13th International Conference on B-Physics at Hadron Machines

Suppressed B_s decays at Tevatron

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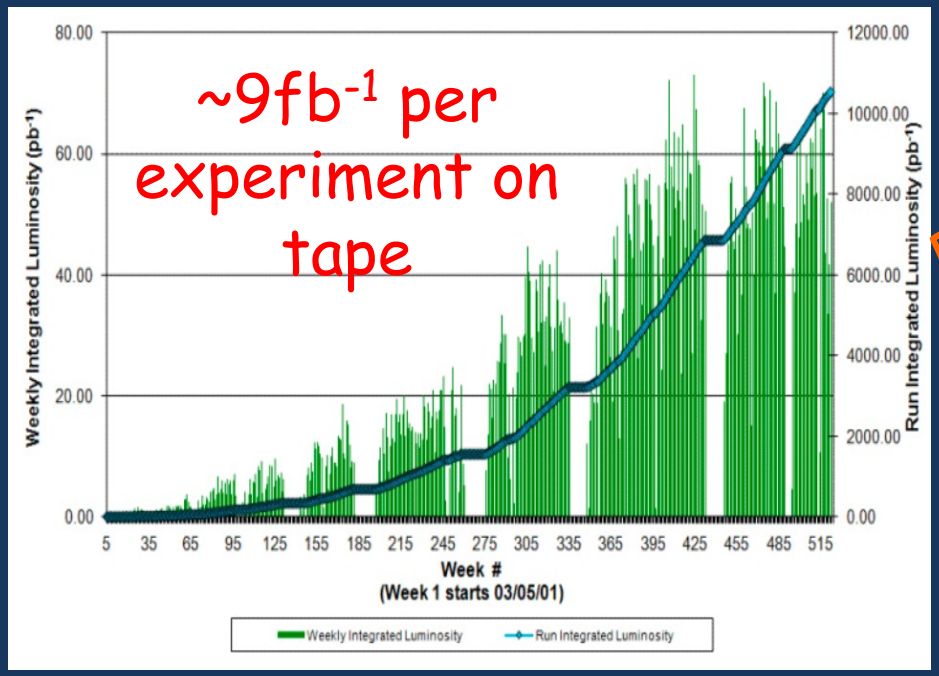
The Strange Beauty of the Tevatron

Tevatron has pioneered the B_s physics sector
- Usable b x-section ~6 μb (p_T>6 GeV/c, |y|<1)
- b-quark fragmentation to B_s mesons f_s/f_d=0.269±0.033

No longer alone: first Belle, then LHC friends join us in this exciting business



10 years of pp collisions (10^{13} collisions): still have something to take out of the oven

Brand New!

Today's Menu:

$B_s^0 \to \phi\phi$	...2.9fb^{-1}
$B_s^0 \to J/\psi\, f_0$	...3.8fb^{-1}
$B_s^0 \to J/\psi\, K^{(*)}$	...5.9fb^{-1}

$B_s^0 \rightarrow \phi\phi$

$B_s^0 \to \phi\phi$

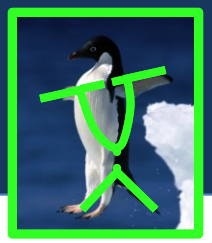
"Suppressed decay"

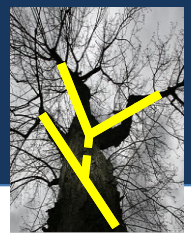
$B_s^0 \to \phi\phi$

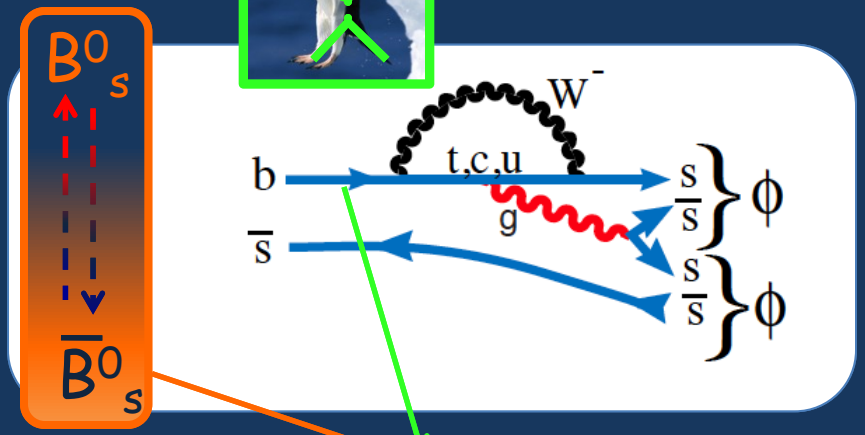
"Favored partner"

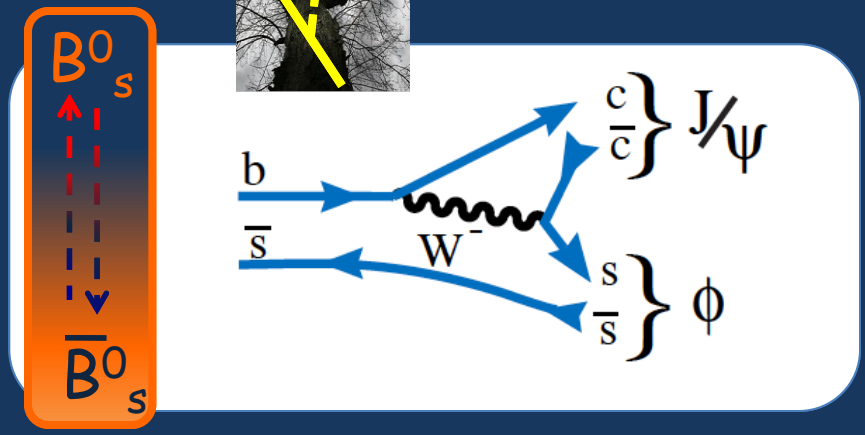
$B_s^0 \to J/\psi\,\phi$

CP admixture:
A_0, $A_{||}$ CP-even
$A_\perp$ CP-odd









Sensitive to NP both in mixing and decay

$$\lambda \equiv \frac{q}{p}\frac{\langle f|\bar{B}^0\rangle}{\langle f|B^0\rangle}$$

Comparing with tree transition could help to disentangle NP contribution in mixing and decay

$B_s^0 \to \phi\phi$ at Tevatron

- CDF first evidence 2005. 8 events in 180 pb^{-1}. PRL 95, 031801 (2005)
- BR measurements: 295±20 events in 2.9 fb^{-1}. CDF-PUB-10064 (2010)

$$BR=(2.40\pm0.21\pm0.86)\times10^{-5}$$

- First Polarization Measurement CDF-PUB-10120 (2010)

Found large transverse polarization

$$(|A_{||}|^2+|A_{\perp}|^2)/|A_0|^2 = 1.9\pm0.2$$

disagreement with SM Naïve expectation

$$(|A_{||}|^2+|A_{\perp}|^2)/|A_0|^2 \ll 1$$

Consistent behaviour with other $b\to s$ penguin.
Both SM (PA or FSI) and NP has been proposed to resolve the puzzle.

NP through a CPV search

- CP-violation (Φ_s) expected very tiny in SM for $B_s^0 \to \phi\phi$.
  NP could enhance it.

- The best (hard) way: measurement from full tagged and time-dependent analysis as case of favored transition
  but: O(1000) events required, lack of statistics…

Can we get something anyway?

I. Bigi: look at an asymmetry of distribution of CP-odd variables.

No need of time-evolution, no need of tagging.
Look at: KTeV Coll., PRL 96,101801 (2006)

BRAND NEW!

CDF 2011: First CPV search in untagged sample

$B_s^0 \to \phi\phi$ Triple Products (TP)

$$\sum_{i=1}^{6} K_i(t) f_i(\vec{\omega})$$

K_4 and K_6:
CP-even/CP-odd interference
($A_0 A_\perp$) and ($A_{||} A_\perp$):

$$\Im(A_\perp A_i^\star) - \Im(\bar{A}_\perp \bar{A}_i^\star) \quad i = 0, \|$$

f_4 and f_6:
Proportional to True
CP-violating Triple Product
observables

$$\vec{p} \cdot (\vec{\varepsilon}_1 \times \vec{\varepsilon}_2)$$

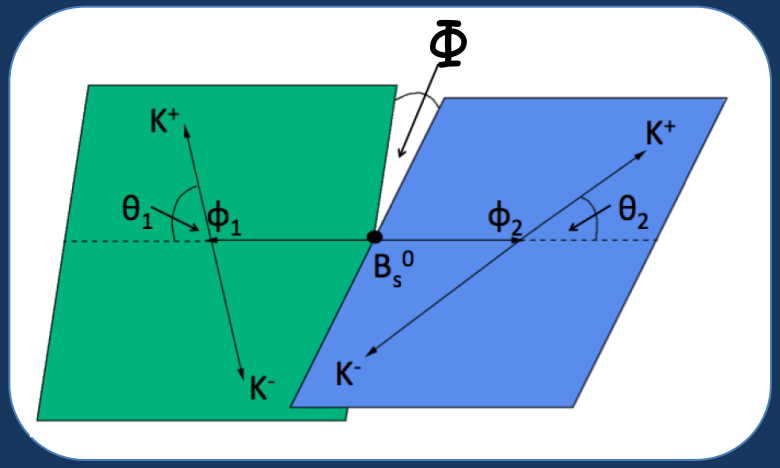
(seen in J. Rosner's talk)

