Measurements of $B \to X_c \ell \nu$ Decays

Vera Lüth, SLAC

BABAR Collaboration

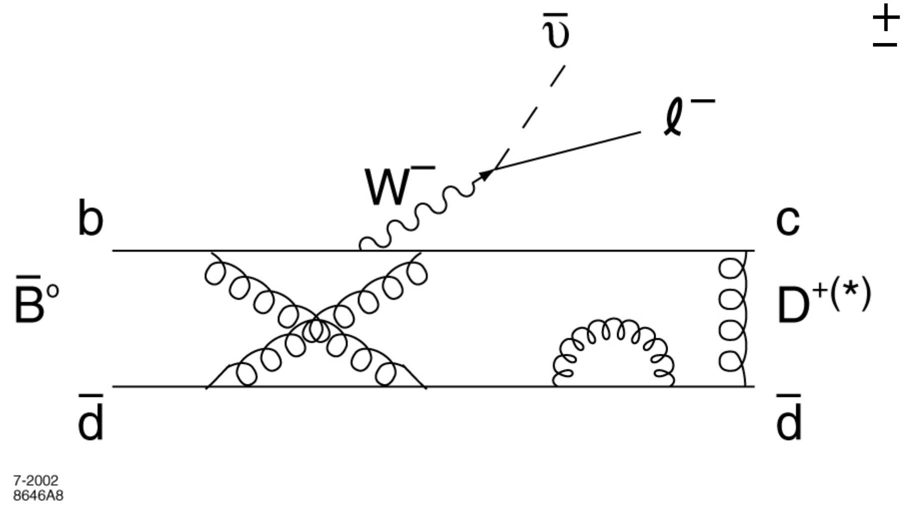
Inclusive BR ($B \to X_c \ell \nu$) and $|V_{cb}|$

Hadronic Mass Moments

(Preliminary Measurement)

Semileptonic B Decays

- Semileptonic decays are
  - relatively simple theoretically at the parton level
  - accessible experimentally
  - sensitive to quark couplings to $W^{\pm}$,
    i.e. CKM elements $|V_{cb}|$ and $|V_{ub}|$
  - probe the dynamics of decays
  - probe impact of strong interactions

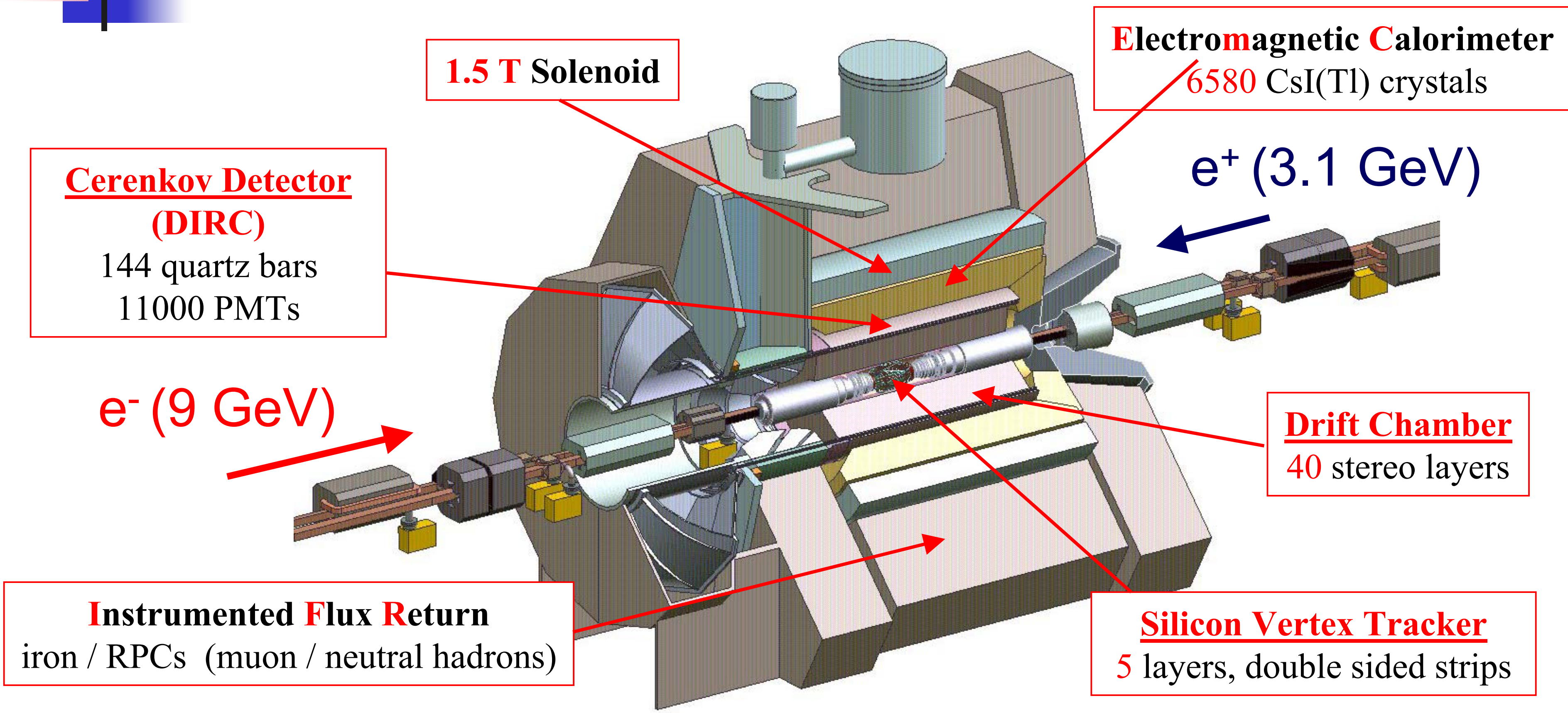


- BR for semileptonic B decays can be related to |Vcb|

$$\Gamma_{sl}^{c} \equiv B\,(B \rightarrow X_c \ell \upsilon)\,/\,\tau_B = \gamma_c |V_{cb}|$$

- γ_c requires theoretical input (perturbative and non-perturbative)
- We try to measure other inclusive variables, like mass distributions, to extract more information

The BaBar Detector



SVT: 97% efficiency, 15 μm z hit resolution (inner layers, perp. tracks)

