Updated measurements of hadronic B decays at CDF

Europhysics Conference on High-Energy Physics (EPS-HEP 2011)

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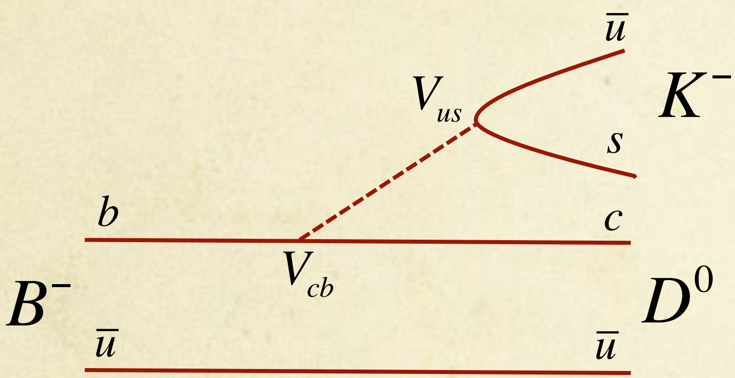
Why hadronic B-decays?

- Hadronic decays very rich field.
- Sensitive to all combinations of:
  - Cabibbo-favored and Cabibbo-suppressed decays,
  - Tree-diagrams and loop-diagrams,
  - Spectator-decays and exchange/annihilation decays,
  - Color-favored and color-suppressed decays.
- Aim: disentangle new physics from hadronic uncertainties.
  - Requires simultaneous measurements of many decays.
- Focus today on modes sensitive to the least known angle γ.
  - $B^- \to DK^-$ (ADS method)
  - $B^0_{(s)} \to h^+h'^-$ decays.

Angle γ from $B^- \to DK^-$

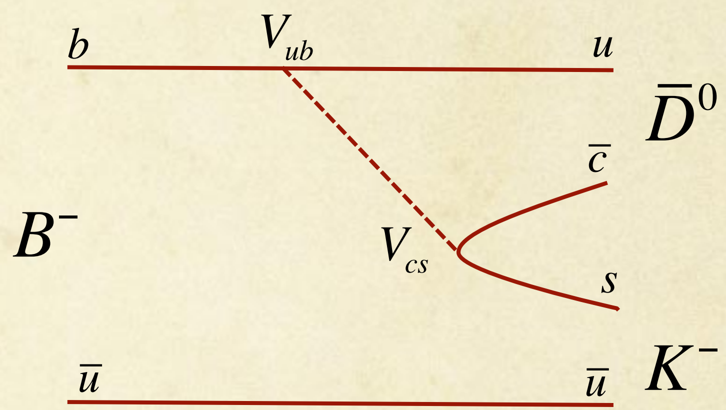
Cleanest ways to measure γ angle. Only tree-level amplitudes are involved. Tiny theoretical uncertainties. Exploit interference between the processes:

$b \to c\bar{u}s$



Favored $b \to c$ decay:
$\sim V_{cb}V^*_{us} \sim \lambda^3$

$b \to u\bar{c}s$



Color Suppressed $b \to u$ decay:
$\sim V_{ub}V^*_{cs} \sim \lambda^3 r_B e^{-i\delta B} e^{i\gamma}$

Several methods depending on $D^0 \to f$ and $\bar{D}^0 \to f$: GLW $D \to \pi\pi/KK$, ADS $D \to K\pi$ suppressed decays, etc. No tagging or time dependent analysis is needed, well suited for hadronic environment.
CDF already provided results for GLW method in $1fb^{-1}$ [*PRD81, 031105(2010)*].

ADS method

ADS method [*PRL78,3257(1997)*;*PRD63,036005(2001)*] uses the $B^- \to D K^-$ decays with D reconstructed in $D \to K^+\pi^-$:

$$B^- \to D^0 K^- \to [K^+\pi^-]K^-$$

→ Color allowed $B^- \to D K^-$ and Doubly Cabibbo Suppressed $D^0 \to K^+\pi^-$.

$$B^- \to \bar{D}^0 K^- \to [K^+\pi^-]K^-$$

→ Color suppressed $B^- \to D K^-$ and Cabibbo Favored anti$D^0 \to K^+\pi^-$.

