Rare B–decays in ATLAS

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Introduction - I

Physics: **b → d, s** transitions (**FCNC**) are forbidden at the tree level in SM and occur at the lowest order through one-loop-diagrams **"penguin"** and **"box"**.

Main points for study:

a) The good test of SM and its possible extensions

- SUSY, Two Higgs-doublet, LR, Extra Dimensions;

b) Information of the long-distance QCD effects;

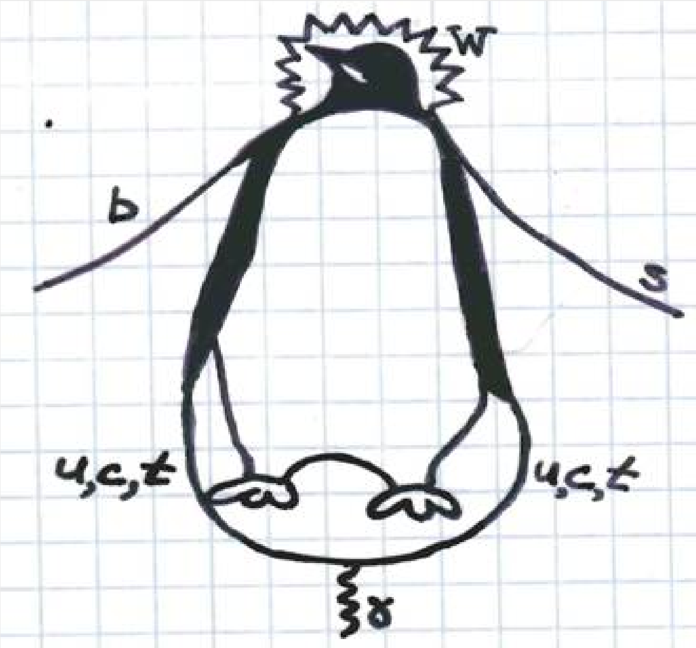
c) Determination of the $|V_{td}|$ and $|V_{ts}|$;

d) Some of rare decays as BG to other rare decays

(for example: $B^0_d \to \pi^0 \mu^+ \mu^-$ as BG to $B^0_{d,s} \to \mu^+ \mu^-$).

Introduction - II

Branching Ratios Hierarchy in SM:



$Br(B^0_d \to \mu^+ \mu^-)$ ~ "a few" * 10^{-10}

$Br(B^0_d \to \mu^+ \mu^- \gamma)$ ~ "a few" * 10^{-10}

$Br(B^0_s \to \mu^+ \mu^-)$ ~ "a few" * 10^{-9}

$Br(B^0_s \to \mu^+ \mu^- \gamma)$ ~ "a few" * 10^{-8}

$Br(B^0_d \to \pi^0 \mu^+ \mu^-)$ ~ "a few" * 10^{-8}

$Br(B^0_d \to K \mu^+ \mu^-) = (5.6 \pm 2.5) * 10^{-7}$ (BaBar, Belle, '02)

$Br(\Lambda_b \to \Lambda \mu^+ \mu^-)$ ~ "a few" * 10^{-6}

$Br(B^0_s \to \varphi \mu^+ \mu^-)$ ~ "a few" * 10^{-6}

$Br(B^0_d \to K^* \mu^+ \mu^-) = (1.3 \pm 0.4) * 10^{-6}$ (BaBar, Belle, '03)

$Br(B^0_d \to K^* \gamma) = (4.3 \pm 0.4) * 10^{-5}$ (CLEO, '93)

Current status of the branchings

BABAR N_{BB}=123M

$$B(B \to K l^+ l^-) = \left(6.5^{+1.4}_{-1.3} \pm 0.4\right) \times 10^{-7}$$
$$B(B \to K^* l^+ l^-) = \left(8.8^{+3.3}_{-2.9} \pm 1.0\right) \times 10^{-7}$$

BELLE N_{BB}=273M

$$B(B \to K l^+ l^-) = \left(5.50^{+0.75}_{-0.70} \pm 0.27 \pm 0.02\right) \times 10^{-7}$$
$$B(B \to K^* l^+ l^-) = \left(16.5^{+2.3}_{-2.2} \pm 0.9 \pm 0.4\right) \times 10^{-7}$$

BABAR N_{BB}=123M

- $B(B^0 \to e^+ e^-) < 6.1 \times 10^{-8}$ (90%CL)
- $B(B^0 \to \mu^+ \mu^-) < 8.3 \times 10^{-8}$ (90%CL)
- $B(B^0 \to e^+ \mu^-) < 18 \times 10^{-8}$ (90%CL)

BELLE N_{BB}=85M

$$B(B^0 \to e^+ e^-) < 19 \times 10^{-8}$$
$$B(B^0 \to \mu^+ \mu^-) < 16 \times 10^{-8}$$
$$B(B^0 \to e^\pm \mu^\mp) < 17 \times 10^{-8}$$

D0 $B_s \to \mu^+\mu^-$ result: 240pb^{-1}

$$BF(B_s \to \mu^+ \mu^-) < 3.8 \times 10^{-7}\ 90\%\ CL$$

CDF $B_{(s,d)} \to \mu^+\mu^-$ results: 171pb^{-1}

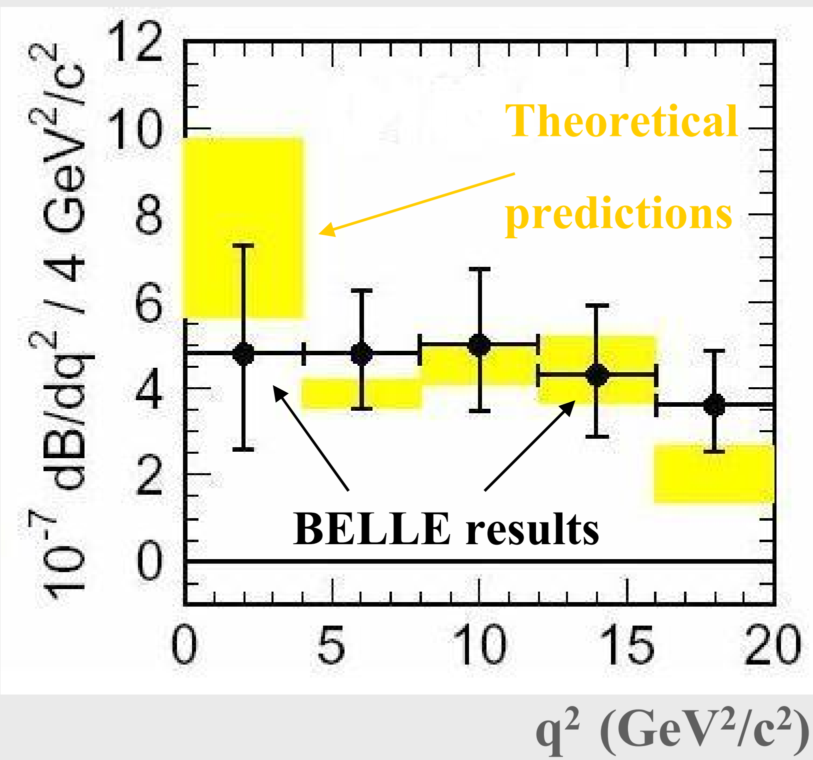
$$BF(B_s \to \mu^+ \mu^-) < 5.8 \times 10^{-7}\ 90\%\ CL$$
$$BF(B_d \to \mu^+ \mu^-) < 1.5 \times 10^{-7}\ 90\%\ CL$$

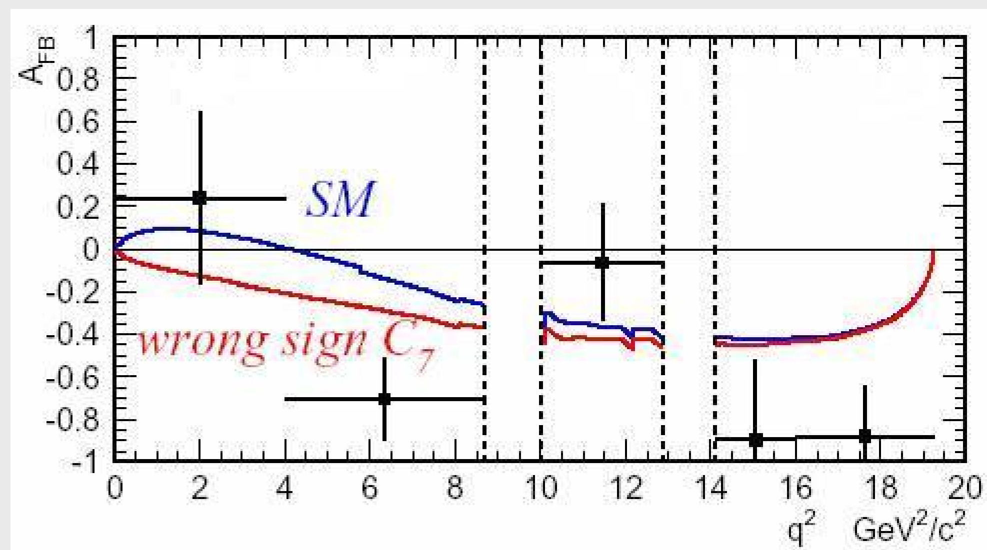
Y.Kwon (BELLE Colab.), "EW Penguin & Leptonic B decays", Report on FPCP 2004, Oct. 4-9 04.

