Study of Spectral Moments in Semileptonic b Decays with the DELPHI Detector at LEP

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Outline:

- Moments of hadronic mass spectrum
- Moments of lepton energy spectrum
- Interpretation

Motivation (I)

- V_{cb}, m_b and m_c are fundamental parameters of the Standard Model which have to be measured by experiments

At present, the best accuracy is achievable in the determination of V_{cb} from inclusive semileptonic b-hadron decays:

$$\Gamma_{sl}(b \to c\ell^-\overline{\upsilon}) = |V_{cb}|^2 f(parameters) = \frac{BR(b \to c\ell^-\overline{\upsilon})}{\tau_b}$$

Evaluated by theory based on O.P.E., few % accuracy

1 % accuracy

Improvement are possible with additional measurements of the characteristics of b-hadron semileptonic decays:

- Moments of hadronic mass spectrum
- Moments of lepton energy spectrum

- Comparison of results from different measurements provides a test of the consistency of O.P.E. predictions and of underlying assumptions

Motivation (II)

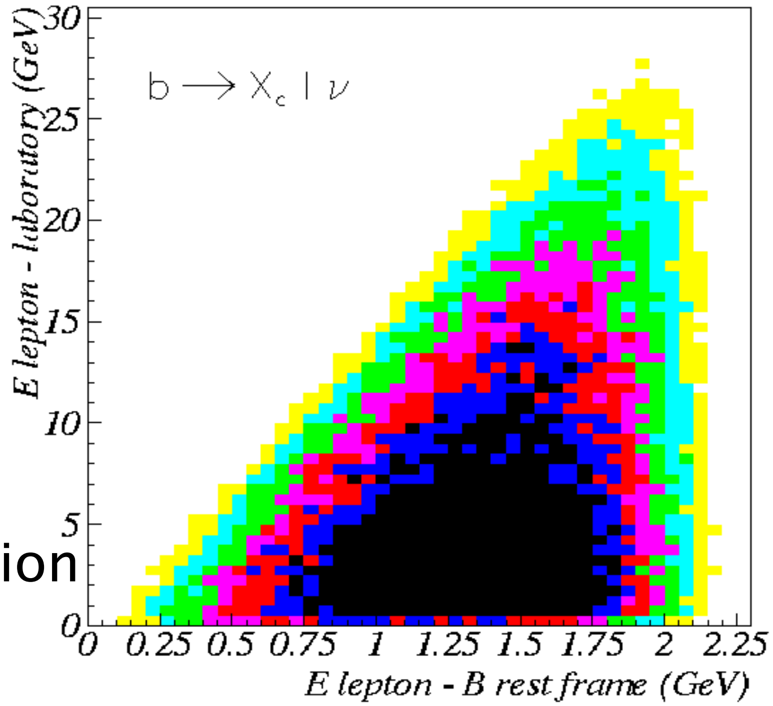
First measurement of spectral moments in semileptonic b decays at the Z^0

- Advantages of Z^0 kinematics:

E_B ~ 30 GeV ⇒ large boost
Use full lepton energy spectrum in the B rest frame

b and $\bar{b}$ in separate hemispheres ($\gamma c\tau$ ~ 2 mm) ⇒ good secondary vertex reconstruction and signal/background separation

- Challenge: complete reconstruction of the B system



Get new insight:

- Use of different theoretical formulations
- Possible use of higher moments

Moments of hadronic mass distribution in b semileptonic decays (I)

- $\bar{B}_d^0 \to D^{**} \ell^- \nu$ exclusively reconstructed in the three channels: $D^{**} \to D^0 \pi^+$, $D^{**} \to D^+ \pi^-$, $D^{**} \to D^{*+} \pi^-$

  with D^0, D^+ and D^{*+} fully reconstructed and $p_\pi > 0.5$ GeV/c

- Leptons with p(Lab)>2 GeV/c

  theoretical expression for the moments with coefficients different wrt analyses with more stringent limits to the lepton phase space region

- Signal/background separation with a discriminant variable based on:
  - presence of additional charged particles at the charm vertex in addition to $D^{(*)}$, ℓ^- and ν
  - π impact parameter, secondary vertex quality etc..

