Testbeam results: Superpix0 - Hybrid Pixels

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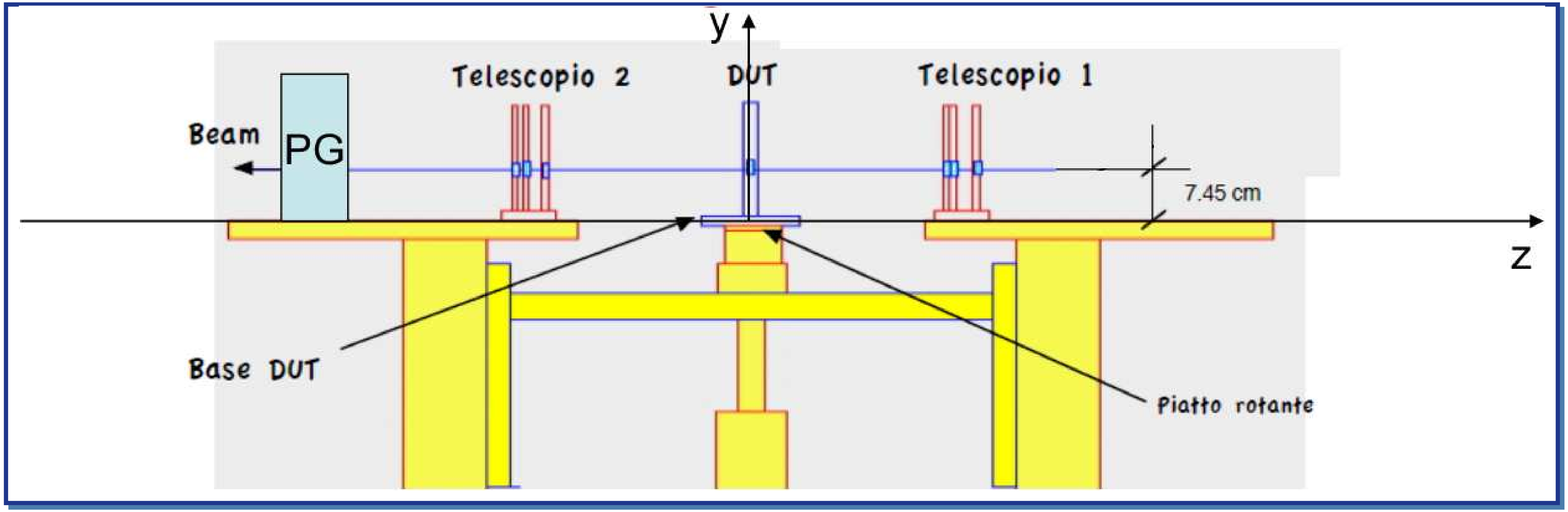
September 2011 test-beam, CERN SPS, 120 GeV pions



- 6-planes Si telescope, 50 μm strips, analog double-side readout, two stations of 3 wafers each
- 3 detectors under test (DUTs): hybrid digital pixels (superpix0), analog pixels (MAPS) and striplets
- here **report on superpix0 hybrid pixels**

Superpix0 hybrid digital pixel prototype

- $50\,\mu\text{m} \times 50\,\mu\text{m}$ pixels
- 4k pixels, 128×32, $0.64\,\text{cm} \times 0.16\,\text{cm}$
- $200\,\mu\text{m}$ thick fully depleted silicon
- digital readout

Additional notes

- main goal: measure efficiency vs. threshold and angle of incidence
- also: resolution, cluster multiplicity
- data taken with:
  - 3 superpix0 chips: #12, #53, #55
  - several thresholds, **reference threshold 1/4 of a m.i.p. at normal incidence**
  - DUT rotated around at $0^\circ, 15^\circ, 30^\circ, 45^\circ, 60^\circ, 70^\circ$ w.r.t. normal incidence
- 128 pixels along x (horizontal, ***u*-axis**), 32 pixels along y (vertical, ***v*-axis**)
- some readout flaws implied:
  - each run, only 1/4 (slice) of DUT was active, i.e. only 8 out of 32 pixel rows in v
  - relatively high reference threshold used (1/4 of a m.i.p. at normal incidence)
- approximately parallel tracks, high momentum, negligible multiple scattering

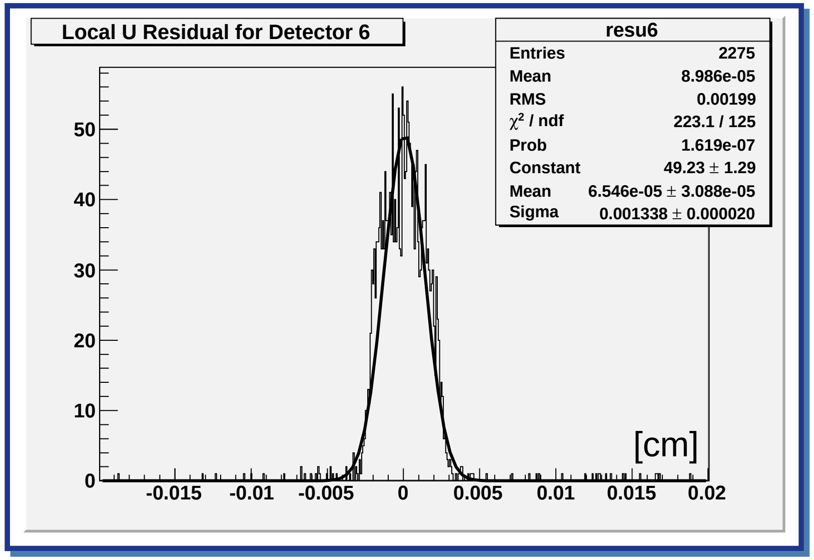
Data analysis

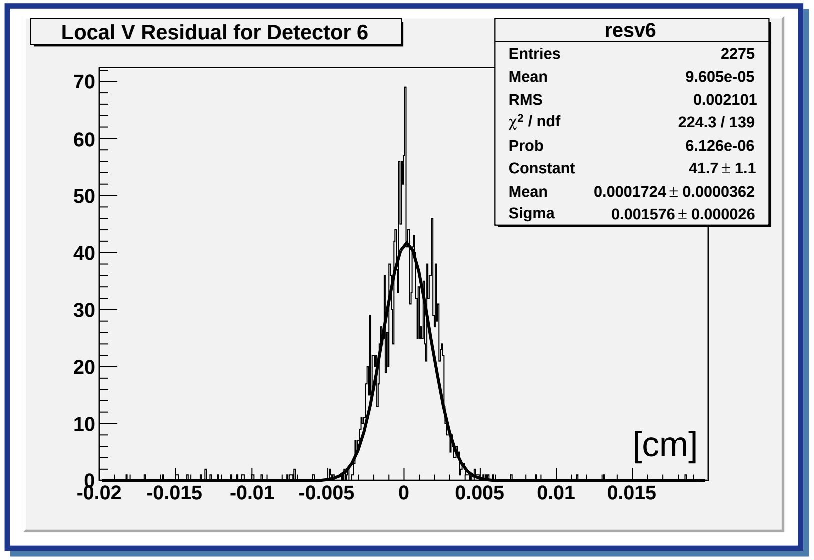
- relied on **Sbt software**, authored by J.Walsh, N.Neri and M.Bomben
- implemented some improvements
  - extend tracking to use variable n. of Si planes (N.Neri)
  - improved to works with more recent Root versions and compilers, improved Makefile
  - can now join runs for reconstruction, alignment
  - alternative new alignment code using MillepedeII (B.Oberhof)
- using Si telescope hits, **reconstruct** strip clusters $\longrightarrow$ wafer space-points $\longrightarrow$ tracks
- require one and only one track, with hits on all 6 planes ($\approx$ 50–70% efficiency)
- **align telescope** (traditional algorithm used so far)

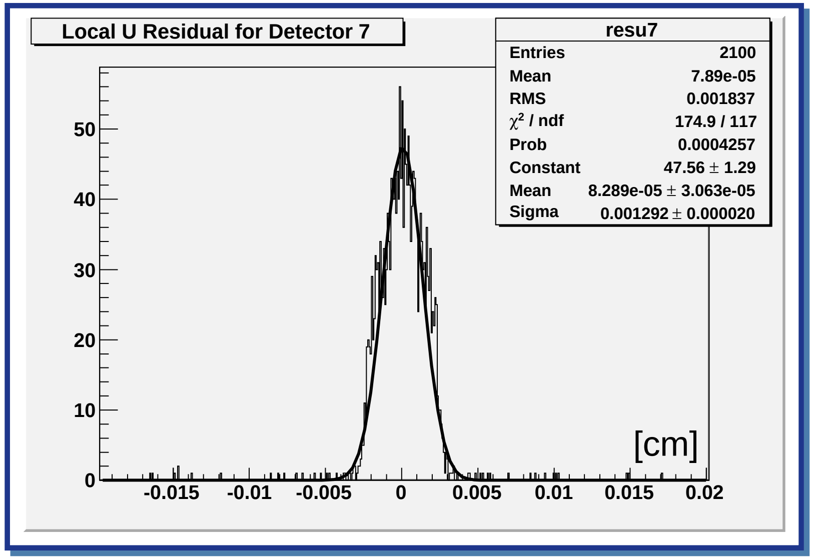
Data analysis - pixel DUT efficiency measurement

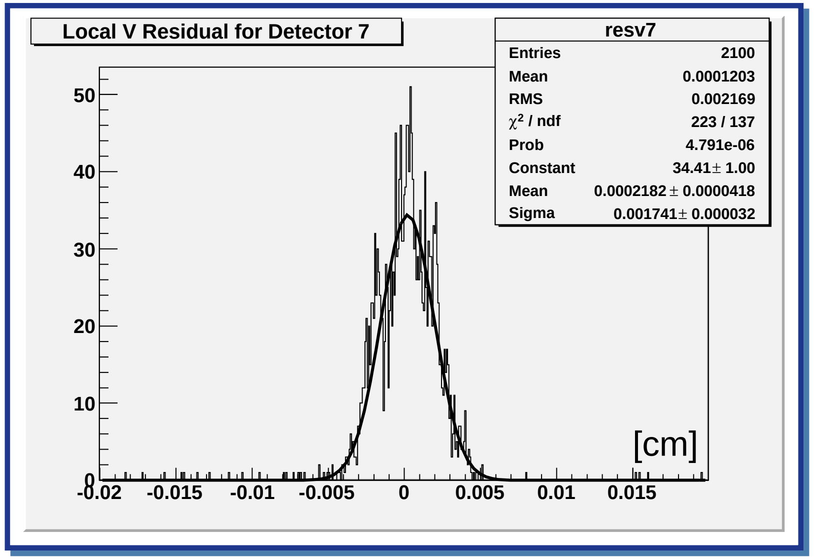
- cluster pixels, one missing pixel in both *u* and *v* axes allowed
- hit = cluster position in *u*, *v* is the average *u*, *v* position of its pixels
- plot hit residuals vs. extrapolated tracks on DUTs
- **align DUTS** by fitting the *x*, *y* residuals with a Gaussian
- count the extrapolated tracks into the sensitive (see later) DUT area
  - in any case, sensitive area excludes 1 row of pixels on all 4 borders
- count events with closest hit within max distance (see later) in *x* and *y*
- **efficiency = <events with associated hit>/<tracks>**

DUTs residuals, normal incidence, angle = 0°, (Run 2665)

