Irradiation and Testbeam of KEK/HPK Planar p-type Pixel Modules for HL-LHC

Koji Nakamura (KEK), Daiki Yamaguchi
On behalf of ATLAS-Japan silicon group,
Hamamatsu Photonics K.K.
and ATLAS PPS collaboration

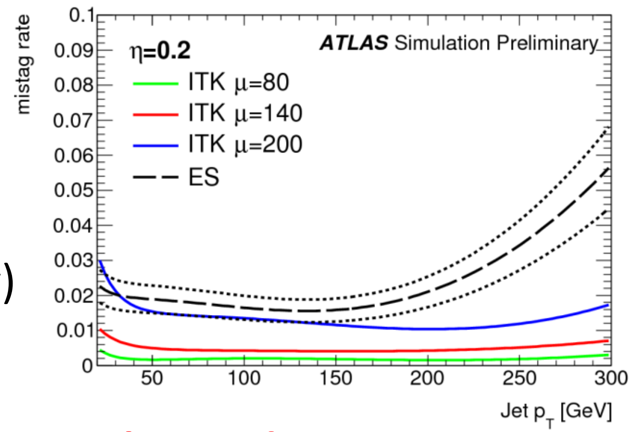
Outline

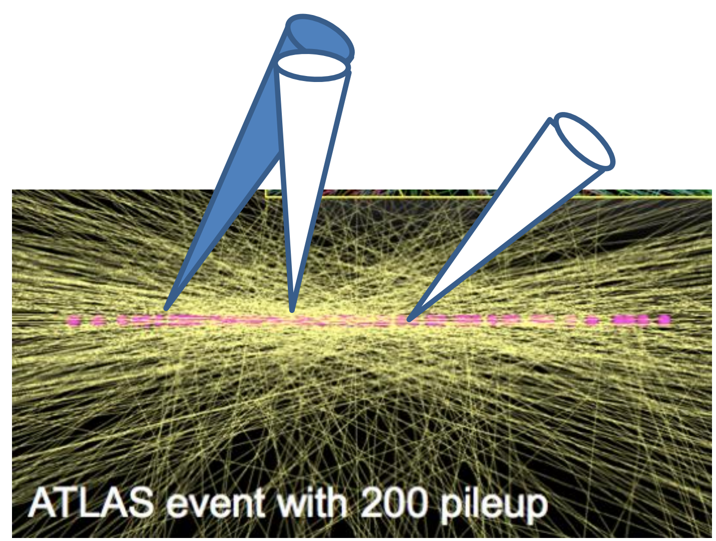
- Introduction
  - HL-HLC and Planer type Pixel sensor
  - Issue of inefficiency spot at pixel boundary.
  - New design to solve this issue
- Testing new design pixel detecotor
  - Irradiation facility in Japan (CYRIC)
  - Testbeam at CERN and DESY
- Result and Conclusion

Introduction

- **High Luminosity LHC (HL-LHC)**
  - Start around 2025- with new crab cavity in the interaction region.
  - Target : $\sqrt{s}$=14TeV L=5x10^{34} $\int Ldt$=3000fb^{-1}
  - Physics program focus the precise measurement of the Higgs coupling (e.g. Y_τ, Y_b and λ_{HHH}) and BSM searches.
- **Tracking detector is key element**
  - To keep B/τ-tagging performance up to μ=200 pileup in an event.
  - Mitigation for the pileup effect for MET calculation can be done by tracking from primary vertex.

B-tagging performance
for each pileup cond.
(keep the same efficiency)

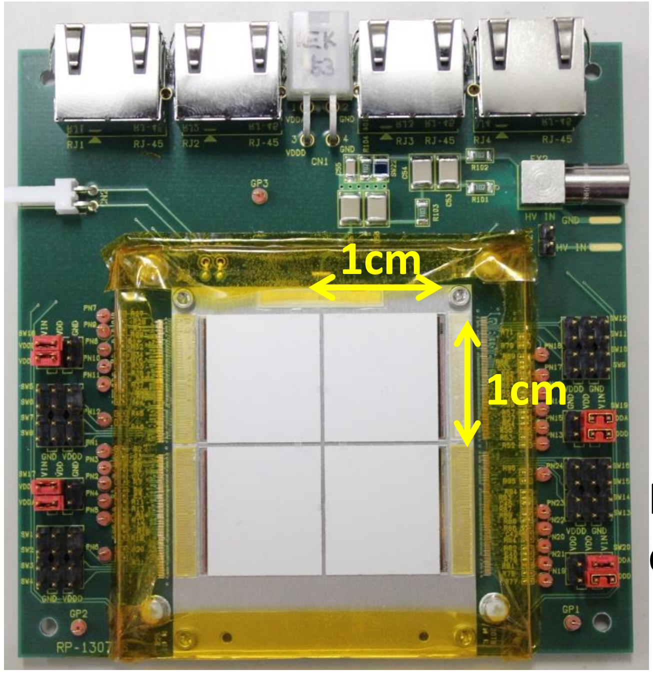




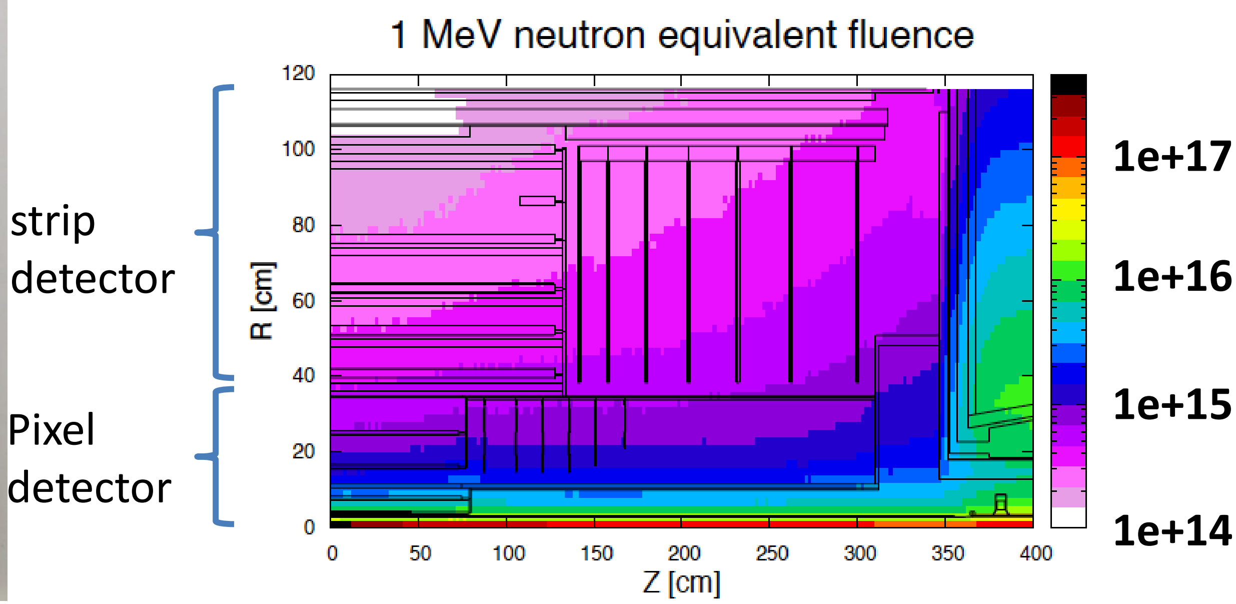
High efficiency and radiation tolerant detector is important

Development of Planer pixel module

- Planer pixel module (Outer Pixel layer(s))
  - FE-I4 read out chip on the **n^{+}-in-p^{+} type** sensor.
  - Pixel size : **50x250μm**, thickness : **150μm**
  - Time-over-threshold (ToT) readout using 15x25ns clock.
- Expected radiation fluence in 3000fb^{-1} is ~1x10^{15} 1MeV neq /cm^{2}
  - test 3-5x10^{15} fluence to confirm radiation-tolerance.



