Results from beamtests of the new designs of pixel structures

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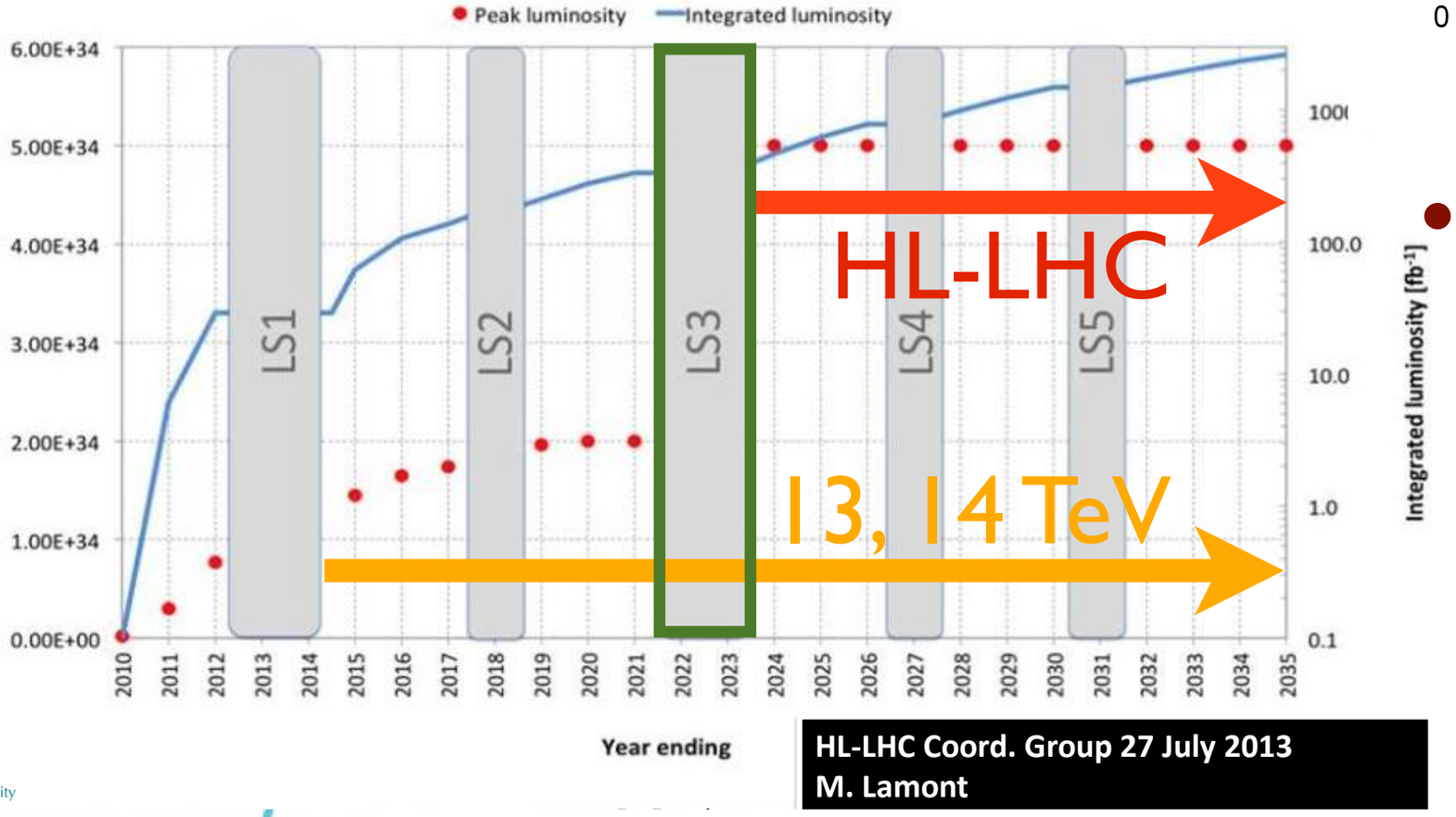
Contents

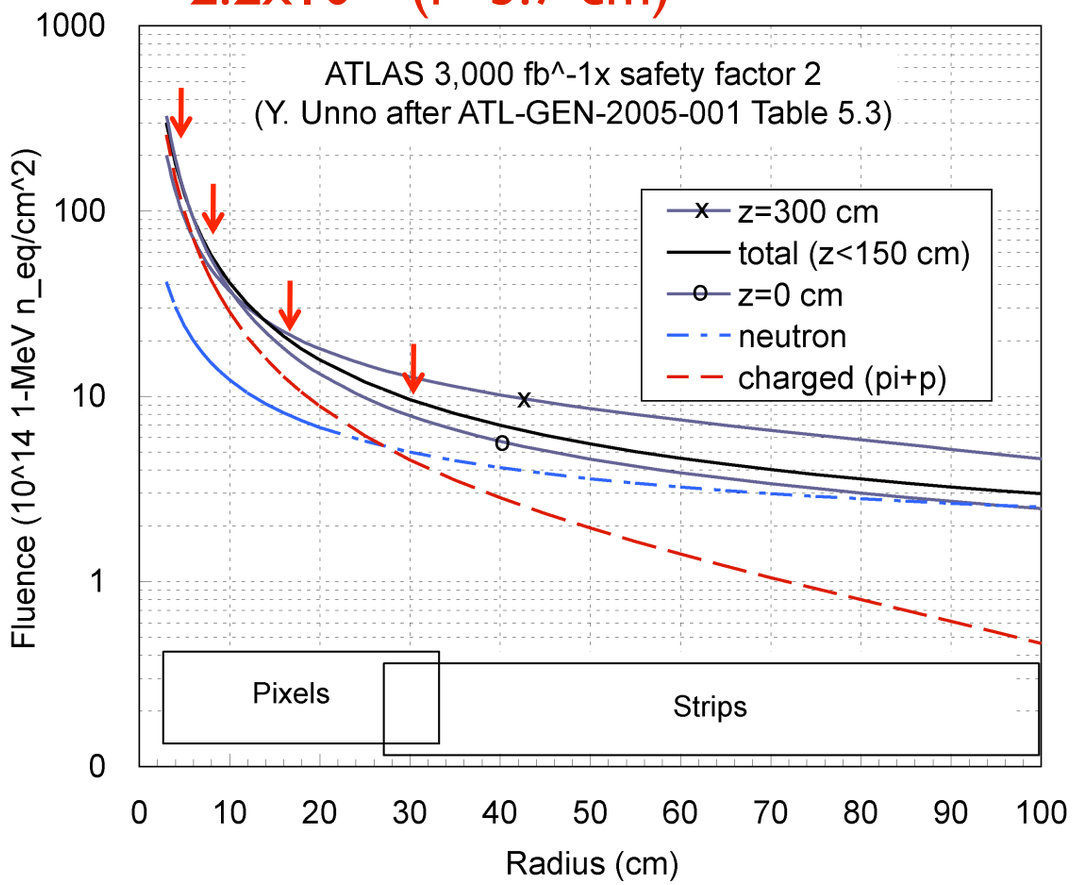
- ATLAS Inner Detector Upgrade for HL-LHC
- KEK/HPK n-in-p planar pixel sensor
- New designs of pixel structures
- Results of testbeams at DESY in 2013
- Conclusion

ATLAS ID Upgrade for HL-LHC

- Peak luminosity: $5 \times 10^{34}\ cm^{-2}s^{-1}$ => <pile up> ~ 140
- Integrated luminosity: 3000 fb^{-1}
  - high particle fluences in ATLAS
- Long Shutdown 3
  - All inner detector will be replaced with new silicon detectors



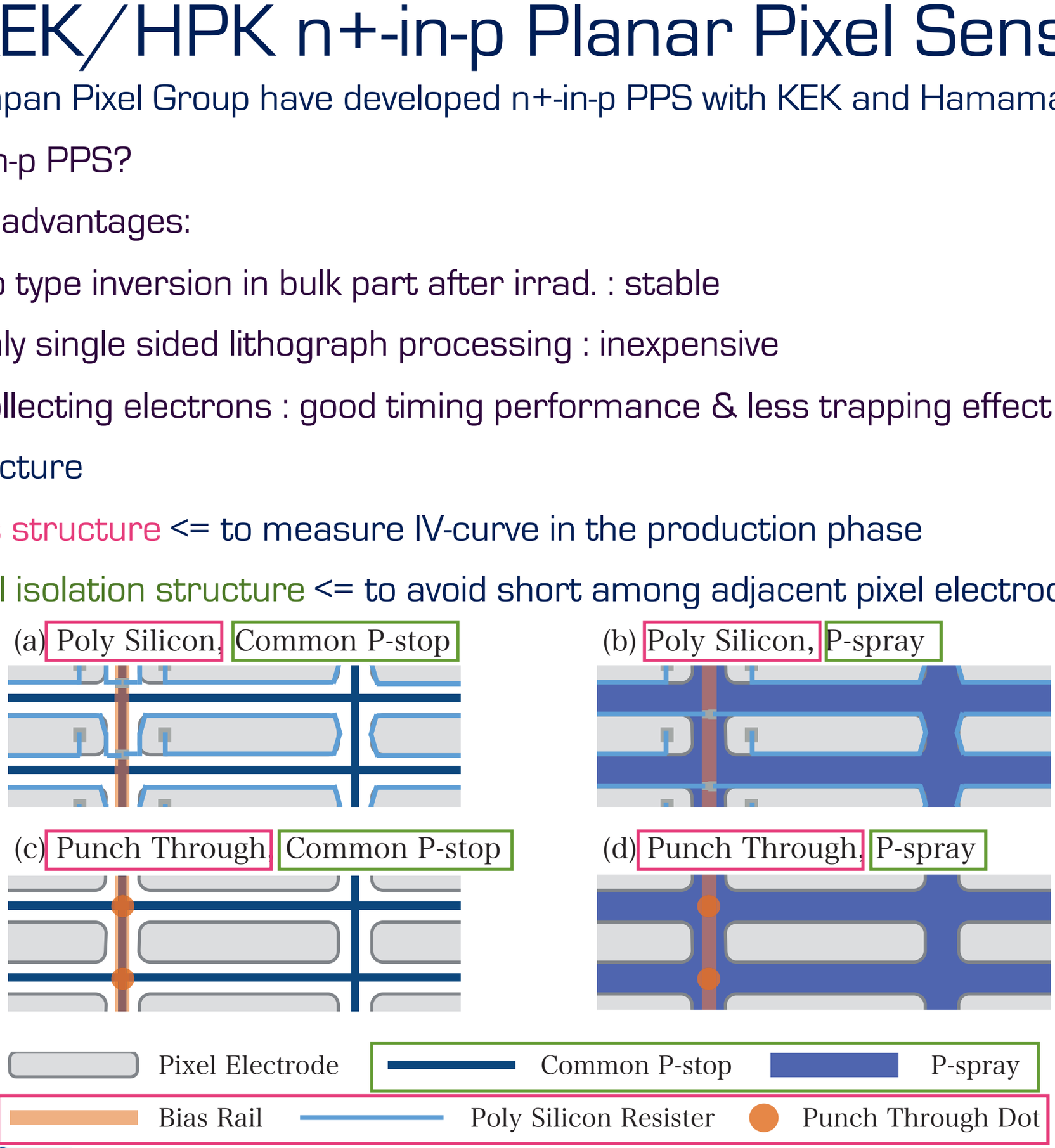
~2.2×10^{16} (r=3.7 cm)



- Requirement for new pixel sensors
  - **High radiation tolerance**
  - High position resolution
  - Low cost

KEK/HPK n+-in-p Planar Pixel Sensor

- ATLAS Japan Pixel Group have developed n+-in-p PPS with KEK and Hamamatsu Photonics K.K
- Why n+-in-p PPS?
  - Many advantages:
    - No type inversion in bulk part after irrad. : stable
    - Only single sided lithograph processing : inexpensive
    - Collecting electrons : good timing performance & less trapping effect
- Pixel Structure
  - 2 bias structure <= to measure IV-curve in the production phase
  - 2 pixel isolation structure <= to avoid short among adjacent pixel electrodes



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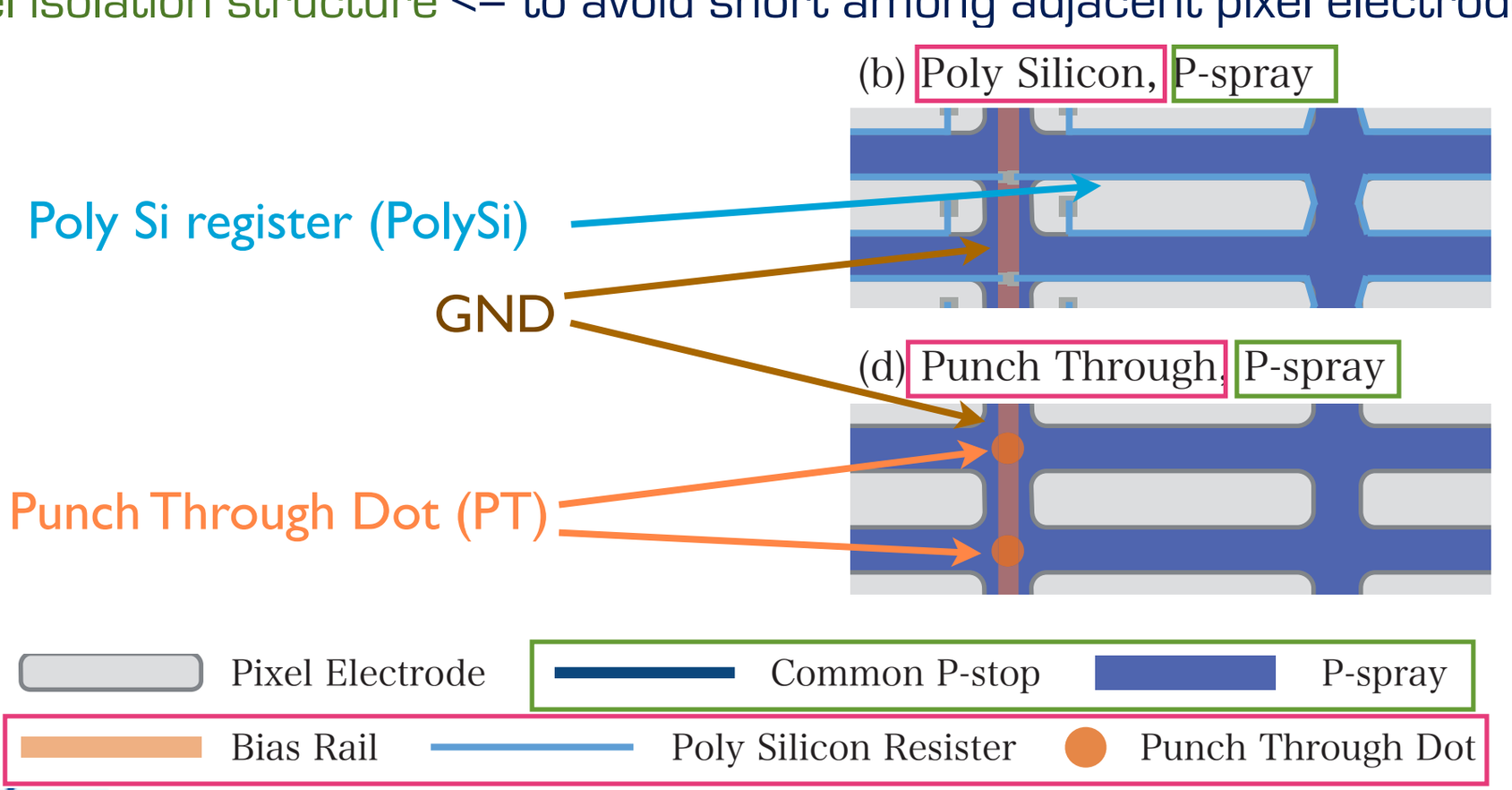

