Study of DiMuon rare beauty decays with ATLAS and CMS

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Antonio Policicchio - Giovanni Crosetti

Università della Calabria & INFN

on behalf of ATLAS and CMS B-Physics groups

Outline

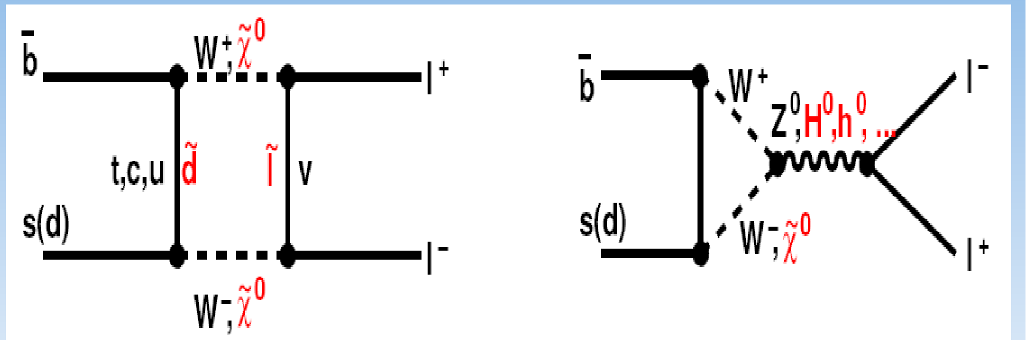
- Introduction
- ATLAS and CMS experiments at LHC from a B-Physics point of view
  - DiMuon trigger
- $B_s \rightarrow \mu^+\mu^-$ in CMS and ATLAS
- $b \rightarrow s\mu^+\mu^-$ rare decays in ATLAS
- Conclusions

B-Physics with ATLAS and CMS

- LHC: proton-proton collisions at $\sqrt{s}$=14TeV and bunch crossing rate 40MHz
- High bb production cross section: $\sigma(bb)=500\mu b$
  - 10^5 bb pairs/s at initial low luminosity ~$10^{33}cm^{-2}s^{-1}$
  - B_s system can be fully exploited at the LHC
- 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. $B \to J/\psi X$)
  - B_s oscillation (low luminosity, e.g. $B_s \to \pi D_s$)
  - rare decays (even with high luminosity, $B \to \mu^+\mu^-$ and $b \to s \mu^+\mu^-$)

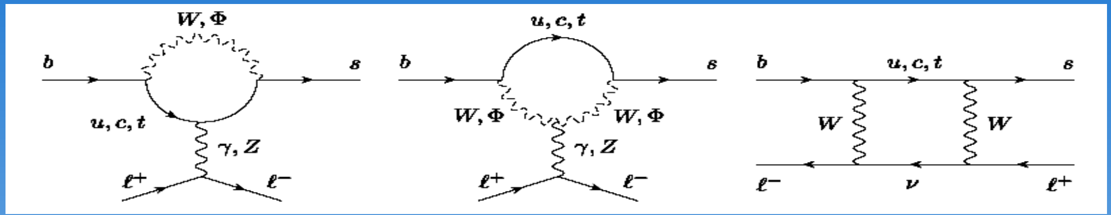
Rare decays (1)

- $B_s \to \mu^+\mu^-$ transition forbidden at the tree level, occur through loop diagrams
  - very low branching ratio in SM
    - $BR(B_s \to \mu^+\mu^-) = (3.35 \pm 0.32) \cdot 10^{-9}$
  - sensitive to new physics: some BSM models predict a larger branching ratio than SM (e.g. in SUSY $BR \sim (\tan\beta)^6$ about 100 times larger than SM)
  - long-distance contributions expected to play a negligible rôle
- CDF measurements with $\sim 1 fb^{-1}$
    - $BR(B_s \to \mu^+\mu^-) < 8 \cdot 10^{-8}$ @ 90% CL
- DØ measurements with $\sim 2 fb^{-1}$
    - $BR(B_s \to \mu^+\mu^-) < 7.5 \cdot 10^{-8}$ @ 90% CL

