DPF 2009

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Wayne State University, Detroit, MI

LHCb Prospects for Rare Decays

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on behalf of the LHCb collaboration

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Flavor-changing neutral currents decays

Indirect search for New Physics through FCNC b → s transitions because:

- suppressed within SM
- precise theoretical predictions for SM values
- NP predictions significantly differ from SM ones

Room to uncover possible NP effects.

Effective Hamiltonian, Operator Product Expansion

$$\mathcal{H}_{\text{eff}} = -\frac{4G_{\text{F}}}{\sqrt{2}} V_{\text{CKM}} V^*_{\text{CKM}} \{ \sum_{i=1}^{10} C_i \mathcal{O}_i + C_P \mathcal{O}_P + C_S \mathcal{O}_s \}$$

i= 1,2	tree
i=3-6,8	g penguin
i=7	γ penguin
i=9,10	EW penguin
P,S	(Pseudo-)Scalar

$C_i(\mu)$ **Wilson coefficients**: short-range information such as mass of particles in loops. Computed perturbatively for various models, SM and NP.

$\mathcal{O}_i(\mu)$ **local operators**: long-range contributions

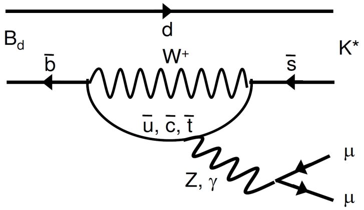
New Physics possibly modifies the Wilson coefficients, affecting **observable quantities** as branching fractions, polarizations, and angular distributions.

Outline

Rare Decays at LHCb

$B^0 \to K^{0*}\mu\mu$

$b \longrightarrow s\, l^+ l^-$



$$\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-) = (9.8 \pm 0.21) \times 10^{-7}$$

C_7 — A_{FB} of the Muons, Angular Distribution

C_7, C_9 and C_{10} — Full Angular Analysis

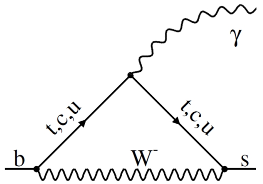
LHCb-roadmap-2

LHCb-2007-039

LHCb-2009-003

$B^0_s \to \phi\gamma$

$b \longrightarrow s\, \gamma$



$$\mathcal{B}(B^0_s \to \phi\gamma) = (5.7^{+2.2}_{-1.9}) \times 10^{-5}$$

$C_7 = C_{7R} + C_{7L}$

$\frac{C_{7R}}{C_{7L}}$

Photon Polarization

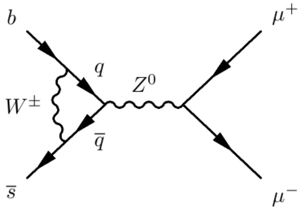
LHCb-roadmap-4

LHCb-2007-030

LHCb-2007-147

$B^0_s \to \mu\mu$

$B \longrightarrow l^+ l^-$



$$\mathcal{B}(B^0_s \to \mu^+\mu^-)\Big|_{\mathrm{SM}} = (3.35 \pm 0.32) \times 10^{-9}$$

C_S, C_P and C_{10} — Branching Fraction

LHCb-roadmap-1

LHCb-2007-033

LHCb-2008-018

LHCb apparatus

See Eddy Jans talk

B-Factory

L = 2 10^{32} $cm^{-2}s^{-1}$ **single interaction**

σ_{bb} = 500 µb

per year: **2 fb^{-1}, 10^{12} bb produced**

Trigger

From 30MHz to 2kHz on tape

Efficiency (all triggers)

$B^0 \to K^{0*}\mu\mu$	~80%
$B^0_s \to \phi\gamma$	~40%
$B^0_s \to \mu\mu$	~90%

MC simulation in this talk

Full detector simulation, pile-up and spill-over at 14 TeV

Vertexing

σ(IP) ≈ 14 µm + 35 µm/p_T [GeV/c]

