LHCb material reduction impact

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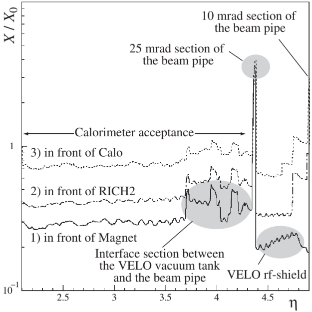
on behalf of the LHCb collaboration

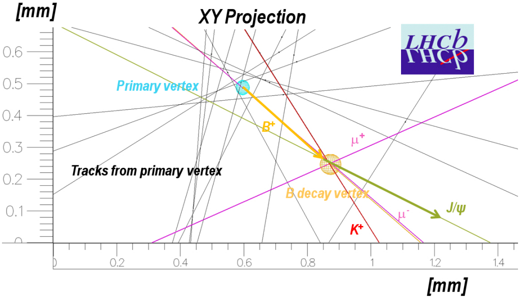
May 17, 2017

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

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

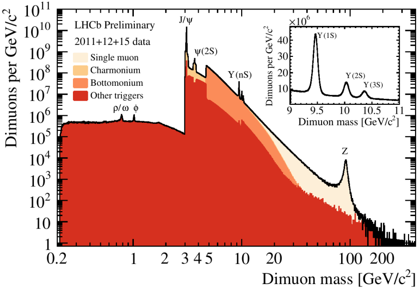
- RF foil is a huge engineering challenge
  - As thin as possible in a complicated structure, maintaining vacuum tightness
- Considerable work put into thinning methods, some gains for Upgrade I
  - This can only be pushed so far
- Discussions ongoing about alternatives: B. Niccolo, "Beyond the LHCb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

What is combinatorial background

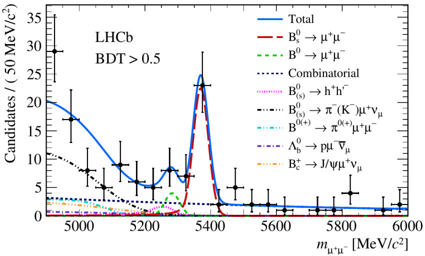
- First background in every heavy flavour measurement - random combinations mimicking the decay final state
- Tracks from PVs
  - Largest, but easiest to remove - impact parameter
  - Currently not a significant problem
- Tracks from mixtures of heavy flavour decays
  - $B\overline{B}$ and $D\overline{D}$ pairs
  - Separation based on geometry
  - Lifetime + boost means pairs are typically separated in Z
  - Currently this is the dominant component

Background rejection

CONF-2016-005

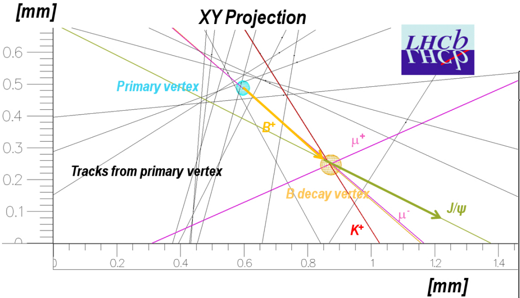


Phys. Rev. Lett. 118, 191801 (2017)



- To give a scale for the problem: all dimuons (left) vs $B_{(s)} \to \mu\mu$ (right)
- Huge amount of background rejected
- Difficult to properly study a background rejection this large...

Background rejection

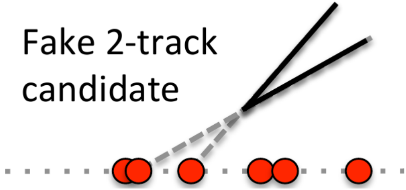


Typical MVA inputs:

Track IPCHI2
Track PT
B Vertex CHI2
PV separation CHI2
B pointing (CHI2)
Track PID
Isolation variables*

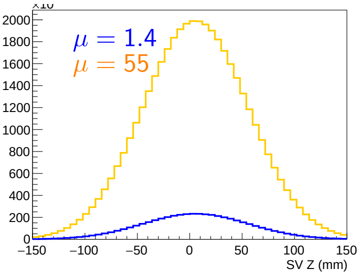
- Typical selection variables, with **VELO quantities in bold**
  - Combinatorial background rejection dominated by VELO
  - Benefit several times from improved VELO resolution
  - (* isolation variables also depend on VELO resolution..)

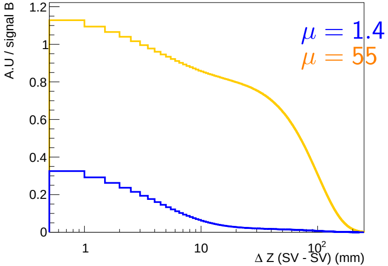
How much worse do things get?



