Flavor Physics with ATLAS
Status and Perspectives

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on behalf of the ATLAS collaboration

Flavor Physics and CP Violation 2010
May 25-29, 2010
Torino - Italy
B-Physics time-line program

Key elements for B-Physics searches:
- Efficient low pt muon trigger
- Good muon coverage $|\eta|<2.7$
- Good track momentum resolution and mass resolution
- Good vertex resolution

Efficient low pt muon trigger
Good muon coverage $|\eta|<2.7$
Good track momentum resolution and mass resolution
Good vertex resolution

B-hadron properties, new decay limits
Understand backgrounds for rare decays

Rare decays
Searches for new CP-violation in weak decays of B-mesons; rare decay searches; $\Lambda_b$ polarization

- Detector & trigger understanding / calibration
- $J/\psi$, $\Upsilon$, and exclusive $B$-channels as a tester
- Early measurements of well known $B$-decays, $b$-production

LHC startup (Nov. 2009)
**The Atlas Detector**

**Muon Spectrometer** (|\(\eta\)|<2.7): air-core toroids with gas-based muon chambers
Muon trigger and measurement with **momentum resolution < 10% up to** \(E_\mu \sim 1\) TeV

- **Length**: ~ 46 m
- **Radius**: ~ 12 m
- **Weight**: ~ 7000 tons
- ~10\(^8\) electronic channels
- 3000 km of cables

**Inner Detector** (|\(\eta\)|<2.5, B=2T):
- Si Pixels, Si strips,
- Transition Radiation detector (straws)
- Precise tracking and vertexing, \(e/\pi\) separation
- **Momentum resolution**: \(\sigma/pT \sim 3.8 \times 10^{-4}\) \(pT\) (GeV)\(\oplus 0.015\)

3-level trigger reducing the rate from 40 MHz to ~200 Hz

**EM calorimeter**: Pb-LAr Accordion
e/\(\gamma\) trigger, identification and measurement
- **E-resolution**: \(\sigma/E \sim 10%/\sqrt{E}\)

**HAD calorimetry** (|\(\eta\)|<5): segmentation, hermeticity
- Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
- Trigger and measurement of jets and missing ET
- **E-resolution**: \(\sigma/E \sim 50%/\sqrt{E} \oplus 0.03\)
First observed collision candidate at 900 GeV, Nov 23 2009

Note: Solenoid off and Si detectors off or at reduced voltage (no stable beam)
Collision Event at 7 TeV with 2 Pile Up Vertices

ATLAS EXPERIMENT

Run Number: 152166, Event Number: 467774
Date: 2010-03-30 13:31:46 CEST

Overall Statistics for 7 TeV Collisions

- Consider period from 30-March till 19 May (31 runs)

- Instantaneous luminosity $L$ derived from:
  - MBTS (trigger scintillators at $\pm 3.5m$ from IP) double-side coincidence trigger rate
  - LAr offline event selection (coincidence of in-time end-cap energy deposits)
  - Measurement from dedicated LUCID forward detectors, at $\pm 17m$ from IP
  - Present overall $L$ scale uncertainty $\sim 20\%$ from systematic uncertainties (MC cross-section)

- Total luminosity about 8.3 nb$^{-1}$

- 94% of luminosity delivered with Stable Beams was recorded by ATLAS
• Detailed studies comparing data/MC
• dedicated care that Monte Carlo samples reflect conditions during data taking (beam spot position, inactive modules, noisy channels)
• In general, there is an excellent agreement between data and Monte Carlo
Weak decay reconstruction provides a stringent test of tracking performance

- reconstructed Ks and Λ masses close to PDG value
- width of the invariant mass peaks well reproduced by Monte Carlo
Observation of $D^* \rightarrow D \pi$ at 7 TeV

Masses and Widths agree well with MC expectations (integrated Luminosity~ 200 $\mu$b$^{-1}$)

$\Delta (M(K\pi\pi) - M(K\pi))$:
- Require: $M(K\pi) = 1865 \pm 20$ MeV
- Right = sideband
- Results: $\Delta M = 145.6 \pm 0.1$ MeV

$M(K\pi)$:
- Require: $\Delta M = 145.4 \pm 1.5$ MeV
- Right = sideband
- Results: $M(K\pi) = 1869.2 \pm 2.4$ MeV
Muon Spectrometer Results

- **Cosmics**: a lot of studies made with cosmic rays allow to evaluate the level of readiness of our Spectrometer.

