Study of Prototype Sensors for the LHCb Upstream Tracker Upgrade

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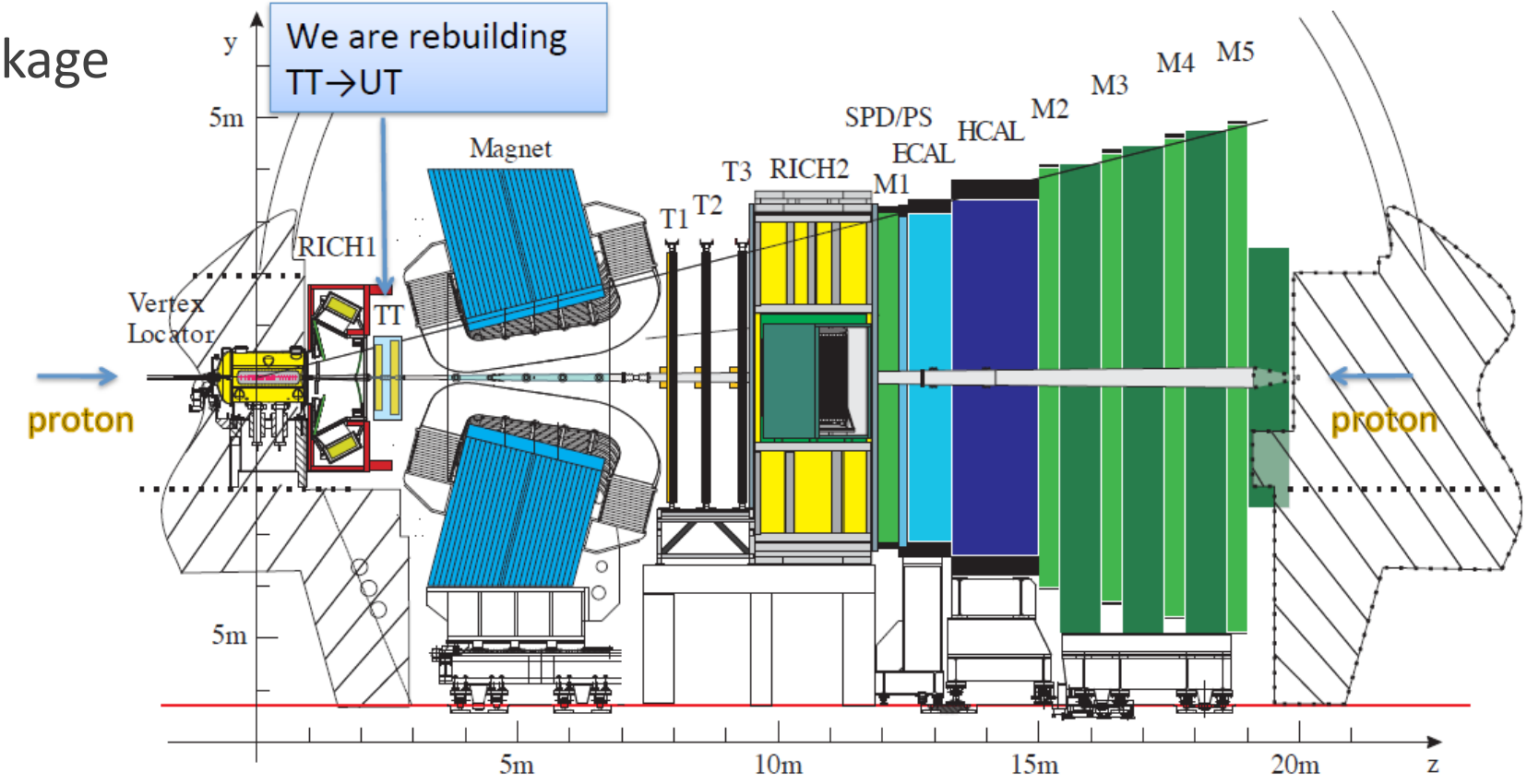
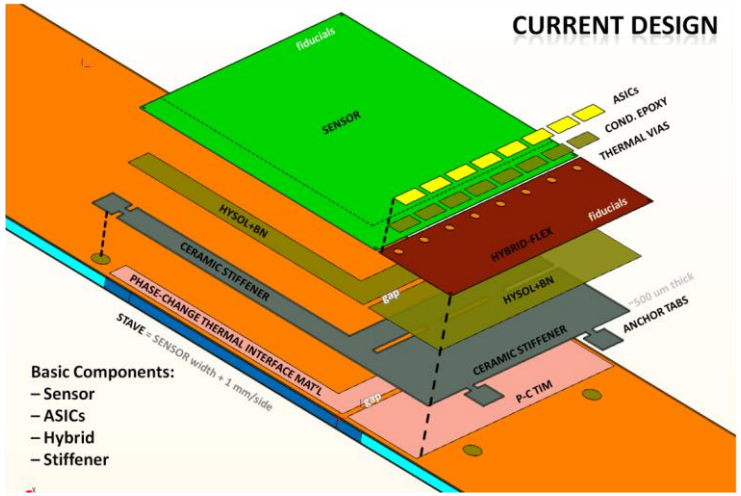
Outline

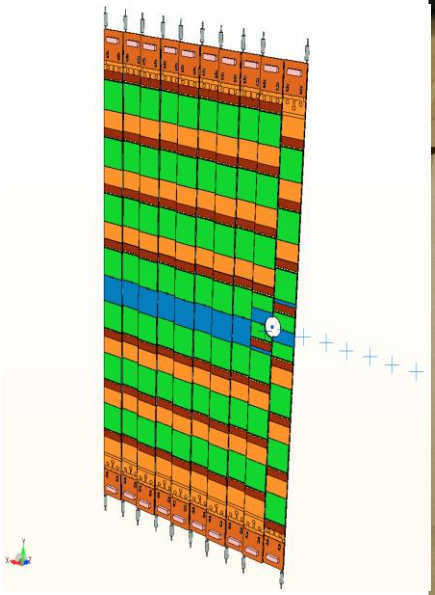
- UT Overview
  - Main Components: Stave, SALT ASIC, Silicon
- Overview of Silicon Work Package
  - Detector Species
  - Key Design Features
    - Embedded Pitch Adapter
    - Top-side bias contact
- Testbeam Results
  - Experimental Setup
  - 2015 Testbeam Campaign
  - 2016 Testbeam Campaign
  - Conclusions



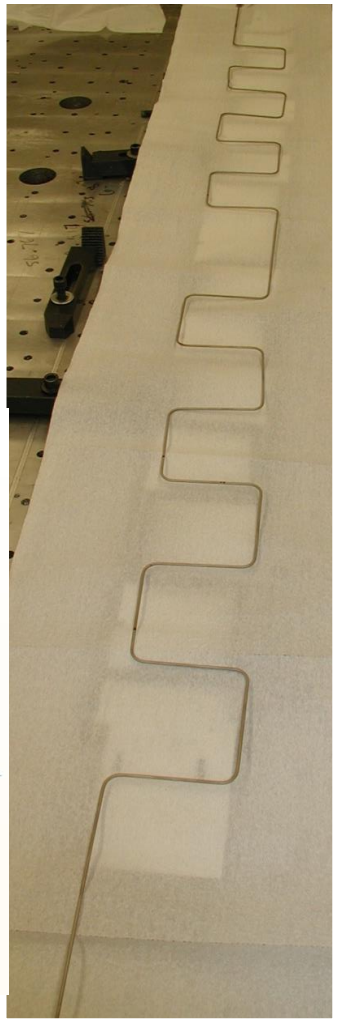
UT Overview

- 4 planes of Silicon Microstrip Detectors
- Stave:
  - 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)
  - Final design submitted in early November

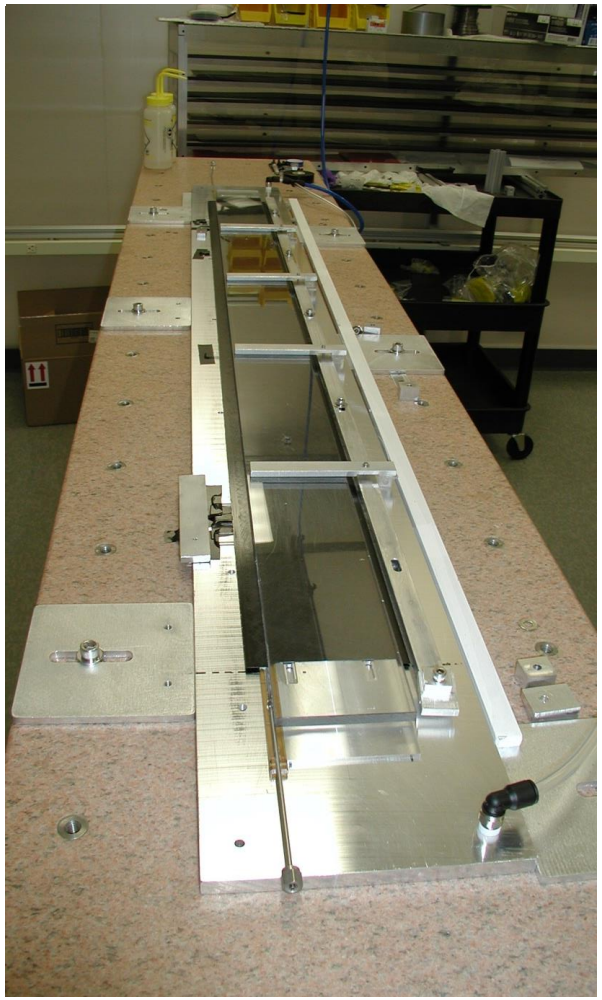




Cooling tube with brazed ends

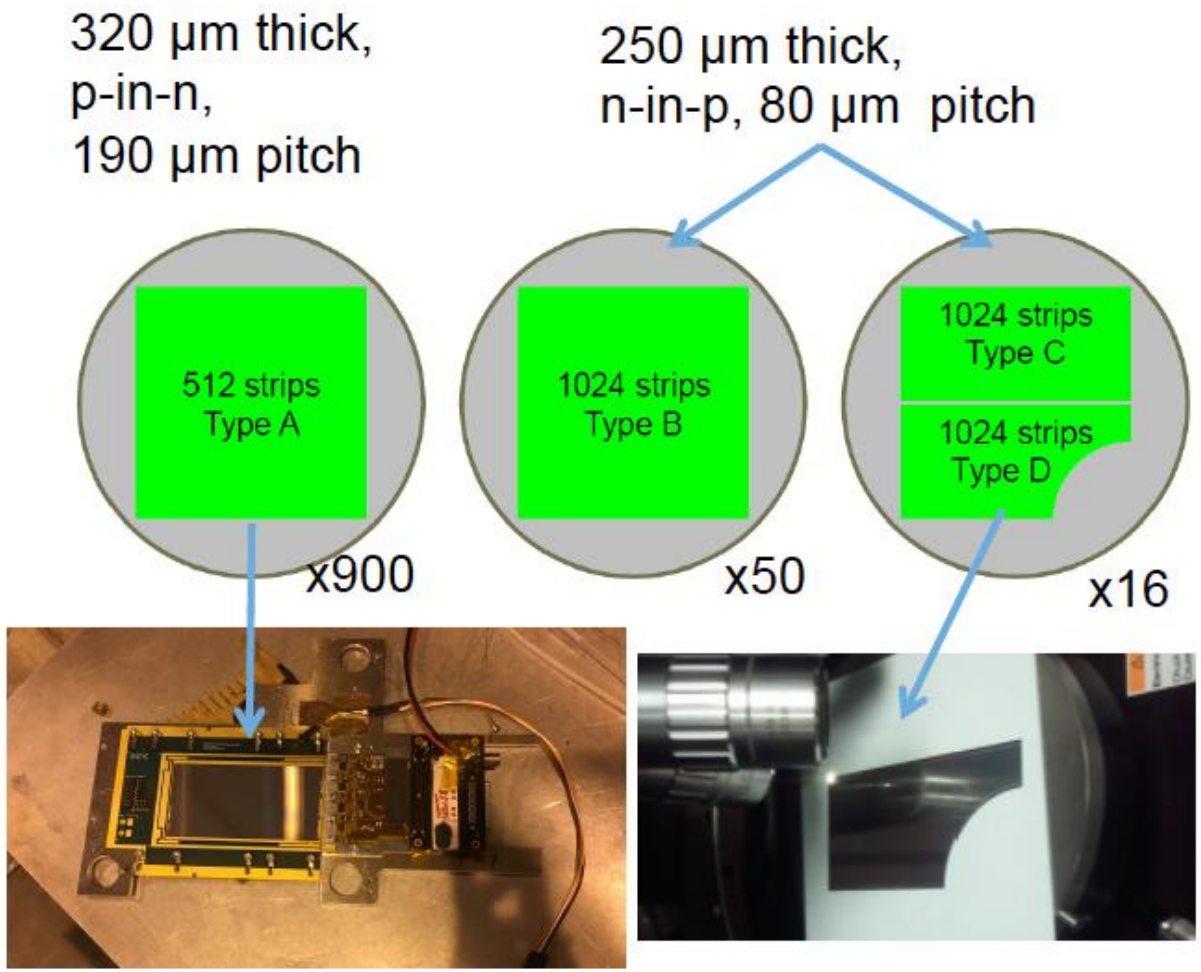


Completed stave



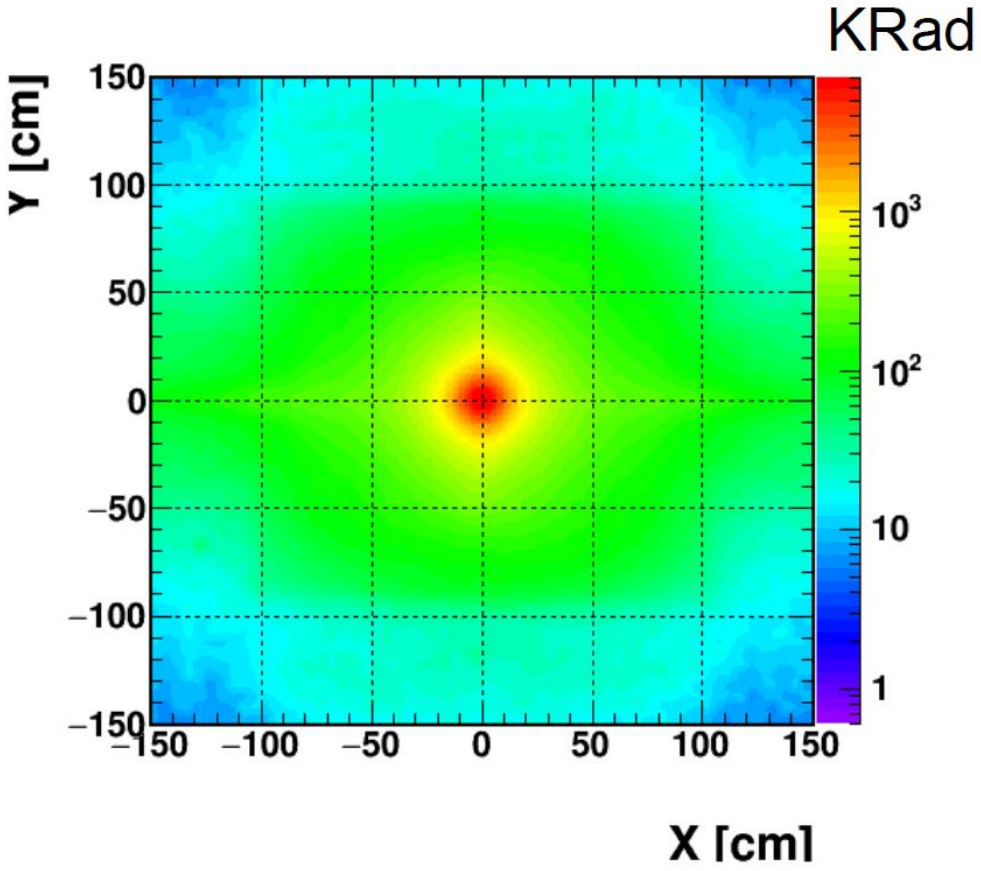
Detector Designs

- Four designs of detectors produced by Hamamatsu:
- Most Sensors are Type A, 320um thickness. B,C,D will be 250um
- Type A has 190um pitch
- All others have will have 80um pitch



