UNIVERSITY OF BERGEN

Radiation hard pixel ’3D’ sensors for use in ATLAS-ITk

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Presenting work by Oslo&Bergen ATLAS groups and

SINTEF MiNaLab

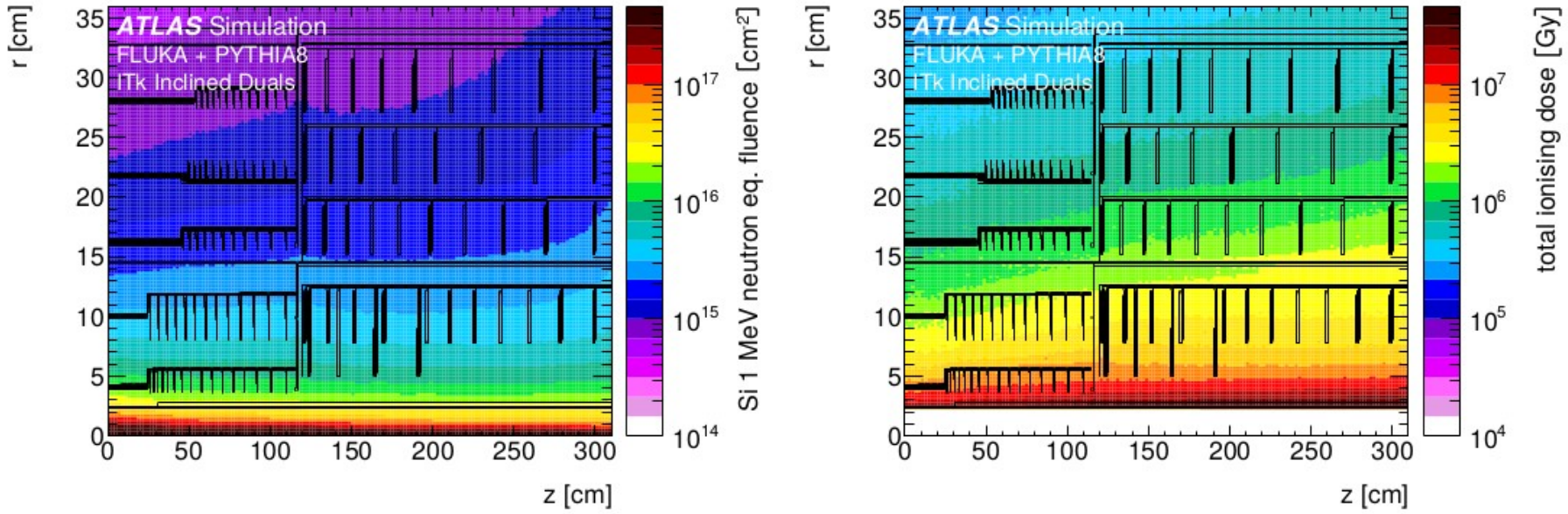
Outlline

- The need for radiation hard sensors
- How to realize them
- 3D sensor productions
- Testing campaigns
- Conclusion/Outlook

Requirements for radiation hardness is unprecedented

- ATLAS SCT: Fluences up to some 1.5 x10^{14} cm^{-2} n_{eq}
- ATLAS IBL: 5 x 10^{15} cm^{-2} n_{eq}
- ATLAS Itk inner pixels: 2.6 x 10^{16} cm^{-2} n_{eq} (4000 fb^{-1})
  - Inner pixel layers to be replaced

Image from Itk pixel TDR



The radiation problem in silicon sensors: Charge trapping due to defects developing Increasingly difficult to fully deplete sensors

- The ’cure’
  - Increase bias voltages
  - Reduce the drift distance
- Design thin planar sensors that can be biassed to very high voltages

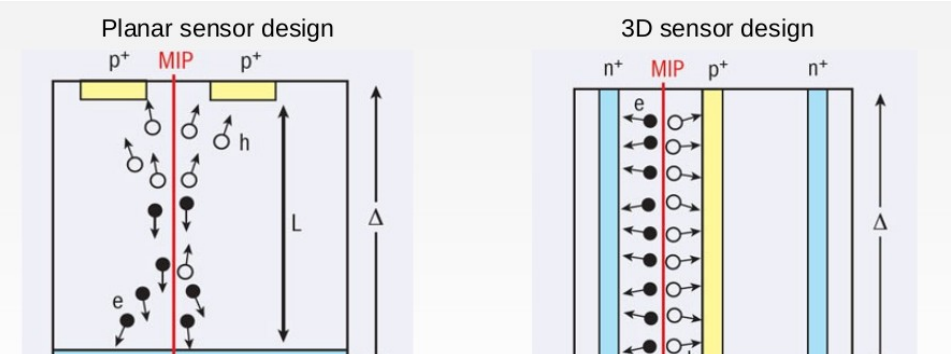
  or

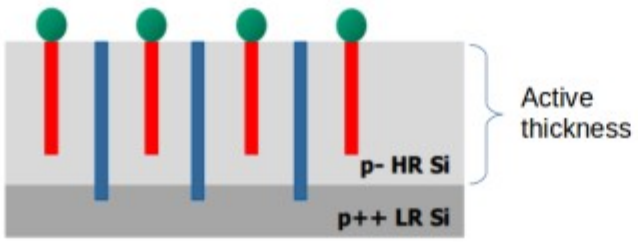
- Rethink the design

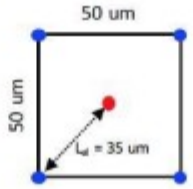
3D Sensor designs: Etch vertical diode structures

(Parker,Kenney,Segal NIM A 395 (1997) 328)

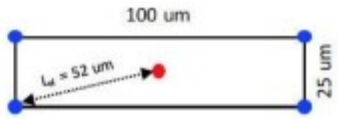
Short drift distances
Runs with very little biasing
Little charge trapping







