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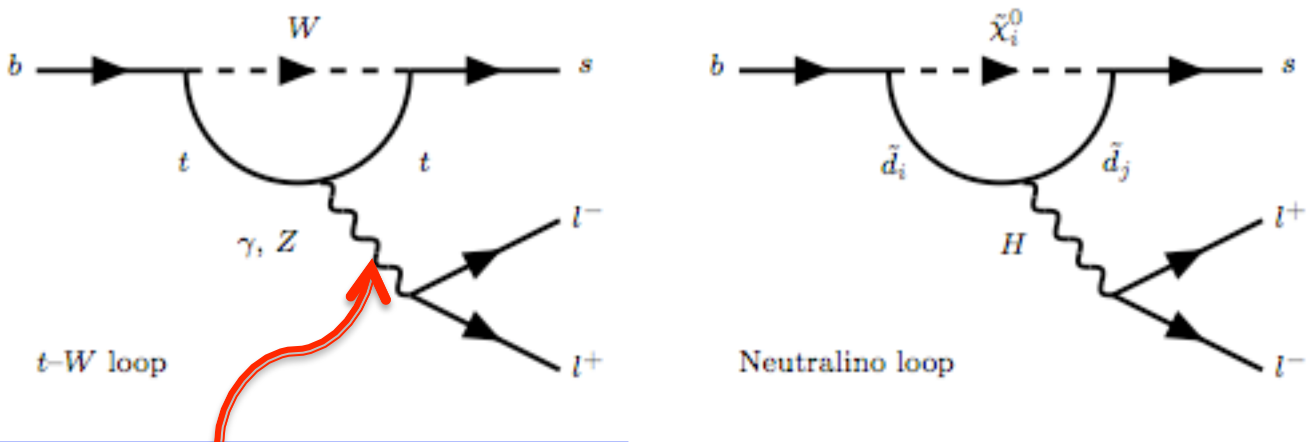
Experimental prospects for $B \rightarrow K ll$

Introduction

- Why are we interested in $b \rightarrow sll$ transitions?
- Overview of the results from TeVatron and B-Factories.
- Prospects at LHCb.

b → s ll

- Flavour changing neutral current process:
  - Forbidden at tree level in SM.
    - Mediated by γ /Z^0 penguin and W box diagrams in SM.
  - New physics can also contribute at loop order leading to large deviations from SM predictions.



SM dominated by contribution from γ*

b → s ll

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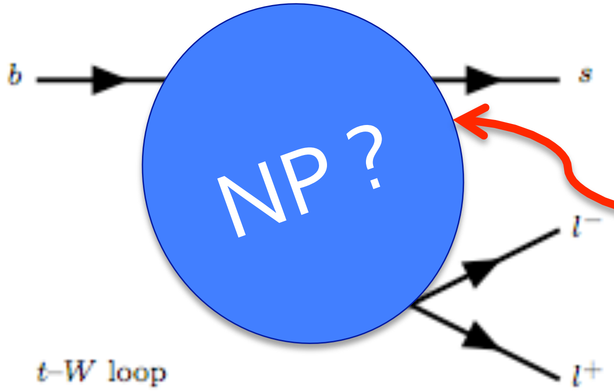


Enhancements from :
SUSY, generic little Higgs,
2 Higgs models ,
graviton exchange,
extra dimension models ....

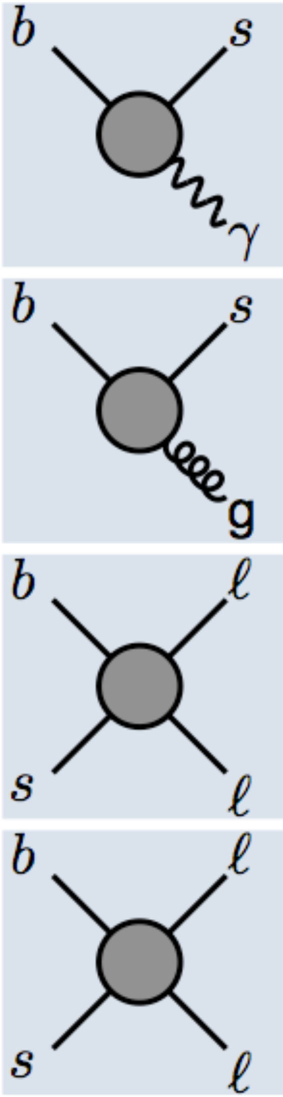
Brief phenomelogical aside

$\mathcal{O}_{7\gamma}$

$\mathcal{O}_{8g}$

$\mathcal{O}_{9\ell,10\ell}$

$\mathcal{O}_{S,P}$



- Three energy scales:
  - $O(\Lambda_{QCD})$ ~ 0.1 GeV, $O(m_b)$ ~ 5 GeV, $O(M_W)$ ~ 90GeV
- Effective Hamiltonian for b ➔ s decay:

$$\mathcal{H} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} [\mathcal{C}_i(\mu)\mathcal{O}_i(\mu) + \mathcal{C}'_i(\mu)\mathcal{O}'_i(\mu)]$$

Right handed currents, suppressed by M_B/M_W in SM

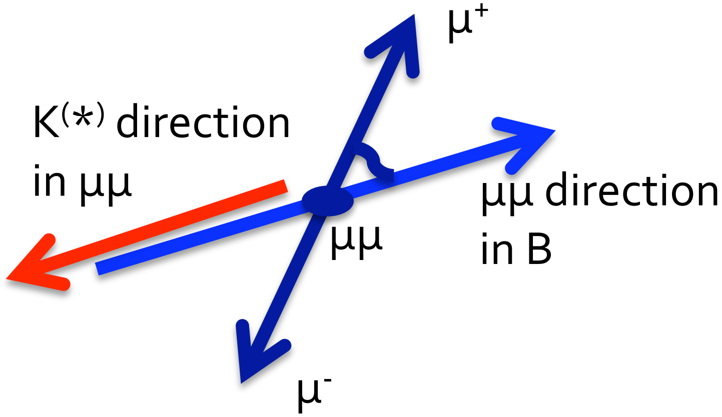
- Separate long and short distance effects:

$\mathcal{O}_i(\mu)$ Operators, containing the long distance effects.

$\mathcal{C}_i(\mu)$ Wilson coefficients, containing the short distance effects that can be calculated perturbatively.

A few definitions ...

