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

**Waleed Ahmed**
Contact: waleeda@physics.mcgill.ca
Supervisor: Steven Robertson
Collaborators: Ulf Stolzenburg, Benjamin Schwenker (University of Gottingen)


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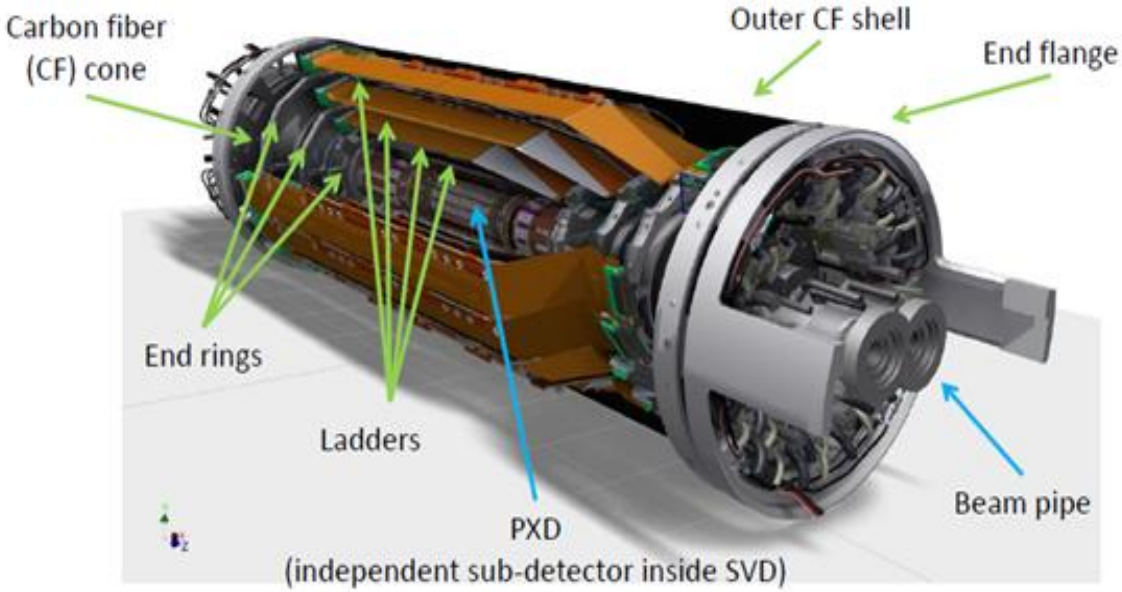
# Introduction

- **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.25$^{o}$ [Lubej et al.]
  - Collision data not available
- **Objective:** compare material profile from radiation length ($X/X_o$) 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




Courtesy:
Chris
Schwanda

# Methodology: Radiation Length ($X/X_o$) 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]

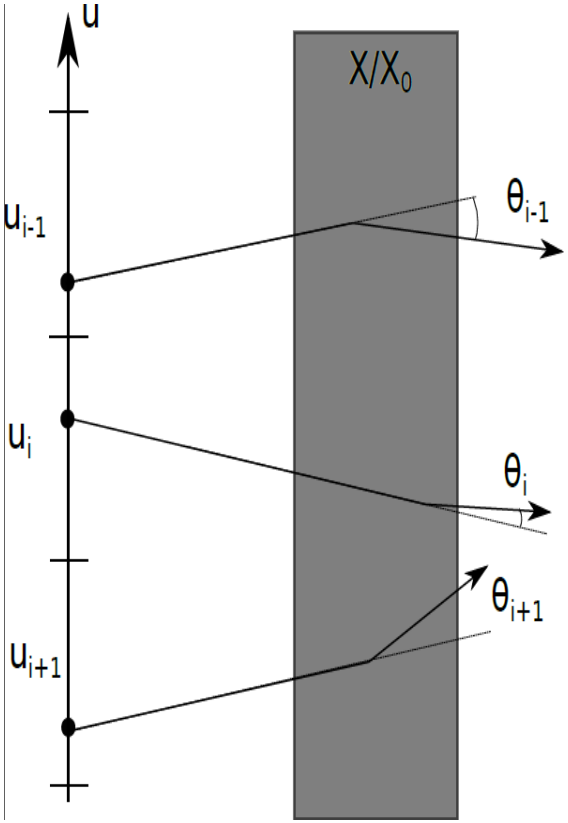
- material content measured in $X_o$ : the mean distance over which an electron loses all but 1/e of its energy by bremsstrahlung

