Digital ECAL: Lecture 3

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DECAL lectures summary

- Lecture 1 – Ideal case and limits to resolution
  - Digital ECAL motivation and ideal performance compared with AECAL
  - Shower densities at high granularity; pixel sizes
  - Effects of EM shower physics on DECAL performance
- Lecture 2 – Status of DECAL sensors
  - Basic design requirements for a DECAL sensor
  - Current implementation in CMOS technology
  - Characteristics of sensors; noise, charge diffusion
  - Results from first prototypes; verification of performance
- Lecture 3 – Detector effects and realistic resolution
  - Effect of sensor characteristics on EM resolution
  - Degradation of resolution due to sensor performance
  - Main issues affecting resolution
  - Remaining measurements required to verify resolution

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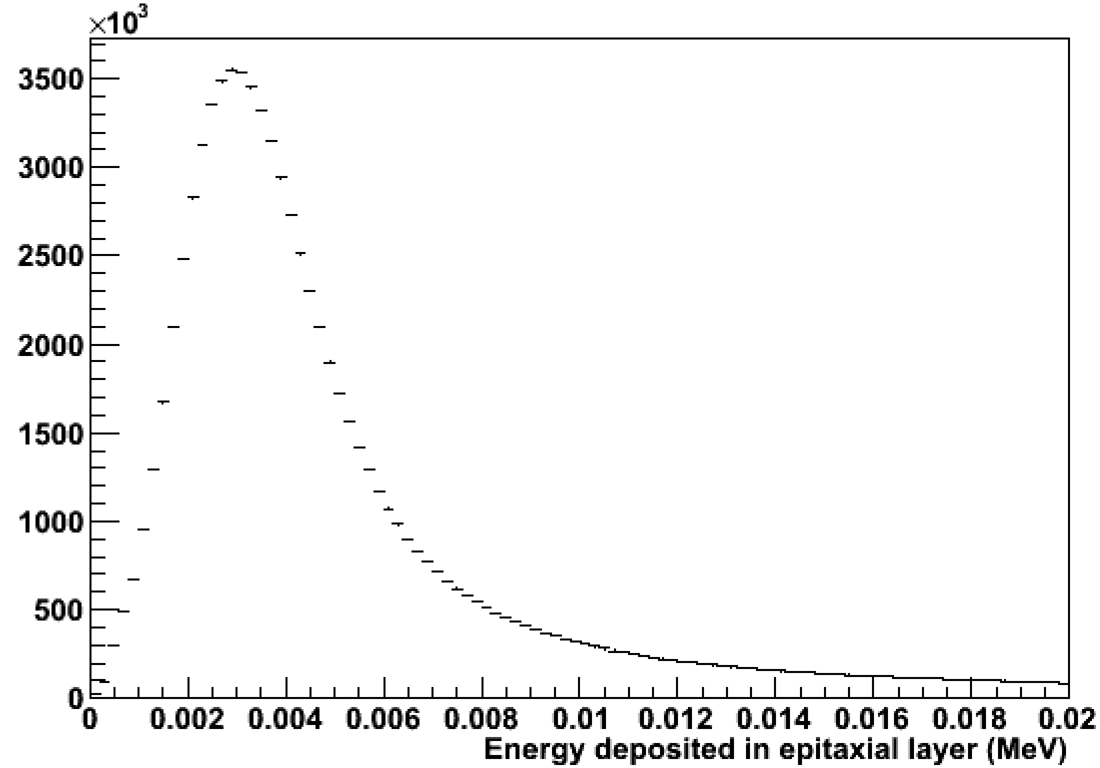
Detector effects