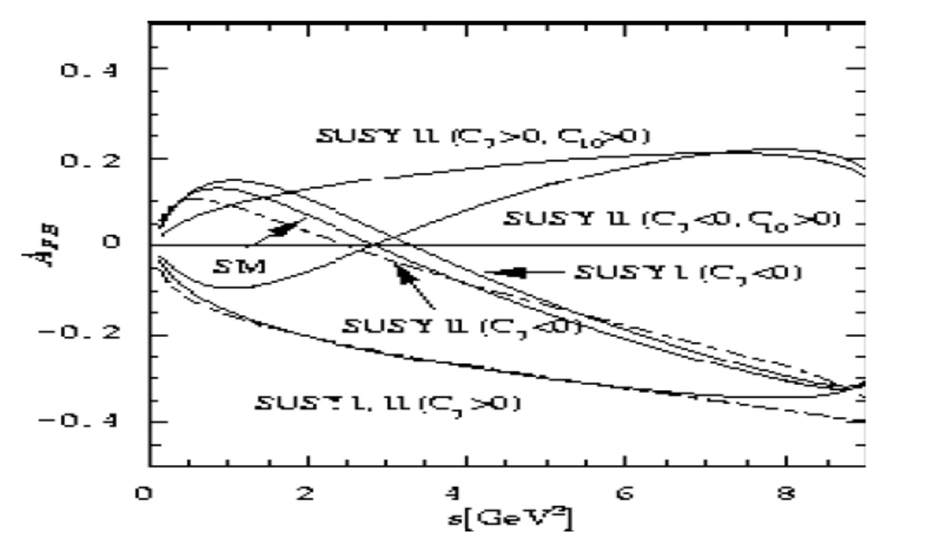


Rare decays (2)

- $b \to s\, \mu^+\mu^-$ FCNC transitions forbidden at the tree level, occur through loop diagrams
  - low branching ratio ($\sim 10^{-7}$)
  - sensitive to new physics

