Results and prospects for di-muon final states at LHCb

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on behalf of the LHCb collaboration

In this talk:

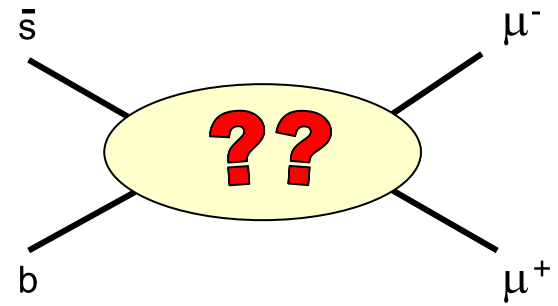
- $B_s \to \mu^+\mu^-$
- $D^0 \to \mu^+\mu^-$
- $B \to K^*\mu^+\mu^-$

Physics at the LHC 2010, Hamburg

Introduction

- $B_s \to \mu^+\mu^-$, $D^0 \to \mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ involve Flavor Changing Neutral Current
  - Forbidden at the tree level in the SM
  - *Virtual* new particles can appear in the loops

    ⇒ Indirect searches for new physics

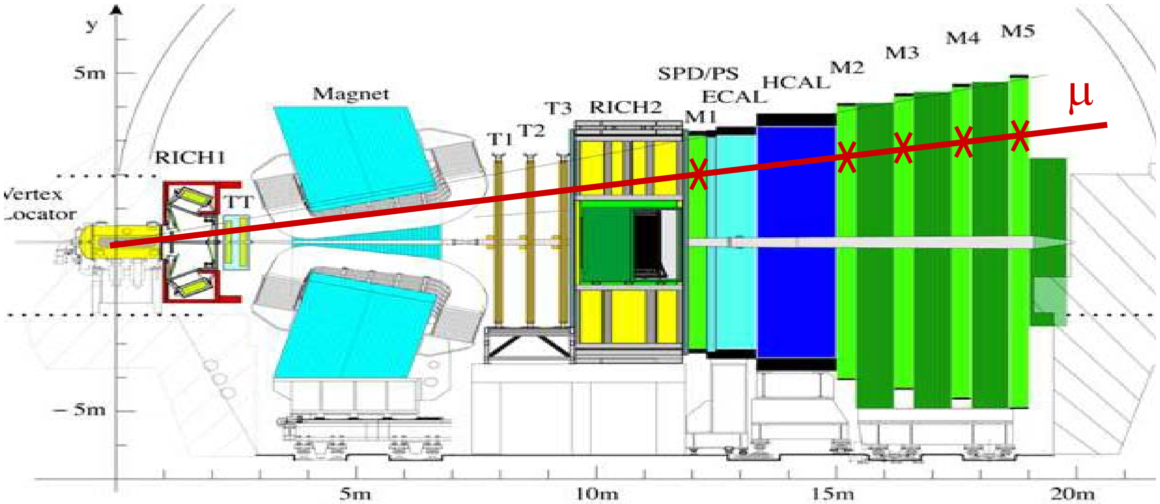


- These analysis require:
  - Efficient trigger on muon
  - Excellent muon identification
  - Excellent tracking and vertexing

Can be validated with currents 2010 data

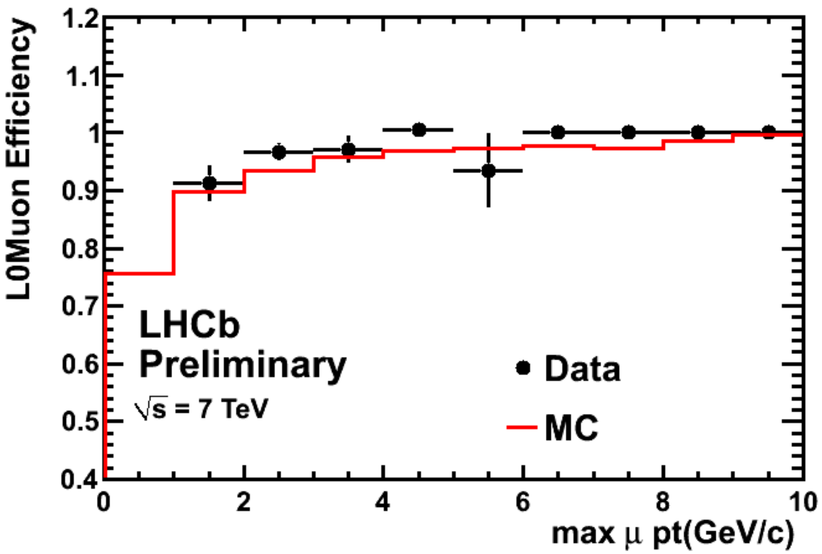
$J/\psi \to \mu\mu$ $D^0 \to K\pi$
$K_s \to \pi\pi$ $\Lambda \to p\pi$

Level 0 Muon trigger



- Hardware trigger
- Search for high pT muon using a standalone reconstruction
- Current running conditions allow to have a low threshold: pT>320MeV (nominal threshold ~1GeV)

L0 Muon trigger efficiency has been validated using J/ψ →μμ events triggered by an independent unbiased trigger:

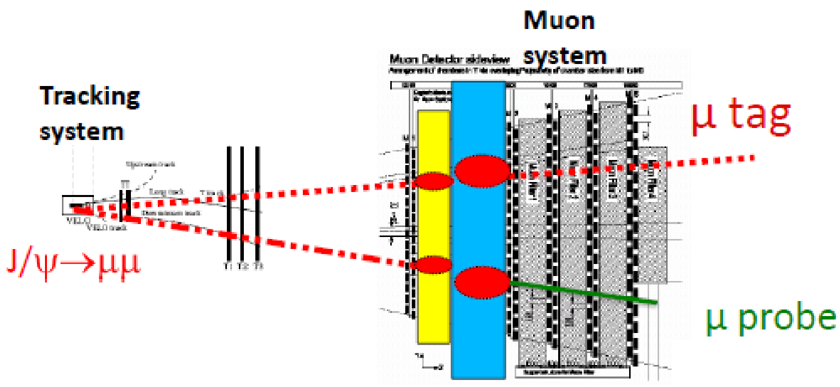


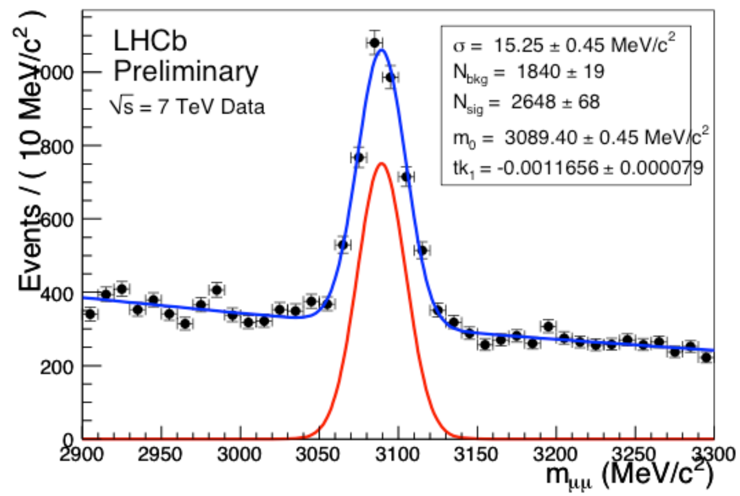
Data: 95.5±1.3%

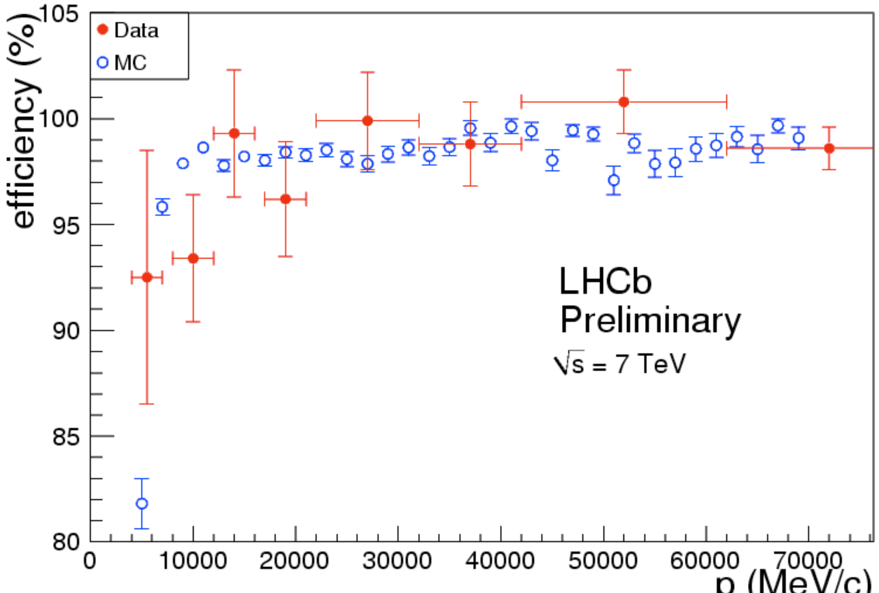
MC: 93.7±0.1%

Muon identification I

Muon identification efficiency using tag and probe method with $J/\psi \to \mu\mu$





