Prospects for CP violation at the Tevatron (all angles)

Petar Maksimovic, for CDF and D0

CDF and D0 caught between

1) **idealistic projections** from long ago

2) **realistic extrapolations** from recent measurements

$\Rightarrow$ report on (2) only in several cases

show progress in other areas

Hadronic environment

Disadvantages:

- "messy"
- opp. side b-hadron not recostructed 20-40%

  of time (coverage an issue -- points for D0)

Advantages:

- huge $b\bar{b}$ cross-section (~100 μb total)
- (still only 1 per ~1000 soft QCD collisions)

$\Rightarrow$ live and die by the trigger

(displaced track triggers: CDF from beginning,

D0 commissioning now; faster DAQ -- points for CDF)

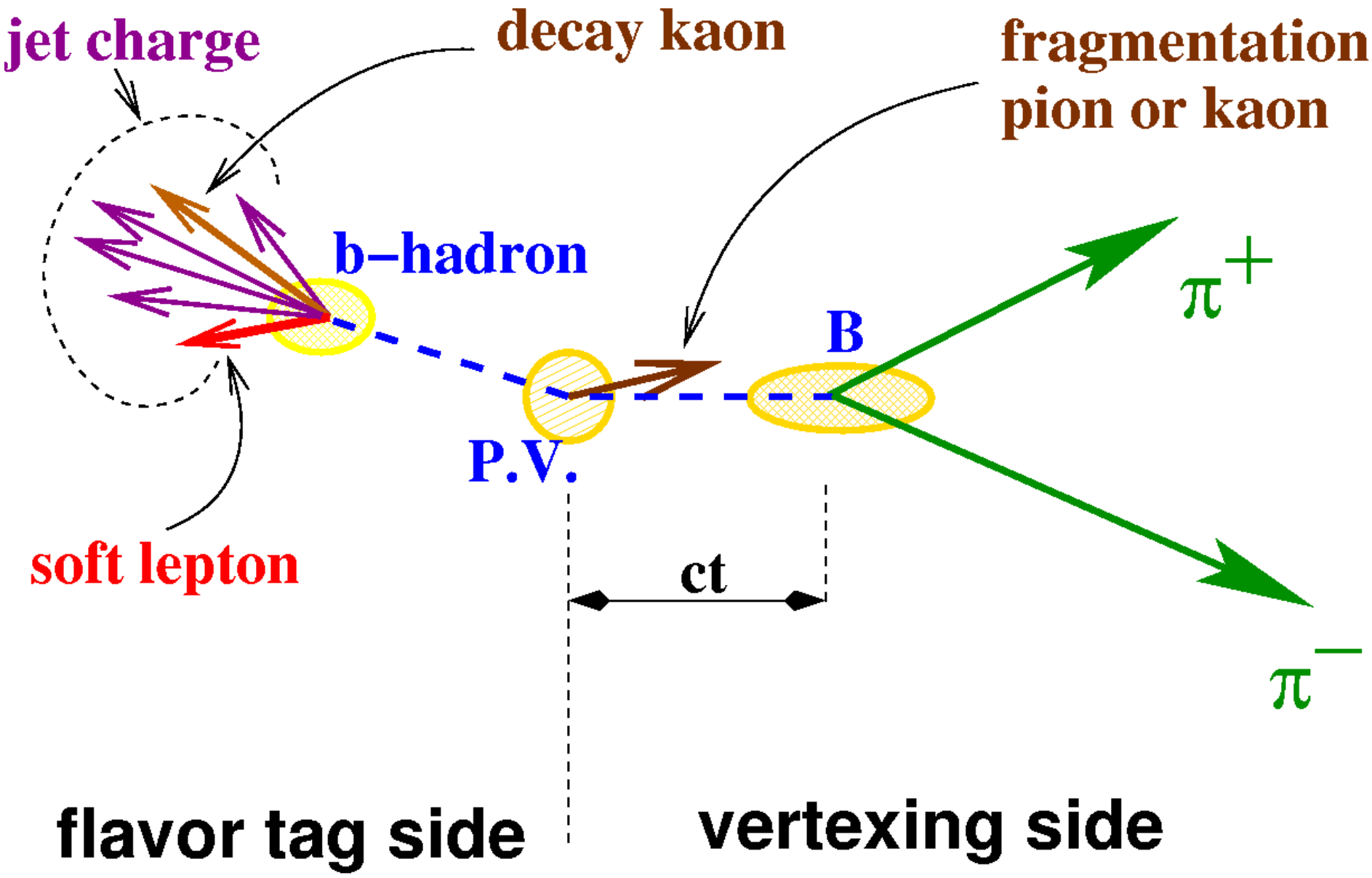
Ingredient #1: Luminosity

Luminosity in inverse fb	By 2008	By 2010 + recycler
Base projection	2.11	4.41
Design projection	3.78	8.57

(more optimistic, relies on electron cooling)

- Consider **2 inv.fb** and **3.5 inv.fb**
- Not clear if current B triggers are OK > 2007

Ingredient #2: flavor tagging



Ingredient #2: flavor tagging

ϵD^2 [%]	CDF	D0
Soft Muons	0.66±0.09	1.6±1.1
Soft Electrons	?	?
Jet Charge	?	3.3±1.7
Same Side	1.9±0.9	5.5±2.0
Opp.Side Kaon	? [4.2]	N/A
Same Side Kaon	? [2.4]	N/A

- For projections, CDF is using $\epsilon D^2 = 5\%$

(Down from > 10% since Kaon tagging not ready)

