Silicon Testbeam Results for the LHCb-UT Detector

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On Behalf of the LHCb-UT Working Group

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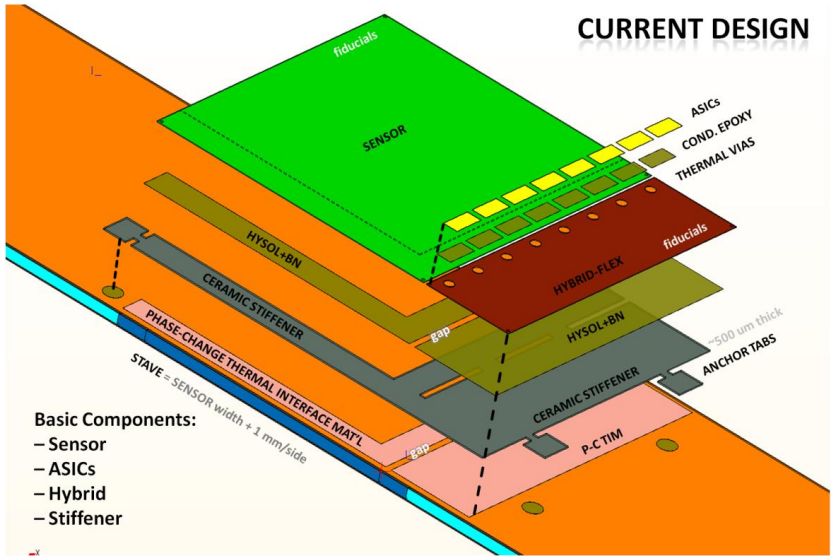
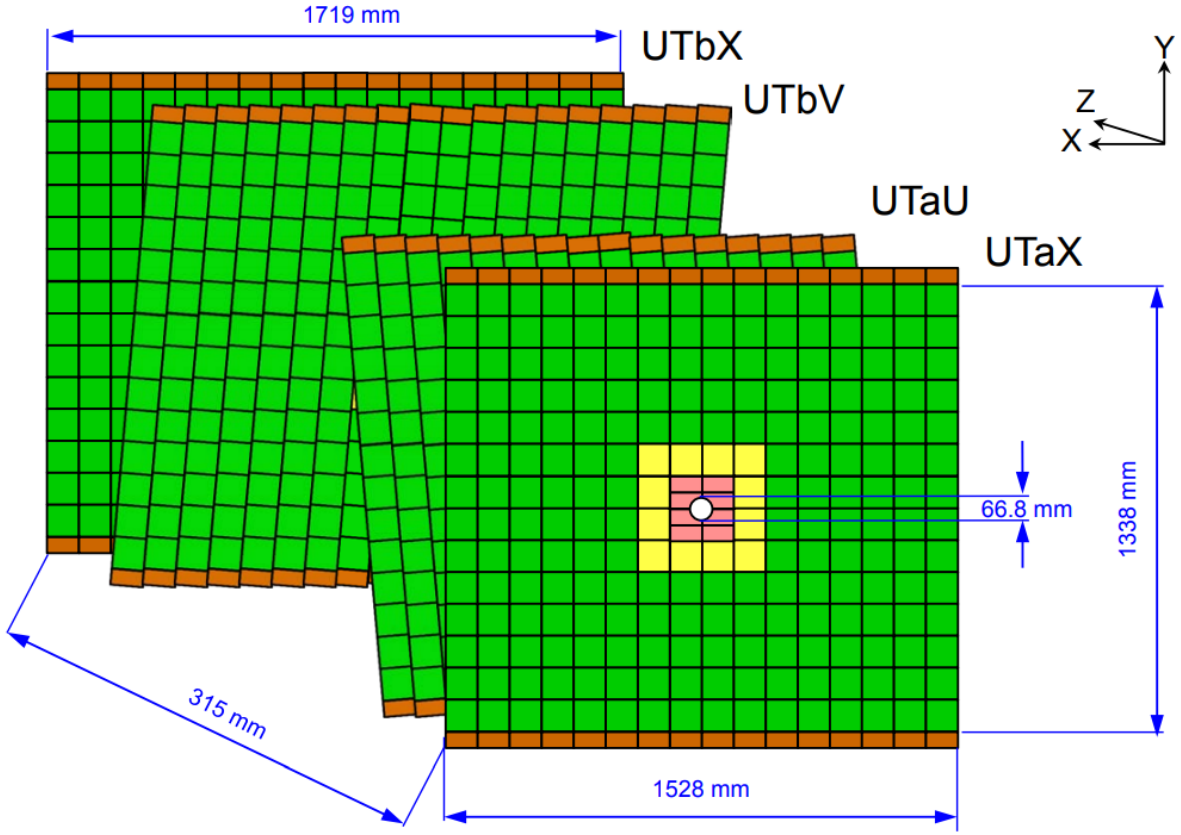
UT Introduction

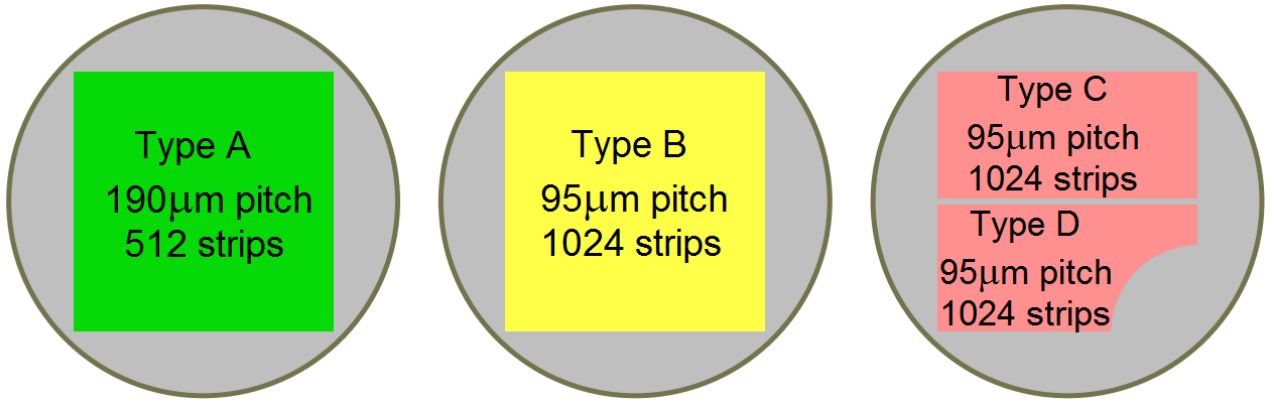
- 4 planes of silicon microstrip detectors
- Silicon modules mounted on staves:
  - **Main structural component of the detector**
  - Houses hybrid-sensor modules vertically on either side
  - Support for Ti tube for CO_2 cooling
- New 128 channel ASIC has been designed for sensor readout: SALT (**S**ilicon **A**SIC for **L**HCb **T**racking)



