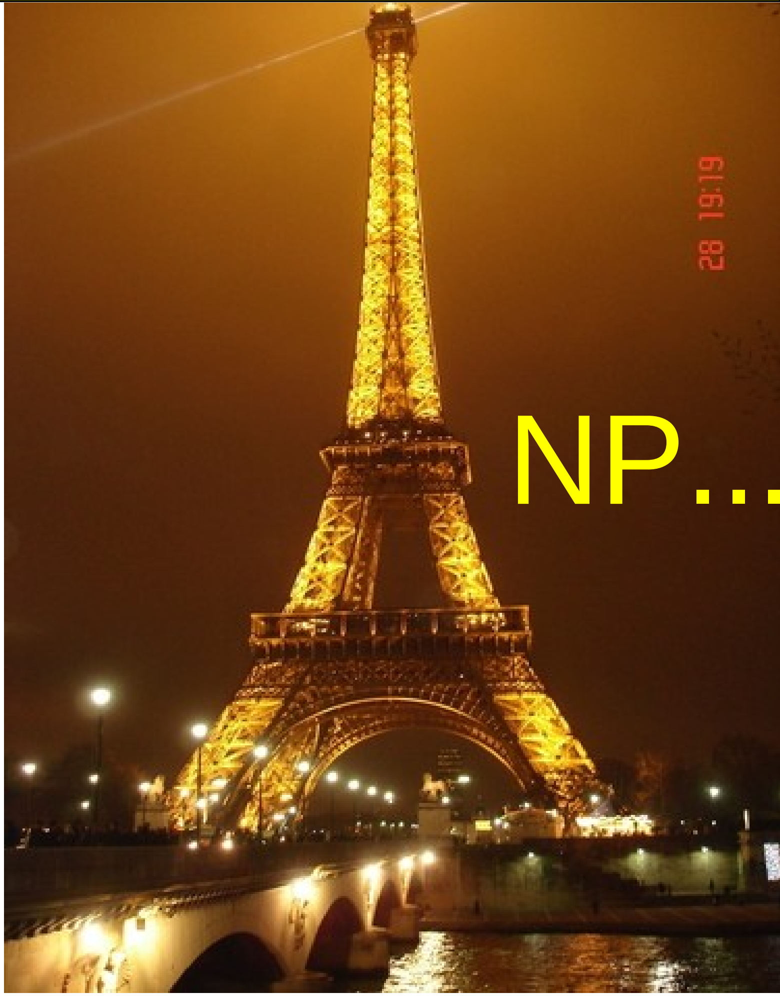
Search for New Physics with Rare Heavy Flavour Decays at LHCb



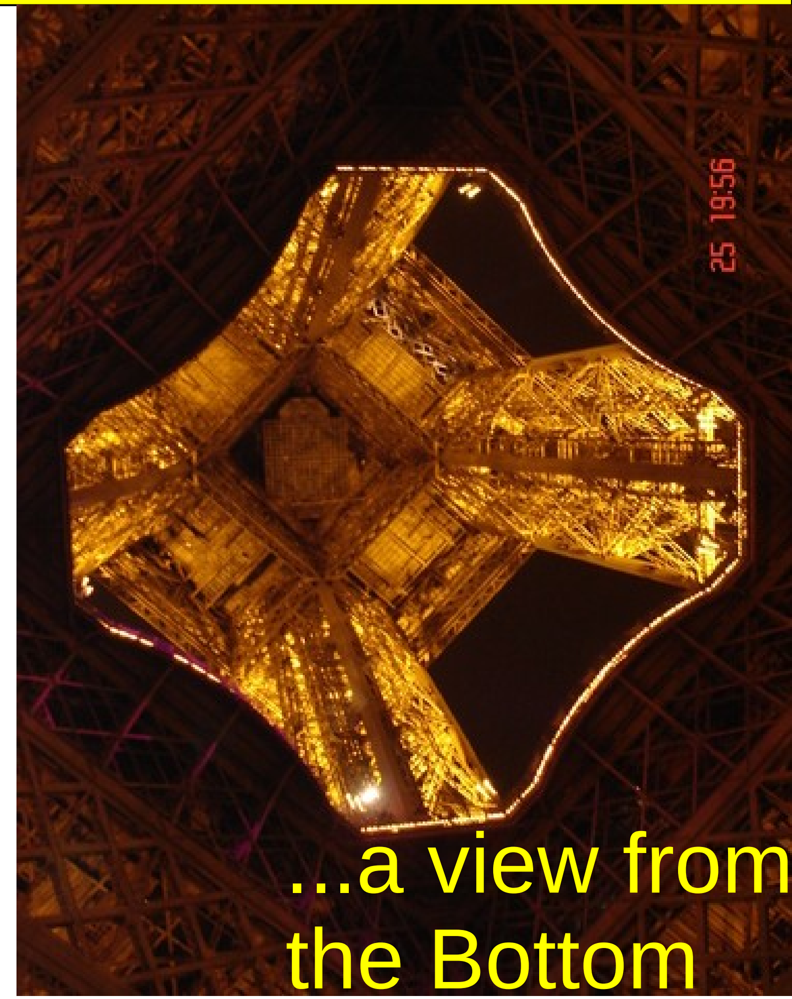
Giampiero Mancinelli

Centre de Physique des Particules de Marseille

(on behalf of the LHCb collaboration)

ICHEP – Paris – July 23rd 2010

Search for New Physics with Rare Heavy Flavour Decays at LHCb



Giampiero Mancinelli

Centre de Physique des Particules de Marseille

(on behalf of the LHCb collaboration)

ICHEP - Paris – July 23rd 2010

New Physics Searches

Yet undiscovered particles can:

- be produced and observed as real particles
- appear as virtual particles (in loop processes), leading to observable deviations from the pure SM expectations in flavour physics e.g.
  - CP violation
  - **rare decays: $B_{s/d}\to\mu^+\mu^-$, $B_d\to K^{*0}\mu^+\mu^-$, $B_s\to\phi\gamma$,...**

These two search methods are complementary

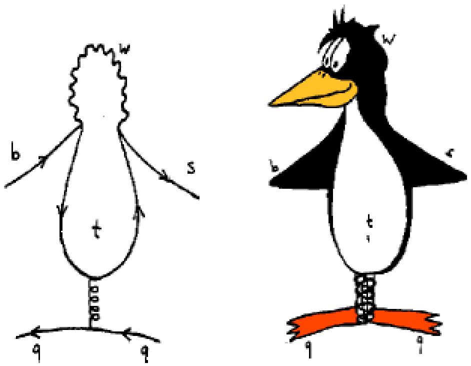
Flavour Physics is an **indirect probe for New Physics**

FCNC have a pivotal role as they constitute an ideal environment:

- highly suppressed in the SM, only realized via boxes or penguins
- least amount of SM "pollution"
- **NP can show up as the same (or higher) level with respect to the SM**
- b→s not too constrained by current data

As LHCb is a hadron collider experiment

- only exclusive final states useful :(
- huge number of these events are triggered :)



LHC & LHCb

LUMINOSITY

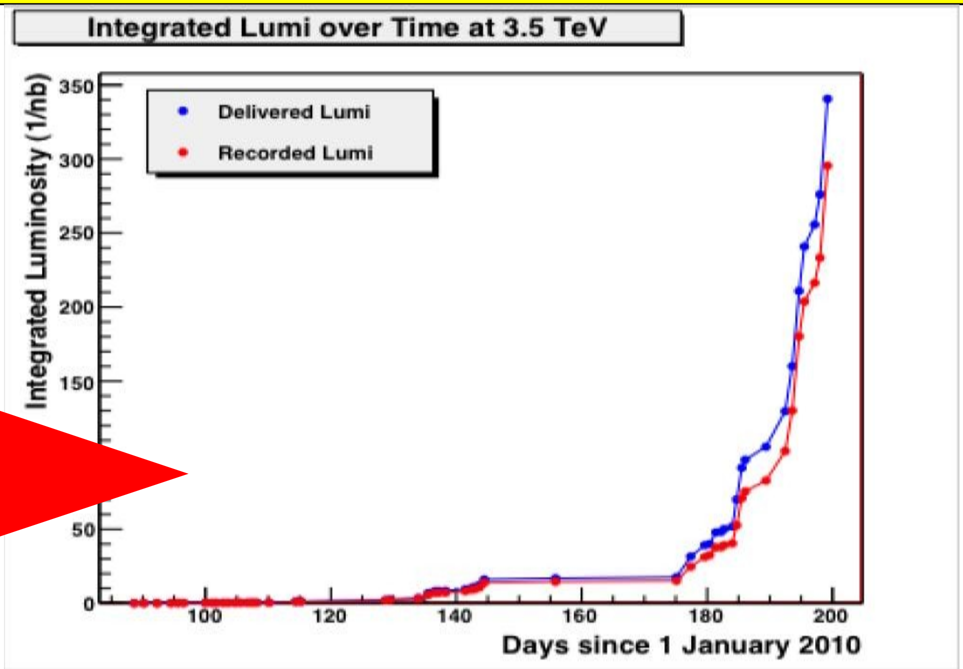
Collected ~ 0.295 pb^{-1}

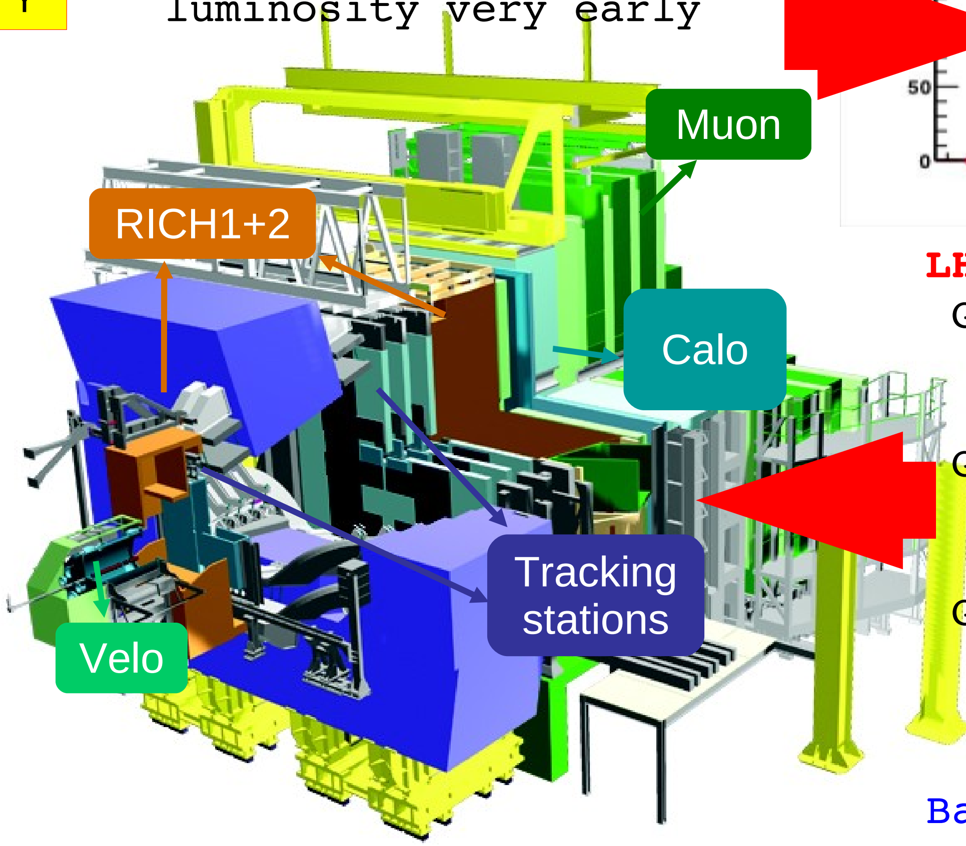
These results ~ 15 nb-1 [control samples]

Expect ~ 1 fb^{-1} by 2011

[O(5x10^{11}) bb events]

