Study of rare and suppressed processes in B meson decays with ATLAS

Jaroslav Günther on behalf of the ATLAS Collaboration
Outline

✦ ATLAS detector at LHC

✦ Study of the decay $B_d \rightarrow K^* (\rightarrow K^+\pi^-) \mu^+\mu^-$

✦ Search for $B_s \rightarrow \mu^+\mu^-$

✦ Conclusions
The ATLAS Detector

**Inner Detector (|η| < 2.4)**
- silicon pixel, strip & transition rad. tracker
  - Impact parameter resolution $\approx 10 \, \mu m$
  - 2T solenoidal field

**Muon Spectrometer (|η| < 2.7)**
- Trigger chambers (RPC, TGC),
- Tracking chambers (MDT, CSC)
- 0.5-2 T toroidal field

**Tracking**
- $\sigma_{pT}/p_T \sim 0.05\% \, p_T + 1.5\%$
  (for $p_T < 100 \, GeV$, ID dominant)
- $\sigma_M(J/\psi-Y) \sim 60-120 \, MeV$
ATLAS Data Taking

2011
- > 5 fb\(^{-1}\) recorded
- Instantaneous luminosity & pile-up steadily increasing

2012
- ~ 20 fb\(^{-1}\) recorded
- Flatter instantaneous luminosity profile
- Challenging pile-up conditions!

Tier-0 processing
- RAW and derived data products registered for export (2010-12)
- Up-to 80k Tier-0 jobs completed/day (May to July 2012)

Armin Nairz, ACAT2013 in Beijing

~20 Petabyte
Study of the decay $B_d \to K^* (\to K^+\pi^-) \mu^+\mu^-$

Motivation
- relatively small SM BR $\approx 1.1 \times 10^{-6}$
- provides exclusive final state for $b \to s + l^+l^-$ transition
- only loop-mediated within SM

Observables sensitive to NP:
- Lepton forward-backward asymmetry – $A_{FB}$
- $K^0$ longitudinal polarization fraction – $F_L$
  (hadronic uncertainties drop out - at some order)

Measurement:
- differential angular distributions of the 4-particle final state as a function of di-muon mass ($q^2$)
**B_d \rightarrow K^* (\rightarrow K^+\pi^-) \mu^+\mu^- decay & analysis method**

**Kinematic observables:**
- 3 angles ($\theta_L$, $\theta_K$, $\Phi$)
- dimuon mass $q^2$ ($K^{*0}$ on shell)
- differential decay rate

**Measured angular distributions:**
- insufficient statistics 2 out of 3 angles integrated out from the 4 diff. decay rate

\[
\frac{1}{\Gamma} \frac{d^2\Gamma}{dq^2d\cos\theta_K} = \frac{3}{2} F_L(q^2) \cos^2\theta_K + \frac{3}{4} (1 - F_L(q^2))(1 - \cos^2\theta_K)
\]

\[
\frac{1}{\Gamma} \frac{d^2\Gamma}{dq^2d\cos\theta_L} = \frac{3}{4} F_L(q^2)(1 - \cos^2\theta_L) + \frac{3}{8} (1 - F_L(q^2))(1 + \cos^2\theta_L) + A_{FB}(q^2)\cos\theta_L
\]

**<A_{FB}> & <F_L> extraction:**
- extended unbinned maximum-likelihood fits
- 1-D fits in bins of $q^2$ to mass and the 2 angles $\Theta_l$, $\Theta_K$
**B_d → K^* (→ K^+π^-) μ^+μ^-** SIGNAL YIELD

**Constraints on measurement:**
- \( q^2 < 2 \text{ GeV}^2 \), limited statistics due to trigger acceptance
- experimental veto on \( J/\psi \) & \( \psi(2S) \) (cc regions)
  - \( 8.68 < q^2 < 10.09 \) \( J/\psi \to \mu^+\mu^- \) (3σ)
  - \( 12.86 < q^2 < 14.18 \) \( \psi(2S) \to \mu^+\mu^- \) (3σ)
- to remove radiative c-decays and remaining \( J/\psi \) & \( \psi(2S) \) in tails:
  - cut \[ |(m(B_d)_{REC} - m(B_d)_{PDG}) - (m(\mu^+\mu^-)_{REC} - m(cc)_{PDG})| < \Delta m \]

**B_d mass likelihood fit:**
- cut based selection optimised on MC
- Gaussian for signal
  (with per-event errors)
- Exponential for the background
- \( K^{*0} \) accepted if \( m(K^+\pi^-) \in (846,946)\text{MeV} \)

