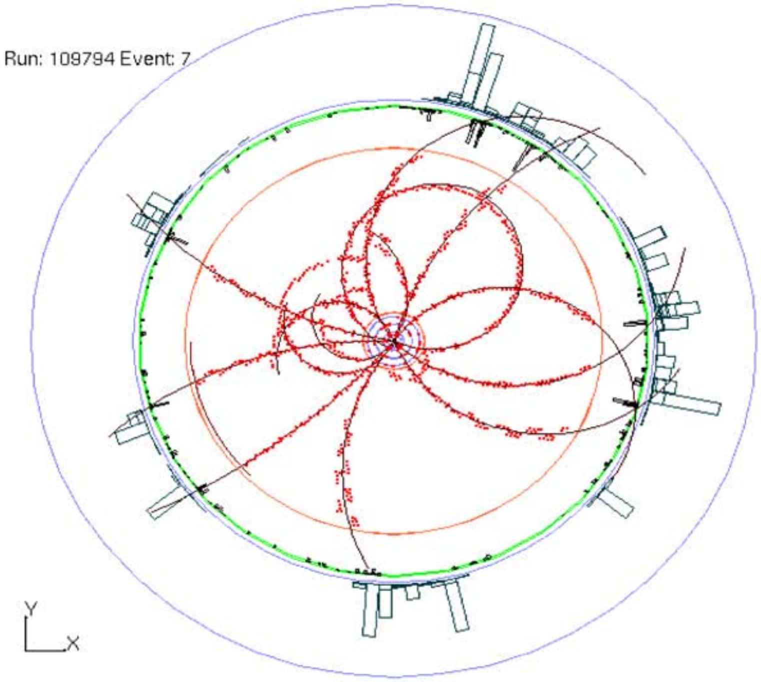
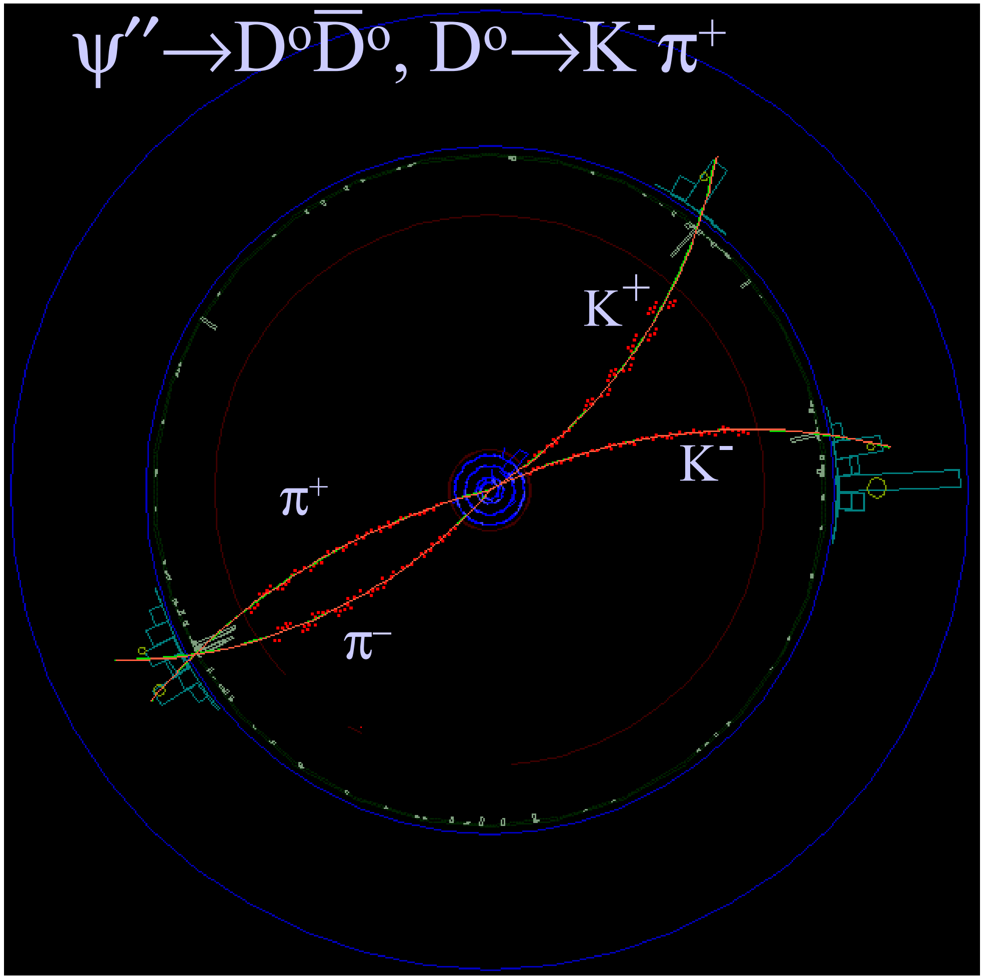
Recent results from CLEO & the CESR/CLEO Charm factory

$\Upsilon(4S) \to B\overline{B}$





Ian Shipsey,
Purdue University
CLEO Collaboration

- As I am completely deaf, please write down your questions.
- Pass them up to me
- I will read out your question before answering it.

The CKM Matrix

- **The parameters of the Standard Electroweak Model are:** $\alpha,\ G_F\ \sin^2\theta_W$

  M_H **& fermion masses and mixings**
- **The 4 quark mixing parameters reside in CKM matrix**

Weak eigenstates

Mass eigenstates

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

*** In SM λ, A, ρ, η are fundamental parameters**

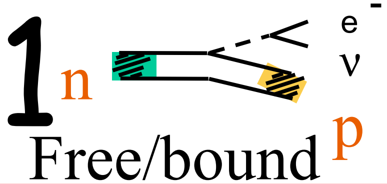
- **Does the CKM fully explain quark mixing? CP Violation?**
- **To detect new physics in flavor changing sector must know CKM well**
- **Must overdetermine the magnitude and phase of each element**

$$\lambda = \sin\Theta_{Cabibbo} \sim 0.22, A, \rho, \eta, O(1)$$

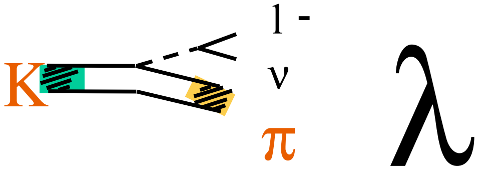
$$V_{CKM} = \begin{pmatrix} \mathbf{1}-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

CKM Matrix Status

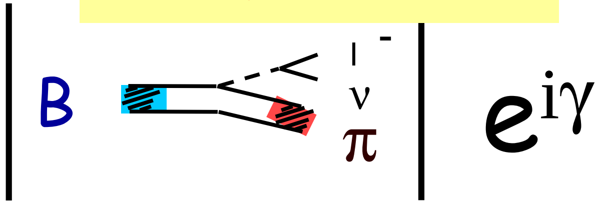
δVud/Vud 0.1%



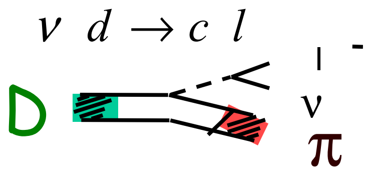
δVus/Vus =1%



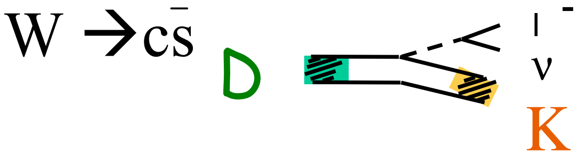
δVub/Vub 25%



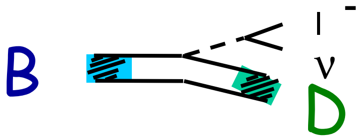
δVcd/Vcd 7%



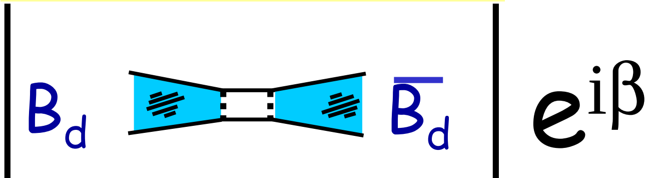
δVcs/Vcs =11%



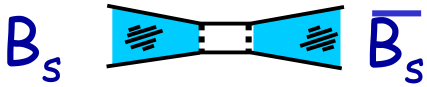
δVcb/Vcb 5%



δVtd/Vtd =36%



δVts/Vts 39%



δVtb/Vtb 29%

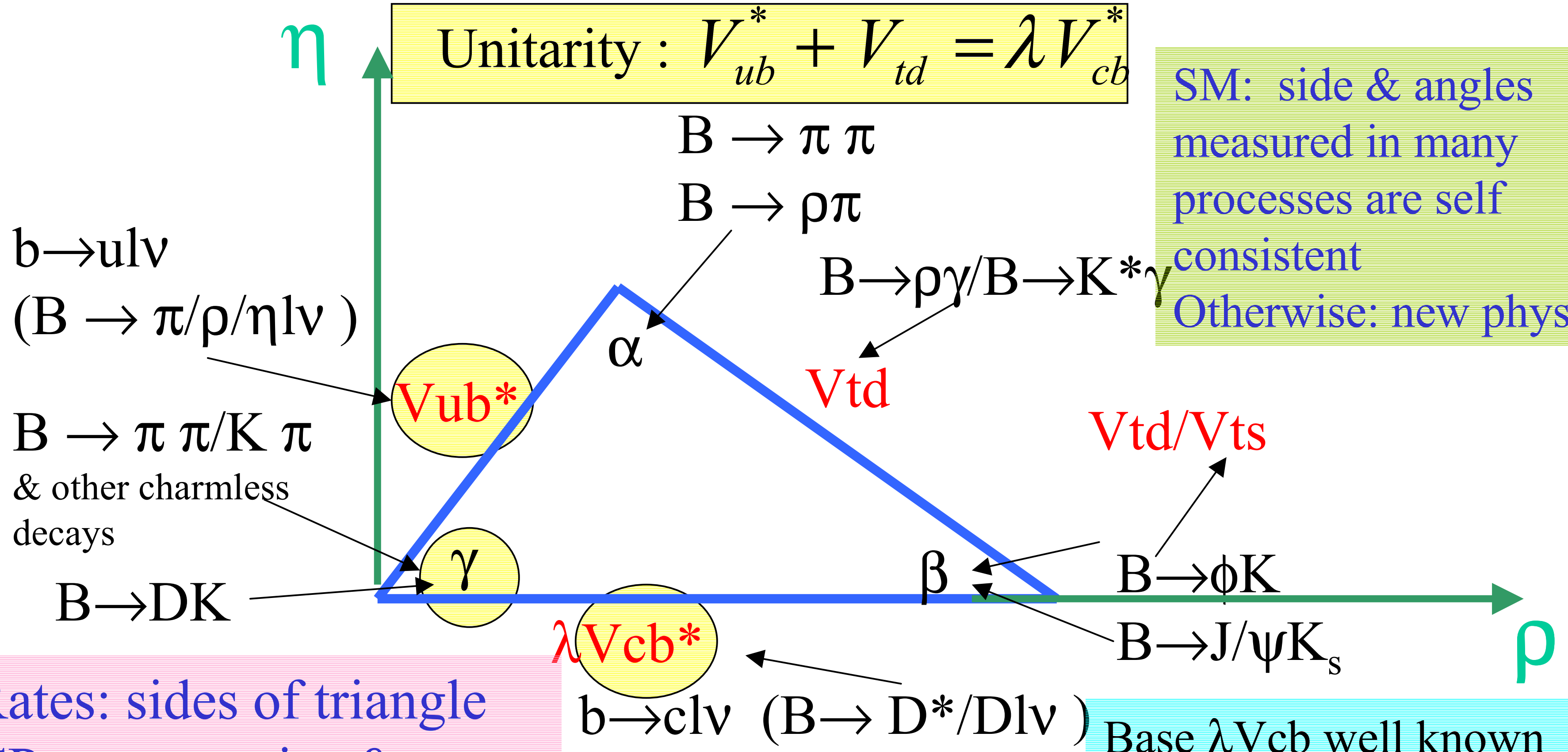
1

Vud, Vus and Vcd are the best determined due to flavor symmetries: I, SU(3), HQS. Charm and the rest of the beauty sector are poorly determined. Theoretical errors on hadronic matrix elements dominate.

B decays & the unitarity triangle

Goals for the decade: precision measurements of Vub, Vcb, Vts, Vtd, Vcs, Vcd, α, β, γ. Test SM description of CP violation and search for new physics.

$$\text{Unitarity}: V_{ub}^{*} + V_{td} = \lambda V_{cb}^{*}$$



SM: side & angles measured in many processes are self consistent
Otherwise: new physics

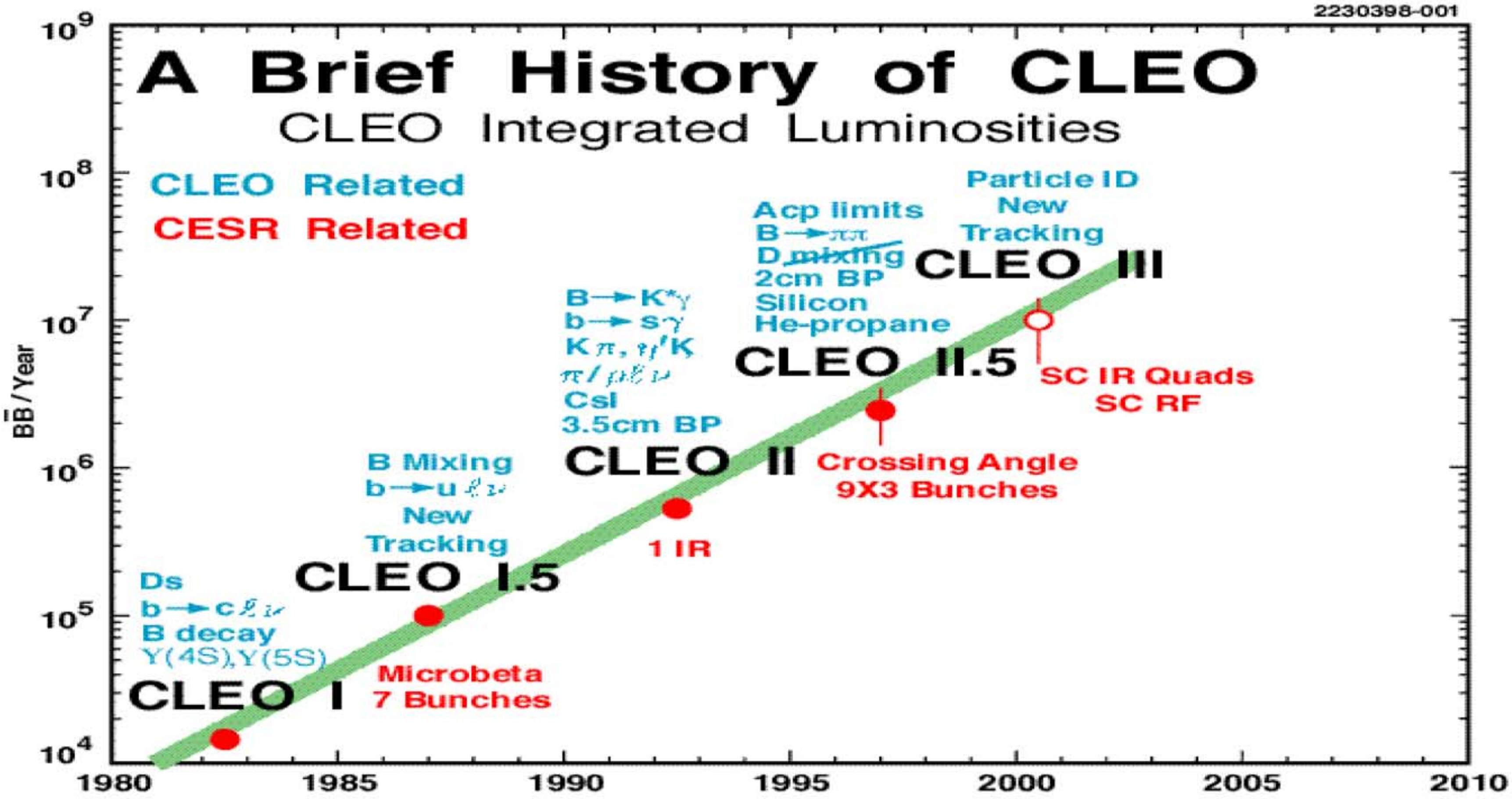
Rates: sides of triangle
CP asymmetries & rates : angles

Base λVcb well known
Other sides poorly known
angles α γ unknown. β soon

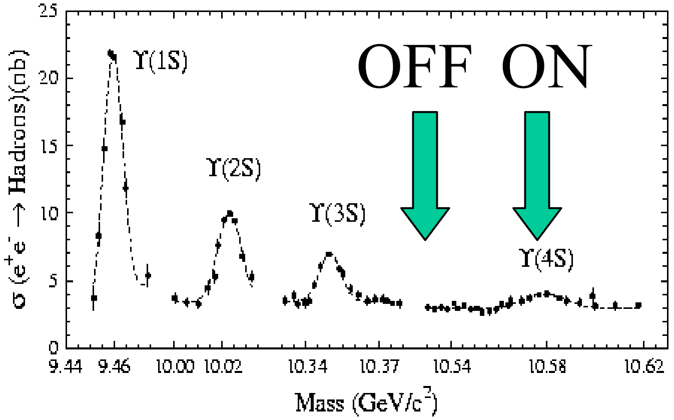
A Short History of CESR/CLEO

- 1968: 10 Gev e^- synchrotron built
  - Size of ring determined by size of playing fields
- 1975: Proposal for e^+e^- storage ring in synchrotron tunnel, E_{beam}=8 GeV
  - PEP/PETRA E_{beam}=15-20 GeV
  - SPEAR E_{beam}=2 GeV
- 1977: b-quark discovered at FNAL!
- 1979: CLEO sees first collisions
- 1980: Y(4S) discovered
  - CLEO 1979
  - CLEO I.V 1986
  - CLEO II 1989
  - CLEO II.V 1995
  - CLEO III 1999

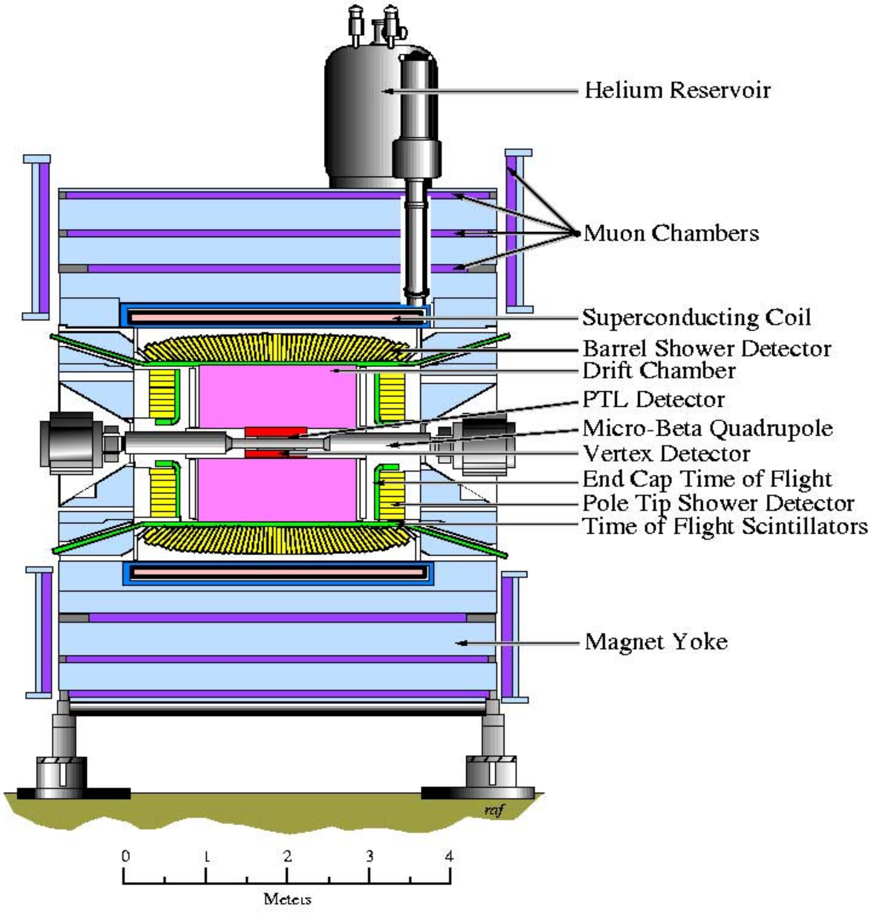
CESR/CLEO 1980-2001



CLEO at CESR



- CLEO at CESR e+e- storage ring √s=10.58 GeV
- Operation at Υ(4S) just above BB threshold
- $\boxed{L_{peak} = 1.3\times10^{33} cm^{-2}s^{-1}}$ $(May\ 24\ \text{'01})$
- $\int Ldt \sim 350\, pb^{-1} \left(0.35 MBB\right)\, week^{-1}$
- 10^7 BB, cc, ττ CLEO II/II.V (1990-99)
- 7 x 10^6 BB. CLEO III (2000-01) Turned off. June 25 1st results at LEPPHO '01
- B's produced nearly at rest
- No B_s or b-baryons
- 25% of hadronic cross section is BB
- CLEO 4pi solenoidal detector
  - si + drift chamber in 1.5T field
  - CsI calorimeter
  - muon identification



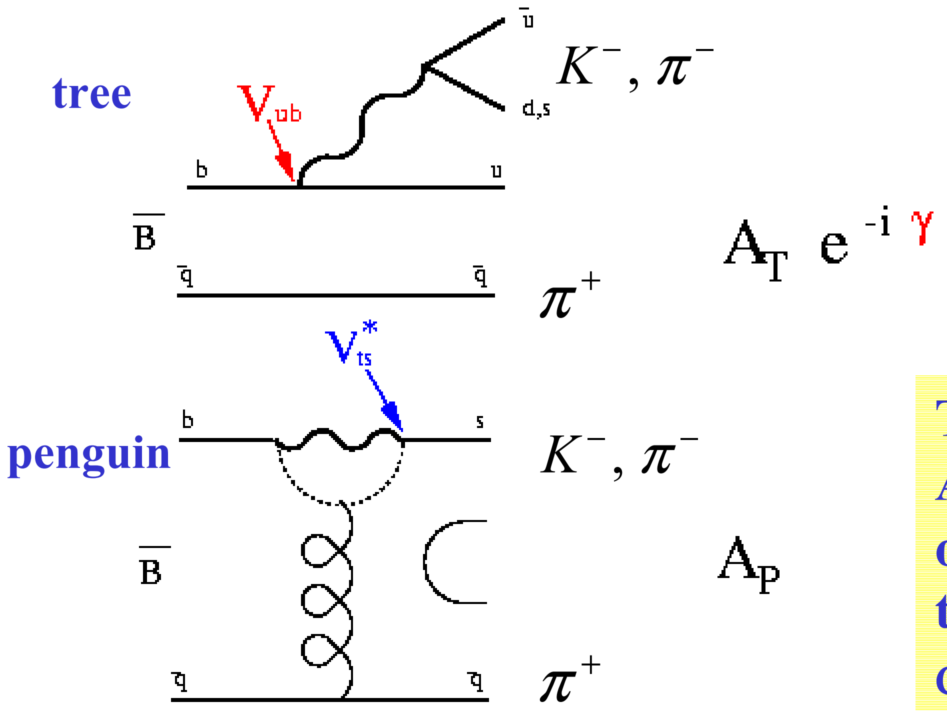
BABAR/Belle/CLEO datasets

CESR		KEKB		PEPII	
→ e-	← e+	→ e-	← e+	→ e-	← e+
5.3 GeV	5.3 GeV	8 GeV	3.5 GeV	9 GeV	3.1 GeV
$\beta\gamma$=0.06		$\beta\gamma$=0.425		$\beta\gamma$=0.56	

Dataset used for analyses: Summer conferences 2001

	$L_{peak} \times 10^{33} cm^{-2} s^{-1}$	$\int Ldt$		$\#B's \times 10^6$
		ON	OFF	
CESR/CLEO	1.3	16.0	6.7	34
KEKB/Belle	4.5	29.1	3.7	62
PEPII/BABAR	3.4	34.1	4.1	74

B →Kπ /ππ : γ via penguin,tree interference



From CKM counting expect:
*** B →Kπ is mostly penguin**
*** B →ππ is mostly tree**

Two approaches: measure rates or Acp both contain information on the product of γ and the (unknown) strong phase difference φ between contributing amplitudes

$$(BR+\overline{BR})/2 = |A_T|^2 + |A_P|^2 + 2|A_T A_P|\cos\gamma\cos\varphi$$

$$A_{CP} = \frac{B(b\to f) - B(\bar{b}\to \bar{f})}{B(b\to f) + B(\bar{b}\to \bar{f})} = \frac{2|A_T A_P|\sin\gamma\sin\Delta\phi}{|A_T|^2 + |A_P|^2 + 2|A_T A_P|\cos\gamma\cos\Delta\phi}$$

B Reconstruction

$\Upsilon(4S) \to B\bar{B}$ **2 kinematic constraints: E,p**

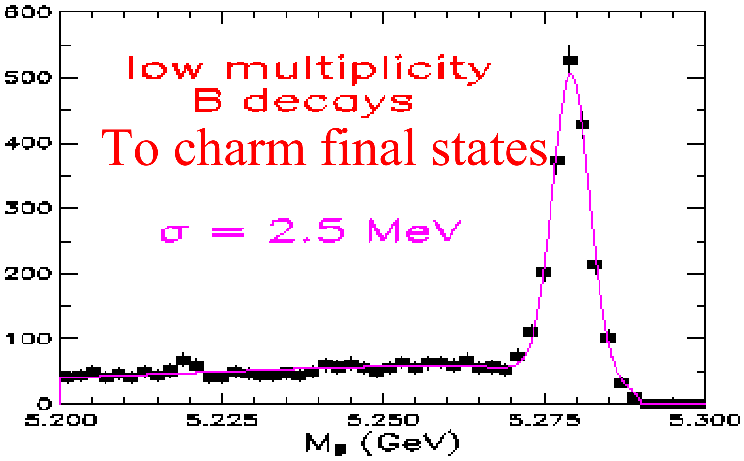
$$example \;\; B \to \pi_1^{\,+}\pi_2^{\,-}$$

- **Each B has energy equal to the beam** $\Delta E = E_1 + E_2 - E_{beam}$
- **For signal events ΔE peaks at 0 σ(ΔE) = 25-100 MeV**

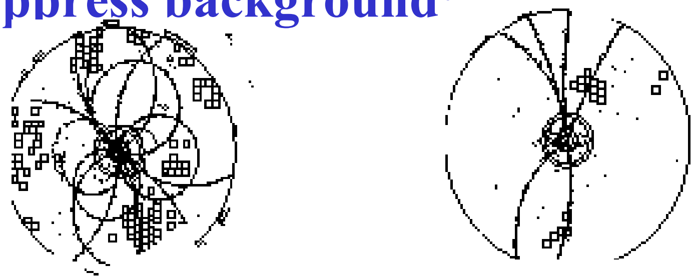
$$M_{B,raw} = \sqrt{(E_1 + E_2)^2 - (p_1 + p_2)^2}$$

- **Constrain ΔE=0**

$$M_B = \sqrt{E_{beam}^2 - (p_1 + p_2)^2} \qquad \sigma M_B \big/ M_B \approx 5\times10^{-4}$$



- **Suppress background·**



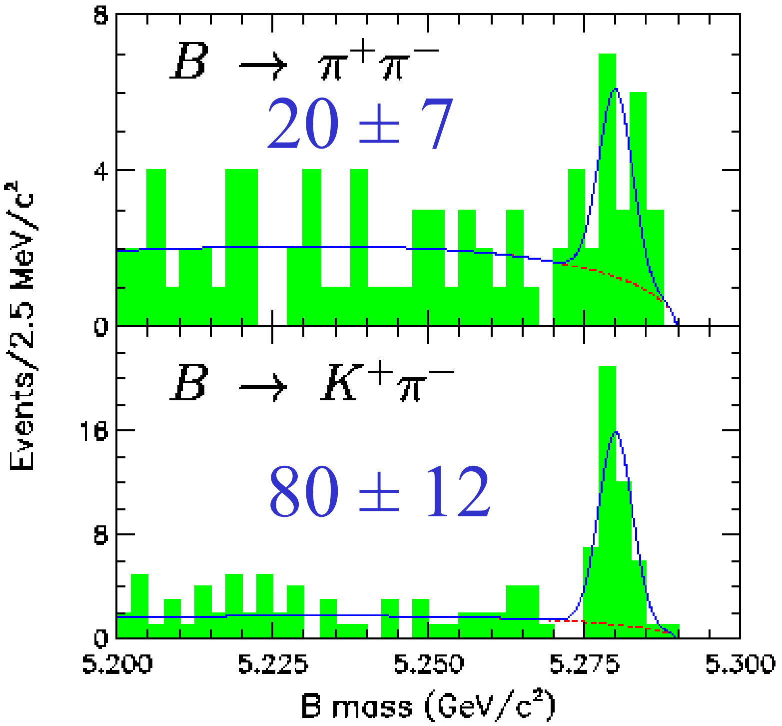
$e^+e^- \to \Upsilon(4S) \to B\bar{B}$ $e^+e^- \to q\bar{q}$

