CDF results on B physics

Lifetimes: $\Delta\Gamma$, Λ_b, B_s, B_c, B^+, B_d

New particles: X(3872), X_b, Pentaquarks

Mixing: B_s, B_d, D^0

Exciting time at the Tevatron for heavy flavor physics!

B and D BR and Acp

Masses: B_c, Λ_b, B_s

Production $\sigma(b)$, $\sigma(J/\psi)$, $\sigma(D^0)$

Rare decays $B_s \to \mu^+\mu^-$, $D^0 \to \mu^+\mu^-$, …

SURPRISES!?

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Table of contents

This talk:

- B_c lifetime and mass
- $B \to h^+h^-$ ($A_{CP}(B^0 \to K\pi)$ and $\Delta\Gamma_s$)
- Same Side Kaon Tagging (for B_s mixing)

Not in this talk:

- many recent result had to be left out
- skipping those that will be updated soon
  - e.g. $B_s \to \mu^+\mu^-$, $\Lambda_b \to J/\psi\Lambda$

Hadronic environment

Disadvantages:

- "messy"
- opp. side b-hadron in central region of detector only 20-40% of time (so flavor tagging is hard)

Advantages:

- Huge *b* cross-section (~100 μb total)
- producing $B^+, B^0, B_s, \Lambda_b, B_c, B^{**}, \Sigma_b, \Omega_b, \ldots$
- however, only 1 $b\bar{b}$ per ~1000 soft QCD collisions)

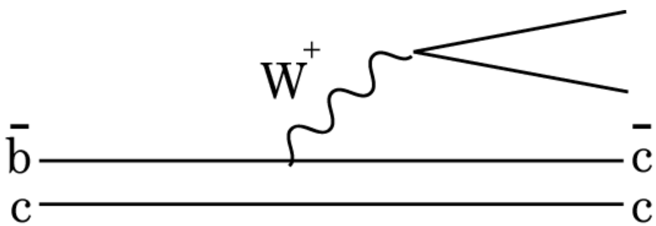
$\Longrightarrow$ **live and die by the trigger**

B_c

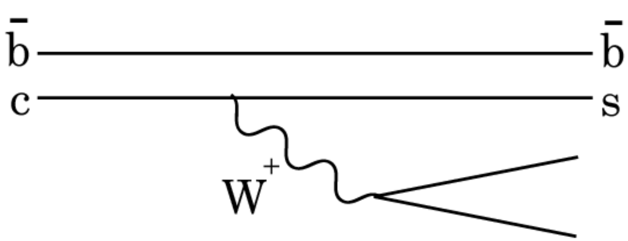
- bound state of two heavy quarks

  $\Longrightarrow$ good lab for potential models, lattice calculations

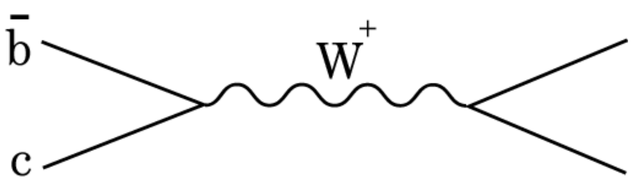
- b,c: different flavor $\Longrightarrow$ only weak decays possible



$$\Gamma(\bar{b} \to \bar{c}) = 9\frac{G_F^2 |V_{cb}|^2 m_b^5}{192\pi^3} \approx 0.6 \text{ ps}^{-1}$$



$$\Gamma(c \to s) = 5\frac{G_F^2 |V_{cs}|^2 m_c^5}{192\pi^3} \approx 1.2 \text{ ps}^{-1}$$



$$\Gamma(ann.) = \sum_i \frac{G_F^2}{8\pi} |V_{cb}|^2 M_{B_c} m_i^2 (1 - \frac{m_i^2}{M_{B_c}^2})^2 f_{B_c}^2 C_i$$

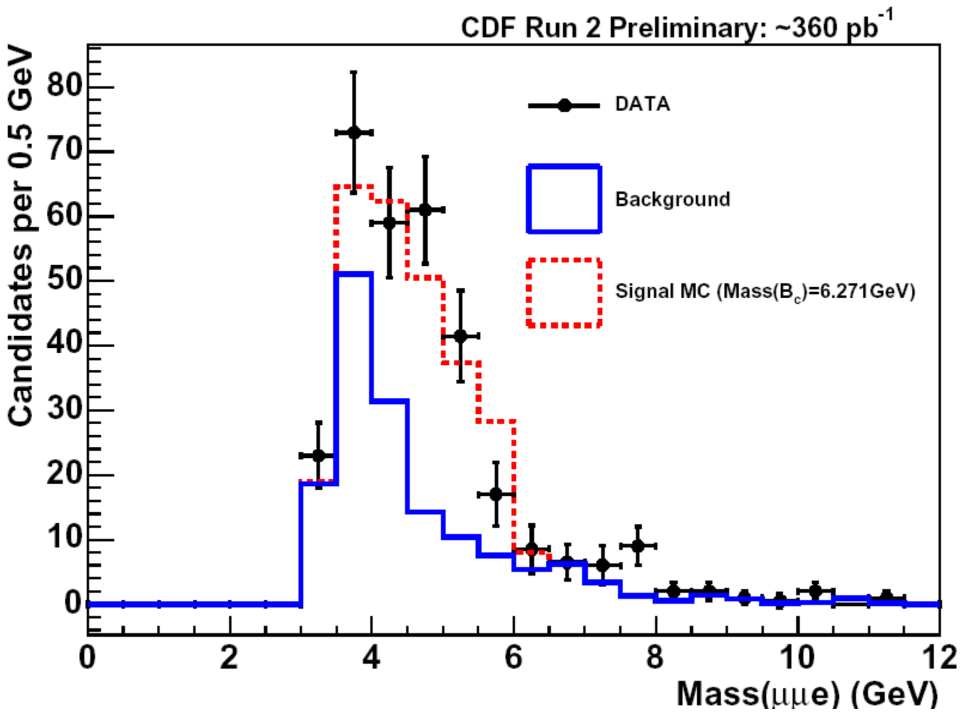
$$(C_i = 1 \text{ for } \tau\nu_\tau, \; C_i = 3|V_{cs}|^2 \text{ for } c\bar{s})$$

