The CKM Matrix

- **We need to connect the weak eigenstates of quarks with the mass eigenstates**

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

↑ weak eigenstates ↑ V_{CKM} ↑ mass eigenstates

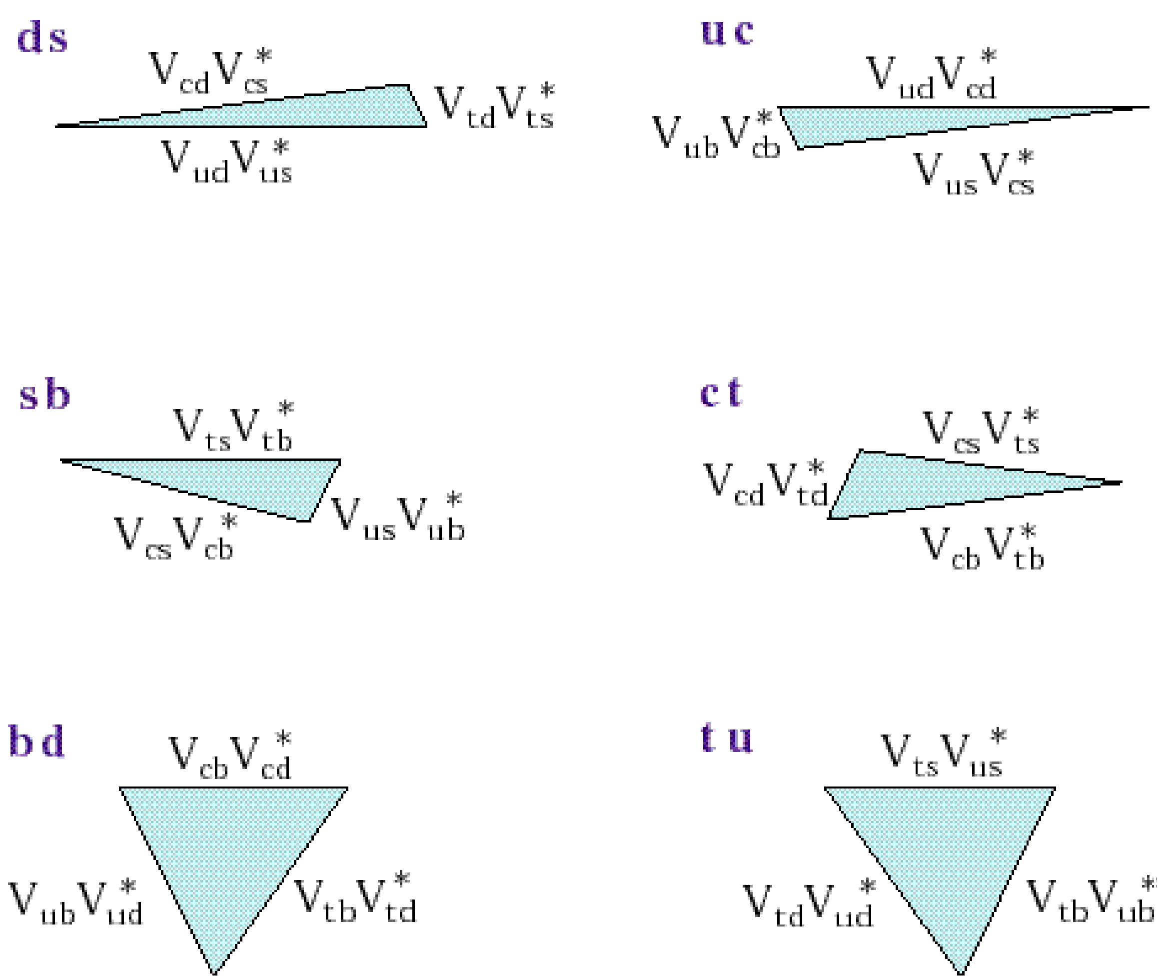
- If ν's have mass there will be analogous matrix

Proper Formulation of CKM Matrix

$$
V = \begin{array}{c} \\ u \\ c \\ t \end{array}
\begin{array}{c}
\begin{array}{ccc} d & s & b \end{array} \\
\begin{pmatrix}
1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3\left(\rho - i\eta\left(1-\frac{1}{2}\lambda^2\right)\right) \\
-\lambda & 1-\frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 & A\lambda^2\left(1+i\eta\lambda^2\right) \\
A\lambda^2\left(1-\rho-i\eta\right) & -A\lambda^2 & 1
\end{pmatrix}
\end{array}
$$

- **Good l ^{3} in real part & l ^{5} in imaginary part**
- **We know l =0.22, A~0.8; constraints on r & h**
- **Due unitarity there are 6 CKM triangles**

The 6 CKM triangles



- **"ds" - indicates rows or columns used**
- **There are 4 independent phases, which can be used to construct entire CKM matrix**

The 4 CKM Phases

$$\beta = \arg\left(-\frac{V_{tb} V_{td}^*}{V_{cb} V_{cd}^*} \right) \qquad \gamma = \arg\left(-\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}} \right)$$

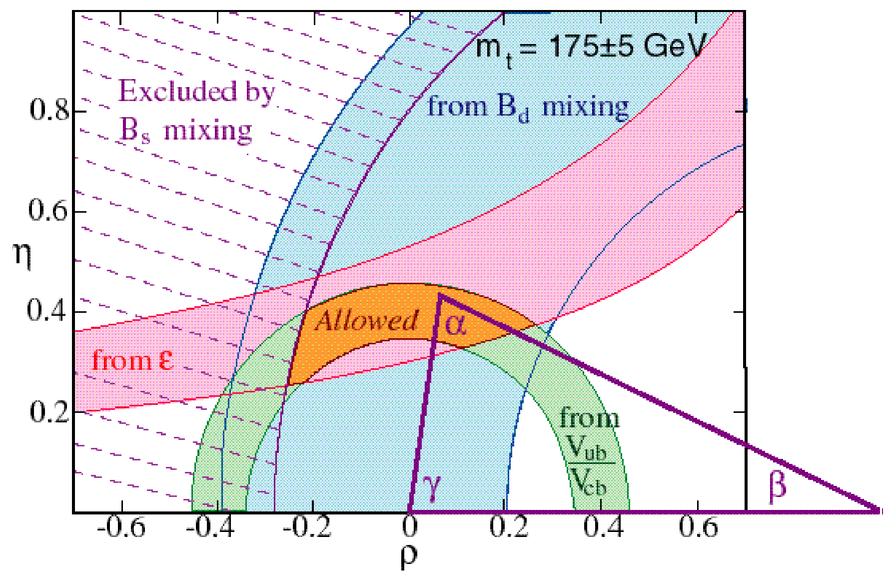
$$\chi = \arg\left(-\frac{V_{cs}^* V_{cb}}{V_{ts}^* V_{tb}} \right) \qquad \chi' = \arg\left(-\frac{V_{ud}^* V_{us}}{V_{cd}^* V_{cs}} \right)$$

β & γ probably large, χ small ~0.02, χ' smaller

Derive reference triangle

Usual Triangle (for ref.)

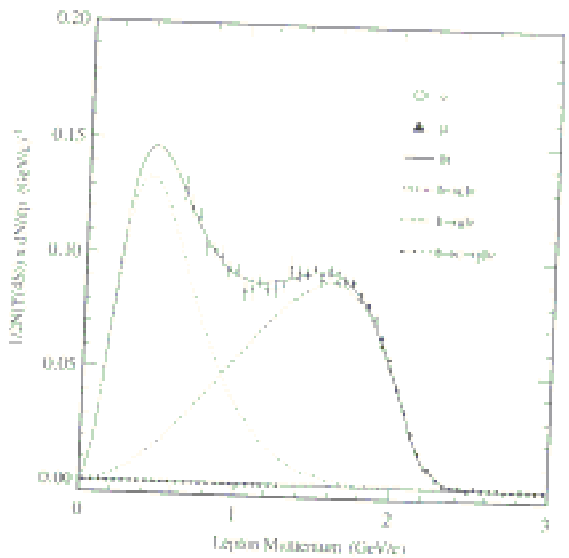
- **Real** a, b **&** g **must sum to 180º**
- **Therefore, any two will do IF we are really measuring the intrinsic angles**
- **New physics can hide, only these angle measurements not sufficient.**
- **Ex: Suppose there is new physics in Bº-Bº mixing (**q**) & we measure CP in** yK_s **and** p^+p^-, **then 2**b¢=2b+q, 2a¢=2a-q, **& 2**b¢+2a¢=2b+2a**, new physics but** b¢+a¢+g= **180º**



- Two sides $|V_{ub}/V_{cb}|$ & $|V_{td}/V_{ts}|$ important.

Ambiguities

- **Suppose we measure sin(2b) using y K_s, what does that tell us about b?**
- **Ans: 4 fold ambiguity- b, p/2-b, p+b, 3p/2-b**
- **Only reason h>0, is B_k>0 from theory, and related theoretical interpretation of e¢**



toward a model independent measurement

Trick: b quarks are produced in pairs

(Measure) (Tag)

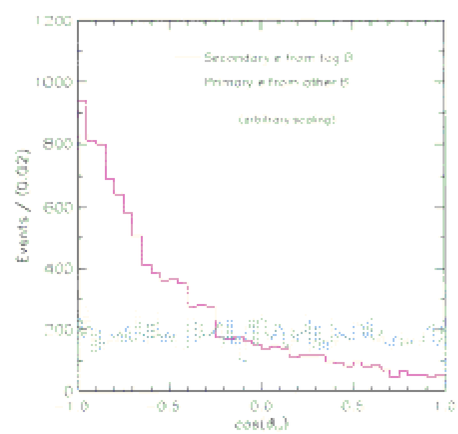
Electron ← b $\bar{b}$ → Positron

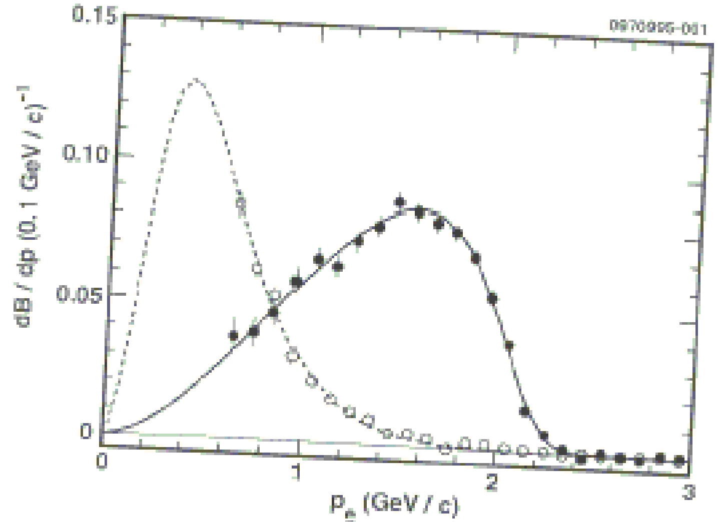
But

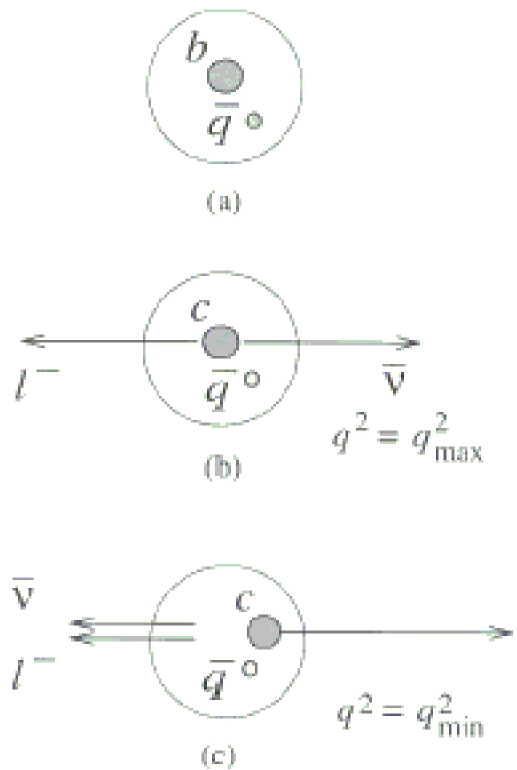
Electron ← b $\bar{b}$ → $\bar{c}$ → Electron

... there is much more to this analysis

e.g. cuts to
suppress more
background




0.15
0.10
0.05
0
dB / dp (0.1 GeV / c)$^{-1}$
0
1
2
3
p_e (GeV / c)


b
q̄
(a)
c
l⁻
q̄
ν̄
$q^2 = q^2_{max}$
(b)
ν̄
c
l⁻
q̄
$q^2 = q^2_{min}$
(c)

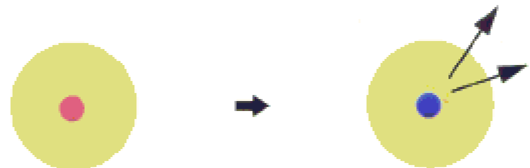
Heavy Quark Effective Theory

- **HQET tells us that in first order when a b quark transforms to a c quark with the c going at the same <u>velocity</u> as the b, the form factor is 1 in first order AND the corrections to 1 can be calculated**
- **The form-factor therefore known to be 1-correction, at maximum q^2, called $w=1$, where**

$$\omega = \frac{M_B^2 + M_{D*}^2 - q^2}{2 M_B M_{D*}}$$

Heavy Quark Effective Theory

B meson D meson



$m_Q \to \infty$ ➡ (Heavy) flavor symmetry, spin symmetry ➡ **Universal Formfactor**

➡ **Absolute Normalization at zero recoil** — $\xi(1) = 1$

$m_Q < \infty$

$$\xi(1) = \eta_A (1 + 0\, \Lambda_{QCD}/m_Q + c_2 (\Lambda_{QCD}/m_Q)^2 \ldots) = \eta_A (1+\delta)$$

for B->D*lν
(Luke)

$\xi(1) = 0.91 +/- 0.03$ (Neubert, Shifman ...)

Experiments ➡

|V$_{cb}$| from B®D*l n

- **Use B®D*l n because the decay rate is largest for and the corrections are better determined.**
- **In HQET there is one "universal" form-factor function, so we don't have to deal with 3 form-factors**
- **To find V$_{cb}$ measure value at w=1, here D* is at rest in B rest frame**

$$\frac{d\Gamma(B \to D^{*}\lambda\nu)}{d\omega} = \frac{G_F^2}{48\pi^3}\left|V_{cb}\right|^2 F^2(\omega)(m_B - m_{D*})^2 m_{D*}^3 \sqrt{\omega^2 - 1} \times \left[4\omega(\omega+1)\frac{1 - 2\omega\frac{m_{D*}}{m_B} + \frac{m_{D*}^2}{m_B^2}}{\left(1 - \frac{m_{D*}}{m_B}\right)^2} \right]$$

V_{cb} results, an example

- **To get results fit using shape proposed by Caprini et al, or Boyd & Grinstein, or in CLEO case by Stone**
- **Use F(1)=0.91±0.03, from Caprini, Uraltsev…..**
- **Results**
  - DELPHI: $(41.2\pm1.5\pm1.8\pm1.4)\times10^{-3}$
  - ALEPH: $(34.4\pm1.6\pm2.3\pm1.4)\times10^{-3}$
  - OPAL: $(36.0\pm2.1\pm2.1\pm1.2)\times10^{-3}$
  - CLEO: $(39.4\pm2.1\pm2.2\pm1.3)\times10^{-3}$
  - World Average 0.0381±0.0021 by adding theoretical error in quadrature with exp error.

Theoretical Value of F(1)

- **Lim F(1) = 1 as m_b ® ¥,**
- **$F(1)=1+O(a_s/p)+d_{1/m^2}+d_{1/m^3}$ (no $d_{1/m}$, Lukes thrm)**
  - F(1)=0.91±0.03, from Caprini, Uraltsev.....
  - F(1)=0.89±0.06, from Bigi
  - Can we get an accurate non-quenched value from the Lattice?
  - The errors are not consistent. What do the errors mean?
- **Bigi: "In stating a theoretical error, I mean that the real value can lie almost anywhere in this range with basically equal probabilty rather than follow a Gaussian distribution. Furthermore, my message is that I would be quite surprised if the real value would fall outside this range. Maybe one could call that a 90% confidence level, but I do not see any way to be more quantitative."**

QCD Sum Rules for $|V_{cb}|$

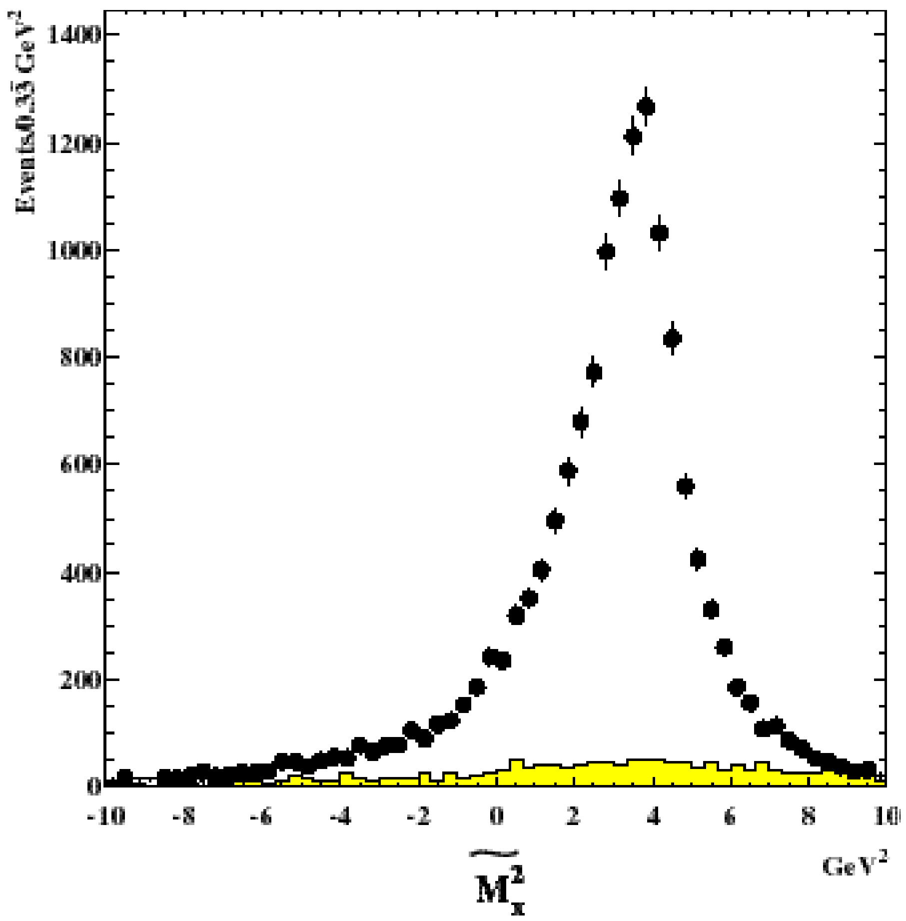
- **Using Operator Product Expansion & Heavy Quark Expansion, in terms of $\alpha_s(m_b)$, Λ, and the matrix elements λ_1 and λ_2, we can accurately determine V_{cb}.**
- **These quantities arises from the differences**

$$m_B - m_b = \bar{\Lambda} - \frac{\lambda_1 + 3\lambda_2}{2m_b} + \ldots, \quad m_{B^*} - m_b = \bar{\Lambda} - \frac{\lambda_1 - \lambda_2}{2m_b} + \ldots,$$

- **From B*-B mass difference, λ_2 = 0.12 GeV^2**
- $$\Gamma_{sl} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} 0.369 \left[1 - 1.54\frac{\alpha_s}{\pi} - 1.65\frac{\bar{\Lambda}}{m_B}\left(1 - 0.87\frac{\alpha_s}{\pi}\right) - 0.95\frac{\bar{\Lambda}^2}{m_B^2} - 3.18\frac{\lambda_1}{m_B^2} + 0.02\frac{\lambda_2}{m_B^2} \right]$$

Measurement of Γ_{sl} & moment analysis

- **Use total Branching Ratio Measurement**
  - CLEO using lepton tags (10.49±0.17±0.43)%
  - Lifetime 1.613±0.020ps Γ_{sl}= 65.0±3.0 ns^{-1}
  - (note LEP 68.6±1.6 ns^{-1})
- **"Moment Analysis" of $B \rightarrow X l \nu$, M_x and E_l**



Result for $|V_{cb}|$ Using Moment Analysis

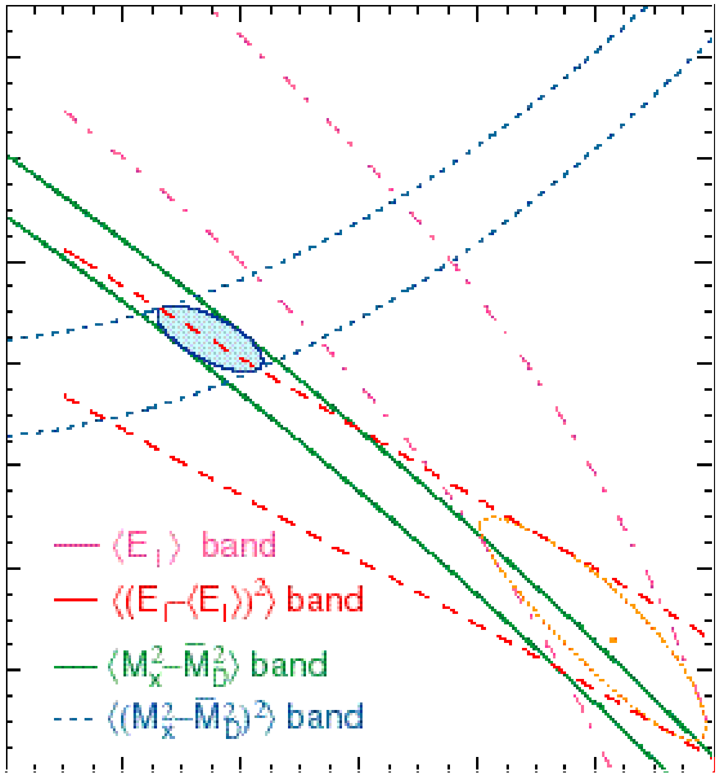
- **Discrepancy between hadronic mass moments and E_l moments**
- **Theoretical estimates favor M_x moments**
- **Taking M_x estimates only:**

  Λ = 0.33±0.02±0.08 GeV

  λ_1=-0.13±0.01±0.06 GeV^2
- **Ligeti claims:**

  $|V_{cb}|$ = 0.0415±0.0012, but

  it would be foolish to use it



Is this an experimental problem or an inherent problem in OPE?

A new measurement of V_{cb}

The differential decay rate, for $B \to D^* l \nu$ is:

$$\frac{d\Gamma}{dw} = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 |F(w)|^2 G(w)$$

w is the Lorentz γ factor of the recoiling D*.
It is a function of masses and q^2. (1 ? w ? 1.5)
w = 1 is the "zero recoil" point.

G(w) is a known kinematic function.