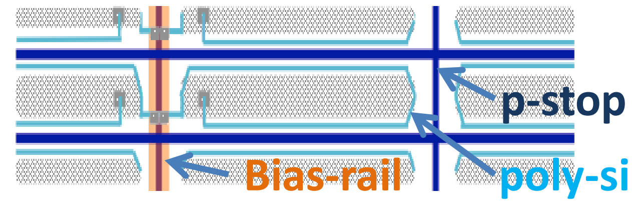
$\int L dt$=3000fb^{-1}



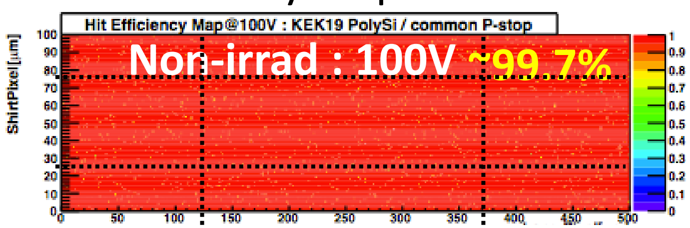
Issue : Inefficiency at pixel boundary

- In results of CERN 2012 testbeam, we observed inefficiency/charge loss at pixel boundary region after irradiation.
- The region is correspond to the bias-rail and poly-si resister structures.

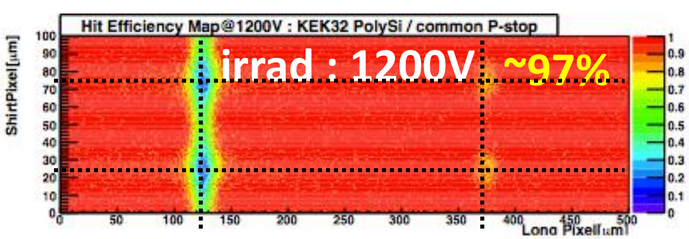
Structure : Bias-rail and poly-si resister

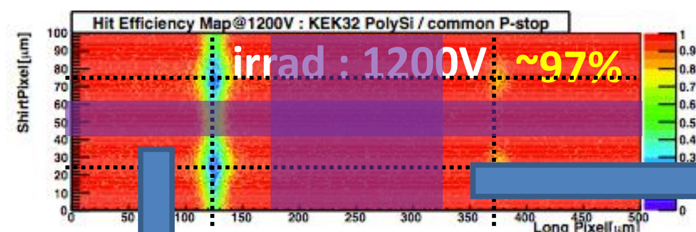


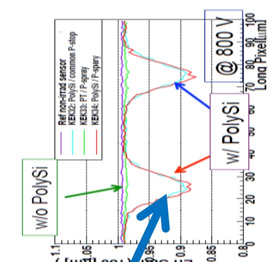
Pixel Efficiency map



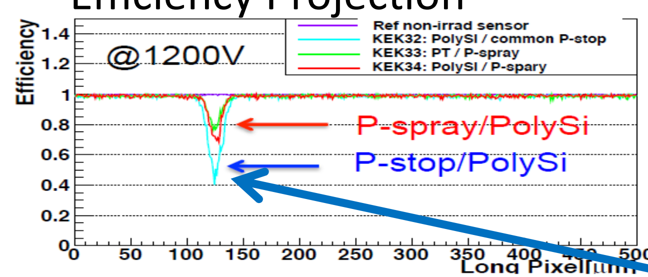
After p+ irradiation (1e16 neq)







Efficiency Projection



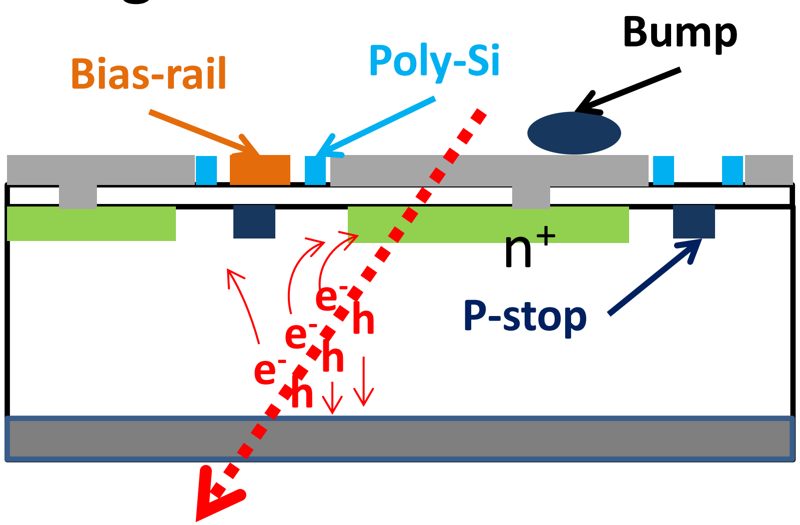
Charge loss (~10%) under the poly-si resister

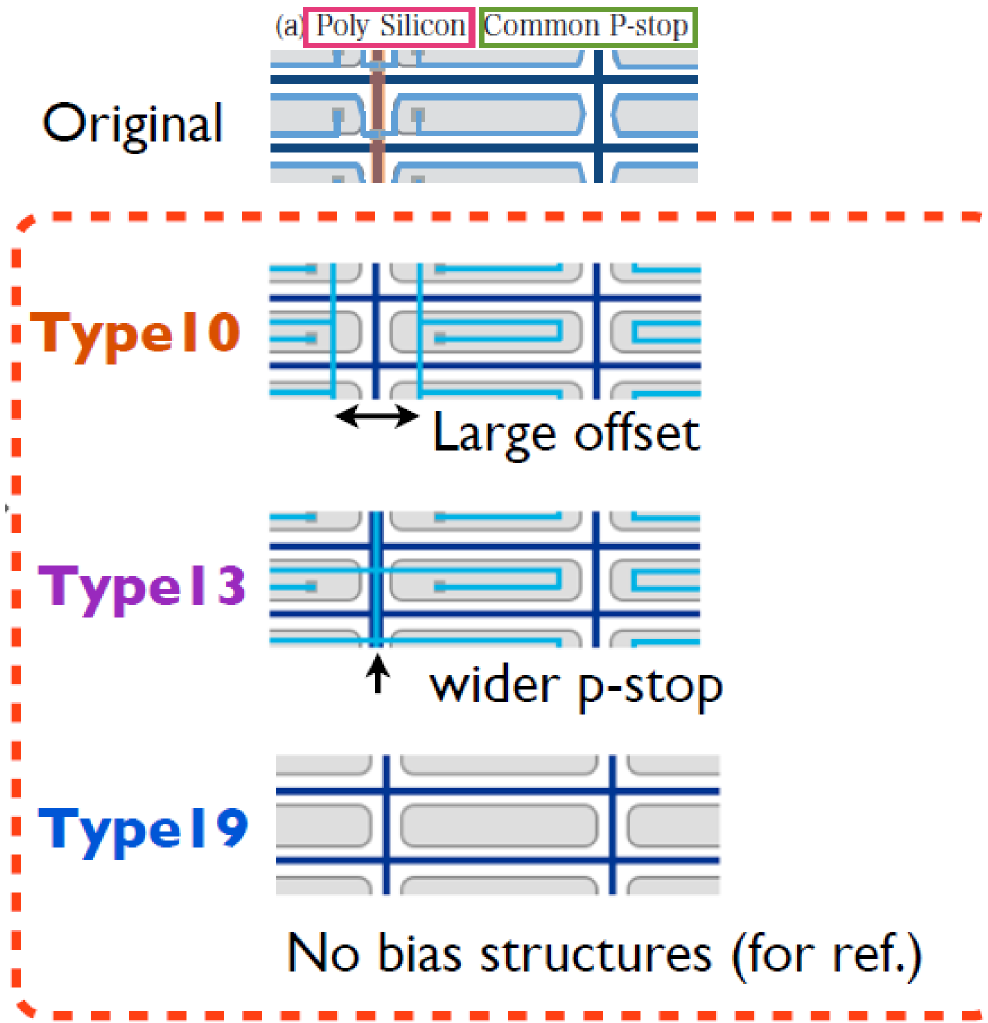
Efficiency loss under bias-rail.

