Leptons at an Exhibition

A Promenade of Recent BaBar Results in Leptonic Decays

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Fermilab Wine and Cheese Seminar
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Programme

- Motivation and Background

- Experiments and Techniques

- Searches and Measurements

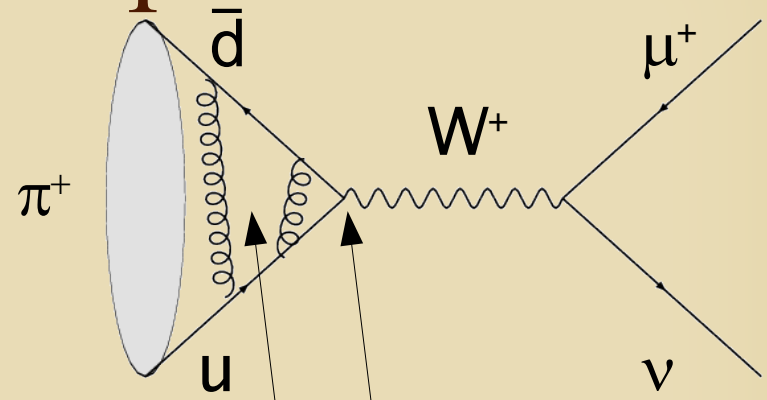
- Interpretation and Outlook

Motivation and Background

The Lure of Leptons

A simple example illustrates the full extent of the attraction:

(And, it scales easily to similar decays starting from a heavy, pseudoscalar meson...)



$$BR(\pi^+ \to \mu^+ \nu) = \frac{G_F^2 m_{\pi^+} m_{\mu^+}^2}{8\pi}\left(1 - \frac{m_{\mu^+}^2}{m_{\pi^+}^2}\right) f_\pi^2 |V_{ud}|^2 \tau_{\pi^+}$$

Pros

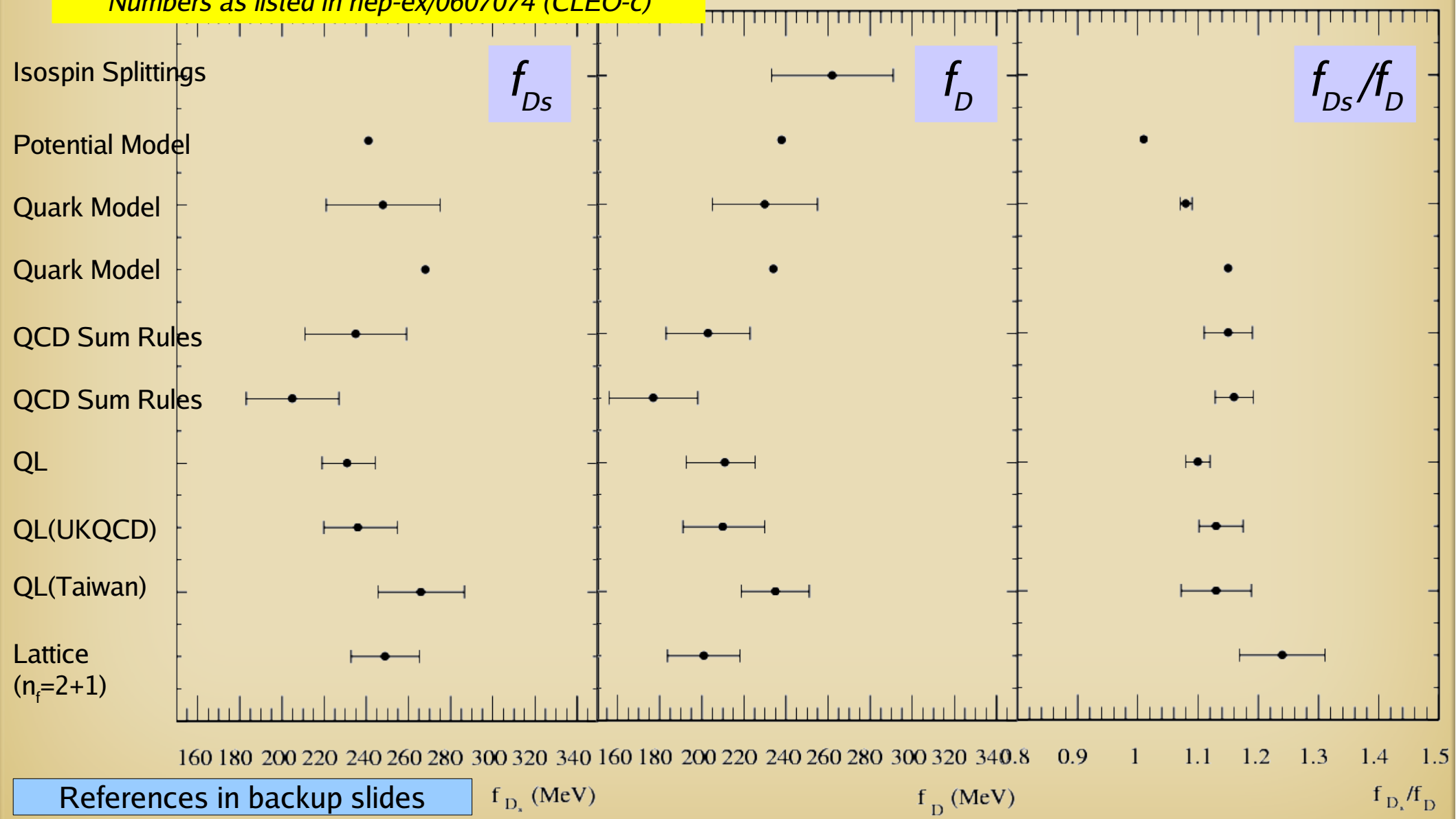
- Relatively free of hadronic uncertainties (encapsulated in "f_X", the "decay constant of meson X")
- Recognizable experimental signature

Cons

- Helicity suppression (m_l^2)
  - less of a con when new physics can enhance the rate over the SM
- Undetectable final state particle

Predictions and Tests of QCD

Numbers as listed in hep-ex/0607074 (CLEO-c)



References in backup slides

Predictions and Tests of QCD

Many predictive techniques in QCD yield expectations for the D and D_s meson decay constants (f_D and f_{Ds}), as well as the B_d and B_s decay constants (f_B and f_{Bs})

Table from talk by G. Shierholz at ICHEP06

Parameter	Estimate	Group	Comments
$\hat{B}_K$	0.83(18) 0.74(2)	HPQCD RBC-UKQCD	$a = 0.125$ fm $a = 0.123$ fm
f_{B_d} [MeV]	216(38)	HPQCD	$a = 0.125$ fm NRQCD* + AsqTad
f_{B_d} [MeV]	216(38)	HPQCD	– ll –
f_{B_s} [MeV]	260(42)	HPQCD	– ll –
$f_{B_s}\sqrt{\hat{B}_{B_s}}$ [MeV]	273(40)	HPQCD	– ll –
ξ	1.21(5)	Okamoto	Combined

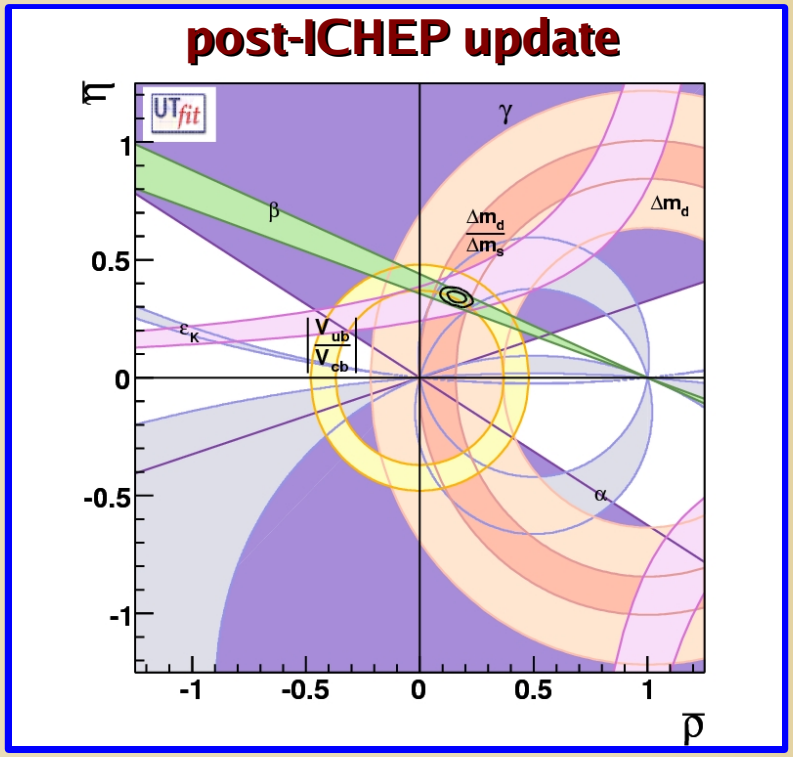
RGI values

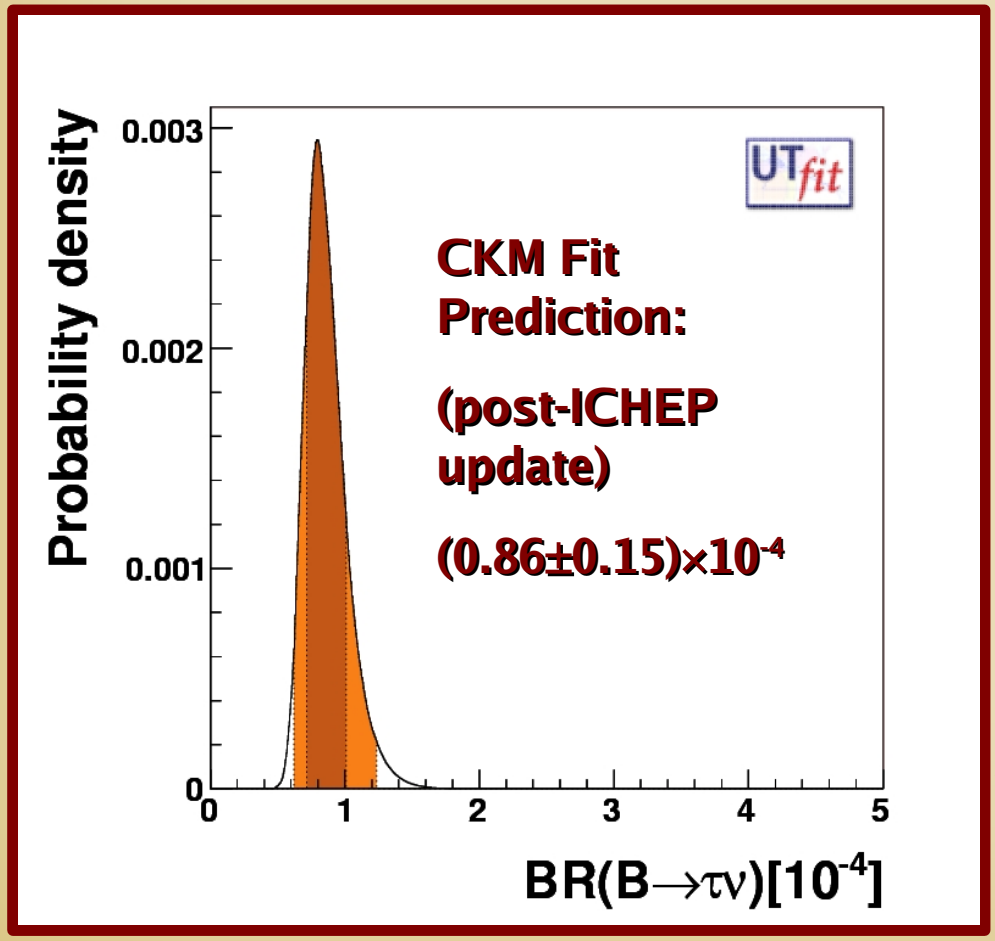
* No continuum limit

We can test QCD computational techniques by measuring leptonic branching fractions, translating them into decay constants, and comparing to prediction.

Leptons and the CKM Formalism

$$\frac{BR(B^+ \to \tau^+ \nu)_{\text{meas}}}{(\Delta m_d)_{\text{meas}}} \xrightarrow{\text{theory}} f(\bar{\rho}, \bar{\eta})$$





The measured branching fraction yields an independent constraint on the plane.

Likewise, all other measurements excluding the BF (and f_B) can constrain it using the theory relations (see left).

Glimpse at New Physics

The most popular New Physics ("NP") scenario to probe is the existence of a charged Higgs boson. An example: a type-II Two-Higgs Doublet Model (2HDM):

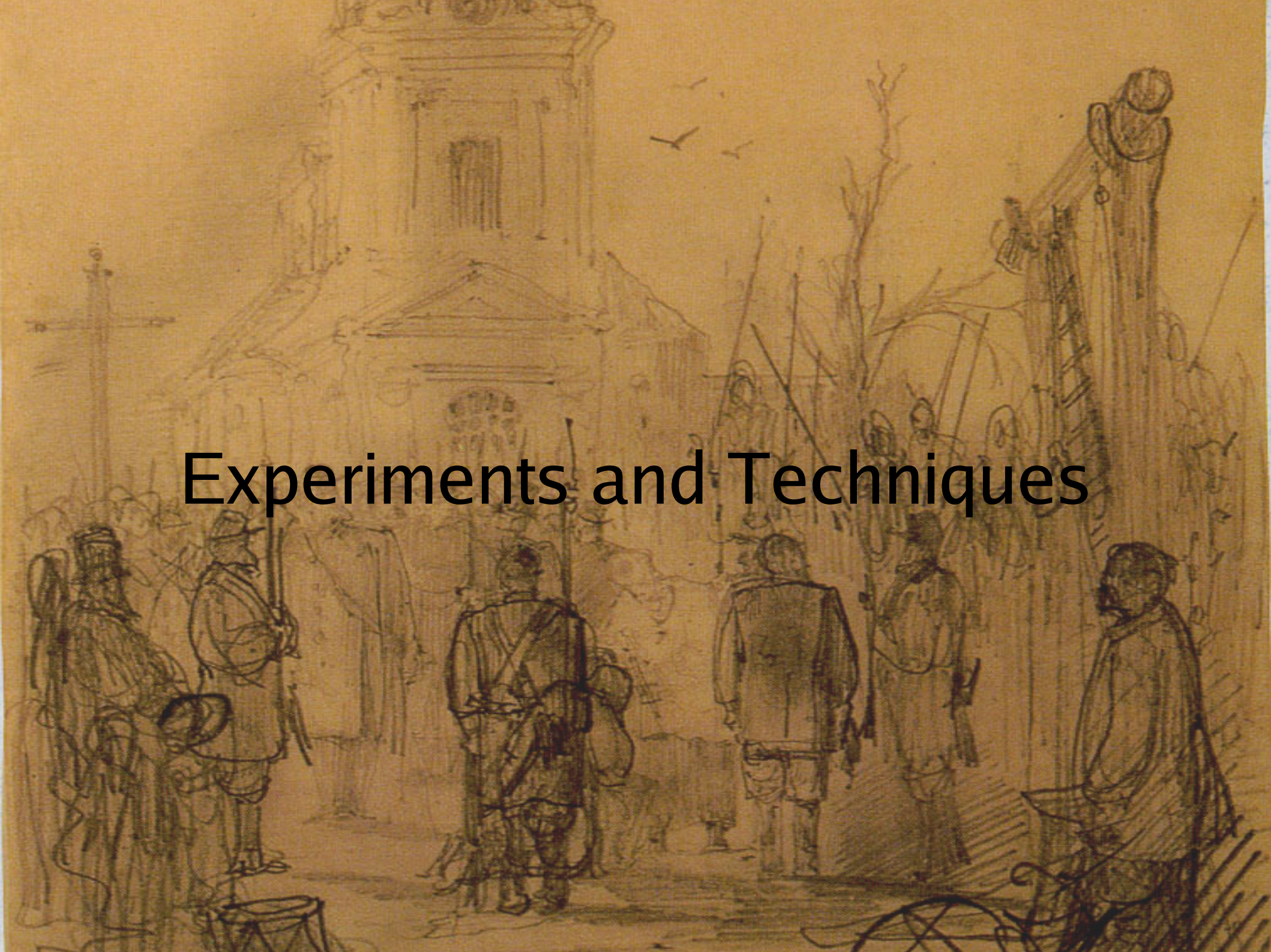
$$BR(B^+ \to l^+ \nu) = BR(B^+ \to l^+ \nu)_{\mathrm{SM}} \times \left| 1 - \tan^2\beta \frac{m^2_{B^+}}{m^2_{H^+}} \right|^2$$