SVT+DCH: $\sigma(p_T)/p_T = 0.13\ \% \times p_T + 0.45\ \%$

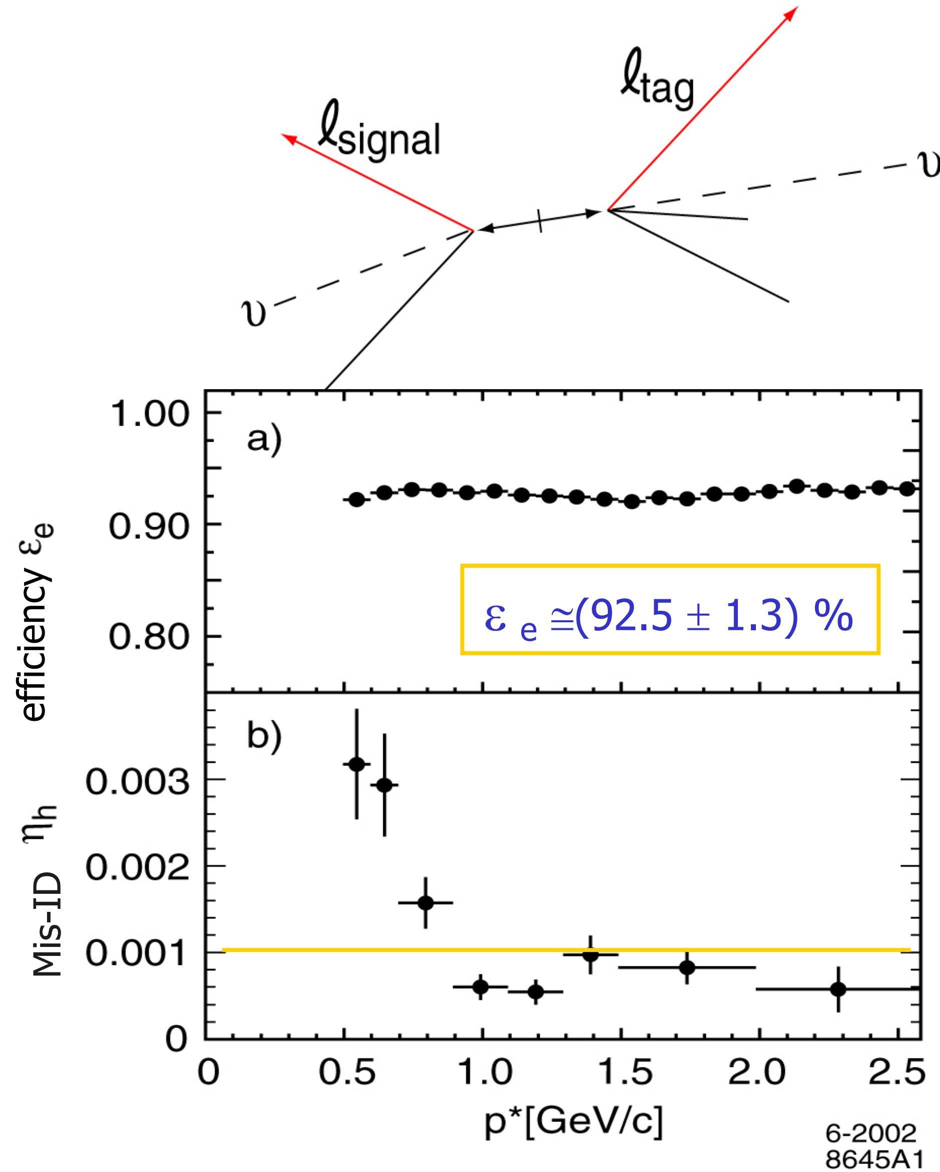
DIRC: K-π separation 4.2σ @ 3.0 GeV/c → >3.0σ @ 4.0 GeV/c

EMC: $\sigma_E/E = 2.3\ \% \cdot E^{-1/4} \oplus 1.9\ \%$

Inclusive Electrons with Electron Tags

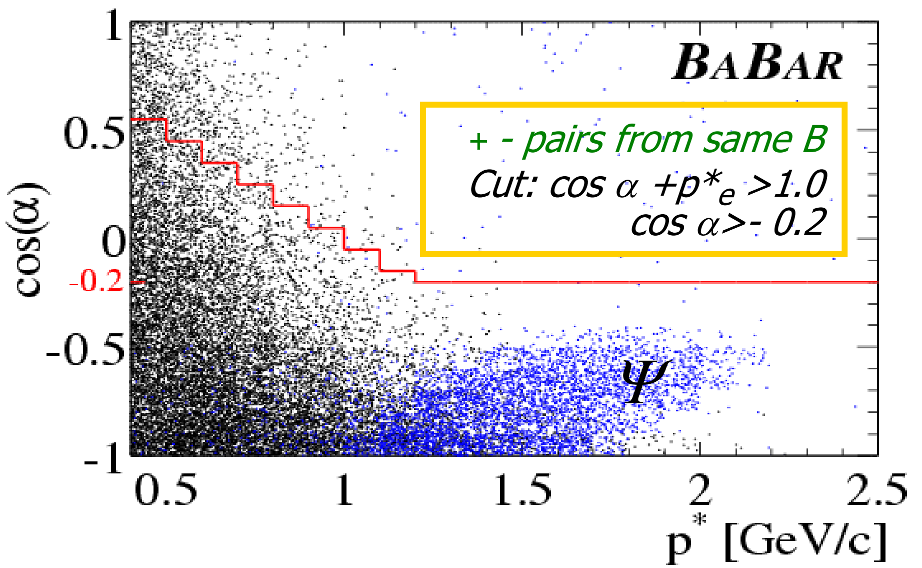
- Analysis based on small sample:
  4/fb on Y(4s), 1/fb off Y(4s)
- Data Selection
  - Electron tag: p^{cms} >1.4 GeV/c
  - Electron signal: p^{cms} > 0.6 GeV/c
  - Electron ID:

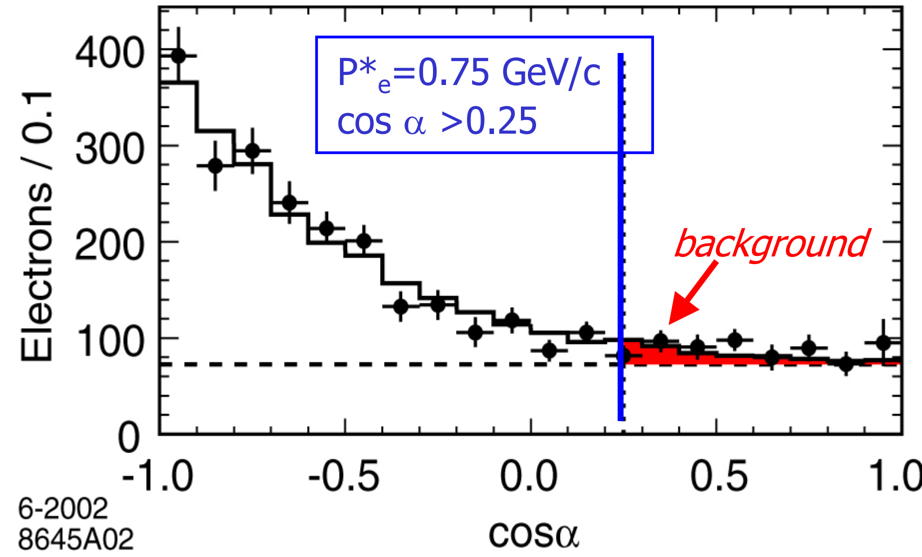
    Combined likelihood based on:
    - Electromagnetic Calorimeter
      (E/p, shower shape)
    - DIRC
      (Cherenkov angle, # of photons)
    - Driftchamber
      (dE/dx)
- Two signal samples:
  - Right sign: + -
  - Wrong sign: ++ or - -



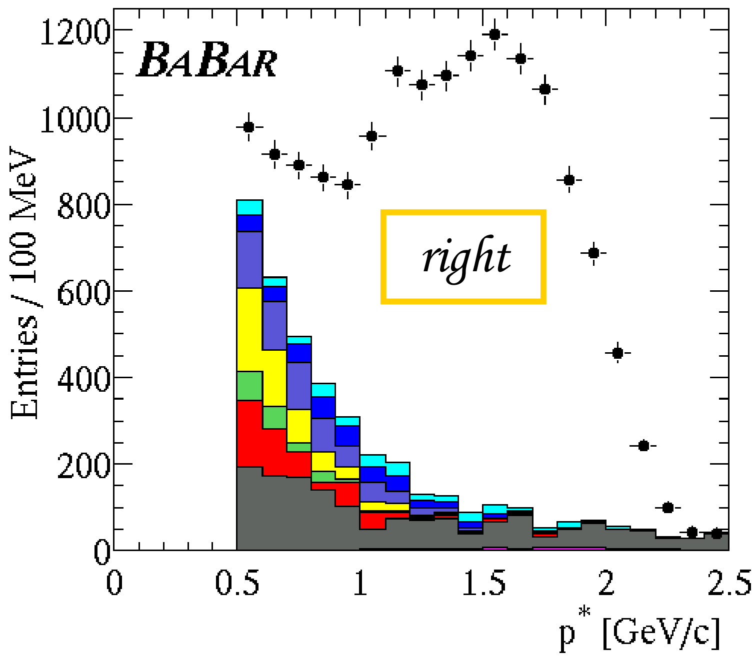
Electron Tagged Sample : Background

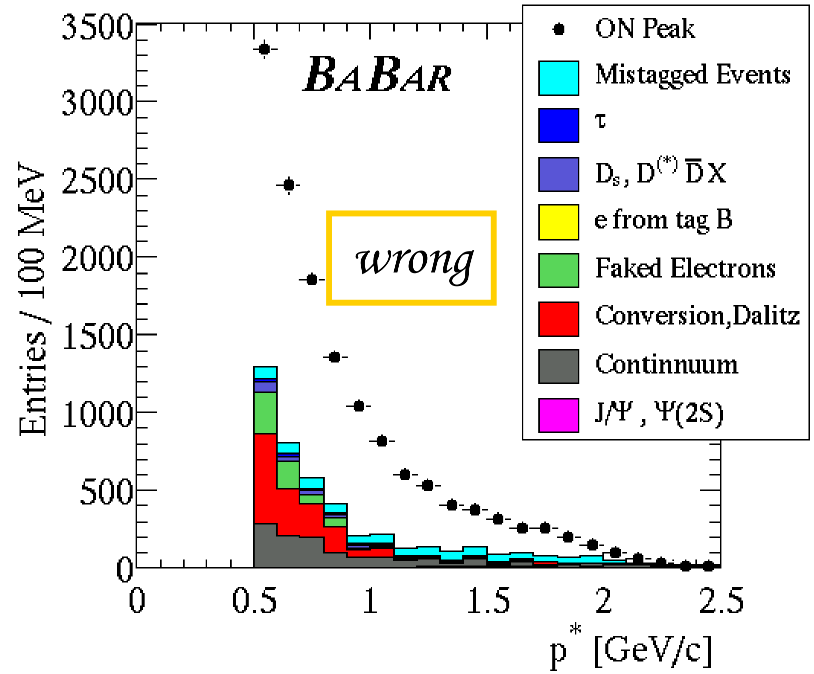
- Principal $e^{\pm}$ Backgrounds
  - Conversion/Dalitz pairs
  - Hadron mis-ID
  - Continuum background
- Physics background
  - Secondary electrons from other B:
    - $b \to c \to e^+$
    - $b \to \tau^- \to e^-$, $b \to c\, cs \to e^-$
  - Secondary electrons from same B
  - charmonium
    - $B \to \psi \to e^+e^-$
  - B – B Mixing
  - Secondary tag electrons





Right- and Wrong Sign Spectra





- Mixing ⇒ both spectra contain prompt and secondary $e^{\pm}$
  - with ε_{oa} = Efficiency of cut on opening angle α:

$$\frac{dN_{right-sign}}{dp^*} = \varepsilon_{oa}(p^*)\left[\frac{dN_{prompt}}{dp^*}(1-f_0\chi_0) + \frac{dN_{secondary}}{dp^*} f_0\chi_0\right]$$

$$\frac{dN_{wrong-sign}}{dp^*} = \left[\frac{dN_{prompt}}{dp^*} f_0\chi_0 + \frac{dN_{secondary}}{dp^*}(1-f_0\chi_0)\right]$$

$\Rightarrow N_{prompt}=25{,}070$

(after correction for electron and tracking efficiency)