- \( N_{\text{sig}} = 466 \pm 34 \)
- \( N_{\text{bkg}} = 1132 \pm 43 \)

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Extended unbinned max-likelihood fit:

- performed sequentially
  1. fit mass distribution, & fixed signal yield
  2. simultaneous unbinned mass-angular fit (a la “BaBar”)
     (the mass PDF param. & signal fraction kept fixed from previous fit)
- done separately in each of 6 $q^2$ bins
Fit Results:
- statistical uncertainty dominates
- ATLAS measurement in agreement with SM
Search for $B_s \rightarrow \mu^+\mu^-$

Motivation
- (SM) helicity suppressed FCNC
- strong QCD-free constraint on NP
- genuine probe of Yukawa interactions
- EW precision test (wrt. Z penguin)

Recent results
- very consistent with SM
- hope for $> \text{BR}$ due to NP (pseudo-)scalar op.
- room for NP also in :
  - destructive interference between NP and SM
  - $\text{BR} \ll \text{BR}_{\text{SM}}$ ???
- waits for LHC RUN II data

Evidences of CMS+LHCb combined:

$$\text{BR} \left( B_s \rightarrow \mu^+\mu^- \right) = (2.9 \pm 0.7) \times 10^{-9}$$

$$\text{BR} \left( B_s \rightarrow \mu^+\mu^- \right) = (3.23 \pm 0.27) \times 10^{-9}$$

LHCb: arXiv:1307.5024
CMS: arXiv:1307.5025

D. Straub (arxiv.1205.6094)
**$B_s \rightarrow \mu^+ \mu^-$ Strategy @ ATLAS**

**Analysis Features:**
- **Blind analysis technique** - $B_s$ signal mass region excluded ($\pm 300$ MeV)
- **sideband events** – split in 1/2:
  - even # events = bkg. interpolation, odd # = selection optimization
- **Multivariate analysis (BDT)**
- **Relative BR measurement:**
  - reference signal decay = $B^+ \rightarrow J/\psi K^+$ (large stat.)
  - partial cancelation of syst. uncertainties on lumi, cross-sec, efficiencies

**Data**
- efficient di-muon trigger
  $\rightarrow 4.9 \text{fb}^{-1}$ (2011)

**Monte Carlo**

$$\mathcal{B}(B_s \rightarrow \mu^+ \mu^-) = \frac{N_{B_s \rightarrow \mu^+ \mu^-} \times 1}{N_{B^+ \rightarrow J/\psi K^+}}$$

$$\times \frac{(\epsilon_{tot} \times A_{tot})_{B^+ \rightarrow J/\psi K^+}}{(\epsilon_{tot} \times A_{tot})_{B_s \rightarrow \mu^+ \mu^-}}$$

- derived from simulation
- “calibrated” on data
- systematics taken from data-MC discrepancies

PDG, LHCb

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**Signal extraction:**
- $N_{B_s}$ is a CLs limit derived from:
  - candidate count &
  - background estimation in signal region
- $N_{B^+}$ is an unbinned extended maximum-likelihood fit

\[ N_{B_s \to \mu^+\mu^-} \propto \frac{1}{N_{B^+ \to J/\psi K^+}} \]

**Background composition:**
- resonant: $B \to hh'$ (K/π)
  - ‘fake’-muon rates (MC) $\pi^\pm/ K^+ /K^- \sim 2.1/4.1/3.3$ \%
  - 0.3 $B \to hh'$ events expected in the signal region
- continuum: non resonant $b\bar{b} \to \mu^+\mu^- X$
  - smooth in dimuon mass
  - sideband interpolation (even # events)
$B_s \rightarrow \mu^+\mu^-$ \textbf{BACKGROUND DISCRIMINATION}

Continuum discrimination:

- 13 best performing discriminating variables chosen by MVA
- BDT shown as most powerful event classifier
  - trained on MC
- plots show Data/MC agreement of pointing angle $\alpha_{2D}$ and Isolation $I_{0.7}$ (among most discriminant variables)

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Kraków, Poland | 29th May – 3rd June 2014 | Jaroslav Guenther
Selection optimised in 2D space ($\Delta m, q$):

- $\Delta m =$ signal mass window width
- $q =$ BDT output (event classifier)
- odd-numbered sideband events and signal MC used

Working point ($\Delta m, q$):

