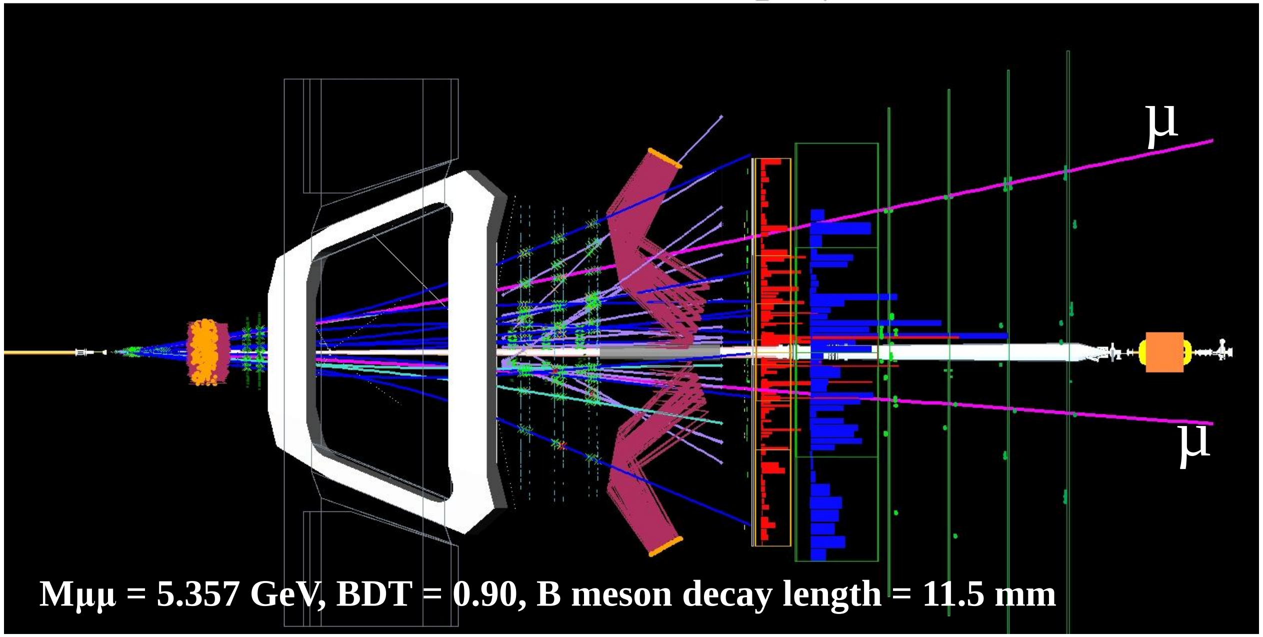
Search for rare B-mesons decays at the LHCB experiment



YURY SHCHEGLOV, PNPI

on behalf of the LHCB collaboration

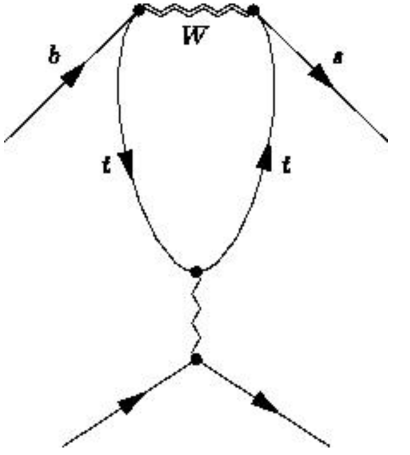
QFTHEP11, September 26

OUTLOOK

- Introduction. Recent $B_{s,d} \rightarrow 2\ \mu$ results
- Physics motivation
- LHCB detector. Fast facts
- Main backgrounds
- Strategy of the analysis. List of BDT input parameters
- $B_s \rightarrow 2\ \mu$ analysis jungle (technology, results, future plans)
- Search for NP in Bd→K*μ+μ-
- Radiative decays
- Conclusions

Introduction. B mesons penguin diagram decays

- SM forbids flavor-changing neutral currents (FCNC) diagrams
- FCNC can be introduced by penguin one loop diagrams
- Due the low SM branching these decays can be sensitive to the new physics



Decay examples: $Bs \rightarrow 2\mu$, $Bd \rightarrow K^*\mu^+\mu^-$, $Bd \rightarrow K^*\gamma$, $Bs \rightarrow \varphi\gamma$, etc.

..and many of them now can be studied at LHCB detector

$B_s \to 2\mu$ decay. Existing upper limits

- Goal: we are looking for some evidence of possible enhancements for the Standard Model . SM gives branching ratios:
  Br($B_s \to 2\mu$) =(3.2±0.2) x10^{-9}, **Br($B_d \to 2\mu$)** = (1.1±0.1) x10^{-10} ,
  (A.J.Buras: arXiv:1012.1447, E. Gamiz et al: Phys.Rev.D 80 (2009) 014503)

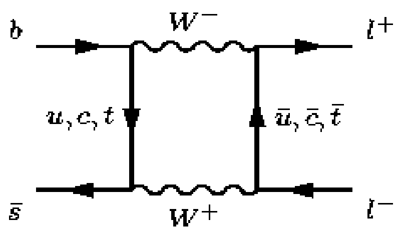
- Observed upper limits at the Tevatron and LHC *before summer 2011*:

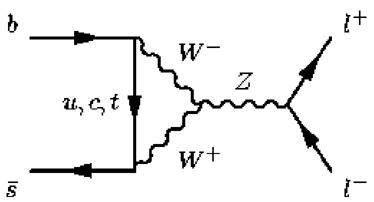
- CDF observed limit at L = 3.7 fb^{-1} : Br ($B_s \to 2\mu$) < 4.3 x10^{-8} (95% CL)
  Br ($B_d \to 2\mu$) < 7.6 x10^{-8} (95% CL), [CDF public note 9892]
- D0 observed limit at L = 6.1 fb^{-1} : Br ($B_s \to 2\mu$) < 5.1 x10^{-8} (95% CL),
  Phys. Lett. B **693**, 539 (2010), [arXiv:1006.3469]
- LHCB published observed limit at L = 37 pb^{-1} : Br ($B_s \to 2\mu$) < 5.6 x10^{-8} ,
  Br ($B_d \to 2\mu$) < 1.5 x10^{-8} at 95% CL, Phys. Lett. B**699** 330 (2011), [hep-ex/1103.2465]
  LHCB provided approximately the same result as CDF and D0 with 100 times less integrated luminosity! (more higher cross –section, better geometric and muon pT acceptance)

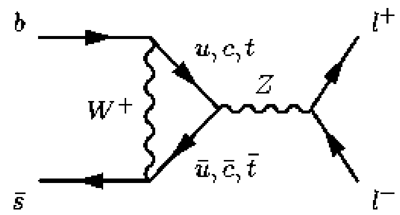
- ***HINT!!…*** *last summer news* from CDF – double sided limit arXiv: 1107.2304 [hep-ex] **:**
  0.46 x 10^{-8} < BR < 3.9x10^{-8} @ 90% CL , (BR=1.8+ 1.1 -0.9) x 10^{-8}
  Not confirmed. Huge signal fluctuation ??

Physics motivation: $B_s \to 2\mu$ Standard Model diagrams

- Physics motivation is new phenomena search
- $B_s \to 2\mu$ is double suppressed decay: FCNC process and helicity suppressed with low branching





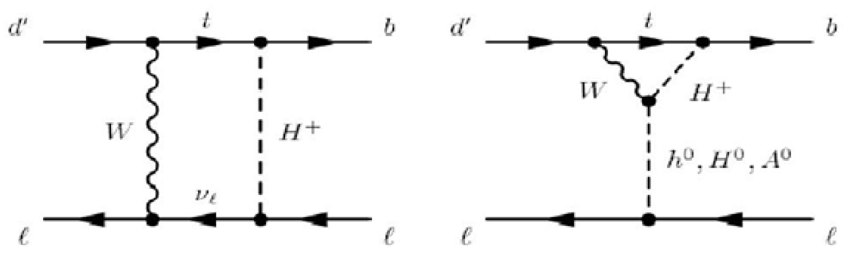


FCNC

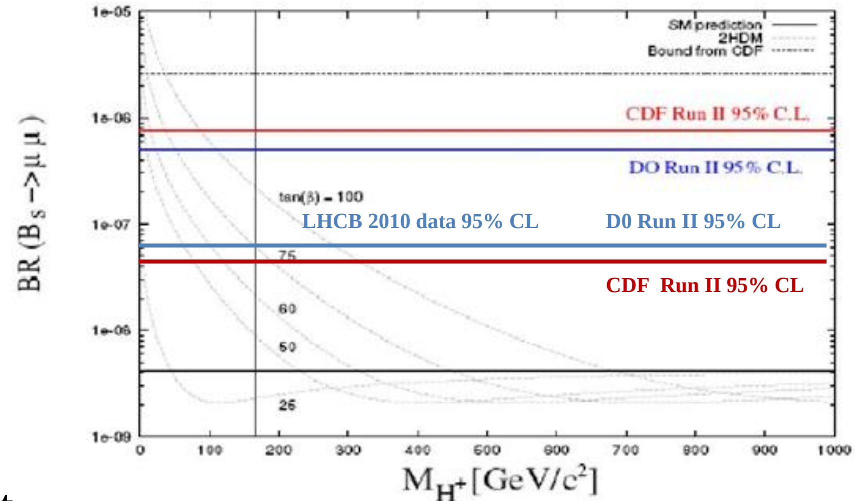
$$BR(B_q \to l^+l^-) \approx \frac{G_F^2\alpha^2 M_{B_q}^3 f_{B_q}^2 \tau_{B_q}}{64\pi^3 \sin^4\theta_W} |V_{tb}V_{tq}^*|^2 \sqrt{1-\frac{4m_l^2}{M_{B_q}^2}}$$
$$\left\{ M_{B_q}^2\left(1-\frac{4m_l^2}{M_{B_q}^2}\right)c_S^2 + \left[M_{B_q}c_P + \frac{2m_l}{M_{B_q}}(c_A - c_A')\right]^2\right\}.$$

