Semileptonic rare B decays in ATLAS and CMS

Physics at LHC

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on behalf of ATLAS and CMS collaborations

Outline

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- Semileptonic DiMuon rare decay channels in ATLAS
  - $B^+ \rightarrow K^+\mu^+\mu^-$
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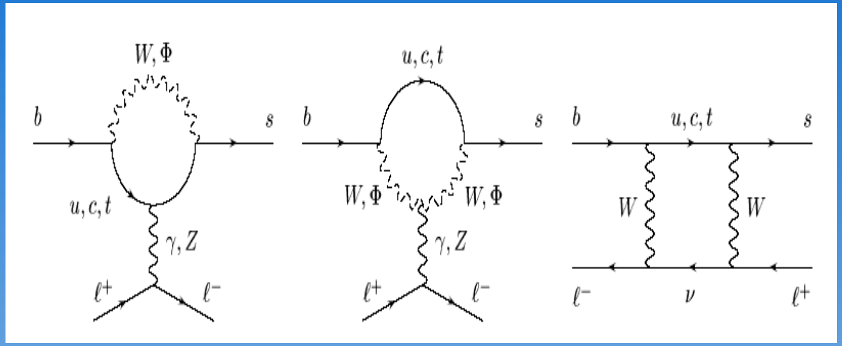
  - $B_s \rightarrow \phi\, \mu^+\mu^-$
- Semileptonic DiMuon rare decay channels in CMS: simulation studies not yet started
- Conclusions and Plans

Introduction



- $b \to s(d) l^+ l^-$ FCNC transitions
  - Forbidden at the tree level, at lowest order occur through 1-loop diagrams (penguin,box)
  - Branching ratio ~ $10^{-6} \div 10^{-7}$
- Their measurements provide a good test of the SM and indirect search for signals of supersymmetric models (SUSY, two Higgs doublet, etc.)
  - Differential decay rate measurement provide input to determine the magnitude and sign of the Wilson Coefficients C_7, C_9, C_{10}
  - Informations on the long-distance QCD effects
  - Determination of $|V_{ts}|$ and $|V_{td}|$
  - Differential decay rate sensitive to new physics
    - Forward-backward asymmetry
    - Di-lepton invariant mass spectrum

Theoretical remarks (1)

- Effective Hamiltonian for b→s(d)l^+l^- transitions integrating out heavy degrees of freedom

$$H_{eff} = -4\frac{G_F}{\sqrt{2}} V_{tq}^{*} V_{tb} \sum_{1=1}^{10} C_i(\mu) O_i(\mu), \quad q=s,d$$

  - includes EW contributions and perturbative corrections for Wilson coefficient C_i
  - μ ~ 5GeV scale parameter separates SD (perturbative) from LD (non-perturbative) contributions
- Free quarks transition amplitude

$$M(b\to q l^+ l^-) = -G_F \frac{\alpha}{\sqrt{2}\pi} V_{tq}^{*} V_{tb} \left\{ C_9^{eff}\left[\bar{q}\gamma_\mu L b\right]\left[\bar{l}\gamma^\mu l\right] + C_{10}\left[\bar{q}\gamma_\mu L b\right]\left[\bar{l}\gamma^\mu \gamma_5 l\right] - 2\,\hat{m}_b C_7^{eff}\left[\bar{q}\, i\sigma_{\mu\nu}\frac{\hat{q}^\nu}{\hat{s}} R b\right]\left[\bar{l}\gamma^\mu l\right] \right\}$$

- FB Asymmetry, di-lepton mass spectrum studied according to parametrization by Wilson coefficients

Theoretical remarks (2)

- SD contributions
  - supersymmetric particles give virtual particles corrections in SM loop processes
  - Wilson coefficient can be calculated perturbatively
    - NLO (SM): A.Buras and M.Munz, PRD 52, 182 (1995)
    - NNLO (SM): C.Bobeth et al, JHEP 0404, 71 (2004)
    - NNLO (MSSM): C.Bobeth et al, NPB 713, 522 (2005)
- LD contributions
  - $O_i(\mu)$ set of basic operators specific for each model (SM, MSSM, etc.)
  - LD contributions are contained in the hadronc matrix elements

    <final hadronic state | $O_i(\mu)$ | initial hadronic state>

    described in terms of **form factors**
  - Non-perturbative methods for calculation of form factors (QCDSR, lattice calculations, Quark Models, etc.)

Models used for MC generation in ATLAS

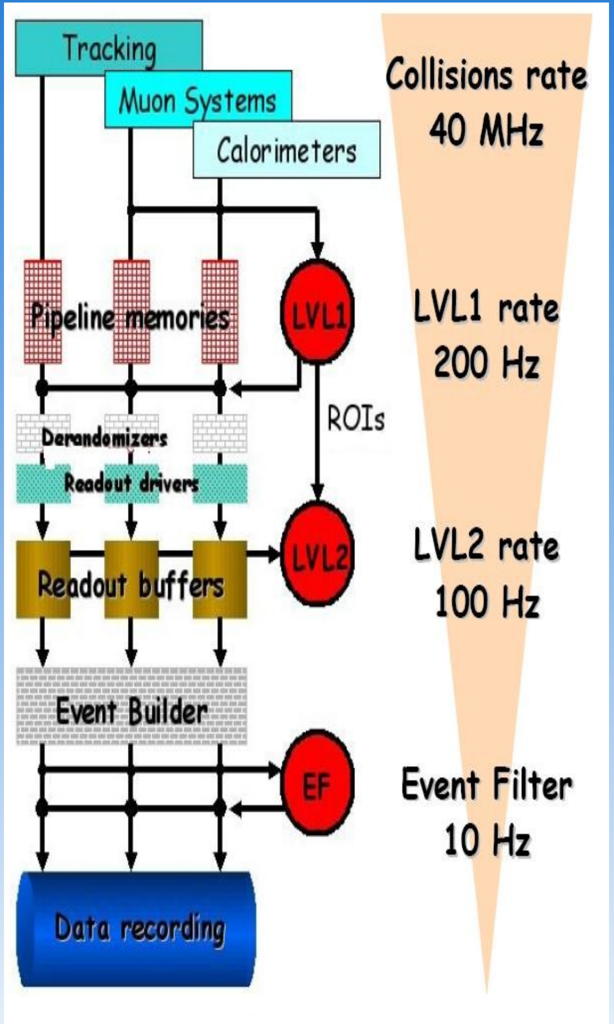
Decay Channel	Model	Theoretical Branching Ratio	Wilson Coefficients	Form Factors
$B^+ \to K^+\mu^+\mu^-$	A. Ali et al., hep-th/0112300 (2002)	$3.5*10^{-7}$	NNLO	QCD LCSR
$\Lambda_b \to \Lambda^0\mu^+\mu^-$	C.H.Chen et al., PRD64, 074001 (2001) T.M.Aliev et.al. , NPB649, 168 (2003)	2.0×10^{-6}	NLO	HQET
$B_d \to K^{0*}\mu^+\mu^-$	D.Melikhov et al., PRD57, 6814 (1998) D.Melikhov et al., PRD62, 014006 (2000)	1.3×10^{-6}	NLO	Relativistic quark model
$B_s \to \phi\, \mu^+\mu^-$	D.Melikhov et al., PRD57, 6814 (1998) D.Melikhov et al., PRD62, 014006 (2000)	$\sim 10^{-6}$	NLO	Relativistic quark model

- Both Pythia and EvtGen MonteCarlo generators used in the ATHENA framework for the samples production

Dimuon trigger in ATLAS

- B-physics mostly during initial period of low luminosity ~10^{33} cm^{-2}s^{-1} : 2-3 interaction/collision
- b-pairs production ~500kHz
  - 1% of collisions
  - 10^{12} b-pairs in a year (10^7s)
- *LVL1* trigger based on detection of two muons

  ($p_{T\mu1} > 6$ GeV, $p_{T\mu2} > 4$ GeV) by the muon trigger chambers
- *LVL2* + *EF* confirm *LVL1* decisions by precise *MDT* and calorimeter measurements and track extrapolation to Inner Detector
  - Refits tracks in *LVL2 ROIs*
  - Decay vertices search, mass cut, opening angle....

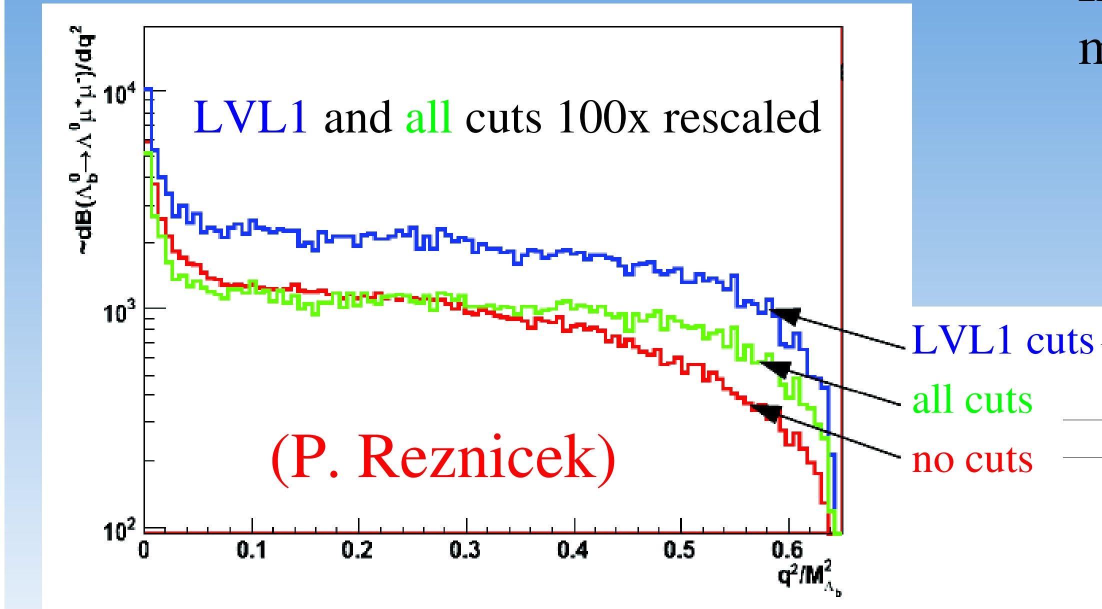


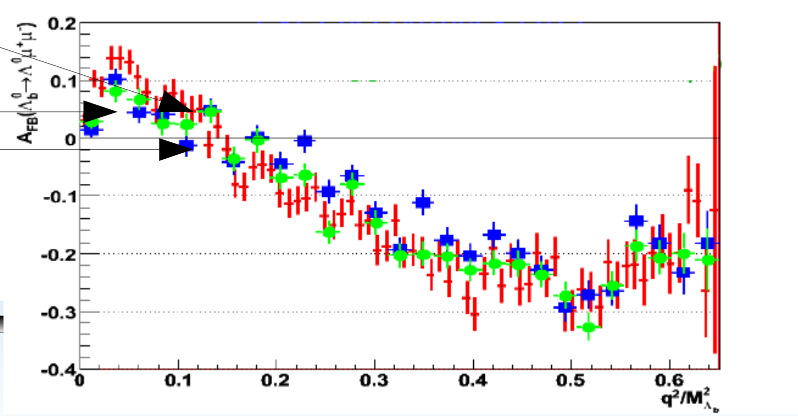
LVL1 Trigger cuts

- Number of events expected for semileptonic dimuon decay channels at the generation level (triggerable and reconstructable events)
  - LVL1 Trigger cuts (p_{T1}>6GeV and p_{T2} >4GeV) and acceptance cut (abs(η)<2.5)

