Production measurements at LHCb with the first data

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Meeting of the Division of Particle and Fields of the American Physical Society
Detroit 26-31 July 2009

Outline

1. Introduction
2. Inclusive productions
   - V0
   - D-mesons
   - J/ψ
3. Other measurements with early data
4. Conclusions

LHCb detector

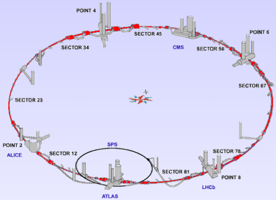
LHCb @ DPF09

- Eddy Jans - LHCb Detector status
- Marc-Olivier Bettler - LHCb prospects for rare decays
- Steven R. Blusk - LHCb prospects for new physics in CPV

The LHCb experiment

LHC

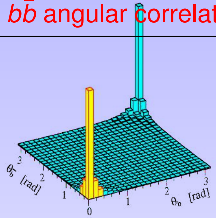
- p-p collisions at 14 TeV
- Large b-quark production in the forward region
- Full b-hadrons spectrum

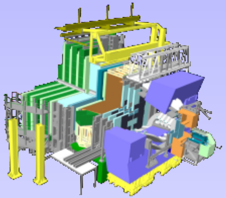


Studies

- CP Violation
- CKM matrix tests
- Rare decays

$b\bar{b}$ angular correlation





LHCb detector

LHCb

Specialized B-physics experiment
Forward single arm spectrometer
Acceptance: 15-300(250) mrad
$\mathcal{L} = 2 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1} \quad \Rightarrow \quad 10^{12}\ b\bar{b}$ pairs per year

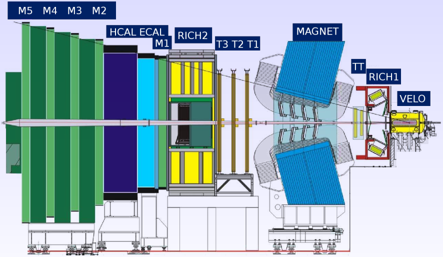
LHCb detector: performance

Vertex Measurement

$\sigma(z) \sim 50[150]\ \mu$m for the Primary [Secondary] Vertices
$\sigma(IP) \sim 14 + 35/p_T(\mathrm{GeV})\ \mu$m
$\sigma(t) \sim 40$ fs on b-hadrons decay times

Energy measurement

$\sigma_E/E \simeq 9\%/\sqrt{E} \oplus 0.8\%$ (ECAL)
$\sigma_E/E \simeq 69\%/\sqrt{E} \oplus 9\%$ (HCAL)



Tracking

$\varepsilon = 95\%$ for $p > 5$ GeV
$\sigma(p)/p \sim 0.4\%$
σ(b-hadrons mass) ~ 14 MeV

Particle Identification

$\varepsilon(K) \sim 95\%$ at 5% of π/K mis-id.
$\varepsilon(\mu) \sim 93\%$ at 1% of π, K/μ mis-id.

Trigger

L0 hardware: 40 MHz $\Rightarrow$ 1 MHz
$\rightarrow$ Information from Muon Stations, Calorimeters and VELO
$\rightarrow$ High p_T e, μ, γ

HLT High Level Trigger: 1 MHz $\Rightarrow$ 2 kHz
$\rightarrow$ software
$\rightarrow$ full detector information

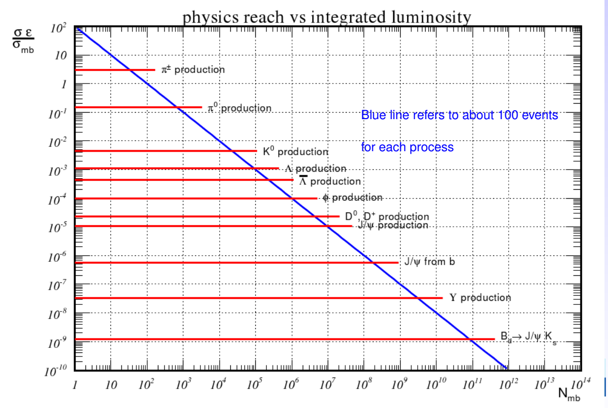
Physics with minimum bias

2009/2010 run conditions:

- Energy $\sqrt{s} \sim 8 - 10$ TeV
- Luminosity $\mathcal{L} \sim 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (optimum for LHCb)
- Up to 432 bunches filled

Start of full LHCb physics program already in 2009/2010.

