Search for Rare Decays at LHCb with 0.2 and 1 fb^{-1}

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on behalf of the LHCb collaboration

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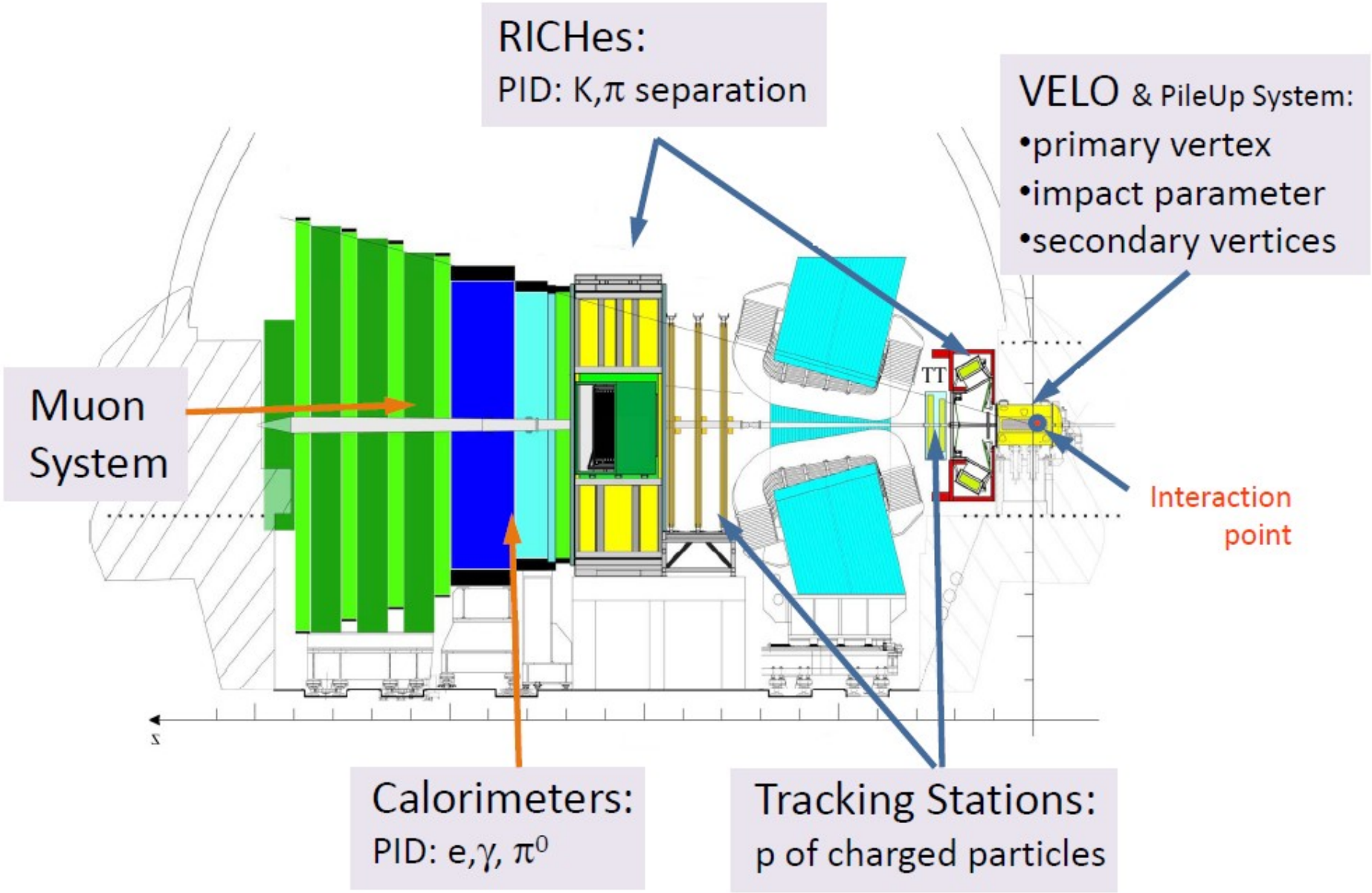
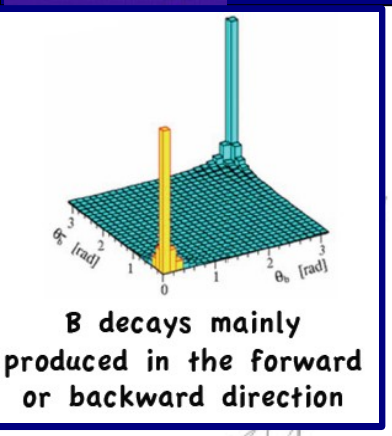
Overview

- LHCb detector at LHC
- Indirect searches for New Physics
- B meson rare decays and New Physics
- LHCb results prospect for key channels with 0.2 and 1 fb^{-1}
- Conclusions

LHCb detector at LHC



B Physics at LHC with LHCb



B decays mainly produced in the forward or backward direction

RICHes:
PID: K,π separation

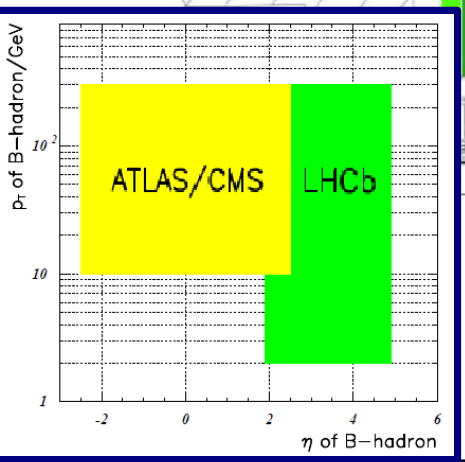
VELO & PileUp System:
- primary vertex
- impact parameter
- secondary vertices