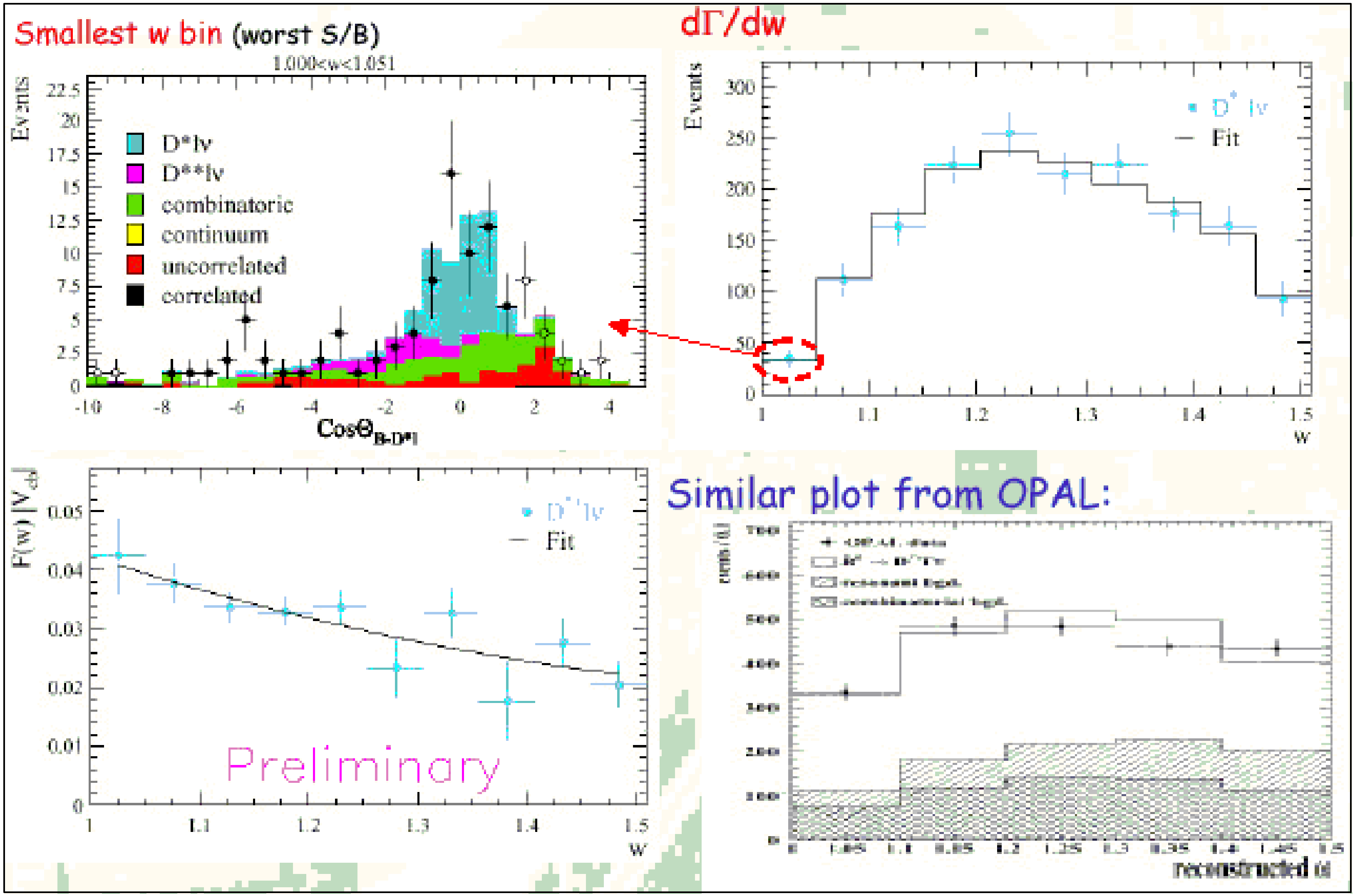
F(w) is the form factor. HQET constrains it.
As $m_{b,c} \to \infty$, F(1) $\to$ 1.
For finite m, the corrections are $O(1/m^2)$.

Two methods:

¥ Extrapolate differential rate to w = 1.
¥ Integrate the total $B(b \to X_c l \nu)$.

The first method is less sensitive to F(w) systematics, but has worse statistics.

Results



Smallest w bin (worst S/B)
1.000<w<1.051
Events
D*lv
D**lv
combinatoric
continuum
uncorrelated
correlated
CosΘ B-D*l
dΓ/dw
Events
D* lv
Fit
w
F(w) |Vcb|
D* lv
Fit
Preliminary
w
Similar plot from OPAL:
reconstructed ω

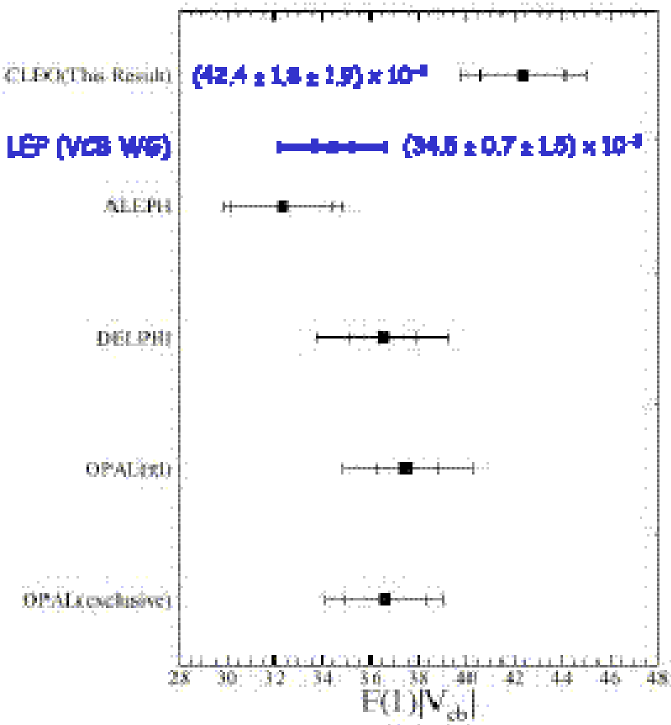
Is there a problem?

$F(1)|V_{cb}| = (42.4 \pm 1.8 \pm 1.9) \times 10^{-3}$ using: $F(1) = 0.913 \pm 0.042$

$BR(D^{*+} l n) = (5.66 \pm 0.29 \pm 0.33)\%$ yields: $|V_{cb}| = (46.4 \pm 2.0 \pm 2.1 \pm 2.1) \times 10^{-3}$

F(1) uncertainty

There appears to be a problem:



This result is strongly correlated with the measured slope, r^2, of $F(w)$:

CLEO: $r^2 = 1.67 \pm 0.11 \pm 0.22$

LEP: $r^2 = 1.01 \pm 0.08 \pm 0.16$

As we saw, LEP and CLEO now agree about the total semileptonic BR.

Preliminary:

Belle: $BR(D^* l n) = (4.74 \pm 0.25 \pm 0.51)\%$

$BR(D l n) = (2.07 \pm 0.21 \pm 0.31)\%$

Waiting for a V_{ub} update...

- **Exclusive (B -> r ln or pln)** **[CLEO]**

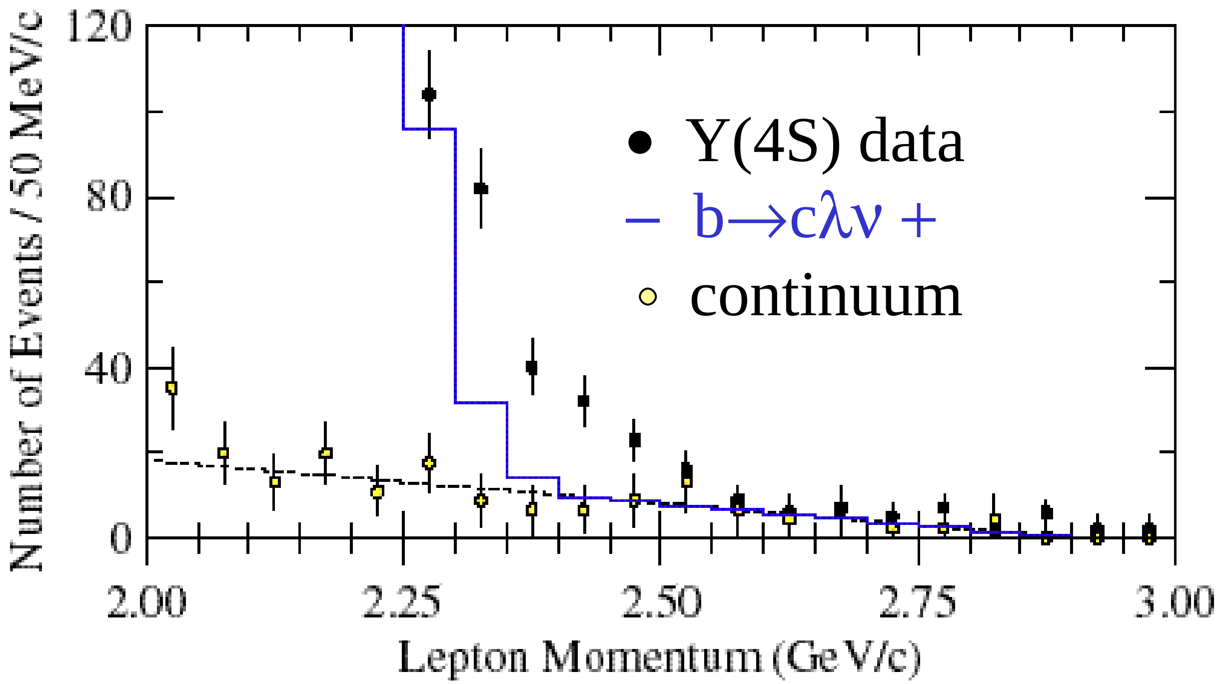
  $|V_{ub}| = (3.25 +/- 0.14^{+0.21}_{-0.29} +/- 0.55) x 10^{-3}$

- **Inclusive (b -> $X_u$ln)** **[LEP, CLEO]**

  $|V_{ub}| / |V_{cb}| = 0.8 +/- 0.2$
- **Rare hadronic decays (e.g. B->pp)** **(seen)**
- **B->$D_s^{(*)}$p$^{+(0)}$** **(not seen)**
- **B -> tn**

V_{ub} from lepton endpoint

- BR & value of V_{ub} depends on model, since fraction of leptons in signal region depends on model!



Neutrino Reconstruction

Resolution

$\sigma_{Emiss} \sim 260$ MeV $\quad \sigma_{|pmiss|} \sim 110$ MeV

σ_{MM}^2 dominated by $2E_{Emiss}\sigma_{Emiss}$ term

Require: $\quad MM^2 / 2E_{miss} < 300$ MeV

⇨ reconstructed $\nu = (|\vec{p}_{miss}|, \vec{p}_{miss})$

traditional full B reconstruction

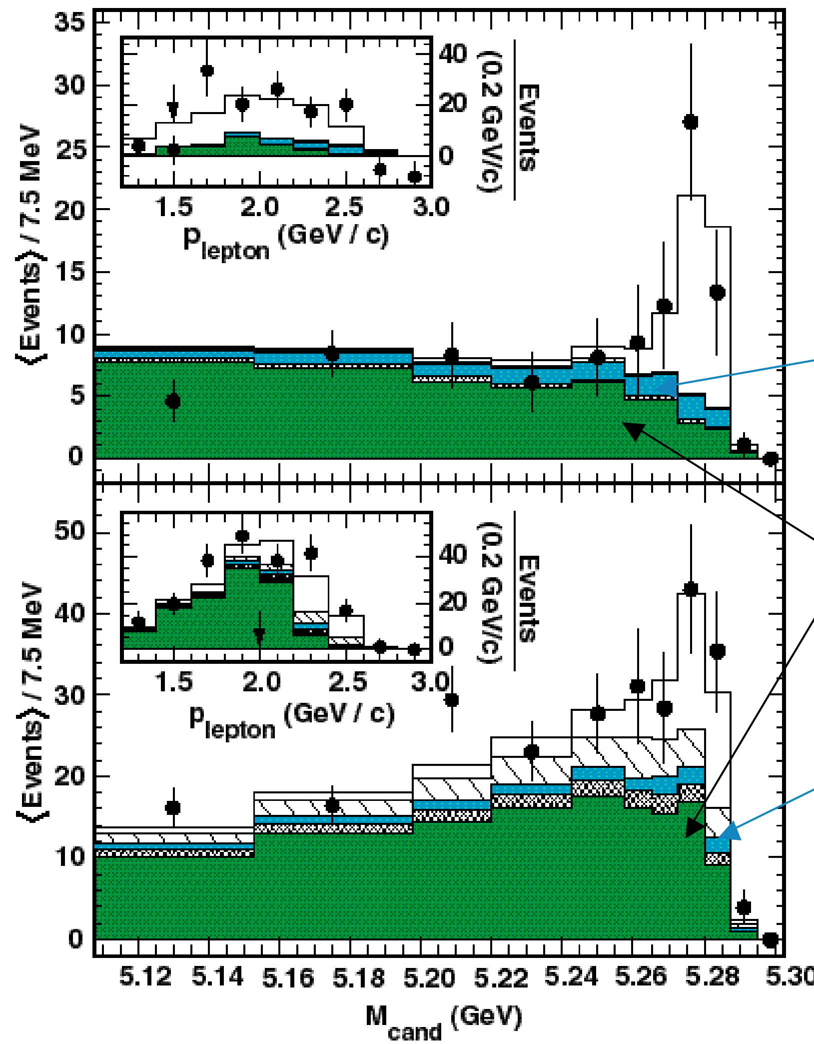
- lepton momentum $\quad p_l > 1.5$ GeV/c
- $\Delta E = E_{beam} - (E_\nu + E_l + E_\pi)$
- $M = \sqrt{E^2_{beam} - (\vec{p}_\nu + \vec{p}_l + \vec{p}_\pi)^2}$

Efficiency (ISGW) = 2.9%

V_{ub} from p l n and r l n

p^{+}l n + p^{0}l n

r^{+}l n + r^{0}l n+
w^{o}l n



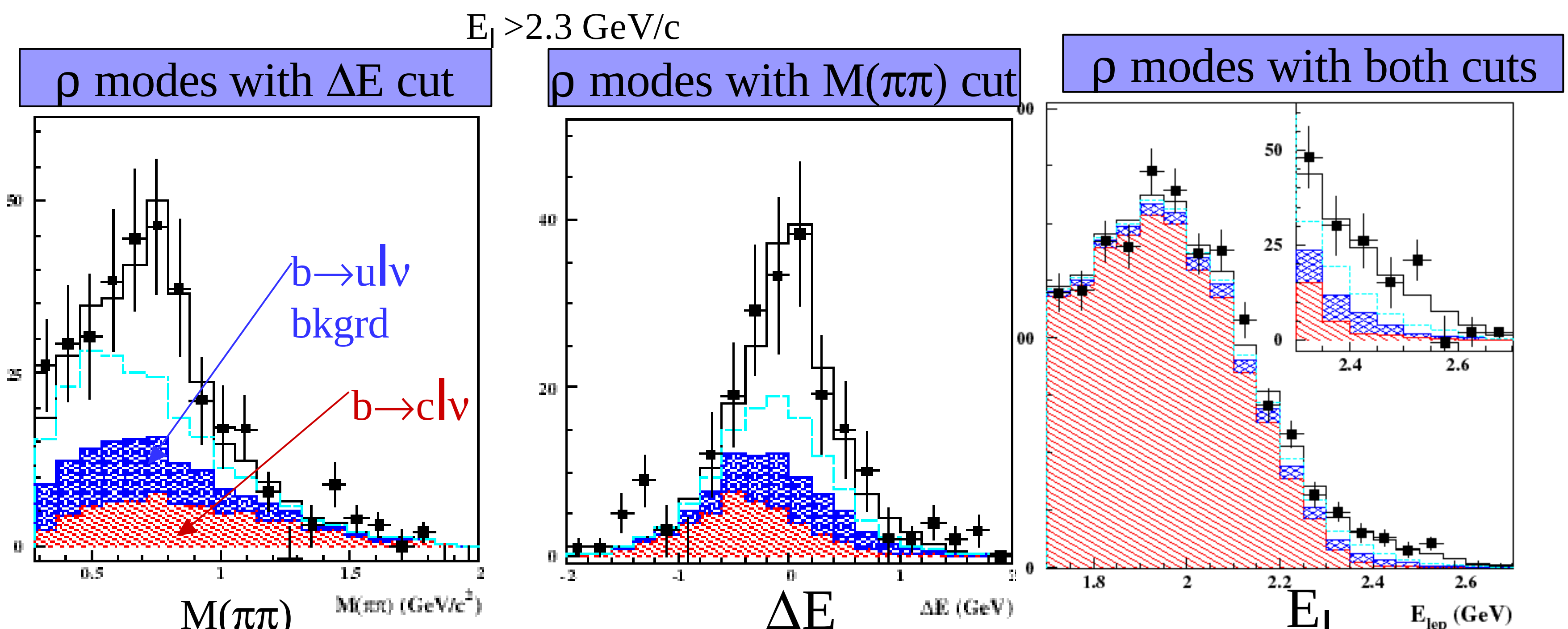
b→u backrounds & cross-feeds

b→c backrounds

b→u backrounds & cross-feeds

New CLEO form-factor Analysis

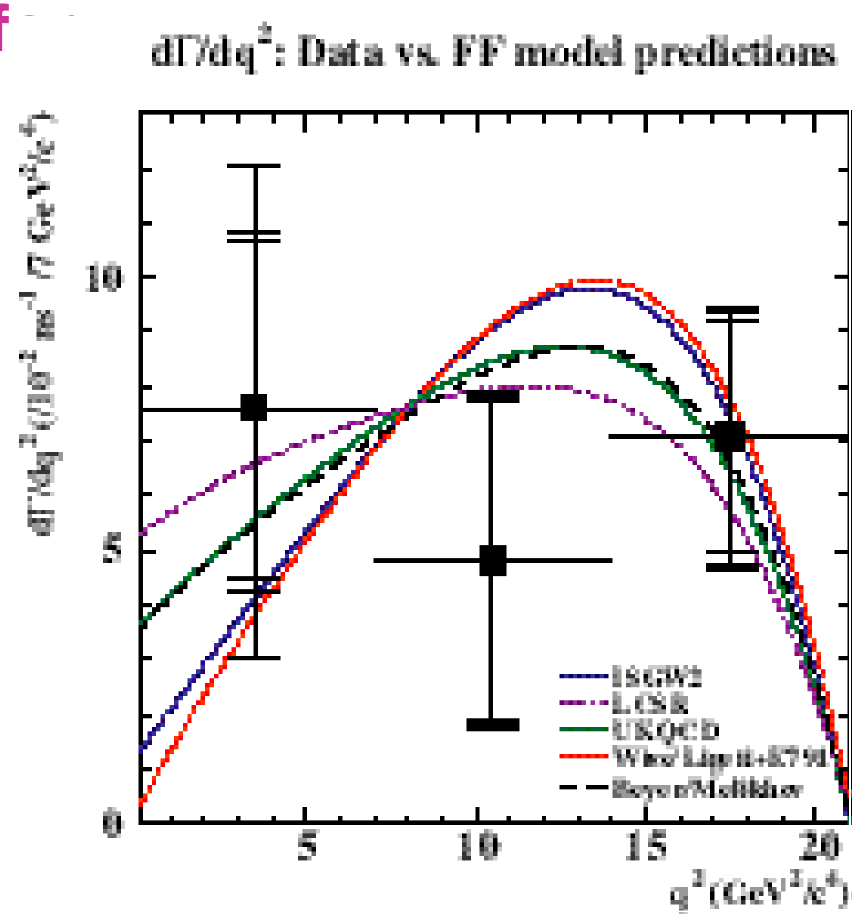
Find $\rho^{+}\lambda\nu + \rho^{0}\lambda\nu + \omega^{o}\lambda\nu$ as function of E_{λ} using likelihood method to fit $M(\pi\pi)$ & ΔE distributions, where $\Delta E = E_{\rho} + E_{l} + |\mathbf{p}_{miss}| - E_{beam}$



Form-factor Results

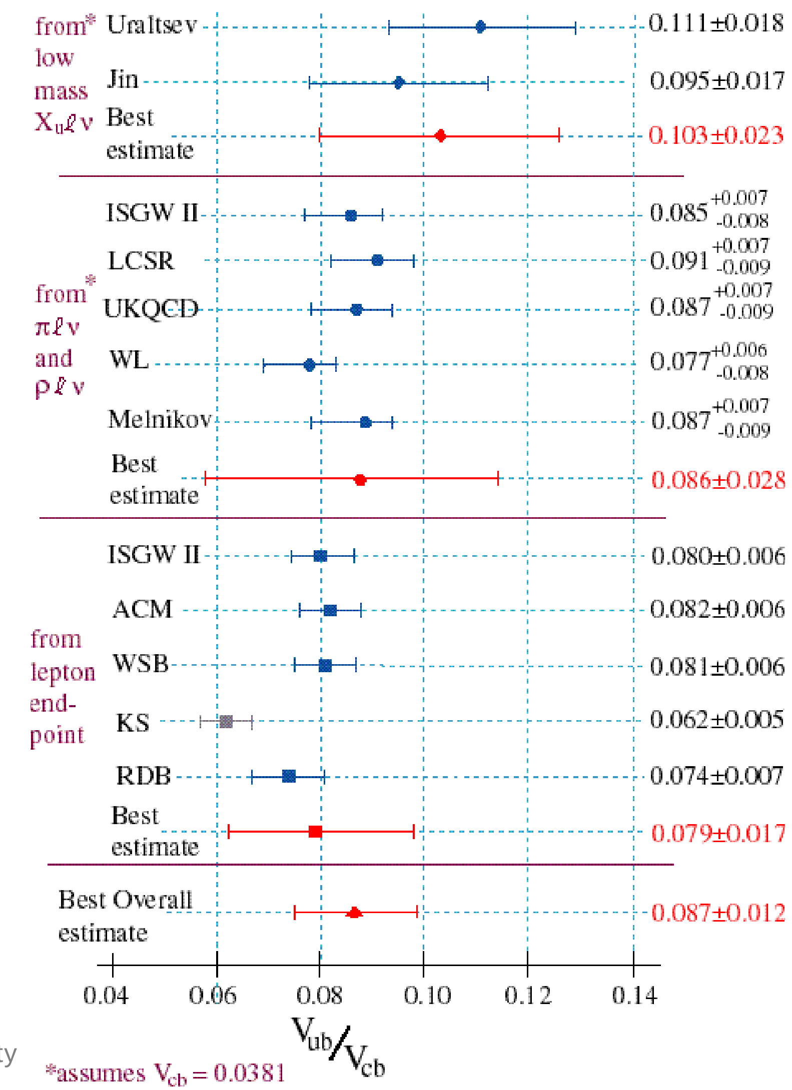
- In general 3 form-factors f
  $0^{-} \rightarrow 1^{-}$ transitions, but we do not have enough precision to disentangle them
- Data shows the need for more data
- Combining with older result:

$$|V_{ub}| = (3.25 \pm 0.14 \,^{+0.21}_{-0.29} \pm 0.55) \times 10^{-3}$$



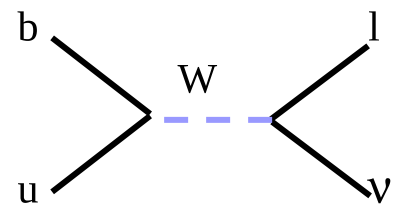
Summary of $|V_{ub}|$ Results

- **LEP measurements use 8% theoretical error as given by Uraltsev. However Jin's similar calculation claims a 10% error but differs by 14%. I use a 14% theory error here**
- **Since the LEP Monte-Carlo calculations are highly correlated, I take a common 14% systematic uncertainty**
- **The exclusive channels rule out the Korner & Schuler (KS) model (gets the wrong V/P ratio), but have large errors**
- **The CLEO endpoint results have the best statistical error. Hard to estimate the theoretical error. I take 14%.**



Pure leptonic decays: B -> tn

$$BR(B^+ \rightarrow l^+\nu) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$



Standard Model: B -> τν ~ (0.2-1) x 10^{-4}

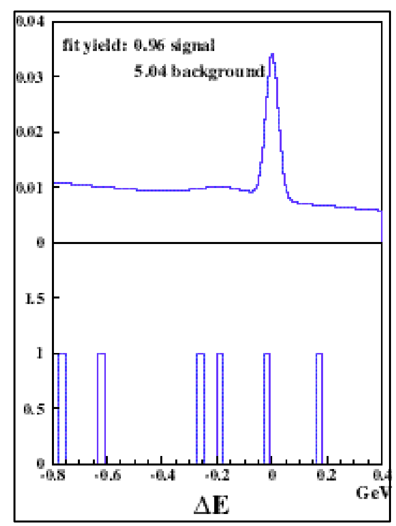
Idee: fully reconstruct on B, look for τ + missing energy

