Measuring V_{ub} From Exclusive Semileptonic Decays

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The Cabibbo-Kobayashi-Maskawa Matrix

- This matrix describes the (SM) weak couplings of the "up" type quarks with the "down".
- It is unitary by construction, and can be described by four, experimentally measured parameters.

The "Wolfenstein" parameterization

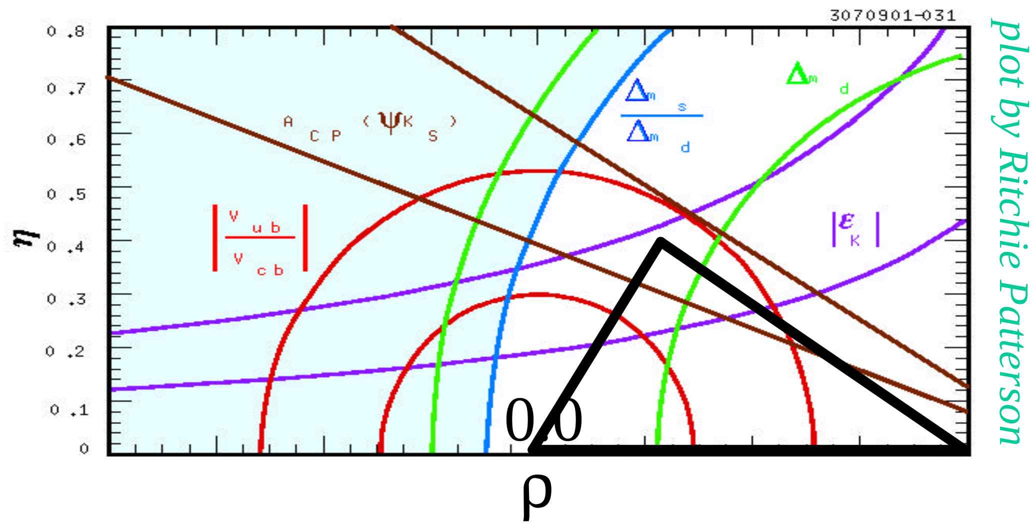
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} = \begin{bmatrix} 1-l^2/2 & l & Al^2(r-ih) \\ -l & 1-l^2/2 & Al^2 \\ Al^3(1-r-ih) & -Al^2 & 1 \end{bmatrix} + \ldots$$

- η is the parameter which characterizes the scale of CP violation in the SM.

V_{ub} and the Unitarity Triangle

We can draw a triangle in the imaginary plane based on the unitarity of this matrix.

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$



- V_{ub}, along with V_{td}, are the most poorly measured elements.
- Experimental Goal: Measure all sides and angles of this triangle in order to look for inconsistencies in the SM.

The Exclusive V_{ub} Measurement

In principle, given the branching fraction and form factor for a specific decay,

$$\overline{B}^0 \to p^+ \, l^- n,$$

one can extract V_{ub} from the following expression:

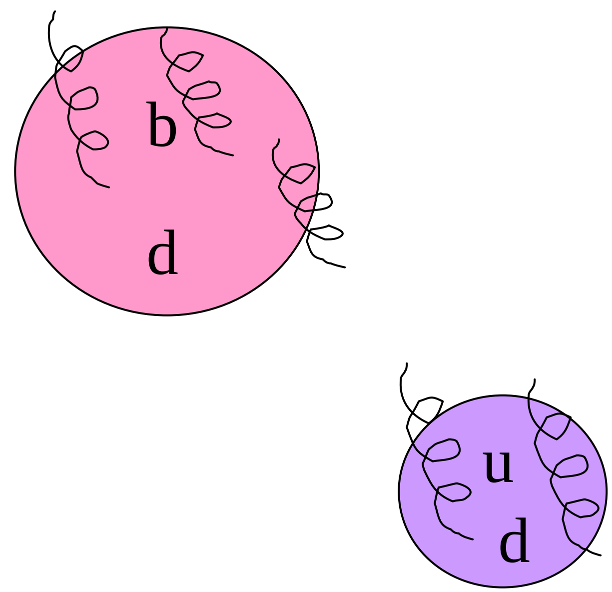
$$\frac{d\Gamma}{dq^2} = (G^2/24\pi^3)\,\text{ï}\,\mathbf{V_{ub}}\,\text{ï}^{\mathbf{2}}\, p_\pi^{\,3}\,\text{ï}\,\boldsymbol{f}\mathbf{(q^2)}\,\text{ï}^{\mathbf{2}}$$

f is the **form factor** and q^2 is the invariant mass of the virtual W.

The biggest errors in determining V_{ub} exclusively are in the theoretical uncertainties of the form factor.

More on Form Factors

- Form factors parameterize the QCD interactions between the quarks in the decay.
- Those of the “heavy to light” quark decays (b->u,d and c-> u,d) must be calculated nonperturbatively and are poorly understood.



Exclusive V_{ub} in the Past and Present

This has been done before at CLEO…

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

8-10% experimental　　17% theoretical

(Average of previous exclusive results from hep-ex/9905056)

We are currently attempting to obtain branching fractions for the following modes: $B \rightarrow \pi, \rho, \eta, \omega l \nu$.

Improvements with this analysis:

- Greater statistics - 3X the luminosity of the previous analysis.
- We expect to obtain better q^2 distributions, and therefore have a much greater sensitivity to theoretical models.

The Basic Analysis Technique

The idea is simple…

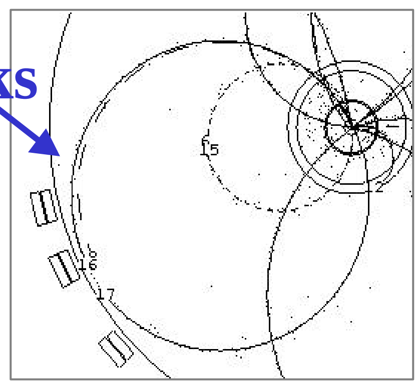
- Sum up the energy and momentum of all the particles in an event and attribute what is missing to the neutrino.