σ(τ) ≈ 40-100 fs $B^0_s \to \phi\gamma$

Tracking

ε ≈ 95%, ghost ≈ 5%, for p > 5 GeV

σ(p)/p ≈ 0.4%

σ(m) ≈ 20 MeV/c^2 $B^0_s \to \mu\mu$

σ(m) ≈ 15 MeV/c^2 $B^0 \to K^{0*}\mu\mu$

Calorimeters

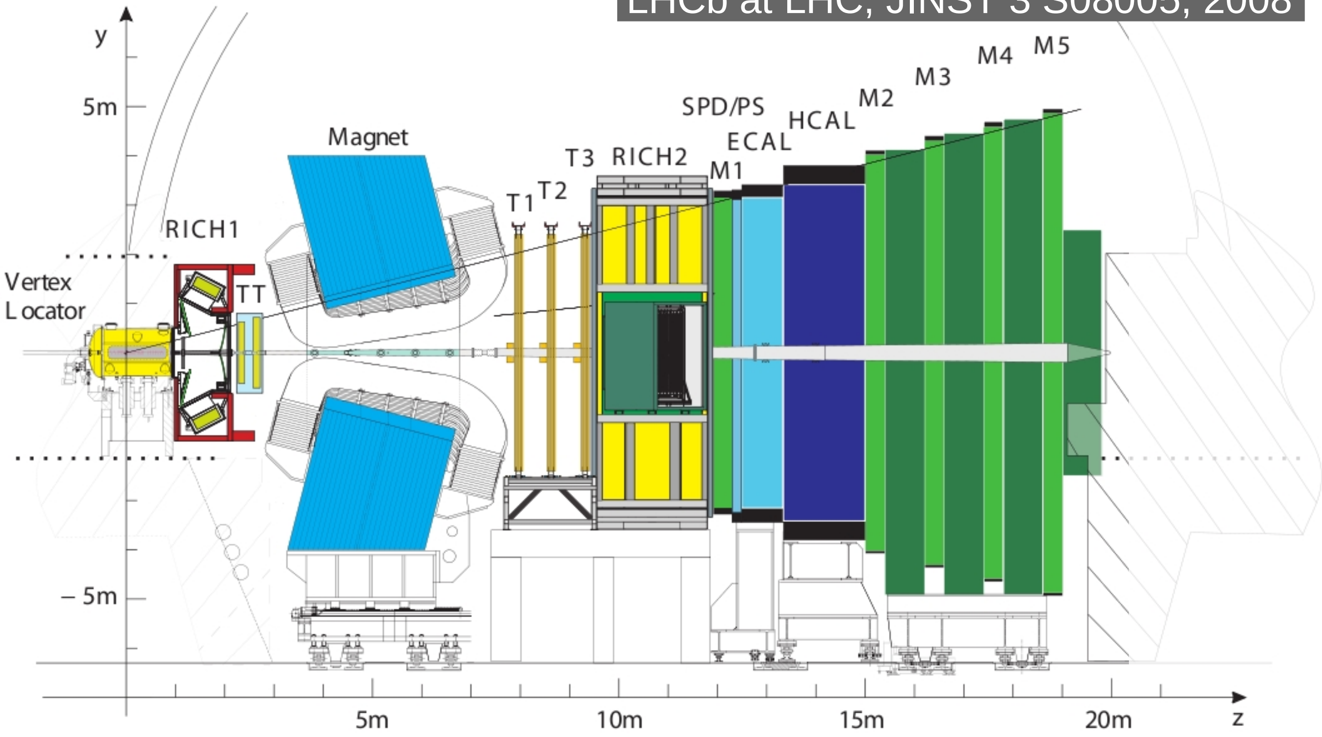
σ(m) ≈ 90 MeV/c^2 $B^0_s \to \phi\gamma$

RICH, Muon

K-id ~97% (~6% π mis-id)

µ-id ~93% (~1% π mis-id)

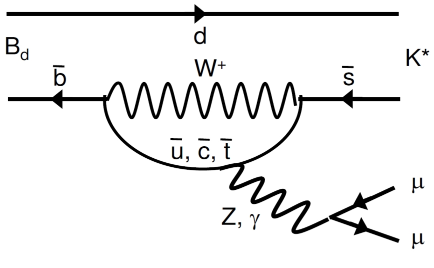
LHCb at LHC, JINST 3 S08005, 2008



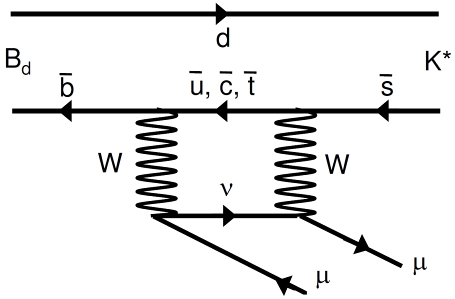
for further LHCb physics talks see
S. Blusk on NP in CPV
F. Dettori on first measurements

B^0-> $K^*\mu\mu$ Decay interest

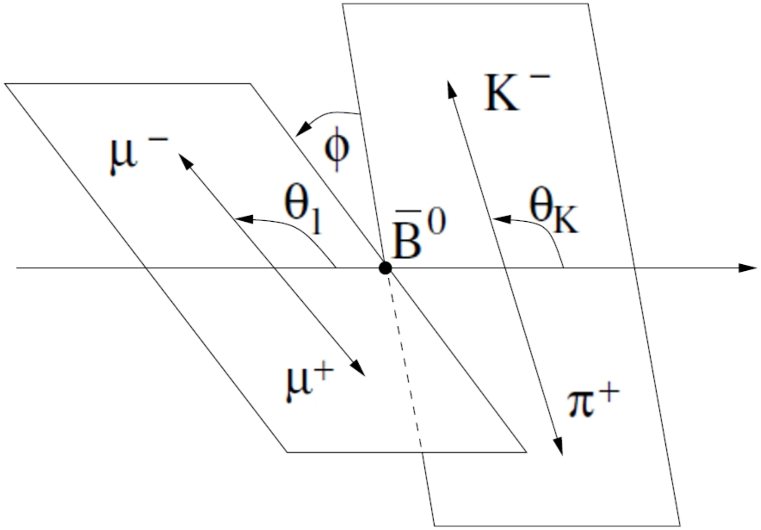
- Flavor-changing neutral current b ⟶s transition
- First observed at Belle, compatible with SM Phys. Rev. Lett. 91:261601, 2003
  $\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-) = 9.8 \times 10^{-7}$ PDGlive



- New Physics particles can enter in the loop and modify Wilson coefficients, particularly C_{7L}, C_{7R}, C_9 and C_{10}.
- The decay kinematics is defined by three angles ϕ, θ_K and θ_l and by q^2 the invariant mass squared of the muon pair.