The ratio of VEVs for the up-type and down-type quarks

The Higgs mass

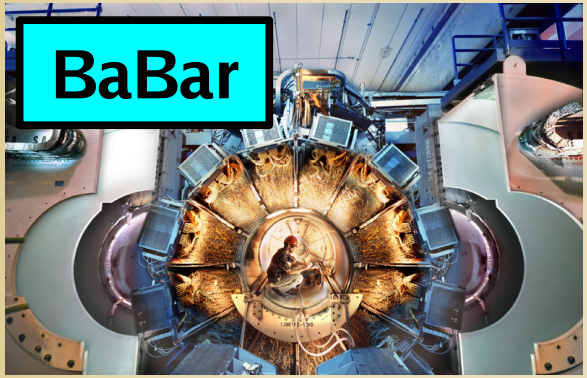
W.-S. Hou, Phys. Rev. D. Brief Report 48 (1993) 2342

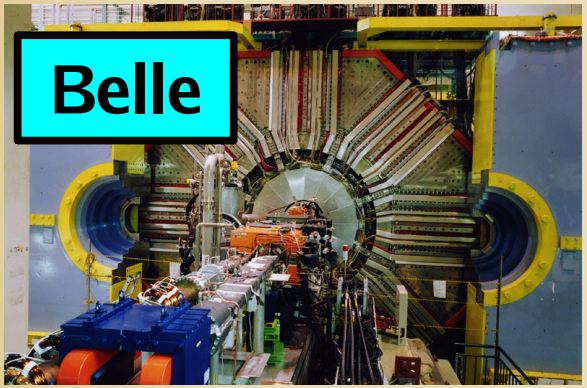
Comparing the measured and SM-predicted branching fractions will help constrain models of NP, such as this one. Other models (full MSSM, etc.) also make predictions about leptonic final states.

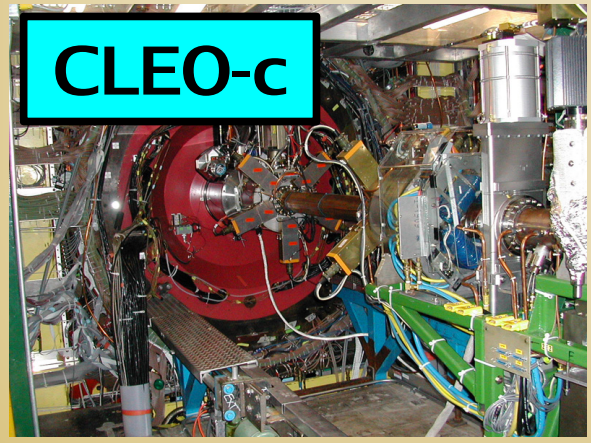


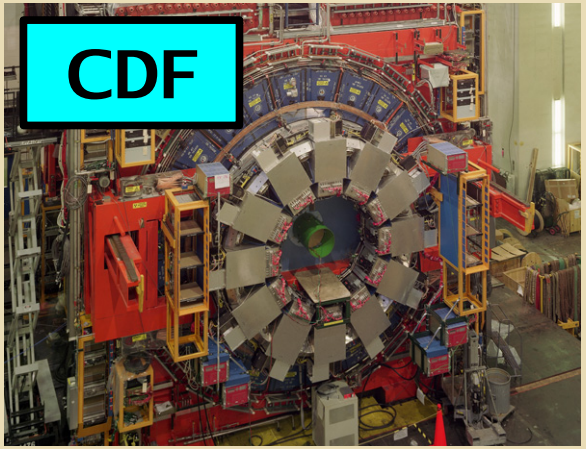
Experiments and Techniques

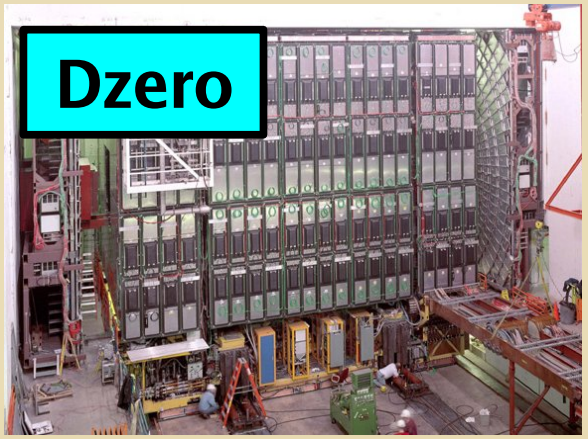
Experiments









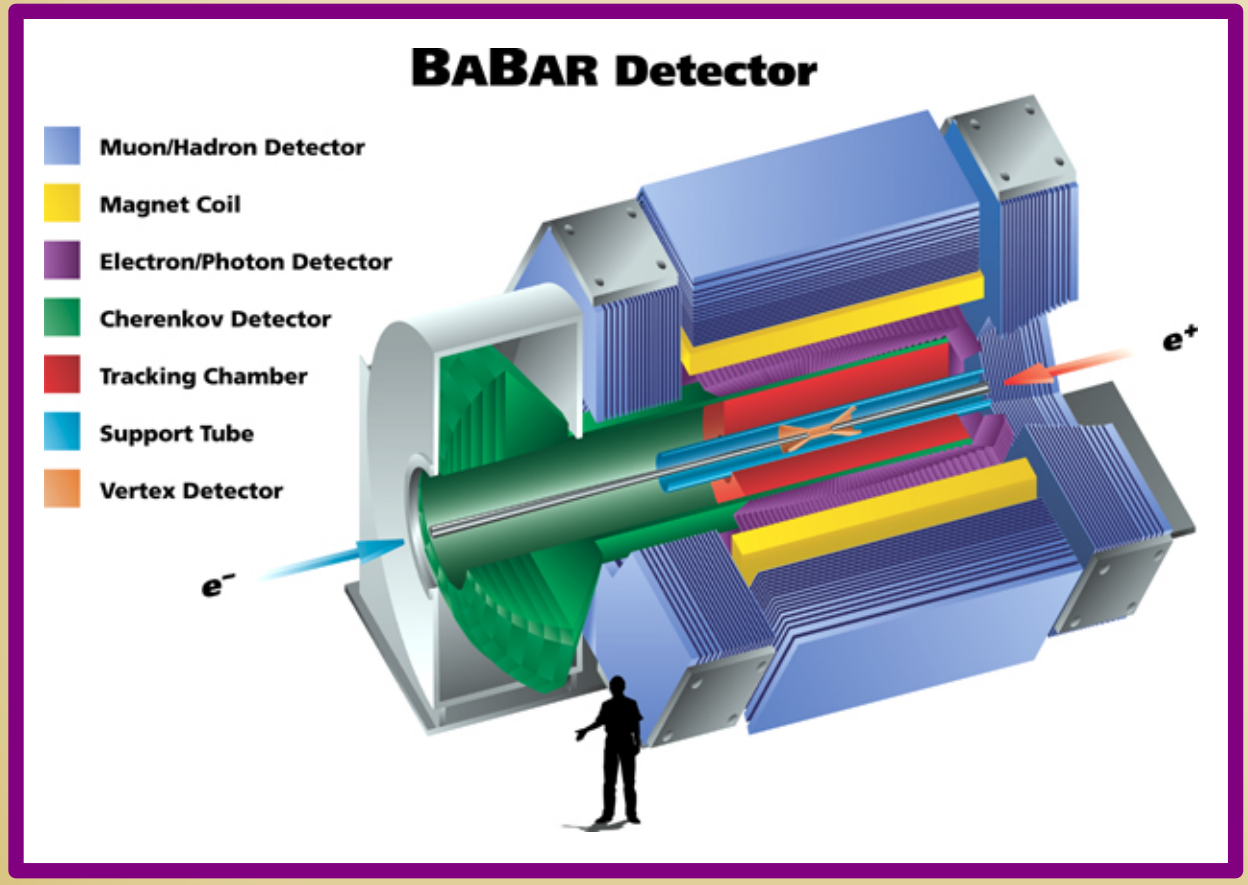


There are currently many active experiments which produce and study heavy flavor in large numbers.

I will present results primarily from BaBar, making comparisons to Belle, CLEO-c, and the Tevatron where appropriate.

The BaBar/PEP-II B-Factory

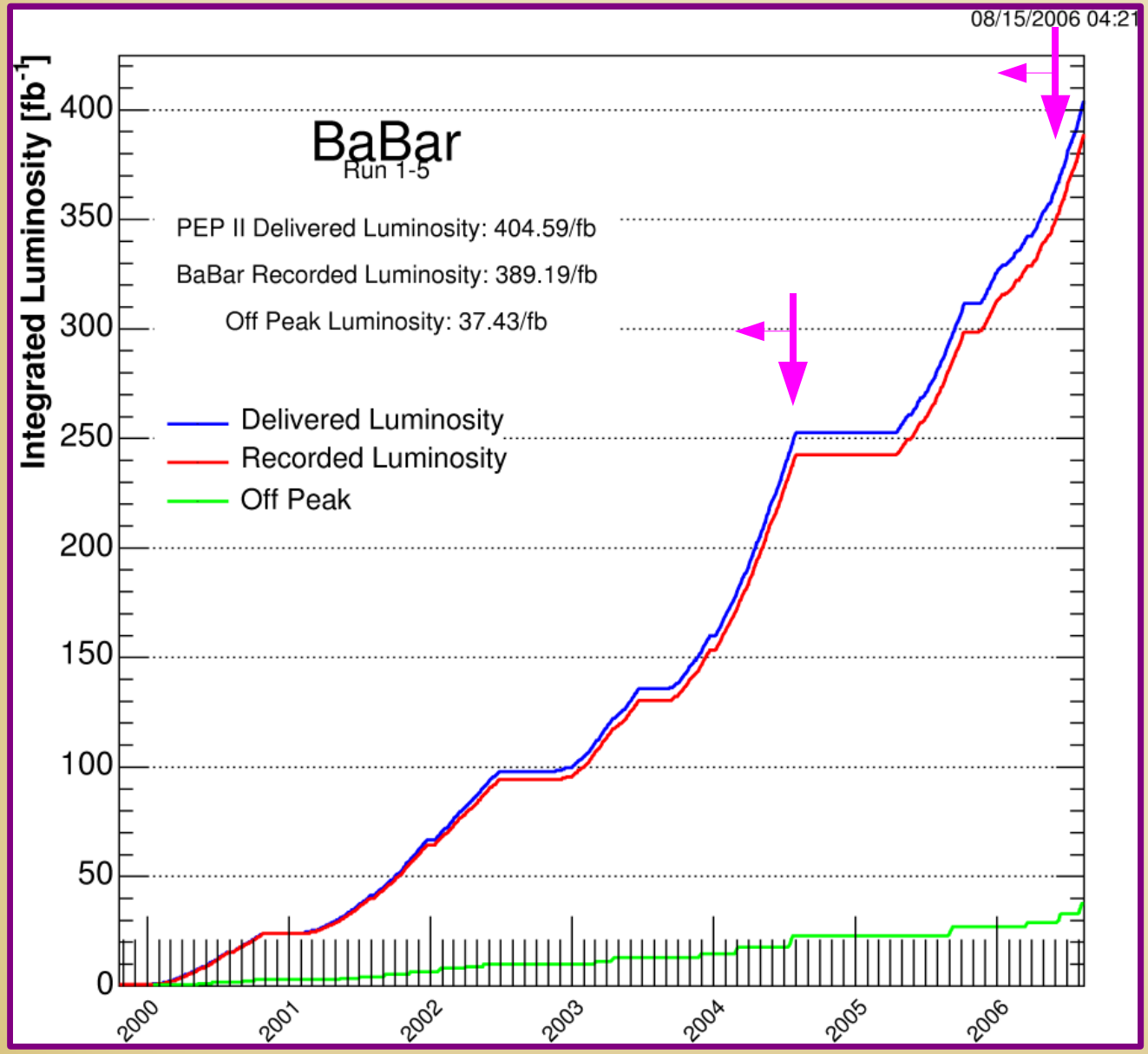
PEP-II: an asymmetry energy electron-positron collider operating at $\sqrt{s}$=10.58 GeV (Υ(4S) resonance)
Routinely exceeds instantaneous luminosities of $10 \times 10^{33}/cm^2/s$ (over 3 times design). In July-August, PEP-II could deliver over $800 pb^{-1}$/day.



BABAR: a multipurpose asymmetric particle detector, providing:

- Excellent charged particle identification (90%/0.1% eff./pion mis-id for electrons, 70%/2.5% eff./pion mis-id for muons)
- Good energy resolution
- Good solid-angle coverage (~90%)

A Data Gallery



PEP-II has now delivered over 400 fb^{-1} of integrated luminosity, of which BaBar recorded 390 fb^{-1}.

Results from BaBar I show today are obtained from two data epochs, indicated with arrows.

I will indicate other experiments' data sets where appropriate.