Silicon Overview

- 4 Detector Types: A, B, C, D
  - Most of the UT will consist of **Type A** sensors
    - 1050 Total: 888 in the UT, 162 spare
    - 10x10cm, 320µm thickness
  - B, C, and D will have 250µm thickness
- Type D sensors feature a cutout region near the beam pipe



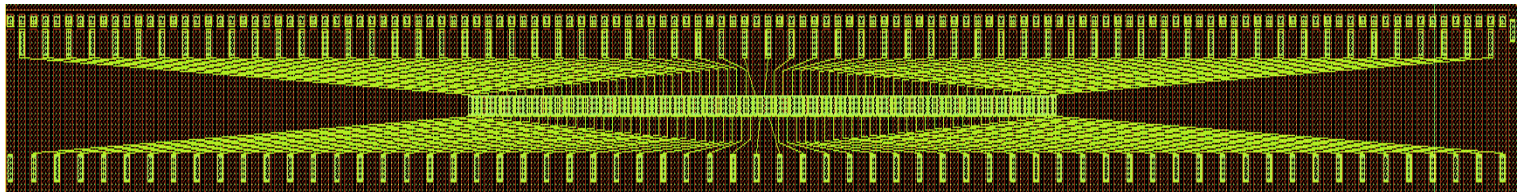


Key Silicon Design Features

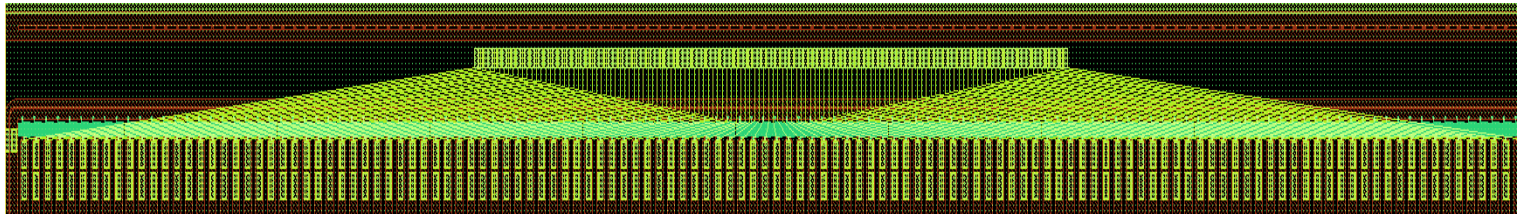
Embedded **P**itch **A**dapters (PA)

- Accomplished via 2nd metal layer
- Scale 190µm pitch of Type A sensors to 80µm SALT ASIC pitch

Fan-In: Traces and bond pads are inside the active area



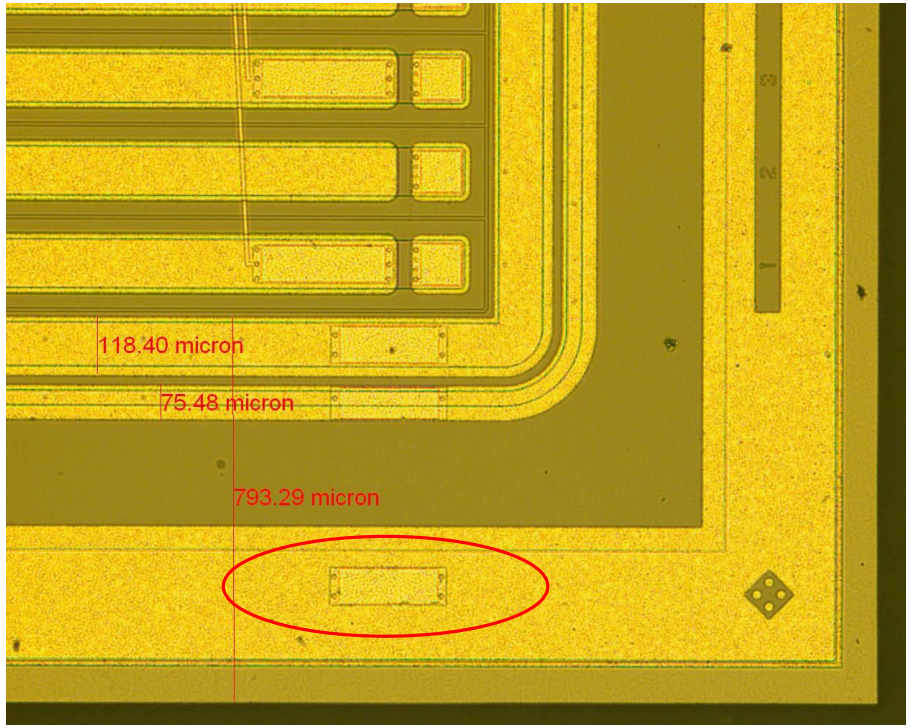
Fan-Up: Traces and bond pads are outside the active area