Current status of the Differencial distributions for $B^0_d \to K^* l^+ l^-$

Y.Kwon (BELLE Colab.), **"EW Penguin & Leptonic *B* decays"**, Report on **FPCP 2004**, Oct. 4-9 **2004**.

N_{BB}=273M





Which new measurements can LHC make in rare B-decays comparing with B-factories?

a) **The rare decays of B^0_s – meson ($B^0_s \to \varphi\gamma$, $B^0_s \to \varphi\, \mu^+ \mu^-$, and $B^0_s \to \mu^+ \mu^- (\gamma)$) and Λ_b – baryon ($\Lambda_b \to \Lambda\, \mu^+ \mu^-$, $\Lambda_b \to \Lambda\, \gamma$);**

b) **Differencial distributions for rare semileptonic B-meson decays (dimuon-mass spectra, forward-backward asymmetries) with needed accuracy – very sensitive to the SM extensions;**

c) **Branching fractions of $B^0_{d,s} \to \mu^+ \mu^-$ and $B^0_{d,s} \to \mu^+ \mu^- \gamma$ decays – good sensitivity to the SM extensions.**

The basic theoretical description -I

Effective Hamiltonian for b → d,s transition:

$$\mathbf{H_{eff}\,(b \to q) \sim G_F V^*_{tq} V_{tb} \sum C_i(\mu)\, O_i\,(\mu)},$$

includes the lowest EW-contributions and perturbative QCD corrections for Wilson coefficients $\mathbf{C_i(\mu)}$.

μ - scale parameter ~ **5 GeV** : separates **SD** (perturbative) and **LD** (nonperturbative) contributions of the strong interactions.

SM NLO: A.Buras, M.Munz, *PRD52, p.182, 1995*

SM NNLO: C.Bobeth et al., *JHEP 0404, 071, 2004*

MSSM NNLO: C.Bobeth et al., *NPB713, p522, 2005*

SUSY: main motivations for study in rare B-decays

1) SUSY is the best from all possible extensions of SM.

2) Only lightest (m ~ 1 TeV) of SUSY- particles can be directly detected on LHC at high luminosity.

3) All SUSY-particles give the virtual particle corrections in SM processes.To find the information on SUSY particles it is necessary to study the decays where:

a) SM contributions are suppressed as much as possible;

b) perturbative and nonperturbative QCD corrections known with high accuracy;

c) branchings can be measured in LHC already at low luminosity.

Rare $B^0_{d,s}$ and Λ_b decays are IDEAL CHOICE for that!

The basic theoretical description -II

$O_i(\mu)$ – set of the basic operators **(specific for each model: SM, MSSM, LR and others);**

LD (nonperturbative) contribution of the strong interactions are contained in the hadronic matrix elements:

$$\langle \text{final hadronic states} \,|\, O_i(\mu) \,|\, \text{initial hadronic states} \rangle$$

and are described in the terms of relativistic invariant function - **transition formfactors**.

⬇ ⬇

Need the nonperturbative methods (SR, QM, Lat).

The accuracy of calculations

Stability of the Wilson coefficients to the choice of m_t and $\mu \in [m_b/2, 2m_b] \approx [2.5$ GeV, 10.0 GeV]:

SM NLO: approximately **15%** ;

SM NNLO: approximately **6% - 7%** ;

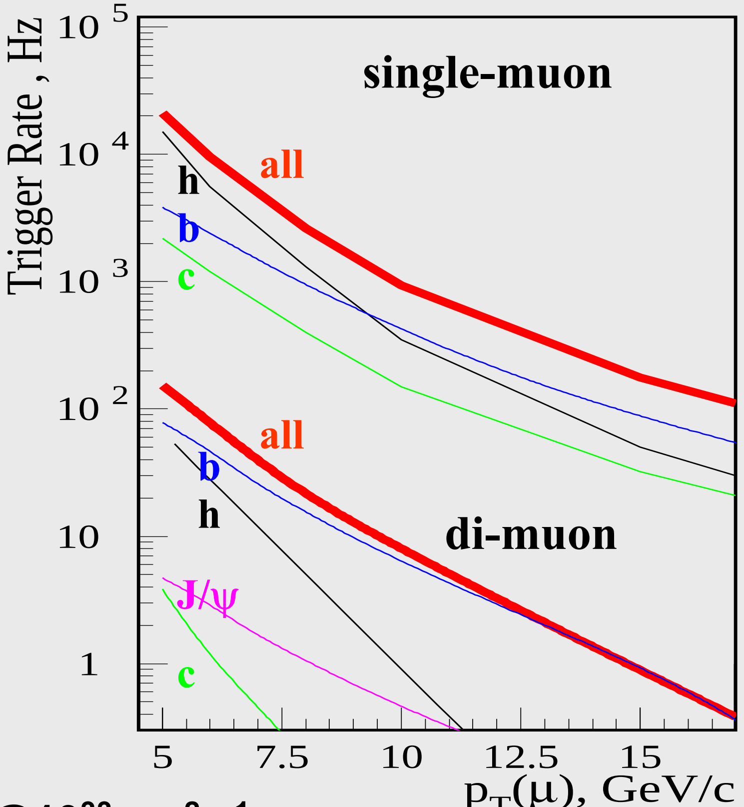
MSSM NNLO: > **30%** strongly depends from the parameters set boundaries!

Accuracy of the nonperturbative calculations: depends on a method, but it's not less, than **15%** .

For SM calculations – NLO, for MSSM – NNLO.

ATLAS muon trigger strategy

ATLAS LVL1, Trigger rates
@$10^{33}cm^{-2}s^{-1}$



@$10^{33}cm^{-2}s^{-1}$

1) The study of two-muons rare decays (**$B^0_s \rightarrow \mu^+ \mu^-$** , **$B^0_d \rightarrow K^* \mu^+ \mu^-$**) based on LVL1 di-muon trigger (can be continued at nominal 10^{34} $cm^{-2}s^{-1}$).

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2) The study of rare radiative decays (**$B^0_s \rightarrow \varphi\gamma$, $B^0_d \rightarrow K^* \gamma$**) based on single muon LVL1 (μ6) with photon recon-struction in EM CALO.

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3) Rare decays (**$B^0_d \rightarrow \pi^0 \mu^+ \mu^-$**, **$B^0_s \rightarrow \mu^+ \mu^- \gamma$**) based on 1) + 2).

Simulations of rare B-decays for ATLAS detector

B-physics simulation history

1) 1998-1999-years simulation

Early ATLAS Detector layout

CERN/LHCC/99-15, ATLAS TDR 15, 25 MAY 1999;

"1999 Workshop on SM Physics (and more) at the LHC", CERN Yellow Reports **CERN-2000-004**.

2) 2002-2003-years simulations

Final ATLAS Detector layout

ATLAS B-Physics Group, ATL-PHYS-2005-002

3) 2004-2005-years simulation

Final ATLAS Detector layout **with new software**

ATLAS Physics workshop (Rome),

http://agenda.cern.ch/fullAgenda.php?ida=a044738

Models used for MC generation

$B^0_s \to \mu^+ \mu^-$	$Br(B^0_s \to \mu^+ \mu^-) = 3.5 * 10^{-9}$ at $\vert V^*_{ts} V_{tb} \vert^2 = 2.2 * 10^{-3}$
$B^0_d \to \mu^+ \mu^-$	$Br(B^0_d \to \mu^+ \mu^-) = 0.9 * 10^{-10}$ at $\vert V^*_{td} V_{tb} \vert^2 = 6.9 * 10^{-5}$
$B^0_d \to K^* \mu^+ \mu^-$ $B^0_s \to \varphi \mu^+ \mu^-$ $B^0_d \to \pi^0 \mu^+ \mu^-$	$Br(B^0_d \to K^* \mu^+ \mu^-) = 1.3 * 10^{-6}$ from PDG'04 $Br(B^0_s \to \varphi \mu^+ \mu^-) / Br(B^0_d \to K^* \mu^+ \mu^-) = 0.8$ D.Melikhov, N.Nikitin, S.Simula, PRD57, 6814, 1998 D.Melikhov, B.Stech, PRD62, 014006, 2000 A.Buras, M.Munz, PRD52, 186, 1995 $Br(B^0_d \to \pi^0 \mu^+ \mu^-) = 2.0 * 10^{-8}$ at $\vert V^*_{td} V_{tb} \vert^2 = 6.9 * 10^{-5}$
$B^0_s \to \mu^+ \mu^- \gamma$	$Br(B^0_s \to \mu^+ \mu^- \gamma) = 1.9 * 10^{-8}$ at $\vert V^*_{ts} V_{tb} \vert^2 = 2.2 * 10^{-3}$ D.Melikhov, N.Nikitin, PRD70, 114028, 2004 F.Kruger, D.Melikhov, PRD67,034002, 2003 A.Buras, M.Munz, PRD52, 186, 1995
$\Lambda_b \to \Lambda \mu^+ \mu^-$	$Br(\Lambda_b \to \Lambda \mu^+ \mu^-) = 2.0 * 10^{-6}$ C-H.Chen, C.Q.Geng, PRD64, 074001, 2001 T.M.Aliev et.al. , NPB649, p. 168-188 , 2003

$B^0_{d,s} \rightarrow \mu^+\mu^-$ decays in ATLAS - I

Points for study in ATLAS:

Very clear signature; BR very tiny in SM ,but good sensitive to the SUSY .