- 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

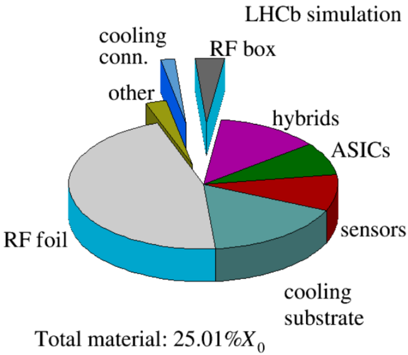
How much worse do things get?





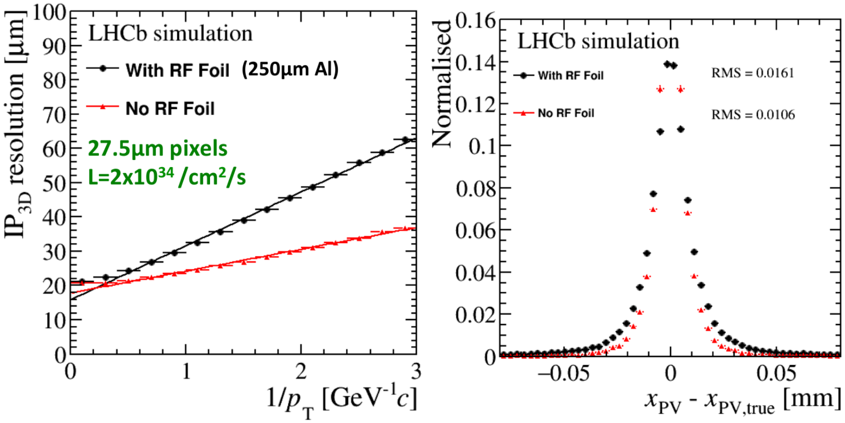
- Overlapping heavy-flavour decays currently our main background
- Naive toy study:
  - PVs spread along Z
  - $B\overline{B}$ and $D\overline{D}$ pairs with exponential lifetimes
  - How many pairs decay with a Z separation below 5mm?
- Overlapping heavy-flavour increases by a factor $\sim$ **3.5**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

RF foil removal



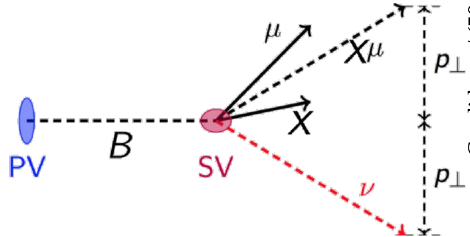
- IP resolution at low PT dominated by multiple scattering before 2nd hit
  - Responsible for slope in plot
- Multiple scattering before 2nd hit dominated by RF foil
  - significant improvement by removing RF foil

Effect of RF foil removal

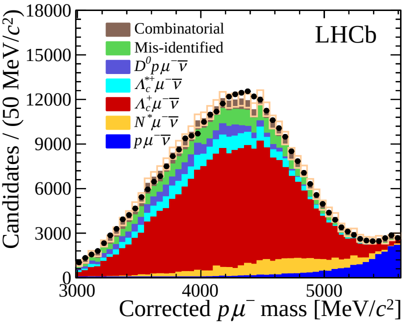


- Nearly doubles IP resolution at low PT!
- Similar improvements in other quantities - e.g primary vertex resolution
- How to quantify impact on physics?
  - Combinatorial background relies on multiple quantities ($\rightarrow$ detailed simulation) and large samples: not yet done
  - First, toy studies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

Flight

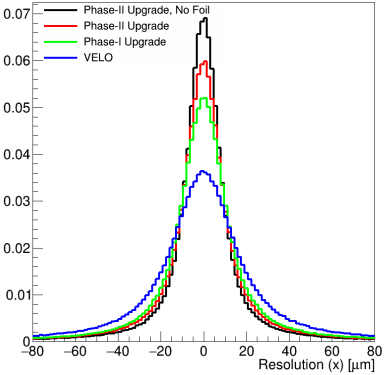


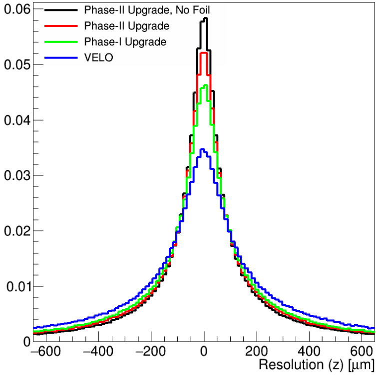
Nature Physics 10 (2015) 1038



- 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

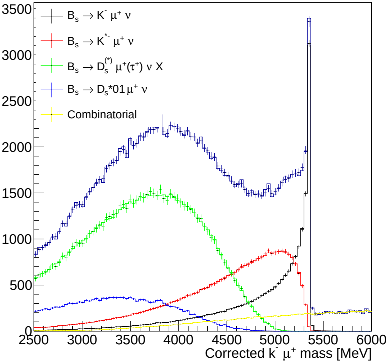
Vertex resolution in semileptonics

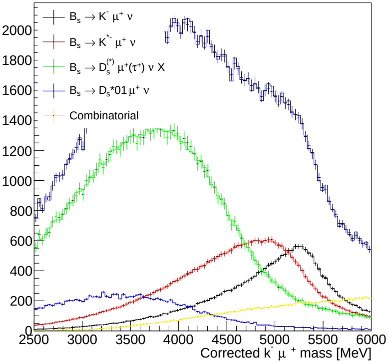




- As with IP resolution, RF foil removal significantly improves secondary vertex resolution (here averaged over PT)
- Use these resolutions to smear MC truth, explore effect on physics sensitivity