TP asymmetries expected
zero in the SM

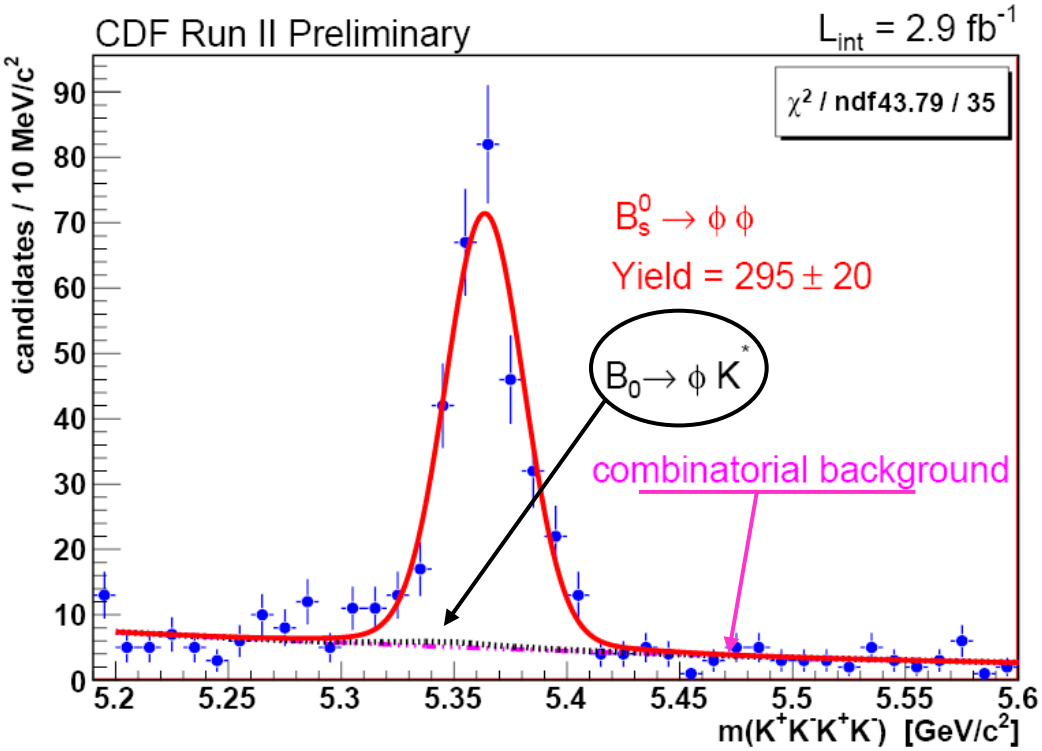
Experimentally accessed by asymmetry of distribution of two angular functions

$$u = \cos\Phi \sin\Phi \longrightarrow A_{||} A_\perp$$

$$v = \begin{cases} \sin\Phi & \text{if } \cos\vartheta_1 \cos\vartheta_2 > 0 \\ \sin(-\Phi) & \text{if } \cos\vartheta_1 \cos\vartheta_2 < 0 \end{cases} \longrightarrow A_0 A_\perp$$



$B_s^0 \rightarrow \phi\phi$ sample

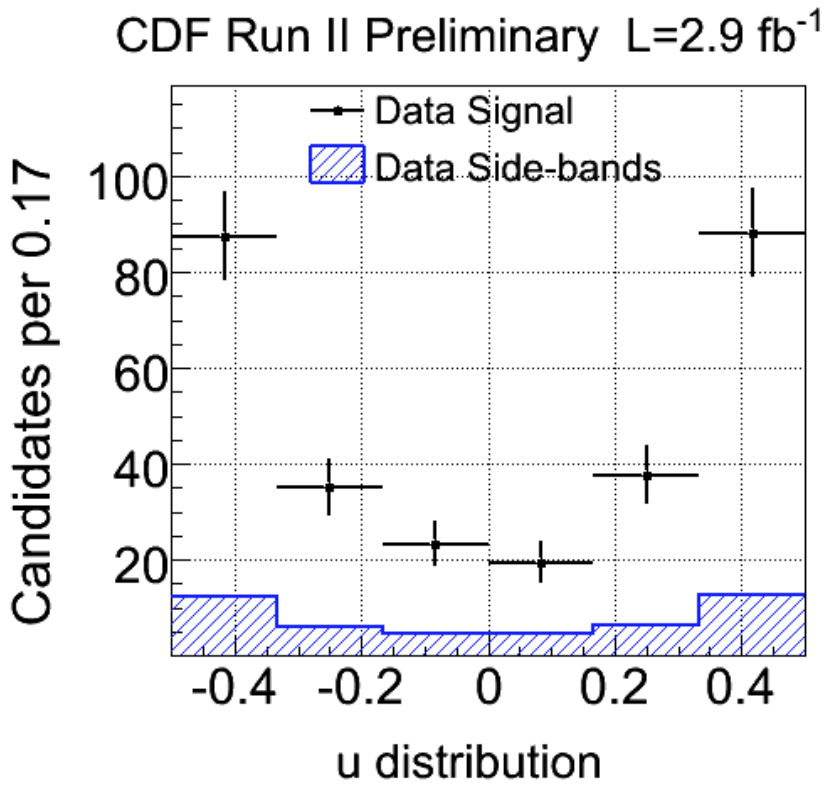


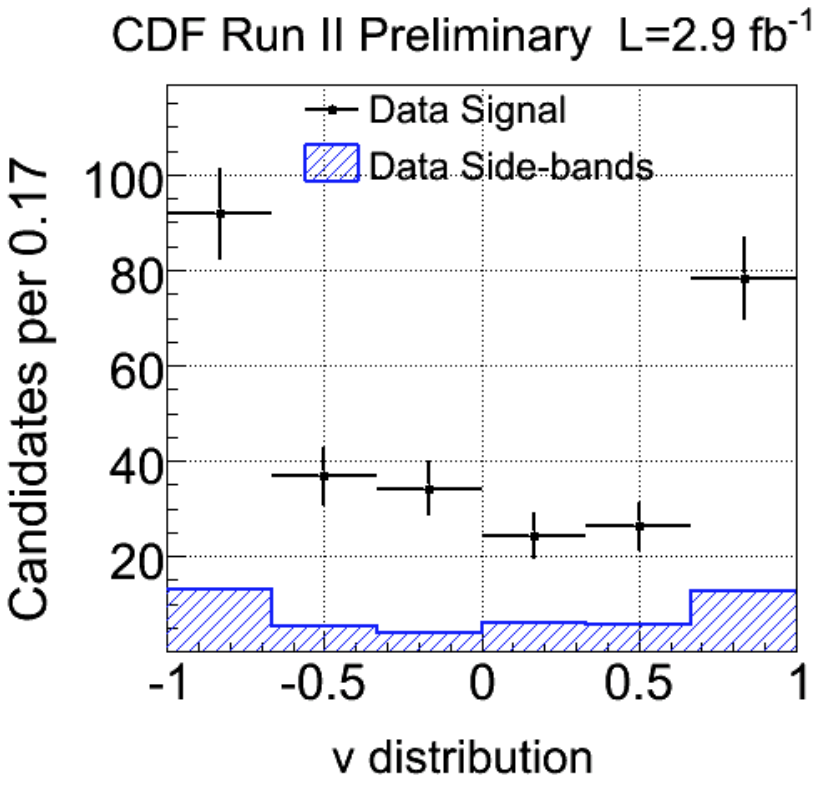
- collected by displaced track trigger
- optimized selection based on kinematic and impact parameter cuts.
- take $|m_{[KK]}-m_{\phi(1020)}|<15$ MeV/c^2

$B_s^0 \rightarrow \phi K^*$ reflection ~3%, no other peaking bkg from simulation of B_s^0 or Λ_b decays