Silicon Requirements

- No breakdown below 600V
- 40 Mrad max dose
- Maximum fluence after total integrated luminosity of **50fb^{-1}:**
  - Type A: **2.0x10^{13}** 1MeV n_{eq}/cm^2
  - All others: **1.0x10^{14}** 1MeV n_{eq}/cm^2 (Type D: 5e14)
- Majority of the UT will be constructed with p-in-n sensors
  - Innermost staves, with sensors around the beam pipe, will be n-in-p

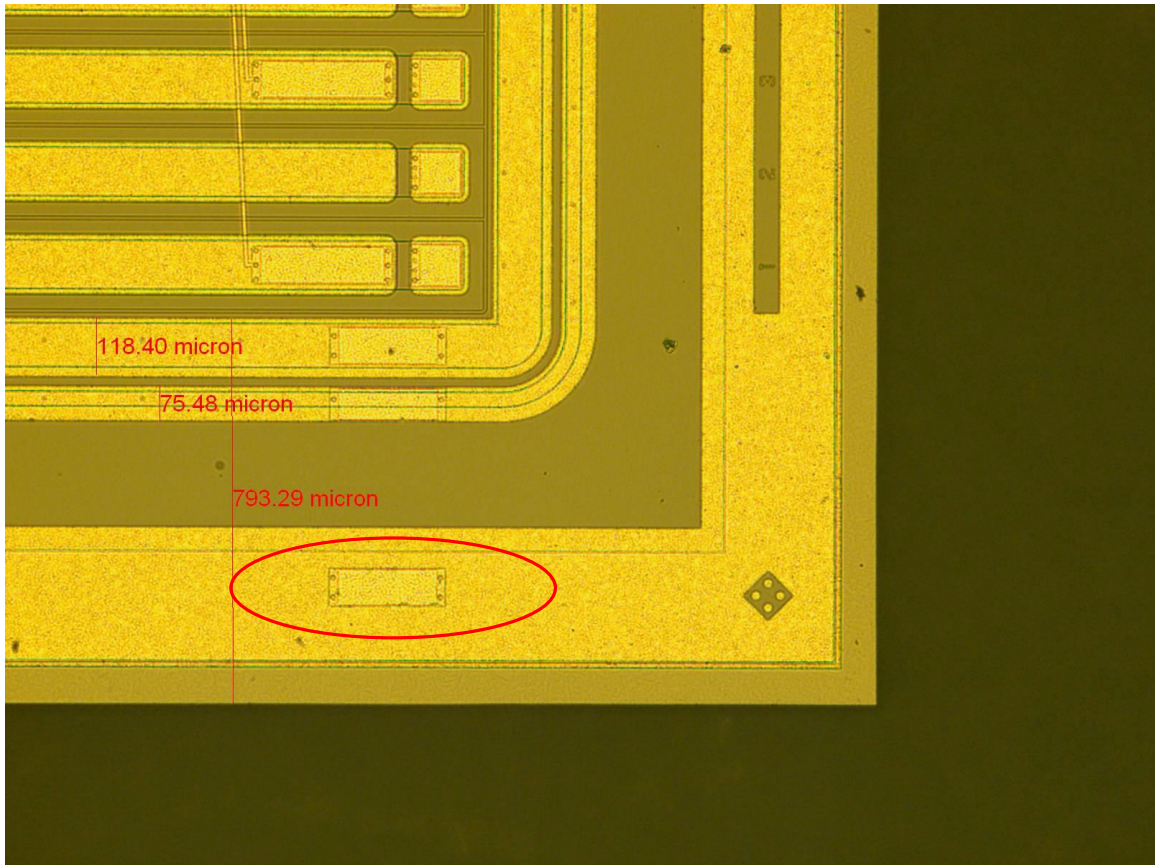


Non-uniform irradiation profile depending on distance from beam center.

Key Design Features

Top-Side Bias Contact

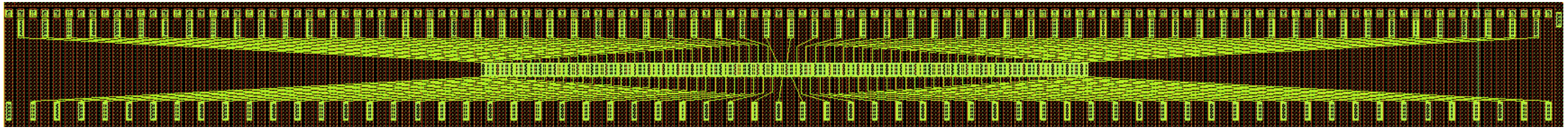
- All detectors will feature a topside contact for biasing, and the HV will be brought to the back via a conductive side edge.
- This is the baseline design – simplifies assembly procedure



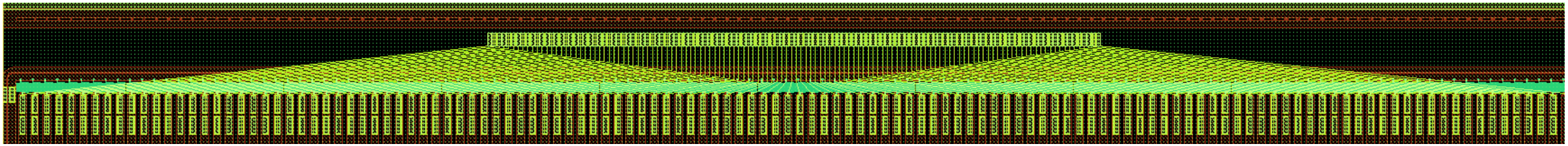
Embedded Pitch Adapters

- Scale the 190um pitch of Type A sensors to 80um pitch of SALT ASIC.
- Accomplished via 2nd metal layer on top of existing strip metallization and SiO_2
- Two designs were studied:

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

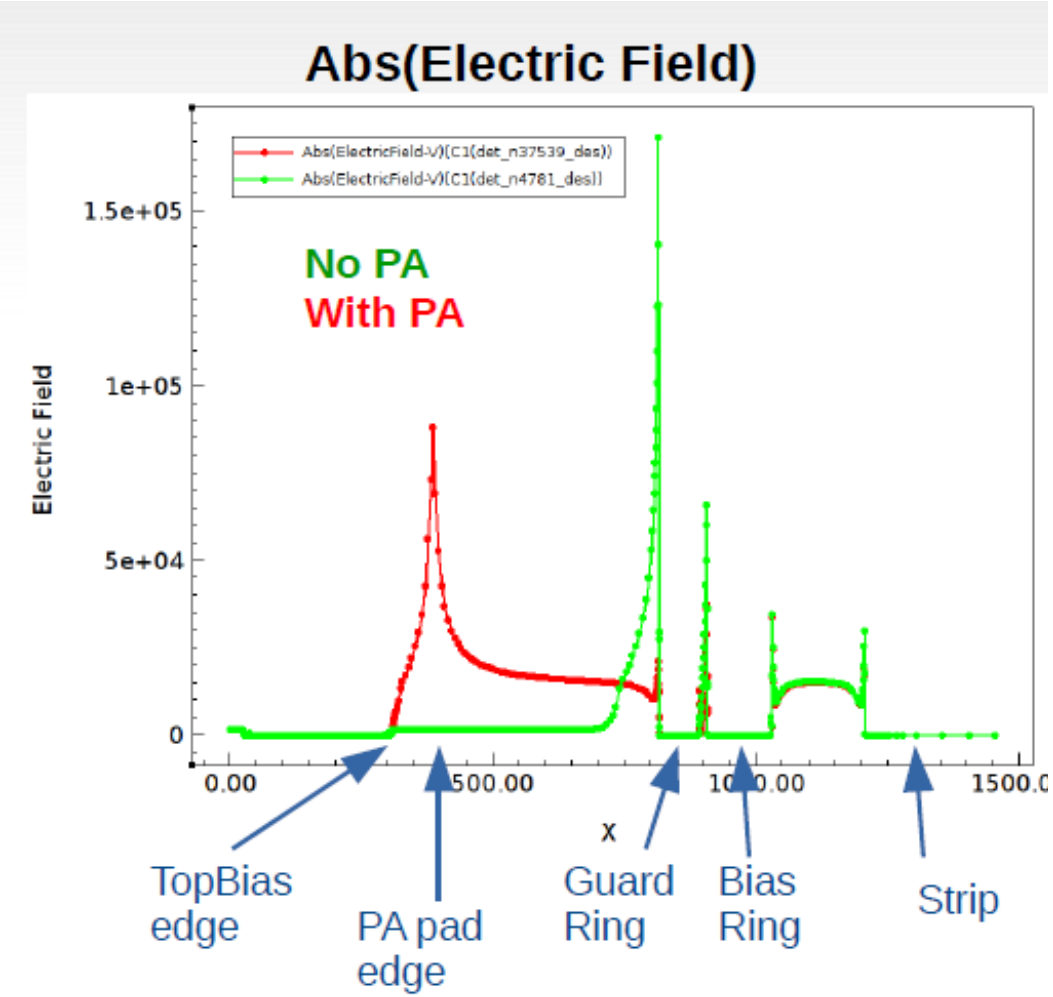


Fan-Up: Traces and bond pads are outside the active area



Fan Up Instability

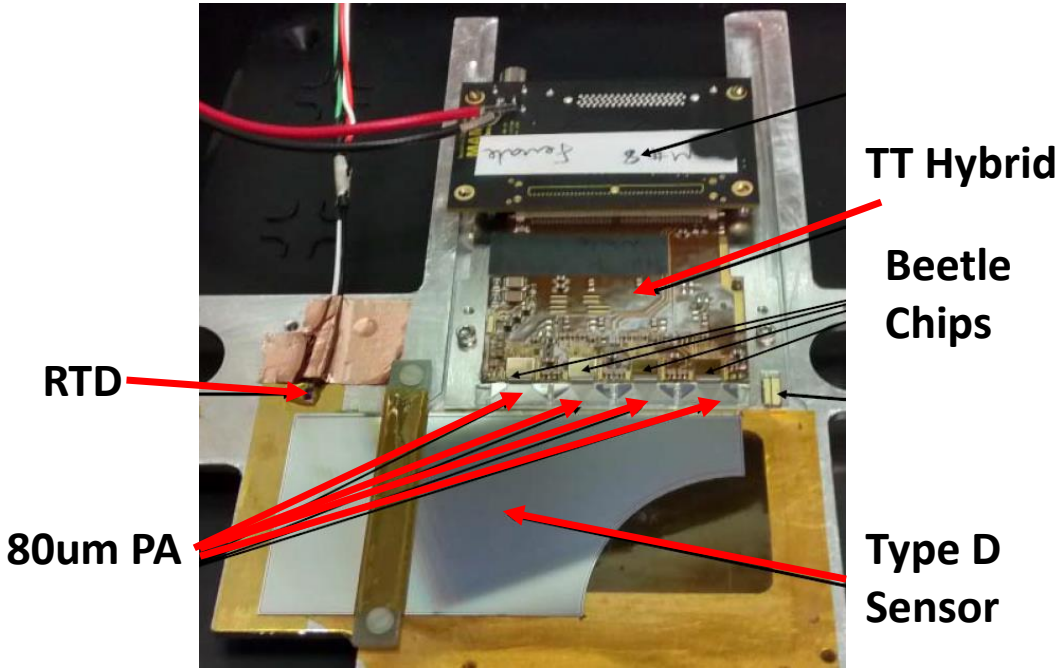
- Simulations show some instability problems with Fan Up
  - Some concerns expressed by Hamamatsu
  - Higher-risk design moving forward

