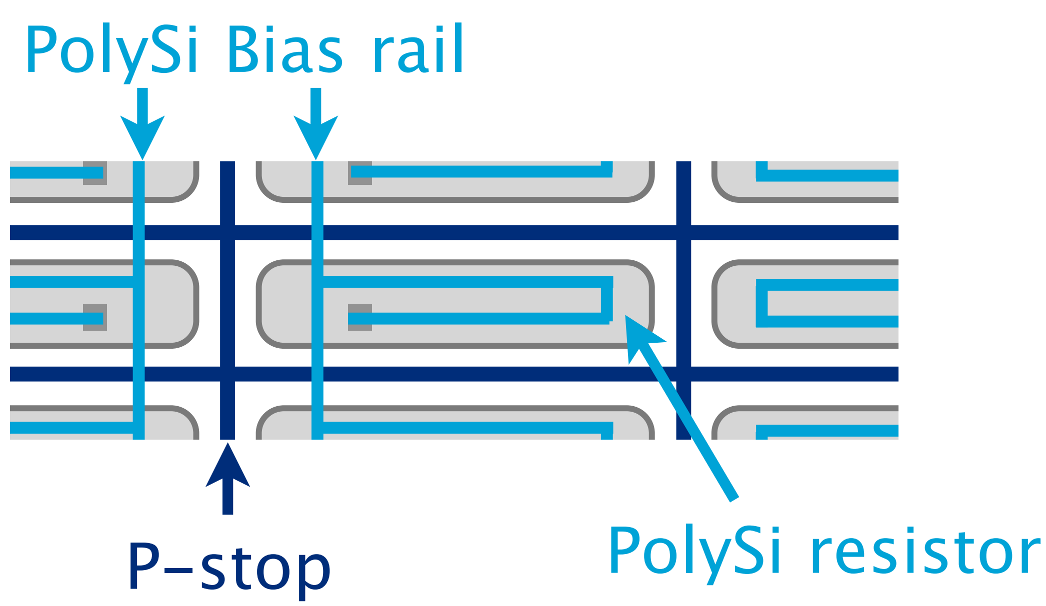
Beamtests of HPK/KEK n^+-in-p pixel sensors for ATLAS HL-LHC upgrade inner tracker

Daiki Yamaguchi (Tokyo Tech.)
on behalf of
ATLAS-J Silicon Group, ATLAS PPS Collaboration, and
Hamamatsu Photonics K.K

ATLAS-J Pixel development

- Develop n^+-in-p planar pixel sensors for ATLAS upgrade, collaborating with Hamamatsu Photonics K.K
- Focus on:
  - Uniformity of high hit efficiency even after irradiation
- Optimize the pixel structures (See Nobu's talk)
- Testbeams
  - DESY in Aug. 2013
  - DESY in Nov. 2013
  - DESY in Feb. 2014
  - SLAC in May 2014
  - (CERN in Oct. 2014)



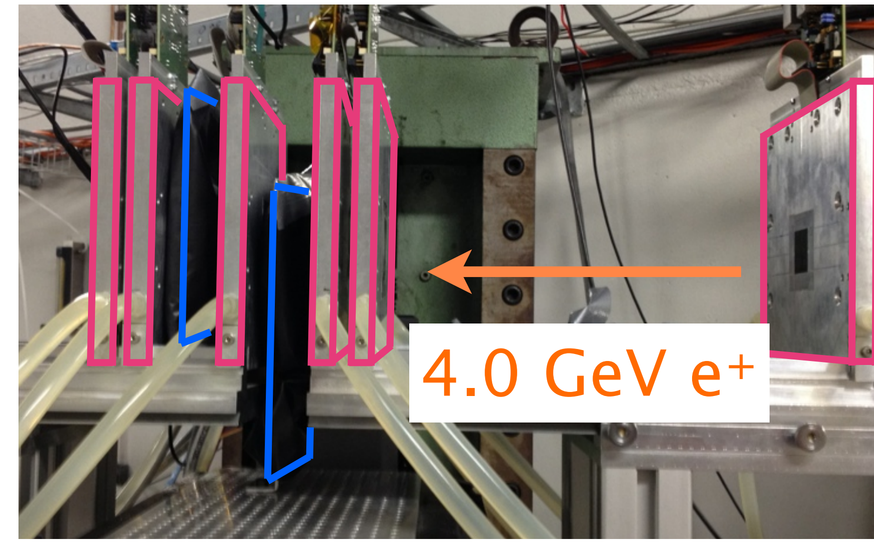
Testbeam Analysis

- Four analysis topics

1) Uniformity of hit efficiency for Non-irrad. sensors
    - TB at DESY in Aug. 2013 & in Feb. 2014
2) Uniformity of hit efficiency for irrad. sensors
    - TB at DESY in Nov. 2013 & in Feb. 2014
3) Performance of Long Staggered pixel
    - TB at DESY in Aug. 2013
4) Performance in dense environment
    - TB at SLAC in May 2014

Non-irrad. sensors

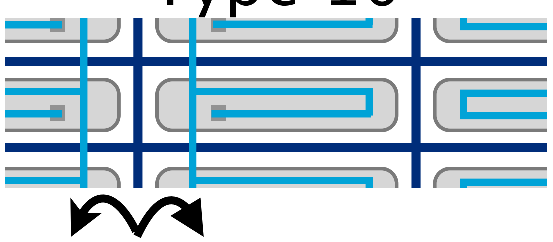
- Testbeam at DESY in Feb. 2014
  - Located as close as possible
    - Pointing Resolution: ~6 μm
- Test samples



6 Telescopes
2 DUTs

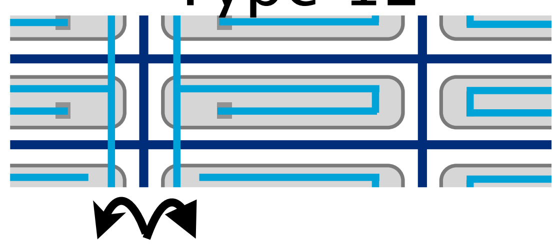
Poly-Si Bias rail

Type 10



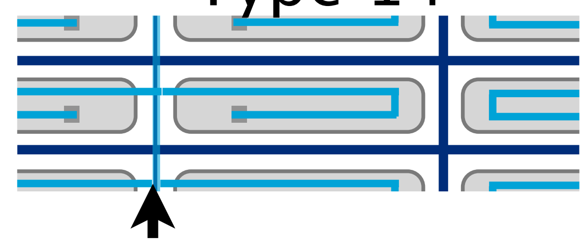
Large Offset

Type 12



Small Offset

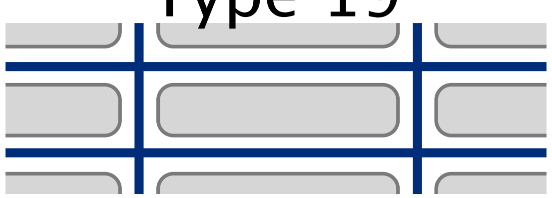
Type 14



Narrow P-stop

No Bias rail

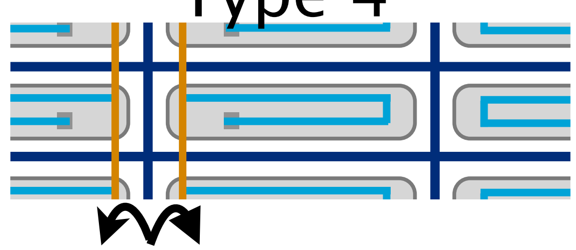
Type 19



No Bias structure

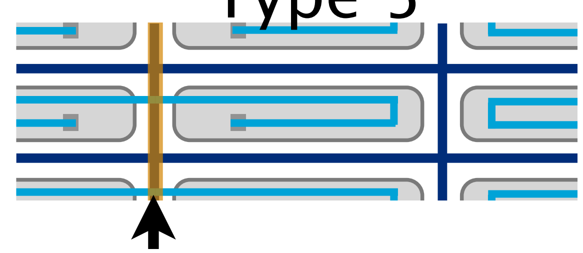
Al Bias rail

Type 4



Small Offset

Type 5



Wide P-stop

Non-irrad. sensors

Overall Hit efficiency

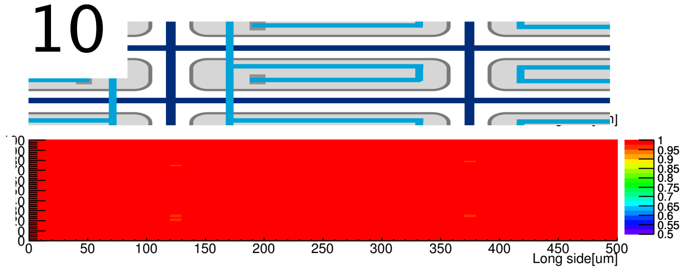
Sensor Type	Hit Efficiency at 15 V [%]	Hit Efficiency at 100 V [%]
Type 10	$88.087^{+0.034}_{-0.034}$	$99.844^{+0.004}_{-0.005}$
Type 12	$88.771^{+0.039}_{-0.039}$	$99.807^{+0.005}_{-0.005}$
Type 14	—	$99.721^{+0.006}_{-0.006}$
Type 4	—	$99.688^{+0.007}_{-0.007}$
Type 5	—	$99.728^{+0.010}_{-0.010}$
Type 19	—	$99.677^{+0.008}_{-0.008}$