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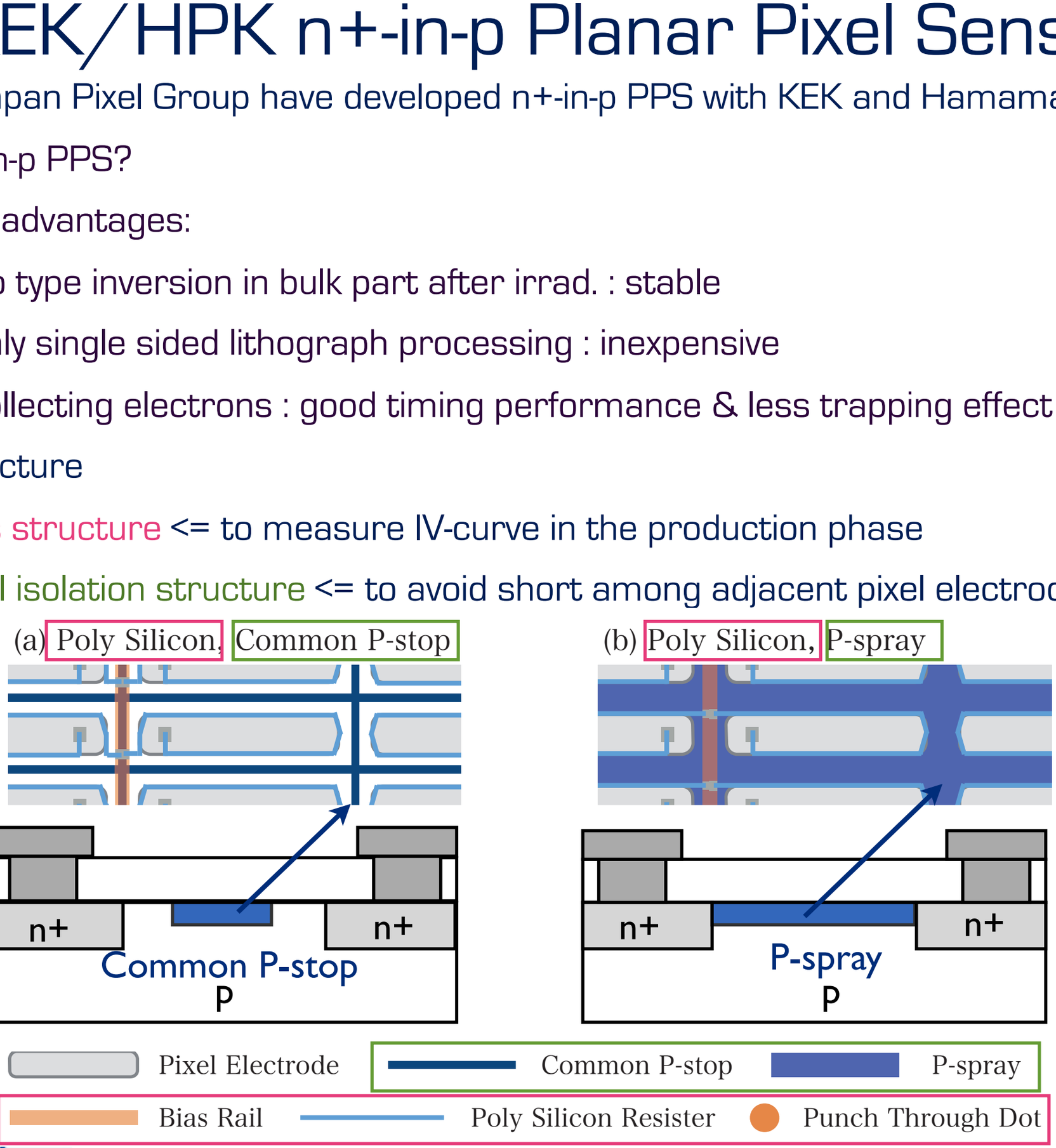
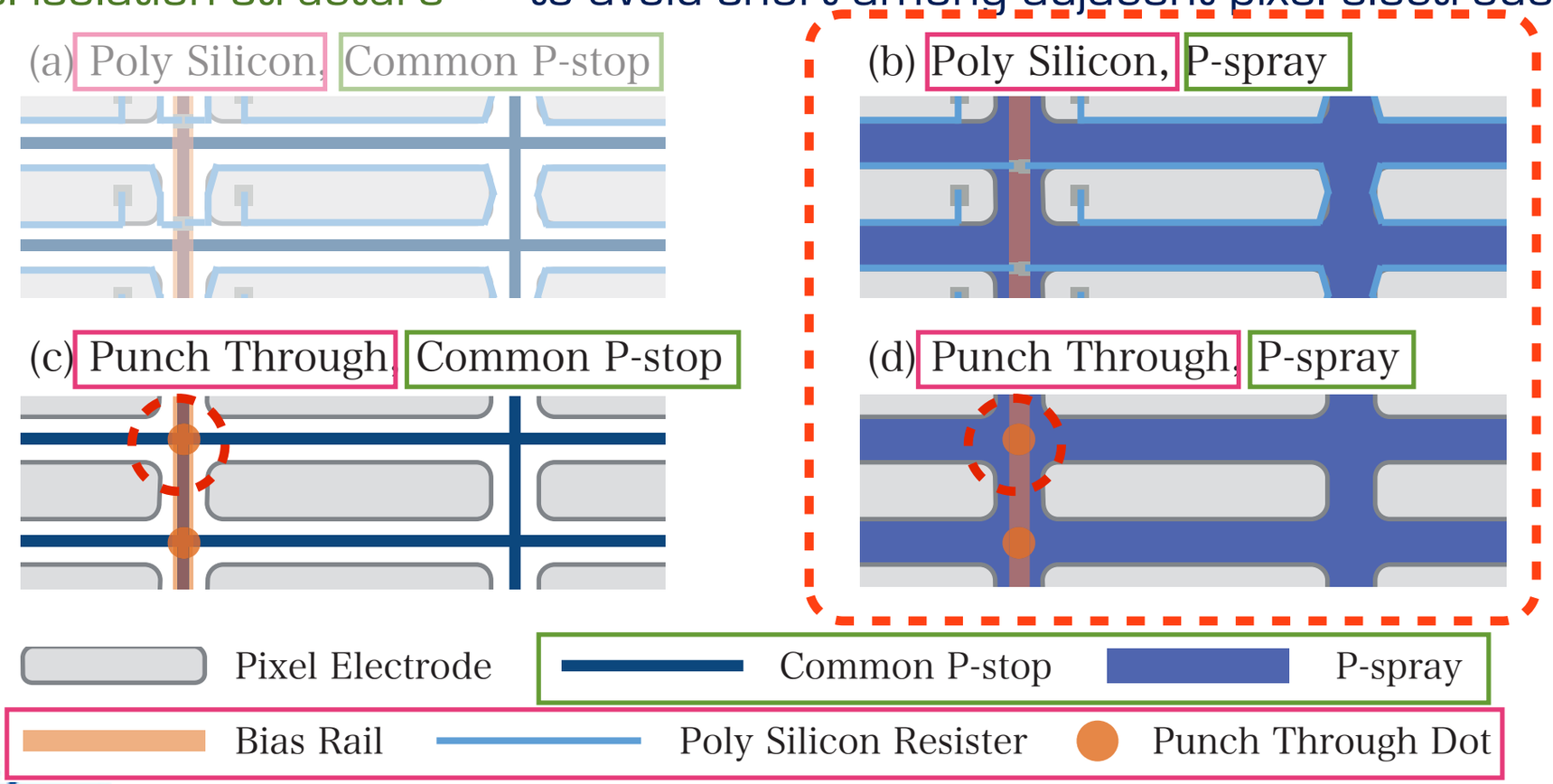


KEK/HPK n+-in-p Planar Pixel Sensor

- We have been developing n+-in-p PPS with KEK and Hamamatsu Photonix K.K
- Why n+-in-p PPS?

The results of test beam at CERN in Sep. 2012:
1) Structures have caused inefficiency region are
  i) P-spray
  ii) PT

- 2 bias structure <= to measure IV-curve in the production phase
- 2 pixel isolation structure <= to avoid short among adjacent pixel electrodes



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The results of test beam at CERN in Sep. 2012:

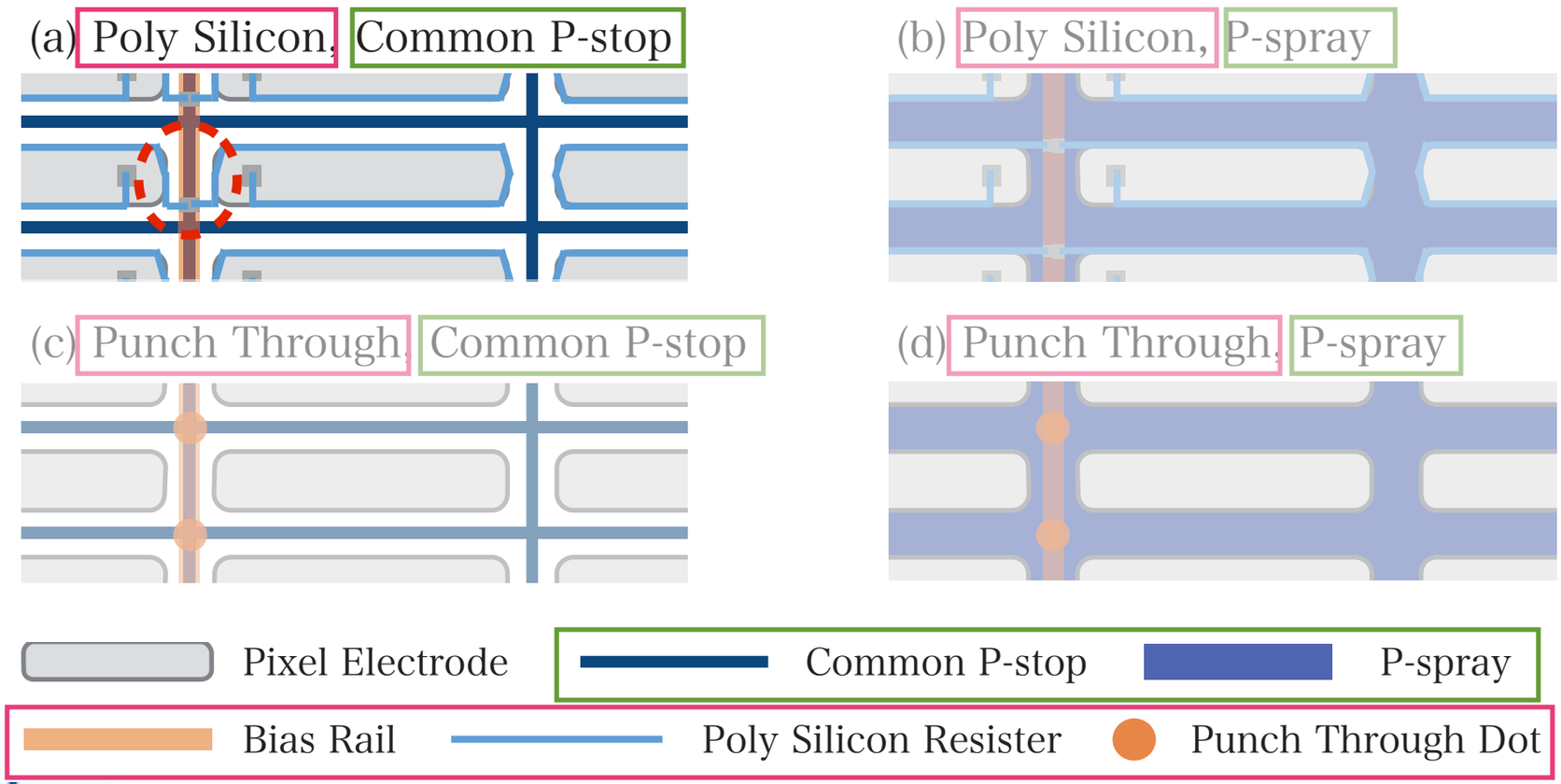
1) Structures have caused inefficiency region are

i) P-spray

ii) PT

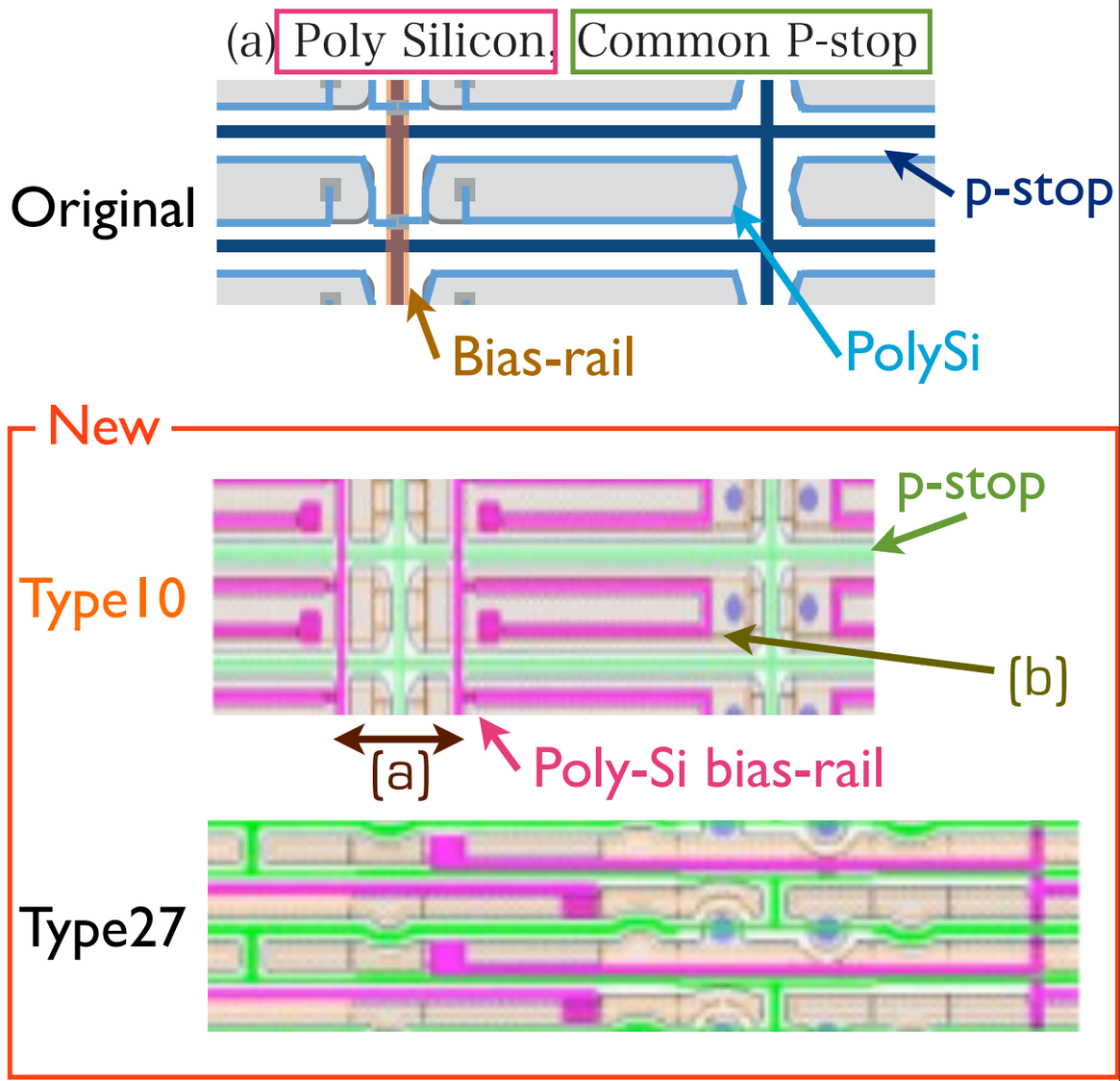
2) Bias rail and PolySi have caused inefficient charge collection

- 2 pixel isolation structure <= to avoid short among adjacent pixel electrodes



New designs of pixel structures

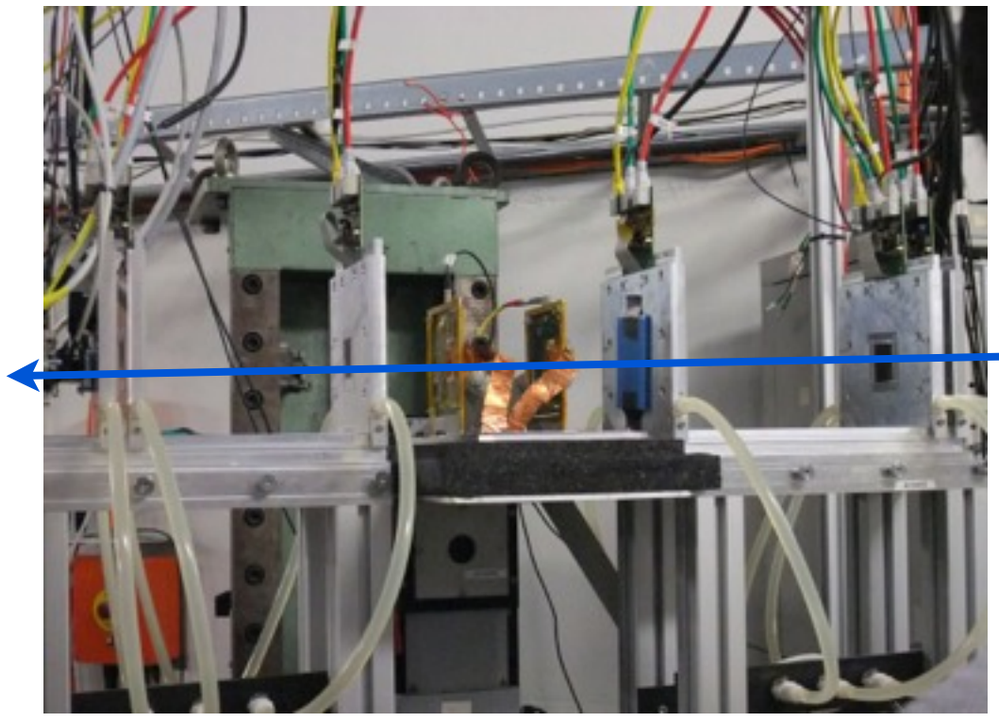
- New design
  - Type 10 : Modified structure of bias-rail and Poly-Si register to improve efficiency around pixel boundary (KEK38, 41, 46)
    - (a) Bias-rail has large offset from p-stop
    - (b) Bias-register is located inside implant
  - Type 27 : Long pixel (25 um x 500 um) with staggered geometry (KEK39, 40)
- 4 chip modules
  - 4 chips on single sensor (KEK35,36,37)
- **Analysis for Type10 module is presented in this talk**



TestBeam at DESY in 2013

- Before Irrad. (in Aug.)
  - **Pixel Structure: Type10 (KEK 41)**
  - **Non - irrad.**
  - Thickness(Sensor/ASIC): 320 um/150 um
  - Tuning: Threshold 2400e ,ToT 7at10ke
  - One reference plane

- **After Irrad. (in Nov.)**
  - **Pixel Structure: Type10 (KEK 46)**
  - **Irrad. 4.18x10^{15} n_{eq}/cm^2**
  - Thickness(Sensor/ASIC): 150 um/150 um
  - Tuning: Threshold 1800e ,ToT 5at5ke
  - No reference plane



(Setup in Nov.)