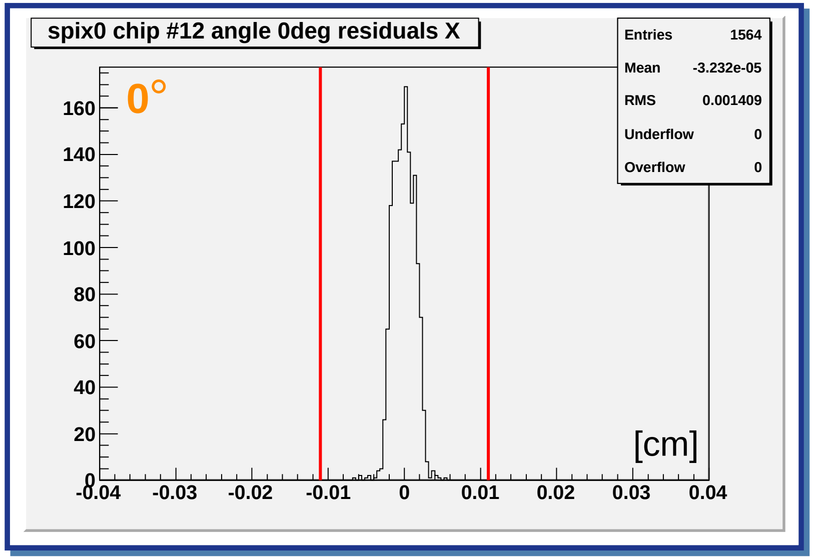


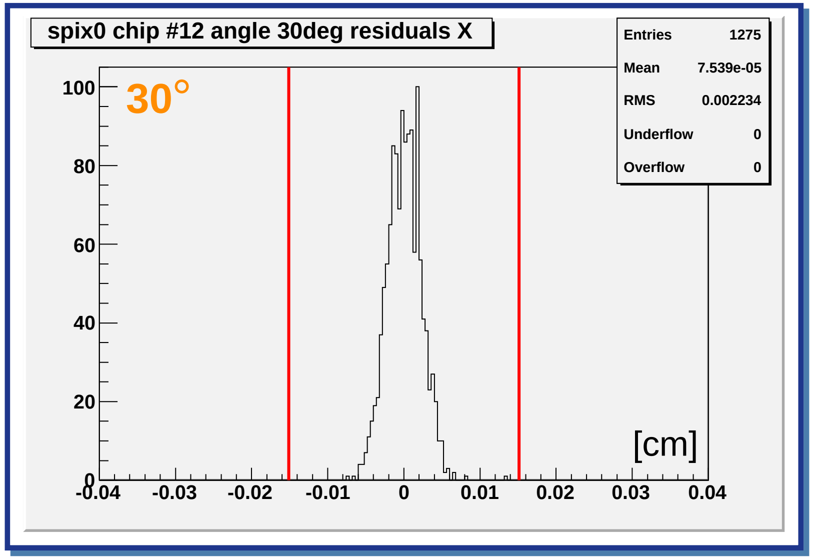


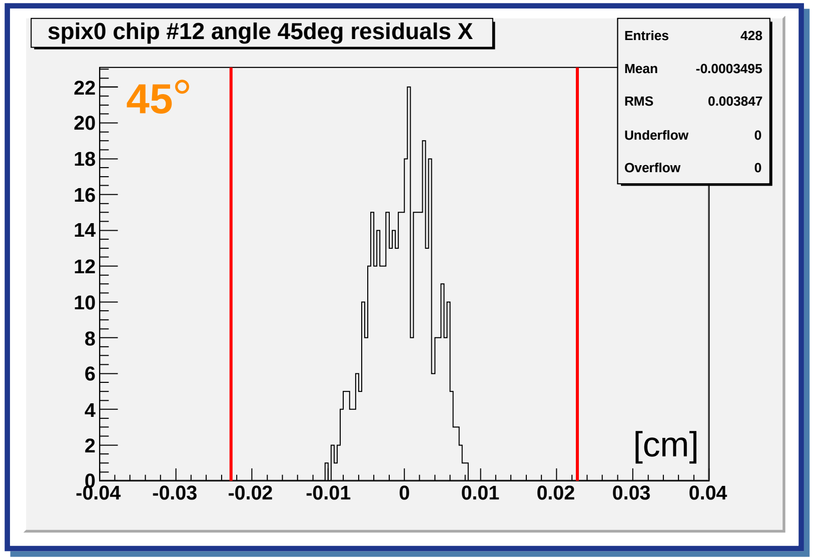


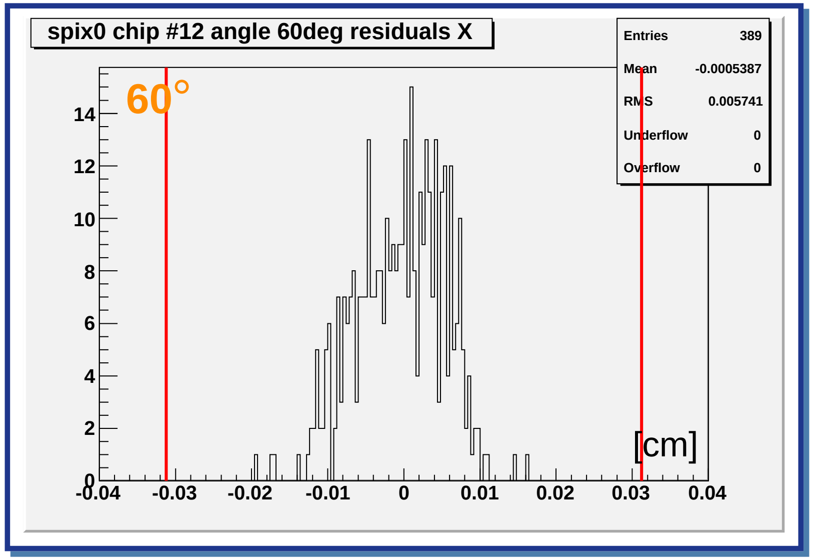


Resolution worsens with angle, geometry and per-pixel charge fluctuations

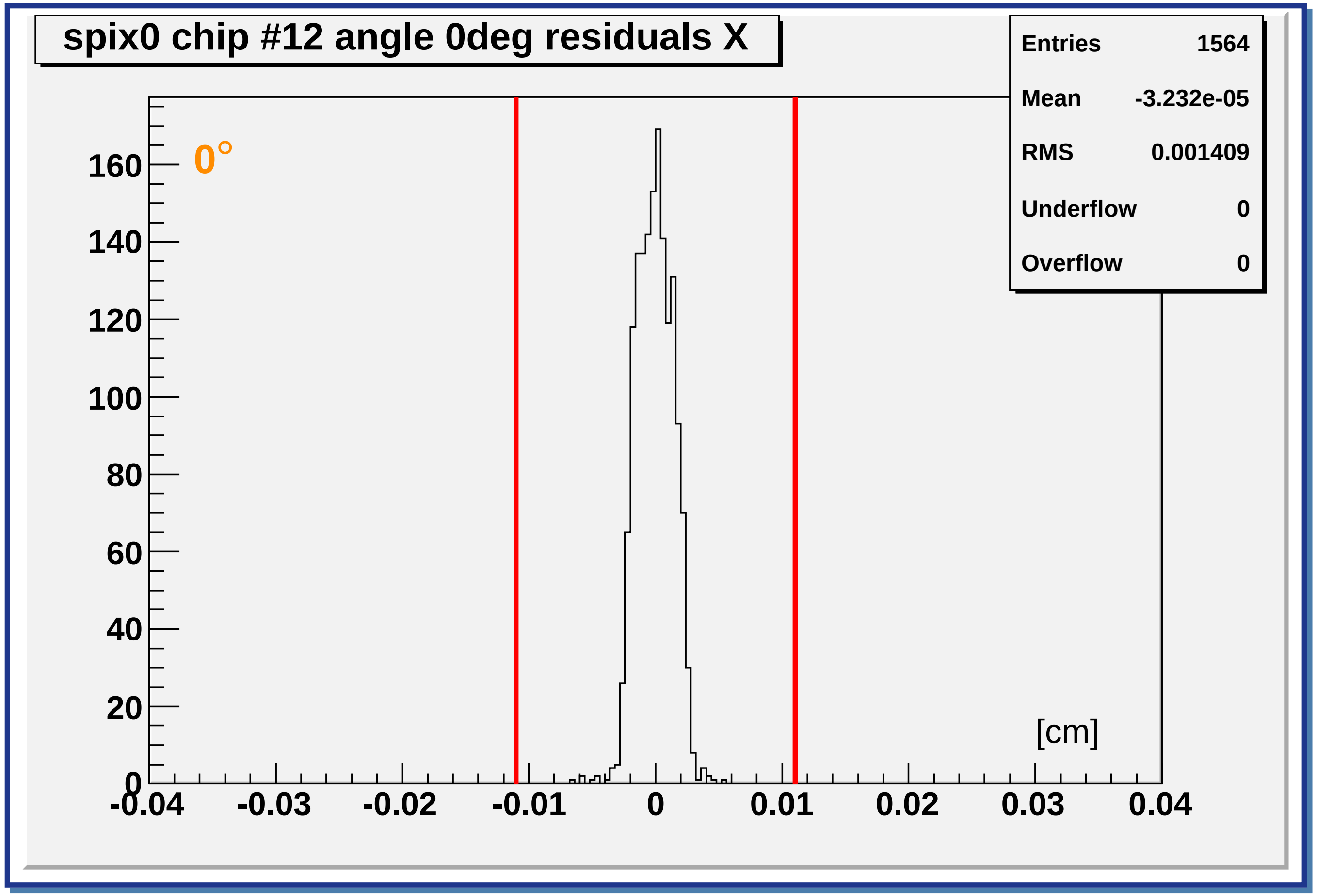






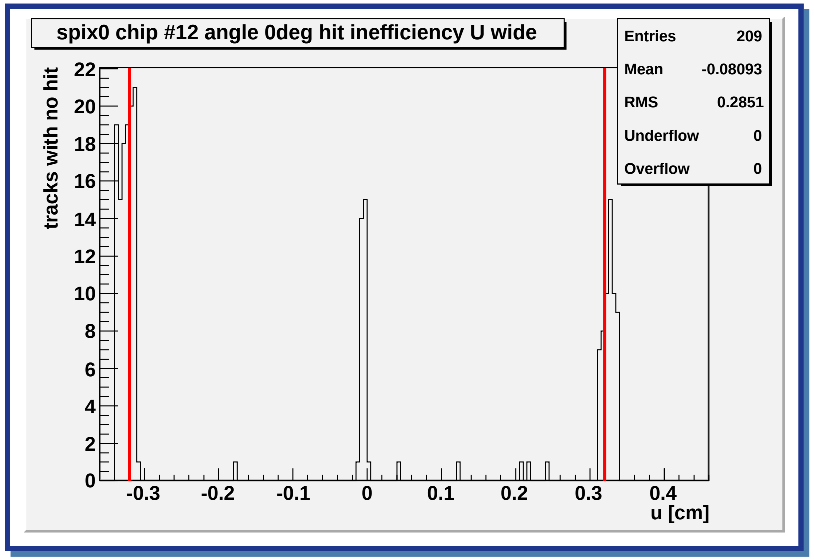


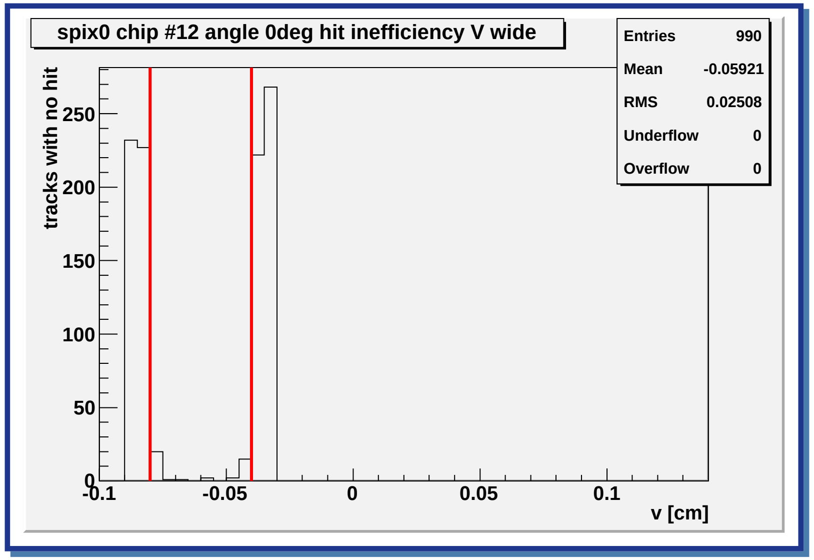
Some non-Gaussian tails due to delta rays



- track-associated hit cut: $4\times\sigma$(Gaussian-fit) + 60 μm(delta rays)

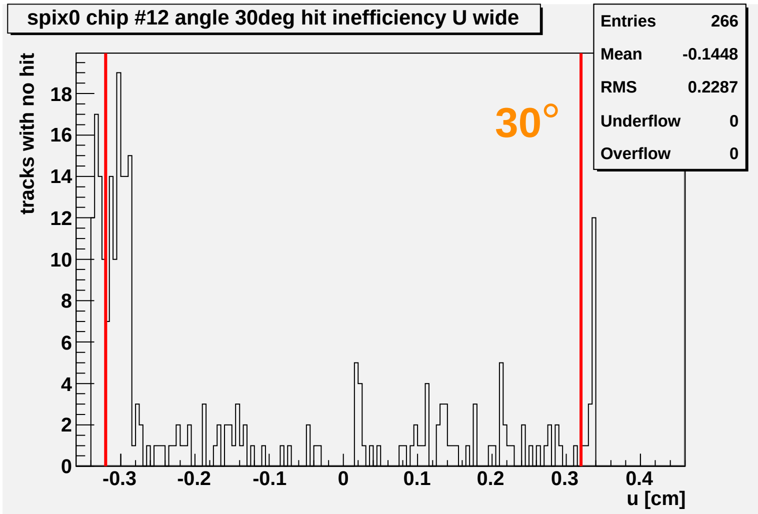
Pixel inefficient areas (0°)