Primary Testbeam Goal: Assess the performance of each of these features

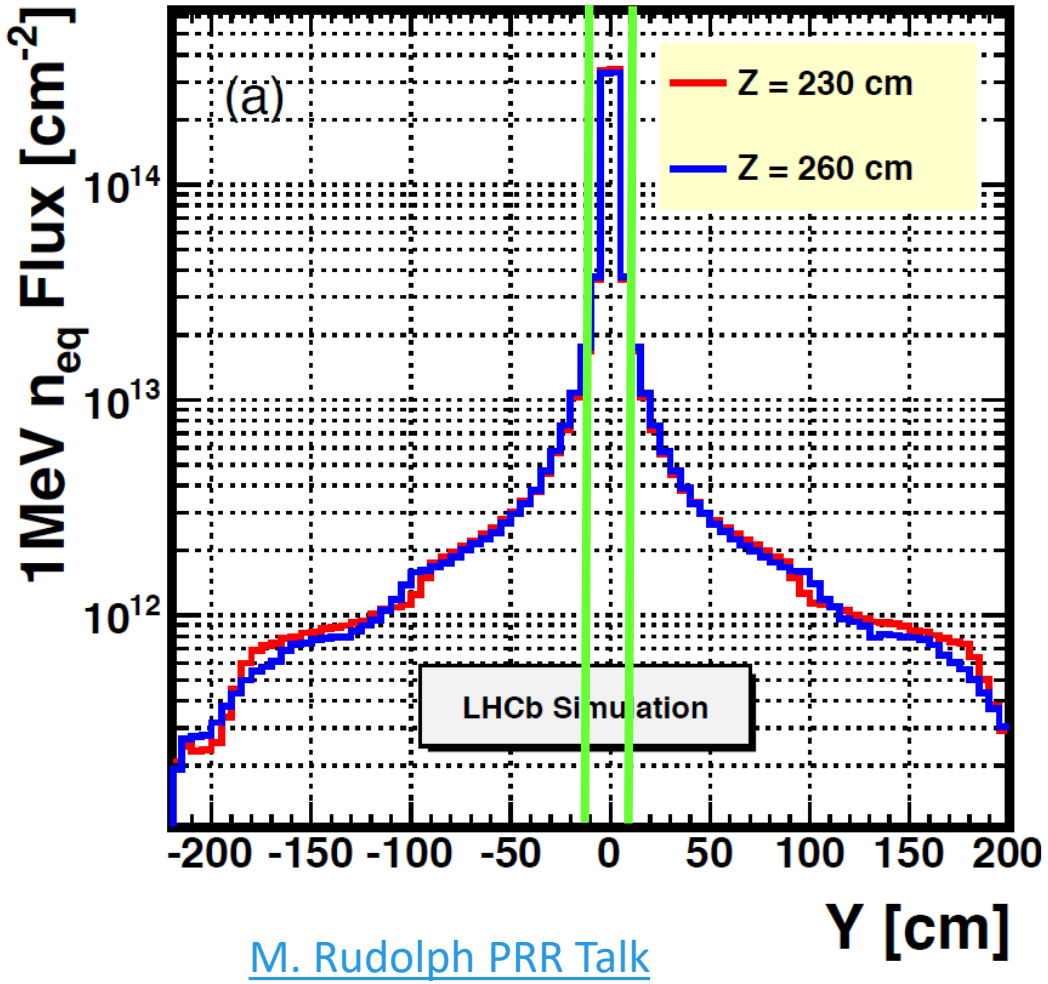
Top Side Bias Contact

- Simplifies assembly procedure. HV brought to back via conductive edge



Irradiation Campaigns

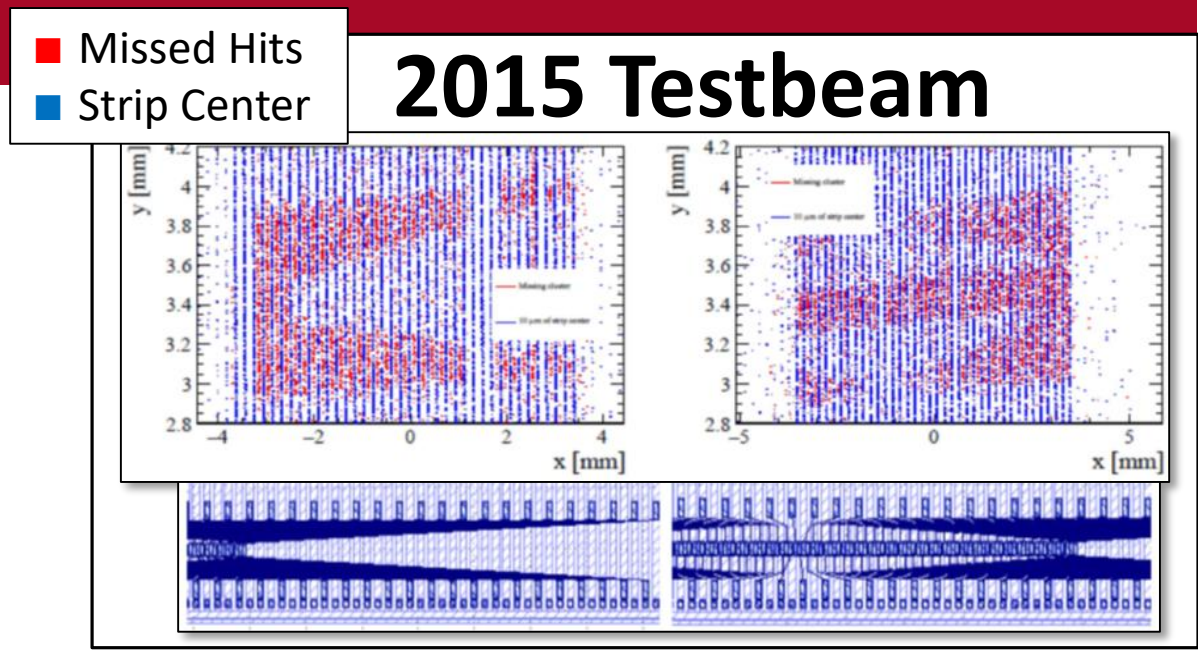
- Want to study detector performance after exposure to irradiaton.
- 40 Mrad max dose:
  - Maximum type A fluence: **$2x10^{13}$ n_{eq}/cm^2** (nominal)
    - **Built in x2 factor for safety**
  - B and C: **$1x10^{14}$ n_{eq}/cm^2**, D: **$4x10^{14}$ n_{eq}/cm^2**
- Sensors irradiated at CERN PS-IRRAD facility: 24 GeV protons
- Fluences studied from ~5%*nominal to 2000%*nominal
- Further studies of irradiation effects have been aided by TCAD simulation, detailed in NIM 877 (2018) 252, and arXiv:1708.03371
- Nine testbeam efforts since Nov. 2014: Focus on 2016 and 2017 results

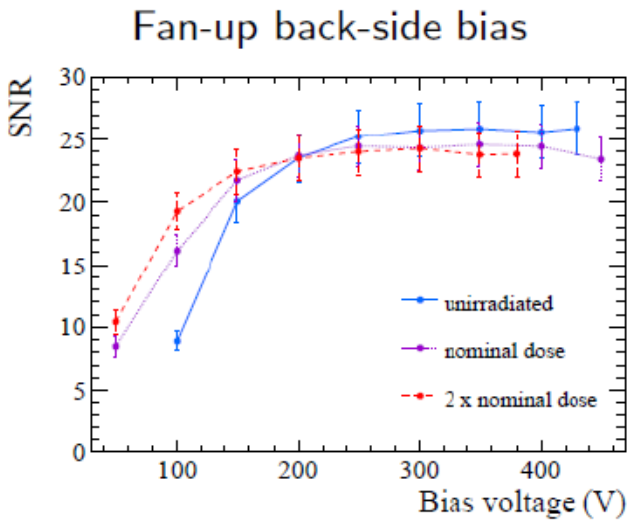


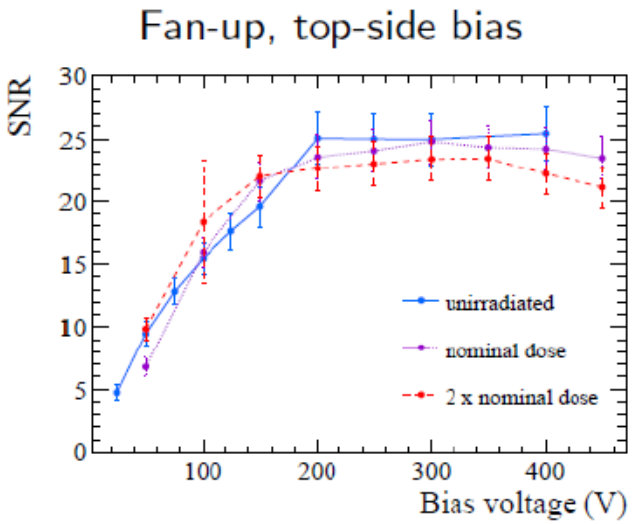
M. Rudolph PRR Talk

2016 Testbeam Results

- Inefficiencies in 2015 motivated studies of p-in-n sensors in 2016
- Fan-Up becomes baseline design, still study Fan-in further
- Two testbeams in May and October, 2016
  - May: p-in-n half-A sensors and mini sensors, top vs. back biasing, SNR performance with irradiation
  - October: p-in-n type mini sensors at 5%, 10%, 20%, 50%, and 100% of nominal fluence