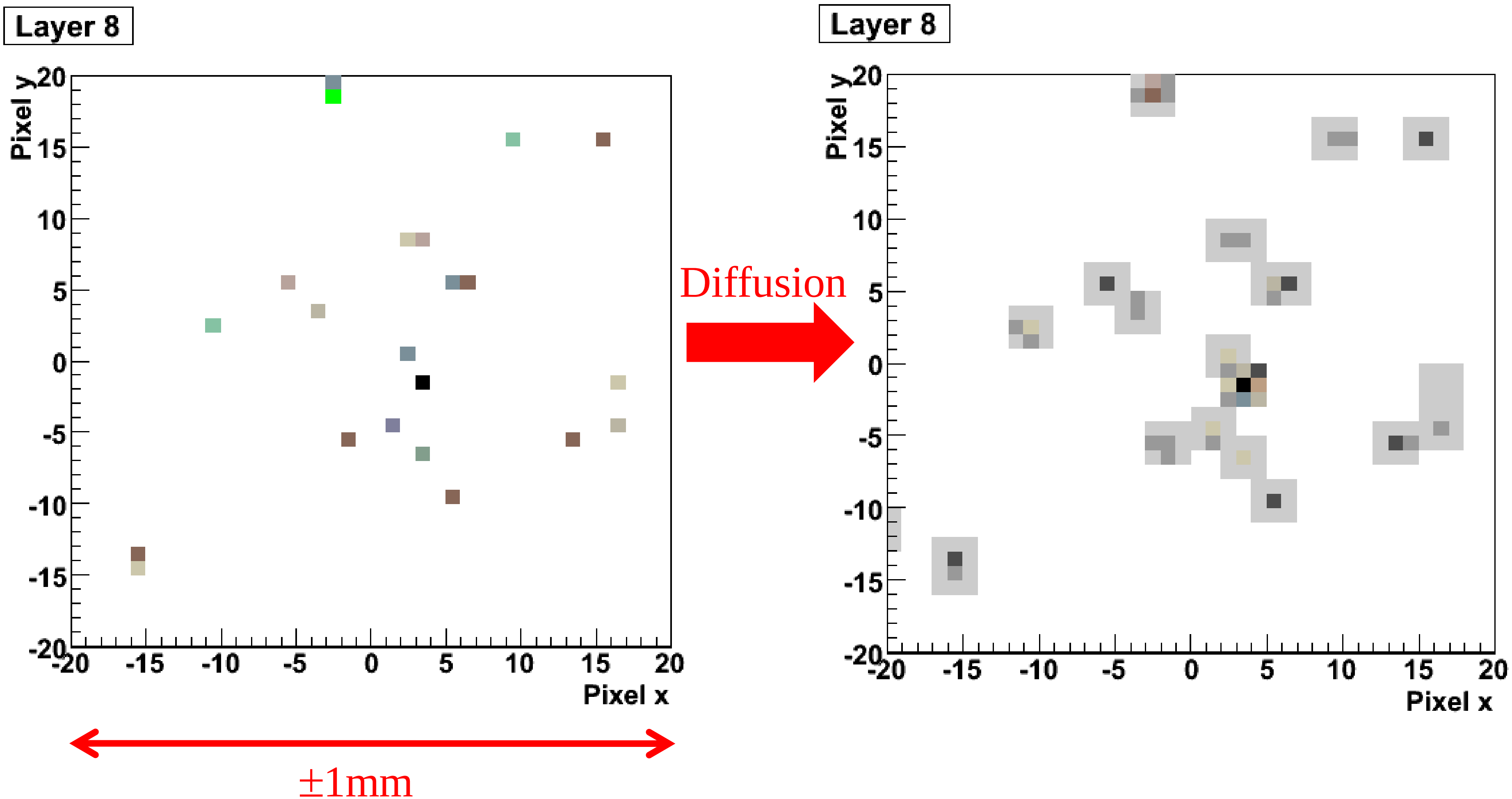
- Lecture 1 showed that a DECAL with 50μm pixels has potential to give good linearity and resolution
- Lecture 2 showed we can characterise the TPAC1 sensor performance
- Now put the two together to show realistic resolution
    - Assume a whole ECAL made from TPAC1-like sensors
- Must include the effects of
    - Noise
    - Charge diffusion between pixels
    - Dead areas

