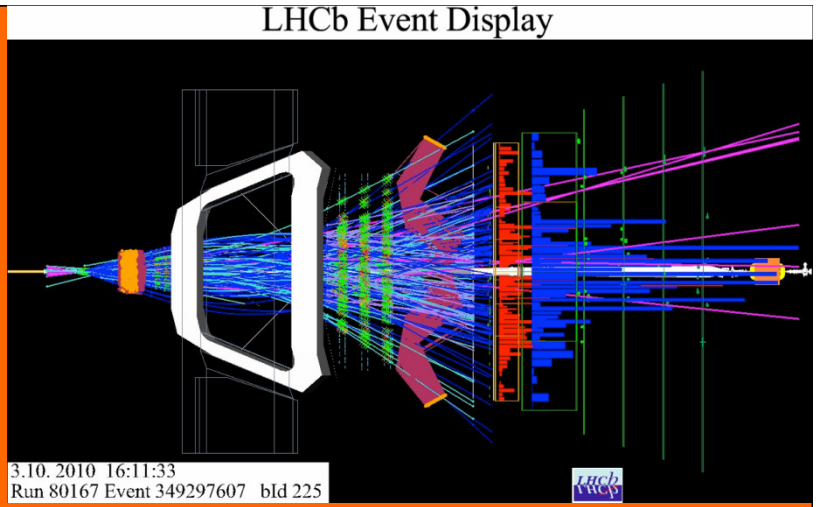

Studies of hadronic B decays with early LHCb data

Rudolf Oldeman
Università di Cagliari e INFN
On behalf of the LHCb Collaboration

Department of Energy
Office of Science
Washington, DC 20585

Office of the Director

JAN 6 2011

Professor Melvyn Shochet
Chairman, High Energy Physics Advisory Panel
Department of Physics
University of Chicago
5630 S. Ellis Ave
Chicago, IL 60637

Dear Professor Shochet:

I am writing to convey the Office of Science's response to the recent High Energy Physics Advisory Panel (HEPAP) report on extending the operation of the Tevatron at Fermi National Accelerator Laboratory. As you know the Office of Science received in the summer of 2010 a widely supported proposal to extend operation of the Tevatron through FY 2014. At our request, HEPAP and its subpanel, Particle Physics Project Prioritization Panel (P5), responded quickly and analyzed both the physics merits of the proposal and the potential impacts on the rest of the field. HEPAP and P5 provided valuable and timely advice to the Office of Science that informed our FY 2012 budget request. I thank HEPAP and P5 for these efforts.

In summary, P5 found the proposed physics program had significant scientific value and would complement what can be accomplished at the Large Hadron Collider (LHC) in the same time period, but recognized that without additional funding the extension of Tevatron operations would delay progress on the development of the Intensity Frontier program by HEP. P5 therefore recommended that extension of the operation of the Tevatron be approved only if additional funds were available to HEP, and encouraged the funding agencies to find the necessary resources. Unfortunately, the current budgetary climate is very challenging and additional funding has not been identified. Therefore, based in part on the P5 recommendation, operation of the Tevatron will end in FY 2011, as originally scheduled.

The strategic plan for the U.S. particle physics program, developed by P5, attacks the most important scientific questions in three broad areas of the field: the Energy, Intensity,

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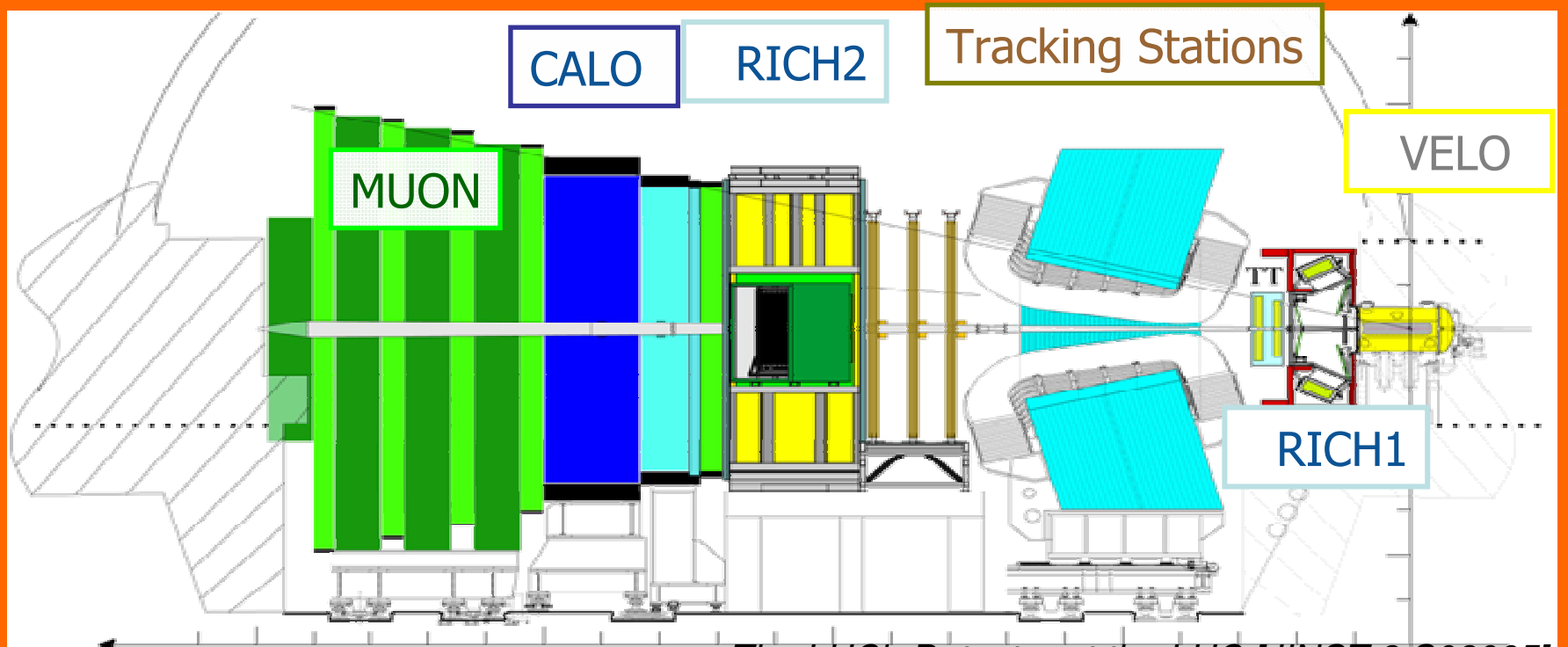
Overview

