Primi risultati di fisica dei sapori pesanti a CMS

Roberto Covarelli – University of Rochester
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Heavy flavors at $pp$ colliders

- Tests of perturbative QCD
  - Heavy flavor production theories at NLO with logarithm resummation (FONLL)

- Fragmentation functions
- In the case of $c\bar{c}$ or $b\bar{b}$ states (low relative velocity of the bound quarks), test NRQCD approaches

- Find indirect hints of NP in rare weak decays, e.g.:
  - Non-SM CP violation in $B_s \rightarrow J/\psi\phi$
  - Probe MSSM and other 2HD models with $BR(B_s \rightarrow \mu\mu)$
The CMS detector

Analyses shown are based on 2010 dataset
Same luminosity collected in 2011 in a few days of running!
Muon reconstruction and triggers

- **Large rapidity coverage:**
  - $|\eta| < 2.4$

- **Excellent muon momentum resolution** down to very low $p_T$:
  - matching between $\mu$-chambers and in silicon tracker (only using the latter for momentum determination at low $p_T$)
  - strong solenoidal magnetic field (3.8 T)

- **Triggers** could be tuned to the rapidly increasing luminosity, thanks to the great versatility of the High-Level Trigger
  - Single muon triggers
  - Double muon triggers at Level-1 only
  - *Ad-hoc* intermediate solutions:
    - after a single muon is triggered, look for another track and check compatibility with a defined invariant mass region (e.g. $J/\psi$, Y’s)
    - use single muon at HLT, but with a double muon Level-1 “seed”
  - Double muon HLT with additional requirements
Muon efficiency measurements

All heavy flavor analyses use data-driven measurements of the muon efficiency ("tag-and-probe" method)

- In events with a $J/\psi$ candidate, ask for one well-identified muon ("tag")
- The other muon ("probe") can pass or not pass the selection $S$ under investigation
- Invariant mass plots separate for the two cases
- The fitted $N_{\text{pass-}S}/N_{\text{all}}$ gives an unbiased estimate of the efficiency $\varepsilon_S$

Limitations of the method:
- Assumes efficiency factorization: does not take into account physical correlations
- Requires averaging over large bins due to limited statistics: distortion of di-muon efficiencies

MC corrections required
CMS heavy-flavor results

- Published or accepted in journals:
  - Prompt and non-prompt $J/\psi$ differential cross-section
  - $Y$ cross-section and $\sigma[Y(2S)] + \sigma[Y(3s)] / \sigma[Y(1S)]$ ratio
  - Production cross-section of $B^\pm$ and $B^0$ mesons
  - Inclusive $b$-hadron production with muons
  - $b\bar{b}$ angular correlation based on secondary vertex reconstruction

- Preliminary:
  - $X(3872) / \psi(2S)$ cross-section ratio
  - Production cross-section of $B_s$ mesons
  - Inclusive $b\bar{b}$ production with $b$-tagged jets

- Other studies ongoing:
  - $J/\psi$ polarization, $\chi_{cJ}$ production, $\Lambda_b \rightarrow J/\psi \Lambda$ ... and many more
J/ψ and Y cross-sections

- Double L1-trigger stream
- Signal selection based on:
  - Global muon quality
  - Muon track quality ($\chi^2$, $n_{\text{hits}}$...)
  - Di-muon vertexing probability
  - Muon $p_T$ (for Y only)
- Acceptance is determined using simulation in five benchmark polarization scenarios
- Muon efficiencies from tag-and-probe method
- Yields from invariant mass fits

arXiv: 1011.4193, accepted by EPJC
arXiv: 1012.5545, accepted by PRD
Prompt / non-prompt J/ψ

- In the case of J/ψ, a 2-dimensional fit to invariant mass and proper decay time of the dimuon yields the fraction of J/ψ from B decays.
- MPV of proper decay time is given by $l_{J/ψ} = L_{xy} \frac{m_{J/ψ}}{p_T}$, where

$$L_{xy} = \frac{u^T \sigma^{-1} x}{u^T \sigma^{-1} u}$$

$u$ = unit vector of $p_T$

$x$ = vector joining the dimuon and primary vertices

$\sigma$ = sum of covariance matrices

- Main systematics from:
  - Misalignment
  - Primary vertex uncertainties
  - $l_{J/ψ}$ resolution function

