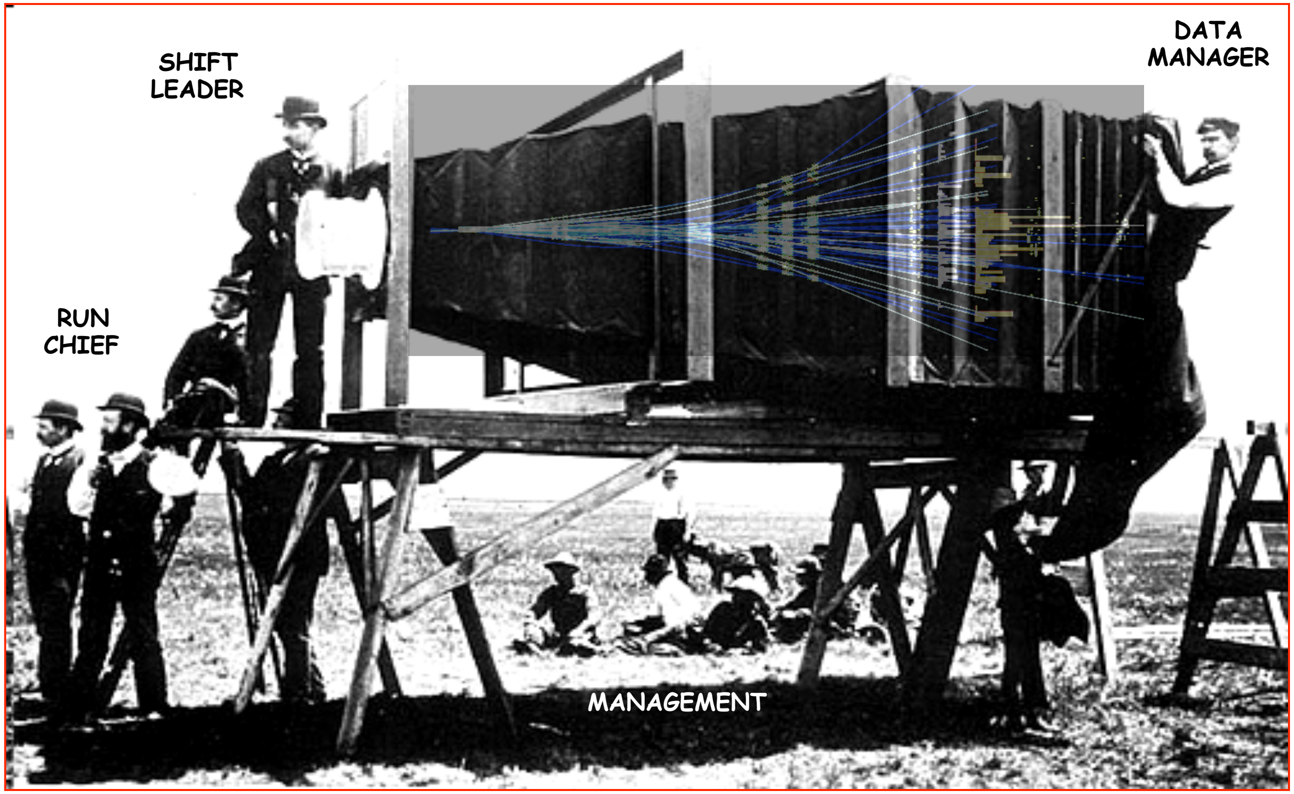
Rare b- and c-decays at LHCb



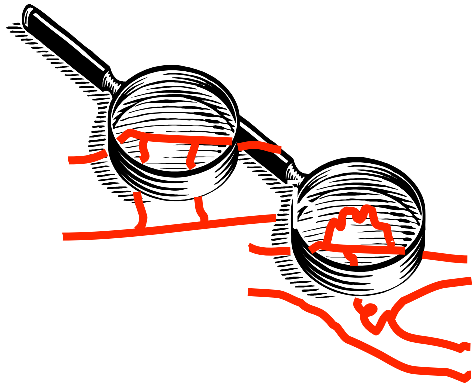
Olivier Deschamps on behalf of LHCb collaboration
Laboratoire de Physique Corpusculaire de Clermont-Ferrand
Université Blaise Pascal & IN2P3/CNRS

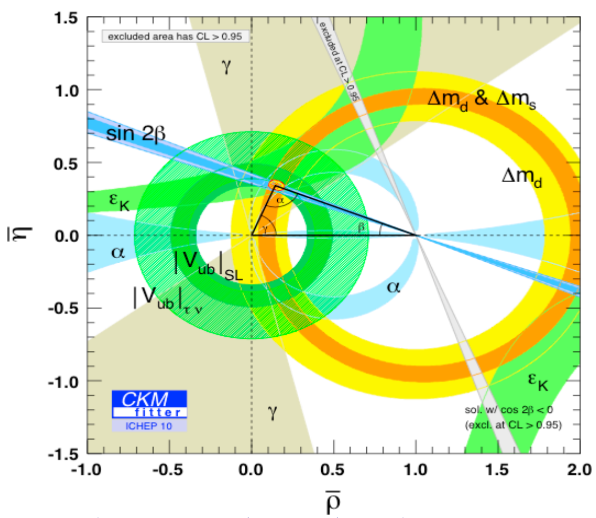
LHCb physics-case

SEARCH FOR NEW PHYSICS

Measuring rare b decays

Loop-mediated decays
are sensitive indirect probe to the NP
heavy particles
that may propagate within the loop





Testing the coherence of the CKM picture

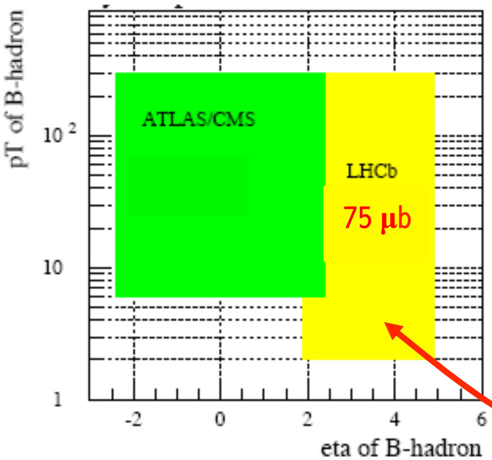
over-constrain the UT triangleS

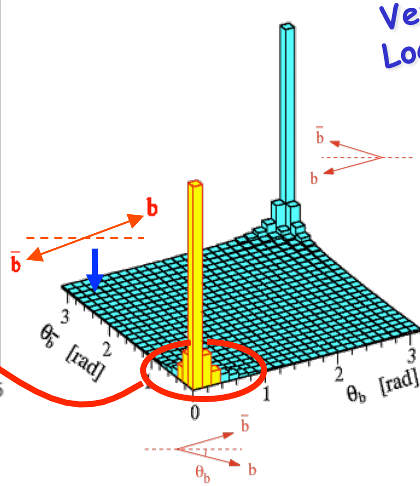
+ charm (tau) physics + spectroscopy + QCD tests + Electro-weak+…

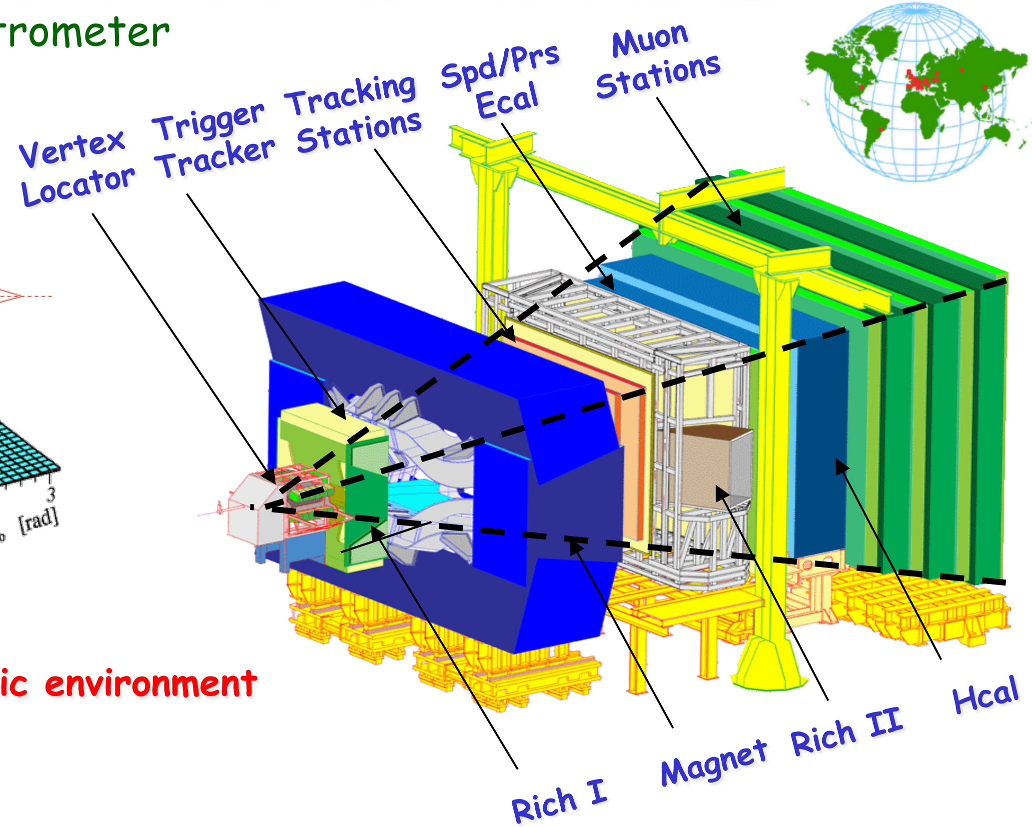
Probes of soft and hard QCD at LHCb, E. Santovetti	yesterday
Study of CPV in b and charm system at LHCb, E. Maurice	today
Heavy Flavour spectroscopy, W. Qian,	today

The LHCb detector

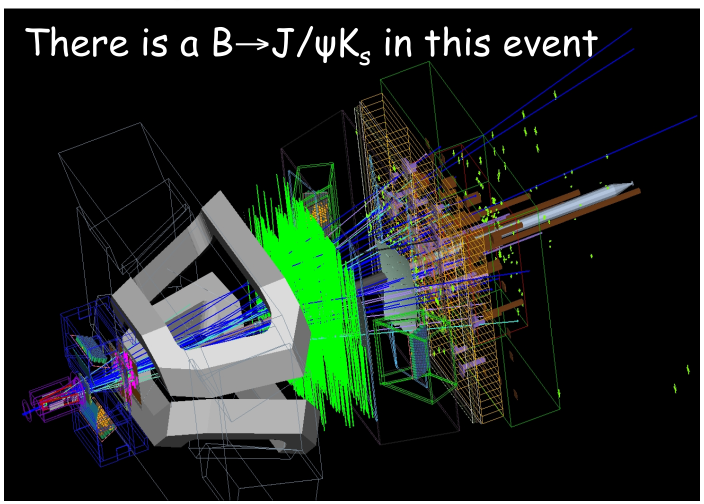
- LHCb detector : single arm forward spectrometer
  - 2 < η < 5







- Main challenge :
  - **Perform precision measurements in hadronic environment**



Large multiplicity : ~30 particles for hard pp collisions
- Large background from high inelastic pp collisions
- Small Branching Ratio for B meson decay