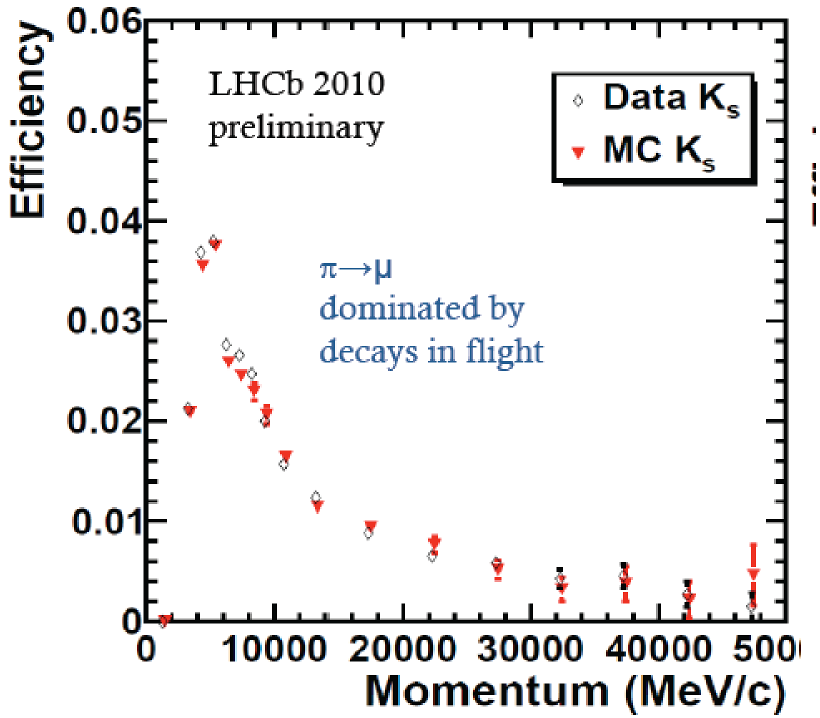


Data: $\varepsilon(\mu) = 97.3 \pm 1.2$ %

MC: $\varepsilon(\mu) = 98\%$

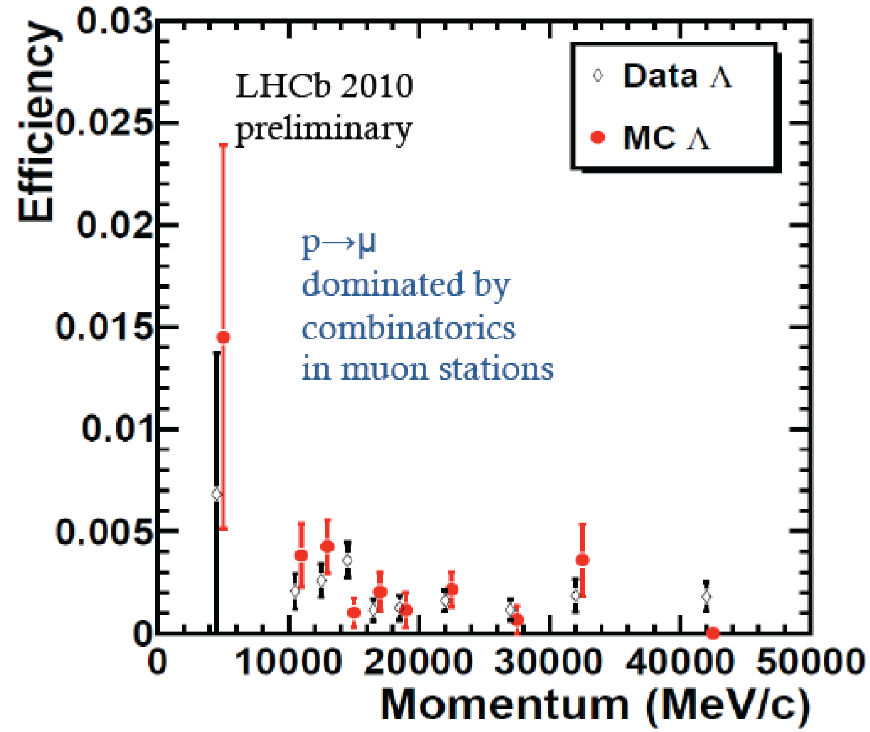
Muon identification II

Pion misidentification using $K_s \to \pi\pi$



Data:
(2.38±0.02)%
MC:
(2.34±0.02)%

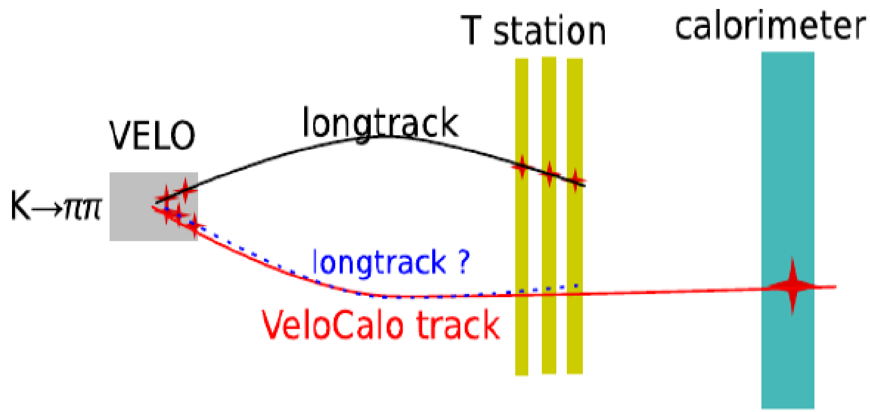
Proton misidentification using $\Lambda \to p\pi$

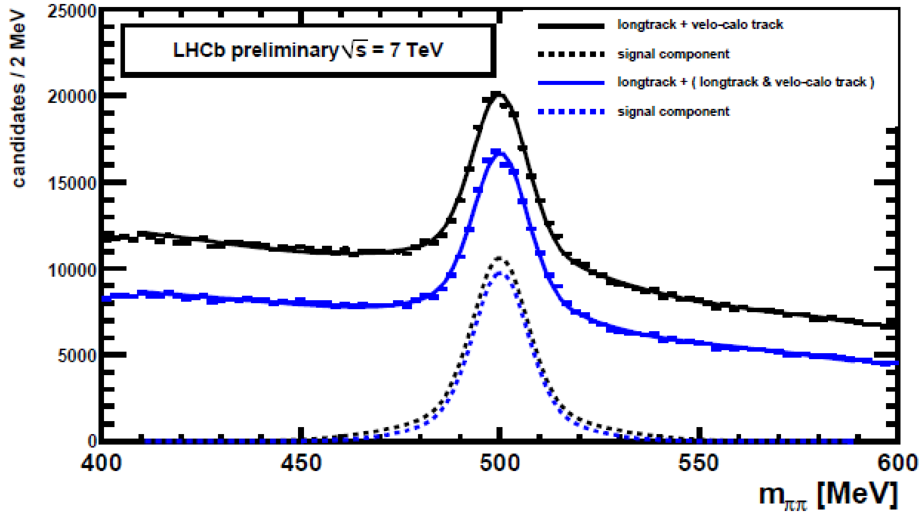


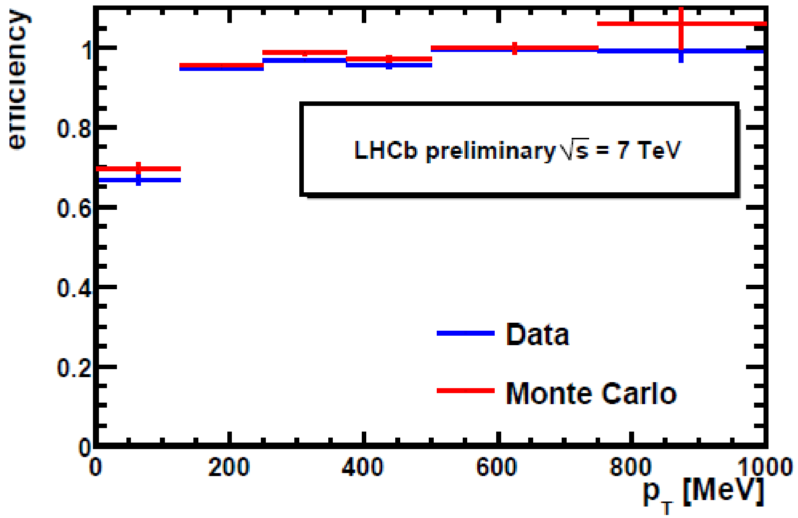
Data:
(0.18±0.02)%
MC:
(0.21±0.04)%

Tracking

Tracking efficiency validated using $K_s \to \pi\pi$





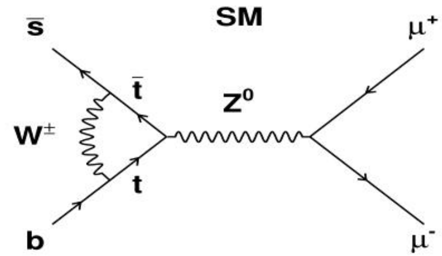


More details in talk by Florin MACIUC

New physics in $B_{s,d} \to \mu^+\mu^-$

New physics in $B_{s,d} \to \mu^+\mu^-$

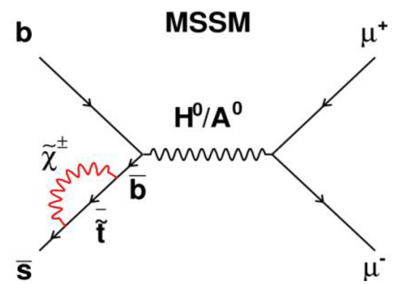
- Highly suppressed decays in the SM:
  $BR(B_s \to \mu^+\mu^-) = (3.6 \pm 0.4) \times 10^{-9}$
  $BR(B_d \to \mu^+\mu^-) = (1.1 \pm 0.1) \times 10^{-10}$
  (A.J.Buras,arXiv:0910.1032)