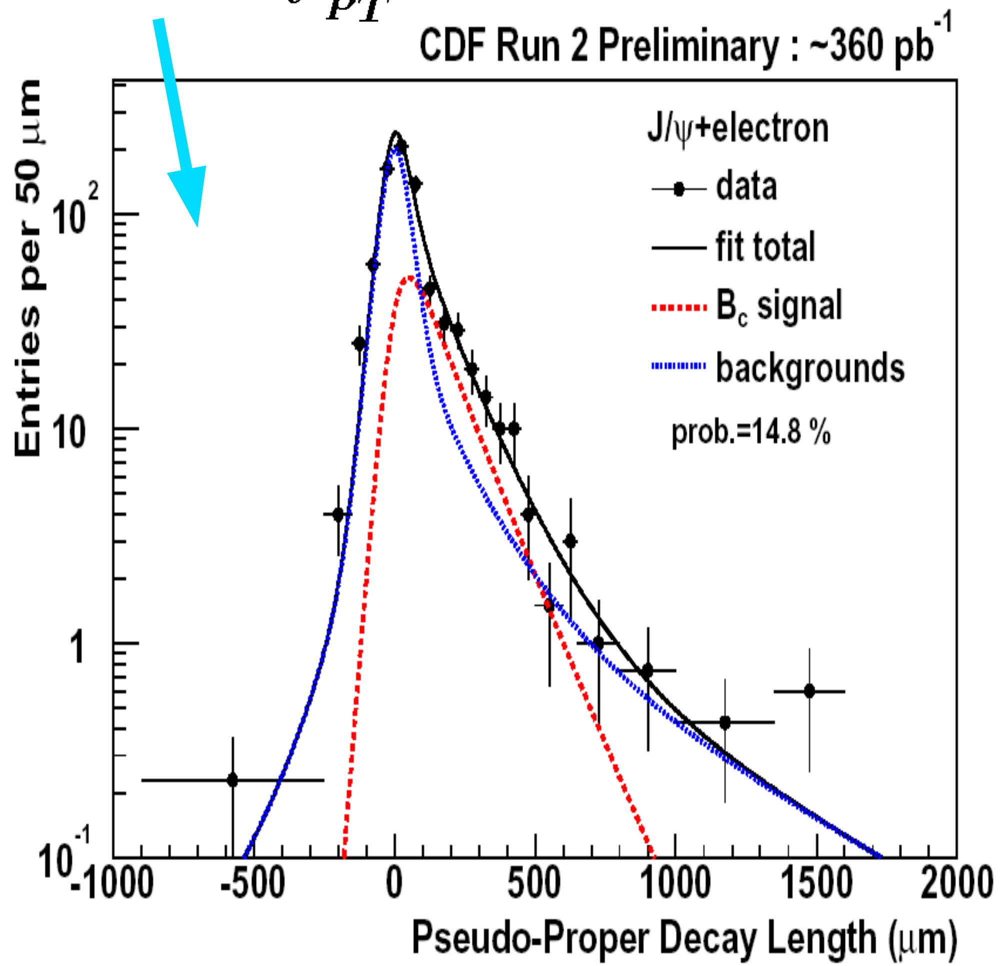
$$\approx 0.1 \text{ ps}^{-1}$$

$\mathrm{B_c}$ lifetime in $B_c \to \nu e J/\psi X$

- excess: 114.9±15.5±13.6
- significance: 5.9 σ

$$ct \equiv L_{xy} \frac{m}{p_T}$$



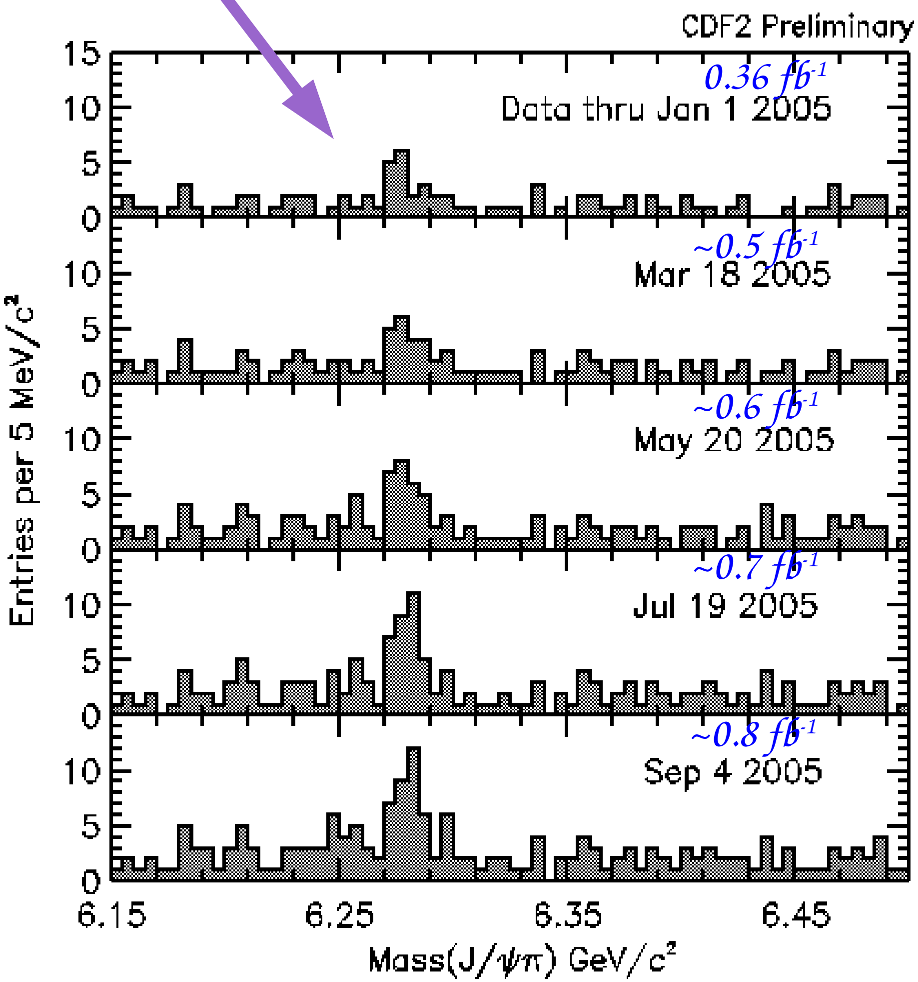


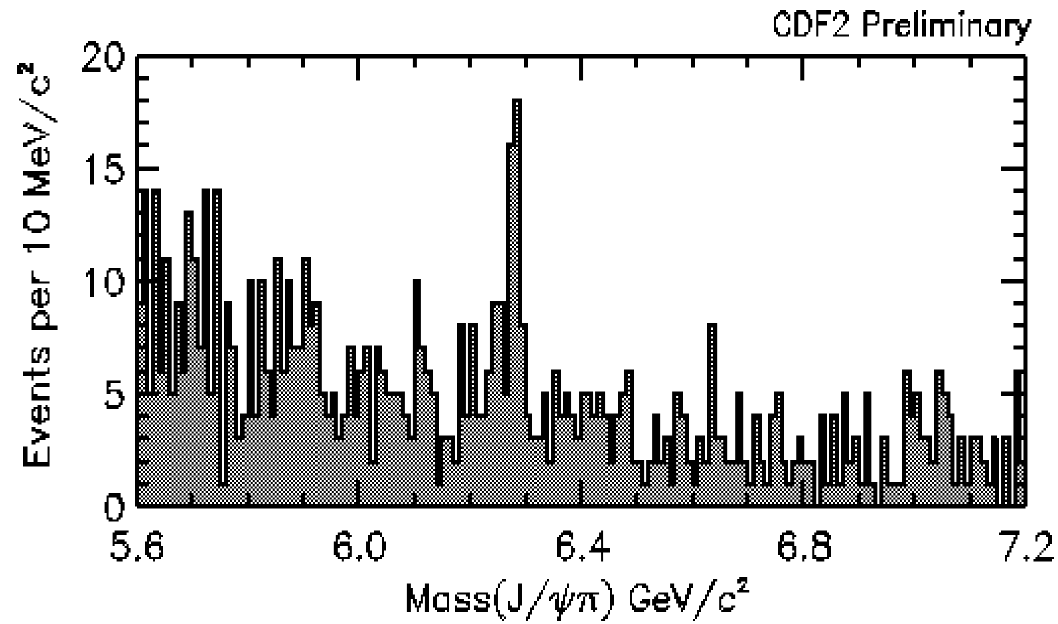
$c\tau(B_c)$ = 142.1 +21.9/-19.7(stat) ±10.0(syst) μm

- **τ ~ 0.5 ps** -- agrees with Γ from all 3 diagrams

B_c mass

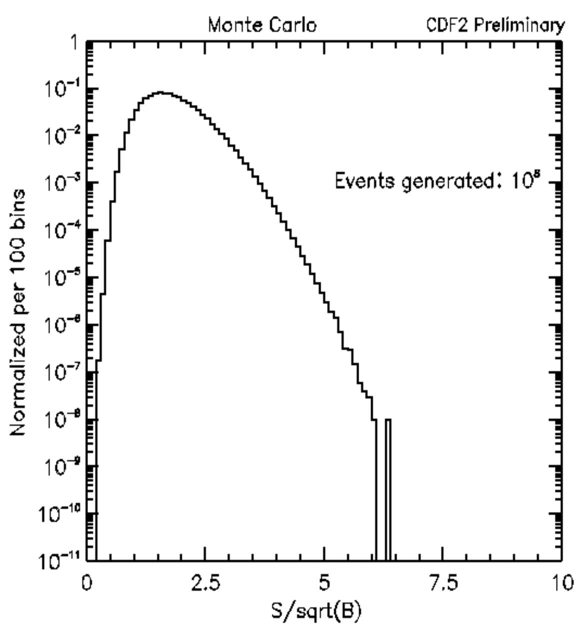
done blind, cuts frozen





Num(events)$_{FIT}$= 38.9 sig 26.1 bkg between 6.24-6.3

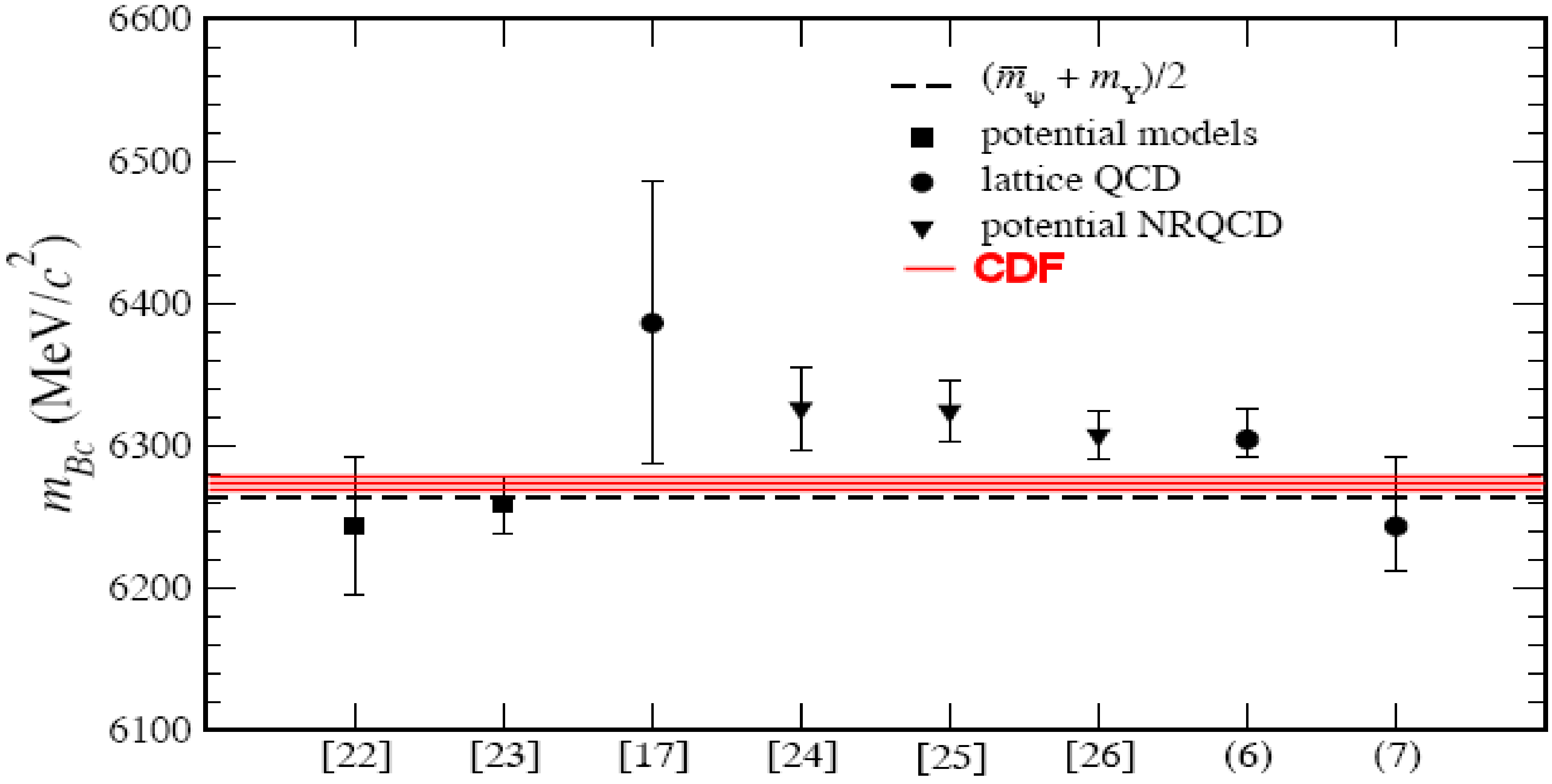
Significance > 6σ over search area



m(Bc) = 6275.2 +/- 4.3 +/- 2.3 MeV/c^2

m(B_c): data *vs* predictions

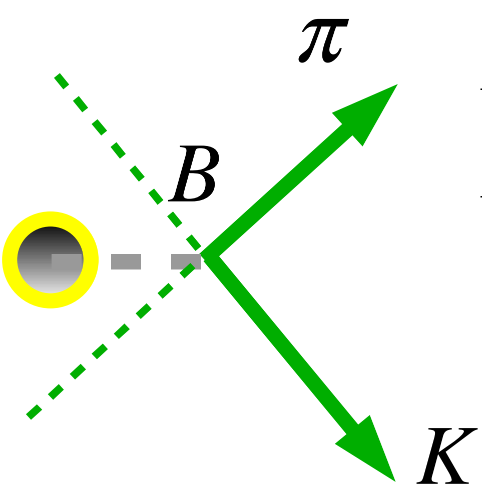
- compare with lattice calculations that agreed with data elsewhere

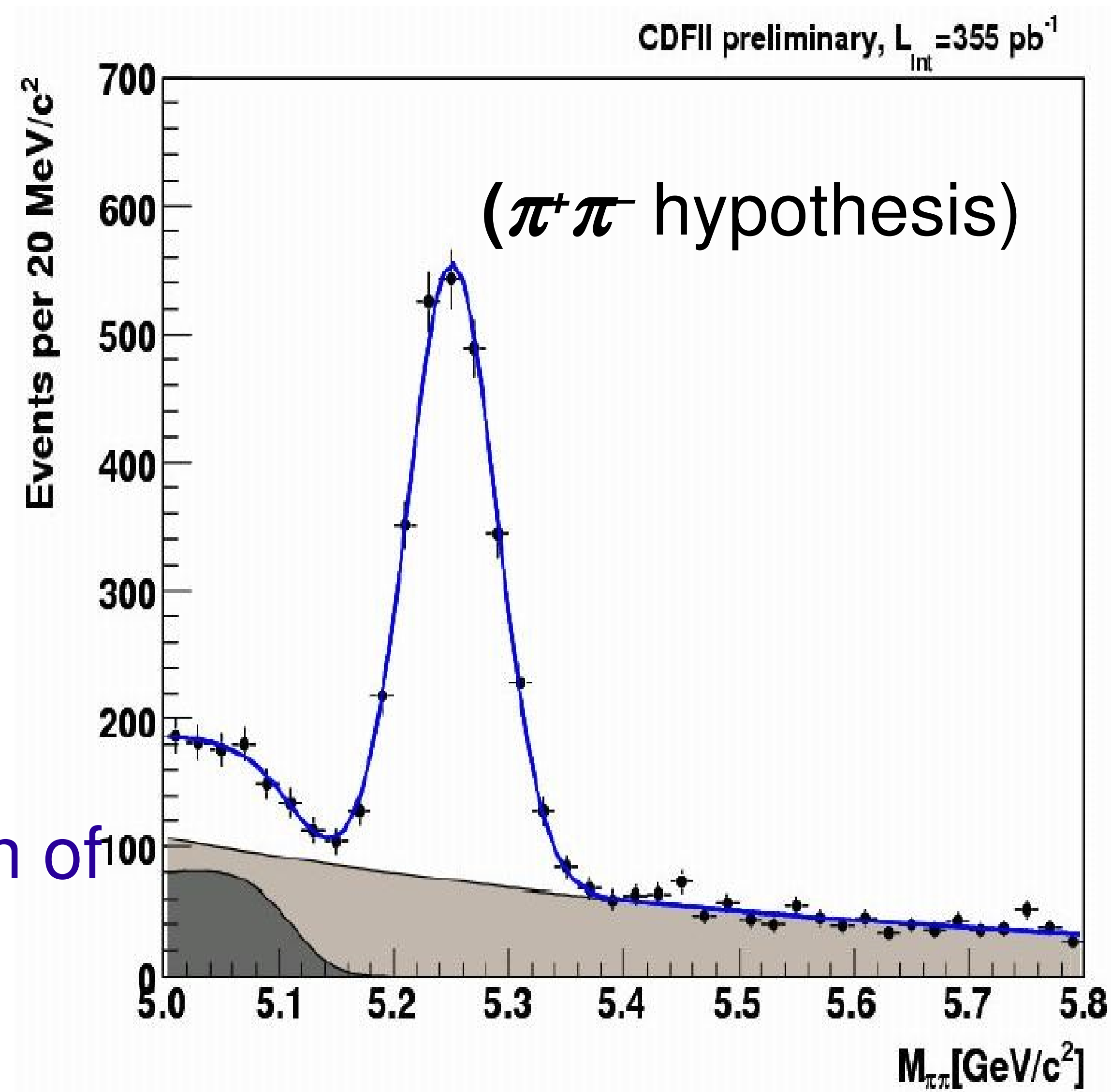


m(Bc)$_{CDF}$ = 6275.2 +/- 4.3 +/- 2.3 MeV/c^2 **m(Bc)$_{LAT}$ = 6304 +/- 12 $^{+18}_{-0}$ MeV/c^2**

