# b-Quark Fragmentation Function in Z0 Decays

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SLAC

**SLD Collaboration Meeting**
**June 23, 2000**

- Introduction
- Status of analysis of 1996-97 R15 data
- Latest updates of 1997-98 R17 data
- Plans for summer conferences and beyond

# Motivation

- **Improve understanding of hadronization process**

  b-quark is the heaviest quark that hadronizes

- **Test heavy quark fragmentation models**

  Many phenomenological models exist, but not well tested

- **Heavy-flavor hadron production**

  B physics in $e^+e^- \to Z^0$: Significant source of systematics

  $b\bar{b}$ production rate in $p\bar{p}$: ~ Twice that of theory prediction

  Top physics: $t \to bW \to 3$ jets

# What was done before?

- Indirect $\langle x_B \rangle$ measurement (by PEP, PETRA, LEP)

  $\Rightarrow$ $\langle x_B \rangle \approx 0.7$ with % statistics, but model-dependent.

  e.g. inclusive lepton momentum spectra

- Indirect shape measurements (by L3, OPAL)

  $\Rightarrow$ B energy NOT reconstructed.

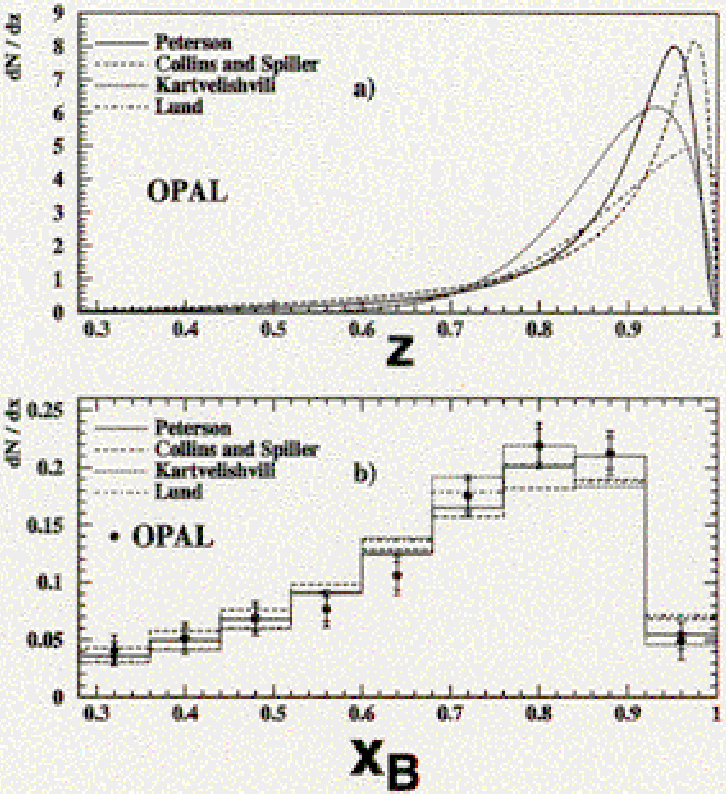
  e.g. 2-D ($E_{D\ell}$ , $M_{D\ell}$) fits

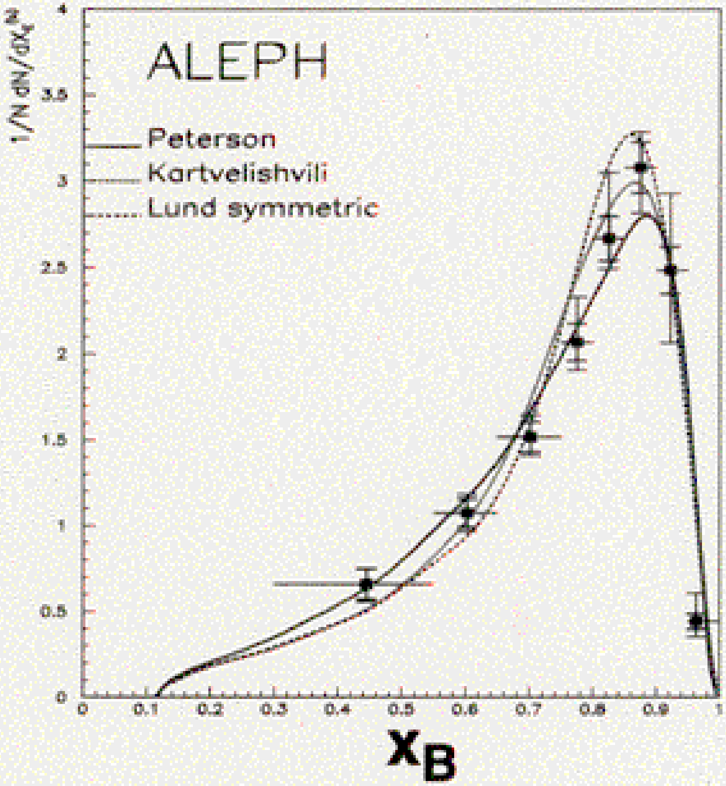
- Direct shape measurements (by ALEPH, DELPHI, SLD)

  $\Rightarrow$ B energy reconstructed.

  e.g. $B \rightarrow D\ell\nu X$ with (partially) reconstructed D

# Problems with Earlier Results




1) limited statistics and poor coverage at low $X_B$

2) large model-dependence

3) Uncertainty in B/D decay $\Rightarrow$ large systematic errors

Conclusion: Poor discrimination between models.

# The Analysis of 1996-97 Data
# ( using 150,000 $Z^0$ decays )

- Improved efficiency and energy resolution, using

1. topological vertexing and b mass-tag
2. the small SLC IP
3. missing-mass technique to measure B-hadron energy

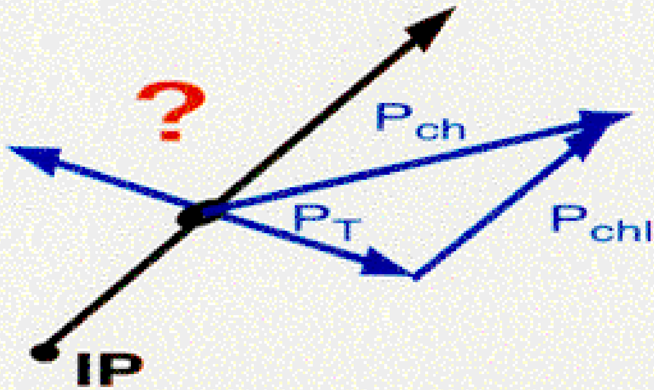
- Main conclusions ( PRL 84:4300-4304, 2000 )

1. Exclusion of several fragmentation models
2. The most precise average B hadron energy among direct measurements from LEP and SLD :

$\langle x_B \rangle = 0.714 \pm 0.005(\text{stat.}) \pm 0.007(\text{syst.}) \pm 0.002(\text{model})$

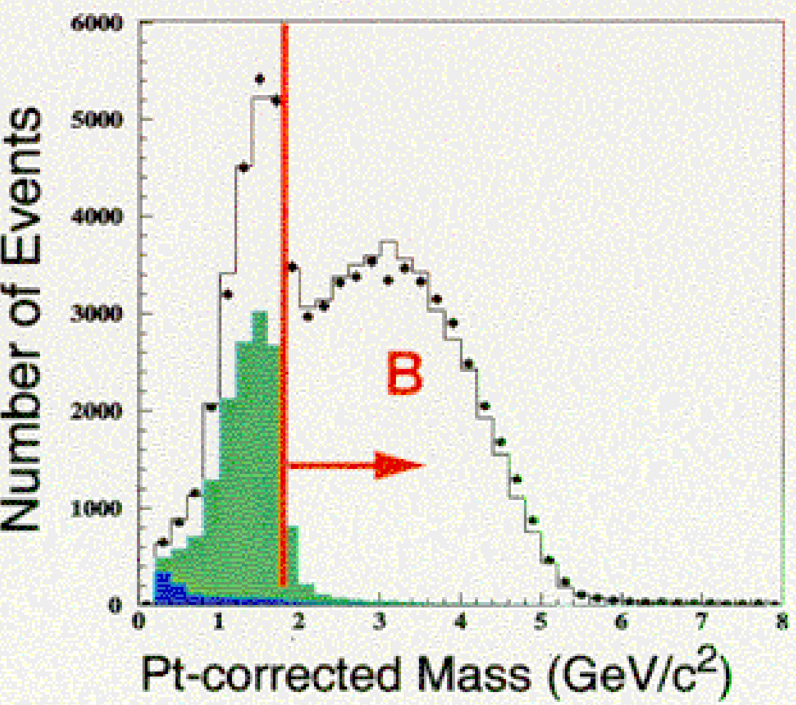
# 1997-98 R17 Analysis (350,000 Z0 Decays)

