# Recent Results from CLEO

## SLAC Summer Institute Topical Conference

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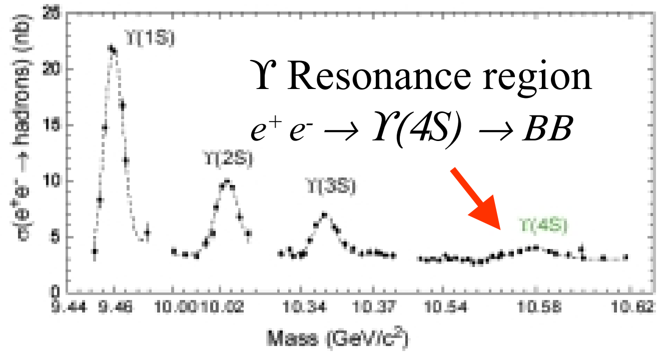
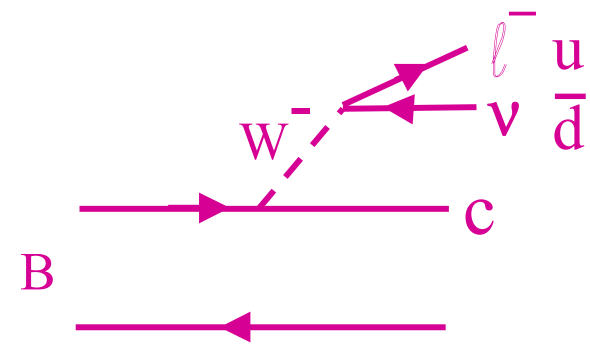
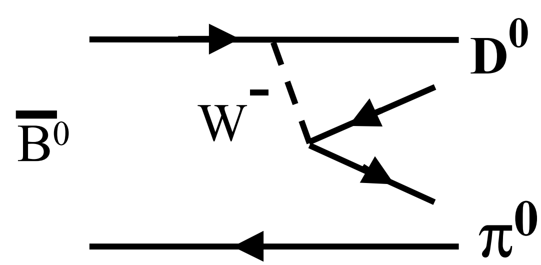
# Outline

* CLEO at CESR
* $V_{cb}$ and $V_{ub}$ from Semi-Leptonic B decays
* Rare B decays $B \to K\pi\pi$, etc.
* Hadronic B decays
* CLEO-III Results from the $\Upsilon(3S)$
* CLEO-c Outlook



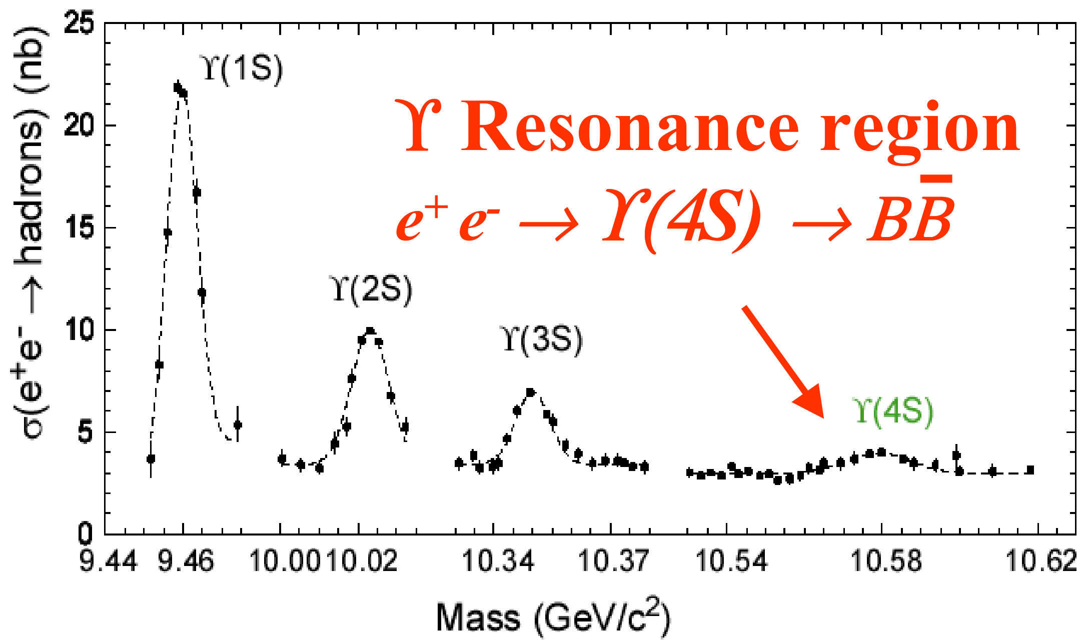



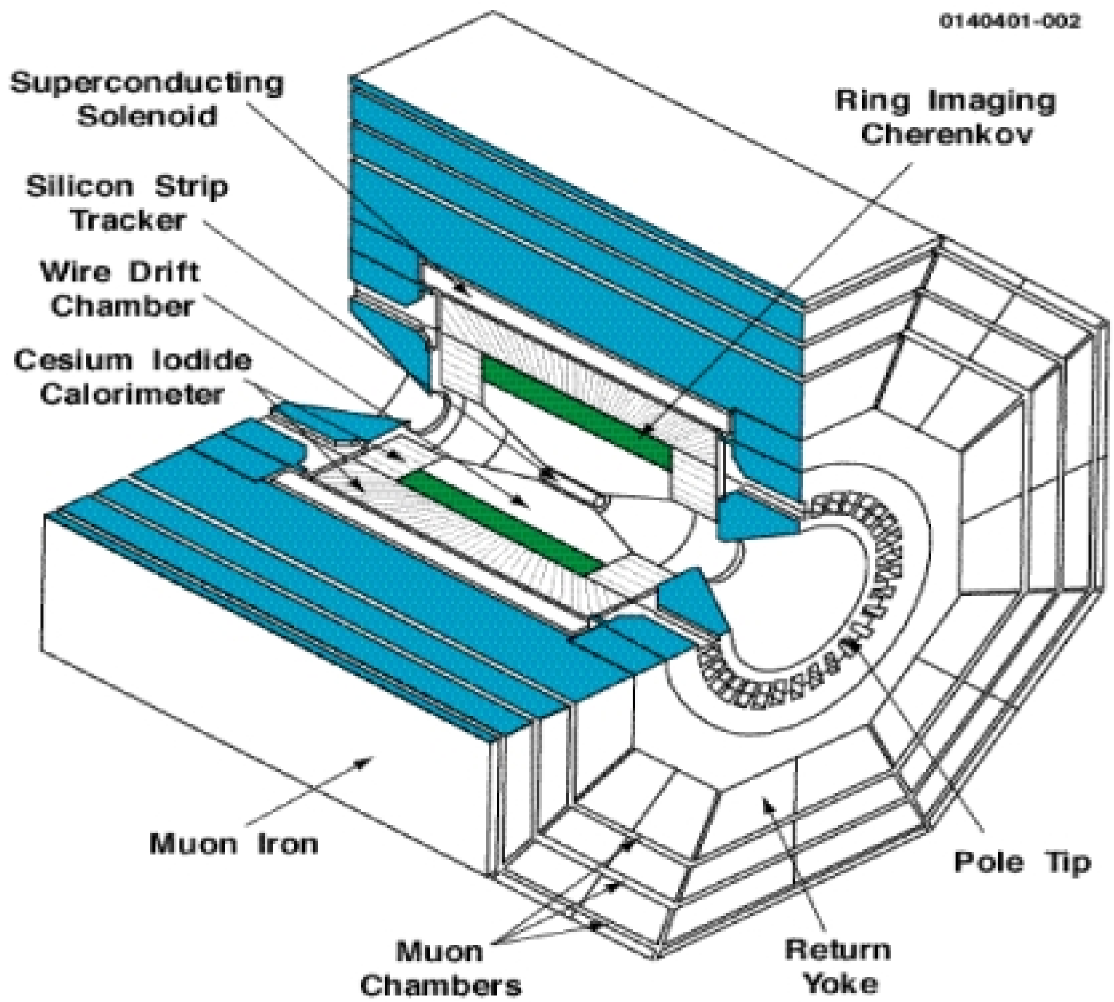
# The Experiment

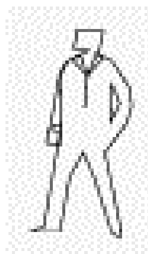
- CESR = Cornell Electron Positron Storage Ring
- Symmetric $e^+e^-$ collider ($e^-$ and $e^+$ have equal energy and opposite momentum)
- Luminosity ~ $10^{33}$ $cm^{-2}$ $sec^{-1}$ (1 B-pair per second)
- **$\Upsilon$(4S), first $b\bar{b}$ resonance above B-pair threshold**

| Detector | $\Upsilon(4S)$ $fb^{-1}$ | Cont. $fb^{-1}$ | $B\bar{B}$ $(10^6)$ |
|---|---|---|---|
| CLEO II | 3.1 | 1.6 | 3.3 |
| CLEO II.V | 6.0 | 2.8 | 6.4 |
| Subtotal | 9.1 | 4.4 | 9.7 |
| CLEO III | 6.9 | 2.3 | 7.4 |
| Total | 16.0 | 6.7 | 17.1 |



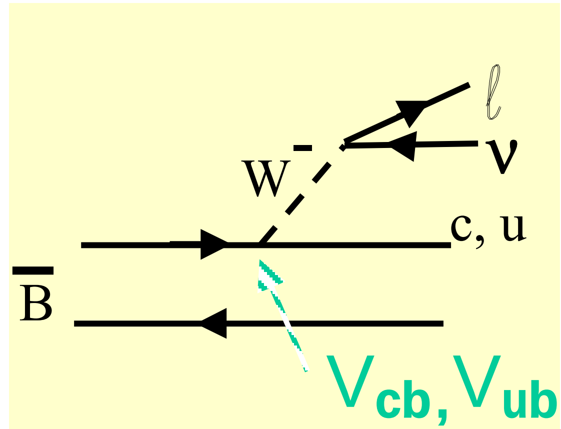
# The CLEO III Detector



# Measuring CKM in B Decays

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$




* Two approaches: inclusive + exclusive
* Experimental issues: Lepton rates & spectra, exclusive branching fractions, full B meson reconstruction
* Theoretical Issues: Prediction of lepton spectra, quark-hadron duality, form factors, heavy quark expansion of inclusive semileptonic width

# Semileptonic Decay Width $\Gamma(B \to X_c l^+ \nu)$

$$\Gamma_{SL}^{c} = \frac{G_F^2 |V_{cb}|^2 M_B^5}{192\pi^3} \left[ G_0 + \frac{1}{M_B} G_1(\bar{\Lambda}) + \frac{1}{M_B^2} G_2(\bar{\Lambda}, \lambda_1, \lambda_2) + O\left(\frac{1}{M_B^3}\right) \right]$$

Heavy Quark Expansion

$$\Gamma_{SL}^{c,\,exp} = (0.43 \pm 0.01) \times 10^{-10}\ \text{MeV}$$

World average in hep-ph/0205163

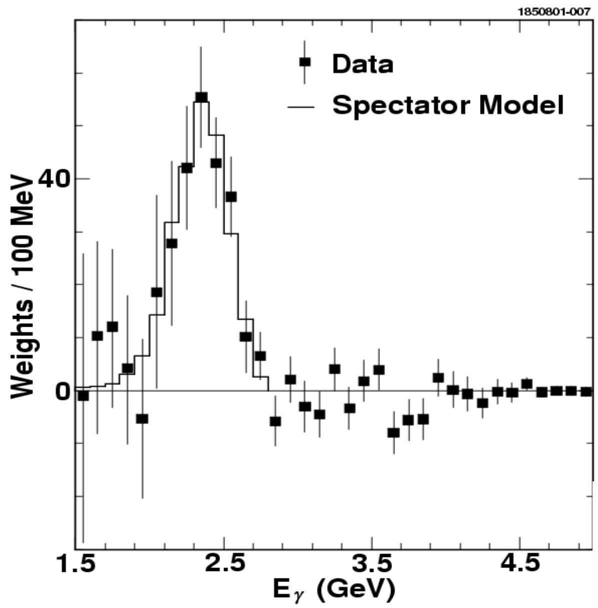
- Nonperturbative QCD parameters
- $\bar{\Lambda}$ (b-quark pole mass shift) — $b \to s \gamma$
- $\lambda_1$ (b quark kinetic energy) — $M_{had}$ in $B \to X_c l^+ \nu$
- $\lambda_2$ (HQ spin symmetry breaking) — **B*-B mass splitting**

All inclusive semileptonic quantities can be expanded in $\bar{\Lambda}$, $\lambda_1$, $\lambda_2$

# Moment Analysis

b→s γ

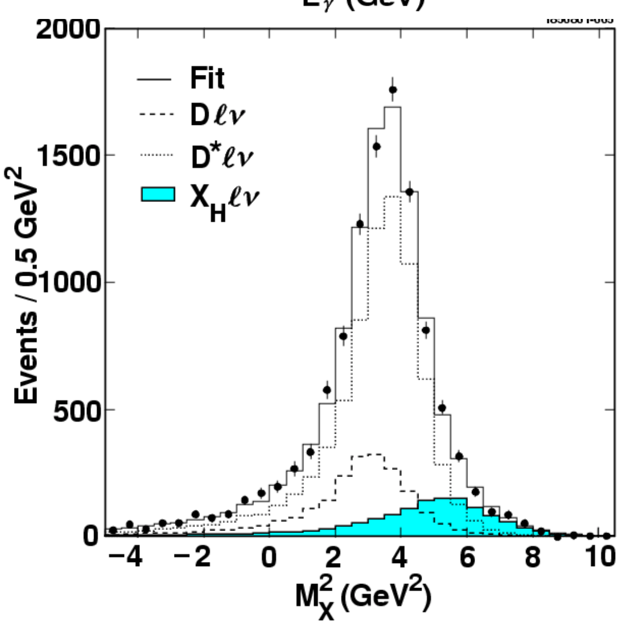
PRL 87:251807, (2001)

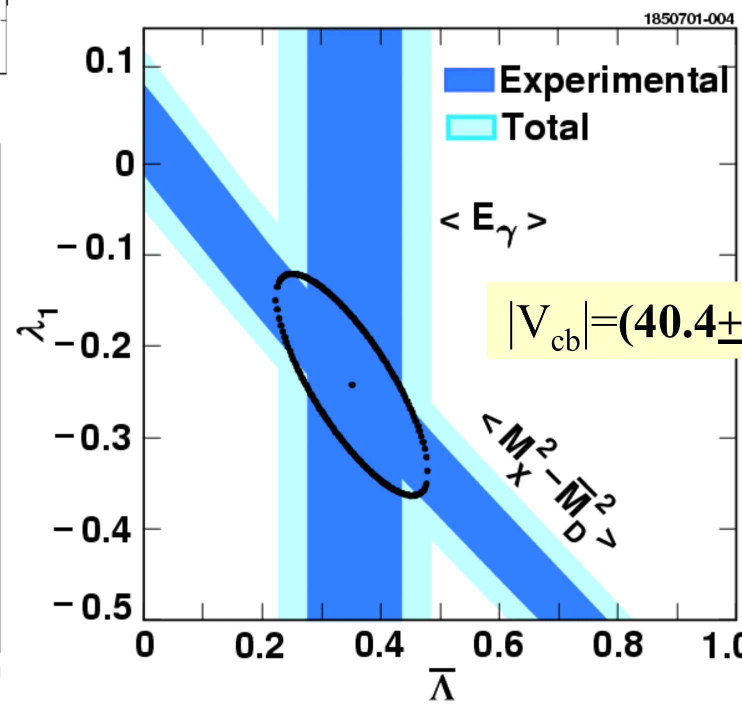



$$\langle E_\gamma \rangle = 2.346 \pm 0.032 \pm 0.011 \ GeV$$
$$\langle (M_X^2 - \overline{M}_D^2) \rangle = 0.251 \pm 0.023 \pm 0.062 \ GeV^2$$
$$\langle (M_X^2 - \langle M_X^2 \rangle)^2 \rangle = 0.576 \pm 0.048 \pm 0.163 \ GeV^4$$

$B \rightarrow X_c l^+ \nu$

PRL 87:251808, (2001)



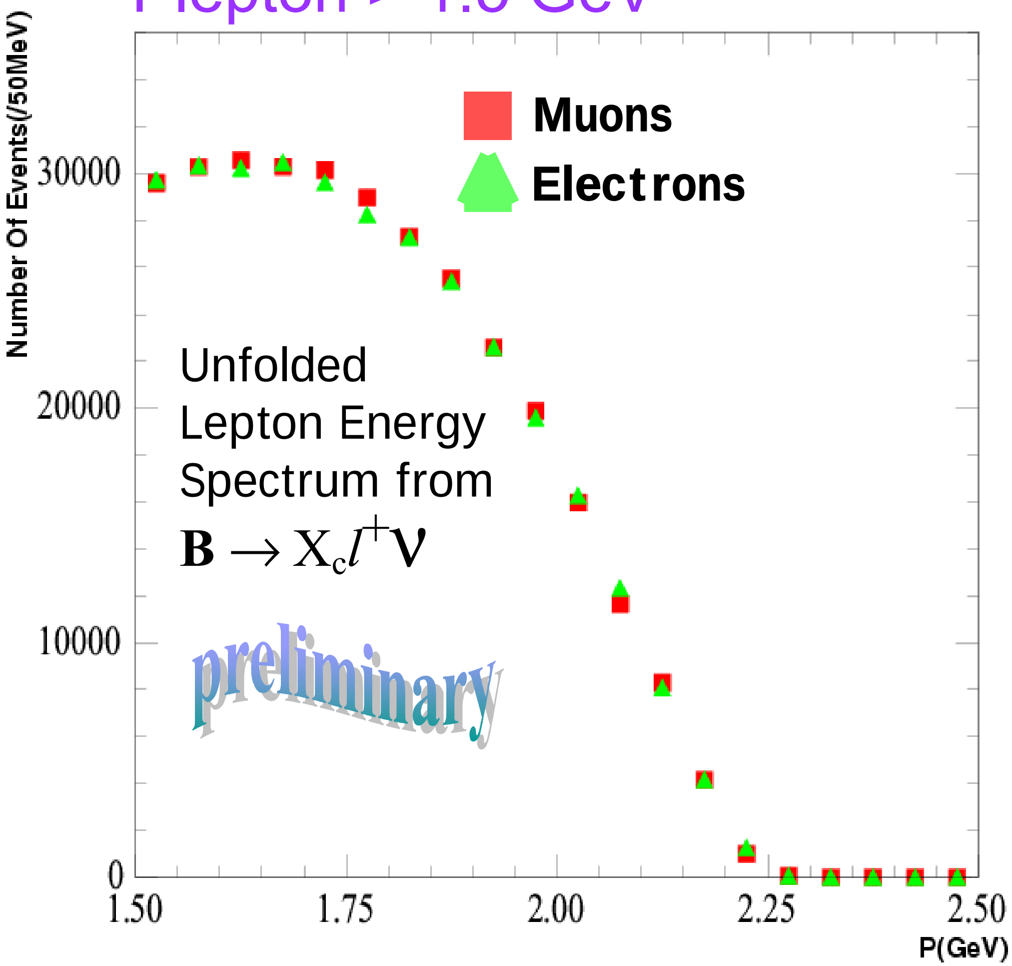




$|V_{cb}|$=**(40.4$\pm$1.3)*10$^{-3}$**

PRL 87:251808, (2001)