- Hadronic decays very rich field:
  - *100's of 2-body decay modes*
  - *1000's of 3-body decay modes*
- Sensitive to all combinations of
  - *Cabibbo-favoured and Cabibbo-suppressed decays*
  - *Tree-diagrams and loop-diagrams*
  - *Spectator-decays and exchange/annihilation decays*
  - *Color-favoured and color-suppressed decays*
- Aim: disentangle new physics from hadronic uncertainties
  - *Requires measurements of many decays*
- Focus today on modes sensitive to measure γ
  - *The weak phase of the $b \to u$ transition relative to $b \to c$*

The LHCb detector

- VELO: 21 (R+φ) silicon stations
  - *Movable:7mm when stable beams*
  - *IP resolution 14 μm at high p_T*
- RICH1: C_4F_{10} + AEROGEL
  - *π/K separation for 2<p<60 GeV*
- Tracking: Si + straw tubes + 4Tm
  - *δp/p=0.45%*
- RICH2: CF_4
  - *π/K separation for 20<p<100 GeV*
- CALO:
  - *ECAL: lead+scintillating tiles*
  - *HCAL: iron+scintillation tiles*
- MUON



The LHCb Detector at the LHC [JINST 3 S08005]

Trigger for hadronic decays

~10-20 MHz

Level 0
Custom hardware

~1 MHz
(300kHz achieved)