LHCb can reach its design luminosity very early





LHCb Optimized for Heavy Flavor

Good spacial resolution
- Time-dependent measurements
- PV-SV position

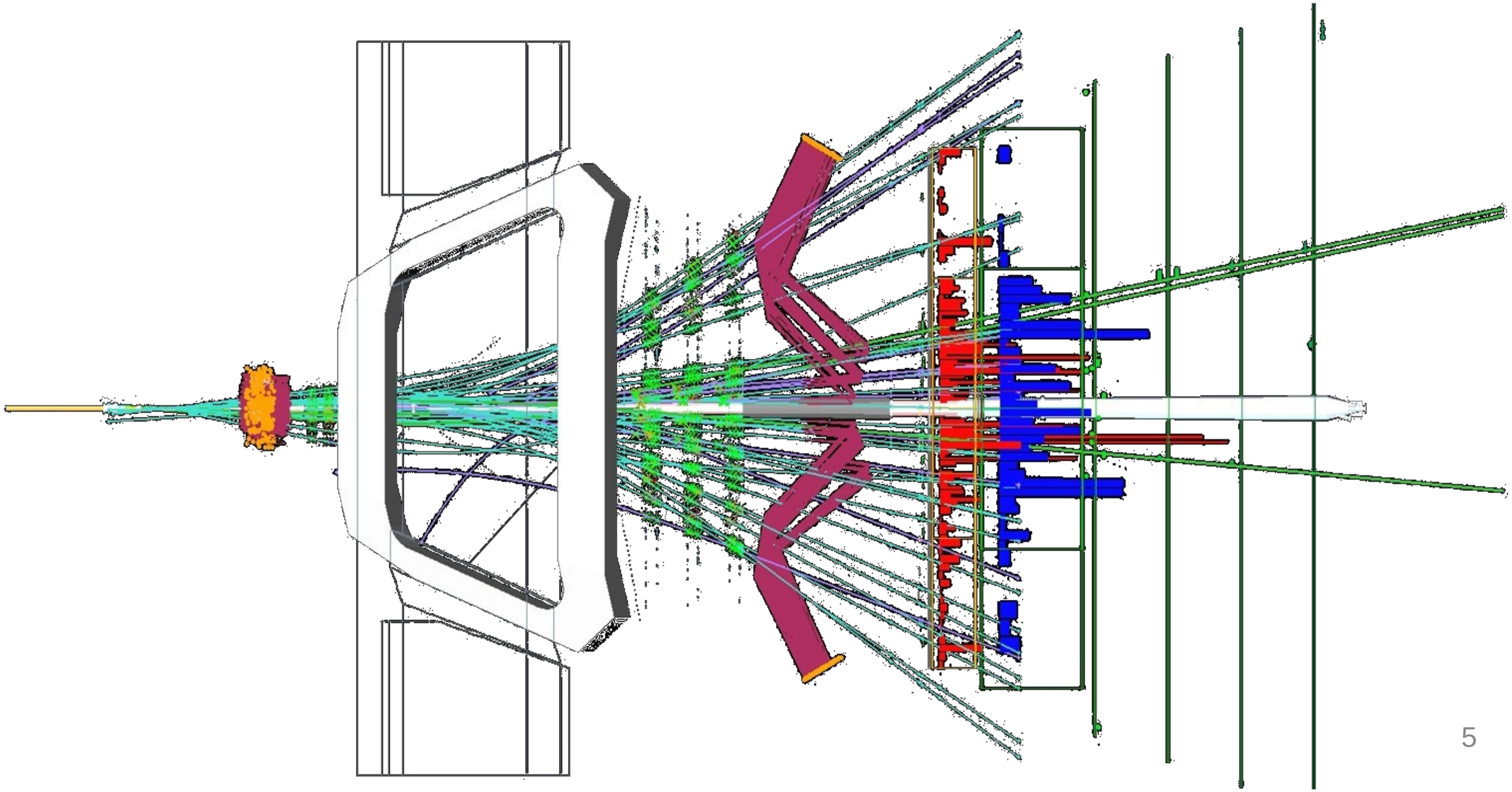
Good particle identification
- Trigger
- Flavour tagging

Good momentum resolution
- Mass resolution (of heavy hadrons)

Background suppression

DETECTOR

$B_{s/d} \rightarrow \mu^+\mu^-$



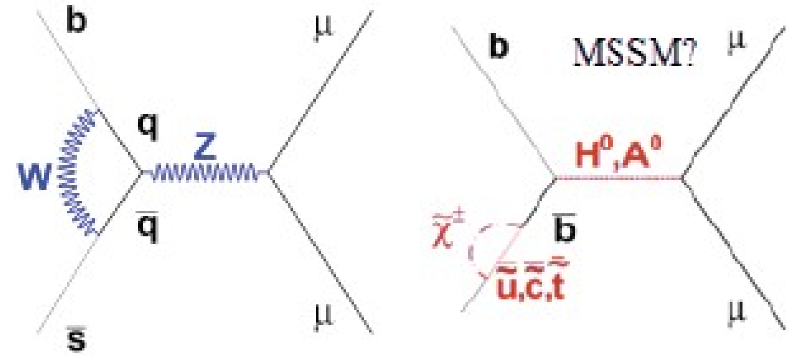
Giampiero Mancinelli,
CPPM - Marseille

5

Status and Motivations

Very rare decay (penguins and boxes in SM and CMFV)

FCNC + helicity suppression



Prediction in SM:

$BR(B_s \to \mu^+\mu^-) = (3.2\pm0.2)\times10^{-9}$

$BR(B_d \to \mu^+\mu^-) = (1.1\pm0.1)\times10^{-10}$

Buras (Physics @ LHC 2010)

error dominated by $\hat{\mathbf{B}}$

Expect:

~10+ decays selected by 2011

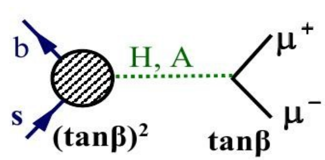
CDF 90%CL limit (3.7 fb^{-1})

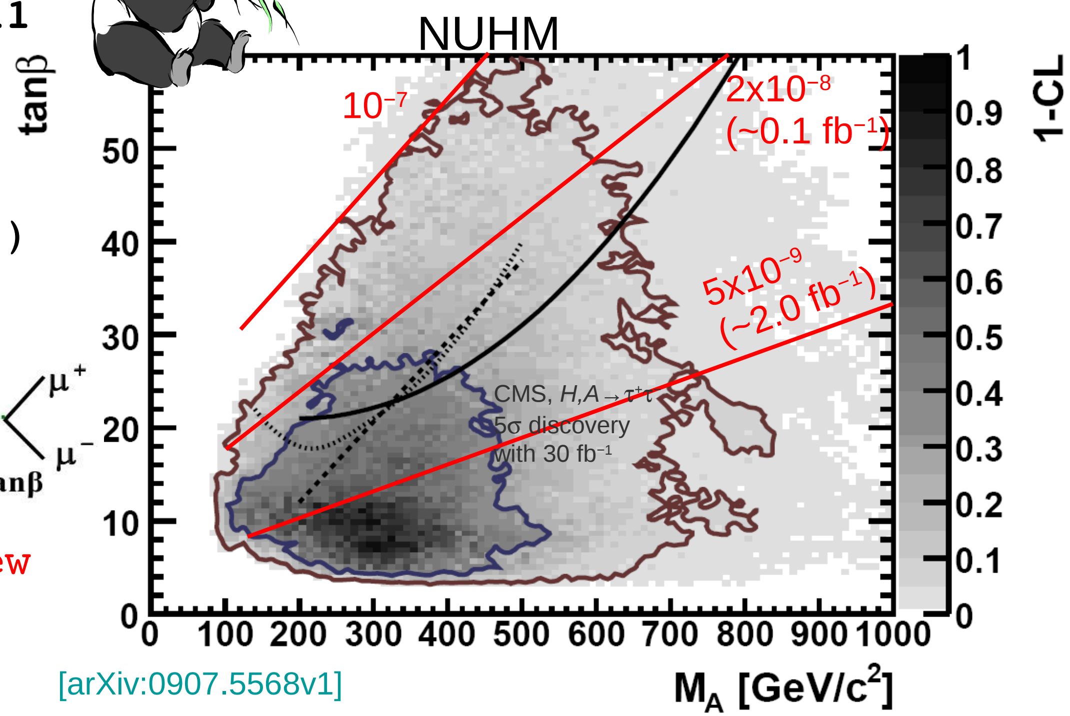
$BR(B_s \to \mu^+\mu^-) < 3.6\times10^{-8}$

New D0 90%CL limit (6.1 fb^{-1})

$BR(B_s \to \mu^+\mu^-) < 4.2\times10^{-8}$

$$BR(B_s \to \mu^+\mu^-) \propto \frac{(\tan\beta)^6}{(M_A)^4}$$





[arXiv:0907.5568v1]

Very sensitive to NP with new scalar or pseudoscalar interactions, models with extended Higgs sector.

Analysis Strategy

Reconstruction of all $\mu^+\mu^-$ candidates on L0+HLT triggered events

Selection of $B_s \rightarrow \mu^+\mu^-$ as common as possible with the control channels

$B^+ \rightarrow J/\psi\ (\mu^+\mu^-)\ K^+$, $B \rightarrow J/\psi\ (\mu^+\mu^-)\ K^*\ (K^+\pi^-)$, $B_{d/s} \rightarrow h^+h'^-$ ...

Each candidate is given a likelihood to be signal or background in a 3D space:

Geometrical Likelihood (GL):

Observables where the vertex detector provides the main discrimination

Invariant Mass:

Power determined by the tracking system resolution/alignment

Muon ID:

Dominated by muon system with information from calorimeters and RICHes

Likelihoods are largely uncorrelated.

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

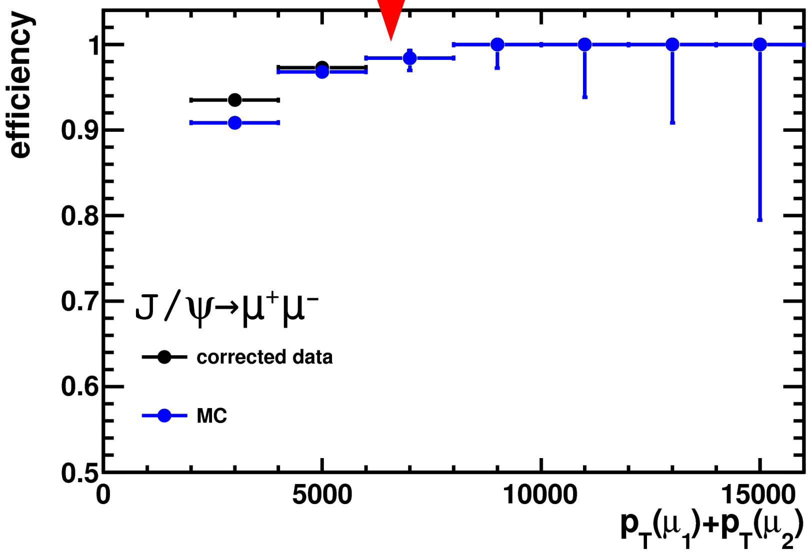
Hadronization fraction ($f_{Bs} = P(b \rightarrow B_s)$)