1998-2004 simulations history:

Full Inner detector simulation and reconstruction at initial and nominal LHC luminosity

1) for TDR layout signal + background (ATLAS TDR 15, Vol.II, 1999)

2) for Initial layout only signal (ATL-PHYS-2005-002).

1998-year simulation results (TDR results):

Using SM branchings: Br($B^0_{d,} \rightarrow \mu^+\mu^-$) ≈ $1.5 * 10^{-10}$ and Br($B^0_{d,} \rightarrow \mu^+\mu^-$) ≈ $3.5 * 10^{-9}$

we obtaned the following sensitivities for ATLAS

After 3 year LHC work at $L=10^{33}$ $cm^{-2}s^{-1}$ (30 fb^{-1}) will be expected

B^0_d : 4 signal ev., B^0_s : 27 signal ev., 93 BG ev. common to both

After 1 year LHC work at $L=10^{34}$ $cm^{-2}s^{-1}$ (100 fb^{-1}) will be expected

B^0_d : 14 signal ev., B^0_s : 92 signal ev., 660 BG ev. common to both

$B^0_d \rightarrow \mu^+\mu^-$: $3 * 10^{-10}$ upper limit at CL 95%

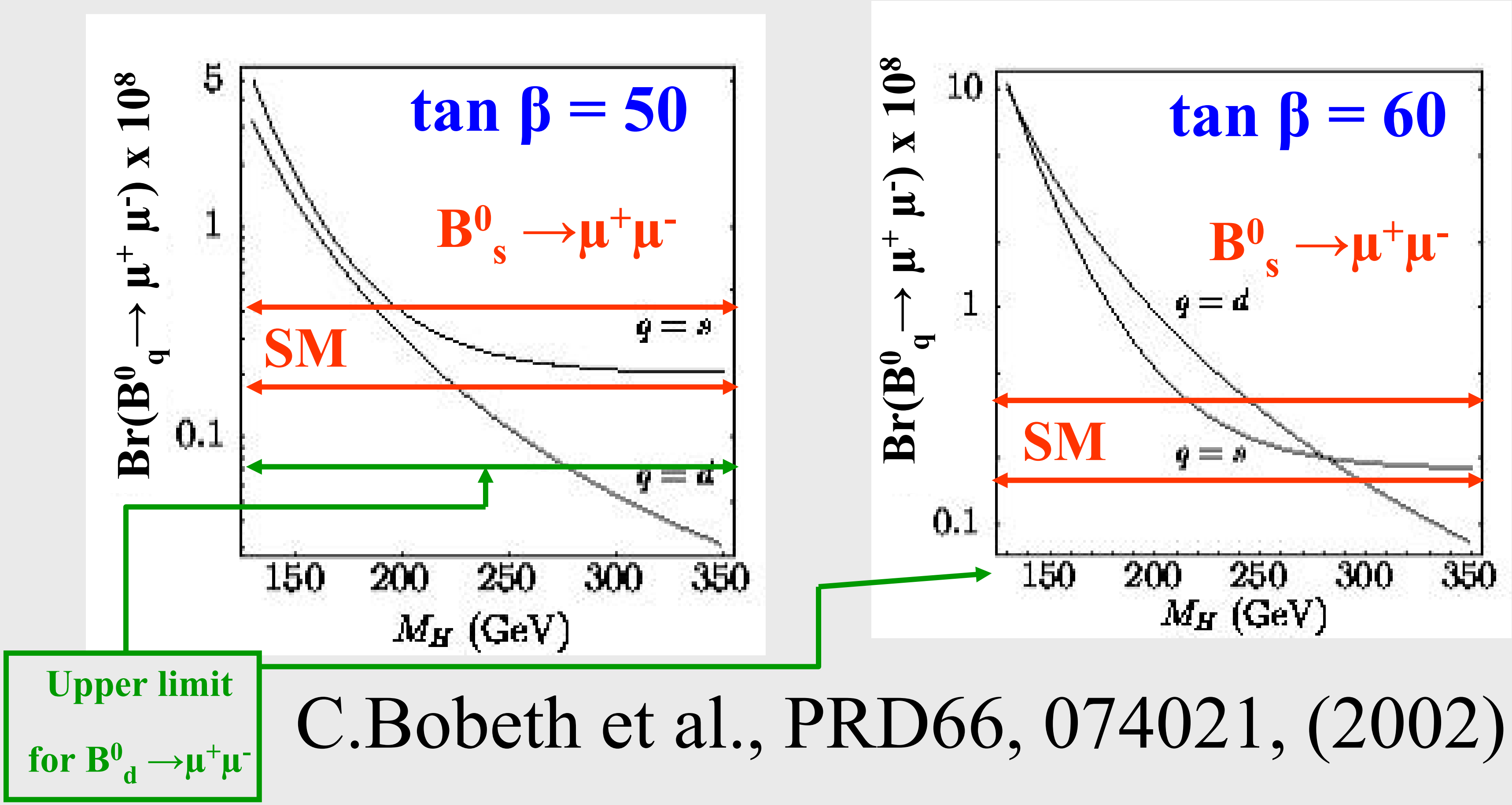
$B^0_s \rightarrow \mu^+\mu^-$: 2.8σ at 3year@10^{33} and combining wiht 1year@10^{34} - 4.3σ

$B^0_s \to \mu^+\mu^-$ decays in ATLAS –II 2005 year results

Signal, BG and efficiencies of selection cuts (30 fb^{-1})

Cuts	Background		B^0_s - Signal	
Vertexing procedure	CTMVFT	VKalVrt	CTMVFT	VKalVrt
$p_T(\mu) > 6$ Gev, $\Delta R_{\mu\mu} < 0.9$	**1.8×10^7 events**		**150 events**	
$M(\mu\mu)=M_B{}^{+140}_{-70}$ MeV	2×10^{-2}	—	0.77	—
Isolation cut: no ch.tracks p_T>0.8 GeV in cone with $\theta < 15^o$	5×10^{-2}	5×10^{-2}	0.36	0.36
$\sigma < 90\mu m$, $L_{xy}/\sigma > 15$, $\alpha < 1^o$	2.8×10^{-3}		0.2	
$L_{xy}/\sigma > 11$, $\chi^2 < 15$		$< 0.7 \times 10^{-4}$		0.4
Number of events after cuts	**45±30**	**< 60**	**9**	**21**
$S/\sqrt{BG}$			**(1.7±0.6)σ**	**>2.7σ**

MSSM for $B^0_{d,s} \to \mu^+\mu^-$ decays and ATLAS sensitivity (2005 - results ony for low luminosity)

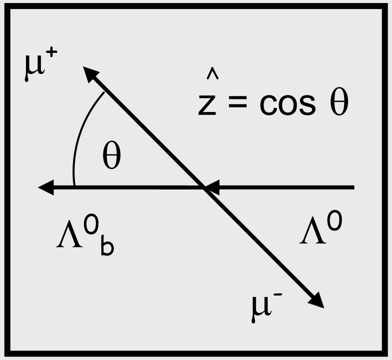


C.Bobeth et al., PRD66, 074021, (2002)

The $\mathbf{B^0_{d,s} \to \mu^+\mu^-}$ branchings as functions of charge Higgs boson mass $\mathbf{M_H}$ for two choice the **tan β**.

