Search for New Physics in Heavy Flavour Rare decays

Antonio Pellegrino on behalf of the LHCb Collaboration,
Kruger 2010, Protea Hotel Kruger Gate, 05-12-2010

Outline:

- heavy flavor rare decays *(introduction)*
  - key measurements at LHCb
- first data *(where we are, LHC start-up)*
  - performance (trigger, PID, etc.)
  - analysis steps (signal and background, normalization, etc.)
- prospects *(where we are going)*

The Mission

- Search for New Physics (NP) in "Heavy Flavor Rare Decays"
  - $B_s \to \varphi\gamma$, $B_d \to K^{0*}\mu^+\mu^-$, $B_s \to \mu^+\mu^-$, etc.

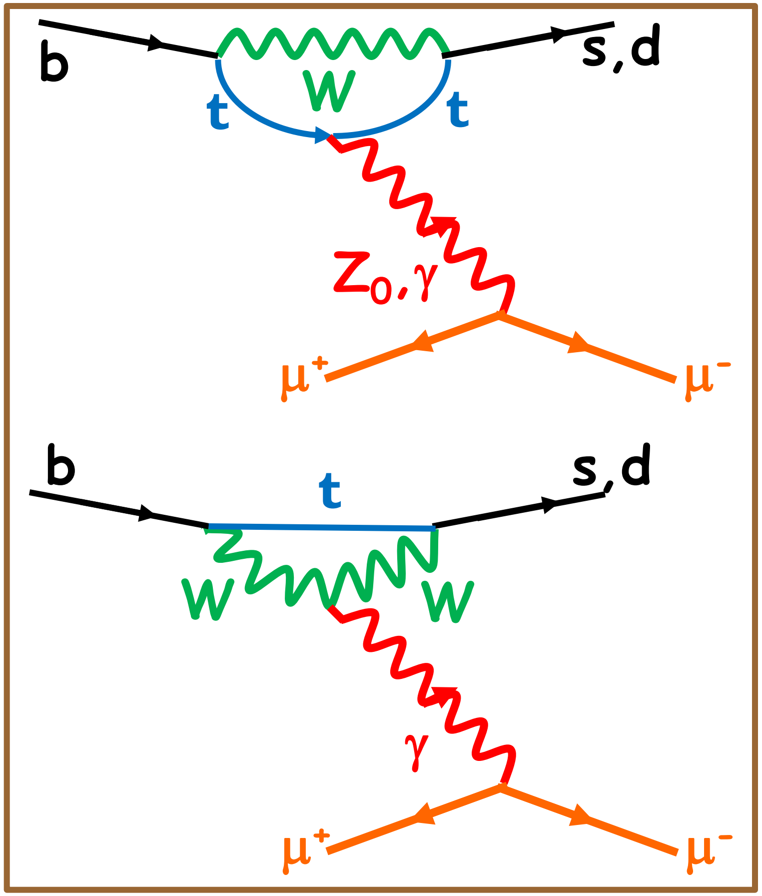
    small branching fractions, leptonic or electromagnetic final states

- Why "Heavy Flavor Rare Decays"?
  - Flavor-Changing ($b \to s,d$ transitions) Neutral Currents (γ,Z0,…) in the SM induced only through loop
  - sensitive to much larger masses than m_b
    - top quark mass in the SM and new particles in NP models
    - provide important constraints for parameters of NP models
  - *also more theoretically (in terms of QCD) tractable than non-leptonic*

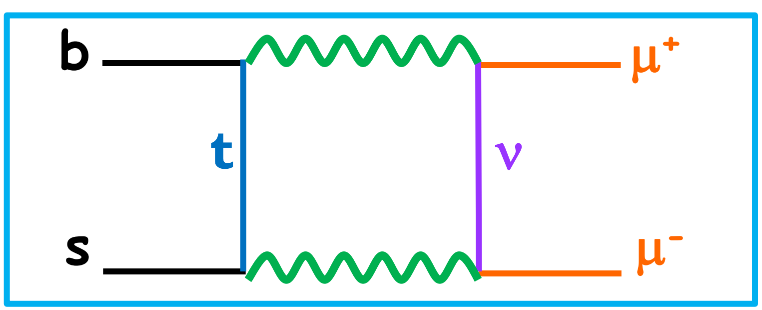
- Why at LHC?
  - because they're rare and LHC produces a lot of heavy quarks!
  - because LHCb is equipped to trigger and measure them very efficiently
    - *despite of the fact that at a pp collider one looks at exclusive final states*

Rare Decays - SM

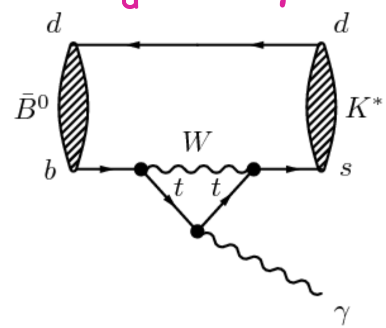
“penguin” loop



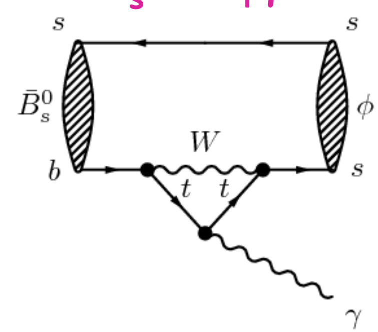
“box” loop



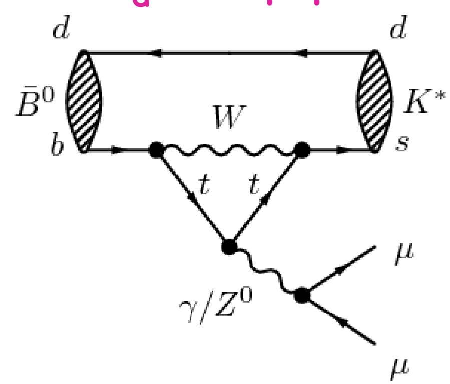
$B_d \to K^* \gamma$



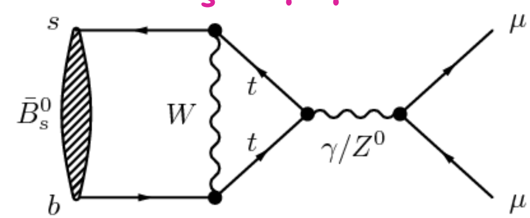
$B_s \to \varphi \gamma$

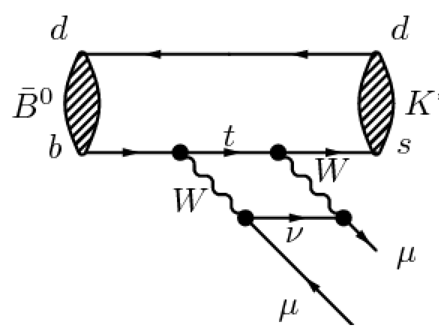


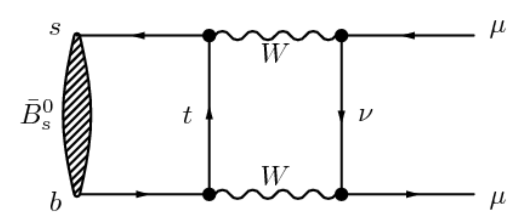
$B_d \to K^{0*} \mu^+ \mu^-$



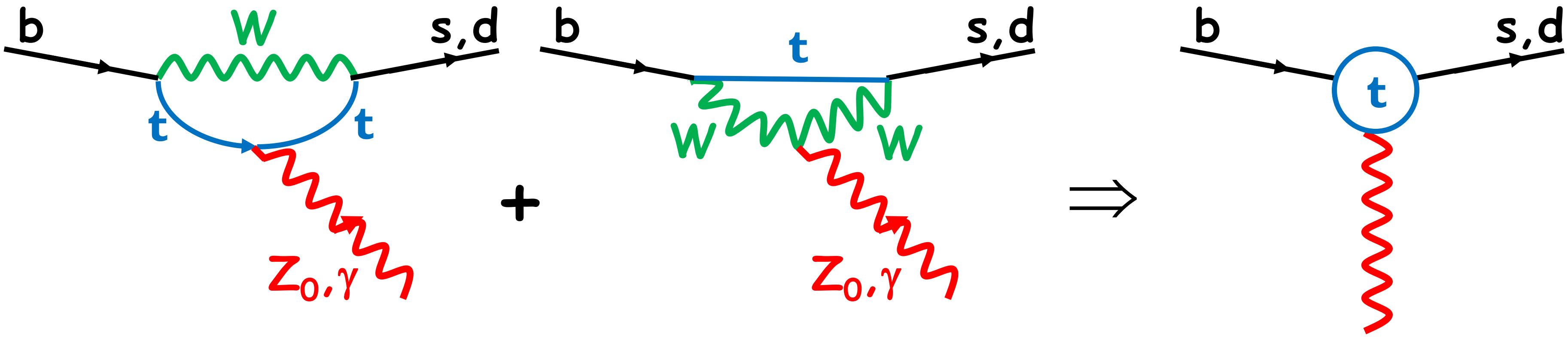
$B_s \to \mu^+ \mu^-$







Effective Theory



In practice, describe b→d,s transitions through an effective Hamiltonian

CKM matrix elements

Wilson coefficients (current model, perturbative)

$$H^{eff}(b \to q) = \frac{G_F}{\sqrt{2}} V_{tb} V_{tq}^{*} \sum_i C_i(\mu) O_i(\mu) + h.c.$$

pQCD/non-pQCD separation scale

Hadronic operators
non perturbative methods ⇒ $\langle f \mid O_i(\mu) \mid i \rangle$

$C_i(\mu)$ can contain New Physics

e.g. through modification to Lorentz structure

(onset of significant right-handed currents)

