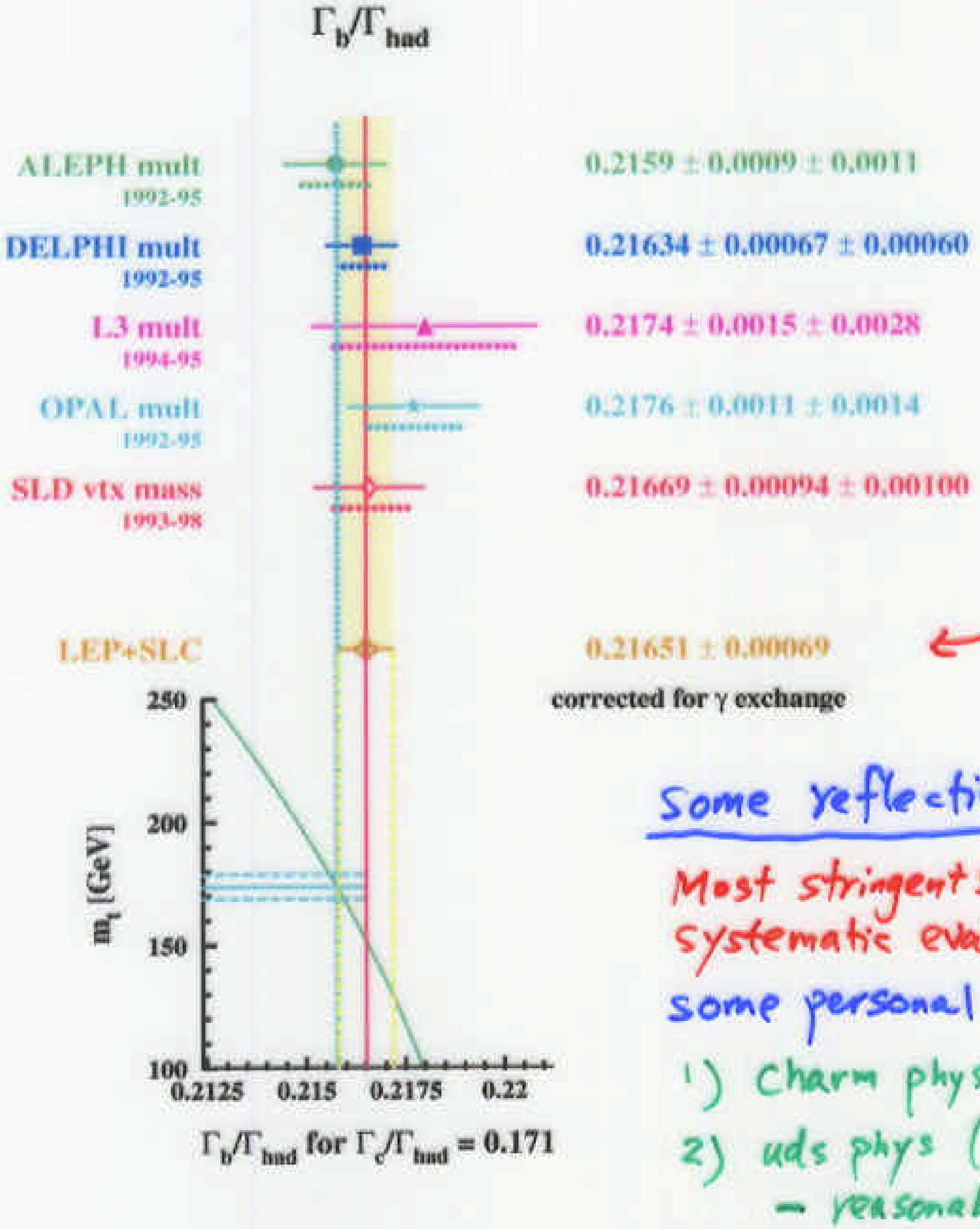
Complication : LO QCD calculation under estimate all 4 jet events by a factor of 2.
⇒ Need to scale effect × 2.

JETSET does get 4 jet rate = data
but what m_b is it using effectively for 4 jet rates?

What if you don't use $N_{jet} \leq 3$ or thrust cut ?
⇒ Problem propagates to hemisphere correlation...