more than 99%

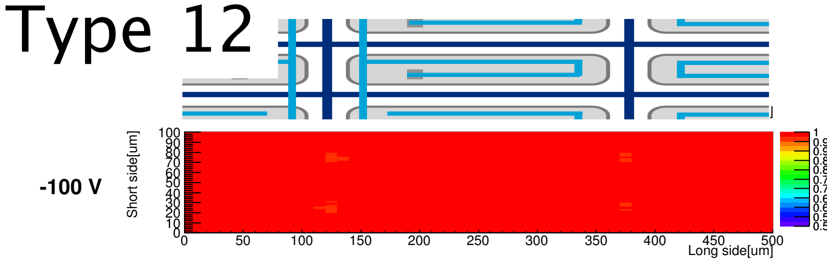
Hit Efficiency pixel map

Type 10

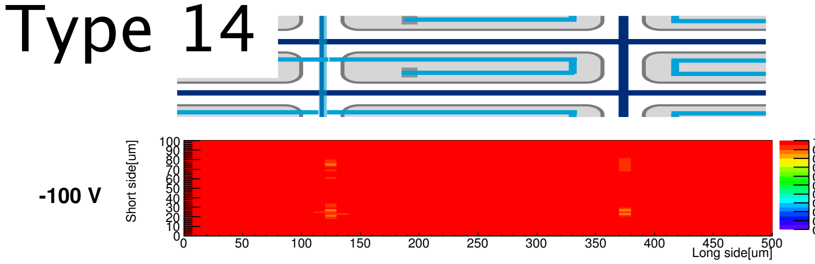
-100 V



Type 12

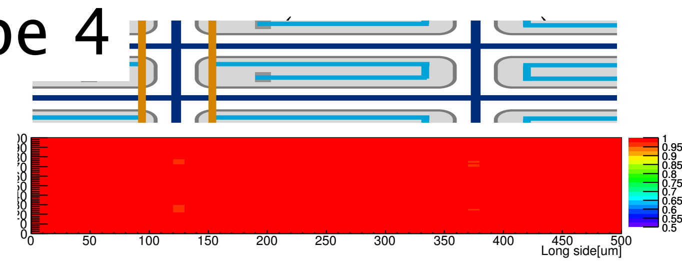


Type 14

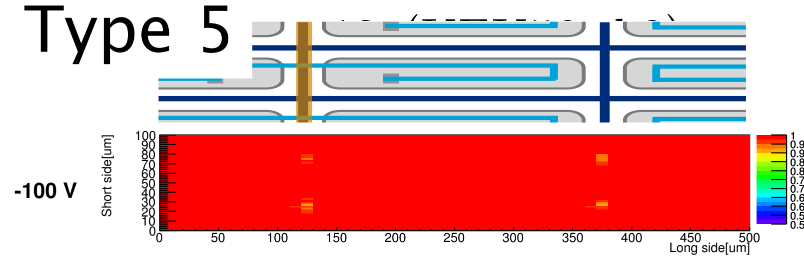


Type 4

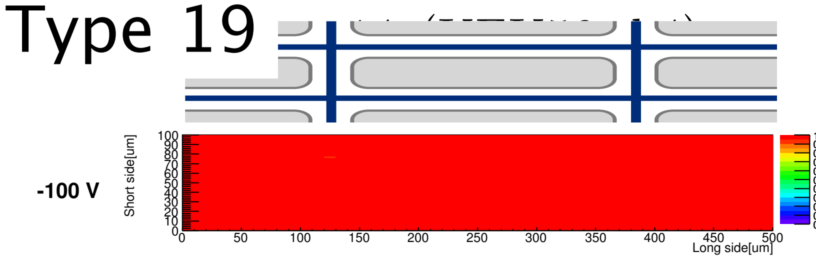
-100 V



Type 5



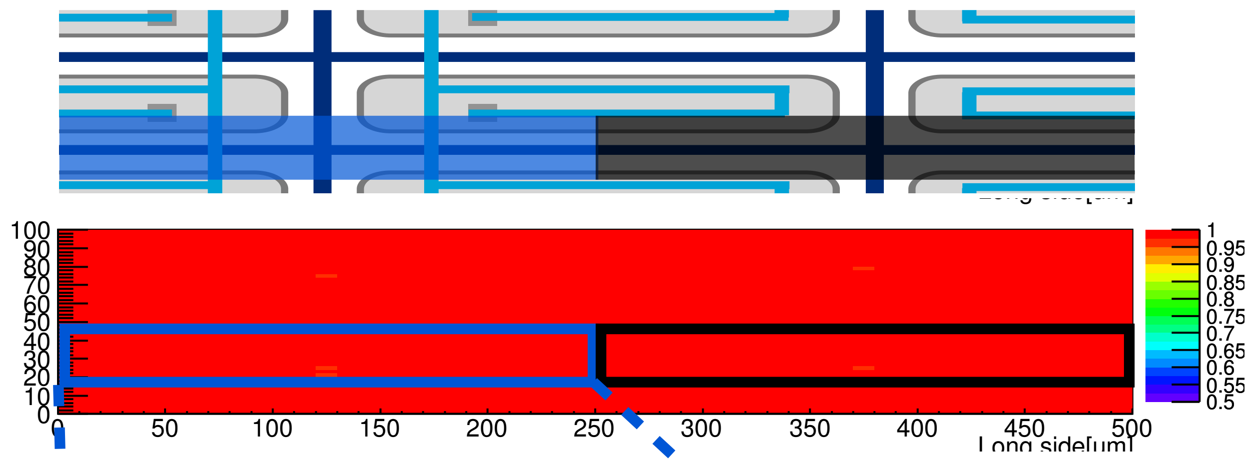
Type 19



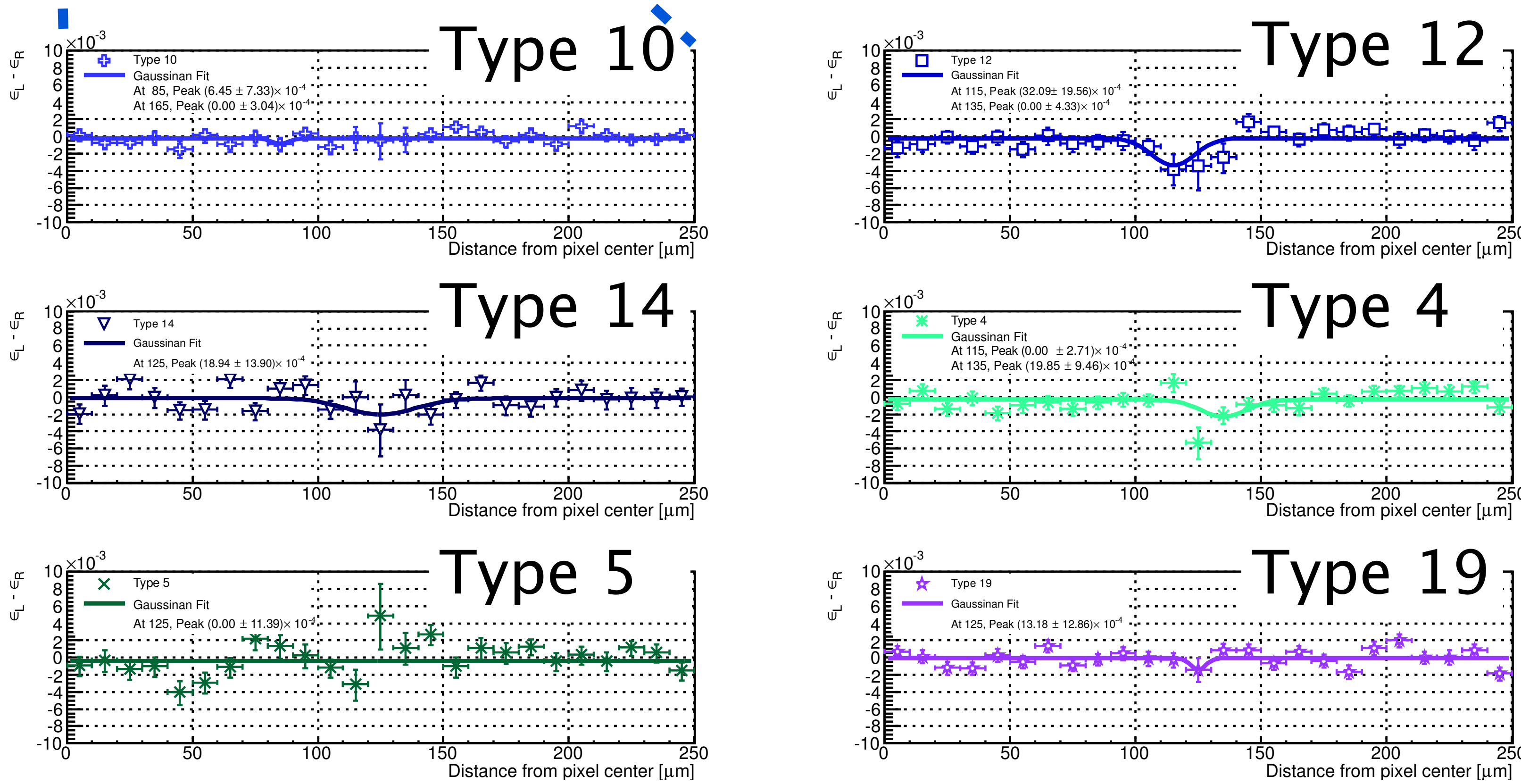
Uniform hit efficiency for all non-irrad. sensors

Non-irrad. sensors

- Influence by Bias rail



Hit Eff. in blue – Hit Eff. in black
= influence by bias rail



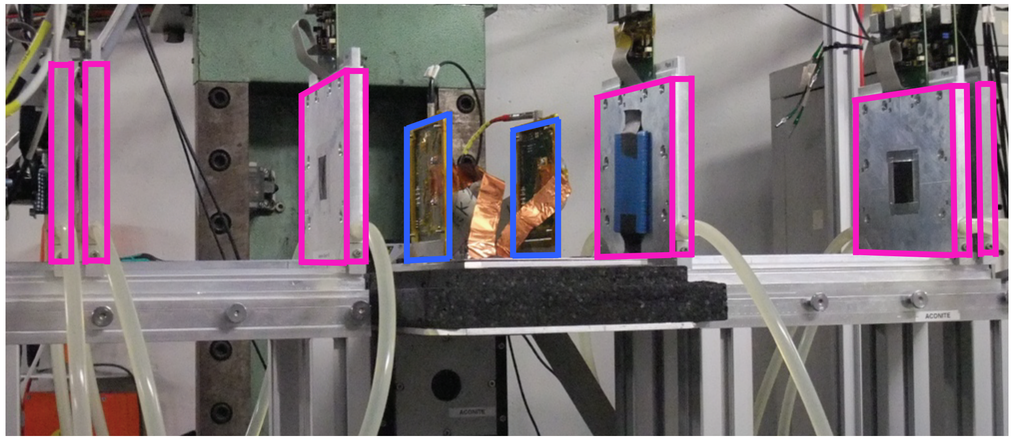
Project hit efficiency pixel map to long side

Fit it by Gaussian

– Hit Efficiencies are not affected by the bias rail

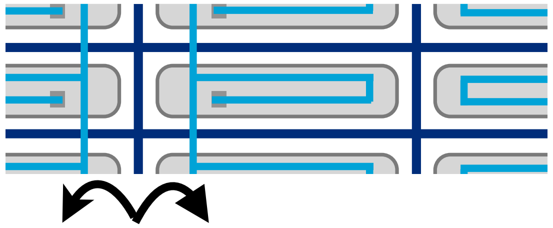
Irrad. sensors

6 Telescopes & 2 DUTs



- Testbeams at DESY
  - Multiple scattering
    - Pointing Resolution: ~26 μm
- Test samples

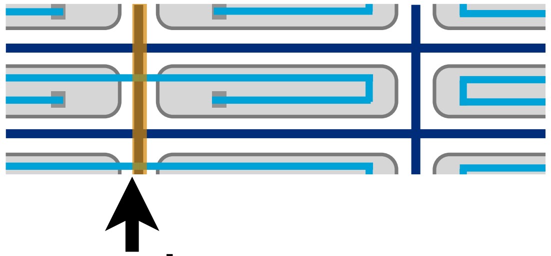
Large Offset
(Type 10)



Large Offset

- Fluence: 5×10^{15} [n_{eq} cm^{-2}]
  Thickness: 320 μm
- Fluence: 5×10^{15} [n_{eq} cm^{-2}]
  Thickness: 150 μm

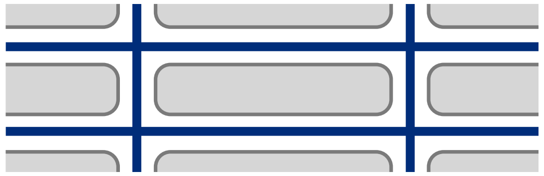
Wide P-stop
(Type 13)



Wide P-stop

- Fluence: 3×10^{15} [n_{eq} cm^{-2}]
  Thickness: 320 μm

No bias
(Type 19)