A lot of interesting physics will be feasible with very first data
Inelastic minimum bias cross section $\sigma_{mb} \sim 80$ mb
$\Rightarrow 10^8$ events already during first days.



Motivation for V0 studies: theory

Hadronization is not well understood: at present different phenomenological models are available but no theory can describe this process consistently.

At hadron colliders the production of strange quarks, due to their absence in the valence quarks of initial state, can probe the hadronization process.

Few families of phenomenological models can reproduce the fragmentation into strange hadrons and explain phenomena and distributions.

Within Monte Carlo event simulators (e.g. PYTHIA) different tunings are available: although they do agree at Tevatron energies, there are divergences in the extrapolation at the LHC energies.

Measurements at these energies will help in discerning between different models.

Motivation for V0 studies: experiment

There are also experimental motivations that justify V0 production studies:

- Minimal requirements for the detector: just VELO and tracker
- Simple minimum bias trigger
- Momentum calibration cross-checks with the mass distributions
- No particle identification required: RICH calibration
- Monte Carlo detector description tuning
- Preparation for subsequent more complex analysis (e.g. $B_d \to J/\psi K_S$)

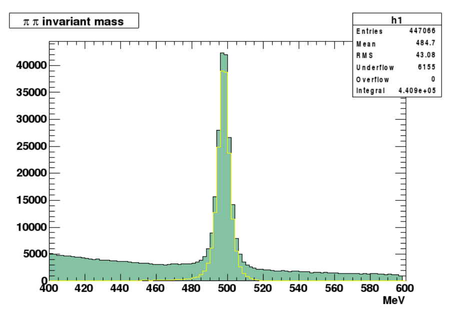
V0 analysis

- Studied channels: $K_S \to \pi^+\pi^-$, $\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$
- Studied a sample of 10^7 minimum bias events (Monte Carlo 2006 production).
- Events with just one primary vertex
- Simple analysis: two opposite charge tracks.
- Initially just *long* tracks (hits along the whole tracker and VELO).
- No particle identification requirements: analysis based on geometry and kinematics.

Selection: K_S

Simple cut based analysis relying on few variables:

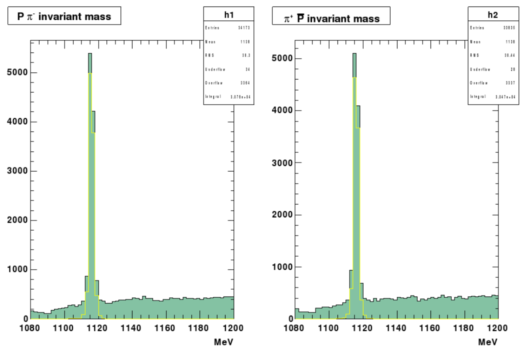
- Cut on proper time: $c\tau > 4$ mm
- Distance of Closest Approach between the two tracks: DOCA < 0.2 mm



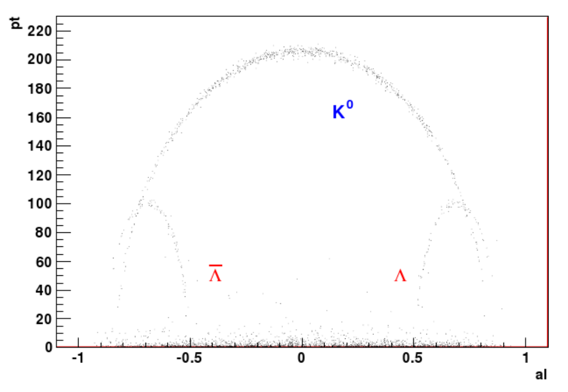
Selection: Λ

Same cuts as K_S plus:

- impact parameter of the mother ($IP < 0.1$ mm)



Armenteros-Podolanski plot



p_t with respect to the mother

$\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$ (longitudinal momentum asymmetry)

Kinematic particle identification: unbiased π and p sample for PID (RICH) calibration.