… but …

- 30 kHz bb rate
- Access to all b species : B_d, B_u, B_s, B_c, Λ_b, Ξ_b…

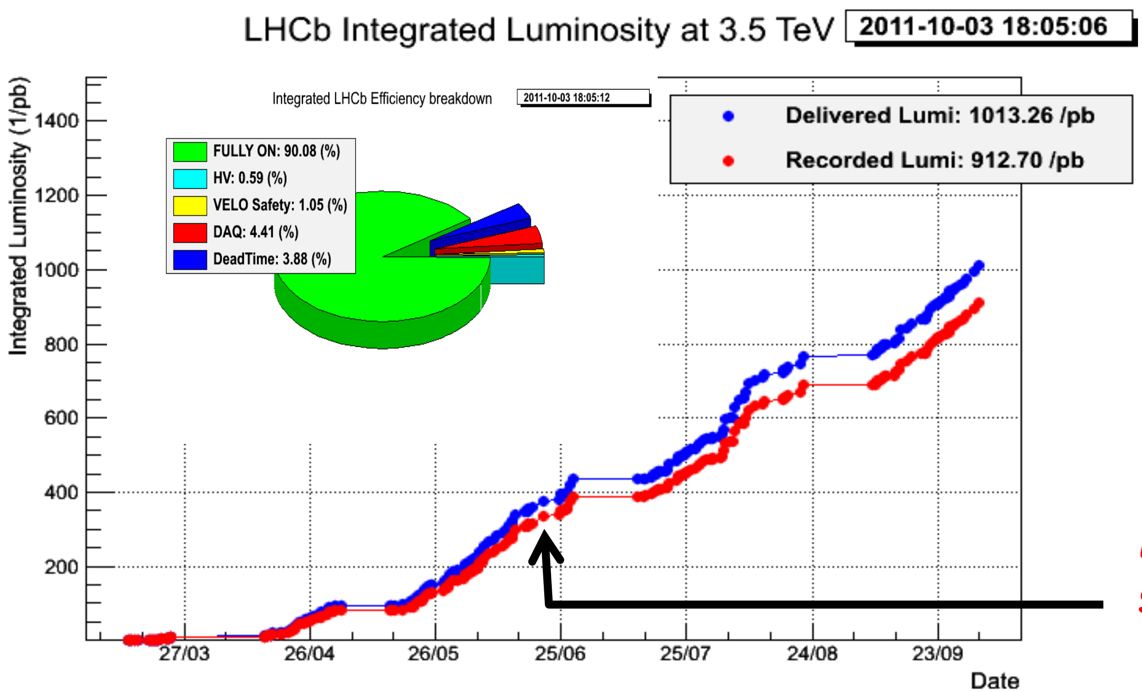
Operation

LHC delivers $\sqrt{s}$=7 TeV pp collisions since spring 2010

1380 colliding bunches in 2011

Instantaneous luminosity : **3.5x10^{32} cm^{-2}s^{-1}** (beyond the design)

visible pp interaction per bunch crossing of O(1.5)



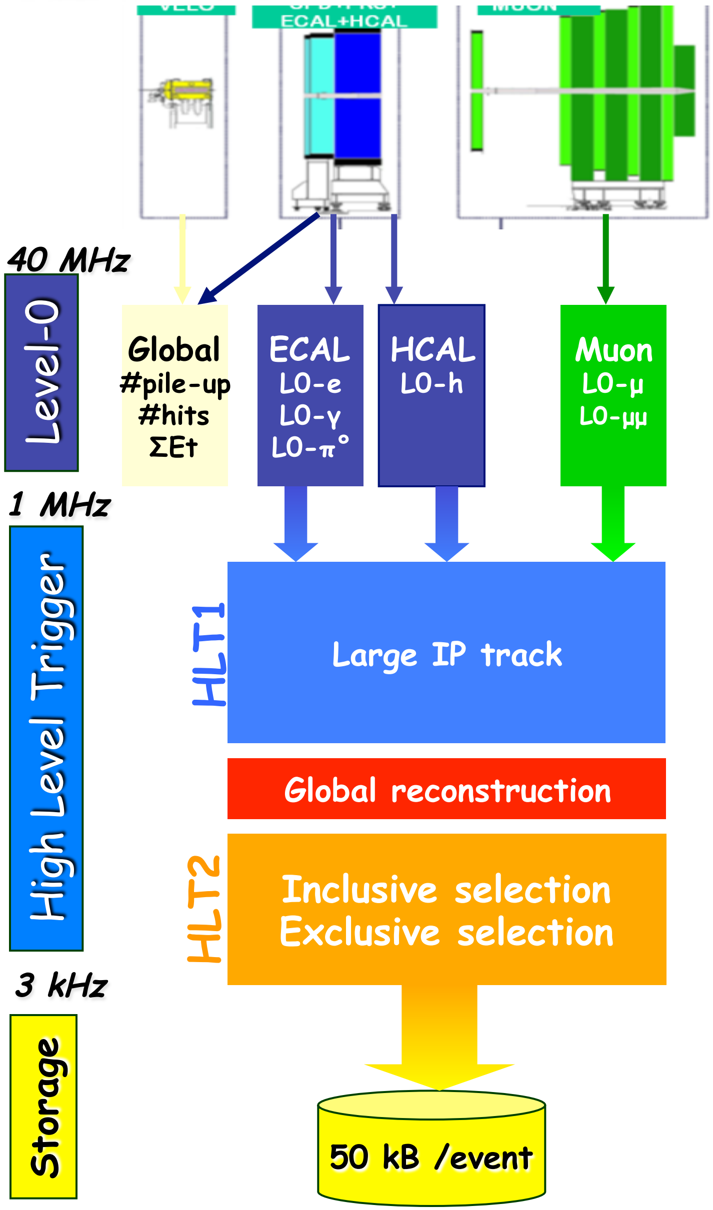
Most of the results shown today

LHCb collected 37 pb^{-1} in 2010 -> ~2.5 x 10^{9} b in the LHCb acceptance

0.37 fb^{-1} for summer 2011 conference -> ~2.5 x 10^{10} b

1.0 fb^{-1} by the end of 2011 -> ~8.0 x 10^{10} b

Trigger system



The trigger strategy is a sensitive part of the rare decay selection and reconstruction

Level-0 Trigger (Hardware)

- Fully synchronous (40 MHz) custom electronics
  - Visible interaction rate 10 MHz → 850 kHz
- Identification of highest P_T : h, e, γ, π° and μ candidates
  - typical threshold : μ ~ 1 GeV/c - h, e, γ, π° ~ 3-4 GeV/c

High-Level Trigger (Software)

- 1500 multi-processor boxes farm (busy 90%).

- **HLT1 :**
  - add info from tracking, Vertex Locator
  - add impact parameter and lifetime cuts

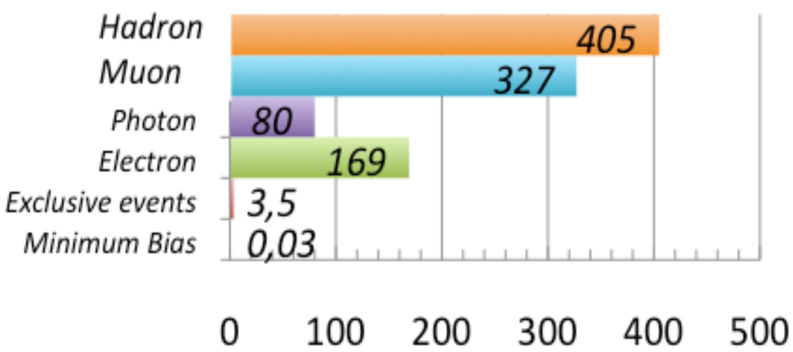
- **HLT2 :**
  - global event reconstruction exclusive & inclusive selections

Storage @ 3 kHz

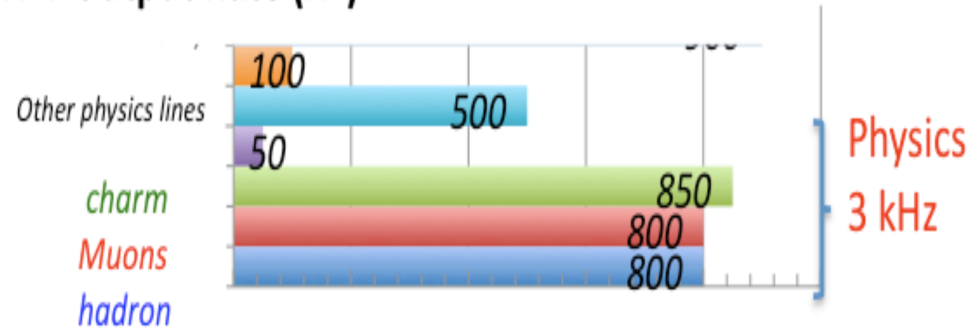
Trigger system

- Bandwidth sharing

L0 Output Rate (kHz, non exclusive)



HLT Output Rate (Hz)



- Trigger typical performance

	ε(L0)	ε(HLT)	ε(total)
Hadronic	50%	80%	40%
Electromagnetic	60 %	50%	30%
Muon	90%	80%	70%

ε corrected for acceptance and selection

Rare decays

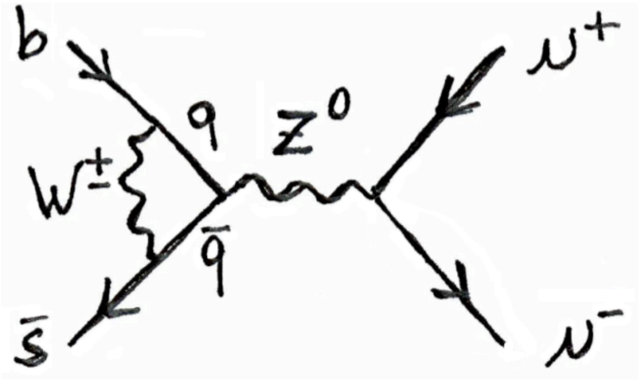
- program :

  - $B_{s,d} \rightarrow \mu^+\mu^-$
  - $b \rightarrow q l^+ l^-$
  - $B \rightarrow V\gamma$

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

- Z-penguin suppressed diagram

doubly suppressed : FCNC & helicity



- SM-expected Branching Ratio :

$$B_{SM}(B_s \to \mu^+\mu^-) = (3.64^{+0.17}_{-0.31}) \times 10^{-9}$$

$$B_{SM}(B_d \to \mu^+\mu^-) = (1.13^{+0.06}_{-0.11}) \times 10^{-10}$$

[The CKMFitter group - hep-ph 1106.4041]

- Pre-summer 2011 limits (@ 95% CL):

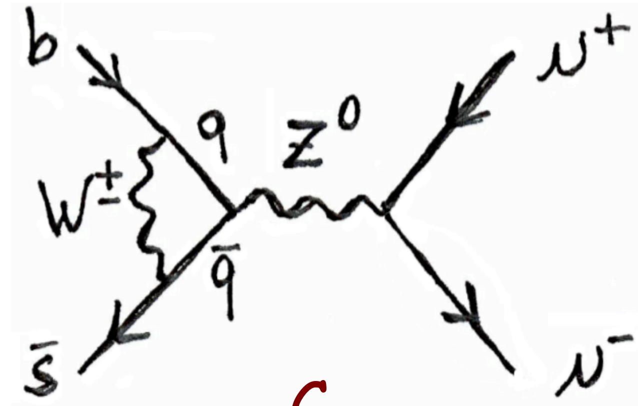
D0 (3.7 fb-1) :	$B(B_s \to \mu^+\mu^-) < 51 \times 10^{-9}$	*[PLB 693 539 (2010)]*
CDF (6.1 fb-1):	$B(B_s \to \mu^+\mu^-) < 43 \times 10^{-9}$ $B(B_d \to \mu^+\mu^-) < 7.6 \times 10^{-9}$	*[CDF note 9892 (2009)]*
LHCb (0.036 fb-1):	$B(B_s \to \mu^+\mu^-) < 56 \times 10^{-9}$ $B(B_d \to \mu^+\mu^-) < 15 \times 10^{-9}$	*[PLB 699 (2011) 330-340]*

- Very sensitive to NP

SM

$$BR(B_q \to l^+l^-) \approx \frac{G_F^2 \alpha^2 M_{B_q}^3 f_{B_q}^2 \tau_{B_q}}{64\pi^3 \sin^4\theta_W} |V_{tb}V_{tq}^*|^2 \sqrt{1 - \frac{4m_l^2}{M_{B_q}^2}}$$
$$\left\{ M_{B_q}^2 \left(1 - \frac{4m_l^2}{M_{B_q}^2}\right) c_S^2 + \left[M_{B_q} c_P + \frac{2m_l}{M_{B_q}} (c_A - c'_A) \right]^2 \right\}.$$

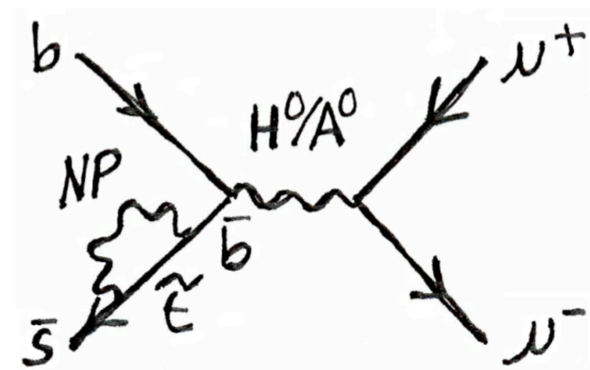
In the SM $C_{s,p}$ via Higgs exchange ~$(m_\mu m_b)/m^2_W$ negligible