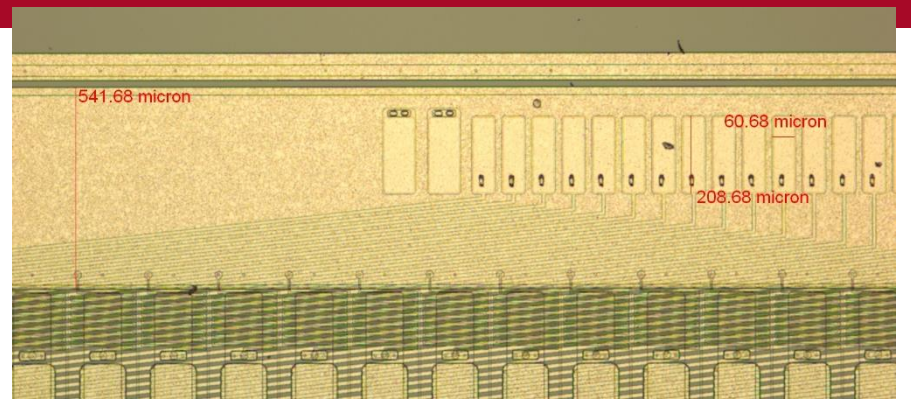


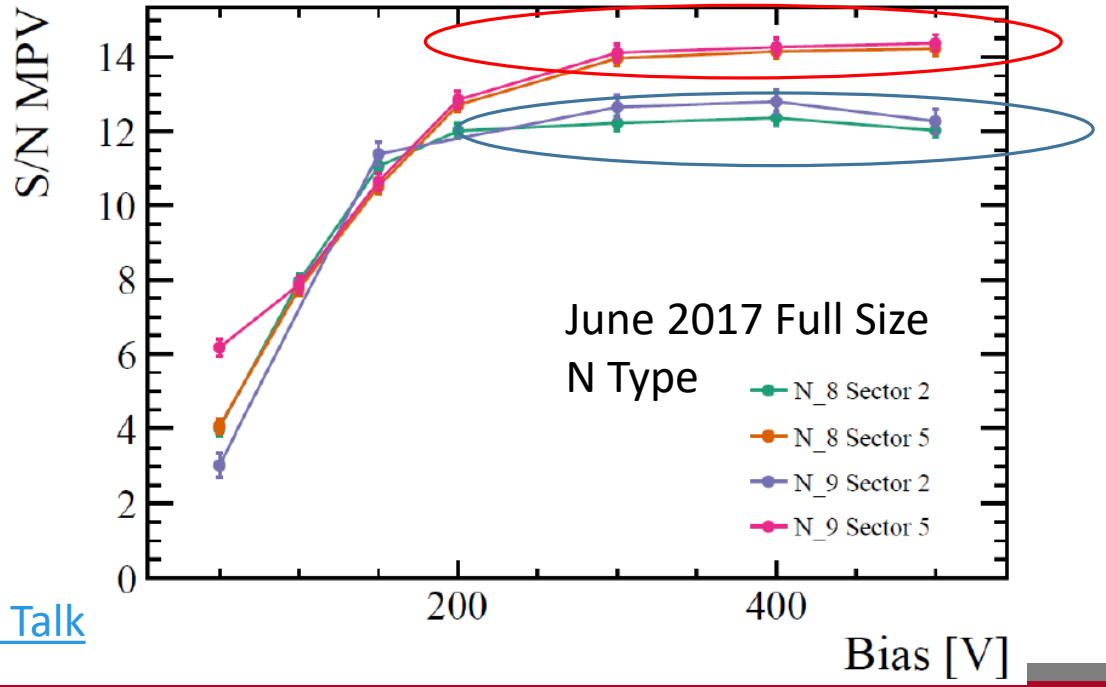
S. Blusk PRR Talk

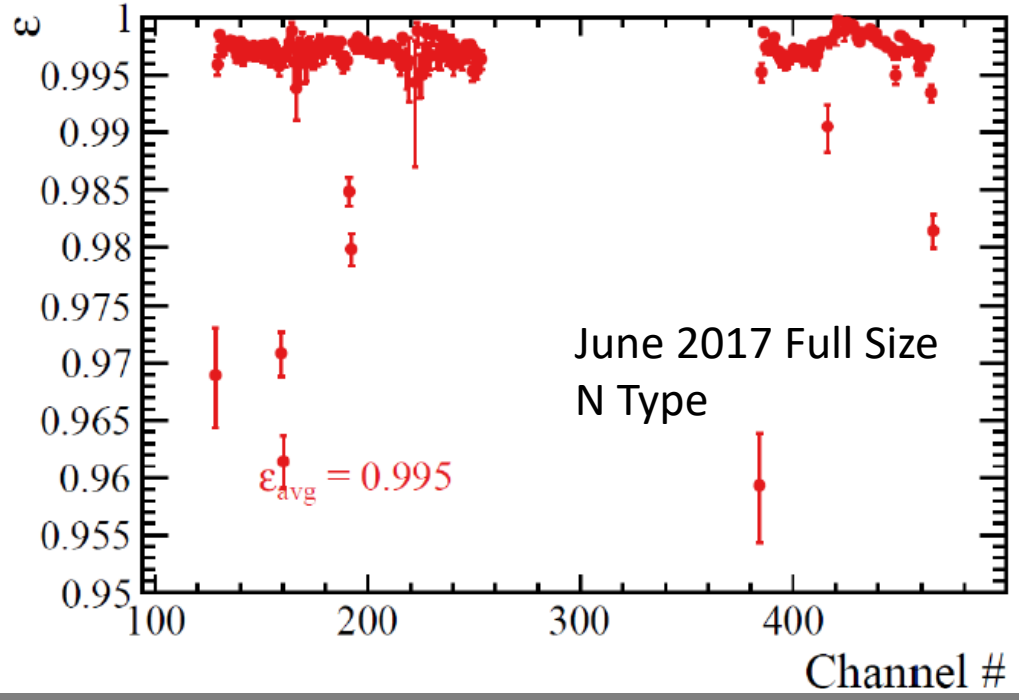
- See LHCb-PUB-2016-007 for a detailed discussion of 2015 results:
- Study of n-in-p sensors
- Type D prototypes studied as well, see backup