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

- Mixture of: $B_d \to K\pi$
  $B_d \to \pi\pi$
  $B_s \to KK$
  $B_s \to K\pi$

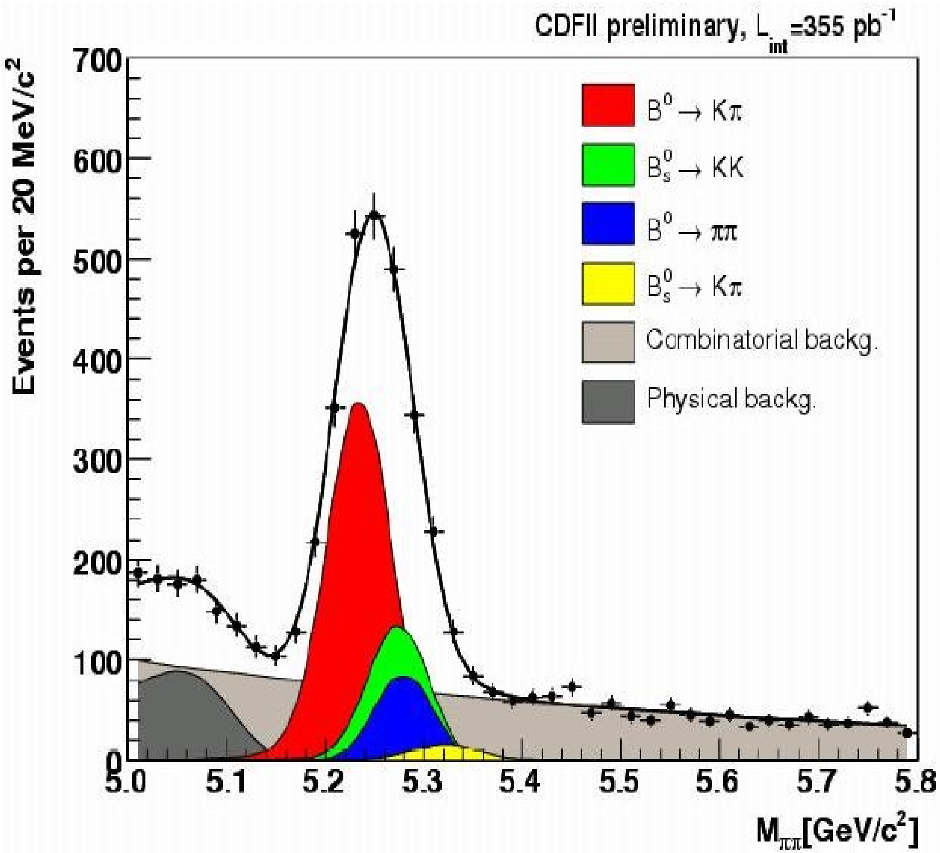


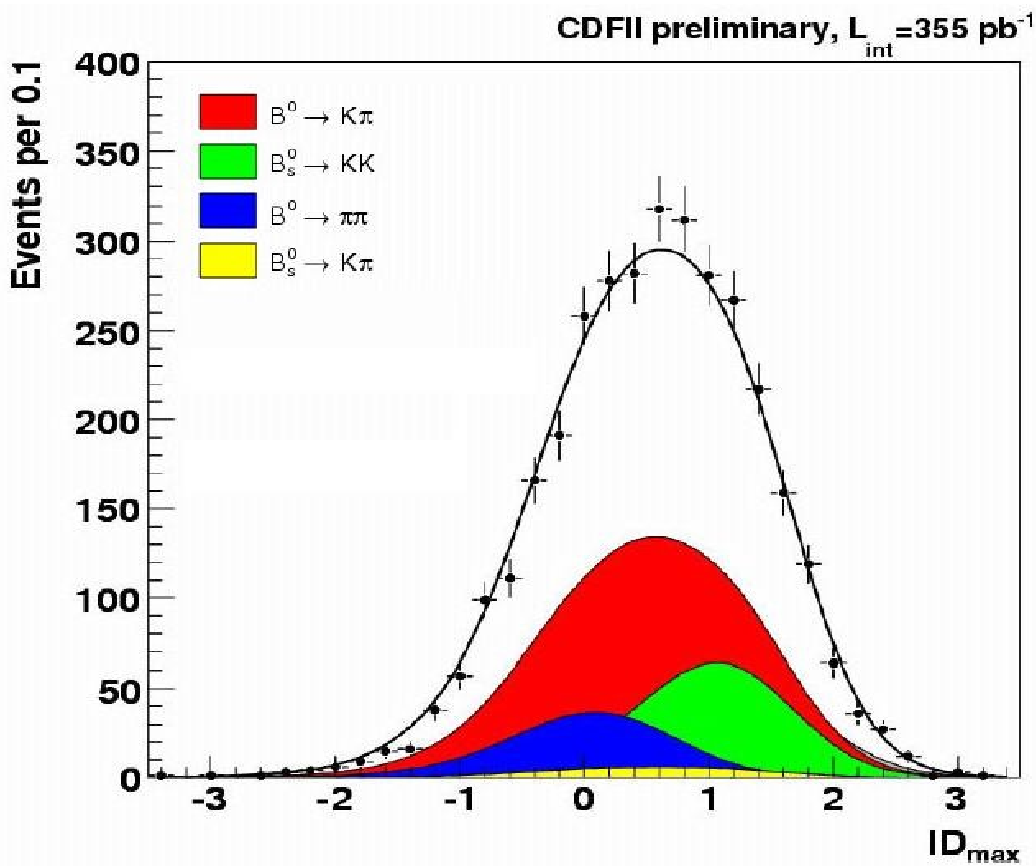


- Using dE/dx and ToF
- Effective K/π separation of dE/dx ~ 1.4 σ

$\Longrightarrow$ Separate on statistical basis

$B \to h^+h'^-$: fit projections





$$A_{CP} = \frac{N(\overline{B}^0_d \to K^-\pi^+) - N(B^0_d \to K^+\pi^-)}{N(\overline{B}^0_d \to K^-\pi^+) + N(B^0_d \to K^+\pi^-)}$$

(consistent with both 0 and B factories)

$$A_{CP}(B^0 \to K^+\pi^-) = -0.058 \pm 0.039\ (stat.) \pm 0.007\ (syst.)$$

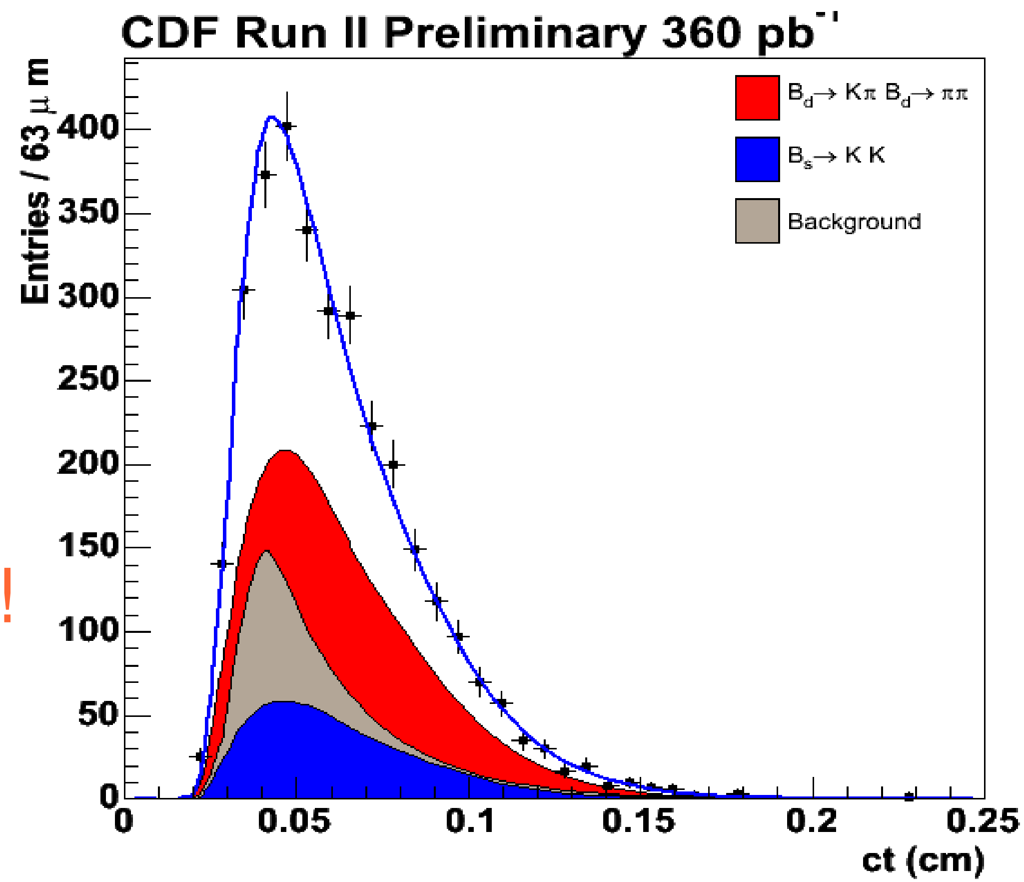
$B_s \to K^+K^-$ lifetime

- Proper time of B_s decay:

$$ct \equiv L_{xy}\frac{m}{p_T}$$

- Get $c\tau$ of each component
- First measurement of B_s lifetime in $B_s \to K^+K^-$!

  (~95% CP even, measures lifetime of "B_s light")

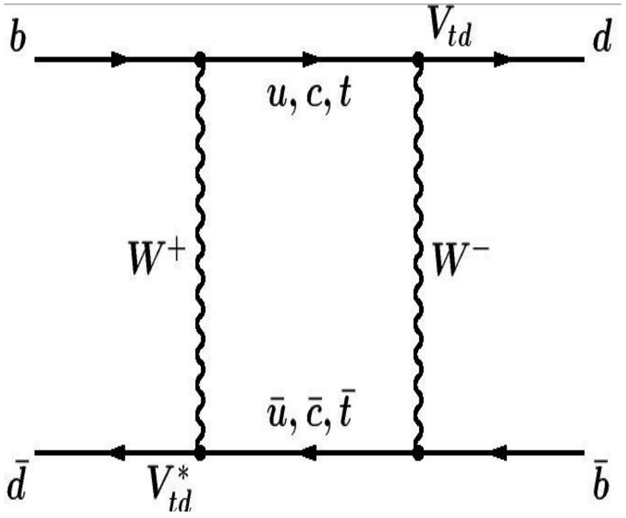


- $c\tau_L$ = $c\tau(B_s \to K^+K^-)$ = 458 ± 53 (stat)± 6(sys) um
- World ave $\tau(B_s) = (\tau_L^2 + \tau_H^2)/(\tau_L + \tau_H)$, extract $\Delta\Gamma_s(CP)$:

$\Delta\Gamma_s(CP) / \Gamma_s(CP)$ = -0.08 ± 0.23(stat) ± 0.03(sys)

B mixing refresher

- Flavor asymmetry:



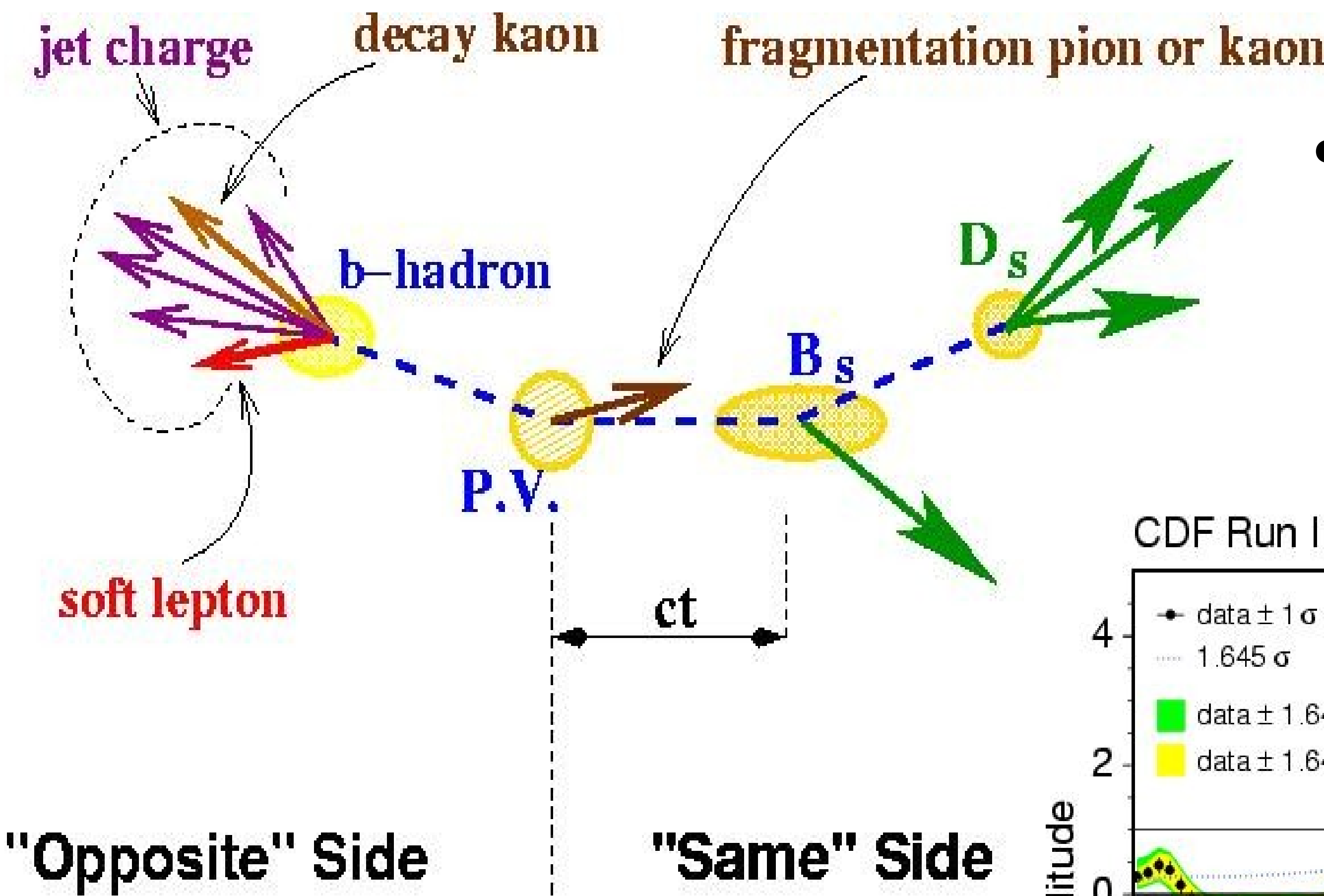
$$A(t) \equiv \frac{N_{\text{unmix}} - N_{\text{mix}}}{N_{\text{unmix}} + N_{\text{mix}}} = D cos \Delta m_s t$$