C_A

... in the scalar/pseudo-scalar sector

$$(C_{s,p}^{MSSM})^2 \propto \frac{\tan^6\beta}{M_A^4}$$

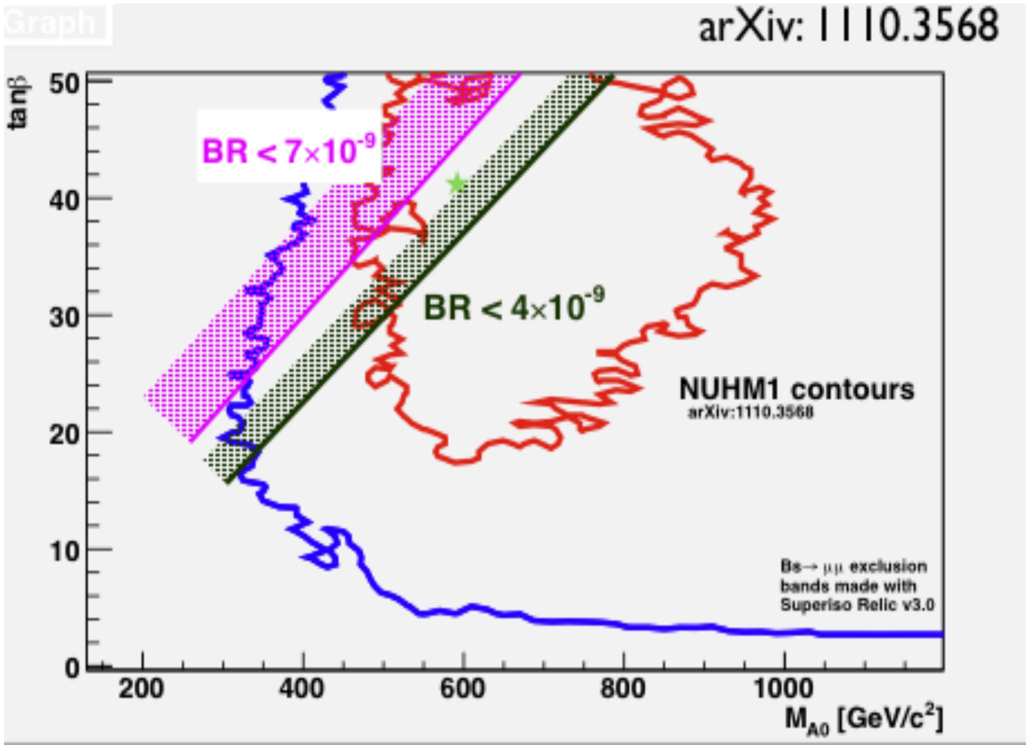


C_s , C_p

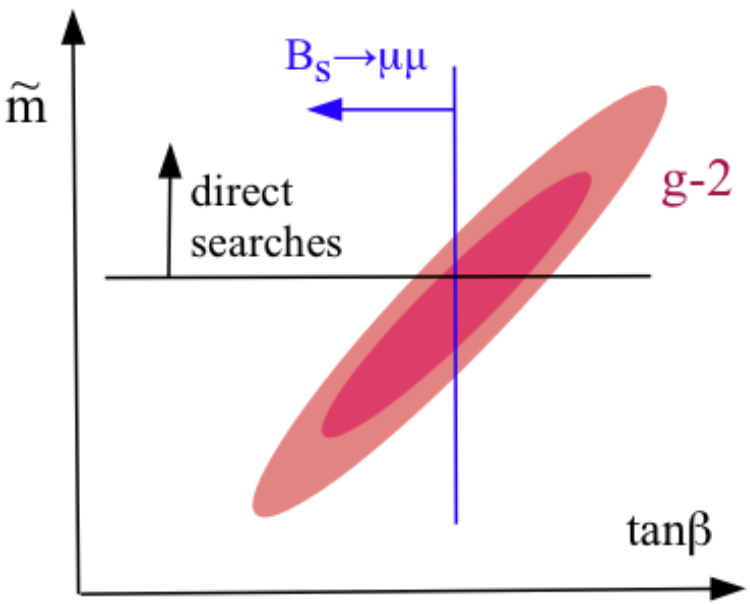
$B_{s,d} \rightarrow \mu^+ \mu^-$

- Constraint on specific NP models

Constraints on Susy models, incl. direct search, flavor, g-2, DM



G. Isidori, ICFA seminar



- BR($B_s \rightarrow \mu\mu$) sets strong bounds on *tanβ*, at least in MSSM, complementary to direct searches and in tension with g-2

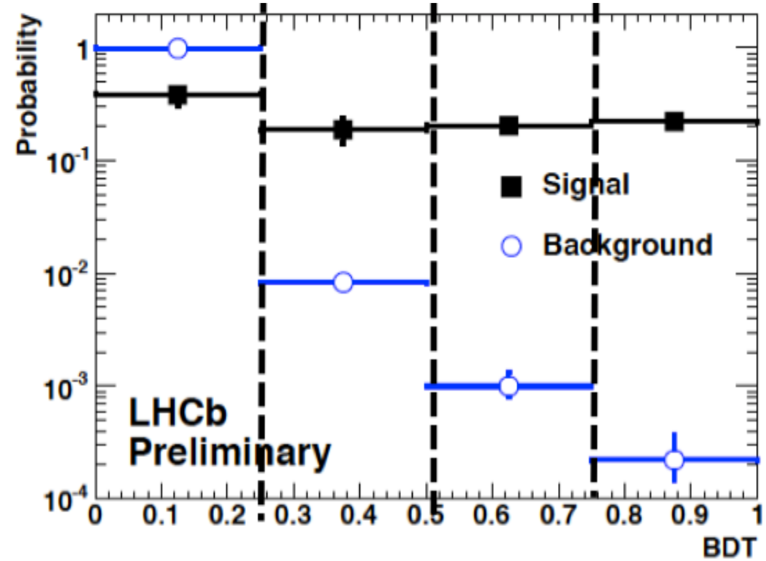
$B_{s,d} \to \mu^+\mu^-$

- LHCb analysis strategy :

Event selection based on 2D analysis :

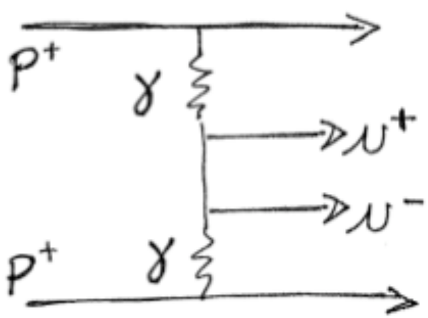
- Geometrical & kinematical (Boosted Decision Tree)
  Impact Parameter, B vertex, Isolation

- Invariant mass Likelihood
  modelled with a Crystal Ball function



- main background is combinatorial. Extracted from mass side-bands
- Small contamination from specific backgrounds. Under control.

$pp \to X\mu^+\mu^-$



$B \to h^+h^-$ with mis-identification

- Background due to misidentified muons from $B_{d/s} \to h^+h^-$ decays
  - Evaluated from $B_{d/s} \to h^+h^-$ MC reweighted according to misID probablity measured in data
  - Cross checked with $B_{d/s} \to h^+h^-$ data, requiring one muon in the final state

We expect:

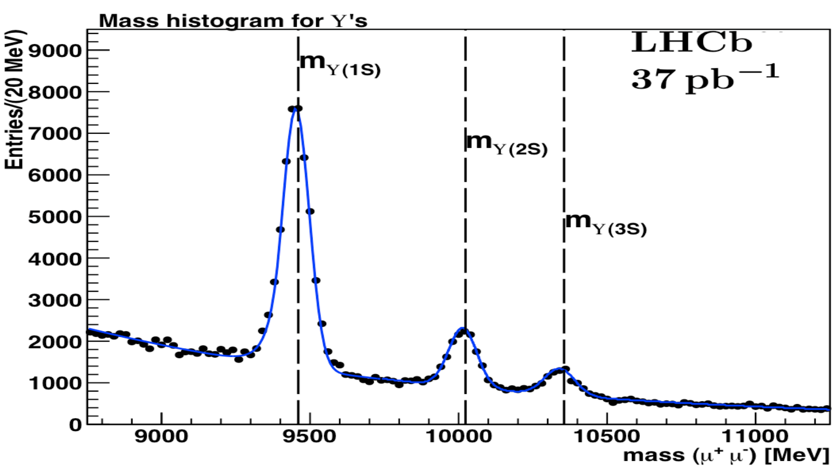
2.5±0.5 misID events in B_d region ⇨ 0.6±0.1 per BDT bin

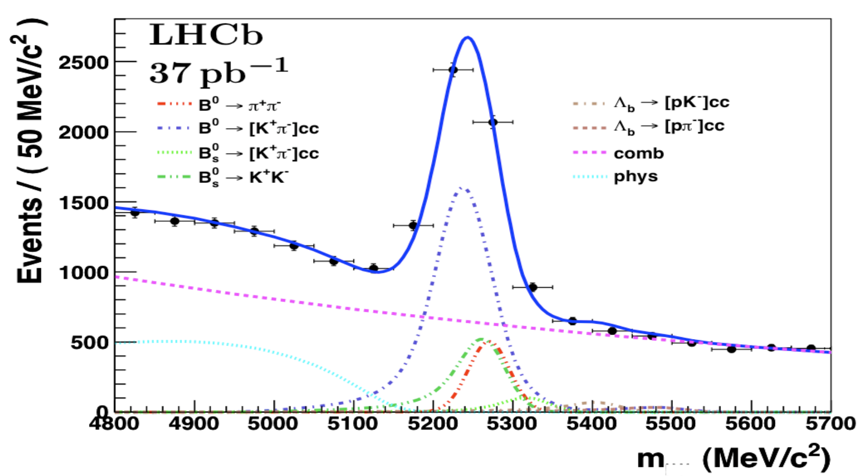
0.5±0.4 misID events in B_s region ⇨ 0.01±0.011 per BDT bin

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

- LHCb analysis strategy (con't) :
  - Data driven calibration
    - Geometrical Boosted Decision Tree (BDT)
      - trained on MC ($B_{s,d} \rightarrow \mu^+\mu^-$ vs $bb \rightarrow \mu^+\mu^- X$)
      - calibrated on data using $B_{s,d} \rightarrow hh$ for signal and mass side-bands for background
    - Invariant mass Likelihood
      - mean peak position from $B_{s,d} \rightarrow K^+\pi^-$ (K^+K^-)
      - resolution from interpolation of di-μ resonances ($J/\psi, \psi(2S), \Upsilon$'s) checked on inclusive di-hadron B decays

$$\sigma(m_{B_s}) = (24.6 \pm 0.2 \pm 1.0) MeV / c^2$$

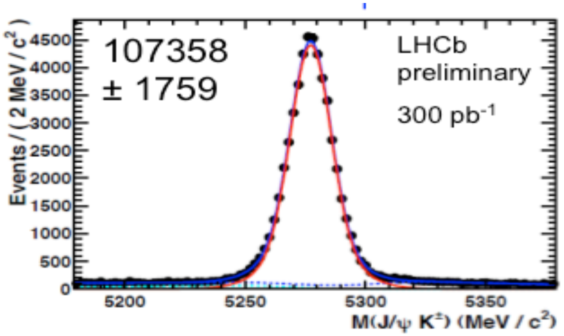




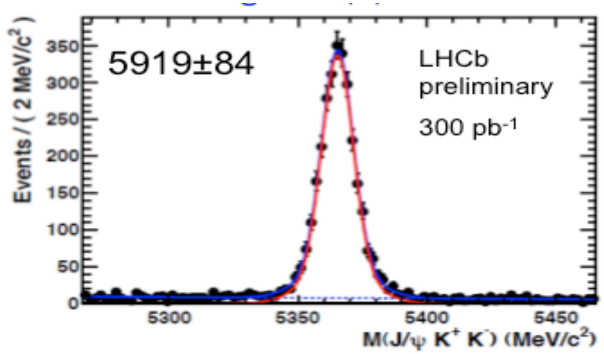
$B_{s,d} \to \mu^+\mu^-$

- LHCb analysis strategy (con't):
  - Normalisation
    - Use know normalisation channels to derive BR from the event yield

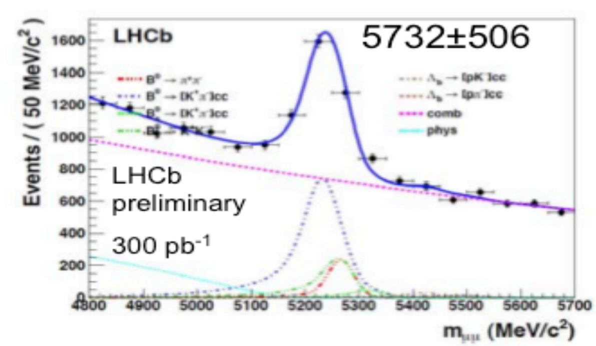
$B^+ \to J/\psi(\mu^+\mu^-)K^+$



$B_s \to J/\psi(\mu^+\mu^-)\Phi(K^+K^-)$



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



complementary in term of trigger, PID, final state reconstruction, B species

$$B(B_{s,d} \to \mu^+\mu^-) = \left(\frac{B_{norm}}{N_{norm}} \cdot \frac{\varepsilon_{sig}^{rec,sel,trig}}{\varepsilon_{norm}^{rec,sel,trig}} \cdot \frac{f_{q_{norm}}}{f_{s,d}}\right) \cdot N_{B_{s,d} \to \mu\mu} = \alpha_{s,d} \cdot N_{B_{s,d} \to \mu\mu}$$