Physics motivation: MSSM models

❑ $B_s \to 2\mu$ branching ratio can be very sensitive to the SUSY diagrams contributions. Two Higgs-Doublet (2HDM) model provides a big contribution in the region of large tan β

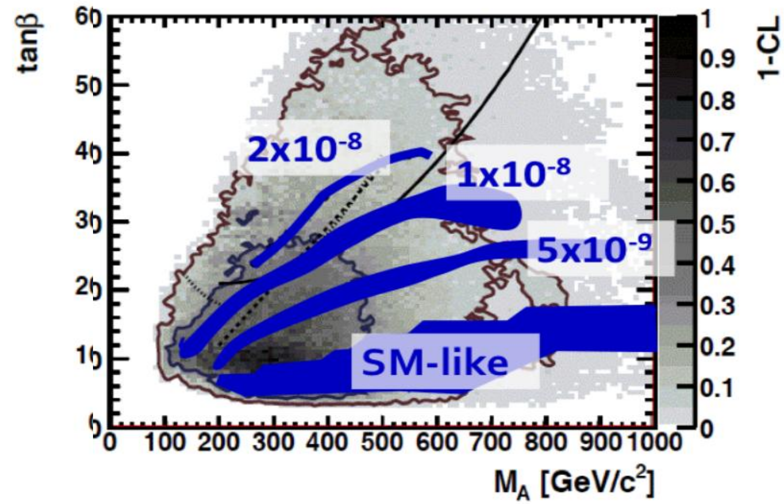


$$BR(SUSY) \propto BR(SM) \cdot \frac{m_b^4 \cdot (\tan\beta)^6}{m_{H^0}^4}$$



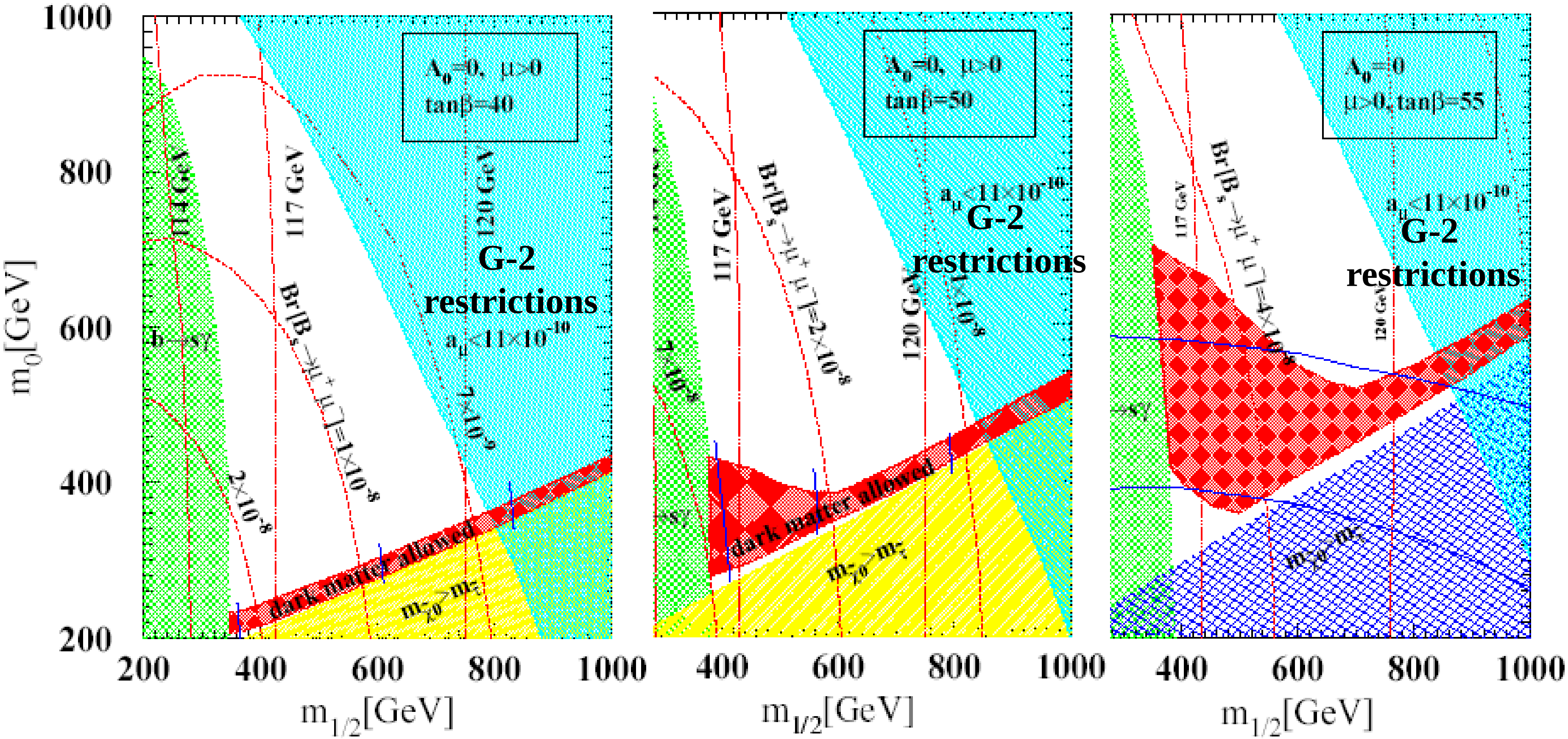
❑ $B_s \to 2\mu$ search can be used to restrict MSSM parameters

❑ NUHM1 model. The indirect $B_s \to 2\mu$ search power (blue regions) can be comparable with the results of direct SUSY searches (gray region):