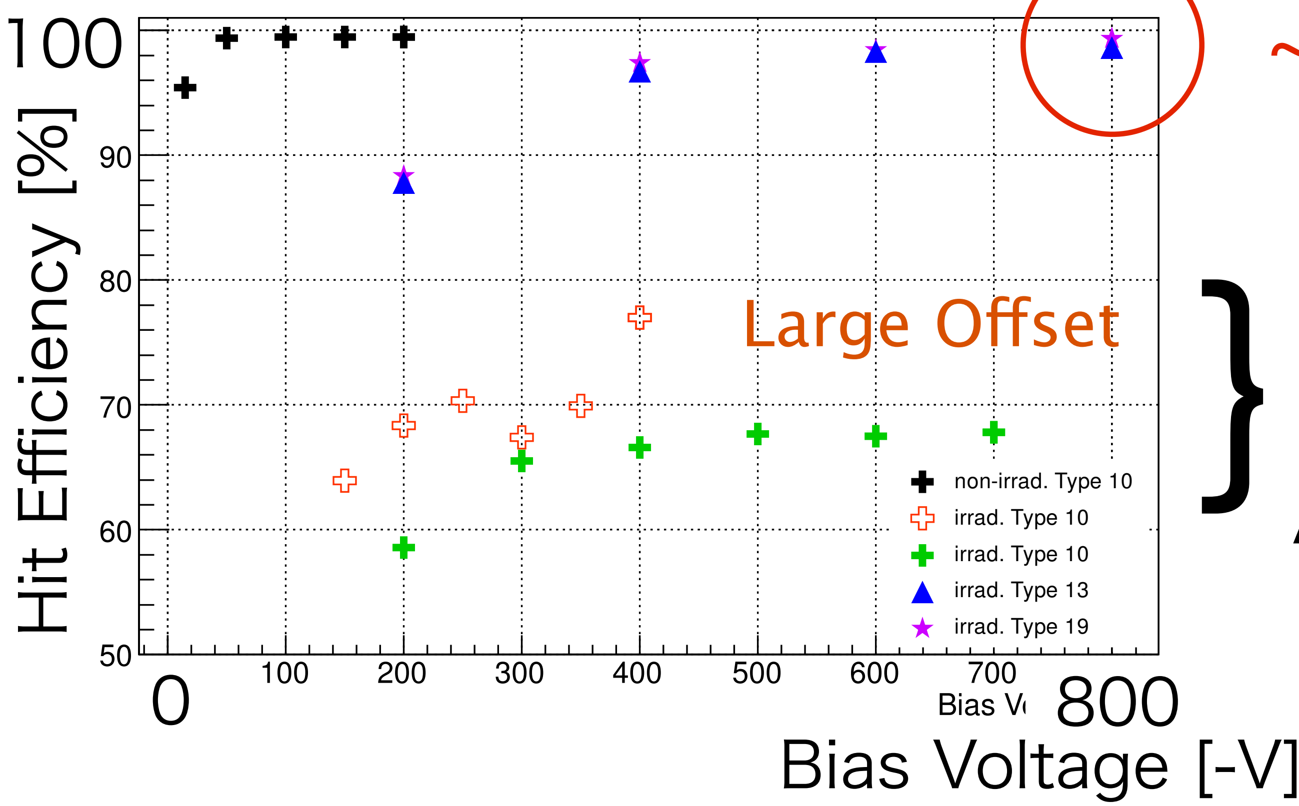


No Bias structure

- Fluence: 3×10^{15} [n_{eq} cm^{-2}]
  Thickness: 320 μm

Irrad. sensors

Overall Hit Efficiency



~99% at −800 V

Wide P-stop, No bias

No reference planes available
Issue about sync. of signals
Abs. values are not reliable...

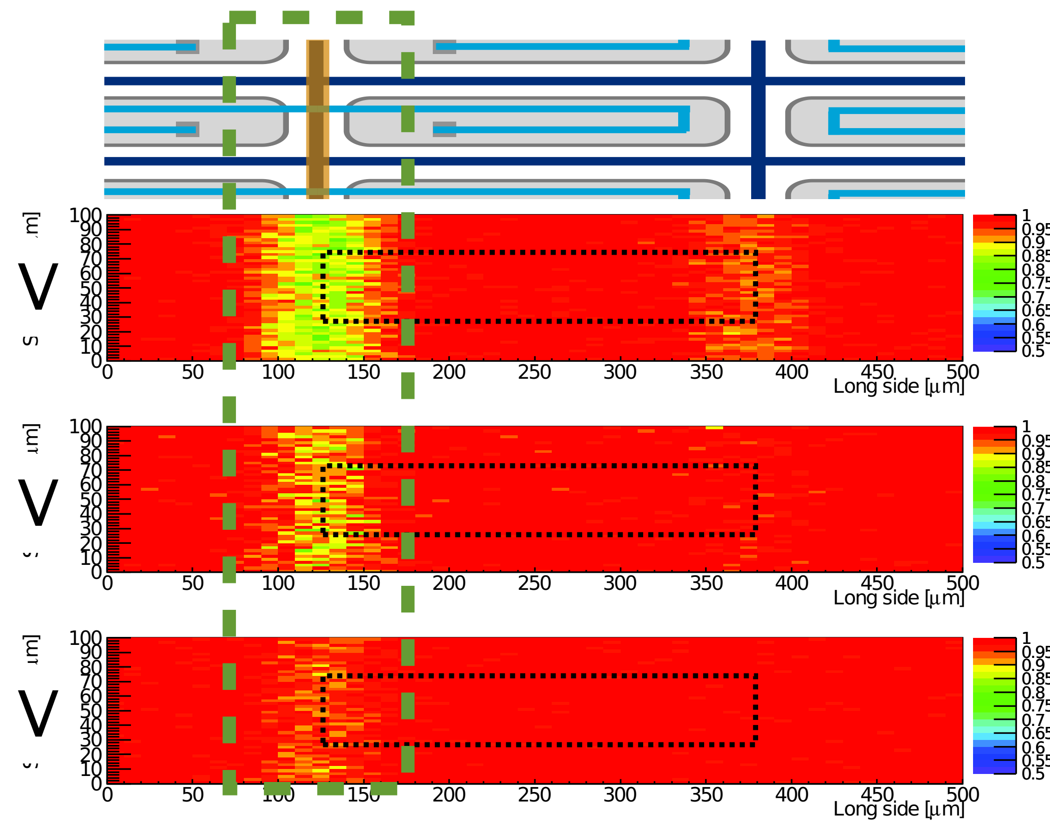
Hit Efficiency Pixel map

– Wide P-stop:
Hit Efficiency drops under the bias rail
(but see the later slides)

−400 V

−600 V

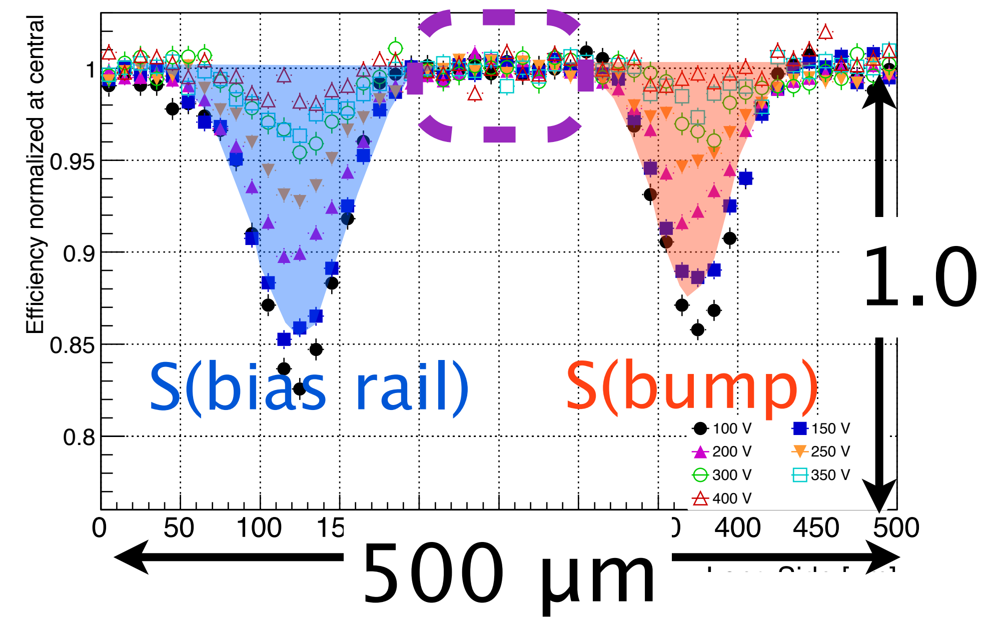
−800 V



Irrad. sensors

- Evaluate the hit eff. drop under the bias rail quantitatively
  - Hit Eff. pixel map is projected into long side
  - Normalize, Fit by Gaussian and calculate the area
- Efficiency Loss per pixel = S / (1.0 x 500 μm)
- But we have samples w/ different sensor thickness & radiation fluences...

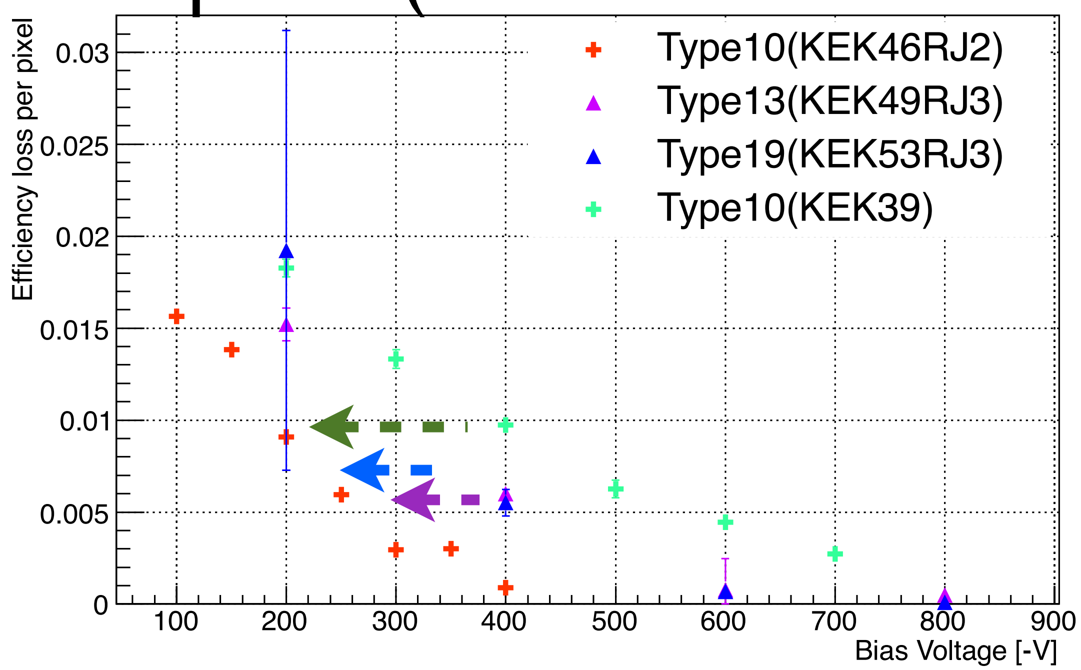
Hit Efficiency
(normalized at center)



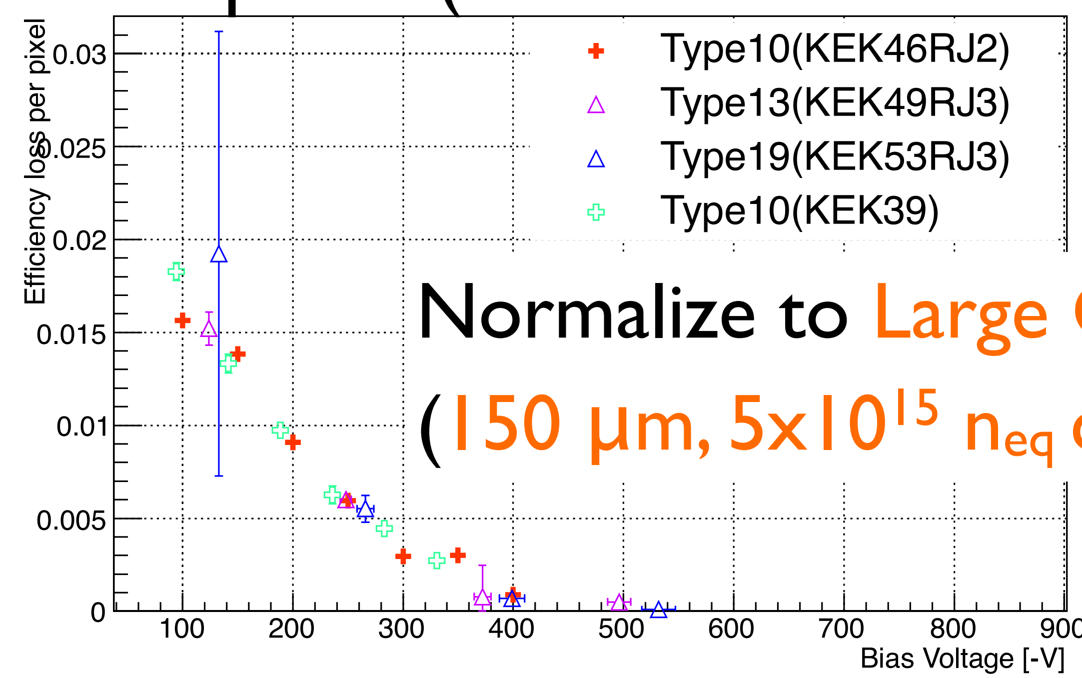
Thickness & Fluence Correction

- Take the differences of thickness & fluence into account
  - Approximately, fit bump side by an error function
  - Normalize to
    Large Offset sensor with 150 um, $5x10^{15}$ n_{eq} cm^{-2}
  - calculate transfer function

