A photograph of the main building of Moscow State University at night. The building is illuminated with warm lights, and its central spire is topped with a sphere. The sky is dark blue.

Search for New Physics in rare heavy flavour decays at LHCb

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On behalf of the LHCb collaboration.

Like a backdoor to the building of the New Physics:
 Instead of search for the real non-standard particles
 decays – we look at the impact of the unknown
 virtual particles to the (well) known decays...

Which are “rare”?

Suppressed or forbidden at the tree level in the SM
 Occur only through loop diagrams (box or penguin)
 involving FCNC

Why them?

New Physics impact is at the same (or even higher)
 order as the SM – even small effect is
 immediately visible

Sensitive to the larger mass scales than the directly
 accessible effects

One-arm forward spectrometer covering $1.9 < \eta < 4.9$

Specific features:

Muon System

RICH Detectors

Vertex Locator
VELO

Proton-proton
collision point

Calorimeters

Tracking System

See talk by E.Gushchin for the details

One-arm forward spectrometer covering $1.9 < \eta < 4.9$

Specific features:

Vertex Locator with perfect vertex separation

Muon System

RICH Detectors

Vertex Locator
VELO

x-,y- resolution $\sim 13\mu\text{m}$
z- resolution $\sim 70\mu\text{m}$
proper time resolution $\sim 50\text{fs}$

Proton
collision

Calorimeters

Tracking System

See talk by E.Gushchin for the details

One-arm forward spectrometer covering $1.9 < \eta < 4.9$

Specific features:

Vertex Locator with perfect vertex separation

Two RICH detectors for particle identification

Muon System

RICH Detectors
 π/K separation
 $\sim 100 \text{ GeV/c}$
momentum range

Calori

Vertex Locator
VELO

x-,y- resolution $\sim 13 \mu\text{m}$
z- resolution $\sim 70 \mu\text{m}$
proper time resolution
 $\sim 50 \text{ fs}$

One-arm forward spectrometer covering $1.9 < \eta < 4.9$

Specific features:

Vertex Locator with perfect vertex separation

Two RICH detectors for particle identification

Very efficient 5-station Muon System

Muon System
MuonID efficiency $\sim 99\%$

RICH Detectors
 π/K separation
 $\sim 100 \text{ GeV/c}$
momentum range

Calori

Vertex Locator
VELO

x-,y- resolution $\sim 13 \mu\text{m}$
z- resolution $\sim 70 \mu\text{m}$
proper time resolution
 $\sim 50 \text{ fs}$

See talk by E.Gushchin for the details

Operating at $\sqrt{s} = 7$ TeV with instant luminosity up to $3.5 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$

Achieved at the low number of bunches $\Rightarrow$ 1.5 – 2 visible interactions per crossing

Data collected:

2010: 37.5 pb^{-1}

2011: 584.1 pb^{-1} (gaining order of 1 pb^{-1} per hour)

Results shown today were obtained with $\sim 300 \text{ pb}^{-1}$ of data taken during 2011

Several world best measurements already!

The aim is to achieve 1 fb^{-1} by the end of the year

Large physics program:

Direct CP asymmetries in $B \rightarrow hh'$

Mixing in $B_s \rightarrow Ds\pi$

Time dependent CPV in $B_s \rightarrow J/\psi\phi$

Angle gamma

Charm physics

Spectroscopy, EW physics, searches for nonSM higgs, ...

In this talk:

Measurement of the $B(s,d) \rightarrow \mu\mu$ decay branching fraction

Analysis of the angular distributions in $B_d \rightarrow K^*\mu\mu$ decay

Measurement of the photon polarization in the $B_s \rightarrow \phi\gamma$ decay

Theoretical branching predictions:

$$B(B_s \rightarrow \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$$

$$B(B_d \rightarrow \mu\mu) = (0.10 \pm 0.01) \times 10^{-9}$$

arXiv:1007.5291

Theoretical uncertainties are very small

Sensitive to the to the models with extended Higgs and high $\tan\beta$

Experimentally only upper limit is set at the moment (@95% CL):

	<i>Dataset</i>	<i>Upper Limit</i>
CDF (2009) $B_s \rightarrow \mu\mu$	3.7 fb^{-1}	43×10^{-9}
D0 (2010) $B_s \rightarrow \mu\mu$	6.1 fb^{-1}	51×10^{-9}
LHCb (2011) $B_s \rightarrow \mu\mu$	37.5 pb^{-1}	56×10^{-9}
CDF (2009) $B_d \rightarrow \mu\mu$	3.7 fb^{-1}	7.6×10^{-9}
LHCb (2011) $B_d \rightarrow \mu\mu$	37.5 pb^{-1}	15×10^{-9}

Large field for studies left!

