CP and charge asymmetries at CDF

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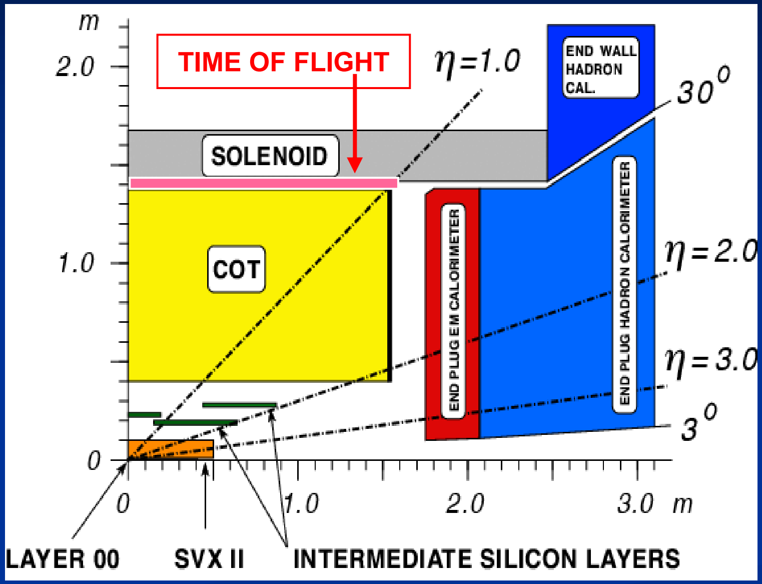
on behalf of CDF Collaboration

Motivations & outline

- CP violation and flavour physics particularly interesting to probe "New Physics".
- First essential to understand them in the SM framework.
  - Key problem → interpretation of "hadronic uncertainties"
- B meson system offers several strategies to constrain or partially eliminate hadronic uncertainties
  (simply speaking there are many B decays)
- Need measurements of B^0,B^+ **and B^0_s**
  - CDF ideal environment
- In this talk
  - BR($B^0_s \to D_s K$), direct CP asymmetries $A_{CP}(B^0 \to K^+\pi^-)$, $A_{CP}(B^0_s \to K^-\pi^+)$ and BR($B^0_s \to K^+K^-$)

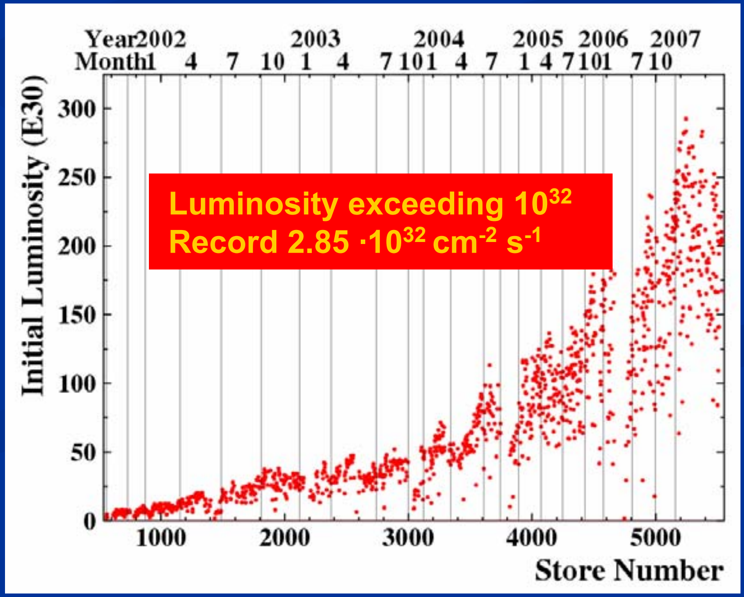
Important CDF features

- Central Drift chamber (COT)
  - $\sigma(p_T)/p_T^{\,2} \sim 0.1\%\ \mathrm{GeV}^{-1}$
  - dE/dx measurement:
    - 1.5σ sep. K/π @ p>2GeV/c.
- Silicon VerteX detector (SVX)
  - I.P. resolution: 35μm @ p=2GeV/c.
- Tracking trigger:
  - On-line impact parameter measurement



In this talk measurements with 1-1.2 fb^{-1}.

Delivered 3 fb^{-1} (on tape 2.5 fb^{-1})
Expect ~ 6/8 fb^{-1} by 2009.



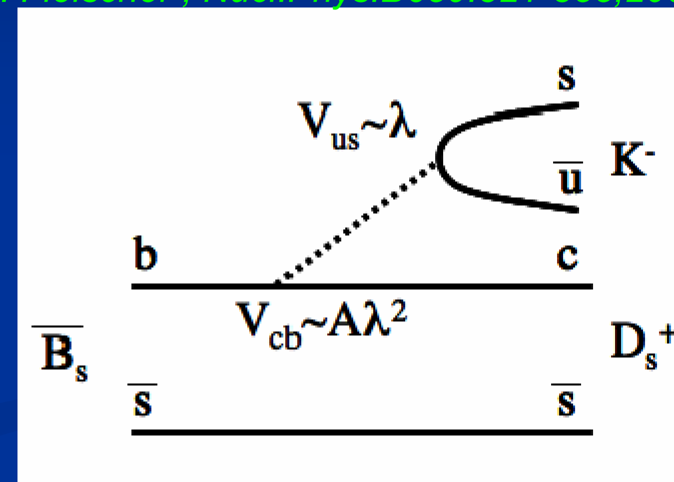
$B^0_s \rightarrow D_s K$ mode

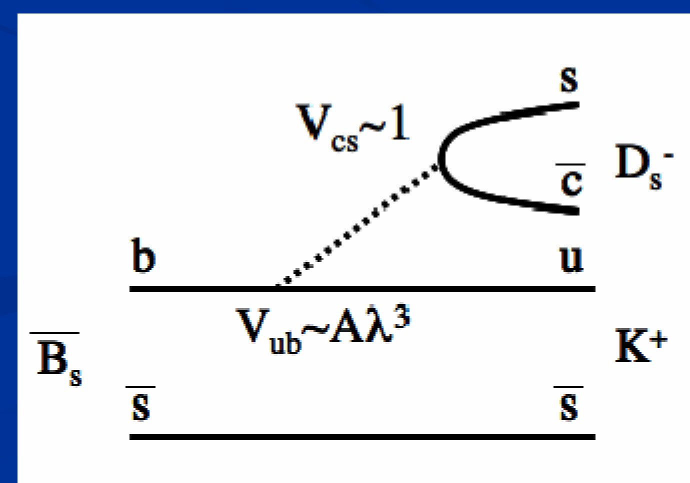
- Final states of both sign are accessible by both B^0_s and antiB^0_s mesons with similar size amplitude ($\sim\lambda^3$)

$$B^0_s \rightarrow D^\pm_s K^\mp$$
$$\overline{B}^0_s \rightarrow D^\mp_s K^\pm$$

- CP violation due to mixing can occur from the mixed and unmixed interference paths
- Need time-dependent CP asymmetries measurement
- Interesting comparison: $B^0_s \rightarrow D_s K$ can be suppressed or enhanced compared with $B^0 \rightarrow DK$
- First step: observation and BR measurement.

[R. Aleksan et al. Phys. C54,653 (1992)
R. Fleischer , Nucl.Phys.B659:321-355,2003]

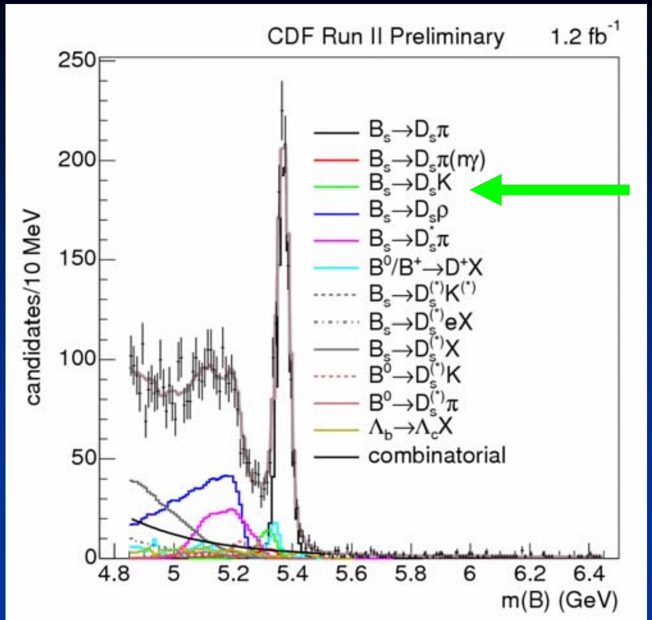


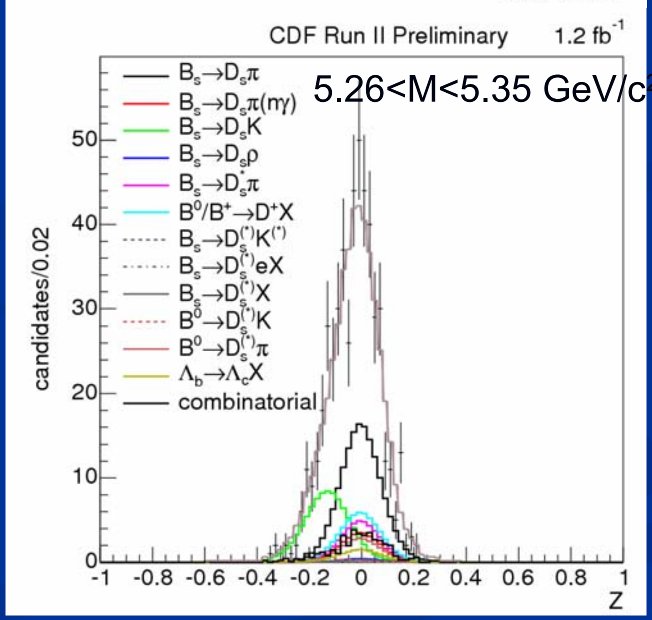


$BR(B^0_s \to D_s K)$

First observation

- Combined mass and PID maximum likelihood fit on 1.2 fb^{-1}
  - $M_{D_s\pi}$ ($B^0_s \to D_s X \to [\phi\pi]X$)
  - dE/dx for the B-daughter track
- Important features:
  - Accurate study of physics background components from MC: $B^0_s \to D^{(*)}_s X, D_s\rho$ etc.
  - FSR tail from $B^0_s \to D_s\pi(n\gamma)$
- Main systematics from dEdx templates