- Two-step strategy:
  - From start, A_{FB} of the θ_l distribution, and particularly its zero-crossing point is particularly well predicted (FF cancel out) and experimentally accessible (acceptance distortion disappears)
  - With more data (>2 fb^{-1}) a full angular (ϕ, θ_K and θ_l) analysis becomes possible, giving sensitivity to C_7, C_9 and C_{10} Wilson coefficients.

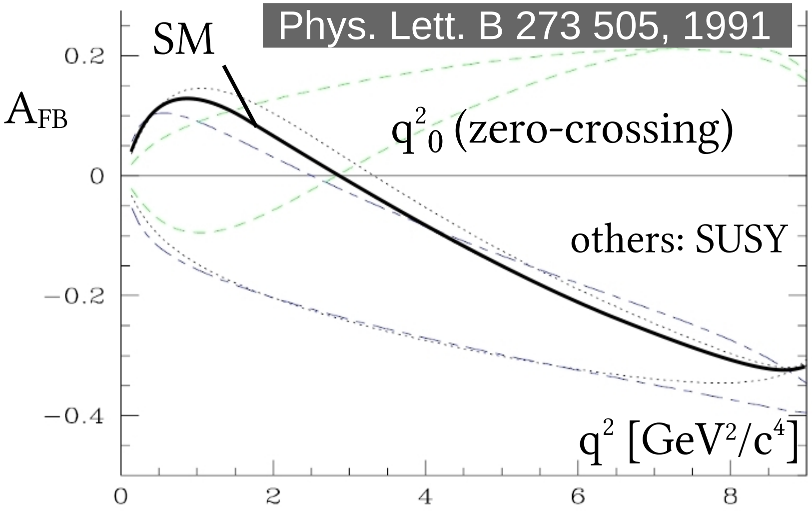


B^0-> $K^*\mu\mu$ θ_l A_{FB}

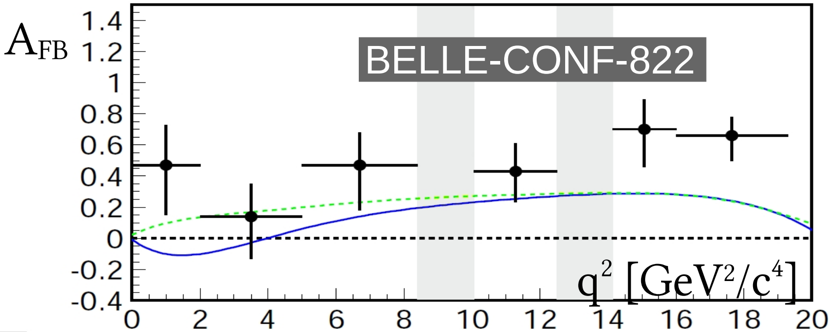
- A_{FB} and $q^2{}_0$ theoretically well predicted and differ with models. $q^2{}_0 = 4.36^{+0.33}_{-0.31}$ GeV²/c⁴ in SM.

Eur. Phys. J. C41 173, 2005

- Belle and Babar results shows hint of discrepancy w.r.t SM. note: opposite A_{FB} sign convention between LHCb and B-factories !
- With a few hundreds pb^{-1} LHCb can compete with B-factories.



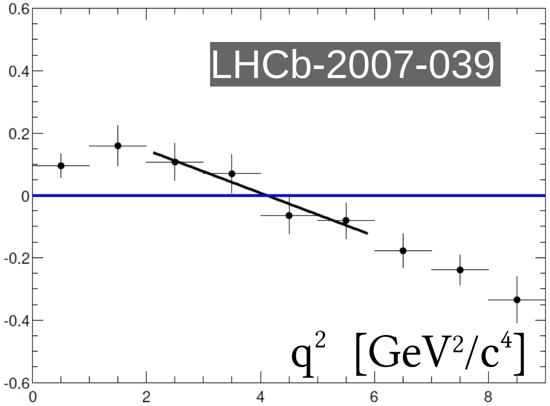
Phys. Lett. B 273 505, 1991



BELLE-CONF-822

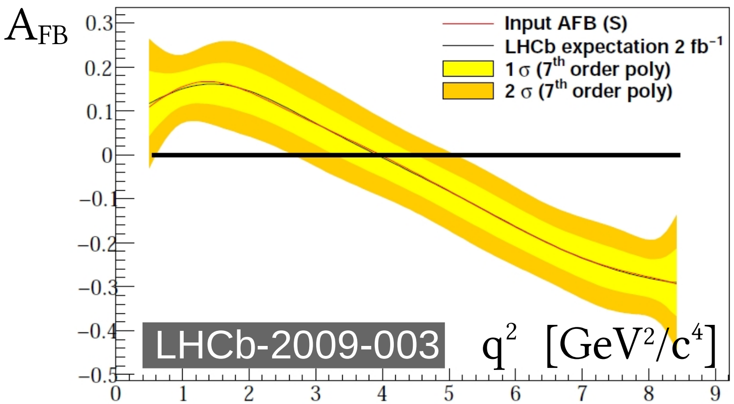
Belle results with 230 events from 657M BB