Very efficient di-muon trigger

- Efficiency is estimated with the help of $J/\psi \rightarrow \mu\mu$ channel: $88.7 \pm 0.5\%$

Soft cut-based analysis

- Aimed to reduce the dataset to the usable level
- Similar for both signal and normalization channels

Signal/Background discrimination with 2D likelihood

- Boosted decision tree (BDT) with 9 topological variables
- Dimuon invariant mass

Normalization

- Translate the number of selected events into the BR making use of the normalization channels

Limit extraction

Trained with Monte-Carlo:

Signal: $B_s \rightarrow \mu\mu$

Background: $bb \rightarrow \mu\mu X$

Calibrated with real data:

Signal: $B_d, s \rightarrow h+h-$

Background: data sidebands

Dimuon invariant mass

Resolution: interpolation of dimuon resonances (J/Ψ , $\Psi(2S)$, Y 's),
crosschecked with $B \rightarrow h^+h^-$

Mean: exclusive $B_s \rightarrow K^+K^-$ and $B^0 \rightarrow K^+\pi^-$

$$\sigma(B_s) = (24.6 \pm 0.2 \pm 1.0) \text{ MeV/c}^2$$

$$\sigma(B_d) = (24.3 \pm 0.2 \pm 1.0) \text{ MeV/c}^2$$

$B^+ \rightarrow J/\Psi(\rightarrow \mu\mu) K^+$: similar trigger and PID, but tracking efficiency (+1 track) dominates the systematic, needs f_d/f_s as an input;

$B_s \rightarrow J/\Psi(\rightarrow \mu\mu) \phi(\rightarrow KK)$: similar trigger and PID, tracking efficiency (+2 tracks) dominates the systematics

$B^0 \rightarrow K^+\pi^-$: same topology in the final state, different trigger dominates the systematics, needs f_d/f_s

$$\text{BR} = \text{BR}_{\text{cal}} \times \frac{\epsilon_{\text{cal}}^{\text{REC}} \epsilon_{\text{cal}}^{\text{SEL|REC}} \epsilon_{\text{cal}}^{\text{TRIG|SEL}}}{\epsilon_{\text{sig}}^{\text{REC}} \epsilon_{\text{sig}}^{\text{SEL|REC}} \epsilon_{\text{sig}}^{\text{TRIG|SEL}}} \times \frac{f_{\text{cal}}}{f_{B_s^0}} \times \frac{N_{B_s^0 \rightarrow \mu^+ \mu^-}}{N_{\text{cal}}} = \alpha \times N_{B_s^0 \rightarrow \mu^+ \mu^-}$$

Evaluated from MC

Cross-checked with data

Evaluated from data

Probability of a b-quark to hadronize in a given meson

LHCb measured value:

$$f_s/f_d = 0.267^{+0.021}_{-0.020}$$

LHCb-CONF-2011-034

$B_s \rightarrow J/\psi(\rightarrow \mu\mu) \phi(\rightarrow KK)$: similar trigger and PID, tracking efficiency (+2 tracks) dominates the systematics

$B^0 \rightarrow K^+ \pi^-$: same topology in the final state, different trigger dominates the systematics, needs f_d/f_s

$$\text{BR} = \text{BR}_{\text{cal}} \times \frac{\epsilon_{\text{cal}}^{\text{REC}} \epsilon_{\text{cal}}^{\text{SEL|REC}} \epsilon_{\text{cal}}^{\text{TRIG|SEL}}}{\epsilon_{\text{sig}}^{\text{REC}} \epsilon_{\text{sig}}^{\text{SEL|REC}} \epsilon_{\text{sig}}^{\text{TRIG|SEL}}} \times \frac{f_{\text{cal}}}{f_{B_s^0}} \times \frac{N_{B_s^0 \rightarrow \mu^+ \mu^-}}{N_{\text{cal}}} = \alpha \times N_{B_s^0 \rightarrow \mu^+ \mu^-}$$

Average of three channels:

$$\alpha(B_s \rightarrow \mu\mu) = (9.84 \pm 0.91) \times 10^{-10}$$

$$\alpha(B_d \rightarrow \mu\mu) = (2.89 \pm 0.15) \times 10^{-10}$$

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	@ 90%	@ 95%
$B_s \rightarrow \mu\mu$	12×10^{-9}	15×10^{-9}
$B_d \rightarrow \mu\mu$	4.2×10^{-9}	5.2×10^{-9}

CDF collaboration

Arxiv 1107.2304v1, 12 July 2011

In summary, we have performed a search for $B^0 \rightarrow \mu^+\mu^-$ and $B_s^0 \rightarrow \mu^+\mu^-$ decays using 7 fb^{-1} of integrated luminosity collected by the CDF II detector at the Fermilab Tevatron. The data in the B^0 search region are consistent with background expectations and the world's most stringent upper limit on $\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)$ is established. The data in the B_s^0 search region are in excess of the background predictions. A fit to the data determines $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (1.8_{-0.9}^{+1.1}) \times 10^{-8}$ including all uncertainties. Although of moderate statistical significance, this is the first indication of a $B_s^0 \rightarrow \mu^+\mu^-$ signal.