# Truncated Lepton Spectrum in $B \to X_c l^+ \nu$

Plepton > 1.5 GeV




$$R_0 = \frac{\int_{1.7}^{E_l \max} \frac{d\Gamma_{sl}}{dE_l} dE_l}{\int_{1.5}^{E_l \max} \frac{d\Gamma_{sl}}{dE_l} dE_l}$$

*M.Gremm, A. Kapustin, Z. Ligeti M. Wise, I. Stewart*

$$R_1 = \frac{\int_{1.5}^{E_l \max} E_l \frac{d\Gamma_{sl}}{dE_l} dE_l}{\int_{1.5}^{E_l \max} \frac{d\Gamma_{sl}}{dE_l} dE_l}$$

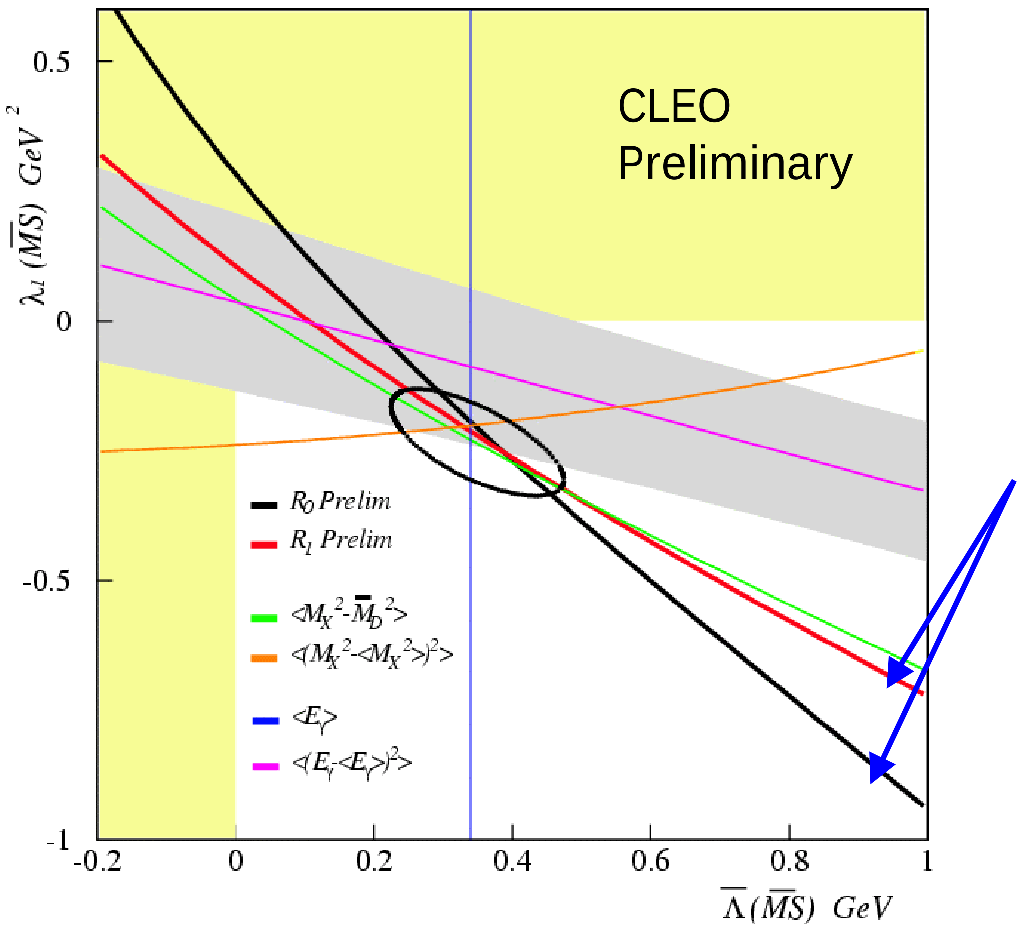
$R_0 = 0.6187 \pm 0.0014 \pm 0.0016$

$R_1 = 1.7810 \pm 0.0007 \pm 0.0009$ GeV

CLEO CONF 02-10

Good agreement between muon/electron spectra !

# Moments from Lepton Spectrum in $B \rightarrow X_c l^+ \nu$




L and $l_1$ ellipse extracted from 1st moment of $B \rightarrow X_s \gamma$ photon energy spectrum and 1st moment of hadronic mass$^2$ distribution($B \rightarrow X_c l^+ \nu$). We use the HQET equations in MS scheme at order $1/M_B^3$ and $\alpha_s^2 \beta_o$.

**MS Expressions:** *A. Falk, M. Luke, M. Savage, Z. Ligeti, A. Manohar, M. Wise, C. Bauer*

The red and black curves are derived from the new CLEO results for $B \rightarrow X_c l^+ \nu$ lepton energy moments.

**MS Expressions:** *M.Gremm, A. Kapustin, Z. Ligeti and M. Wise, I. Stewart (moments) and I. Bigi, N.Uraltsev, A. Vainshtein(width)*

Gray band represents total uncertainty for the 2nd moment of photon energy spectrum.

# $V_{cb}$ from Lepton Energy Spectrum

$\bar{\Lambda}$= 0.39±0.03±0.06±0.12 GeV

stat sys theory

$\lambda_1$=-0.25±0.02±0.05±0.14 GeV²

stat sys theory

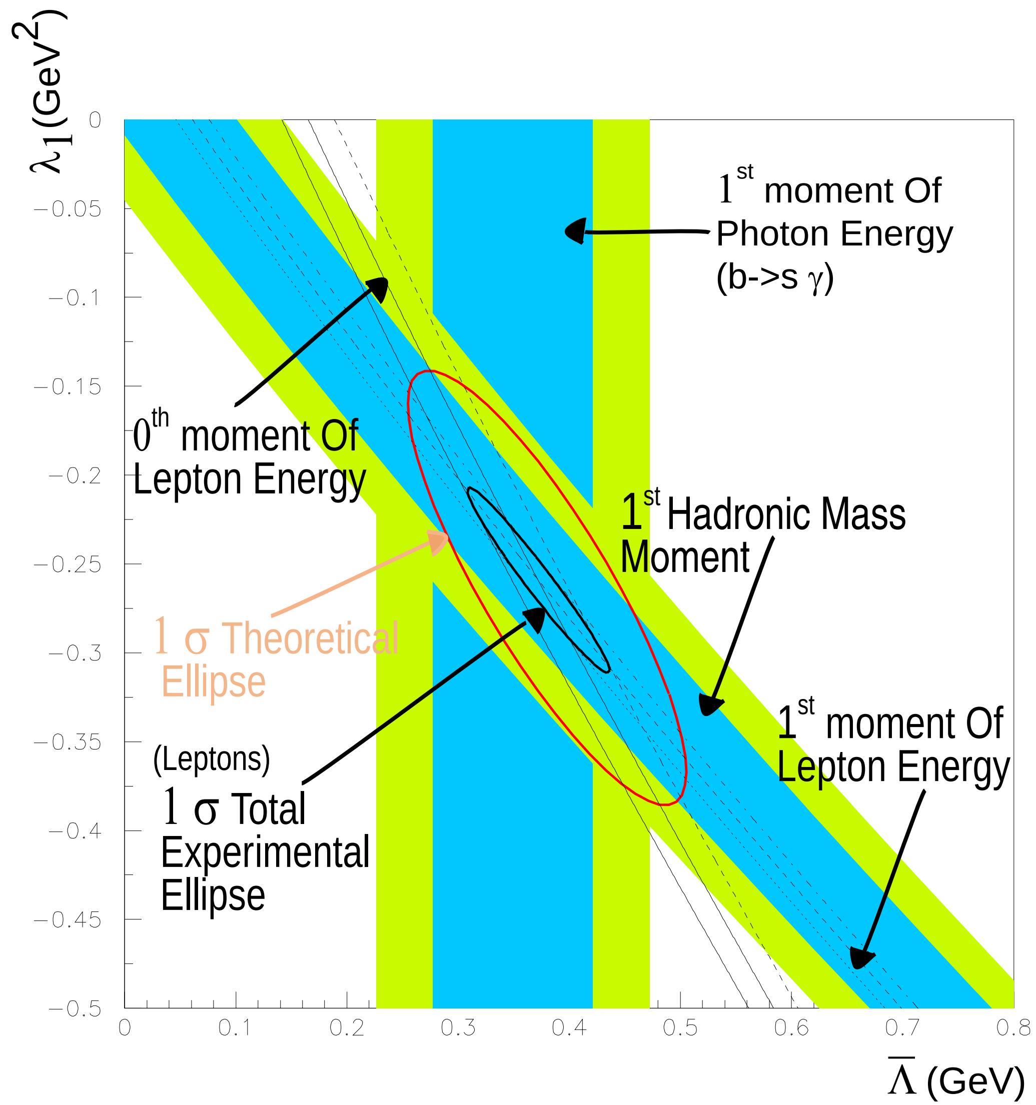
**$V_{cb}$** with all moments considered:

$|V_{cb}|$=

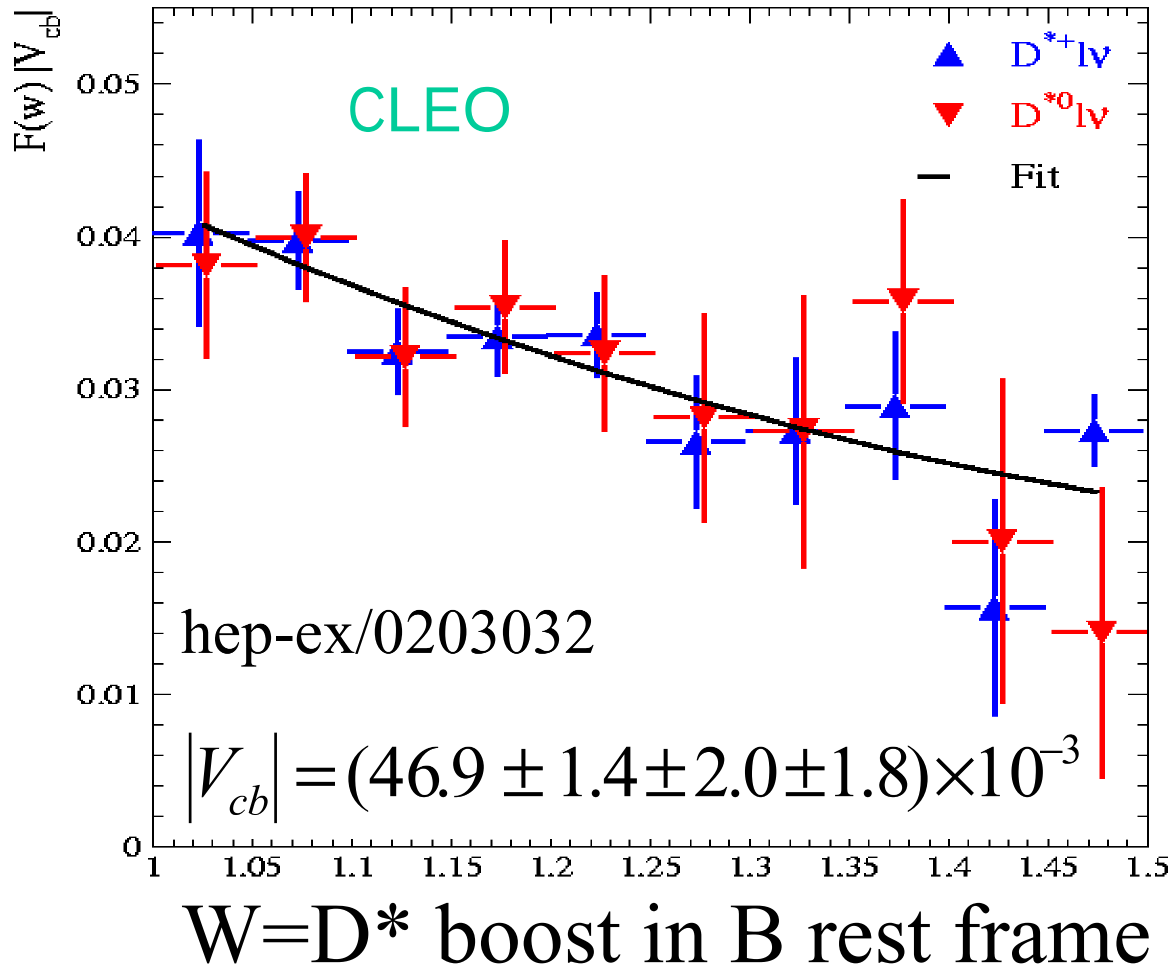
(40.8±0.5 ±0.4 ±0.9)*10$^{-3}$

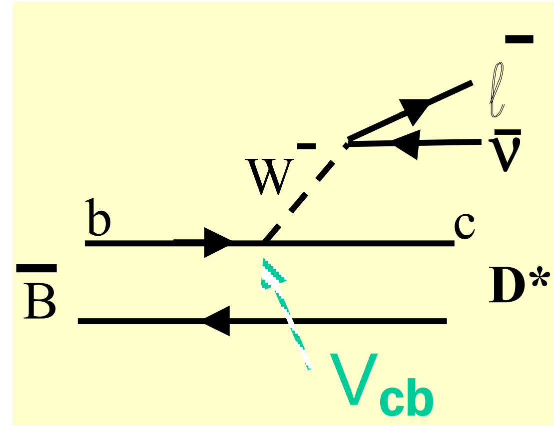
$\Gamma sl$ $\bar{\Lambda}, \lambda_1$ theory

preliminary



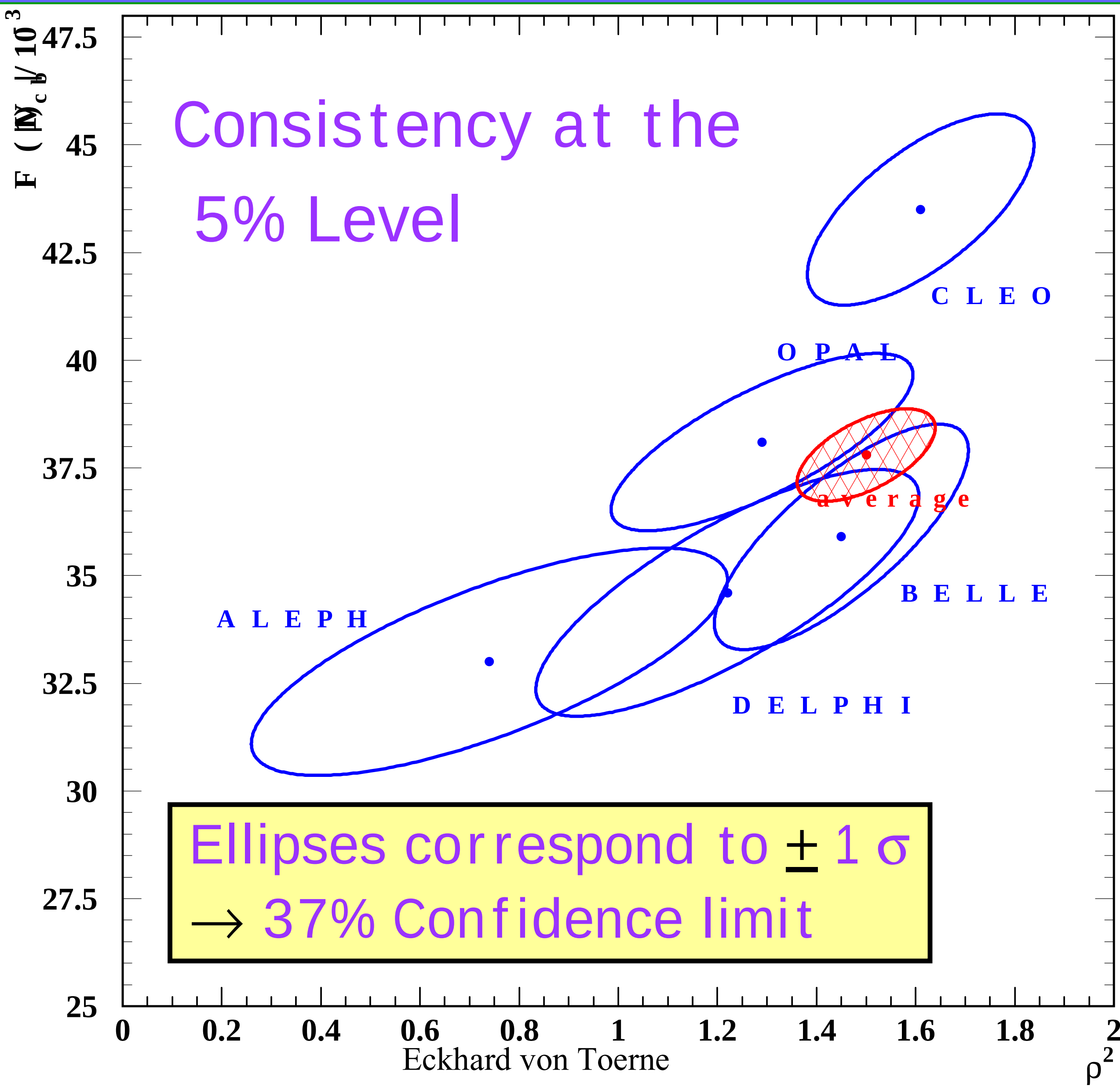
# $V_{cb}$ from zero recoil in $\bar{B} \rightarrow D^* l^- \bar{\nu}$