Bump side (**before correction**)



Bump side (**after correction**)

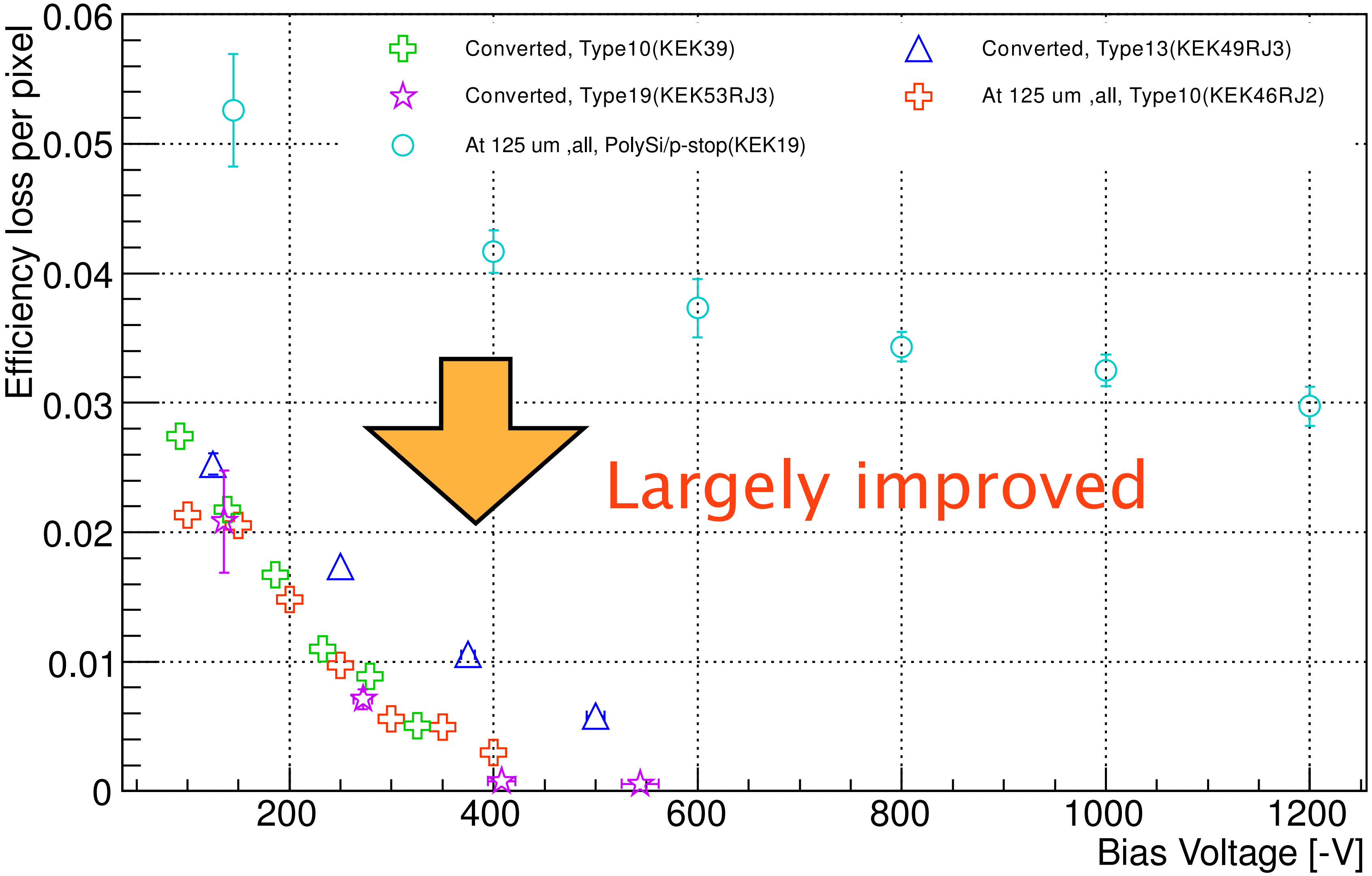


Normalize to Large Offset
(150 μm, $5x10^{15}$ n_{eq} cm^{-2})

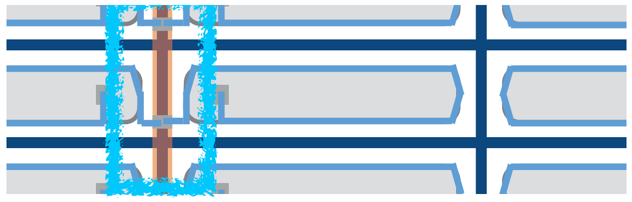
- Apply the transfer function to bias rail side

Irrad. sensors (5x10^{15} n_{eq} cm^{-2}, 150 μm)

- Efficiency loss per pixel under the bias rail

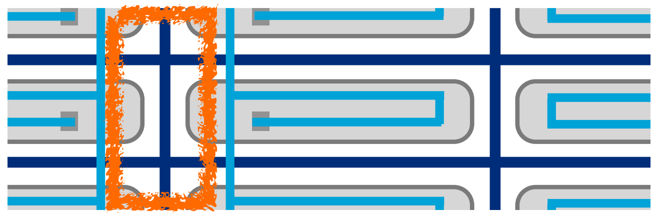


Original

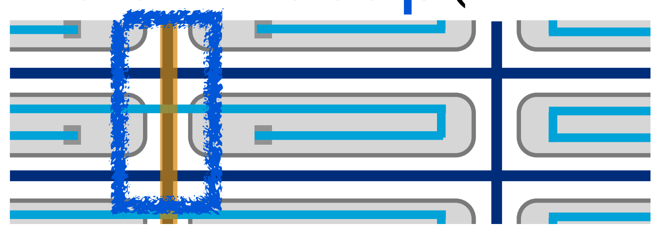


Large Offset

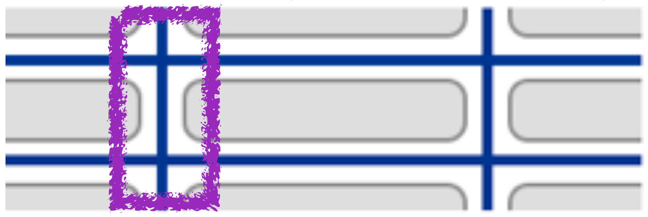
Large Offset(converted)



Wide P-stop(converted)



No bias(converted)