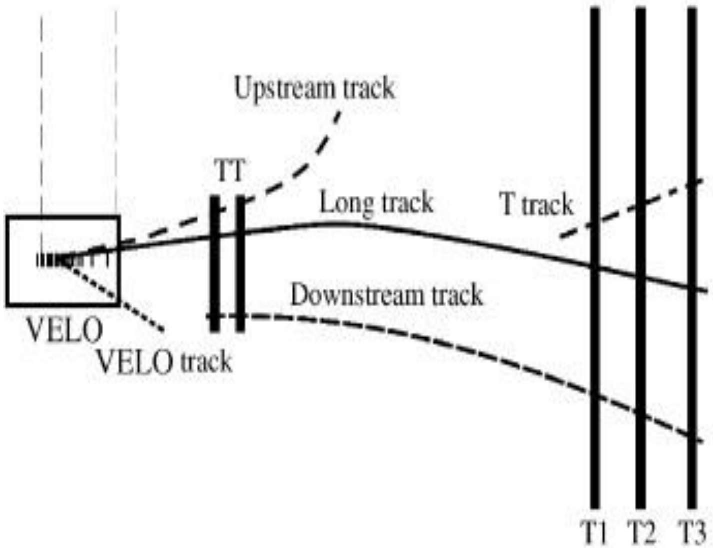
Physics motivation: mSUGRA model

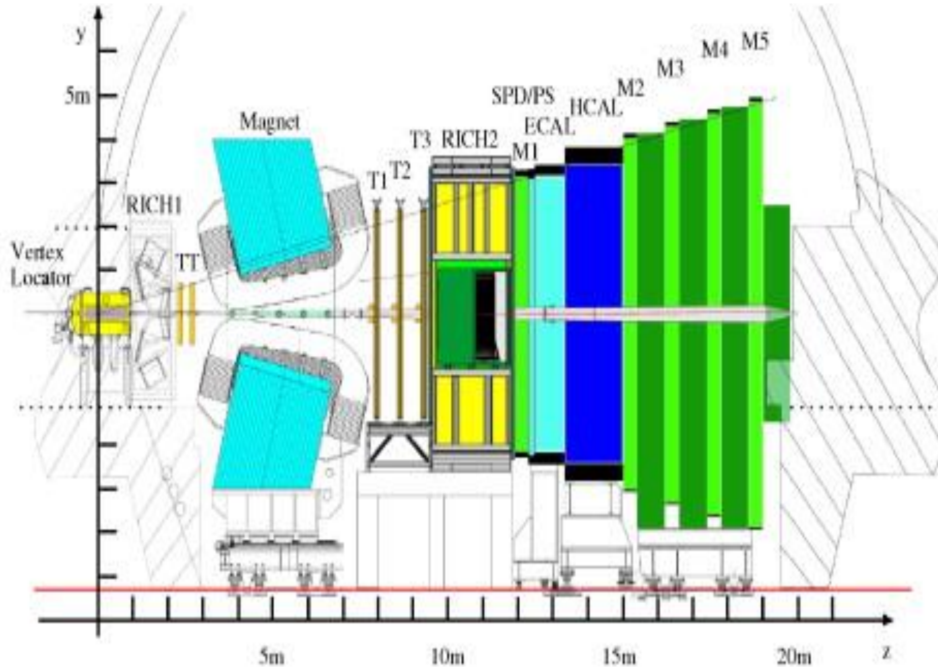
- Evaluation of the $Br(B_s \rightarrow 2\mu)$ behavior for the different mSUGRA model parameters



- If we believe to the G-2 experiment restriction (light blue color) we have a chance to have very exiting time on LHCB in the end of this year, because LHCB has a plan to reach the sensitivity $Br(B_s \rightarrow 2\mu) \sim 6\text{-}7 \times 10^{-9}$ (90% CL)

LHCb detector





Detectors are critical for $B_s \rightarrow 2\ \mu$ analysis:

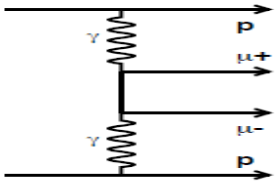
- M1, M2, M3, M4, M5 – muon stations
- VELO (Vertex Locator) – vertex detector
- TT, T1,T2,T3 – tracking stations
- RICH1, RICH2 – Cherenkov detectors

Fast facts

- Luminosity and interactions in LHCB detector
  - $\sigma_{\text{inelastic}}$(pp, $\sqrt{s}=7$ TeV) = *60 mb*, $\sigma(bb) \sim 300\ \mu b$ *(75 μb in acceptance)*
  - Number of bunches 1296 (most recent conditions)
  - $L = 3.5 \times 10^{32}$
  - Average number of interactions $\mu = 1.4$
  - The total recorded luminosity (19/09/11), $\int Ldt = 773\ pb^{-1}$
  - $\int Ldt = 300\ pb^{-1}$ used for the $B_S \to \mu\mu$ analysis
- Some number are relevant to the analysis
  - muon identification efficiency : $\varepsilon(\mu\mu) \sim 98\%$
  - misidentification rate for muons $\varepsilon(h \to \mu) < 1\%$ for p>10 GeV/c
  - σ (M, $B_s \to \mu\mu$) = 25 MeV/c^2
  - impact parameter resolution (distance between vertex and track): $\sigma(IP)$ =25 μm at pT=2 GeV/c

Main backgrounds for $B_s \to 2\mu$

- the main backround is from b semileptonic decays, $bb \to \mu\mu X$ events
- can be suppressed using different geometric and kinematic criteria
- photoproduction dimuon background
- isolated muons with a possible contribution to the B_s mass region (removed at pT(B)> 500 MeV/c)



- misidentified muons from $B_{d/s} \to h^+h^-$ decays
- contribution from $B_{d/s} \to h^+h^-$ can be calculated from $B_{d/s} \to h^+h^-$ MC with a known misidentification probablity measured in data
- Resulting misID expectations for the 300 pb^{-1}:

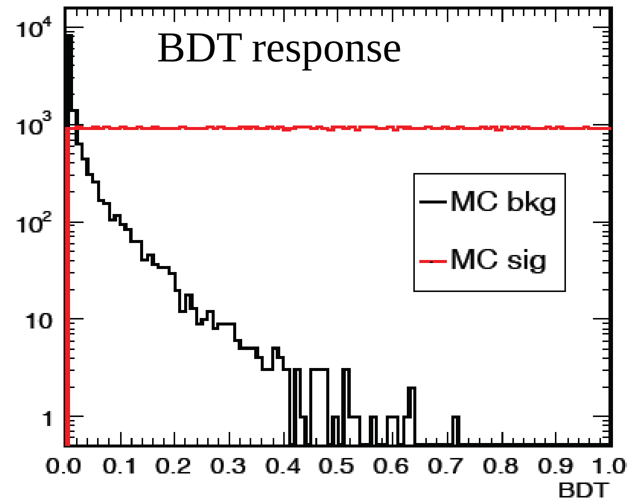
  0.5±0.4 misID events in B_s region

  2.5±0.5 misID events in B_d region

- After reconstruction the SM prediction for *300 pb^{-1}* is 3.4 (0.32) B_S $(B_d) \to \mu\mu$ events

Strategy of analysis

- **Selection conditions**
  - Muon trigger
  - Some preliminary selections to reduce datasets size
  - Blind signal region $5.306 < M_{Bs} < 5.426$ GeV



- **Signal and background training**
  - Use $B_s \to 2\mu$ and $bb \to \mu\mu X$ Monte–Carlo events to train the signal and background for the BDT method
- **Signal calibration**
  - Use the control channel **B→hh**
- **Upper limit calculation**
  - the signal and normalization channel efficiency used to calculate the normalization factor
  - the predicted background and number of observed events with the modified frequentist CLs method used to estimate the upper limit and confidence level

List of input parameters for Boosted Decision Tree method

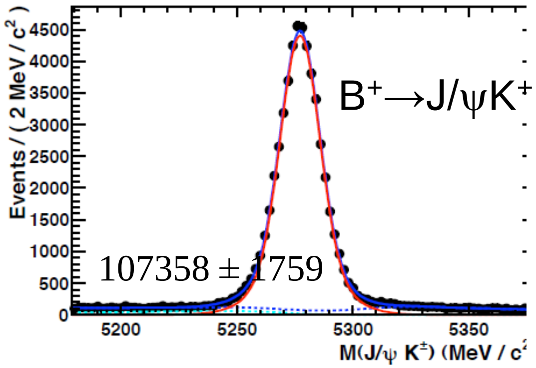
- A decision tree is able to split the phase space into a large number of hypercubes , where each can be identified as “signal-like” or “background-like”

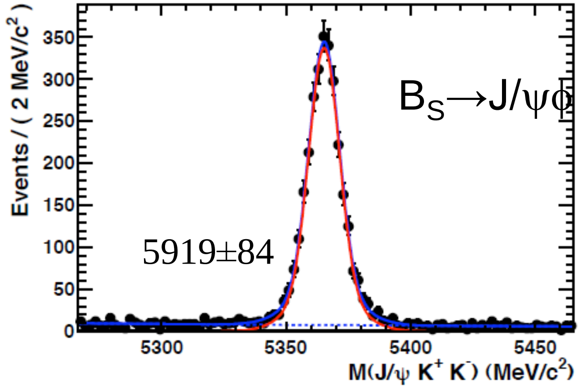
- The analysis phase space is defined by 9 input parameters:

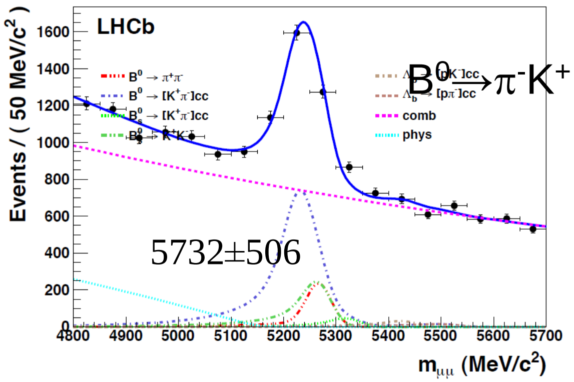
  - ✓ Transverse momentum of the B_s - *meson*
  - ✓ Minimum muon ***pT***
  - ✓ Cosine of the B_s polarization angle, ***cos P***
  - ✓ B_s meson impact parameter significance, ***IPS_Bs***
  - ✓ Minimum distance between muon tracks, ***DOCA***
  - ✓ Muon track impact parameter significance, ***IPS_μ***
  - ✓ Bs time life , $t(B_s)$
  - ✓ Secondary vertex χ^2 : ***Vchi2***
  - ✓ Bs isolation criterion

Normalization channels

- To calculate the $\mathbf{B_s \to \mu^+\mu^-}$ branching ratio we need to know the total number of Bs mesons and next to use this number for the normalization
- We have used 3 normalization channels :







Normalization channel branching

Fragmentation ratio $f_s / f_d = 0.267^{+0.021}_{-0.020}$ *combined LHCB measurements