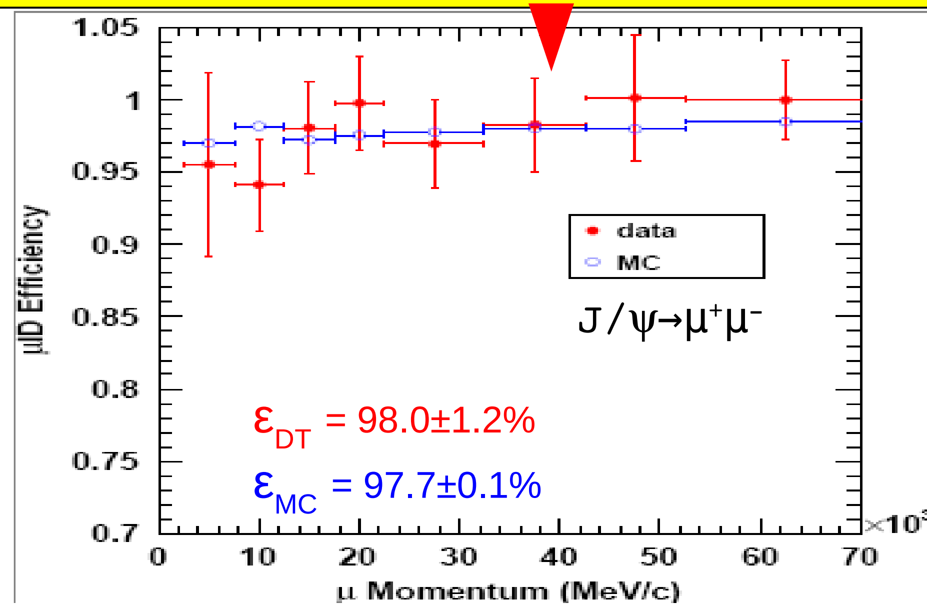
Main source of uncertainty (~13 %) for normalization with $B^+ \rightarrow J/\Psi\ K^+$ (or any other B^+/B_d channel)

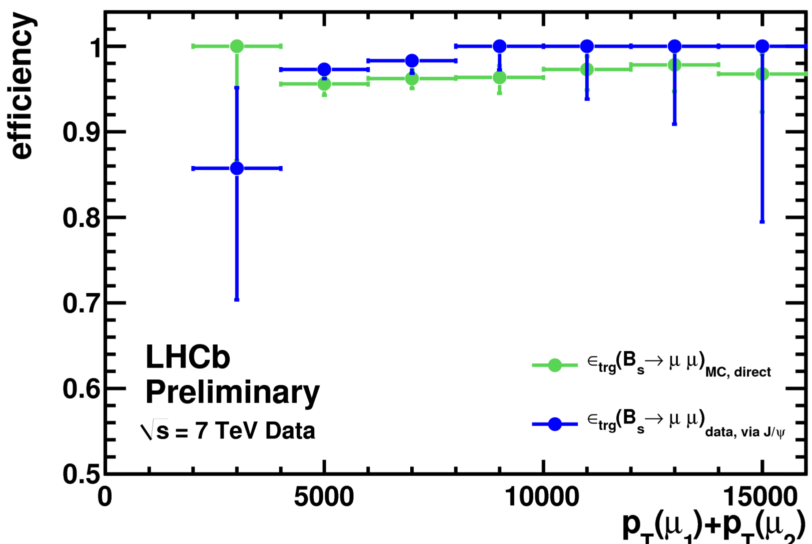
Plan to use new method to measure fs/fd (arXiv:1004.3982) at LHC energies

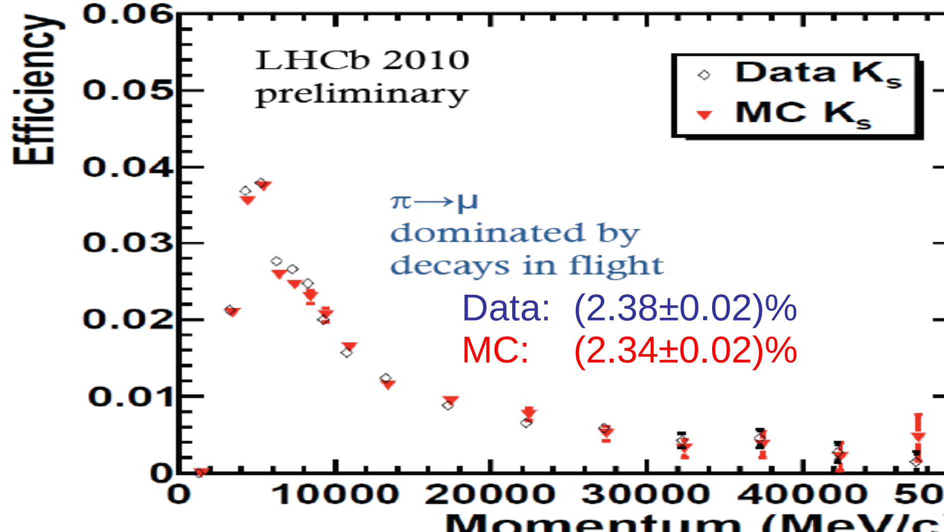
Giampiero Mancinelli, CPPM - Marseille

Trigger and Muon ID







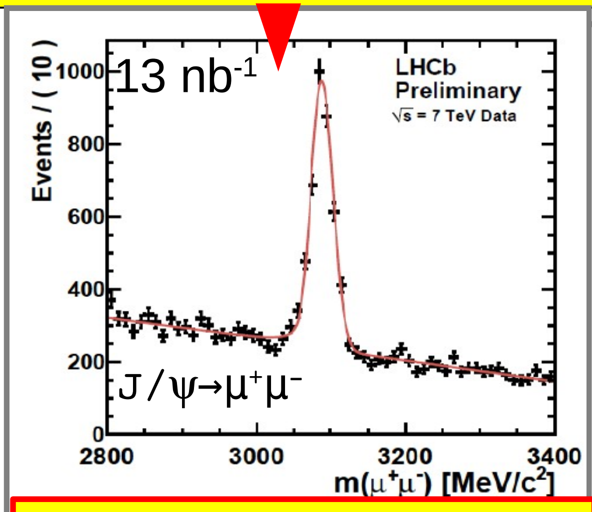


ε = 98.8 ± 0.2(stat) ± 1.3(syst)
(current trigger configuration)

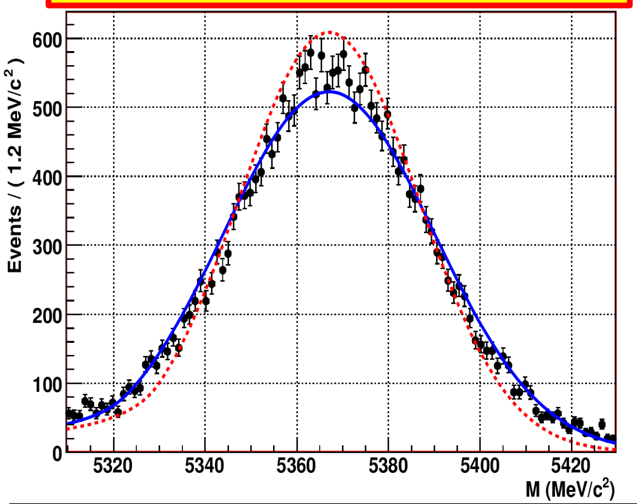
Tag-and-probe method
p>3GeV using *J/ψ data*

Giampiero Mancinelli,
CPPM - Marseille

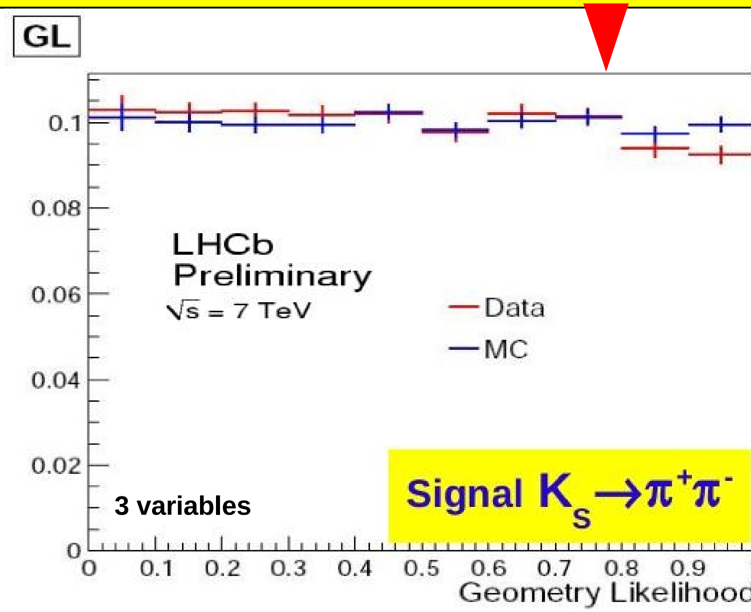
Mass Resolution and GL

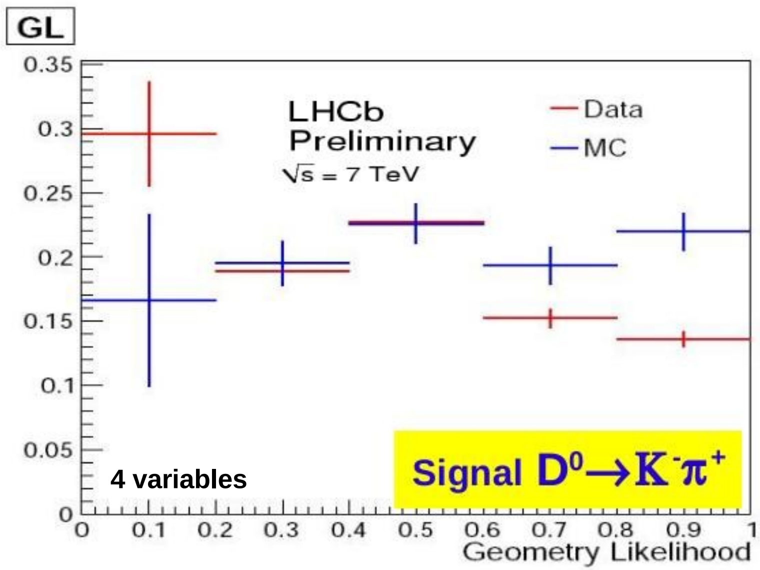


$\sigma \sim 15.0 \pm 0.4$ MeV/c^2



Points: MC $B_s \to \mu^+\mu^-$ mass
Red curve: from $B_s \to K^+K^-$
Blue curve: from $B_s \to K^+K^-$ (with correction for PID)





Geometrical Likelihood Ingredients:

Impact parameters, isolation, B lifetime, vertex chi2

Signal response calibrated with data

So far test on:

$K^0_s \to \pi^+\pi^-$

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

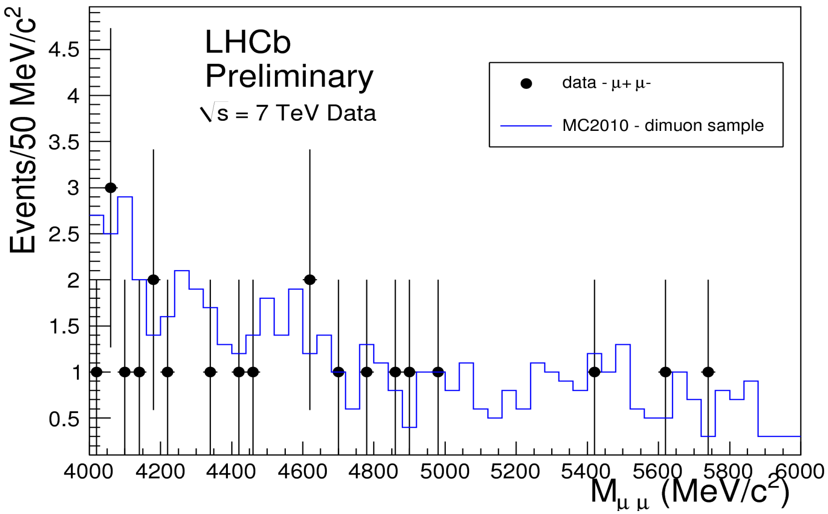
Eventually:

$B \to h^+h^-$

Not yet appropriate control samples to test isolation criteria

The Road to New Physics

All studies on data so far indicate that sensitivity estimate from MC is realistic (e.g. background level)