Some definitions: $\vec{p}_\nu = -\sum_{\substack{i=\text{good tracks} \\ \text{and showers}}} \vec{p}_i$

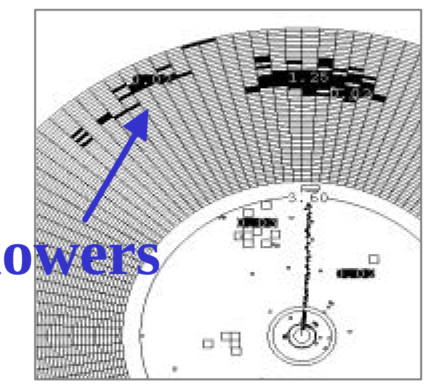
Reconstruct the B using this *n* ***plus the candidate lepton and hadron tracks.***

…but the requirements for good neutrino reconstruction make this analysis difficult.

extra tracks



extra showers



The Basic Analysis Technique

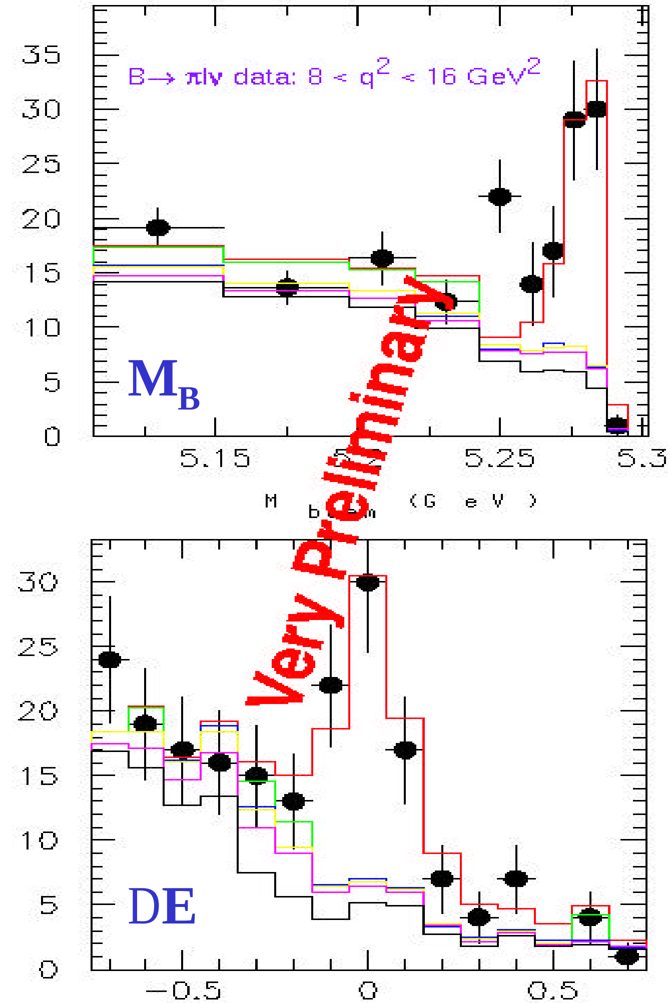
continued…

- Simultaneously fit the $\mathbf{M_B}$ and D**E** distributions to extract a yield.

Some more definitions:

$$\Delta E = (E_u + E_l + E_h) - E_{beam}$$

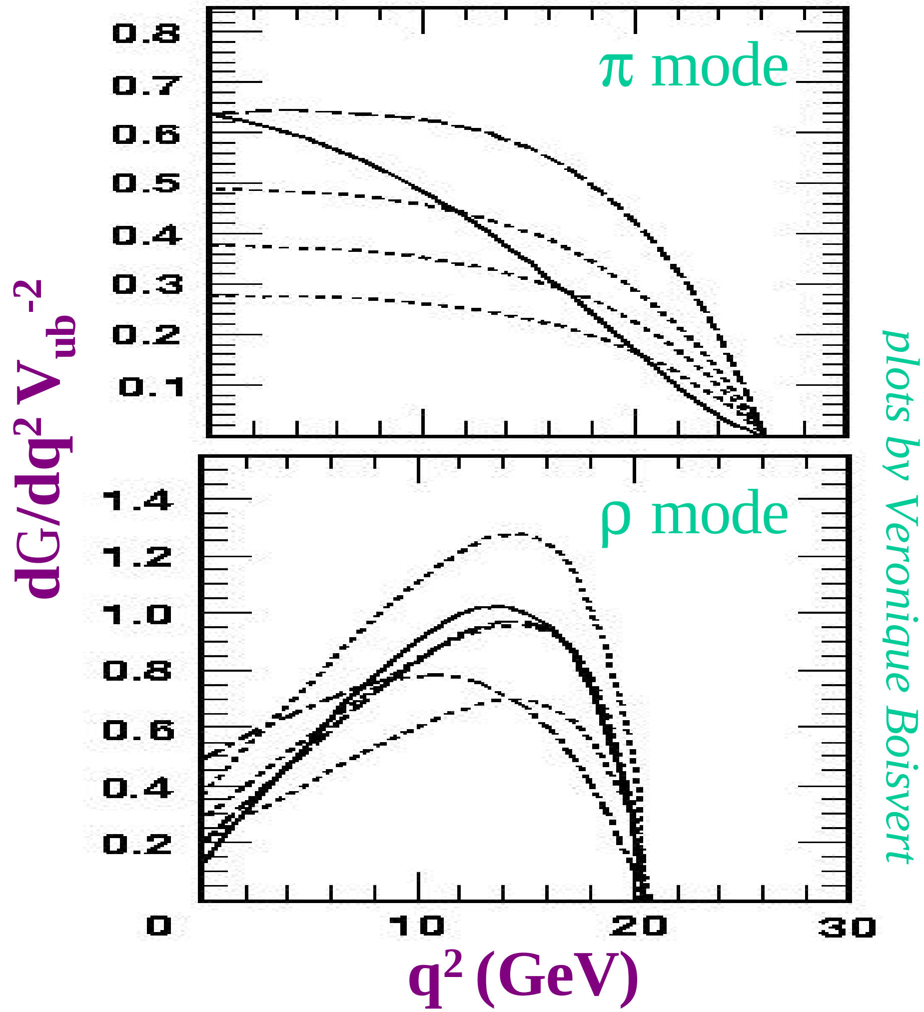
$$M_B = \sqrt{E_{beam}{}^2 - \left|\vec{p}_\nu + \vec{p}_l + \vec{p}_h\right|^2}$$