- Reconstruction: Eutelescope v00-09-03
- Analysis: TBmon release1.2

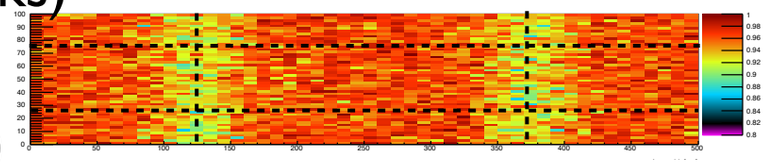
4 GeV positron beam
=> large multiple scattering effect
=> worsen pointing resolution: ~23um

Before Irrad. (KEK41)

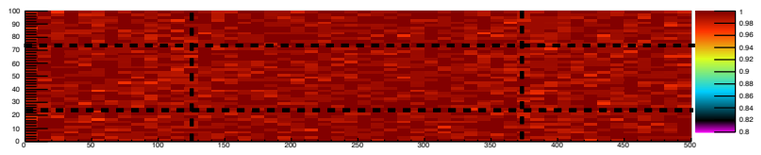
- Efficiency Pixel Map

HV (#tracks)

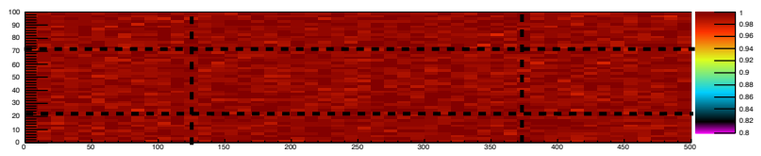
-15 V (0.4M)



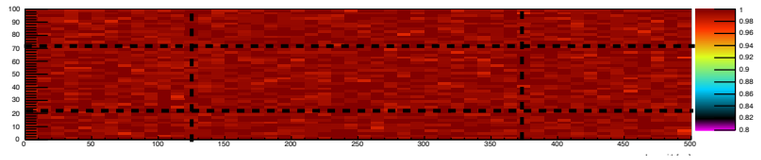
-50 V (0.4M)



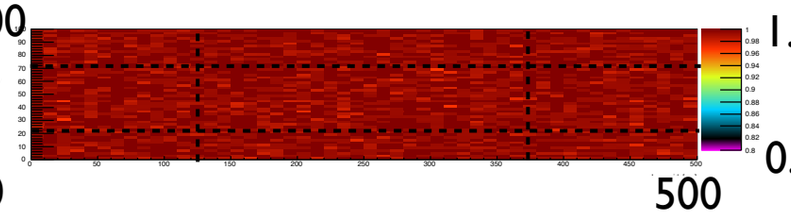
-100 V (0.7M)



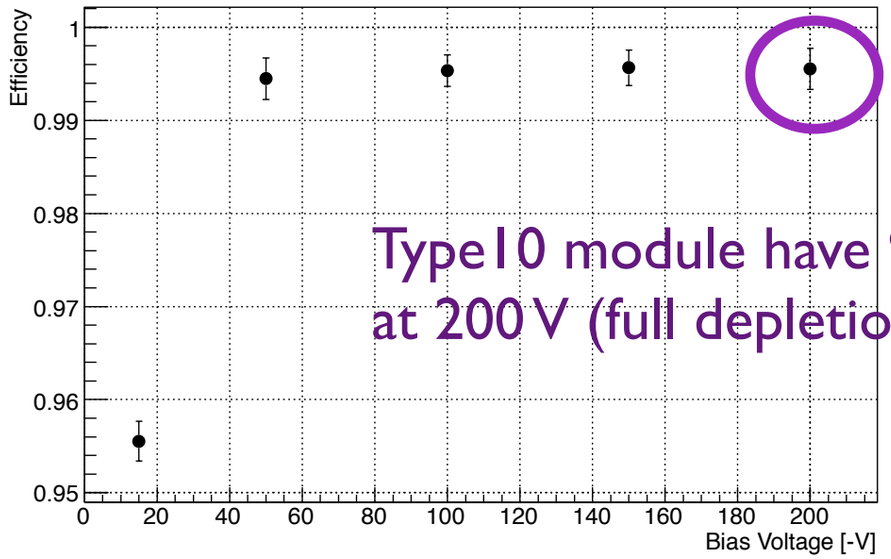
-150 V (0.6M)



-200 V (0.4M)

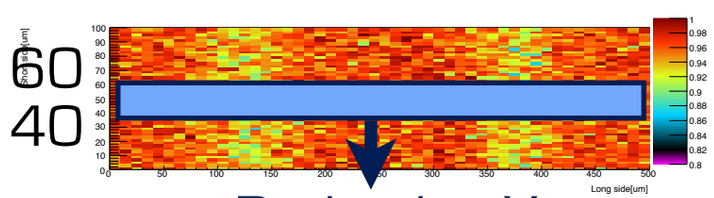


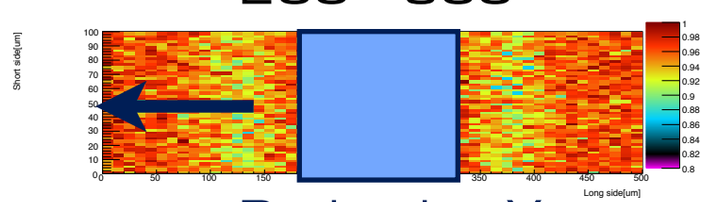
- Bias Voltage vs Efficiency



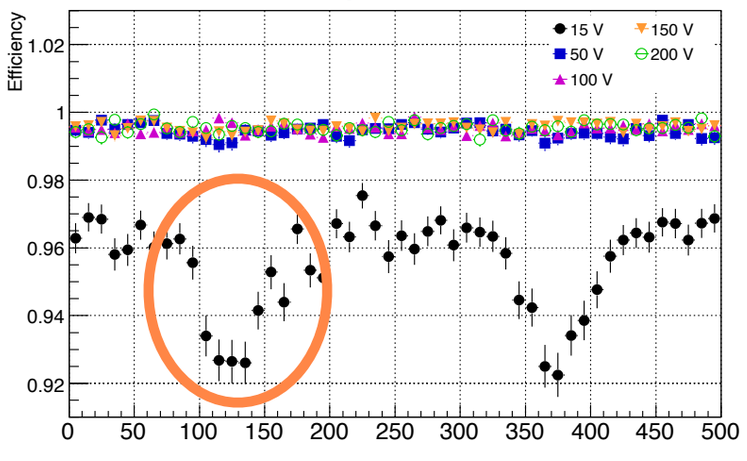
Type10 module have 99.5% overall efficiency at 200 V (full depletion)

- Efficiency Pixel Map Projection

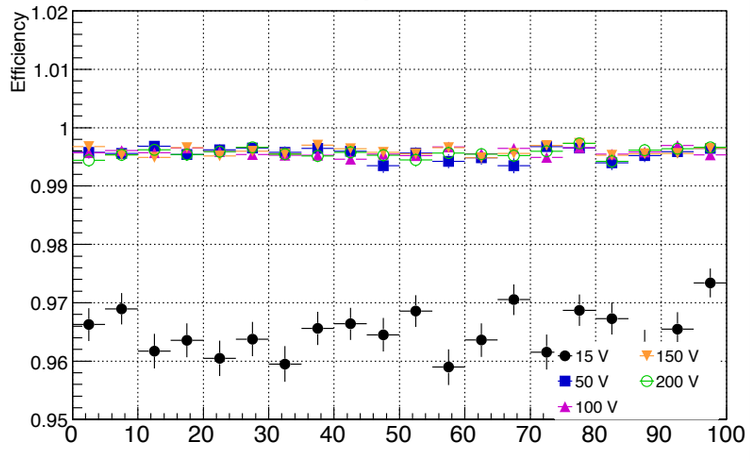




Projection X



Projection Y



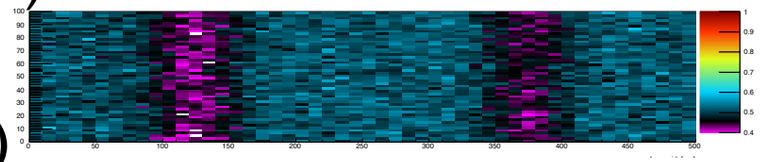
Pixel boundary for X-axis is seen, but not Y-axis

After Irrad. (KEK46)

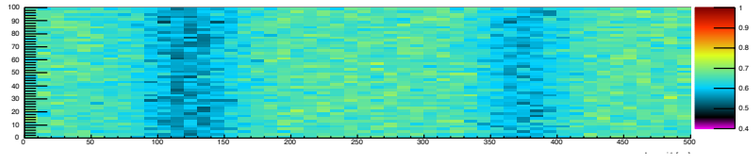
- Efficiency Pixel Map

HV (#tracks)

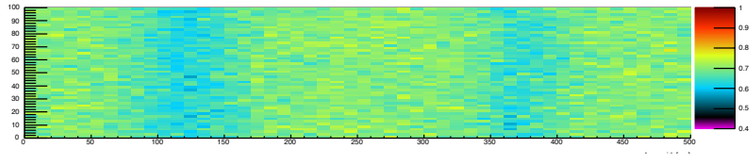
-100 V (1.4M)



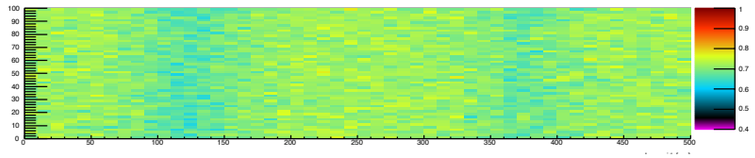
-150 V (1.1M)



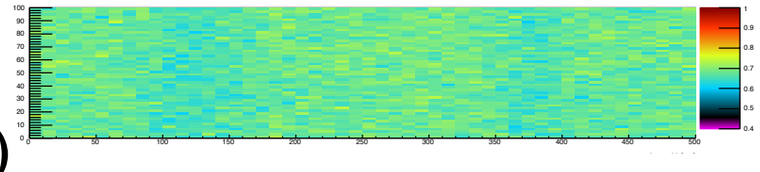
-200 V (1.2M)



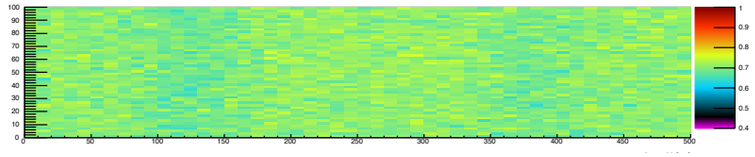
-250 V (1.3M)



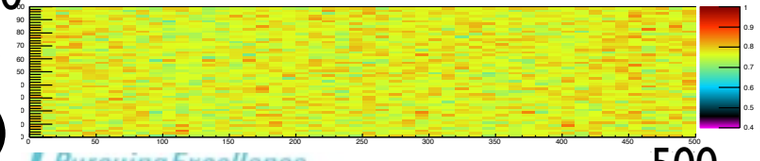
-300 V (1.4M)



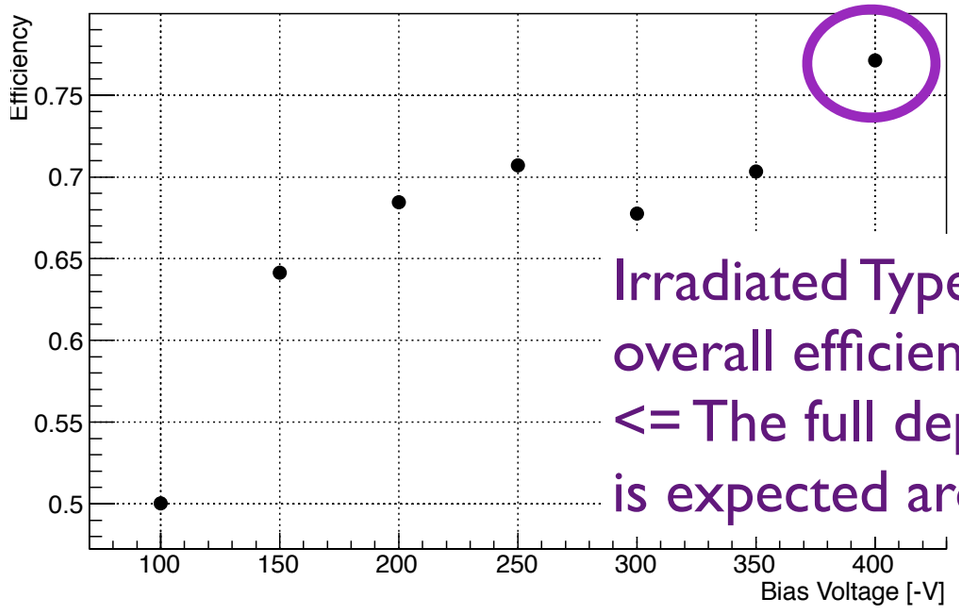
-350 V (1.7M)



-400 V (0.7M)

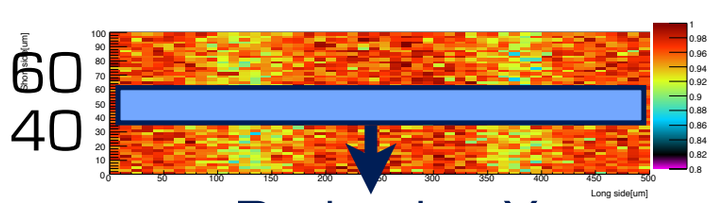


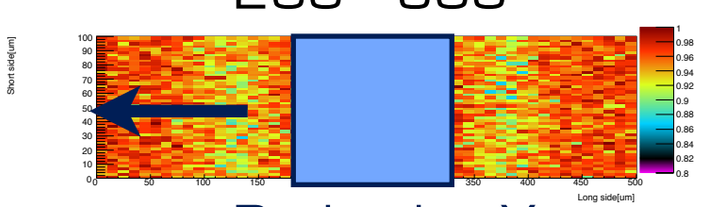
- Bias Voltage vs Efficiency



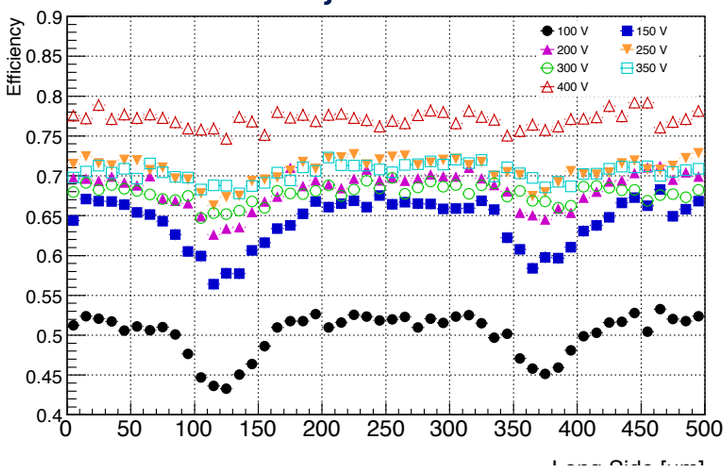
Irradiated Type10 module have ~78% overall efficiency at 400V.
<= The full depletion voltage is expected around 800 V.

- Efficiency Pixel Map Projection

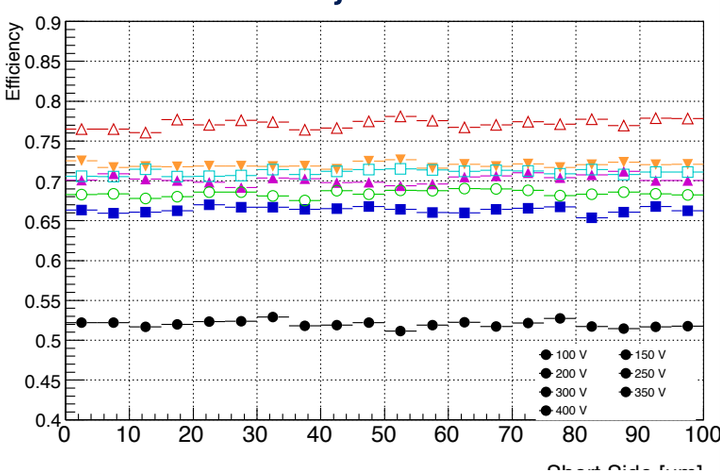




Projection X



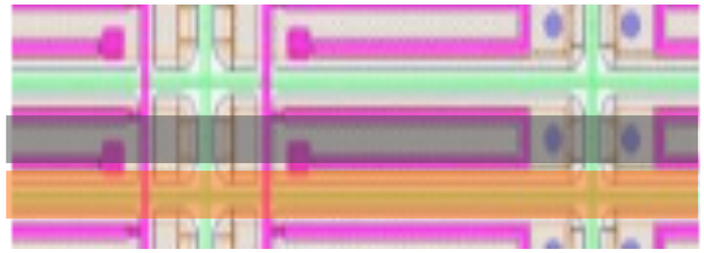
Projection Y



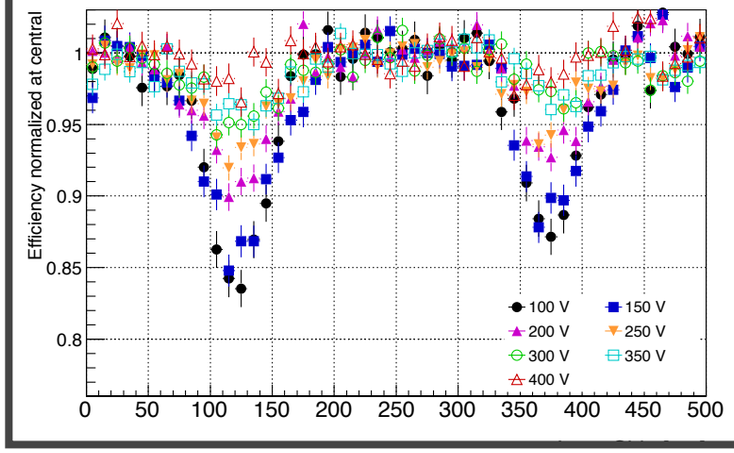
At low voltage, inefficiency at pixel boundary is seen.
But at 400 V, no clear inefficiency around the boundary

Inefficiency areas at 125 um and 375 um

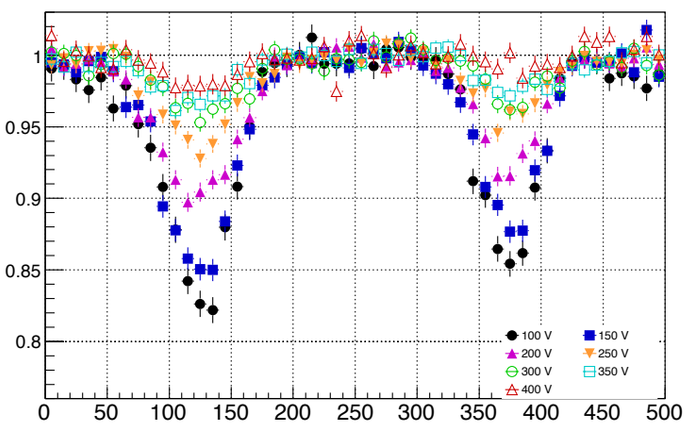
- **Evaluate inefficiency at pixel boundary quantitatively**
- Definition of two regions



