# Prospects for rare B decays at LHCb

*XIV Lomonosov Conference on Elementary Particle Physics*

**Nicola Serra** on behalf of the **LHCb** collaboration

"Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed"
A. Soni

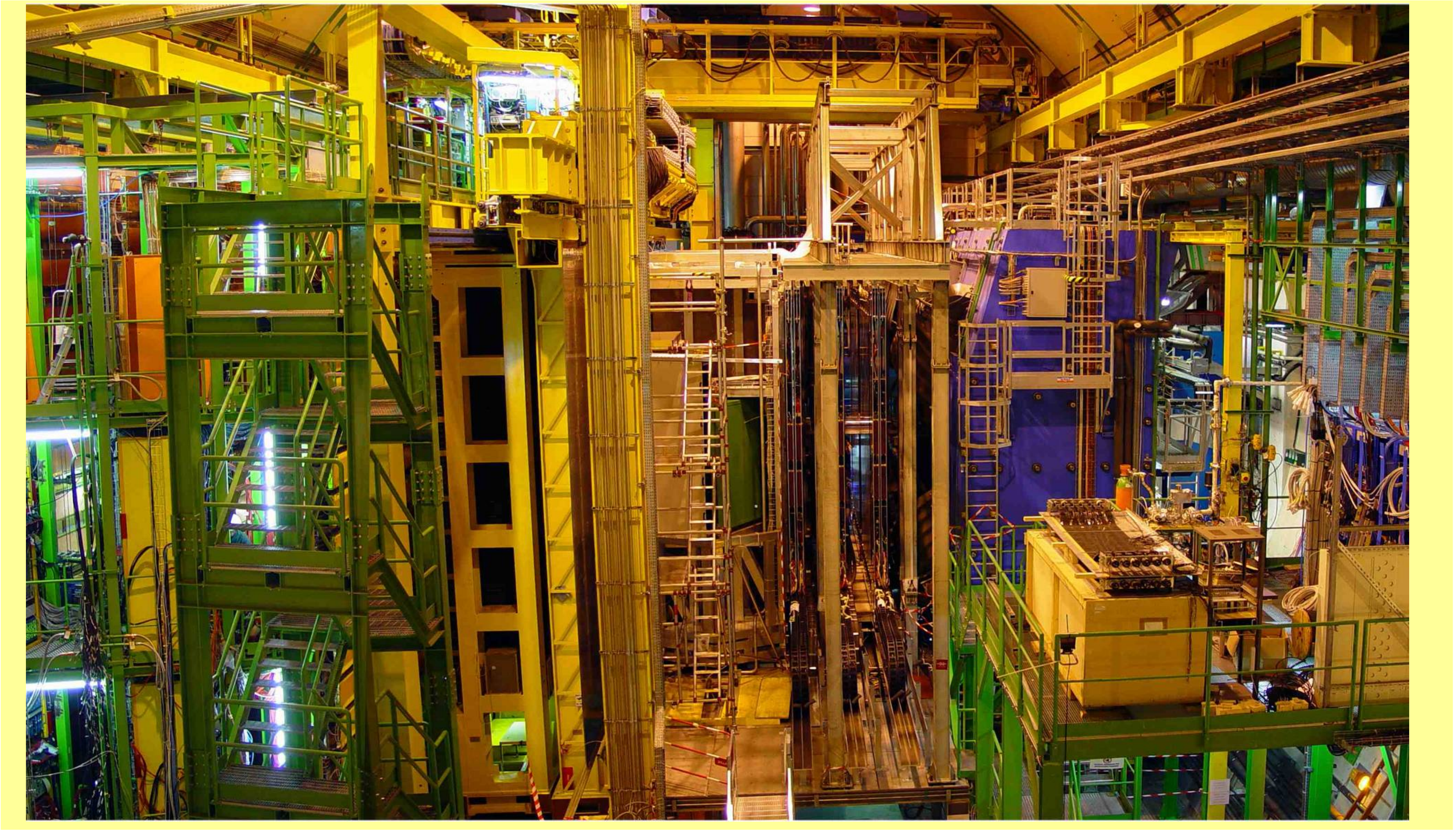
# RDs: finding a needle in a haystack

$B_s \rightarrow \mu\mu$ $(Br \sim 10^{-9})$

$B_d \rightarrow K^{*}\mu\mu$, $B_s \rightarrow \phi\gamma$ $(Br \sim 10^{-6(5)})$