Overall efficiency ~97% is caused by inefficiency at pixel boundary region.

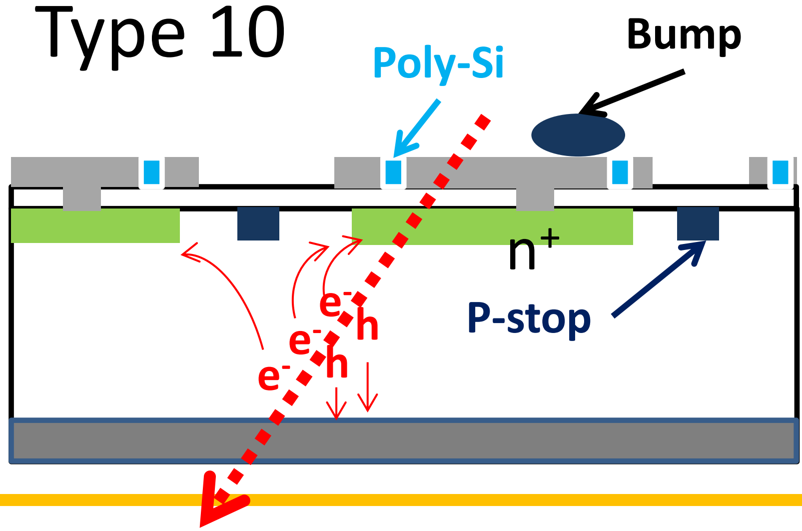
Possible solution of new structure

- Original Structure





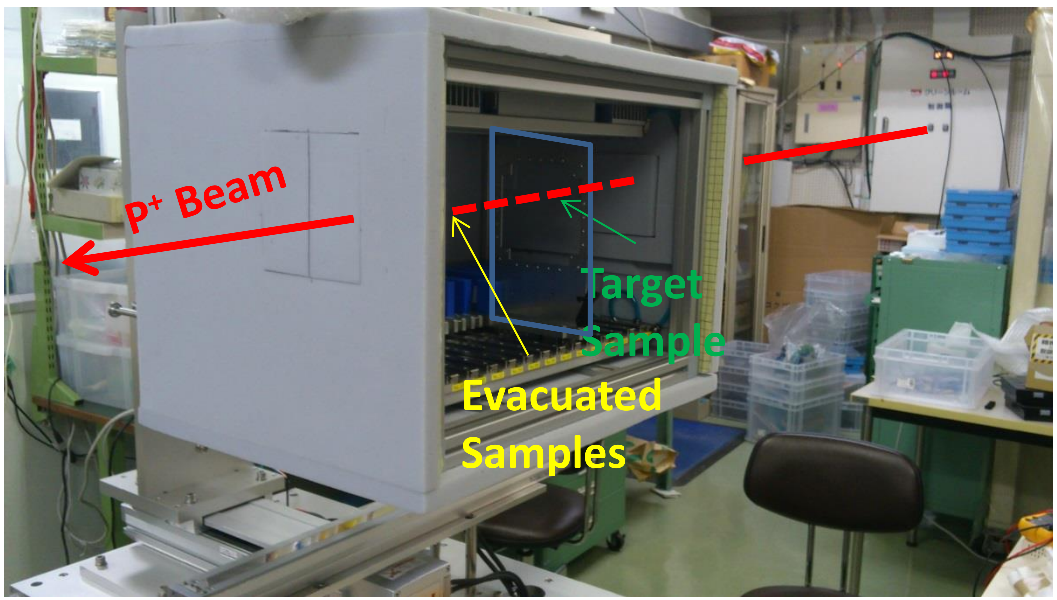
- Type 10



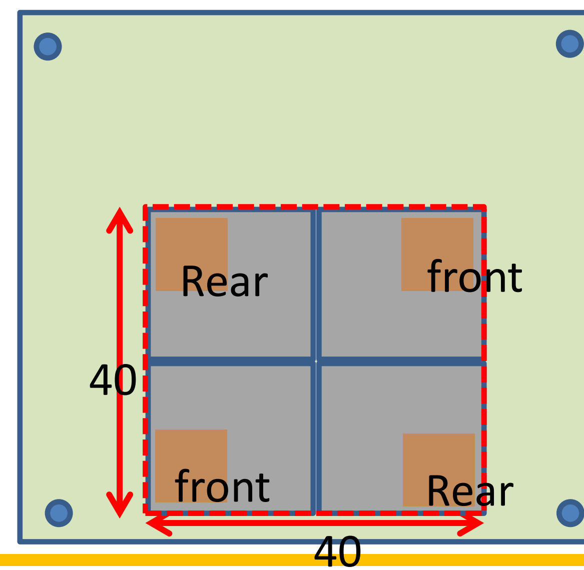
Irradiation

Irradiation @ CYRIC

- CYRIC@Tohoku Univ. is a irradiation facility with 70MeV proton beam (~1μA).
  - This allows 2-3 pixel module with back Al plain at the same time(3% E loss/pixel).
  - Operated at -5℃ temprature with dry N_2 gas. ➔trying to make lower Temp.
- Programmable X-Y stage and “push-pull” mechanism are implemented to the machine.
  - choose one or a few target samples in max 15 pre-installed samples.
- Scanning over full pixel range during irradiation.



Fluence calculation by Al dosimetry



- $1\times1\,cm^2$ Al foils are put on the irradiation samples.
- Produced ^{24}Na are measured by Ge Photon counter.
- Proton dose(D) is obtained as follows :

$$D\ [\text{neq}/\text{cm}^2] = \frac{N_{^{24}Na}}{N_{target} \times \sigma_{p-Al}} \times \frac{\tau \cdot t}{1 - e^{-\tau \cdot t}} \times 0.7$$

$N_{^{24}Na}$: Number of produced ^{24}Na

N_{target} : Number of target Al atoms

σ_{p-Al} : proton – Al cross section [cm^2]

τ : ^{24}Na decay constant [1/s]

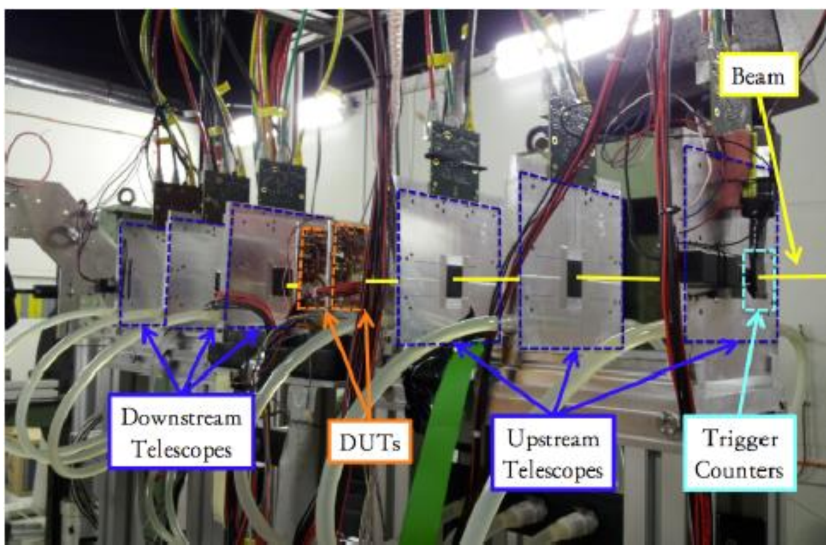
t : irradiation duration [s]

Difference of target and actual fluence is within 10% level.