## Hadron Flight Direction

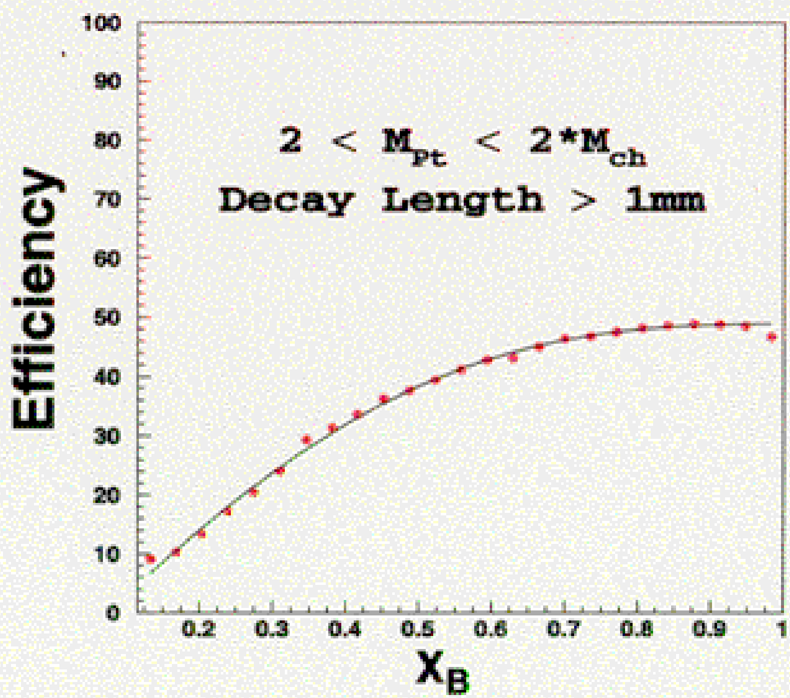



To accout for missing particles, the mass of the vertex is $P_T$ - corrected:

$$M_{PT} = (M_{ch}^2 + P_T^2)^{1/2} + P_T$$




### Efficiency vs $E_B$



## How to obtain $P_{0L}$ and $M_0$?

**In the B rest frame,**

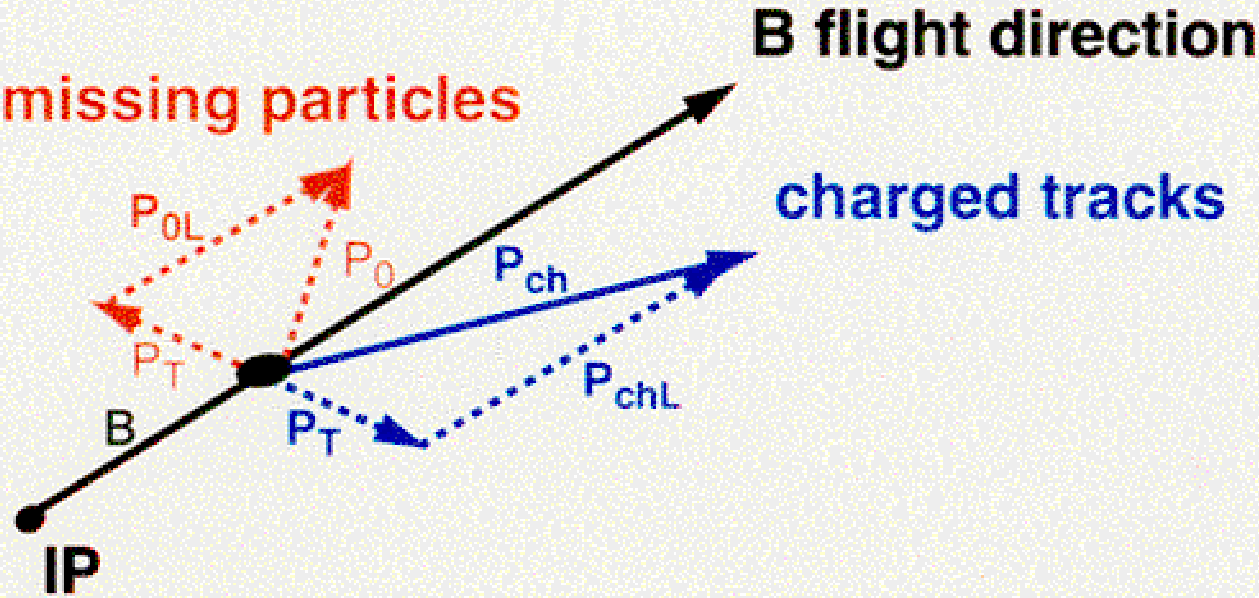
**B energy = the 'known' B mass.**

**This equation leads to**

1) $P_{0L}$ can be solved if $M_0$ is known.

2) $M_0$ has an upper bound.

# The Missing Mass Technique to reconstruct the B energy

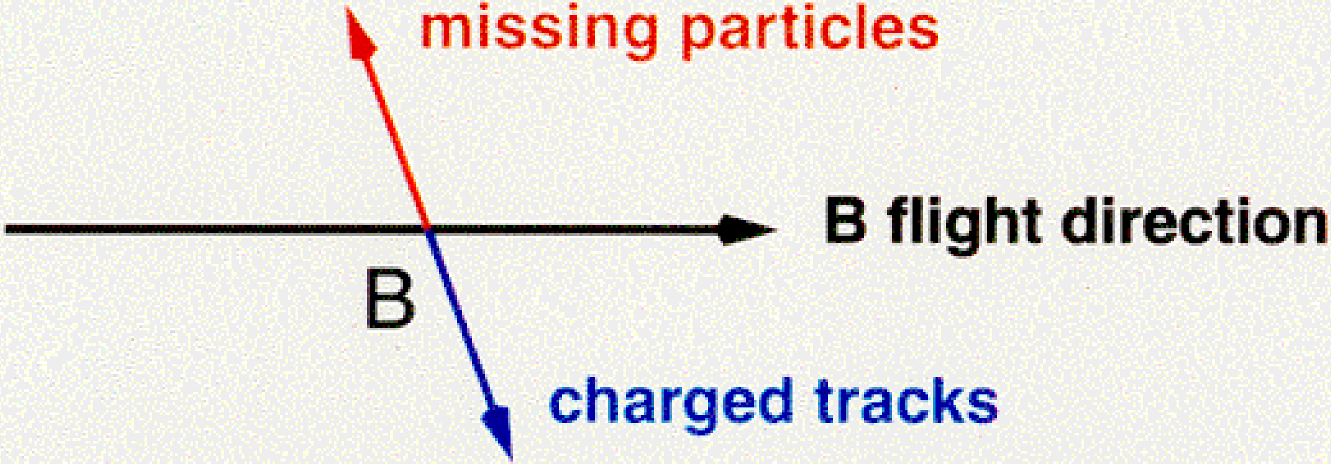



## The B energy

**B energy = Charge-track Energy + Missing Energy**

- **Charge-track Energy = known**
- **Missing Energy = $(M_0^2 + P_{0L}^2 + P_T^2)^{1/2}$ = ?**