Muon System

TT

Interaction point

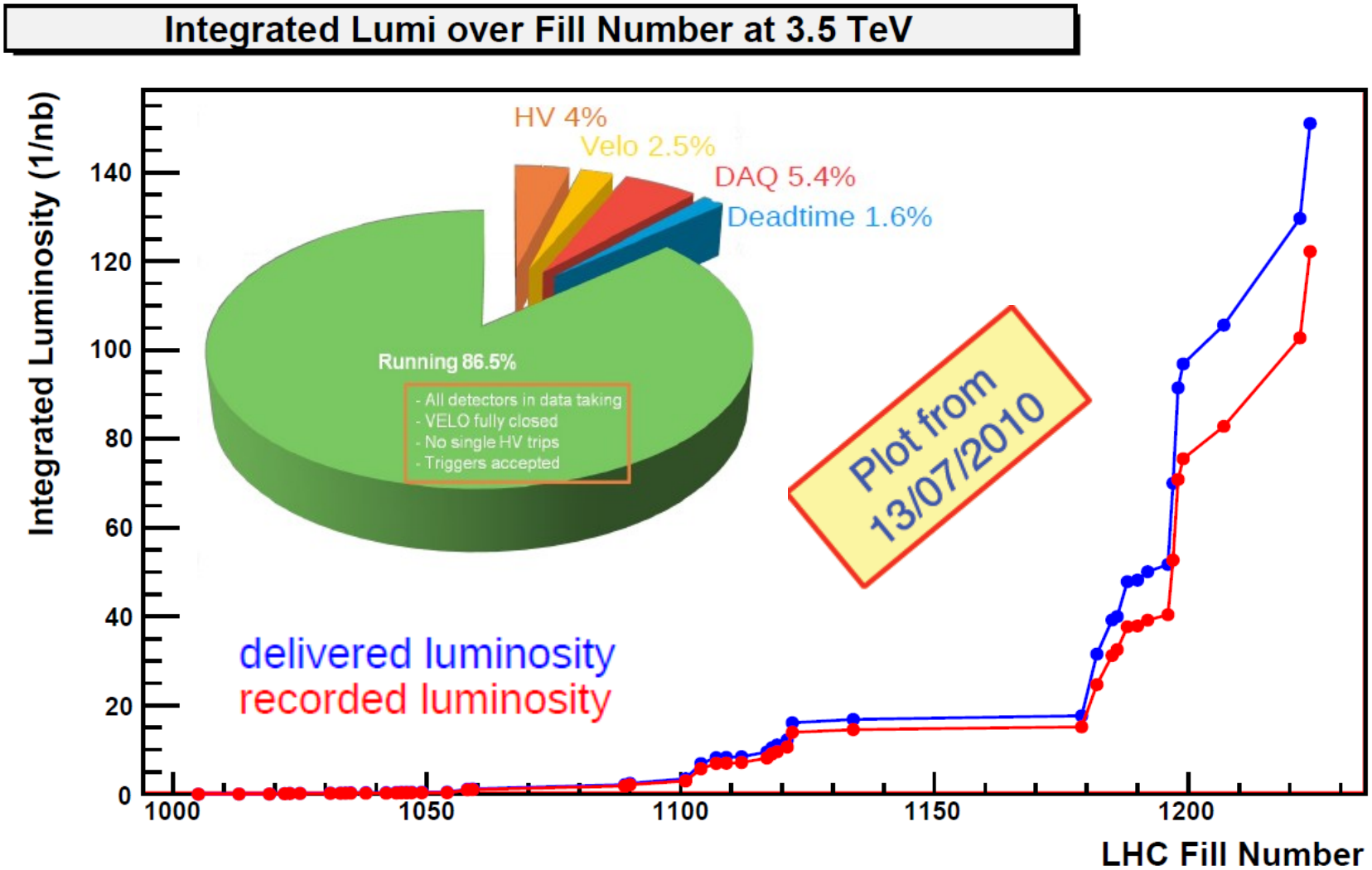
Calorimeters:
PID: e,γ, π^0



LHCb excels at:

-displaced vertices resolution
-mass resolution
-particle identification
-efficient and flexible trigger

Integrated luminosity and outlook



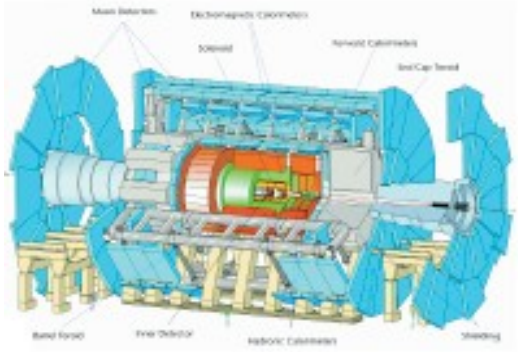
Expected: 0.2 fb^{-1} end 2010 and 1.0 fb^{-1} by end 2011

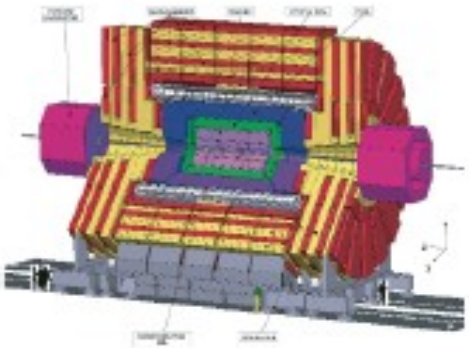
New Physics discovery at LHC

Two **complementary approaches** to New Physics at LHC:

- Direct: look for new massive **real particles** with predicted decay modes

ATLAS

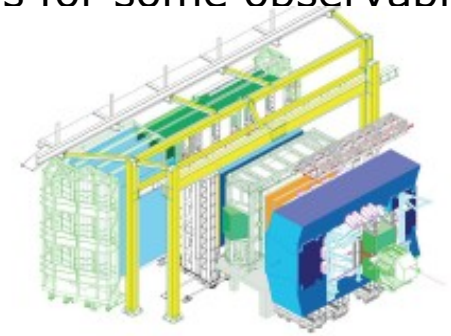




CMS

- Indirect: search for deviations from SM expectations for some observables due to **virtual particles** contributing to loop processes

LHCb



Remarkable precedents

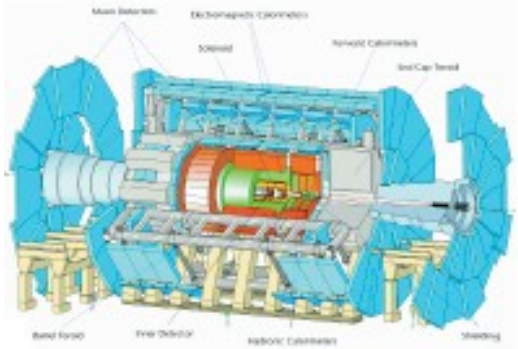
- Introduction of **charm in GIM mechanism** (1970): charm observed directly 1974.
- Observation of **neutral currents** effects ($\nu+N\rightarrow\nu+N$) in 1973:Z vector boson Z 1983.
- Introduction of **third quark family** (1973) to explain CP violation (1964): detection **b** in 1977 and **t** in 1995.
- Measured **B^0 mixing** (1987): top quark much heavier than expected.

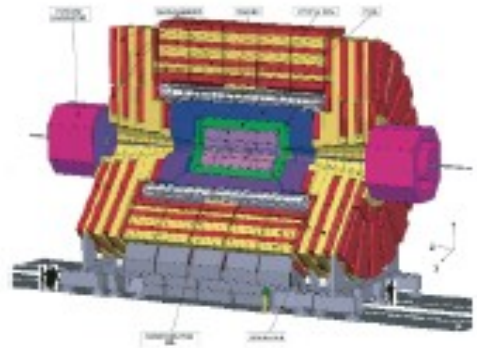
New Physics discovery at LHC

Two **complementary approaches** to New Physics at LHC:

- Direct: look for new massive **real particles** with predicted decay modes

ATLAS





CMS

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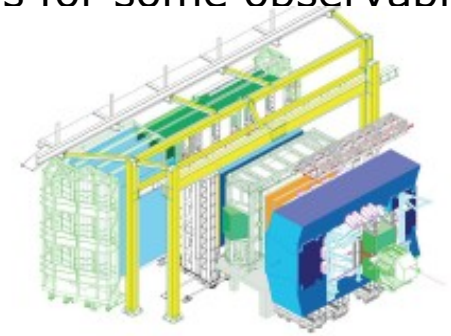
LHCb