2017 Testbeam Results

- Two testbeam campaigns in June and August 2017
- June: mask updated with thicker oxide layer, wider bias ring near bond bads
  - Full size p-in-n Type-A sensors irradiated to peak fluence of $2x10^{13}$ n_{eq}/cm^2 **along one edge**, Fan-Up PA
  - Mini sensors at 0%, 25%, 100% fluence, updated Fan-UP and Fan-In designs



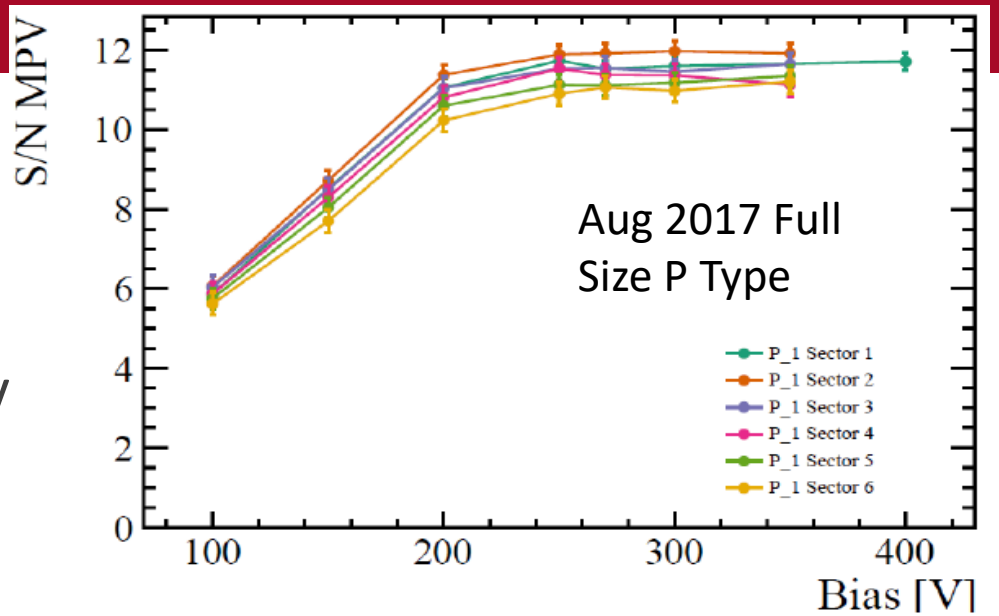


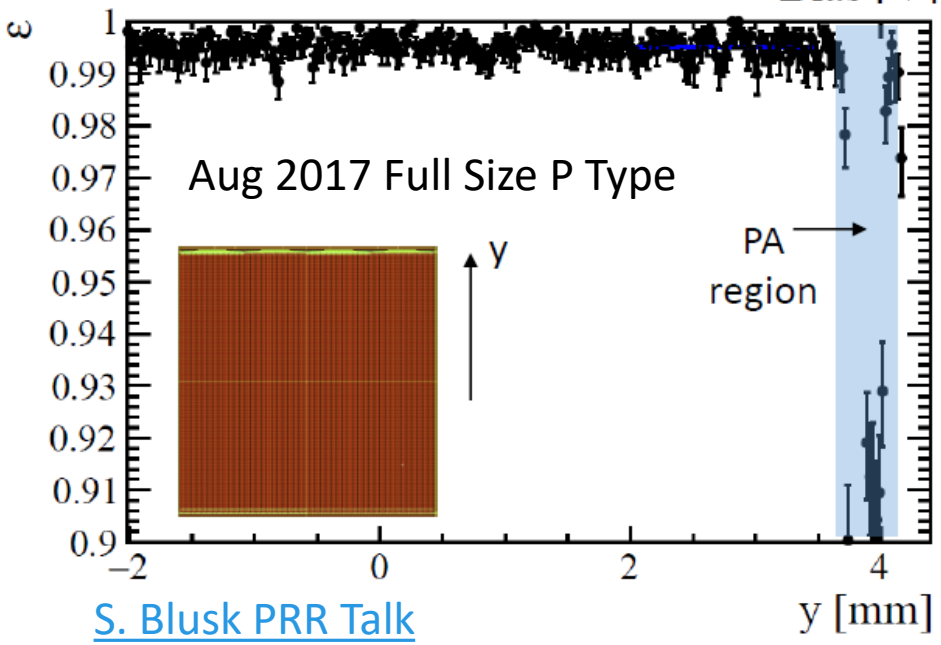


S. Blusk PRR Talk

2017 Testbeam Results

- August: p-type sensors using updated mask:
  - Two full size n-in-p Type A sensors: One irradiated to $2x10^{13}$ n_{eq}/cm^2 across the entire area, other with only one edge irradiated
  - Mini sensors at 0, 25%, 500%, 2000%
  - Highest fluences showed voltage drop in bias
- SNR not representative of final electronics
- Clear inefficiency in Fan-Up PA region
- **All Type-A sensors will be p-in-n**





