Gluon splitting to $b\bar{b}$
&
B fragmentation function Measurement

OPAL detector @ LEP

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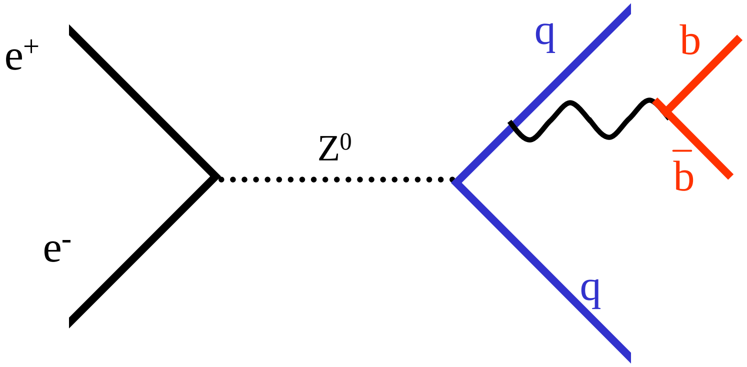
Outlines

- Introduction to gbb
- gbb at OPAL
- gbb at ALEPH, DELPHI, SLD
- b Fragmentation function at OPAL

Gluon splitting to $b\bar{b}$ AKA gbb



$$g_{b\bar{b}} = \frac{N(Z^0 \to q\bar{q}g \quad , \quad g \to bb)}{N(Z^0 \to hadrons)}$$

$$g_{4b} = \frac{N(Z^0 \to b\bar{b}g \quad , \quad g \to b\bar{b})}{N(Z^0 \to hadrons)}$$

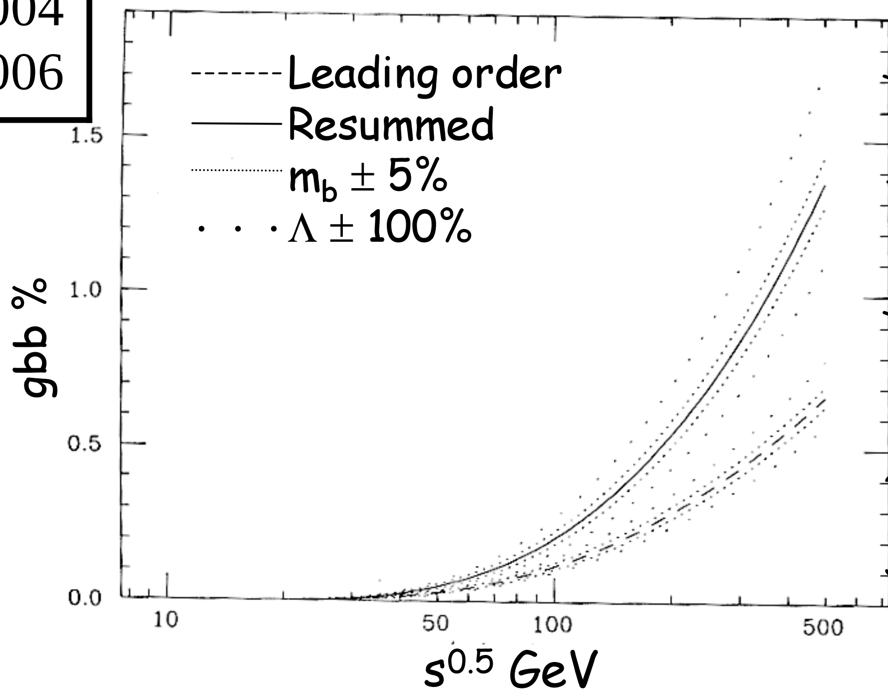
Theoretical predictions (gbb)

Theoratical Prediction	* 10^{-2}
Resummed + Leading Order	0.18
Leading Order	0.1
Herwig	0.227 ± 0.001
Jetset	0.160 ± 0.004
Ariadne	0.326 ± 0.006

$g_{cc}=1.05 - 2.55 \times 10^{-2}$

$Rb = 0.21680 \pm 0.00073$

$Rc = 0.1694 \pm 0.0038$



M.H.Seymour, NucPhys B 436 (1995) 163

Why (gbb) ? ? ? ?

- gbb larger at higher energies .
- QCD TEST - Sensitive to b quark mass and strong coupling constant.
- Main uncertainty source in Rb ($\Delta R_b(g_{QQ})$ ~ 0.00028) and in other EW measurements.

Recent analyses: gbb

ALEPH	CERN-EP-98-103
DELPHI	CERN-EP-99-081 CERN-PPE-97-39
OPAL	CERN-EP-2000-123
SLD	SLAC-PUB-8737 / hep-ex/0102002

Experimental signature

Four jets, two of jets (low-energy, close in phase space) with b decay products

Strategy

1. Select hadronic Z^0 decays

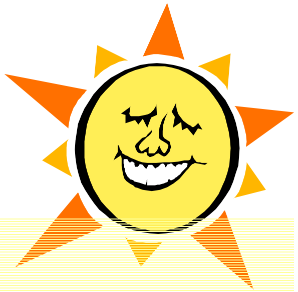
2. Look for 4 jet events

3. Choose two jets to have originated from gluon

4. b-tagging

gbb

4 jet events



- Gluon splitting to ccbar

- Two primary b quarks (bbxx)

- Other 4jet events (qqxx)
  - Double bremsstrulong
  - Triple gluon vertex

- gluon splitting to bbbar with primary !b quarks

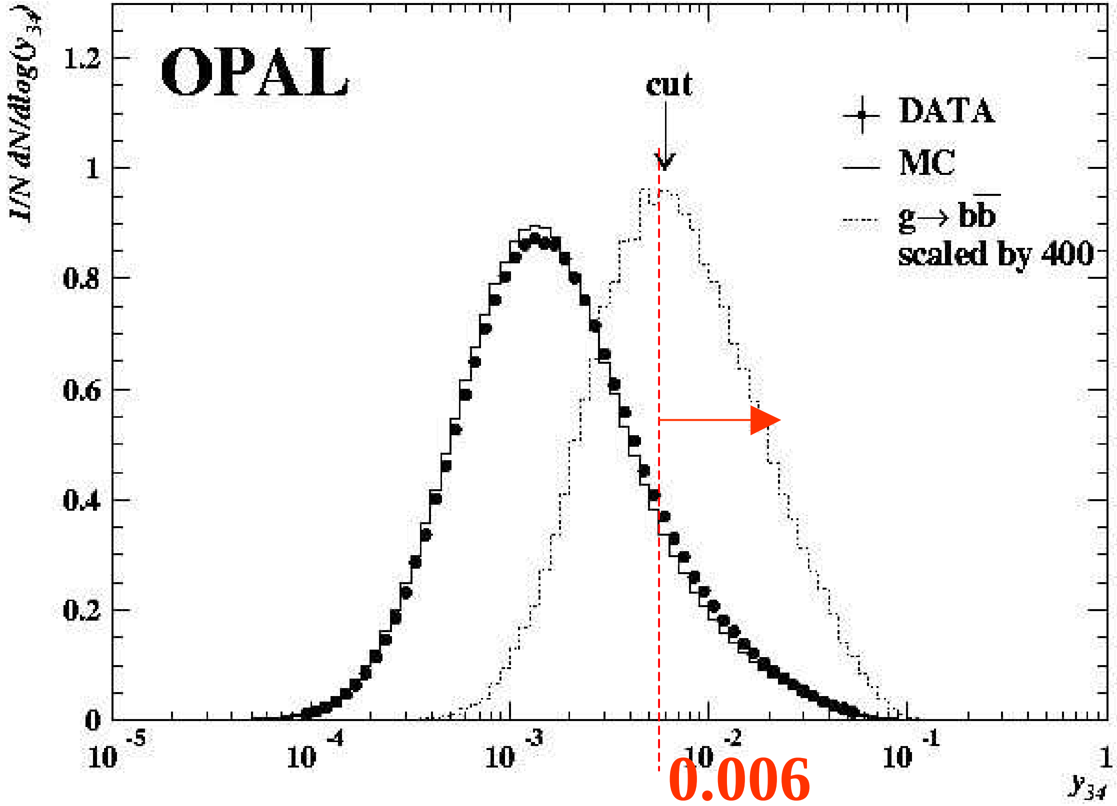
- gluon splitting to bbbar with primary b quarks