$$\left|\frac{\mathcal{M}(B^- \to K^- D^0[\to f])}{\mathcal{M}(B^- \to K^- \overline{D}^0[\to f])}\right|^2 \approx \left|\frac{V_{cb}V_{us}^*}{V_{ub}V_{cs}^*}\right|^2 \left|\frac{a_1}{a_2}\right|^2 \frac{Br(D^0 \to f)}{Br(\overline{D}^0 \to f)} \approx 1$$

← color suppression

$B^- \to DK^- \to [K^+\pi^-]K^-$ suppressed by factor of about 10^{-3} wrt favored $B^- \to DK^- \to [K^-\pi^+]K^-$

The two interfering amplitudes are comparable. Large CP violation can be observed.

ADS method (cont'd)

- Expected large CP asymmetries.
- Results have to be combined with other methods to obtain γ measurement.
- Observables:

$$R_{ADS}(h) = \frac{BR(B^- \to D_{sup} h^-) + BR(B^+ \to D_{sup} h^+)}{BR(B^- \to D_{fav} h^-) + BR(B^+ \to D_{fav} h^+)}$$

$$A_{ADS}(h) = \frac{BR(B^- \to D_{sup} h^-) - BR(B^+ \to D_{sup} h^+)}{BR(B^- \to D_{sup} h^-) + BR(B^+ \to D_{sup} h^+)}$$

h = K or π
$D_{fav} \to K^- \pi^+$
$D_{sup} \to K^+ \pi^-$

From theory: $R_{ADS}(K) = r_D^2 + r_B^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma$
$A_{ADS}(K) = 2 r_B r_D \sin(\delta_B + \delta_D) \sin\gamma / R_{ADS}(K)$

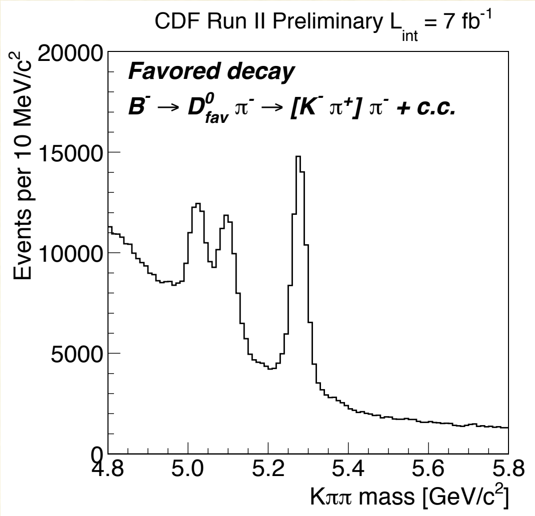
$$r_B = \left| \frac{A(b \to u)}{A(b \to c)} \right| \quad r_D = \left| \frac{A(D^0 \to K^- \pi^+)}{A(D^0 \to K^+ \pi^-)} \right|$$

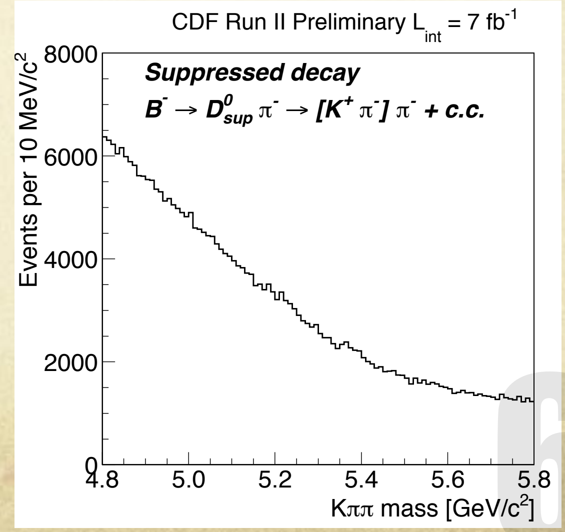
δ_B and δ_D relative strong phases of B and D decays.

$B^- \to DK^-$ ADS analysis

Before optimization

- Selection is crucial to search for highly suppressed signals.
- Optimal point chosen using large sample of favored decays (same final states).
  - Maximize the sensitivity for discovery of limit setting for an unobserved mode [*physics/0308063*].
- Simultaneous Extended Unbinned Maximum Likelihood fit on Favored and Suppressed modes.
- Using masses and particle identification (dE/dx) information to determine the signal composition.