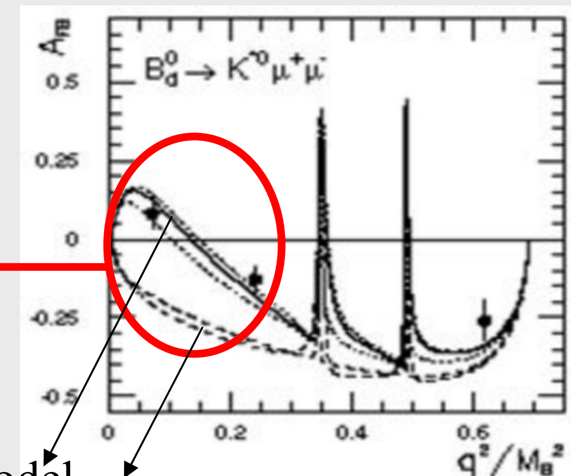
$\Lambda_b \rightarrow \Lambda\, \mu^+ \mu^-$ - motivation for study

A_{FB} – is very sensitive to the SUSY



Main definition for A_{FB}

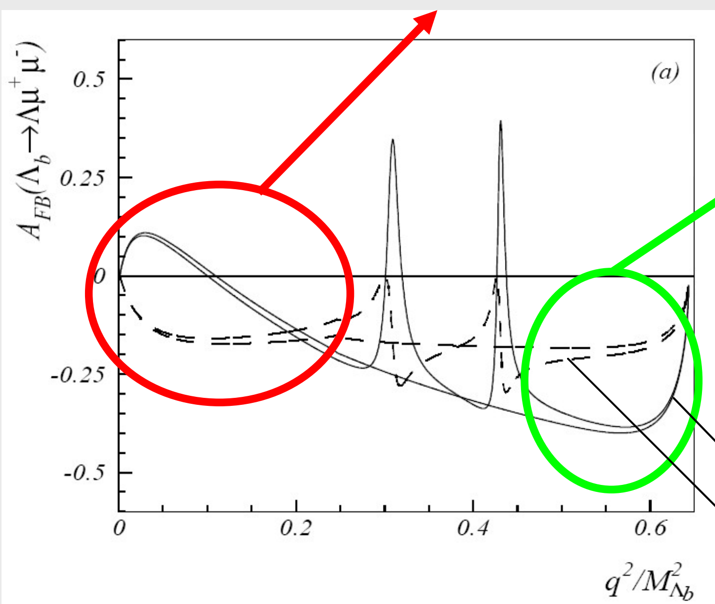
A_{FB} in low di-muon invariant mass region (outside J/ψ resonances) shows significant sensitivity to new physics effects



ATLAS TDR vol II, 1999

Standard model

MSSM model (C_{7g}^{eff}>0 and <0): [P.Cho et al., PRD54,p.3329, 1996]



[C-H.Chen et al., Phys.Rev.D64,074001 2001]

Also sensitive, but:

- higher ψ resonances
- more sensitive to $\Lambda^0_b \rightarrow \Lambda^0$ transition form-factors

[C-H.Chen et al., Phys.Lett.B516,327-336, 2000]

Standard model, W.C.: [A.J.Buras et al., Phys.Rev.D52,186 1995]

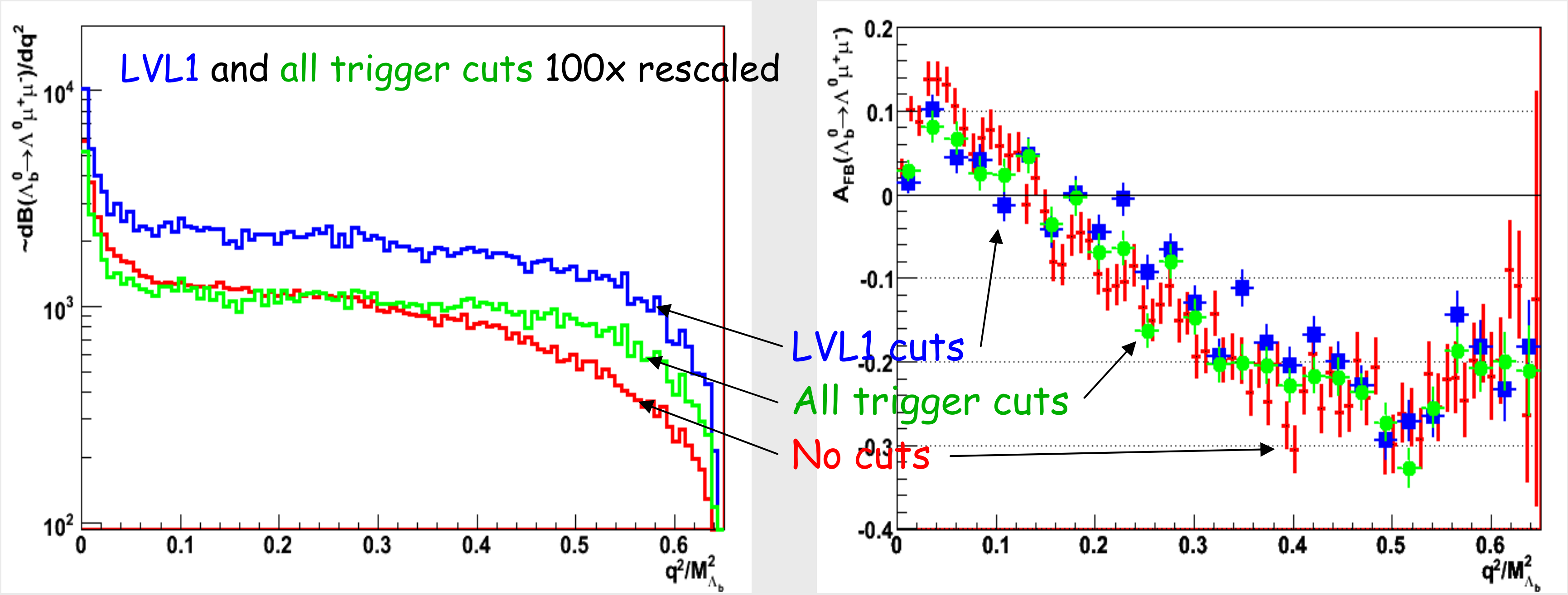
SUSY model: [E. Lunghi et al., Nucl.Phys.B568,120-144 2000]

Impact of Trigger Cuts for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$

- expected number of triggered events for 30 fb^{-1}

Λ_b - production	**σ_{bb} = 500μb, Br(b→Λ_b) = 0.071**	**1.1×10^{12}**
Λ_b rare decay	**Br(Λ_b→Λμμ) = 2×10^{-6} , Br(Λ→pπ) = 0.64**	**1.400.000**
Di-muon LVL1 cuts	**p_T > 6/4 GeV, |η| < 2.5**	**26.000**
Hadron cuts	**p_T >0.5 GeV, |η| < 2.5**	**14.000**

- trigger cuts prefers higher di-muon invariant masses and slightly lowers absolute value of A_{FB} in region of lower di-muon masses



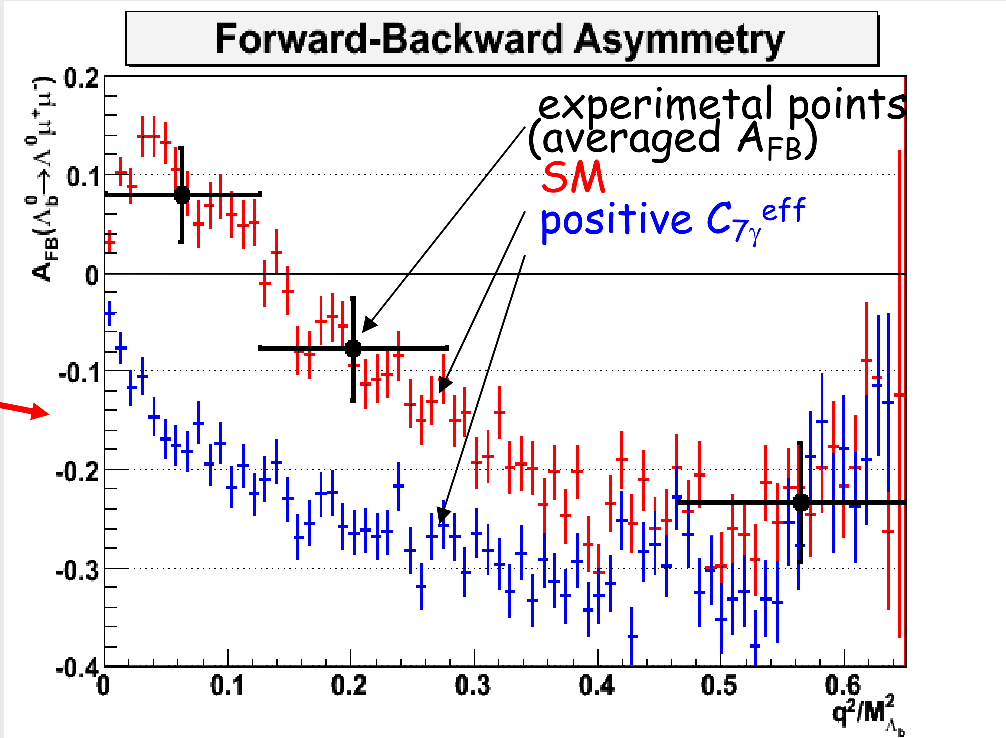
2005 – year simulation results for A_{FB}

Expected precision for 30 fb^{-1}:

14% - reconstruction efficiency accounting 75% LVL1 efficiency

q^2/M_{Λ_b}	min .. 0.13	0.13 .. 0.28	0.47 .. max
$\langle A_{FB}\rangle$ for SM	7.9%	-7.8%	-23.3%
$\langle A_{FB}\rangle$ for $C_{7\gamma}^{eff} > 0$	-13.8%	-25.0%	-27.9%
$\langle A_{FB}\rangle$ statistical error	4.8%	5.2%	6.2%
Number of events	430	370	280

1500 events



$B^0_d \to K^*(892)\mu^+\mu^-$ decay at ATLAS - I

Points for study in ATLAS:

Branching ratio - sensitive to the SUSY ;

Differencial distributions (dimuon-mass spectra, A_{FB})

→ very sensitive to the SUSY.