Analysis Techniques I

Beam Kinematics

- Mesons produced directly by the beams must satisfy collider-based kinematic constraints
- Define "Energy-Substituted Mass" (m_{ES}) and "Energy Difference" (ΔE) variables, characterizing such production:

$$m_{ES} = \sqrt{(E^*_{beam})^2 - (p^*_B)^2} \qquad \Delta E = \sqrt{m_B^2 + p_B^{*2}} - E^*_{beam}$$

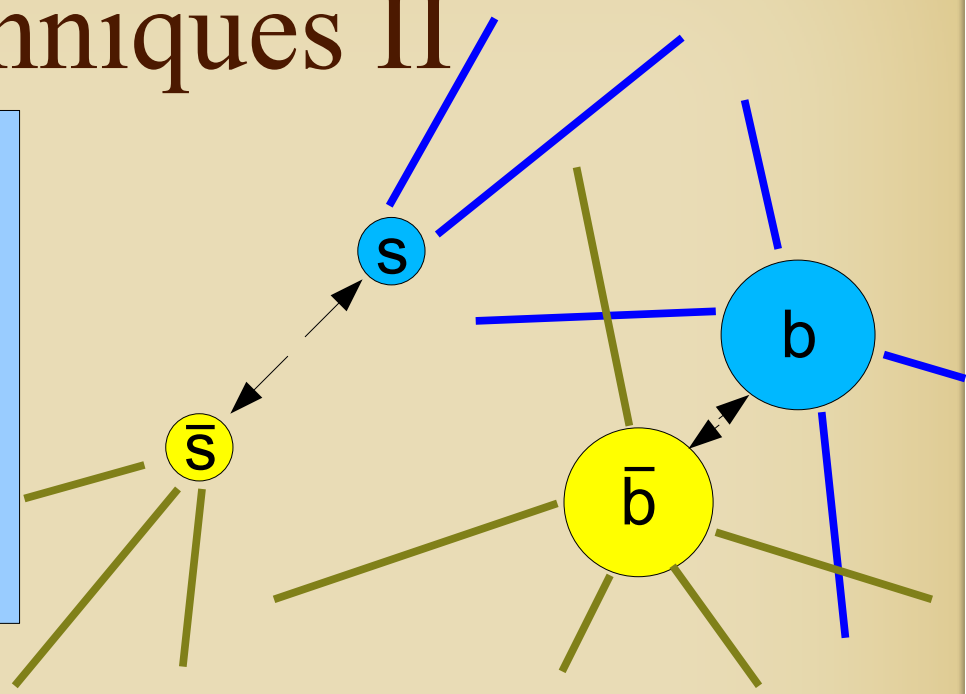
"Single B/c Beam" or "Tag B/c" Methods

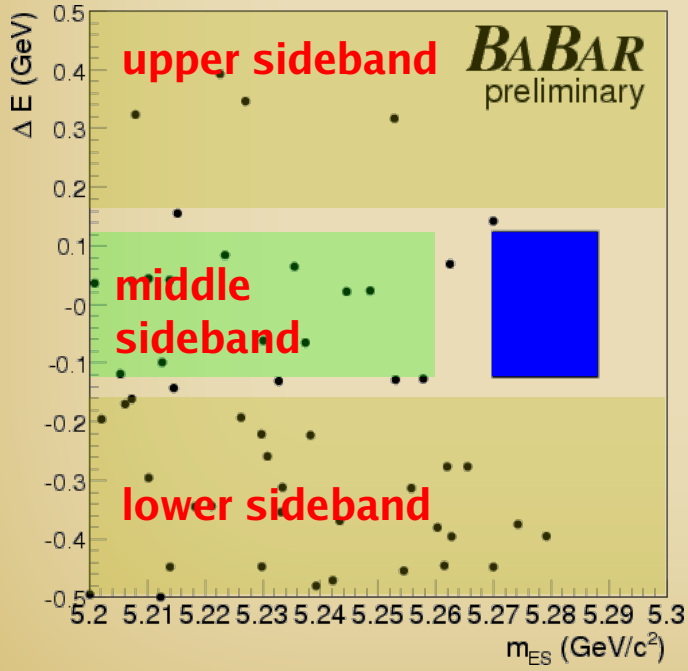
- Takes advantage of anticipated quark/anti-quark system (b,c)
- Reconstruct one of the two bottom/charm mesons in a well-defined final state, "tagging" the event as either $B\bar{B}$ or $c\bar{c}$.
- Search in the recoiling particles (the "single B/c beam") for evidence of the target rare decay

Analysis Techniques II

Non-resonant Background Rejection

- Light quark events typically more “jetty”
- Use a suite of event-shape variables, such as thrust angles, Fox-Wolfram moments, etc. as selection variables or in a multivariate (Fisher, NN) approach.





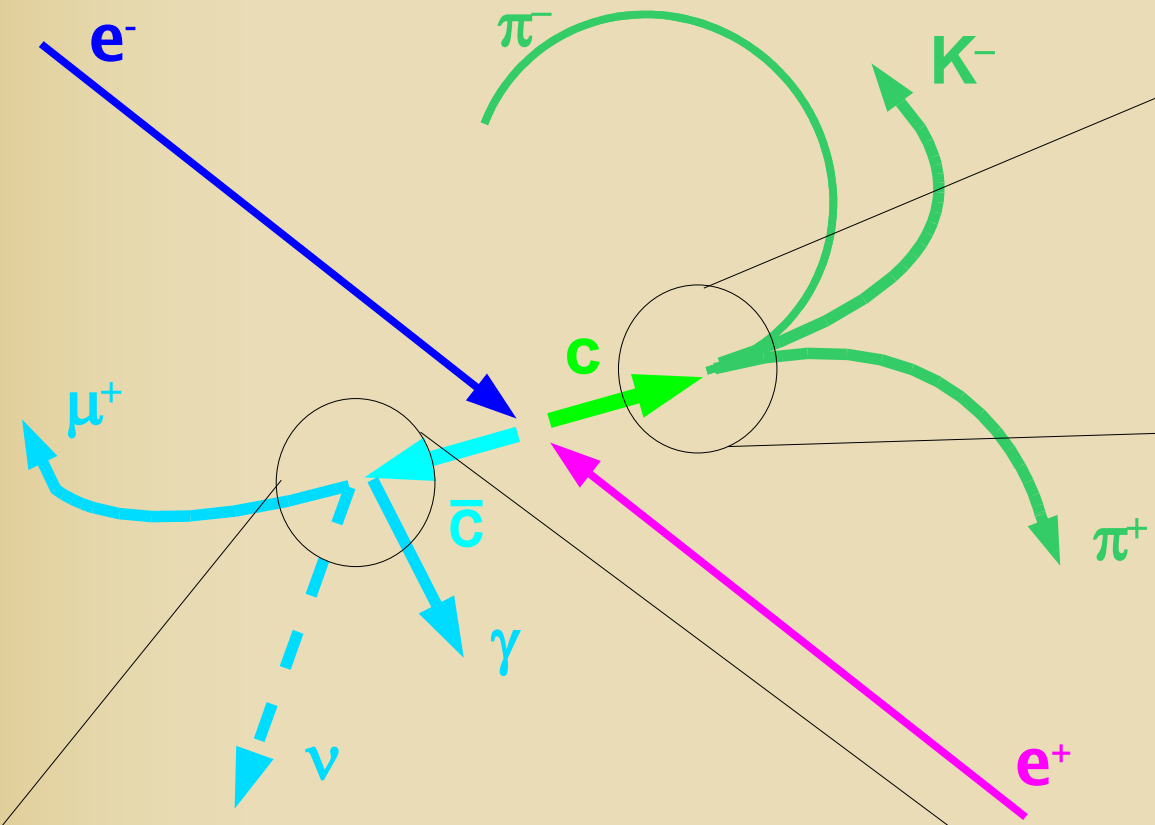
“Blind” signalbox

Signalbox(es)/Sideband(s)

- Use one or more discriminating variables in which signal “peaks” and backgrounds are distributed (or also peak)
- Define signal-rich regions (signal box) and background-rich regions (sidebands) as control samples

Searches and Measurements I: $D_s^+ \to \mu^+\nu$ and $D_s^+ \to \tau^+\nu$

Charm Tagging



Reconstruct one charm quark fragmentation in one of many well-defined final states, "tagging" the events as $c\bar{c}$.

Identify $D_s^+ \to \mu^+\nu$ by reconstructing

$$D_s^{*+} \to \gamma D_s^+ (\to \mu^+ \nu)$$

performing a neutrino reconstruction by using both signal and tag kinematic information...

Charm tagging yields a powerful suppression of backgrounds from light-quark, non-resonant and b-quark decays.

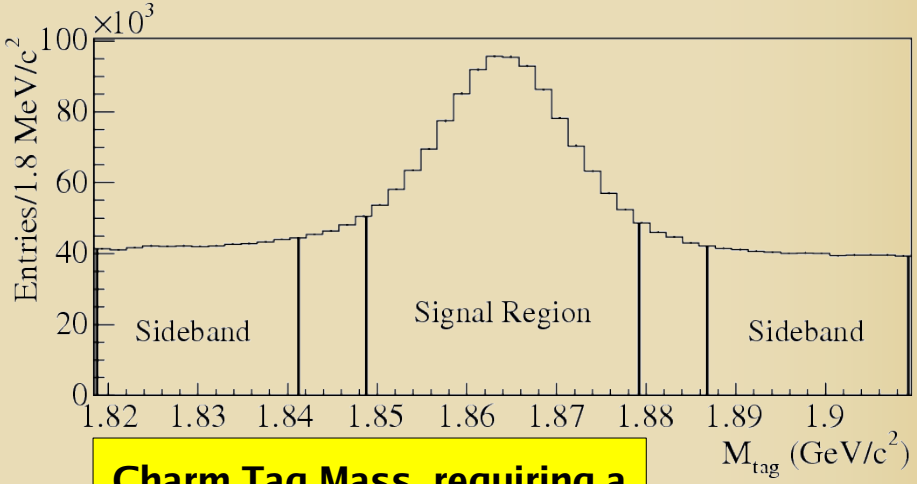
Signal Selection

BABAR: 230.2 fb^{-1} (at or near the Υ(4S) resonance)

Charm Tagging: Modes

$$D^0 \to K^-\pi^+(\pi^0), K^-\pi^+\pi^-\pi^+$$
$$D^+ \to K^-\pi^+\pi^-(\pi^0), K_s^0\pi^+\pi^+\pi^-, K^+K^-\pi^+, K_s^0K^+$$
$$D_s^+ \to K_s^0K^+, \phi\rho^+$$
$$D^{*+} \to \pi^+D^0, D^0 \to K_s^0\pi^+\pi^-(\pi^0), K_s^0K^+K^-, K_s^0\pi^0$$

Tag purity and, if needed, vertex probability are used to decide among multiple candidates.



Charm Tag Mass, requiring a recoiling muon

Select signal candidates in the recoil:

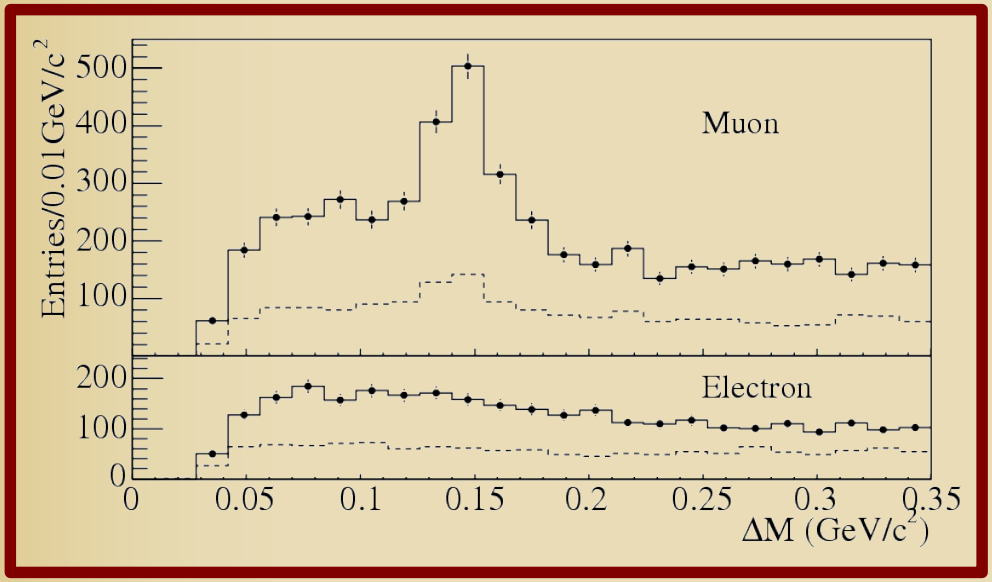
- Identify muon candidate with p_{CM}>1.2 GeV/c
- Identify photon candidate from D_s^{*+} decay to γ D_s^+ (E_{CM}>0.115 GeV)
- Require Missing Energy > 0.38 GeV

Signal Reconstruction Efficiency: 8.13%

- Reconstruct neutrino momentum
  - Estimate from muon and missing momenta
  - Rescale by minimizing the magnitude of the difference between the hypothetical neutrino and missing momenta, while constraining $M_{\mu\nu} = M_{Ds+}$
  - Require the difference in the missing momentum and neutrino momentum magnitudes to exceed -0.06 GeV/c, and $\theta_\nu^* > 38°$

Background Estimate

Define ΔM variable: $\Delta M = M_{\mu\nu\gamma} - M_{\mu\nu}$



Events from tag signalbox

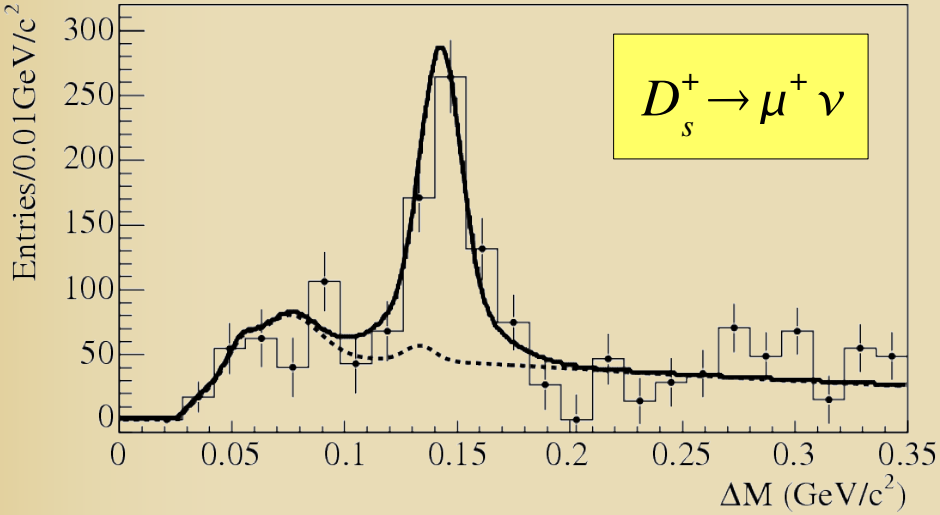
Events from tag sidebands

Several classes of background:

- Non-resonant background (light quark, etc.) with a fake charm tag (42%) *(ESTIMATE FROM SIDEBANDS)*
- Correct tags with muons from semileptonic charm decay or tau decay to muon (26%) *(ESTIMATE FROM ΔM DISTRIBUTION USING RECOIL ELECTRONS)*
- Muons from $D_{(s)}^+ \to \mu^+\nu$ where the photon is really from π^0 decay, or where the decay was really $D^+ \to \mu^+\nu$. (20%) *(ESTIMATE FROM MC SIMULATION)*
- Remaining background (~12%) estimated from MC (flat ΔM shape)

Determine the shape of signal and background using MC where necessary and data (sidebands) where possible. Perform maximum likelihood (ML) fit to extract signal yield...