binned A_{FB} analysis 2 fb^{-1}



LHCb-2007-039

unbinned A_{FB} analysis 2 fb^{-1}

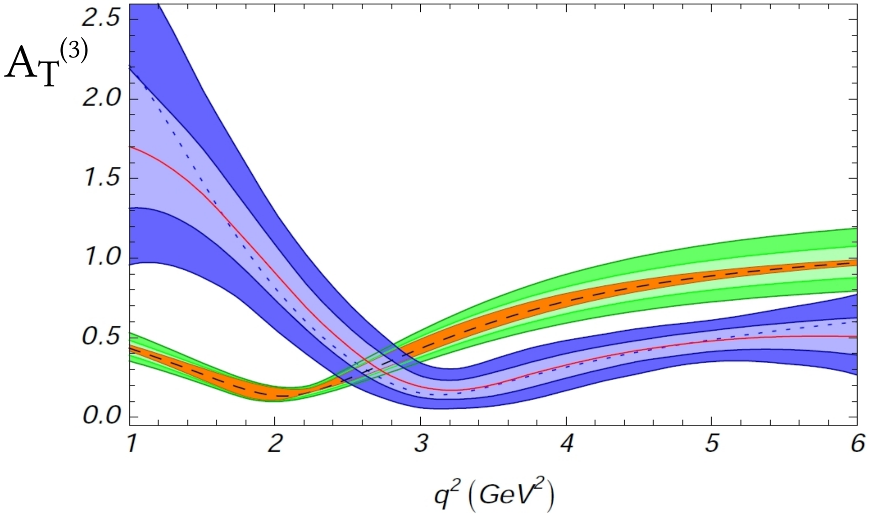


LHCb-2009-003

Yield (2 fb^{-1}) and expected **resolution**
7000 signal events
1700 b→μ b→μ events
$\sigma(q^2{}_0) \approx 0.5$ GeV²/c⁴ with 2 fb^{-1}
$\sigma(q^2{}_0) \approx 0.3$ GeV²/c⁴ with 10 fb^{-1}

B^0-> $K^*\mu\mu$ Full Angular Analysis

- requires at least 2 fb^{-1} together and full acceptance correction understanding.
- uses further observable quantities F_L, $A_T^{(2)}$, $A_T^{(3)}$, $A_T^{(4)}$
- some of which have NP predictions very different from the SM ones.

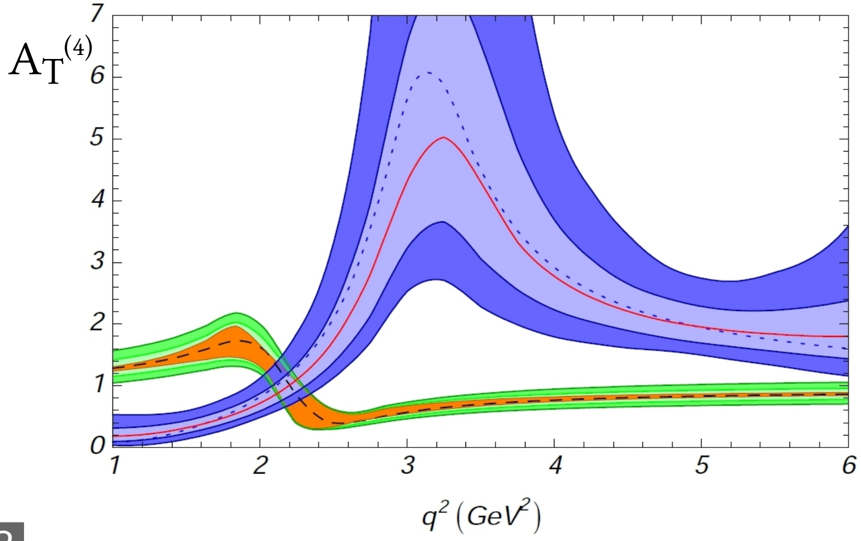


LHCb sensitivity for the full angular analysis with 10 fb^{-1}, the case of $A_T^{(3)}$ and $A_T^{(4)}$.