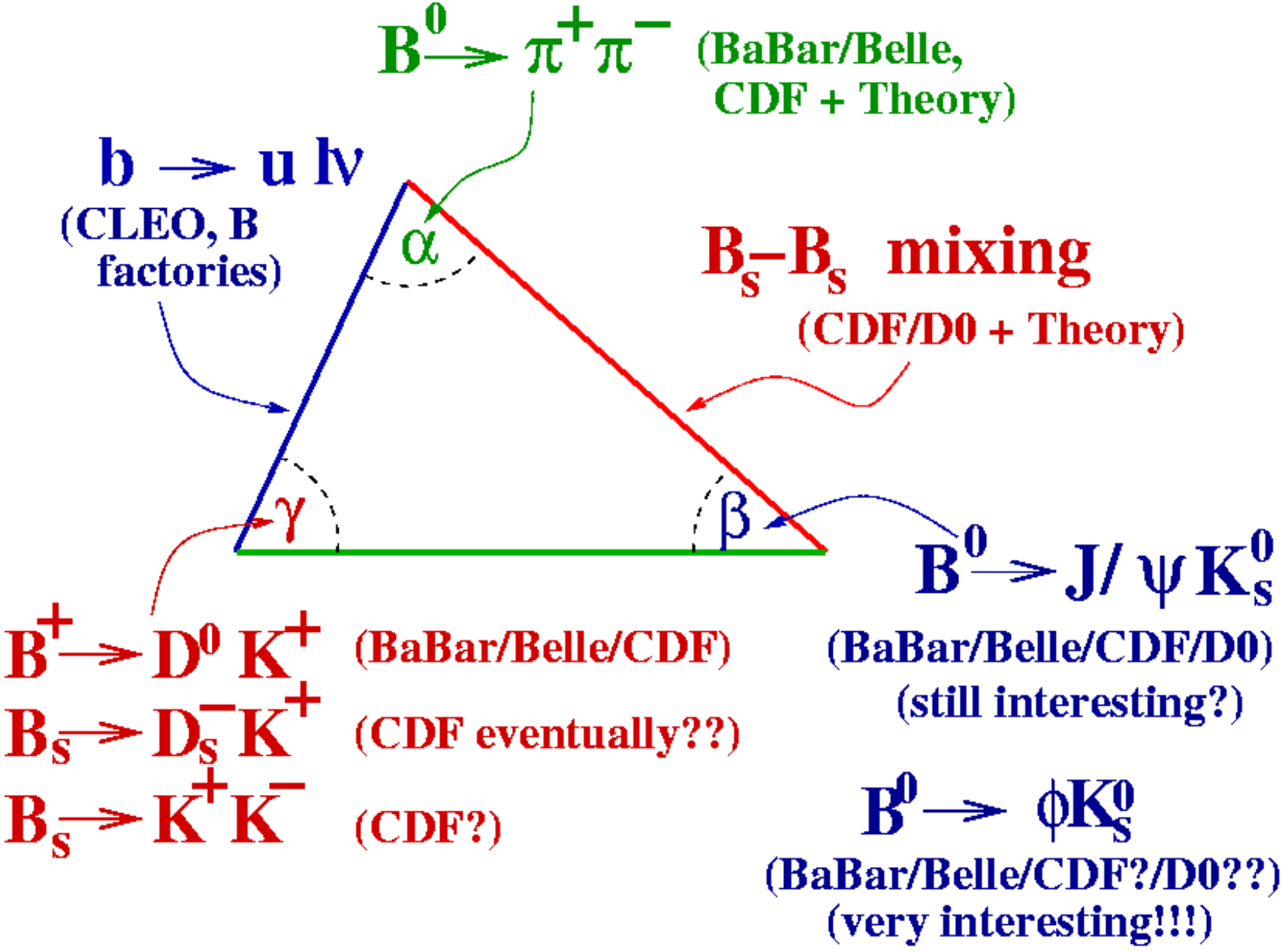
Ingredient #3: time resolution

	Proper time resol [fs]
CDF	67 (50 with L00)
D0	110

Other expected improvements:

- D0: significant trigger upgrade just installed -- **adding track-based triggers!**
- CDF: upgrades to DAQ and trigger logic in 2004 and 2005
- CDF's Layer 00 ready for physics