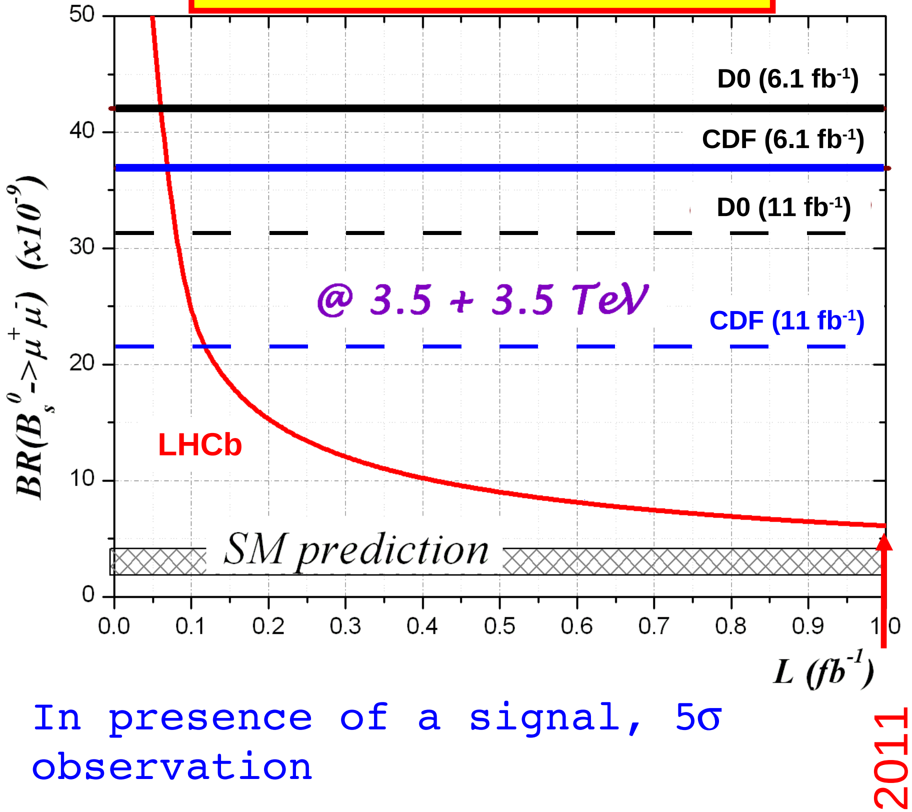
In absence of signal, 90% C.L. limits:

Current limit improved with < 100 pb^{-1}

Expected Tevatron limit improved with < 200 pb^{-1}

Exclusion of significant enhancement from the SM ($7x10^{-9}$) with <1.0 fb^{-1}

Exclusion limit at 90% CL at √s=7 TeV



In presence of a signal, 5σ observation

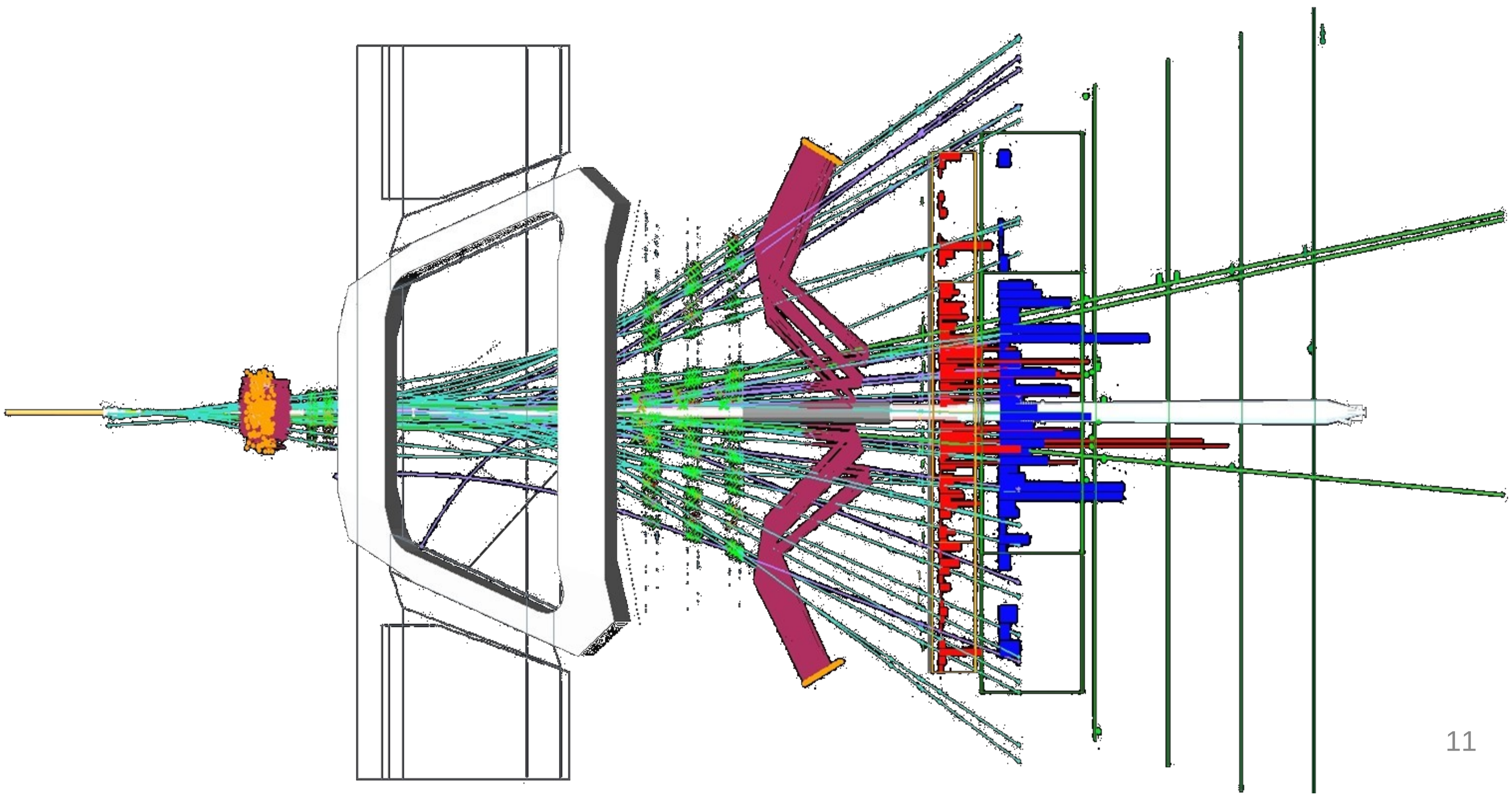
for BR = 3.5 SM with ~1 fb^{-1}

for the SM BR need ~10 fb^{-1} @14TeV

NP discovery potential already @BR 17-21x10⁻⁹ with 1 fb^{-1} @7TeV (depending on f_s/f_d systematic)

Giampiero Mancinelli, CPPM - Marseille

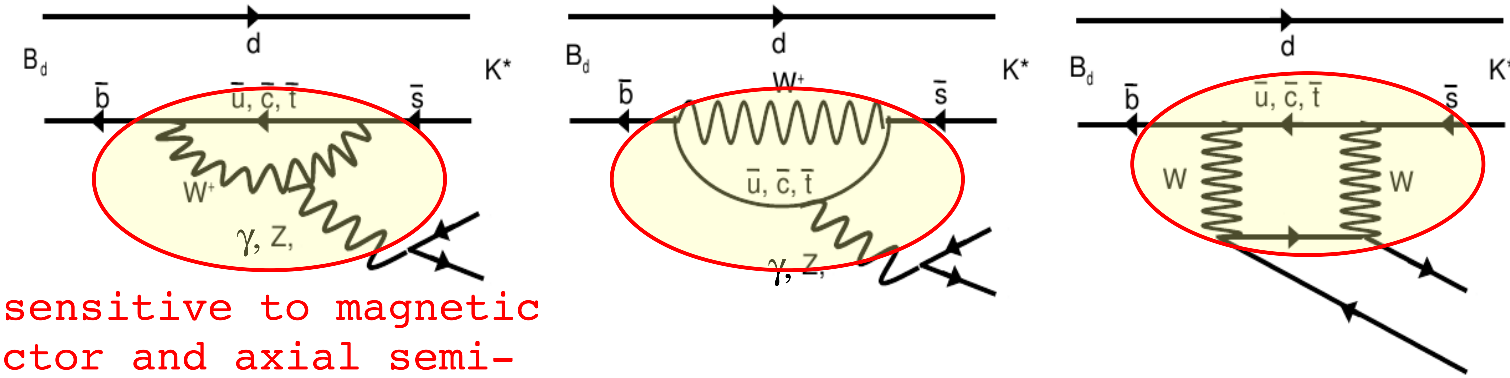
$B^0 \to K^*\mu^+\mu^-$



Giampiero Mancinelli,
CPPM - Marseille

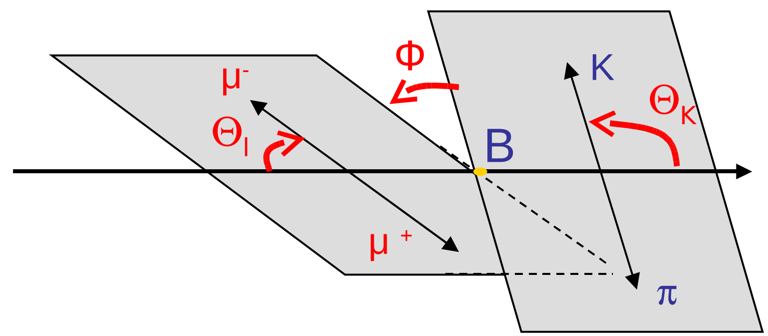
Introduction

Standard Model



Modes sensitive to magnetic and vector and axial semi-leptonic penguin operators

Decay described by three angles (θ_l, ϕ, θ_K) and di-invariant mass q^2

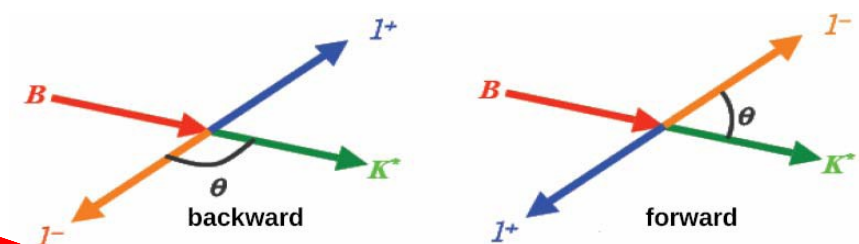


Many variables sensitive to new physics but:

BR = $(1.15^{+0.16}_{-0.15})10^{-6}$ (HFAG)

agrees to within ~20% with SM

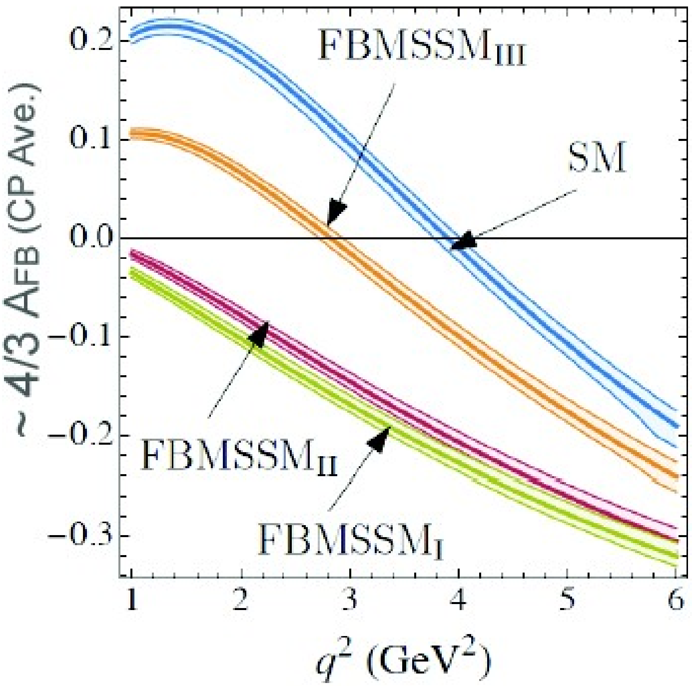
With first data, focus on forward backward asymmetry