1998-1999 years simulations :

Full ATLAS Inner detector simulation and reconstruction at initial luminosity (ATLAS TDR 15, Vol.II, 1999) using theoretical matrix element from paper D.Melikhov, N.Nikitin, S.Simula, PRD57, 6814, 1998.

Results of 1998-1999 years simulation:

After 3 year LHC work at $L=10^{33}$ $cm^{-2}s^{-1}$ (30 fb^{-1}) will be expected

~2000 signal events at 290 BG events

$B^0_d \to K^*(892)\mu^+\mu^-$ decay at ATLAS – II 2005-year results

~120 kEv of signal before the cuts for 30 fb^{-1}.

Cuts:

$p_T(\mu) > 6$ Gev, $|\eta(\mu)| < 2.5$

$M(h^+h^-) = M(K^*) \pm 30$ MeV

Vertexing procedure VkalVrt:

$\chi^2 < 18$, $L_{xy}/\sigma > 35$

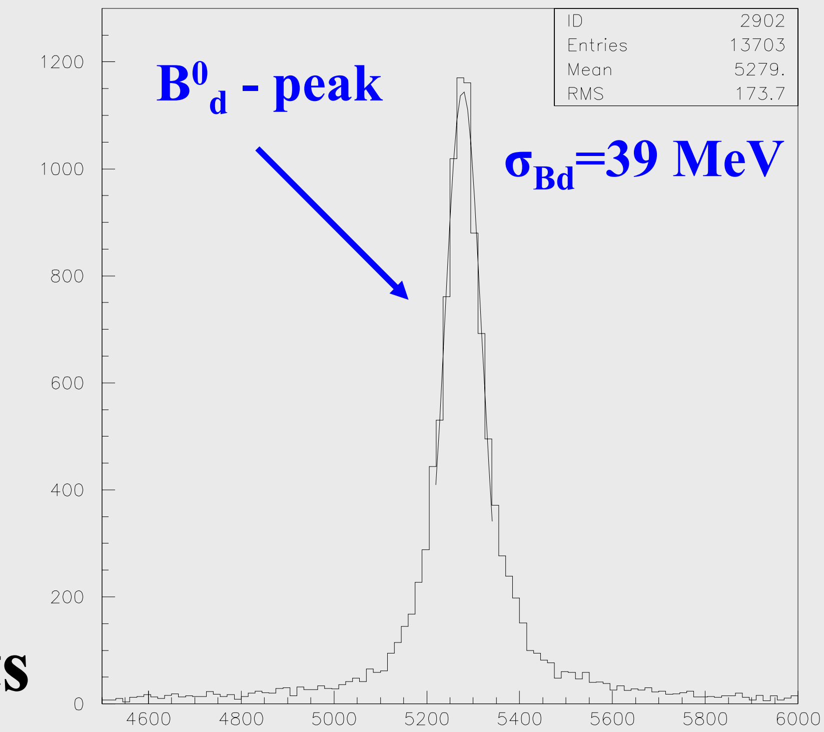
Isolation cut: no ch.trecs

$p_T > 0.8$ GeV in cone with $\theta < 5^o$

~ 3000 signal events after all cuts

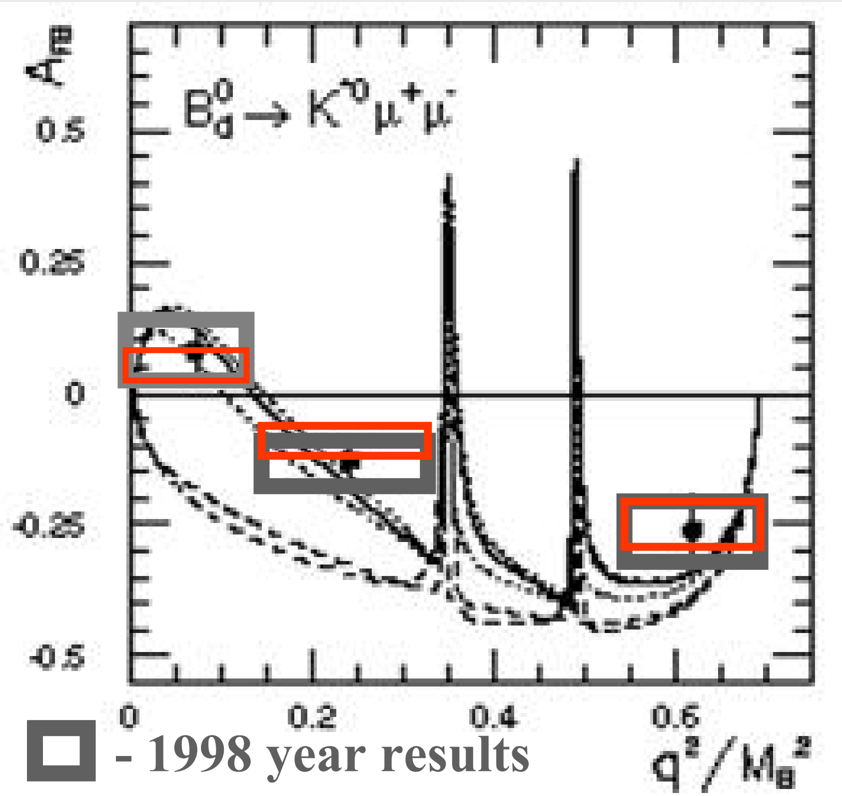
< **3000 BG** (events, will be reconsidered when high statistics available)

Number of reconstructed events (2005 year)



K*μμ – invariant mass (MeV)

MSSM in B →K*(892) μ+μ- decay and ATLAS precision



- 1998 year results

- 2005 year results

Sensitivity of A_{FB} to the choice of the Wilson coefficients in one MSSM scenario:

P.Cho, M.Misiak, D.Wyller, PRD54, p.3329, 1996.

Interval		min − 0.14	0.14−0.33	0.55−max
SM	1998	10%	-14%	-26%
SM	2005	5%	-12%	-25%
MSSM		-17 – 5%	-35 − -13%	~ 30%
ATLAS Accuracy	98	5%	4.5%	6.5%
ATLAS Accuracy	05	2%	2%	5%

Three intervals for variable q^2/M_B^2. If in the first interval the negative average asymmetry will be measured, it will be convincing demonstration of a SM extensions reality.

$B^0_s \to \varphi\mu^+\mu^-$ decay at ATLAS
1998 and 2005 year results

~21 kEv of signal before the cuts for 30 fb^{-1}.