Rare Decays at LHCb

wide range of rare decay measurements at LHCb

$B_s \to \varphi\mu^+\mu^-$

$D^0 \to K^+K^-\mu^+\mu^-$

$D^0 \to \mu^+\mu^-$

$B^+/D^+_{(S)} \to K^-\mu^+\mu^-$

$\Lambda_B \to \mu^+\mu^-$

$\tau^+ \to \mu^+\mu^-\mu^+$

$B_s \to \mu^+\mu^-$

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

$B_s \to \varphi\gamma$

$B_d \to K^*\gamma$

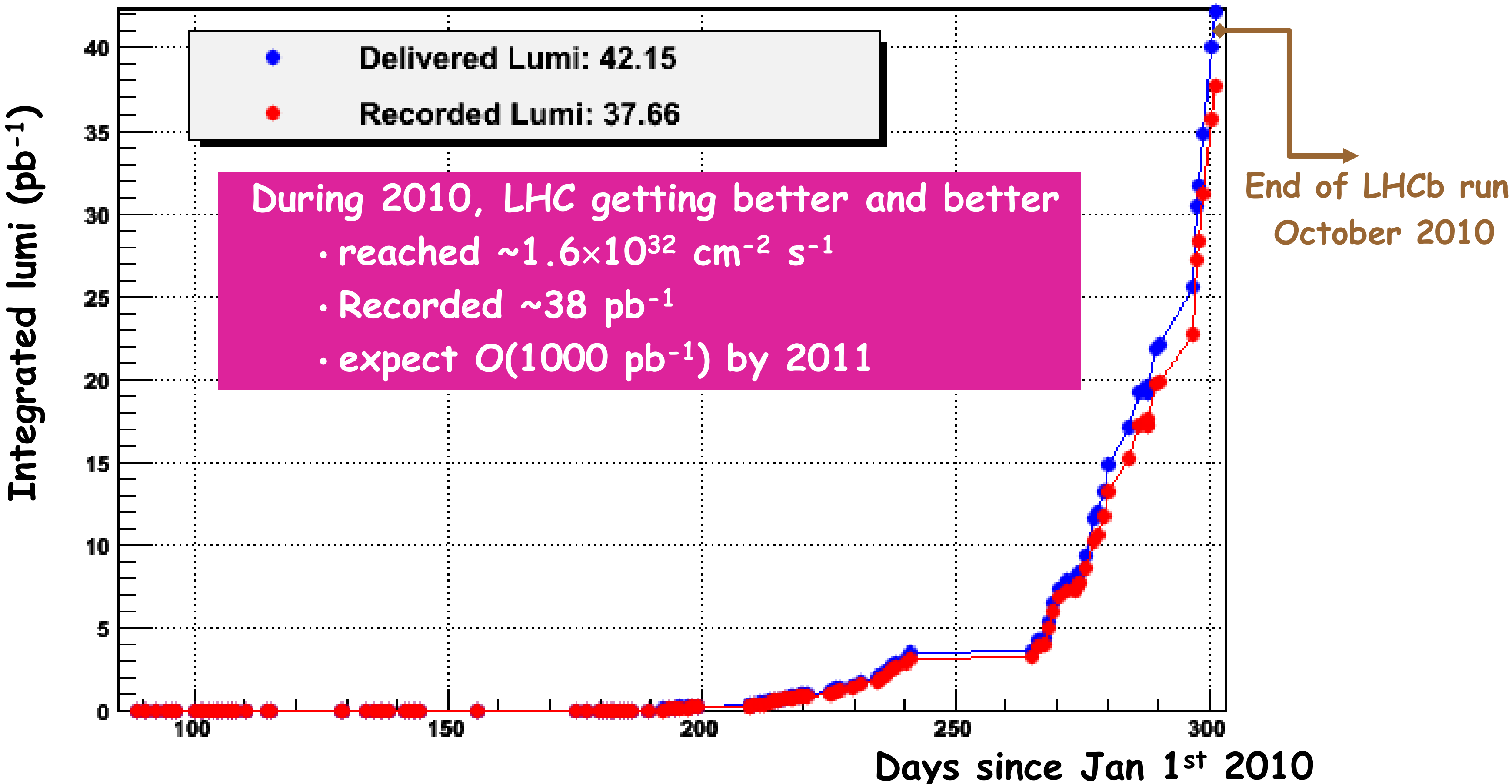
$B_d \to K^*e^+e^-$

Will focus on the ones most actively pursued at present

- best perspective for NP in 2011/2012

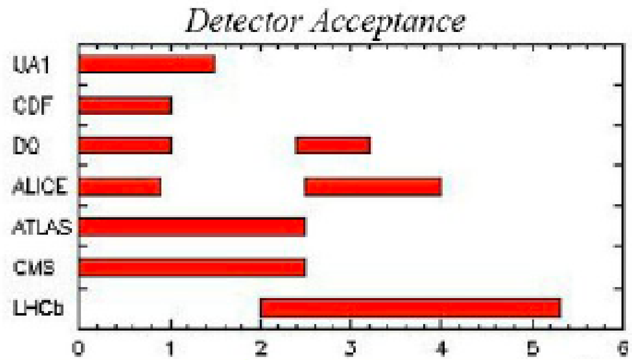
Potentia et Actus

- LHCb rare decays program starts flourishing in the ~100-1,000 pb^{-1} regime

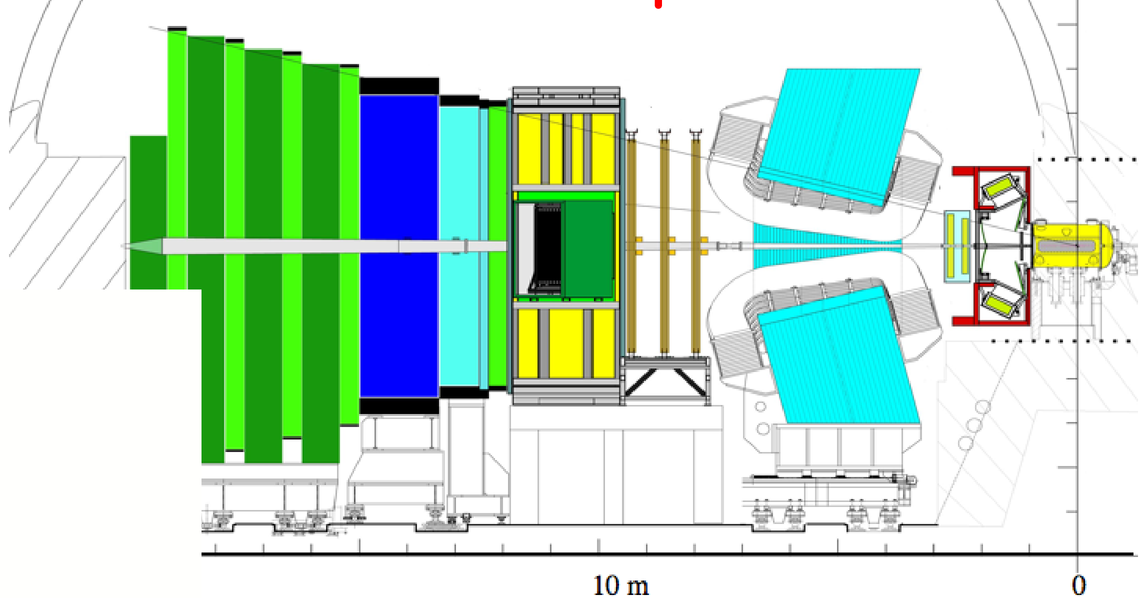


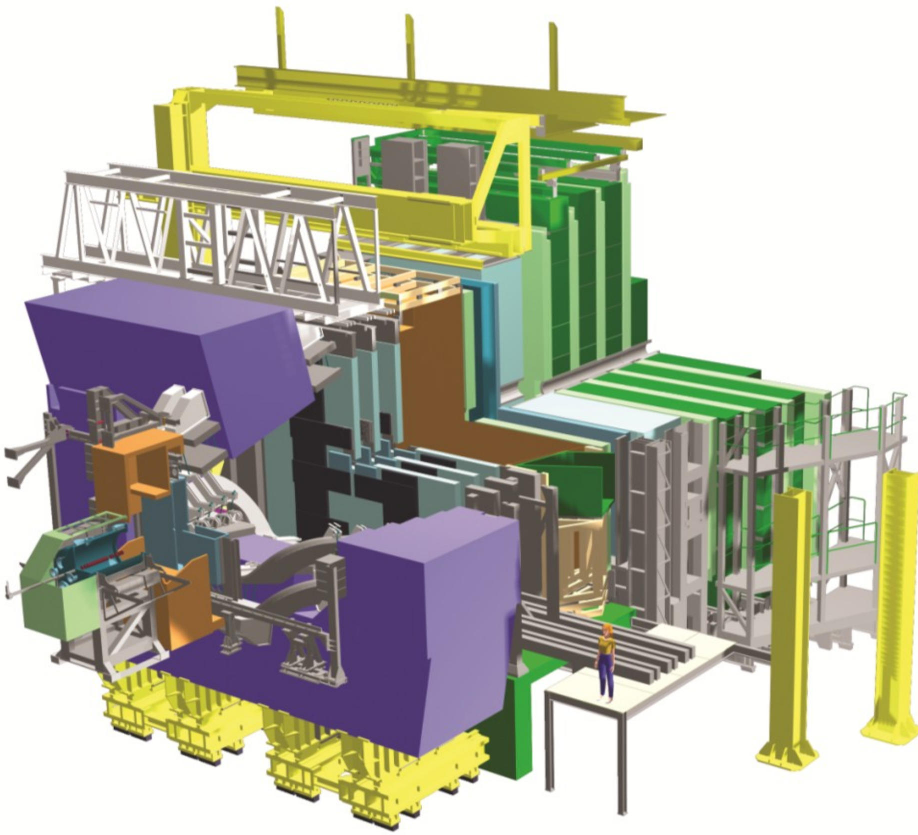
- data processing and analysis still in progress
- results presented today statistics between 1 and 35 pb^{-1}
- 2011 "annus mirabilis" for $B_s \to \mu\mu$ and $B_d \to K^*\mu\mu$