High Level Trigger
16k CPU farm

~2 kHz

LHC computing
grid

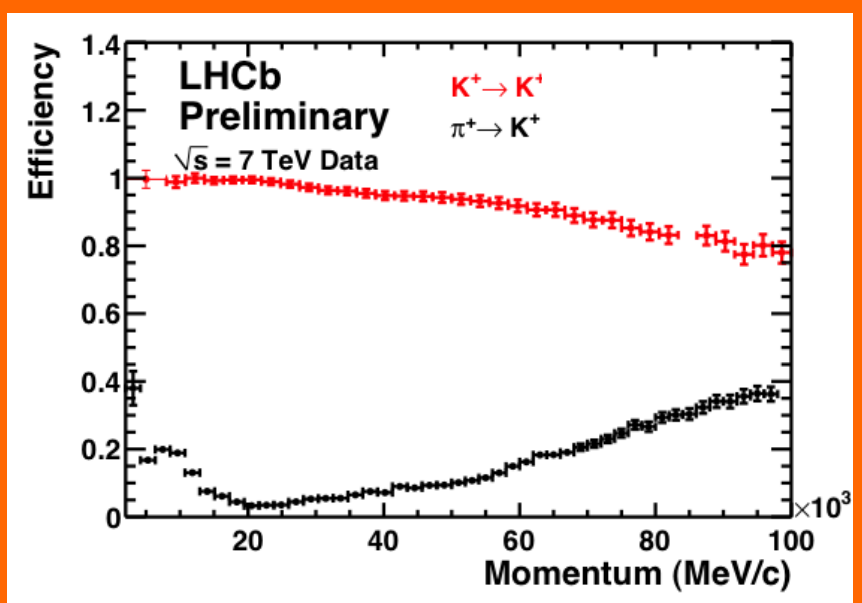
~200 Hz

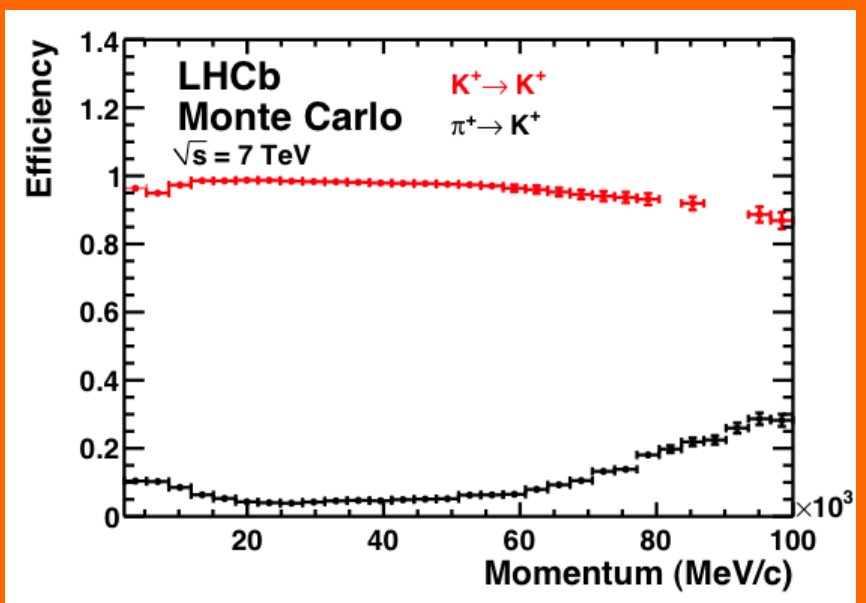
user-accessible
storage

- L0:
  - *3.6 GeV E_T CALO cluster*
- HLT1: single track
  - *p_T>1.45GeV,IP>110μm*
  - *10ms/evt.*
- HLT2: 2,3,4 track combinations
  - *Compensate for missing p_T*
  - *300ms/evt*
- Stripping:
  - *~200 user-written lines*
  - *2010 data already stripped twice*

Particle identification performance

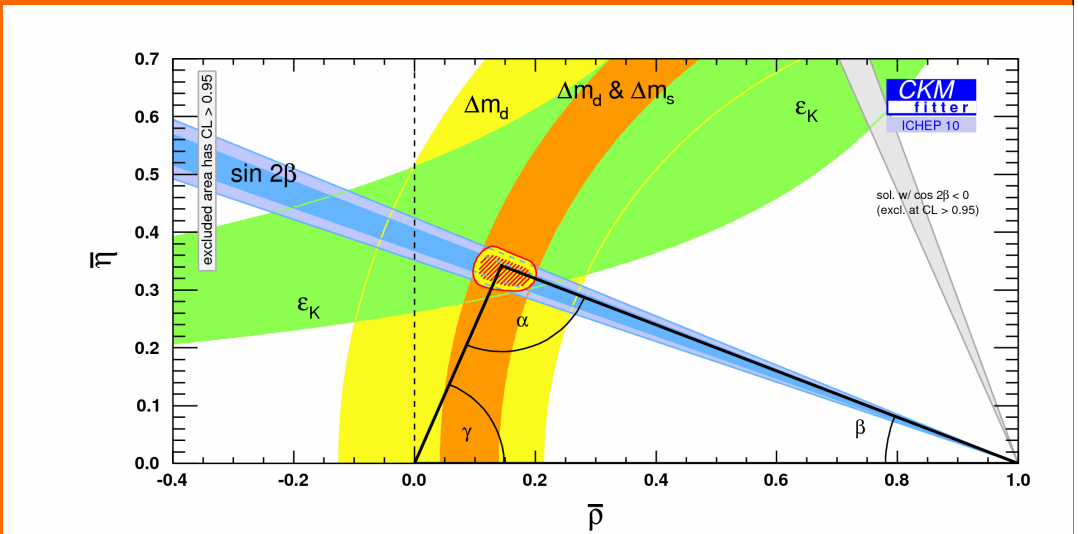
- Small $B \to DK^+$ signal close to large $B \to D\pi^+$ peak
- Calibrated with $K_S \to \pi^+\pi^-$, $\Lambda \to p\pi^-$, $D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+$
- Extremely good performance
  - *but not as good as MC yet*



