Atlas direct J/Ψ production studies.

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Motivation

- Measurements done at CDF are not consistent with the predictions of the $J/\psi$ polarization $P_T$ dependence. There is a large discrepancy between some theoretical prediction and the CDF measurements mainly at high $P_T$ range.

- **Recent measurements**
  April 28, 2005

[Link to recent measurements]

Various models in Charmonium Production

- **The Color Evaporation Model (CEM)**
  It assumes that there is no correlation between the initial $Q\bar{Q}$ state and the final quarkonium state.

- **The Color Singlet Model (CSM)**
  It assumes that each quarkonium state can only be produced by a $Q\bar{Q}$ pair in the same color and angular momentum state as that quarkonium.

- **The Nonrelativistic QCD Model (NRQCD)**
  It treats quarkonium as an approximately nonrelativistic system. When applied to production, this implies that $Q\bar{Q}$ pairs produced with one set of quantum numbers can evolve into a quarkonium state with different quantum numbers, by emitting low energy gluons.
NRQCD

NRQCD makes systematic nonrelativistic corrections to effective field theory using an expansion series in $v$ (the velocity of the heavy quark in the quarkonium rest frame) and $\alpha_s$.

At high $P_T$ ($P_T >> mc$) the dominant process in NRQCD is the fragmentation of a single gluon to a pair in a $[8,^3S_1]$ state (c). In comparison to the color singlet fragmentation process in (b) this occurs at a higher order of $v_c$ ($v_c^7$ versus $v_c^3$) but at a lower order of $\alpha_s$ ($\alpha_s^3$ versus $\alpha_s^5$).

Taking into account these facts, it is indeed plausible that the color octet process could explain the observed direct cross sections.
ATLAS DETECTOR AT LHC

Length of the tunnel is 26.6 km (existing LEP tunnel)
Maximum Energy 14 TeV
Frequency 40 MHz (25nsec)
Low Luminosity-$10^{33}$ cm$^{-2}$s$^{-1}$
High Luminosity-$10^{34}$ cm$^{-2}$s$^{-1}$

Atlas one of the four LHC experiments that will study p-p collisions

- Beam pipe.
- Tracking detector.
- Solenoidal Magnet.
- Electromagnetic Calorimeter.
- Hadron Calorimeter.
- Muon Toroidal Magnets.
- Muon Detectors.
Tracking in Inner Detector

**Pixel Detectors** - The silicon sensors closest to the collision point. (Resolution: $\sigma_{\phi}=12\ \mu m$, $\sigma_{z}=66\ \mu m$)

**Strip Detectors** – The additional layers of silicon narrow strips. Additional position measurements (5cm<radii<50cm)  
Resolution: $\sigma_{\phi}=16\ \mu m$, $\sigma_{z}=580\ \mu m$

**Transition Radiation Tracker (TRT)** - Gas-wire drift detectors that consist of 4mm-diameter tubes (straws like) with thin wires running through the tube centers. (50<radii<100 cm)  
Resolution: $\sigma=170\ \mu m$ per straw.

- The silicon pixel and strip detectors - 10 azimuthal position measurements ($\sigma \sim 10 - 20$ microns.)
- The TRT - 36 azimuthal position measurements, ($\sigma \sim 150$ microns each).
- The directions, momenta and charge corresponding to all the trajectories, can be determine.
Muon Spectrometer

- The momentum of the muons is determined from the curvatures of their tracks in a toroidal magnetic field.
- Muon tracks are identified and measured after their passage through ~2m of material.

Track measurement with $\sigma=60\mu$m intrinsic resolution in three precision measurement stations (MDT).
Atlas Trigger

- The information of one event is approximately 1MB.
- Block diagram shows a simplified functional view of the Trigger system.
- The goal of the first level trigger is to select from $10^9$ to $75 \times 10^6$ events within the time interval of the 25 nsec.