Fully Corrected Electron Spectrum

- Corrections of prompt spectrum:
  - external bremsstrahlung
    2.20 ± 0.35%
  - geom. acceptance 84%

nce 84%

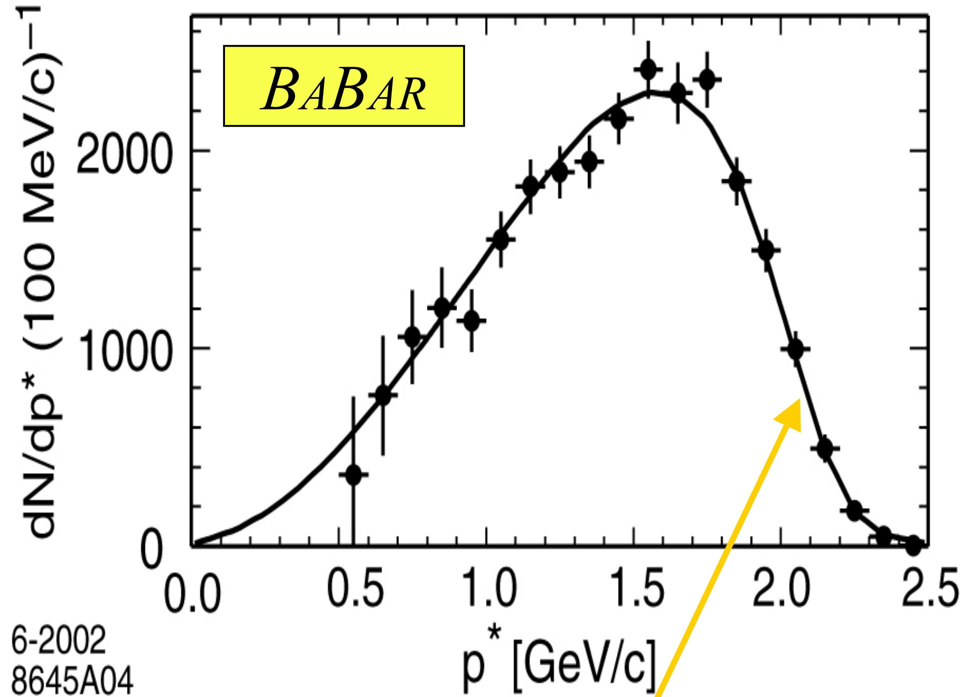
ton eff. 98%

on signal

n signal

n tags:

- Extrapolation to p = 0:
  correction: 6.1± 0.9%



Fit to sum of spectra from:
$B \to D\, e\, \nu$, $D^{*}\, e\, \nu$,
$D^{**}\, e\, \nu$, $D^{(*)}\, \pi\, e\, \nu$

Semileptonic Branching Ratio and $|V_{cb}|$

- Integration over spectrum & extrapolation to $p_\ell^*=0$:

$$BR(B\to X\, e\, \nu) = (10.87 \pm 0.18_{stat} \pm 0.30_{sys})\%$$

- ARGUS : (9.7 ±0.5 ±0.4)%
- CLEO2: (10.49 ±0.17 ±0.43)%
- BELLE : (10.90 ±0.12 ±0.49)%
- OPAL: (10.78 ±0.08 ±0.5)%
- L3: (10.89 ±0.20 ±0.51)%
- ALEPH: (10.70 ±0.10 ±0.35)%

- Relation to $|V_{cb}|$ (A. Hoang, Z. Ligeti, A.V.Monahar) [1] :

$$|V_{cb}| = 0.0419\sqrt{\frac{B(B\to X_c \ell \upsilon}{0.105}\frac{1.6\,ps}{\tau_B}}(1.0 \pm 0.019_{pert} \pm 0.017_{\lambda_1} \pm 0.012_{m_b})$$

- With $\tau_B=(1.601\pm0.022)$ps, and $BR(B\to X_u\, e\, \nu) = (1.7\pm0.5)\ 10^{-3}$

$$|V_{cb}| = 0.0423 \pm 0.0017_{exp} \pm 0.0020_{theory}$$

N.B. the theoretical errors have been added linearly

[1] Phys. Rev. Lett. 82 (1999) 591.

OPE Parameters and Mass Moments

- Parameterization of decay rate in terms of Operator Product Expansion in HQET in powers of $\alpha_s(m_b)\beta_0$ and Λ/m_B:

$$\Gamma_{sl} = \frac{G_F^2|V_{cb}|^2}{192\pi^3} m_B^5 c_1 \left\{1 - c_2 \frac{\alpha_s}{\pi} + \frac{c_3}{m_B}\bar{\Lambda}(1 - c_4 \frac{\alpha_s}{\pi}) + \frac{c_5}{m_B^2}(\bar{\Lambda}^2 + c_6\lambda_1 + c_7\lambda_2) + O(\frac{1}{m_B^3}) + O(\frac{\alpha_s^2}{\pi}) \cdots \right\}$$

- Λ, λ_1, λ_2, are non-perturbative parameters
  - λ_1 (-) kinetic energy of the motion of the b-quark
  - λ_2 chromo-magnetic coupling of b-quark spin to gluon
    from B*-B mass difference, λ_2=0. 12GeV^2
  - $\Lambda = m_B - m_b + (\lambda_1 - 3\lambda_2)/2m_B$ …
  - Additional parameters enter at higher orders (ρ_1, ρ_2, τ_1, τ_2, τ_3, τ_4)
    use theoretical estimates

- Similar expressions for moments of hadron mass spectrum or the lepton energy spectrum

- Coefficients c_i (not dependent on quark masses) can be calculated, as a function of the minimum lepton momentum (Luke, Falk) [1]

[1] PR D57, 424 (1998)