Results (I)



Fitted signal yield:

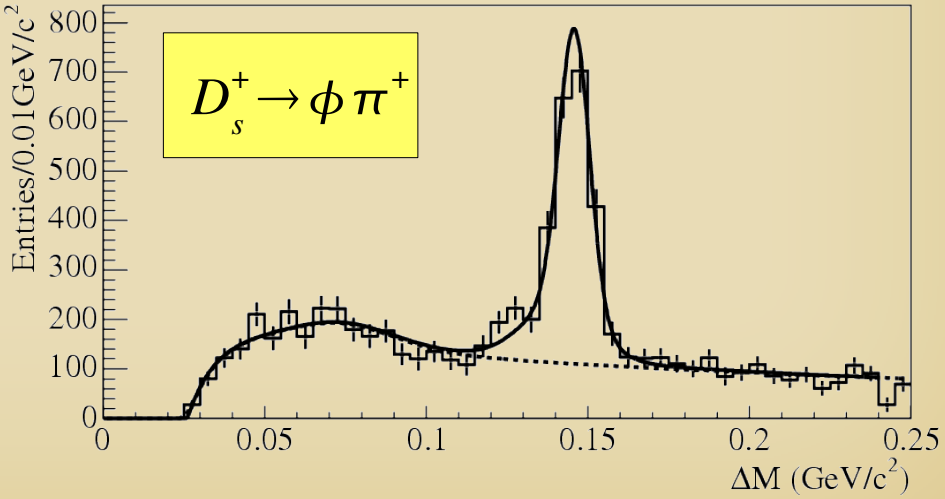
$$N_{\text{sig}}^{\mu\nu} = 489 \pm 55\,(\text{stat.})$$

We cannot measure the BF absolutely, since we do not know the production cross-section. Instead, measure:

$$\Gamma(D_s^+ \to \mu^+\nu)/\Gamma(D_s^+ \to \phi\pi^+)$$

Reconstruct $\phi \to K^+K^-$, requiring ϕ and D_s^+ candidates to be within 2σ of nominal masses (determined from fit to data and MC). The efficiency of the reconstruction is 9.9%. Perform similar ML fit:

$$N_{\text{sig}}^{\phi\pi} = 2093 \pm 99\,(\text{stat.})$$



Results (II)

We determine the branching fraction to be:

$$B(D_s^+ \to \mu^+ \nu) = (6.74 \pm 0.83(stat.) \pm 0.26(syst.) \pm 0.66(\phi\pi)) \times 10^{-3}$$

(using the BaBar measurement:

$$B(D_s^+ \to \phi\pi^+) = (4.71 \pm 0.46)\%)$$

We determine the meson decay constant to be:

$$f_{D_s} = (283 \pm 17(stat.) \pm 7(syst.) \pm 14(\phi\pi))\,\mathrm{MeV}$$

Using $f_D = 222.6 \pm 16.7^{+2.8}_{-3.4}\,\mathrm{MeV}$

CLEO-c, Phys. Rev. Lett. **95**, 251801 (2005)

$$f_{D_s} / f_D = (1.27 \pm 0.14)$$

BaBar Results submitted to PRL (hep-ex/0607094)

Corrections

Correction due to tag efficiency difference between $\phi\pi$ and $\mu\nu$	-1.4%
Correction due to simulation of D_s^{*+} momentum spectrum	+1.5%

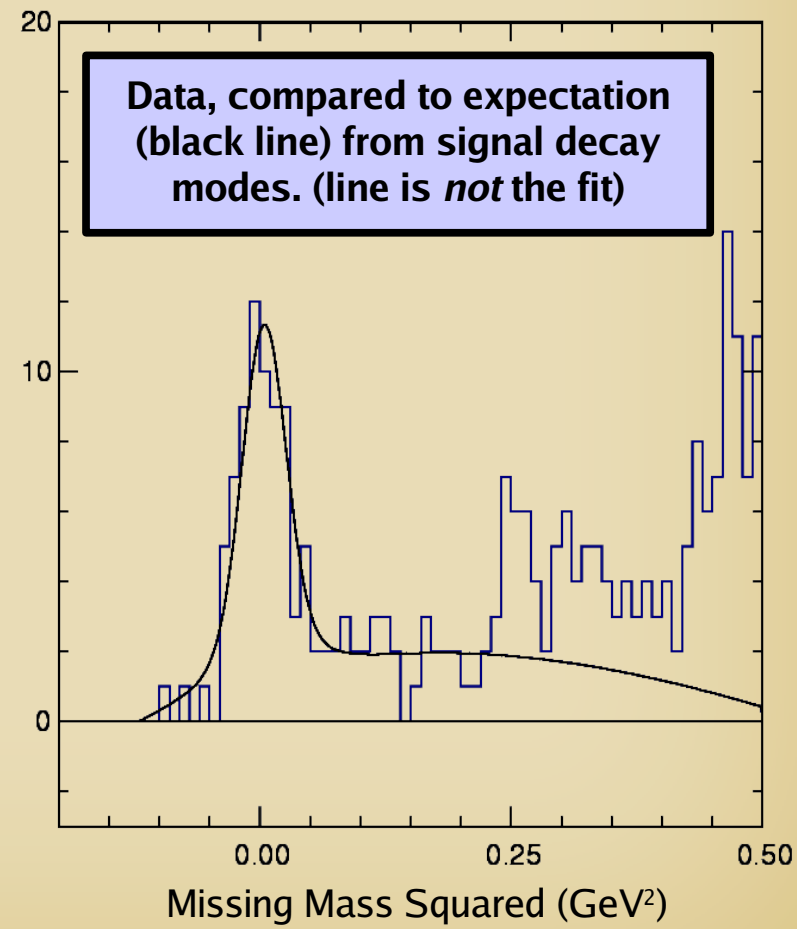
Uncertainties

Above corrections	1.0%
Signal efficiency	1.4%
$\phi\pi$ Vertexing	0.7%
Track Reconstruction	1.2%
Signal MC statistics	1.1%
PDF Shape (signal)	0.9%
PDF Shape (bkg.)	2.3%
Electron subtraction	0.4%
$B(\phi \to K^+K^-)$	1.2%
Background from $f^0(980)\pi^+$	1.1%

RESULTS ARE PRELIMINARY

Hot Off the Press

CLEO-c presented at ICHEP '06 their results on the search for both $D_s^+ \to \mu^+\nu$ and $D_s^+ \to \tau^+\nu$. They use data taken at the $D_sD_s^*$ threshold (4170 MeV), and also charm tag to identify the D_s meson. See hep-ex/0607074 and Sheldon Stone's ICHEP Heavy Quark session talk (07/27/06).



Signal events are determined by a fit to the event's missing mass spectrum. They can study the muon and tau contributions separately, and determine:

$$B(D_s^+ \to \mu^+\nu) = (6.57 \pm 0.90(stat.) \pm 0.28(syst.)) \times 10^{-3}$$

$$B(D_s^+ \to \tau^+\nu) = (62.9 \pm 7.8(stat.) \pm 5.2(syst.)) \times 10^{-3}$$

BaBar and CLEO-c

Branching Fraction ($\times 10^{-3}$)

BaBar Measurement	CLEO-c Measurement	
$6.74 \pm 0.83(stat.) \pm 0.26(syst.) \pm 0.66(\phi\pi)$	$6.57 \pm 0.90(stat.) \pm 0.28(syst.)$	$\mu^+\nu$
	$62.9 \pm 7.8(stat.) \pm 5.2(syst.)$	$\tau^+\nu$

Meson Decay Constant (f_{Ds})

BaBar Measurement	CLEO-c Measurement
$(283 \pm 17(stat.) \pm 7(syst.) \pm 14(\phi\pi))\,\mathrm{MeV}$	$(280.1 \pm 11.6(stat.) \pm 6.0(syst.))\,\mathrm{MeV}$

The above combines $\mu^+\nu$ and $\tau^+\nu$

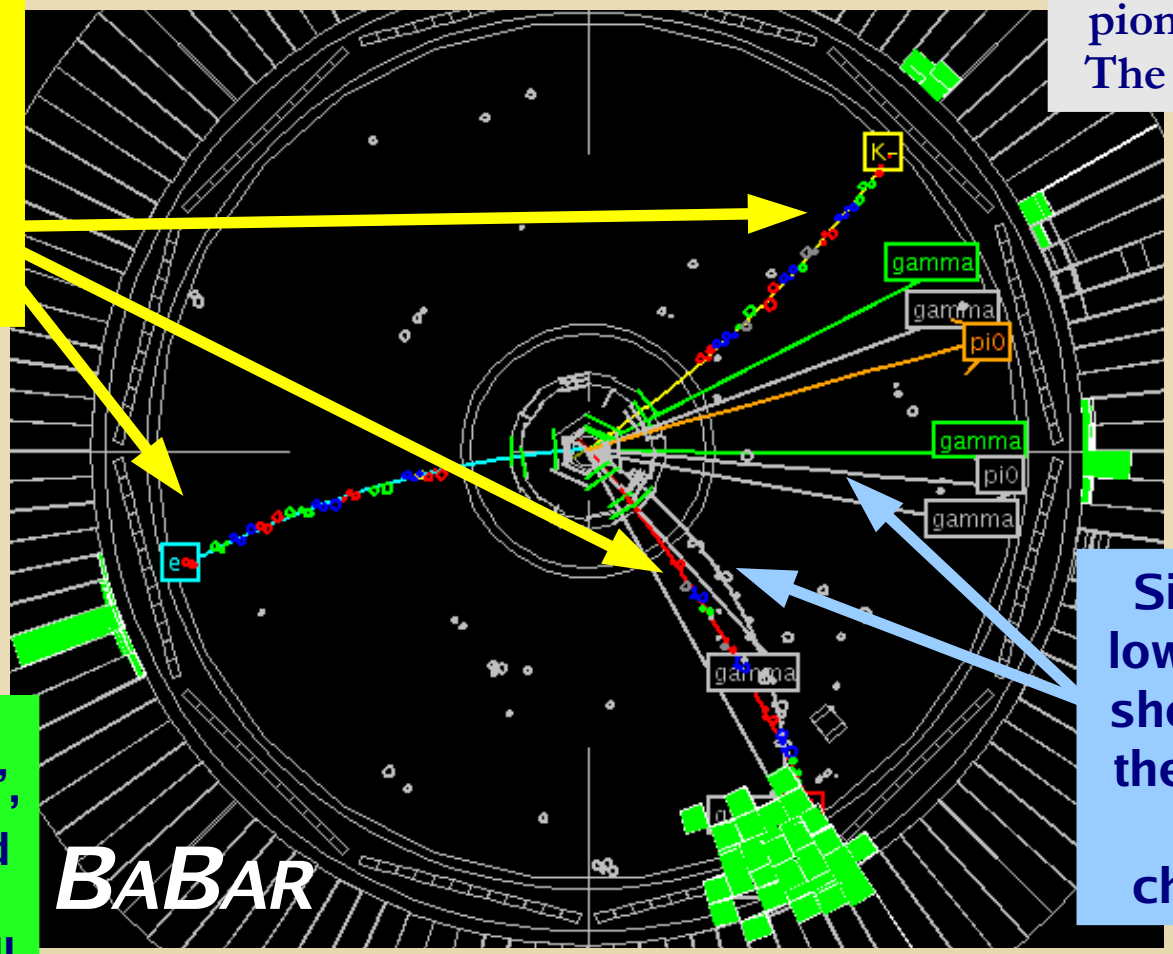
These are very comparable measurements. BaBar's can improve with more data, but a more precise measurement of the $\phi\pi$ branching fraction is needed to make future progress. CLEO-c's measurement is limited only by statistics for now.

Searches and Measurements II: $B^+ \to \tau^+ \nu$

A Sketch: $B^+ \rightarrow \tau^+ \nu$

Tagged signal MC event, where $D^0 \rightarrow K\pi$ and there is a neutral pion from D^{*0} decay. The tau decays to $\pi\pi^0$

Event contains a well-reconstructed "tag" B, here decaying into a semileptonic final state



Signal B decay is low multiplicity and should comprise of the remaining well-reconstructed charged particles

Events then characterized by "E_{extra}", the sum of neutral (and in cases, charged) energy left over after all tag and signal sources are accounted.

Reminder: using all constraints from CKM and lattice QCD, the SM prediction is ~1×10^{-4}

Event Selection I

- Starting from 324×10^6 $B\bar{B}$ events, reconstruct tag B in a semileptonic final state $B\to D^0 l\nu X$

  $D^0\to K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, $K^-\pi^+\pi^0$, $K^0_s\pi^+\pi^-$

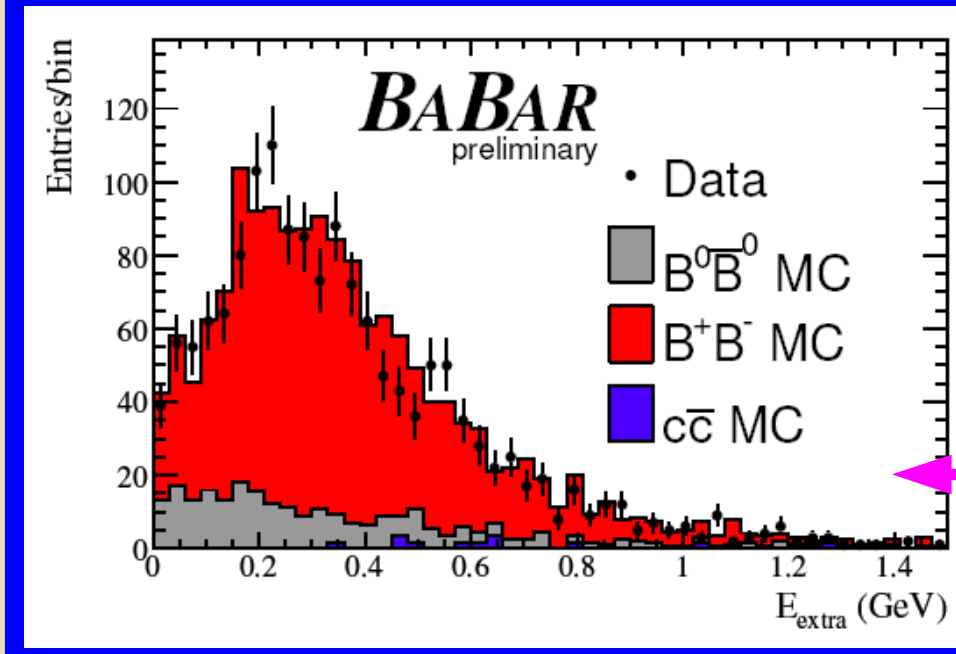
  $X = \gamma, \pi^0$ from D^{*0} decay, which we do not explicitly reconstruct

  Require lepton CM momentum > 0.8 GeV/c

  Require that $-2.0 < \cos\theta_{B\text{-}D0l} < 1.0$, where

$$\cos\theta_{B^+-D^0l^+} = \frac{2E_{B^+}E_{D^0l^+} - m_B^2 - m_{D^0l^+}^2}{2|\vec{p}_{B^+}||\vec{p}_{D^0l^+}|}$$

  and we determine the parent B energy and momentum from the collider energy



Data are from double-tag events, showing the extra energy distribution.

- **Tag B reconstruction efficiency:** $(6.77\pm0.05(stat.)\pm0.10(syst.))\times10^{-3}$

  We study the tag reconstruction efficiency in "double-tag" events, where both B mesons are reconstructed as $B\to D^0 l\nu X$, and correct based on the data/MC comparison

Event Selection II

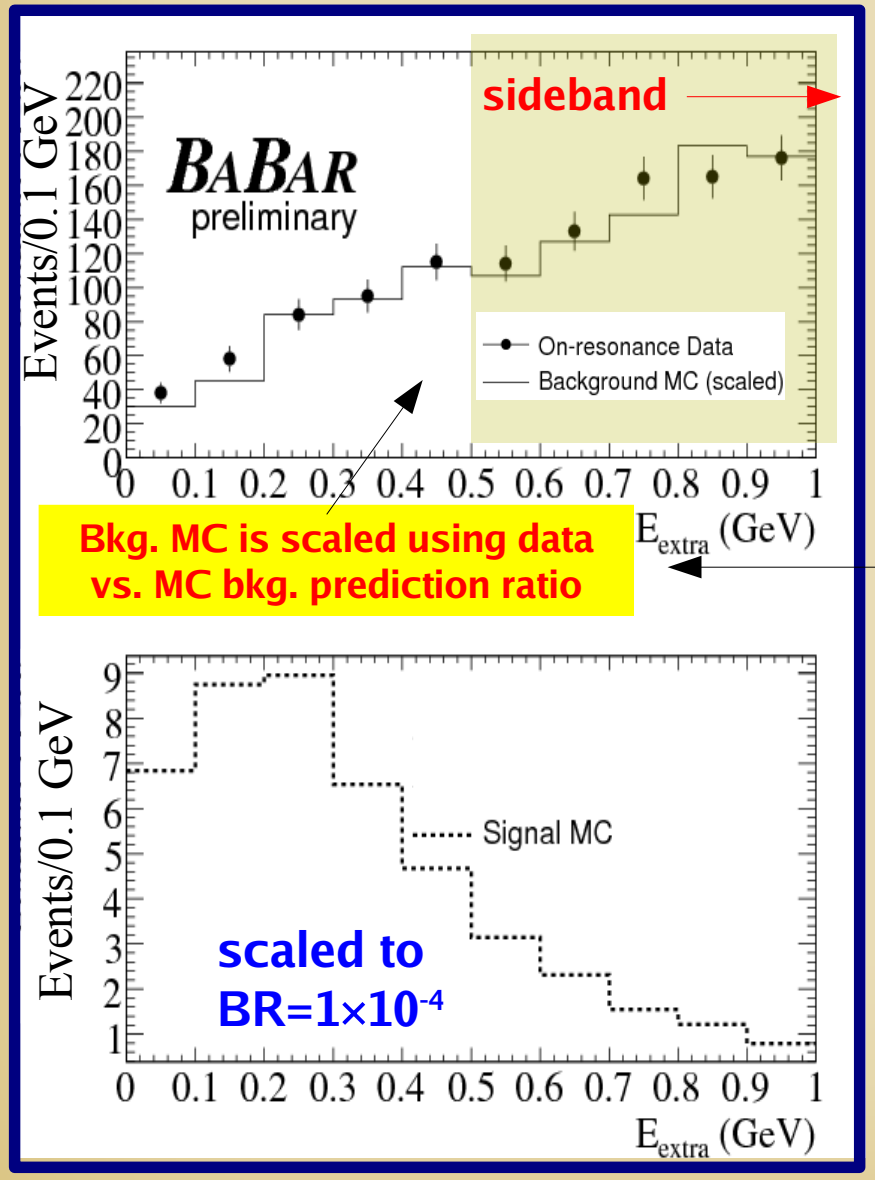
We select signal candidates as $\tau^+ \to \varrho^+\nu$, $\mu^+\nu\nu$, $e^+\nu\nu$, $\pi^+\nu$

