Precision Material Studies using Radiation Length Imaging for the Belle-II Vertex Detectors

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Introduction

• **Motivation:** detector’s measurement quality depends on material distribution
  – Extra material causes scattering and degrades momentum resolution
  – Vertex resolution depends heavily on material model
    → Material impacts track reconstruction e.g. for 1 GeV/c electron, 1% material difference corresponds to spatial scattering angle of $0.25^\circ$ [Lubej et al.]
  – Collision data not available

• **Objective:** compare material profile from radiation length \((X/X_0)\) images of vertex detectors with simulation and identify discrepancies to improve it
Pixel Vertex Detector (PXD) and Silicon Vertex Detector (SVD)

- First detectors outside the interaction point (IP)
- Used to identify the position of the decay vertex; enable the reconstruction software to find vertices by providing precise hit information very close to IP.
- Consists of *ladders* with semiconductor-based sensors that record hit and timing information
- Ladders assembled in a cylinder around the IP; 2 layers for PXD, 4 for SVD

![Diagram of Pixel Vertex Detector (PXD) and Silicon Vertex Detector (SVD)](image)
Methodology: Radiation Length ($X/X_0$) Imaging

**Idea:** Create 2D material profiles by using multi GeV test beam on detector components and reconstruct multiple scattering angles from charged particle tracks [ArXiv:1609.02402]

- Material content measured in $X_0$: the mean distance over which an electron loses all but $1/e$ of its energy by bremsstrahlung

- Scattering angles associated with a set of tracks are grouped together; width of angular distribution is proportional to radiation length in that region:

  $$\theta \propto \sqrt{\frac{X}{X_0}}$$

- Radiation length extracted by fitting the angular distribution of each region to Highland’s multiple scattering model [1]

- 4 GeV electron beam used at DESY; measurement conducted with AIDA tracking telescope [2]
$X/X_0$ Imaging: SVD ladder

Cooling pipe  Keratherm  APV chip  clamp  Solder bumps

Courtesy: Chris Schwanda
Methodology: Material Scan in Belle-II software (basf2)

- Simulation creates fictitious particles called geantinos.
- Non-interacting particles -> amount of material they traverse is computed by simulation.
- ‘Particle gun’ shoots geantinos around the detector and creates a 2D profile of the material ‘seen’ by the particle.

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Differences: cooling pipe material, clamps, keratherm, copper layer, vias
SVD Material Scan Vs $X/X_0$ – $u$ profile

Before

Pipes mismatch (~ 1.25%)
Keratherm missing

After Improvements

Fixed pipe dimensions
Added Keratherm + Cu layer
SVD Material Scan Vs $X/X_0$ – v profile

Before

After Improvements

Copper layer added
Clamp added
Adjusted Cu content
SVD Material Scan Vs $X/X_0$ – improved model

Added: clamp, keratherm, copper layer, fixed pipe dimensions
$X/X_0$ Imaging of PXD Half-Ladder module

- X-ray image of PXD ladder, balcony region
- X/X0 image of PXD ladder, balcony region
- Groove profile In balcony
- Switcher
- Capacitor
- SWB balcony
- Sensitive pixel region
- EOS
- Module label
PXD Ladder, Balcony region: MaterialScan Vs. $X/X_0$

Differences: capacitors, groove profile, bump bonds in switcher
PXD Material Scan Vs. $X/X_0$ – u profile

Before

Missing capacitor ~ 1.5 % difference

After Improvements

Added capacitor

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PXD Material Scan Vs. $X/X_0 - v$ profile

Before Improvements

After Improvements

Missing groove profile
PXD Ladder, Balcony region: Material Scan Vs. $X/X_0$ – improved model

Added: capacitors, groove profile
Summary of PXD/SVD Studies

-> Improved Belle-II material simulation through precision material studies

-> New components added:
  PXD: capacitors, grooves, fixed dimensions
  SVD: keratherm, clamp, copper layer, fixed dimensions

-> Better agreement with actual detector material profile
Future Prospects

• Work in progress – addition of new parts still being validated and improved to match the real detector

• Once phase 3 data taking starts, more validation can be performed using photon conversion studies in the real detector

• $X/X_0$ imaging approach is not limited to vertex detectors. Other groups are using it to measure $X/X_0$ for various glues, support materials and even FPGA boards at Belle-II.
The End
Thank you!
References

• Radiation Length Imaging Using High Resolution telescopes
  http://arxiv.org/abs/1609.02402