The LHCb Detector

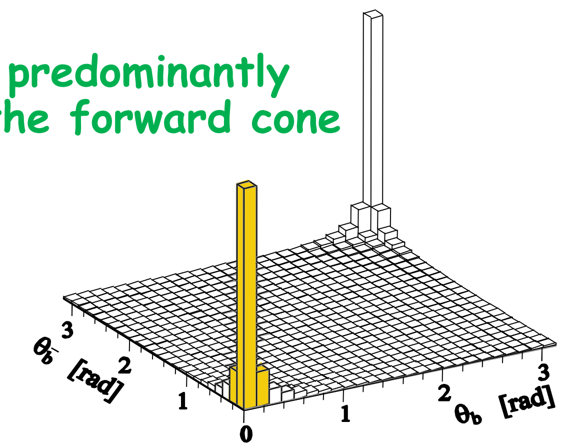


LHCb is a forward spectrometer

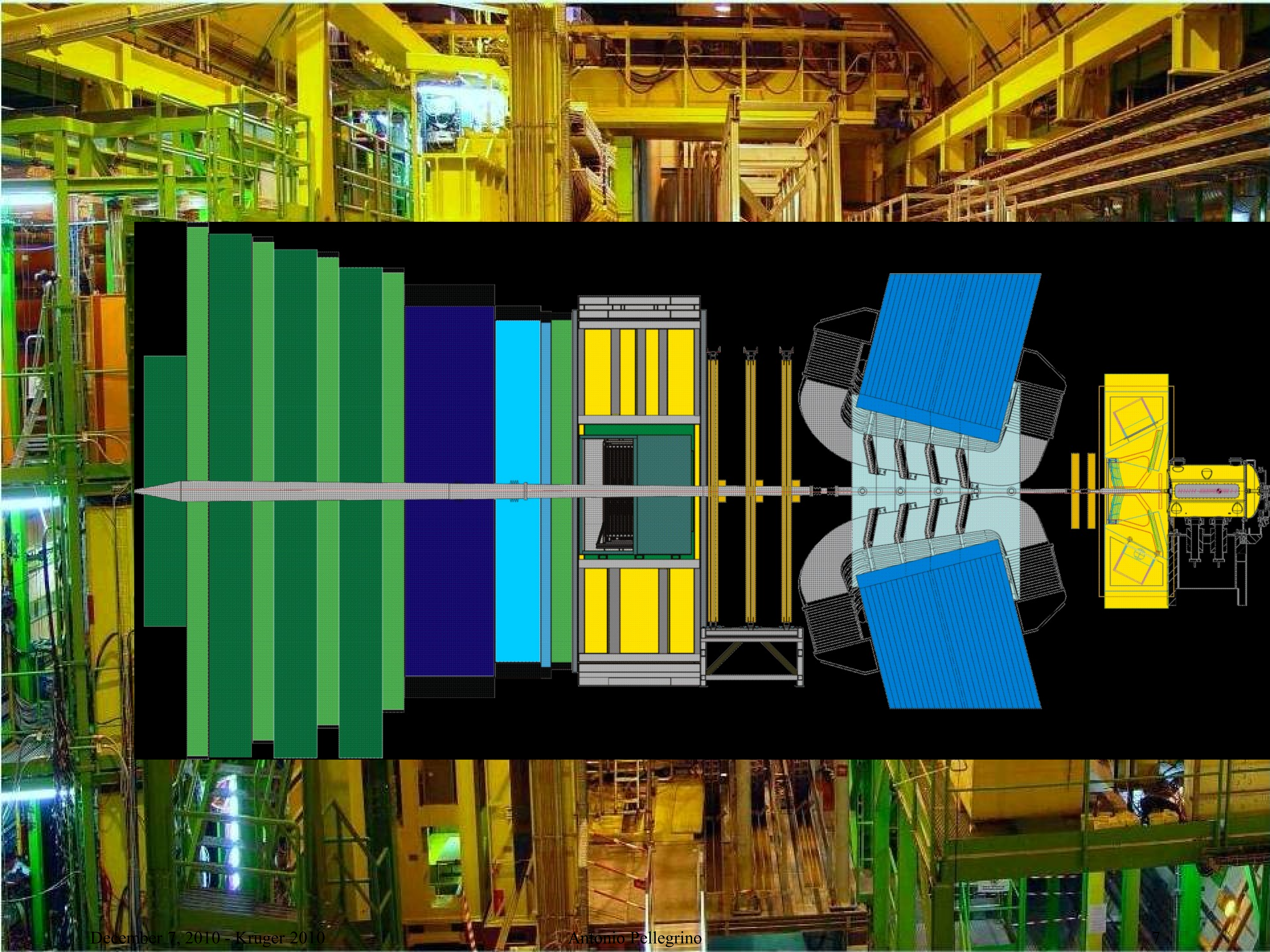




b-hadrons predominantly produced in the forward cone



See "LHCb Status, First Physics and Discovery Potential", O. Steinkamp, this conference

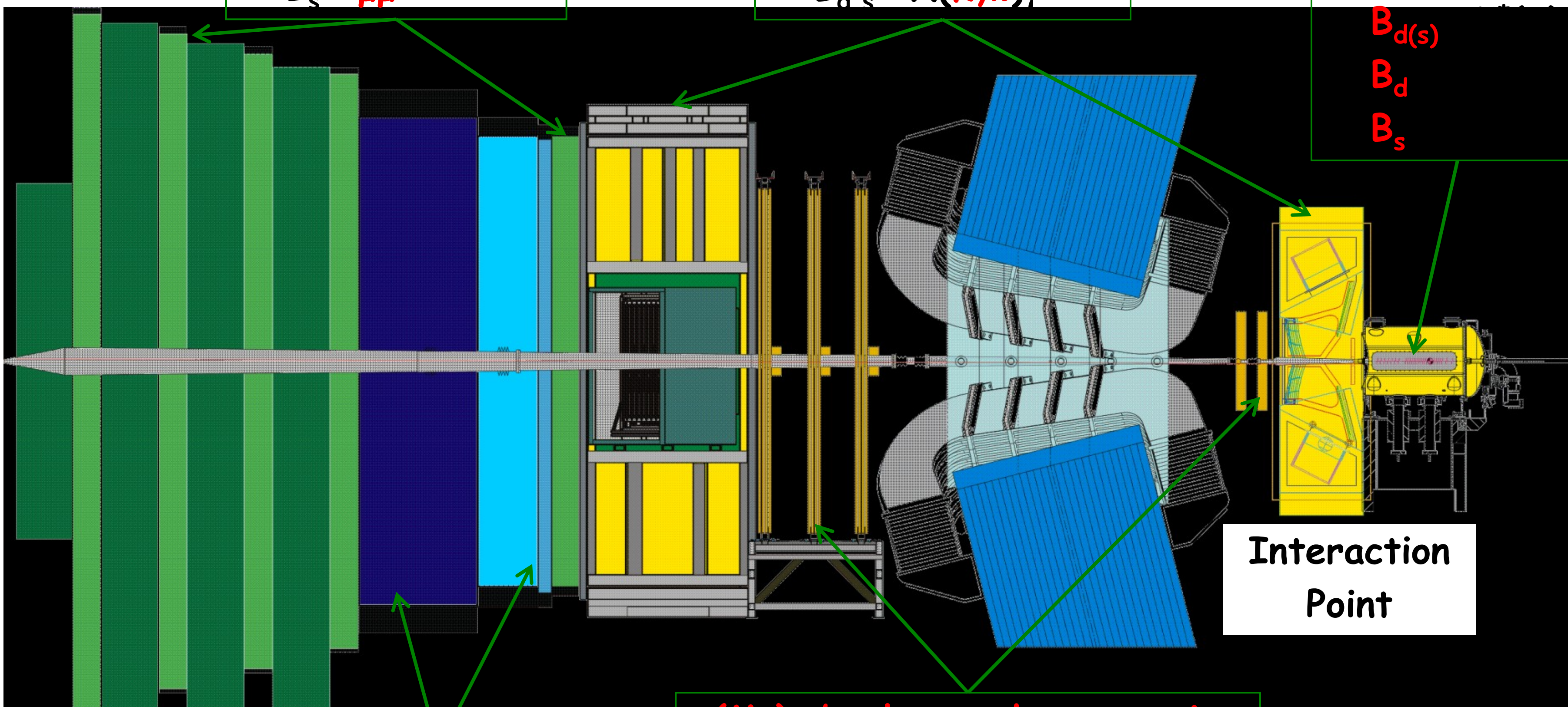


Crucial Ingredients

Trigger + μ-ID:
$B_d \to K^* \mu\mu$
$B_s \to \mu\mu$

K,π-ID:
$B_d \to K^* (K\pi)\mu\mu$
$B_{d,s} \to X(K,\pi)\gamma$

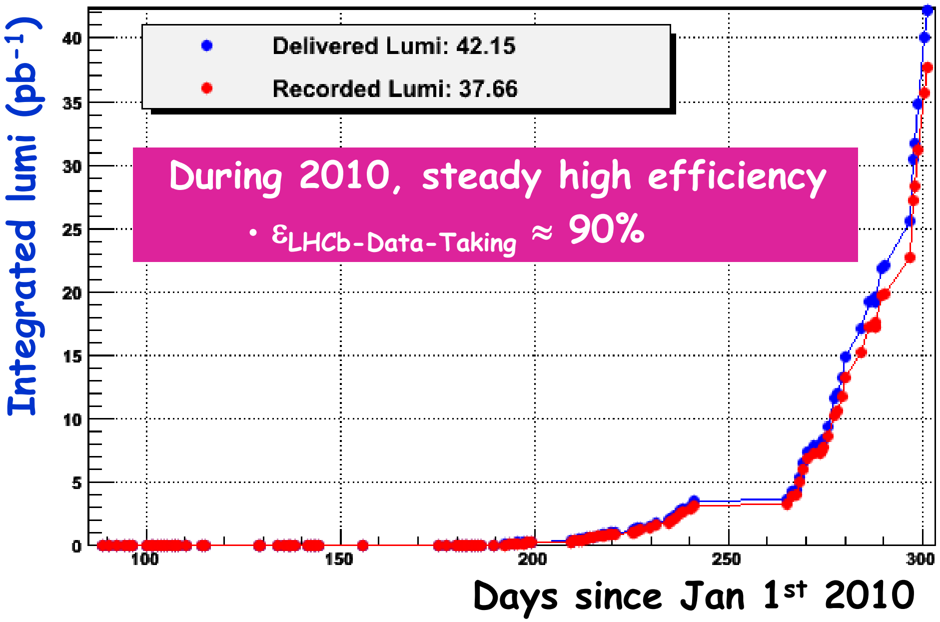
Lifetime
$B_{d(s)}$
B_d
B_s



Trigger + γ-ID:
$B_{d(s)} \to K^*(\varphi)\gamma$

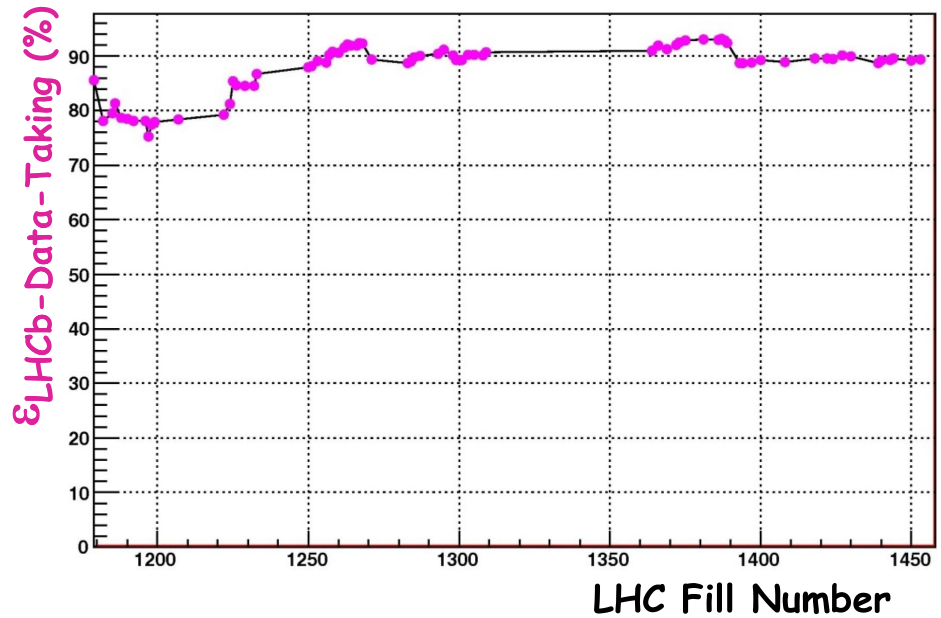
σ(M_B), background suppression
$B_{d(s)} \to K^*(\varphi)\gamma$
$B_d \to K^* \mu\mu$
$B_s \to \mu\mu$

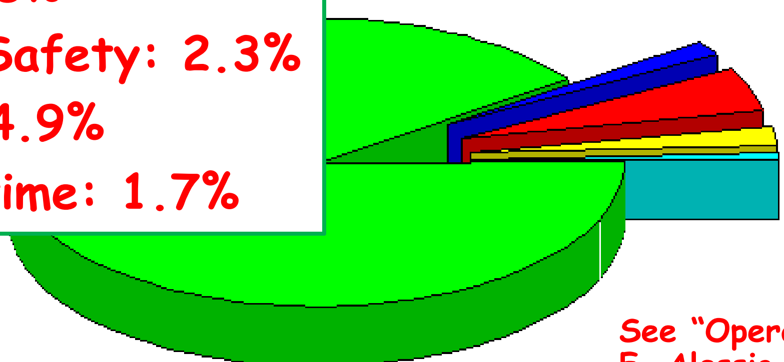
LHCb Data Taking Performance



During 2010, steady high efficiency

- $\varepsilon_{LHCb\text{-}Data\text{-}Taking} \approx 90\%$





FULLY ON: 90%

- HV: 0.8%
- VELO Safety: 2.3%
- DAQ: 4.9%
- Dead-time: 1.7%

Excellent performance

- recorded 38 pb^{-1}

See "Operation and Performance of the LHCb Experiment", F. Alessio, this conference

$B_s \to \mu^+\mu^-$

The $B_s \to \mu^+\mu^-$ is a very rare (also helicity suppressed) decay:

Blanke et al., JHEP 0610:003, 2006 $BR_{SM}(B_s \to \mu^+\mu^-) = (3.35 \pm 0.32) \times 10^{-9}$

Experimentally not observed yet

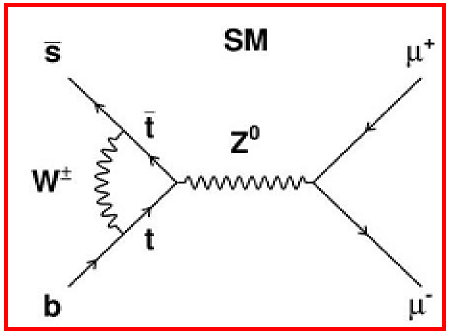
$BR(B_s \to \mu^+\mu^-) < 4.7\times10^{-8}$ at 90% C.L. *CDF, PRL 100, 101802 (2008), with 2 fb^{-1} (PDG 2010)*

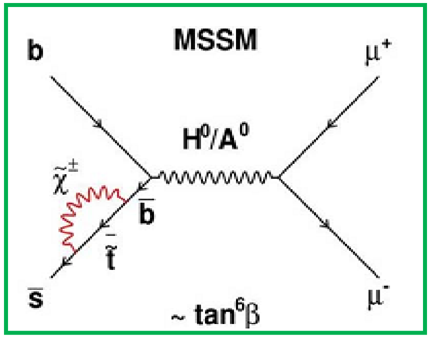
$BR(B_s \to \mu^+\mu^-) < 4.2\times10^{-8}$ at 90% C.L. *D0, arXiv:1006.3469v2 [hep-ex] , Oct 2010, with 6.1 fb^{-1}*

$BR(B_s \to \mu^+\mu^-) < 3.6\times10^{-8}$ at 90% C.L. *CDF prelim., CDF Public Note 9892, Aug 2009, with 3.7 fb^{-1}*

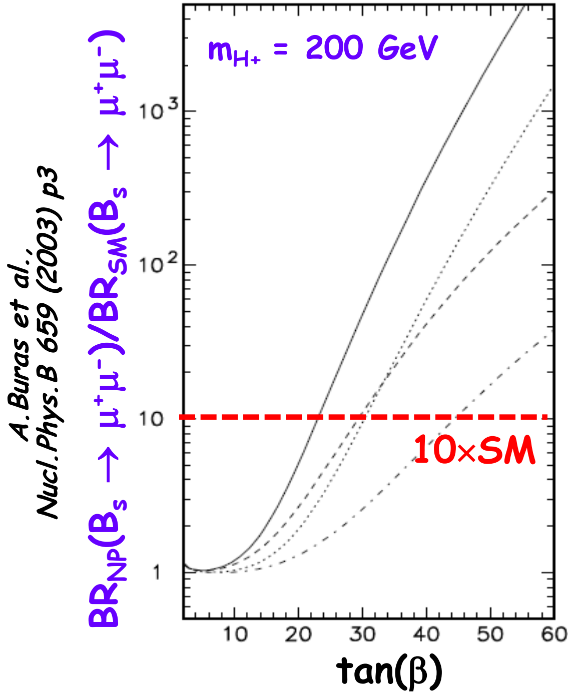
Sensitive to NP involving scalar/pseudo-scalar couplings

- enhance BR (lift helicity suppression)

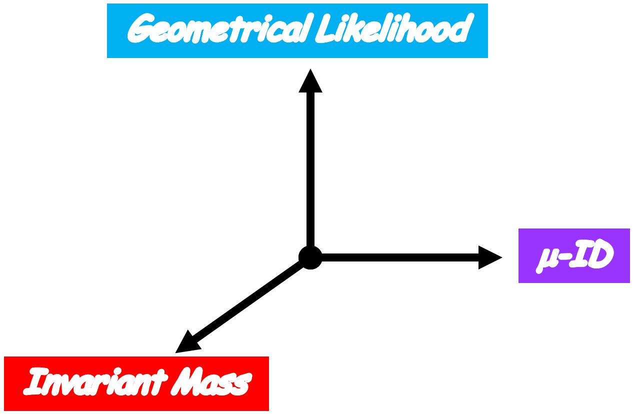




- very sensitive to models with high tan(β)
  - *e.g. all MSSM*



$B_s \to \mu^+\mu^-$ Analysis



Geometrical Likelihood

B Decay

impact parameters, isolation, lifetime, etc.

Mainly Vertex info

μ-ID

Muon Identification

- mis-ID π,K

Mainly Muon Detector

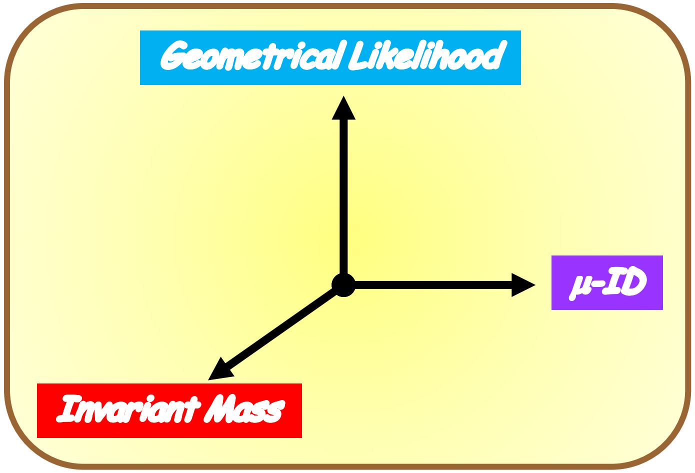
$B_s \to \mu^+\mu^-$

Invariant Mass

Invariant Mass

- background
- mass resolution
  - mainly tracking system (resolution, alignment)

$B_s \to \mu^+\mu^-$ with Early Data: IM



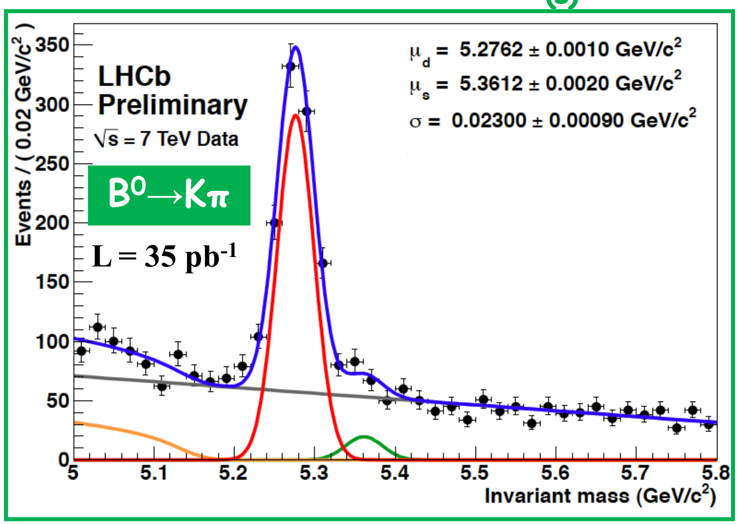
each event is assigned likelihood to be signal-like and background-like

Construct a Likelihood in 3D bins

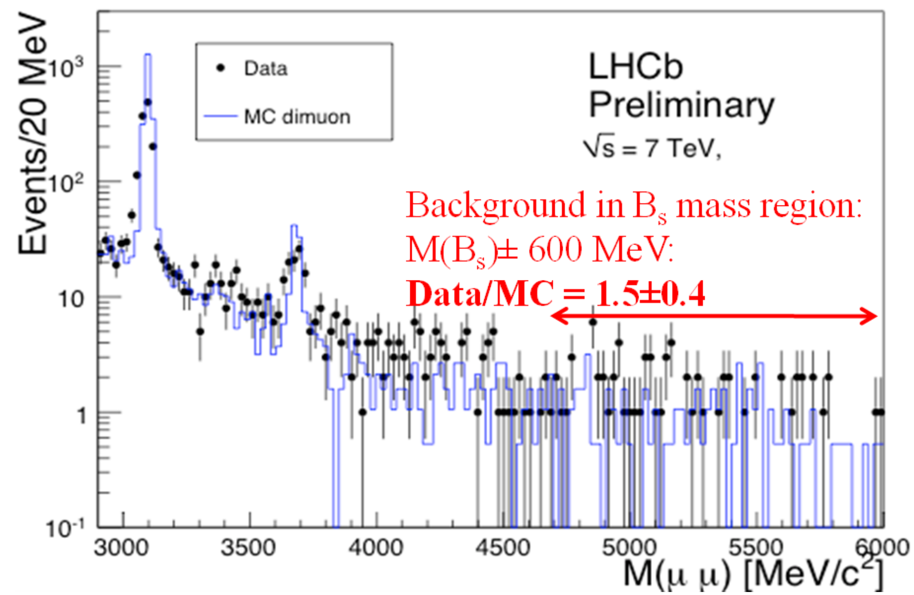
$\Lambda(GL, IML, PIDL)$

Likelihood that an event with a given IM is signal or background

Can be checked on $B^0_{(s)} \to hh$

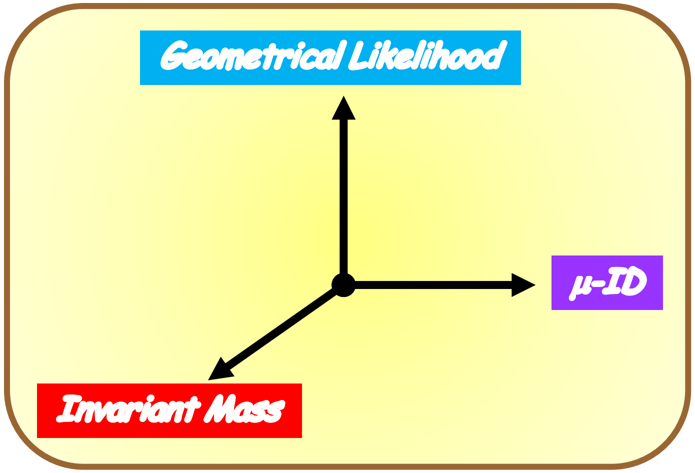


Mass resolution ~23 MeV, close to the expected 22 MeV



Background well described by MC

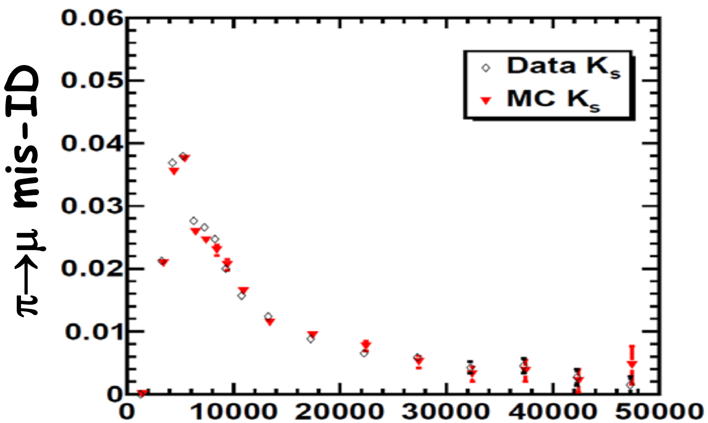
$B_s \to \mu^+\mu^-$ with Early Data: μ-ID



Λ(GL, IML, PIDL)