Decay Channel	BR	Events in 30 fb^{-1}
$B^+ \to K^+\mu^+\mu^-$	$3.5 * 10^{-7}$	40000
$\Lambda_b \to \Lambda^0\mu^+\mu^-$	2.0×10^{-6}	28000
$B_d \to K^{0*}\mu^+\mu^-$	1.3×10^{-6}	120000
$B_s \to \phi\, \mu^+\mu^-$	$\sim 10^{-6}$	21000

- Impact of trigger cuts on $\Lambda_b \to \Lambda^0\mu^+\mu^-$: LVL1 muon cuts and p_t>0.5GeV, |η|<2.5 hadron cuts
  - Trigger cuts prefer higher dimuon invariant mass
  - suppression of $|A_{FB}|$ in low q^2/M^2 region





Background sources

- The background studies are already started but still preliminary
- Background sources
  - Channels with J/Ψ and Ψ(2S) cc-bar resonances: irreducible background
  - Combinatorial background
    - Semileptonic decays of both b and b-bar quarks
    - Double semileptonic decay of b quark (b->cμν, c->sμν)
  - kaons and pions misidentification as muons at low P_T
    - as example for $B^+ \to K^+\mu^+\mu^-$ channel

      $B^+ \to (D^0 \to K^+\pi^-)\,\mu^+\nu_\mu$ where pion is misidentified as muon and neutrino is missed

Cut efficiencies for $B^+ \rightarrow K^+\mu^+\mu^-$

- signal and (very few yet) bb $\rightarrow\mu(4)\mu(6)X$ background events

Cut	Signal efficiency	BG efficiency
$PT(\mu_1) > 6GeV$, $PT(\mu_2) > 4GeV$, $\lvert\eta(\mu_{1,2})\rvert < 2.5$, dimuon invariant mass kinematic window, $P_T(k^+)>0.5GeV$ and $\eta\lvert(k^+)\rvert<2.5$	0.73	0.087
Dimuon vertex $\chi^2 < 3$	0.92	0.833
$\Psi(2S)$ area excluded ($m(\Psi(2S)) \pm 3x36MeV$)	0.91	0.996
J/Ψ area excluded ($m(J/\Psi) \pm 3x36MeV$)	0.92	0.766
B^+ vertex $\chi^2 < 3$	0.13	0.0045
$M(B^+) \pm 3x40Mev$	0.88	0.402
B^+ proper time > 0.5ps	0.80	0.250
Total	0.05	$2x10^{-5}$

- With dimuon trigger efficiency 75%, 1500 signal and <40000 BG events expected in $30fb^{-1}$
- More cuts can be added to reduce background (additional cut on Kaon P_T, muon isolation)... waiting for higher statistic

Cut efficiencies for $\Lambda_b \to \Lambda^0\mu^+\mu^-$

(P.Reznicek)

- Signal and bb $\to\mu(4)\mu(4)X$ background events

Cut	Signal efficiency	BG efficiency
$P_T(\mu_1) > 6$GeV, $P_T(\mu_2) > 4$GeV, $\lvert\eta(\mu_{1,2})\rvert < 2.5$, dimuon vertex $\chi^2 < 3$, dimuon invariant mass kinematic window	0.920	0.230
J/Ψ and $\Psi(2S)$ areas excluded ($m(J/\Psi) \pm 3\times40$MeV and $m(\Psi(2S)) \pm 3\times45$MeV)	0.860	0.740
Hadron cuts: tracks $P_T>0.5$GeV, $\lvert\eta\rvert<2.5$, $P_T(p)>P_T(\pi)$, $\chi^2/NDOF < 3$, $M(\Lambda^0) \pm 3\times2$MeV	0.240	0.130
Λ^0 vertex transverse position >1cm and <45cm	0.940	0.240
$P_T(\Lambda^\circ)>4$GeV	0.720	0.440
Λ_b vertex $\chi^2/NDOF < 2$, $M(\Lambda_b) \pm 100$Mev	0.690	0.005
Λ_b proper time > 0.5ps	0.620	0.100
Difference in Λ momenta ($\Delta P_T<0.3$GeV, $\Delta\phi<0.05°$, $\Delta\eta<0.01$) from single and combined Λ_b fit	0.710	0.200
Difference in Λ_b momentum and pos. direction < 2.3°	0.750	0.750
Total	0.038	$\sim10^{-6}$

- With dimuon trigger efficiency ~75%, 800 signal and <4000 BG event expected in 30fb^{-1}

Cut efficiencies for $B_d \rightarrow K^{0*}\mu^+\mu^-$

(K. Toms, N.Nikitine, S.Sivoklokov)

- signal and bb →μ(4)μ(4)X background events

Cut	Signal efficiency	BG efficiency
$P_T(\mu 1) > 6$GeV, $P_T(\mu_2) > 4$GeV, $\lvert\eta(\mu_{1,2})\rvert < 2.5$, J/Ψ and Ψ(2S) areas excluded	0.690	0.220
Vertex $\chi^2 < 25$	0.121	0.010
B_d proper time > 0.5ps	0.832	0.032
$P_T(K^*) > 6$GeV	0.406	0.074
Total	0.03	2.6×10^{-6}

- With dimuon trigger efficiency 75%, 2500 signal and <10000 BG events expected in $30 fb^{-1}$

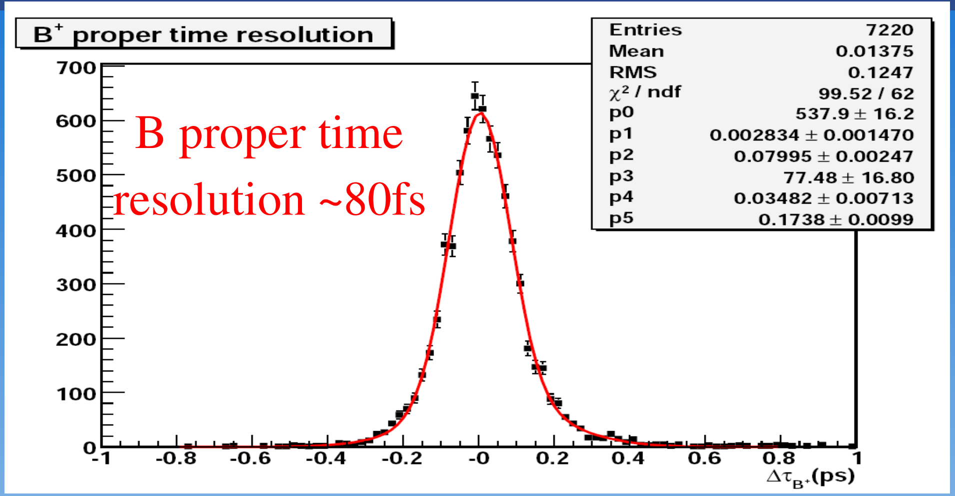
Expected ATLAS statistic at $30fb^{-1}$

- Full detector simulation and reconstruction for final ATLAS layout
  - Signal and background (in progress, waiting for higher statistic of $bb \to \mu(4)\mu(6)X$ events)
  - 75% trigger efficiency included

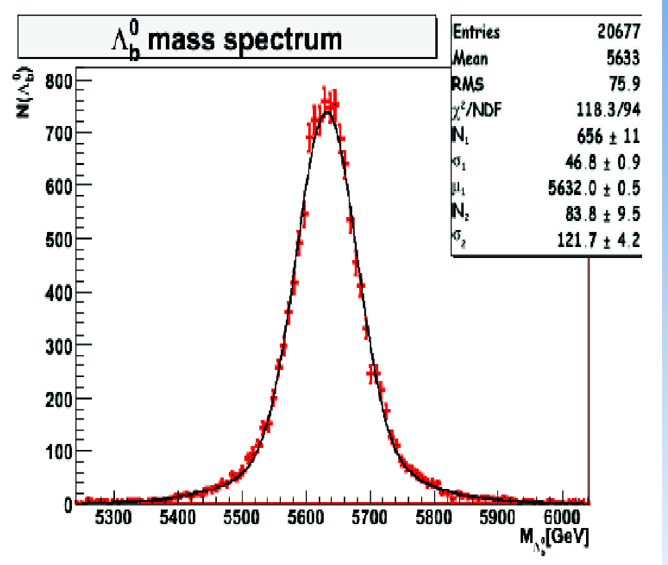
Decay Channel	Signal events after trigger and offline cuts	Background events after trigger and offline cuts
$B^+ \to K^+\mu^+\mu^-$	1500	<40000
$\Lambda_b \to \Lambda^0\mu^+\mu^-$	800	<4000
$B_d \to K^{0*}\mu^+\mu^-$	2500	<10000
$B_s \to \phi\, \mu^+\mu^-$	900	<10000

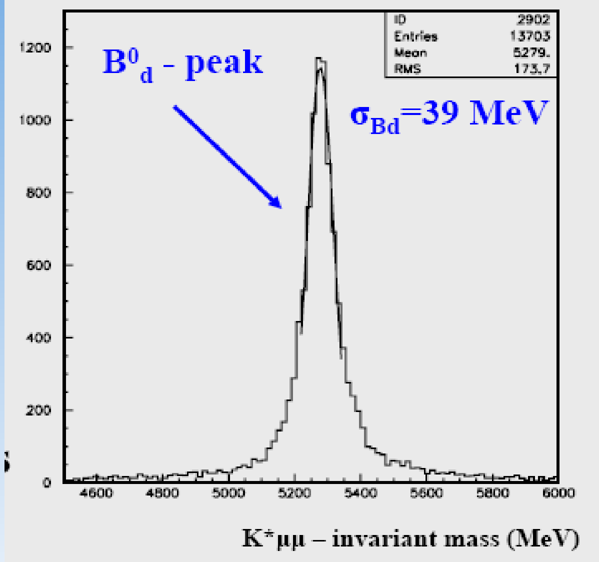
Signal Reconstruction: B mesons and Λ_b masses

