A study of the b-fragmentation function in $t\bar{t}$-production with the ATLAS experiment at the LHC

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Introduction

Our current understanding of QCD is based on the factorization theorem

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\mathcal{O}} = \sum_{i,j} \int_0^1 \mathrm{d}x_i \, \mathrm{d}x_j \sum_f \int \mathrm{d}\Phi_f \, f_{i/h_1}(x_i, \mu_F^2) f_{j/h_2}(x_j, \mu_F^2) \frac{\mathrm{d}\hat{\sigma}_{ij \to f}}{\mathrm{d}\hat{\mathcal{O}}} D_f(\hat{\mathcal{O}} \to \mathcal{O}, \mu_F^2)$$

In the String (Lund) Model used in Pythia, the fragmentation function is given by (up to a normalization constant)

$$f_B(z) \propto \frac{1}{z}(1-z)^a e^{-bm_T^2/z}$$

The Bowler modification introduces an additional parameter, rb, which acts as an effective mass for the quark

$$f_B(z) \propto \frac{1}{z^{1+br_b m_q^2}}(1-z)^a e^{-bm_T^2/z}$$

The observables considered which are sensitive to the b-fragmentation function are

$$x_B = 2\frac{p_b . Q}{Q^2}$$

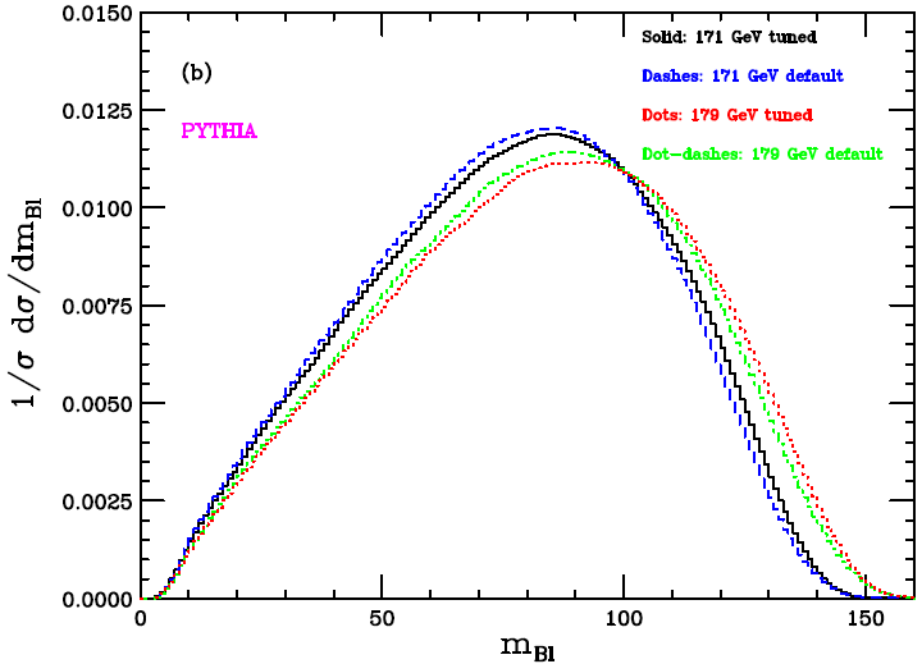
Where p_b is the 4-momentum of the B-hadron and Q is the 4-momentum of the Z boson, in e+e- -> Z -> b-bbar production at LEP.

The b-jet shapes in ttbar production measured by ATLAS.

$$\rho(r) = \frac{1}{\Delta r}\frac{p_{\mathrm{T}}(r-\Delta r/2, r+\Delta r/2)}{p_{\mathrm{T}}(0,R)}$$

Which is the fraction of transverse energy contained in an annulus of the jet divided by the total energy.

The incomplete knowledge of the b-fragmentation function is an important contributor to the uncertainty in top mass measurements from final states in B-hadron production



B-lepton invariant mass distribution in top decay according to Pythia6, using default and tuned versions for m_t = 171 GeV and 179 GeV (Taken from arxiv:1008.4498)

Three Pythia 8 tunes are considered.

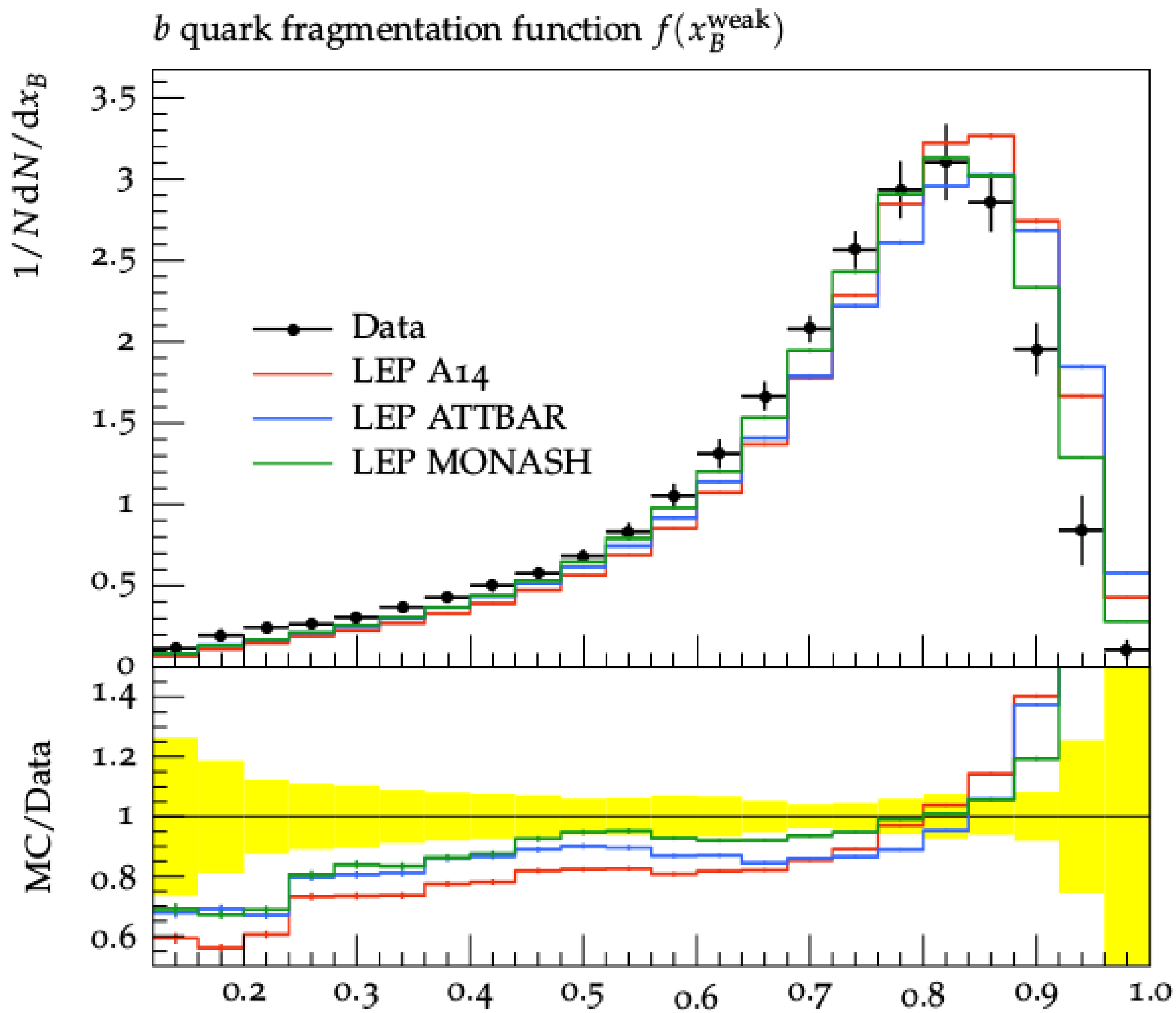
MONASH: The default Pythia 8 settings, the fragmentation functions are tuned to LEP data.

A14: Uses MONASH as baseline and retunes ISR, MPI and FSR to ATLAS data.