q=udsc
x=guds

gbb
OPAL

4 jet selection

3.35 M hadronic events



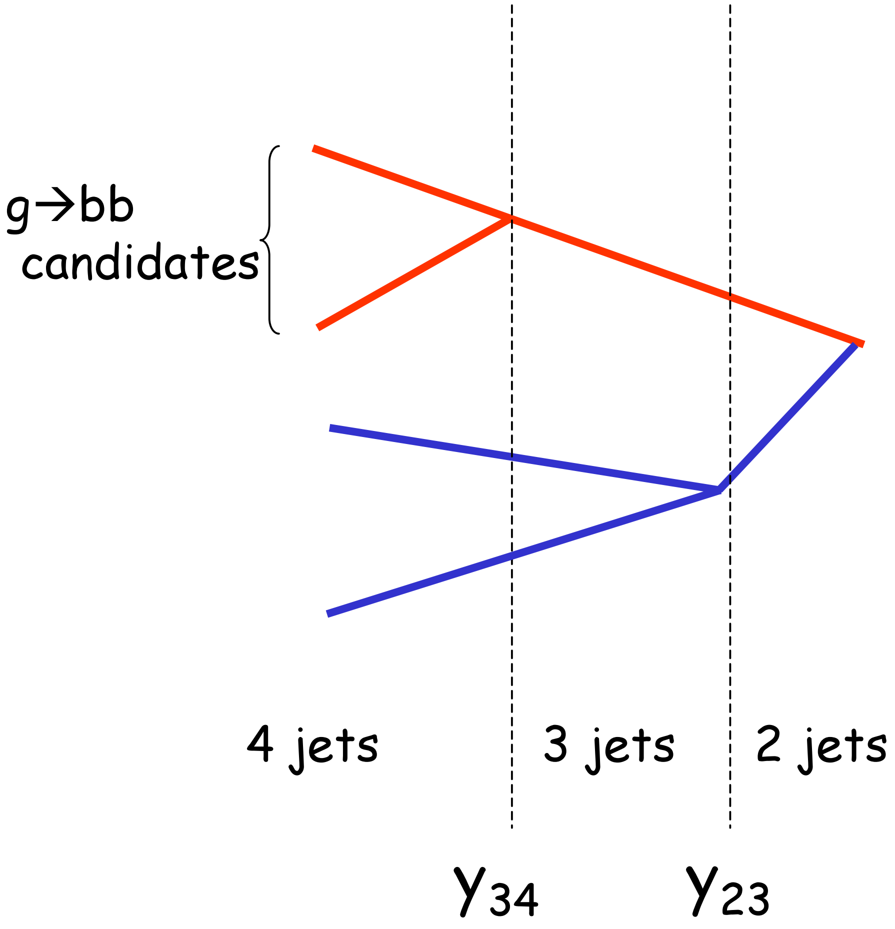
Durham algorithm($K_\perp$):

- Number of jets falls monotonically as y_{cut} is increased.
- When 4jet event turn to a 3jet event, two jets merge into one: **g→bb candidate.**

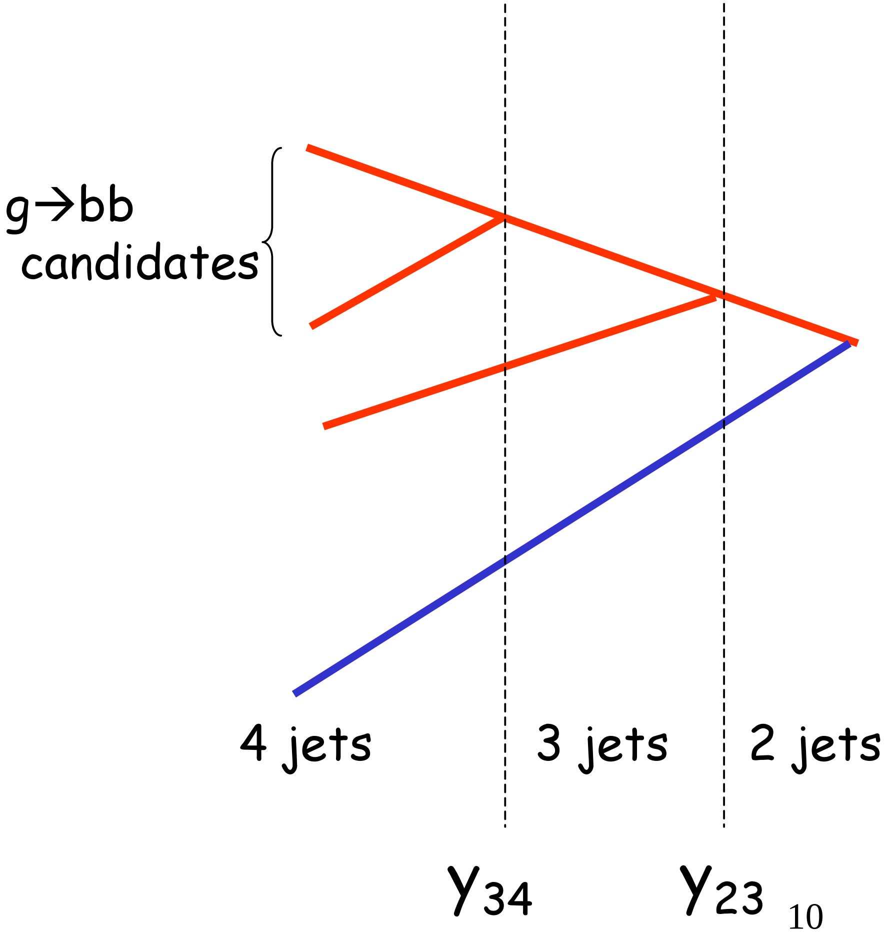
Y_{34} - value of y_{cut} at which an event makes a transition between a 3jet and a 4jet assignment.