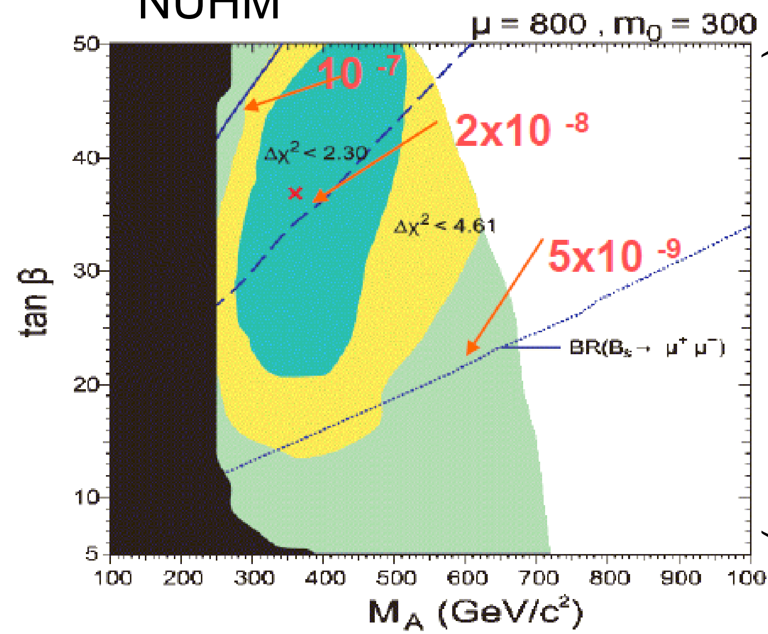
- Current best limit: CDF (3.7 fb^{-1})
  $BR(B_s \to \mu^+\mu^-) < 3.6 \times 10^{-8}$ @ 90% CL
  $BR(B_d \to \mu^+\mu^-) < 6.0 \times 10^{-9}$ @ 90% CL

- New D0 result (6.1 fb^{-1})
  $BR(B_s \to \mu^+\mu^-) < 5.2 \times 10^{-8}$ @ 95% CL

- New physics expectation:
  - MSSM: BR ~ $\tan^6\beta / m^4_H$
  - Little Higgs with T parity: BR enhanced up to 30%
  - Constrained MFV: BR enhanced up to 20%
  - Randall Sundrum: BR enhanced up to 10%



NUHM

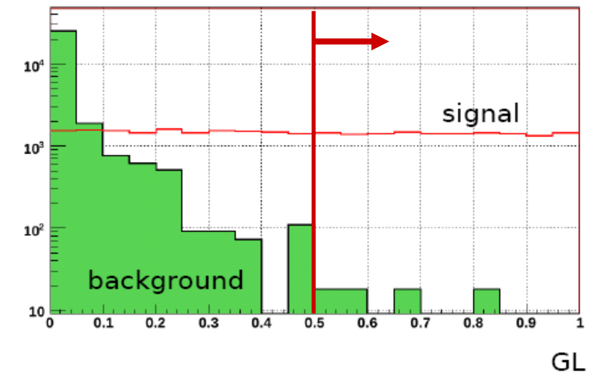


•(J. Ellis et al arXiv:0709.0098)

Analysis overview

- Same philosophy as the one used at the Tevatron: loose preselection then classify events according to a 3D likelihood:
  - $\mu^+\mu^-$ Invariant mass
  - Geometrical likelihood (GL):
    Impact Parameter, B life time, Isolation, DOCA
  - μ identification

Control channels ($B_{(s)} \rightarrow h^+h'^-$) will be used to calibrate with data the geometry and invariant mass likelihoods



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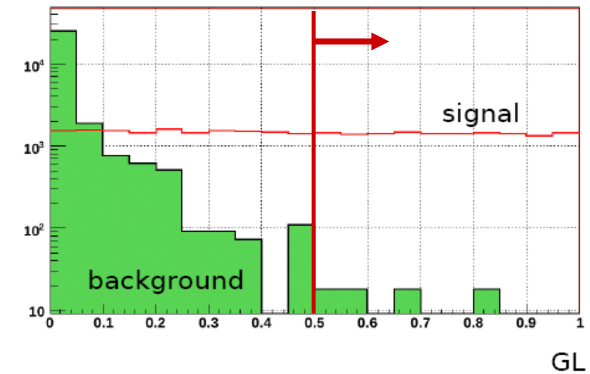


- Use known normalisation channels to derive BR from the event yield

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

  - Normalization channel: $B_d \to K^+\pi^-$ or $B_u \to J/\psi(\mu\mu)K^+$

    $\Rightarrow$ main systematics (~13%) from hadronization rate $f_{u,d} / f_s$

    New method to extract f_d / f_s proposed using $B_s \to D_s\pi$ and $B_d \to D^+K^-$

    (R. Fleischer, N. Serra, N. Tuning, arXiv:1004.3982)

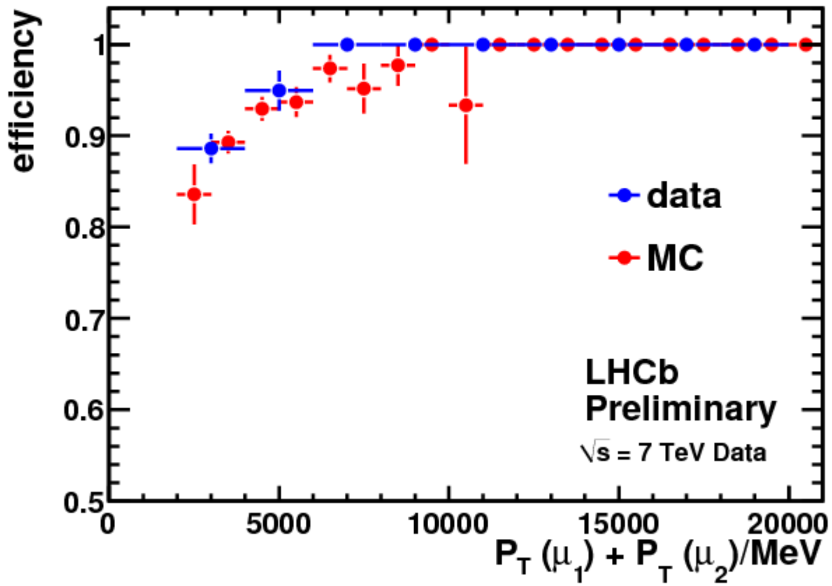
- Extract limit using the modified frequentist approach

Trigger efficiency

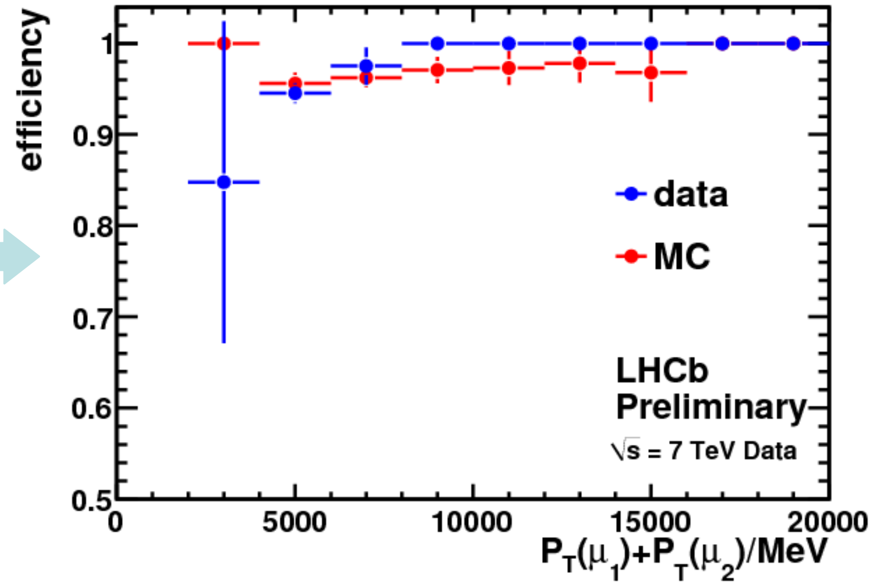
Measure performance of L0*HLT1 (using lifetime unbiased HLT1 lines) for $J/\psi \to \mu\mu$