Using 9.7 x 106 BB events we find

BR(B -> τν) < 8.4 x 10^{-4}

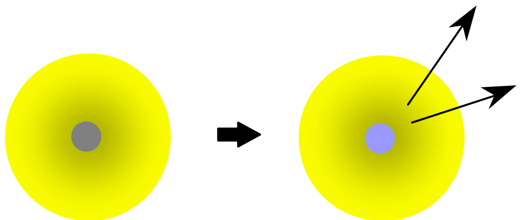
Bonus:

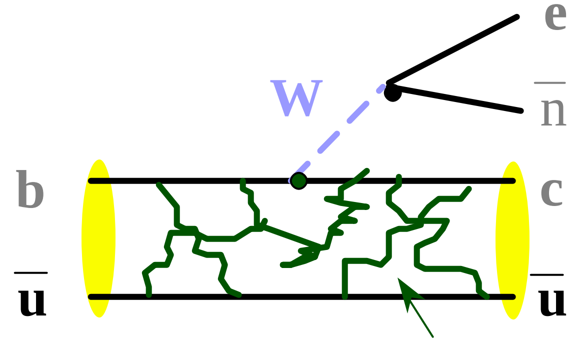
BR(B -> Kνν) < 2.4 x 10^{-4}



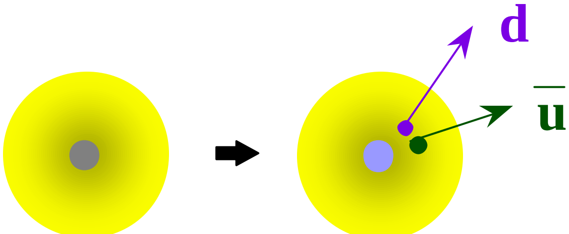
Understanding Hadronic Decays

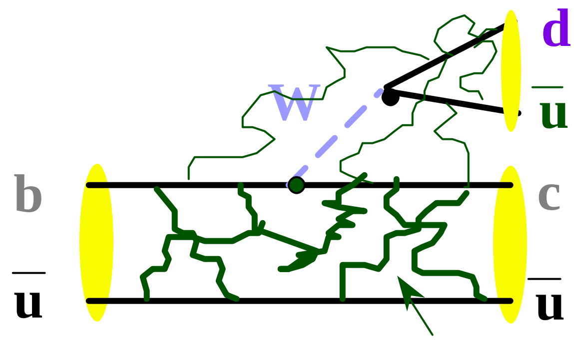
Semileptonic





Hadronic

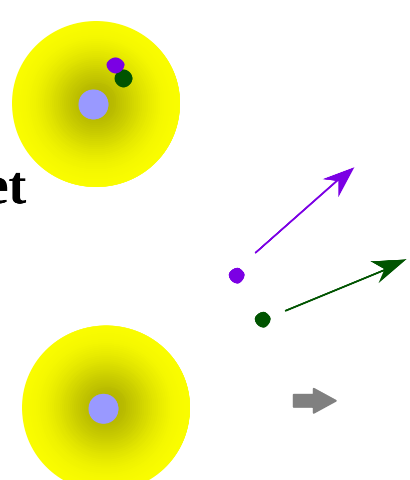


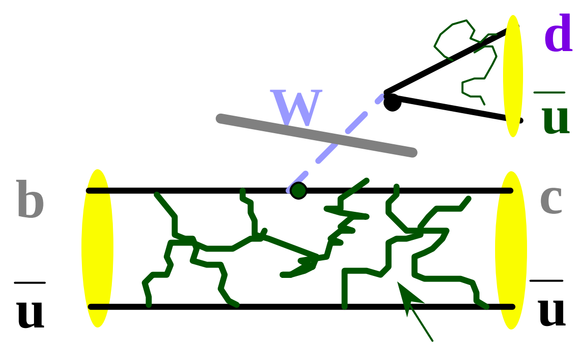


But if …

W creates $\bar{u}d$ pointlike
➡ color singlet

if they get out fast enough …





Hadronic B Decays

- **Semileptonic Decay**

$$A = \frac{G_F}{\sqrt{2}} V_{cb} V_{ub}^{*} < \nu | \gamma_\mu (1 - \gamma_5) | l >< D^{*-} | (cb) | B^0 >$$

- **Hadronic + Factorization**

$$A = \frac{G_F}{\sqrt{2}} V_{cb} V_{ub}^{*} < \pi | (du) | 0 >< D^{*-} | (cb) | B^0 >$$

Factorization Tests:

- **Branching Ratios**

$$\frac{\Gamma(B \to D^{*+} h^-)}{\frac{d\Gamma}{dq^2}(B \to D^{*+} l \nu)|_{q^2 = m_h^2}} = 6\pi^2 c_1^2 f_h^2 |V_{ud}|^2$$

- **Polarization**

$$\Gamma_L / \Gamma \, (B \to D^{*+} h^-) = \Gamma_L / \Gamma \, (B \to D^{*+} l^- \nu)|_{q^2 = m_h^2}$$

Hadronic Decays and Factorization

(1997)

Semileptonic (e.g. $B \to D^{*-} l^+ \nu$)

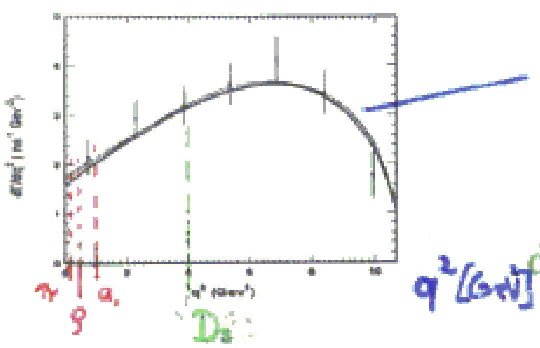
$$A = G_F/1.4\, V_{cb} <\nu|\gamma_\mu(1-\gamma_5|\, l> <D^{*-}|\, (cb)|\, B^0>$$

Hadronic (+Factorization) (e.g. $B \to D^{*-} \rho^+$)

$$A = G_F/1.4 V_{cb} <\pi|\, (du)|\, 0> <D^{*-}|\, (cb)|\, B^0>$$

I. Branching Ratio Tests

Input: π decay constant ✓
semileptonic decay rate ✓



$$\frac{\Gamma(B^0 \to D^{*-} \pi^+)}{d\Gamma/dq^2(B^0 \to D^{*-} l^+ \nu)} = 6\, \pi^2 c_1^{\,2} f_\pi^{\,2} |V_{ud}|^2$$

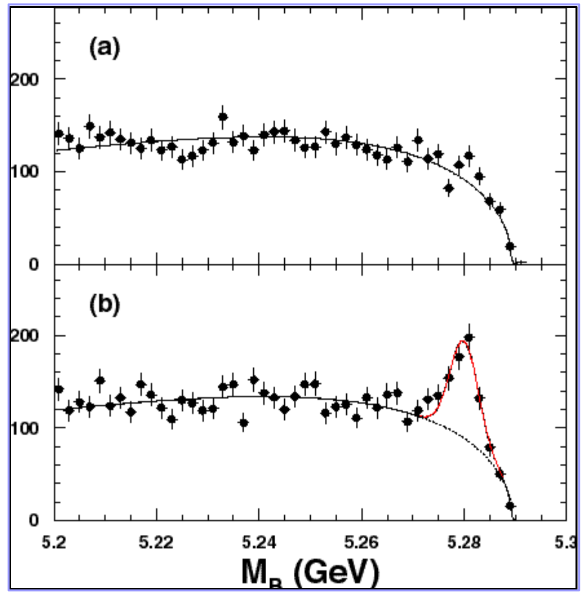
	B->D*	B->D	"Theory"
$B^0 \to D^{(*)-}\pi^+$	1.18+/-0.21	0.94+/-0.30	1.22+/-0.15
$B^0 \to D^{(*)-}\rho^+$	2.92+/-0.70	2.63+/-0.88	3.26+/-0.42
$B^0 \to D^{(*)-}a_1^+$	3.8+/-1.0		3.0+/-0.5

II. Polarization Tests

$\Gamma_L / \Gamma(B^0 \to D^{*-}\rho^+) = 90+/-7+/-5\%$ ⇒ $\Gamma_L / \Gamma(B^0 \to D^{*-} l^+ \nu) = 88\%$

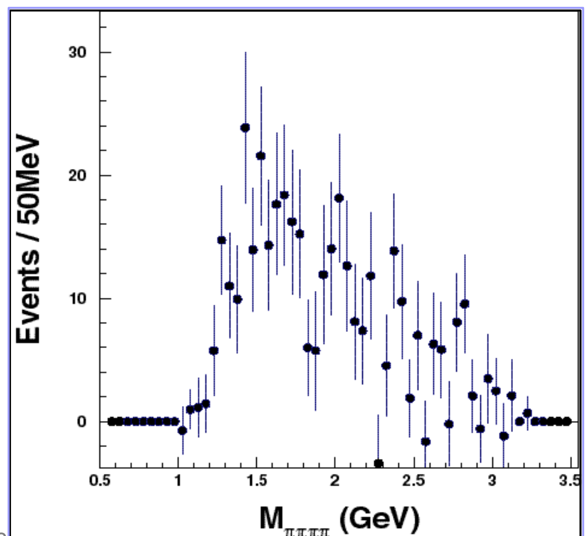
The D*$^+$p$^+$p$^-$p$^-$p^o Final State

- (a) DE sidebands
  |3.0 – 5.0 s |
- (b) DE around 0 ±2.0s fit with sideband shape fixed & norm allowed to float
- Also signals in D^o®K$^-$p$^+$ p^o and D^o®K$^-$p$^+$ p$^+$ p$^-$ (not shown)
- Fit B yield in bins of M(4p)



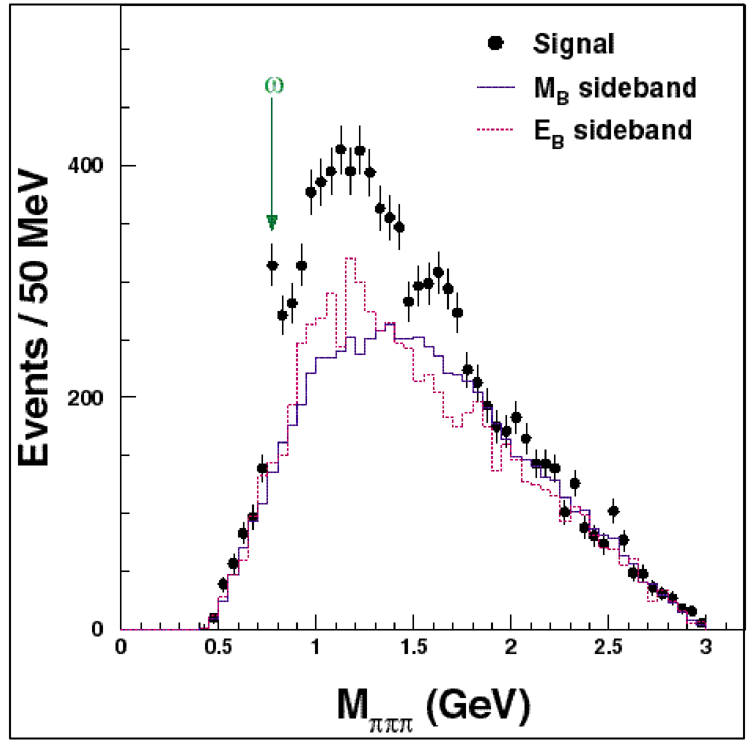
(D^o→K$^-$π$^+$)

358±29

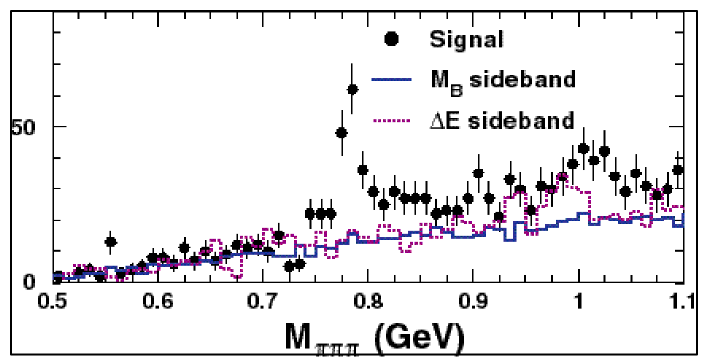


The $p^+p^- p^o$ Mass Distribution

- What are the decay mechanisms for the $(4p)^-$ final state?
- We examine the $p^+p^-p^o$ mass spectrum (2 combinations/event). All 3 D^o decay modes summed



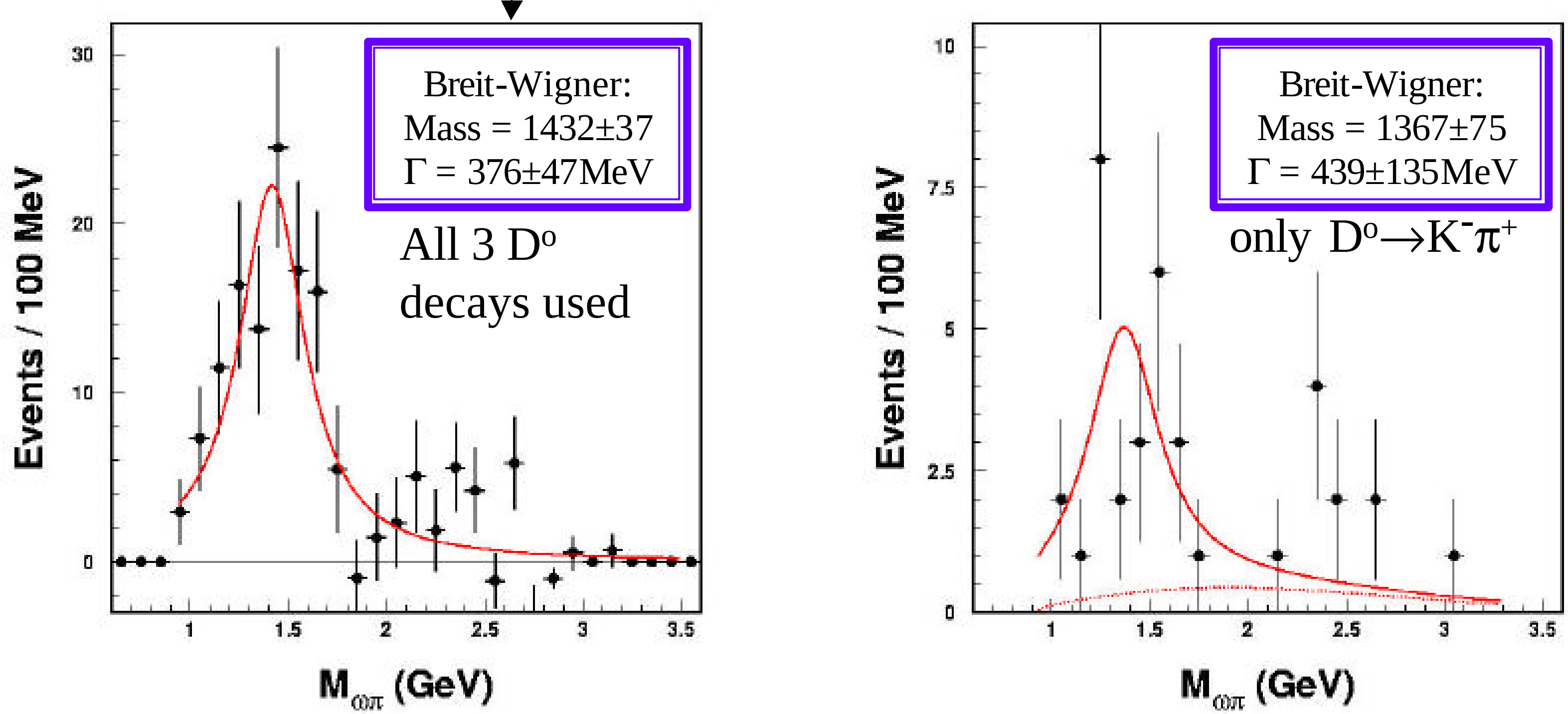
Enlarged & Dalitz plot exterior removed



The wp$^-$ Mass Distribution

Fit M_B distribution in $\omega\pi$ mass bins

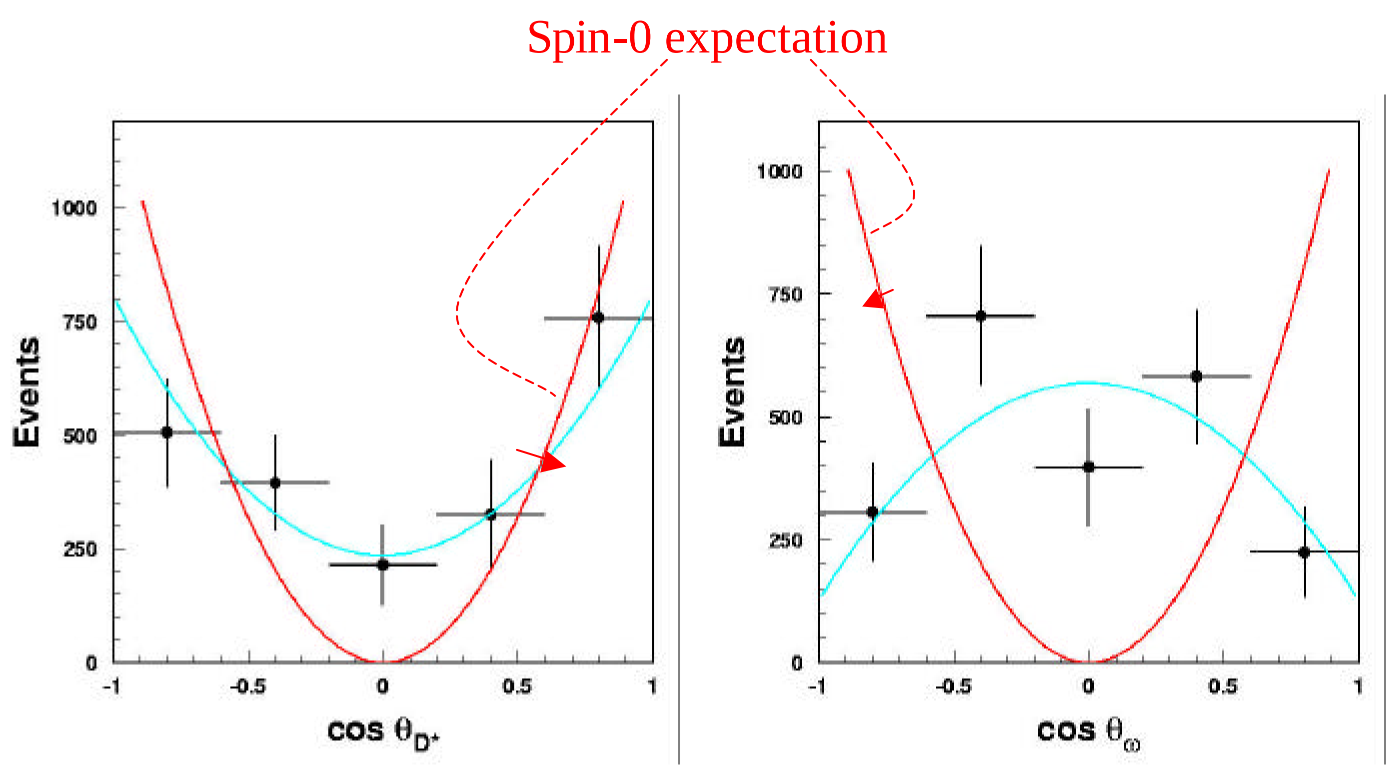
$D^{*+}\omega\pi^-$ $D^{*\circ}\omega\pi^-$



Possible resonance (A) at M=1419±33 MeV, G=382±44 MeV

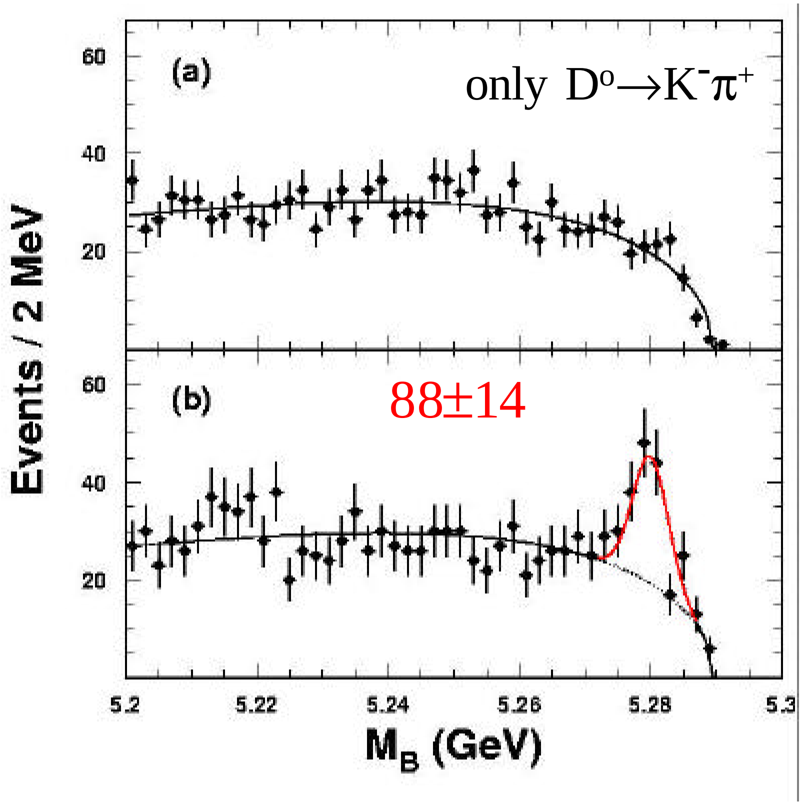
$D^{*+}(wp)^{-}$ Angular Distributions

- For a spin-0 A the D* & w would be fully polarized
- Spin 0 Þ c^2/dof = 3.5 ($\cos q_{D*}$), 22 ($\cos q_w$) Þ Ruled out
- Best fit Þ G_L/G = 0.63±0.09 (D^{*+}), 0.10±0.09 (w)