Cuts:

$p_T(\mu) > 6$ Gev, $|\eta(\mu)| < 2.5$

$M(h^+h^-) = M(\varphi) \pm 9$ MeV

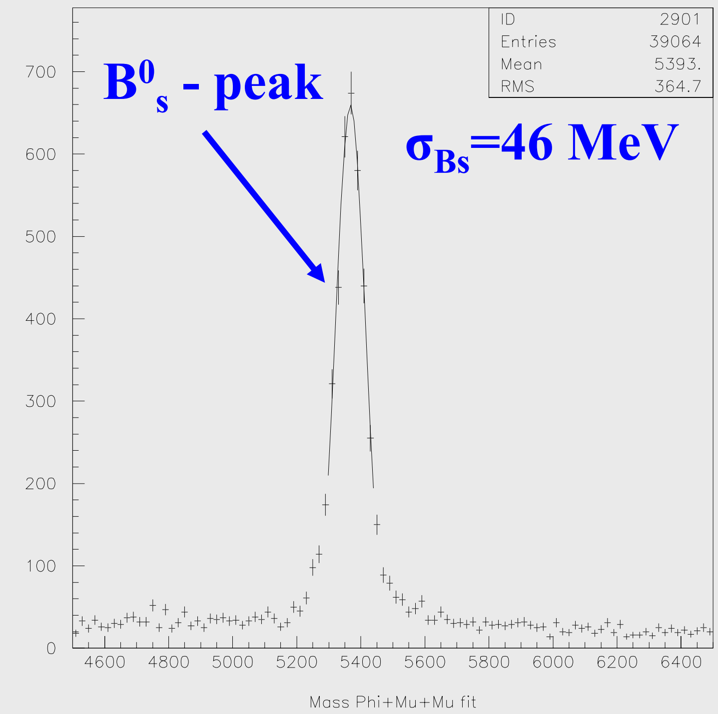
Vertexing procedure VkalVrt:

$\chi^2 < 18$, $L_{xy}/\sigma > 35$

Isolation cut: no ch.trecs

$p_T > 0.8$ GeV in cone with $\theta < 5^o$

Number of reconstructed events (2005 year)



2005-year

~ 900 signal events after all cuts;

< **3000 BG** (events, will be reconsidered when high statistics available)

1998-year (TDR)

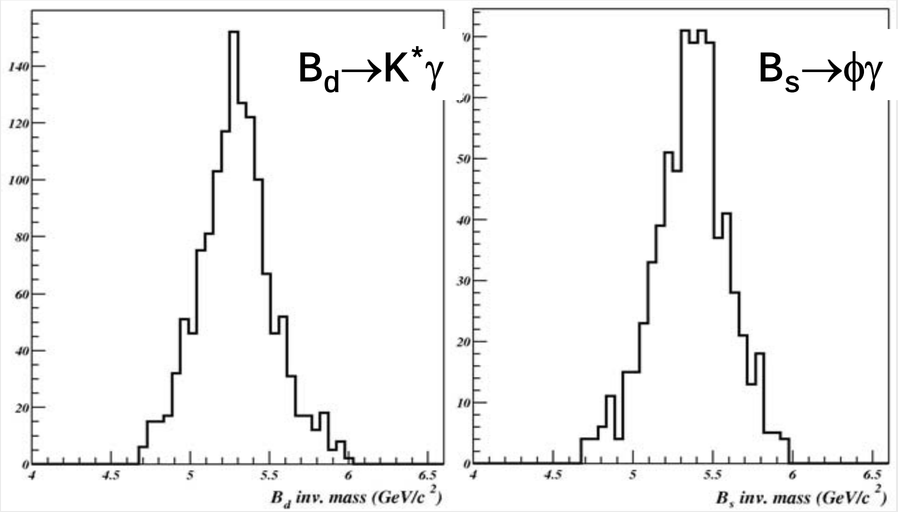
410 signal events after all cuts;

140 BG events.

Radiative penguins in ATLAS: 2002-2004

Points for study in ATLAS:

Branching for $B_s \to \phi\ \gamma$, angular distributions measurements.



ATL-PHYS-PUB-2005-006

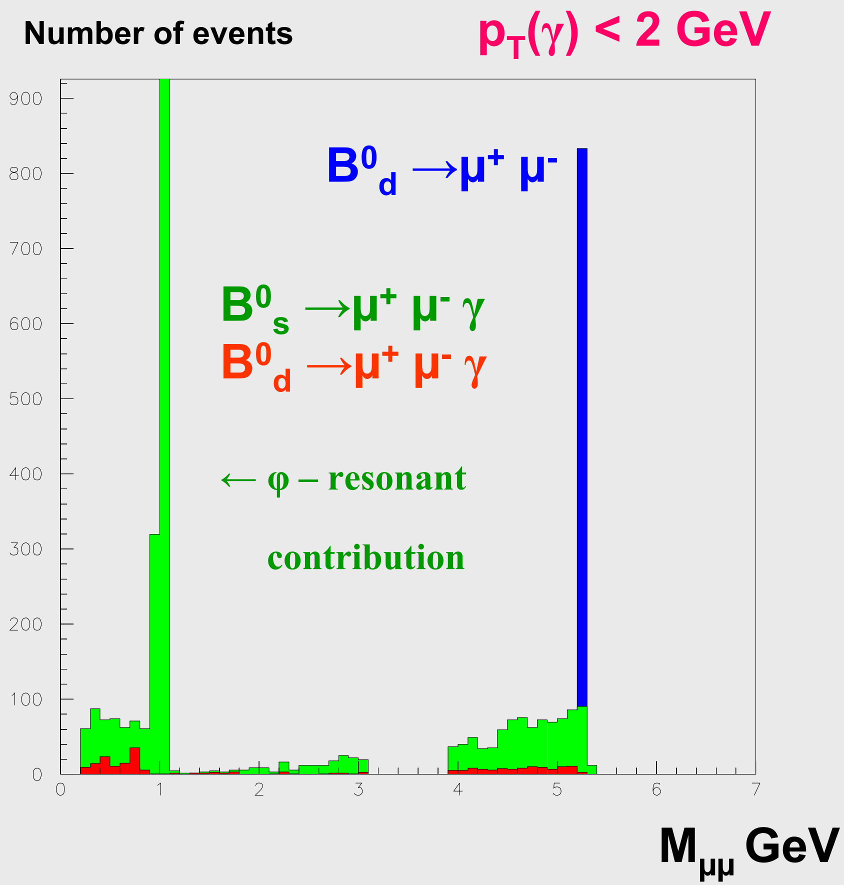
Estimations based on the simplified trigger and the complete off-line studies for 3years LHC work at $L=10^{33} cm^{-2} s^{-1}$ ($30 fb^{-1}$) :

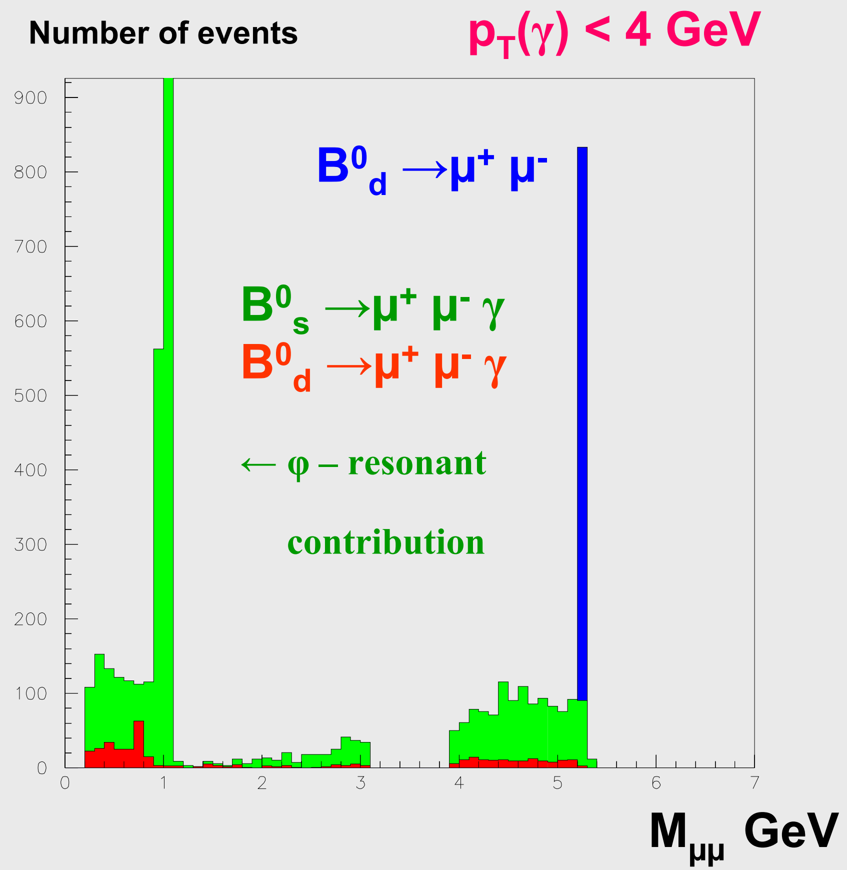
$B_s \to \phi\ \gamma$: **3400 signal ev., $S/\sqrt{BG} > 7$;**

$B_d \to K^{*0}\ \gamma$: **~10000 signal ev., $S/\sqrt{BG} > 5$.**

$B \to K^{*0}\pi^0$ BG rejection under investigation combining $\pi^0/\ \gamma$ rejection cuts, kinematics and angle between B^0 and K^+ at K^*rest frame cuts.

