Searches for BSM Physics in Rare B-Decays in ATLAS

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FSP 101 ATLAS

SPONSORED BY THE Federal Ministry of Education and Research

on behalf of the ATLAS Collaboration

SUSY 2014

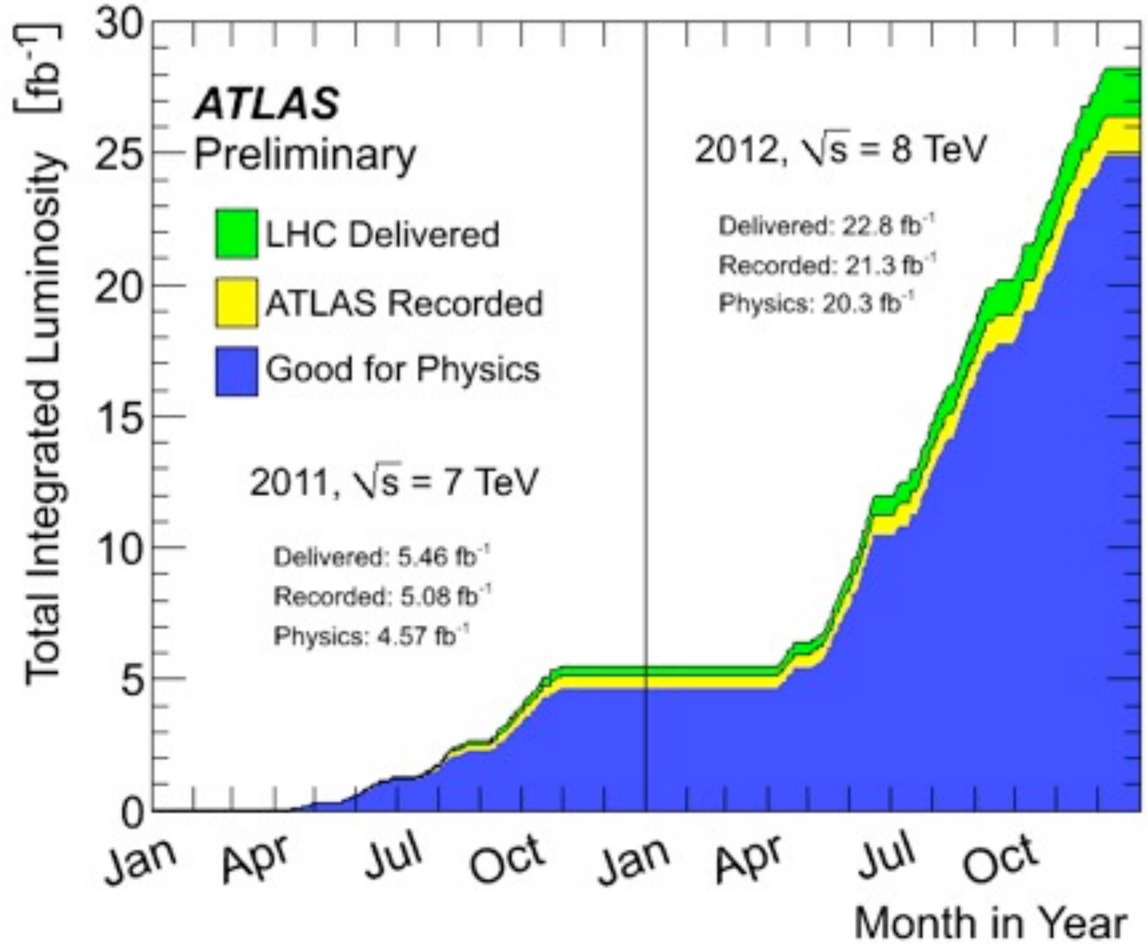
The 22nd International Conference on Supersymmetry and Unification of Fundamental Interactions

University of Manchester

21-26 July 2014, Manchester (England)

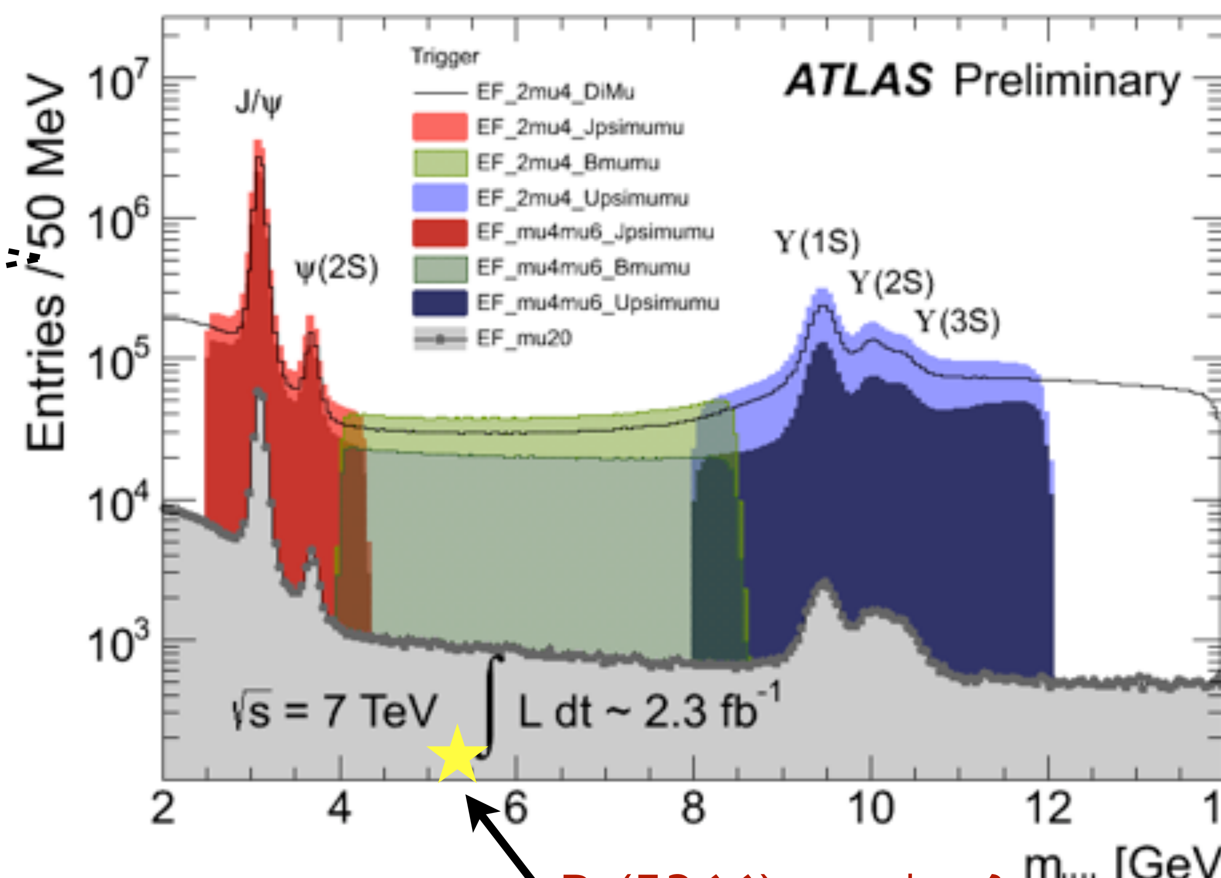
ATLAS B-Physics Data

- excellent data taking efficiency and quality of data
- multiple interactions per bunch crossing (<μ>)
  - > 5 fb^{-1} recorded in 2011 (7 TeV)
    - <μ> = 9
  - > 20 fb^{-1} recorded in 2012 (8 TeV)
    - <μ> = 20



only 2011 data are used in the presented searches

- topological di-muon triggers
  - require two muons with $p_T(\mu)$ > 4 GeV or more at the first trigger level
  - full track reconstruction and loose mass selection at the higher trigger levels
    - no trigger prescales applied in 2011

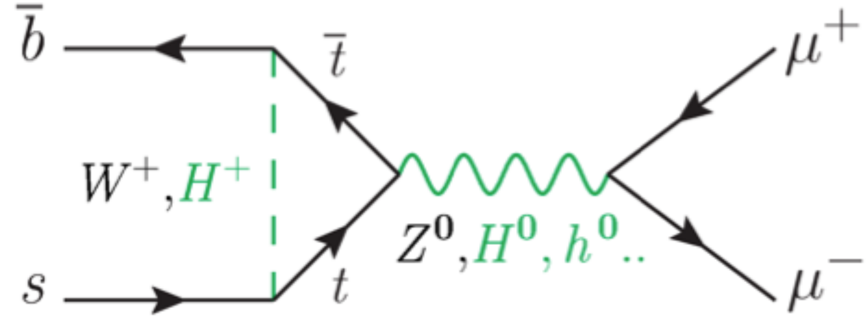


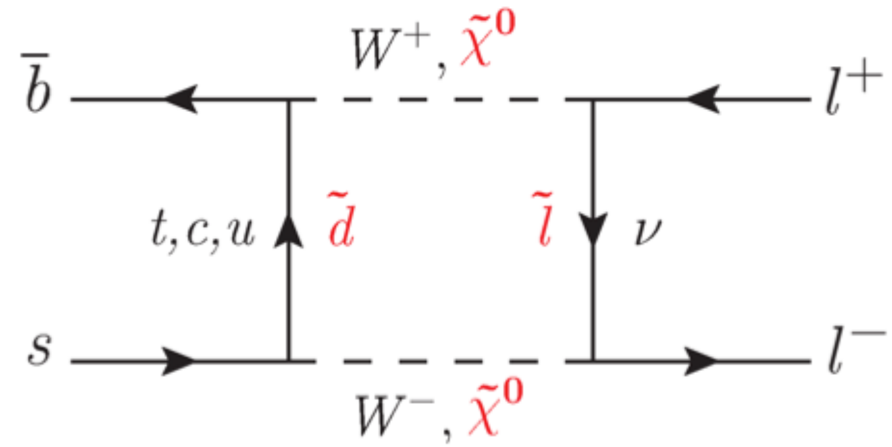
B_s(5366) → $\mu^+\mu^-$?