b-particle	Reconstructed mass width
B^+	42 MeV
Λ_b	47 MeV
B_d	39 MeV
B_s	46 MeV



B proper time resolution ~80fs

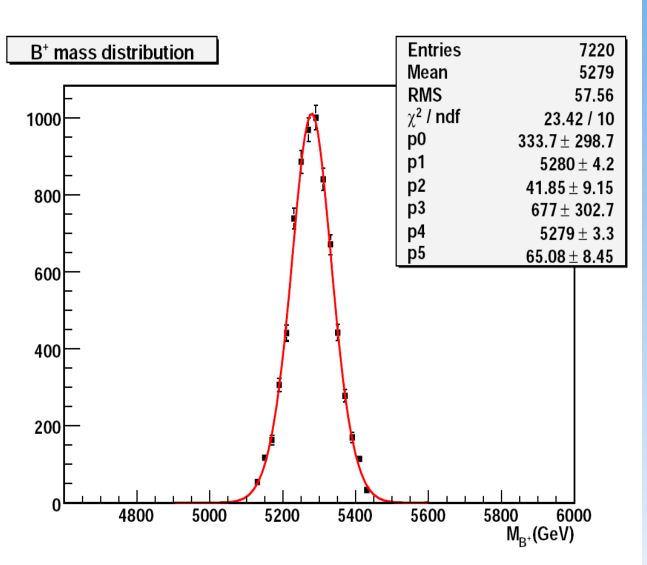




B^0_d - peak

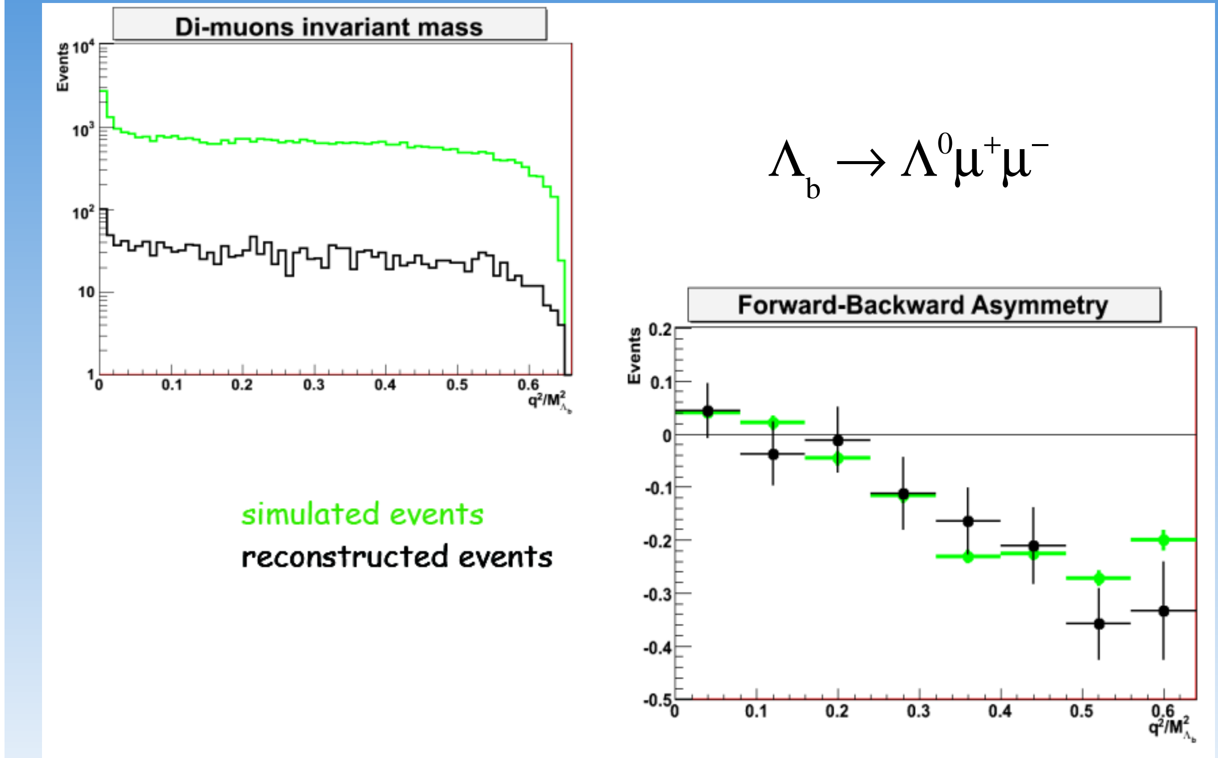
σ_{Bd}=39 MeV

K*μμ – invariant mass (MeV)



Signal Reconstruction: dimuon mass and A_{FB} distributions

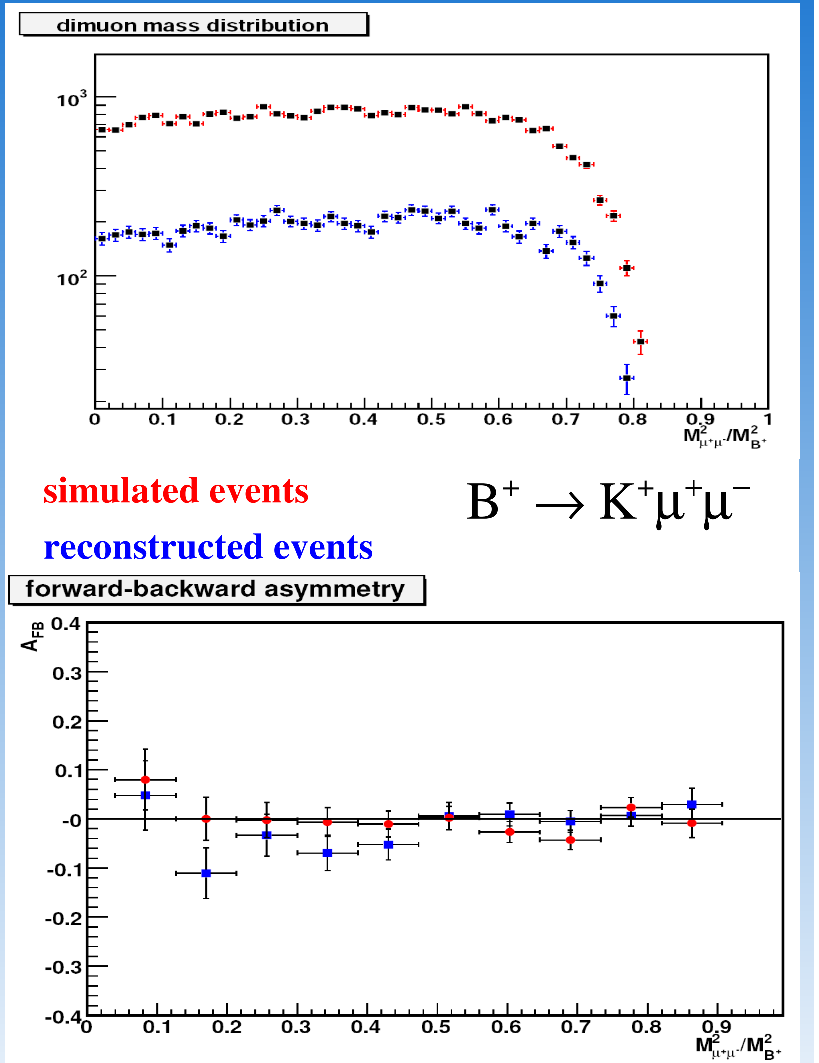
Trigger and offline analysis cuts do not change significantly dimuon invariant mass spectrum and A_{FB}



$\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$

simulated events

reconstructed events



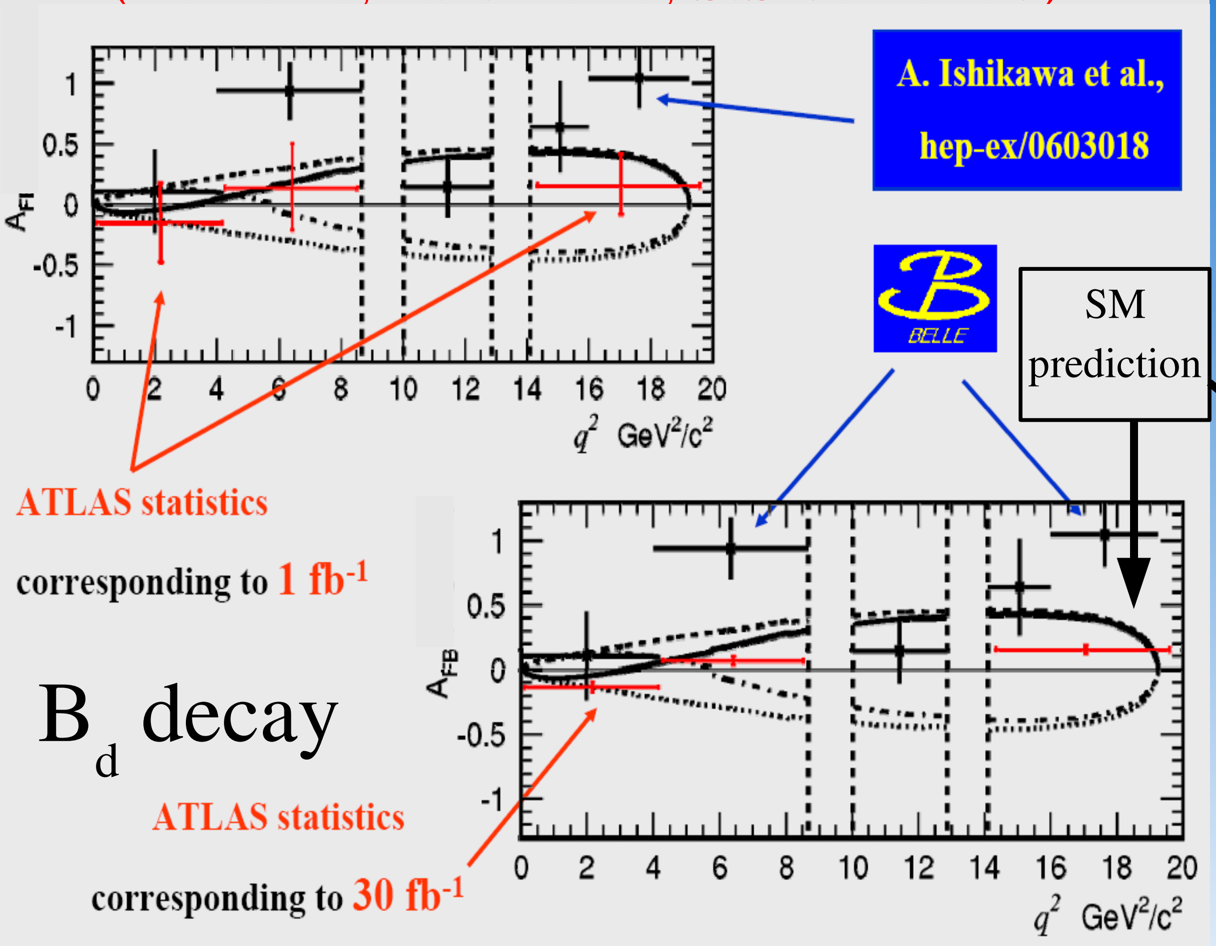
simulated events

reconstructed events

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

Forward-Backward Asymmetry for B_d and B^+ decays

(K. Toms, N.Nikitine, S.Sivoklokov)