The excess seen by CDF is not confirmed

$\sim 6 \times \text{SM}$
prediction

$B_d \rightarrow K^* \mu \mu$

HFAG for branching: $(1.09 \pm 0.12) \times 10^{-6}$

The new physics may be accessed through the angular distributions studies

- sensitive to the right-handed currents
- new scalar/pseudoscalar operators

Decay described by three angles θ_1, θ_K and ϕ and the invariant di-muon mass squared, q^2

Forward-backward asymmetry is of the special interest as the leading form-factor uncertainties cancel out

The aim of this summer is to perform measurements in 6 bins of q^2 in 1-6 GeV^2/c^4 range

Long-term plan to make the measurements in the whole q^2 region

Select events with the help of the BDT

- trained on the 2010 data

Signal: $B_d \rightarrow K^* J/\psi$

Background: $B_d \rightarrow K^* \mu\mu$ sidebands

- remove the J/ψ and $\Psi(2S)$ resonances impact

Signal to background ratio ~ 0.3 : comparable with B-factories

Perform acceptance correction for angular and q^2 distributions

- calculate the event-by-event weight using the MC-simulated data
- verify MC with control channels ($B_d \rightarrow K^* J/\psi$, $J/\psi \rightarrow \mu\mu$, $D^* \rightarrow D0(K\pi)\pi$)

Fit the distributions for observables

- Simultaneous fit of mass, θ_l and θ_K
- Signal angular distributions:

$$\frac{\partial^2 \Gamma}{\partial \theta_L \partial q^2} = \left(\frac{3}{4} F_L \sin^2 \theta_L + \frac{3}{8} (1 - F_L) (1 + \cos^2 \theta_L) + A_{FB} \cos \theta_L \right) \sin \theta_L$$

$$\frac{\partial^2 \Gamma}{\partial \theta_K \partial q^2} = \frac{3}{4} \sin \theta_K \left(2 F_L \cos^2 \theta_K + (1 - F_L) \sin^2 \theta_K \right).$$

- Signal mass distribution: double gaussian
- Background angular distributions: 2nd order polynomials
- Background mass distribution: exponent

Cross-checked with $B_d \rightarrow K^* J/\psi$

q^2 (GeV ²)	n_{sig}	n_{bkg}	significance (σ)
$0 < q^2 < 2$	40.9 ± 7.5	14.4 ± 8.5	7.7
$2 < q^2 < 4.3$	23.3 ± 6.2	15.3 ± 8.6	4.9
$4.3 < q^2 < 8.68$	93.3 ± 11.3	30.0 ± 12.5	11.7
$10.09 < q^2 < 12.9$	57.3 ± 8.8	18.6 ± 9.7	9.3
$14.18 < q^2 < 16$	42.2 ± 6.8	3.6 ± 4.7	10.1
$16 < q^2 < 19$	48.1 ± 7.8	6.7 ± 6.4	9.2
$1 < q^2 < 6 \text{ GeV}^2$	70.0 ± 10.2	$32. \pm 3.2$	9.4
Full	302.3 ± 20.1	91.0 ± 5.4	—

Theory predictions from C. Bobeth *et al.* arXiv:1105.0376v2

$$F_L = 0.57^{+0.11}_{-0.10} \pm 0.03$$

$$\text{Belle } 0.67 \pm 0.23 \pm 0.07$$

$$A_{FB} = -0.10 \pm 0.14 \pm 0.05$$

$$\text{Belle: } 0.26^{+0.27}_{-0.30} \pm 0.07$$

The errors are smaller than in previous measurements (and mostly dominated by statistics)

All three measurements show no discrepancy with the Standard Model predictions at the moment

No large asymmetry in the first bin of the q^2

Not as rare, theoretical prediction $(4.3 \pm 1.4) \times 10^{-5}$ for both $B_s \rightarrow \phi \gamma$ and $B \rightarrow K^* \gamma$
HFAG

Were already observed by Belle, BaBar and CLEO

- in good agreement with the Standard Model

However observation of the photon polarization may give a hint of the new physics:

- in decays of B-mesons the left-handed photons dominate with a factor of m_b/m_s
- in $B_s \rightarrow \phi \gamma$ decay the photon polarization may be accessed through the time dependant CP-violation measurement:

$$\Gamma_{B(s)^0 \rightarrow \Phi^{CP} \gamma}(t) = |A|^2 e^{-\Gamma(s)t} \left(\cosh \frac{\Delta\Gamma(s)t}{2} - \mathcal{A}^\Delta \sinh \frac{\Delta\Gamma(s)t}{2} + \mathcal{C} \cos \Delta m(s)t - \mathcal{S} \sin \Delta m(s)t \right)$$

$$\mathcal{A}^\Delta \approx \sin 2\psi \cos \varphi(s) \quad \text{where} \quad \tan \psi \equiv \left| \frac{\mathcal{A}(\bar{B}(s) \rightarrow \Phi^{CP} \gamma_R)}{\mathcal{A}(\bar{B}(s) \rightarrow \Phi^{CP} \gamma_L)} \right|$$