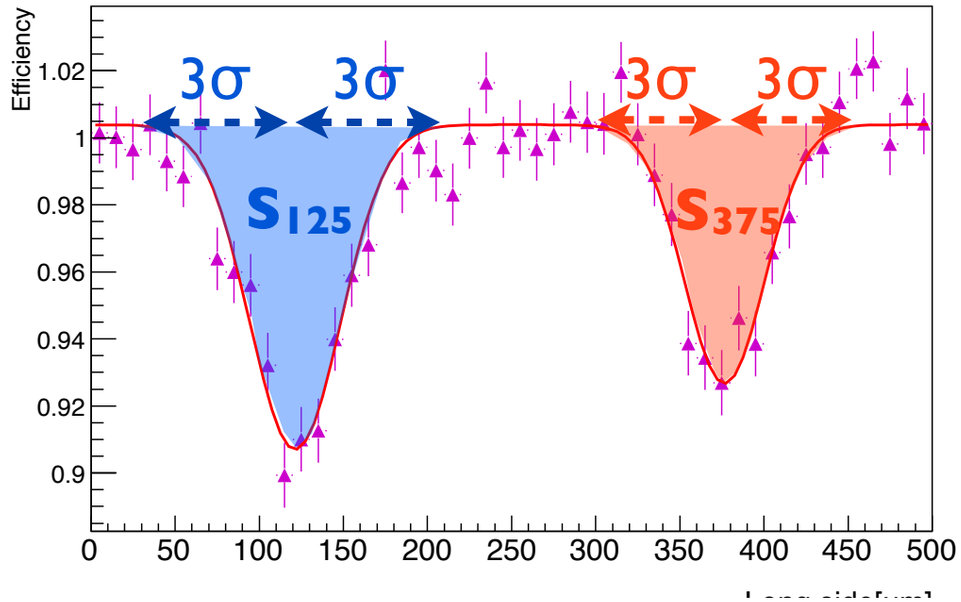
Pixel central region



Pixel boundary region

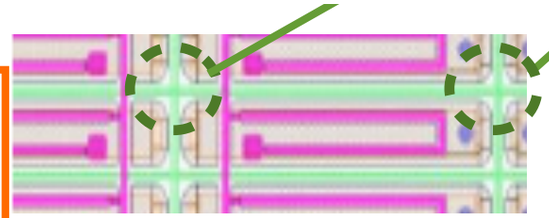


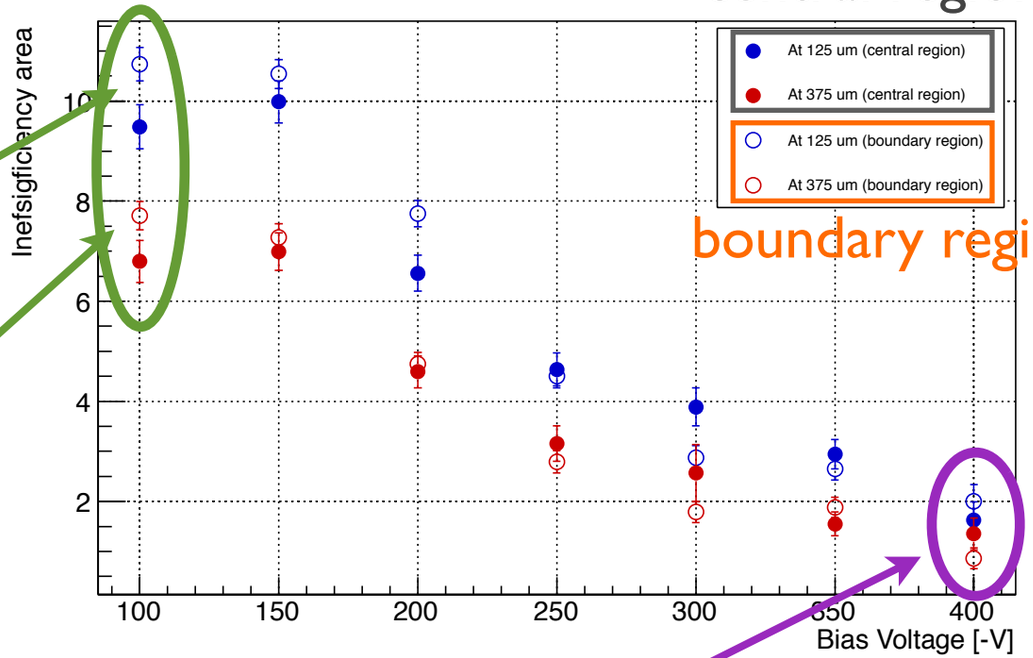
Fit by gaussian
and Calculate area



central region

4-corners effect



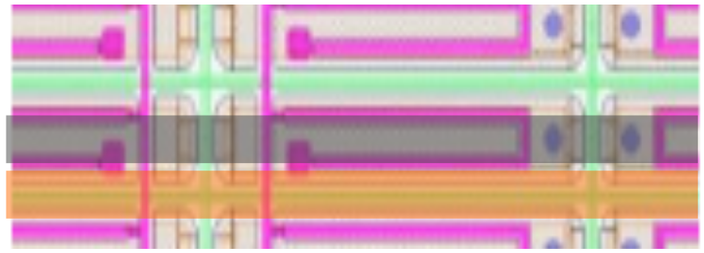


boundary region

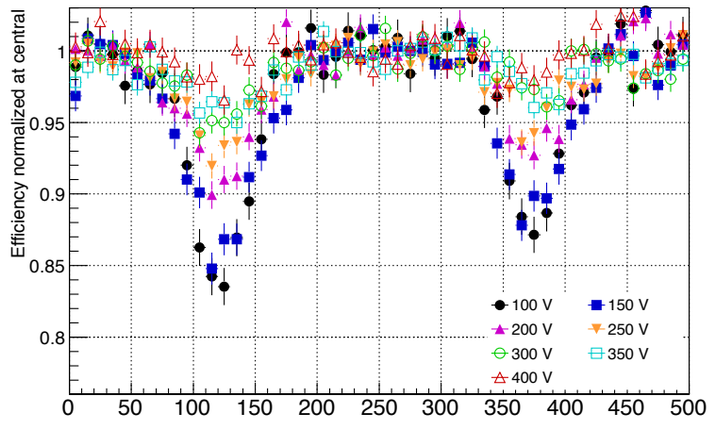
Difference seems insignificant

Inefficiency areas at 125 um and 375 um

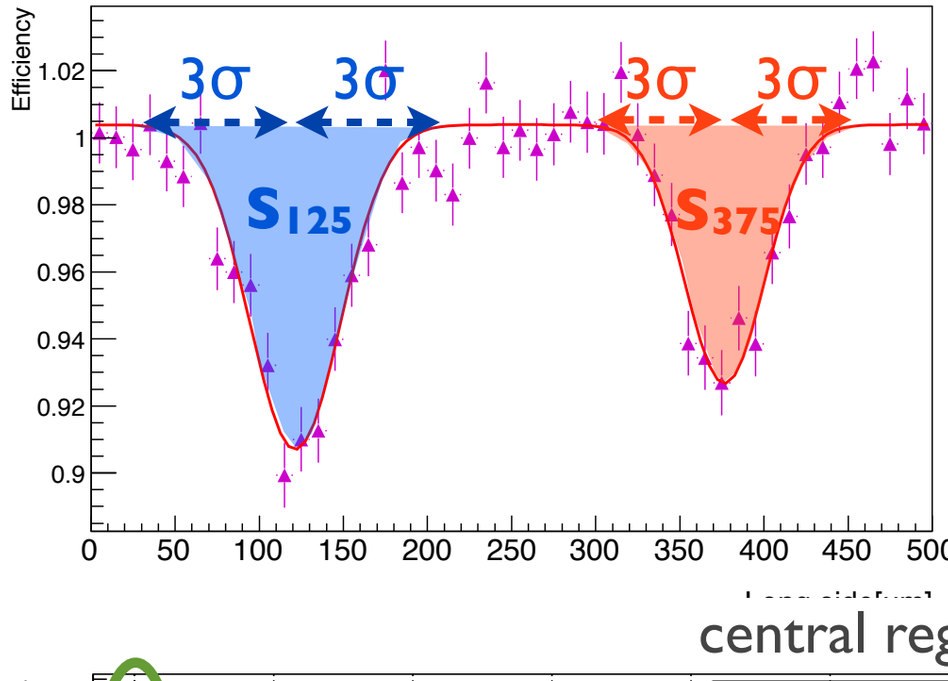
- Definition of two regions



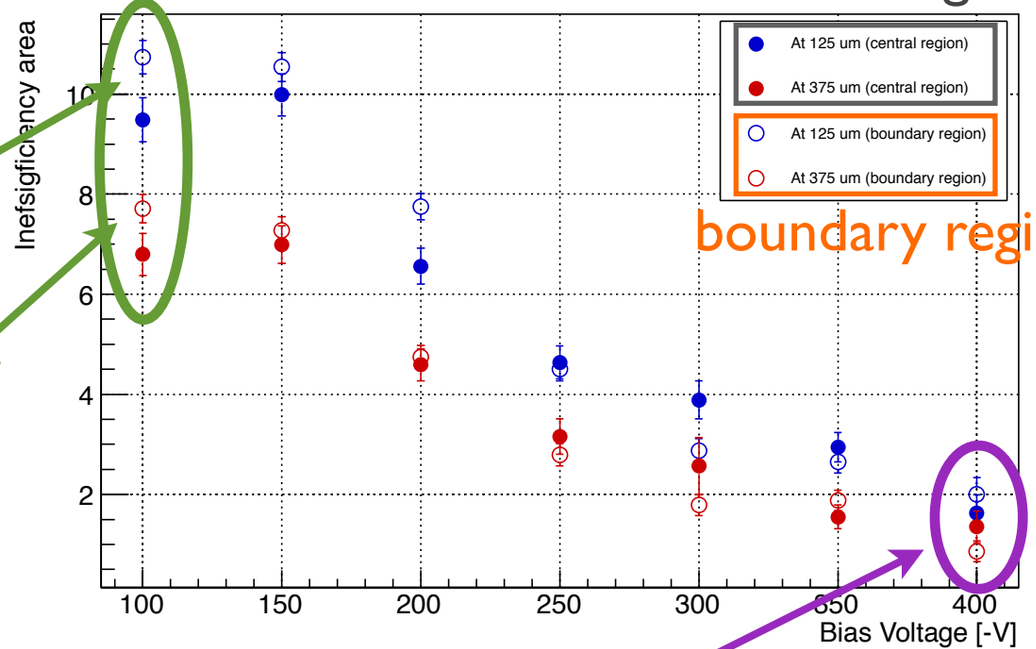
Pixel central region



Fit by gaussian
and Calculate area



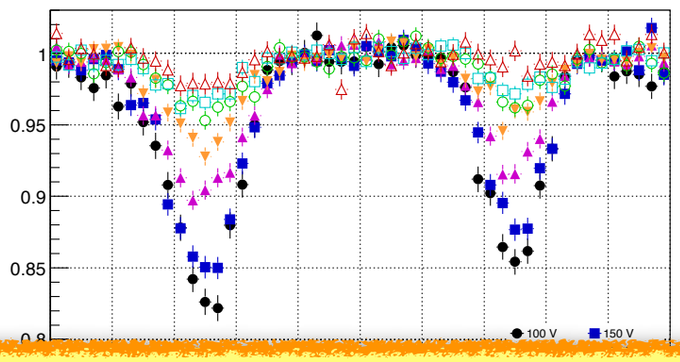
central region



boundary region

4-corners effect

Pixel boundary region

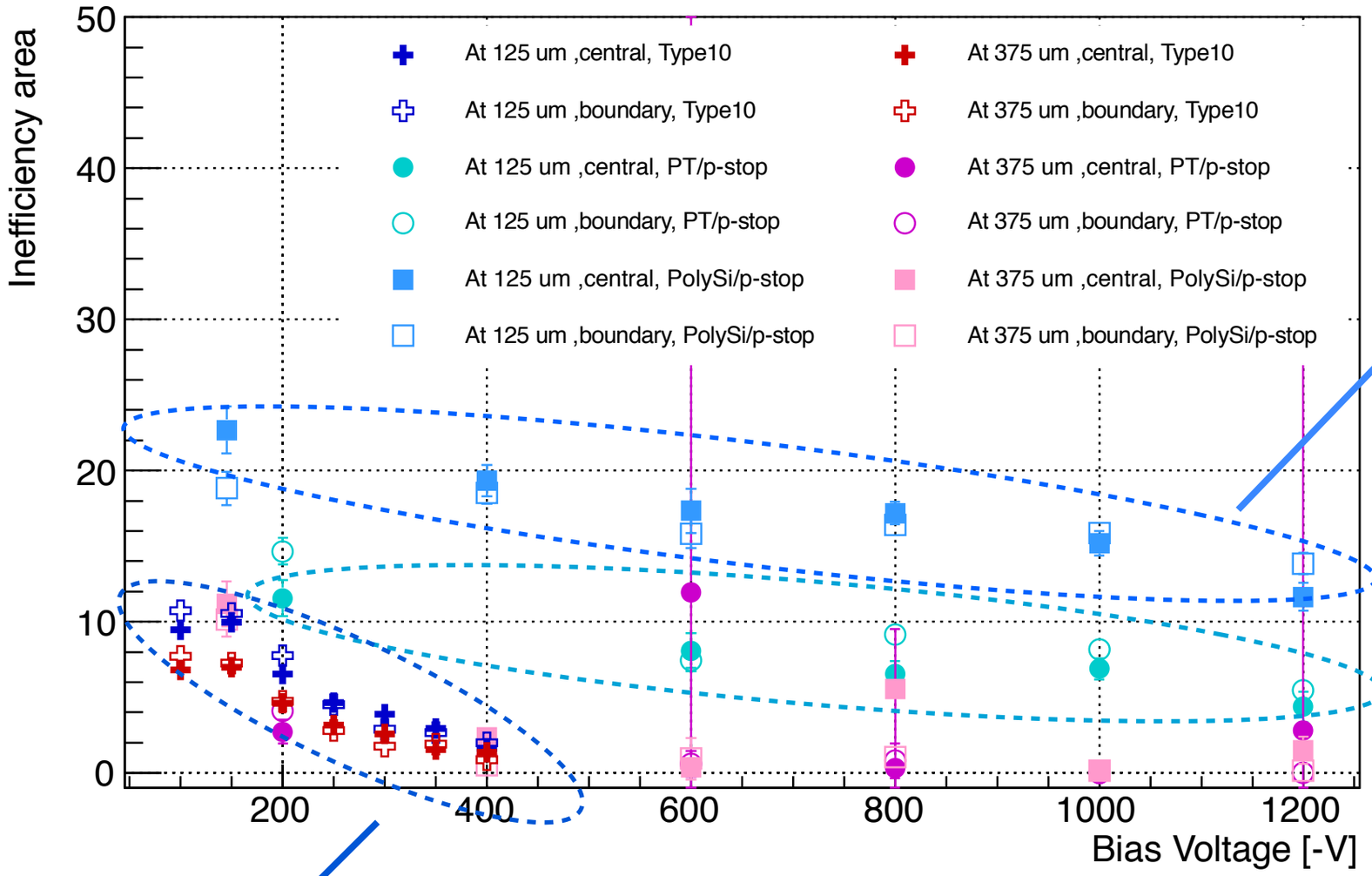


Difference seems insignificant

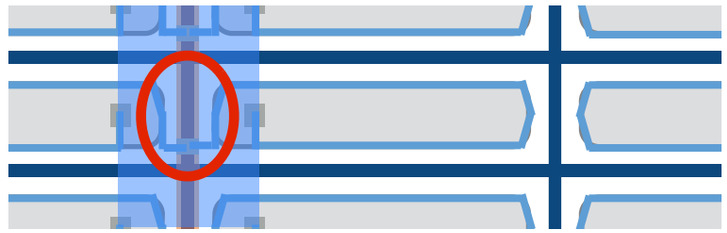
Is the inefficiency area of Type 10 larger or smaller than original ?
Inefficiency area should hardly depend on pointing resolution.
Compare with original sensors

Comparison with Type10 and P-stop

- TestBeam at DESY in Mar. 2013



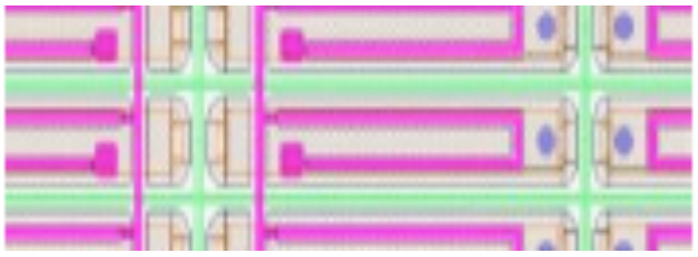
(a) Poly Silicon, Common P-stop



(c) Punch Through, Common P-stop

PolySi register has caused inefficient charge collection i.e. PolySi/p-stop has larger inefficient region

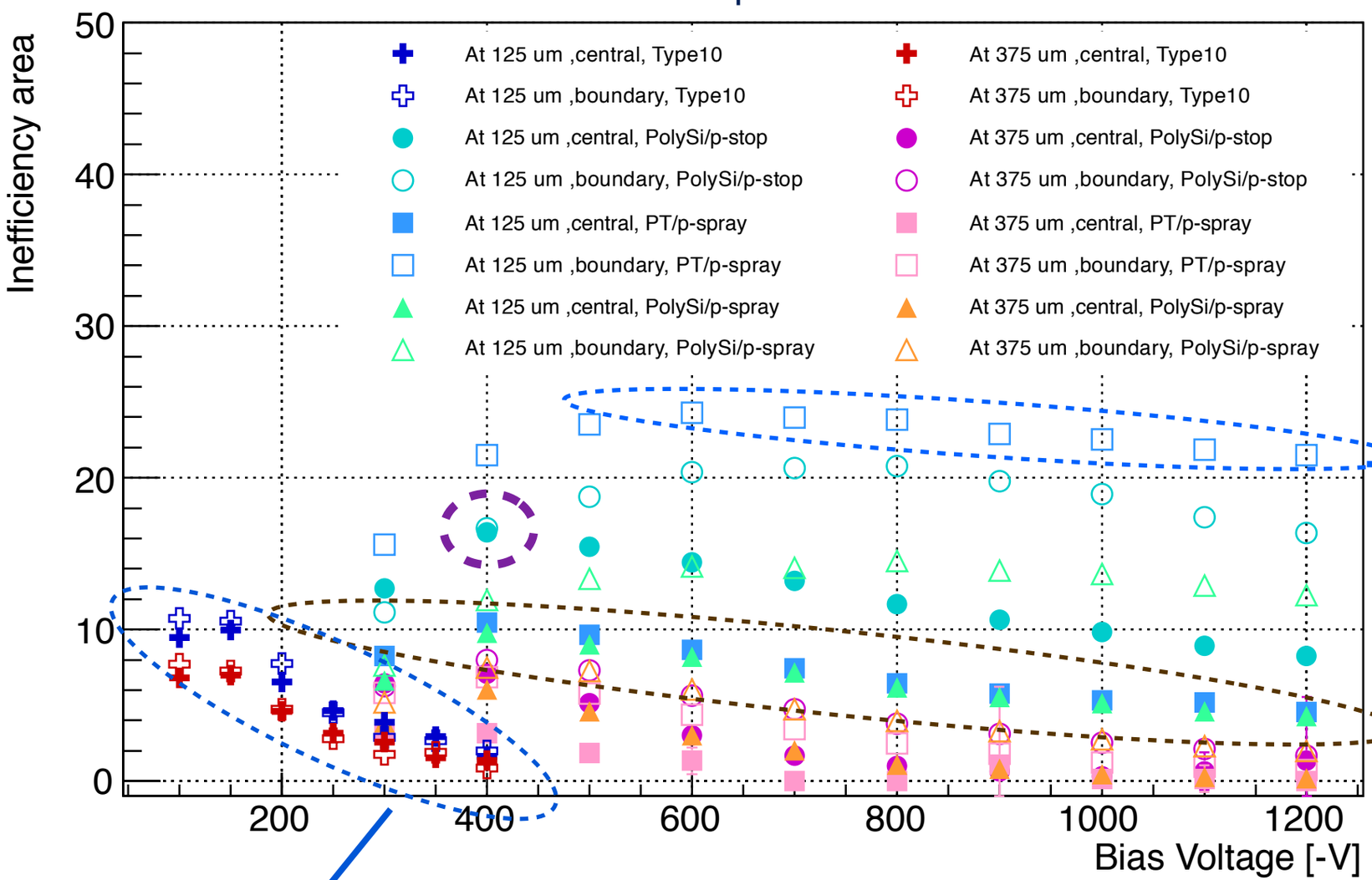
Type10



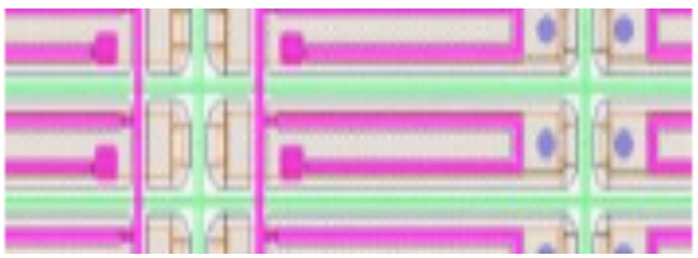
1) The less inefficiency area than original common p-stop sensors