A. Ishikawa et al., hep-ex/0603018

SM prediction

ATLAS statistics

corresponding to 1 fb^{-1}

B_d decay

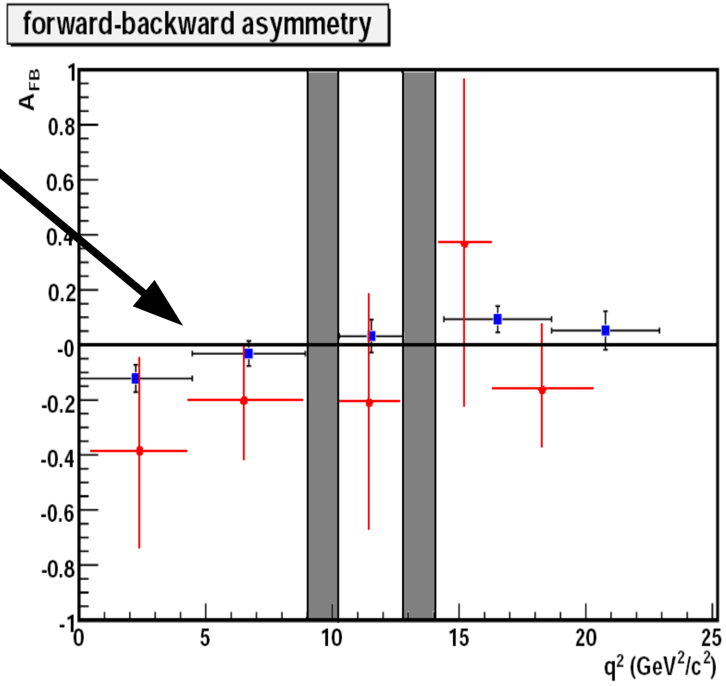
ATLAS statistics

corresponding to 30 fb^{-1}

B^+ decay

ATLAS after 30fb^{-1}

Belle (hep-ex/0410006)

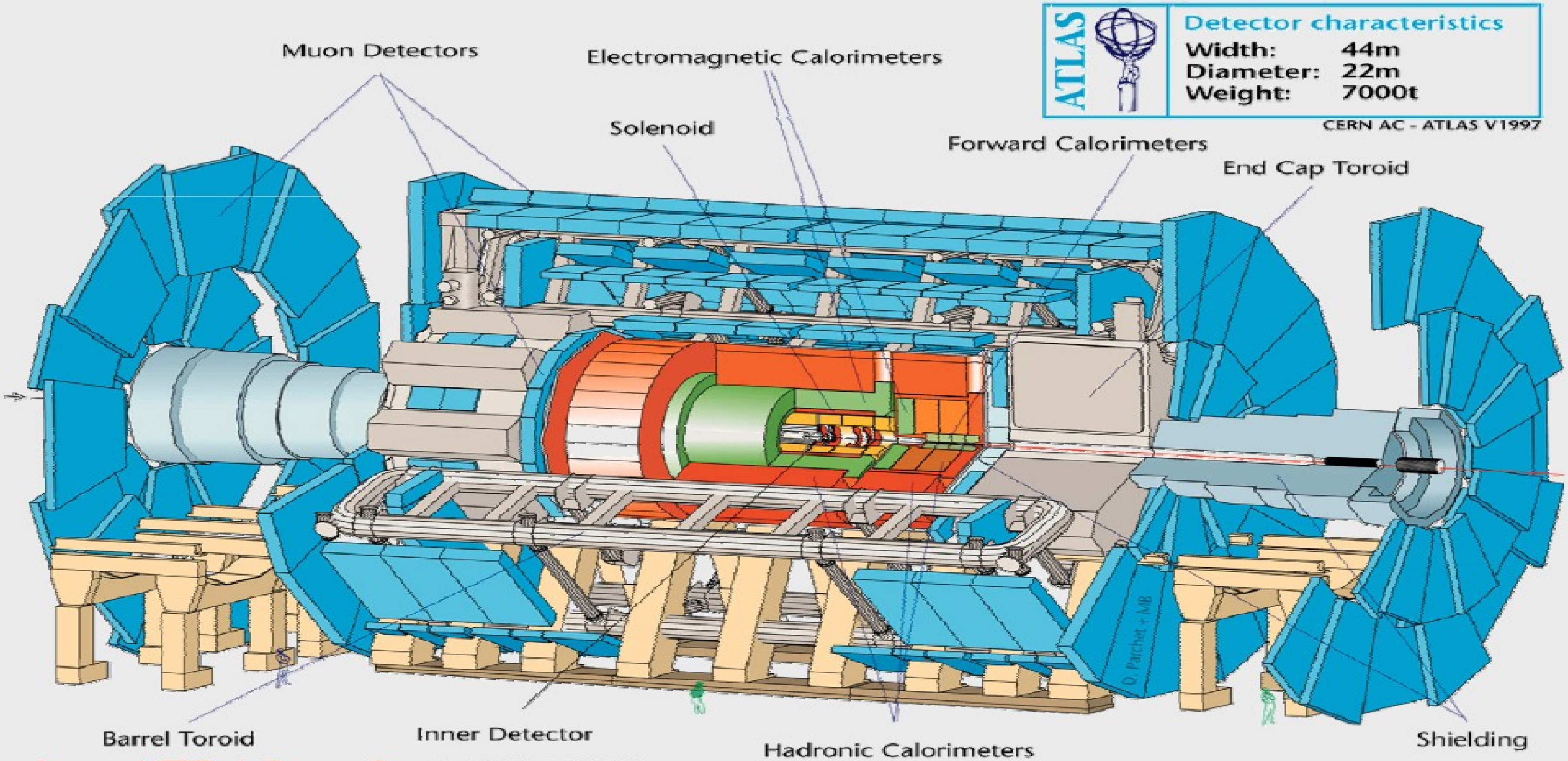


Conclusions and Plans

- ATLAS B-Physics group is studying many rare semileptonic decay channels
  - Rare decays measurements offer a test of SM prediction and indirect search for new physics signals
  - Trigger and offline analysis cuts do not change the most interesting distributions: dimuon invariant mass spectrum and forward-backward asymmetry
  - After 30fb^{-1} ATLAS should have enough statistic for measurements of differential distributions of rare semileptonic decays
- Plans
  - More background is needed for further studies
  - High Level Trigger simulation studies
  - $B^+ \rightarrow K^{*+}\mu^+\mu^-$ studies already started (Università della Calabria & INFN group)
- CMS rare decay studies will be available soon

BACKUP SLIDES

ATLAS



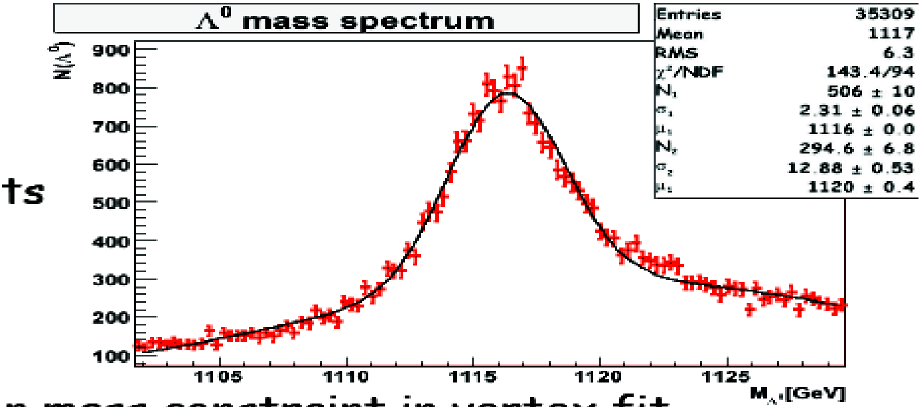
The prime ATLAS goals (2007-2011):

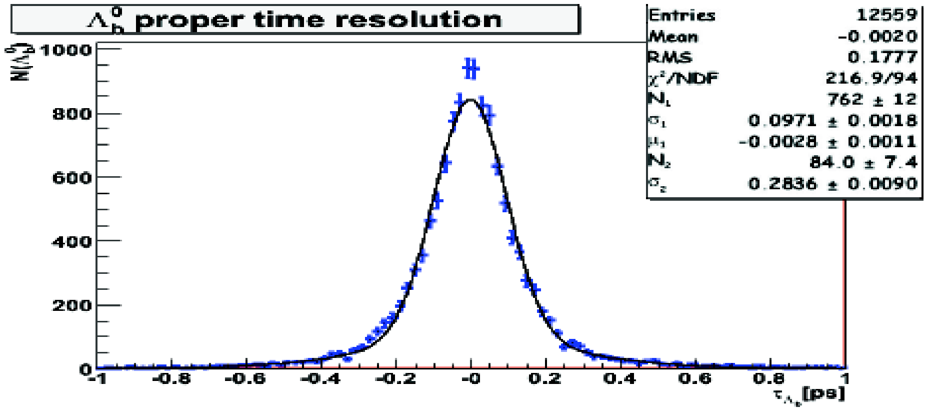
1) Higgs boson discovery;

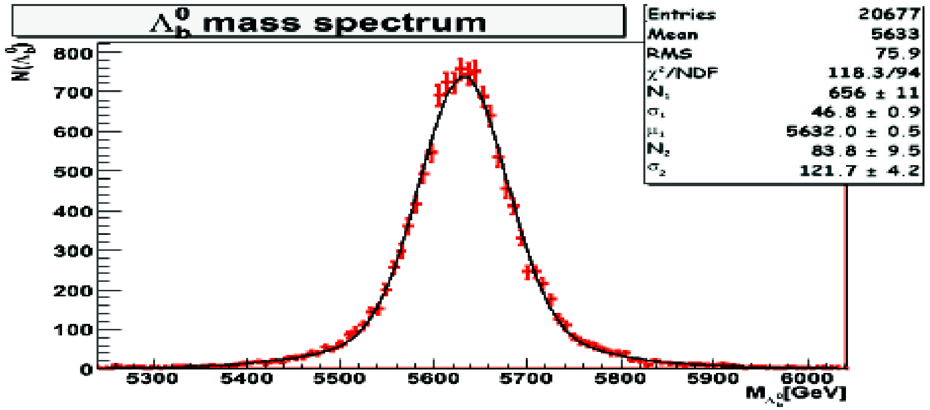
2) **Discovery of SUSY or others SM extensions. Rare b-decays with muons in final state are able to make an essential contribution in solution of the second task!**

Λ_b reconstruction (P.Reznicek)

- ~ 50k events fully simulated, digitized and reconstructed using 9.0.4 and 10.0.1 software releases, analysis of AODs in 10.0.1
  - using xKalman reconstruction algorithm with modified parameters optimized to V^0 finding
- combined fit of 4 tracks using CDF fitting routine with uniform magnetic field 2T
- overall reconstruction efficiency mostly driven by Λ^0 reconstruction - **38%** only due to long Λ^0 lifetime → not enough space-points to reconstruct proton and pion tracks
- $\Lambda^0{}_b$ reconstruction efficiency ~ 27%
- mass resolution degraded compared to $\Lambda^0{}_b \rightarrow J/\psi \Lambda^0$ decay due to not existing di-muon mass constraint in vertex fit