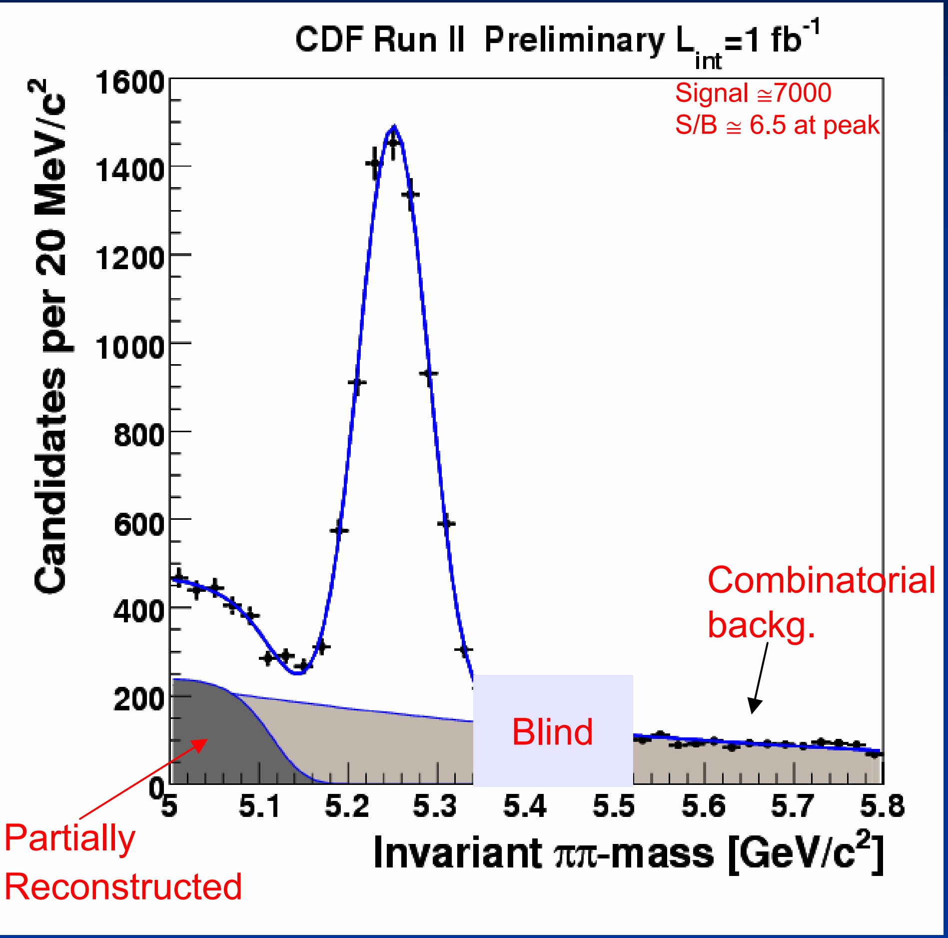


7.9 σ

Yield ~109 ±19 $B^0_s \to D_s K$ events

$$\mathcal{B}(\overline{B}^0_s \to D_s^\pm K^\mp)/\mathcal{B}(\overline{B}^0_s \to D_s^+\pi^-) = 0.107 \pm 0.019(\text{stat}) \pm 0.008(\text{sys})$$

$B \to h^+h^-$ signal (loose cuts)



Selection optimized to minimize statistical uncertainty on $A_{CP}(B^0 \to K\pi)$

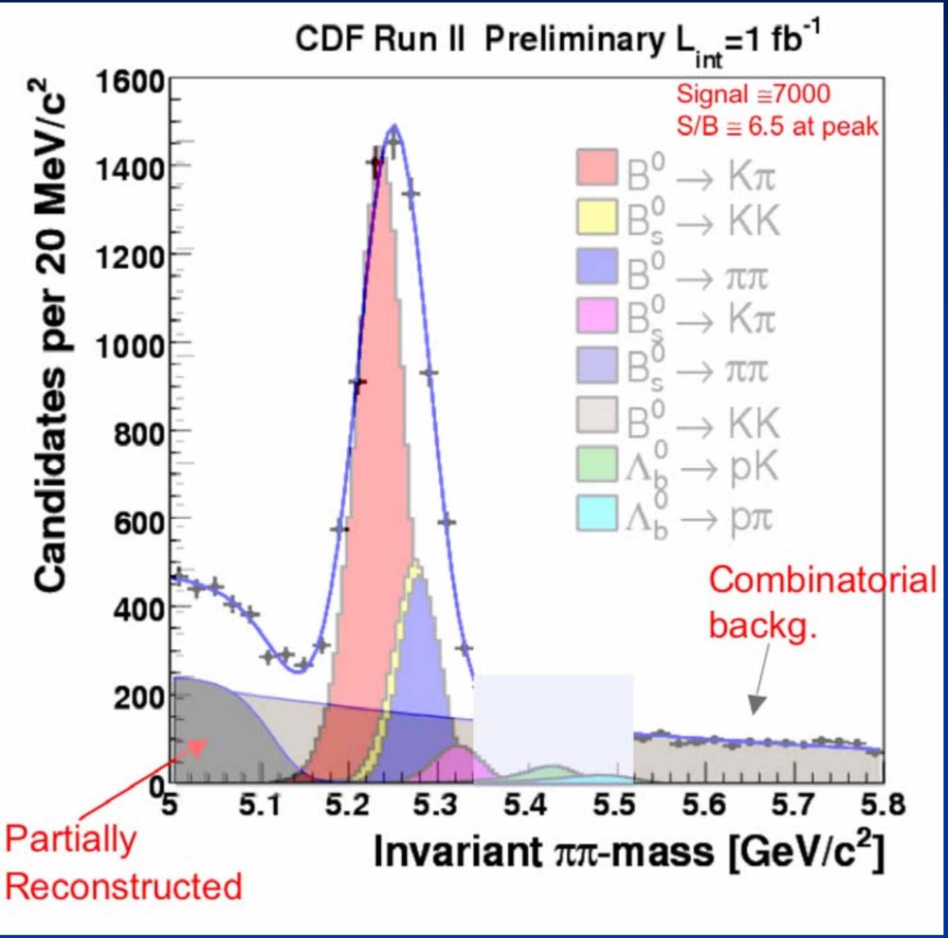
Despite good mass resolution (≅22 MeV/c^2), individual modes overlap in a single peak (width ~35 MeV/c^2)

Note that the use of a single mass assignment (ππ) causes overlap even with perfect resolution

Blinded region of unobserved modes: $B^0_s \to K\pi$, $B^0_s \to \pi\pi$, $\Lambda^0_b \to p\pi/pK$.

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

$B \to h^+h^-$ signal (loose cuts)