Remarkable precedents

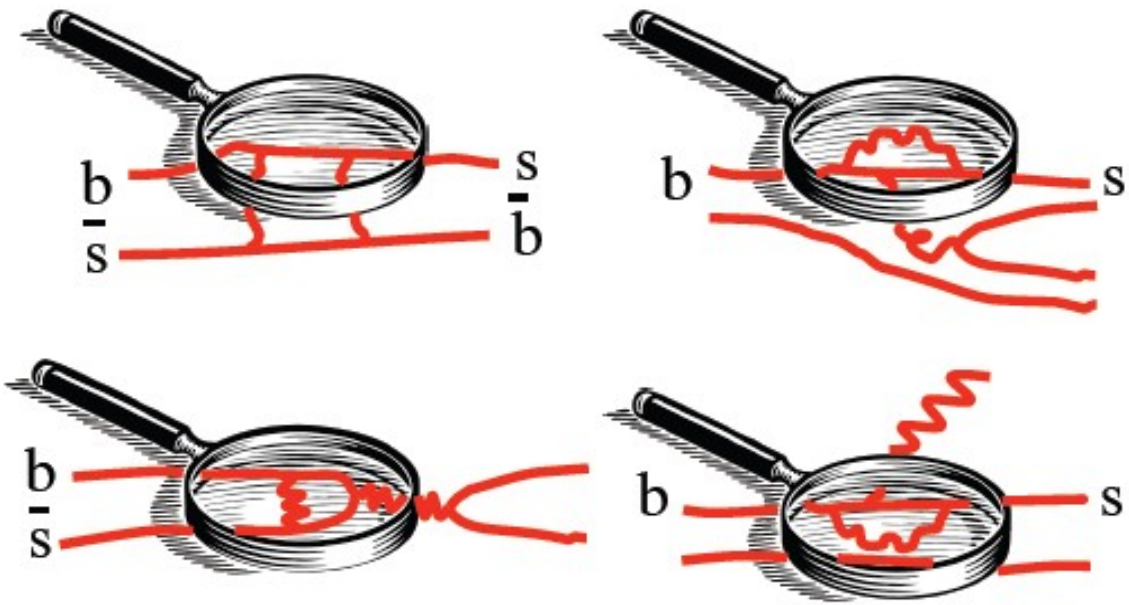
- Introduction of **charm in GIM mechanism** (1970): charm observed directly 1974.

Allows access to higher energy scales and detection of effects from New Physics before direct searches

- Measured **B^0 mixing** (1987): top quark much heavier than expected.

B rare decays and New Physics

- Transitions such as b→d and b→s are produced by flavor changing neutral currents (**FCNC**), only allowed in the SM at **loop level** (hence ***rare***)
- **b→s are less constrained** by current data, so ideal system to dedicate careful study
- Probe NP indirectly through **properties of Bd and Bs decays** mediated by loop (***box*** or ***penguin***) diagrams



B rare decays and New Physics

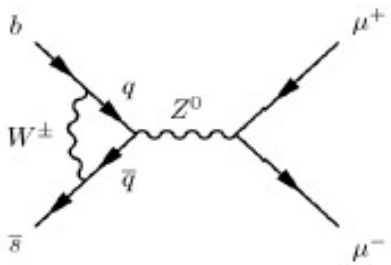
- These processes can be described by an effective Hamiltonian, in the form of an **Operator Product Expansion**

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \Big[\underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C_i'(\mu) O_i'(\mu)}_{\text{right-handed part suppressed in SM}} \Big]$$

$i = 1,2$	Tree
$i = 3-6,8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9,10$	Electroweak penguin
$i = S$	Higgs (scalar) penguin
$i = P$	Pseudoscalar penguin

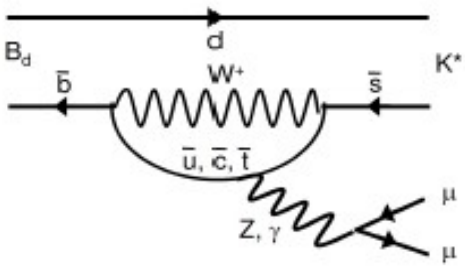
- New Physics **modifies C_i (Wilson coefficients)**, affecting observables
- **LHCb rare decays program: measure observables from which NP contribution can be extracted in order to constraint BSM models**

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



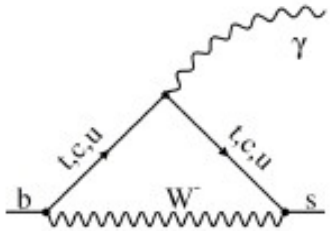
C_S, C_P and C_{10}

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



C_7, C_9 and C_{10}

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



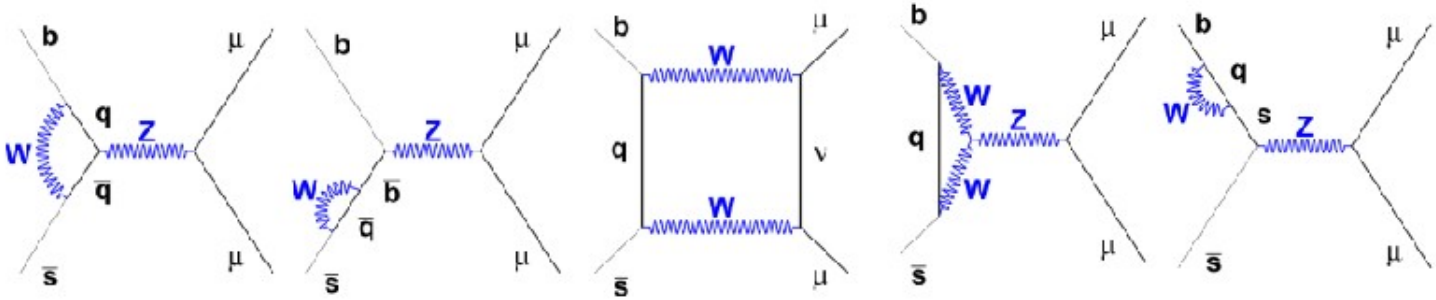
$\frac{C_{7R}}{C_{7L}}$

$$\mathcal{B}^{0}_{s} \to \mu\mu$$

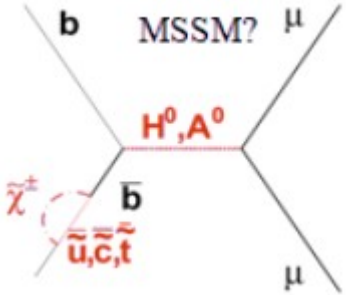
C_S, C_P and C_{10}

$B_s \to \mu\mu$

- Highly **suppressed decay** in SM: $(3.2 \pm 0.2) \times 10^{-9}$ (Buras, Physics at LHC 10)



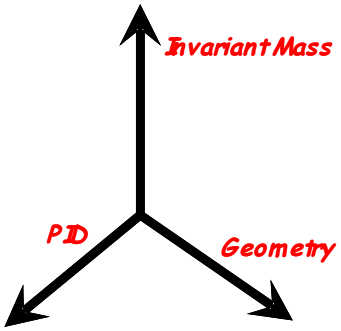
- Branching Ratio can be strongly **enhanced** by contribution from Higgs sector in NP models



- Present limit from CDF ($3.7\ fb^{-1}$): $BR < 3.6 \times 10^{-8}$ at 90% CL

$B_s \to \mu\mu$

- **$B_s \to \mu\mu$ analysis at LHCb** is based on a loose preselection followed by classification of events as signal or background based on a likelihood built from 3 independent variables, validated with control channels ($J/\Psi \to \mu\mu$,$B \to hh$):
  - **Invariant dimuon mass**: Tracking system
  - **Particle ID**: Muon detector, Calorimeter, RICH
  - **Geometrical likelihood** (IP, Doca, B lifetime, etc): Vertex detector