**In the B rest frame,**



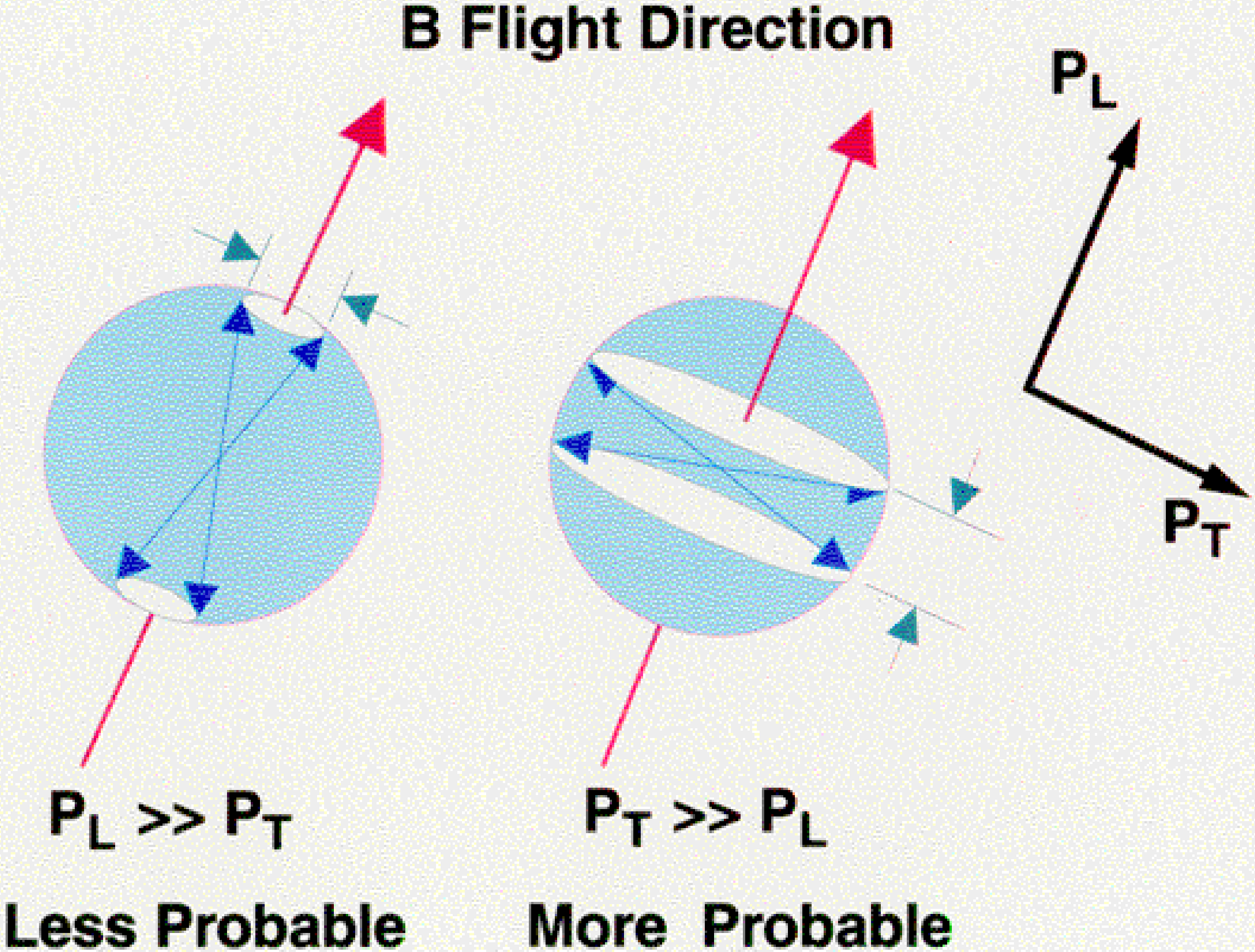

$$M_B = \sqrt{M_{ch}^2 + P_T^2 + P_L^2} + \sqrt{M_0^2 + P_T^2 + P_L^2}$$

$$M_B \geq \sqrt{M_{ch}^2 + P_T^2} + \sqrt{M_0^2 + P_T^2}$$

$$M_0^2 \leq M_{0max}^2 = M_B^2 + M_{ch}^2 - 2M_B\sqrt{M_{ch}^2 + P_T^2}$$

**Note that $M_0 = M_{0max}$ if $P_L = 0$ in rest frame.**

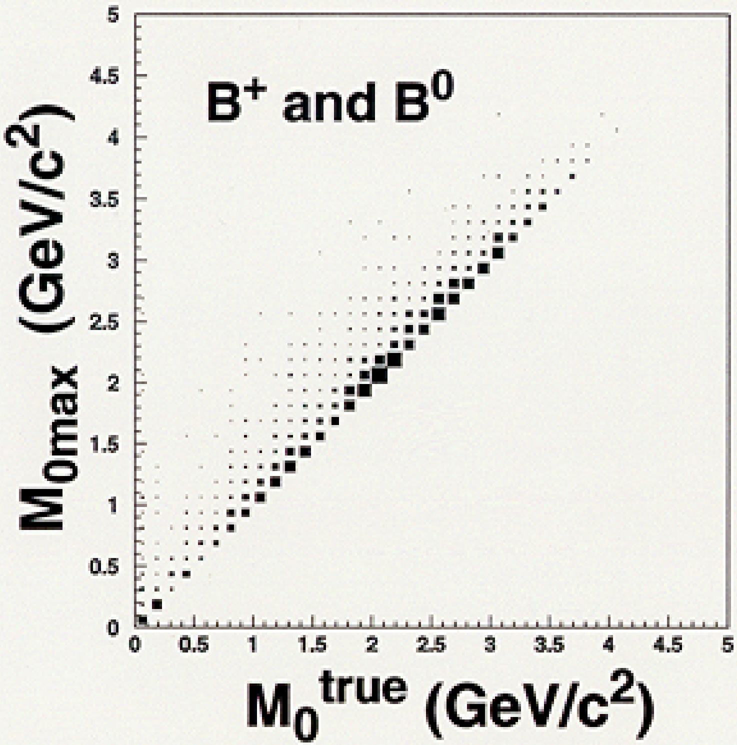
# In B rest frame, $P_L << P_T$ is more probable.

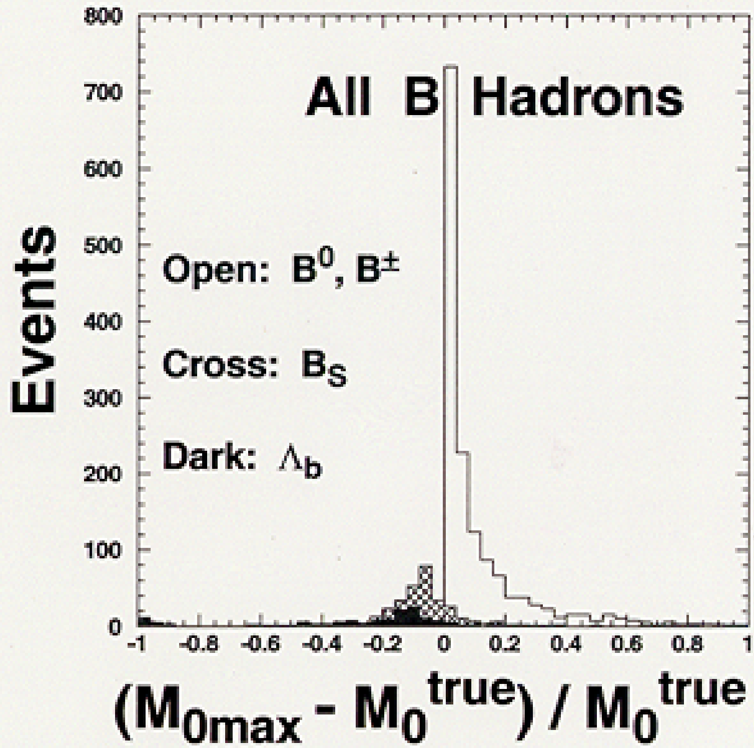



Very small $P_L$ corresponds to $M_0 \approx M_{0max}$

In addition, large B decay multiplicity $\Rightarrow$

Missing mass is close to its upper bound $M_{0max}$




If $M_{0max}$ is small, we obtain a very good estimate of $M_0$:

$$M_0 \approx M_{0max}$$

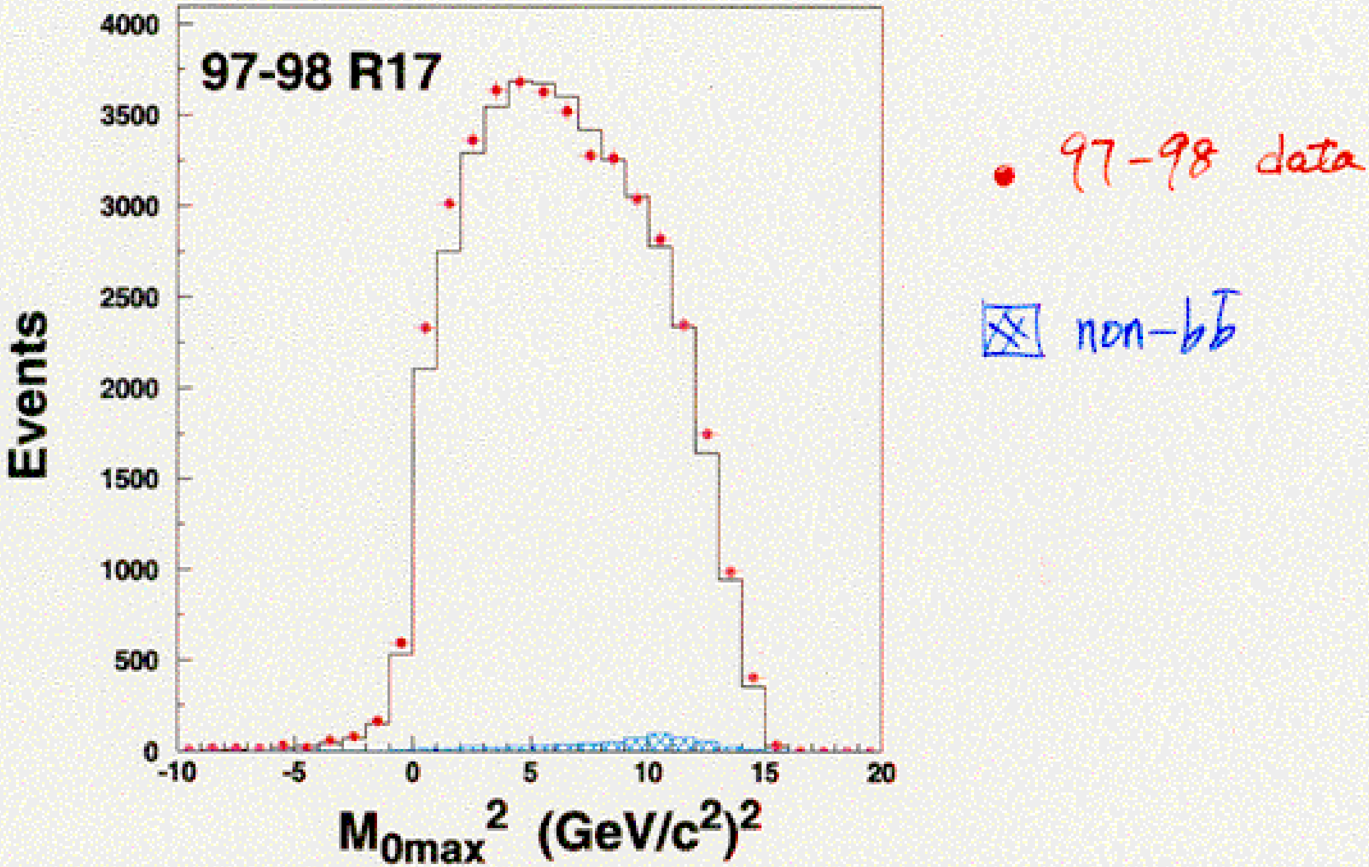
## Summary of the technique

- The missing mass $M_0$ is bounded by $M_{0max}$.
- On average, $M_0$ clusters near $M_{0max}$.
- If $M_{0max}$ is small, it is a good estimate of $M_0$.
- Using this estimate of $M_0$, solve for the missing energy.

## Remarks

- $M_{0max}$ is boost-invariant and independent of the B energy.
- Only tracking and vertexing information are used.
- Beam energy is not used.

# $M_{0max}{}^2$ for B-Tagged Sample

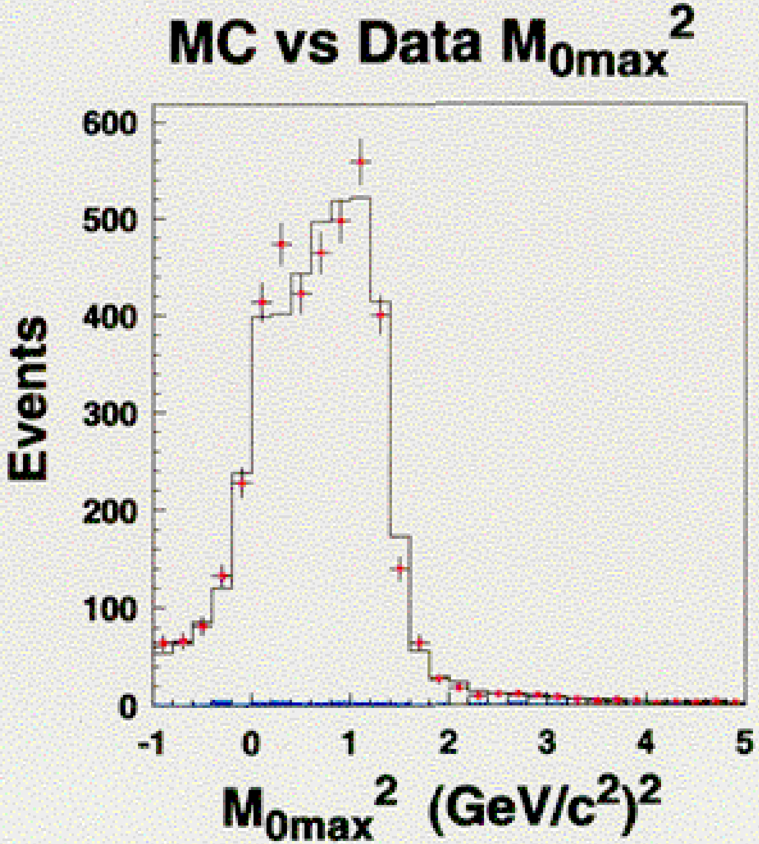


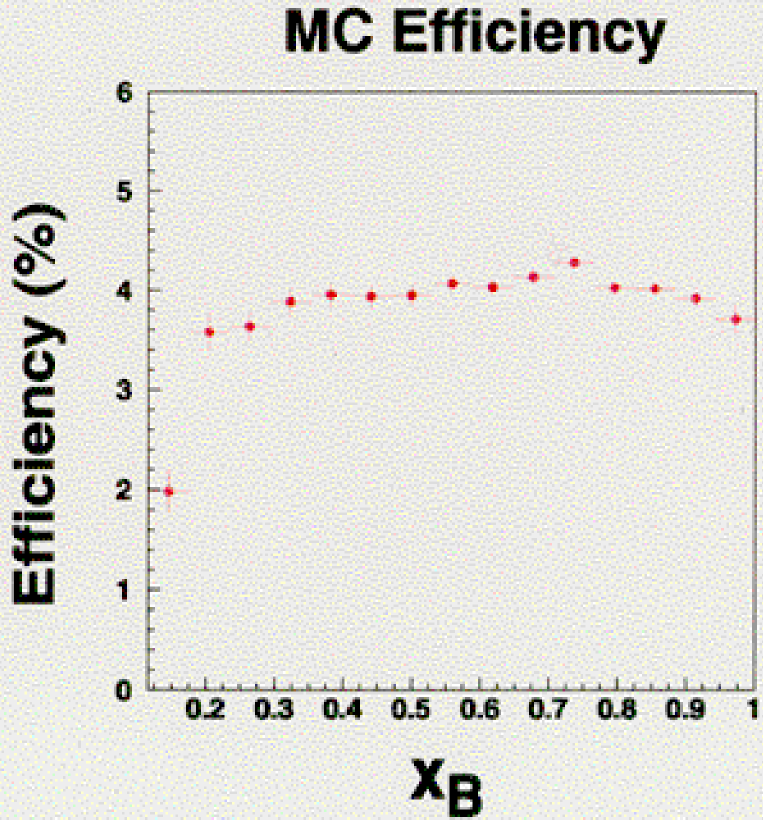

- $M_{0max}{}^2 < 0$ is due to detector resolution
- Non-$b\overleftarrow{b}$ background concentrates at large $M_{0max}{}^2$
- B energy resolution is good for small $M_{0max}{}^2$, but is poor for $M_{0max}{}^2 < -1$

# Final B Sample Selection

- Final cut on missing mass: $-1 < m_{0max}^2 < f(x_B^{rec})$
- Good energy resolution