Definition of Mass Moments

- First hadron mass moment

$< M_X^2 - M_{Dspin}^2 >$

$= f_D (M_D^2 - M_{Dspin}^2)$

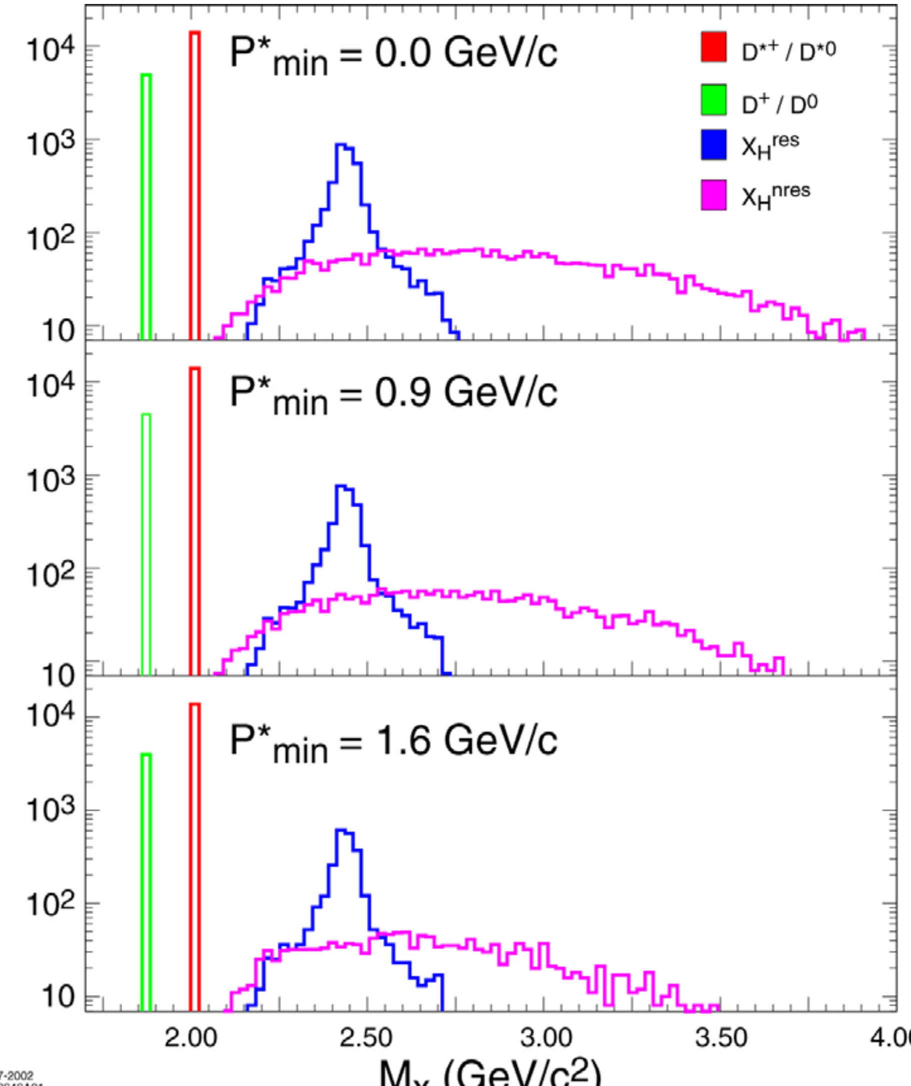
$+ f_{D*} (M_{D*}^2 - M_{Dspin}^2)$

$+ f_{XH} < M_{XH}^2 - M_{Dspin}^2 >$

f: fractions obtained by fit to data

$M_{Dspin} = (m_D + 3m_{D*})/4 = 1.975$ GeV/c²

Decay Mode	<Mass>	$f_{p*min=0}$	Model
D l ν	1.867	≈0.20	ISGW2
D* l ν	2.009	≈0.50	HQET-FF
X_H^{res} l ν	≈2.40	≈0.21	ISGW2
$X_H^{non-res}$ l ν	≈2.86	≈0.16	P.S.

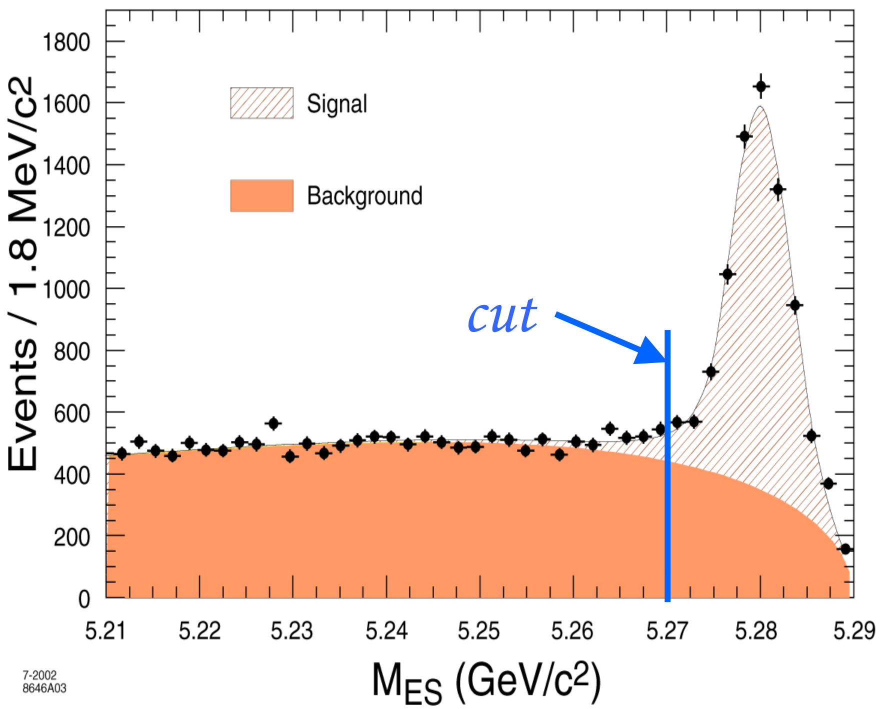


Event Selection

- Data set: 55 M BB events
- Analysis based on events with one fully hadronic B decay
  - $B \rightarrow D\, Y^{\pm}$ with $D=(D^0, D^+, D^{*0}, D^{*+})$ and $Y^{\pm}=(n_1\pi^{\pm}, n_2K^{\pm}, n_3K_S, n_4\pi^0)$
  - Select candidates

$$|\Delta E| = \left| E_B^* - E_{beam}^* \right| < 3\sigma_{\Delta E}$$

$$M_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}} > 5.27 GeV/c^2$$



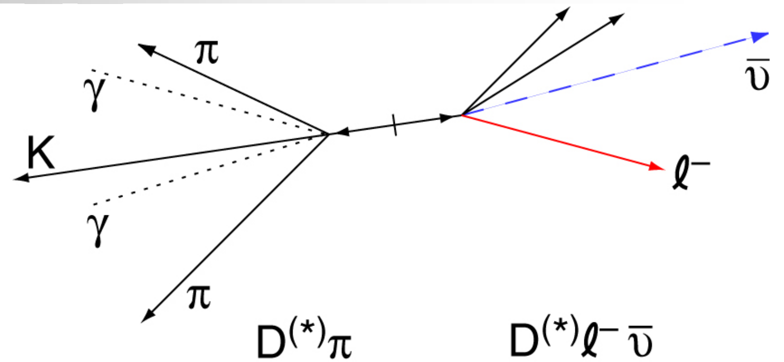
- The events are further selected
  - ≥ 1 e or μ with $p^* > 0.9$ GeV/c
  - $|Q| \leq 1$
  - $Q_l = Q_B$ for $B^{\pm}$
  - $|M_{miss}^{\ 2}| < 1.0\ GeV^2$
- Final Sample