- For $B \rightarrow K^{(*)}$ ll decays, parameterise the decay in terms of the Helicity angle of the μ^+ θ_L:
  - The angle between the direction of the μ^+ in the rest frame of the dimuon pair and the direction of the dimuon in the B-rest frame.



and the invariant mass of the dimuon pair q^2.

Observables

- Focus on measuring ratios where the dominant hadronic uncertainties (e.g. those coming from the B $\rightarrow$ K form factors) cancel.

- Experimental observables:
  - Forward-backward asymmetry
  - Isospin asymmetry
  - R_K

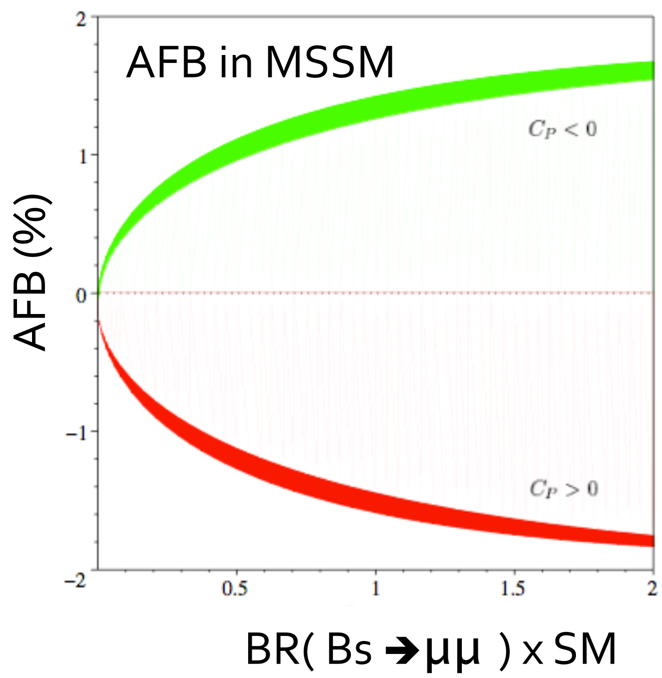
Why have we focused on K* ll ?

- A large number of existing measurements (and phenomenology papers) focus on the B ➔ K* ll rather than B^+ ➔ K^+ ll .
  - B ➔V ll decays are highly sensitive to presence of new physics through the angular distribution (FL, AFB etc).
  - Effect on angular distribution is small for B ➔ K ll:

$$A_{FB} \propto \mathcal{R}e(A_S A_V^*)$$

Wilson coefficient for the scalar operator highly suppressed in SM ,

$$C_S^{SM} \propto \frac{m_l M_B}{M_W^2}$$

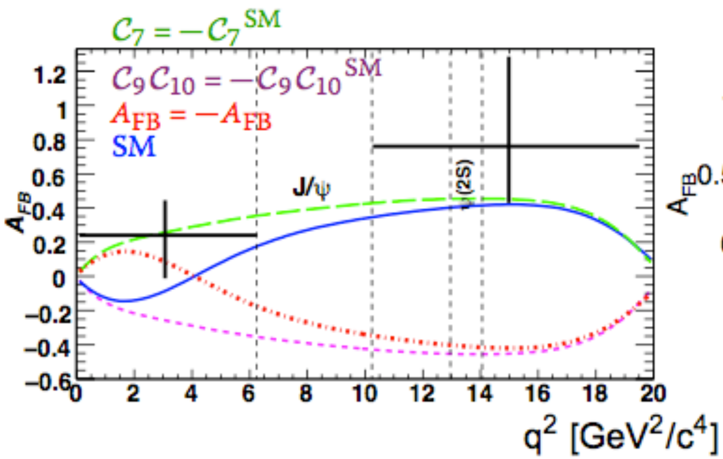


$B^0 \rightarrow K^{*0}$ ll

- Forward backward asymmetry is sensitive to C_7, C_9 and C_{10} Wilson coefficients.
  - Magnitude of C_7 constrained by inclusive b ➔ s γ .
- BaBar, BELLE and CDF have O(100) events.

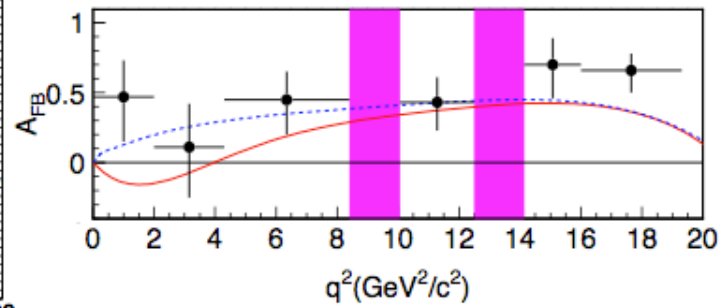
BaBar (384M $B\bar{B}$ pairs)

PRD **79** 031102 (0804.4412)

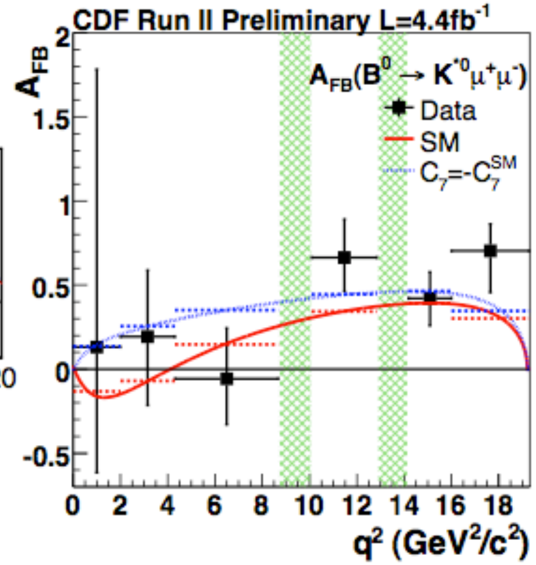


BELLE (657M $B\bar{B}$ pairs)

PRL **103** 171801 (0904.0770)