(0.37 fb^{-1})

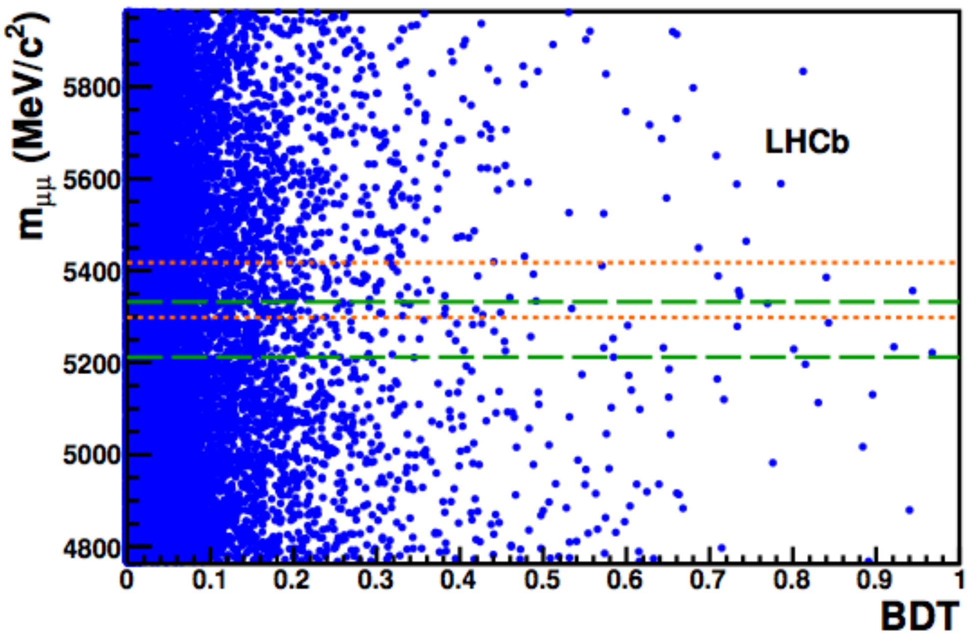
Weighted-average:

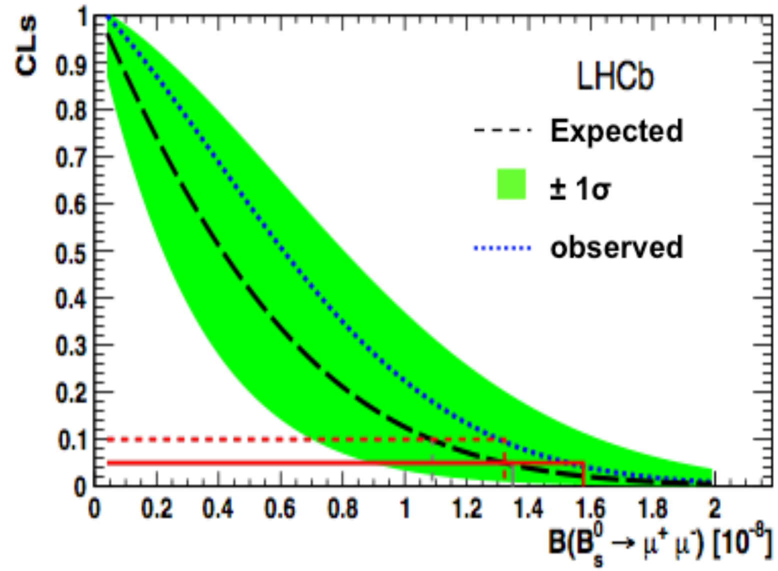
$$\alpha(B_s \to \mu^+\mu^-) = (8.38 \pm 0.74) \times 10^{-10}$$
$$\alpha(B^0 \to \mu^+\mu^-) = (2.20 \pm 0.11) \times 10^{-10}$$

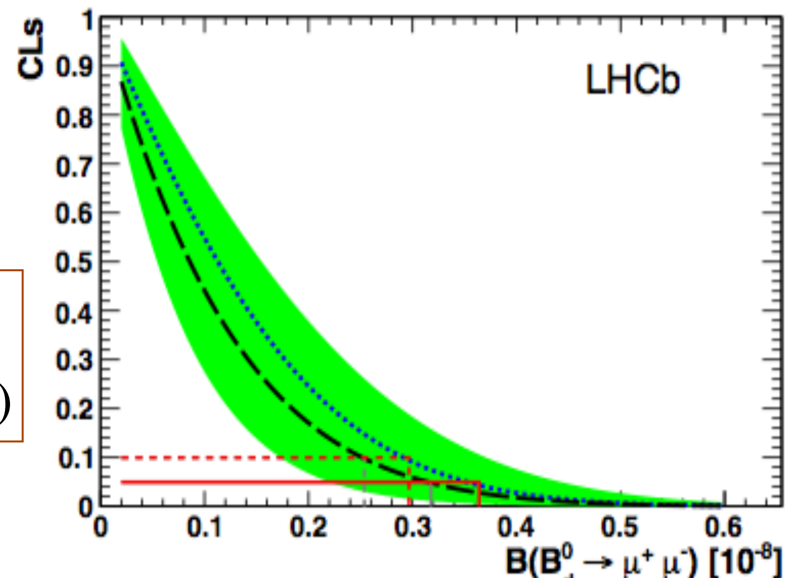
$$f_s / f_d = 0.267^{+0.021}_{-0.020}$$

[PRD 85 (2012)]

$B_{s,d}\to\mu^+\mu^-$: results







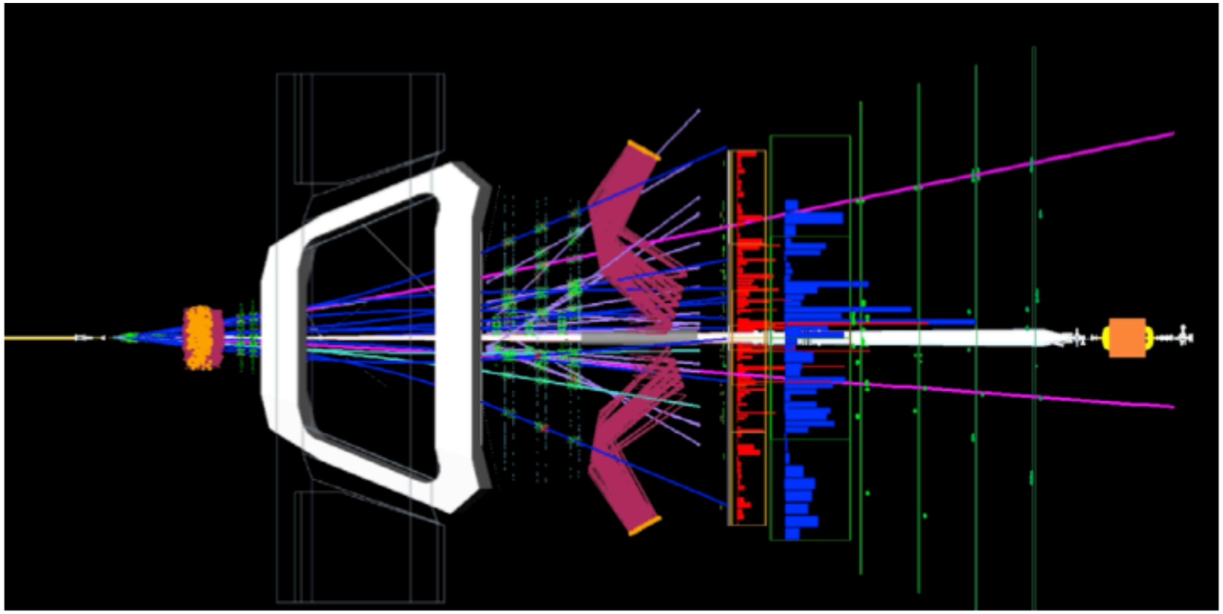
95% CL limits (2010 + 0.37 fb^{-1} of 2011 data)

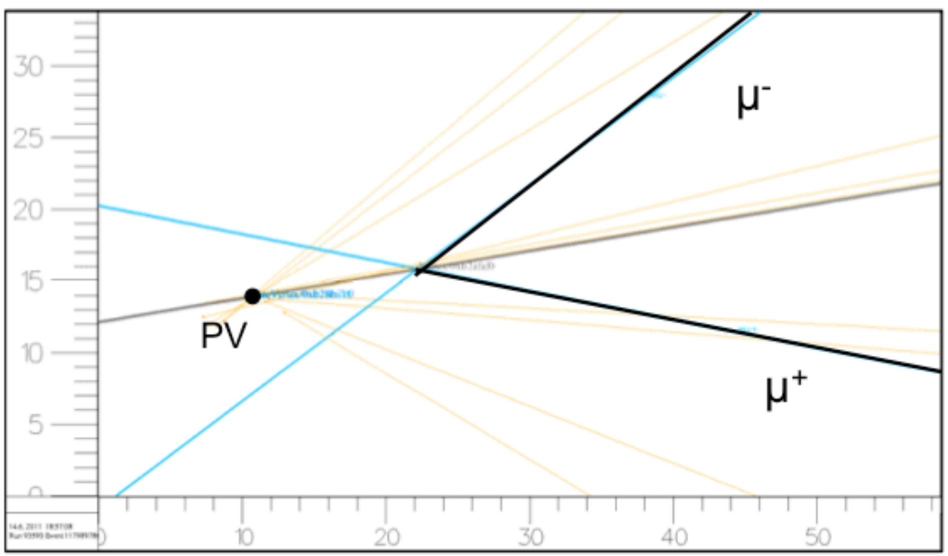
$$B(B_s \to \mu^+\mu^-) < 14\times10^{-9} \quad (\text{exp. limit : } 13\times10^{-9})$$

$$B(B_d \to \mu^+\mu^-) < 3.2\times10^{-9} \quad (\text{exp. limit : } 2.6\times10^{-9})$$

[Phys. Lett. B 708 (2012) 55-67]

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





Mμμ = 5.357 GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for *p*T > 0.5 GeV

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

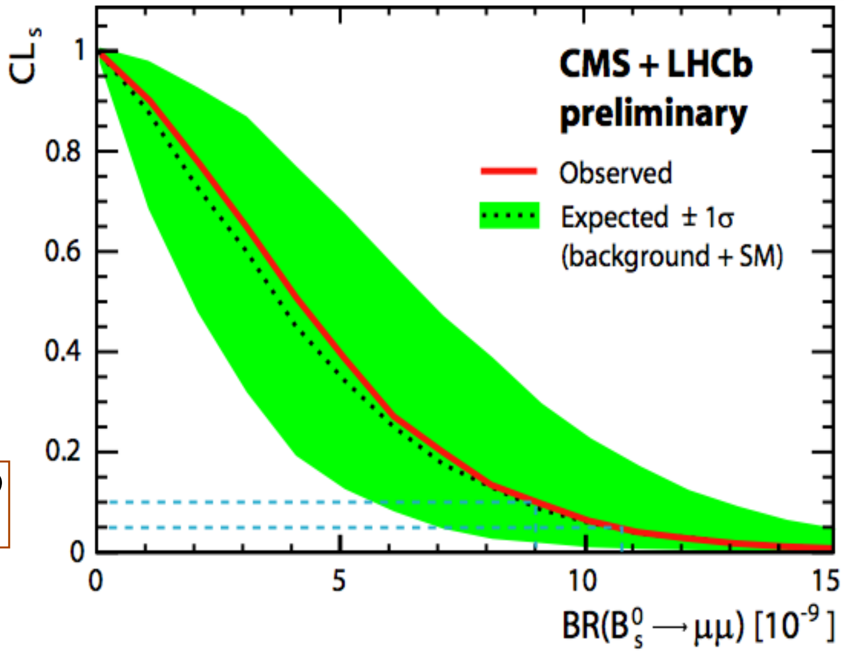
- LHCb + CMS combination @ summer 2011

95% CL limits

$$LHCb: B(B_s \to \mu^+\mu^-) < 16\times10^{-9} \quad (\text{exp. limit}: 15\times10^{-9})$$
$$CMS: B(B_s \to \mu^+\mu^-) < 19\times10^{-9} \quad (\text{exp. limit}: 18\times10^{-9})$$

[LHCb-CONF-2011-047, CMS PAS BPH-11-019.]