Some Other rare decays : $B_{s,d} \rightarrow e\mu$ , $B_d \rightarrow K^{*}ee$

# The LHCb detector



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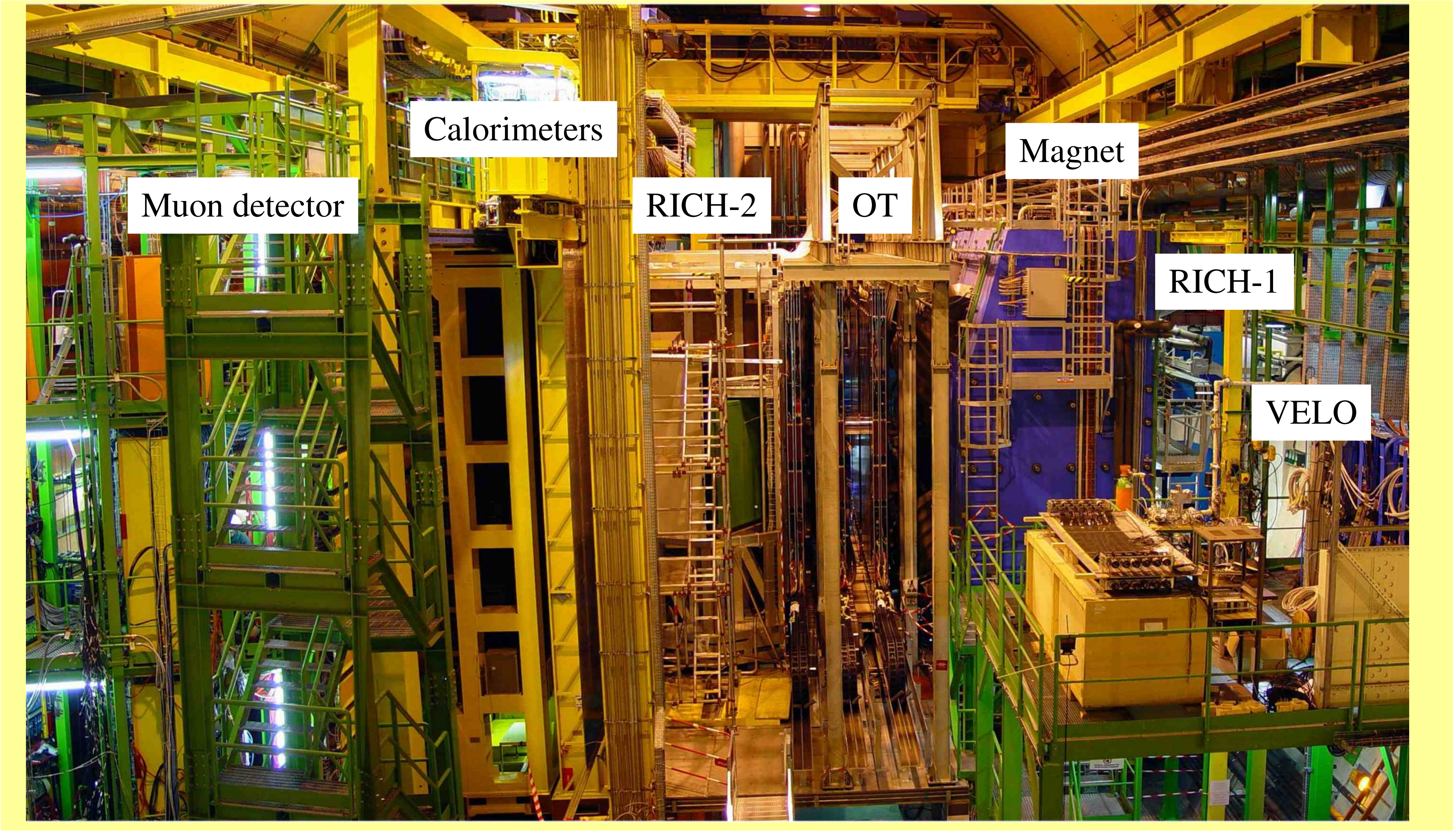
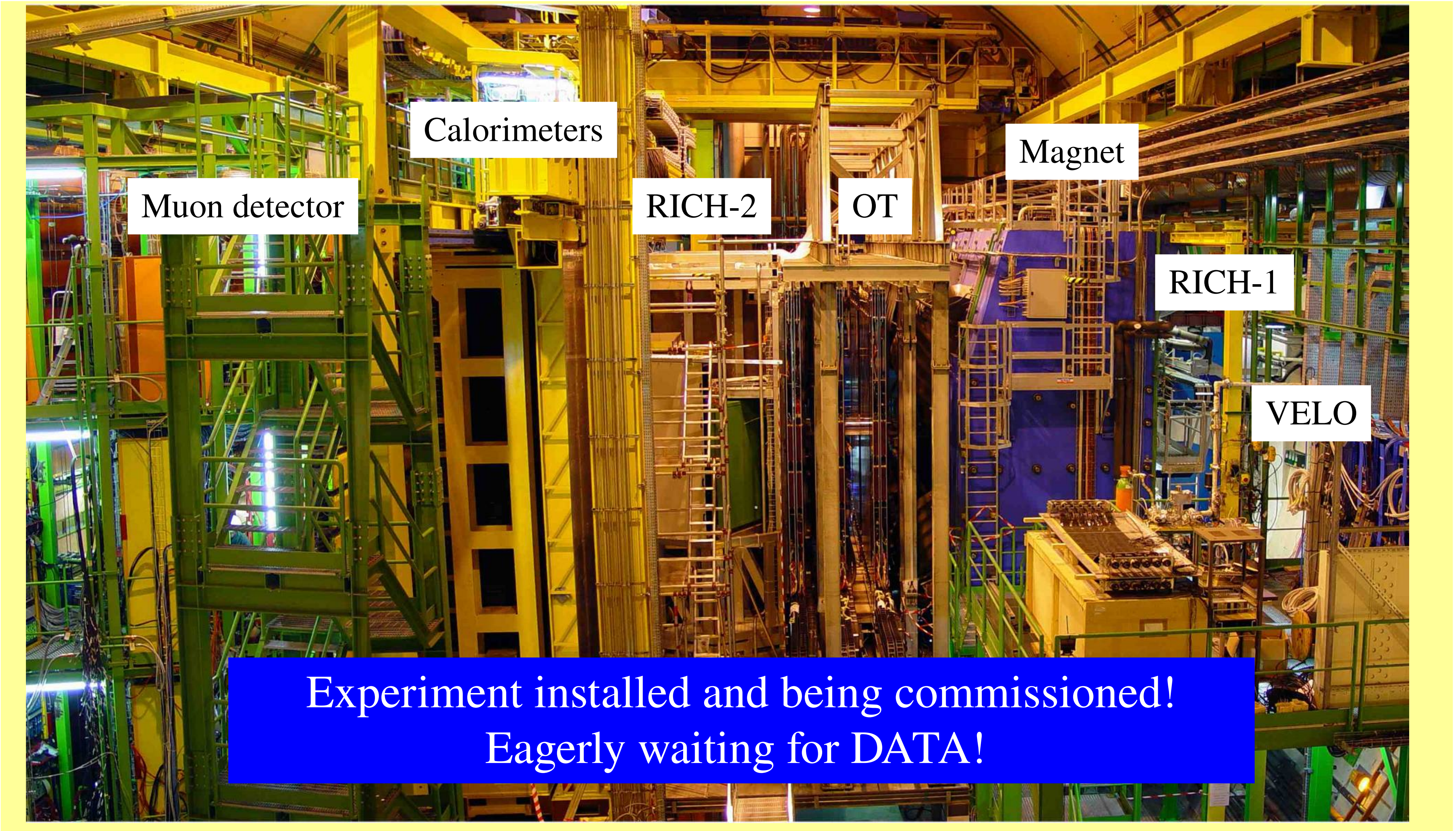
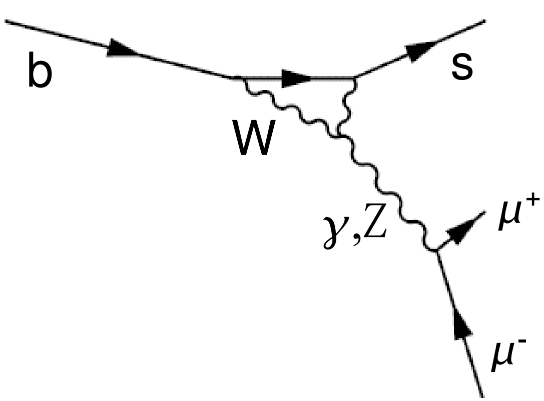


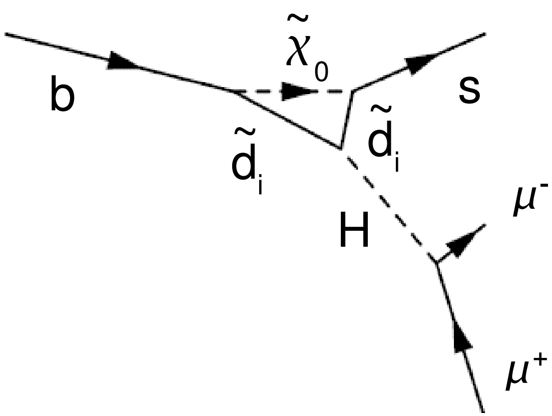
# The LHCb detector



# Introduction: (Semi)-leptonic B-decays

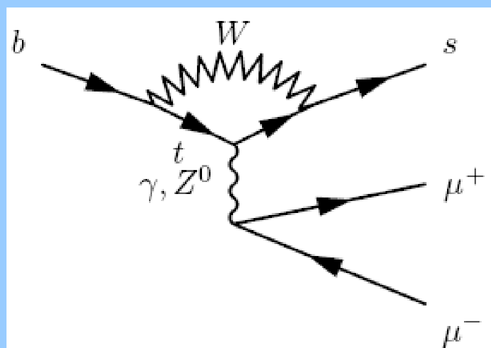
- **Indirect searches are very promising for doing a precise test of SM in a model independent way;**
- **A FCNC NP contribution could be at the same level as SM contribution;**
- **NP virtual particles can vary amplitudes wrt SM expectations;**
- **The challenge is to find quantities which are theoretically clean and experimentally accessible.**