To measure mixing: →

- Flavor at production (tagging)
- Flavor at decay
- $ct \equiv L_{\text{xy}} \frac{m}{p_T}$

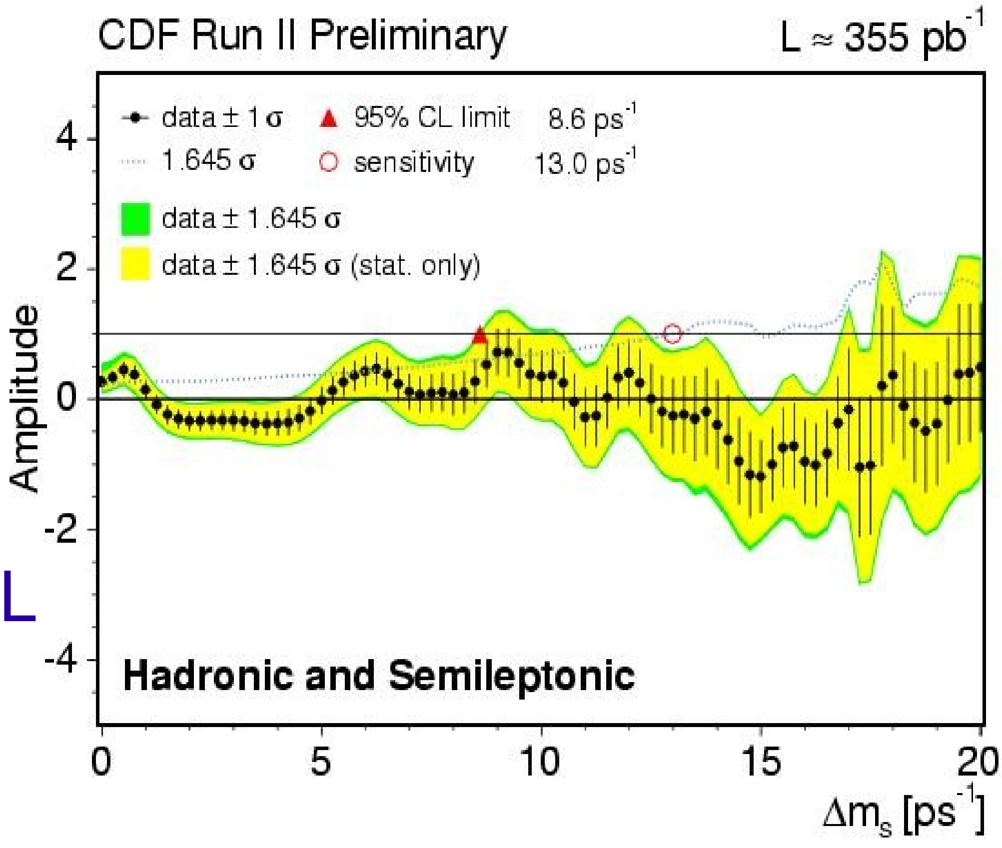
- Flavor tagging characterized by: efficiency ϵ and dilution D (= 1-2w)
- Statistical power ~ ϵD^2

Flavor tagging at CDF



- For Opposite Side Tagging,

$$\epsilon D^2_{OST} = 1.5\%$$

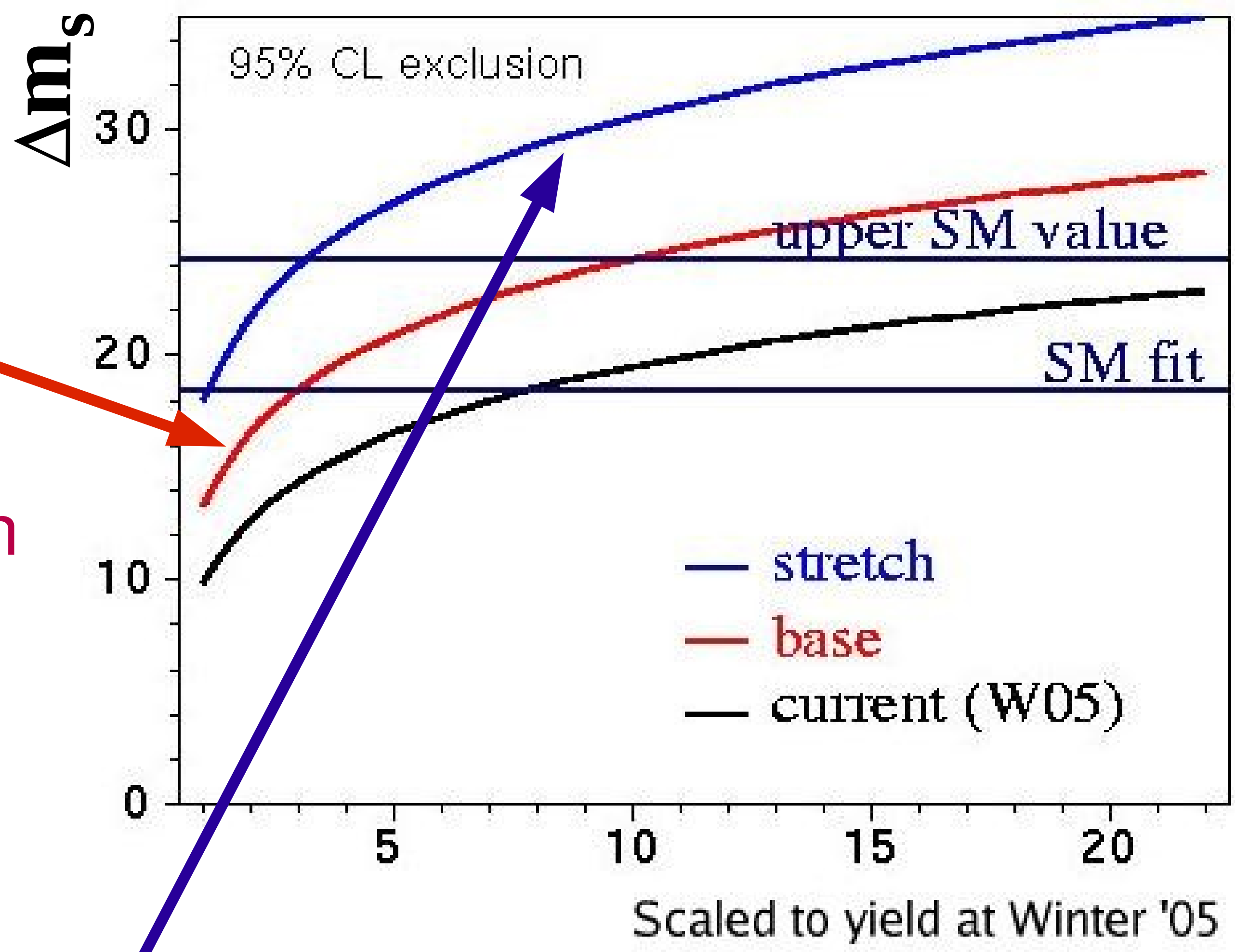


Sensitivity = 13.0 ps^{-1}

Exclusion: $\Delta m_s < 8.6$ ps^{-1} @95%CL

Enter Same Side Kaon Tagging

- Opposite Side Tagging, $\epsilon D^2_{OST} = 1.5\%$
- opp.side b-hadron often not reconstructed

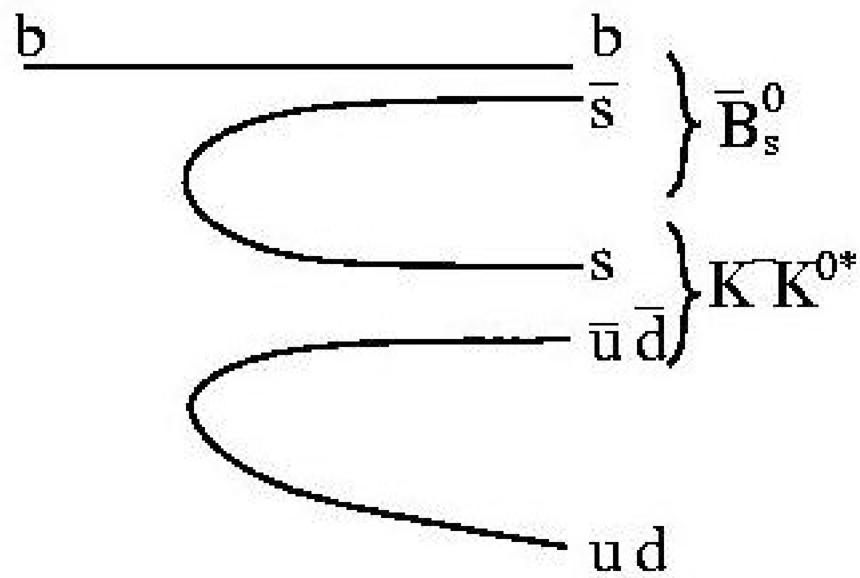


- Same Side Taggers use particles around B meson
- SSKT potential ~3-4% $\Longrightarrow$ x1.7 increase in sensitivity!