plots by Veronique Boisvert

Extracting V_{ub}

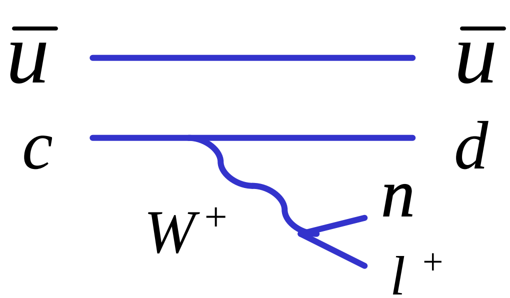
- The last step is to use various theoretically determined form factors to extract a value of V_{ub}.
- Quark Models, Dispersion Relations, Light Cone Sum Rules, and Lattice QCD will all be used.

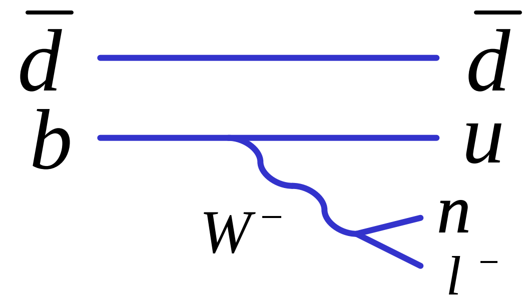


D^0 ® $p\ ln$ and V_{ub}

Now switching to a different, but related analysis…

- The decay D^0 ® $p\ ln$ is also a "heavy to light" decay.





- Because the CKM element involved in this decay is already well measured via deep inelastic neutrino scattering, a measurement of this branching fraction could provide better understanding of "heavy to light" form factors.

$$\frac{d\Gamma}{dq^2} = (G^2/24\pi^3)\text{ï}\mathbf{V_{cd}}\text{ï}^2\, p_\pi^{\,3}\text{ï}\boldsymbol{f(q^2)}\text{ï}^2$$

Past Measurements and New Expectations

We have some knowledge of this branching fraction through previous measurements of the ratio $\frac{D^0 \to pl u}{D^0 \to K l u}$.

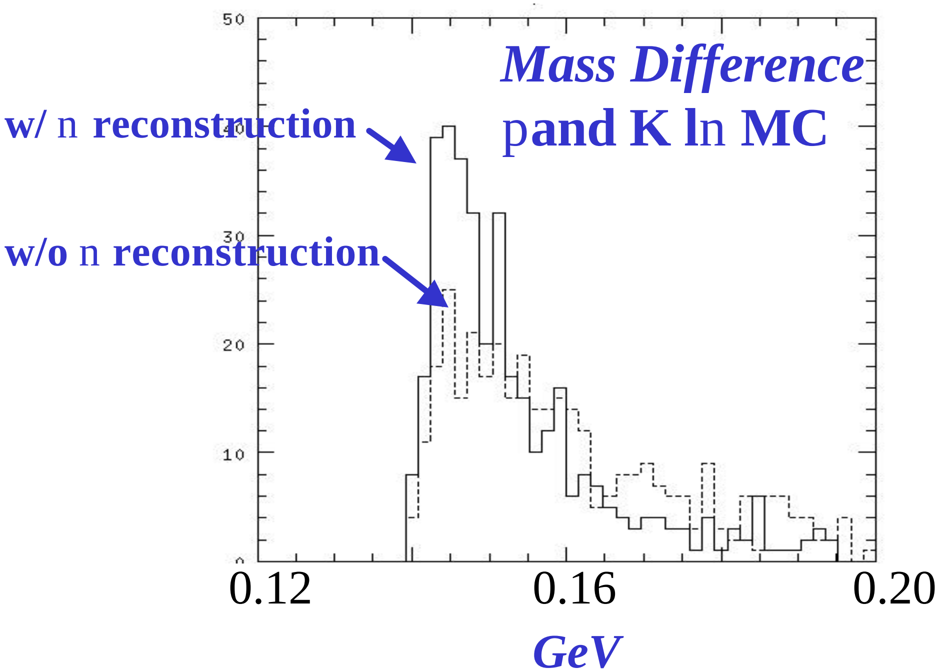
Experiment	*Ratio*	*Statistical Error*	*Systmatic Error*
Mark III	0.115	+0.073/-0.037	0.018
CLEO II	0.170	0.054	0.028
CLEO II and II.V	0.103	0.039	0.013
E687	0.101	0.020	0.003
CLEO III	??	~0.012	??

CLEO hopes to make a new measurement of this ratio with data from our new (CLEO III) detector.