CDF note 10047

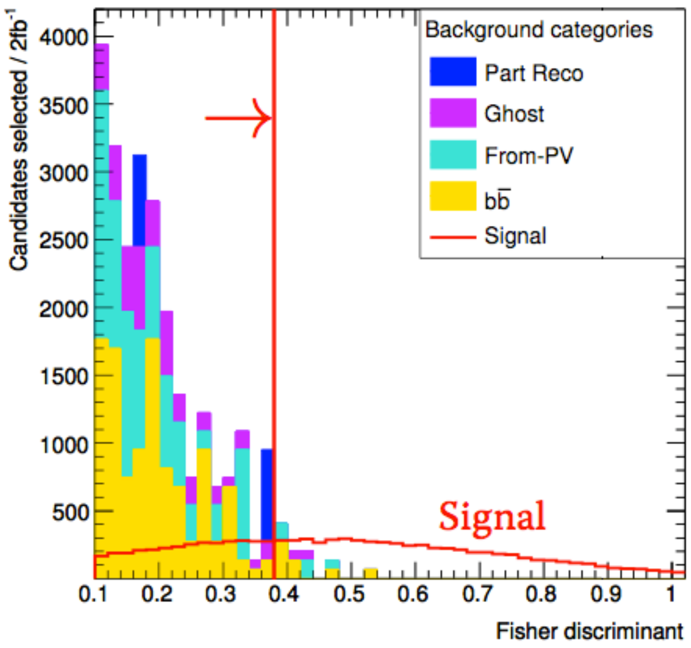


$B^0 \to K^{*0} \mu\mu$ at LHCb

- In the trigger and the offline selection, try to avoid cutting on p_T/IP of both muons that can bias θ_L (and AFB)
  - Rely on B flight distance, B vertex quality and the B p_T that are uncorrelated to the angular variables.
  - Largest acceptance biases come from the muon reconstruction (and are geometrical).
- Offline selection based on Fisher discriminant.
  - In nominal year (2fb-1) expect:

6200 signal candidates

with S/B ~ 4

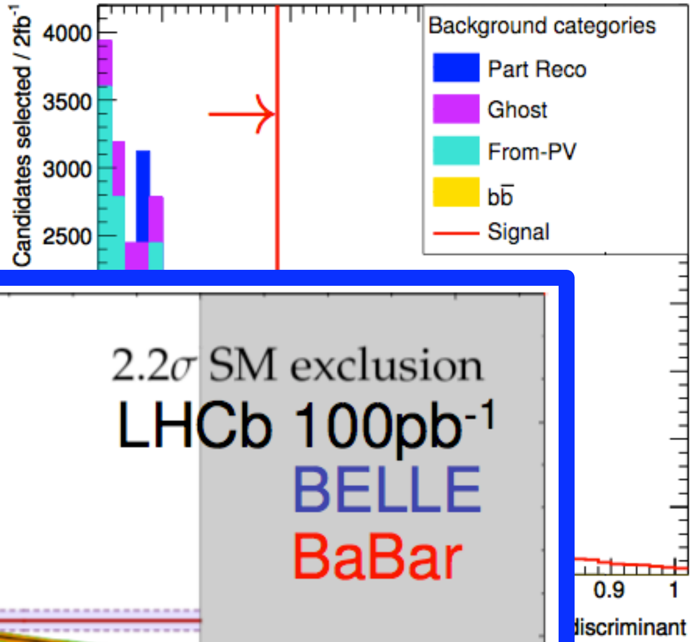


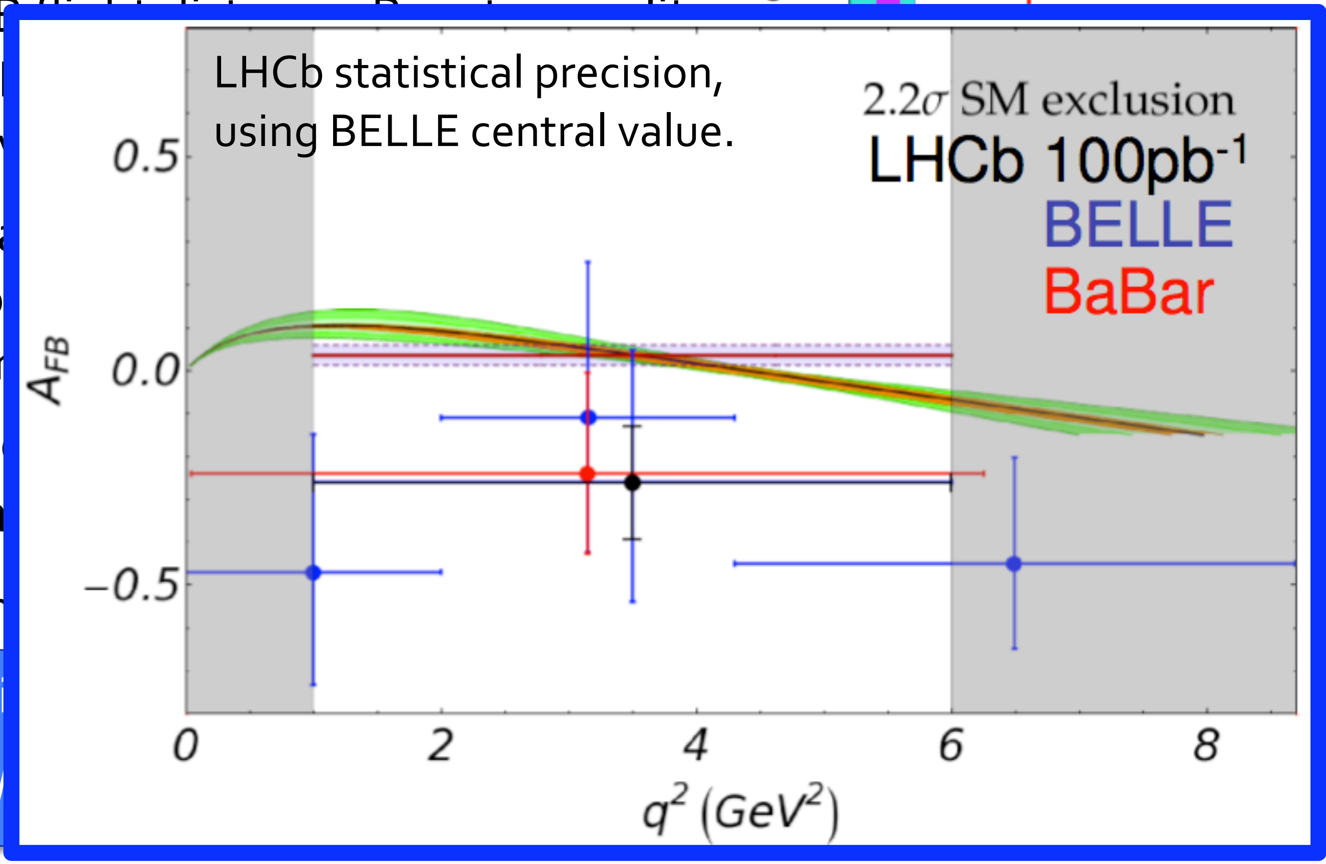
$B^0 \rightarrow K^{*0}$ μμ at LHCb

- In the trigger and the offline selection, try to avoid cutting on p_T/IP of both muons that can bias θ_L (and AFB)
  - Rely on B flight distance, B pt, … ali…
    and the I…
    angular v…
  - Largest a…
    the muo…
    geometr…
- Offline sel…
  discrimina…
  - In nomin…