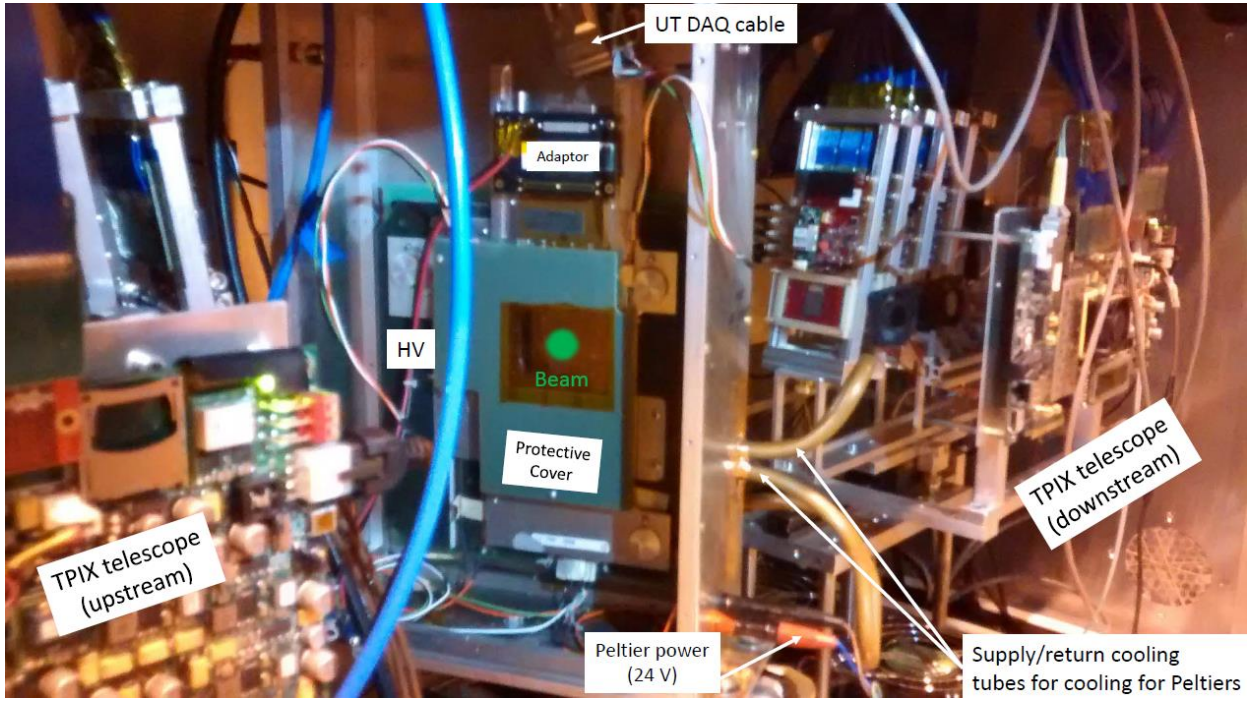


Testbeam 2015

Experimental Setup

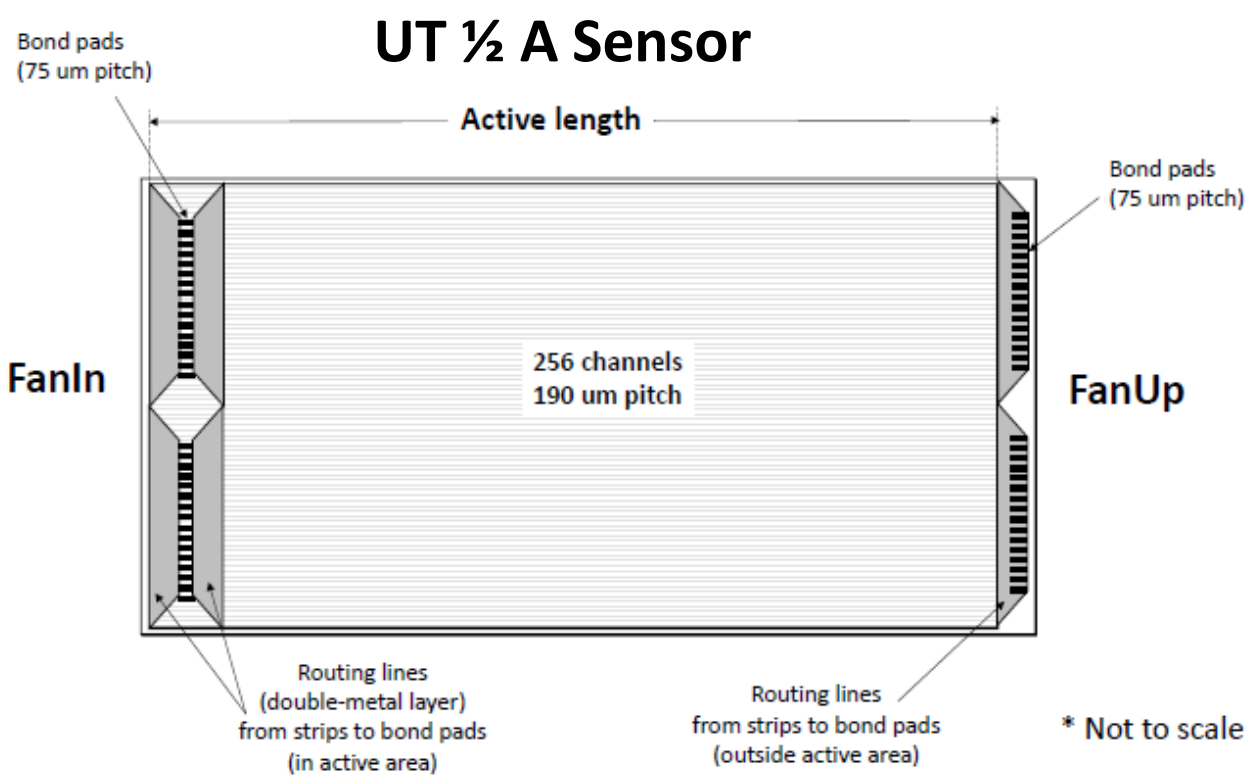
- Both testbeam efforts used the MAMBA (**M**ilano **A**dvanced **M**ulti **B**eetle-chip **A**cquisition **B**oard) system.
- Accommodates multiple TT Hybrids, each with 4 beetle chips: **Beetles used in Testbeams**
- Tracking accomplished with the Timepix3 Telescope:
  - 55um pitch pixel sensors, 4 planes upstream of DUT, 4 downstream.





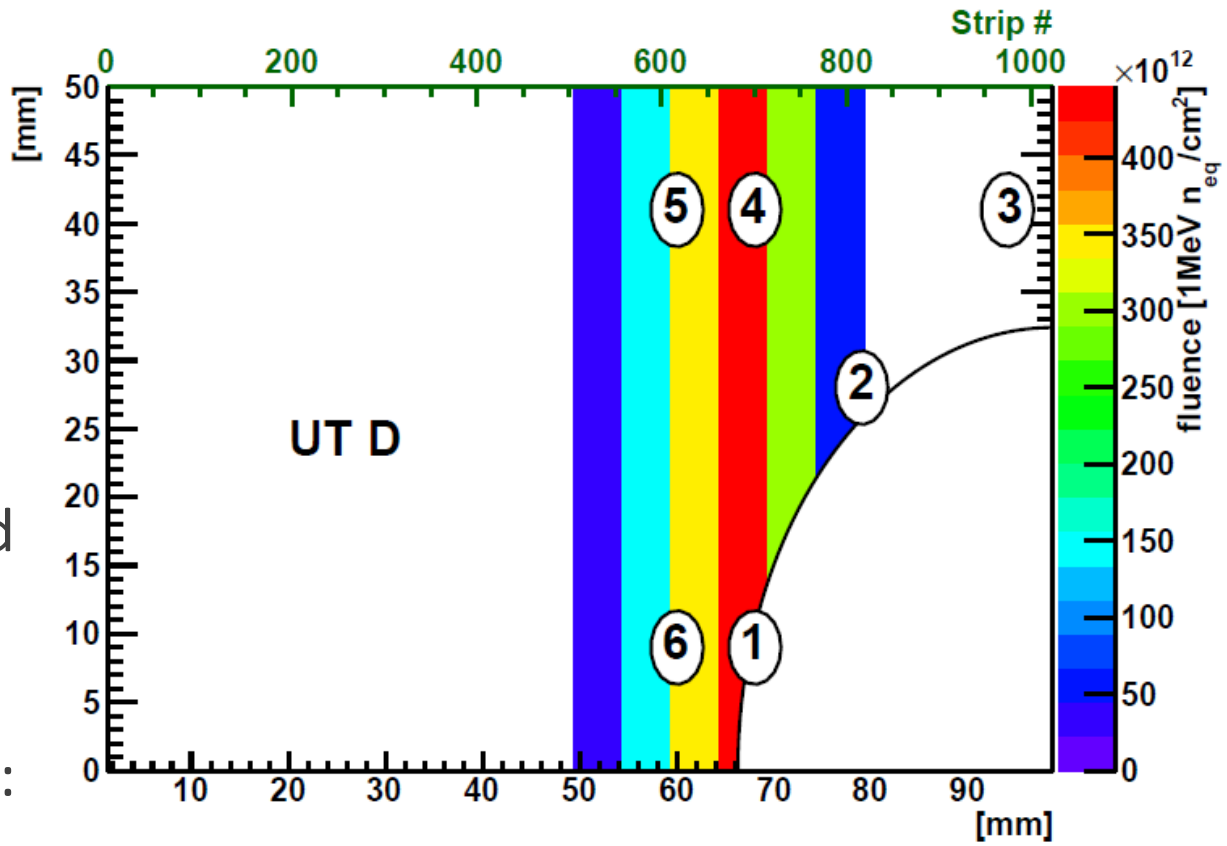
2015 Testbeam Campaign

- Three testbeams were carried out in July, October, and November.
- Main Goals:
  - Characterize the CCE of full size Type D sensor in the circular cut-out region, at multiple fluences
  - Characterize the CCE of “1/2 A” sensors using either type of embedded pitch adapter.



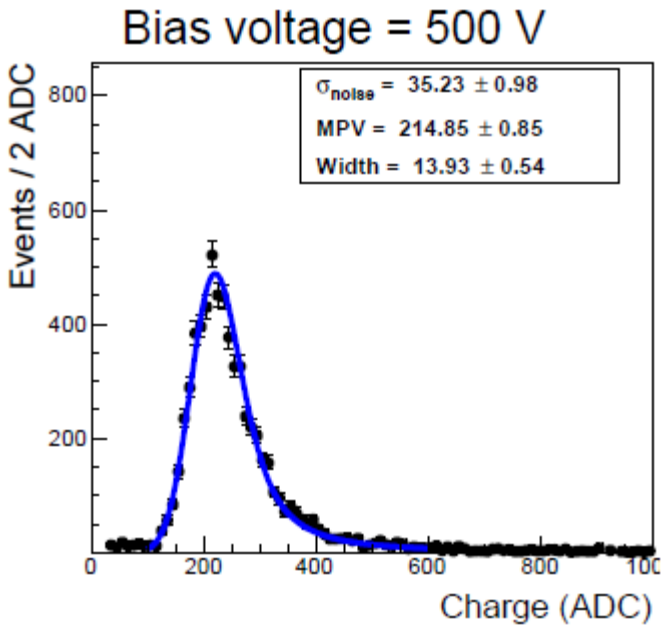
Type D Irradiation

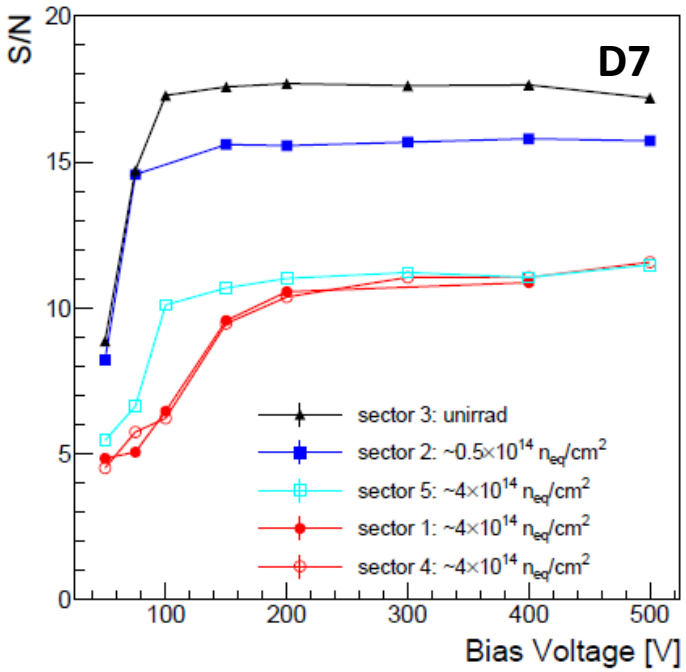
- 33.4mm radius cutout around beam pipe region
- Closest to beam pipe, must tolerate highest fluence
- Irradiation performed at CERN IRRAD facility with 24 GeV proton beam.
- Goal was to illuminate both cutout region and full strip length.
- Max delivered fluence: 4.4×10^{14} n_{eq}/cm^2 . Maximum expected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

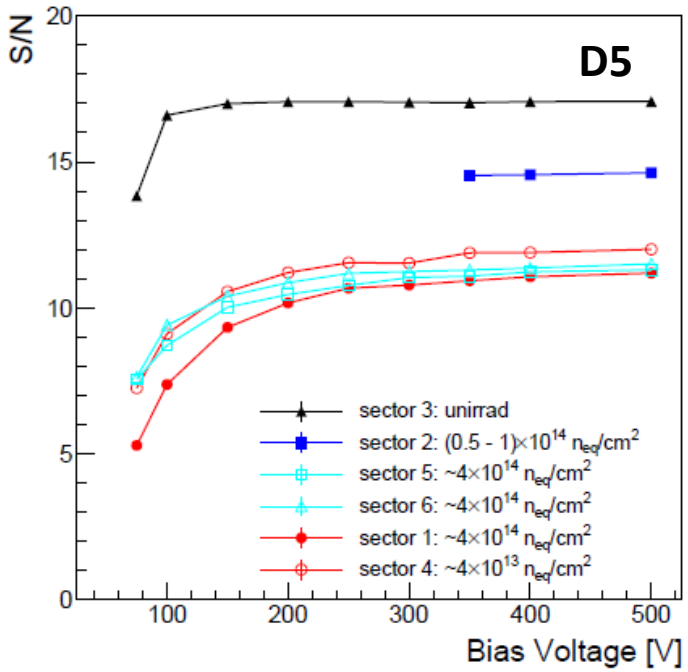


Type D Performance

- 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



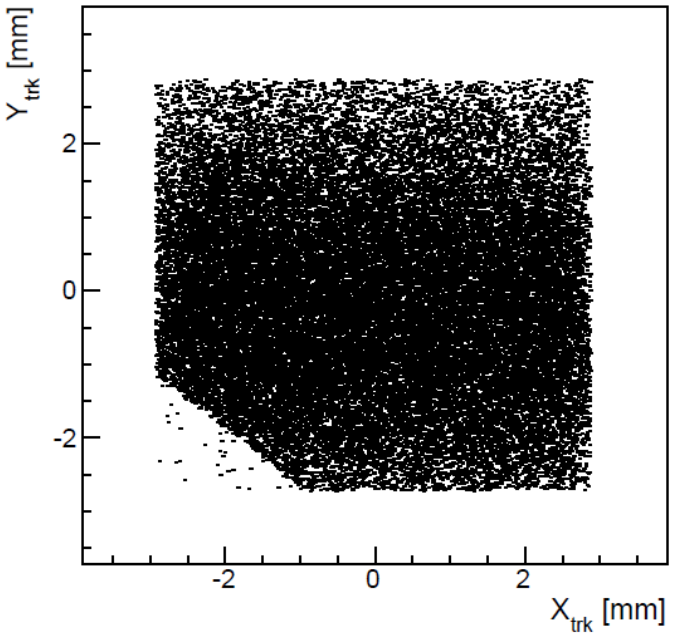


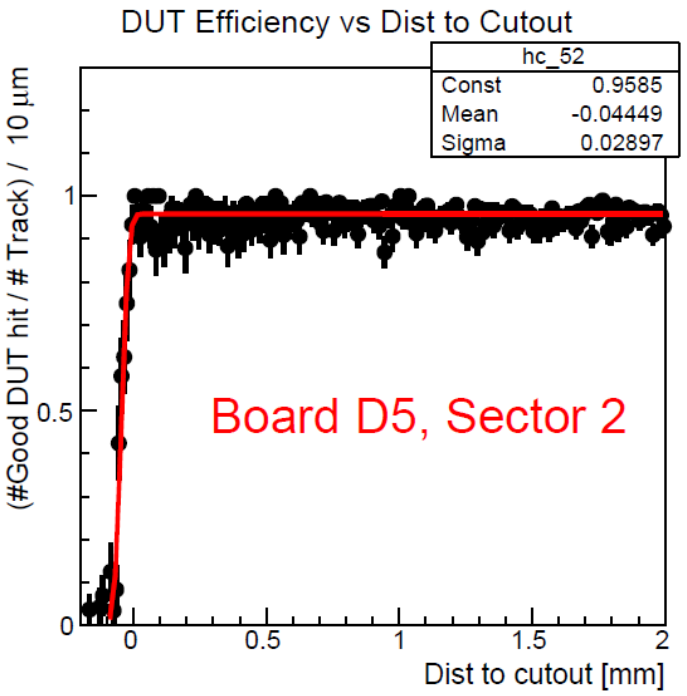


Type D Cutout

- 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.