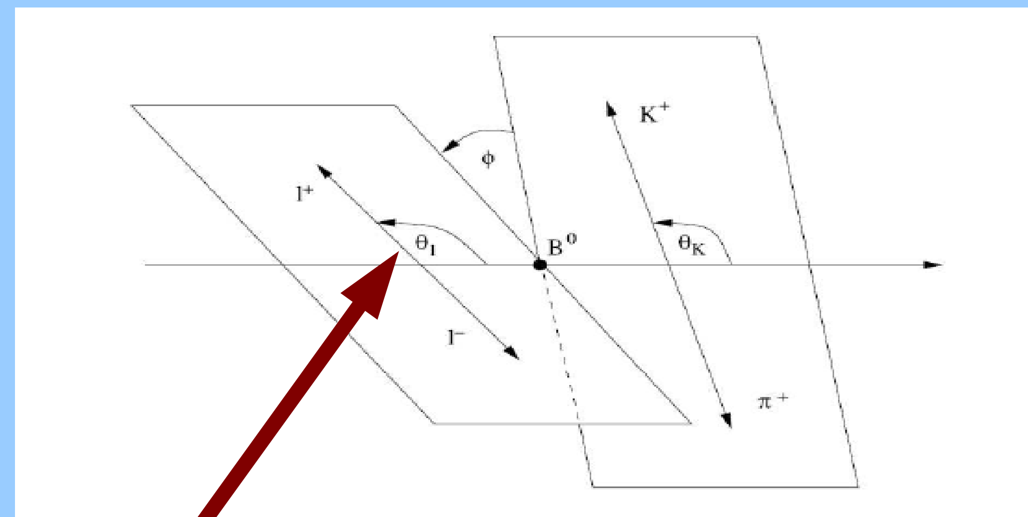




# Angular observables in $B_d \to K^*\mu\mu$

Lowest order Feynman diagrams




Sensitive to several NP models!
(e.g. Sugra with low tan$\beta$ ,
MIA SUSY, Left-right symmetric models)




In the OPE formalism this decay is function of three coefficients: $C_7$ ,$C_9$ ,$C_{10}$ ($C_7'$ ,$C_9'$ ,$C_{10}'$) .

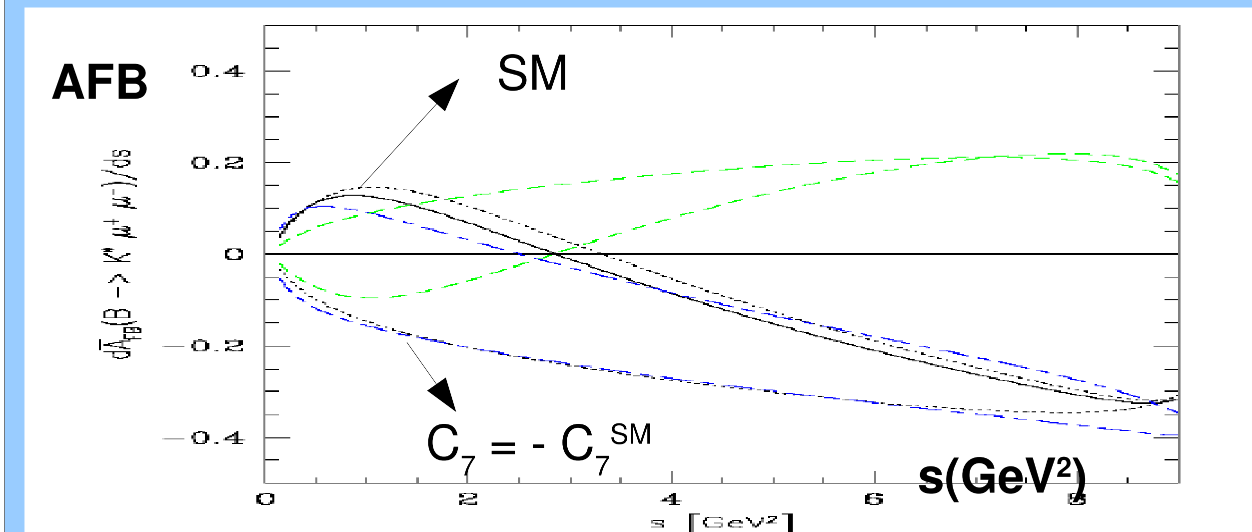
$$H_{eff} = \frac{4G_F}{\sqrt{2}} V_{tb} \bar{V}_{ts} \Sigma_i \{ C_i O_i \}$$

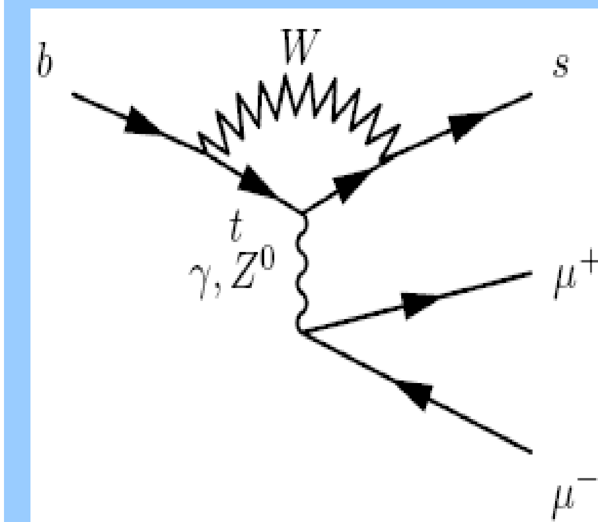
**The most popular of these observables is the AFB:**

$$AFB(s) = \frac{N_f(s) - N_b(s)}{N_f(s) + N_b(s)}$$

**S = dimuon invariant mass squared.**
**The point where AFB(s)=0 is very well predicted.**

# AFB in $B_d \rightarrow K^{*}\mu\mu$



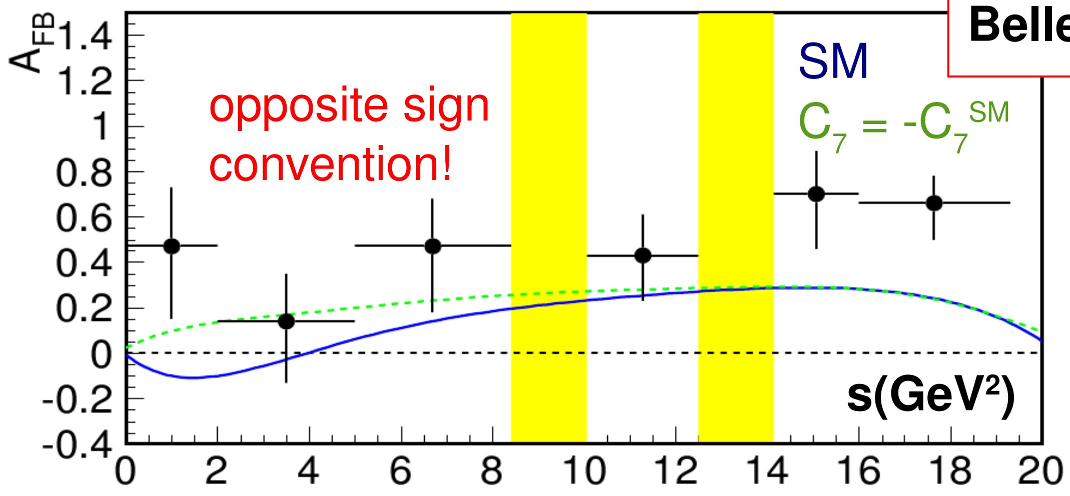

**The AFB arise from the interference between the $\gamma$ and the Z in the electroweak penguin.**

$$AFB(s=m_{\mu\mu}) = C_{10}\xi(s)\left(\Re(C_9)F_1 + \frac{1}{s}F_2 C_7\right)$$

