Rare Beauty Decays with ATLAS and CMS Experiments at LHC

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Outline

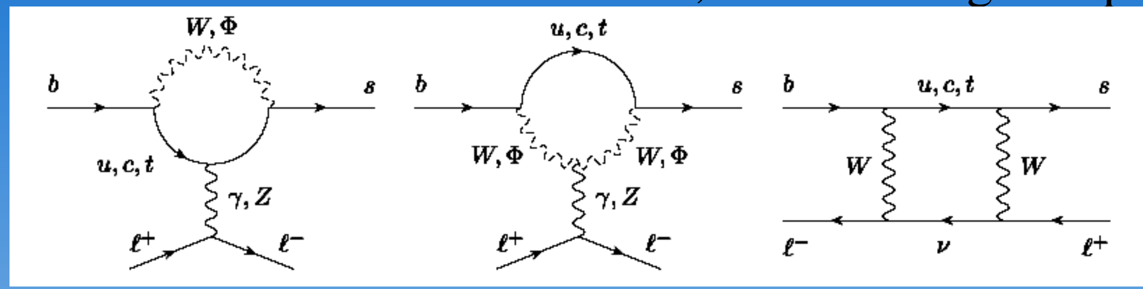
- Introduction
- ATLAS and CMS experiments at LHC: a B-Physics point of view
- $B_s \to \mu^+\mu^-$ in ATLAS and CMS
- Semileptonic DiMuon rare decay channels in ATLAS
  - $B^+ \to K^+\mu^+\mu^-$
  - $B^+ \to K^{*+}\mu^+\mu^-$
  - $B_d \to K^{0*}\mu^+\mu^-$
  - $B_s \to \phi\, \mu^+\mu^-$
  - $\Lambda_b \to \Lambda^0\mu^+\mu^-$
- Differences and comparison with LHCb (where possible)
- Conclusions

B-Physics in ATLAS and CMS

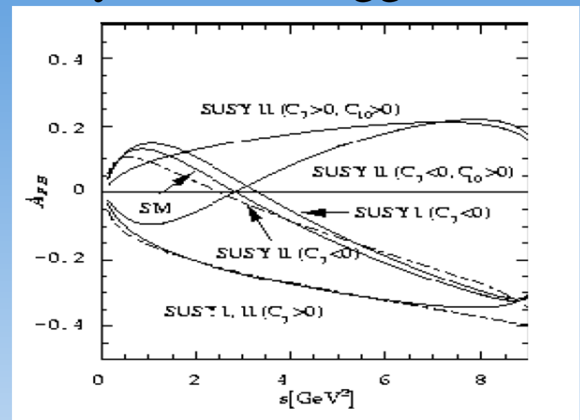
- LHC: proton-proton collisions at $\sqrt{s}$=14TeV and bunch crossing rate 40MHz
- High *bb* production cross section: $\sigma(bb)$=500μb
  - 10^5 *bb* pairs/s at initial low luminosity ~$10^{33}cm^{-2}s^{-1}$
- ATLAS and CMS design dedicated to high-p_T physics
  - majority of B-events has low p_T particles
  - a challenge for the trigger and the analysis
  - B-decays with muons in the final state are the most promising
- B-Physics programme
  - CP violation (low luminosity, e.g. $B \rightarrow J/\psi X$)
  - B_s oscillation (low luminosity, e.g. $B_s \rightarrow \pi D_s$)
  - rare decays (even with high luminosity, e.g. $b \rightarrow s \mu^+\mu^-$, $B \rightarrow \mu^+\mu^-$)

Rare B decays

- $b \to s\,\mu^+\mu^-$, $B \to \mu^+\mu^-$ (FCNC) transitions forbidden at the tree level, occur through loop diagrams