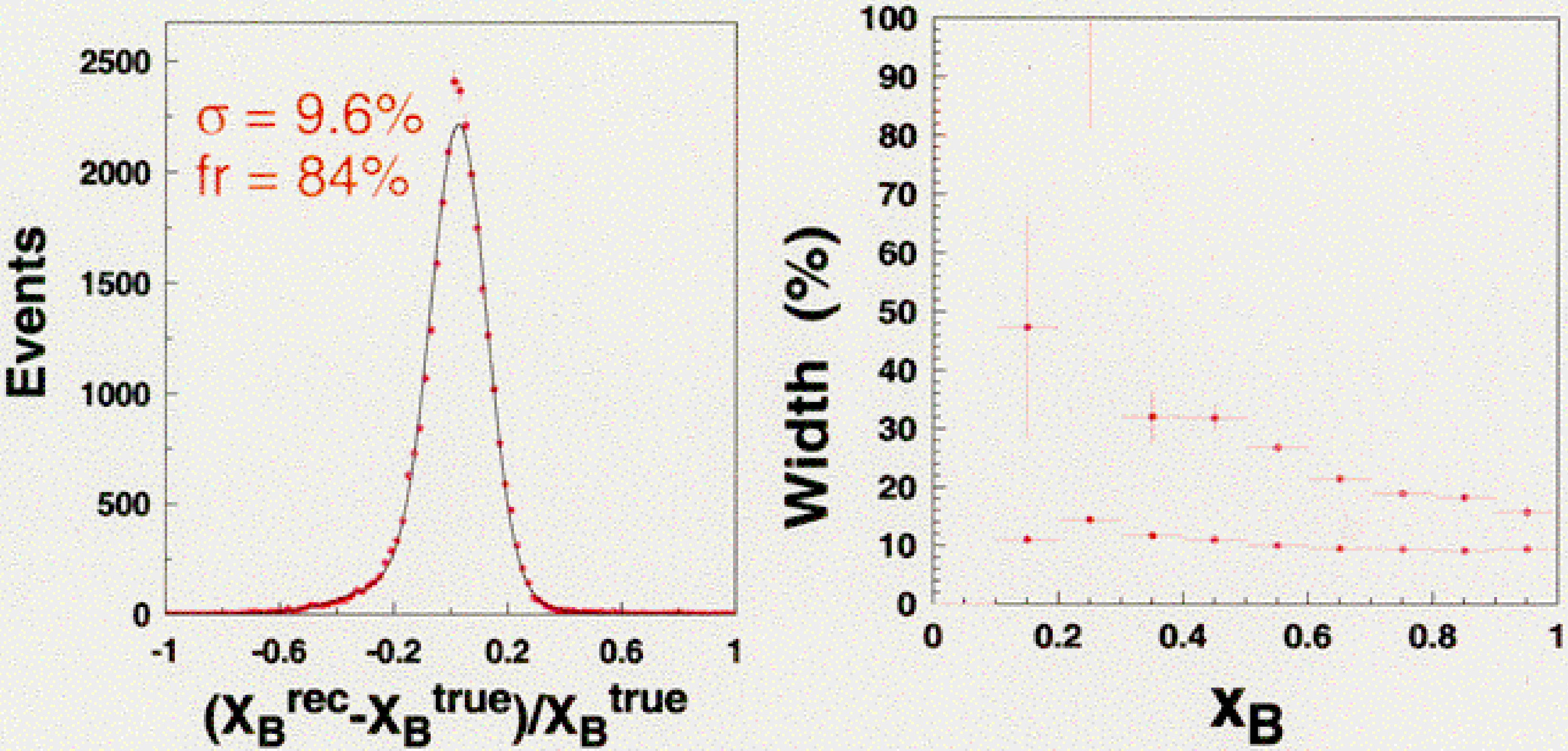
4164 vertices for 97-98 data (1920 for 96-97 data)




Sample b purity = 99.0%

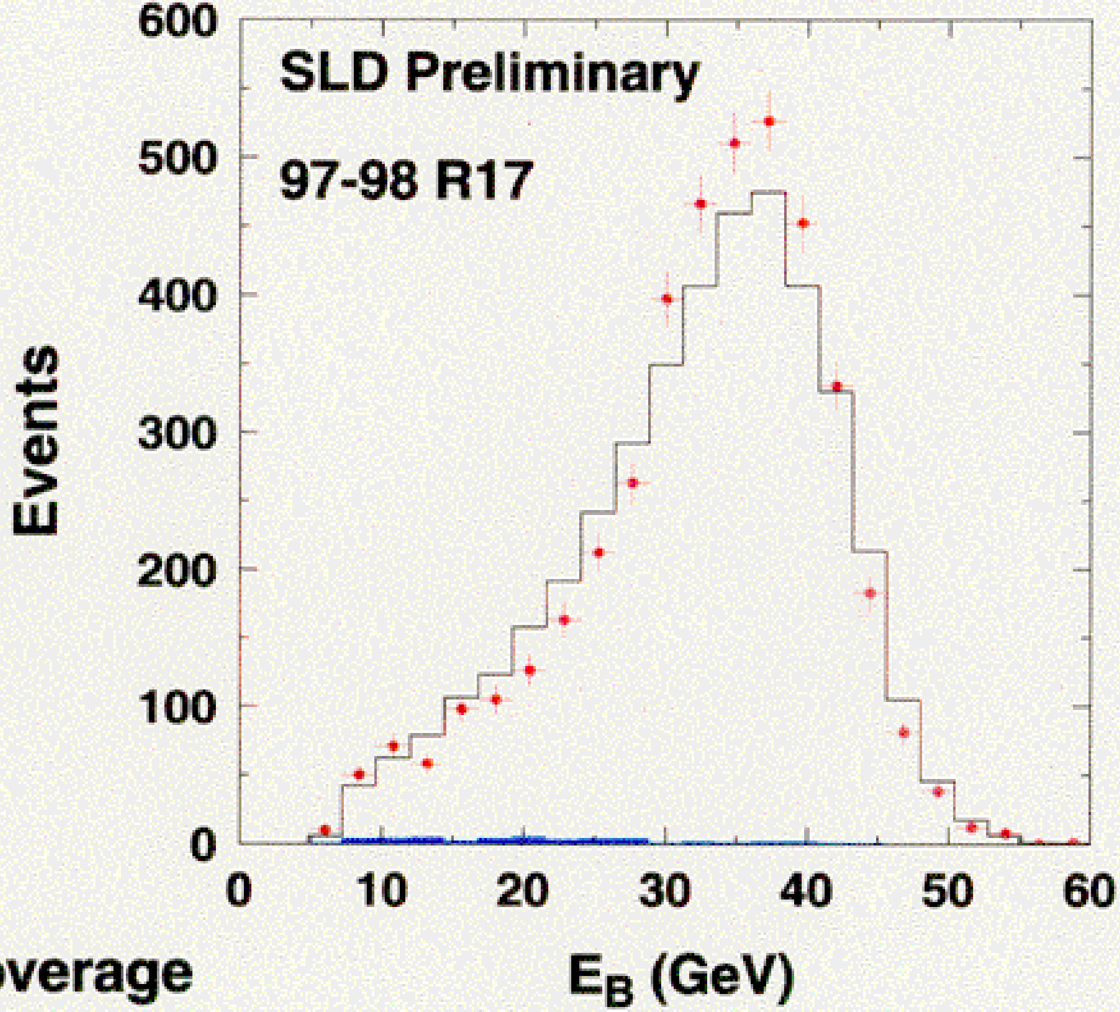
# Resolution




- Improved core resolution (10.4% from 1996-97)

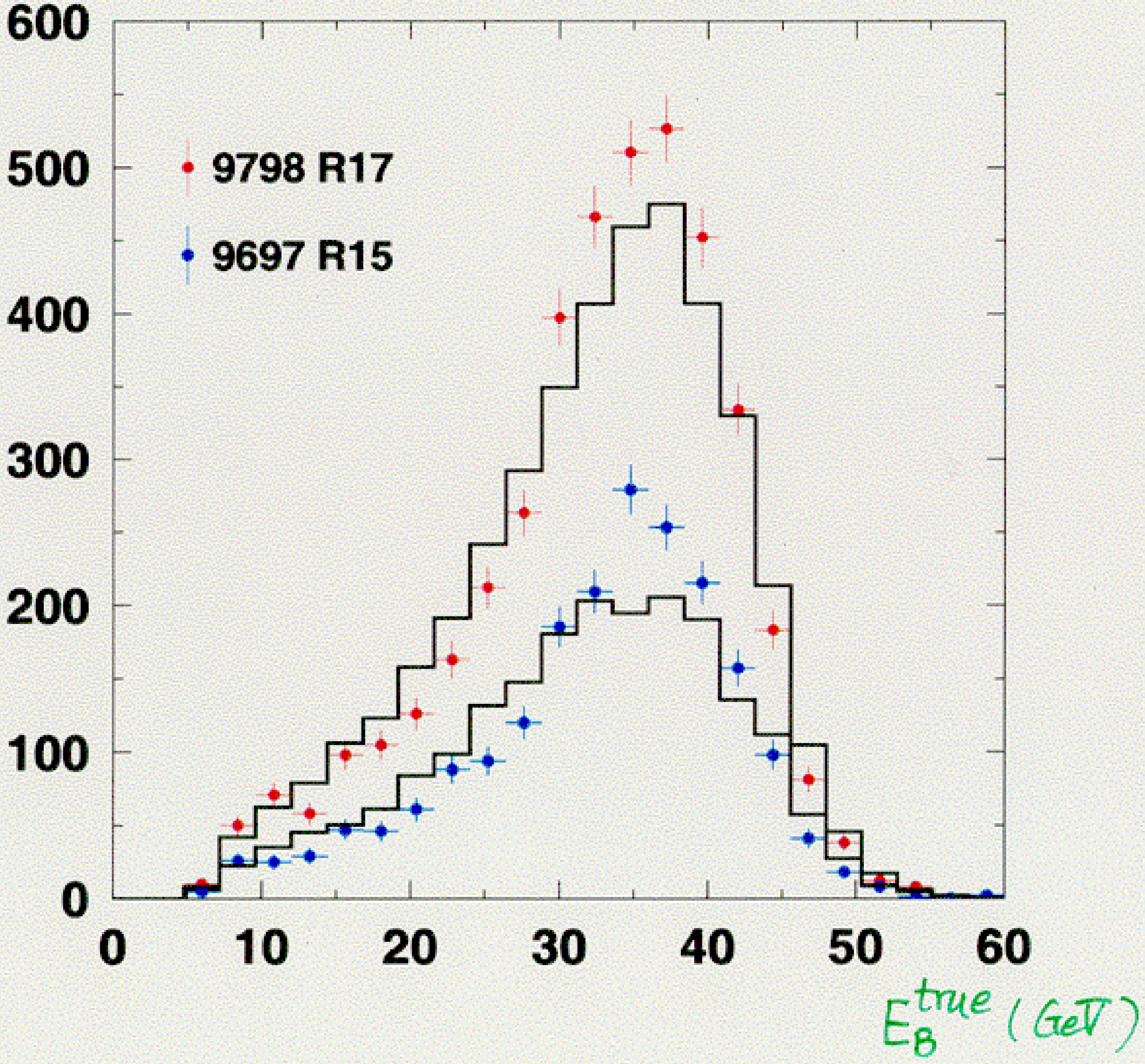
- Smaller tail fraction = 16.4% (17% for 1996-97)