Same Side **Kaon** Tagging

- Opp. Side: D same for all species;

⟹ measure D in B^+, B^0;
apply to B_s

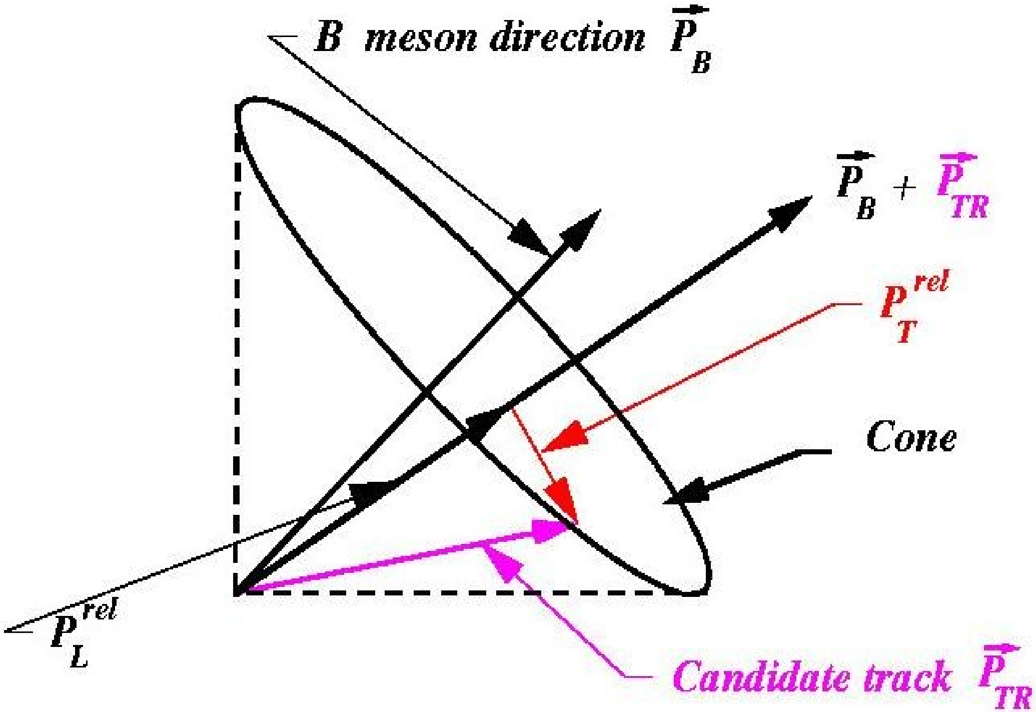


- SST species-dependent: meas. D *from amplitude of B0 oscillations*

- How to estimate D before seeing B_s mixing?
  - Ensure that Pythia matches data in all respects
  - Measure D in B_s decays from Pythia
  - Systematics cover any (minor) discrepancies

SSKT algorithms

- If # tracks in cone > 1, choose one as the tag
- Explored several algorithms
- Best one based on kinematics is max p_L^{rel}



- Best overall: CLL = **C**ombined Particle Id. **L**og **L**ikelihood

$$CLL = \log\left(\frac{P_{tof}(K)\cdot P_{dEdx}(K)}{0.1\cdot P_{tof}(p)\cdot P_{dEdx}(p)+0.9\cdot P_{tof}(\pi)\cdot P_{dEdx}(\pi)}\right)$$

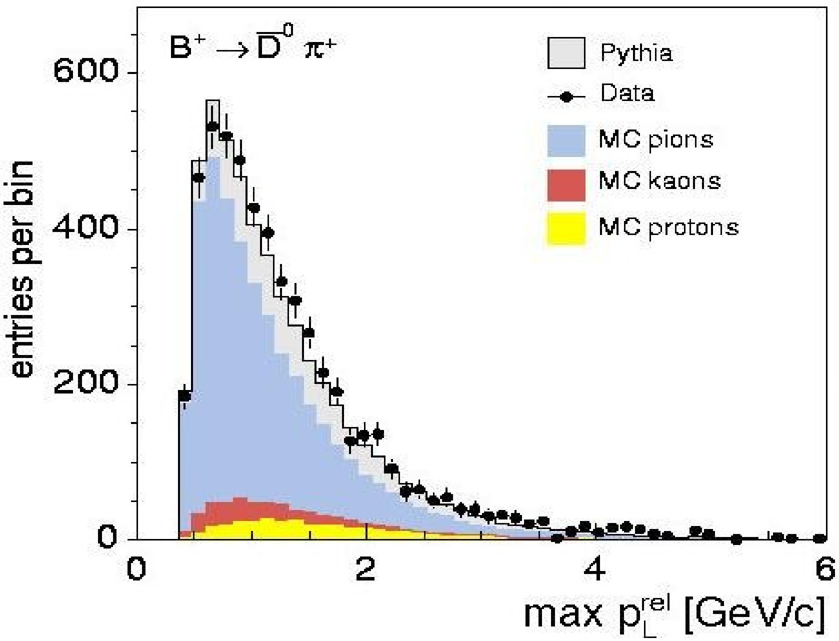
In a cone around Bs, chooses track most likely to be kaon

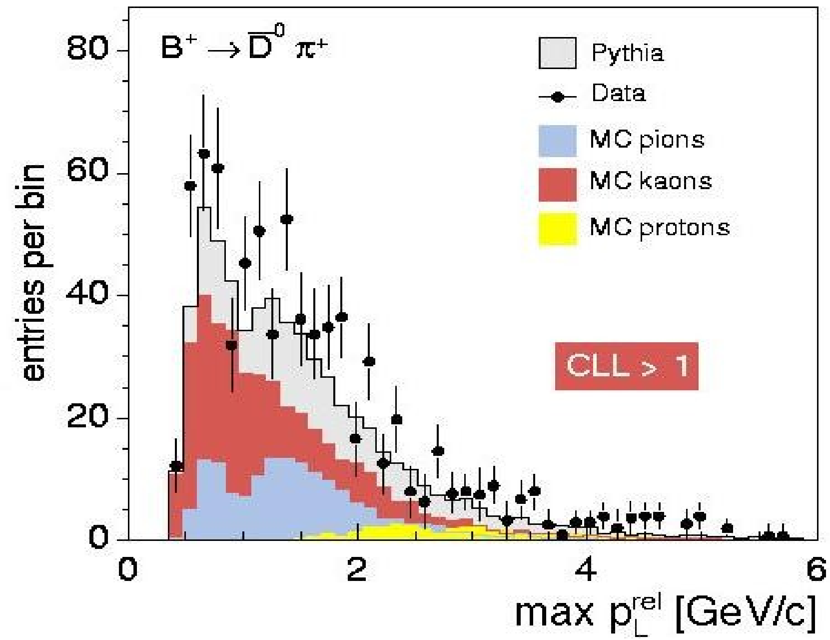
Making Pythia do SSKT right

- Extensive tuning of underlying event in QCD data
- Measure Gluon Splitting (data/pythia $= \mathbf{1.14 \pm 0.10}$)
- Observe narrow B^{**} states
- Check fragmentation function (using Lund shape)
- Measure particle content around B^+, B^0, B_s
  - B^+, B^0 agree well, B_s data has 3% fewer kaons
  - syst: randomize charge of excess K's in Pythia
- Finally, measure dilutions and many other quantities and verify that they agree

(Make sure systematics cover any discrepancies)

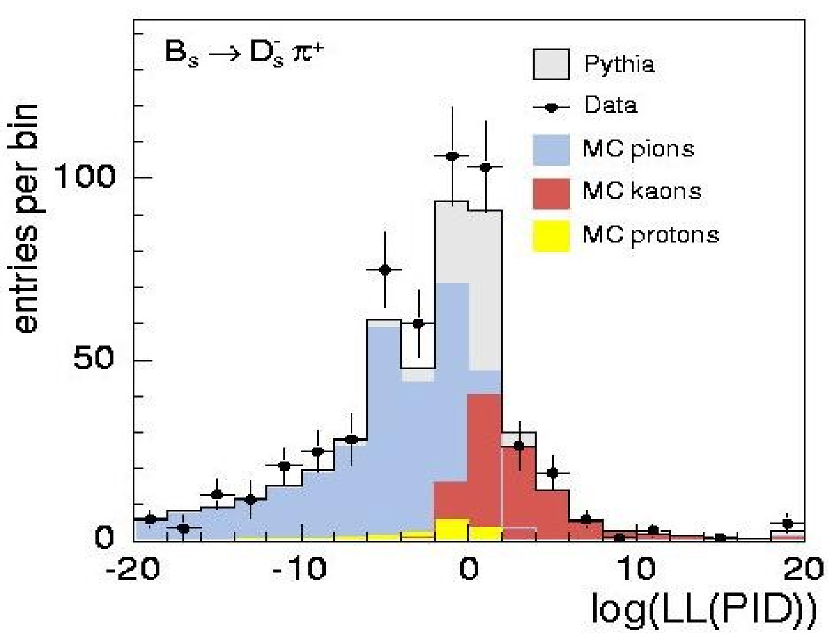
SSKT: comparing tagging variables

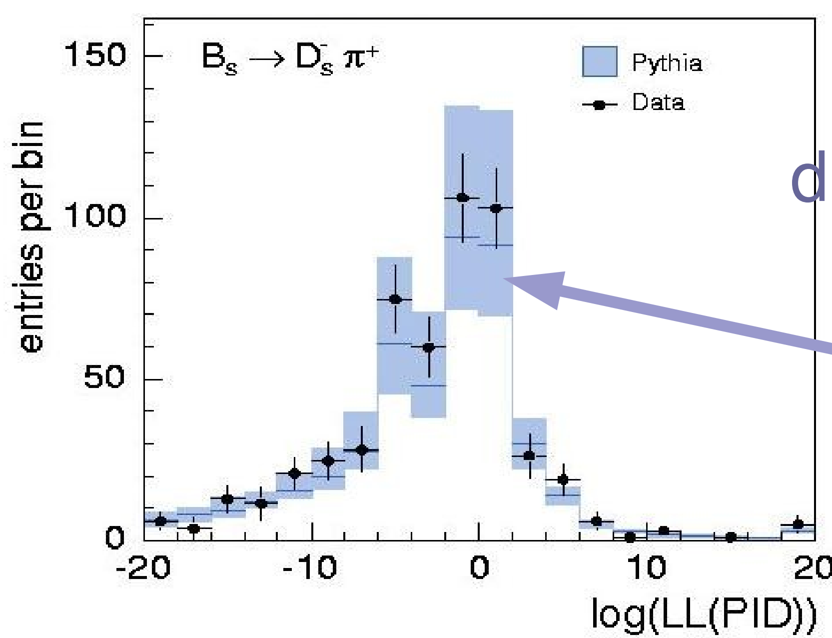




checked many variables

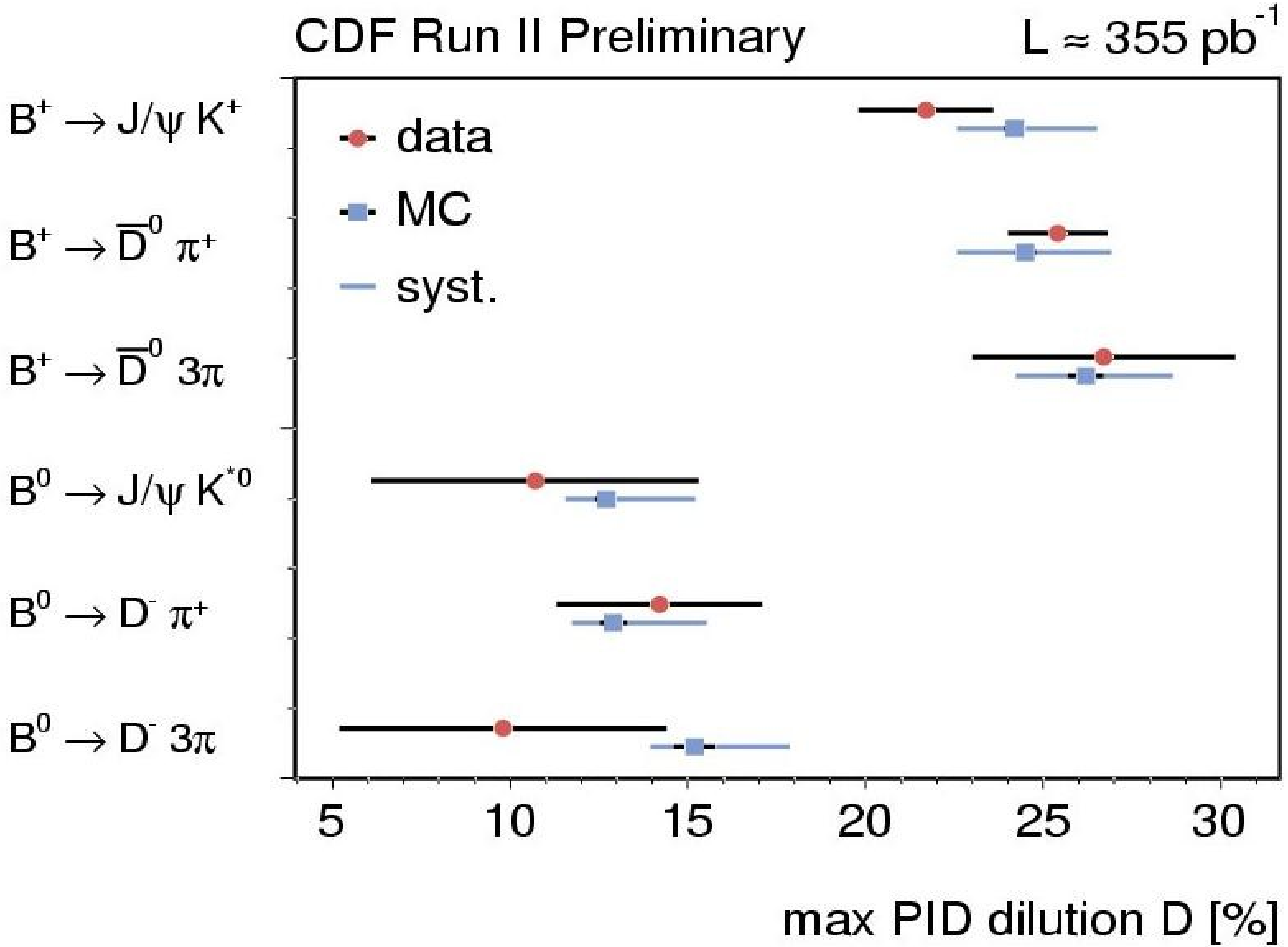
very similar shapes





discrepancies covered by syst. errors.

