Analysis of $B_s^0 \longrightarrow \phi\phi$ decay mode

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CDF ITALY

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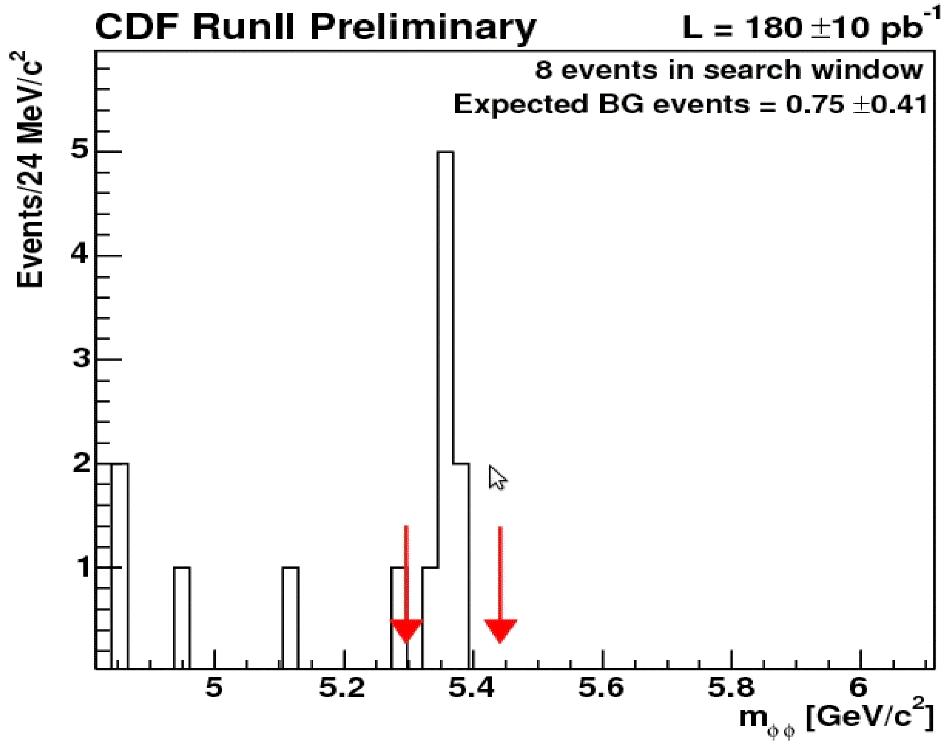
INTRODUCTION

The $B_s^0 \to \phi\phi$ decay was observed for the first time by CDFII in 2005:
D.Acosta et al. (CDF Collaboration), Phys. Rev. Lett. 95,031801 (2005).

Using 180 pb-1 of data available at that time 8 events where observed.



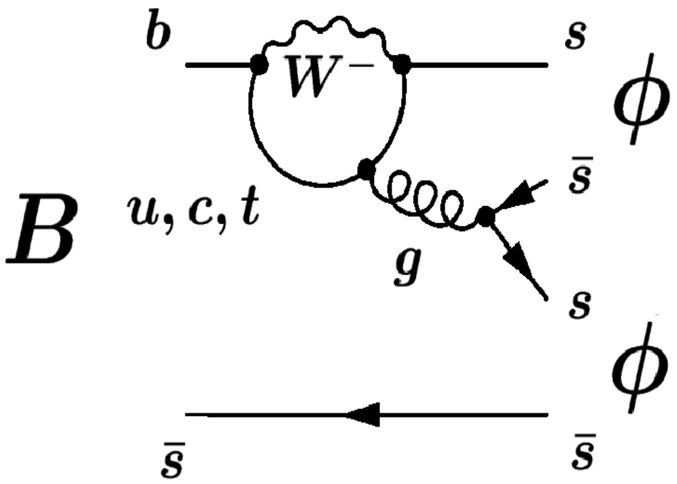
Now this measurement was done using 2.9 fb-1 of data available at CDFII (2002-up to April 2008).

OUTLINE

1) Motivation.
2) Theoretical predictions:
   the polarization puzzle.
3) Analysis strategy.
4) Signal selection.
5) Background evaluation.
6) Branching ratio measurement.
7) Conclusions and perspectives.

MOTIVATION

The $B_s^0 \to \phi\,\phi$ is a vector vector decay mode



The dominant decay element

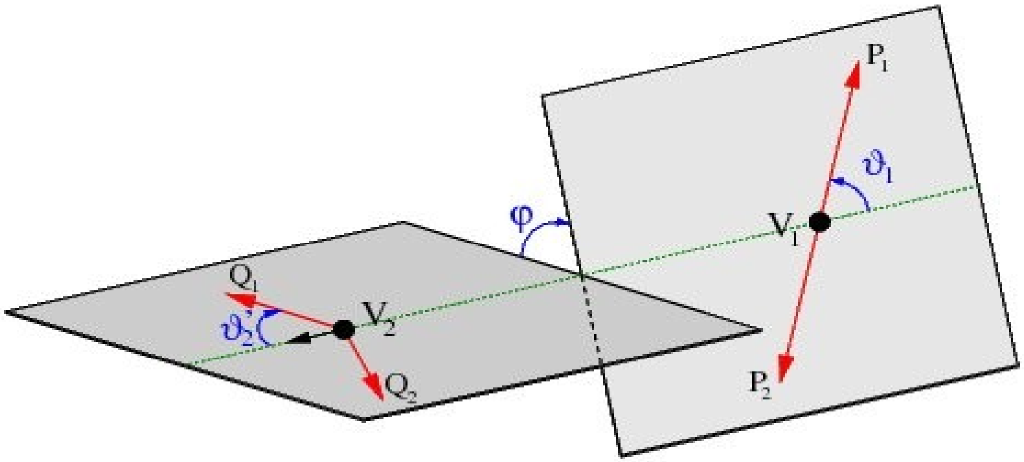
is the penguin $b \to s\,\bar{s}\,s$

The final state is self - conjugate.
It can be used to measure $\Delta\Gamma_s$, CKM studies,
and test of decay polarization prediction.

MOTIVATION

The relation between differential cross-section and the observable angular distribution in the B meson and V rest frame using a helicity basis is:

$$\frac{d\Gamma_{B\to V_1 V_2 \to \dots}}{d\cos\vartheta_1 d\cos\vartheta_2 d\varphi} \propto |\mathcal{A}_0|^2 \cos^2\vartheta_1 \cos^2\vartheta_2 + \frac{1}{4}\sin^2\vartheta_1 \sin^2\vartheta_2 \left(|\mathcal{A}_+|^2 + |\mathcal{A}_-|^2\right)$$
$$- \cos\vartheta_1 \sin\vartheta_1 \cos\vartheta_2 \sin\vartheta_2 \left[\mathrm{Re}\left(e^{-i\varphi}\mathcal{A}_0\mathcal{A}_+^*\right) + \mathrm{Re}\left(e^{+i\varphi}\mathcal{A}_0\mathcal{A}_-^*\right)\right]$$
$$+ \frac{1}{2}\sin^2\vartheta_1 \sin^2\vartheta_2 \,\mathrm{Re}\left(e^{2i\varphi}\mathcal{A}_+\mathcal{A}_-^*\right),$$



MOTIVATION

In Experimental analyses, observables are preferably defined in terms of the transversity as they have definite CP transformation properties. A typcal set of observable consists of the brancing fraction, two out of the three polarization fractions f_L, $f_{\|}$, $f_{\perp}$, and two phases $\phi_{\|}$, $\phi_{\perp}$, where

$$f^B_{L,\|,\perp} = \frac{|\mathcal{A}_{0,\|,\perp}|^2}{|\mathcal{A}_0|^2+|\mathcal{A}_{\|}|^2+|\mathcal{A}_{\perp}|^2}; \quad \phi^B_{\|,\perp} = arg\frac{\mathcal{A}_{\|,\perp}}{\mathcal{A}_0}$$

and naively, within the Standard Model, one expects

$$\frac{f_T}{f_L} \propto \frac{m_V}{m_B}$$

Polarization puzzle

Within the standard model one expect:

$$\frac{f_T}{f_L} \propto \frac{m_V}{m_B}$$

And for the $B_s^0 \to \phi\phi$ decay: $\frac{f_T}{f_L} \propto \frac{1020}{5369}$

However it was observed in some decays, for example

$B \to \varphi K^*$ and $B \to \rho K^*$

that this relation is not valid

Babar collaboration : hep-hex: 0705.1798 :
f_T =0.21+-0.05+-0.02 f_L=0.49+-0.05+-0.03

Polarization puzzle

Explanations of this puzzle inside the SM are in:

Ali & Kramer hep-ph/070316: on recent BR and polarization prediction in the pertubative QCD approach.