$\tau^+ \to e^+\nu_e\bar{\nu}_\tau$	$\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$	$\tau^+ \to \pi^+\bar{\nu}_\tau$	$\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$
$4.6 \leq M_{miss} \leq 6.7$	$3.2 \leq M_{miss} \leq 6.1$	$1.6 \leq M_{miss}$	$M_{miss} \leq 4.6$
$p^*_{signal} \leq 1.5$	–	$1.6 \leq p^*_{signal}$	$1.7 \leq p^*_{signal}$
No IFR K^0_L			
$2.78 < R_{\tau\tau} < 4.0$	$2.74 < R_{\tau\tau}$	$2.84 < R_{\tau\tau}$	$2.94 < R_{\tau\tau}$
$m_{ee} > 0.1\,\mathrm{GeV}/c^2$			
$N^{extra}_{\pi^0} \leq 2$	$N^{extra}_{\pi^0} \leq 2$	$N_{EMCK^0_L} \leq 2$	–
–	–	–	$\rho^\pm$ selection: $0.64 < M_{\rho^\pm} < 0.86$ GeV $0.87 < Cos\theta_{\tau-\rho}$
$E_{\mathrm{extra}} < 0.31$ GeV	$E_{\mathrm{extra}} < 0.26$ GeV	$E_{\mathrm{extra}} < 0.48$ GeV	$E_{\mathrm{extra}} < 0.25$ GeV

Background rejection

- constrain the event missing mass and signal candidate momentum
- veto events with reconstructed K^0_L candidates or extra neutral pions
- reject non-resonant background using a combination of thrust and minimum invariant mass information ($R_{\tau\tau}$)

Extra Energy



The final discriminant is E_{extra}, the sum of all unused energy from charged and neutral particles. We obtain our final background prediction by scaling the sideband region in data using the sideband/signalbox ratio from MC:

Mode	signal region (Proj)	signal region (MC)
electron	41.91 ± 5.19	39.72 ± 4.07
muon	35.39 ± 4.16	36.13 ± 4.02
pion	99.09 ± 9.10	87.69 ± 7.72
rho	15.30 ± 3.48	15.81 ± 3.58

Signal efficiency (relative to the number of semileptonic tag Bs):

Mode	Efficiency (BF Included)
$\tau^+ \to e^+\nu_e\bar{\nu}_\tau$	0.0414 ± 0.0009
$\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$	0.0242 ± 0.0007
$\tau^+ \to \pi^+\bar{\nu}_\tau$	0.0492 ± 0.0010
$\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$	0.0124 ± 0.0005

ALL RESULTS ARE PRELIMINARY

Hot Off the Press

Selection	Expected Background Events	Observed Events in On-resonance Data
$e^+\nu_e\bar{\nu}_\tau$	41.9 ± 5.2	51
$\mu^+\nu_\mu\bar{\nu}_\tau$	35.4 ± 4.2	36
$\pi^+\bar{\nu}_\tau$	99.1 ± 9.1	109
$\pi^+\pi^0\bar{\nu}_\tau$	15.3 ± 3.5	17
All modes	191.7 ± 11.8	213

BaBar uses a modified frequentist technique to interpret the results, using a ratio of likelihoods, including systematics as Gaussians convoluted with the likelihoods

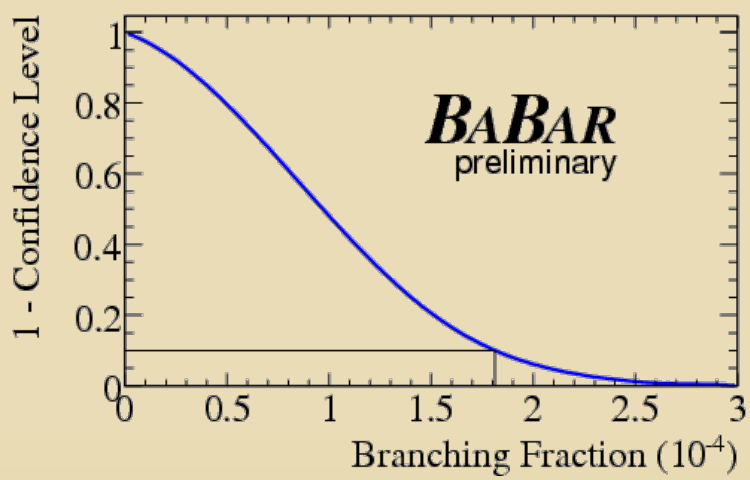
$$BR(B^+ \to \tau^+ \nu) < 1.8 \times 10^{-4} \text{ at the 90\% CL}$$

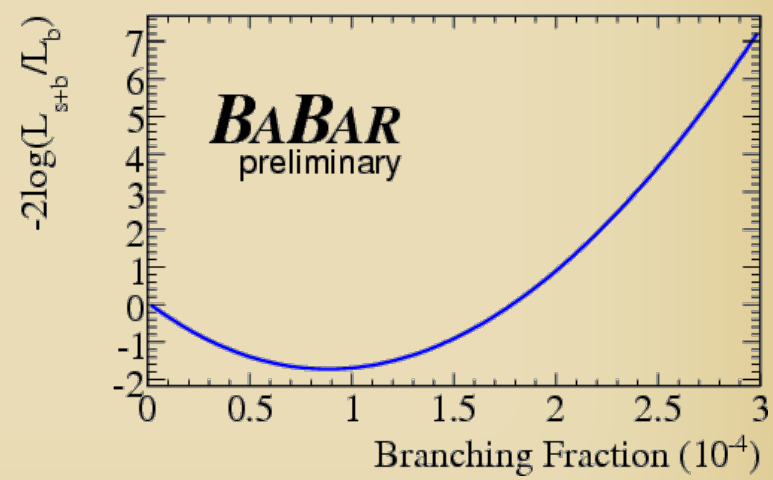
$$N_s = 21.3 \pm 18.8$$

"Naive" signal yield

$$BR(B^+ \to \tau^+ \nu) = (0.88^{+0.68}_{-0.67}(stat.) \pm 0.11(syst.)) \times 10^{-4}$$

BaBar observes a result consistent with zero signal at 1.3σ, so we set a limit and quote a central value.





From this, calculate the product $f_B|V_{ub}|$

$$f_B|V_{ub}| = \left(7.0^{+2.3}_{-3.6}(stat.)^{+0.4}_{-0.5}(syst.)\right) \times 10^{-4} \text{ GeV}$$

ALL RESULTS ARE PRELIMINARY

BaBar and Belle Compared

Compare the measured branching fractions ($\times 10^{-4}$):

$$0.88^{+0.68}_{-0.67}(stat.)\pm 0.11(syst.)$$ **BABAR (324M $B\bar{B}$)**

$$1.79^{+0.56}_{-0.49}(stat.)^{+0.39}_{-0.46}(syst.)$$ **Belle (447M $B\bar{B}$)**

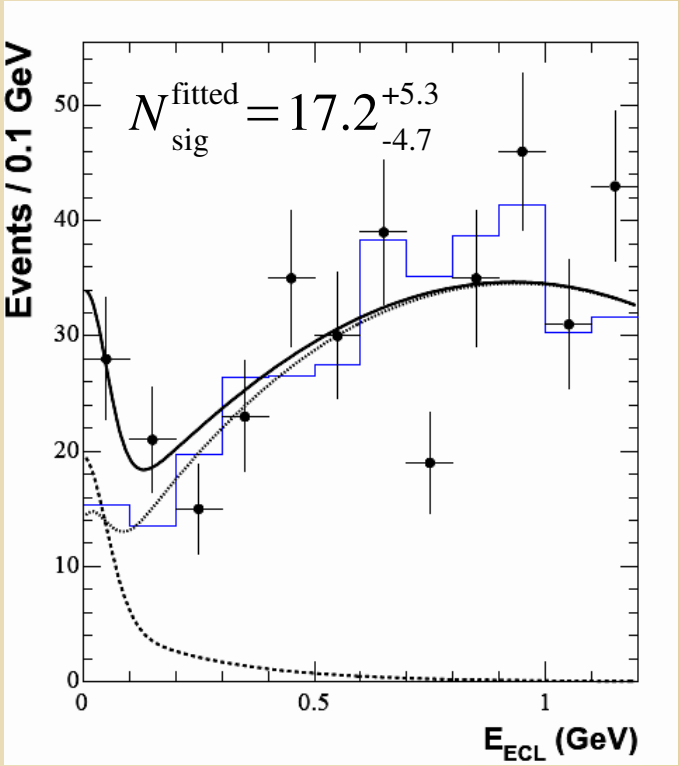
The measurements have comparable uncertainty but differing central values (compatible within uncertainty), allowing Belle to claim 3.5σ evidence.

Compare $f_B|V_{ub}|\times 10^{-4}$ GeV:

$$7.0^{+2.3}_{-3.6}(stat.)^{+0.4}_{-0.5}(syst.)$$ **BABAR (324M $B\bar{B}$)**

$$10.1^{+1.6}_{-1.4}(stat.)^{+1.1}_{-1.3}(syst.)$$ **Belle (447M $B\bar{B}$)**

Belle (447M $B\bar{B}$)
Revised for ICHEP06



Belle uses hadronic tag Bs and fits the extra energy distribution in five tau decay modes (includes 3 pion mode)

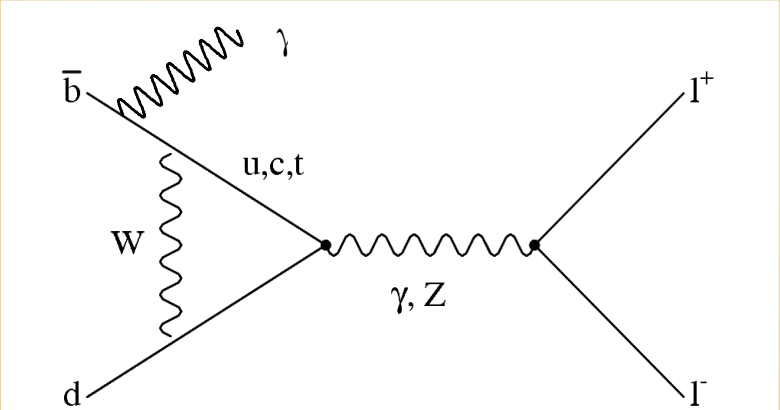
Searches and Measurements III: $B^0 \to \ell^+\ell^-(\gamma)$

Expectations from Theory

Standard Model

Channel	Branching Fraction
$B^0 \to e^+e^-\gamma$	$1.5 \sim 4 \times 10^{-10}$
$B^0 \to \mu^+\mu^-\gamma$	$1.2 \sim 3 \times 10^{-10}$
$B^0 \to e^+e^-$	2.1×10^{-15}
$B^0 \to \mu^+\mu^-$	9×10^{-11}

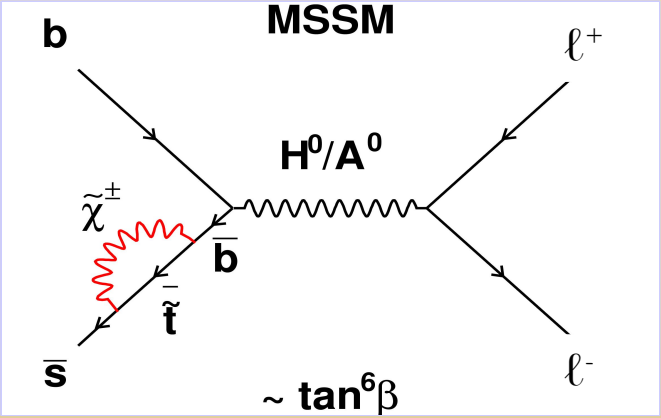
- Photon emission from the initial state relaxes the helicity suppression
- Unlikely to observe SM with current datasets
- Fully reconstructable final state



An example Standard Model diagram

New Physics Models

- Supersymmetry: different models predict different mechanisms
- R-parity violating models allow for tree-level FCNC, enhancing the rate at smaller tanβ.
- MSSM models predict ~tan^{6}β enhancement, allowing for up to 100x enhancement over SM

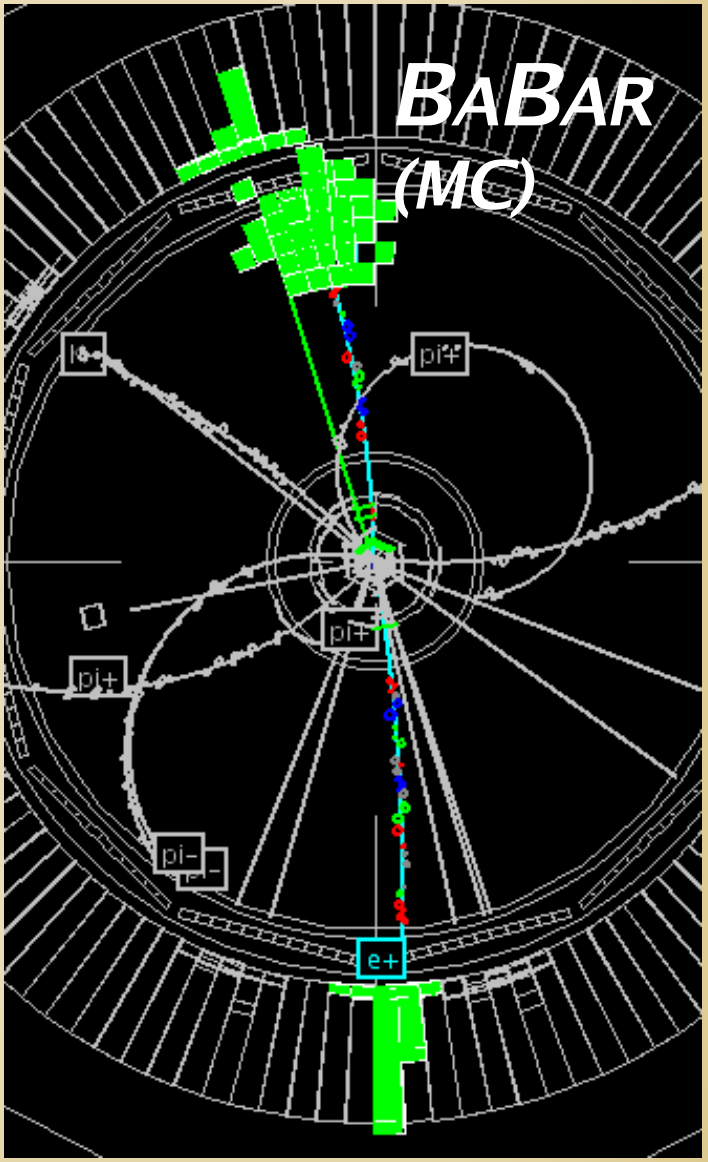


Signal Selection

We search for $B^0 \to \ell^+\ell^-\gamma$ in a sample of 324×10^6 $B\bar{B}$ events