- **900 GeV data**: Statistics limited, dominantly in the forward region.

- Data and Monte Carlo are consistent with available statistics ($P>4$ GeV, $p_T>2.5$ GeV, $|\eta|<2.5$).
Observation of $J/\psi \rightarrow \mu \mu$ at 7 TeV

Gaussian-mean mass: $3.06 \pm 0.02$ GeV
Resolution: $0.08 \pm 0.02$ GeV
Number of signal events: $49 \pm 12$
Number of background events: $28 \pm 4$
Signal and background are computed in a mass range: $2.82 - 3.30$ GeV (3σ around the peak).
1) **B-Trigger Strategy**
2) **Onia Production and Polarization**
3) $B^+ \rightarrow J/\psi K^+$
4) $B_s \rightarrow J/\psi \phi$ and $B_d \rightarrow J/\psi K^*_{0}$
5) $B_s \rightarrow \mu \mu$
B-Trigger Strategy

- **Low $p_T$ single / two muons**
  - Control samples, only at very low luminosity
B-Trigger Strategy

- **Low p\_T** single / two muons
  - Control samples, only at very low luminosity
  - Di-muon (common vertex) in the final state, invariant mass ranges:
    - J/\(\psi\) and other heavy quarkonia (\(\Upsilon\)) decaying to \(\mu\mu\)
**B-Trigger Strategy**

- **Low $p_T$ single / two muons**
  - Control samples, only at very low luminosity

→ **Di-muon (common vertex) in the final state**, invariant mass ranges:
  - $J/\psi$ and other heavy quarkonia ($\Upsilon$) decaying to $\mu\mu$
  - Very rare $B \rightarrow \mu\mu$

![Diagram showing the decay of $B$ to $\mu\mu$](image)
B-Trigger Strategy

- Low $p_T$ single / two muons
  - Control samples, only at very low luminosity

- Di-muon (common vertex) in the final state, invariant mass ranges:
  - $J/\psi$ and other heavy quarkonia ($\Upsilon$) decaying to $\mu\mu$
  - Very rare $B \to \mu\mu$
  - Semileptonic rare $B \to X_{s}\mu\mu$

![Diagram showing the decay processes and mass distributions](image_url)
B-Trigger Strategy

- **Low pₜ single / two muons**
  - Control samples, only at very low luminosity

> **Di-muon (common vertex) in the final state**, invariant mass ranges:
  - J/ψ and other heavy quarkonia (ϒ) decaying to μμ
  - Very rare B → μμ
  - Semileptonic rare B → Xₜμμ
  - Need to cover sidebands around the signal peak
B-Trigger Strategy

- **Low $p_T$ single / two muons**
  - Control samples, only at very low luminosity

- **Di-muon (common vertex) in the final state**, invariant mass ranges:
  - $J/\psi$ and other heavy quarkonia ($\Upsilon$) decaying to $\mu\mu$
  - Very rare $B \rightarrow \mu\mu$
  - Semileptonic rare $B \rightarrow \chi_s\mu\mu$
  - Need to cover sidebands around the signal peak
  - Control measurements of di-muon low-mass (bb, cc, contributions)

- **Trigger for mass range**
  $M(\mu\mu) < \sim 13 \text{ GeV}$
**B-Trigger Strategy**

### Di-muon Trigger
- **Two L1 muons**
  - confirm muon at L2
  - Tracking in small RoI
  - Mass & vertex cuts

### Single μ Trigger
- **One L1 muon**
  - confirm muon at L2
  - Tracking in one large RoI, search for the 2\textsuperscript{nd} muon
  - Mass & vertex cuts

### FullScan Trigger
- **One L1 muon**
  - confirm muon at L2
  - Tracking in entire detector, search for the 2\textsuperscript{nd} muon
  - Mass & vertex cuts

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The lowest level 1 muon trigger threshold are **4 GeV, 6 GeV**

- **Single L1 muon triggers:**
  - Use lowest muon pT threshold and FullScan (time consuming) to give highest efficiency at startup
- **L1 di-muon triggers:**
  - Use lowest muon pT threshold (MU4)
  - Reduce the background and will be needed at higher luminosity.
Onia Production

- **Seeded by Level1 Di-μ trigger**
  μ tracks are fitted to a common vertex
  For J/ψ, pseudo-proper time < 0.2 ps
  (background suppression)