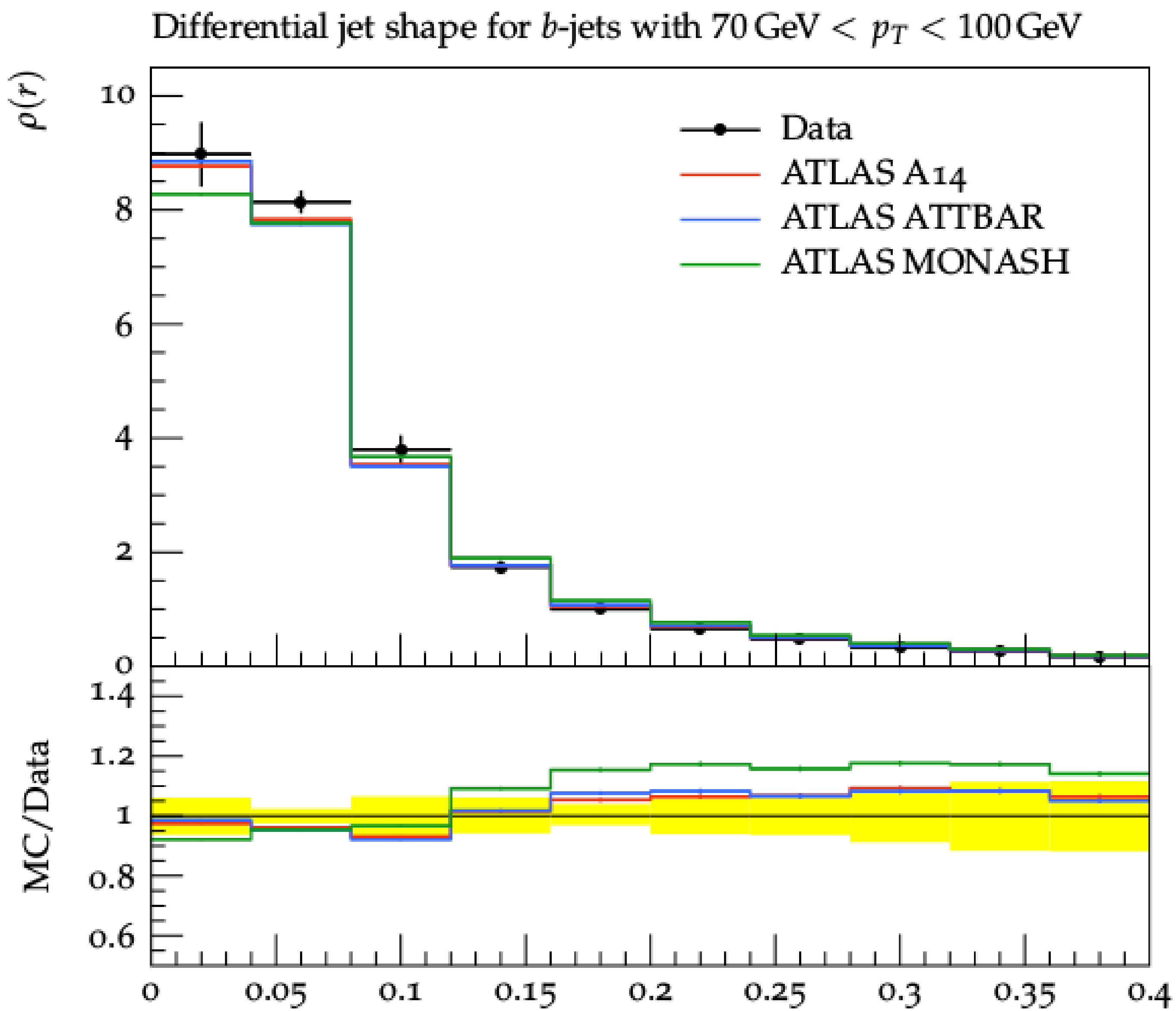
ATTBAR: Uses MONASH as baseline and retunes ISR and FSR to ATLAS top-antitop data. This tune is used as baseline for the extraction of rB.

The main difference between the three tunes lies in the value of $\alpha_s^{FSR}(m_Z)$, which is 0.1365 for MONASH, 0.127 for A14 and 0.1374 for ATTBAR.

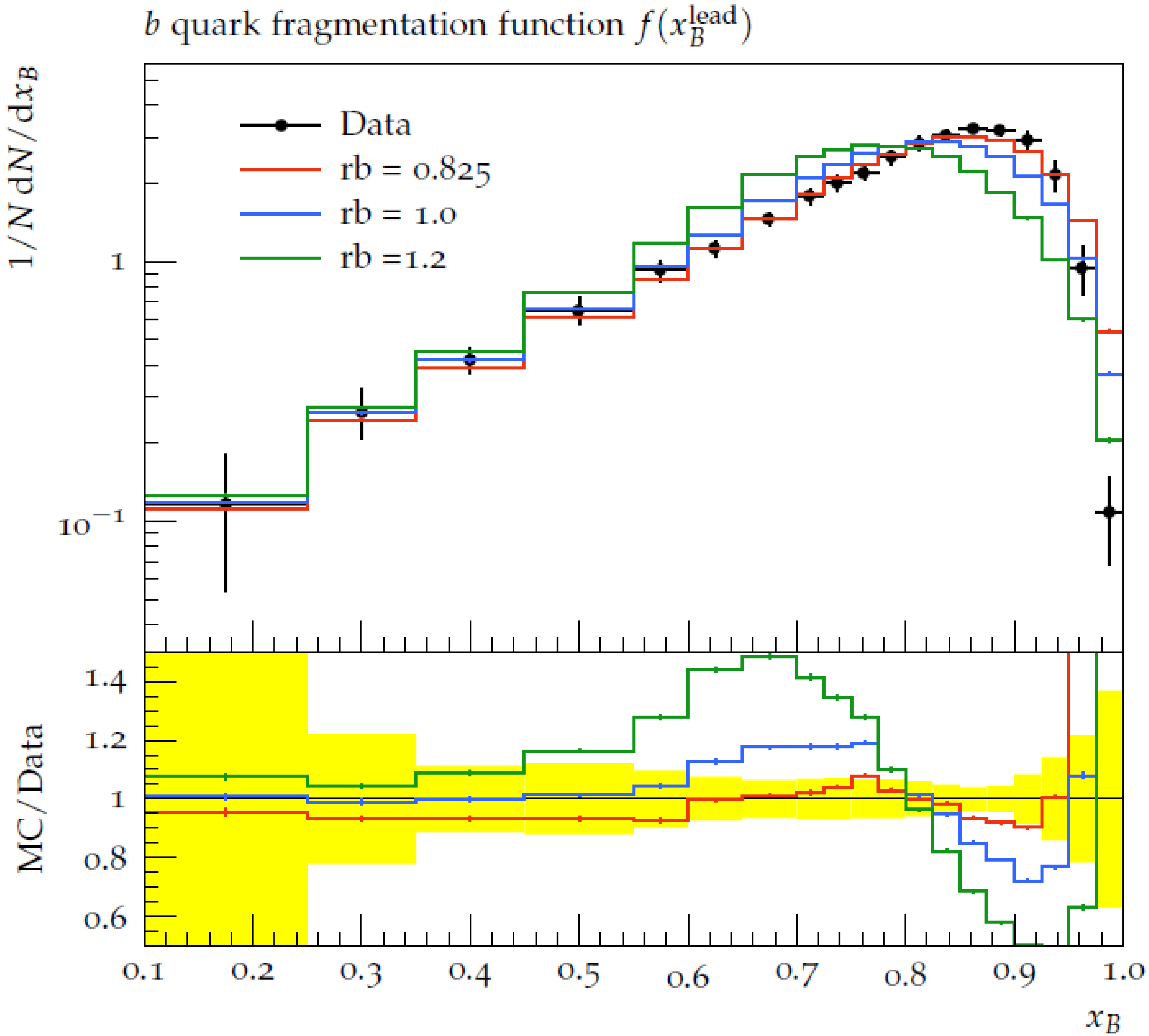
Comparison of the three tunes for LEP (SLD)