Fleisher & Gronau in hep-ph/07094013

Some of them predict the Branching ratio too:

	$BR[10^{-6}]$
QCD Factorisation	$21.8^{+1.1+30.4}_{-1.1-17.0}$ $19.5^{+1.0+13.1}_{-1.0-8.0}$
QCD Factorisation Naive Factorisation	13.1 9.05

M. Beneke et al., hep-hex/0612290.

X. Li et al. P.R.L. D.68, 114015(2003);
D71 019902(2005);
hep-hex/030936.

MEASUREMENT STRATEGY

The measurement consists in the determination of this ratio:

From MC

From PDG

From data

$$\frac{BR(B_s \mapsto \phi\phi)}{BR(B_s \mapsto J/\psi\ \phi)} = \frac{N_{\phi\phi}}{N_{J/\psi\phi}} \cdot \frac{\epsilon(B_s \mapsto J/\psi\phi)}{\epsilon(B_s \mapsto \phi\phi)} \frac{BR(J/\psi \mapsto \mu\mu)}{BR(\phi \mapsto KK)} \cdot \epsilon_\mu$$

$$\phi \rightarrow K^+K^-$$

Where

$$J/\psi \rightarrow \mu\mu$$

We have performed a normalized branching ratio and not absolute because:

1) The two decays are topologically very similar.

2) In the ratio we can simplify a lot of sistematics.

Selection Optimization

In order to choice the variables to be used in the event selection and select the best interval values of this variables, we followed the procedure of the "maximization of the score function" $\frac{S}{\sqrt{(S+B)}}$

$B_s \longrightarrow \phi\phi$

Variable	cut
L_{xy}	$> 330\mu m$
$\mathrm{P}_T^{K\ min}$	> 0.7 GeV/c
χ^2_{xy}	< 17
d0(B)	$< 65\mu m$
$d0^{\phi}_{max}$	$> 85\mu m$

$B_s \longrightarrow J/\psi\phi$

Variable	cut
L_{xy}	$> 290\mu m$
P_T^{ϕ}	> 1.4 GeV/c
χ^2_{xy}	< 15
d0(B)	$< 80\mu m$
$P_T^{J/\psi}$	> 2.0 GeV/c

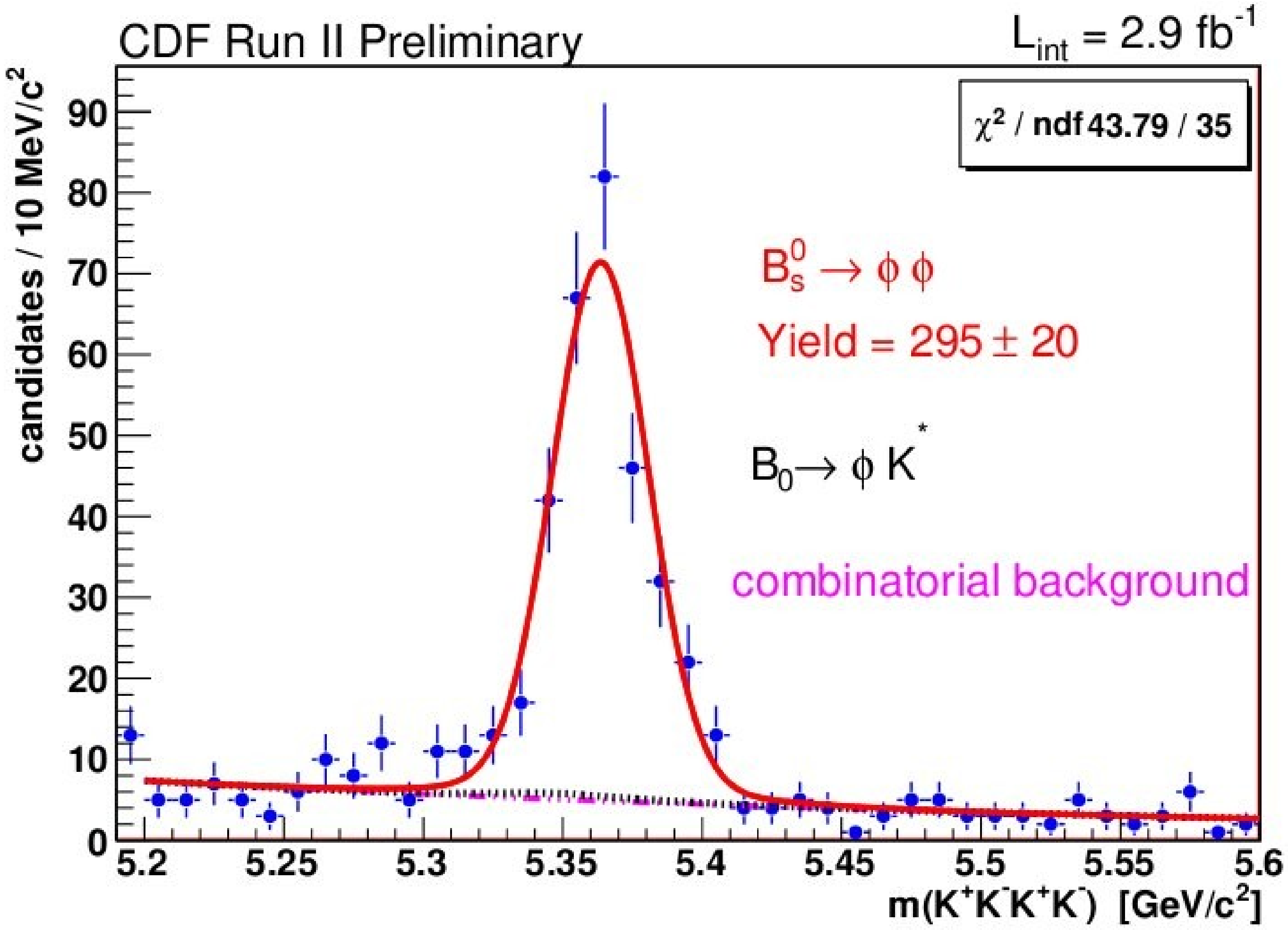
Backgrounds

Expected background are:

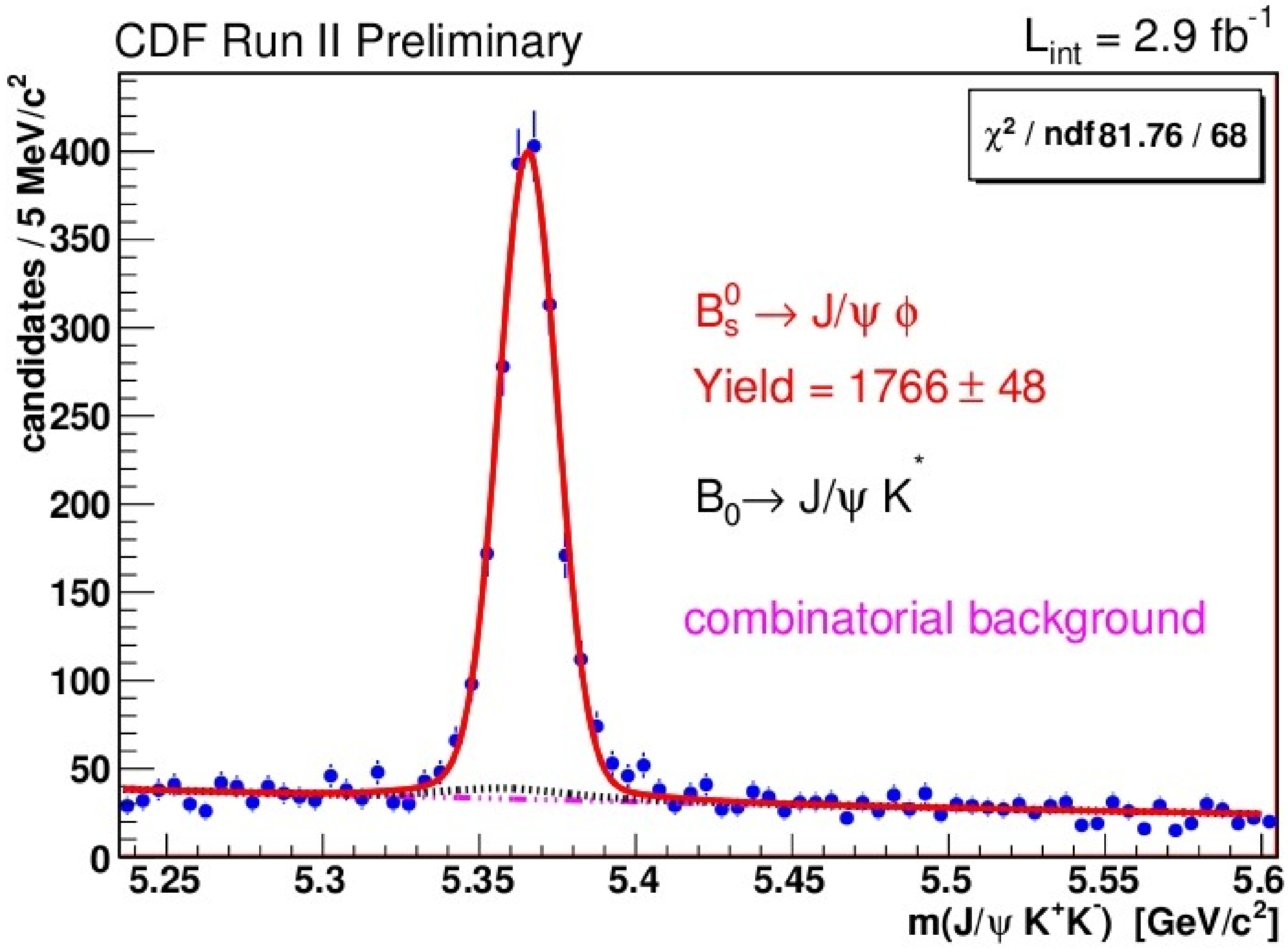
- combinatorics (expected smooth function);
- decays not correctly reconstructed (reflections) peaking under the signal:
- for $B_s \longrightarrow J/\psi\phi$:
  - $B_d \longrightarrow J/\psi K^*$ ~ 4.2 % of the signal
- for $B_s \longrightarrow \phi\phi$:
  - $B_d \longrightarrow \phi K^*$ ~ 2.7 % of the signal
  - $B_s \longrightarrow \overline{K}^* K^*$ ~ 0 % of the signal

The reflections were evaluated using Monte Carlo sample

Selected events



Selected events



Efficiencies

Evaluated using MC

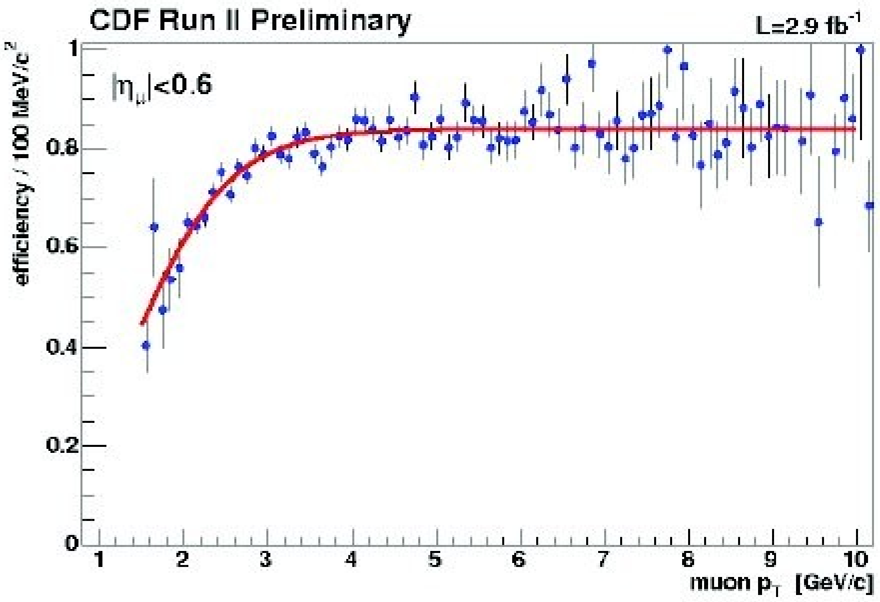
$$\frac{BR(B_s \mapsto \phi\phi)}{BR(B_s \mapsto J/\psi\ \phi)} = \frac{N_{\phi\phi}}{N_{J/\psi\phi}} \cdot \frac{\epsilon(B_s \mapsto J/\psi\phi)}{\epsilon(B_s \mapsto \phi\phi)} \cdot \frac{BR(J/\psi \mapsto \mu\mu)}{BR(\phi \mapsto KK)} \cdot \epsilon_\mu$$

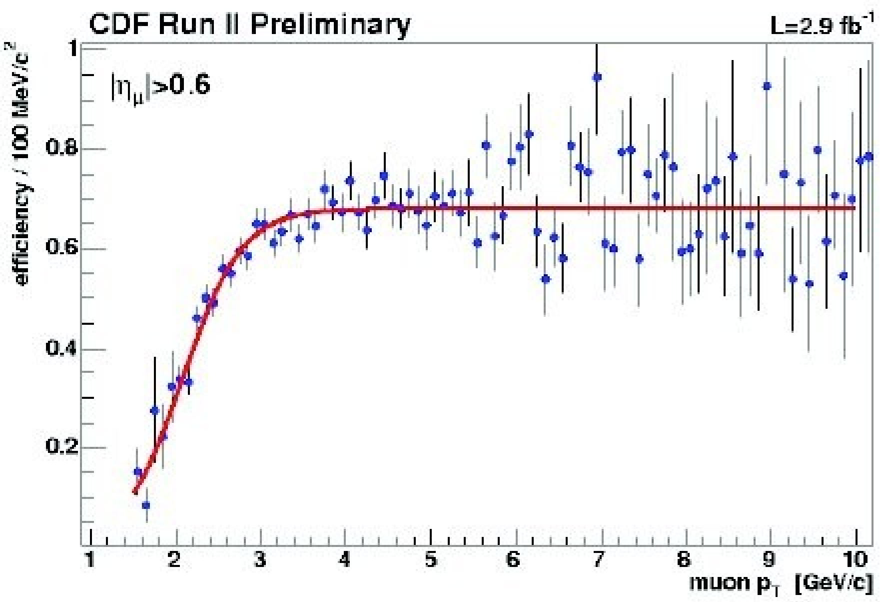
Evaluated on data

Efficiencies

$$\frac{\epsilon_{\psi\phi}}{\epsilon_{\phi\phi}} = 0.939 \pm 0.030 \pm 0.009$$

$$\epsilon^{\mu}_{\psi\phi} = 0.8695 \pm 0.0044(\mathrm{stat})$$





Systematics Evaluation

We evaluated systematic uncertainty:

- due to different parametrization:
  - change in fit range ⇒ take into account possible structures below the mass peak due to unknown partially reconstructed
  - using one gaussian instead of two for the signal
- change in background subtraction ⇒ driven by $B_s \to J/\psi\phi$
- due to effect not simulated in MonteCarlo used for example:
  - the polarization

BR result

The result is:

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

$$\mathrm{BR}(B_s^0 \rightarrow \phi\phi) = [24.0 \pm 2.1(stat) \pm 2.7(syst) \pm 8.2(BR)]10^{-6}$$

BR result

$$BR(B_s^0 \to \phi\phi) = [24.0 \pm 2.1(stat) \pm 2.7(syst) \pm 8.2(BR)]10^{-6}$$

	$BR[10^{-6}]$
Experiment	$14^{+6}_{-5}(\text{stat.}) \pm 6(\text{syst.})$
QCD Factorisation	$21.8^{+1.1+30.4}_{-1.1-17.0}$ $19.5^{+1.0+13.1}_{-1.0-8.0}$
QCD Factorisation Naive Factorisation	13.1 9.05

Conclusion and perspectives

1) The final result is in agrement with SM prediction.

2) Error is dominated by Jpsi/Phi Branching ratio error

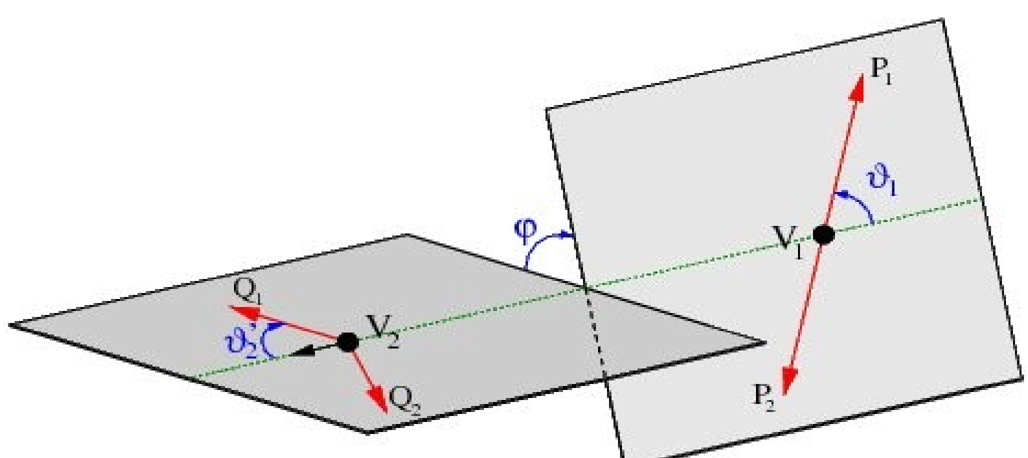
3) The sample selected allow to polarization studies

Backup slides

The Bs->VV decays

The relation between differential cross-section and the observable angular distribution in the B meson rest frame is :

$$\frac{d\Gamma_{B\to V_1V_2\to\ldots}}{d\cos\vartheta_1 d\cos\vartheta_2 d\varphi} \propto |\mathcal{A}_0|^2\cos^2\vartheta_1\cos^2\vartheta_2 + \frac{1}{4}\sin^2\vartheta_1\sin^2\vartheta_2\left(|\mathcal{A}_+|^2+|\mathcal{A}_-|^2\right)$$
$$-\cos\vartheta_1\sin\vartheta_1\cos\vartheta_2\sin\vartheta_2\left[\mathrm{Re}\left(\mathrm{e}^{-i\varphi}\mathcal{A}_0\mathcal{A}_+^*\right)+\mathrm{Re}\left(\mathrm{e}^{+i\varphi}\mathcal{A}_0\mathcal{A}_-^*\right)\right]$$
$$+\frac{1}{2}\sin^2\vartheta_1\sin^2\vartheta_2\,\mathrm{Re}\left(\mathrm{e}^{2i\varphi}\mathcal{A}_+\mathcal{A}_-^*\right),$$



The Bs->VV decays

Considering a B meson with four-momentum p_B decaying into light vector mesons $V_1(p_1, \eta^*)$, $V_2(p_2, \epsilon^*)$, with masses $m_{1,2}$ of order Λ_{QCD}, the decay amplitude can be decomposed into three scalar amplitude $S_{1,2,3}$ according to

$$\mathcal{A}_{B\to V_1 V_2} = i\eta^{*\mu}\epsilon^{*\nu}\left(S_1 g_{\mu\nu} - S_2 \frac{p_{B_\mu} p_{B_\nu}}{m_B^2} + S_3 i\epsilon_{\mu\nu\rho\sigma}\frac{p_1^\rho p_2^\sigma}{p_1 \cdot p_2}\right),$$

or alternatively an helicity basis can be defined as :

$$\begin{aligned}
\mathcal{A}_0 &= \mathcal{A}\left(B \to V_1(p_1, \eta_0^*) V_2(p_2, \epsilon_0^*)\right) = \frac{i m_B^2}{2 m_1 m_2}\left(S_1 - \frac{S_2}{2}\right), \\
\mathcal{A}_\pm &= \mathcal{A}\left(B \to V_1(p_1, \eta_\pm^*) V_2(p_2, \epsilon_\pm^*)\right) = i\left(S_1 \mp S_2\right),
\end{aligned}$$

or a transversity amplitude basis can be defined using $\mathcal{A}_L = \mathcal{A}_0$, and replacing $\mathcal{A}_\pm$ with

$$\begin{aligned}
\mathcal{A}_\parallel &= \frac{(\mathcal{A}_+ + \mathcal{A}_-)}{\sqrt{2}} \\
\mathcal{A}_\perp &= \frac{(\mathcal{A}_+ - \mathcal{A}_-)}{\sqrt{2}}
\end{aligned}$$