6200 si…

with S/…





Branching ratios

$$\mathcal{B}(B \to K l^+ l^-) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}$$

657M BB pairs,
Phys. Rev. Lett. 103 (09)

$$\mathcal{B}(B \to K l^+ l^-) = (3.4 \pm 0.7 \pm 0.2) \times 10^{-7}$$

383M BB pairs,
Phys. Rev. D 103 (09)

$$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}) < 1.4 \times 10^{-5}$$

$$\mathcal{B}(B^0 \to K^0 \nu\bar{\nu}) < 16 \times 10^{-5}$$

535M BB pairs,
Phys. Rev. Lett. 99 (07)

$$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}) < 4.5 \times 10^{-5}$$

351M BB pairs,
arXiv:0911.1988

Buras et al., JHEP 2009, BR = 4.5 ± 0.7 x 10^{-6}

Branching ratios at CDF

- CDF measure only the final states with muons:

$$\mathcal{B}(B^+ \to K^+\mu^+\mu^-) = [0.38 \pm 0.05(\text{stat}) \pm 0.03(\text{syst})] \times 10^{-6}$$

CDF Note 10047, 2010

Note systematic error not dissimilar to the statistical error

- Breakdown of systematic contributions:

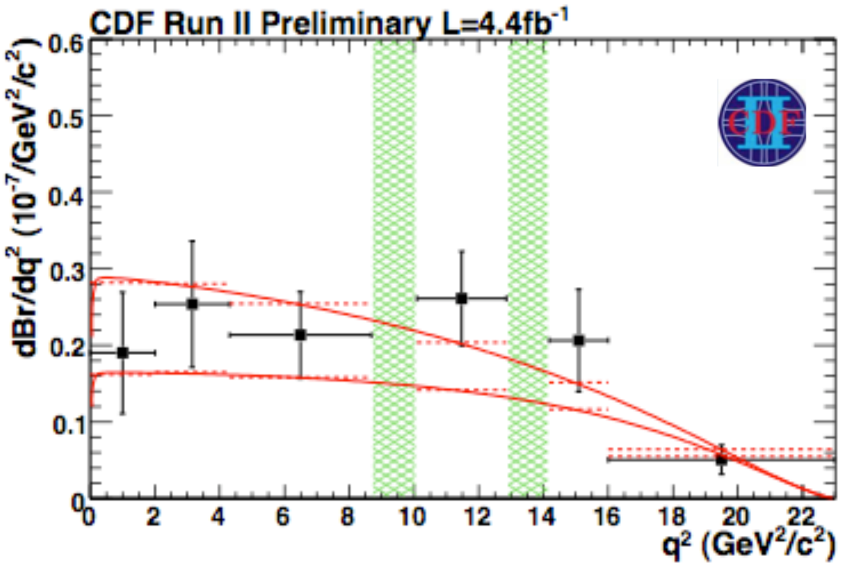
Source	$B^+ \to K^+\mu^+\mu^-$
Efficiency	4.2
$\mathcal{B}(J/\Psi \to \mu^+\mu^-)$	1.0
Signal PDF	0.4
Background PDF	3.9
Peaking BG	0.1
$\mathcal{B}(B \to J/\Psi h)$	3.5
Total	6.8 %

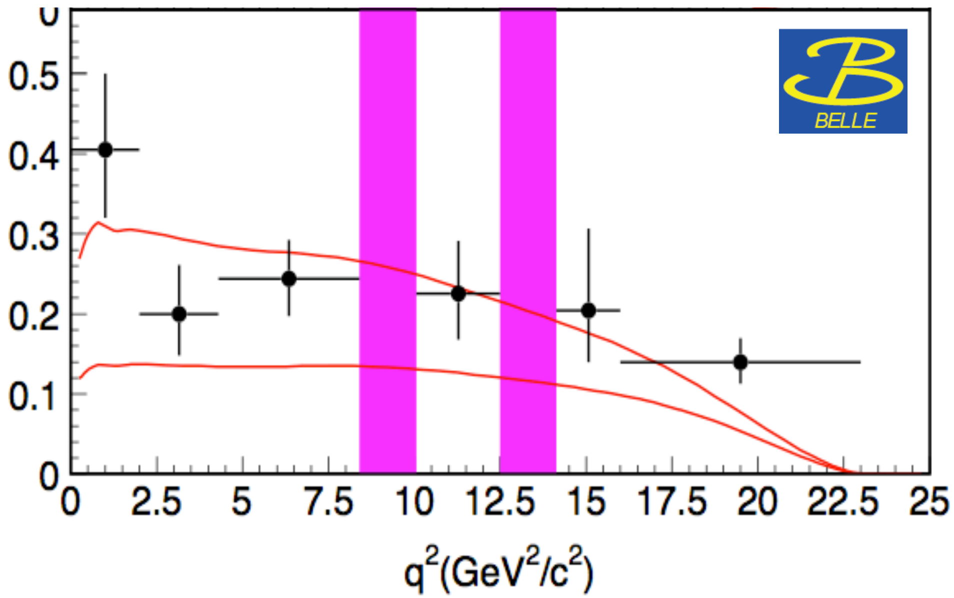
Dominated by uncertainties on MC reweighting and NN output.

CDF measure the ratio w.r.t. $B^+ \to J/\psi K^+$

Differential BR, $d\Gamma/dq^2$

- Differential branching fraction consistent with SM prediction.
  - Sensitive to to C_7, C_9 and C_{10} Wilson coefficients.