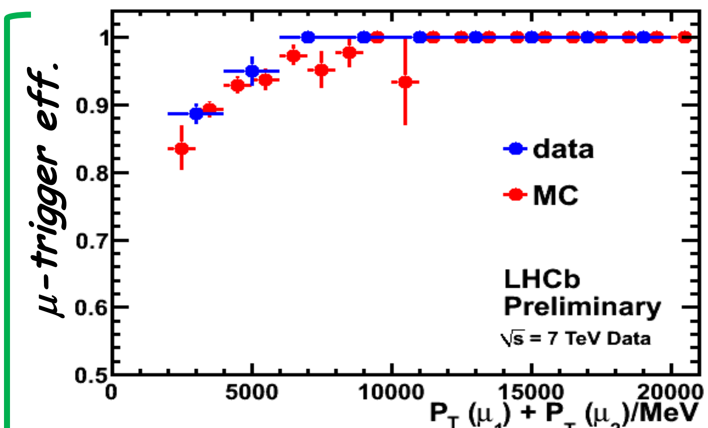
Likelihood that two μ candidates are muons
combination of DLL(π-μ) and DLL(K-μ)
mainly MUON (but also CALO and RICH)

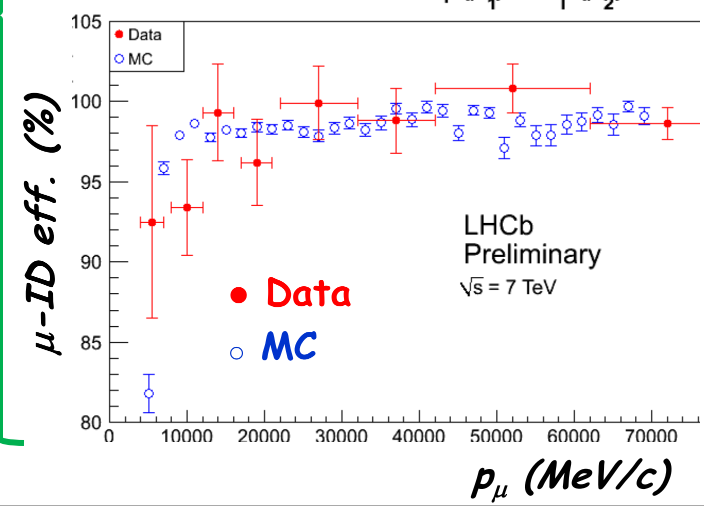
$\pi \to \mu$ mis-ID (from $K_S \to \pi^+\pi^-$)



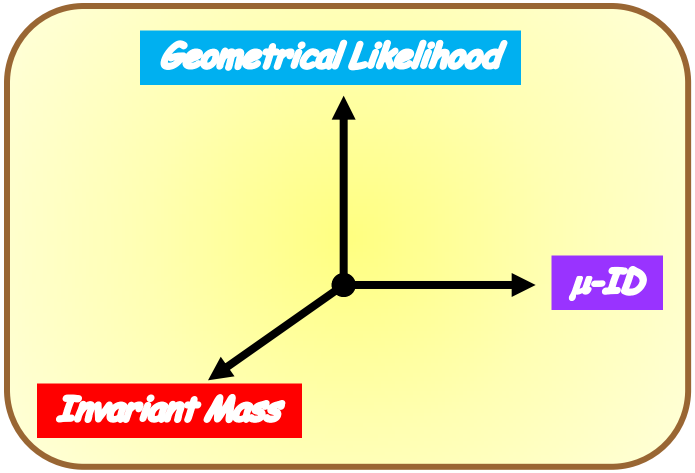
- Low mis-ID rate (typical p_μ~30 GeV)
- Good agreement data/MC

And we can do it efficiently!
(also good agreement data/MC)





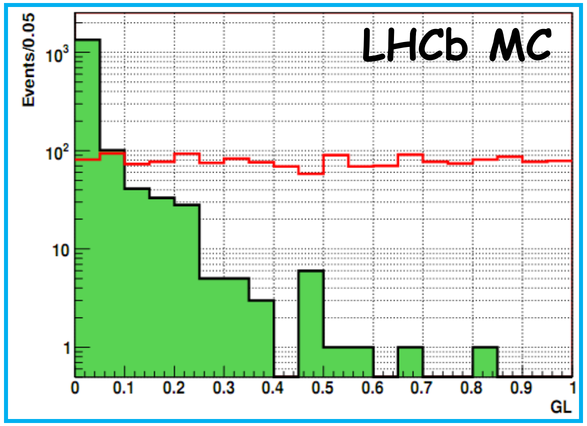
$B_s \to \mu^+\mu^-$ with Early Data: GL

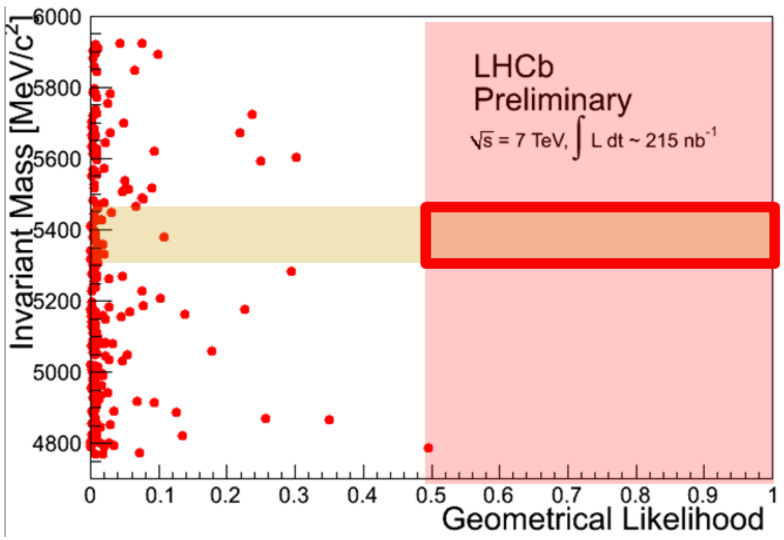


Λ(GL, IML, PIDL)

Likelihood that an event with a given "geometry" (IP, etc.) is signal or background

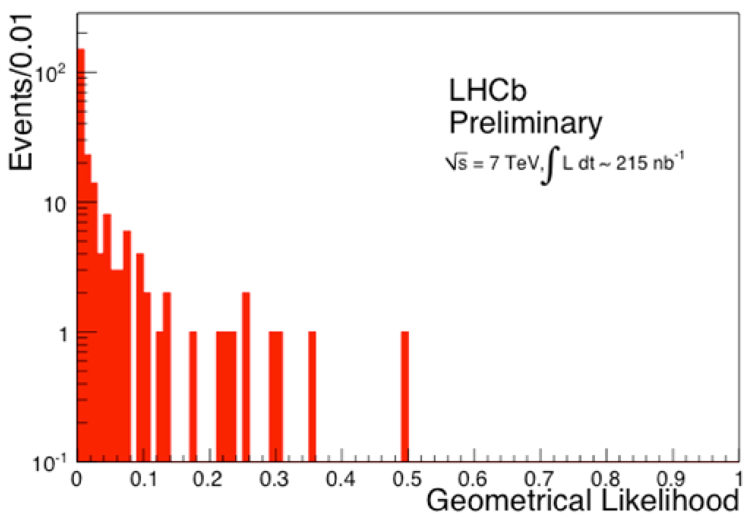
Background at GL>0.5





Sensitive region (GL>0.5)$\cap$($M_{B_s}\pm$60MeV)

- in 2011 expected (SM) 6 signals and 21 background events



"background" at low GL as expected

$B_s \to \mu^+\mu^-$ Normalization

signal candidates $N(B_s \to \mu^+\mu^-)$ in each bin $\Rightarrow$ normalization $\Rightarrow$ BR

choose a "normalization channel" $B_q \to X$ with a precisely known BR

- beside efficiencies ratio, need fragmentation functions

$$BR\left(B_s \to \mu^+\mu^-\right) = BR\left(B_q \to X\right)\left(\frac{f_q}{f_s}\right)\left(\frac{\varepsilon^{TRIG|SEL}_{B_q \to X}\,\varepsilon^{SEL|REC}_{B_q \to X}\,\varepsilon^{REC}_{B_q \to X}}{\varepsilon^{TRIG|SEL}_{B_s \to \mu\mu}\,\varepsilon^{SEL|REC}_{B_s \to \mu\mu}\,\varepsilon^{REC}_{B_s \to \mu\mu}}\right)\frac{N_{B_s \to \mu\mu}}{N_{B_q \to X}}$$

Choice of normalization channel:

- $B_s \to J/\psi\ \varphi$ — no f_q/f_s, but $BR(B_s \to J/\psi\phi) = 1.15\times10^{-3}$ ±25%
  (Belle prelim., arXiv:0905.4345v2, 23.6 fb^{-1}, 20% of available dataset)
- $B_d \to J/\psi\ K^*$ — $f_s/(f_d+f_u) = 0.142$ ±12% *PDG 2010*
  (CDF, Phys.Rev.D77:072003,2008), but environment-dependent, ignored SU(3) breaking)

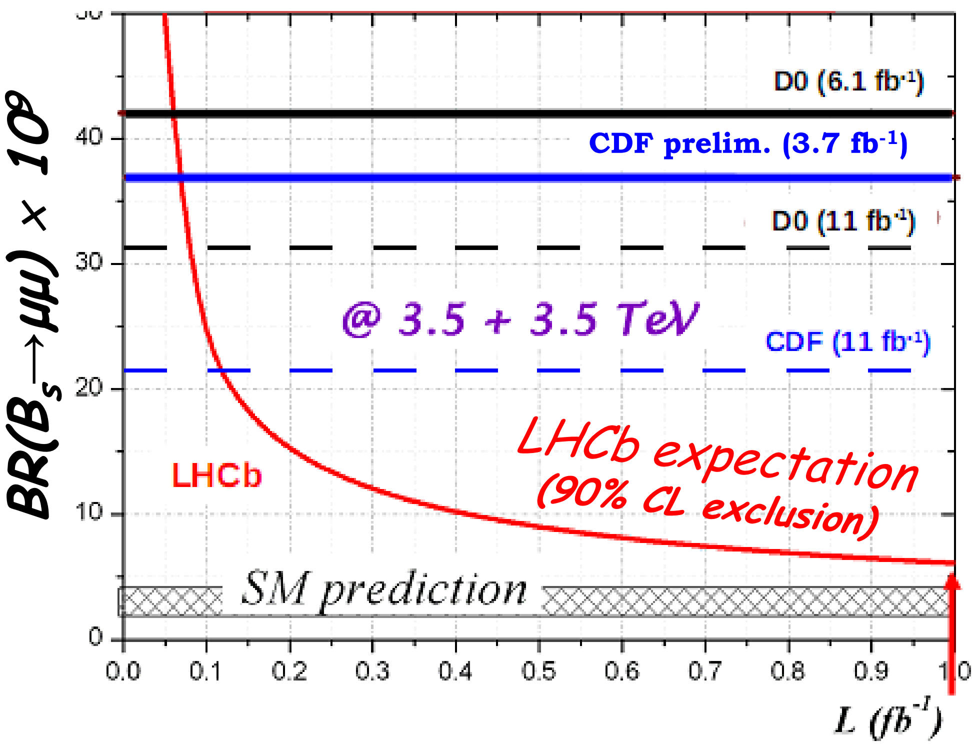
At LHCb our own program to measure f_s/f_d more precisely:

- from semi-leptonic b decays into a charmed hadron and a muon
- from $B_s \to D_s^-\pi^+$ and $B^0 \to D^-K^+$ *(R. Fleischer et al., Phys.Rev.D 82:034038,2010)*