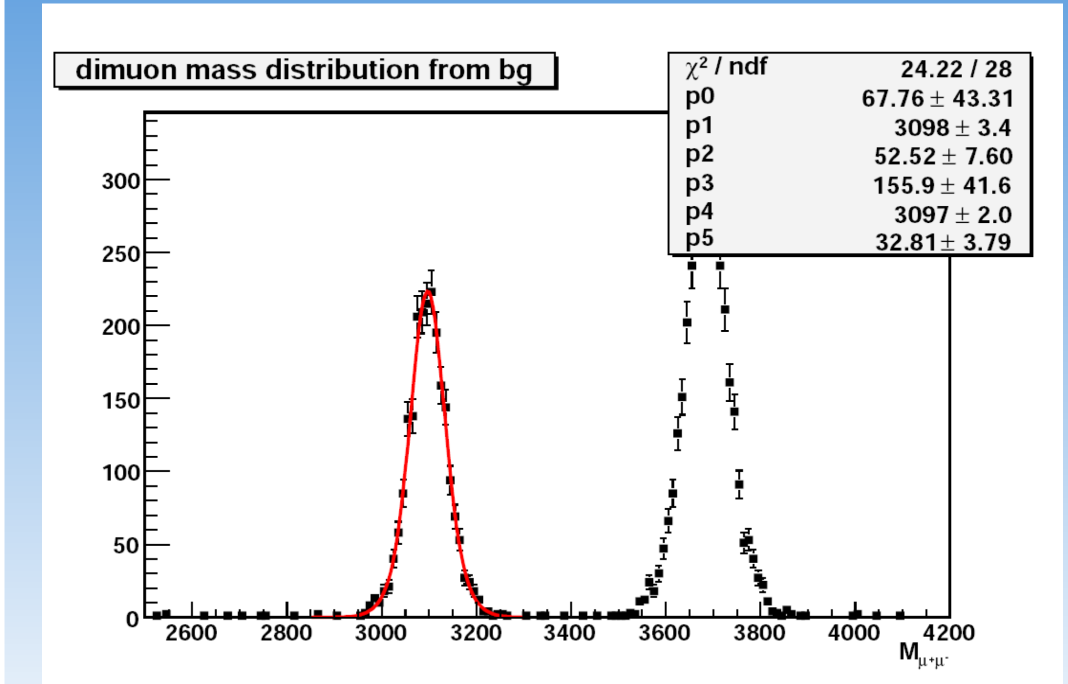


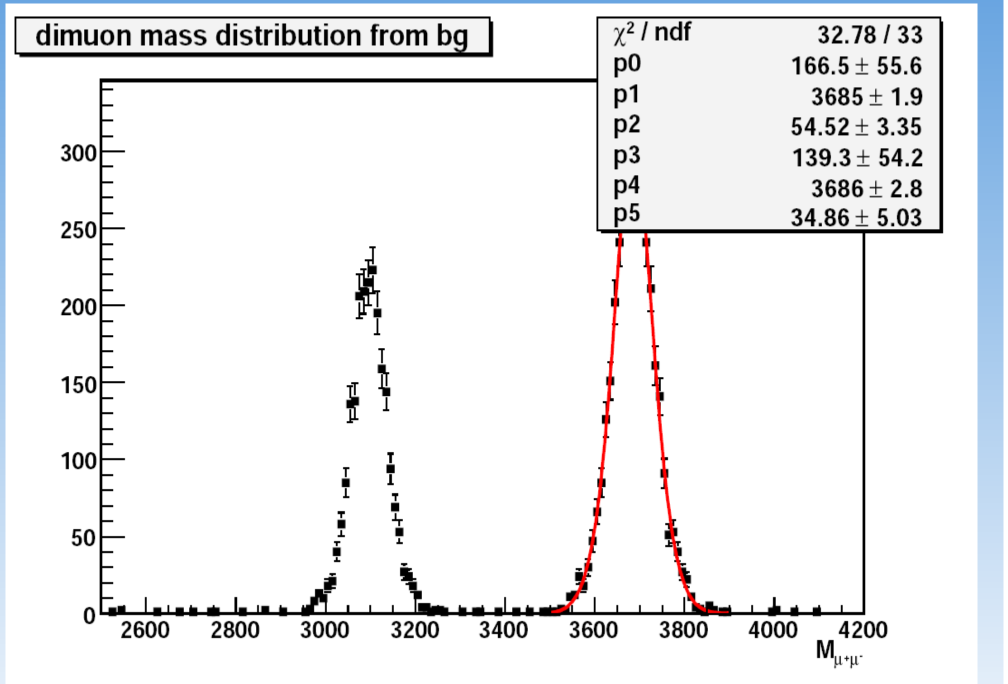




J/Ψ and Ψ(2S) mass reconstruction

- background source from resonant channels removed with a cuts ±3σ around J/Ψ and Ψ(2S) mass





Theory in *SM*: b→sl^{+}l^{-} transitions

- Effective Hamiltonian for b→sl^{+}l^{-} transitions integrating out heavy degrees of freedom (*top* quark and $W^{\pm}$ bosons in *SM*)

$$H_{eff}=-4\frac{G_F}{\sqrt{2}}V_{ts}^{*}V_{tb}\sum_{1=1}^{10}C_i(\mu)O_i(\mu)$$

[A.J. Buras et al., Nucl. Phys. B424, 374 (1994)]

- Free quarks transition amplitude (with m_s/m_b=0)

$$M(b\rightarrow s l^{+} l^{-})=-G_F\frac{\alpha}{\sqrt{2}\pi}V_{ts}^{*}V_{tb}\left\{C_9^{eff}\left[\bar{s}\gamma_{\mu}Lb\right]\left[\bar{l}\gamma^{\mu}l\right]+C_{10}\left[\bar{s}\gamma_{\mu}Lb\right]\left[\bar{l}\gamma^{\mu}\gamma_5 l\right]-2\hat{m}_b C_7^{eff}\left[\bar{s}i\sigma_{\mu\nu}\frac{\hat{q}^{\nu}}{\hat{s}}Rb\right]\left[\bar{l}\gamma^{\mu}l\right]\right\}$$

[for ex. A. Ali et al., hep-ph/9910221 (1999)]

- FB Asymmetry, dimuon mass spectrum studied according to parametrization by Wilson coefficients

Theory in *SM*: Pseudoscalar transition B→K (1)

- Wilson Coefficient calculated at *NNLO*
- Pseudoscalar meson transition B→ K parametrized in terms of form factors ($q=p_B-p$):

$$\langle K(p)|\bar{s}\gamma_\mu b|B(p_B)\rangle = f_+(s)\left\{(P_B+p)_\mu - \frac{m_B^2-m_K^2}{s}q_\mu\right\} + \frac{m_B^2-m_K^2}{s} f_0(s)\, q_\mu$$

$$\langle K(p)|\bar{s}\sigma_{\mu\nu}q^\nu(1+\gamma_5)b|B(p_B)\rangle = \langle K(p)|\bar{s}\sigma_{\mu\nu}q^\nu b|B(p_B)\rangle = i\left\{(P_B+p)_\mu s - q_\mu(m_B^2-m_K^2)\right\} f_T\frac{(s)}{m_B+m_K}$$

- Hadronic form factors calculated in *LCSR*

$$BR(B\rightarrow Kl^+l^-) = (0.35\pm0.12)x10^{-6}$$

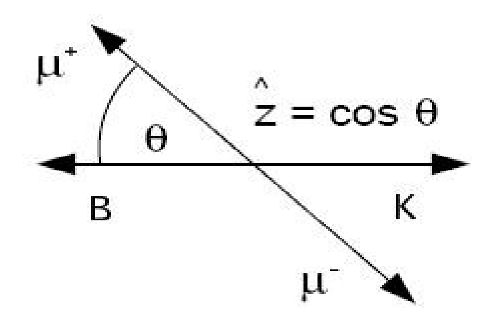
[A. Ali et al., hep-ph/0112300 (2002)]

Theory in *SM*: Pseudoscalar transition B→K (2)

- Differential decay width and dilepton invariant mass distribution depend on hadronic form factors and Wilson Coefficient

- *FB* asymmetry vanishes in B→K decays since there is not terms containing $cos\theta$ with an odd power

$$A_{FB}=\frac{1}{d\Gamma/d\hat{s}}\left\{\int_0^1 d\hat{z}\frac{d^2\Gamma}{d\hat{z}d\hat{s}}-\int_{-1}^0 d\hat{z}\frac{d^2\Gamma}{d\hat{z}d\hat{s}}\right\}$$



Theory in *SM*: vectorial transition B→K* (1)

- Wilson Coefficient calculated at *NNLO*
- Pseudoscalar meson transition B→ K* parametrized in terms of form factors ($q = p_B - p$, ε polarization vector):

$$\langle K^*(p)|(V-A)_\mu|B(p_B)\rangle = -i\epsilon^*_\mu (m_B+m_K)A_1(s) + i(P_B+p)_\mu(\epsilon^* P_B)\frac{A_2(s)}{m_B+m_K} + i(q)_\mu(\epsilon^* P_B)\frac{2m_K}{s}(A_3(s)-A_0(s)) + \epsilon_{\mu\nu\rho\sigma}\epsilon^{*\nu}P_B^\rho p^\sigma \frac{2V(s)}{m_B+m_K}$$

$$\langle K^*(p)|\bar{s}\sigma_{\mu\nu}q^\nu(1+\gamma_5)b|B(p_B)\rangle = i\epsilon_{\mu\nu\rho\sigma}\epsilon^{*\nu}P_B^\rho p^\sigma 2T_1(s) + T_2(s)\left\{\epsilon^*_\mu(m_B^2-m_K^2)-(\epsilon^* P_B)(P_B+p)_\mu\right\} + T_3(s)(\epsilon^* P_B)\left\{q_\mu - \frac{s}{m_B^2-m_K^2}(P_B+p)_\mu\right\}$$

$$\langle K^*(p)|\partial_\mu A^\mu|B(p_B)\rangle = 2m_K(\epsilon^* P_B)A_0(s)$$

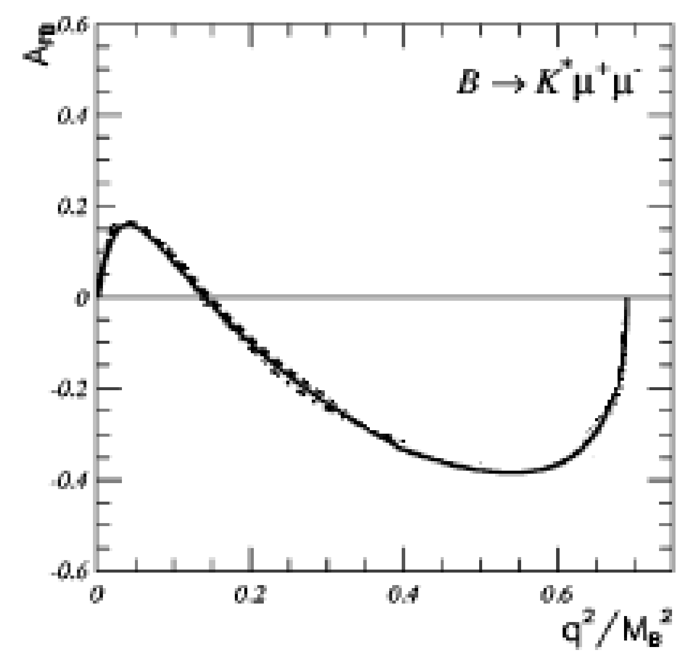
- Hadronic form factors calculated in *LCSR*

$BR(B \to K^*\mu^+\mu^-) = (1.19 \pm 0.39)x10^{-6}$ [A. Ali et al., hep-ph/0112300 (2002)]