$$\boxed{LHCb + CMS: B(B_s \to \mu^+\mu^-) < 11\times10^{-9}}$$

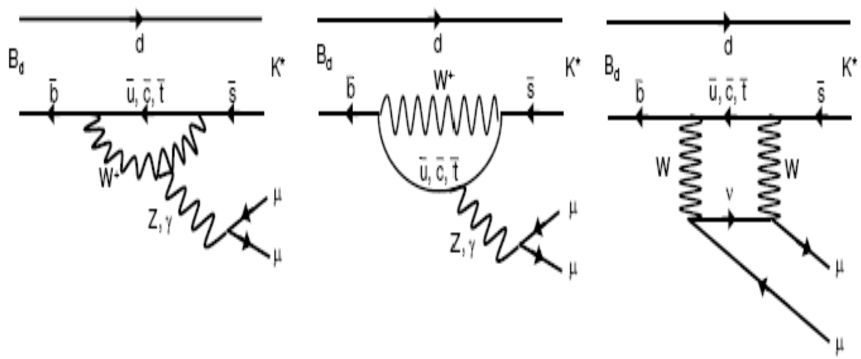


LHCb update on 1.0 fb^{-1} in the coming week(s)

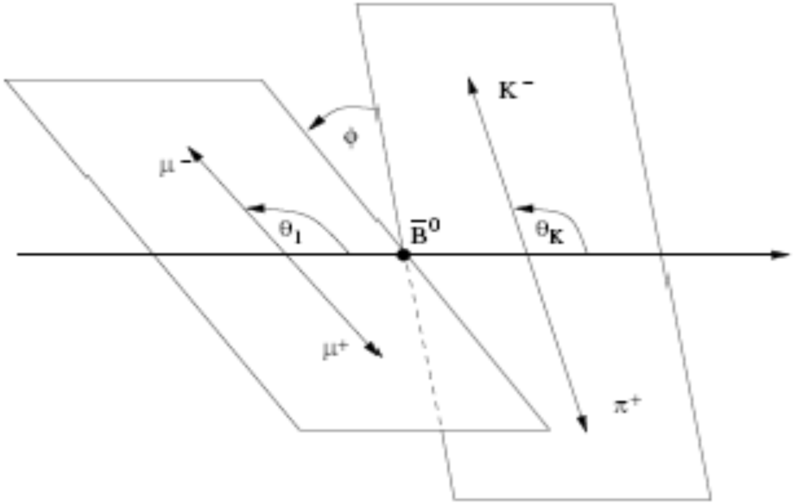
Also $B\to4\mu$ and rare leptonic charmed meson decay $D\to\mu\mu$

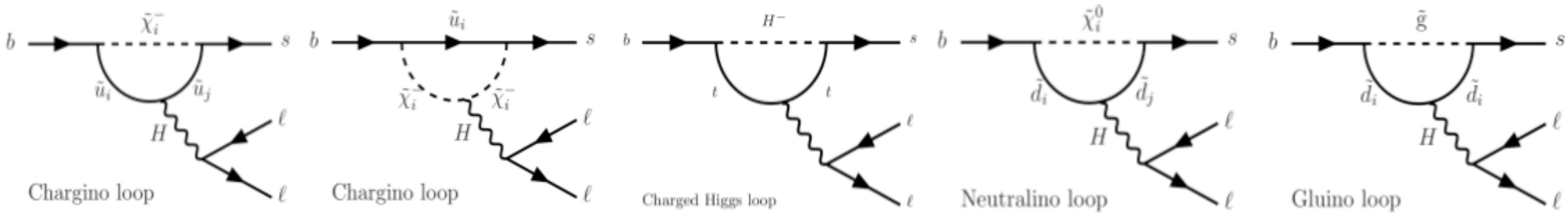
$B^0 \to K^* \mu^+ \mu^-$

- Suppressed FCNC in b→s EW-penguin transition
    - BR = $(1.09 \pm 0.12)\ 10^{-6}$ *[HFAG 2010]*



- Lepton angular distribution affected by NP





Chargino loop
Chargino loop
Charged Higgs loop
Neutralino loop
Gluino loop

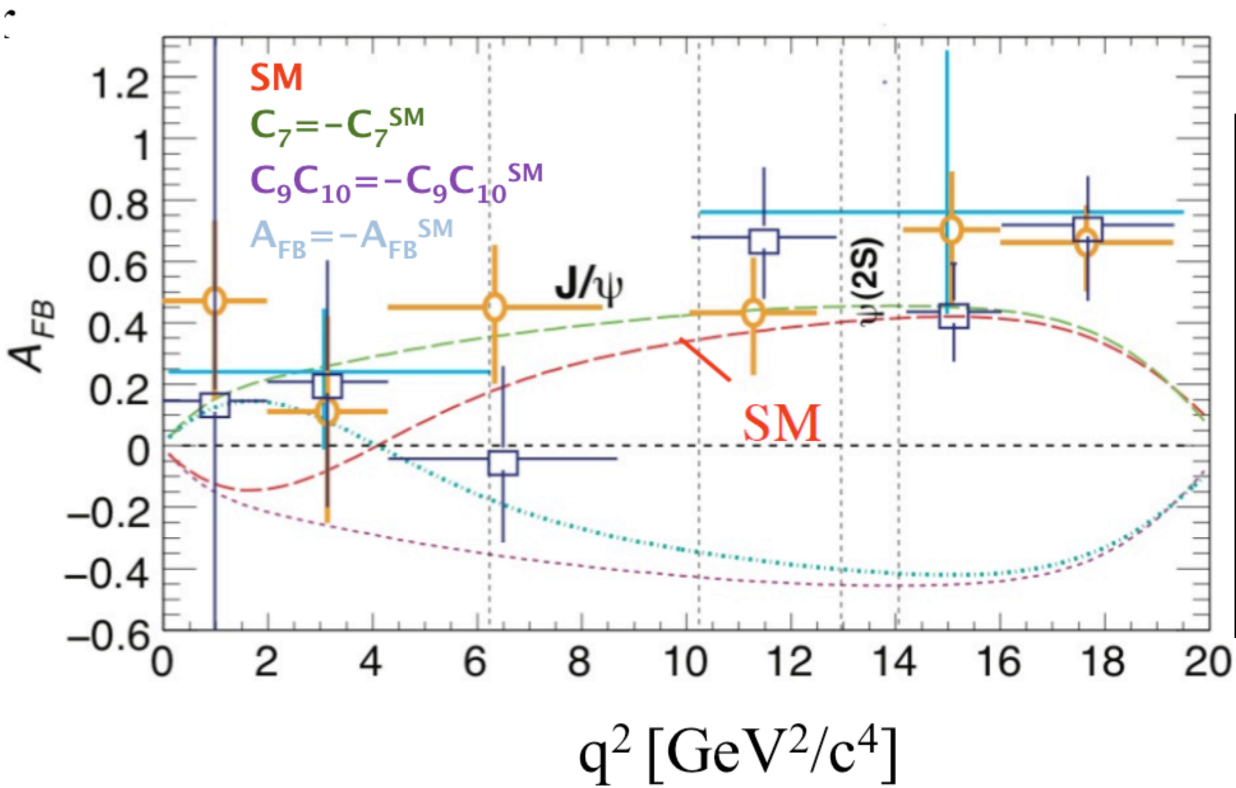
$B^0 \to K^* \mu^+ \mu^-$

- Several observable to test the dynamics
  - $q^2 = m^2_{\mu+\mu-}$ distribution
  - $A_{FB}(q^2)$: forward-backward asymmetry in Θ_μ

[Beneke et al. EPJC41:173-188;2005]

- Zero-crossing point $A_{FB}(s_0) = 0$ prediction depends on Wilson Coefficient C_7 & C_9

$$q_0^2 = (4.36^{+0.33}_{-0.31})\ GeV^2/c^4$$



PRL 103 (2009)

250 $K^*l^+l^-$
80% of data

PRD 79 (2009)

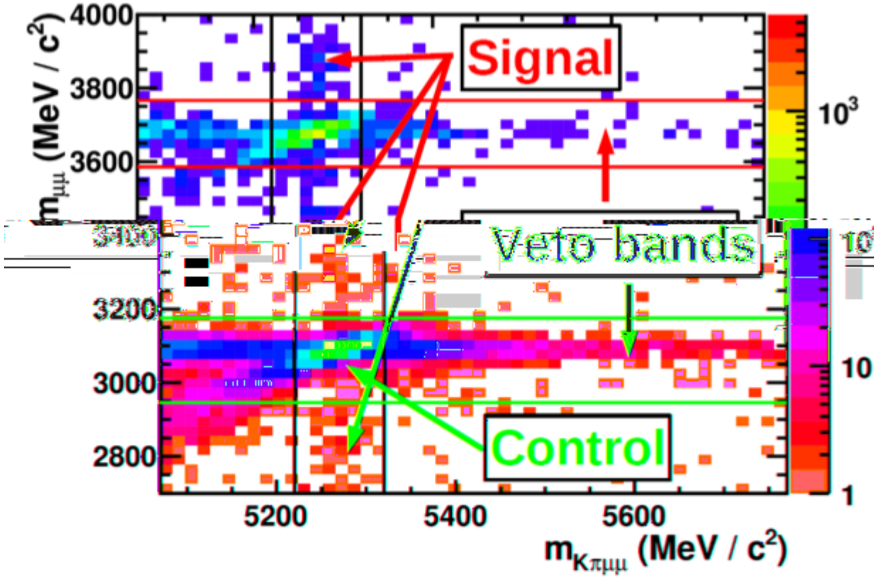
100 $K^*l^+l^-$
75% of data

1108.0695 (2008)