Expect ~6-9% uncertainty

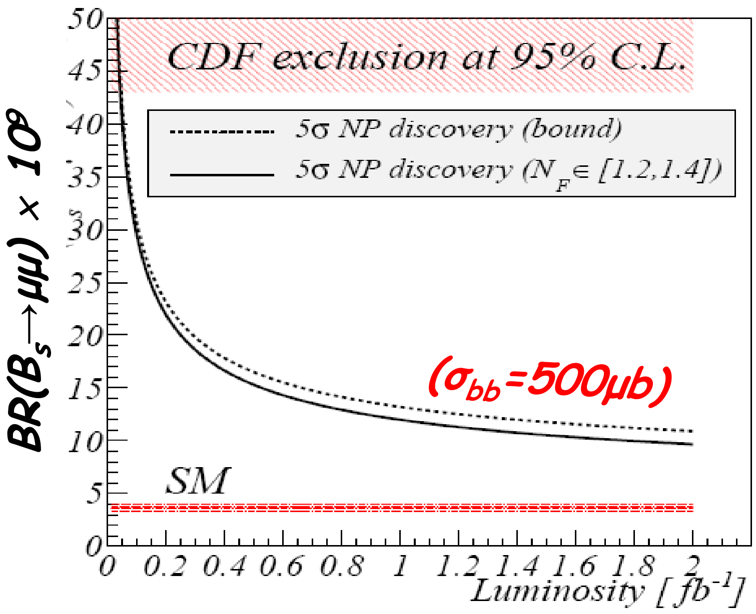
Perspectives on $B_s \to \mu^+\mu^-$

- With ~100 pb^{-1} approach new limit
- With 1 fb^{-1} could claim NP at 5σ if $BR(B^0_s \to \mu\mu) > 1.7\times10^{-8}$ ($BR \sim 5\times BR_{SM}$)



NP discovery potential

(R. Fleischer et al., Phys.Rev.D82:034038,2010)



2011 "annus mirabilis" for $B_s \to \mu\mu$ @ LHCb!!

$B_s \to \mu^+\mu^-$ Perspectives (cont'd)

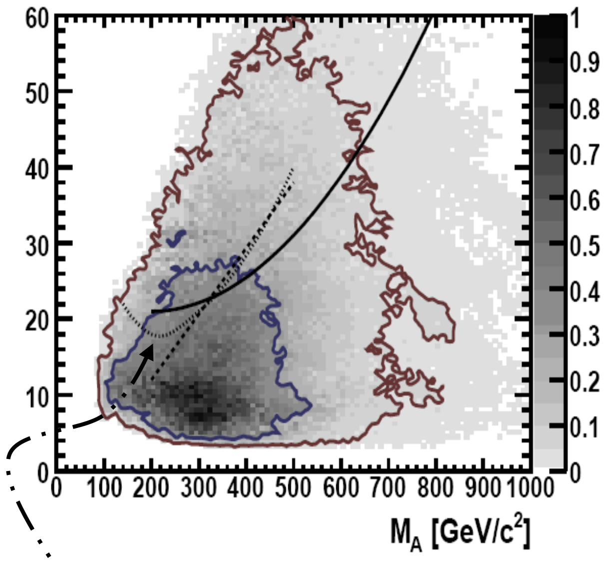
$BR(B_s \to \mu^+\mu^-)$ strongly enhanced in MSSM at large $\tan\beta$

In some models $BR(B_s \to \mu^+\mu^-)$ roughly proportional to $(\tan\beta)^6 / (M_A)^4$

Measurement of $BR(B_s \to \mu^+\mu^-)$ will significantly constrain the allowed $(\tan\beta, M_A)$ parameter space

$(\tan\beta, M_A)$ plots from O.Buchmueller et al. Eur.Phys.J.C64:391-415,2009
(frequentist analysis of experimental constraints from electroweak precision data, $(g-2)\mu$, B-physics and cosmological data)

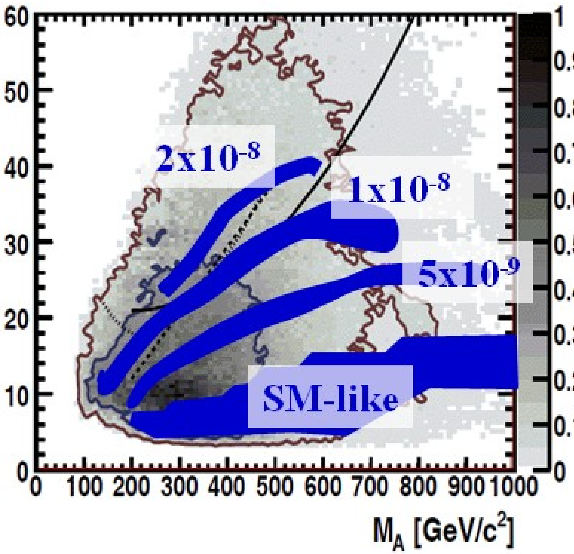
Non-universal H mass



Gennai et al. Eur.Phys.J. C52:383-395,2007

(E.g. CMS $H,A \to \tau^+\tau^-$ 30/60 fb^{-1} $\Rightarrow$ 5σ discov.)

NUHM and $BR(B_s \to \mu\mu)$



Curves obtained through SuperIso, (e.g. F.Mahmoudi, arXiv:0906.0369)

Forward/Backward Asymmetry

Expected good yield of $K^*\mu^+\mu^-$ at LHCb

(final-state di-muons efficient trigger and reconstruction)

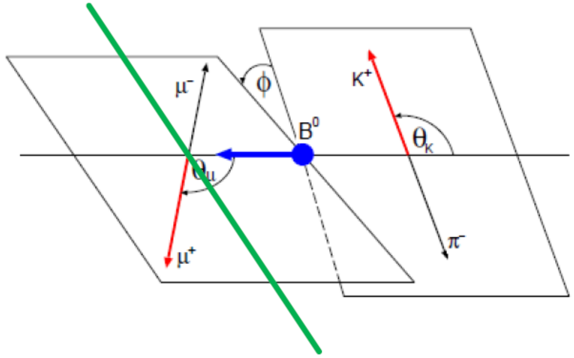
BR measured: $BR(B_d \to K^*\mu^+\mu^-) = (1.05^{+0.16}_{-0.13}) \times 10^{-6}$ *PDG 2010 Average (BaBar, Belle, CDF)*

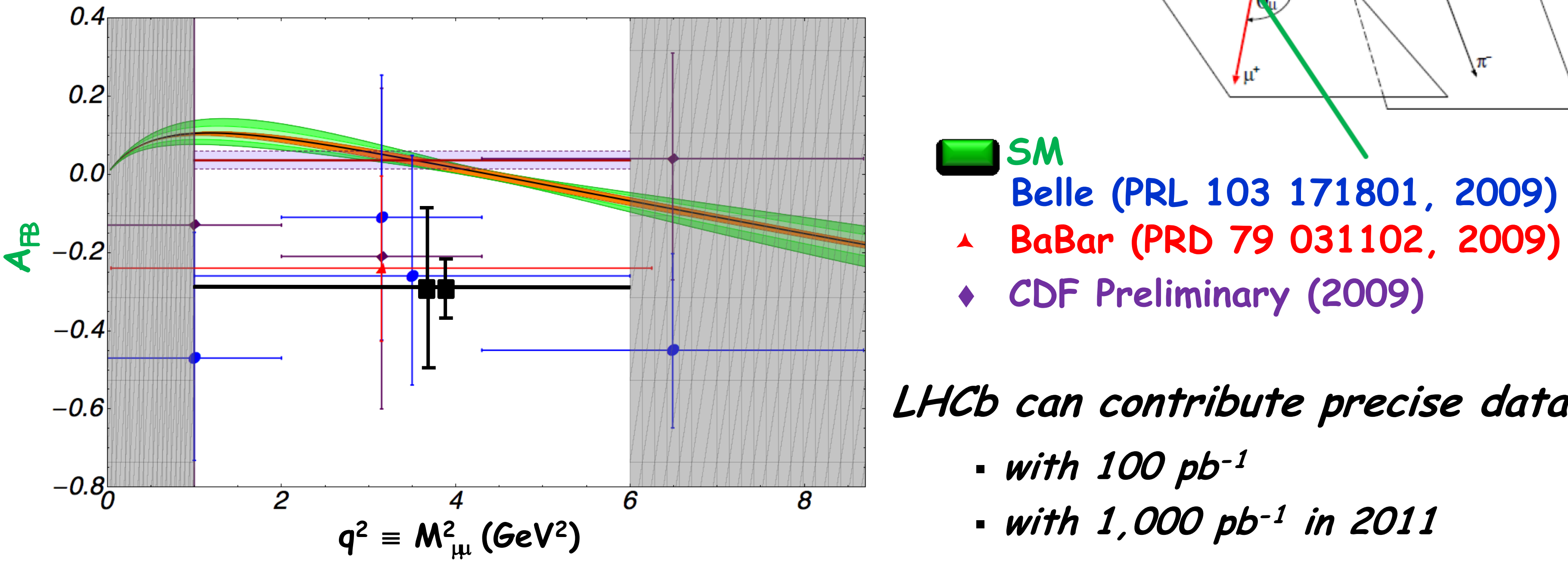
Theoretical predictions dominated by hadronic uncertainties from the form factors

$BR(B_d \to K^*\mu^+\mu^-) = (1.9^{+0.5}_{-0.4}) \times 10^{-6}$ *(Ali et al., PRD 61, 074024, 2000)*

Largely reduced in the forward/backward asymmetry

- (form-factors "cancelation" at zero-crossing point)





LHCb can contribute precise data

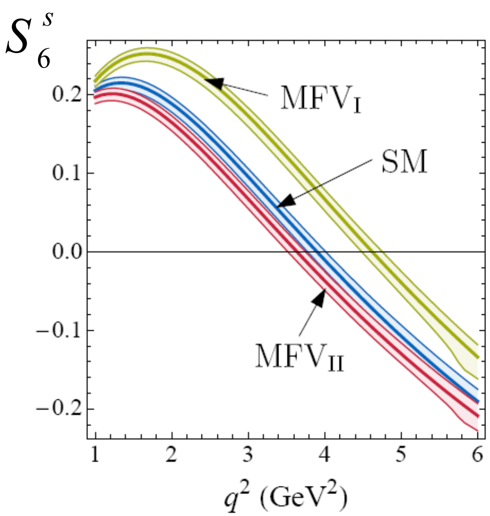
- *with 100 pb^{-1}*
- *with 1,000 pb^{-1} in 2011*