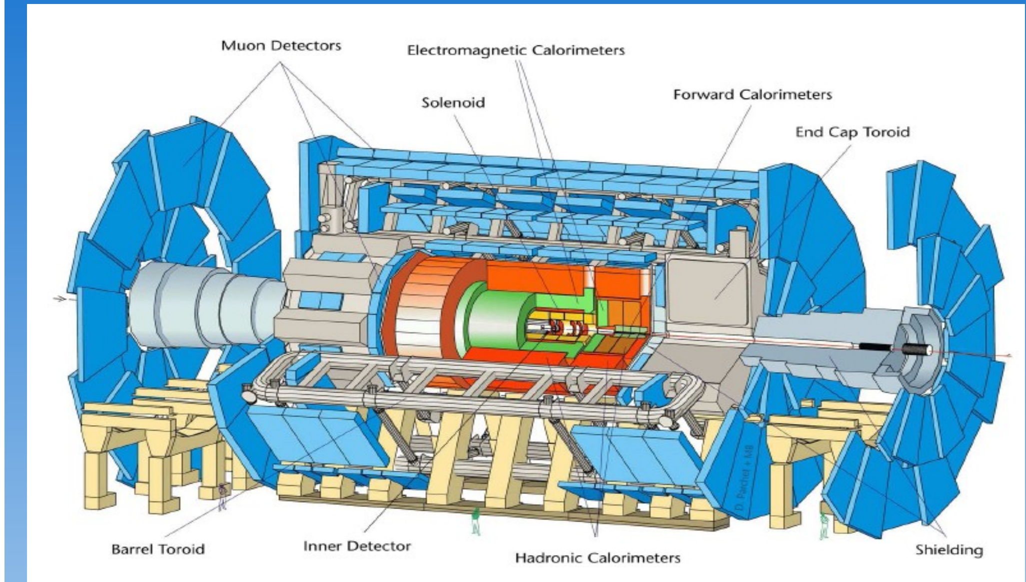


  - very low branching ratio
  - sensitive to new physics
- For semimuonic exclusive decays (the only accessible at LHC), theory authors suggest to measure variables describing dimuon system, function of $s=m_{\mu\mu}^{2}$

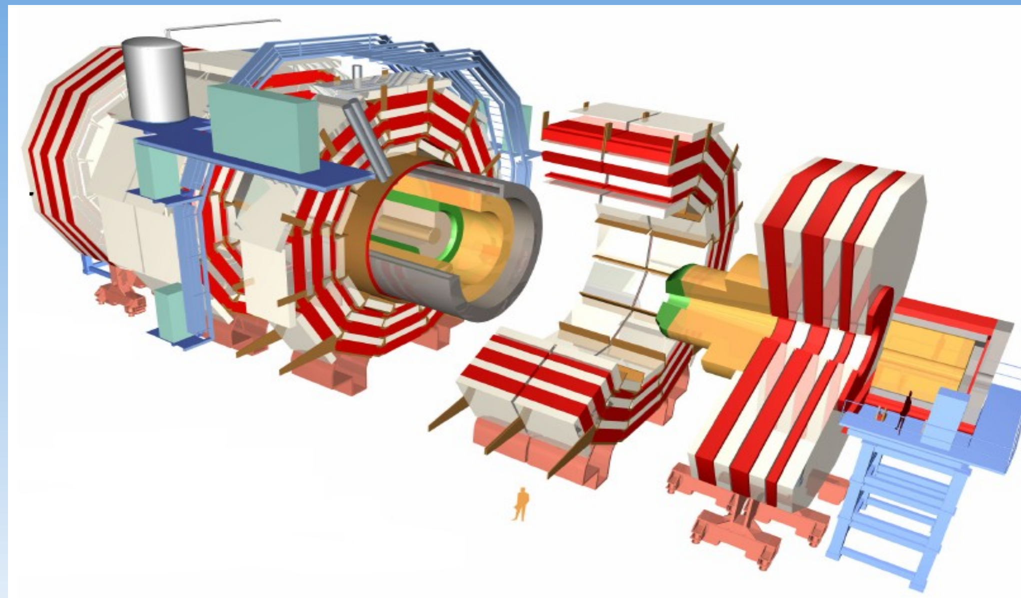


  - forward-backward asymmetry as a function of s
  - zero of the A_{FB} curve: $s_0=2C_7/C_9$
  - CP asymmetry
- For $B_s \to \mu^+\mu^-$ some BSM models predict a larger branching ratio than SM
- Need very good precision measurements to find differences with SM predictions
  - excellent calibrations and efficient muon trigger and offline reconstruction