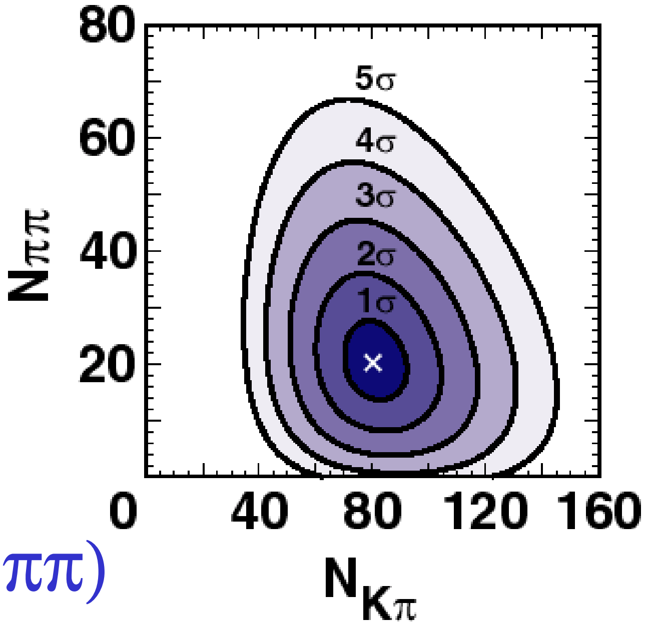
Spherical event shape 2-jet structure

- **and energy flow**
- **E,p constraints do not fix B direction: Y(4S) is transverse polarized**
- **dE/dx K/π separation**
- **maximise differences between sig and bkgd Fisher discriminant**
- **multidimensional unbinned maximum likelihood fit using all available information**

B →Kπ/ππ

CLEO II/II.V





↑

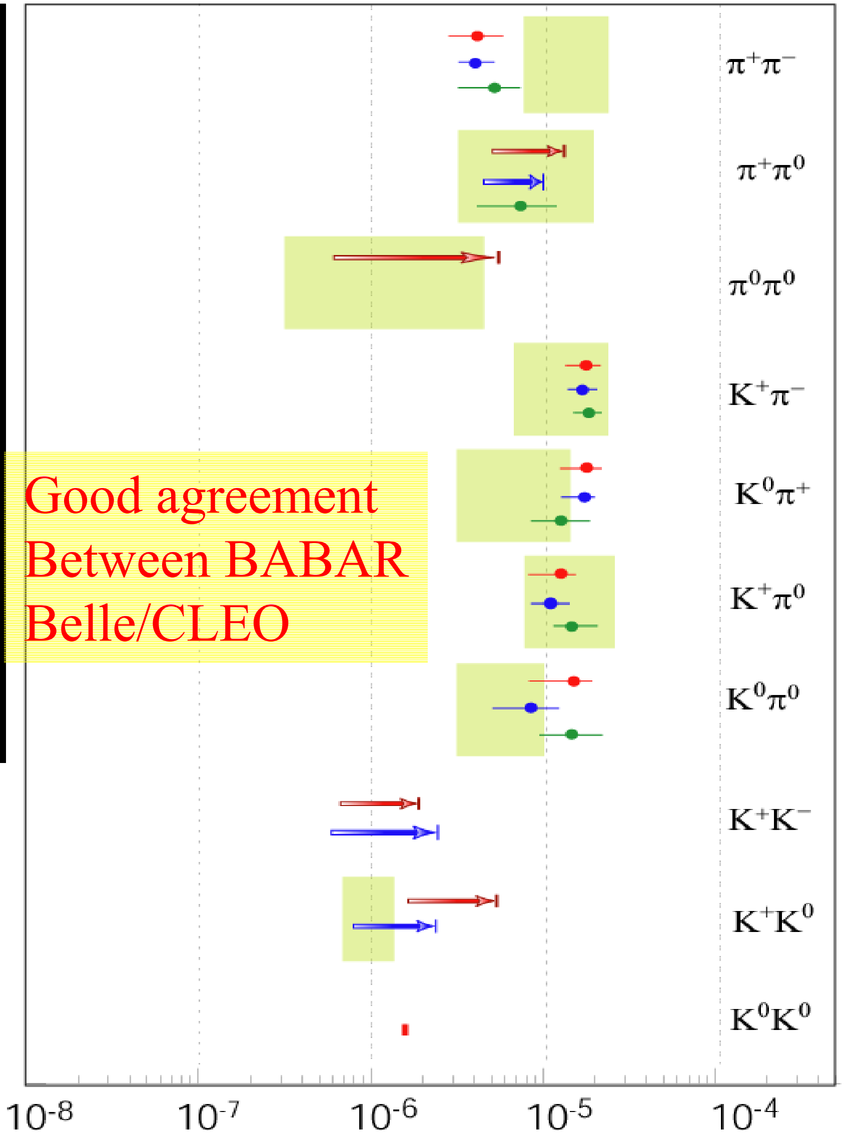
N(ππ)

N(Kπ)→

$$Br(B \to K^+\pi^-) = \frac{N(B \to K^+\pi^-)}{\varepsilon \bullet N_{BB}} = \frac{80}{.48 \bullet 9.7\times10^6} = 17.2\times10^{-6}$$

B →Kπ/ππ Summary

	Mode	CLEO (9.7M$B\bar{B}$)				Theory BF × 10-6
		N_{Sig}	Signif.	Eff (%)	BF × 10-6	
→	$\pi^+\pi^-$	$20.0^{+7.6}_{-6.5}$	4.2σ	48	$4.3^{+1.6}_{-1.4} \pm 0.5$	8-26
	$\pi^+\pi^0$	$21.3^{+9.7}_{-8.5}$	3.2σ	39	< 12.7	3-20
→	$\pi^0\pi^0$	$6.2^{+4.8}_{-3.7}$	2.0σ	29	< 5.7	0.3-4.6
→	$K^+\pi^-$	$80.2^{+11.8}_{-11.0}$	11.7σ	48	$17.2^{+2.5}_{-2.4} \pm 1.2$	7-24
	$K^0\pi^+$	$25.2^{+6.4}_{-5.6}$	7.6σ	14	$18.2^{+4.6}_{-4.0} \pm 1.6$	3-15
	$K^+\pi^0$	$42.1^{+10.9}_{-9.9}$	6.1σ	38	$11.6^{+3.0}_{-2.7}{}^{+1.4}_{-1.3}$	8-26
	$K^0\pi^0$	$16.1^{+5.9}_{-5.0}$	4.9σ	11	$14.6^{+5.9}_{-5.1}{}^{+2.4}_{-3.3}$	3-9
	K^+K^-	$0.7^{+.3.4}_{-0.7}$	0σ	48	< 1.9	
	K^+K^0	$1.4^{+2.4}_{-1.3}$	1.1σ	14	< 5.1	0.7-1.5
	$K^0\bar{K}^0$	0	0σ	5	< 17	



Good agreement
Between BABAR
Belle/CLEO

*** General agreement theory**

*** Large Br(B →Kπ)/Br(B→ππ) ➔**

*** severe penguin pollution complicating extraction of α at BaBar/Belle**

*** B → $\pi^0\ \pi^0$ submitted to PRL**

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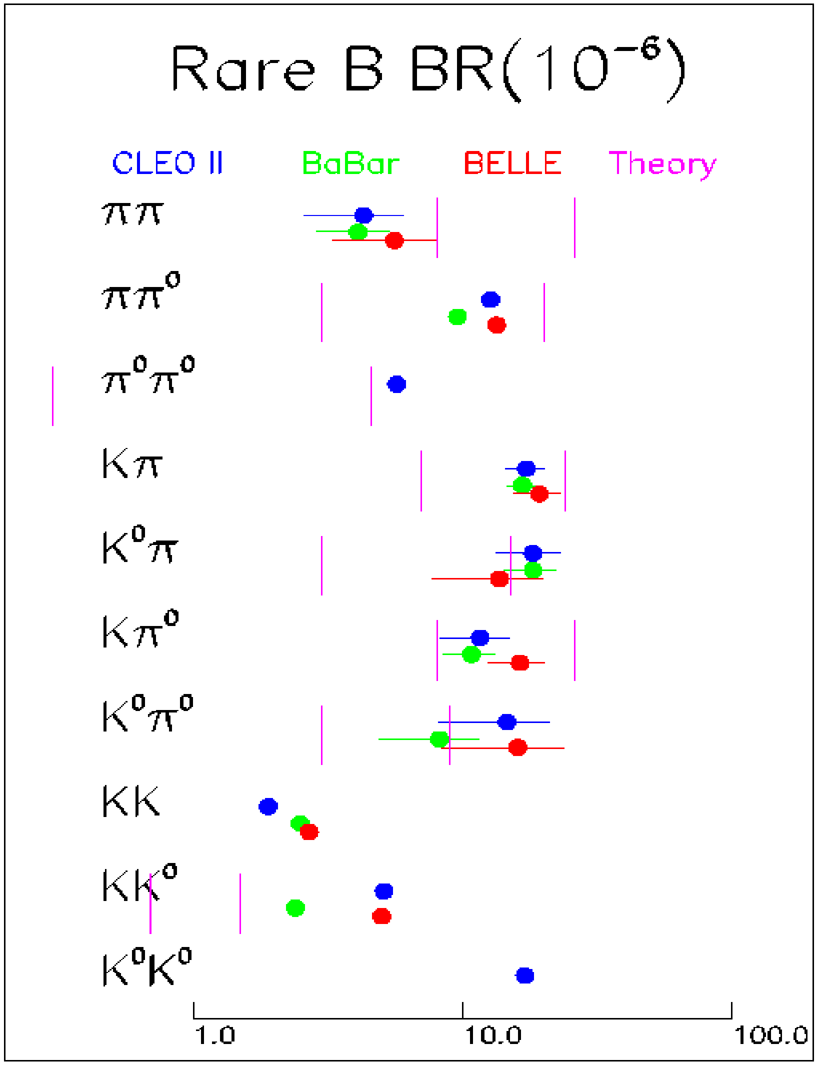
	K^+K^0	$1.4^{+2.4}_{-1.3}$	1.1σ	14	< 5.1	0.7-1.5
	$K^0\bar{K}^0$	0	0σ	5	< 17	



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Good agreement between BABAR Belle/CLEO

Measuring γ via penguin,tree interference

- **Comparison of rates between several modes related by isospin or SU(3) allow a low statistics determination of γ.**
- **Example: Fleischer -Mannel**

$$R=\frac{Br(B\to K^{-}\pi^{+})}{Br(B^{+}\to K_{S}^{0}\pi^{+})}=\frac{P+T}{P}$$

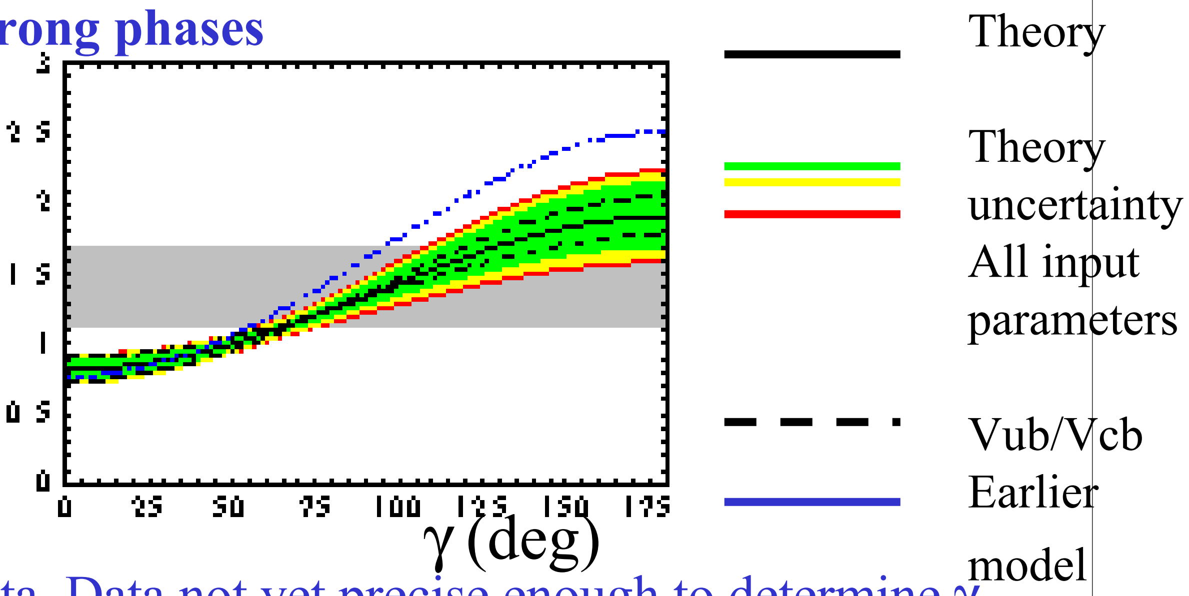
if R <1 interference is at work

- **Recent improved theoretical treatment of hadronic B decays: QCD factorization Beneke, Buchalla, Neubert Sachrajda hep/ph0104110 provides amplitudes & strong phases**

$$R_{*}=\frac{2Br(B^{\pm}\to K^{\pm}\pi^{0})}{Br(B^{\pm}\to K_{S}^{0}\pi^{\pm})}$$

$R_{*}=1.41\pm0.29$ → R_{*}

Babar/Belle/CLEO average



Good global fit to all Kπ/ππ data. Data not yet precise enough to determine γ

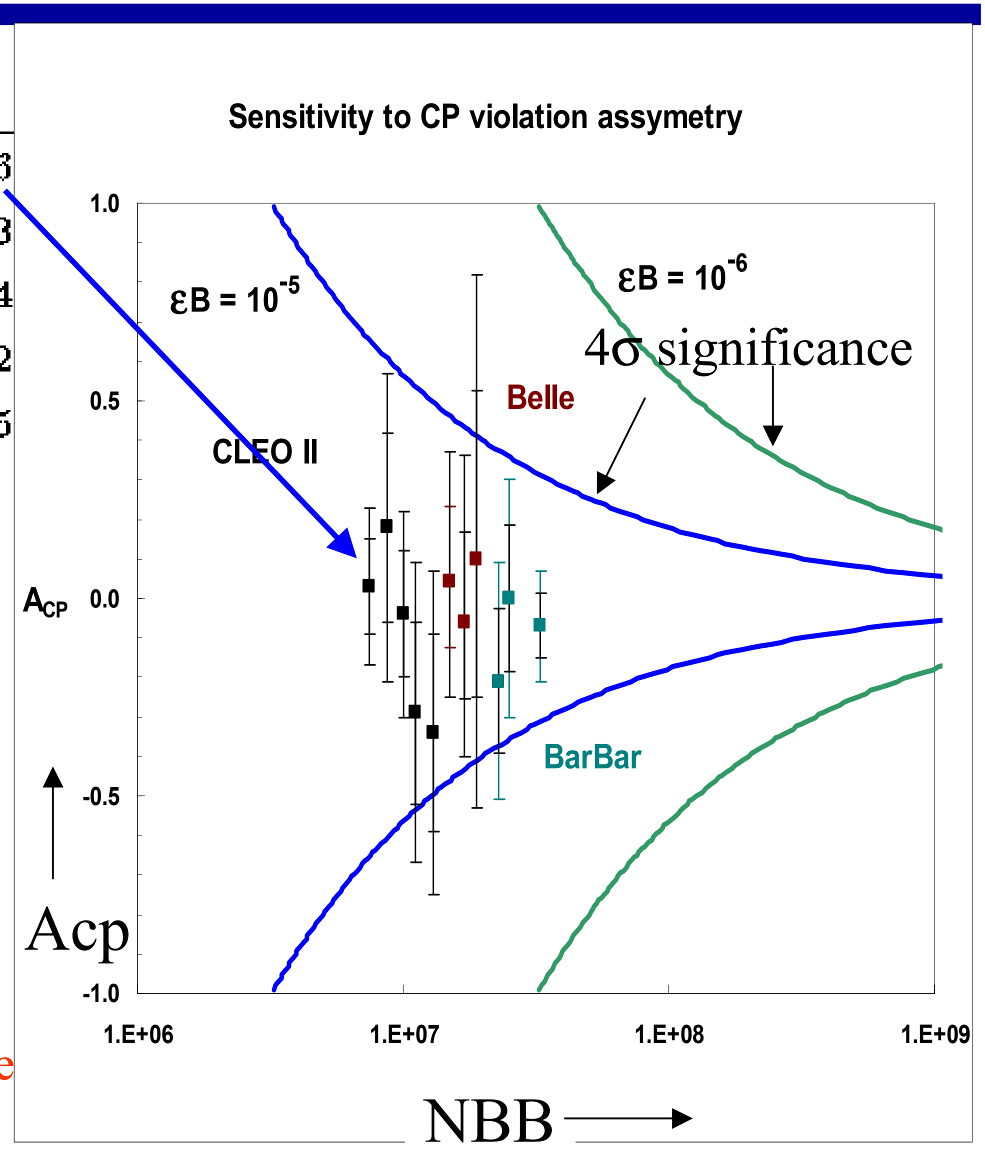
Near future: $\delta R_{*}/R_{*}=10\%$ $\delta\gamma=11^{0}$ need ~ 75M BB

Future: $Acp(B^{\pm}\to\pi^{\pm}K_{s}^{0})$ & $Acp(B^{\pm}\to\pi^{0}K^{\pm})$ measures Δϕ need 175M BB

Search for Direct CP Violation in B →Kπ

CLEO	Events	$\mathcal{A}_{CP}^{\text{Theory}}$ (Ali *et al.*)	$\mathcal{A}_{CP}$
$K^{\pm}\pi^{\mp}$	$80.2^{+11.8}_{-11.0}$	$[+0.037, +0.106]$	-0.04 ± 0.16
$K^{\pm}\pi^{0}$	$42.1^{+10.9}_{-9.9}$	$[+0.026, +0.092]$	-0.29 ± 0.23
$K_S^0\pi^{\pm}$	$25.2^{+6.4}_{-5.6}$	$+0.015$	$+0.18 \pm 0.24$
$K^{\pm}\eta'$	100.0^{+13}_{-12}	$[+0.020, +0.061]$	-0.03 ± 0.12
$\omega\pi^{\pm}$	$28.5^{+8.2}_{-7.3}$	$[-0.120, +0.024]$	-0.34 ± 0.25

- **Summary: no evidence for direct CP violation in five modes**
- **Statistics limited >0.12**
- **Systematic error 0.02 mostly dE/dx**
- **Very large Acp are excluded**
- **BABAR/Belle/CLEO results in good agreement**
- **Precision Acp will require very large data sets!**



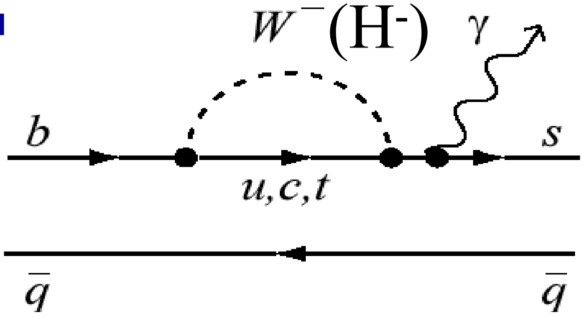
1 σ & 90% CL are shown

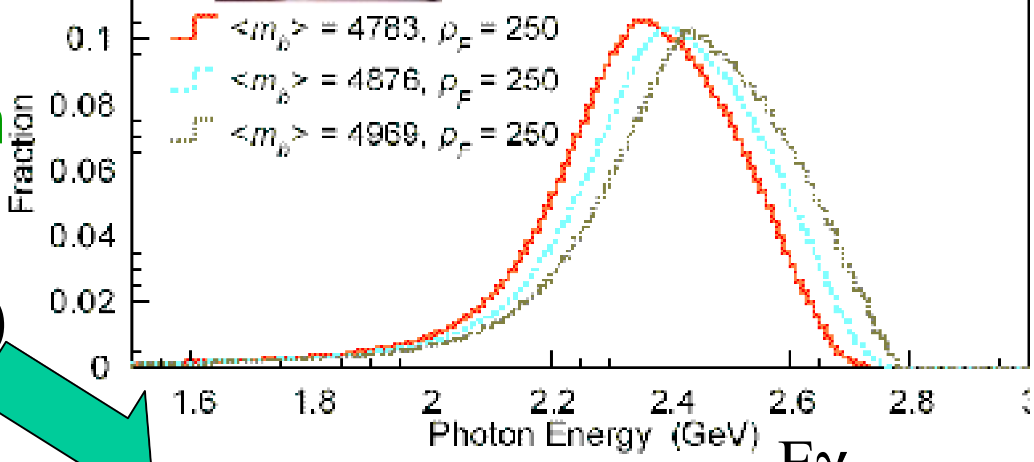
Inclusive EM penguins: b→sγ

- No tree level FCNC in SM
- Sensitive to new physics in loop H^-…
- Calculated to NLO in SM

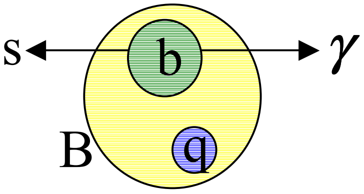
$$(3.3 - 3.7 \pm 0.33) \times 10^{-4}$$

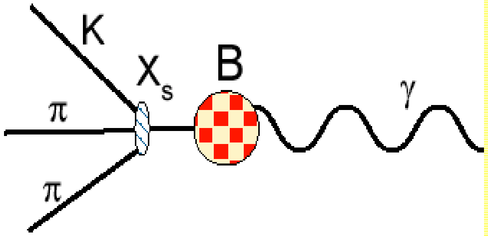
- Measure: inclusive γ spectrum
- Past: Branching ratio & Acp.
- Now: (+ shape of γ spectrum)
- not sensitive to new physics





quark level hadron level





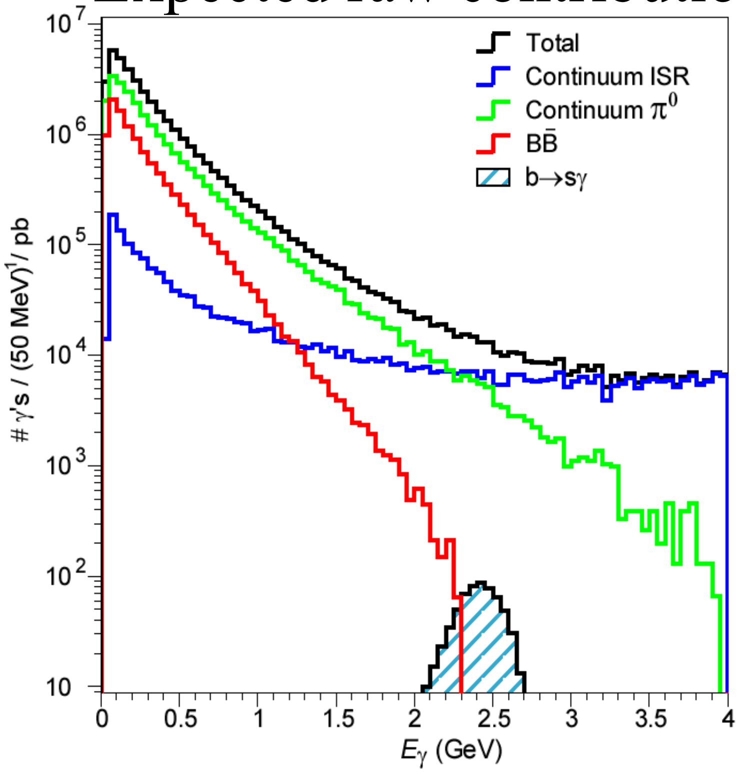
Mean : $\langle E\gamma \rangle \sim m_b/2$
Width: non-perturbative interactions between b quark and light degrees of freedom in hadron (Fermi motion)
Both quantities needed for extraction of Vcb & Vub from B →Xlν

$b \to s\gamma$: Measuring the γ spectrum

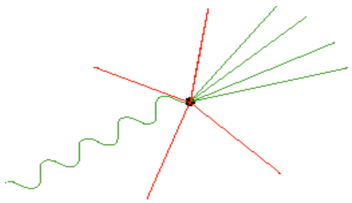
(CLEO Lepton Photon 01)

- **Signal: isolated γ $2.0 < E\gamma < 2.7$ GeV**
- **Measure γ spectrum for ON and OFF resonance and subtract**
- **But: $b \to s\gamma$ isn't only source of γ**
- **I B $\to X\gamma$: $\pi^0 \to \gamma\gamma$ $\eta \to \gamma\gamma$ ➔ previous analysis photon cut at 2.2 GeV, now model and subtract, significantly reduces model dependence**
- **II huge continuum background: reduce by**
- **I shape cuts**
- **II leptons (suppression and tagging)**
- **III Identify Xs system recoiling against γ**

Expected raw contributions

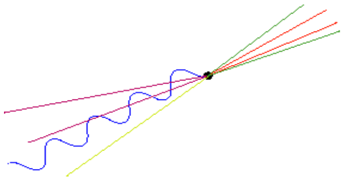


Signal



vs.

Continuum



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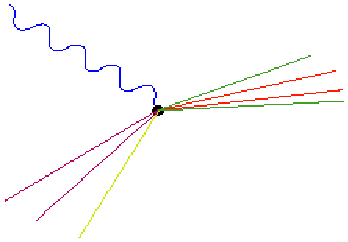


$b \to s\gamma$

Preliminary

- **Full Cleo II + II.V dataset *BF* measured for ~90% of full spectrum (2.0 GeV cutoff)**

$$\mathcal{B}(b \to s\,\gamma)$$
$$= 3.21 \pm 0.43 \pm 0.27^{+0.18}_{-0.10} \times 10^{-4}$$

Theory: (3.3 - 3.7 ± 0.33) × 10^{-4}

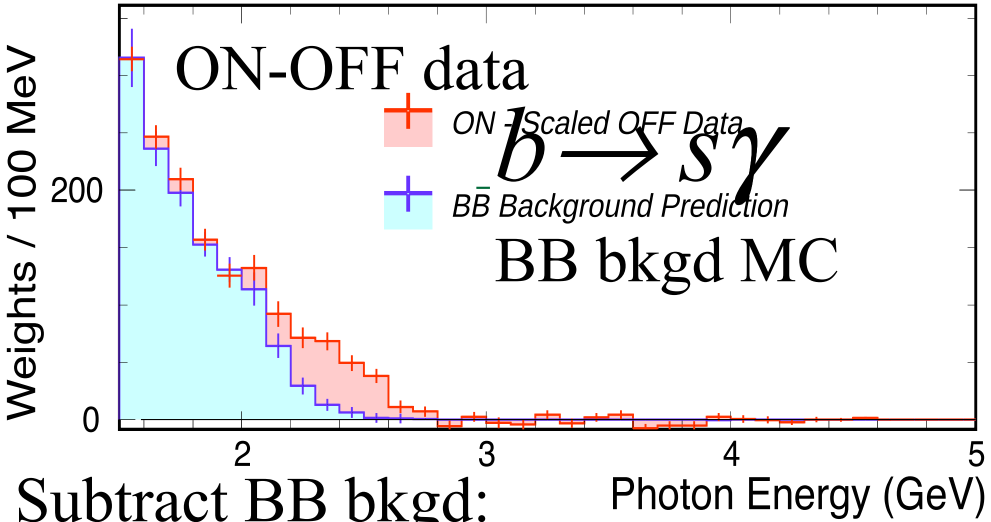
(Chetyrkin, Misiak,& Münz/ Kagan &Neubert,Gambino&Misiak)

- **Expt & theory agree**
- **Expt error close to theoretical uncertainty**
- **not much room for new physics**
- **Belle (BCP4) measures: (2.25 GeV cutoff)**

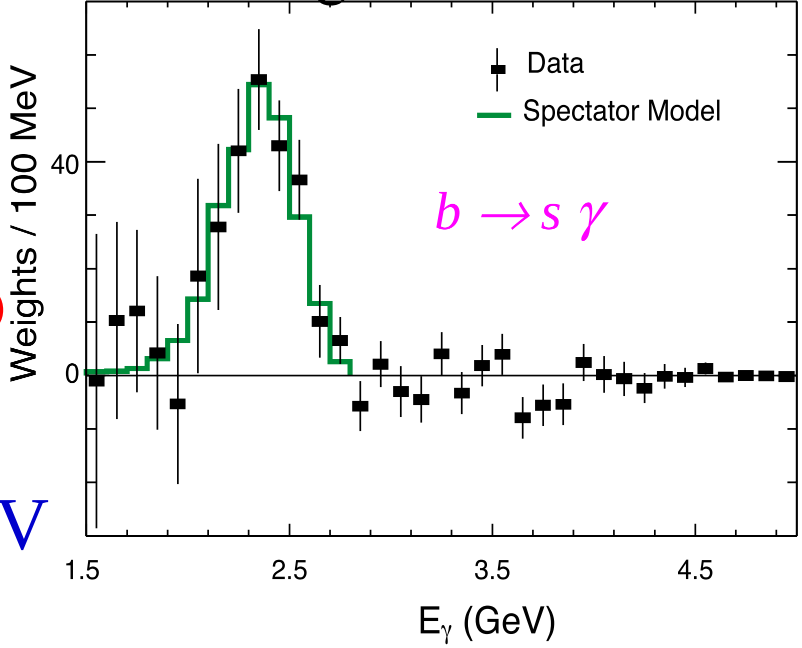
$$\left(3.37 \pm 0.53 \pm 0.42^{+0.50}_{-0.54}\right) \times 10^{-4}$$

1st moment:

$$\langle E_\gamma \rangle = 2.346 \pm 0.032 \pm 0.011 \text{ GeV}$$



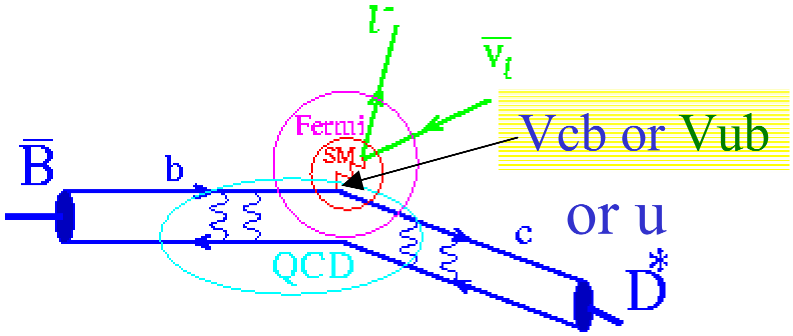
Subtract BB bkgd:



Direct Determination of CKM matrix

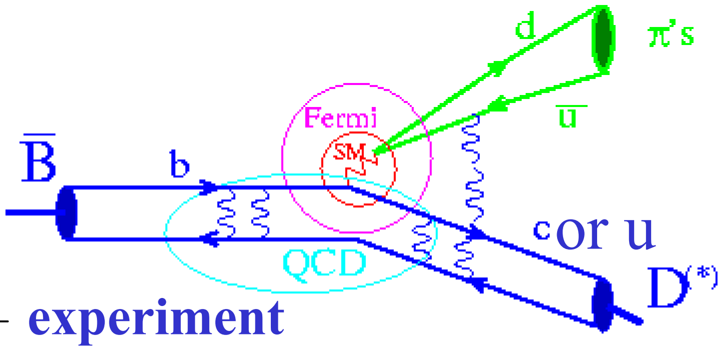
- Semileptonic decays are used to determine the quark couplings as they are simple: strong interaction is confined to the lower vertex
- $\Gamma \propto |V_{cb}|^2$ for final states with charm (D D* etc.)
- $\Gamma \propto |V_{ub}|^2$ for final states without charm (ρ/π/η…)
- Since of necessity we must work with hadrons rather than quarks, theory is needed to relate the underlying quark decay to hadronic reality:

Semileptonic:



or ρ/π/η

hadronic:



or ρ/π/η

theory

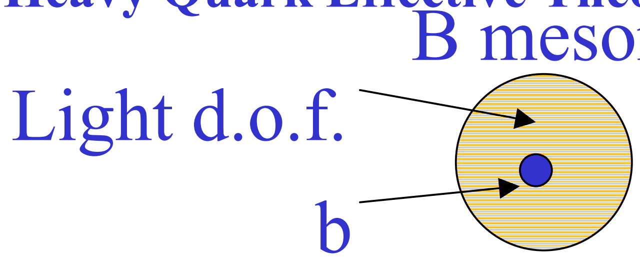
$$\Gamma = \Gamma_{theory} |V_{ub}|^2 = \frac{Br}{\tau}$$

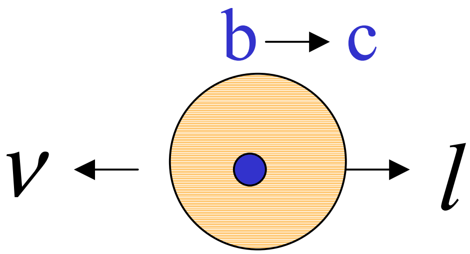
experiment

- Two approaches inclusive B→ X l ν or exclusive B → D* l ν, B→πlν

Determination of V_{cb} from $B \to D^* \ell^+\nu$

- **Heavy Quark Effective Theory**





b quark is nearly at rest
b spin has little effect on energy

$$\frac{d\Gamma}{dq^2} \propto V_{cb}^2 F_{D^*}(q^2)^2$$

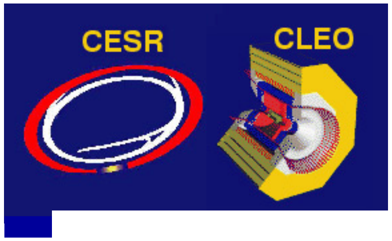
At $q^2_{\max}$ c quark nearly at rest, light degrees of freedom unaware of flavor change

$$m_Q \to \infty,\ F_{D^*}(q^2_{\max}) = 1$$

- **For $m_Q \to \infty$ the form factor (strong interaction physics) which measures the probability that the c quark forms a D* is unity.**
- **Corrections for finite m_Q are 2nd order for B→D*lυ and calculable**
- **Since this is a $0^- \to 1^-$ S,P,D wave decay large rate near $q^2_{\max}$**
- **Measure $\frac{d\Gamma}{dq^2}(B \to D^* l\nu)$ and extrapolate to $q^2_{\max}$**

$B \to$ **D^{*+}** $\ell^+\nu$ Osaka (2000) , now also $B \to$ **D^{*0}** $\ell^+\nu$ Rome (2001)

(systematics limited ~1/3 of the CLEO data set)



V_{cb} from $B \to D^* \ell^+ \nu$

Form factor

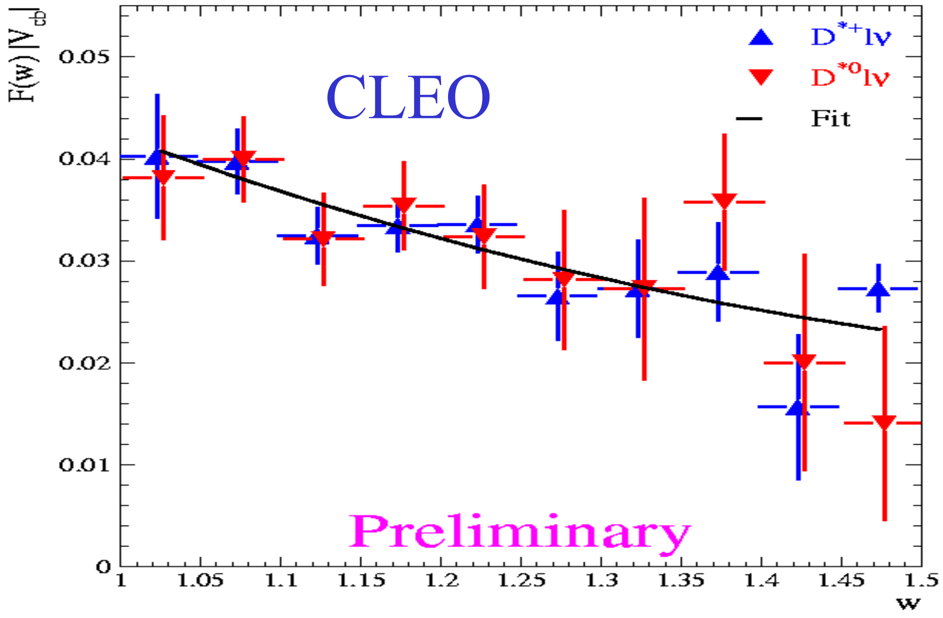
Phase space

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{48\pi^2} V_{cb}^2 F_{D*}(q^2)^2 G(q^2)$$

$$w = \frac{m_B^2 + m_{D*}^2 - q^2}{2 m_B m_{D*}}$$

$m_Q \to \infty,\ F_{D*}(q^2_{\max}) = 1$

Consistency at the 7% CL



↑ $q^2 = q^2_{\max}$ $q^2 = 0$ ↑

$$F(1)|V_{cb}| = (42.2 \pm 1.3 \pm 1.8) \times 10^{-3}$$

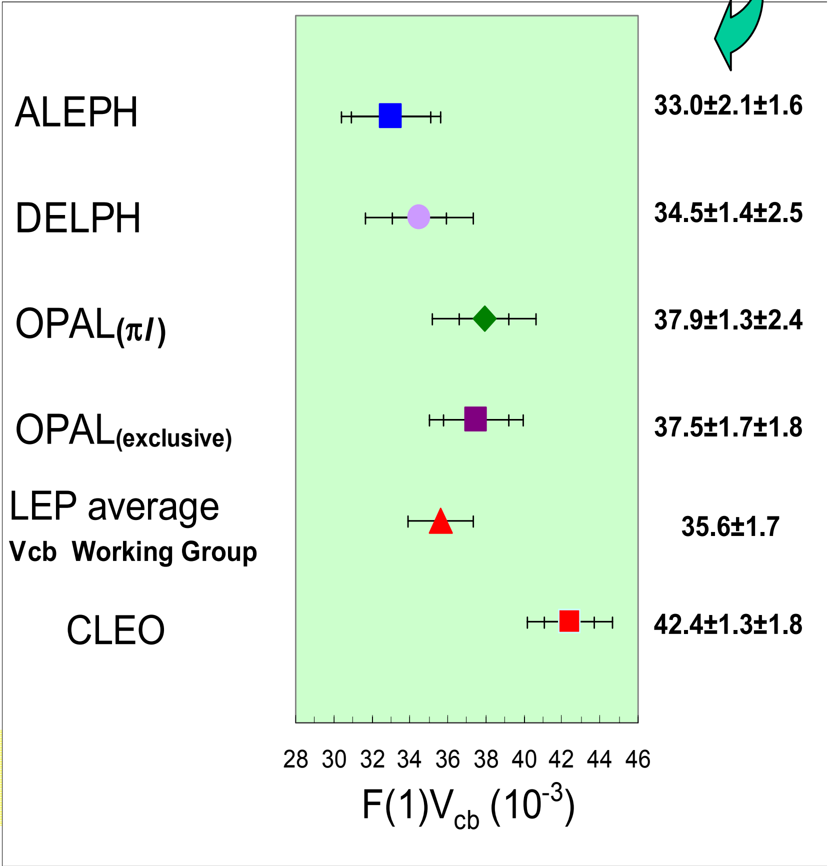
$(F_{D^*}(1) = 0.913 \pm 0.042)$ 3.1% 4.3%

theory

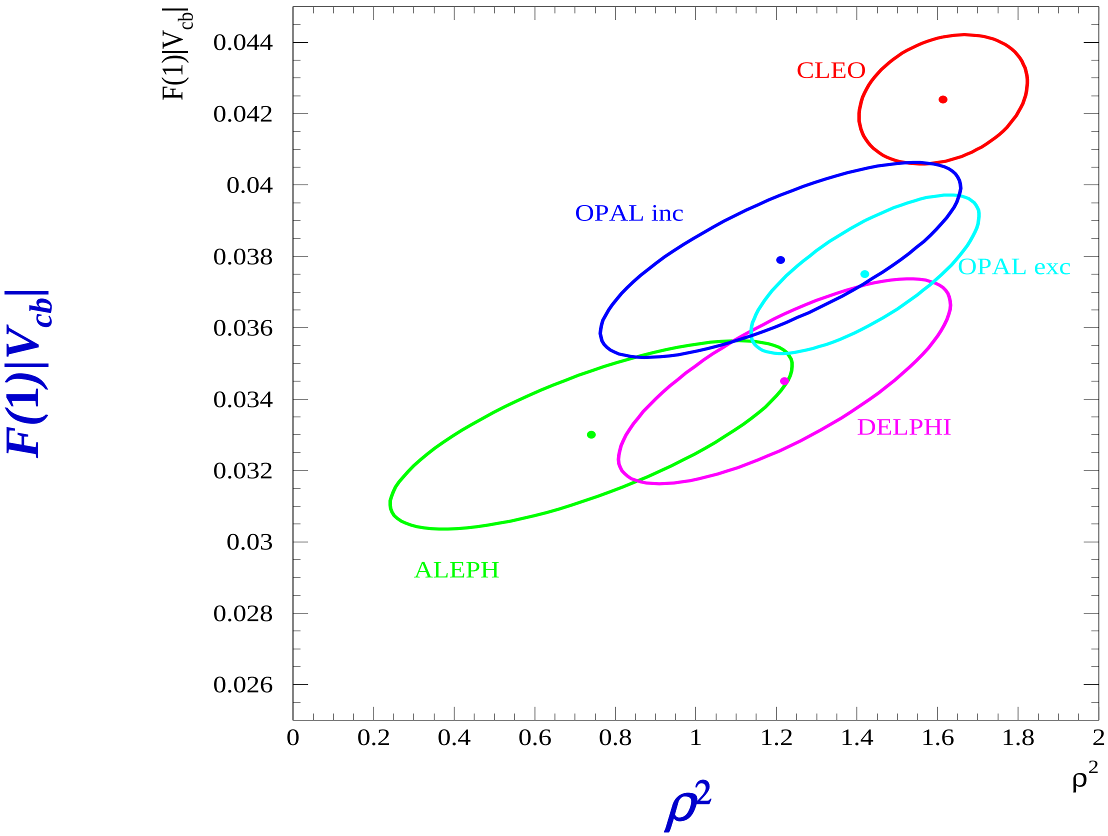
$$\boxed{|V_{cb}| = (46.4 \pm 1.4 \pm 2.0 \pm 2.1) \times 10^{-3}}$$

Dominant sys errors $\varepsilon_\pi$slow, form factors & B(D→Kπ)

Single most precise Vcb



V_{cb} from $B \rightarrow D^* \ell^+ \nu$



Possible sources of apparent difference between CLEO and LEP

$D^*X \ell^+\nu$ component
CLEO fits
LEP uses a model

Large slope vs. F(1)|Vcb| correlation at LEP

A Road-map for inclusive $|V_{cb}|$

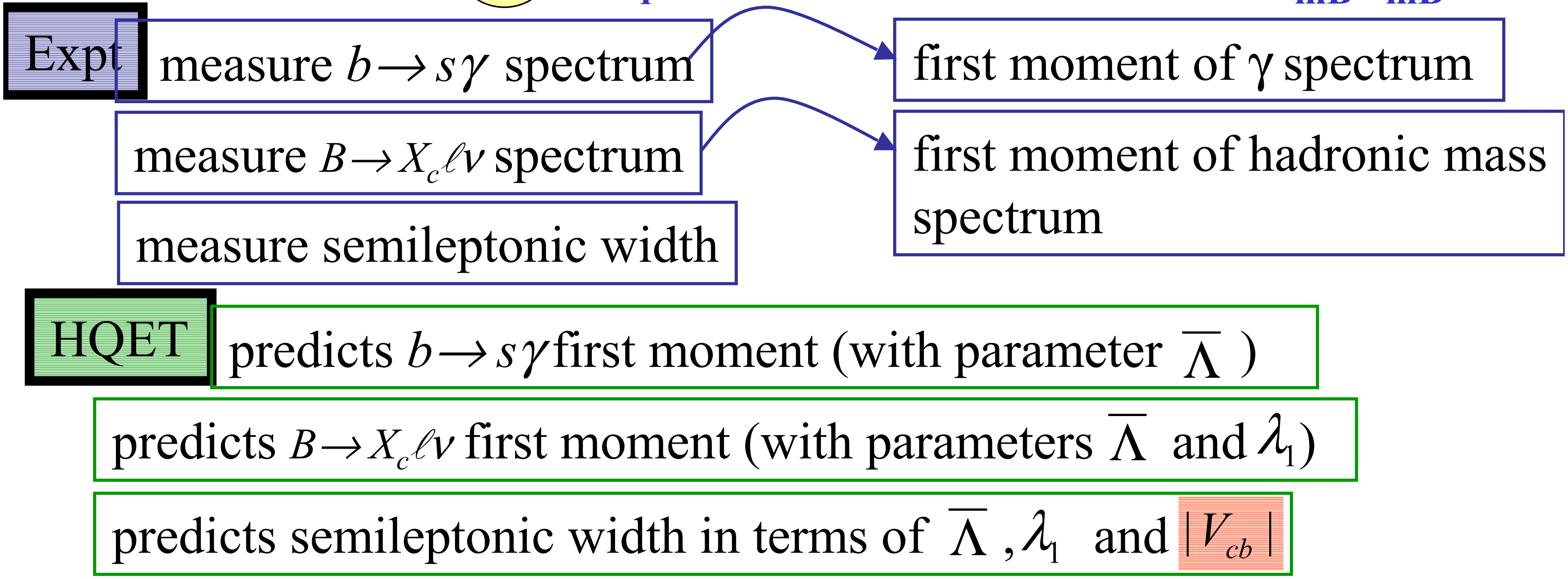
Spectator model (free quark decay) made rigorous by HQET+OPE a controlled expansion in α_s and $1/M_B$. Schematically:

$$\Gamma(B\to X_c\ell\nu)\propto\left|Vcb\right|^2\frac{G_F^2M_B^5}{192\pi^3}\left[1+\left(\frac{\bar{\Lambda},\bar{\Lambda}\alpha_s}{M_B}\right)+\left(\frac{f(\lambda_1,\lambda_2\bar{\Lambda}^2)}{M_B^2}\right)+O\left(\frac{1}{M_B^3}\right)\right]+rad\,cor.(\alpha_s,\alpha_s^2..)$$

$\bar{\Lambda}$ **relates mb to mB**

λ_1 **~average kinetic energy b quark in B meson**

$\lambda_2=0.12\,GeV^2$ **~hyperfine interaction mB*-mB**



Expt

measure $b\to s\gamma$ spectrum → first moment of γ spectrum

measure $B\to X_c\ell\nu$ spectrum → first moment of hadronic mass spectrum

measure semileptonic width

HQET

predicts $b\to s\gamma$ first moment (with parameter $\bar{\Lambda}$)

predicts $B\to X_c\ell\nu$ first moment (with parameters $\bar{\Lambda}$ and λ_1)

predicts semileptonic width in terms of $\bar{\Lambda}$, λ_1 and $|V_{cb}|$

(Falk, Ligeti, Luke, Wise, Savage, Manohar, Bauer, Bigi)

$B \to X_c \ell \nu$ Hadronic Mass Moments

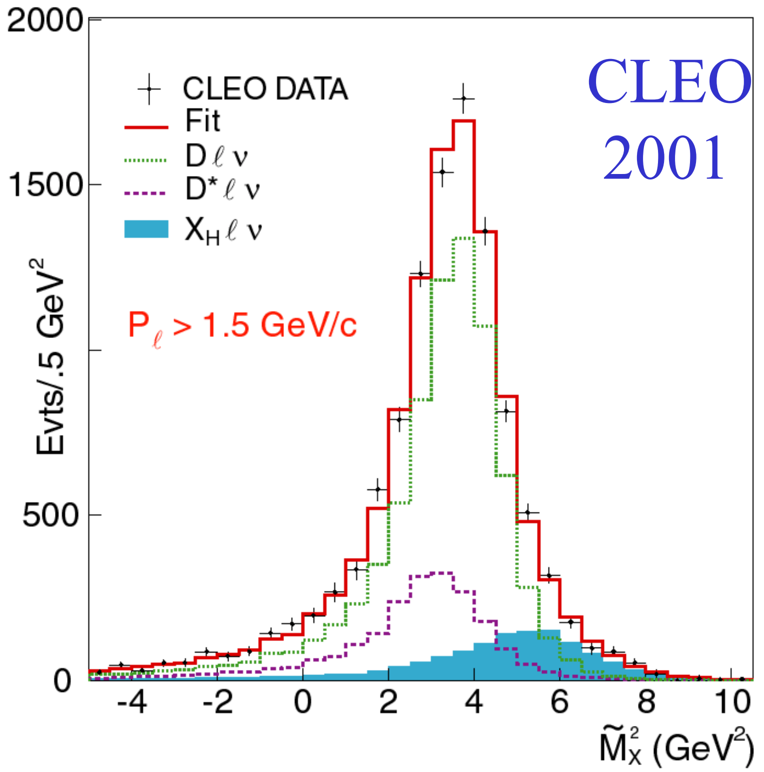
Want $B \to X_c \ell \nu$ hadronic mass distribution

- **Identify lepton (P>1.5 GeV)**
- **Measure neutrino as missing particle**
- **Calculate hadronic recoil mass**

$$M_X^2 = M_B^2 + M_{\ell\nu}^2 - 2(E_B E_{\ell\nu} - P_B P_{\ell\nu} \cos\theta_{B-\ell\nu})$$

- **Drop** $\cos\theta_{B-\ell\nu}$ **because** P_B **is small**

- **Then** $\tilde{M}_X^2 = M_B^2 + M_{\ell\nu}^2 - 2E_B E_{\ell\nu}$
- **Fit spectrum with**
  - $B \to D\ell\nu$
  - $B \to D^*\ell\nu$
  - $B \to X_H\ell\nu$ **(various models for** X_H**)**
- **Find moments of true** M_X^2 **spectrum**

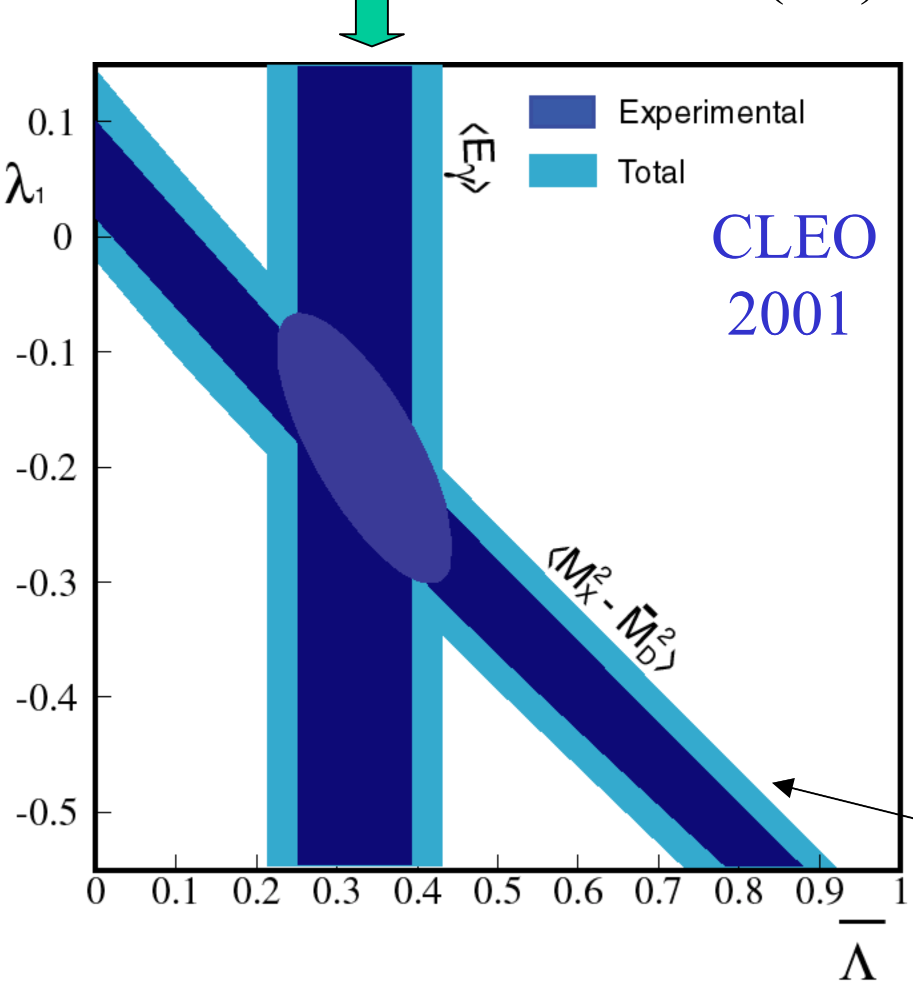


$$\boxed{\left\langle M_x^2 - \overline{M}_D^2 \right\rangle = 0.251 \pm 0.066\ GeV^2}$$

$\overline{M}_D$ is spin averaged D, D* mass

$\bar{\Lambda}$ and λ_1

b→sγ 1st moment f($\bar{\Lambda}$)



Preliminary

$$\bar{\Lambda} = 0.35 \pm 0.07 \pm 0.10 \text{ GeV}$$

$$\lambda_1 = -0.238 \pm \underset{\substack{\uparrow \\ \text{moments}}}{0.071} \pm \underset{\substack{\uparrow \\ 1/M_B^3}}{0.078} \text{ GeV}^2$$

B→Xlν 1st moment f(λ_1 $\bar{\Lambda}$)

CLEO 2001

Extraction of $|V_{cb}|$ hep-ex : 0108033

Measured Γ_{sl}

$$\mathcal{B}(B \to X_c \ell \nu) = (10.39 \pm 0.46)\% \text{ [CLEO]}$$

$$\tau_{B^\pm} = (1.548 \pm 0.032) \times 10^{-12} \text{ sec [PDG]}$$

$$\tau_{B^0} = (1.653 \pm 0.028) \times 10^{-12} \text{ sec [PDG]}$$

$$f_{+-}/f_{00} = 1.04 \pm 0.08 \text{ [CLEO]}$$

$$\Gamma_{s\ell} = (0.427 \pm 0.020) \times 10^{-10} \text{ MeV}$$

Combine with $\bar{\Lambda}$ and λ_1:

$$|V_{cb}| = (40.4 \pm 0.9 \pm 0.5 \pm 0.8) \times 10^{-3}$$

$$\uparrow \qquad \uparrow \qquad \uparrow$$

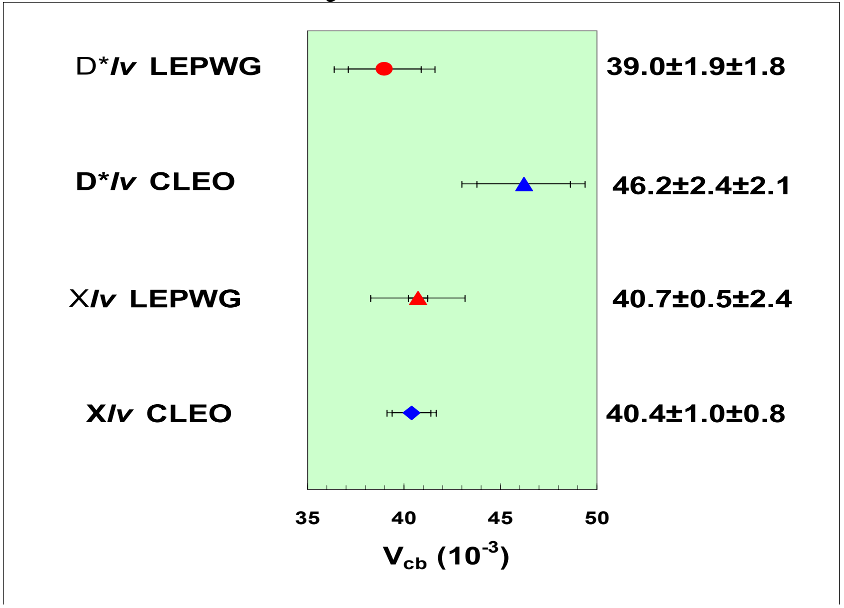
$$\Gamma_{s\ell} \qquad \bar{\Lambda}, \lambda_1 \qquad 1/M_B^3, \alpha_S$$

Preliminary

$$\boxed{|V_{cb}| = (40.4 \pm 1.3) \times 10^{-3}}$$ (3.2% error)

(smallest error yet! Submitted to PRL)

CLEO exclusive assumes duality.
Moments can validate inclusive method
Inclusive & exclusive both needed.
Agreement: confidence in Vcb determination



Determination of Vub

- the quark process b→ulν is simple
- Theoretically difficult to calculate strong interaction effects when a heavy B meson becomes a light ρ/π (no Heavy Quark symmetry)
- theoretical uncertainties enter twice, 1st the shape of the form factors determines the acceptance and hence Br
- 2nd , the absolute normalization is needed for Vub
- Severe background: b→clν~ x100 b→ulν lead to measurements in small regions of phase space
  large extrapolation to obtain Vub
- Two approaches: inclusive and exclusive

$$B(b \to ul\nu) = \frac{N_{sig}}{\varepsilon \bullet N_{BB}}$$

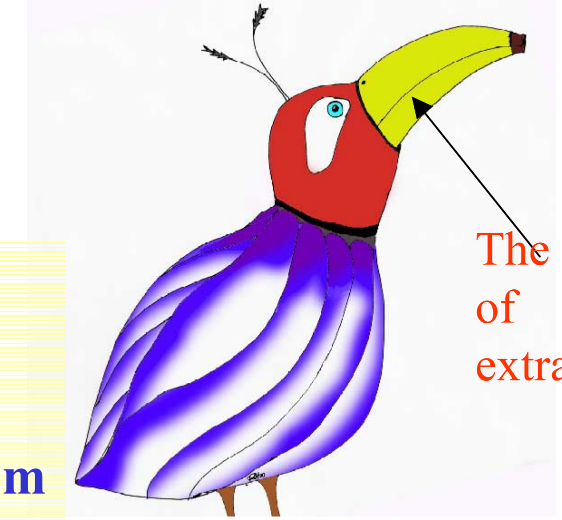
$$V_{ub} = \sqrt{\frac{B(b \to ul\nu)}{\tau_B \bullet \Gamma_{theory}}}$$

Inclusive methods:

To distinguish b→u from b→c theoretically:

q^2 spectrum $\overset{\text{better}}{>}$ m_{had} spectrum $\overset{\text{better}}{>}$ E_{lepton} spectrum

But experimental difficulty is in opposite order



The dangers of extrapolation

New Lepton endpoint
Inclusive Determination of Vub

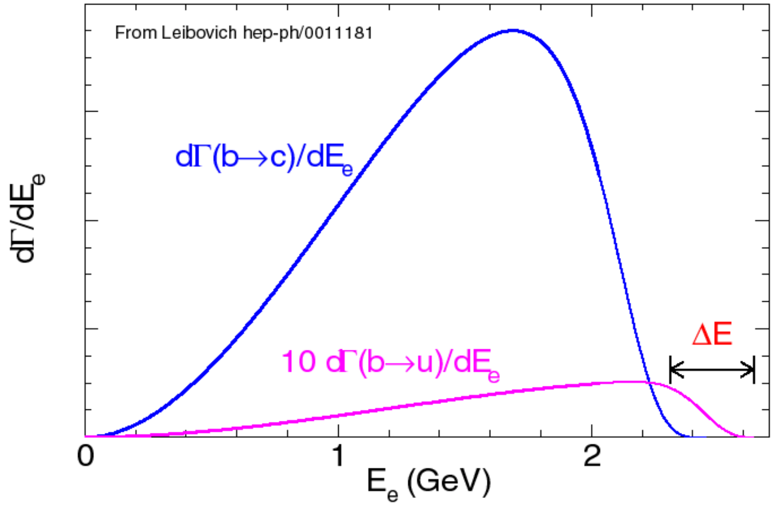
- 1% of lepton spectrum is $b \to u l \nu$
- →Go beyond kinematic limit for $b \to c l \nu$
- Experiment measures B_{ub}(end) :

$B(B \to X \ell \nu)$ in endpoint region

Challenges: Limited understanding of decay spectrum/form factors

Large extrapolation to get Vub

(5-20% $b \to u$ in endpoint) = f_u(end)

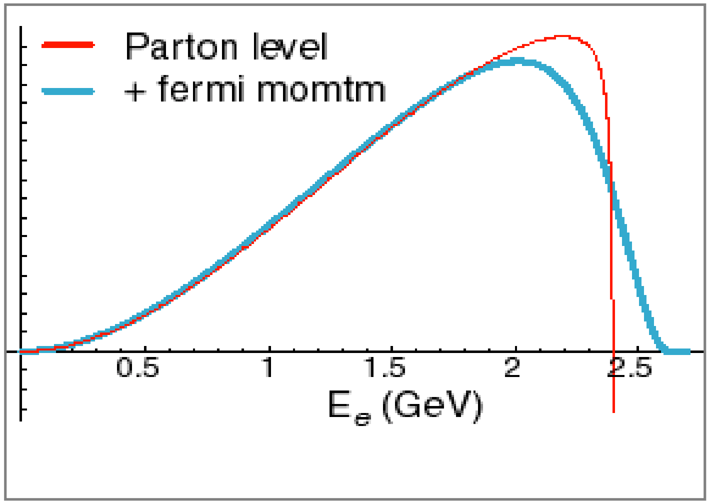

From Leibovich hep-ph/0011181

The endpoint is most influenced by the Fermi motion of the b quark in the B meson

Uncertainty can be reduced by using $b \to s \gamma$ shape parameters to determine f_u(end)

Same effects of b quark motion for "massless" Partons: $b \to s \gamma$ a laboratory for $b \to u l \nu$

$\Rightarrow f_u(\mathrm{end}) = 0.138 \pm 0.034$



New Lepton endpoint
Inclusive Determination of Vub

After continuum, & background suppression:

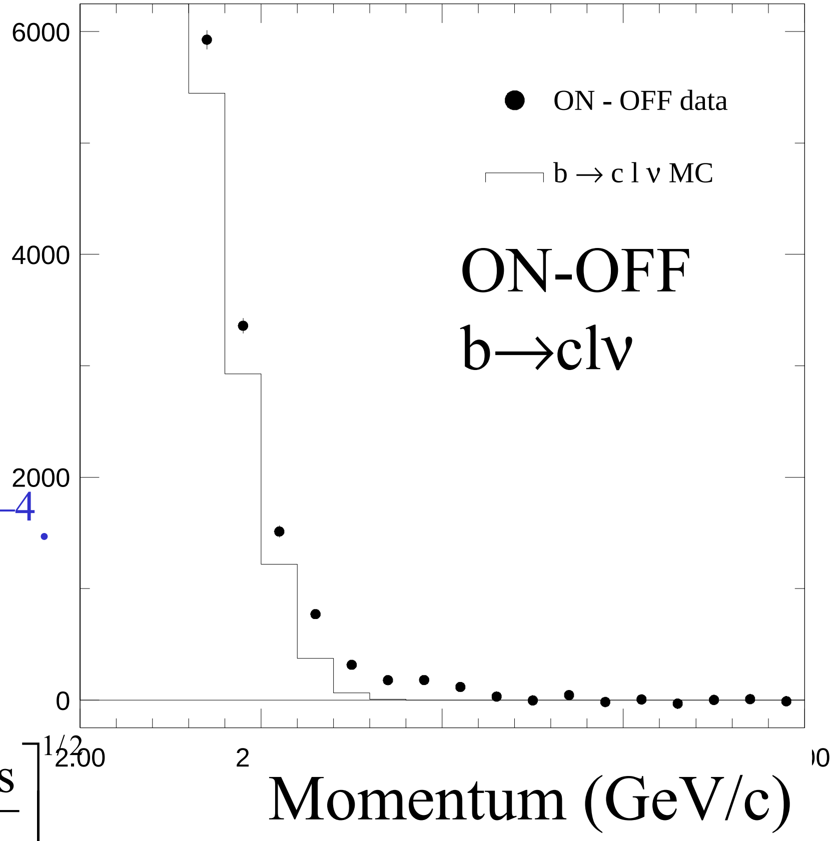
- ($2.2 < p_l \leq 2.6$ GeV/c),
- Nub *(end)* = 1874 ± 123 ± 326

Apply the f_u(end)

- B_{ub}*(end)* = $(2.35 \pm 0.15 \pm 0.45) \times 10^{-4}$.