The Bs->VV decays

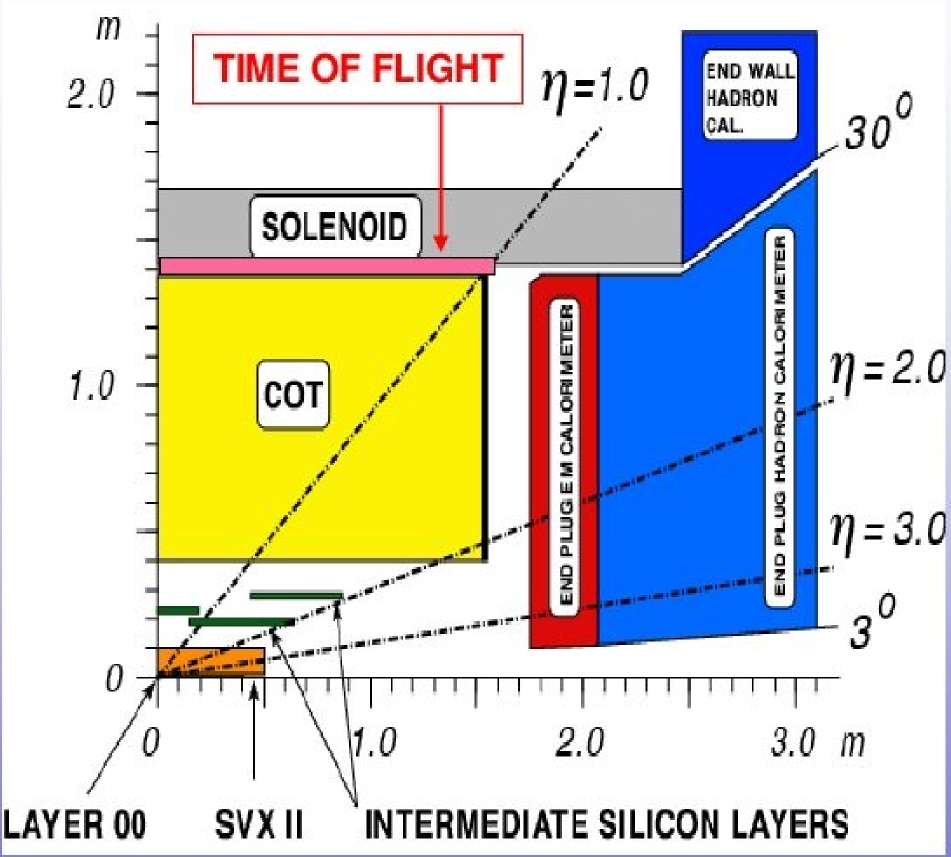
In Experimental analyses, observables are preferably defined in terms of the transversity as they have definite CP transformation properties. A typcal set of observable consists of the brancing fraction, two out of the three polarization fractions f_L, $f_{||}$, $f_\perp$, and two phases $\phi_{||}$, $\phi_\perp$, where

$$f^B_{L,||,\perp} = \frac{|\mathcal{A}_{0,||,\perp}|^2}{|\mathcal{A}_0|^2+|\mathcal{A}_{||}|^2+|\mathcal{A}_\perp|^2}; \quad \phi^B_{||,\perp} = arg\frac{\mathcal{A}_{||,\perp}}{\mathcal{A}_0}$$

and naively, within the Standard Model, one expects

$$\frac{f_T}{f_L} \propto \frac{m_V}{m_B}$$

Tracking system



TOF: 100ps resolution, 2 sigma K/π separation for tracks below 1.6 GeV/c (significant improvement of B_s flavor tag effectiveness)

COT: large radius (1.4 m) Drift C.

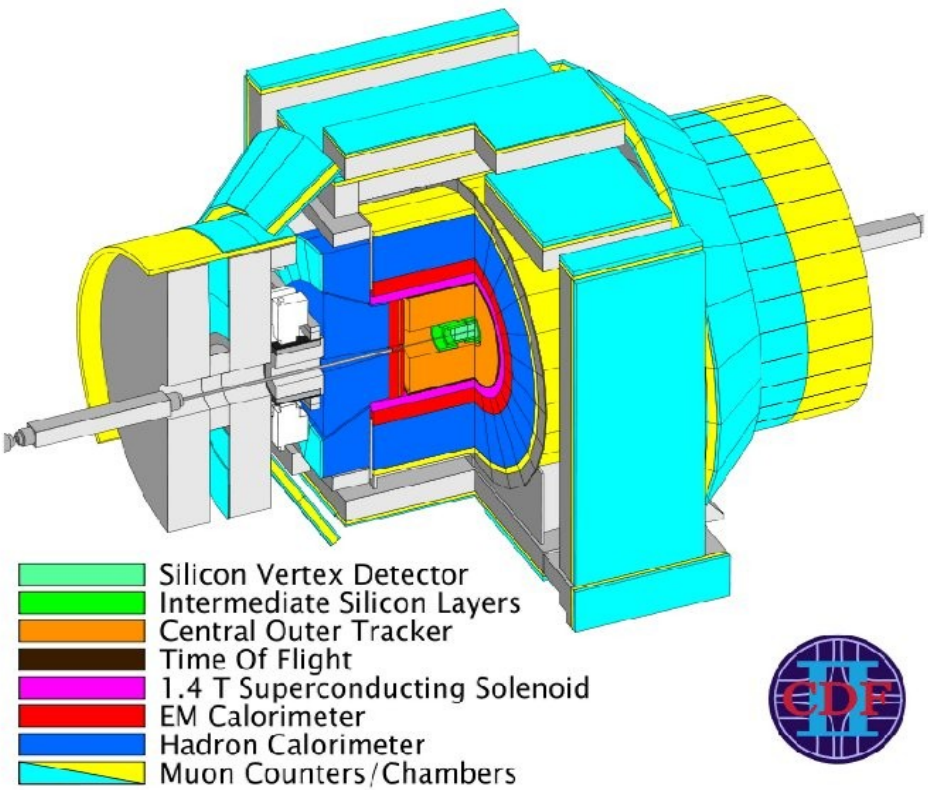
- 96 layers, 200ns drift time
- Precise P_T above 400 MeV/c
- Precise 3D tracking in $|\eta|<1$

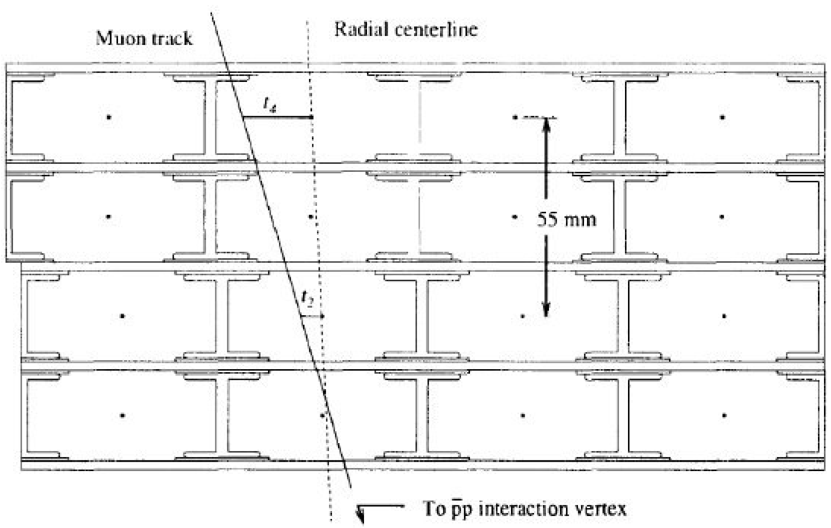
$\sigma(1/P_T)$ ~ 0.1%GeV^{-1}; σ(hit)~150μm

- dE/dx info provides >1.3 sigma K/π separation above 2 GeV

SVX-II + ISL: 6 (7) layers of double-side silicon (3cm < R < 30cm)
- Standalone 3D tracking up to $|\eta|$ = 2
- Very good I.P. resolution: ~30μm (~20 μm with Layer00)