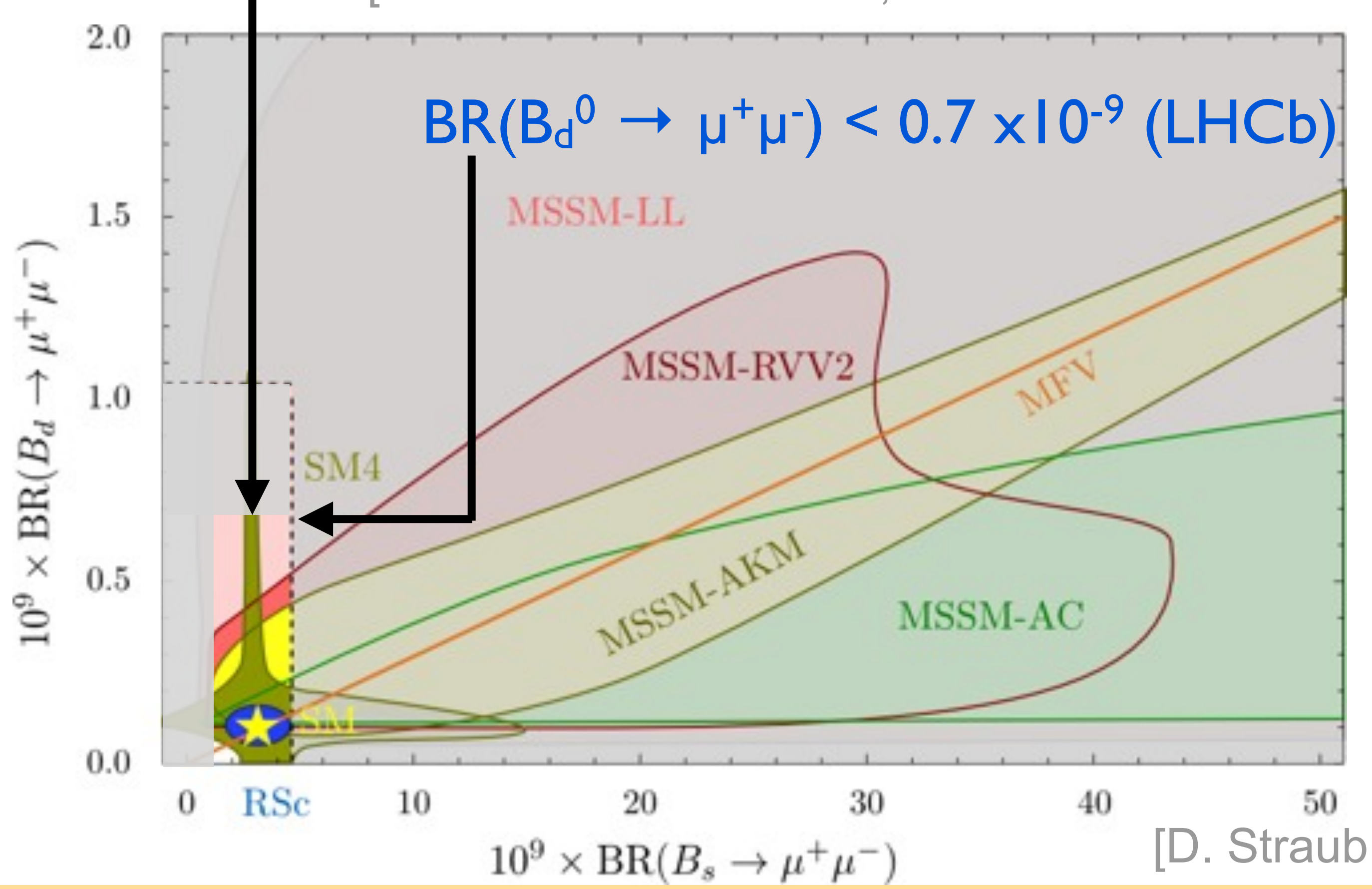
- single muon triggers also used (e.g. in $B_d^0 \rightarrow K^{*0}\mu^+\mu^-$ analysis)
  - high-rate triggers prescaled at higher instantaneous luminosity (2nd half of 2011, at the beginning of a run)

$B_s \rightarrow \mu^+\mu^-$: Introduction

- flavor changing neutral current (FCNC) decay
- strongly suppressed in the SM at tree level, loop-dominated
- coupling to non-SM particles can affect BR
  => powerful indirect search for New Physics
- $BR(B_s \rightarrow \mu^+\mu^-)$
  $= (3.27 \pm 0.27) \times 10^{-9}$
  [Buras et al., Eur.Phys.J. C72 (2012) 2172]
  $= (3.54 \pm 0.30) \times 10^{-9}$ (time-integrated)
  [K. De Bruyn et al., Phys.Rev.Lett 109 (2012) 041801]
  = $(2.9 \pm 0.7) \times 10^{-9}$ (LHCb and CMS)
  [LHCb: arXiv:1307.5024, CMS: arXiv:1307.5025]







[D. Straub arxiv:1205.6094]

- still some room for NP left !
- LHC Run II data may give an answer...

$B_s \to \mu^+\mu^-$: Analysis Strategy

- **Relative BR measurement:**
  - partial cancelation of uncertainties (luminosity, cross-section, ...)
  - reference channel $B^\pm \to J/\psi K^\pm$

Single Event Sensitivity (SES): BR if one signal event observed

$$BR(B_s \to \mu\mu) = N_{B_s \to \mu\mu} \frac{1}{N_{B^\pm \to J/\psi K^\pm}} BR(B^\pm \to J/\psi K^\pm) \frac{f_u}{f_s} \frac{\varepsilon_{B^\pm \to J/\psi K^\pm}}{\varepsilon_{B_s \to \mu\mu}} \frac{A_{B^\pm \to J/\psi K^\pm}}{A_{B_s \to \mu\mu}}$$

counting in signal region

yield from mass fit to data

[PDG 2012]

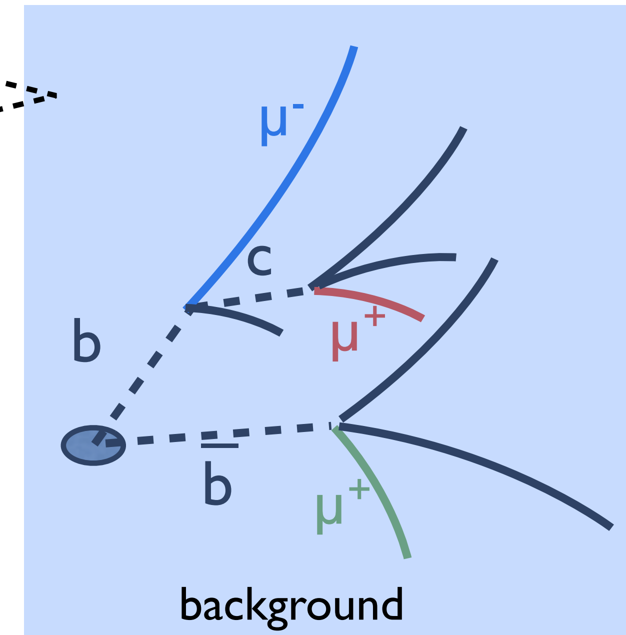
[LHCb: JHEP 1304 (2013) 001]]

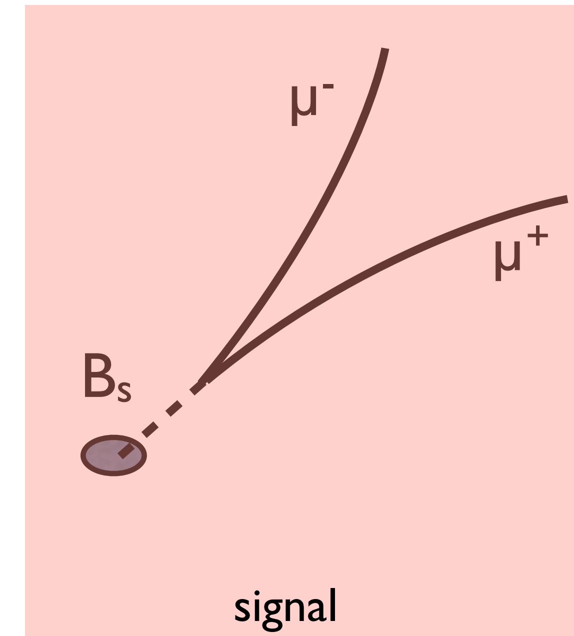
$\varepsilon \times A = N_B^{reco\ \&\ sel} / N_B^{gen}$ on MC "tuned" to data

- use MVA technique (BDT) for signal/background discrimination
- optimize discrimination avoiding biasses =>
  - independent datasets used for
    - BDT training (MC modeling)
    - selection optimization (50% of sideband data)
    - background measurement (remaining 50% of sideband data)
  - blind analysis (region ± 300 GeV around B_s mass blinded)