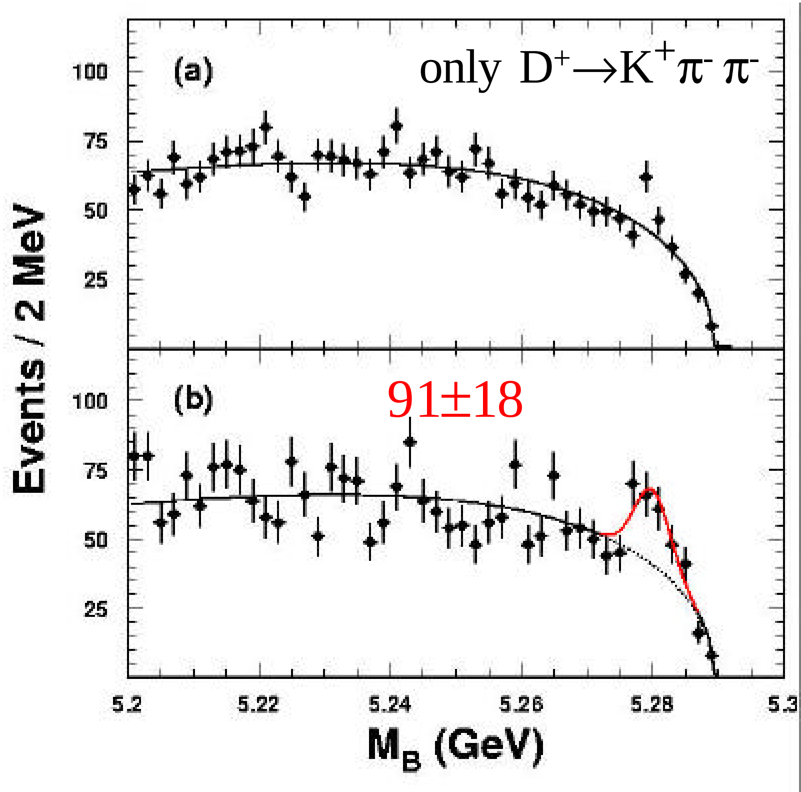


The Dwp$^-$ Final State

$D^{\circ}\omega\pi^-$

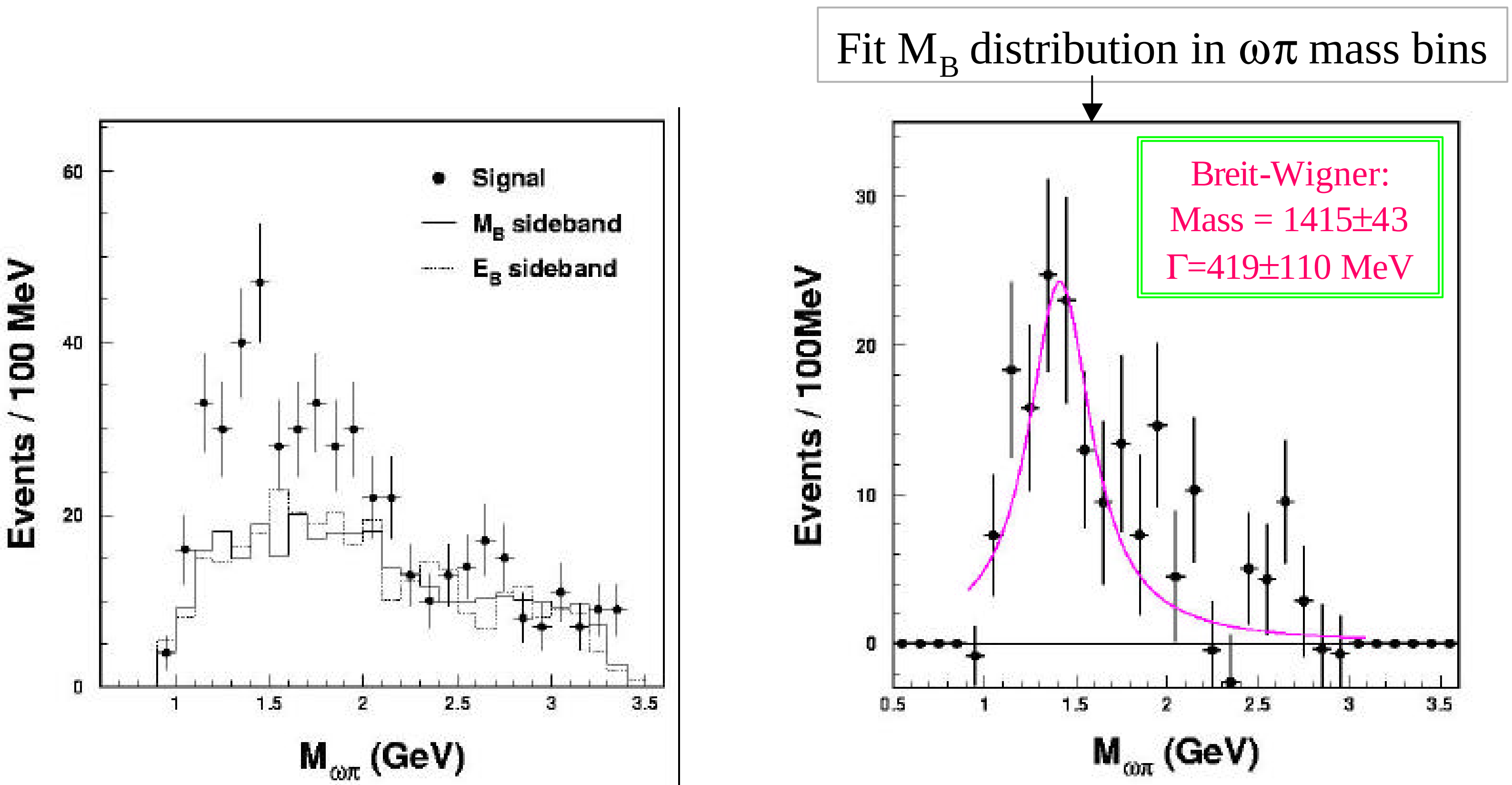


$D^+\omega\pi^-$



- Signal: $|\Delta E| < 2\sigma$ (18MeV) Sideband: $3\sigma < |\Delta E| < 7\sigma$
- No signal in ω sidebands

The wp$^-$ Mass Distribution



- Combined $D^\circ\omega\pi^-$ and $D^+\omega\pi^-$ modes (179 events)
- Consistent with $D^*\omega\pi$ result
- Select (1.1–1.7 GeV) for angular study (104 events)

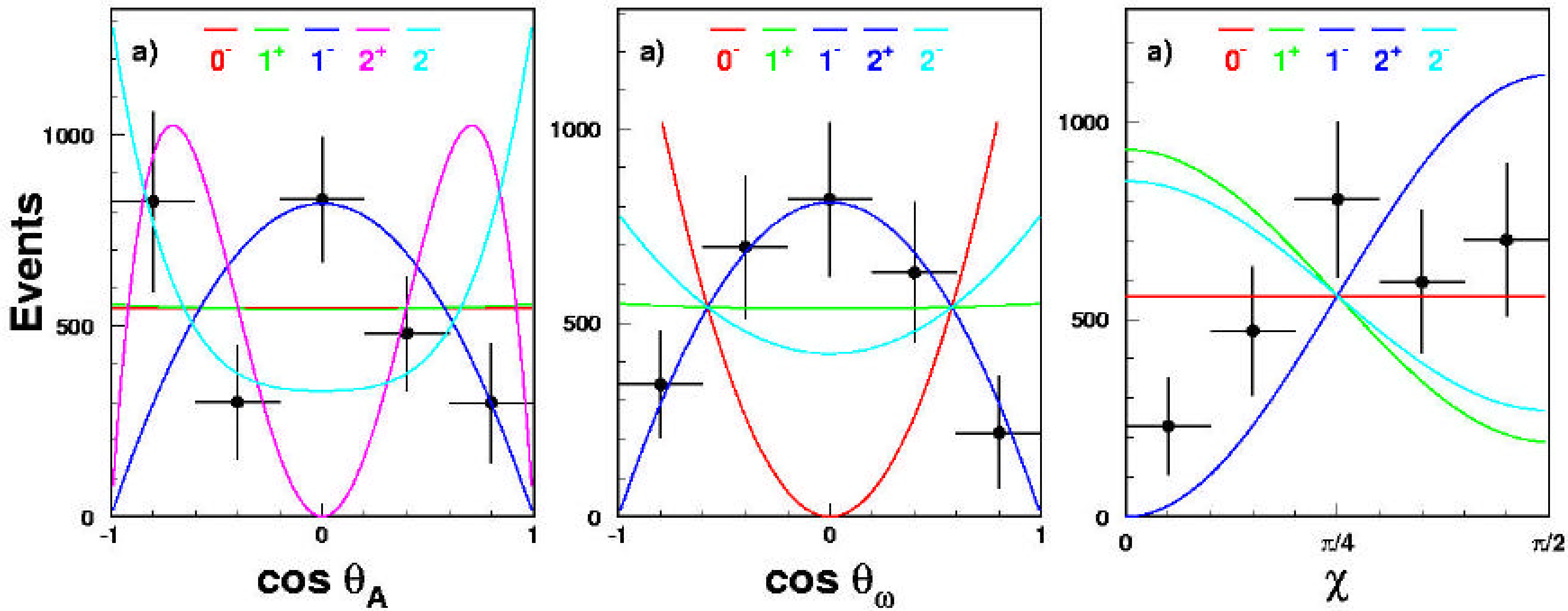
The Angular Distributions in

B ® **D A**$^-$: **A**$^-$ ® w p$^-$, w ® p°p$^+$p$^-$

∠ between ω in A frame & A boost direction

∠ between normal of ω decay plane & ω boost

∠ between A & ω decay planes



- Small efficiency corrections applied
- For 1^+ and 2^-, the longitudinal ratio (Γ_L/Γ) floats
- 1^- preferred, χ^2/dof (1^-) = 1.7, (2^+) = 3.2
- A^- properties: mass = 1418±26±19 MeV, Γ=388±41±32 MeV

Identifying the A^- with the ρ'

- **Clegg & Donnachie: ($\tau \rightarrow (4\pi)\nu$, $e^+e^- \rightarrow \pi^+\pi^-$, $\pi^+\pi^+\pi^-\pi^-$) find two 1^- states with (M, Γ)= (1463$\pm$25, 311$\pm$62) MeV & (1730$\pm$30, 400$\pm$100) MeV, mixed with non-$q\bar{q}$ states, only the lighter one decays to $\omega\pi$**
- **Godfrey & Isgur: Predict first radial excited ρ at 1450 MeV, Γ=320 MeV, $B(\rho'^- \rightarrow \omega\pi^-)=39\%$**

Summary & Discussion of Rates

Mode	Br (%)	# of events
$\overline{B}^{\circ}\to D^{*+}\pi^{\circ}\pi^{+}\pi^{-}\pi^{-}$	1.72±0.14±0.24	1230±70
$\overline{B}^{\circ}\to D^{*+}\omega\pi^{-}$	0.29±0.03±0.04	136±15
$\overline{B}^{\circ}\to D^{+}\omega\pi^{-}$	0.28±0.05±0.03	91±18
$B^{-}\to D^{*\circ}\pi^{\circ}\pi^{+}\pi^{-}\pi^{-}$	1.80±0.24±0.25	195±26
$B^{-}\to D^{*\circ}\omega\pi^{-}$	0.45±0.10±0.07	26± 6
$B^{-}\to D^{\circ}\omega\pi^{-}$	0.41±0.07±0.04	88±14

r¢ **dominates the** wp- **final state**

G(**B̄°**® **D**$^{*+}$r¢-) **/** G(**B°**® **D**$^{+}$r¢-) **= 1.04±0.21±0.06**

G(**B-** ® **D**$^{*\circ}$r¢-) **/** G(**B-** ® **D°**r¢-) **= 1.10±0.31±0.06**

G(**B**® **D*** r¢-) **/** G(**B**® **D**r¢-) **= 1.06±0.17±0.04**

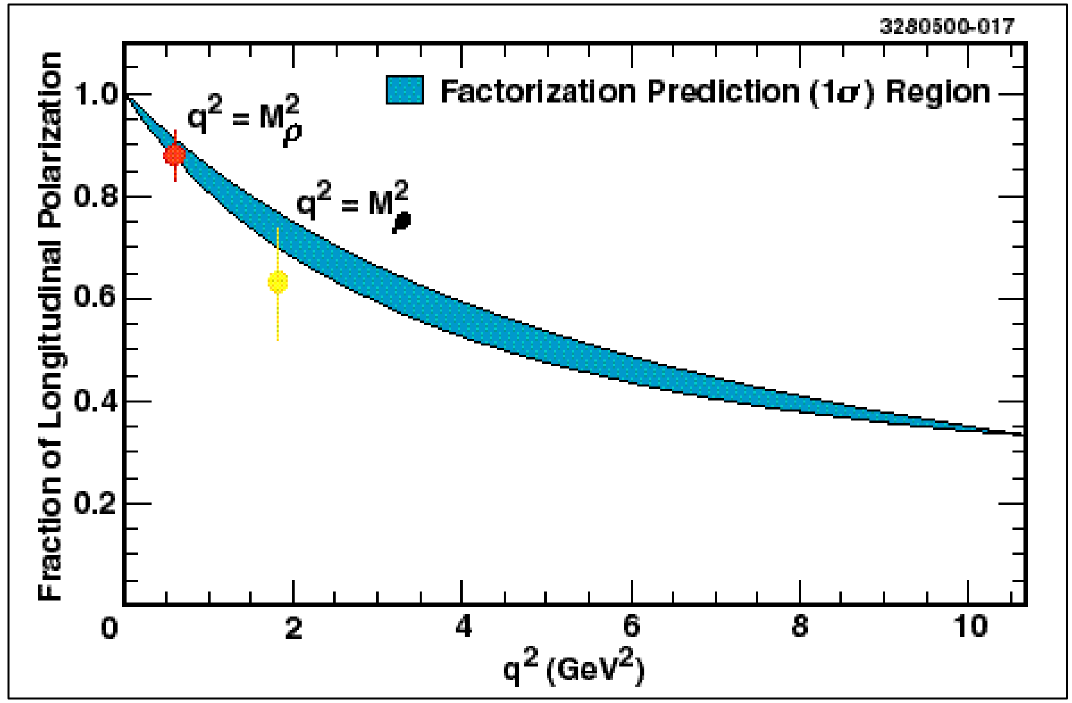
- **Consistent with Heavy Quark Symmetry prediction (ratio = 1)**
- **With** *B* **(**r¢- ®wp-**)=39%,** G**(B® D**$^{(*)}$r¢-**) ~** G(**B® D**$^{(*)}$r-**)**

Testing Factorization

Polarization:

$\Gamma_L/\Gamma\ (B \rightarrow D^{*+} h^-) \ =$

$\Gamma_L/\Gamma\ (B \rightarrow D^{*+} l^- n\ )|_{q^2=m_h^2}$

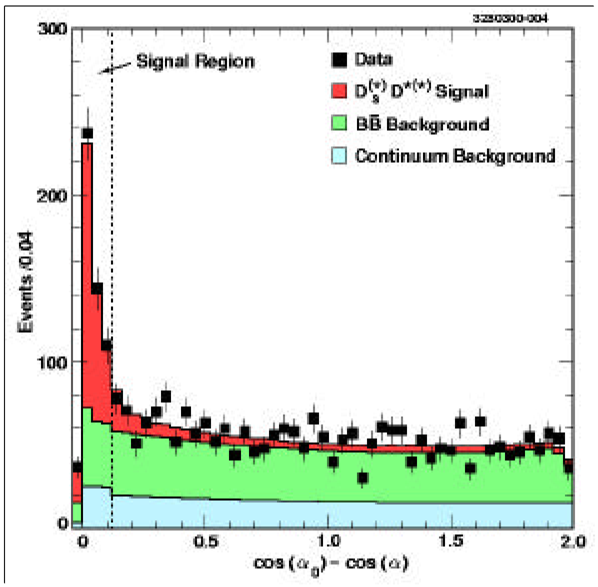


Branching Fractions:

$\Gamma(B \rightarrow D^{*+} h^-)\ /\ d\Gamma/dq^2\ (B \rightarrow D^{*+} l^- n\ )|_{q^2=m_h^2} = 6\pi^2 c_1{}^2 f_h{}^2\ |V_{ud}|^2$

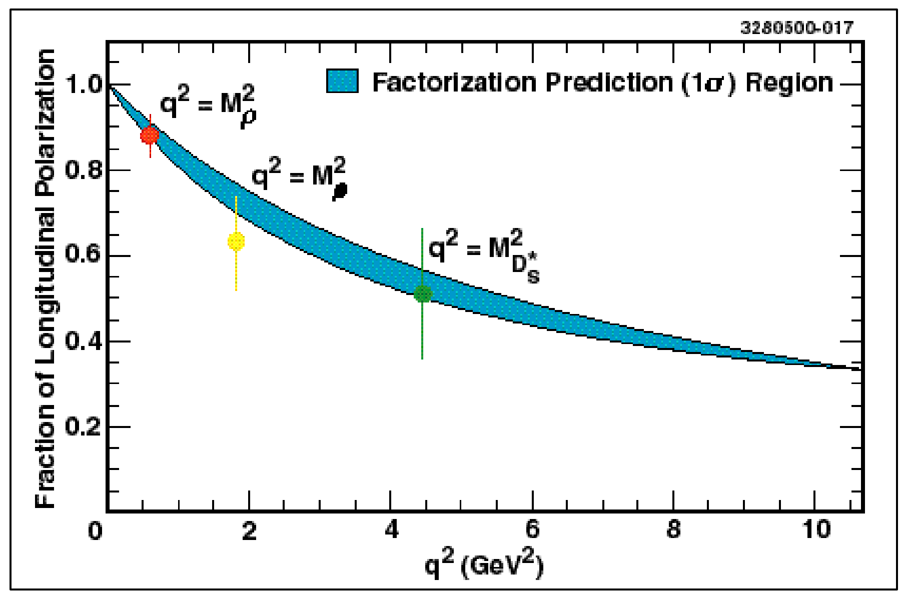
Using $B\,(\rho'^- \rightarrow \omega\pi^-)=39\%$ $\quad \Rightarrow \quad$ $f_{\rho'} = 167 \pm 23\text{MeV}$

Extending q^2: B ® $D^*D_s^*$



Final State	*B*(%)
$D^{*+}D_s^-$	1.10±0.18±0.10±0.28
$D^{*+}D_s^-$	1.82±0.37±0.24±0.46
$D^{(*)+}D_s^{**o}$	2.73±0.78±0.48±0.68

D^{*+} +	G_L / G (%)
r^-	87.8±5.3
$r¢^-$	63 ± 9
D_s^-	50.6±13.9±3.6



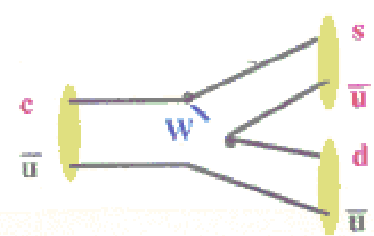
What About Charm?

$m_c << m_b$ ⇨ less energy release
stronger FSI

Factorization is in trouble!

	$R_{Experiment}$	R_{Theory}
$D^0 \to K^-\pi^+$	1.19+/-0.14	1.18+/-0.03
$D^0 \to K^{*-}\pi^+$	3.09+/-0.82	1.18+/-0.03

Color Suppression



$B(D^0 \to \bar{K}^0\rho^0)/B(D^0 \to K^-\rho^+)$	0.08 ± 0.04	0.08
$B(D^0 \to \bar{K}^0\pi^0)/B(D^0 \to K^-\pi^+)$	0.57 ± 0.13	
$B(D^0 \to \bar{K}^{*0}\pi^0)/B(D^0 \to K^{*-}\pi^+)$	0.47 ± 0.23	
$B(D^0 \to \pi^0\pi^0)/B(D^0 \to \pi^-\pi^+)$	0.77 ± 0.25	0.77
$B(D_s^+ \to \bar{K}^{*0}K^+)/B(D_s \to \phi\pi^+)$	0.95 ± 0.10	
$B(D_s^+ \to \bar{K}^0K^+)/B(D_s \to \phi\pi^+)$	1.01 ± 0.16	

➡ not effective in Charm decay

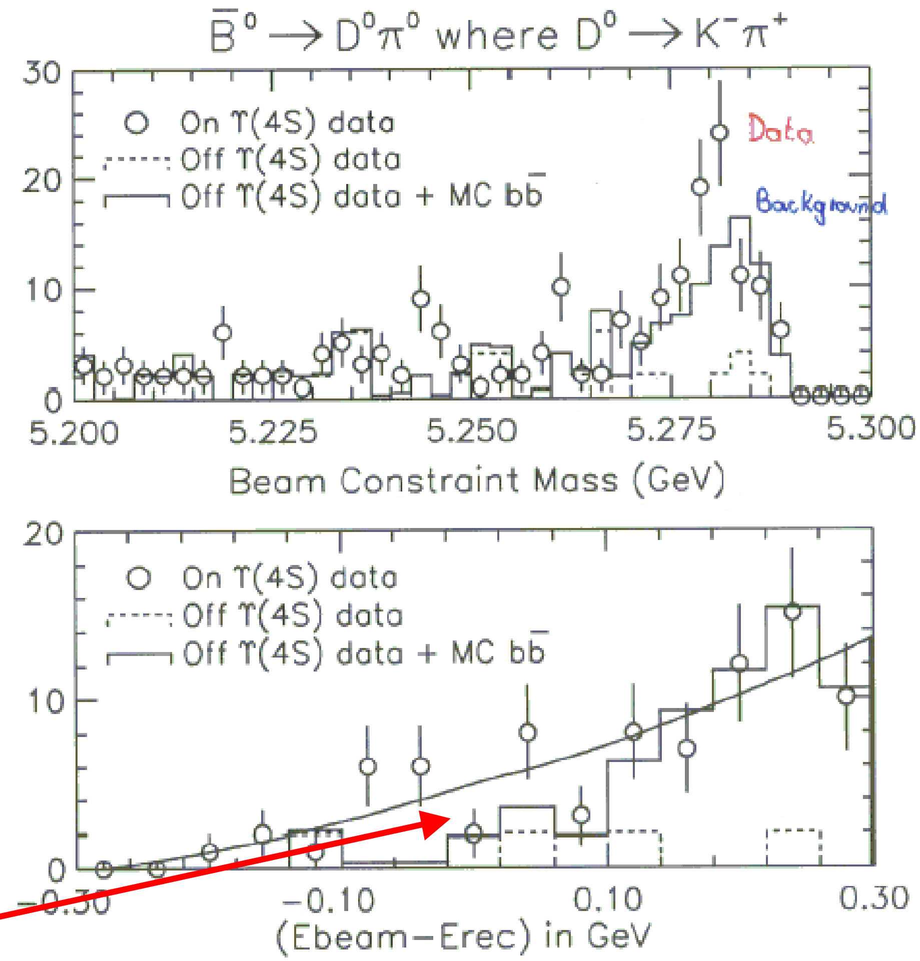
$\tau_{D+} \sim 2.5\, \tau_{D0}$

➡ Destructive Interference

Color Suppression in B Decays ...

CLEO:

Decay Mode	U. L. (90% CL)	BSW (%
$\bar{B}^0 \to D^0\pi^0$	< 0.012	0.012
$\bar{B}^0 \to D^0\rho^0$	< 0.040	0.008
$\bar{B}^0 \to D^0\eta$	< 0.068	0.006
$\bar{B}^0 \to D^0\eta'$	< 0.086	0.002
$\bar{B}^0 \to D^0\omega$	< 0.056	0.008
$\bar{B}^0 \to D^{*0}\pi^0$	< 0.044	0.012
$\bar{B}^0 \to D^{*0}\rho^0$	< 0.060	0.013
$\bar{B}^0 \to D^{*0}\eta$	< 0.069	0.007
$\bar{B}^0 \to D^{*0}\eta'$	< 0.27	0.002
$\bar{B}^0 \to D^{*0}\omega$	< 0.080	0.013



No Signal!

