Exclusive rare B decays: $B^0_d \rightarrow \mu^+\mu^-$ and $B_s \rightarrow \mu^+\mu^-$

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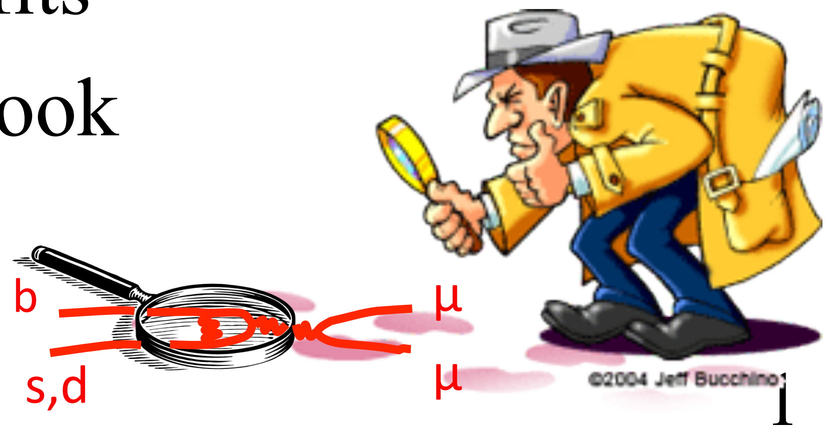
LNF-INFN

on behalf of the LHCb Collaboration

Flavour and the forth family, Durham 13-16 September 2011

Outline

- (Brief) theoretical introduction
- Experimental status
- LHCb-CMS analysis strategies
- Results
- $B_s \rightarrow \mu\mu$ and global fits
- Conclusions & outlook

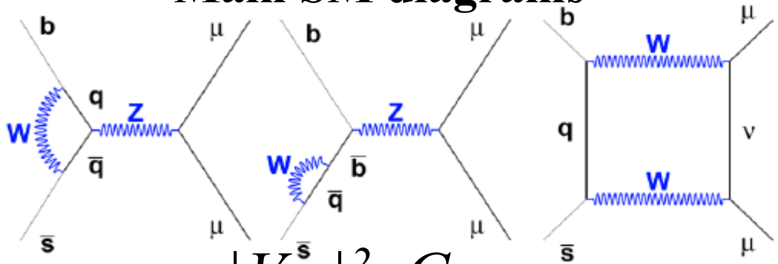


The LHCb hunt for non-SM Higgs(es)

$B_{(d,s)} \rightarrow \mu\mu$ is the best way for LHCb to constrain the parameters of the extended Higgs sector in MSSM, fully complementary to direct searches

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

Main SM diagrams



$\sim |V_{ts}|^2,\ C_A$

Double suppressed decay: **FCNC process** and **helicity suppressed**:

→ **very small in the Standard Model but very well predicted:**

$\mathbf{B_s \rightarrow \mu^+\mu^- = (3.2 \pm 0.2) \times 10^{-9}}$	$\mathbf{B_d \rightarrow \mu^+\mu^- = (1.0 \pm 0.1) \times 10^{-10}}$

Buras et al., arXiv:1007.5291 and references therein

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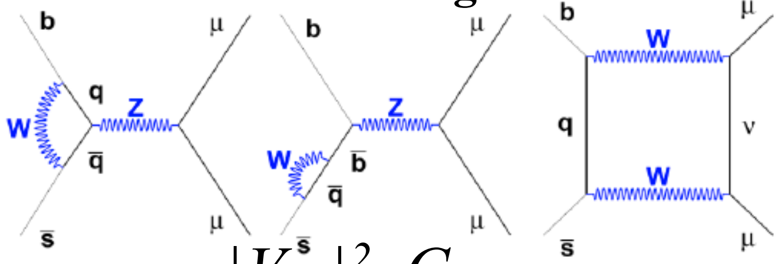

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Helicity suppression:
all relevant SM diagrams contribute to C_A
as the diagram with Higgs exchange is fully negligible $\sim (m_b/m_W)^2$

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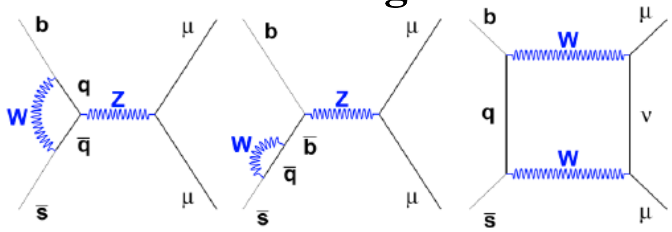

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In SM $BR(B_{s(d)} \rightarrow l^+l^-)$ is proportional to $|V_{ts(d)}|^2$:

1. $BR(B_d \rightarrow l^+l^-) \sim 30$ times lower than the $B_s \rightarrow l^+ l^-$
2. The ratio of $BR(B_s \rightarrow ll)/BR(B_d \rightarrow ll) = |V_{ts}|^2/|V_{td}|^2$ in SM and MFV models

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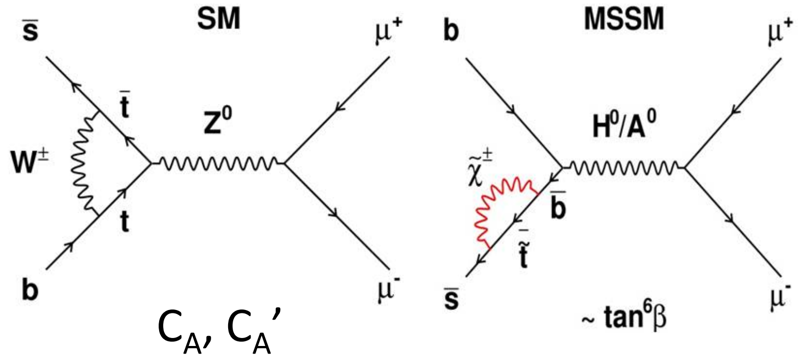

C_S, C_P'

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$B_s \rightarrow \mu^+\mu^- = (3.2\pm0.2)\times10^{-9}$ **$B_d \rightarrow \mu^+\mu^- = (1.0\pm0.1)\times10^{-10}$**

→ **sensitive to New Physics** contributions in the **scalar/pseudo-scalar sector:**

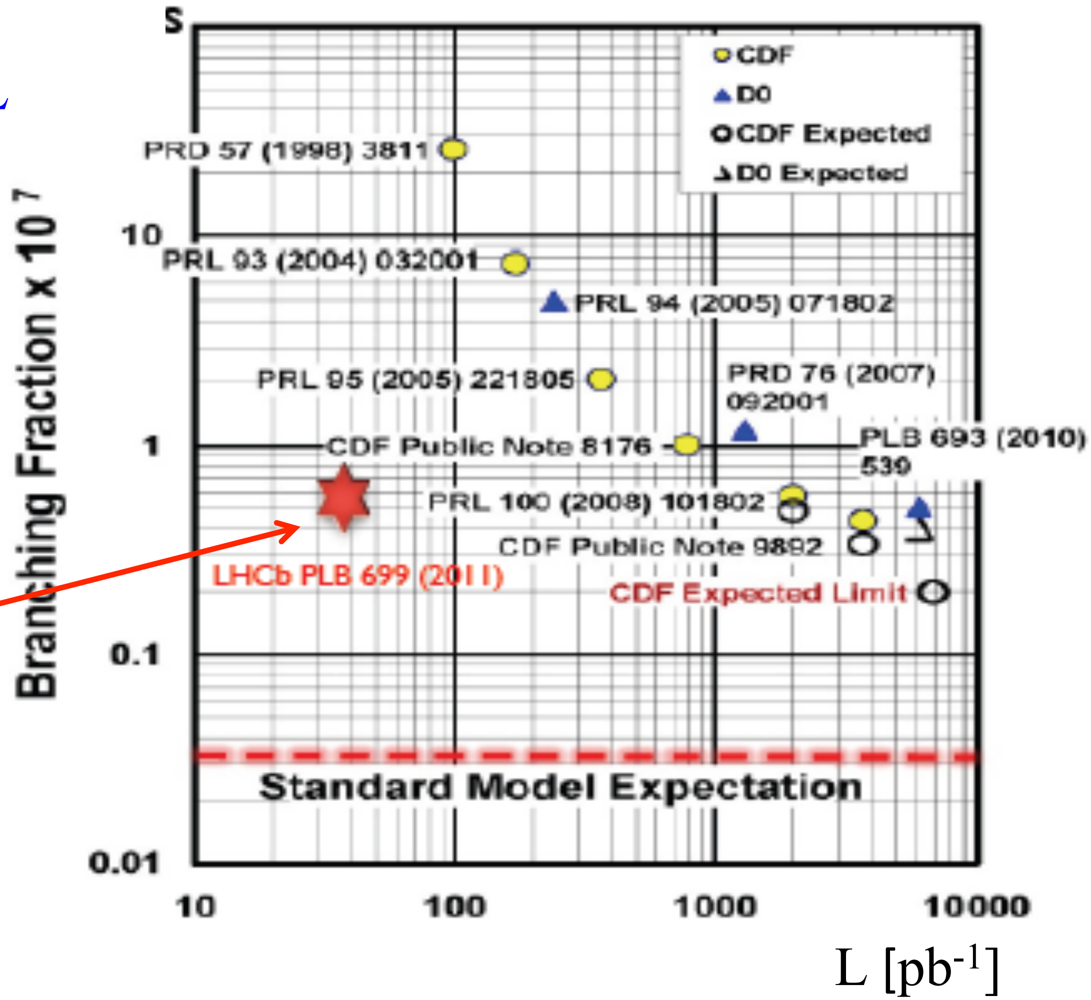
$$\left(c_{S,P}^{MSSM} \right)^2 \propto \left(\frac{m_b m_\mu \tan^3\beta}{M_A^2} \right)^2$$

MSSM, large tanβ approximation

Experimental results (before summer 2011)

Published $B_s \rightarrow \mu\mu$ limits @ 95% CL

Experiment	Data set	Limit
CDF	3.7 fb^{-1}	4.3 x 10^{-8}
D0	6.1 fb^{-1}	5.1 x 10^{-8}
LHCb	0.036 fb^{-1}	5.6 x 10^{-8}



LHCb equivalent to CDF with ~100 times less luminosity

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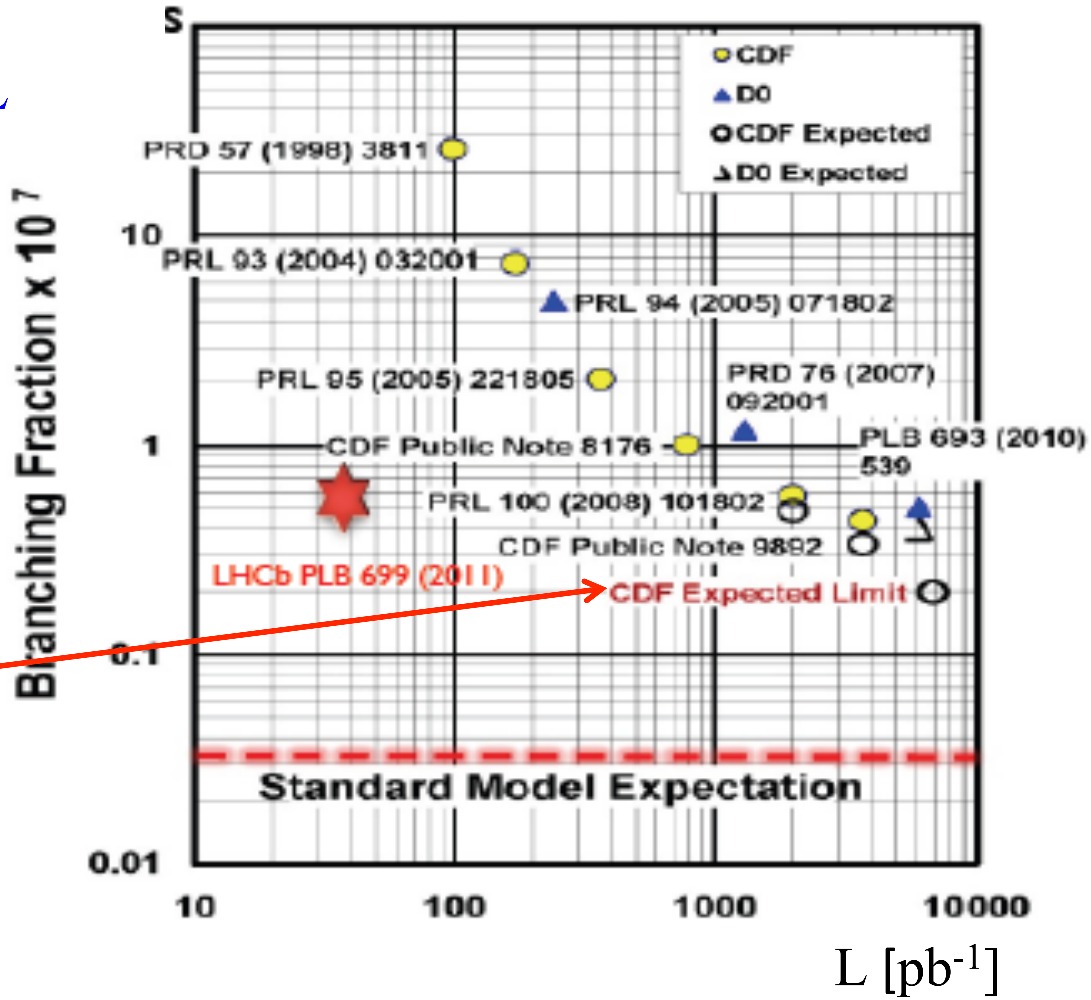
But also an anomaly:

long-staying (since La Thuile)

expected-only limit from CDF:

BR($Bs \rightarrow \mu\mu$) < 2 x 10^{-8} @ 95% CL



July 12th, 2011:
CDF sends to archive the following paper:

Search for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ Decays with CDF II