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

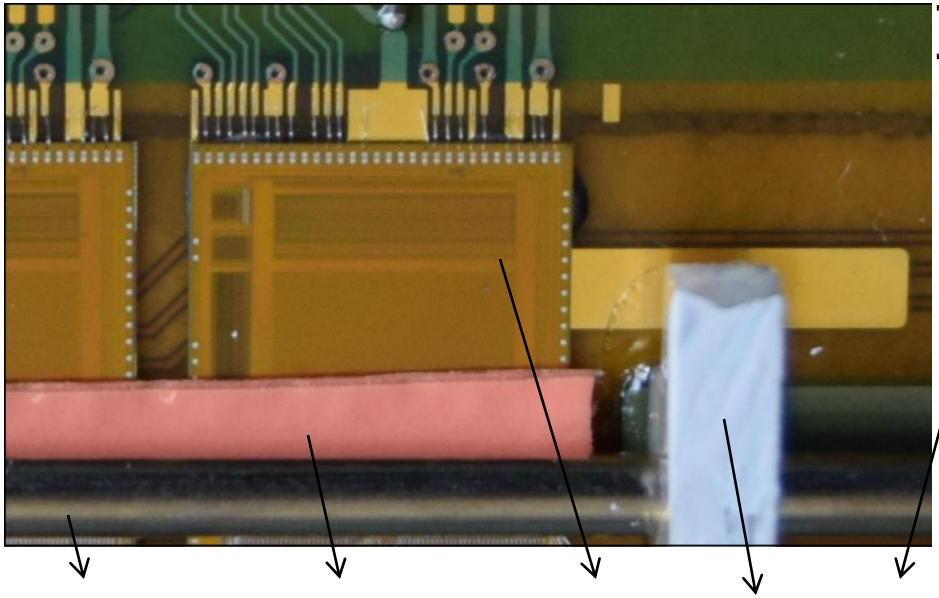
$$\theta \propto \sqrt{\frac{X}{X_0}}$$

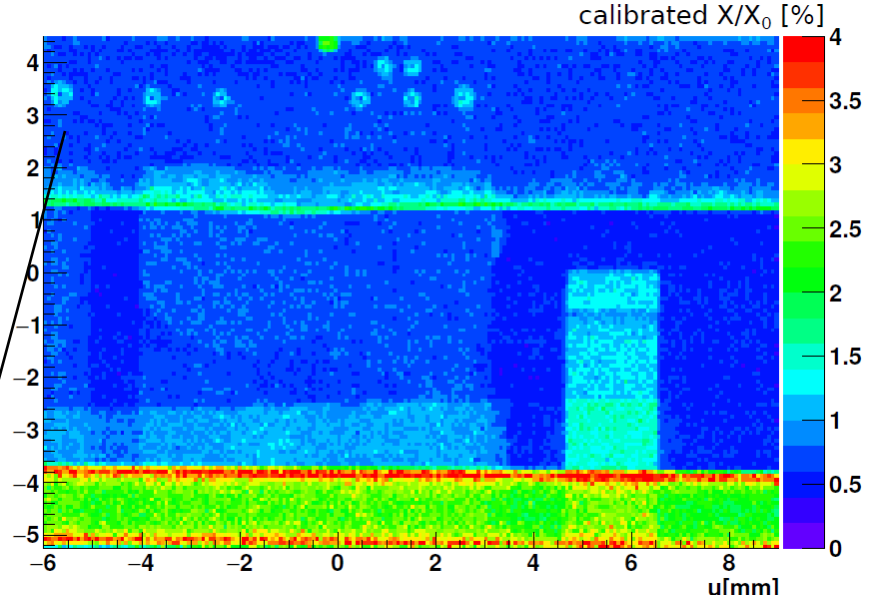
- radiation length extracted by fitting the angular distribution of each region to Highland's multiple scattering model [1]

- 4 GeV electron beam used at DESY; measurement conducted with AIDA tracking telescope [2]



# $X/X_0$ Imaging: SVD ladder

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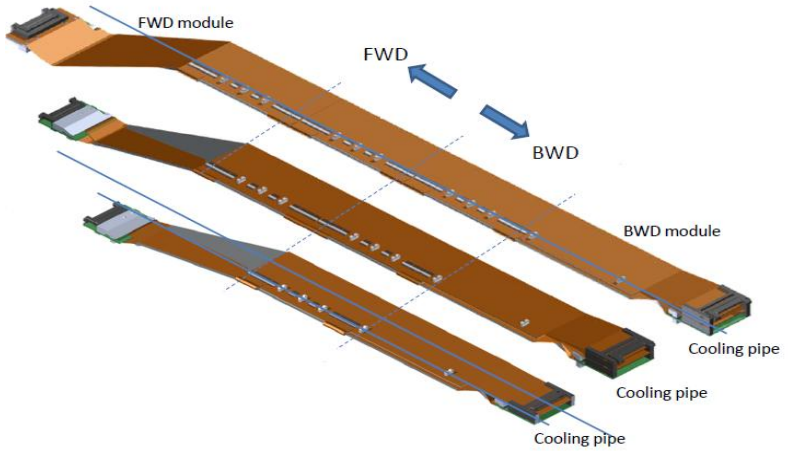
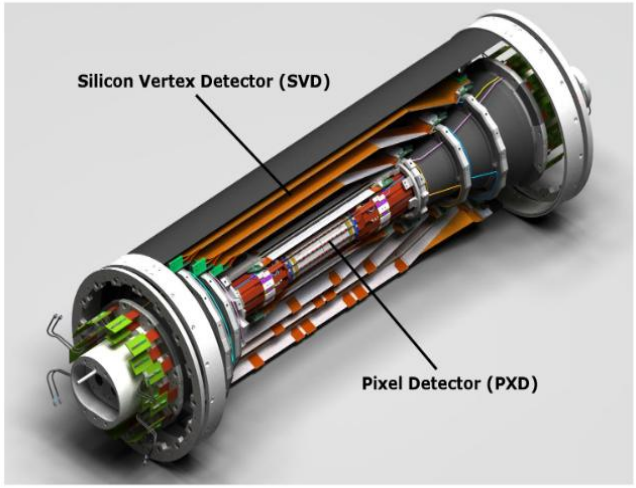
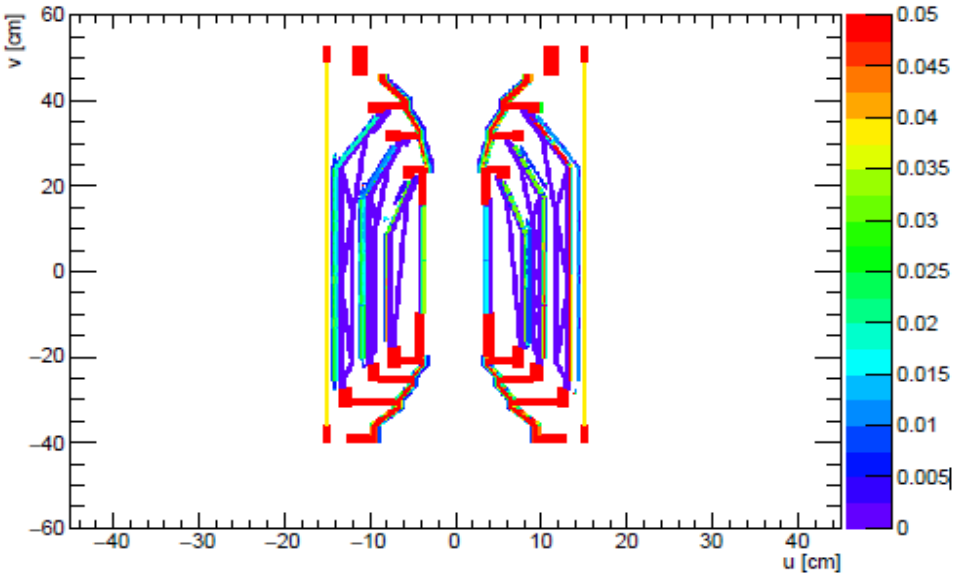