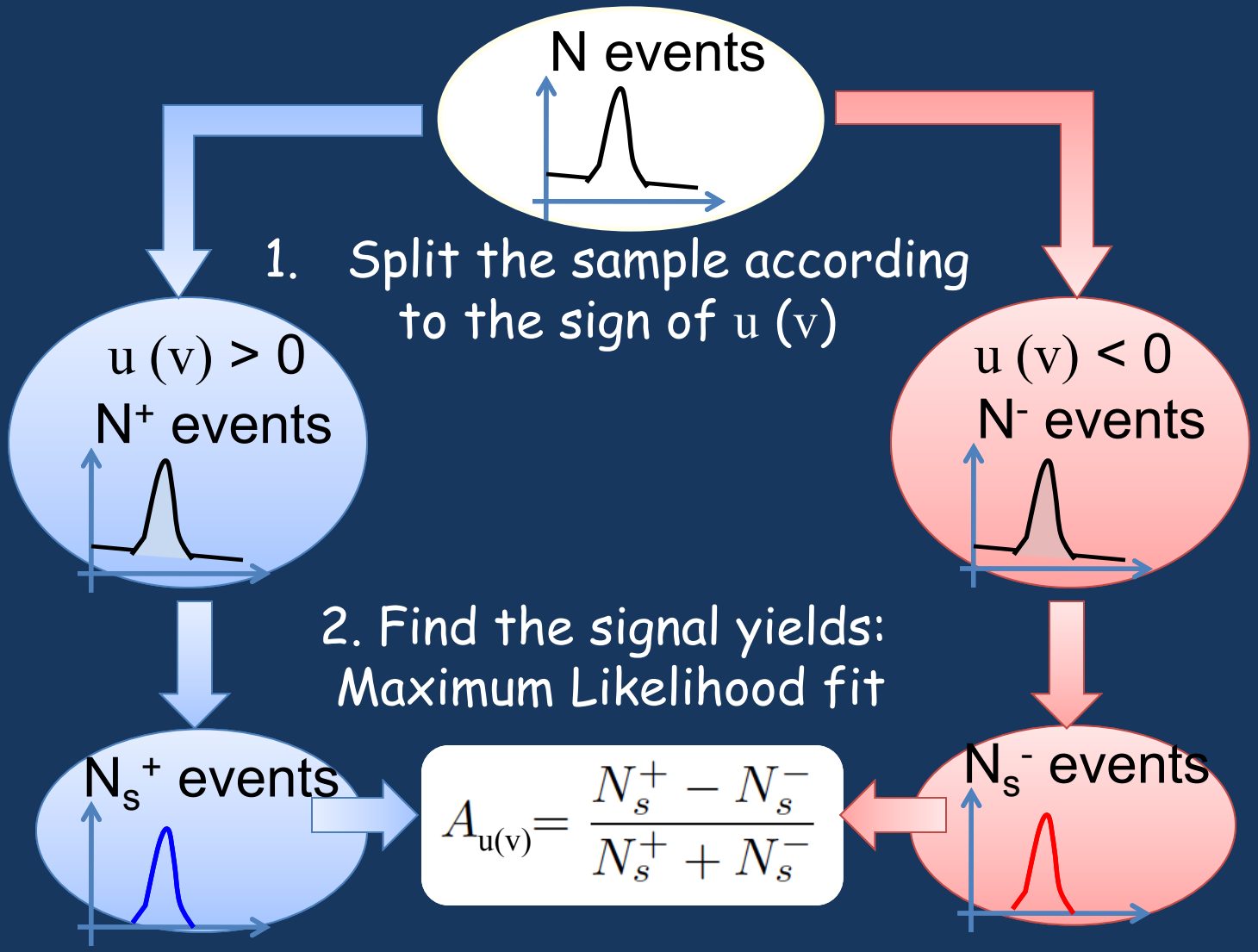
u and v distributions

Measure u and v asymmetries
(proportional to TP asymmetries)



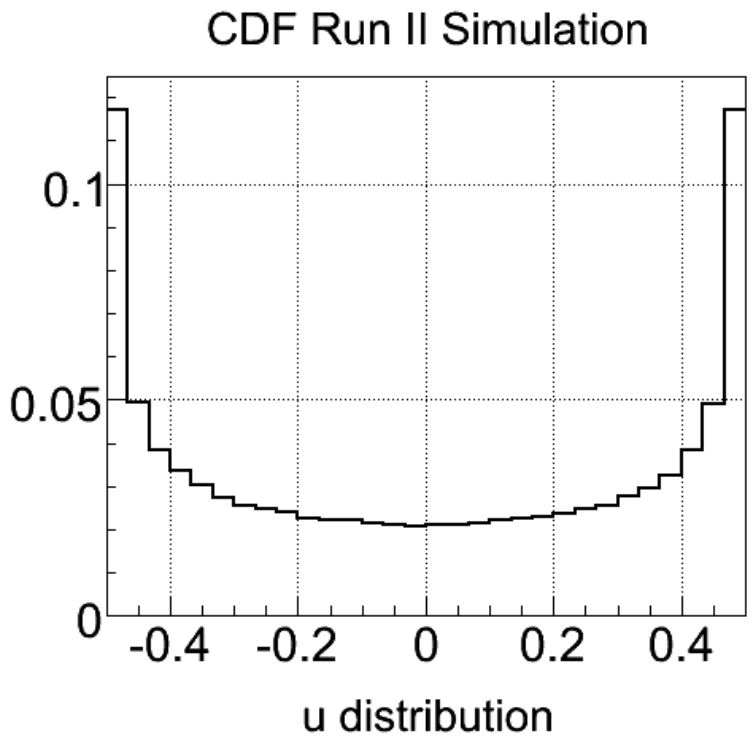


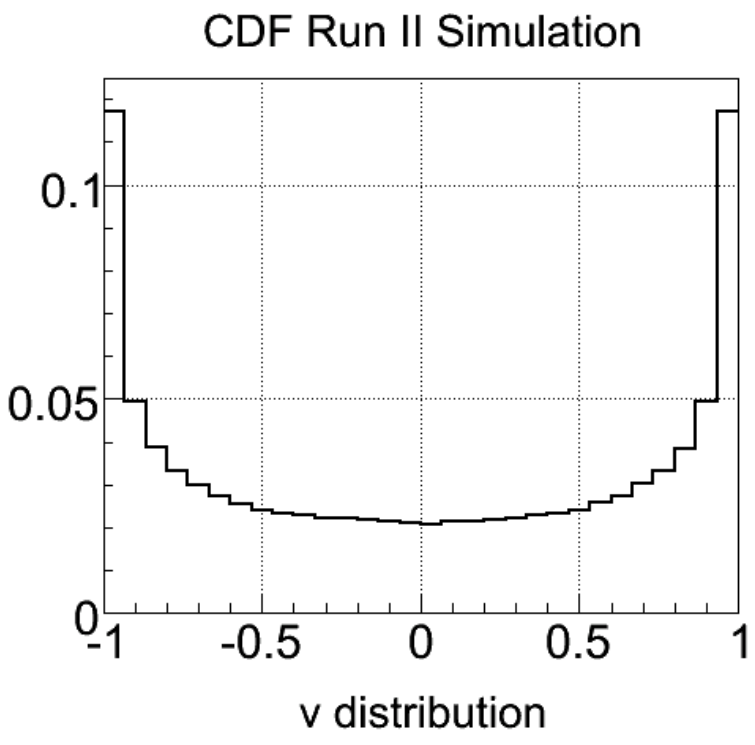
Strategy


N events
1. Split the sample according to the sign of u (v)
u (v) > 0
N+ events
u (v) < 0
N- events
2. Find the signal yields: Maximum Likelihood fit
Ns+ events
Ns- events
$A_{u(v)} = \frac{N_s^+ - N_s^-}{N_s^+ + N_s^-}$

Is the splitting biased?

Variables u and v defined by helicity angles.
Is the angular acceptance introducing artificial asymmetries?
From full MC simulation: check no bias at permille level.

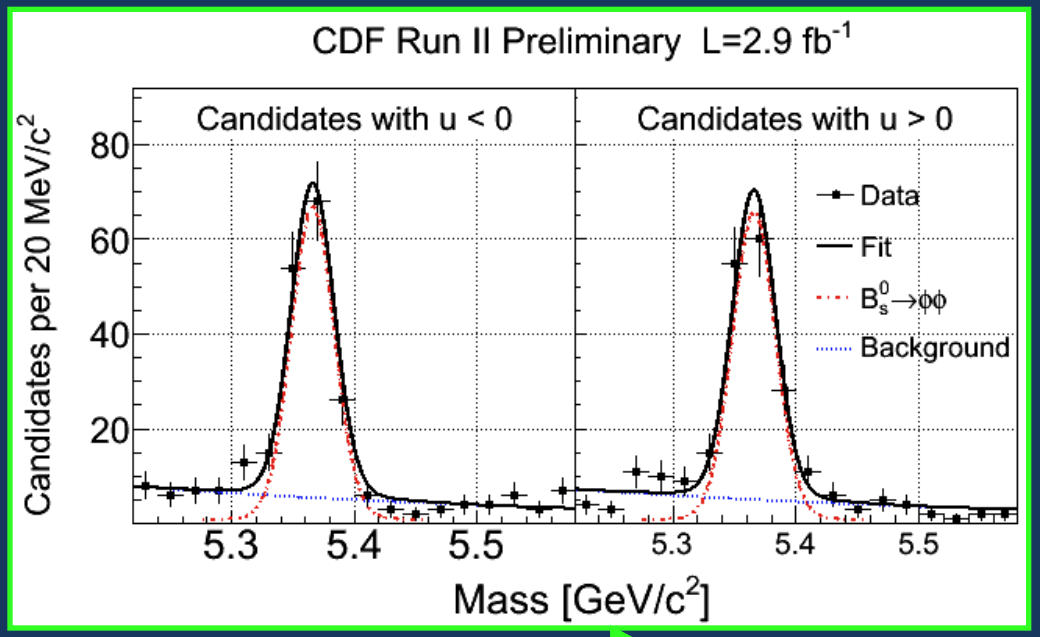




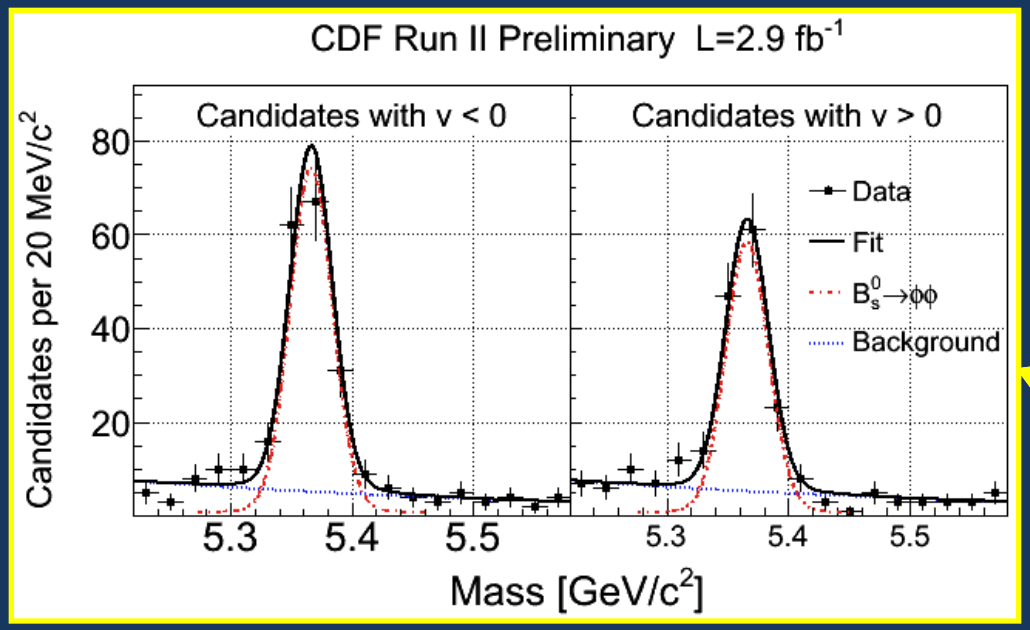
Asymmetries fit

Unbinned Max Likelihood fit:

- Signal asymmetry enter directly the Likelihood
- Backg asymmetry consistent with zero.



u observable



v observable

$B_s^0 \rightarrow \phi\phi$ TP results

Systematics: potential contribution of physics background ($B^0_s \rightarrow \phi K^*$, $B^0_s \rightarrow \phi K^+K^-$ and $B^0_s \rightarrow \phi f_0$). Negligible bias from time-acceptance from MC simulations.

CDF-PUB-10424 (2011)

$A_u = (-0.8 \pm 6.4(\text{stat.}) \pm 1.8(\text{syst.}))\%$

$A_v = (-12.0 \pm 6.4(\text{stat.}) \pm 1.6(\text{syst.}))\%$

Constrain TP asymmetries of SM

arXiv:hep-ph/11032442

$$\propto \sin \varphi_{weak} \cos \delta_{strong}$$

First measurement of CP violation in the $B_s^0 \rightarrow \phi\phi$

Sensitive to CP-violation (i.e. NP) both in mixing and decay

$$\lambda \equiv \frac{q}{p}\frac{\langle f|\bar{B}^0\rangle}{\langle f|B^0\rangle}$$

$B_s^0 \rightarrow J/\psi\, f_0$

$B_s^0 \to J/\psi f_0$ at CDF

- CP-odd final state. Potential clean measurement of Γ_{odd} ($= \Gamma_H$). β_s (w/o angular analysis).

CDF 2011 observation (see I. Ripp-Baudot's talk for D0)

BRAND NEW!

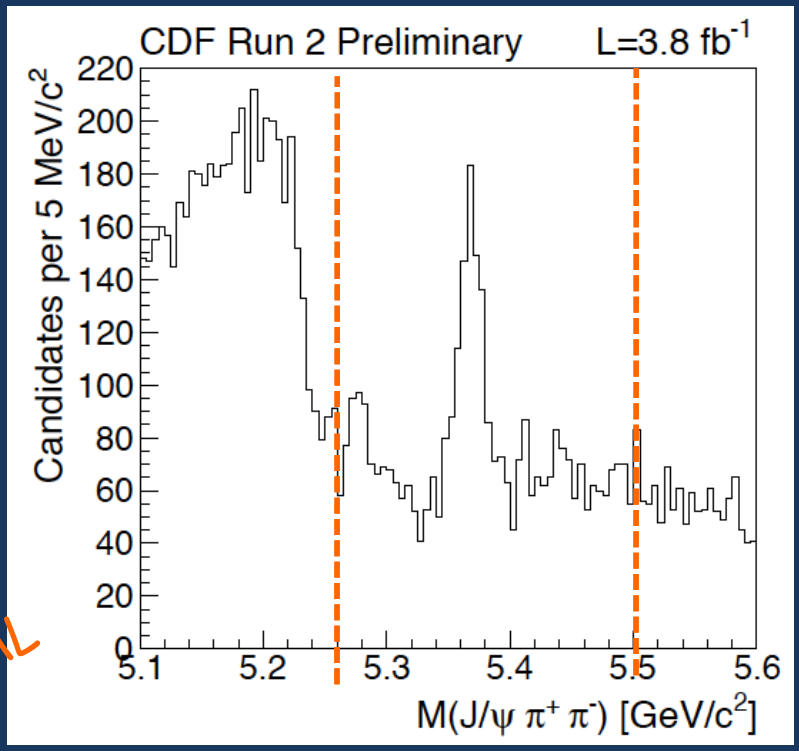
$$R_{f_0/\phi} = \frac{\mathcal{B}(B_s^0 \to J/\psi f_0(980))}{\mathcal{B}(B_s^0 \to J/\psi\phi)} \frac{\mathcal{B}(f_0(980) \to \pi^+\pi^-)}{\mathcal{B}(\phi \to K^+K^-)}$$

from PDG

$$\frac{N(B_s^0 \to J/\psi f_0)}{N(B_s^0 \to J/\psi\phi)} \frac{\varepsilon_{J/\psi\phi}}{\varepsilon_{J/\psi f_0}}$$

from data: from MC

- dimuon trigger, 3.8 fb^{-1}
- optimized selection: NN for unbiased maximization of $\varepsilon/(2.5+\sqrt{B})$. ε from simulaton, B from mass sideband.



Unbinned extended ML fit

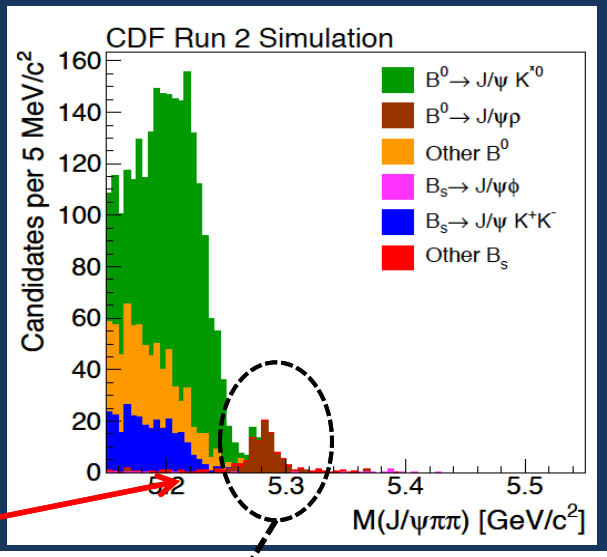
$B_s^0 \to J/\psi f_0$ fit

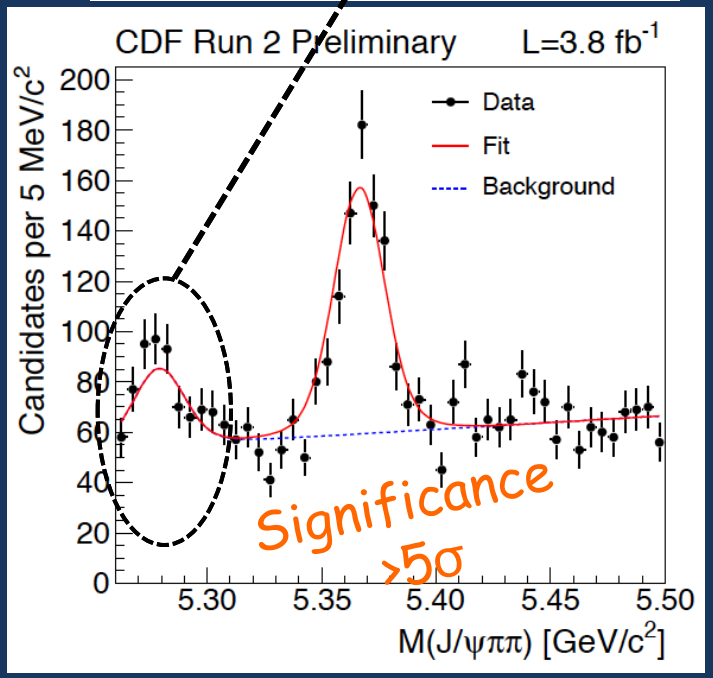
$$\frac{N(B_s^0 \to J/\psi f_0)}{N(B_s^0 \to J/\psi \phi)} \frac{\varepsilon_{J/\psi\phi}}{\varepsilon_{J/\psi f_0}}$$

careful understanding of background components:

- ✓ linear combinatorial
- ✓ physics from MC

$B^0 \to J/\psi\pi^+\pi^-$





$N(B_s^0 \to J/\psi f_0) = 571 \pm 37 \pm 25$

$N(B_s^0 \to J/\psi \phi) = 2302 \pm 49 \pm 49$

Systematic: signal-background modeling

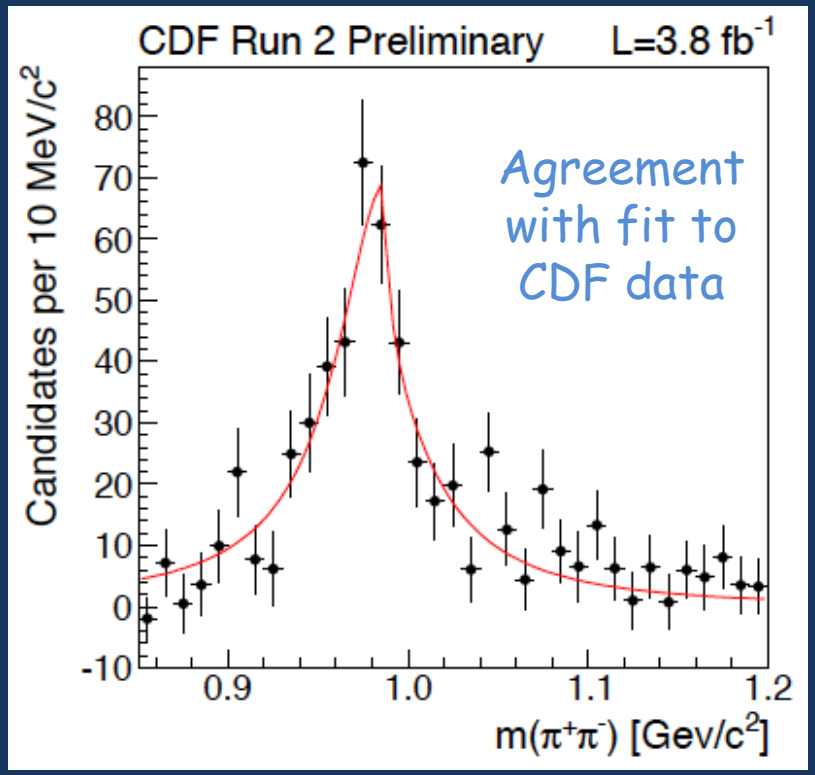
$B_s^0 \to J/\psi\, f_0$ efficiency

$$\frac{N(B_s^0 \to J/\psi f_0)}{N(B_s^0 \to J/\psi\phi)} \frac{\varepsilon_{J/\psi\phi}}{\varepsilon_{J/\psi f_0}}$$

= 1.178 ± 0.040 from full MC simulation.

$B_s^0 \to J/\psi\, \phi$ from CDF Note 10206
$B_s^0 \to J/\psi\, f_0$ modeled by Flattè distr. (input from BES, PLB 607, 243(2005)).

Systematic:
MC-data agreement, input uncertainties



$B_s^0 \to J/\psi\, f_0$ result

Final Resuts

CDF-PUB-10404 (2011)

CDF: $R_{f_0/\phi} = 0.292 \pm 0.020 \pm 0.017$

In agreement with D0: R = 0.210 ± 0.032 ± 0.036

and with LHCb: $R_{f_0/\phi} = 0.252^{+0.046\ +0.027}_{-0.032\ -0.033}$

Expectation: R in 0.1-0.5

Fixing BR($B_s^0 \to J/\psi\ \phi$) to PDG value

$$\mathcal{B}(B_s^0 \to J/\psi f_0(980))\mathcal{B}(f_0(980) \to \pi^+\pi^-) = (1.85 \pm 0.13 \pm 0.11 \pm 0.57) \cdot 10^{-4}$$

Agreement with Belle: $(1.16^{+0.31\ +0.15\ +0.26}_{-0.19\ -0.17\ -0.18}) \cdot 10^{-4}$

$B_s^0 \rightarrow J/\psi\ K^{(*)}$

$B_s^0 \to J/\psi\, K^{(*)}$ analysis

CDF 2010 first observation (5.9 fb^{-1})

Reconstruct $J/\psi \to \mu^+\mu^-$. $K_S \to \pi^+\pi^-$, K_S decay length> 5 mm.

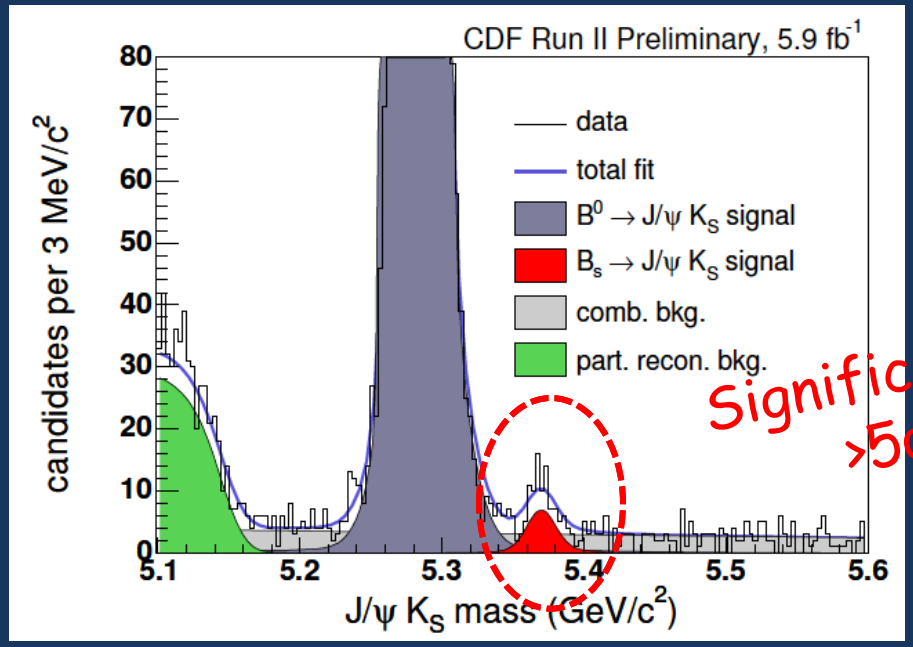
$K^*(892) \to K\pi$, $|M_{K\pi} - M_{K^*}| < 50$ MeV/c^2

Binned fit to extract signal yield:

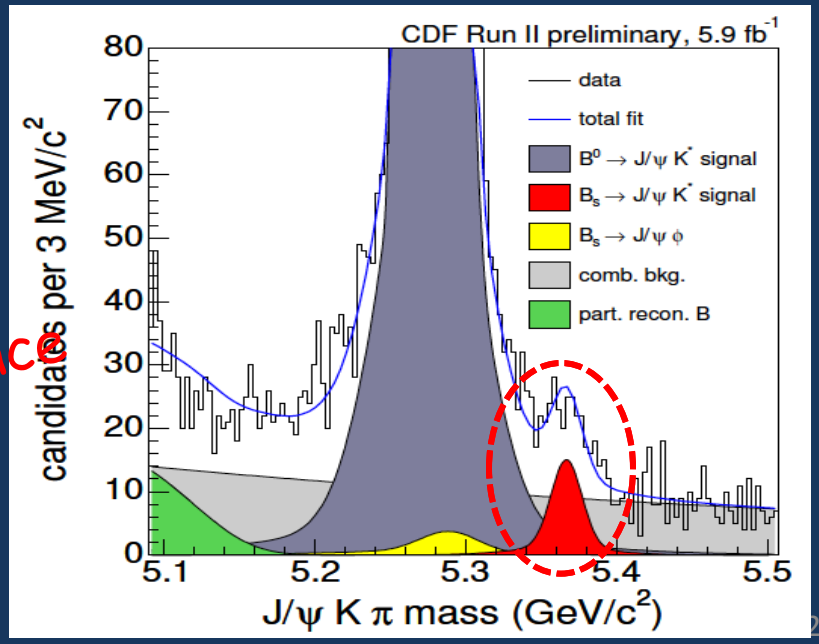
$N(B_s^0 \to J/\psi\, K_S) = 64 \pm 14$

$N(B_s^0 \to J/\psi\, K^*) = 151 \pm 25$

Main background: combinatorial and partially reconstructed decays



Significance >5σ



$B_s^0 \to J/\psi\, K^{(*)}$ results

$$\frac{\mathcal{B}(B_s^0 \to J/\psi\, K_S^0)}{\mathcal{B}(B^0 \to J/\psi\, K_S^0)} = 0.041 \pm 0.007(\text{stat}) \pm 0.004(\text{syst}) \pm 0.005(\text{frag})$$

$$\frac{\mathcal{B}(B_s^0 \to J/\psi\, K^{*0})}{\mathcal{B}(B^0 \to J/\psi\, K^{*0})} = 0.062 \pm 0.009(\text{stat}) \pm 0.025(\text{syst}) \pm 0.008(\text{frag})$$

Dominated by backg. modeling and knwoledge of polarization

Fixing reference mode's BR's to PDG:

$$\mathcal{B}(B_s^0 \to J/\psi\, K^0) = (3.5 \pm 0.6(\text{stat}) \pm 0.4(\text{syst}) \pm 0.4(\text{frag}) \pm 0.1(\text{norm})) \times 10^{-5}$$

$$\mathcal{B}(B_s^0 \to J/\psi\, K^{*0}) = (8.3 \pm 1.2(\text{stat}) \pm 3.4(\text{syst}) \pm 1.0(\text{frag}) \pm 0.4(\text{norm})) \times 10^{-5}$$

confirmed by LHCb

Published in PRD 83, 052012 (2011)

Conclusion

Rewarding results from Tevatron on B_s suppressed decays.

$B_s^0 \to \phi\phi$: probing NP with b→s penguin. Update BR and first polarization measurement 2010. NEW: First search for CP violation through TP in untagged sample.

$B_s^0 \to J/\psi\, f_0$: clean mode for Γ_{odd} measurement. Potential simpler analysis for β_s (w/o angular analysis). Tevatron confirms LHCb and Belle observation with higher precision.