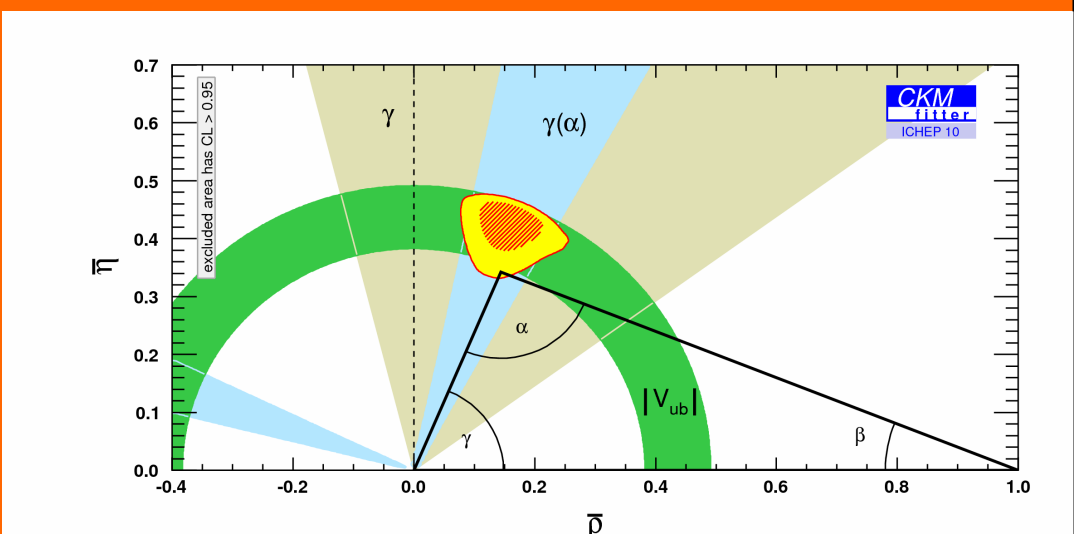


Trees and loops for γ measurements

- Loops:
  - *Best constraints*
  - *New physics enters*

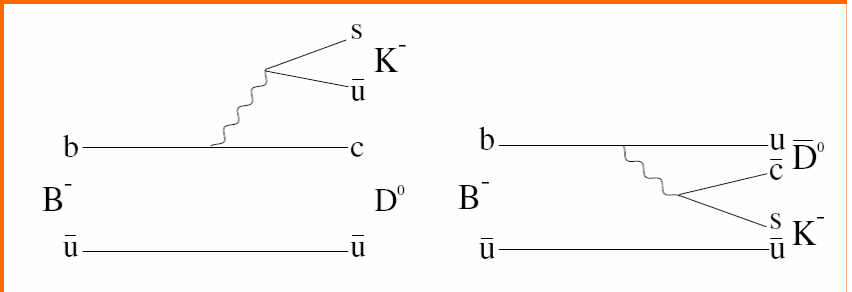


- Trees:
  - *Less well constrained*
  - *~20° uncertainty on γ*
  - *Insensitive to new physics*



CKMfitter Group (J. Charles et al.), EPJC41, 1-131(2005),
updated results and plots available at: http://ckmfitter.in2p3.fr

Trees: CP violation in B→DK



- $B^+ \to \overline{D}^0 K^+$ from b→c transition
- $B^+ \to D^0 K^+$ from b→u transition
- Ratio of amplitudes r_B~0.1
- For common D^0 final state these interfere
- Direct CP violation:
  - *No need for flavour tagging*
  - *Four main techniques:*
    - **CP eigenstate K^+K^-, $\pi^+\pi^-$ [GLW]**
    - **Non-CP eigenstate $K^-\pi^+$ [ADS]**
    - **Multibody $K_S h^+ h^-$ [GGSZ]**
    - **$B^0 \to DK^{*0}$ [Dunietz]**
- Time-dependent CP violation:
    - **$B_s \to D_s K^+$**

Roadmap for selected key measurements of LHCb, arχiv:0912.4179v2

GLW technique: $D^0 \to$ CP eigenstate

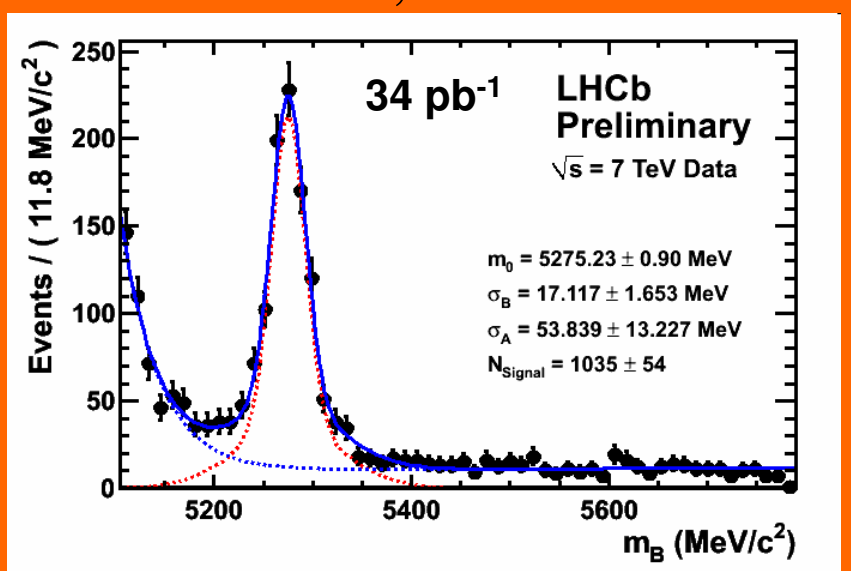
- measure:

$$A_\pm = \frac{\Gamma(B^- \to D_\pm K^-) - \Gamma(B^+ \to D_\pm K^+)}{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)}$$

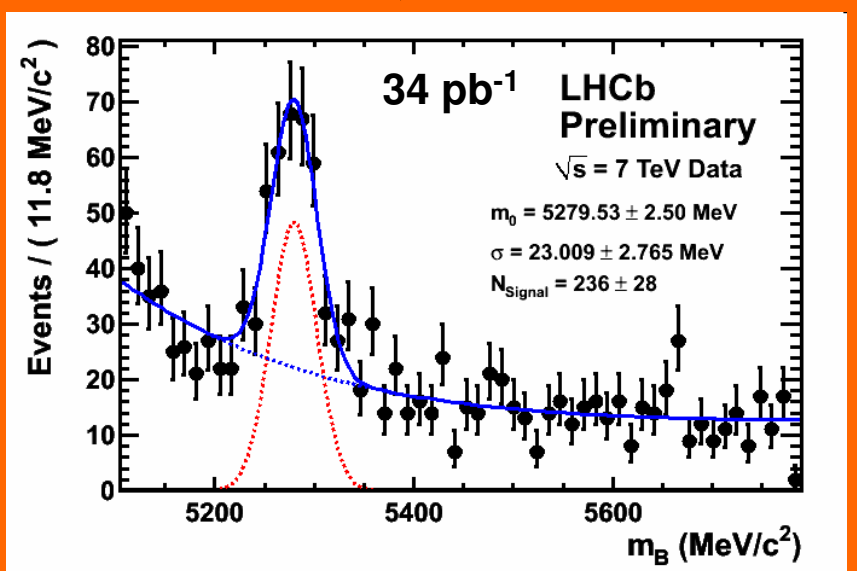
current status:

DK	A_{CP+}
BaBar	0.25 ± 0.06 ± 0.02
Belle	0.06 ± 0.14 ± 0.05
CDF	0.39 ± 0.17 ± 0.04

$B^+ \to \overline{D}^0 \pi^+, D^0 \to K^- K^+$



$B^+ \to \overline{D}^0 \pi^+, D^0 \to \pi^- \pi^+$

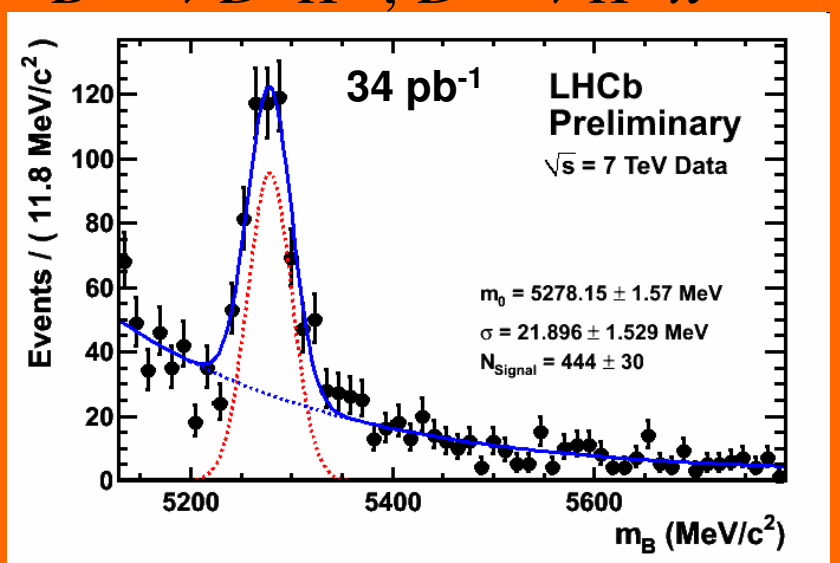


- 2011 data:
  - *Expect ~3k* $B^+ \to \overline{D}^0 K^+, D^0 \to K^- K^+, \pi^- \pi^+$ *in 1 fb*$^{-1}$

ADS technique: $D^0 \to$ flavour eigenstate ($K^-\pi^+$,$K^+\pi^-$)

- 4 observables, but 5 parameters
  - *γ, r_B ,δ_B,$\delta_{K\pi}$ and normalisation*
- Performed simultaneously with GLW for 2 more observables
- Use constraints on $\delta_{K\pi}$ from CLEO

$$B^+ \to \overline{D}^0 K^+,\ D^0 \to K^-\pi^+$$



$$A_{\rm ADS} = \frac{\Gamma(B^- \to D(K^+\pi^-)K^-) - \Gamma(B^+ \to D(K^-\pi^+)K^+)}{\Gamma(B^- \to D(K^+\pi^-)K^-) + \Gamma(B^+ \to D(K^-\pi^+)K^+)}$$

DK	A_{ADS}
BaBar	$-0.86 \pm 0.47\ ^{+0.12}_{-0.16}$
Belle	$-0.39 \pm 0.26\ ^{+0.06}_{-0.04}$
CDF	$-0.63 \pm 0.40 \pm 0.23$

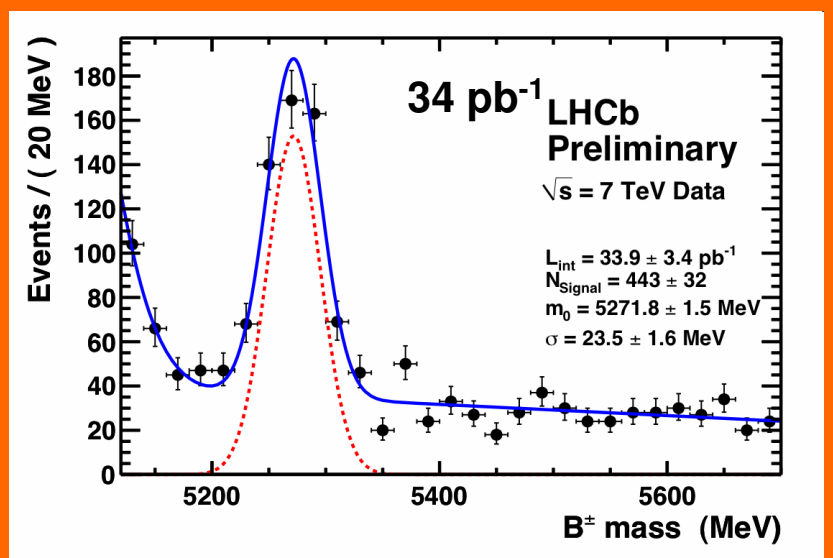
- *2011 prospect:*
  - *Expect ~13k $B^+ \to \overline{D}^0 K^+$ in 1fb^{-1}*