100 $K^*\mu^+\mu^-$
4.4 fb^{-1}

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

- LHCb selection
  - multivariate analysis (BDT)
  - J/ψ & ψ(2S) region vetoed

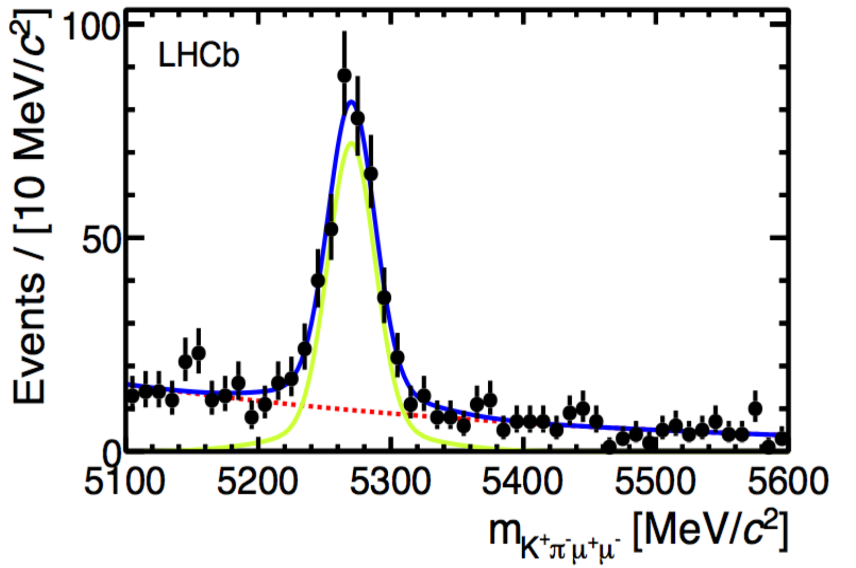


- Decay dynamics parametrized in 4D space

3 angles (θ_μ ,Φ,θ_K) and di-muon mass q^2

- Focus on 3 (theoretically clean) observables

A_{FB}, F_L, dB/dq^2



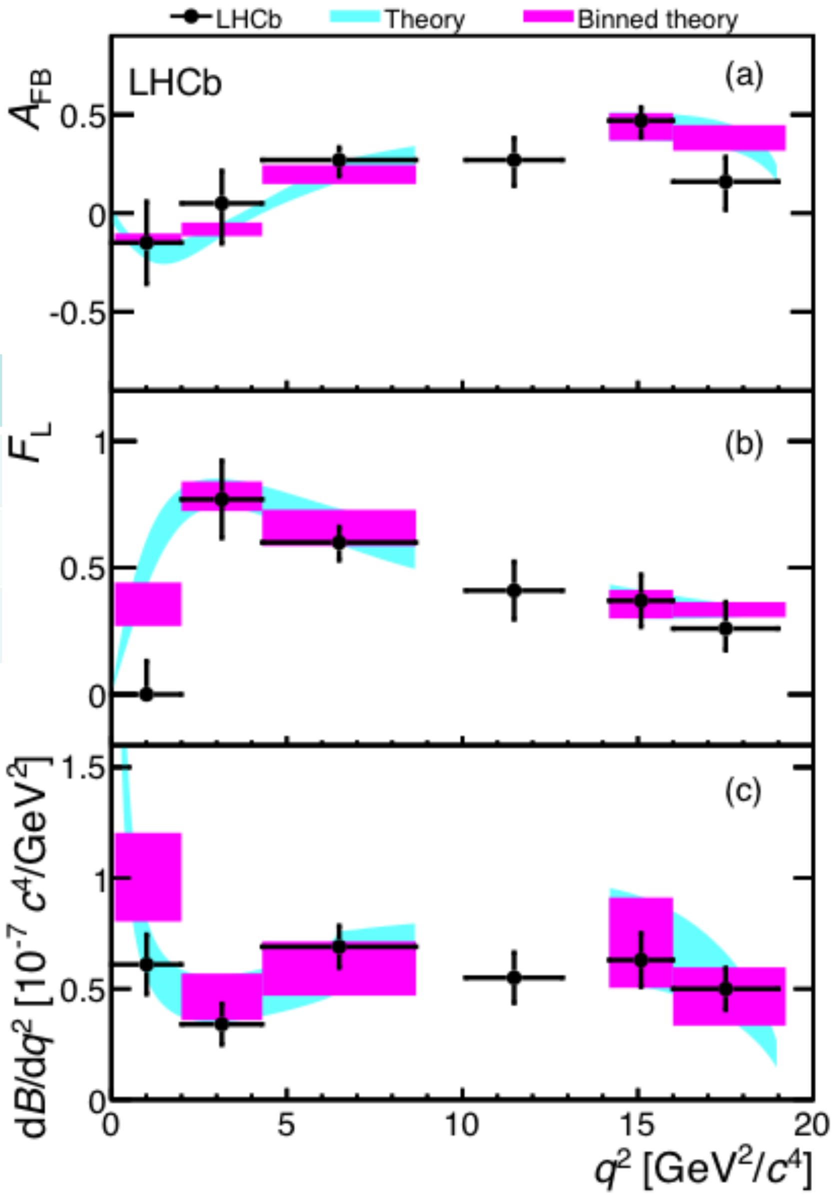
$B^0 \rightarrow K^* \mu^+ \mu^-$

- LHCb result ($0.37\ pb^{-1}$) [hep-ex:1112.3515]

$1 < q^2 < 6\ GeV^2/c^4$

	LHCb	Theo.
A_{FB}	$-0.06\ ^{+0.13}_{-0.14} \pm 0.04$	-0.04 ± 0.03
F_L	$+0.55 \pm 0.10 \pm 0.03$	$+0.74\ ^{+0.06}_{-0.07}$
$(dB/dq^2) \times 10^7$	$+0.42 \pm 0.06 \pm 0.03$	$+0.50\ ^{+0.11}_{-0.10}$

STANDARD MODEL
AGAIN !



$b \to q l^+ l^-$: prospects

- Rich $b \to q l^+ l^-$ program in LHCb

Measure	In decay	Motivation
Differential BR and angular distributions	$B_d \to K^{*0}\mu\mu$ $B^+ \to K^+\mu\mu$ $\Lambda_b \to \Lambda^{(*)}\mu\mu$ $B_s \to \phi\mu\mu$	Mass scale, couplings and helicity structure of NP operators
Isposin and CP asymmetries	$B_d \to K^{*0}\mu\mu$ $B^+ \to K^+\mu\mu$	Very small in SM, can be enhanced due to NP

  - Search for majorana neutrino via $B^+ \to h^- \mu^+ \mu^+$ [LHCb-PAPER-2011-038]

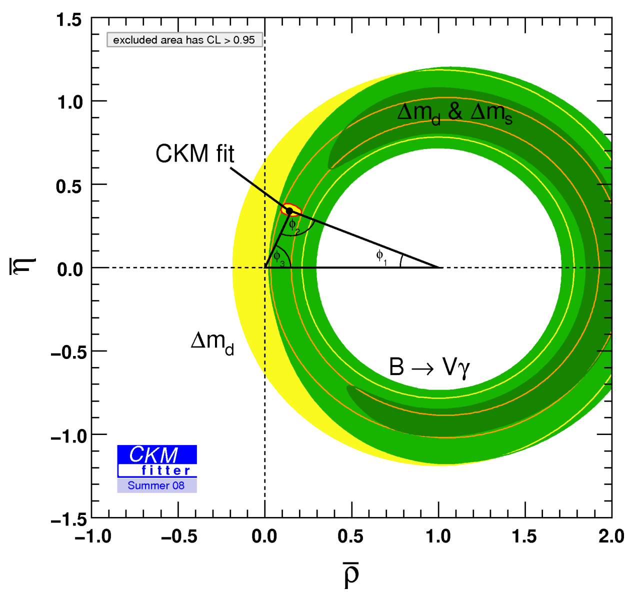
- Analysis with $1 fb^{-1}$ coming soon

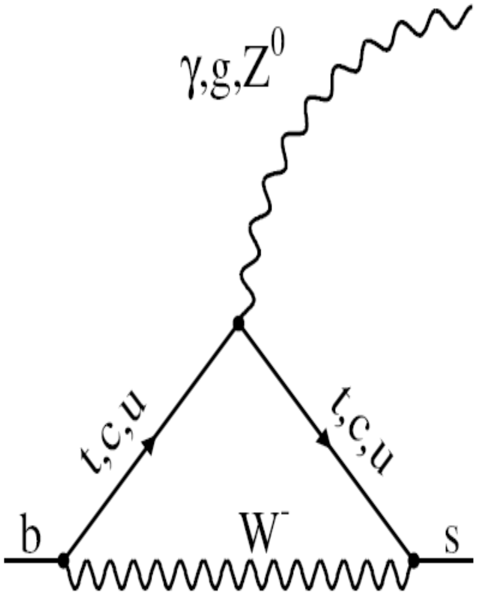
  - Angular analysis update with new variables (A_T^2, A_{Im}) in $B^0 \to K^* \mu^+ \mu^-$
  - $B_s \to \phi \mu^+ \mu^-$, $B^+ \to K^+ \mu^+ \mu^-$, …

b→qγ : radiative decays

- Radiative b→qγ FCNC penguin transition:

Branching ratio & asymmetry of exclusive b→(d,s)γ modes provide a direct constraint on UT



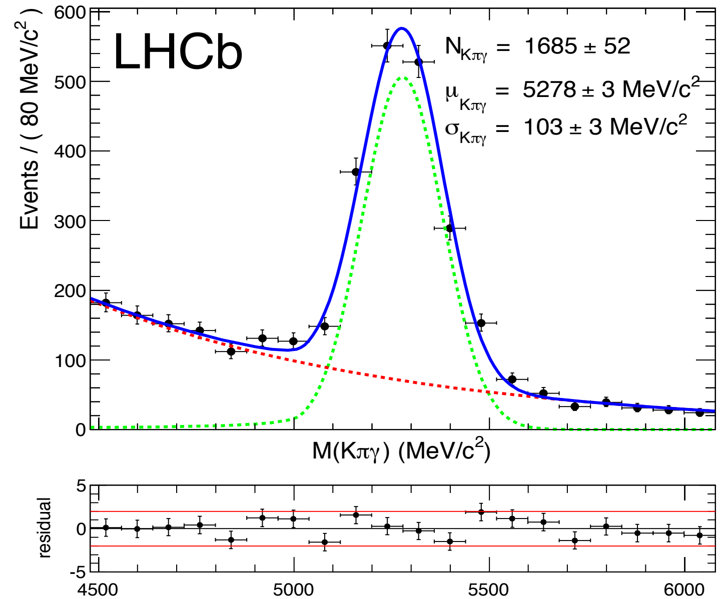


New physics to affect the transition dynamics

BR, A_{CP}, Isospin asymmetry,
helicity structure of the photon

Radiative decays : B→Vγ

- $B^0 \to K^{*0}\gamma$ and $B_s \to \phi\gamma$
- Resolution ~100 MeV/c² dominated by Ecal resolution



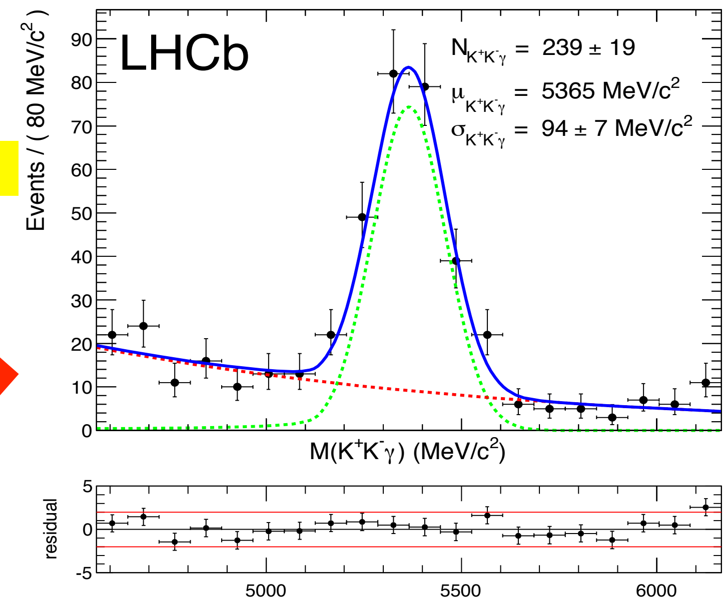
Branching fractions :

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

$BR(B_s \to \phi\gamma) \quad = (5.7^{+2.1}_{-1.8}) \times 10^{-5}$ [HFAG, 2010]

SM-predictions have large hadronic uncertainty mostly canceling in the ratio :

$R = BR(K^{*0}\gamma)/BR(\Phi\gamma) = 1.0 \pm 0.2$ [Ali, Pecjak, Greub, 2008]



LHCb result (0.37 fb⁻¹)

NEW

$$\frac{B(B_d \to K^*\gamma)}{B(B_s \to \Phi\gamma)} = 1.12 \pm 0.08(stat)^{+0.06}_{-0.04}(syst)^{+0.09}_{-0.08}(f_d / f_s)$$

$$B(B_s \to \Phi\gamma) = (3.9 \pm 0.5)\cdot 10^{-5}$$

[LHCb-PAPER-2011-042]

Radiative decays : $A_{CP}(B0 \rightarrow K^{*0}\gamma)$

Direct CP asymmetry in $B^0 \rightarrow K^{*0}\gamma$

SM-prediction :

$A_{CP} = -0.0061 \pm 0.0043$

A_{CP} enhanced in NP scenarii

Previous best measurement :

$A_{CP} = -0.016 \pm 0.022 \pm 0.007$

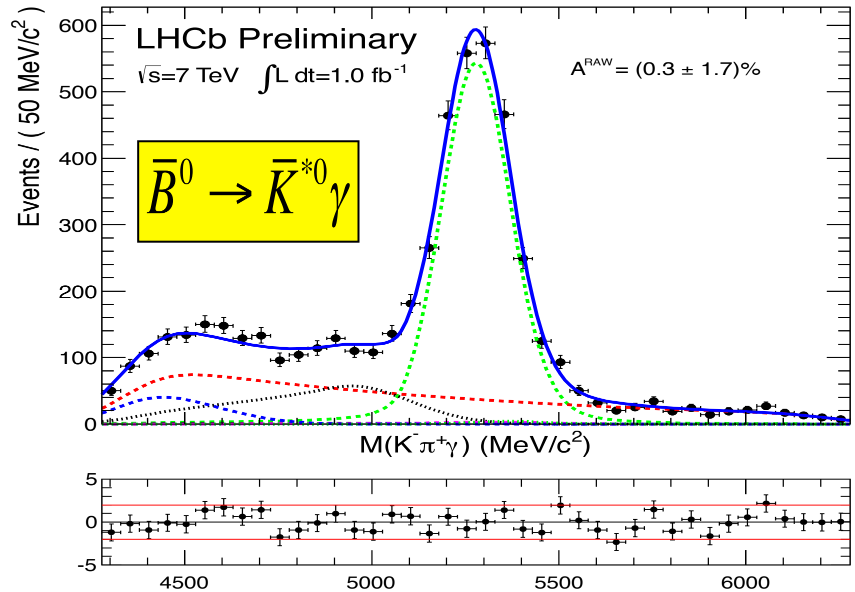
Preliminary LHCb result (1.0 fb^{-1}) :

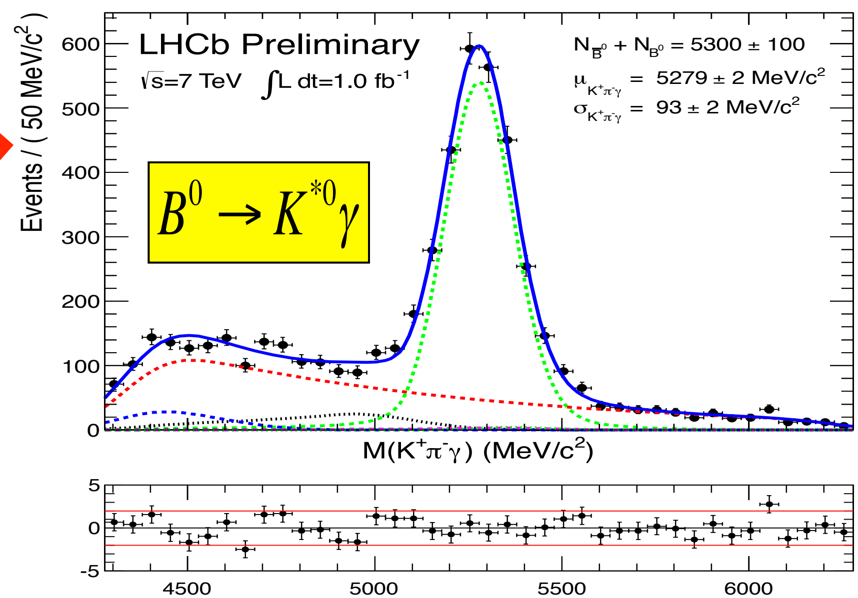
[LHCb-CONF-2012-004] NEW

$$N_{B^0} + N_{\bar{B}^0} = 5300 \pm 100$$

$$A_{CP}(B^0 \rightarrow K^{*0}\gamma) = 0.008 \pm 0.017(stat) \pm 0.009(syst)$$

Systematic dominated by background model, b/bbar production asymmetry in *pp* collisions and $(K^+\pi^-)/(K^-\pi^+)$ detection asymmetry.