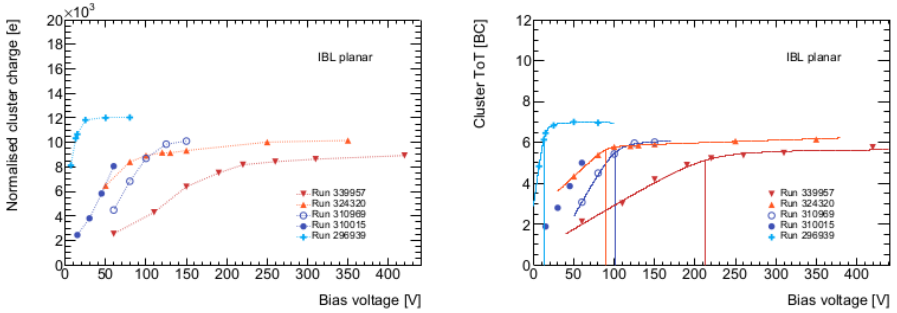
50x50 um², 1E



25x100 um², 1E

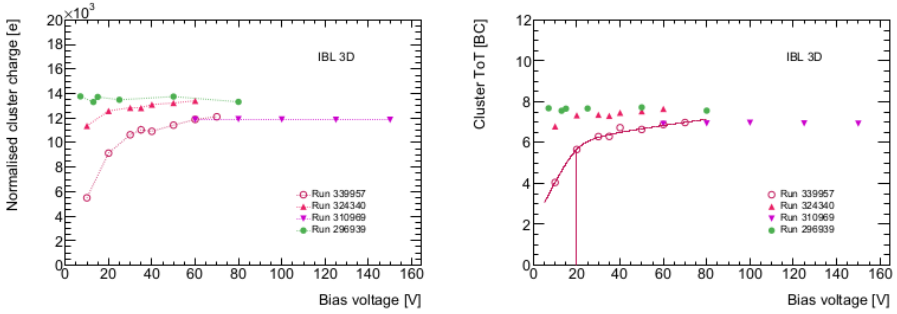
Technologically very challenging

Some 3D sensors have been installed in the forward parts of the ATLAS IBL



(a) Cluster charge (b) Cluster ToT

Figure 5.4: IBL, planar sensors



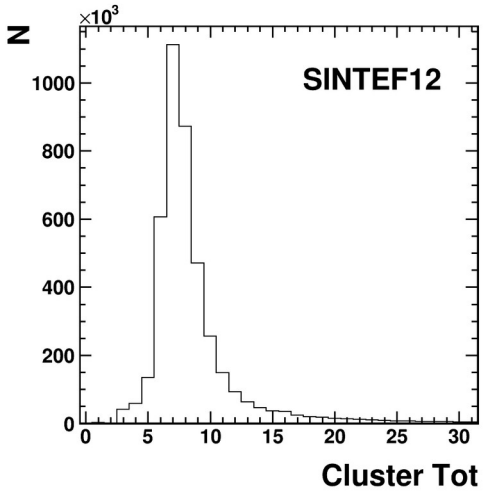
(a) Cluster charge (b) Cluster ToT

Figure 5.5: IBL, 3D sensors

In situ study of the charge collection in the IBL demonstrates the low voltage advantage

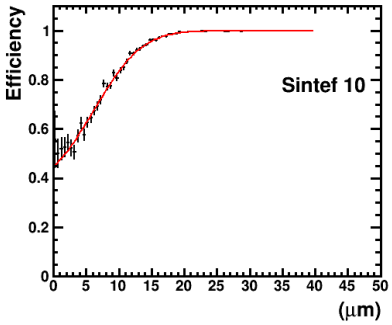
S. Mæland:
PhD thesis UiB (2018)

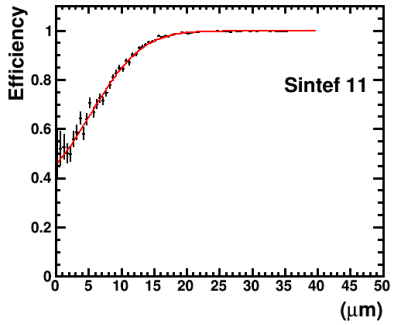
Sintef's 'run3' produced IBL-compatible sensors that were tested in a pion beam (SpS H8) at perpendicular incidence

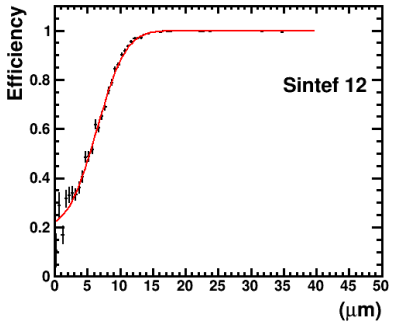


Average eff,: 96.4% (as expected for a fully efficient sensor)

Width of the depletion region compatible with expectation



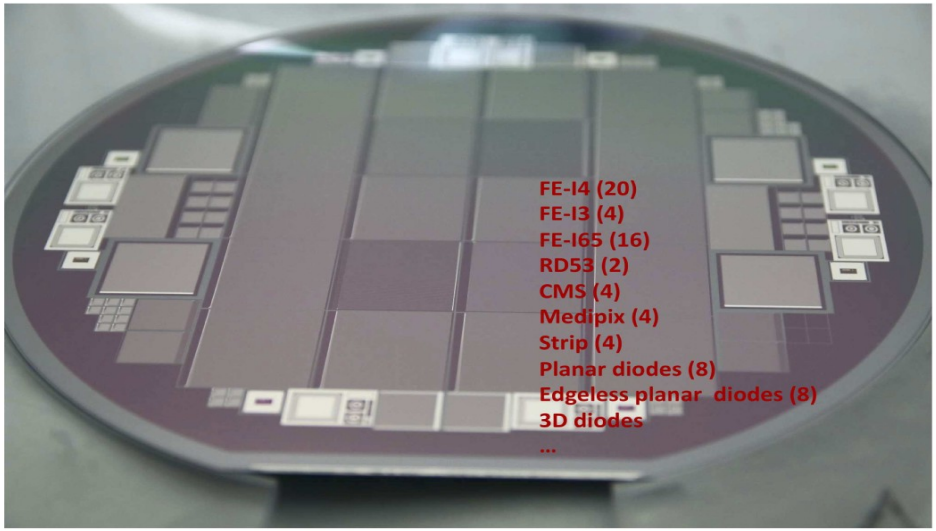




O. Dorholt et al.: JINST_074P_0618

Sintef 'run4' production:

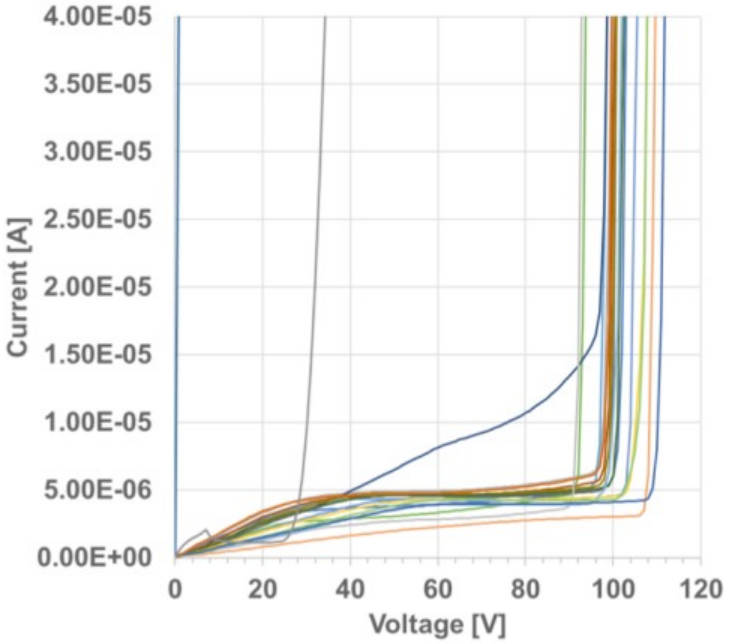
- Sensors of 100 um and 50 um thickness
- $2*N_{wafers}$ RD53A sensors
  - RD53: Collaboration to develop an ASIC for reading out pixel sensors for use in LHC phase 2
- $20*N_{wafers}$ FEI4 sensors
- N_{wafers} =10
-