Transport results to harder p_t spectrum of $B_s \to \mu\mu$

$J/\psi \to \mu\mu$ measured…



…transformed to $B_s \to \mu\mu$

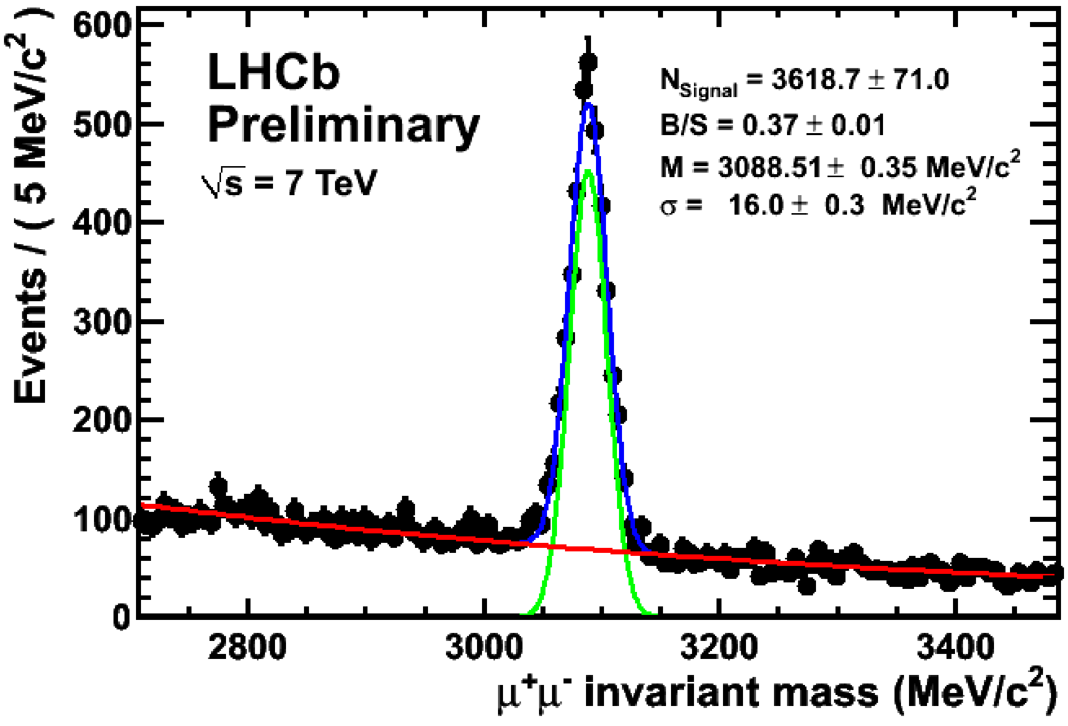


Data	90 %
MC	91 %

Data	94 %
MC	96.5 %

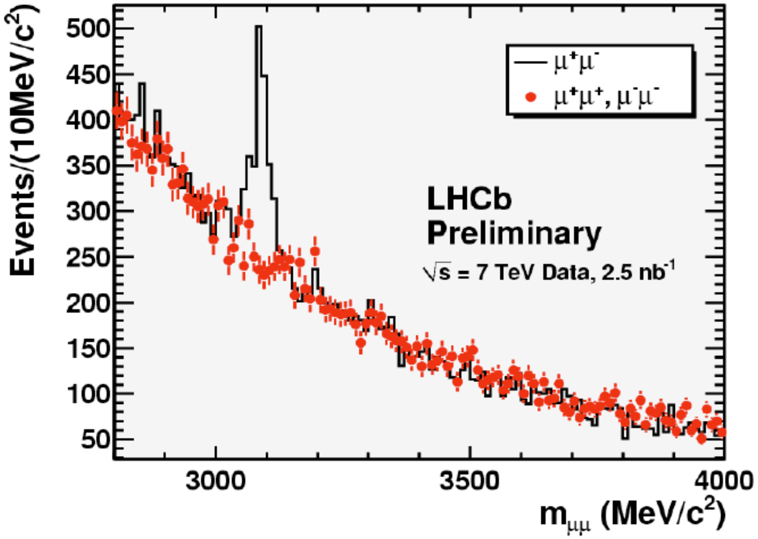
J/ψ studies

Mass resolution with $J/\psi \to \mu\mu$: $\sigma = 16\ MeV/c^2$

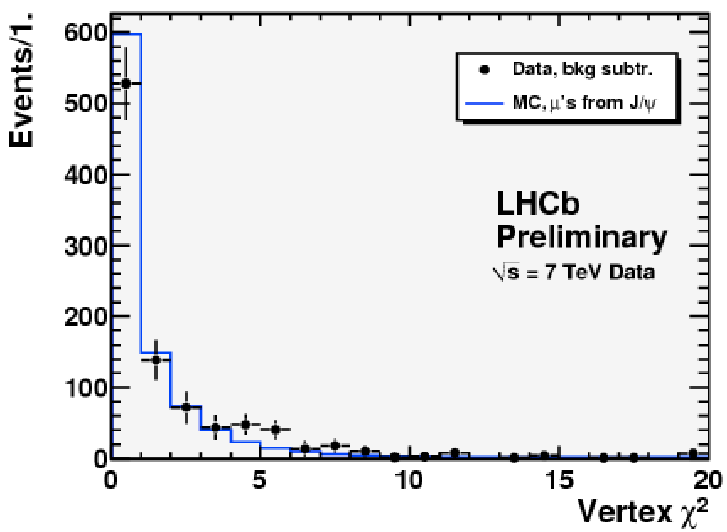


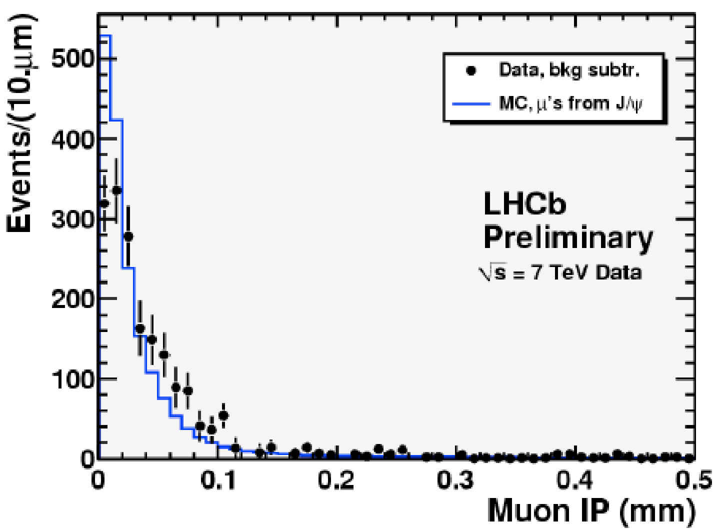
J/ψ studies

Use of same sign events to study J/ψ distributions:



Combinatorial background well reproduced by same sign muons

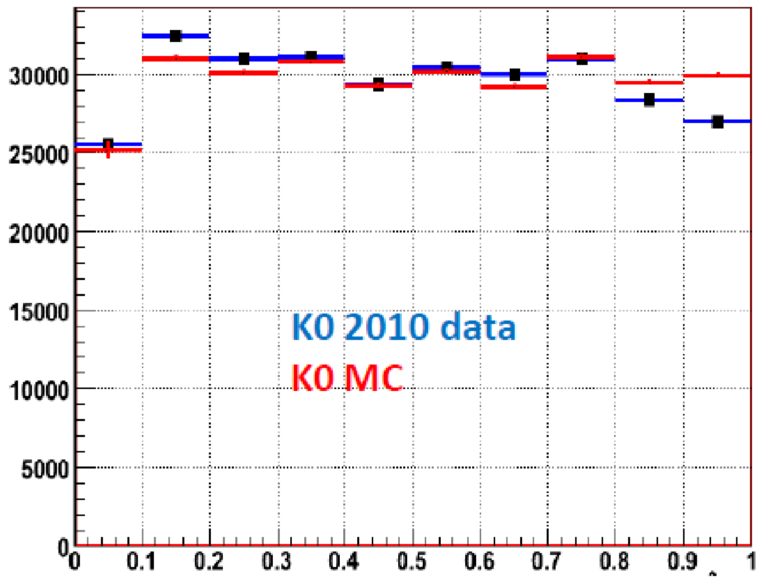




GL studies

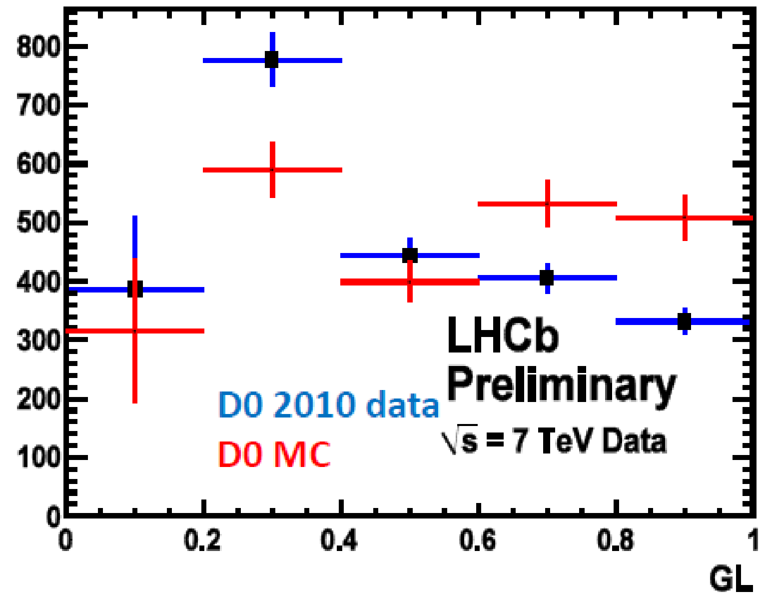
Behaviour of Geometrical Likelihood for signal can already be studied on data by looking at same topology decays

$K_s \to \pi\pi$



GL K^0_S

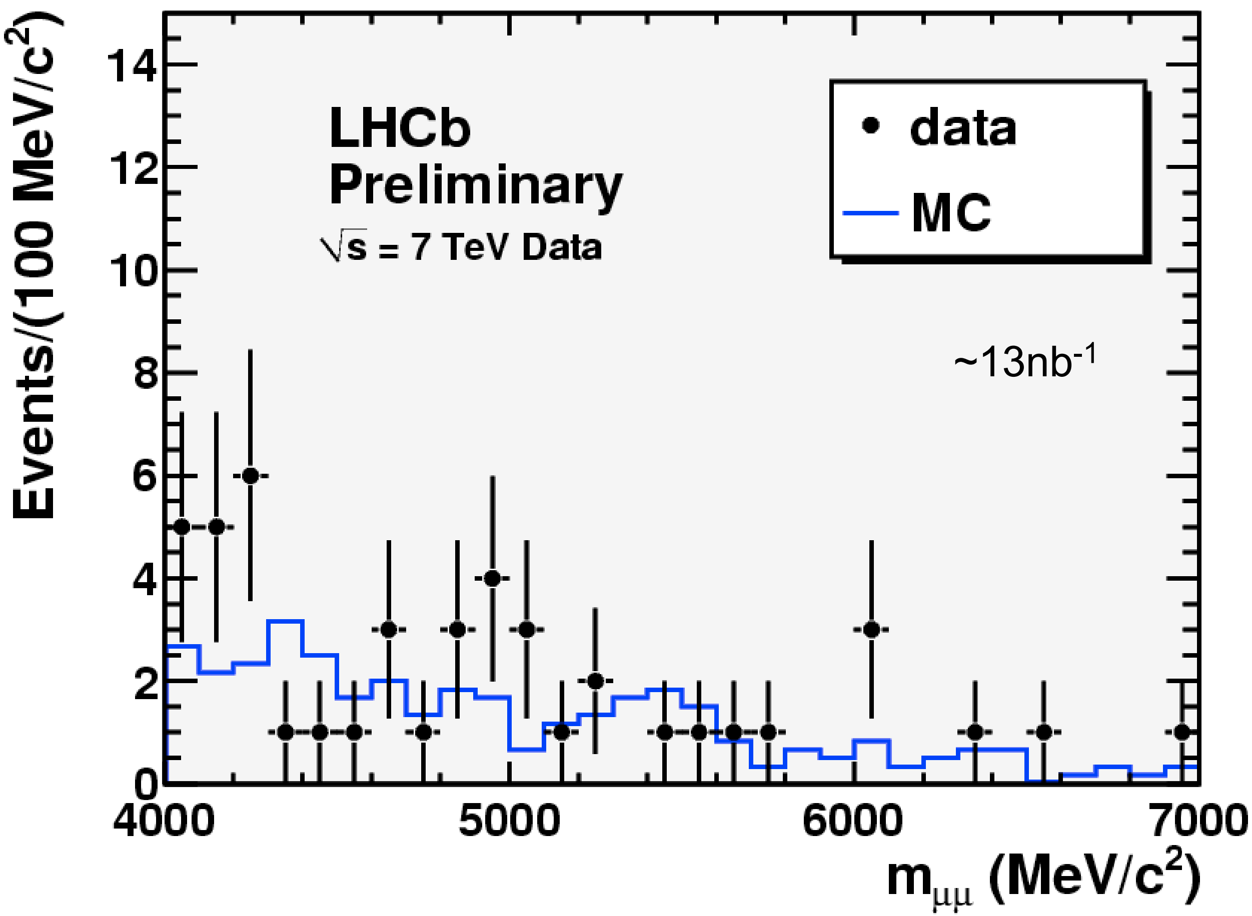
$D^0 \to K\pi$



Reasonable agreement between data and MC, discrepancy mainly due to impact parameter