ATLAS and CMS detectors

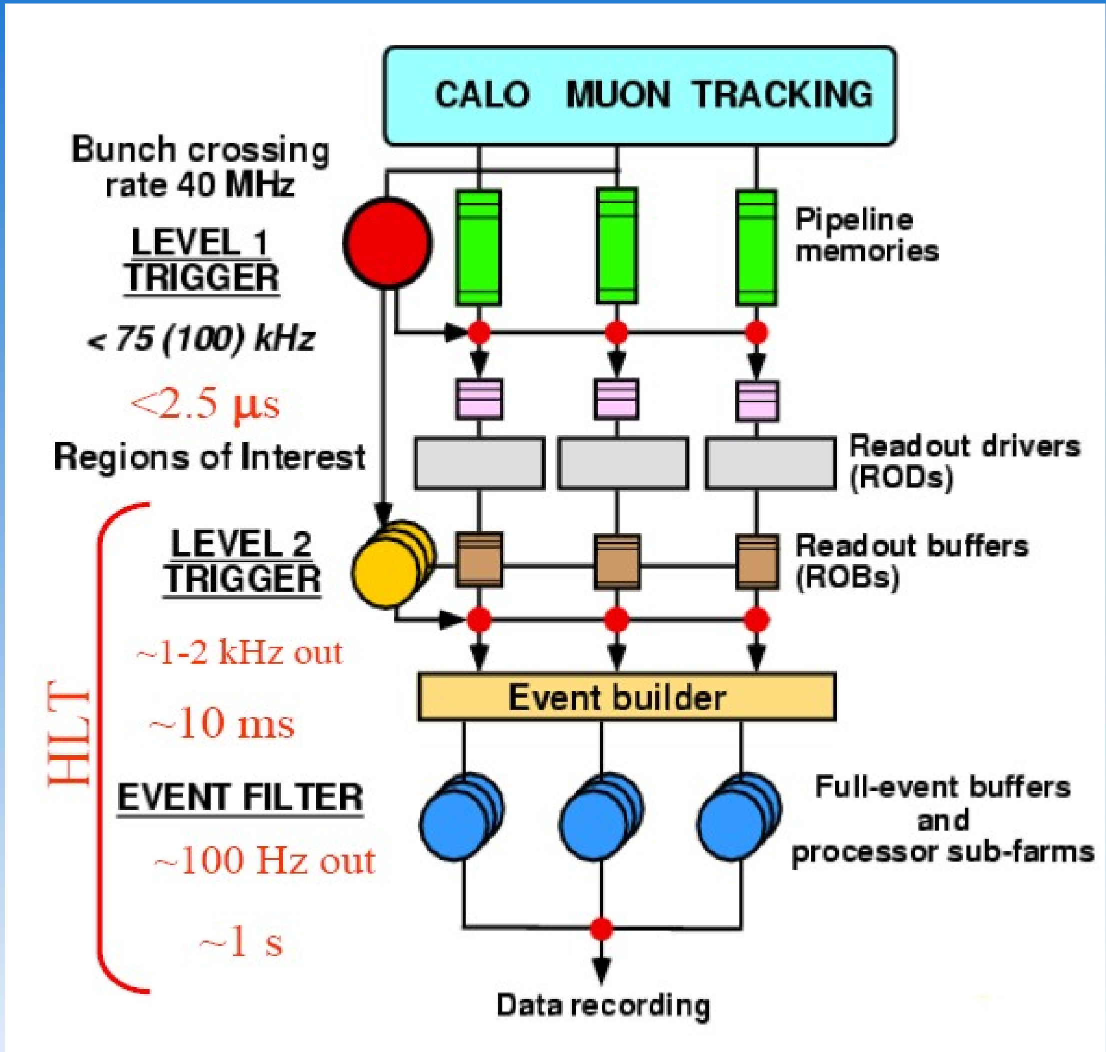


- ATLAS and CMS are general purpose detector
  - $|\eta|<2.5$
  - B-physics using trigger with high p_T muons



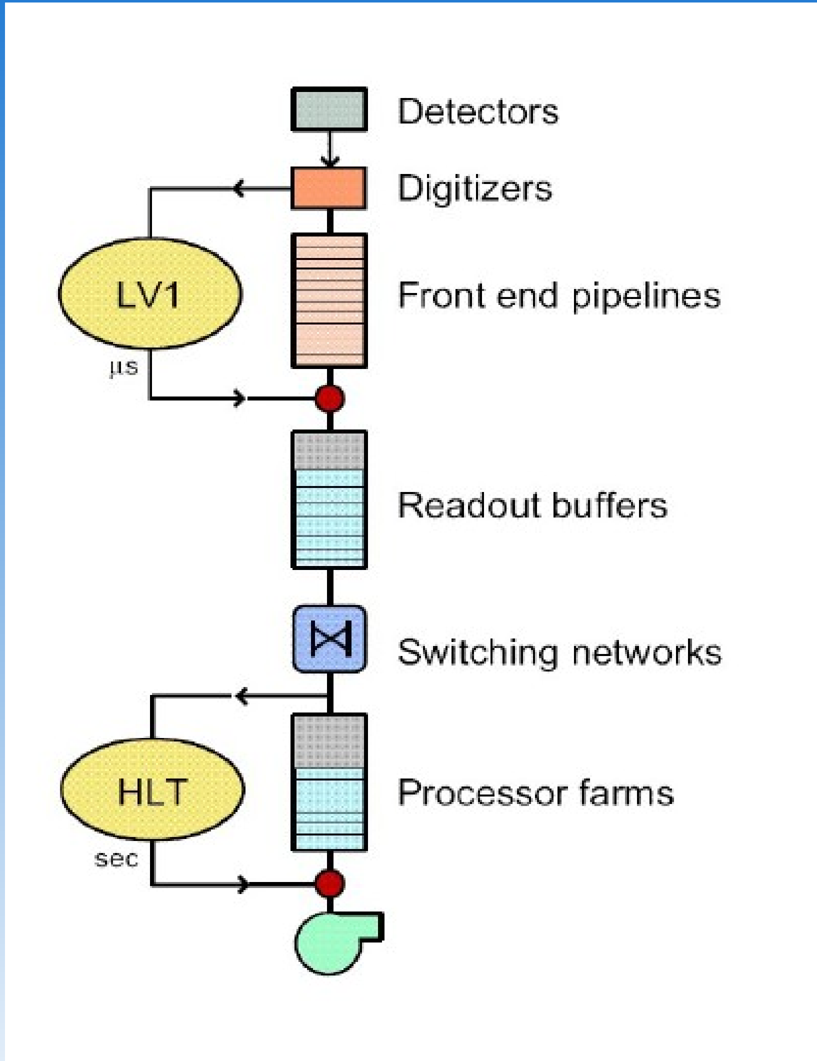
- LHCb optimized for B-Physics
  - particle ID
  - designed to maximize acceptance for *bb* forward pair
  - low p_T trigger