ADS [PRL 78 3257(1997); PRD 63 036005(2001)],

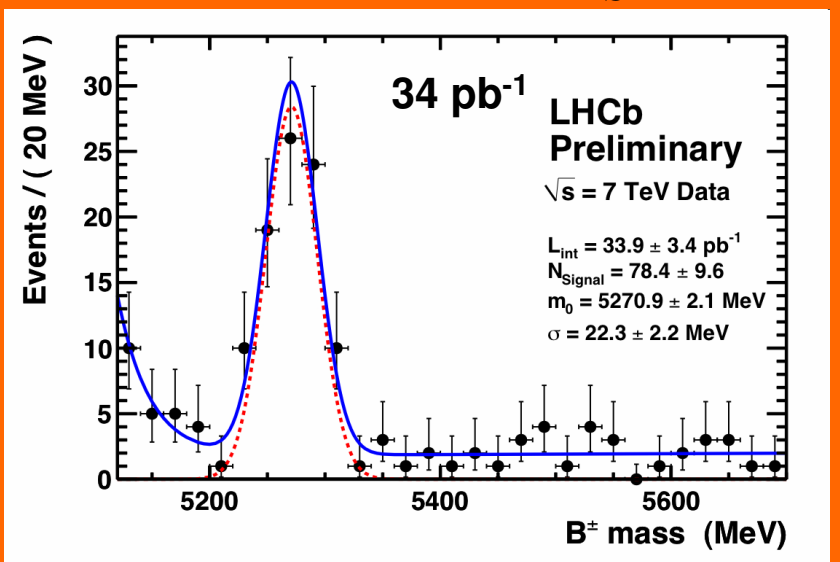
GGSZ technique: $D^0 \to K_S \pi^+ \pi^-$

- Needs knowledge of strong phase over all Dalitz space
  - *binned approach, using ψ(3770) data*
  - *unbinned, using decay model for $K_S \pi^+ \pi^-$*

$$B^+ \to \overline{D}^0 \pi^+, D^0 \to K_S \pi^- \pi^+$$



$$B^+ \to \overline{D}^0 \pi^+, D^0 \to K_S K^- K^+$$

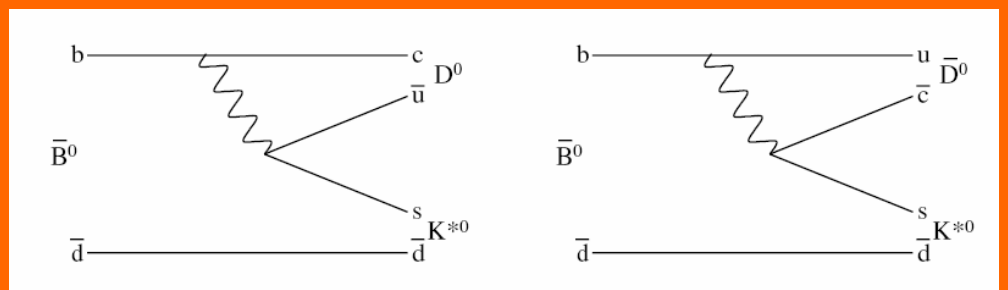


- *2011 prospect:*
  - *Expect ~1k* $B^+ \to \overline{D}^0 K^+, D^0 \to K_S \pi^- \pi^+$ *in 1fb^{-1}*

GGSZ [PRD 68 054018(2003)]

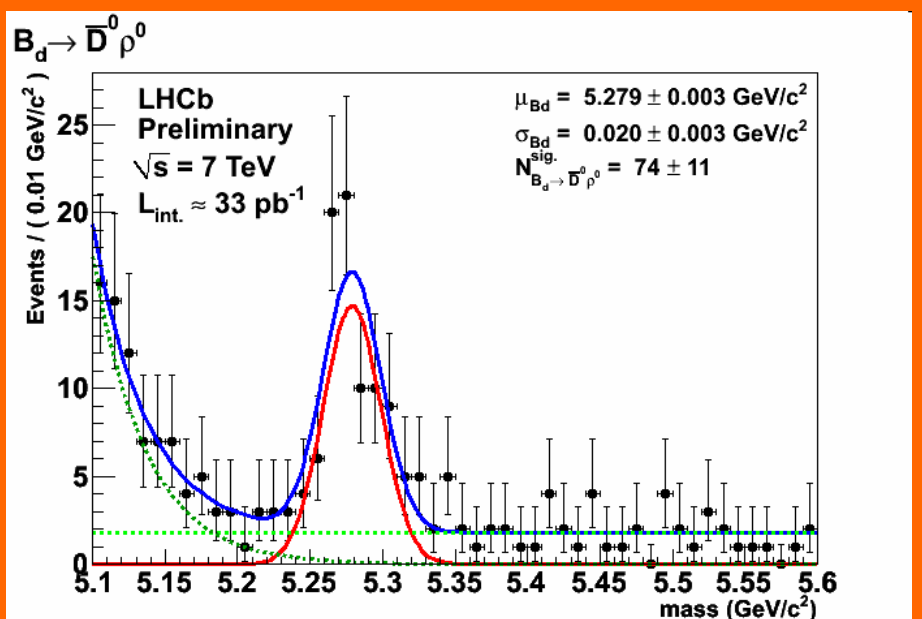
Dunietz: $B^0 \to DK^{*0}$

- Both $b \to c$ and $b \to u$ are Color suppressed
  - *smaller BR, but r_B~0.3 → more CP violation than in $B^+ \to D^0K^+$*



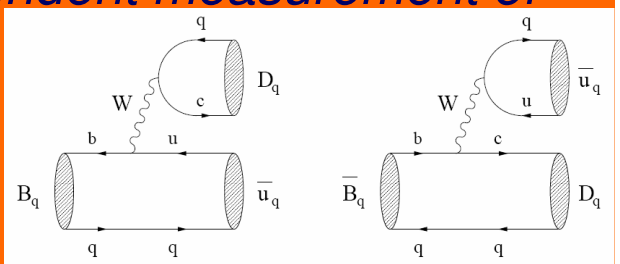
	BR	r_B
$B^+ \to D^0K^+$	$(3.7 \pm 0.3)\ 10^{-4}$	~0.1
$B^0 \to D^0K^{*0}$	$(4.2 \pm 0.6)\ 10^{-5}$	~0.3