**The zero-crossing point is the most clean against theoretical uncertainty**

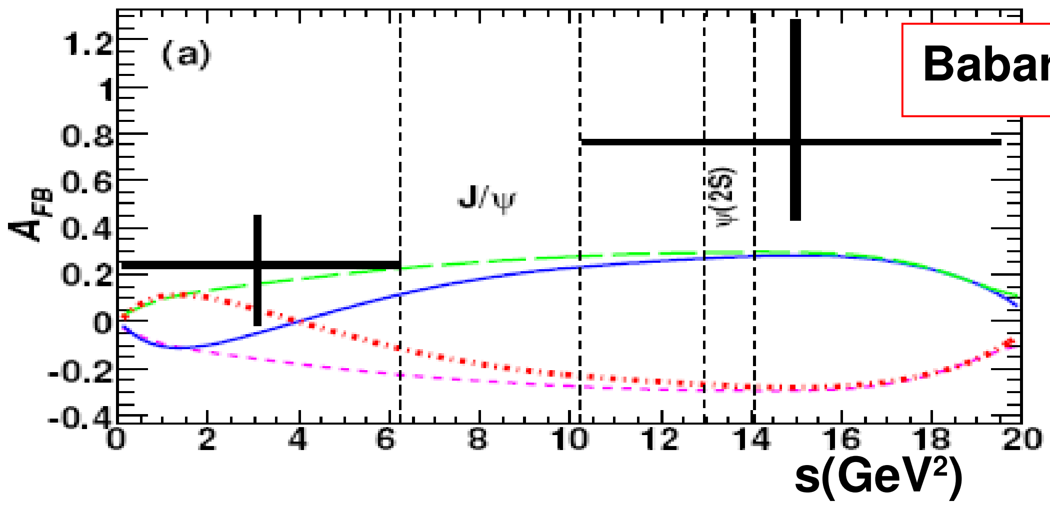
$$S_0^{SM} = 4.36^{+0.33}_{-0.31}\,GeV^2$$

# Most recent Measurements




Belle: arXiv:0810.0335v1

Babar/Belle ~ O(100) events
CDF ~ 20 events
LHCb~ 7200 events in 1 year

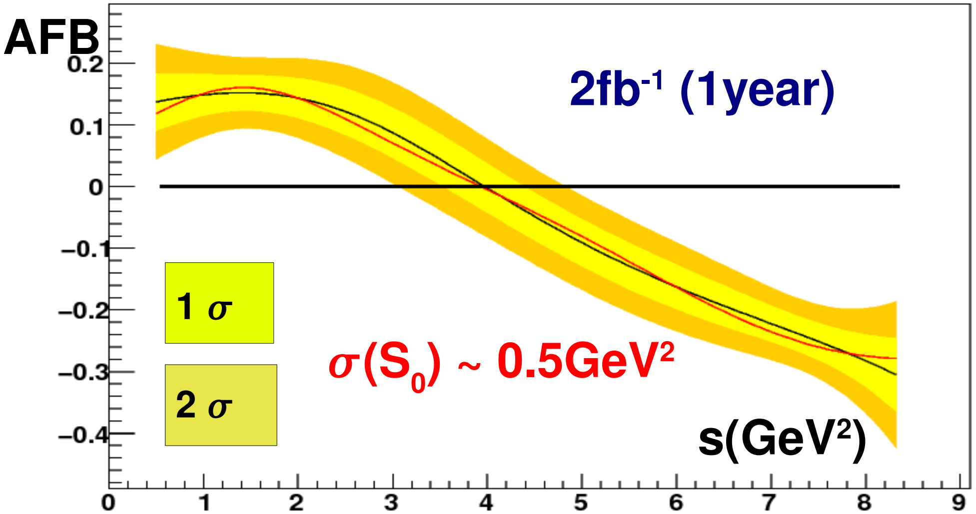


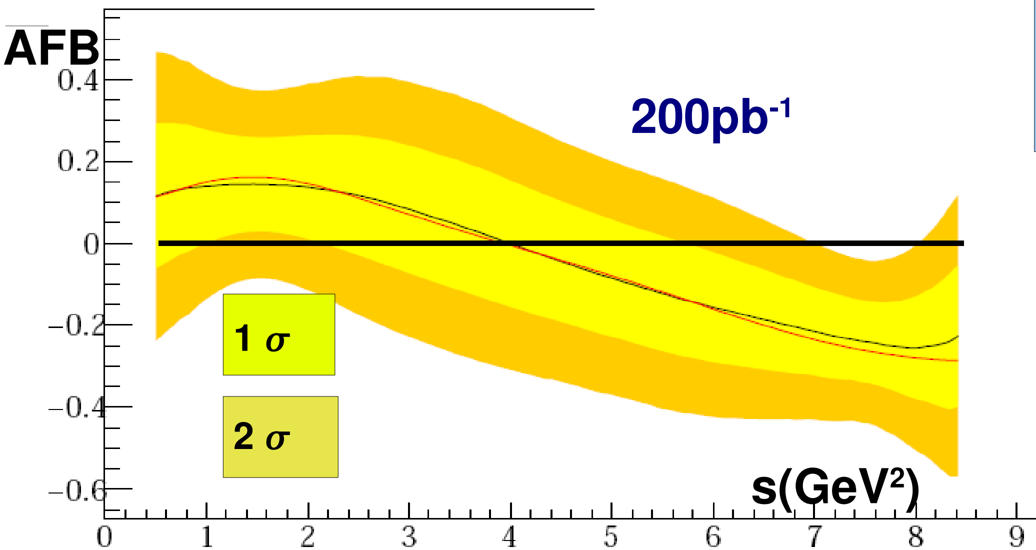

Babar: Phys.Rev. D73,092001,2006

No evidence of NP … yet...