Overview of ATLAS trigger



- Three level trigger
- LVL1
  - coarse granularity calorimeter and muon information
  - identifies Region of Interest (RoI) for further processing
- LVL2
  - full granularity
  - confirm LVL1 trigger
  - precision muon chamber and inner detector measurements in LVL1 RoI
- Event Filter (EF)
  - refines LVL2 selection using offline-like algorithms
  - alignment and calibration data available
- B-Physics allowed 5-10% of total trigger resources: it must be fast, efficient and selective

Overview of CMS trigger

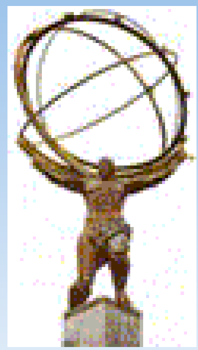


- Two level trigger
- LVL1 based on muon detector and calorimeter measurements
  - 40MHz $\rightarrow$ ~100kHz
  - latency 3.2µs
- High Level Trigger (HLT) with fast reconstruction
  - uses reconstruction code and informations similar to off-line
  - 100kHz $\rightarrow$ ~150Hz

ATLAS/CMS trigger for rare decays

ATLAS dimuon trigger

- LVL1
  - 2μ RoI with $p_T(\mu)>6GeV$ (500Hz @ $L=10^{33}cm^{-2}s^{-1}$)
- LVL2
  - confirm each μ RoI with precision muon chamber and inner detector measurements
  - mass cut > 2GeV
- EF
  - refit inner detector tracks in LVL2 RoI
  - decay vertex reconstruction
  - proper time cut
  - angular distribution cuts
- Output rate <10Hz
- Efficiency estimated after EF
  - 70% for $B \to \mu^+\mu^-$
  - 60% for $B \to K^{(*)} \mu^+\mu^-$



CMS dimuon trigger

- Level1
  - 2μ with $p_T(\mu)>3GeV$
- HLT
  - primary vertex reconstruction with pixel detector
    - use the three most probable vertex
  - track reconstruction in cones around Level1-muon candidates
    - partial reconstruction using ≤6 hits
  - vertex fit
    - $\chi^2<20$
    - decay flight length > 150μm
  - mass windows for signal
- Output rate <1.7Hz