Event classes

Class "2+2"



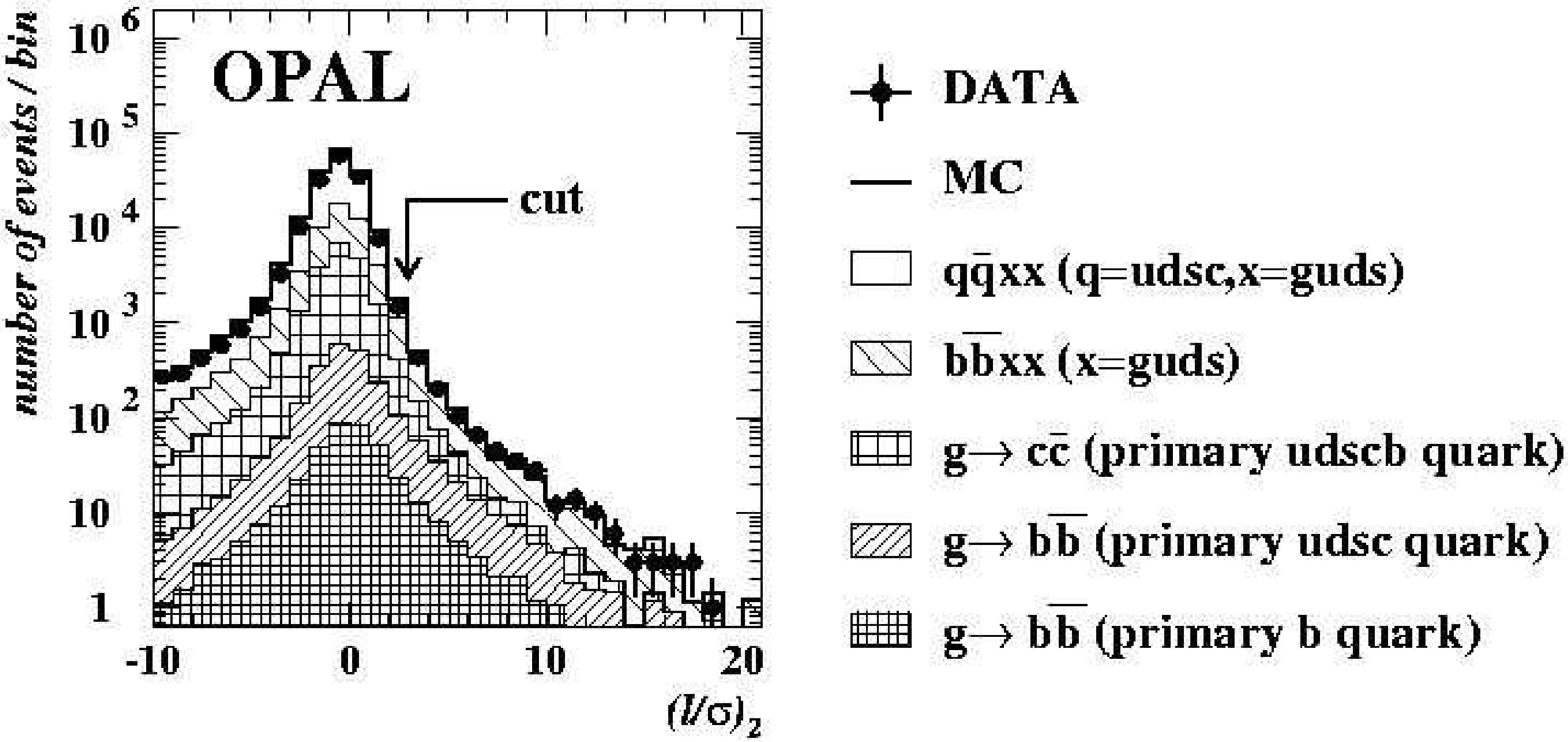
Class "3+1"



B-tagging

decay length significance + ANN

both g→ bb jets must have l/σ > 3.



gbb
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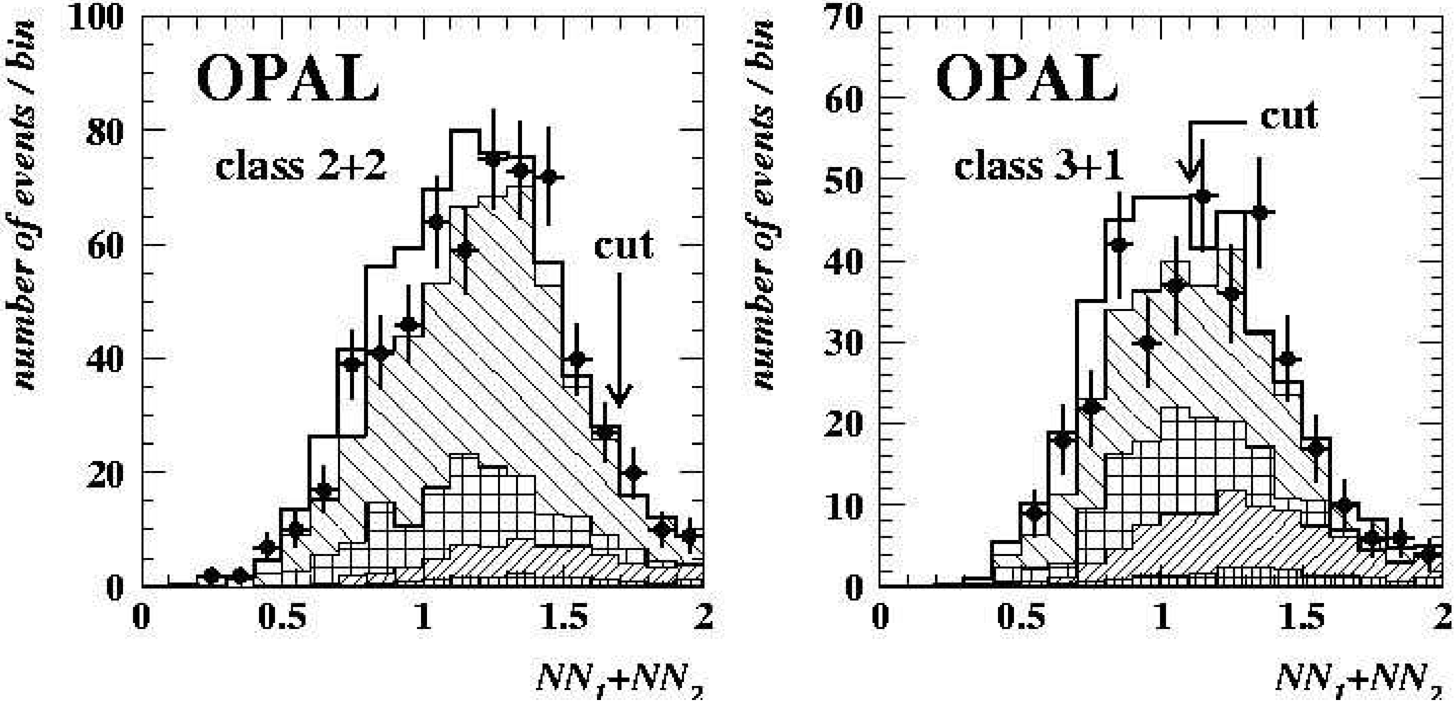
Further B-tagging