Red bands correspond to estimated theoretical uncertainty on SM prediction.
Theory uncertainty comparable to existing experimental precision.

Differential BR, $d\Gamma/dq^2$

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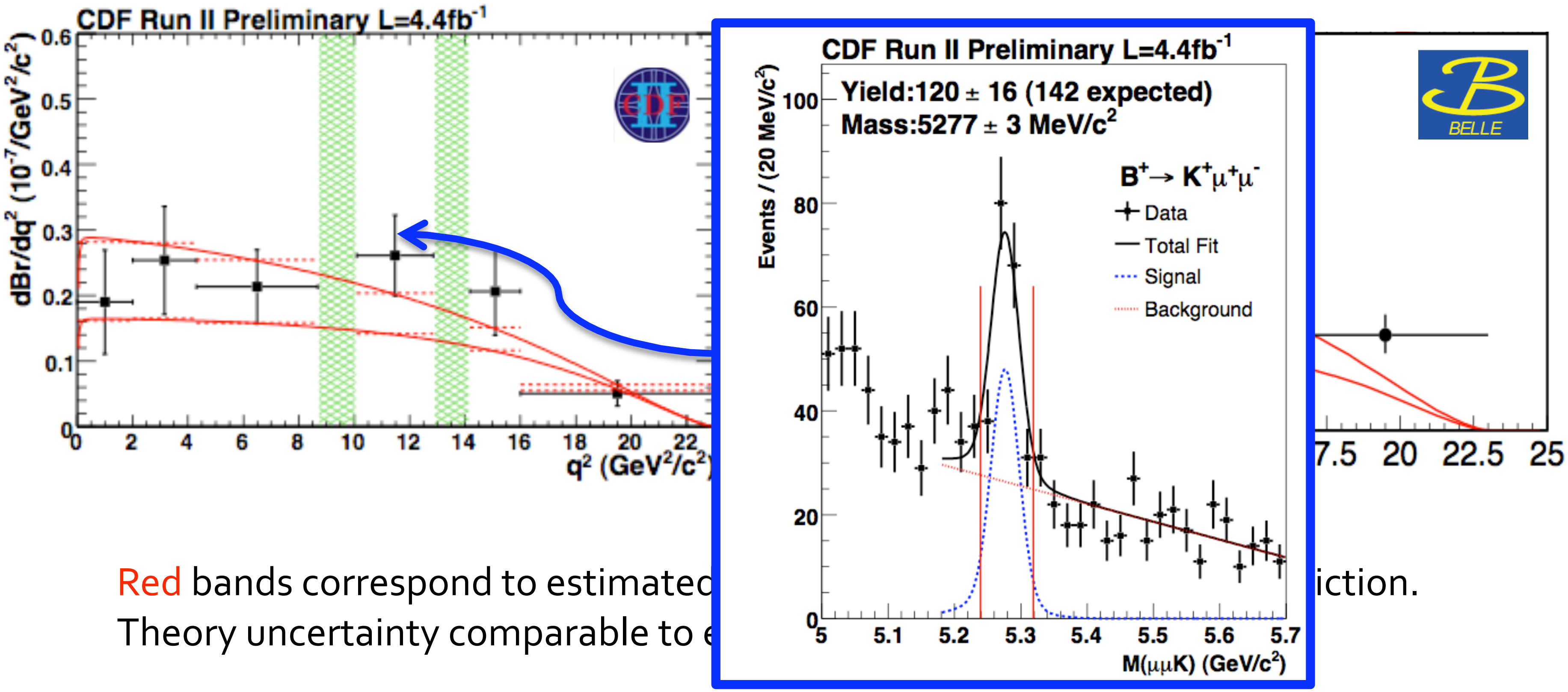
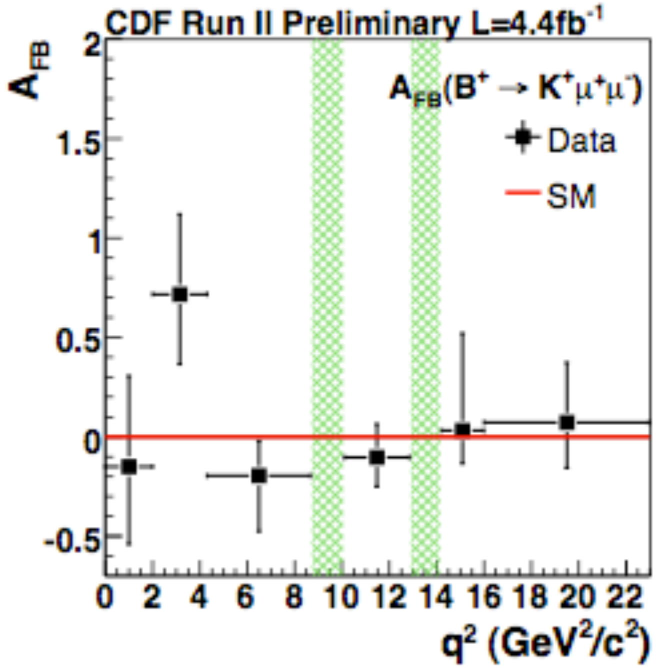


Red bands correspond to estimated … iction.
Theory uncertainty comparable to e…

Forward-backward asymmetry

- Reminder, non-zero AFB comes from the scalar contribution, C_S.
- Expect AFB ≈ 0 in SM and plausible NP models.
  - Existing experimental results are consistent with AFB = 0.