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

Calculated from MC **Measured from data** **Number of events in normalization channel**

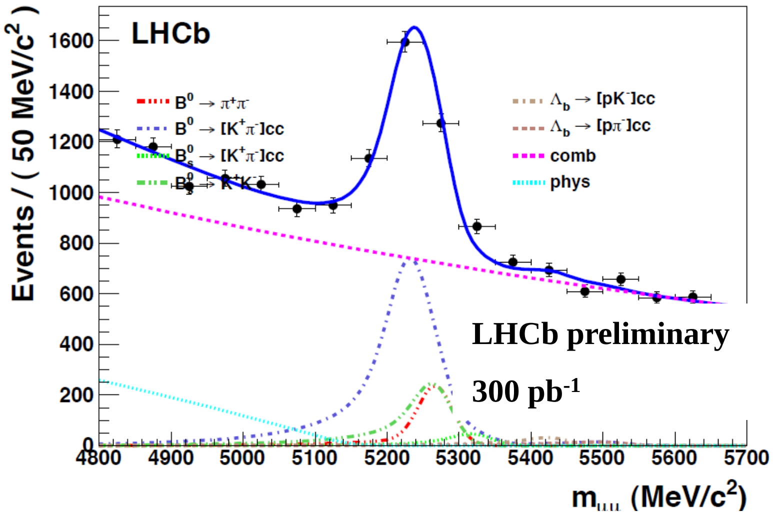
- At 300 pb^{-1} the averaging of 3 the normalization channels gives us :

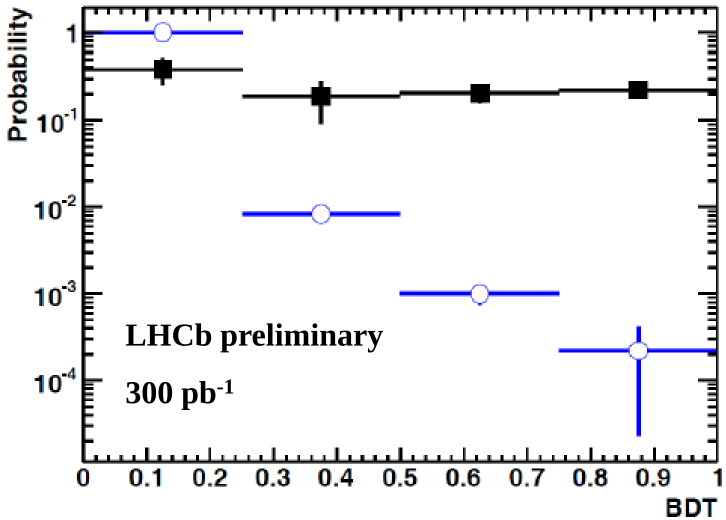
$\alpha(\mathbf{B_s \to \mu^+\mu^-}) = 9.84 \pm 0.91 \times 10^{-10}$, $\alpha(\mathbf{B_d \to \mu^+\mu^-}) = 2.89 \pm 0.15 \times 10^{-10}$

* lhcb-conf-2011-034 note

BDT response calibration

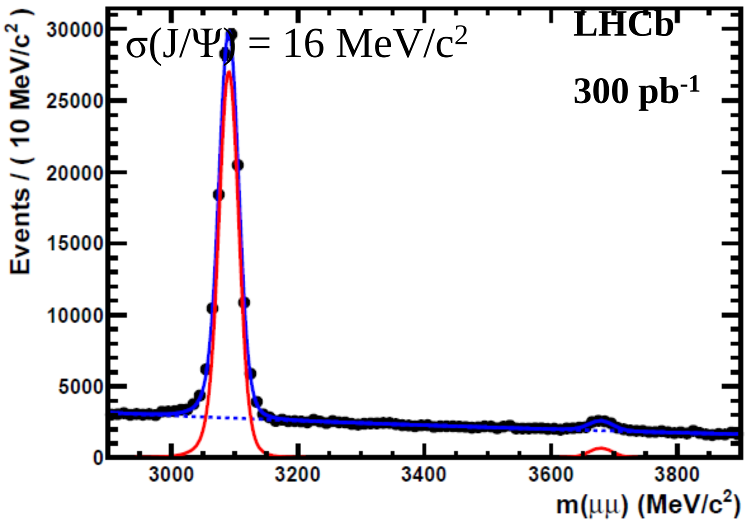
- To reduce the systematics error for the signal efficiency we need to calibrate the signal BDT response
- For the calibration we have used the data from B mesons hadronic decays - $B_{d/s} \to h^+h^-$
- The main advantage of $B_{d/s} \to h^+h^-$ is same topology as for $B_s \to \mu^+\mu^-$. The problem is a difference between muon and hadronic triggers. As a result only events triggered independently of the $B_{d/s} \to h^+h^-$ signal can be considered
- To train the BDT with the dimuon background the data from signal sidebands was used

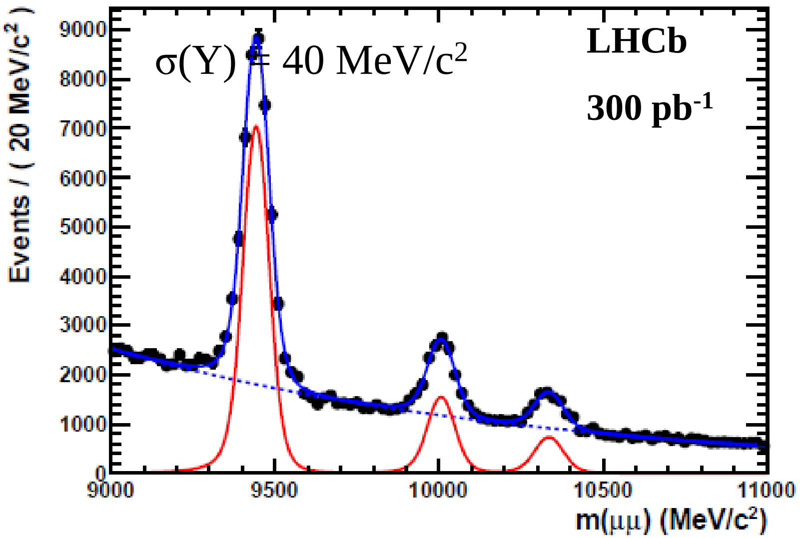




Invariant mass calibration

- For the calibration goals the invariant mass shape was modeled by a Crystal Ball function (Gaussian core portion + low end tail)
- To calculate the resolution we interpolate dimuon resonances (J/ψ,ψ(2s),Upsilons)





- As a result we have :

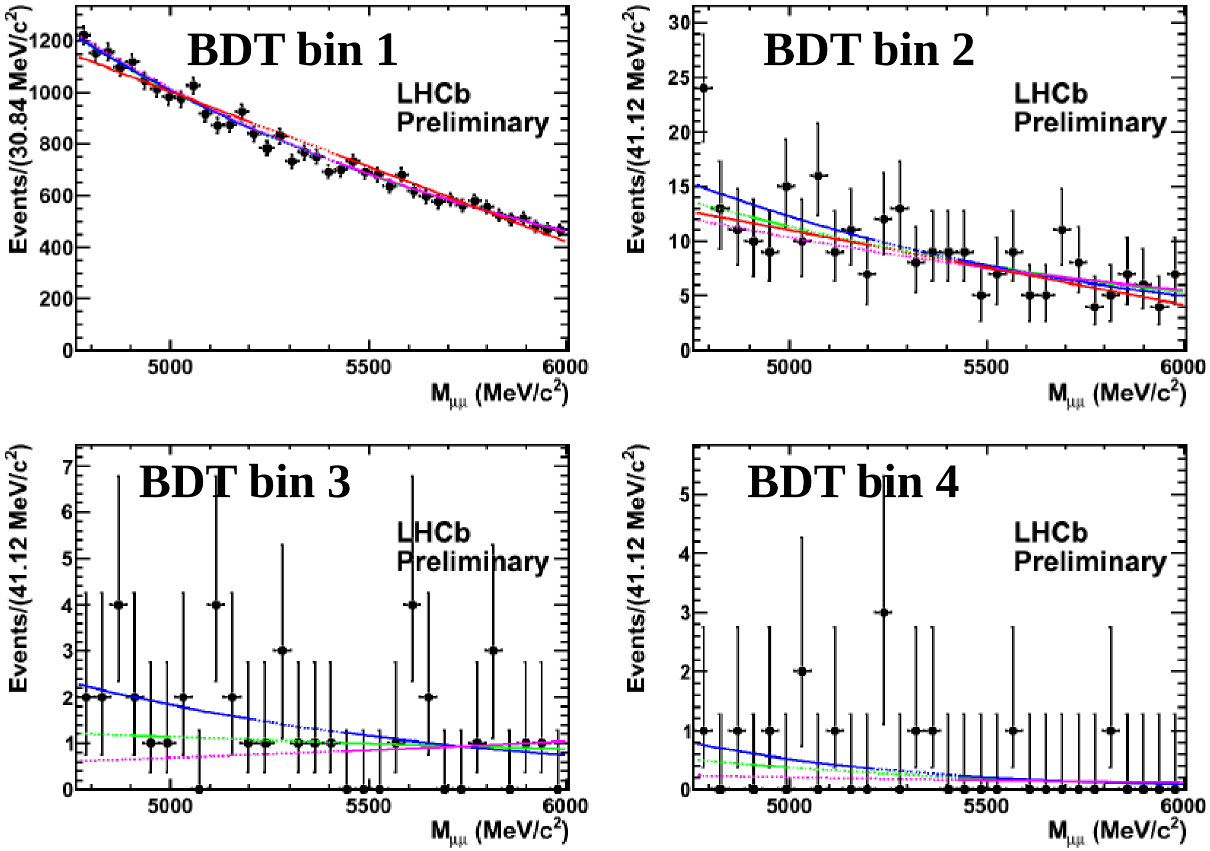
$\sigma(B_s) = (24.6\pm0.2\pm1.0)$ MeV/c^2 (same as in CDF)