	$B \rightarrow K^* \gamma$	$B_s \rightarrow \phi \gamma$
BaBar ($\times 10^{-5}$)	$4.47 \pm 0.10 \pm 0.16$	
Belle ($\times 10^{-5}$)	$4.01 \pm 0.21 \pm 0.17$	$5.7^{+1.8+1.2}_{-1.5-1.1}$
CLEO ($\times 10^{-5}$)	$4.55^{+1.8+1.2}_{-1.5-1.1} \pm 0.34$	

The aim of this summer:

- observation of the $B \rightarrow \phi \gamma$;
- relative branching measurement;

By the end of the year:

- CP-asymmetry in $K^* \gamma$

Select events of both decays in a quite similar way (cut-based selection)

- thus making use of similar topology, kinematics, photon efficiency;
- allows many systematic terms to cancel out in the final ratio.

Simultaneously fit $B^0 \rightarrow K^{*0}\gamma$ and $B_s \rightarrow \phi\gamma$ distributions

- mass difference is fixed

Take into account the background contamination

- contribution estimated from MC or the real data, where possible
- the corresponding correction to the number of events is applied

Extract the ratio:

$$\frac{\mathcal{B}(B^0 \rightarrow K^{*0}\gamma)}{\mathcal{B}(B_s \rightarrow \phi\gamma)} = \frac{N_{sig}^{B^0 \rightarrow K^{*0}\gamma}}{N_{sig}^{B_s \rightarrow \phi\gamma}} \frac{\mathcal{B}(\phi \rightarrow K^+ K^-)}{\mathcal{B}(K^* \rightarrow K^+ \pi^-)} \frac{f_s}{f_d} \frac{\epsilon_{B_s \rightarrow \phi\gamma}}{\epsilon_{B^0 \rightarrow K^{*0}\gamma}}$$

From fit:

- Crystal Ball for signal
- exponent+Crystal Ball for bkg

From PDG:

$$\frac{\mathcal{B}(\phi \rightarrow K^+ K^-)}{\mathcal{B}(K^* \rightarrow K^+ \pi^-)} = 0.735 \pm 0.008$$

From Monte-Carlo

LHCb measurement:

$$f_s/f_d = 0.267^{+0.021}_{-0.020}$$

$S/B = 1.81 \pm 0.15$ in $\pm 3\sigma$

$S/B = 1.6 \pm 0.3$ in $\pm 3\sigma$

Largest $B_s \rightarrow \phi\gamma$ evidence in the world!

$$\frac{\mathcal{B}(B^0 \rightarrow K^{*0}\gamma)}{\mathcal{B}(B_s^0 \rightarrow \phi\gamma)} = 1.41 \pm 0.15(\text{stat}) \pm 0.07(\text{syst}) \pm 0.11(f_s/f_d)$$

Using the previously measured value for the $K^*\gamma$ branching fraction

$\mathcal{B}(B_s^0 \rightarrow \phi\gamma) = (3.1 \pm 0.5) \times 10^{-5}$ - uncertainty is twice smaller than in previous Belle measurement

The most precise measurements by the moment

Consistent with the SM predictions

With $\sim 300\text{pb}^{-1}$ of data taken during 2011

A tighter limit is set up for $B_s \rightarrow \mu\mu$ and $B_d \rightarrow \mu\mu$ decays

$$\text{BR}(B_s \rightarrow \mu\mu) = 15 \times 10^{-9} \text{ (@ 95\%)}$$

$$\text{BR}(B_d \rightarrow \mu\mu) = 5.2 \times 10^{-9} \text{ (@ 95\%)}$$

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The excess seen by CDF is not confirmed

The longitudinal polarization and forward-backward asymmetry were measured in $B_d \rightarrow K^* \mu\mu$ decay

$$A_{\text{FB}} = -0.10 \pm 0.14 \pm 0.05$$

$$\text{FL} = 0.57^{+0.11}_{-0.10} \pm 0.03$$

Both show no discrepancy with the Standard Model predictions at the moment

Both $B^0 \rightarrow K^* \gamma$ and $B_s \rightarrow \phi \gamma$ decays are observed

Their branching fractions ratio is calculated

The branching fraction of $B_s \rightarrow \phi \gamma$ is evaluated

By the moment the most precise measurement of the $B_s \rightarrow \phi \gamma$ branching

Looking forward for the new exciting measurements!