FB Asymmetry and Sensitivity to NP

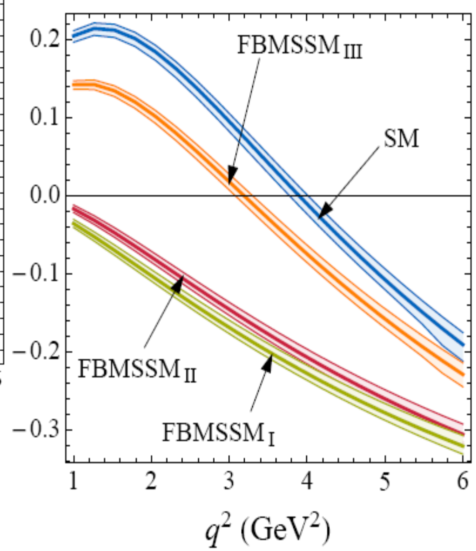
To get an idea of the sensitivity of the forward-backward asymmetry to NP models (through modifications of C_7 and C_9)

see e.g. W.Altmannshofer et al., JHEP 0901:019,2009

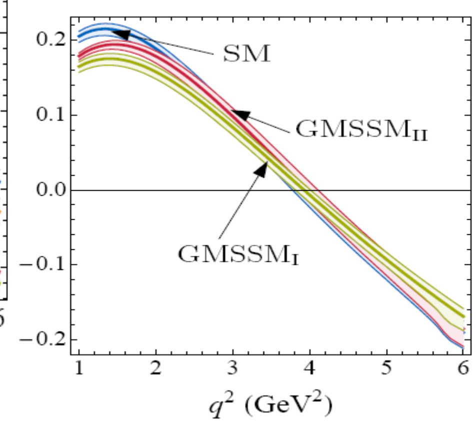
Minimal Flavour Violation



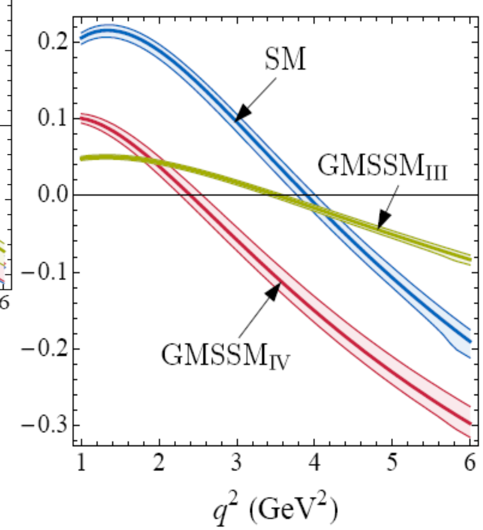
Flavour Blind MSSM



General MSSM
(large Im(C_7'))



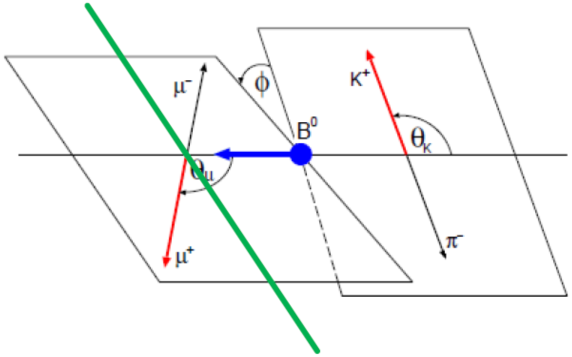
General MSSM
(modified C_7,C_7',C_{10})



S_6^s □ $\frac{4}{3}$ $_{FB}$

$K^*\mu\mu$ Reconstruction

$$A_{FB}(q^2) \equiv \frac{\Gamma(q^2, \cos\theta_\mu > 0) - \Gamma(q^2, \cos\theta_\mu < 0)}{\Gamma(q^2, \cos\theta_\mu > 0) + \Gamma(q^2, \cos\theta_\mu < 0)}$$



K,π Identification

Muon Identification

$B_d \rightarrow K^* (\rightarrow K\pi)\, \mu^+\mu^-$

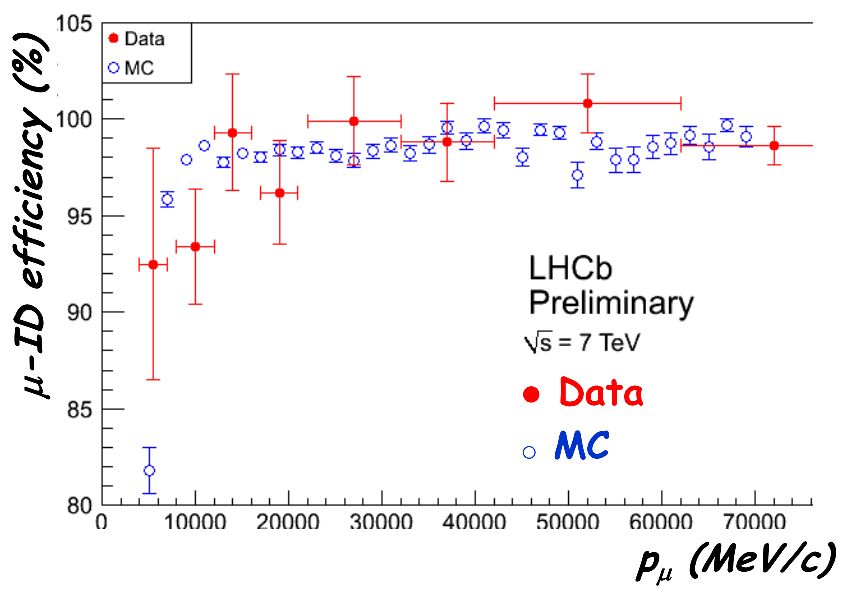
four-particles ($K\pi\mu\mu$) final state

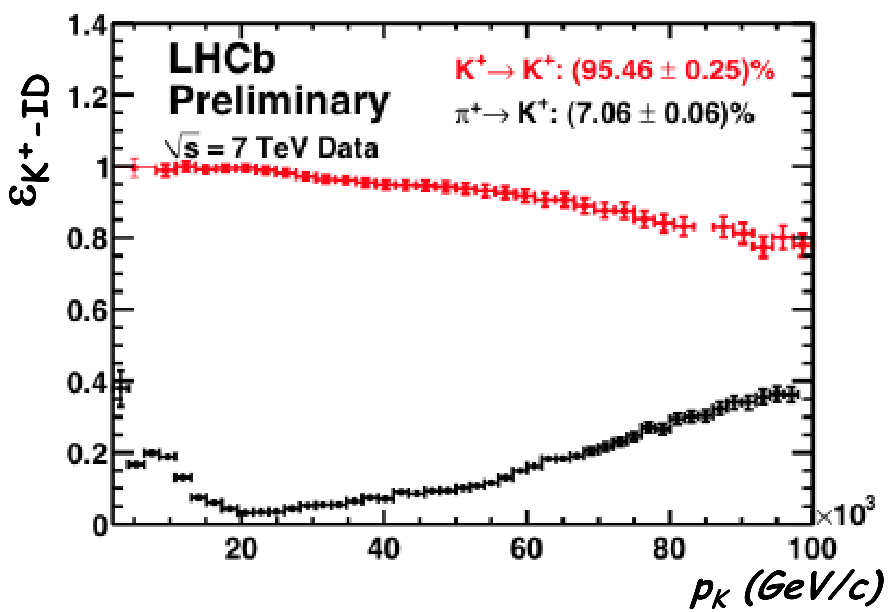
- minimize θ_μ-dependent effects in efficiency
  - special care in trigger and offline selection
- understanding and correcting remaining effects
- background distributions

- study with $B_d \rightarrow J/\psi\, K^*$ control channel
  - $BR(B_d \rightarrow J/\psi\, K^*) = (1.33 \pm 0.06) \times 10^{-3}$
  - with early data look at $D^0 \rightarrow K\pi\pi\pi$

$K^*\mu\mu$: Kaon and Muon ID

- Reconstruction working properly
  - μ-ID efficient, as in MC
  - K,π-ID OK
    - $\langle\varepsilon_{K\text{-}ID}\rangle \approx 96\%$
    - $\langle \text{mis-ID}_{K\text{-}\pi}\rangle \approx 7\%$

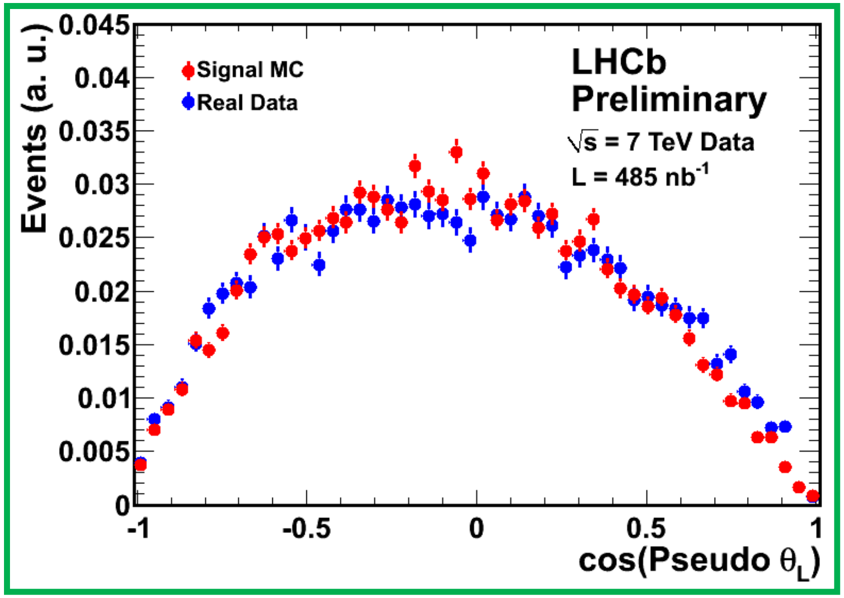


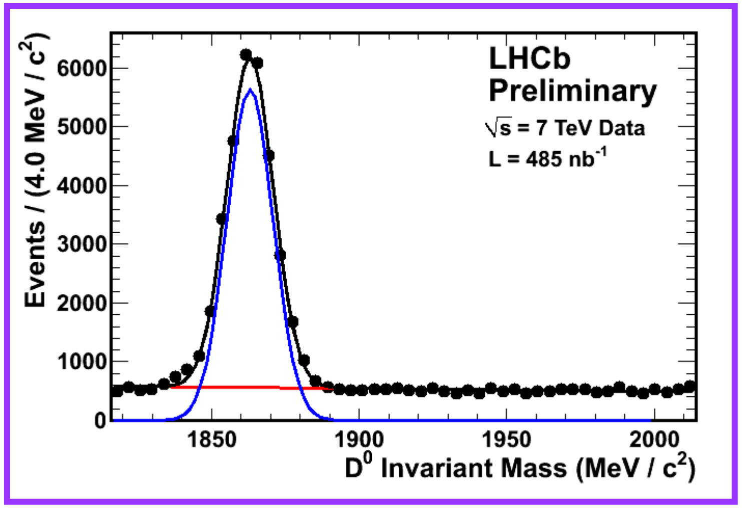


$K^*\mu\mu$: lessons from early data

Check bias introduced in the F/B asymmetry by trigger and offline selection

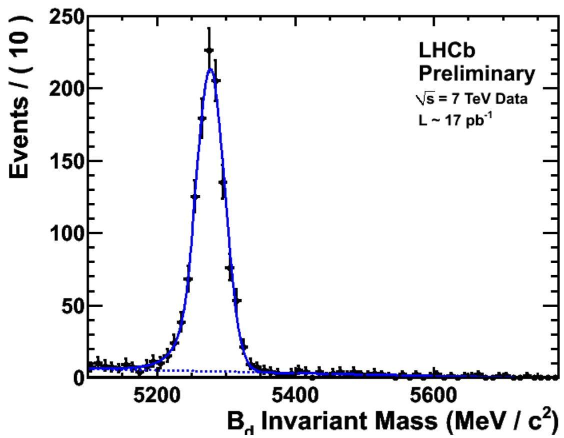
- *Ultimately use $B_d \to J/\psi\ K^*$ events*
  - *same final state*
- with early data, look at $D^0 \to K\pi\pi\pi$
  - same final state topology
  - selection without μ-ID