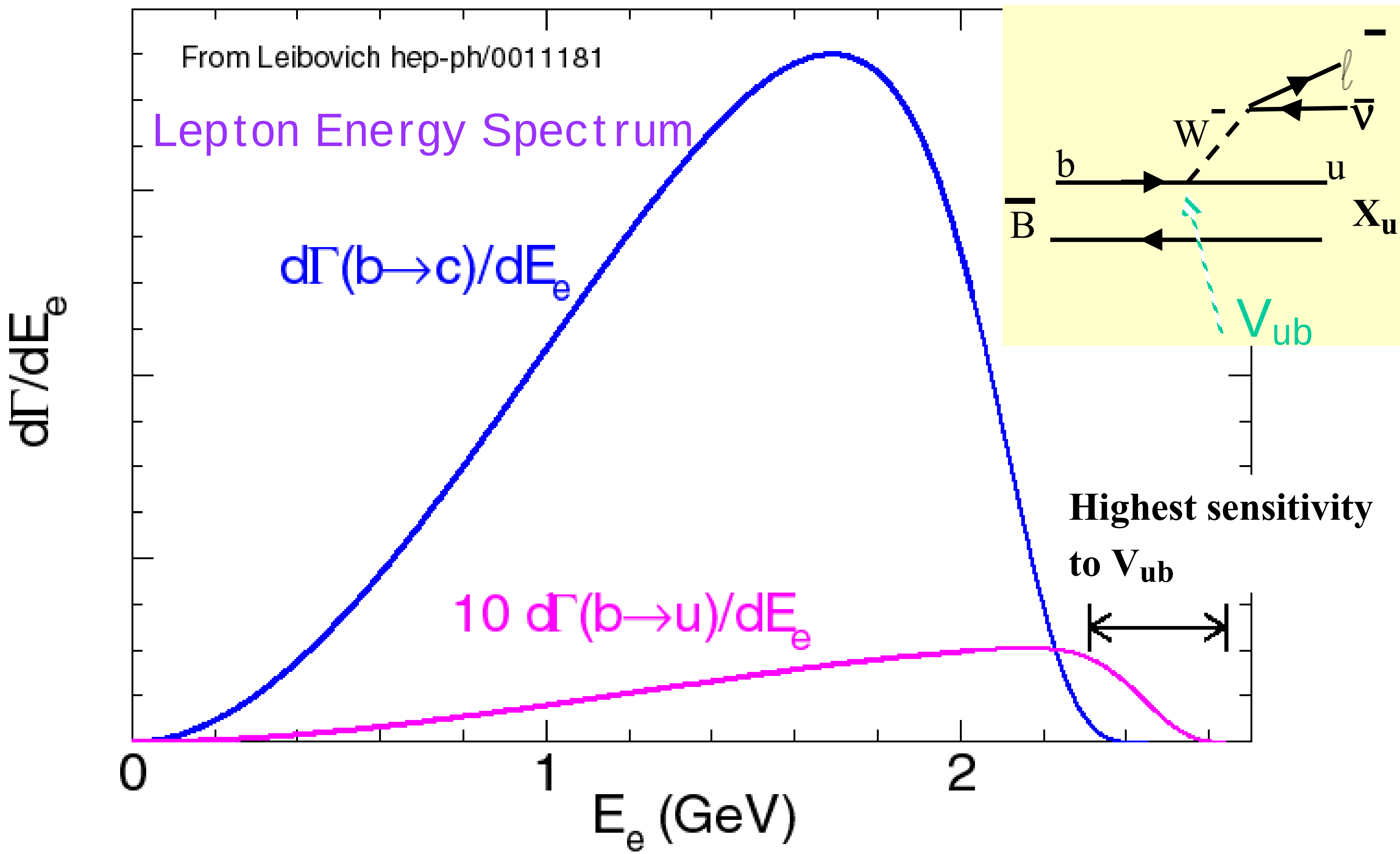




- $F(1)\,|V_{cb}|$ (intercept)
- $\rho^2$ (slope)
- Uses formfactor $F(W)|_{W=1}$ of $0.91 \pm 0.04$
- W=1 corresponds to D* at rest in B rest frame

# $V_{cb}$ from zero recoil in $\bar{B} \rightarrow D^{*} l^{-} \bar{\nu}$



# bottom→ up transitions ($V_{ub}$)

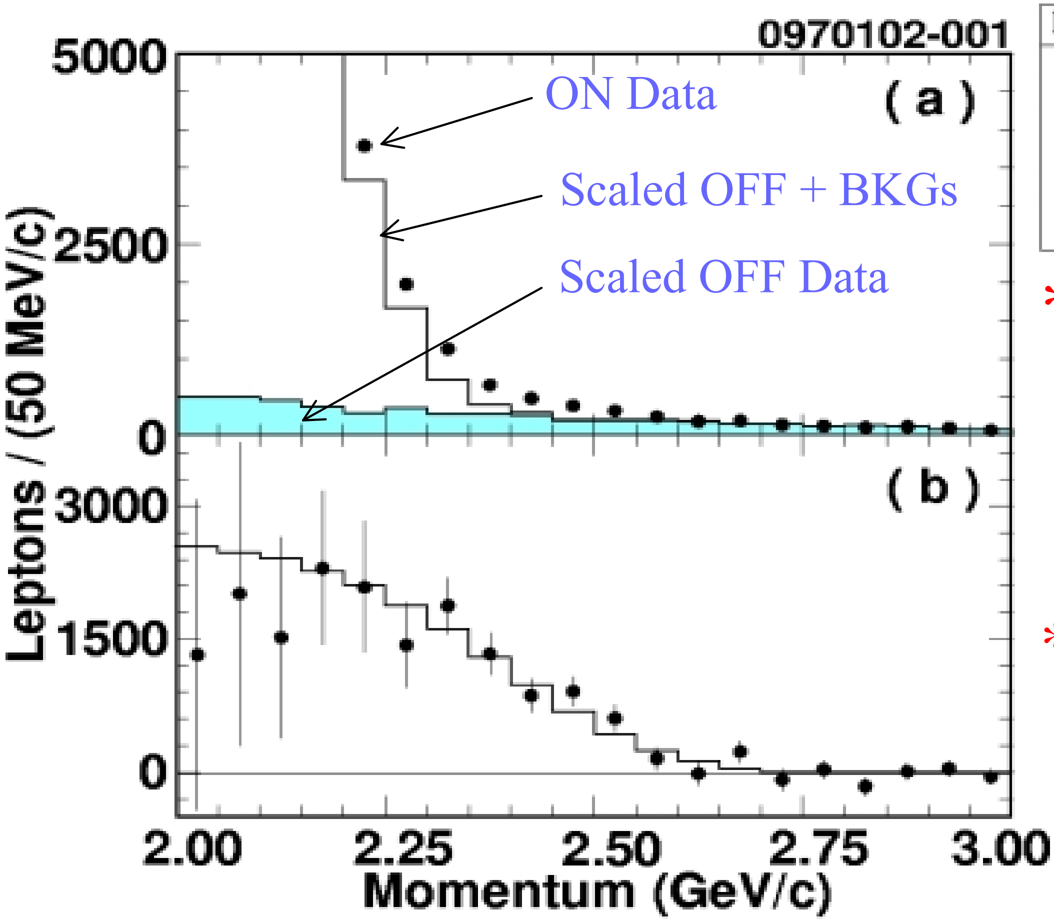


# $V_{ub}$ Lepton Yields

Phys. Rev. Lett.88:231803,2002

$$|V_{ub}| = (3.07 \pm 0.12) \times 10^{-3} \times \left[\frac{B(B \to X_u l\nu)}{0.001}\right]^{\frac{1}{2}} \times \left(\frac{1.6\ \text{ps}}{\tau_B}\right)^{\frac{1}{2}}$$

(Hoang, Ligeti, Manohar; Uraltsev)




| Momentum Interval (GeV/$c$) | $V_{ub}(10^{-3})$ |
|---|---|
| $2.0 \le p_\ell < 2.6$ | $3.87 \pm 0.83 \pm 0.35 \pm 0.15 \pm 0.12$ |
| $2.1 \le p_\ell < 2.6$ | $3.95 \pm 0.46 \pm 0.40 \pm 0.16 \pm 0.16$ |
| $2.2 \le p_\ell < 2.6$ | $4.08 \pm 0.34 \pm 0.44 \pm 0.16 \pm 0.24$ |
| $2.3 \le p_\ell < 2.6$ | $4.27 \pm 0.24 \pm 0.47 \pm 0.17 \pm 0.34$ |
| $2.4 \le p_\ell < 2.6$ | $4.05 \pm 0.28 \pm 0.45 \pm 0.16 \pm 0.45$ |

* Uncertainties:
  - End-point yield
  - $f_u$ measurement
  - $|V_{ub}|$ expression
  - Theoretical assumptions
* We quote result for 2.2-2.6 GeV region

$|V_{ub}|=$

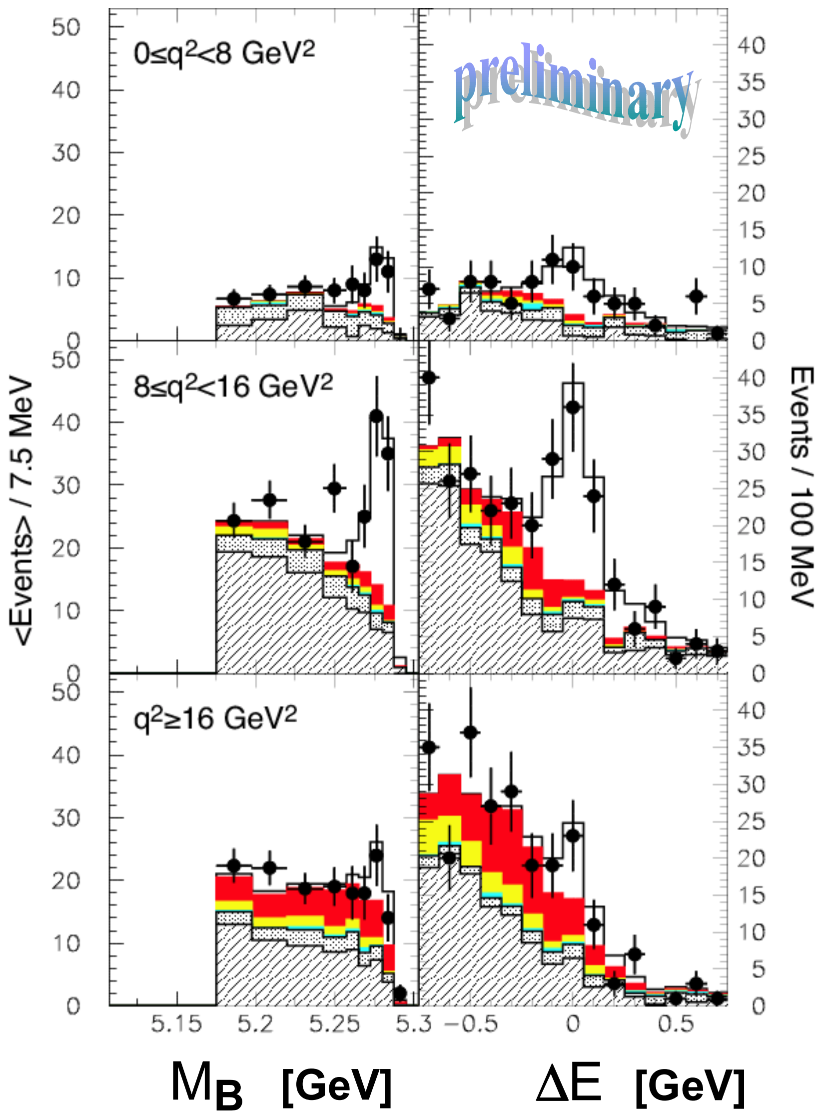
$(4.08 \pm 0.34 \pm 0.44 \pm 0.16 \pm 0.24) * 10^{-3}$

# $V_{ub}$ from $BR(B^0 \to \pi^- l^+ \nu)$

Use missing four momentum in full B reconstruction.

9.7 BB pairs (CLEO II+II.V).

Data sample allows parsing into 3 bins of $q^2$ (reduces dependence on $q^2$ shape models)




**$BR(B^0 \to \pi^- l^+ \nu)$=** preliminary

**$(1.376 \pm 0.180\,^{+0.116}_{-0.135} \pm 0.008 \pm 0.102 \pm 0.021)\ 10^{-4}$**

*stat syst formfactor(π,ρ) model*

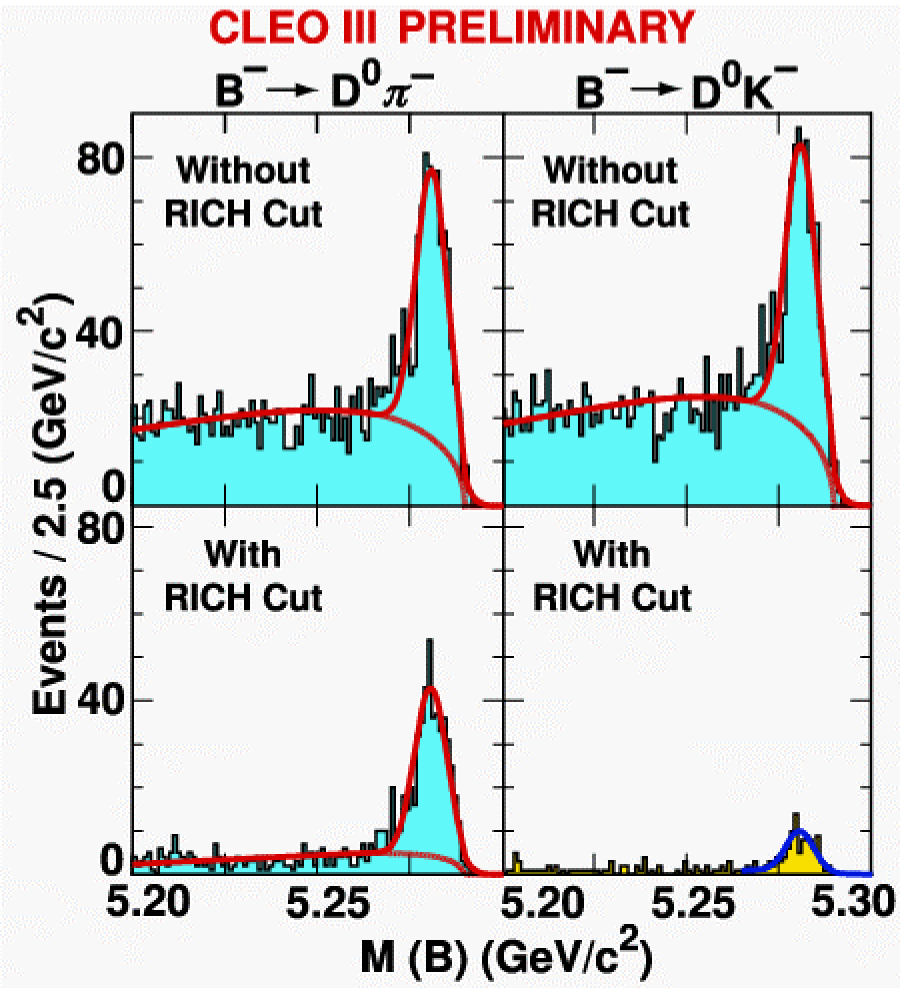
$|V_{ub}| = \mathbf{(3.25 \pm 0.21\,^{+0.16}_{-0.18} \pm 0.49 \pm 0.10 \pm 0.07) * 10^{-3}}$