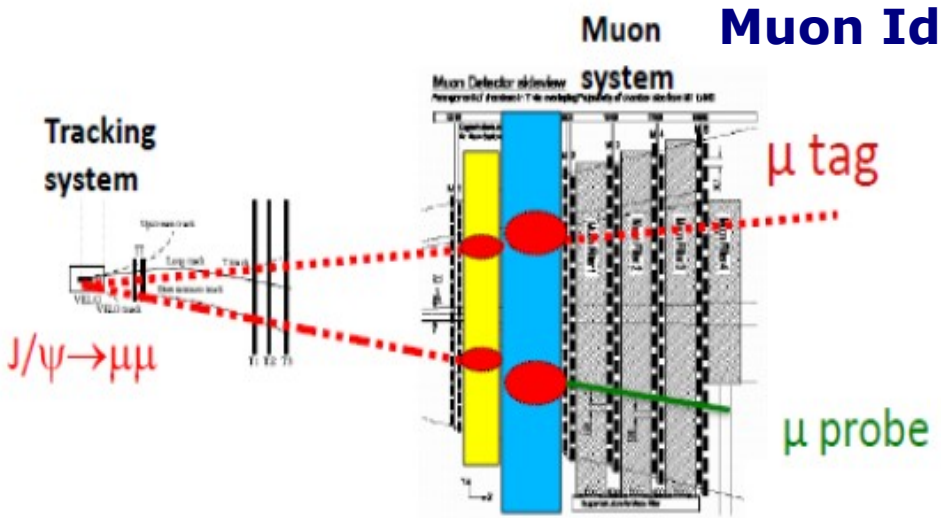
- Branching Ratio extracted using Bd and Bu **normalization channels** with well known BRs. This introduces main systematic uncertainty (~13%) from hadronization fractions

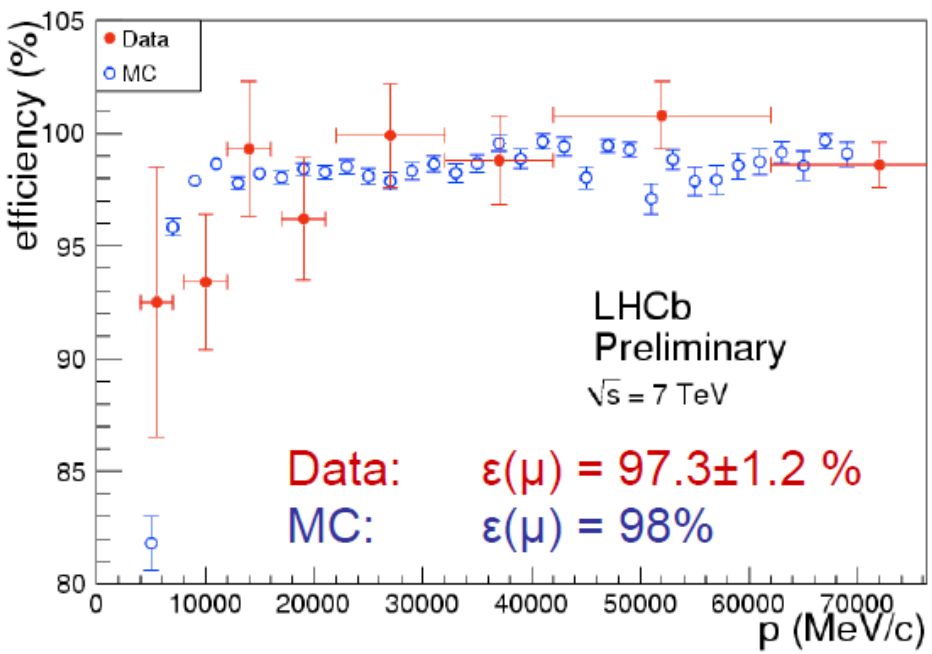
$$BR(B_s) = BR(B^{norm}) \times \frac{N_{Bs}^{GL}}{N_{Bnorm}^{Tight}} \times \frac{\varepsilon_{Bnorm}^{REC}}{\varepsilon_{Bs}^{REC}} \times \frac{\varepsilon_{Bnorm}^{Sel|REC}}{\varepsilon_{Bs}^{Sel/REC}} \times \frac{\varepsilon_{Bnorm}^{Trig|Sel}}{\varepsilon_{Bs}^{Trig|Sel}} \times \boxed{\frac{f_{Bnorm}}{f_{Bs}}}$$

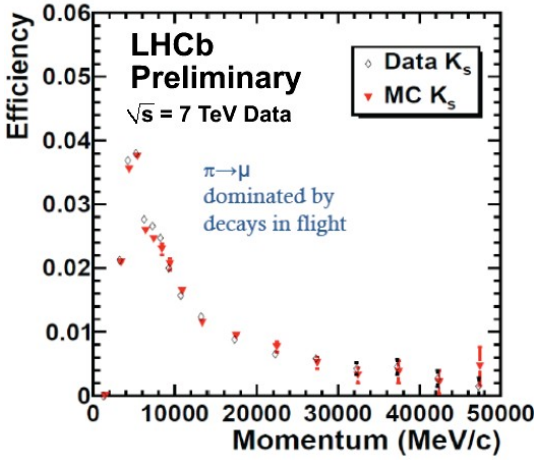
- Plan to use **new method to measure fd/fs** from $Bs \to Ds\pi$ and $Bd \to DK$ (R. Fleischer, N. Serra, N. Tuning, arXiv:1004.3982)