QED radiative correction: 5%

Use:



$$|V_{ub}| = [(3.06\pm0.08\pm0.08)\times10^{-3}]\times\left[\frac{B_{ub}(\text{end})\,1.6\,\text{ps}}{0.001\tau_B}\right]^{1/2}$$

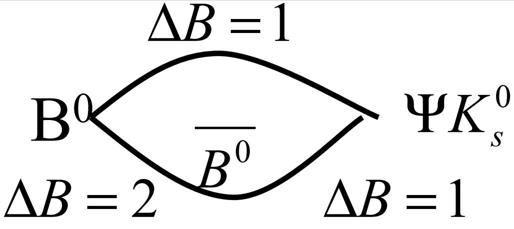
Hoang,Ligeti,Manohar, hep-ph/9811239

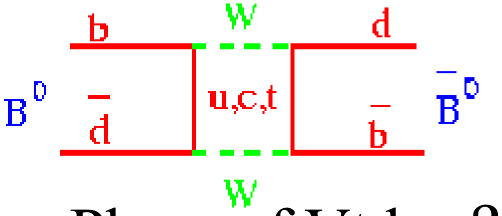
$|Vub| = (4.09 \pm 0.14 \pm 0.66) \times 10^{-3}$.

δ |Vub| / |Vub| =16%

The most precise inclusive determination to date

sin2β & Vub/Vcb





Phase of Vtd = β

From CLEO data Vub/Vcb is determined to 17%

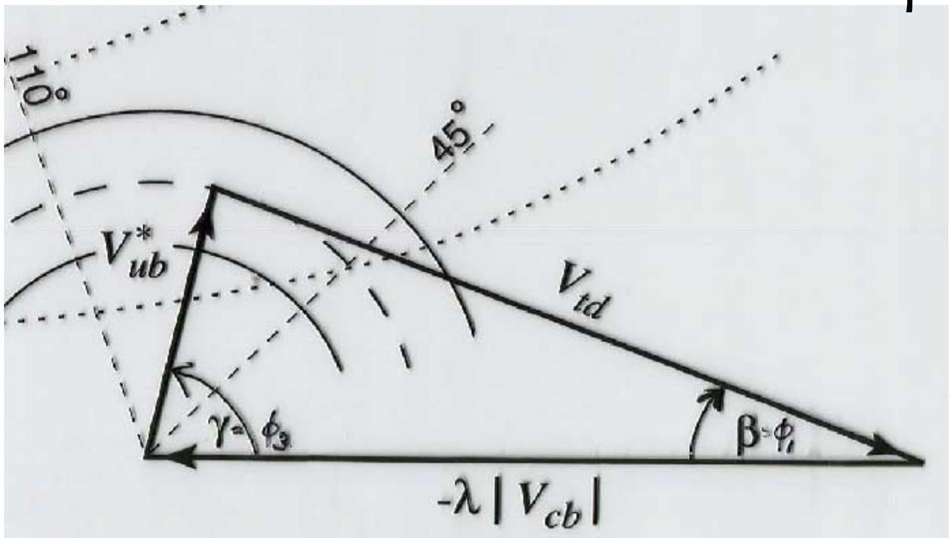
What are the implications ?

- **BABAR & Belle immediate objective: $(\sin2\beta)_{mixing}$**
- **Mixing :box diagrams new physics may enter: $(\sin2\beta+\Theta)_{mixing}$**
- **The goal compare $(\sin2\beta)_{mixing}$ to $\sin2\beta_{CKM}$ i.e β from Vub/Vcb**
- **β depends strongly on |Vub/Vcb| but weakly on γ for $45^0 < \gamma < 110^0$**

|Vub/Vcb|	0.101 ± 0.017
$\sin2\beta_{CKM}$	0.95 < @ 90% CL

- **Take $45^0 < \gamma < 110^0$**

$\sin2\beta_{CKM} = 0.74 \pm 0.09 \pm 0.08$



(1st error stat, 2nd error γ **range)**

sin2β & Vub/Vcb

$|V_{ub}/V_{cb}| = 0.101 \pm 0.017$

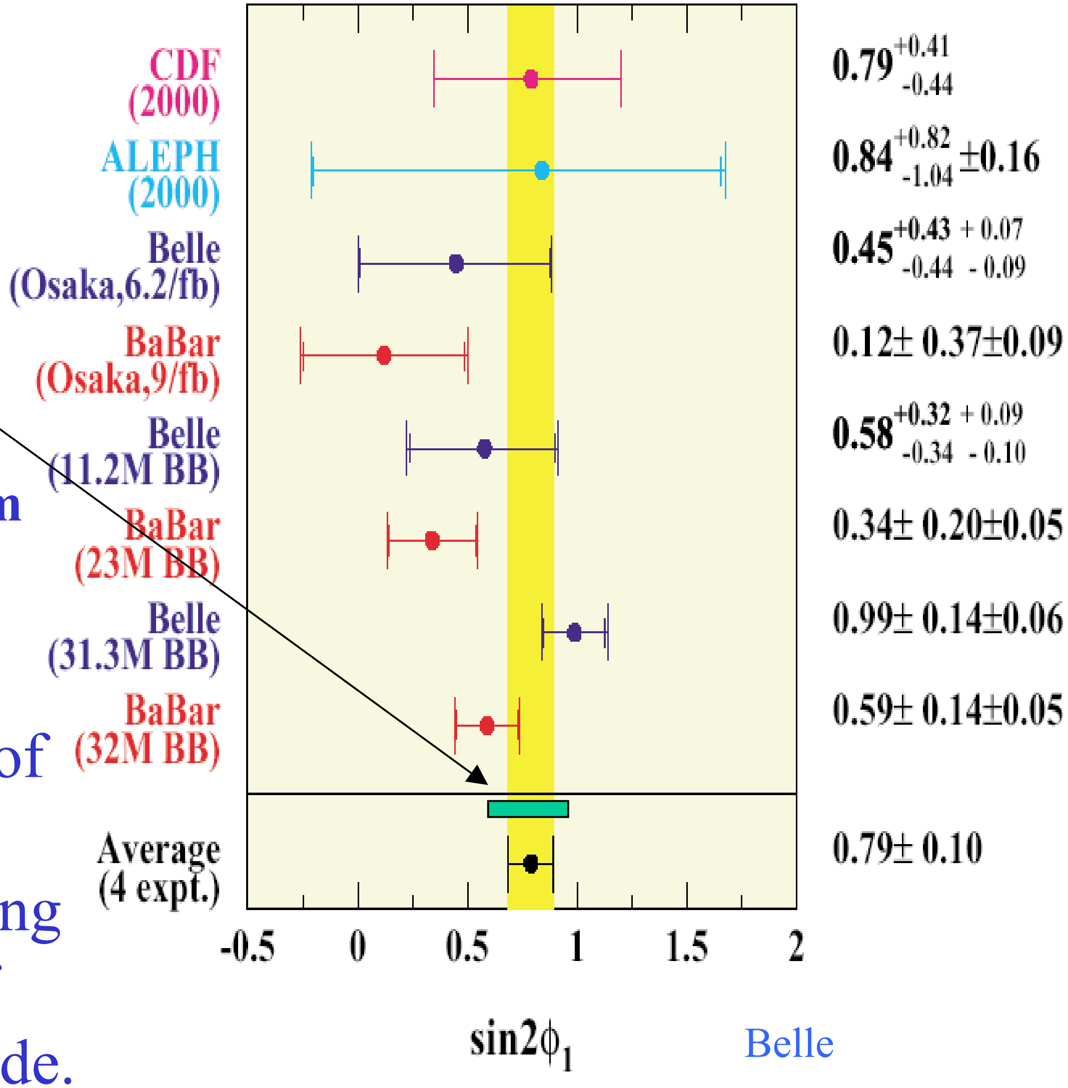
$\sin 2\beta_{CKM} = 0.74 \pm 0.09 \pm 0.08$

(Assumes $45^0 < \gamma < 110^0$)

This agrees well with **sin2β from BABAR and Belle:**

$(\sin 2\beta)_{mixing} = 0.79 \pm 0.10$

A significant consistency check of the CKM mechanism of CPV, This type of check, with increasing precision will be the hallmark of heavy flavor physics in this decade.



Belle Collaboration

B→ π/ρl υ
Vub Exclusive reconstruction

Since heavy → light HQET does not help

Theoretically difficult: evolution of form factor over large q2 range.

Neutrino reconstruction:

- $$\Delta E = E(\pi l\upsilon) - E_{beam} \approx 0$$

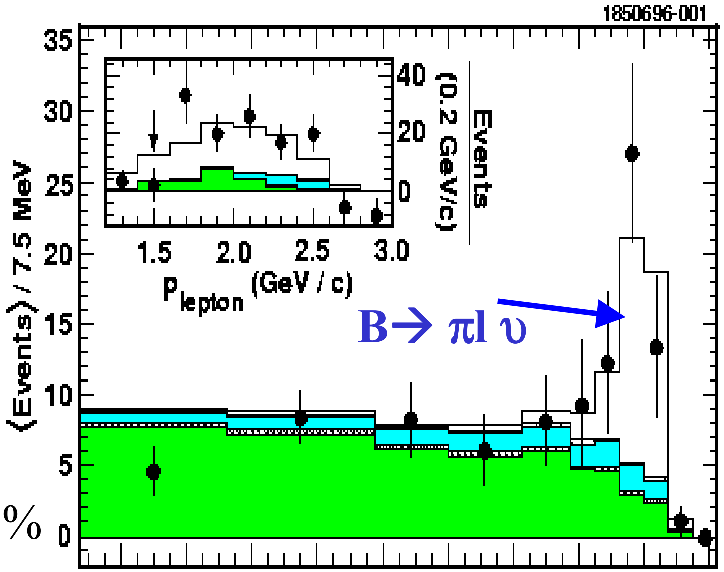
$$M(\pi l\upsilon) = \sqrt{E_{beam}^2 - \left|\vec{P}(\pi l\nu)\right|^2} \approx M_B$$

•* Model dependence dominates

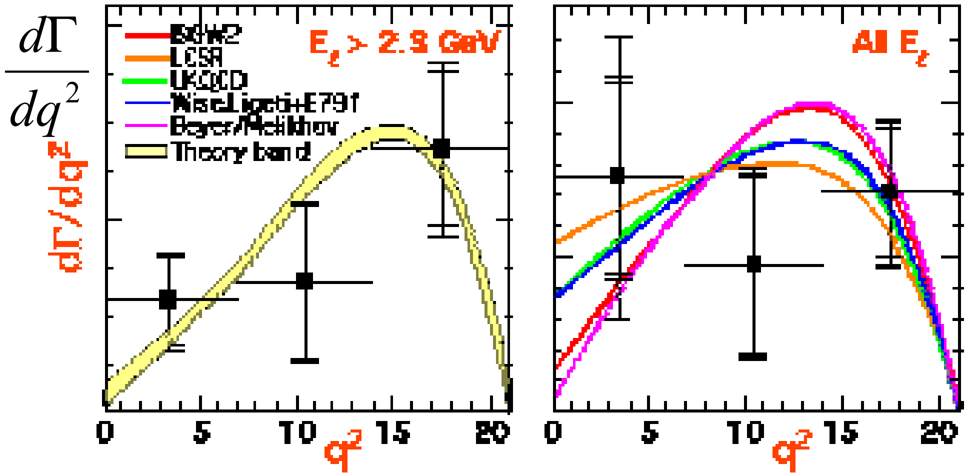
$$\frac{\delta V_{ub}}{V_{ub}} = 20\%$$

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

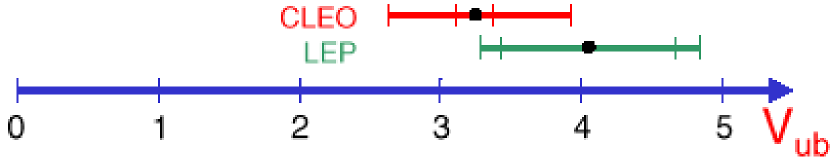
CLEO (B→ρlυ)



$$M(\pi l\upsilon)$$



$$\frac{d\Gamma}{dq^2}$$

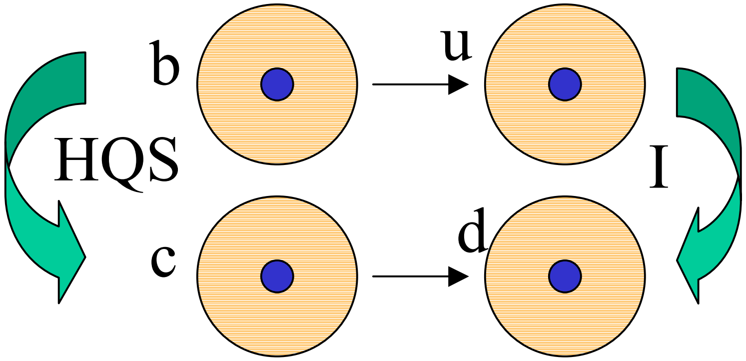


●**Sort between models:** **probe q^2 distribution no discriminating power at high lepton energy. New results soon**

B → π/ρl υ E_l> 1.0 GeV

Future of Vub

- **future of Vub:** ~100% phase space ~20% phase space
- **inclusive: reduce extrapolation error fit $m_x^2 < m_D^2$ or large q^2 region depends on size of accessible region 5% may be possible**
- **ultimate exclusive method:**



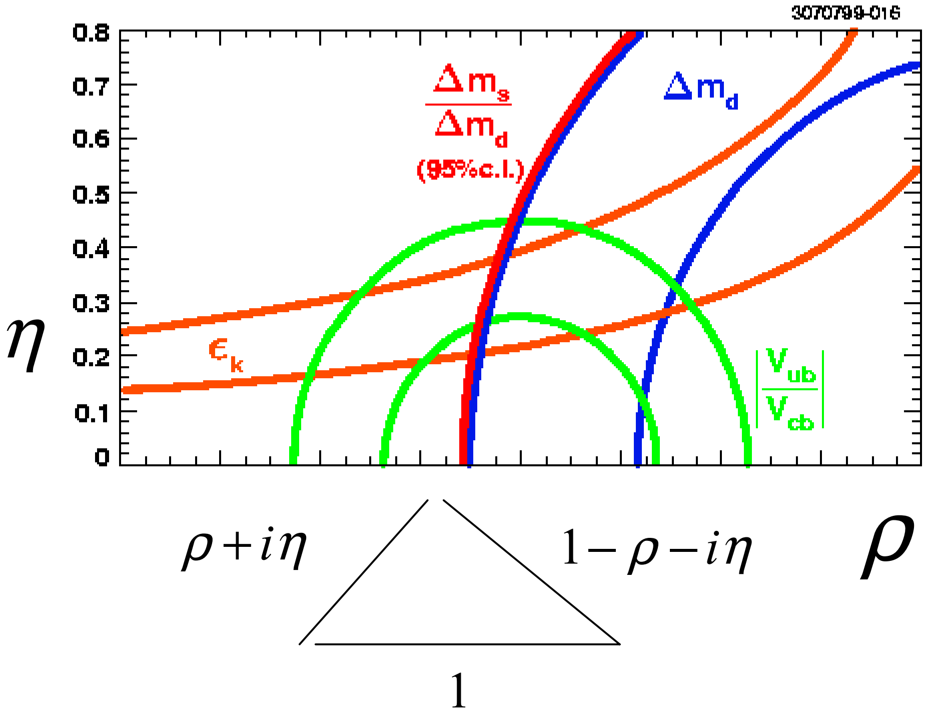
ℓ ν $$\frac{d\Gamma(B \to \pi\ell\nu)}{dE_\pi} \propto |V_{ub}|^2 (F_{B\to\pi}(E_\pi))^2$$

ℓ ν $$\frac{d\Gamma(D \to \pi\ell\nu)}{dE_\pi} \propto |V_{cd}|^2 (F_{D\to\pi}(E_\pi))^2$$

$(F_{B\to\pi}(E_\pi))^2$ Is related to $(F_{D\to\pi}(E_\pi))^2$ at the same E_π (corrections O(1/M))

Measure $(F_{D\to\pi}(E_\pi))^2$ in D→πlν, assume unitarity: calibrate lattice to 1%
Lattice error on $(F_{D\to\pi}(E_\pi))^2$ ~ 3% expected unquenched (Cornell/FNAL)
Extract Vub at BaBar/Belle using calibrated lattice calc. of $(F_{B\to\pi}(E_\pi))^2$
But: need absolute Br(D →πlν) and high quality $d\Gamma(D \to \pi\ell\nu)/dE_\pi$ neither exist

Vtd & Vts



$$\Delta M_d = 0.50\,ps^{-1}\left[\frac{\sqrt{B_{B_d}}\,f_{B_d}}{200MeV}\right]^2\left[\frac{|V_{td}|}{8.8\times10^{-3}}\right]^2$$

$$\frac{\sigma(\rho)}{\rho} = 0.5\,\frac{\sigma(\Delta M_d)}{\Delta M_d} \oplus \frac{\sigma(f_B\sqrt{B_{B_d}})}{f_B\sqrt{B_{B_d}}}$$

1.8%

~20%

$$\frac{\Delta M_d}{\Delta M_s} \propto \left[\frac{\sqrt{B_{B_d}}\,f_{B_d}}{\sqrt{B_{B_s}}\,f_{B_s}}\right]^2\left[\frac{|V_{td}|}{|V_{ts}|}\right]^2$$

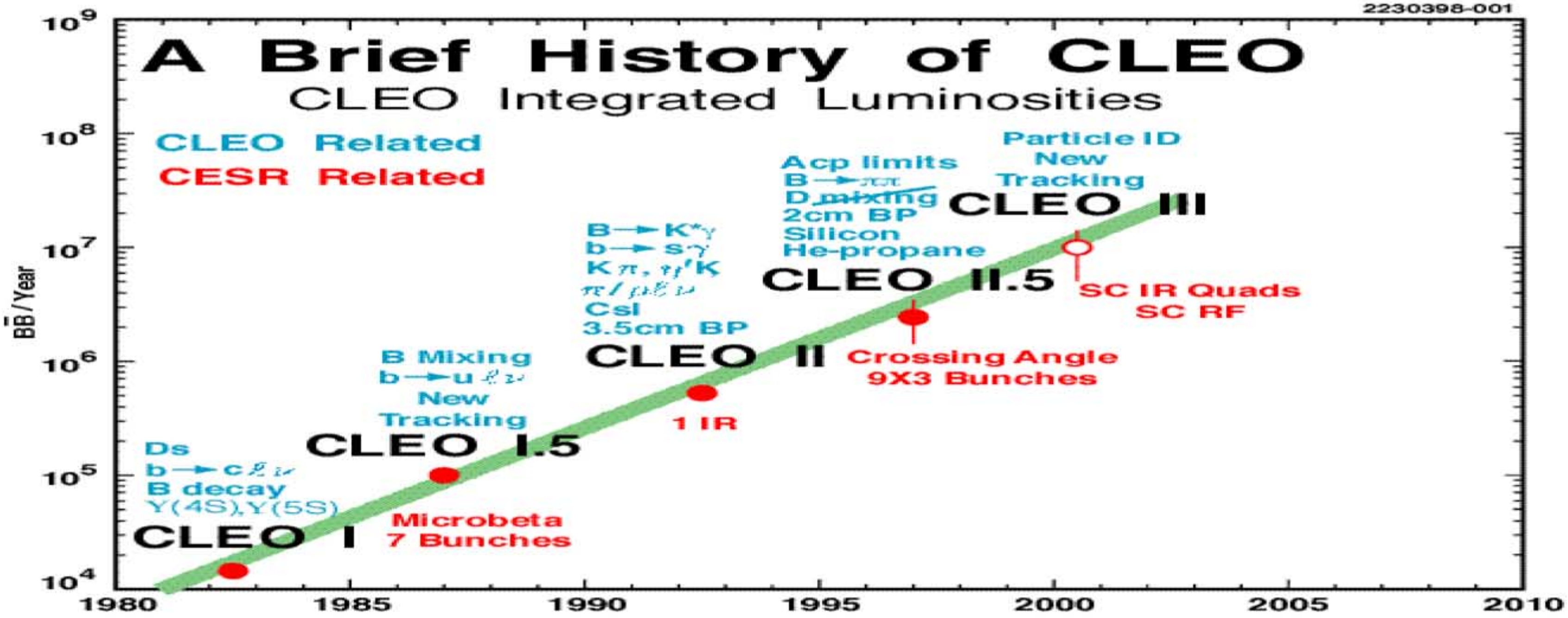
~5% (lattice)

Lattice predicts f_B/f_D & f_{Bs}/f_{Ds} with small errors
if precision measurements of f_D & f_{Ds} existed (they do not)
could substitute in above ratios to obtain precision estimates of
f_B & f_{Bs} and hence precision determinations of Vtd and Vts
Similarly f_D/f_{Ds} checks f_B/f_{Bs}

Summary of Results

- >60 rare B decays observed by CLEO. Branching ratios in good agreement with theory. No CPV observed. In almost all cases BABAR/Belle confirm CLEO results, & in some cases extend them. This trend will accelerate
- New Vcb from B→D*lν (to <5%) $|V_{cb}| = (46.4 \pm 1.4 \pm 2.0 \pm 2.1) \times 10^{-3}$
- New Vcb from moments analysis of b→sγ & B→Xlν (to <5%)
  $$|V_{cb}| = (40.4 \pm 1.3) \times 10^{-3}$$
- New Vub from endpoint of lepton spectrum, where faction of rate in endpoint given by analysis of b→sγ spectrum.
  $$|Vub| = (4.09 \pm 0.14 \pm 0.66) \times 10^{-3}.$$
- Provides a useful constraint on sin 2β. This is the beginning of the era of precision cross checks of the b sector of the CKM matrix. To make this cross check much more precise theory needs measurements of absolute charm semileptonic branching ratios and form factors
- Vtd & Vts extraction: lattice needs precision measurements of charm meson decay constants

CESR/CLEO 1980-2001



Very(!) productive experimental program

Exciting physics

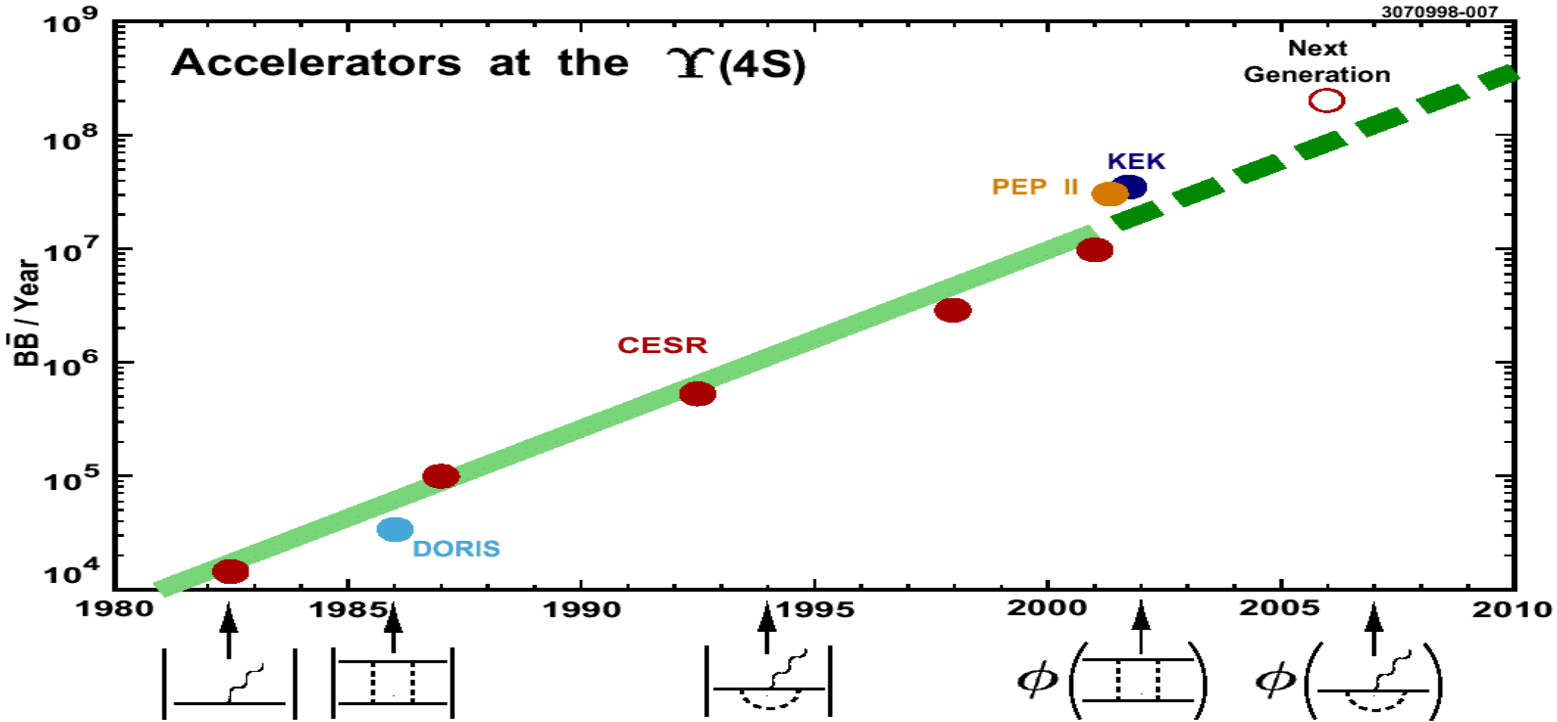
Summer ‘01: new V_{cb}, V_{ub}, $b \rightarrow s\gamma$, D*width, ππ, Kπ

20 abstracts at EPS & LEPPHO

But……..

Thread # 1

PEPII/KEK-B 1999



PEPII & KEKB are recording larger $\int Ldt$ than CESR and much larger $\int Ldt$ expected soon

CLEO cannot remain competitive

CLEO/CESR stopped running at the Y(4S) on June 25, 2001………forever! Whither the CESR/CLEO Program?