- **Expected statistics**: 15,000 J/ψ and
  2000 Y per 1 pb⁻¹ using di-μ trigger
  \( p_T(\mu_1,2) > 4 \text{ GeV} \)
  \( S/B = 60 \,(\text{J/ψ}), \, 10 \,(\text{Y}) \)

- **Measurement of prompt J/ψ to indirect cross-section relies on separation (and understanding of separation) of these two processes**

- **With 1pb⁻¹, the ratio** \( R = \sigma(\, bb \rightarrow J/\psi)/\sigma(pp \rightarrow J/\psi) \)
  can be measured as a function of \( p_T, \eta \) with a statistical precision of 10%.
Onia Cross Section and Polarization

- In Atlas, measurement of high-$p_T$ polarization will allow to distinguish production models
- In order to have a full $\cos\theta^*$ coverage, combine di-muon and single-$\mu$ trigger measurements

\[
\frac{dN}{d\cos \theta} \propto 1 + \alpha \cos^2 \theta
\]

Precision on polarization of $J/\psi$ about 0.02-0.05 after 10 pb$^{-1}$ and cross-section measurement precision in bins of $p_T$ of the order of 1% (dependent on the polarisation)

<table>
<thead>
<tr>
<th>Sample</th>
<th>$p_T$, GeV</th>
<th>9 – 12</th>
<th>12 – 13</th>
<th>13 – 15</th>
<th>15 – 17</th>
<th>17 – 21</th>
<th>&gt; 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi$, $\alpha_{\text{gen}} = 0$</td>
<td>$\alpha$</td>
<td>0.156</td>
<td>−0.006</td>
<td>0.004</td>
<td>−0.003</td>
<td>−0.039</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>$\sigma$, nb</td>
<td>87.45</td>
<td>9.85</td>
<td>11.02</td>
<td>5.29</td>
<td>4.15</td>
<td>2.52</td>
</tr>
<tr>
<td></td>
<td>$\pm 0.166$</td>
<td>$\pm 0.032$</td>
<td>$\pm 0.029$</td>
<td>$\pm 0.037$</td>
<td>$\pm 0.038$</td>
<td>$\pm 0.057$</td>
<td></td>
</tr>
<tr>
<td>$J/\psi$, $\alpha_{\text{gen}} = +1$</td>
<td>$\alpha$</td>
<td>1.268</td>
<td>0.998</td>
<td>1.008</td>
<td>0.9964</td>
<td>0.9320</td>
<td>1.0217</td>
</tr>
<tr>
<td></td>
<td>$\pm 0.290$</td>
<td>$\pm 0.049$</td>
<td>$\pm 0.044$</td>
<td>$\pm 0.054$</td>
<td>$\pm 0.056$</td>
<td>$\pm 0.088$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\sigma$, nb</td>
<td>117.96</td>
<td>13.14</td>
<td>14.71</td>
<td>7.06</td>
<td>5.52</td>
<td>3.36</td>
</tr>
<tr>
<td></td>
<td>$\pm 6.51$</td>
<td>$\pm 0.12$</td>
<td>$\pm 0.12$</td>
<td>$\pm 0.07$</td>
<td>$\pm 0.05$</td>
<td>$\pm 0.05$</td>
<td></td>
</tr>
<tr>
<td>$J/\psi$, $\alpha_{\text{gen}} = -1$</td>
<td>$\alpha$</td>
<td>−0.978</td>
<td>−1.003</td>
<td>−1.000</td>
<td>−1.001</td>
<td>−1.007</td>
<td>−0.996</td>
</tr>
<tr>
<td></td>
<td>$\pm 0.027$</td>
<td>$\pm 0.010$</td>
<td>$\pm 0.010$</td>
<td>$\pm 0.013$</td>
<td>$\pm 0.014$</td>
<td>$\pm 0.018$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\sigma$, nb</td>
<td>56.74</td>
<td>6.58</td>
<td>7.34</td>
<td>3.53</td>
<td>2.78</td>
<td>1.68</td>
</tr>
<tr>
<td></td>
<td>$\pm 2.58$</td>
<td>$\pm 0.06$</td>
<td>$\pm 0.06$</td>
<td>$\pm 0.04$</td>
<td>$\pm 0.03$</td>
<td>$\pm 0.02$</td>
<td></td>
</tr>
<tr>
<td>$\Upsilon$, $\alpha_{\text{gen}} = 0$</td>
<td>$\alpha$</td>
<td>−0.42</td>
<td>−0.38</td>
<td>−0.20</td>
<td>0.08</td>
<td>−0.15</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>$\pm 0.17$</td>
<td>$\pm 0.22$</td>
<td>$\pm 0.20$</td>
<td>$\pm 0.22$</td>
<td>$\pm 0.18$</td>
<td>$\pm 0.22$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\sigma$, nb</td>
<td>2.523</td>
<td>0.444</td>
<td>0.584</td>
<td>0.330</td>
<td>0.329</td>
<td>0.284</td>
</tr>
<tr>
<td></td>
<td>$\pm 0.127$</td>
<td>$\pm 0.027$</td>
<td>$\pm 0.029$</td>
<td>$\pm 0.016$</td>
<td>$\pm 0.015$</td>
<td>$\pm 0.012$</td>
<td></td>
</tr>
</tbody>
</table>
B⁺→J/ψ(μμ) K⁺