Basic epitaxial layer energy deposits

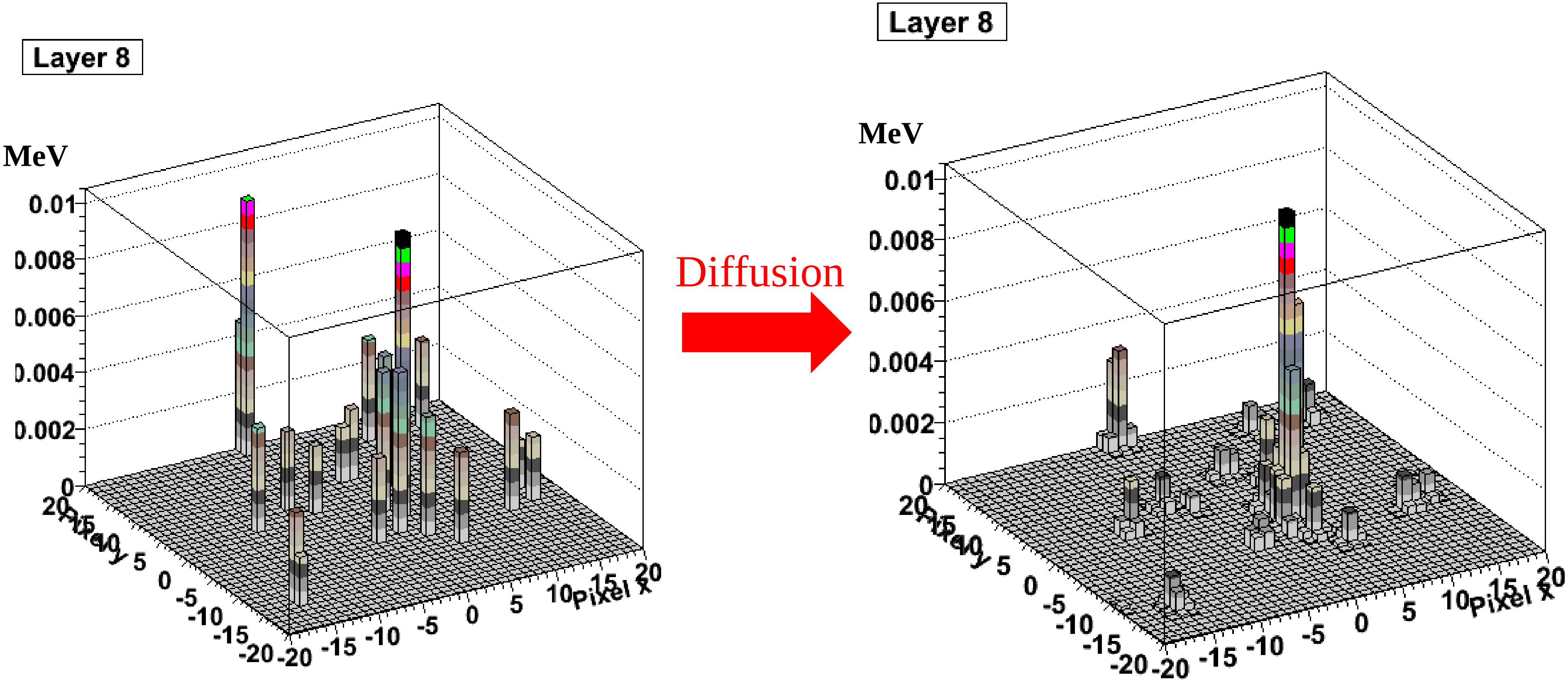
- A MIP creates ~80 electron-hole pairs in silicon per 1μm
  - Equivalently, deposits energy with dE/dx ~ 300eV/μm
- Passing through 12μm of the epitaxial layer at normal incidence leaves an average of ~1000e⁻ signal charge
  - Equivalently, deposits a total of ~3.6keV
- Noise is ~20e⁻
  - Equivalent to ~70eV deposit