Production yield around 70% (excellent for 3D sensors)

From I-V characteristics performed at SINTEF on wafers

On-wafer I-V was not possible on RD53A sensors



I-V curves for all FE-I4 sensors on one wafer

(M.Povoli 13th 'Trento' workshop)

Pixel Sensors for ITk

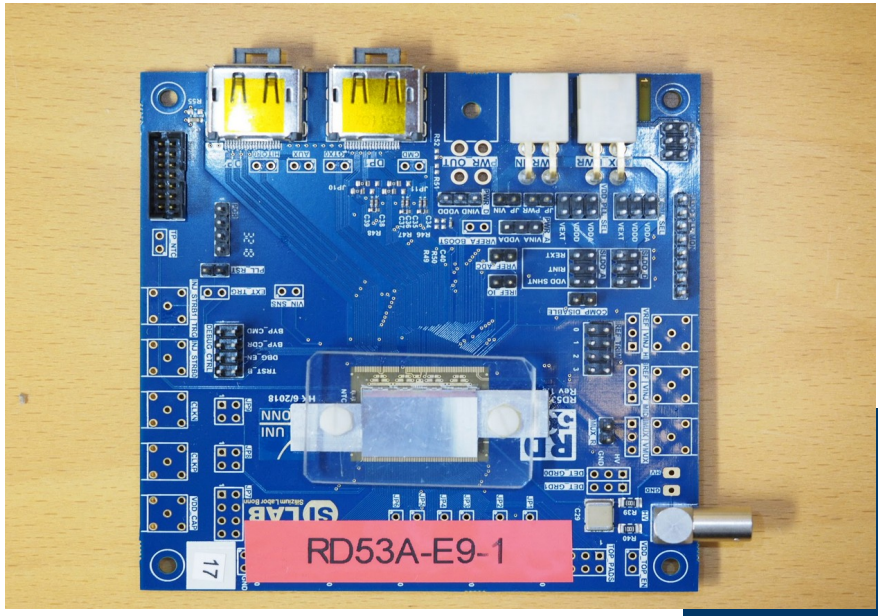
- To be mounted on readout electronics ASIC developed by the RD53 collaboration
- 50x50 um^2 readout pitch
- RD53A: 3 frontend designs on 400x192 pixels (corresponding to half the area of the design size of Itk pixel sensors)
-

SINTEF

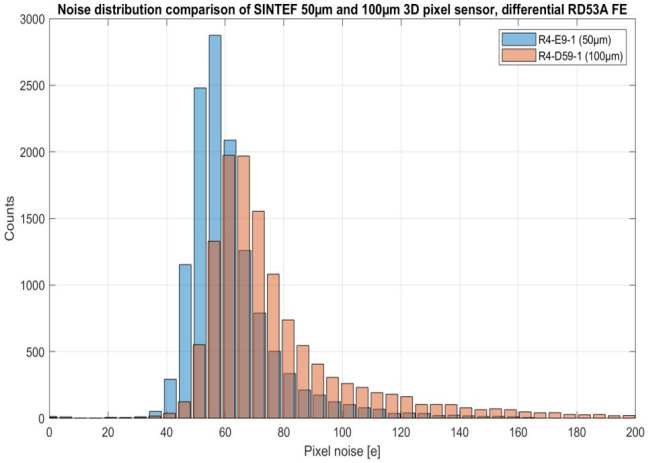
Produced modules

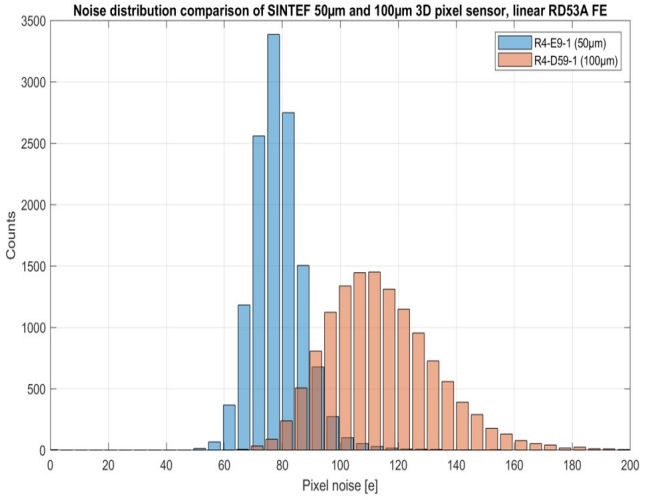
- Bump bonding with IZM
  - 40 FEI4 , 9 RD53A
- Modules mounted and bonded **(in Oslo)**:
  - 4 100 um FEI4
  - 4 50 um FEI4
  - 3 100 um RD53A
  - 2 50 um RD53A
  - A few more in the pipeline

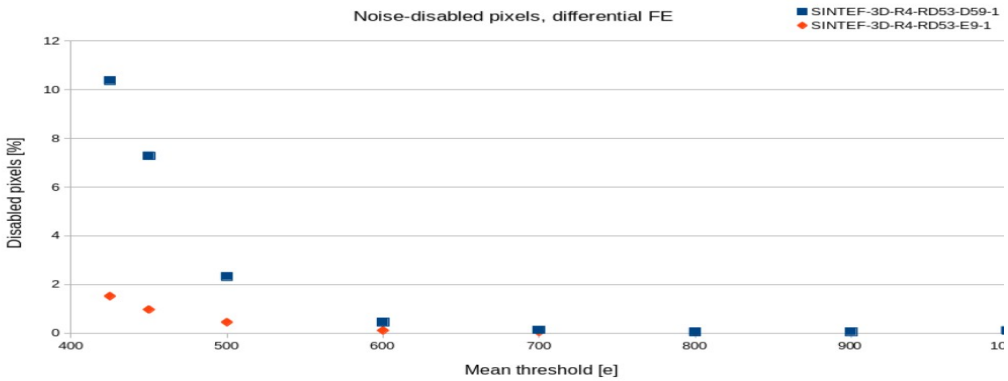
RD53A hybrid pixel assemblies, ready for mounting