Overall game plan



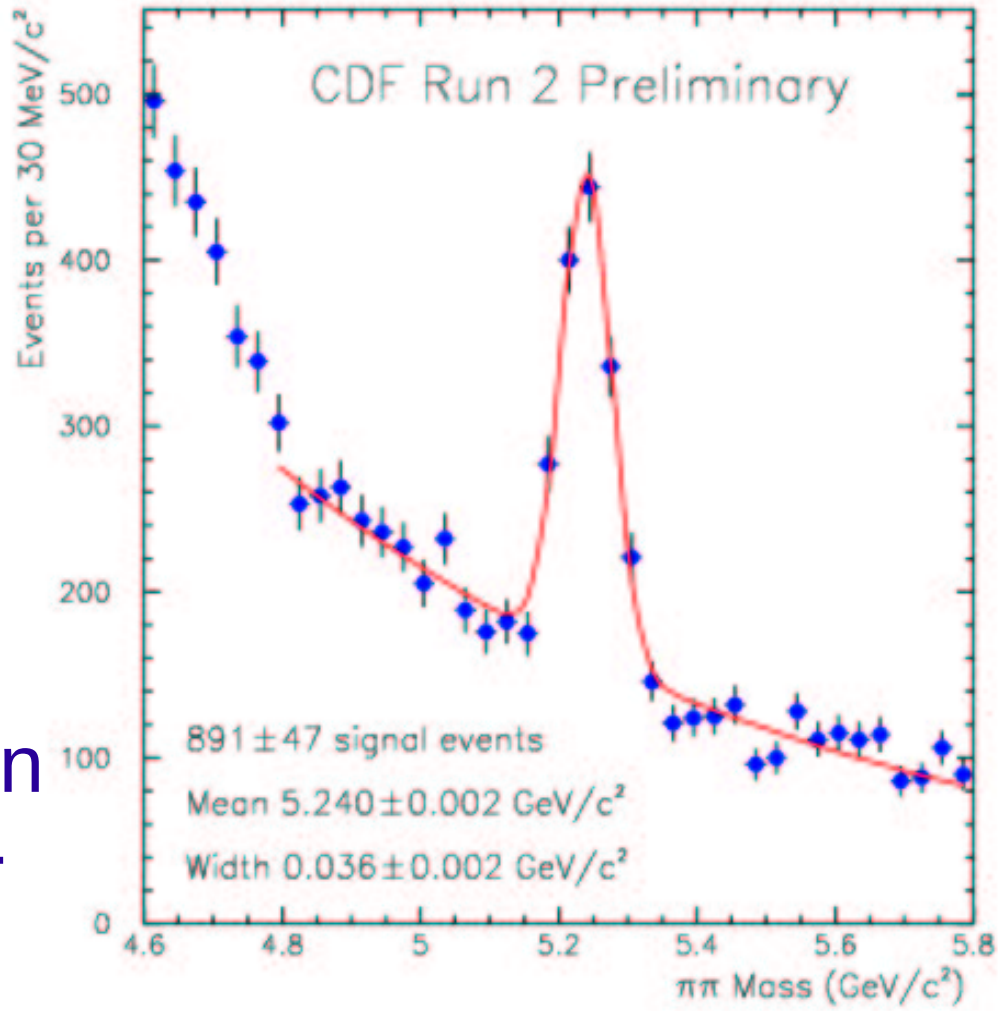
Composition of $B \to h^+h^-$

- Mixture of:

$$B_d \to K\pi$$
$$B_d \to \pi\pi$$
$$B_s \to KK$$
$$B_s \to K\pi$$

- Can't use ToF
- Effective K/π separation of dE/dx only ~ 1.16 σ

($\pi^+\pi^-$ hypothesis)



$\Rightarrow$ Separate on statistical basis

Multi-dim unbinned likelihood fit

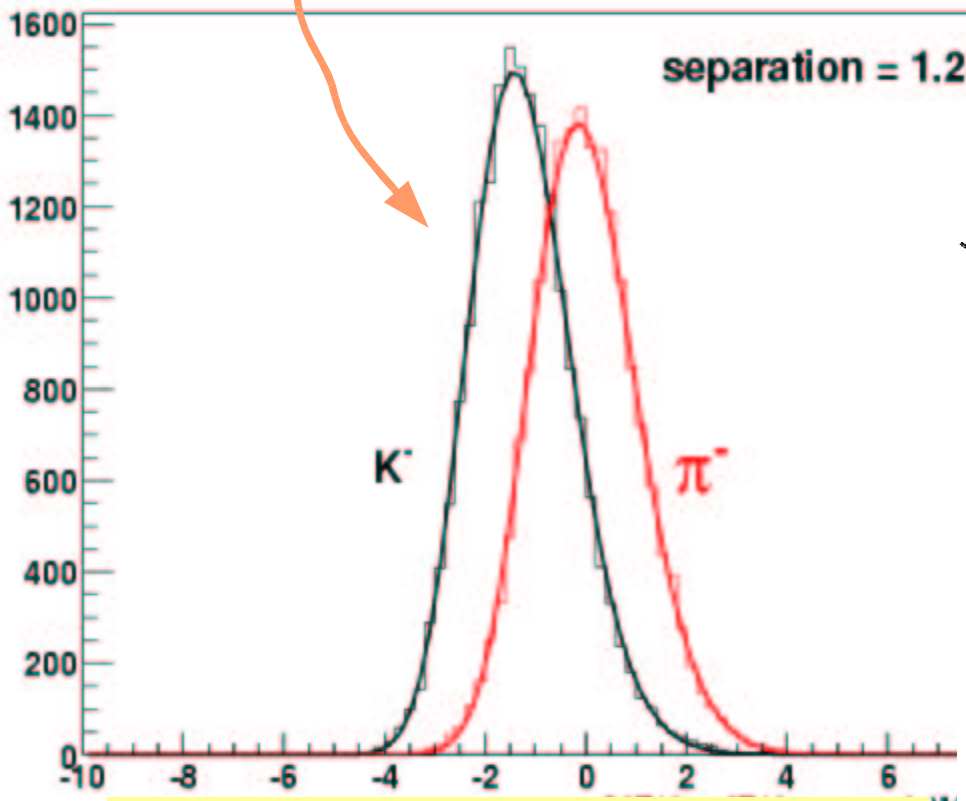
For each particle, use:

- dE/dx (calibrated on D*)
- Kinematic: m($\pi\pi$) and α

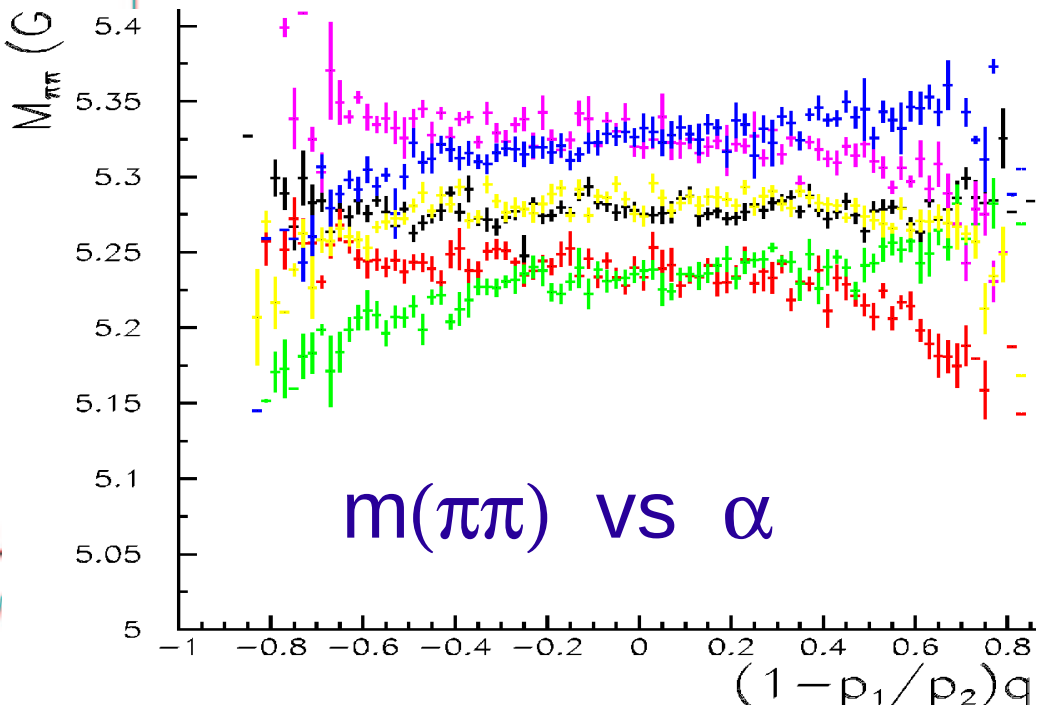
Pion momenta, $p_1 < p_2$

$$\alpha = \left(1 - \frac{p_1}{p_2}\right) \cdot q_1$$

Charge of #1



(dE/dx – dE/dx(h))/σ(dE/dx)



m($\pi\pi$) vs α

$B \to h^+h^-$ Results

- 65/pb of data
- First observation of
- Includes error on f_s/f_d

mode	Yield (65 pb^{-1})
$B^0 \to K\pi$	148±17(stat.)±17(syst)
$B^0 \to \pi\pi$	39±14(stat.)±17(syst)
$B_s \to KK$	90±17(stat.) ±17(syst)
$B_s \to K\pi$	3±11(stat.) ±17(syst)

$$\frac{BR(B_s \to K^{\pm}K^{\mp})}{BR(B_d \to K^{\pm}\pi^{\mp})} = 2.71 \pm 1.15$$

Already interesting

- Direct A_{CP} ~ 0, syst comparable to B factories

$$A_{CP}(B^0 \to K^-\pi^+) = 0.02 \pm 0.15\ (\text{stat}) \pm 0.02\ (\text{syst})$$

Projected yields in $B \to h^+h^-$

Mode	Yield 2 fb^{-1}	Yield 3.5 fb^{-1}
$B_d \to K\pi$	6700	11,725
$B_d \to \pi\pi$	1770	3097
$B_s \to KK$	4040	7070
$B_s \to K\pi$	1070	1870

- $B_s \to K^+\pi^-$ -- **from theory** (no sensitivity yet)
- Simultaneous fit to kinematics + mass + dE/dx

  $\Longrightarrow$ errors not ~ $\sqrt{N}$ -- **N must be scaled by x0.7**
- Systematics dominated by dE/dx

  calibrated by D* $\Longrightarrow$ **improve with more data**

Angles α and γ: fitting for A_{CP}

- Use flavor tagging -- $\epsilon D^2 = 5\%$
- *R.Fleischer, PLB 459 (1999) 306*
- Separate Acp components into $B^0 \to \pi^+\pi^-$ (measures sin2α) and $B_s \to K^+K^-$ (sin2γ)

Small

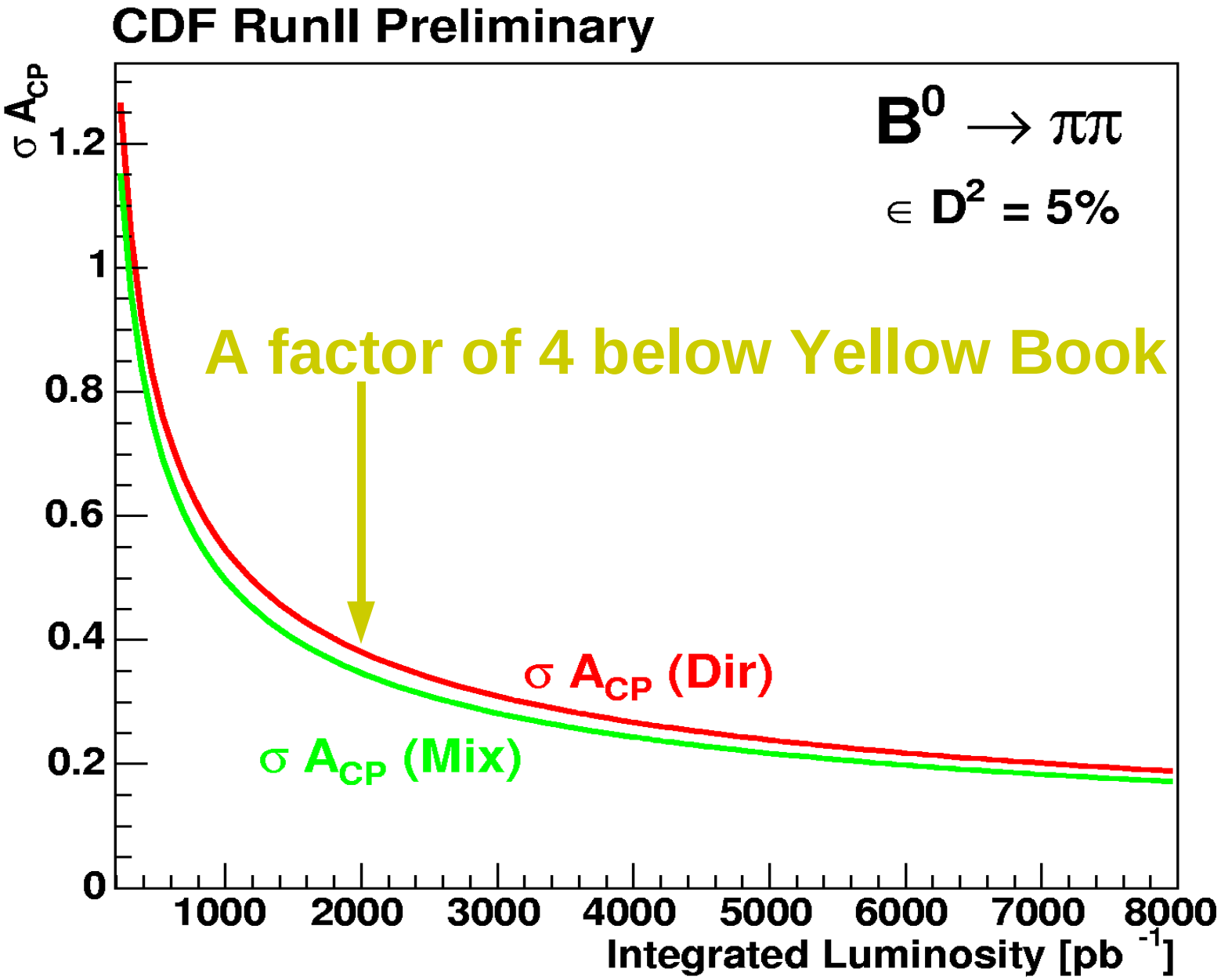
$$A_{CP}(B^0) = A_{CP}^{\rm dir}\cos\Delta m_d t + A_{CP}^{\rm mix}\sin\Delta m_d t$$