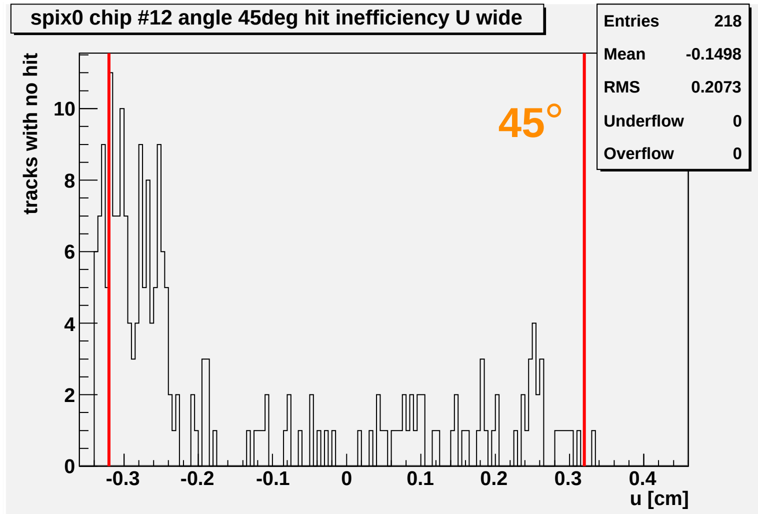


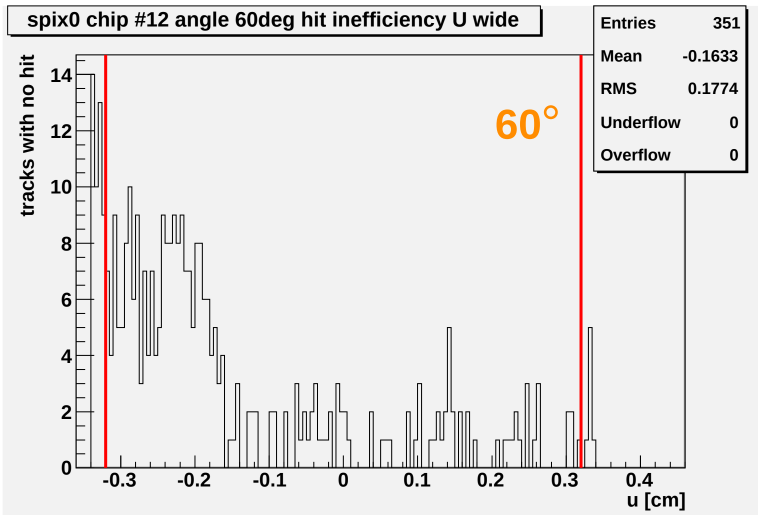


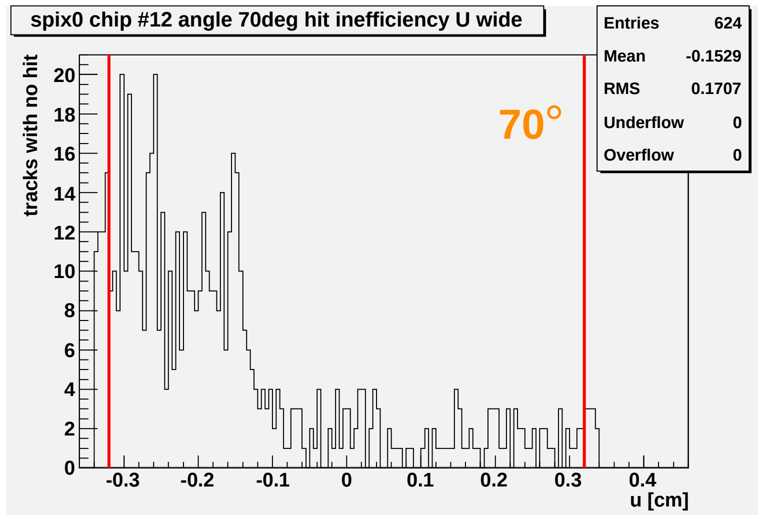
- central pixels in *x* are inactive for known reasons related to readout
- pixels at borders inefficient: appears to be related to shadowing from the frame borders
- sensitive area escludes 1 row of pixels on vertical borders (also more inefficient)
- sensitive area escludes angle-dependent area on horizontal borders