The Analysis Technique

- “Tag” the D^0 with the decay $D^{*+} \rightarrow \pi_s^+ D^0$
  $\hookrightarrow p\ (K\ )l n$
- Then we construct a mass difference.

$$\Delta M = M_{p_{slow} p (K) ln} - M_{p (K) ln}$$



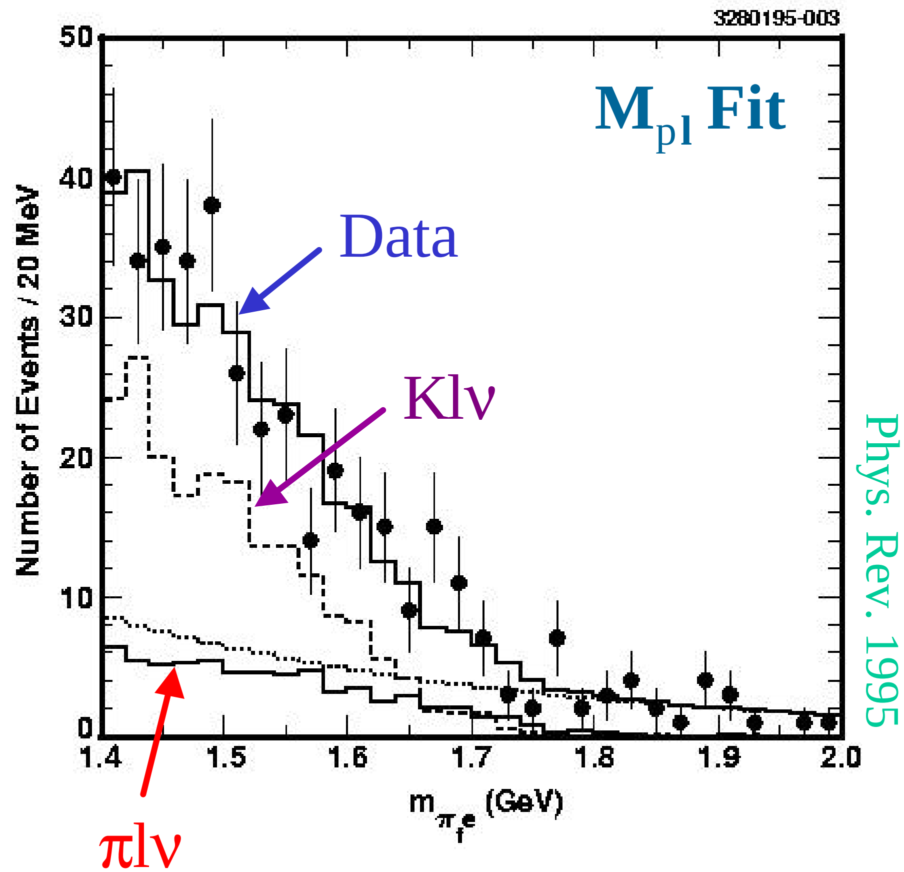
We expect improvements with the addition of neutrino reconstruction...

The CLEO III Analysis of $D^0 ® p\ ln$

…but there's room for an even bigger improvement!

- Previously, the decay $D^0 ® K^- l^+ n$ contributed a large background.
- We hope to improve greatly on the old CLEO analysis because we can now distinguish pions from kaons well with our new particle ID detector.

(CLEO II Result)

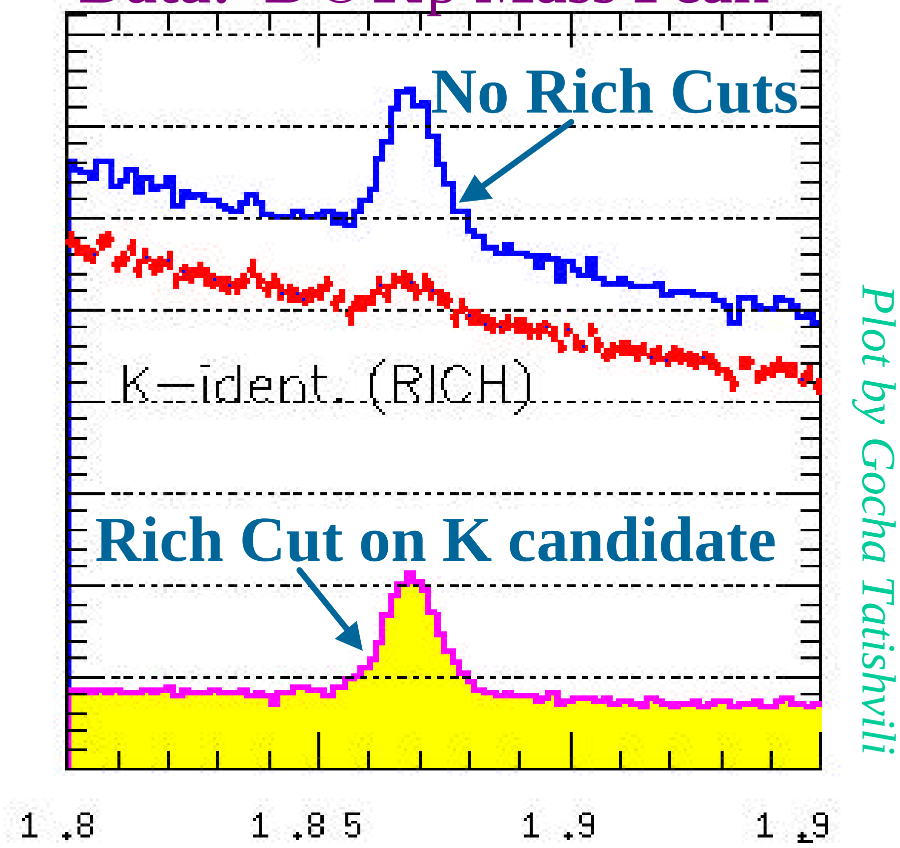


CLEO III Particle ID

A new feature in CLEO!

- The Rich detector is a ring imaging Cherenkov detector.
- It covers 83% of the solid angle in CLEO III.
- We expect 90% efficiency in the RICH for both pion and kaon detection with p>0.7GeV.

Data: D®Kp Mass Peak



In Summary

We are expecting results soon on two interesting analyses being performed at CLEO:

$B \to p\,,\, r\,, w\,, h l u$

- A CLEO II/II.V analysis from which we hope to extract one of the most current and precise measurements of V_{ub}.