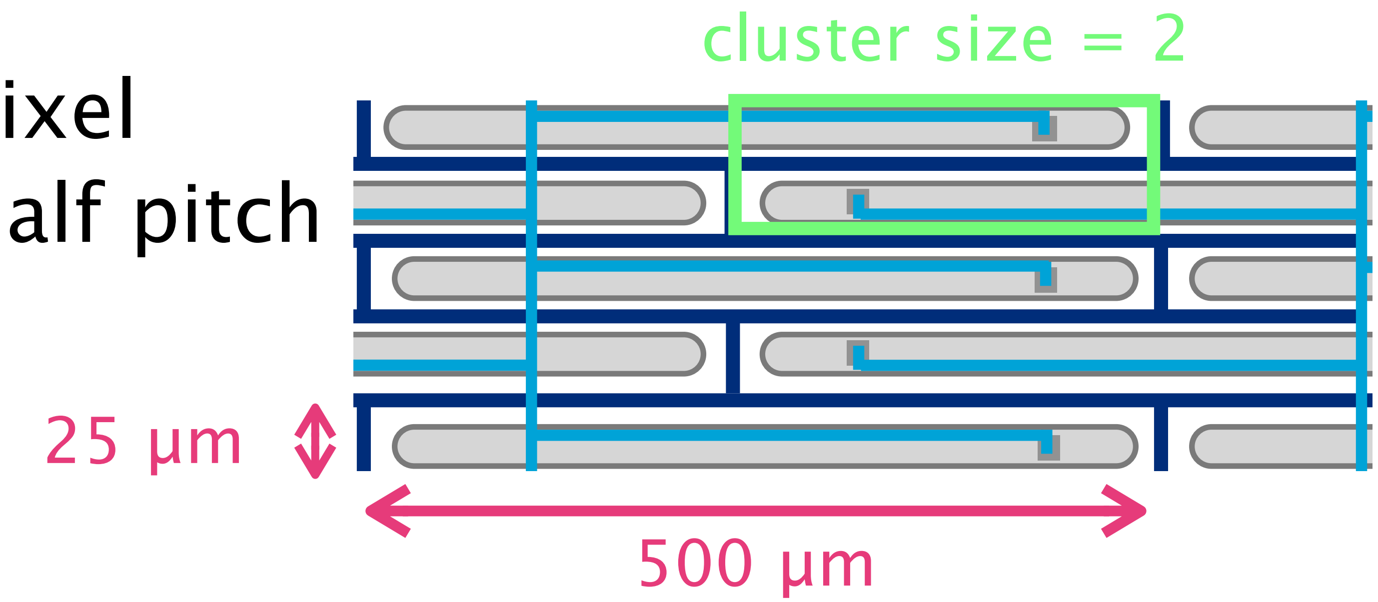
Eff. loss per pixel under the bias rail

No bias ~ Large Offset

< Wide P-stop << Original

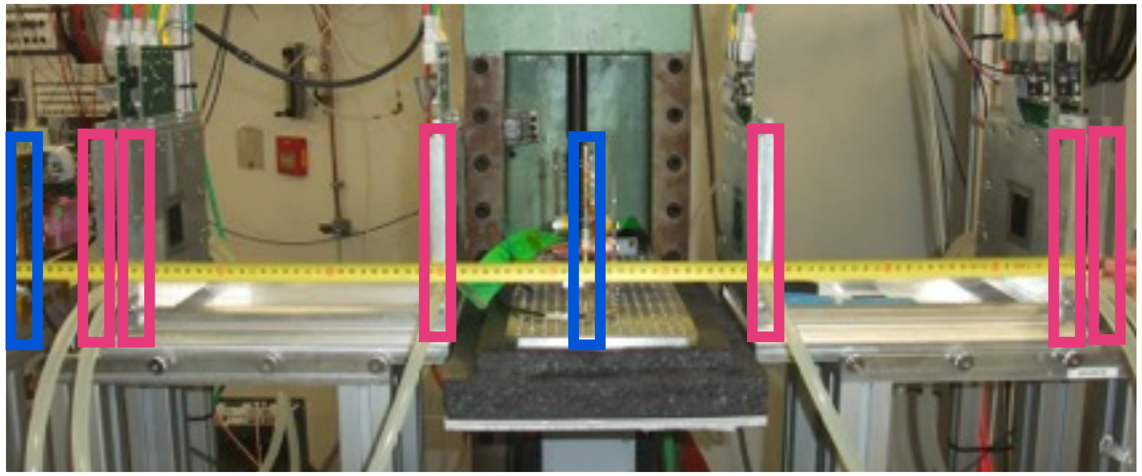
Long Staggered Pixel

- “Long” = 25 x 500 μm^2 pixel
  “Staggered” = Offset by half pitch



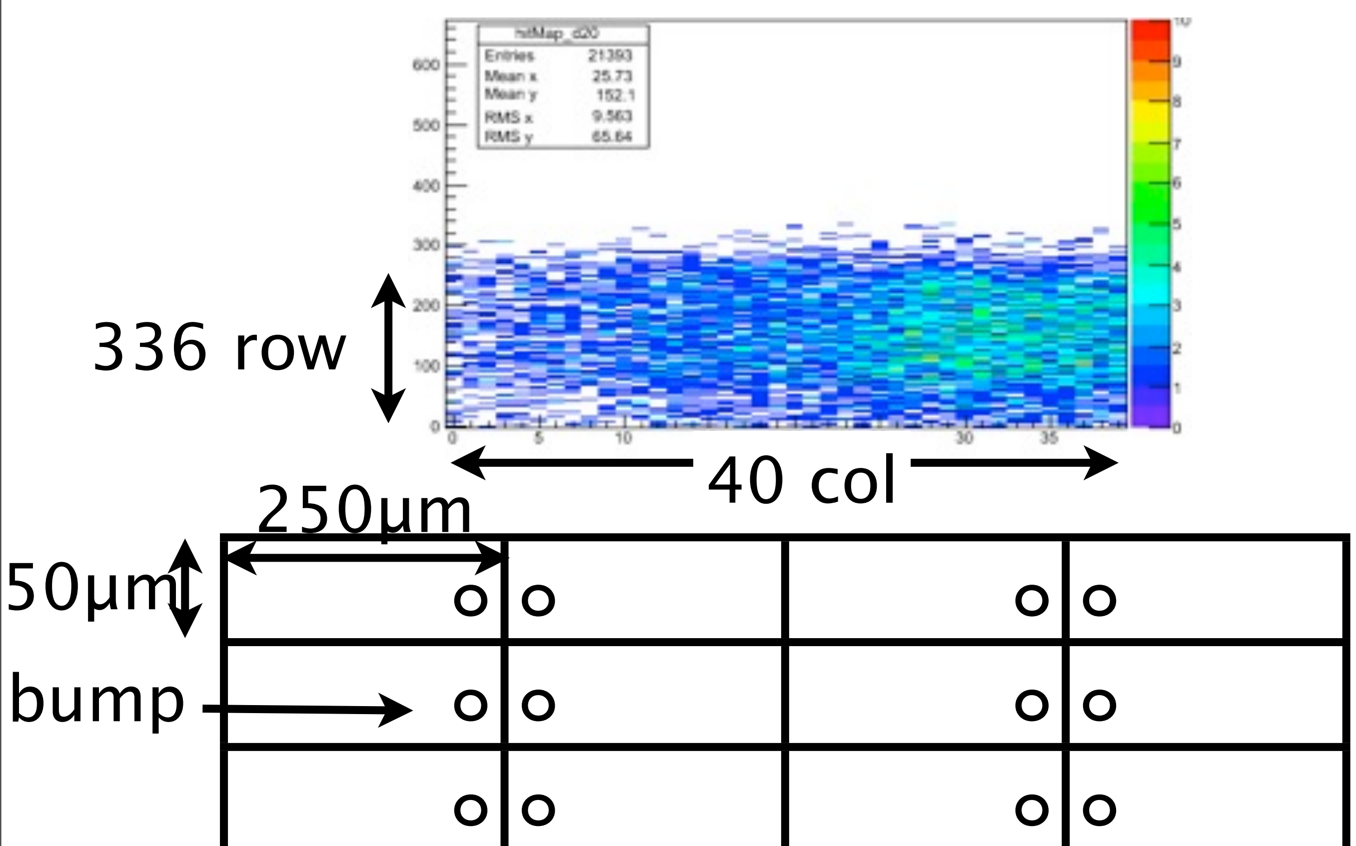
- Position resolution
  - Short side: 25 µm pitch
    better position resolution than 50 µm pitch
  - Long side w/ clustering: 250 µm pitch
    due to staggered geometry
- Testbeam at DESY in Aug. 2013
  - Non-irrad. sensors
    w/ 320 µm thick

6 Telescopes & 2 DUTs

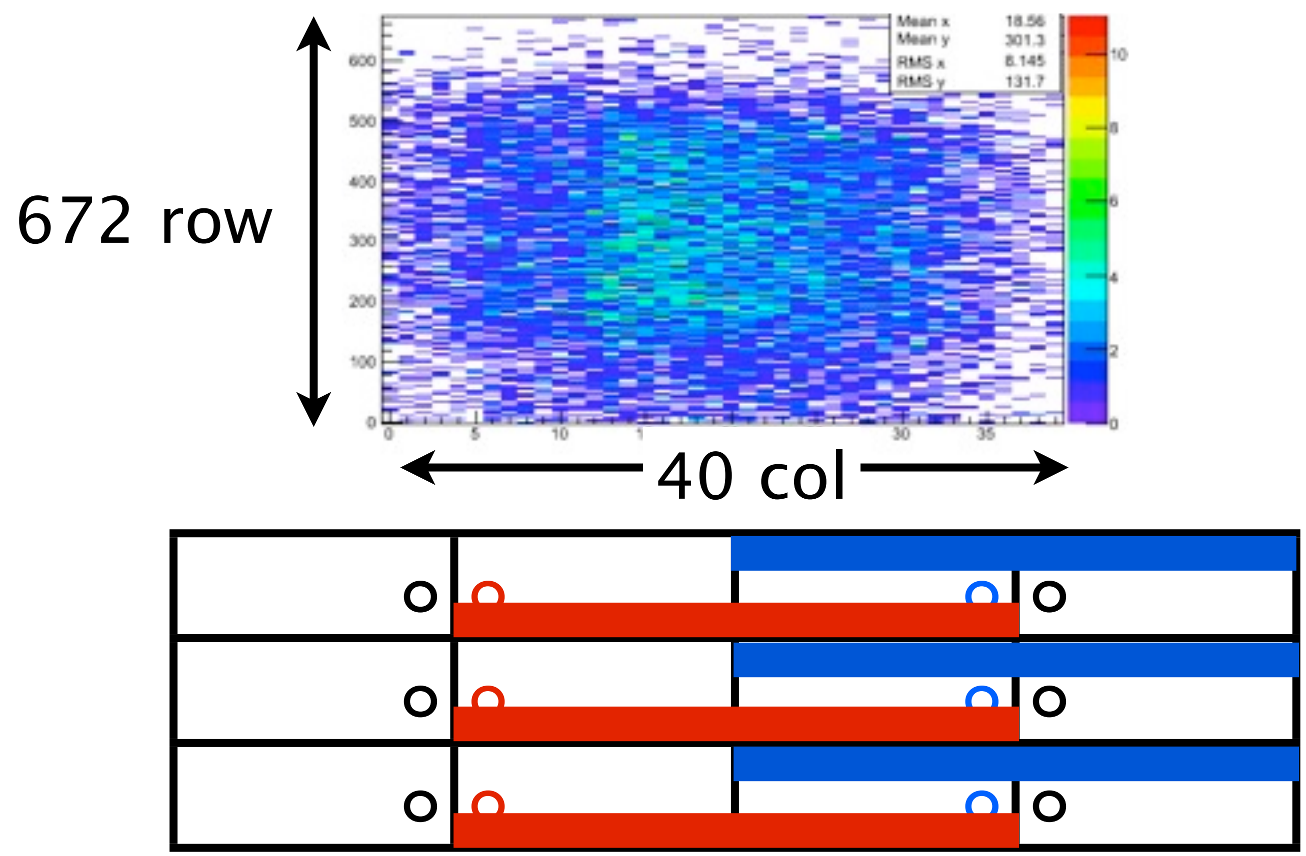


Reconstruction

- Convert FE-I4 pixel configuration (to “Long” pixel sensor)
  - FE-I4 chip: 80 col x 336 row pixels (default)
  - Long pixel sensor: 40 col x 672 row pixels
- Clustering is done with “Long” pixel, not “staggered pixel”
- Shift hit positions for odd row pixels (to “staggered” pixel)