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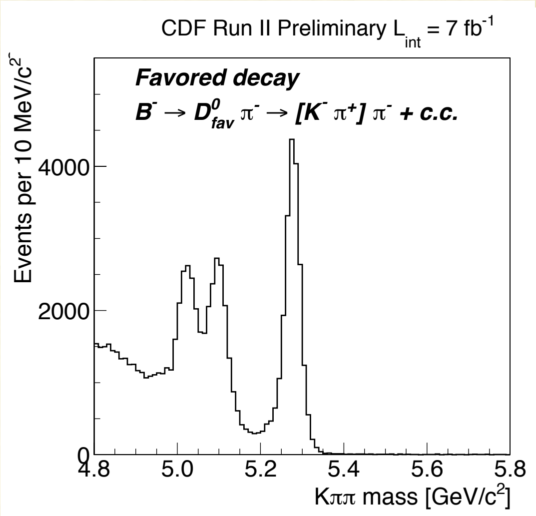
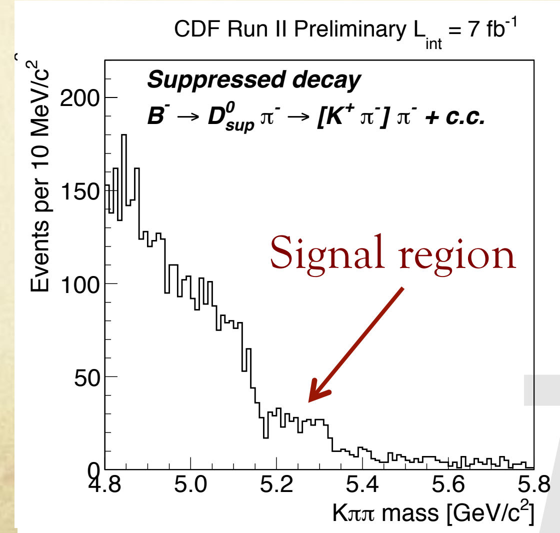
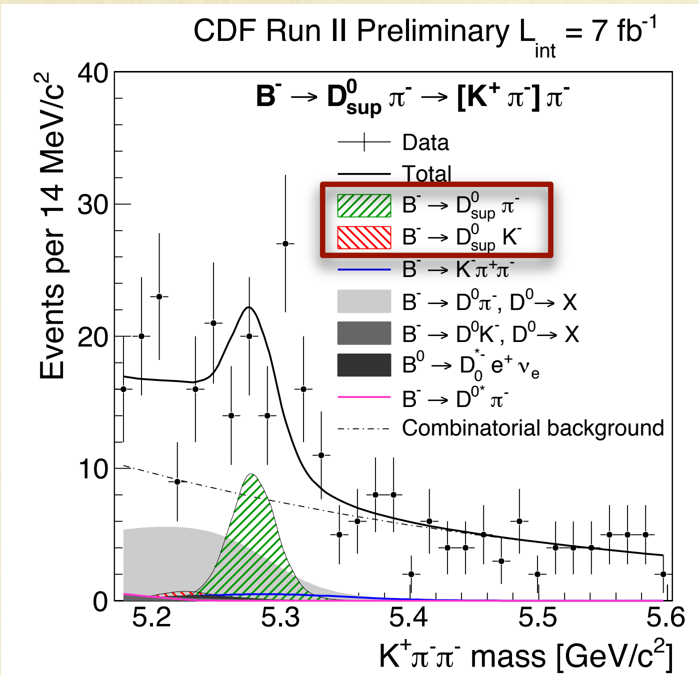
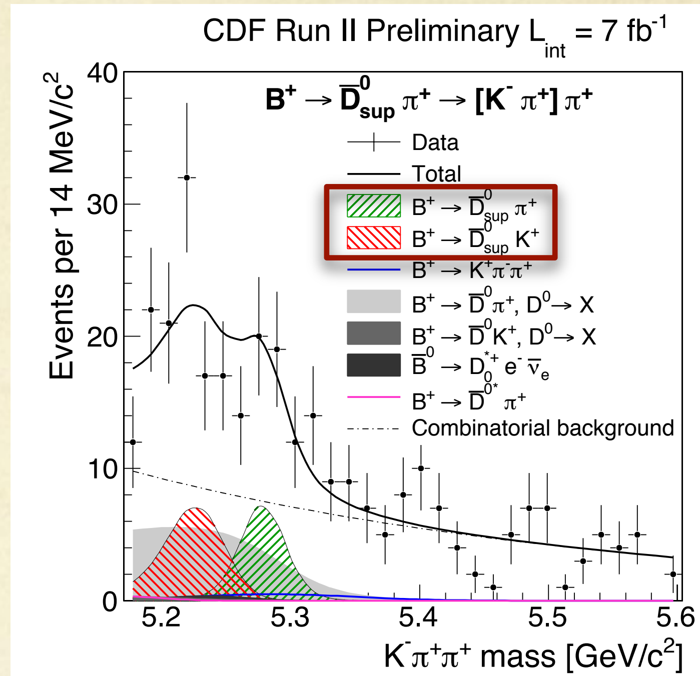