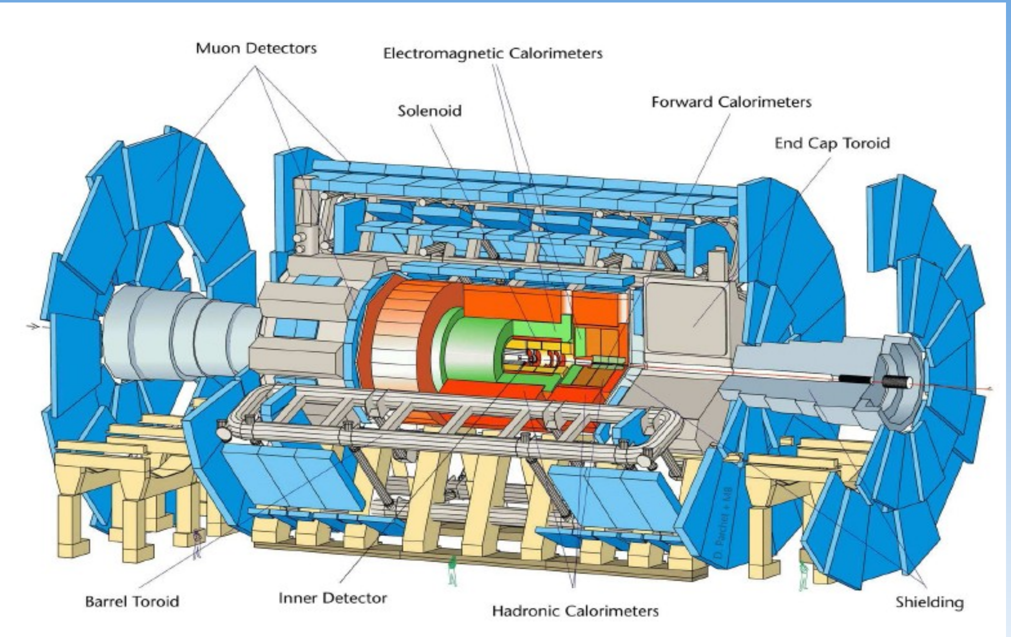


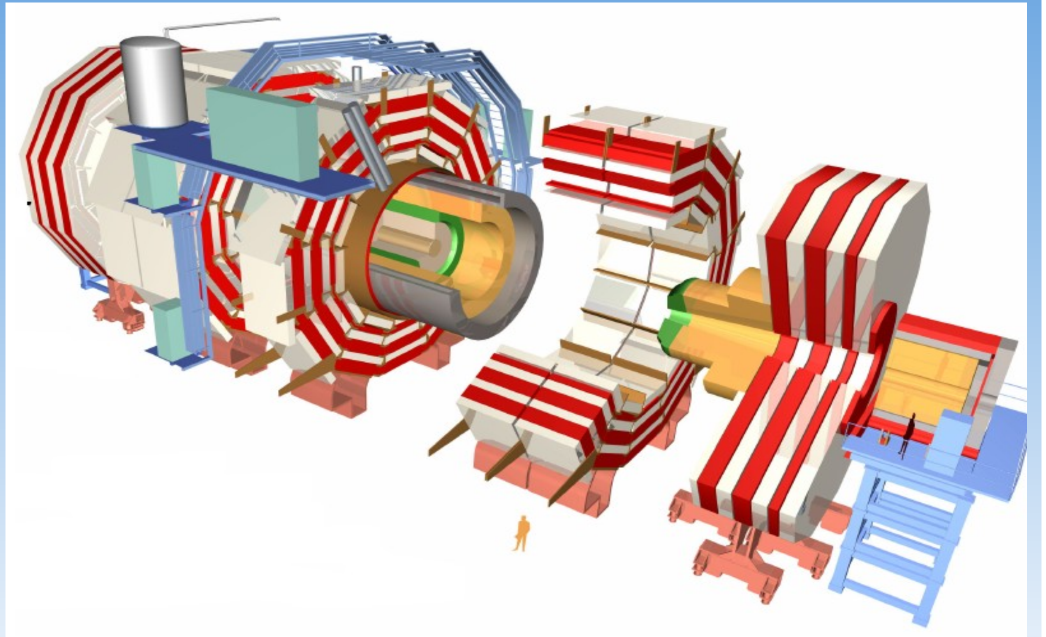
- For semimuonic exclusive decays (the only accessible at LHC), theorists suggest to measure variables describing dimuon system
  - forward-backward asymmetry (A_{FB}) as a function of s
  - zero of the A_{FB} curve: $s_0=2C_7 / C_9$ (quite robust with respect to hadronic uncertainties)
- Current B-factory data for inclusive $b \to s\, \mu^+\mu^-$ branching ratios and A_{FB} are in accordance with SM, but suffer from large uncertainties
  - LHC measurements will improve this situation
- Rare decays need very precise measurements to find deviations from SM predictions
  - excellent calibrations and efficient muon trigger