Threads #2 & #3

#2 Progress in flavor physics is limited by the absence of sufficient charm data to calibrate theory needed to extract Vub, Vtd & Vts

#3 Non perturbative QFT's are an outstanding challenge to theoretical physics

- LHC may uncover strongly coupled sectors in the physics that lies beyond the Standard Model
- Critical need for reliable theoretical techniques & detailed data to calibrate them
- Modify CESR for operation as a charm/QCD factory: CESR-c/CLEO-c
- Two part program:

I Weak Interaction physics
II Tests of non-perturbative QCD

I & II inextricably linked

CLEO-c Physics Program

- Progress in flavor physics limited by understanding of QCD.
- CLEO-c: precise absolute br, form factors, decay constants. Confront theory in c sector apply theory in b sector(Vtd Vts)

- Probe essential nature of weak decays
- CLEO-c: direct: precision Vcs,Vcd, indirectly Vub,Vcb

- Physics beyond the Standard Model may have non-perturbative sectors.
- CLEO-c: precise measurements of quarkonia spectroscopy & decay.

- Physics beyond the Standard Model may appear in unexpected places
- CLEO-c: D-mixing, charm CPV, rare decays of charm and tau.

CLEO Run Plan

2002: Prologue: Upsilons ~1-2 fb^{-1} each at Y(1S),Y(2S),Y(3S),…
Spectroscopy, matrix element, $\Gamma_{ee,}$ η_B h_b
10-20 times the existing world's data

2003: $\psi(3770)$ – 3 fb^{-1}
30 million events, 6 million *tagged* D decays
(310 times MARK III)

2004: $\sqrt{S} \sim 4100 MeV$ – 3 fb^{-1}
1.5 million D_sD_s events, 0.3 million *tagged* D_s decays
(480 times MARK III, 130 times BES)

2005: $\psi(3100)$, 1 fb^{-1} $\psi(3686)$
–1 Billion J/ψ decays
(170 times MARK III, 20 times BES II)

CLEO-c

A 3 year program

The CLEO III Detector

1.5 T now,... 1.0T later

93% of 4π
$\sigma_p/p = 0.35\%$
@1GeV
dE/dx: 5.7% π @minI

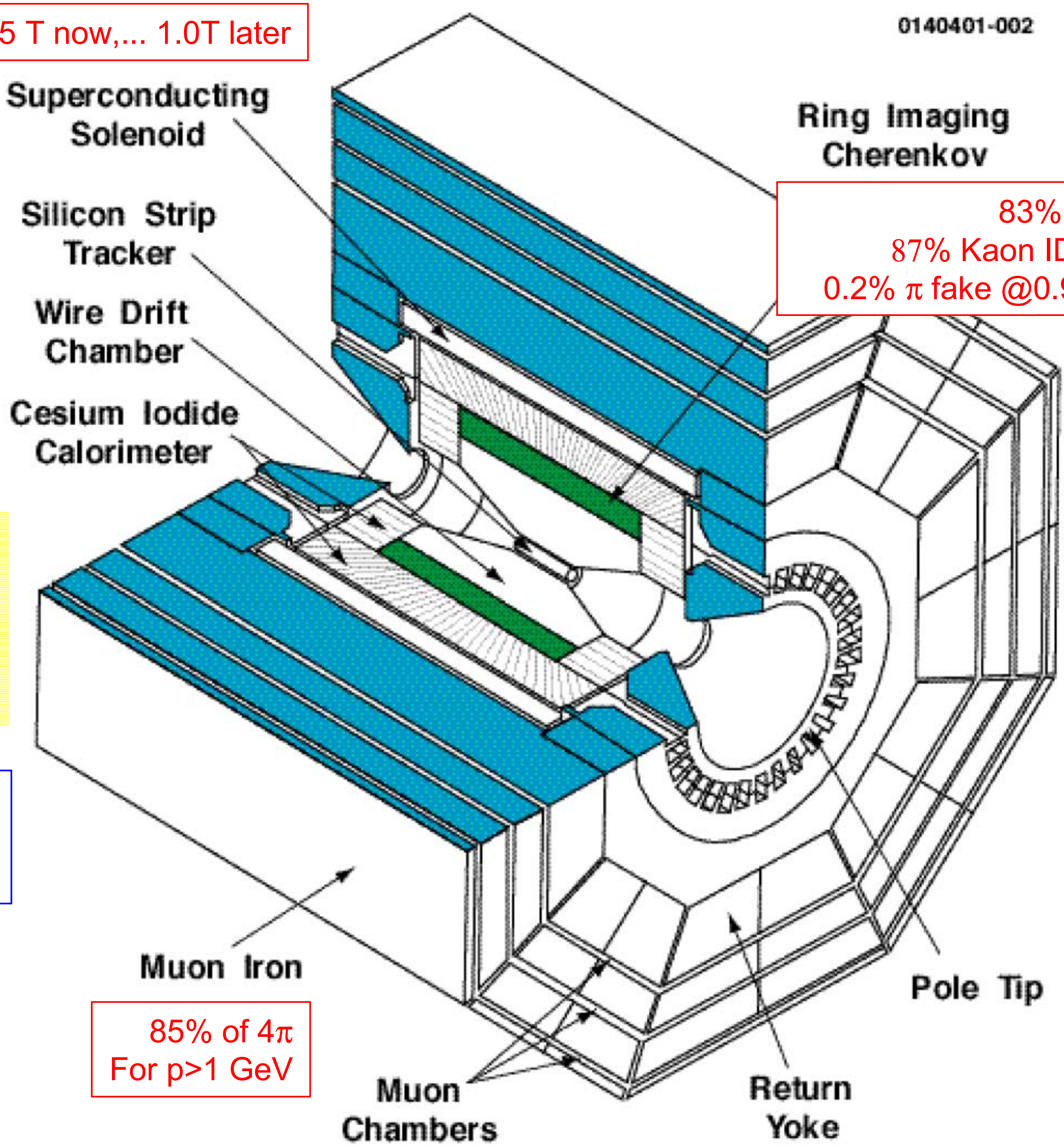
93% of 4π
$\sigma_E/E = 2\%$ @1GeV
= 4% @100MeV

83% of 4π
87% Kaon ID with
0.2% π fake @0.9GeV

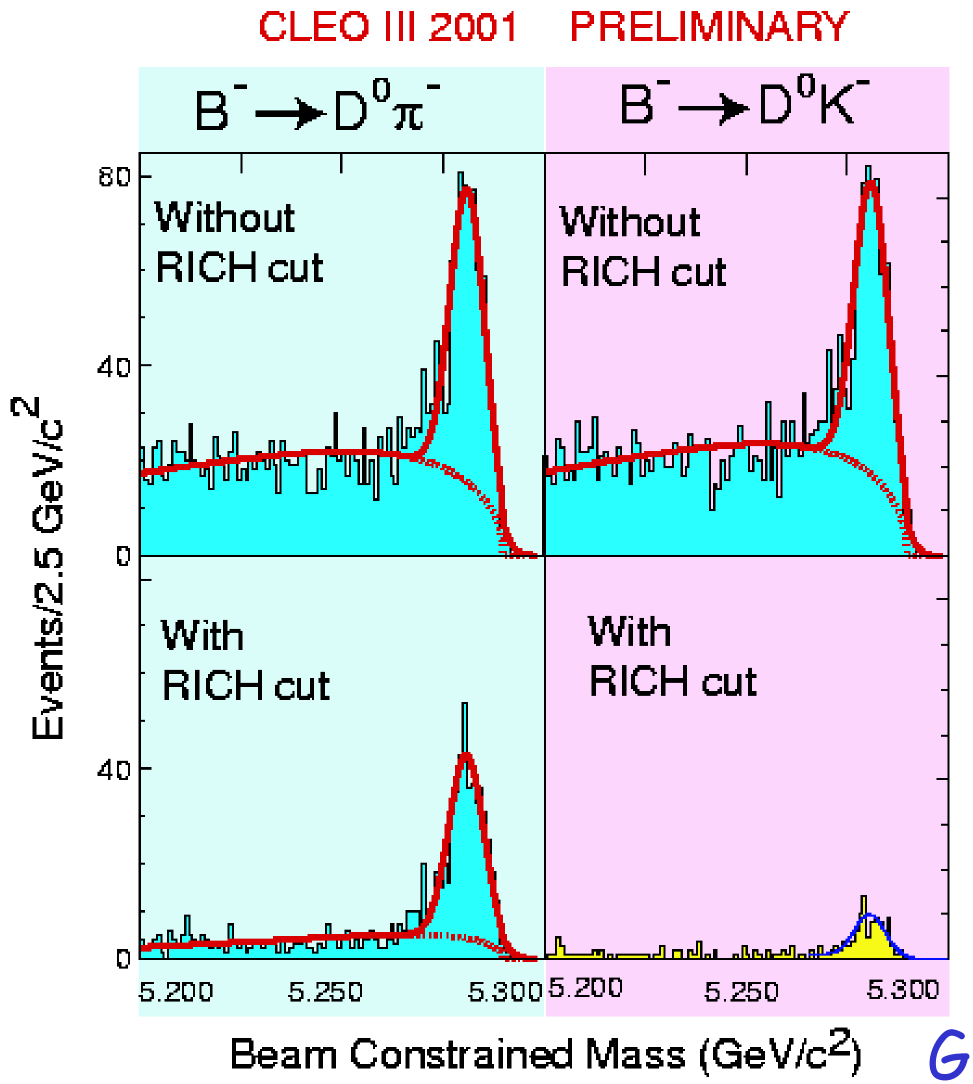
Trigger: Tracks & Showers
Pipelined
Latency = 2.5μs

Data Acquisition:
Event size = 25kB
Thruput < 6MB/s

85% of 4π
For p>1 GeV



1st results from CLEO III data
LEPPHO 2001



Preliminary result using ~1/2 of the CLEO III data

Clean K/ π separation at ~2.5 GeV using RICH

Rest of reconstruction technique similar to previous CLEO analyses

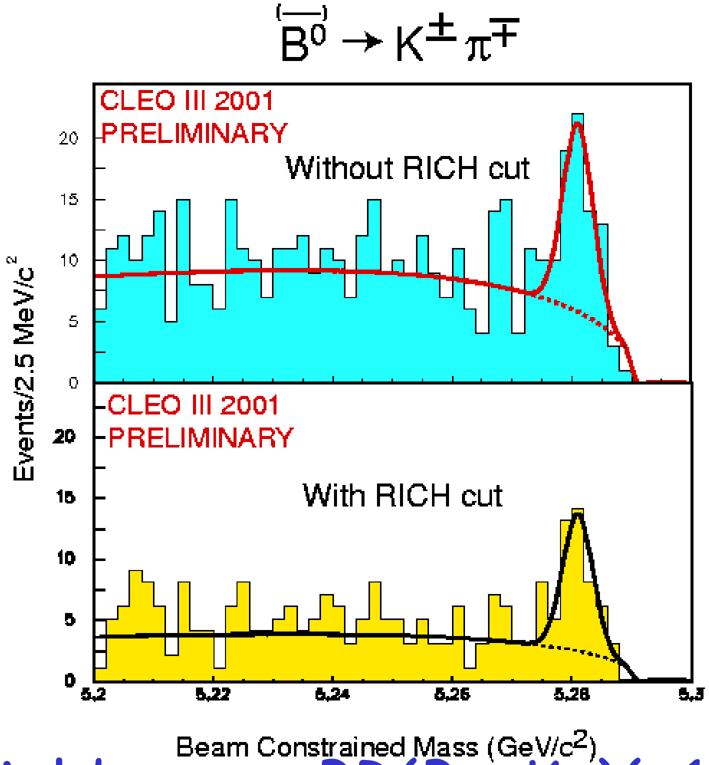
$B(B^- \rightarrow D^0K^-) =$

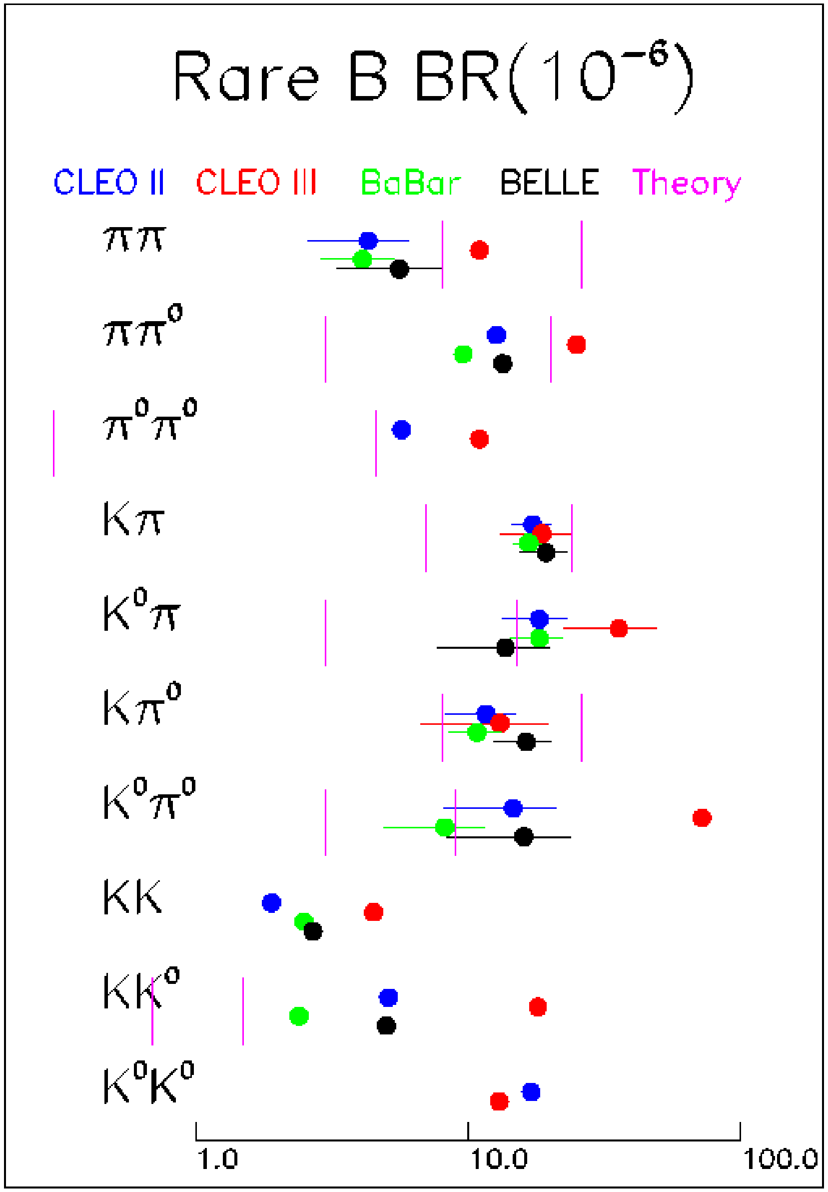
(3.8 ±1.3) x10^{-4} CLEOIII

(2.9 ± 0.8) x10^{-4} CLEO II

Good agreement: CLEOIII:II

1st results from CLEO III data
LEPPHO 2001





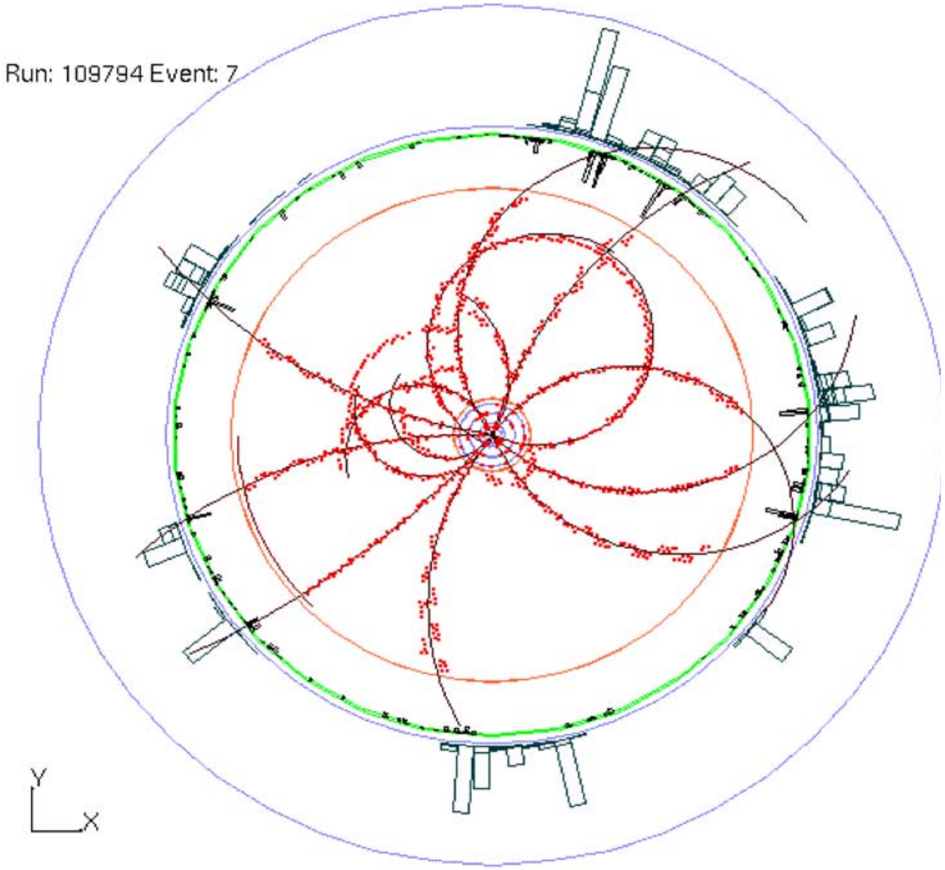
Yield	BR(B→Kπ)($\times10^{-6}$)	
B→Kπ	CLEOIII	CLEO(1999)
$29.2^{+7.1}_{-6.4}$	$18.6^{+4.5+3.0}_{-4.1-3.4}$	$18.8^{+2.8}_{-2.6} \pm 1.3$
	(Preliminary)	

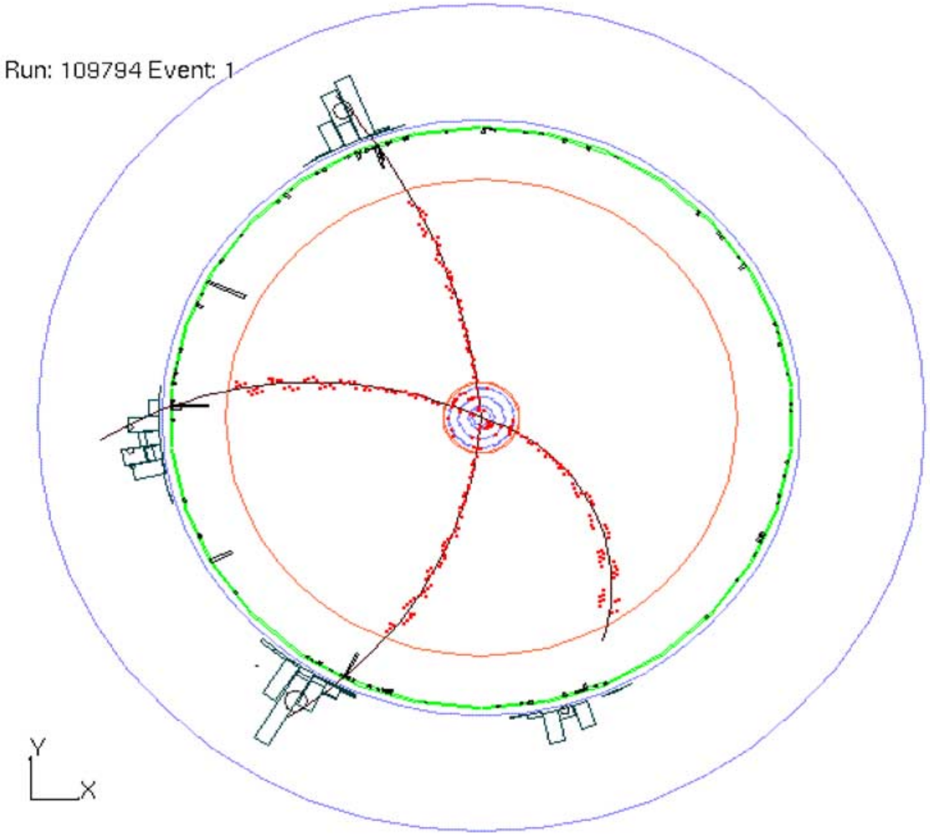
Good agreement: CLEOIII:II/II.V

ψ(3770) events: simpler than Υ(4S) events

A typical Υ(4S) event:

A typical ψ(3770) event:





Detector Summary

- CLEO III was built for
  - excellent tracking resolution
  - excellent photon resolution
  - maximum hermeticity
  - excellent particle identification
  - flexible triggering
  - high throughput DAQ
- The demands of doing physics in the 3-5 GeV range are easily met by the existing detector.

- The CLEO Collaboration has a history of diverse interests spread over b physics, charm, tau, resonance and QCD studies & great enthusiasm for CLEO-c

Modifications and Issues

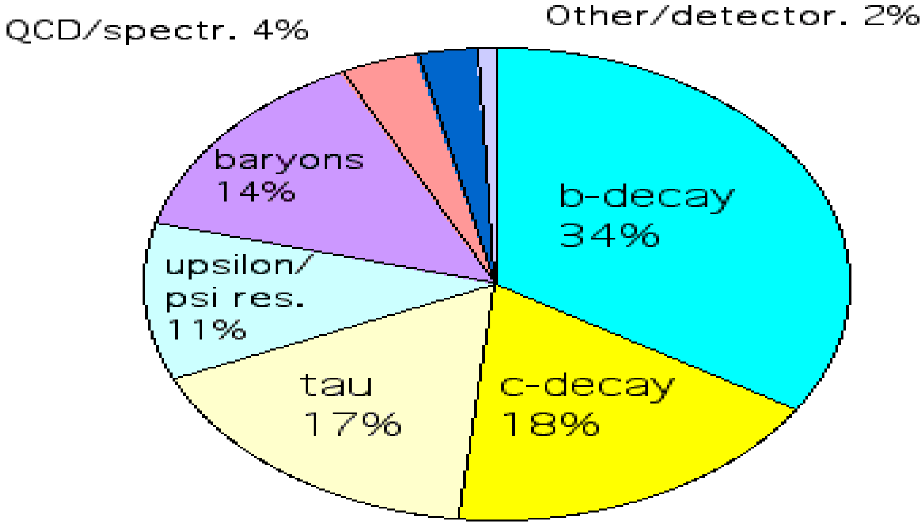
- The CLEO-III Detector
  - Silicon vertex detector may be replaced with wire vertex chamber
  - Lower solenoid field strength to 1 T from 1.5 T (machine issues)
  - The dE/dx and Ring Imaging Cerenkov counters are expected to work well over the CLEO-c momentum range
  - Electromagnetic calorimeter works well and has fewer photons to deal with
  - Triggers will work as before
  - Minor upgrades may be required of Data Acquisition system to handle peak data transfer rates

CLEO-III works well in this energy range and at these rates with little modification

- CESR conversion to CESR-c will be discussed in summary talk of working group M2 (next speaker)

The CLEO Collaboration

- Membership:
  - ~20 Institutions
  - ~155 physicists
  - Currently expanding in response to CLEO-c proposal
- Publication history 1980-
  - ~320 papers
  - diverse physics:



Albany
Caltech
CMU
Cornell
Florida
Harvard
Illinois
Kansas
Minnesota
Ohio State
Oklahoma
Pittsburgh
Purdue
Rochester
SMU
UCSD
Syracuse
Vanderbilt
Wayne State

CESR-C

- Luminosity governed by:

$$L \propto (1+r)\frac{\xi}{\beta^*}\gamma N \qquad \xi \propto \frac{N}{\gamma}\frac{1}{A^*}$$

A^* Cross section at collision point
N = Number of particles
γ = Lorentz factor
r = vert/horiz beam size
ξ = beam beam parameter
β^*= external focussing

- Without artificial radiation aids, $L \sim E_b^4$
  - Long damping times --> wigglers to decrease τ
  - Decrease β^* $\longrightarrow$ $L \sim E_b^{\ 2}$
  - Wigglers being prototyped
  - 2T over 5cm (SC)
  - Cost ~ 5M$

$L = 1.3 \times 10^{33}$ @Y(4S)

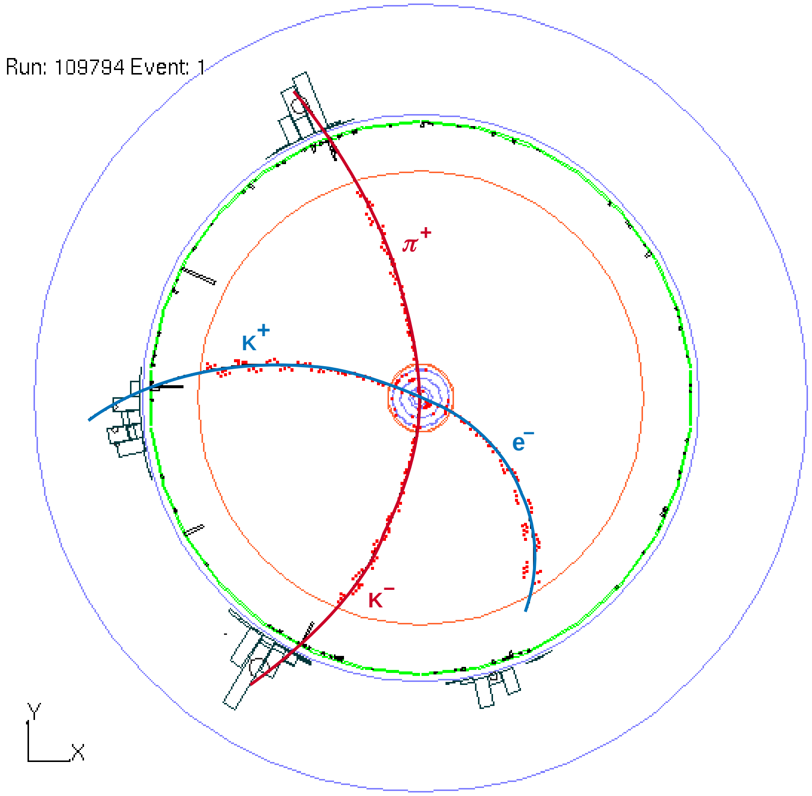
Expected machine performance

$\sqrt{s}$	$L\ (10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1})$
4.1 GeV	3.6
3.77 GeV	3.0
3.1 GeV	2.0

- ΔE_{beam} ~ 1.2 MeV at J/ψ

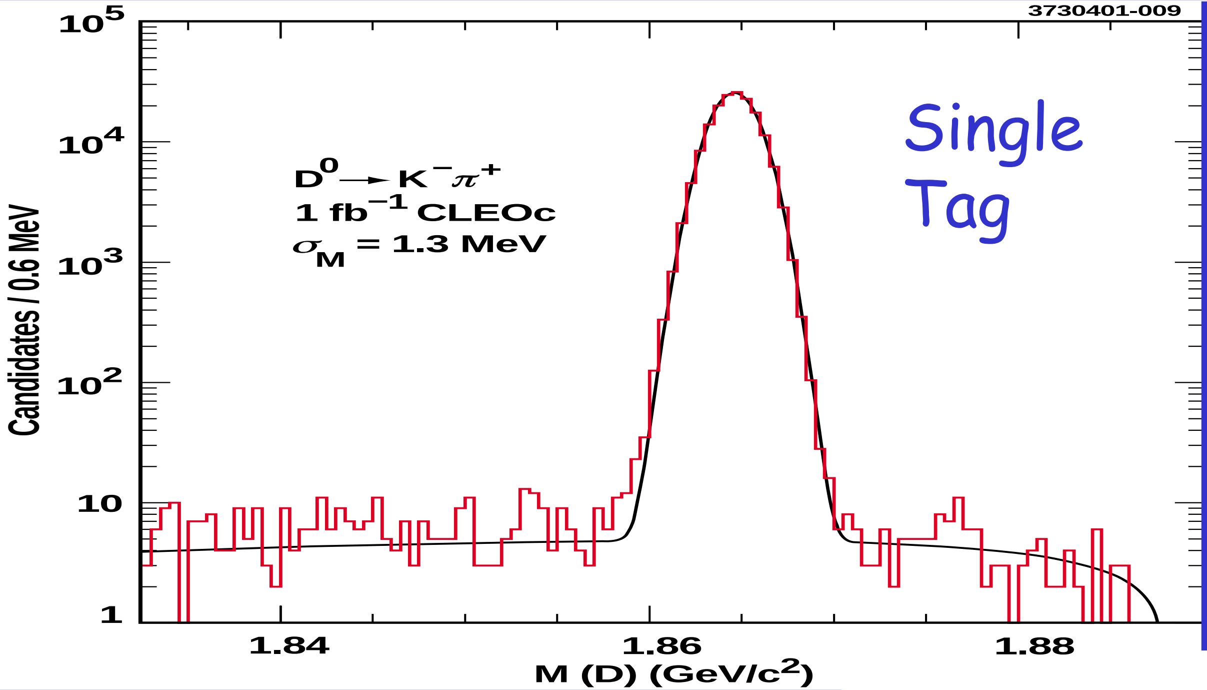
Advantages of Running on Threshold Resonances

- Charm events produced at threshold are extremely clean
- Double tag events are pristine
  - These events are key to making absolute branching fraction measurements
- Signal/Background is optimum at threshold
- Neutrino reconstruction is clean
- Quantum coherence aids D mixing and CP violation studies



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

Tagging Techniques, Signal Purity



Single Tag

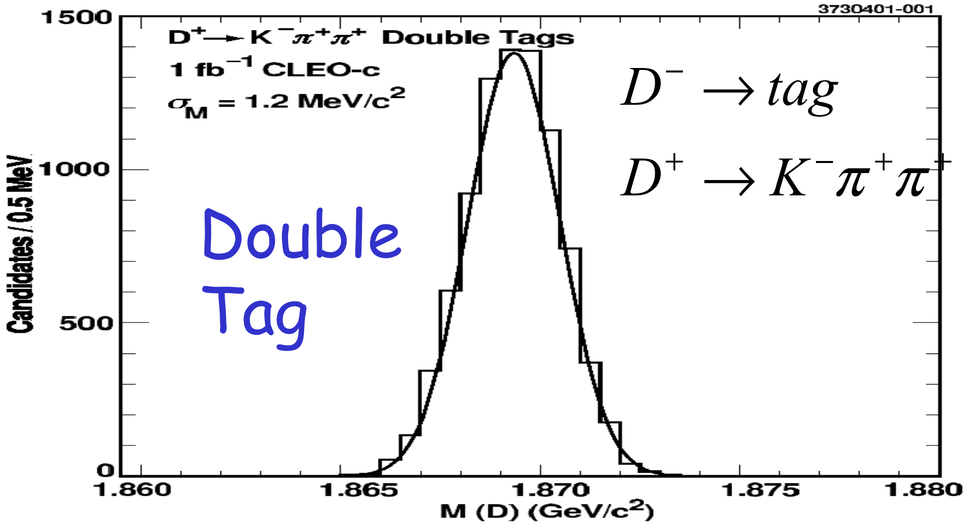
D mesons have many large Br's (~1-15%) with high reconstruction eff. Tagging efficiency based on several modes is 20%. S/B = 5000/1!