CDF-note 10309

First evidence of $B^{-} \rightarrow D_{sup}K^{-}$





$$N(B^{-} \rightarrow D_{sup}K^{-}) + N(B^{+} \rightarrow D_{sup}K^{+}) = 32 \pm 12$$

$$N(B^{-} \rightarrow D_{sup}\pi^{-}) + N(B^{+} \rightarrow D_{sup}\pi^{+}) = 55 \pm 14$$

First Evidence of $B^{-} \rightarrow D_{sup}K^{-}$ signal at hadron collider (3.2σ level)

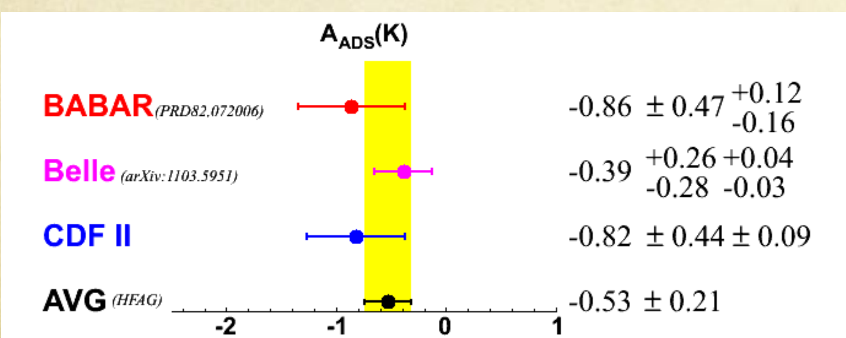
Physics observables

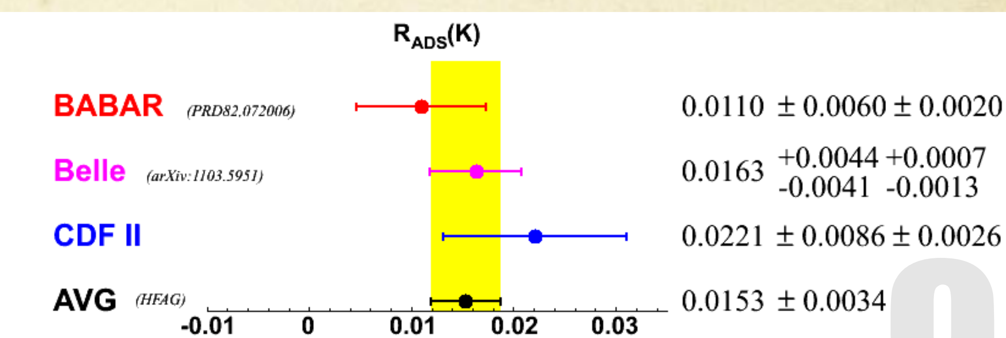
CDF-note 10309

$$R_{ADS}(\pi) = [2.8 \pm 0.7(stat) \pm 0.4(syst)] \cdot 10^{-3}$$
$$A_{ADS}(\pi) = 0.13 \pm 0.25(stat) \pm 0.02(syst)$$
$$R_{ADS}(K) = [22.0 \pm 8.6(stat) \pm 2.6(syst)] \cdot 10^{-3}$$
$$A_{ADS}(K) = -0.82 \pm 0.44(stat) \pm 0.09(syst)$$