LHCb will collect the world largest data sample with $(200\text{-}300)pb^{-1}$

# $B_d \to K^* (\to K^+\pi^-)\mu^+\mu^-$: LHCb expectation




**Different fit methods studied:**

- **Binned counting experiment**
- **Unbinned counting experiment**
- **4D Unbinned Fit**

**Ongoing studies to correct for acceptance, using the control channel $B_d \to J/\psi(\to \mu^+\mu^-) K^*$.**

**The robustest method will be use at the beginning (e.g counting experiment)**

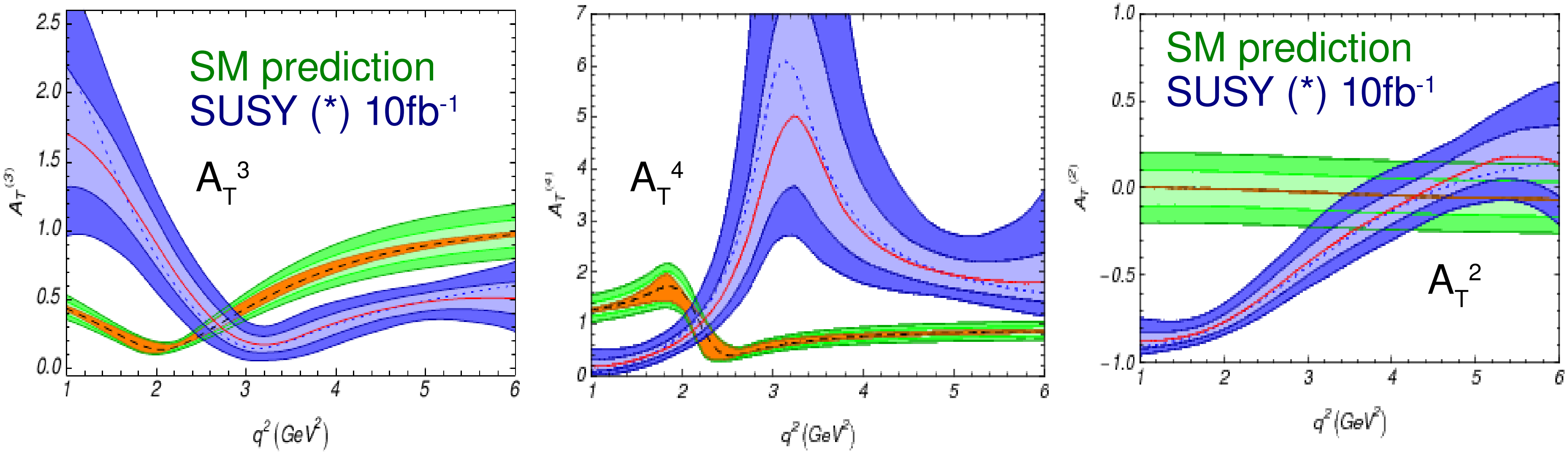
# $B_d \to K^* \mu^+ \mu^-$: 4D fit (other asymmetries)

**The $I_i$ terms are functions of the amplitudes**
**$A_\parallel^{L,R}$, $A_\perp^{L,R}$ and $A_0^{L,R}$ (6 complex numbers, which depend on $q^2$) .**

$$\frac{d^4\Gamma_{\overline{B}_d}}{dq^2\, d\theta_l\, d\theta_K\, d\phi} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_K, \phi) \sin\theta_l \sin\theta_K$$

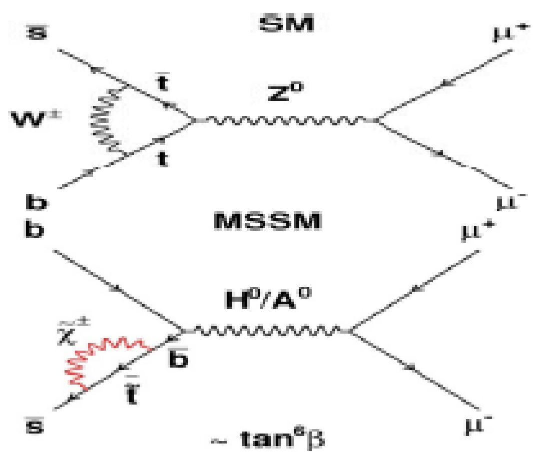
**Better sensitivity wrt counting analysis.**
**More observables.**
**caveat: systematics more difficult to understand.**

**(*)SUSY (b) of JHEP 0811:032,2008**



# $B_s \to \mu^+\mu^-$ : Branching Ratio

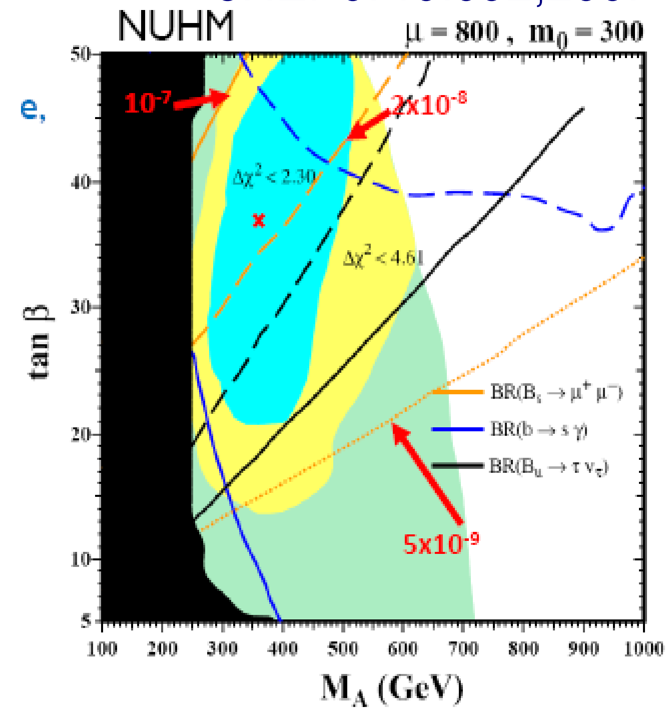
**SM Br(Bs → $\mu^+\mu^-$) = (3.5 ± 0.32)x$10^{-9}$**
**Sensitive to NP involving new (pseudo)scalar interactions e.g. models with 2Higgs doublets (like MSSM); For all MSSM models prop to $\tan^6\beta$ .**




**For high tan($\beta$)**

$$Br^{MSSM}(Bq \to l^+l^-) \propto \frac{m_b^2 m_l^2 \tan^6\beta}{M_{A0}^4}$$

**J.Ellis et al.:**
JHEP0710:092,2007

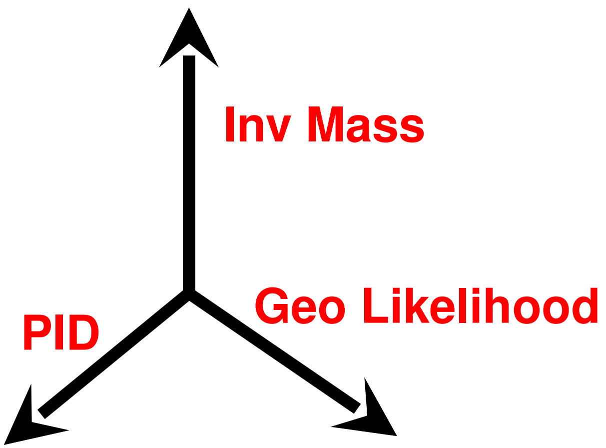



**In NUHM (which includes mSugra)**
**Preferred value:**
**BR($B_s \to \mu^+\mu^-$ ) ~ 2.0 $10^{-8}$**
**Possible explanation of 3.4$\sigma$ discrepancy in ($g_\mu$ -2)**