$\sigma(B_d) = (24.3\pm0.2\pm1.0)$ MeV/c^2

Background estimate

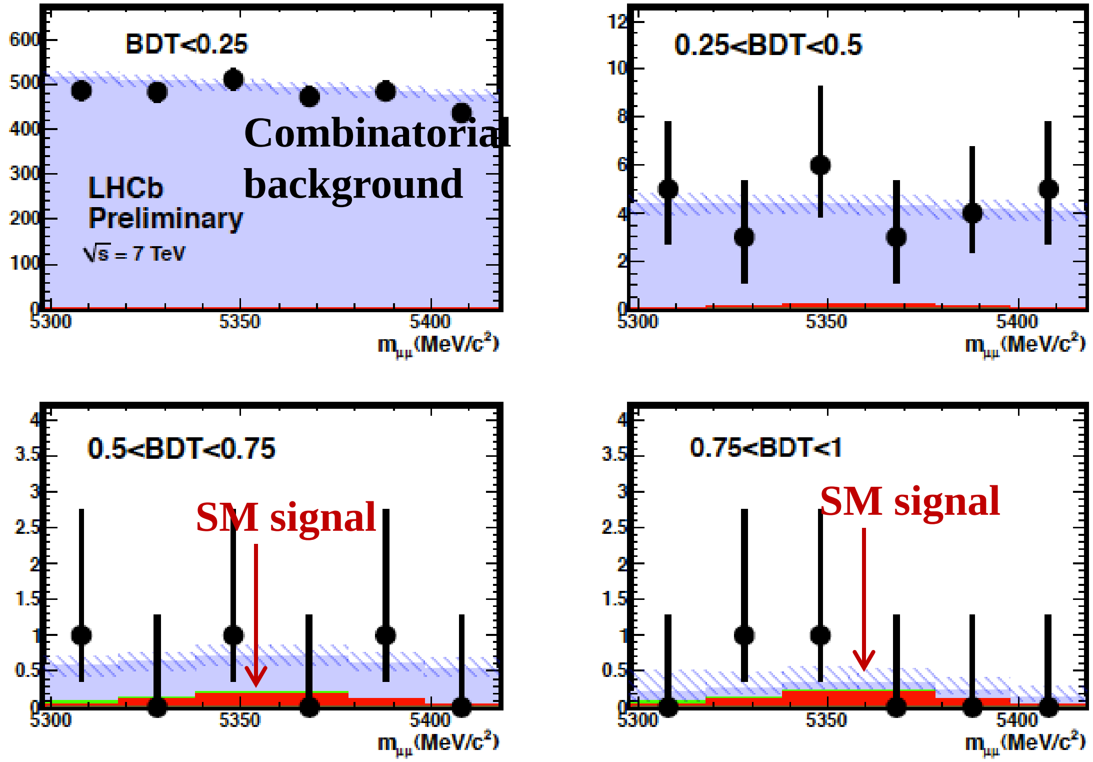
➢The combinatorial background estimate was derived from a fit of the mass sidebands for 4 BDT response bins . The signal region was blind

➢The systematics of the backround prediction was studied using the exponential, double exponential and linear fitting functions



B_s signal mass region for BDT response bins

- As a result we have got good enough agreement between expected background, Standard Model predictions and number of events observed in the signal region

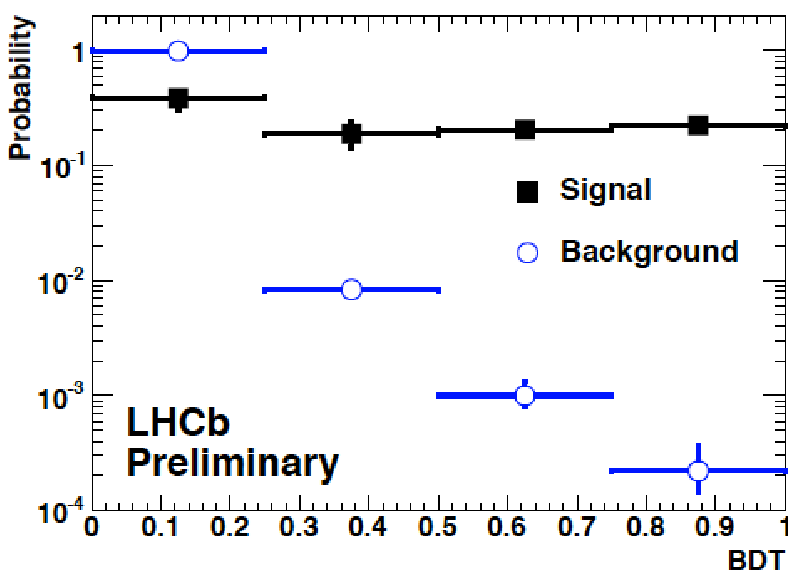


Misidentification background from $b \to hh$ 0.1±0.1 in the each BDT response bin

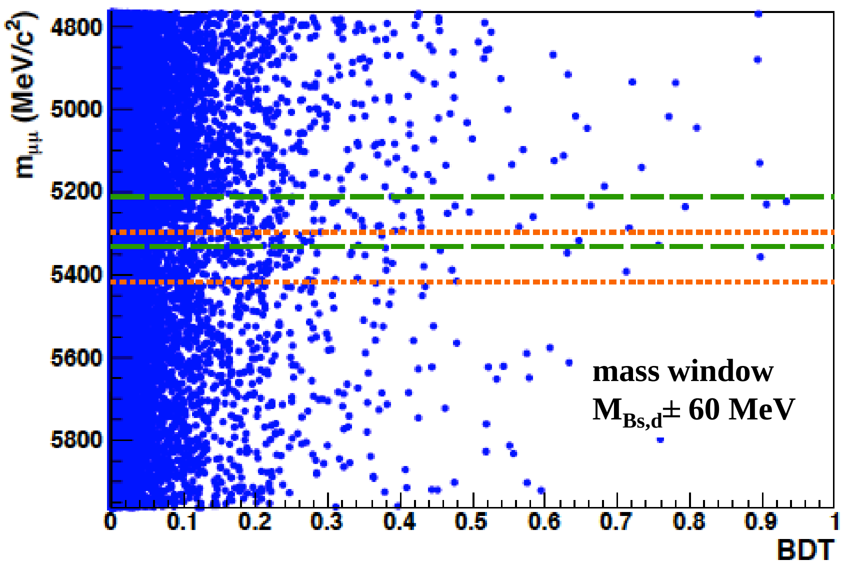
	BDT<0.25	0.25<BDT<0.5	0.5<BDT<0.75	0.75<BDT
Exp.combinatorial	2968 ± 69	25 ± 2.5	2.99 ± 0.89	0.66 ± 0.40
Exp. SM signal	1.26 ± 0.13	0.61 ± 0.06	0.67 ± 0.07	0.72 ± 0.07
Observed	2872	26	3	2