- $= \text{max of Punzi estimator}$
  - $P(\Delta m, q) = \varepsilon_{\text{sig}} / (1 + \sqrt{N_{\text{bkg}}})$
    (@95% CL)
- $\varepsilon_{\text{sig}}$ calculated directly on simulated signal events
- $N_{\text{bkg}}$ in sig. region estimated from sideband data

$B_s \rightarrow \mu^+ \mu^-$  BDT selection

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**B_s → μ⁺μ⁻ Reference Decay Yield**

**N_{B⁺→J/ψK⁺} extraction:**
- by unbinned maximum likelihood fit
- per-event mass resolution δm in the fit
- selection as close as possible to Bs
- same B_s-trained BDT used to min. systematics
- main systematics from varying continuum background fit models

\[ N_{B⁺→J/ψK⁺} = \text{by unbinned maximum likelihood fit} \]

**B⁺ → J/ψ(→ μ⁺μ⁻) K⁺ yield:**
- \[ N_{B⁺→J/ψ(→ μ⁺μ⁻) K⁺} = 15214 \pm 1.1\%(\text{stat}) \pm 2.4\%(\text{syst}) \]

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**ATLAS-CONF-2013-076**
$B_s \rightarrow \mu^+\mu^-$ Box opening

$N_{B_s}$ extraction:

- Single Event Sensitivity
  \[ SES = (2.07 \pm 26\%\text{(stat)} \pm 12.5\%\text{(syst)}) \times 10^{-9} \]
- Systematic uncertainty dominated by
  - reference channel BR contribution
  - acceptance and efficiency ratio
- $N_{bkg}$ expected in signal window = 6.75
- $N_{obs}$ in signal window = 6

\[ B(B_s \rightarrow \mu^+\mu^-) = \frac{N_{B_s \rightarrow \mu^+\mu^-}}{N_{B^+ \rightarrow J/\psi K^+}} \times \frac{1}{(\epsilon_{tot} \times A_{tot})_{B^+ \rightarrow J/\psi K^+}} \times \frac{(\epsilon_{tot} \times A_{tot})_{B_s \rightarrow \mu^+\mu^-}}{f_u/f_s} \times B(B^+ \rightarrow J/\psi K^+) \times \frac{f_u}{f_s} \]

CLs @ 95% CL:
\[ BR(B_s \rightarrow \mu^+\mu^-) < 1.6 \times 10^{-9} \]
\[ BR(B_s \rightarrow \mu^+\mu^-) < 1.5 \times 10^{-9} \]

New ATLAS result on 2012 data soon!
Conclusions

✦ Results from the full 2011 dataset

✦ No NP signs or significant deviation from SM predictions

✦ ATLAS has high quality b-physics program
  ✦ search for the rare decay $B_s \rightarrow \mu^+\mu^-$
  ✓ ATLAS-CONF-2013-076
  ✦ angular analysis of the decay $B_d \rightarrow K^{*0} (\rightarrow K^+\pi^-) \mu^+\mu^-$
  ✓ ATLAS-CONF-2013-038

✦ Improved analysis techniques are being developed

✦ Plans:
  ✓ Publish result on the full 2012 dataset (>20fb$^{-1}$) ASAP
  stay tuned!
Thank you for your attention!
BACKUP SLIDES
**di-muon trigger event selection:**

- 5 fb-1 ~ 150G B0−pairs, ~ 30M Bs → J/ψ Φ
- specific dimuon selections with Barrel/Endcap logic introduced in 2012
- new dedicated μ+μ-X trigger introduced in 2012
- B-physics trigger (mu4mu4) thresholds un.prescaled during 2011 despite the increasing instantaneous luminosity
BS → \( \mu^+ \mu^- \) event reconstruction

Signal candidate selection

- 2, 3 or 4 prong vertex constraint depending on decay topology
- Primary vertex selection:
  - Closest in z to the B candidate
  - Re-fit excluding B daughters
- Tracks:
  - At least 1 pixel, 6 SCT and 9 TRT hits (good tracks)
  - \(|\eta| < 2.5\) and \(p_T > 4\) (2.5) GeV for muons (kaons)
  - tracks from the tracking systems matched to muon spectrometer tracks
- B candidates \(p_T > 8\) GeV and \(|\eta| < 2.5\)
  - Events selected based on their decay topology using many discriminating variables
**$B_s \rightarrow \mu^+\mu^-$Sel. of Discriminating Variables**