- $B^- \to D_{fav}\pi^-$ ~19700ev
- $B^- \to D_{fav}K^-$ ~1460 ev
- $B^- \to D_{sup}\pi^-$ ~55 ev
- $B^- \to D_{sup}K^-$ ~32 ev

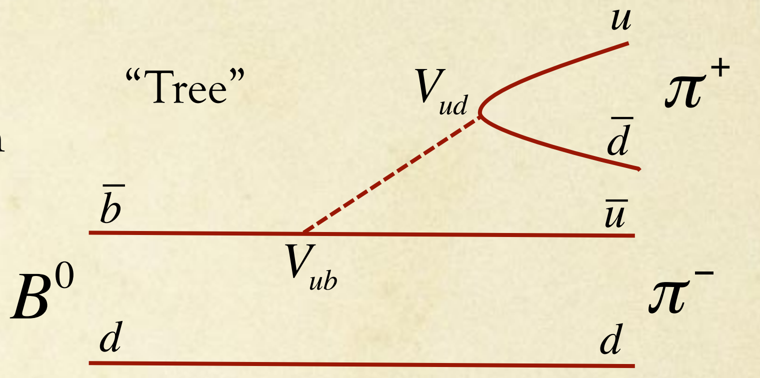
First measurement of A_{ADS} and R_{ADS} at hadron collider. They agree with other experiments.

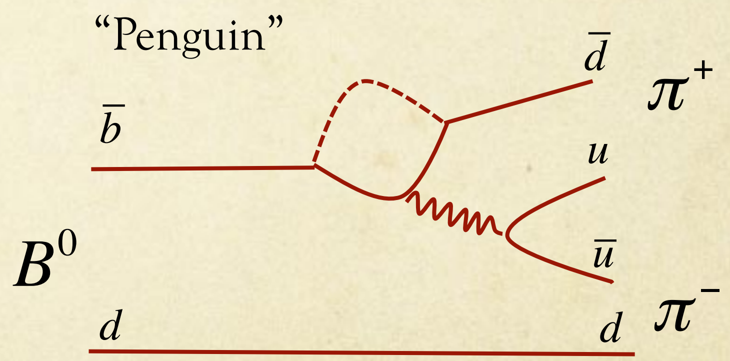




Two-body non-leptoninc Charmless B-decays

- Among the most widely studied processes in flavor physics.
- Many B^0, B^0_s (and Λ^0_b) channels involving similar final states provide crucial experimental information to improve knowledge of strong interactions dynamics.
- Sensitive to V_{ub} phase, CKM angle γ
- Significant contribution from higher-order ("penguin") transitions provides sensitivity to NP.





$B^0_{(s)} \to h^+h'^-$ at CDF

PRL **97,** 211802 (2006) PHYSICAL REVIEW LETTERS week ending 24 NOVEMBER 2006

Observation of $B_s^0 \to K^+K^-$ and Measurements of Branching Fractions of Charmless Two-Body Decays of B^0 and B_s^0 Mesons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.96$ TeV

$B^0_s \to K^+K^-$

PRL **103,** 031801 (2009) PHYSICAL REVIEW LETTERS week ending 17 JULY 2009

Observation of New Charmless Decays of Bottom Hadrons

$B^0_s \to K^-\pi^+$,
$\Lambda^0_b \to p\pi^-$,
$\Lambda^0_b \to pK^-$

PRL **106,** 181802 (2011) PHYSICAL REVIEW LETTERS week ending 6 MAY 2011

Measurements of Direct *CP* Violating Asymmetries in Charmless Decays of Strange Bottom Mesons and Bottom Baryons

$A_{CP}(B^0_s \to K^-\pi^+)$
$A_{CP}(\Lambda^0_b \to p\pi^-)$
$A_{CP}(\Lambda^0_b \to pK^-)$

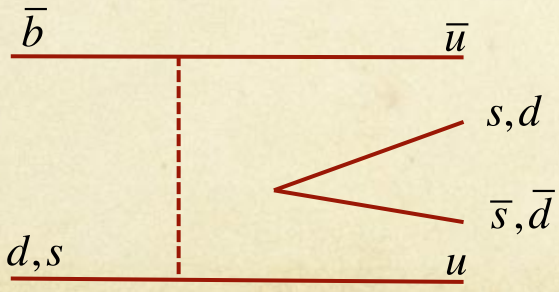
Today

First evidence for $B^0_s \to \pi^+\pi^-$ and first two-sided bound for $B^0 \to K^+K^-$