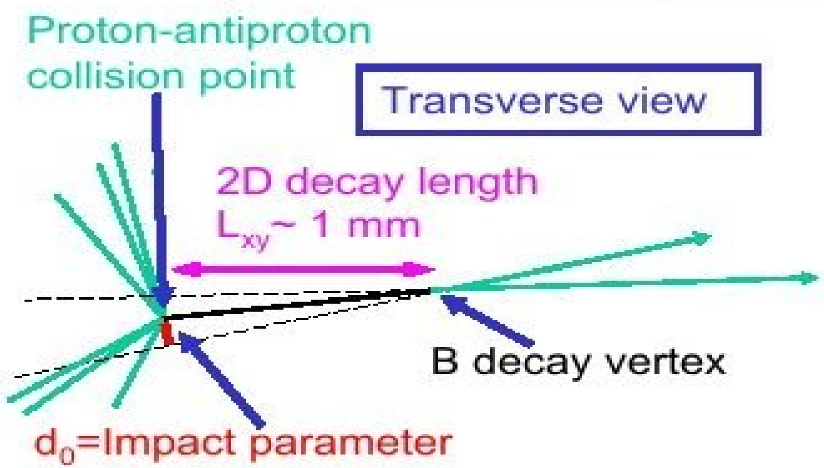
Muons detectors



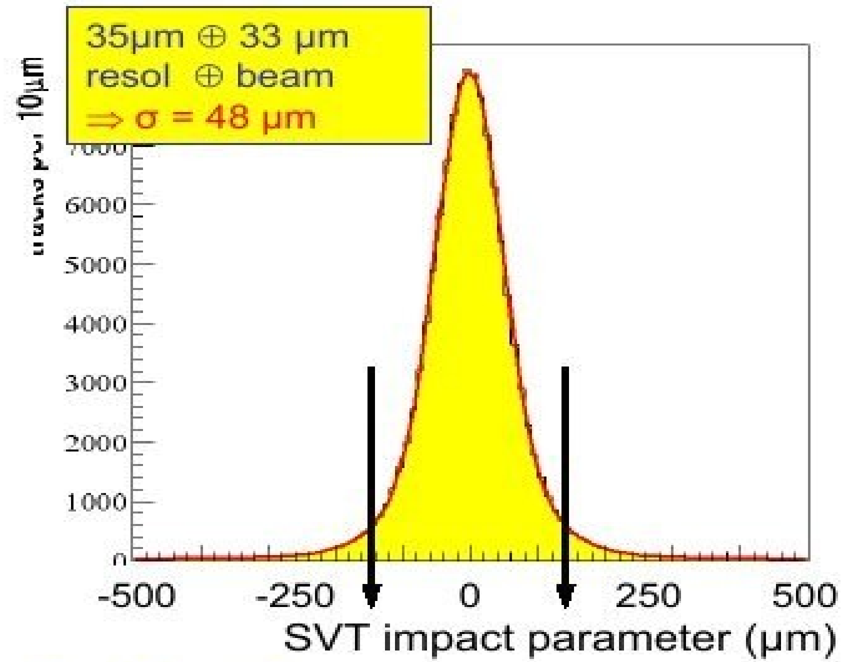


Relevants detector elements for this analysis:

CDF Level 2 Silicon Vertex Trigger



Exploit long b, c lifetimes in Trigger!
L1 track + Si hits = Impact parameter @L2
A first at a hadron collider!
CDF is a charm/ B Factory!



Lepton (e, μ) + displaced track trigger

Lepton:p_T>4 GeV
Track: p_T>2 GeV, d_0>120 μm
Semi-leptonic B decays (B→ℓνX)

Displaced two track trigger

Tracks: p_T>2 GeV, d_0>120 μm
Σp_T>5.5 GeV
Fully hadronic B decays (B→hh', $B_s \to D_s\pi$, D→Kπ ...)

systematics

	$B_s^0 \rightarrow \phi\phi$	$B_s^0 \rightarrow J/\psi\phi$
	$\Delta N_{\phi\phi}/N_{\phi\phi}$	$\Delta N_{J/\psi\phi}/N_{J/\psi\phi}$
fit range	3%	-
signal parametrization	3%	2%
background subtraction: error on BRs	1%	1%
	$\Delta\varepsilon_{\phi\phi}/\varepsilon_{\phi\phi}$	$\Delta\varepsilon_{J/\psi\phi}/\varepsilon_{J/\psi\phi}$
polarization in MC	7%	6%
	$\Delta\varepsilon_{\phi\phi}/\varepsilon_{J/\psi\phi}$	
XFT particle dep.	4%	
p_T reweight	0.9%	
	$\Delta\varepsilon_{\mu}/\varepsilon_{\mu}$	
η parametrization & correlation	0.9%	

Table 16: *Contributions to the total relative uncertainty from the systematic uncertainty sources considered.*

MOTIVATION

Considering a B meson with four-momentum p_B decaying into light vector mesons $V_1(p_1, \eta^*)$, $V_2(p_2, \epsilon^*)$, with masses $m_{1,2}$ of order Λ_{QCD}, the decay amplitude can be decomposed into three scalar amplitude $S_{1,2,3}$ according to

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or alternatively an helicity basis can be defined as :

$$\mathcal{A}_0 = \mathcal{A}\left(B \to V_1(p_1, \eta_0^*)V_2(p_2, \epsilon_0^*)\right) = \frac{im_B^2}{2m_1 m_2}\left(S_1 - \frac{S_2}{2}\right),$$

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or a transversity amplitude basis can be defined using $\mathcal{A}_L = \mathcal{A}_0$, and replacing $\mathcal{A}_\pm$ with

$$\mathcal{A}_\parallel = \frac{(\mathcal{A}_+ + \mathcal{A}_-)}{\sqrt{2}}$$

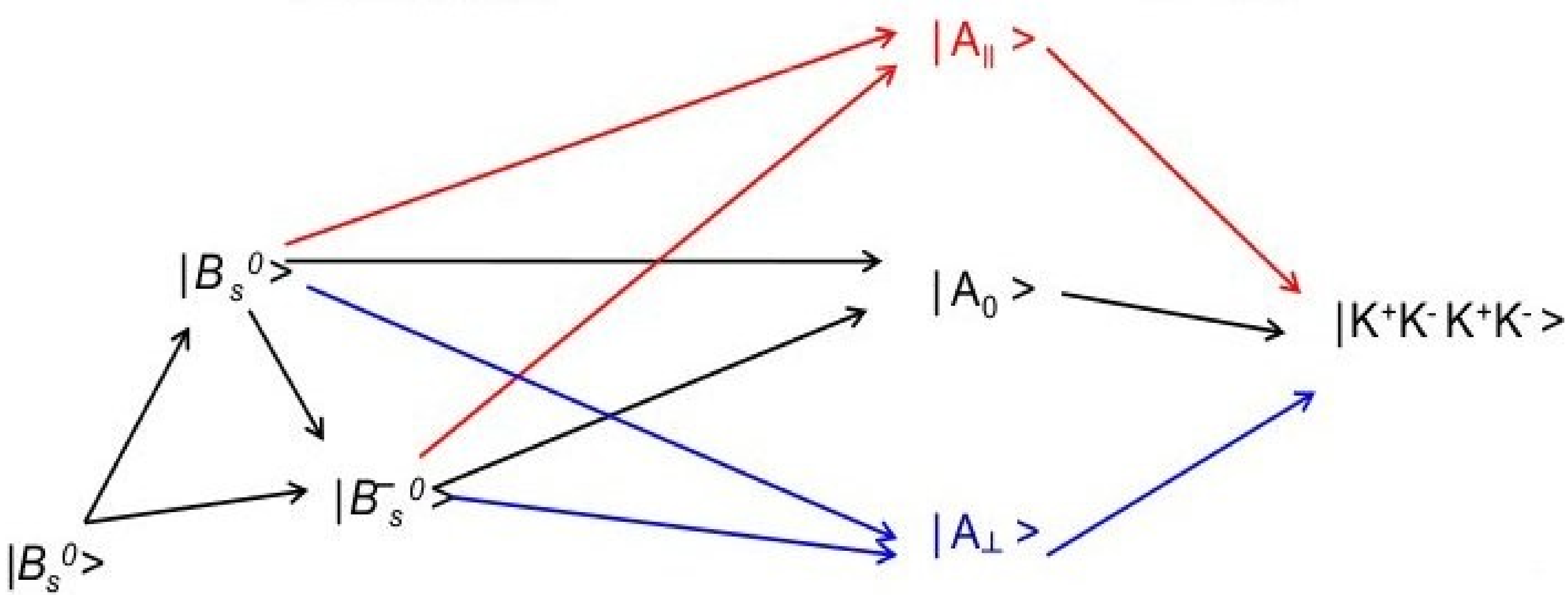
$$\mathcal{A}_\perp = \frac{(\mathcal{A}_+ - \mathcal{A}_-)}{\sqrt{2}}$$