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J/ψ and Y cross-section results

- $B \to J/\psi$
  - Very good agreement with FONLL theory down to low $p_T$

- Prompt quarkonia
  - Pythia (Leading Order / Color Singlet + Color Octet model) gives reasonable agreement in shape, not in normalization $\Rightarrow$ waiting for exact calculation including $\chi_c$, $\psi(2S) \to J/\psi$
  - All models (including $k_T$ factorization, Color Evaporation) underestimate $J/\psi$ cross-section at low $p_T$
Inclusive $b \rightarrow \mu$

- Technique: after selecting a muon + jet signature, discriminate $b$ from light jets using the relative transverse momentum of the muon w.r.t. the jet thrust axis

- Selection:
  - HLT muon with $p_T > 3$ GeV/c
  - Offline $p_T > 6$ GeV/c and muon quality cuts from $W \rightarrow \mu\nu$ selection (except isolation)
  - $E_T$(jet) (excluding muon) $> 1$ GeV

- From MC simulation:
  - Template functions for light and $b$ jets
  - Muon acceptance

arXiv:1101.3512, accepted by JHEP
Inclusive $b \to \mu :$ results

- Differential cross-sections in $p_T$ or rapidity
- Main systematics:
  - $b$ and light jets MC templates (2-20%)  
  - Luminosity (11%)
- Reasonable agreement with MC@NLO within uncertainties
- Pythia failing both in shape and normalization (predicted cross-section almost double than measured)

$$\sigma(pp \to b + X \to \mu + X') = 1.32 \pm 0.01 \text{(stat)} \pm 0.30 \text{(syst)} \pm 0.15 \text{(lumi)} \mu b,$$

$p_T > 6 \text{ GeV}, |\eta| < 2.1$
B-meson cross-sections

- Using exclusive decays $B^\pm \rightarrow J/\psi K^\pm$, $B^0 \rightarrow J/\psi K_s$, $B_s \rightarrow J/\psi \phi$
- $J/\psi$ selection as in previous studies
- Track selection with quality criteria plus:
  - $K^\pm$: $p_T > 0.9$ GeV/c
  - $K_s$: two tracks with $V^o \ (l_{xy} / \sigma_{l_{xy}} > 5)$ and invariant mass requirements
  - $\phi$: two tracks with invariant mass requirements
- Secondary vertex fitting with all tracks and muons and $P(\chi^2)$ cut
- Additional signal-background discrimination from proper decay time

[Graphs showing data and fits]

arXiv:1104.2892, accepted by PRL
PAPER-BPH-10-013, in progress

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B-meson results

- Differential cross-sections in $p_T$ or rapidity
- Main systematics:
  - Pion/kaon tracking efficiency uncertainty ($\sim 4\%$ per track from $D^0 \rightarrow K\pi$ vs $D^0 \rightarrow K\pi$ yield ratio)
  - Luminosity (4%)
- Inclusive results confirmed:
  - Quite good agreement with MC@NLO
  - Pythia failing both in shape and normalization (here with tune “Z2”, i.e. improved MPI description)
Brand new stuff...

• Presented by CMS at the Vienna quarkonium workshop last week
  • First measurement of the $X(3872) / \psi'$ [cross-section x BR] ratio at 7 TeV
    \[ R = 0.087 \pm 0.017 \text{(stat.)} \pm 0.009 \text{(syst.)}, \]
  • Separation of $\chi_{c1} / \chi_{c2}$ states using the $J/\psi \gamma (\gamma \rightarrow e^+e^-)$ final state using a novel tracker-based method to reconstruct very low energy conversions
Conclusion and prospects

• Several production cross-section and related measurements in the field of heavy-flavor physics have already been released by CMS on the 2010 dataset (≤ 40 pb⁻¹), in a large phase space that complements LHCb measurements
  • proving detector excellence in trigger capabilities, tracking and muon reconstruction
  • discriminating between QCD models (both in perturbative and NR regimes) and their implementation in MC generators
• Next steps are high-statistics measurements, including:
  • Quarkonium polarization
  • Neutral-B (B⁰, B_s) CP violation and rare decays
• Keeping up the pace with LHCb results is a challenge
  • Low p_T reach not competitive, but no luminosity leveling in CMS
  • Smart triggering techniques are the essential ingredient