FE-I4 pixel configuration

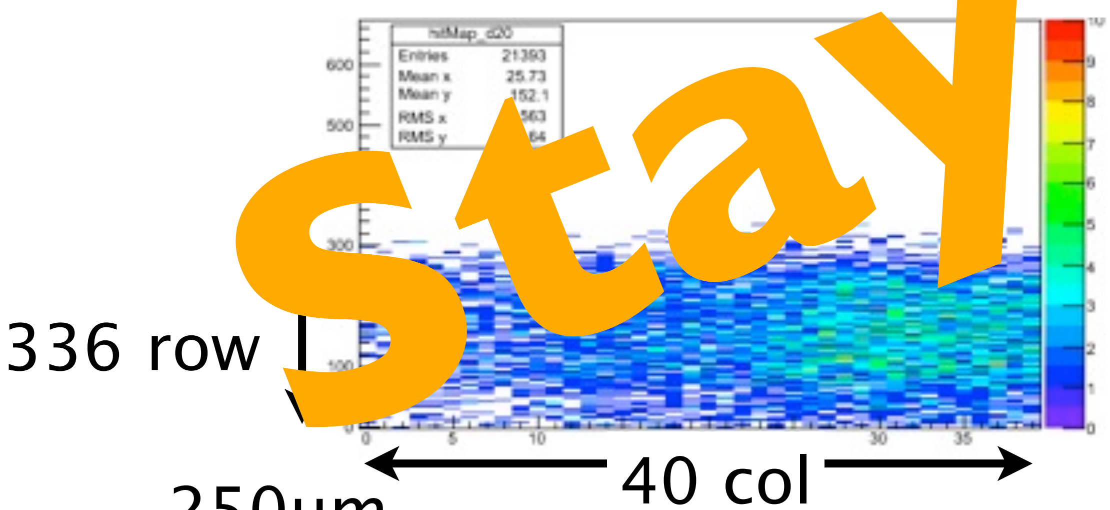


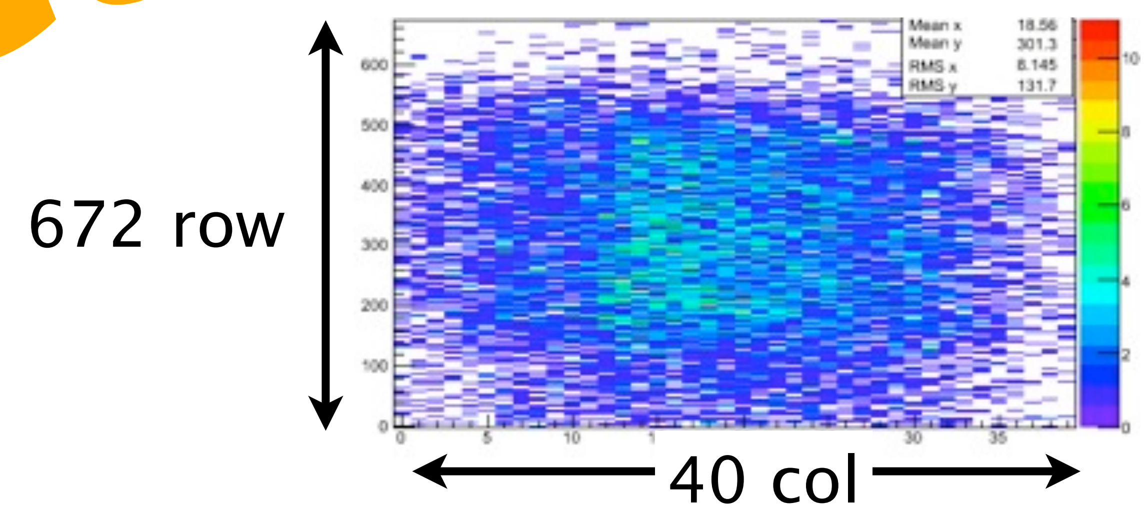
Sensor pixel configuration

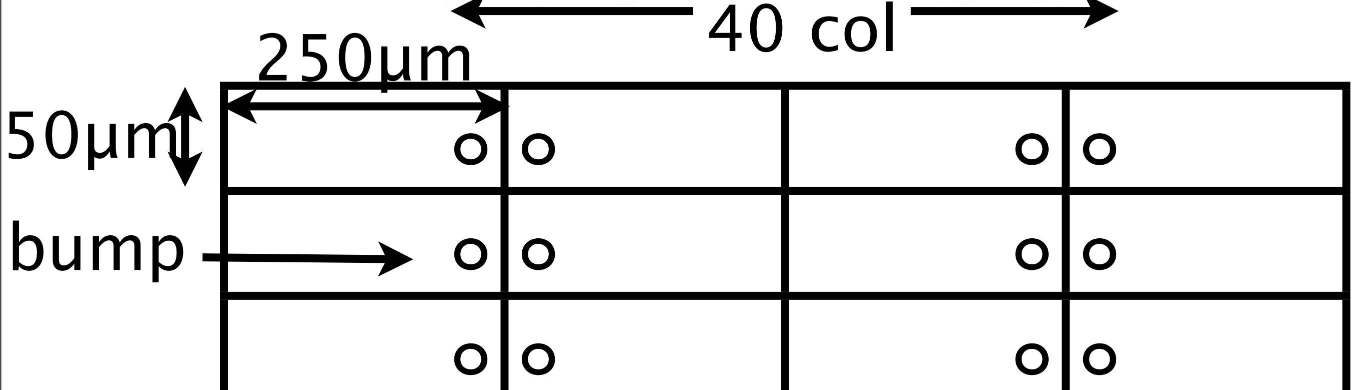
Reconstruction

- Convert FE-I4 pixel configuration (to “Long” pixel sensor)
  - FE-I4 chip: 80 col x 336 row pixels (default)
  - Long pixel sensor: 40 col x 672 row pixels
- Clustering is done with “Long” pixel and “staggered pixel”
- Shift hit positions for odd row pixels (to “staggered” pixel)

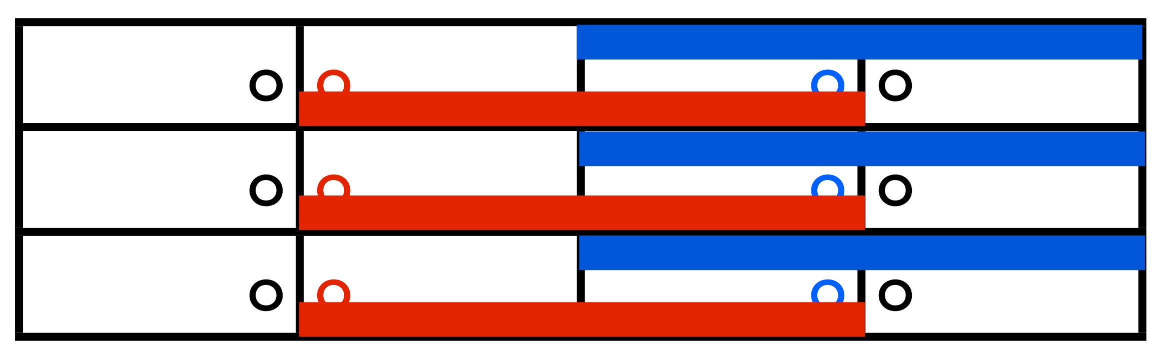
Stay tuned!







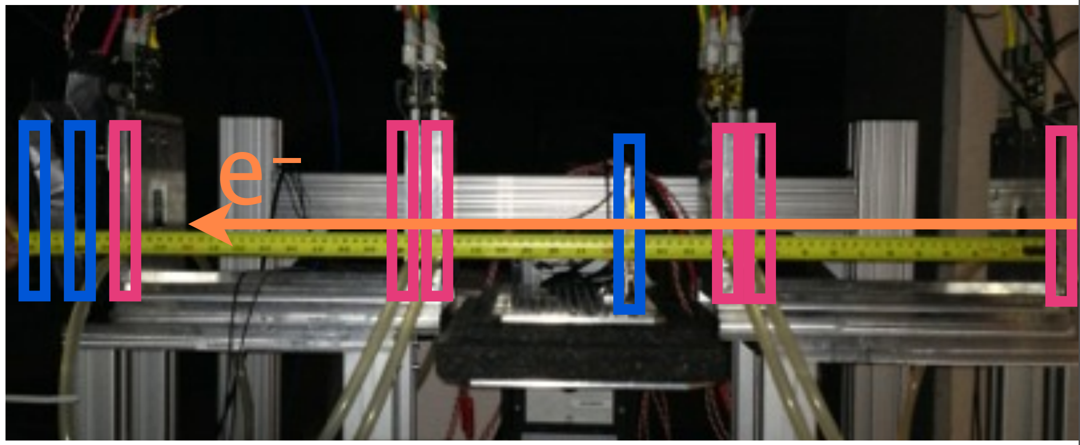
FE-I4 pixel configuration



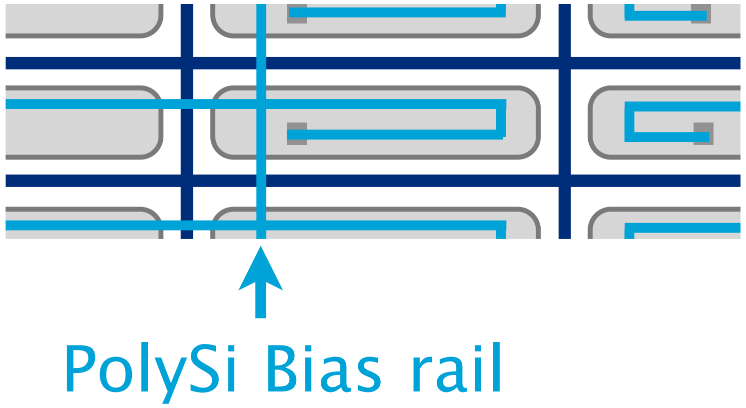
Sensor pixel configuration

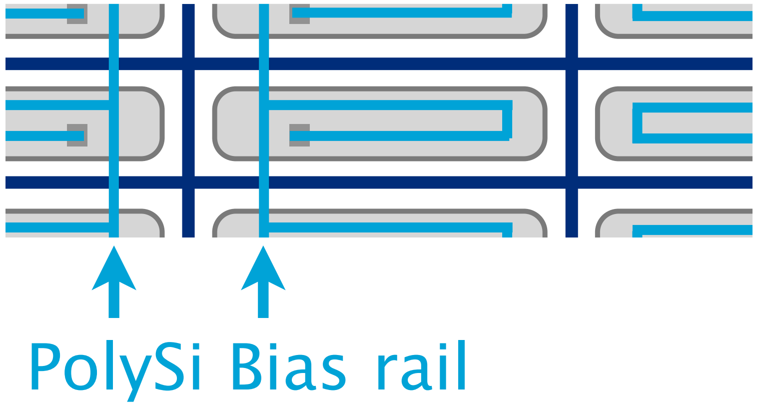
Performance at dense env.

- Evaluate performance of new pixel sensors in dense environment
- Testbeam at SLAC in May 2014
  - 2.5 GeV e⁻: ~10 particles/event
  - 13 GeV e⁻: ~70 particles/event
    (particles/event is measured at the most downstream telescope)



- Test samples (Non-irrad. w/ 150 μm thk.)





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- Reconstruction & Analysis are on-going

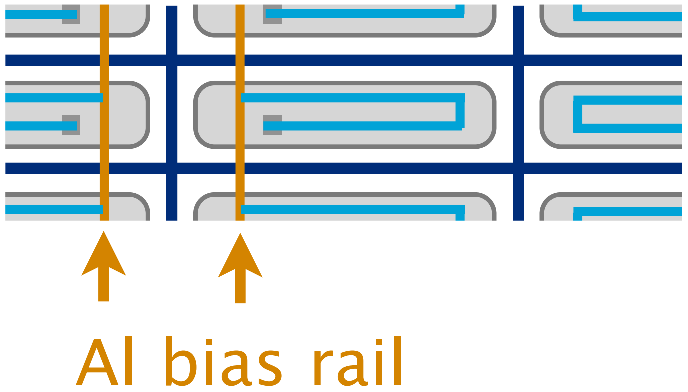
Summary

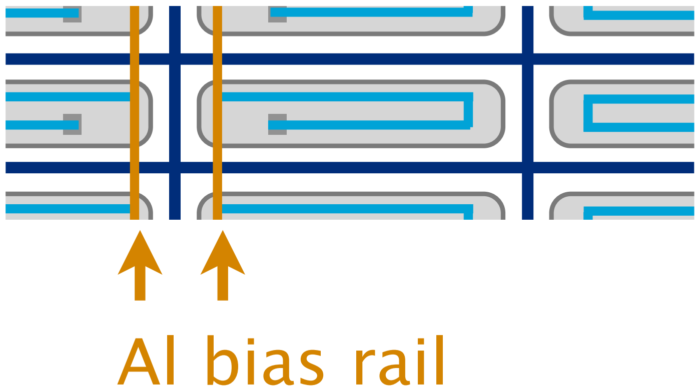
- ATLAS-J Silicon Group has developed n^+-in-p planar pixel sensors, collaborating with Hamamatsu Photonics K.K
- Optimizing the sensor structures
- Testbeam analysis
  - Non-irrad. sensors: uniform hit efficiency more than 99%
  - Irrad. sensors: Hit Eff. under the bias rail is largely improved from original sensors
    Especially, the offset of bias rail helps well
  - Long Staggered pixel & Evaluation in dense env. Reconstruction and Analysis are on-going