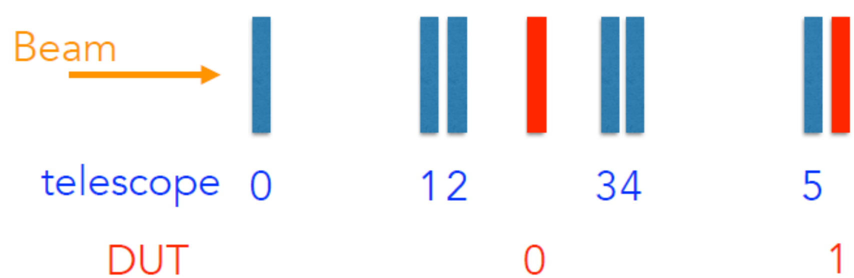
Testbeam

Testbeam @ CERN and DESY

- Performed testbeam at CERN in 2012 and at DESY 2013-2014.
  - **CERN H6 beamline : 120GeV π+ beam** (Test traditional structure)
  - **DESY T22 beamline : 4 GeV e+ beam** (Test new structure)
- 6 Telescope plain (FE: Mimosa26, 18.4x18.4μm^2) and Detector-Under-Testing (DUT) are installed.
  - 4 DUTs at CERN and 2DUTs at DESY.
- For DESY testbeam, to reduce multiple scattering effect Telescope positions are optimized.



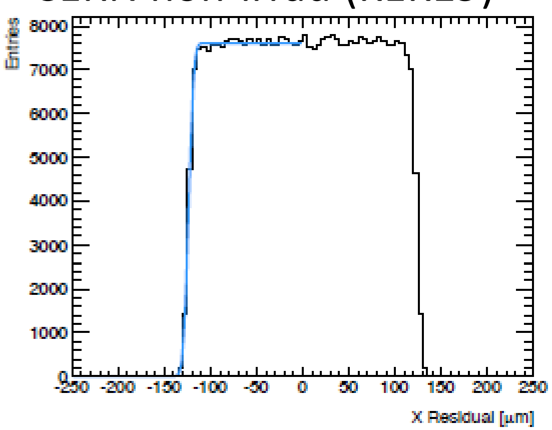
Typical DESY testbeam setup



Reconstruction and pointing resolution

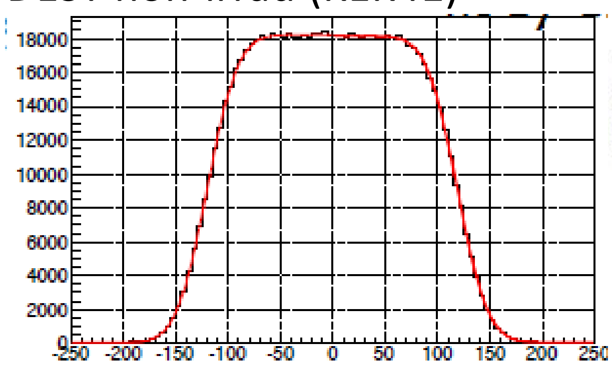
- EUTelescope based on ILCSoft/Marlin framework is used for alignment and reconstruction.
- Pointing resolution by the telescope plains interpolating to the DUT position are quantified as fitting the shoulder of residual distribution by error function.
  - 23µm resolution for DESY data by multiple scattering.

CERN non-irrad (KEK19)

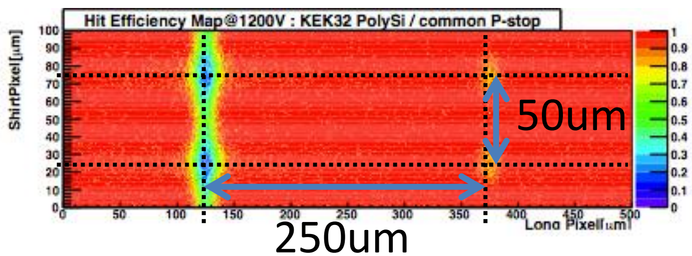


$\sigma_{CERN} = 4.5$ +- 0.1

DESY non-irrad (KEK41)



σ_{DESY} =23.2 +-0.2

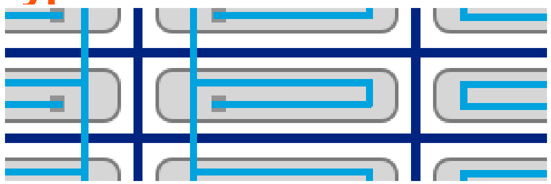
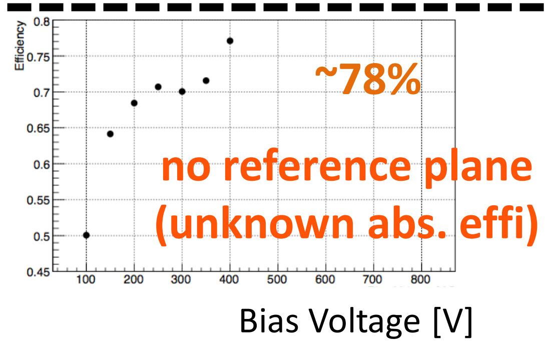
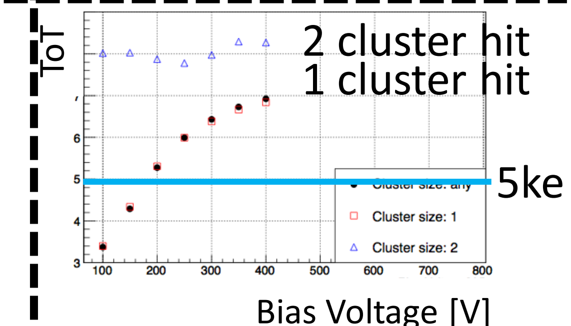
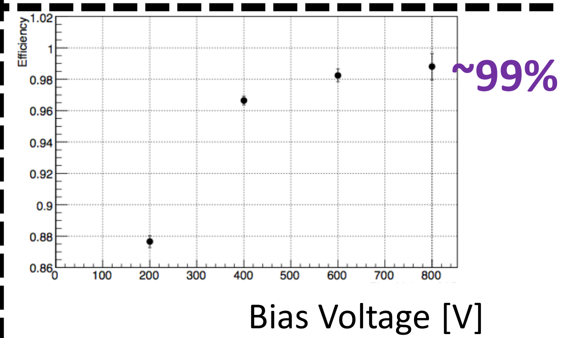
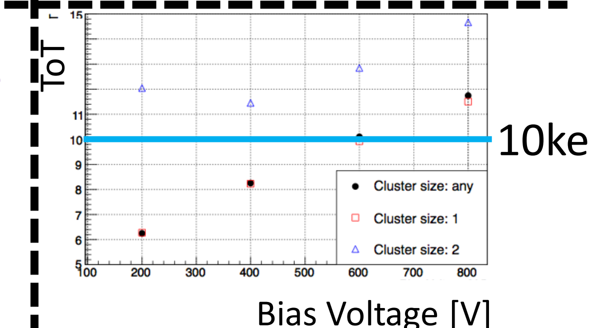
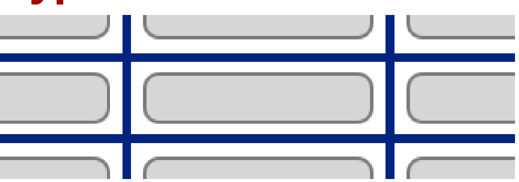
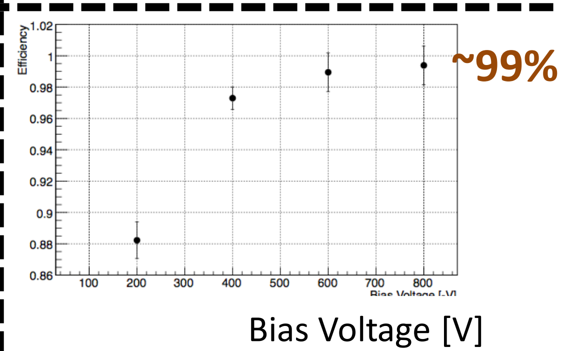
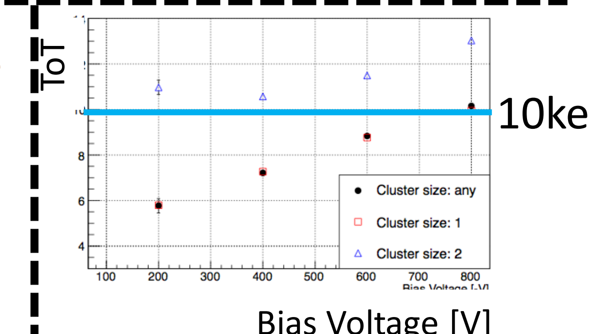


23um resolution is enough to see structure for long direction.