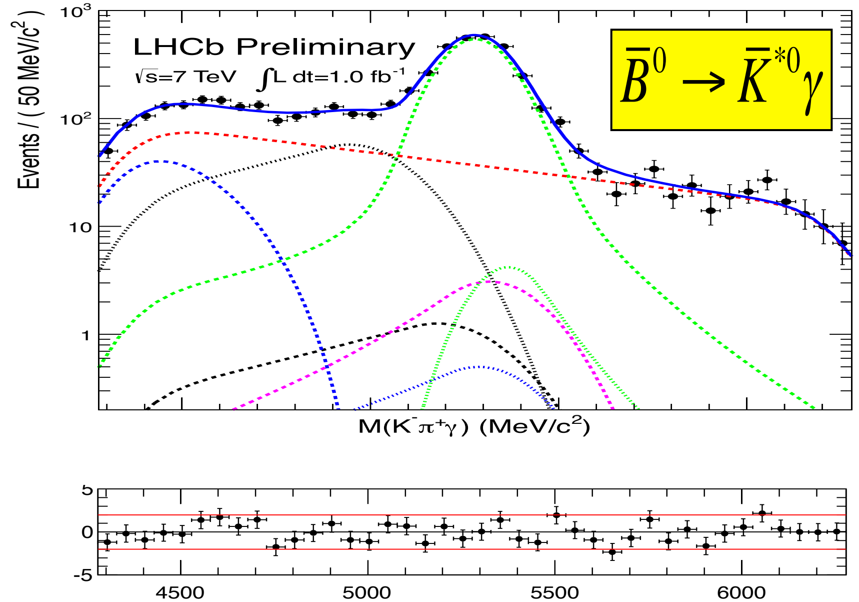


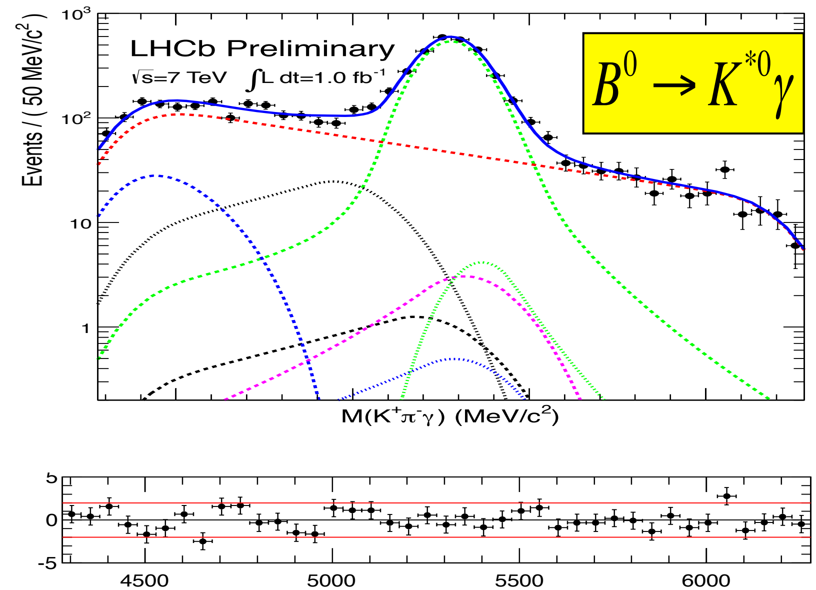


Radiative decays : $A_{CP}(B0 \rightarrow K^{*0}\gamma)$

Direct CP asymmetry in $B^0 \rightarrow K^{*0}\gamma$

- No trivial side-bands shape
  - Threshold effect due to different mass resolution in trigger and offline analysis
- Background contamination :
  - b-baryons $\Lambda_b \rightarrow \Lambda^*(K^-p)\gamma$
  - Charmless $B_{d,s} \rightarrow K^{*0}\pi^0$
  - Irreducible $b \rightarrow d\gamma$: $B_s \rightarrow K^{*0}\gamma$
  - Partially reconstructed $B^{+,0} \rightarrow Vh^{+,0}\gamma$ decay





Radiative decays : prospects

- Several other radiative decays already observed in LHCb

  b-Baryons : $\Lambda_b \to \Lambda^*(K^- p)\gamma$: used to normalize the contamination to $K^*\gamma$ signal
  Charged B : $B^+ \to K^{*0}\pi^+\gamma$, $\phi K^+\gamma$

  BR, CP asymmetries to be measured with 2012 data

- Investigating the photon helicity structure in radiative decay
  - Right-handed photon in $b \to q\gamma$ is suppressed by (m_q/m_b) within SM

$$\tan\Psi = \left|\frac{A(B_q \to f^{CP}\gamma_R)}{A(B_q \to f^{CP}\gamma_L)}\right|$$

is a sensitive parameter for NP search

  - Time-dependent decay rate is sensitive to photon helicity

$$\Gamma(\overset{(-)}{B}_q \to f^{CP}\gamma) = |A|^2 e^{-\Gamma_q \tau}\left[\cosh(\Delta\Gamma_q \tau/2) + A_q^{\Delta}\sinh(\Delta\Gamma_q \tau/2) \pm C_q\cos(\Delta m_q \tau) \mp S_q \sin(\Delta m_q \tau)\right]$$

$$A_s^{\Delta} \approx \sin(2\psi) \approx 0.1 \text{ within SM}$$

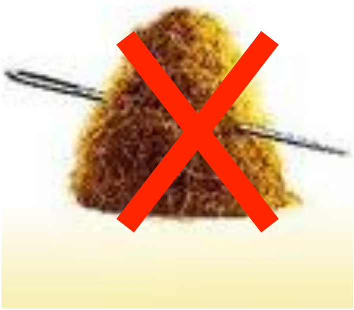
  - $B_s \to \Phi\gamma$ is a promising channel for the extraction of $\sin(2\Psi)$
  - Reliable theoretical prediction at NNLO $\to$ probe for NP in loop

Conclusion

LHCb 2011 harvest has been fantastic …

World best limits or measurements in many rare decays …

… but no hint of New Physics



Results with $1 fb^{-1}$ (statistics x 3) coming soon

update of $B \to \mu\mu$, $B \to qll$, $B \to V\gamma$
and a lot of new rare b (and c) decay analysis

Spare

Detector performance

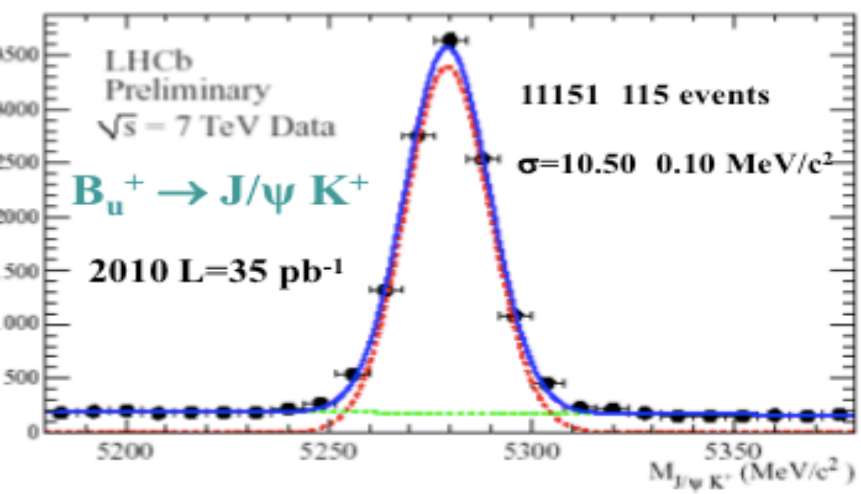
Mass resolution

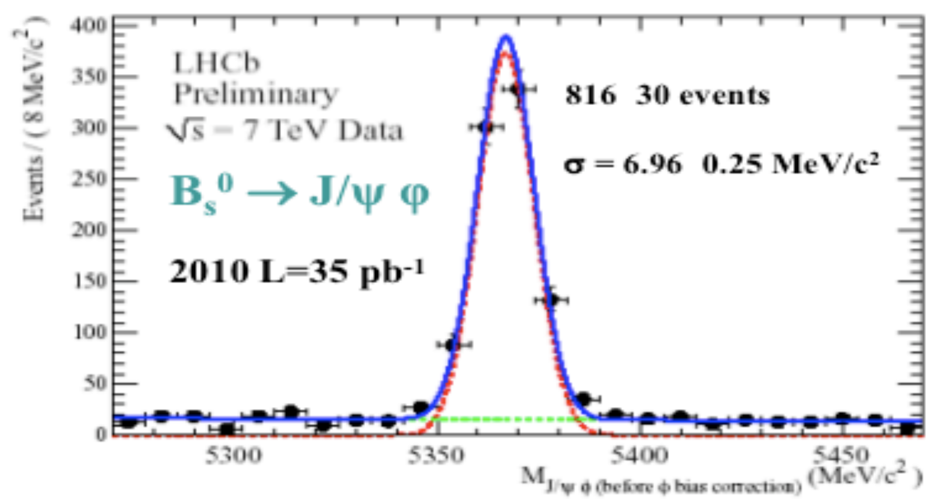
Mass resolution is based on precise momentum measurement with LHCb magnet and tracker: $\Delta p/p<0.5\%$ up to 100 GeV/c

With 2010 data!

LHCb-CONF-2011-027: masses [MeV/c²]		PDG [MeV/c²]	
$M(B^+ \to J/\psi K^+)$	$= 5279.27 \pm 0.11\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.17	0.29
$M(B^0 \to J/\psi K^{*0})$	$= 5279.54 \pm 0.15\,(\text{stat}) \pm 0.16\,(\text{syst})$	5279.50	0.30
$M(B^0 \to J/\psi K^0_S)$	$= 5279.61 \pm 0.29\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.50	0.30
$M(B^0_s \to J/\psi \phi)$	$= 5366.60 \pm 0.28\,(\text{stat}) \pm 0.21\,(\text{syst})$	5366.30	0.60
$M(\Lambda_b \to J/\psi \Lambda)$	$= 5619.49 \pm 0.70\,(\text{stat}) \pm 0.19\,(\text{syst})$	5620.2	1.6
$M(B^+_c \to J/\psi \pi^+)$	$= 6268.0 \pm 4.0\,(\text{stat}) \pm 0.6\,(\text{syst})$	6277	6

World-best mass measurements!

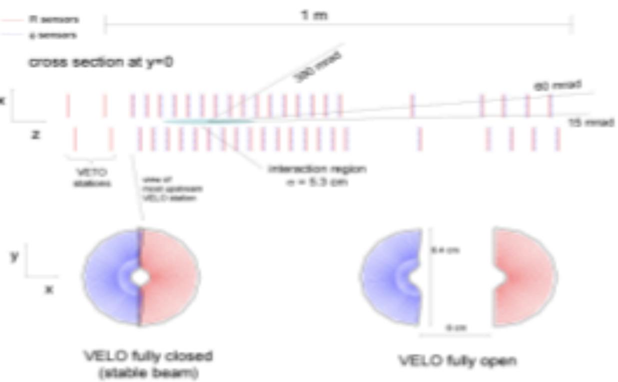




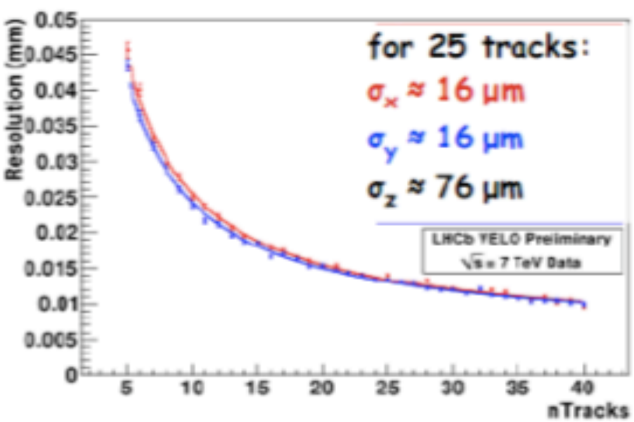
Detector performance

Vertex / Time resolution

LHCb lifetime measurements using 36 pb^{-1} of 2010 data – **world class**!

