B_s Decays at the Tevatron

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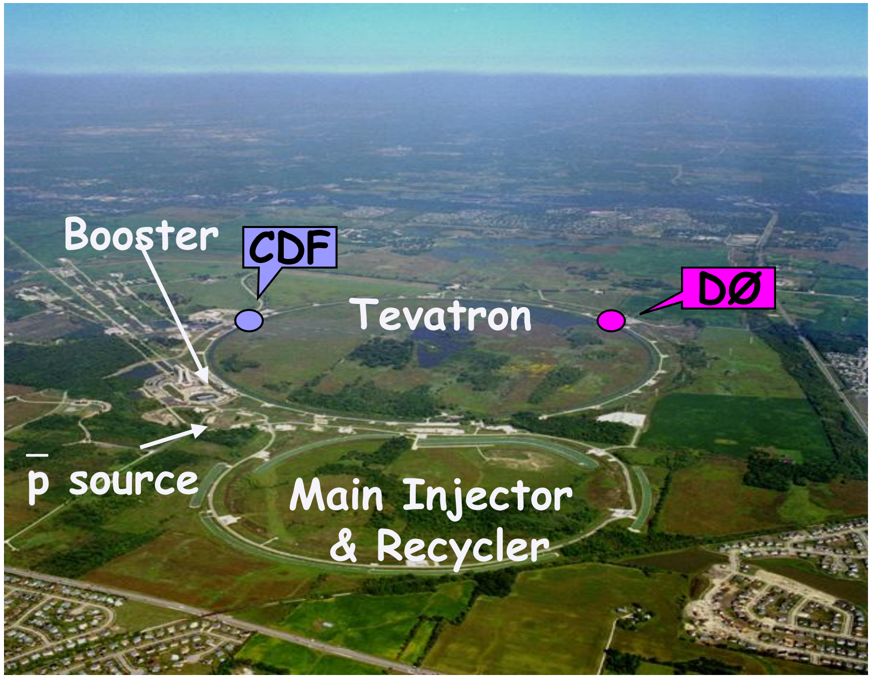
Introduction

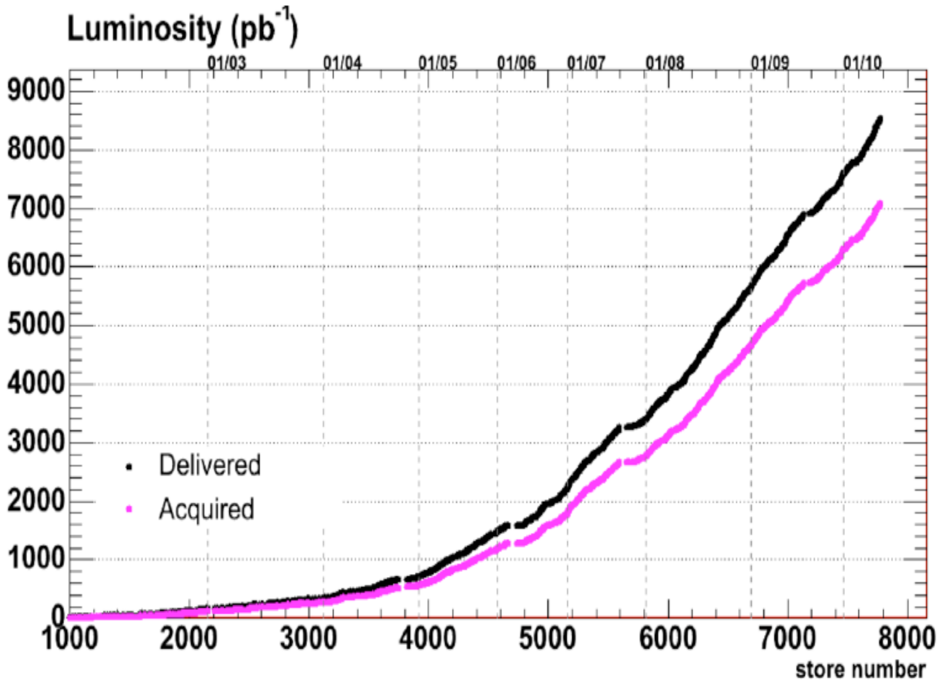
- B_s mesons were initially studied at LEP experiments and then CLEO, running at $\Upsilon(5S)$

- More recently, KEKB has been running at $\Upsilon(5S)$ as well, enabling Belle to do B_s physics

- The largest B_s samples are collected by the CDF and DØ experiments at the Fermilab

- The Tevatron has delivered 8 fb^{-1}; each experiment recorded 7 fb^{-1} on tape