Theory in *SM*: vectorial transition $B\rightarrow K^*$ (2)

- Differential decay width and dilepton invariant mass distribution depend on hadronic form factors and Wilson Coefficient

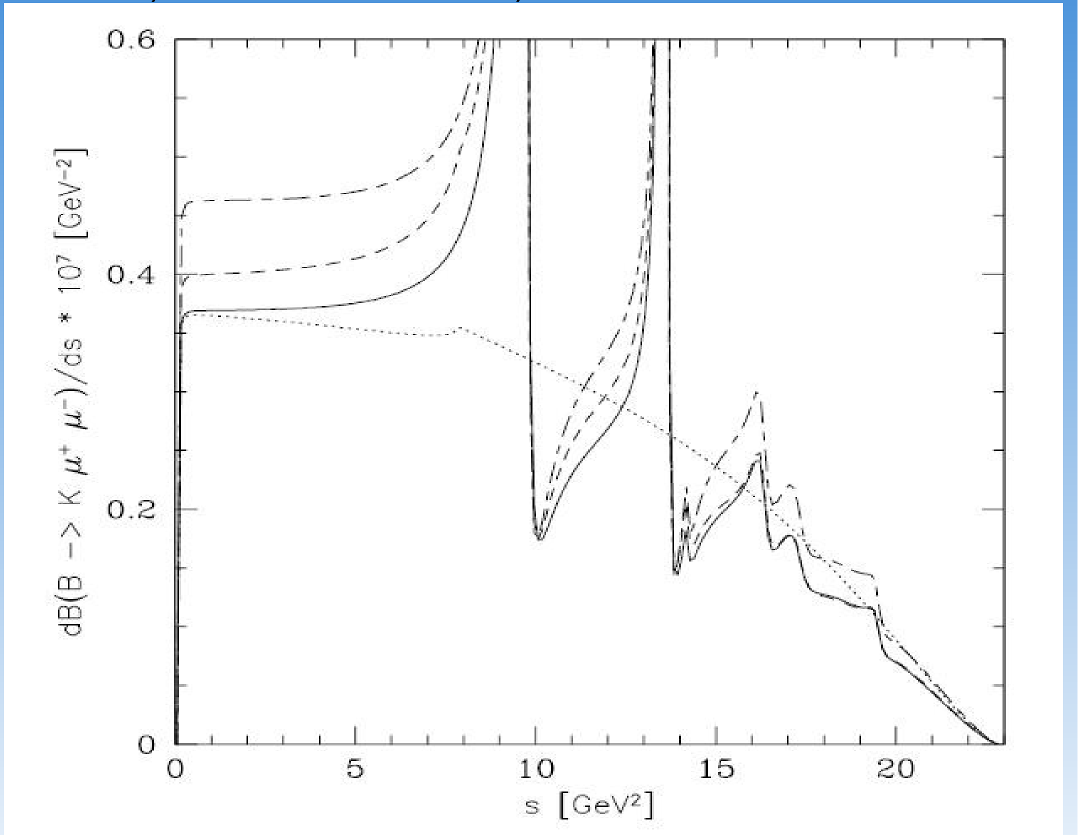
- *FB* asymmetry does not vanish in $B\rightarrow K^*$ decays



Supersymmetric Models: B→K (1)

- Generic *SUSY* effects in differential decay rate distribution assuming C_9 and C_{10} to their respective *SM* values, $C_7(SUSY) = - C_7(SM)$ and form factors from *LCSR*

[A. Ali et al., hep-ph/9910221 (1999)]



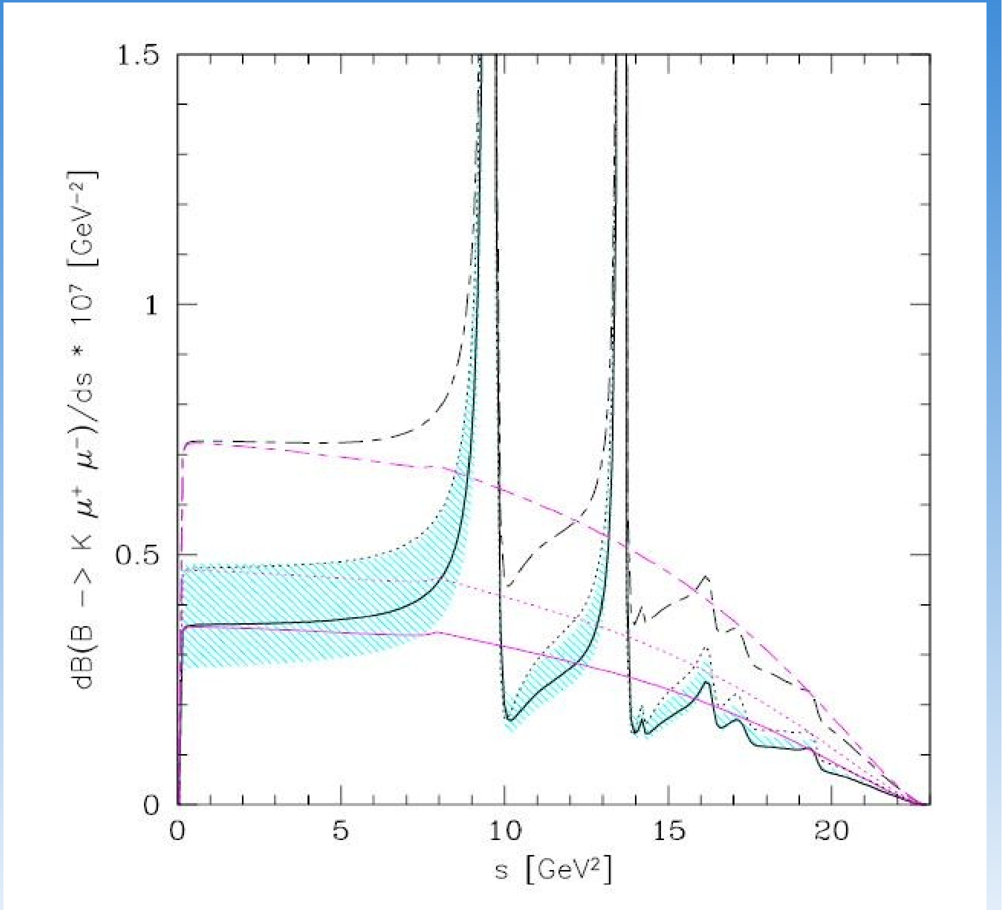
  - Solid curve: *SD* + *LD*
  - Dotted: pure *SD*
  - Long-short dashed: *SD* + *LD* *(SUSY)*

Supersymmetric Models: B→K (2)

- Differential decay rate using form factors from *LCSR* in *SM*, *SUGRA*, *MIA-SUSY* models

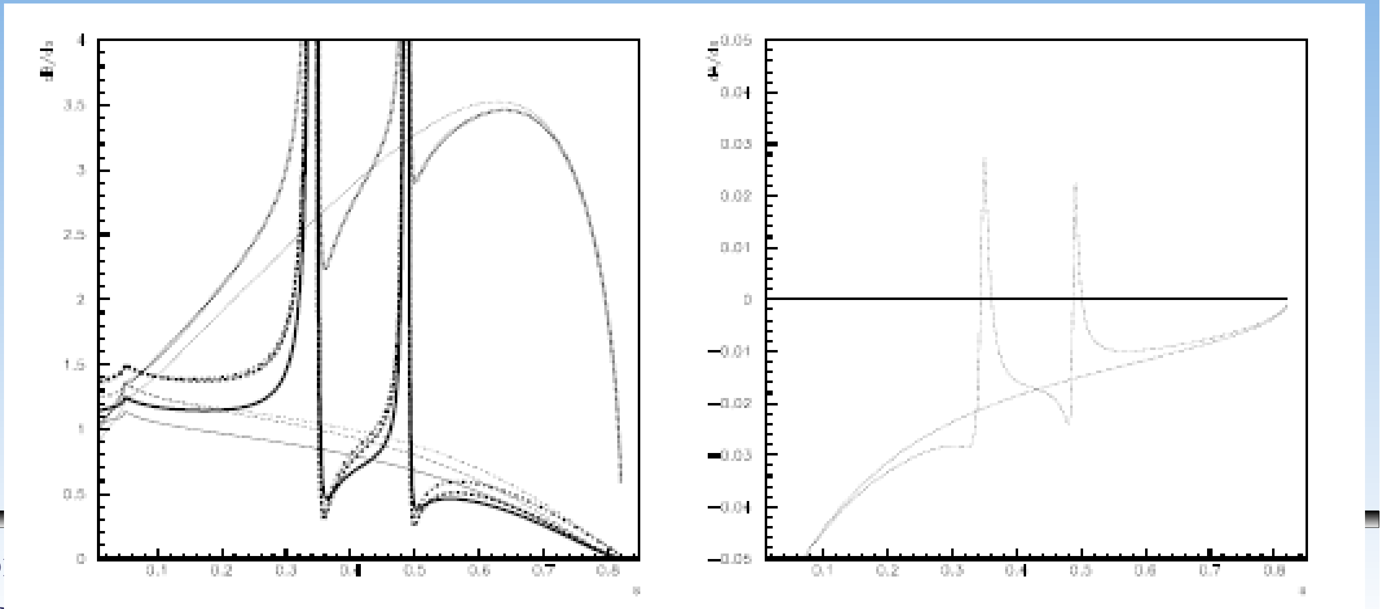
[A. Ali et al., hep-ph/9910221 (1999)]

  - Solid line: *SM* with shaded area depicts the form factor uncertainties
  - Dotted line: *SUGRA* model
  - Long-short dashed lines: *MIA-SUSY* model



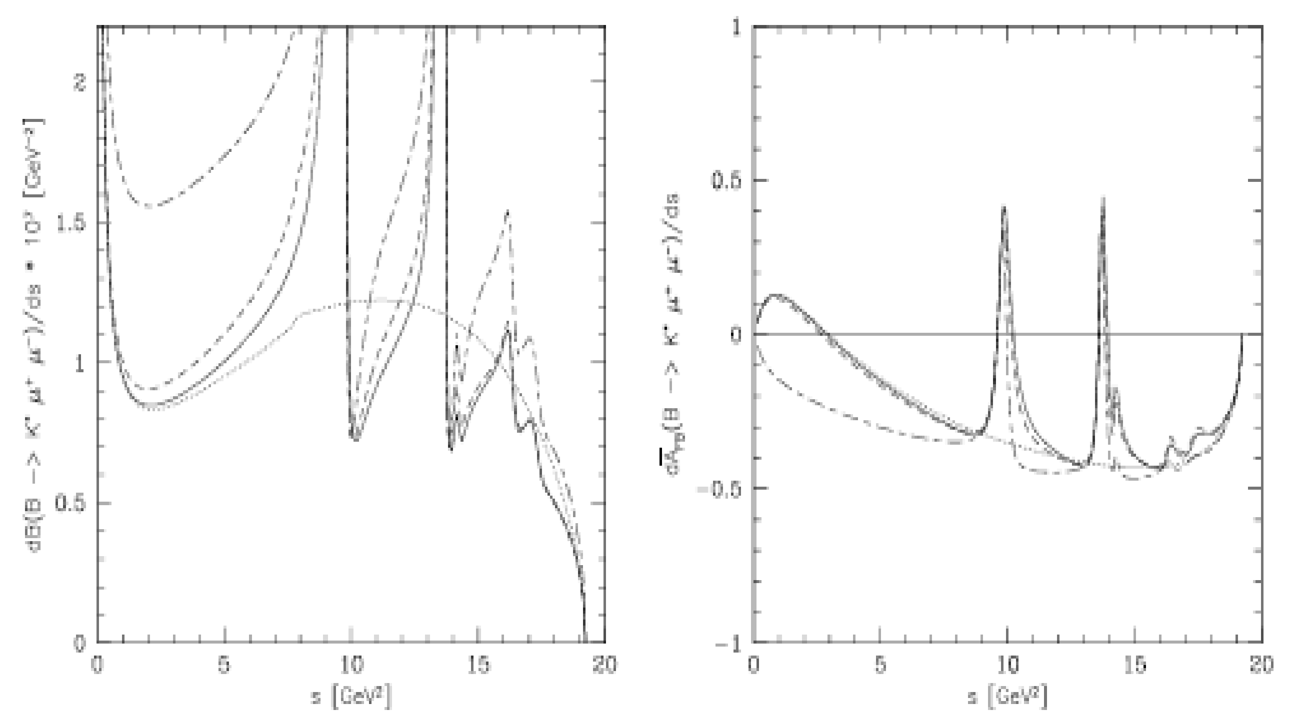
Supersymmetric Models: B→K (3)