S. Blusk PRR Talk

Summary & Outlook

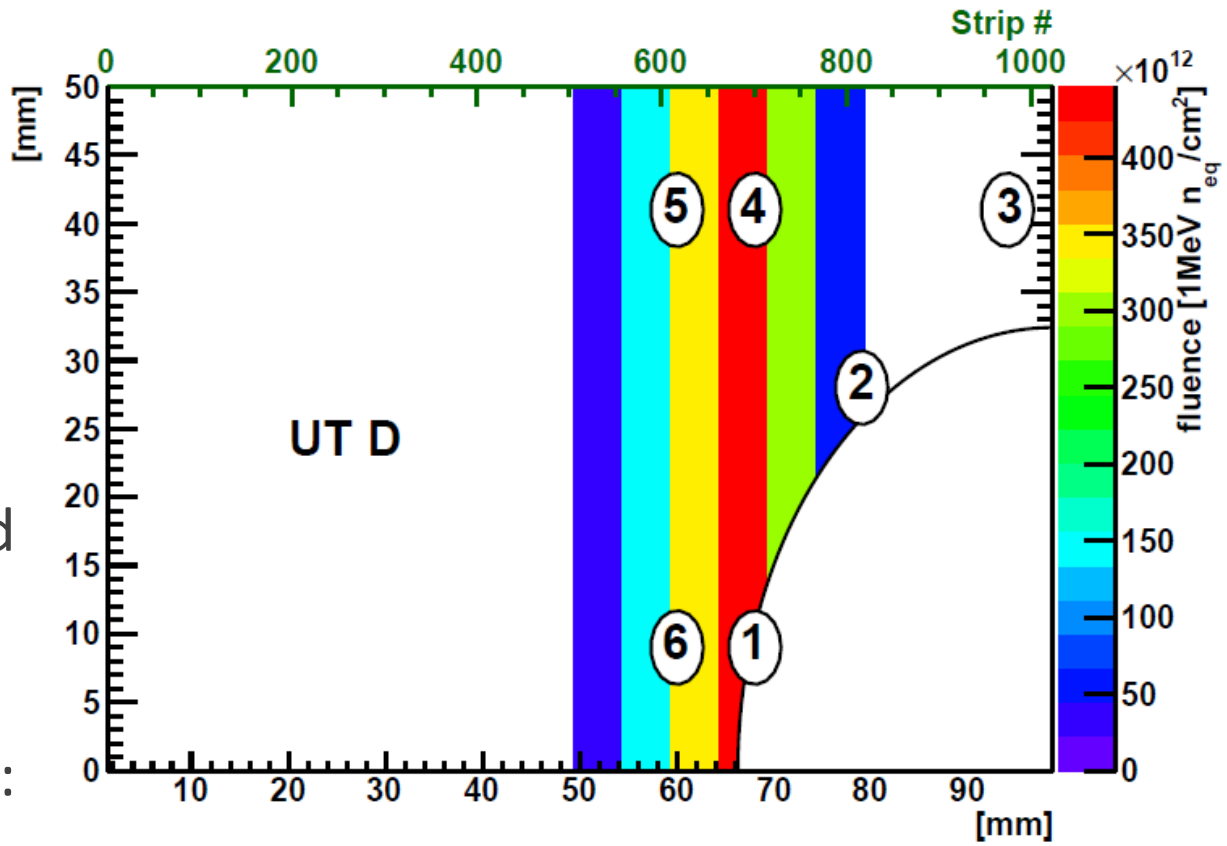
- Thorough testbeam effort has been carried out to validate the performance of the UT sensors.
- Final Type-A design has been verified:
  - All Type-A sensors will be p-in-n. First production batch expected in January 2018
  - Fan-Up PA will be employed in all Type-A sensors: Significantly reduces total number of wirebonds, saves from requiring extra PA components apart from silicon
  - Top-side biasing will be used for all sensors (B,C,D as well)
  - Prototypes of B and C sensors to be ordered soon (see backup for Type D results).
- Testbeams in 2018: Focus will be on SALT + Hybrid performance

The End

Backup Slides Follow

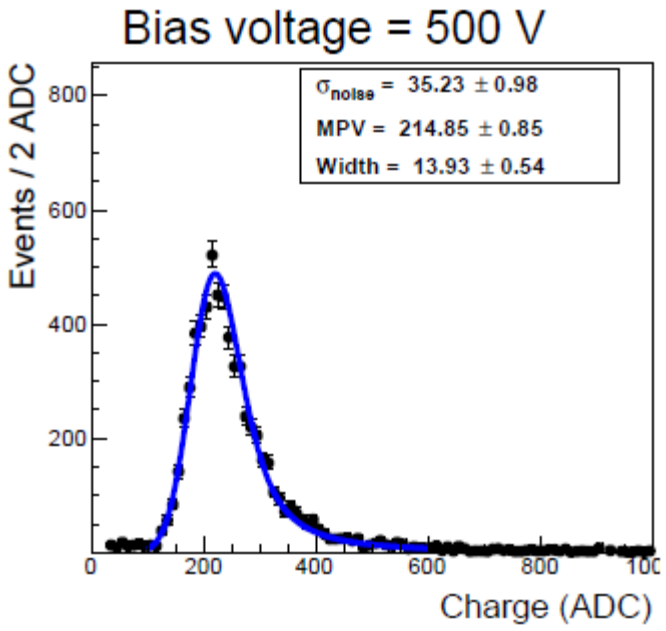
Type D Irradiation

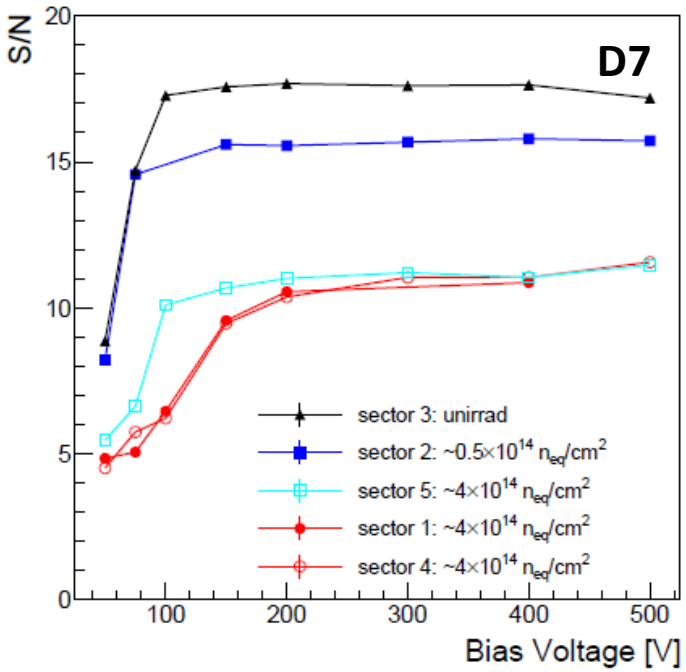
- 33.4mm radius cutout around beam pipe region
- Closest to beam pipe, must tolerate highest fluence
- Irradiation performed at CERN IRRAD facility with 24 GeV proton beam.
- Goal was to illuminate both cutout region and full strip length.
- Max delivered fluence: 4.4×10^{14} n_{eq}/cm^2 . Maximum expected after 50 fb^{-1} of data taken: 5×10^{14} n_{eq}/cm^2

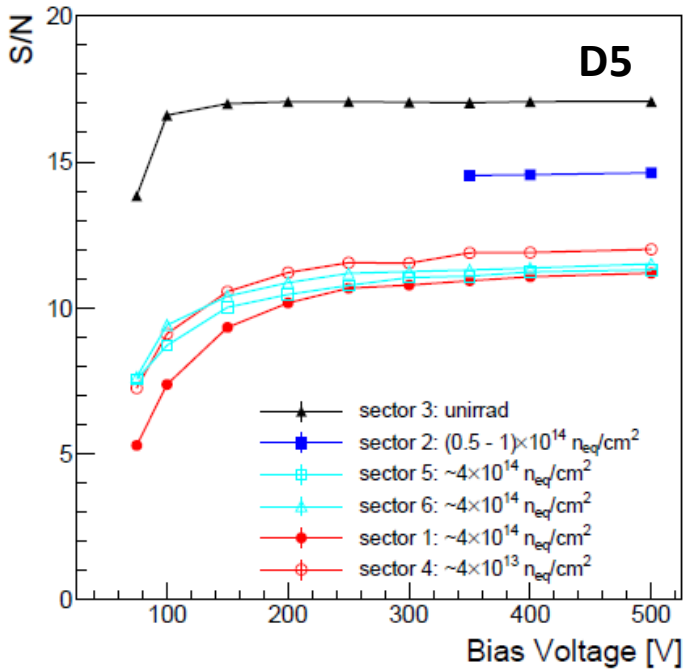


Type D Performance

- Two type D detectors studied:
- **SNR is not representative of final system:**
  - Used here to assess detector performance at various fluences
- SNR ≈ **17** for unirriadated, ≈**11** for irradiated