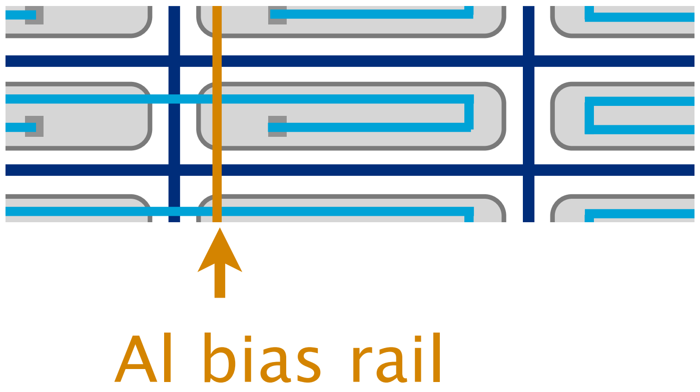
Back Up

Future

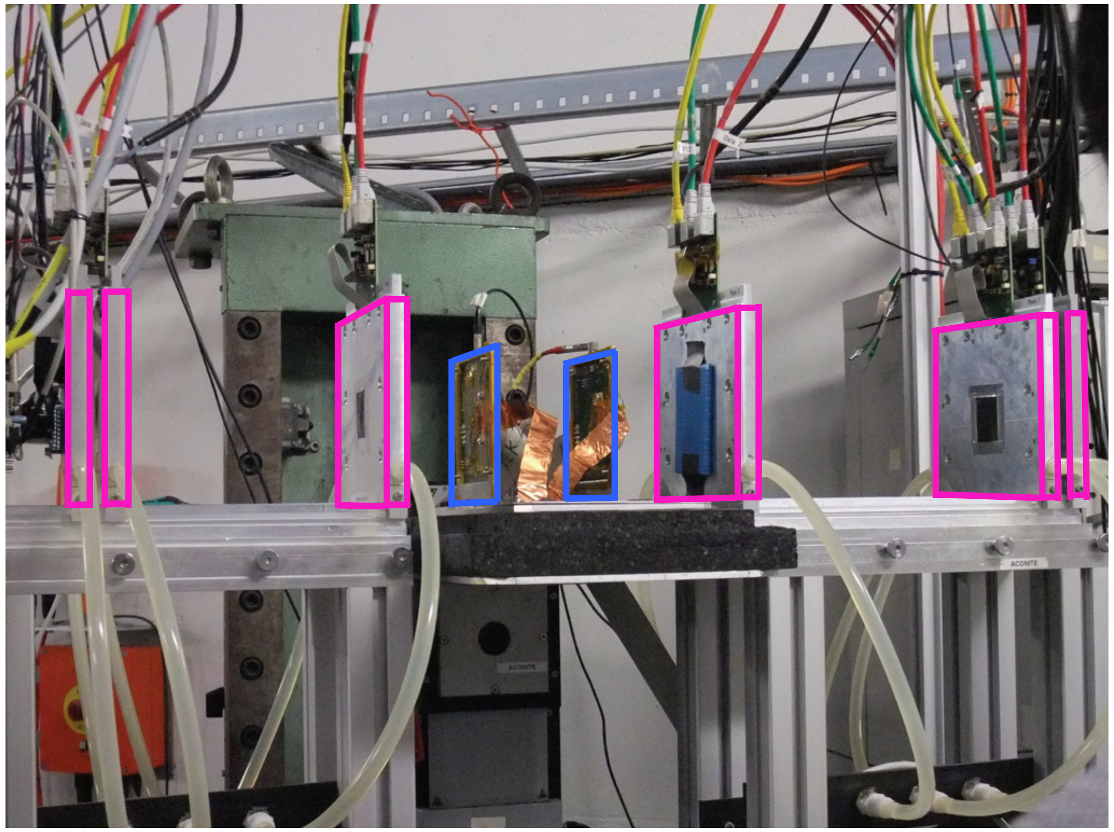
- Irradiation at CYRIC in Feb.
  - 5 x pseudo-4chip samples w/ 150 µm thick
  - Target Fluence: 3×10^{15} n_{eq} cm^{-2}
- Testbeam at DESY in March
  - untested irrad. sensors:

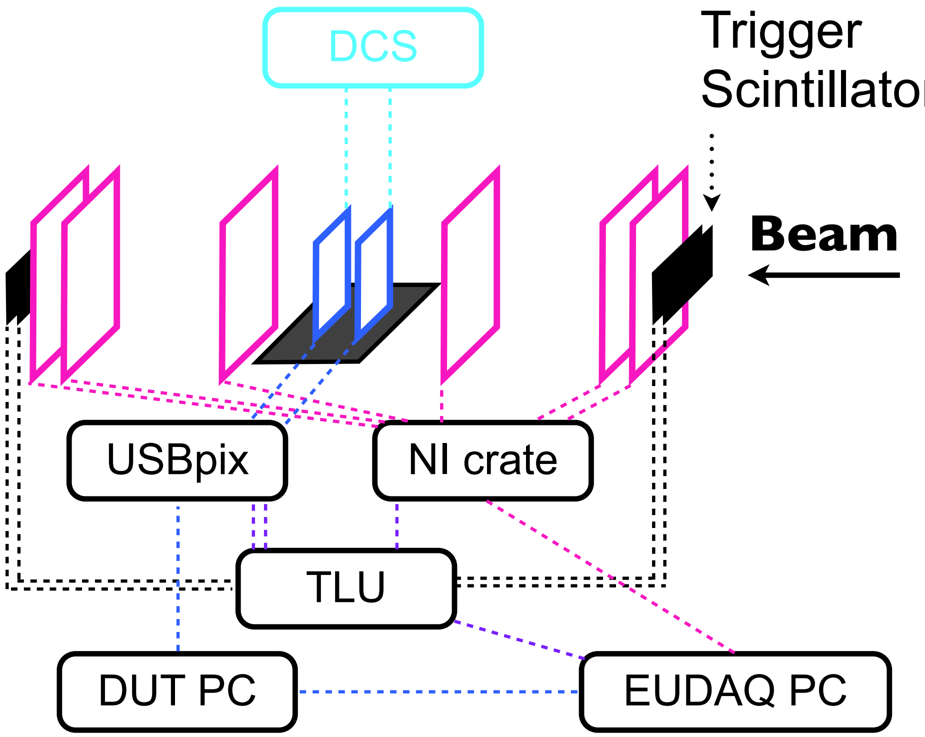


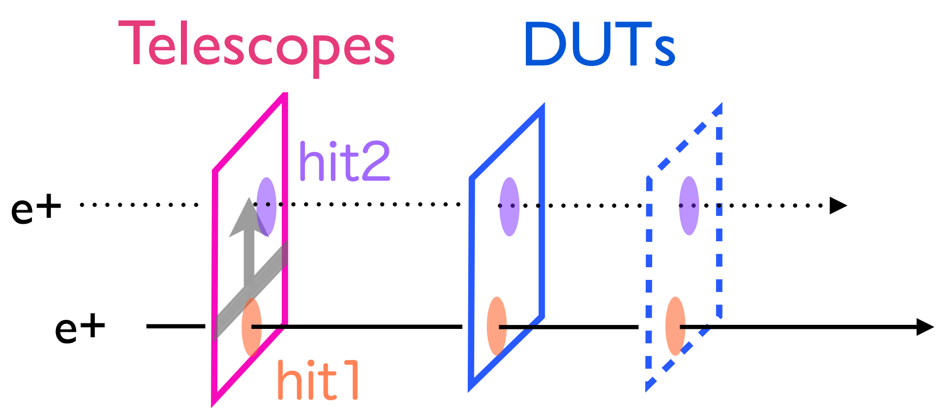


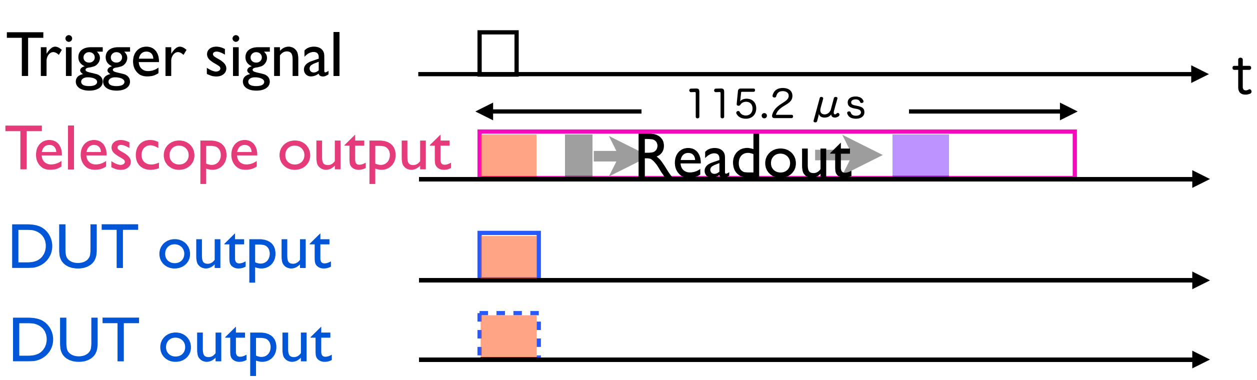


Issue about no ref. planes



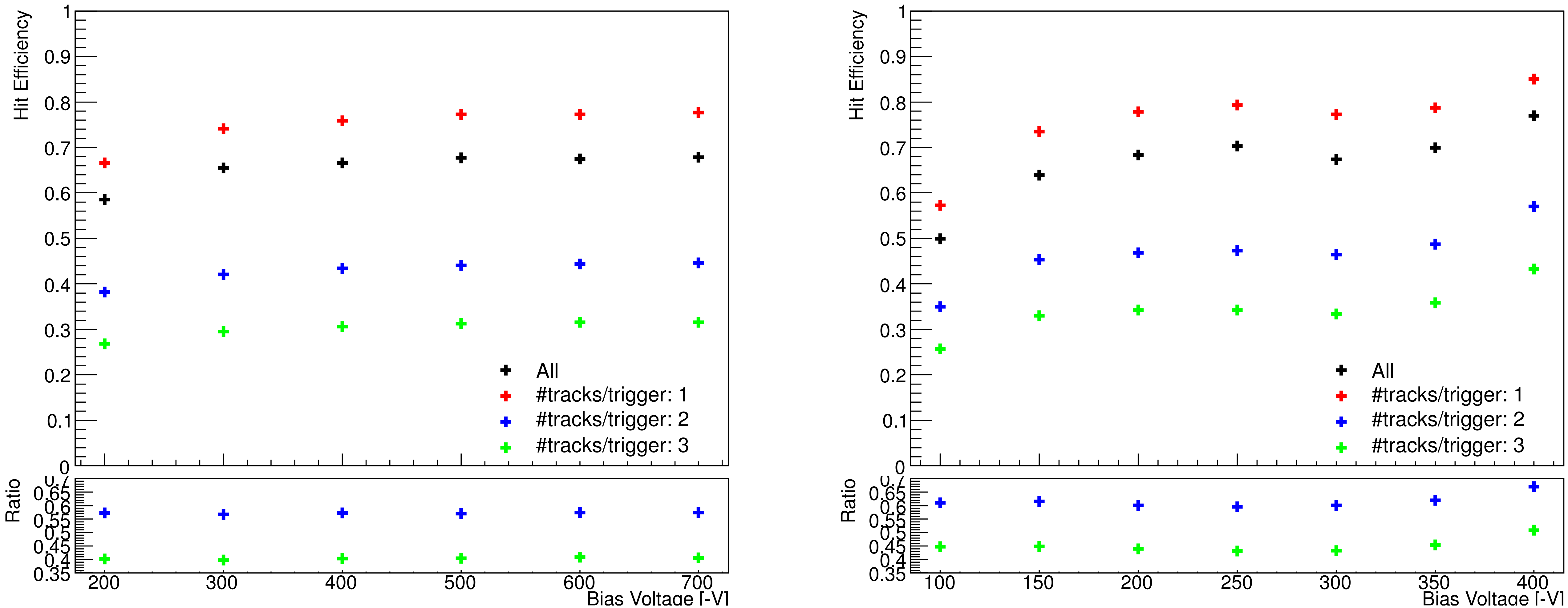






Testbeam in Nov. 2013

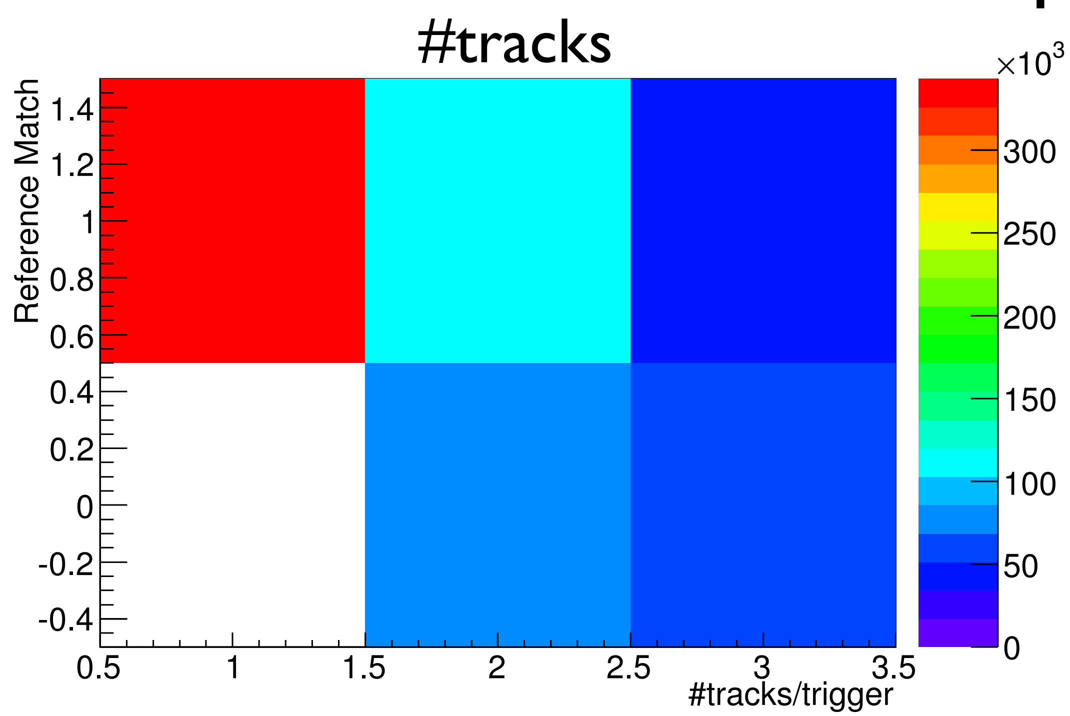
- Without refrence planes
- Hit efficiency by the number of tracks per trigger