**Discriminating variables:**
- Distinguish B and continuum events
- Highest discriminating power
- Exclusion of highly correlated variables
- Only variables not correlated with invariant mass were taken
- Exploit PV-SV separation ($L_{xy}$), symmetry of the final state ($d_0$), pointing angle, b-hadronisation features (isolation, $p_T$ of the B)
## $\mathbf{B_s \to \mu^+ \mu^-}$ Discriminating Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{xy}$</td>
<td>Scalar product in the transverse plane of $(\Delta \vec{x} \cdot \vec{p}^B)/</td>
<td>\vec{p}^B_T</td>
</tr>
<tr>
<td>$I_{0.7}$</td>
<td>Ratio of $</td>
<td>\vec{p}^B_T</td>
</tr>
<tr>
<td>$</td>
<td>\alpha_{2D}</td>
<td>$</td>
</tr>
<tr>
<td>$p_L^{\text{min}}$</td>
<td>Minimum momentum of the two muon candidates along the $B$ direction</td>
<td>4</td>
</tr>
<tr>
<td>$p_B^T$</td>
<td>$B$ transverse momentum</td>
<td>5</td>
</tr>
<tr>
<td>$ct$ significance</td>
<td>Proper decay length $ct = L_{xy} \times m_B / p_B^T$ divided by its uncertainty</td>
<td>6</td>
</tr>
<tr>
<td>$X_z^2, X_{xy}^2$</td>
<td>Significance of the separation between production (PV) and decay vertex (SV) $\Delta \vec{x}^T \cdot \left(\sigma_{\Delta \vec{x}}^2\right)^{-1} \cdot \Delta \vec{x}$, in $z$ and $(x, y)$, respectively</td>
<td>7, 13</td>
</tr>
<tr>
<td>$</td>
<td>D_{xy}</td>
<td>_{\text{min}},</td>
</tr>
<tr>
<td>$\Delta R$</td>
<td>Angle $\sqrt{(\Delta \phi)^2 + (\Delta \eta)^2}$ between $\Delta \vec{x}$ and $\vec{p}^B$</td>
<td>9</td>
</tr>
<tr>
<td>$</td>
<td>d_0</td>
<td>_{\text{max}},</td>
</tr>
</tbody>
</table>
Isolation variable:

- Tracks with \( p_T > 0.5 \text{ GeV} \) excluding B daughters in cone \( \Delta R < 0.7 \)
  \[ \Delta R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)} \]
- Only tracks associated with the corresponding PV are taken to avoid isolation cut efficiency to depend on pile-up
### Bs → μ⁺μ⁻ (acceptance × efficiency) ratio

\[
\frac{(\epsilon_{\text{tot}} \times A_{\text{tot}})_{B^+ \rightarrow J/\psi K^+}}{(\epsilon_{\text{tot}} \times A_{\text{tot}})_{B_s \rightarrow \mu^+ \mu^-}}
\]

- Determined on reweighted Bs and B+ MC samples wrt the fiducial volume

- Systematic uncertainties:
  - Dominant contribution from data-MC discrepancies of separation variables
  - Main discrepancies come from: Isolation and Lxy
  - Isolation is B-flavour dependent
  - Lxy is correlated with the vertex reconstruction (→ with other discriminant variables) but is it B-flavour independent

<table>
<thead>
<tr>
<th>Channel</th>
<th>(A \times \epsilon)</th>
<th>(R_{A\epsilon})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B^+)</td>
<td>(1.317 \pm 0.008% \text{ (stat)})</td>
<td>(0.267 \pm 1.8% \text{ (stat)} \pm 6.9% \text{ (syst)})</td>
</tr>
<tr>
<td>(B_s^0)</td>
<td>(4.929 \pm 0.084% \text{ (stat)})</td>
<td></td>
</tr>
</tbody>
</table>
**$B_s \rightarrow \mu^+\mu^-$ systematics on SES**

## SES systematic uncertainties

- Table shows summary of $\Delta$SES/SES uncertainty (due to syst. uncertainty sources) → SES statistical uncertainty of 2.1%