- Reference channel for the search for rare B-decays
- Using di-muon trigger (pt>4, pt>6 GeV), expect ~1600 events for 10 pb⁻¹

- Cross section (stat) (total)
- Total to ~3 % ~15 %
- dσ/dpT to ~10 % ~16-20 %
- Signal lifetime to ~ 2.5 % (stat only)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>stat. + s [%]</td>
<td>7.7</td>
<td>6.9</td>
<td>10.5</td>
<td>13.9</td>
<td>4.3</td>
</tr>
<tr>
<td>total [%]</td>
<td>16.1</td>
<td>15.8</td>
<td>17.6</td>
<td>19.8</td>
<td>14.8</td>
</tr>
</tbody>
</table>
The channel $B_s \rightarrow J/\psi(\mu\mu)\phi$ is a promising indirect route to New Physics
- "Weak mixing phase" $\phi$s has been calculated in the SM and is very small (-0.0368±0.0018) but may be enhanced by BSM processes
- The topologically identical $B_d \rightarrow J/\psi K_0^*$ (15x greater statistics) is the primary background and is also essential as a control channel (test of lifetime measurement and tagging calibration)
- Simultaneous fit to mass and decay time can be used to extract signal mass and lifetime from data in the channel $B_d \rightarrow J/\psi K_0^*$ with 10pb$^{-1}$

- In early data, loose cuts will be used (No vertex displacement cut)
- After 10 pb$^{-1}$ the precision on the $B_d$ lifetime will be 10% and similar precision for the $B_s$ mean lifetime will be available after 150 pb$^{-1}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$B_d \rightarrow J/\psi K_0^*$ after 10 pb$^{-1}$</th>
<th>$B_s \rightarrow J/\psi\phi$ after 150 pb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulated value</td>
<td>Fit result + st error</td>
</tr>
<tr>
<td>Mean lifetime, ps$^{-1}$</td>
<td>0.651</td>
<td>0.73 ± 0.07</td>
</tr>
<tr>
<td>Mean mass, GeV</td>
<td>5.279</td>
<td>5.284 ± 0.006</td>
</tr>
<tr>
<td>Lifetime resolution $\sigma$, ps</td>
<td>0.132 ± 0.004</td>
<td>0.152 ± 0.001</td>
</tr>
<tr>
<td>Mass resolution $\sigma$, GeV</td>
<td>0.054 ± 0.006</td>
<td>0.061 ± 0.006</td>
</tr>
<tr>
<td>$n_{sig}/N$</td>
<td>0.16</td>
<td>0.155 ± 0.006</td>
</tr>
<tr>
<td>$n_{bck}/N$</td>
<td>0.062</td>
<td>0.595 ± 0.017</td>
</tr>
</tbody>
</table>
After about 1 fb\(^{-1}\), it will be possible to extract interesting parameters from the \(B_s \rightarrow J/\psi \phi\) decays. FLAVOUR TAGGING (attempting to determine whether the decay is from a \(B_s\) or an anti-\(B_s\)) is an essential part of this decay. \(B_s \rightarrow J/\psi \phi\) is not self-tagging.

In ATLAS, the best flavour tagging performance for \(B_s \rightarrow J/\psi \phi\) is obtained using the jet charge tagging algorithm, which is a “same side” tag.

Utilize correlations between the original quark flavour and momenta, and the charge and momenta of the fragmentation products (jet charge tagging).