First look at background

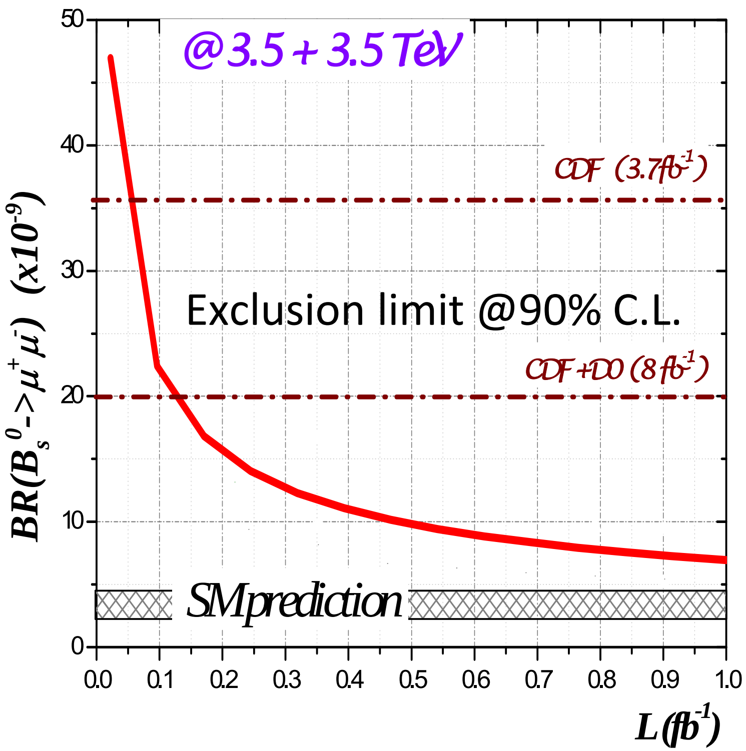
Applying the nominal preselection (LHCb Collaboration, arXiv: 0912.4179)

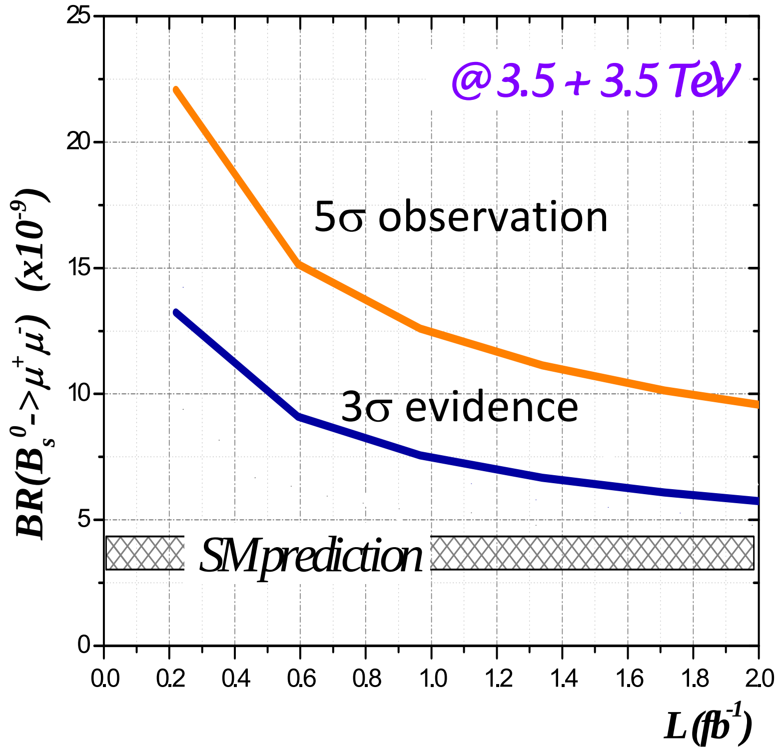


MC normalized to data luminosity

LHCb prospects for $B_s \to \mu^+\mu^-$

All studies with existing data indicate that $B_s \to \mu\mu$ sensitivity as determined from simulation is realistic



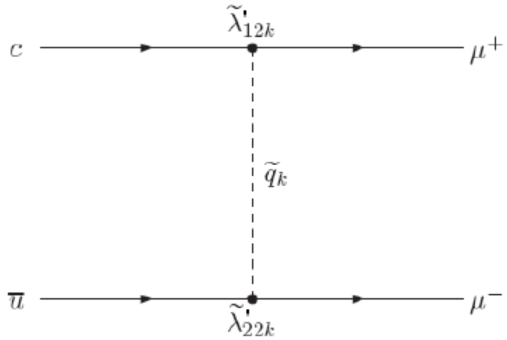


With $0.1\,fb^{-1}$ we can improve the current best experimental limit

With $1\,fb^{-1}$ we can expect to exclude BR up to $\sim 7\times10^{-9}$ @ 90% CL

New physics in $D^0 \rightarrow \mu^+ \mu^-$

New physics in $D^0 \to \mu^+\mu^-$



- Highly suppressed decay in the SM: $BR(D^0 \to \mu^+\mu^-) \sim 3.10^{-13}$
- Can be enhanced in MSSM with R-parity violation up to 10^{-6}

- Current best experimental limit by Belle $BR(D^0 \to \mu^+\mu^-) < 1.4\ 10^{-7}$ @ 90%CL (arXiv:1005.5445)

New physics in $D^0 \to \mu^+\mu^-$

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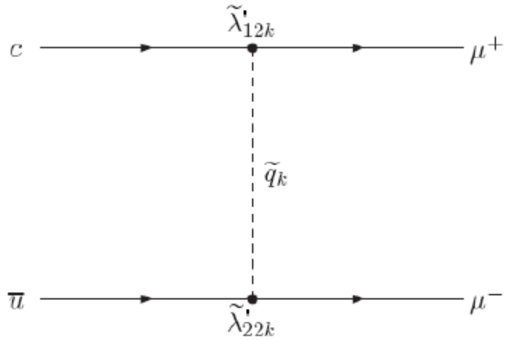


- Current best experimental limit by Belle $BR(D^0 \to \mu^+\mu^-) < 1.4\ 10^{-7}$ @ 90%CL (arXiv:1005.5445)

- Analysis overview :
  - Use $D^* \to D^0\ \pi$
  - Preselection cuts
  - Multivariate analysis based on impact parameter, pT, difference in φ and η between the D^0 and soft π
  - Normalization to $D^0 \to \pi\pi$

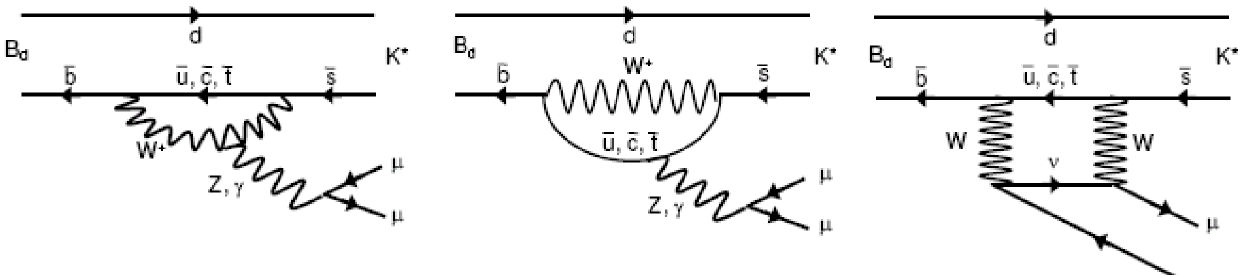
  ⇒ Similar to $B_s \to \mu\mu$ but more difficult due to lower invariant mass and higher background
- LHCb prospects: expected limit for 100 pb^{-1}

$BR(D^0 \to \mu^+\mu^-) < 4.10^{-8}$ @ 90% CL

New physics in $B \rightarrow K^{*} \mu^{+} \mu^{-}$

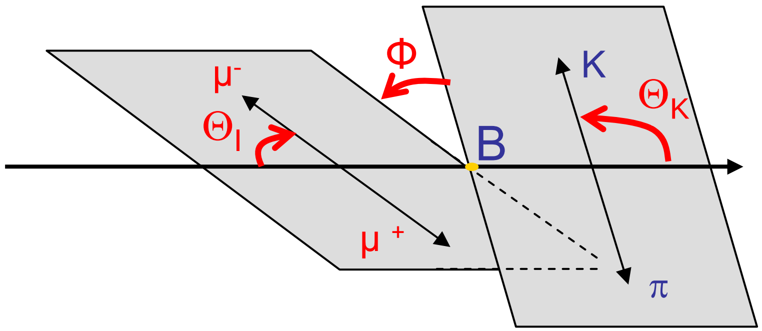
New physics in $B \to K^* \mu^+ \mu^-$

- SM: box and loop diagram, $BR(B \to K^* \mu^+ \mu^-) \sim 10^{-6}$



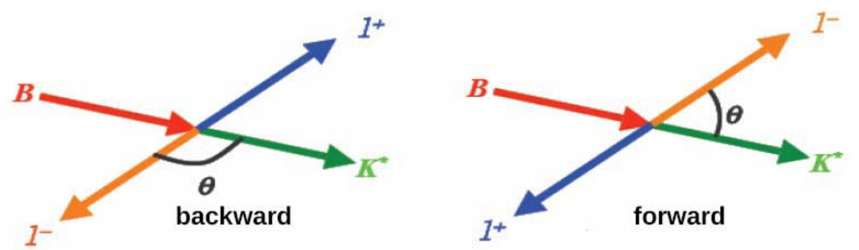
- 4 kinematic variables:

  θ_L, θ_K , φ and $m_{\mu\mu}^2 = q^2$ or s



- Many variables sensitive to new physics

  With the first data, focus on the forward backward asymmetry A_{FB}

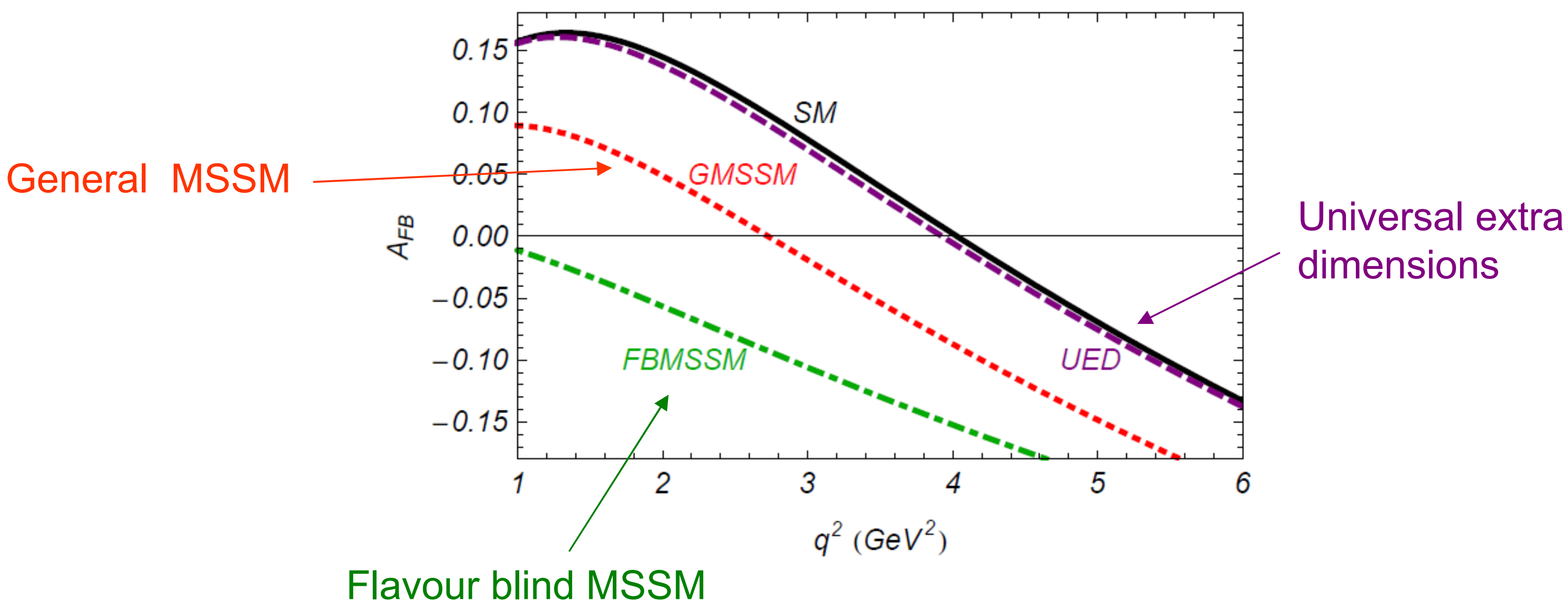


$$A_{FB}(q^2) = \frac{N_F - N_B}{N_F + N_B}$$

New physics in $B \to K^{*} \mu^{+} \mu^{-}$

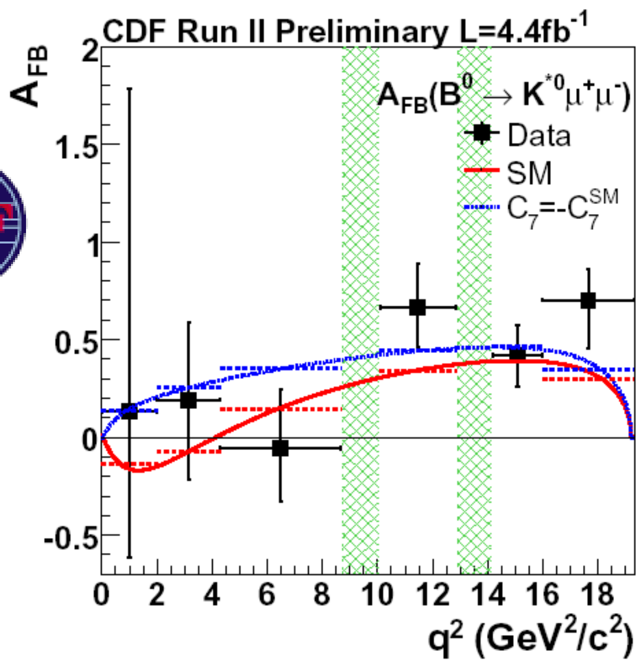
A_{FB} well predicted in the SM, especially at the zero crossing point where hadronic uncertainties minimized

W. Altmannshofer et al
arXiv:0811.1214

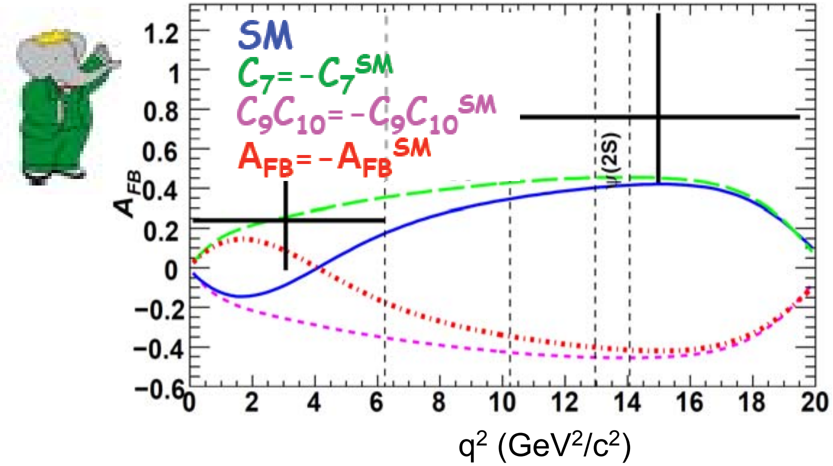


Measurement status

CDF: ~100 $K^*l^+l^-$ events

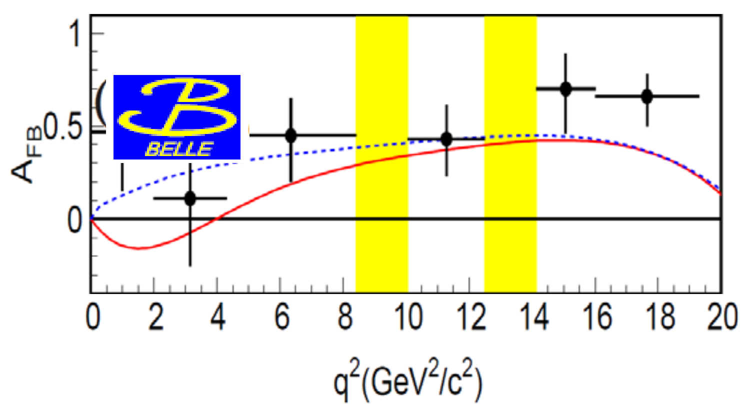


BABAR: ~100 $K^*l^+l^-$ events



PRD 79 (2009) 031102

Belle: ~250 $K^*l^+l^-$ events

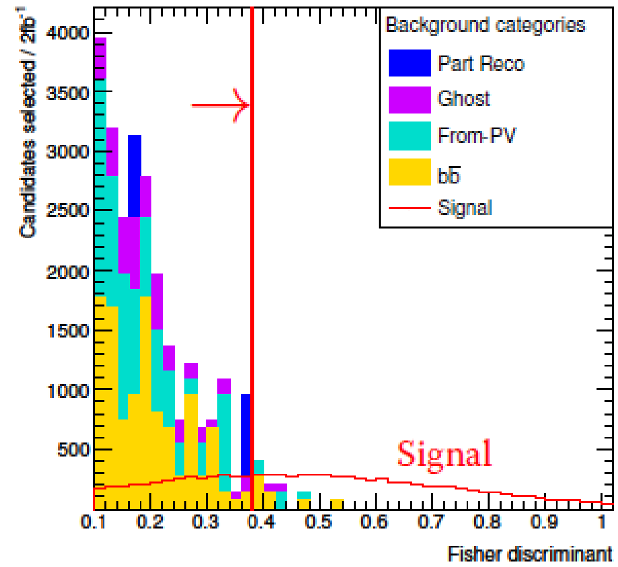


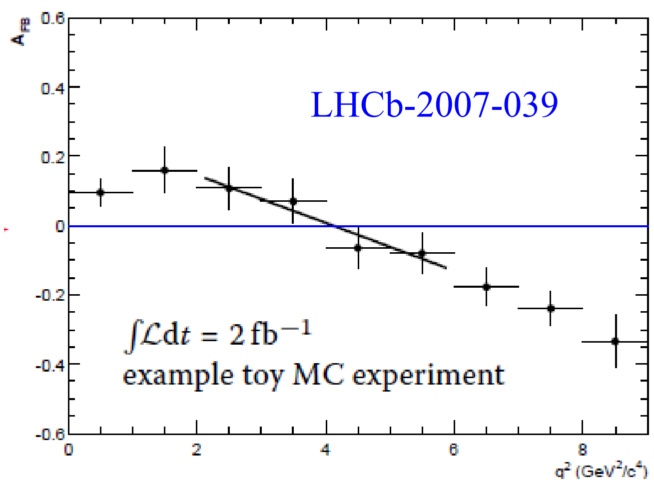
PRL 103 (2009) 171801

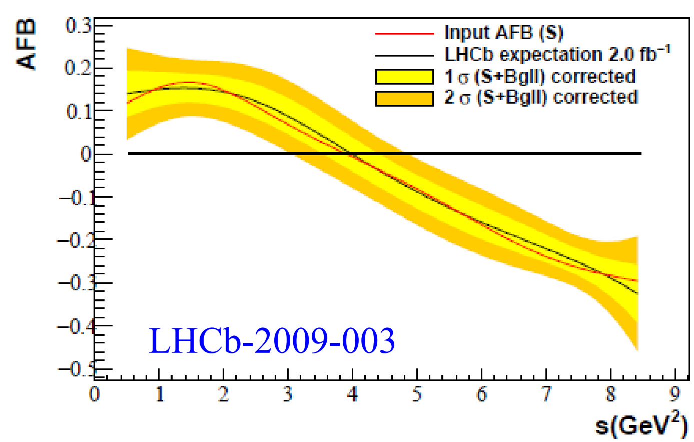
Note: opposite sign convention to previous slide for A_{FB}