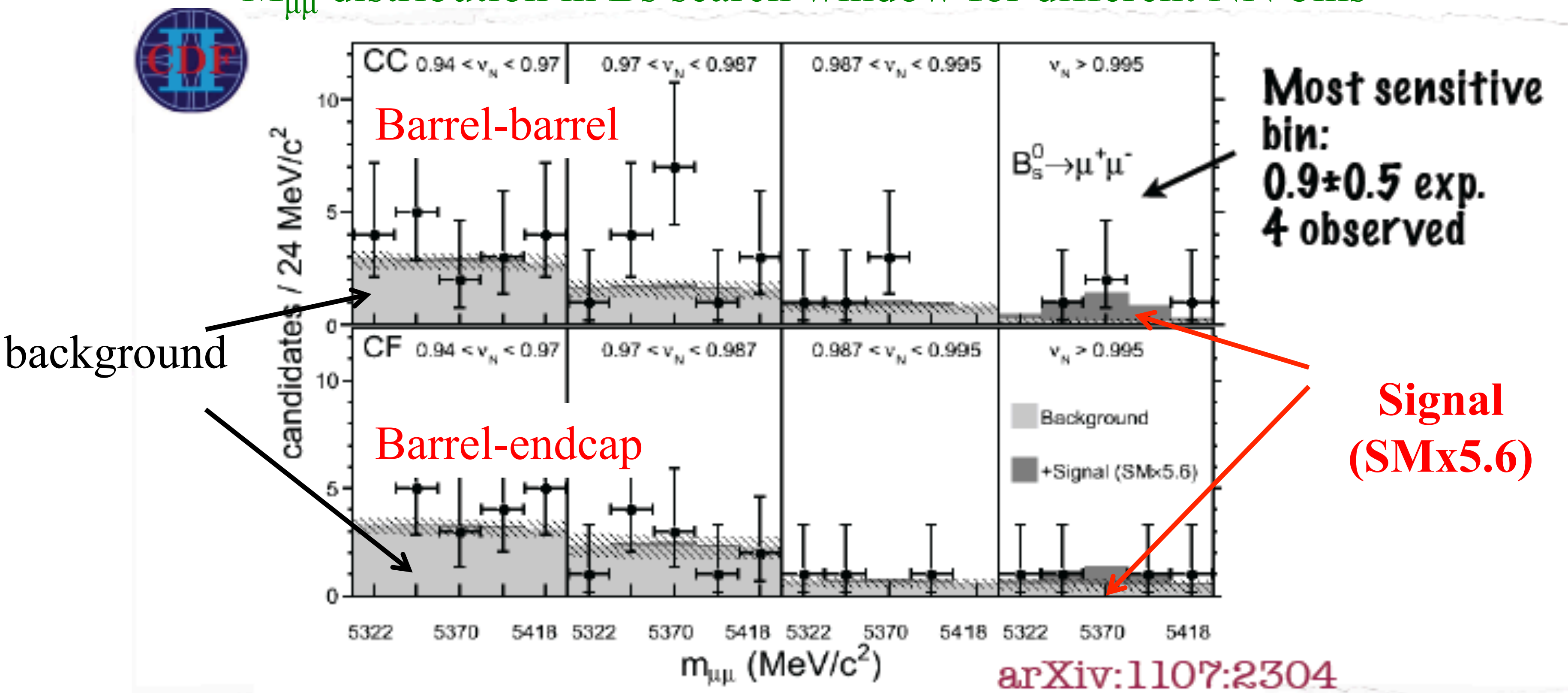
A search has been performed for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ decays using 7 fb^{-1} of integrated luminosity collected by the CDF II detector at the Fermilab Tevatron collider. The observed number of B^0 candidates is consistent with background-only expectations and yields an upper limit on the branching fraction of $\mathcal{B}(B^0 \to \mu^+\mu^-) < 6.0 \times 10^{-9}$ at 95% confidence level. We observe an excess of B_s^0 candidates. The probability that the background processes alone could produce such an excess or larger is 0.27%. The probability that the combination of background and the expected standard model rate of $B_s^0 \to \mu^+\mu^-$ could produce such an excess or larger is 1.9%. These data are used to determine $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (1.8^{+1.1}_{-0.9}) \times 10^{-8}$ and provide an upper limit of $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 4.0 \times 10^{-8}$ at 95% confidence level.

arXiv: 1107.2304 [hep-ex]

CDF result based on:

1) double sample size ($3.7\ fb^{-1} \rightarrow 7\ fb^{-1}$)
2) +20% acceptance for muons
3) improved Neural Network

$M_{\mu\mu}$ distribution in Bs search window for different NN bins



2.8 σ assuming bkg-only hypothesis

1.9% compatibility with bkg+SM hypothesis

$0.46 \times 10^{-8} < BR < 3.9 \times 10^{-8}$ @ 90% CL ($BR = 1.8^{+1.1}_{-0.9}$) $\times 10^{-8}$

Given the CDF central value, LHCb should see
~20 events in the Bs mass window (a mountain)!
…but on July 12th we had still the search window blinded
(the unblinding of the result for EPS was foreseen
only few days later)

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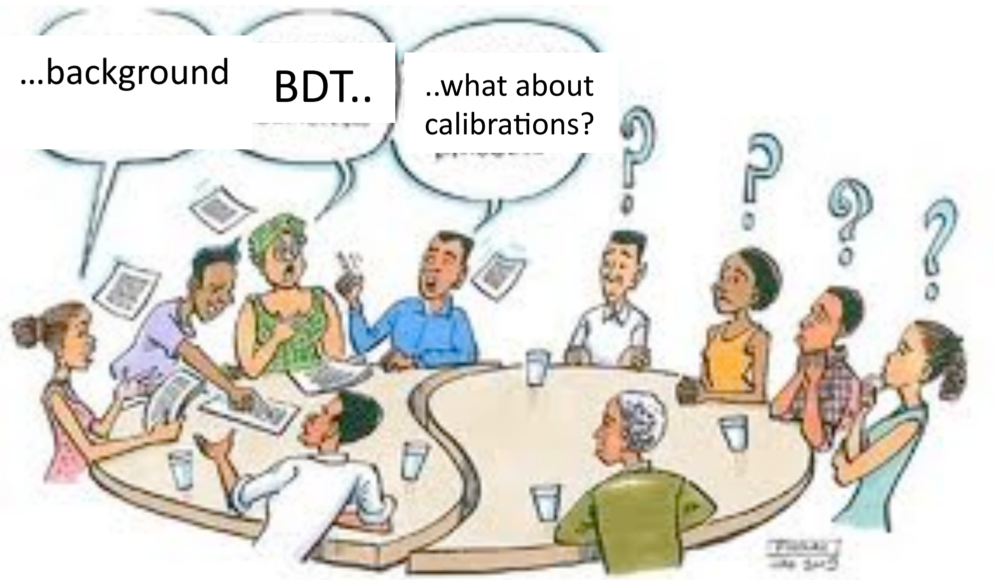
Bs→μμ Working Group



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LHCb management

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Bs→μμ Working Group

LHCb management

we managed to stick on the plans in an ordered way (almost)..

…we performed the final checks and three days later we opened the window in front our internal referees.. July 15th, 5 days to EPS….

Experimental parameters for the search of $B_{s,d} \rightarrow \mu\mu$

- Huge cross section:

  LHC $\sigma(pp \rightarrow bbX)$ @ 7 TeV ~ 300 μb (Tevatron ~ 100 μb)

- Large acceptance (bb are produced forward/backward):

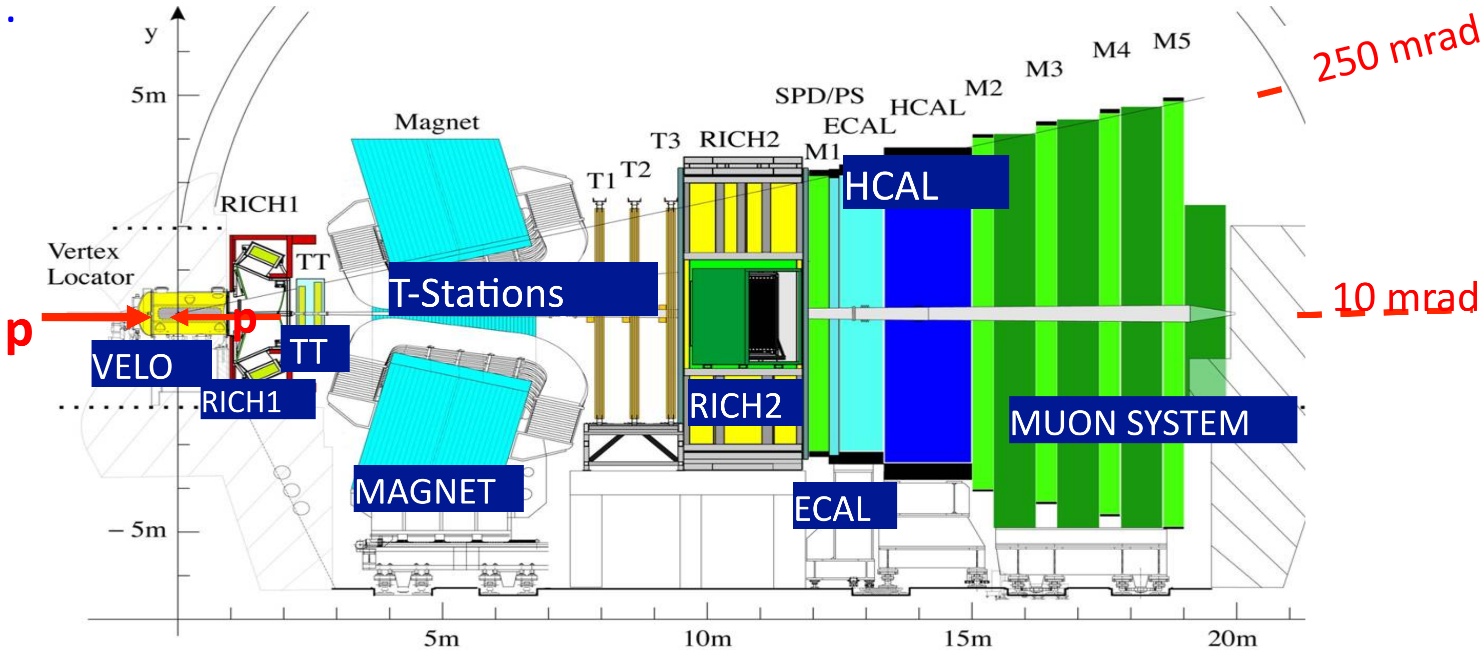
  LHCb acceptance **$1.9<\eta<4.9$** (CDF: $|\eta|<1$; D0: $|\eta|<2$, CMS: $|\eta|<2.4$)

  → ε(acceptance) in LHCb for $B_{sd} \rightarrow \mu\mu$ ~ 10% (CDF~1%)

- Large boost:

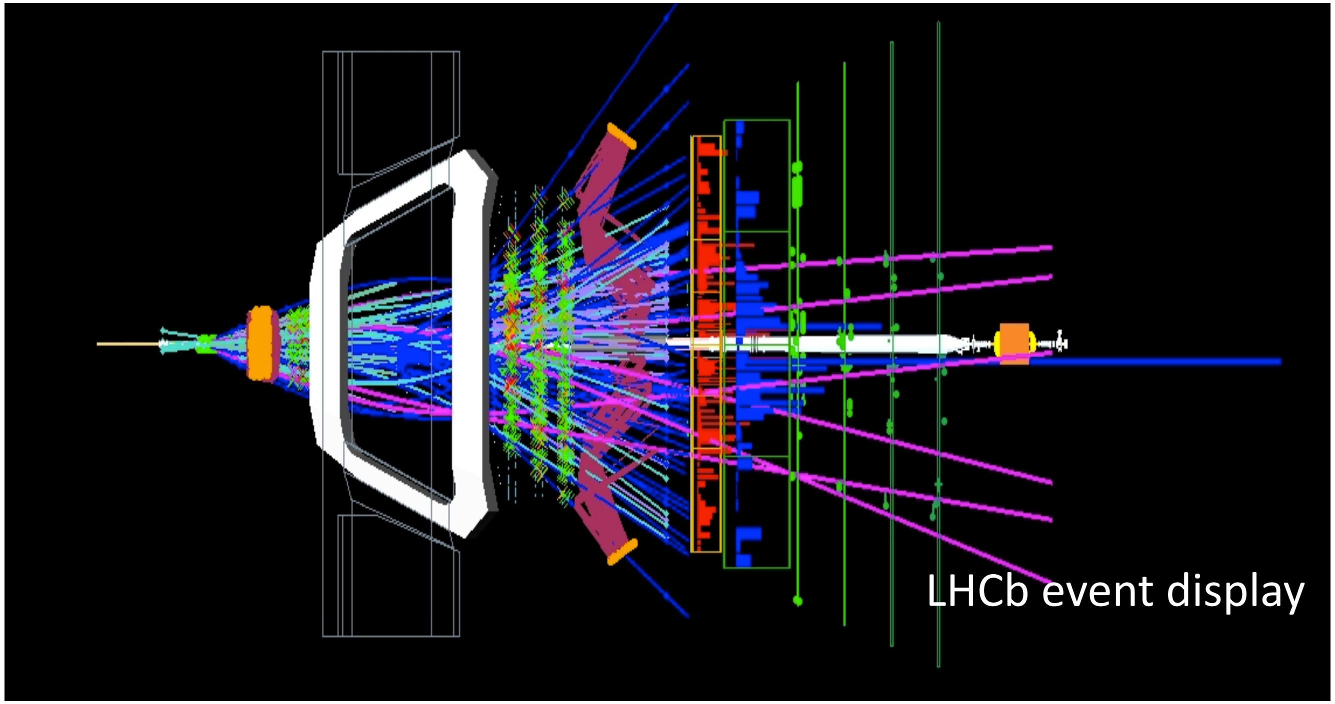
→ average flight distance of B mesons @ LHC~ 1 cm (Tevatron: 2 mm)

…. LHCb has a huge amount of very displaced b's…….



…. But in a harsh environment!

- σ(pp, inelastic) @ $\sqrt{s}$=7 TeV ~ 60 mb
  - 60 tracks per event in ‘high’-pileup conditions (~2 pp interactions Xing)
  - only 1/200 event contains a b quark , and we are looking for BR ~ 10^{-9}



LHCb expects 3.4 (0.32) B_S (B_d)→$\mu\mu$ events triggered and reconstructed in ~300 pb^{-1} if BR = BR(SM)

Key ingredients for $B_{s,d} \rightarrow \mu\mu$

1) Efficient trigger:

- to identify leptonic final states with low-pT thresholds

2) Background reduction:

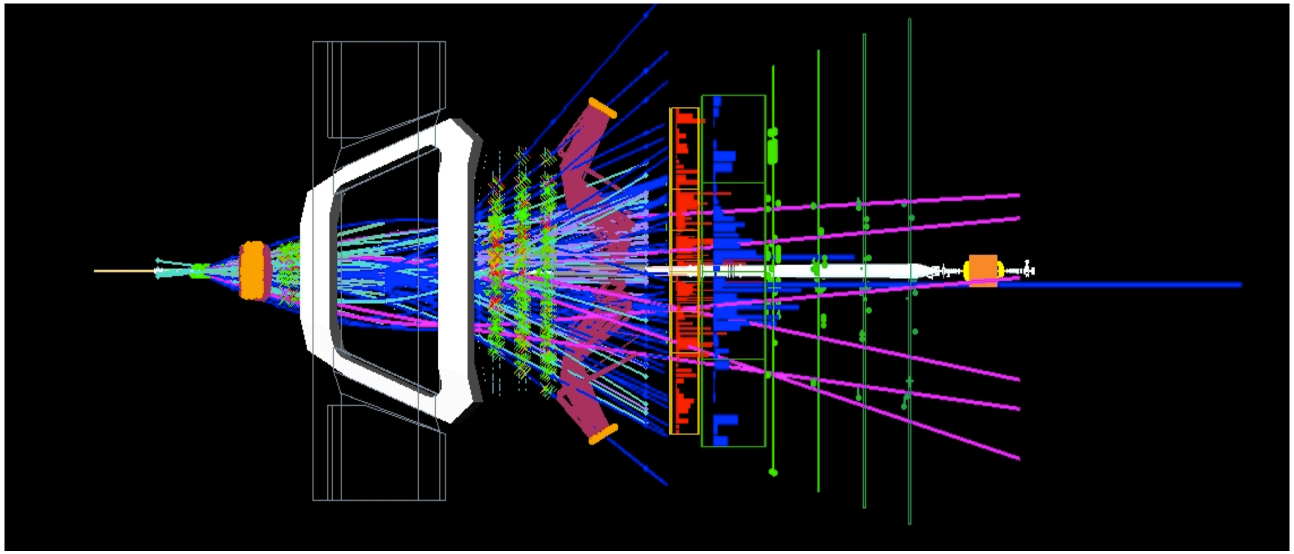
- Very good mass resolution :

$\rightarrow$ sigma($MB_{s,d}$) ~ 26 MeV [CDF**: 25 MeV, CMS: 40 $\rightarrow$ >80 MeV]**

- Good particle identification: $\varepsilon(\mu \rightarrow \mu)$ ~ 98% for $\varepsilon(h \rightarrow \mu)$< 1% for p>10 GeV/c

- **Excellent vertex & IP resolution** to separate signals from background :

σ(IP)~ 25 μm @ p_T=2 GeV/c (the best at LHC)



LHCb analysis strategy

- Soft selection:

  - reduces the dataset to a manageable level

- Discrimination between S and B via Multi Variate Discriminant variable (Boosted Decision Tree) and Invariant Mass (IM)

  - events in the sensitive region are classified in bins of a 2D plane Invariant Mass and BDT variables, expected background from the fit of the mass sidebands.

