Studies of Semileptonic B Decays at LHCb

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Outline

• Semileptonic $B^0$ Decays:
  1. Theory & Motivation;
  2. $B^0 \rightarrow D^* \mu^+ \nu$ sample;
  3. Monte Carlo Studies;
  4. Conclusions

• Summary
Neutral B mixing and CP Violation

- Neutral B mesons: mass eigenstates are not flavour eigenstates \( \langle B_{L,H} \rangle = p \langle B_q \rangle = q \langle \overline{B}_q \rangle \);

\[
\text{Prob}(B^0; B^0(t)) = \Gamma^U(t) = e^{-\Gamma t} \frac{(1 + \cos \Delta m t)}{2}
\]

\[
\text{Prob}(B^0; \overline{B}^0(t)) = \Gamma^M(t) = e^{-\Gamma t} \left| \frac{p}{q} \right|^2 \frac{(1 - \cos \Delta m t)}{2}
\]

Current WA

\( \Delta m_d = (0.510 \pm 0.004) \text{ ps}^{-1} \)
Flavour specific asymmetries

$B^0 \rightarrow D^{*-} \mu^+ \nu$ is a flavour specific decay, we can compute

$$a_{fs} = \frac{\Gamma(\bar{B}^0 \rightarrow B^0 \rightarrow D^{*-} \mu^+ \nu_\mu) - \Gamma(B^0 \rightarrow \bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu)}{\Gamma(\bar{B}^0 \rightarrow B^0 \rightarrow D^{*-} \mu^+ \nu_\mu) + \Gamma(B^0 \rightarrow \bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu)}$$

$$a_{fs}^d = (-4.1 \pm 0.6) \times 10^{-4},$$

$$a_{fs}^s = + (1.9 \pm 0.3) \times 10^{-5}$$

Current WA $a_{fs} = (-0.03 \pm 0.20) \%$
We have 500k signal events with 2011 data, including also 2012 data (2M events in total) we get a statistical error on $\Delta m_d$ of 0.002 (half the error from the world average) and of 0.18% on $a_f$ (from the WA it is 0.20%).
Decay time

• For oscillation and CPV studies it is required to compute the decay time:

\[ t = \frac{m_B}{p_B} d = \frac{d^* m_B}{p_{D^* \mu}} k \]
\[ k = \frac{p_{D^* \mu}}{p_B} \]

where \( k \) is a correction due to the missing neutrino and is parameterized as a function of momentum and invariant mass of detectable particles

• \( k \)-factor can be computed from Monte Carlo but there are limitations due to:
  • Statistics;
  • Production mechanisms;
  • Decay dynamics;
  • Limited knowledge of processes that are indistinguishable from signal (e.g. \( B \rightarrow D^* \mu \nu X \));

What is the impact of all this? How can we put remedy to these limitations?
MC Studies

- The idea is to generate several sets of MC samples (~50M events each) with different parameterizations of poorly known quantities, in order to assess their impact on systematic uncertainties;
- Performing these studies on the Full Simulation would require excessive computing time. Therefore, we generate the decay of interest and simulate the detector response parametrically;
- We compare the parameterized Monte Carlo with the Full Monte Carlo Simulation. We must check the observables to be in good agreement with the Full Simulation.
Smearing

- We apply smearing, detection efficiencies and other corrections only to the signal particles. Given the kinematical range of the signal particles, we do not apply any momentum resolution;
- $B^0$ decay length;
- $z(B^0) - z(PV)$;
- $z(D^0) - z(B^0)$;
- Cuts on $IP_{PV}$, $p$, $p_T$;
- $\mu$ & $K$ simulated PID;
- Magnetic Field Effect;
- Trigger

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Resolutions from Full Simulation

![Graphs showing distributions for dReco-dTrue, z(B0)-z(PV), and z(D0)-z(B0)]

- **dReco-dTrue**
  - Entries: 229318
  - Mean: 0.002176
  - RMS: 0.04804

- **z(B0)-z(PV)**
  - Entries: 229318
  - Mean: 0.01068
  - RMS: 0.4989
  - Underflow: 4921
  - $\chi^2$/ndf: 388.1/141
  - Prob: 5.98e-25