u-axis pixel inefficient areas increase with angle on one side

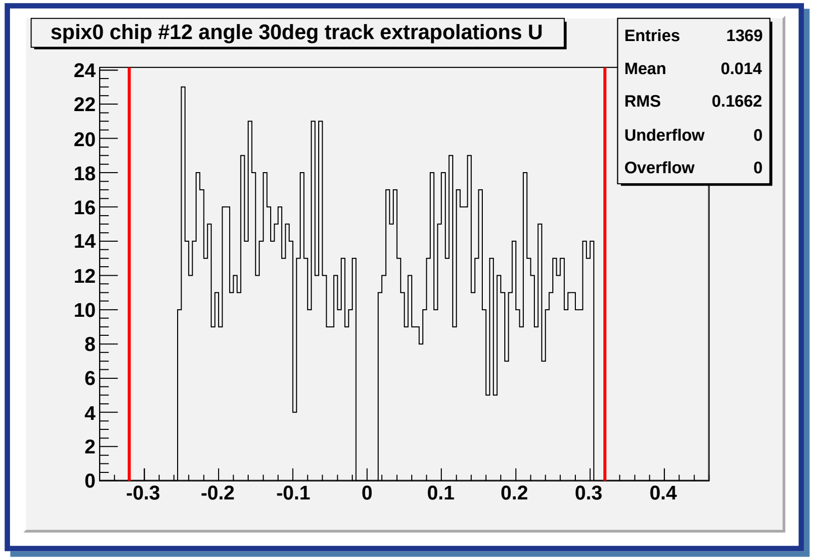


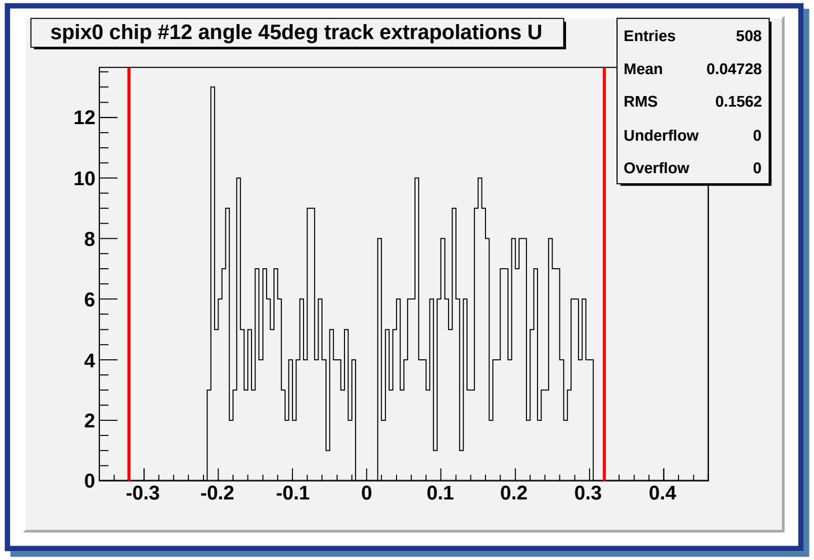


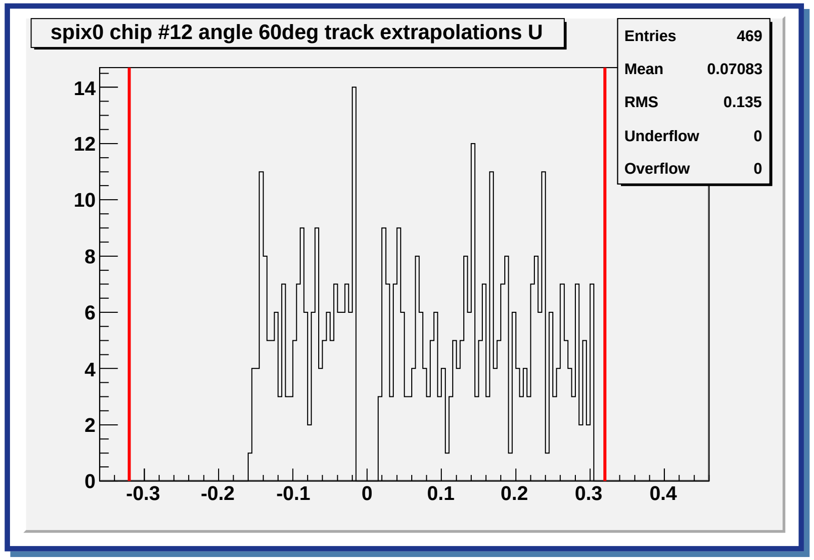


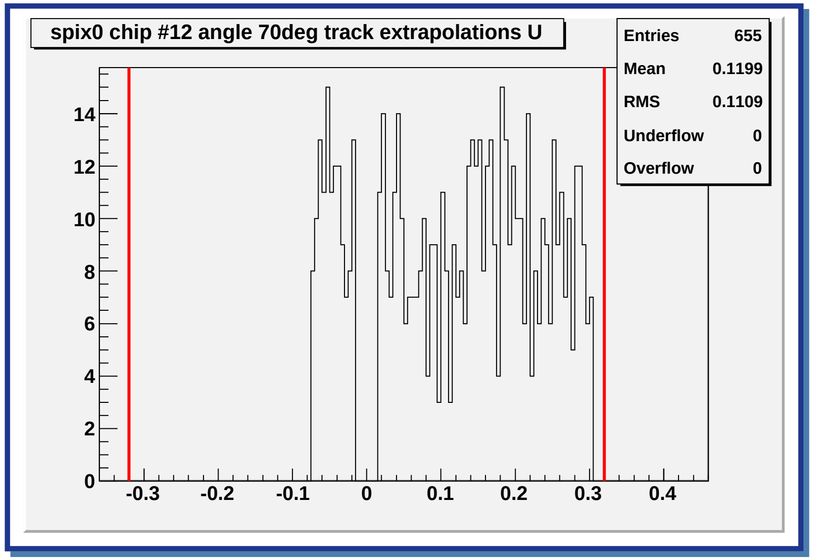


u-axis tracks into sensitive area

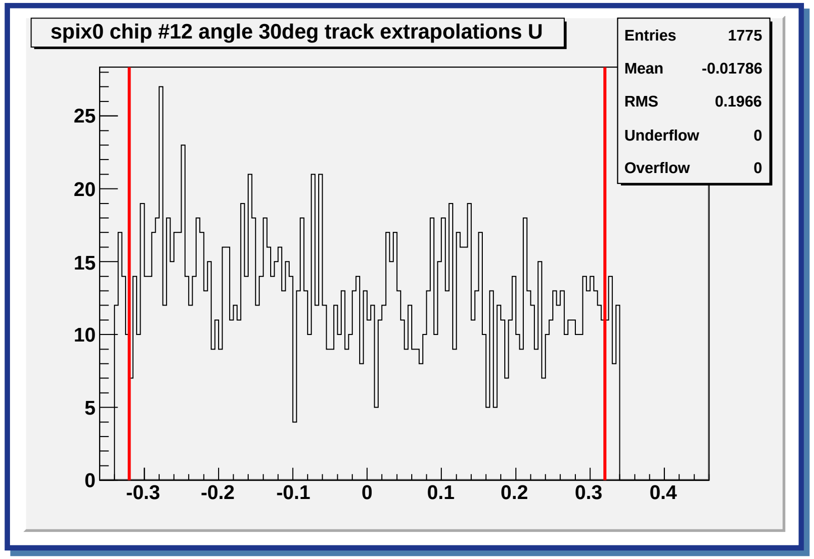


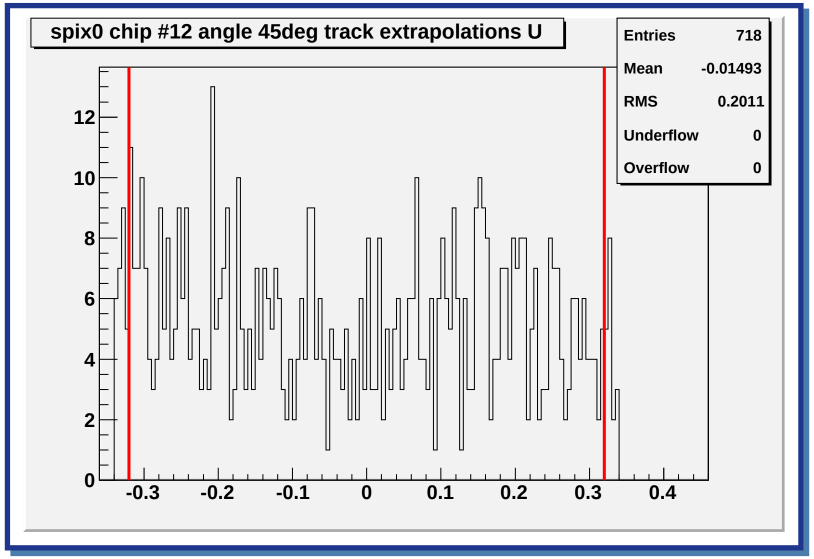


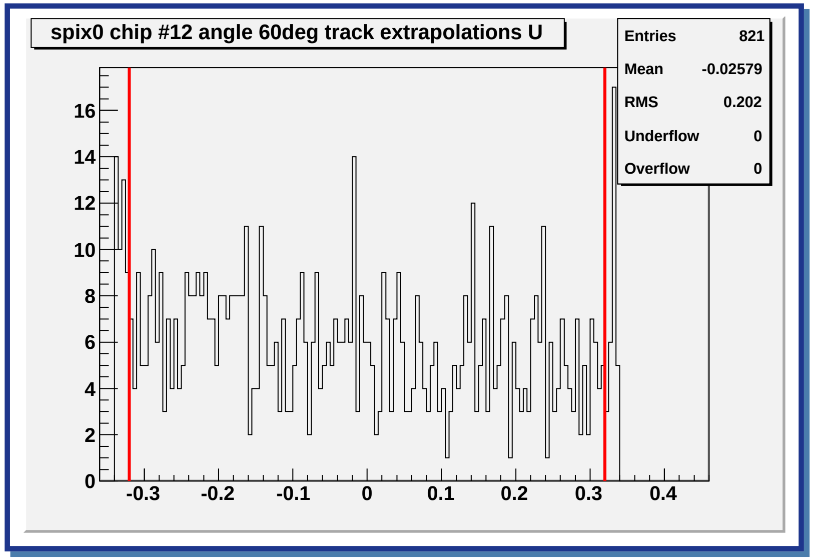


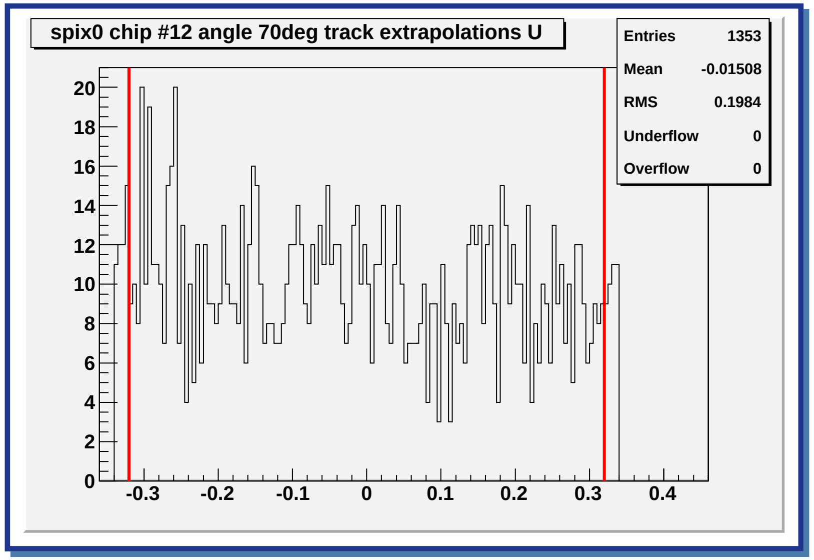


u-axis tracks (wide plots)

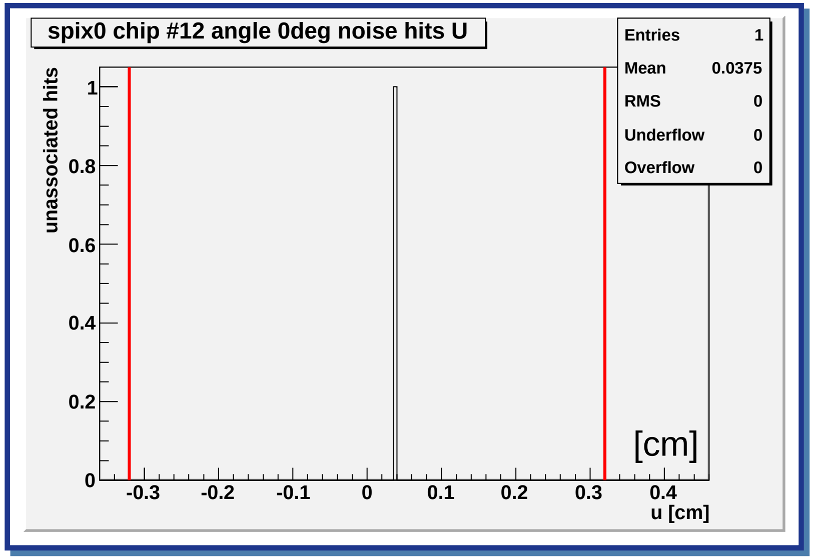


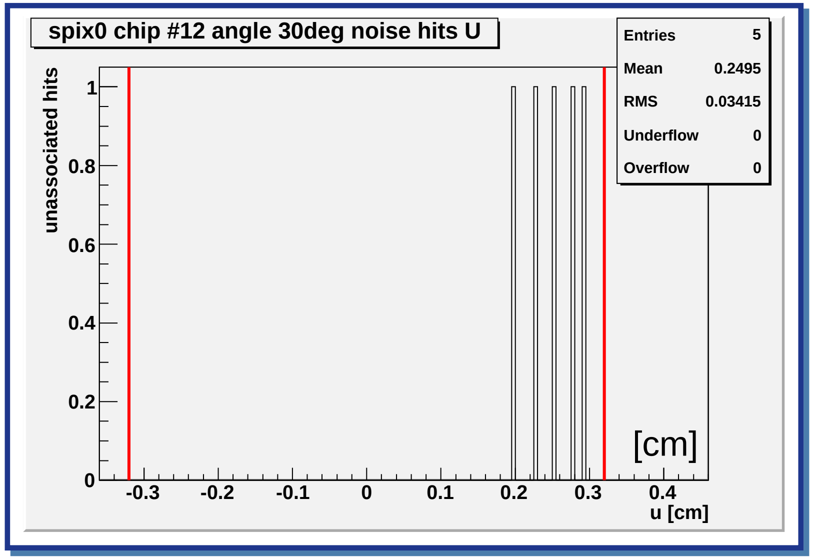


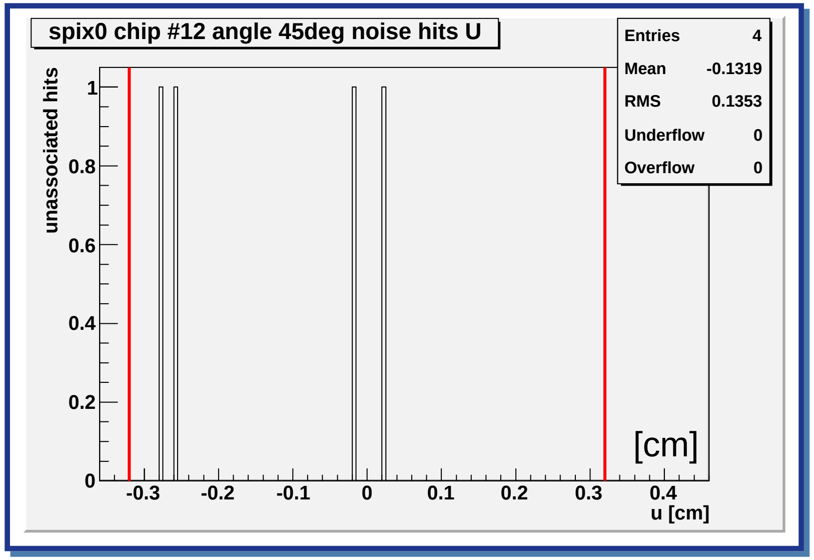


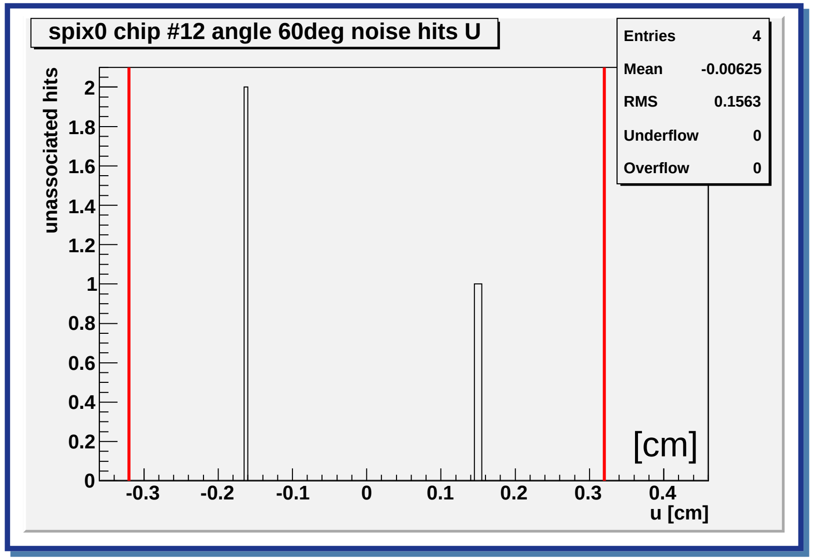


Noise hits are negligible at reference threshold

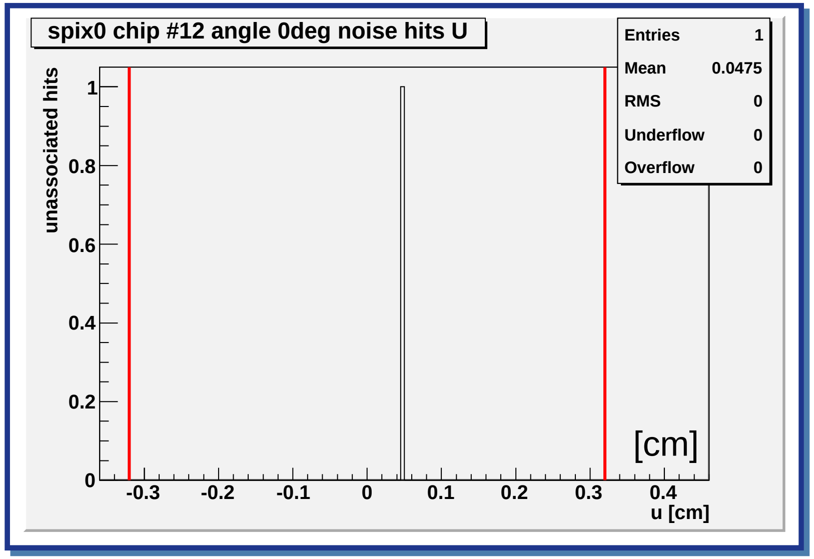


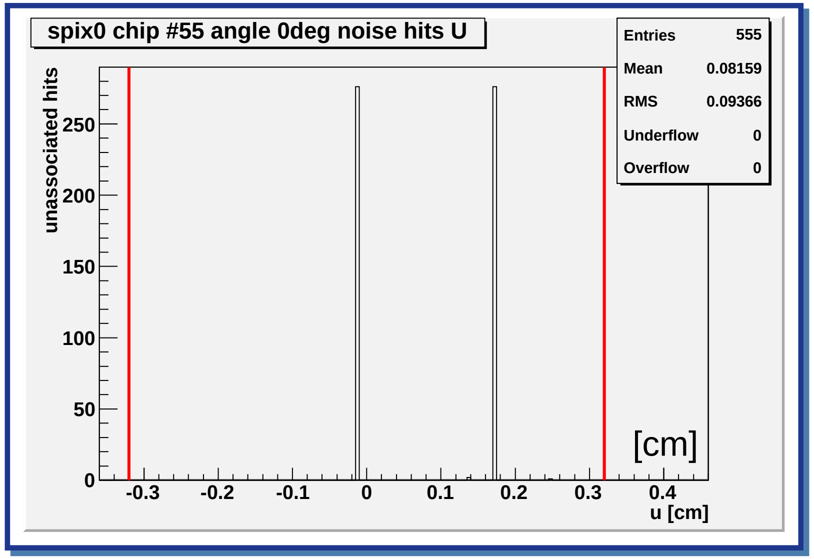


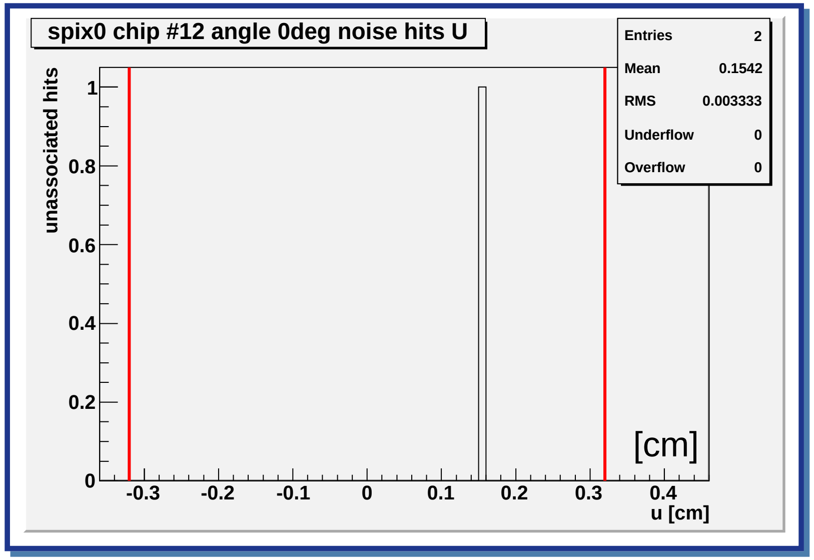


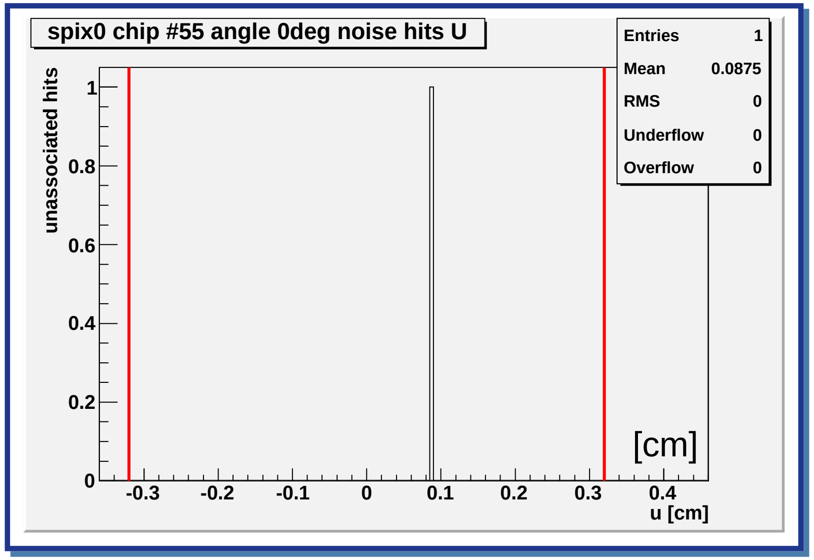


Noise hits are negligible also at lowest tested thresholds, ~1/8 m.i.p.