- Normalization:

  Convert the signal PDFs into a number of expected signal events by normalizing to channels of known BR (this get rid of L and σ(bb)):

  → use B+→ J/ψK+, Bs→J/ψφ, Bd→Kπ

  → use fd/fs combined LHCb result: fs/fd = $0.267^{+0.021}_{-0.020}$

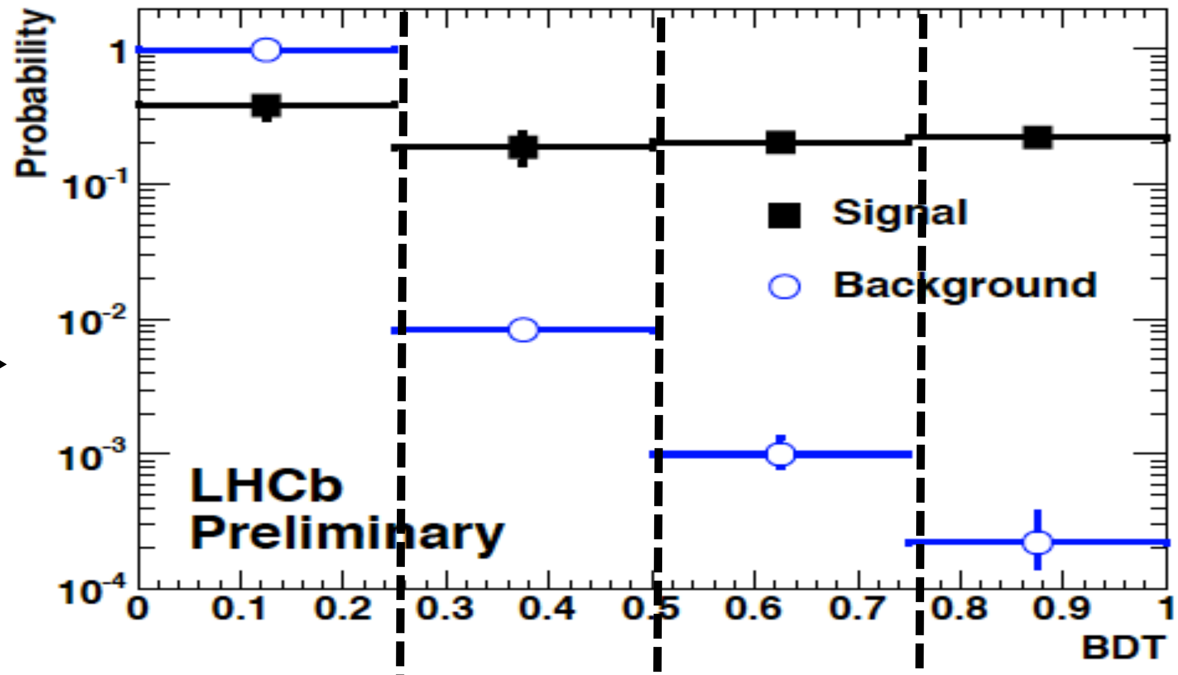
  (LHCb-CONF-2011-028 & arXiv: 1106.4436 [hep-ex])

- Extraction of the limit:

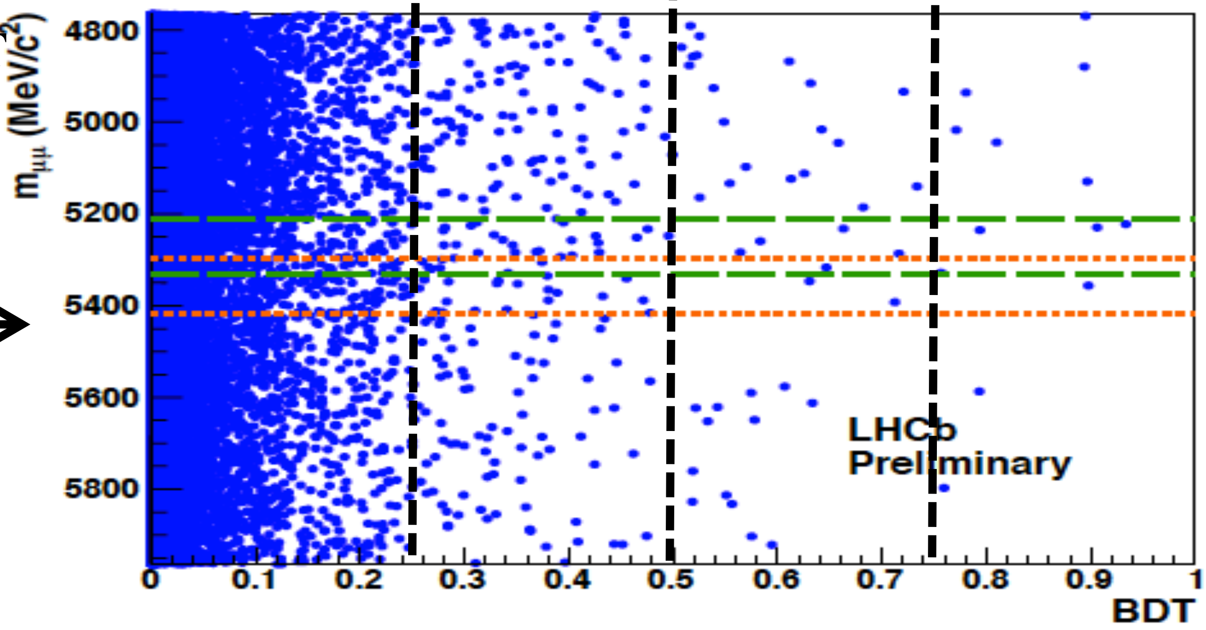
  - assign to each observed event a probability to be S+B or B-only as a function of the BR($B_{s,d}$→μμ) value; exclude (observe) the assumed BR value at a given confidence level using the **CLs binned method.**

Analysis performed in the 2D plane: Invariant mass vs BDT

BDT distributions for signal and background

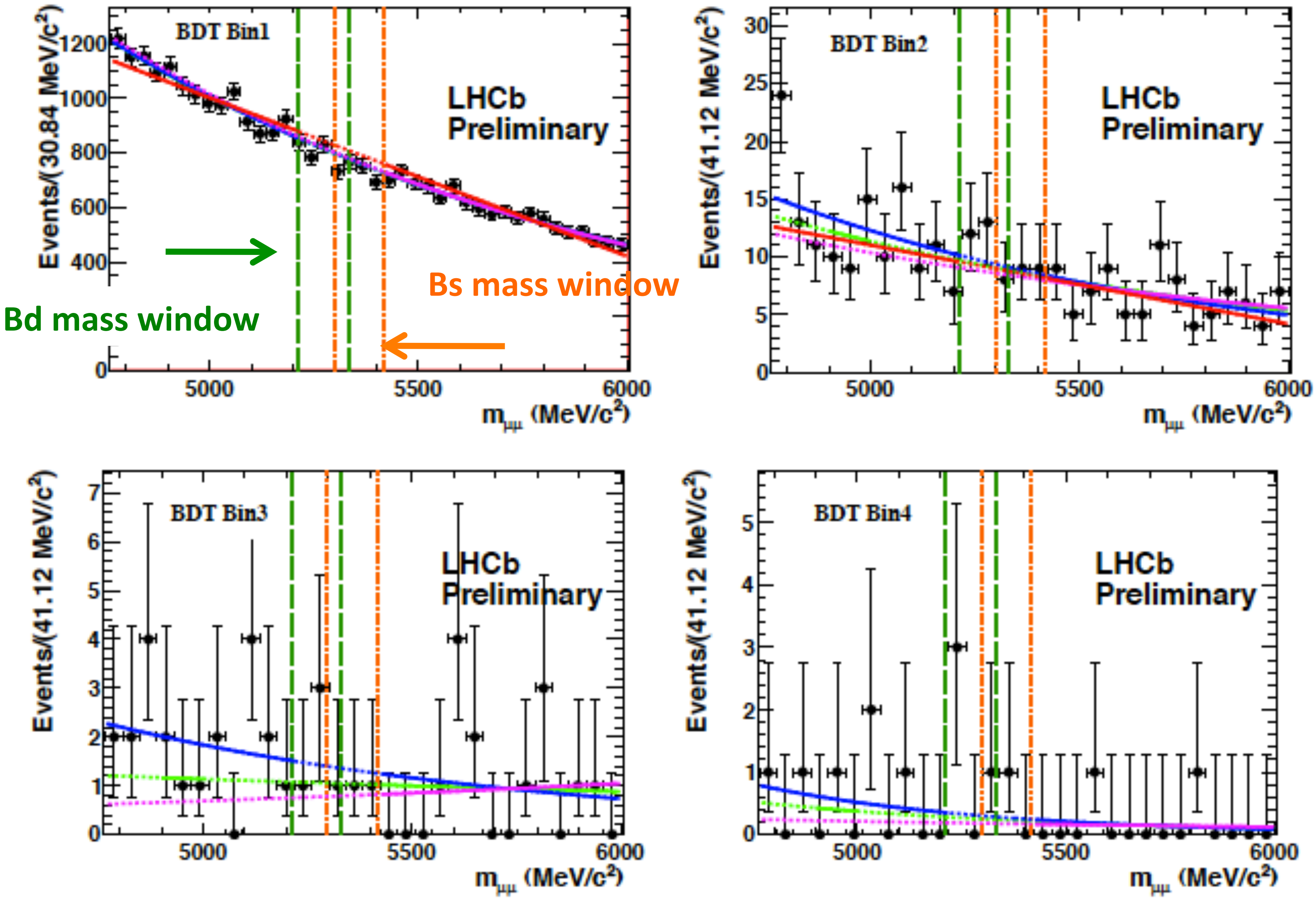


M(μμ) vs BDT plane
4 BDT bins
6 mass bins

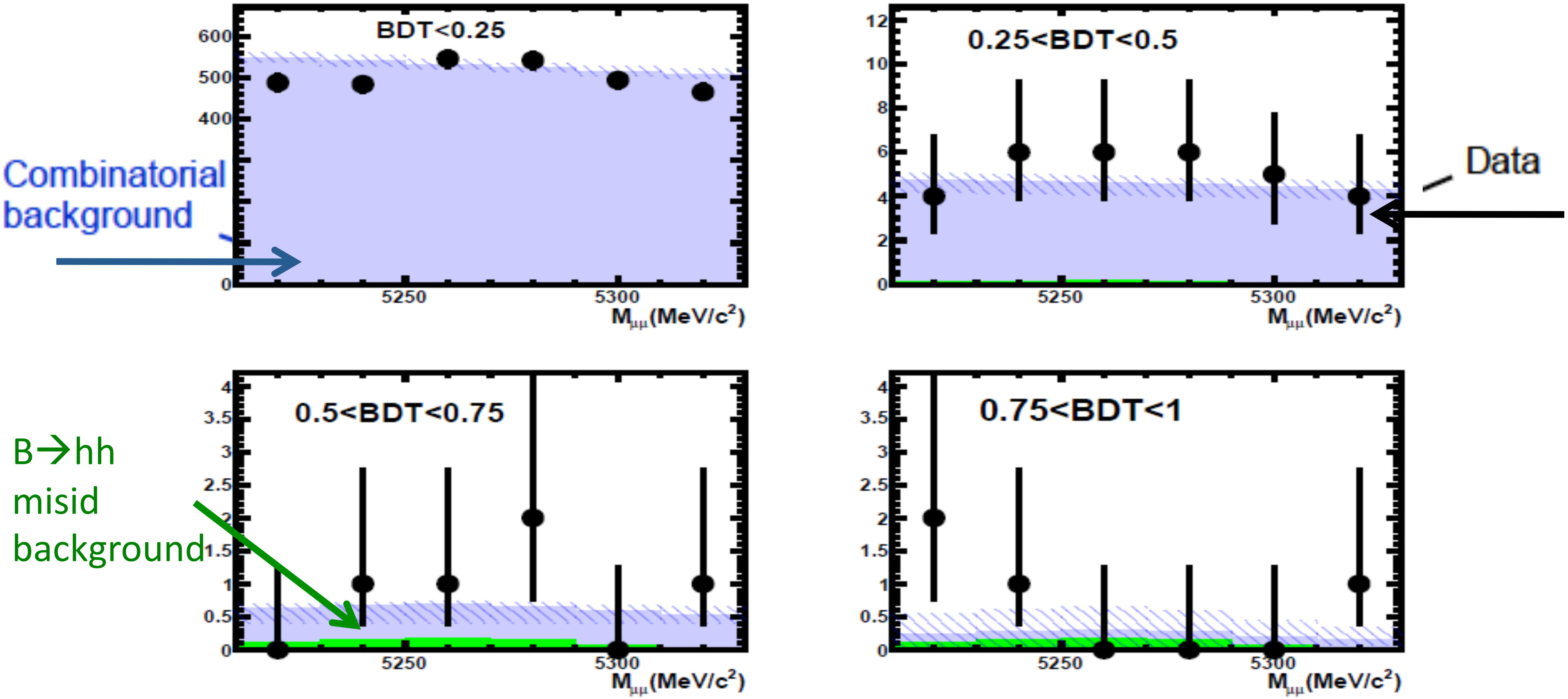


Search windows (M(Bs,d) ± 60 MeV

LHCb: background in the search windows from fit to data sidebands
(…..no peak, clearly….)