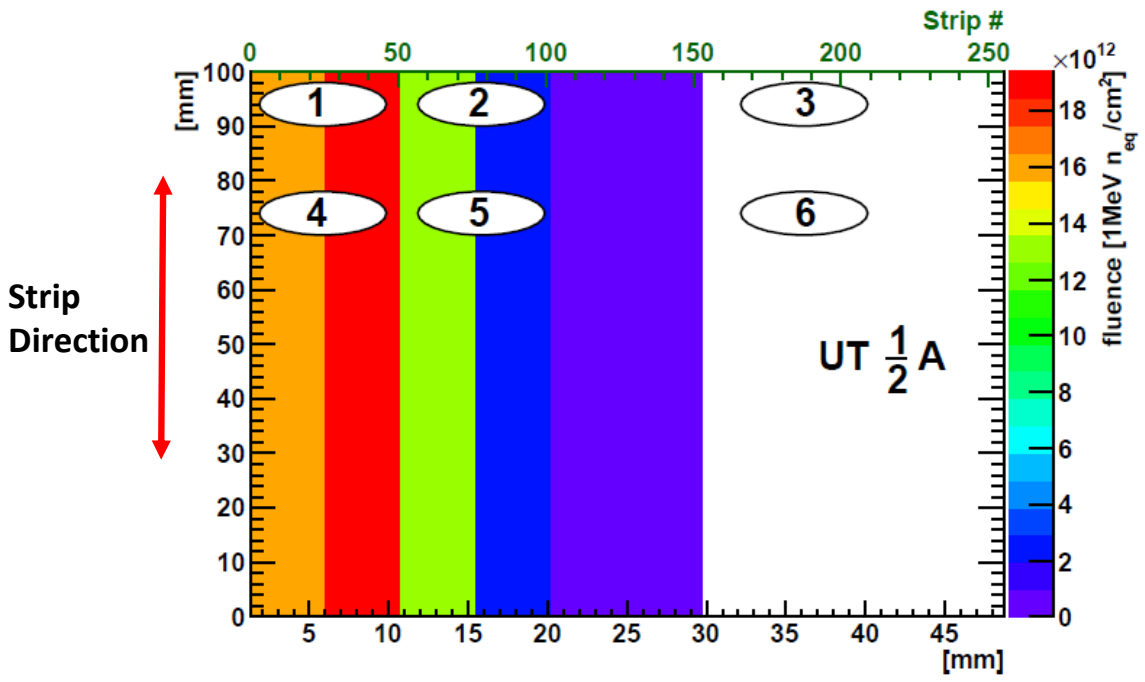
*Only small region of cutout visible here, see backup for other sectors

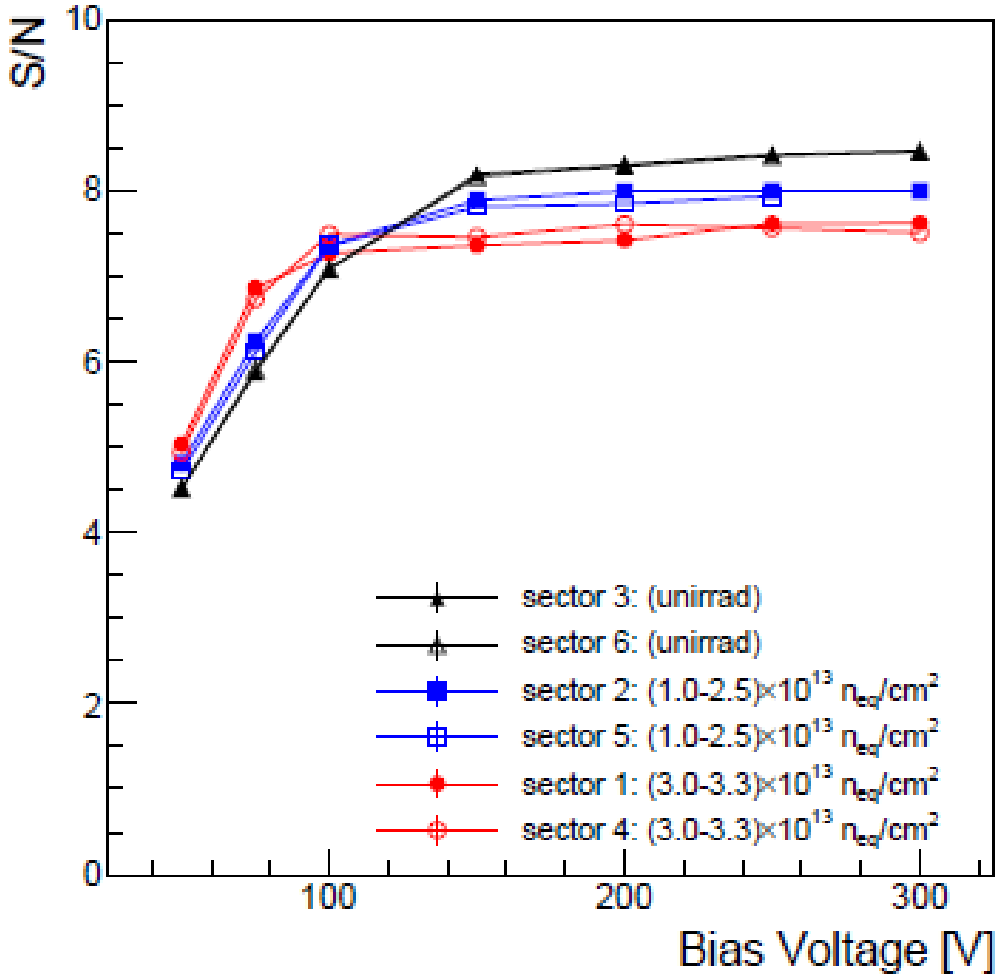




Type ½ A Performance

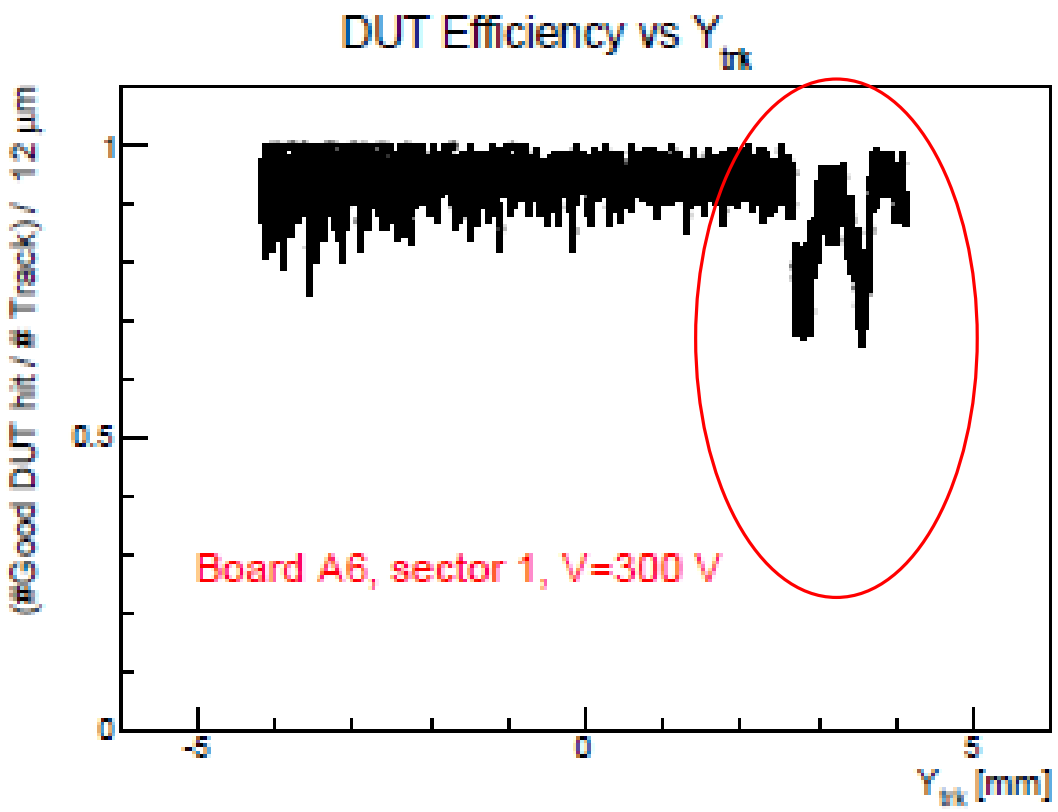
- Expecting higher SNR:
  - 200um sensor – Final type A will be 320um
  - Using Beetles in TB environment
  - This sensor has both embedded PA designs



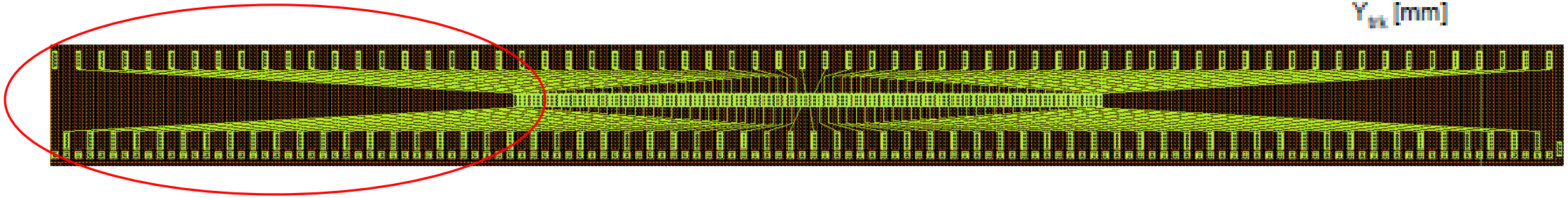


Type ½ A: Fan In

- Study efficiency of detector vs Y position above depletion voltage (140V).
- **Large inefficiency in Y near sensor edge!**

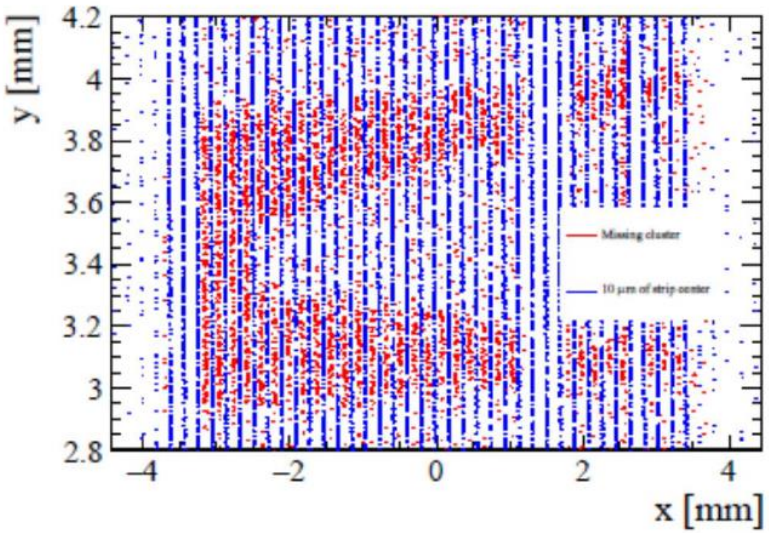


Sector 1

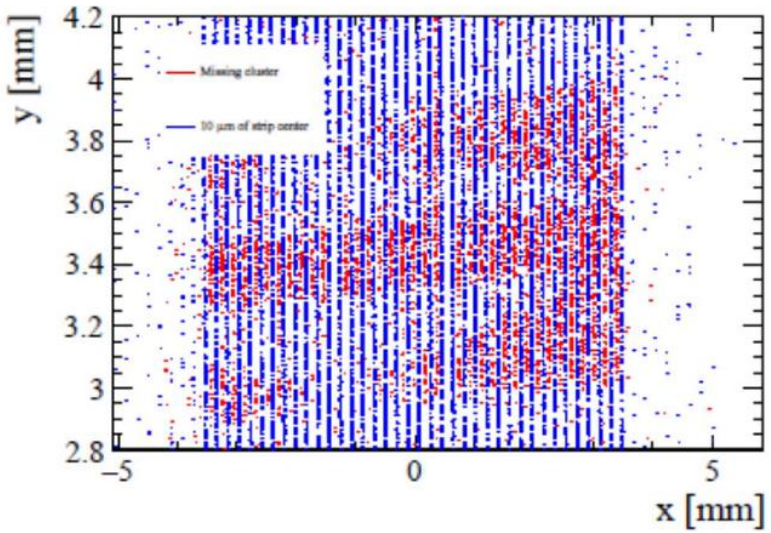


Fan In Efficiency

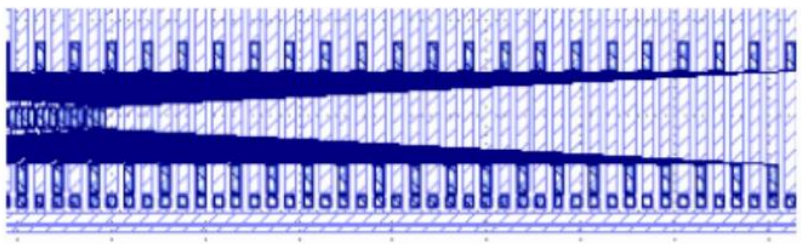
- Plot shows Y vs. X position of a track when there are missing clusters (red).
  - Strip locations are shown in blue for reference (matched cluster found within 10um of strip center)
- Clearly we are losing charge in the PA region from both traces and bond pads
  - Occurs in the middle between two strips
- We suspect that we are not losing charge, but it is being picked up on other strips due to 2nd metal traces…