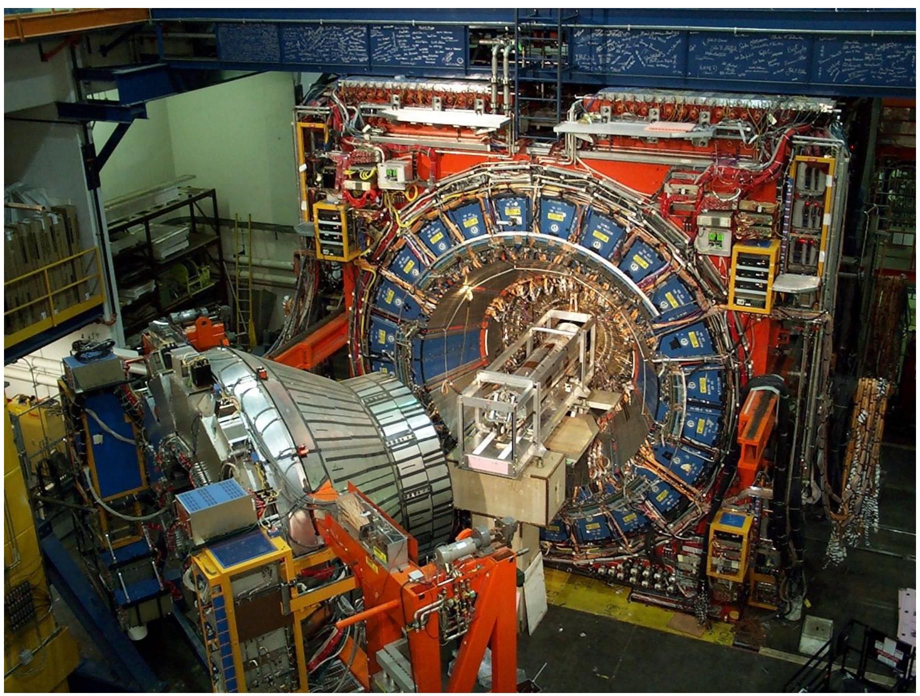
CDF II Detector

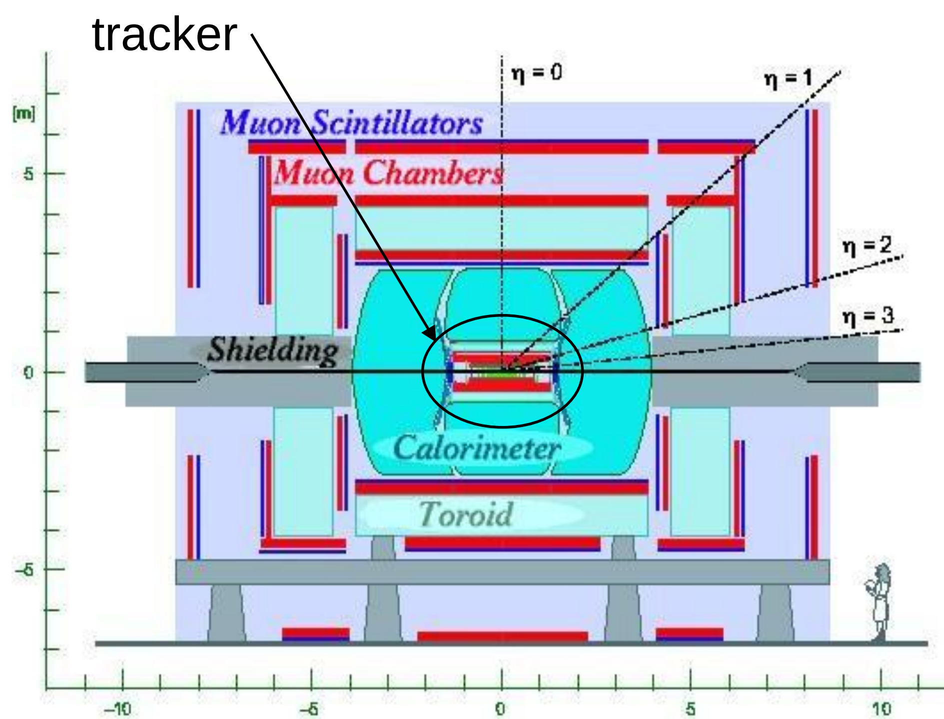
- Central tracking: - silicon vertex detector
  - drift chamber

  → excellent vertex, momentum and mass resolution
- Particle identification: dE/dX and TOF
- Electron and muon ID by calorimeters and muon chambers

DØ Detector

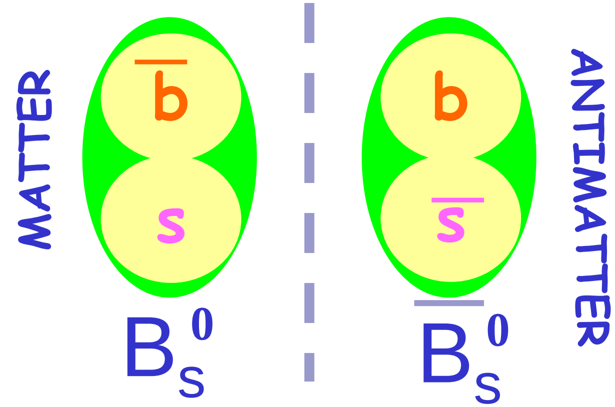
- Excellent tracking and muon coverage
- Excellent calorimetry and electron ID
- Silicon layer 0 installed in 2006 improves track parameter resolution





Neutral B_s System

- A B_s meson is a $|b\bar{s}\rangle$ state with $I(J^P) = 0(0^{-1})$
- Time evolution of B_s flavor eigenstates described by Schrodinger equation:



$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle\\|\bar{B}_s^0(t)\rangle\end{pmatrix} = \left(\mathbf{M} - \frac{i}{2}\mathbf{\Gamma}\right)\begin{pmatrix}|B_s^0(t)\rangle\\|\bar{B}_s^0(t)\rangle\end{pmatrix}$$

- Diagonalize mass (M) and decay (Γ) matrices

→ mass eigenstates :

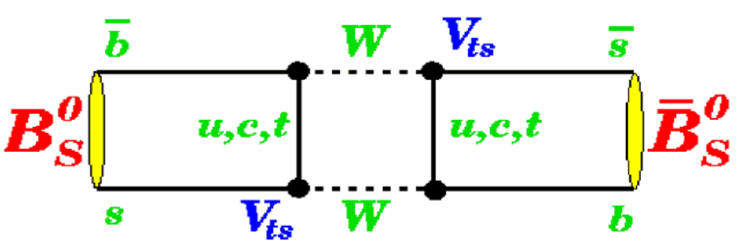
$$|B_s^H\rangle = p\,|B_s^0\rangle - q\,|\bar{B}_s^0\rangle \qquad |B_s^L\rangle = p\,|B_s^0\rangle + q\,|\bar{B}_s^0\rangle$$

- Flavor eigenstates differ from mass eigenstates and mass eigenvalues are different ($\Delta m_s = m_H - m_L \approx 2|M_{12}|$)

→ B_s oscillates with frequency Δm_s precisely measured by

CDF $\Delta m_s = 17.77 \pm 0.12\ ps^{-1}$

DØ $\Delta m_s = 18.56 \pm 0.87\ ps^{-1}$



- Mass eigenstates have different decay widths

$\Delta\Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos(\Phi_s)$ where $\phi_S^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \approx 4 \times 10^{-3}$

Recent B_s Results at the Tevatron

- Rare decays (see talk by Masato Aoki):
  - DØ: A new expected upper limit on $B(B_s \to \mu^+\mu^-)$ using 5 fb^{-1} of Run II data,
    DØ Conference Note 5906-CONF
  - CDF: Search for FCNC Rare Decay: $B_{s,d} \to \mu^+ \mu^-$, PRL 100,101802 (2008)
  - CDF: Forward-backward asymmetry in $B \to K^{(*)}\mu\mu$ and observation of $B_s \to \Phi\mu\mu$,
    Phys. Rev. D79, 011104(R) (2009)
  - CDF: Search for Lepton Flavor Violating Decays $B_{s,d} \to e\mu$, Phys. Rev. Lett. 102, 201801 (2009)

- Mixing and CP Violation (see talks by L. Oakes and A. Chandra and G. Brooijmans):
  - CDF: Calibration of the Same Side Kaon Tagger using B_s mixing,
    http://www-cdf.fnal.gov/physics/new/bottom/100204.blessed-sskt-calibration/cdf10108_ssktcalib.pdf
  - DØ and CDF: Measurements of CP Violating Phase β_s in $B_s \to J/\Psi\Phi$ Decays
  - DØ: Evidence for an anomalous like-sign di-muon charge asymmetry, arXiv:1005.xxx [hep-ex]
    http://www-d0.fnal.gov/Run2Physics/WWW/results/final/B/B10A/

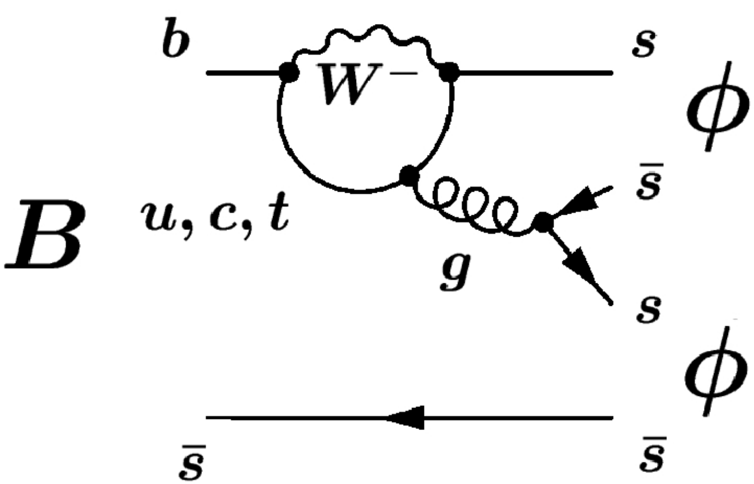
- $B_s \to \Phi\Phi$ Decays (this talk)
  - CDF: Ratio of branching fractions: $BR(B_s \to \Phi\Phi) / BR(B_s \to J/\psi\Phi)$
    http://www-cdf.fnal.gov/physics/new/bottom/090618.blessed-Bsphiphi2.9/
  - CDF: Measurement of the Polarization Amplitudes of the $B_s \to \Phi\Phi$ Decays,
    http://www-cdf.fnal.gov/physics/new/bottom/100304.blessed-Bsphiphi_amplitudes/index.html