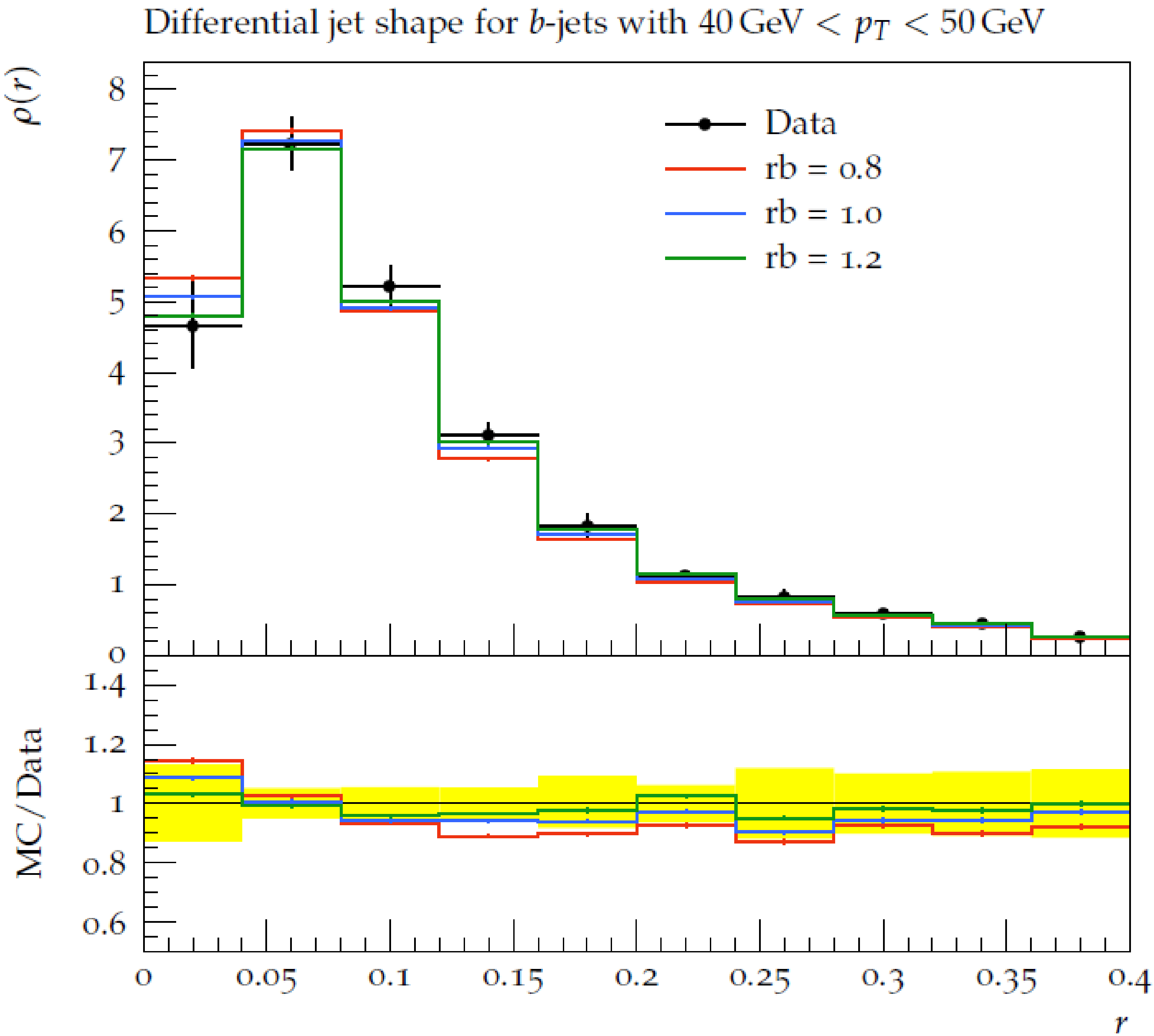
Comparison of the three tunes for ATLAS



The following plot shows sensitivity to variations of r_B in ATTBAR for LEP (ALEPH)



The following plot shows sensitivity to variations of r_B in ATTBAR for ATLAS



Methodology

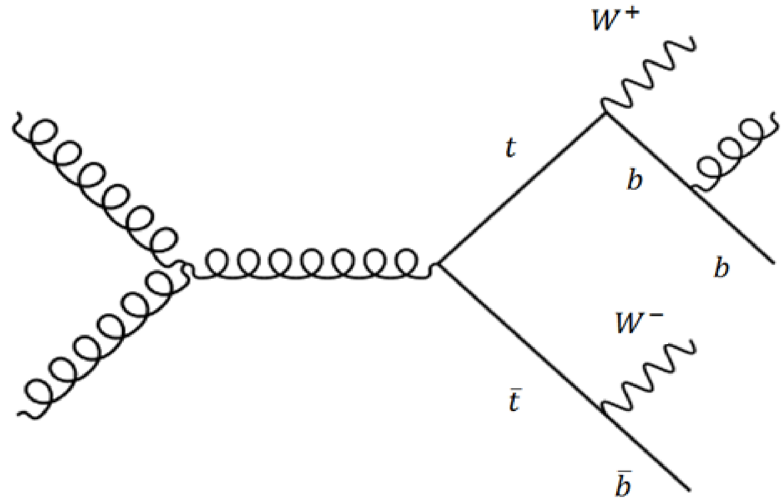
Used the following RIVET routines:

- $t\bar{t}$ b-jet shapes
  - ATLAS_2013_I1243871

- LEP b-fragmentation function
  - ALEPH_2001_S4656318
  - SLD_2002_S4869273
  - DELPHI_2002_069_CONF_603

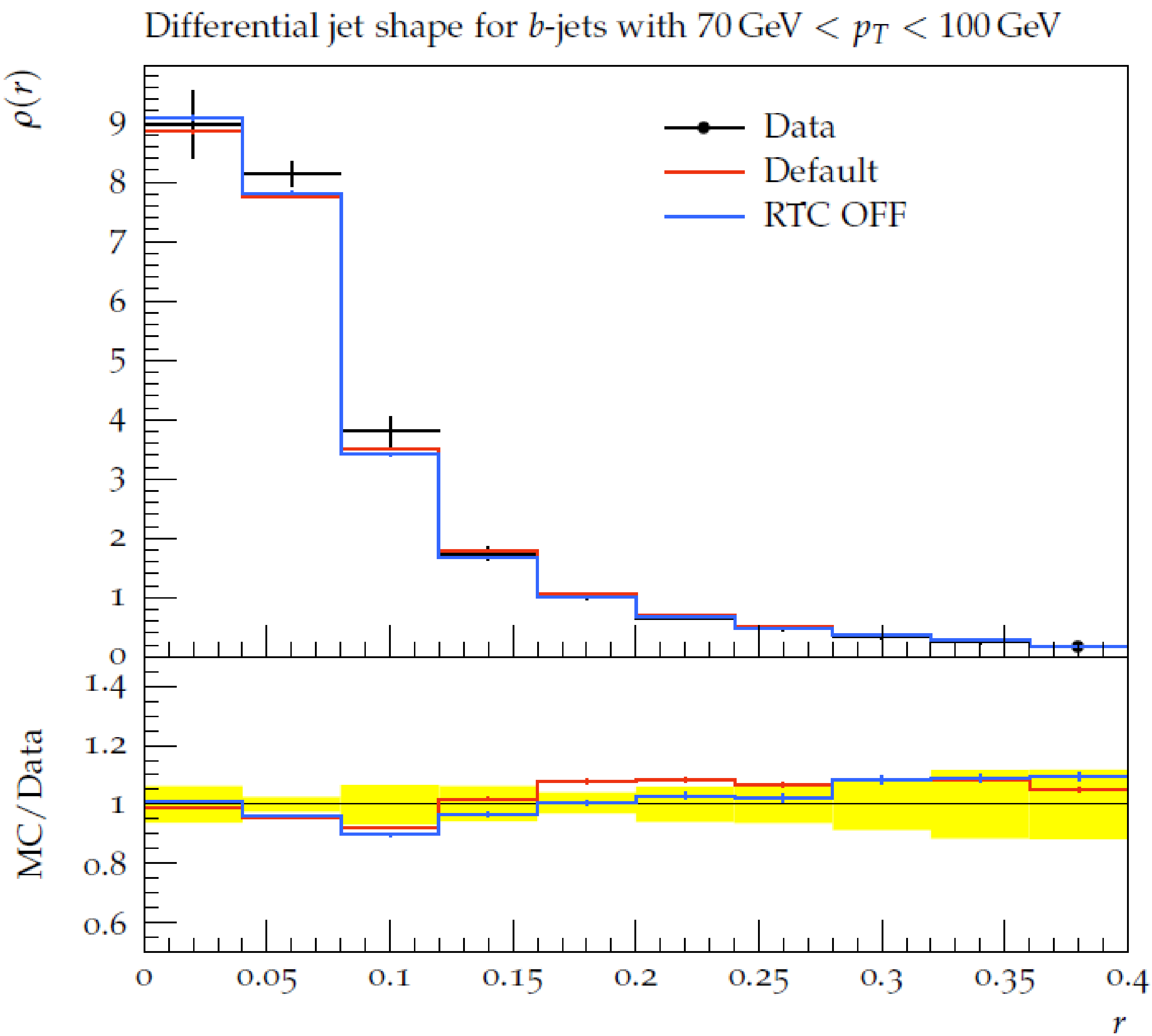
The last numbers in the analysis correspond to the Inspire Record. Pythia8.219 was used to generate predictions for several values of r_B. The ATTBAR tune is used as a baseline. The default value of r_B is 0.855.

Top quarks decay almost exclusively into b quark and W.



B-jet shapes depend on the details of the FSR recoil strategy, which can be modified with a switch available in Pythia: RecoilToColoured (*on* by default).