# Uncorrected B Energy Distribution




- Full kinematic coverage
- Small non-bb background
- MC (JETSET+Peterson model) is inconsistent with data

# Compare with 96-97 MC vs Data

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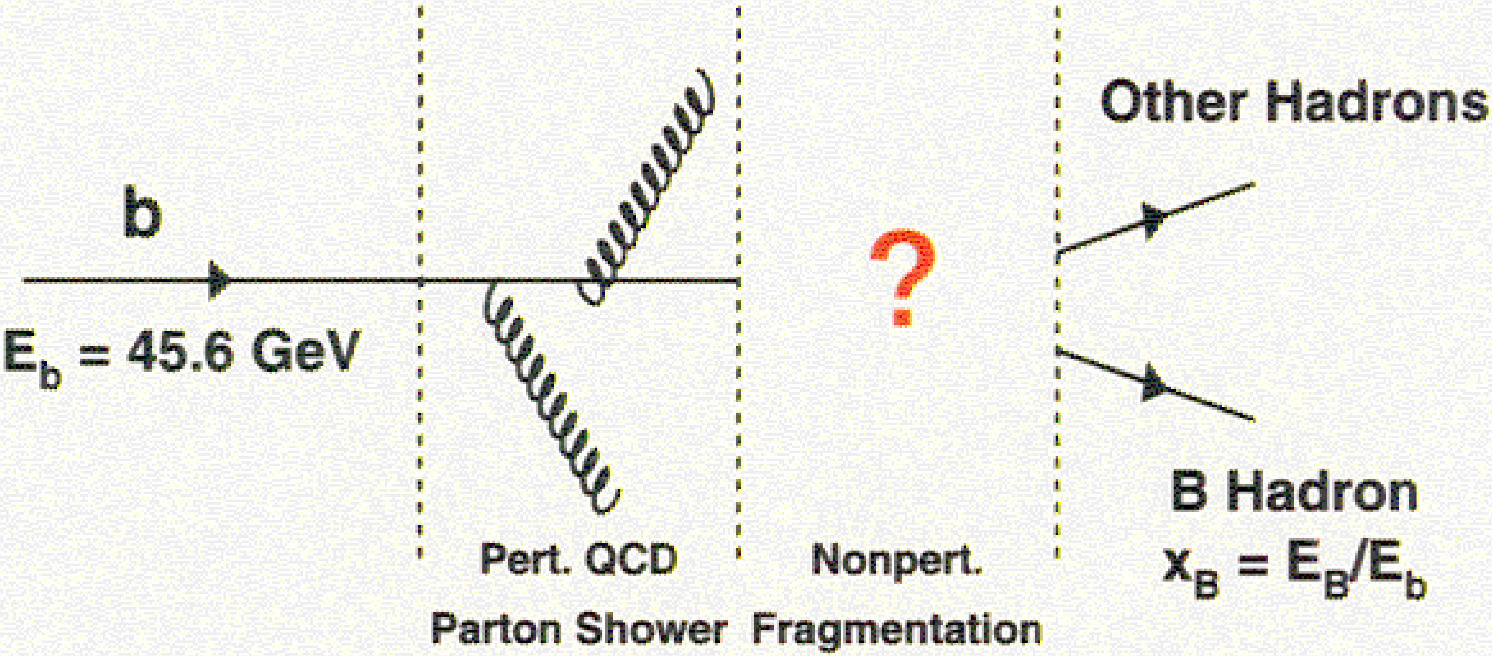
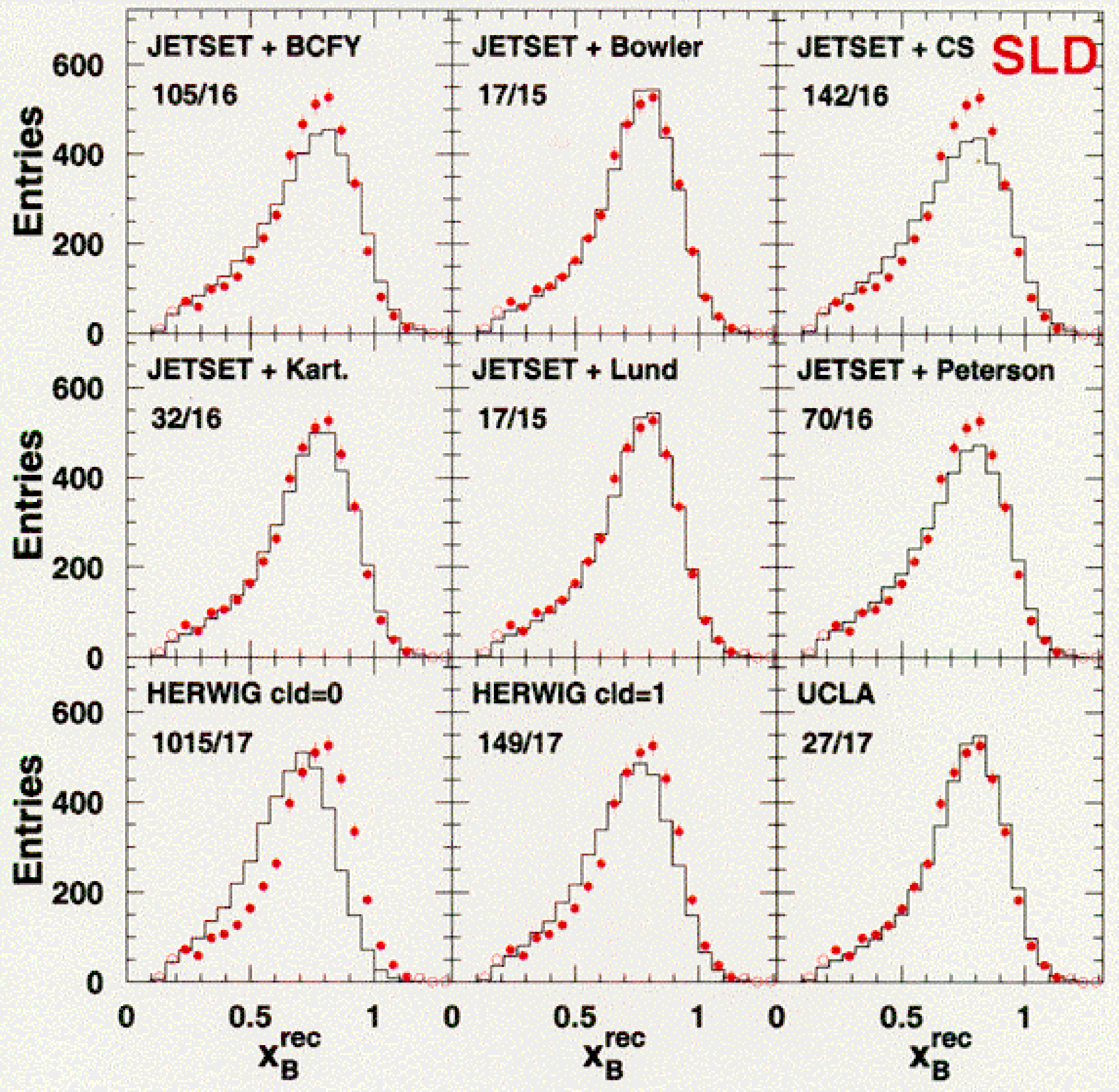
# Test of b Fragmentation Models




- JETSET MC is used to simulate parton shower.
- Models can be put into MC to simulate hadronziation.

Many models exist, but which ones produce the "right" shape that is consistent with SLD data?