Analysis overview

- Event selection based on a Fisher discriminant (B vertex, pT, flight distance, IP)
  $\Rightarrow$ B/S=0.25±0.08
- Correction of acceptance biases caused by detector geometry and reconstruction based on simulation and $B_d \rightarrow J/\psi K^*$
- Measure A_{FB}, 2 methods considered
  - Binned counting analysis
  - Fit forward and backward distributions separately



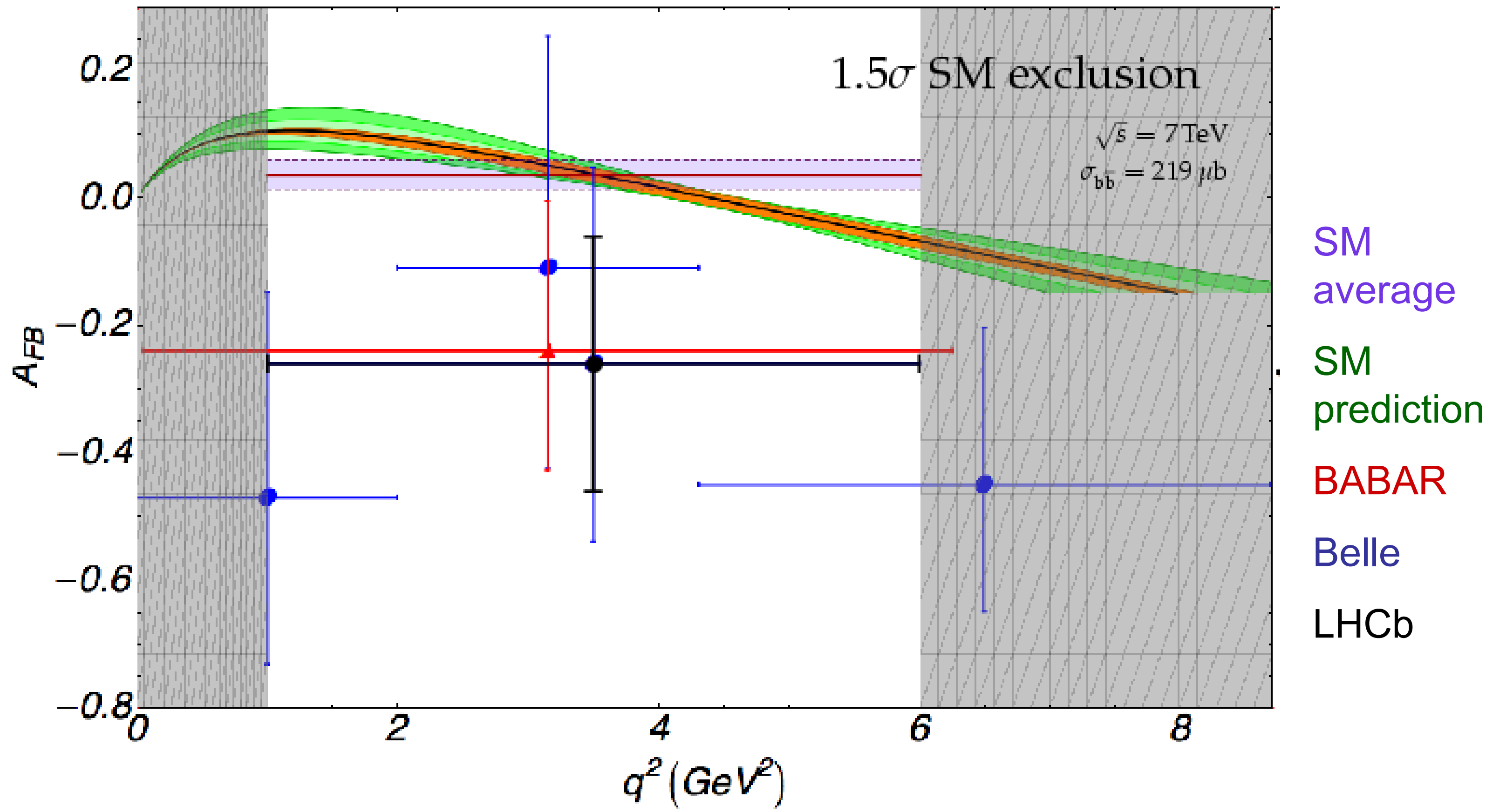




Both method give $\sigma(s_0)$~0.5 GeV^2 for 2 fb^{-1}

LHCb prospects for $B \to K^* \mu^+ \mu^-$

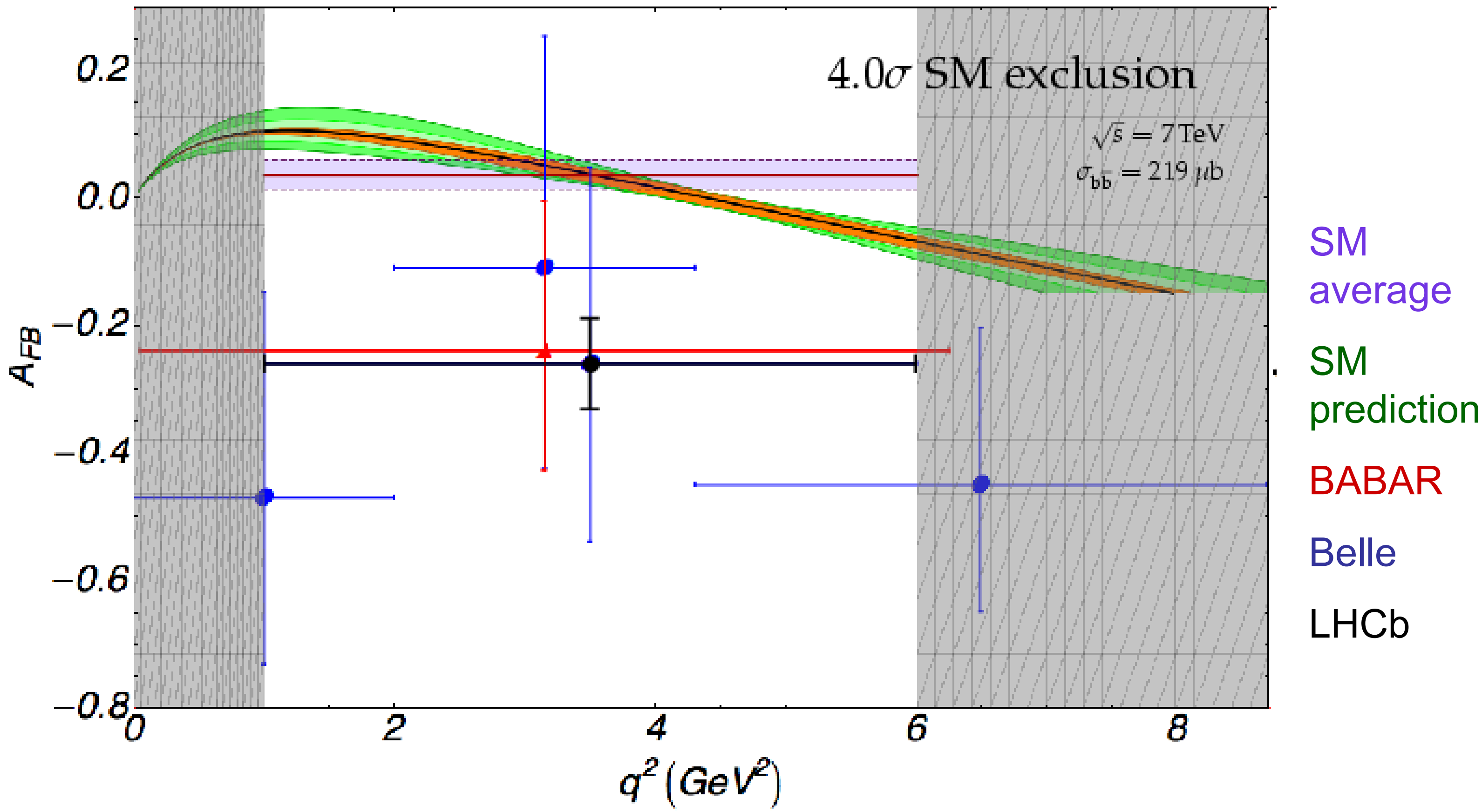
$0.1 fb^{-1} \Rightarrow 140$ events expected at LHCb



LHCb expectation assuming Belle A_{FB} measured value

LHCb prospects for $B \to K^{*} \mu^{+} \mu^{-}$

$1\ fb^{-1} \Rightarrow$ 1400 events expected at LHCb



LHCb expectation assuming Belle A_{FB} measured value

Conclusion

- First validation work with 2010 data is very promising
- Muon trigger, muon identification and tracking efficiencies are close to expectations