ANN

Five inputs:

- Decay length significance
- Decay length
- Number of tracks in secondary vertex
- Reduced decay length
- X_D



gbb
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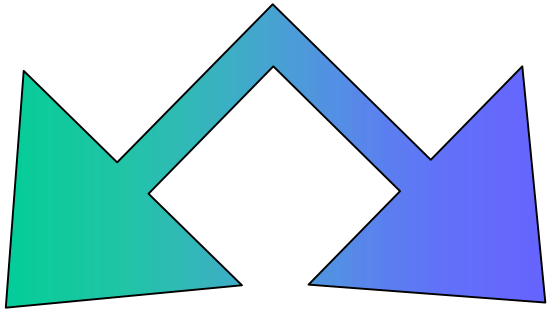
bbbb



Following previous cuts…

Look for secondary vertex in
of the “not gluon” jets.

at least one

dedicated

Start again with 4jet….
Look for good :

at least three

- Secondary vertices
- NN

Exclude previously selected events

gbb
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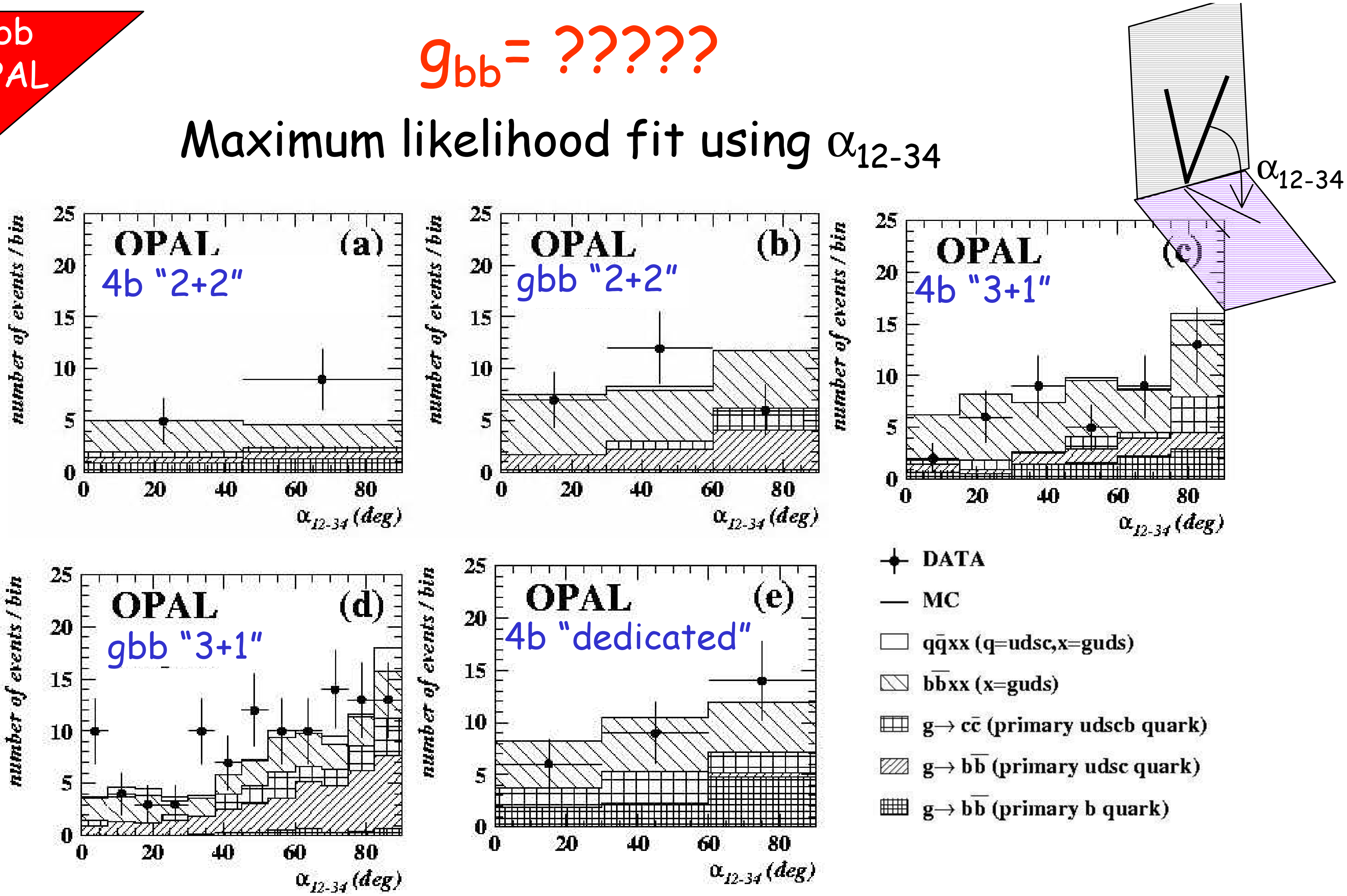
g_{bb}= ?????