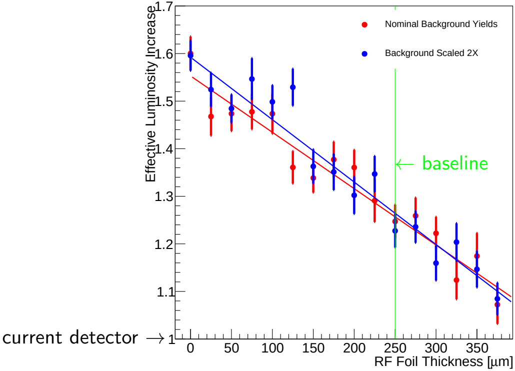
Toy measurement





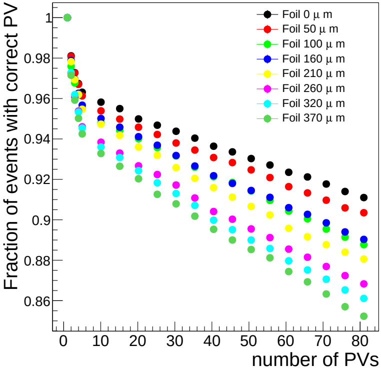
- Template fit used to measure $B_s \to K^-\mu^+\nu$ yield, and determine $|V_{\mathrm{ub}}|$
  - Perfect resolution(left) vs current VELO (right)
- Generate toys for different RF foil thicknesses
- Signal and background yields kept constant

Impact



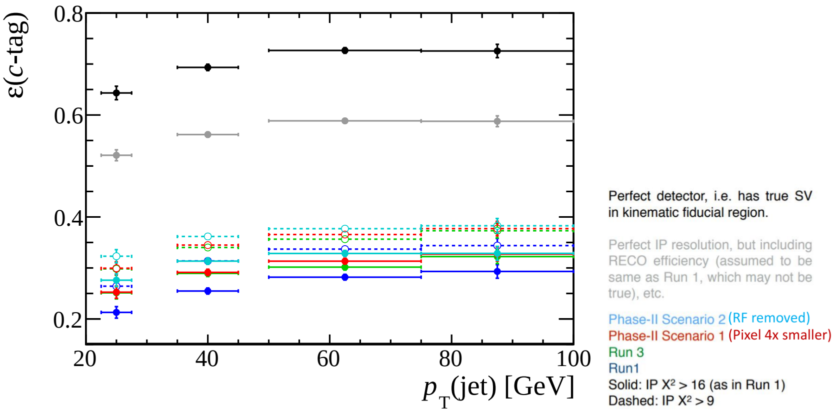
- RF foil thickness has clear impact on sensitivity
- No RF foil gives 25% gain in effective luminosity **from fit resolution alone**
    - Increase in background rejection will result in larger gain
- See poster by Iwan Smith

PV association



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

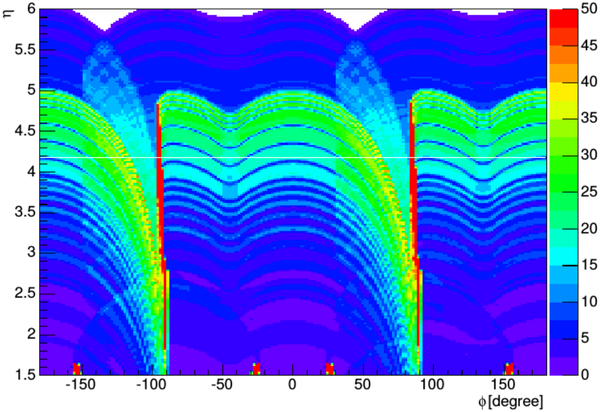
Jet tagging



- IP resolution also key for b, c jet tagging
  - See talk by Oscar Augusto

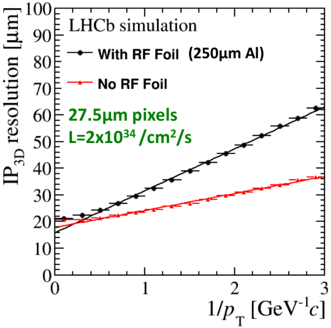
Material description

LHCb-PUB-2014-035



- RF foil has a highly non-trival 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