MOTIVATION

In the trasversity basis the amplitudes have defined CP value:

Corresponding decay amplitudes: A_0, $A_\parallel$, $A_\perp$

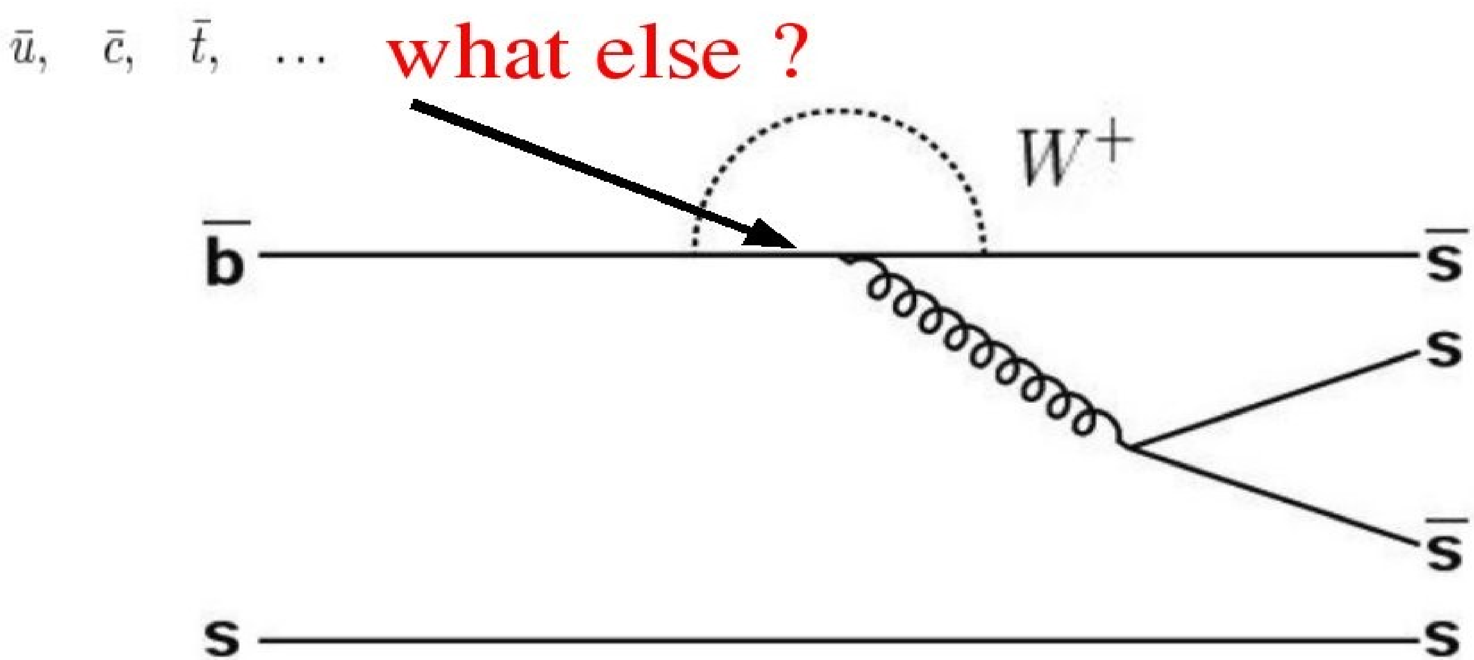
- transverse ($\perp$ perpendicular to each other) $\rightarrow$ CP odd
- transverse ($\parallel$ parallel to each other) $\rightarrow$ CP even
- longitudinal (0) $\rightarrow$ CP even



Polarization puzzle

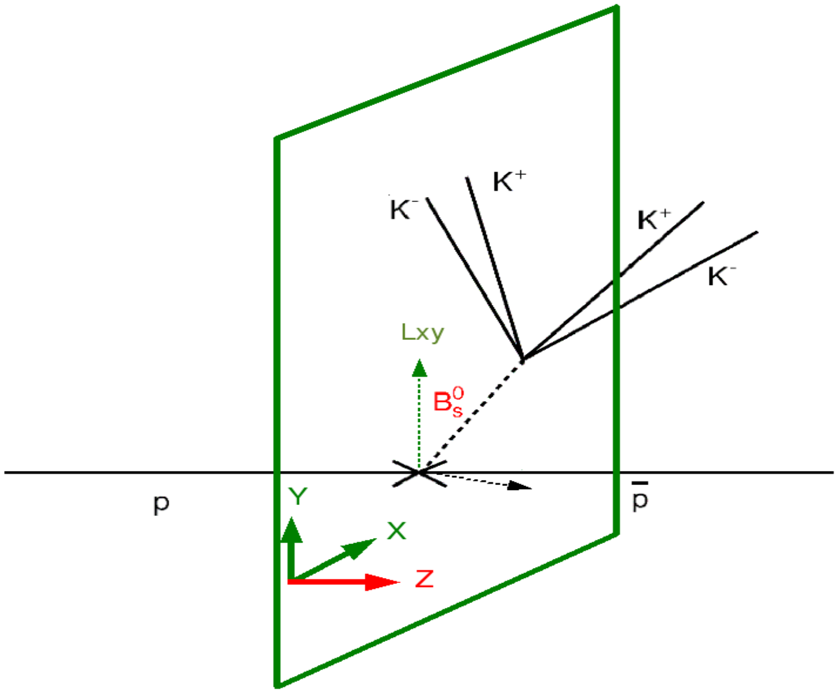
This result, known also as “Polarization Puzzle”, is more evident in the B meson decays involving penguin diagram decays. Different solutions were proposed for this “puzzle”, beyond and inside the Standard Model.