🟧🟩 SM predictions (theoretical errors)

🟦 SUSY (MSSM with large-gluino and positive mass insertion (with right-handed current);
bands are 1σ and 2σ at LHCb

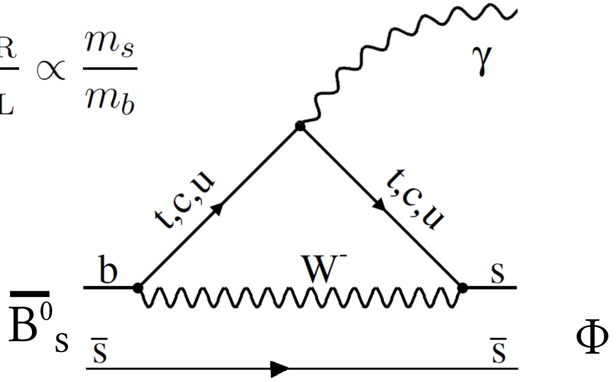
LHCb-2008-041
JHEP 0811 032, 2008



$B^0_s \to \phi\gamma$ Photon polarization

- In the SM, right-handed photons (for $\overline{B}^0_s$) are suppressed by $\tan\psi \equiv \frac{\mathcal{A}_R}{\mathcal{A}_L} \propto \frac{m_s}{m_b}$
- In New Physics models (Left-Right symmetry, uMSSM) the photon polarization is free.

Phys.Rep. 117 75, 1985
Phys.Rev.D11 566, 1975



- One indirectly access the photon polarization ratio through the time-dependent decay rate. Contrarily from the B^0 case, it is particularly simple in the B^0_s case, thanks to $\Delta\Gamma_S \neq 0$ and $\sin\varphi_S \approx 0$, no tagging needed:

$$\Gamma_{B^0_s(\overline{B}^0_s)\to\phi\gamma}(t) = |A^2|\, e^{-\Gamma_s t}\left\{\cosh\frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta}\,\sinh\frac{\Delta\Gamma_s t}{2}\right\}$$

$$\mathcal{A}^{\Delta}_{B^0_s} \approx \sin 2\psi$$

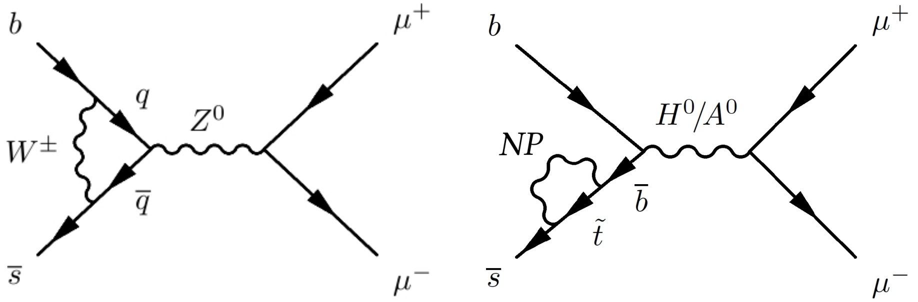
- Experimental issue:
  trigger and offline selection uses IP cut for φ , which directly affects the B^0_s proper time resolution.
  Control channel: $B^0 \to K^{*0}\gamma$

Yield and expected resolution
~10k selected events for 2 fb^{-1}
~6k background events
$\sigma(A^{\Delta}) \approx 0.22 \longrightarrow \sigma(\psi) \approx 0.1$ with 2 fb^{-1}

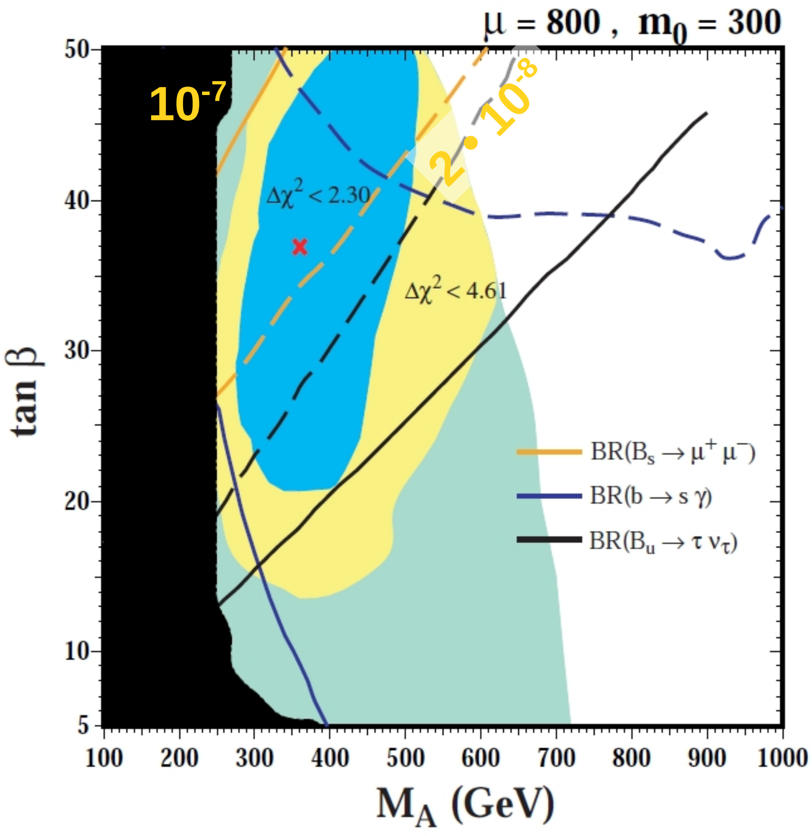
- Other possible channels to probe photon polarization.