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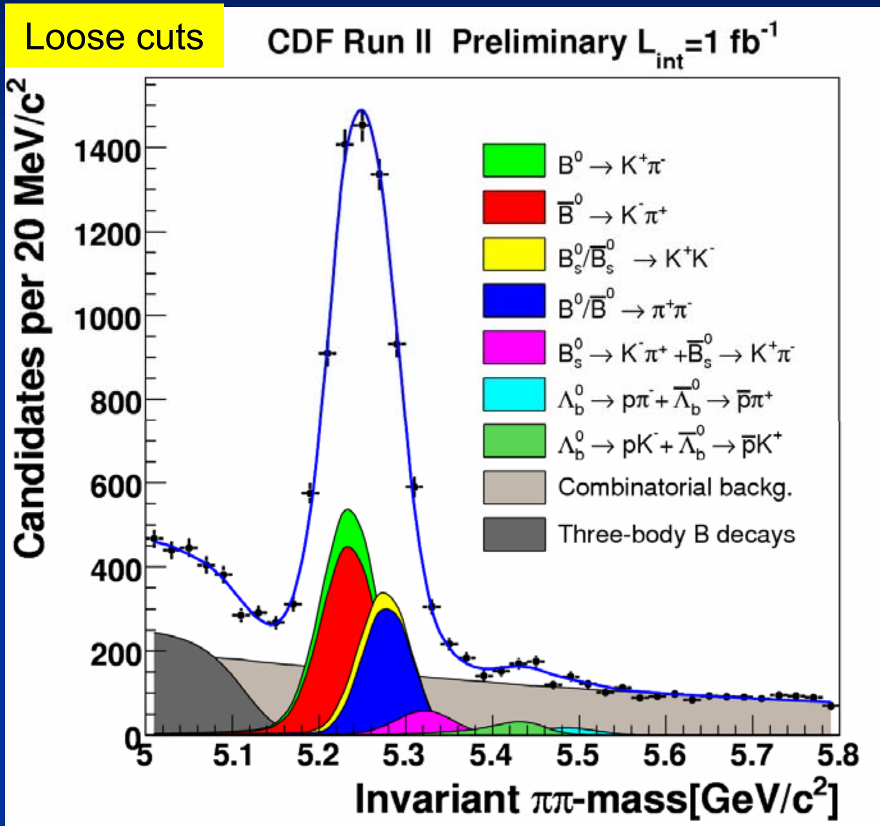
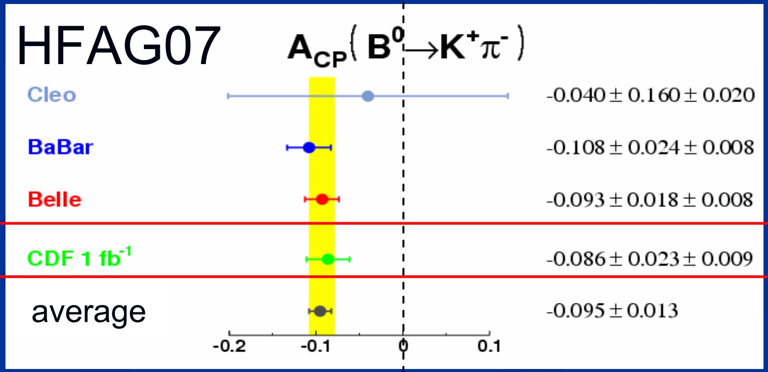
Result on $A_{CP}(B^0 \to K^+\pi^-)$



B^0 yields comparable to e^+e^-
4045 ± 84 $B^0 \to K^+\pi^-$
Large $B^0_s \to K^+K^-$ sample



WA significance $6\sigma \to 7\sigma$
Discrepancy with $A_{CP}(B^+ \to K^+\pi^0)$ up to **4.9 σ.**

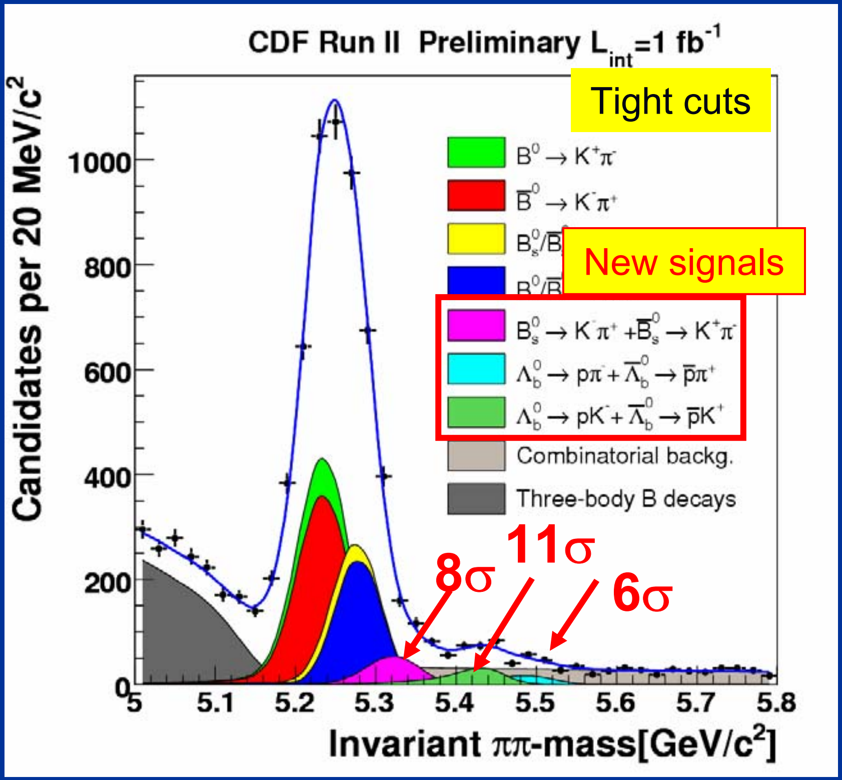
[hep-ex/0612018]

3.5 σ

$$A_{CP} = \frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.086 \pm 0.023\ (stat.) \pm 0.009\ (syst.)$$

Goal with Full Run II statistics 1%

BR($B^0_s \to K^-\pi^+$) (tight cuts)



Selection optimized to observe and limit setting of $B^0_s \to K^-\pi^+$

First observation of three rare charmless decays:
$B^0_s \to K^-\pi^+$, $\Lambda^0_b \to p\pi^-$ and $\Lambda^0_b \to pK^-$

BR($B^0_s \to K^-\pi^+$) theoretical expectations are strongly related to α and γ:

QCDF, pQCD [6 ÷ 10] $\cdot 10^{-6}$

[Beneke&Neubert, NP B675, 333(2003)]
[Yu, Li, Lu, PRD71,074026 (2005)]

SCET: $(4.9 \pm 1.8) \cdot 10^{-6}$

[Williamson,Zupan,PRD74, 014003(2006)]

$B^0_s \to K\pi$ yield = 230 ± 34(stat.) ± 16(syst.)

$$BR(B^0_s \to K^-\pi^+) = (5.0 \pm 0.75\ (stat.) \pm 1.0\ (syst.)) \times 10^{-6}$$

[hep-ex/0612018]

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

Observation of this decay offers a unique opportunity of checking for the SM origin of direct CP violation. Proposed in *[Gronau Rosner Phys.Rev. B482, 71(2000)],* later shown to hold under much weaker assumptions in *[Lipkin, Phys. Lett. B621,126, (2005)]*.

$$\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-) = \Gamma(B^0_s \to K^-\pi^+) - \Gamma(\overline{B}^0_s \to K^+\pi^-)$$

Currently unique to CDF. From our measured BR, we can predict DCPV using:

$$A_{CP}(B^0_s \to K^-\pi^+) = -A_{CP}(B^0 \to K^+\pi^-) \cdot \frac{\mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(B^0_s \to K^-\pi^+)} \cdot \frac{\tau(B^0)}{\tau(B^0_s)}$$

Low BR($B^0_s \to K^+\pi^-$) implies large asymmetry: DCPV$\cong$ +**37%**

Interesting case of large DCPV predicted under SM

Direct CPV in $B^0_s \to K^-\pi^+$

2.5 σ

$$A_{CP} = \frac{N(\overline{B}^0_s \to K^+\pi^-) - N(B^0_s \to K^-\pi^+)}{N(\overline{B}^0_s \to K^+\pi^-) + N(B^0_s \to K^-\pi^+)} = 0.39 \pm 0.15\ (stat.) \pm 0.08\ (syst.)$$

[hep-ex/0612018]

$$\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(B^0_s \to K^-\pi^+) - \Gamma(\overline{B}^0_s \to K^+\pi^-)} = 0.84 \pm 0.42(\text{stat.}) \pm 0.15(\text{syst.})$$ (SM =1)

First measurement of DCPV in the B^0_s
Sign and magnitude agree with SM predictions within errors ⇒
no evidence for 'exotic' sources of CP violation (yet)

It can shed light on the Belle and BaBar discrepancy. Assuming perfect SU(3) symmetry and neglecting annihilation diagrams *[Buras et al., Nucl. Phys. B697, 133,2004]* : $A_{CP}(B^0 \to \pi^+\pi^-) \approx A_{CP}(B^0_s \to K^-\pi^+)$.
Exciting to pursue with more data, already on tape 2.5 fb^{-1}.

$B^0_s \to K^+K^-$ and Prospects for $A_{CP}(t)$

$$BR(B^0_s \to K^+K^-) \;=\; (24.4 \pm 1.4\,(stat.) \pm 4.6\,(syst.)) \times 10^{-6}$$

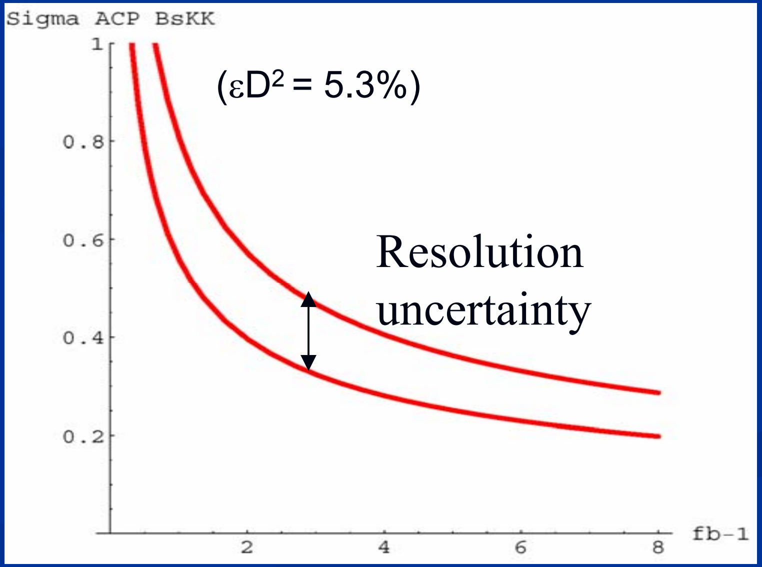
[hep-ex/0612018]

BR → preliminary systematics at the moment, expect syst≅ stat for final result.
Interesting comparison to predictions to evaluate the SU(3)-breaking size.