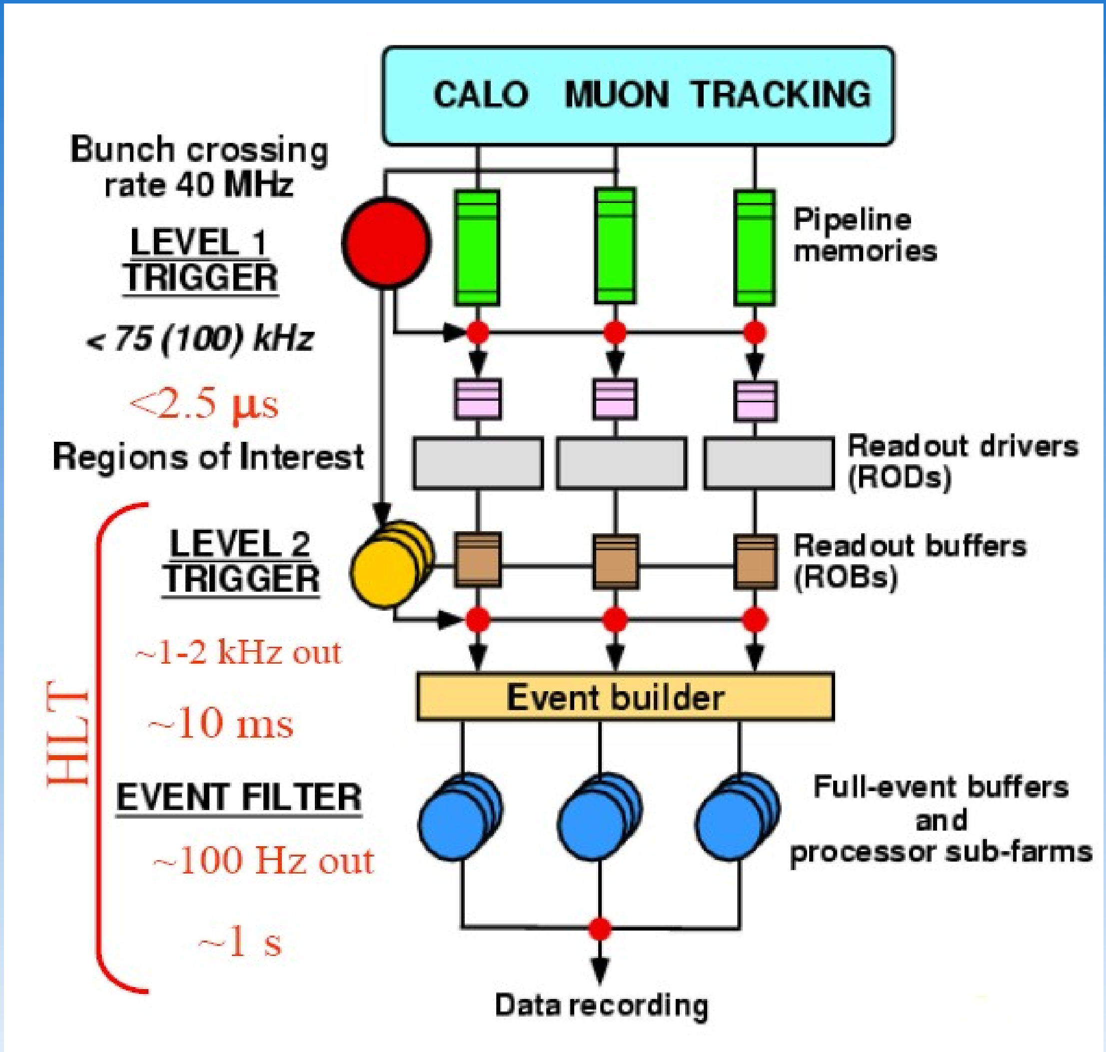
ATLAS and CMS detectors

- ATLAS and CMS are general purpose detectors
  - $|\eta|<2.5$
  - B-physics using trigger with relatively high p_T muons
  - for B-Physics ATLAS and CMS performances are similar (especially for vertexing and muon system acceptance)