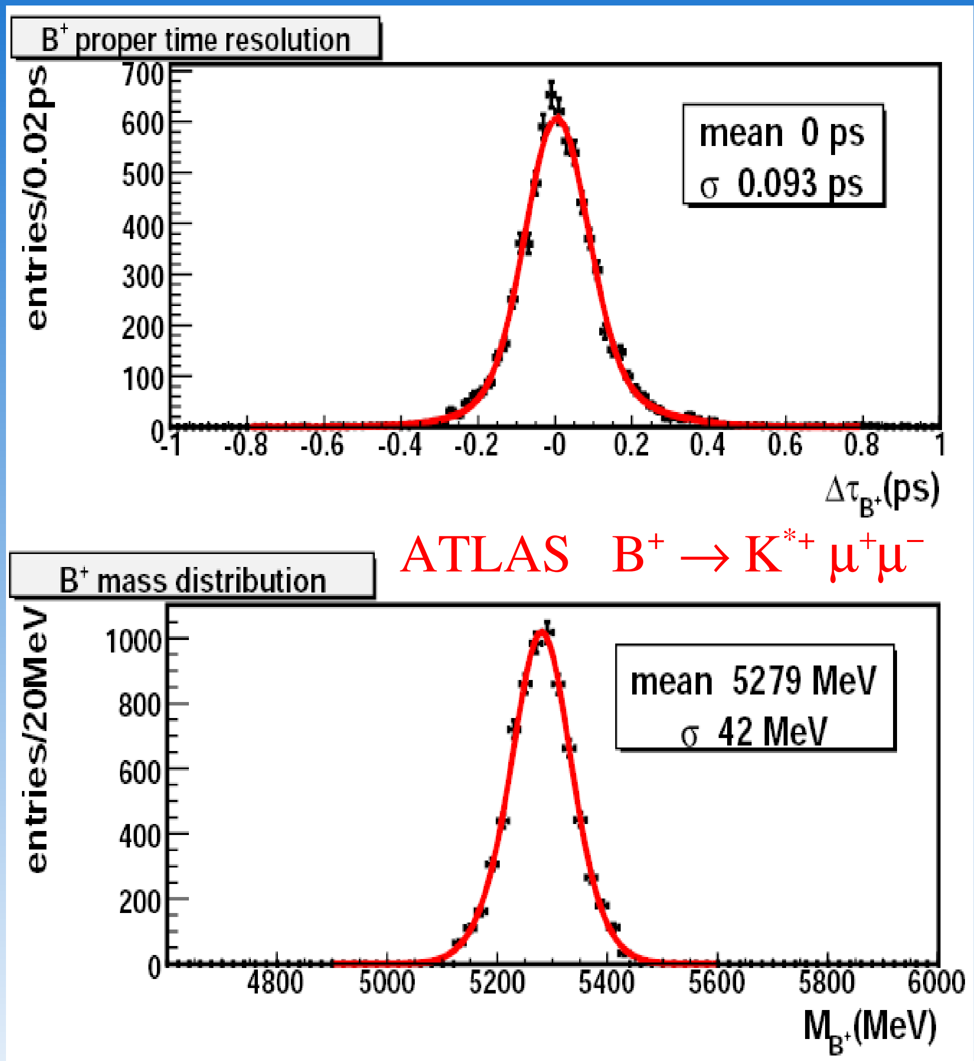
Tracking performance

- Proper time resolution
  - a good proper time resolution is necessary for time dependent asymmetry and oscillation measurements

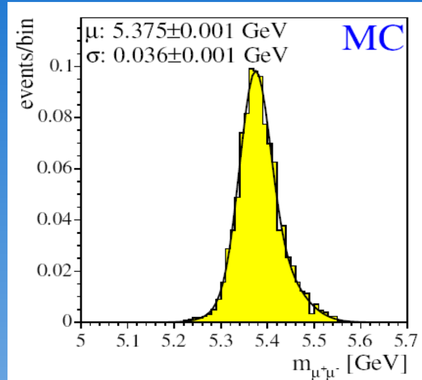
	σ_t (fs)
ATLAS	~95
CMS	~100
LHCb	~40

- Mass width in MeV/c^2

	ATLAS	CMS	LHCb
$B \to \mu^+\mu^-$	~80	~40	~18
$B \to K^* \mu^+\mu^-$	~40		~15
$\Lambda b \to \Lambda^0 \mu^+\mu^-$	~47		



$B_s \rightarrow \mu^+\mu^-$ in CMS



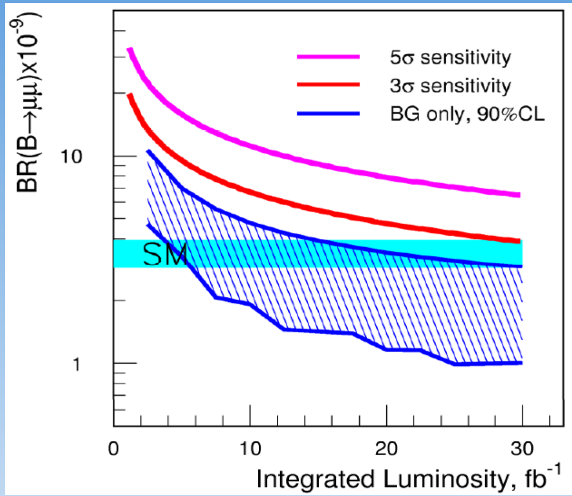
- Low branching ratio (3.5×10^{-9} in SM) requires a good background rejection
  - combinatorial with muons mainly from *b* decays
  - rare B decays
  - mis-identified hadrons - e.g. $B \rightarrow \pi\pi$, $K\pi$, KK
- Analysis variables in CMS
  - decay flight length significance on transverse plane $l_{xy}/\sigma_{xy} > 18$
  - muon separation $\Delta R(\mu\mu) = \sqrt{(\eta_{\mu_1} - \eta_{\mu_2})^2 + (\phi_{\mu_1} - \phi_{\mu_2})^2}$ $0.3 < \Delta R(\mu\mu) < 1.2$
  - isolation of the muon pair in a cone with *R=1 (and p_T>0.9GeV)*

$$I = \frac{p_\perp(B_s)}{p_\perp(B_s) + \sum_{trk} |p_\perp|} > 0.85$$

  - secondary vertex: pointing angle $\cos(\alpha) > 0.995$ and vertex fit with $\chi^2 < 1$
  - mass cut $|M(\mu\mu) - M(B_s)| < 40\text{MeV}$ for separation with B_d
- 6.1 ± 0.6 signal events and $13.8^{+22.0}_{-13.8}$ background events in 10fb^{-1}
- Upper limit on branching ratio 1.4×10^{-8} @ 90% CL (CDF+D0 with 1fb^{-1}, $\sim 7 \times 10^{-8}$)
- Rare B decays to be included