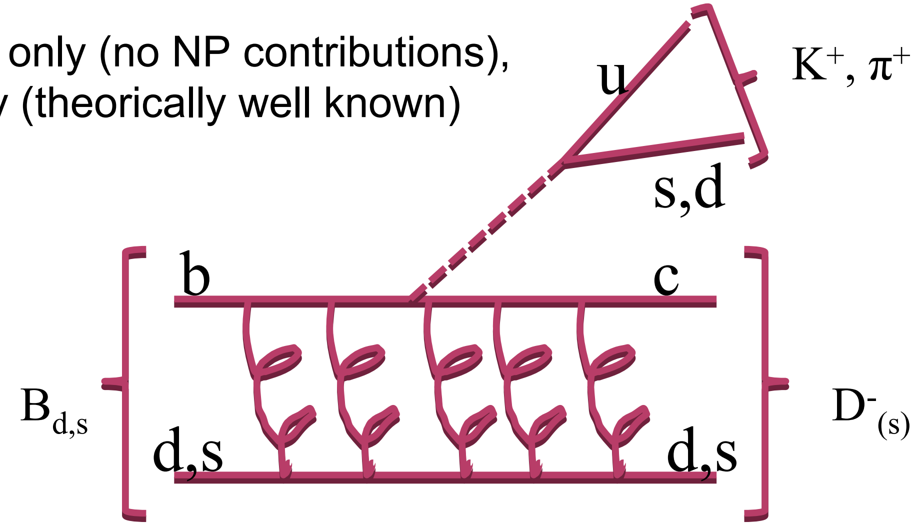
  ⇨ LHCb is in good shape to start physics analysis!

- Exciting prospects with $100pb^{-1}$
  - $B_s \rightarrow \mu^+\mu^-$: improve tevatron limit
  - $D^0 \rightarrow \mu^+\mu^-$: improve Belle limit
  - $B \rightarrow K^*\mu^+\mu^-$: yield comparable to B factories

BACK UP

f_d / f_s extraction

$B_d \to K^+\pi^-$ or $B_u \to J/\psi(\mu\mu)K^+$ are tree diagram only (no NP contributions), no colour suppressed and exchange topology (theorically well known)



$$\frac{N_{D_s\pi}}{N_{D_dK}} = \frac{f_s}{f_d}\frac{\epsilon_{D_s\pi}}{\epsilon_{D_dK}}\frac{\mathrm{BR}(\bar{B}_s^0 \to D_s^+\pi^-)}{\mathrm{BR}(\bar{B}_d^0 \to D^+K^-)}$$

We can compute the ratio of the BR as:

$$\frac{\mathrm{BR}(\bar{B}_s^0 \to D_s^+\pi^-)}{\mathrm{BR}(\bar{B}_d^0 \to D^+K^-)} \sim \frac{\tau_{B_s}}{\tau_{B_d}}\left|\frac{V_{ud}}{V_{us}}\right|^2 \times \left(\frac{f_\pi}{f_K}\right)^2 \left[\frac{F_0^{(s)}(m_\pi^2)}{F_0^{(d)}(m_K^2)}\right]^2 \left|\frac{a_1(D_s\pi)}{a_1(D_dK)}\right|^2$$

The theoretical uncertainty (due to SU(3) breaking) are:

$$\mathcal{N}_a \equiv \left|\frac{a_1(D_s\pi)}{a_1(D_dK)}\right|^2$$

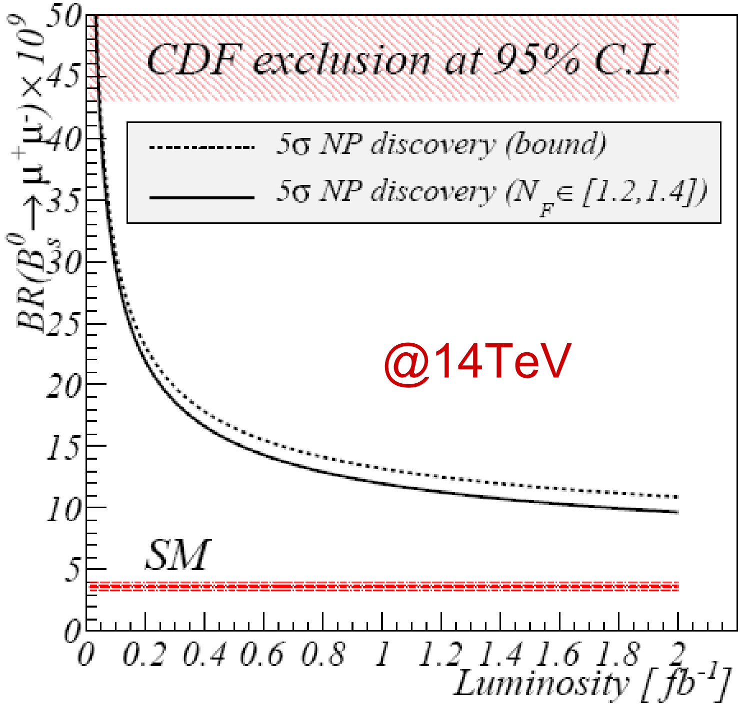
$$\mathcal{N}_F \equiv \left[\frac{F_0^{(s)}(m_\pi^2)}{F_0^{(d)}(m_K^2)}\right]^2$$

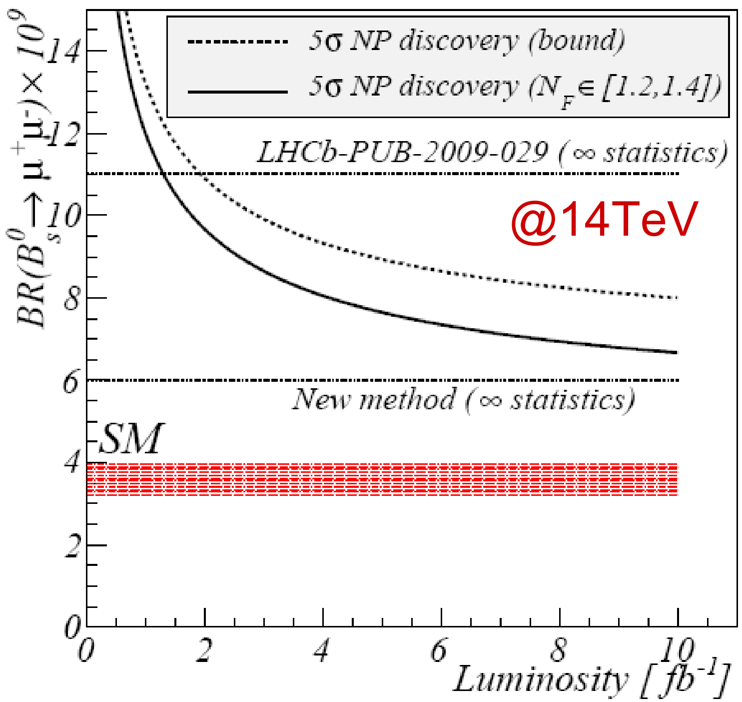
$\Rightarrow$

$$\frac{f_d}{f_s} = 12.88 \times \frac{\tau_{B_s}}{\tau_{B_d}} \times \left[\mathcal{N}_a\mathcal{N}_F\frac{\epsilon_{D_s\pi}}{\epsilon_{D_dK}}\frac{N_{D_dK}}{N_{D_s\pi}}\right]$$

NP discovery potential in $B_s \to \mu^+\mu^-$

• Assuming an uncertainty on $\boldsymbol{N_F}$ of 5% we expect an uncertainty of 7% on f_s/f_d (for $1fb^{-1}$ in 2011)!



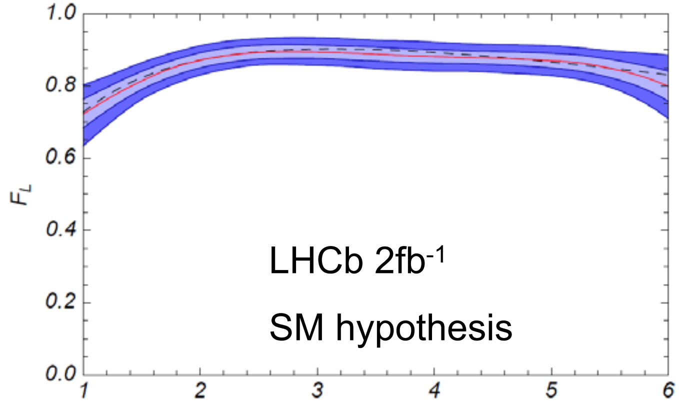


Solid line assuming $\boldsymbol{N_F \in [1.2, 1.4]}$

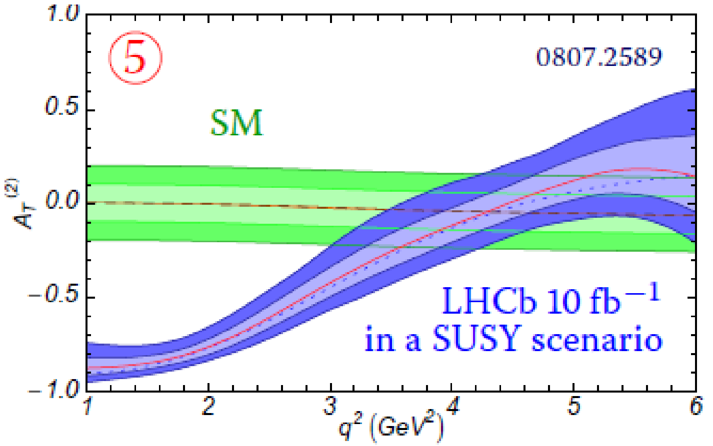
Dashed line ***bound*** $\boldsymbol{N_F = 1.0}$

LHCb prospects for $B \to K^* \mu^+ \mu^-$

- With more data: fit angular projection ⇒ FL



- Fill angular fit: need more than 2fb^{-1}



Tevatron projection for $B_s \to \mu^+\mu^-$