Extraction of the limit

BDT distribution for signal and background



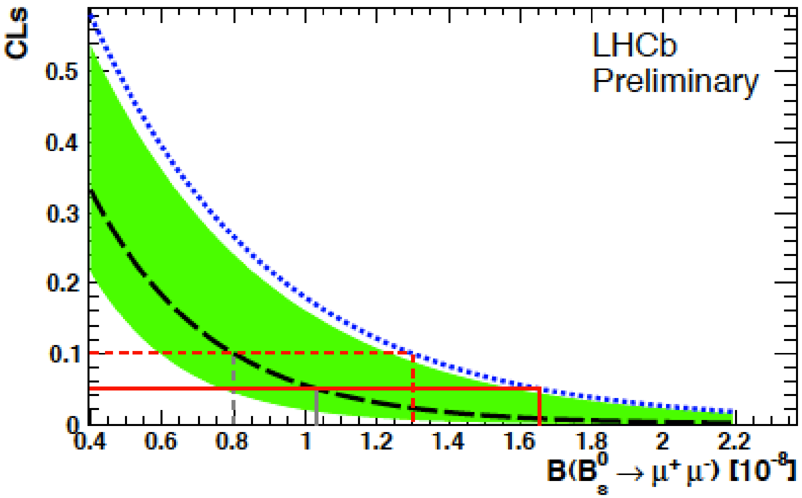
μμ mass – BDT response plane

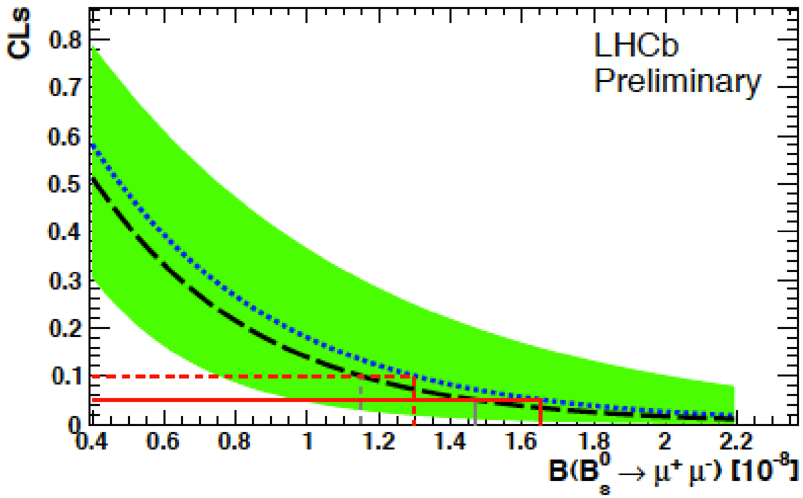


- ❑ The CLs analysis was performed in 2D space *(dimuon mass & BDT response)*
- ❑ For the each observed event we calculated a probability to be compatible with the Signal + Background hypotheses or only Background hypotheses as a function of the branching ratio. Next we exclude the assumed branching ratio value at a given confidence level

LHCB preliminary upper limit with 300 pb^{-1} 2011 data

$B_s^0 \to \mu^+\mu^-$	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}	
observed limit	1.3×10^{-8}	1.6×10^{-8}	0.80



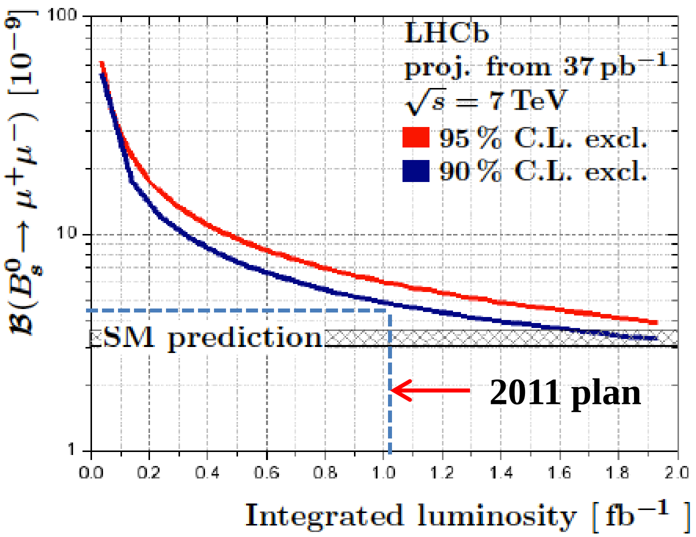


Combination with 2010 data (37pb^{-1}), ***Br* < *1.5 x 10^-8^ at 95 % CL***

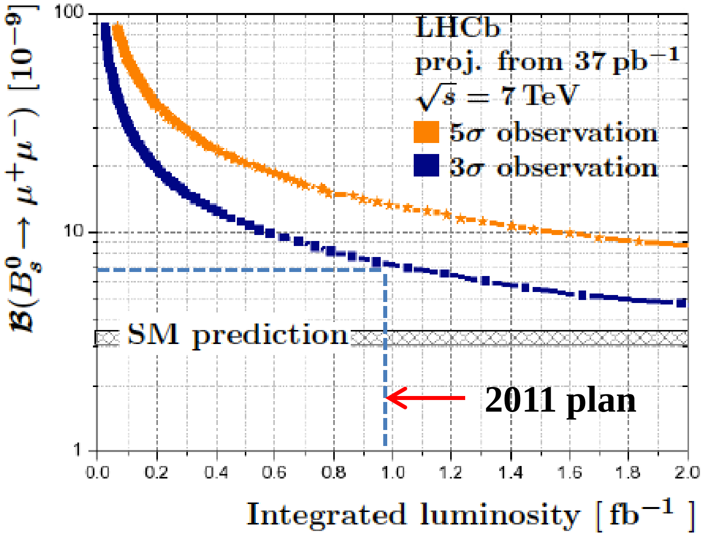
Improvement with the factor ~3.7 by comparison with 2010 data result!

Future plans (2011- beginning of 2012)

Exclusion curves for the $B_s \to \mu^+ \mu^-$ branching (LHCB conditions)



3 sigma evidence and 5 sigma discovery curves

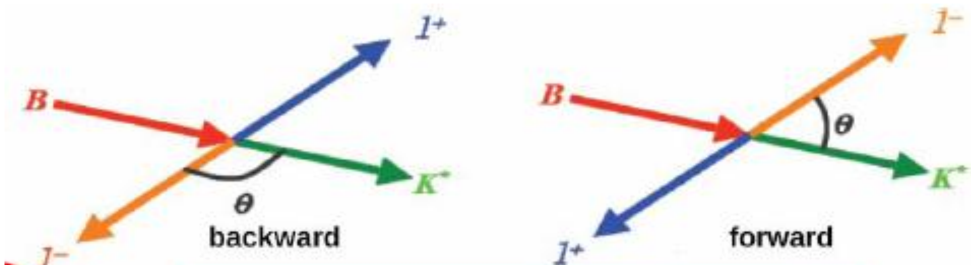


- We have a **chance** to exclude $\boldsymbol{B_s \to \mu^+ \mu^-}$ decay on the level Br =7÷8x10^{-9} with the 95% CL at the integrated luminosity 1 fb^{-1} in the end of this year
- .. or to provide 3 sigma evidence for the Br = 8x10^{-9}

Search for NP in $B_d \to K^* \mu^+ \mu^-$

- The rare decay $B_0 \to K0\mu^+\mu^-$ is a b →s flavour changing neutral current decay. This decay in the SM mediated by electroweak box and penguin diagrams
- New particles (beyond the SM) can contribute to the loop-order diagrams. It can lead to the large deviations from SM predictions

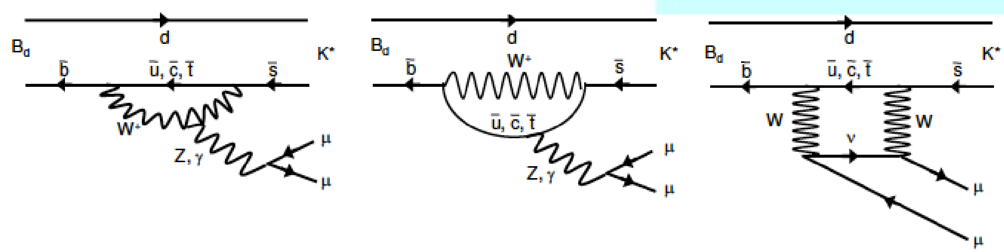
$$A_{FB} = \int \frac{d^2 B(B \to K^* \mu^+ \mu^-)}{d\cos\theta} sgn(\cos\theta)$$