$\Longrightarrow$ Trigger favors mixing Acp (due to Lxy cut)

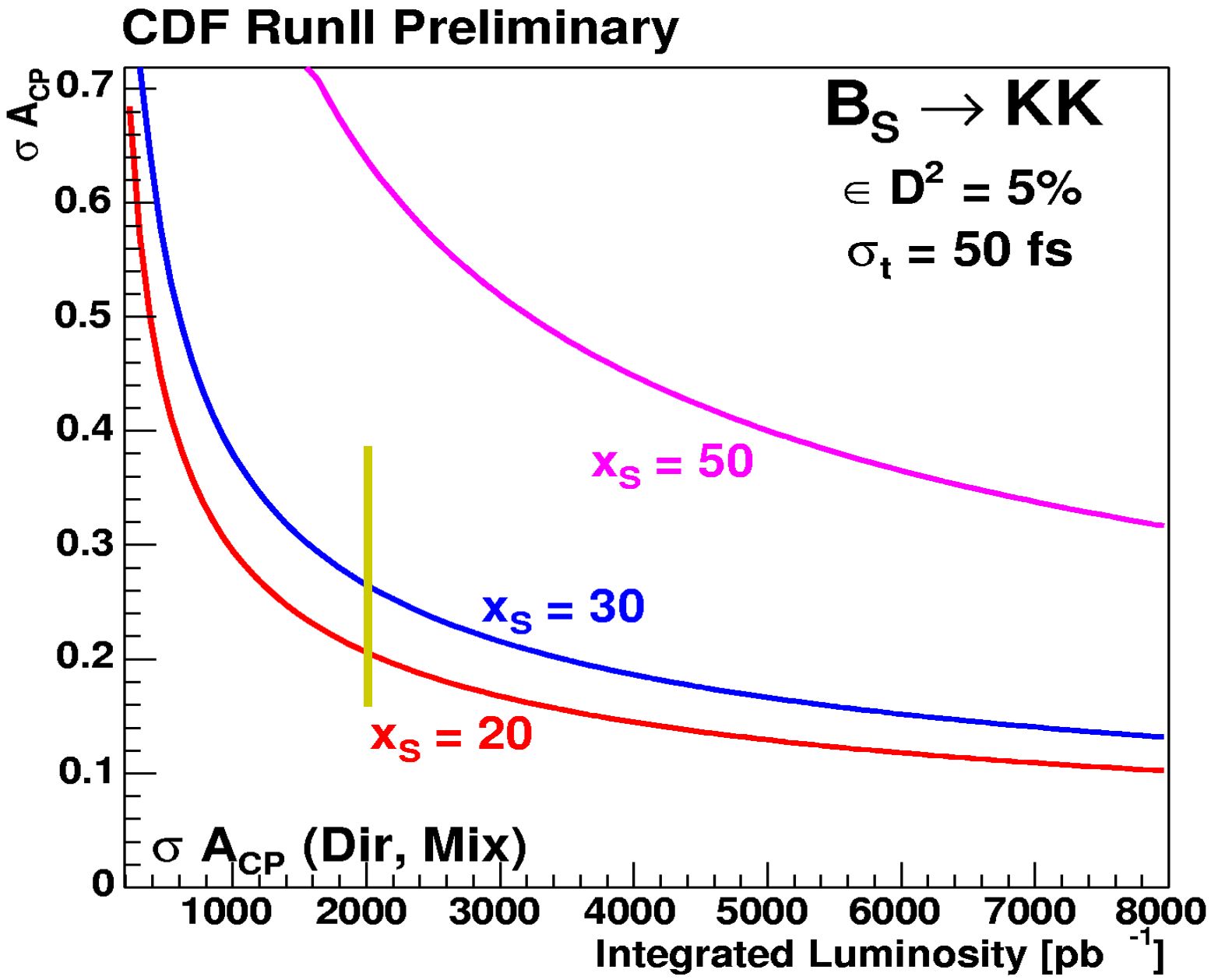
$$A_{CP}(B_s) = A_{CP}^{\rm dir}\cos\Delta m_s t + A_{CP}^{\rm mix}\sin\Delta m_s t$$