(YARR) Tuning of RD53 sensors with 50 and 100 um thickness

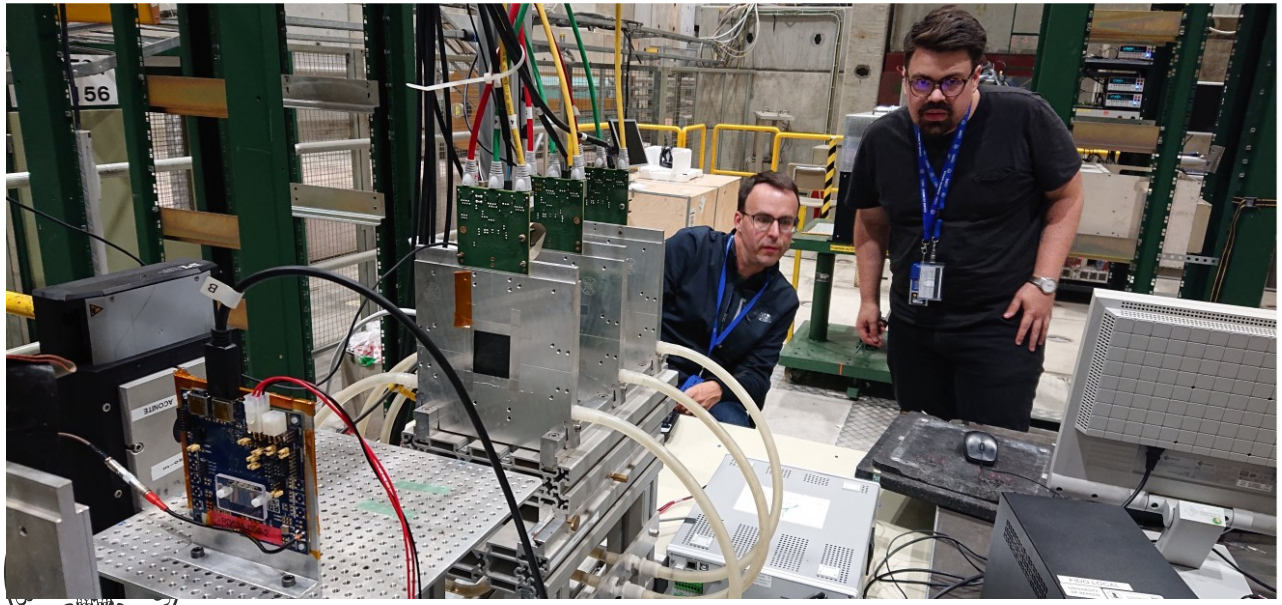






Tests in pion testbeam at Cern

- Sensor: RD53A-D59-1
- 100 micron thickness
- Data collected in H6B , normal incidence
- Threshold 800e, Tuning: 4ke at Tot=8
- **The next slides are for V_bias = 10V**

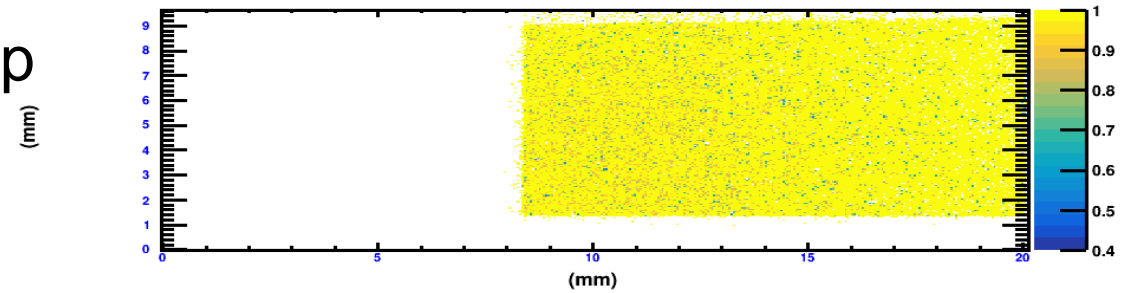


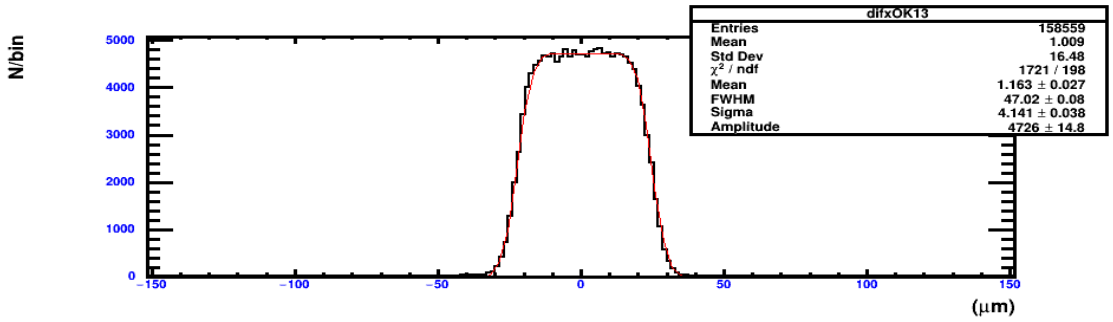
Whole sensor efficiency map and alignment
NB: average number of tracks/pixel is small 3-5