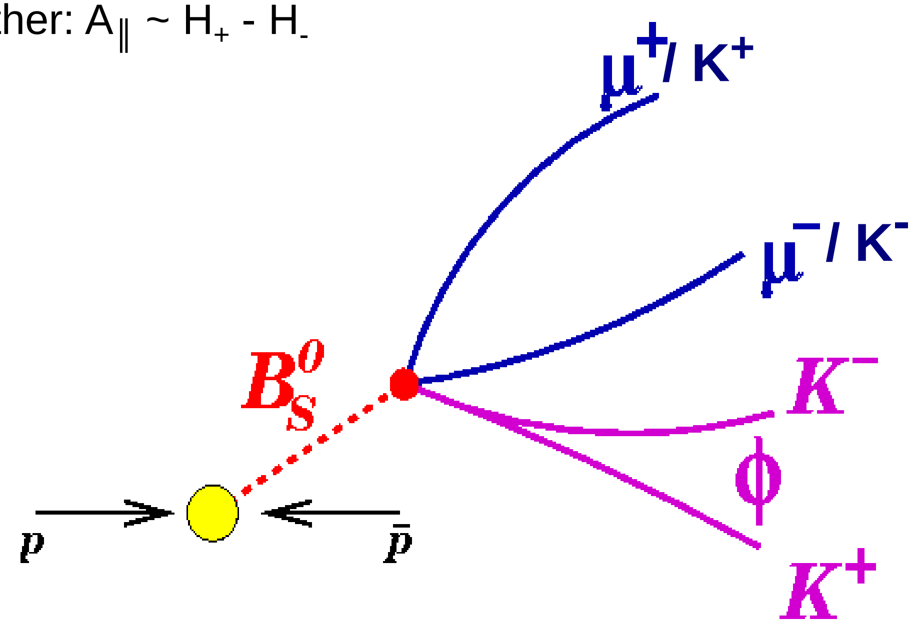
$B_s \to \Phi\Phi$ Decays

- Part of the $B \to$ *Vector Vector* decay "family"
    - initial state - a pseudo-scalar (spin 0) *B*-meson
    - final state - two light vector (spin 1) mesons

- Conservation of total angular momentum requires that the *VV* final state has orbital angular momentum of 0, 1 or 2

- Alternative bases in the angular momentum space are used to describe such decays:
    - helicity basis: each V meson can have helicity +1 (H_+), 0 (H_0) or -1 (H_-)
    - transversity basis: V meson polarizations w.r.t. direction of motion are either:
        - transverse, perpendicular to each other: $A_\perp \sim H_+ + H_-$
        - transverse, parallel to each other: $A_\parallel \sim H_+ - H_-$
        - longitudinal ($A_0 = H_0$)





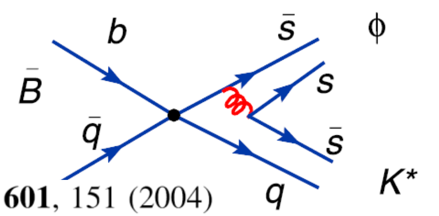
“Polarization Puzzle” and CP Violation

- “Naïve” SM analyses based on *V-A* nature of weak interactions and helicity conservation in QCD predict that longitudinal component (A_0/H_0) dominates in $B \to VV$ decays, while transverse component is suppressed by m_V / m_B

- Expectation confirmed by *B* factories in tree dominated $B \to VV$ decays but not in penguin decays like $B \to \Phi K^*$ where transverse and longitudinal components are found to of similar intensity

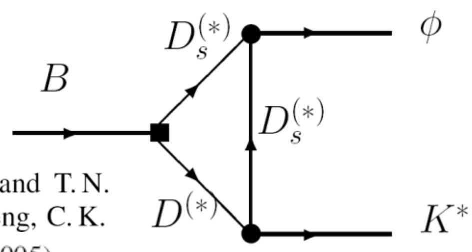
- Both new physics and SM (penguin annihilation, re-scattering) explanations proposed to explain the “polarization puzzle”

penguin annihilation:



A. L. Kagan, Phys. Lett. B **601**, 151 (2004)

re-scattering:



For example, see P. Colangelo, F. De Fazio, and T. N. Pham, Phys. Lett. B **597**, 291 (2004); H. Y. Cheng, C. K. Chua, and A. Soni, Phys. Rev. D **71**, 014030 (2005).

- Another interesting reason for studying $B_s \to \Phi\Phi$ decays is the expected negligible CP violation phase:

$$\phi_s \simeq \arg(V_{tb}V_{ts}^{\star})^2 - \arg(V_{cb}V_{cs}^{\star})^2 = 0.0041 \pm 0.0008$$

- New physics contributions (in the penguin loop) would be seen as non-zero *CP* violation phase Φ_s

$B_s \to \Phi\Phi$ Branching Ratio Measurement

- First $B_s \to \Phi\Phi$ observation and branching fraction measurements performed by CDF with 180 pb^{-1}, PRL 95 031801 2005:

- Analysis updated with 2.9 fb^{-1} collected by the CDF displaced track trigger
- Branching ratio measured relative to the better known $B_s \to J/\Psi\Phi$ decay mode (both $B_s \to \Phi\Phi$ and $B_s \to J/\Psi\Phi$ collected from displaced track trigger)

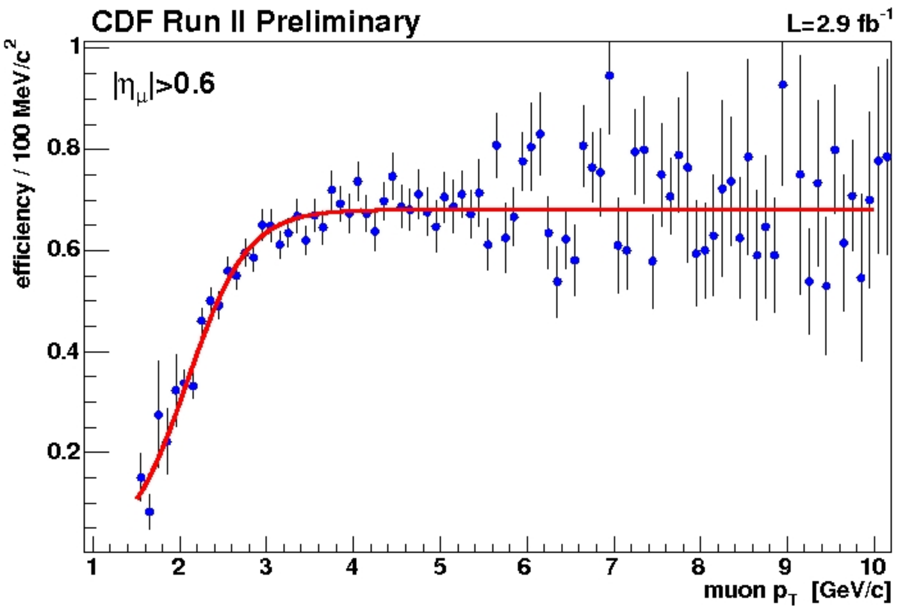
$$\frac{\mathcal{B}(B_s^0 \to \phi\phi)}{\mathcal{B}(B_s^0 \to J/\psi\ \phi)} = \frac{N_{\phi\phi}}{N_{J/\psi\phi}} \cdot \frac{\mathcal{B}(J/\psi \to \mu\mu)}{\mathcal{B}(\phi \to K^+K^-)} \cdot \frac{\varepsilon_{TOT}^{J/\psi\phi}}{\varepsilon_{TOT}^{\phi\phi}} \cdot \varepsilon_{\mu}^{TOT}$$

- $\varepsilon^{J/\Psi} / \varepsilon^{\Phi\Phi}$ reconstruction efficiency ratio determined from simulation