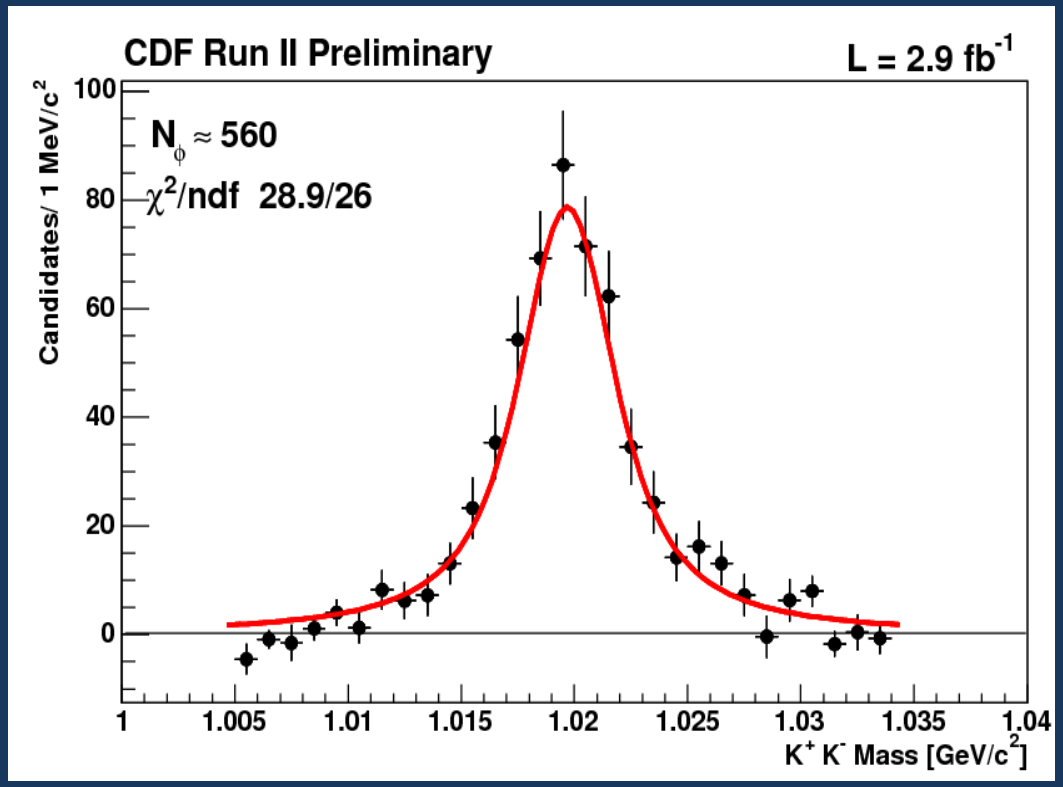
$B_s^0 \to J/\psi\, K^{(*)}$: disentangle penguin contribution. With K_S CP-odd mode, sensitive to γ. First observation 2010 and BR measurement.

Expected ~10 fb^{-1} per experiment in October. Analyses steadily improving. Still some aces up our sleeves.

Backup

$B_s^0 \to \phi\phi$ selection requirements

Take $|m_{[KK]}-m_{\phi(1020)}|<15$ MeV/c^2

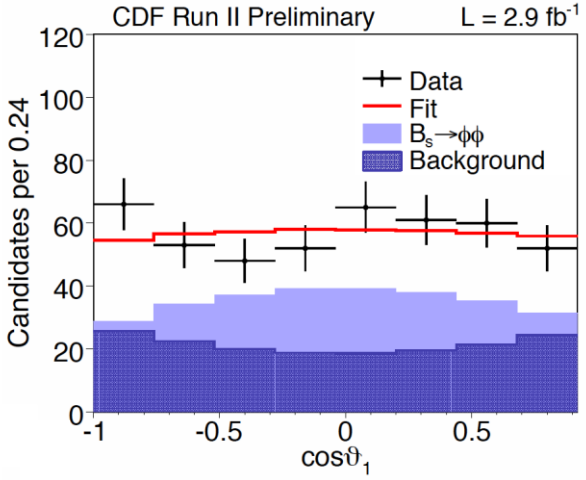


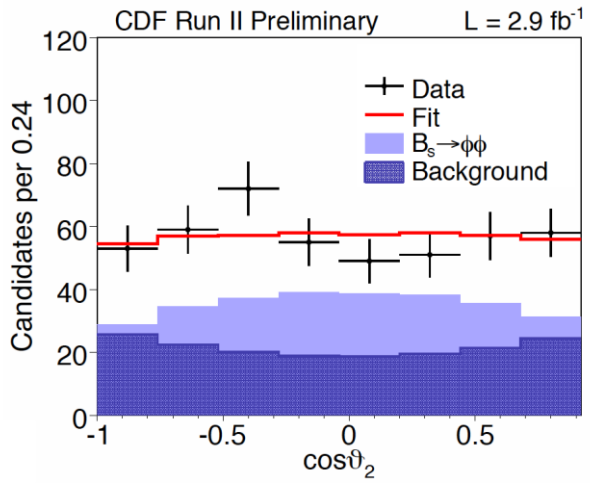
Optimized selection

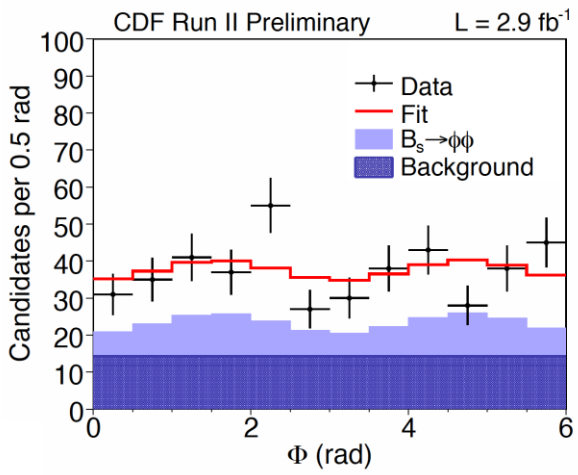
L_{xy}^B	$[\mu\mathrm{m}]$	> 330
$p_{\mathrm{T\,min}}^K$	$[\mathrm{GeV}/c]$	> 0.7
p_{T}^ϕ	$[\mathrm{GeV}/c]$	
χ^2_{xy}		< 17
d_0^B	$[\mu\mathrm{m}]$	< 65
$d_0^{\phi\mathrm{max}}$	$[\mu\mathrm{m}]$	> 85
$p_{\mathrm{T}}^{J/\psi}$	$[\mathrm{GeV}/c]$	

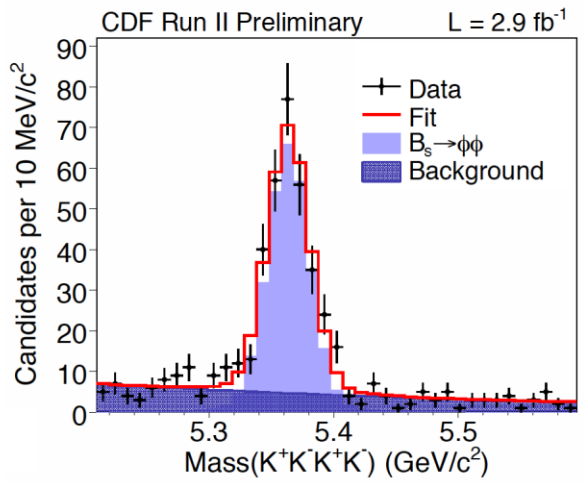
1° Polarization Measurement

Unbinned Maximum Likelihood fit to Mass and Angles









- Acceptance correction from simulation
- background modeled on sideband (polynomials) and fitted in the whole mass range

Polarization Results

- Cross check with $B^0_s \to J/\psi\phi$ sample used in BR measurement (same trigger, ~1800 ev.) consistent with WA within stat. uncertainties
- Systematics dominated by:
  - Non-resonant contributions ($B^0_s \to \phi$(KK) and $B^0_s \to \phi f_0$): ~1%
  - Dependence of acceptance on $\Delta\Gamma_s$: ~1%
  - Uncertainties of $\tau_{L(H)}$: ~1%

$$
\begin{aligned}
|A_0|^2 &= 0.348 \pm 0.041(\text{stat}) \pm 0.021(\text{syst}), \\
|A_\parallel|^2 &= 0.287 \pm 0.043(\text{stat}) \pm 0.011(\text{syst}), \\
|A_\perp|^2 &= 0.365 \pm 0.044(\text{stat}) \pm 0.027(\text{syst}), \\
\cos\delta_\parallel &= -0.91^{+0.15}_{-0.13}(\text{stat}) \pm 0.09(\text{syst}).
\end{aligned}
$$

CDF-PUB-10120 (2010)