Isospin asymmetry

- Isospin asymmetry is the asymmetry between the charged and neutral B decay modes (as a function of q^2):

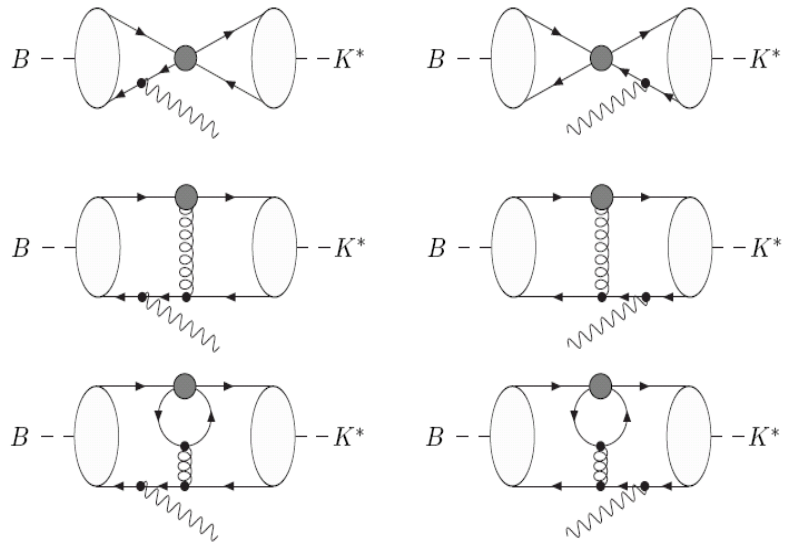
$$A_{\mathrm{I}}(q^2) = \frac{\mathcal{B}\left(B^0 \to K^0\mu^+\mu^-\right) - (\tau_0/\tau_+) \times \mathcal{B}\left(B^\pm \to K^\pm\mu^+\mu^-\right)}{\mathcal{B}\left(B^0 \to K^0\mu^+\mu^-\right) + (\tau_0/\tau_+) \times \mathcal{B}\left(B^\pm \to K^\pm\mu^+\mu^-\right)}$$

  - Expect $A_I \approx 0$ away from charmonium resonances in SM.

Sensitive to the spectator quark interactions.

(operators O_1–O_6 and O_8)

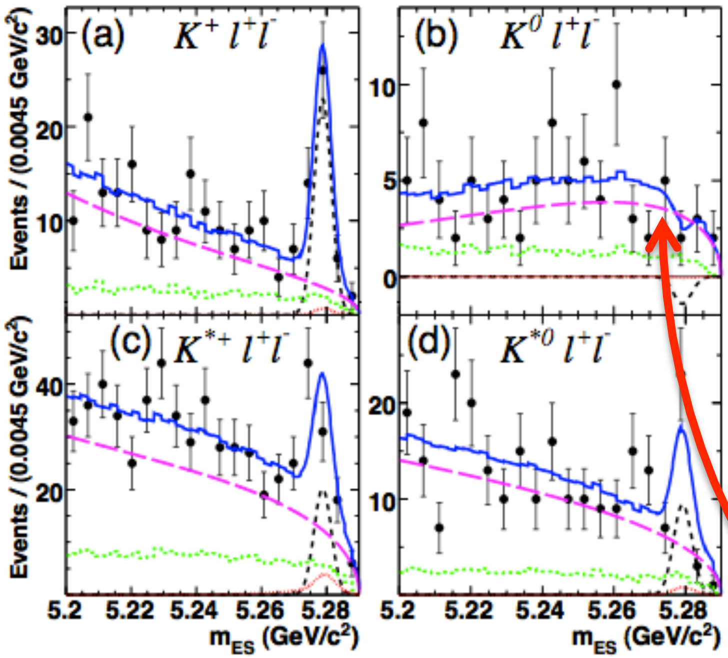
T. Feldmann, J. Matias
hep-ph/0212158v2 (2002)

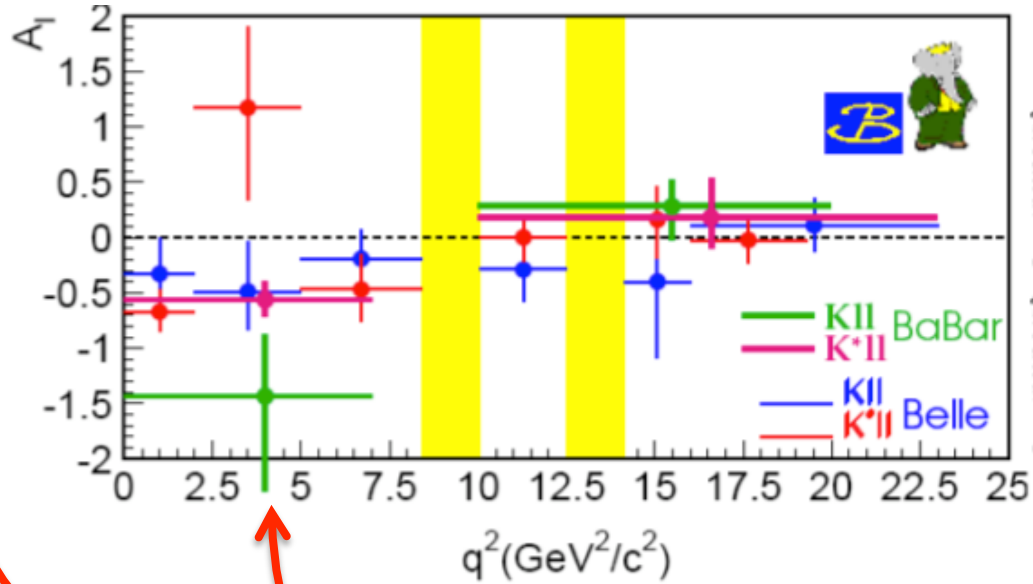


Isospin asymmetry

- Babar/BELLE observe large asymmetry at low q^2

384M BB pairs, arXiv 0807.4119



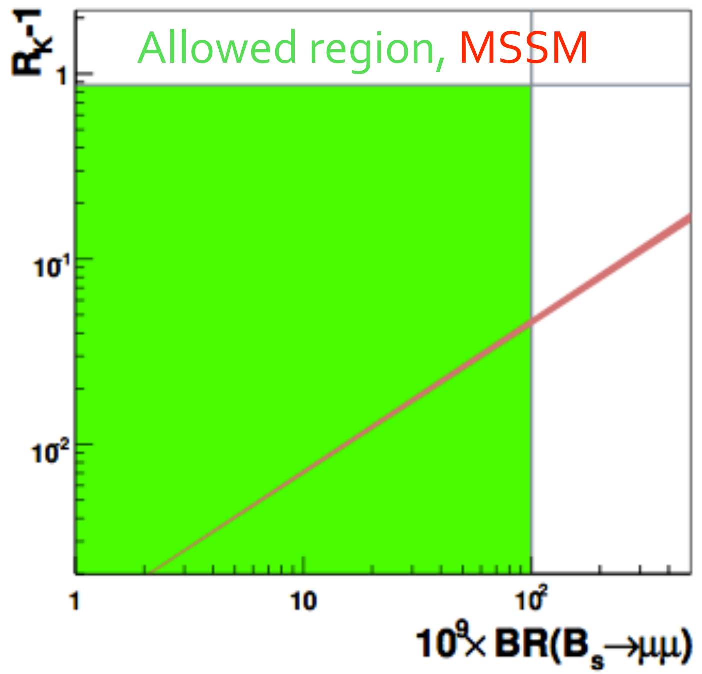


Negative A_I due to deficit of events in signal region.