- To increase selection efficiency, only one muon is identified by muon chamber

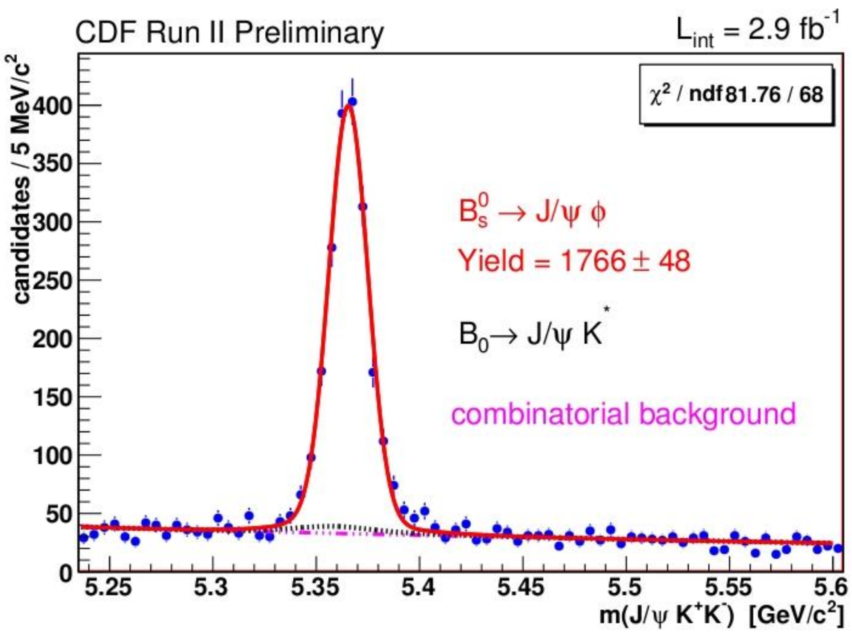
- Need to determine ε_{μ}^{TOT} muon efficiency from data by counting J/Ψ states with either one or both muons identified by muon systems

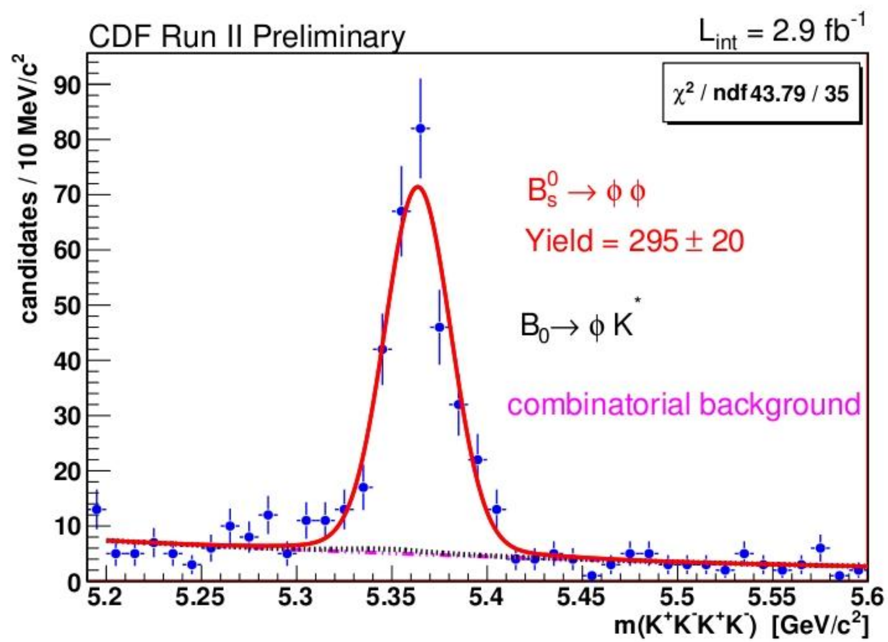
- Muon efficiencies measures as function of muon transverse momentum



$B_s \to \Phi\Phi$ and $B_s \to J/\Psi\Phi$ Signal Yields

- Reconstruct $\Phi[\to KK]\Phi[\to KK]$ and $\Phi[\to KK]J/\Psi[\to \mu\mu]$ final states
- Signal selection based on optimized requirements on kinematic and topological quantities





$B_s \to J/\Psi\Phi$ selection

Variable	Cut
L_{xy}	$> 290\ \mu m$
P_T^{ϕ}	> 1.36 GeV/c
$P_T^{J/\psi}$	> 2.0 GeV/c
χ^2_{xy}	< 18
$d_0{}^B$	$< 65\ \mu m$
confirmation of ≥ 1 muon	

$B_s \to \Phi\Phi$ selection

Variable	Cut
L_{xy}	$> 330\ \mu m$
$P_T^{K\ min}$	> 0.7 GeV/c
$d0^{\phi}_{max}$	$> 85\ \mu m$
χ^2_{xy}	< 17
$d_0{}^B$	$< 65\ \mu m$

$B_s \to \Phi\Phi$ Branching Ratio Results

- Signal yields: $N_{\phi\phi} = 295 \pm 20(\text{stat}) \pm 12(\text{syst})$ $N_{J/\psi\phi} = 1766 \pm 48(\text{stat}) \pm 41(\text{syst})$

$$\frac{\mathcal{B}(B_s^0 \to \phi\phi)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = [1.78 \pm 0.14(stat) \pm 0.20(syst)] \cdot 10^{-2}$$

$$\mathcal{B}(B_s^0 \to \phi\phi) = [2.40 \pm 0.21(stat) \pm 0.27(syst) \pm 0.82(BR)] \cdot 10^{-5}$$

- Compared to the 180 fb^{-1} result: BR($B_s \to \Phi\Phi$) = (1.4 ± 0.6(stat.) ± 0.2(syst.) ± 0.5(BR))x10^{-5}
- Main systematic uncertainties from polarization amplitudes
- Comparison with theoretical calculations (from LHCb public note 2007-047):

http://www-cdf.fnal.gov/physics/new/bottom/090618.blessed-Bsphiphi2.9/lhcb-2007-047.pdf

	BR[10^{-6}]	f_L	Γ_T/Γ [%]	Comments	Reference
Experiment	14^{+6}_{-5}(stat.) ± 6(syst.)	—	—		[4]
QCD Factorisation	$21.8^{+1.1+30.4}_{-1.1-17.0}$	43^{+0+61}_{-0-34}			[5]
	$19.5^{+1.0+13.1}_{-1.0-8.0}$	48^{+0+26}_{-0-27}		WA from data [a]	
QCD Factorisation	13.1		13.4	see erratum	[6]
Naive Factorisation	9.05		11.7	see erratum	
NLO EWP [a]	6.80		13.7	T and P [b]	[7]
	5.20		13.7	T, P and EWP [b]	
Factorization	0.37 — 25.1			Range	[8]

[a] WA stands for "Weak Annhilation".
[b] T, P and EWP stand for "Tree", "Penguin" and "Electroweak Penguin",

[4] D. Acosta *et al.*, Phys. Rev. Lett. **95**, 031801 (2005).

[5] M. Beneke *et al.*, hep-ph/0612290.