<table>
<thead>
<tr>
<th>Description</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDG branching fractions and $f_s/f_d$</td>
<td>8.5%</td>
</tr>
<tr>
<td>$K^\pm$ tracking efficiency</td>
<td>5%</td>
</tr>
<tr>
<td>Vertexing efficiency</td>
<td>2%</td>
</tr>
<tr>
<td>$K^\pm$ charge asymmetry. in $B^\pm \rightarrow J/\psi K^\pm$</td>
<td>1%</td>
</tr>
<tr>
<td>$B^\pm \rightarrow J/\psi K^\pm$ yield</td>
<td>2.4%</td>
</tr>
<tr>
<td>$R_{Ae}$</td>
<td>6.9%</td>
</tr>
<tr>
<td>Total (comb. in quadrature)</td>
<td>12.5%</td>
</tr>
</tbody>
</table>

- Contributions from backgrounds:
  - Background interpolation from sidebands → 4% on Rbkg
  - $B \rightarrow hh'$ negligible
  - Mainly contribute: BRref and $fu/fs$, acc-vs-eff ratio (data-MC discrepancies), K tracking efficiency
\[ L = \text{Poisson}(N_{SR}^{obs}|\epsilon B + N_{bkg} + N_{B\rightarrow hh}) \text{Poisson}(N_{bkg,SB}^{obs}|R_{bkg} N_{bkg}) \times \]
\[ \text{Gauss}(\epsilon^{obs}|\epsilon, \sigma_{\epsilon}) \text{Gauss}(R_{bkg}^{obs}|R_{bkg}, \sigma_{R_{bkg}}) \]

\[ \epsilon = 1/\text{SES} \]
\[ R = \Delta_{SB}/\Delta_{SR} \]

- the expected UL is calculated assuming the number of events in the signal region as the number of expected events obtained from the sideband interpolation (6.75 events):
- peeking background negligible, but included in the optimization procedure and in the upper limit calculation

<table>
<thead>
<tr>
<th>quantity</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{J/\psi K^\pm} )</td>
<td>15 214 ± 1.10% ± 2.39%</td>
</tr>
<tr>
<td>( R_{A\epsilon} )</td>
<td>0.267 ± 1.8% ± 6.9%</td>
</tr>
<tr>
<td>SES</td>
<td>(2.07 ± 0.26) \cdot 10^{-9}</td>
</tr>
<tr>
<td>( R_{bkg}^{obs} )</td>
<td>1.240 ± 0.050</td>
</tr>
<tr>
<td>( N_{SR}^{exp} )</td>
<td>( N_{SR}^{obs} )</td>
</tr>
<tr>
<td>( N_{bkg,SB}^{obs} )</td>
<td>8</td>
</tr>
<tr>
<td>( N_{B\rightarrow hh} )</td>
<td>0.30</td>
</tr>
</tbody>
</table>
\[
\text{BR}(B_s \rightarrow \mu^+\mu^-) = \frac{N_{N_{\text{ref}}} \times \text{BR}(\text{ref}) \times (f_u/f_s) \times (\varepsilon_{\text{tot}} \times A_{\text{tot}})_{\text{ref}}}{(\varepsilon_{\text{tot}} \times A_{\text{tot}})_{B_s \rightarrow \mu^+\mu^-}}
\]
Baseline:
- $p_T(\mu) > 3.5$ GeV
- $|\eta| < 2.5$ for all tracks
- $\chi^2$/n.d.f. ($\mu\mu$) < 10
- $846 < M(K^{*0}) < 946$ MeV
- $p_T(K) > 0.5$ GeV
- $p_T(\pi) > 0.5$ GeV

$J/\psi$, $\psi'(2S)$ regions are excluded

Selection (cut values are optimized):
- $\tau/\Delta \tau (B_d) > 12.75$
- $\cos(\theta) > 0.999$
- $\chi^2$/n.d.f. ($B_d$) < 2.0
- $p_T(K^*) > 3$ GeV
- $|M(B^0_{rec} - M(B^0_{PDG})| - |M(\mu\mu_{rec} - M(J/\psi_{PDG})| > 130$ MeV
Extended unbinned maximum likelihood fit (performed sequentially):

1) mass ($K\pi\mu\mu$) distribution fitted to separate signal and background yields

2) mass-angular simultaneous fit performed on the signal events from the previous fit (fixed mass)

Done separately for each of the 6 $q^2$ bins

The procedure checked to give the same results as single-step fit except the lowest $q^2$ bin (included in systematics there).