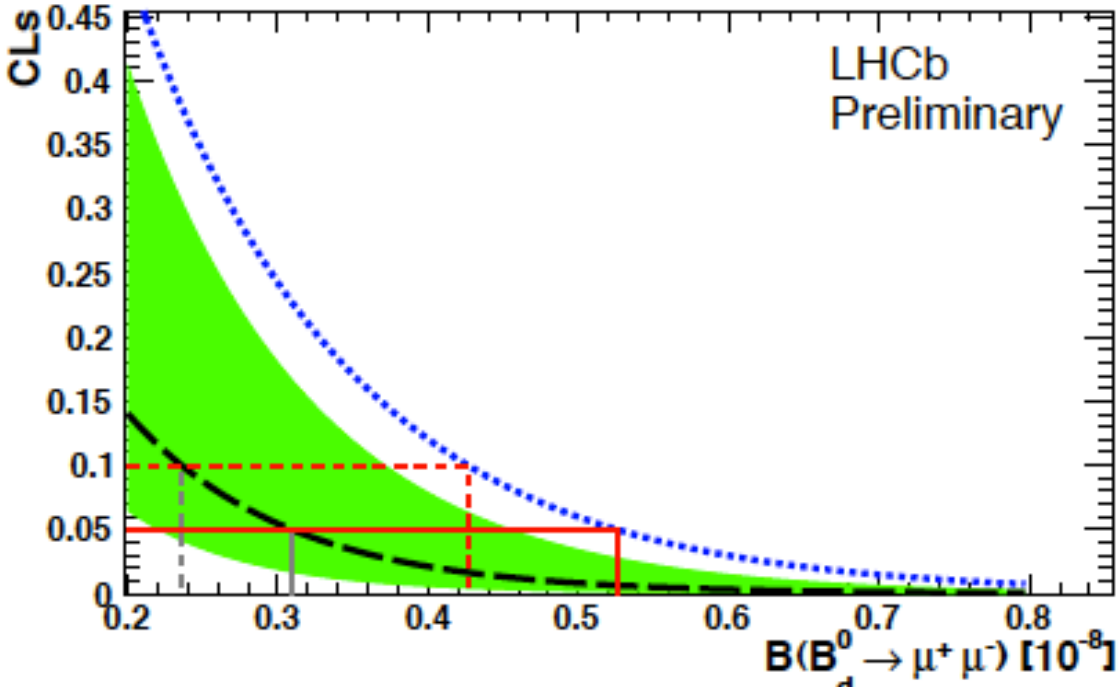


LHCb result in the B_d mass window with $300\ pb^{-1}$ (preliminary)



	BDT<0.25	0.25<BDT<0.5	0.5<BDT<0.75	0.75<BDT
Exp.combinatorial	3175 ± 72	26.6 ± 2.5	3.1 ± 0.8	0.7 ± 0.4
Exp. MisID	0.6± 0.1	0.6± 0.1	0.6± 0.1	0.6± 0.1
Observed	3025	31	5	4

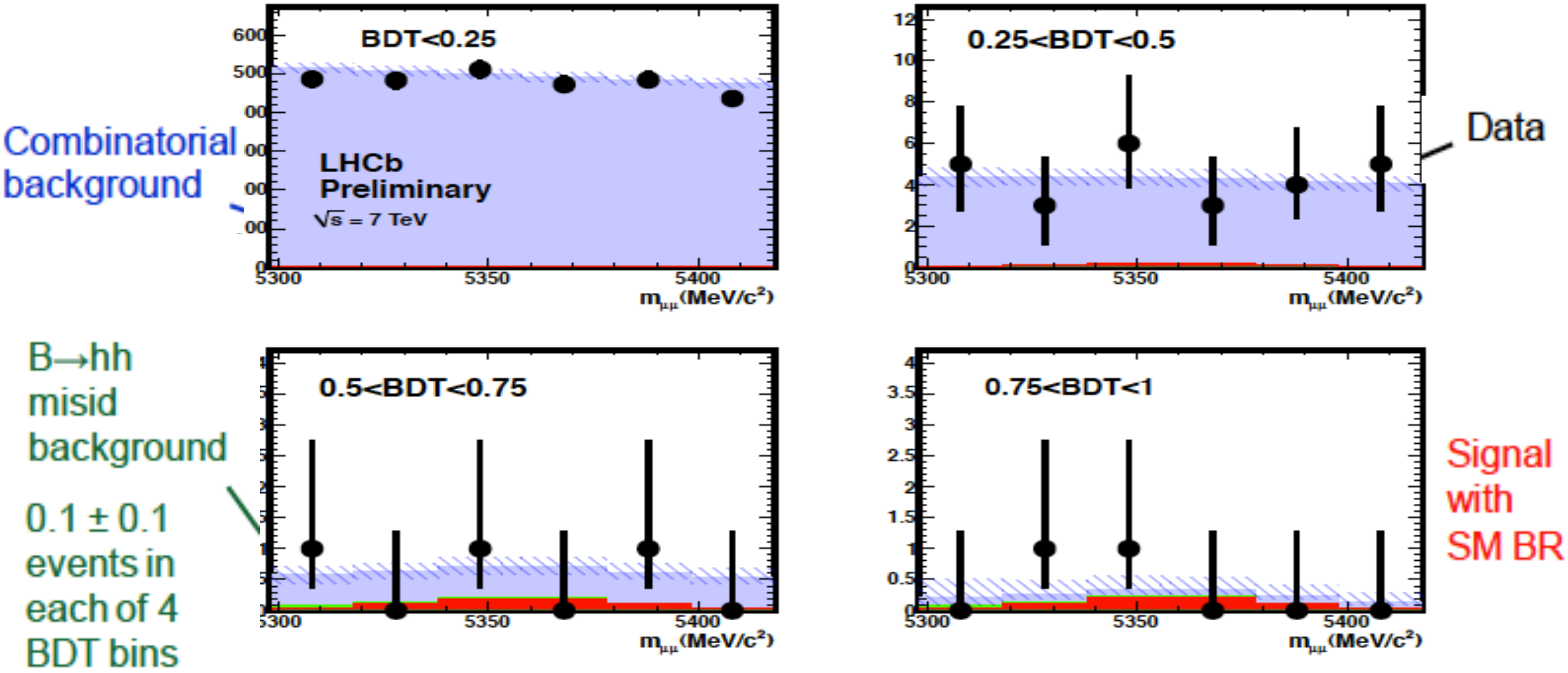
LHCb preliminary limit for BR($B_d \rightarrow \mu\mu$) with 300 pb^{-1} (world best)



$B^0 \rightarrow \mu^+\mu^-$	at 90% CL	at 95% CL	CL_b
expected limit (bkg only hypothesis)	2.4×10^{-9}	3.1×10^{-9}	
observed limit	4.2×10^{-9}	5.2×10^{-9}	0.79

CDF: 6.0×10^{-9} @ 95% CL

LHCb result in the B_s mass window with 300 pb^{-1} (preliminary)



	BDT<0.25	0.25<BDT<0.5	0.5<BDT<0.75	0.75<BDT
Exp.combinatorial	2968 ± 69	25 ± 2.5	2.99 ± 0.89	0.66 ± 0.40
Exp. SM signal	1.26 ± 0.13	0.61 ± 0.06	0.67 ± 0.07	0.72 ± 0.07
Observed	2872	26	3	2

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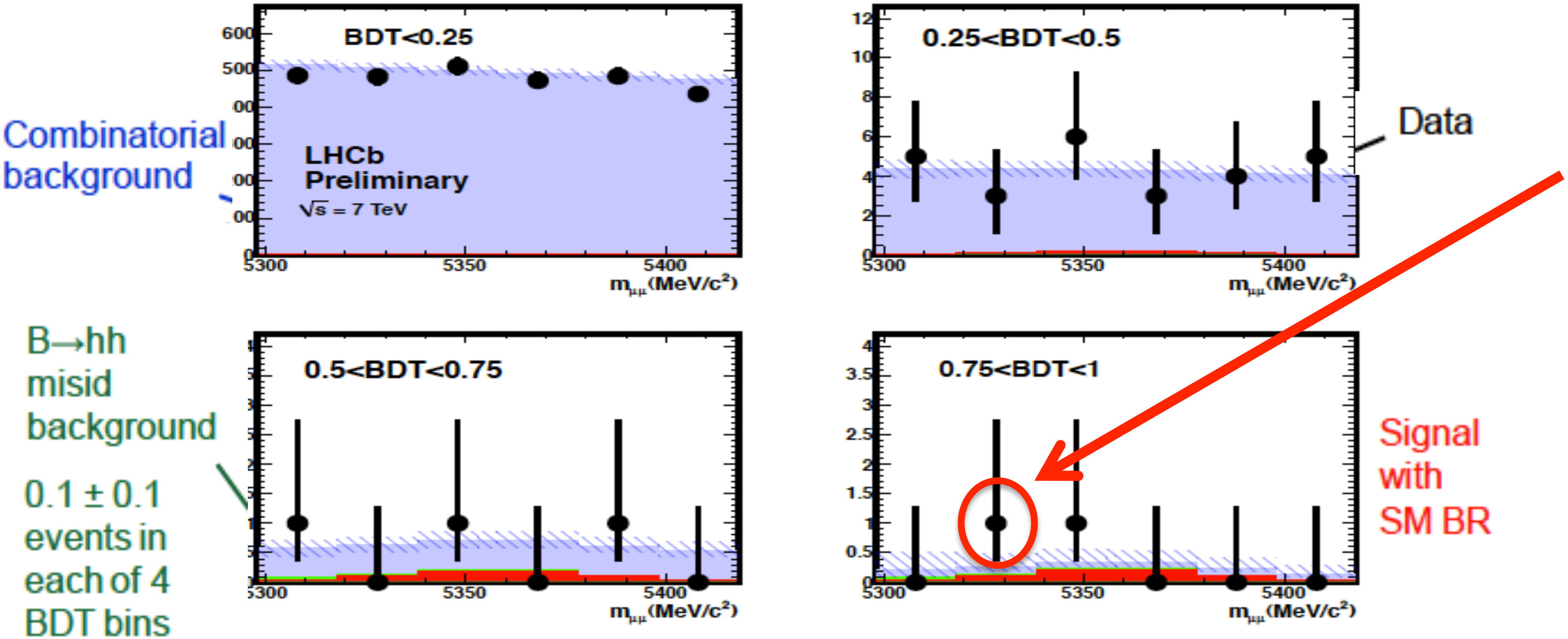

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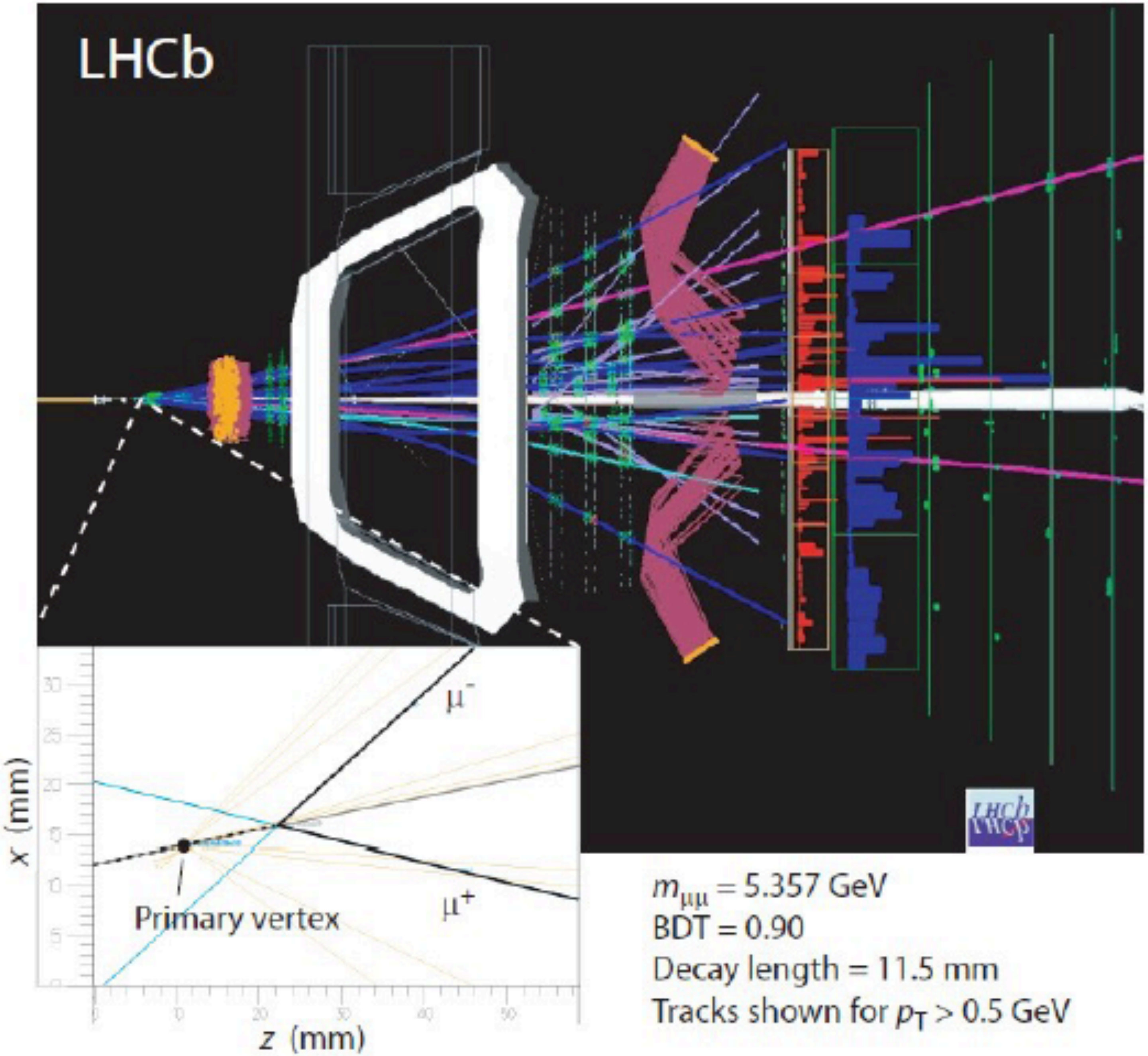
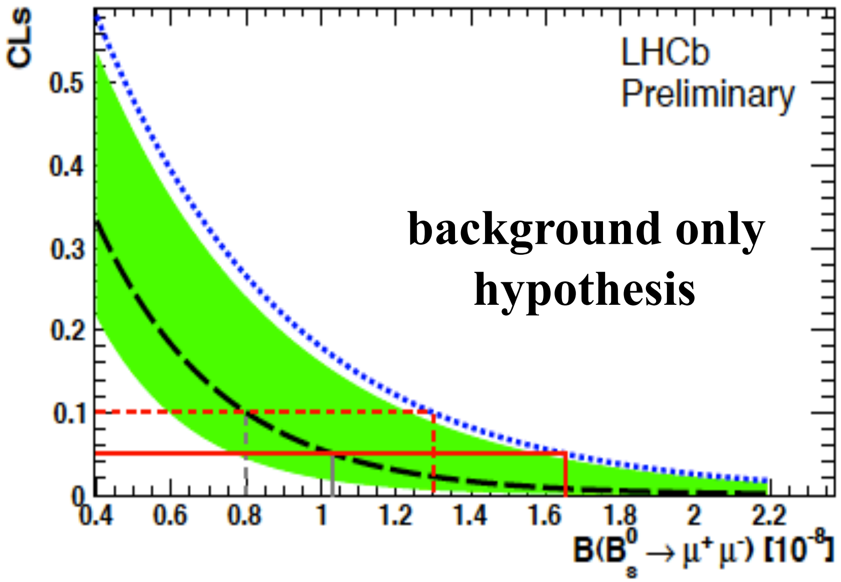
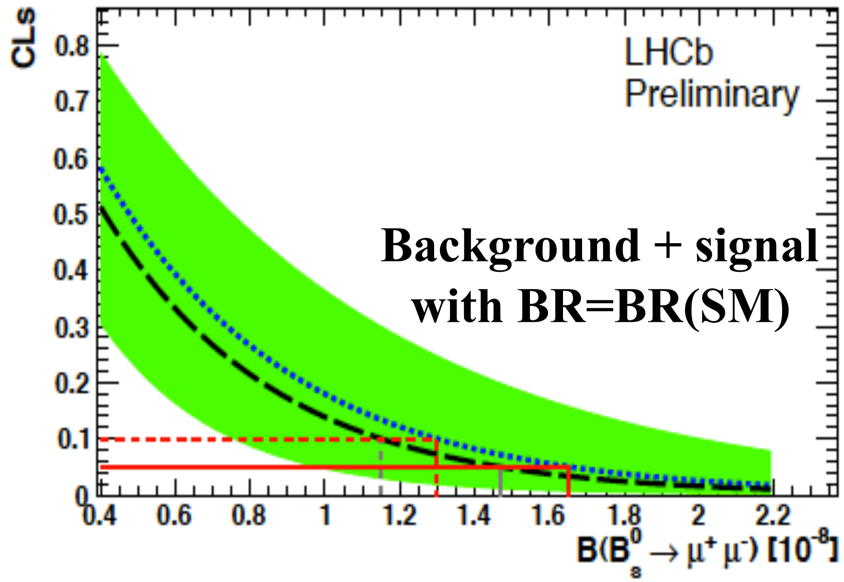
A $B_s \rightarrow \mu\mu$ candidate in the LHCb event display:



$m_{\mu\mu} = 5.357$ GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for $p_T > 0.5$ GeV

LHCb preliminary limit for BR($B_s \rightarrow \mu\mu$) with 300 pb^{-1} (world best)





	$B_s^0 \to \mu^+\mu^-$	at 90% CL	at 95% CL	CL_b
	expected limit (bkg only hypothesis)	0.8×10^{-8}	1.0×10^{-8}	
	expected limit (bkg+SM hypothesis)	1.2×10^{-8}	1.5×10^{-8}	
2011 only	observed limit	1.3×10^{-8}	1.6×10^{-8}	0.80
2010+2011 combined		**1.2 x 10^{-8}**	**1.5x10^{-8}**	

CMS result for $B_s \rightarrow \mu\mu$ search with 1.14 fb^{-1}

[arXiv:1107.5834v1, CMS-BPH-11-002]

- Cut based analysis, sample divided in two bins: both muons in barrel ($|\eta|<1.4$), one μ in barrel one in endcap ($1.4<|\eta|2.4$).
- Normalization with $B+ \rightarrow J/\psi K$ using $f_d/f_s=0.282\pm0.037$ [pdg]

	Barrel	Endcap
N^{exp}_{signal}	0.80 ± 0.16	0.36 ± 0.07
N^{exp}_{bg}	0.60 ± 0.35	0.80 ± 0.40
N^{exp}_{peak}	0.07 ± 0.02	0.04 ± 0.01
N_{obs}	2	1

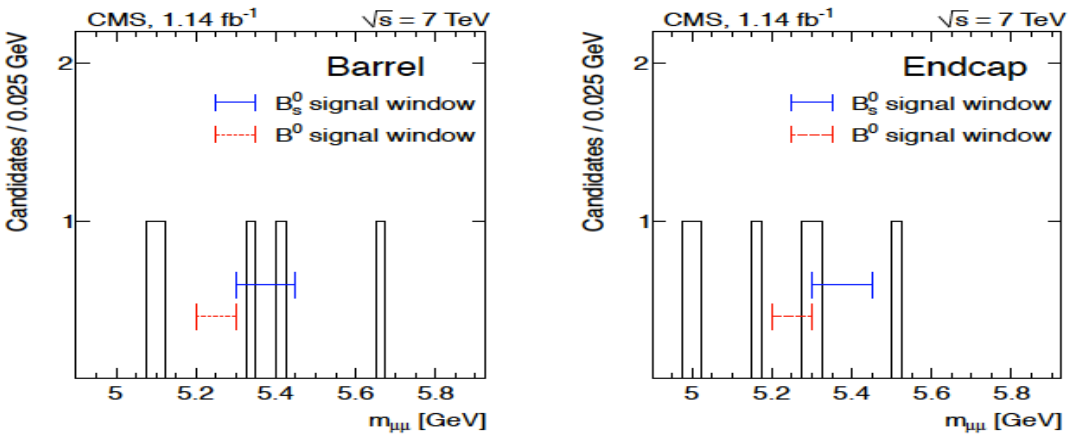


Figure 4: Dimuon invariant mass distributions in the barrel (left) and endcap (right) channels. The signal windows for B^0_s and B^0 are indicated by horizontal lines.

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$N^{\rm exp}_{\rm peak}$	0.07 ± 0.02	0.04 ± 0.01
$N_{\rm obs}$	2	1

Expected limit at 95% C.L. (including presence of SM signal)	1.8×10^{-8}
Observed limit at 95% (90%) C.L.	$\boxed{1.9\ (1.6) \times 10^{-8}}$
p-value of bckg only hypothesis	11%

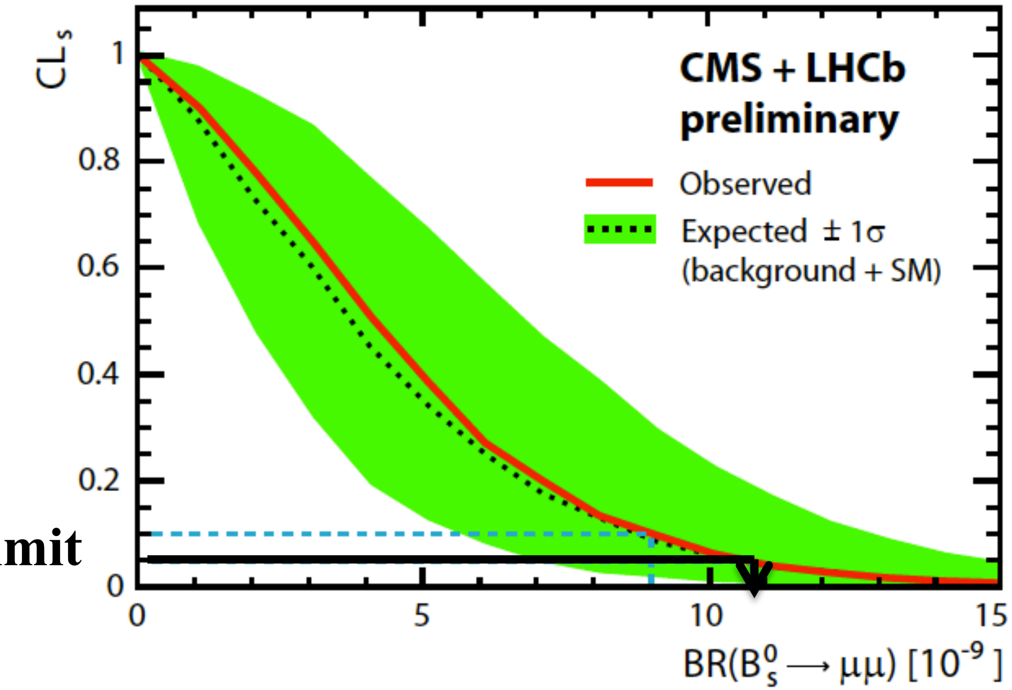
LHCb-CMS combination

[LHCb-CONF-2011-047]

- Combination has been performed by LHCb just adding 2 CMS bins (1 for barrel, 1 for endcap):

CMS+LHCb combined

95% exclusion limit



BR($B_s \rightarrow \mu\mu$) < 1.1 x 10^{-8} @ 95% CL (3.4xSM)

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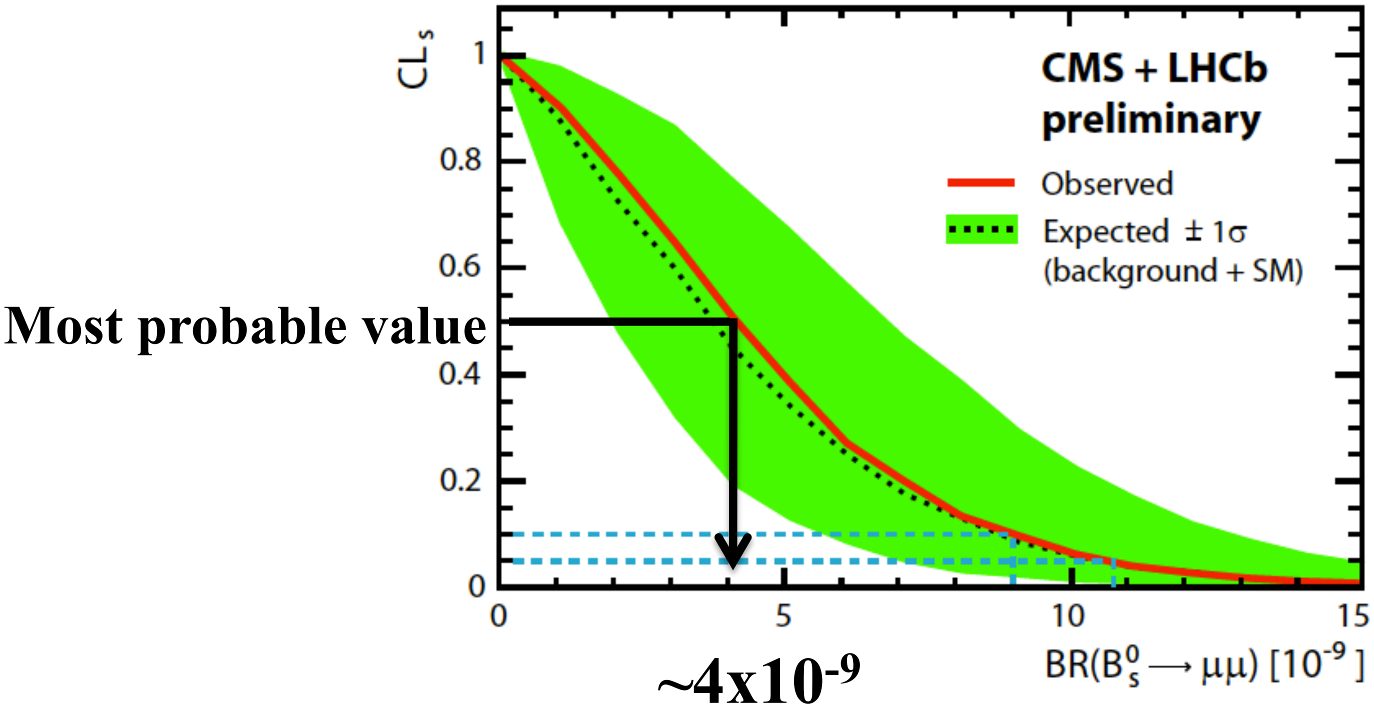


BR($B_s \rightarrow \mu\mu$) and Global Fits

An example: MasterCode (J. Ellis et al.) (http://www.cern.ch//mastercode)
Goal: perform global fits to measured quantities (including direct) and build a χ^2:searches) compare with prediction from a given model (CMSSM, NUMH1, mSugra, etc.)

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_i^M \frac{\left(f_{\mathrm{SM}_i}^{\mathrm{obs}} - f_{\mathrm{SM}_i}^{\mathrm{fit}}\right)^2}{\sigma(f_{\mathrm{SM}_i})^2}$$
$$+ \chi^2(b \to s\gamma) + \chi^2(g_\mu - 2) + \chi^2(\Omega h^2) + \chi^2(m_h)$$
$$\boxed{+ \chi^2(\mathrm{BR}(B_s \to \mu\mu)) + \chi^2(\mathrm{LHC}) + \chi^2(\mathrm{XENON100})}$$

Recent Experimental Data!

N: number of observables studied

M: SM parameters: $\Delta\alpha_{\mathrm{had}}, m_t, M_Z$

C_i: experimentally measured value (constraint)

P_i: MSSM parameter-dependent prediction for the corresponding constraint

Global fits: input data

EW observables
(largest inpact M_W, A^e_{LR}, A^b_{FB})

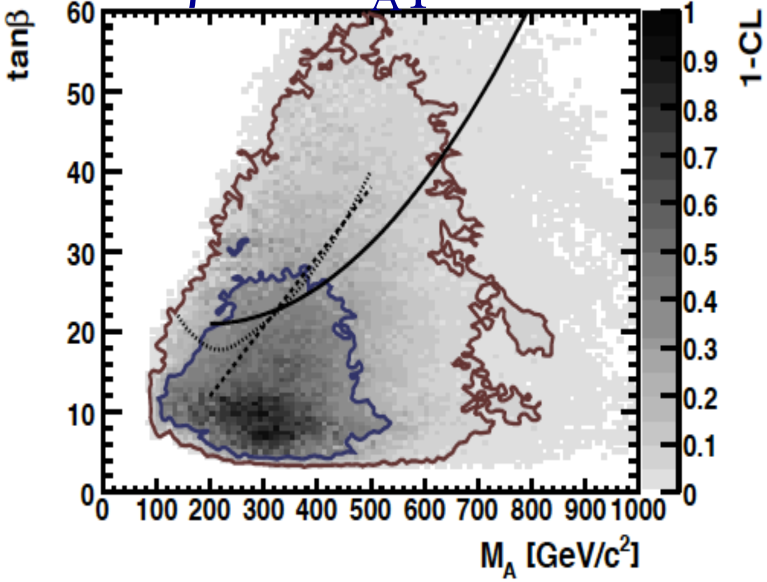
Flavour physics observables
(largest inpact $b \to s\gamma$, $B_s \to \mu\mu$)

$(g-2)_\mu$
Higgs Mass
Cold Dark matter density
LHC direct searches

Observable	Source Th./Ex.	Constraint
m_t [GeV]	[39]	173.2 ± 0.90
$\Delta\alpha^{(5)}_{\rm had}(m_Z)$	[38]	0.02749 ± 0.00010
M_Z [GeV]	[40]	91.1875 ± 0.0021
Γ_Z [GeV]	[24] / [40]	$2.4952 \pm 0.0023 \pm 0.001_{\rm SUSY}$
$\sigma^0_{\rm had}$ [nb]	[24] / [40]	41.540 ± 0.037
R_l	[24] / [40]	20.767 ± 0.025
$A_{\rm fb}(\ell)$	[24] / [40]	0.01714 ± 0.00095
$A_\ell(P_\tau)$	[24] / [40]	0.1465 ± 0.0032
R_b	[24] / [40]	0.21629 ± 0.00066
R_c	[24] / [40]	0.1721 ± 0.0030
$A_{\rm fb}(b)$	[24] / [40]	0.0992 ± 0.0016
$A_{\rm fb}(c)$	[24] / [40]	0.0707 ± 0.0035
A_b	[24] / [40]	0.923 ± 0.020
A_c	[24] / [40]	0.670 ± 0.027
A_ℓ(SLD)	[24] / [40]	0.1513 ± 0.0021
$\sin^2\theta^\ell_{\rm w}(Q_{\rm fb})$	[24] / [40]	0.2324 ± 0.0012
M_W [GeV]	[24] / [40]	$80.399 \pm 0.023 \pm 0.010_{\rm SUSY}$
${\rm BR}^{\rm EXP}_{b\to s\gamma}/{\rm BR}^{\rm SM}_{b\to s\gamma}$	[41] / [42]	$1.117 \pm 0.076_{\rm EXP}$ $\pm 0.082_{\rm SM} \pm 0.050_{\rm SUSY}$
${\rm BR}(B_s \to \mu^+\mu^-)$	[27] / [37]	$(< 1.08 \pm 0.02_{\rm SUSY}) \times 10^{-8}$
${\rm BR}^{\rm EXP}_{B\to\tau\nu}/{\rm BR}^{\rm SM}_{B\to\tau\nu}$	[27] / [42]	$1.43 \pm 0.43_{\rm EXP+TH}$
${\rm BR}(B_d \to \mu^+\mu^-)$	[27] / [42]	$< (4.6 \pm 0.01_{\rm SUSY}) \times 10^{-9}$
${\rm BR}^{\rm EXP}_{B\to X_s\ell\ell}/{\rm BR}^{\rm SM}_{B\to X_s\ell\ell}$	[43]/ [42]	0.99 ± 0.32
${\rm BR}^{\rm EXP}_{K\to\mu\nu}/{\rm BR}^{\rm SM}_{K\to\mu\nu}$	[27] / [44]	$1.008 \pm 0.014_{\rm EXP+TH}$
${\rm BR}^{\rm EXP}_{K\to\pi\nu\bar\nu}/{\rm BR}^{\rm SM}_{K\to\pi\nu\bar\nu}$	[45]/ [46]	< 4.5
$\Delta M^{\rm EXP}_{B_s}/\Delta M^{\rm SM}_{B_s}$	[45] / [47, 48]	$0.97 \pm 0.01_{\rm EXP} \pm 0.27_{\rm SM}$
$\frac{(\Delta M^{\rm EXP}_{B_s}/\Delta M^{\rm SM}_{B_s})}{(\Delta M^{\rm EXP}_{B_d}/\Delta M^{\rm SM}_{B_d})}$	[27] / [42, 47, 48]	$1.00 \pm 0.01_{\rm EXP} \pm 0.13_{\rm SM}$
$\Delta\epsilon^{\rm EXP}_K/\Delta\epsilon^{\rm SM}_K$	[45] / [47, 48]	$1.08 \pm 0.14_{\rm EXP+TH}$
$a^{\rm EXP}_\mu - a^{\rm SM}_\mu$	[49] / [38, 50]	$(30.2 \pm 8.8 \pm 2.0_{\rm SUSY}) \times 10^{-10}$
M_h [GeV]	[26] / [51, 52]	$> 114.4 \pm 1.5_{\rm SUSY}$
$\Omega_{\rm CDM}h^2$	[29] / [53]	$0.1109 \pm 0.0056 \pm 0.012_{\rm SUSY}$
$\sigma^{\rm SI}_p$	[23]	$(m_{\tilde\chi^0_1}, \sigma^{\rm SI}_p)$ plane
jets $+ \not{E}_T$	[16, 18]	$(m_0, m_{1/2})$ plane
$H/A, H^\pm$	[19]	$(M_A, \tan\beta)$ plane