Ingredients for a time-dependent $A_{CP}(t)$ ready:
large samples (1300 ev/fb^{-1})
tag dilutions calibrated, x_s measured

Can have $\sigma(A_{CP})$ ~0.2÷0.15 in runII
(translate to sensitivity on γ ~ 10 deg.)

This resolution allows tests for NP.
[Baek et al, hep-ph/0610109]



Conclusions

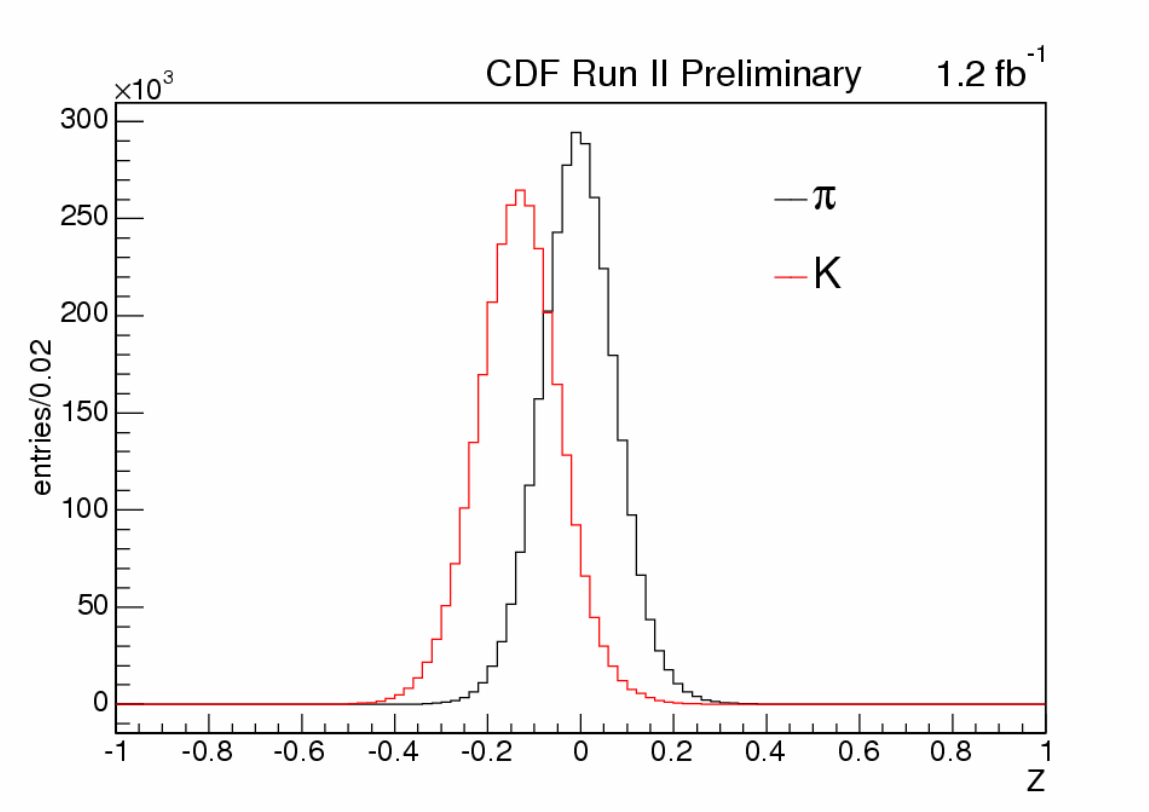
- First observation of $B^0_s \to D_s K$ mode
  - Shooting for an asymmetry measurement with increased statistics.
- First observation of $B^0_s \to K^- \pi^+$ mode
- First measurement of DCPV in B^0_s
  - SM prediction of large $A_{CP}(B^0_s \to K^- \pi^+)$ confirmed (for now)
- Precision $A_{CP}(B^0 \to K^+ \pi^-)$ confirms B-factories results.
  - Expect final measurement below 1%.
- Observed at the first time also $\Lambda_b \to pK$, $\Lambda_b \to p\pi$, direct CP asymmetries expected large, up-coming soon..
- Time-dependent $B^0 \to \pi^+ \pi^-$ and $B^0_s \to K^+ K^-$ is starting up.

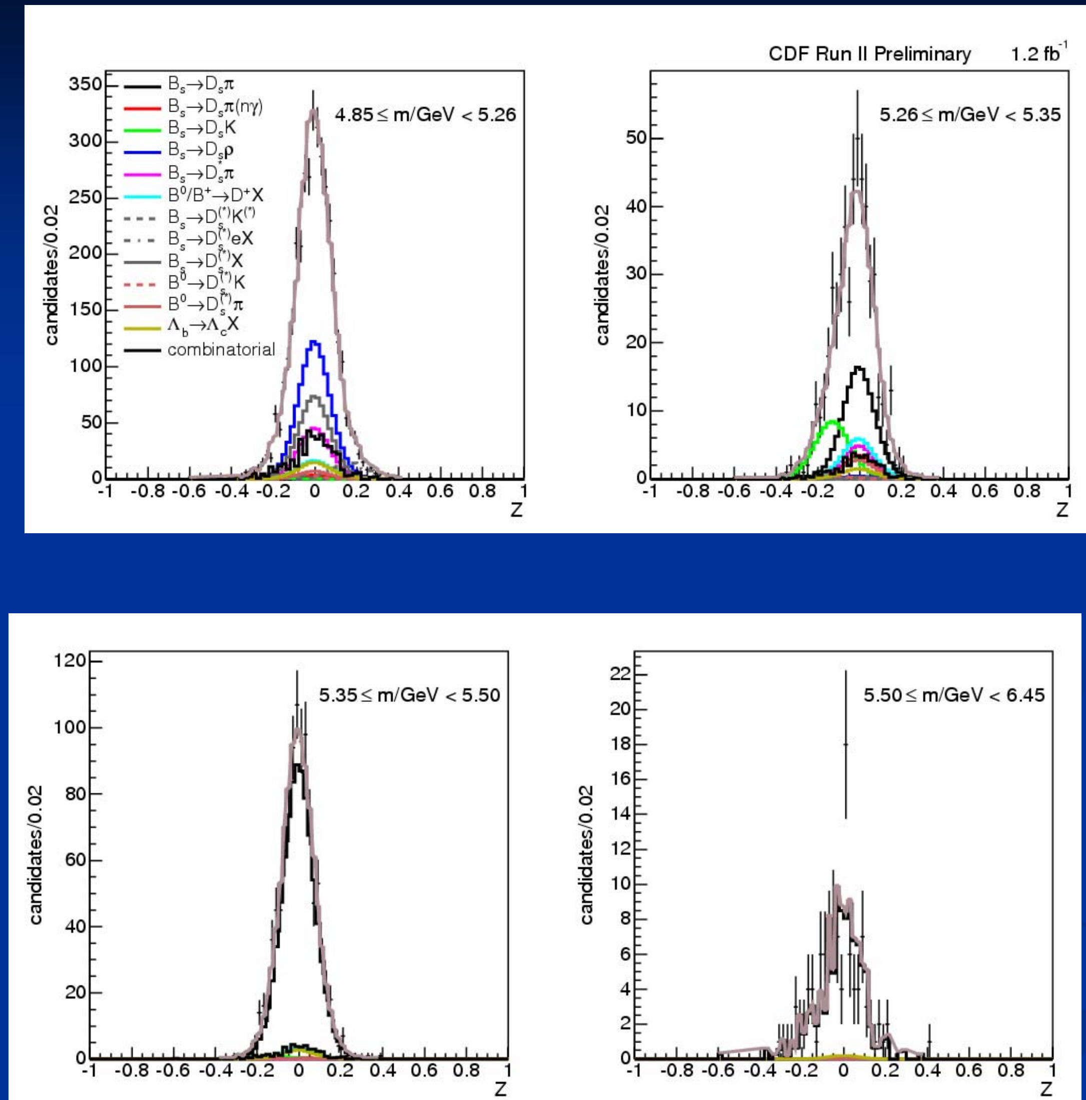
- CDF with $1 fb^{-1}$ already major player in B-meson physics. Several more to follow. Several measurements of CP asymmetries up-coming.