$B_s \rightarrow \mu^+\mu^-$ in ATLAS

- Analysis variables in ATLAS
  - Muon separation $\Delta R(\mu\mu)<0.9$
  - Isolation cut: no charged tracks with $p_T>0.8$ in a cone with $\theta=15°$
  - Decay flight length significance on transverse plane > 15
  - Matching between the direction from the primary to secondary vertex and the dimuon momentum (pointing angle) $\alpha<1°$
  - vertex fit with $\chi^2<15$
  - Mass cut $M(\mu\mu)=M(B_s)^{+140}_{-70}\,MeV$
- 7 signal events and 20 background events expected in $10fb^{-1}$
- Upper limit on branching ratio $7x10^{-9}$ @ 90% CL
- ATLAS expects to reach the sensitivity of the level of SM prediction with $30fb^{-1}$ (3 years of data taking)



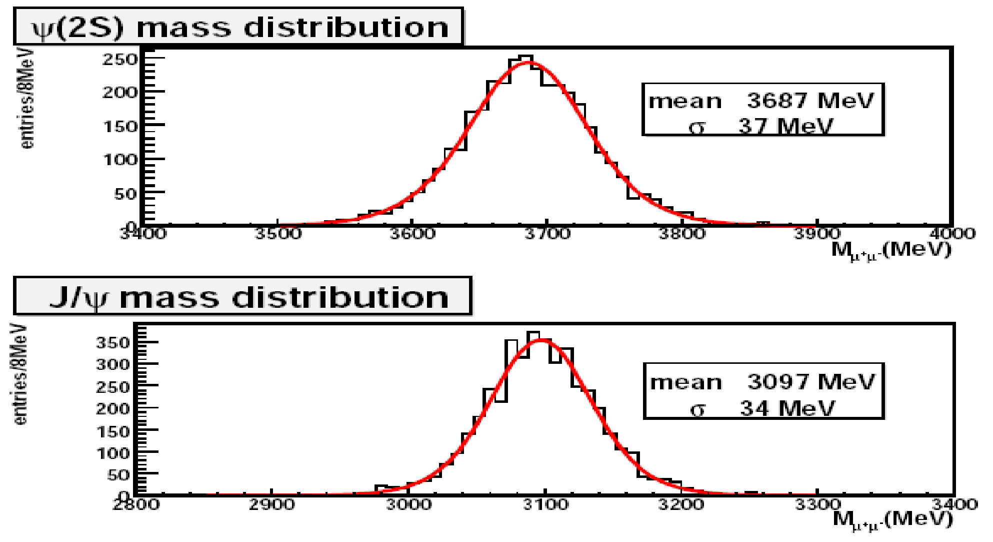
- Rare decays as background: studies limited to particle level show that the background is small in comparison with signal and negligible comparing to combinatorial background
- LHCb expects to reach the sensitivity of the SM prediction in $2fb^{-1}$ (1 year of data taking)

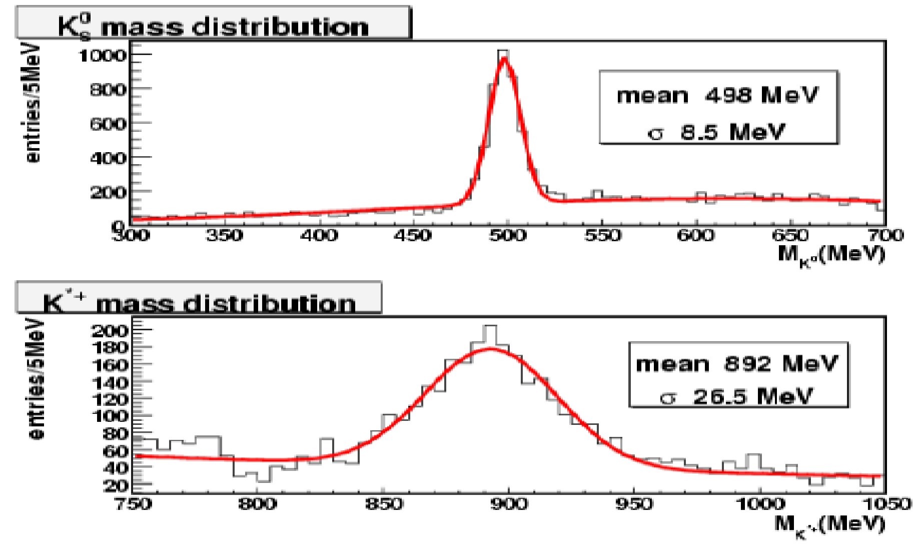
Semileptonic rare decays of B meson in ATLAS (1)