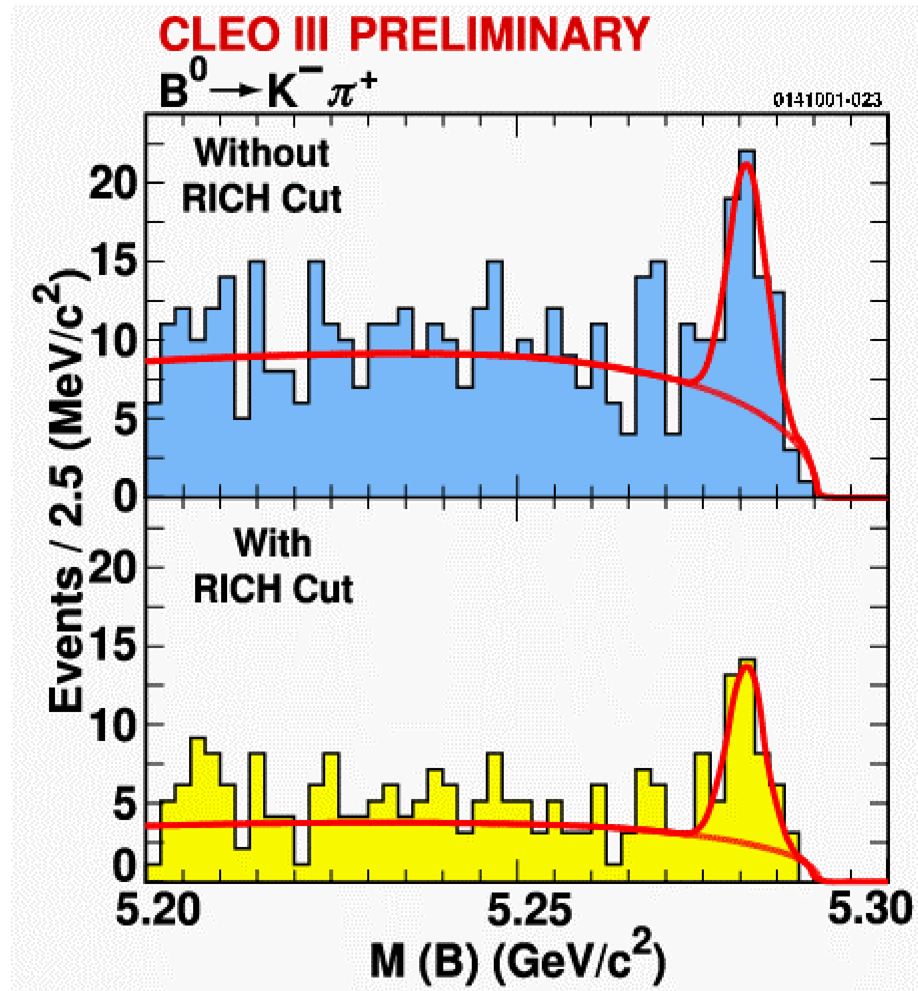
Standard quantities for $\Upsilon(4S)$ kinematics:

$M_B \equiv \sqrt{E_{beam}^2 - P_B^2} \approx 5.28$ GeV

$\Delta E \equiv E_B - E_{beam} \approx 0$

# CLEO III Rare Hadronic B Results



# Rare B Branching Fraction Results

| Mode | Efficiency | Yield | Significance | $\mathcal{B}$ $(10^{-6})$ | UL $(10^{-6})$ |
|---|---|---|---|---|---|
| $K^\pm\pi^\mp$ | 46% | $29.2^{+7.1}_{-6.4}$ | $5.4\sigma$ | $18.6^{+4.5}_{-4.1}{}^{+3.0}_{-3.4}$ | |
| | 45% | $80.2^{+11.8}_{-11.0}$ | $11.7\sigma$ | $18.8^{+2.8}_{-2.6} \pm 1.3$ | |
| $K^\pm\pi^0$ | 32% | $12.9^{+6.5}_{-5.5}$ | $3.8\sigma$ | $13.1^{+5.8}_{-4.9}{}^{+2.8}_{-2.9}$ | |
| | 38% | $44.9^{+11.3}_{-10.3}$ | $6.1\sigma$ | $12.1^{+3.0}_{-2.8}{}^{+2.1}_{-1.4}$ | |
| $K^0\pi^\pm$ | 12% | $14.8^{+4.9}_{-4.1}$ | $6.2\sigma$ | $35.7^{+12}_{-9.9}{}^{+5.4}_{-6.2}$ | |
| | 14% | $25.2^{+6.4}_{-5.6}$ | $7.6\sigma$ | $18.2^{+4.6}_{-4.0} \pm 1.6$ | |
| $K^0\pi^0$ | 8.5% | $3.0^{+2.9}_{-2.5}$ | $1.6\sigma$ | $10.4^{+10}_{-8.3}{}^{+2.9}_{-2.9}$ | 72 |
| | 11% | $15.5^{+5.9}_{-5.0}$ | $4.7\sigma$ | $14.8^{+5.9}_{-5.1}{}^{+2.4}_{-3.3}$ | |
| $\pi^\pm\pi^\mp$ | 35% | $3.9^{+1.5}_{-1.2}$ | $2.2\sigma$ | $3.2^{+3.3}_{-2.5}{}^{+1.0}_{-1.0}$ | 11 |
| | 45% | $20.0^{+7.6}_{-6.5}$ | $4.2\sigma$ | $4.7^{+1.8}_{-1.5} \pm 0.6$ | |
| $\pi^\pm\pi^0$ | 29% | $11.5^{+5.6}_{-4.5}$ | $3.4\sigma$ | $11.7^{+5.7}_{-4.6}{}^{+2.2}_{-2.4}$ | 25 |
| | 41% | $23.1^{+9.1}_{-8.7}$ | $3.2\sigma$ | $5.6^{+2.6}_{-2.3}{}^{+1.7}_{-1.7}$ | 12 |
| $\pi^0\pi^0$ | 29% | $2.7^{+2.4}_{-1.6}$ | $2.9\sigma$ | | 11 |
| | 29% | $6.2^{+4.8}_{-3.7}$ | $2.0\sigma$ | | 5.7 |
| $K^\pm K^\mp$ | 36% | $1.0^{+2.4}_{-1.7}$ | $0.6\sigma$ | | 4.5 |
| | 45% | $0.0^{+3.4}_{-0.0}$ | $0.0\sigma$ | | 2 |
| $K^0K^\pm$ | 12% | $0.5^{+1.9}_{-1.1}$ | $0.8\sigma$ | | 18 |
| | 14% | $1.4^{+2.4}_{-1.3}$ | $1.1\sigma$ | | 5.1 |
| $K^0\bar{K}^0$ | 13% | $0.0^{+0.5}_{-0.5}$ | | | 13 |
| | 19% | $1.0^{+1.9}_{-1.0}$ | | | 6.1 |

CLEO III (prelim.)

CLEO II+ II.V

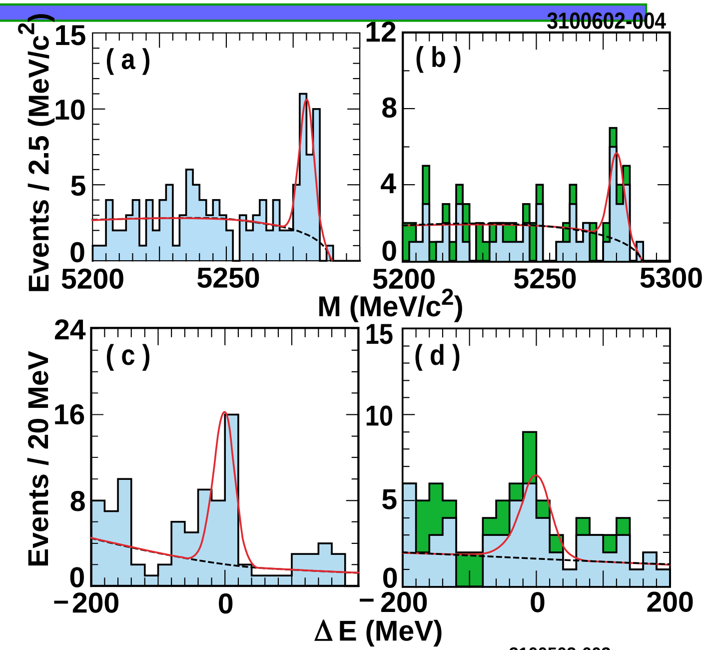
CLEO III (~3fb$^{-1}$) confirms prev. CLEO results.

Results will be published based on ~6fb$^{-1}$(on-resonance) in late Summer.

(Upper Limits are 90% C.L.)

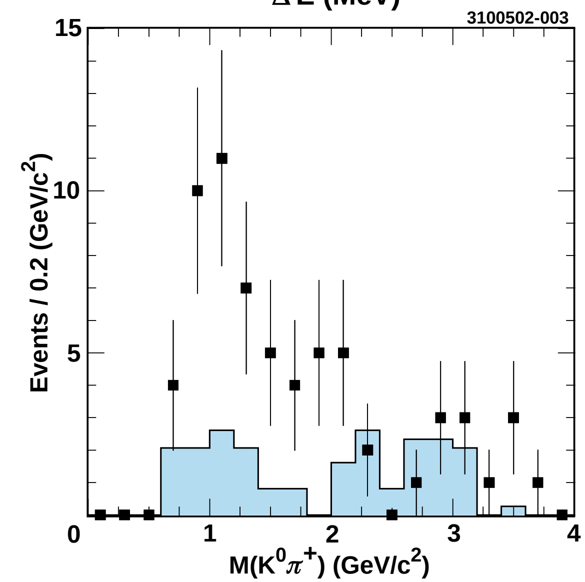
# $B \to K^0_s \pi^+\pi^-$ and $B \to K^{*+}\pi^-$

* CLEO II+ II.5 Data Sample (9.7 M B-pairs)
* $D \to K\pi$, $D \to \pi\pi$ veto
* ML fit with several Dalitz amplitudes
* Substructure $B \to K^{*+}\pi^-$ observed



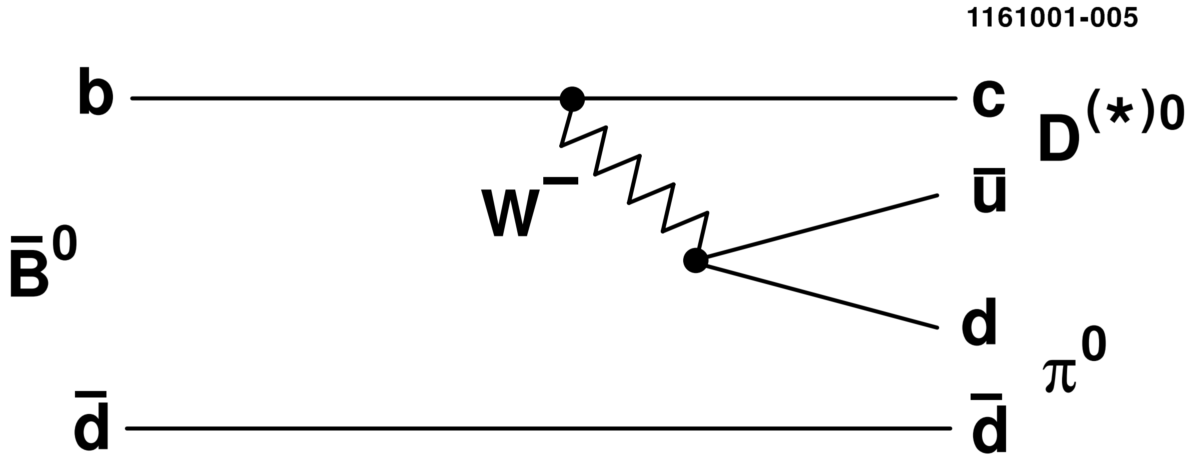

$$\mathbf{Br}(B \to K_s\pi^+\pi^-) = (50\,^{+10}_{-9} \pm 7\,)\,\mathrm{x}10^{-6}$$

$$\mathbf{Br}(B \to K^{*+}\pi^-) = (16\,^{+6}_{-5} \pm 2\,)\,\mathrm{x}10^{-6}$$




hep-ex/0206024, subm. to PRL

# Color-Suppressed B decays

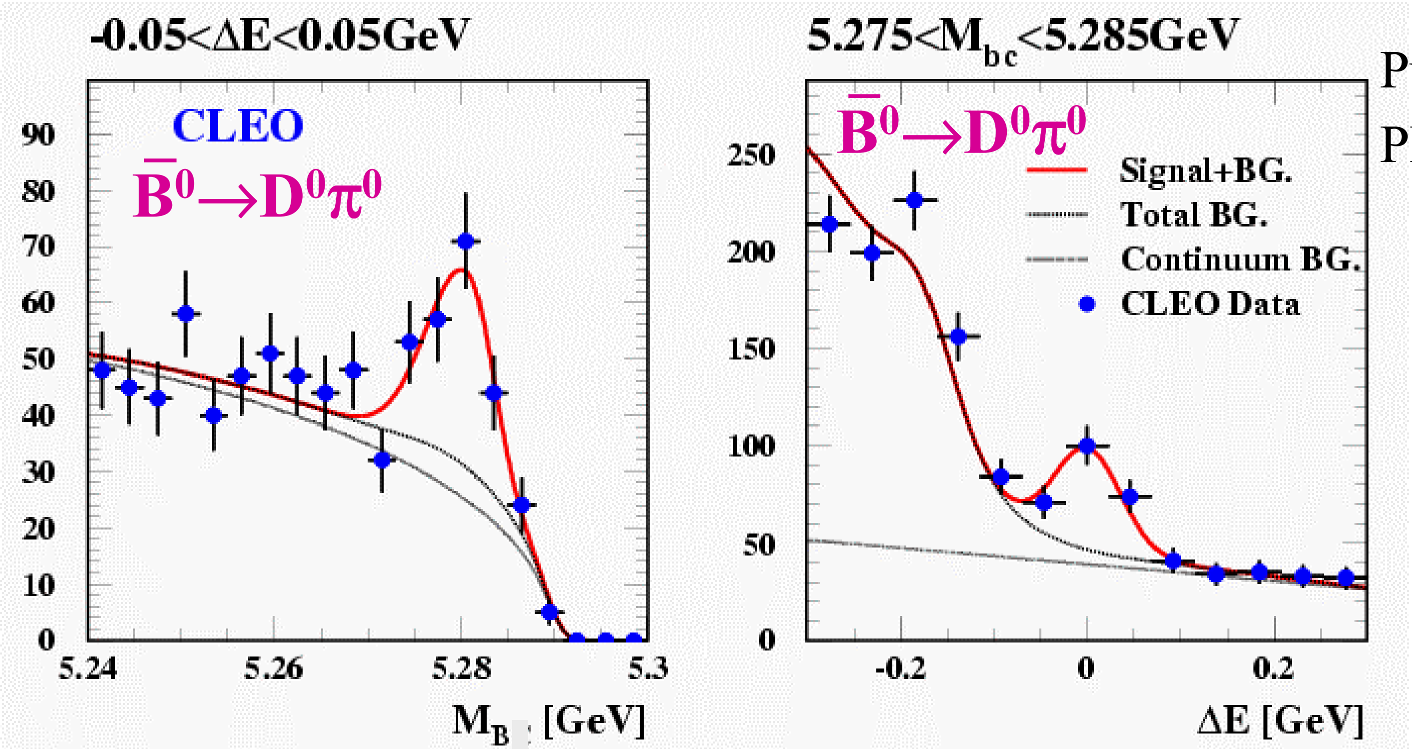



* Internal spectator diagram is color-suppressed
* Until 2001, only color-suppressed decays into charmonium states had been observed.
* First Observations of $\bar{B}^0 \rightarrow D^{(*)0}\pi^0$ were recently published by CLEO, **Phys.Rev.Lett.88 062001 (2002)**

  Belle, **Phys.Rev.Lett.88 052002 (2002)**

  **(preliminary BaBar results at ICHEP'02)**

# Hadronic Decay $\bar{B}^0 \rightarrow D^{(*)0} \pi^0$




Published in
PRL 88, 062001 (2002)

clear signal visible!

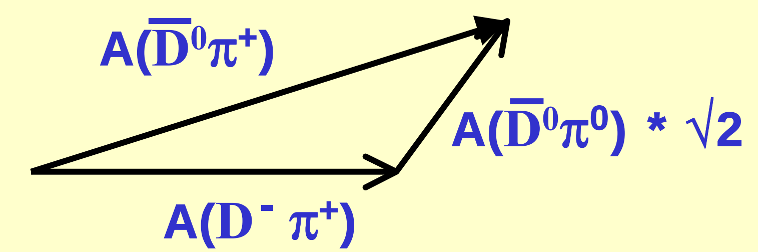
$$\mathbf{Br}(\bar{B}^0 \rightarrow D^0\pi^0) = (2.74\,^{+0.36}_{-0.32} \pm 0.55\,) \times 10^{-4}$$

$$\mathbf{Br}(\bar{B}^0 \rightarrow D^{*0}\pi^0) = (2.20\,^{+0.59}_{-0.52} \pm 0.79\,) \times 10^{-4}$$

# $B \to D\pi$ Amplitude Triangles

- BR($\bar{B}^0 \to D^0\pi^0$) completes $B \to D\pi$ system
- Measurement of relative phase between isospin amplitudes I=1/2, 3/2 possible.