$B_s \to \mu^+\mu^-$: Background Composition

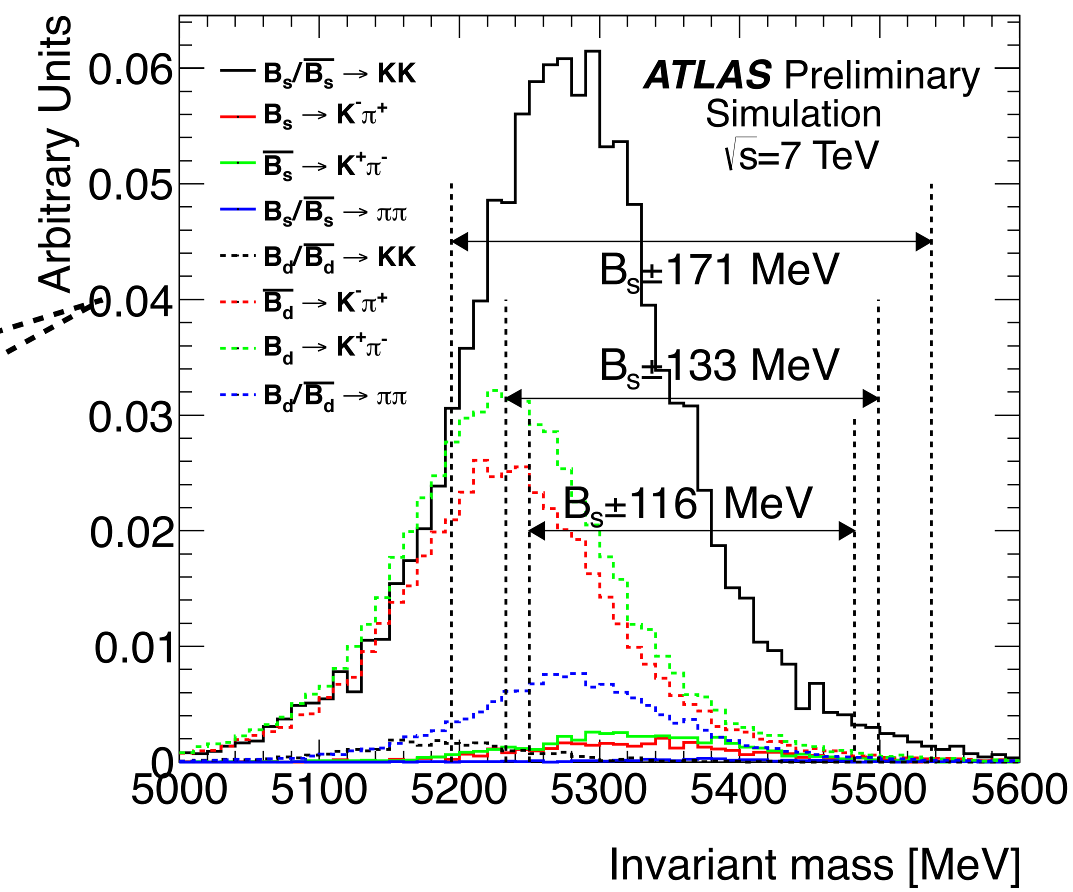
- continuum (from real muons)
  - dominated by $b\bar{b} \to \mu^+\mu^- X$
  - measured by interpolation from sideband data
  - modeled with dedicated MC sample





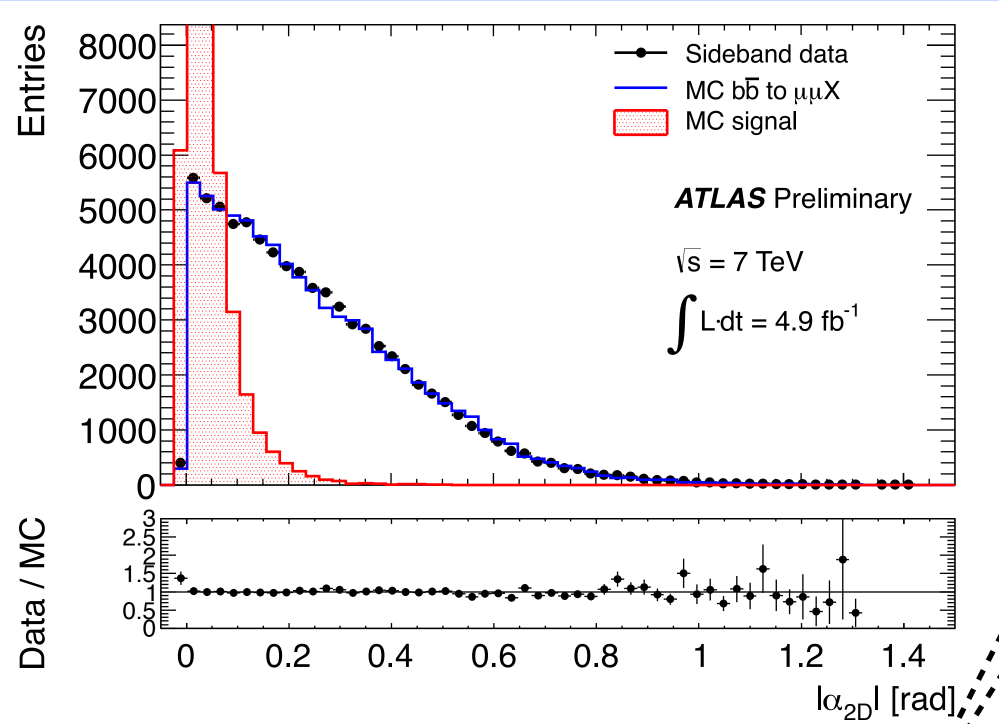
- continuum (muon + "fake", i.e. hadrons reconstructed as muons due to decays in flight or punch-through)
  - e.g. $B_d \to \pi^-\mu^+\nu$, $B_s \to K^-\mu^+\nu$
  - populate mostly left sideband
  - contribution negligible for 5 fb^{-1} analysis

- peaking $B \to hh'$ ("fake" + "fake")
  - mainly $B_s \to K^+K^-$, $B_d \to K^\pm\pi^\pm$, $B_s \to \pi^+\pi^-$ decays
  - BR x (fake rate) $\approx 10^{-9}$ (non-negligible due to signal-like topology)



$B_s \to \mu^+\mu^-$: Background Discrimination

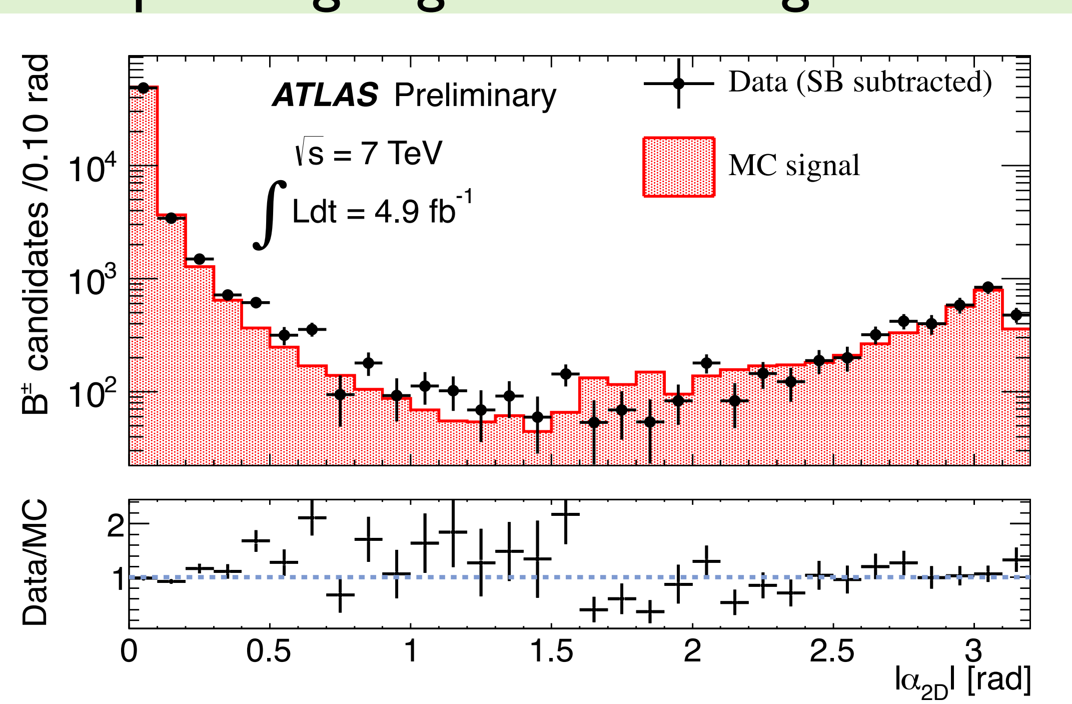
pointing angle: modeling in background MC

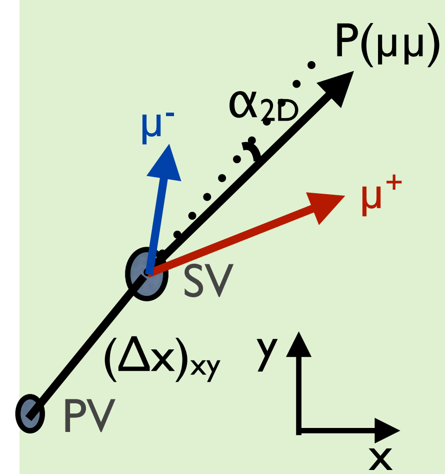


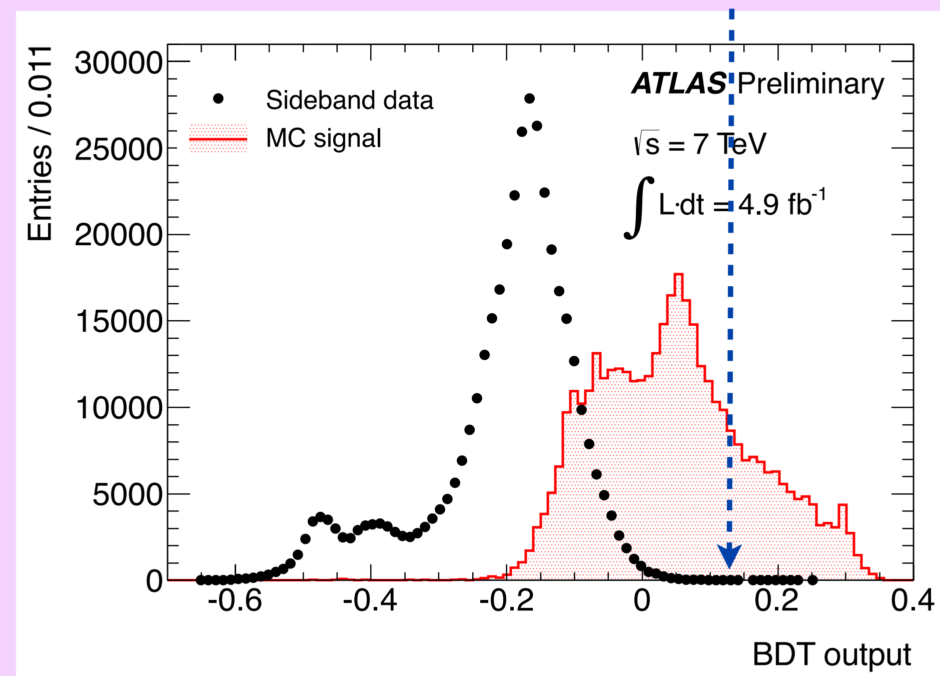
- MVA for continuous background separation
  - Boosted Decision Trees (BDT) trained with 13 best separation variables
  - pointing angle is one of the most powerful
  - good modeling in background MC, good data/MC agreement