$D^0 \to p \;\, l n$

- A CLEO III analysis!
- Will help provide understanding of “heavy to light” form factors which are a major source of theoretical uncertainty in determining V_{ub}.

For the Future…

CLEO has been making contributions to B physics for over 20 years, but our time is coming to an end…

So what is next?

- In the next decade, we will be changing our focus from b-physics to charm-physics.
- $\pi l \nu$ is among the modes we expect to make a precision measurement of with a less than 2% error on the branching fraction.
- Much promise lies ahead in understanding these non-perturbative form factors and extracting a precise value of V_{ub}

Why an Exclusive Measurement?

The <u>advantage</u> <u>of</u> an <u>exclusive</u> B®uln measurement:

- ***B®cln*** contributes large backgrounds, making the inclusive measurement of ***B®uln*** difficult for all but the very endpoint of the lepton momentum spectrum.
- Ultimately, tools such as lattice QCD will give us very precise model independent ways to measure V_{ub} exclusively.
- An exclusive measurement would serve as a much needed cross check for the inclusive measurement.

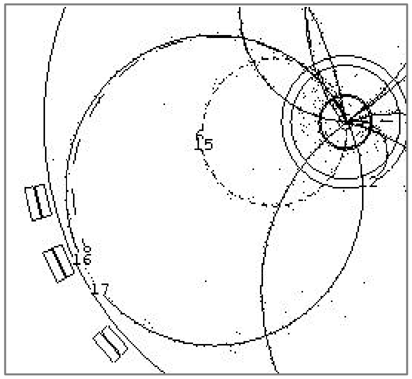
The Cornell Electron Storage Ring

- Located at Wilson Synchrotron Lab in Ithaca NY
- CESR is a ***symmetric*** e+e- collider with a CM energy of 10.56 GeV.
- CLEO and CESR have been producing results in B physics for over 20 years.

Neutrino Reconstruction Tools

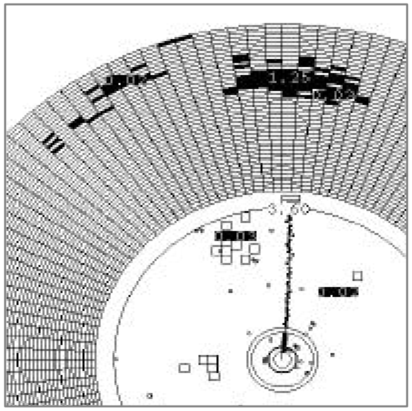
…but the requirements for good neutrino reconstruction make this analysis difficult.

Trackman



- Ensures that we have good tracking by eliminating extra tracks introduced by pattern recognition artifacts.

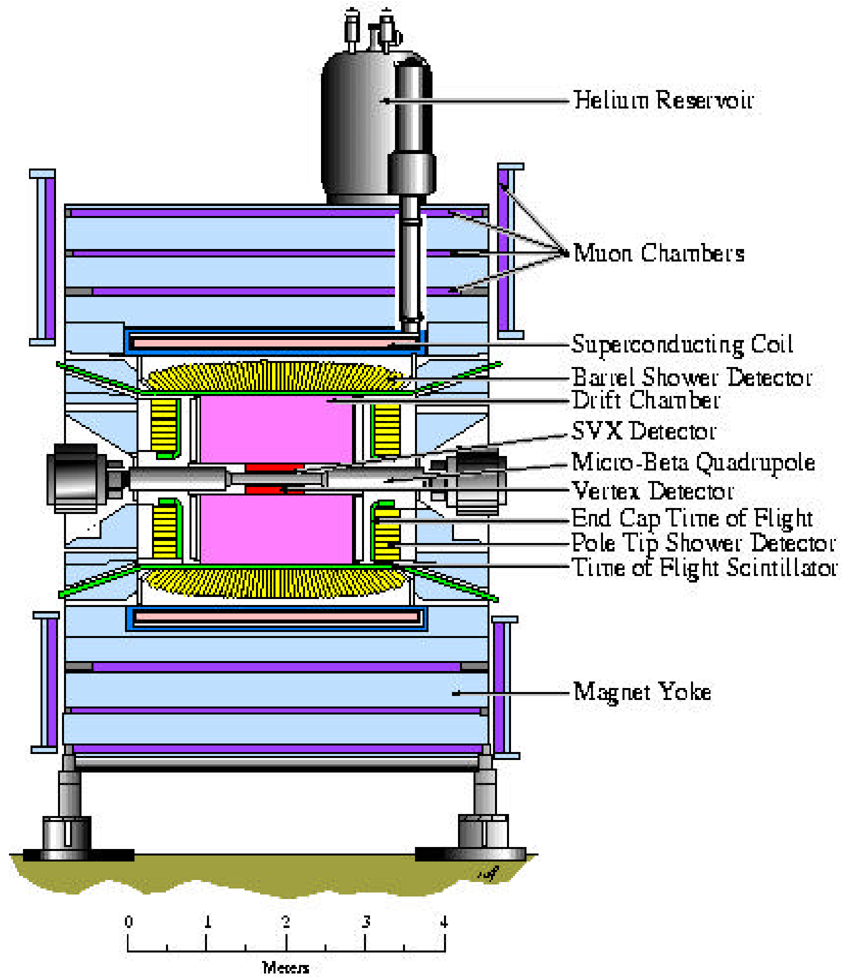
Splitoff



- Since we only take ***either*** a good track or a good shower, scattering in the calorimeter can mimic extra neutral particles which are not real.