…a little insight the Puzzle

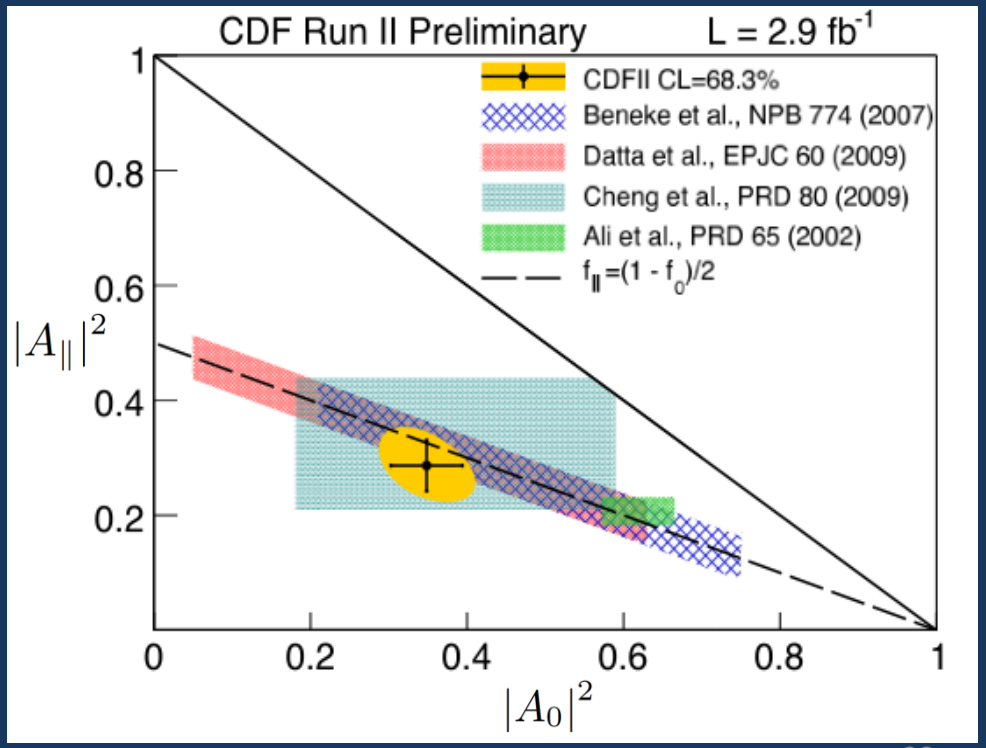
Naïve expectation: $|A_0|^2 \gg |A_{||}|^2 \sim |A_\perp|^2$
- V-A nature of weak interaction and conservation helicity in QCD

Experimentally violated in penguin decays (BaBar, Belle):
- PA [e.g. PL B601, 151 (2004); NP B774, 64 (2007)]
- FSI [PL B597, 291 (2004) + many others]
- NP? [PR D76, 075015 (2007)]

Agreement with QCDf prediction

$\cos\delta_{||}$

CDF	$-0.91^{+0.15}_{-0.13}(stat) \pm 0.09(syst)$	
QCDf	$-0.80^{+0.31}_{-0.16}$	NP B774 (2007)
QCDp	$0.27^{+0.09}_{-0.27}$	PR D76 (2007)



TP in $B_s^0 \to \phi\phi$

Two TP's in $B_s^0 \to \phi\phi$:

TP_1

$$(\hat{n}_1 \times \hat{n}_2) \cdot \hat{n}_z (\hat{n}_1 \cdot \hat{n}_2)$$

$$\downarrow$$

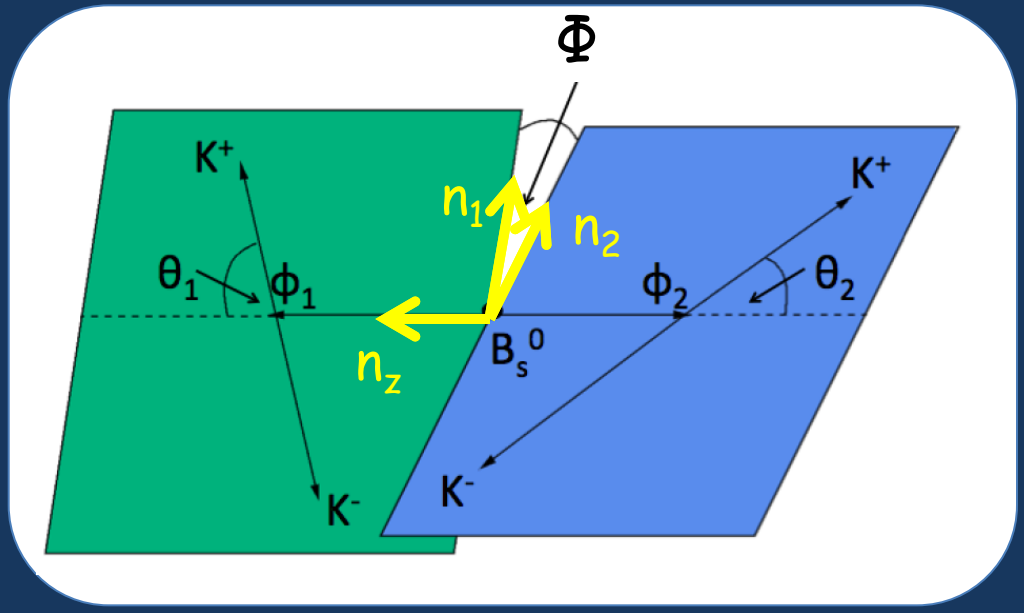
$$f_4, K_4$$

TP_2

$$(\hat{n}_1 \times \hat{n}_2) \cdot \hat{n}_z$$

$$\downarrow$$

$$f_6, K_6$$



$B_s^0 \to J/\psi\, f_0$

$B_s^0 \to J/\psi\, f_0$

Potential S-wave contamination of $B_s^0 \to J/\psi\phi$ sample biasing β_s analysis

PRD, 074024 (2009)

CP-odd:

Potential clean measurement of Γ_{odd} ($= \Gamma_H$)

If no CPV in mixing

Could be used to measure β_s without angular analysis

arXiv:hep-ex/09095442

$B_s^0 \to J/\psi\, \phi$

CP admixture:

- both Γ_L and Γ_H
- angular analysis

$B_s^0 \to J/\psi\, f_0$ efficiency

$B_s^0 \to J/\psi\, \phi$: CDF Pub Note 10206

$$\tau = 458.6 \pm 8.4\ \mu\text{m},$$
$$\Delta\Gamma = 0.075 \pm 0.036\ \text{ps}^{-1},$$
$$|A_0|^2 = 0.524 \pm 0.020,$$
$$|A_{||}|^2 = 0.231 \pm 0.021.$$

$$\phi_{||} = -2.86 \pm 0.11$$

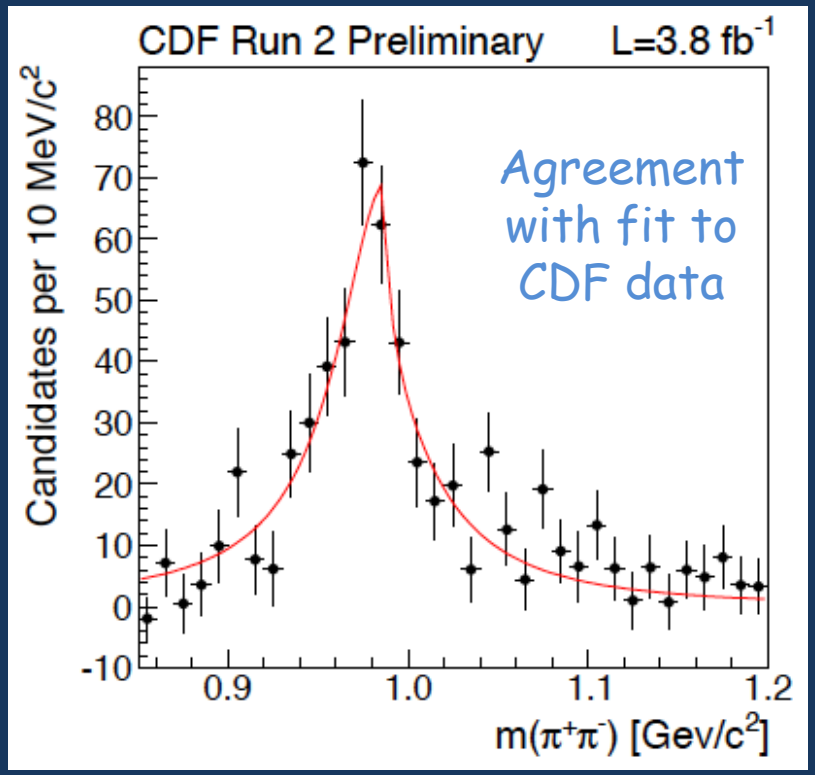
PDG for $B^0 \to J/\psi\, K^*$

$B_s^0 \to J/\psi\, f_0$ modeled by Flattè distr. input from BES, PLB 607, 243(2005):

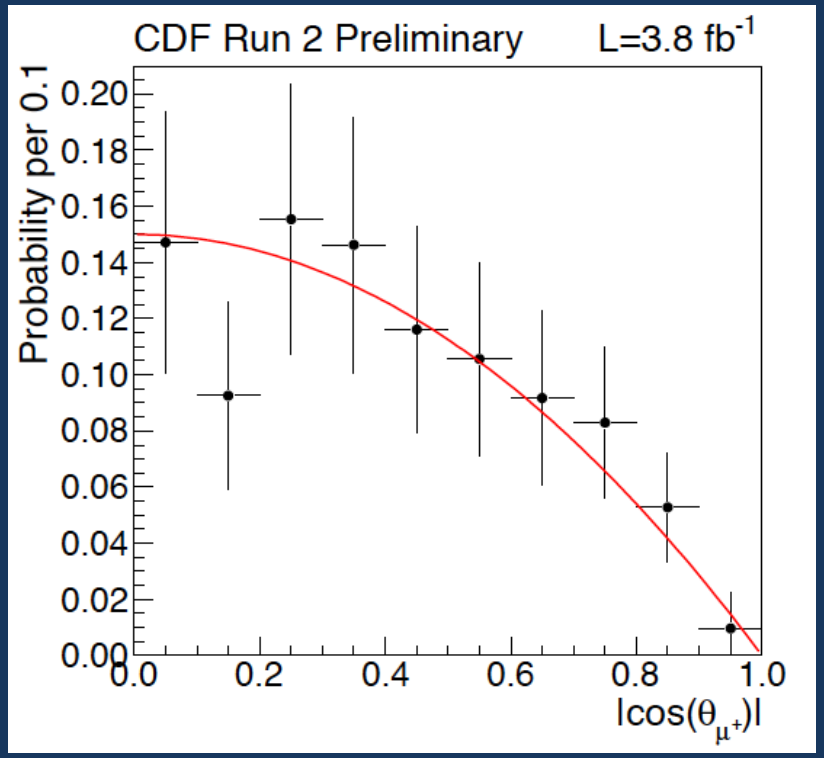
$$m_0 = 965 \pm 8 \pm 6\ \text{MeV}/c^2,$$
$$g_\pi = 165 \pm 10 \pm 15\ \text{MeV}/c^2,$$
$$g_K/g_\pi = 4.21 \pm 0.25 \pm 0.21.$$