$$\Lambda_b \to \Lambda^0\gamma, \quad \Lambda_b \to (\Lambda^* \to \mathrm{p}K^-)\gamma, \quad B^+ \to \phi K^+\gamma$$

$B^0_s \to \mu\mu$ Decay interest



- Very rare decay, further helicity suppressed, proceed through loops diagrams.
  Clean theoretical framework, precise SM prediction:
  $$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.35 \pm 0.32) \times 10^{-9}$$
  JHEP 10 003, 2006
- Current experimental limit, by CDF and DØ:
  $$\mathcal{B}(B^0_s \to \mu^+\mu^-) < 4.7 \times 10^{-8} \text{ at } 90\% \text{ C.L.}$$
  PRL 100 101802, 2008
  PRD 72 092001, 2007
- Branching fraction sensitive to C_S and C_P Wilson coefficients, is strongly enhanced by NP by a factor **$(\tan\beta)^6$**
- in cMSSM generalization (NUHM realization), best fit using WMAP Dark Matter, $(g\text{-}2)_\mu$ constraints gives:
  $$\mathcal{B}(B^0_s \to \mu^+\mu^-) \sim 10^{-8}$$
  JHEP 10 092, 2007



$B^0_s \to \mu\mu$ Analysis Strategy I

Strategy for finding needles in one haystack

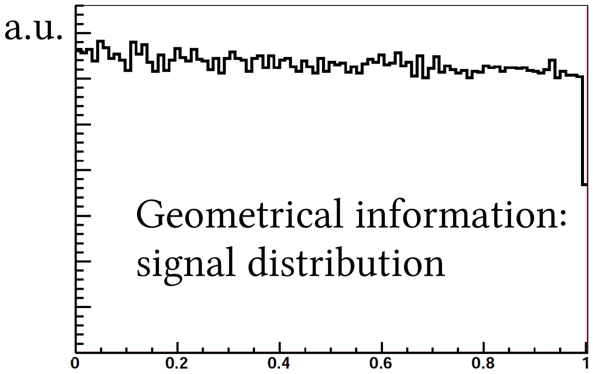
- **loose selection**
- Categorization of candidate events along **three criteria:**

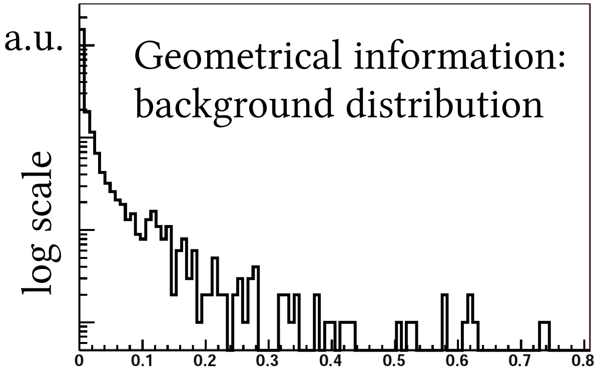
Likelihoods calibration on real data solely

1 Geometrical information

- B_s impact parameter with respect to the PV
- B_s proper time
- Smallest impact parameter significance of the muons candidates wrt any PVs
- The distance of closest approach of the two muons
- The isolation of the two muons tracks

$B^0_{(s)} \to h^+h^-$ for signal
mass sidebands for bkgd





2 muon identification

$J/\psi \to \mu^+\mu^-$ for signal
$\Lambda \to p\pi^-$ for bkgd

3 **invariant mass** of the di-muon

$B^0_s \to K^+K^-$ for signal
mass sidebands for bkgd

A 3D space is populated with the candidates, composing a distribution that can be tested against various branching fraction hypotheses.

B^0_s -> μμ Analysis Strategy II

- **Normalization** necessary to access absolute branching fraction.

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \mathcal{B}_{\mathrm{norm}} \times \frac{f_{\mathrm{norm}}}{f_s} \times \frac{\epsilon_{\mathrm{norm}}}{\epsilon_{\mathrm{sig}}} \times \frac{\mathcal{N}_{\mathrm{sig}}}{\mathcal{N}_{\mathrm{norm}}}$$

Requires channels with well measured branching fraction and close to $B^0_s \to \mu^+\mu^-$ to control the efficiency ratio. The channels considered are $B^0 \to K^+\pi^-$ and $B^+ \to J/\psi(\mu^+\mu^-)K^+$

f_s represents the main systematic error ~13%.

- The 3D distribution obtained experimentally is tested against branching ratio hypotheses using the three likelihoods calibrated on data for signal and background with the **CL method**. **One Exclude/Observe** a branching fraction.