The CLEO II/II.V Detector

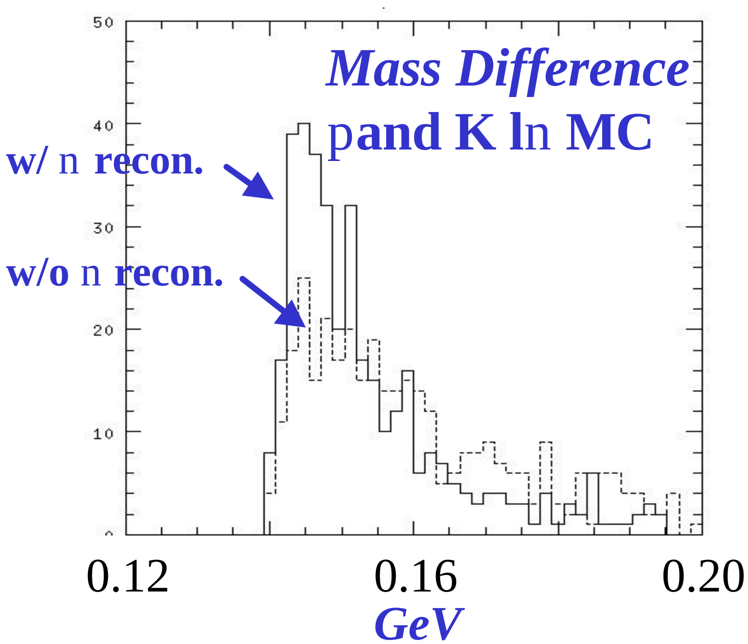
- Symmetric e+e- collider.
- Good Hermiticity - 93% of the solid angle is covered in tracking, and 98% in calorimetry. This is necessary for good neutrino reconstruction.
- We operate at the $\Upsilon(4S)$ resonance.

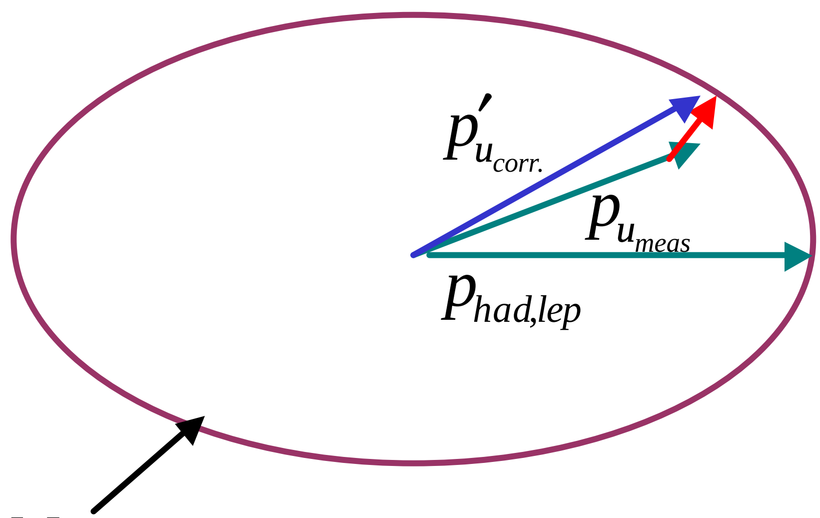


Possible Improvements to the Analysis Technique

We are hoping to improve on the old CLEO analysis technique.

- Previously there was no attempt to reconstruct neutrinos.
- We are investigating the potential for improvement with neutrino reconstruction.





Fixing M_{D^0} gives an ellipse of possible neutrino momenta, for a given $p_{had,lep}$.

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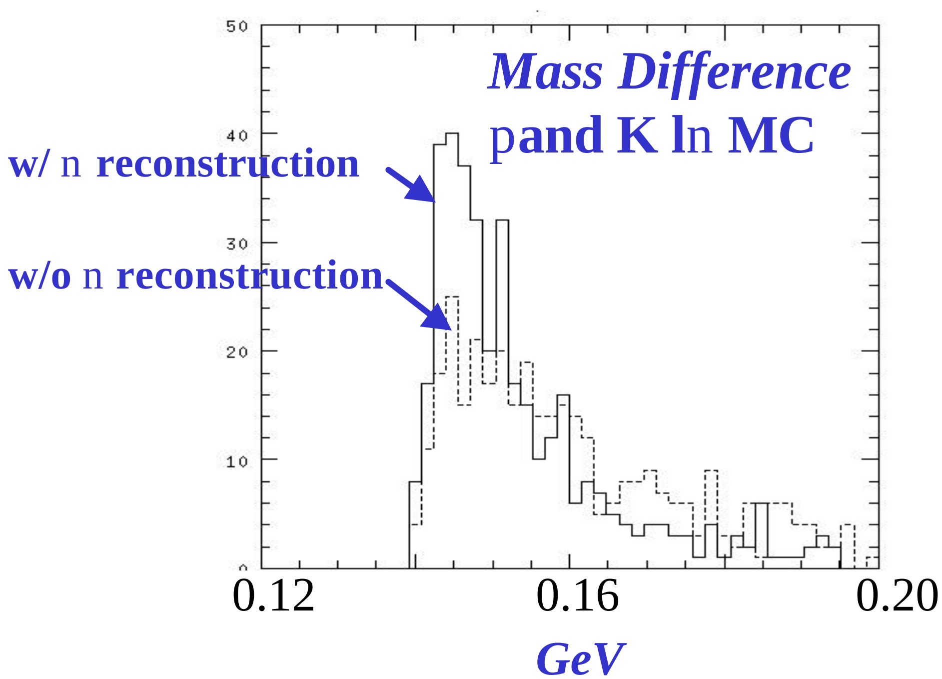
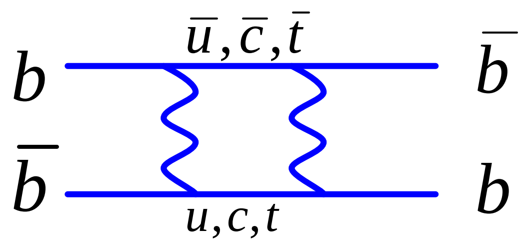
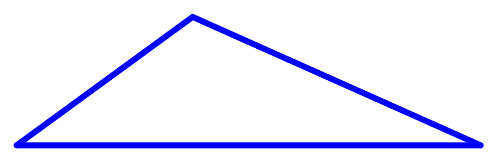


Testing the Standard Model

CP violation is an area in which we can test for "new physics"

- Our goal is to check whether the rate of CP violation predicted by the Standard Model matches what we see in nature.