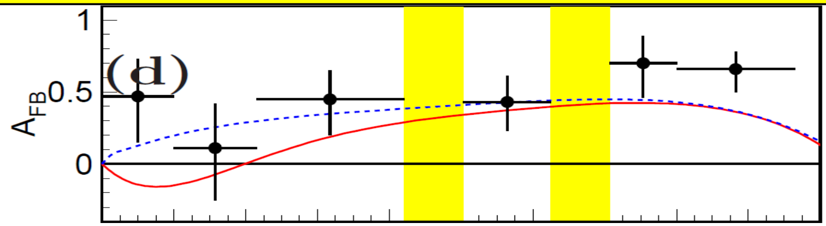
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

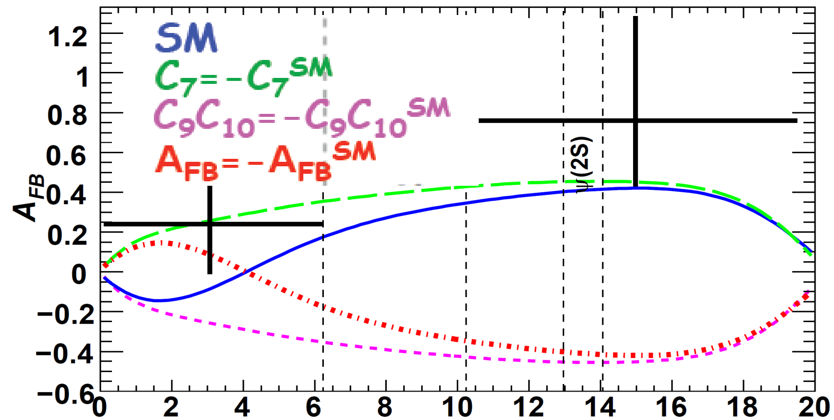
AFB now

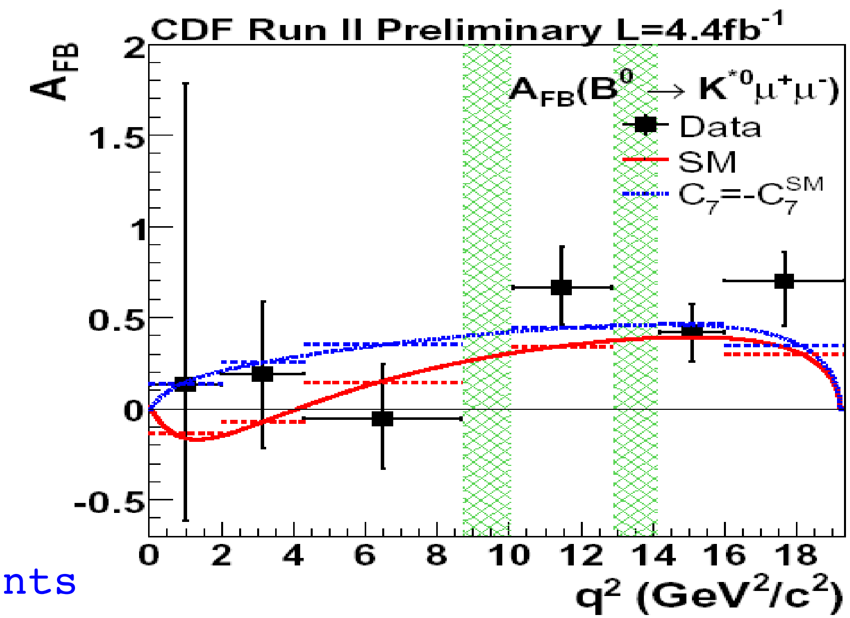
- FF cancellation only at zero crossing point
- Sensitive to C_7 and C_9



Altmannshofer et al, JHEP 0901:019,2009







All:~450 $K^*l^+l^-$ events

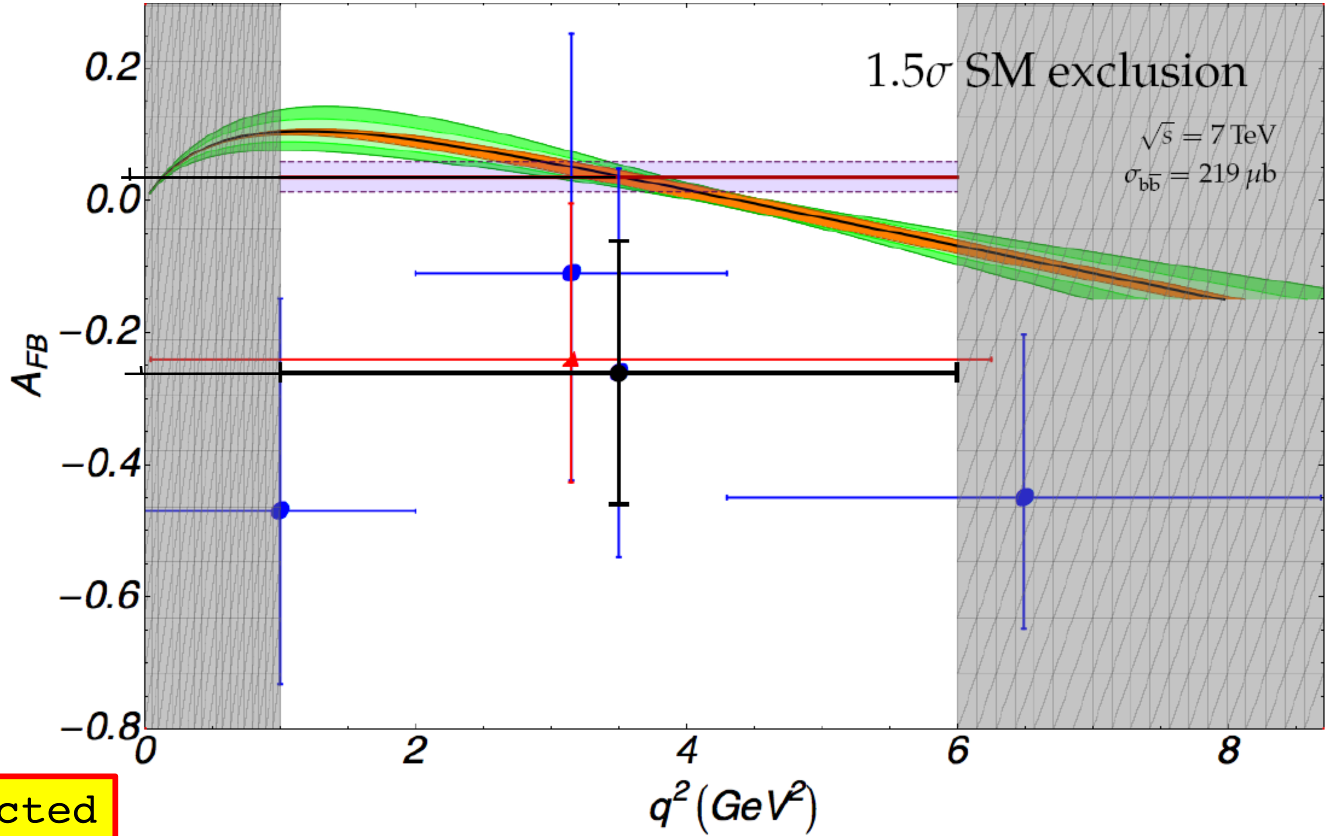
AFB with 100 pb^{-1}

Estimated error on A_{FB} in most sensitive bin (1-6 GeV^2), assuming Belle's central value

0.1 fb^{-1}: $\sigma(A_{FB})=0.20$

Just 0.1 fb^{-1} will give equivalent error to current B-factory measurements

SM prediction
Egede et al
JHEP 0811:032
Belle (2009)
PRL 103 171801
BABAR (2009)
PRD 79 031102
LHCb-MC (projection) at 0.1 fb^{-1}



140 events expected

note : σ(bb) meaured to be 1/3 higher than what assumed here

Giampiero Mancinelli,
CPPM - Marseille

AFB 2011

Estimated error on A_{FB} in most sensitive bin (1-6 GeV^2), assuming Belle's central value

0.1 fb^{-1}: $\sigma(A_{FB})=0.20$

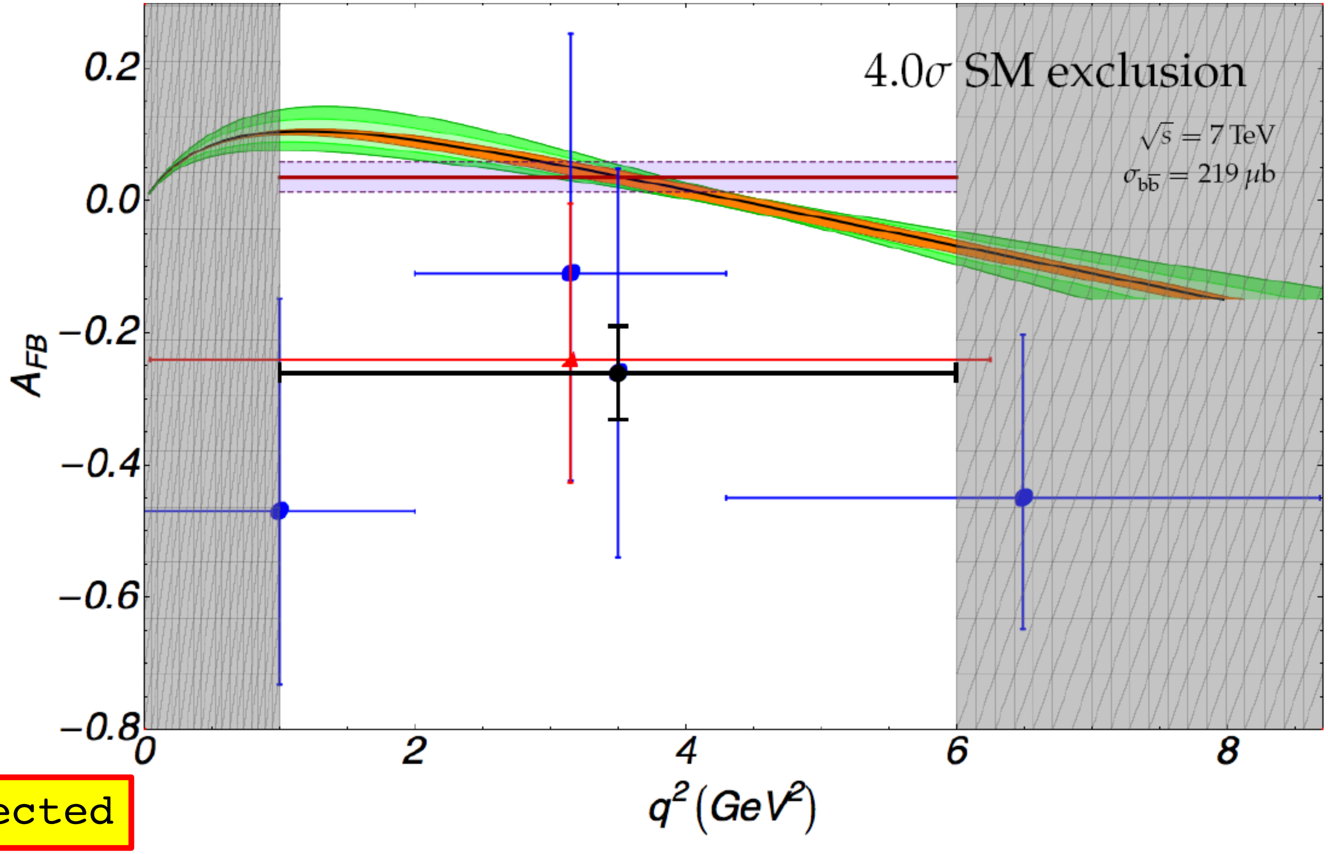
1.0 fb^{-1}: $\sigma(A_{FB})=0.07$ (end of 2011)