$A(\bar{D}^0\pi^+) = A(D^-\pi^+) + \sqrt{2}\, A(\bar{D}^0\pi^0)$




Branching Fractions ($10^{-4}$)

**BR($\bar{B}^0 \to D^0\pi^0$) = 2.7±0.3±0.6±0.1**

**BR($B^+ \to D^0\pi^+$) = 49.7±1.2±2.9±2.2**

**BR($\bar{B}^0 \to D^-\pi^+$) = 26.8±1.2±2.4±1.2**

New CLEO II+II.V Results hep-ex/0206030, accepted by PRD

With the new CLEO $B \to \mathbf{D}\pi$ and CLEO+Belle BR($B^0 \to D^0\pi^0$) we obtain

$$\cos\delta_I = 0.863^{+0.024}_{-0.023}\,^{+0.036}_{-0.035}\,^{+0.038}_{-0.030}$$

A non-zero phase, $\cos\delta_I \neq 1$, would indicate **Final State Interactions**

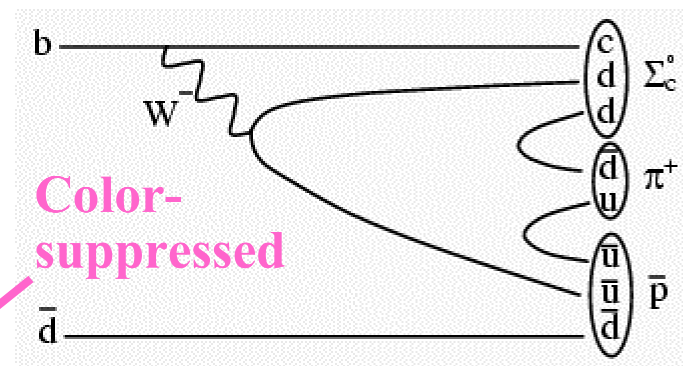
# $B \to \Lambda_c \bar{p}\, n(\pi)$, n=0,1,2,3

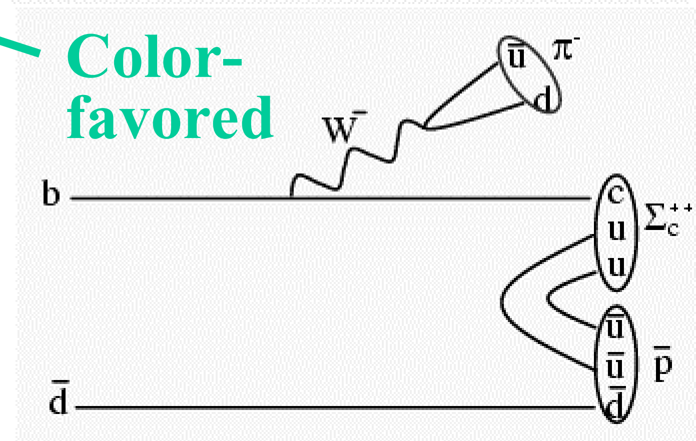
- Enough phase space available for baryonic B decays
- $B \to \Lambda_c$ inclusive rate ~6%
- No two-body decays known → multi-body decays dominate

Color suppressed decays not much smaller than color-favored decays

preliminary

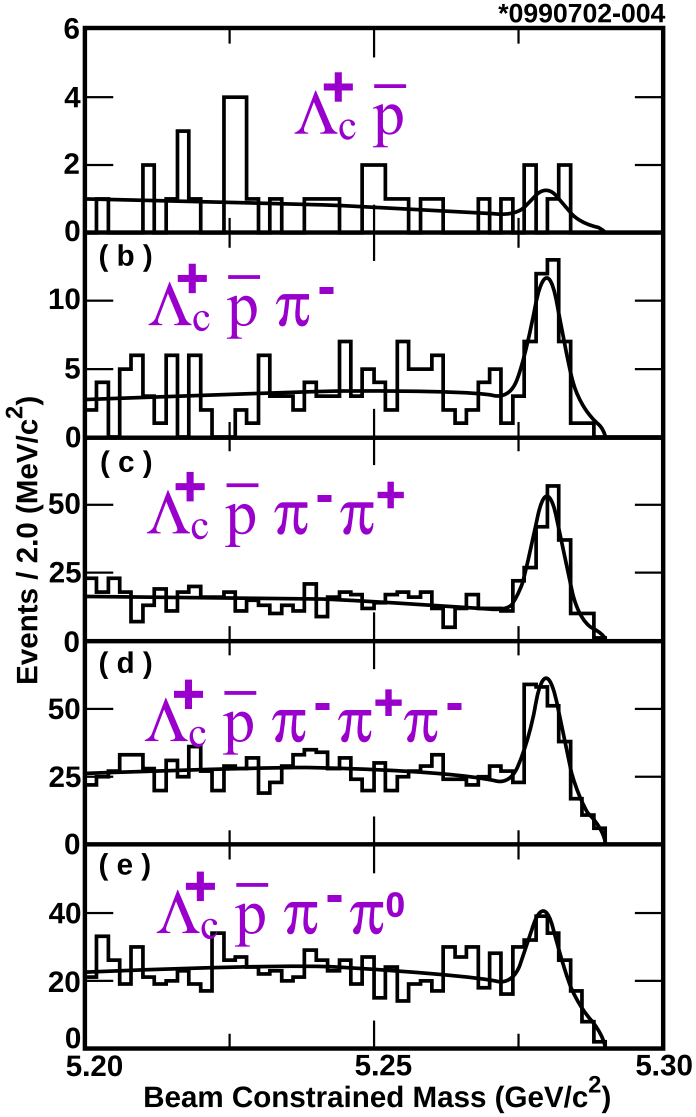
| Mode | $\mathcal{B}\ (10^{-4})$ |
|---|---|
| $\Lambda_c^+ \bar{p}$ | $< 0.9$ |
| $\Lambda_c^+ \bar{p} \pi^-$ | $2.4 \pm 0.6^{+0.19}_{-0.17} \pm 0.6$ |
| $\Sigma_c^0 \bar{p}$ | $< 0.8$ |
| $\Lambda_c^+ \bar{p} \pi^- \pi^+$ | $16.7 \pm 1.9^{+1.9}_{-1.6} \pm 4.3$ |
| $\Sigma_c^0 \bar{p} \pi^+$ | $2.2 \pm 0.6 \pm 0.4 \pm 0.5$ |
| $\Sigma_c^{++} \bar{p} \pi^-$ | $3.7 \pm 0.8 \pm 0.7 \pm 0.8$ |
| $\Lambda_{c1}^+ \bar{p}$ | $< 1.1$ |
| $\Lambda_c^+ \bar{p} \pi^- \pi^+ \pi^-$ | $22.5 \pm 2.5^{+2.4}_{-1.9} \pm 5.8$ |
| $\Sigma_c^0 \bar{p} \pi^+ \pi^-$ | $4.4 \pm 1.2 \pm 0.5 \pm 1.1$ |
| $\Sigma_c^{++} \bar{p} \pi^- \pi^+$ | $2.8 \pm 0.9 \pm 0.5 \pm 0.7$ |
| $\Lambda_{c1}^+ \bar{p} \pi^-$ | $< 1.9$ |
| $\Lambda_c^+ \pi^- \pi^0$ | $18.1 \pm 2.9^{+2.2}_{-1.6} \pm 4.7$ |
| $\Sigma_c^0 \bar{p} \pi^0$ | $4.2 \pm 1.3 \pm 0.4 \pm 1.0$ |



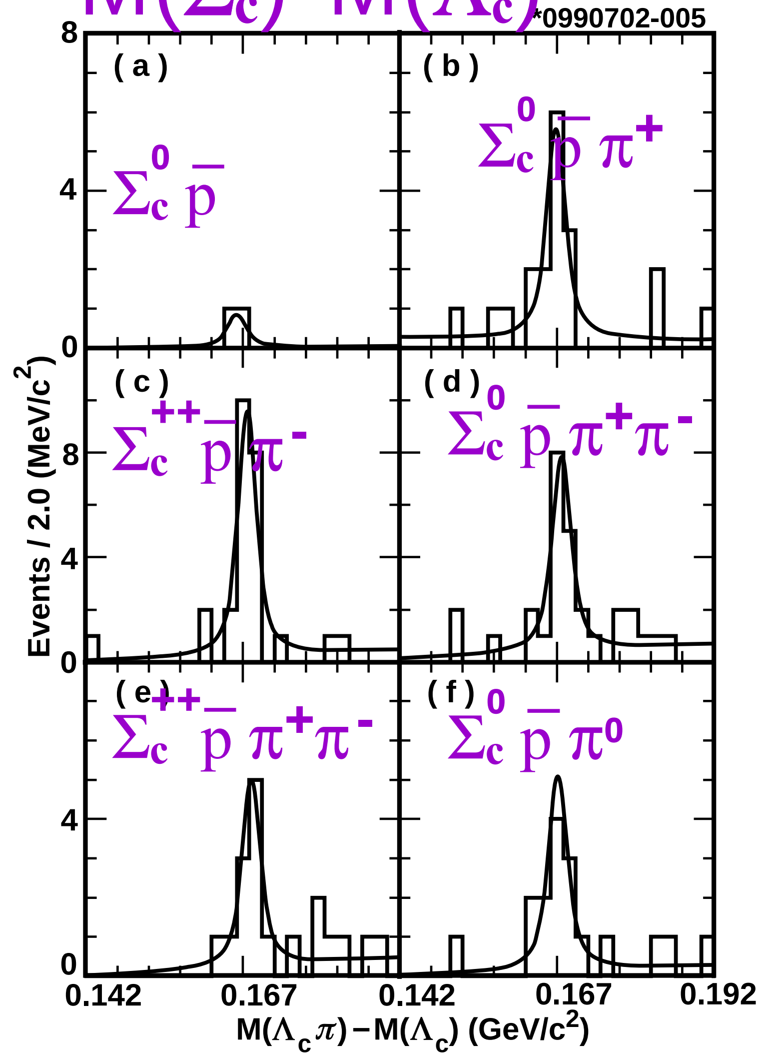



# B to $\Lambda_c \bar{p}$ n($\pi$), n=0,1,2,3

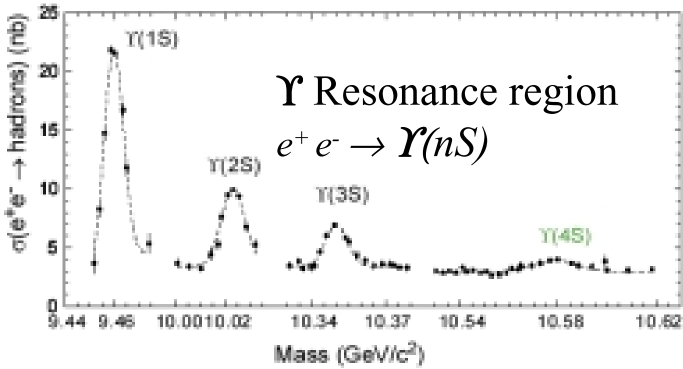
$M_B$ plots

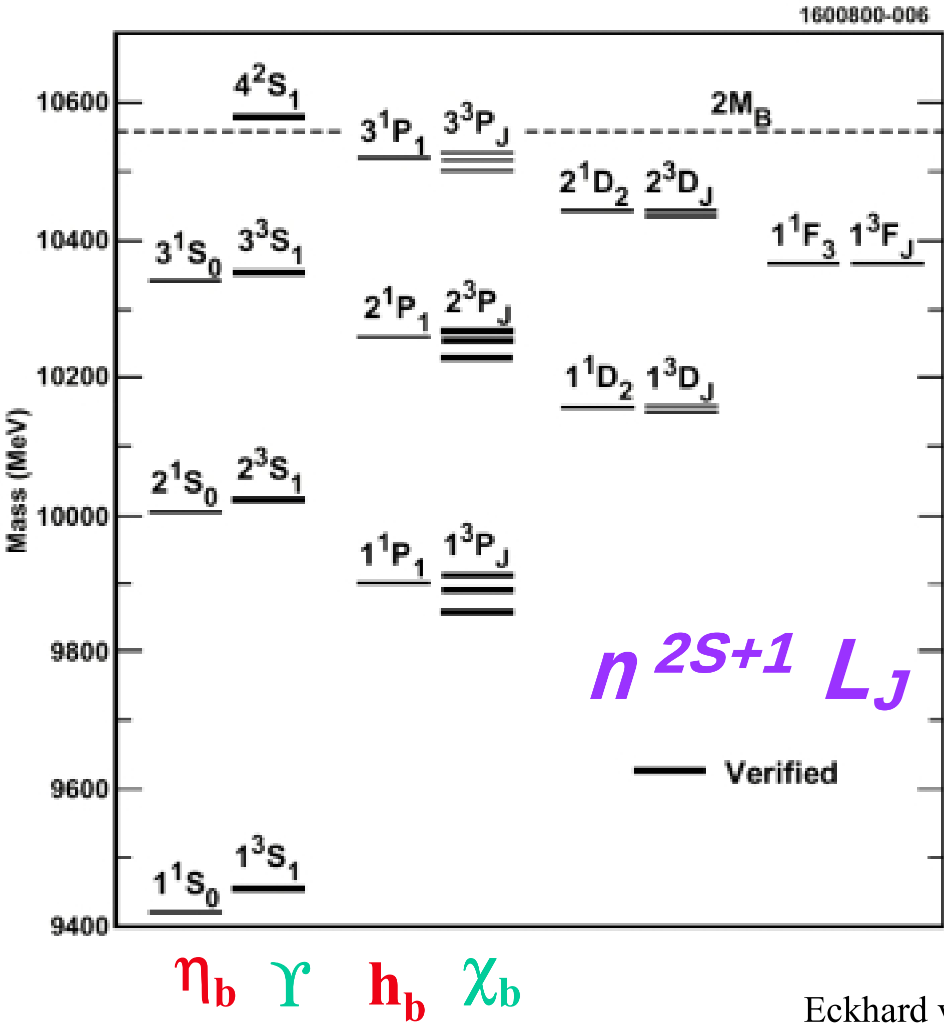



$M(\Sigma_c)$-$M(\Lambda_c)$



# Upsilon Spectroscopy




- *CLEO left the Υ(4S) in Summer 2001 and collected data on Υ(1S), Υ(2S), Υ(3S)

| Resonance | 1S | 2S | 3S |
| --- | --- | --- | --- |
| Int. Lumi. ($pb^{-1}$) | 1500 | 700 | 1400 ($47*10^6$ Evts) |

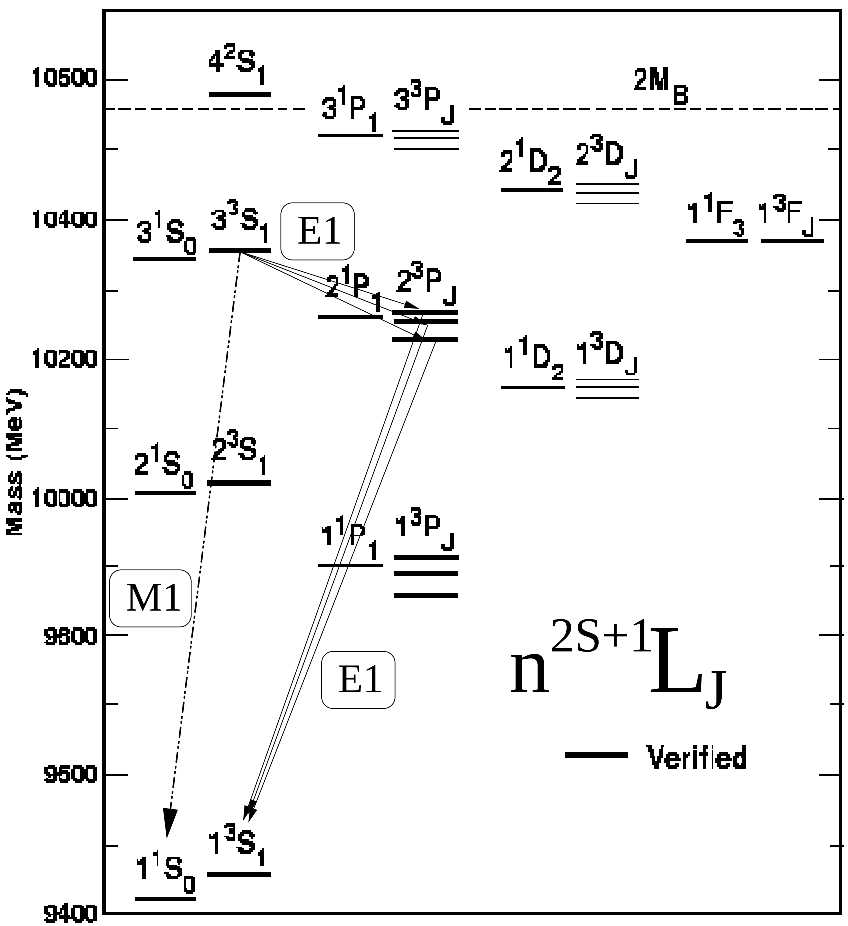
- *3 - 10 times the previous world data set + higher efficiency
- *Discovery of new states possible ($\eta_b$, $h_b$ and $1^3D_J$)
- *Test of lattice QCD

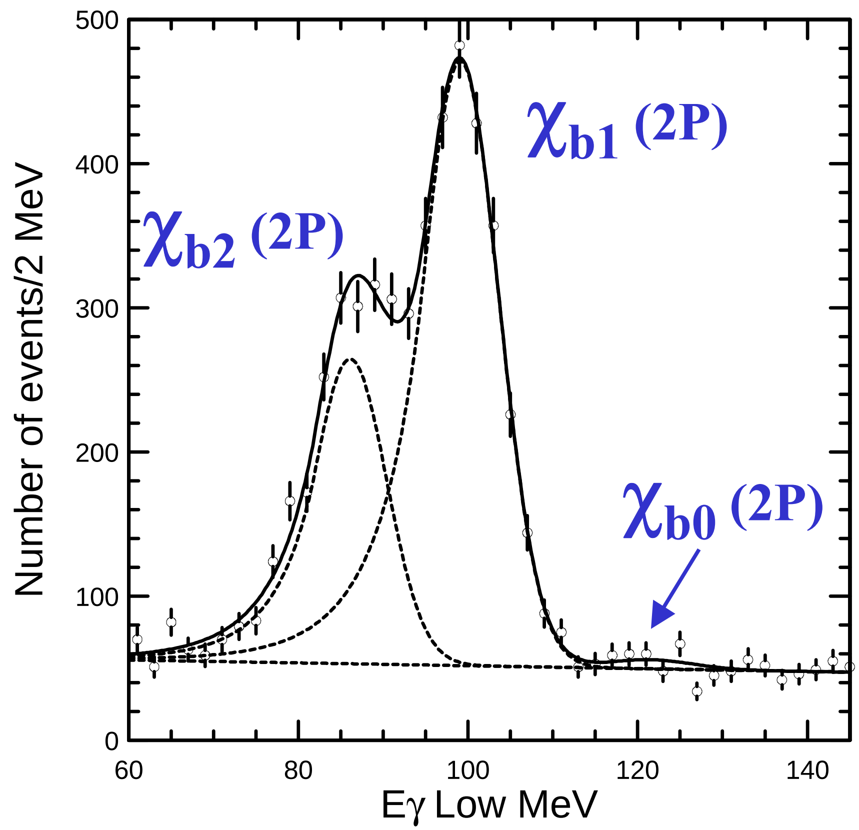
# Two-Photon transitions from the ϒ(3S)

preliminary

$M(\chi_{b2}\,(2P)) = $ **10268.8±0.3±0.6 MeV**

$M(\chi_{b1}\,(2P)) = $ **10255.6±0.2±0.6 MeV**



# Two-Photon transitions from the $\Upsilon(3S)$

* Limits on hadronic transitions

  $BR(\Upsilon(3s) \rightarrow \pi^0\Upsilon(1S)) < 0.17 * 10^{-3}$

  $BR(\Upsilon(3s) \rightarrow \pi^0\Upsilon(2S)) < 1.2 * 10^{-3}$

  $BR(\Upsilon(3s) \rightarrow \eta\Upsilon(1S)) < 0.90 * 10^{-3}$

preliminary

* $\Gamma_{had}$ ratios

$$\frac{\Gamma_{had}(2P_{Ja})}{\Gamma_{had}(2P_{Jb})} = \left(\frac{E_\gamma(2P_{Ja} \rightarrow 2S)}{E_\gamma(2P_{Jb} \rightarrow 2S)}\right)^3 \frac{1/\mathcal{B}(2P_{Ja} \rightarrow \gamma 2S) - 1}{1/\mathcal{B}(2P_{Jb} \rightarrow \gamma 2S) - 1}$$