θ = angle between μ^+ & B in the dilepton rest frame

q^2 = dilepton invariant mass

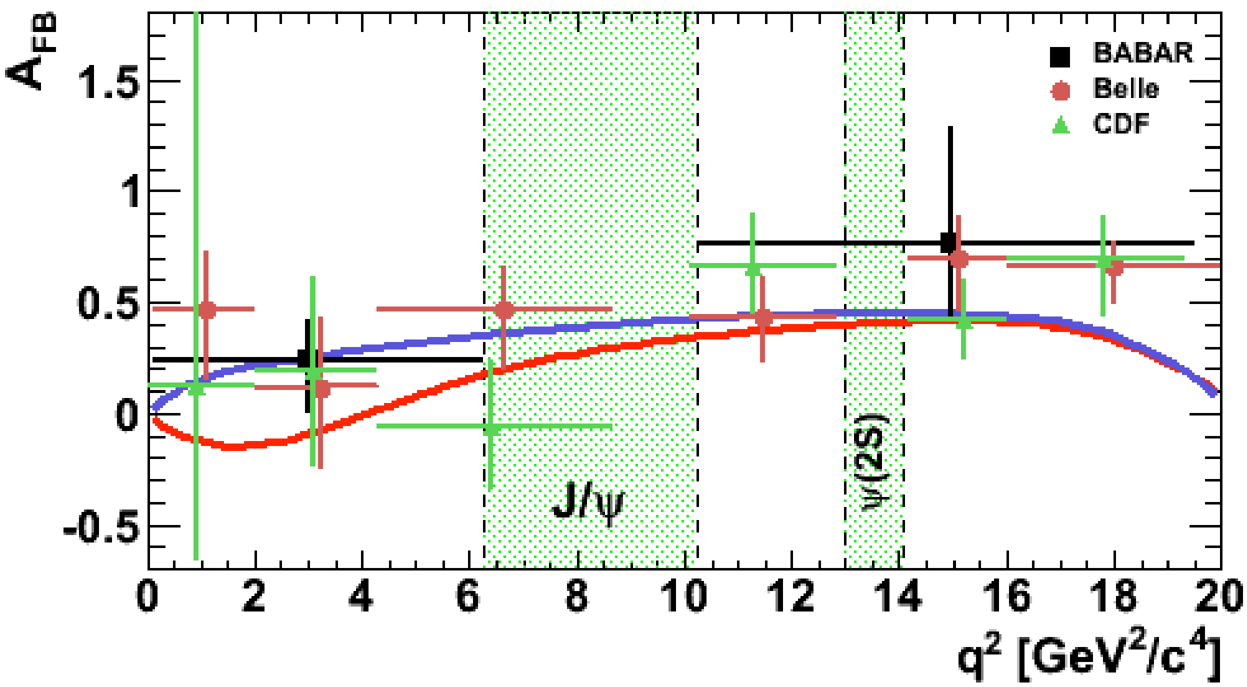
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$



- The observable forward-backward asymmetry A_{FB} of lepton system is a function of lepton invariant mass (q^2). It is sensitive to the helicity structure of possible New Physics

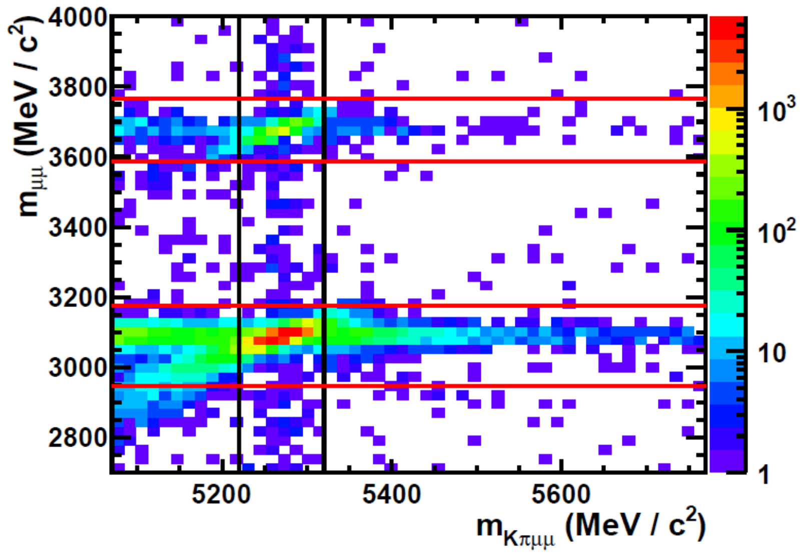
Search for NP in $B_d \rightarrow K^* \mu^+ \mu^-$

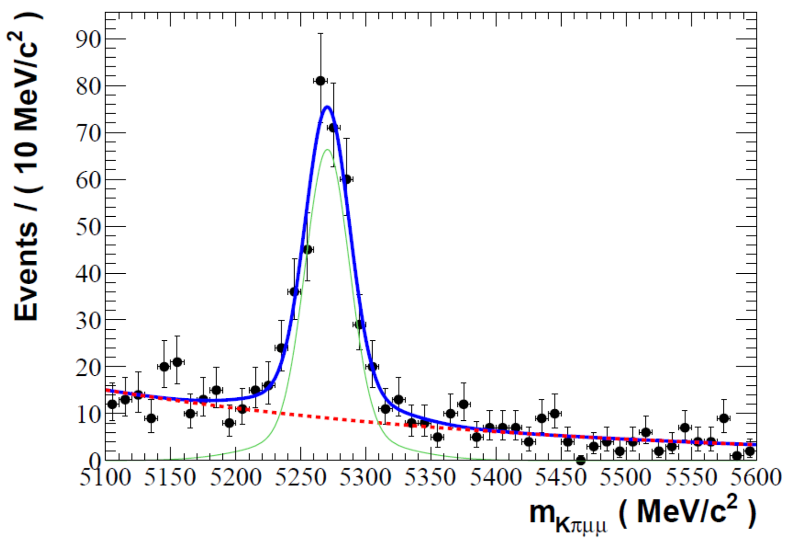
- Results from CDF and B-factories show possible disagreement with SM at low q^2
- Despite to Standard model predictions, BABAR, BELLE and CDF experiments demonstrate positive magnitudes for the A_{FB} in the region $0 < q^2 < 4$ GeV^2/c^4



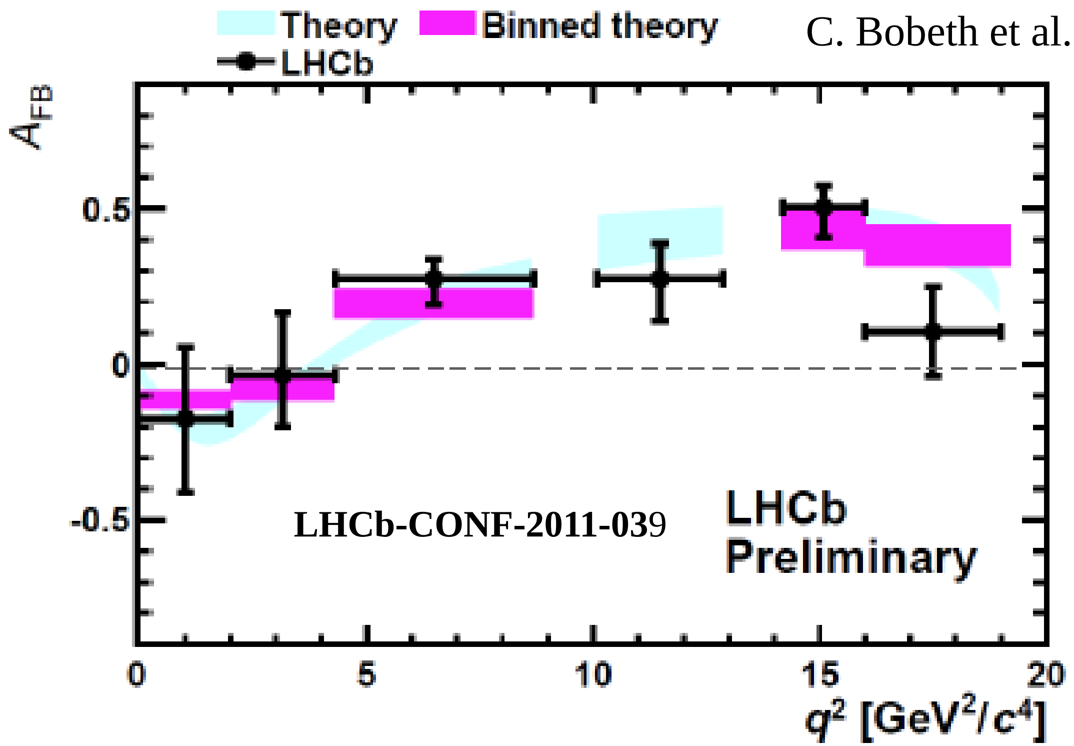
Search for NP in $B_d \to K^* \mu^+ \mu^-$. Experimental approach

- To measure $B_d \to K^*(K\pi)\ \mu^+\mu^-$ a veto was applied to decays in J/Ψ and Ψ(2S) resonance mass regions
- Events selected using Boosted Decision Tree method from sample of 309 pb^{-1}





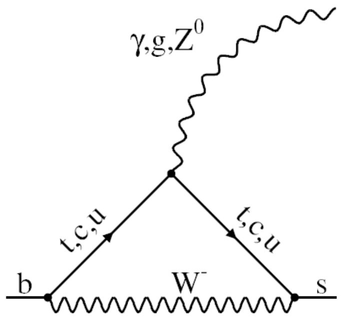
Search for NP in $B_d \to K^* \mu^+ \mu^-$



C. Bobeth et al. [arXiv:1105.0376v2]

- Data are consistent with the SM predictions at present sensitivity. Result indicates for the first time that the asymmetry possibly is changing sign as predicted by the SM
- LHCb result based on 309 pb^{-1} and 300 candidates (largest data sample)