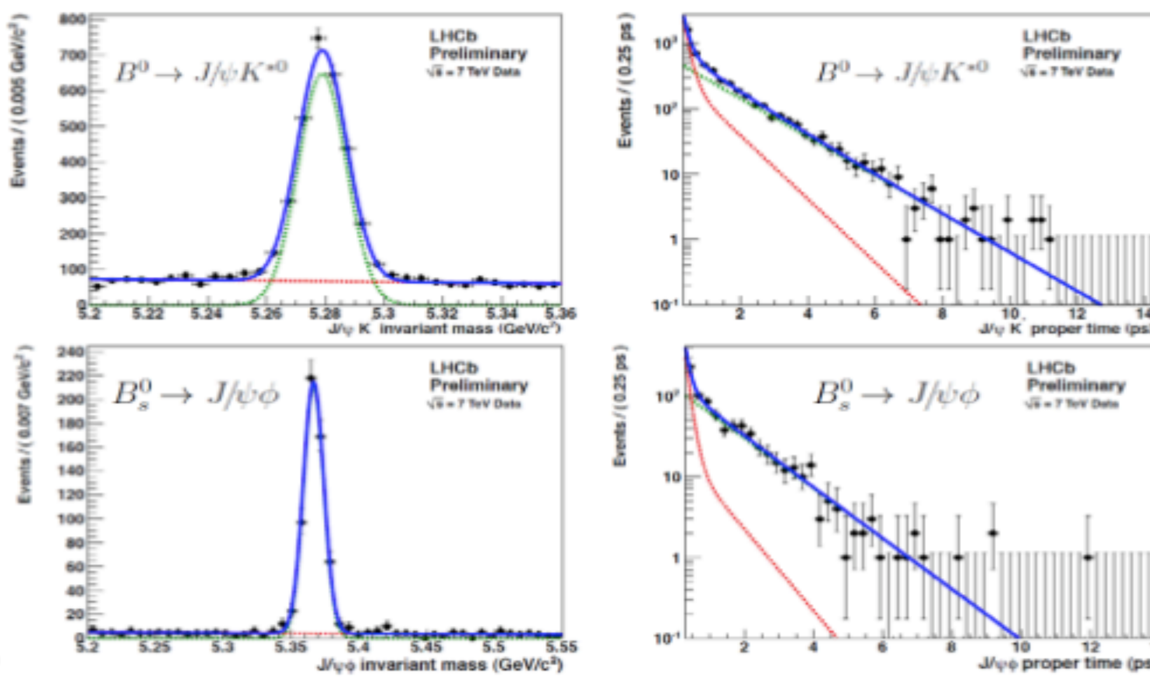


Vertex Locator (VELO) provides excellent proper time resolution of ~50 fs



Both statistical and systematical errors are expected to be significantly improved with 2011 data!

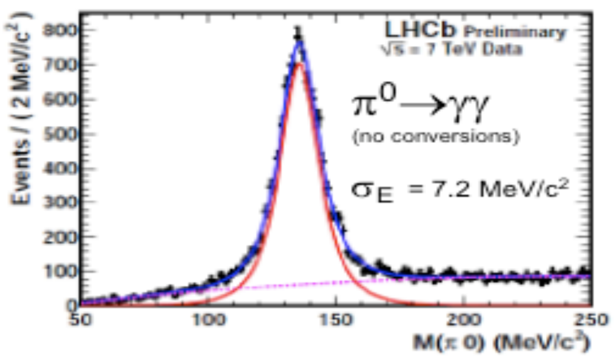
	LHCb-CONF-2011-001 [ps]	PDG [ps]	
$\tau(B^+ \to J/\psi K^+)$	$= 1.689 \pm 0.022$ (stat.) ± 0.047 (syst.)	1.638	0.011
$\tau(B^0 \to J/\psi K^{*0})$	$= 1.512 \pm 0.032$ (stat.) ± 0.042 (syst.)	1.525	0.009
$\tau(B^0 \to J/\psi K^0_S)$	$= 1.558 \pm 0.056$ (stat.) ± 0.022 (syst.)	1.525	0.009
$\tau^{\text{single}}(B^0_s \to J/\psi \phi)$	$= 1.447 \pm 0.064$ (stat.) ± 0.056 (syst.)	1.477	0.046
$\tau(\Lambda_b \to J/\psi \Lambda)$	$= 1.353 \pm 0.108$ (stat.) ± 0.035 (syst.)	1.391	0.038



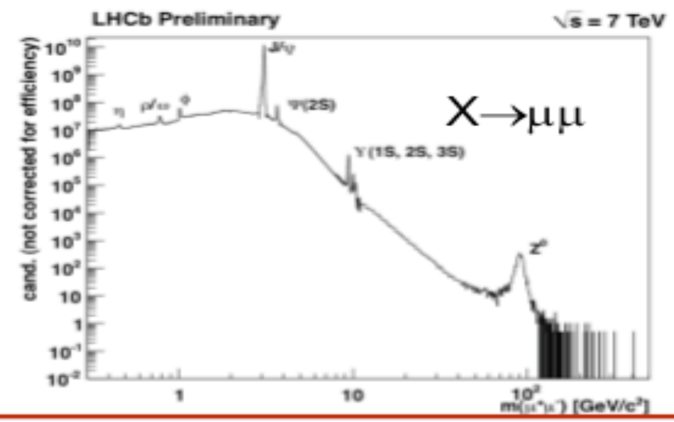
Detector performance

Particle Identification

photon/electron/hadron PID – SPD/PRS/ECAL/HCAL

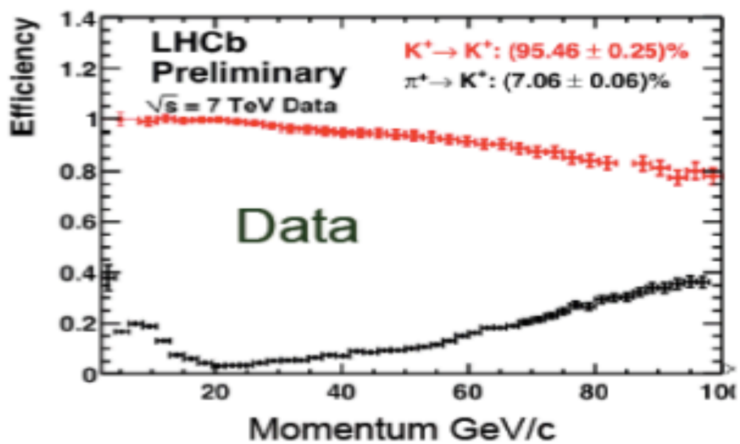


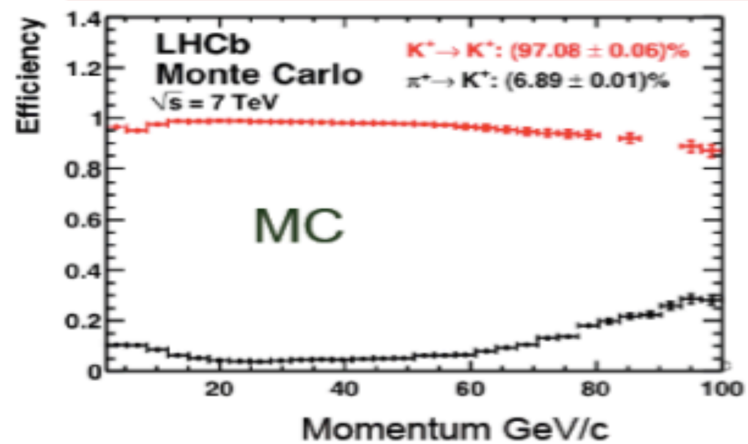
Muon PID – Muon system



Hadron PID – RICH1 and RICH2

RICH PID absolutely necessary to identify charged hadrons in $B \to hh$



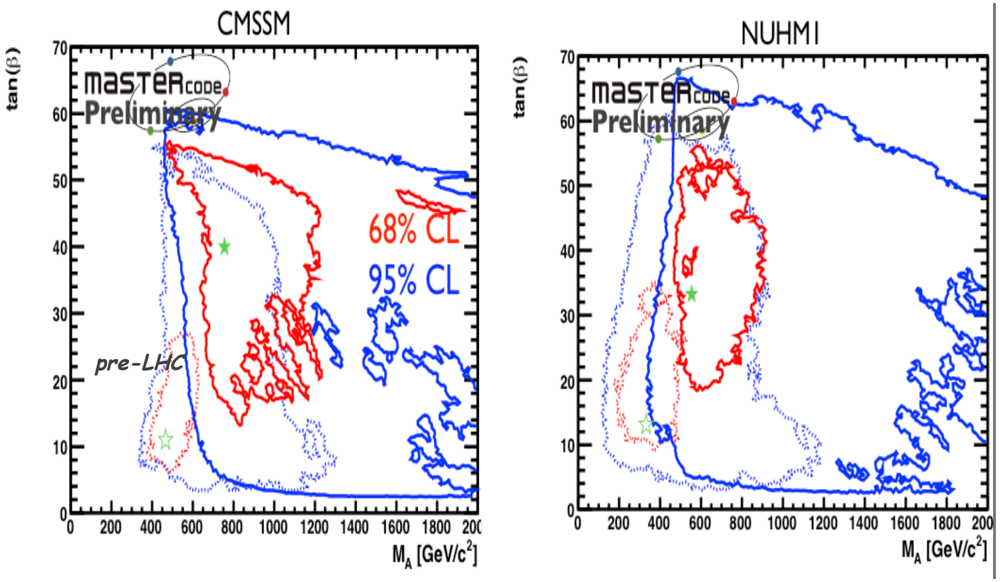


$B_{s,d} \to \mu^+\mu^-$

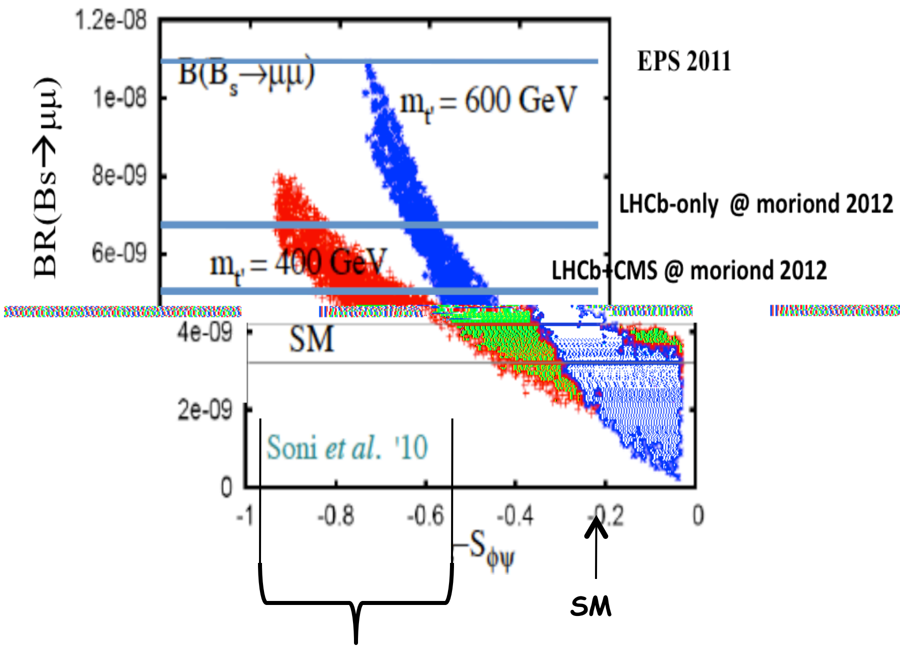
- Constraint on specific NP models

Constraints on Susy models, incl. direct search, flavor, g-2, DM

F. Runga (sept 2011)



4th generation model



$B_s \to \mu^+\mu^-$ limit push down $\tan^6(\beta)/m^4_A$

Higher m_A for both models

low tan(β) no longer favoured

2010 Tevatron 1σ interval ...

... before LHCb measured it !