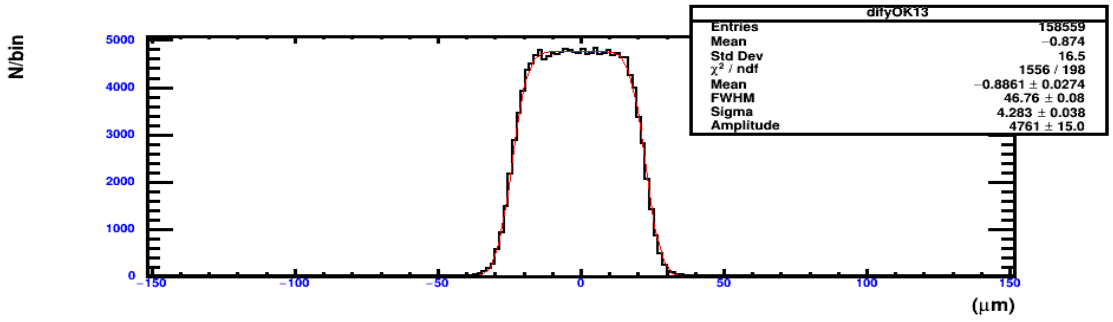
Efficiency map

Track-hit residuals

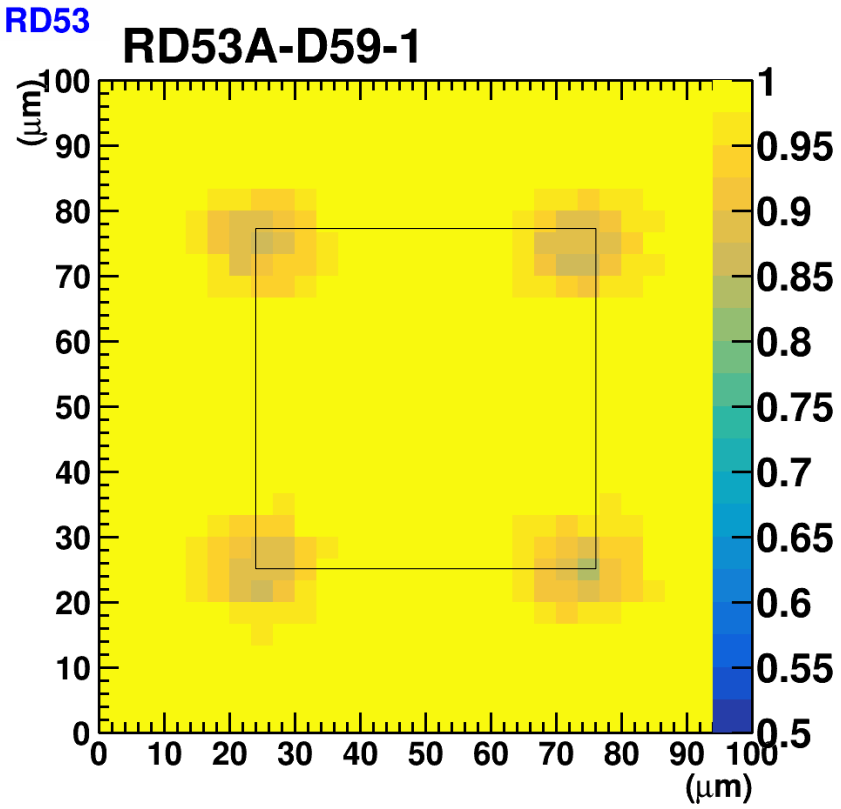
Pointing resolution 4.5 microns

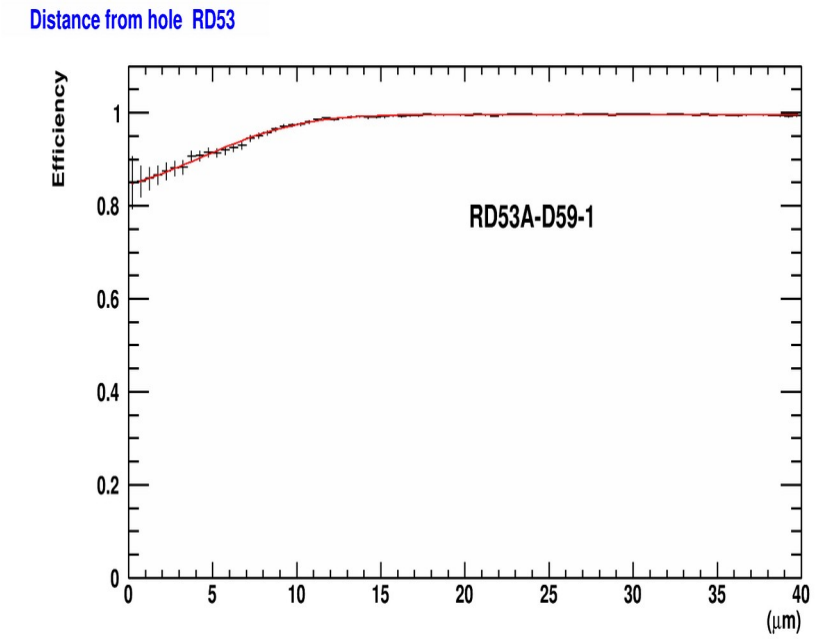






Pixel efficiency map & efficiency vs. distance to hole





Too low spacial resolution to be able to determine the **radius** of the hole (fixed to design 1.5 um)

Overall efficiency 98.7%

RD53a module irradiations

- 2 Modules were irradiated with protons to a proton fluence of 0.5 x10^{16} cm^{-2} at KIT (Karlsruhe Institute of Technology)
- 2 modules were irradiated with neutrons to a fluence of of 1 x10^{16} cm^{-2} in Josef Stefan institute (Ljubljana)
  - and subsequently mounted/bonded in Oslo
- Tested in a 4 GeV electron beam in DESY.