Comparison with Type10 and P-spray

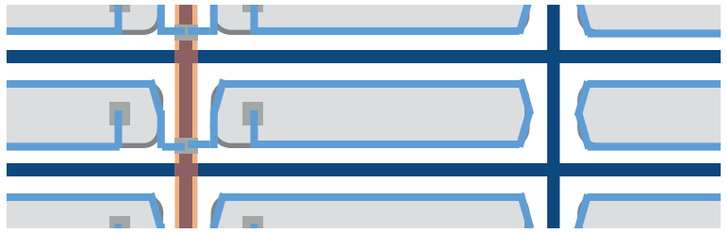
- TestBeam at CERN in Sep. 2012



Type10

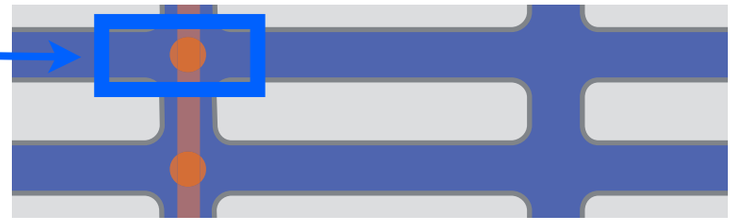


(a) Poly Silicon, Common P-stop



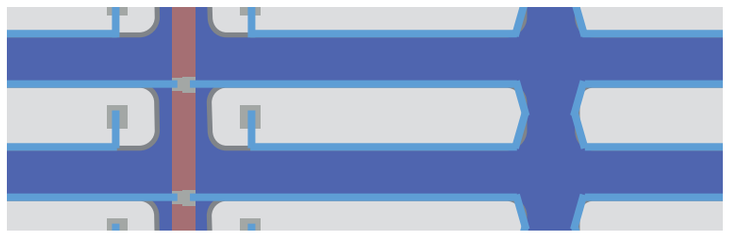
Inefficiency area: ~19@400V, DESY
Consistent with DESY results

(d) Punch Through, P-spray



Central region of p-spray
(almost same structure)

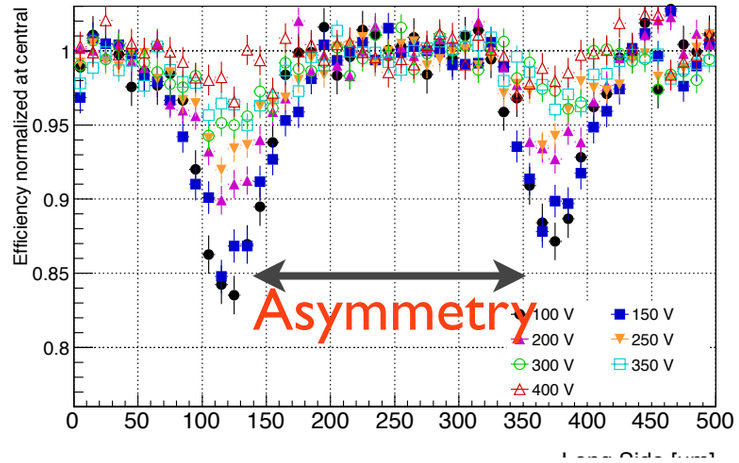
(b) Poly Silicon, P-spray

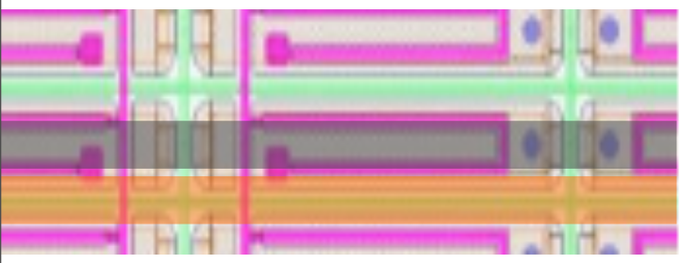


3) The less inefficiency area than original p-spray sensors
4) These results agree with expectation of Type 10 design
5) Inefficiency areas are expected to disappear symmetrically around full depletion voltage (800 V)
6) ~80% reduces compared with PolySi/P-spray @400 V

Asymmetric Inefficiency at Pixel boundary

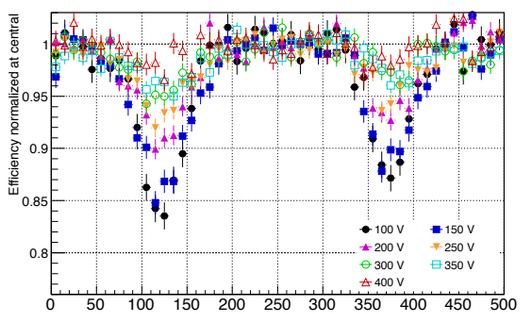
- **What causes this asymmetric inefficiency?**



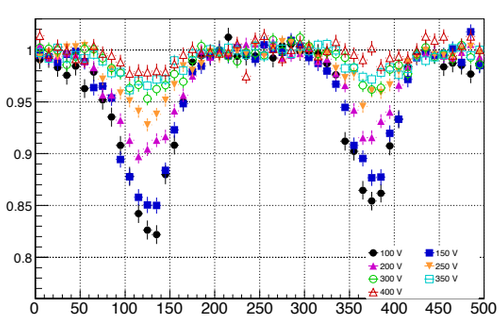


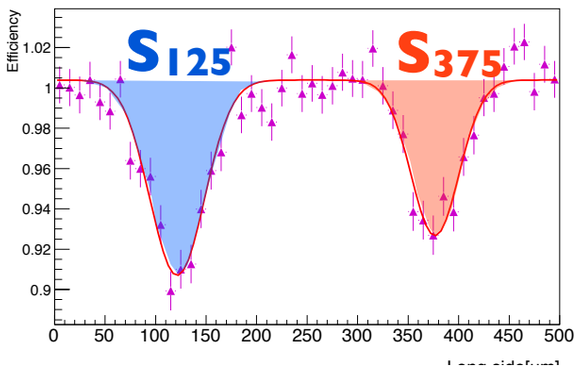
- If bias rail has caused this inefficiency...
- At high voltage, the ratio at boundary are expected to be seen more explicitly than that at central

Pixel central region

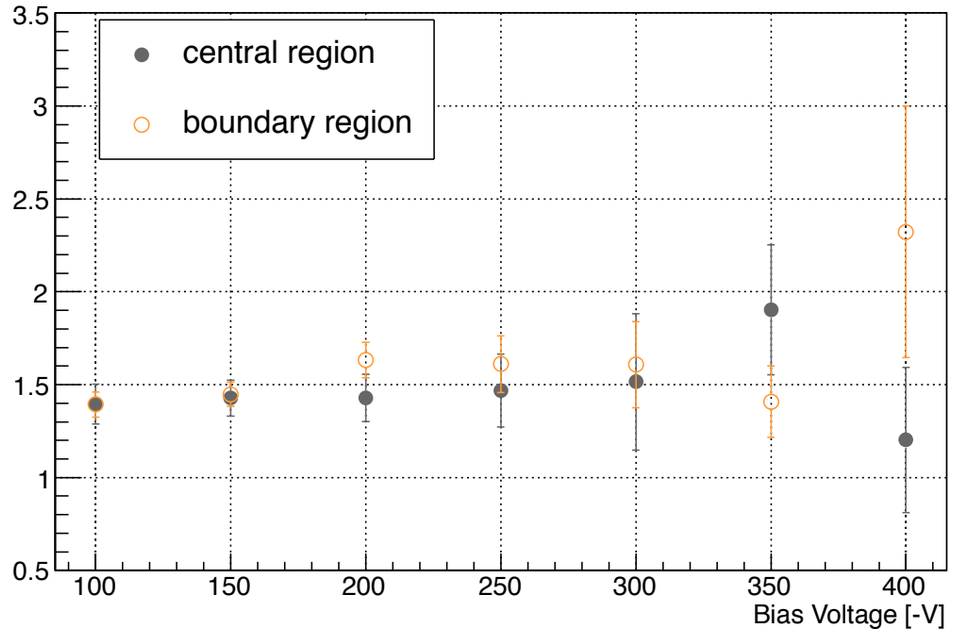


Pixel boundary region





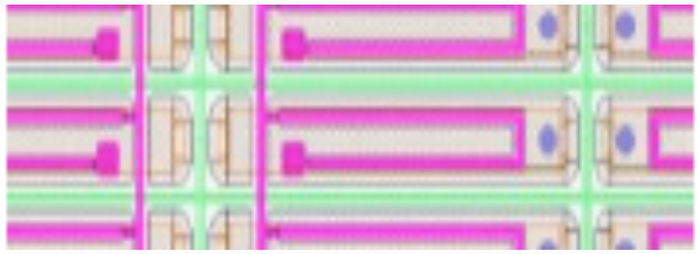
S_{125}/S_{375}



- At 400V, the ratio at boundary is consistent with that at central within error bar
- The behavior was not found out clearly at this testbeam because bad pointing resolution

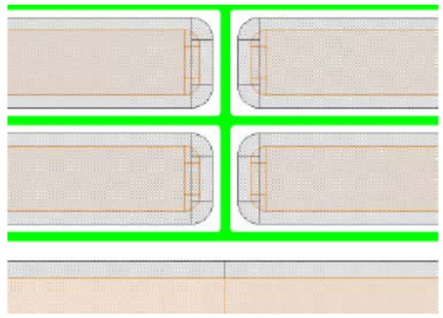
Future plan for asymmetric inefficiency

- To verify the behavior of bias rail
  - Compare with other structures



Type10

No bias structure



Type19

  - Verify if bias rail has caused inefficiency
  - Testbeam at DESY in next week

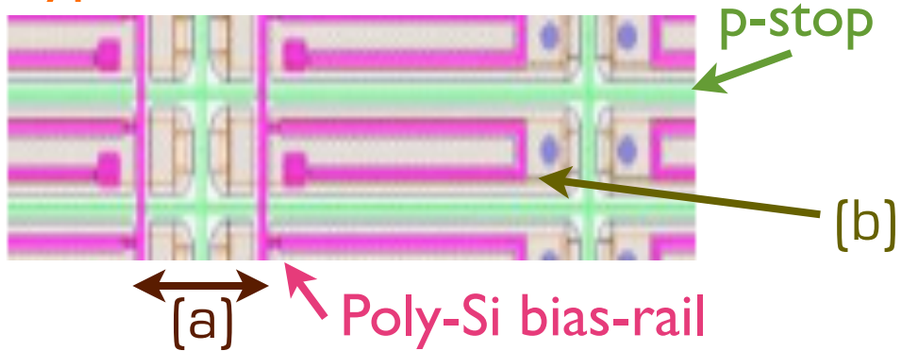
  - Use higher energy beam to improve pointing resolution
    - Testbeam at SLAC in May.
      - 13 GeV electron beam (DESY beam: 4.0 GeV positron)
    - Testbeam at CERN SPS in middle of Oct.
      - 120 GeV pion beam

1) To evaluate quantitatively
2) To verify inefficiency behavior
will have been done in this year

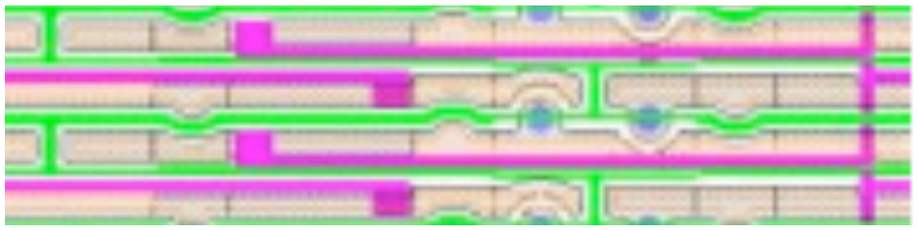
Conclusion

- In association with LHC upgrade, ATLAS ID will be upgraded in LS3
- We have developed n-in-p planar pixel sensors
- Test beams have been carried out for evaluating sensor performances
- Making use of results for TB at CERN in Sep. 2012, sensor modules with new pixel structure were produced
  - Type 10
    - (a) Bias-rail has large offset from p-stop
    - (b) Bias-register is located inside implant
  - Type 27
    - Long pixel (25 um x 500 um)
    - staggered geometry

Type10



Type27



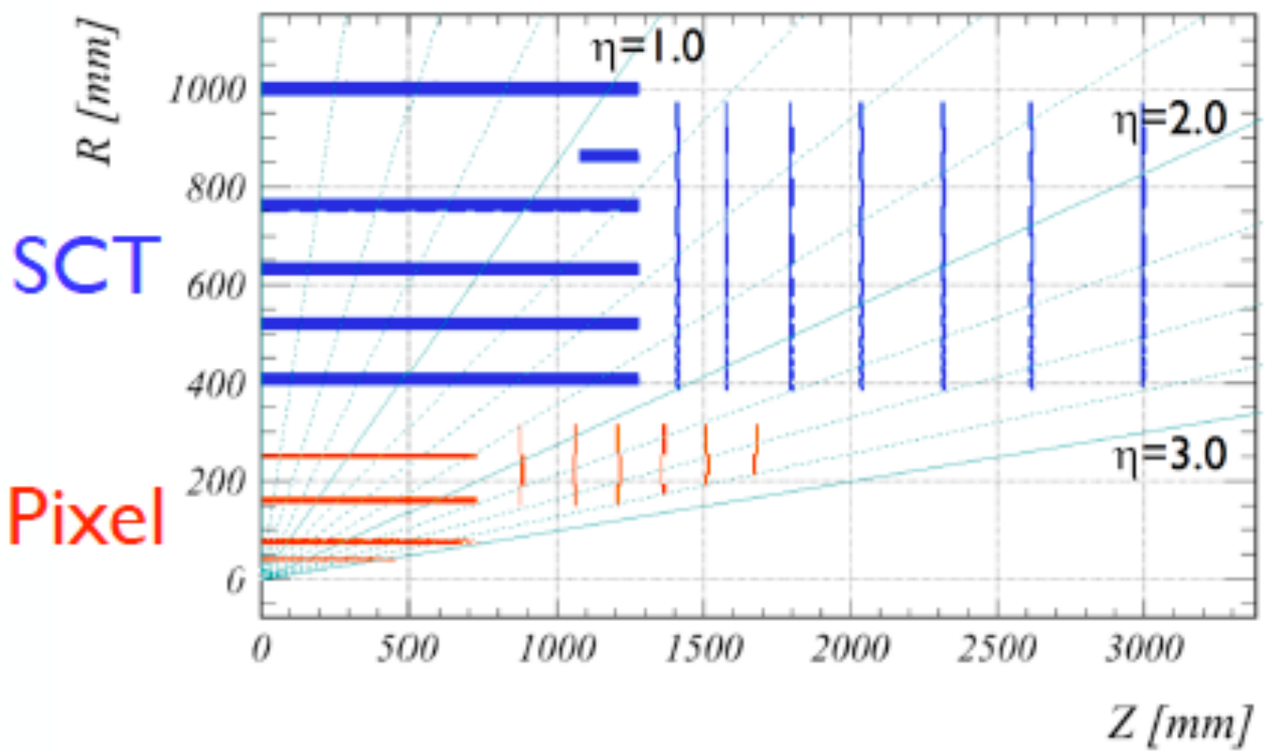
- Type 10 is found to have the least inefficient area of all original sensors
  - Inefficiency area reduces by **~80%** at central, compared with PolySi/P-spray at 400 V
  - To verify inefficient behavior of bias-rail, next testbeams will be carried out

Back Up

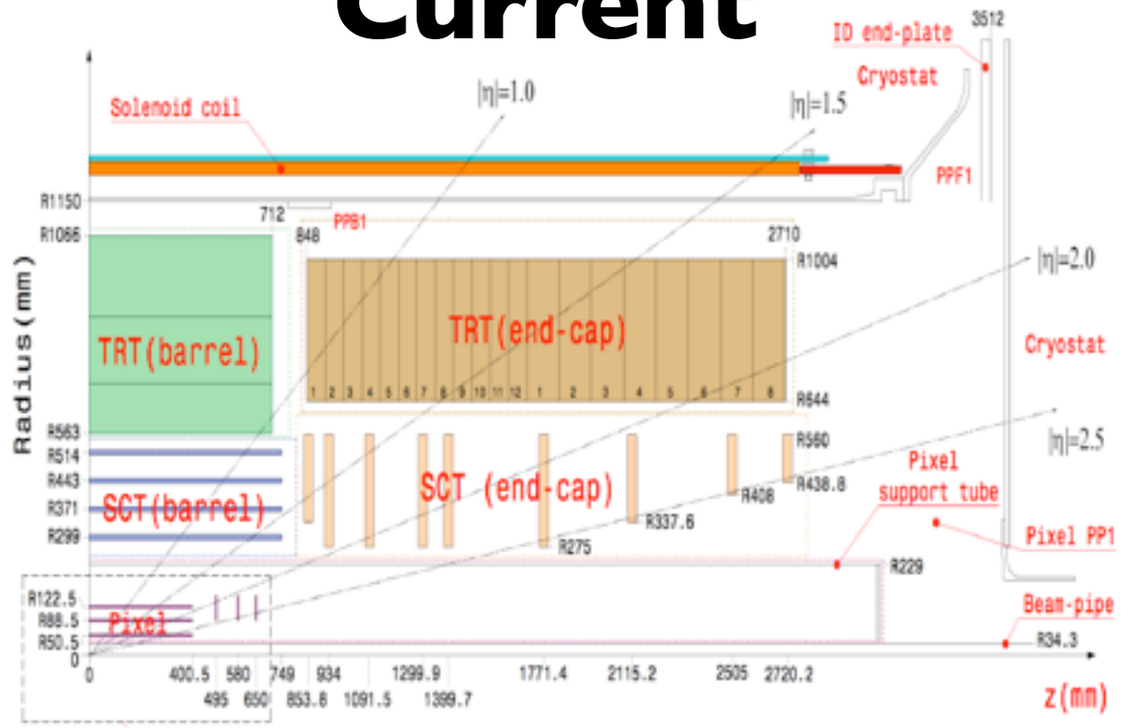
ATLAS ID Upgrade

- All inner detectors will be replaced with new silicon detecotors
- Requirement for new pixel sensors
  - **High radiation tolerance**
  - (The innermost layers will have to withstand in excess of 1×10^{16} neq/cm2)
  - High position resolution
  - Low cost

New



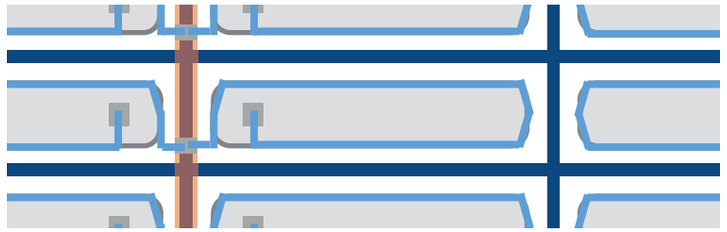
Current



Comparison with original sensors

- TestBeam at DESY in Mar. 2013
- **After Irrad.**
  - Pixel Structure: Common p-stop, PT(KEK18), Poly Si (KEK19)
  - Thickness(**Sensor**/ASIC): **150 um**/720 um
  - Tuning: **Threshold 2000e ,ToT 6at5ke**
  - Irrad. **$5x10^{15}$ n_{eq}/cm^2**
  - 1 reference plane