# Methodology: Material Scan in Belle-II software (basf2)

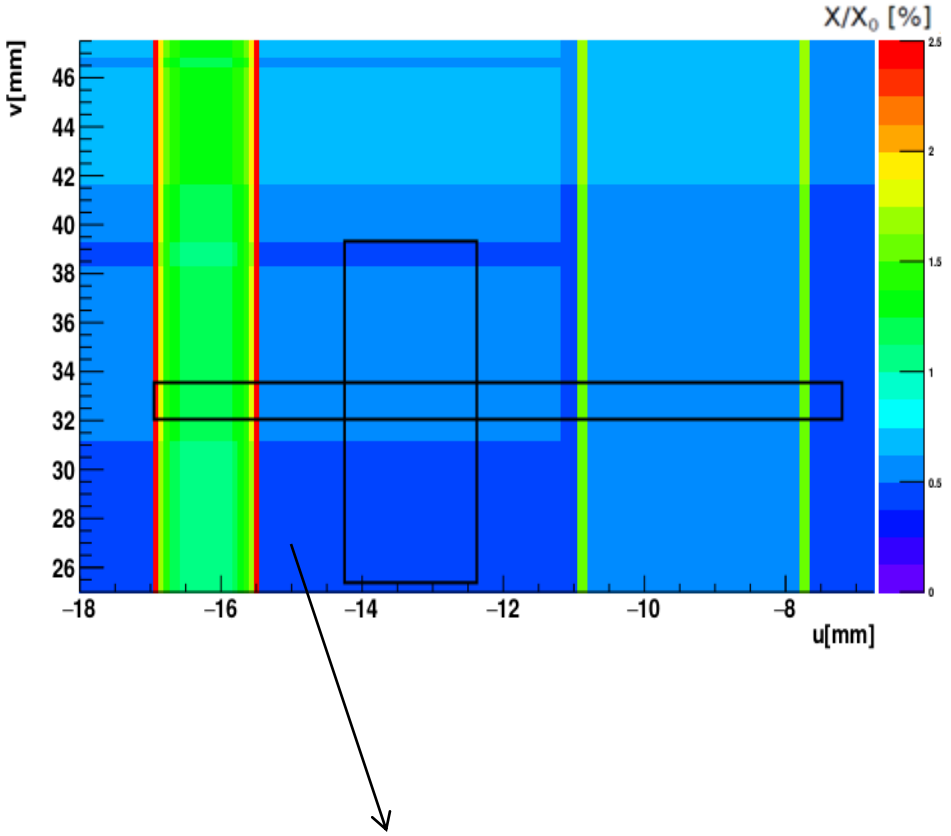
- Simulation creates fictitious particles called geantinos
- Non-interacting particles -> amount of material they traverse is computed by simulation
- ‘Particle gun’ shoots geantinos around the detector and creates a 2D profile of the material ‘seen’ by the particle