~ Zero background in hadronic tag modes

*Measure Br (D→ X) by

Br = # of X/# of D tags

# of D's is well determined

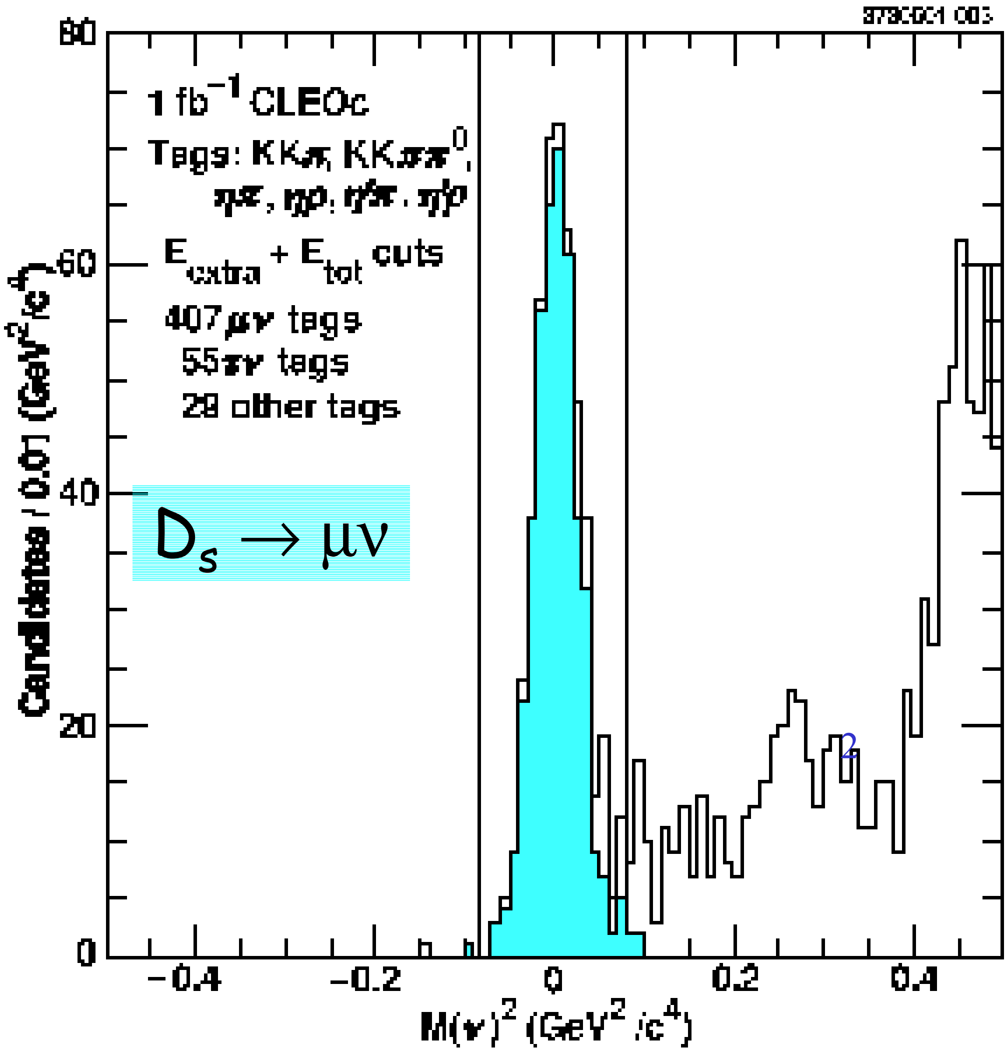


Double Tag

$D^- \to tag$

$D^+ \to K^-\pi^+\pi^+$

Example: $D_s^+ \to \mu^+\nu$



- Fully reconstruct one D
- Require one additional charged track and no additional photons
- Compute MM² Peaks at zero for $D_s^+ \to \mu^+\nu$ decay.
  - No need to identify muon-helps systematic error
  - Can identify electrons to check background level
  - Expect resolution of ~M_{π^0}

$$\frac{\delta f_{Ds}}{f_{Ds}} \approx 1.7\%$$

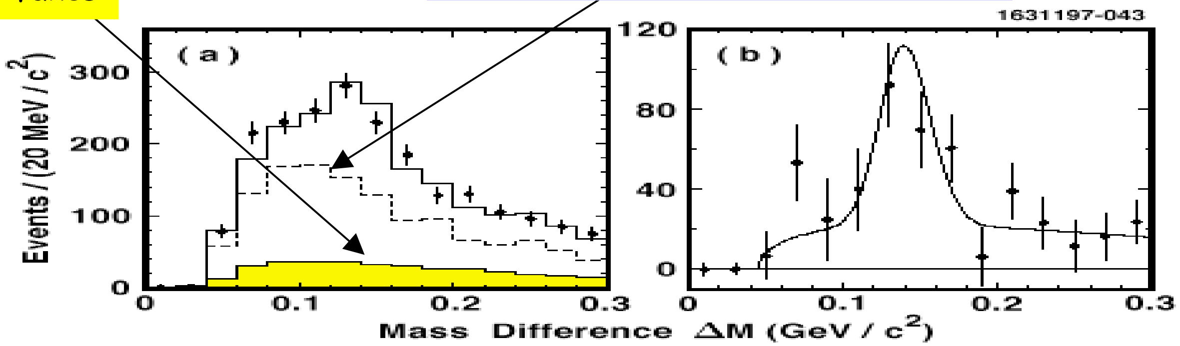
(Now: ±35%)

B Factories can do this too

Scale from CLEO analysis

- –Search for D_s* -> D_s γ, D_s -> μν
  - –Directly detect γ, μ, Use hermeticity of detector to reconstruct ν
  - –Backgrounds are LARGE!
- •Precision limited by systematics of background determination
  - –Error ~25% now
  - –400 fb-1 ~8-15%

CLEO signal 4.8fb^{-1}



Excess of μ over e fakes

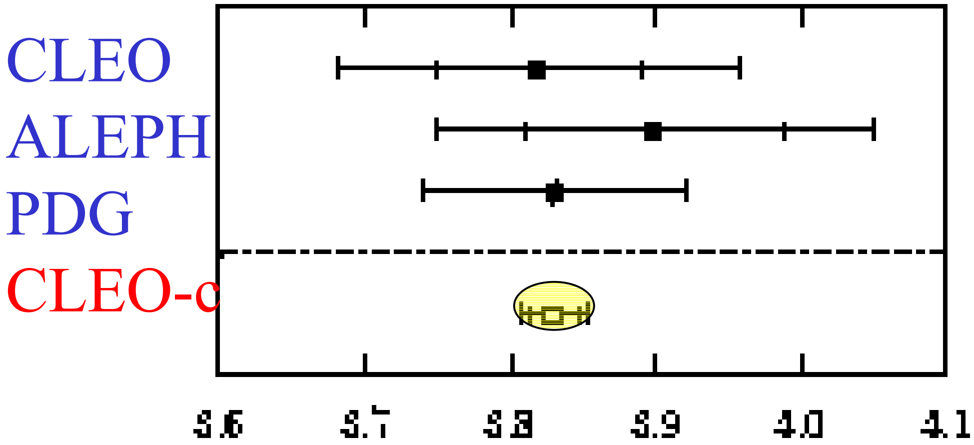
Background measured with electrons

FIG. 9. (a) The ΔM mass difference distribution for D_s^{*+} candidates for both the muon data (solid points), the electron data (dashed histogram) and the excess of muon fakes over electron fakes (shaded). The histogram is the result of the fit described in the text. (b) The ΔM mass difference distribution for D_s^{*+} candidates with electrons and excess muon fakes subtracted. The curve is a fit to the signal shape described in the text.

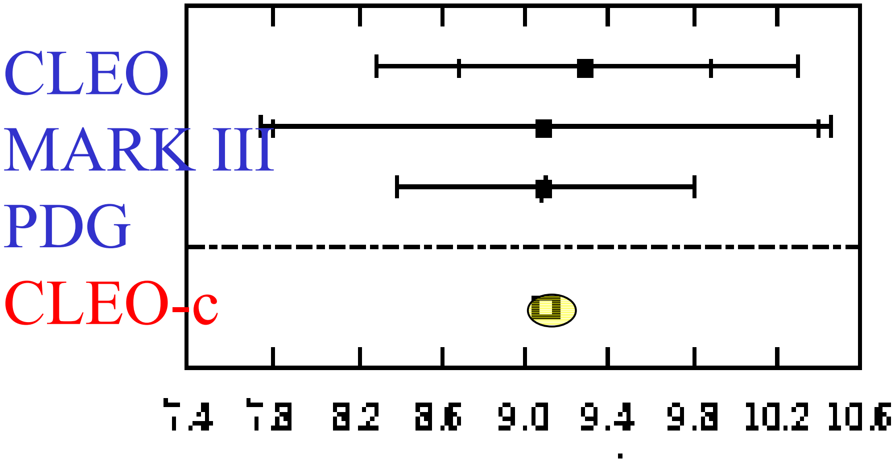
CLEO-c Charm Decay Measurements

Topic	Reaction	Energy MeV	L fb^{-1}	Current Sensitivity	CLEO-c Sensitivity
Decay Constant:					
f_{D^+}	$D^+ \rightarrow \mu^+ \upsilon$	3770	3	UL	2.3%
$f_{D_s^+}$	$D_s^+ \rightarrow \mu^+ \upsilon$	4140	3	35%	1.7%
$f_{D_s^+}$	$D_s^+ \rightarrow \tau^+ \upsilon$	4140	3	60%	1.6%
Absolute Branching fractions:					
$Br(D^0 \rightarrow K^- \pi^+)$		3770	3	2.4%	0.6%
$Br(D^+ \rightarrow K^- \pi^+ \pi^+)$		3770	3	7.2%	0.7%
$Br(D_s^+ \rightarrow \varphi^0 \pi^+)$		4140	3	25%	1.9%
$Br(\Lambda_c^+ \rightarrow p K^- \pi^+)$		4600	1	26%	4%

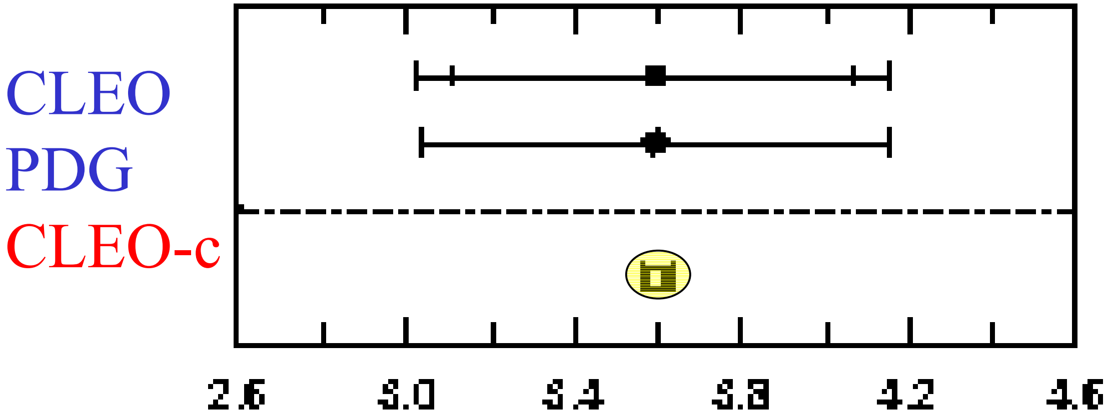
Absolute Branching Ratios



$B(D^0 \rightarrow K^-\pi^+)\%$



$B(D^+ \rightarrow K^- \pi^+\pi^+)\%$

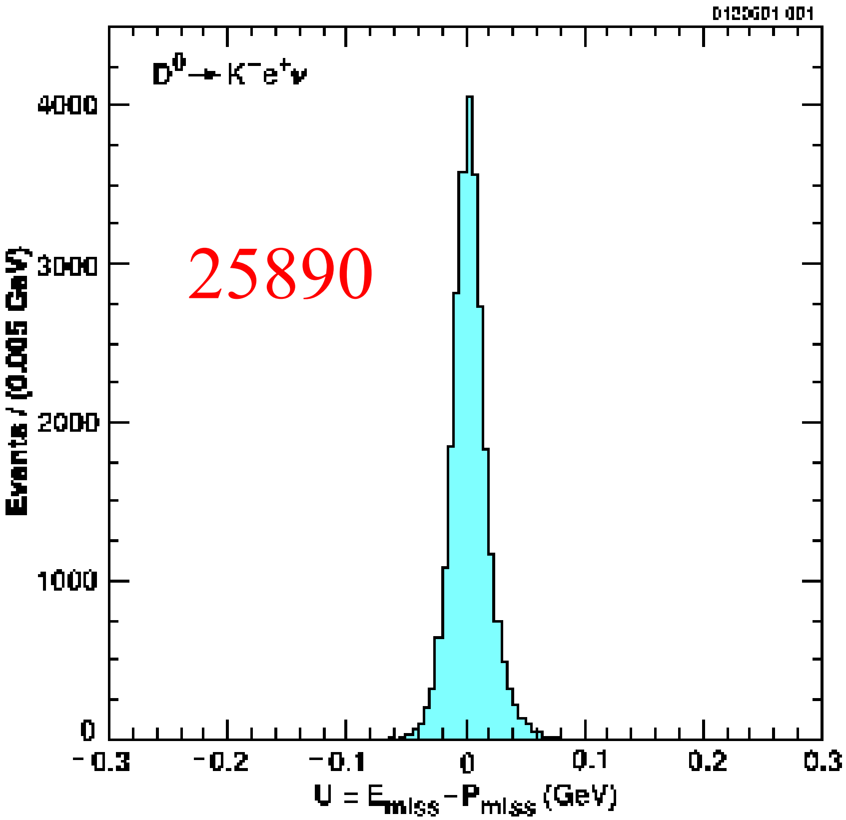


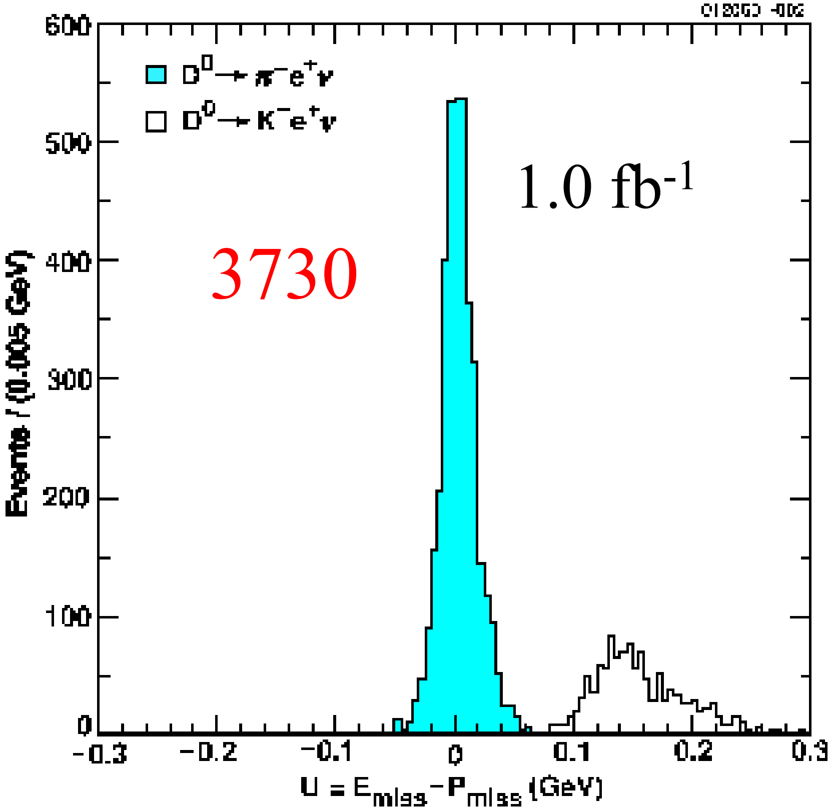
$B(D_s \rightarrow \phi\pi)$ %

CLEO-c sets absolute scale for all heavy quark measurements

Semileptonic Decay Reconstruction

- **Tagged events: identify electron plus hadronic tracks (muons not used)**
- **Kinematics at threshold cleanly separates signal from background**
- **Use** $U = E_{miss} - P_{miss}$ **to separate signal from background**





Excellent separation of **D→πlν D→klν despite B(D→klν)~10B(D→πlν)**

CLEO-C Impact on dB/B, Vcd, & Vcs

$1: D^0 \to K^- e^+ \nu$

$2: D^0 \to K^{*-} e^+ \nu$

$3: D^0 \to \pi^- e^+ \nu$

$4: D^0 \to \rho^- e^+ \nu$

$5: D^+ \to \bar{K}^0 e^+ \nu$

$6: D^+ \to \bar{K}^{*0} e^+ \nu$

$7: D^+ \to \pi^0 e^+ \nu$

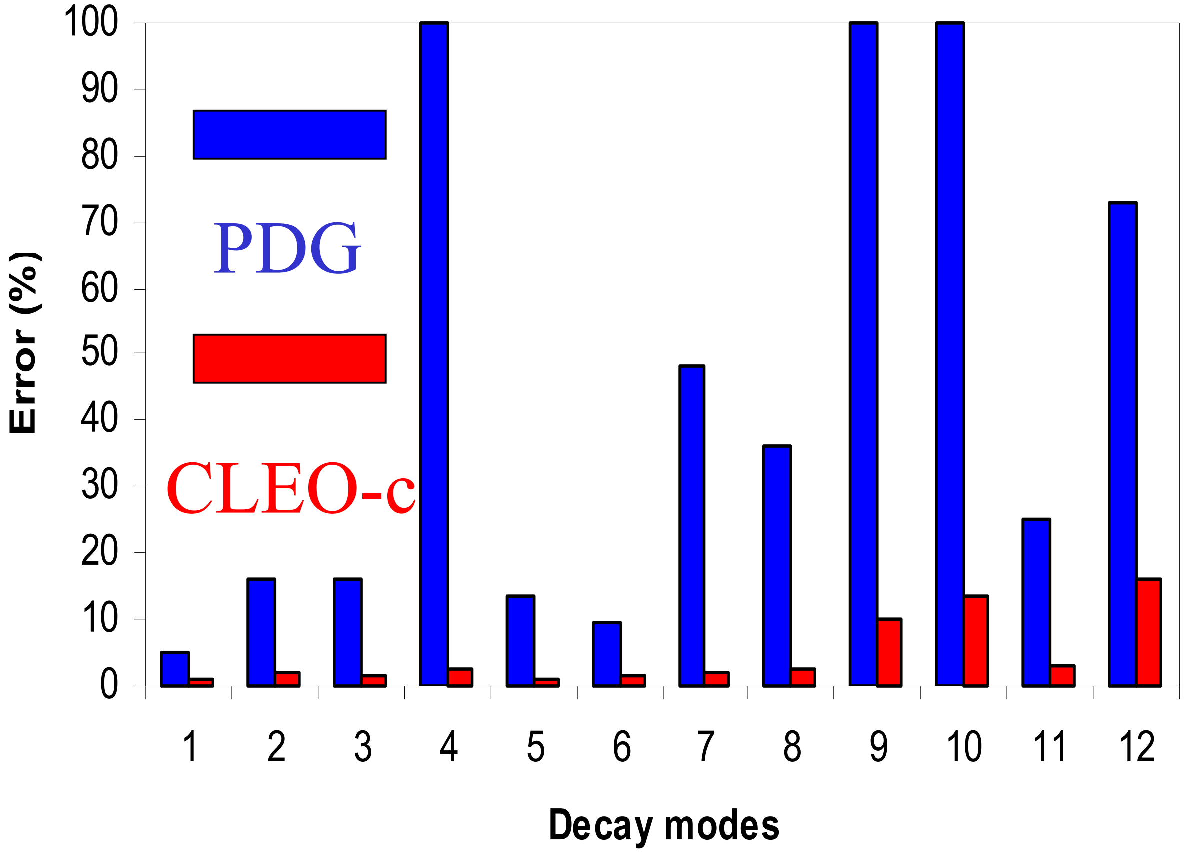
$8: D^+ \to \rho^0 e^+ \nu$

$9: D_s \to K^0 e^+ \nu$

$10: D_s \to K^{*0} e^+ \nu$

$11: D_s \to \phi e^+ \nu$

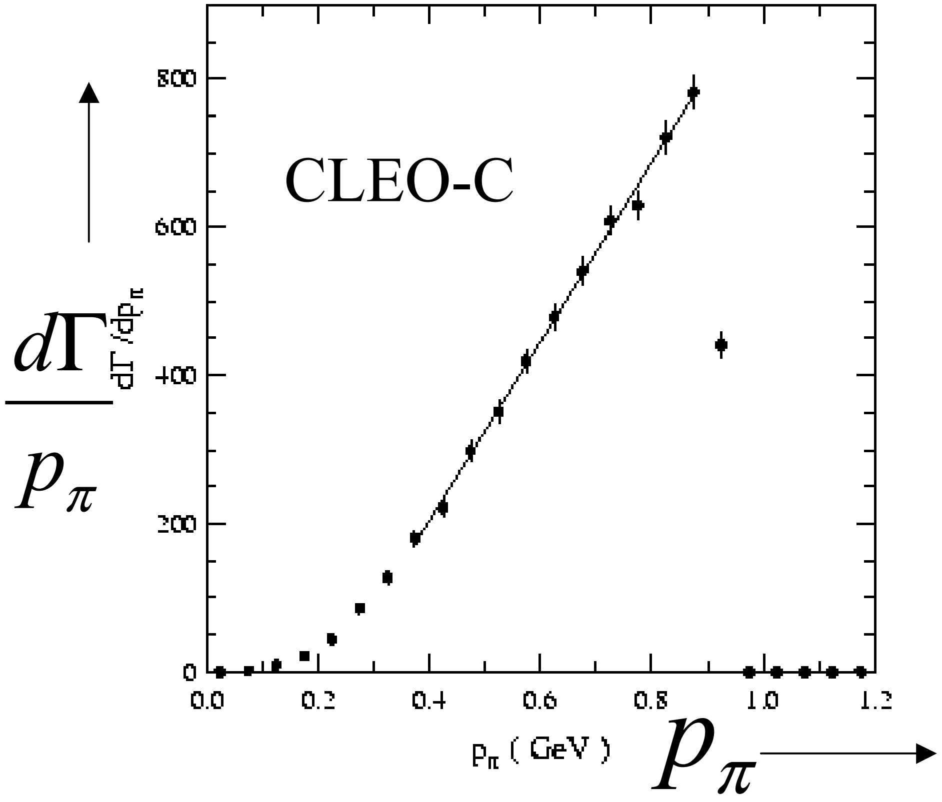
$12: \Lambda_c \to \Lambda e^+ \nu$

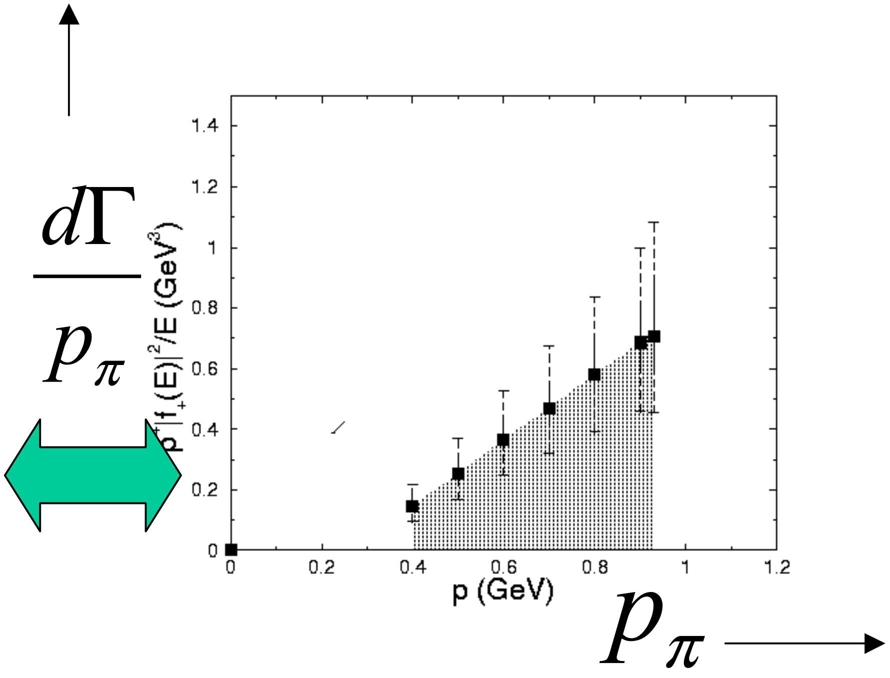


$D^0 \to K^- e^+ \upsilon$ δVcs /Vcs = 1.6% (now: 11%)

$D^0 \to \pi^- e^+ \upsilon$ δVcd /Vcd = 1.7% (now: 7%)

Calibration of the Lattice





Can test shape

Using V_{cd} from unitarity,

Can test normalization

calibration good to ~1%

compare to lattice prediction

ex: hep-ph/0101023 El-Khadra

Note: lattice error large ~15% on normalization but in future few % predicted

Summary so far

- Semileptonic decays: $|V_{CKM}|^2 \; |f(q^2)|^2$
  - Form factor *shapes* and *normalizations*
  - Calibrate theory! Extract $|V_{cd}|$, $|V_{cs\square}|$
  - Theory → Extract $|V_{ub}|$ from B
- Leptonic decays: $|V_{CKM}|^2 \; |f_D|^2$
  - Decay constants
  - Calibrate theory! Extract $|V_{cd}|$, $|V_{cs\square}|$
  - Theory → Extract $|V_{td}|$, $|V_{ts}|$ from B
- Hadronic decays:
  - Set scale of heavy quark decays
  - Enables precision tests in B decays (Vcb), nc
  -

Probes of New Physics

$\psi(3770) \rightarrow DD (C = -1)$

$\psi(4140) \rightarrow \gamma DD \ (C = +1)$

- DD mixing
  - exploit coherence:
    for mixing: no DCSD.
    $R_D = \sqrt{(x^2+y^2)/2} < 0.01$ @ 95%CL
- CP violating asymmetries
  - Sensitivity: $A_{cp} < 0.01$
  - Unique: $CP=\pm1 \leftarrow \psi(3770) \rightarrow CP=\pm1$
- Rare Decays. Sensitivity: 10^{-6}
- CP eigenstate tag X flavor mode

$K^+K^- \leftarrow D_{CP} \leftarrow \psi(3770) \rightarrow D_{CP} \rightarrow K^-\pi^+$

Measure strong phase diff. CF DCSD

Needed for γ from $B \rightarrow DK$

Compare to B Factories

	CLEO-C 2-4fb-1	BaBar 400 fb-1	Current Knowledge
f_D |	2.3%	10-20%	n.a.
f_Ds	1.7%	5-10%	19%
Br(D+ -> $K\pi\pi$)	0.7%	3-5%	7%
Br(Ds -> $\phi\pi$)	1.9%	5-10%	25%
Br(D->$\pi l\nu$)	1.3%	3%	18%
Br(Λc -> p$K\pi$)	6%	5-15%	26%
A(CP)	~1%	~1%	3-9%
x'(mix)	0.01	0.01	0.03

Statistics limited.

Systematics & background limited.