SM prediction
Egede et al
JHEP 0811:032

Belle (2009)
PRL 103 171801

BABAR (2009)
PRD 79 031102

LHCb-MC (projection) at 1.0 fb^{-1}

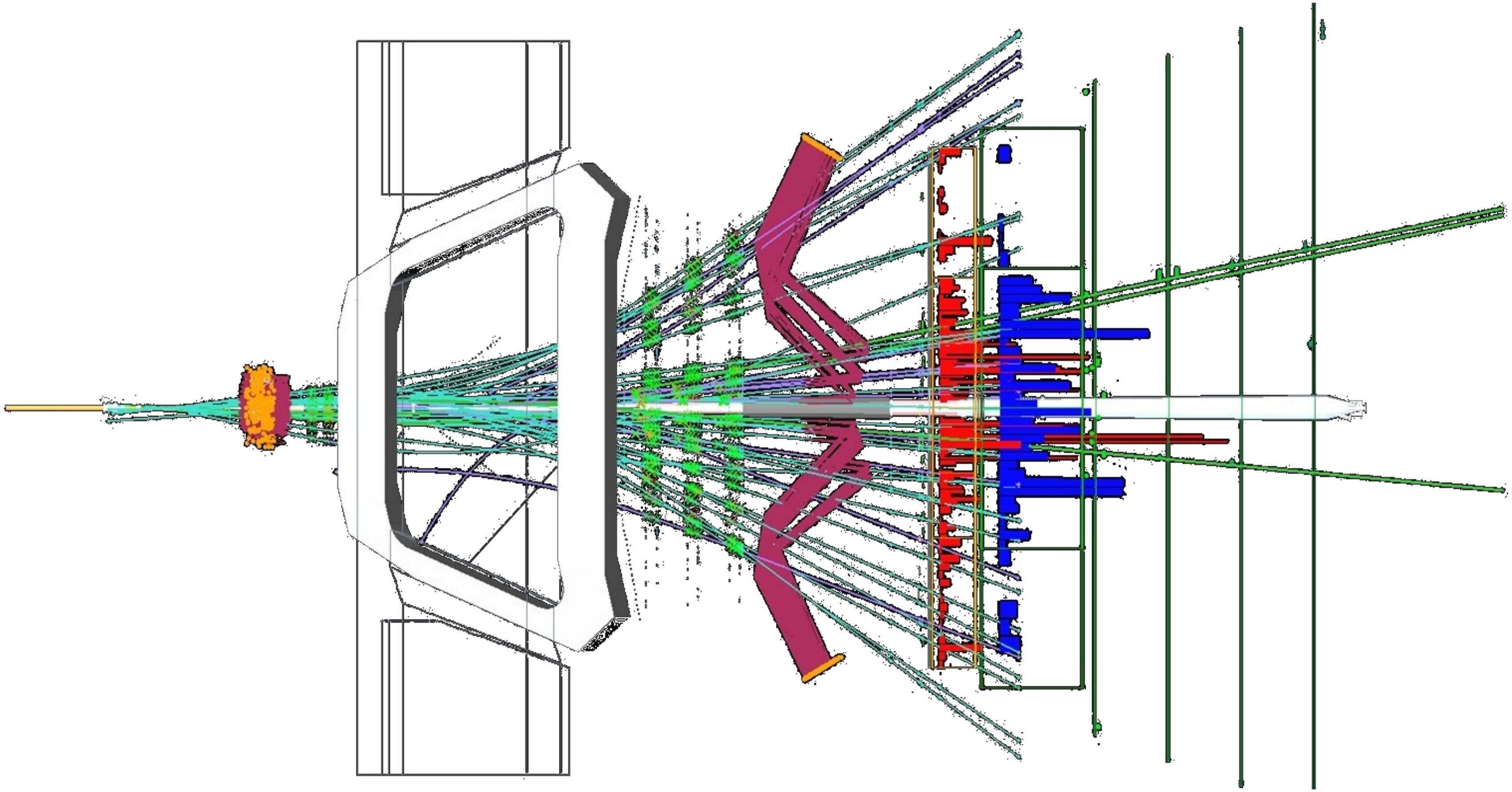


1400 events expected

note : σ(bb) meaured to be 1/3 higher than what assumed here

Giampiero Mancinelli,
CPPM - Marseille

$B_s \rightarrow \phi\gamma$, et al.

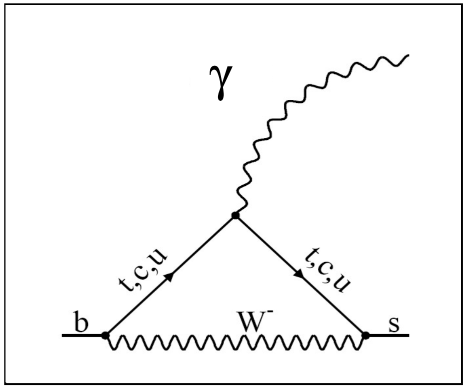


Giampiero Mancinelli,
CPPM - Marseille

Current Status

Inclusive results of b→sγ BR in agreement with the SM expectation (E_{min} = 1.6 GeV):

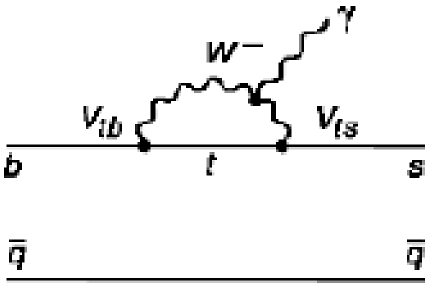
$BR\ (b \to s\gamma) = (315 \pm 23)\ 10^{-6}$ (theo) NNLO
$BR\ (b \to s\gamma) = (355 \pm 24 \pm 9)\ 10^{-6}$ (HFAG)



Stringent constraints to NP contributions

Exclusive results have very large theoretical uncertainties, (measure $|C_7^{(eff)}|^2 + |C_7'^{(eff)}|^2$)

Measurements powerless due to form factors that add large uncertainties



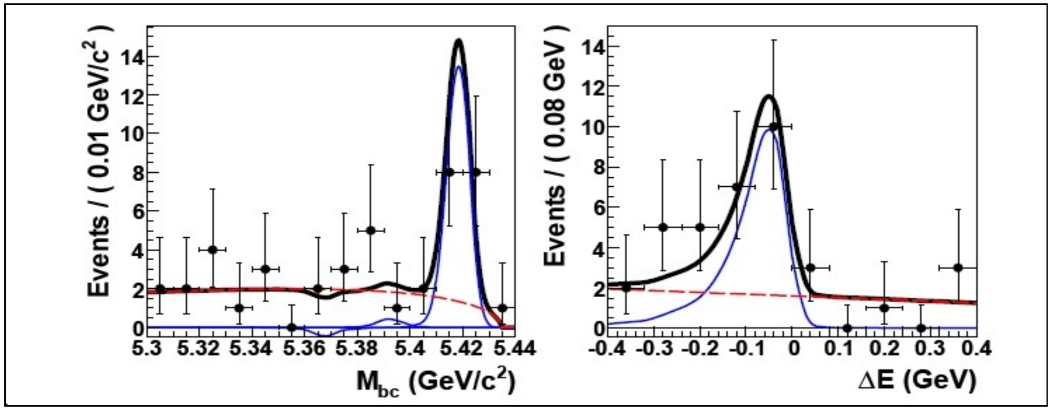
$BR\ (B^0 \to K^{*0}\gamma) = (43 \pm 14)\ 10^{-6}$ (theo)
$BR\ (B^0 \to K^{*0}\gamma) = (43.3 \pm 1.5)\ 10^{-6}$ (exp) HFAG

Challenge to the theorists!

Recently discovered also the radiative decays of B_s

$BR\ (B_s \to \phi\gamma) = (57^{+18}_{-12}{}^{+12}_{-11})\ 10^{-6}$ Belle'08

$BR\ (B_s \to \phi\gamma) = (43 \pm 14)\ 10^{-6}$ (theo)



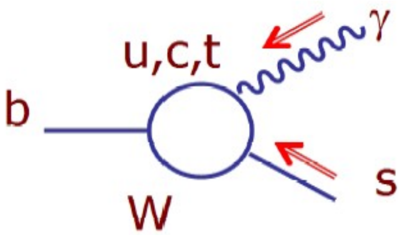
Theoretical Introduction

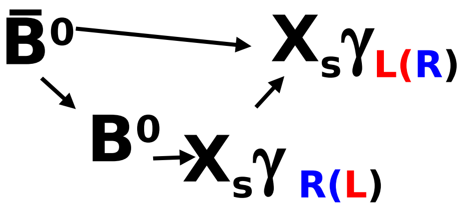
The Q7 operator, main responsible for $b \to s\gamma$ processes, produces mostly **leftly-polarized photons** in the SM

$C_7'^{(eff)}/C_7^{(eff)} \sim 0.04$ *(more or less ~ A_R/A_L ~ m_s/m_b)*

Mixing CP-asymmetries almost vanish

- $B \to f^{CP}\gamma$ is (usually) not a *CP* eigenstate!





We can consider anyway the «**wrongly**» **polarized photons:**

$$\Gamma(\mathrm{B}_q(\bar{\mathrm{B}}_q) \to f^{CP}\gamma) \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm \pm\mathcal{C}\cos\Delta m_q t \mp \mathcal{S}\sin\Delta m_q t\right)$$

F.Muheim, Y.Xie, and R.Zwicky, Phys.Lett.B664:174-179,2008

$\tan\psi = |A\_L/A\_R|$

$\mathbf{A^{\Delta} = \sin 2\psi \cos\phi}$

$\mathbf{B^0 : \Delta\Gamma \approx 0}$

No sensitivity to A^{Δ}

$\phi = 2\beta - \phi^{peng} \approx 2\beta$

$\sin 2\psi = S / \sin 2\beta$

$\mathbf{B_s: \Delta\Gamma_s/\Gamma_s \sim \mathit{O}(10\%)}$

Sensitive to A^{Δ}

$\phi = 2\beta_s - \phi^{peng} \approx 0$

$S = 0$, double smallness

$\sin 2\psi = A^{\Delta} \sim 2C_7'^{(eff)}/C_7^{(eff)}$

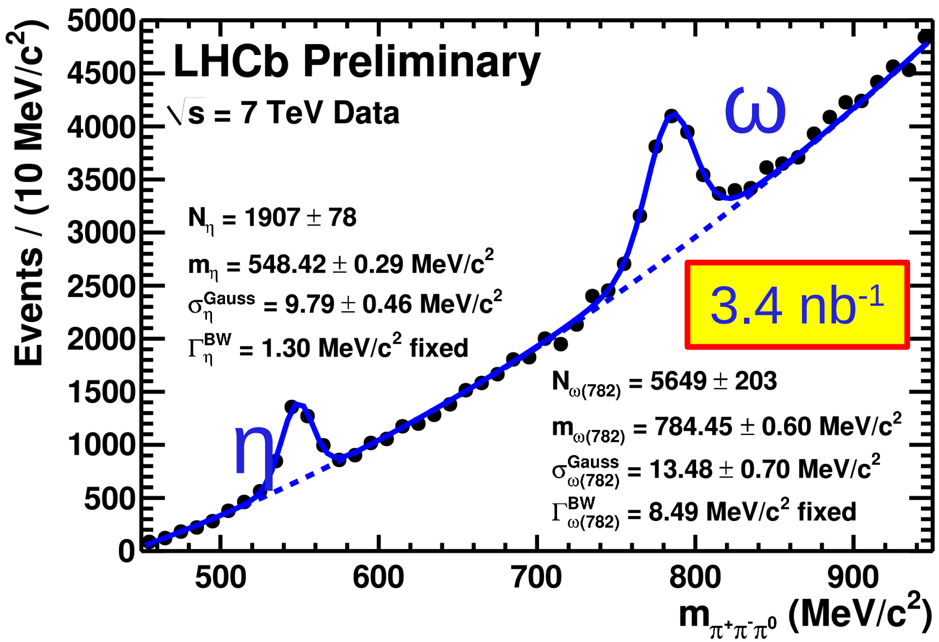
Validation and Reach

Energy calibration very promising

- Calibration now based on low mass resonances
- High energy calibration will first come when $B_d \to K^{*0}\gamma$ available.