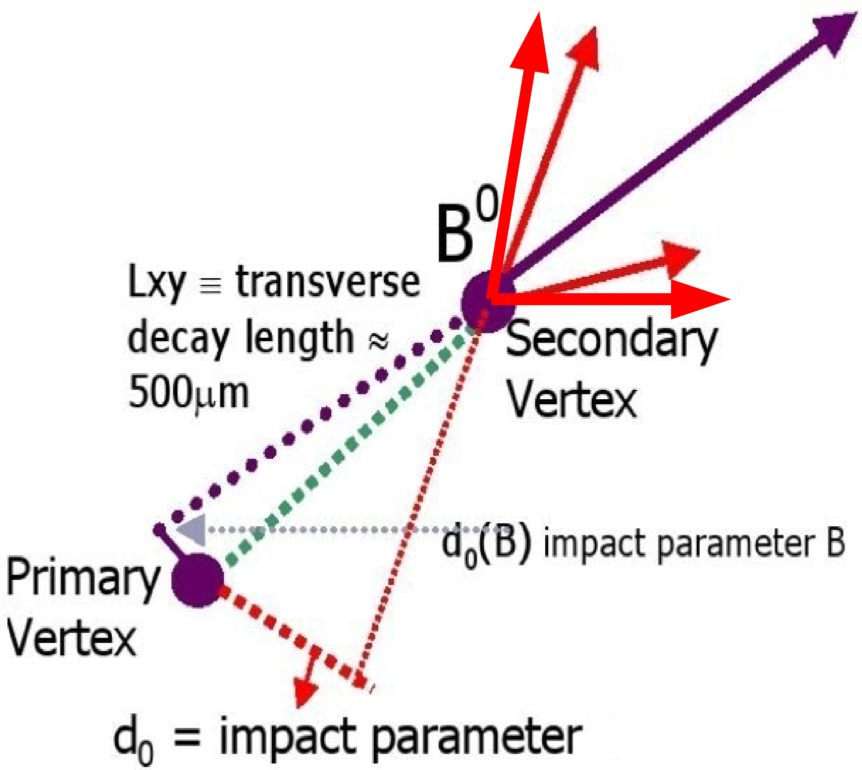
One solution beyond the SM could be New Physics inside the penguin loop:
(Grossman hep-ph/03110229; Yang et al. hep-ph/0411211)



Event signature

The events are caracterized by 4 charged particle in the final state





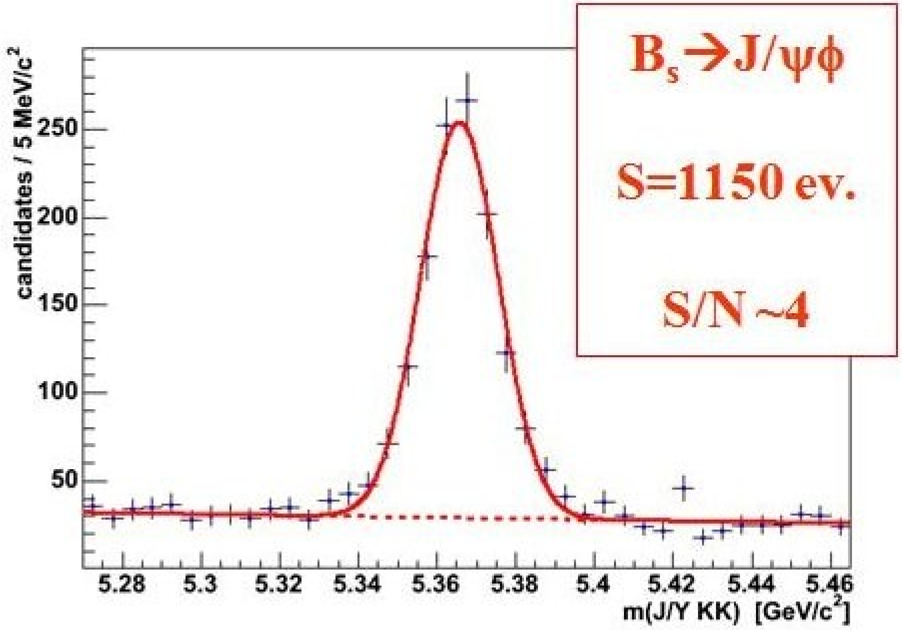
Optimization Selection procedure

Event selection is performed using the following variables

- transverse momentum of the B meson: p_T^B;
- transverse decay length of the B meson: L_{xy};
- impact parameter of the B meson: d_0^B;
- impact parameter of the more energetic ϕ: $d0_{max}^{\phi}$;
- impact parameter of the less energetic ϕ: $d0_{min}^{\phi}$;
- transverse momentum of the J/ψ: $p_T^{J/\psi}$;
- transverse momentum of the less energetic kaon from ϕ decay: p_T^K;
- the bi-dimensional χ^2 of the primary vertex fit: χ^2_{xy}.

Selected events

Additing more trigger restriction:



These events are only in the trigger sample we used in this analysis (TwoTrackTrigger), not in the samples used for other J/psi phi measurements (DI_MUON Trigger)

Systematics Evaluation

	$B_s^0 \to \phi\phi$	$B_s^0 \to J/\psi\phi$
	$\Delta N_{\phi\phi}/N_{\phi\phi}$	$\Delta N_{J/\psi\phi}/N_{J/\psi\phi}$
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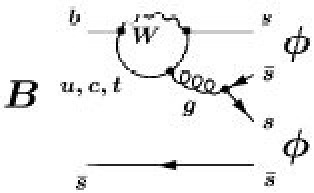
	$\Delta\varepsilon_{\mu}/\varepsilon_{\mu}$	
η parametrization & correlation	0.9%	

Measurement of BR($B_s^0 \to \phi\phi$) in 2.9 fb^{-1}

of Two Track Trigger data

G.Artoni, B. Di Ruzza, M.Dorigo, L.Ortolan, M.Rescigno, A.M. Zanetti



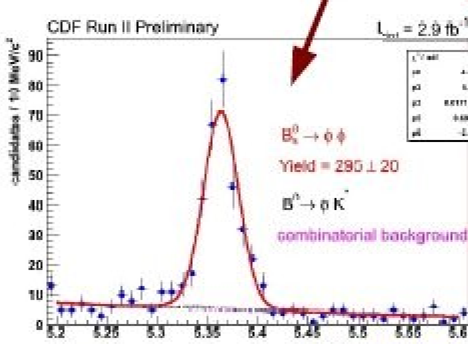
Experimental interest: improve precision w.r.t. to earlier pub.(180 pb-1). Expected sensitivity in future sin(2betas) measurement in Bs->phi phi.

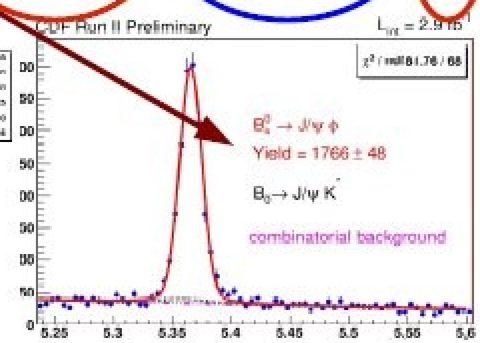
Theoretical interest: test recent QCD factorization calculations in B->VV.

		BR[10^{-6}]
a	Experiment	$14^{+6}_{-5}(\text{stat.}) \pm 6(\text{syst.})$
b	QCD Factorisation	$21.8^{+1.1+30.4}_{-1.1-17.0}$ $19.5^{+1.0+13.1}_{-1.0-8.0}$
c	QCD Factorisation	13.1
	Naive Factorisation	9.05

WE MEASURE: From MC, From PDG, From data

$$\frac{BR(B_s \mapsto \phi\phi)}{BR(B_s \mapsto J/\psi\,\phi)} = \frac{N_{\phi\phi}}{N_{J/\psi\phi}} \cdot \frac{\epsilon(B_s \mapsto J/\psi\phi)}{\epsilon(B_s \mapsto \phi\phi)} \cdot \frac{BR(J/\psi \mapsto \mu\mu)}{BR(\phi \mapsto KK)} \cdot \epsilon_\mu$$





a: D. Acosta et al. P.R.L. 95, 031801 (2005)
b: M. Beneke et al., hep-hex/0612290
c: X. Li et al. P.R.L. D.68, 114015 (2003); D71 019902(2005); hep-hex/030936

The result is:

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

$$\mathrm{BR}(B_s^0 \to \phi\phi) = [24.0 \pm 2.1(stat) \pm 2.7(syst) \pm 8.2(BR)]10^{-6}$$

Perspectives: Measure polarization in this decay through the study of angular distributions