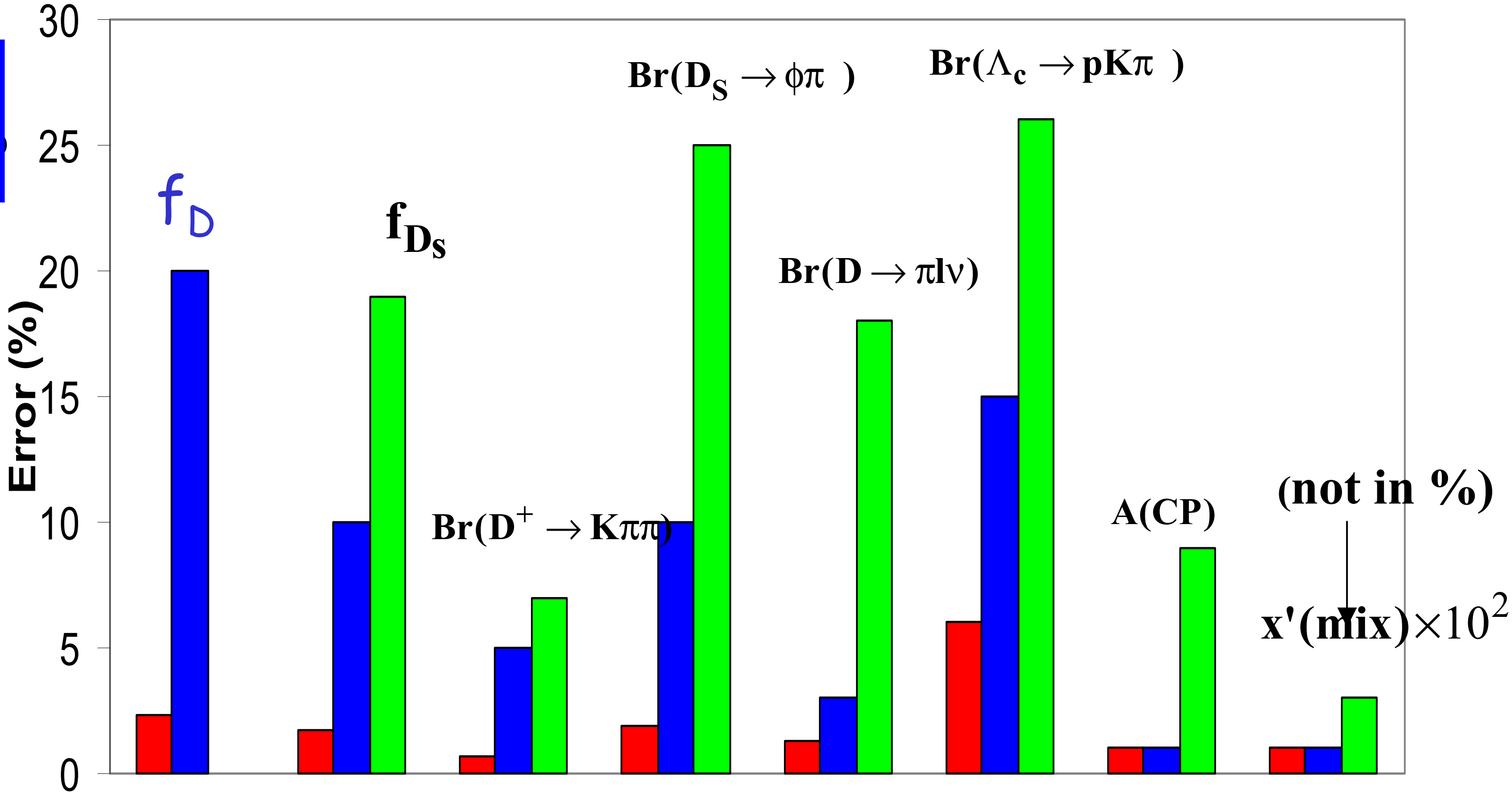
Comparison between B factories & CLEO-C

COMPARISON

CLEO-c
3 fb^{-1}

BaBar
400 fb^{-1}

Current



Probing QCD

- ψ and Y Spectroscopy
  - Masses, spin fine structure
  - Leptonic widths for S-states.
  - EM transition matrix elements
    - Will run on Y resonances winter ’01-summer’02
    - ~ 4 fb^{-1} total

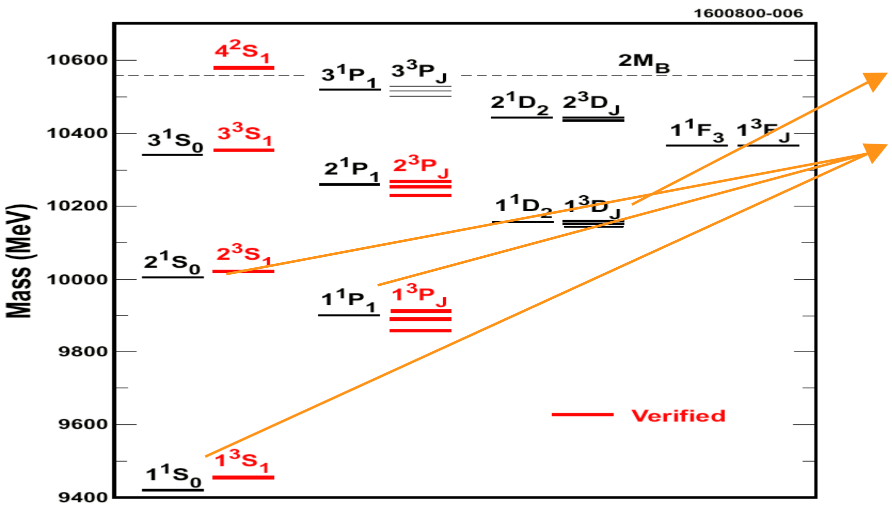
Calibrate and test theoretical tech.

J/Ψ running 2005

- Uncover new states of matter
  - Glueballs $G=|gg\rangle$
  - Hybrids $H=|gq\bar{q}\rangle$
    - Requires detailed understanding of ordinary hadron spectrum in 1.5-2.5 GeV mass range.

Study fundamental states of the theory

Upsilon Resonances : start 2002



Establish D states in 3S decays
Important for potential models

Discover/probe $\eta_b^{(')}$, h_b

$\Upsilon(3S)\to\gamma\eta_b$ (photon:900 MeV)
$\Upsilon(2S)\to\gamma\eta_b$ (photon:600 MeV)
$\Upsilon(3S)$: $\to h_b\gamma$

Scans: Γ_{ee} to few %
$\Upsilon(n+1S)\to\Upsilon(n+1S)\pi\pi$
➥ee/$\mu\mu$

➥B_{ll} < 1%

Search for cgg in Y(1S) & bgg above Y(6S)

Gluonic Matter

- Gluons carry color charge: *should bind!*
- But, like Jim Morrison/Elvis, glueballs have been sighted too many times without confirmation....
  - *CLEO-c: find it or debunk it!*

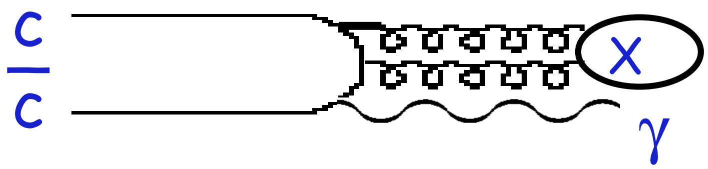
  - Radiative ψ decays are ideal
  - glue factory:

✔ huge data set

✔ modern detector

✔ 95% solid angle coverage

1

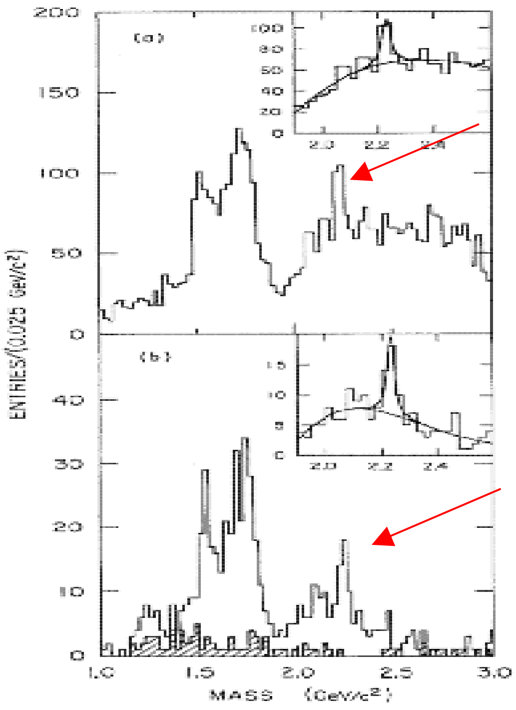


- perfect initial state
- perfect tag
- glue pair in color isosinglet

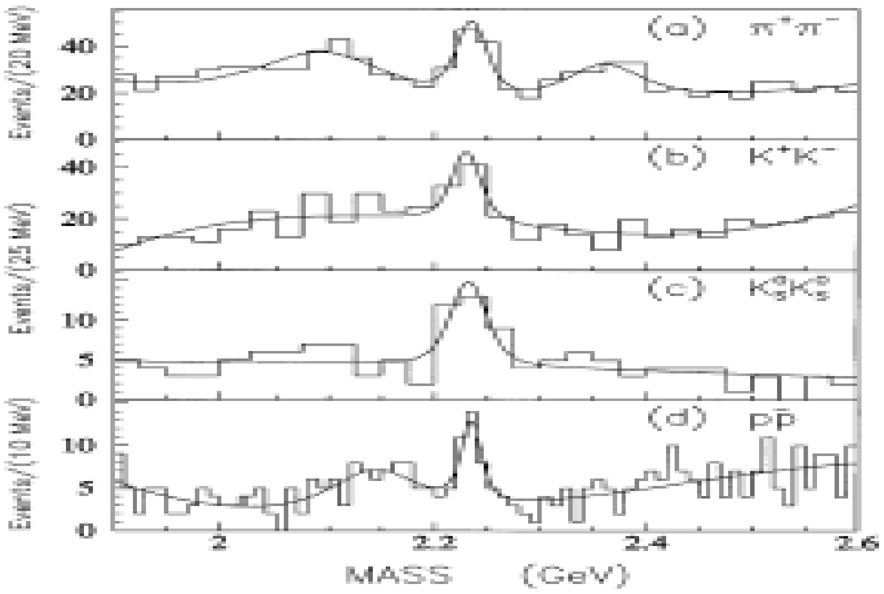
- CLEO-c: 10^9 $J/\psi \Rightarrow$ ~60M $J/\psi \rightarrow \gamma X$
  - Partial Wave analysis
  - Absolute BF's: $\pi\pi$,KK,pp,$\eta\eta$,...

The dubious life of the $f_J(2220)$
(A case study)

Now you see it…

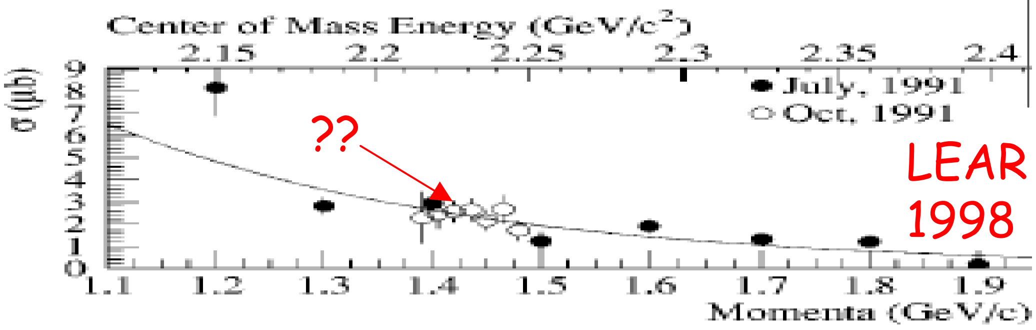


MARKIII
(1986)



BES
(1996)

Now you don't…



??

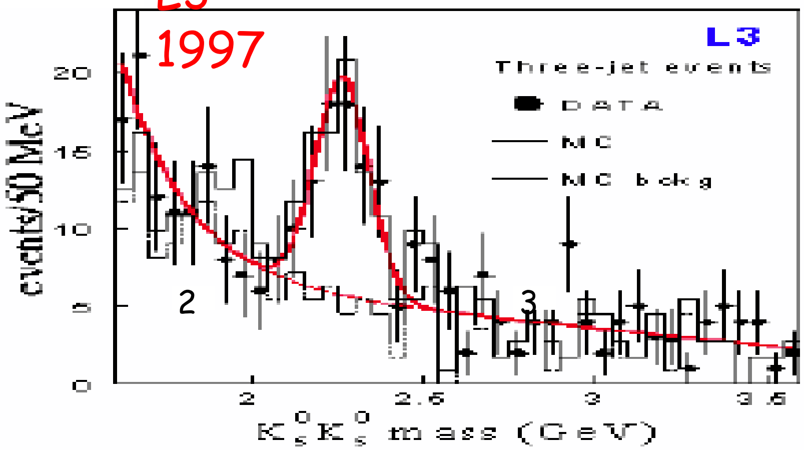
LEAR 1998

Crystal barrel:

$pp \to K^0_s K^0_s$

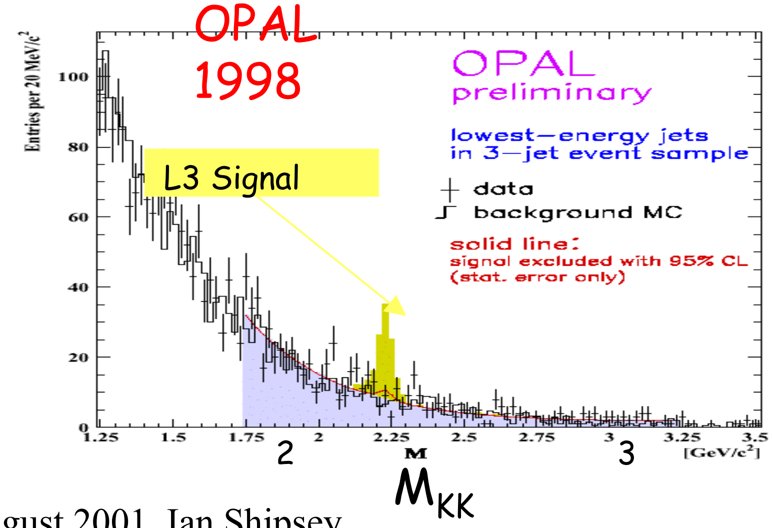
… or do you?

L3 1997

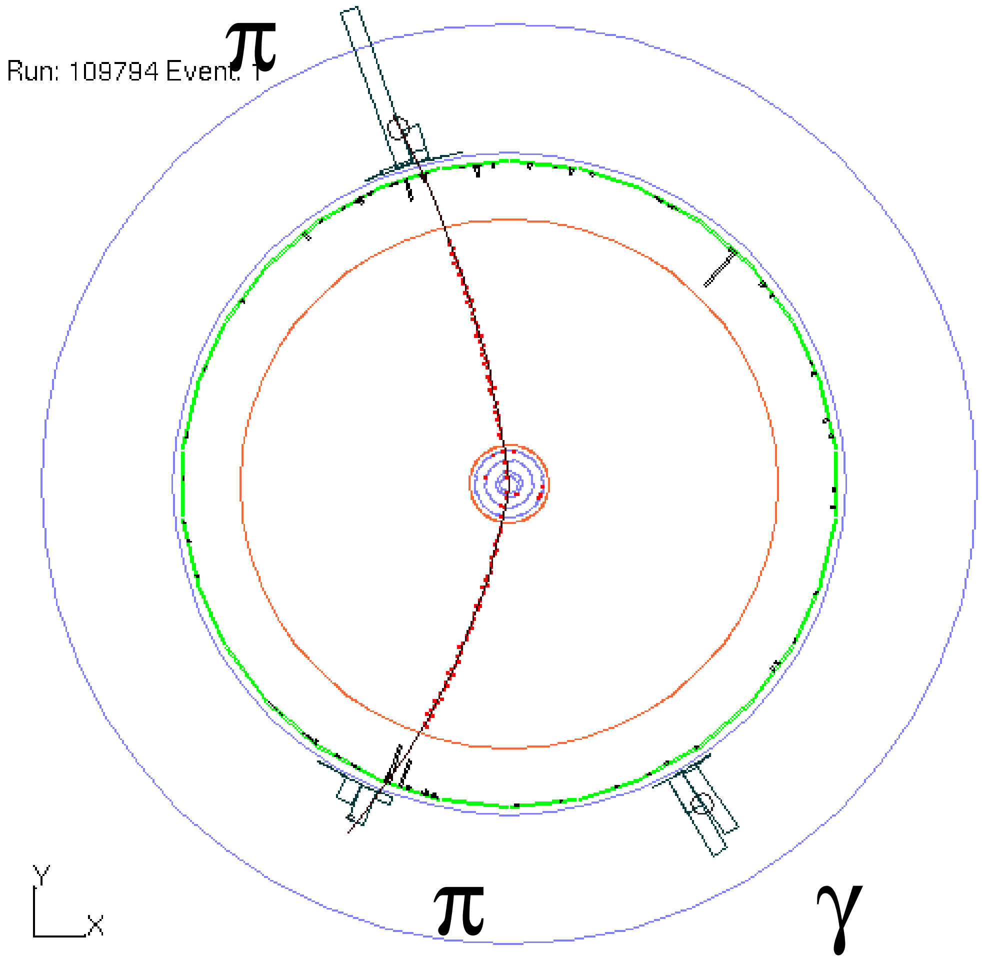


… or don't you?

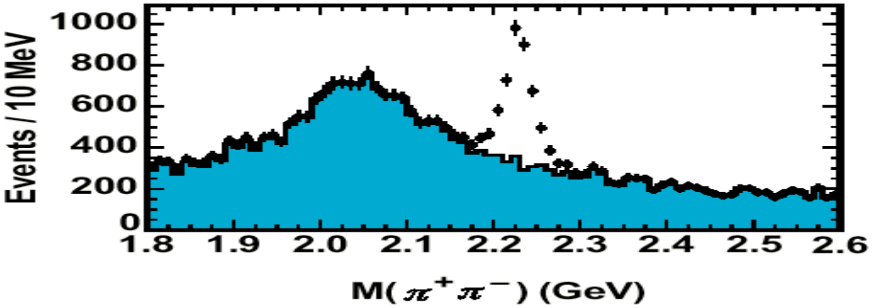
OPAL 1998

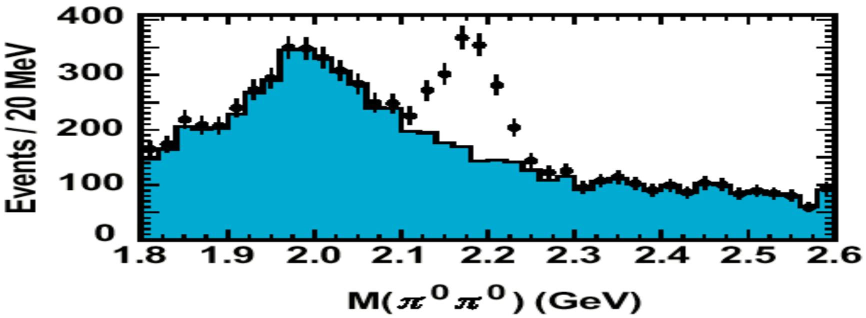


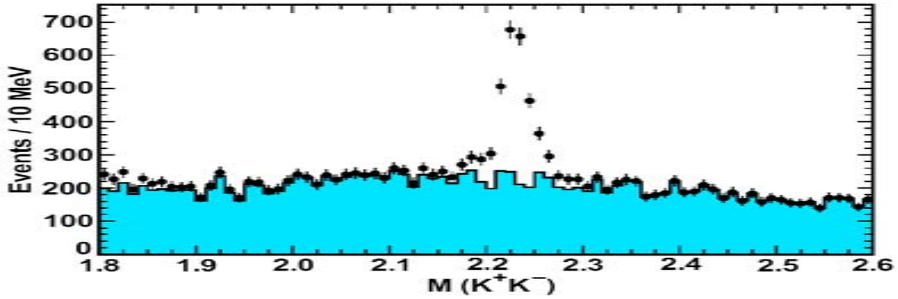
$\psi(3100) \rightarrow \gamma f_J(2230)$



$f_J(2220)$ in CLEO-c?







	BES	CLEO-C
$\pi^+\pi^-$	74	32000
$\pi^0\pi^0$	18	13000
K^+K^-	46	18600
K_SK_S	23	5300
pp	32	8500
ηη	–	5000

CLEO-c has *corroborating checks:*

2

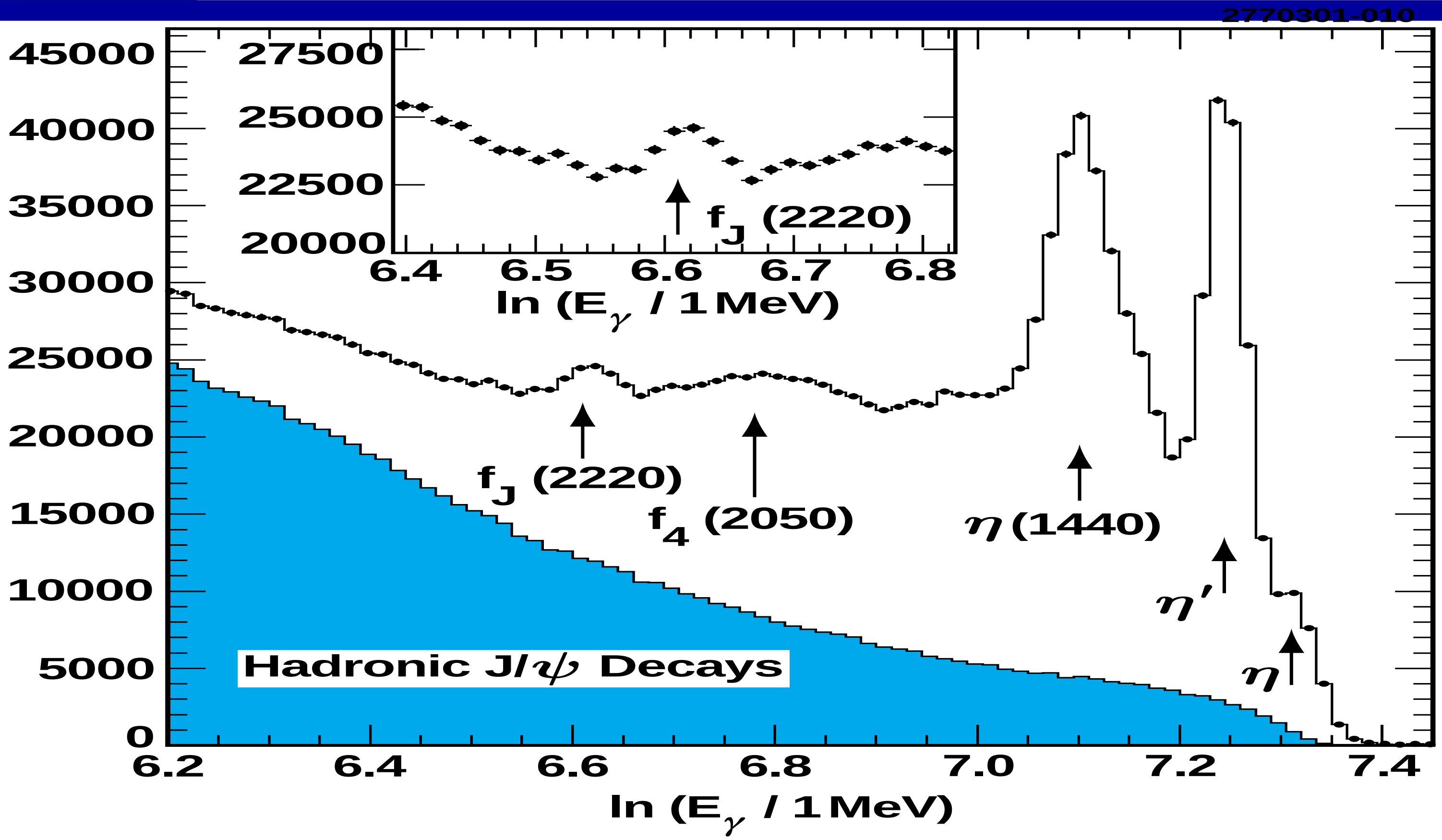
Two Photon Data: $\gamma\gamma \rightarrow f_J(2220)$:

- CLEO II: $\Gamma_{\gamma\gamma}B(f_J \rightarrow \pi\pi/K_SK_S) < 2.5(1.3)$ eV
- CLEO III: sub-eV sensitivity

3

- Upsilonium Data: ϒ(1S): Tens of events

Inclusive Spectrum $J/\psi \to \gamma X$



10^{-4} sensitivity for narrow resonance

Eg: ~25% efficient for $f_J(2220)$

Suppress hadronic bkg: $J/\psi \to \pi^0 X$

Unique features of CLEO-c

- Huge data set
  - 20-500 times bigger than previous experiments
- Modern detector
  - solid angle
  - tracking resolution
  - photon resolution
  - particle identification
  - trigger and DAQ flexibility, capacity
- Extra data sets for corroboration
  - Upsilons: 4fb^{-1}
  - Two Photon: 25 fb^{-1}

Comparison with Other Expts

China:

BES II is running now.
BES II --> BES III upgrade
BEPC I --> BEPC II upgrade, ~10^{32}
2 ring design at 10^{33}under consideration
being proposed
Physics after 2005 if approval & construction go ahead.

Quantity	BES II	CLEO-C
J/psi yield	50M	> 1000M
dE/dx res.	9%	4.9%
K/pi separation up to	600 MeV	1500 MeV
momentum res. (500Mev)	1.3%	0.5%
Photon resolution (100 Mev)	70 MeV	4 MeV
Photon resolution (1000 Mev)	220 MeV	21 MeV
Minimum Photon Energy	80 MeV	30 MeV
Solid angle for Tracking	80%	94%

HALL-D at TJNAL (USA)

γp to produce states with exotic Quantum Numbers
Focus on light states with J^{PC} = 0+-, 1+-, …
Complementary to CLEO-C focus on heavy states with J^{PC}=0++, 2++, …
Physics in 2007+ ?

+ **HESR at GSI Darmstadt** $p\,\bar{p}$ complementary. physics in 2007?

Possible additional topics

- Ψ' spectroscopy (10^{8} decays) $\eta'_c h_c$.....

- $\tau^+\tau^-$ at threshold (0.25 fb^{-1})
  - measure m_τ to ± 0.1 MeV
  - heavy lepton, exotics searches

- $\Lambda_c\Lambda_c$ at threshold (1 fb^{-1})
  - calibrate absolute BR($\Lambda_c \to pK\pi$)

- $R=\sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$
  - spot checks

Tying the threads

- CLEO-c probes QCD in the non-perturbative regime

Decay constants   Form Factors   meson spectra ψ and Ψ spectroscopy

- CLEO-c probes the essential nature of weak decays

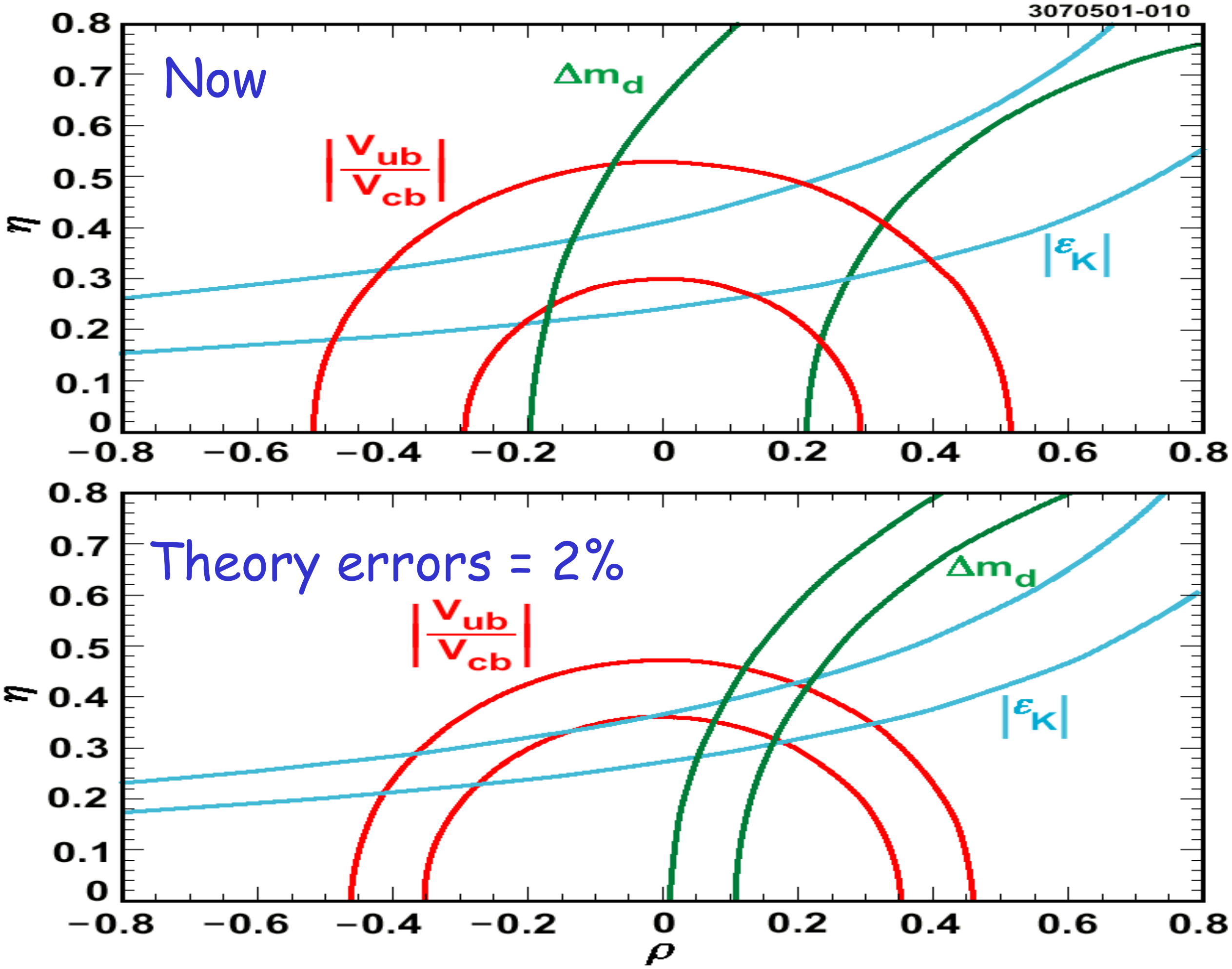
Vcd Vcs

- CLEO-c provides engineering inputs and independent cross checks for precision weak physics at B factories and hadron machines

Absolute BR’s   Decay constants

- Imagine a world where we have theoretical mastery of non-perturbative QCD at the 1-2% level

CKM Impact


3070501-010
Now
Δm_d
$\left|\frac{V_{ub}}{V_{cb}}\right|$
$|\varepsilon_K|$
η
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
Theory errors = 2%
Δm_d
$\left|\frac{V_{ub}}{V_{cb}}\right|$
$|\varepsilon_K|$
η
ρ

Next Steps

- CLEO-C workshop (May 2001) : successful
  ~120 participants, 60 non-CLEO
- Informational sessions with funding agencies & HEPAP (April/May ‘01) : positive response
- Snowmass working groups E2/P2/P5 : acclaimed CLEO-c
- CESR/CLEO Program Advisory Committee (9/01)
- Proposal submission to funding agencies (Feb. ‘02)
- See http://www.lns.cornell.edu/CLEO/CLEO-C/ for project description
- We welcome discussion and new members

The CLEO-c Program: Summary

- Powerful physics case
  - Precision flavor physics – *finally*
  - Nonperturbative QCD – *finally*
  - Probe for New Physics
- Unique: not duplicated elsewhere
- High performance detector
- Flexible, high-luminosity accelerator
- Experienced collaboration

- Optimal timing
  - Flavor physics of this decade
  - Beyond the SM in next decade
  - Resonance with LQCD...