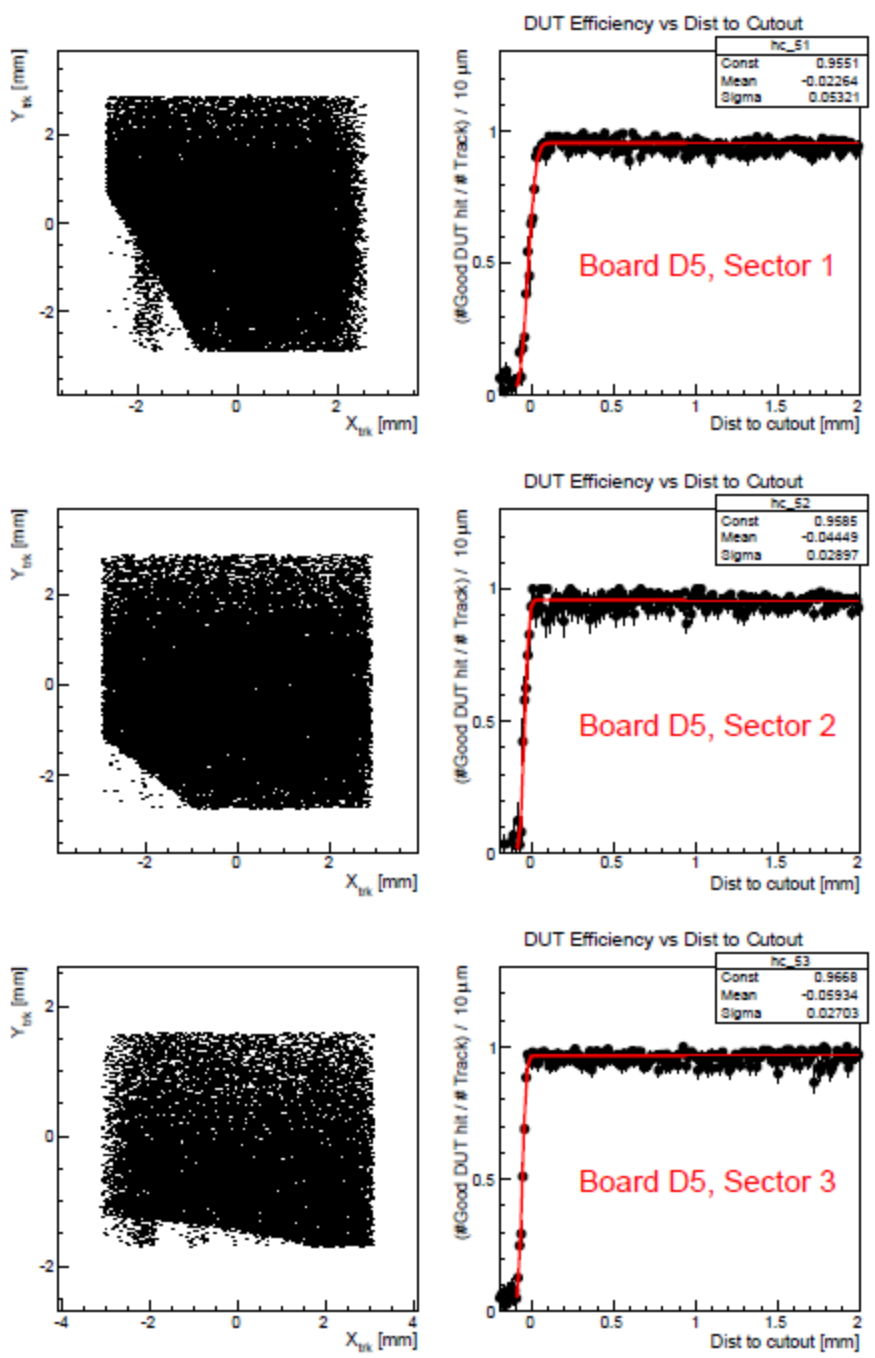






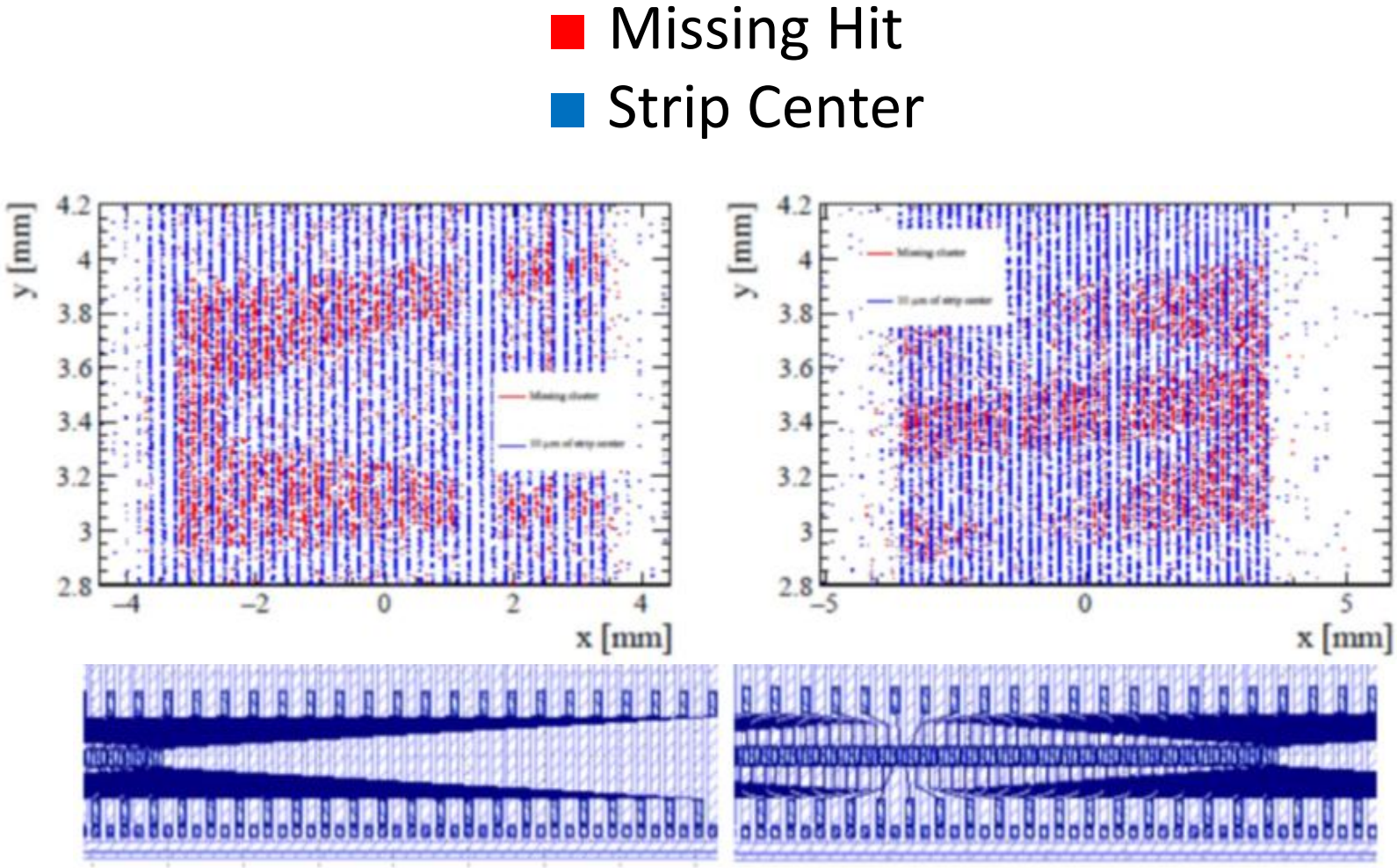
Type D Cutout

- Cutout region clearly visible in TrackY vs TrackX
- Cutout is fit to second order polynomial.
- Closest approach distance is computed, then look at the efficiency within 200um of track projection vs distance to edge.



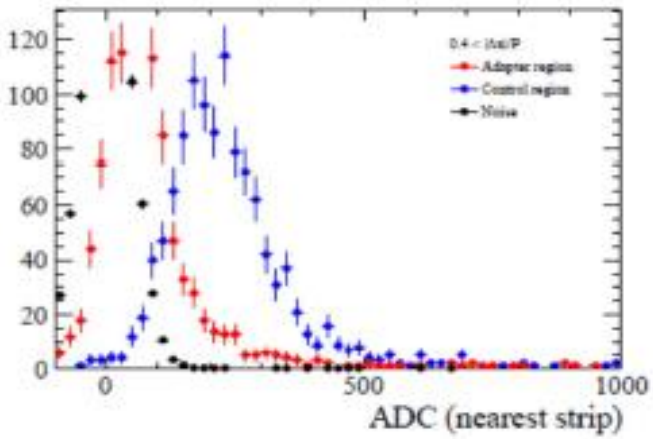
2015 Testbeam Results

- Study of n-in-p 'half-A' sensors at $2x10^{13}$ n_{eq}/cm^2 both Fan-In and Fan-Up sensors
- Frightening result: Significant inefficiency in PA region for Fan-In
- Found that this is not charge loss, but rather coupling to other strips via 2nd metal layer