**Limits of Tevatron at 90%:**
**4.5 $10^{-8}$ present**
**2.0 $10^{-8}$ expected final**

# $B_s \to \mu^+\mu^-$ : Analysis Strategy

- **Soft Preselection**
- **Selection:**
  - **Geometrical Likelihood (5 Geo Variables)**
  - **PID**
  - **Invariant Mass**




**Modified Frequentist approach for BR extraction**
**http://doc.cern.ch/yellowrep/2000/2000-005/p81.pdf**

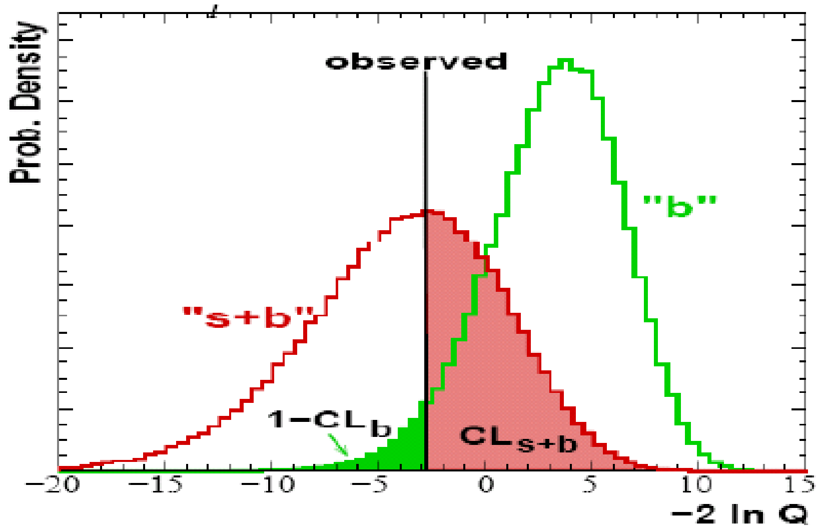
$s_i$ = expected signal events in bin
$b_i$ = expected bkg. events in bin
$d_i$ = measured events in bin

$$X_i = \frac{Poisson(d_i, <d_i>= s_i + b_i)}{Poisson(d_i, <d_i>= b_i)} \qquad X = \prod^{N} X_i$$

$$CL_{s+b} = P_{s+b}(X \leq X^{OBSERVED})$$

$$CL_b = P_b(X \leq X^{OBSERVED})$$

$$CL_{s+b} = CL_b * CL_s$$

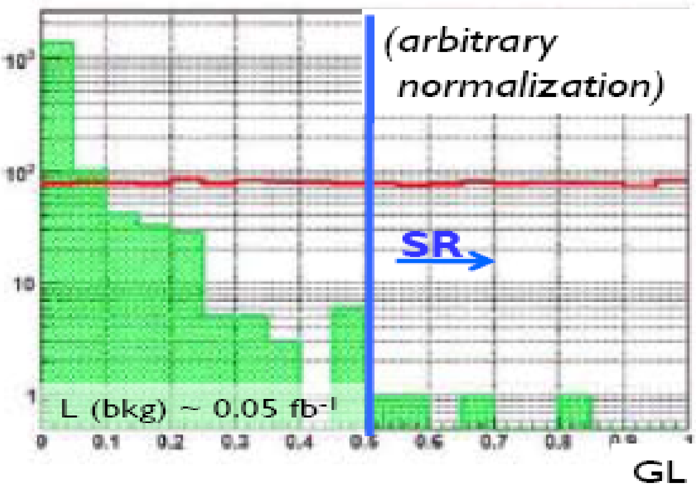



BR exclusion at 90 % if CLs(BR) ≤ 10 %

# Signal, Bg and Control Channels

**Main background consist of two muons coming from different b-decays (b-bbar→$\mu^+\mu^-$).**
**Many other specific bg analyzed (B →hh, B → J/$\psi$ $\mu\nu$, ... ) and found to be negligible**

**Geometrical likelihood distribution**




$$BR = \frac{BR_{cal} \cdot \varepsilon_{cal}^{REC} \varepsilon_{cal}^{SEL/REC} \varepsilon_{cal}^{TRIG/SEL}}{\varepsilon_{sig}^{REC} \varepsilon_{sig}^{SEL/REC} \varepsilon_{sig}^{TRIG/SEL}} \cdot \frac{f_{cal}}{f_{Bs}} \cdot \frac{N_{sig}}{N_{cal}}$$

Hadronization fraction ( $f_{Bs}$ = P(b→ $B_s$) )

Main source of uncertainty (~13 %) for normalization with $B^+$→ J/Ψ $K^+$ (or any other $B^+/B_d$ channel)

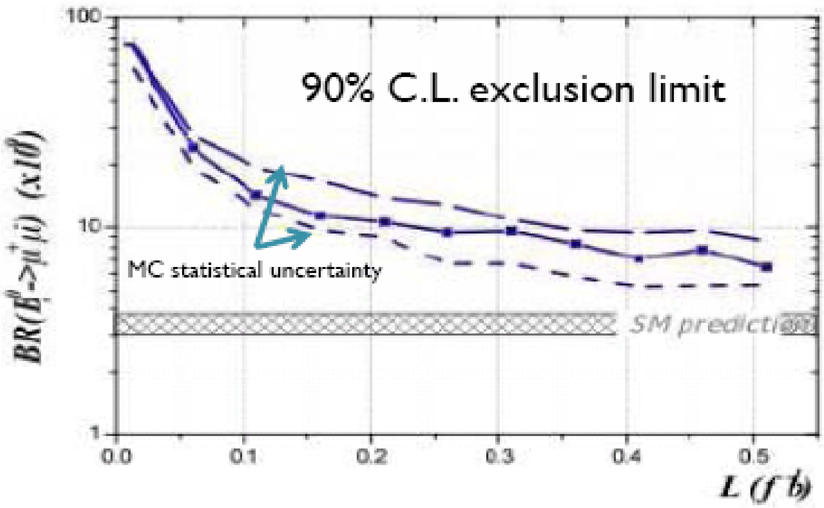
**We use a double ratio of control channels to account for the extra-track.**

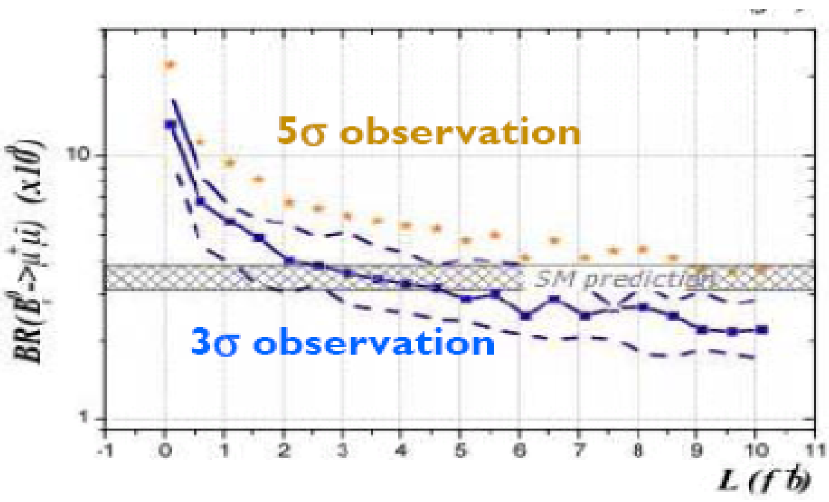
**R1 = ($B_s \to \mu^+\mu^-$ )/($B^+ \to J/\psi K^+$)**