SSKT: dilutions in data vs Pythia



SSKT – bottom line

- dilution

$$D = 28.3^{+3.2}_{-4.2}\%$$

- tagging power

$$\epsilon D^2 = 4.0^{+0.9}_{-1.2}\%$$

$\Longrightarrow$ CDF tagging power more than tripled!

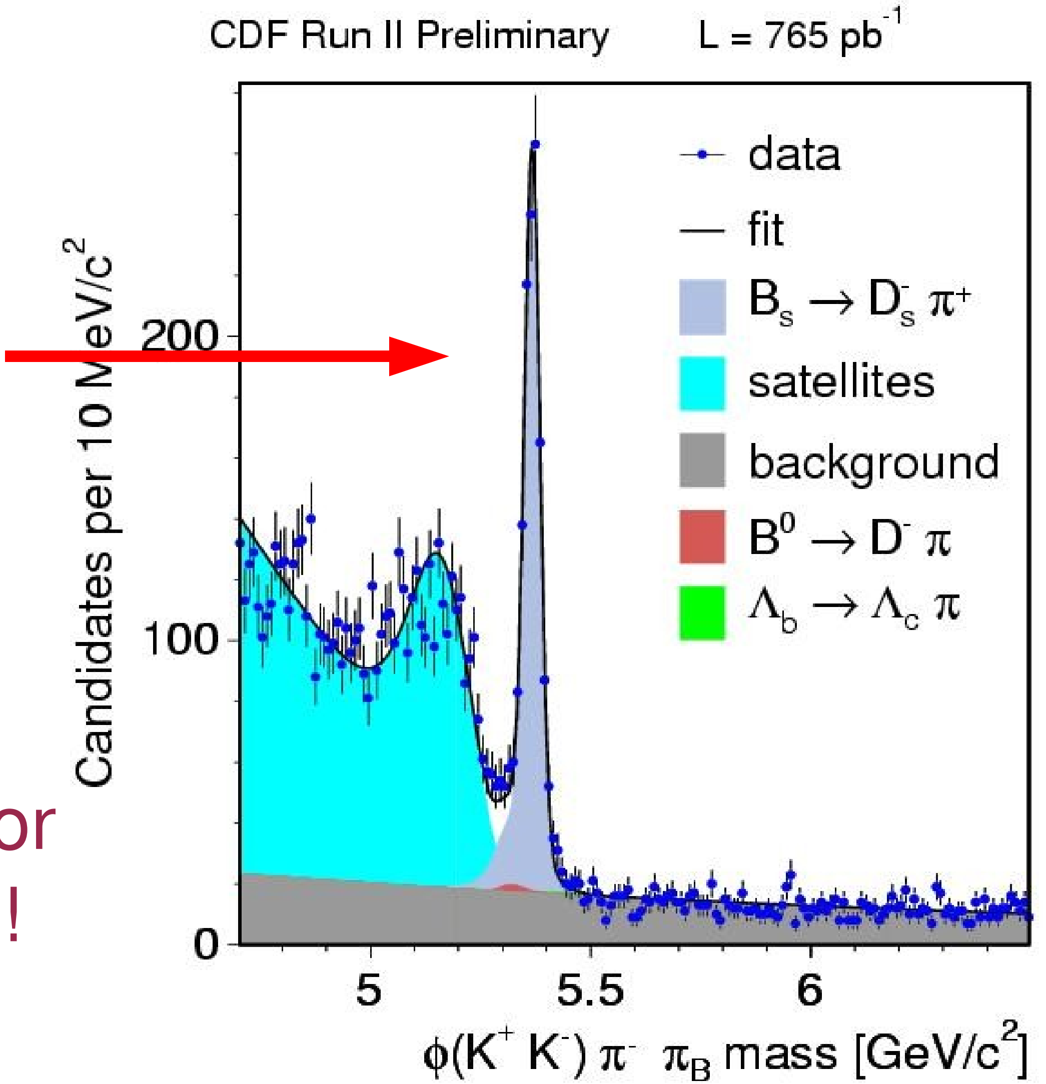
- will be applied to all fully reconstructed B_s decay modes!

  (easy to transfer... only $p_T(B_s)$ spectra are different)

Summary

- Tevatron and CDF detector working great
- Several interesting analysis in the works
- Exciting times!

- **Application of SSKT to fully reconstructed Bs decays**
- Add semileptonics by summer
- Will be able to cover region allowed by SM very soon!



Backup slides

Indirect searches for New Physics

- Energy Frontier

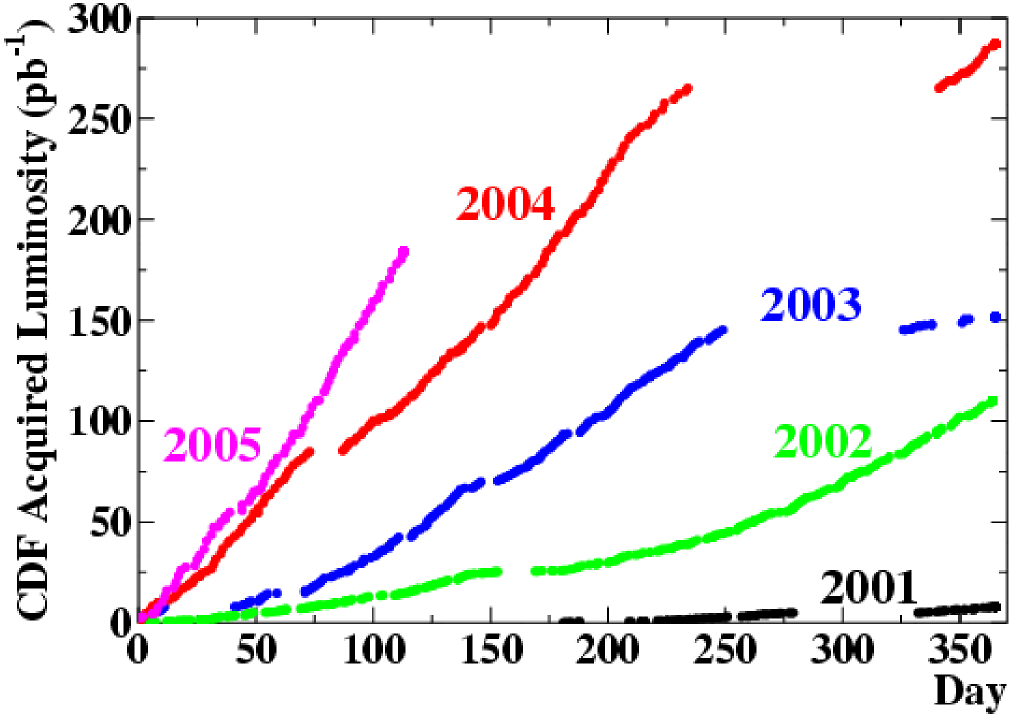
- Direct searches:
  - Higgs
  - SUSY
  - Extra dimensions...

- Data volume Frontier

- **Indirect searches:**
  - **some weak B decays have very low Prob.**
  - **look for contribution from New Phys**

The `Curse' of High Luminosity

- Tevatron is doing splendidly!
- But: high Luminosity means more `pile-up' (a soft scattering elsewhere in along Z)



- TTT trigger rate goes as N^2_{tracks}

$\Longrightarrow$ prohibitive at high Luminosity!

$\Longrightarrow$ start high Lumi runs without TTT, then add it back in as Lumi goes down

$B \to h^+ h'^-$: the fit

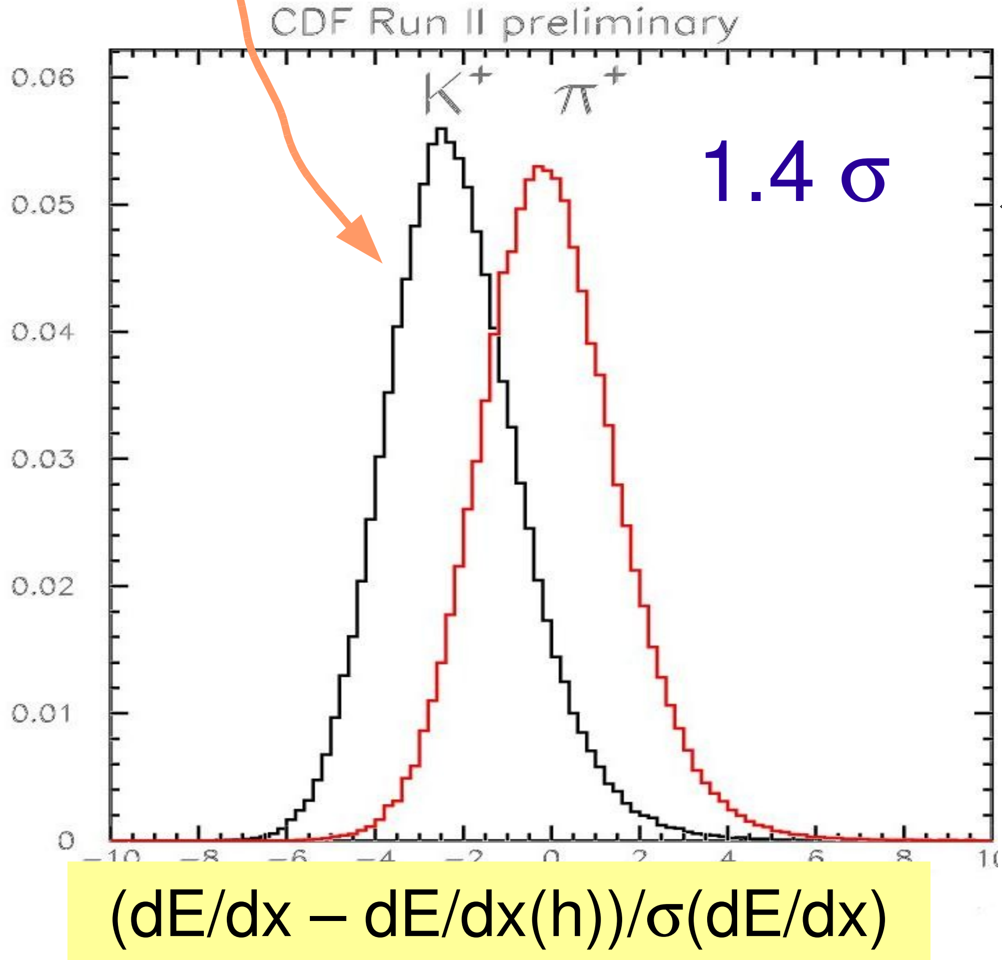
For each particle, use:

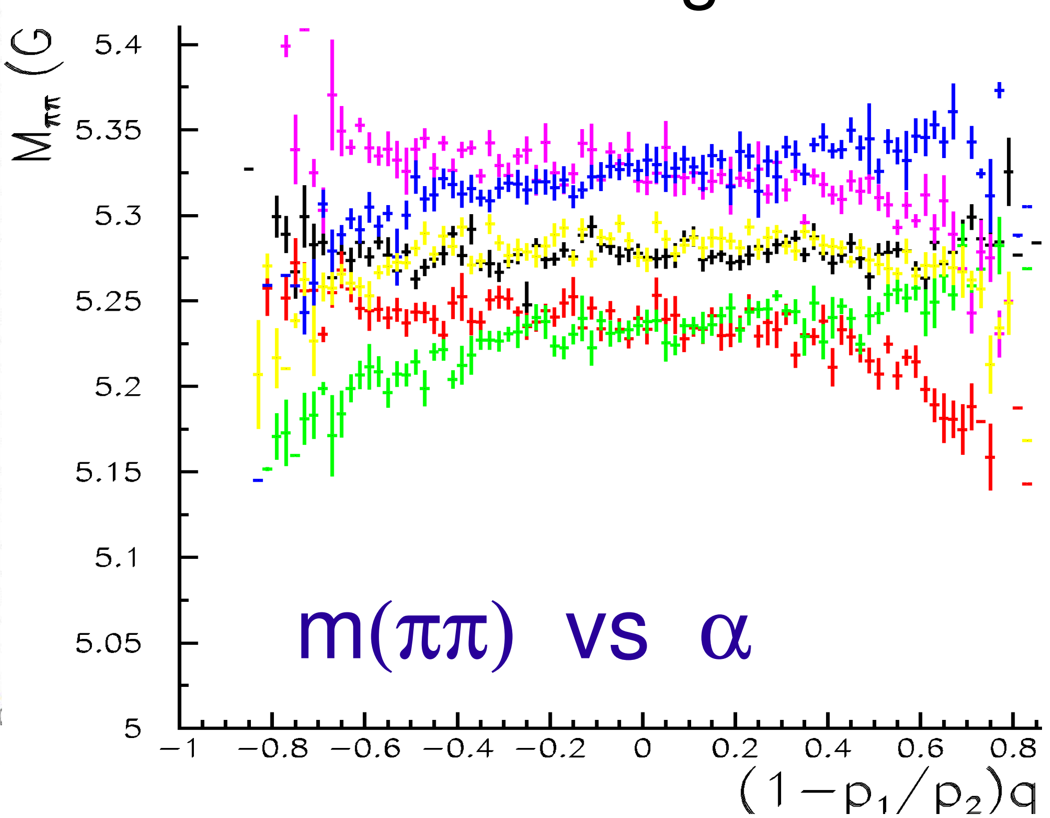
- dE/dx (calibrated on D*)
- Kinematic: m(ππ) and α