- 2011 expectation:
  - *~300 $B^0 \to D^0K^{*0}$, $D^0 \to K^-\pi^+$*
  - *~700 $B^0 \to D^0K^+\pi$, $D^0 \to K^-\pi^+$*



Time-dependent CP violation: $B_s \to D_s K^+$

- Modulated by B_s mixing frequency $\Delta m_s = 17.8 ps^{-1}$
  - *Require flavour tagging and good proper time resolution*
  - *Measure $\gamma + \phi_s \to$ need an external model independent measurement of the mixing phase*



- Lifetime difference $\Delta\Gamma_s$ also plays a role:

$$A(t) = \frac{\frac{1-|\xi|^2}{1+|\xi|^2}\cos(\Delta m_s t) + \frac{2\,\mathrm{Im}(\xi)}{1+|\xi|^2}\sin(\Delta m_s t)}{\cosh(\frac{\Delta\Gamma_s t}{2}) - \frac{2\,\mathrm{Re}(\xi)}{1+|\xi|^2}\cosh(\frac{\Delta\Gamma_s t}{2})} \quad \text{, where} \quad \xi = -\frac{e^{-i(\phi_s+\gamma)}}{x_s e^{i\delta_s}}$$

x_s: level of interference ~0.4

δ_s: strong phase difference

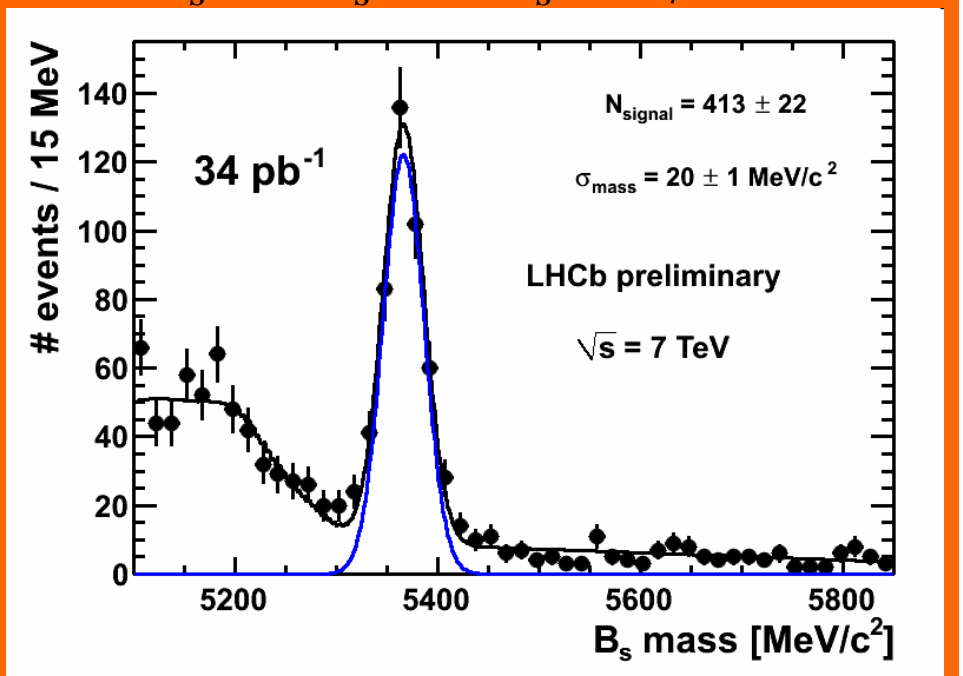
- Twofold ambiguity for non-zero $\Delta\Gamma_s$
  - *better than the 8-fold ambiguity in equivalent $B_d \to D^- \pi^+$*

R. Fleischer Nucl.Phys.B671:459-482,2003.

Time-dependent CP violation: $B_s \to D_s K^+$: LHCb status

- Proper time resolution: 50fs (MC expectation: 40fs)
- Flavour tagging:
  - *opposite side: εD^2(MC)=4%*
    - **data presently underperforms MC**
  - *same-side: εD^2(MC)=2%*
    - **to be calibrated on Bs oscillations**

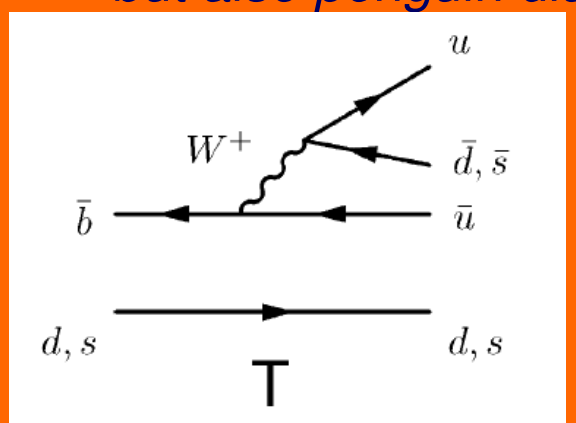
$$B_s \to D_s^- \pi^+, D_s^+ \to \phi\pi^+$$