In the decays of coloured resonances, it is not possible to set up dipoles with matched colours. Originally the b radiator therefore has W as recoiler, and that choice is unique. Once a gluon has been radiated, however, it is possible either to have the unmatched colour (inherited by the gluon) still recoiling against the W (off), or else let it recoil against the b also for this dipole (on)



With RecoilToColoured off the agreement improves at high pt and high r

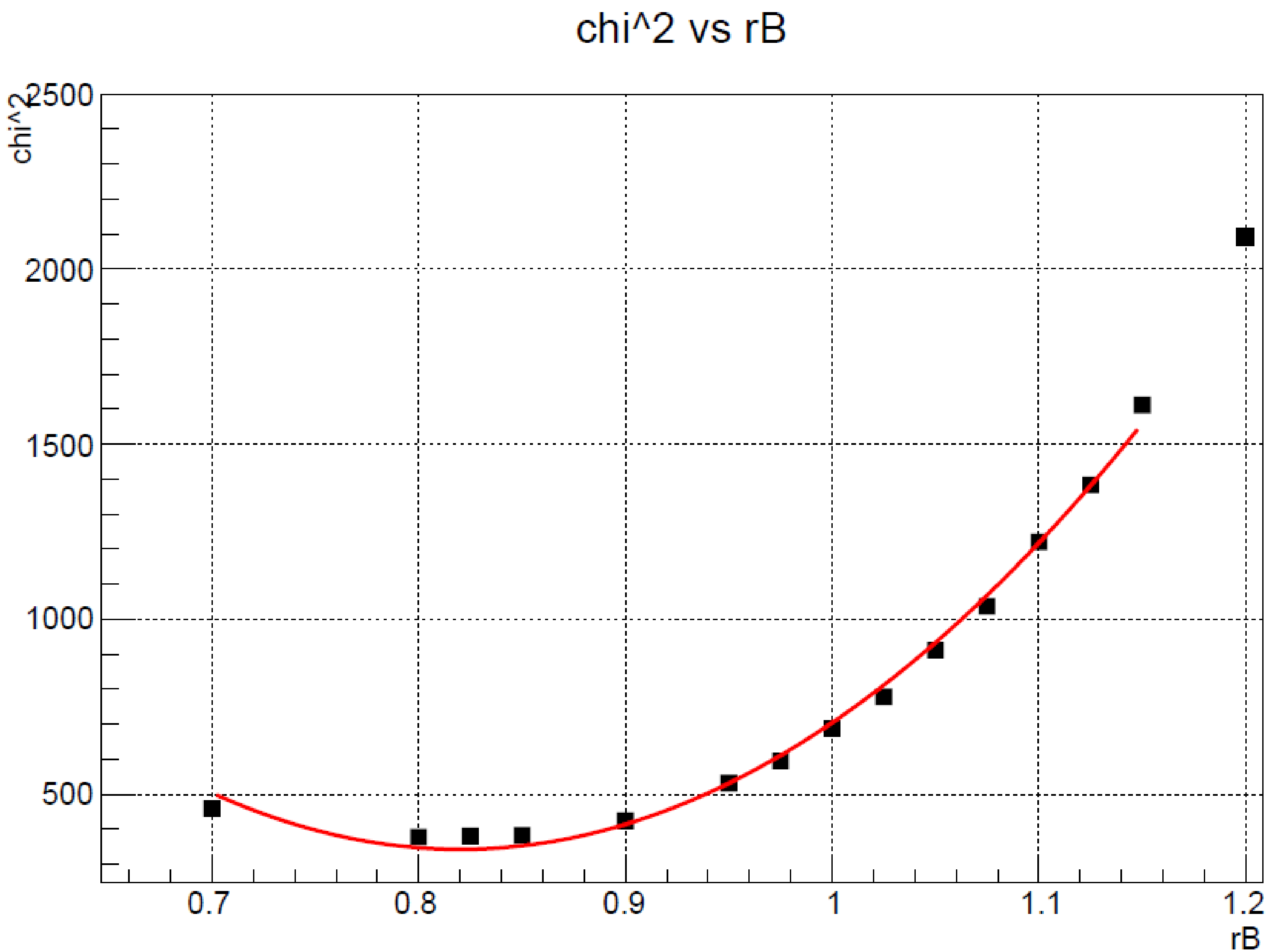
For the uncertainty in the value of r_B, several runs were made and the plots of χ^2 vs. r_B were interpolated with a parabola near the minimum.

The following formula for χ^2 was taken for the calculation of the uncertainty (Here, the Δ are taken as fully uncorrelated)

$$\chi^2 = \sum_i \frac{(\mu_i - n_i)^2}{{\Delta_i}^2}$$

Finally, the points where $\chi^2_{min} + 1$ cuts the parabola were taken as the uncertainty in r_B

The following plot corresponds to the fit of the averages of the LEP measurements near the minimum value of r_B



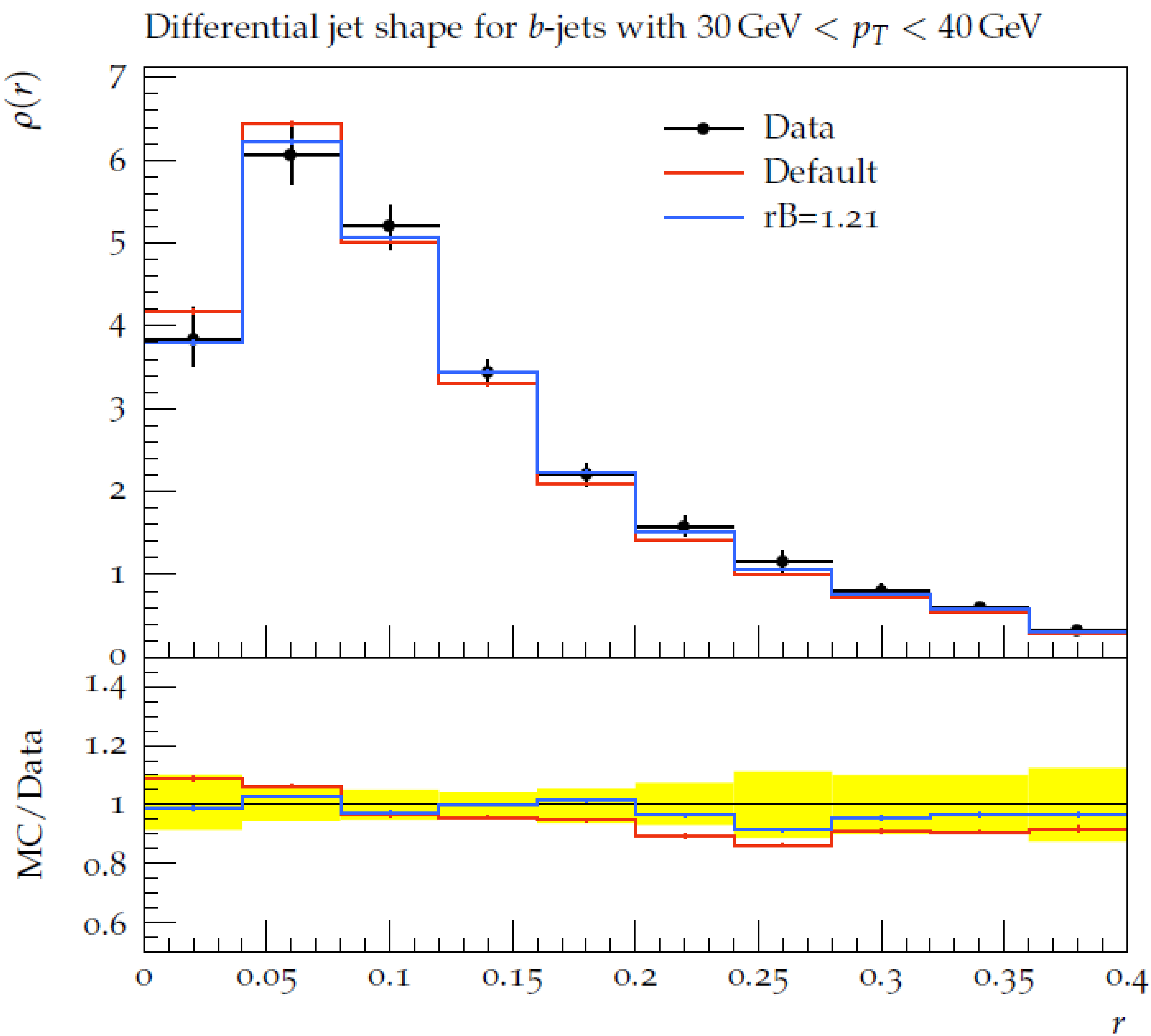
rb extracted from the ATLAS t-tbar b-jet shapes

Pt jet [GeV]	rb	delta rb	X^2/dof
30 – 40	1,3	0,1	2/9
40 – 50	1,3	0,1	1/9
50 – 70	1,3	0,1	1/9
70 – 100	1,1	0,1	4/9
100 – 150	1,2	0,4	4/9
COMBINATION	1,25	0,06	13/49
COMBINATION (NO RTC)	1,04	0,08	37/49