$B_s \to \mu\mu$

Muon Identification

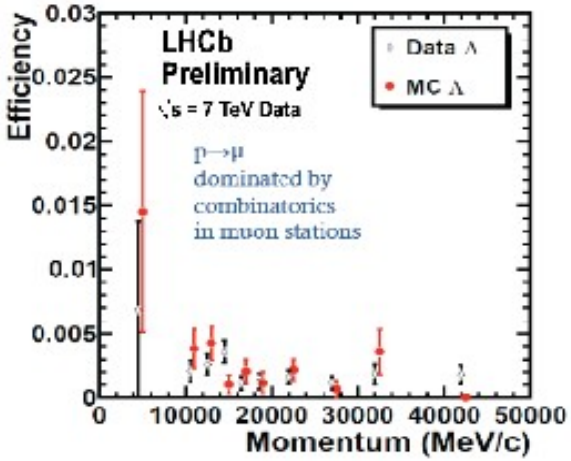






$P(\pi \to \mu)_{Data} = 2.38 \pm 0.02\,\%$

$P(\pi \to \mu)_{MC} = 2.34 \pm 0.02\,\%$

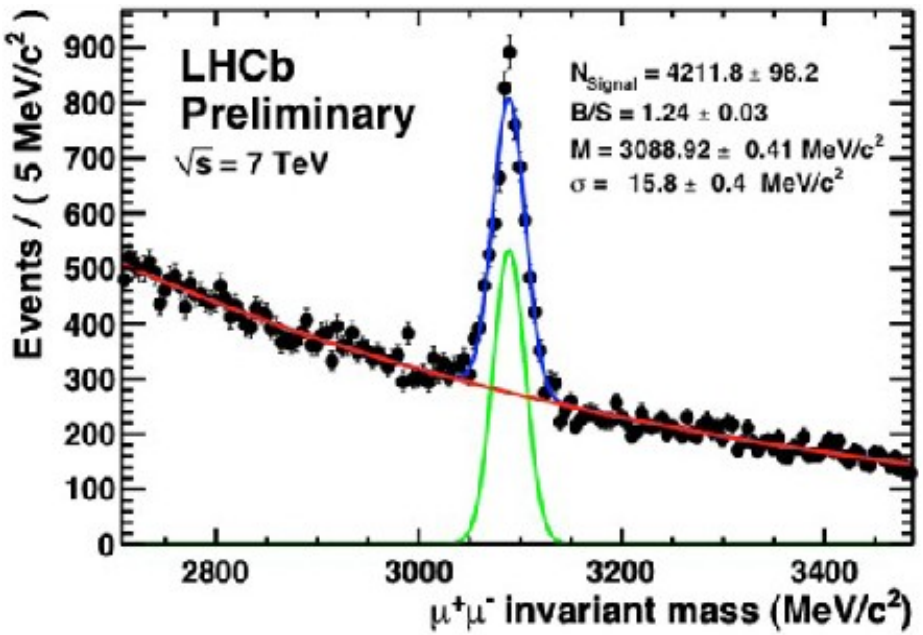


$P(p \to \mu)_{Data} = 0.18 \pm 0.02\,\%$

$P(p \to \mu)_{MC} = 0.21 \pm 0.04\,\%$

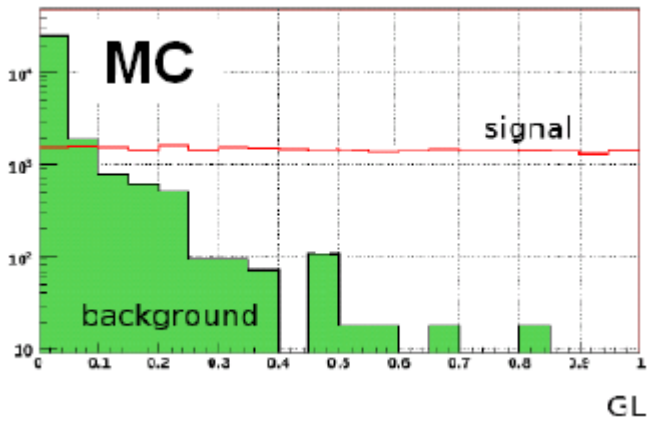
$B_s \to \mu\mu$

Invariant mass resolution from $J/\Psi \to \mu\mu$

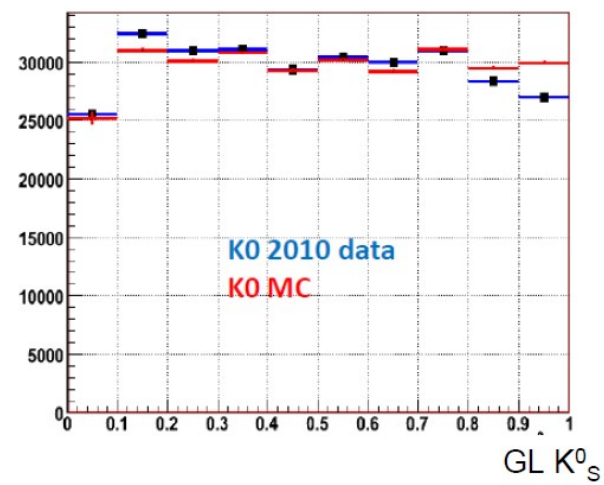


$\sigma = 15.8 \pm 0.4 \ \mathrm{MeV/c^2}$

Geometrical likelihood and validation with V0 data



$K_s \to \pi\pi$

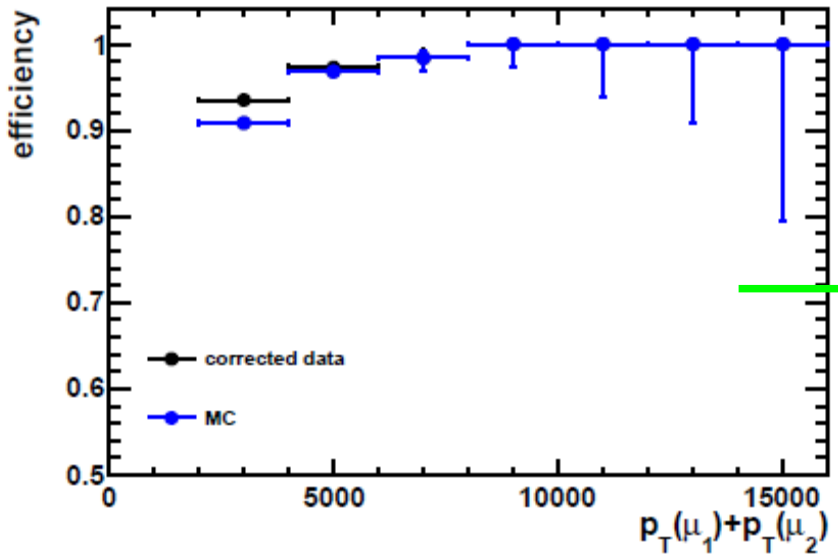


$B_s \to \mu\mu$

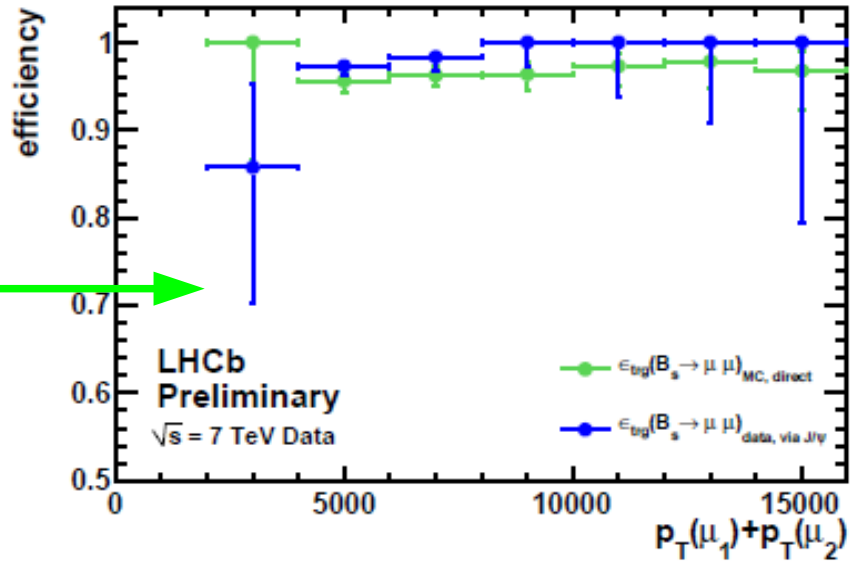
Muon Trigger efficiency:

- extracted from trigger unbiased $J/\Psi \to \mu\mu$ data
- extrapolated to MC $Bs \to \mu\mu$ spectrum