Interaction rate $\sim 1$GHz
Bunch crossing rate 40 MHz (25 nsec)

First level trigger
Events rate $\sim 75$ kHz

Second level trigger
Events rate $\sim 2$ kHz

Third level trigger
Events rate $\sim 200$ Hz
**Trigger System**

- The first level muon trigger is derived from three trigger stations formed of Resistive Plate Chambers (RPC) in the barrel and Thin Gap Chambers (TGC) in the end-caps.
- Each station is made of 2 (or 3) planes of strips (or/and wires) with x or y readout.
- The trigger is based on a coincidence between a strip(or wire) hit in the 1\textsuperscript{st} station and a range of strips(or wires) in the 2\textsuperscript{nd} or 3\textsuperscript{rd} station. Typical momentum resolution is 20%.
- Low $p_T$ trigger: $p_\mu > 6\text{GeV}$
- High $p_T$ trigger: $p_\mu > 20\text{GeV}$.
Cross Sections \((g+g \rightarrow J/\Psi + g)\)

The prompt \(J/\Psi\) direct production using 3 different parton distribution functions. CTEQ3L-Green CTEQ5L-Red CTEQ6M-Blue

- Trigger efficiency (low luminosity) to select \(pp \rightarrow J/\Psi \rightarrow \mu(6\text{GeV})\mu(3\text{GeV})\) is \(~10\%\)
- Reconstruction algorithm efficiency \(~60\%\)
- First year run \(~100\) days

\[10^{33}[\text{bar}^{-1}\text{sec}^{-1}] \cdot 10^{-24}[\text{particles}/\text{cm}^2] \cdot 10^{-8}[\text{bar}] \cdot 10^7[\text{sec/ run _ year}] = 10^8[\text{events/ year}]\]

\[10^8[\text{events/ year}] \times 0.1 \times 0.6 \approx 6 \times 10^6[\text{events/ year}]\]

After one year we expect 6 million events of \(pp \rightarrow J/\Psi \rightarrow \mu^{-}\mu^{+}\)
Background

The main background for our process is \( pp \rightarrow B \rightarrow J/\Psi + X \). The cross-section for this process is:

\[
\sigma(pp \rightarrow B \rightarrow J/\Psi \rightarrow \mu(6\text{GeV}) + \mu(3\text{GeV})) \approx 10^{-2}\mu\text{b}.
\]
Monte Carlo Study

- Generation was done with Pythia 6.221
- Parton distribution function - CTEQ6M
- The Octet model was implemented in Pythia 6.221 software (adding two extra differential cross-sections for the process $pp \rightarrow J/\Psi + X$ corresponding to the colored $^3S_1$ and $^1S_0 + ^3P_0$ states)
- Di-muon filter on $P_T$ of more than 3 and 6 GeV was applied in the event production.
- All the generated events were processed with Geant-4 Simulation, Digitization, Reconstruction and “My Analysis” algorithms.
- We are currently moving to new Pythia 6.326 version
New Pythia versions

- Implementation of Non Relativistic QCD model (NRQCD) original code (by Stefan Wolf) within the new PYTHIA versions.
  - This PYTHIA implementation was already in use via external code in our previous studies.
  - PYTHIA 6.326 enables a full **charmonia** and **bottomonia** production.
  - The new PYTHIA code is under validation;
  - Realistic parameter values (e.g. NRQCD MEs) have to be fixed.

- The default parameters are incorrect:
New Corresponding Matrix elements

- 10 new values for NRQCD matrix elements inserted based on values extracted from: hep-ph/0003142

| PARP(141) | \(\langle O^{J/\psi}[^3S_1^{(1)}] \rangle\) | 1.16 |
| PARP(142) | \(\langle O^{J/\psi}[^3S_1^{(8)}] \rangle\) | 0.0119 |
| PARP(143) | \(\langle O^{J/\psi}[^1S_0^{(8)}] \rangle\) | 0.01 |
| PARP(144) | \(\langle O^{J/\psi}[^3P_0^{(8)}]/m_c^2 \rangle\) | 0.01 |
| PARP(145) | \(\langle O^{X_{c0}}[^3P_0^{(1)}]/m_c^2 \rangle\) | 0.05 |
| PARP(146) | \(\langle O^{Y}[^3S_1^{(1)}] \rangle\) | 9.28 |
| PARP(147) | \(\langle O^{Y}[^3S_1^{(8)}] \rangle\) | 0.15 |
| PARP(148) | \(\langle O^{Y}[^1S_0^{(8)}] \rangle\) | 0.02 |
| PARP(149) | \(\langle O^{Y}[^3P_0^{(8)}]/m_b^2 \rangle\) | 0.48 |
| PARP(150) | \(\langle O^{X_{b0}}[^3P_0^{(1)}]/m_b^2 \rangle\) | 0.09 |
Events Kinematics

Normalized to the total number of events

In Blue Pythia version 6.323 with external Color Octet implementation (11.0.4)

In Red Pythia version 6.326 (11.5.0)

Pseudorapidity distribution
Selection of $J/\Psi$ to Muon pair

- To properly select $J/\Psi$ events, pairs of differently charged muons are chosen.
Selection II

- The selection is based on the dimuon invariant mass reconstruction.