- optimization of BDT selection (q) and search window (Δm):
  - maximum of $P(q, \Delta m) = \varepsilon_{sig}/(1+\sqrt{N_{bkg}})$
  - ε_{sig} from MC, N_{bkg} from data (50% of events)
  - optimized selection : q > 0.118, Δm = 121 MeV

pointing angle: data/MC agreement







$B_s \rightarrow \mu^+\mu^-$: Reference Channel Yield and εxA Ratio

N(B± → J/ψK±) extraction:

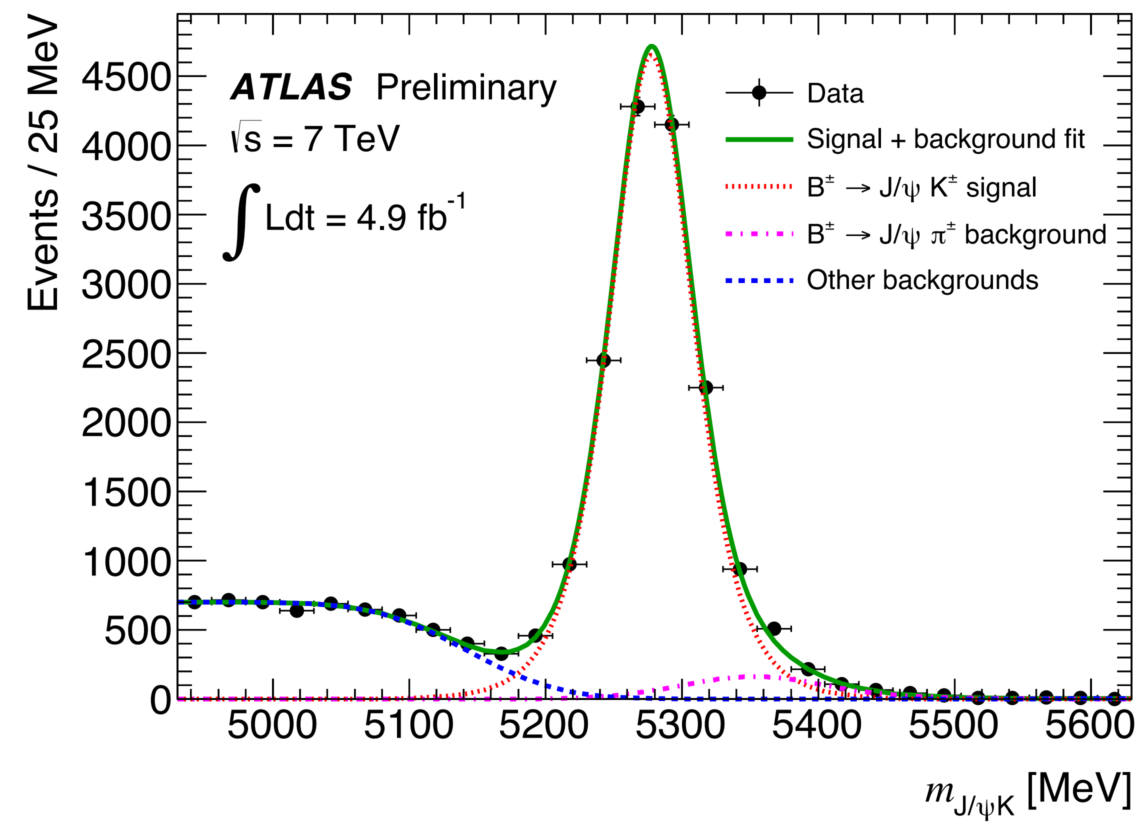
- selection as close as possible to Bs (to minimize overall systematics)
  - use BDT trained on Bs
  - use the same BDT selection
- unbinned max. likelihood fit
  - use per-event mass resolution δm
- systematics accessed by varying background fit model

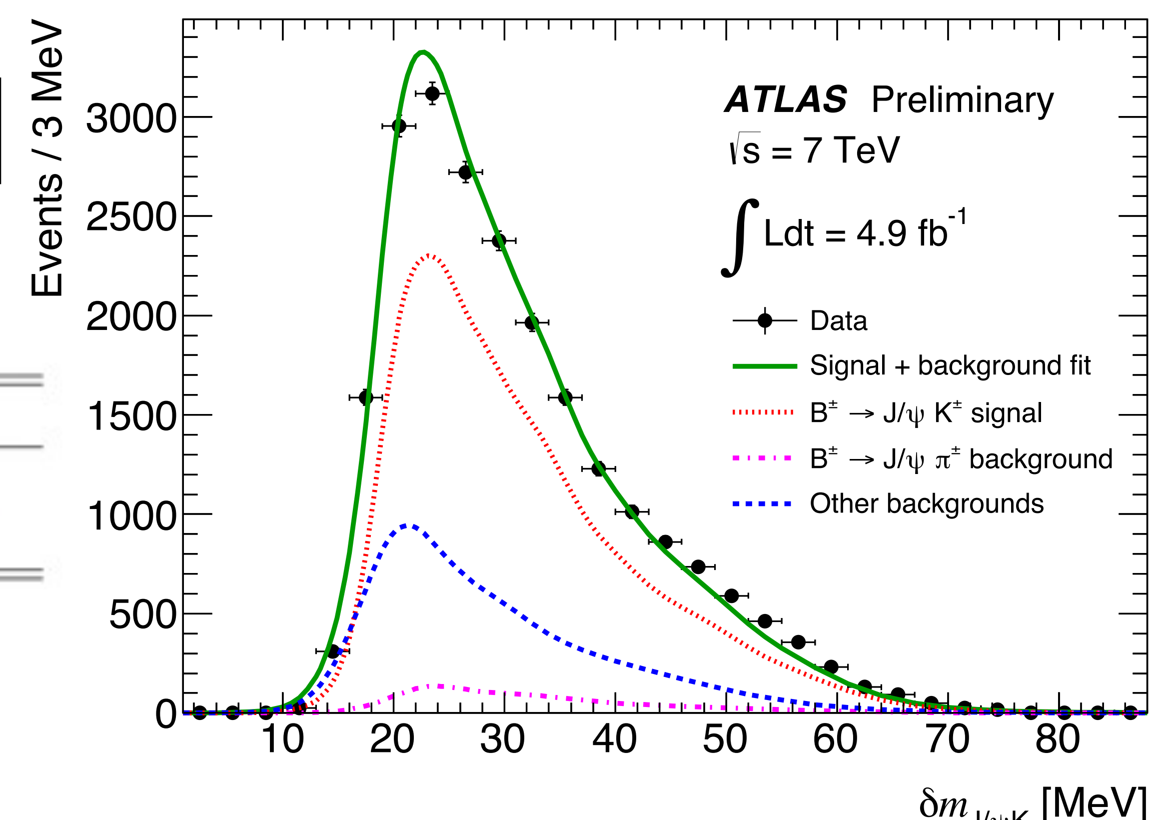
N(B± → J/ψK±) = 15214 ± 1.1% (stat.) ± 2.4% (syst.)

ε x A measurement:

Channel	$A \times \epsilon$	$R_{A\epsilon}$
B^+	$1.317 \pm 0.008\%$ (stat)	$0.267 \pm 1.8\%$ (stat) $\pm$ 6.9% (syst)
B_s^0	$4.929 \pm 0.084\%$ (stat)	