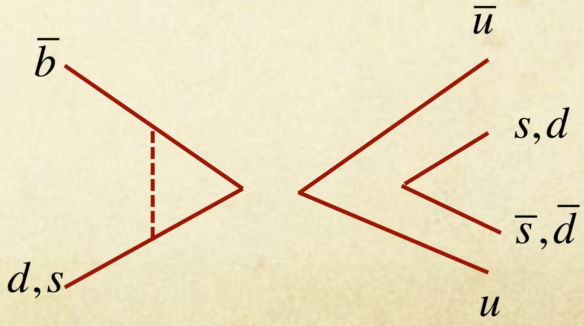
Annihilation topologies

- All initial-state quarks undergo a transition.
- Not yet observed. Small BR ~10^{-7}, with large uncertainties.
- Uncertainty depends on hard-to-predict hadronic parameters
  — large source of uncertainty in many other calculations.

“W-exchange”



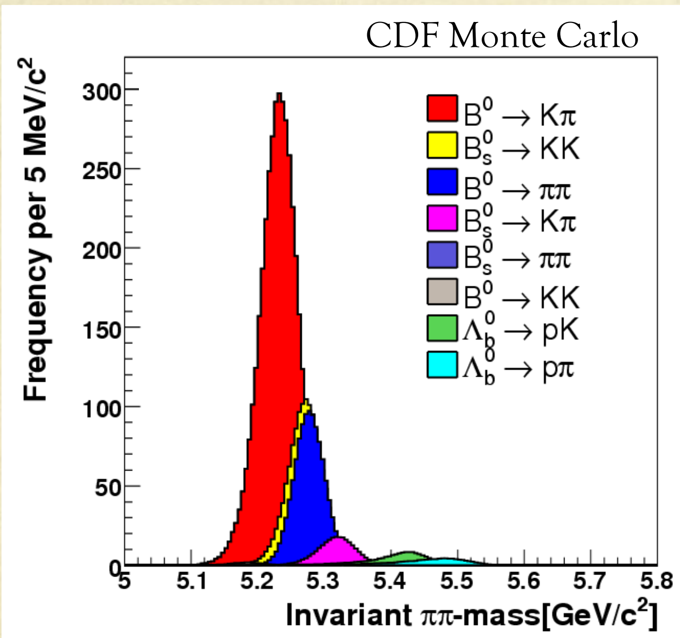
“Penguin annihilation”

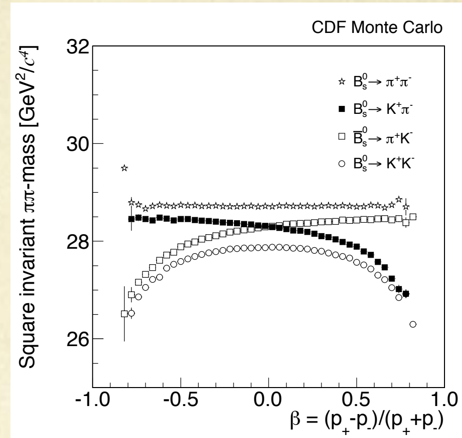


A challenging analysis

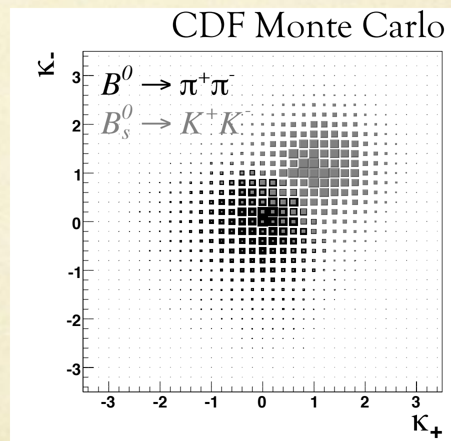
CDF-note 10498

Despite good mass resolution (~22 MeV/c^2), individual modes overlap in a single peak (width ~35 MeV/c^2)





Exploit correlation between momenta and invariant mass.



dE/dx: 1.4σ K/π power separation for track p>2GeV/c. Becomes 2.0σ for the pairs KK/ππ and $K^+\pi^-/\pi^+K^-$.