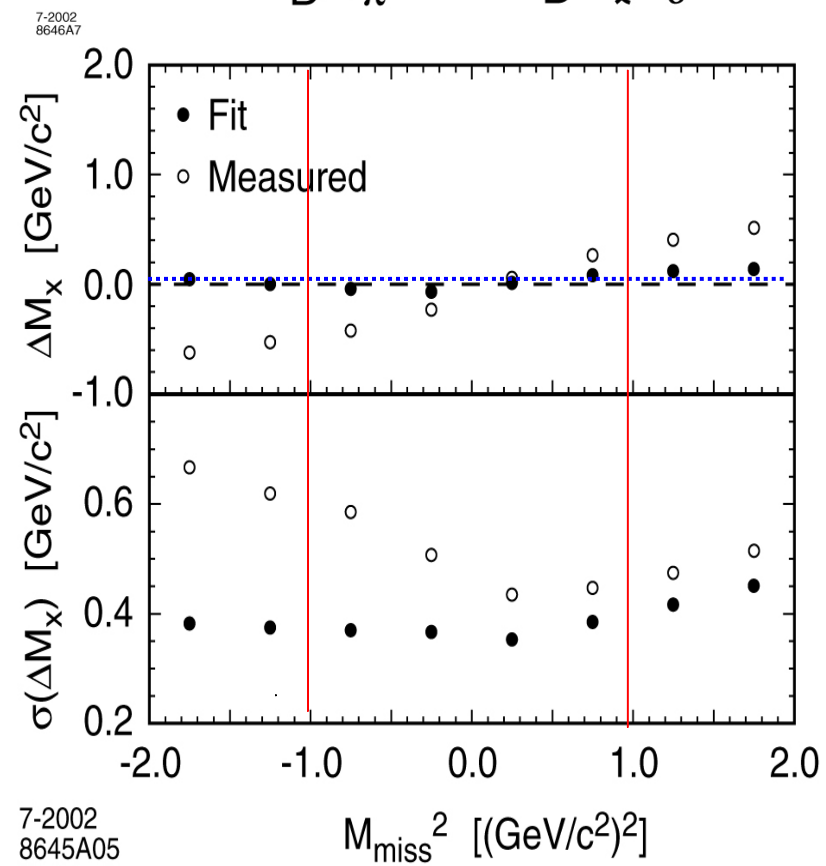
  5819 Signal Events, 3585 Background

Kinematic Fits to Events

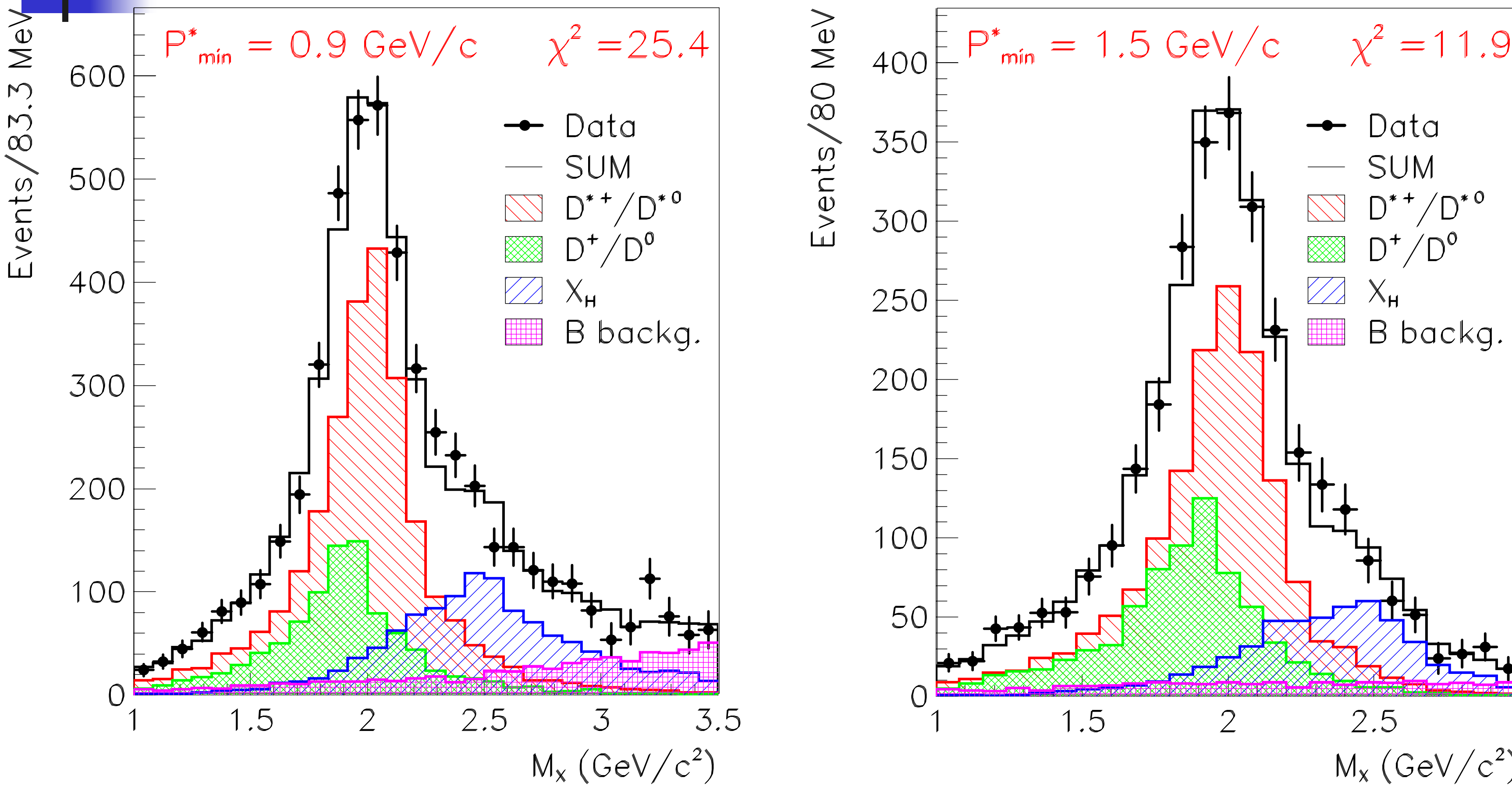
- A 2-C kinematic fit is performed to the whole event
  - $B_1 \to D\ Y$
  - $B_2 \to X\ l\ \nu$
- Constraints of energy-momentum conservation
  - $|M_{miss}^2| = 0$
  - $M_1 = M_2$