But may be difficult to see short direction.

Results

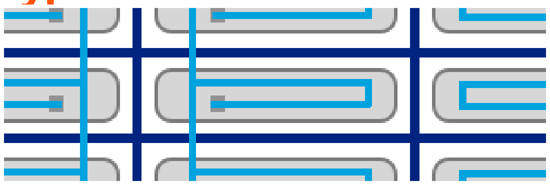
Overall Efficiency and ToT

	Bias Voltage vs Efficiency	Bias Voltage vs ToT
Type10  Sensor: 150 μm Dose: 4 x 10^{15} n_{eq} Th:1800e, ToT: 5 @5ke		
Type13  Sensor: 320 μm Dose: 3 x 10^{15} n_{eq} Th:2600e, ToT: 7 @10ke		
Type19  Sensor: 320 μm Dose: 3 x 10^{15} n_{eq} Th:1800e, ToT: 7 @10ke		

Efficiency Pixel Map

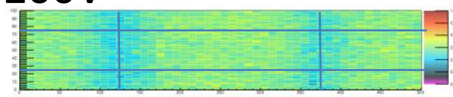
	Efficiency Pixel Map	Projection to X (long axis)

Type10



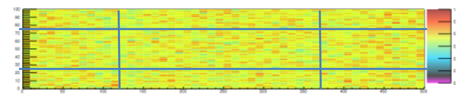
Sensor: 150 μm Dose: 4 x 10^{15} n_{eq}
Th:1800e, ToT: 5 @5ke

200V

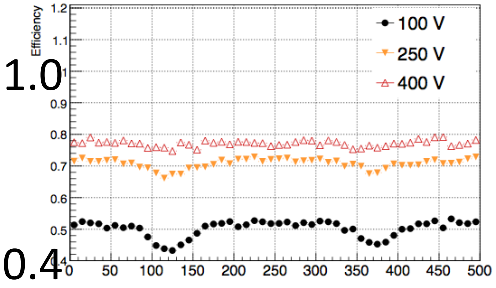


1.0
0.4

400V



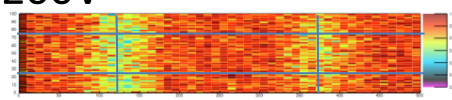
1.0
0.4



Type13

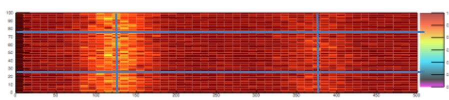
Sensor: 320 μm Dose: 3 x 10^{15} n_{eq}
Th:2600e, ToT: 7 @10ke

200V

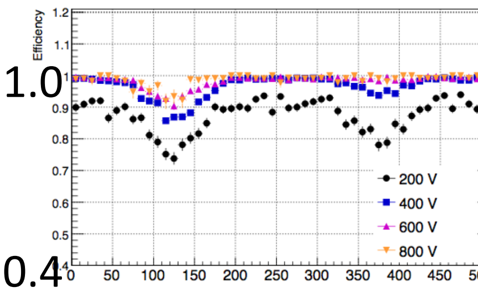


1.0
0.4

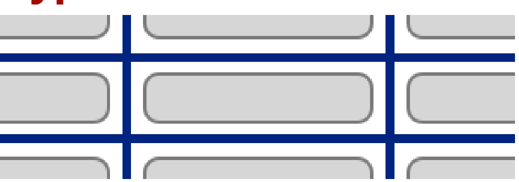
400V



1.0
0.4

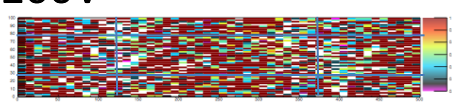


Type19



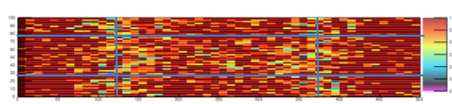
Sensor: 320 μm Dose: 3 x 10^{15} n_{eq}
Th:1800e, ToT: 7 @10ke

200V

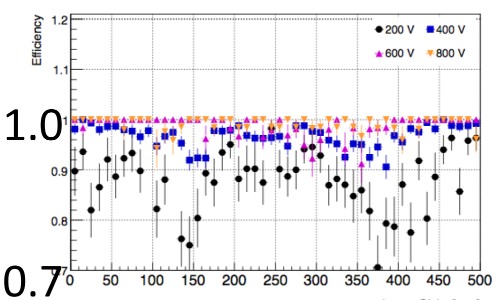


1.0
0.4

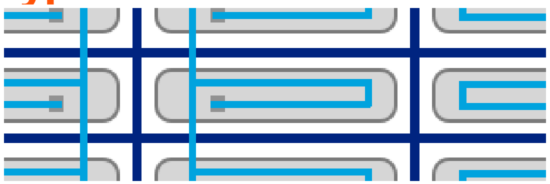
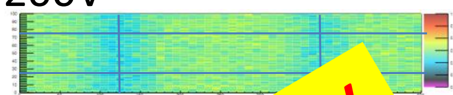
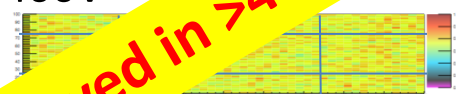
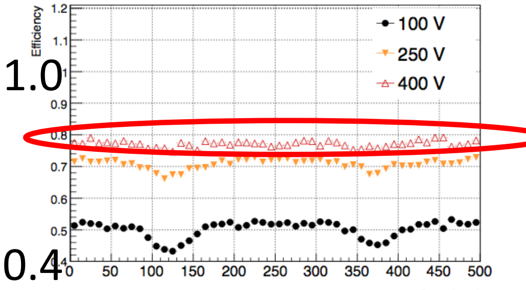
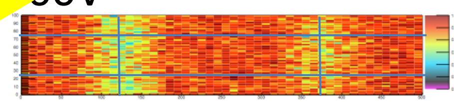
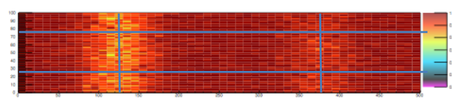
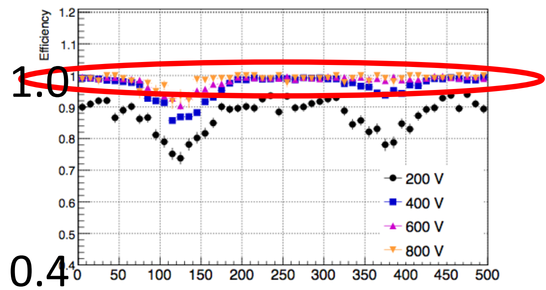
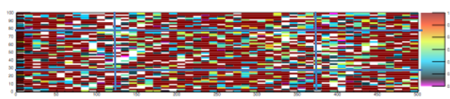
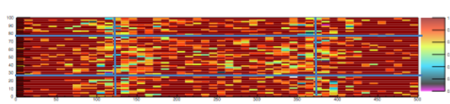
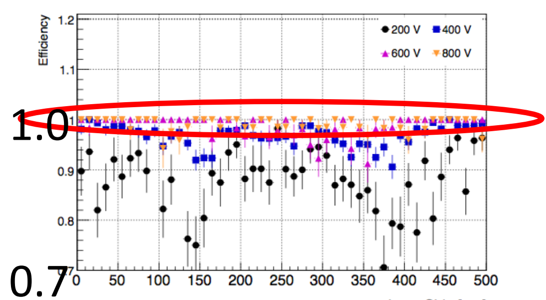
400V