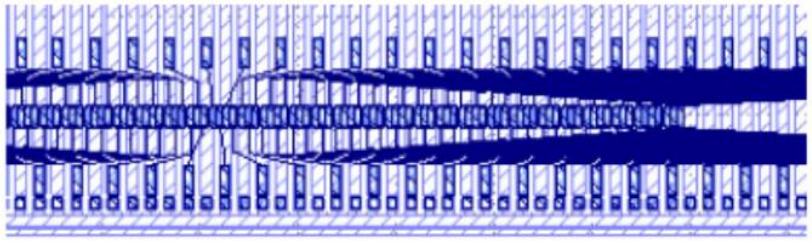


(a) Edge of pitch adapter region



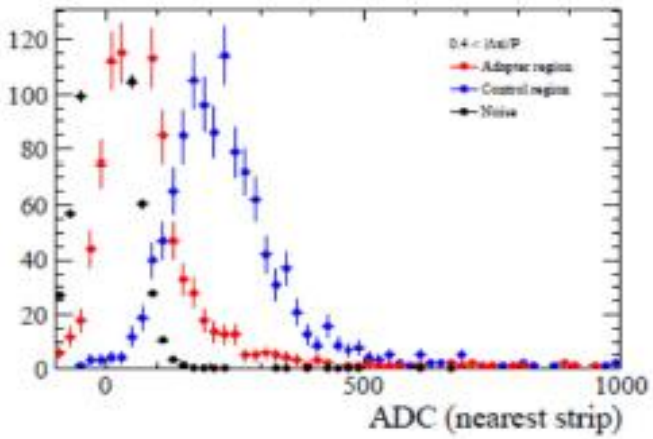
(b) Center of pitch adapter region



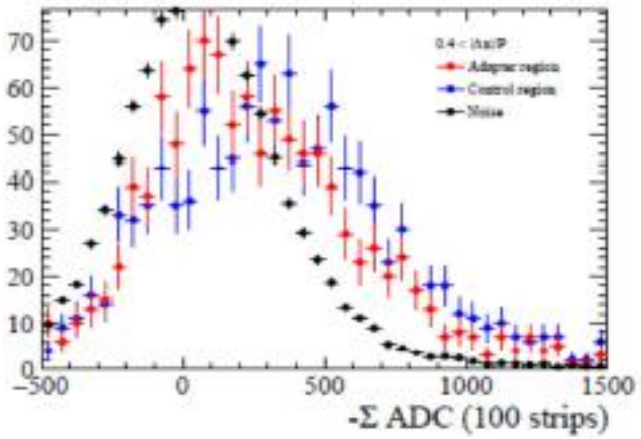


Charge Sharing: PA vs Control

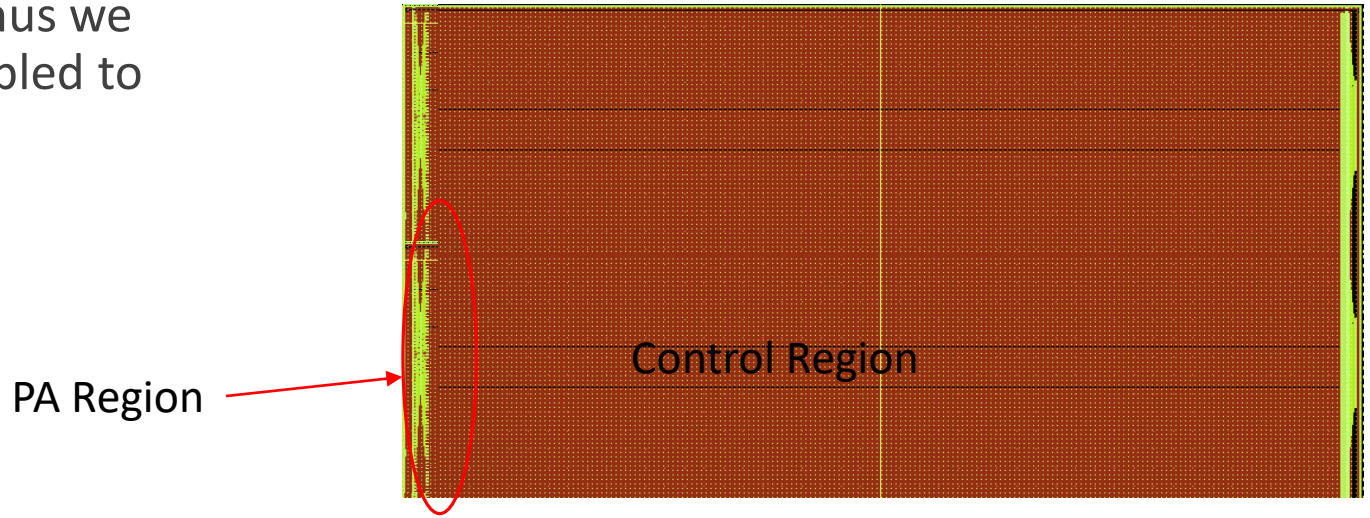
- We study charge seen on the neighboring strip for the PA region (red) and the control region (blue).
- As seen in (a), there is a significant charge loss in the PA region, not seen in the control.
- (b) shows charge sum on 100 strips.
  - the two regions appear similar, thus we don't lose charge, rather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



(a) Signal on nearest strip

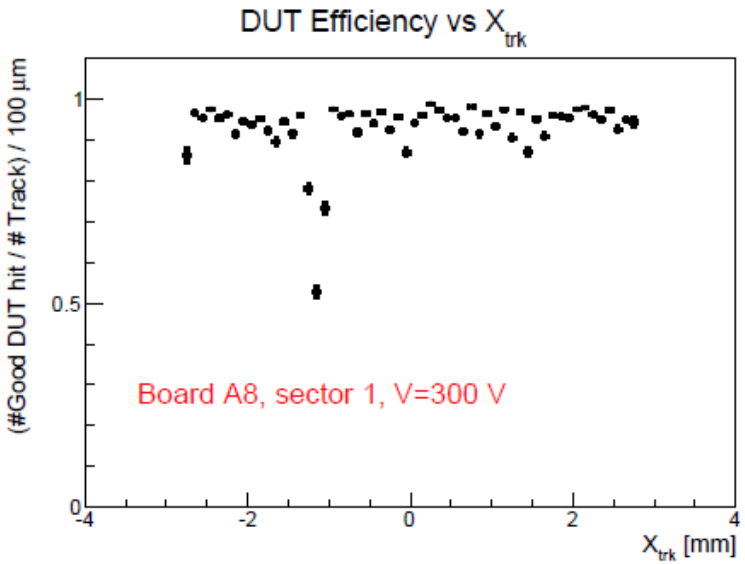


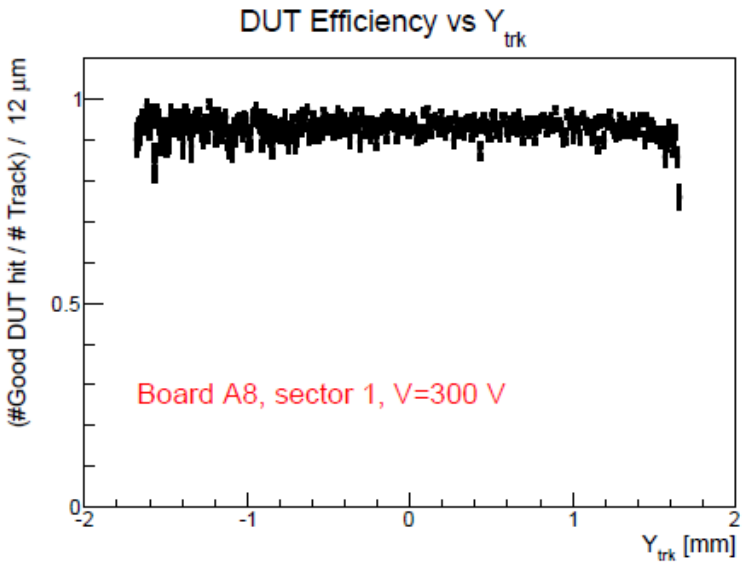
(b) Sum of signal over 100 strips

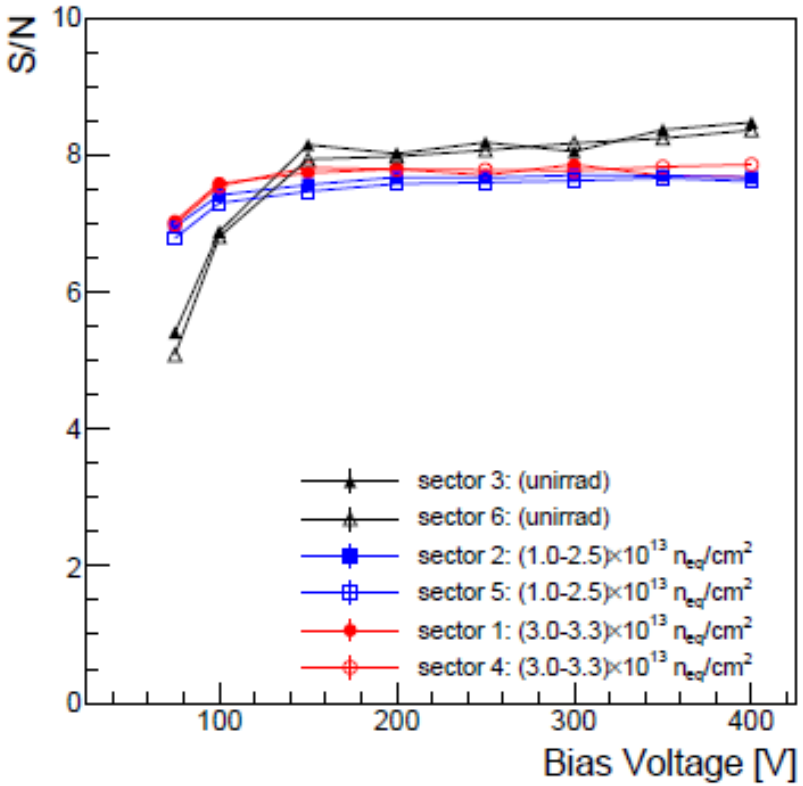


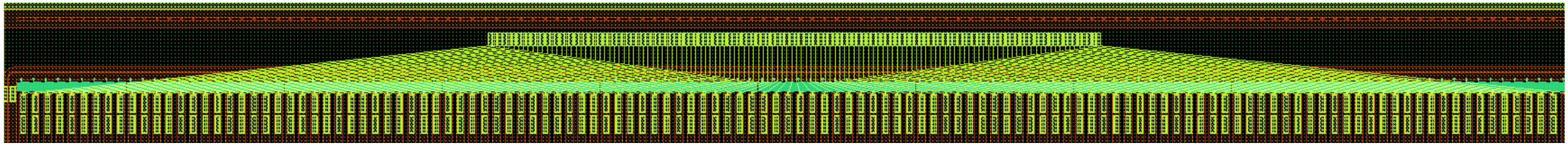
Type ½ A: Fan Up

- Here we do not see any inefficiency in Y (no PA effect)
  - Bulk of the PA is outside of the active region





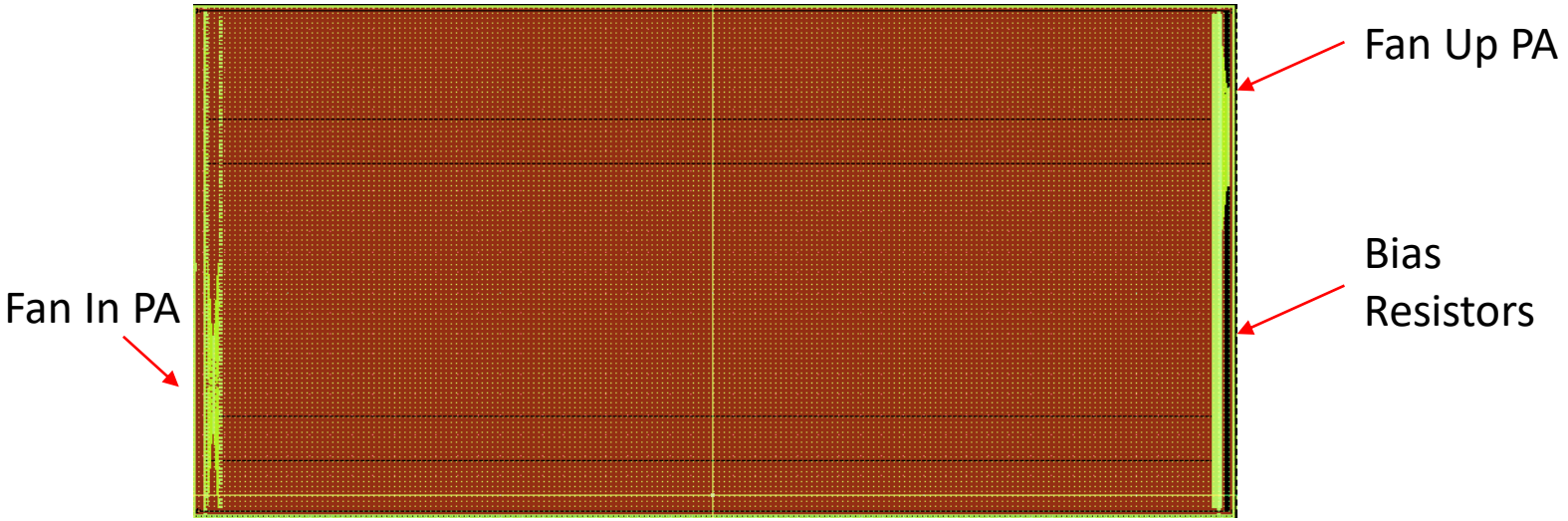


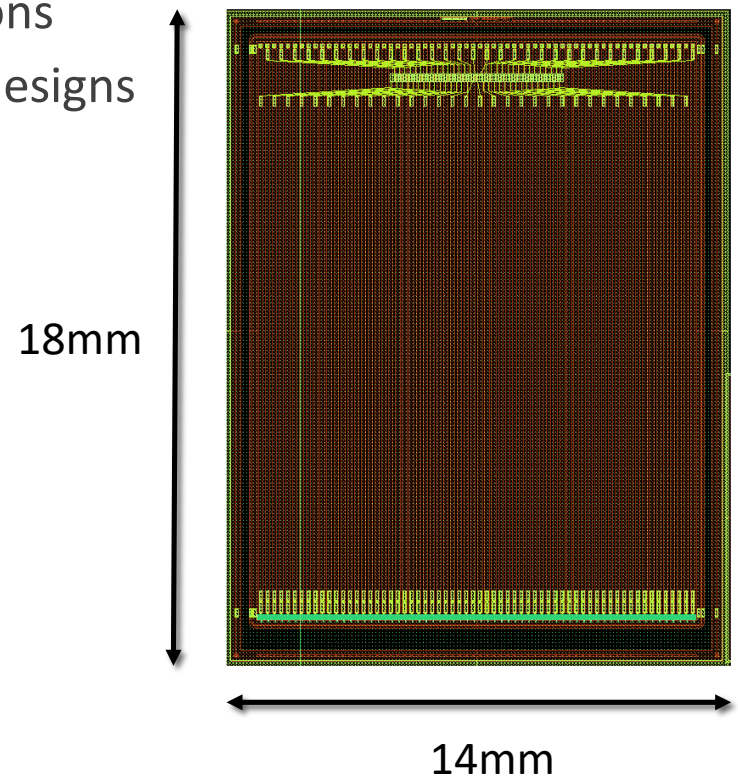


Testbeam 2016

2016 Testbeam Campaign

- Two testbeams were carried out in May and October of 2016 (only May results presented here as Oct. analysis is still in progress).
- Goals of May Testbeam:
  - Study the performance of **p-in-n** mini sensors with updated mask (only 1 PA design on the strips, see below.)
  - Verify that there is no performance difference between biasing configurations
  - Characterize CCE of mini and ½ A p-in-n sensors with either embedded PA designs