Moments of hadronic mass distribution in b semileptonic decays (II)

D** production rates

$D\pi$ candidates separated in:

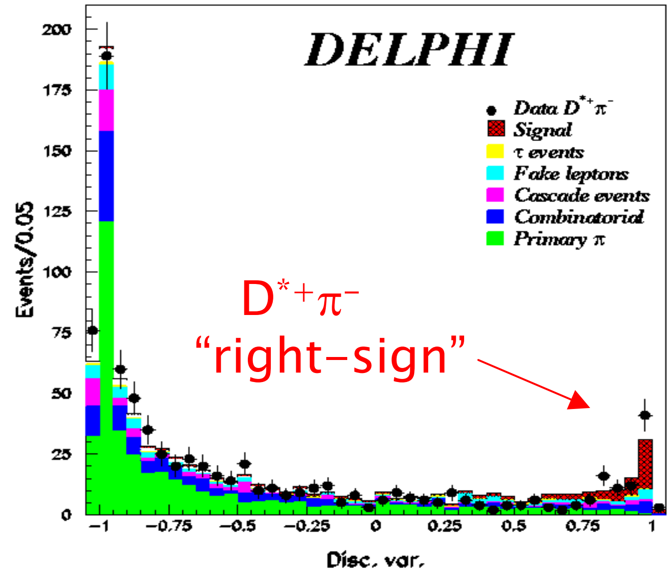
- "right-sign" ($D^0\pi^+$, $D^+\pi^-$, $D^{*+}\pi^-$)
- "wrong-sign" $\rightarrow$ contributions only from $D^{(*)}\pi^+\pi^-$

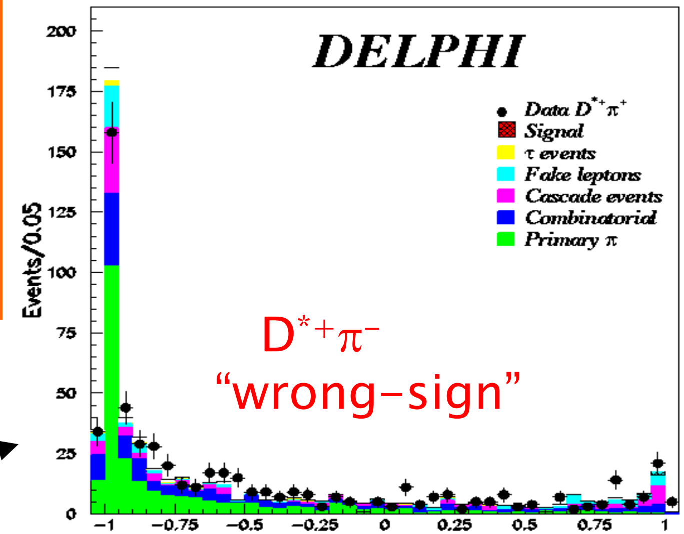
No evidence for signal in $D\pi^+\pi^-$ states:

$$BR(b \to D^0\pi^+\pi^-\ell^-\nu) = BR(b \to D^+\pi^+\pi^-\ell^-\nu)$$

$$< 0.18\% \text{ at } 90\% \text{ C.L.}$$

$$BR(b \to D^{*+}\pi^+\pi^-\ell^-\nu) < 0.17\% \text{ at } 90\% \text{C.L.}$$





Discriminant variable

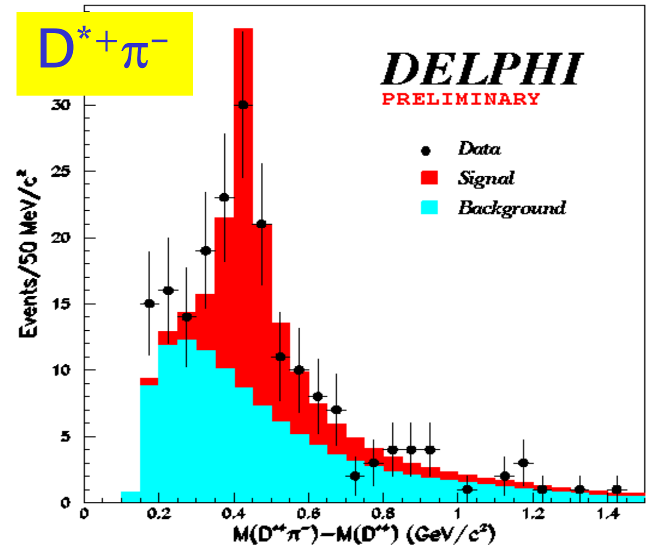
Fit using background distributions from simulation and data