1.0
0.4



Efficiency Pixel Map

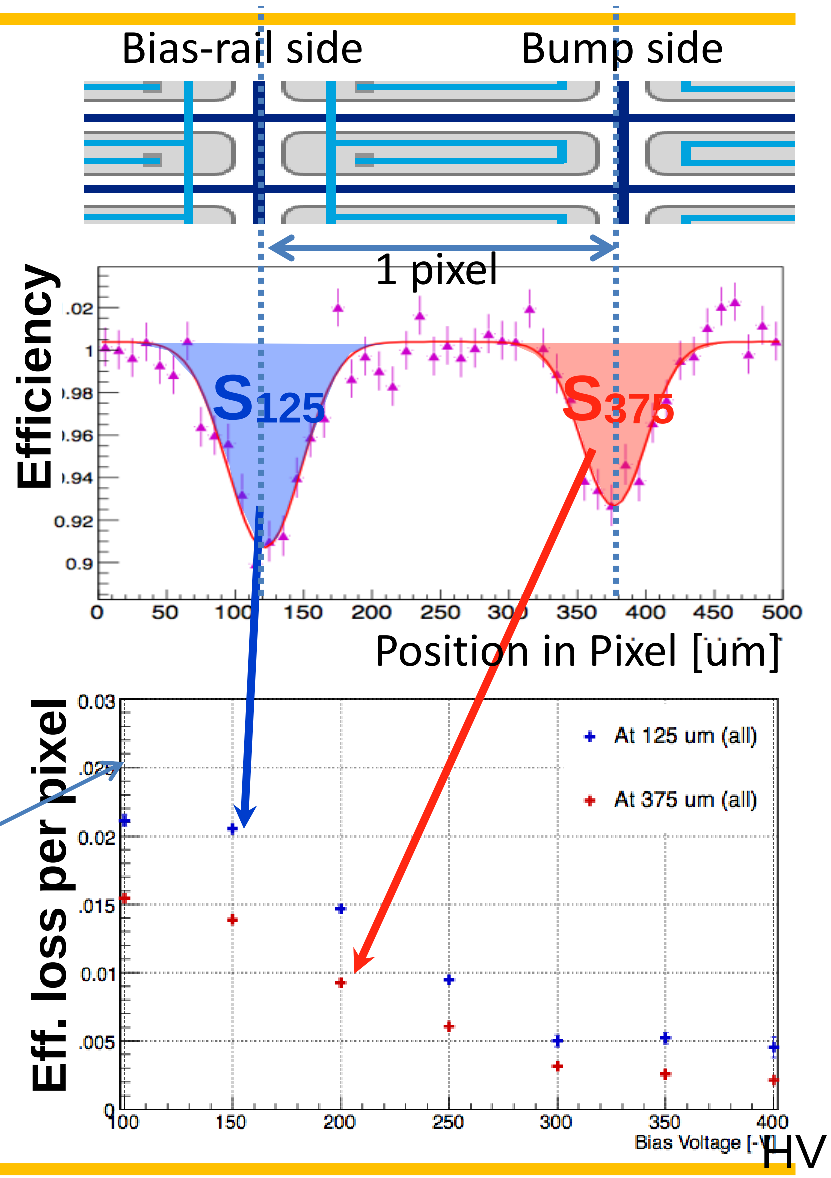
	Efficiency Pixel Map	Projection to X (long axis)
Type10  Sensor: 150 μm Dose: 4 x 10^{15} n_{eq} Th:1800e, ToT: 5 @5ke	200V  1.0 0.4 400V  1.0 0.4	
Type13  Sensor: 320 μ… 3 x 10^{15} n_{eq} Th:26… T: 7 @10ke	…0V  1.0 0.4 400V  1.0 0.4	
Type1…  Sensor: 320 μm Dose: 3 x 10^{15} n_{eq} Th:1800e, ToT: 7 @10ke	200V  1.0 0.4 400V  1.0 0.4	

No large Efficiency loss are observed in >400V

Definition of Efficiency loss

Since pointing resolution is different between CERN and DESY testbeam, to Quantify the effect of Efficiency loss, area of inefficiency is used by fitting Gaussian distribution.

Eff. loss per pixel := S / (1.0 x 500 µm)



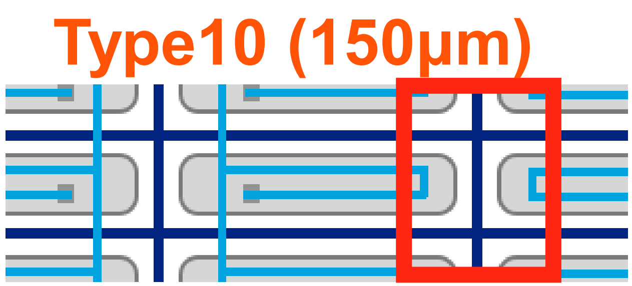
e.g.

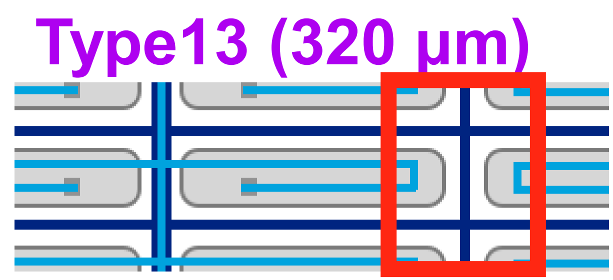
5% region in 2 pixel length have 50% efficiency

→ Eff. Loss per pixel = 0.025

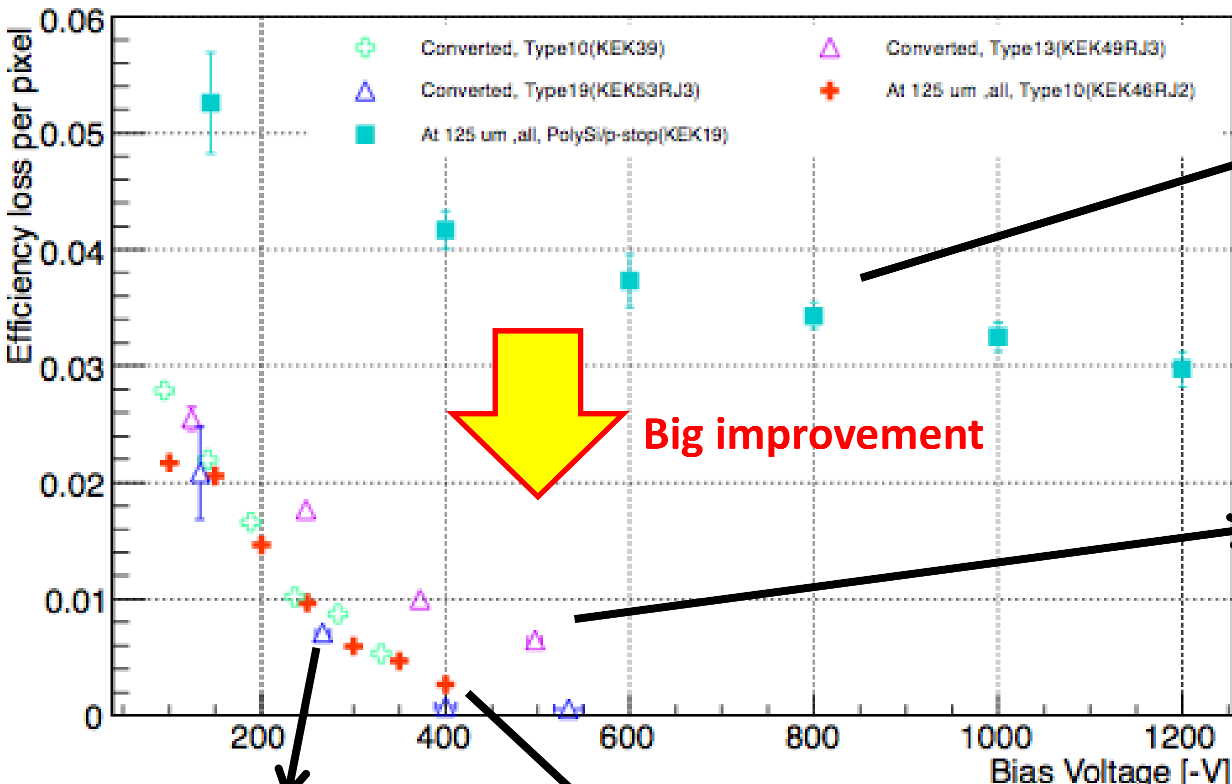
Thickness and Fluence Correction

- Thickness and fluence are not identical for each Type of samples.
  - Type 13 & 19 sensors are 320μm thick.
  - The others are 150μm thick.
  - Fluence are also different 3-5x10^{15}
- To compare the efficiency drop for the different thickness and Fluence :
  - Efficiency loss of bump-side of Type 13 should agree with one of Type 10.
  - Approximately, fit by an error function and calculate transfer function.
  - Apply the transfer function to the Bias-rail side.