...works

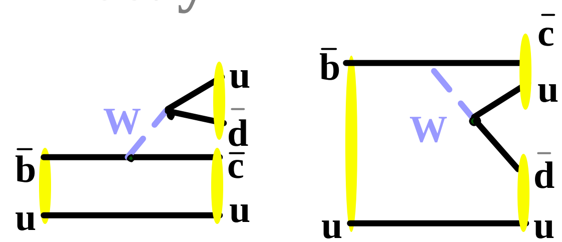
Charged B Decay and Interference

B^0 Decay

$B^0 \to D^- p^+$ $B^0 \to D^0 p^0$

Different final states

Decay



$B^+ \to D^0 p^+$

Interference

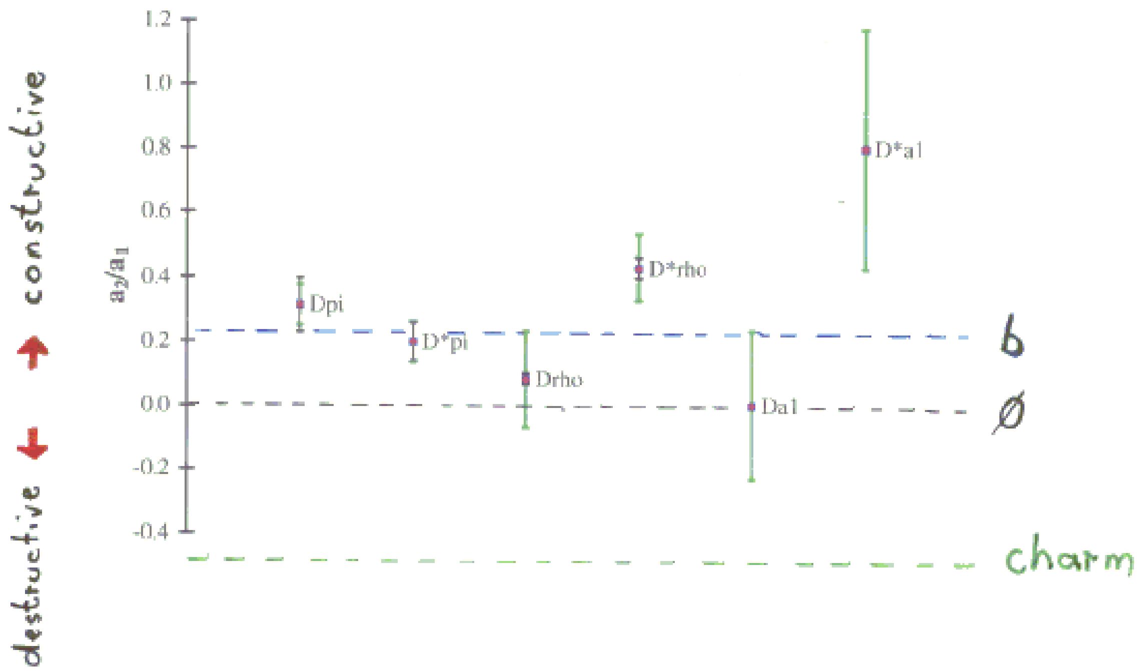
BSW: a_1 a_2 $a_1 + z\, a_2$

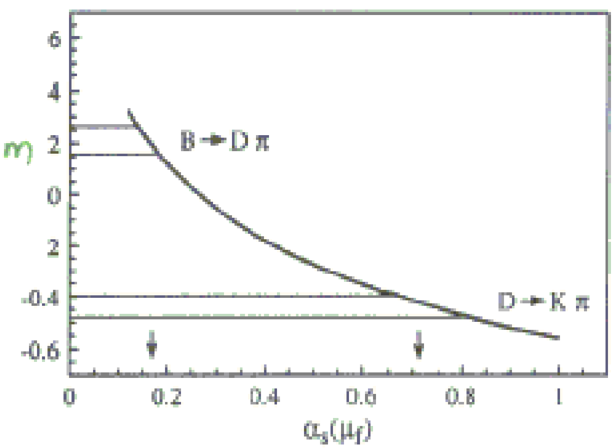
Mode	B^0 ($x10^{-3}$)	B^+ ($x10^{-3}$)
Dπ	3.0+/-0.4	5.3+/-0.5
Dρ	7.9+/-1.4	13.4+/1.8
Da_1	6.0+/-3.3	
Dρ’	2.8+/-0.6	4.1+/-0.8
D*π	2.8+/-0.2	4.6+/-0.4
D*ρ	6.8+/-3.4	15.5+/-3.1
D^*a_1	13+/-2.7	19+/-5
D*ρ’	2.9+/-0.5	4.1+/-0.8

- a_1, a_2 are phenomenological constants
- process dependent
- great success in charm decay:
  - destructive interference
  - smaller $G_{Hadronic}$ for D^+
  - $t_{D+} >> t_{D0}$

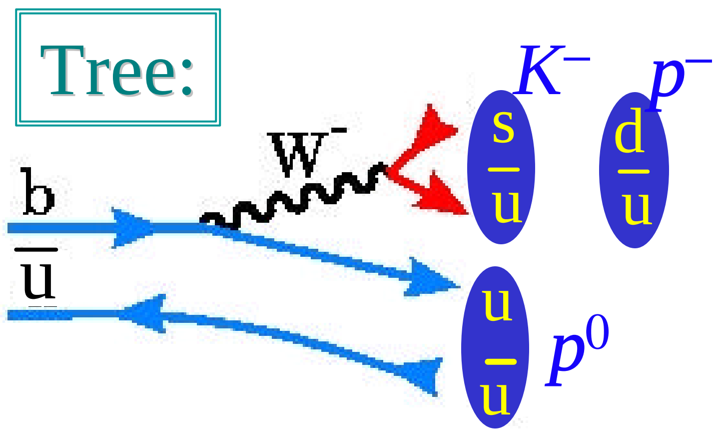
More on charged B Decays

$B \to D^{(*)}(n\pi)^-$: FITS FOR a_2/a_1

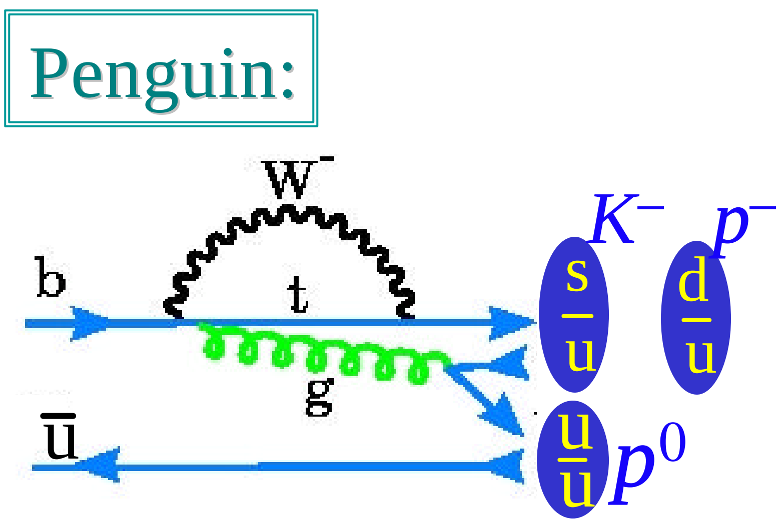




Rare B Decay

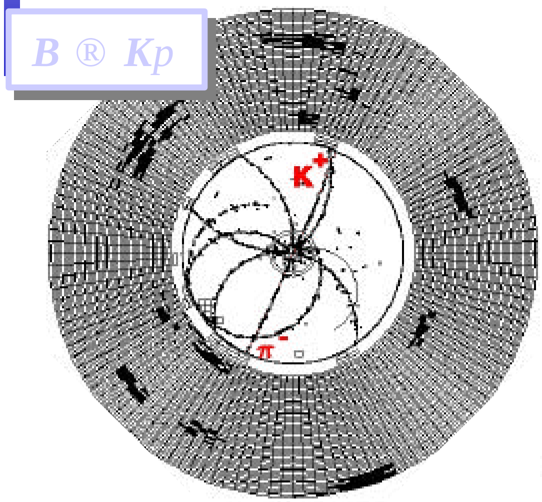


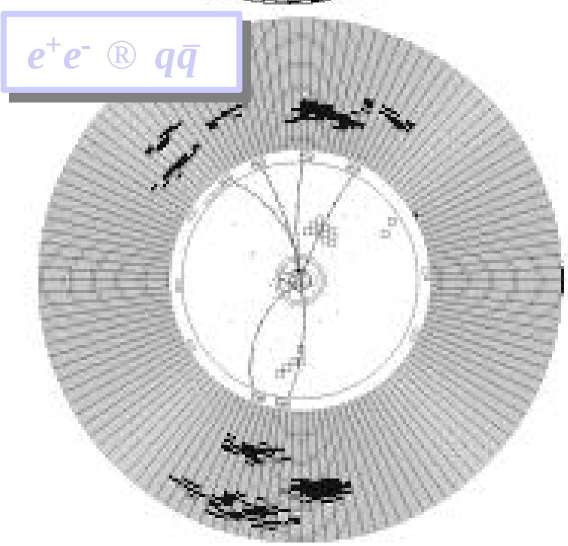
- Tree decays *b* ® *u* vs. *b* ® *c* suppressed by $|V_{ub}|^2 / |V_{cb}|^2$ ~ 0.01
- Additional $|V_{us}|^2 / |V_{ud}|^2$ ~ 0.04 for K^-
- Expect tree dominantly *b* ® *uūd*.



- Decays *b* ® *s,d* GIM-suppressed
- Loop diagram µ $(m_t / m_W)^2$.
- $|V_{td}|^2 / |V_{ts}|^2$ ~ 0.01
- Expect penguins dominantly *b* ® *uūs.*

B ® *K*$^+p^-$ */* p^+p^- Topology



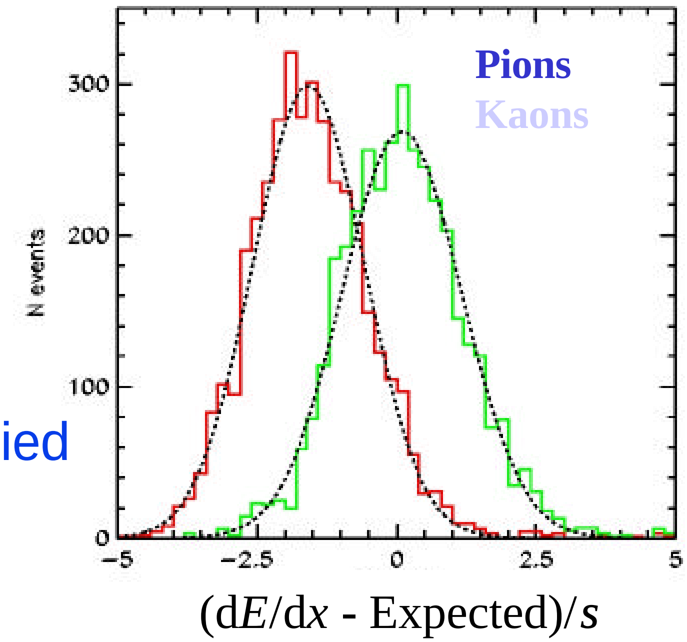


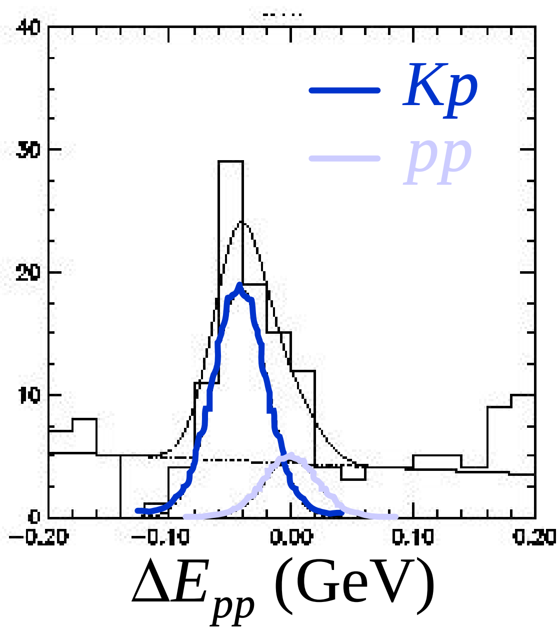
- $P_{\text{daughter}} \sim 2.55 - 2.85$ GeV/c (higher than for $b \to c$ decays)
- Major background from $e^+e^- \to q\bar{q}$ “continuum”
- Continuum events are “jetty” in topology
- $P_B \sim 300$ MeV/$c \Rightarrow B\bar{B}$ events “spherical”
- Continuum suppression from ML fit to several kinematic and topological variables (more efficient).
- Continuum suppression factor of $\sim 10^6$, efficiency for *Kp*/*pp* of ~ 40%

K/*p* Separation

- ***Kp*** **vs. *pp* from *dE/dx* in drift chamber**
  - Resol. confirmed with $D^{*-} \to D^0\pi^-$, $D^0 \to K^-\pi^+$
- **Also separation from kinematics:**

$$\mathrm{D}E_{pp} = E_p + E_p - E_{beam}$$

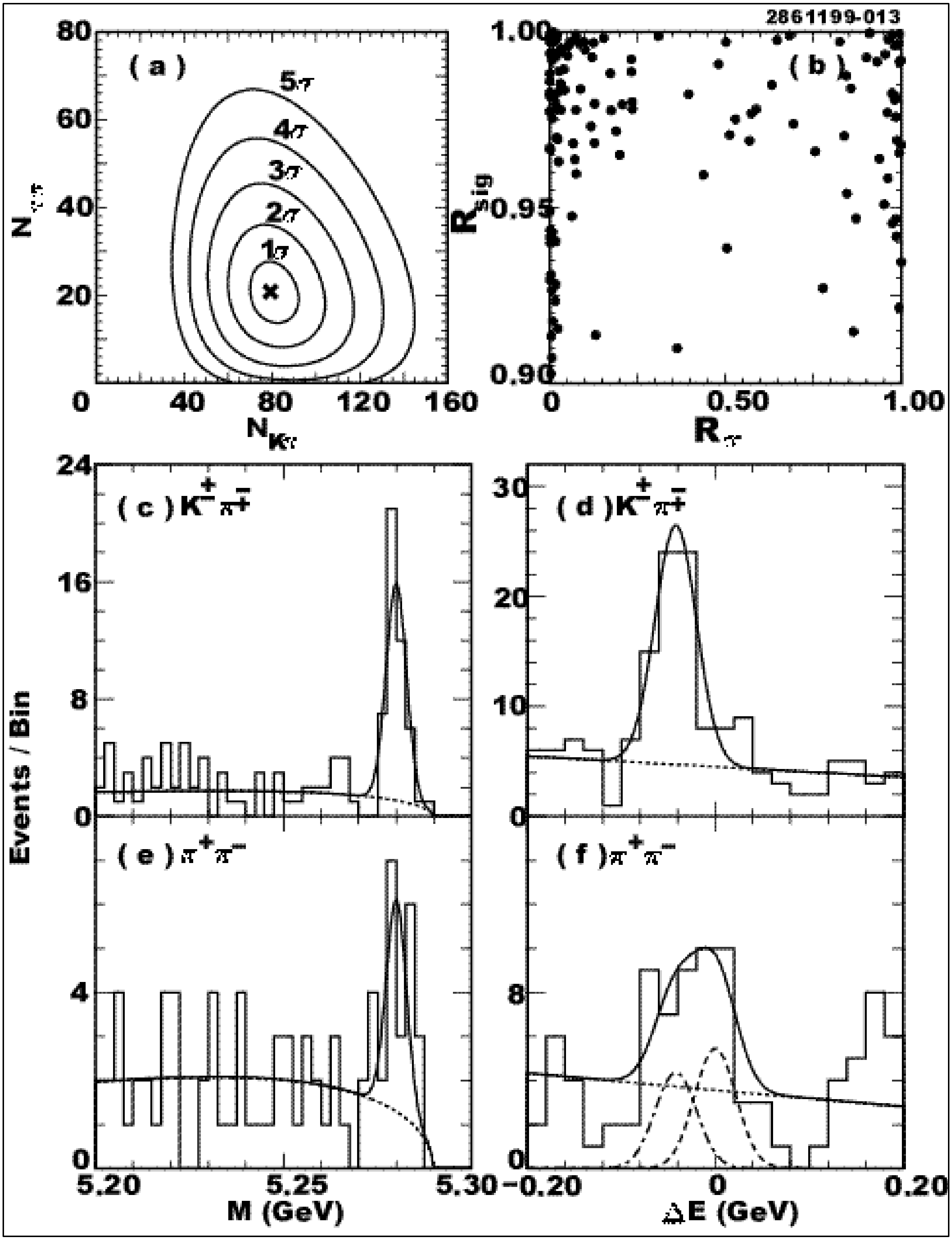




- ΔE resolution studied with $D^0 \to K^-\pi^+(\pi^0)$ mass resolutions

	$s_{\mathrm{D}E}$	D*E*	***dE/dx***
CLEO II	**25 MeV**	**1.7***s*	**1.7***s*
CLEO II.V	**20 MeV**	**2.1***s*	**2.0***s*

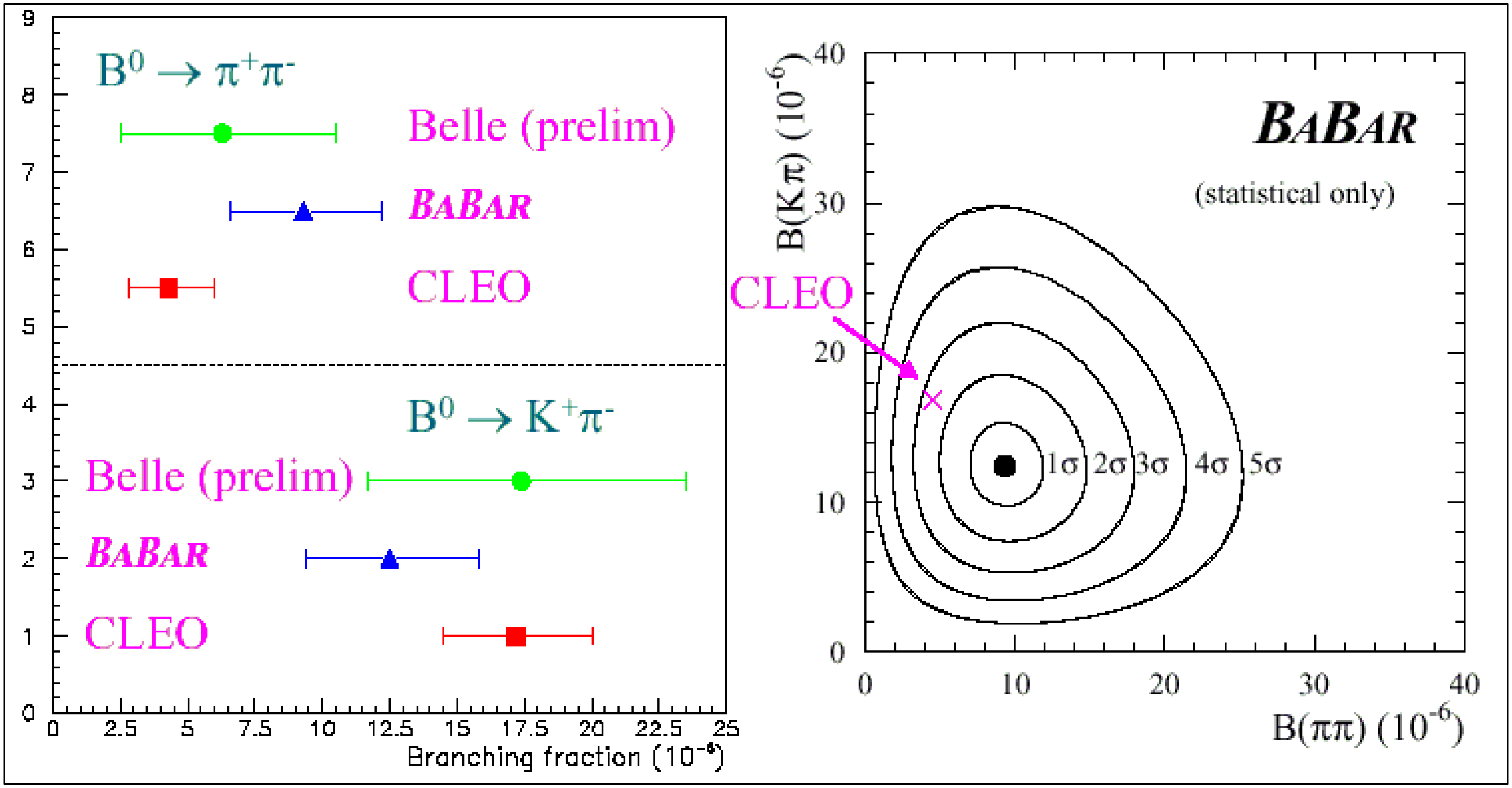
Fit Results for $B \to K p$, $B \to p p$



B®Kp, B®pp Summary

	Signal (events)	# s	e (%)	BR (´ 10^{-6})
p^+p^-	$20.0^{+7.6}_{-6.5}$	4.2	48	$4.3^{+1.6}_{-1.4} \pm 0.5$
p^+p^0	$21.3^{+9.7}_{-6.5}$	3.2	39	< 12.7
p^0p^0	$6.2^{+4.8}_{-3.7}$	2.0	29	< 5.7
K^+p^-	$80.2^{+11.8}_{-11.0}$	11.7	48	$17.2^{+2.5}_{-2.4} \pm 1.2$
K^+p^0	$42.1^{+10.9}_{-9.9}$	6.1	38	$11.6^{+3.0}_{-2.7} \pm 1.4$
K^0p^+	$25.4^{+6.4}_{-5.6}$	7.6	14	$18.2^{+4.6}_{-4.0} \pm 1.6$
K^0p^0	$16.1^{+5.9}_{-5.1}$	4.9	11	$14.6^{+5.9}_{-5.1}{}^{+2.4}_{-3.3}$
K^+K^-	$0.7^{+3.4}_{-0.0}$	0.0	48	< 1.9
K^+K^0	$1.4^{+2.4}_{-1.3}$	1.1	14	< 5.1

Comparision of B-> pp Results



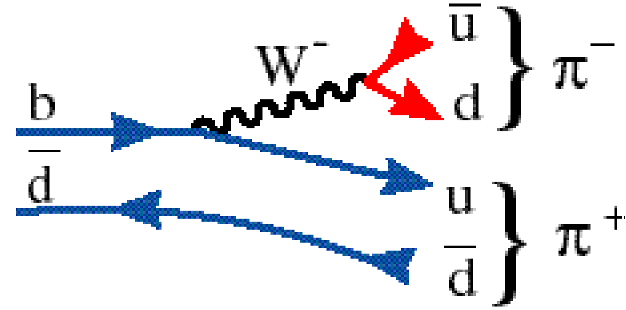
Problems with measuring a using B^o® p^+p^-

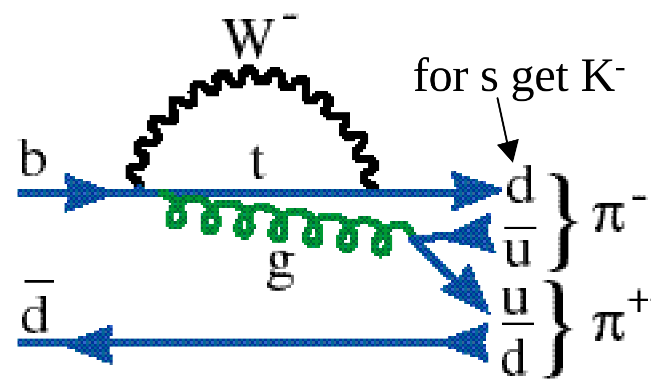
- Using B^o® p^+p^- would be nice, but large Penguin term, CLEO:

  $B(B^o$ ® $p^+p^-)$ ~ 0.8×10^{-5}, while
  $B(B^o$ ® $K^+p^-) = (1.4 \pm 0.3 \pm 0.2) \times 10^{-5}$

- The effect of the Penguin must be measured in order to determine a. Can be done using Isopsin, but requires a rate measurements of

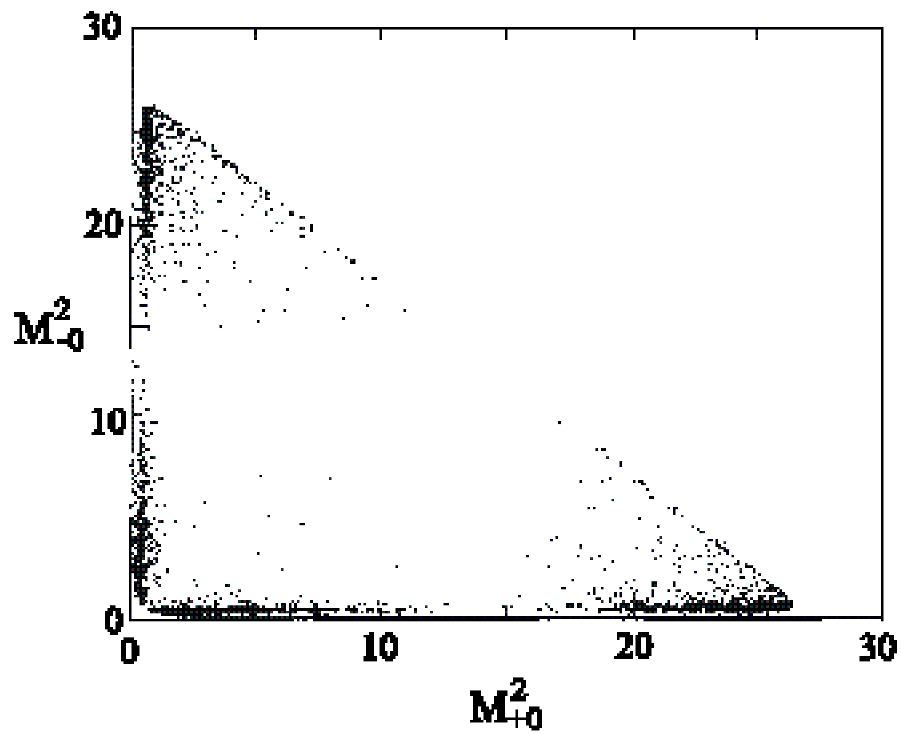
  p^-p^o and p^op^o (Gronau & London). However, this is daunting.