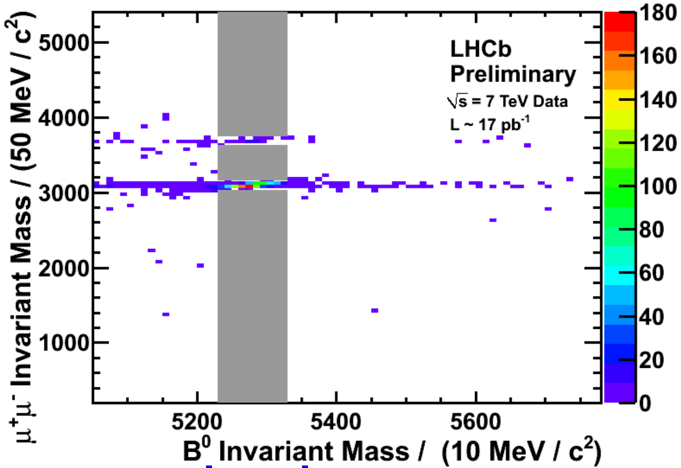


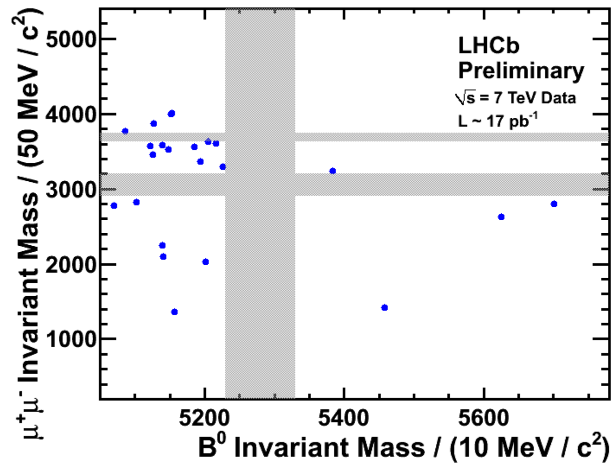
Good Data/MC agreement

K*μμ Expectation



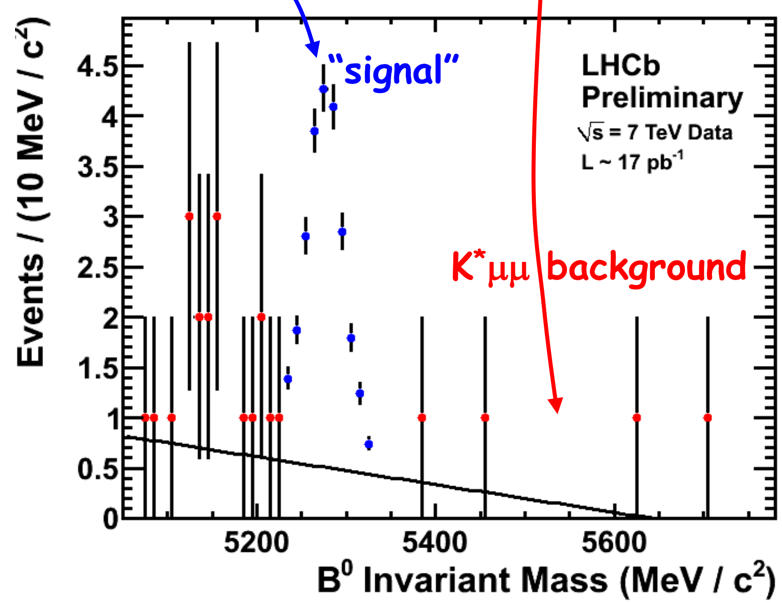
Control channel
$B_d \rightarrow J/\psi(\rightarrow\mu\mu)\ K^*$





Exercise for a realistic estimate of the expected $B_d \rightarrow K^*\mu\mu$ yield

- $B_d \rightarrow K^*\mu\mu$ background from side-bands
  - *i.e. "vetoing" J/ψ and $\psi(2S)$ regions*
- $B_d \rightarrow K^*\mu\mu$ expectation from $B_d \rightarrow J/\psi(\rightarrow\mu\mu)\ K^*$
  - *scaled by branching-fractions ratio*



Expect ~1,000 evts / fb^{-1}

Radiative Decays

In 1993 (PRL 71 p.674), CLEO published the first evidence of $b \to s\gamma$ transitions

$B^{0(-)} \to K^{*0(-)}\gamma$ BRs were found compatible with SM penguin diagrams

$BR(B^0 \to K^*\gamma) = (4.33 \pm 0.15) \times 10^{-5}$ *PDG 2010 Average*

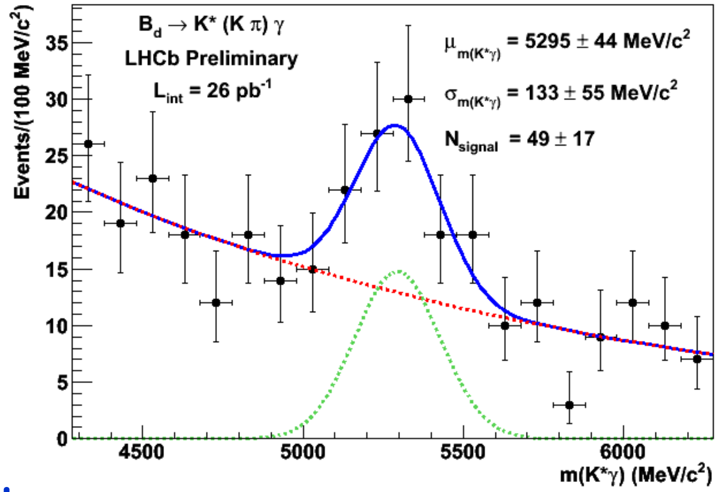
$BR(B_s \to \varphi\gamma) = (5.7^{+2.2}_{-1.9}) \times 10^{-5}$ *Belle, PRL, 100:121801,2008*

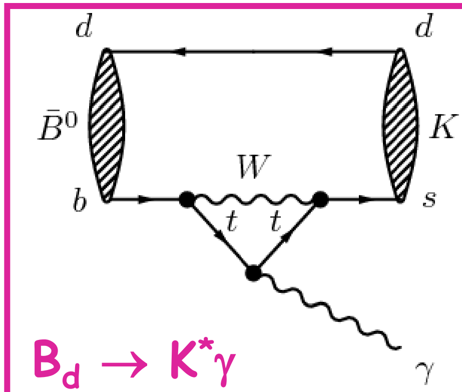
$BR_{theory}(B^0 \to X\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ *M. Misiak, PRL, 98:022002,2007*

$BR_{exp}(B^0 \to X\gamma) = (3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$ *Heavy Flavor Averaging Group 2010*

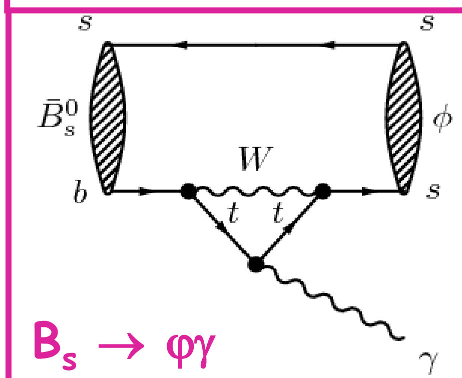
First $B_d \to K^*\gamma$ events already measured

- Unbinned Maximum likelihood fit (signal + exp. backg.)
- somewhat low yield (work on L0 resolution + calo calibration)





$B_d \to K^*\gamma$



$B_s \to \varphi\gamma$

- BRs already constrain NP models
- γ polarization can still reveal large effects
  - V-A SM structure ⇒ γ almost completely L-polarized
  - enhancement of R-polarized contribution ⇒ NP
- How can we determine the photon polarization at LHCb?

Radiative Decays (cont'd)

How can we determine the photon polarization at LHCb ?

$B_s \rightarrow \varphi\gamma$

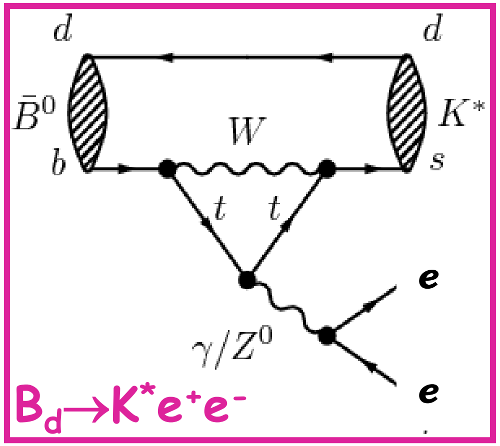
Time-dependent analysis

(~2,000 pb^{-1}, no flavor tagging)

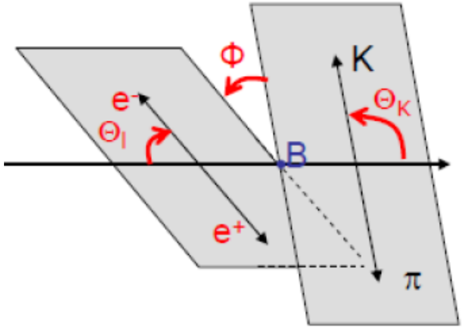
$B_d \rightarrow K^* e^+ e^-$

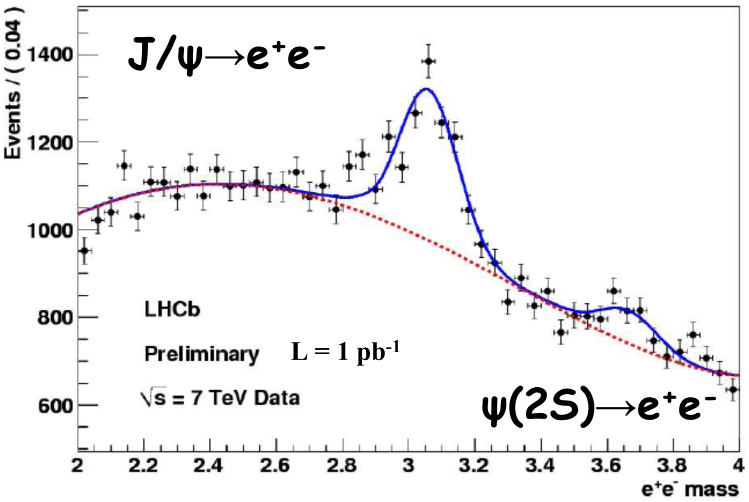
Virtual-γ, Angular analysis

(~250 events in 2,000 pb^{-1})



$BR(B_d \rightarrow K^* e^+ e^-) = (1.03\,^{+0.19}_{-0.17}) \times 10^{-6}$ *PDG 2010 Average (BaBar, Belle)*





- already measuring $J/\psi \rightarrow e^+e^-$ decays
  - ECAL calibration OK
  - almost no radiative tails (energy recovery OK)

Summary and Outlook

- LHCb Experiment excellent capabilities for Rare Decays studies

- the detector worked successfully in 2010, collecting $38pb^{-1}$

- first results on rare decays expected soon with $O(100\ pb^{-1})$
  - improve limit on $B_s \to \mu^+\mu^-$ branching fraction
  - improve error on $K^*\mu\mu$ backward/forward asymmetry
  - competitive measurement of direct CP asymmetry in $B^0 \to K^*\gamma$

- by end of 2011 $O(1fb^{-1})$ sensitivity to New Physics