Pion momenta, $p_1 < p_2$

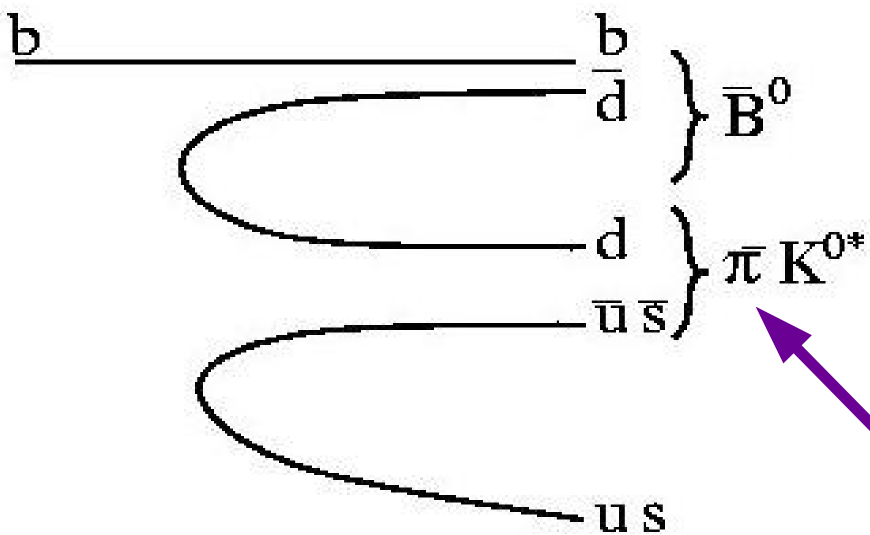
$$\alpha = \left(1 - \frac{p_1}{p_2}\right) \cdot q_1$$

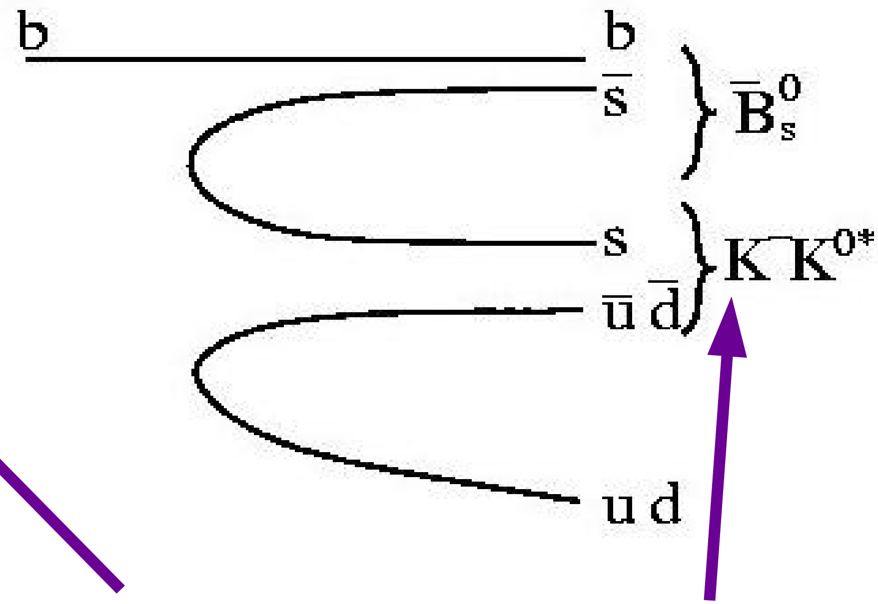
Charge of #1

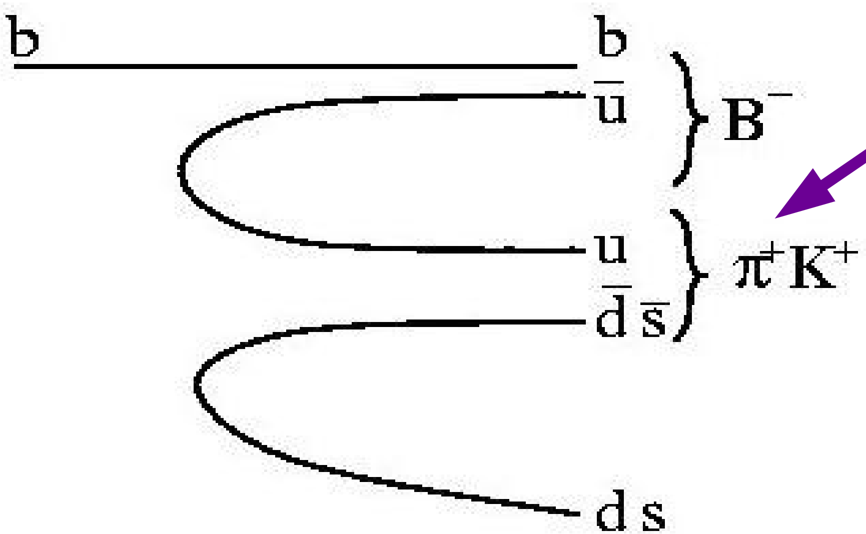




Basics of Same Side Tagging

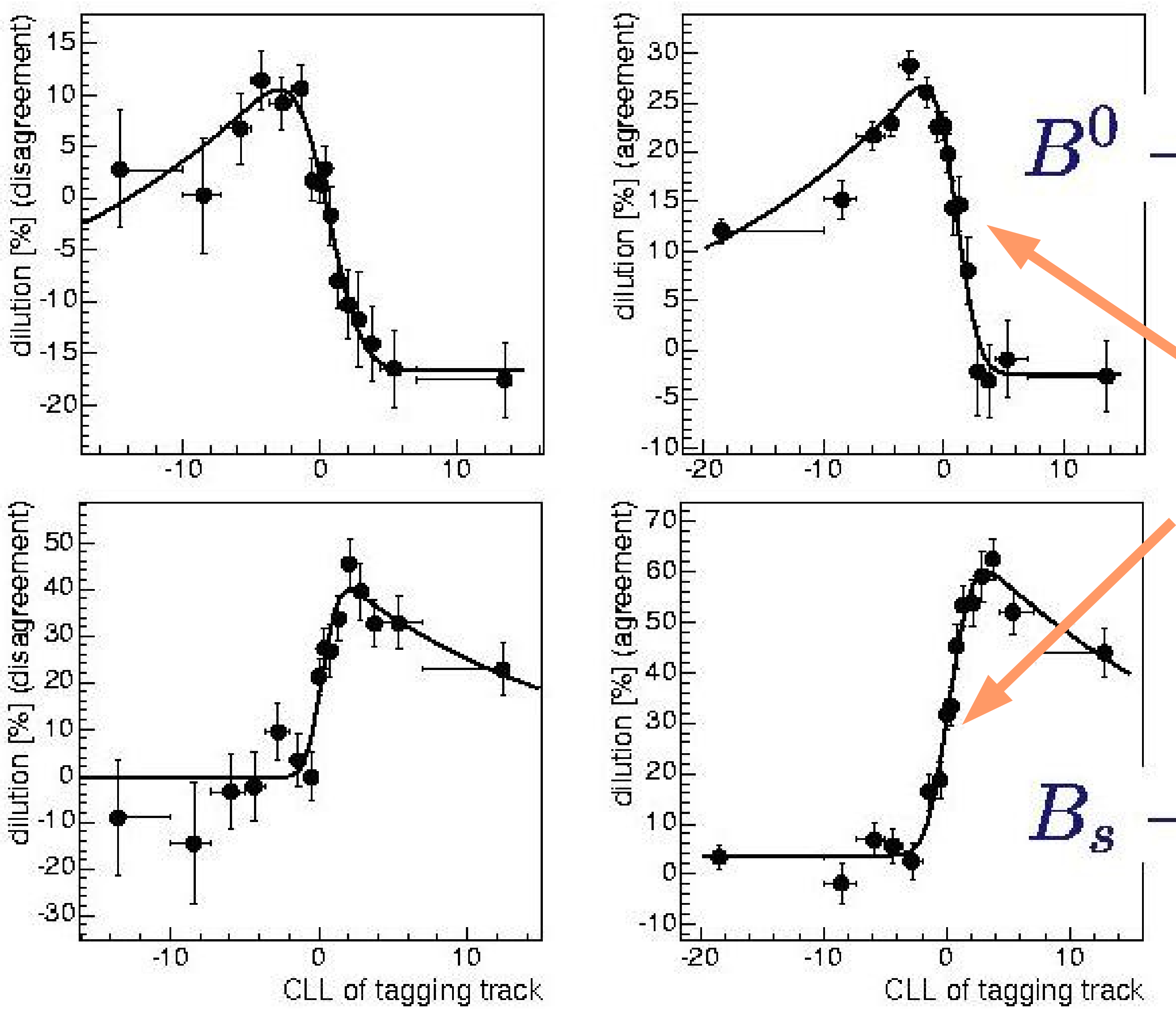






- First charged particle carries info on B flavor
- D depends on species
- For Bs: find kaons (from fragm. or K*0) using Particle Id.

Dilution vs CLL of tagging track



$B^0 \to D\pi$

(π good, K bad)

Sharp change when switching from π to K

$B_s \to D_s\pi$

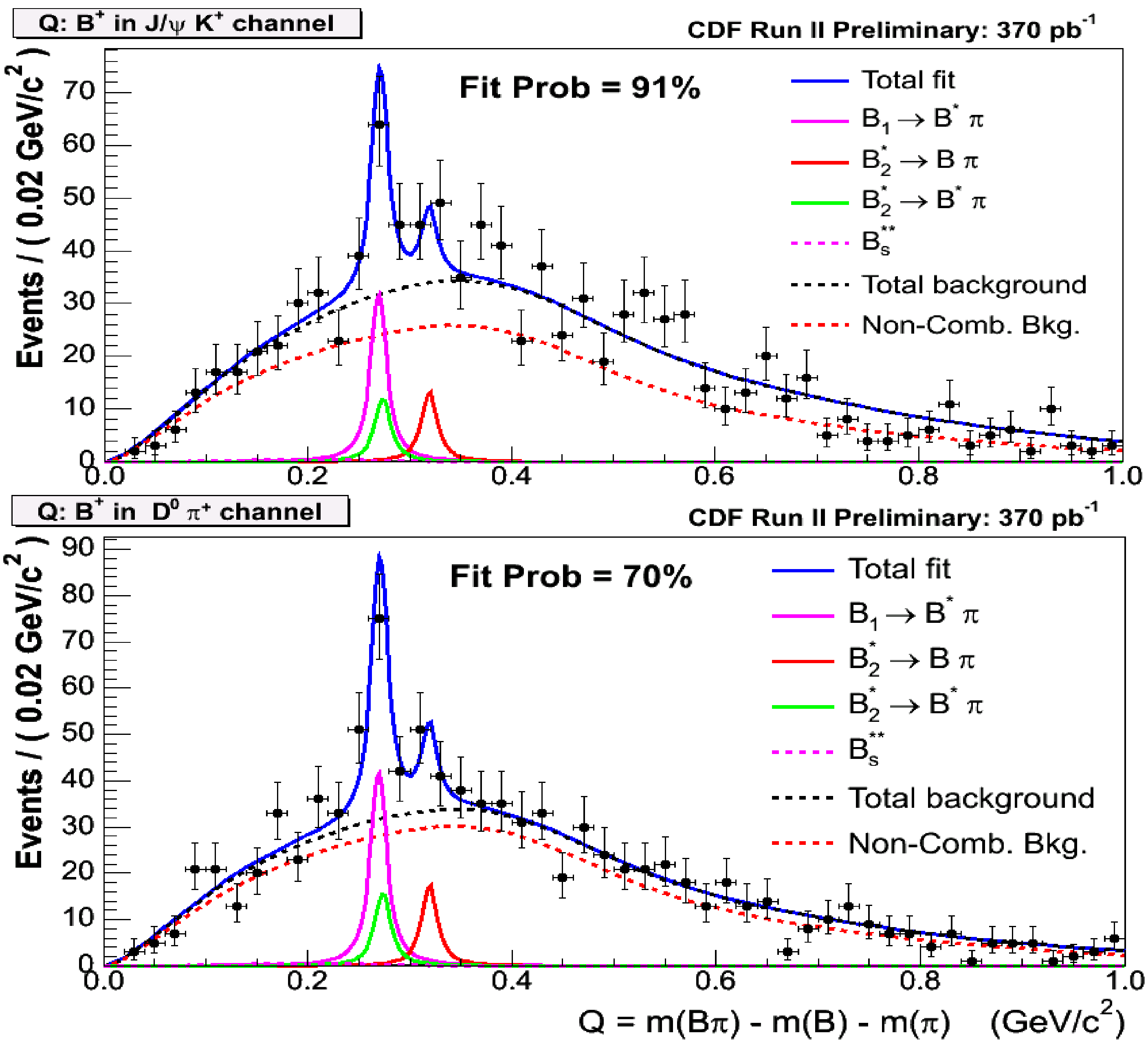
(π bad, K good)

- D(CLL) used in the fit as event weight.