JETSET + BCFY
105/16
JETSET + Bowler
17/15
JETSET + CS
142/16
SLD
JETSET + Kart.
32/16
JETSET + Lund
17/15
JETSET + Peterson
70/16
HERWIG cld=0
1015/17
HERWIG cld=1
149/17
UCLA
27/17
Entries
0
200
400
600
0
0.5
1
$x_B^{rec}$

# Model Test Results

**The same four models were found to be consistent with the SLD data:**

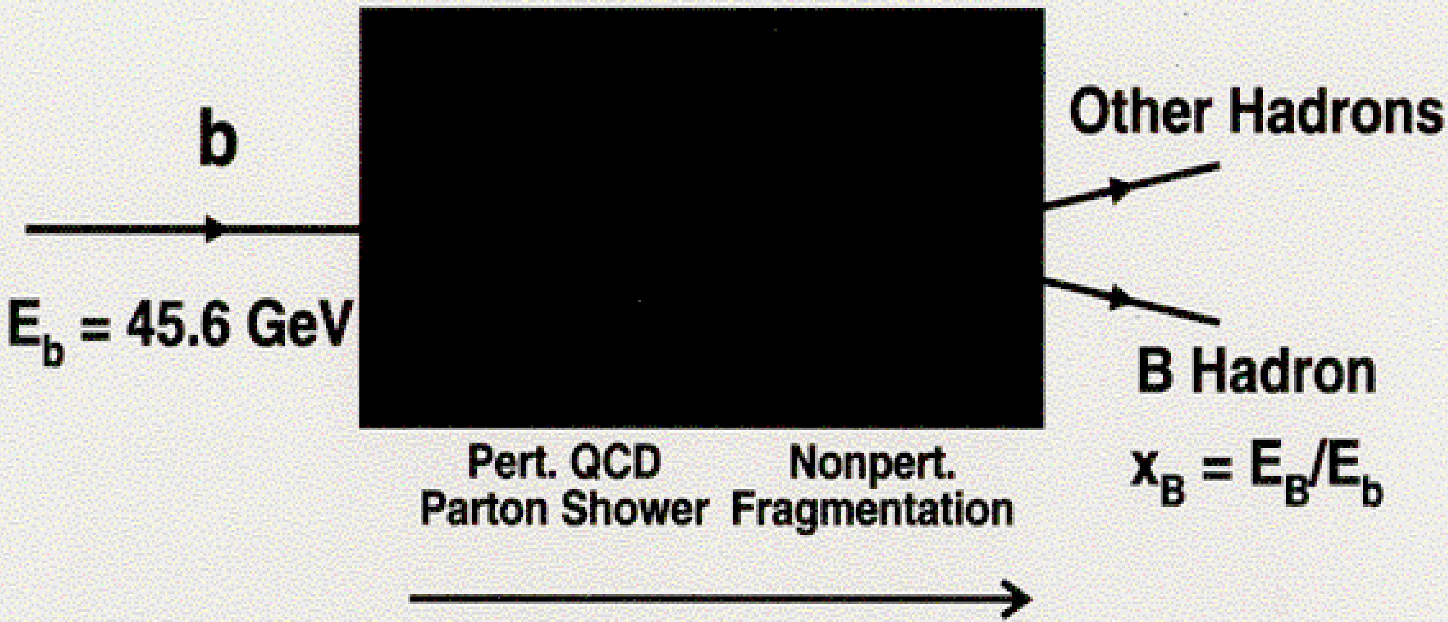
1. JETSET + Lund
2. JETSET + Bowler
3. JETSET + Kartvelishvili ( 0.5% → 1% )
4. UCLA ( 10% → 6% )

**The other five models are excluded in this context:**

1. JETSET + BCFY
2. JETSET + Collins and Spiller
3. JETSET + Peterson
4. HERWIG (old version)
5. HERWIG (last version)

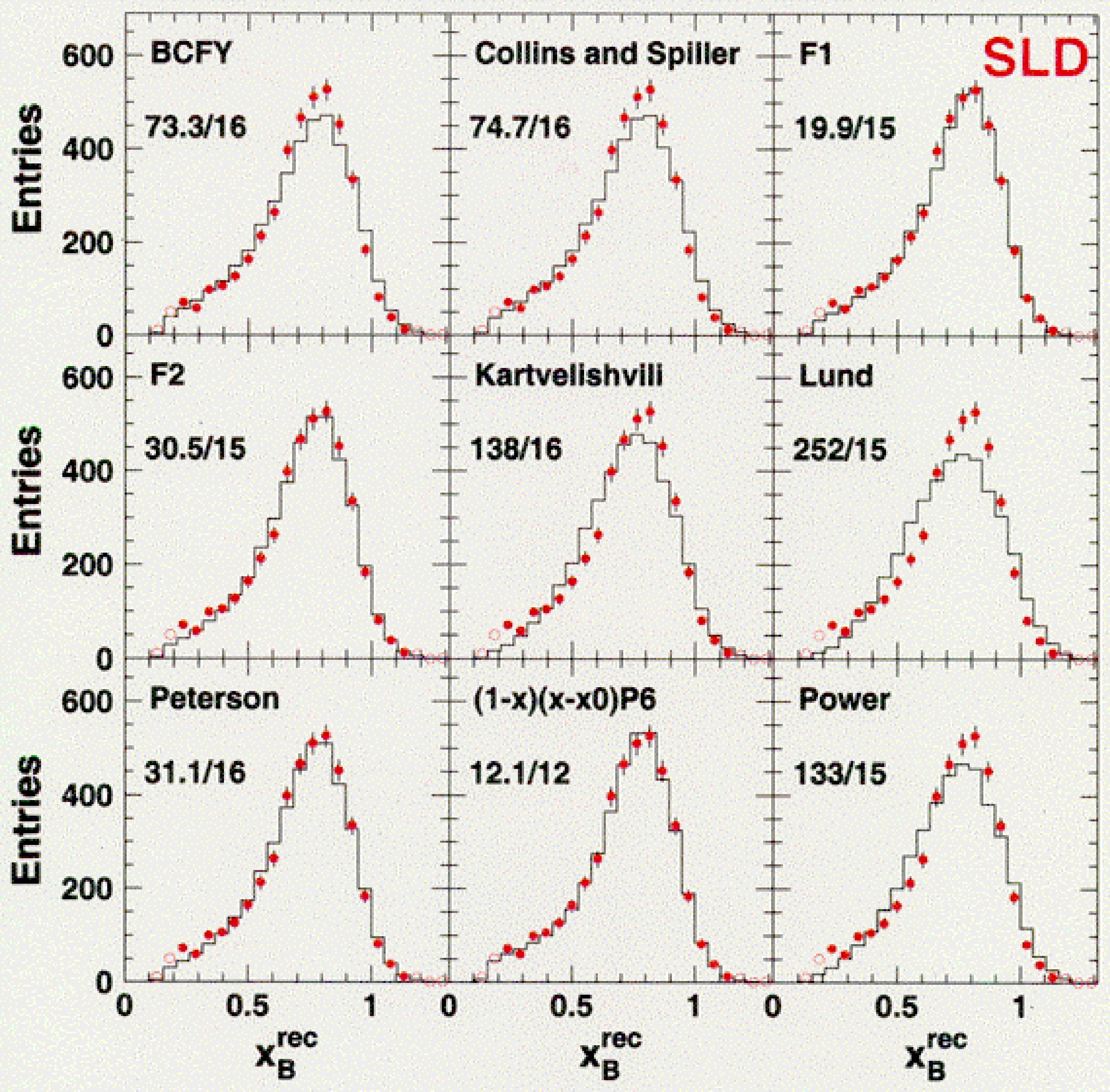
- DELPHI and OPAL are tuning HERWIG 6.1 using SLD data

# Test of $x_B$ Functional Forms $f(x_B,\lambda)$




$f(x_B,\lambda) = ?$

- Improve estimate of the shape of $x_B$ distribution.
- Unfolding the raw $x_B$ distribution.
- Improve estimate of the $<x_B>$ model-dependence.