Moments of hadronic mass distribution in b semileptonic decays (III)

Study of the mass distribution of D** states

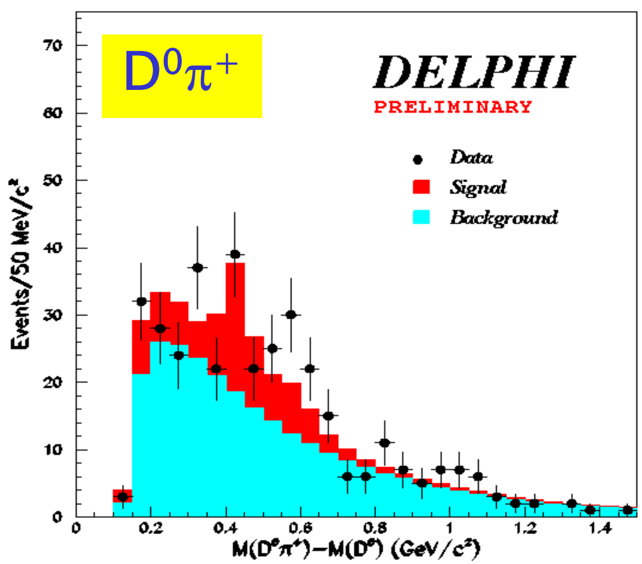
- Fit to $\Delta_m = m(D^{(*)}\pi) - m(D^{(*)})$ distributions considering resonant $D_0^{*+}, D_1^{*+}, D_1^{+}, D_2^{+}$ and non resonant $D\pi$ states

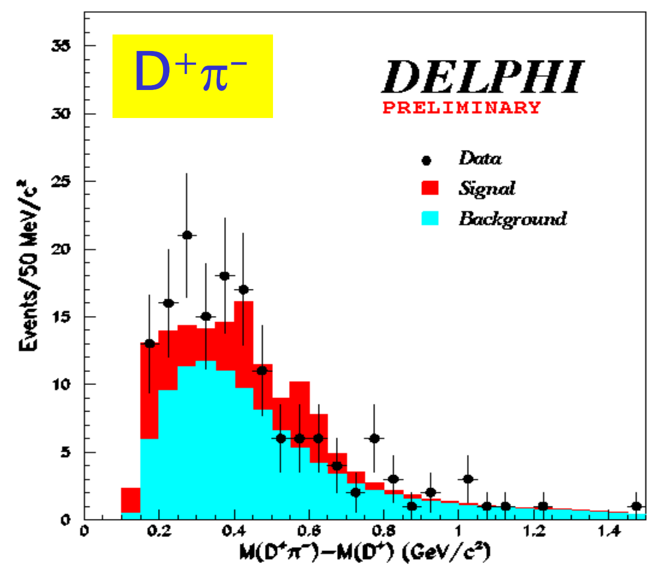
- Evaluate moments from the fitted D** mass distribution: $\langle m^n_{D^{**}} \rangle$



4 MeV resolution for completely reconstructed D π

Plus 4/15 MeV smearing for missing π^0/γ





Moments of hadronic mass distribution in b semileptonic decays (IV)

From the fit:

$BR(\bar{B}^0 \to D^{**}\ell^- \nu)=(2.6 \pm 0.5 \pm 0.4)\%$

with broad D_1^* dominant contributing channel

DELPHI preliminary results

From the measured $<m^n_{D^{**}}>$ and using:

$<m^n_H> = p_D\, m^n_D + p_{D^*}\, m^n_{D^*} + p_{D^{**}} <m^n_{D^{**}}>$ $\qquad p_{D^{**}} = 1 - p_D - p_{D^*}$

derive moments of hadronic mass distribution:

$$M_1 = <m^2_H - m^2_{\bar{D}}> \quad = 0.534 \pm 0.041 \pm 0.074 \text{ GeV}/c^2$$

$$M_2 = <(m^2_H - m^2_{\bar{D}})^2> = 1.51 \pm 0.20 \pm 0.23 \ (\text{GeV}/c^2)^2$$

$$M_2' = <(m^2_H - <m^2_H>)^2> = 1.23 \pm 0.16 \pm 0.15 \ (\text{GeV}/c^2)^2$$

$$M_3' = <(m^2_H - <m^2_H>)^3> = 2.97 \pm 0.67 \pm 0.48 \ (\text{GeV}/c^2)^3$$

Moments of lepton spectrum in b s.l. decays (I)