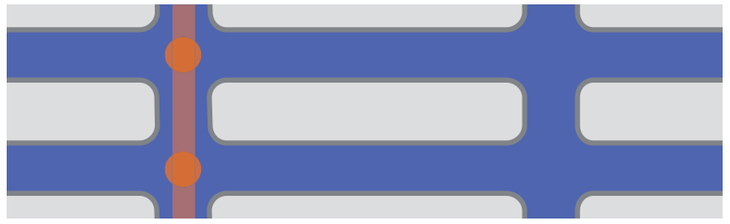
(a) Poly Silicon, Common P-stop



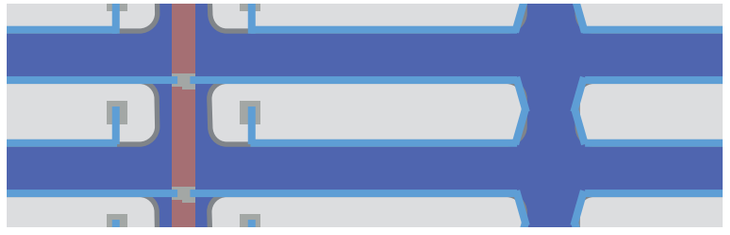
(c) Punch Through, Common P-stop

- TestBeam at CERN in Sep. 2012
- **After Irrad.**
  - Pixel Structure: P-spray, PT(KEK33), Poly Si (KEK34)
  - Thickness(**Sensor**/ASIC): **150 um**/720 um
  - Tuning: **Threshold 2000e ,ToT 6at5ke**
  - Irrad. **$1x10^{16}$ n_{eq}/cm^2**
  - 3 reference planes

(d) Punch Through, P-spray



(b) Poly Silicon, P-spray



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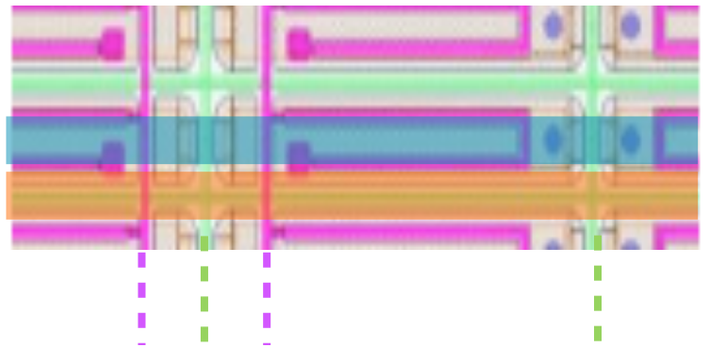
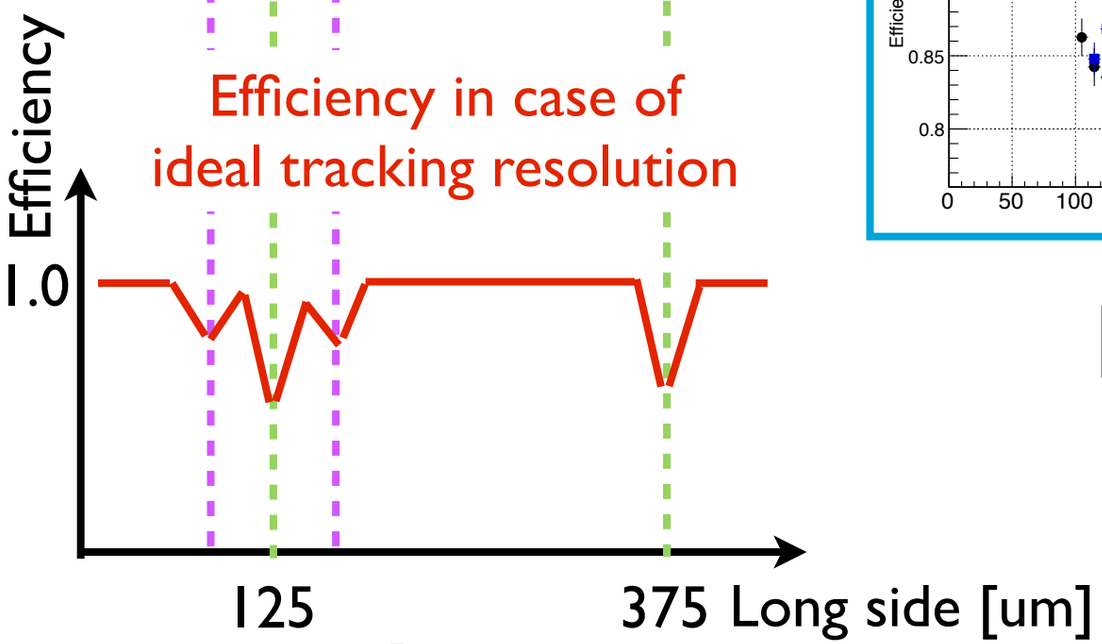
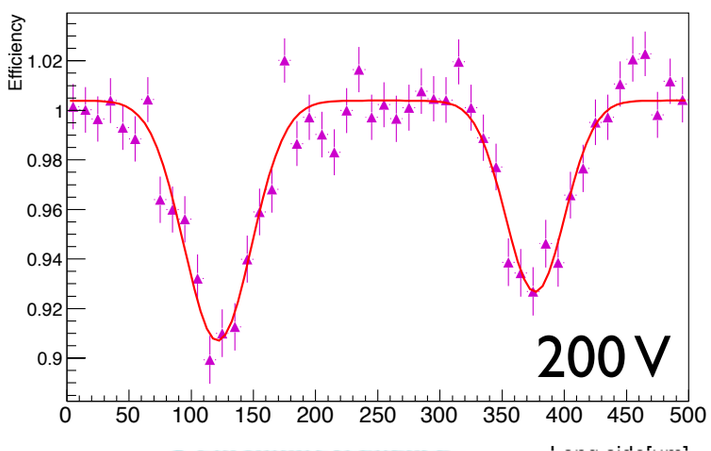
Inefficiency at Pixel boundary