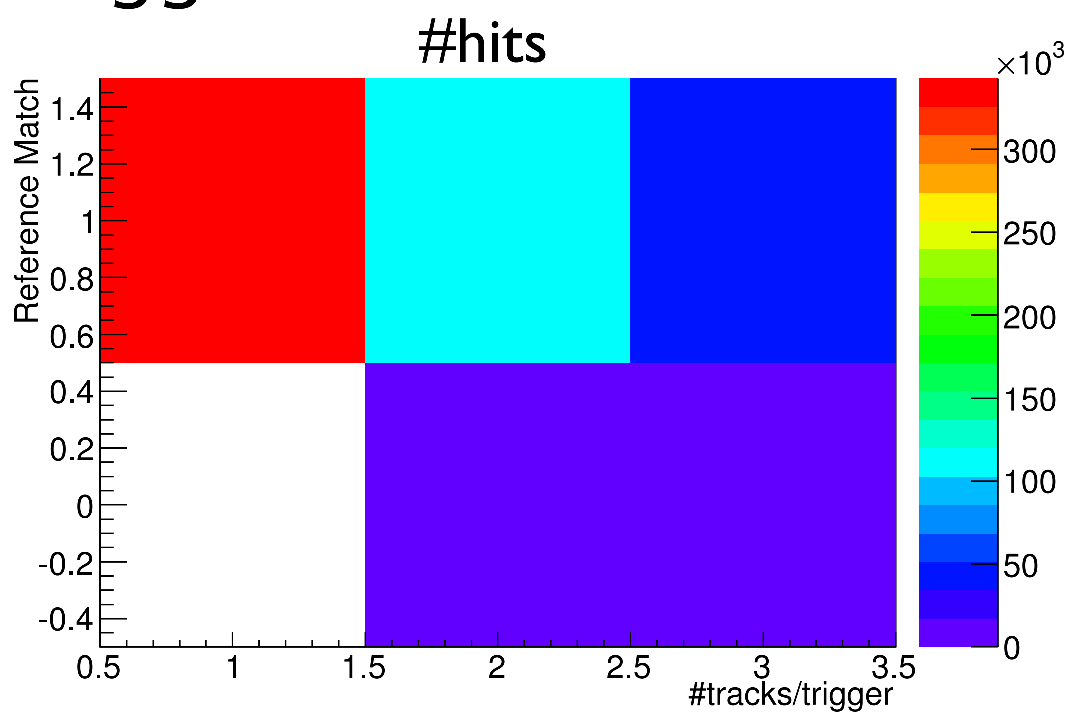


(a) KEK41 (b) KEK46 ch2

Testbeam in Feb. 2014

- With reference plane
- Categorize tracks by two condition:
  - exist hits on reference plane or not
  - the number of tracks per trigger

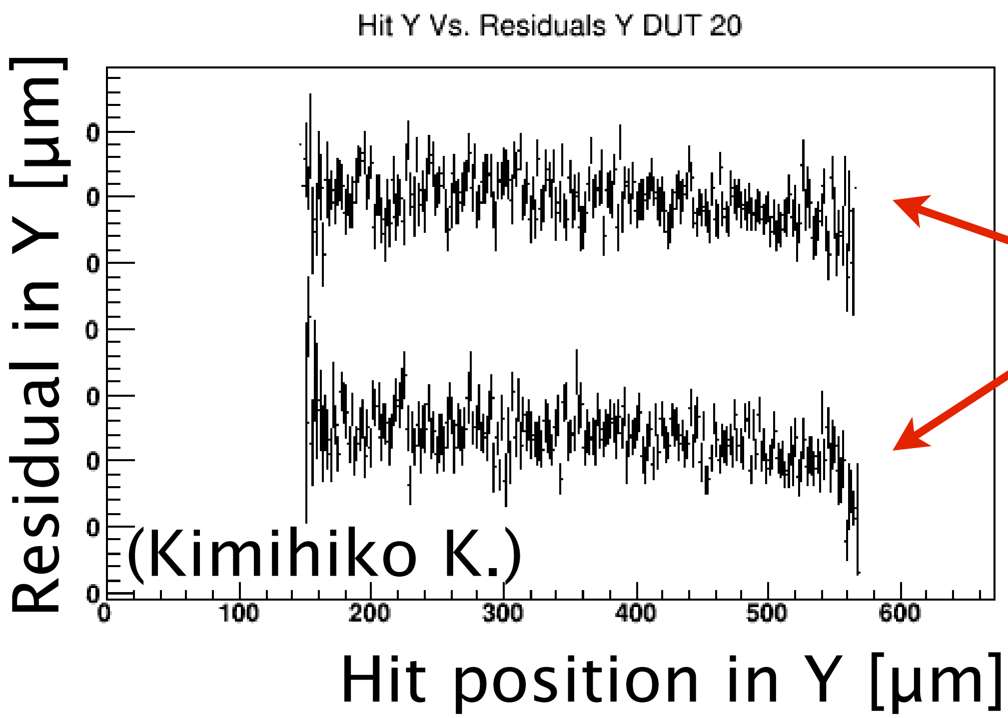




Hit Efficiency [%]	#tracks/trigger			
Ref. Match	1	2	3	sum
1	$99.88^{+0.01}_{-0.01}$	$99.81^{+0.01}_{-0.01}$	$99.75^{+0.02}_{-0.03}$	$99.85^{+0.01}_{-0.01}$
0	—	$0.014^{+0.004}_{-0.004}$	$0.009^{+0.005}_{-0.003}$	$0.013^{+0.003}_{-0.003}$
sum	$99.88^{+0.01}_{-0.01}$	$58.34^{+0.11}_{-0.11}$	$41.50^{+0.16}_{-0.16}$	$77.96^{+0.05}_{-0.05}$

Residual Problem

- Analyzed with TBmon v2.0
  and got the hit position Y vs residual Y plot below:



two residual values for each hit position
=> clustering or alignment problem

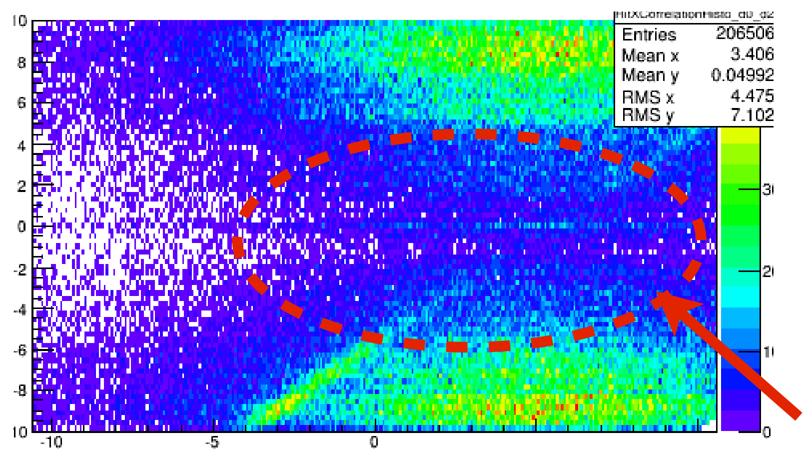
- To solve this problem,
  reconstruction is on-going with EUTelescope v1.0.0
  - Clustering with long staggered geometry

Reconstruction issue

- Recognize hits as noise due to very high multiplicity

Correlation Tel0 vs DUT20

X at DUT20



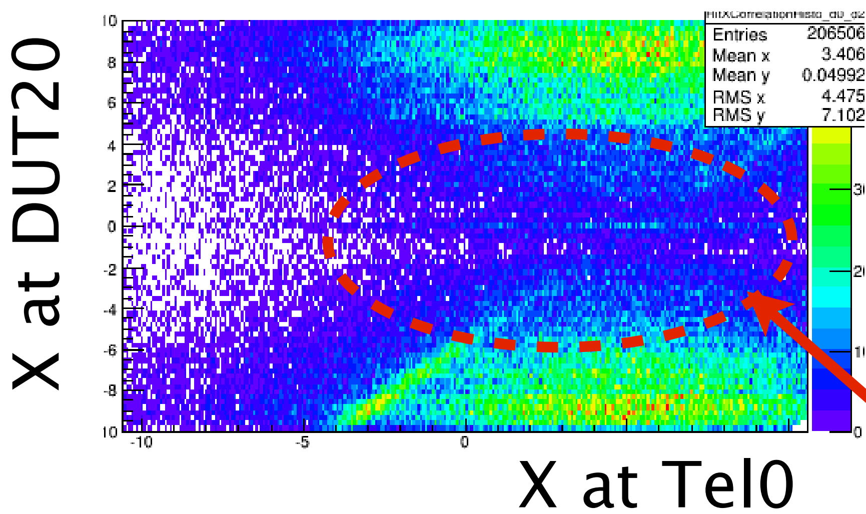
X at Tel0

hits at beam center
are masked...

Reconstruction issue

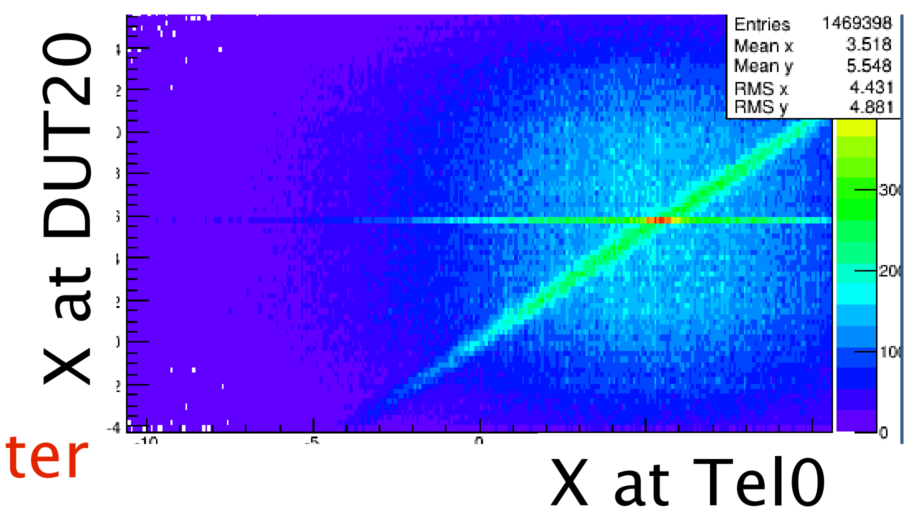
- Recognize hits as noise due to very high multiplicity

Correlation Tel0 vs DUT20



hits at beam center are masked...

Correlation Tel0 vs DUT20



  – Threshold to distinguish hits and noise is set larger (Kimihiko K.)

- Further reconstruction and analysis is on-going