Inclusive semileptonic B decay reconstruction

- Select $Z^0 \rightarrow b\bar{b}$ events with b-tag algorithm
- Reconstruct the B system:

✦ $E(B) = E(\text{vertex}) + E(\ell) + E(\nu)$

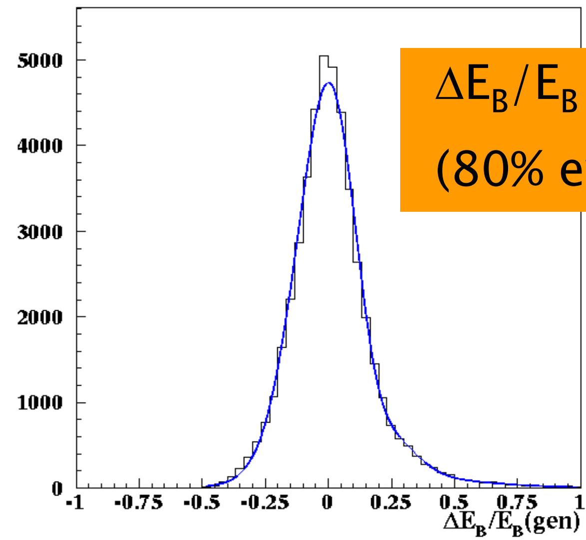
Charm vertex reconstruction with iterative procedure

from missing energy $\Delta E_\nu = 3.2$ GeV

✦ B direction from B reconstructed momentum and B decay flight direction

- Tag leptons

muons ($p > 2.5$GeV/c)
electrons ($p > 3$GeV/c)



$\Delta E_B / E_B = 12\%$

(80% evts)

- Boost lepton in B rest frame

$\Delta E^*_{\text{lepton}} \approx 250$ MeV

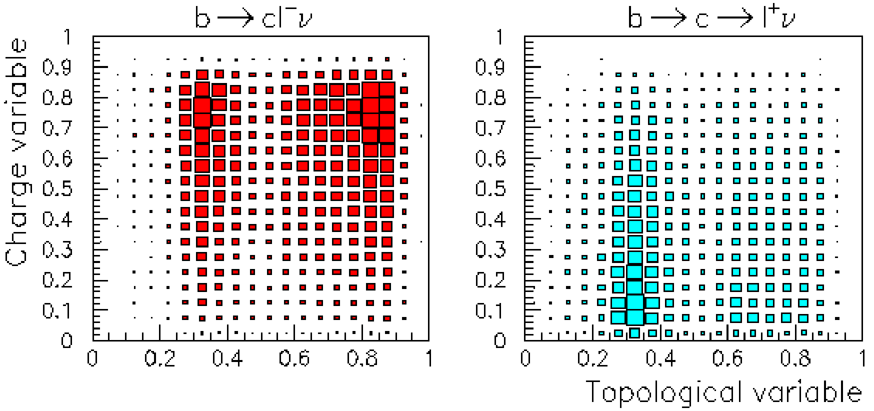
Moments of lepton spectrum in b s.l. decays (II)