May be a redherring but needs to be understood.

R_b comparison



← ±0.32% !

Some reflections:

Most stringent scrutiny on systematic evaluation uniformity

some personal opinion:

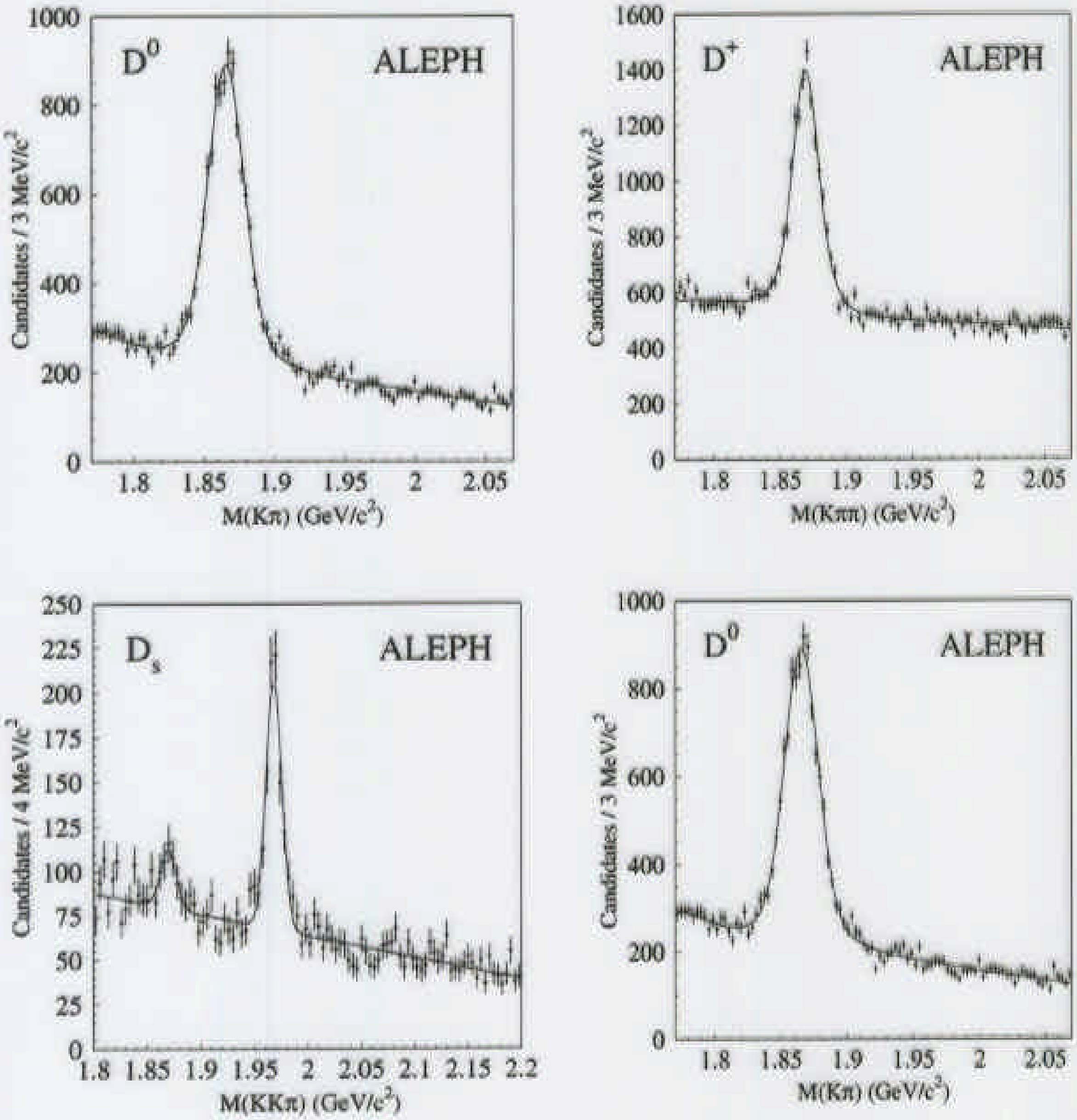
1) Charm phys sys. – solid
2) uds phys (mainly $g \to Q\bar{Q}$)
   – reasonably under control
3) correlation
   – many checks & look satisfactory but have we missed something?
4) Detector effect
   – Was the source of the '3σ effect'
   very subjective and hopefully now reasonably conservative
5) Event selection bias – need some work