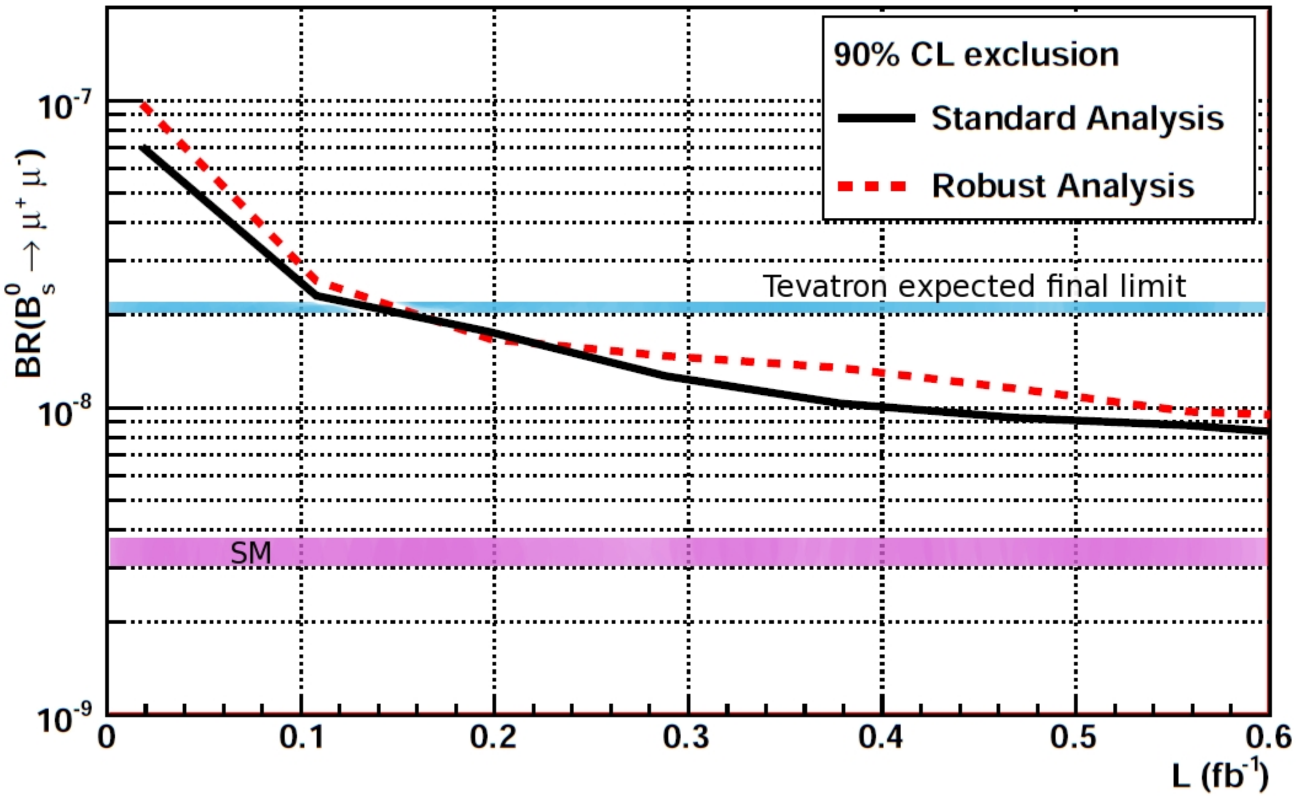
Yellow report 2000-005

Since a result is possible with very little data already, an alternate analysis suitable for a not perfectly understood detector has been developed. This robust analysis is based on variables which do not involve error estimates. The overall strategy being identical to the standard analysis.

$B^0_s \to \mu\mu$ LHCb Sensitivity I

LHCb expected **exclusion** sensitivity to $B^0_s \longrightarrow \mu\,\mu$ (in case no signal is observed) as a function of the integrated luminosity with **plain black curves for the standard analysis** and **red dashed curves for the robust analysis.**