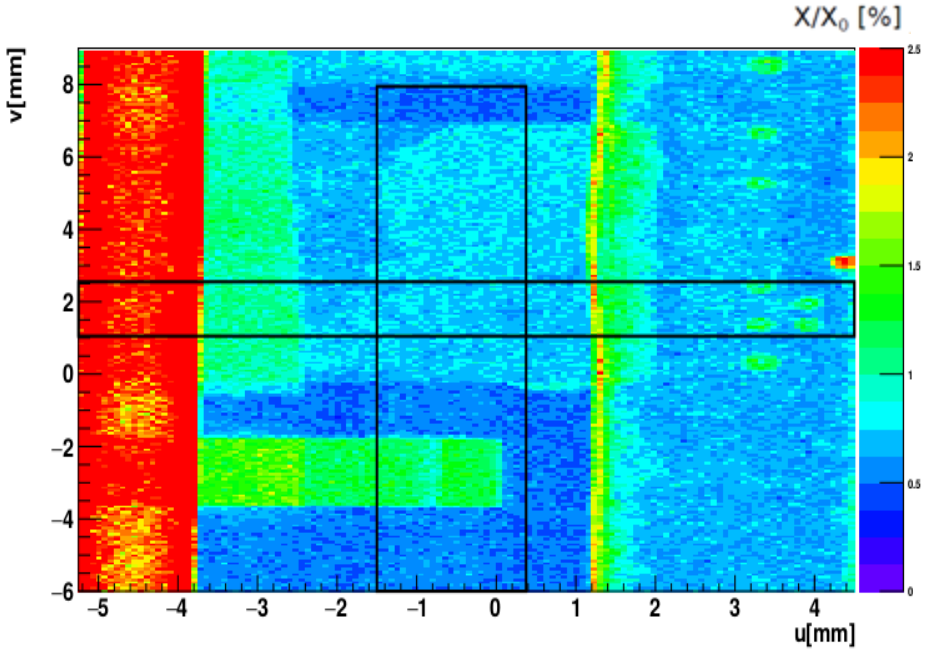



Planar Material Scan of SVD in the XZ plane

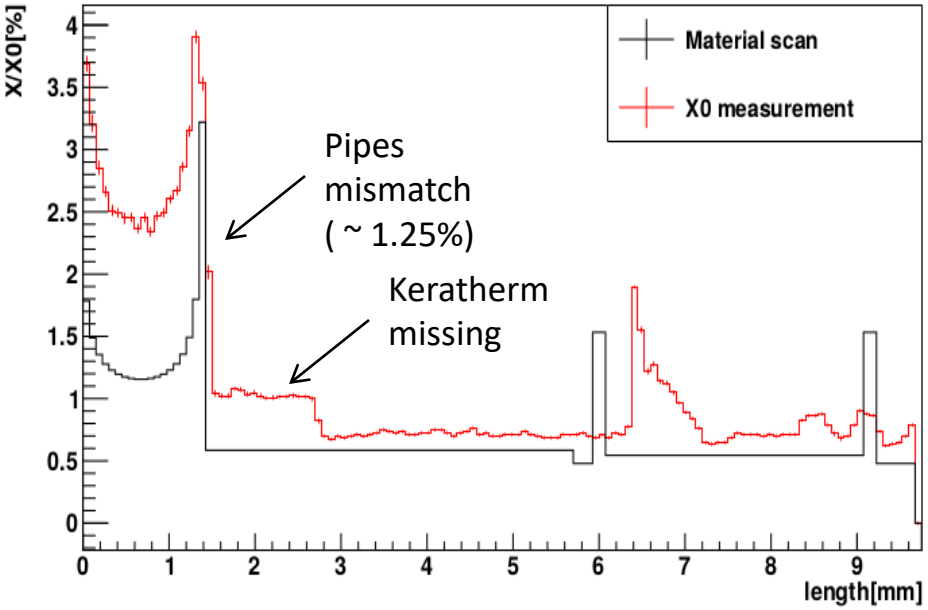
# SVD Material Scan Vs $X/X_o$



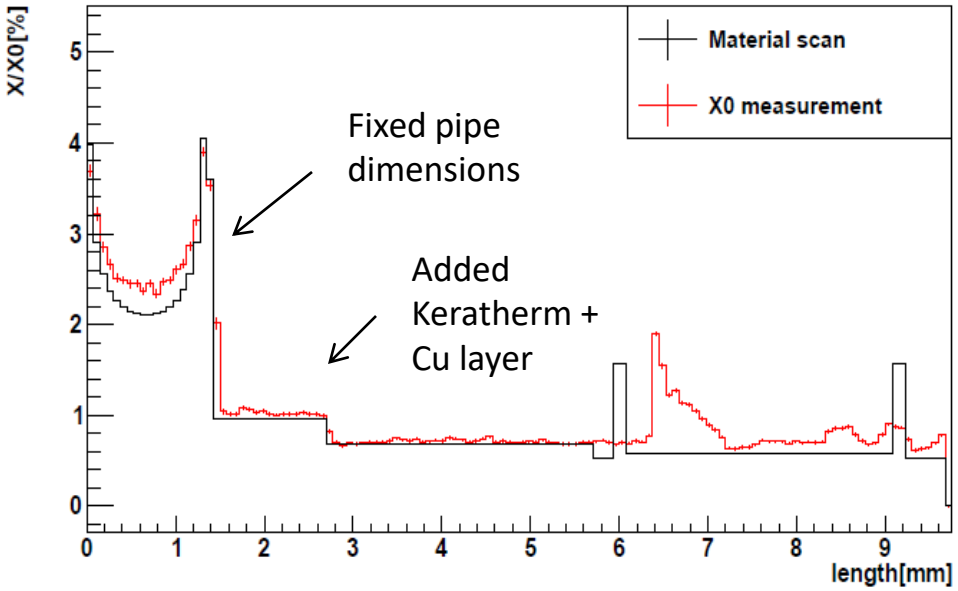




Differences: cooling pipe material, clamps, keratherm, copper layer, vias