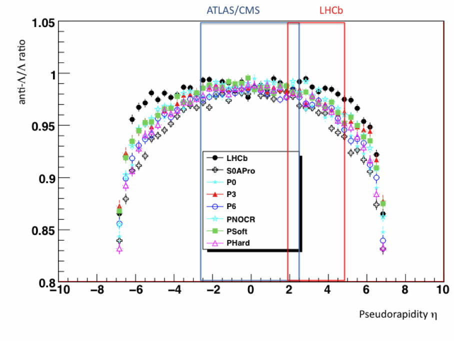
V0 measurements: production

Production measured in p_T and η bins.
Background subtraction with mass distribution sidebands fit
Measurements with 10^8 minimum bias events:

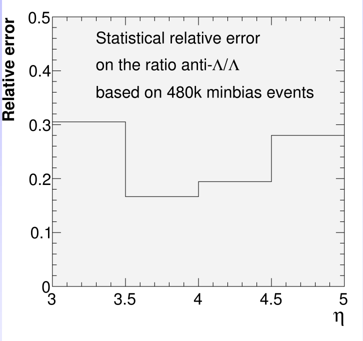
- Around $2 \cdot 10^6$ K_S reconstructed
- Around 10^5 Λ and $\bar{\Lambda}$
- Baryon anti-baryon asymmetries (next slide)
- RICH calibration

V0 measurements: $\bar{\Lambda}/\Lambda$ ratio

- Provides discrimination between hadronization processes[1]
- Largest sensitivity in the LHCb (forward) region



(a) $\bar{\Lambda}/\Lambda$ ratio for different "Perugia" tunings



(b) $\bar{\Lambda}/\Lambda$ ratio relative error

Expected statistical error at 10^8 minimum bias events $\sim 1.5\%$
$\Rightarrow$ Discrimination between different models

[1] See also: P. Skands, arXiv/hep-ph:0905.3418

D-mesons selection

Early studies on D-mesons production will be made, looking for charm signals in first minimum bias events, by means of the decays:
$D^0 \to K^- \pi^+$ and $D^+ \to K^- \pi^+ \pi^+$ plus charge conjugate modes.

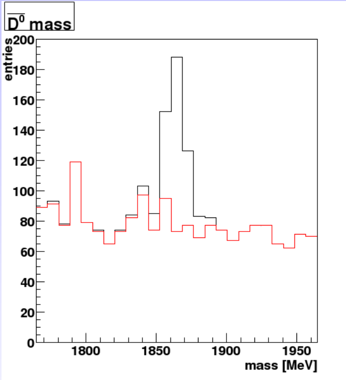
Analysis strategy is similar to V0 analysis

- Detector minimal requirements (VELO and Tracker)
- No particle identification
- Only geometric and kinematic variables (no significances)
- Particle ratios: systematics cancel out

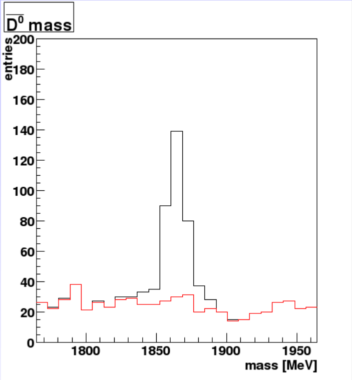
Moreover:
Exploitation of Multivariate analysis methods to reduce background: in particular the rule-based RIPPER algorithm

Example: $\bar{D} \rightarrow K^{+}\pi^{-}$

Analysis on 9.5 M minimum bias events



(c) Cut-based analysis



(d) MVA method

MVA-methods reduced background by a factor $\sim$ 3 with respect to cut based.