  $\Gamma_{had}(\chi_{b0}(2P)) / \Gamma_{had}(\chi_{b2}(2P)) = 2.4 \pm 1.0$ (PQCD: 3.75)

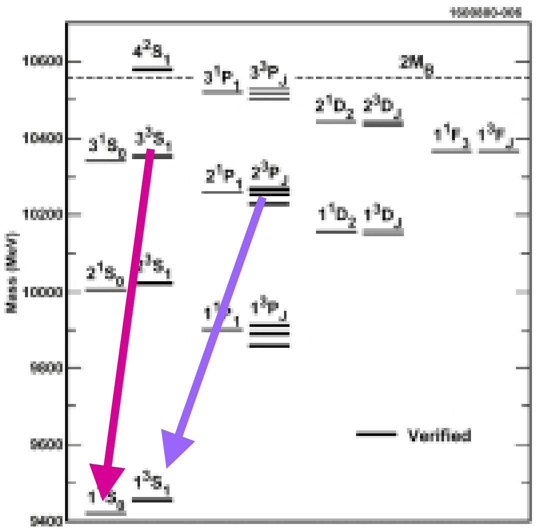
  $\Gamma_{had}(b1) / \Gamma_{had}(b2) = 0.29 \pm 0.06$

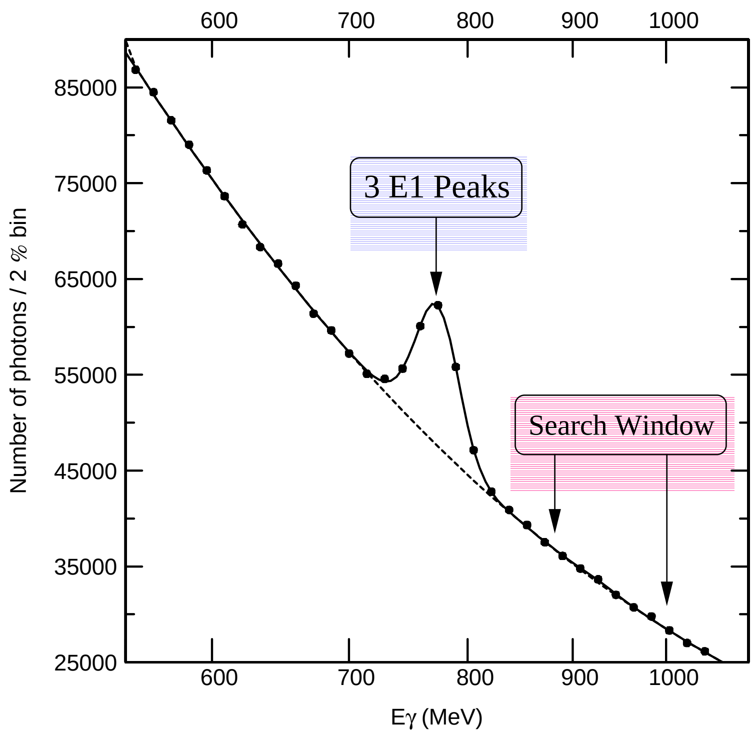
  (as expected, J=1 state decay to two hard gluons is suppressed)

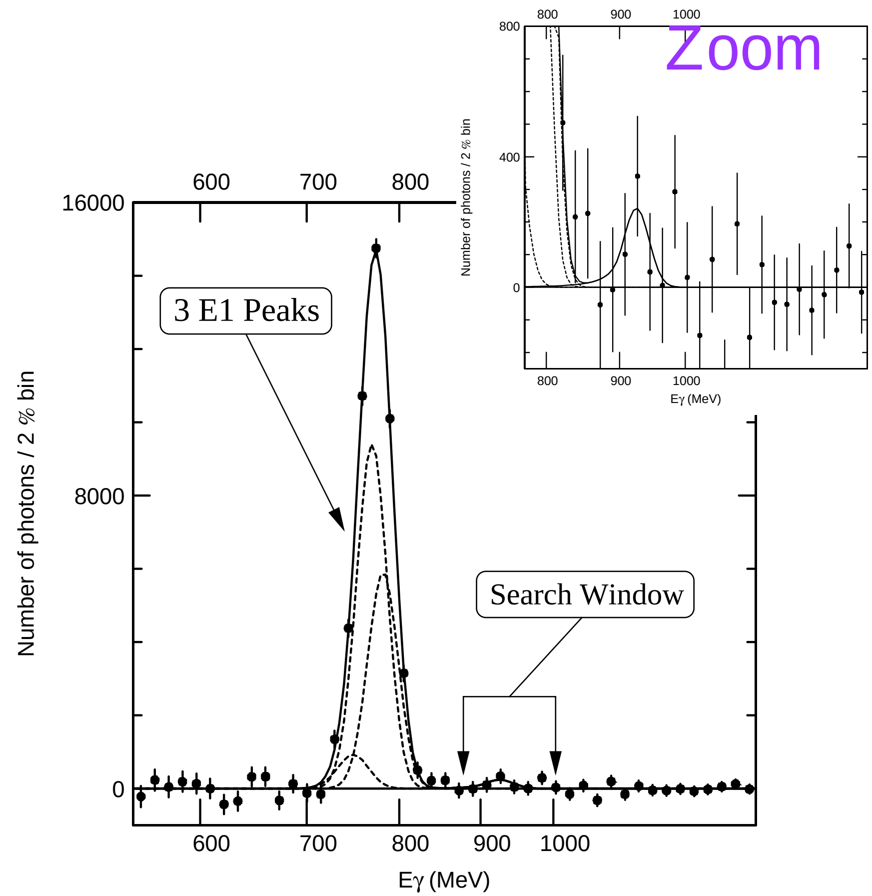
* Exact Calibration of $\gamma$ Cascades
* Study of backgrounds for multi-$\gamma$ cascades

# Search for $\Upsilon(3S) \rightarrow \eta_b \gamma$

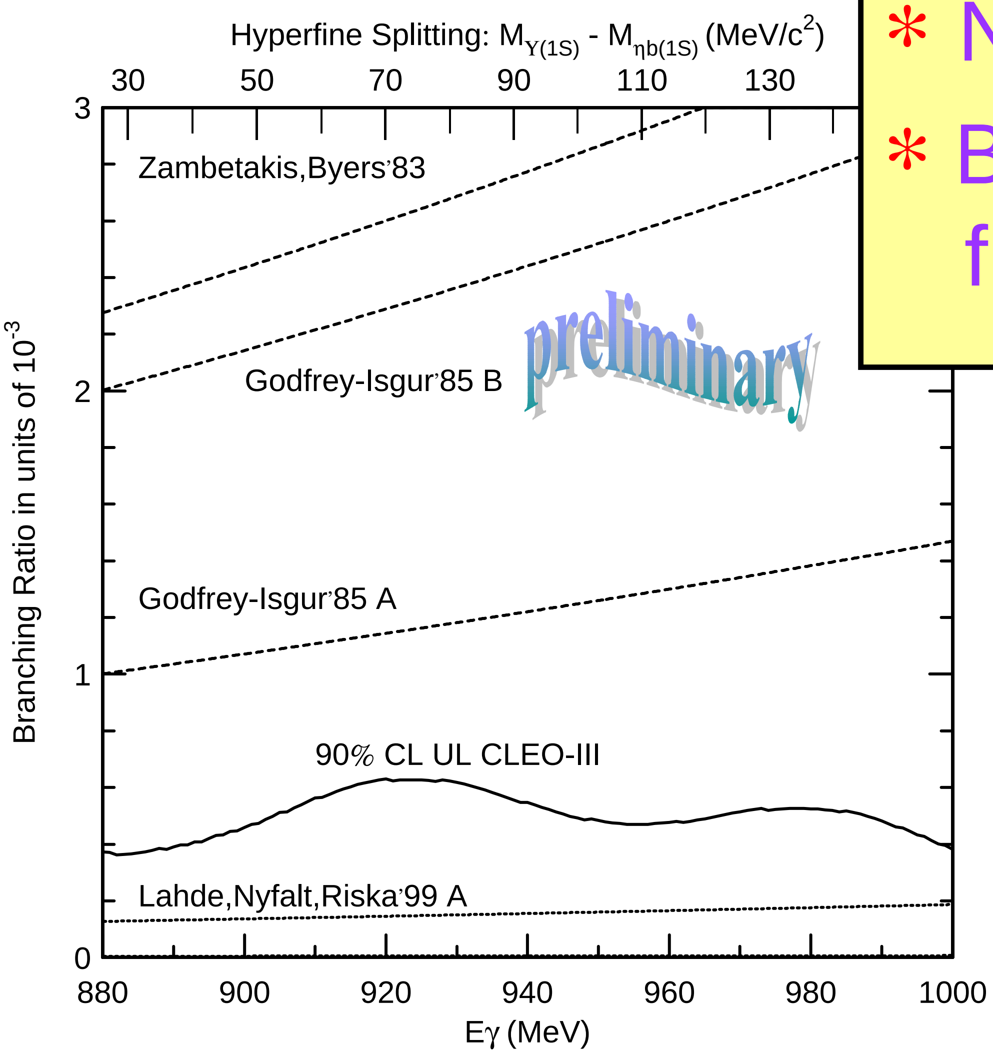
## Inclusive Search for Hindered M1 transition



# Search for the $\eta_b$ in $\Upsilon(3S) \to \eta_b \gamma$




- * No signal observed
- * BR Limits as a function of $M(\eta_b)$

Models from the compilation by Godfrey&Rosner PRD64, 074011 (2001) (scaled here by the phase-space)

# $\Upsilon(3S) \to \Upsilon(1S)$ 4-photon cascades

Exclusive Reconstruction

Final State $l^- l^+$ 4 $\gamma$

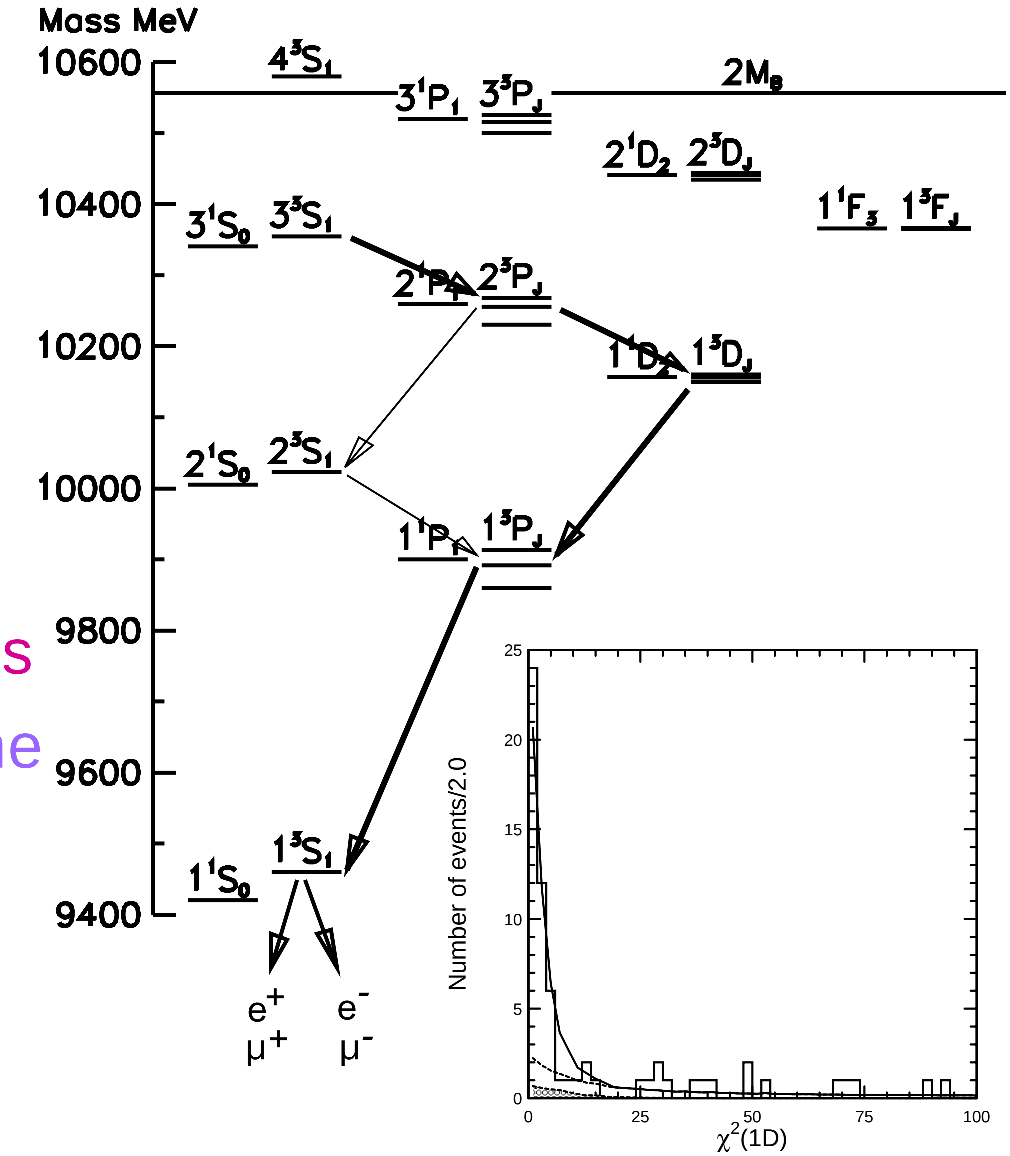
4 $\gamma$ Cascades origin from

- $\Upsilon(3s) \to \pi^0\pi^0\ \Upsilon(nS)$
- 4 $\gamma$ Cascades via $\chi$'s and $\Upsilon(2S)$
- 4 $\gamma$ Cascades via $\chi$'s and $\Upsilon(1D)$

Veto $\Upsilon(3s) \to \pi^0\pi^0\Upsilon(nS)$ Cascades

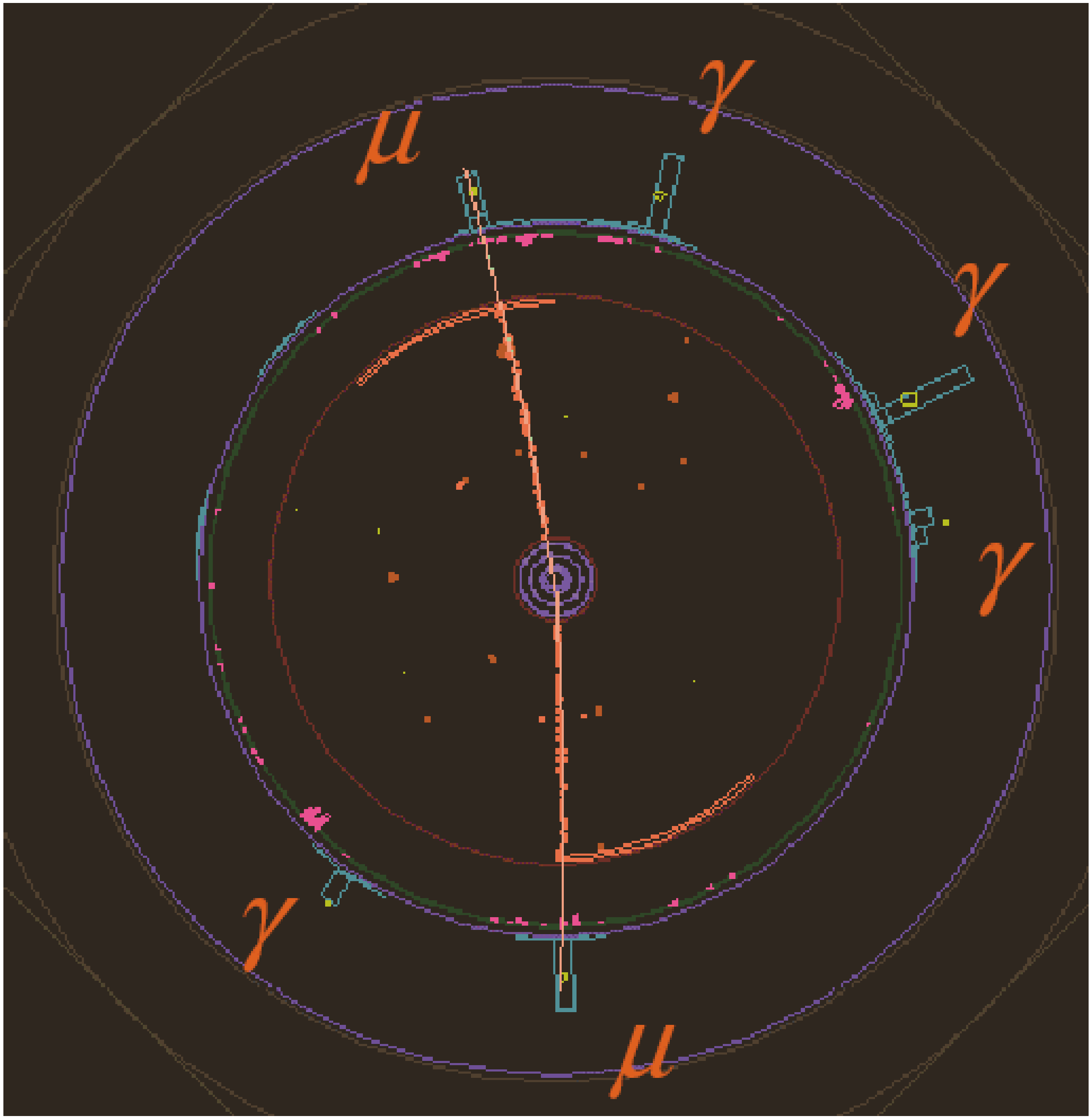
$\Upsilon(1D)$ Mass unknown $\to$ 2 of the $\gamma$-Energies are unknown.