Lifetime calibration

- Measurement sensitive to bias in lifetime.
- Need to know acceptance very well
- Validation started with prompt $\varphi \to K^+K^-$ events



Outlook

LHCb expects:

4.8k $B_s \to \phi\gamma$ events by the end of 2011 (for $\sigma(bb) \sim 292\mu b$)

and

$\sigma(A^{\Delta}) \sim 0.3$

Photons in $B_d \to K^{*0} l^+ l^-$

Another way to find the photon polarization is $B_d \to K^{*0} e^+ e^-$ for very low e^+e^- invariant masses

Distribution in φ angle measures $C_7^{'(eff)}/C_7^{(eff)}$

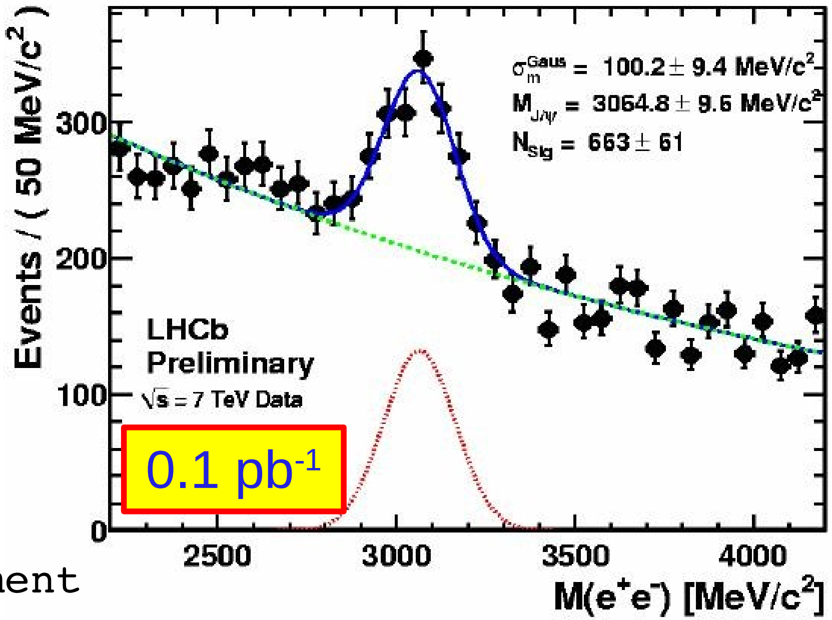
Small statistics

Background rejection a big issue

Easy systematics

As good as $B_s \to \varphi\gamma$?

We clearly see $J/\Psi \to e^+e^-$ →

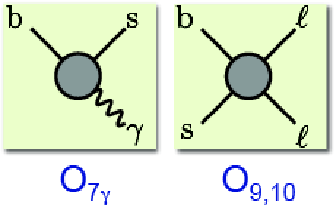


Much better statistics for $B_d \to K^{*0} \mu^+ \mu^-$

Muon mass means we can't just replicate the previous measurement

However, we get access to so much more

Interference between these



... and their primed counterparts

Conclusions

First B decays have been recorded
(though we're more interested in the “last ones”)

LHCb is well on track for its heavy flavour program:

- First validation work with 2010 data is very promising
- Trigger, particle identification and tracking efficiencies are reasonably close to expectations

Excellent Performance for Rare Decays!

Exciting prospects already with 100 pb^{-1}

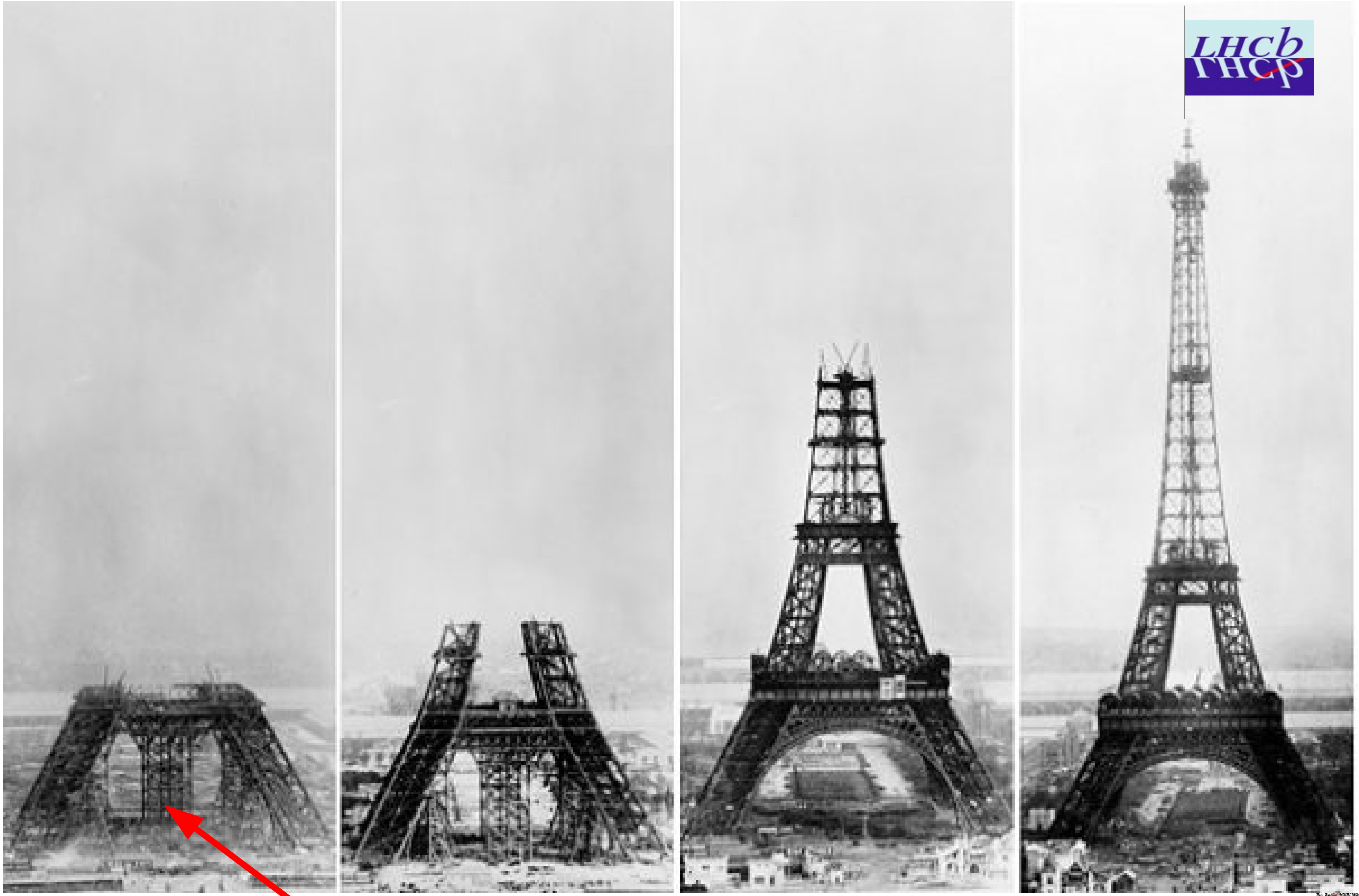
$B_s \to \mu^+\mu^-$: improve Tevatron's limits