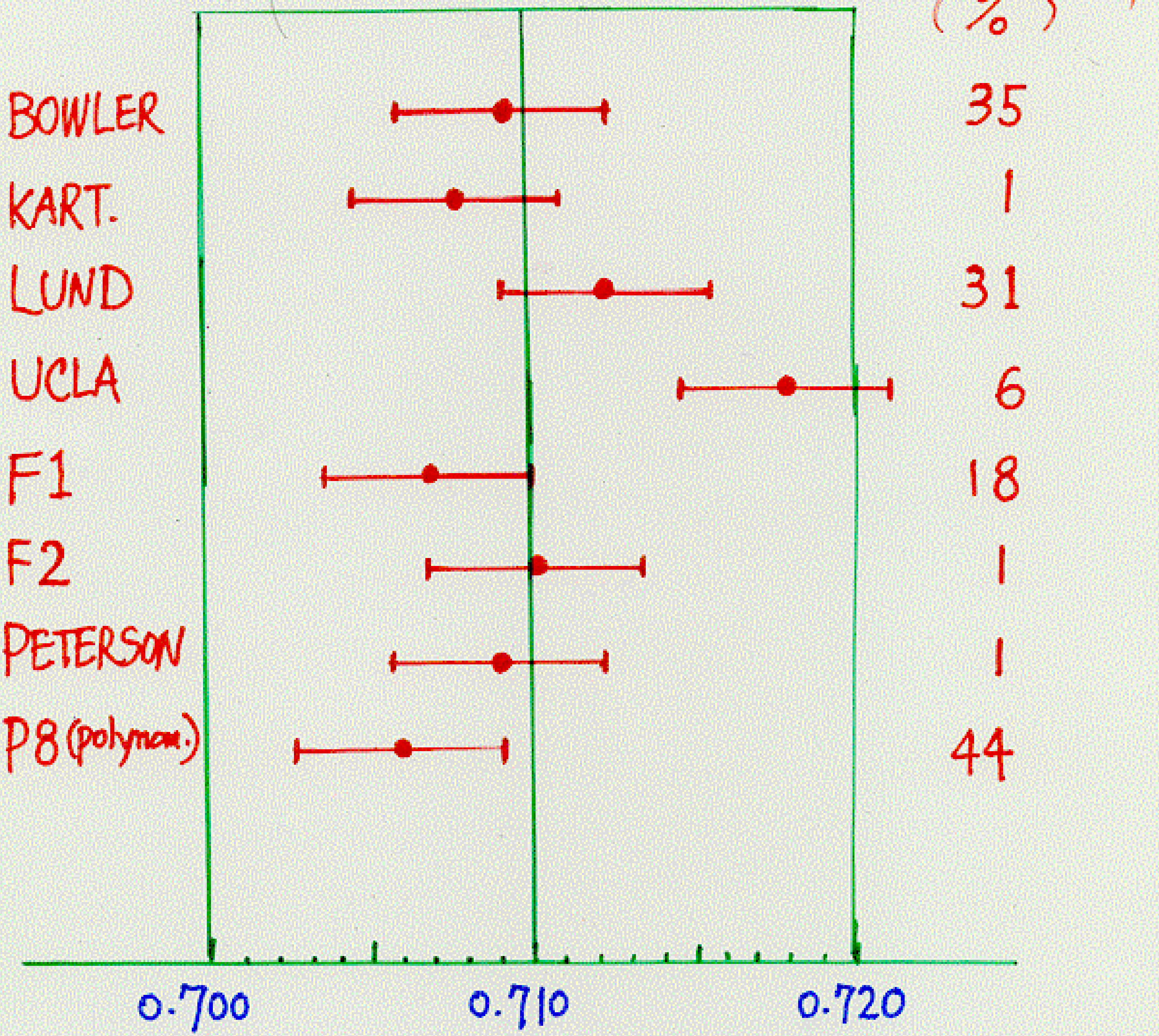

SLD
BCFY
73.3/16
Collins and Spiller
74.7/16
F1
19.9/15
F2
30.5/15
Kartvelishvili
138/16
Lund
252/15
Peterson
31.1/16
(1-x)(x-x0)P6
12.1/12
Power
133/15
Entries
0
200
400
600
0
0.5
1
$x_B^{rec}$

# Average B Energy

**Table 1:**

| Models | $\chi^2$ | Prob % | $<x_B>$ |
|---|---|---|---|
| Bowler | 17/15 | 35 | 0.7087 |
| Kartvelishvili | 32/16 | 1 | 0.7077 |
| Lund | 17/15 | 31 | 0.7119 |
| UCLA | 27/17 | 6 | 0.7178 |
| F1 | 20/15 | 18 | 0.7070 |
| F2 | 31/15 | 1 | 0.7100 |
| Peterson Form | 31/16 | 1 | 0.7093 |
| 8th-order Polynomial | 12/12 | 44 | 0.70~~42~~<br>60 |

# Model Dependence



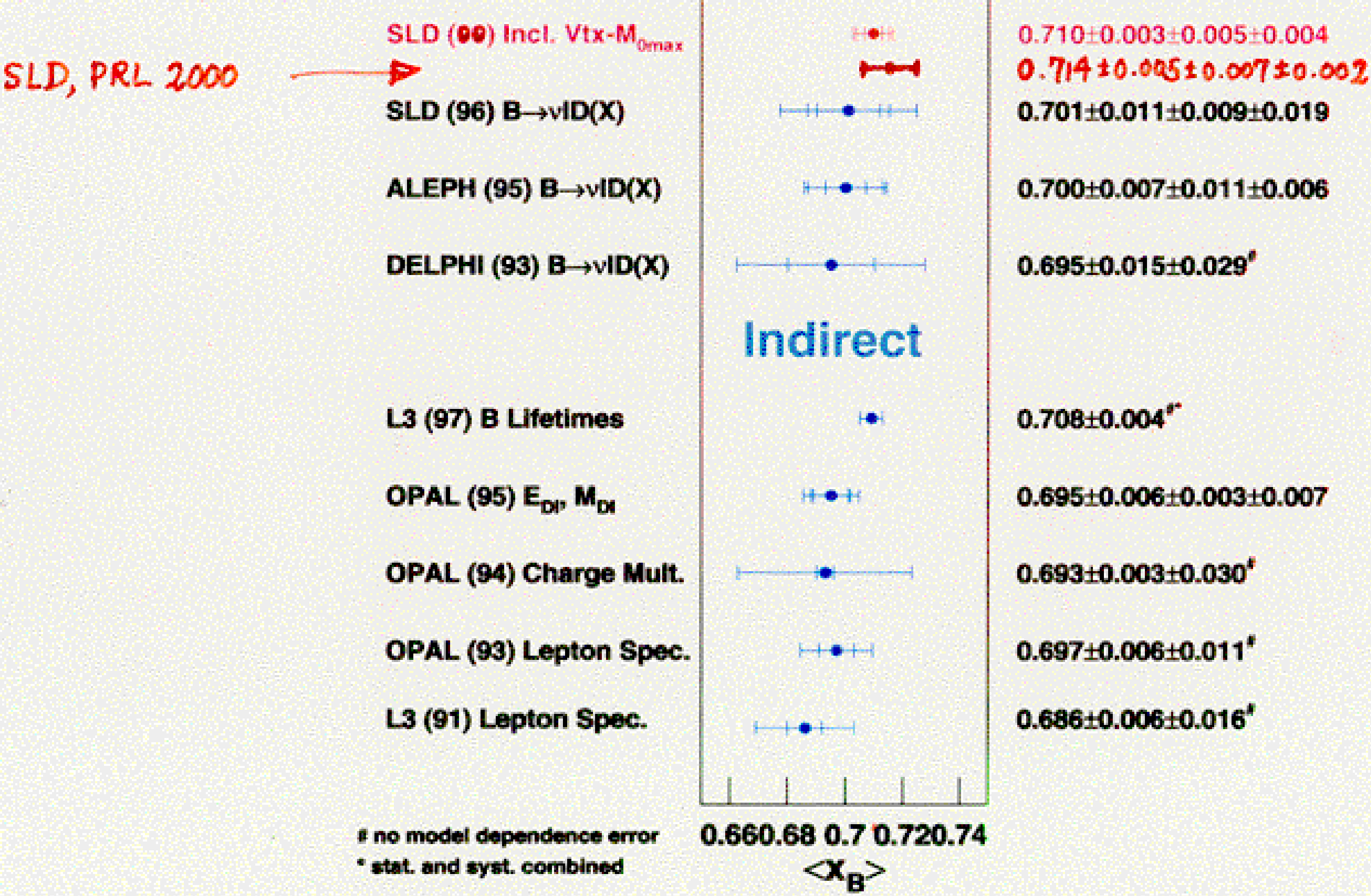

$$\langle x_B \rangle = 0.7098 \pm 0.0030 \pm 0.0048 \pm 0.0037$$

What would you have done ?

# 1997-98 R17 Result

$\langle x_B \rangle = 0.710 \pm 0.003(\text{stat.}) \pm 0.005(\text{syst.}) \pm 0.004(\text{model})$

(Preliminary)



# Conclusions

1) The analysis of 1997-98 data benefited from

   1. Larger data set (350,000 vs 150,000 Z decays)
   2. Improved data reconstruction (R17 vs R15)
   3. Potentially improved b-tagging (work in progress)

2) All conclusions of 1996-97 analysis still hold.

3) New preliminary $\langle x_B \rangle$

$$\langle x_B \rangle = 0.710 \pm 0.003 \text{ (stat.)} \pm 0.005 \text{ (syst.)} \pm 0.004 \text{ (model)}$$

# Plan for Summer Conferences

New preliminary result at ICHEP 2000 in Osaka. (unfolding will be done)

Gavin Nesom will present this new result at DPF 2000.