**R2 = ($B^+ \to J/\psi K^+$)/($B_d \to J/\psi K^*$ )**

**Invariant Mass calibration with the control channels $B_s$ → KK and $B_d$ → $\pi\pi$;**
**Geometrical likelihood calibration with $B_{(s)}$ → $h^+h^-$;**
**PID likelihood calibration with J/$\psi$ →$\mu^+\mu^-$ and with $\Lambda$→p$\pi$;**
**BR Normalization with the two channels $B^+$→ J/$\psi$ $K^+$ and $B_d$ → J/$\psi$ $K^*$ ;**

# $B_s \to \mu^+\mu^-$ : expected results



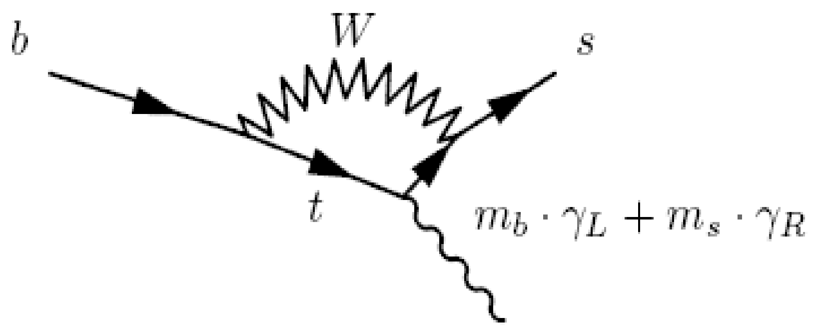

**Exclusion at 90% CL:**
**- Tevatron expected final limit reached @ 200pb$^{-1}$**
**- Reach SM prediction with @ 2fb$^{-1}$**
**Observation:**
**- 5σ observation of BR ~ 2x10$^{-8}$ @ 500pb$^{-1}$**
**- 3σ observation of SM BR @ 3fb$^{-1}$**
**- 5σ observation of SM BR @ 10fb$^{-1}$**

$$Br(B_s \to \mu^+\mu^-) = (3.35 \pm 0.32) \times 10^{-9}$$

| Channel | Yield (2 fb$^{-1}$) | B |
|---|---|---|
| $B_s \to \mu^+\mu^-$ | 21 (SM) | $180^{+140}_{-80}$ |

# Photon Polarization in $B_s \to \Phi\gamma$

Photon polarization is sensitive to V-A structure
Photon polarization can be measured by time dependent analysis




**Dominated by the $C_7$ Wilson coefficient.**

- **In the SM, the photon is mostly LEFT-handed in b decays and RIGHT-handed for anti-b decays.**
- **Presence of NP can modify the handness of the photon.**

**$B_s \to \Phi\gamma$ observed by BELLE at the Υ(5s) (Phys. Rev. Lett. 100, 121801 (2008) ):**
**$Br(B_s \to \Phi\gamma) = 57^{+18}_{-15}\,(stat)\ ^{+12}_{-11}(syst) \cdot 10^{-6}$**

**SM prediction:**
**$Br(B_s \to \Phi\gamma) = (39.4 \pm 10.7 \pm 5.4) \cdot 10^{-6}$**

# $B_s \to \Phi\gamma$ : what to measure

Signal yield (Bs → Φ( → $K^+K^-$ )γ) :7700 in $2fb^{-1}$ (1 year of LHCb)
Background events (in $2fb^{-1}$)< 4700 ( LHCb-2007-147).

Time dependent decay rate for B/anti-B : arXiv:0802.0876v1

$$B/\overline{B}(t) = B_0 e^{-\Gamma t}\left\{\cosh\left(\frac{\Delta\Gamma}{2}t\right) - H\cdot\sinh\left(\frac{\Delta\Gamma}{2}t\right) \pm C\cdot\cos(\Delta m_s t) \mp S\cdot\sin(\Delta m_s t)\right\}$$

*Free parameters: C,S* and *H*

To measure the parameters C and S the knowledge of the initial B-flavor is needed.
For the measurement of H (possible thanks to $\Delta\Gamma_s$ != 0) no-flavor tagging is needed.
H sensitive to right handed currents.

$$H \simeq \sin(2\cdot\psi),\ tg(\psi) = \frac{A_R}{A_L} \qquad SM\ prediction: \frac{A_R}{A_L} \sim 0.04$$

Sensitivity 2fb-1

$\sigma_H \sim 0.2$
$\sigma(A_R/A_L) \sim 0.1$

# Some other RDs: $B_d \to K^* e^+ e^-$

Another way for accessing the photon polarization in $b \to s\gamma$ is by measuring the the virtual photon in $B_d \to K^* e^+ e^-$ (possible thanks to the low electron inv mass). The region where the $\gamma$ is quasi-real is inaccessible in $B_d \to K^* \mu^+ \mu^-$ .

**Full angular analysis**

$$\frac{d\Gamma}{dq^2\, d\cos\Theta_\ell\, d\cos\Theta_K\, d\phi} = \frac{9}{32\pi}\left[ I_1(\cos\Theta_K) + I_2(\cos\Theta_K)\cos 2\Theta_\ell + I_3(\cos\Theta_K)\sin^2\Theta_\ell\cos 2\phi + I_9(\cos\Theta_K)\sin^2\Theta_\ell \sin 2\phi \right]$$

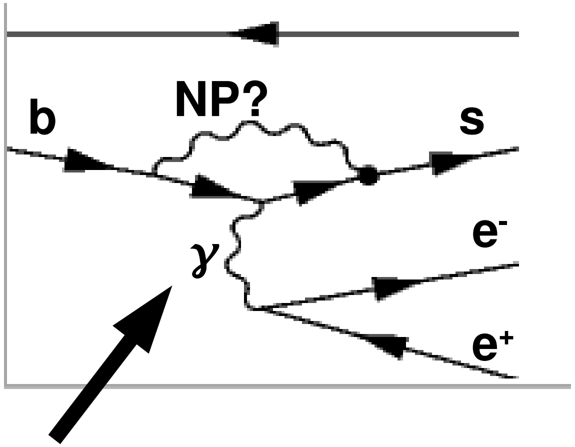
$$I_1(\cos\Theta_K) = \frac{3}{4}(1-\mathrm{F_L})\times(1-\cos^2\Theta_K) + \mathrm{F_L}\times\cos^2\Theta_K$$

$$I_2(\cos\Theta_K) = \frac{1}{4}(1-\mathrm{F_L})\times(1-\cos^2\Theta_K) - \mathrm{F_L}\times\cos^2\Theta_K$$

$$I_3(\cos\Theta_K) = \frac{1}{2}(1-\mathrm{F_L})\times \mathrm{A_T^{(2)}}\times(1-\cos^2\Theta_K)$$

$$I_9(\cos\Theta_K) = \mathrm{A_{Im}}\times(1-\cos^2\Theta_K)$$

$$A_T^{(2)} \sim \frac{2\cdot A_R}{A_L} \qquad \textit{SM prediction}: \frac{A_R}{A_L} \sim 0.04$$