- Other calculations:
  - 2 Higgs doublet model and *SUSY* with minimal flavour violation (large *tan*β): no appreciable *FBA* or any large deviation from the *SM* prediction for the B→Kl$^+$l$^-$ branching fraction [C. Bobeth et al., hep-ph/0104284 (2002)]
  - In supersymmetric theories *FBA* and muon invariant mass spectrum difference with respect to *SM* [Q. Yan et al., hep-ph/0004262 (2000)]
    - Solid line: *SM*
    - Dotted line: *SUSY*



Supersymmetric Models: B→K* (1)

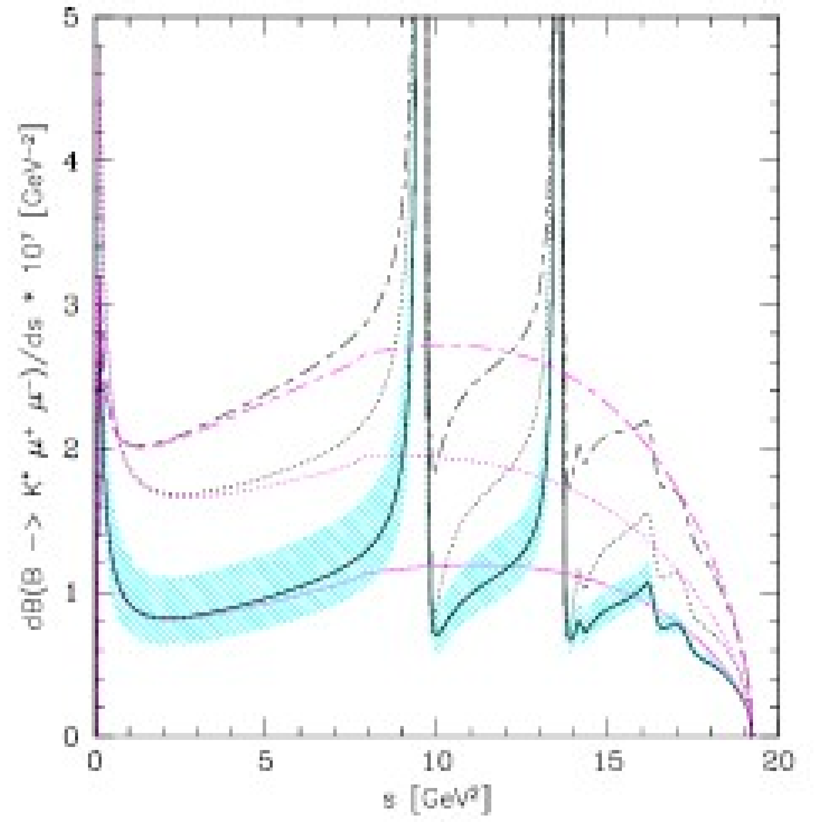
- Generic *SUSY* effects in differential decay rate distribution and AFB assuming C_9 and C_{10} to their respective *SM* values, $C_7(SUSY) = - C_7(SM)$ and form factors from *LCSR* [A. Ali et al., hep-ph/9910221 (1999)]



- Solid curve: *SD + LD*
- Dotted: pure *SD*
- Long-short dashed: *SD + LD (SUSY)*

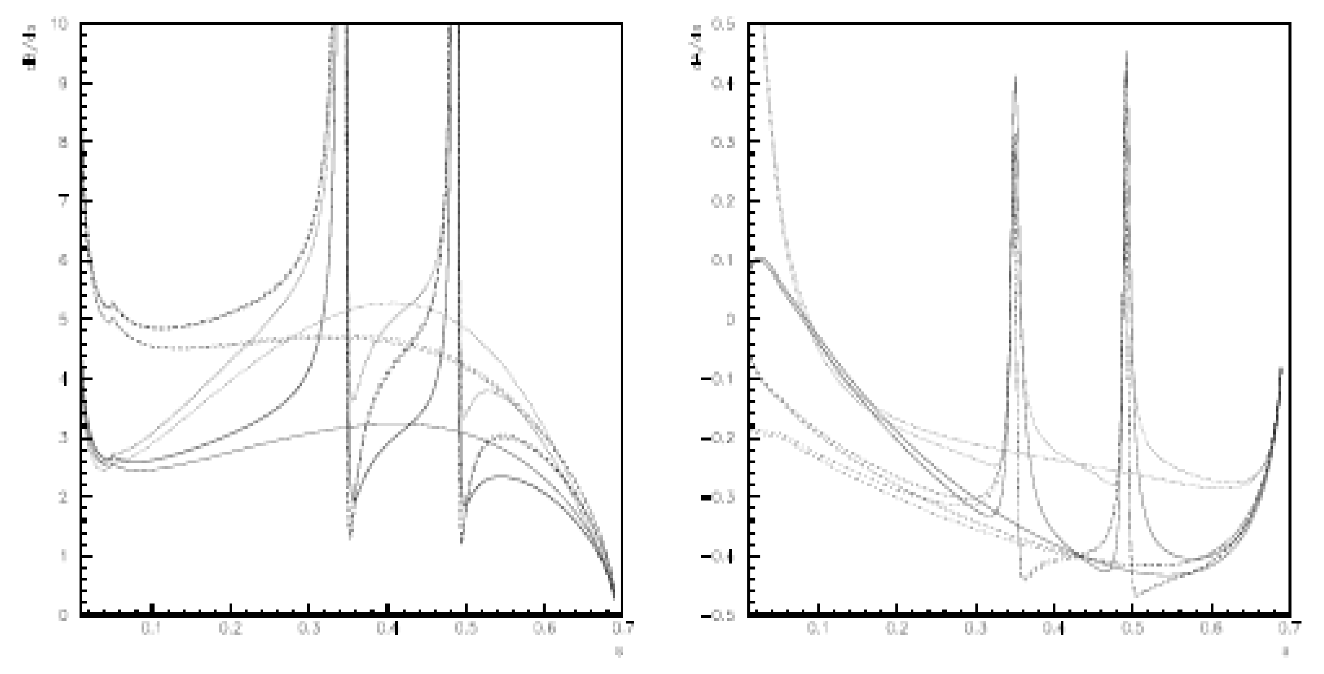
Supersymmetric Models: $B \rightarrow K^*$ (2)

- Differential decay rate using form factors from *LCSR* in *SM*, *SUGRA*, *MIA-SUSY* models
  - Solid line: *SM* with shaded area depicts the form factor uncertainties
  - Dotted line: *SUGRA* model
  - Long-short dashed lines: *MIA-SUSY* model



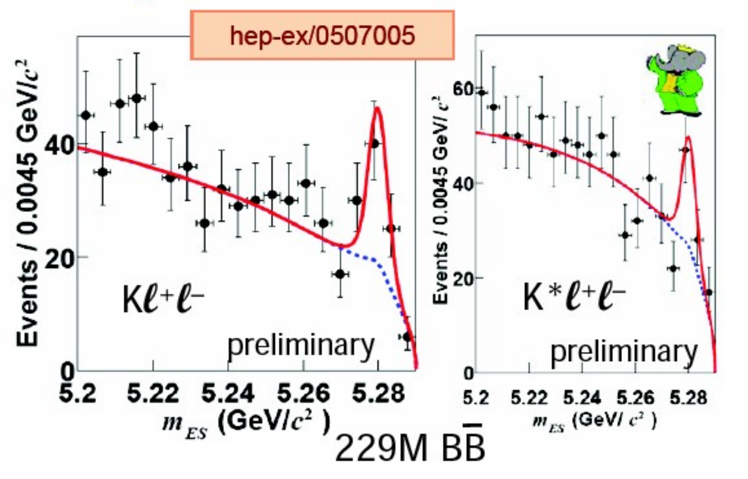
Supersymmetric Models: $B \rightarrow K^*$ (3)

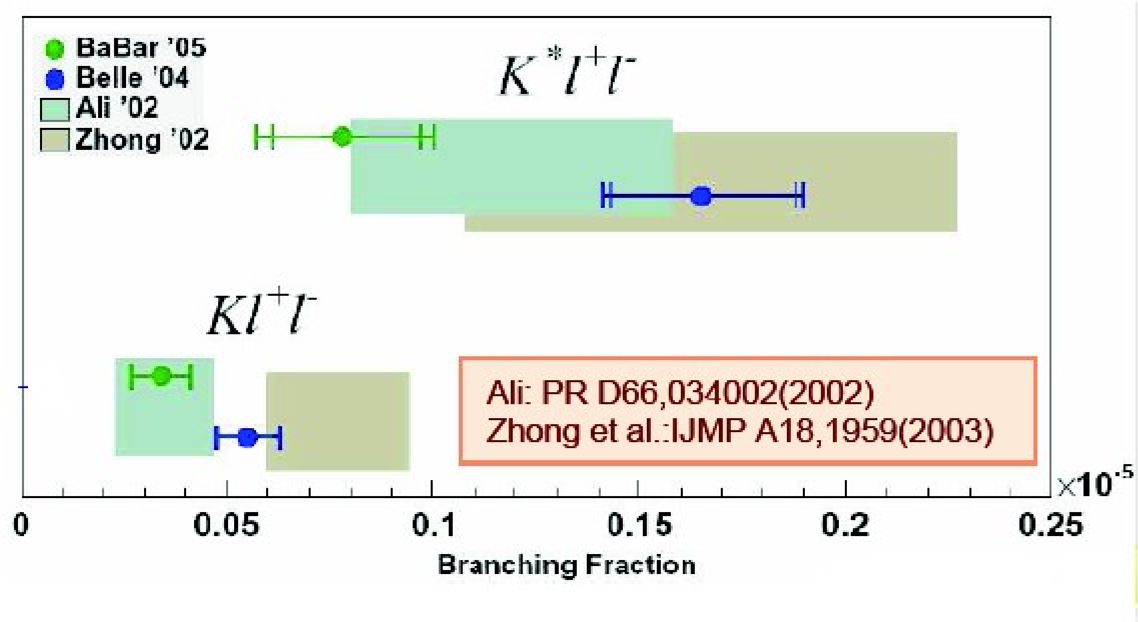
- Other calculations:
  - In supersymmetric theories *FBA* and muon invariant mass spectrum difference with respect to *SM* [Q. Yan et al., hep-ph/0004262 (2000)]
    - Solid line: *SM*
    - Dotted line: *SUSY*