$J/\Psi \to \mu\mu$ eff. data and MC



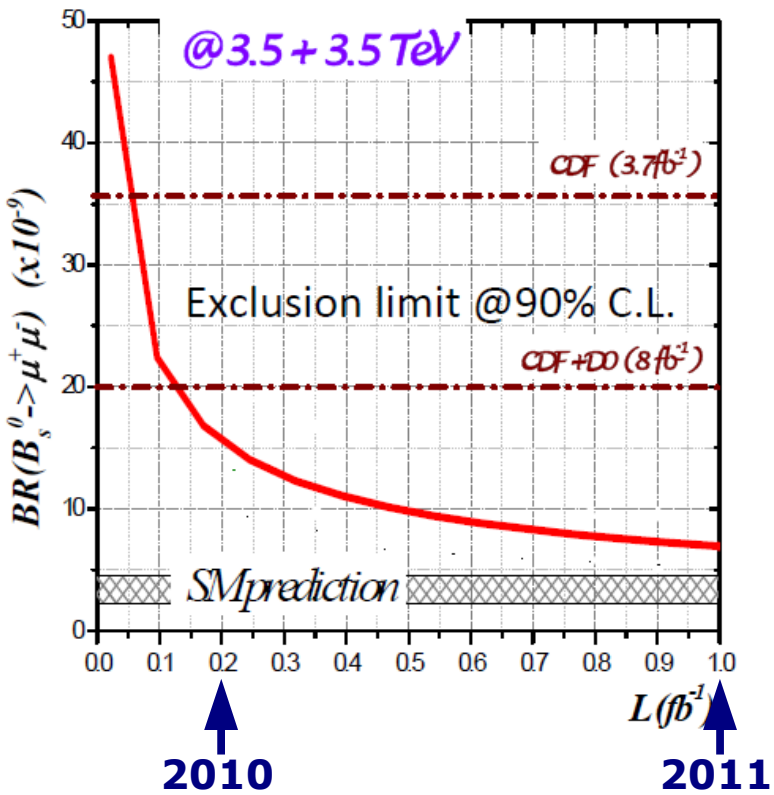
MC $Bs \to \mu\mu$ eff from data $J/\Psi \to \mu\mu$ and MC

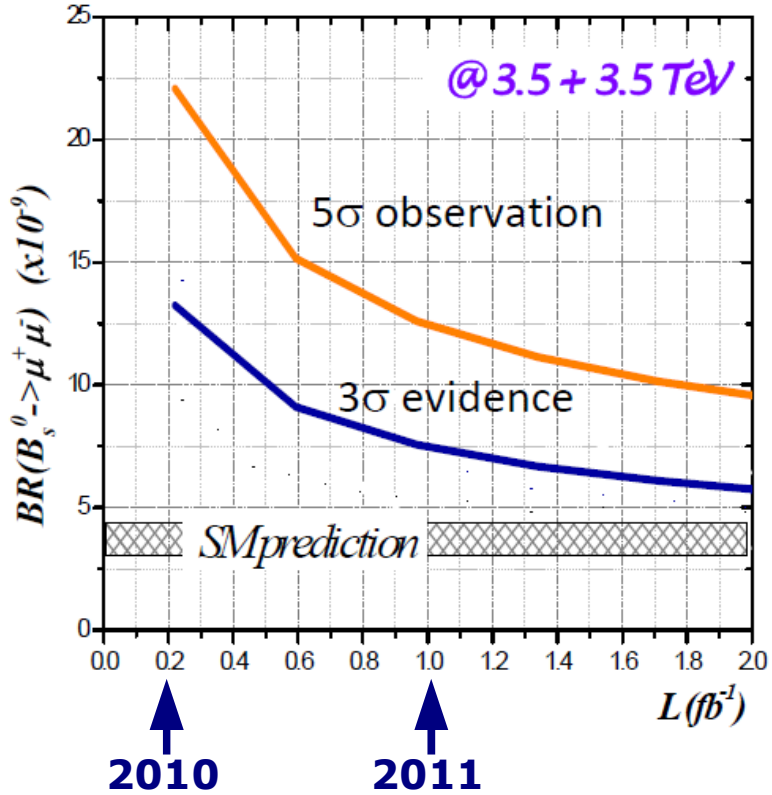


$$\epsilon_{trg}(B_s^0 \to \mu^+\mu^-)_{data} = 98.8 \pm 0.2(stat) \pm 1.3(syst)\%,$$

$B_s \to \mu\mu$

- **Prospects for $B_s \to \mu\mu$ analysis at LHCb:** Having validated with data main parts of the analysis, we regard as realistic





- **Improve current best experimental limit: 0.1 fb^{-1}**
- **Exclude BR above ~7×10^{-9}: 1 fb^{-1}**
- **5σ observation to BR=3xSM: 2 fb^{-1}**

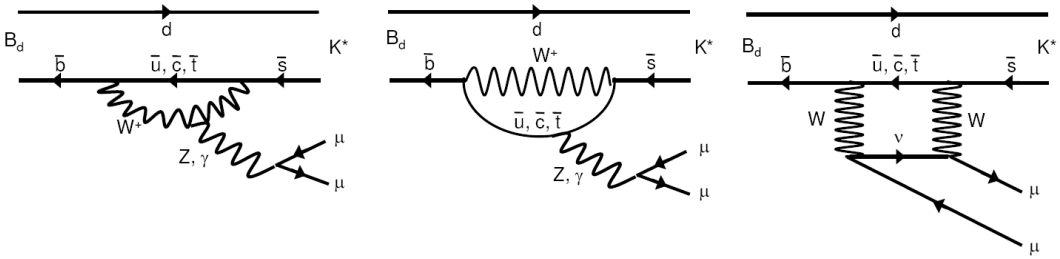
$B^0 \to K^{0*}\mu\mu$

C_7, C_9 and C_{10}

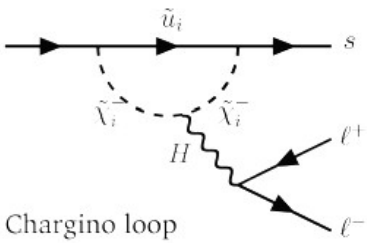
$B_d \to K^* \mu\mu$

- Rare decay whose amplitude gets contributions from several operators

SM

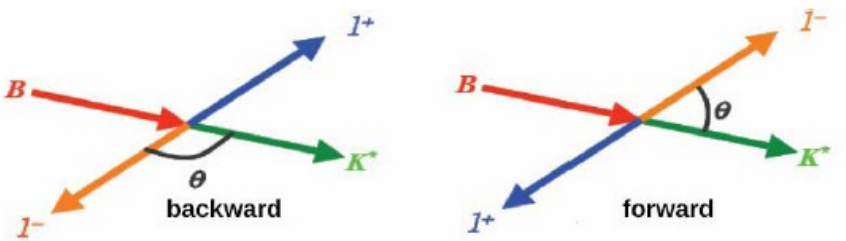


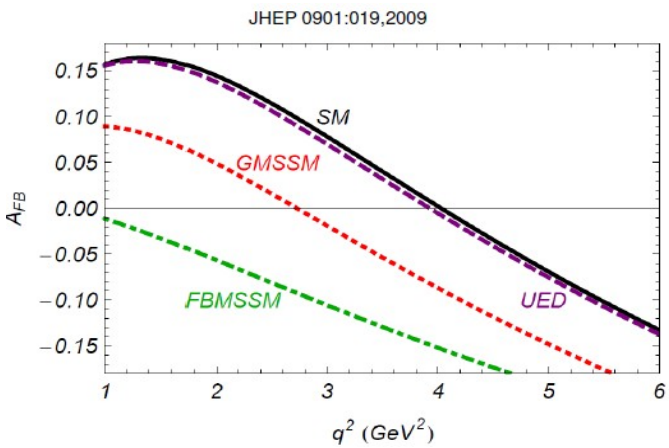
NP



- Measured **BR in agreement** with SM ($\sim 10^{-6}$)
- However **angular distributions are sensitive to NP**
- Cleanest observable is zero crossing point in the Forward-Backward asymmetry (defined by the direction of $\mu+$ with respect to B in the rest frame of the $\mu+\mu-$ system, as a function of $q^2 = m^2_{\mu\mu}$)