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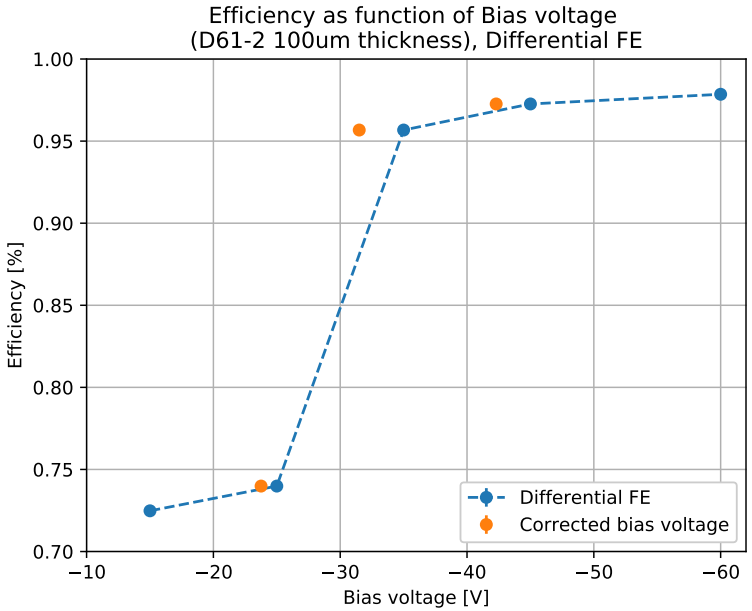
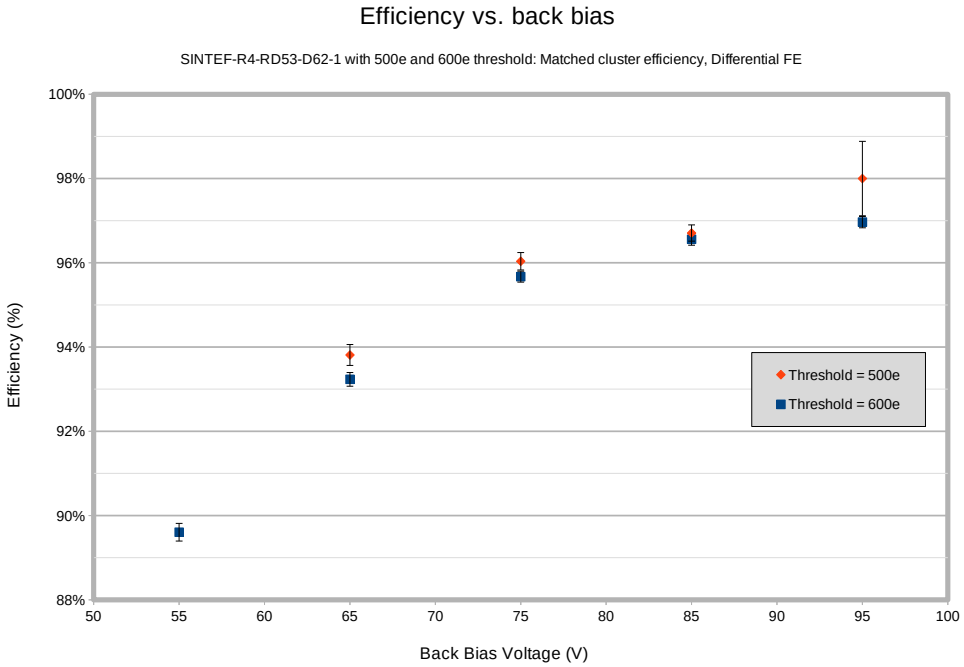
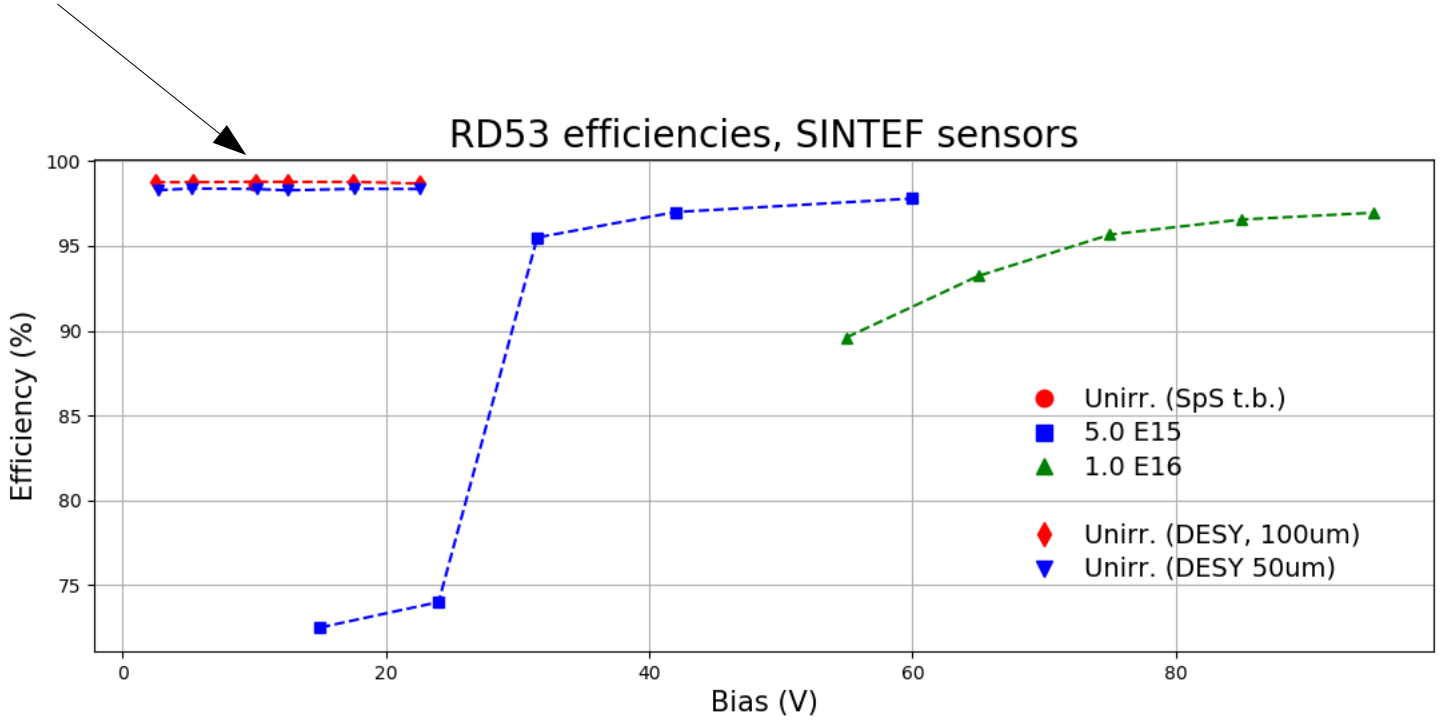




(plots & analysis by A. Heggelund and S. Huiberts)