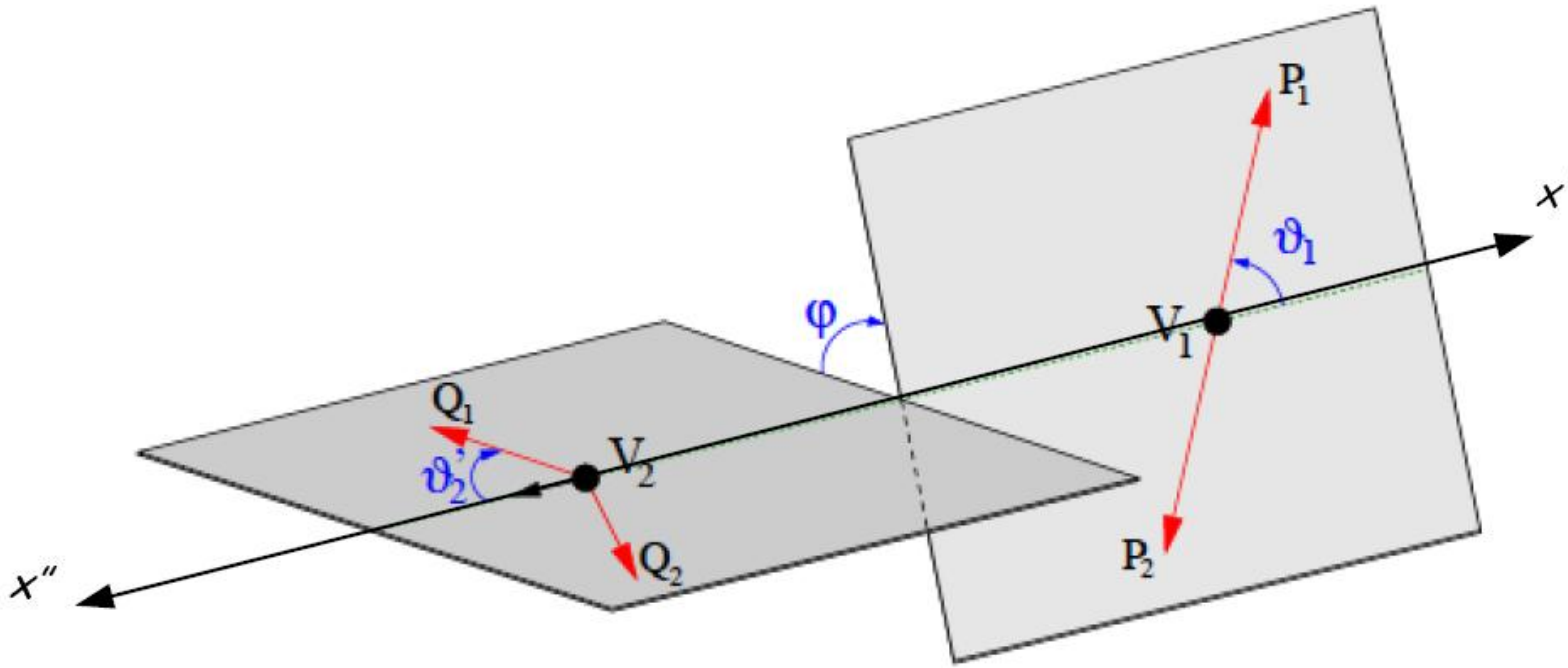
[6] X. Li *et al.*, Phys. Rev. **D68**, 114015 (2003); Erratum-ibid. **D71**, 019902 (2005 ph/0309136.

[7] D. Du and L. Guo, J. Phys. G: Nucl. Part. Phys. **23**, 525 (1997).

[8] Y.H. Chen *et al.*, Phys. Rev. **D59**, 074003 (1999).

Decay Angles in Helicity Basis

- Angles θ_1 and θ_2 are polar angles of positive kaons in each Φ rest frame
- φ is angle between two KK decay planes



$B_s \to \Phi\Phi$ Polarization Measurement

- Polarization measurement performed
  - without attempting to identify B_s flavor at production (un-tagged analysis) and
  - assuming CP violation phase $\Phi_s = 0$

- Decay rate

$$\frac{d^4\Lambda(\vec{\omega},t)}{dt d\vec{\omega}} = \frac{9}{32\pi}\sum_{i=1}^{6} K_i(t) f_i(\vec{\omega})$$

in helicity basis:

$$f_1(\vec{\omega}) = 4\cos^2\vartheta_1\cos^2\vartheta_2$$
$$f_2(\vec{\omega}) = \sin^2\vartheta_1\sin^2\vartheta_2(1+\cos 2\Phi)$$
$$f_3(\vec{\omega}) = \sin^2\vartheta_1\sin^2\vartheta_2(1-\cos 2\Phi)$$
$$f_4(\vec{\omega}) = -2\sin^2\vartheta_1\sin^2\vartheta_2\sin 2\Phi$$
$$f_5(\vec{\omega}) = \sqrt{2}\sin 2\vartheta_1\sin 2\vartheta_2\cos\Phi$$
$$f_6(\vec{\omega}) = -\sqrt{2}\sin 2\vartheta_1\sin 2\vartheta_2\sin\Phi$$

- After time integration:

$$g_s^{(\omega)} = \frac{d^3\Lambda(\vec{\omega})}{d\vec{\omega}} = \frac{9}{32\pi}\frac{1}{\tilde{W}}\left[\tilde{\mathcal{F}}_e(\vec{\omega}) + \tilde{\mathcal{F}}_o(\vec{\omega})\right]$$

where:

$$\tilde{\mathcal{F}}_e = \frac{2}{\Gamma_L}\left[|A_0|^2 f_1(\vec{\omega}) + |A_\parallel|^2 f_2(\vec{\omega}) + |A_0||A_\parallel|\cos\delta_\parallel f_5(\vec{\omega})\right]$$

$$\tilde{\mathcal{F}}_o = \frac{2}{\Gamma_H}|A_\perp|^2 f_3(\vec{\omega})$$

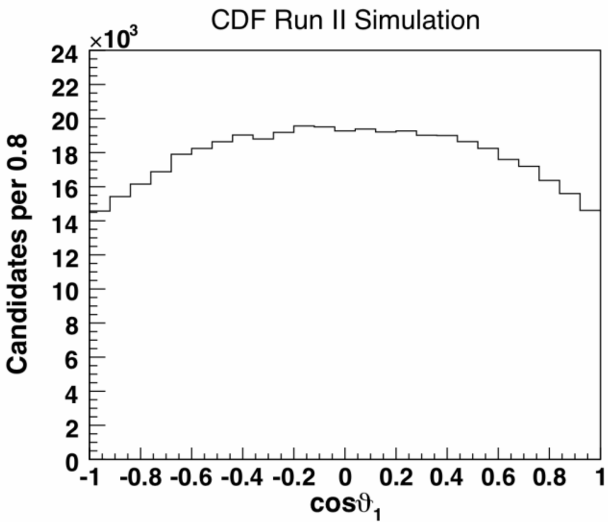
$$\tilde{W} = \frac{|A_0|^2 + |A_\parallel|^2}{\Gamma_L} + \frac{|A_\perp|^2}{\Gamma_H}$$

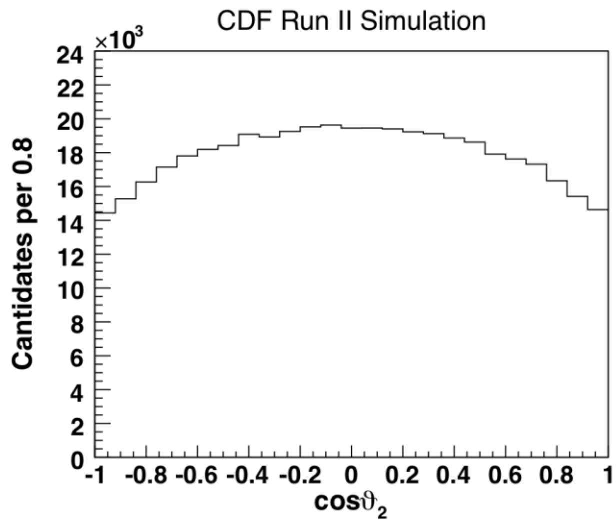
$$\delta_\parallel = \arg(A_0^\star A_\parallel)$$
$$\delta_\perp = \arg(A_0^\star A_\perp)$$