Ratio R_K

- Ratio of final states with muons to final states with electrons:

$$R_K = \frac{\int \frac{d\Gamma\left(B^+ \to K^+ \mu^+ \mu^-\right)}{dq^2} dq^2}{\int \frac{d\Gamma(B^+ \to K^+ e^+ e^-)}{dq^2} dq^2} \overset{SM}{\simeq} 1.0$$



- SM contribution from Higgs exchange diagram.
- In MSSM R_K –1 proportional to $BR(B_S \to \mu\mu)$, enhanced at large tanβ.

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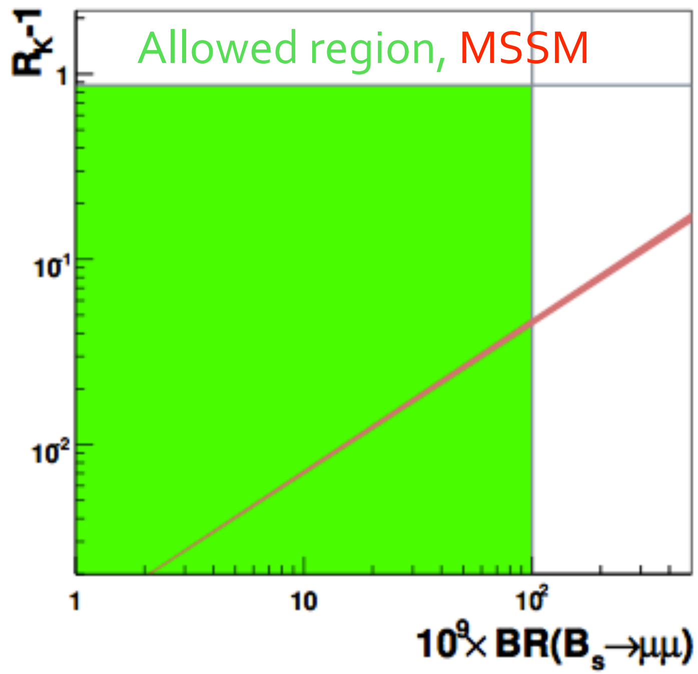


- SM contribution from Higgs exchange diagram.

$$R_K = 0.96^{+0.44}_{-0.34} \pm 0.05$$ 384M BB pairs, arXiv 0807.4119

$$R_K = 1.03 \pm 0.19 \pm 0.06$$ 657M BB pairs, arXiv 0904.0770

BELLE

What can we measure at LHCb ?

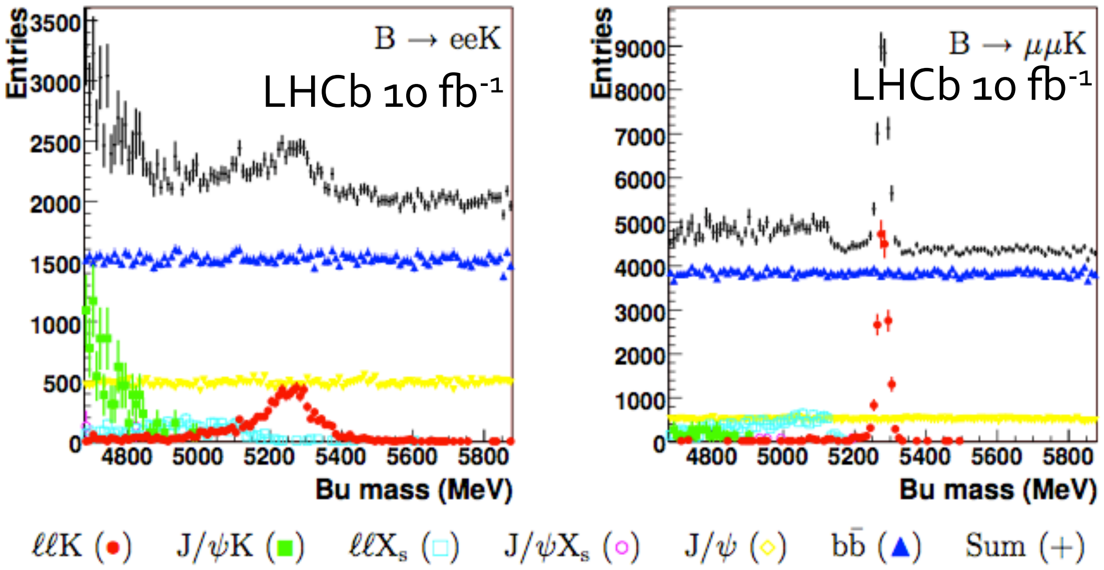
- Difficult to measure modes with one or more neutral final state particles:
  - Higher background and smaller signal.

	✓	difficult	super b-factory
✓	$B^+ \rightarrow K^+ \mu\mu$	$B_d \rightarrow K_S \mu\mu$	$B_d \rightarrow K_L \mu\mu$
difficult	$B^+ \rightarrow K^+ ee$	$B_d \rightarrow K_S ee$	$B_d \rightarrow K_L ee$
super b-factory	$B^+ \rightarrow K^+ \nu\nu$	$B_d \rightarrow K_S \nu\nu$	$B_d \rightarrow K_L \nu\nu$

B → K ll at LHCb

- For B → K ll LHCb focus has been:
  - $B^+ \rightarrow K^+\mu\mu$ and $B^+ \rightarrow K^+ ee$
- In a nominal year of data taking (2fb^{-1}) expect:
  - 1840 $B^+ \rightarrow K^+ ee$ candidates.
  - 3750 $B+ \rightarrow K^+ \mu\mu$ candidates.