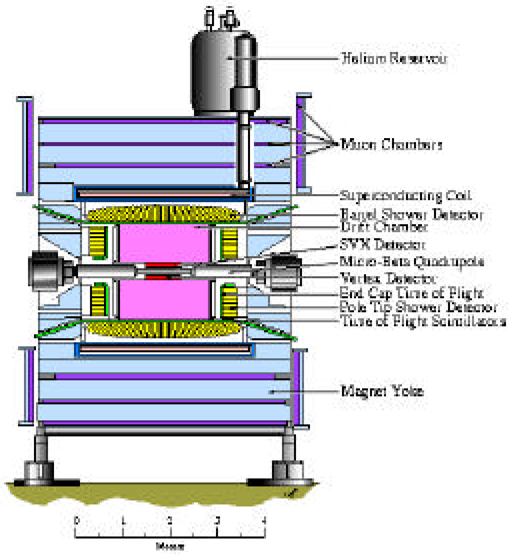
- Inconsistencies would signify new physics.

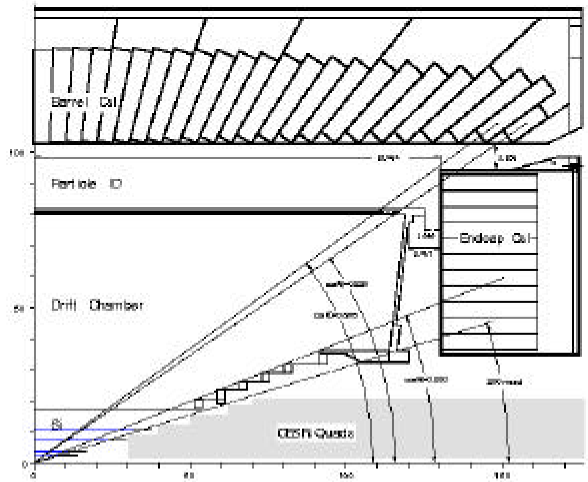
V_{ub} and the Unitarity Triangle

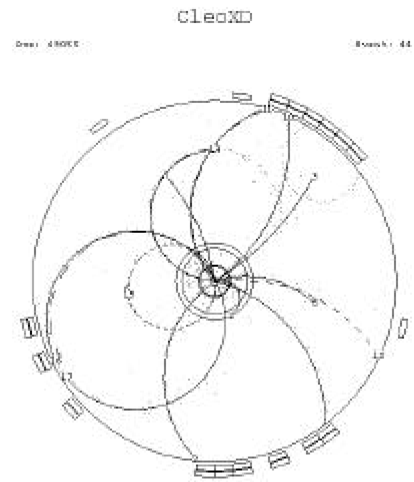
- In this parameterization, V_{ub} and V_{td} are the only terms which can produce CP violation.

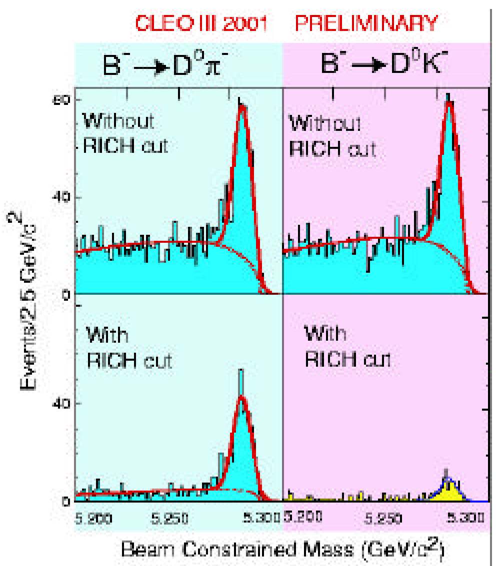
$$\begin{Bmatrix} 1-l^2/2 & l & Al^2(r-ih) \\ -l & 1-l^2/2 & Al^2 \\ Al^3(1-r-ih) & -Al^2 & 1 \end{Bmatrix}$$

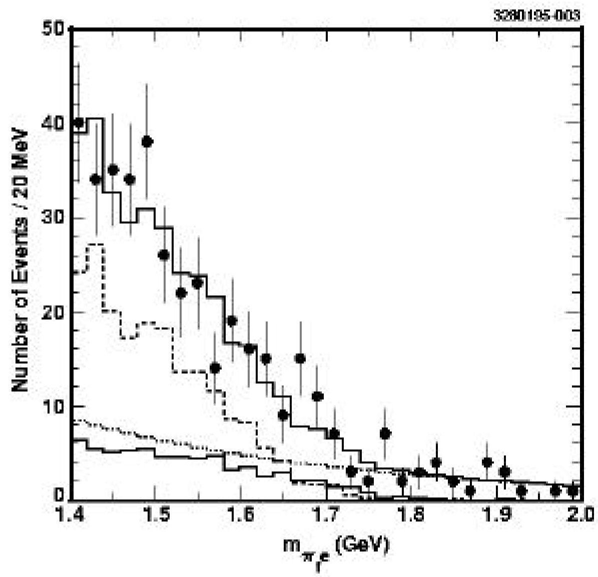
The sizes of the four parameters are as follows: $A \approx 1,\ l \approx 0.22,$