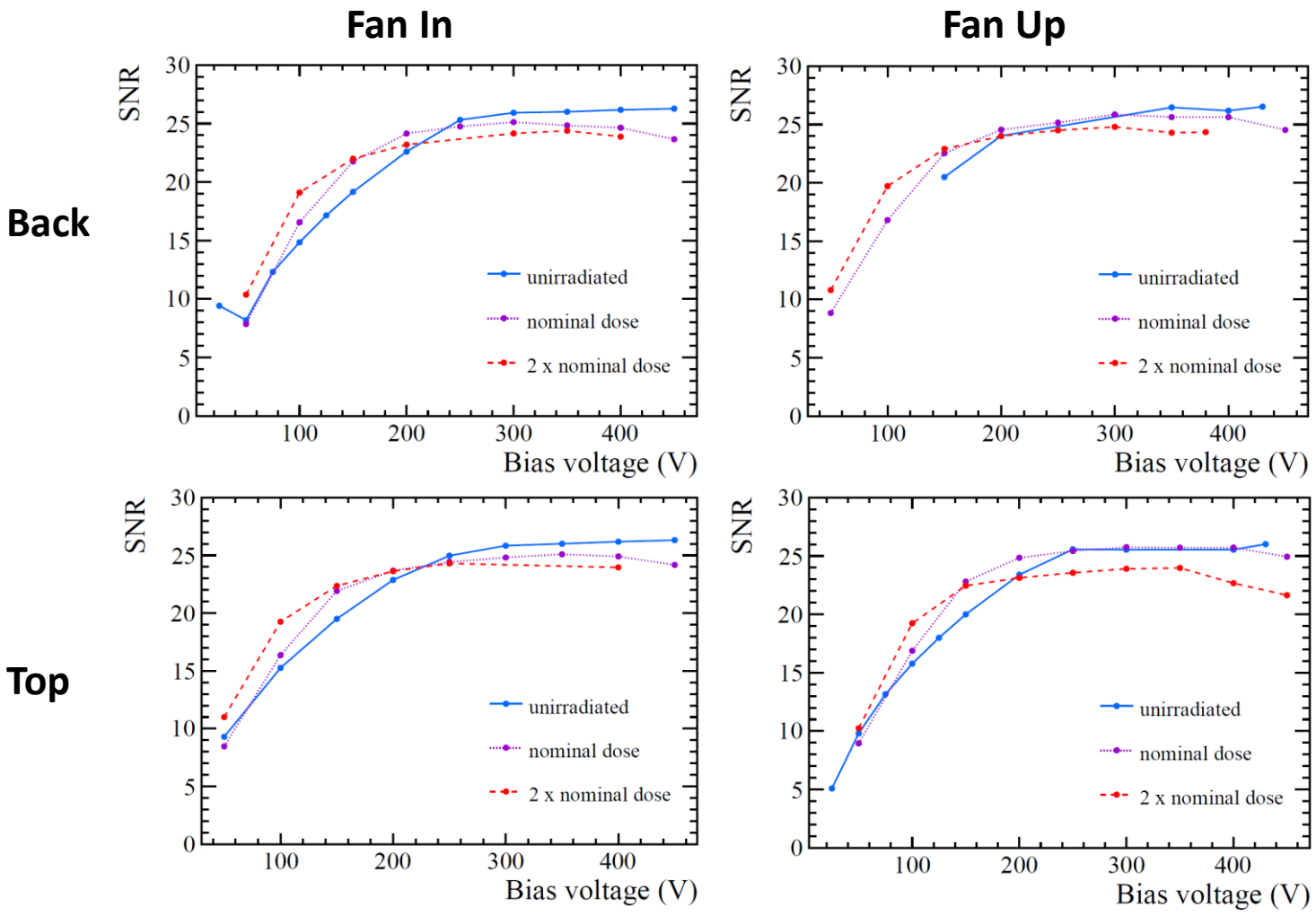


Mini Sensors

- A total of 6 Hamamatsu mini sensors were studied in May of 2016:
  - Half-A style layout (embedded PA, 190um pitch, 320um thickness)
  - 64 channels
  - Only 1 species of PA on each detector
    - 3x Fan-In
    - 3x Fan-Up
- Mini sensors were studied at three levels of irradiation:
  - Zero fluence (unirradiated)
  - 2.0×10^{13} n_{eq}/cm^2 (nominal expected dose)
  - 4.0×10^{13} n_{eq}/cm^2 (2x nominal)
- Irradiation carried out at Massachusetts General Hospital:
  - 226 MeV proton beam, 2cm diameter beam
  - >90% uniformity of irradiation across sensor

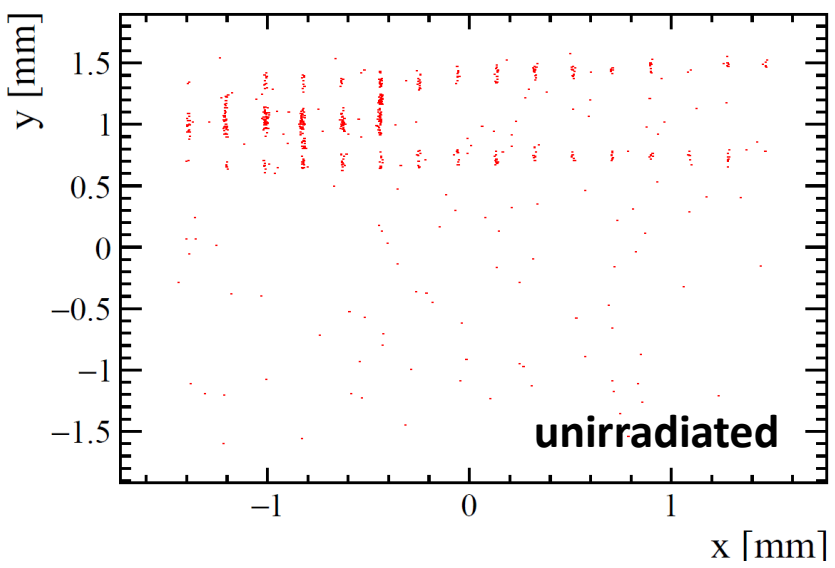
Topside vs Backside Biasing: Mini Sensors

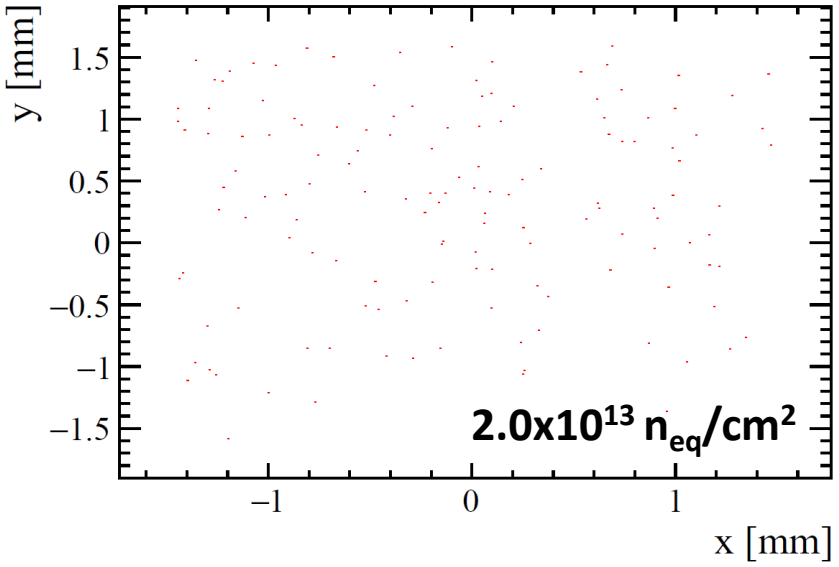
- Sensors allowed to be biased either in Top or Backside configuration (no passivation)
- Allows for direct comparison of Top vs Back, for each style of PA
- SNR ≈ **25** in each case, decreasing with fluence
- **No significant decrease in performance between biasing schemes**

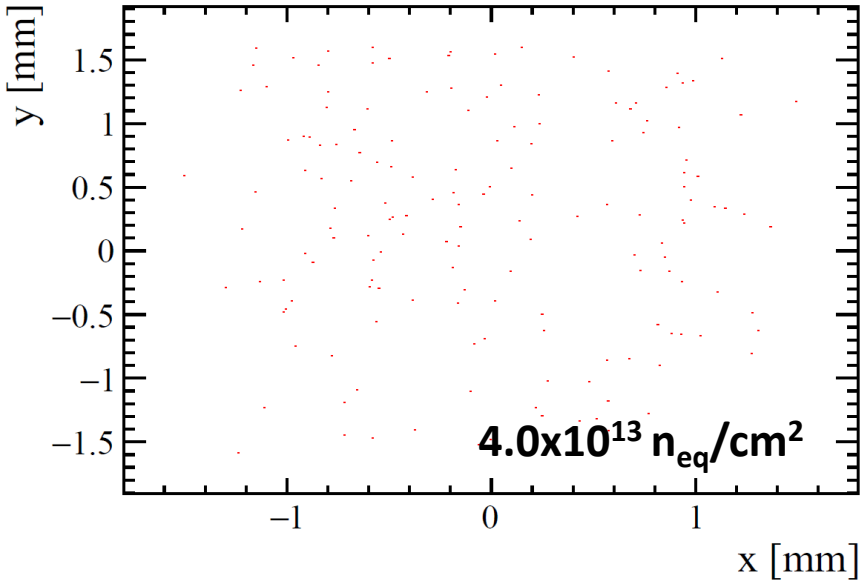


Fan In PA Performance: Mini Sensors

- Efficiency of **p-in-n** sensors in PA region studied for each fluence level
- Similar inefficiency seen in unirradiated detector, not as much as p-type:
  - **These plots scale up noise by 3x**
- Disappears at the nominal dose
- Again, no inefficiency seen in Fan Up sensors

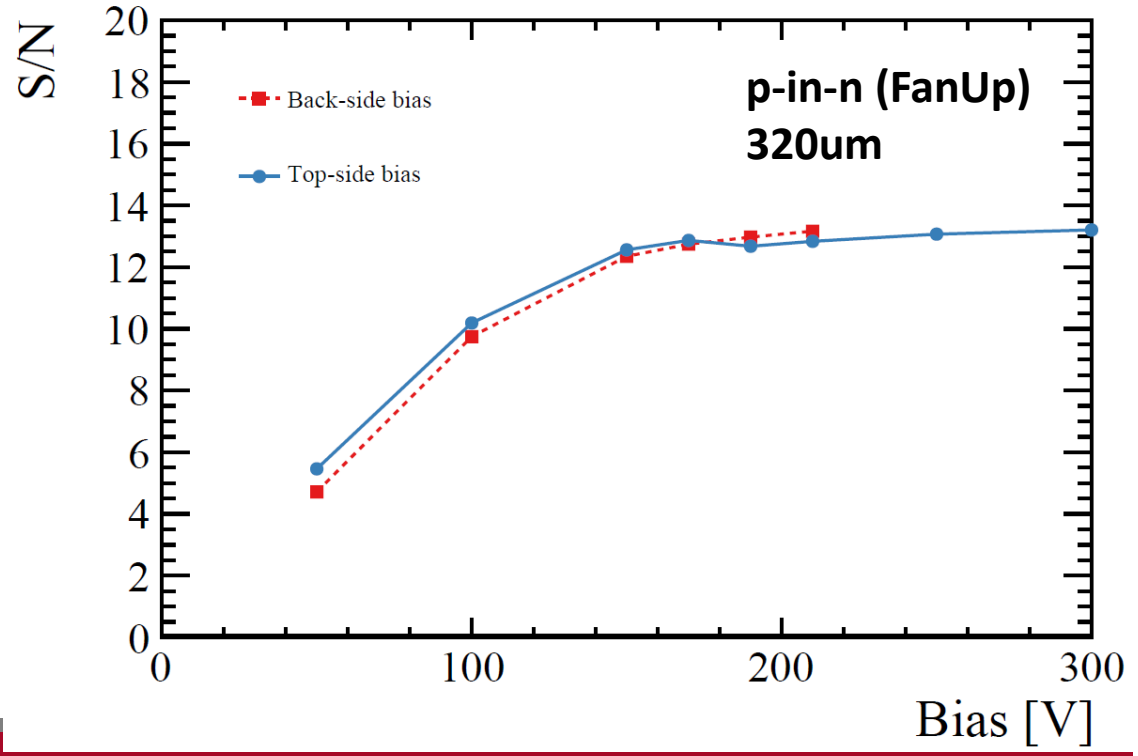


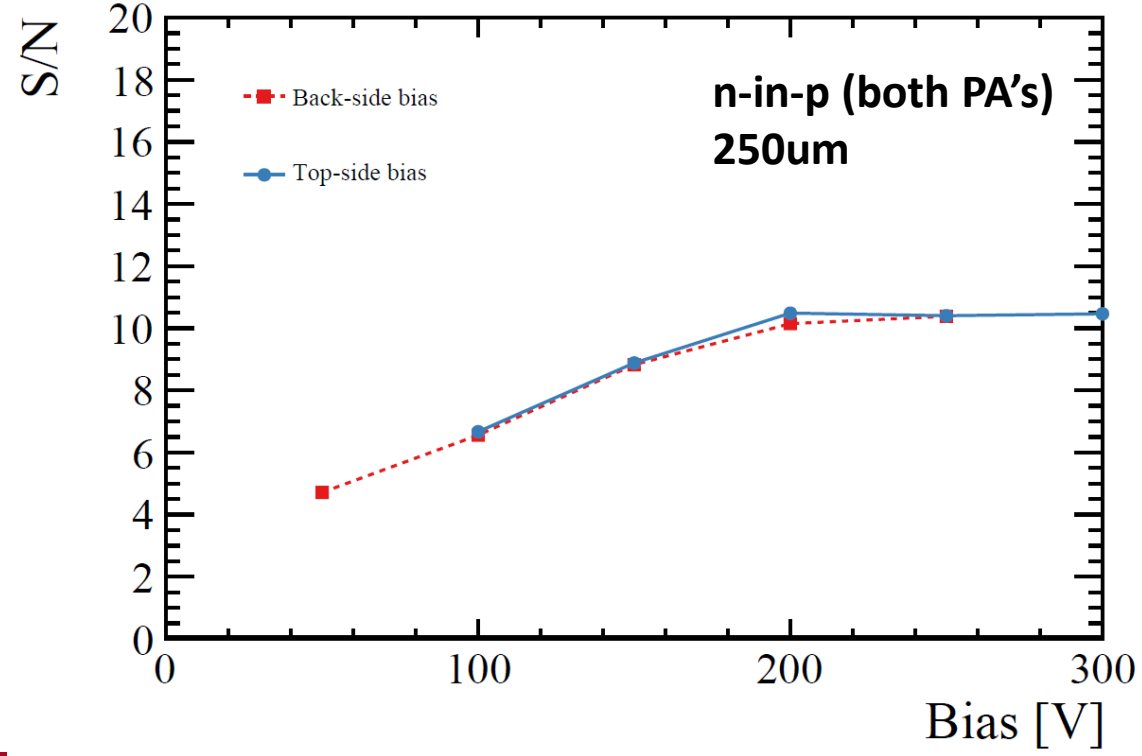




Type ½ A Performance

- SNR studied for two Type ½ A sensors:
  - Irradiated at CERN IRRAD to 2.45 n_{eq}/cm^2
  - One n-in-p sensor, with only 1 PA per strip
  - One p-in-n sensor, with both PA's at either strip end.
  - Slight improvement of SNR from 2015 ½ A, however significantly lower than mini's