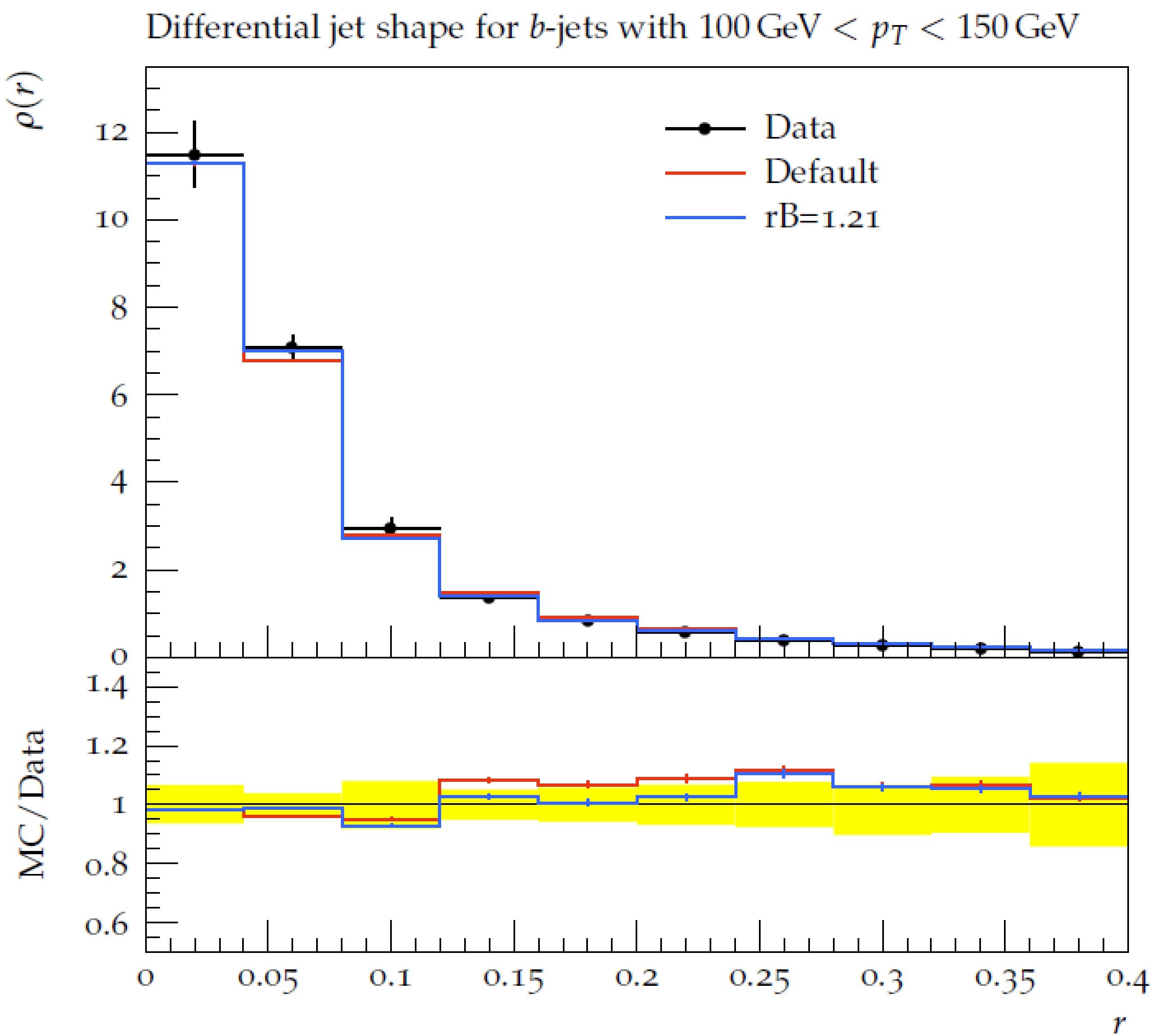
The various pt-jet bins yield compatible results

ATLAS ATTBAR, low p_T $r_B = 1.21 \pm 0.08$ $\chi^2/\text{dof} = 13/49$

Average for ATLAS



ATLAS ATTBAR, high p_T $r_B = 1.21 \pm 0.08$ $\chi^2/\mathrm{dof} = 13/49$ Average for ATLAS

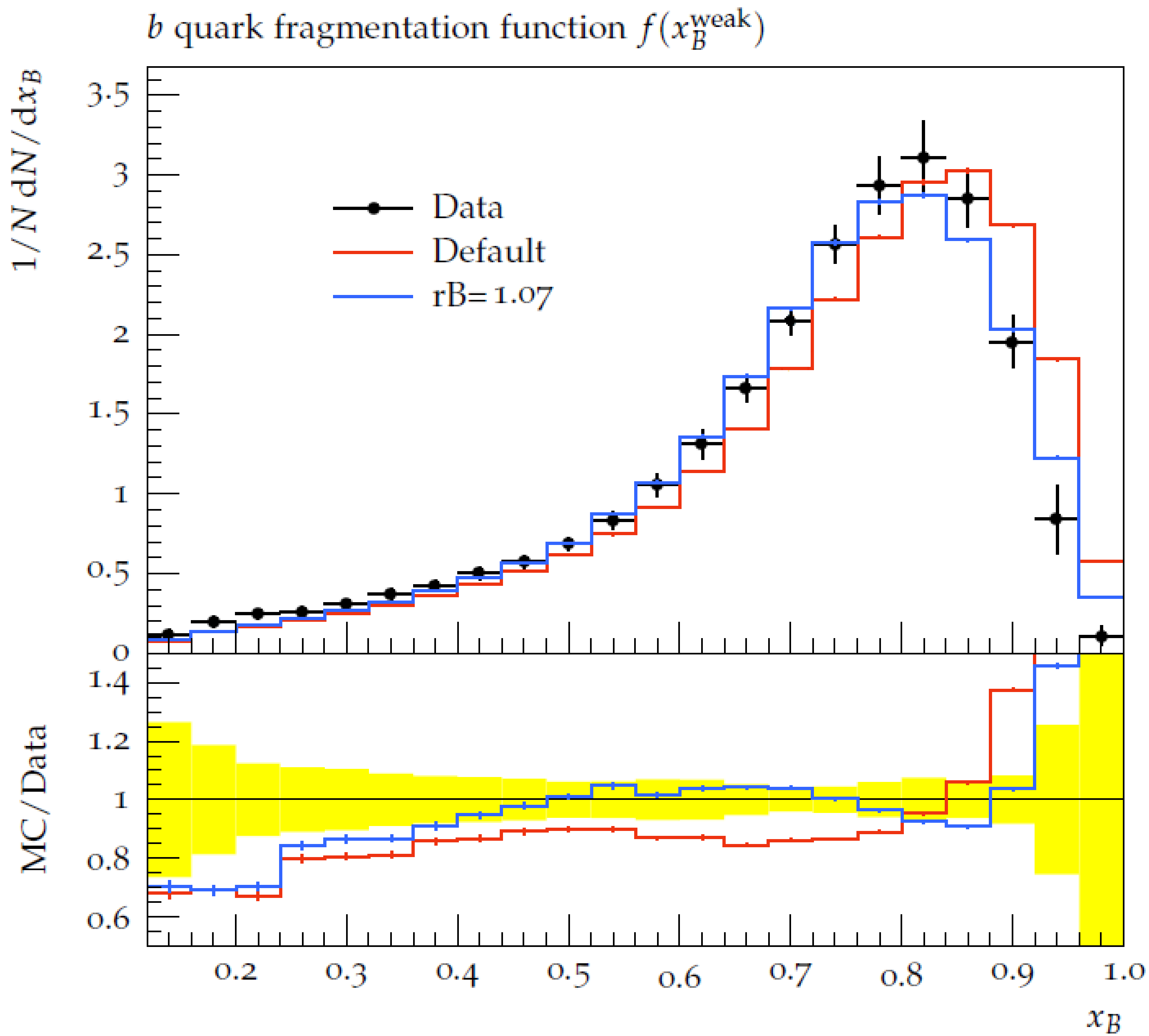


Now we compare the extraction of rb from ATLAS t-tbar data to the same extraction from LEP Z -> b-bbar data.