Maximum likelihood fit using $\alpha_{12\text{-}34}$

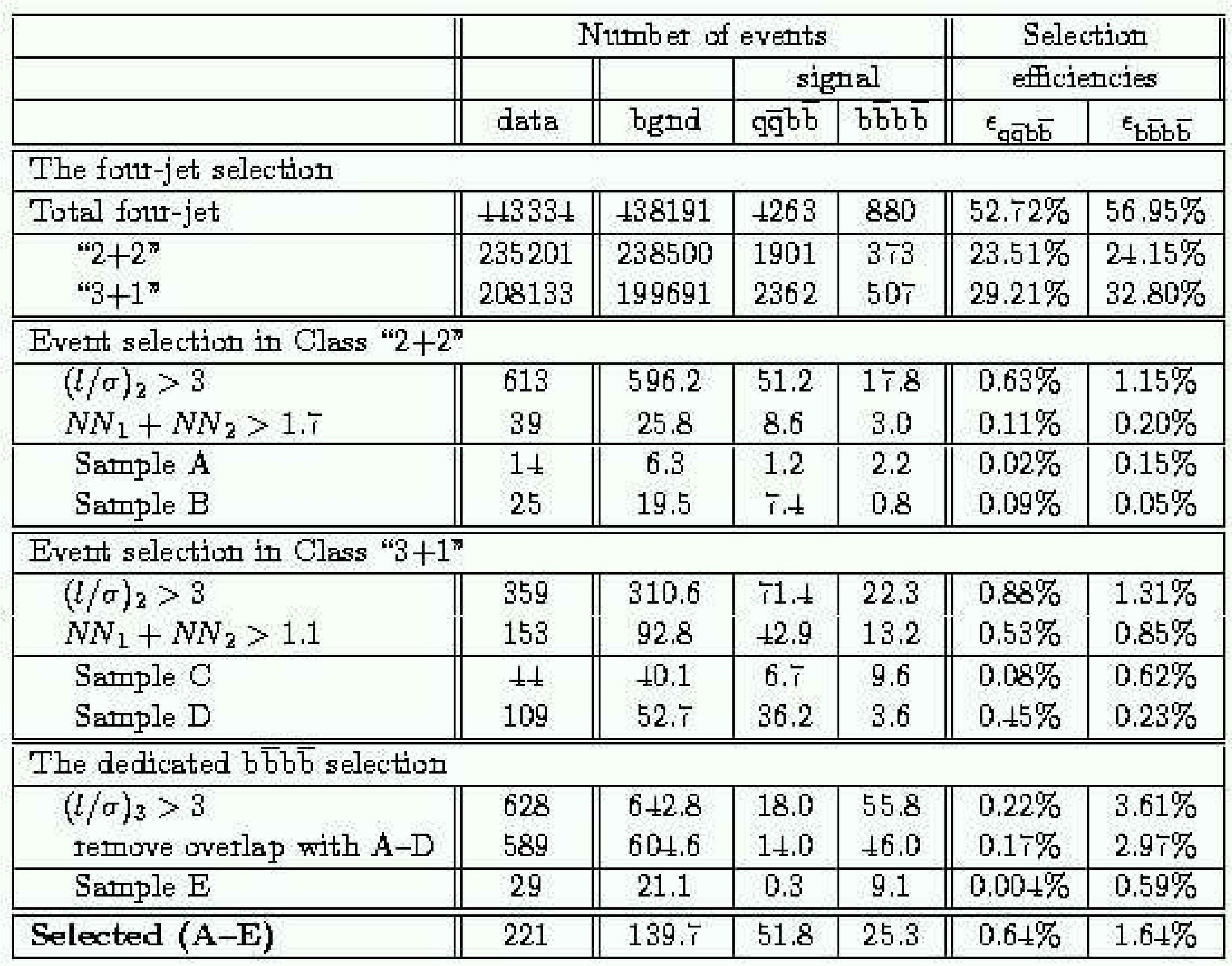


a,c). btag in 'other' 2 jets

b,d). no btag in 'other' 2 jets

gbb
OPAL

Events selected - step by step

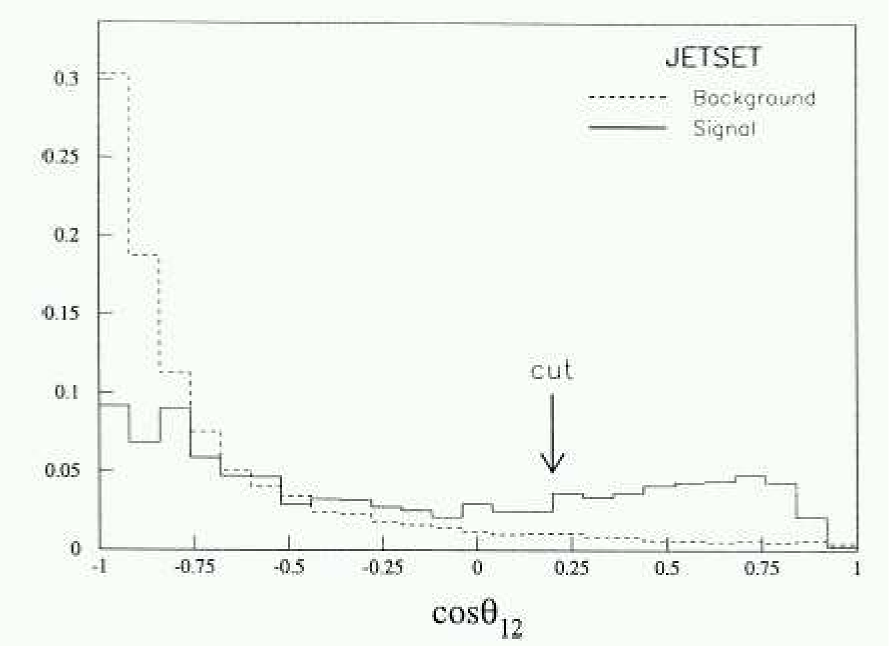


	Number of events				Selection	
			signal		efficiencies	
	data	bgnd	$q\bar{q}b\bar{b}$	$b\bar{b}b\bar{b}$	$\epsilon_{q\bar{q}b\bar{b}}$	$\epsilon_{b\bar{b}b\bar{b}}$
The four-jet selection						
Total four-jet	443334	438191	4263	880	52.72%	56.95%
"2+2"	235201	238500	1901	373	23.51%	24.15%
"3+1"	208133	199691	2362	507	29.21%	32.80%
Event selection in Class "2+2"						
$(\ell/\sigma)_2 > 3$	613	596.2	51.2	17.8	0.63%	1.15%
$NN_1 + NN_2 > 1.7$	39	25.8	8.6	3.0	0.11%	0.20%
Sample A	14	6.3	1.2	2.2	0.02%	0.15%
Sample B	25	19.5	7.4	0.8	0.09%	0.05%
Event selection in Class "3+1"						
$(\ell/\sigma)_2 > 3$	359	310.6	71.4	22.3	0.88%	1.31%
$NN_1 + NN_2 > 1.1$	153	92.8	42.9	13.2	0.53%	0.85%
Sample C	44	40.1	6.7	9.6	0.08%	0.62%
Sample D	109	52.7	36.2	3.6	0.45%	0.23%
The dedicated $b\bar{b}b\bar{b}$ selection						
$(\ell/\sigma)_3 > 3$	628	642.8	18.0	55.8	0.22%	3.61%
remove overlap with A–D	589	604.6	14.0	46.0	0.17%	2.97%
Sample E	29	21.1	0.3	9.1	0.004%	0.59%
Selected (A–E)	221	139.7	51.8	25.3	0.64%	1.64%

Aleph's gbb

3.7 M hadronic events

- choose 4 jet events (Durham Ycut=0.006)
- Pick two jets with smallest likelihood to have originated from the primary vertex.
- Use angular separation and jet momentum to reject z➔bb



222 events

$\varepsilon_{gbb}=0.958\pm0.055\%$

$\varepsilon_{gcc}=0.0029\pm0.0002\%$

$\varepsilon_{other}=0.023\pm0.003\%$

$$gbb=\frac{f_d-(1-g_{cc})\varepsilon_{other}-g_{cc}\varepsilon_{gcc}}{\varepsilon_{gbb}-\varepsilon_{other}}$$

$2.77 \pm 0.42 \pm 0.57 \times 10^{-3}$

gbb
Delphi

Delphi's gbb (i)

1.4 M hadronic events

- Select 4 jet event (Durham Y_{cut}=0.017)
- Choose 2 jets with smallest angle between them as gluon candidates.
- use impact parameter to calculate probability for a jet to containe only tracks coming from the primary vertex.
- reject events where selected jets are the most energetic ones.
- rapidity, α_{12-34}

22 events selected
10.9 ± 1.4 background
2.0 ± 0.9 gcc

$2.1 \pm 1.1 \pm 0.9 \times 10^{-3}$

gbb
Delphi

Delphi's gbb (ii) (based on 4b)