Need to determine signal composition with a Likelihood fit, combining information from kinematics (mass and momenta) and particle ID (dE/dx).

Results $6fb^{-1}$

CDF-note 10498

Mode	N_s	Significance
$B^0 \to K^+K^-$	$120 \pm 49 \pm 42$	2.0σ
$B_s^0 \to \pi^+\pi^-$	$94 \pm 28 \pm 11$	3.7σ

$B^0 \to K^+\pi^-$ ~ 10.200 ev
$B^0_s \to K^+K^-$ ~ 3.008 ev
$B^0 \to \pi^+\pi^-$ ~ 2.600 ev
$B^0_s \to K^-\pi^+$ ~ 760 ev

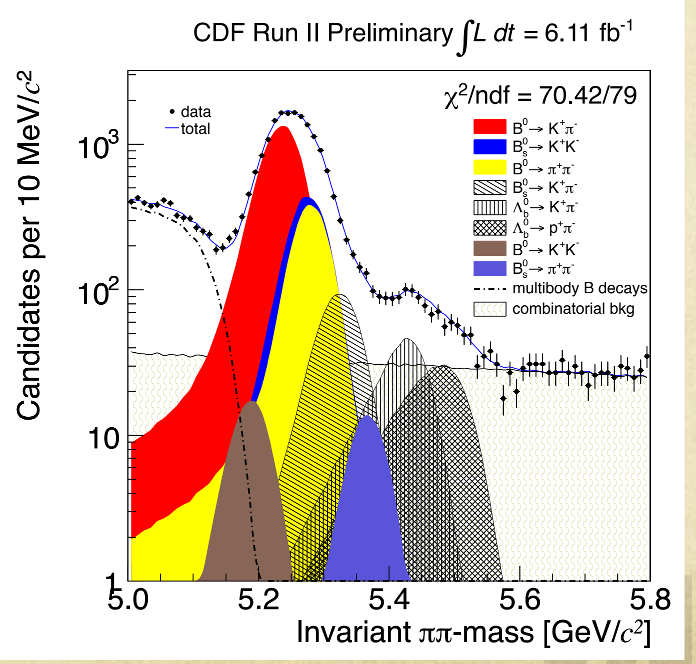
First evidence for the $B^0_s \to \pi^+\pi^-$

$$BR(B_s^0 \to \pi^+\pi^-) = [0.57 \pm 0.15(stat) \pm 0.10(syst)] \times 10^{-6}$$

First two sided bound for the $B^0 \to K^+K^-$

$$BR(B^0 \to K^+K^-) \in [0.05, 0.46] \times 10^{-6} \text{ @ } 90\%CL$$

$$BR(B^0 \to K^+K^-) = [0.23 \pm 0.10(stat) \pm 0.10(syst)] \times 10^{-6}$$



Consistent with previous upper limits from CDF.
$B^0_s \to \pi^+\pi^-$ in agreement with recent pQCD estimates, higher than other predictions.
$B^0 \to K^+K^-$ in agreement with predictions, but large theoretical uncertainty on them.

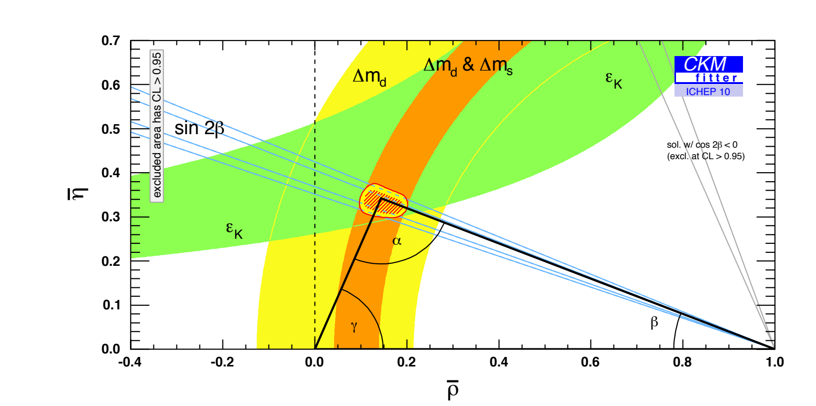
Conclusions

- CDF continuing to produce a rich and exciting program in heavy flavor physics.
  - Exciting competition with LHCb,
  - Complementary to e^+e^- machines.
- Many interesting results will benefit from more data.
  - Anticipate ~$10fb^{-1}$ for analysis by the end of this year.
- Results will continue beyond the end of the Run.