Radiative decays



- Radiative penguins diagrams have a very clear experimental signature : photon in the final state
- Observables : branching fractions, direct CP and isospin asymmetries, photon polarization

$$\Delta_{0+}(B^0 \to K^{*0}\gamma) = \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)} \qquad \lambda_\gamma = \frac{|\mathcal{A}_R|^2 - |\mathcal{A}_L|^2}{|\mathcal{A}_R|^2 + |\mathcal{A}_L|^2}$$

- Isospin asymmetry: strong sensitivity to NP effects. Theoretically predicted
- Photon polarization: admixture of photons with the "wrong" polarization can be large in SM extensions. In the SM photons are ~100% polarized

- Experimental status (branching ratios):

Belle , Babar results

	Theory ($\times 10^{-5}$)	Experiment ($\times 10^{-5}$)
$B^0 \to K^{*0}\gamma$	4.3 ± 1.4	4.33 ± 0.15
$B_s \to \phi\gamma$	4.3 ± 1.4	$5.7^{+4.8\ +1.2}_{-1.5\ -1.1}$
$B \to \rho\gamma$	$0.130^{+0.018}_{-0.019}$	$0.139^{+0.022}_{-0.021}$

Experimental measurement of radiative decays. Fast facts

- Experimental signature of radiative decays is a photon (γ)
- Resolution in the B mass peak is completely dominated by γ (150 MeV/c^2)
- Calorimeter calibration is essential
- Difficult separation between γ and $\pi 0$
- High background level due to proton-proton interactions
- In $b \to d\gamma$ decays, huge background from $b \to s\gamma$
- Both BaBaR and Belle radiative decays measurements were established in the later stages of the experiments

LHCb prospects in radiative decays

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

  Expected statistical precision at the level of ~2% with 1fb-1

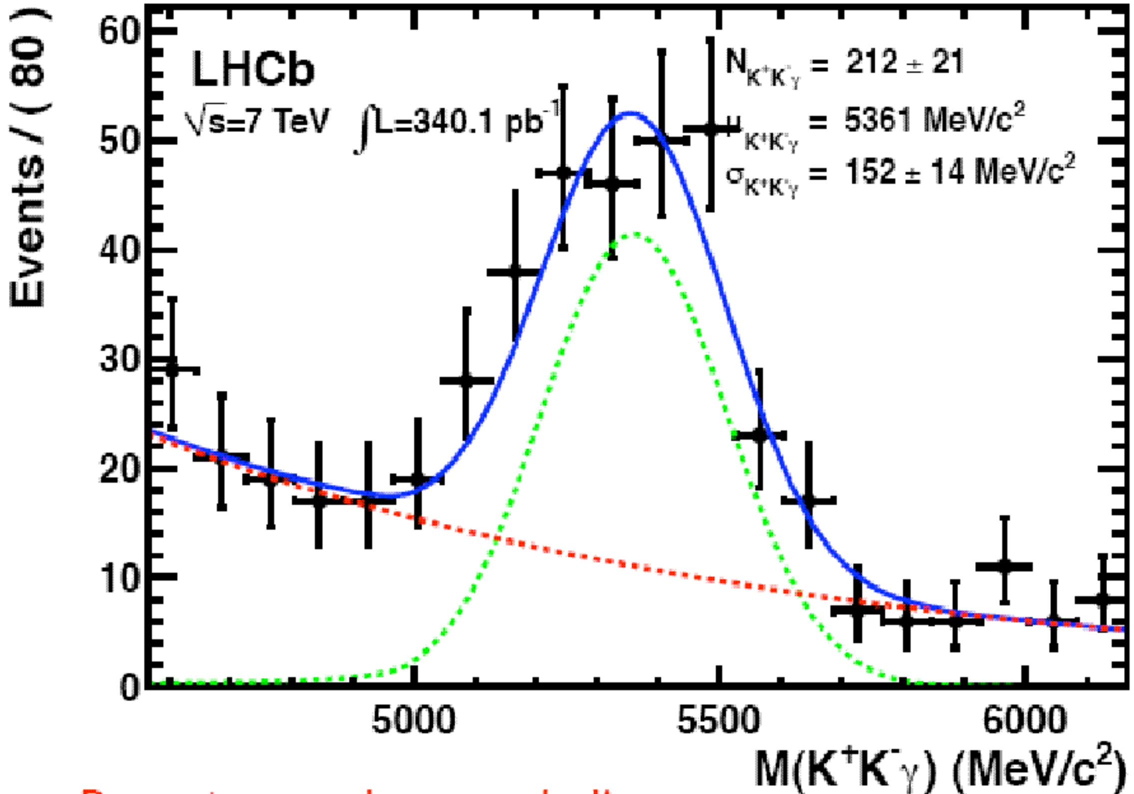
- ✓ Isospin asymmetry in $B_s \rightarrow K^{*}\gamma$. Studies will start soon

- ✓ Photon polarization in $B_s \rightarrow \varphi\gamma$. Direct access the "wrongly" polarized fraction (if any exists)

  Need 2fb^{-1} to achieve a precision of 20% for polarization parameters

LHCB $B_s \to \varphi\gamma$

- $N_{kk\gamma} = 212$ $B_s \to \varphi(K^+K^-)\gamma$ events reconstructed at 340 pb^{-1}



Largest $B_s \to \phi\gamma$ sample recorded!

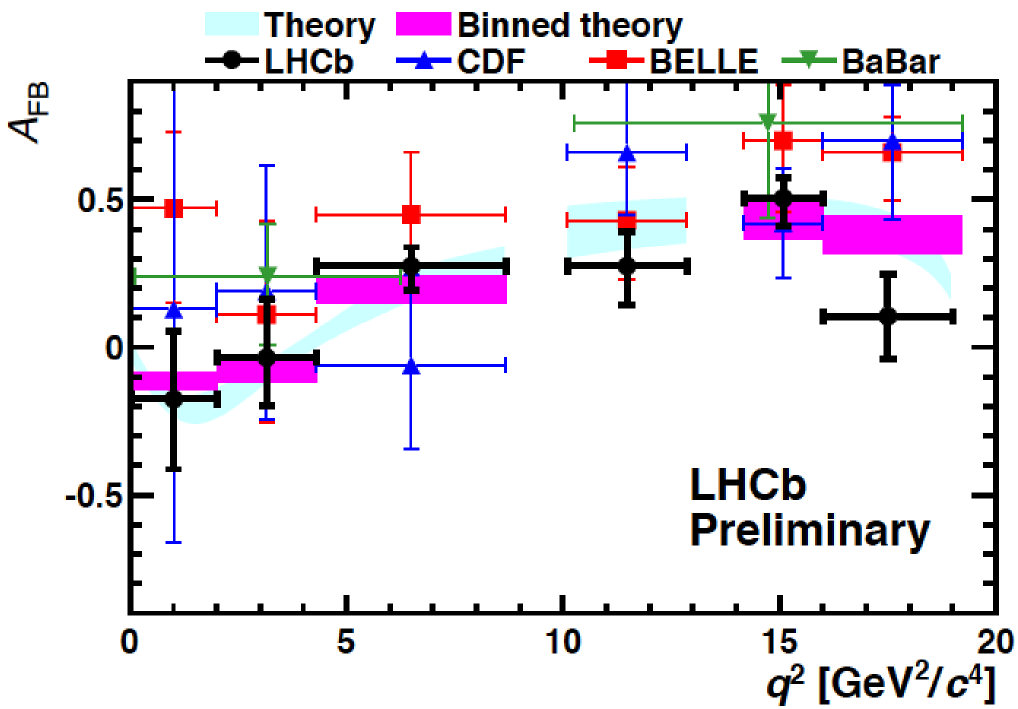
- The studies will be continued with higher integral luminosity

Conclusions

- LHCb in 2011 year with the integrated luminosity 300 pb^{-1} provided the upper limits :
  $Br(B_s \to \mu^+ \mu^-) < 1.5 \times 10^{-8}$ at 95 % CL
  $Br(B_d \to \mu^+ \mu^-) < 5.2 \times 10^{-9}$ at 95 % CL
- LHCB-CMS combined result is $Br(B_s \to \mu^+ \mu^-) < 1.1 \times 10^{-8}$ at 95 % CL (CMS result $Br(B_s \to 2\mu) < 1.8 \times 10^{-8}$ (95 % CL)
- Excess of the $B_s \to \mu^+ \mu^-$ events reported by CDF (hep-ex/1107.2304) not confirmed
- LHCb plans to reach the sensitivity $Br(B_s \to 2\mu) = 8 \times 10^{-9}$ (95 % CL) in the end of this year
- $Bd \to K^* \mu^+ \mu^-$ data are consistent with the SM predictions at present sensitivity Indication that the asymmetry is changing sign as predicted in the SM.
- Radiative decays are starting to give results in LHCb
- *We are waiting a lot of new results with 3 times more integrated luminosity in December 2011!*

Backup slides

Search for NP in Bd→K*μ+μ-



BaBar [PRD **79** (2009)], Belle [PRL **103** (2009)], CDF [PRL **106** (2011)]