Large but unknown

Error on A_{CP} vs luminosity



Error on A_{CP} vs luminosity

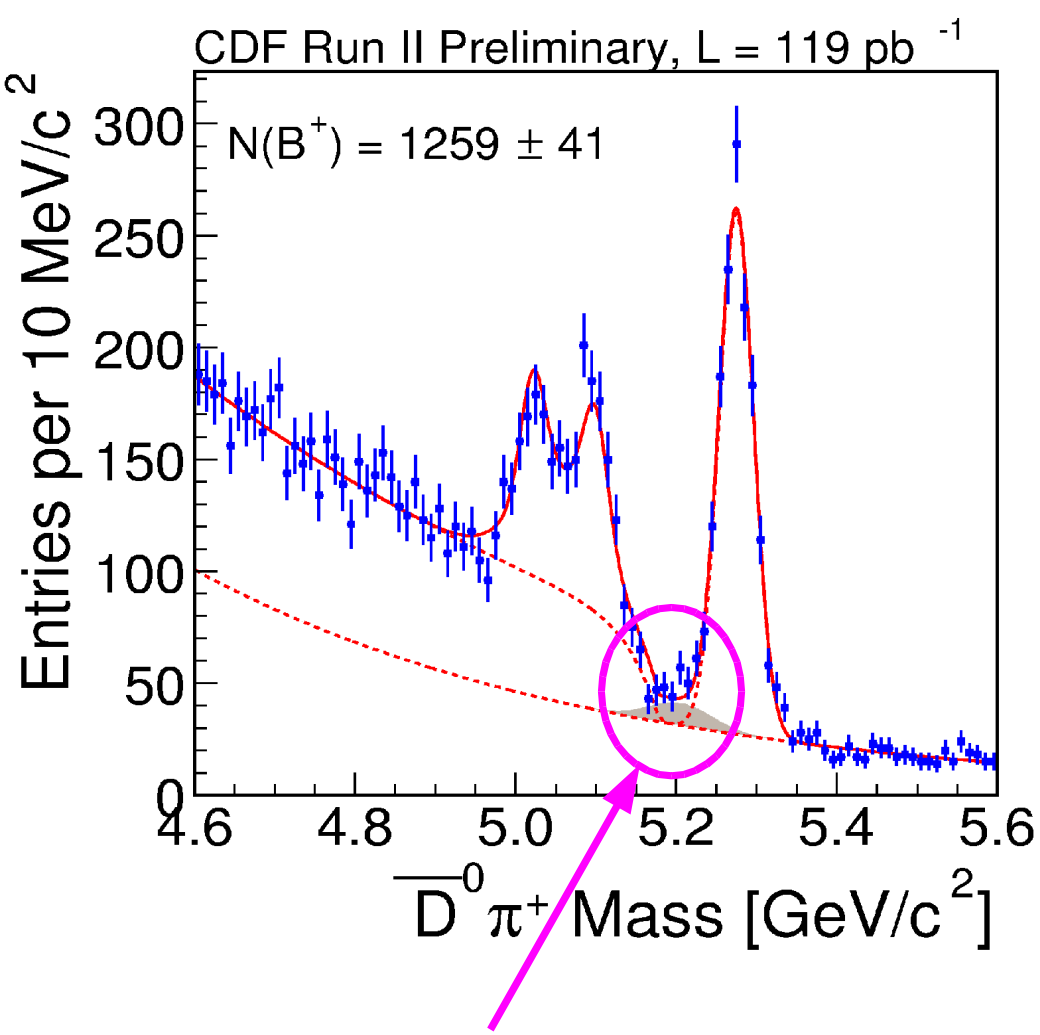


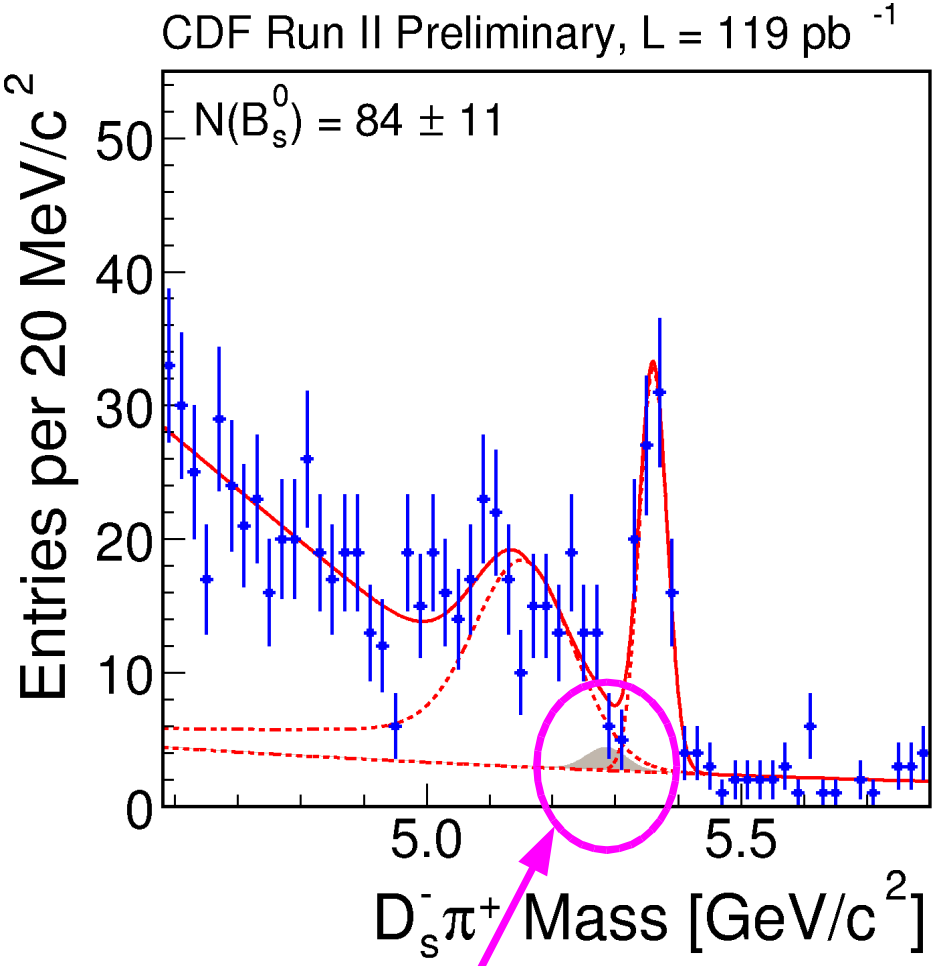
$B \to DK$ Decay modes

- Estimates of yields only
- Need to do a combined mass vs dE/dx fit for Cabibbo suppressed $B \to DK$ modes first
- $B_s \to D_s K$ tied to Bs mixing in $B_s \to D_s \pi$
- BaBar/Belle: $\dfrac{BR(B^+ \to D^0 K)}{BR(B^+ \to D^0 \pi)} = (8.31 \pm 0.35 \pm 0.20)\%$