Global Fits

tanβ vs M_A plane



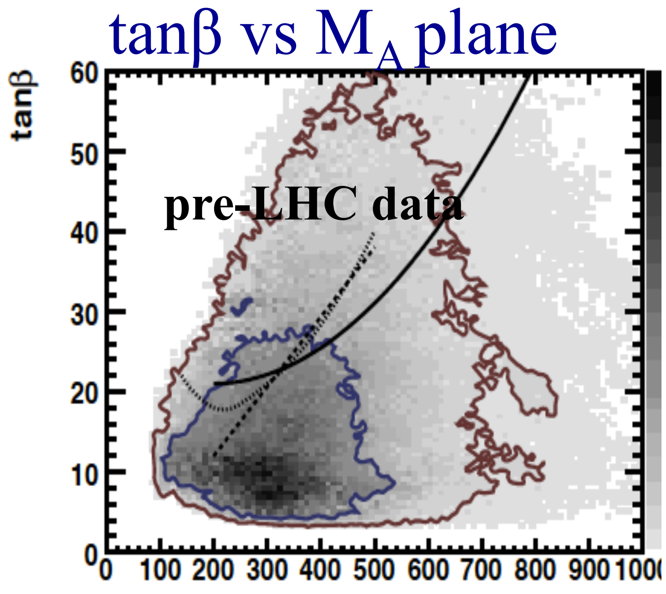
Best fit contours in tanβ vs M_A plane in the NUHM1 model, *[O. Buchmuller et al, arxiv:0907.5568]*

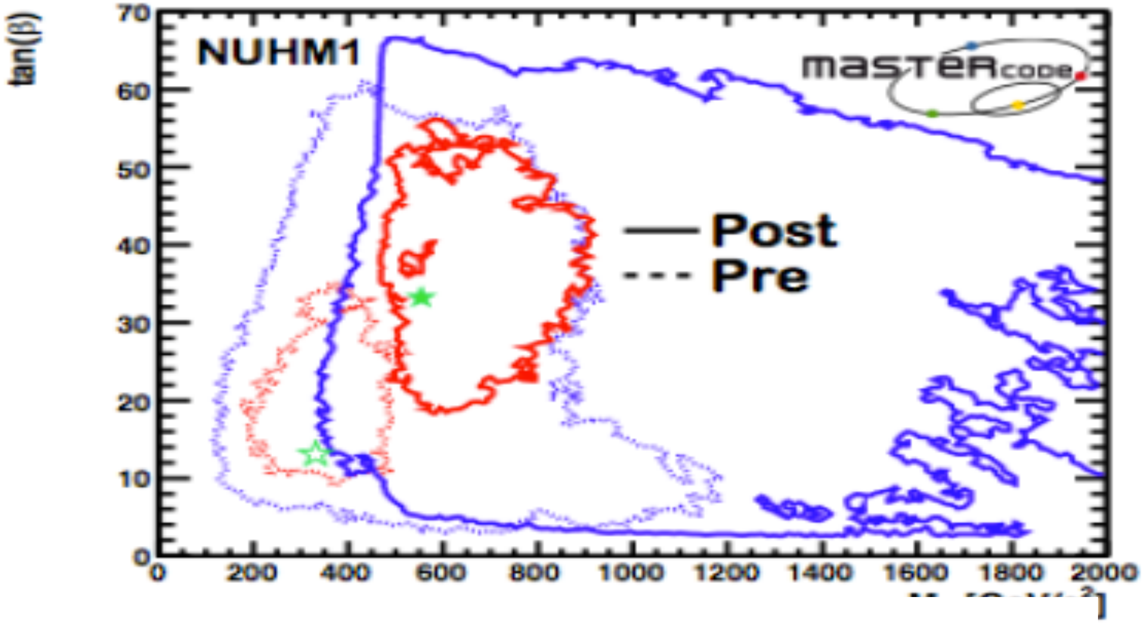
(pre-LHC results)

Low tan(β) and heavy Higgs mass~300 GeV

Global Fits: masterCode

F. *Ronga at Workshop LHC results for TeV scale physics, CERN, August 2011*





- CMSSM and NUHM1 still on the safe(ish) side

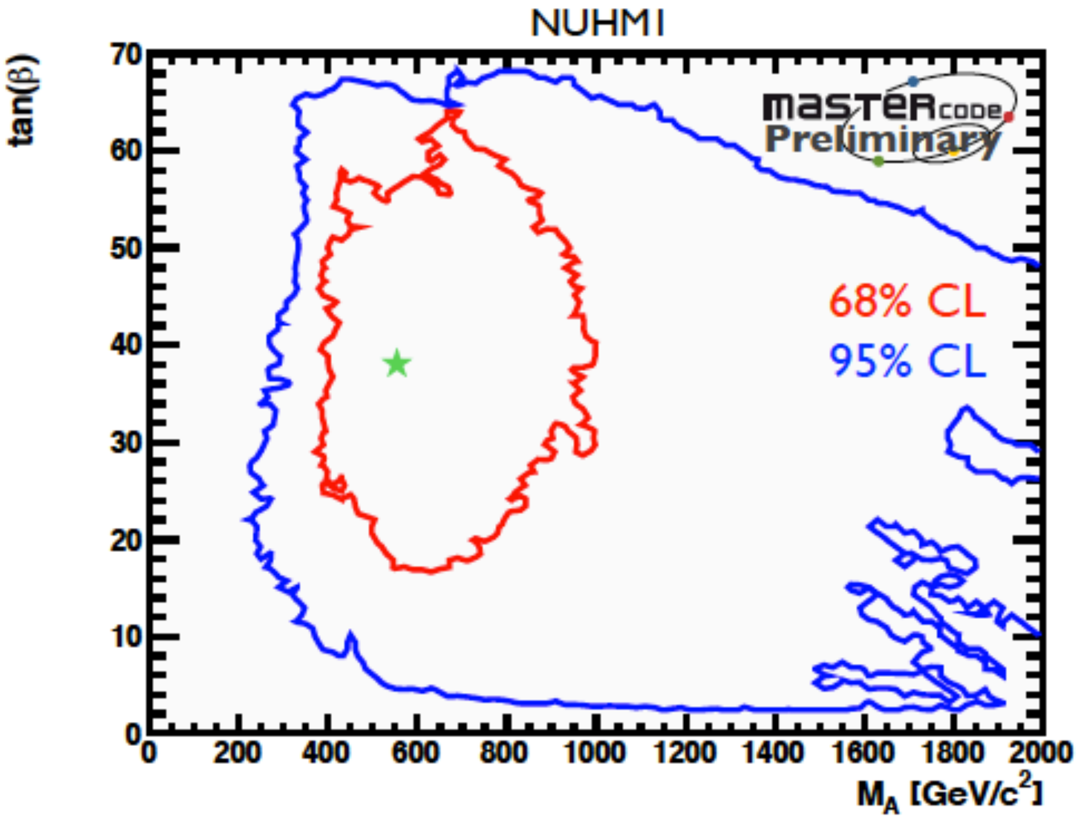
P~10%

  - new 1/fb LHC data significantly pushes the allowed mass scale up
  - effect visible on M_A and tanβ as well
  - low tanβ no longer favoured!

.. Remember that Bs→μμ is proportional to $\tan^6\beta$....

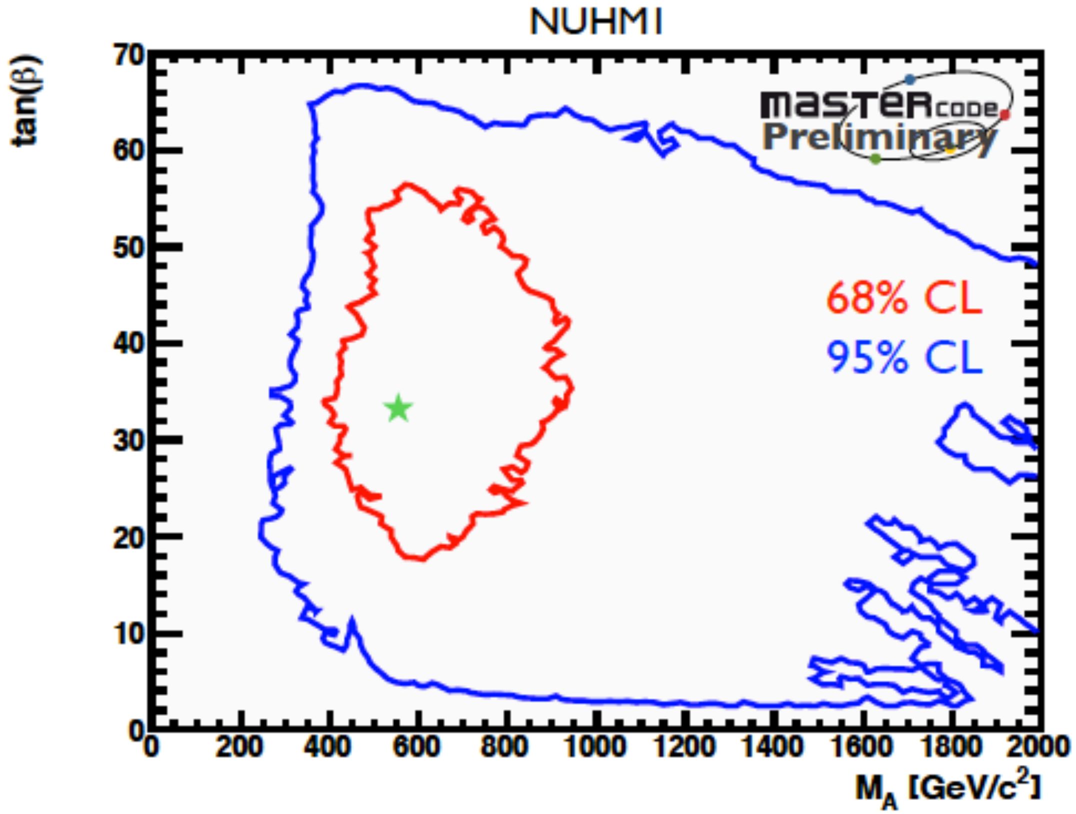
Global Fits & $B_s \rightarrow \mu\mu$

- LHC 2011 MET searches only



Global Fits & $B_s \rightarrow \mu\mu$

- LHC 2011 MET searches and $B_s \rightarrow \mu\mu$



$B_s \rightarrow \mu\mu$ upper limit pushes down tan(β)
(opposite direction wrt direct searches)

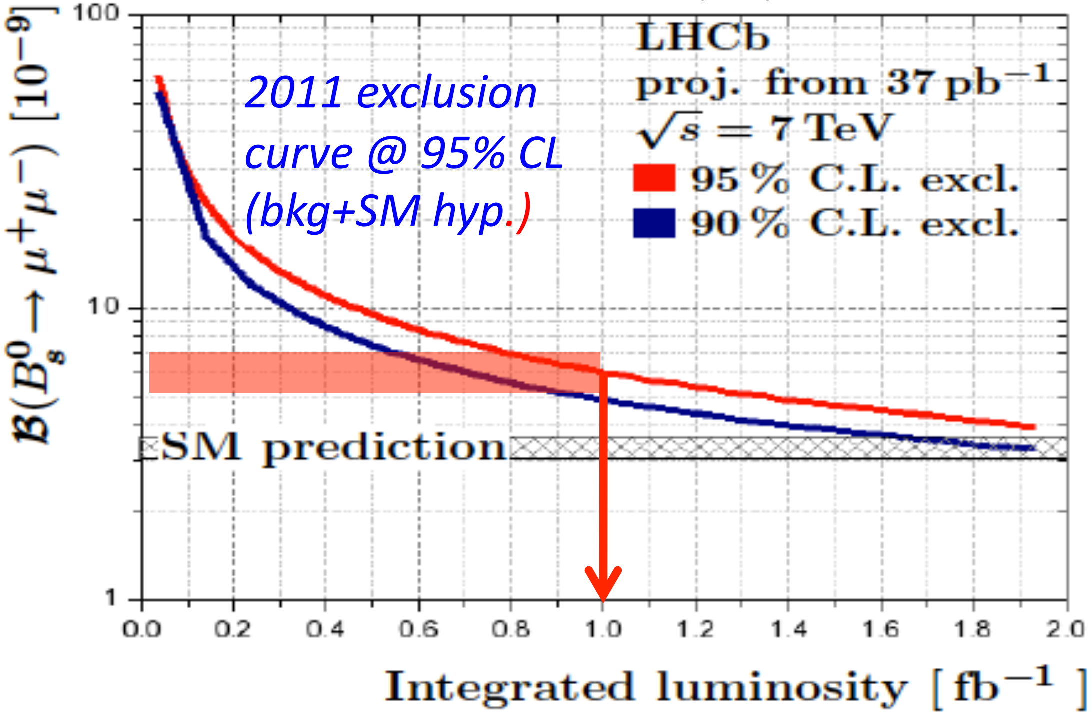
No New Physics…

No New Physics…yet!