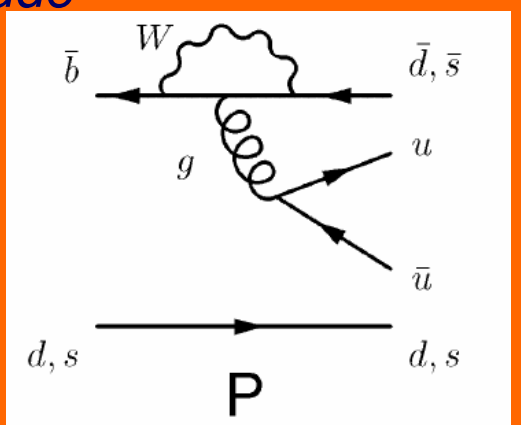
- Expectation for 2011:
  - *Roadmap expectation was 10° in 2fb^{-1}*
  - *2k $B_s \to D_s K^+$ events in 1fb^{-1}*
  - *Need at least 4k to resolve two-fold ambiguity*

γ from loops

- Inclusive B→hh or hhh analyses
  - *Few final state particles→ efficient trigger and reconstruction*
  - *b→u involved in many (2,3)-bodies charmless B decays*
  - *but also penguin diagrams of similar amplitude*



Examples of contributing and interfering diagrams



Decay mode	Contributing diagrams
$B^0 \to \pi^+\pi^-$	$T,\ P,\ PA,\ P^C_{EW},\ E$
$B^0 \to K^+\pi^-$	$T,\ P,\ P^C_{EW}$
$B^0_s \to \pi^+K^-$	$T,\ P,\ P^C_{EW}$
$B^0_s \to K^+K^-$	$T,\ P,\ PA,\ P^C_{EW},\ E$
$B^0 \to K^+K^-$	$PA,\ E$
$B^0_s \to \pi^+\pi^-$	$PA,\ E$

BR $10^{-6} \to 10^{-5}$

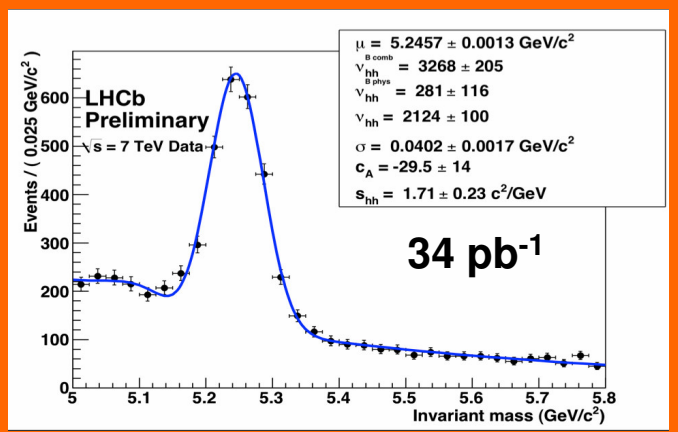
Upper limits 10^{-6}

Fleischer [PLB 459(1999) 306 arXiv:9903456, EPJ C52(2007) 267 arXiv:0705.1121]

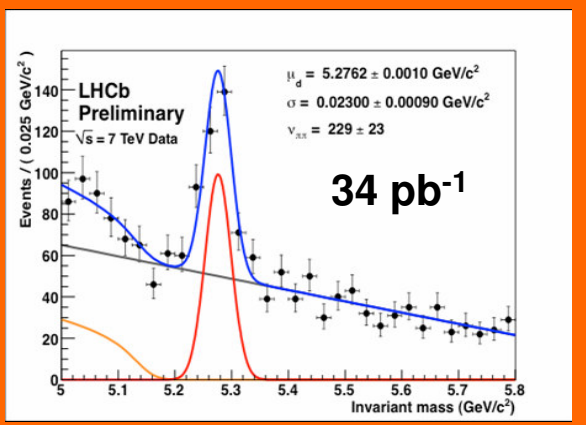
U-spin symmetry $B \to \pi^+\pi^-$ and $B_s \to K^+K^-$

- Symmetric under d→s exchance → same diagrams contribute
- Measure simultanous time-dependent CP asymmetry
- hadronic uncertainties cancel *(but assume U-spin symmetry)*

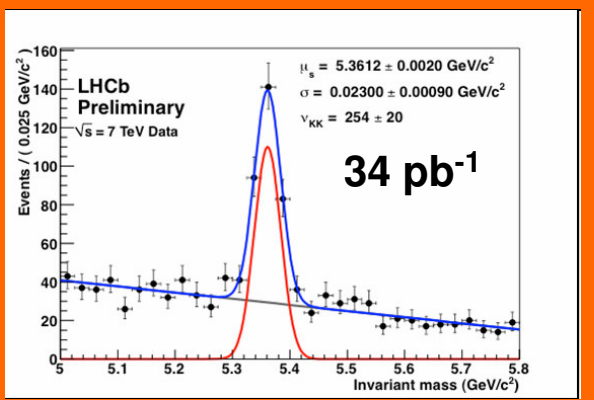
$\pi^+\pi^-$ mass, no PID



pion PID cuts



kaon PID cuts



- 2011: expect 7k each

Conclusions

- 37 pb^{-1} from 2010 run demonstrate excellent performance
  - *Great vertex and momentum resolution, good PID*
  - *World best B yields per pb^{-1}*
  - *Expects results on 2010 data soon*
- Exciting prospects for 2011
  - *Resolution on γ ~10° from trees, ~15° from loops*
- Open trigger and stripping scheme
  - *Study many more decays than mentionned here*