Calibration of the jet-charge tag will be done with the self-tagging reference channel \(B_d \rightarrow J/\psi K^0\), and will validate Monte Carlo models for fragmentation.

Validated Monte Carlo will be used to determine the tagger quality for \(B_s \rightarrow J/\psi \phi\).

### Tuned jet charge tagger performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(B_d \rightarrow J/\psi K^0)</th>
<th>(B_s \rightarrow J/\psi \phi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>150 pb(^{-1})</td>
<td>1.5 fb(^{-1})</td>
</tr>
<tr>
<td>Tag Efficiency</td>
<td>0.870 ± 0.003</td>
<td>0.625 ± 0.005</td>
</tr>
<tr>
<td>Wrong tag fraction</td>
<td>0.380 ± 0.004</td>
<td>0.374 ± 0.005</td>
</tr>
<tr>
<td>Dilution</td>
<td>0.240 ± 0.009</td>
<td>0.251 ± 0.010</td>
</tr>
<tr>
<td>Quality</td>
<td>0.050 ± 0.004</td>
<td>0.039 ± 0.003</td>
</tr>
</tbody>
</table>
ATLAS performance for $B_s \rightarrow \mu \mu$

- $B_s \rightarrow \mu+\mu-$ is highly suppressed in SM (box, penguin diagr.)
  - $\text{BR SM}(B_s \rightarrow \mu \mu) = (3.42 \pm 0.52) \times 10^{-9}$
  - Best exp. limit $\text{BR CDF}(B_s \rightarrow \mu \mu) < 5.8 \times 10^{-8}$ (95%CL)
- Sensitive to New Physics (new particles in the loop)
- Main challenge is to control the background, the ATLAS strategy is:
  - Trigger on events with $B_s \rightarrow \mu+\mu-$ candidates using dedicated trigger algorithms
  - Discriminating variables:
    - decay flight length (significance)
    - pointing angle between di-muon momentum and vector from primary vertex to di-muon vertex
    - isolation (no hadronic activity around $B_s$ flight direction)
    - mass window around $m(B_s)$
The ATLAS $B_s \rightarrow \mu\mu$ program will continue throughout the lifetime of the detector.

- After 1 $fb^{-1}$ ATLAS will have collected $O(10^6)$ dimuons in the invariant mass range 4-7 GeV.
  - This will allow tuning of cuts and potentially training of multivariate procedures.
- Use $B^+ \rightarrow J/\psi(\mu\mu)K^+$ as a reference channel (similar to CDF & D0).
- Branching Ratio will be estimated by normalization to the $B^+ \rightarrow J/\psi(\mu\mu)K^+$ events.
- After 10 $fb^{-1}$ (1 year @ $10^{33}$) we expect (SM):

<table>
<thead>
<tr>
<th>Expected #ev after kinemat. preselect.</th>
<th>150</th>
<th>7000000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow \mu\mu$ efficiency</td>
<td>0.24</td>
<td>$(2.6 \pm 0.3) \times 10^{-2}$</td>
</tr>
<tr>
<td>$b \bar{b} \rightarrow \mu\mu$ efficiency</td>
<td>0.26</td>
<td>$(1 \pm 0.3) \times 10^{-3}$ *)</td>
</tr>
<tr>
<td>$L_{xy} &gt; 0.5$ mm</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>$\alpha &lt; 0.017$ rad</td>
<td>0.76</td>
<td>0.079</td>
</tr>
<tr>
<td>$M = M_{B_{s}}^{+140} - 70$ MeV</td>
<td>5.7</td>
<td>$14^{+13}_{-10}$</td>
</tr>
</tbody>
</table>

The ATLAS $B_s \rightarrow \mu\mu$ program will continue throughout the lifetime of the detector.
Summary

- ATLAS detector is performing remarkably well as commissioning for physics advances in the month since first 7 TeV collisions:
  - Tracking studies very advanced, including detailed understanding of material, and first physics results. Precise comparisons of data and MC in many domains, signals for meson/baryon resonances and charm.
  - First significant number of collision muons have led to J/ψ→μμ observation, and muon spectrometer is performing very well.

- An efficient, fast and clean di-muon trigger scheme will allow ATLAS to collect large numbers of B-hadron decays involving μμ final states, throughout the lifetime of the experiment.

- Early B-Physics data will provide valuable information on the detector performance, but will also allow calibration studies in support of New Physics searches.