Projections for early 2012: LHCb

- Luminosity projections from present data-taking assume that LHCb will collect between 1 fb^{-1} by the end of the year

Bs→μμ exclusion limit at 90% and 95% CL: projections from 2010 data

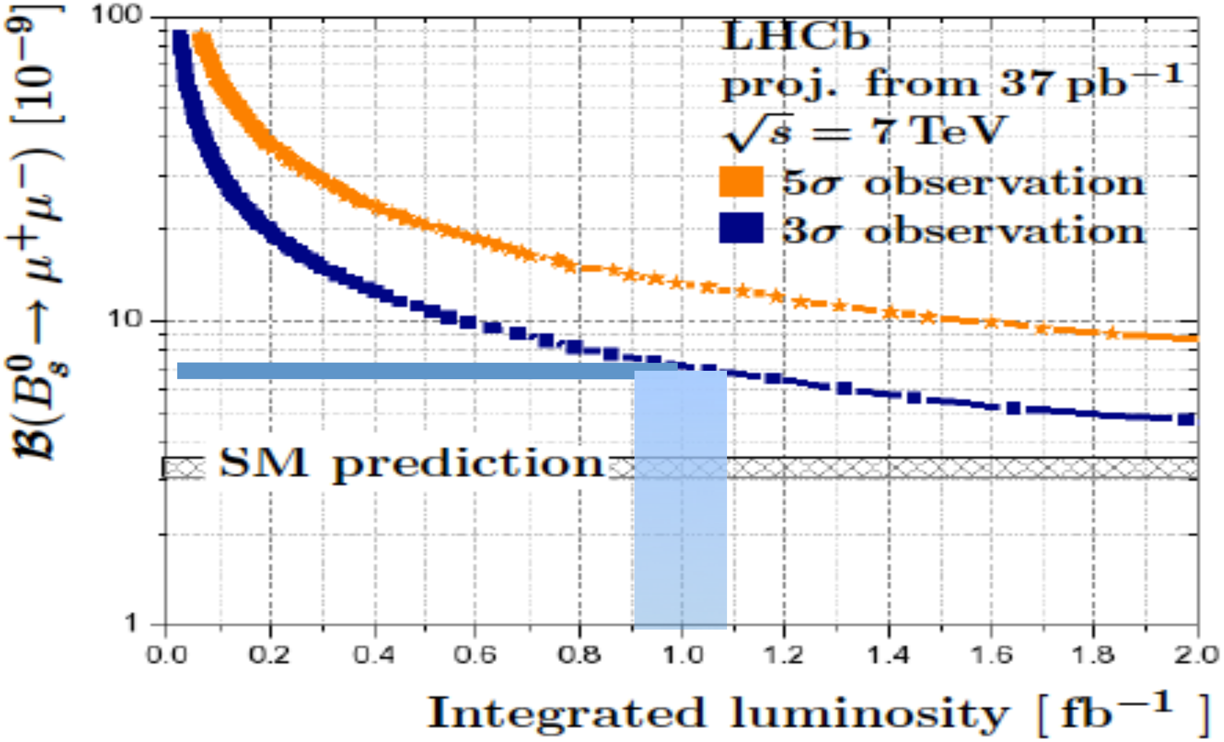


For the winter conferences (assuming no changes in the analysis / data quality)

→ LHCb might put a limit down to (6-7)x10^{-9} @ 95%CL…..

Projections for early 2012: LHCb

- Luminosity projections from present data-taking assume that LHCb will collect between 1 fb^{-1} by the end of the year.



… or could claim a 3 sigma evidence if the BR is ~8 $x10^{-9}$

Projections for CMS and LHCb
3σ /5σ observations

arXiv:1108.3018v1

LHCb: 3σ/5σ CMS: 3σ/5σ

BR~8x10⁻⁹

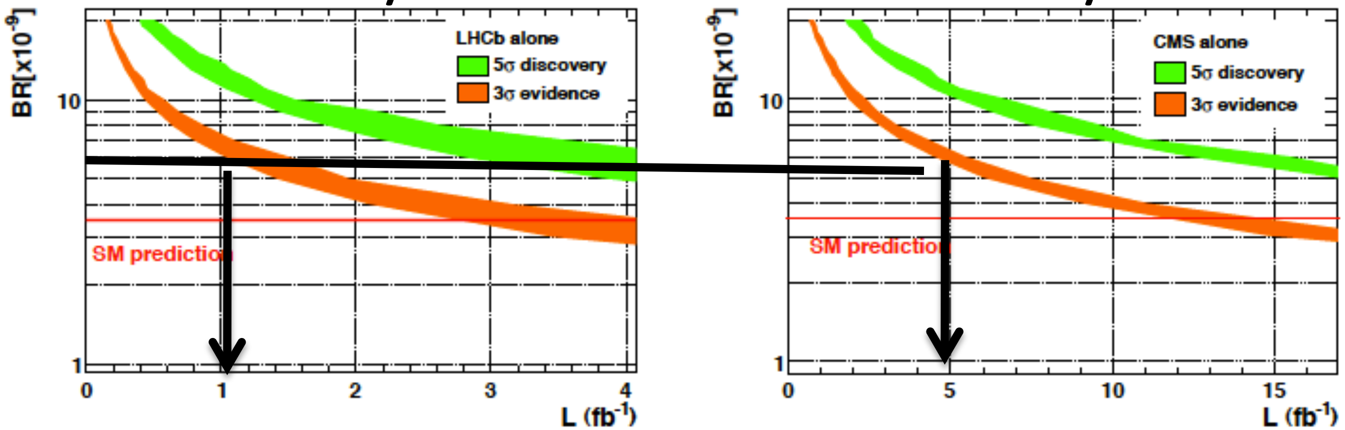
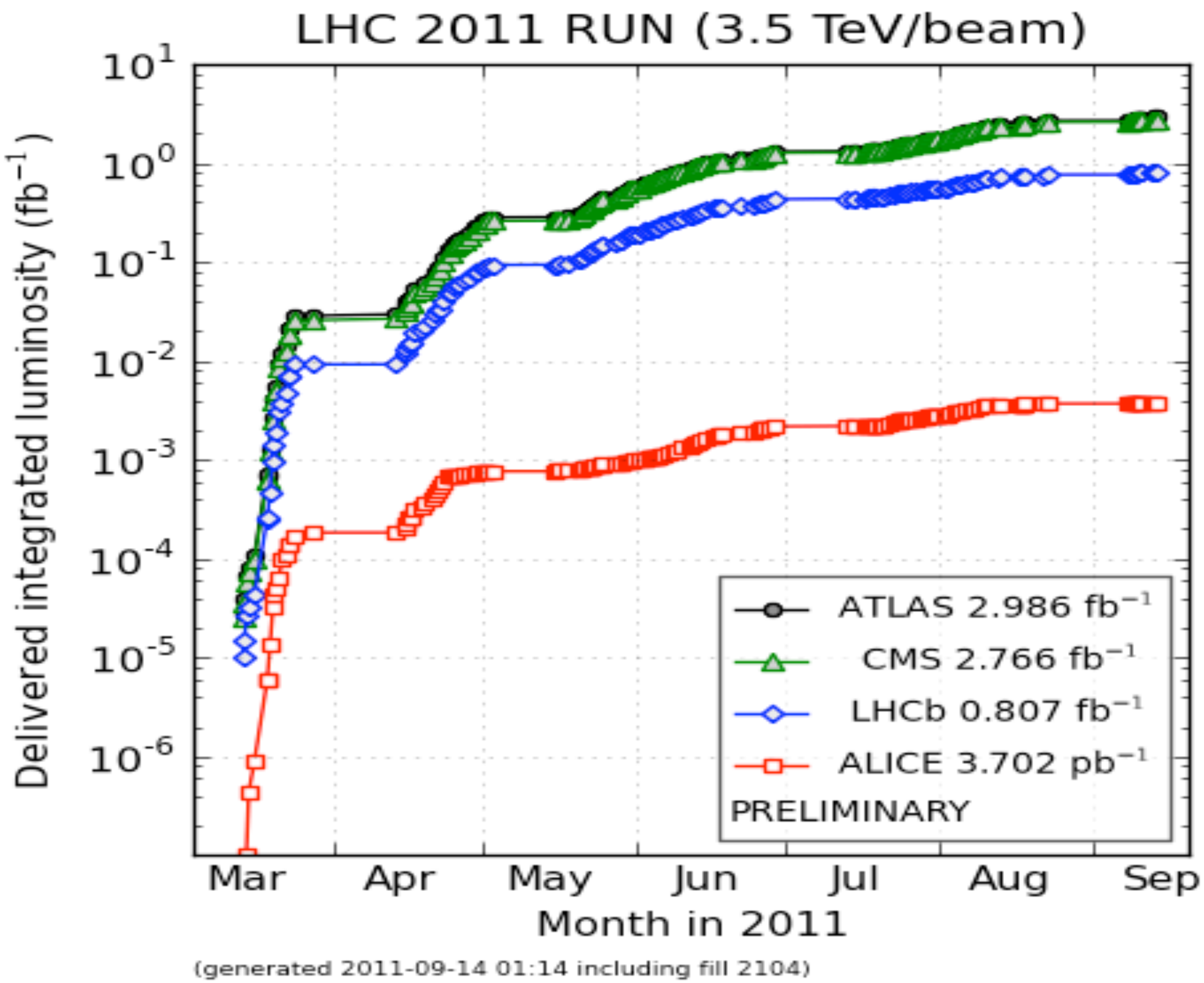


Figure 18: Required luminosity in order to provide a 3σ evidence (orange) or a 5σ discovery (green) of a given BR($B_s \to \mu^+\mu^-$) on the left for LHCb and on the right for CMS.

a 3σ evidence for BR= BR~$8\text{x}10^{-9}$ will require:
1 fb^{-1} for LHCb and 5 fb^{-1} for CMS

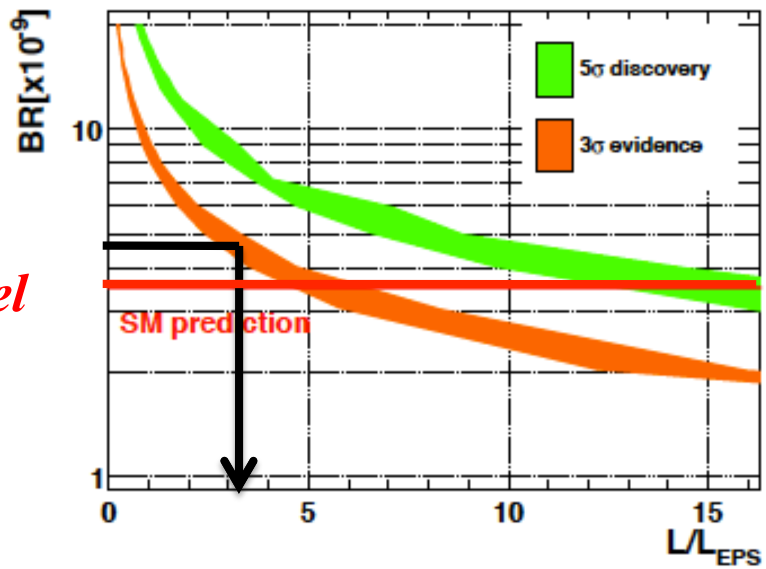
Integrated Luminosity delivered to each LHC experiment (updated yesterday)



L(CMS)/L(LHCb)~3.4

Projections for early 2012: CMS+LHCb combination: 3 sigma evidence

Standard model



arXiv:1108.3018v1

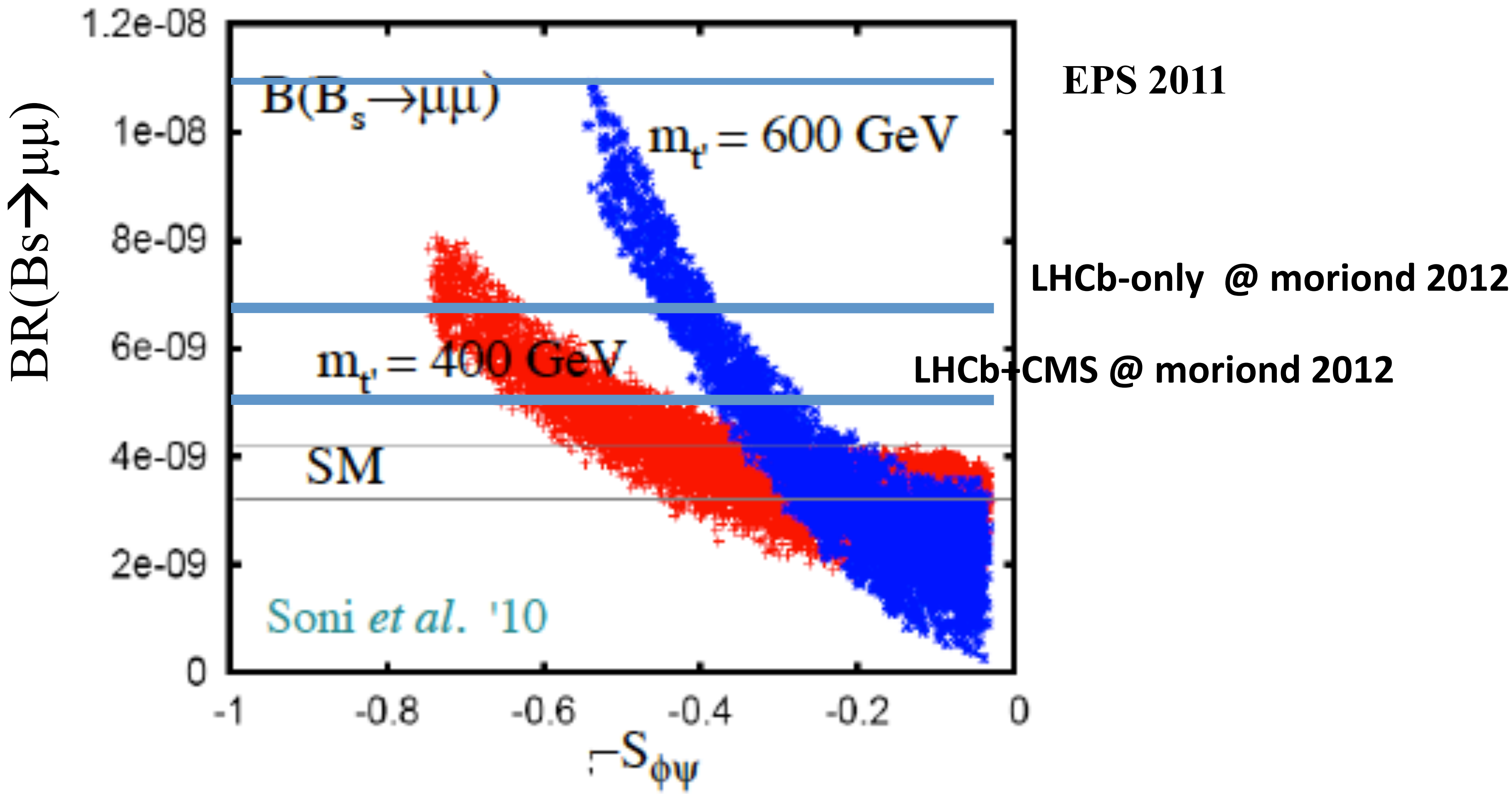
L=3xL(EPS) [~1 fb^{-1} for LHCb, ~3.3 fb^{-1} for CMS]

Figure 19: Required luminosity in order to provide a 3σ evidence (orange) or a 5σ discovery (green) of a given BR($B_s \to \mu^+\mu^-$) for LHCb and CMS combined. The luminosity is expressed in terms of the luminosity used in [13], (0.34 fb^{-1} for LHCb and 1.14 fb^{-1} for CMS).