R_c Measurements

Charm tag is harder to reach the same level of efficiency as b-tag, A larger variation of methods are used for R_c measurements:

- **Lepton spectra (A)**
  Need c-> spectrum & Br(c->l).
- **Charm counting (A,D,O)**
  Sum D^0,D^+,D_s,Λ_c -> all charm hadrons.
  Need charm decay Br.
- **D* Incl/Excl mixed tag (ADO)**
  Use well known exclusive decays to calibrate inclusive tag.
  Background subtraction tricky.
- **Vertexing double tag (SLD)**
  Genuine double tag measurement

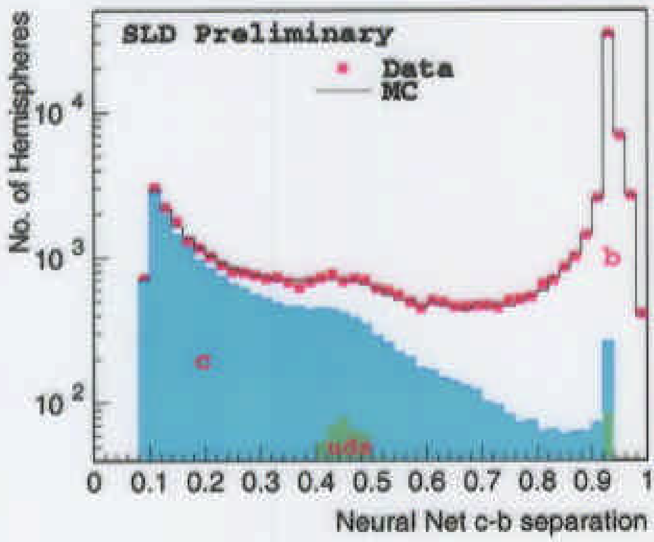
Charm Counting

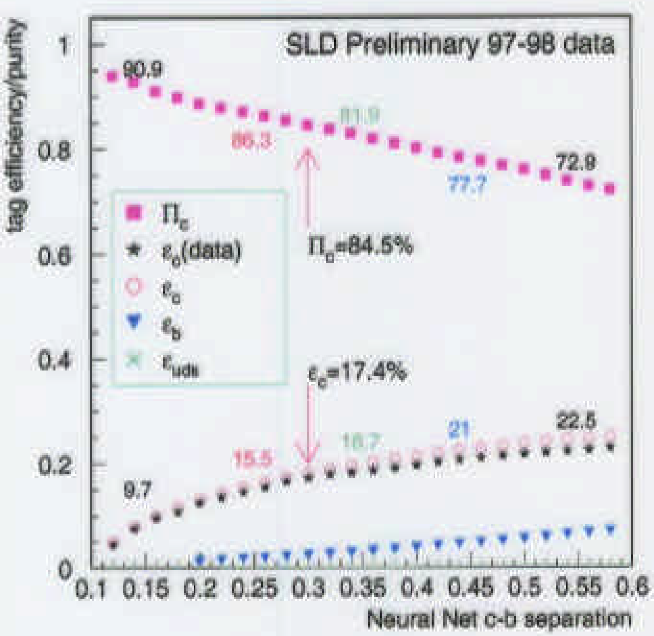


$R_c = 0.1738 \pm 0.047 \pm 0.0116$ (ICHEP-178)

Main systematics: Fragmentation &
D decay Br.