Expected sensitivities on D signals

From a sample of $9.5 \cdot 10^6$ (Monte Carlo) minimum bias events
an average of about 200 events for each species was extracted.

For the expected analysis sample of 10^8 minimum bias events around 2000 for each species are foreseen;
in the sensitivity region ($p_T < 12$ GeV and $2 < y < 4.5$),
the expected errors on particle ratios are:

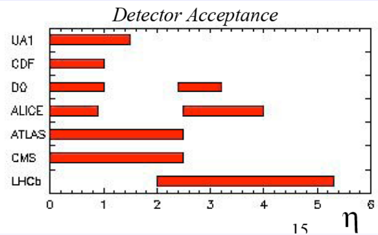
- $\sigma(\frac{\bar{D}^0}{D^0}) = 5\%$
- $\sigma(\frac{D^-}{D^+}) = 6\%$

J/ψ production

J/ψ prompt production not completely understood:
NRQCD (Colour Octet Model) is able to reproduce the p_T spectrum measured at Tevatron, but not the production polarization (predicting an increasing with p_T not observed).
Other models also predict same p_T spectrum but no polarization.
Hence cross-section and polarization measurements are important to understand charmonium production.

Given the big cross-section of J/ψ production and the unique LHCb coverage, large data samples will be available already in the first days of LHC running.

At the same time also J/ψ from $b\bar{b}$ production will be measured.



J/ψ selection

Decay studied: $J/\psi \rightarrow \mu^+\mu^-$

- Muon trigger
- Two *long* tracks with hit in the muon stations and $\chi^2_{track} < 5$
- One muon with $p_T > 1.5$ GeV
- One muon with tight PID: $\Delta ln(L(\mu, \pi) > -1$, L = identification likelihood, ($\varepsilon_\mu \sim 90\%$, $\varepsilon_\pi \sim 1.4\%$)
- Good J/ψ vertex with reduced $\chi^2 < 6$

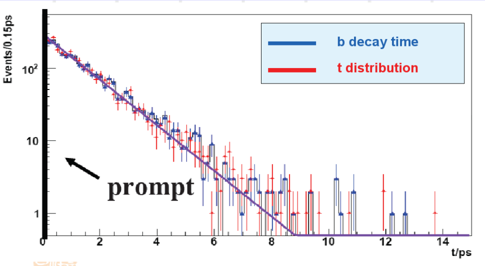
Prompt J/ψ and J/ψ from b

Expected 8% J/ψ to come from b decays.

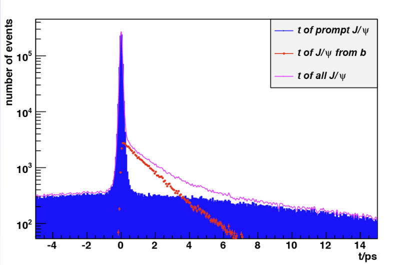
Use of the discriminant variable: $t = \frac{z_{J/\psi} - z_{PV}}{p_z^{J/\psi}} \cdot m_{J/\psi}$

From studies at generator level t is known to be a good approximation of b-quark lifetime.

Different component contribute: tail of prompt J/ψ comes from wrong PV assignment.



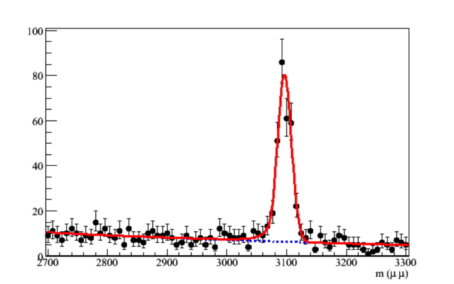
(e) Generator level



(f) t distribution: different components

J/ψ measurement

Using the first $5pb^{-1}$ of integrated luminosity at $\sqrt{s} = 8$ TeV
3 M reconstructed J/ψ are expected.
The event counting will be made in η and p_T bins.
The mass distribution will be used to fit the number of reconstructed J/ψ