CDF measures:

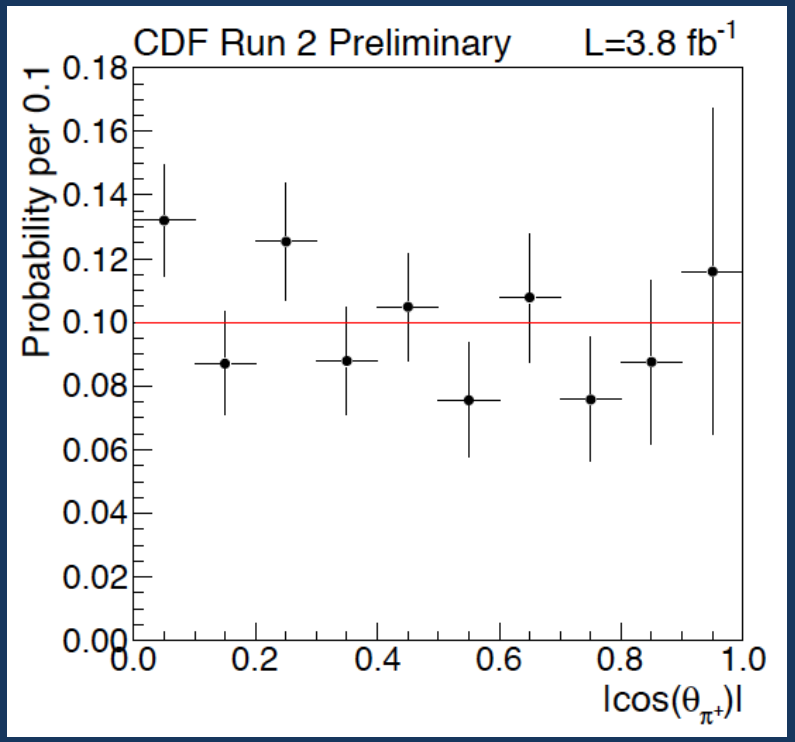
$$m_0 = 989.6 \pm 9.9(\text{stat})\ \text{MeV}/c^2,$$
$$g_\pi = 141 \pm 19(\text{stat})\ \text{MeV}/c^2$$
$$g_K/g_\pi = 2.3 \pm 1.3(\text{stat})$$



$B_s^0 \rightarrow J/\psi f_0$ checks



Positive muon helicity angle (corrected for efficiency)



Positive pion helicity angle (corrected for efficiency)

$B_s^0 \to J/\psi\, K^{(*)}$

1. "Suppressed decay"

$B_s^0 \to J/\psi\, K_S$

T+ O(λ)P

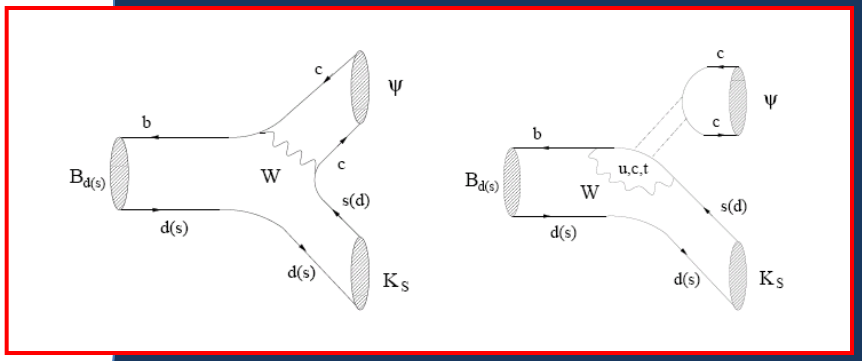
- Greater sensitivity to penguin in B_s decays
- CP-odd: clean measurement of $\Gamma_{s,odd}$ ($= \Gamma_{s,H}$)

  If no CPV in mixing
- sensitive to γ (EPJC 10,299 (1999))

"Favored partner"

$B^0 \to J/\psi\, K_S$

$T + O(\lambda^2)P$



2. "Suppressed decay"

$B_s^0 \to J/\psi\, K(892)^*$ → CP admixture ← $B^0 \to J/\psi\, K(892)^*$

Help to disentagle penguin contribution in $B_s^0 \to J/\psi\, \phi$ (PRD 79, 014005 (2009)).

$B_s^0 \to J/\psi\, K^{(*)}$: selection

Reconstruct $J/\psi \to \mu^+\mu^-$

$K_S \to \pi^+\pi^-$, K_S decay length> 5 mm

$K^*(892) \to K\pi$, $|M_{K\pi} - M_{K^*}| < 50$ MeV/c^2

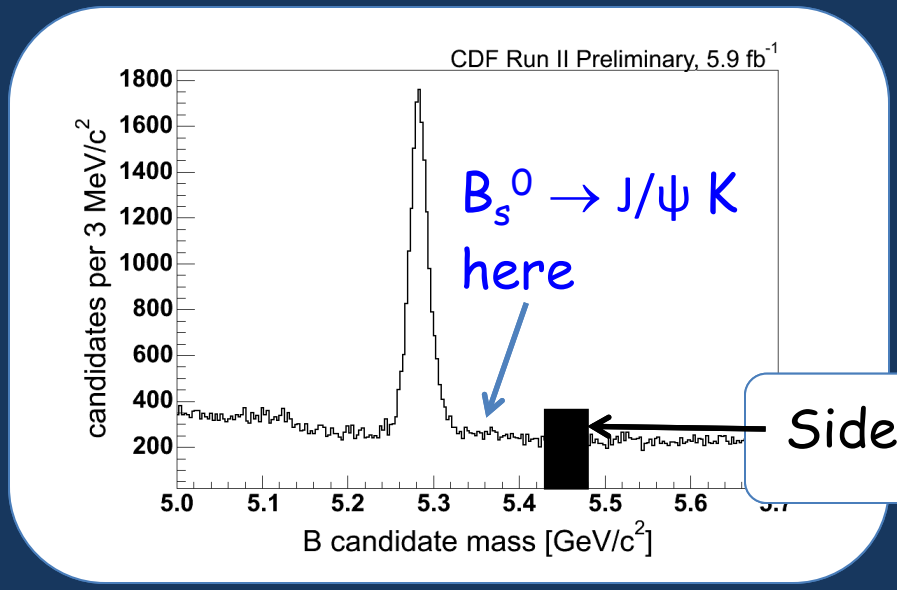
With loose vertexing requirement B_d signal very clear already.

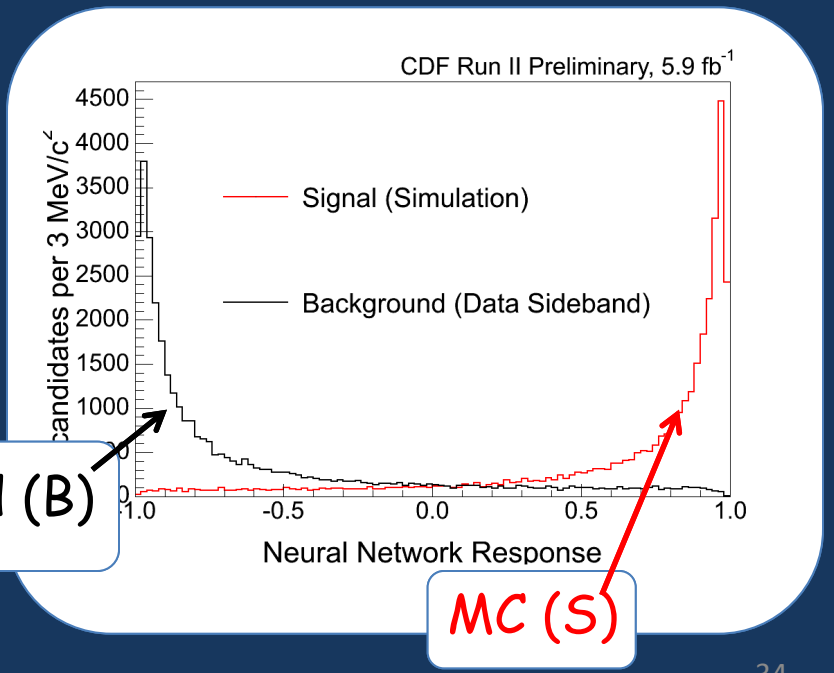
Optimization: maximize

$S/(1.5+\sqrt{B})$

$B_s^0 \to J/\psi\, K^*$: rectangular cuts

$B_s^0 \to J/\psi\, K_S$: use of NN





$B_s^0 \rightarrow J/\psi\ K^{(*)}$

Λ_b reflection removed by $\cos\theta_{K\pi} > -0.75$