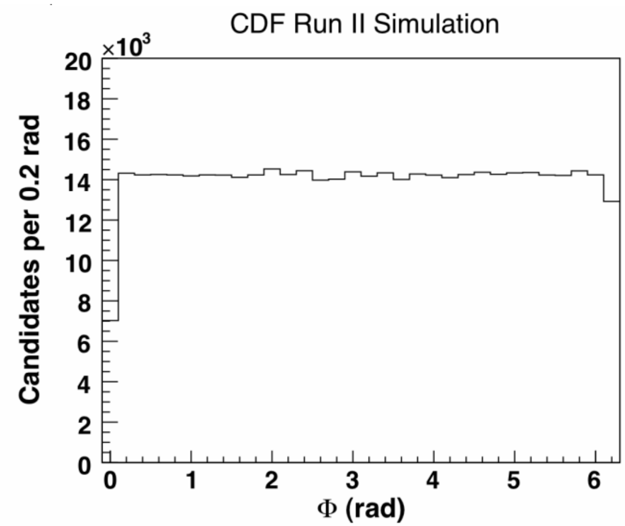
OBSERVABLES ($|A_0|^2$, $|A_\parallel|^2$, $|A_\perp|^2$, $\delta_\parallel$)

Angular Acceptance and Background Distributions

- Detector acceptance sculpts angular distributions
    - Acceptance function determined from simulation

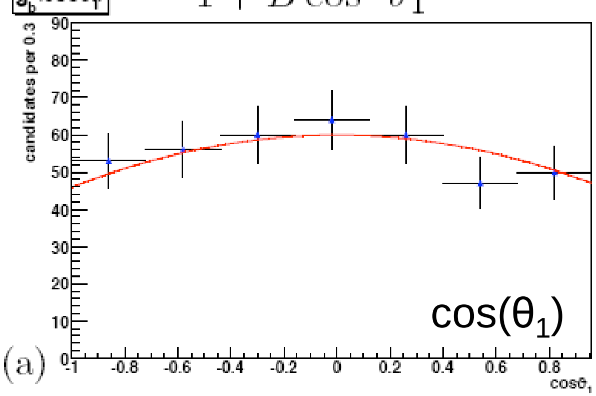




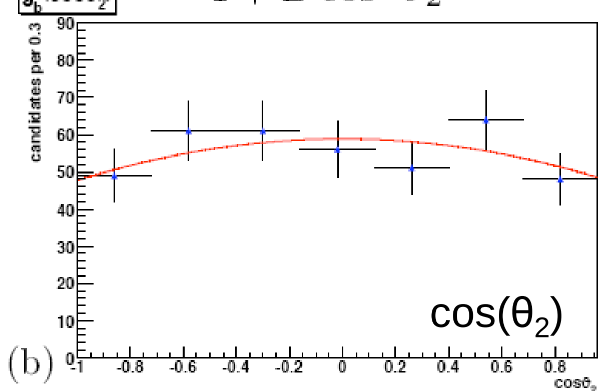


- Background distributions (from B_s mass sidebands) consistent with acceptance functions:

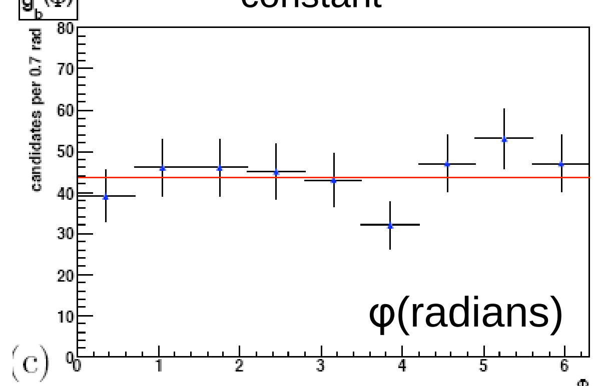
$1 + B\cos^2\vartheta_1$



$1 + B\cos^2\vartheta_2$



constant



Systematic Uncertainties

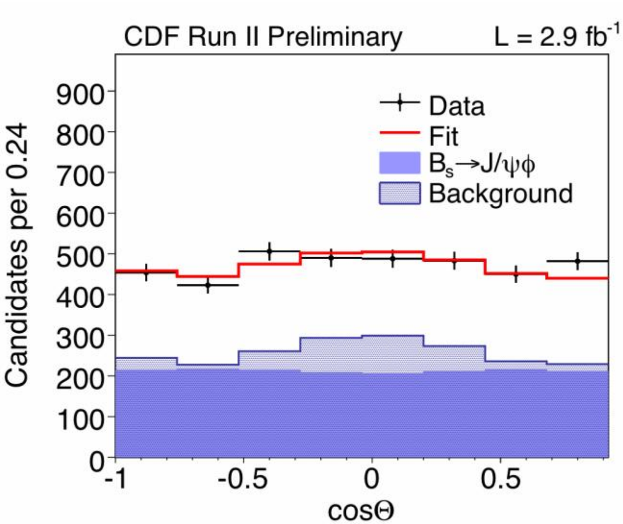
- The largest systematic uncertainties come from:
  - possible s-wave contributions like $B_s \to \Phi f^0$ *or* $B_s \to \Phi(KK)^{non\text{-}resonant}$
  - assumptions on heavy and light lifetimes and their effect on polarization via the lifetime dependent trigger acceptance

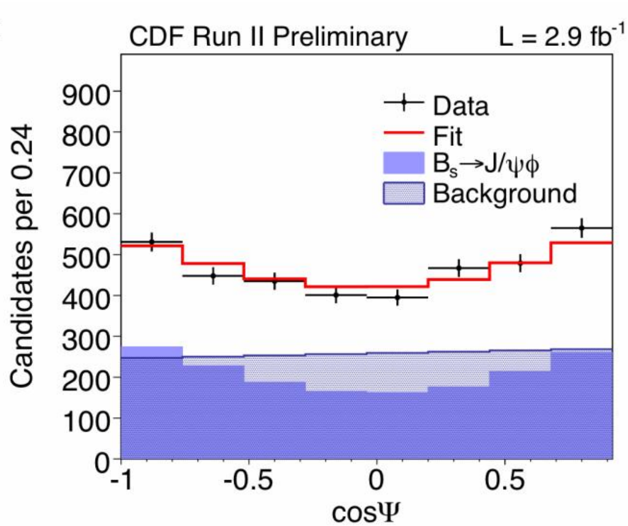
	$\|A_0\|^2$ syst	$\|A_\parallel\|^2$ syst	$\|A_\perp\|^2$ syst	$\cos\delta_\parallel$ syst
MC reweight	±0.003	±0.001	±0.002	±0.007
Acceptance binning	±0.001	±0.001	±0.000	±0.004
Acceptance Model	±0.005	±0.002	±0.003	±0.005
Background Model	±0.001	±0.001	±0.002	±0.009
Acceptance *ct*-dependence	±0.000	±0.001	±0.001	±0.004
Reflection component	±0.008	±0.002	±0.006	±0.019
Non-resonant contribution	±0.013	±0.003	±0.010	±0.084
Satellite peak	±0.004	±0.000	±0.004	±0.020
Acceptance $\Delta\Gamma$-dependence	±0.009	±0.009	±0.016	±0.011
$\tau_{L(H)}$ uncertainties	±0.008	±0.006	±0.017	
CP-violation	±0.002	±0.001	±0.003	±0.009
total	±0.021	±0.011	±0.027	±0.090