Mode	Yield in 2 fb^{-1}	Yield in 3.5 fb-1
$B^\pm \to \overline{D}^0 \pi,\ \overline{D}^0 \to K\pi$	48,000	84,000
$B^\pm \to \overline{D}^0 K,\ \overline{D}^0 \to K\pi$	3990	6980
$B^\pm \to \overline{D}^0 K,\ (\overline{D}^0 \to KK + \overline{D}^0 \to \pi\pi)$	520	910
$B_s \to D_s \pi,\ D_s \to \phi\pi$	3200	5600
$B_s \to D_s K,\ D_s \to \phi\pi$	256	448

$B \to DK$ mass plots





8% D0 K

8% Ds K

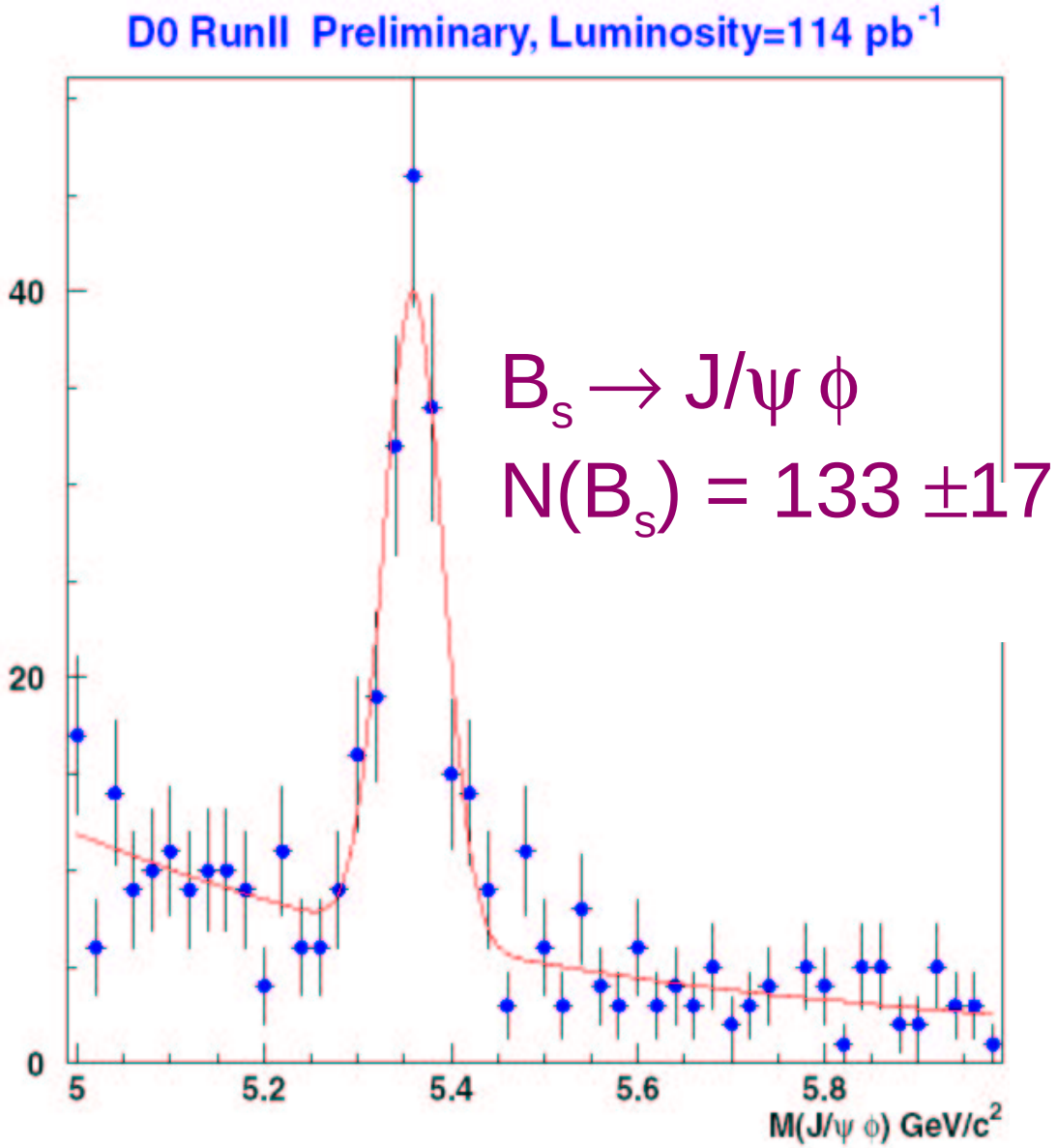
CP violation in $B_s \to J/\psi\,\phi$

- Both D0 and CDF
- Needs x_s first
- Measures

$$\beta_s \equiv \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

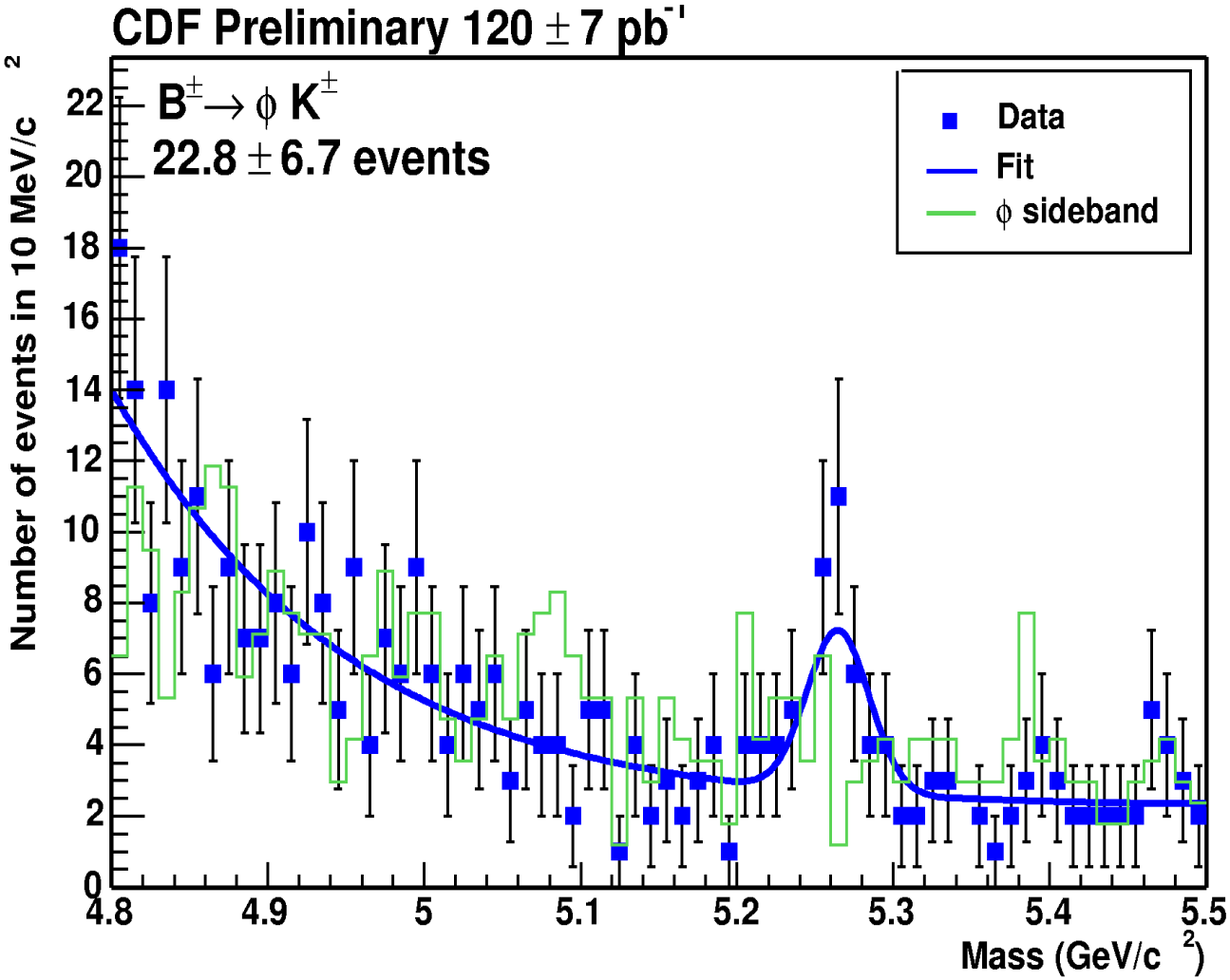
(directly ~ η)

- CDF's yield:
  120 ± 13 events
  in 140 pb-1



Direct CP violation

- $B^+ \to \phi K^+$ etc. especially interesting
- $B^0 \to \phi K_s^0$: a dedicated phi trigger will help
- Measure A_{CP} for all decay modes



- Baryons too! e.g. $\Lambda_b \to pK$, and $\Lambda_b \to p\pi$

Food for thought: what if $A_{CP} \neq 0$?

Direct CP violation in Charm

- $D^{*+} \to D^0_{CP}\pi^+$ (comparison from a recent review):

Table 7: Comparison of measurements in A_{CP} for D^0 modes, from E791 (89), FOCUS (90),CDF (88), and CLEO (78)

	Mode	A_{CP}	Mode	A_{CP}