- systematics from data/MC discrepancies

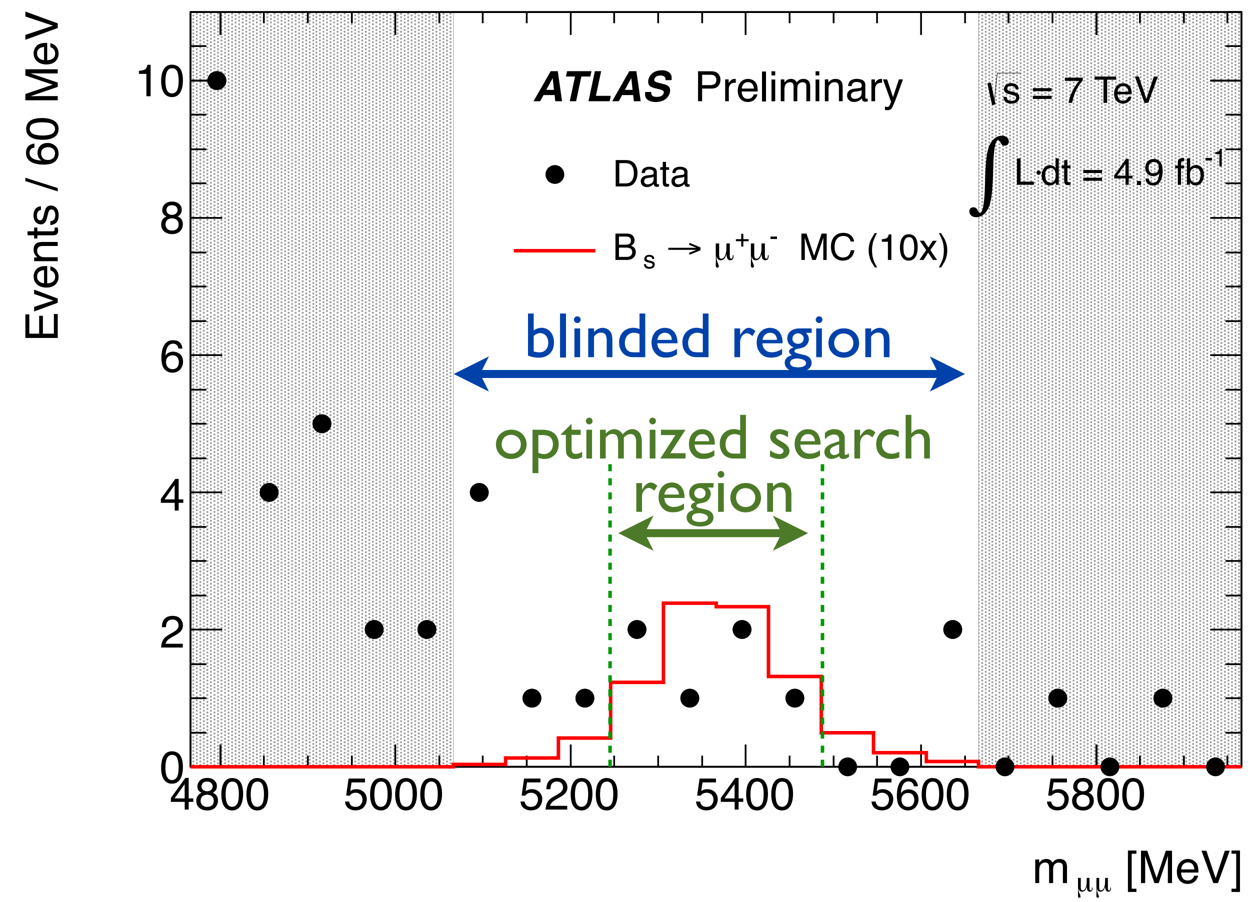


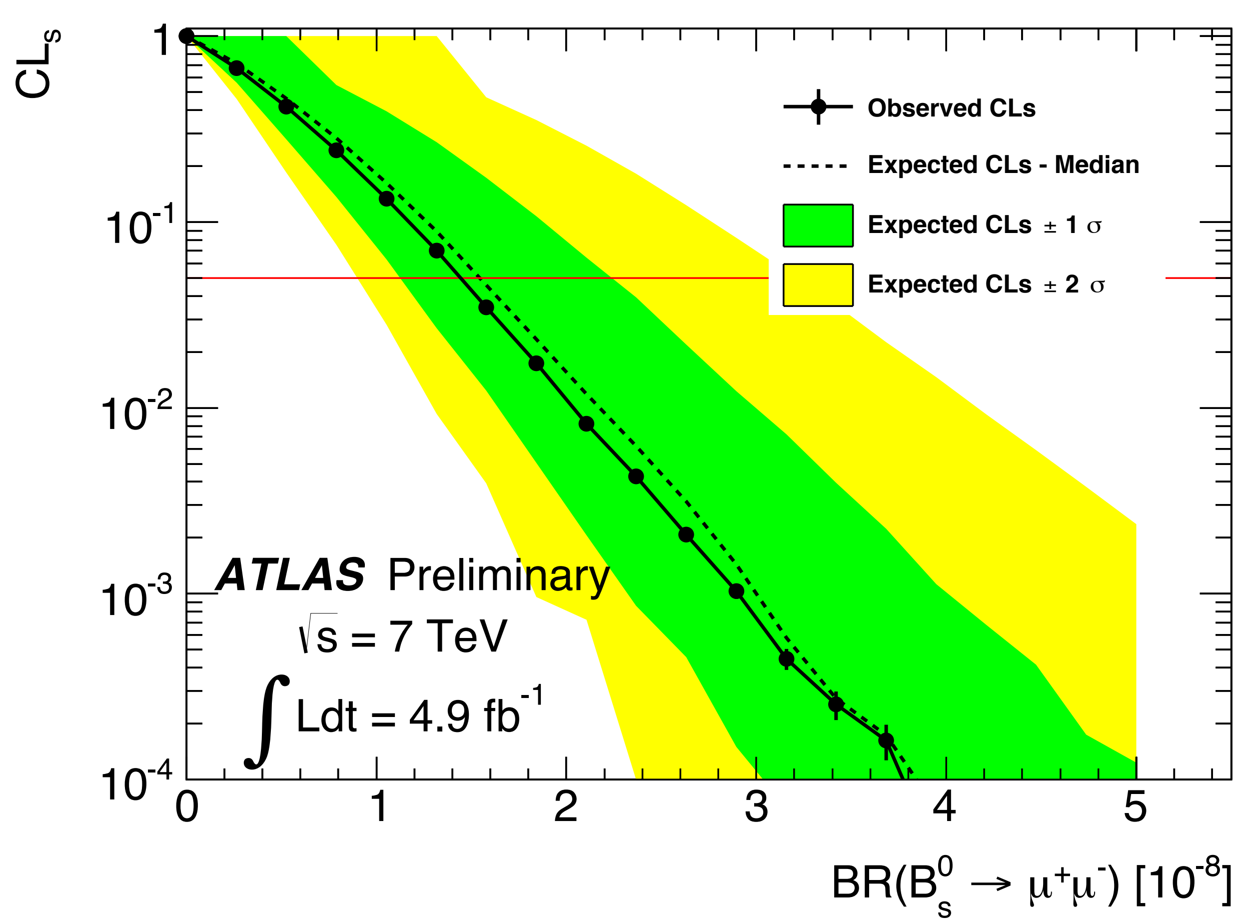


$B_s \to \mu^+\mu^-$: Result

Single Event Sensitivity:
SES = $(2.07 \pm 0.26) \cdot 10^{-9}$

- 12.5 % error dominated by systematics, mainly:
  - $BR(B^\pm)$, f_u/f_s : 8.5 %
  - ε x A ratio : 6.9 %
  - absolute $K^\pm$ tracking efficiency: 5 %





- total N_{bkg} expected in search region: 6.75 events (with 0.3 events from B → hh')

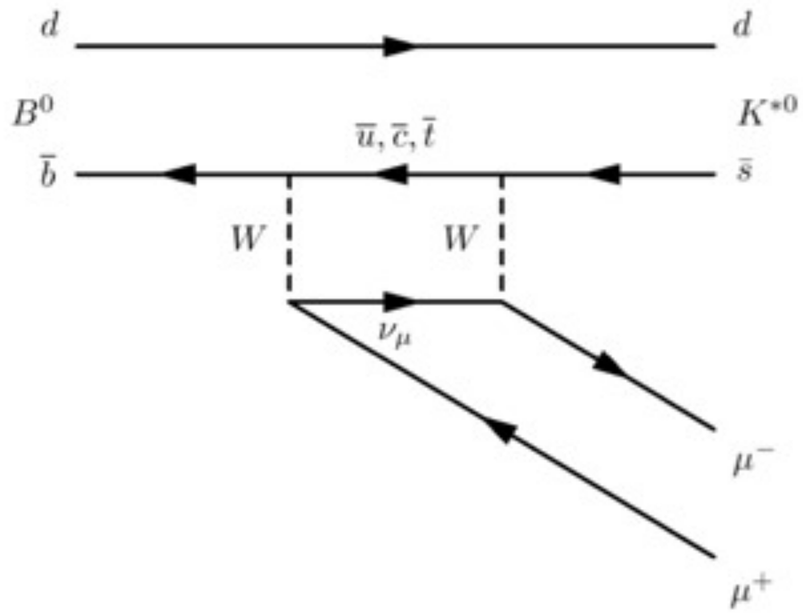
=> $BR(B_s \to \mu^+\mu^-) < 1.6 \times 10^{-8}$ (@ 95% CL)

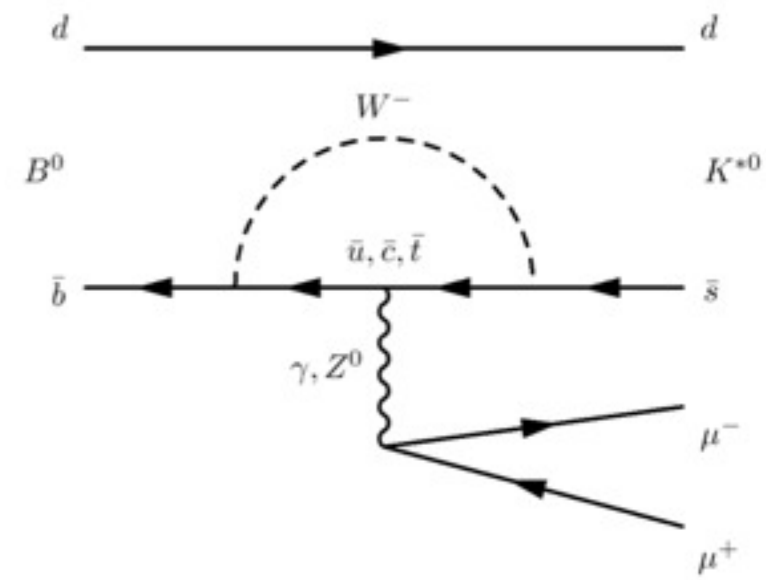
- $N_{\mu\mu}$ observed in search region: 6 events

=> $BR(B_s \to \mu^+\mu^-) < 1.5 \times 10^{-8}$ (@ 95% CL)