# SVD Material Scan Vs $X/X_o$ – u profile

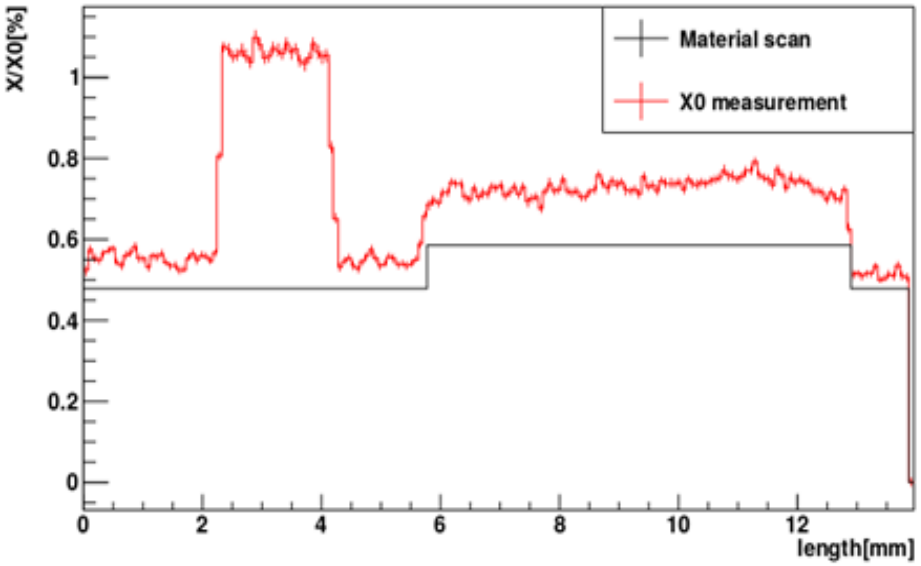



**Before**

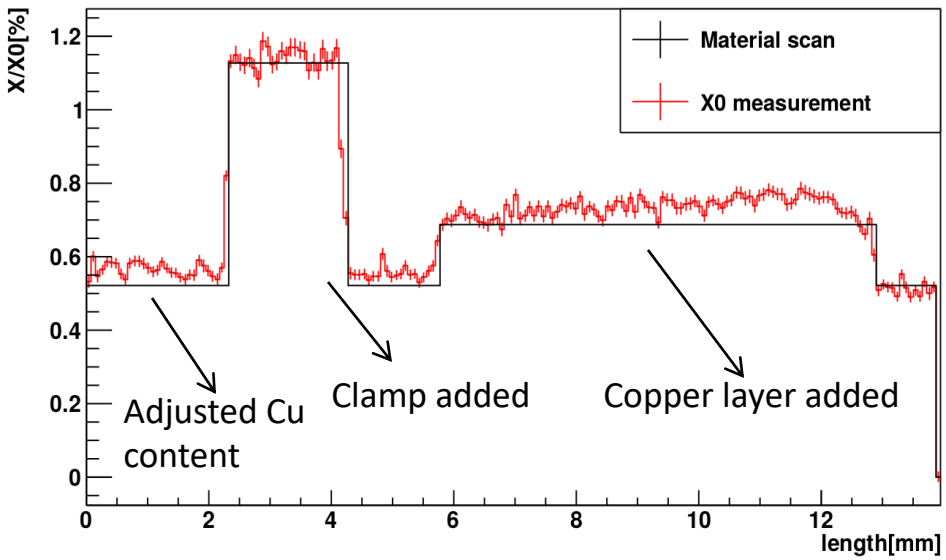



**After Improvements**

# SVD Material Scan Vs $X/X_o$ – v profile

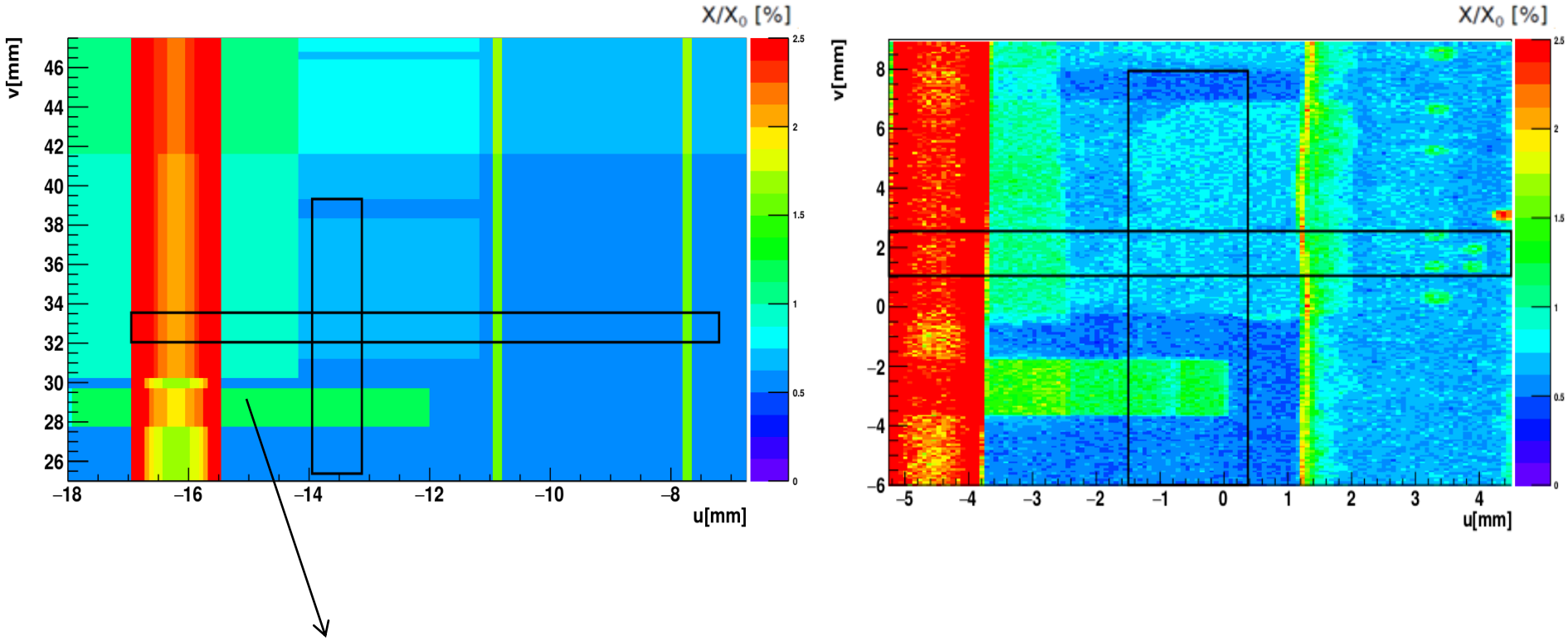



**Before**



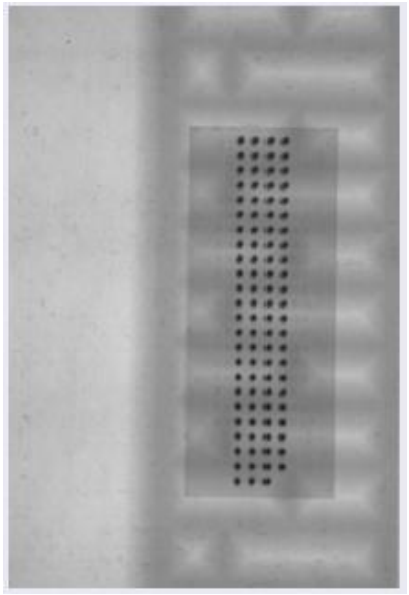