CLEO	$D^0 \to K^+K^-$	$(0.0 \pm 2.2 \pm 0.8)\%$	$D^0 \to \pi^+\pi^-$	$(1.9 \pm 3.2 \pm 0.8)\%$
E791	$D^0 \to K^+K^-$	$(-1.0 \pm 4.9 \pm 1.2)\%$	$D^0 \to \pi^+\pi^-$	$(-4.9 \pm 7.8 \pm 2.5)\%$
FOCUS	$D^0 \to K^+K^-$	$(-0.1 \pm 2.2 \pm 1.5)\%$	$D^0 \to \pi^+\pi^-$	$(4.8 \pm 3.9 \pm 2.5)\%$
CDF	$D^0 \to K^+K^-$	$(2.0 \pm 1.7 \pm 0.6)\%$	$D^0 \to \pi^+\pi^-$	$(3.0 \pm 1.9 \pm 0.6)\%$
CLEO	$D^0 \to K^0_S\pi^0$	$(0.1 \pm 1.3)\%$	$D^0 \to \pi^0\pi^0$	$(0.1 \pm 4.8)\%$
CLEO	$D^0 \to K_S\bar{K}^0_S$	$(-23 \pm 19)\%$		

- Projections for 2 fb-1:

$D^0 \to \pi^+\pi^-$	0.4%	1.9%*sqrt(65/2000)
$D^0 \to K^+K^-$	0.3%	1.7%*sqrt(65/2000)
$D^+ \to \pi^+\pi^-\pi^+$	0.2%	1/sqrt(5nb*2fb^-1/30)

Summary

- CDF and D0 **ready for CP violation studies**:
  - excellent understanding of tracking and of
  - most low-level components (e.g. dE/dx)
  - New: *use of L00* in CDF and *D0 trigger hardware*
- Bottom line: **below Yellow Book estimates**
  - Improvements possible, require work
- Focus on **Bs, baryons** and **low rate modes**
- Exploit searches for **direct CP violation**
- Hidden opportunities in **charm sector!**

Backup slides

sin2β

- D0 yield will improve due to new trigger hardware (just coming online)
- No updates on σ(sin2β) yet