Conclusions

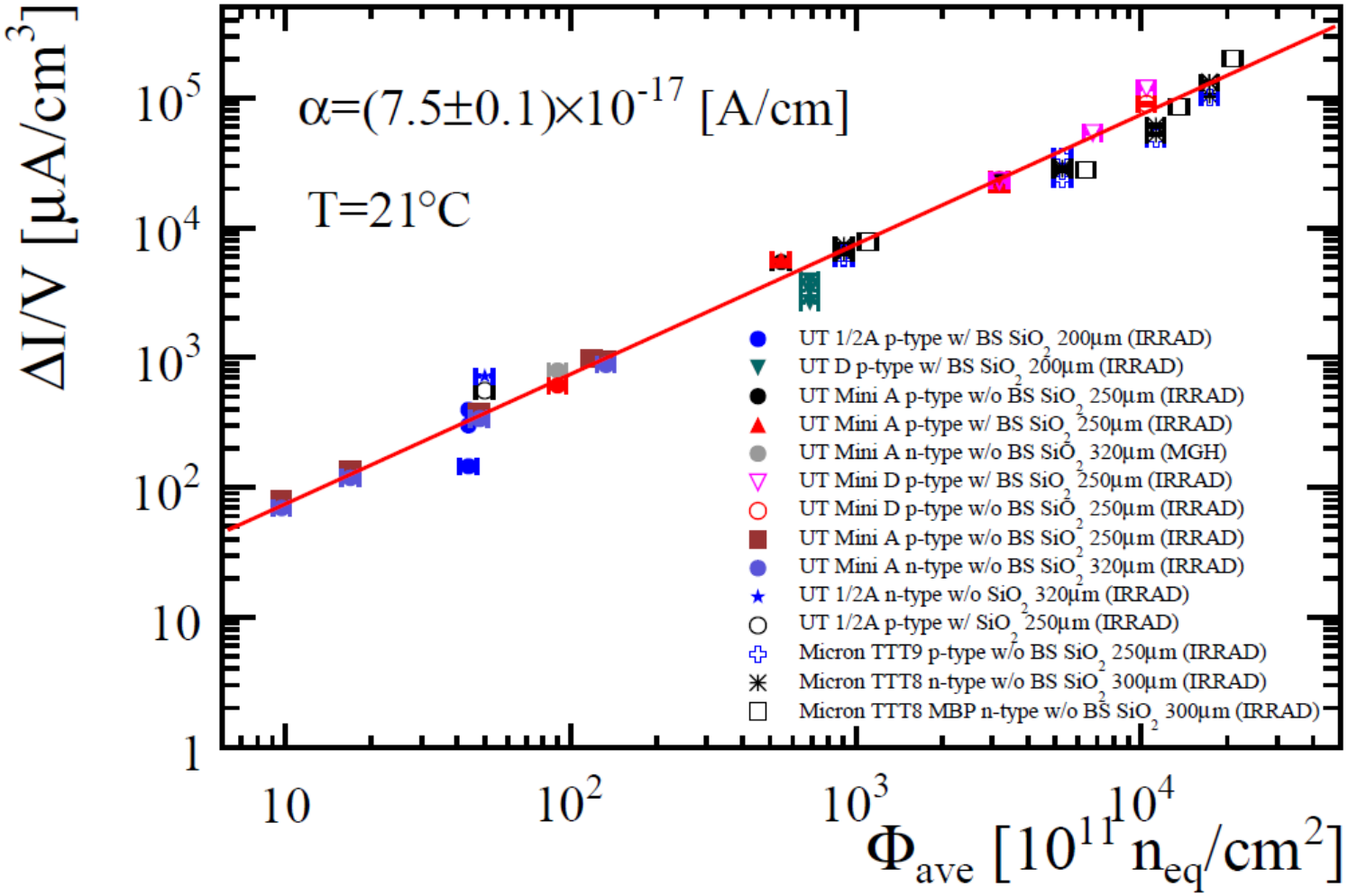
- Many useful results from 2015 and 2016 Testbeam campaigns:
  - Unacceptable inefficiency in Fan In PA
  - n-type sensors show less much less inefficiency than p-type
  - Testbeam results show that topside bias contact is a viable option for sensor biasing – this is our preferred design.
- Most of the UT will be Type A sensors:
  - Current plan is to use mostly n-type sensors; p-type sensors preferred for inner-most staves.
- PA studies still ongoing
  - New mask design of Fan-Up PA has been submitted to Hamamatsu to eliminate possible defects/inefficiencies.
  - This will be used for all sensors; to be tested in Spring/Summer 2017

The End

Backup Slides follow

Irradiation Effects

- Change in leakage current after irradiation vs fluence:
- Our sensors agree well with theoretical prediction
- Depletion voltages pre irrad:
  - p-type, 200µm thick: ~135V
  - p-type, 250µm thick: ~180V
  - n-type, 320µm thick: ~240V



Fall Testbeam 2016

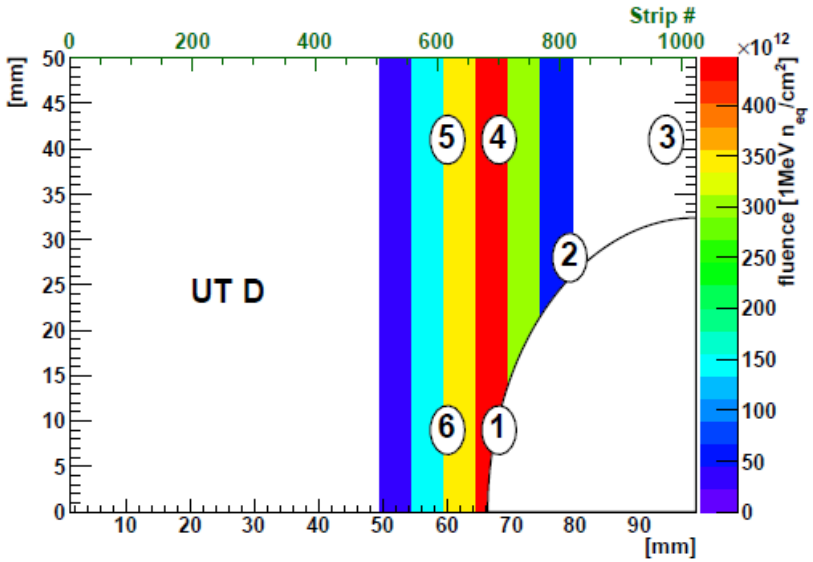
- One more testbeam was carried out in October 2016
- Main Goals:
  - In depth study p-in-n Fan In sensors at various fluences to determine at which point inefficiency disappears
  - Study n-in-p Fan In sensors to see how inefficiency evolves with fluence
- Irradiation performed at CERN IRRAD facility.

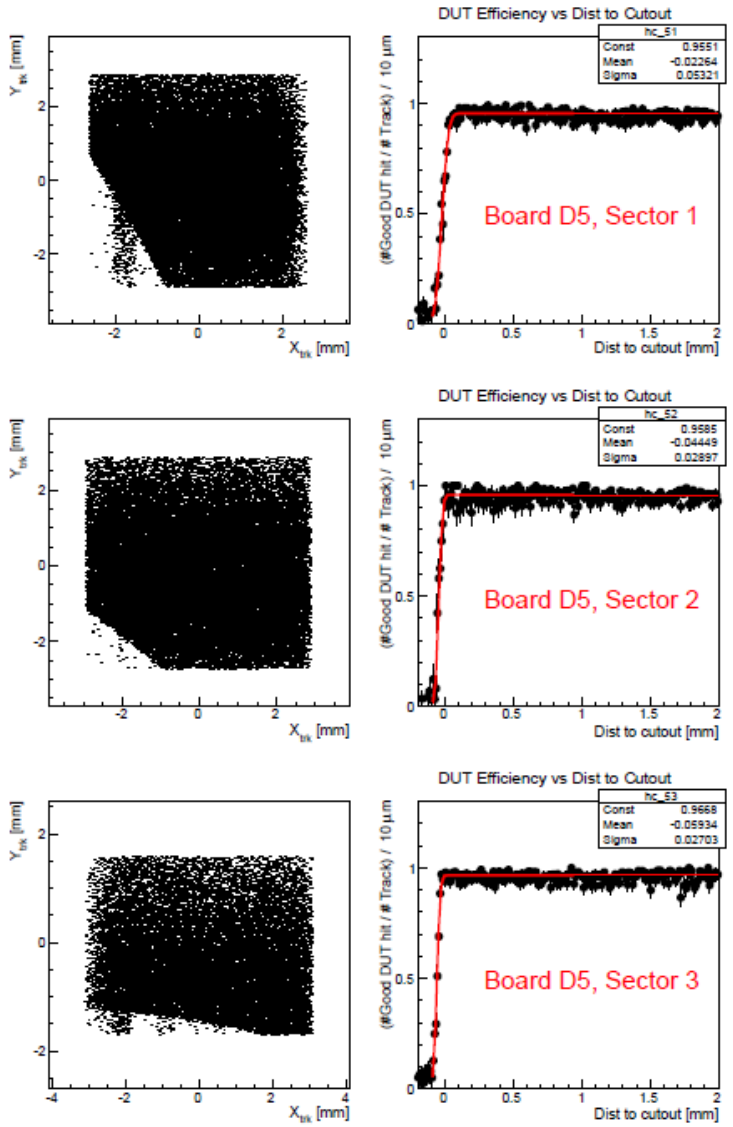
- Analysis still in progress… many interesting results to come

Peak Delivered Dose (n_{eq}/cm^2)	% nominal (peak)	PA Delivered Dose (n_{eq}/cm^2)	% nominal (PA)
1.51E+12	7.54%	8.60E+11	4.3%
2.49E+12	12.45%	1.55E+12	7.73%
6.66E+12	33.32%	4.80E+12	24.02%
1.72E+13	86.24%	1.15E+13	57.26%
2.09E+13	104.54%	1.73E+13	86.33%

Type D Cutout Region

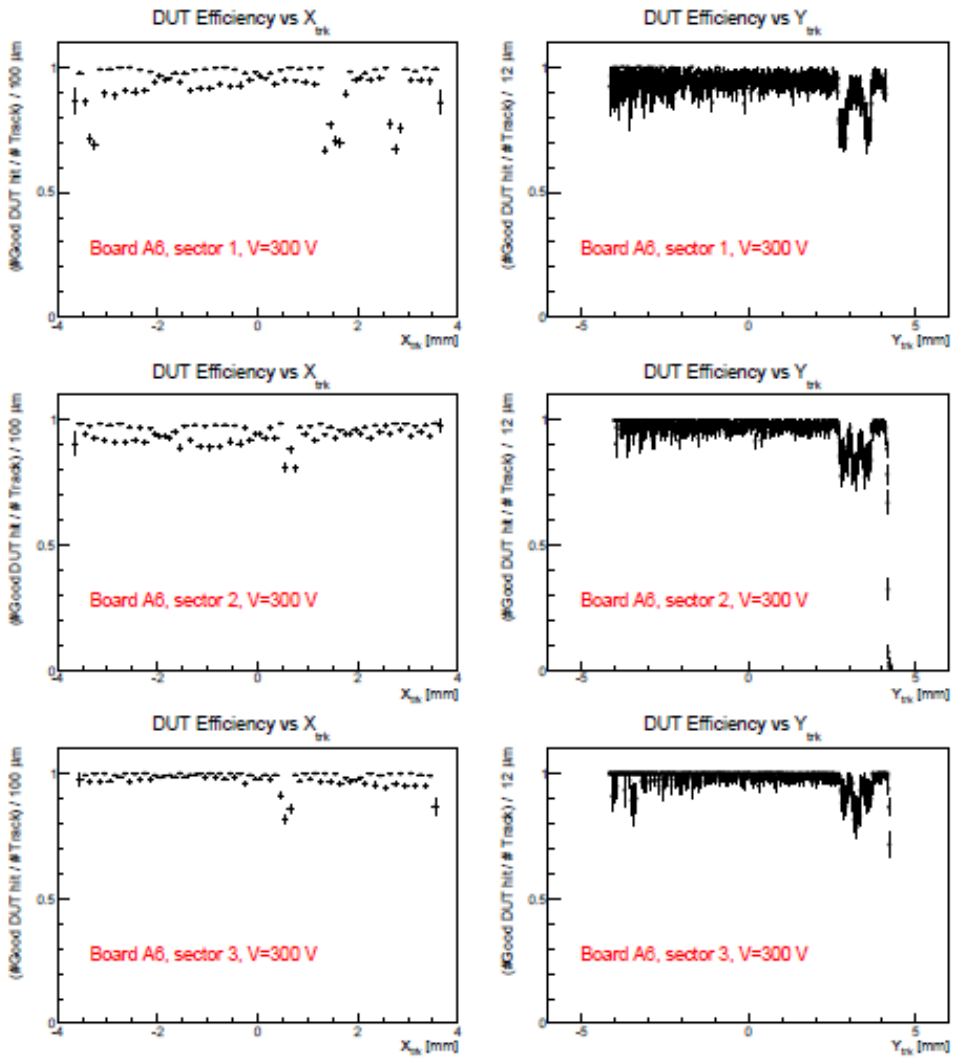
- Efficiency measurements along the cutout region:
  - Some noisy strips present in sectors 1 & 3, shows some hits in the cutout region
  - Width of edge:
    - Sectors 2 & 3: ~30um
    - Sector 1: ~50um
    - Higher width due to steeper edge and higher fluence.