CLEO-c Physics Impact

- Crucial Validation of Lattice QCD: Lattice QCD will be able to calculate with accuracies of 1-2%. The CLEO-c decay constant and semileptonic data will provide a "golden," and timely test. QCD and charmonium data provide additional benchmarks.
- Knowledge of absolute charm branching fractions is now contributing significant errors to measurements involving b's. CLEO-c can also resolve this problem in a timely fashion
- Improved Knowledge of CKM elements, which is now not very good.

CLEO-c data and **LQCD**

Vcd	**Vcs**	**Vcb**	**Vub**	**Vtd**	**Vts**
7%	**16%**	**5%**	**25%**	**36%**	**39%**
1.7%	**1.6%**	**3%**	**5%**	**5%**	**5%**

CLEO-c

Lattice

Validation

- The potential to observe new forms of matter – glueballs, hybrids, etc –and new physics- charm mixing, CP violation, and rare decays provides a discovery component to the program

Backup Slides

Acp values used in plot

TABLE 1. CLEO II A_{cp} measurements using 9.7 million BB events

Mode	A_{cp}	$A_{cp}^{90\%\ CL}$	A_{cp}^{Theory}
$K^{\pm}\eta'$	$+0.03 \pm 0.12$	$[-0.17, 0.23]$	$[+0.020, +0.061]$
$K_S^0\pi^{\pm}$	$+0.18 \pm 0.24$	$[-0.22, 0.56]$	$+0.015$
$K^{\pm}\pi^{\mp}$	-0.04 ± 0.16	$[-0.30, 0.22]$	$[+0.037, +0.106]$
$K^{\pm}\pi^0$	-0.29 ± 0.23	$[-0.67, 0.09]$	$[+0.026, +0.092]$
$\omega\pi^{\pm}$	-0.34 ± 0.25	$[-0.75, 0.07]$	$[-0.120, +0.024]$

TABLE 2. BELLE A_{cp} measurements using 11.1 million BB events

Mode	A_{cp}	$A_{cp}^{90\%\ CL}$
$K^{\pm}\pi^{\mp}$	$0.044^{+0.187}_{-0.168}$	$[-0.25, 0.37]$
$K^{\pm}\pi^0$	$-0.059^{+0.228}_{-0.197}$	$[-0.40, 0.36]$
$K_S^0\pi^{\mp}$	$0.098^{+0.430}_{-0.348}$	$[-0.53, 0.82]$

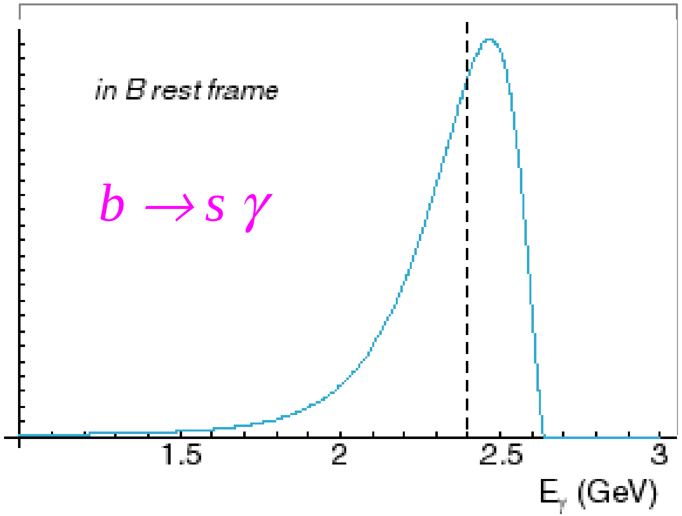
Top to bottom
Corresponds to
Left to right

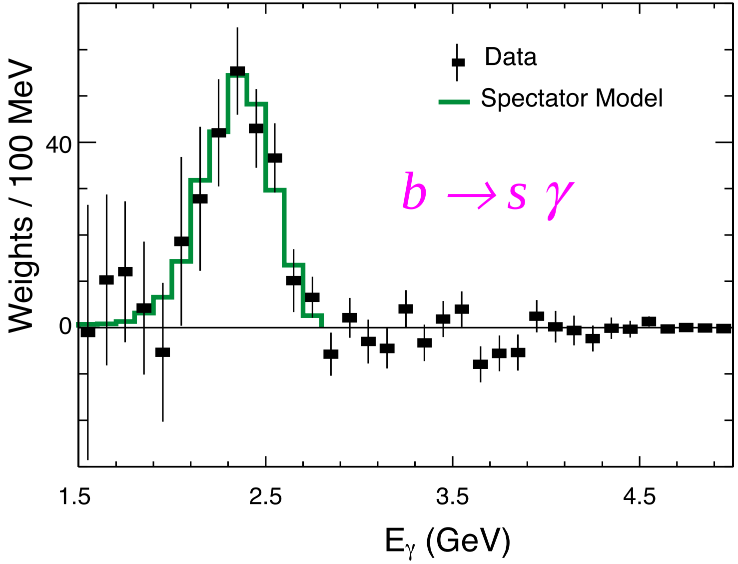
TABLE 3. BaBar A_{cp} measurements

Mode	A_{cp}	$A_{cp}^{90\%\ CL}$	# $B\bar{B}$ (in million)
$K^0\pi^{\pm}$	-0.21 ± 0.18	$[-0.51, 0.09]$	23
$K^{\pm}\pi^0$	0.00 ± 0.18	$[-0.30, 0.30]$	23
$K^{\pm}\pi^{\mp}$	-0.07 ± 0.08	$[-0.21, 0.07]$	33

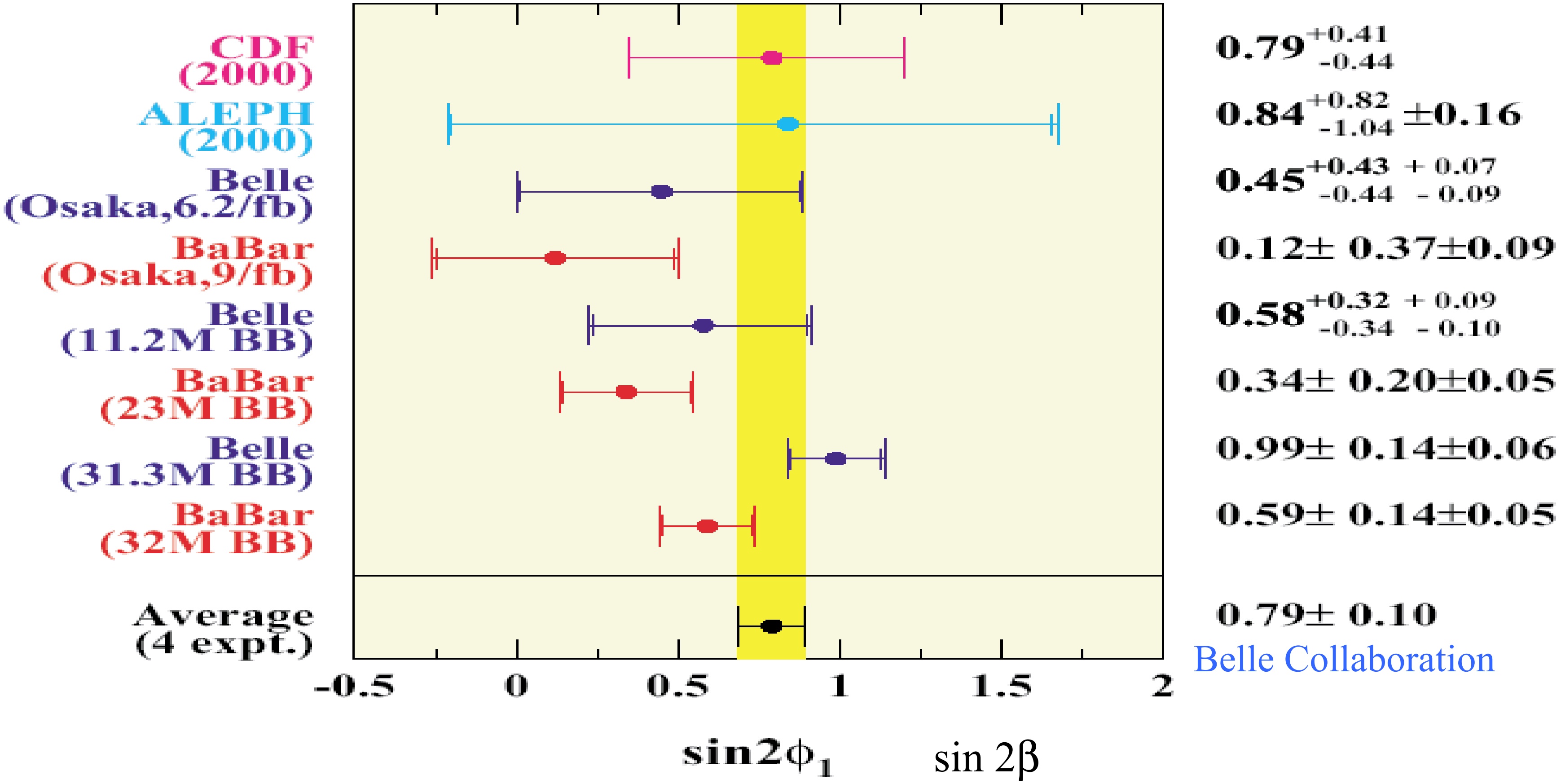
$|V_{ub}|$: Untangling the Fermi motion

- Use the photon spectrum from $b \to s\,\gamma$ to understand Fermi motion.
  - Fermi motion broadens the simple, well understood photon spectrum.
  - Fit the *measured* spectrum of photons in $b \to s\,\gamma$ using shape function [Ali & Greub,1991]
  - Extract p_{Fermi} & m_b from the photon spectrum.
  - Apply the same parameters to the lepton spectrum & determine the fraction f(p) of the spectrum measured. [Kagan & Neubert, hep-ph/9805303]





Angles



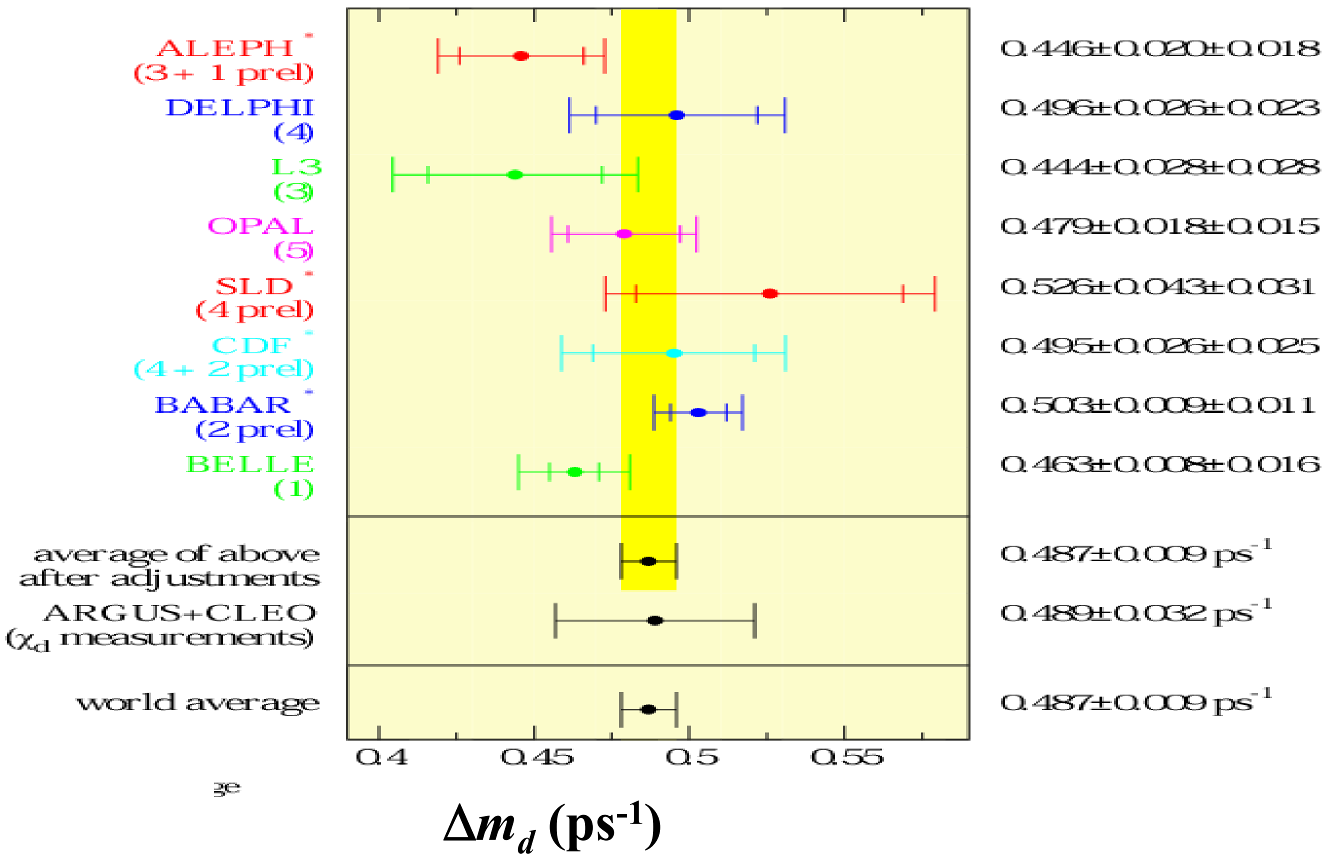
Belle Collaboration

$\sin 2\beta$

α: B → ρπ. Requires large statistics to understand 3π Dalitz plot.

γ: rare decays require large statistics

$B_{d,s}$ Mixing: $\Delta m_{d,s}$



LEP Working Group

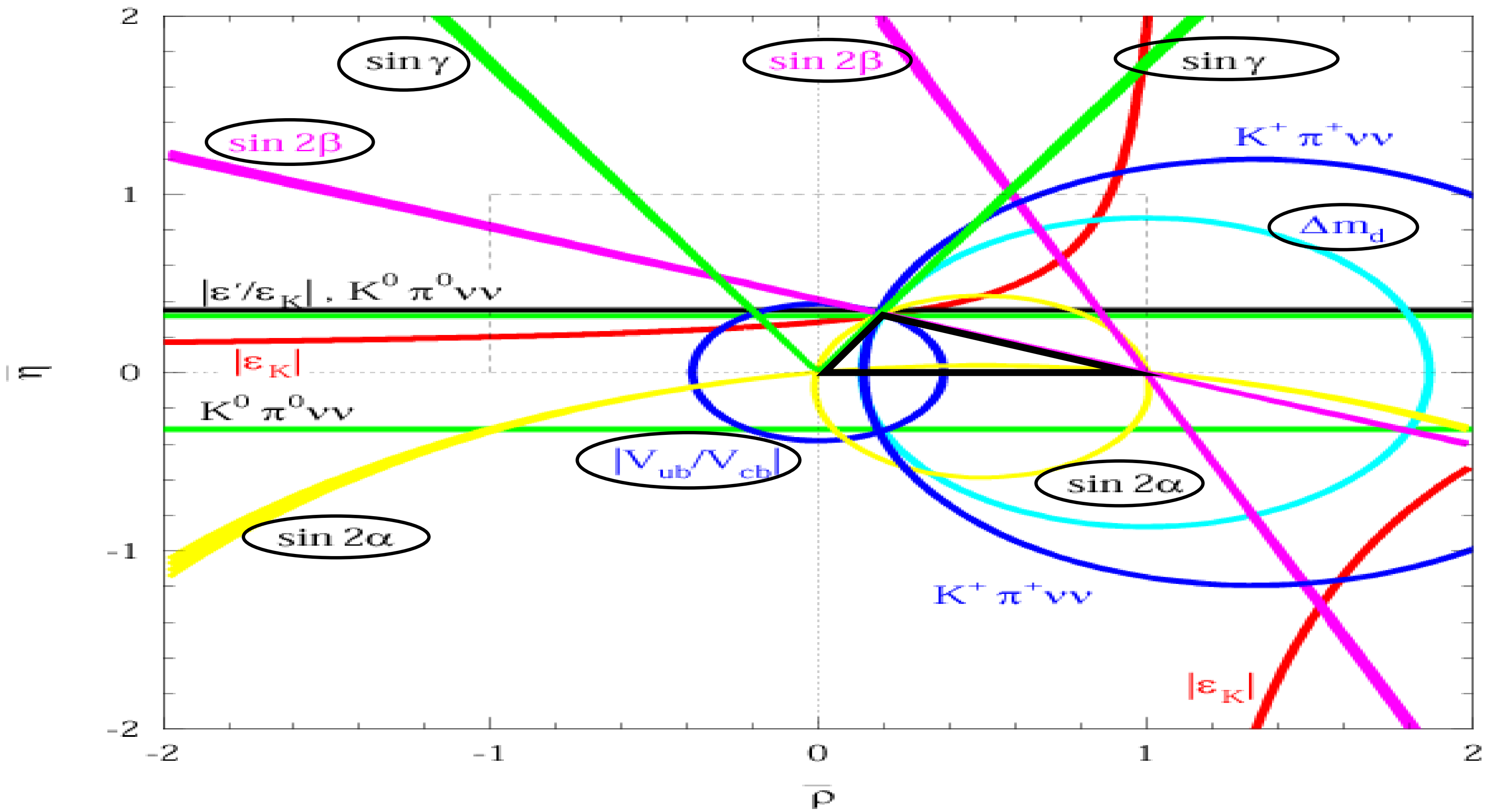
t-dependent Δm_d $\cong 1/\tau_B$

t-integrated χ-method

B_s: Near Maximal Mixing: $\Delta m_s >> 1/\tau$.
Lower limit: $\Delta m_s > 15 ps^{-1}$

LEP B Oscillations Working Group

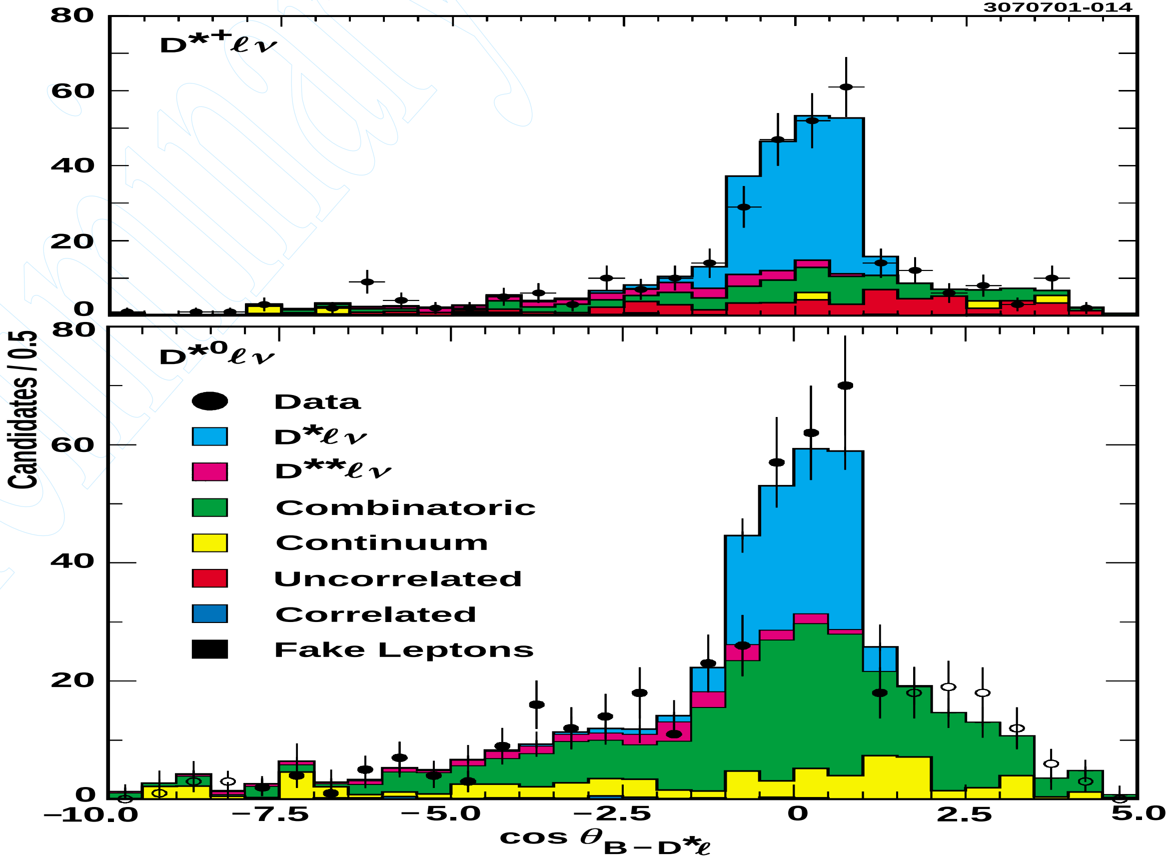
(Over) Constraining the Unitarity Triangle



From A. Hocker, et al. hep-ph/0104062

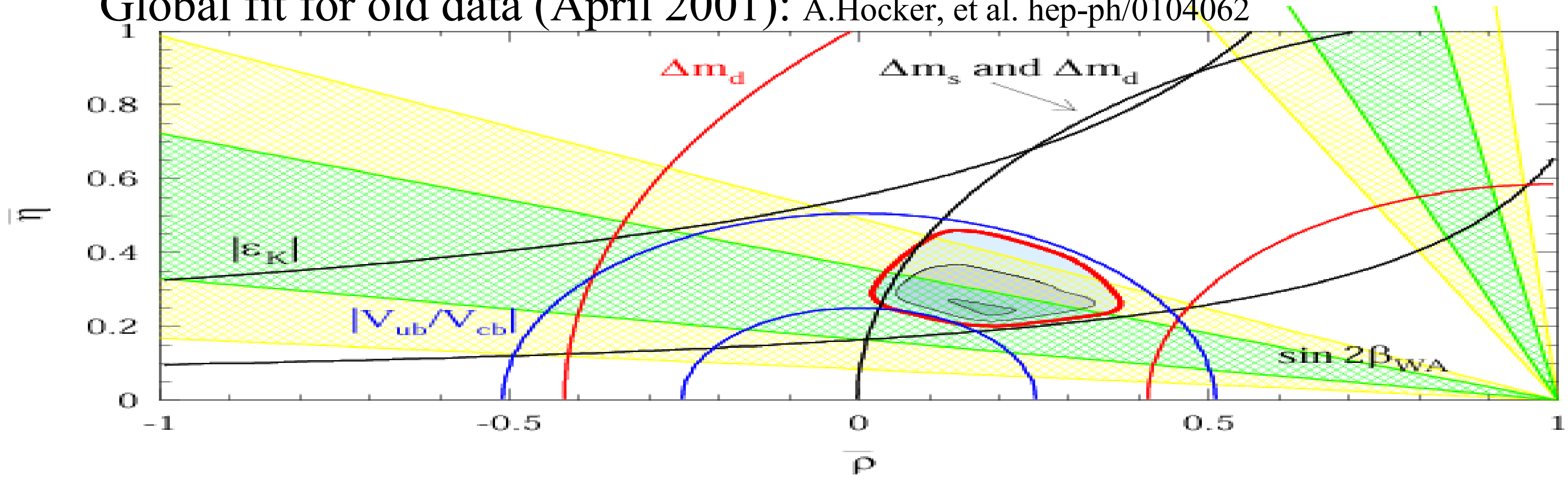
Vcb from $B \to D^*\ell\nu$

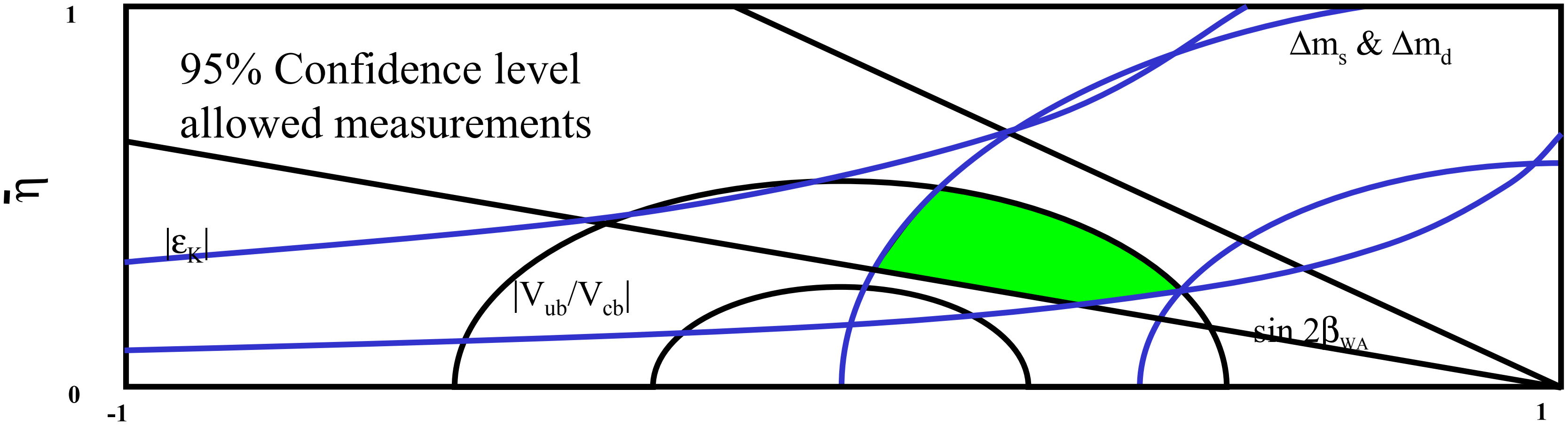
- Fit each w-bin for $B \to D^*\ell\nu + D^{**}\ell\nu$+bkgds
- charged channel limited by slow π resolution
- neutral channel by combinatoric background
- w resol.: 0.03



Unitarity Triangle Constraints

Global fit for old data (April 2001): A.Hocker, et al. hep-ph/0104062





Averages used: V_{ub}: $(3.7\pm0.6)\text{x}10^{-3}$, V_{cb}: $(42.6 \pm2.8)\text{x}10^{-3}$, $\sin2\beta$: 0.79 ± 0.1

Summary and Outlook

V_{ud} $\beta - decay$ exp : th : 0 .1 %	V_{us} $K \to \pi e \nu$ exp : th : 1 .1	V_{ub} $B \to \pi l \nu , B \to \rho l \nu$ exp : suppress b → c th : form factor 16 % → 5 %
V_{cd} $D \to \pi l \nu$ exp : statistics th : form factor 6% → 1.4%	V_{cs} $D \to Kl \nu$ exp : statistics th : form factor 6% → 1.1%	V_{cb} $B \to D^{*} l \nu$ exp : systematic th : form factor 7%(3%) → 3%
V_{td} $B_d - Mixing$ exp : th : form factor f_B 19 % → 5 %	V_{ts} $B_s - Mixing$ exp : statisitcs th : form factor f_B 25 % → 5 %	V_{tb} $t \to bl \nu$ exp : statistics th : 29 % → 15 %

We need: Validation of lattice QCD results.

$D_{(s)} \to \mu\nu$, $D \to Ke\nu$, $D \to \pi e\nu$ measurements

A Selection of Other Key CLEO-c Physics

Semi-leptonic Decays	Reaction	Energy MeV	L fb^{-1}	Current Sensitivity	CLEO-c Sensitivity
V_{cs}	$D^0 \to K^- e^+ \upsilon$	3770	3	16%	1.6%
V_{cd}	$D^0 \to \pi^- e^+ \upsilon$	3770	3	7%	1.7%

Mode	CLEO-c	BES-II projected
#J/ψ	10^9	$50\text{x}10^6$
$J/\psi \to \gamma\, f_j(2220)$, $f_J \to \pi^+\pi^-$	23,000	462
$f_J \to \pi^0\pi^0$	13,000	115

On ψ', can do charmonium Spectroscopy, e.g.: $^1P_1$,η_c'

New Physics in D decays:
Mixing: $\sqrt{R_D} \le 1\%$ at 95% CL
CP violation: ~1%
Rare Decays: many modes with UL~1-10x10^{-6}

Comparison with BABAR & BES

Quantity	CLEO-c	BaBar
f_D	2.3%	10-20%
f_{D_s}	1.7%	5-10%
$Br(D^+ \to K^+\pi^-\pi^-)$	0.7%	3-5%
$Br(D_s^+ \to \phi^0\pi^+)$	1.9%	5-10%
$Br(D^0 \to \pi^- l^+ \upsilon)$	1.3%	3%
$Br(\Lambda_c^+ \to pK^-\pi^+)$	6.0%	5-15%

Quantity	CLEO-c	BES-II
#J/ψ	10^9	$5\text{x}10^7$
Ψ'	10^8	$3.9\text{x}10^6$
4.14 GeV	1 fb^{-1}	23 pb^{-1}
3-5 R Scan	2%	6.6%

BEPC-II /BES-III a proposed double ring machine L = 2 x 10^{33} (x10 CESR-c) to come online in ~2005 - if approved. Will make an important contribution as data improves and theory sharpens