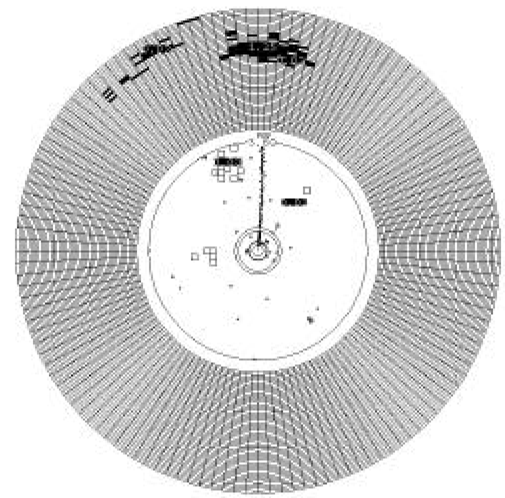

Helium Reservoir
Muon Chambers
Superconducting Coil
Barrel Shower Detector
Drift Chamber
SVX Detector
Micro-Beta Quadrupole
Vertex Detector
End Cap Time of Flight
Pole Tip Shower Detector
Time of Flight Scintillators
Magnet Yoke
0
1
2
3
4
Meters

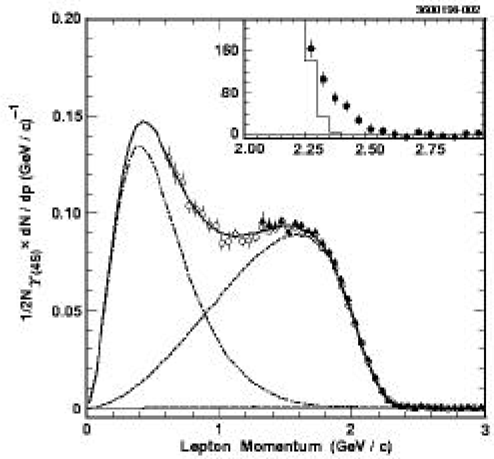

Barrel Cal
Particle ID
Endcap Cal
Drift Chamber
Si
CESR Quads

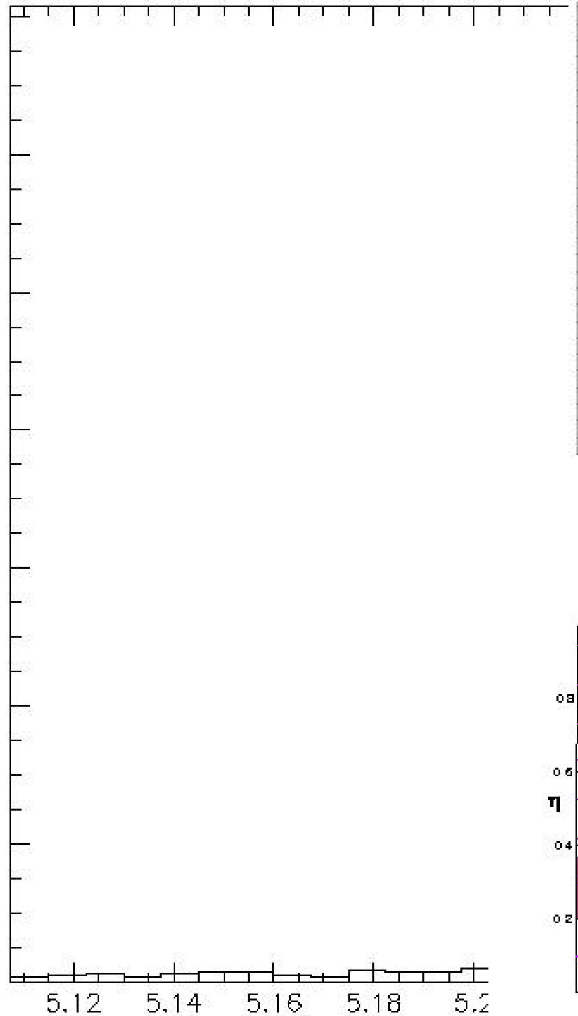

CleoXD

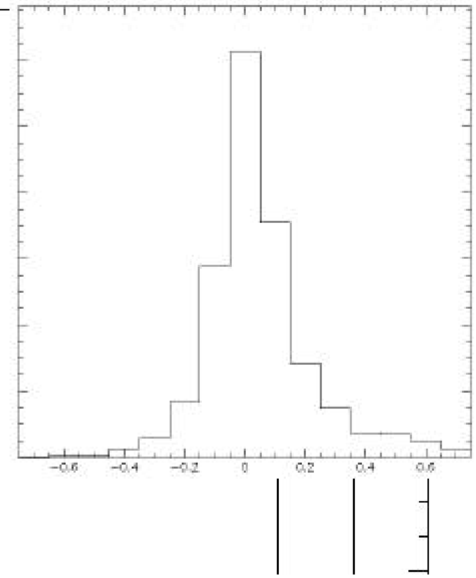

CLEO III 2001
PRELIMINARY
$B^- \rightarrow D^0\pi^-$
$B^- \rightarrow D^0K^-$
Without RICH cut
Without RICH cut
With RICH cut
With RICH cut
Events/2.5 GeV/c^2
Beam Constrained Mass (GeV/c^2)

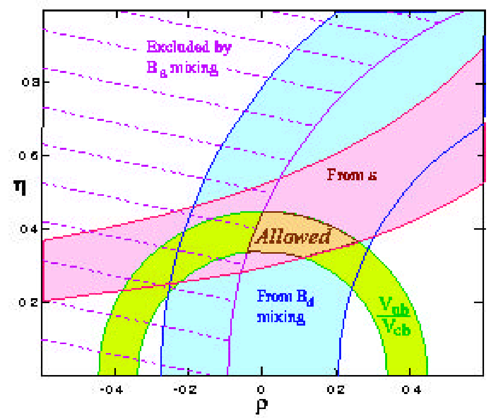

3280195-003
Number of Events / 20 MeV
$m_{\pi_f e}$ (GeV)




Lepton Momentum (GeV / c)
1/2N_Υ(4S) × dN / dp (GeV / c)^-1


5.12 5.14 5.16 5.18 5.2




Excluded by B_s mixing
From ε
Allowed
From B_d mixing
V_ub / V_cb
η
ρ