LHCb material reduction impact

Greg Ciezarek,
on behalf of the LHCb collaboration

May 17, 2017
Detector material

- Keeping a low material budget essential for many aspects of performance
  - Track finding efficiency (+ charge asymmetry)
  - Mass resolution (especially electrons)
  - Vertex resolution
- LHCb design went through an extensive reoptimisation in 2003 to reduce detector material TDR
  - Too broad a topic, too early for Upgrade II detector
- Instead, will focus on one troublesome piece of material: VELO RF foil
What the VELO does

- VELO precisely measures the origin trajectories of tracks
  - Primary Vertex (PV) and secondary Vertex (SV) finding + position
  - Track Impact Parameter (IP)
  - Primary tool for background suppression
  - Directly measures physics quantities - lifetimes, missing PT for partial reconstruction
1. Introduction

The RF foil

- Thin, corrugated AlMg$_3$ foil
  - Separates VELO vacuum from primary LHC vacuum
  - Isolates sensors from RF pickup
- Introduces significant material in the worst possible place: right after the interaction point...
Improving RF foil

- RF foil is a huge engineering challenge
  - As thin as possible in a complicated structure, maintaining vacuum tightness
- Considerable work put into thinning methods, some gains for Upgrade I
  - This can only be pushed so far
- Discussions ongoing about alternatives: B. Niccolo, “Beyond the LHCb Phase-1 Upgrade”, Elba, May 2017
  - Most radical option: complete removal
  - Why do we want to do this?
What is combinatorial background

- First background in every heavy flavour measurement - random combinations mimicking the decay final state
- Tracks from PVs
  - Largest, but easiest to remove - impact parameter
  - Currently not a significant problem
- Tracks from mixtures of heavy flavour decays
  - $B\bar{B}$ and $D\bar{D}$ pairs
  - Separation based on geometry
  - Lifetime + boost means pairs are typically separated in $Z$
  - Currently this is the dominant component
To give a scale for the problem: all dimuons (left) vs $B_{(s)} \rightarrow \mu\mu$ (right)

Huge amount of background rejected

Difficult to properly study a background rejection this large...
Background rejection

• Typical selection variables, with **VELO quantities in bold**
  • Combinatorial background rejection dominated by VELO
  • Benefit several times from improved VELO resolution
  • (* isolation variables also depend on VELO resolution..)
How much worse do things get?

- In upgrade II, we go from a pileup of 1.4 (now) to $\sim 55(!)$
  - Multiple heavy flavour decays per event
- Prompt background vastly increases, but currently subdominant
  - Will this still be the case?
  - IP resolution (+ PV finding efficiency) crucial
- Needs detailed study
2. Combinatorial background

How much worse do things get?

- Overlapping heavy-flavour decays currently our main background
- Naive toy study:
  - PVs spread along Z
  - $B\bar{B}$ and $D\bar{D}$ pairs with exponential lifetimes
  - How many pairs decay with a $Z$ separation below 5mm?
- Overlapping heavy-flavour increases by a factor $\sim 3.5$ relative to signal
  - Before any improvement in VELO resolution
  - (Or timing...)
  - Tractable!
RF foil removal

- IP resolution at low PT dominated by multiple scattering before 2nd hit
  - Responsible for slope in plot
- Multiple scattering before 2nd hit dominated by RF foil
  - Significant improvement by removing RF foil

Total material: $25.01\% X_0$
Effect of RF foil removal

- Nearly doubles IP resolution at low PT!
- Similar improvements in other quantities - e.g. primary vertex resolution
- How to quantify impact on physics?
  - Combinatorial background relies on multiple quantities (→ detailed simulation) and large samples: not yet done
  - First, toy studies for a simpler case: missing PT resolution
Flight

- Measure $B$ decay, origin positions $\rightarrow B$ momentum vector should point back along this 'flight direction'
  - Can infer unreconstructed momentum transverse to flight direction ($p_\perp$)
- Construct “Corrected mass” variable $M_{corr} = \sqrt{p_{\perp}^2 + M_{reco}^2} + p_\perp$
  - Dates back to SLD: hep-ex/0202031v1
  - $M_{corr}$ resolution dominated by SV resolution
4. Impact on semileptonics

Vertex resolution in semileptonics

- As with IP resolution, RF foil removal significantly improves secondary vertex resolution (here averaged over PT)
- Use these resolutions to smear MC truth, explore effect on physics sensitivity
Toy measurement

- Template fit used to measure $B_s \rightarrow K^- \mu^+ \nu$ yield, and determine $|V_{ub}|$
  - Perfect resolution(left) vs current VELO (right)
- Generate toys for different RF foil thicknesses
- Signal and background yields kept constant
Impact on semileptons

- RF foil thickness has clear impact on sensitivity
- No RF foil gives 25% gain in effective luminosity from fit resolution alone
  - Increase in background rejection will result in larger gain
- See poster by Iwan Smith
PV association

- As discussed before, timing is needed for good PV association.
- Nonetheless, spatial resolution is important.
- Removing RF foil reduces the wrong association rate by \( \sim 30\% \).
- Needs to be studied together with timing performance.
Jet tagging

- IP resolution also key for b, c jet tagging
  - See talk by Oscar Augusto
RF foil has a highly non-trivial material distribution

We are particularly sensitive to getting this right in the simulation
  - Historically, one of the biggest problems in our simulation

Removing this helps limit our final systematics
Conclusion

- VELO resolution key for controlling backgrounds
- RF foil key limiting factor for VELO resolution
- We want to run without RF foil!
  - For equal background, 25% gain in effective luminosity for semileptonic decays
  - 30% reduction in wrong PV association
- Studies ongoing
  - We’d like to thank CERN RF and Vacuum groups