\[ \mathcal{L} = \prod_{i=1}^{N} \left[ N_{\text{sig}} \cdot \mathcal{M}_{\text{sig}}(m_i, \delta m_i) + N_{\text{bckg}} \cdot \mathcal{M}_{\text{bckg}}(m_i) \right], \]

\[ \mathcal{M}_{\text{sig}}(m_i, \delta m_i) = \frac{1}{\sqrt{2\pi} s_m \delta m_i} \exp \left( \frac{-(m_i - m_{B_d}^0)^2}{2(s_m \delta m_i)^2} \right) \]

\[ \mathcal{M}_{\text{bckg}}(m_i) = e^{-\lambda \cdot m_i} \]
B_d \rightarrow K^* (\rightarrow K^+\pi^-) \, \mu^+\mu^- \text{ FIT STRATEGY}

- Angular fit (in each q^2 bin):
  \[\mathcal{L} = \prod_{i=1}^{N} \left[ N_{\text{sig}}^{\text{fix}} \cdot M_{\text{sig}}(m_i, \delta_{m_i} | \text{fixed}) \cdot A_{L,\text{sig}}(\cos \theta_{L,i}) \cdot \alpha_L(\cos \theta_{L,i}) \cdot A_{K,\text{sig}}(\cos \theta_{K,i}) \cdot \alpha_K(\cos \theta_{K,i}) + N_{\text{bckg}}^{\text{fix}} \cdot M_{\text{bckg}}(m_i | \text{fixed}) \cdot A_{L,\text{bckg}}(\cos \theta_{L,i}) \cdot A_{K,\text{bckg}}(\cos \theta_{K,i}) \right]\]

- Signal PDFd:
  \[A_{L,\text{sig}}(\cos \theta_{L,i}) = \frac{3}{4} F_L(q^2) \left( 1 - \cos^2 \theta_{L,i} \right) + \frac{3}{8} \left( 1 - F_L(q^2) \right) \left( 1 + \cos^2 \theta_{L,i} \right) + A_{FB}(q^2) \cos \theta_{L,i} \]
  \[A_{K,\text{sig}}(\cos \theta_{K,i}) = \frac{3}{2} F_L(q^2) \cos^2 \theta_{K,i} + \frac{3}{4} \left( 1 - F_L(q^2) \right) (1 - \cos^2 \theta_{K,i}) \]

- Background PDF – linear combination of Chebyshev polynomials (to 2nd order)
  \[A_{L(K),\text{bkg}} = 1 + p_{1L(K)} \cos \theta_{L(K),i} + p_{2L(K)} \left( 2 \cos^2 \theta_{L(K),i} - 1 \right) \]

- detector and selection effects on the angular shapes taken into account via the acceptance functions \(\alpha_L(\cos \theta_{L,i}), \alpha_K(\cos \theta_{K,i})\)

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$B_d \rightarrow K^* (\rightarrow K^+\pi^-) \mu^+\mu^-$ systematic

- Ranges of the mass fit region
  - Differ in $q^2$ bins due to deltaM cut effect
- Angular background shapes
  - Varied between 2nd and 3rd Chebyshev polynomials
- Contribution of $B^\pm \rightarrow \mu^+\mu^- K^\pm$ events
  - estimated by removing potential $B^\pm \rightarrow \mu^+\mu^- K^\pm$ candidates
- Angular acceptance effects
  - Mainly from limited MC statistics
  - Various signal angular shapes tested
- Sequential fitting approach
  - Non-negligible effect only in $2.00 < q^2 < 4.30$ GeV$^2$ bin due to low statistics

Negligible sources:
- Contribution from S-wave ($B_d \rightarrow K^+\pi^- \mu^+\mu^-$)
- Contribution from $B_s \rightarrow \Phi (\rightarrow K^+ K^-) \mu^+\mu^-$
- Background mass shape
- Possible bias due to angular fit approach (neglecting correlation)
$B_d \to K^* (\to K^+\pi^-) \mu^+\mu^-$ Likelihood fit - other bins

$1.00 < q^2 < 6.00$

Anna Usanova

ATLAS-CONF-2013-038
$B_d \rightarrow K^* (\rightarrow K^+\pi^-) \mu^+\mu^-$  **LIKELIHOOD FIT - OTHER BINS**

$2.00 < q^2 < 4.30$

Anna Usanova
$B_d \rightarrow K^* (\rightarrow K^+\pi^-) \mu^+\mu^-$ likelihood fit - other bins

$10.09 < q^2 < 12.86$

Anna Usanova
$B_d \to K^* (\to K^+\pi^-) \mu^+\mu^-$ LIKELIHOOD FIT - OTHER BINS

$14.18 < q^2 < 16.00$

Anna Usanova

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