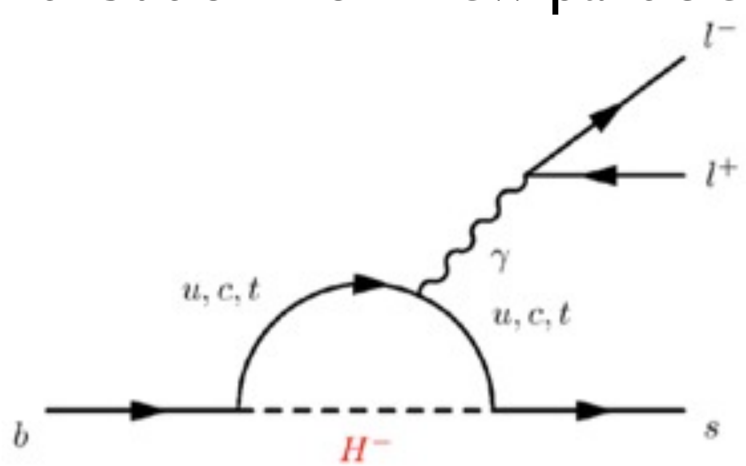
$B_d^0 \to K^{*0}\mu^+\mu^-$: Introduction

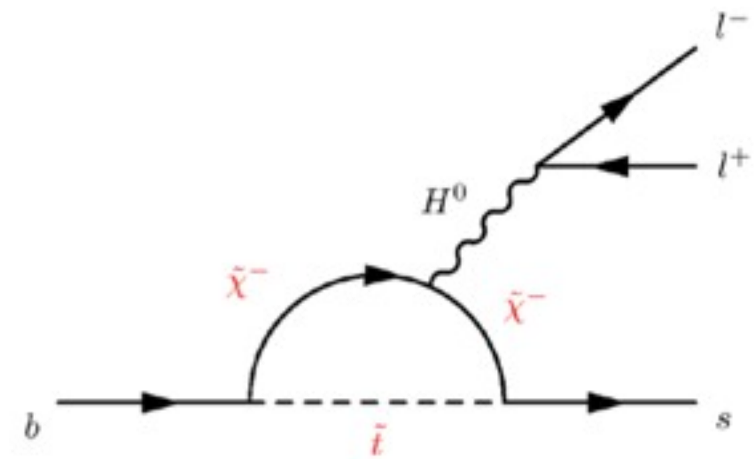
- exclusive final state for $b \to sl^+l^-$ transition
- $b \to sl^+l^-$ can occur only via loop-suppressed W-exchange:





- SM expectation BR = $(1.06 \pm 0.10) \cdot 10^{-6}$ [PDG 2013]
- contribution from new particles can affect BR



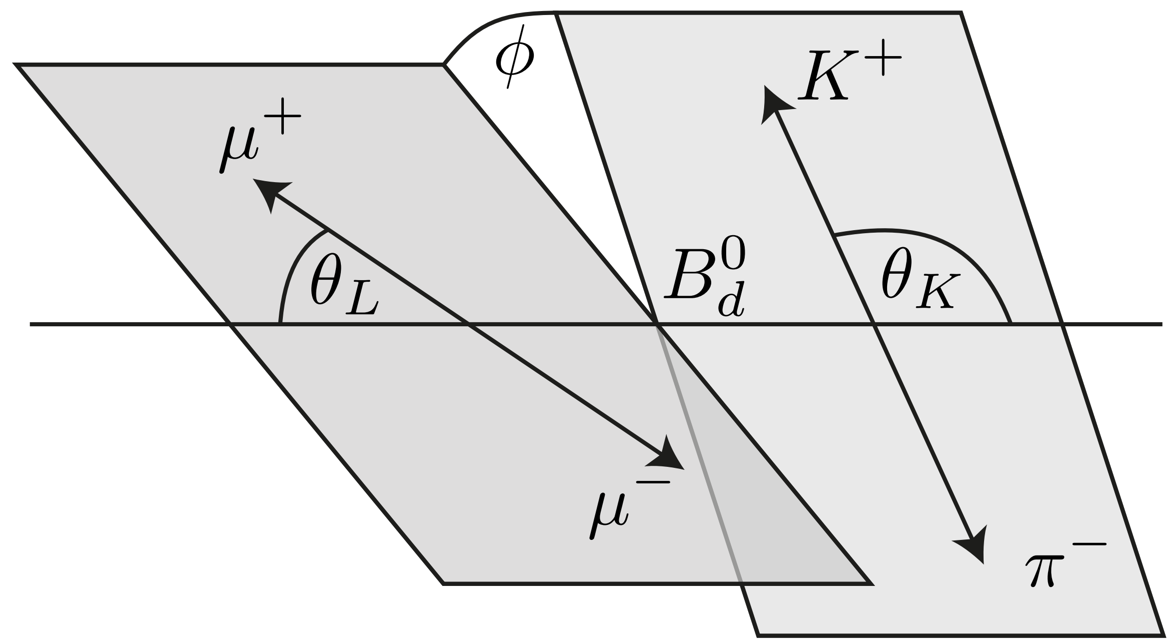


- angular observables sensitive to NP:
  - A_{FB} - muon forward-backward asymmetry
  - F_L - fraction of longitudinally polarized K^{*0} mesons

$B_d^0 \to K^{*0}\mu^+\mu^-$: Analysis Strategy

- kinematic observables
  - dimuon mass q^2
  - 3 angles: θ_L, θ_K, ϕ => decay rate

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_L d\cos\theta_K d\phi}$$



- limited statistics => use ϕ symmetry
  - integrate over ϕ, cos θ_L :

$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_K} = \frac{3}{2}F_L(q^2)\cos^2\theta_K + \frac{3}{4}\left(1 - F_L(q^2)\right)\left(1 - \cos^2\theta_K\right)$$

  - integrate over ϕ, cos θ_K :

$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_L} = \frac{3}{4}F_L(q^2)\left(1 - \cos^2\theta_L\right) + \frac{3}{8}\left(1 - F_L(q^2)\right)\left(1 + \cos^2\theta_L\right) + A_{FB}(q^2)\cos\theta_L$$

- extract A_{FB} (q^2) and F_L (q^2) via unbinned max. likelihood fit

$B_d^0 \rightarrow K^{*0}\mu^+\mu^-$: Signal Selection

Background contributions:

- $b\bar{b} \rightarrow \mu^+\mu^- X$ (main), $c\bar{c} \rightarrow \mu^+\mu^- X$, Drell-Yan
  => require $\tau/\sigma_\tau > 12.75$ and $\cos\theta_{pointing} > 0.999$ (selections optimized on MC)
- radiative decays of charmonium in $B_d^0 \rightarrow K^{*0} J/\psi$, $B_d^0 \rightarrow K^{*0}\psi(2S)$ and J/ψ , $\psi(2S)$ tails
  => veto mass regions in $|(m(B_d^0)_{rec} - m(B_d^0)_{PDG}) - (m_{\mu\mu, rec} - m_{J/\psi, PDG})| < \Delta m$ (130 MeV)

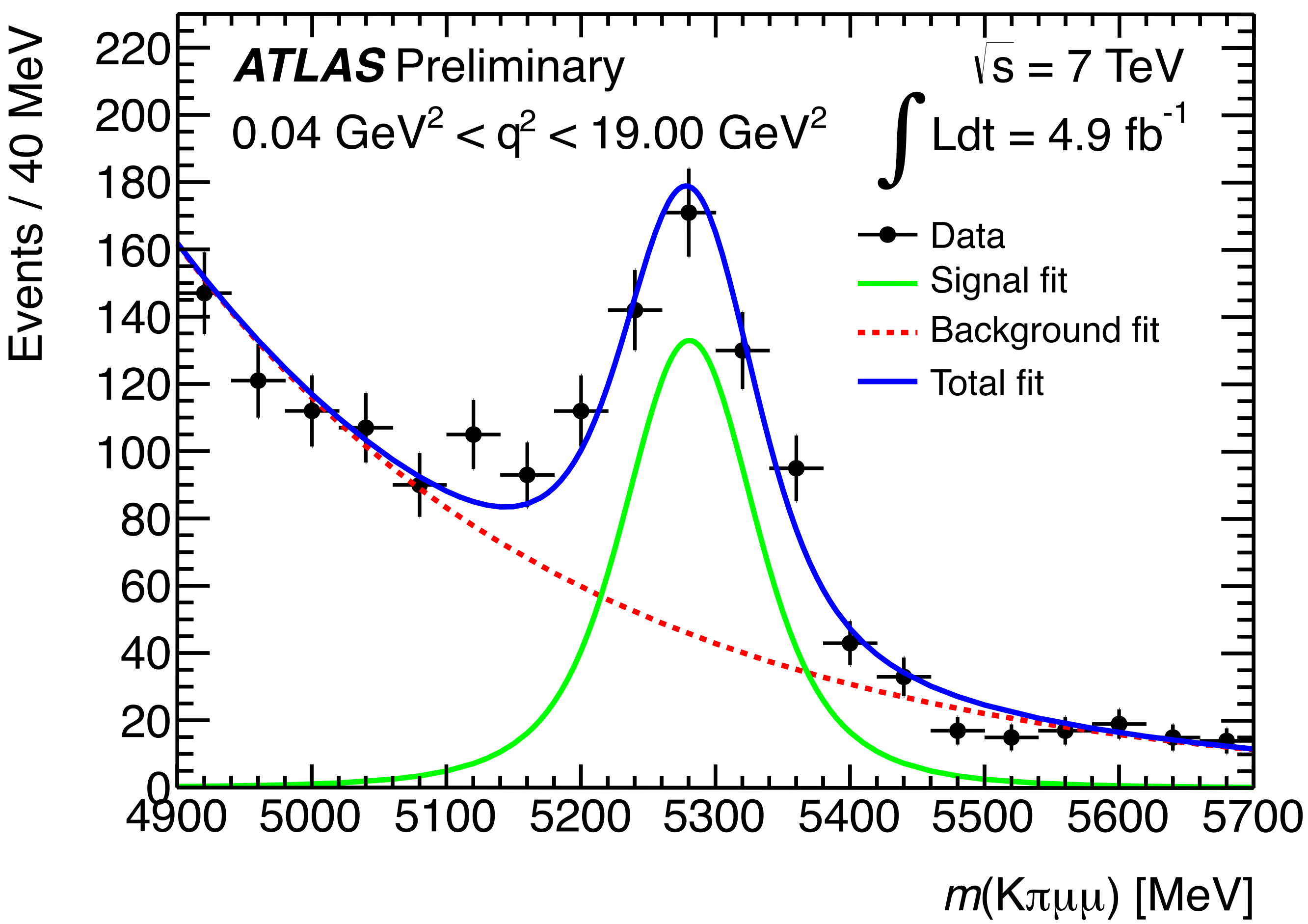
Additional selections:

- K^{*0} ($\rightarrow K^+\pi^-$) mass acceptance range [846, 946] MeV
- veto $B_d^0 \rightarrow K^{*0} J/\psi$, $B_d^0 \rightarrow K^{*0}\psi(2S)$ decays:
  - $8.68 < q^2 < 10.09$ ($J/\psi \rightarrow \mu\mu$)
  - $12.86 < q^2 < 14.18$ ($\psi(2S) \rightarrow \mu\mu$)

B_d^0 mass likelihood fit:

- signal model: Gaussian with per-event errors
- background model: exponential

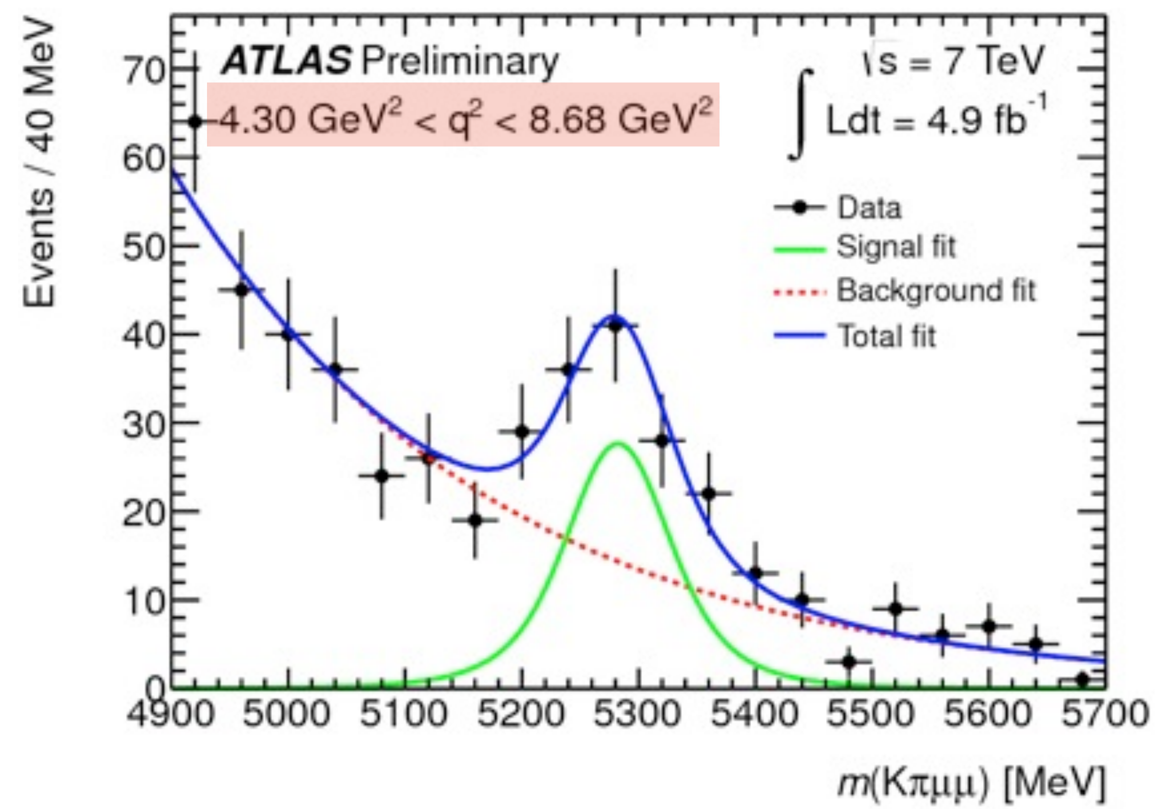
$N_{sig} = 466 \pm 34$
$N_{bkg} = 1132 \pm 43$

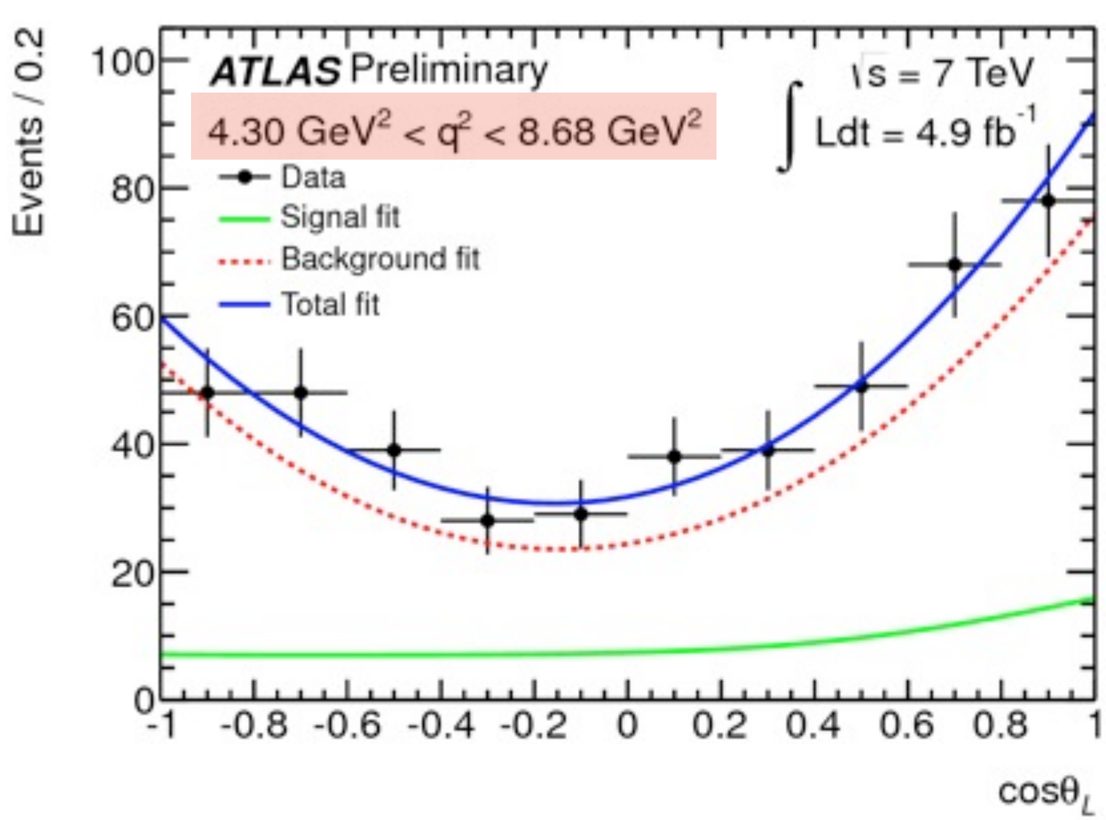


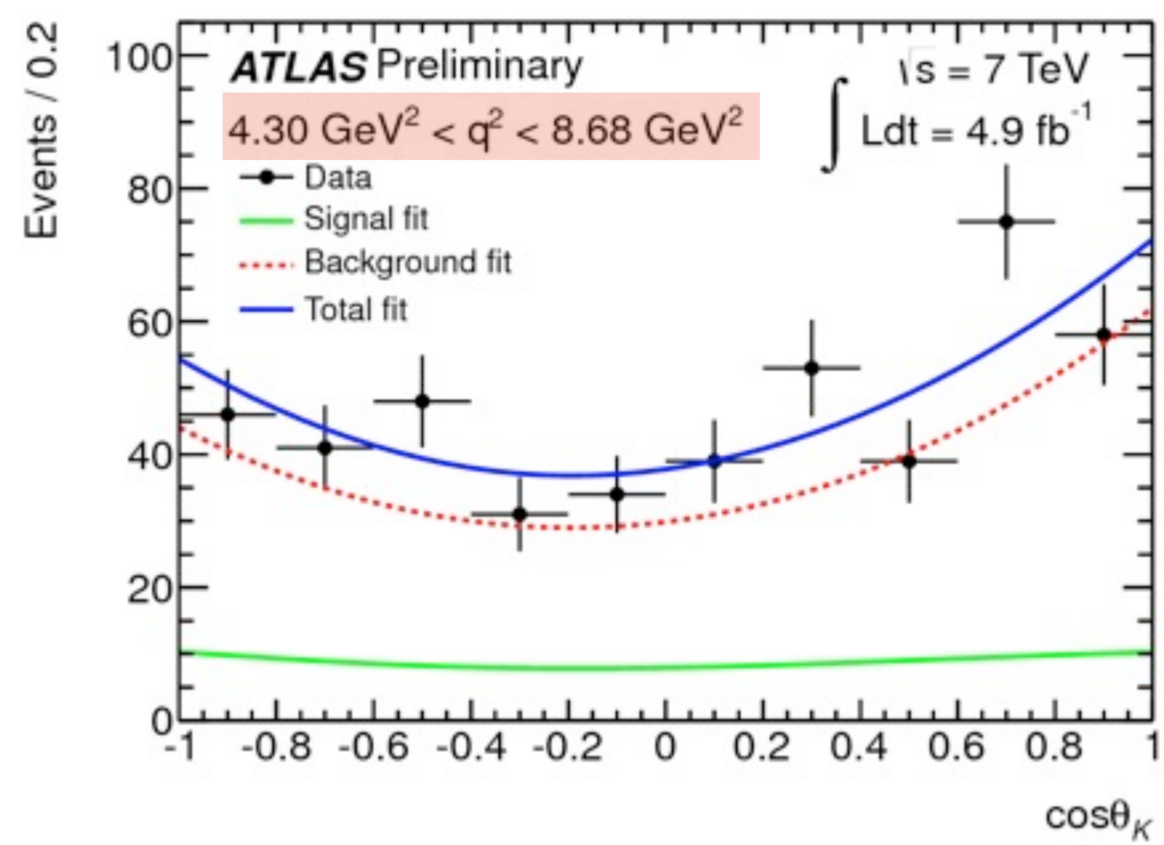
$B_d^0 \rightarrow K^{*0}\mu^+\mu^-$: Angular Fits