**Define** $\chi^2$ for $\Upsilon(1D)$ cascade hypothesis. Calculate M(1D) that minimizes the $\chi^2$



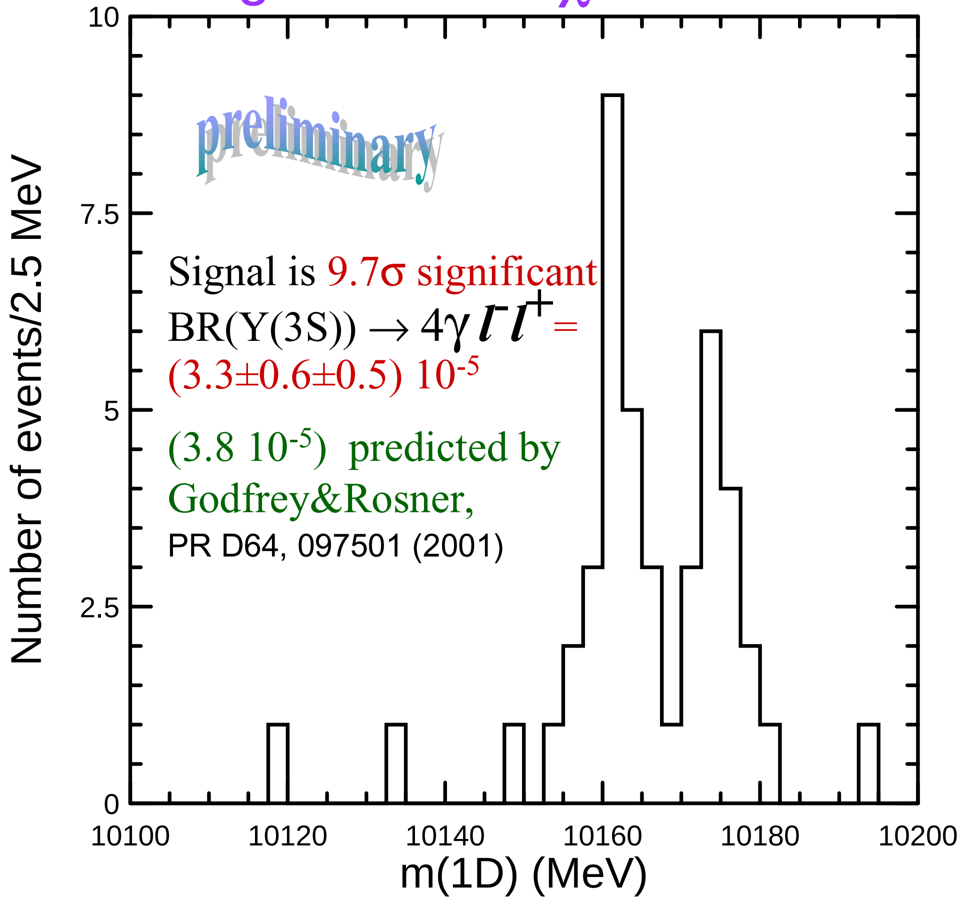
$\Upsilon(3S) \rightarrow \Upsilon(1S) + 4\gamma$

$\hookrightarrow \mu^+\mu^-$

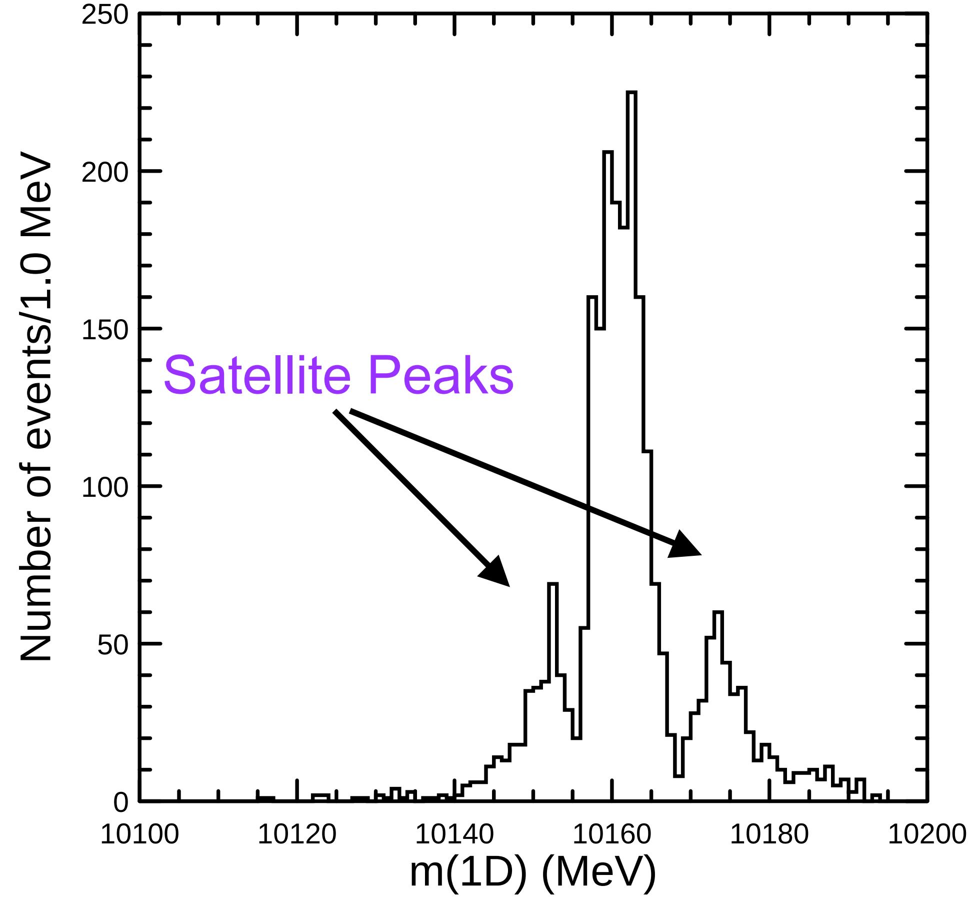


# Discovery of the $\Upsilon(1D)$

M(1D) := $\Upsilon$(1D) Mass that gives best $\chi^2$




MC Simulation for M(1D) = 10160 MeV

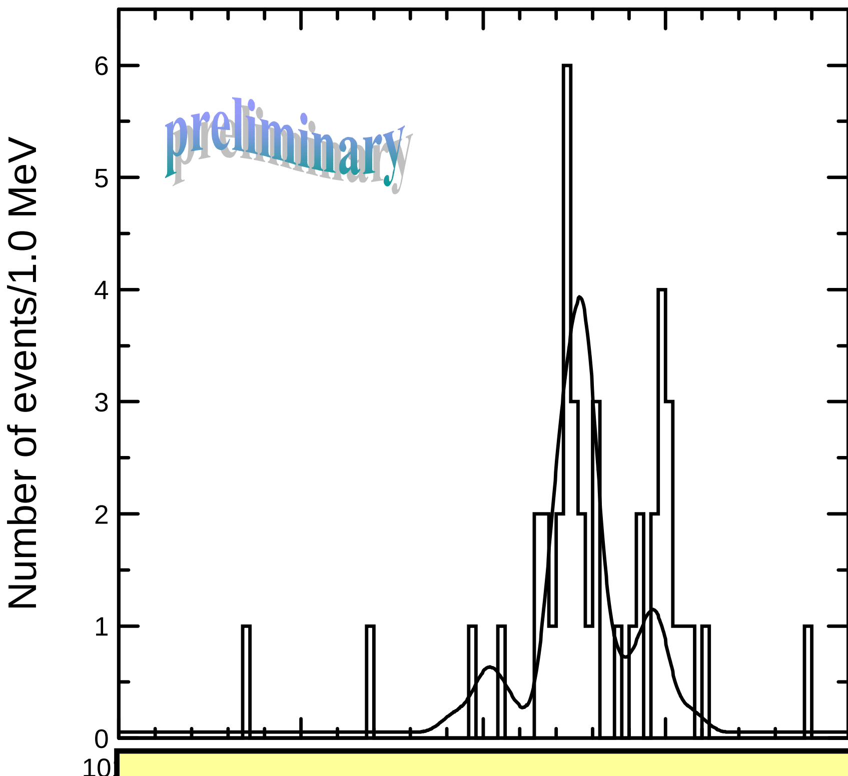


# Discovery of the $\Upsilon(1D)$, Mass Fits

**Fit with one 1D State**

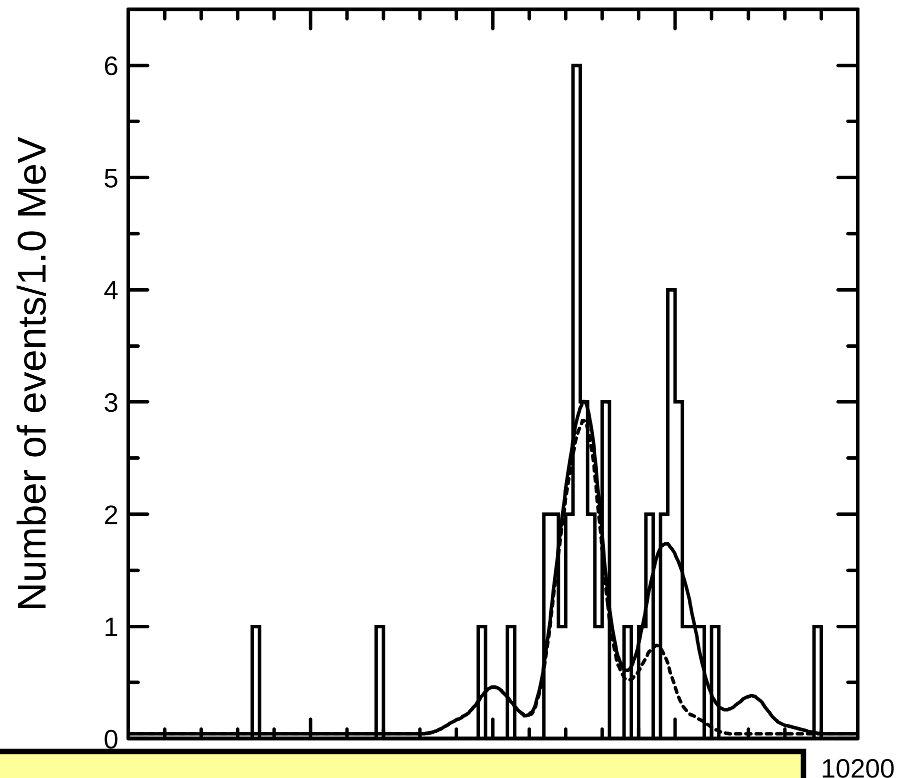
**M(1D) = 10163.4 ± 1.3 MeV**

**With Significance=6.8σ**




**Fit with two 1D States**

**masses at M(1D) = 10161 and 10174 MeV.**



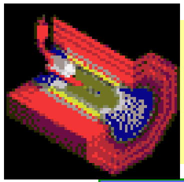

**M(1D) = 10162.2 ± 1.6 MeV (average of 1 and 2 state fits)**

**Most likely Spin assignment: J=2**

# Recent Charm Results

* Charm
  - $D^0 \rightarrow K_s^0 \pi^+ \pi^-$ CLNS 02/1792
  - $\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e$ CLNS 02/1782
  - $D^+ \rightarrow K^{*0} l^+ \nu_l$ CLNS 02/1776
  - (See also Ian Shipsey's Lecture)

* Many CLEO contributions to $\gamma\gamma$ and $\tau$ physics



# Outlook: The CLEO-c Program

2002

Prologue: Upsilons ~1-1.5 $fb^{-1}$ each

$\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$... Spectroscopy, Matrix Elements

$\Gamma_{ee}$, 10-15 times existing world's data

Presented here

2003

Act I: $\psi(3770)$ -- 3 $fb^{-1}$

30M events, 6M *tagged* D decays

(310 times MARK III)

2004

Act II: $\sqrt{s} \sim 4100$ -- 3 $fb^{-1}$

1.5M $D_sD_s$, 0.3M *tagged* $D_s$ decays

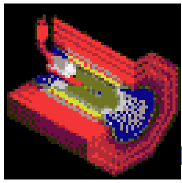
(480 times MARK III, 130 times BES II )

2005

Act III: $\psi(3100)$ -- 1 $fb^{-1}$

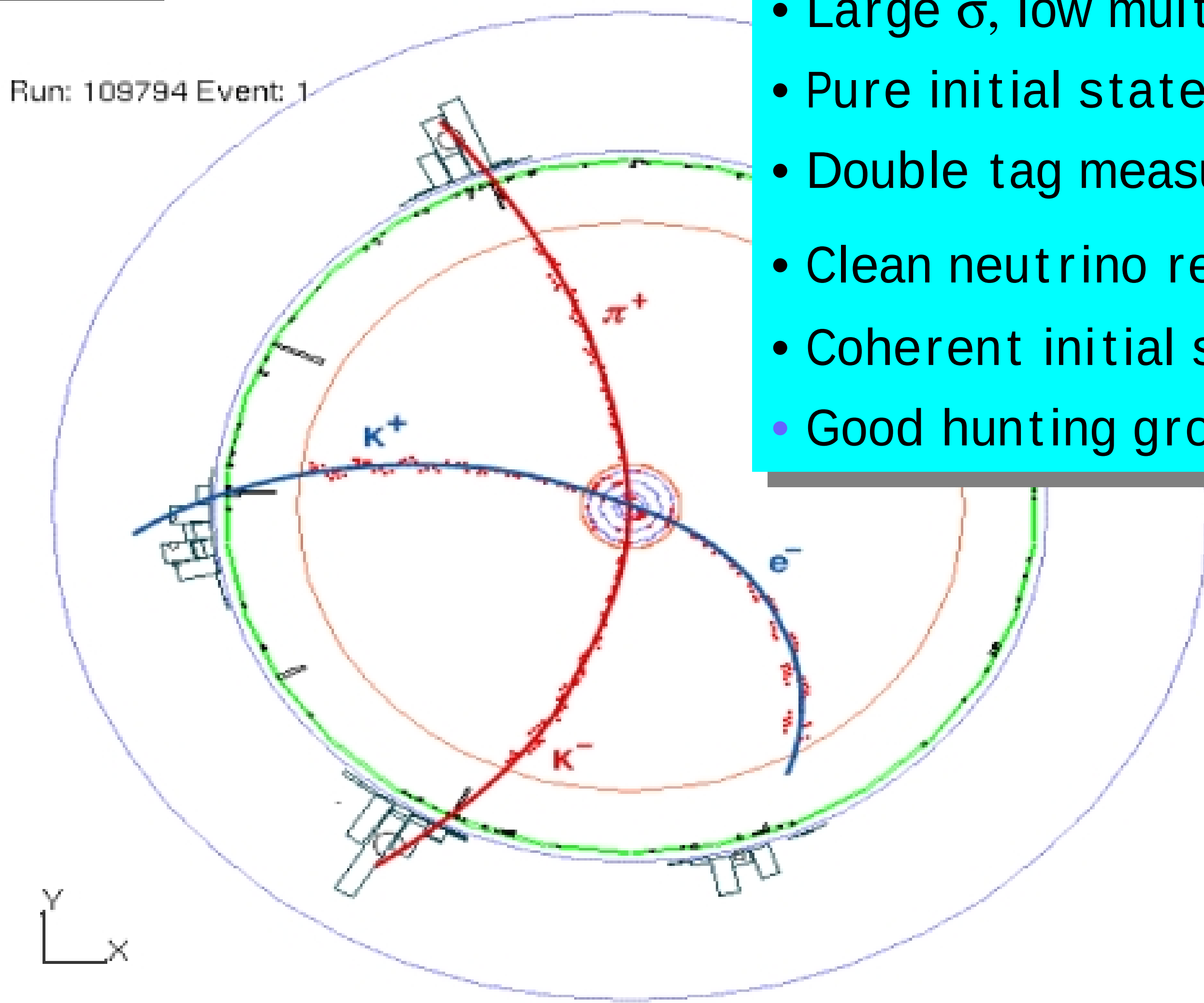
1 Billion $J/\psi$ decays

(170 times MARK III, 20 times BES II)



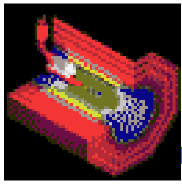
# Why charm threshold?