- **Why is the efficiency at 125 um lower than that at 375 um?**

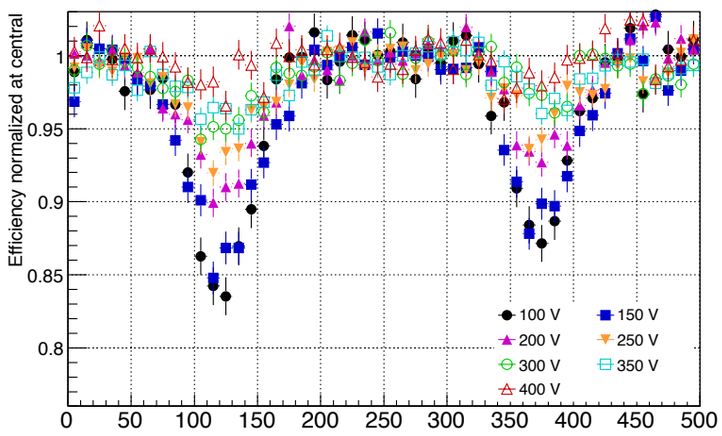




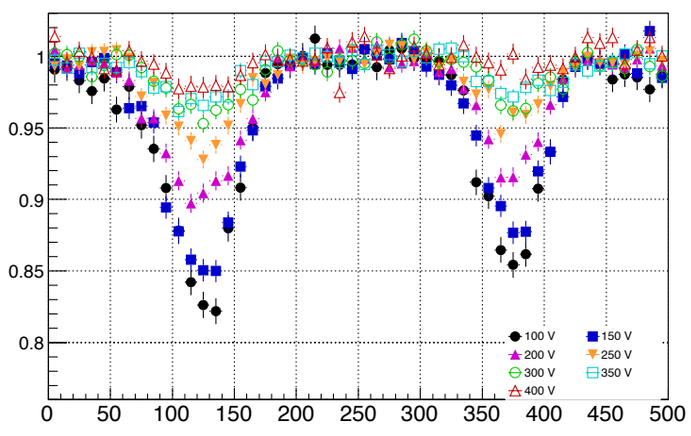
smeared by tracking resolution



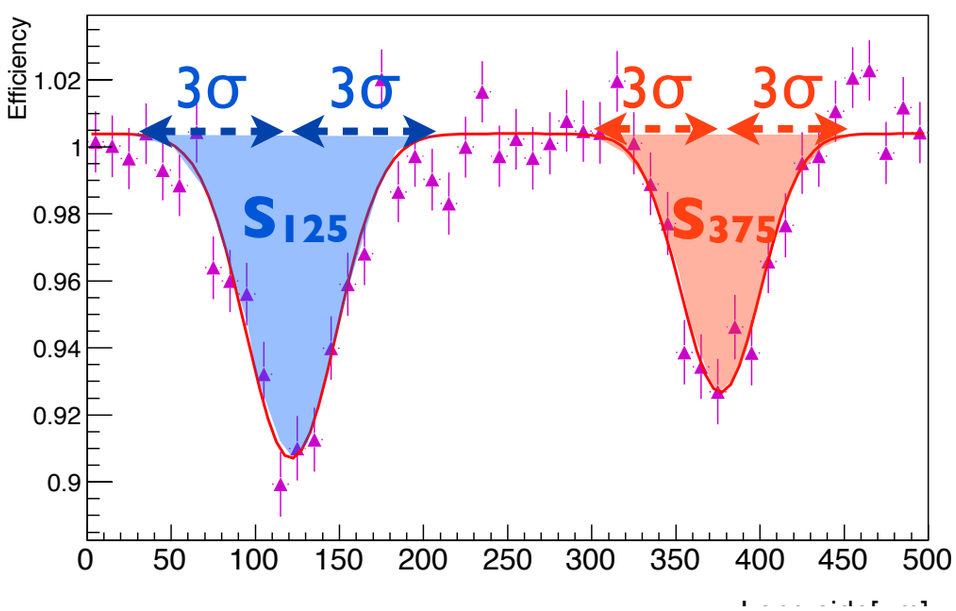
Pixel central region



Pixel boundary region

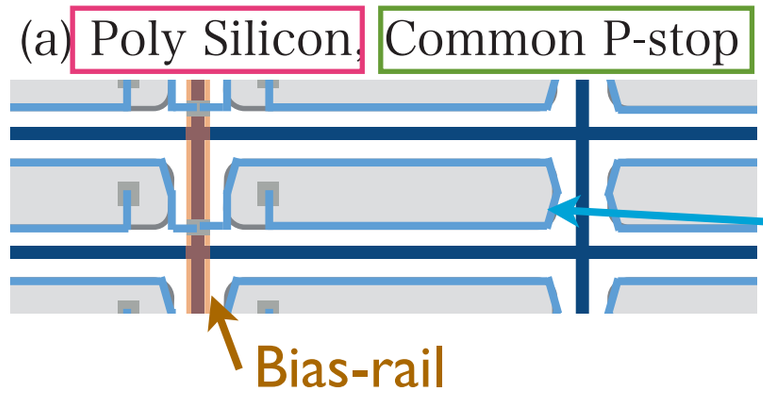


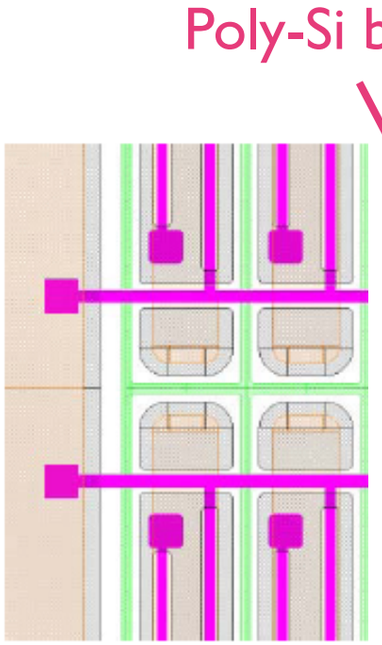
Fit by gaussian and Integral



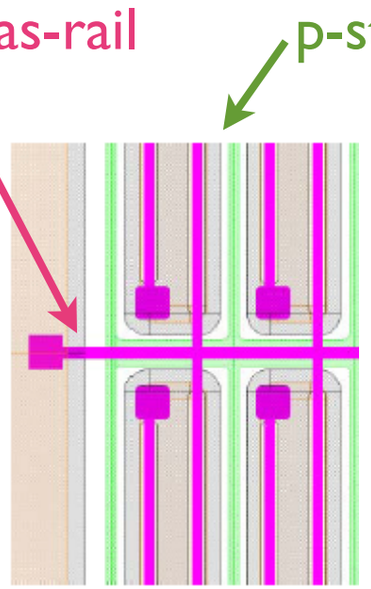
New designs of pixel structure

Original

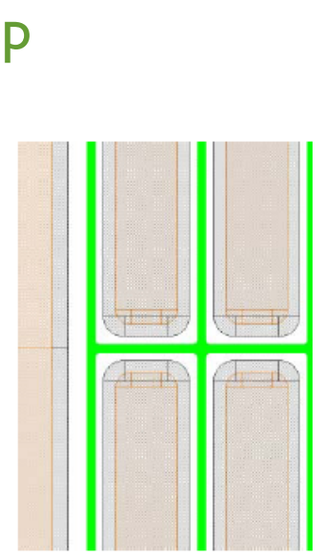




Type10

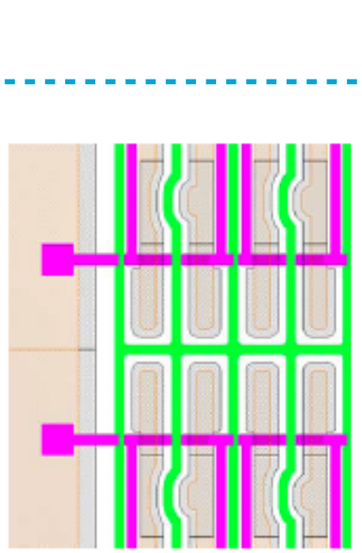


Type13

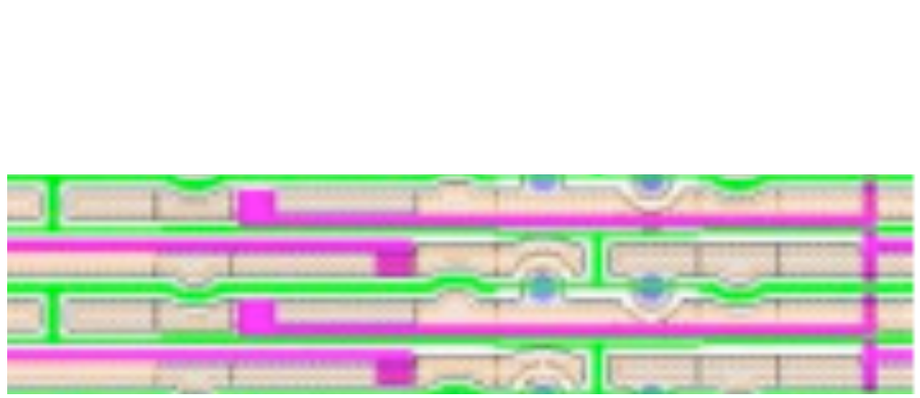


Type19

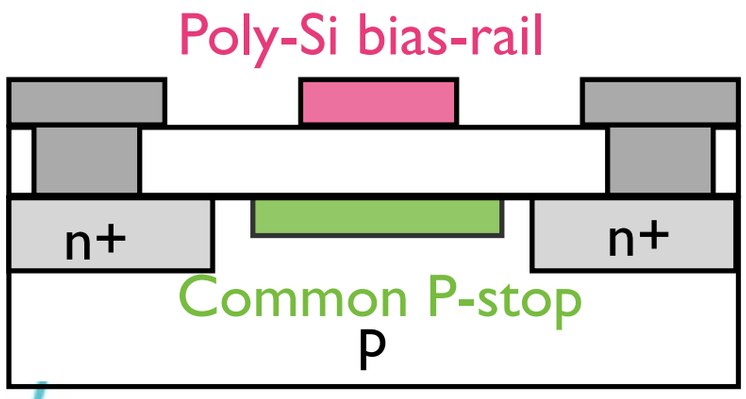
staggered geometry



Type26

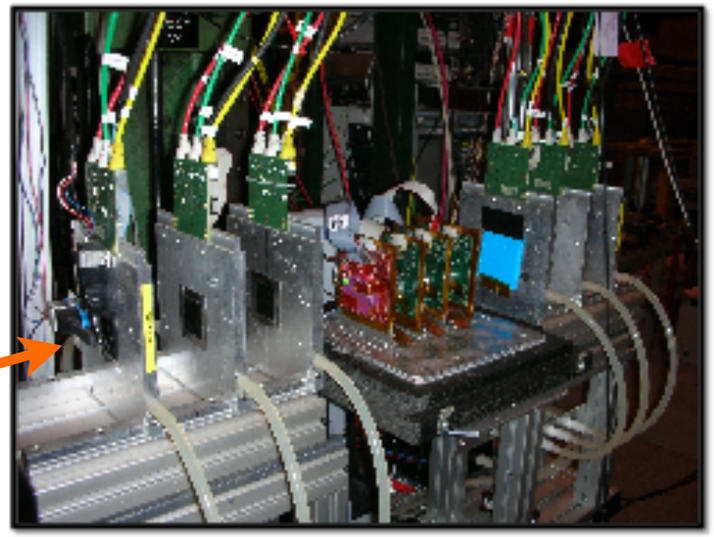


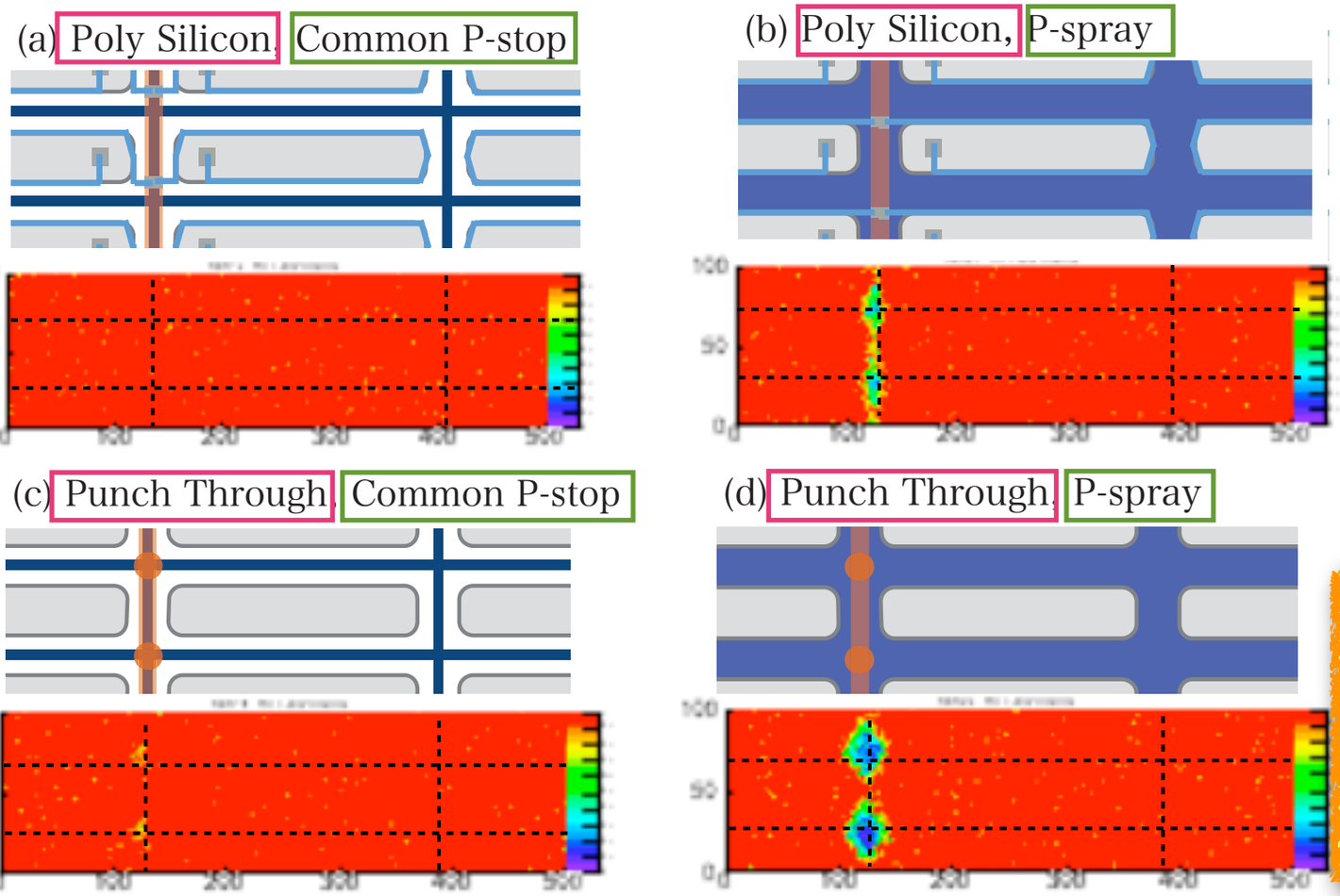
Type27

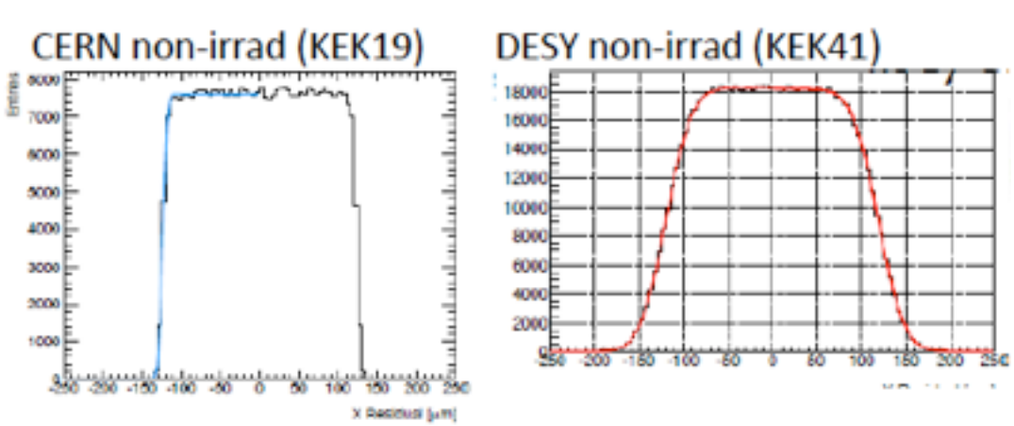


TestBeam at CERN in 2012

- CERN SPS
  - 120 GeV/c pion beam
  - 4 DUTs in each batch
  - 6 Telescopes "EUDET" for tracking
- Non - irrad. sensor (KEK18 - 21)
- Thickness (Sensor/ASIC): 150 / 720 um
  - Hit Efficiency Pixel Map (Overall eff ~99.7%) @400 V (full dep.)



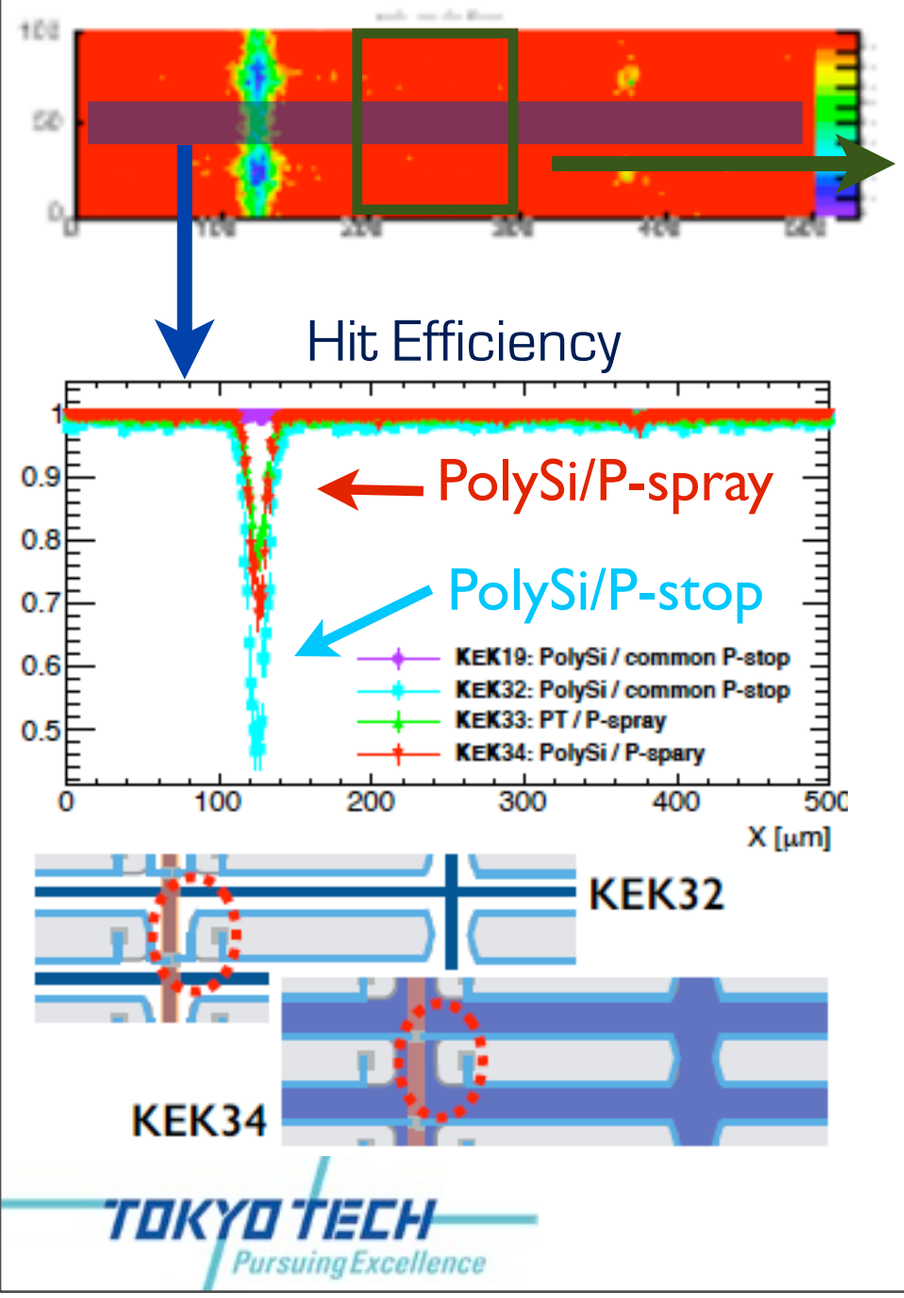




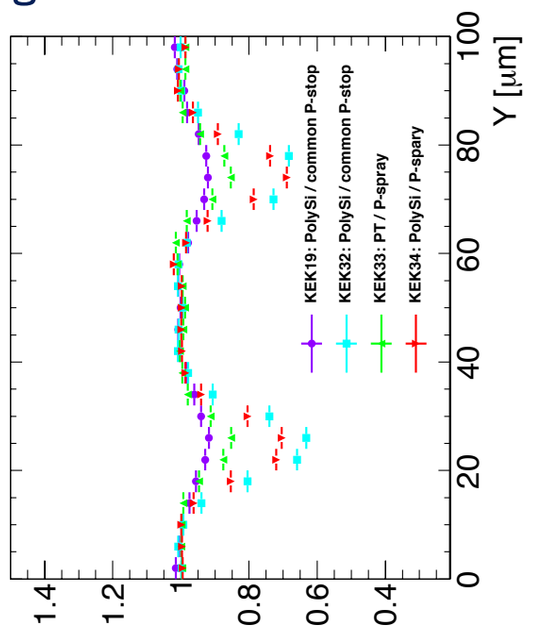
1) Inefficiency at pixel boundary region
2) Structure has caused inefficiency region
   i) P-spray
   ii) PT

TestBeam at CERN in 2012

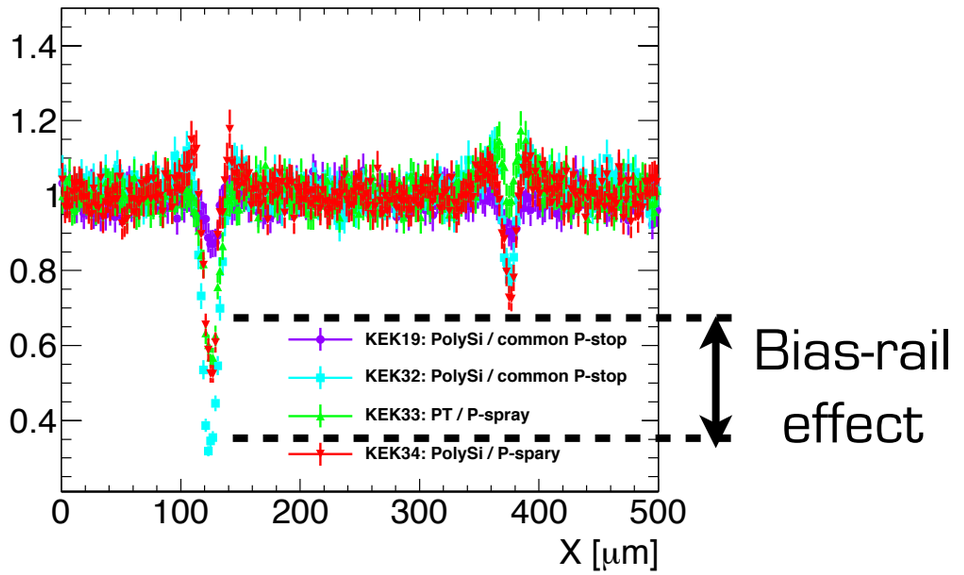
- **Irrad. sensor (KEK32- 34)**
- **Irrad. 1x10^{16} neq/cm2**
- Thickness (Sensor/ASIC): 150 / 720 um
  - Hit Efficiency Pixel Map (Overall eff ~97%) @1200V



Charge Collection Efficiency



Charge Collection Efficiency



1) Inefficiency at pixel boundary region
2) Structure causing inefficiency region
   i) P-spray
   ii) PT
3) Bias rail and PolySi register have caused inefficient charge collection

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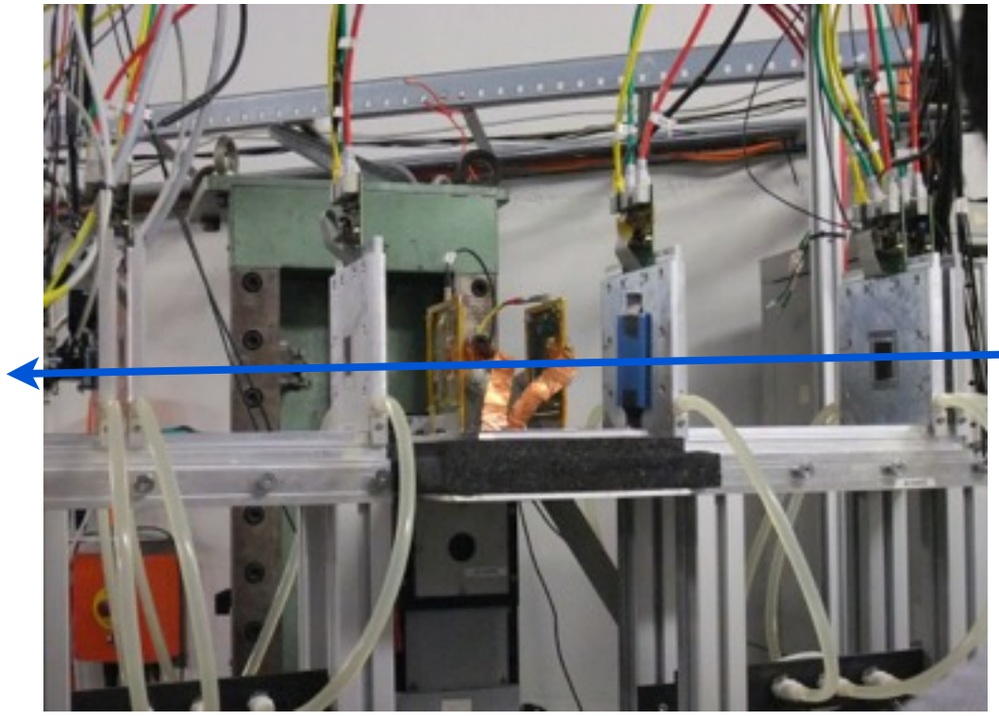
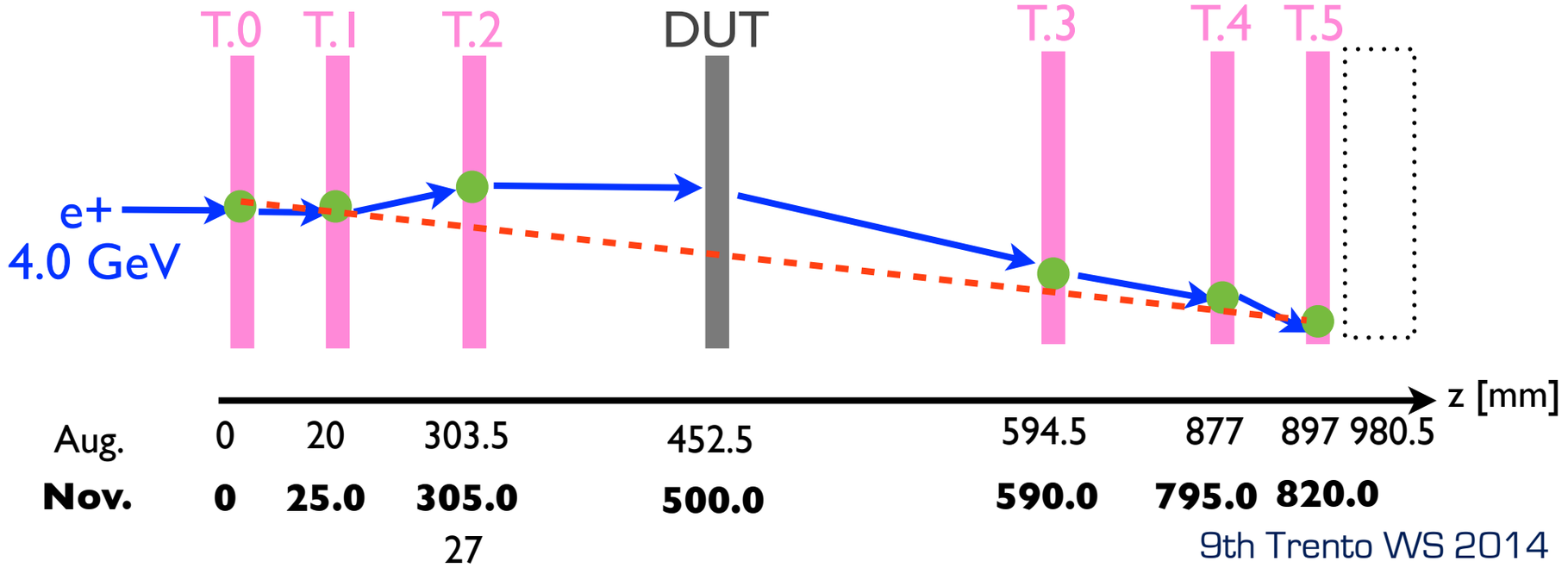
TestBeam at DESY in 2013

- Before Irrad. (in Aug.)
  - **Pixel Structure: Type10 (KEK 41)**
  - **Non - irrad.**
  - Thickness(Sensor/ASIC): 320 um/150 um
  - Tuning: Threshold 2400e ,ToT 7at10ke
  - One reference plane
- **After Irrad. (in Nov.)**
  - **Pixel Structure: Type10 (KEK 46)**
  - **Irrad. 4.18x10^{15} n_{eq}/cm^2**
  - Thickness(Sensor/ASIC): 150 um/150 um
  - Tuning: Threshold 1800e ,ToT 5at5ke
  - No reference plane



(Setup in Nov.)