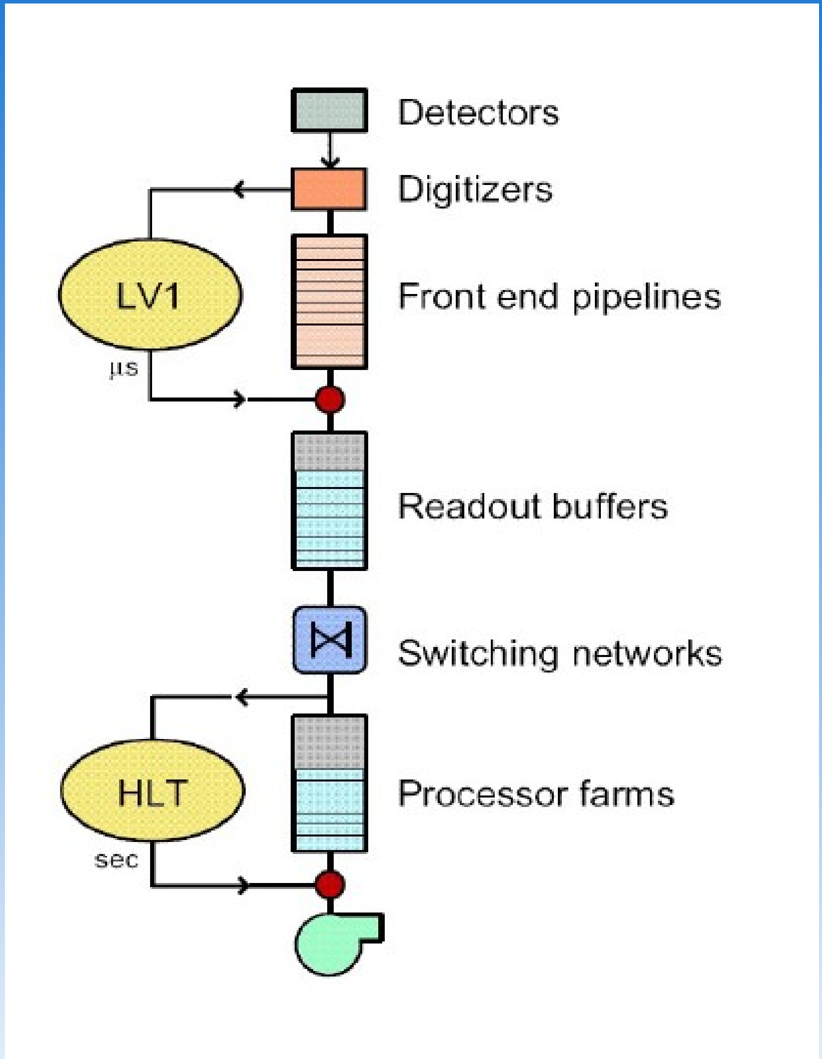


Overview of ATLAS trigger



- Three level trigger
- LVL1
  - coarse granularity calorimeter and muon information
  - identifies Regions 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)
  - refine LVL2 selection using offline-like algorithms
  - alignment and calibration data available
- B-Physics is accounted for 5-10% of total trigger resources: it must be fast, efficient and selective

Overview of CMS trigger

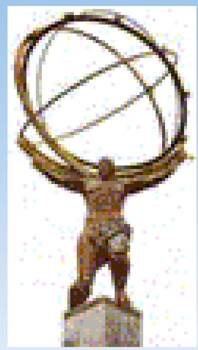


- Two level trigger
- Level 1 is based on muon detector and calorimeter measurements
  - 40MHz → ~100kHz
  - latency 3.2µs
- High Level Trigger (HLT) with fast reconstruction
  - uses reconstruction code and informations similar to off-line
  - 100kHz → ~150Hz

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
  - dimuon vertex reconstruction
- EF
  - refit inner detector tracks in LVL2 RoI
  - decay vertex reconstruction
  - proper time cut
  - angular distribution cuts
- Output rate <10Hz



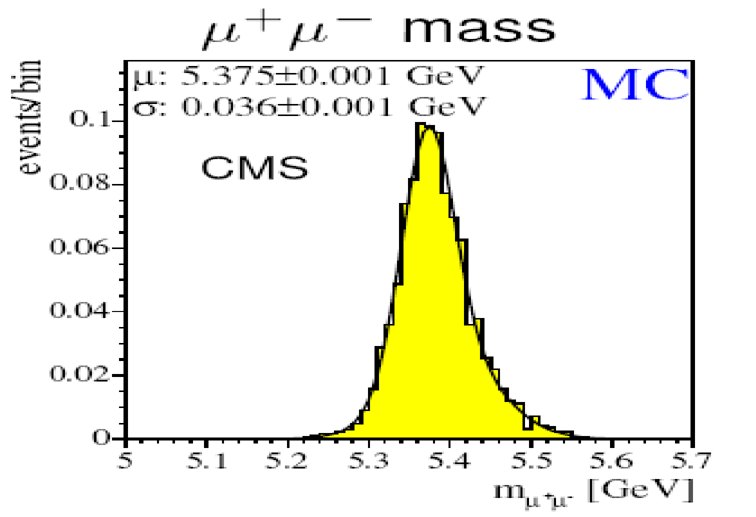
CMS dimuon trigger

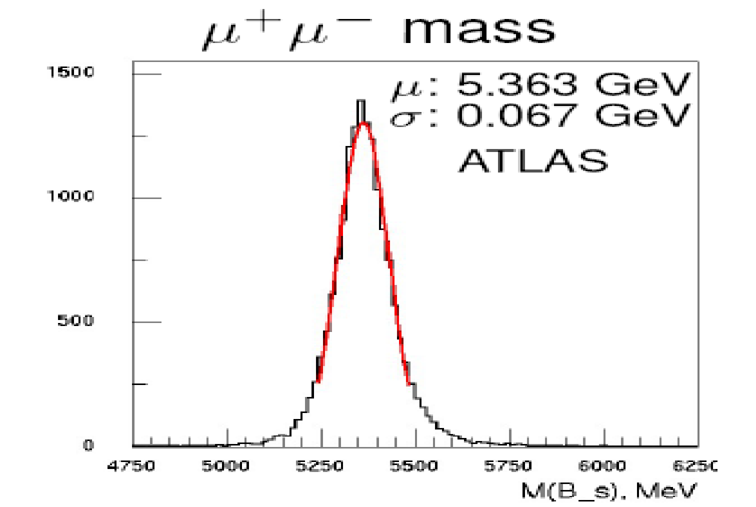
- Level 1
  - 2μ with $p_T(\mu)>3GeV$
- HLT
  - Level 1 muon confirmation with full muon system and improvement of the momentum measurement with the tracker
  - primary vertex reconstruction with pixel detector
    - use the three most probable vertexes
  - track reconstruction in cones around Level1-muon 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