Summary of TB efficiencies at different V_{bias}

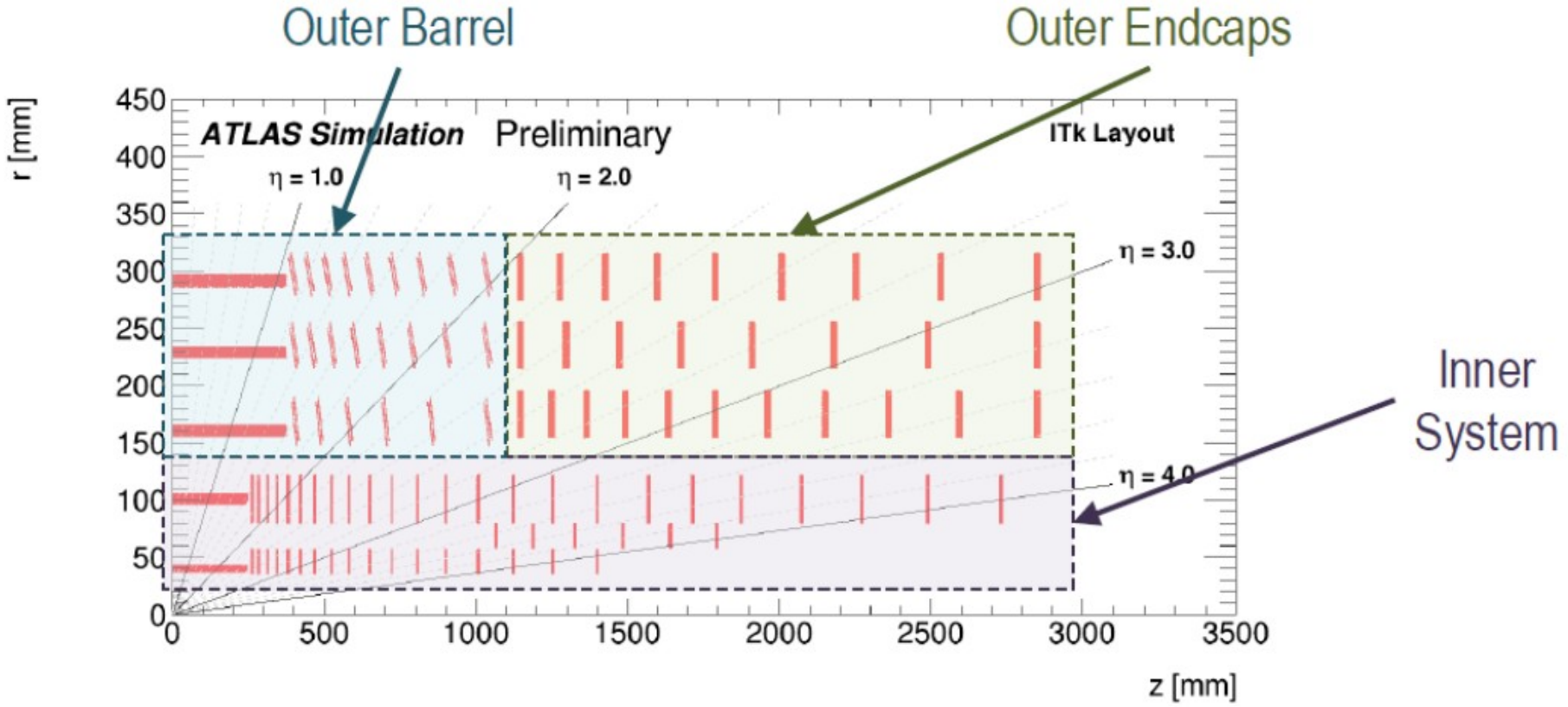
SpS result and DESY results are the same



SINTEF RUN5

- 12 wafers layout A:
  - 26 identical 2xRD53B die 1E 50x50 μm^2 pixels
- 12 wafers layout B:
  - 1E & 2E 25x100 μm^2 pixels
- Designs to ’nominal ITk’ specs
  - thickness, electrode widths etc..
- Processing is progressing well
  - On wafer measurements expected this month
  - Delivery beg. March
- Will be ready for bump-bonding to ITKpixV1 (the next RD53 chip) when they arrive

3D sensors in the ATLAS ITk



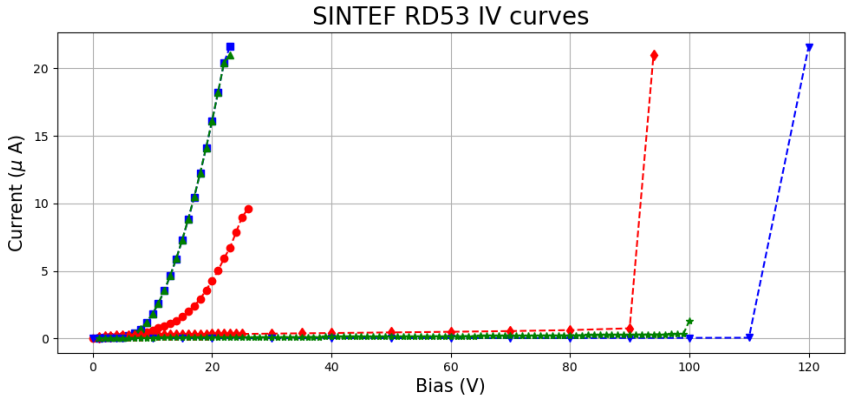
3D Sensors will be used for module production in Layer 0

- 0.53 m^2
- 1400 sensors (of size about 2x2 cm^2)
- A 3D sensor design review was performed (Dec. ’19) with inputs from three vendors (including Sintef)
  - Positive informal feedback
- Module production with 3D sensors is the task of three ’clusters’, from Italy, Spain and Norway, with a commitment of 1/3 of the production in each cluster.

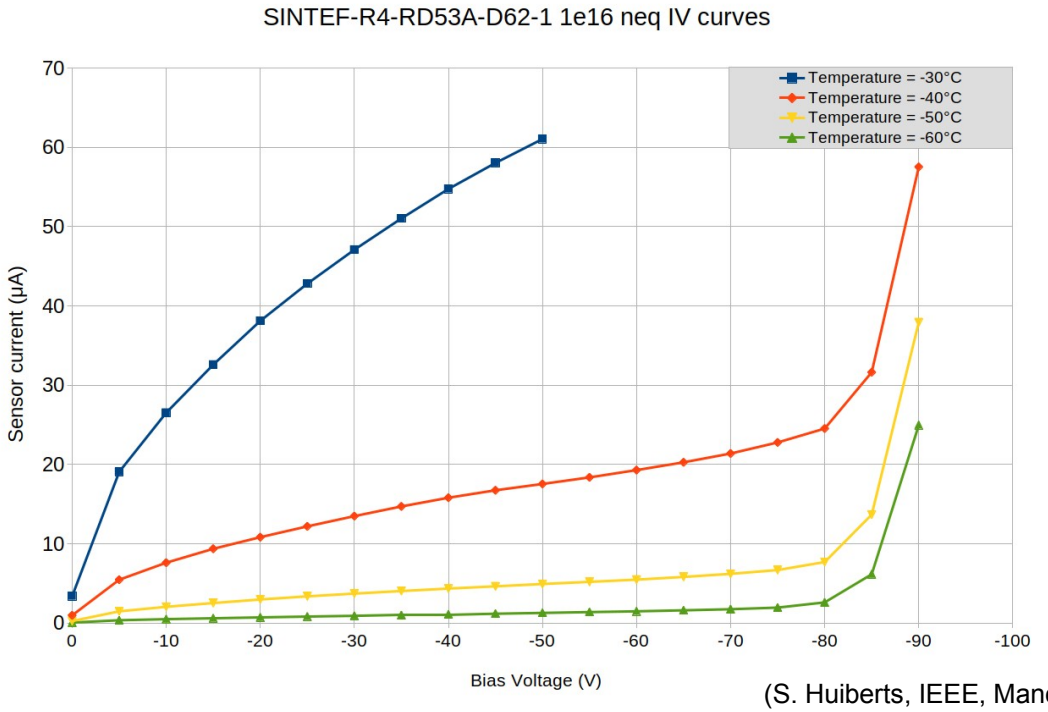
Conclusions and outlook

- SINTEF run4 sensors seem to perform well
- Demonstrated to meet efficiency requirements after being exposed to large fluences
- Run5 progressing well and is as expected.