Backup

$B^0_s \rightarrow D_s K$: dEdx variable

$$Z = \log\left(\frac{dE/dx(\text{measured})}{dE/dx(\text{expected for }\pi)}\right)$$

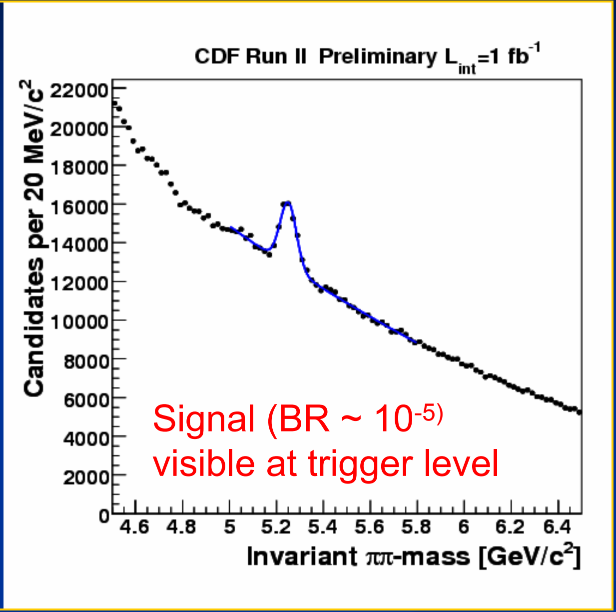



CDF Run II Preliminary 1.2 fb^{-1}
4.85 ≤ m/GeV < 5.26
5.26 ≤ m/GeV < 5.35
5.35 ≤ m/GeV < 5.50
5.50 ≤ m/GeV < 6.45
$B_s \to D_s\pi$
$B_s \to D_s\pi(n\gamma)$
$B_s \to D_sK$
$B_s \to D_s\rho$
$B_s \to D_s\pi$
$B^0/B^+ \to D^+X$
combinatorial
candidates/0.02
Z

Sample selection

TRIGGER cuts

- Reject light-quark background
  - Two oppositely-charged tracks
  - Transverse opening angle;
  - p_{T1} , p_{T2};
  - $p_{T1} + p_{T2}$.
- Long-lived candidate
  - Track impact parameters;
  - Transverse decay length;
- Reject multi-prongs and backgrounds
  - B impact parameter.



OFFLINE cuts

- Further observables:
  - 3D Vertex chi-square
  - Isolation:

$$I(B) = \frac{p_T(B)}{p_T(B) + \sum_{cone} p_{Ti}}$$

- Effective in reducing light-quark background, 85% efficient. (analog of event shape at e^+e^-)

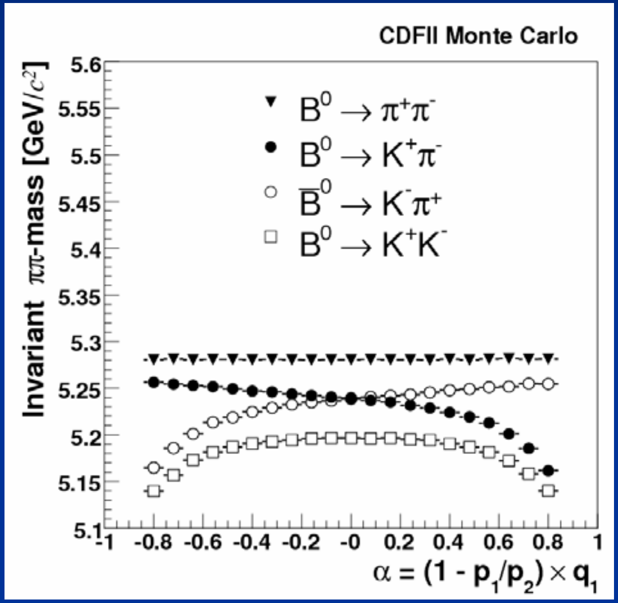
2 sets of cuts:

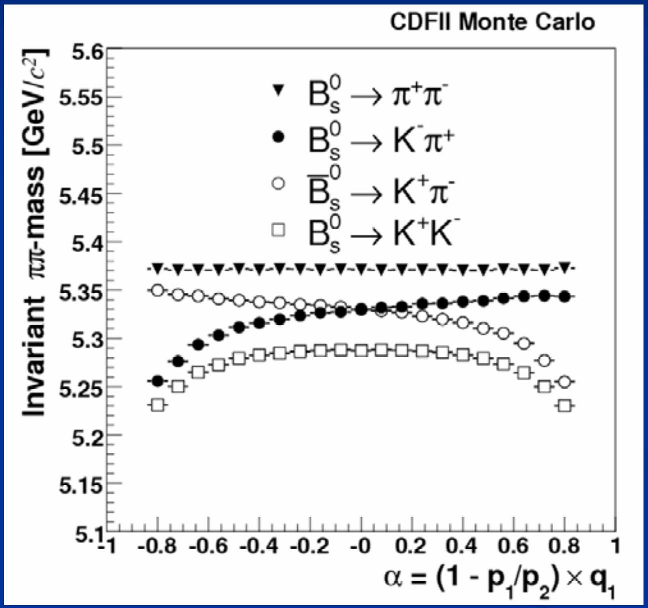
- Loose: optimize for $A_{CP}(B^0 \to K^+\pi^-)$
  (good for all three "large modes")
- Tight: optimize for $B^0_s \to K^-\pi^+$
  (good for all "rare modes")

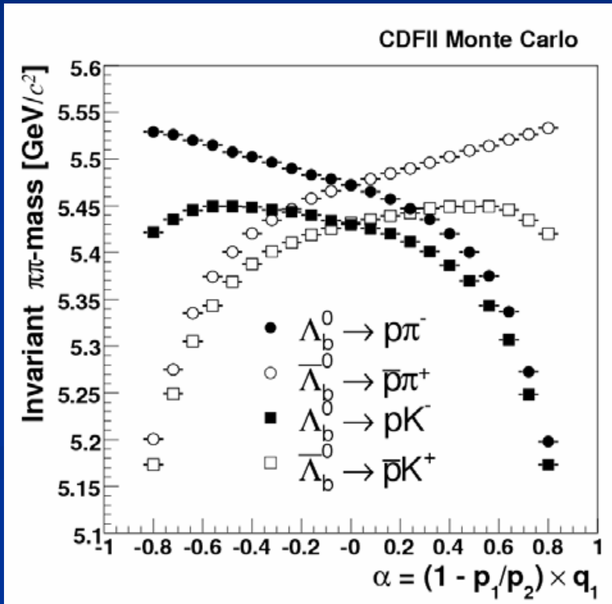
Kinematics

Exploit dependence between invariant mass and momentum imbalance

CDF MC



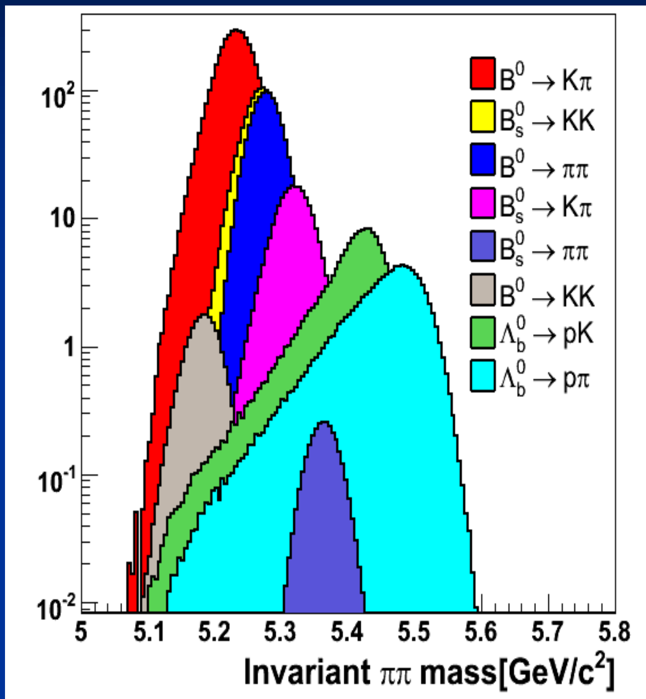




1) $M_{\pi\pi}$ invariant $\pi\pi$-mass
2) $\alpha = (1-p_{min}/p_{max})q_{min}$ signed p-imbalance
3) $p_{tot}= p_{min}+p_{max}$ scalar sum of 3-momenta

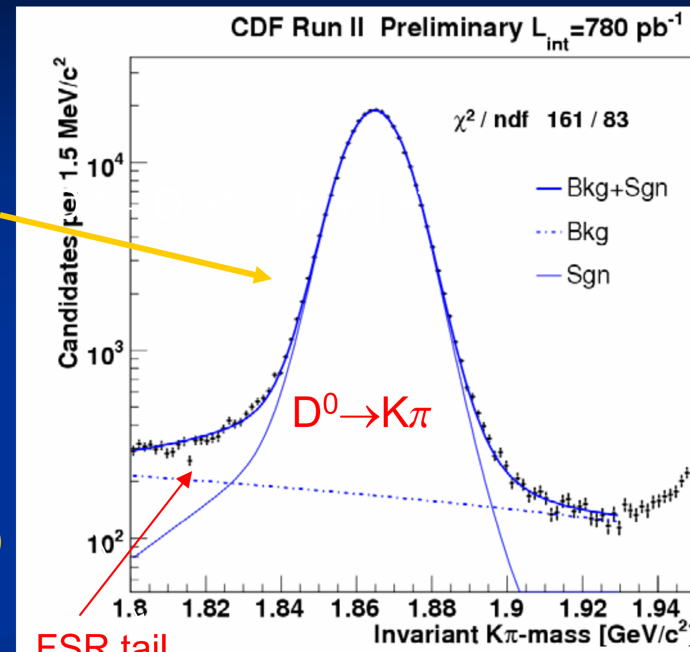
This offers good discrimination amongst modes and between $K^+\pi^-$ / $K^-\pi^+$.