- Motivation to redesign mask for Fall 2016, June 2017

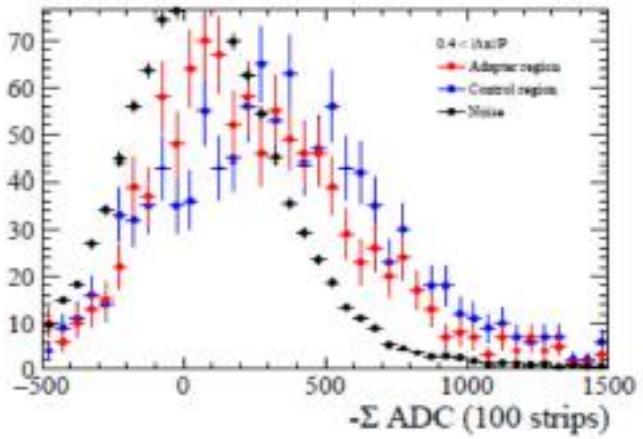
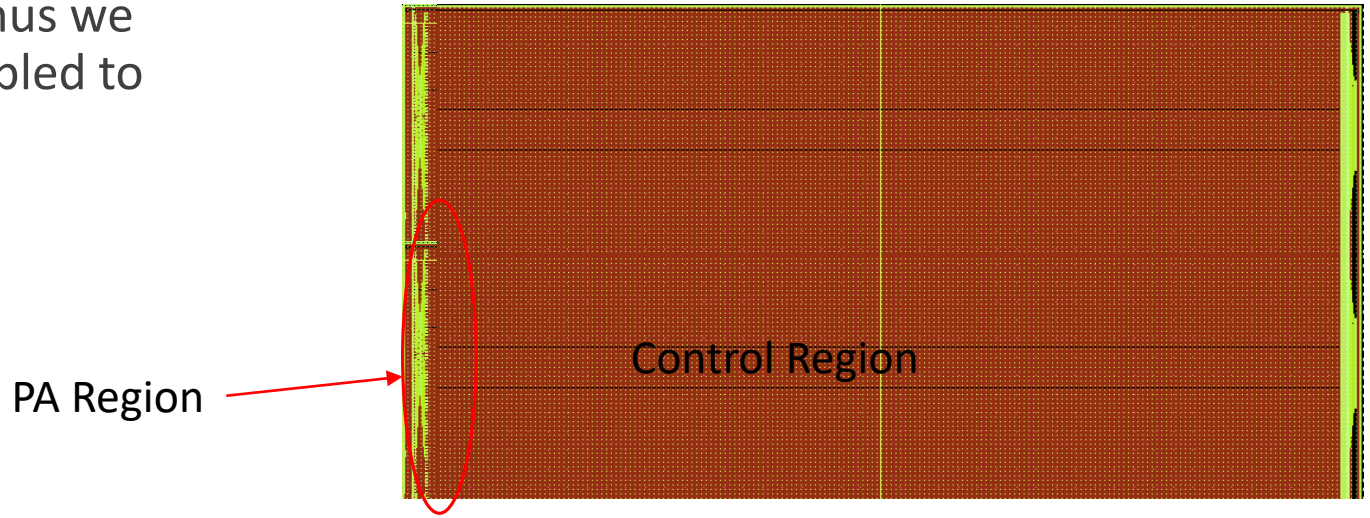


Charge Sharing: PA vs Control

- We study charge seen on the neighboring strip for the PA region (red) and the control region (blue).
- As seen in (a), there is a significant charge loss in the PA region, not seen in the control.
- (b) shows charge sum on 100 strips.
  - the two regions appear similar, thus we don't lose charge, rather it is coupled to 2nd metal layer



(a) Signal on nearest strip



(b) Sum of signal over 100 strips