- **z(D0)-z(B0)**
  - Entries: 229318
  - Mean: -0.008016
  - RMS: 0.6525
  - Underflow: 6541
  - $\chi^2$/ndf: 468.8/141
  - Prob: 8.086e-37

- Parameters:
  - p0: 60.5 ± 6046
  - p1: 0.0166 ± 0.2249
  - p2: 0.002732 ± 0.004991
  - p3: 0.0077 ± 0.2494
  - p4: 0.00338 ± 0.01079
  - p5: 0.0227 ± 0.5629
  - p6: 0.0127 ± 0.5073
  - p7: 0.01495 ± 0.03441
  - p8: 0.2 ± 1.5
PID efficiency from real data

The proton misidentification probability is smaller than 1% for all $p_T$ ranges and momentum above 3 GeV/c. It drops quickly with momentum for the lowest $p_T$ ranges, reaching a plateau at about 3.5 GeV/c. The pion and kaon misidentification probabilities have a similar behavior, increasing with decreasing $p_T$. Above 4 GeV/c, the pion misidentification probability is almost at the level of the proton misidentification probability. At low momentum, decays in flight are the dominant source of incorrect identification, as can be seen from the difference between the pion-kaon and proton curves. While the proton misidentification probability, within the $p_T$ intervals chosen, lies within 0.1-0.3, the pion and kaon misidentification probabilities are within

\begin{align*}
\text{Momentum [GeV/c]} & \quad \text{Efficiency} \\
0 \quad & 20 \quad 40 \quad 60 \quad 80 \quad 100 \\
0.8<p_T<1.7 & 1.0 \quad 1.05 \\
1.7<p_T<3.0 & 0.95 \quad 0.9 \\
3.0<p_T<5.0 & 0.9 \quad 0.85 \\
p_T>5.0 & 0.8 \quad 0.75
\end{align*}

Figure 5: IsMuon efficiency and misidentification probabilities as a function of momentum in ranges of transverse momentum: $\mu \rightarrow K \nu$, $\mu \rightarrow \pi \nu$, $K \rightarrow K$, $\pi \rightarrow K$.
Magnetic field effect

- The LHCb magnet has a bending power of 4Tm. Since $p(\text{GeV}) = 0.3B(\text{T})R(\text{m})$ we correct for the Lorentz force due to the magnet field (along the y axis) by giving a “kick” to $p_x$ of $\pm 1.2$ GeV;

- $(x,y)_{\mu,\pi,K,\pi^0}$ required to be in the active regions of tracking detectors;

- Same for $(x,y)_{\mu}$ with respect to muon stations
A parametric description of trigger lines is not straightforward. The reason is that information available in the Full Simulation are not accessible in parameterized Monte Carlo; therefore, we limit our studies to trigger lines which can be reproduced by simple cuts on signal particles;
k-factor matching

- **k_binM_3_binP_2_GLb**
  - Entries: 4415

- **k_binM_3_binP_5_GLb**
  - Entries: 1220

**Legend**:
- MC11 = yellow
- GL = red
Momentum distributions

B0 momentum

- **pBzero**
  - Entries: 244030
  - Mean: 1.188e+05
  - RMS: 7.751e+04

B0 transverse momentum

- **ptBzero**
  - Entries: 244030
  - Mean: 8098
  - RMS: 4497

MC11 = yellow
MC12 = green
GL = red

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MC11 = yellow
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theta slow pion

phi slow pion

eta slow pion

SlowPion momentum

SlowPion transverse momentum

Entries 213129
Mean 0.09152
RMS 0.0524

Entries 213129
Mean 3.138
RMS 1.8

Entries 213129
Mean 3.25
RMS 0.598

Entries 213129
Mean 4529
RMS 3297

Entries 213129
Mean 327.4
RMS 189.5

MC11 = yellow
MC12 = green
GL = red
Conclusions

- Semileptonic B decays offer the highest statistical power;
- The fast simulation is very useful to study systematic uncertainties, however it needs more tuning (work in progress);
- In principle this could also be a very important tool for the whole collaboration, provided it is generalized;
Summary

• In my first year I worked on the development of a fast and simplified Monte Carlo;
• Status of my work was presented regularly at the Ferrara LHCb group, to the LHCb Simulation Working Group and to the Semileptonic Asymmetry Working Group;
• I also worked on the data acquisition system of a prototype for the LHCb Muon Detector to be installed after the second LHC long shutdown;
• In October I performed tests on the Front End electronics of the LHCb Muon Detector, to be concluded in December;
Other Activities