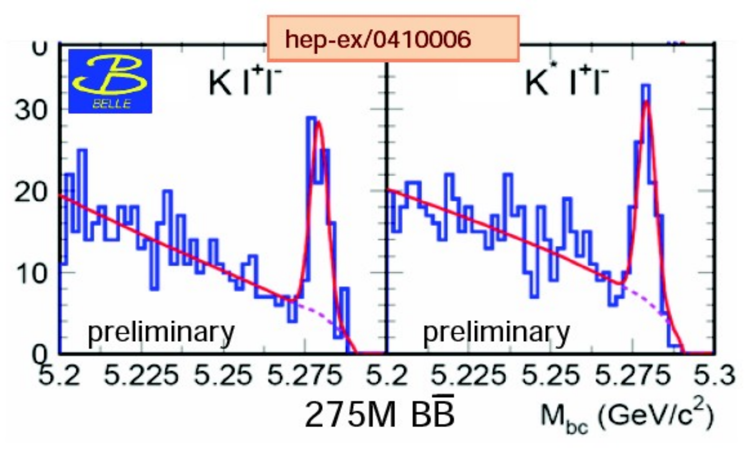
Experimental Results

- from BABAR Analysis Document #963 (08/03/2005)
  - $\mathrm{BR}(\mathbf{B^+ \rightarrow K^+ \mu^+ \mu}) = (0.31 \pm 0.4) \times 10^{-6}$
  - $\mathrm{BR}(\mathbf{B^+ \rightarrow K^{*+} \mu^+ \mu}) = (0.97 \pm 0.14) \times 10^{-6}$



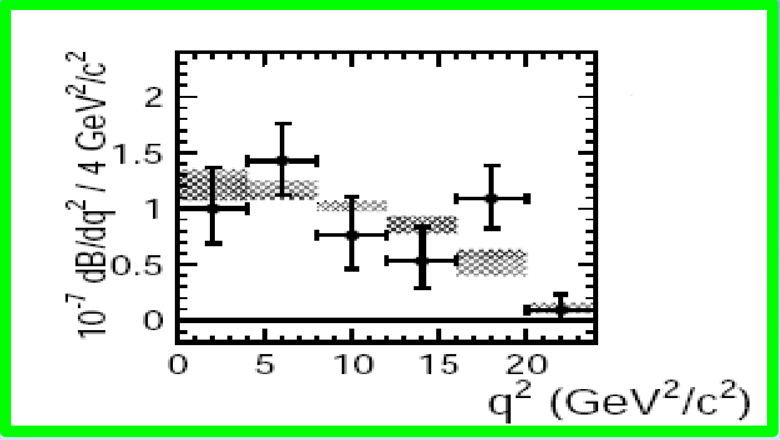


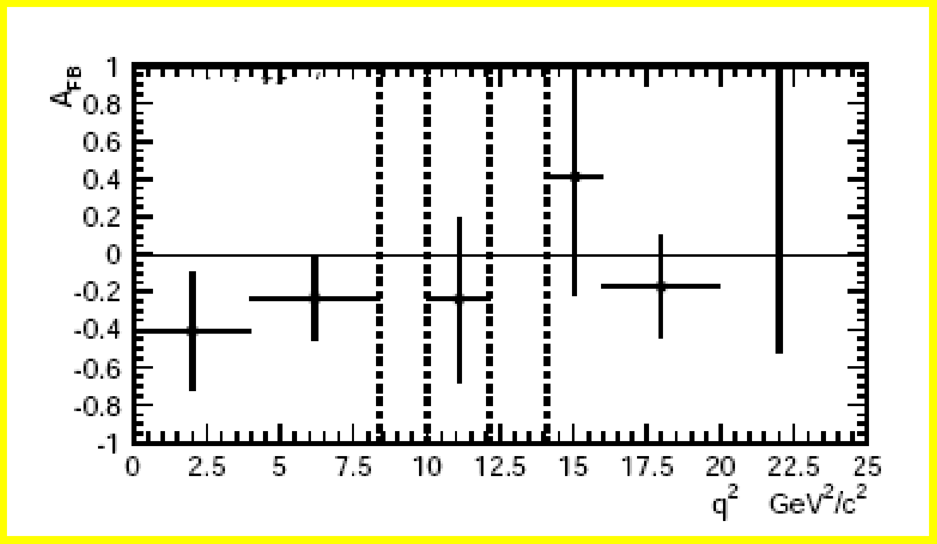
Ali: PR D66,034002(2002)
Zhong et al.:IJMP A18,1959(2003)



Experimental Results: $B^+ \rightarrow K^+\mu^+\mu^-$

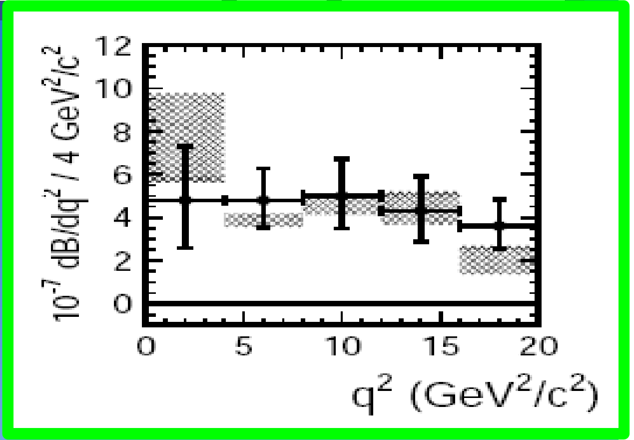
- FBAsymmetry and differential decay rate from hep-ex/0410006 (Belle Coll.) (bands represent the SM prediction)
  - High statistical errors

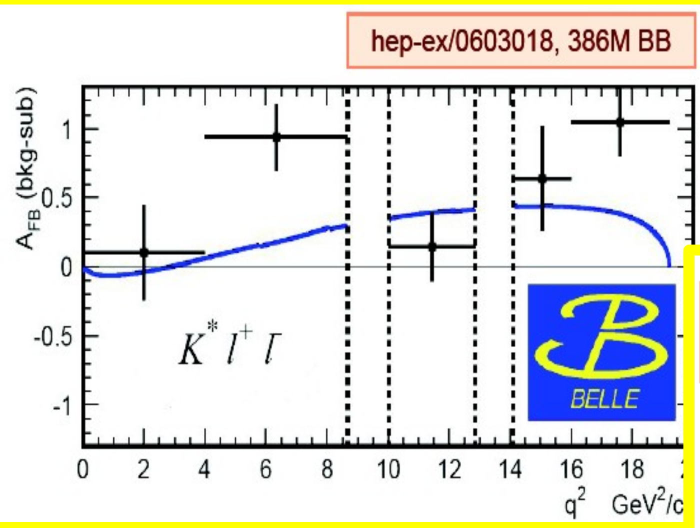


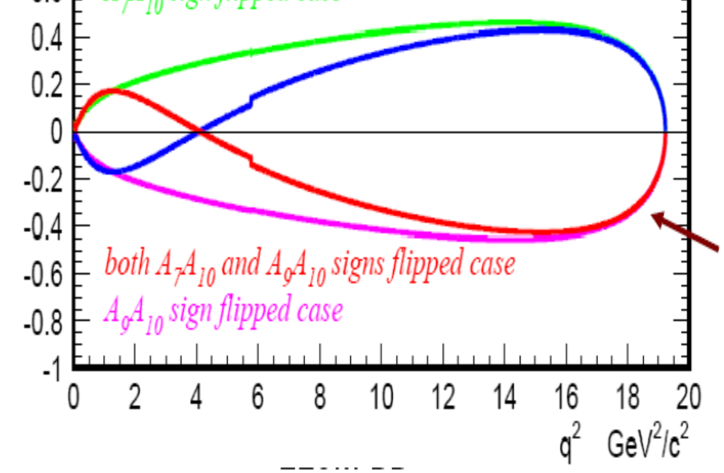


Experimental Results: $B^+ \to K^{*+}\mu^+\mu^-$

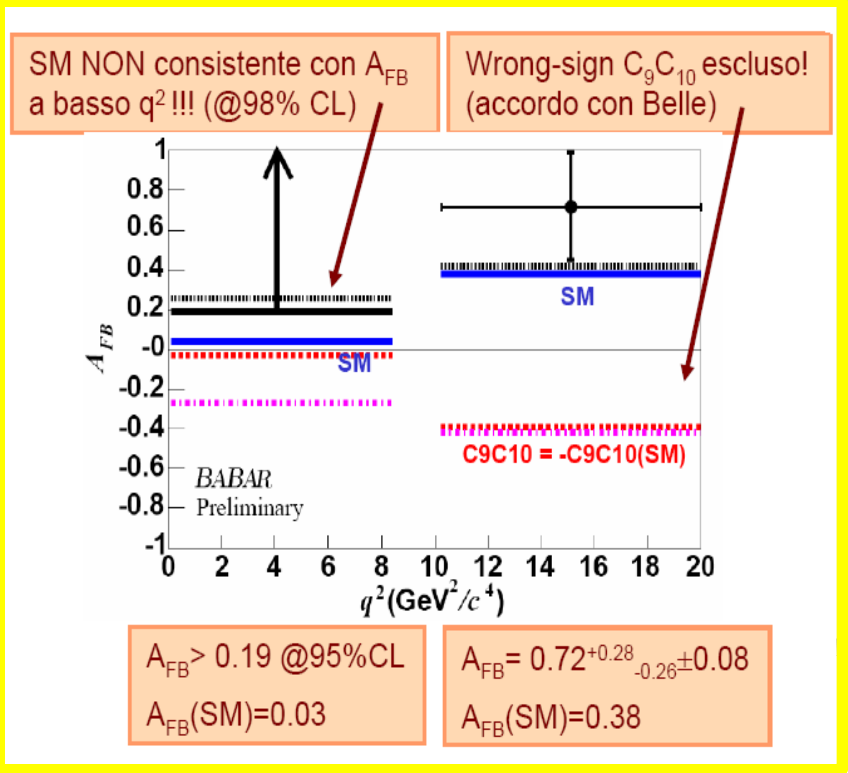
- differential decay rate from hep-ex/0410006 (Belle Coll.) (bands represent the SM prediction) and FBAsymmetry







Contributi di NP



SM NON consistente con A_{FB} a basso q^2 !!! (@98% CL)

Wrong-sign C_9C_{10} escluso! (accordo con Belle)

A_{FB}> 0.19 @95%CL

A_{FB}(SM)=0.03

A_{FB}= $0.72^{+0.28}_{-0.26}$±0.08

A_{FB}(SM)=0.38