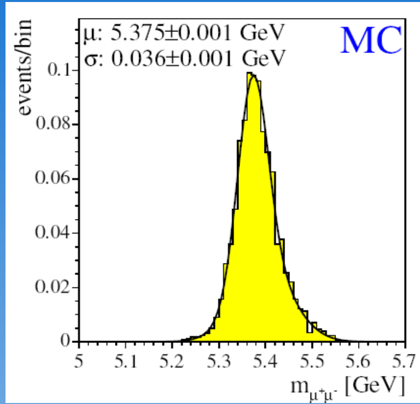
- Proper time resolution
  - a good proper time resolution is necessary for time dependent asymmetry and oscillation measurements
  - the proper time resolution for ATLAS and CMS is comparable: ~95fs for $B_s \to \mu^+\mu^-$ decay
- Mass resolution in MeV/c^2

	ATLAS	CMS
$B \to \mu^+\mu^-$	~67	~36
$B \to K^*\mu^+\mu^-$	~40	
$\Lambda_b \to \Lambda^0\,\mu^+\mu^-$	~47	





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



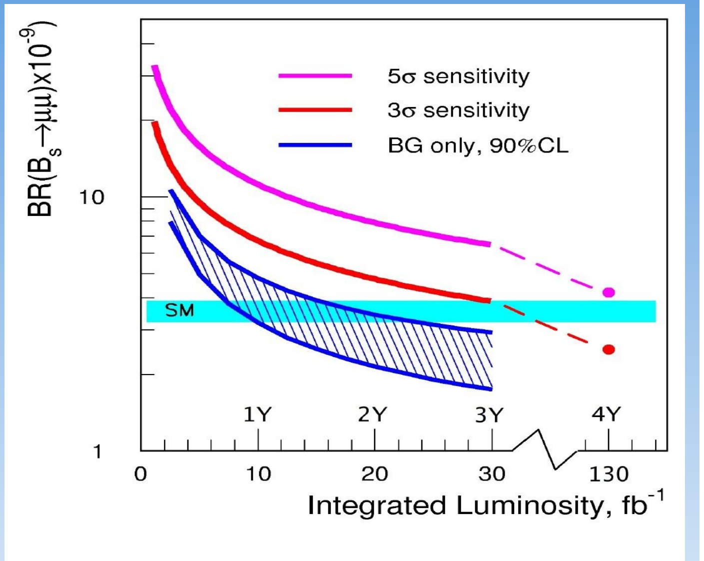
- Low branching ratio ($3.5 \cdot 10^{-9}$ in SM) requires a good background rejection
  - combinatorial with muons mainly from *b* decays
  - rare B decays
  - mis-identified hadrons - e.g. $B \rightarrow \pi\pi$, $K\pi$, KK
- Analysis variables in CMS
  - decay flight length significance on transverse plane $l_{xy}/\sigma_{xy} > 18$
  - muon separation $\Delta R(\mu\mu) = \sqrt{(\eta_{\mu_1} - \eta_{\mu_2})^2 + (\phi_{\mu_1} - \phi_{\mu_2})^2}$ $\quad 0.3 < \Delta R(\mu\mu) < 1.2$
  - 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
- $6.1 \pm 0.6(\text{stat}) \pm 1.5(\text{sys})$ signal events and $13.8^{+22.0}_{-13.8}$ background events in 10fb^{-1}
- Upper limit on branching ratio $1.4 \cdot 10^{-8}$ @ 90% CL

$B_s \to \mu^+\mu^-$ 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±2.6 signal events and 20 ±12 BG events expected in $10fb^{-1}$
- Upper limit on branching ratio $7\cdot10^{-9}$ @ 90% CL
- ATLAS expects to reach the sensitivity at the level of SM predictions 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

Semileptonic rare decays in ATLAS (1)