- Reconstruction: Eutelescope v00-09-03
- Analysis: TBmon release1.2



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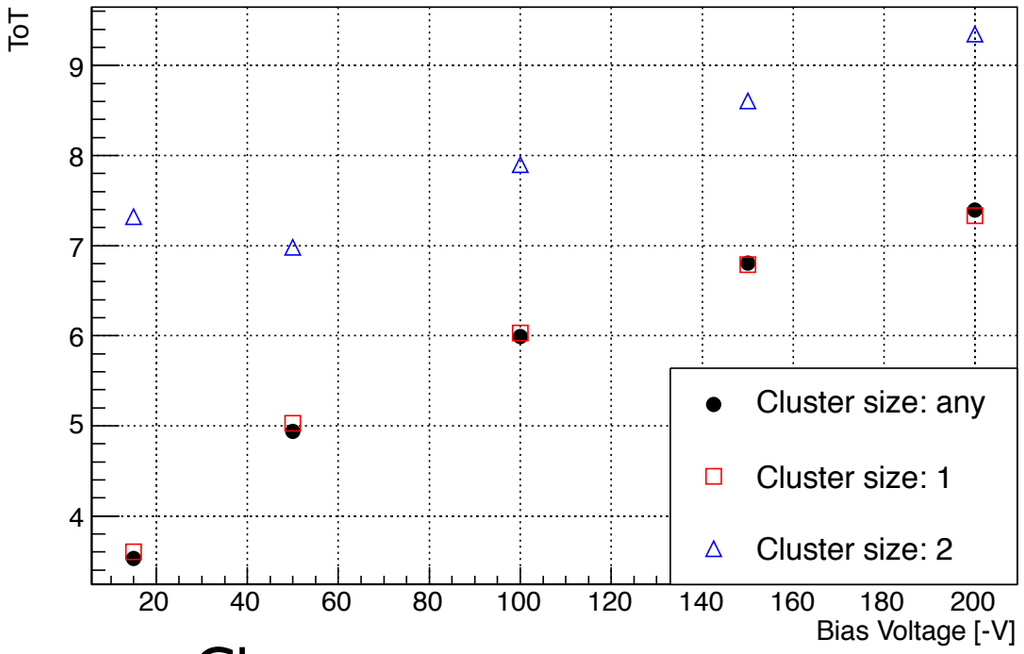
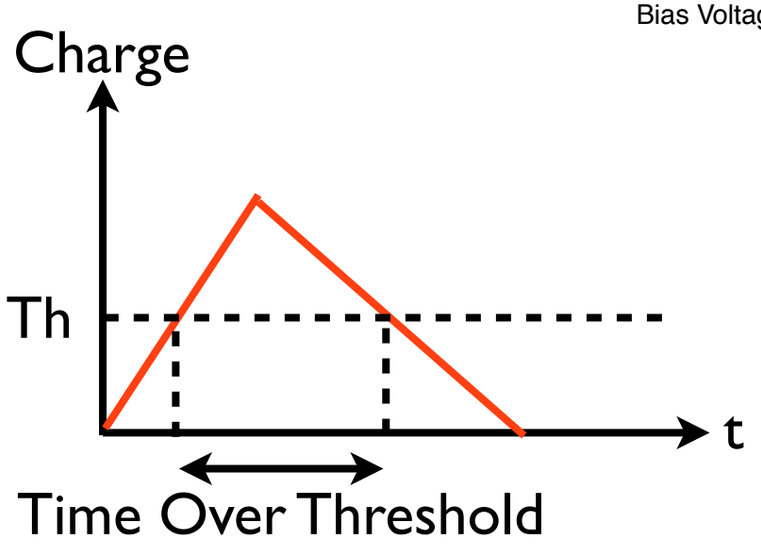
Type 10 Before Irrad.

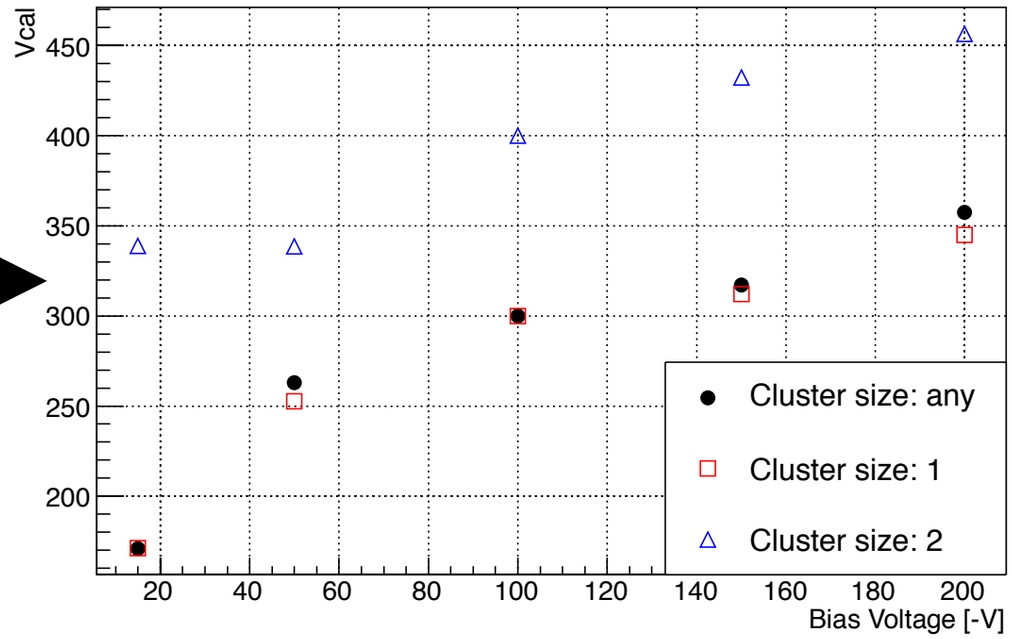
- Bias Voltage vs ToT





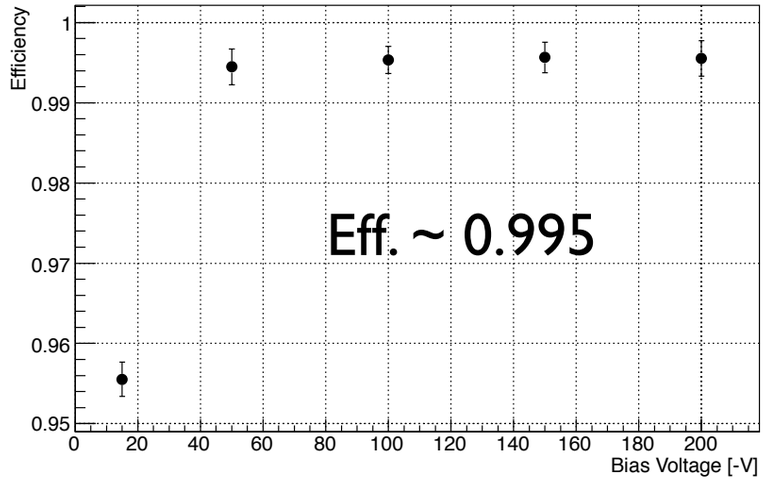
Calibration

- Bias Voltage vs Vcal



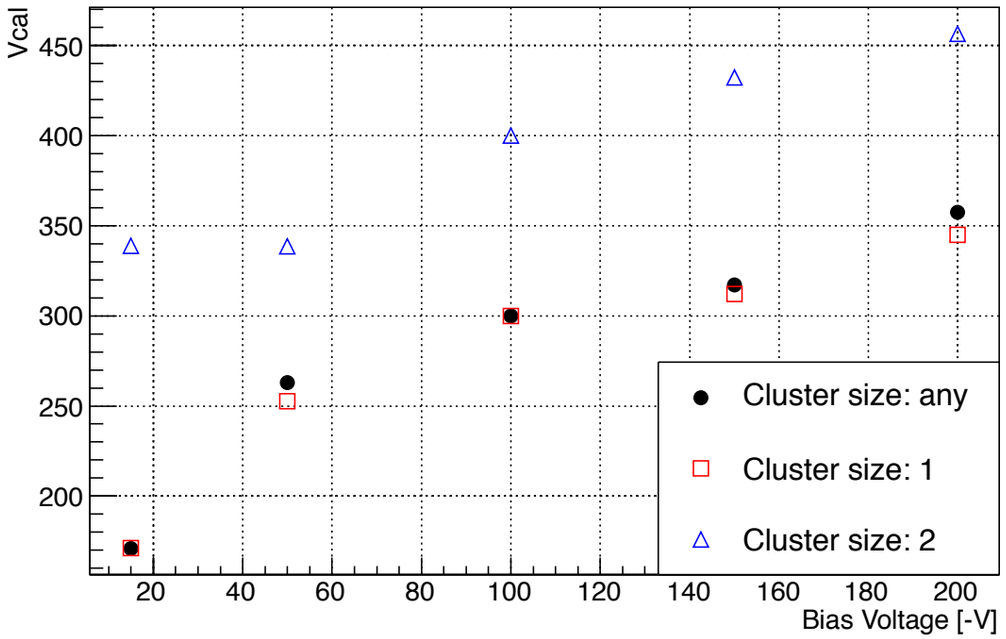
VCal ∝ Charge

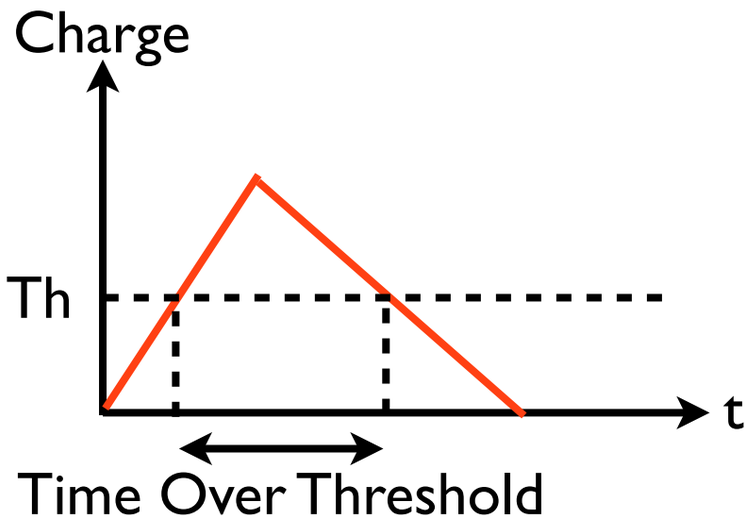
- Bias Voltage vs Efficiency



Type 10 After Irrad.

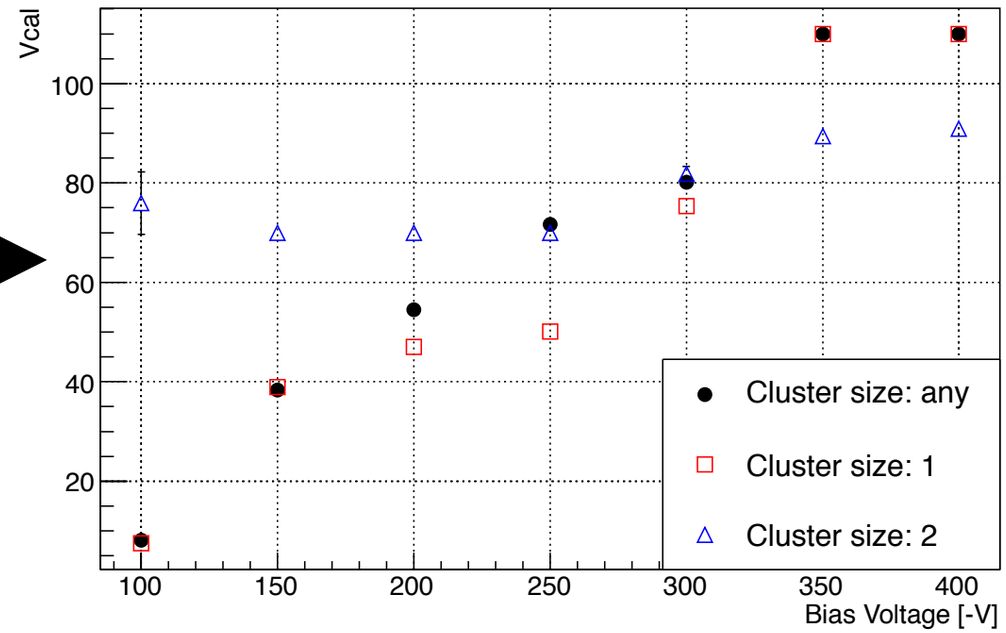
- Bias Voltage vs ToT





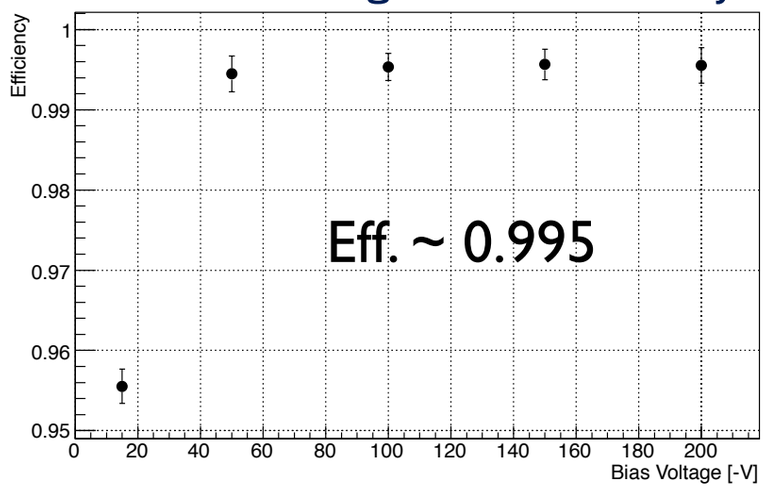
Calibration

- Bias Voltage vs Vcal



VCal ∝ Charge

- Bias Voltage vs Efficiency



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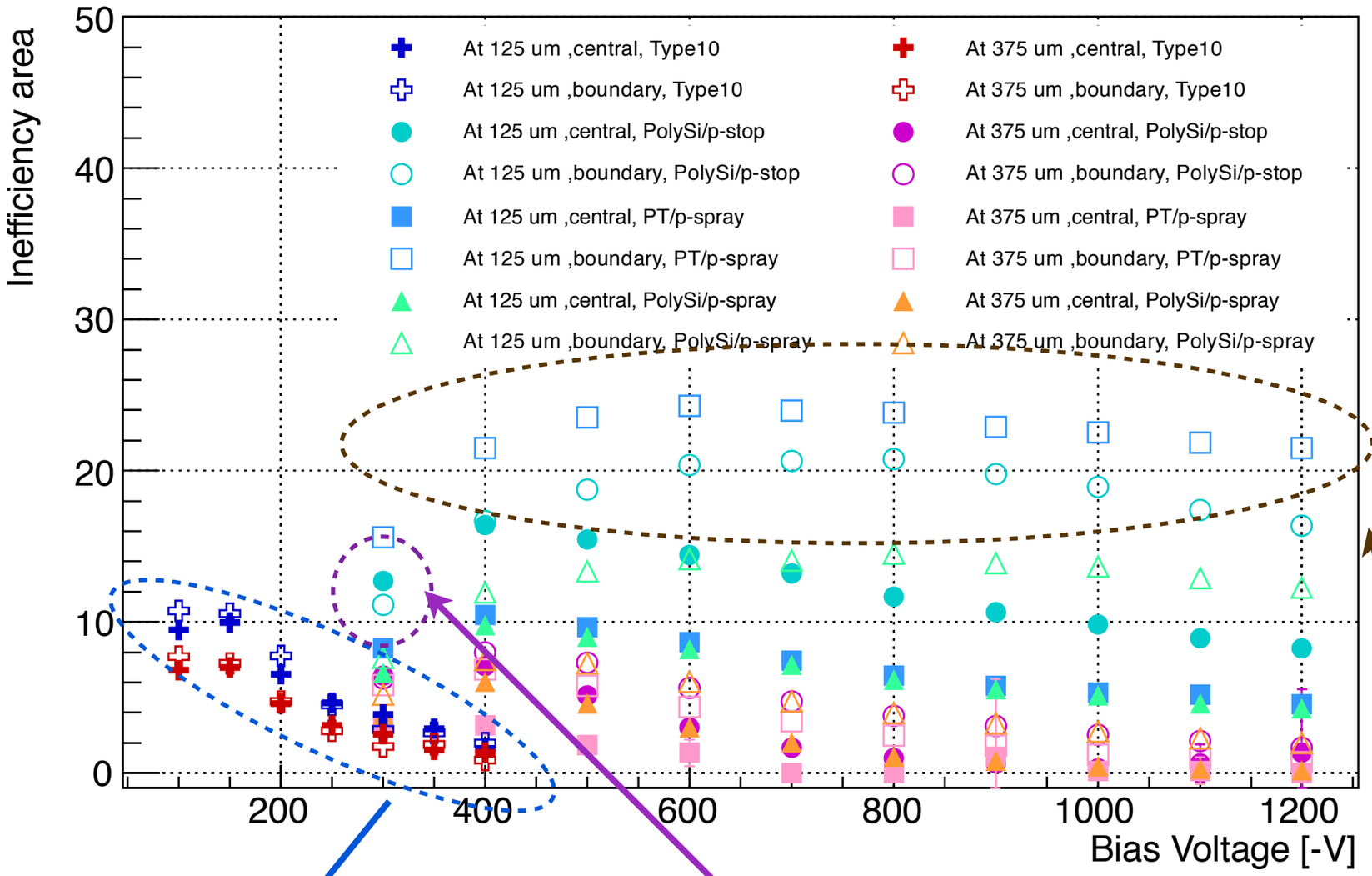
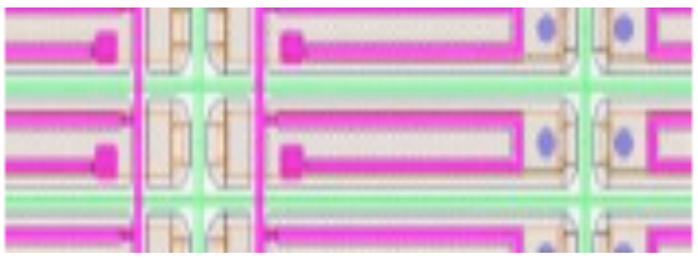
Comparison with Type10 and P-spray

- TestBeam at CERN in Sep. 2012

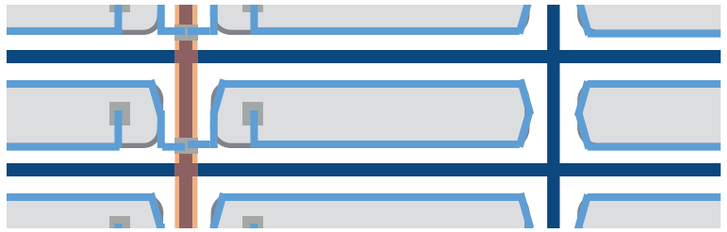


Type10

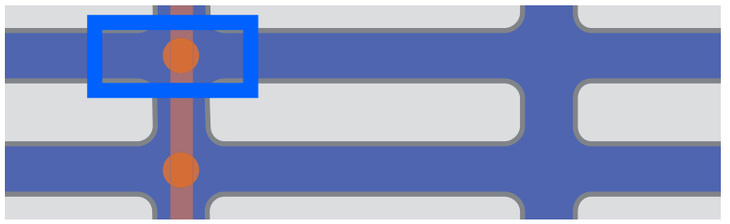


HV is low ... dep. zone is small
4 - corner effect < polySi effect

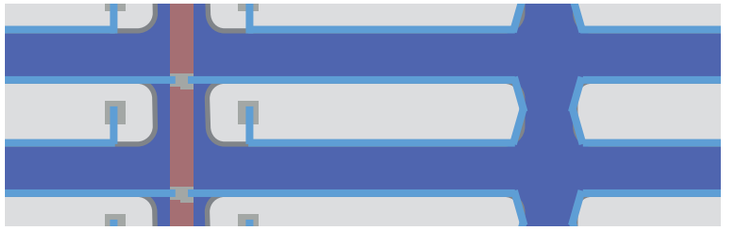
(a) Poly Silicon, Common P-stop



(d) Punch Through, P-spray



(b) Poly Silicon, P-spray



HV < Full dep. voltage
Eff (center) is not high.
relatively, bias rail effect get smaller