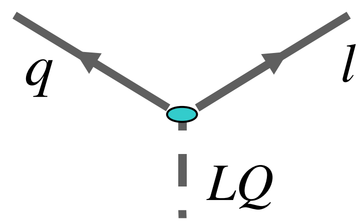

SM: $m_b\,\gamma_L + m_s\,\gamma_R$

$N_{sig}$ ~ 500 in $2\,fb^{-1}$ (1 nominal year) → $\sigma(A_T^{(2)})$ ~ 0.2 → $\sigma(A_R/A_L) \sim 0.1$
Competitive with $B_s \to \phi\gamma$

# Some other RDs: $B_{s,d} \rightarrow e\mu$

**LFV decay forbidden by the SM, but is allowed by some extensions of the SM involving Lepto-Quarks, as the Pati-Salam SU(4) model.**
**It explain why quarks experience the strong force and lepton do not.**

$$\begin{pmatrix} u_R & u_G & u_B & \nu_l \\ d_R & g_G & d_B & l \end{pmatrix}$$




**Lepton number thought as the fourth colour.**

*CDF limits:*

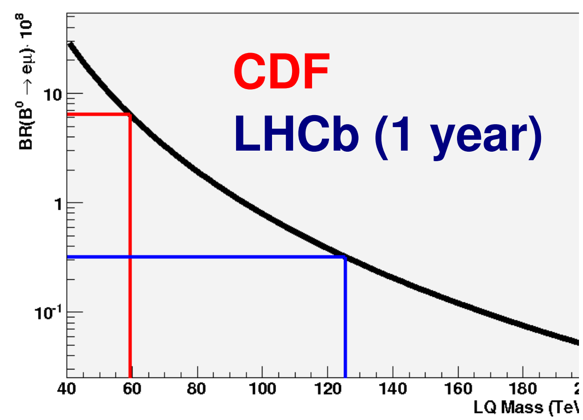
$Br(B_d \rightarrow e^{\pm}\mu^{\mp}) < 6.4\cdot 10^{-8}$ at 90% CL

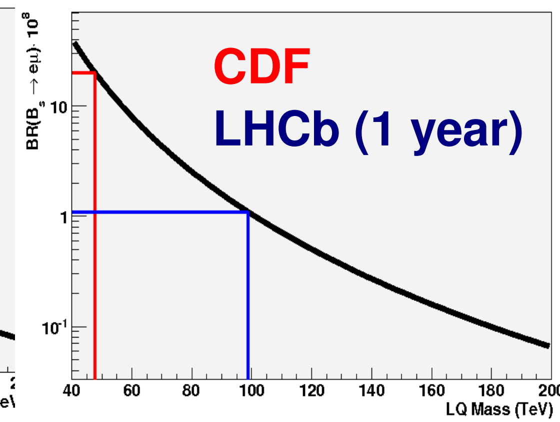
$Br(B_s \rightarrow e^{\pm}\mu^{\mp}) < 2.0\cdot 10^{-7}$ at 90% CL

*LHCb limits in 1 year*

$Br(B_s \rightarrow e^{\pm}\mu^{\mp}) < 1.1\cdot 10^{-8}$ in 2 $fb^{-1}$ at 90% CL

$Br(B_d \rightarrow e^{\pm}\mu^{\mp}) < 3.2\cdot 10^{-9}$ in 2 $fb^{-1}$ at 90% CL




**Limit can improve with a multidimensional analysis (ongoing study)**

# Other ongoing studies

Some other RDs I have not mentioned
(ongoing studies in LHCb):

Other semileptonic decays:
- $B_s \to \phi\mu\mu$
- B -> K $l^+l^-$

Other radiative decays:
- $\Lambda_b \to \Lambda\,\gamma$
- $B_d \to K^*\gamma$

Rare D-decays:
- $D \to \mu\mu$, $D \to e\mu$ , $D \to V\mu\mu$

# Conclusions:

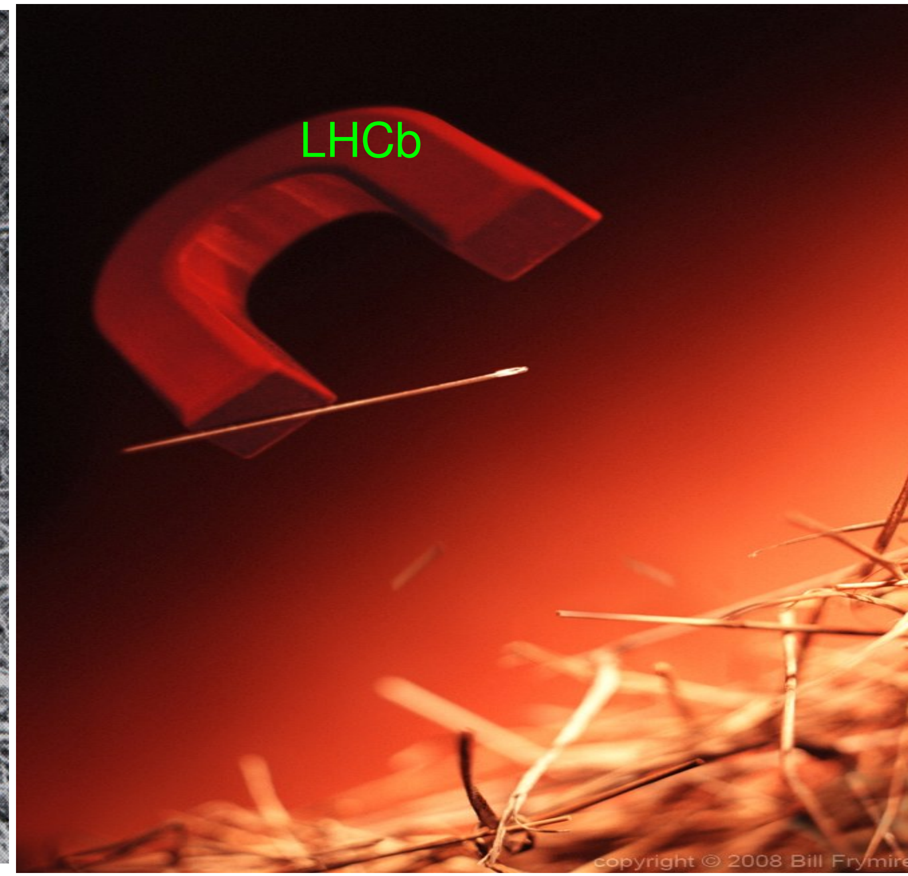
- RDs allow for testing NP in model independent way:
  Left-Right symmetric models, NUHM ($\supset$ mSugra)
  with large/small tan$\beta$ ;

- Combining different measurements allows us to understand NP;

- LHCb can significantly improve present knowledge of FCNC.
  (in particular for (semi)-leptonic and radiative decays).

-The challenge is now to control systematics and to achieve
 MC results with real data.

# How difficult is it to find a needle in a haystack?




**Depends on how you do it!**

"Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed"
A. Soni

# Questions