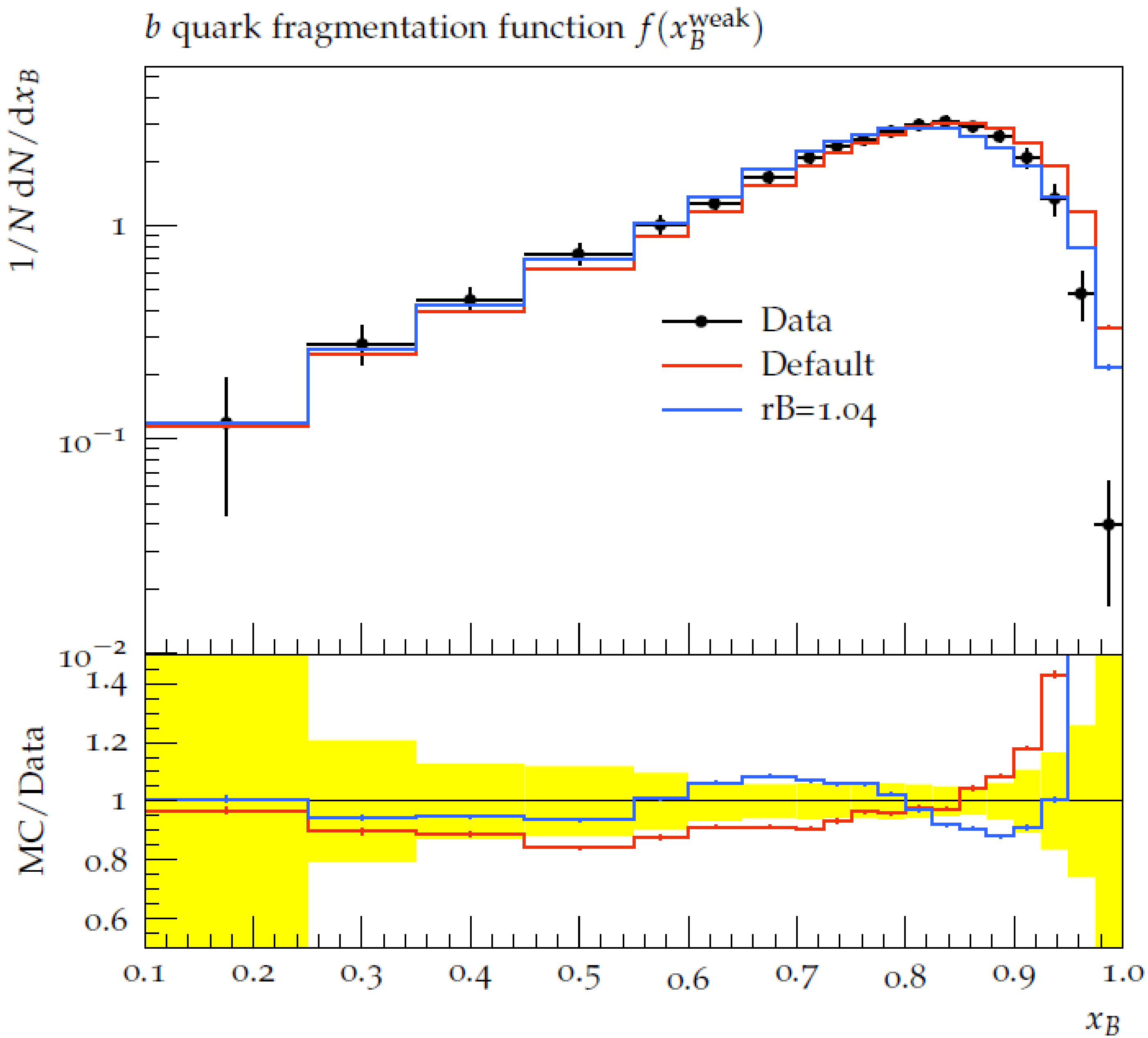
At LEP xb was measured from the semi-leptonic decays with (xb lead) or without (xb weak) reconstructing the missing energy of the neutrino.

	rB	delta rB	X^2/dof
SLD (weak)	1,08	0,02	39/21
ALEPH (weak)	1,05	0,02	75/18
DELPHI (weak)	1,02	0,02	96/9
ALEPH (lead)	0,92	0,02	106/18
DELPHI (lead)	0,82	0,02	136/9
COMBINED	0,978	0,007	560/79

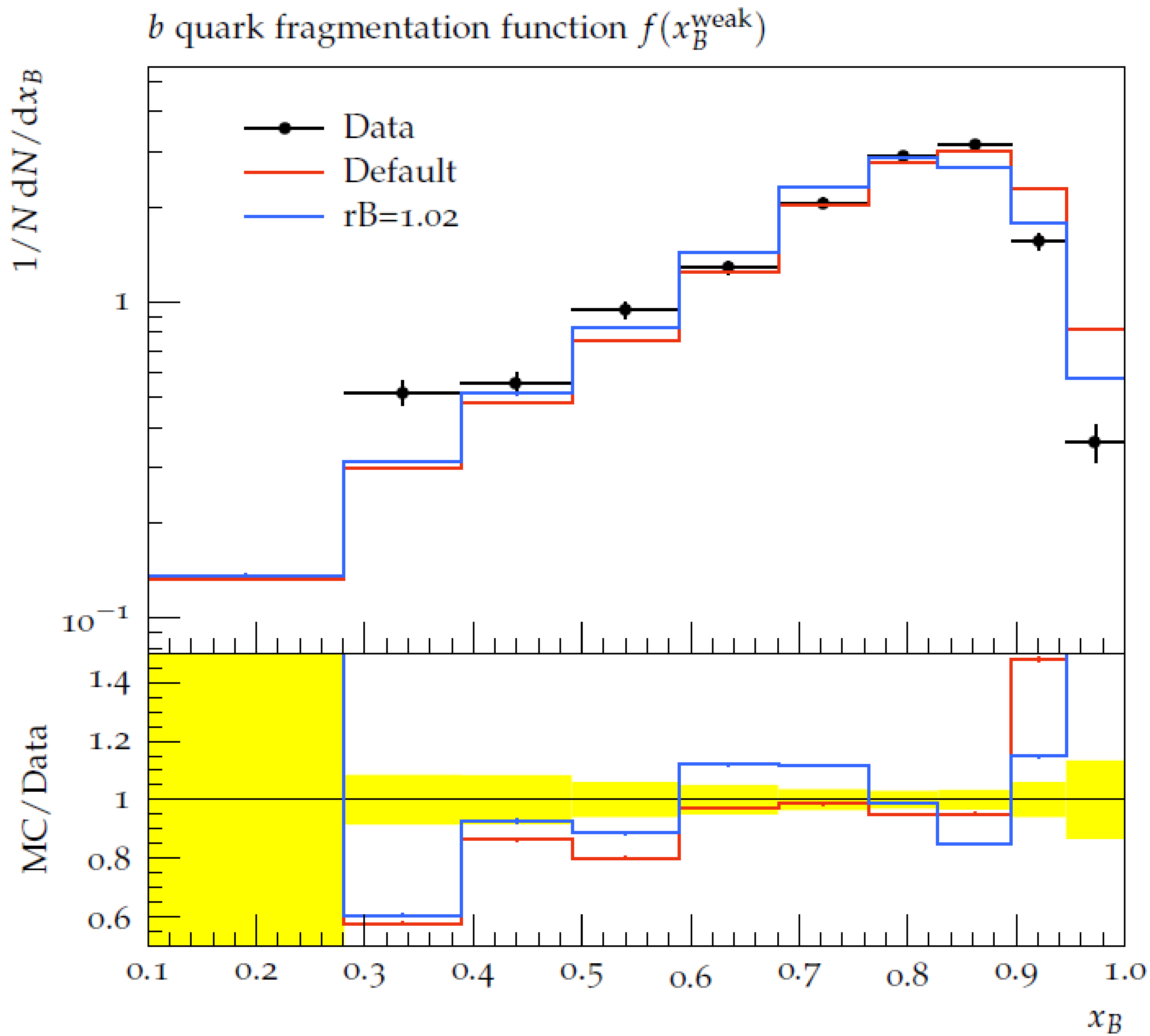
SLD Data for ATTBAR $r_B = 1.07 \pm 0.02$ $\chi^2/\text{dof} = 39/21$



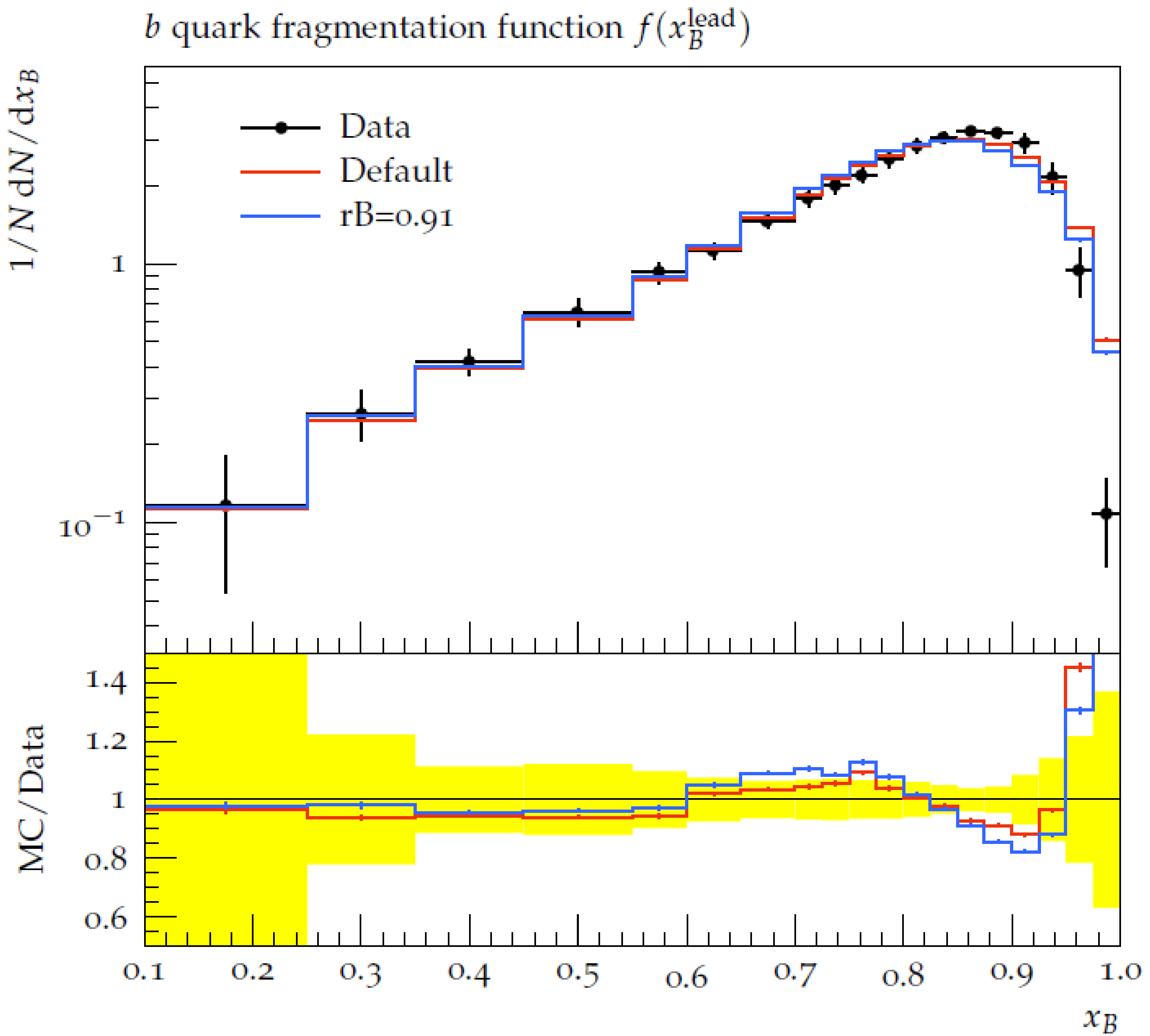
ALEPH Data for ATTBAR $r_B = 1.04 \pm 0.02$ $\chi^2/\text{dof} = 75/18$