Construct B^0 candidates from two leptons (electron or muon) and a photon

- leptons and photon required to be well within the fiducial region of the detector (reduce ISR, higher-order QED backgrounds)
- leptons required to meet at a common vertex, and $0.3 < m_{ll} < 4.9$ (4.7) GeV/c^2 for electrons (muons)
- Constrain the B candidates to be consistent with production at the $\Upsilon(4S)$ using m_{ES} and ΔE:

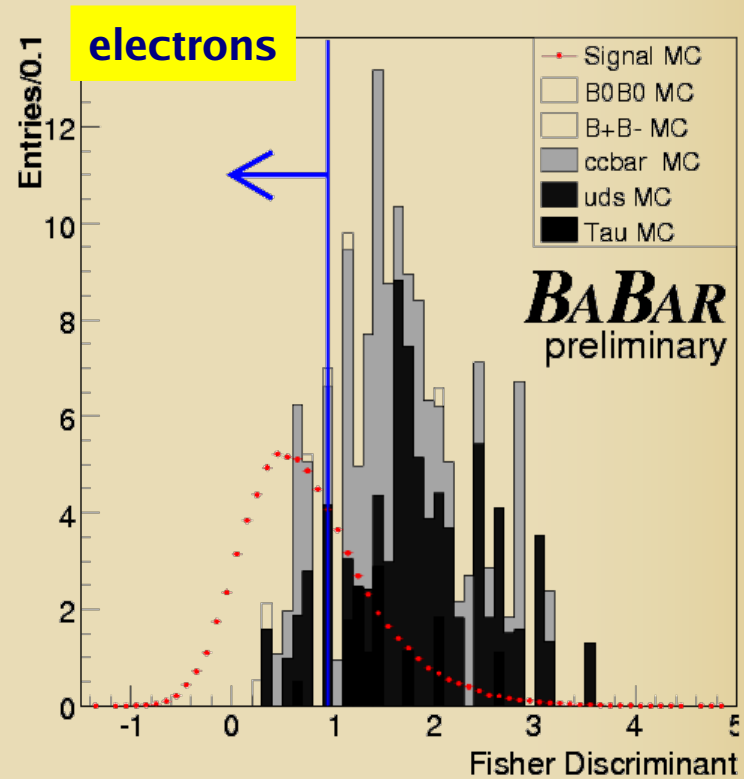


Fully reconstructing the signal B means that a "tag B" technique is unnecessary.

Background Rejection

Reject backgrounds from J/ψ, ψ(2S) decay (leptons) or π^0 decay (photon)

Reject non-resonant $e^+e^- \to q\bar{q}$ (q=u,d,s,c) background using signal B kinematics and event shape information in a Fisher discriminant



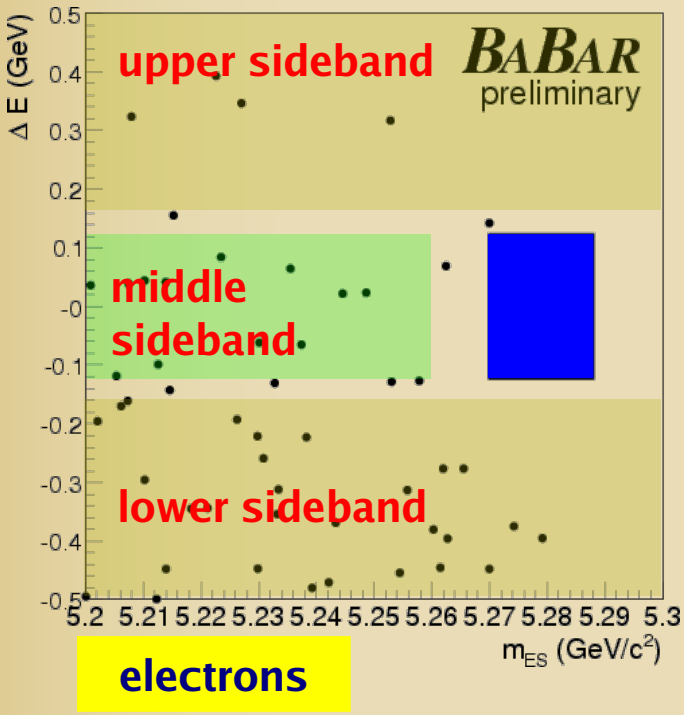
Optimal selection criteria are determined using Monte Carlo simulations and minimizing the predicted upper limit (assuming no signal is observed).

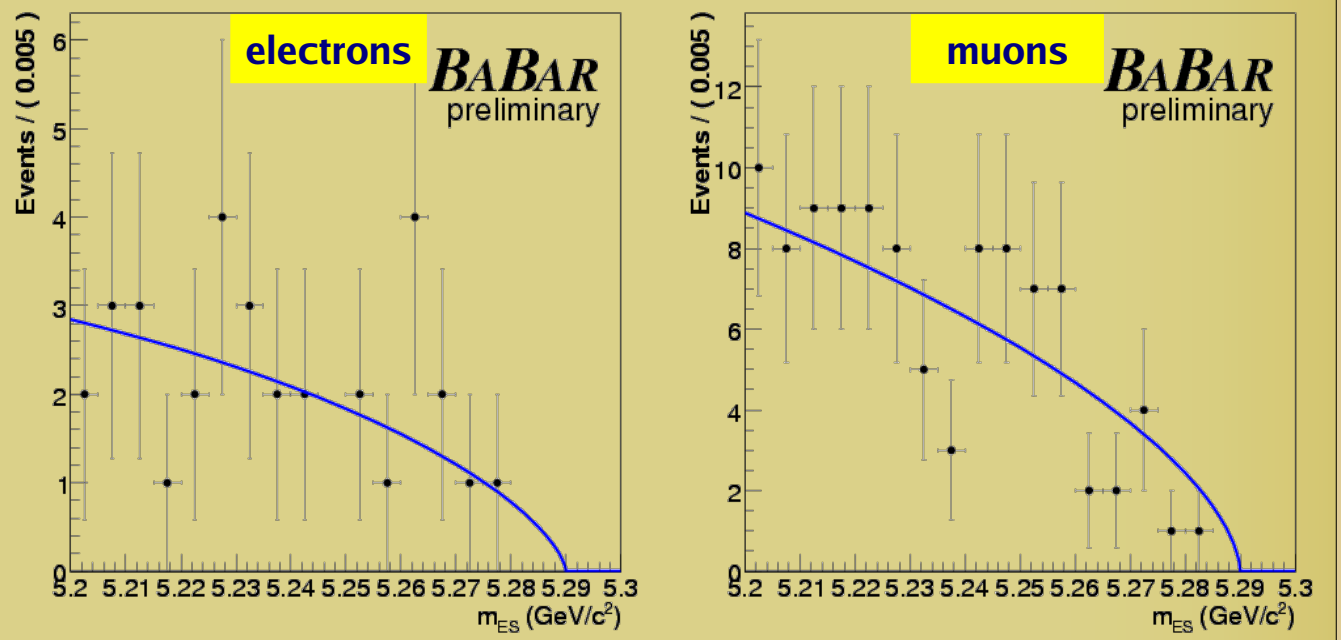
Define a plane in m_{ES} and ΔE in which to perform the final signal extraction:

$$m_{ES} > 5.2\ \mathrm{GeV}/c^2 \quad \text{and} \quad -0.5 < \Delta E < 0.5$$

$$\varepsilon^{e}_{signal} = (6.07 \pm 0.14)\% \qquad \varepsilon^{\mu}_{signal} = (4.93 \pm 0.12)\%$$

Background Estimate





Data shown are from the upper+lower sidebands

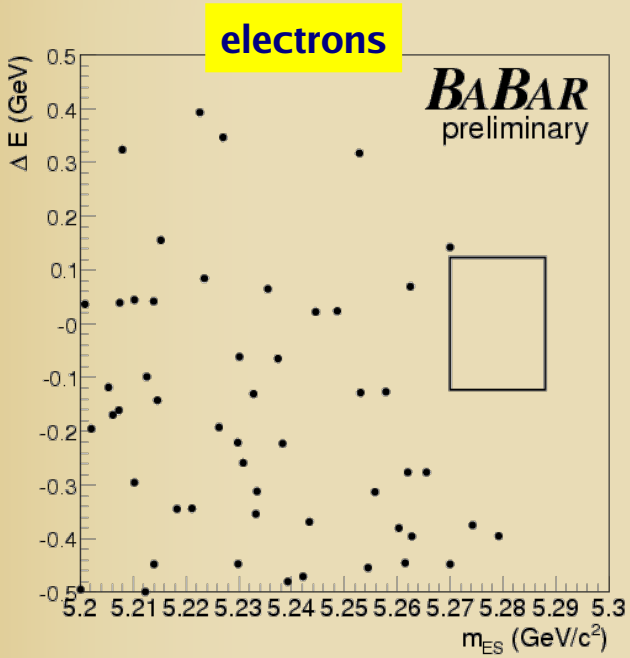
Determine the m_{ES} shape of backgrounds using the upper+lower sideband - extrapolate the middle sideband into the signal box:

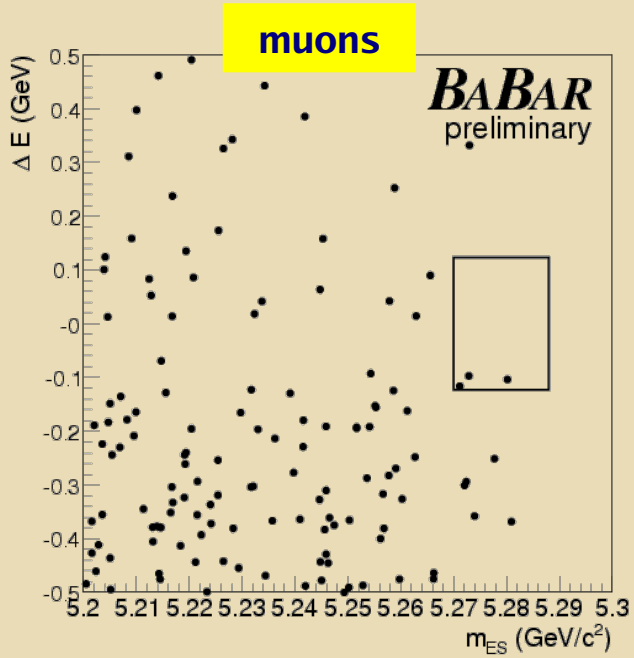
electrons $$n_{bkg}^{\exp} = 1.28 \pm 0.80$$

muons $$n_{bkg}^{\exp} = 1.40 \pm 0.42$$

ALL RESULTS ARE PRELIMINARY

Hot Off the Press





Systematic Uncertainties	e (μ)
Photon Energy	1.6% (1.6%)
Particle ID	0.7% (1.3%)
B counting	1.1% (1.1%)
Charged Particle Reconstruction	0.94% (0.94%)
Total:	2.3% (2.5%)

We observe 0 (3) events in the signal box in electron (muon) events. We set frequentist upper limits on the branching fractions (including systematic uncertainties):

PRELIMINARY

$$BR(B^0 \to e^+ e^- \gamma) < 0.7 \times 10^{-7} \text{ at the 90\% C.L.}$$

$$BR(B^0 \to \mu^+ \mu^- \gamma) < 3.4 \times 10^{-7} \text{ at the 90\% C.L.}$$

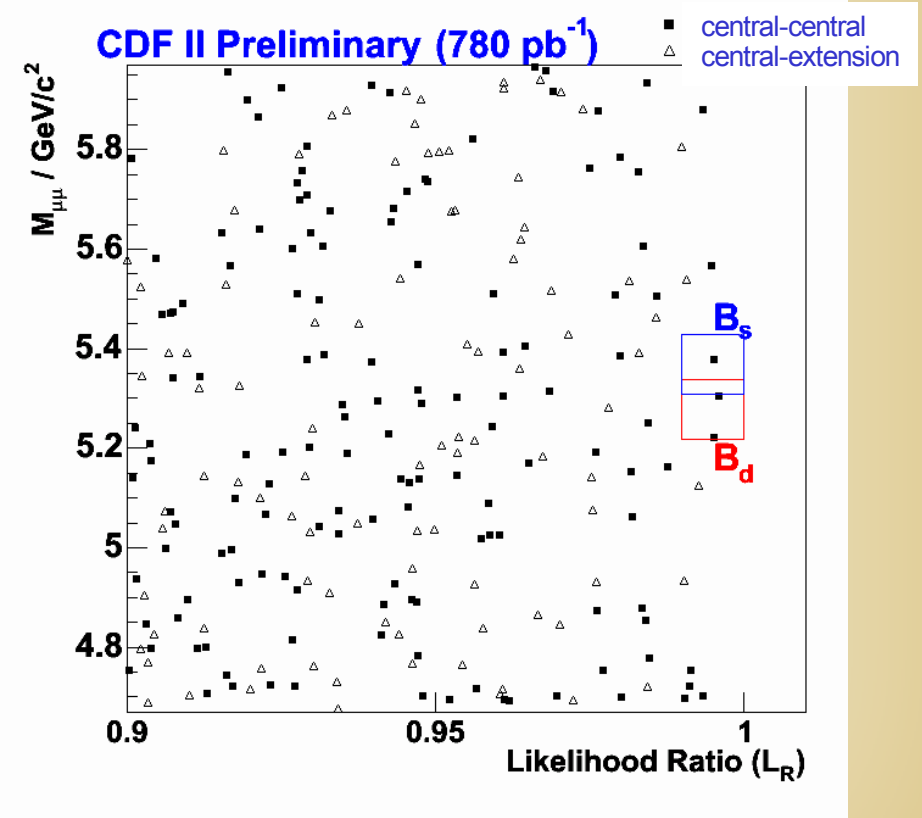
RESULTS ARE PRELIMINARY

Hot Off the Press

CDF presented their latest result in the search for $B_d \rightarrow \mu^+\mu^-$ at ICHEP '06 (S. Farrington, 07/28/2006). Using vertexed muon pairs and a likelihood discriminant, search for $B(s,d) \rightarrow \mu^+\mu^-$.