Mass line shape and FSR

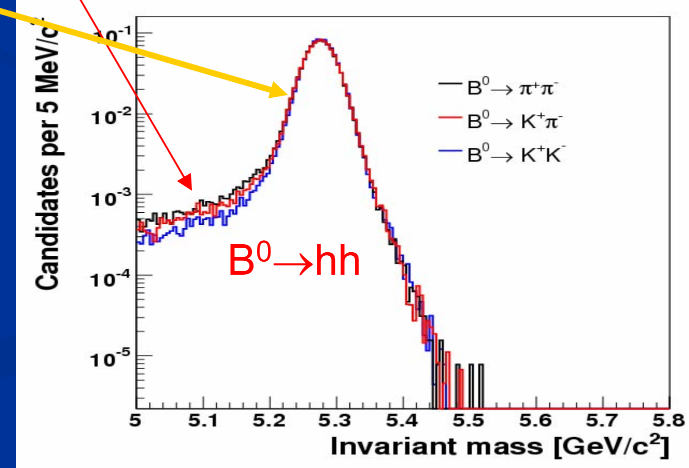


1) TEST on $D^0 \to K^-\pi^+$

2) APPLY to $B \to h^-h^+$



FSR tail



Results depend on assumed mass resolution and details of the lineshape (rare modes confuse with the tails of larger modes)

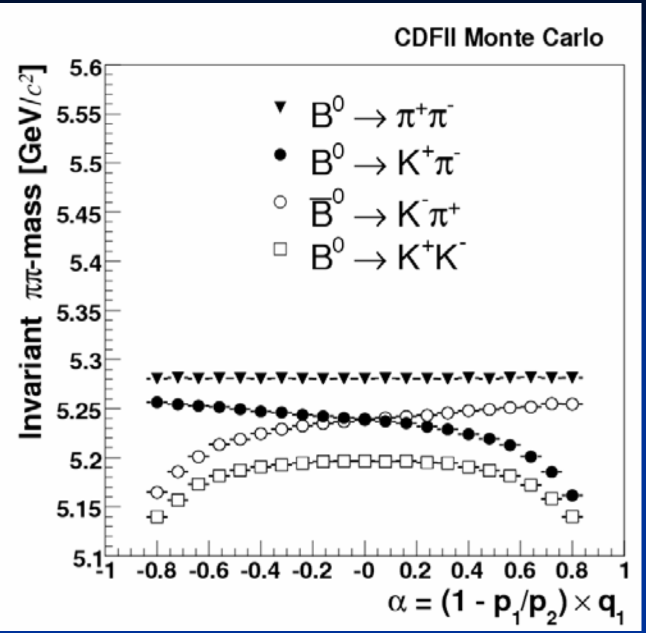
Need good control of non–gaussian resolution and effects of Final State Radiation

QED: [Baracchini,Isidori PL B633:309-313,2006]

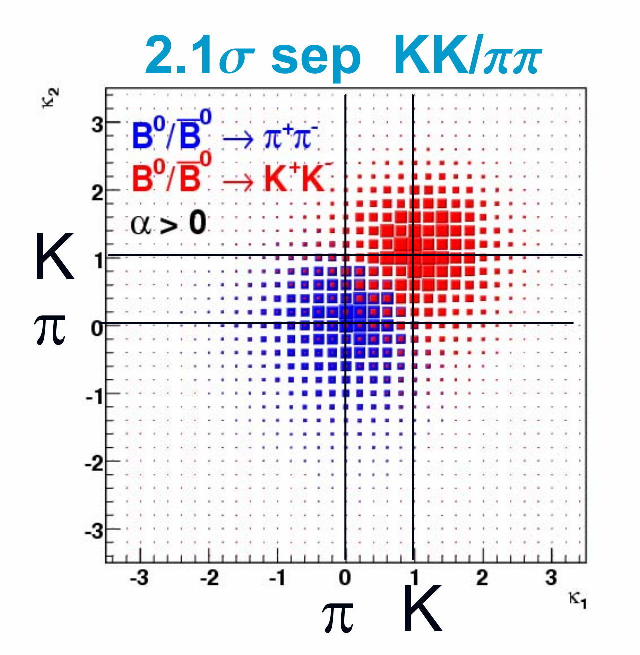
Kinematics and PID

Exploit dependence between invariant mass and momentum imbalance.

1) $M_{\pi\pi}$ invariant $\pi\pi$-mass
2) $\alpha = (1-p_{min}/p_{max})q_{min}$
signed p-imbalance
3) $p_{tot} = p_{min}+p_{max}$
scalar sum of 3-momenta



dE/dx carefully calibrated on pure K and π samples from 1.5M decays: $D^{*+} \to D^0\pi^+ \to [K^-\pi^+]\ \pi^+$ (sign of D^{*+} pion tags D^0 sign)



1.5σ K/π power separation for track p>2GeV/c achieve a statistical uncertainty on separating classes of particles which is just 60% worse than 'perfect' PID (≡75% for 2 particles)
[arXiv:physics/0611219]

Kinematics

Exploit dependence between invariant mass and momentum imbalance. This offers good discrimination amongst modes and between $K^+\pi^-$ / $K^-\pi^+$.

1) $M_{\pi\pi}$ invariant $\pi\pi$-mass

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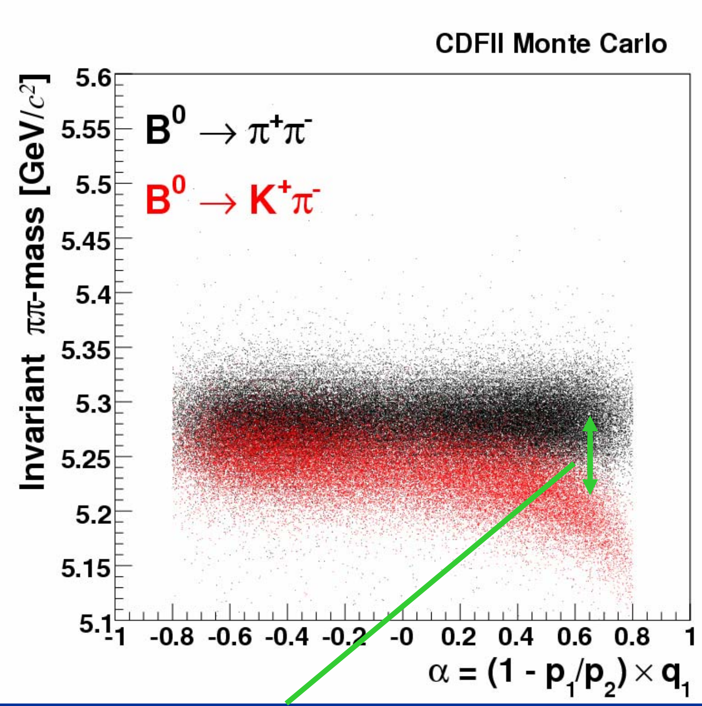
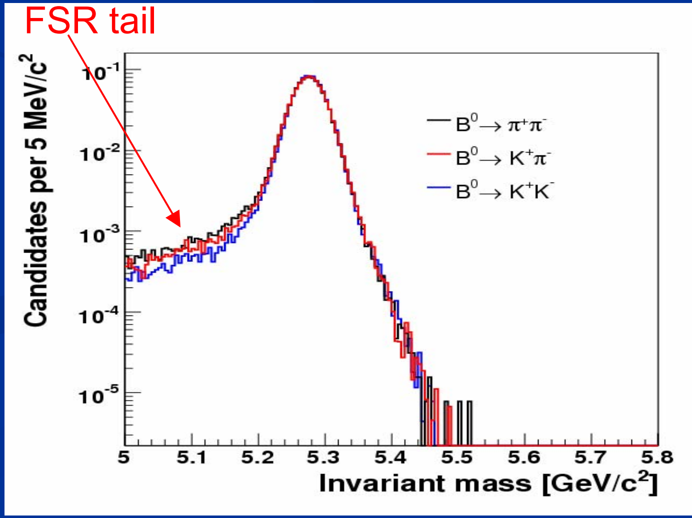


analytical function of momenta $f(\alpha, p_{tot})$



Results depend on assumed mass resolution and details of the lineshape

Final State Radiation treated in the simulation using *QED: [Baracchini,Isidori PRL B633:309-313,2006]* .
Check on 1.5M of $D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-\pi^+]\,\pi^+$