Plot using 19 M minimum bias events (or ~ seconds of running at nominal luminosity)
Mass resolution $\sigma_M \sim 11$ MeV

The $b \to J/\psi$ component will be estimated by fitting the t distribution.
To estimate the cross-section:

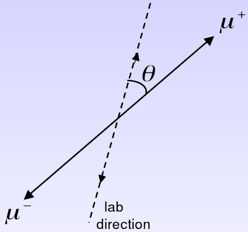
- Need to measure the integrated luminosity
- Correct for η and p_T efficiencies using Monte Carlo data

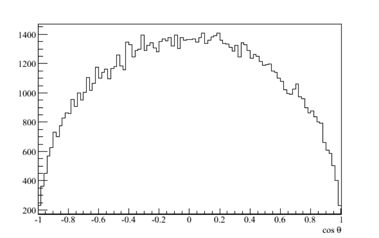
J/ψ polarization

θ is the angle between μ^+ momentum in CM frame and J/ψ momentum in the lab frame

Polarization: $\frac{dN}{dcos(\theta)} \propto 1 + \alpha \cos^2(\theta)$ in the helicity frame

$$\begin{cases} \alpha = 1 \text{ transverse polarization} \\ \alpha = -1 \text{ longitudinal polarization} \\ \alpha = 0 \text{ no polarization} \end{cases}$$





(g) MC events with no polarization, after reconstruction in LHCb

Input α	Input σ	Measured σ ($\alpha = 0$)
0	4340 nb	(4337.3 ± 7.7) nb
1	4909 nb	(4305.4 ± 7.7) nb
-1	3518 nb	(4383.0 ± 7.9) nb

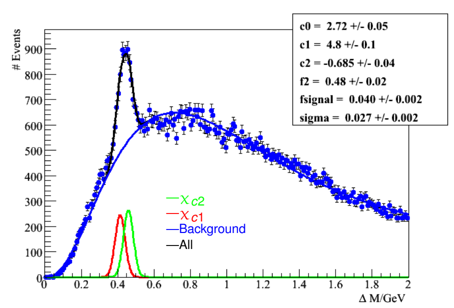
LHCb geometry and L0 Trigger efficiency will induce a fake J/ψ polarization.

Polarization to be taken into account for σ measurement.

χ_c production

From Tevatron measurements $\sim 30\%$ of J/ψ are known to come from:
$\chi_{c(1,2)} \to J/\psi\gamma$
This production has to be taken into account for polarization measurements
Moreover the relative ratio $R_{\chi_c} = \sigma(\chi_1)/\sigma(\chi_2)$ is important to distinguish different production models.

Selection:
A photon with $p_T > 500$ MeV is combined with a J/ψ selected as before (restricted to a ± 40 MeV mass window)
$\Delta M = M_{\mu\mu\gamma} - M_{\mu\mu}$ distribution is fitted to extract the χ_{c1} and χ_{c2} signals using 2 gaussians and a background component:
$P(\Delta M) = \Delta M^{c_0} \cdot \exp(-c_1 \cdot \Delta M - c_2 \cdot \Delta M^2)$
$\sigma(\Delta M) \sim 27$ MeV
$m(\chi_{c2}) - m(\chi_{c1}) = 46$ MeV
$\Rightarrow$ limited separation but some sensitivity.