**After Improvements**

# SVD Material Scan Vs $X/X_o$– improved model

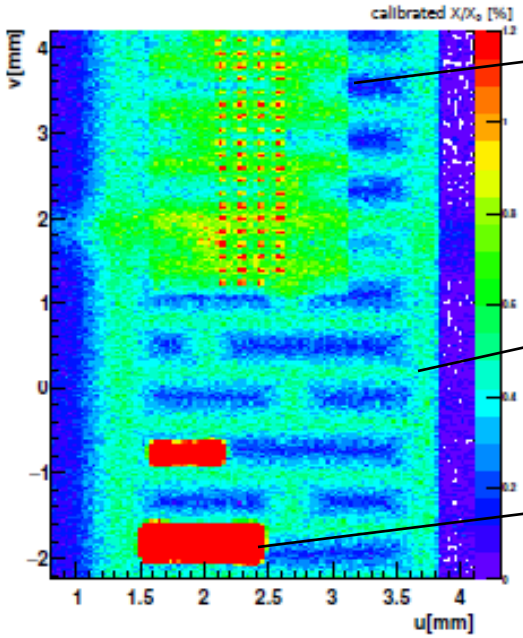



Added: clamp, keratherm, copper layer, fixed pipe dimensions

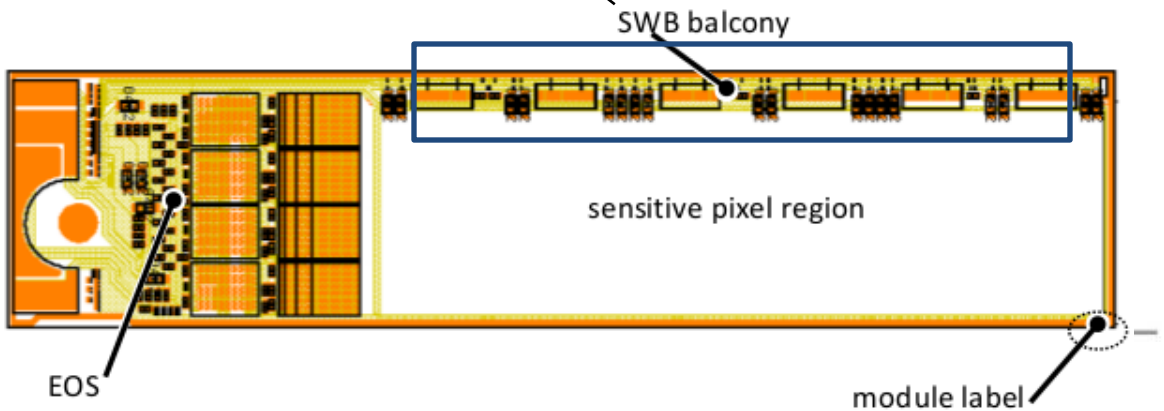
# $X/X_o$ Imaging of PXD Half-Ladder module



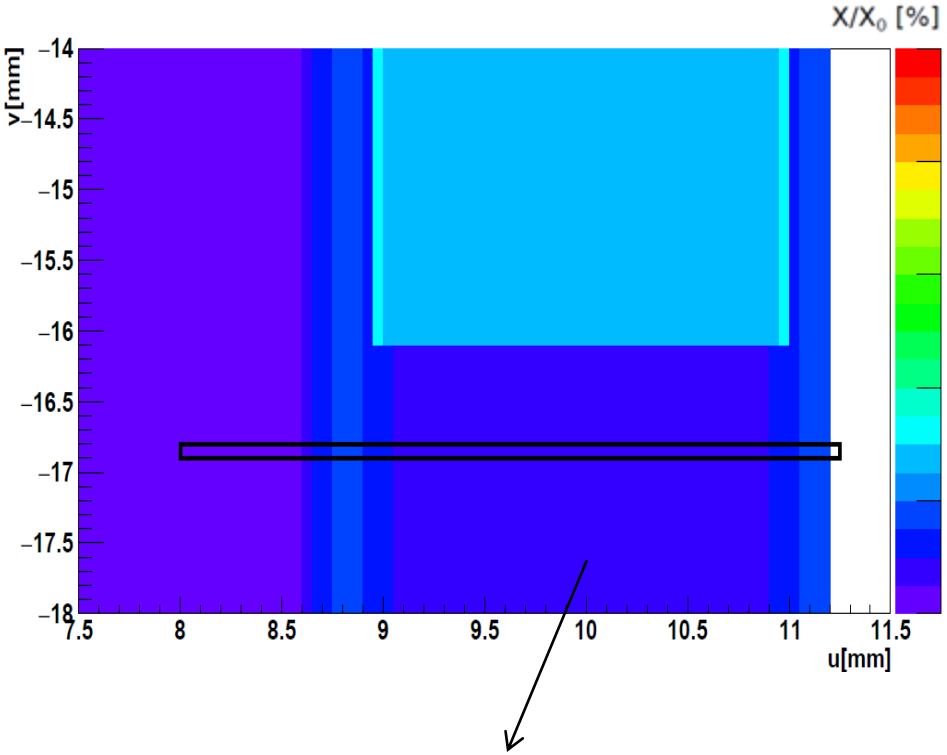
X-ray image of PXD ladder, balcony region