  Fit relies on event-by-event errors of measured particles and M_{miss}^2.
- The fit improves the resolution and reduces the need to reconstruct all final state particles
- The fitted M_X is largely bias free





Fit to M_x Distribution



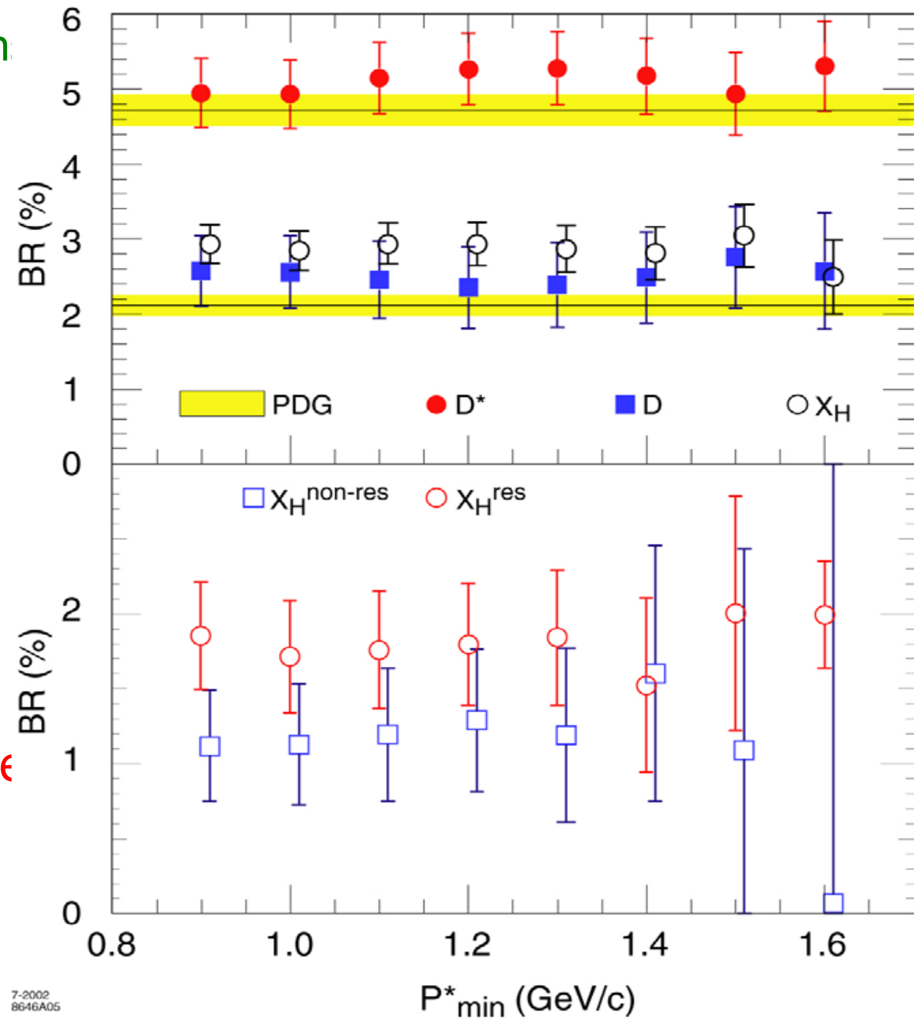
Binned χ^2 fit to M_X Distribution: 4 Contributions

$$D = f_D P_D + f_{D*} P_{D*} + f_{HX} P_{HX} + f_{BG}(\text{fixed}) P_{BG}$$

Cross Checks of Fit to M_X

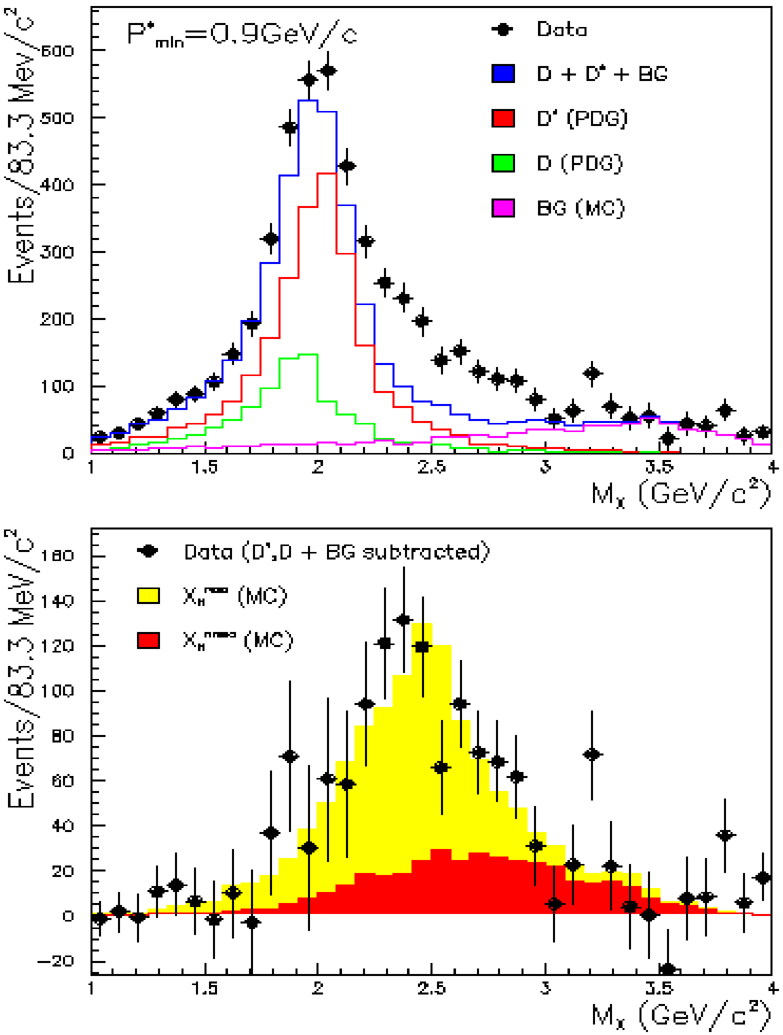
- Multiple checks – vary fit input
  - branching fractions of high mass resonance and non-resonant contribution
  - Background levels, M_{miss}^2 cut
  - M_{ES} sideband subtractions
  - Sample purity
- Check subsamples,
  - e vs μ
  - B^0 vs B^+
  - sample purity
- Translate fraction f into BR
  - standard 3 distributions
  - split M_{XH} into M_{XH}^{res} and $M_{XH}^{non-res}$
- Observed variations are basis of estimate for systematic errors
- Data highly correlated in p^*_{min}