Standard Model Prediction:

$$BR(B_s \rightarrow \mu^+\mu^-) = (3.4 \pm 0.5) \times 10^{-9}$$

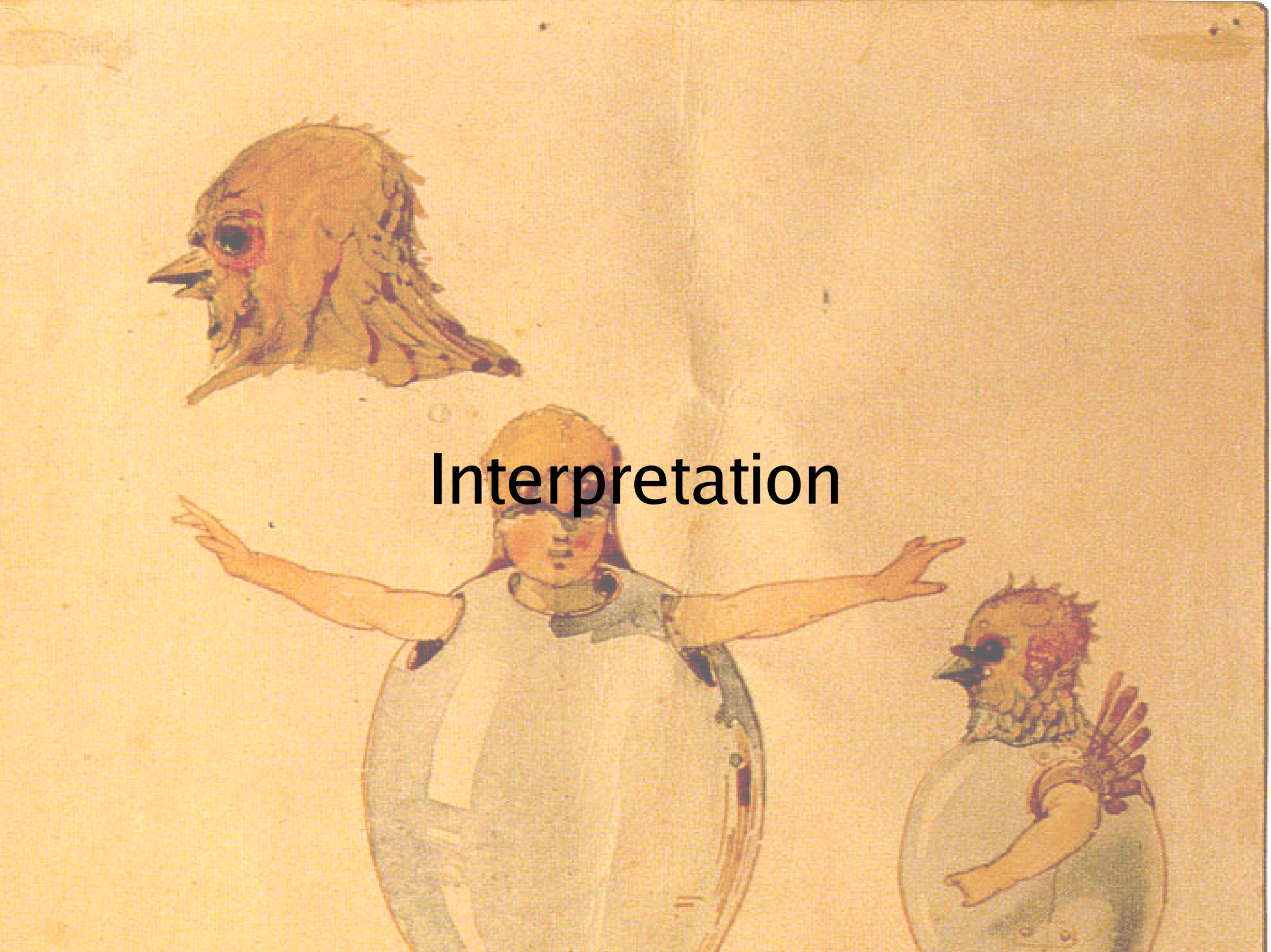


CDF observes 1 (2) events in the B_s (B_d) channel (consistent with background). Upper limits are set:

$BR(B_s \rightarrow \mu\mu) < 1.0\times10^{-7}$ @ 95% CL
$< 8.0\times10^{-8}$ @ 90% CL

$BR(B_d \rightarrow \mu\mu) < 3.0\times10^{-8}$ @ 95% CL
$< 2.3\times10^{-8}$ @ 90% CL

Currently world's best limits.



Interpretation

Standard Model: Decay Constants

The ratio f_{Ds}/f_D is a key prediction of lattice QCD. Compare with the BaBar and CLEO-c measurements

$$f_{D_s}/f_D = 1.24 \pm 0.01 \pm 0.07$$

Lattice Gauge QCD with n_f = 2+1
(Aubin et al., Phys.Rev.Lett.95:122002,2005)

BABAR, 230fb^{-1}

$$f_{D_s}/f_D = (1.27 \pm 0.14)$$

CLEO-c, √s=4170 MeV

$$f_{D_s}/f_D = (1.26 \pm 0.11)$$

f_D is taken from CLEO-c (Phys. Rev. Lett. 95, 251801 (2005))

We see that lattice QCD predicts well the ratio, and the individual values. Other calculations appear to underpredict this ratio. This suggests that lattice QCD also predicts f_B:

$$f_{B_d} = (216 \pm 38)\,MeV$$

Lattice Gauge QCD
(HPQCD, Phys.Rev.Lett.95:212001,2005)

BABAR, 324M $B\bar{B}$

$$f_{B_d} = (159 \pm 69)\,MeV$$

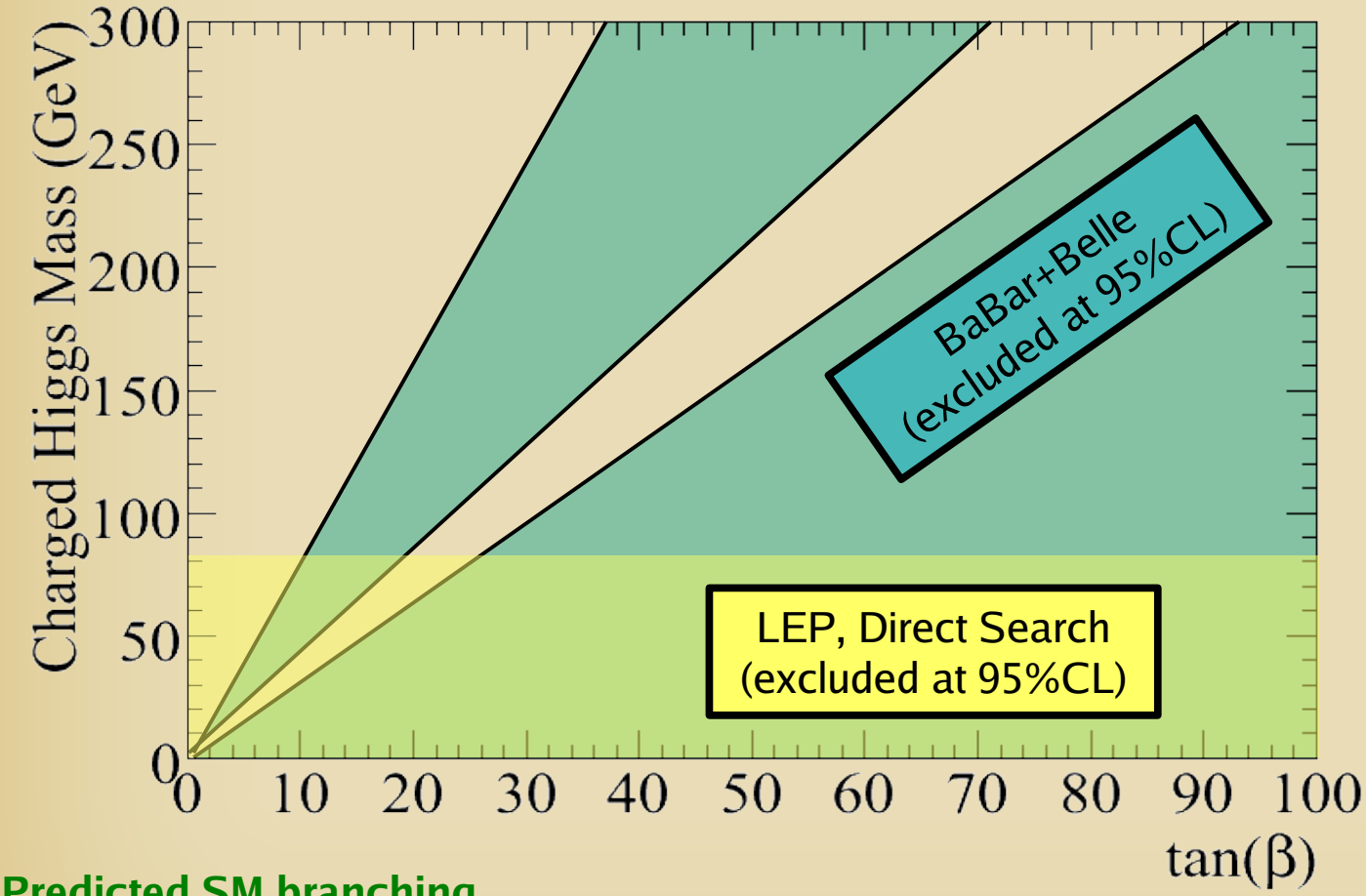
Belle, 447M $B\bar{B}$

$$f_{B_d} = (229 \pm 46)\,MeV$$

$|V_{ub}|$ taken from HFAG: $(4.39 \pm 0.33) \times 10^{-3}$

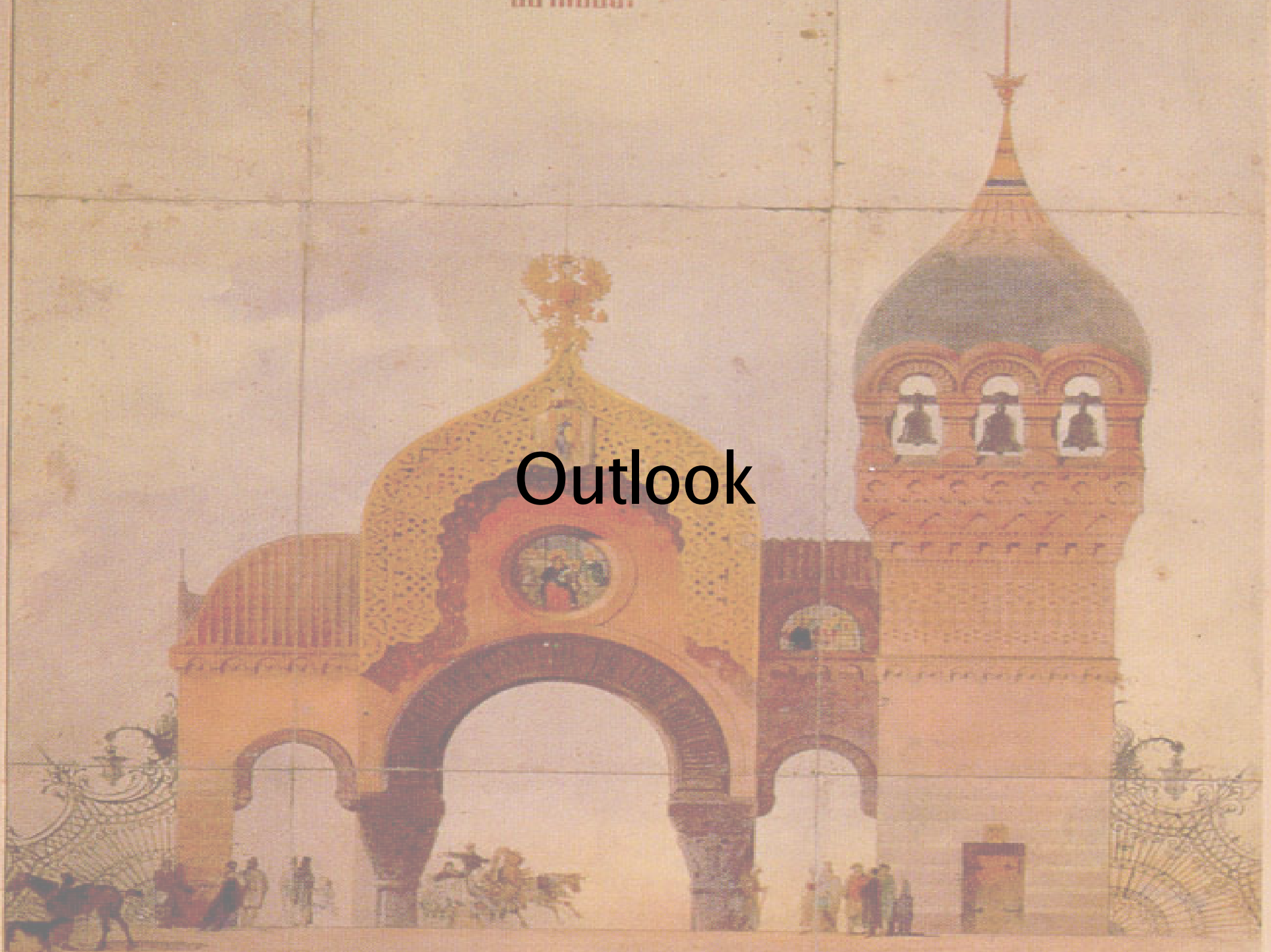
New Physics: Charged Higgs

Let's interpret the results from $B^+ \to \tau^+ \nu$ using the type II 2HDM:



The *excluded regions* (colored) are determined using the naive BaBar+Belle average for $B^+ \to \tau^+ \nu$, the LEP direct search limit (>79.3 GeV)

Predicted SM branching fraction taken from UTFit prediction.



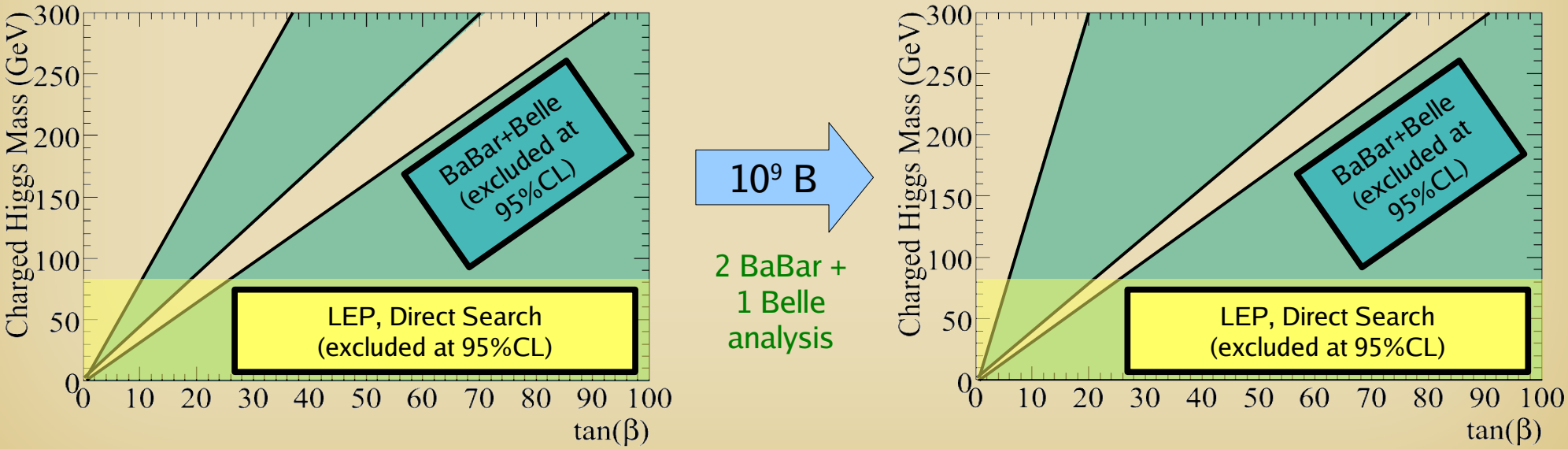
Outlook

Physics Reach: Expectations

$B^+ \to \tau^+ \nu$:

Expect each experiment's branching fraction uncertainty to go from ~0.68×10^{-4} to ~0.4×10^{-4} with the advent of 10^9 B^+ mesons at the factories (assuming no improvements)

BaBar also has a statistically independent hadronic-tagged analysis comparable to Belle's, which effectively "doubles" the number of Bs, bringing the BaBar error down to 0.48 (0.3) with the current (future 10^9) B^+ sample.



Physics Reach: Expectations

$B^0 \to \ell^+\ell^-(\gamma)$

The Tevatron dataset should swell to 6-8 fb^{-1}. Assuming the search is not background-limited and there are no improvements, $B_d \to \mu^+\mu^-$ limit per experiment will improve to ~2-3x10^{-9} (90% CL), compared to 10^{-10} SM BF.

Expect this measurement, in conjunction with BaBar and Belle searches for the electron and muon final states, to continue to constrain new physics.

The Tevatron should be within range of the SM prediction for $B_s \to \mu^+\mu^-$ -- very exciting!