$B \to K^*\mu^+\mu^-$: yield comparable to B factories

$B_s \to \phi\gamma$: ~10 times the current world sample

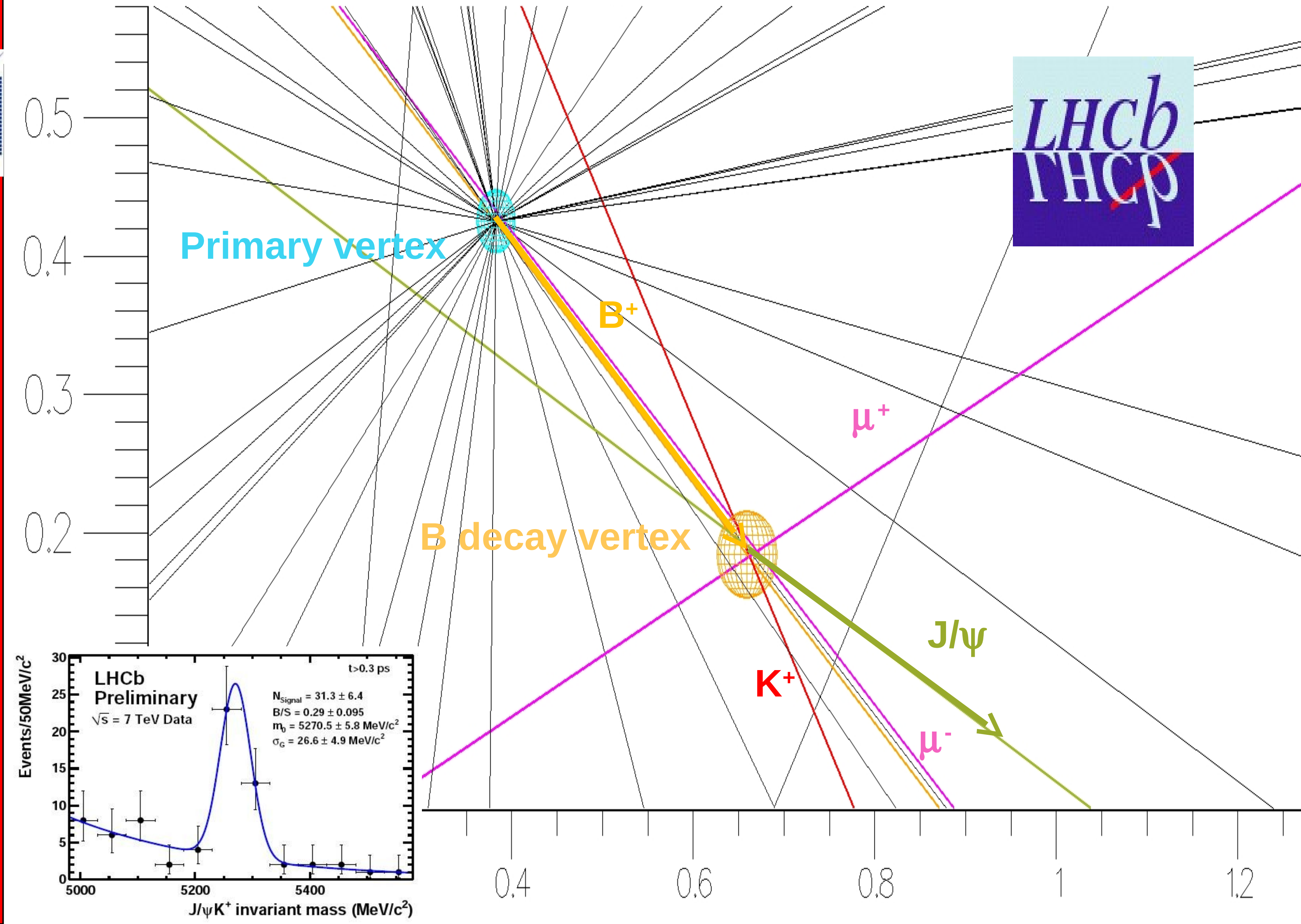
Giampiero Mancinelli,
CPPM - Marseille

Conclusions



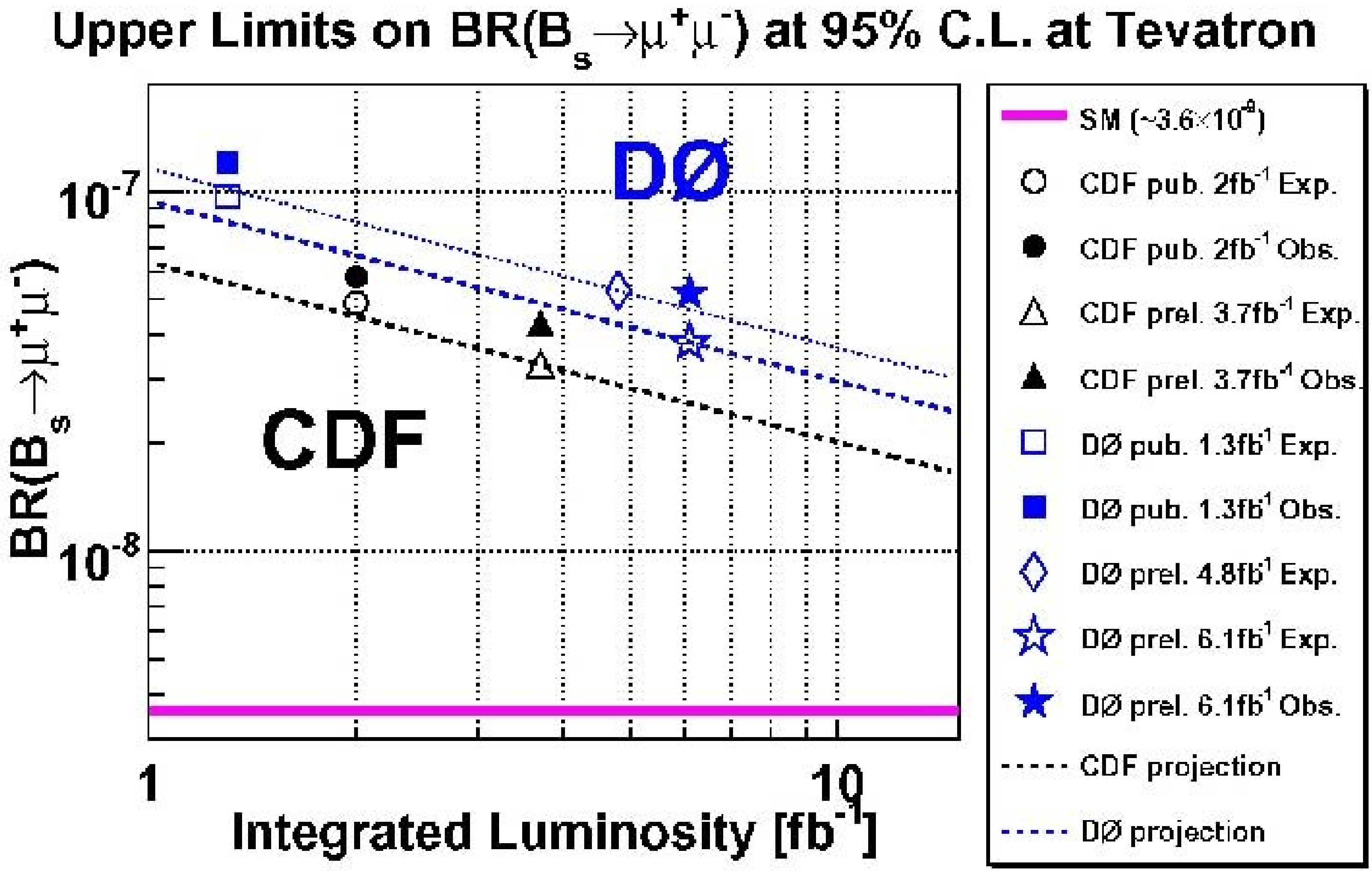
We're about here...

Questions?



Giampiero Mancinelli,
CPPM - Marseille

BACKUP – Bsmumu



BACKUP – Bsmumu

New Physics expectations:

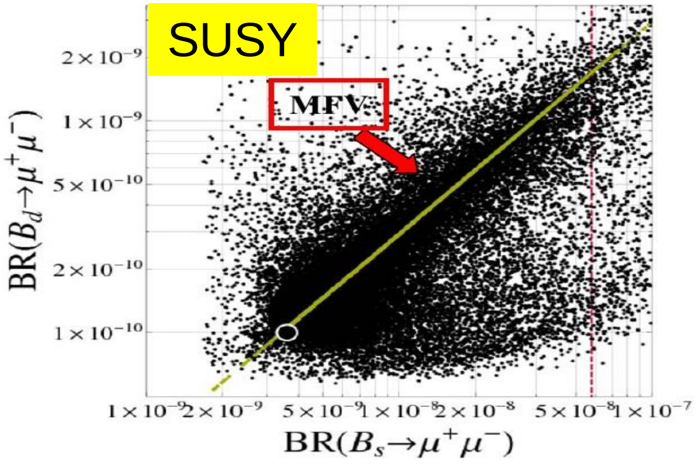
MSSM:	BR enhanced up to 20 times
4G:	BR enhanced up to 4 times
Little Higgs with T parity:	BR enhanced up to 30%
Constrained MFV:	BR enhanced up to 20%
Extra Dimentions:	BR enhanced up to 10-80%

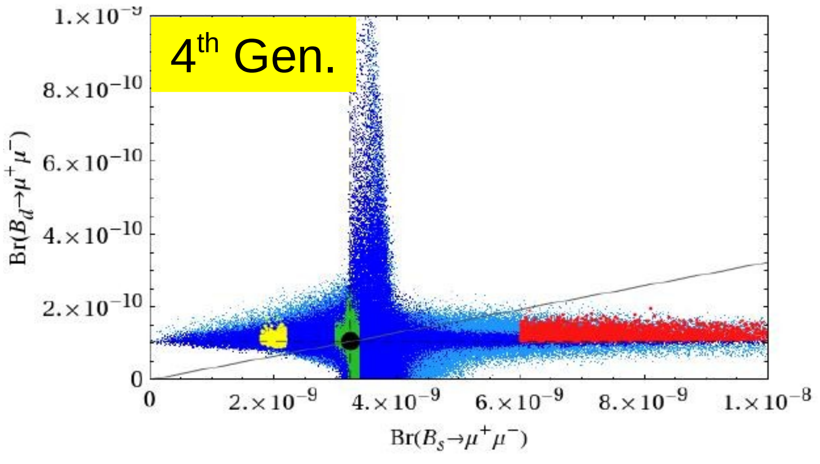
Bd vs Bs Interest:
- Golden relation in CMFV
- can be strongly violated in SUSY, 4G, Little Higgs, Extra Dimensions (RS)...

$$\frac{\mathrm{Br}(B_s \to \mu^+\mu^-)}{\mathrm{Br}(B_d \to \mu^+\mu^-)} = \frac{\hat{B}_d}{\hat{B}_s}\frac{\tau(B_s)}{\tau(B_d)}\frac{\Delta M_s}{\Delta M_d}$$

$(\Delta B = 1)$ $(\Delta B = 2)$

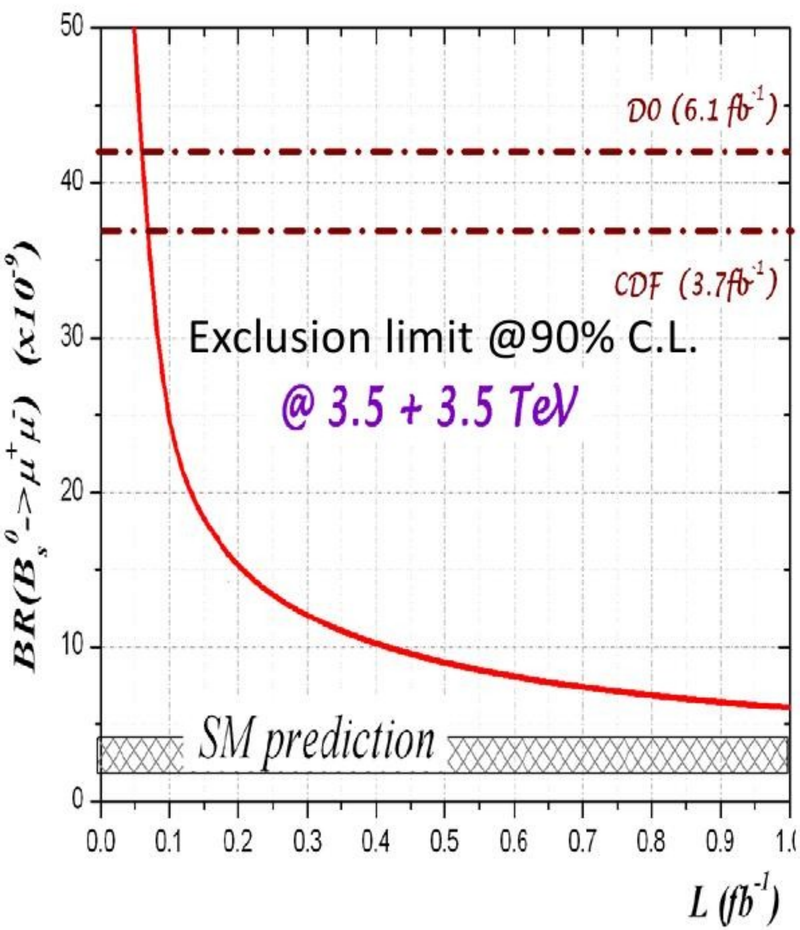
$\hat{B}_d/\hat{B}_s$: (0.95±0.03) Lattice

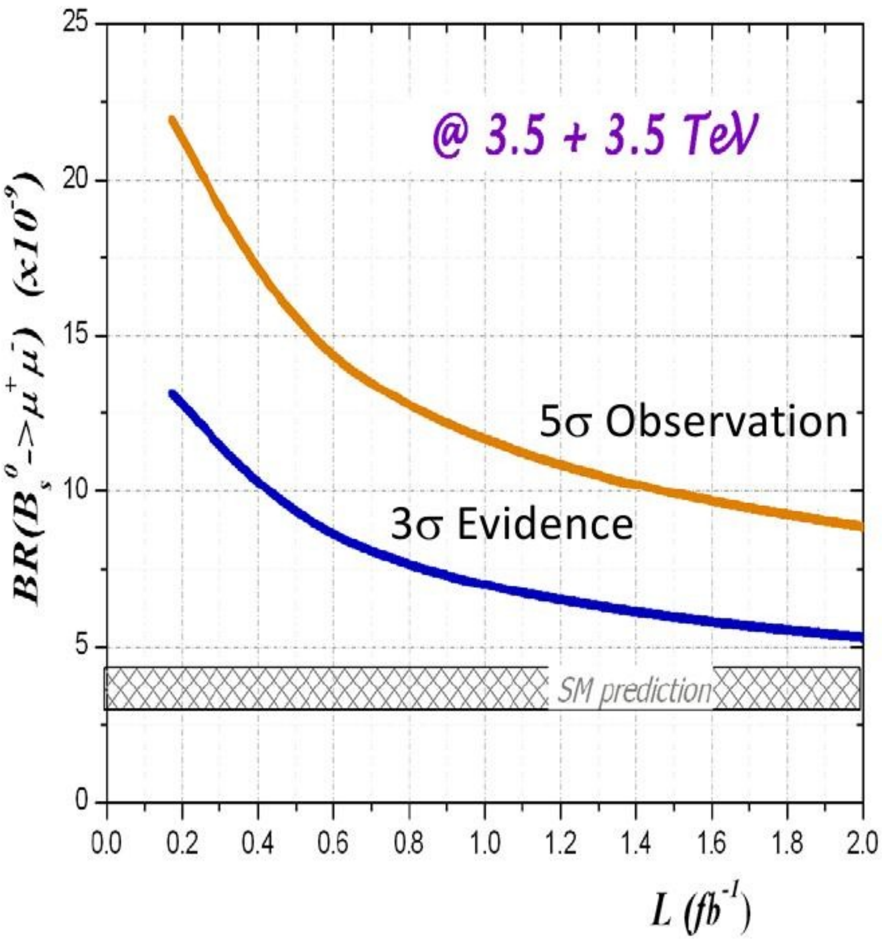




BACKUP–bsmumu

Sensitivity at 7 TeV CoM with σ(bb)=292 μb





Giampiero Mancinelli,
CPPM - Marseille

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

The One Page of Rare Charm

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**)

Analysis overview :

- Use $D^* \to D^0 \pi$
- 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
  - lower invariant mass
  - higher background

LHCb prospects: expected limit for 100 pb^{-1}

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