- Force events to 3 jets (Durham Ycut>0.006) 2.0 M hadronic events
- btag in all 3 jets (Decay length sig., jet mass, rapidity and more)
- calculate g_{4b}

140 events
$\varepsilon_{4b}=3.16\pm0.11\%$
$\varepsilon_{bbcc}=0.321\pm0.023\%$
$\varepsilon_{bb}=0.0164\pm0.0006\%$
$\varepsilon_{other}=0.00002\pm0.00002\%$

$$g_{4b}=\frac{f_d-\varepsilon_{other}-R_b\left[g_{cc}\left(\varepsilon_{bbcc}-\varepsilon_{bb}\right)+\varepsilon_{bb}\varepsilon_{other}\right]}{\varepsilon_{4b}-\varepsilon_{bb}}$$

$=6.0\pm1.9\pm1.4\ \mathrm{x}10^{-4}$

- Extract gbb

gbb= $R_{4b} \times R_{th}$

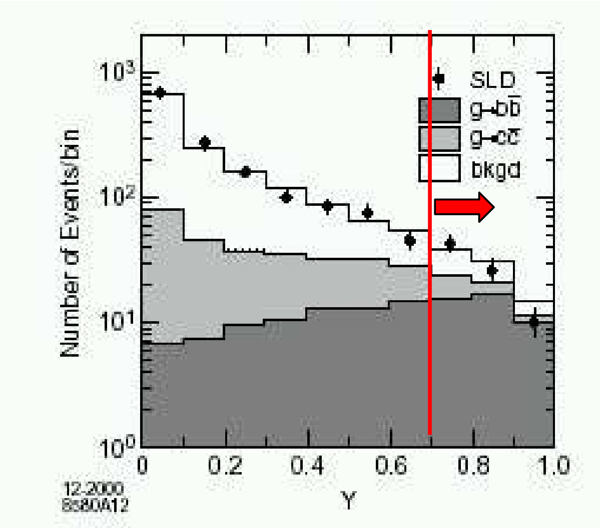
$$R_{th}=\frac{Br(Z\rightarrow qqg, g\rightarrow bb)}{Br(Z\rightarrow bbg, g\rightarrow bb)}=5.457\pm0.008$$

gbb
SLD

SLD's gbb

0.4 M hadronic events

- choose 4 jet events (Durham Ycut=0.005)
- Pick two jets closest in angle.
- Btag those jets: Decay length
- ANN (α_{12-34}, jet energy, $M_{PT} = \sqrt{M_{Vtx}^2 + P_T^2} + |P_T|$ ...)



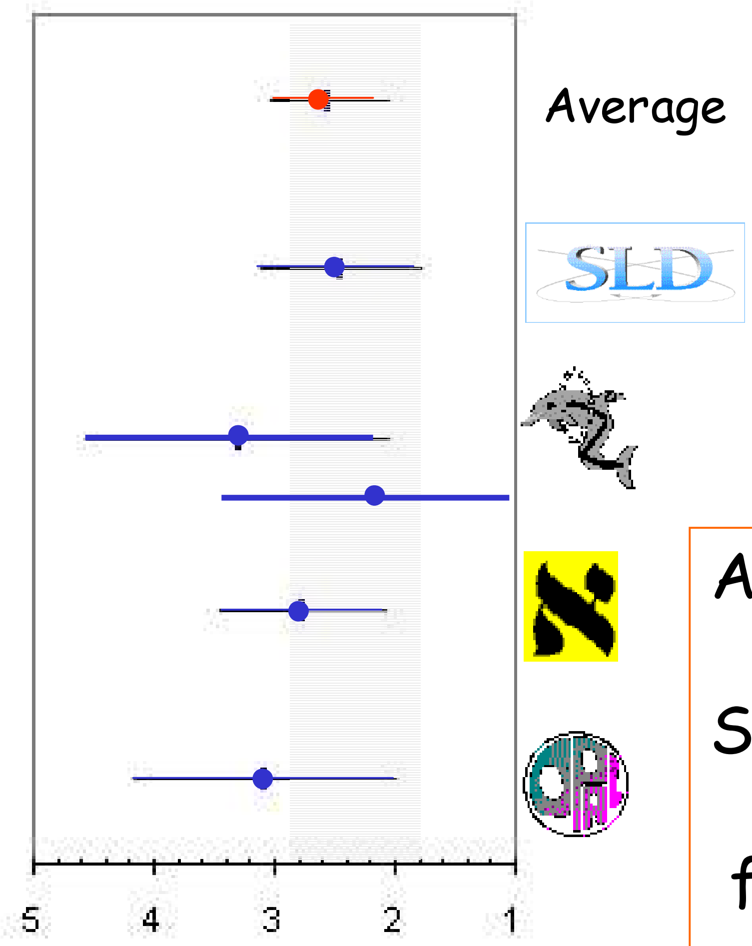
79 events

ε_{gbb}=5.28 ±0.09%
ε_{gcc}=0.165 ±0.018%
ε_{other}=0.00967 ±0.00038%

2.44 ±0.59 ±0.34 x10^{-3}

$$gbb = \frac{f_d - (1 - g_{cc})\varepsilon_{other} - g_{cc}\varepsilon_{gcc}}{\varepsilon_{gbb} - \varepsilon_{other}}$$

Results gbb



SLD		2.44 ±0.59 ±0.34
Delphi	i	2.10 ±1.10 ±0.9
	ii	3.30 ±1.00 ±0.8
Aleph		2.77 ±0.42 ±0.57
OPAL		3.07±0.53 ±0.97
Average		2.54 ± 0.51

$\times 10^{-3}$

Aleph, OPAL – largest data sample

Systematics – g_{bb} Modeling.
MC statistics

for delphi ii –g_{cc}
MC statistics

Results 4b

OPAL 3.6±1.7 ±2
Delphi 6 ±1.9 ±1.4

Delphi : $$\frac{g_{4b}}{g_{bb}} = 0.1833 \pm 0.0003$$ (calculated)