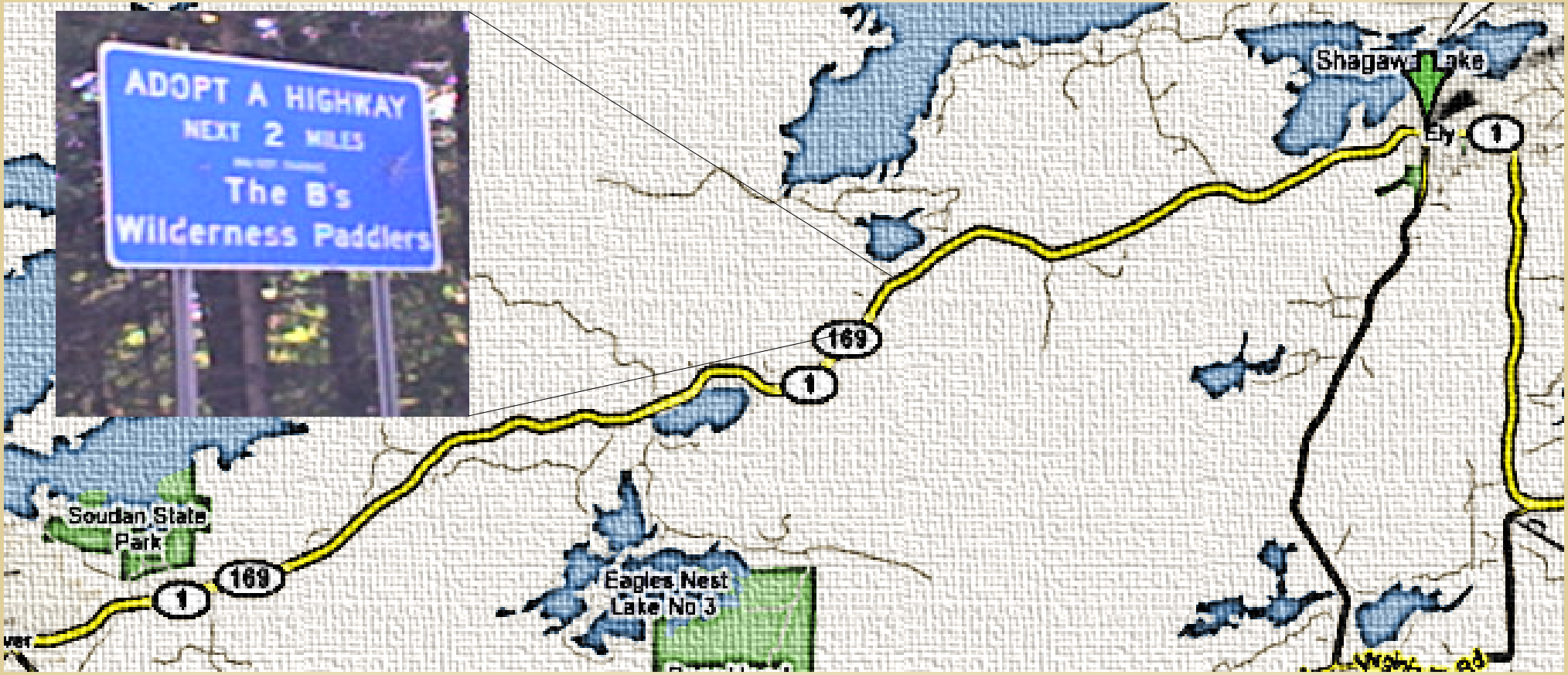
With 10^9 neutral Bs at the B factories, expect the limit on the radiative decay to improve by a factor of ~3 (per experiment)

Expect this measurement to also constrain new physics.

Conclusions

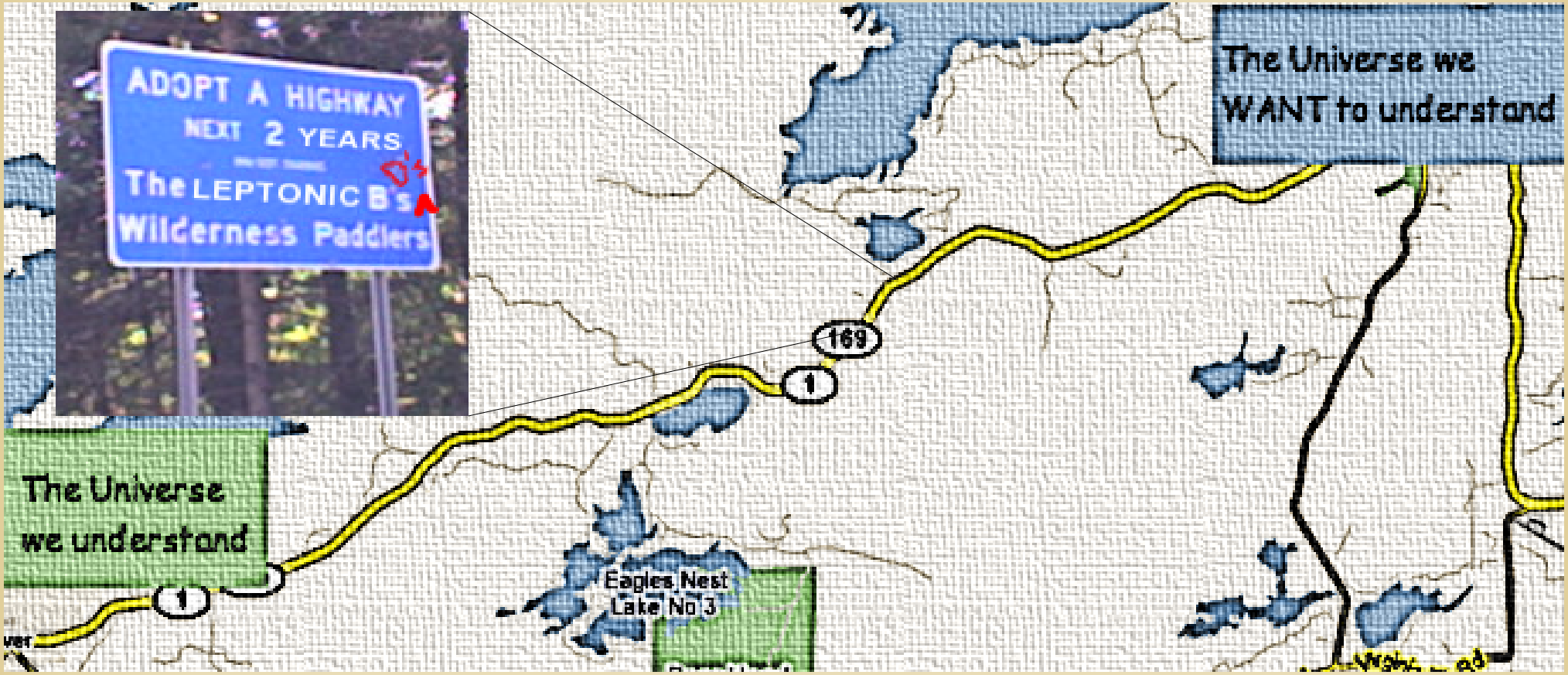
- Leptonic decays of heavy mesons (B/D) are
  - Experimentally interesting
  - Critical tests of the Standard Model
  - Potential gateways to new physics phenomena
- Large datasets at many experiments will
  - Allow further reach in the rarest decays, making some of them accessible
  - Allow experimental limitations to be placed on new physics in time for LHC

My recent vacation in northern Minnesota took me through wilderness between Soudan and Ely (for coffee, so I could write this seminar).

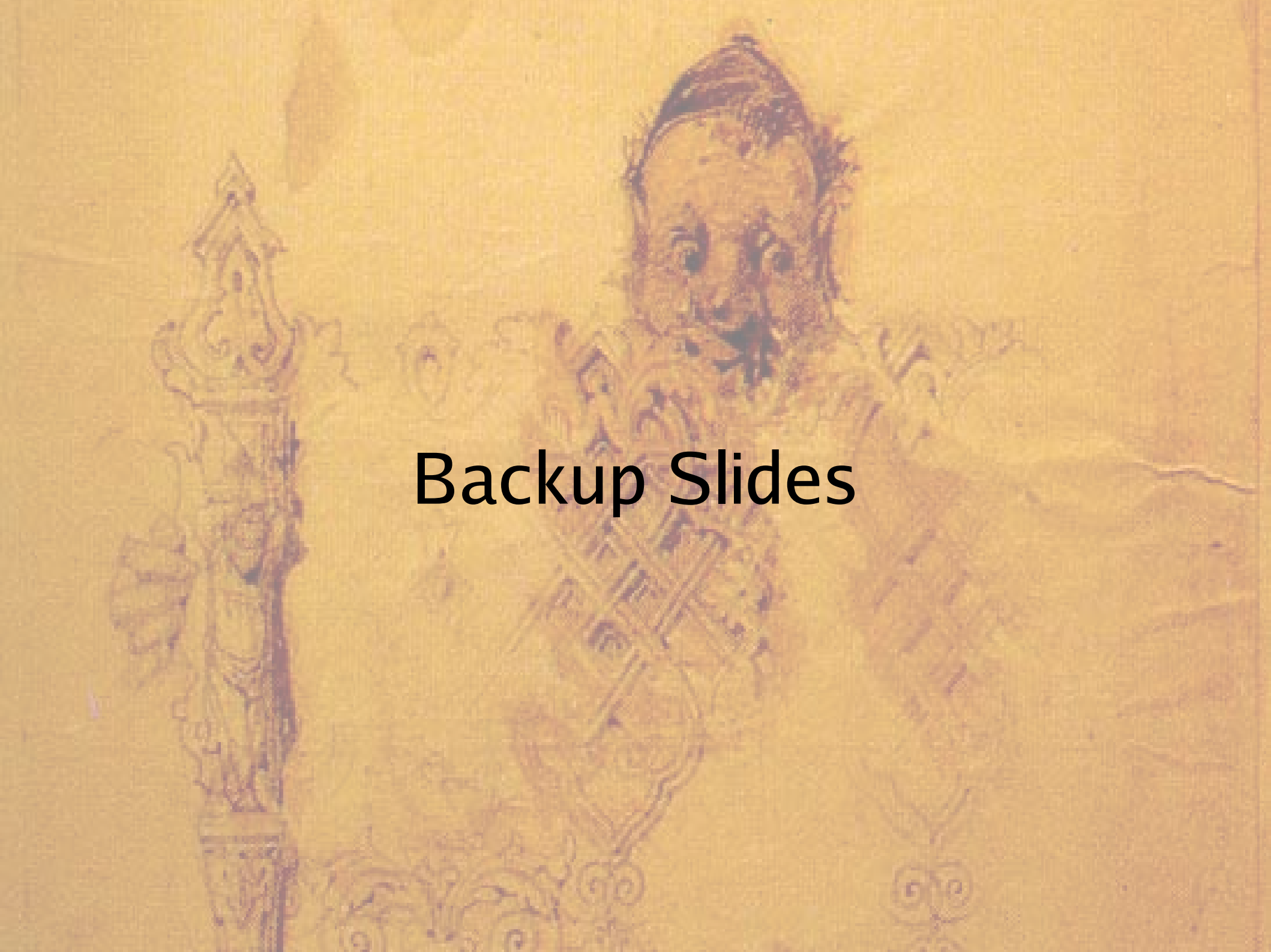


The journey, on a highway maintained by local business and citizens, got me thinking about the journey we're on as we head into the LHC era...

There is a similar road between the universe we do understand and the one we WANT to understand.



That road is maintained by a multi-pronged approach to understanding the universe, an important part of which (I believe) is the use of leptonic decays of heavy mesons.



Backup Slides

QCD Prediction References

Taken from the references of hep-ex/0607074 (CLEO-c)

Model	$f_{D_s^+}$ (MeV)	f_{D^+} (MeV)	$f_{D_s^+}/f_{D^+}$
Lattice (n_f=2+1) [20]	$249 \pm 3 \pm 16$	$201 \pm 3 \pm 17$	$1.24 \pm 0.01 \pm 0.07$
QL (Taiwan) [21]	$266 \pm 10 \pm 18$	$235 \pm 8 \pm 14$	$1.13 \pm 0.03 \pm 0.05$
QL (UKQCD) [22]	$236 \pm 8^{+17}_{-14}$	$210 \pm 10^{+17}_{-16}$	$1.13 \pm 0.02^{+0.04}_{-0.02}$
QL [23]	$231 \pm 12^{+6}_{-1}$	$211 \pm 14^{+2}_{-12}$	1.10 ± 0.02
QCD Sum Rules [24]	205 ± 22	177 ± 21	$1.16 \pm 0.01 \pm 0.03$
QCD Sum Rules [25]	235 ± 24	203 ± 20	1.15 ± 0.04
Quark Model [26]	268	234	1.15
Quark Model [27]	248±27	230±25	1.08±0.01
Potential Model [28]	241	238	1.01
Isospin Splittings [29]		262 ± 29	

[20] C. Aubin *et al.*, Phys. Rev. Lett. **95**, 122002 (2005).

[21] T. W. Chiu *et al.*, Phys. Lett. **B624**, 31 (2005)[hep-ph/0506266].

[22] L. Lellouch and C.-J. Lin (UKQCD), Phys. Rev. D **64**, 094501 (2001).

[23] D. Becirevic *et al.*, Phys. Rev. D **60**, 074501 (1999).

[24] J. Bordes, J. Peñarrocha, and K. Schilcher, "D and D_s Decay Constants from QCD Duality at Three Loops," [hep-ph/0507241].

[25] S. Narison, "Light and Heavy Quark Masses, Flavour Breaking of Chiral Condensates, Meson Weak Leptonic Decay Constants in QCD," [hep-ph/0202200] (2002).

[26] D. Ebert *et al.*, Phys. Lett. **B635**, 93 (2006).

[27] G. Cvetič *et al.*, Phys. Lett. **B596**, 84 (2004).

[28] Z. G. Wang *et al.*, Nucl. Phys. **A744**, 156 (2004); L. Salcedo *et al.*, Braz. J. Phys. **34**, 297 (2004).

[29] J. Amundson *et al.*, Phys. Rev. D **47**, 3059 (1993).

Inputs to UTFit

Constraints, Parameters	Value	Gauss Error	Flat Error	Comments
$\sin 2\beta$	0.675	0.026	-	
λ	0.2258	0.0014	-	
$\lvert V_{cb}\rvert$ (10^{-3})	41.3	1.0	1.8	Average of exclusive
$\lvert V_{cb}\rvert$ (10^{-3})	41.6	0.7	-	Average of inclusive
$\lvert V_{ub}\rvert$ 10^{-4} (excl.)	35.0	4.0	-	
$\lvert V_{ub}\rvert$ 10^{-4}(incl. HFAG)	44.9	3.3	-	HFAG average
m_b (GeV/c^2)	4.21	0.08	-	
m_c (GeV/c^2)	1.3	0.1	-	
$\Delta(m_d)$ (ps^{-1})	0.507	0.005	-	WA (CDF/CLEO/LEP/Babar/Belle)
$\Delta(m_s)$ (ps^{-1})	17.35	0.25	-	CDF Likelihood is used.
m_t (GeV/c^2)	163.8	3.2	-	(CDF/D0)
$f_{Bs}\sqrt{B_{Bs}}$ (MeV)	262	35	-	Lattice QCD
ξ	1.23	0.06	-	Lattice QCD
$\lvert\varepsilon_K\rvert 10^{-3}$	2.280	0.013	-	
B_K	0.79	0.04	0.08	Lattice QCD
f_K (GeV)	0.160	-	-	
$\Delta(m_K)$ (10^{-2} ps^{-1})	0.5301	-	-	
$\alpha_s(M_Z)$	0.119	0.003	-	
G_F (10^{-5} GeV^{-2})	1.16639	-	-	
m_W (GeV/c^2)	80.425	-	-	
m_{Bd} (GeV/c^2)	5.279	-	-	
m_{Bs} (GeV/c^2)	5.375	-	-	
m_{K^0} (GeV/c^2)	0.497648	-	-	

www.utfit.org