• I participated to the Hadron Collider Summer School in Goettingen, Germany where I gave a seminar talk about “Bayesian Inference”; to the Cabeo School in Ferrara about Physics beyond Standard Model and to a detector school in Legnaro (PD);

• I participated to the International Conference on B-Physics at Hadron Machines (Beauty) in Bologna;

• I attended three Particle Physics seminars at the Physics Department in Ferrara;

• I attended the LHCb Analysis&Software Week at CERN and will attend the next LHCb week in December
Backup Slides
Muon Detector Front-End Board Calibration
LHCB (muon) detector
A Multi Wire Proportional Chamber

• Gas detector (Ar, CO$_2$, CF$_4$);
• The signal can be read on:
  – Wire: anode $\rightarrow$ negative charge collection
  – Pad: cathode $\rightarrow$ positive charge collection
• LHCb MWPCs have both readings mode
  – FEBs for anodic (negative) reading [AN]
  – FEBs for cathodic (positive) reading [CP]
• For the short LHC upgrade it’s needed to test the spare FEBs ($\approx$ 800)
A Front-End Board of the Muon Detector

- Each Region (R1, R2, R3, R4) of MD has a different number of FEBs per MWPC;
- Each FEB has 16 channels;
- One FEB can be used in anodic or cathodic readings;
- One FEB is a PCB with three chips:
  - 2 CARIOCA:s: analog part (amplification and discrimination 8+8)
  - 1 DIALOG: digital part (logical combination of discriminated signal, internal counter for measuring the rate)
FEBs TEST: goal

1. Check if they are workable;
2. Measurement of the electronic noise
   – Dark Rate Threshold scan
   – Evaluation of the RMS
3. FEB Ranking;
4. Substitution of broken or noisy FEBs currently on the detector with the tested ones
FEBs test: setup

• a tester MWPC [M2R2] because it has the most complicated reading approach;
• 6AN + 8CP = 14FEBs connected to the tester;
• The tests were done only in the CP positions, because we just need the FEB to see a MWPC;
• Readout electronics;
• Power supply (HV $\rightarrow$ M2R2 and LV $\rightarrow$ FEB)
1) Tester MWPC

2) 4 FEBs (right side) connected to tester MWPC

3a) Readout electronics

3b) LV Power supply

4) PC for data acquisition
Data Acquisition

1) Threshold scan: for each threshold the dark rate is measured;
2) The mean and RMS of the Rate Distribution as a function of the threshold are evaluated;
3) As a reference we took the \(<\text{RMS}>\) of all Channels of all FEBs;
4) Then we evaluated the pull defined as:

\[ \text{pull}_i = \frac{\text{RMS}_i - \langle \text{RMS} \rangle}{\sigma_{\text{tot}}} \]
Data Analysis AN (315 FEBs)

• **STRATEGY**: in each FEB we evaluate the pull\_i (i=1,...,16) mean value and rank the FEBs in four categories:
  
  – A: very good (pull <= -0.30) → 30 FEBs = 10%
  – B: good (-0.30 > pull >= 0.15) → 241 FEBs = 76%
  – C: noisy (0.15 > pull >= 2.00) → 33 FEBs = 10%
  – D: very noisy (pull >= 2.00) → 11 FEBs = 4%
Data Analysis CP (301 FEBs)

• **STRATEGY**: in each FEB we evaluate the pull \( p_i \) (i=1,...,16) mean value and rank the FEBs in four categories:
  
  - A: very good \( (p_i \leq -0.30) \) \( \Rightarrow \) 59 FEBs = 20%
  - B: good \( (-0.30 > p_i \geq 0.15) \) \( \Rightarrow \) 141 FEBs = 47%
  - C: noisy \( (0.15 > p_i \geq 2.00) \) \( \Rightarrow \) 97 FEBs = 32%
  - D: very noisy \( (p_i \geq 2.00) \) \( \Rightarrow \) 4 FEBs = 1%
Conclusion

• 616 FEBs were tested;
• We studied the electronic noise and classified them;
• More than 70% of them can be considered good;
• We are aware that CP FEBs are more noisy;
• Residual FEBs will be tested in December 2013