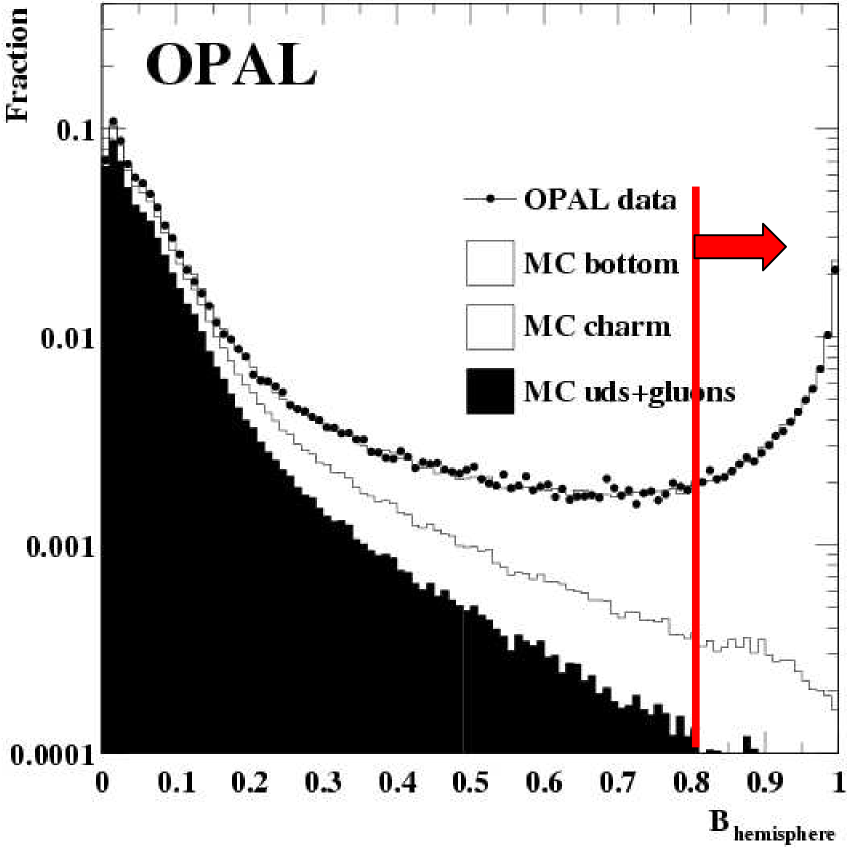
OPAL : $$\frac{g_{4b}}{g_{bb}} = 0.116 \pm 0.088$$ (measured)

Rb : 0.21680 ± 0.00073

Frag
OPAL

Fragmentation function at OPAL
B tagging

- Jet btagging: Lifetime, Lepton's pt, jet shape
- Opposite hemisphere tag.
- Secondary vertex requirment



ε=16%
p=96%

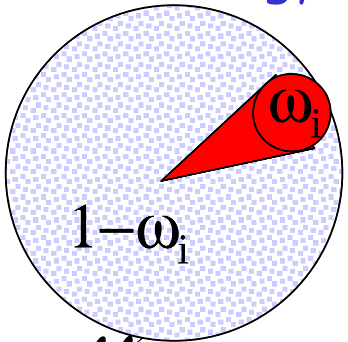
Fragmentation function at OPAL
Inclusive B hadron reconstruction

- ANN weight to each track/cluster

Probability the track/cluster i

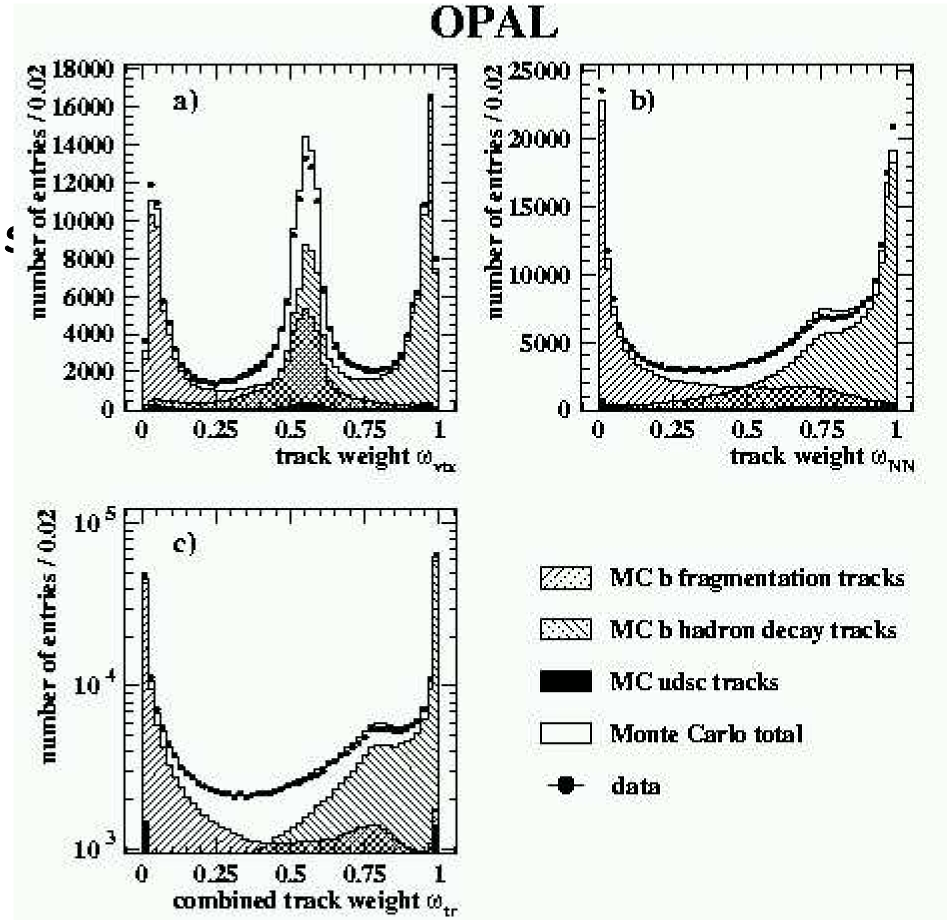
a B decay product.

Track momentum, impact parameters cluster Energy….



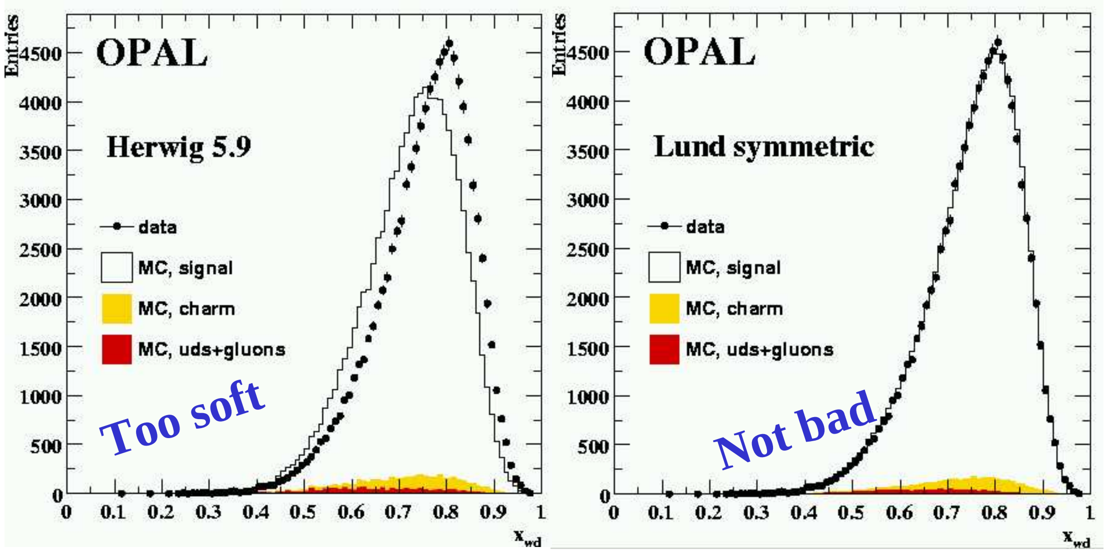
$$E_B = \frac{E_{cm}^2 - M_{recoil}^2 + M_B^2}{2E_{cm}}$$