R_c with vertex NN double tag





New summer-99
SLD Preliminary
(ICHEP-739)

Same NN tag
Used for R_b

Measured:

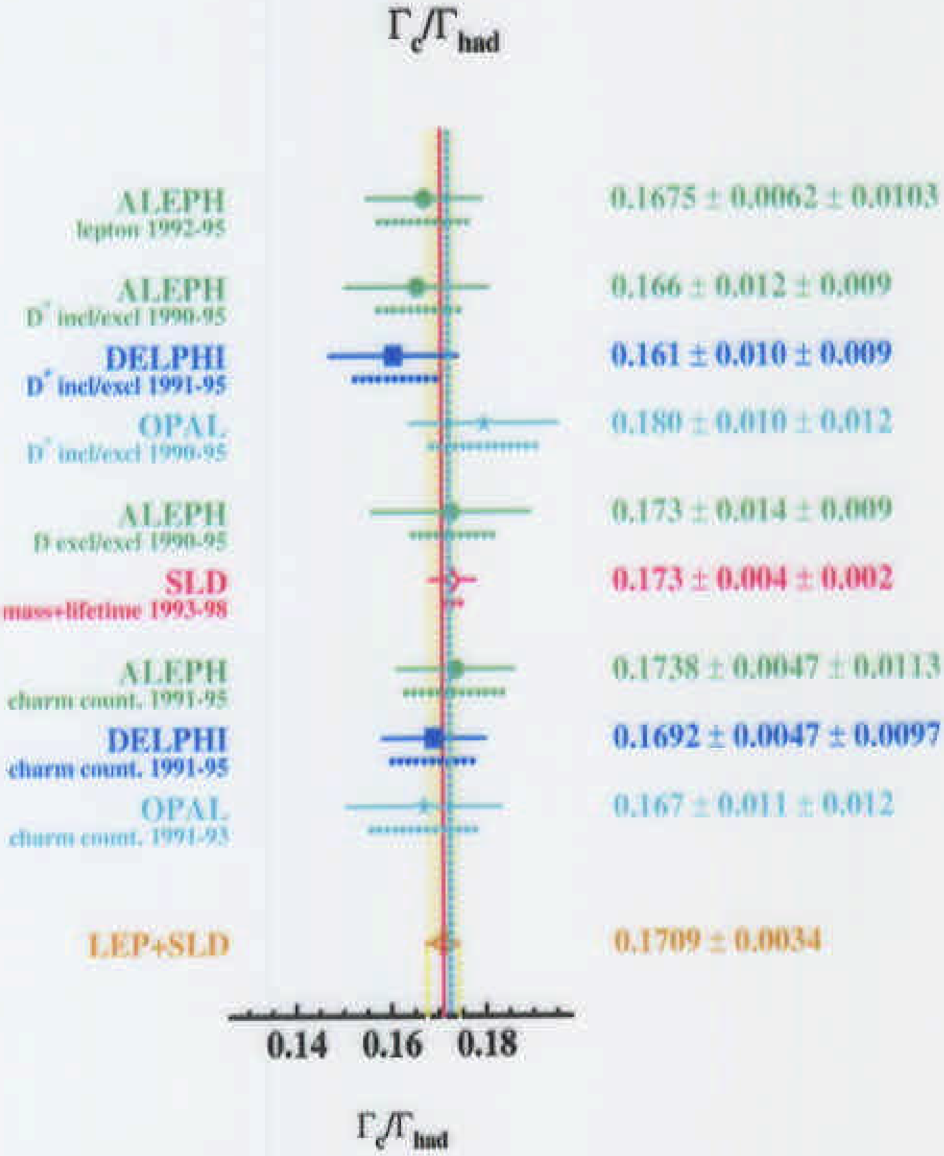
$\varepsilon_c = 17.4\%$

$\varepsilon_b = 2.6\%$

C-purity = 85%

$$R_c = 0.1732 \pm 0.0041 \pm 0.0025$$

R_c comparison



Conclusions

LEP + SLD

$R_b = 0.21651 \pm 0.00069$ ($\pm 0.32\%$)

$R_c = 0.1709 \pm 0.0034$ ($\pm 2\%$)

Good agreement with SM.

All LEP experiments published R_b measurements
Most LEP R_c measurements also published.
still a few possible future LEP updates:

1) ALEPH just made another improved data processing...
2) L3 had an improved b-tag never made to R_b measurement...
3) OPAL has a double tag R_c measurement to come...

SLD just presented new preliminary R_b, R_c from full data sample, with improved tracking & NN tag. Will try to finalize in next ½ year. The charm tag may have another major upgrade...

A great deal of knowledge gained from doing these high precision EW tests. The heavy flavor tagging developed has far reaching effects in other HF physics, QCD, top, Higgs programs...