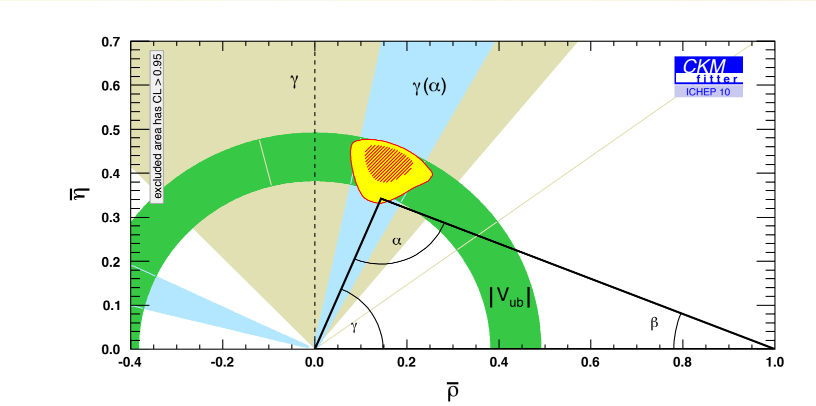
Backup

Trees and loops for γ measurement

- Loops:
  - Better constraints.
  - New Physics may enter.



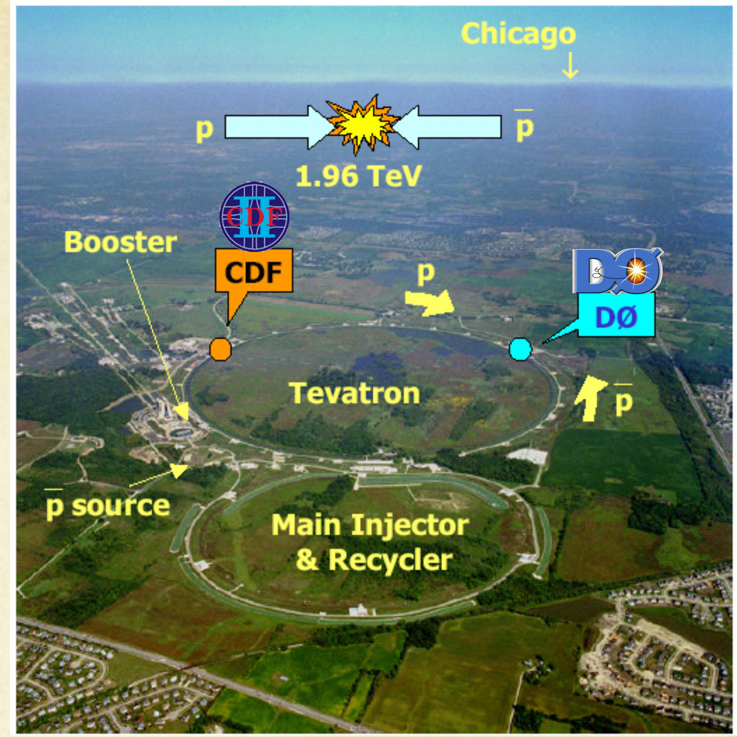
- Trees:
  - Less well constrained.
  - ~20° uncertainty on γ.
  - Insensitive to New Physics.



Very interesting to compare at high precision the two approaches.

Fermilab Tevatron

- $p\bar{p}$ collisions at 1.96 TeV
- Peak luminosity $3.5\text{–}4 \times 10^{32} cm^{-2}s^{-1}$
- ~9 fb^{-1} "good" data on tape per experiment.
- End of operation by September 2011.



CDFII detector

- Central Drift Chamber ($\delta p_T/p_T \sim 0.0015\ (GeV/c)^{-1} p_T$)
- Silicon Vertex Detector (Hadronic Trigger)
- Particle identification (dE/dx and TOF)