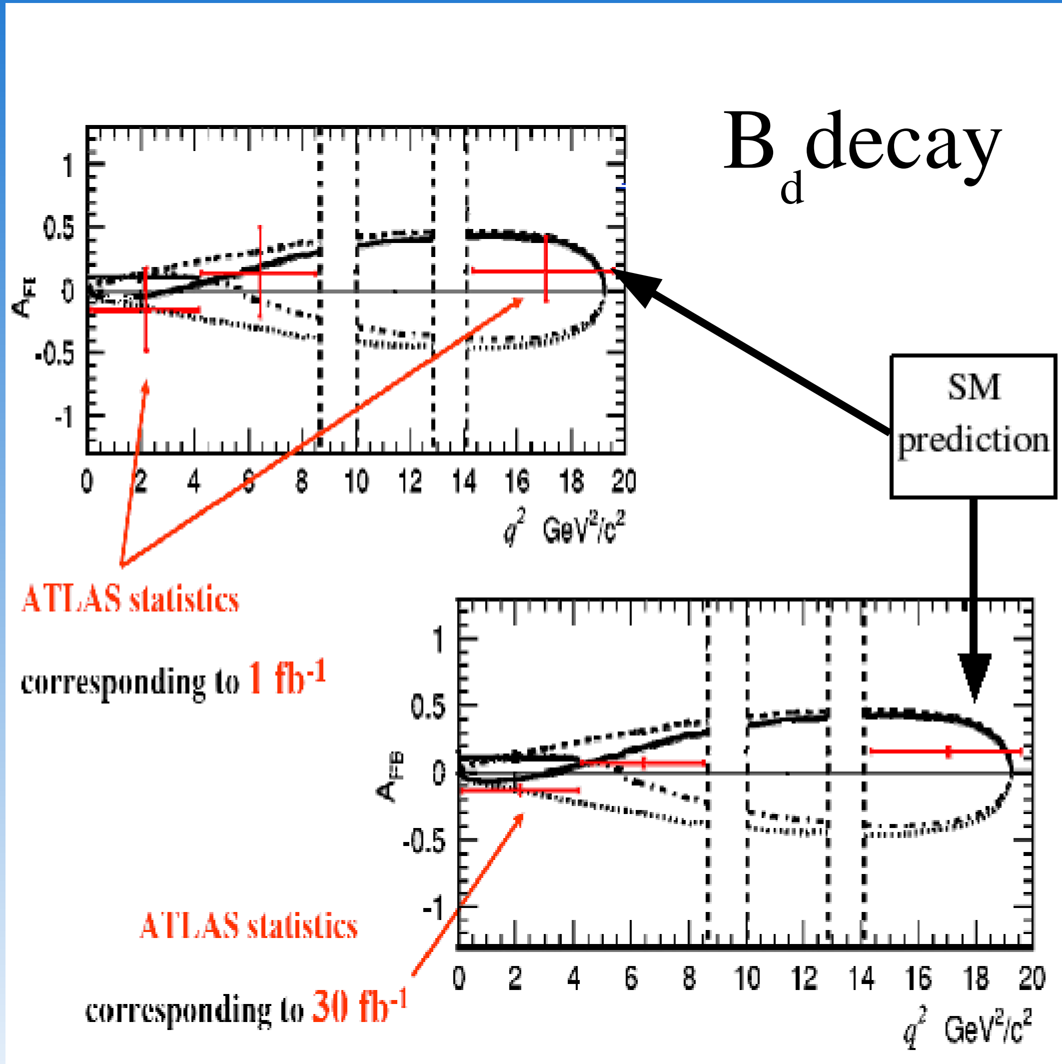
- $B^+ \to K^+\mu^+\mu^-$, $B^+ \to K^{*+}\mu^+\mu^-$, $B_d \to K^{0*}\mu^+\mu^-$, $B_s \to \phi\, \mu^+\mu^-$, $\Lambda_b \to \Lambda^0\mu^+\mu^-$
- Background sources
  - Channels with J/Ψ and Ψ(2S) resonances: irreducible background, cut on dimuon invariant mass
  - Combinatorial background
    - Semileptonic decays of both b and b-bar quarks
    - Double semileptonic decay of b quark (b->cμν, c->sμν)
    - 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
    - their contribution is expected poor with respect to combinatorial background
- Analysis variables
  - Good dimuon vertex with χ^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 χ^2/NDF<2, p_T>3GeV and mass in $m_h \pm 3\sigma$
  - Good B meson vertex with χ^2/NDF<2
  - b-hadron mass in $m_B \pm 3\sigma$ and proper time > 0.5ps

Semileptonic rare decays in ATLAS (2)