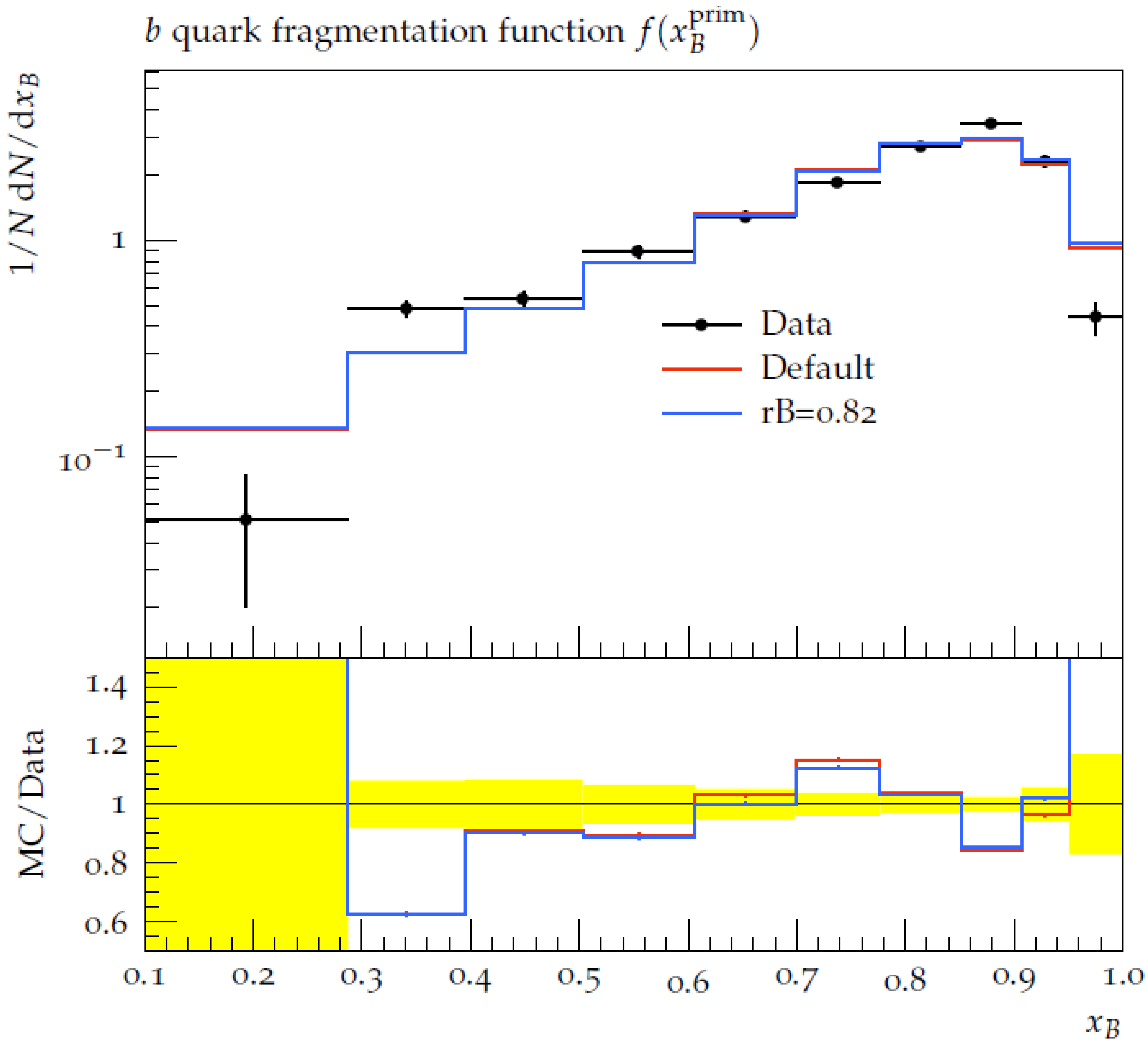
DELPHI Data for ATTBAR $r_B = 1.02 \pm 0.02$ $\chi^2/\text{dof} = 96/9$



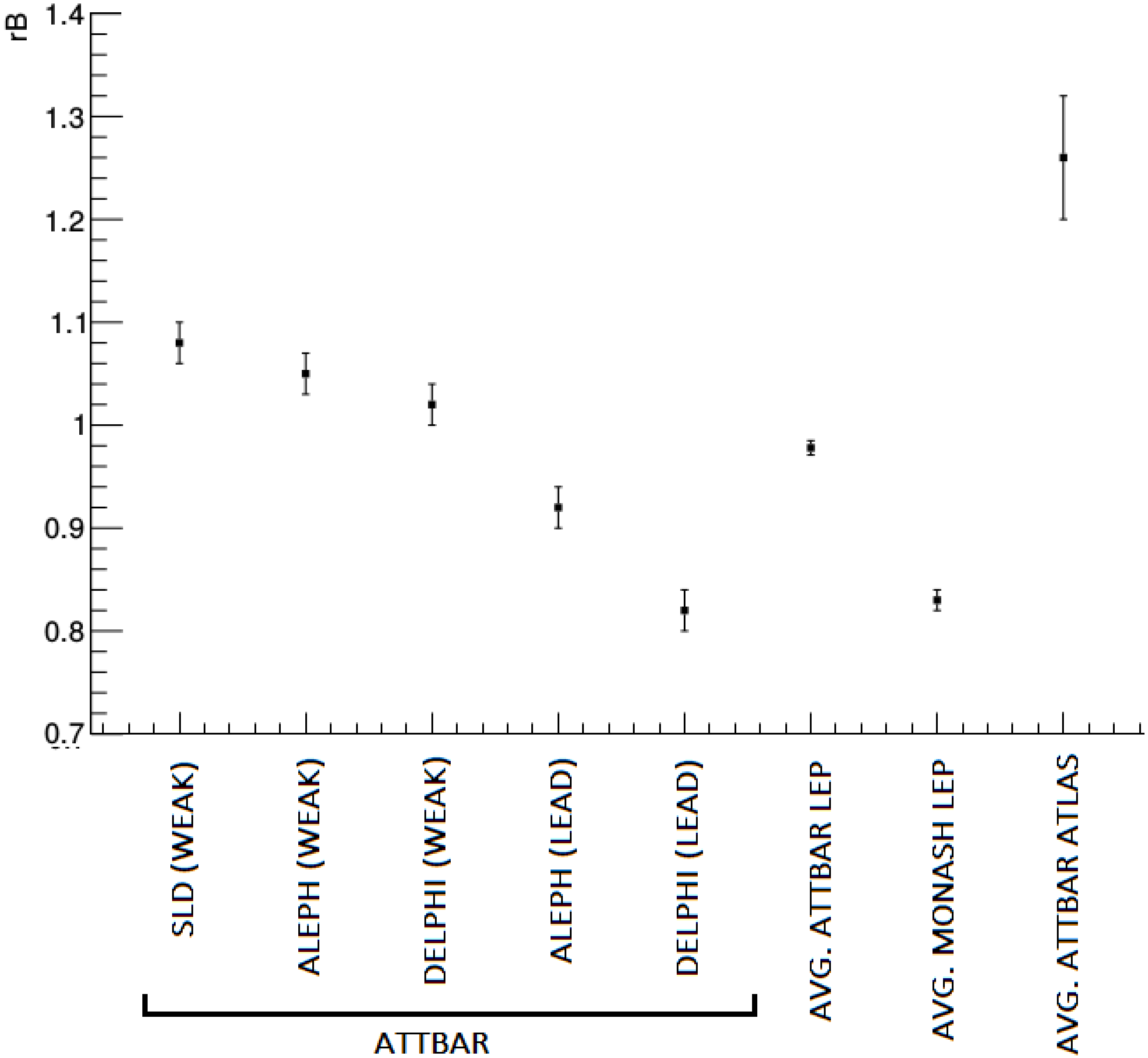
ALEPH Data for ATTBAR $r_B = 0.91 \pm 0.02$ $\chi^2/\text{dof} = 106/18$