Measuring a using B^o® rp ® $p^+p^-p^o$

- **A Dalitz Plot analysis gives** both **sin(2a) and cos(2a)** (**Snyder & Quinn)**
- **CLEO has measured the branching ratios B(B^-** ® r^op^-) **= (1.5±0.5±0.2)x10^{-5}**
- **0.5B (B^o® r^-p^+ + r^+p^-) =(3.5±1.0±0.5)x10^{-5}**



Snyder & Quinn showed that 1000-2000 tagged events are sufficient

Comparison of rp modes

Final State:	r^-p^+	r^+p^-	r^-p^o	r^op^-	r^op^o
CLEO(10^{-5}):	<3.5±1.2>		<7.7	1.5±0.5±0.2	<1.8
Ciuchini et al.:	1.0-7.5	0.2-1.9	0.3-2.6	0.5-1.1	0.00-0.02
Ali et al.:	2.1-3.4	0.6-0.9	1.1-1.6	0.1-0.7	0.00-0.02

$B(B^+$ ® $r^oK^+) = < 2.2 \times 10^{-5}$ @ 90% c.l. (CLEO)

{To measure the three neutral rp modes, requires triggering on hadronic decays with high efficiency, RICH particle ID and high quality photon detection}

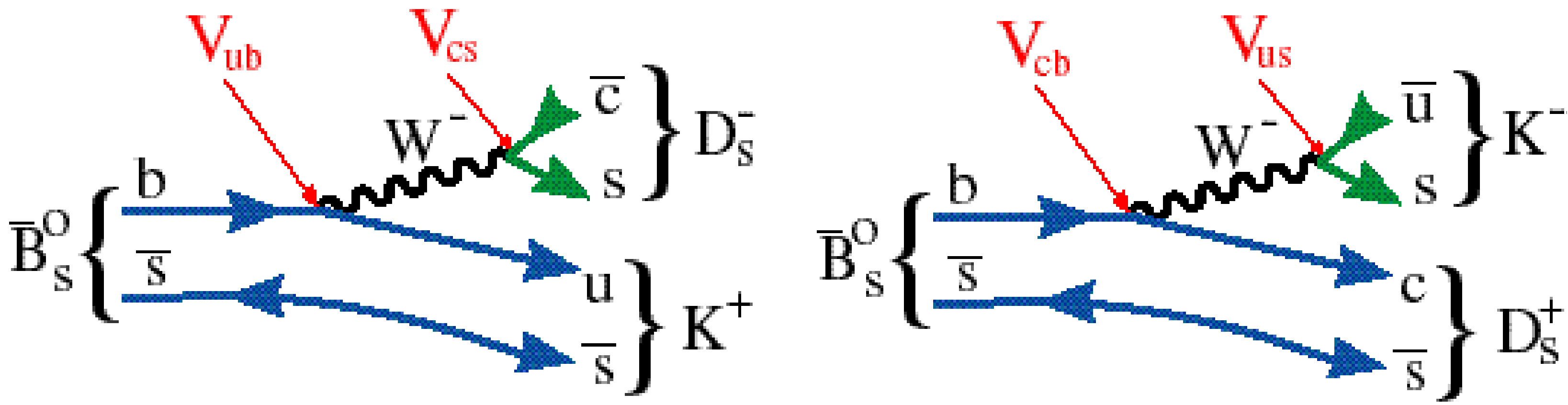
Ways of measuring g

- **May be easier to measure than a**
- **There are 4 ways of determining g**
  - Time dependent flavor tagged analysis of $B_s \to D_s K^-$
  - Measure rate difference between $B^- \to D^o K^-$ and $B^+ \to D^o K^+$
  - Rate measurements in $K^o\pi^\pm$ and $K^\pm\pi^\mu$ (Fleisher-Mannel) or rates in $K^o\pi^\pm$ & asymmetry in $K^\pm\pi^o$ (Neubert-Rosner) . Has theoretical uncertainties but can be useful.
  - Use U spin symmetry d⇔s: measure time dependent asymmetries in both $B^o \to \pi^+\pi^-$ & $B_s \to K^+K^-$ (Fleischer).
  - Ambiguities here as well but they are different in each method, and using several methods can resolve them.

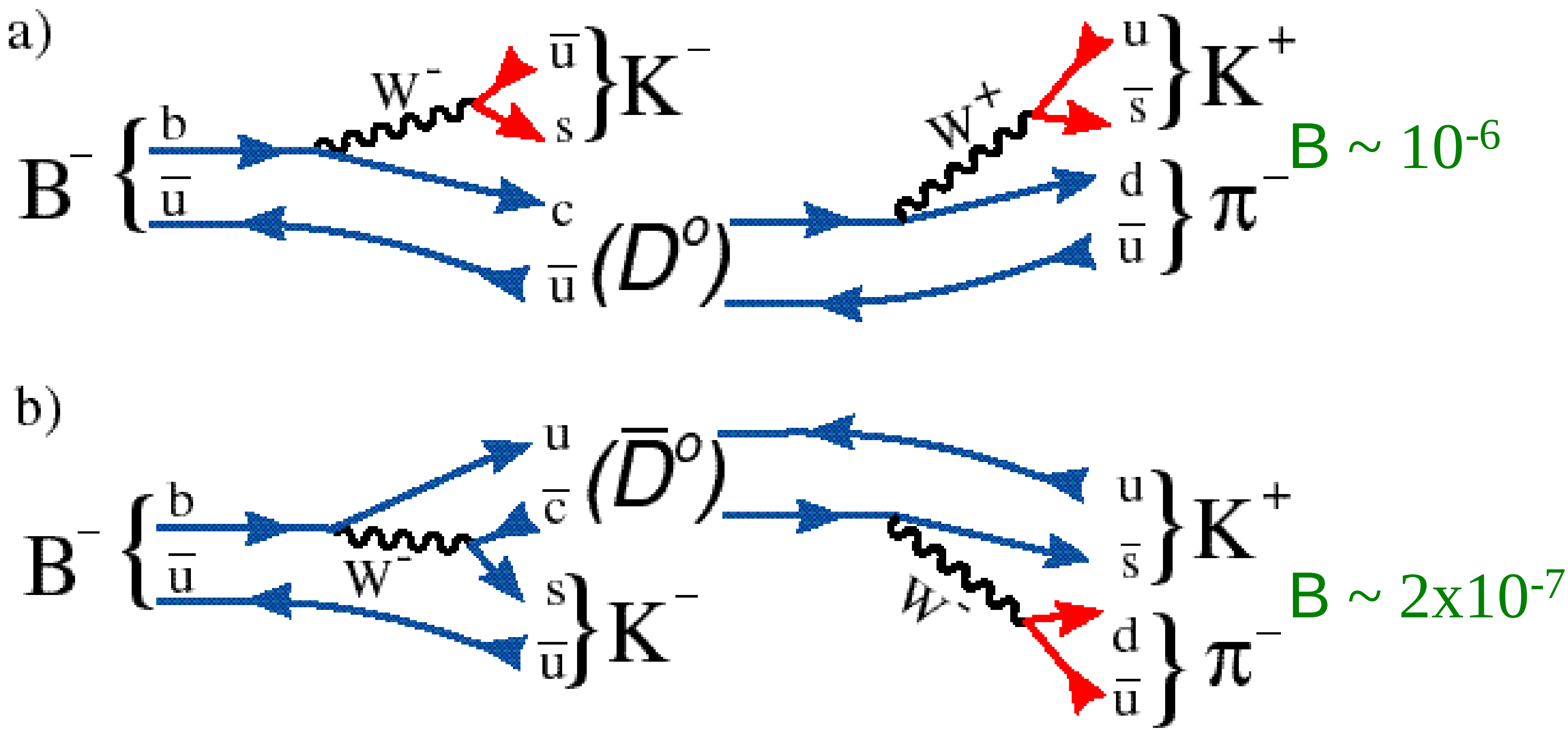
±

B_S® D_SK^{m} Decay processes

Diagrams for the two decay modes, B ~ 10^{-4} for each



B^- ® $[K^+p^-]K^-$ Decay processes



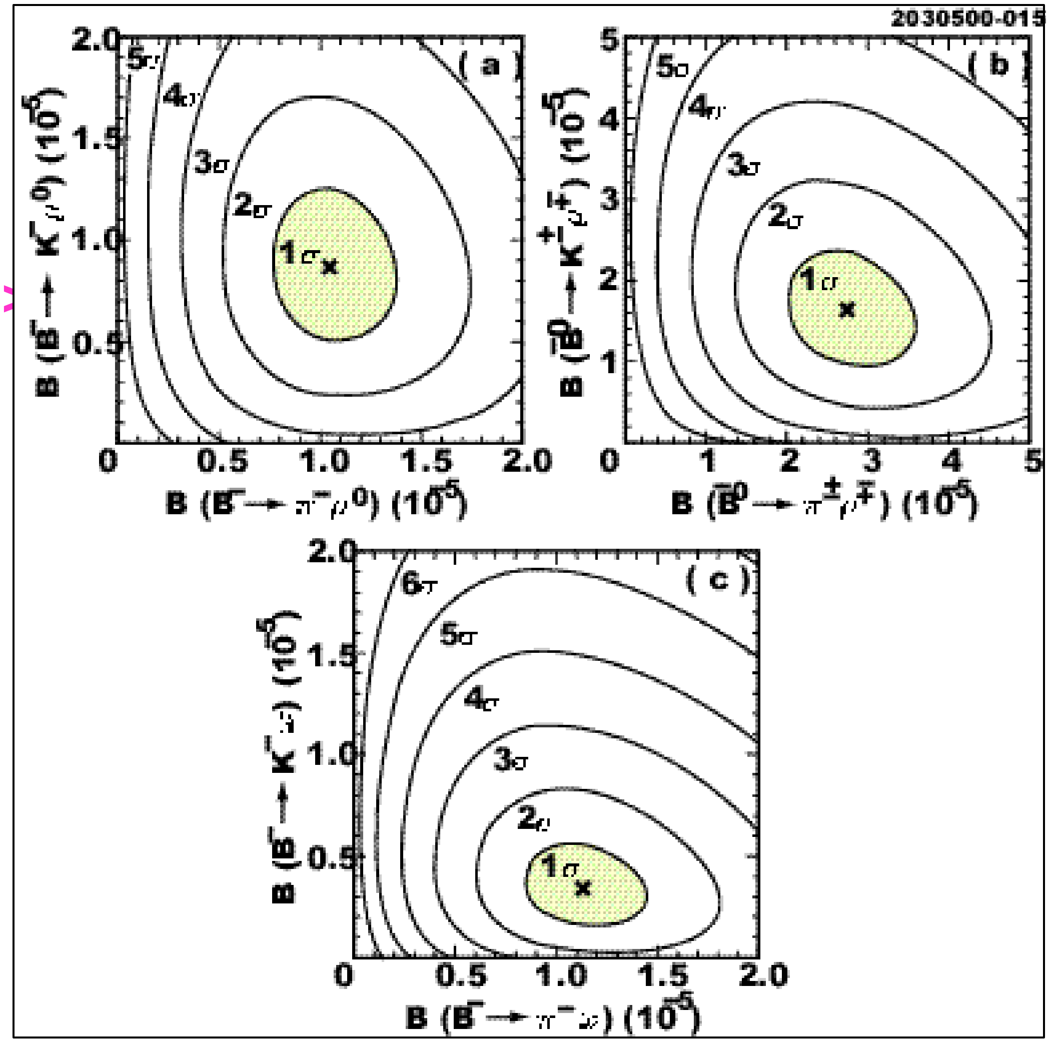
Exclusive b ® u Transitions

- Many hadronic b ® u transitions observed
- New study includes 14 channels (hep-ex/0006008)
- In general - good agreement with theory
- Full Dalitz analyses could determine a and g

Mode	Yield	Signif.	$\mathcal{B}$ (10^{-6})	Theory
$B^- \to \pi^- \rho^0$	$29.8^{+9.3}_{-9.6}$	5.4σ	$10.4^{+3.3}_{-3.4} \pm 2.1$	0.4 - 13.0
$B^- \to K^- \rho^0$	$22.4^{+10.7}_{-9.1}$	3.7σ	< 17	0.0-6.1
$B^- \to \pi^0 \rho^-$	$22.7^{+8.4}_{-7.4}$	5.1σ	< 43	3.0 - 27.0
$B^- \to \pi^0 K^{*-}$	$2.6^{+4.2}_{-2.6}$	1.0σ	< 31	0.5 - 24.0
$B^- \to \pi^- \omega$	$28.5^{+8.2}_{-7.3}$	6.2σ	$11.3^{+3.3}_{-2.9} \pm 1.4$	0.6 - 24
$B^- \to K^- \omega$	$7.9^{+6.0}_{-4.7}$	2.1σ	< 7.9	0.2 - 14.0
$B^- \to \pi^- K^{*0}$	$13.4^{+6.2}_{-5.3}$	3.6σ	< 16	3.4 - 13.0
$B^- \to K^- K^{*0}$	$0.0^{+2.2}_{-0.0}$	0.0σ	< 5.3	0.2 - 1.0
$B^0 \to \pi^\pm \rho^\mp$	$31.0^{+10.4}_{-8.3}$	5.6σ	$27.6^{+8.4}_{-7.4} \pm 4.2$	12 - 93
$B^0 \to K^\pm \rho^\mp$	$16.4^{+7.8}_{-6.6}$	3.5σ	< 32.3	0. 0- 12.0
$B^0 \to \pi^0 \rho^0$	$5.4^{+6.5}_{-4.8}$	1.2σ	< 5.5	0.0 - 2.5
$B^0 \to \pi^0 \omega$	$1.5^{+3.5}_{-1.5}$	0.6σ	< 5.5	0.0 - 12.0
$B^0 \to K^0 \omega$	$7.0^{+3.8}_{-2.9}$	3.9σ	< 21	0.0 - 17.0
$B^0 \to \pi^0 K^{*0}$	$0.0^{+3.0}_{-0.0}$	0.0σ	< 3.6	0.7 - 6.1

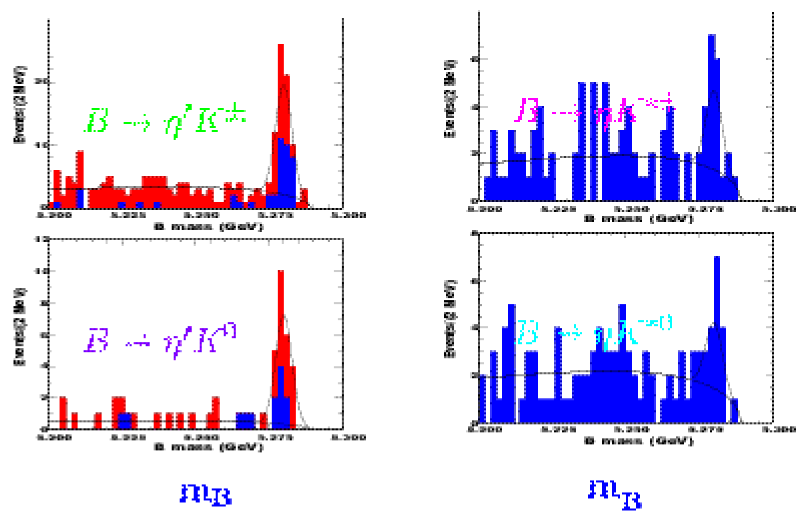
Likelihood Contours

- ***B*® r^+p/rK and *B*® r^0p/rK fitted simulataneously**
- ***BR(B*® r^+p*)* / BR(*B*® r^0p*)* smaller than expected (**



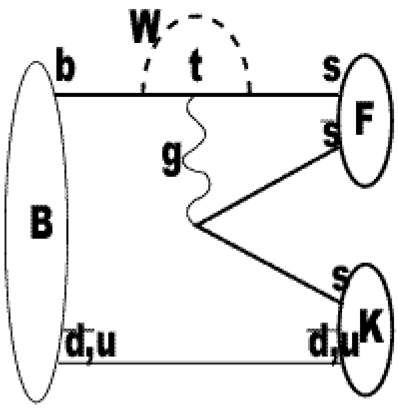
Modes with *h* and *h* ¢

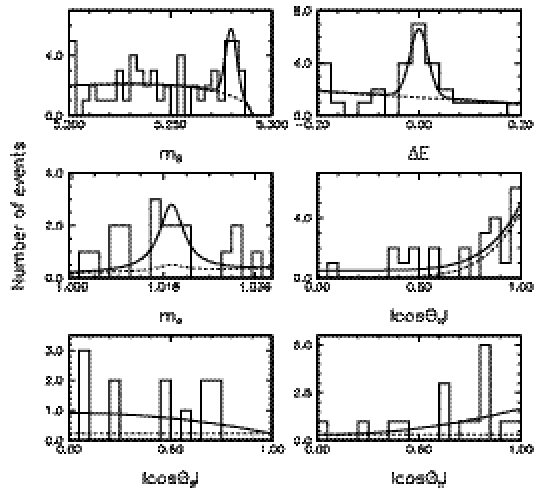
Mode	Signif.	$\mathcal{B}$ (10^{-6})
$B^+ \to \eta' K^+$	10.8σ	$80^{+10}_{-9} \pm 7$
$B^0 \to \eta' K^0$	11.7σ	$89^{+18}_{-16} \pm 9$
$B^+ \to \eta' \pi^+$	0.0σ	< 12
$B^0 \to \eta' \pi^0$	0.0σ	< 5.7
$B^+ \to \eta' K^{*+}$	1.8σ	< 35
$B^0 \to \eta' K^{*0}$	1.8σ	< 24
$B^+ \to \eta' \rho^+$	2.4σ	< 33
$B^0 \to \eta' \rho^0$	0.0σ	< 12
$B^+ \to \eta K^+$	0.8σ	< 6.9
$B^0 \to \eta K^0$	0.0σ	< 9.3
$B^+ \to \eta \pi^+$	0.6σ	< 5.7
$B^0 \to \eta \pi^0$	0.0σ	< 2.9
$B^+ \to \eta K^{*+}$	4.8σ	$26.4^{+9.6}_{-8.2} \pm 3.3$
$B^0 \to \eta K^{*0}$	5.1σ	$13.8^{+5.5}_{-4.6} \pm 1.6$
$B^+ \to \eta \rho^+$	1.3σ	< 15
$B^0 \to \eta \rho^0$	1.3σ	< 10



PRL 80, 3710 (1998) + PRL 85, 520 (2000)

Pure Penguins: *B* ® fK





$BR(B^- \to \phi K^-) = (6.4^{+2.5+0.5}_{-2.1-2.0}) \times 10^{-6}$

$BR(B^0 \to \phi K^0) = (5.9^{+4.0+1.1}_{-2.9-0.9}) \times 10^{-6} \to < 1.2 \times 10^{-5}$

Combined result: $BR(B \to \phi K) = (6.2^{+2.0+0.7}_{-1.8-1.7}) \times 10^{-6}$

- Pure gluonic penguin, simple final state, sensitive to $\sin 2\beta$
- Theoretical uncertainties are large
  - Deshpande+He: inclusive $B \to \phi X_s \sim (0.6 - 2.0) \times 10^{-4}$
  - ϕK fraction of $\phi X_s \sim 10\%$

arg(V_{ub}) (= g) from Decay Rates

- **Fleischer-Mannel (*Phys. Rev.* D57, 2752(1998))**

$$R \equiv \frac{\Gamma(B^0 \rightarrow K^- \pi^+)}{\Gamma(B^+ \rightarrow K^0 \pi^+)} \geq \sin^2 g \qquad \text{CLEO:} \qquad R = 1.01 \pm 0.26$$

- **Neubert-Rosner (*Phys. Lett.* B441, 403 (1998))**

$$R_* \equiv \frac{\Gamma(B^+ \rightarrow K^0 \pi^+)}{2\Gamma(B^+ \rightarrow K^+ \pi^0)} \qquad (1\text{-}R_*)/e_{3/2} \leq |d_{EW} - \cos g|$$

$$0.58 \pm 0.74 \leq |\, (0.64 \pm 0.15) - \cos g|$$

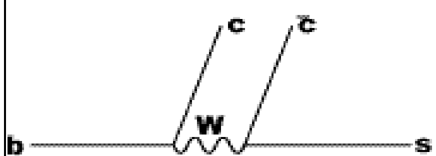
- **Also model-dependent fit to many CLEO branching ratios of** pp**,** Kp**,** rp**,** wp **(Wuerthwein *et al.* hepex/9910014):**

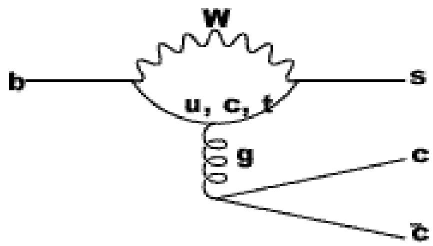
84 < g < 154 (90% C.L.)