dE/dx

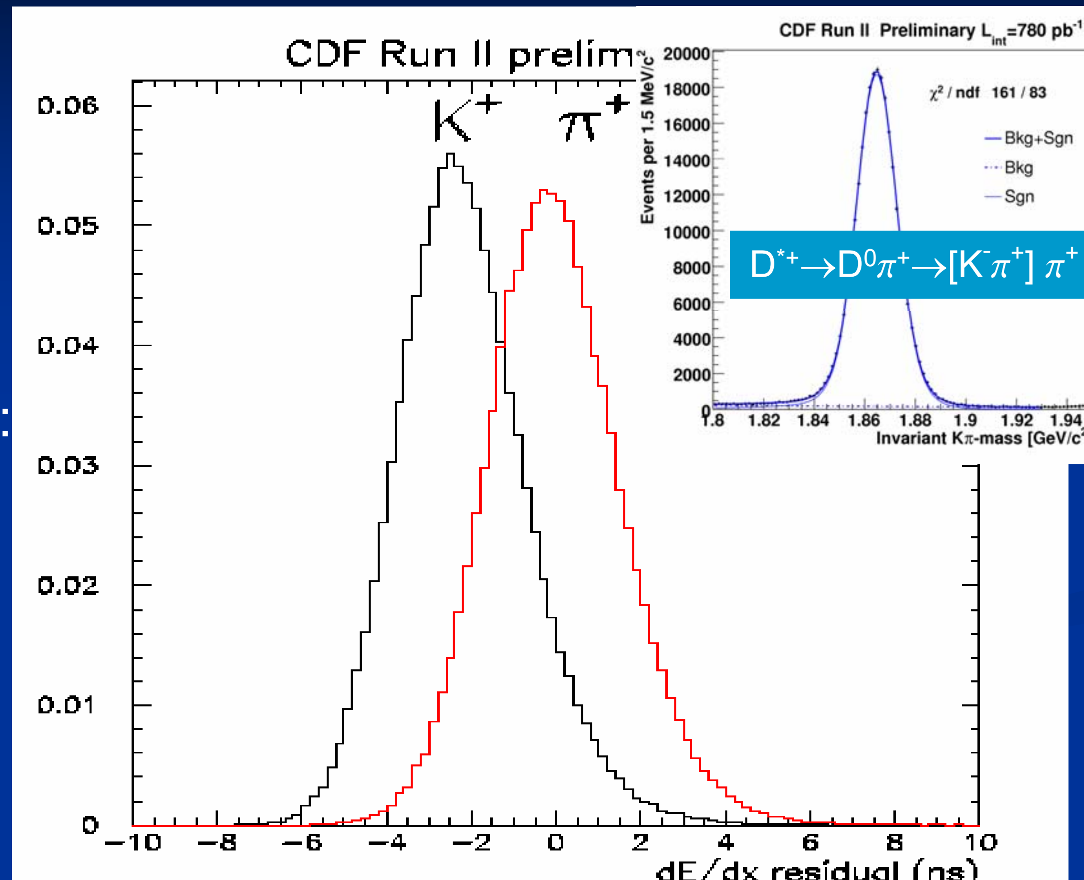
Calibrate on pure K and π samples from decay:
$D^{*+} \to D^0 \pi^+ \to [K^- \pi^+]\ \pi^+$
(sign of D^{*+} pion tags D^0 sign)

Useful quantity to plot ('kaonness'):

$$\frac{\left.\frac{dE}{dx}\right|_{meas}(\text{track}) - \left.\frac{dE}{dx}\right|_{exp-\pi}(\text{track})}{\left.\frac{dE}{dx}\right|_{exp-K}(\text{track}) - \left.\frac{dE}{dx}\right|_{exp-\pi}(\text{track})}.$$

<id>(pion) = 0
<id>(kaon) = 1

(independent of p)



dE/dx carefully calibrated over tracking volume and time.
Detailed model includes tails, momentum dependence, two-track correlations

1.5σ K/π separation for p>2GeV
achieve a statistical uncertainty on separating classes of particles which is just 60% worse than 'perfect' PID

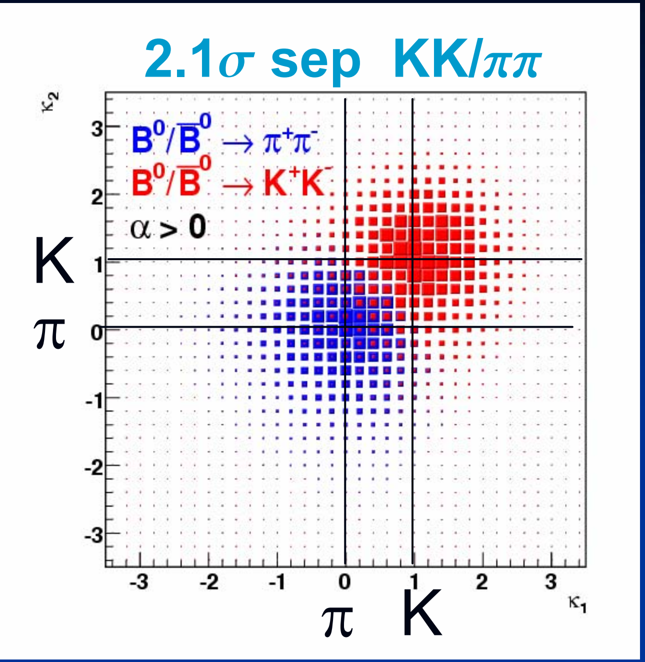
$B \to h^+h^-$: dE/dx

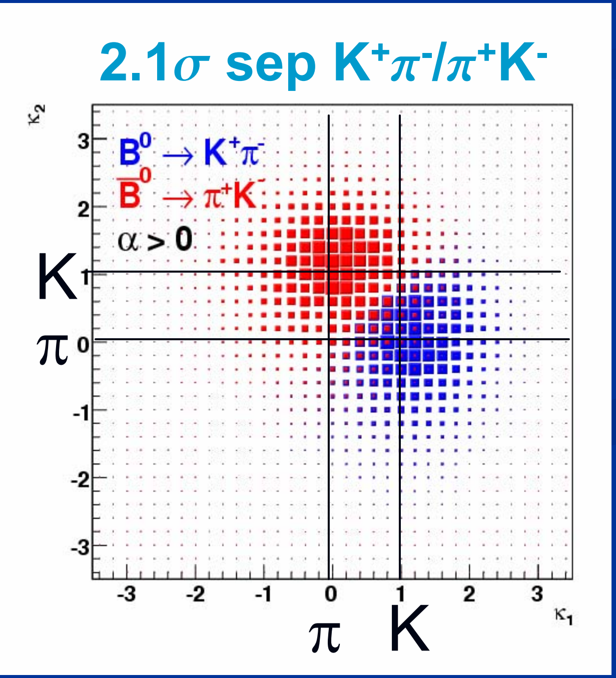
Carefully calibrated on pure K and π samples from 1.5M decays: $D^{*+} \to D^0\pi^+ \to [K^-\pi^+]\,\pi^+$
(sign of D^{*+} pion tags D^0 sign)

Useful dE/dx quantity ('kaonness'):

<kaonness>(pion) = 0 <kaonness>(kaon) = 1

1.5σ K/π power separation for track p>2GeV/c achieve a statistical uncertainty on separating classes of particles which is just 60% worse than 'perfect' PID (≡75% for 2 particles)
[arXiv:physics/0611219]





Separating channels

Unbinned ML fit based on 5 observables (kinematics+PID)

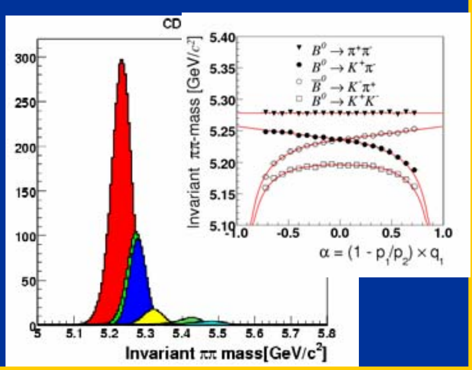
$$\mathscr{L}(\vec{\theta})=\prod_{i=1}^{N}\mathscr{L}_i(\vec{\theta})$$

fraction of j[th] mode, to be determined by the fit

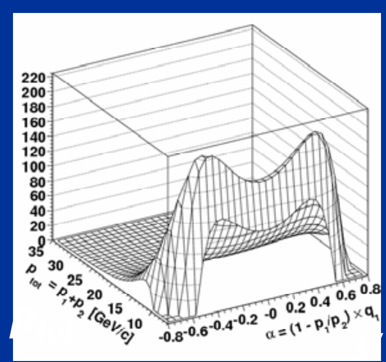
$$\mathscr{L}_i(\vec{\theta})=(1-b)\sum f_j\mathscr{L}_j^{\mathrm{sign}}+b\mathscr{L}^{\mathrm{bckg}}$$

$$pdf_j^{\mathrm{m}}(m_{\pi\pi}|\alpha,p_{tot};\vec{\theta})\cdot pdf_j^{\mathrm{p}}(\alpha,p_{tot};\vec{\theta})\cdot pdf_j^{\mathrm{PID}}(\mathrm{ID}_1,\mathrm{ID}_2|p_{tot},\alpha;\vec{\theta})$$

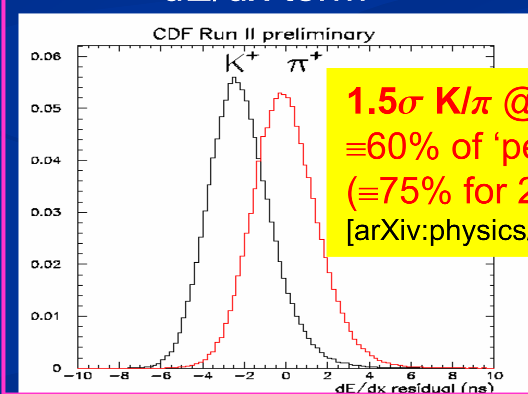
mass term



momentum term



dE/dx term



1.5σ K/π @p>2GeV
≡60% of 'perfect' PID
(≡75% for 2 particles)
[arXiv:physics/0611219]