- $B^+ \to K^+\mu^+\mu^-$, $B^+ \to K^{*+}\mu^+\mu^-$, $B_d \to K^{0*}\mu^+\mu^-$, $B_s \to \phi\, \mu^+\mu^-$
- Background sources
  - Channels with J/Ψ and $\Psi(2S)$ resonances: irreducible background
    - cut on dimuon invariant mass
  - Combinatorial background
    - Semileptonic decays of both *b* and *b-bar* quarks
    - Double semileptonic decay of *b* quark ($b\text{->}c\mu\nu$, $c\text{->}s\mu\nu$)
    - topological and vertex requirements to eliminate this background
  - kaons and pions misidentification as muons (mainly at low P_T) still missed in the present results
    - 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
    - their contribution is expected poor with respect to combinatorial background

Semileptonic rare decays of B meson in ATLAS (2)

- Analysis variables
  - Good dimuon vertex with $\chi^2/NDF<3$
  - Dimuon mass in kinematical allowed window and J/Ψ and Ψ(2S) areas excluded $m_{\mu\mu} \notin [m_\psi \pm 3\sigma]$
  - Secondary hadron reconstruction with vertex $\chi^2/NDF<2$, $p_T>3$GeV and mass in $m_h \pm 3\sigma$
  - Good B meson vertex with $\chi^2/NDF<2$
  - B meson mass in $m_B \pm 3\sigma$ and proper time > 0.5ps



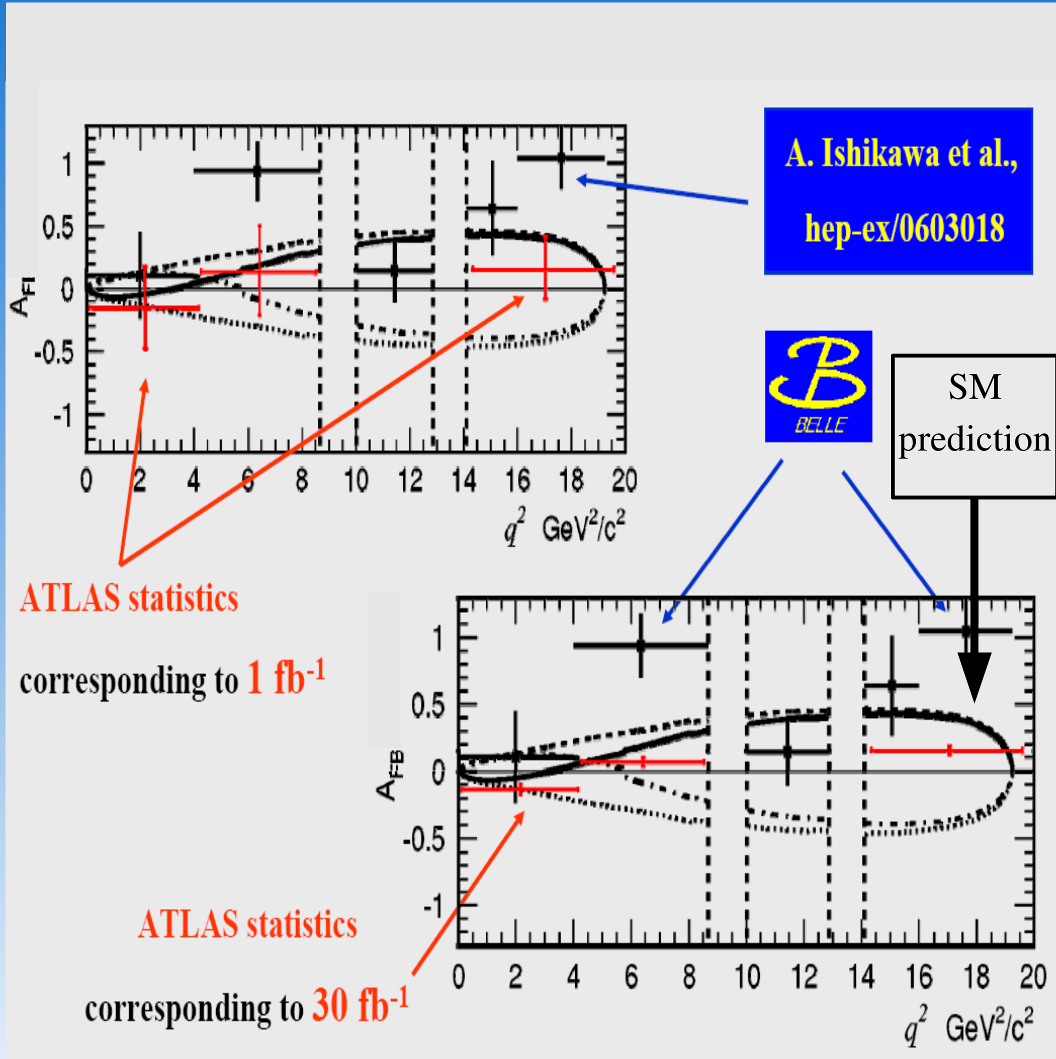


Semileptonic rare decays of B meson in ATLAS (3)