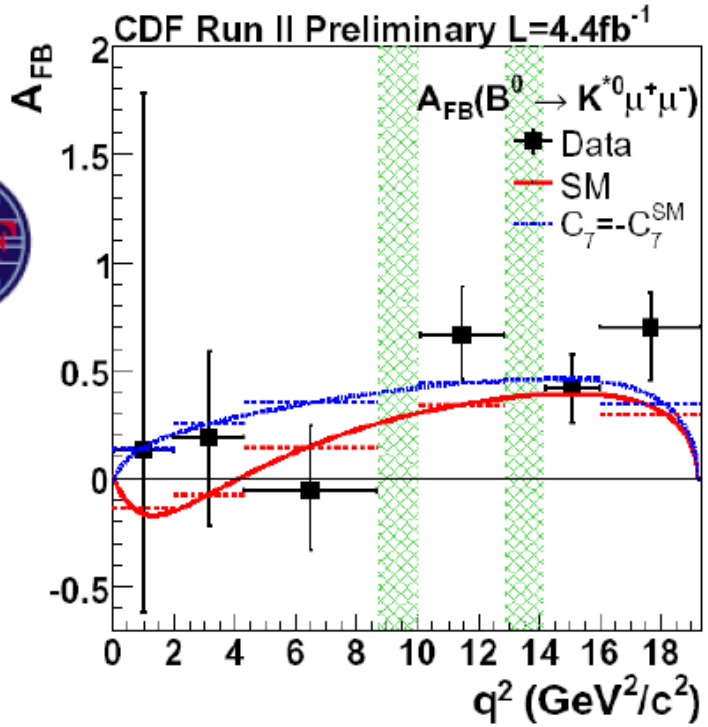
$$A_{FB}(q^2) = \frac{N_F - N_B}{N_F + N_B}$$