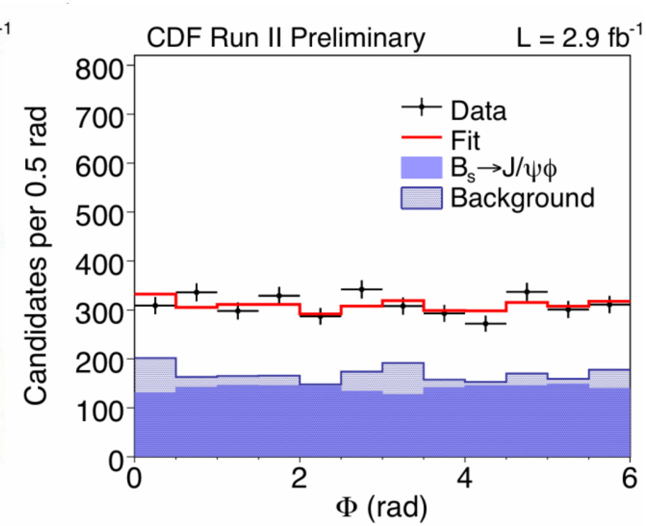
Analysis Cross-Check with $B_s \rightarrow J/\Psi\Phi$ Decays

- In same $B_s \rightarrow J/\Psi\Phi$ sample used for branching ratio analysis measure polarization in $B_s \rightarrow J/\Psi\Phi$ decays
- Analysis performed in transversity basis
- Assume no CP violation: $\beta_s = 0$
- Angular acceptance determined from simulation as in the $B_s \rightarrow \Phi\Phi$ case
- Compared to CDF measurement from di-muon trigger with 5.2 fb^{-1} (see talk by Louise Oakes) and DØ measurement with 2.8 fb^{-1}(Phys.Rev.Lett.102:032001,2009)

	CDF displaced track trigger: *this measurement*	CDF di-muon trigger (5.2 fb^{-1}): *see talk by Louise Oakes*	DØ (2.8 fb^{-1}): *Phys.Rev.Lett.102:032001,2009*
$\lvert A_0\rvert^2$	0.534 ± 0.019	0.523 ± 0.012 (stat) ± 0.014 (syst.)	0.555 ± 0.027
$\lvert A_\parallel\rvert^2$	0.220 ± 0.025	0.232 ± 0.014 (stat) ± 0.014 (syst.)	0.244 ± 0.032





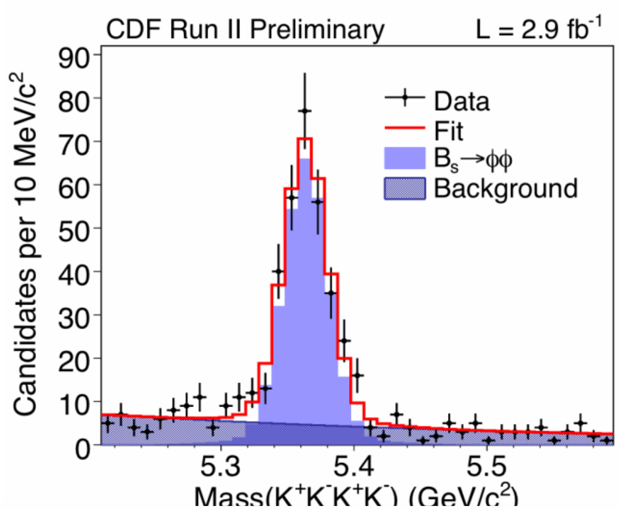


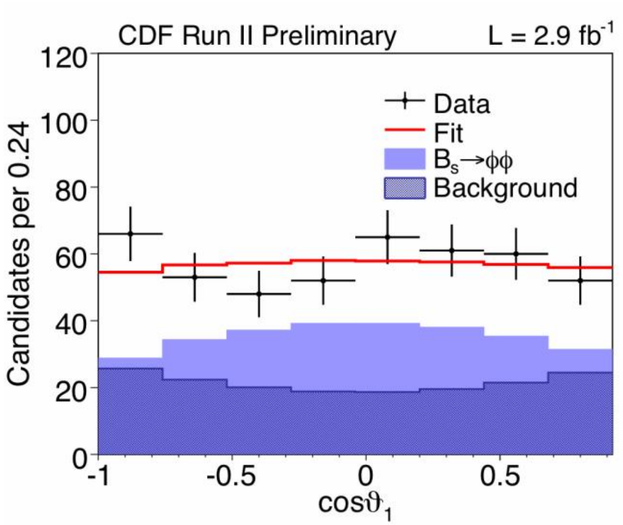
$B_s \to \Phi\Phi$ Fit Projections and Results

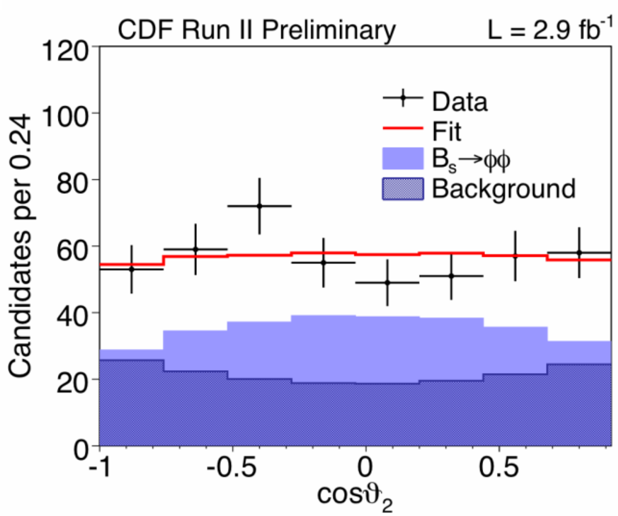
$$
\begin{aligned}
|A_0|^2 &= 0.348 \pm 0.041(\text{stat}) \pm 0.021(\text{syst}) \\
|A_\parallel|^2 &= 0.287 \pm 0.043(\text{stat}) \pm 0.011(\text{syst}) \\
|A_\perp|^2 &= 0.365 \pm 0.044(\text{stat}) \pm 0.027(\text{syst}) \\
\cos\delta_\parallel &= -0.91^{+0.15(\text{stat})+0.09(\text{syst})}_{-0.13(\text{stat})-0.09(\text{syst})}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

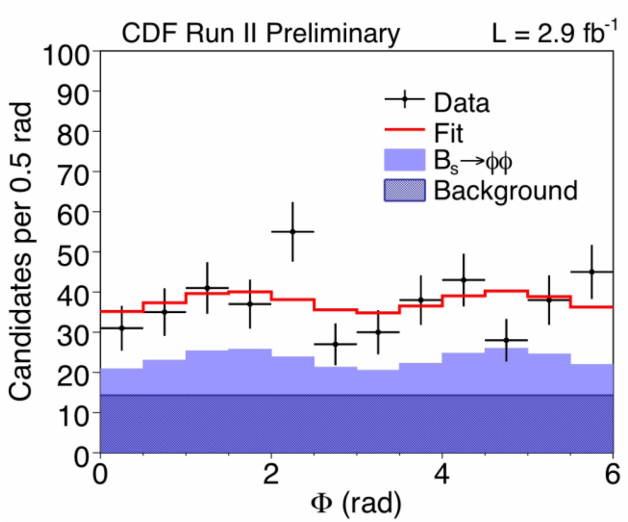
f_L = 0.348±0.041 (stat) ±0.021 (syst)

f_T = 0.652±0.041 (stat) ±0.021 (syst)