$B^0_{d,s} \to \mu^+\mu^-\gamma$ as BG to $B^0_d \to \mu^+\mu^-$

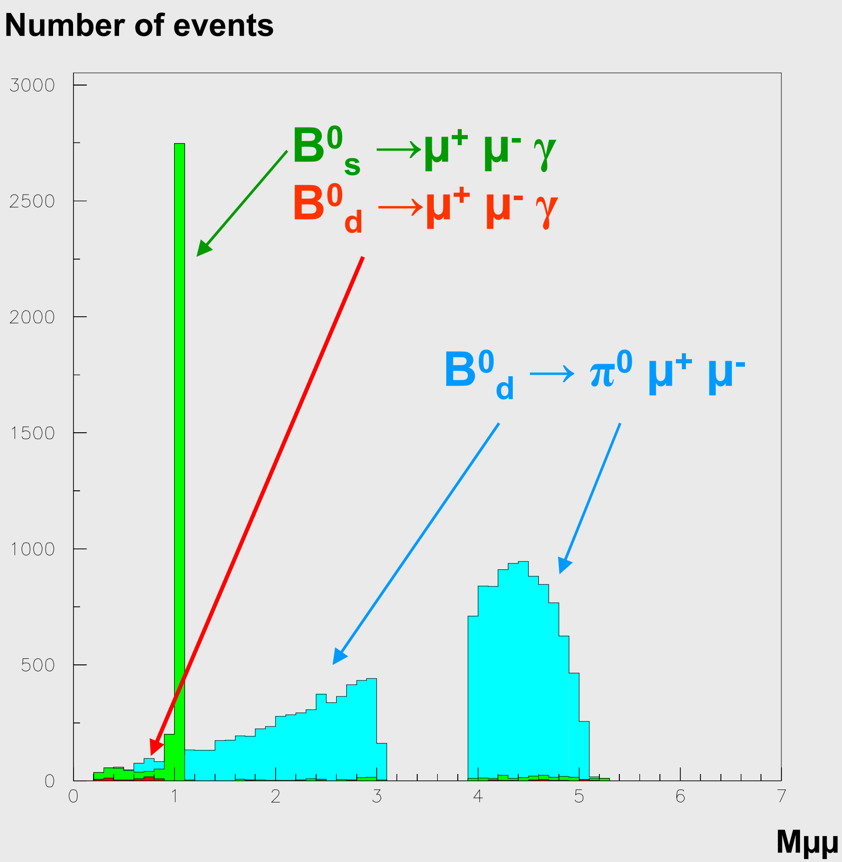


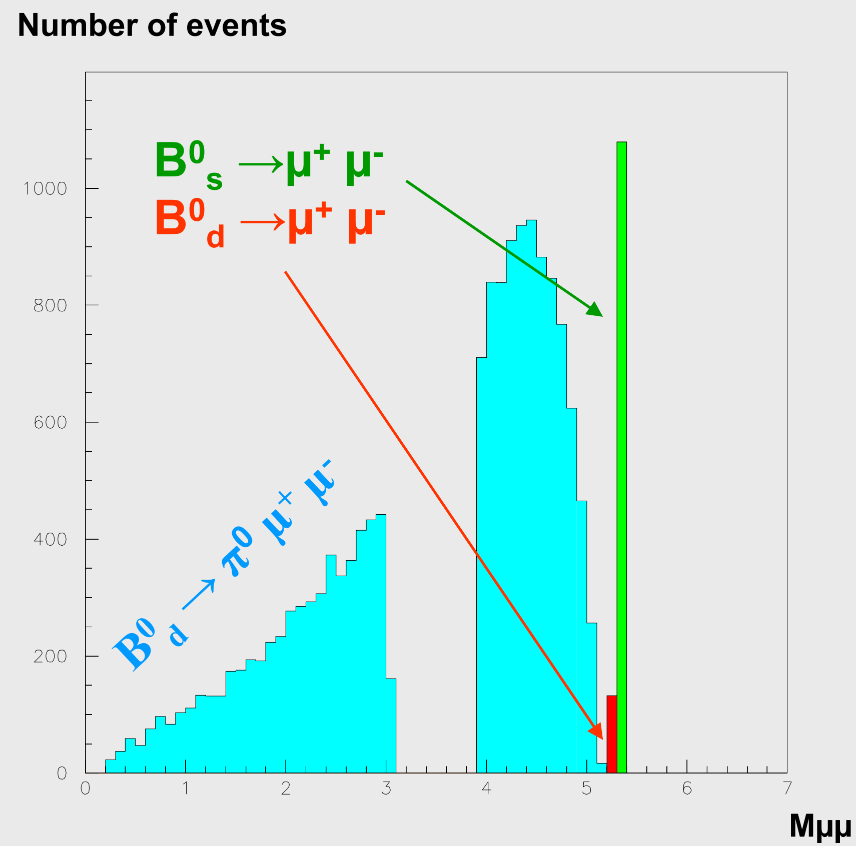


$|\eta(\mu)| < 2.5$, $p_T(\mu) > 6$ GeV

The decays $B^0_{d,s} \to \mu^+ \mu^- \gamma$ are not essential background for the decay $B^0_d \to \mu^+ \mu^-$.

$B^0_d \to \pi^0 \mu^+ \mu^-$ as BG to $B^0_{d,s} \to \mu^+\mu^-\gamma$ and $B^0_{d,s} \to \mu^+\mu^-$ decays

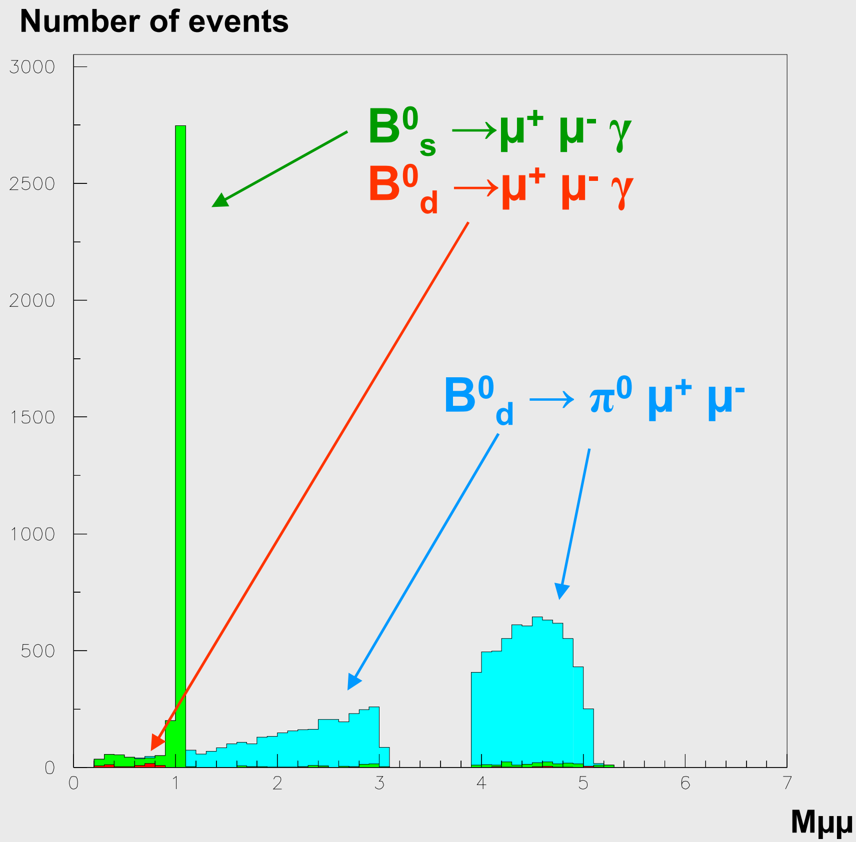


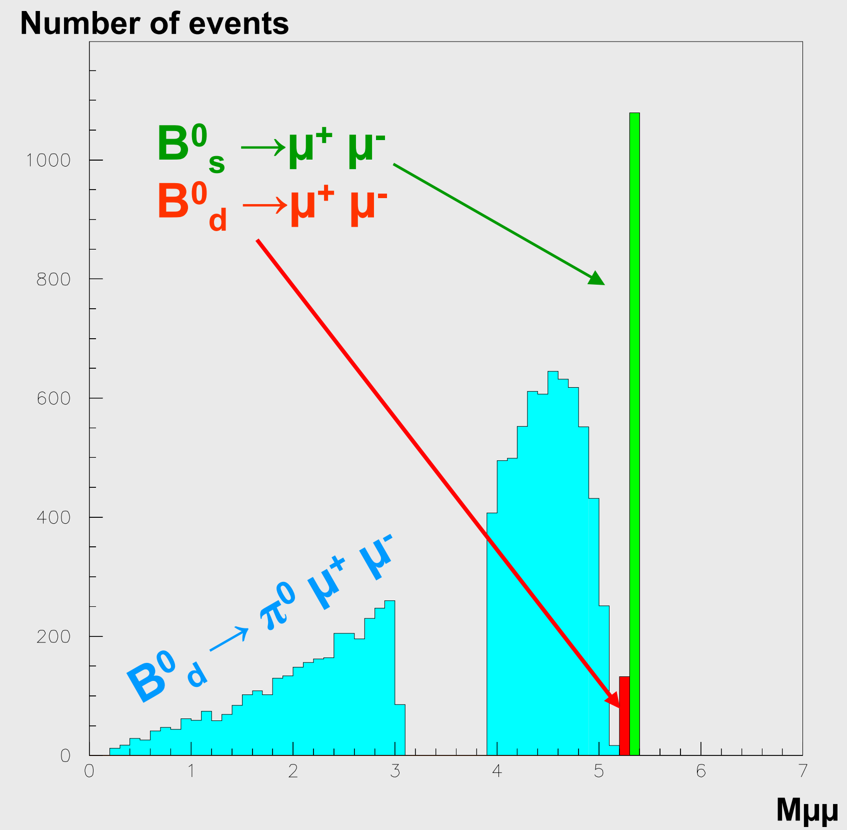


$|\eta(\mu)| < 2.5$, $p_T(\mu) > 6$ GeV, $\pi^0 \to \gamma\gamma$, $p_T(\pi^0) < 4$GeV

The particle level simulation with the theoretical branching ratio predictions for SM.