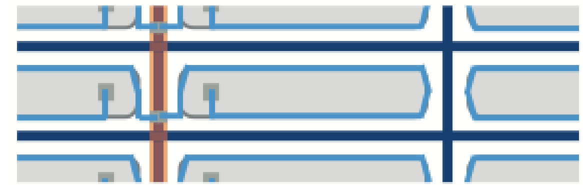


Results (150um, $5x10^{15}$ neq /cm^2 Equivalent)



Traditional Structure

Bias rail(Al)+ Resister(PolySi)



Type 13

Bias rail+Resister(PolySi)

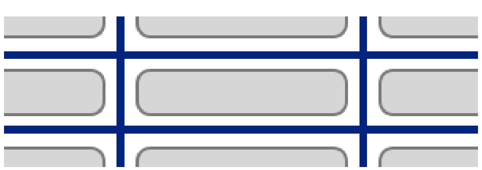
Wide p-stop under bias rail

Bias res. is inside of electrode

Type 19

Ideal situation.

No bias rail and resister.



Type 10

Shifted Bias rail position.

Bias res. is inside of electrode

Type 10 is the best option

→ Almost similar to ideal case

Conclusion and Plan

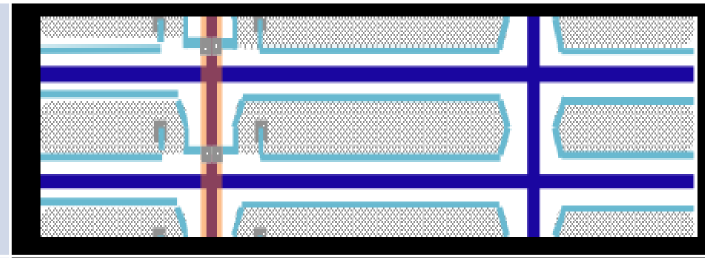
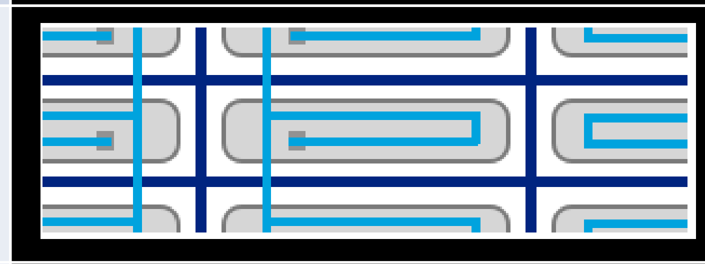
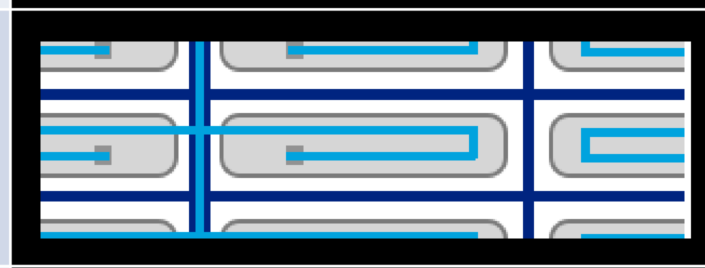
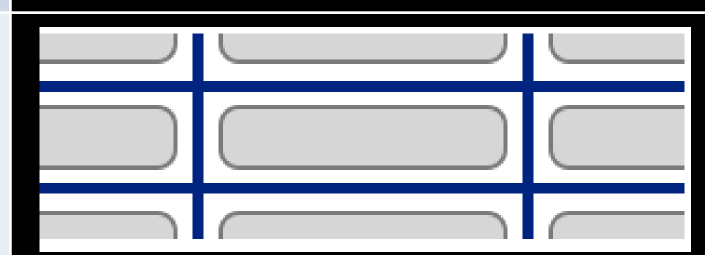
- Irradiation facility, CYRIC, and irradiation technique have been well established.
  - Fluence difference from the target value is within 10% level.
  - **Plan :** Temperature control system is improved for the next irradiation (Sep 15-18, 2014)
- New pixel structures are well tested by testbeam.
  - Largely improved efficiency around pixel boundary.
  - Especially offset of bias-rail helps.
  - **Plan :** Full optimization of structure and material for the bias-rail (Al or Poly-Si). Comparison on the same thickness and fluence (i.e. without correction). Take HV scan upto higher Voltage (1000V).

Contributors

- ATLAS-Japan Silicon Group
  - KEK, Tokyo Inst. Tech., Osaka Uni., Kyoto Uni. Edu., Uni. Tsukuba, Waseda Uni.
- Hamamatsu Photonics K.K
- ATLAS PPS collaboration
  - AS CR, Prague, LAL Orsay, LPNHE/Paris VI, Uni. Bonn, HU Berlin, DESY, TU Dortmund, Uni. Goe?gen, MPP and HLL Munich, Uni. Udine-INFN, KEK, Tokyo Inst. Tech., IFAE-CNM, Uni. Geneve, Uni. Liverpool, UC Berkeley, UNM-Albuquerque,UC Santa Cruz