In the tails of the J/Ψ Invariant Mass histogram there are only 5% of the total number of events.

Mass resolution \( \sigma(M_{2\mu}) = 43 \text{MeV} \)
**bb̄ events rejection (proper-time cut)**

- The displacement of the two-track vertex from the beam line will be used to distinguish between prompt $J/\Psi$ or from B-hadron decays.

![Diagram](image)

- $g+g \rightarrow J/\Psi$
- $pp \rightarrow J/\Psi + X$
- $pp \rightarrow bb \rightarrow J/\Psi + X$

**Zoom and Log scale on Y axis**

Proper time Resolution 0.1 ps
Efficiency and Purity of the proper-time cut

- Selecting events with proper time less than 0.3 ps results in efficiency of 26% and contamination from $b\bar{b} \rightarrow J/\Psi$ at a level of 25%.
General method of polarization measurement

- Polarizations can be measured using the angular distribution of the daughter particles produced in the particle decay.
- The decay angle is called $\theta^*$ and is defined to lie between the direction of muon plus in the $J/\Psi$ rest frame and the $J/\Psi$ direction in the lab frame.

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

The polarization parameter $\alpha$, defined as $\alpha = \frac{\sigma_T + 2 \sigma_L}{\sigma_T - 2 \sigma_L}$, is equal to +1 for transversely polarized production, where transverse polarization refers to helicity $\pm 1$. For longitudinal (helicity 0) polarization $\alpha$ is equal to -1. Unpolarized production consists of equal fractions of helicity states +1, 0 and -1, and corresponds to $\alpha = 0$. 
Polarization measurement

- J/Ψ polarizations can be measured applying appropriate fit to the angular distribution of the muons produced in its decay.

The plan is to apply the study in several ranges (bins) of J/Ψ transverse momentum.
Summary

- A simulation study of direct production of J/ψ in the ATLAS low luminosity runs is shown.
- Although ATLAS is designed to probe the O(1 TeV) scale, it can still make some useful measurements in the heavy quarks physics sector.
- The J/ψ ->di-muons will be one of the main channels in the analysis of the early data to be collected in the experiment.
- The clear signature of this channel enables using it for calibration and alignment of the tracking detectors and algorithms.
- The J/ψ directly produced at PP collisions will be a main source of background to J/ψ produced in B hadrons which is a key channel in the B Physics program.
- CDF Run-I and Run-II measurements show some discrepancy between the polarization $P_T$ dependence in the data and theoretical predictions.
- It is shown that ATLAS can improve the precision of this measurement.
END
New Parameters: the NRQCD matrix elements

NRQCD requires INDIPENDENT matrix elements:

\[ \left\langle O^H \left[ 2S+1L_J^{(C)} \right] \right\rangle \]

to denote the probability that a \( Q \bar{Q} \) pair in a state \( 2S+1L_J^{(C)} \) build up the bound state H.

These matrix elements fulfill the relation due to heavy quark spin symmetry:

\[
\begin{align*}
\left\langle O^{J/\psi} \left[ ^3S_1^{(1)} \right] \right\rangle &= \frac{3Nc}{2\pi} |R(0)|^2, \\
\left\langle O^{\chi_c} \left[ ^3P_0^{(1)} \right] \right\rangle &= \frac{3Nc}{2\pi} |R'(0)|^2.
\end{align*}
\]

\[
\begin{align*}
\left\langle O^{\chi_c} \left[ ^3P_8^{(1)} \right] \right\rangle &= (2J+1) \left\langle O^{J/\psi} \left[ ^3P_0^{(8)} \right] \right\rangle, \\
\left\langle O^{\chi_c} \left[ ^3P_1^{(1)} \right] \right\rangle &= (2J+1) \left\langle O^{\chi_c} \left[ ^3P_0^{(1)} \right] \right\rangle.
\end{align*}
\]