Search for Direct CP Violation

$$A_{CP} = \frac{B(B^- \to \psi^{(\prime)} K^-) - B(B^+ \to \psi^{(\prime)} K^+)}{B(B^- \to \psi^{(\prime)} K^-) + B(B^+ \to \psi^{(\prime)} K^+)} = \frac{b - \bar{b}}{b + \bar{b}}$$

- We can measure $A_{CP}(\psi K^{\pm})$ with 4% precision
- In Standard Model $A_{CP}(\psi K^{\pm}) << 4\%$ (even if penguin amplitude is large)
- $A_{CP} = \frac{-2A_1 A_2 \sin(\delta_1 - \delta_2)_{strong} \sin(\phi_1 - \phi_2)_{weak}}{A_1^2 + A_2^2 + 2A_1 A_2 \cos(\delta_1 - \delta_2)\cos(\phi_1 - \phi_2)}$





- $A(c\bar{c}s) = V_{cb}V_{cs}^*(T_{c\bar{c}s} + P_c - P_u) + V_{tb}V_{ts}^*(P_t - P_u)$
- $\arg(V_{cb}V_{cs}^*/V_{tb}V_{ts}^*) \simeq \lambda^2\eta + \pi$ $(\lambda = 0.22,\ \eta \lesssim 1)$

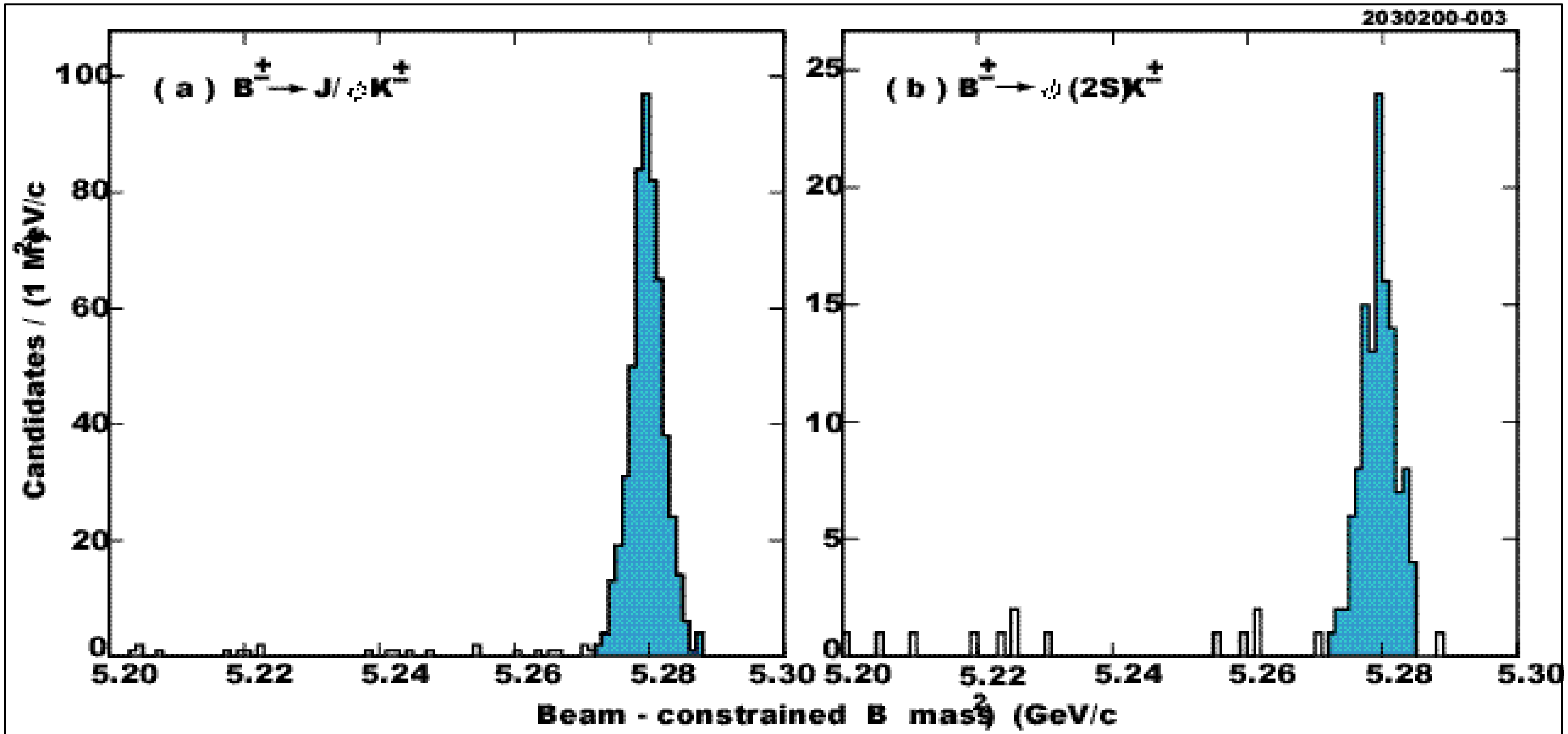
One of the models beyond the Standard

Two-Higgs doublet model with special status for top quark

(Kiers, Soni, and Wu, hep-ph/9811419)

- H^--mediated diagram competes with SM tree W^--mediated diagram and comes with its own CP-odd phase
- $A_{CP}(\psi K^{\pm})$ could be $\mathcal{O}(10\%)$ $\Longrightarrow$ we can measure it right now

Search for Direct CP Violation



Mode	$N(B^\pm)$	$N(B^-)$	$N(B^+)$	$\frac{N(B^-)-N(B^+)}{N(B^-)+N(B^+)}$	$\mathcal{A}_{CP}$
$B^\pm \to J/\psi K^\pm$	534	271	263	$(+1.5 \pm 4.3)\%$	$(+1.8 \pm 4.3 \pm 0.4)\%$
$B^\pm \to \psi(2S) K^\pm$	120	61	59	$(+1.7 \pm 9.1)\%$	$(+2.0 \pm 9.1 \pm 1.0)\%$

CP Asymmetries

- **Measure *B* and $\overline{B}$ reactions described by two amplitudes:**
  - $\Gamma(B \rightarrow f) = |\, a_1 e^{i(f_1+d_1)} + a_2 e^{i(f_2+d_2)} \,|^2$
  - $\overline{\Gamma}(\overline{B} \rightarrow \overline{f}) = |\, a_1 e^{i(-f_1+d_1)} + a_2 e^{i(-f_2+d_2)} \,|^2$
- **CP asymmetry from strong and weak phase differences**
  - $\Delta \equiv (\Gamma - \overline{\Gamma}) / (\Gamma + \overline{\Gamma}) \propto \sin(f_1 - f_2)\sin(d_1 - d_2)$
- **Depends upon comparable magnitudes as well**
- **CLEO can measure decays that are sensitive to g = arg(V_{ub}*)**
  - $B^+ \rightarrow K^+ p^0$, $B^+ \rightarrow K^0 p^+$, $B^+ \rightarrow K^+ h'$

A_{cp} Expectations

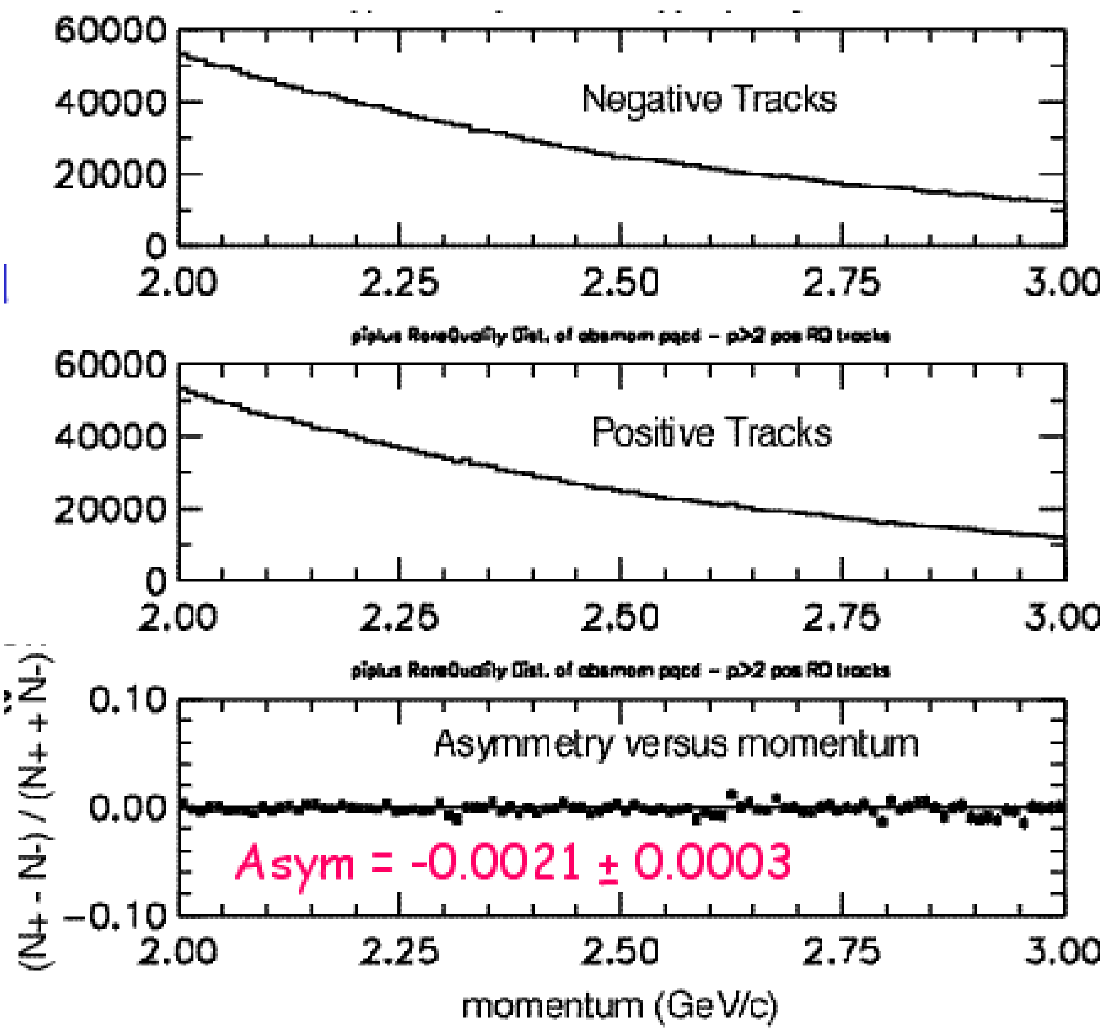
- **Factorization model calculations (no FSI interactions)**
  Ali, Kramer, Liu, hep-ph/9805403
    - » K^+p^+ 0.04 - 0.11 » K^+p^0 0.03 - 0.09
    - » K^0p^+ 0.01 » K^+h' 0.02 - 0.06
    - » wp^+ -0.12 - +0.02

- **Final state interactions may boost A_{CP} ~ 20 - 40%.**
  - He et al, *Phys. Rev. Lett*. **81**, 5738 (1998)
  - Neubert, JHEP 9902, 014 (1999)
  - Deshpande et al., *Phys. Rev. Lett.* **82**, 2240 (1999)

- **New physics could boost A_{CP} ~ 40 - 60%.**
  - He *et al.*, hep-ph/980982

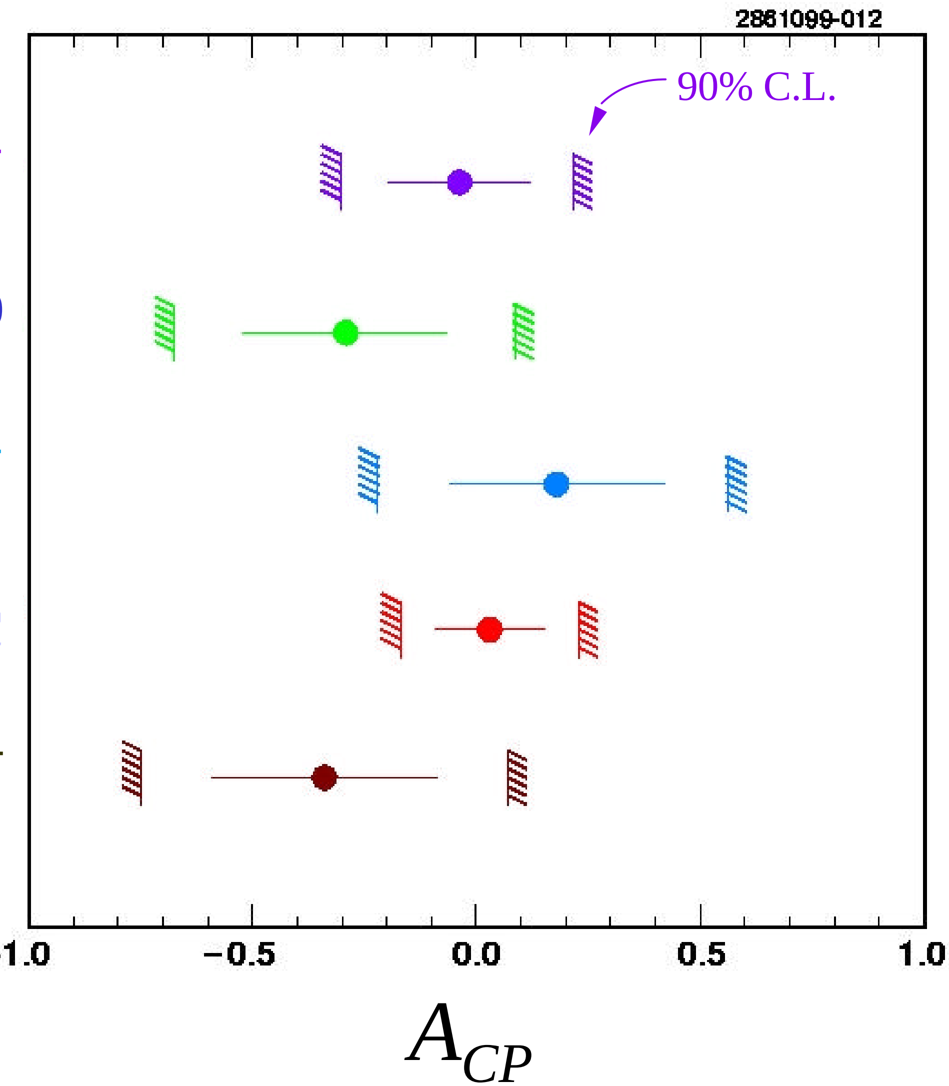
Experimental Bias(es)

- ***B*** **flavor tagged by high momentum track**
- **Must demonstrate reconstruction not charge dependent.**
- **Charge difference in** $K^{-}N$ **and** $K^{+}N$ **cross sections**
- **Track reconstruction difference confirmed in Monte Carlo ~ 0.002**

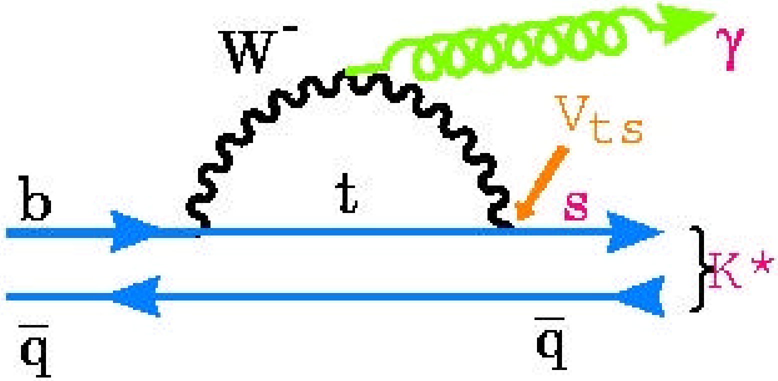


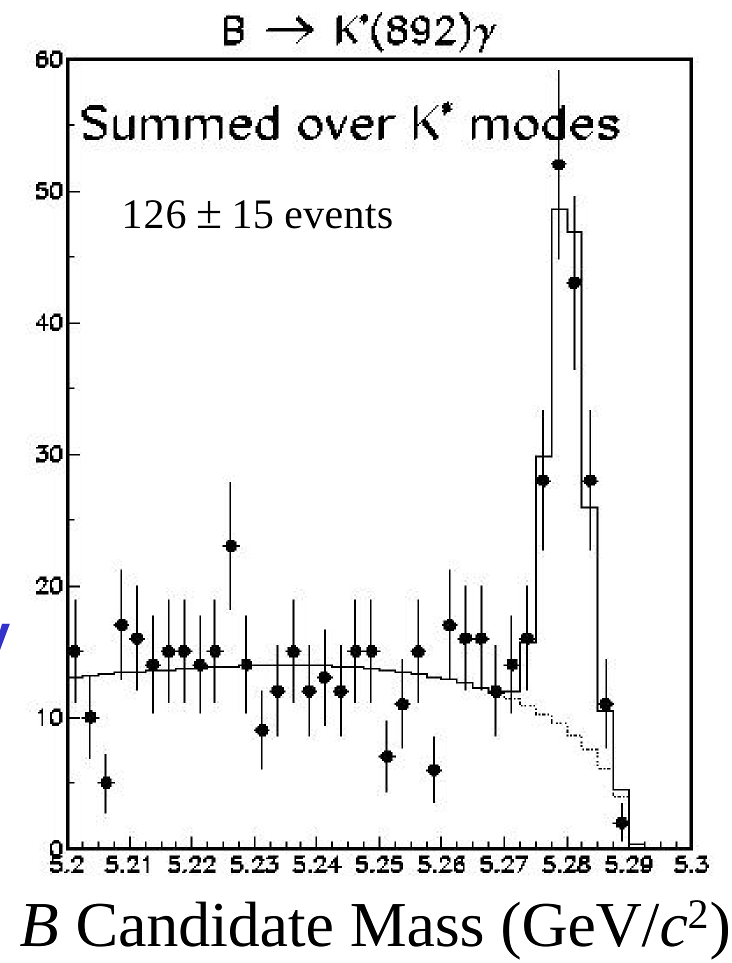
CP Asymmetry Results

Events	Mode
$80.2^{+11.8}_{-11.0}$ events	$K^- p^+$
$42.1^{+10.9}_{-9.9}$ events	$K^+ p^0$
$25.2^{+6.4}_{-5.6}$ events	$K^0 p^+$
101^{+13}_{-12} events	$K^+ h¢$
$28.5^{+8.2}_{-7.3}$ events	$w p^+$



~~*CP*~~ from New Physics?





- **Penguin amplitude $\propto$ $|V_{ts}|$**
- **Other amplitudes, ~~*CP*~~, small in SM**
- **Some Higgs models introduce ~~CP~~, possibly even if $b \to s\gamma$ rate unaffected.**
  - Wolfenstein & Wu, *Phys. Rev. Lett.* **73**, 2809 (1998)
  - Asatrian & Ioannissian, *Phys. Rev.* **D54**, 5642
  - Kagan & Neubert, *Phys. Rev.* **D58**, 094012

b®*sg* Results

- **Updated branching ratio results:**

  BR(*B*⁰®*K⁰*g*) = (4.5±0.7±0.3) ´ 10⁻⁵**

  BR(*B*⁺®*K⁺*g*) = (3.8±0.9±0.3) ´ 10⁻⁵**

  BR(*B*®*K₂(1430)*g*) = (1.6±0.55±0.13)´10⁻⁵**

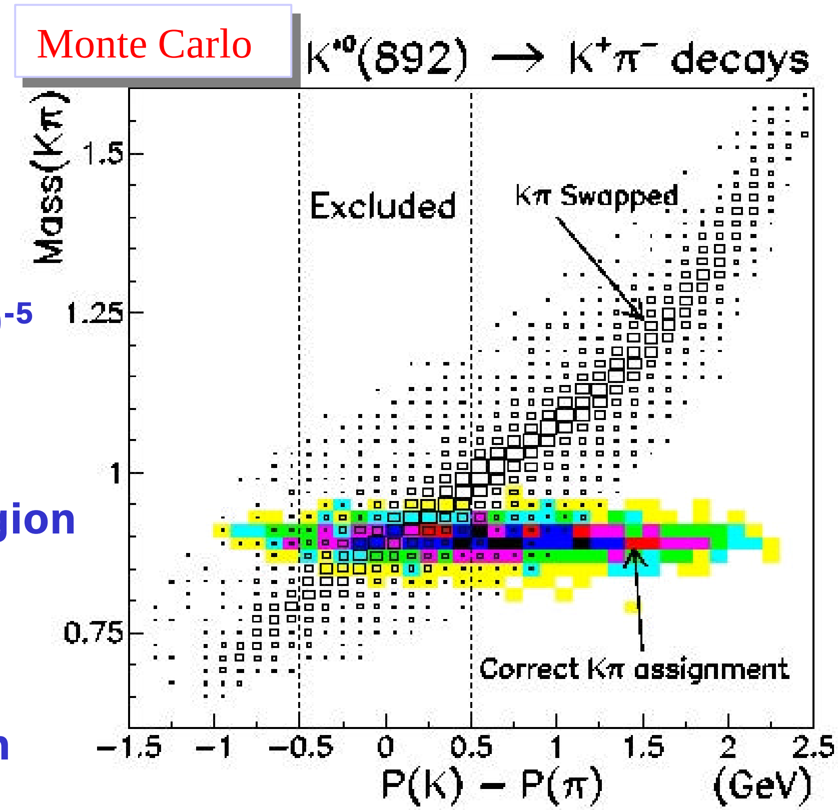
- **CP asymmetry from special kinematic region for best *K*/*p* identificatio**

  A_{CP} = 0.08 ± 0.13 ± 0.03

- **Asymmetry for inclusive *b*®*sg* (based on 9.7M $B\bar{B}$ pairs only):**

  A_{CP} = -0.063 ± 0.090 ± 0.009 or

  -0.21 < A_{CP} < 0.09 (90% C.L.)



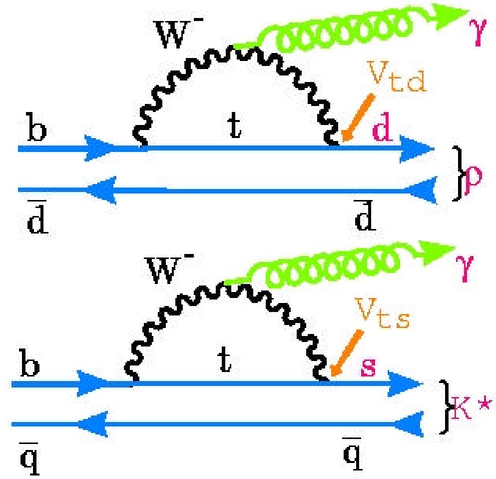
- Upper limit on *b*→*d* exclusive penguins:

  BR(*B*→(*r*,*w*)*g*) < ~10⁻⁵

Search for *b*® *dg*

- **Expect that *B*® *rg* also described by penguin amplitude - dominant top?**

$$\frac{\mathrm{G}(B \text{ ® } rg)}{\mathrm{G}(B \text{ ® } K^* g)} = \frac{|V_{td}|^2}{|V_{ts}|^2} x \qquad x \sim 0.6 - 0.8$$



- **Updated branching ratio limits:**

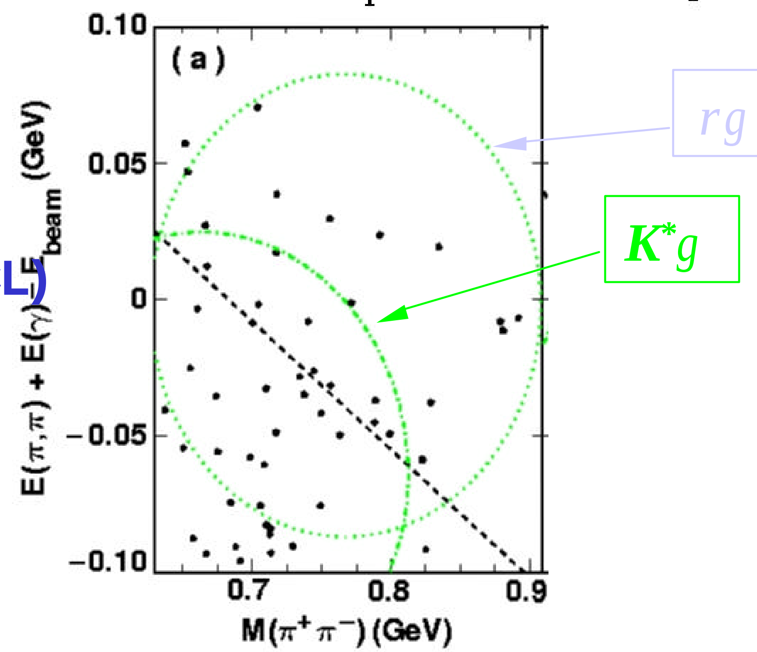
BR(B^0® r^0g) < 1.7 ´ 10^{-5}

BR(B^+® r^+g) < 1.3 ´ 10^{-5}

BR(B^0® wg) < 9.2 ´ 10^{-6}

- **BR(B® *rg*) / BR(B® *K**g*) < 0.32 (90% CL)**

- **|V_{td} / V_{ts}| < 0.72 (90% CL)**



Short Term Future

- **B Factories (BABAR, Belle, (CLEO))**
  - sin(2β) with ~5-10% precision
  - Rare decays with BR $\sim 10^{-6}$
  - Better understanding of V_{cb} and V_{ub}
- **Hadron colliders**
  - HERA-b has the potential to also measure sin(2β)
  - CDF already has already taken the first steps toward measuring sin(2β). Next run will start ~Aug. 2000.
  - CDF could also measure x_s.

Why do b & c decay physics at hadron colliders?