P. Koppenburg, LHCb-2007-034



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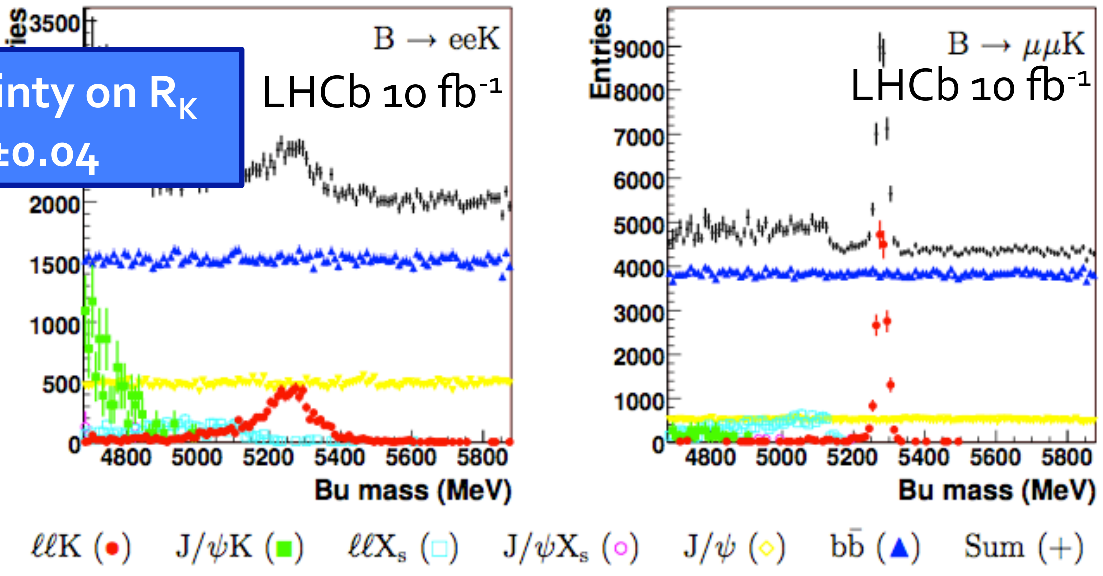
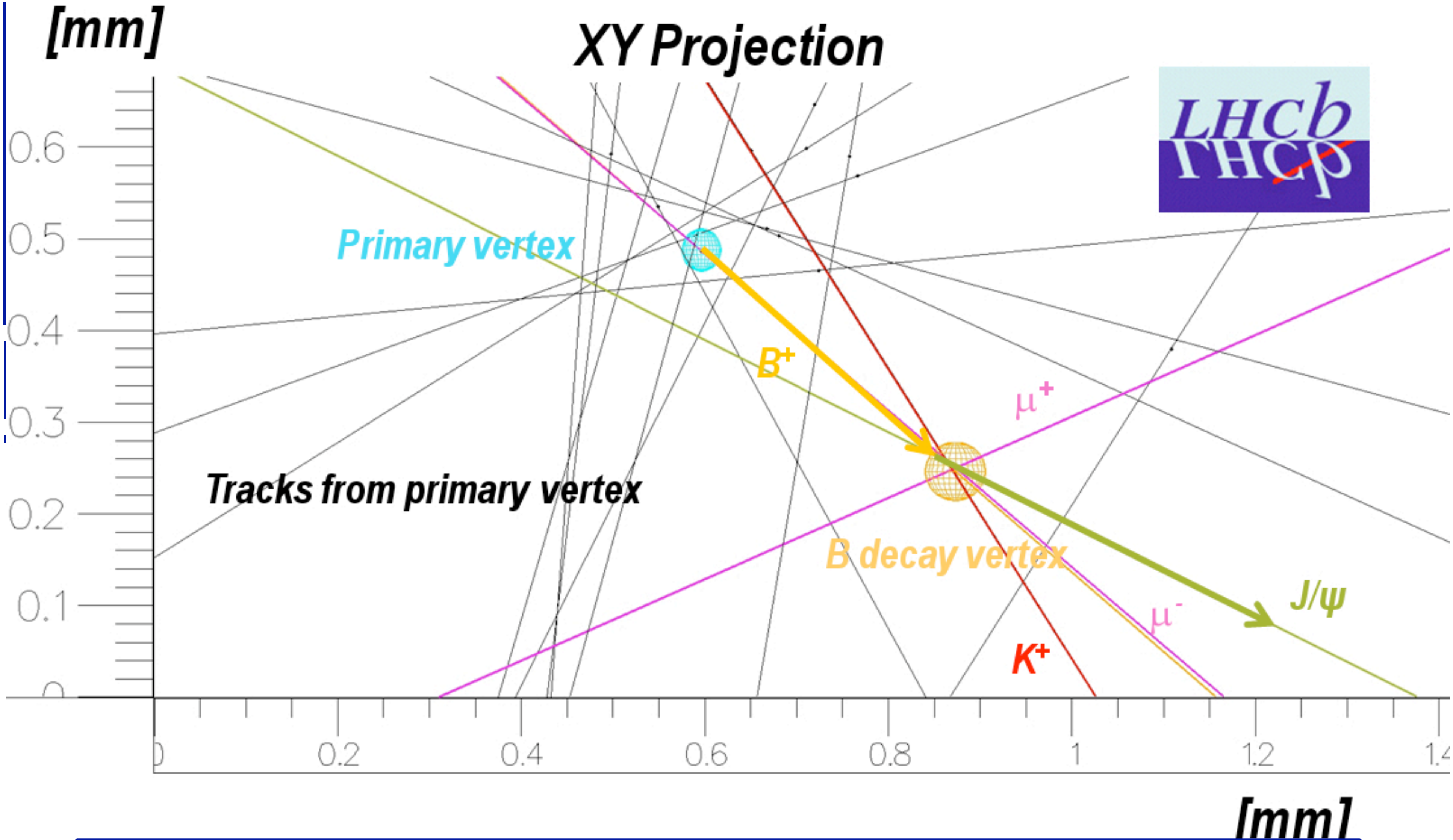
Statistical uncertainty on R_K with $10fb^{-1}$ is ±0.04



$B^+ \rightarrow J/\psi K^+$ candidate



LHCb has started to collect samples of fully reconstructed B candidates !

Conclusions

- Exclusive B ➔ $K^{(*)}$ ll decays are highly sensitive to a range of NP scenarios.
  - Existing measurements are compatible with SM predictions but in many cases are statistically limited.
- LHCb is now taking data, we expect:
  - O(100) nb^{-1} by end of June
  - O(100) pb^{-1} by the end of 2010. ← Expect to have similar statistics to BaBar, BELLE and CDF.
  - O(1) fb^{-1} by the end of 2011.