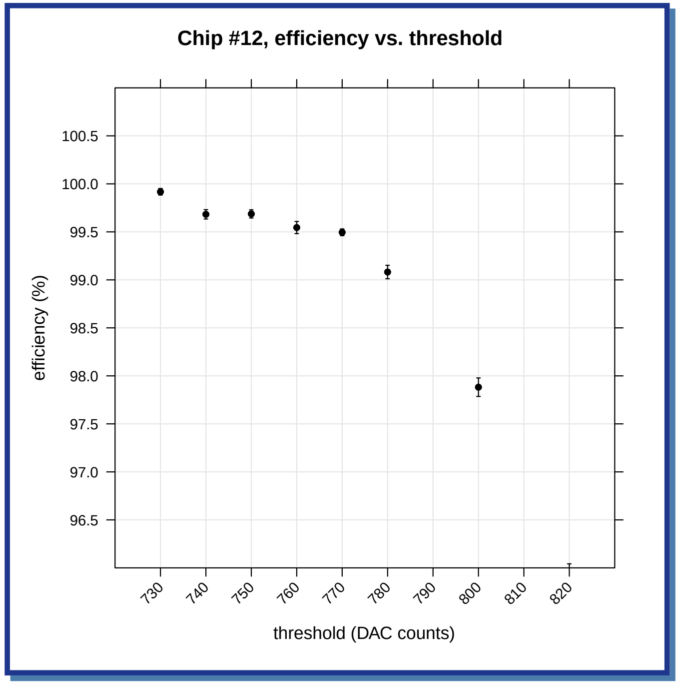


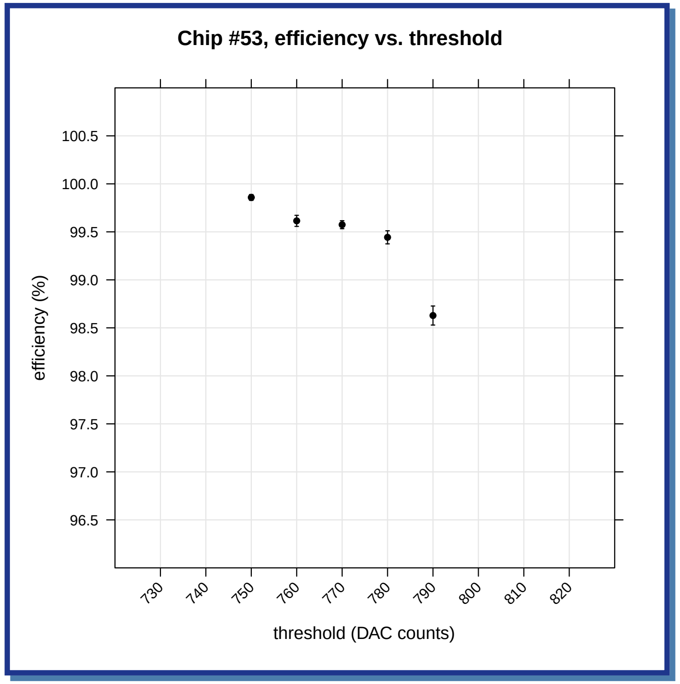


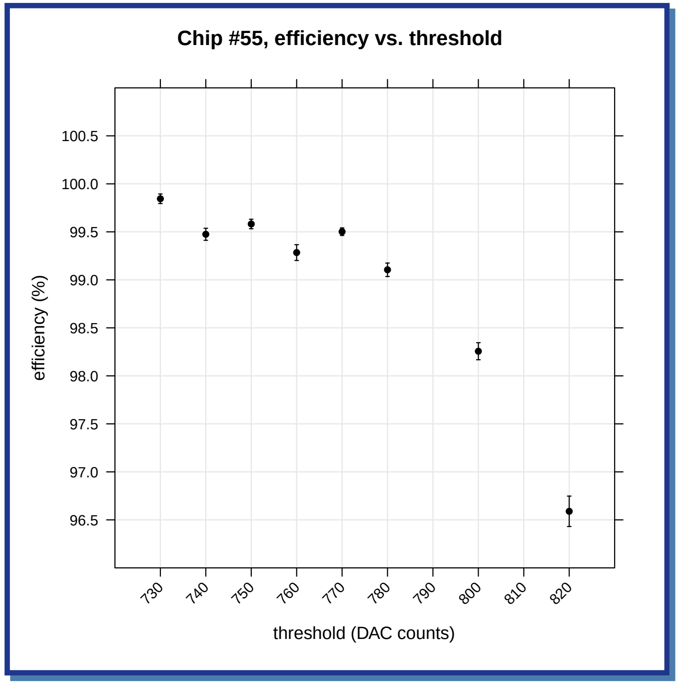




Efficiency vs. threshold at normal incidence

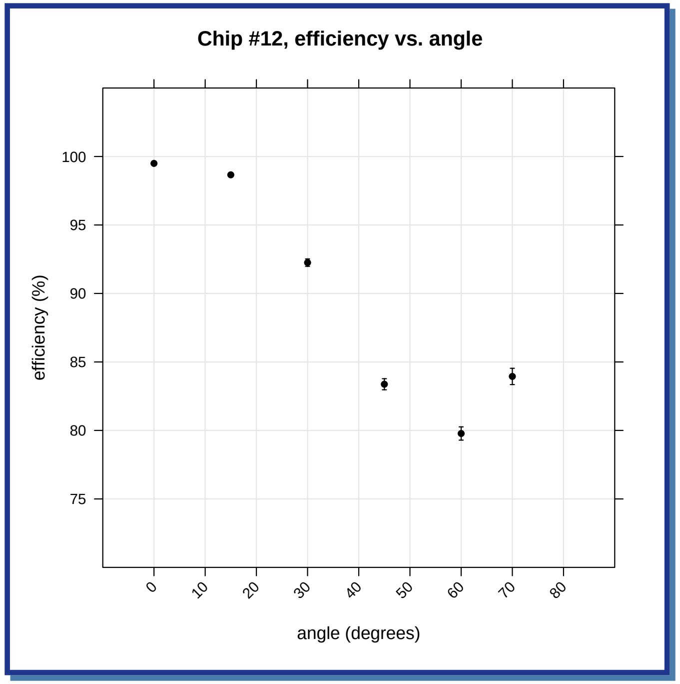


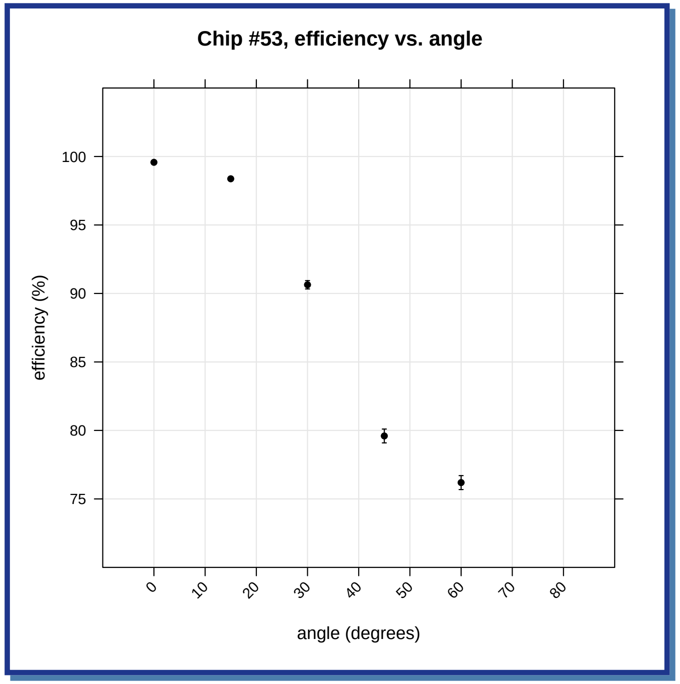


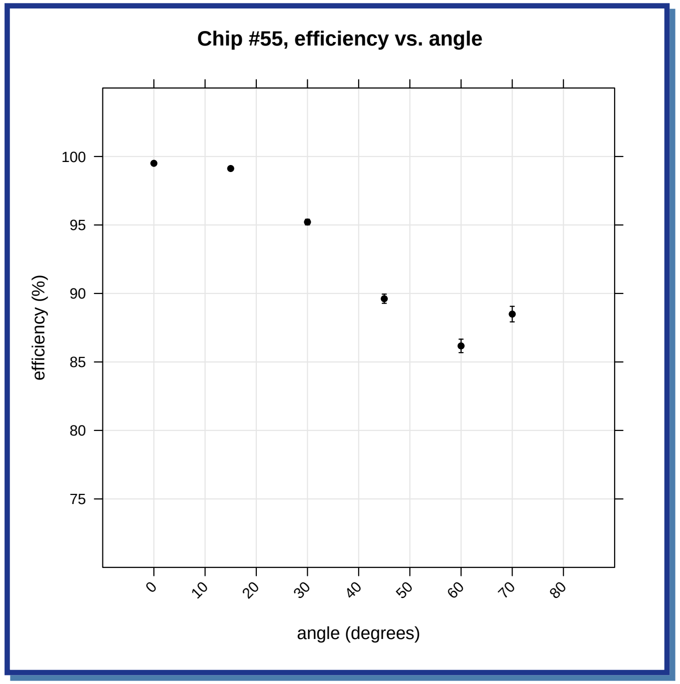


- DAC = 770 ➔ threshold ≈ 1/4 m.i.p.
- DAC = 770 – 40 = 730 ➔ threshold ≈ 1/8 m.i.p.
- DAC = 770 + 40 = 810 ➔ threshold ≈ 3/8 m.i.p.