Branching Fractions



Check of High Mass Charm States

- Largest systematic uncertaintes are the high mass charm states, both resonant and non-resonant
- Estimate contribution from data:
  - assume PDG BR for D l ν and D*l ν
  - fix background
  - Subtract these contributions from data
  - Resultant distribution is fully compatible with MC prediction
  - The mean is consistent with the mean M_X used in the determination of the moments!



NB distribution not corrected for detector effects.

Extraction of HQET Parameter λ_1 and Λ

- Strong dependence of moments on p^*_{min}
- For p^*_{min}=1.5 GeV/c and
  Λ=0.35 ± 0.13 GeV [1]
  (reliance on $b \to s\gamma$ spectrum)

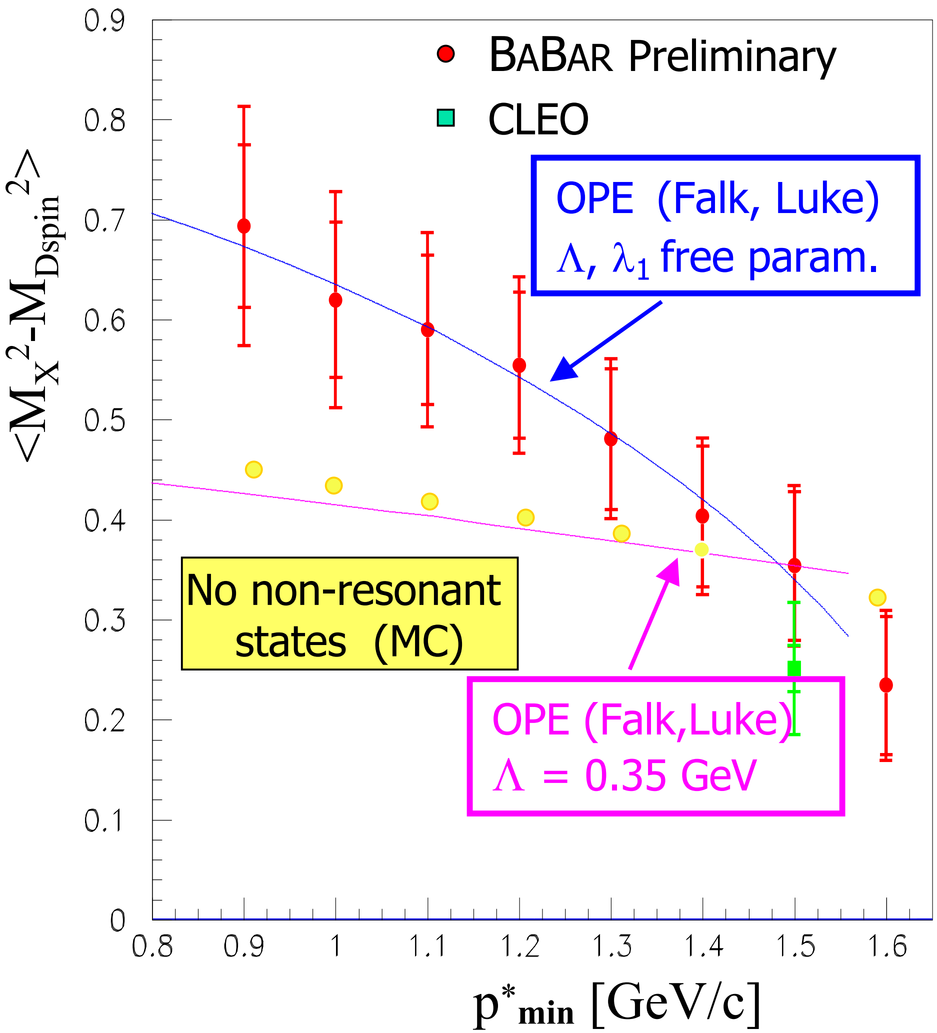
$$\lambda_1 = -0.17 \pm 0.06 \pm 0.07 \text{GeV}^2$$

CLEO [1]

λ_1= - 0.226 ± 0.07 ± 0.08 GeV²

But
these parameters do not describe
P* dependence of the moments!

$$\lambda_1(0.9 \text{ GeV/c}) - \lambda_1(1.5 \text{ GeV/c}) = 0.22 \pm 0.04 \pm 0.05 \text{ GeV}^2$$



NB: Data points highly correlated

[1] CLEO PRL 87, 251808 (2001)

Summary

- From an electron tagged sample of BB events BABAR measured
  - BR = $(10.87 \pm 0.18_{stat} \pm 0.30_{syst})\%$
  - $|Vcb| = 0.0423 \pm 0.0017_{exp} \pm 0.0020_{theory}$
  - These measurements agree well with previous measurements

- From a B tagged sample of BB events BABAR measured the hadronic mass spectrum down to lepton momenta of p*=0.9 GeV/c.

- Observe a strong rise as p* decreases, this is attributed to high-mass, non-resonant D(*) π states

- Momentum dependence of moments not consistent with Λ measurements from $b \rightarrow s\,\gamma$, but can be described by HQE with other values of Λ.

- Measurement for p*>1.5 GeV/c, fully consistent with Λ =0.35±0.07GeV

  λ_1= - 0.17 ± 0.06 ±0.07GeV^2

Outlook

- More data and more detailed studies of higher moments expected
  - Extend measurements to lower p^{*}_{min}
  - Differential measurements
  - Higher moments of hadronic mass distributions
  - Moments of lepton momentum in lepton tagged and fully tagged B events
  - Photon spectrum in $b \to s \gamma$
  - Also studies of $b \to u \, l \, \nu$
- Measurements of exclusive BR in progress
- We are looking forward to these new measurements, more data, and a full assessment of uncertainties.