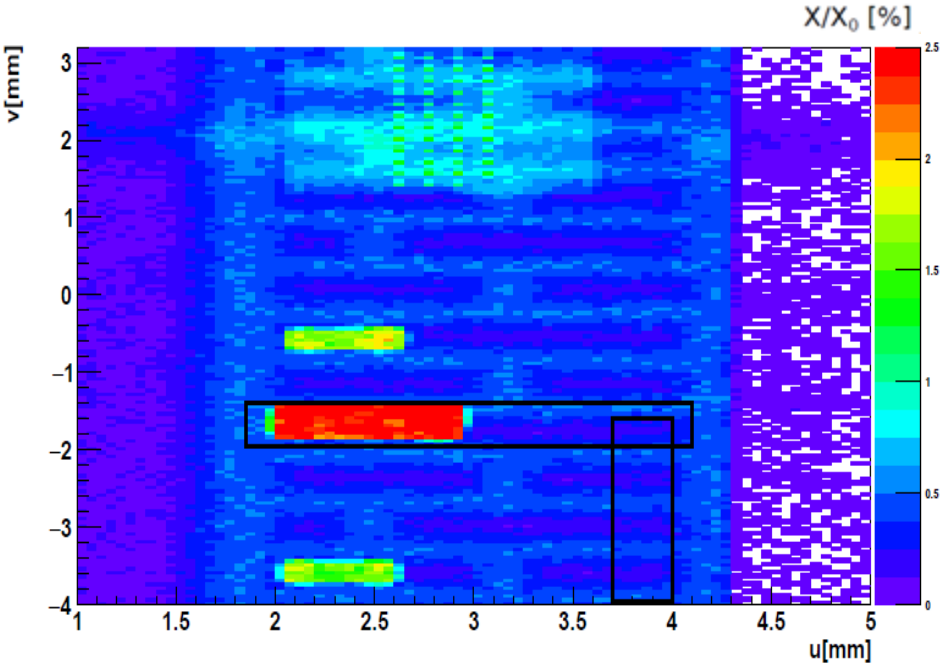



X/X0 image of PXD ladder, balcony region



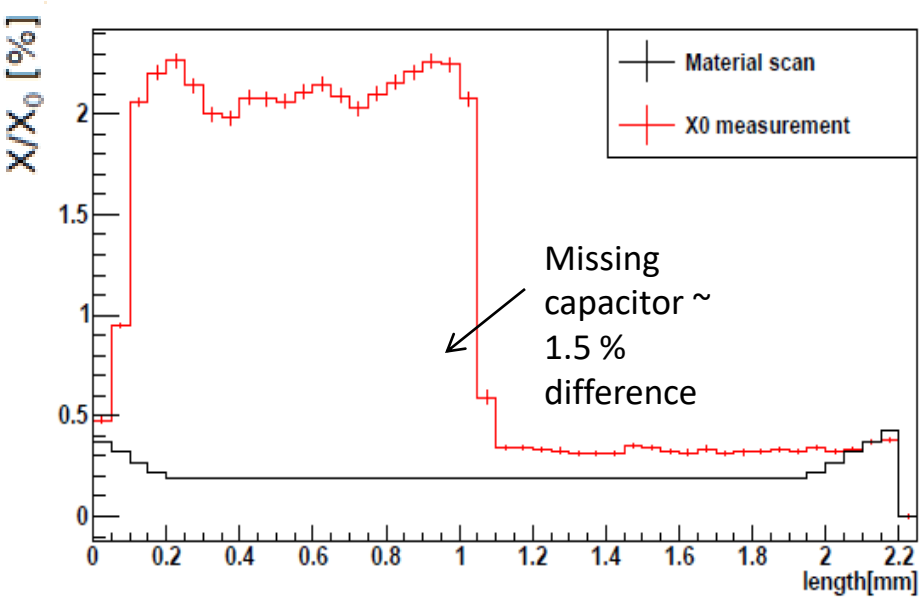

# PXD Ladder, Balcony region: MaterialScan Vs. $X/X_o$



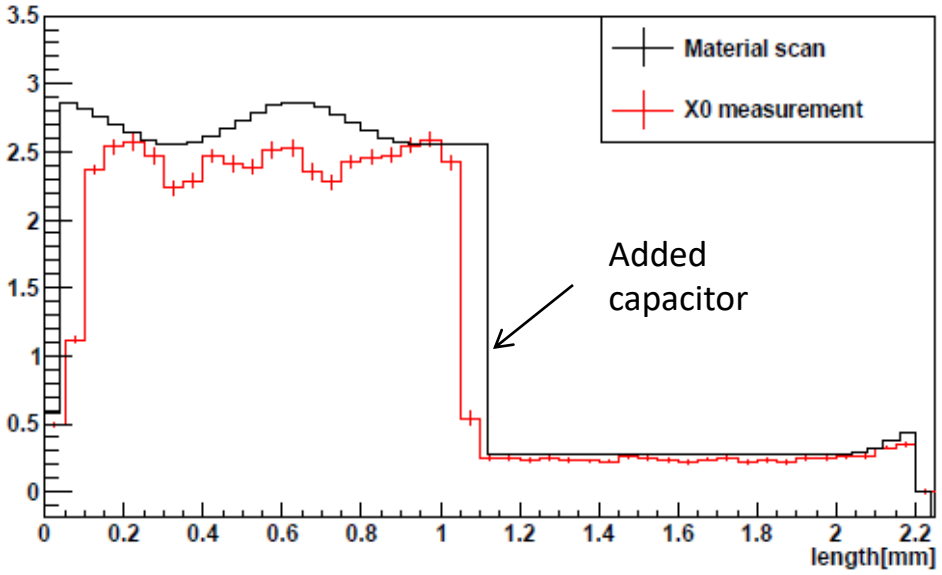




Differences: capacitors, groove profile, bump bonds in switcher

# PXD Material Scan Vs. $X/X_o$ – u profile

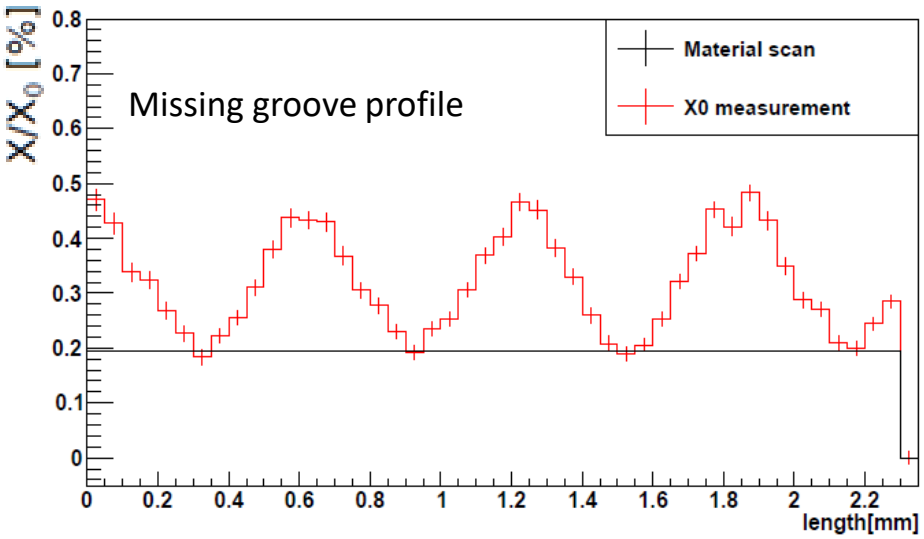


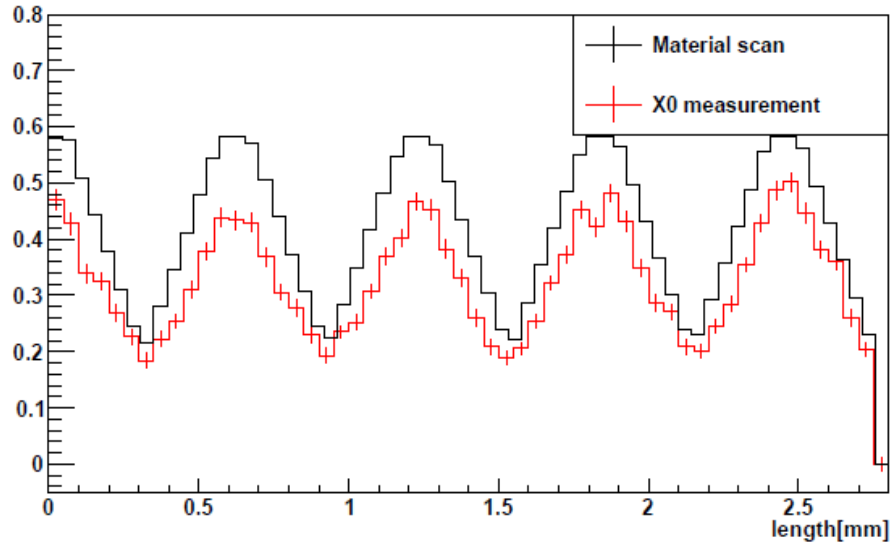

**Before**




**After Improvements**

# PXD Material Scan Vs. $X/X_o$ – v profile

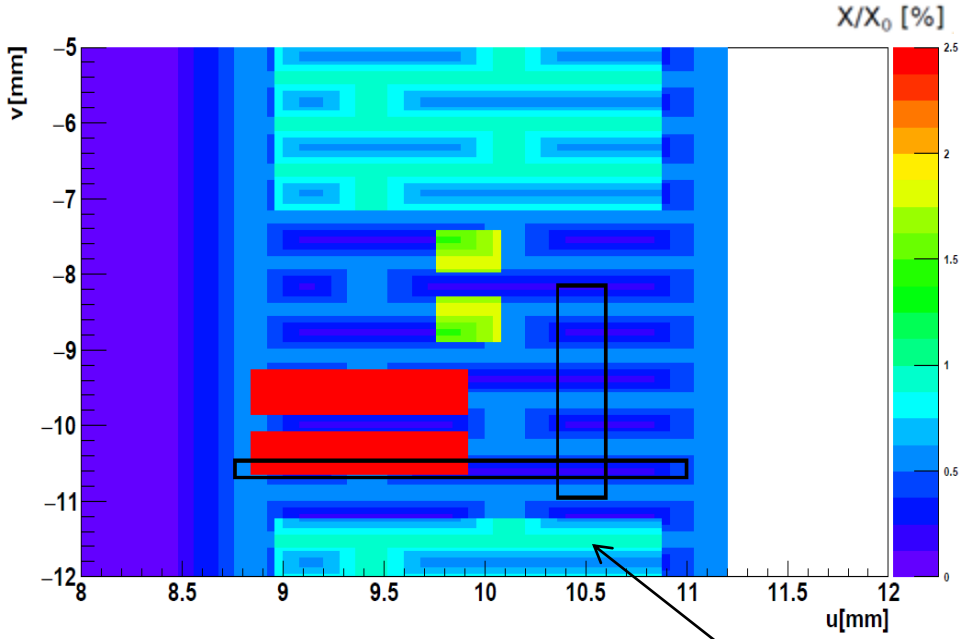