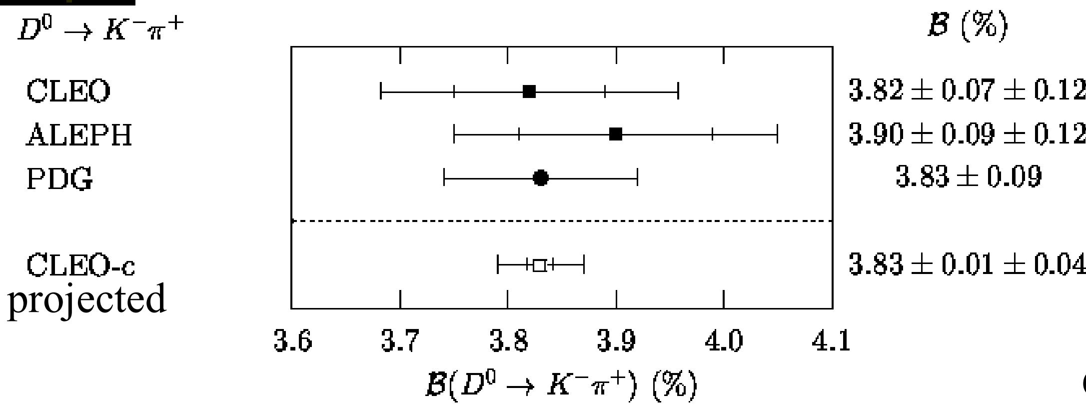
- Large $\sigma$, low multiplicity
- Pure initial state: no fragmentation
- Double tag measurements: no backgr.
- Clean neutrino reconstruction ($D \rightarrow \mu\nu$)
- Coherent initial state ($D^0 \bar{D}^0$ -Mixing)
- Good hunting ground for Rare D decays

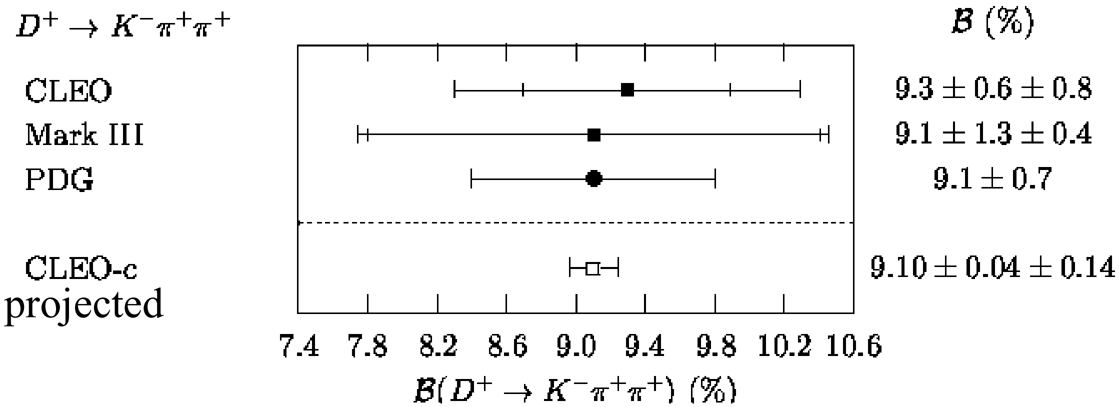


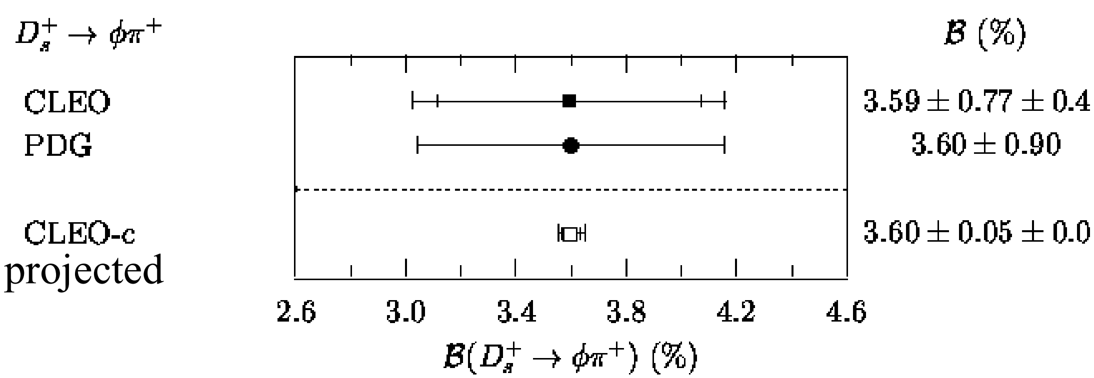

$D^0 \rightarrow K^- \pi^+$ $D^0 \rightarrow K^+ e^- \nu$

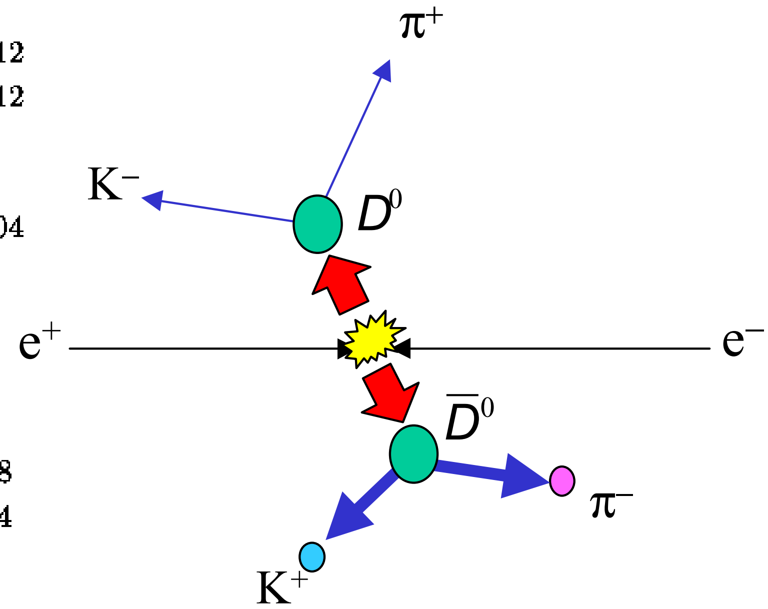
# Absolute D Branching Ratios





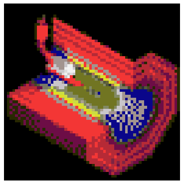



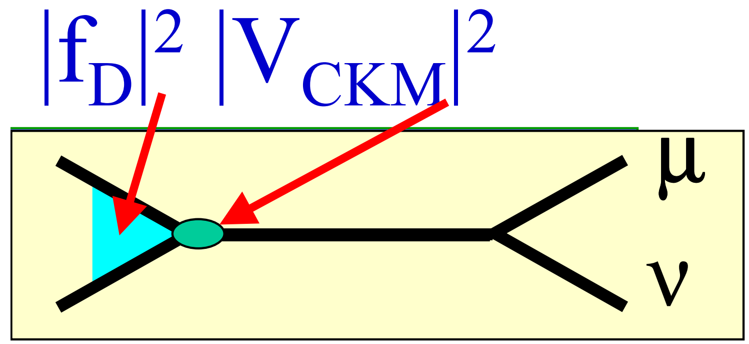



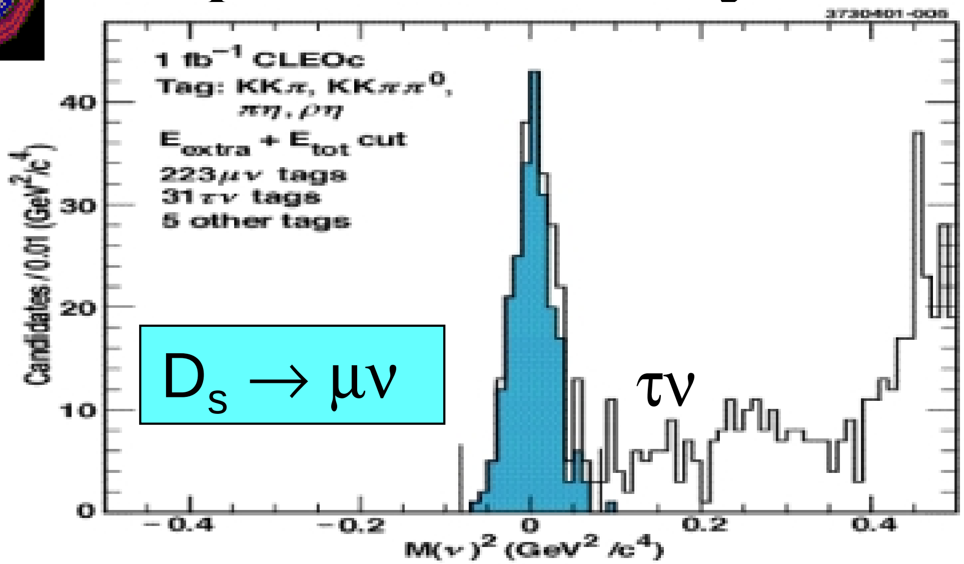

**$\psi(3770) \to D\overline{D}$ dominant**

Double Tag Method allows (almost) BG-free measurement of absolute Branching Fractions



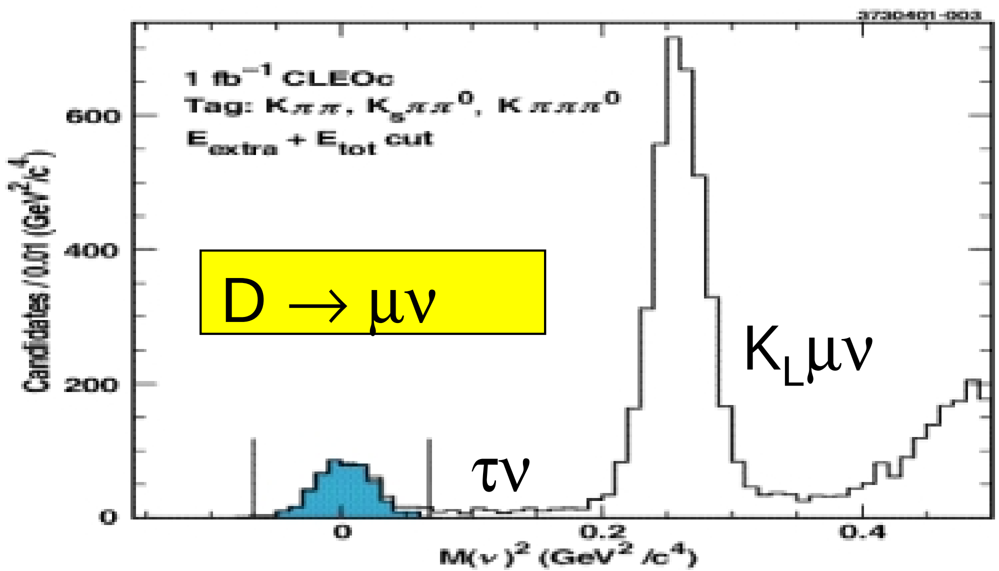
# Leptonic Decays:




$$\frac{\delta f_{D_s}}{f_{D_s}} \approx 2.1\%$$

(Now: ±35%)




$$\frac{\delta f_D}{f_D} \approx 2.6\%$$

(Now: ±100%)

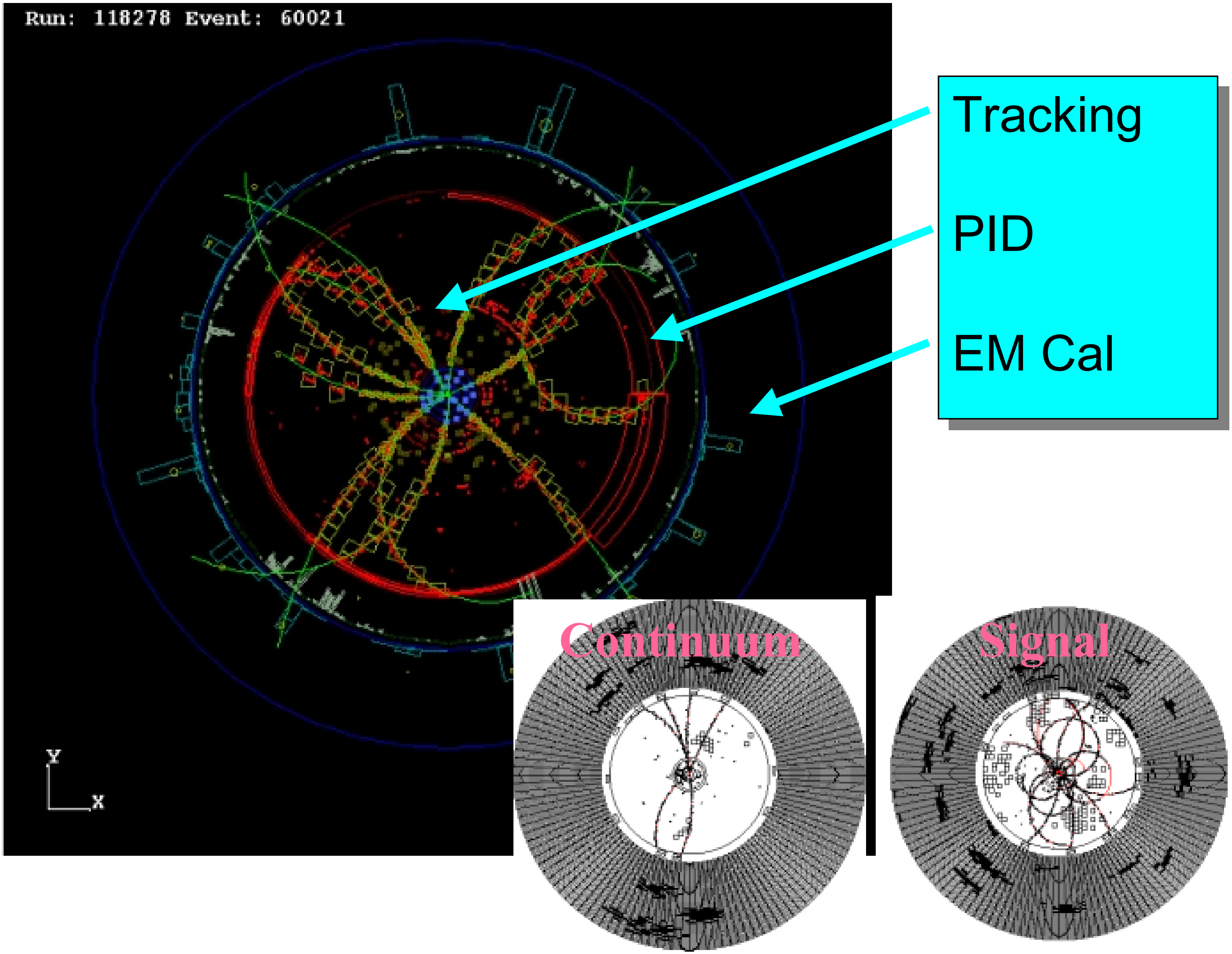
- τν mode to be studied soon

# QCD/Hadron Physics with CLEO-c

* Searches for QCD Hybrids and Glueballs
* Precision Tests of Lattice QCD Predictions
    * $b\bar{b}$ Spectroscopy
    * Charm Meson Formfactors
* Search for New Physics
* Charm Spectroscopy
* R Measurements - Improved Input to Electroweak fits
* Rare Light Meson Decay Modes in two-body $J/\psi$ decays

# Summary

* CLEO contributes significantly to Heavy Flavor Physics
* No time to mention important Charm/tau results from CLEO
* After more than 20 years of data taking, CLEO finished operation at the $\Upsilon(4s)$
* $b\bar{b}$ Resonance scan underway, preliminary results presented here
* CLEO-c will explore Charm region in 2003+


Run: 118278 Event: 60021
Y
X
Tracking
PID
EM Cal
Continuum
Signal

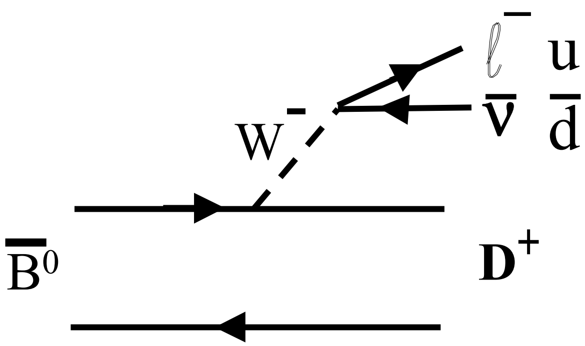
# B Meson Decays at CLEO

**B mesons decay weakly, lifetime ~pico seconds, cτ <1mm**

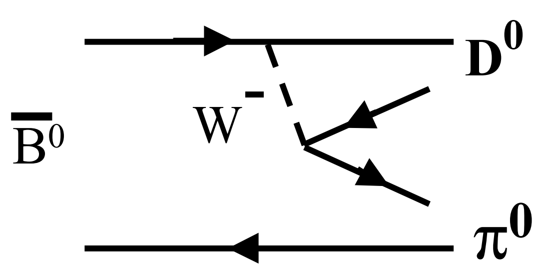
* CLEO investigates $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ and the weak decays of B mesons
* B mesons are produced almost at rest → no time-dependent CP measurements (time-integrated CP measurements possible)

## Example of B decay processes

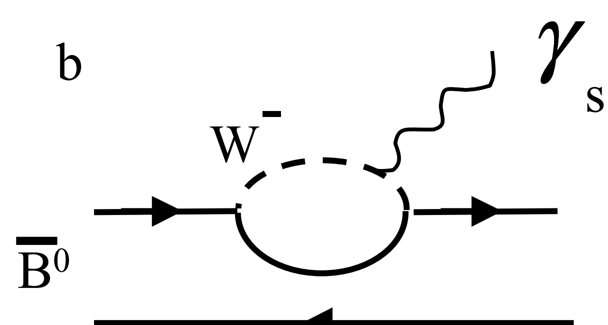
**external spectator**




**internal spectator**




**radiative penguin**



# $B \to X_u l^+ \nu$ with Neutrino Reconstruction

Neutrino four momentum inferred from missing momentum. Requires good solid angle coverage!

Maximum likelihood fit over full three dimensional decay distribution

Contributions from **$B \to X_c l^+ \nu$** (D,D*,D**and NR) and **$B \to X_u l^+ \nu$.**

preliminary $V_{ub} = (4.05 \pm 0.18 \pm 0.58 \pm 0.25 \pm 0.21 \pm 0.56)\ 10^{-3}$

stat syst model theory

b→u