$$M_{recoil}^{new} = M_{recoil}^{old} \frac{E_{cm} - E_B}{E_{recoil}}$$



Frag
OPAL

Fragmentation function at OPAL
Hadronisation models

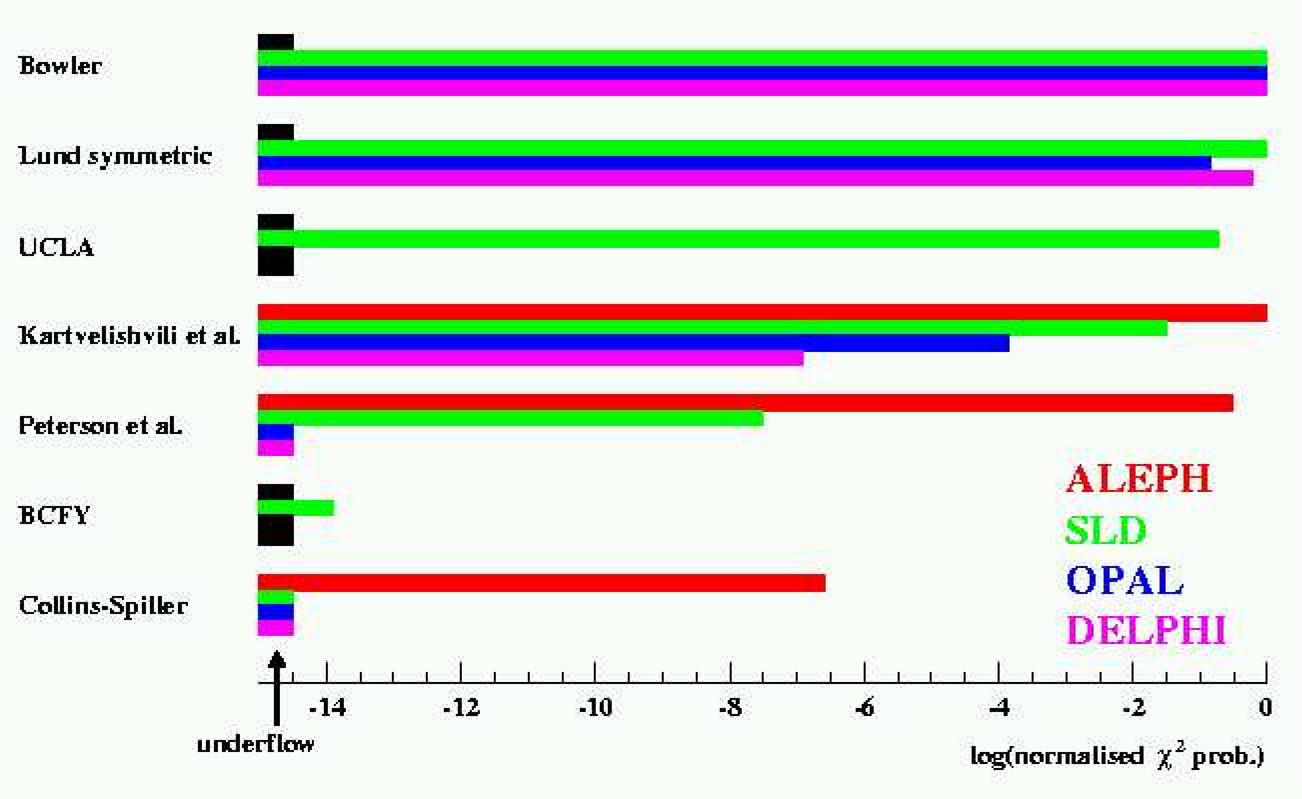


Comparing the reconstructed scaled energy of weakly decaying B hadron distributions predicted by different models to data.

model	parameters	$\langle x_E \rangle$	χ^2/d.o.f.
Bowler [26]	$bm_\perp^2 = 65.1^{+4.8}_{-3.5}{}^{+16.6}_{-13.9}$ $a = 0.80^{+0.08}_{-0.06}{}^{+0.20}_{-0.21}$	$0.7207^{+0.0008}_{-0.0007}{}^{+0.0028}_{-0.0029}$	67/44
Lund symmetric [27]	$bm_\perp^2 = 15.0^{+1.0}_{-0.7} \pm 2.1$ $a = 1.59^{+0.13}_{-0.10} \pm 0.27$	$0.7200^{+0.0009}_{-0.0008}{}^{+0.0028}_{-0.0030}$	75/44
Kartvelishvili et al. [25]	$\alpha_b = 11.9 \pm 0.1 \pm 0.5$	$0.7151 \pm 0.0006\ {}^{+0.0020}_{-0.0023}$	99/45
Peterson et al. [28]	$\varepsilon_b = (41.2 \pm 0.7\ {}^{+3.6}_{-3.5}) \times 10^{-4}$	$0.7023 \pm 0.0006 \pm 0.0019$	159/45
Collins-Spiller [29]	$\varepsilon_b = (22.3^{+0.7}_{-0.6}{}^{+3.5}_{-4.9}) \times 10^{-4}$	$0.6870 \pm 0.0006\ {}^{+0.0035}_{-0.0019}$	407/45
HERWIG 6.2	cldir=1, clsmr(2)=0	0.7074	540/46
HERWIG 5.9	cldir=1, clsmr=0.35	0.6546	4279/46

Model tests: normalized $\chi 2$/d.o.f probabilities

Plot by: Kristian Harder

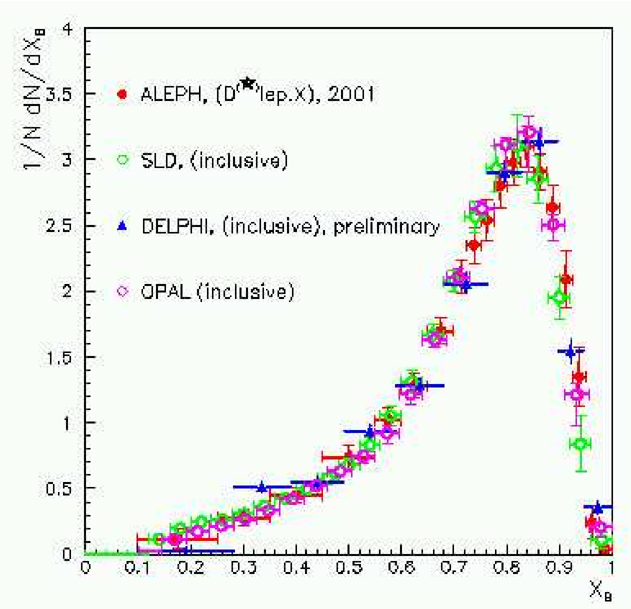


Frag
OPAL

Fragmentation function at OPAL
Model independent measurement

Unfolding the observed energy distribution:
Reweighting true and observed MC till observed distribution agrees in data and MC.

$$< X_E >= 0.7193 \pm 0.0016^{+0.0038}_{-0.0033}$$



G. Barker, E. Ben-Haim et al.