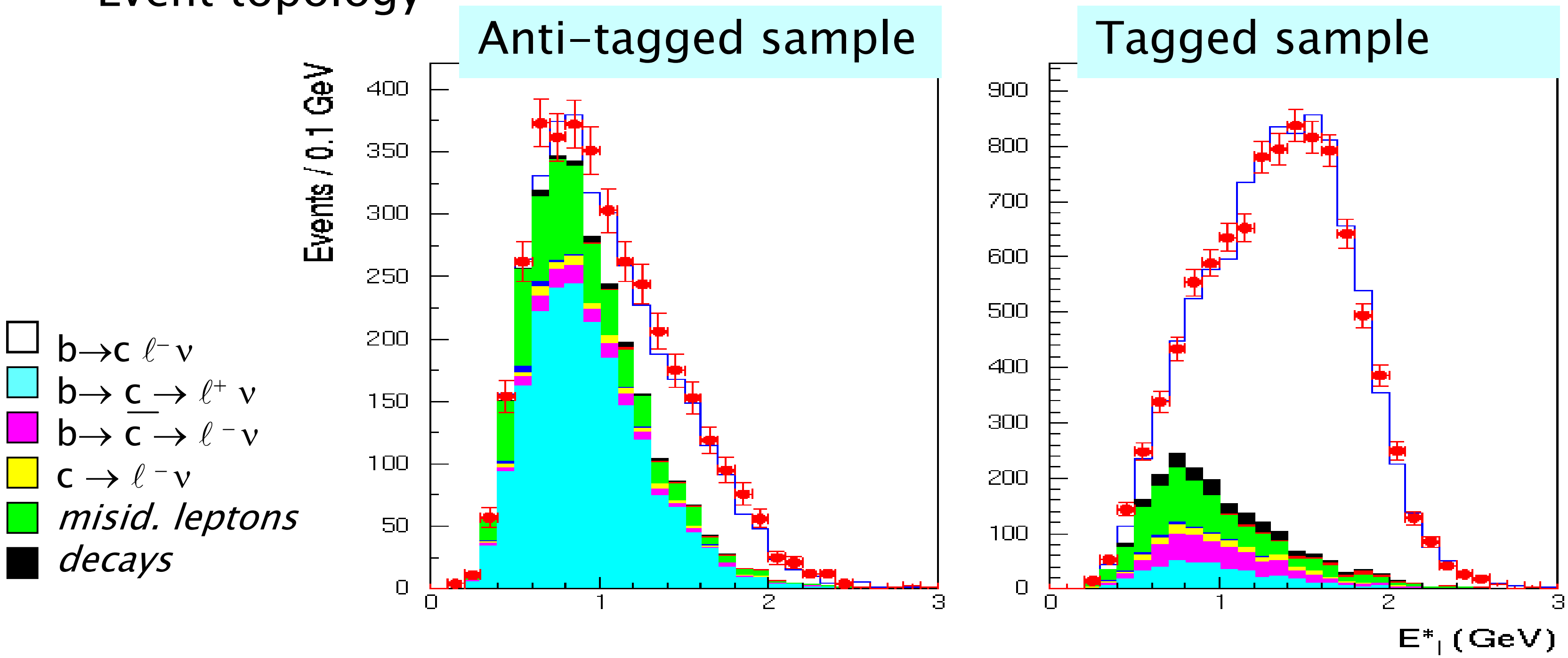
Background reduction

Without introducing a bias to the lepton energy distribution

Use combination of 2 sets of probabilistic variables based on:

- Charge correlation
- Event topology



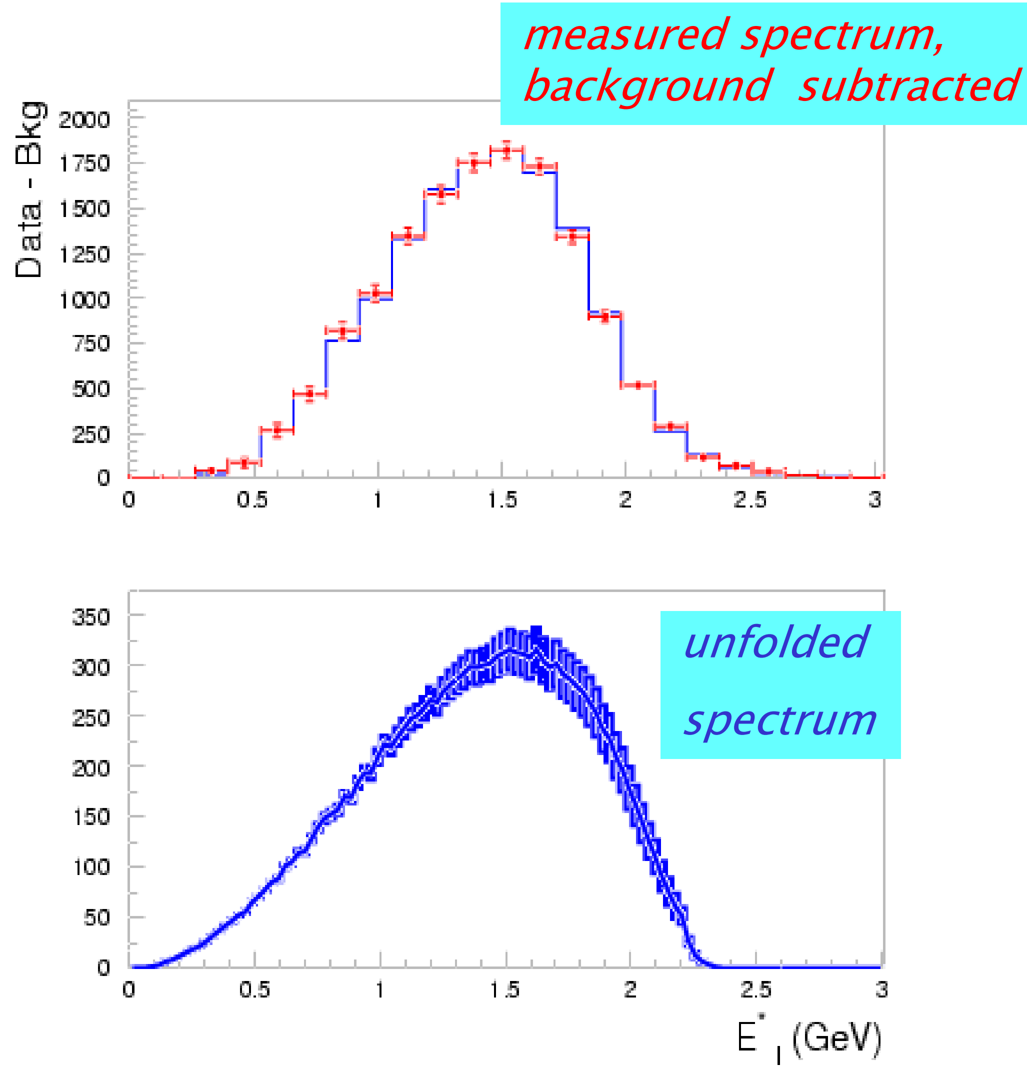


Moments of lepton spectrum in b s.l. decays (III)

Lepton energy spectrum measurement

- ★ Unfold resolution effects to get original spectra
- ★ Correct for:
  - e.m. radiation
  - $b \rightarrow u \ell \nu$ contribution
  - B^0_s and Λ_b contribution

  $\Rightarrow$ 1-3 MeV shifts
- ★ 18,300 electrons+ muons from 1994/95 data



Moments of lepton spectrum in b s.l. decays (IV)

Preliminary DELPHI results:

$<E_\ell> = (1.383 \pm 0.012\,\textit{(stat.)} \pm 0.009\,\textit{(syst.)})$ GeV

$<(E_\ell - <E_\ell>)^2> = (0.192 \pm 0.005\,\textit{(stat.)} \pm 0.008\,\textit{(syst.)})$ GeV^2

$<(E_\ell - <E_\ell>)^3> = (-0.029 \pm 0.005\,\textit{(stat.)} \pm 0.006\,\textit{(syst.)})$ GeV^3

- Stability of the result checked wrt e/μ samples and different working points

Preliminary systematic uncertainty from:

- Monte Carlo modelling: B_d,B_s,Λ_b fractions; D,D*,D** fractions, b fragmentation
- Background subtraction (controlled with anti-tagged lepton sample)
- Unfolding procedure and lepton energy resolution

Interpretation of the measurements

Moments of hadronic mass spectrum and of lepton energy spectrum are sensitive to the nonperturbative parameters of the Heavy Quark Expansion.

At order $1/m_b^2 \Rightarrow \bar{\Lambda}, \lambda_1, \lambda_2$ ($\lambda_2 \approx 0.12$ GeV^2). At order $1/m_b^3 \Rightarrow \rho_1, \rho_2, T_{1-4}$

Two different approaches have been followed in this analysis:

1) Pole mass expansions $M_n = f_n(\lambda_1, \bar{\Lambda}, \lambda_2, T_1, T_2, ..)$

(A.F.Falk, M.Luke and P.Gambino for lepton spectra)

2) Running quark masses $M_n = f_n(\mu_\pi^2, m_b(1GeV), \mu_G^2, \rho_D^3, \rho_{LS}^3, ..)$