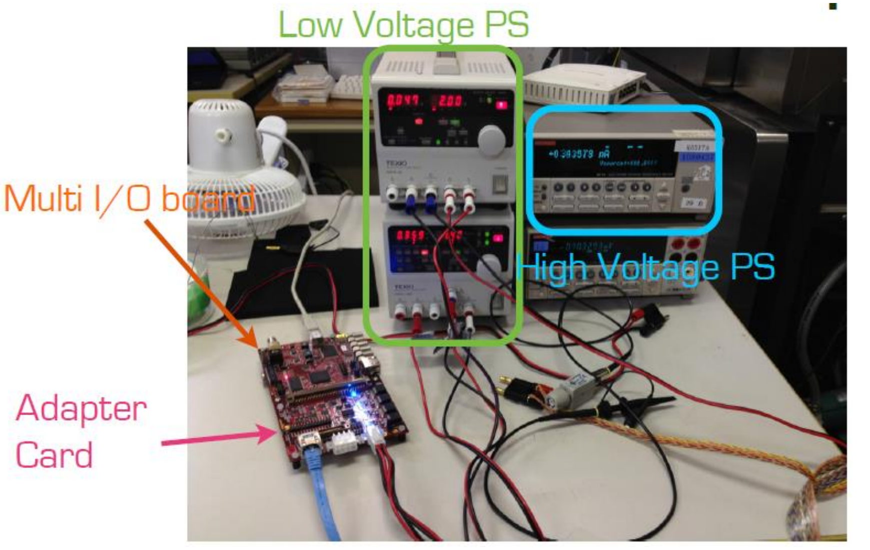
Backup

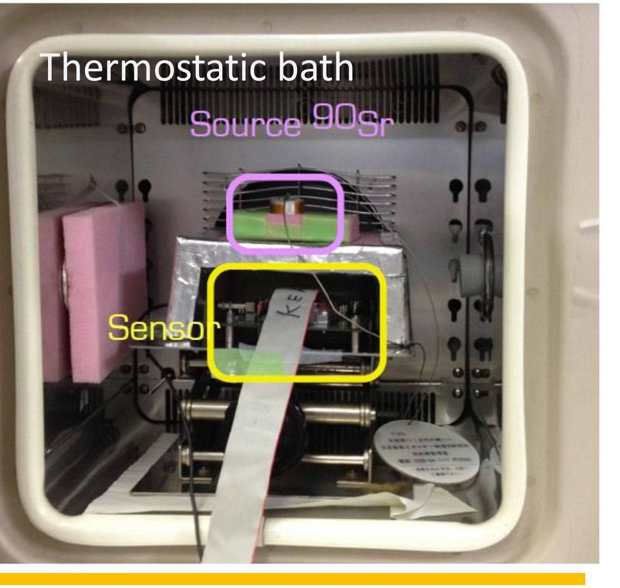
new structure

	Design	Structure image
Original Structure **Bias rail (Al)** **Bias resister(PolySi)**	Traditional structure with bias rail and resister at inter pixel region.	
Type 10 **Bias rail (PolySi)** **Bias resister(PolySi)**	To avoid "efficiency drop" at under bias rail and resister, shift the bias rail and resister position to inside of pixel electrode.	
Type 13 **Bias rail (PolySi)** **Bias resister(PolySi)**	Bias resister is the same as type10 but keep bias rail at traditional position and **made p-stop wider.**	
Type 19 **Bias rail (PolySi)** **Bias resister(PolySi)**	To test **Ideal situation**, remove all bias rail and resister structure. * Note : QA is not possible at sensor level. So this is just for test.	

Our default testing system (USBpix)

- Using USBpix DAQ system to check :
  - Tuning of FE-I4
  - ^{90}Sr Source scan to find disconnected bump. (self trigger)
  - Thermal cycling is operated [-40,40] °C with dry N_2 flow.
- USBpix systems are used for most of testbeams in last a few years.
  - In principle, it's working without major issue.
  - Used RCE system in SLAC testbeam with more stable DAQ.



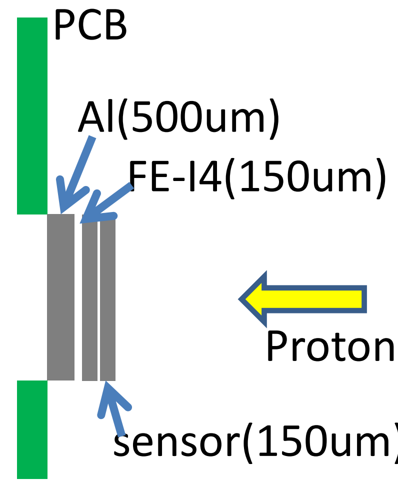


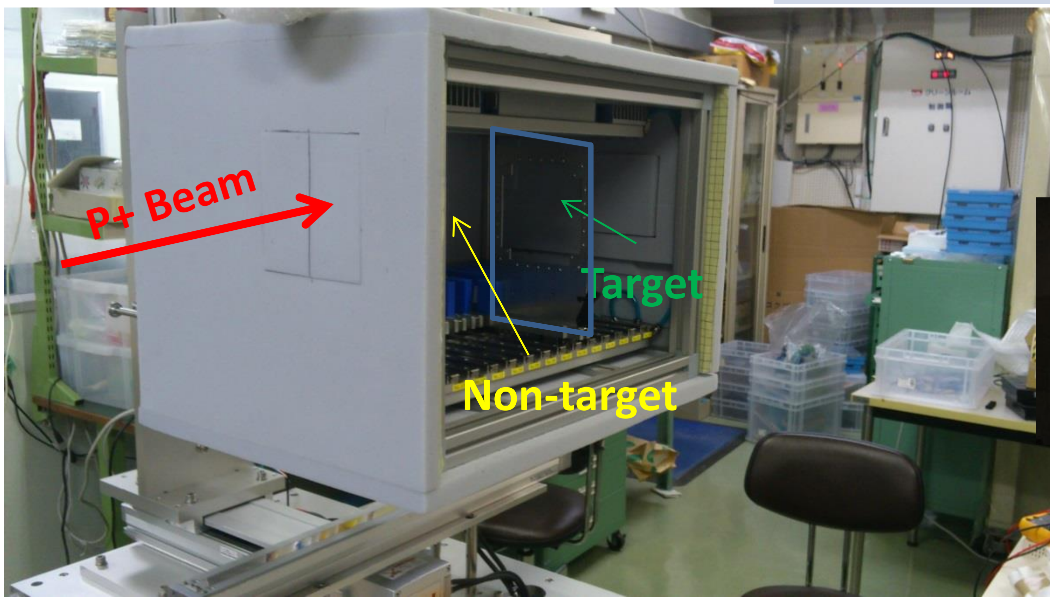
Irradiation facility : CYRIC

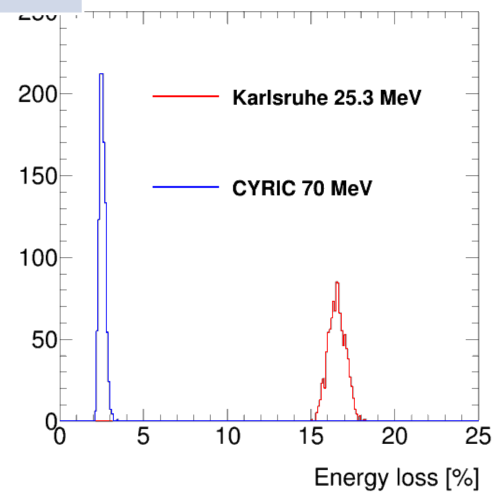
- CYRIC @ Tohoku Univ.
  - Beam energy is 70 MeV which allows to irradiate 3 modules at once. (Karlsruhe is 25.3MeV)
  - With intelligent irrad Box
  - Fluence are evaluated by Al dosimetory (^{24}Na).

Next Irradiation is mid September

	CYRIC (Jan 2014)
P+ Energy	70 MeV
Beam Current	10-1000 nA
Time	6h @ 600nA for 3×10^{15} neq/cm^2
Scan speed	20 mm/s
Temperature	-5-20℃ (Chiller+dry N_2)

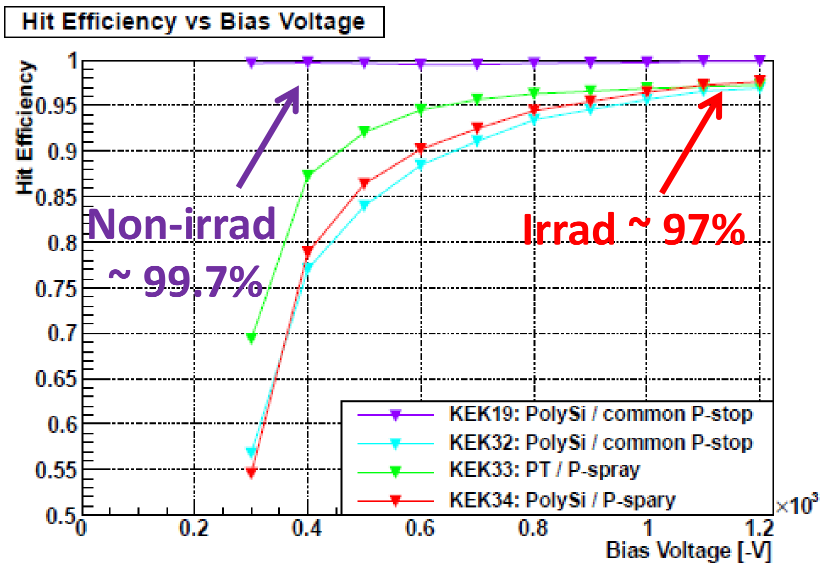






Efficiency drop issue and new structure I

- In the past testbeam we could find small efficiency drop after irradiatiation (99.7→97% at Full depletion voltage).
- The drop is not uniformly over the pixel area but quite specific area : inter pixel region.
  - **Especially the region on the bias rail and bias resister structures.**
- **Goal : To understand this efficiency drop and find solution.**



Typical efficiency map after irradiation