$B^0_d \to \pi^0 \mu^+ \mu^-$ as BG to $B^0_{d,s} \to \mu^+\mu^-\gamma$ and $B^0_{d,s} \to \mu^+\mu^-$ decays





$|\eta(\mu)| < 2.5$, $p_T(\mu) > 6$ GeV, $\pi^0 \to \gamma\,\gamma$, $p_T(\pi^0) < 2$ GeV

At the particle level simulation the decay $B^0_d \to \pi^0 \mu^+ \mu^-$ are essential background for $B^0_{d,s} \to \mu^+ \mu^- (\gamma)$ decays

CONCLUSION

a) **All signal channels of interest and corresponding BG were subject to detail studies at 2004-2005 for final ATLAS Detector layout with new software at initial LHC luminosity $10^{33}cm^{-2}s^{-1}$.**

b) **ATLAS proved to be capable to extracting signals of all main rare B-decays of interest at LHC.**

c) **Earlier ATLAS studies (1998-1999) proved that dimuon channels program can be followed up to nominal LHC luminosity 10^{34} $cm^{-2}s^{-1}$.**

Appendix

Other Wilson Coefficients of SM extensions for rare decays

One-loop SUSY calculations and other SM extensions:

C.Bobeth, T.Ewerth, F.Kruger, J.Urban, PRD66, 074021 (2002)

G.Hiller, F.Kruger, PRD69, 074020 (2004)

... and many-many-many papers ...

For good parametrisations and many references see:

A.Dedes, B. Todd Huffman, PLB600, p.261 (2004)

Two-loop MSSM calculations for rare penguins:

C.H.Chen, C.Q.Geng, PRD71, 054012 (2005)

S.Baek, PLB595, pp.461-468 (2004)

The last work: **J.Ellis, K.A.Olive, V.C.Spanos, hep-ph/0504196**

“Rome production”: 2005 – Data Samples

Generation (with theoretical matrix elements), full simulation, digitization and reconstruction with **9.0.4** and **10.0.1** software releases, analysis of AOD in **10.0.1** .

Signal channels:

$B \to \mu6\mu6$ Rome production. **5 kEv** in analysis (AOD)

$B \to K^{*0}\mu6\mu4$ Private (evgen-simul-digi-reco) **30 kEv** (AOD)

$B \to \varphi\ \mu6\mu4$ Private (evgen-simul-digi-reco) **12 kEv** (AOD)

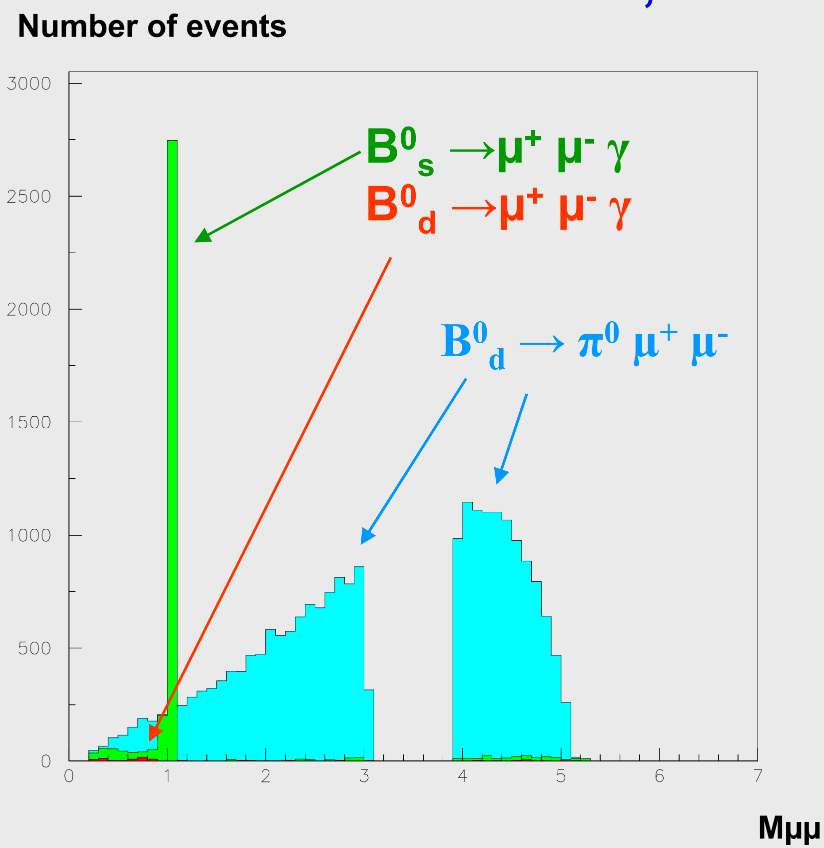
$\Lambda_b \to \Lambda\ \mu5\mu5$ Private (evgen-simul-digi-reco) **~50 kEv** (AOD)

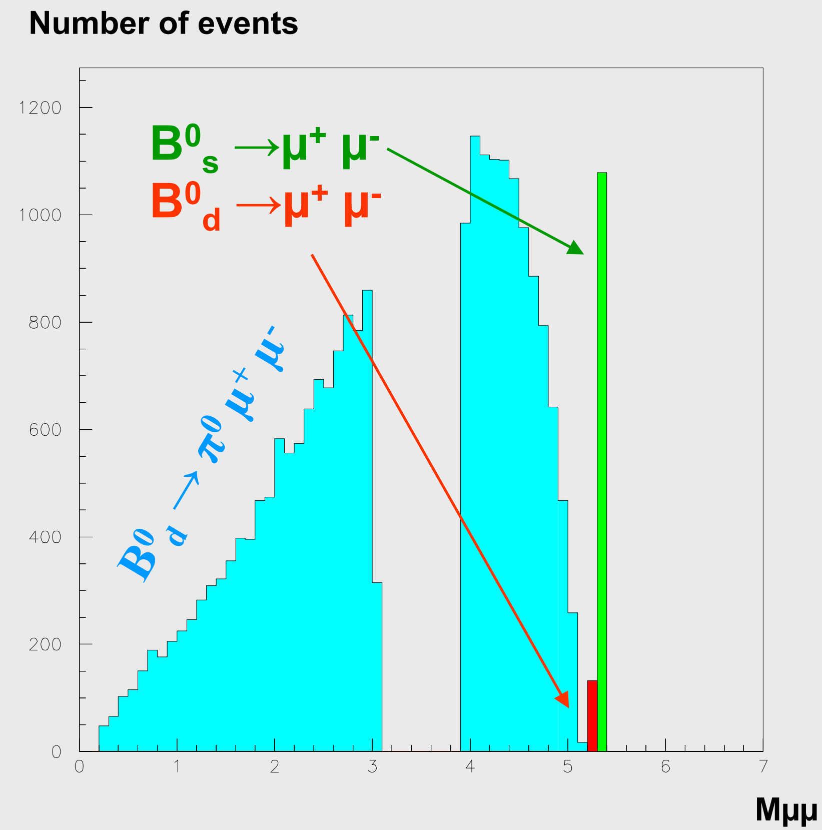
Background samples:

$bb \to \mu6\mu6X$ **23kEV** included cut on $M(\mu\mu) \sim M(B^0_s)$

$bb \to \mu4\mu4X$ **23kEV** for B-decays and **~31kEv** for Λ_b-decays

$B^0_d \to \pi^0 \mu^+ \mu^-$ as BG to $B^0_{d,s} \to \mu^+\mu^-\gamma$ and $B^0_{d,s} \to \mu^+\mu^-$ decays





$|\eta(\mu)| < 2.5$, $p_T(\mu) > 6$ GeV, $\pi^0 \to \gamma\gamma$, **no cuts on $p_T(\pi^0)$**

The particle level simulation with the theoretical branching ratio predictions for SM.