- Signal after $30fb^{-1}$

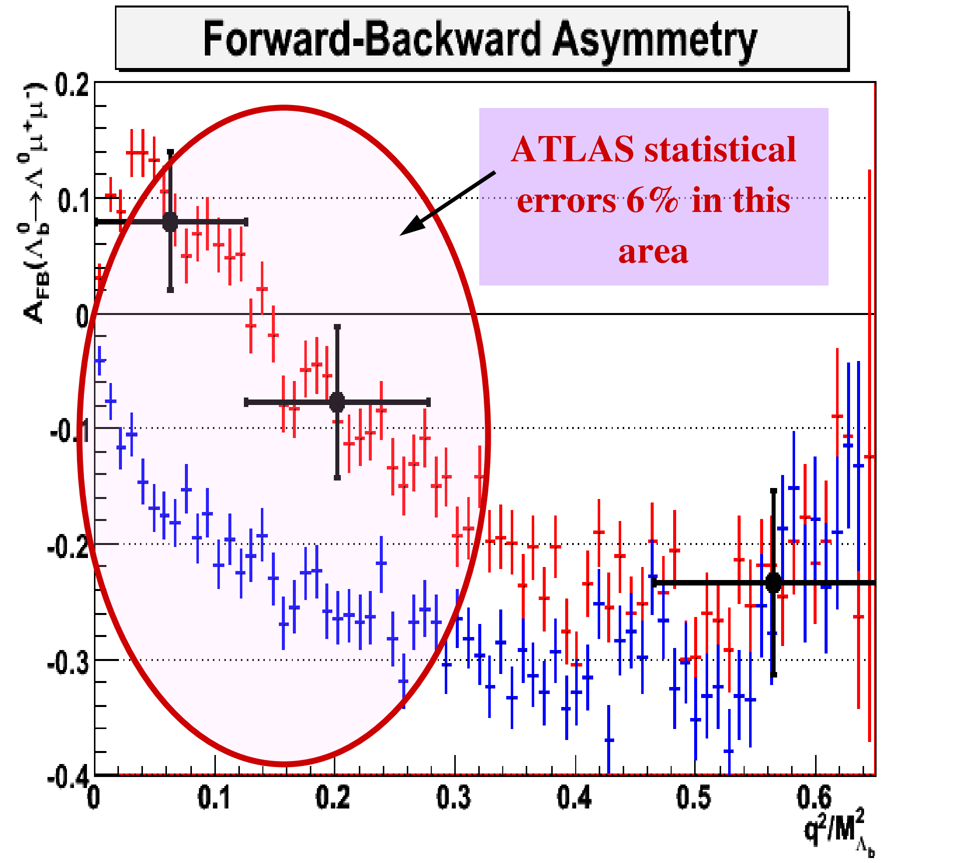
Decay Channel	Signal	Background
$B^+ \to K^+\mu^+\mu^-$	4000	<10000
$B^+ \to K^{*+}\mu^+\mu^-$	2300	<10000
$B_d \to K^{0*}\mu^+\mu^-$	2500	<10000
$B_s \to \phi\, \mu^+\mu^-$	900	<10000
$\Lambda_b \to \Lambda^0\mu^+\mu^-$	800	<4000

- Good sensitivity to forward backward asymmetry measurements for $B \to K^*\mu^+\mu^-$ decays
- Statistical error on $B \to K\mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ branching ratio measurements ~3.5% and ~6.5% respectively



Semileptonic rare decays in ATLAS (3)

- $\Lambda_b \to \Lambda^0\mu^+\mu^-$ decay: after 3 years @ $10^{33}cm^{-2}s^{-1}$ ATLAS can distinguish MSSM (C_{7eff}>0) from SM in the region with low values of dimuon mass
- The study on semileptonic rare decays is yet limited by the size of the background MC sample
- Further BG and trigger efficiency studies are ongoing



- ATLAS expected events after 3 years @ $10^{33}cm^{-2}s^{-1}$
- ATLAS MC events generated with SM
- ATLAS MC events generated with MSSM (C_{7eff}>0)

Conclusions

- LHC potential for flavor physics is enormous
  - high luminosity allows to study rare decays
- ATLAS and CMS will use this potential for precise measurements of quantities sensitive to New Physics
  - after 3 years of data taking at $L=10^{33} cm^{-2} s^{-1}$ there will be enough statistics to find deviations from SM predictions and to set strong limits on New Physics beyond SM
  - measurements on rare decays will continue even at nominal luminosity ($L=\sim10^{34} cm^{-2} s^{-1}$) thanks to final state muons