LHCb-CMS combined could claim a 3σ evidence if BR=(5-6)x10^{-9} by 2012 winter conferences

$B_s \to \mu\mu$ and 4th generation

Preliminary projections for 2012 winter conferences for exclusion limits @ 95% CL:



Conclusions

Excess of $B_s \rightarrow \mu\mu$ events seen by CDF not confirmed.

LHCb with 300 pb^{-1} has put the best world upper limit:

$BR(B_s \rightarrow \mu\mu) < 1.5 \times 10^{-8}$ @ 95% CL

LHCb combined with CMS brings the limit down to:

$BR(B_s \rightarrow \mu\mu) < 1.1 \times 10^{-8}$ @ 95% CL

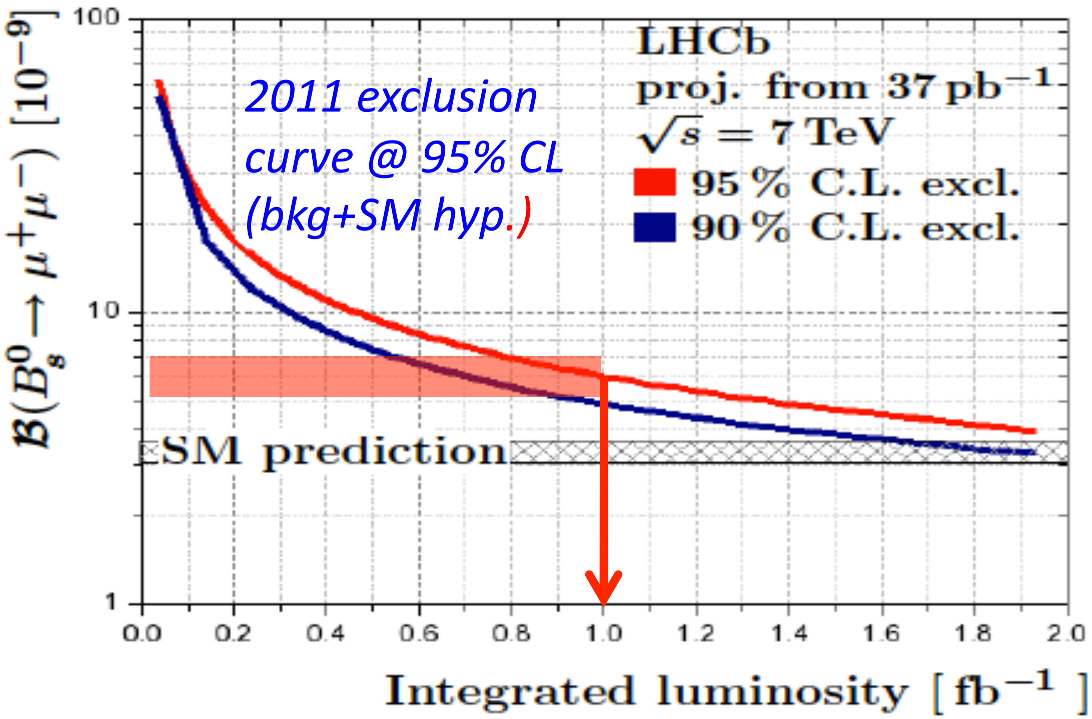
This limit has a direct impact on the global fits and on 4^{th} generation models.

The best has to come… Wait for Winter Conferences..

STOP

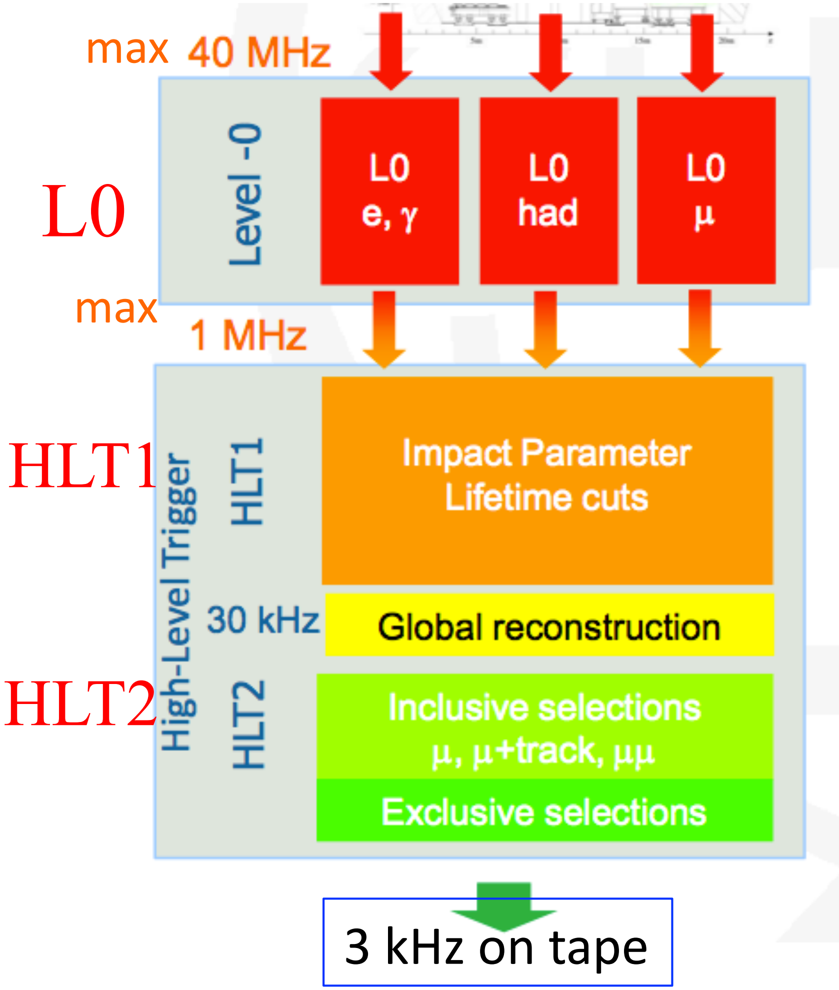
Projections for early 2012: LHCb

- Luminosity projections from present data-taking assume that LHCb will collect between 1 fb^{-1} by the end of the year



CAVEAT: Given the present accuracy on fd/fs (~8%) and BR(SM) predictions (~6%) only if BR (NP) is larger than 1.3xBR(SM) (BR>4.2x10^{-9}) we can exclude SM-like rate at 3 σ

LHCb trigger for $B_{s,d} \rightarrow \mu\mu$



	Muon Lines
L0	Single- μ: **p_T> 1.5 GeV/c** μμ: sqrt(**p_{T1}xp_{T2})>1.3 GeV/c**
HLT1	single-μ: p_T>1.8 GeV/c IP>0.01 mm
HLT2	Several dimuon lines with $M_{\mu\mu}$ cuts and/or displaced vertex

+ Global Event Cuts for events with high multiplicity

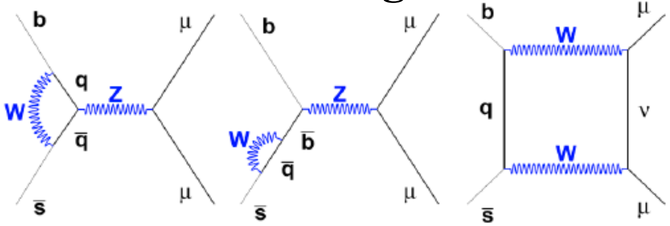
- 1/3 of the bandwidth (~0.8 kHz) given to the muon lines
- p_T cuts on muon lines kept very low → ε(trigger $B_{sd} \rightarrow \mu\mu$) ~ 90%
- Trigger rather stable during the whole period

The LHCb hunt for non-SM Higgs(es)

$B_{(d,s)} \to \mu\mu$ is the best way for LHCb to constrain the parameters of the extended Higgs sector in MSSM, fully complementary to direct searches

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

Main SM diagrams



Double suppressed decay: **FCNC process** and **helicity suppressed**:
→ **very small in the Standard Model but very well predicted:**

$\boxed{\mathbf{B_s \to \mu^+\mu^- = (3.2 \pm 0.2) \times 10^{-9}}}$ $\boxed{\mathbf{B_d \to \mu^+\mu^- = (1.0 \pm 0.1) \times 10^{-10}}}$

Parameterization of the BR(Bs→ μμ) in terms of SM quantities:

$$BR(B_s \to \mu^+\mu^-)_{SM} = 3.5 \cdot 10^{-9} \times \frac{\tau_s}{1.6 \text{ ps}} \times \left(\frac{f(Bs)}{210 \text{ MeV}}\right)^2 \times \left(\frac{|V_{ts}|}{0.04}\right)^2 \times \left(\frac{m_{top}}{170 \text{ GeV}/c^2}\right)^{3.12}$$

The (dominant) error on f(Bs) has been replaced by the error on ΔMs

Normalization

- The signal PDFs can be translated into a number of expected signal events by normalizing to a channel with known BR

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon^{\mathrm{REC}}_{\mathrm{cal}}\epsilon^{\mathrm{SEL|REC}}_{\mathrm{cal}}\epsilon^{\mathrm{TRIG|SEL}}_{\mathrm{cal}}}{\epsilon^{\mathrm{REC}}_{\mathrm{sig}}\epsilon^{\mathrm{SEL|REC}}_{\mathrm{sig}}\epsilon^{\mathrm{TRIG|SEL}}_{\mathrm{sig}}} \times \frac{f_{\mathrm{cal}}}{f_{B^0_s}} \times \frac{N_{B^0_s\to\mu^+\mu^-}}{N_{\mathrm{cal}}} = \alpha \times N_{B^0_s\to\mu^+\mu^-}$$

Three different channels used:

1) **$BR(B^+\to J/\psi(\mu^+\mu^-)K^+) = (5.98\pm0.22)\,10^{-5}$ 3.7% uncertainty**

→ Similar trigger and PID. Tracking efficiency (+1 track) dominates the systematic in the ratio of efficiencies. Needs f_d/f_s as input: 13% uncertainty

2) **$BR(B_s\to J/\psi(\mu^+\mu^-)\,\varphi(K^+K^-)) = (3.35\pm0.9)\,10^{-5}$ 26% uncertainty**

Similar trigger and PID. Tracking efficiency (+2 tracks) dominates the systematic

3) **$BR(B^0\to K^+\pi^-) = (1.94\pm0.06)\,10^{-5}$ 3.1% uncertainty**

Same topology in the final state. Different trigger dominate the syst. Needs f_d/f_s

$B_s \rightarrow \mu\mu$ search window

Invariant Mass bins (MeV/c^2)		Geometrical Likelihood Bins: [0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
[−60, −40]	Exp. bkg.	$56.9^{+1.1}_{-1.1}$	$1.31^{+0.19}_{-0.17}$	$0.282^{+0.076}_{-0.065}$	$0.016^{+0.021}_{-0.010}$
	Exp. sig.	$0.0076^{+0.0034}_{-0.0030}$	$0.0050^{+0.0027}_{-0.0020}$	$0.0037^{+0.0015}_{-0.0011}$	$0.0047^{+0.0015}_{-0.0010}$
	Observed	39	2	1	0
[−40, −20]	Exp. bkg.	$56.1^{+1.1}_{-1.1}$	$1.28^{+0.18}_{-0.17}$	$0.269^{+0.072}_{-0.062}$	$0.015^{+0.020}_{-0.009}$
	Exp. sig.	$0.0220^{+0.0084}_{-0.0079}$	$0.0146^{+0.0066}_{-0.0053}$	$0.0107^{+0.0036}_{-0.0026}$	$0.0138^{+0.0034}_{-0.0024}$
	Observed	55	2	0	0
[−20, 0]	Exp. bkg.	$55.3^{+1.1}_{-1.1}$	$1.24^{+0.17}_{-0.16}$	$0.257^{+0.069}_{-0.059}$	$0.014^{+0.018}_{-0.009}$
	Exp. sig.	$0.038^{+0.015}_{-0.014}$	$0.025^{+0.012}_{-0.010}$	$0.0183^{+0.0063}_{-0.0047}$	$0.0235^{+0.0059}_{-0.0042}$
	Observed	73	0	0	0
[0, 20]	Exp. bkg.	$54.4^{+1.1}_{-1.1}$	$1.21^{+0.17}_{-0.16}$	$0.246^{+0.066}_{-0.057}$	$0.013^{+0.017}_{-0.008}$
	Exp. sig.	$0.03761^{+0.015}_{-0.015}$	$0.025^{+0.012}_{-0.010}$	$0.0183^{+0.0063}_{-0.0047}$	$0.0235^{+0.0060}_{-0.0044}$
	Observed	60	0	0	0
[20, 40]	Exp. bkg.	$53.6^{+1.1}_{-1.0}$	$1.18^{+0.17}_{-0.15}$	$0.235^{+0.063}_{-0.054}$	$0.012^{+0.015}_{-0.007}$
	Exp. sig.	$0.0220^{+0.0084}_{-0.0081}$	$0.0146^{+0.0067}_{-0.0054}$	$0.0107^{+0.0036}_{-0.0027}$	$0.0138^{+0.0035}_{-0.0025}$
	Observed	53	2	0	0
[40, 60]	Exp. bkg.	$52.8^{+1.0}_{-1.0}$	$1.15^{+0.16}_{-0.15}$	$0.224^{+0.060}_{-0.052}$	$0.011^{+0.014}_{-0.007}$
	Exp. sig.	$0.0076^{+0.0031}_{-0.0027}$	$0.0050^{+0.0025}_{-0.0019}$	$0.0037^{+0.0013}_{-0.0010}$	$0.0047^{+0.0013}_{-0.0010}$
	Observed	55	1	0	0

The models: 1.) CMSSM (or mSUGRA):

$\Rightarrow$ Scenario characterized by

$$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sign}\,\mu$$

$$\left.\begin{array}{l} m_0 : \text{universal scalar mass parameter} \\ m_{1/2} : \text{universal gaugino mass parameter} \\ A_0 : \text{universal trilinear coupling} \end{array}\right\} \text{at the GUT scale}$$

$\tan\beta$: ratio of Higgs vacuum expectation values

sign(μ) : sign of supersymmetric Higgs parameter

$\Rightarrow$ particle spectra from renormalization group running to weak scale

The models: 2.) NUHM1: (Non-universal Higgs mass model)

Assumption: no unification of scalar fermion and scalar Higgs parameter at the GUT scale

$\Rightarrow$ effectively M_A or μ as free parameters at the EW scale

$\Rightarrow$ besides the CMSSM parameters

$$M_A \text{ or } \mu$$

Further extension: NUHM2:
Assumption: no unification of the Higgs parameters at the GUT scale

$\Rightarrow$ effectively M_A and μ as free parameters at the EW scale

$\Rightarrow$ besides the CMSSM parameters

$$M_A \text{ and } \mu$$

The models: 3.) VCMSSM: (Very Constrained MSSM)

$\Rightarrow$ In addition to CMSSM: assume relation between A_0 and m_0:

$$A_0 = m_0 + B_0$$

$\tan\beta$ fixed (e.g. via CDM constraint)

Free parameters: $m_{1/2}$, A_0, m_0

Lightest SUSY particle (LSP) is the lightest neutralino

The models: 4.) mSUGRA: (Gravitino DM in mSUGRA)

$\Rightarrow$ In addition to CMSSM: assume relation between A_0 and m_0:

$$A_0 = m_0 + B_0$$

mSUGRA: $m_{\text{gravitino}} = m_0$ $\Rightarrow$ gravitino can be the LSP

Free parameters: $m_{1/2}$, A_0, m_0

Lightest SUSY particle (LSP) is the gravitino