- Signature after 30fb^{-1}

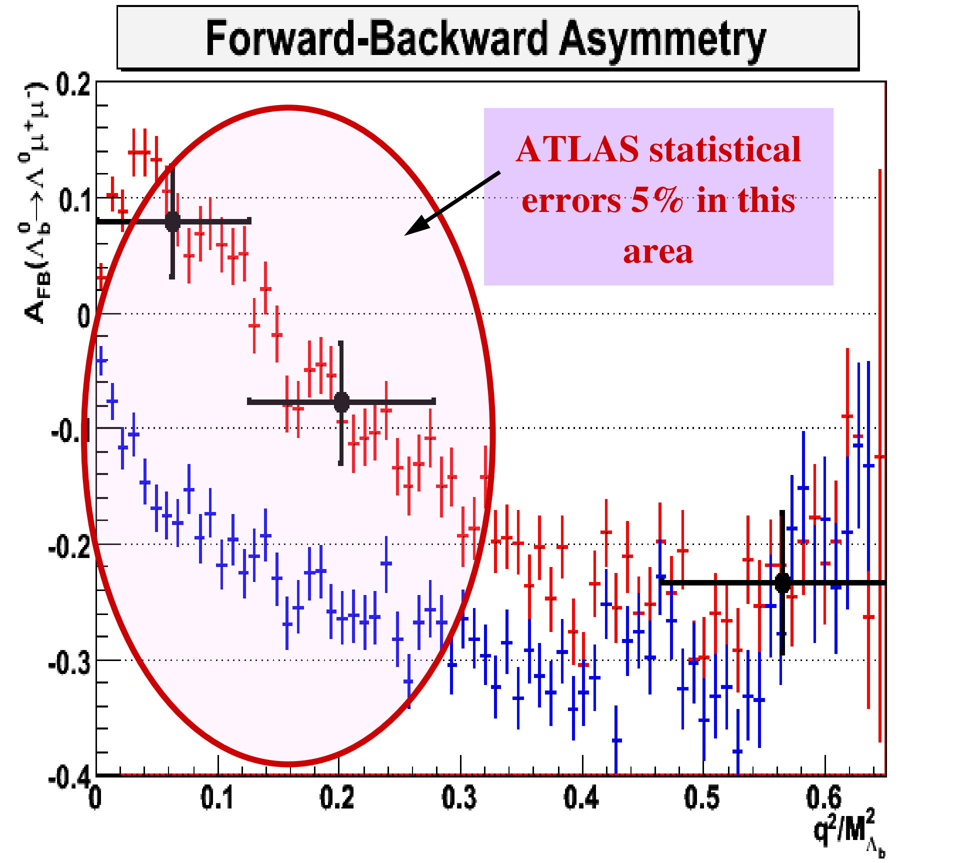
Decay Channel	Signal	Background
$B^+ \to K^+\mu^+\mu^-$	4000	<10000
$B^+ \to K^{*+}\mu^+\mu^-$	2300	<10000
$B_d \to K^{0*}\mu^+\mu^-$	2500	<10000
$B_s \to \phi\,\mu^+\mu^-$	900	<10000

- Good sensitivity to forward backward asymmetry measurements for $B \to K^*\mu^+\mu^-$ decay
- Statistical error on $B \to K\mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ branching ratio measurements ~3.5% and ~6.5% respectively
- Study limited by the size of background MC sample
- LHCb: S/B=0.5±0.2 and good sensitivity on A_{FB} measurements after 2fb^{-1}



Semileptonic decays $\Lambda_b \to \Lambda^0\mu^+\mu^-$ in ATLAS

- background sources and analysis strategy similar to meson decays
- 800 signal events and upper limit of 4000 background events @90%CL expected after 30 fb^{-1}
- After 3 years @ $10^{33}cm^{-2}s^{-1}$ ATLAS can distinguish MSSM (C_{7eff}>0) from SM in low values of dimuon mass



•ATLAS expected events after 3 years @ $10^{33}cm^{-2}s^{-1}$

•ATLAS MC events generated with SM after trigger and reconstruction analysis

•ATLAS MC events generated with MSSM (C_{7eff}>0)

Conclusions

- LHC potential for flavor physics is enormous
  - high luminosity allows to study very rare decays
- ATLAS and CMS will use this potential for precise measurements of quantities sensible to New Physics
  - after 3 years of data taking at $L=10^{33}cm^{-2}s^{-1}$ there will be enough statistic to find deviations from SM predictions and to set strong limits on possible physics beyond SM
  - continue measurements on rare decays even at high luminosity thanks to muons in the final state