Efficiency vs. incidence angle w.r.t. normal

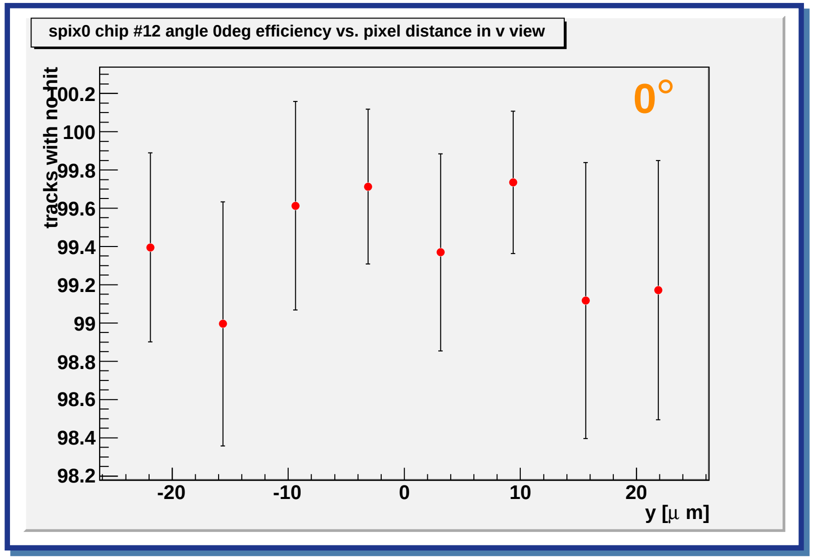


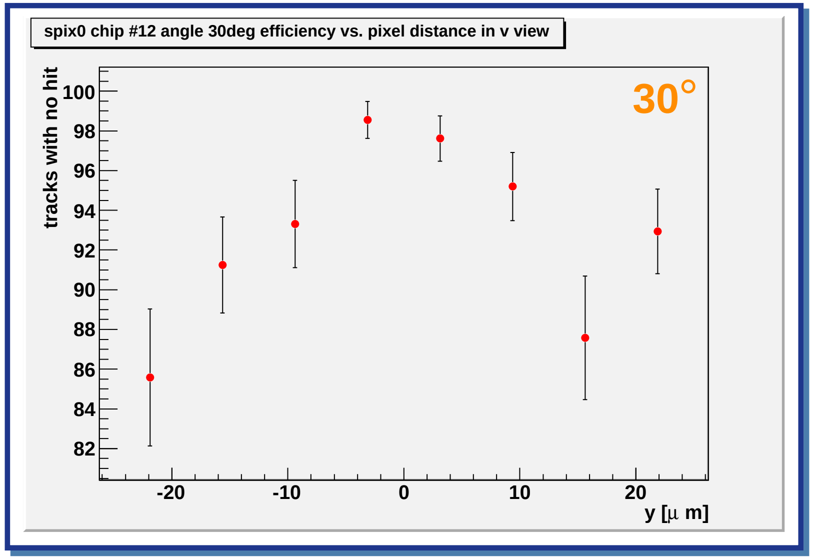


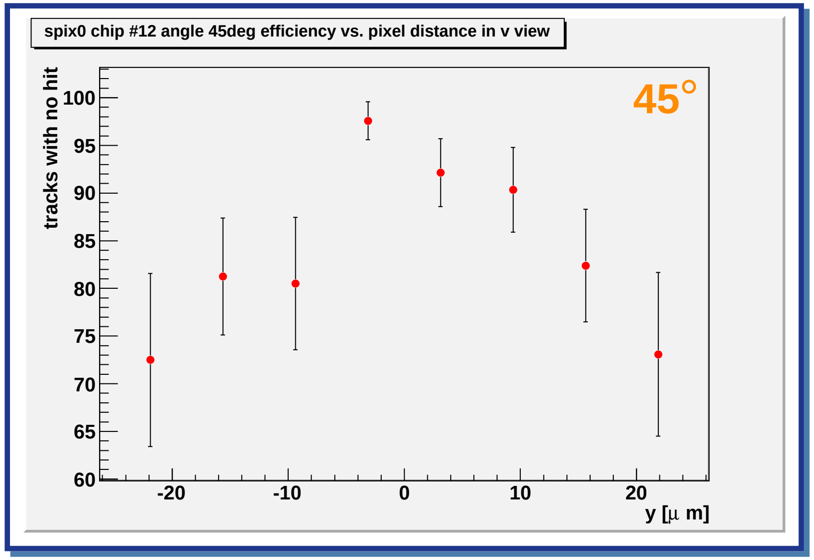


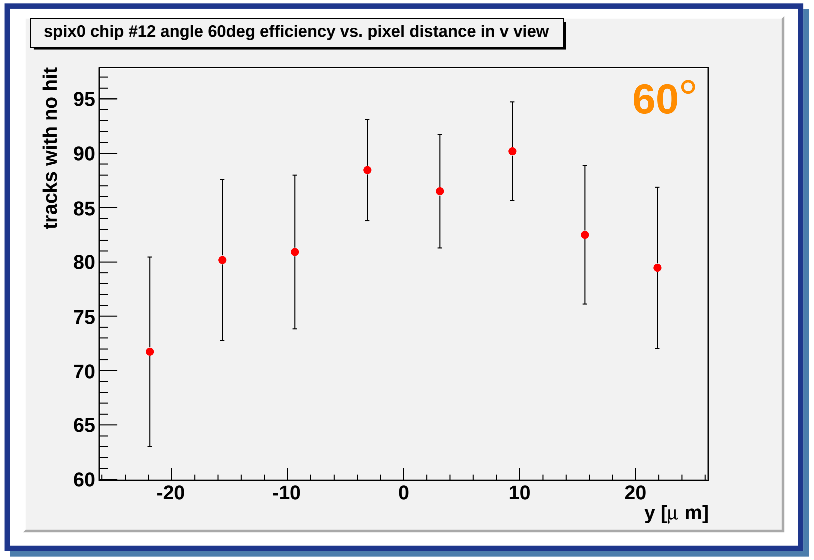
- significant drop of efficiency with angle (charge shared by more pixels along *x*)
- when neglecting increase of “shadowed” area, much larger efficiency drop

Charge sharing & inefficiency maximal when track in-between two pixels in *y*

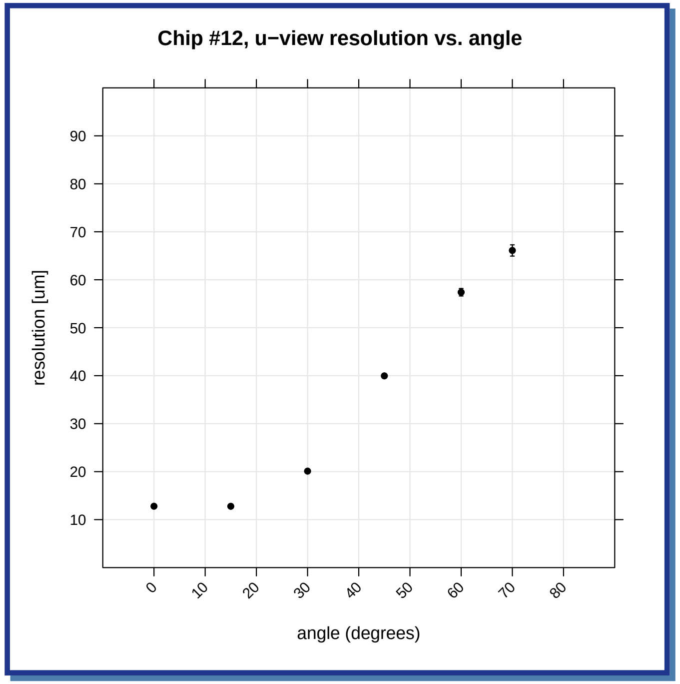


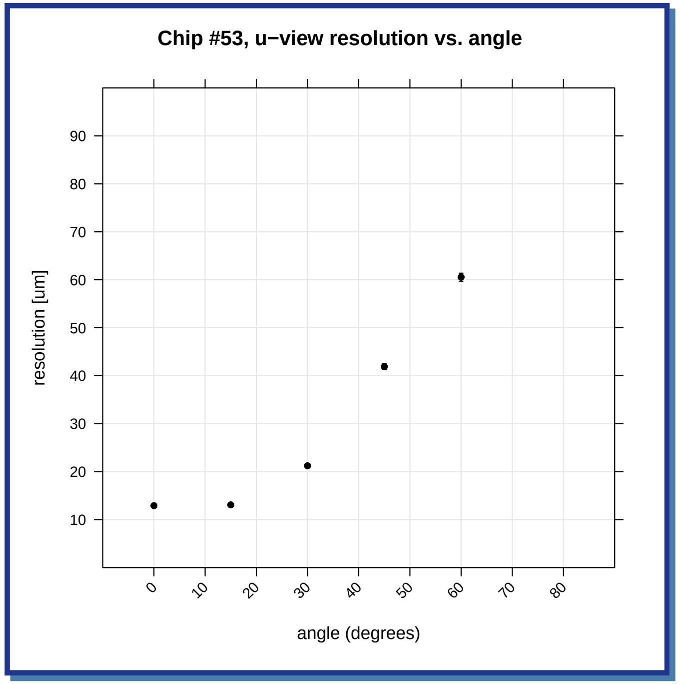


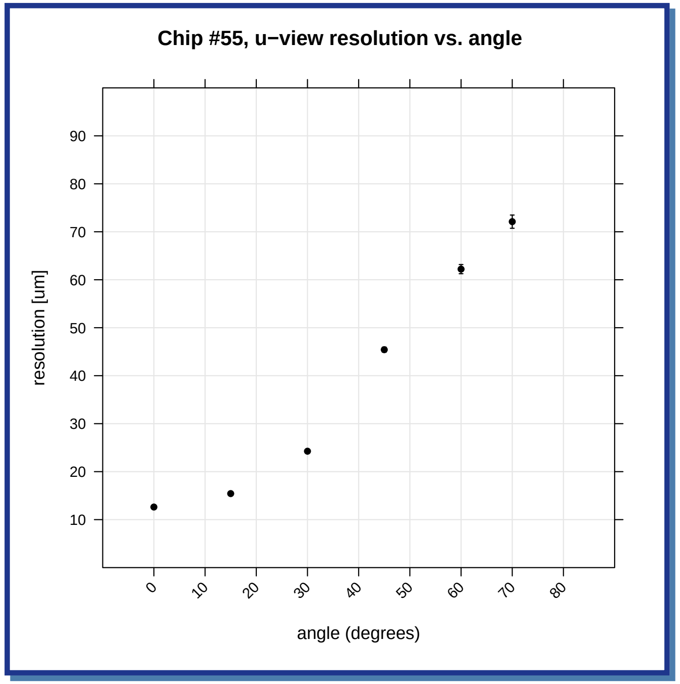




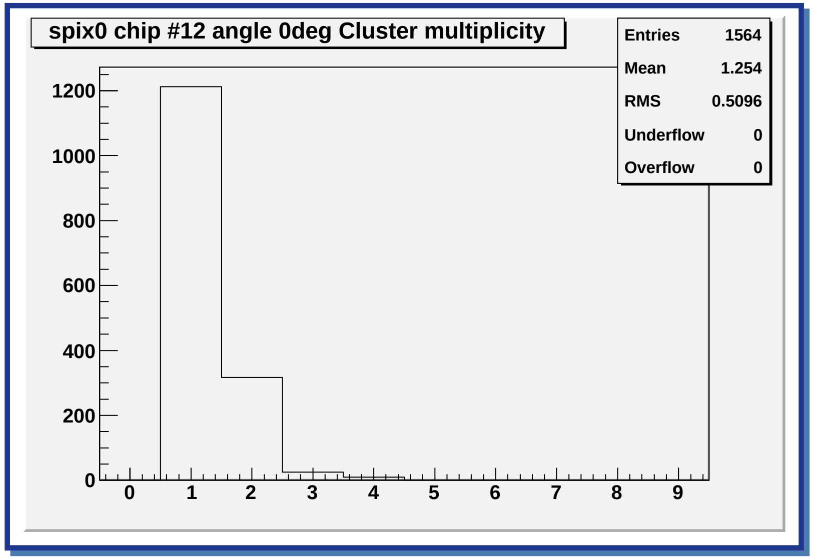
Resolution vs. incidence angle w.r.t. normal