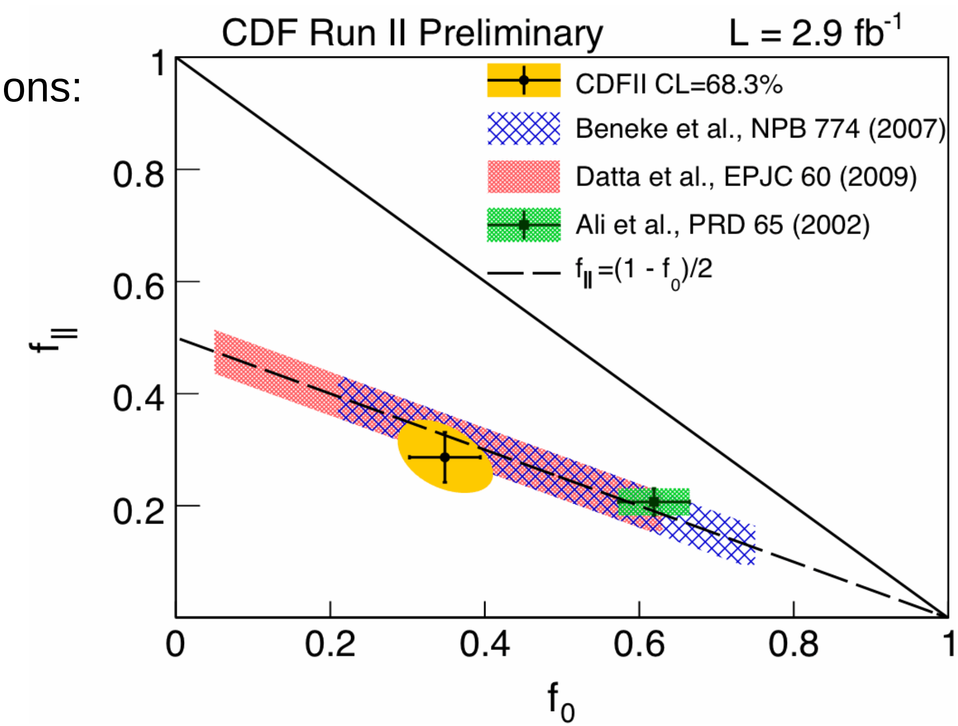
Remarks

- Naïve SM hierarchy $|A_0| \gg |A_{\|}| \simeq |A_{\perp}|$ not satisfied in $B_s \rightarrow \Phi\Phi$

- Instead, we observe $|A_0| \simeq |A_{\perp}| \gtrsim |A_{\|}|$

- Longitudinal polarization fraction $f_L \approx 0.35$ smaller than transverse component $f_T \approx 0.65$ different than:
  - SM expectation that transverse component is suppressed by m_{Φ}/m_{Bs}
  - $B^+ \rightarrow \Phi K^{*+}$ (f_L = 0.50 +/- 0.05) and $B^0 \rightarrow \Phi K^{*0}$ (f_L = 0.484 +/- 0.033)

- Comparison with theoretical predictions:



Conclusions and Outlook

- First measurement of the polarization amplitudes in $B_s \rightarrow \Phi\Phi$ decays performed at the Tevatron by the CDF experiment using 2.9 fb^{-1} of data:

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

- Already 7 fb^{-1} of data on tape and about 10 fb^{-1} expected by the end of the Tevatron running in 2011

- Expect half statistical errors with 10 fb^{-1} by end of 2011

- A time dependent analysis with 10 fb^{-1} will also measure $\Delta\Gamma_s$ in this decay mode

Backup

Backgrounds

- B decays mis-reconstructed as $B_s \to \Phi\Phi$ when a pion is mis-identified as a kaon:

$$B^0 \to \phi K^{*0} \to K^+K^-K^+\pi^-$$
$$B_s^0 \to \overline{K}^{*0} K^{*0} \to K^-\pi^+K^+\pi^-$$

- Estimated as:

$$N(B^0 \to \phi K^*) = \frac{f_d}{f_s}\frac{\mathcal{B}(B^0 \to \phi K^{*0})}{\mathcal{B}(B_s^0 \to J/\psi\phi)}\frac{\mathcal{B}(K^{*0} \to K^+\pi^-)}{\mathcal{B}(J/\psi \to \mu\mu)}\frac{\varepsilon^{\phi K^*}(\phi\phi)}{\varepsilon^{J/\psi\phi}} N(B_s^0 \to J/\psi\phi)$$

$$N(B_s^0 \to \overline{K^{*0}} K^{*0}) = \frac{\mathcal{B}(B_s^0 \to \overline{K^{*0}} K^*)}{\mathcal{B}(B_s^0 \to J/\psi\phi)}\frac{\mathcal{B}(K^{*0} \to K^+\pi^-)}{\mathcal{B}(J/\psi \to \mu\mu)}\frac{\mathcal{B}(K^{*0} \to K^+\pi^-)}{\mathcal{B}(\phi \to K^+K^-)}\frac{\varepsilon^{\overline{K^*}K^*}(\phi\phi)}{\varepsilon^{J/\psi\phi}} \cdot N(B_s^0 \to J/\psi\phi)$$

reflection	$\varepsilon(\phi\phi)$	number of events
$B_s^0 \to \bar{K}^{*0} K^{*0}$	$\sim 10^{-6}$	0
$B^0 \to \phi K^{*0}$	$(0.0134 \pm 0.0002)\%$	8 ± 3

- $B^0 \to J/\Psi\, K^{*0}$ decays mis-reconstructed as $B_s \to J/\Psi\Phi$ decays

$$f_{J/\psi K^{*0}} = \frac{f_d}{f_s}\frac{\mathcal{B}(B^0 \to J/\psi K^{*0})}{\mathcal{B}(B_s^0 \to J/\psi\phi)}\frac{\mathcal{B}(K^{*0} \to K^+\pi^-)}{\mathcal{B}(\phi \to K^+K^-)}\frac{\varepsilon^{J/\psi K^{*0}}(J/\psi\phi)}{\varepsilon^{J/\psi\phi}} = 0.0419 \pm 0.0093$$

Comparison with theoretical predictions:

	f_L[%]	f_T[%]
CDFII experimental result 2.9 fb-1	34.8±4.1(stat.)±2.1(syst.)	65.2±4.1(stat.)±2.1(syst.)
QCD factorization (2009)	34 ±28	66±28

A. Datta, D. London, J. Matias, M. Nagashimaand A. Szynkman, **Final-state Polarization in B^0_s Decays**, arXiv:hep-ph/0802.0897v2

	f_L[%]	f_T[%]
QCD factorization 1.a (2007)	$43 \pm 0^{+61}_{-34}$	$57 \pm 0^{+61}_{-34}$
QCD factorization 1.b (2007)	$48 \pm 0^{+26}_{-27}$	$52 \pm 0^{+26}_{-27}$

M. Beneke, J. Rohrerand and D. Yang, **Branching fractions, polarization and asymmetries of B→VV decays.**
Nuclear physics B,vol. 774(Issues 1-3):pgs.64-101,9 July 2007 or arXiv:hep-ph/0612290v2

	f_L[%]	f_T[%]
QCD factorization 2	86.6	13.4
NAIVE factorization	88.3	11.7

X. Li, G. Lu and Y. Yang,**Charmless B→VV decays in QCD Factorization.** *Phys. Rev. D* 71, 019902(E) (2005)

	f_L[%]	f_T[%]
NLO EWP 1	86.3	13.7
NLO EWP 2	86.3	13.7

D. Du and L. Guo, **Electroweak penguin contributions in charmless B→VV decays beyond leading logarithms**, *J.Phys.G 23, 525.(1997)*

	f_L[%]	f_T[%]
Perturbative QCD (2002)	$61.9^{+3.6+2.5}_{-3.2-3.3}$	$38.1^{+3.6+2.5}_{-3.2-3.3}$

A. Ali, G. Kramer, Y. Li, C. Lu, Y. L. Shen, W. Wang and Y. Wang, **Charmless nonleptonic B0s decays to PP, PV and VV final state in the pQCD approach.** *Phys. Rev. D 76, 074018 (2007)*