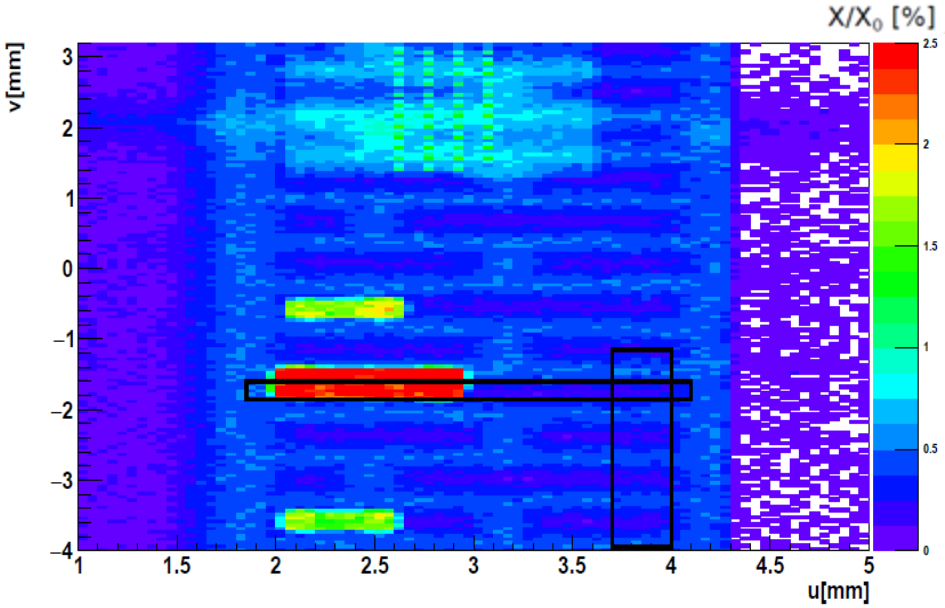




**Before**

**After Improvements**

# PXD Ladder, Balcony region: Material Scan Vs. $X/X_o$ – 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
- $X/X_o$ imaging approach is not limited to vertex detectors. Other groups are using it to measure $X/X_o$ 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
- M. Lubej,B.Golob. Belle2 Note: Amount of material in Belle-II Simulation, 2012.