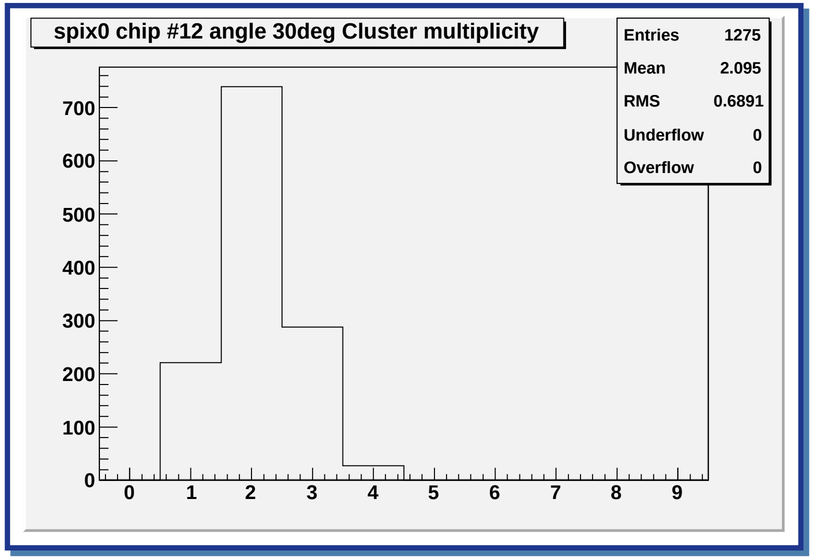


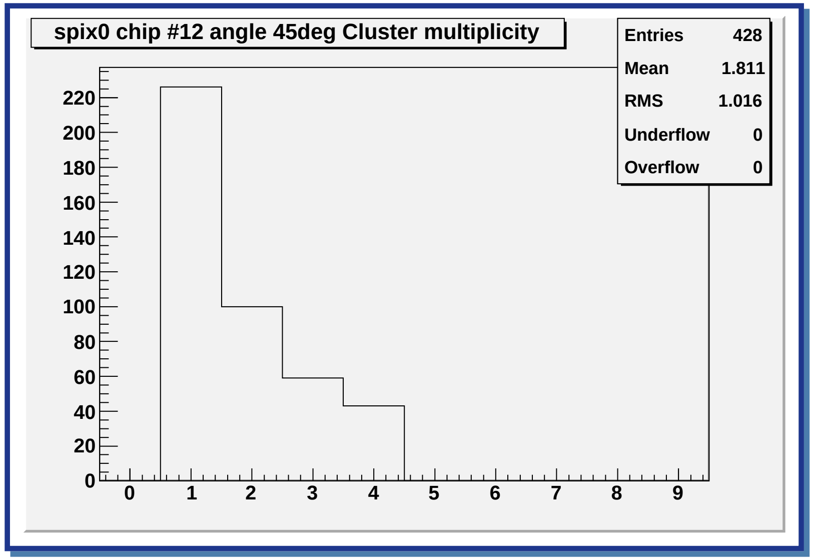


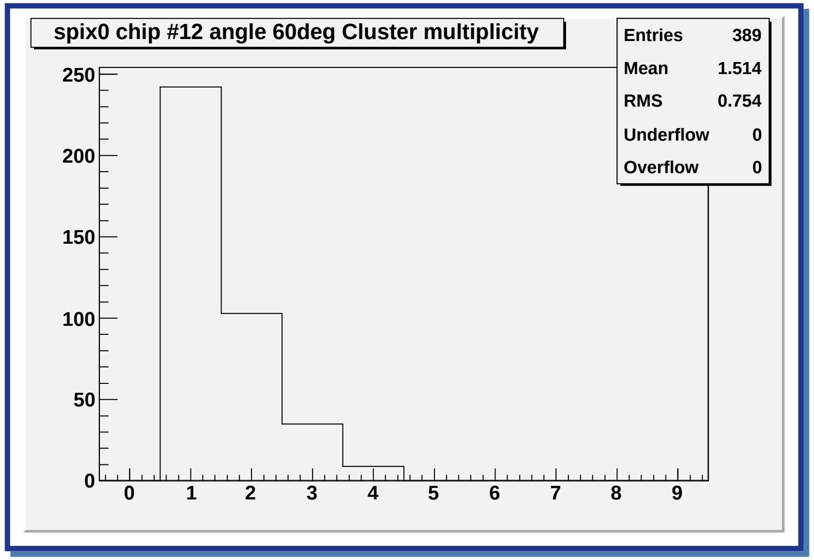


Cluster multiplicity up with geometry but down from larger charge sharing

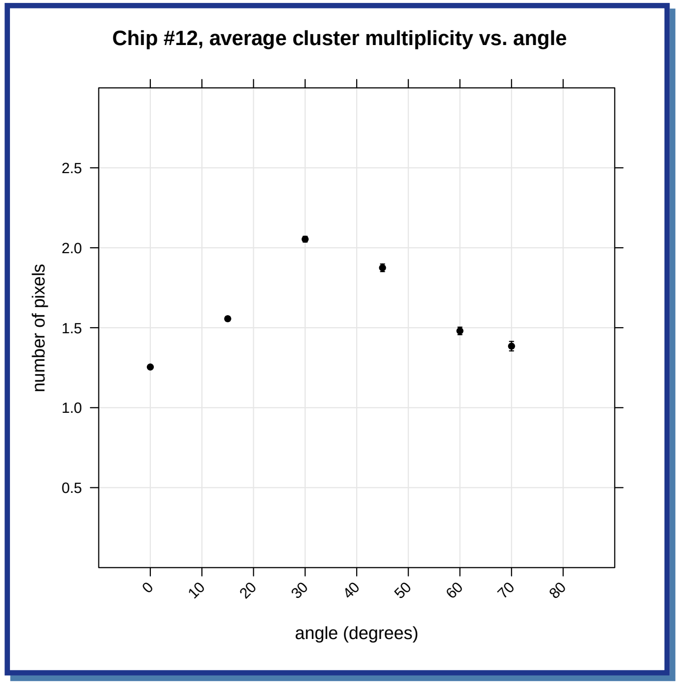


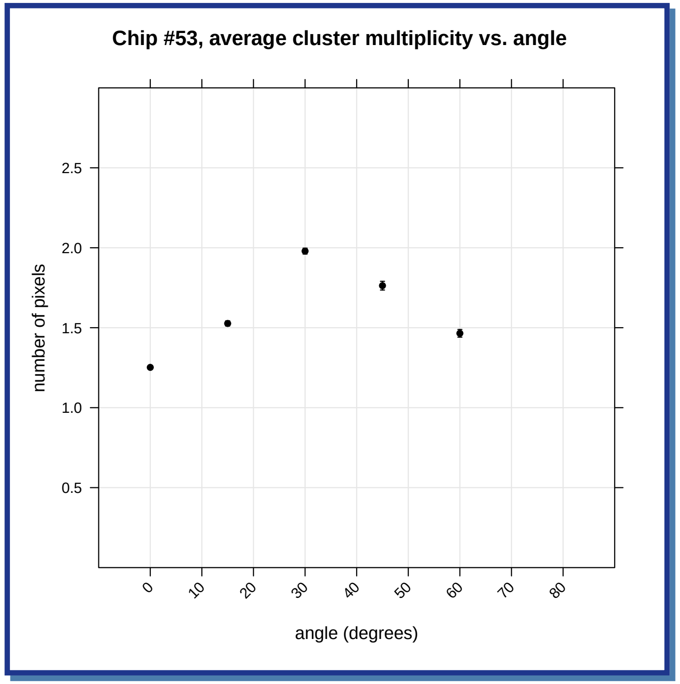


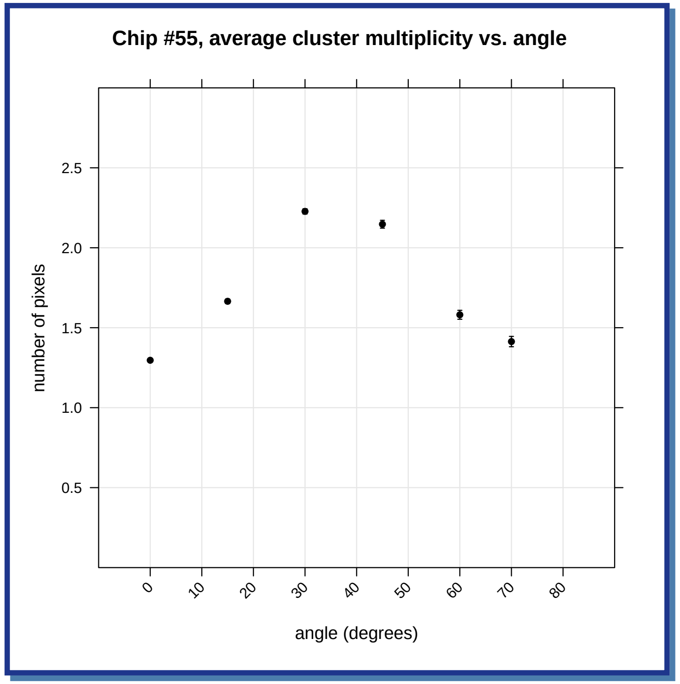




Cluster multiplicity vs. incidence angle w.r.t. normal







Understanding efficiency loss vs. angle

- are measurements compatible with pixel charge sharing and threshold = 1/4 m.i.p.?
  → **simulation by Marcin Chrzaszcz (Cracow)**
- particle energy loss in Si simulated with Landau with real-data-fitted mean & width
  (H. Bichsel, Rev. Mod. Phys. 60 (1988) 663)
- Landau fluctuations computed for track segments corresponding to each crossed pixel
- charge in one pixel shared linearly with neighbours
  (100% on one pixel if itx exact center is hit, 50% when middle point of two pixels, and so on)
- threshold dispersion of 1.5% of the baseline simulated, 2.5% improves agreement
- **best match to data with threshold 0.29 m.i.p.**
  used threshold: 0.25 m.i.p., set according to:
  - calibration with charge injection (known voltage, known capacitor)
  - detector response to ^{90}Sr β source (end-point at 546 keV)

- Parameters of Landau distribution as showed in Rev. Mod. Phys. 60, 663699 (1988) can be obtain in a simple function of thickness of the silicon bulk(z-distance in μm, p-MPV):

  if $(z < 110)$ $p = z(100.6 + 35.35 ln(z))$

  if $(z \geq 110)$ $p = z(190 + 16.3 ln(z))$

  w -FWHM

if $(z < 11)$ $w = z(298.3 - 53.53 ln(z))$

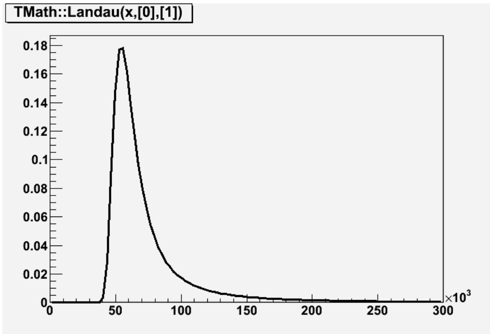
if $(z \geq 11 \wedge z < 30)$ $w = z(174.7 - 2.72 ln(z))$

if $(z \geq 30 \wedge z < 260)$ $w = z(259.6 - 28.41 ln(z))$

if $(z \geq 260)$ $w = 71.3z(1 + \frac{39.4}{z^{0.8}})$

ξ is the ROOTs second parameter for Landau distribution.

$$\xi = \frac{w}{4.018}$$

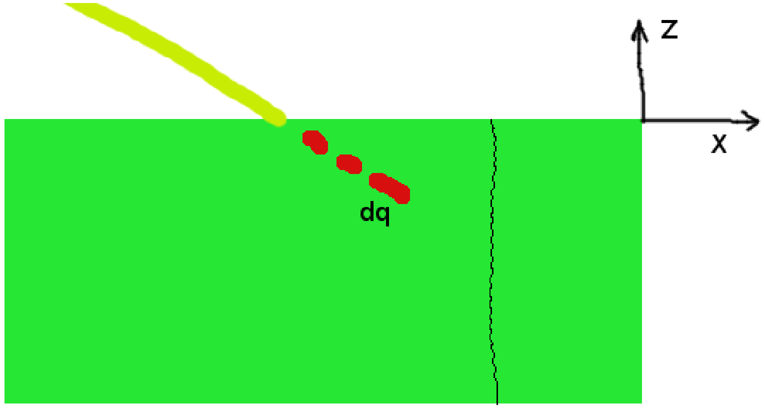


Assumption: $1e^- = 3.7eV$

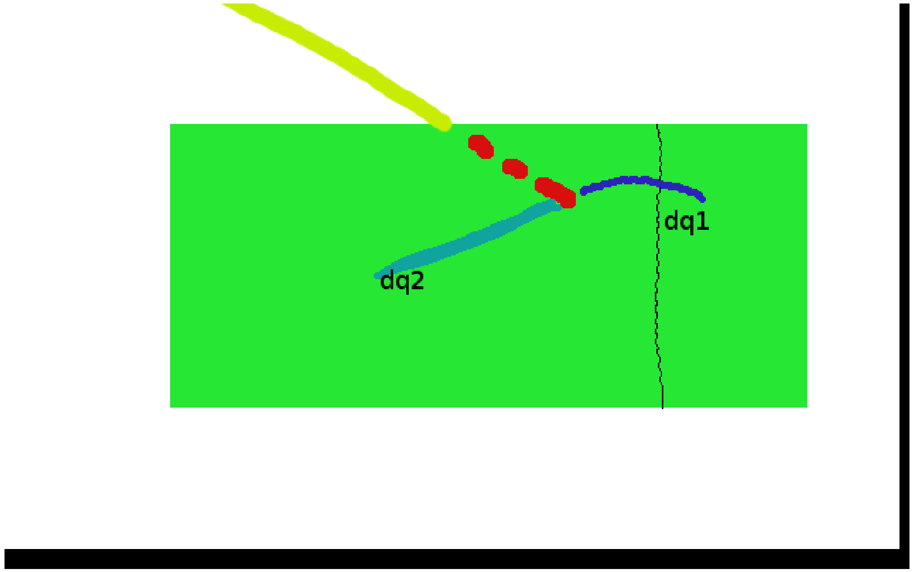
$p = 55272.5eV(14938.5e^-)$

$\xi = 5429.31eV(1467.3e^-)$

- For each angle of detector rotation a particle is considered hitting the pixel with uniform distribution in xy plane. Than the program calculates the distance that particle travels in each pixel on its track. For each distance program generates the charge deposited in each pixel according to Landaus distribution. Than for each step $dr = 0.01\mu m$ calculates equivalent of charge deposited dq on that way.