For 8 TeV collisions



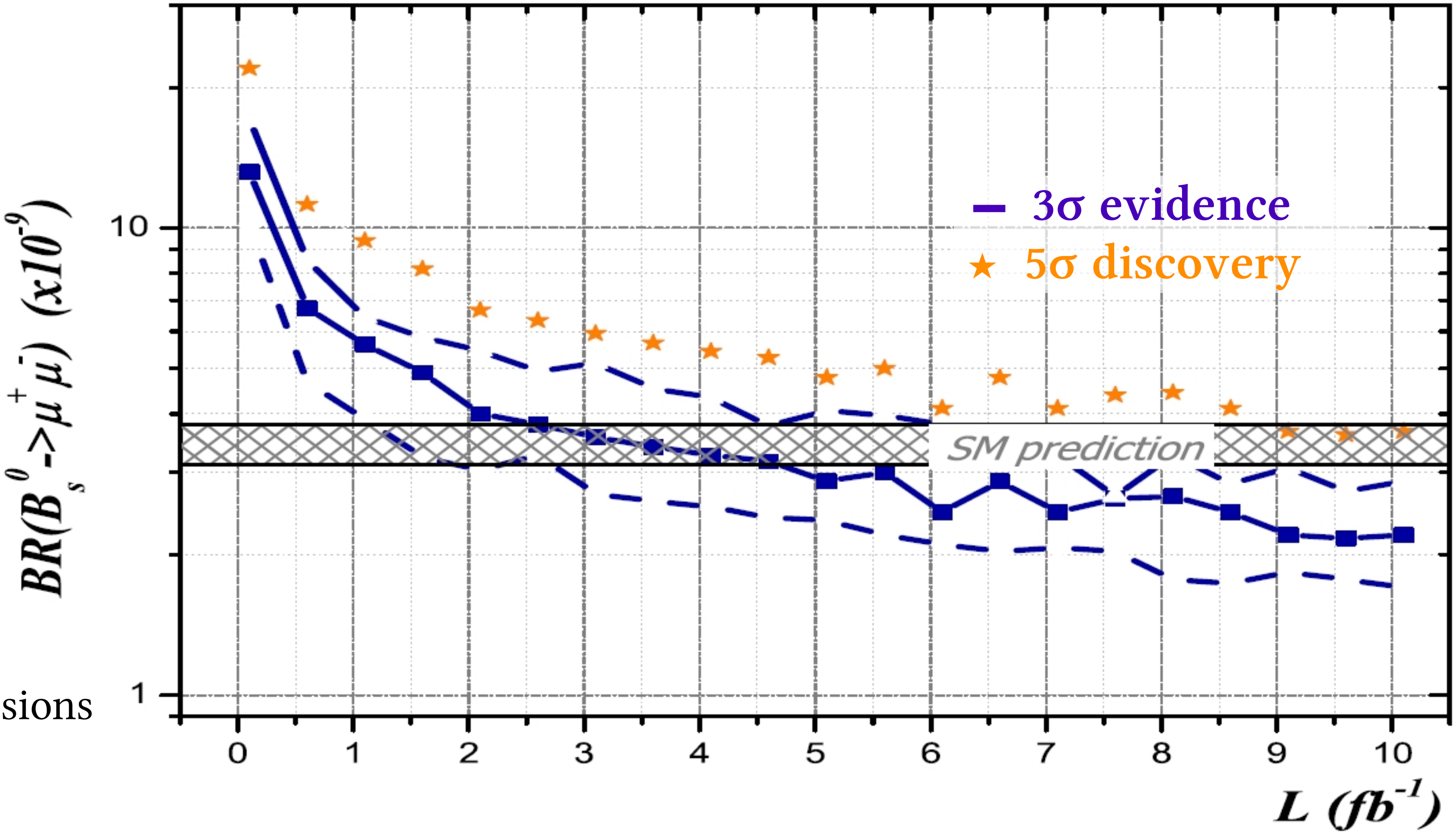
Tevatron expected final limit is extrapolated from the current limit assuming 8 fb^{-1} per experiment.

The background was conservatively set to its 90% CL upper value.

LHCb competes with the current Tevatron limit (4.7 10^{-8}) with less than 0.1 fb^{-1}, and overtake Tevatron expected final limit with about 0.2 fb^{-1}.
NP models with high tanβ value are strongly constrained in the process.

B^0_s -> μμ LHCb Sensitivity II

LHCb expected **observation** sensitivity to $B^0_s \rightarrow \mu\,\mu$ as a function of the integrated luminosity.



14 TeV collisions

About 3 fb^{-1} are enough for a 3σ observation if the branching fraction is the SM prediction.
Any enhancement driven by NP will be observed sooner.
If the branching fraction is ~2 $\cdot 10^{-8}$ as in NUHM scenario, a 5σ discovery is possible with very little luminosity (< 0.5 fb^{-1}).
With 10 fb^{-1}, a 5σ discovery occurs if the branching fraction is close to the SM one.

JHEP 10 092, 2007

Conclusions

LHCb is ready to collect the largest B meson sample ever.

Interesting new results will follow:

Possible NP discovery very early with the $B^0_s \to \mu\mu$ decay, or at least strong constraints on NP models with high tanβ value within the first run of data-taking.

With 2 fb^{-1}, i.e. one year of data taking in nominal conditions:

$B^0 \to K^*\mu\mu$	The zero crossing point of θ_l A_{FB} is measure with $\sigma(q^2_0) \approx 0.5$ GeV^2/c^4
$B^0_s \to \phi\gamma$	The Time-dependent analysis leads to $\sigma(A^\Delta) \approx 0.22$, which gives $\sigma(\psi) \approx 0.1$
$B^0_s \to \mu\mu$	Limit on the branching fraction down to the SM prediction if no signal is observed, possible NP observation if the branching fraction is enhanced.

On the long term:

$B^0 \to K^*\mu\mu$	Full angular analysis, sensitive to C_7, C_9 and C_{10}
$B^0_s \to \mu\mu$	5σ discovery if branching fraction at SM level with about 10 fb^{-1}.

You will hear from Rare Decays at LHCb soon, and for a long time !