(h) Signal in inclusive J/ψ

Other quarkonia measurements

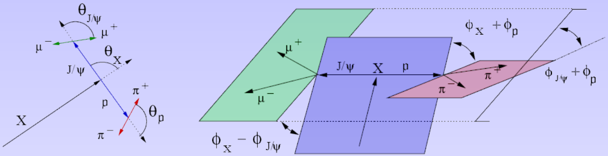
- Measurement of the production and polarization of $\psi(2S)$ and in particular of the $\sigma(\psi(2S))/\sigma(J/\psi)$ ratio
- Bottomonium production and spectroscopy: $\Upsilon(1S, 2S, 3P)$, $\chi_b \rightarrow \Upsilon\gamma$
- exotic X, Y, Z states

$X(3872) \to J/\psi\pi^+\pi^-$

Charmonium-like state

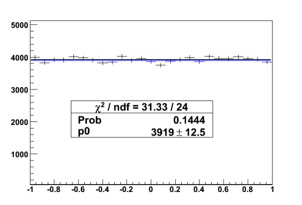
Either from $B \to X(3872)K$ or prompt production

$J^{PC} = 1^{++}$ or 2^{-+} from CDF angular analysis

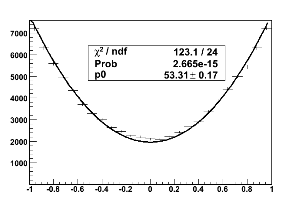


$\cos(\theta_X)$ not used at CDF: negligible information if X is not polarized

$\Rightarrow$ investigating the possibility to exploit $\cos(\theta_X)$ for X from B.



(i) $\cos(\theta_X)$ for $J^{PC} = 1^{++}$



(j) $\cos(\theta_X)$ for $J^{PC} = 2^{-+}$

Conclusions and outlook

LHCb will exploit very first minimum bias data
Monte Carlo tuning, PID calibration and tests of future analysis will be done while studying very interesting physics:

- Probe hadronization models through V0 production
- Study D-mesons production ratios with $\sim$ 5% error
- Study quarkonia spectroscopy and exotic resonances
- Measure J/ψ production and polarization

Backup slides

D data

Overall efficiencies:

- $\varepsilon(D^0) = 2.7 \cdot 10^{-3}$
- $\varepsilon(\bar{D}^0) = 3.2 \cdot 10^{-3}$
- $\varepsilon(D^+) = 6.0 \cdot 10^{-3}$
- $\varepsilon(D^-) = 8.1 \cdot 10^{-3}$

Main background contributions to D^0:

- 35% combinatorial
- 42% reflections ($\bar{D}^0$)
- 22% from other D or B decays

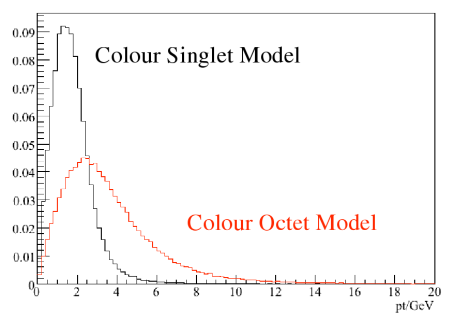
$D^0 \to K^-\pi^+$ and $\bar{D}^0 \to K^+\pi^-$ variables

Variables used for cuts or as input to MVA (without cutting).

- Long Tracks (VELO + Tracker)
- $p_T(D^0) > 700$ MeV
- $p_T(daughters) > 500$ MeV
- $\cos(\xi) < -0.7$ (angle between daughters IP vectors)
- Flight Lenght > 1.5 mm
- $DoCA < 0.07$ mm
- $\log \frac{DOCA}{FL} < -4.0$
- $IP(D^0) < 0.08$ mm
- $IP(daughters) > 0.05$ mm
- $\log(\frac{IP_K^2 + IP_\pi^2}{IP^2}) > 3.0$

J/ψ production

LHCb with Pythia 6.4 with Colour Octet Model
Model parameters tuned to reproduce CDF data



$\sigma(J/\psi\ prompt) = 3100$ nb
$\sigma(b \rightarrow J/\psi) = 240$ nb

Luminosity determination in LHCb

- Direct methods:
  - Beam-gas interaction in VELO
  - Van der Meer Scan (10% accuracy)
- Indirect estimation:
  - Z^0 and $W^\pm$ rapidity distribution fit (accuracy $\sim$ 1.6% in 100 pb^{-1})
  - Elastic di-muon production (accuracy $\sim$ 3% in 100 pb^{-1})