- Large samples of b quarks are available, with the Fermilab Main Injector, the collider will produce ~4×10^{11} b hadrons per 10^7 sec at L = 2×10^{32} $cm^{-2}s^{-1}$.
- e^+e^- machines operating at the Y(4S) at L of 3×10^{33} produce 6×10^7 B's per 10^7 s.
- B_s & Λ_b and other b-flavored hadrons are accessible for study.
- Charm rates are ~10x larger than the b rate

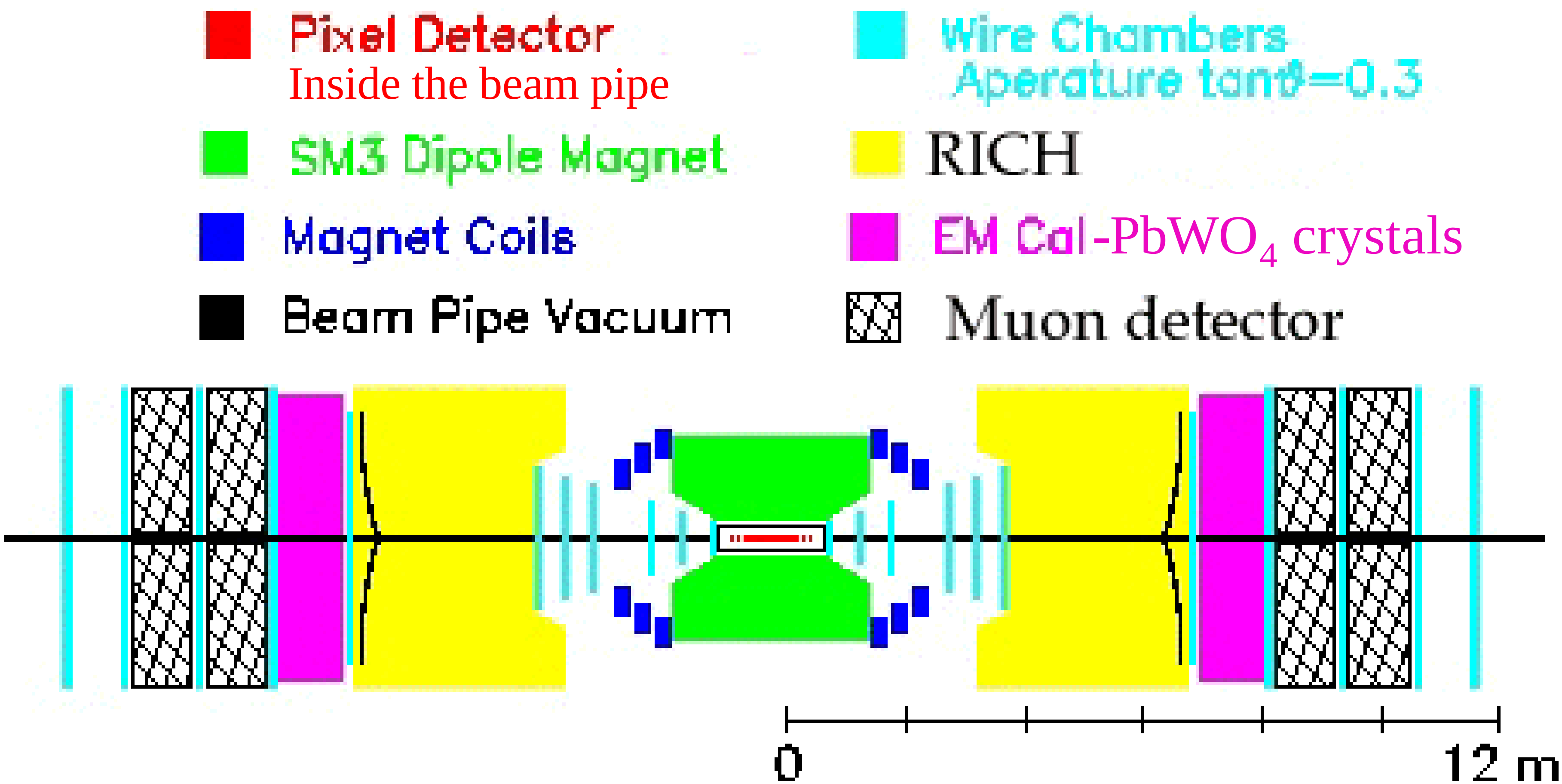
Main detector challenges

- **Problems:**
  - σ_b/σ_{tot} ~ 1/500 at Fermilab, 1/100 at LHC
  - Background from b's can overwhelm "rare" processes
  - Large data rate just from b's - 1 kHz into detector
  - Large rates cause Radiation damage to EM calorimeter; photon multiplicities may obscure signals
- **Solutions for BTeV:**
  - Use **detached vertices** for trigger and background rejection
  - Have excellent charged **particle identification** & lepton id
  - Dead-timeless trigger and DAQ system capable of writing kHz of events to tape
  - Use $PbWO_4$ crystal calorimeter

Fundamental Detector Principles

- Necessary to trigger efficiently on purely hadronic final states - detached vertex trigger
- Necessary to reconstruct final states with excellent decay time resolution, good efficiency and mass resolution
- Necessary to detect final states with γ or π^o efficiently with good energy resolution
- Necessary to able to identify π/K/p

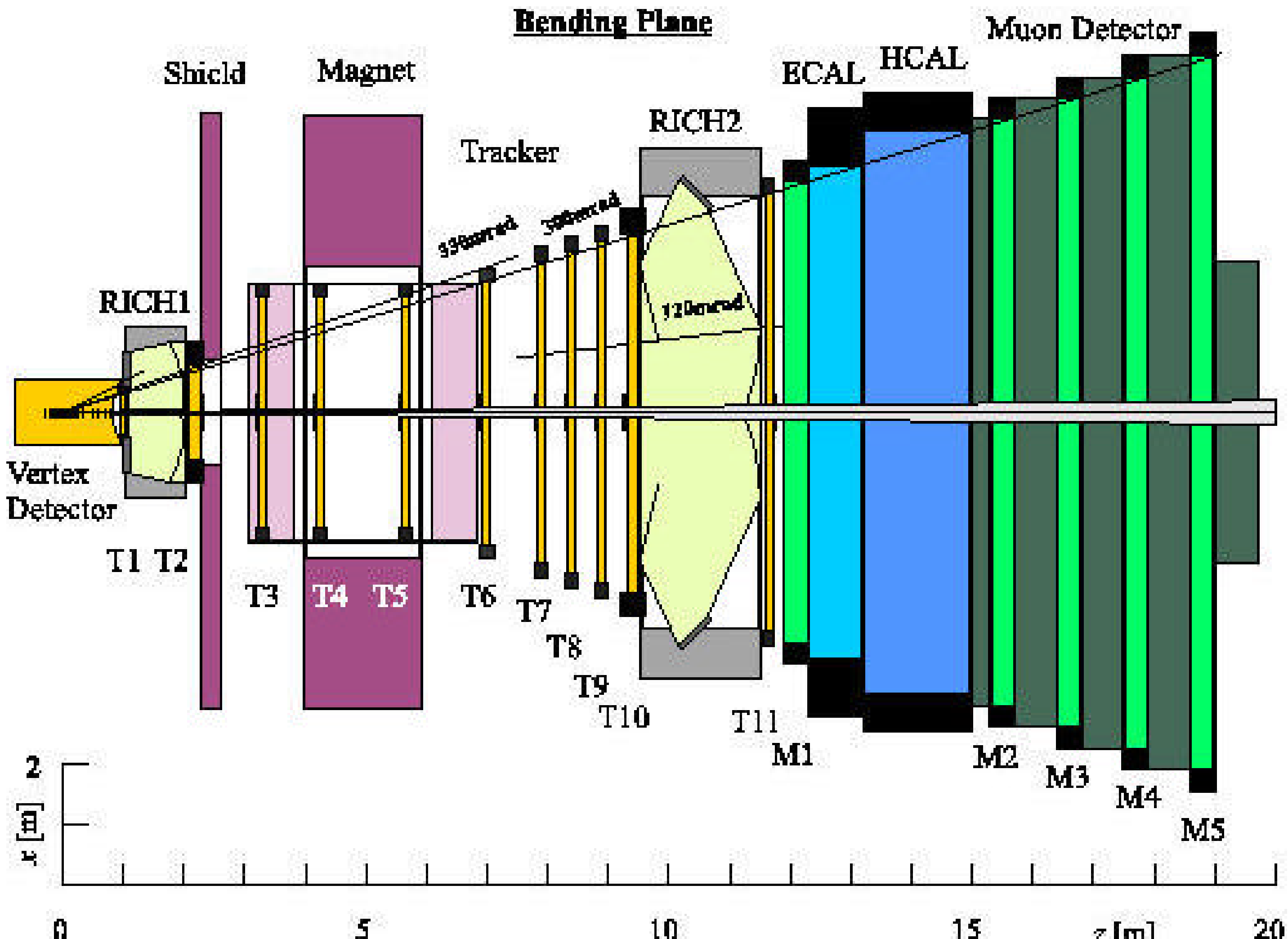
The BTeV Detector



The C0 Interaction Region

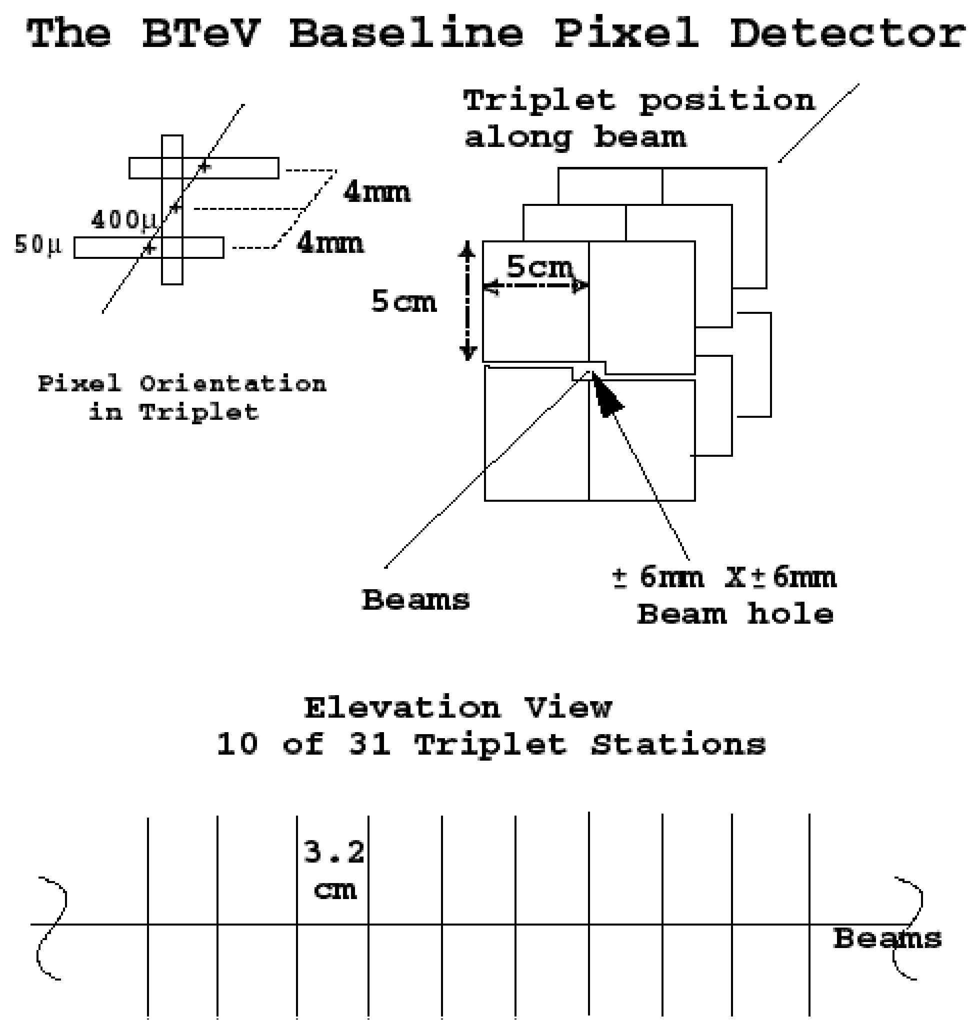
- **Construction finished**
- **BTeV is designed to be compatible**

The LHCb Detector



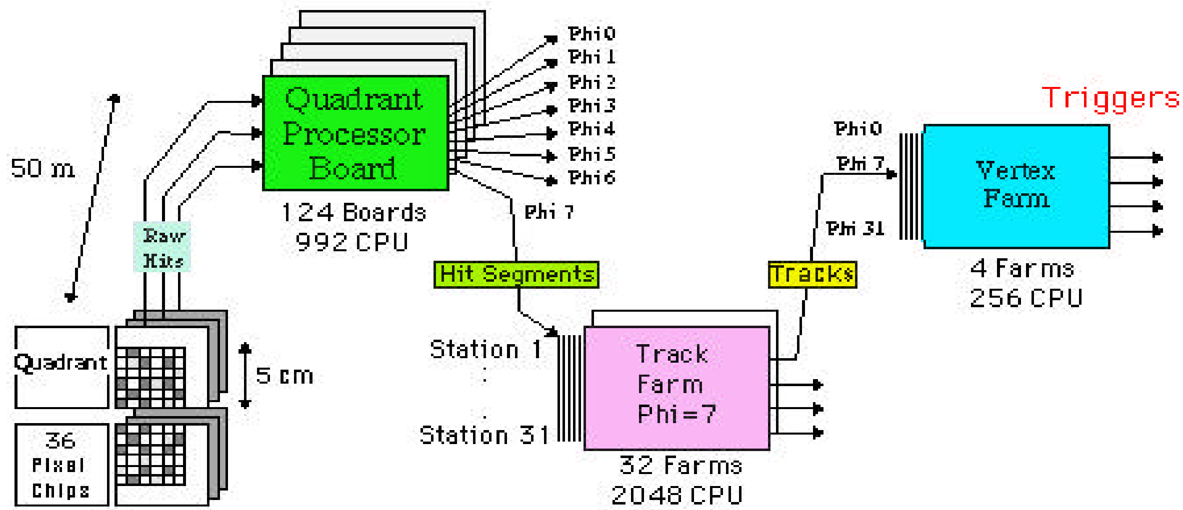
The BTeV Pixel Detector

- Pixels necessary to eliminate ambiguity problems with high track density; Essential to our detached vertex trigger
- Crucial for accurate decay length measurement
- Radiation hard
- Low noise



Pixel Trigger Description

- Triplets used to get space point & mini-vector, called a 'station hit'
- Station hits are organized
- into f-slices
- Tracks are found in these f-slices
  - full pattern recognition is performed
  - Minimum track p cu
- Event level processor



Detached Vertex Trigger

- Level I Trigger uses information from the Pixel Detector to find the primary vertex and then look for tracks that are detached from it
- The simulation does the pattern recognition. It uses hits from MCFast including multiple scattering, bremsstrahlung, pair conversions, hadronic interactions and decays in flight
- Detailed studies of efficiency and rejection for up to an average of three interactions/crossing

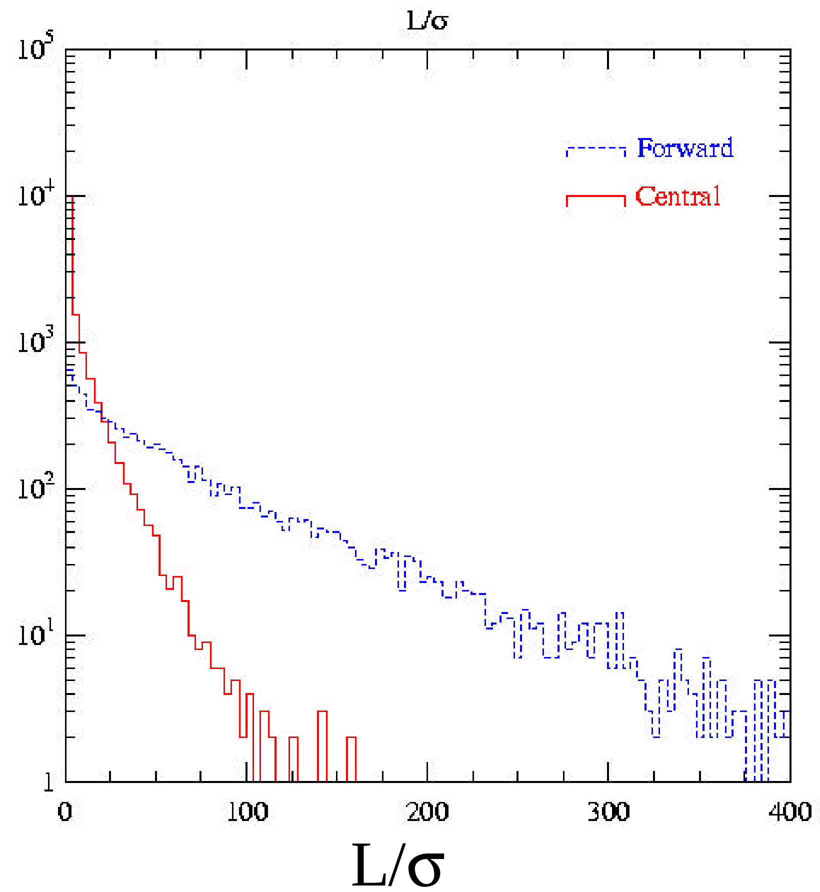
BTeV Trigger Performance

- **For a requirement of at least 2 tracks detached by more than 4σ, BTeV triggers on only 1% of the beam crossings and achieve the following efficiencies for these states:**

State	efficiency(%)	State	efficiency(%)
$B \rightarrow \pi^+\pi^-$	55	$B^o \rightarrow K^+\pi^-$	54
$B_s \rightarrow D_s K$	70	$B^o \rightarrow J/\psi\ K_s$	50
$B^- \rightarrow D^o K^-$	60	$B_s \rightarrow J/\psi K^*$	69
$B^- \rightarrow K_s \pi^-$	40	$B^o \rightarrow K^*\gamma$	40

B^{o} ® p^{+} p^{-}: L/ s distribution

- **L/ s = Decay length/error is very important in rejecting background both at trigger level and in analysis**
- **Much better in Forward (BTeV) geometry than Central geometry because b's are moving faster**



A sample calculation: Bº ® p^{+}p^{-}

	BTeV	LHCb
Cross-section	100 μb	500 μb
Luminosity	2×10^{32}	2×10^{32}
# of B^o/Year (10^7 s)	1.4×10^{11}	7×10^{11}
$\mathcal{B}(B^o \to \pi^+\pi^-)$	0.75×10^{-5}	0.75×10^{-5}
Reconstruction efficiency	0.06	0.032
Triggering efficiency (after all other cuts)	0.50	0.17
# ($\pi^+\pi^-$)	34,000	28,560
εD^2 for flavor tags ($K^\pm$, $\lambda^\pm$, same + opposite side jet tags)	0.1	0.1
# of tagged $\pi^+\pi^-$	3,400	2,900
Signal/Background	0.6	1
Error in $\pi^+\pi^-$ asymmetry (including bkgrd)	±0.023	±0.019

Comparisons of BTeV With e^+e^- B factories

- **Number of flavor tagged B^o® p^+ p^- ($B = 0.75x10^{-5}$)**

	L ($cm^{-2}s^{-1}$)	σ	$\#B^o/10^7s$	ε	$εD^2$	#tagged
e^+e^-	$3x10^{33}$	1nb	$3.0x10^7$	0.4	0.4	46
BTeV	$2x10^{32}$	100μb	$1.4x10^{11}$	0.03	0.1	3400

- **Number of B^-® D^o K^-**

	L ($cm^{-2}s^{-1}$)	σ	$\#B^o/10^7s$	ε	#
e^+e^-	$3x10^{33}$	1nb	$3.0x10^7$	0.5	2
BTeV	$2x10^{32}$	100μb	$1.4x10^{11}$	0.015	320

- **B_s , B_c and L_b not done at Y(4S) e^+e^- machines**
- **Number of tagged, reconstructed B^o decays to rp is a factor of at least 10 higher for BTeV.**

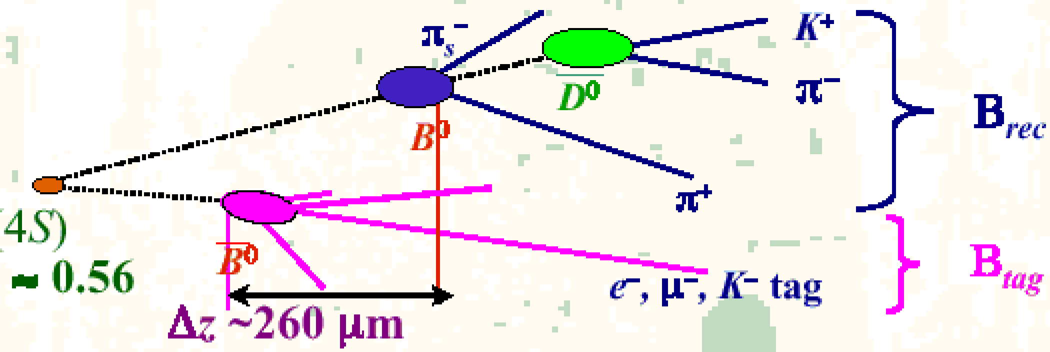
Comparisons of BTeV with LHCb

- **Advantages of LHCb**
  - σ_b 5x larger at LHC, while σ_t is only 1.6x larger
  - The mean number of interactions per beam crossing is 3x lower at LHC, when the FNAL bunch spacing is 132 ns
  - LHCb HAS BEEN APPROVED!
- **Advantages of BTeV (machine specific)**
  - The 25 ns bunch spacing at LHC makes 1st level detached vertex triggering more difficult.
  - The 7x larger LHC beam energy causes problems: much larger range of track momenta that need to be analyzed and large increase in track multiplicity, which causes triggering and tracking problems
  - The long interaction region at FNAL, σ=30 cm compared with 5 cm at LHC, somewhat compensates for the larger number of interactions per crossing, since the interactions are well separated

Comparisons with LHCb II

- **Advantages of BTeV (detector specific)**
  - BTeV is a two-arm spectrometer (gives 2x advantage)
  - BTeV has vertex detector in magnetic field which allows rejection of high multiple scattering (low p) tracks in the trigger
  - BTeV is designed around a pixel vertex detector which has much less occupancy, and allows for a detached vertex trigger in the first trigger level.
    - Important for accumulation of large samples of rare hadronic decays and charm physics.
    - Allows BTeV to run with multiple interactions per crossing, L in excess of $2x10^{32}$ cm^{-2} s^{-1}
  - BTeV will have a much better EM calorimeter

Babar and Belle time measurement:



The time resolution is about $\tau_B/2$.

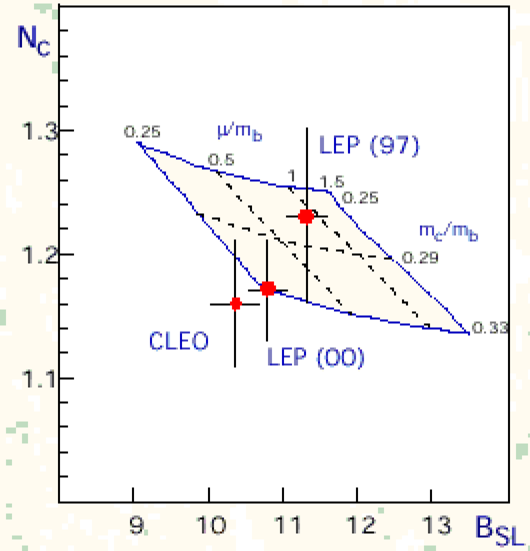
The primary vertex is not used (z_V is poorly known), except in dilepton analyses.

One B decay defines t = 0.

DPF2000 8/9/00 Jon J Thaler

Charm Counting

It is possible to calculate both the inclusive semileptonic BR and the number of charmed particles per decay in terms of fundamental quantities. In the past, the measurements have disagreed, making interpretation difficult. New ALEPH & DELPHI results change the picture. There is now experimental consistency.



$N_c = 1.171 \pm 0.040$
$B_{SL} = 10.79 \pm 0.25$
(Barker & Blyth @ ICHEP)

Using new lifetimes

CLEO: $B_{SL} = (10.49 \pm 0.17 \pm 0.43)\%$
$Nc = 1.10 \pm 0.05$

Note: LEP Vcb WG says: $B_{SL} = 10.56 \pm 0.11 \pm 0.18$