- unbinned max. likelihood fits using sequential approach
- for each of six q^2 bins:
  1. fit mass distribution
     => get PDF mass parameters and signal fraction
  2. fit angular distributions with parameters of the first step fixed
     => extract A_{FB} and F_L

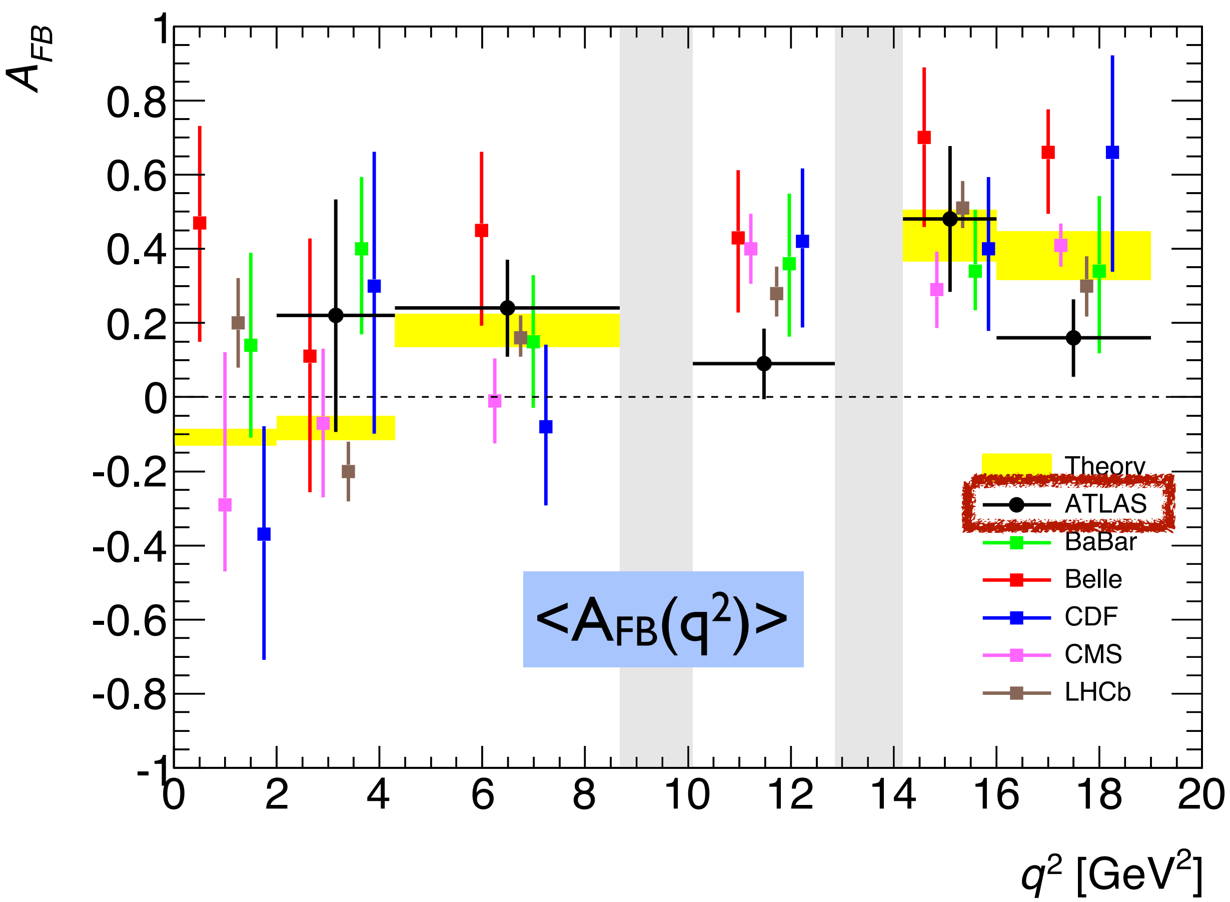
(using q^2 bin definitions of BELLE)

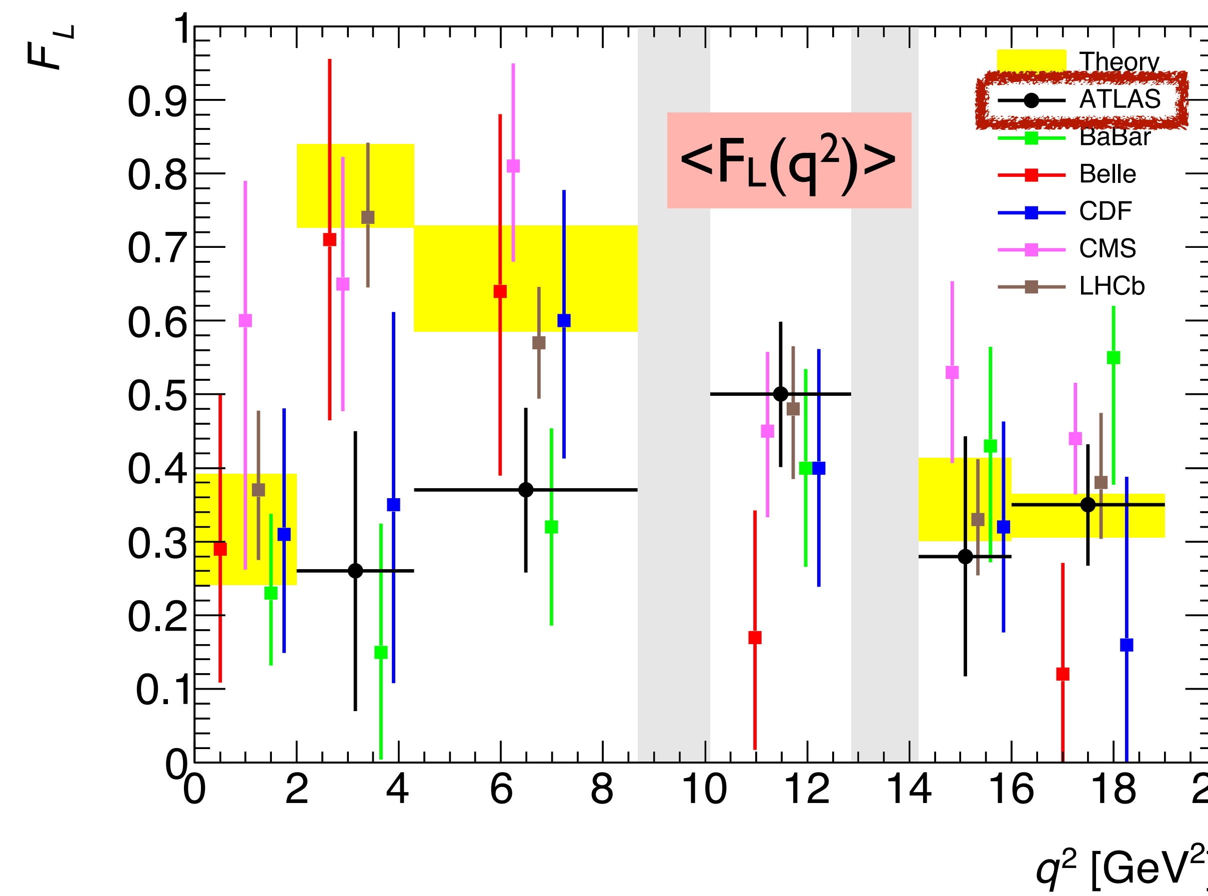






$B_d^0 \rightarrow K^{*0}\mu^+\mu^-$: Results





- measurements agree with SM and other experiments
- statistical uncertainties dominate
- in high q^2 bin ATLAS results are competitive

q^2 range (GeV^2)	N_{sig}	A_{FB}	F_L
$2.00 < q^2 < 4.30$	19 ± 8	$0.22 \pm 0.28 \pm 0.14$	$0.26 \pm 0.18 \pm 0.06$
$4.30 < q^2 < 8.68$	88 ± 17	$0.24 \pm 0.13 \pm 0.01$	$0.37 \pm 0.11 \pm 0.02$
$10.09 < q^2 < 12.86$	138 ± 31	$0.09 \pm 0.09 \pm 0.03$	$0.50 \pm 0.09 \pm 0.04$
$14.18 < q^2 < 16.00$	32 ± 14	$0.48 \pm 0.19 \pm 0.05$	$0.28 \pm 0.16 \pm 0.03$
$16.00 < q^2 < 19.00$	149 ± 24	$0.16 \pm 0.10 \pm 0.03$	$0.35 \pm 0.08 \pm 0.02$
$1.00 < q^2 < 6.00$	42 ± 11	$0.07 \pm 0.20 \pm 0.07$	$0.18 \pm 0.15 \pm 0.03$

Summary

- high-quality results with full $\sqrt{s}$ = 7 TeV dataset (5 fb^{-1})
  - rare decay $B_s \rightarrow \mu^+\mu^-$ (ATLAS-CONF-2013-076)
  - angular analysis of $B_d^0 \rightarrow K^{*0}\mu^+\mu^-$ (ATLAS-CONF-2013-038)

- no signs of BSM Physics so far
  - $B_s \rightarrow \mu^+\mu^-$: observed BR < 1.5×10^{-8}, consistent with SM
  - $B_d^0 \rightarrow K^{*0}\mu^+\mu^-$: A_{FB} and F_L measurements consistent with theoretical predictions and other measurements

- analyses with $\sqrt{s}$ = 8 TeV dataset (ca. 20 fb^{-1}) in preparation

- data of LHC Run 2 will bring us even more statistical power !