(M.Voloshin and N.Uraltsev for $\beta_0\alpha_s^2$ and $1/m_b^3$ corrections)

$$M_n = \frac{m_b^n(\mu)}{2^n}\phi_n(r)\left(1 + A_{pert}(r,\mu) + \frac{\mu_\pi^2}{m_b^2(\mu)}B(r) + \frac{\mu_G^2}{m_b^2(\mu)}C(r) + \frac{\rho_D^3}{m_b^3(\mu)}D(r) + \frac{\rho_{LS}^3}{m_b^3(\mu)}E(r)\right)$$

with:

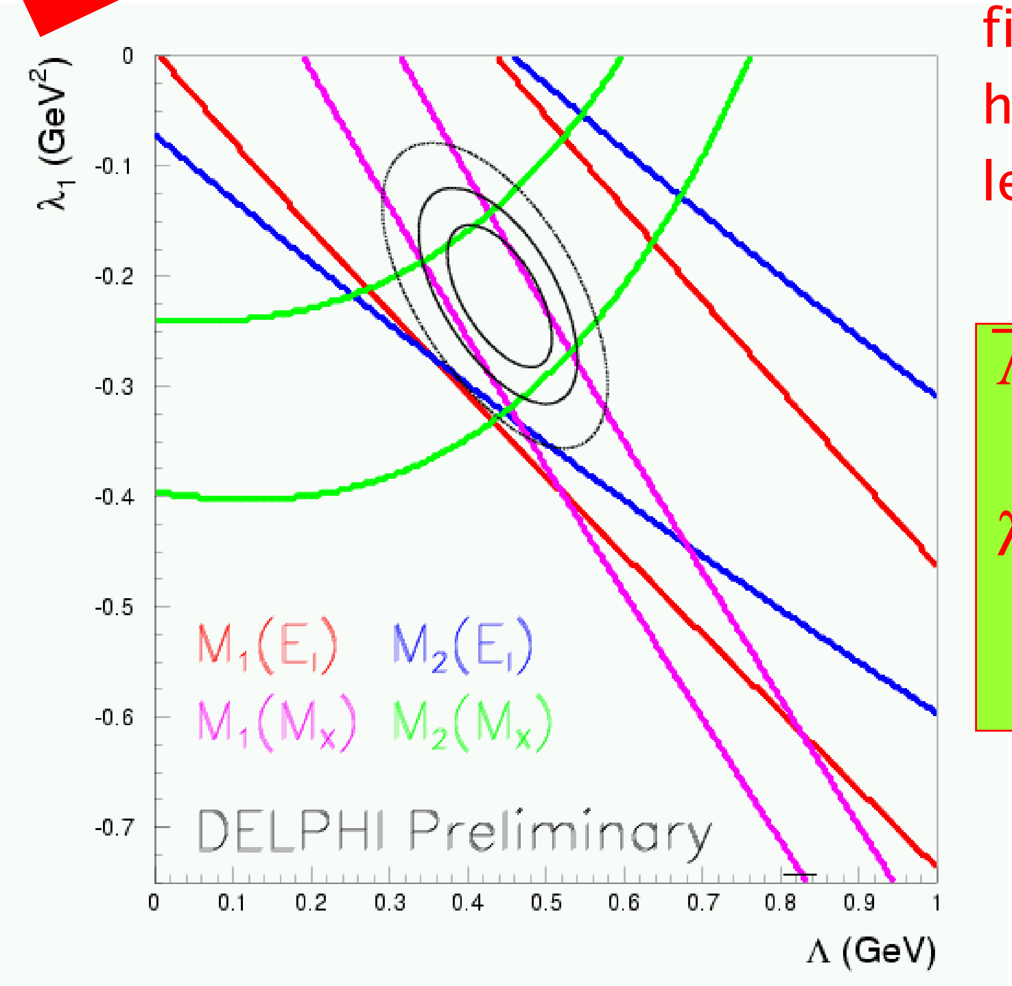
$$r = \frac{m_c^2(\mu)}{m_b^2(\mu)}$$

Mass expansion:

$$m_{b,c}(\mu) = M_{B,D} - \bar{\Lambda}(\mu) - \frac{\mu_\pi^2 - \mu_G^2}{2m_b(\mu)} - \frac{\rho_D^3 - \rho_{LS}^3}{4m_b^2(\mu)} - \delta_{B,D}$$