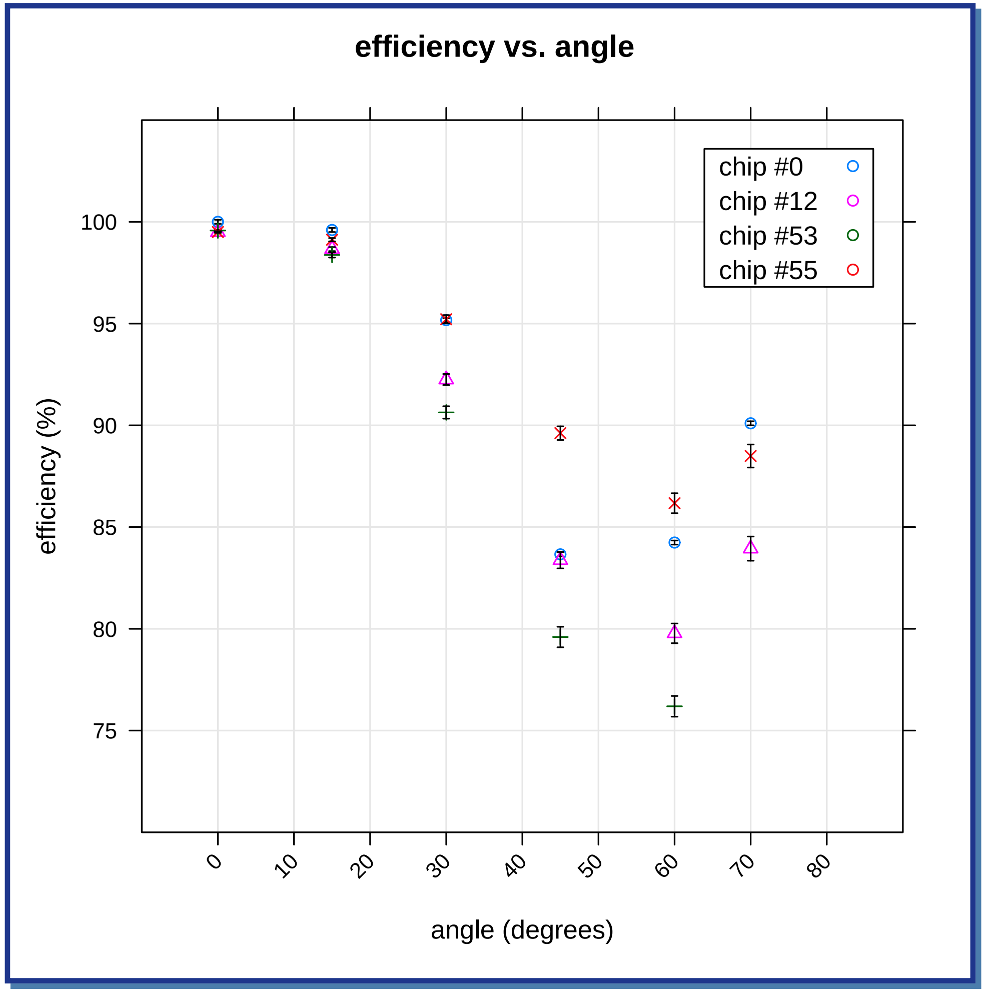


- Each *dq* charge is deposited among neighbouring pixels as a linear function of distance from the center of pixel.

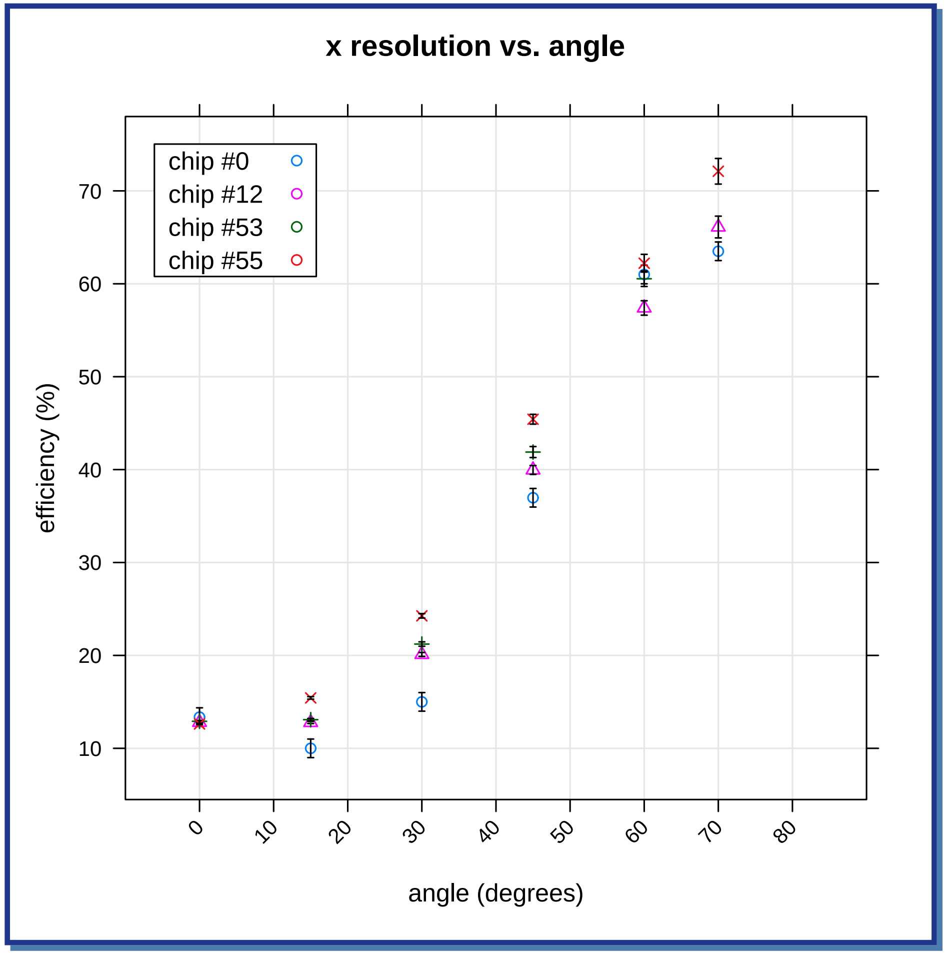


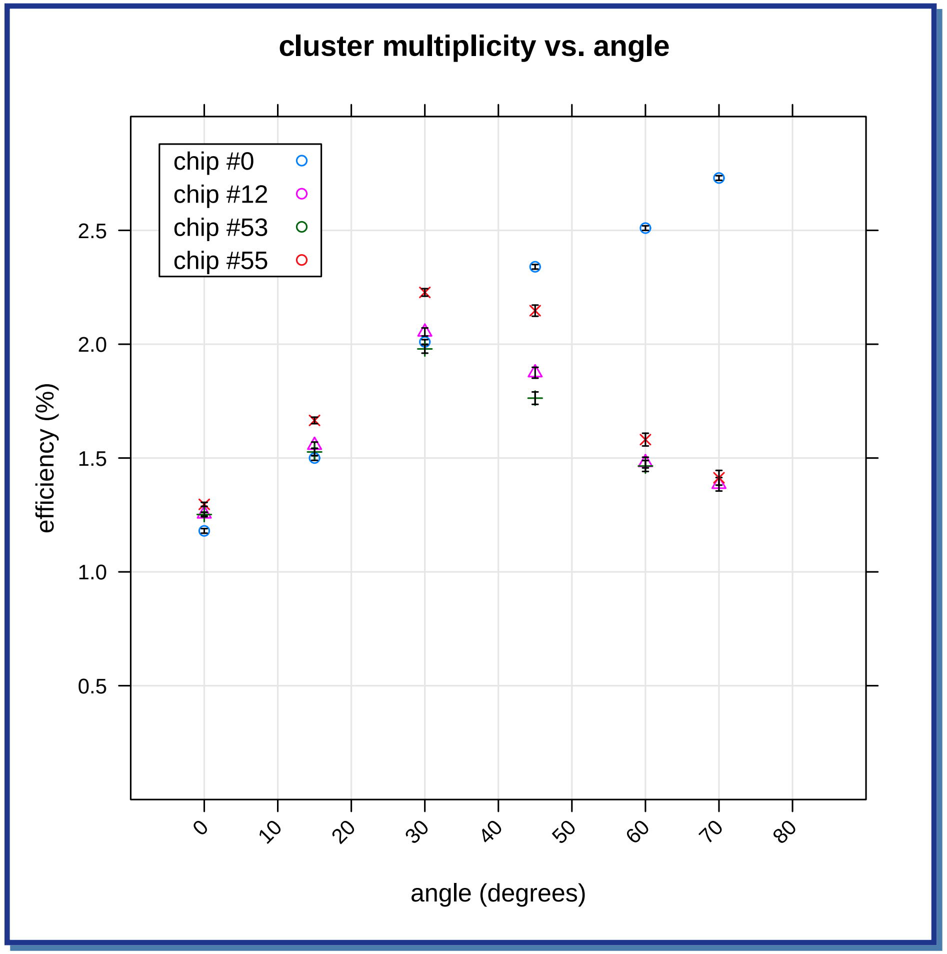
- After particle reaches the end of the bulk all collected charge on each pixel is summed up. The pixel fires up if the collected charge exceeds the threshold.
- The threshold used in the simulation divided the mip mpv in 200um of Si for the nominal threshold data

Simulated efficiency vs. angle, chip #0 = simulation

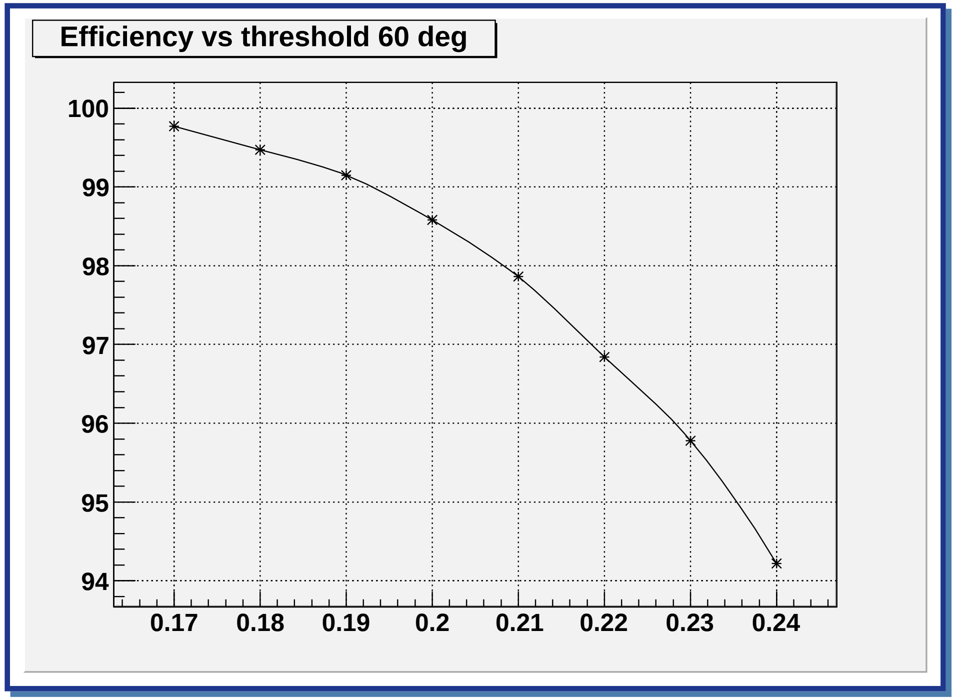


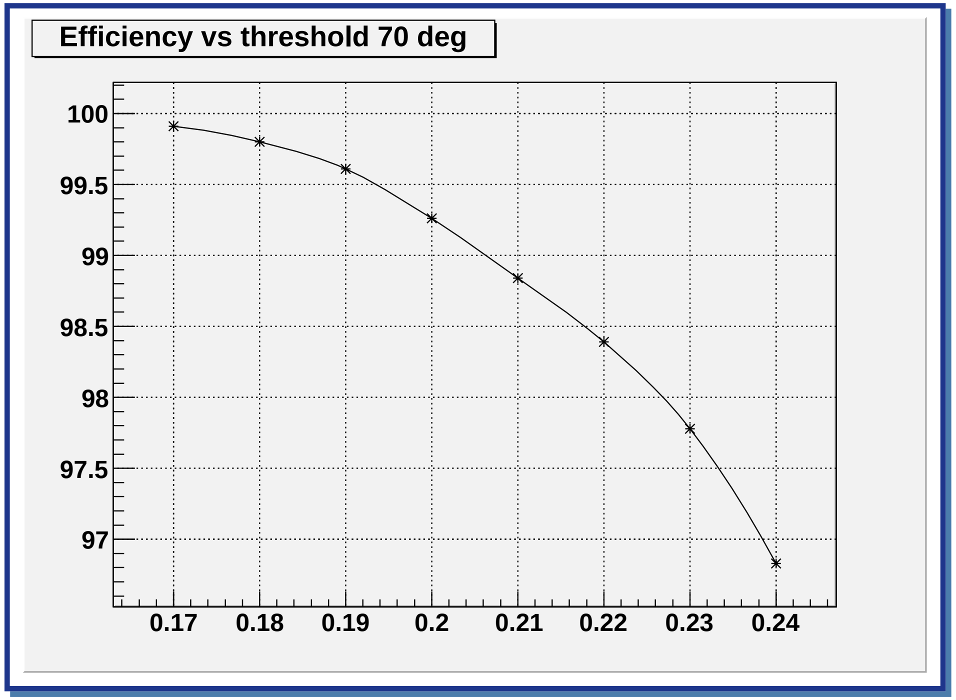
Simulated x resolution and cluster multiplicity vs. angle, chip #0 = simulation





Simulated efficiency at large angles vs. threshold





Conclusions

- measured superpix0 hybrid digital pixels performance with real beam particles
- high efficiency (perhaps limited by readout issues) at normal incidence
- loss of efficiency at large angles
- very little noise
- resolution and cluster multiplicity compatible with observed efficiency
- performance simulated with ~16% larger (0.29 m.i.p.) effective threshold
- simulation ➔ effective threshold $\leq \sim$0.15 m.i.p. required for full efficiency at large angles
- analysis work in collaboration with Marcin Chrzaszcz, Nicola Neri, Benjamin Oberhof, Antonio Paladino, benefited from collaboration and assistance of many others which cannot be exhaustively listed, a partial list includes Stefano Bettarini, John Walsh, Giuliana Rizzo, Marco Bomben, Laura Fabbri, Carla Sbarra