Step 1: $b\bar{b}$ correlations

- Gluon Splitting in Pythia must match data
- fit $\Delta\phi(B^+, \mathrm{displ.vertex})$ in data to templates
- for GS, data/pythia $= \mathbf{1.14 \pm 0.10}$
- reweight Pythia to match
- use error on GS to assign systematics

Step 2: observe B**



- important for calibration of SST in B^+, B^0
- Pythia agrees with data, both when B** is vetoed or included
- syst. err. due to overall yield

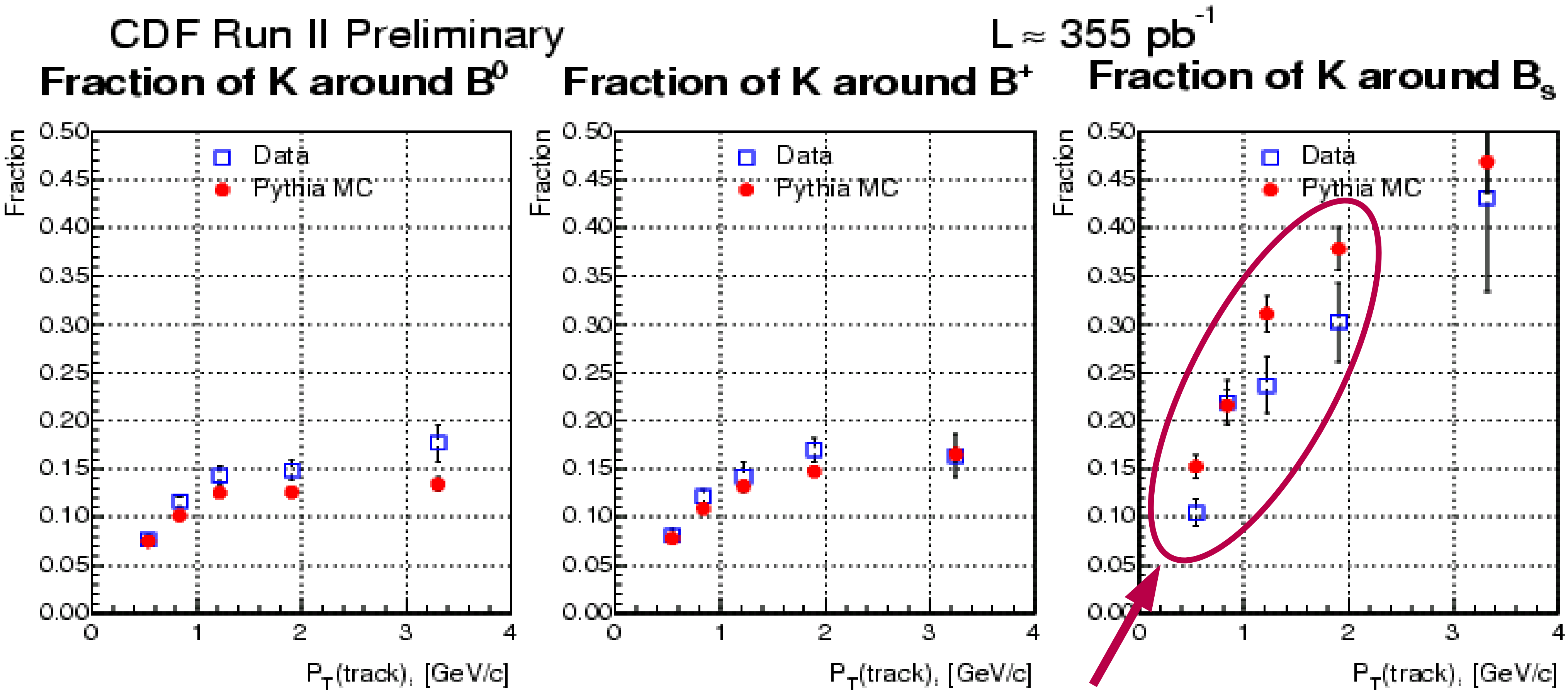
Step 3: measure fragmentation

- use Lund functional form (params "a" and "B")

- sensitive only to linear combo of a & B
- systematics: reweight using 3 points from "valley"

Step 5: particles around B mesons

- fit dE/dx in $B_s \to \nu \ell D_s X$ sample



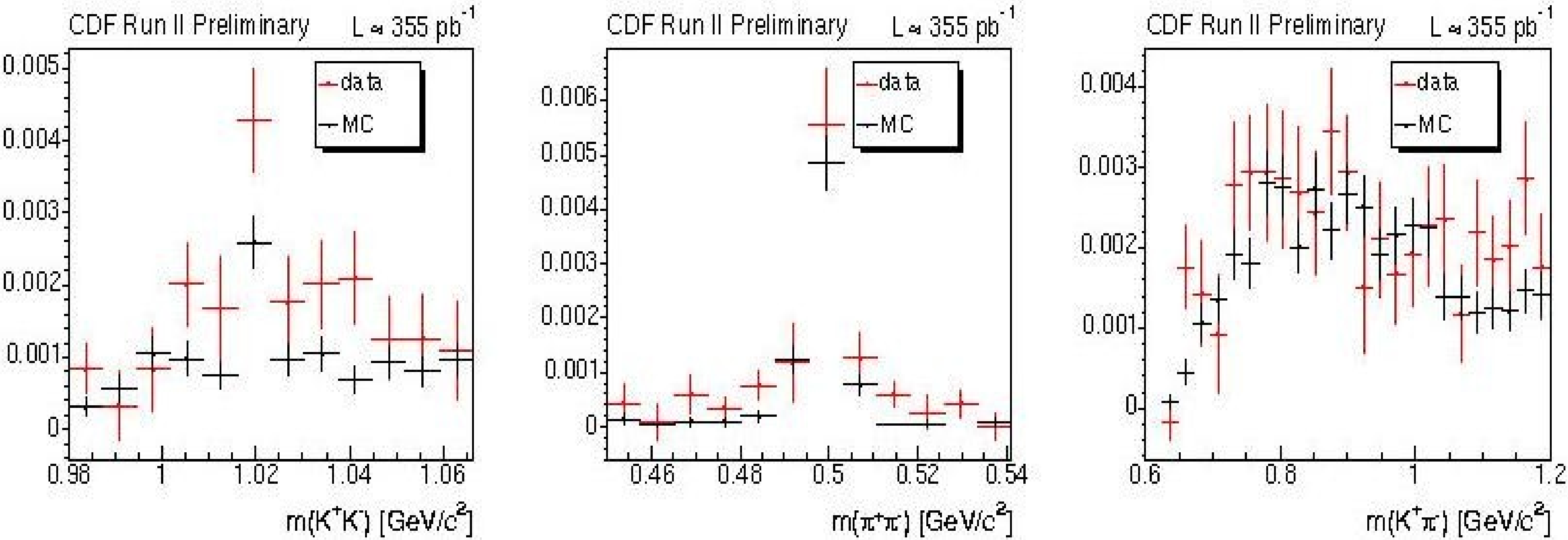
- Pythia has 3% more kaons in Bs cone:

  $\Longrightarrow$ randomize charge of excess kaons

- syst.err: shift `excess K' within data errors

Step 6: resonances in Bs cone

- Sources of non-prompt kaons in data and Pythia



- slightly more in data, but overall very consistent
- syst. err = scale up 100%, down 50%, take largest effect on D

Systematics on SSKT dilution

[%]	$B^+ \to J/\psi K$	$B^0 \to J/\psi K^*$	$B_s \to J/\psi\phi$	$B^+ \to D\pi$	$B^0 \to D\pi$	$B_s \to D_s\pi$
data	87.6 ± 6.7	78.8 ± 25.1	–	95.1 ± 4.7	104.7 ± 14.4	–
nominal MC	100.0 ± 0.7	98.0 ± 1.7	98.8 ± 3.6	100.0 ± 0.9	98.5 ± 2.1	98.8 ± 2.5
fragmentation function	$^{+2.1}_{-0.1}$	$^{+0.3}_{-0.4}$	$^{+3.0}_{-0.0}$	$^{+2.5}_{-0.0}$	$^{+2.4}_{-0.6}$	$^{+4.4}_{-0.0}$
PID simulation & resolution	$^{+1.6}_{-3.1}$	$^{+1.8}_{-4.1}$	$^{+2.0}_{+6.1}$	$^{+1.7}_{-3.4}$	$^{+2.2}_{-3.1}$	$^{+3.6}_{-4.8}$
B^{**} rate	$^{+9.1}_{-2.5}$	$^{+12.1}_{-3.9}$	–	$^{+9.5}_{-2.4}$	$^{+14.6}_{-4.1}$	–
production mechanisms	$^{+0.0}_{-0.8}$	$^{+0.1}_{-2.0}$	$^{+2.0}_{-3.2}$	$^{+0.6}_{-1.2}$	$^{+0.3}_{-1.8}$	$^{+0.6}_{-1.5}$
multiple interactions	$^{+0.5}_{-0.6}$	$^{+0.1}_{-0.7}$	$^{+0.2}_{-0.8}$	$^{+0.2}_{-0.1}$	$^{+0.1}_{-0.5}$	$^{+0.2}_{-0.2}$
kaon fraction	–	–	-9.2	–	–	-5.8
prompt kaon fraction	–	–	-8.8	–	–	-6.4
resonance/$V0$ content	–	–	$^{+5.8}_{-6.1}$	–	–	$^{+4.0}_{-4.1}$
variation within data statistics	$^{+2.3}_{-0.6}$	$^{+1.4}_{-2.0}$	$^{+3.1}_{-11.4}$	$^{+2.7}_{-0.0}$	$^{+2.4}_{-2.2}$	$^{+1.6}_{-4.3}$
Σ+	+9.8	+12.3	+7.7	+10.0	+15.2	+7.1
Σ−	-4.1	-4.8	-19.4	-4.3	-5.9	-11.8

algorithm [%]	value	stat MC	sys MC	data/MC agreement	$\sum$
average dil, max. p_L^{rel}	19.0	± 0.8	$^{+1.9}_{-4.4}$	± 2.1	$^{+2.9}_{-4.9}$
average dil, max. PID	21.8	± 0.8	$^{+2.7}_{-5.2}$	± 1.6	$^{+3.2}_{-5.5}$
predicted dil, max. p_L^{rel}	100.5	± 3.3	$^{+8.6}_{-17.7}$	± 5.5	$^{+10.7}_{-18.8}$
predicted dil, max. PID	98.8	± 2.5	$^{+7.1}_{-11.8}$	± 7.6	$^{+10.7}_{-14.3}$

Syst. on data/MC agreement

- ΔX added in quadrature to stat. and syst. errors

$$\Delta X = \frac{\sum_{1 \le i \le 4} (X_{data,i} - X_{MC,i}) * w_i}{\sum_{1 \le i \le 4} w_i}$$

$$w_i = \frac{1}{\sigma^2_{x_{data,i}} + \sigma^2_{x_{MC,i}}}$$

$$\sigma_{\Delta X} = \frac{1}{\sqrt{\sum_{1 \le i \le 4} w_i}}$$

SSKT result (details)

To maximize stat. power, $\boldsymbol{D}$ is often a function of one or more observables

- Then use scale factor, S_D
- Average dilution = $S_D\sqrt{< D^2 >}$

dilution scale factor $S_D = 98.8^{+10.7}_{-14.3}$

effective dilution $S_D\sqrt{< D^2 >} = 28.3^{+3.2}_{-4.2}$ %

tagging power $\epsilon S_D^2 < D^2 > = 4.0^{+0.9}_{-1.2}$ %