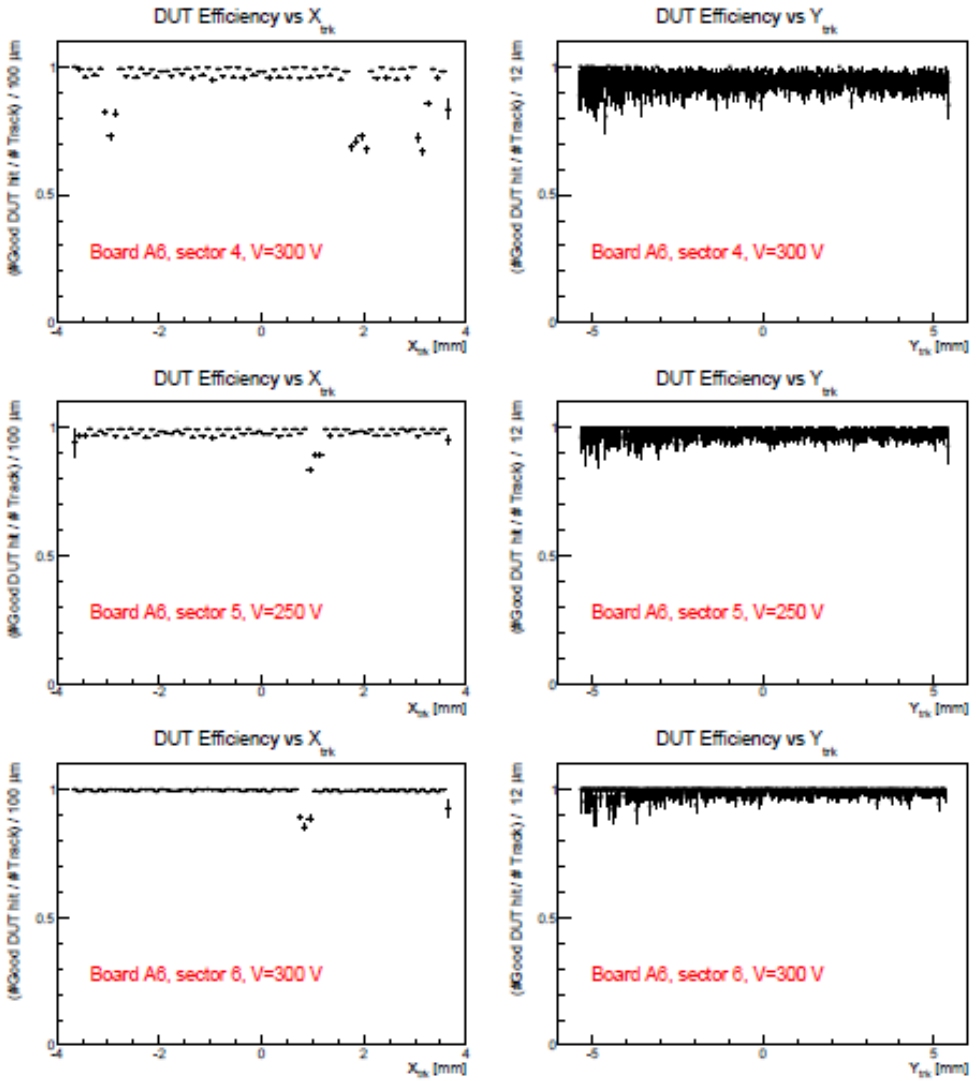


Type ½ A Efficiency

PA region

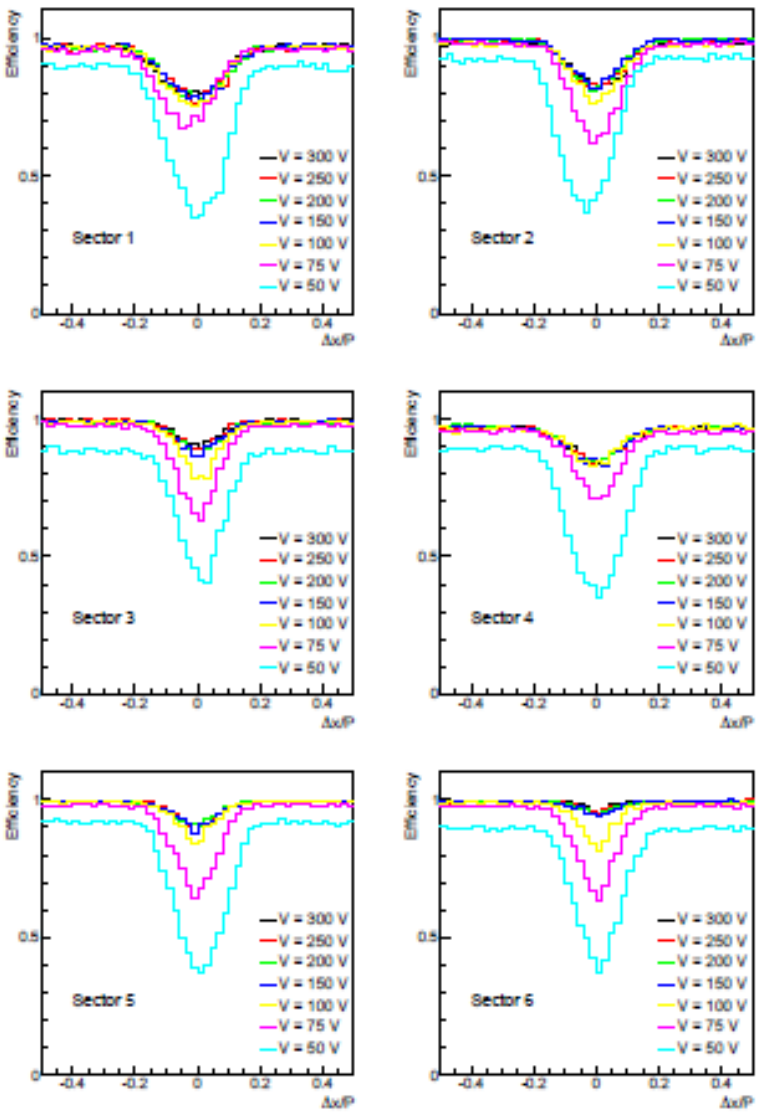


Control region

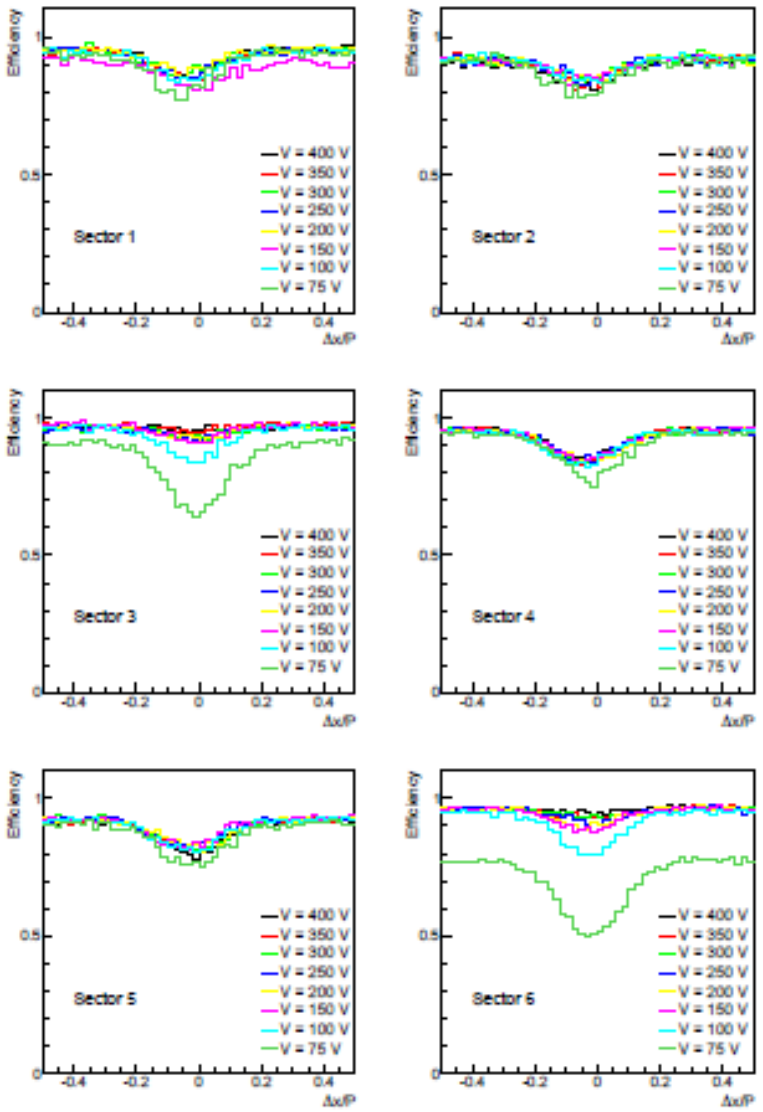


Interstrip Efficiency

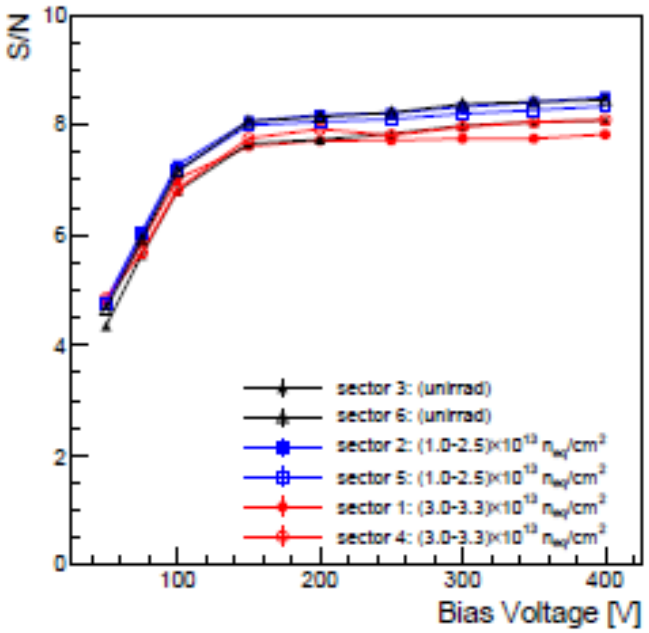
Fan In

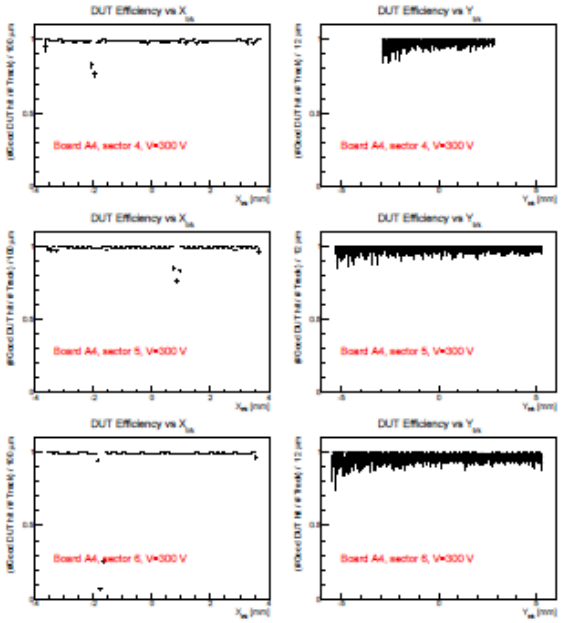


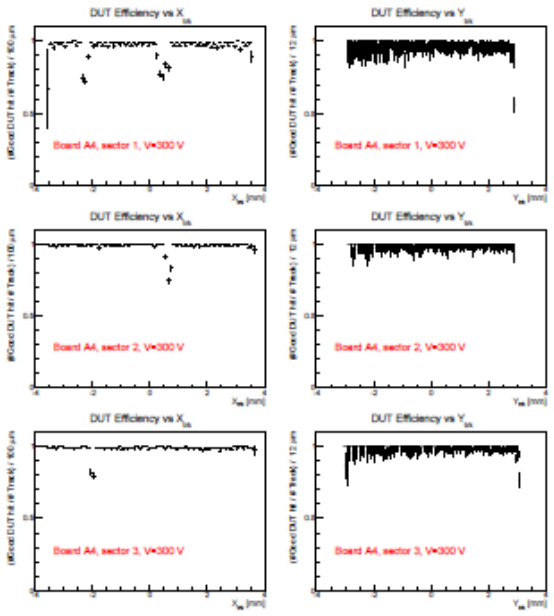
Fan Up

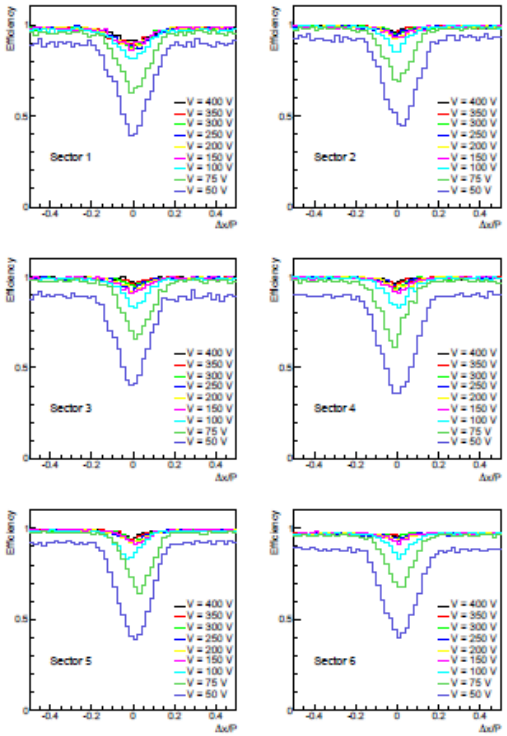


“No Fan” performance



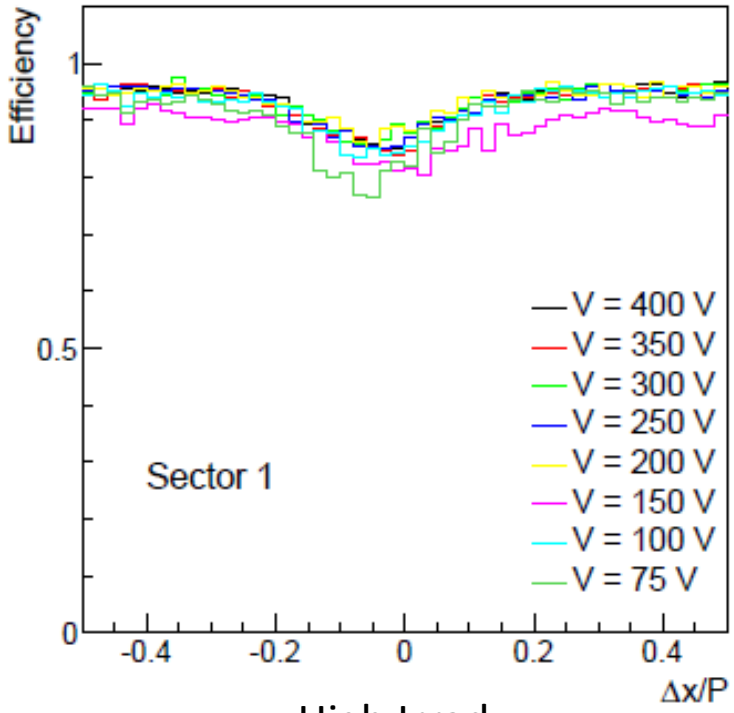




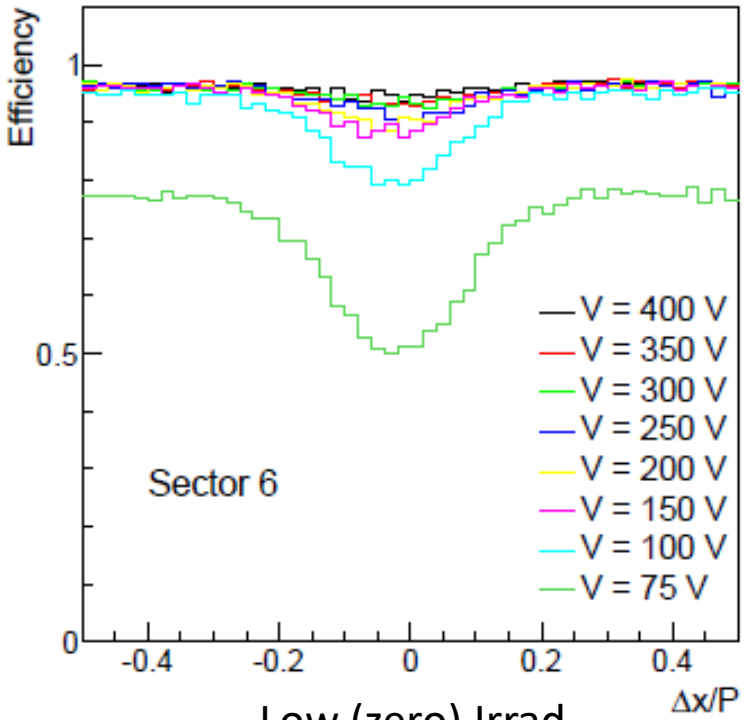


Type ½ A: Fan Up Interstrip efficiency

- Efficiency vs. Interstrip position at various bias voltages:
- Strip N is at -0.5
- Strip N+1 is at +0.5
- Drop in efficiency at center between two strips:
  - SNR ≈ 7.5
  - Clustering: Seed req. 3x noise charge
  - When hit is directly between two strips, neither strip may pass seed requirement resulting in efficiency loss.
  - Similar results for Fan In (see backup)



High Irrad.



Low (zero) Irrad.

Topside vs. Backside Biasing: 2015 Minis

- Topside: contact is wirebonded, HV brought to back via conductive edge
- Backside: un-passivated backplane in direct contact with gold trace at voltage.
- All previous results are in topside configuration.
- Four mini Hamamatsu mini's tested (half-A layout, 64ch., 250um):
  - 2 sensors irradiated to 1.1×10^{14} n_{eq}/cm^2 (top)
  - 2 sensors irradiated to 6.4×10^{14} n_{eq}/cm^2 (bottom)
    - Unfortunately corrupted data for backside biasing case yielded no useful measurements.
- Preliminary results show no performance differences between biasing configurations (will be addressed in 2016 section).