Constraints to $\bar{\Lambda}$ and λ_1

DELPHI preliminary results



Constraints to λ_1 and $\bar{\Lambda}$ from first and second moment of hadronic mass spectrum and lepton energy spectrum

$\bar{\Lambda}$ = (0.44 ± 0.07 *(exp.)* ± 0.07 *(1/m_b^3,α_s)*) GeV

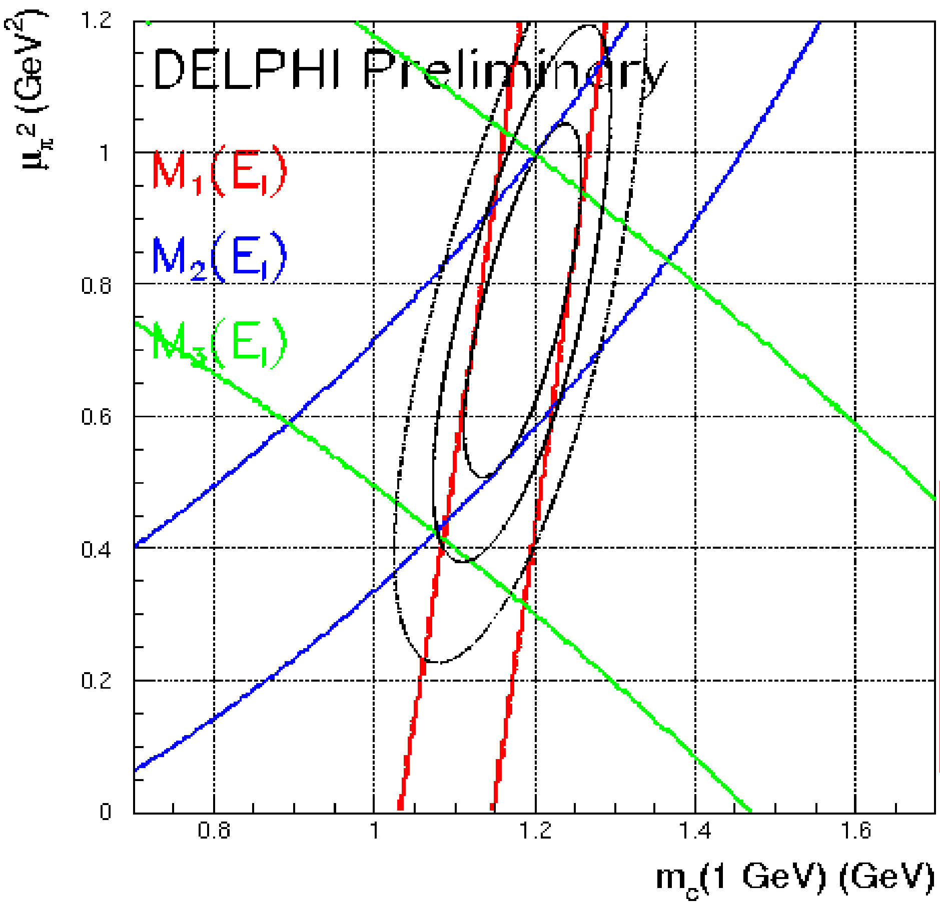
λ_1 =(−0.23 ± 0.07 *(exp.)* ± 0.08 *(1/m_b^3,α_s)*) GeV^2

ρ_1=(0.−0.5^3) GeV^3

ρ_2= T_i=(−0.5^3,0.5^3) GeV^3

Constraints to m_c(1GeV) and μ_π^2

DELPHI preliminary results



Use the correlation between m_b and m_c:

Fix bottom mass from external measurements:

m_b = 4.60 ± 0.05 GeV

and extract m_c :

m_c*(1GeV)* = (1.19
± 0.07 *(exp.)*
± 0.07 *(m_b)*
± 0.04 *(ρ_D^3)*) GeV

CONCLUSIONS

- Measurement of the first three moments of hadronic mass distribution and lepton energy spectrum in semileptonic b decays at the Z^0 has been performed for the first time.

- Comparison with calculations for non-truncated spectra are satisfactory

- Constraints on non-perturbative parameters of Heavy Quark Expansion have been derived