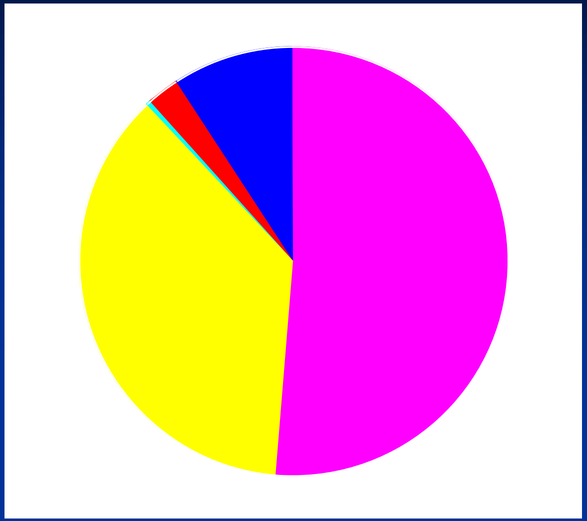
Signal shapes: from MC and analytic formula
Background shapes: from data sidebands

sign and bckg shapes from $D^0 \to K^- \pi^+$

Mode	N_s	Quantity	Measurement	$\mathcal{B}(10^{-6})$
$B^0 \to K^+\pi^-$	4045 ± 84	$\frac{\mathcal{B}(\overline{B}^0\to K^-\pi^+)-\mathcal{B}(B^0\to K^+\pi^-)}{\mathcal{B}(\overline{B}^0\to K^-\pi^+)+\mathcal{B}(B^0\to K^+\pi^-)}$	-0.086 ± 0.023 ± 0.009	
$B^0 \to \pi^+\pi^-$	1121 ± 63	$\frac{\mathcal{B}(B^0\to\pi^+\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)}$	0.259 ± 0.017 ± 0.016	5.10 ± 0.33 ± 0.36
$B^0_s \to K^+K^-$	1307 ± 64	$\frac{f_s}{f_d}\frac{\mathcal{B}(B^0_s\to K^+K^-)}{\mathcal{B}(B^0\to K^+\pi^-)}$	0.324 ± 0.019 ± 0.041	24.4 ± 1.4 ± 4.6
$B^0_s \to K^-\pi^+$	230 ± 34 ± 16	$\frac{f_s}{f_d}\frac{\mathcal{B}(B^0_s\to K^-\pi^+)}{\mathcal{B}(B^0\to K^+\pi^-)}$	0.066 ± 0.010 ± 0.010	5.0 ± 0.75 ± 1.0
		$\frac{\mathcal{B}(\overline{B}^0_s\to K^+\pi^-)-\mathcal{B}(B^0_s\to K^-\pi^+)}{\mathcal{B}(\overline{B}^0_s\to K^+\pi^-)+\mathcal{B}(B^0_s\to K^-\pi^+)}$	0.39 ± 0.15 ± 0.08	
		$\frac{f_d}{f_s}\frac{\Gamma(\overline{B}^0\to K^-\pi^+)-\Gamma(B^0\to K^+\pi^-)}{\Gamma(\overline{B}^0_s\to K^+\pi^-)-\Gamma(B^0_s\to K^-\pi^+)}$	-3.21 ± 1.60 ± 0.39	
$B^0_s \to \pi^+\pi^-$	26 ± 16 ± 14	$\frac{f_s}{f_d}\frac{\mathcal{B}(B^0_s\to\pi^+\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)}$	0.007 ± 0.004 ± 0.005	0.53 ± 0.31 ± 0.40 (< 1.36 @ 90% CL)
$B^0 \to K^+K^-$	61 ± 25 ± 35	$\frac{\mathcal{B}(B^0\to K^+K^-)}{\mathcal{B}(B^0\to K^+\pi^-)}$	0.020 ± 0.008 ± 0.006	0.39 ± 0.16 ± 0.12 (< 0.7 @ 90% CL)
$\Lambda^0_b \to pK^-$	156 ± 20 ± 11	$\frac{\mathcal{B}(\Lambda^0_b\to p\pi^-)}{\mathcal{B}(\Lambda^0_b\to pK^-)}$	0.66 ± 0.14 ± 0.08	
$\Lambda^0_b \to p\pi^-$	110 ± 18 ± 16			

Systematics $A_{CP}(B^0 \to K^+\pi^-)$

- dE/dx model (±0.0064);
- Nominal *B*-meson masses (±0.005);
- Background model (±0.003);
- Charge-asymmetries (±0.0014);
- Global mass scale.



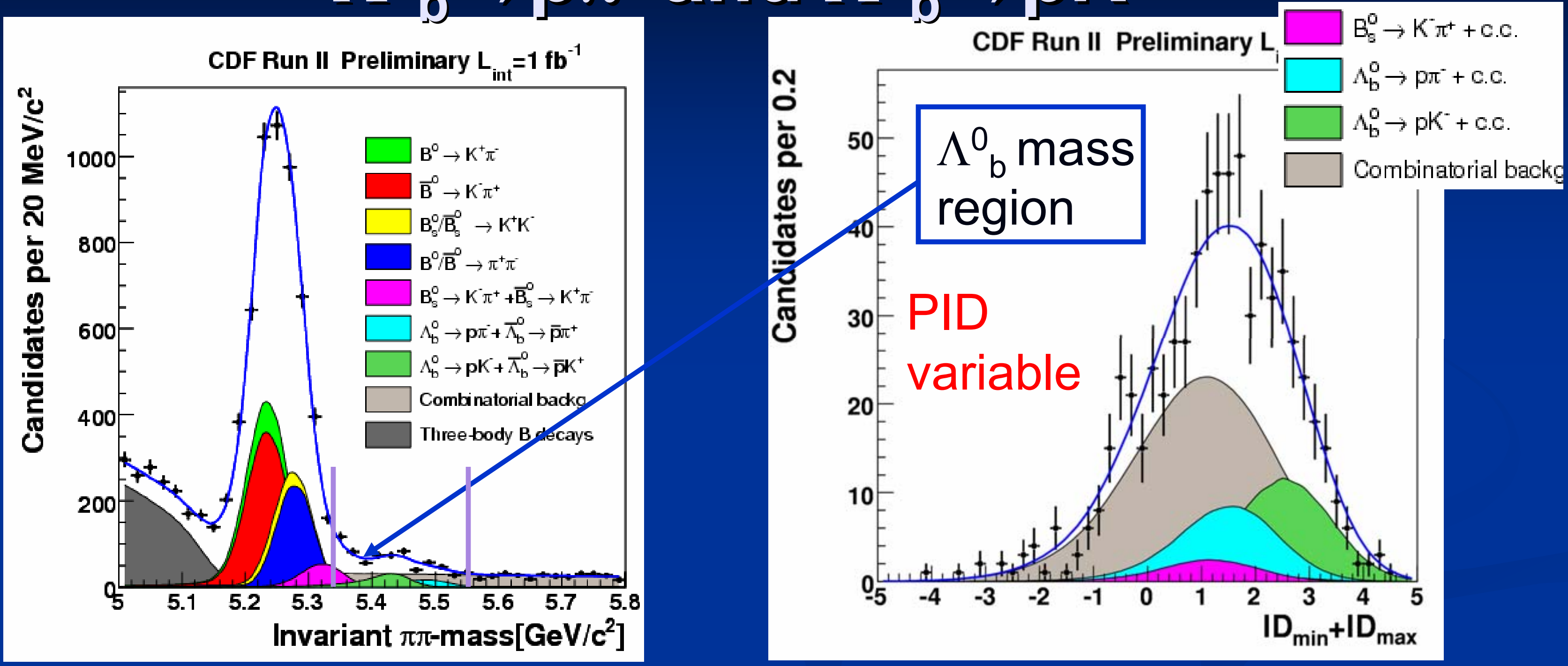
Total systematic uncertainty is 0.9%, compare with 2.3% statistical.

Huge sample of prompt $D^0 \to h^+h^-$ (15M).
Kinematic fit using *same code* of $B \to hh$ fit. Direct $A_{CP}(D^0 \to K\pi)$ very small:
$\Rightarrow$ extract from DATA correction for $\epsilon(K^-\pi^+)/\epsilon(K^+\pi^-)$ plus any spurious asymmetries.

Additional check: measurement of $A_{CP}(D^0 \to K\pi)$ based on dE/dx-only.
Discrepancy with the kinematic fit ($\cong$0.006) within quoted systematics.

Systematics can still decrease with larger calibration samples
Prospects for a runII CDF measurement with **<1% uncertainty**.

First observation: $\Lambda^0_b \to p\pi^-$ and $\Lambda^0_b \to pK^-$



$$N_{\mathrm{raw}}(\Lambda^0_b \to pK^-) = 156 \pm 20\ (stat.) \pm 11\ (syst.)$$

11 σ

$$N_{\mathrm{raw}}(\Lambda^0_b \to p\pi^-) = 110 \pm 18\ (stat.) \pm 16\ (syst.)$$

6 σ

$$\frac{BR(\Lambda^0_b \to p\pi^-)}{BR(\Lambda^0_b \to pK^-)} = 0.66 \pm 0.14\ (stat.) \pm 0.08\ (syst.)$$

$\Lambda^0_b \to ph^-$ entangled to $B^0_s \to K^-\pi^+$

Large DCPV expected for both modes

[Mohanta et al. Phys.Rev. D63 (2001) 074001]