Backup



IV curves on several sensor-RD53A assemblies mounted on SCCs



IV curves on a sensor-RD53A assembly after being exposed to $n_{eq} = 10^{16}\,cm^{-2}$ (different temperatures)

(S. Huiberts, IEEE, Manchester)

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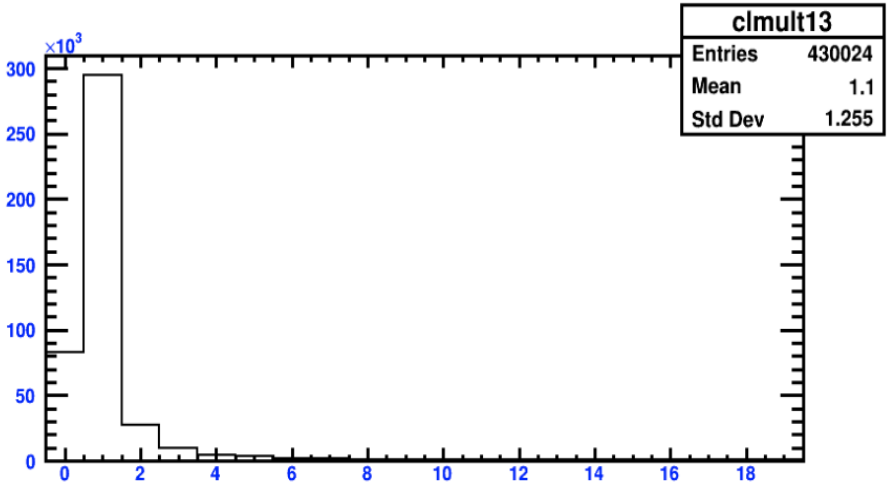
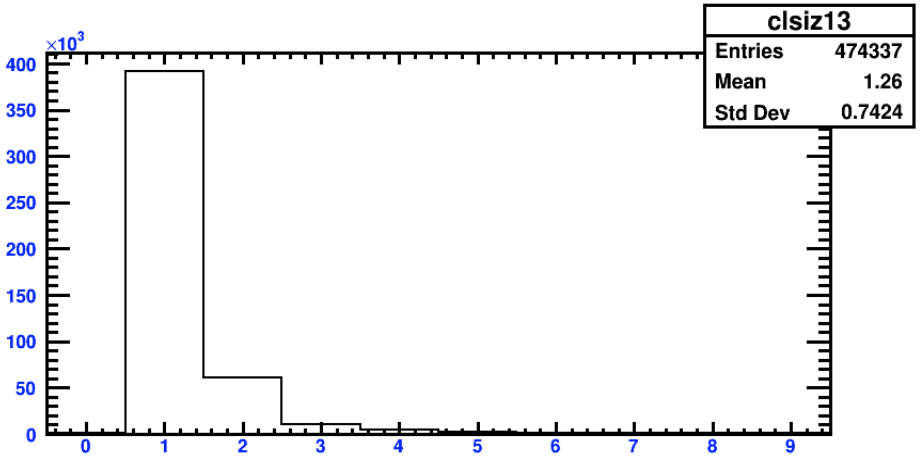
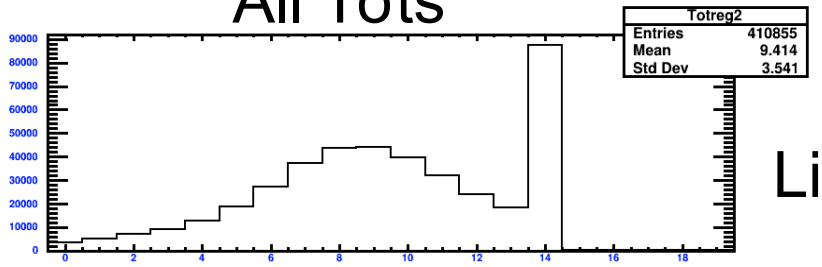
Cluster, multiplicities sizes, Tot basic distributions

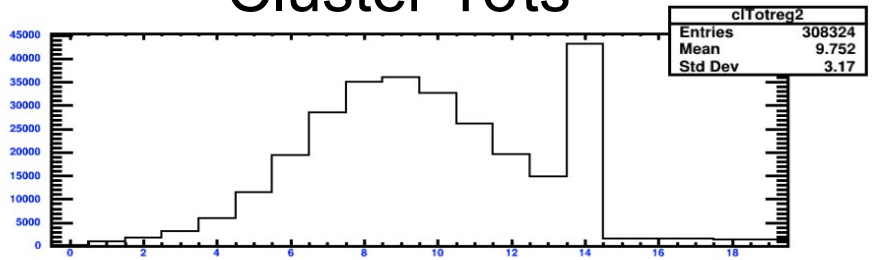




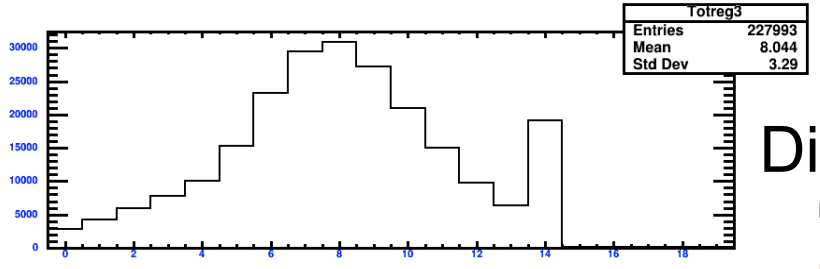
All Tots



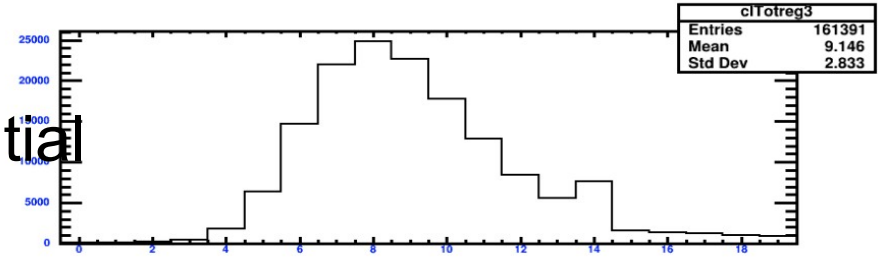
Linear



Cluster Tots



Differential



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