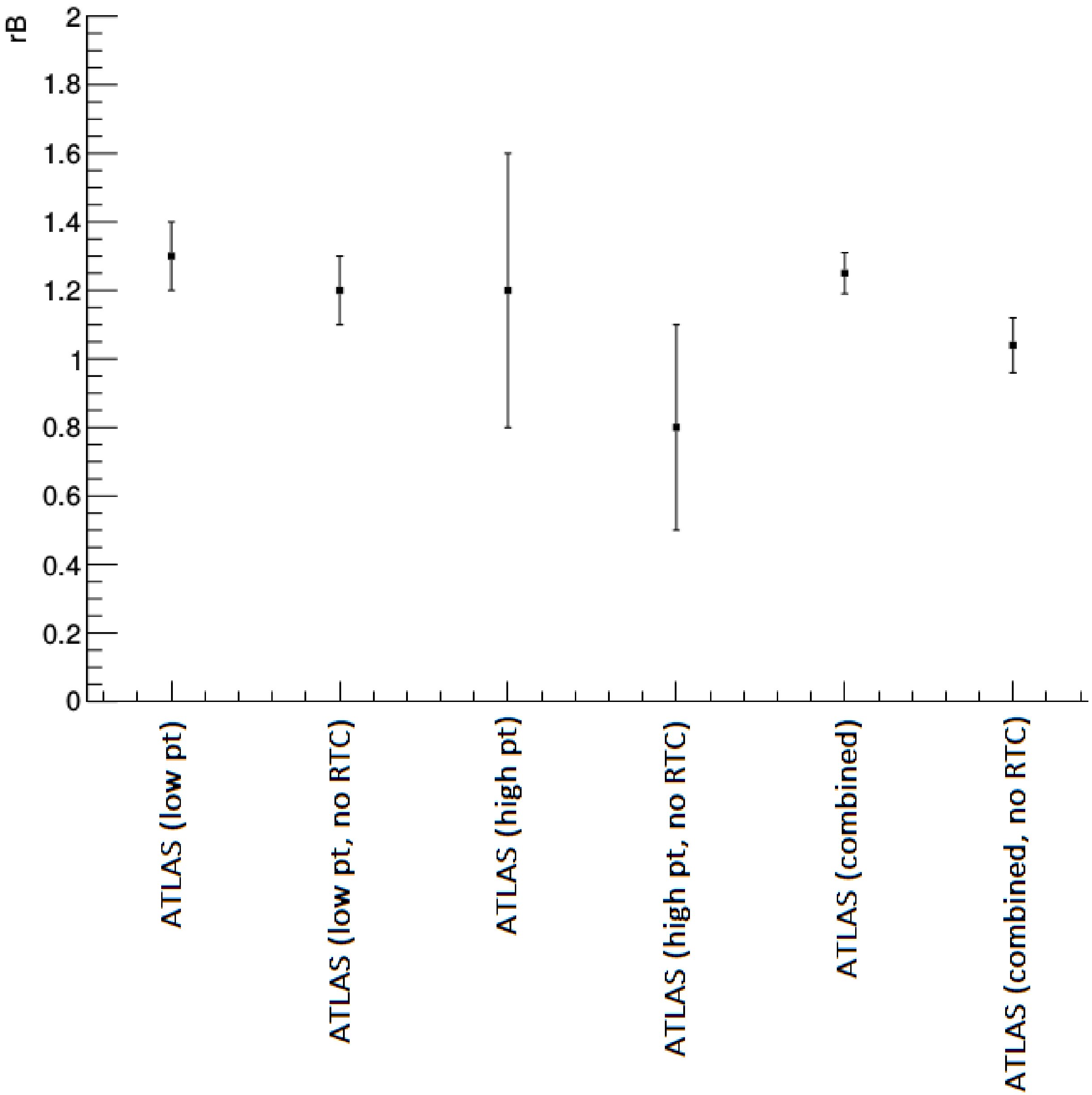
DELPHI Data for ATTBAR $r_B = 0.82 \pm 0.02$ $\chi^2/\mathrm{dof} = 136/9$

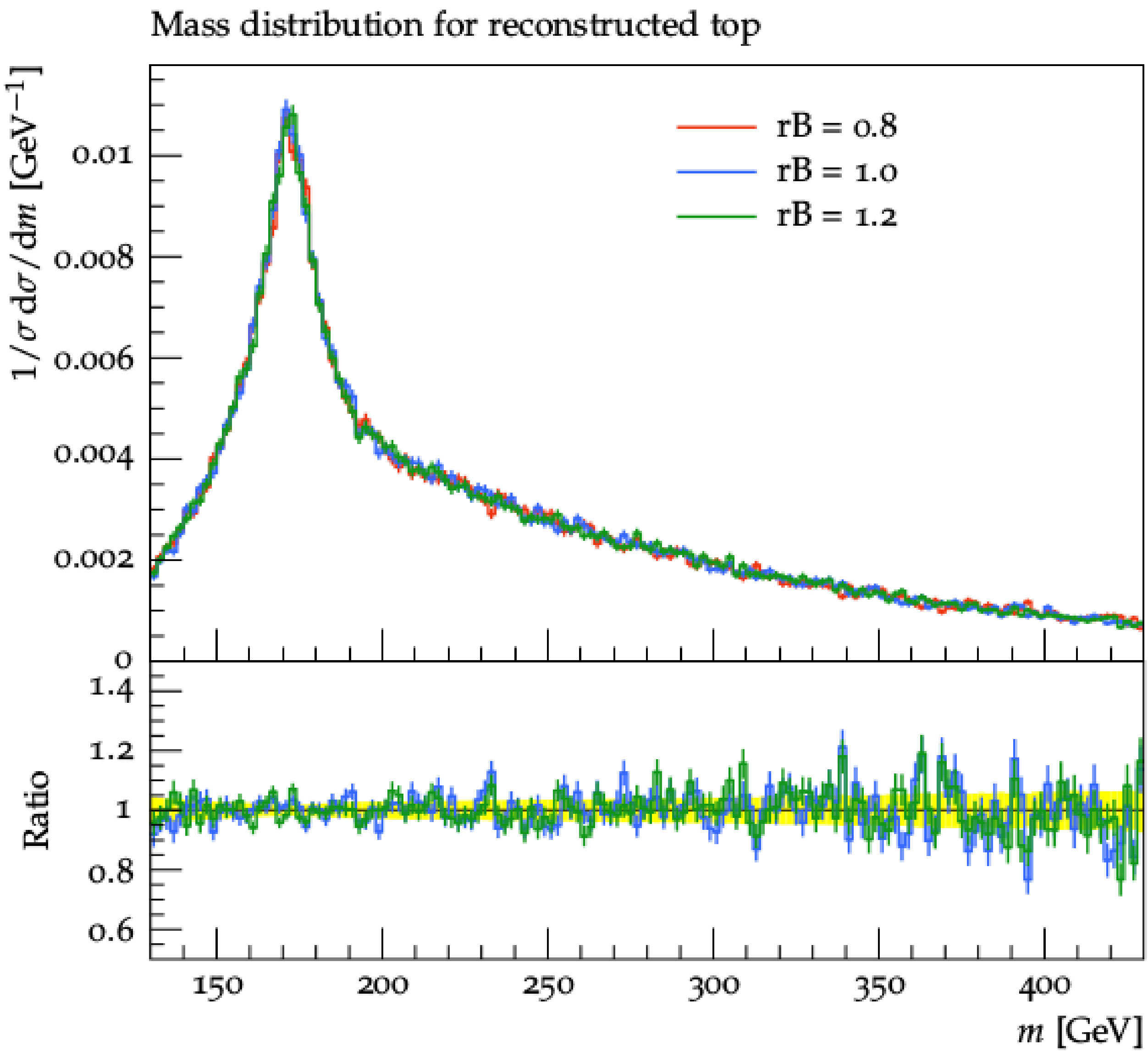


Comparison of r_B measurements (preliminary)



Comparison of r_B measurements for ATLAS (preliminary)




Mass distribution for reconstructed top
rB = 0.8
rB = 1.0
rB = 1.2
1/σ dσ/dm [GeV⁻¹]
0.01
0.008
0.006
0.004
0.002
0
Ratio
1.4
1.2
1
0.8
0.6
150
200
250
300
350
400
m [GeV]

Summary and Conclusions

• The precise determination of the b-fragmentation function is important to reduce the uncertainty on the top-quark mass.

• The rB parameter of the b-fragmentation function in the Bowler modification of the Lund model has been extracted from ATLAS t-tbar b-jet shapes.

• The determination of rB is compatible with the same extraction from LEP measurements of the b-fragmentation function.

• Some tension is observed between the xb weak and xb lead measurements at LEP. The former does not include the reconstructed missing energy of the neutrino.