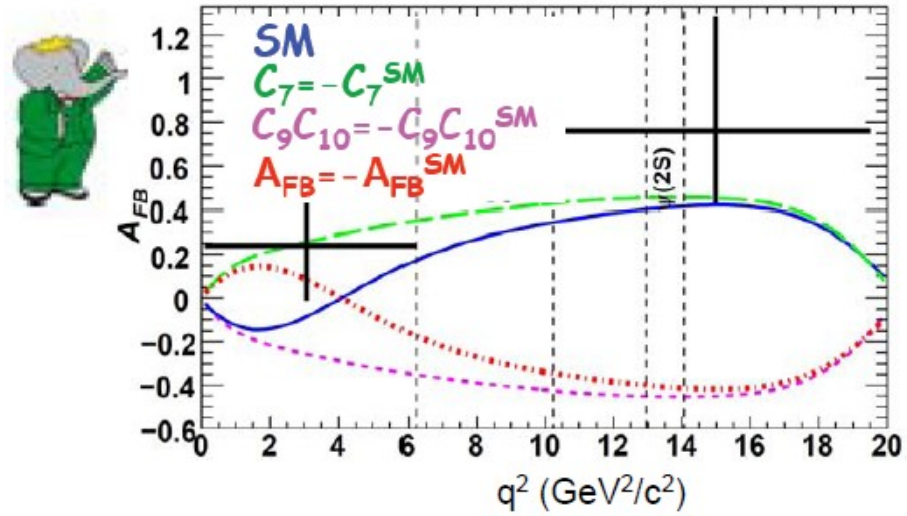




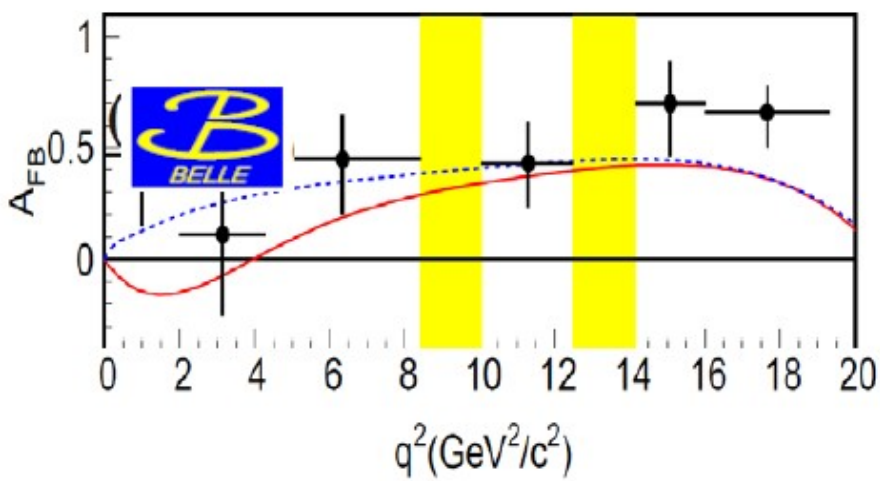
$B_d \to K^* \mu\mu$

- Current knowledge of this observable is still **statistically limited**





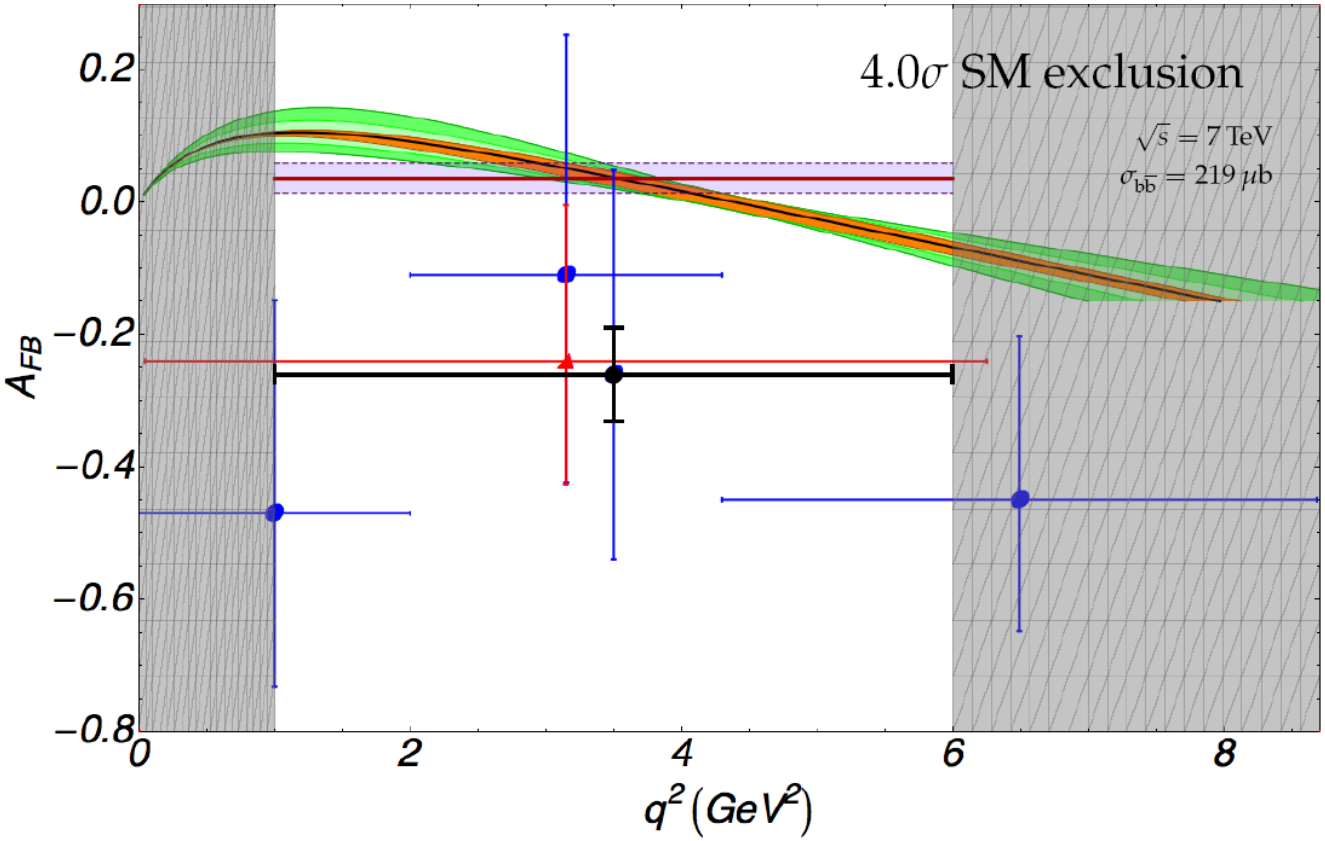
PRD 79 (2009) 031102



PRL 103 (2009) 171801

$B_d \to K^* \mu\mu$

- Prospects at LHCb: if we consider **most sensitive bin** ($1<q^2<6$ GeV^2), and if we assume **Belle central value**: with 1 fb^{-1} (2011) LHCb will get statistical precision enough to exclude SM A_{FB} average value by **4σ**.



Data (fb^{-1})	SM exclusion
0.1	1.5σ
0.3	2.4σ
0.5	3.1σ
1.0	4.0σ

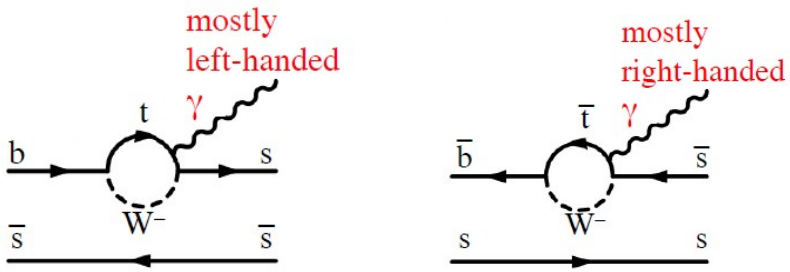
SM bin average
SM prediction
BaBar
Belle
LHCb MC (1 fb-1)

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

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

$B_s \to \phi\gamma$

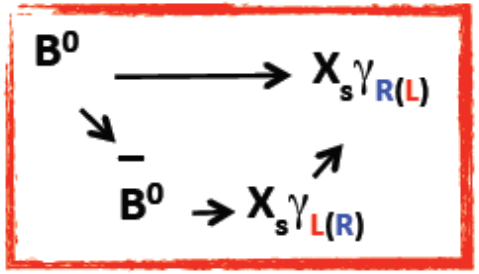
- SM predicts accurately the polarization of the emitted photon: "wrong" polarization is suppressed by m_s/m_b . This is reflected in the ratio of SM value for Wilson coefficients $C'_7/C_7 \sim 0.04$.
- Measurement of $\tan\psi$ (**wrong polarization fraction**) constraints contribution of New Physics to radiative penguin processes



$$\tan\psi = \left| \frac{A(\overline{B}_s^0 \to \phi\gamma_{right})}{A(\overline{B}_s^0 \to \phi\gamma_{left})} \right|$$

$b \to s\gamma_L + (m_s/m_b) \times s\gamma_R$

- Wrong polarization states accessible from decay or via B_s mixing: photon polarization can be observed from the interference and can be extracted from resulting **time-dependent decay rates**



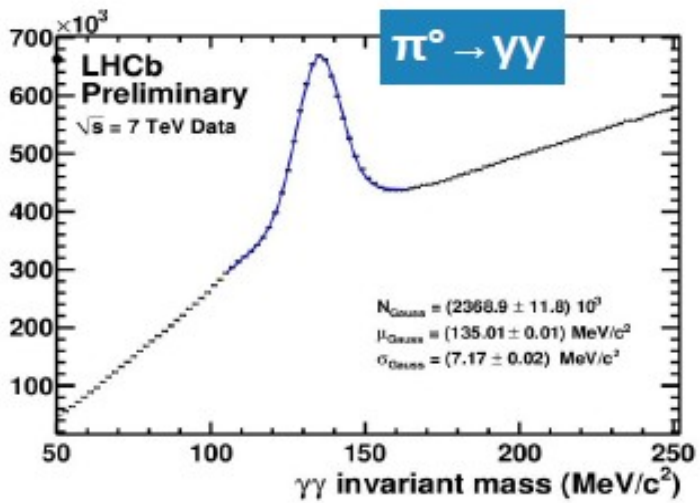
Untagged analysis

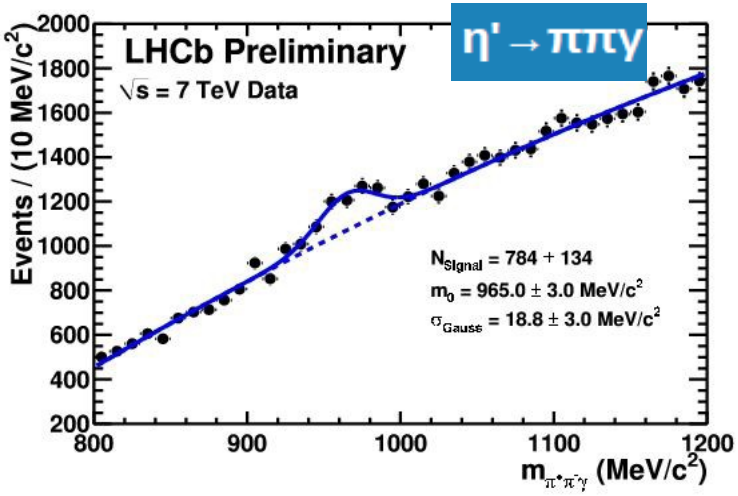
$$\Gamma\left(\overset{(-)}{B}{}_s^0(t) \to \phi\gamma\right) \propto e^{-\Gamma_s t}\left(\cosh(\Delta\Gamma_s t/2) - \sin(2\psi)\sinh(\Delta\Gamma_s t/2)\right)$$

$B_s \to \phi\gamma$

LHCb prospects:

- Low energy **calorimeter calibration** well advanced, for high energy need to collect $B_d \to K^*\gamma$





- To obtain B lifetime, good understanding of **$\phi \to kk$ vertex resolution** is needed. Work started using prompt ϕ
- **Electromagnetic trigger** being commissioned
- **Outlook:**
  - Expect 11×10^3 signal events in nominal year ($2 fb^{-1}$)
  - Statistical resolution in $\sin(2\psi)$ of ~0.2

Summary

- Indirect searches for New Physics is a useful complementary way to direct observation

- LHCb will look for contribution from New Physics to observables in suppressed $b \to s$ decays (FCNC) forbidden at tree level in SM

- Readiness of the LHCb detector suggest promising results:

  - **0.2 fb^{-1} (2010)**: improve on current NP constraints with $B_s \to \mu\mu$

  - **1.0 fb^{-1}(2011)**: find NP or impose tighter constraints with both $B_s \to \mu\mu$ and $B_d \to K^*\mu\mu$

LHCb is a fully functional detector, look out for exciting results very soon!