Effect of diffusion; example layer

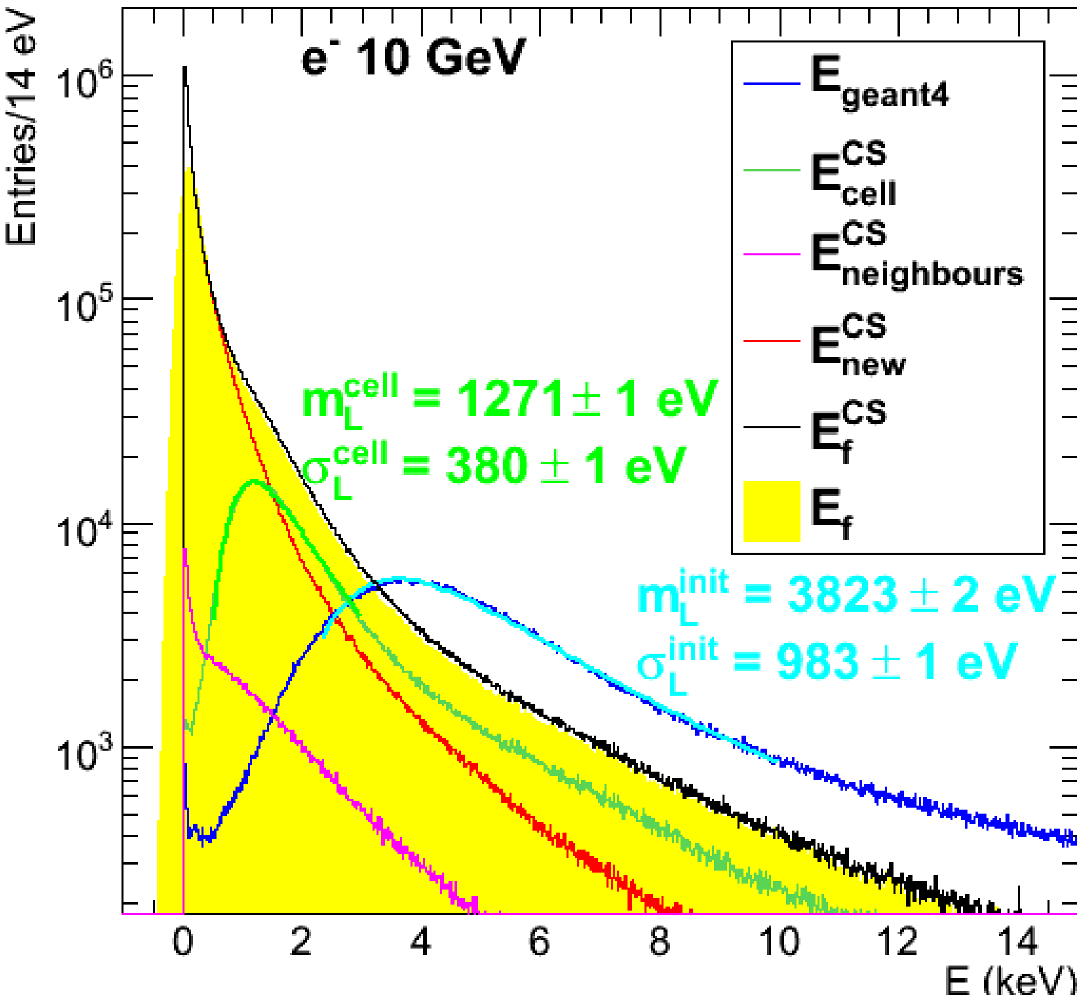


Effect of diffusion

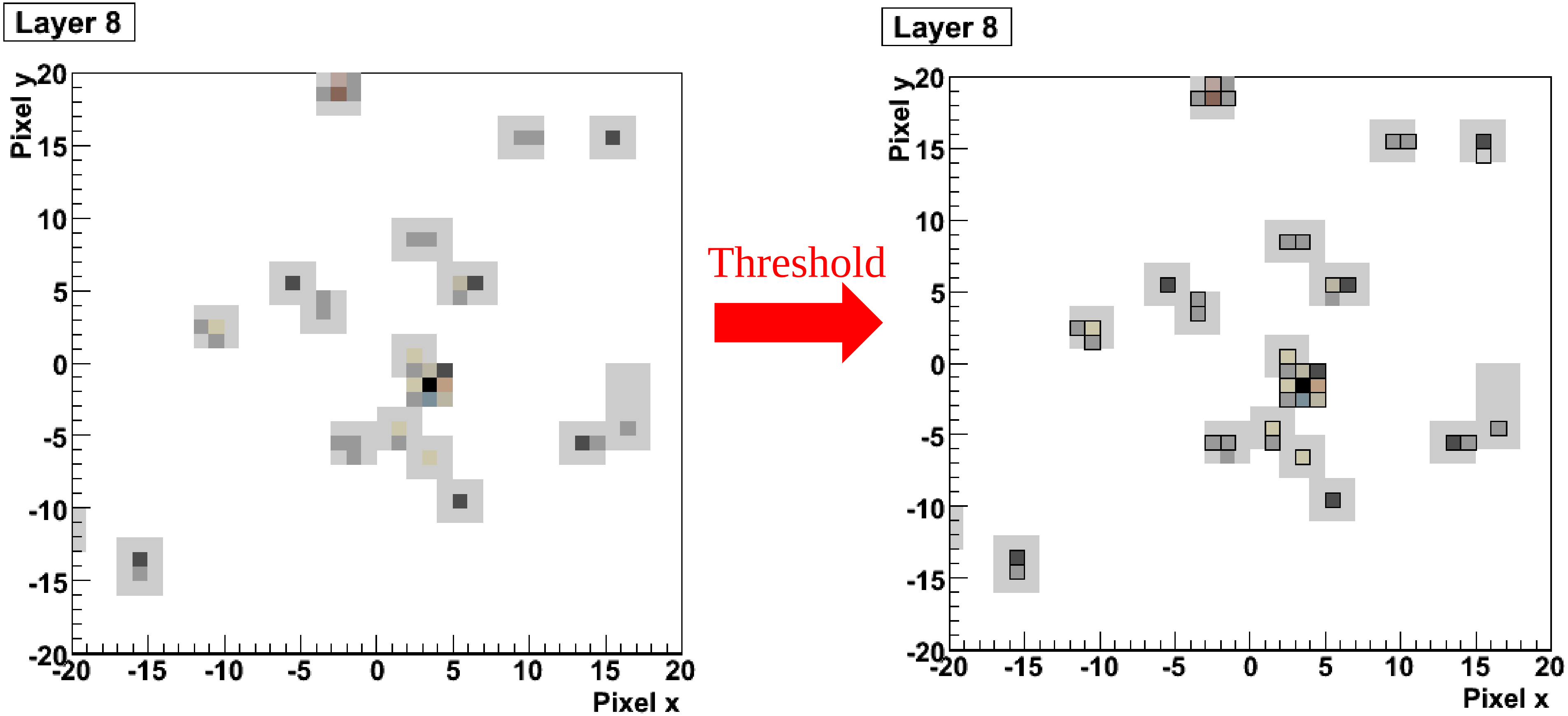


Effect of diffusion on signal charge

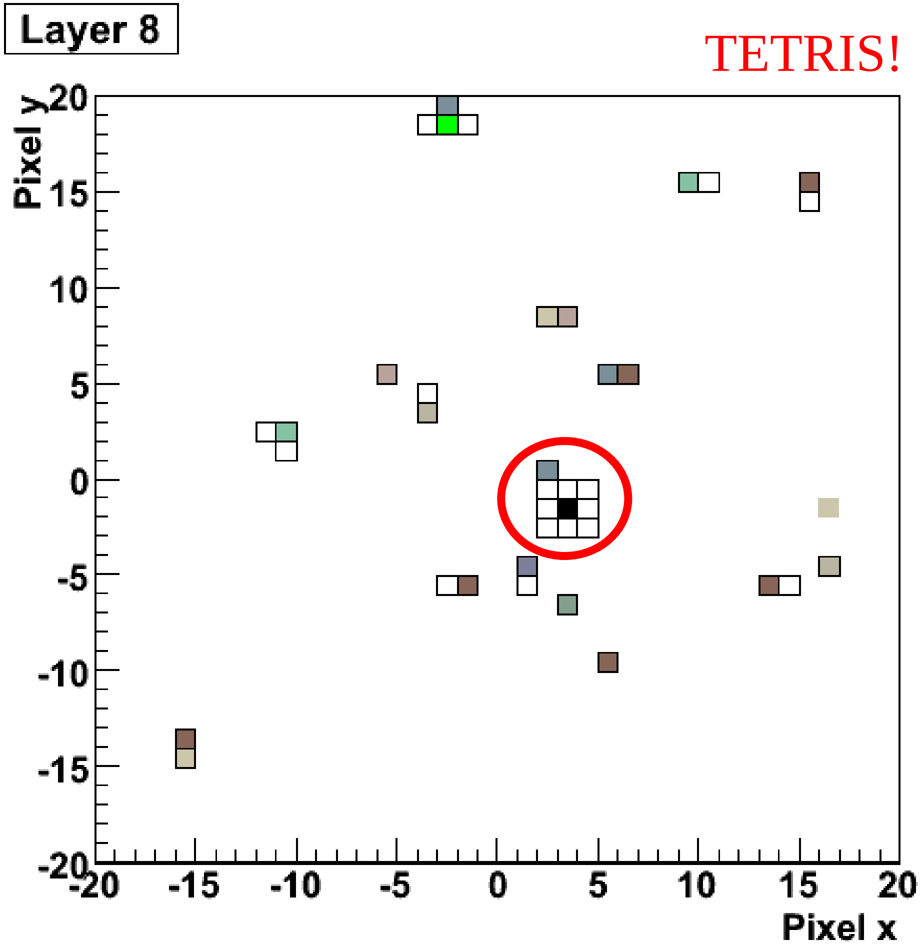
- Original charge (energy) deposited in hit pixel
- Remaining charge in hit pixel after diffusion
- Charge diffused into hit pixels from neighbours
- Charge diffused into non-hit pixels
- Total charge distribution
- Total distribution including noise



Effect of threshold

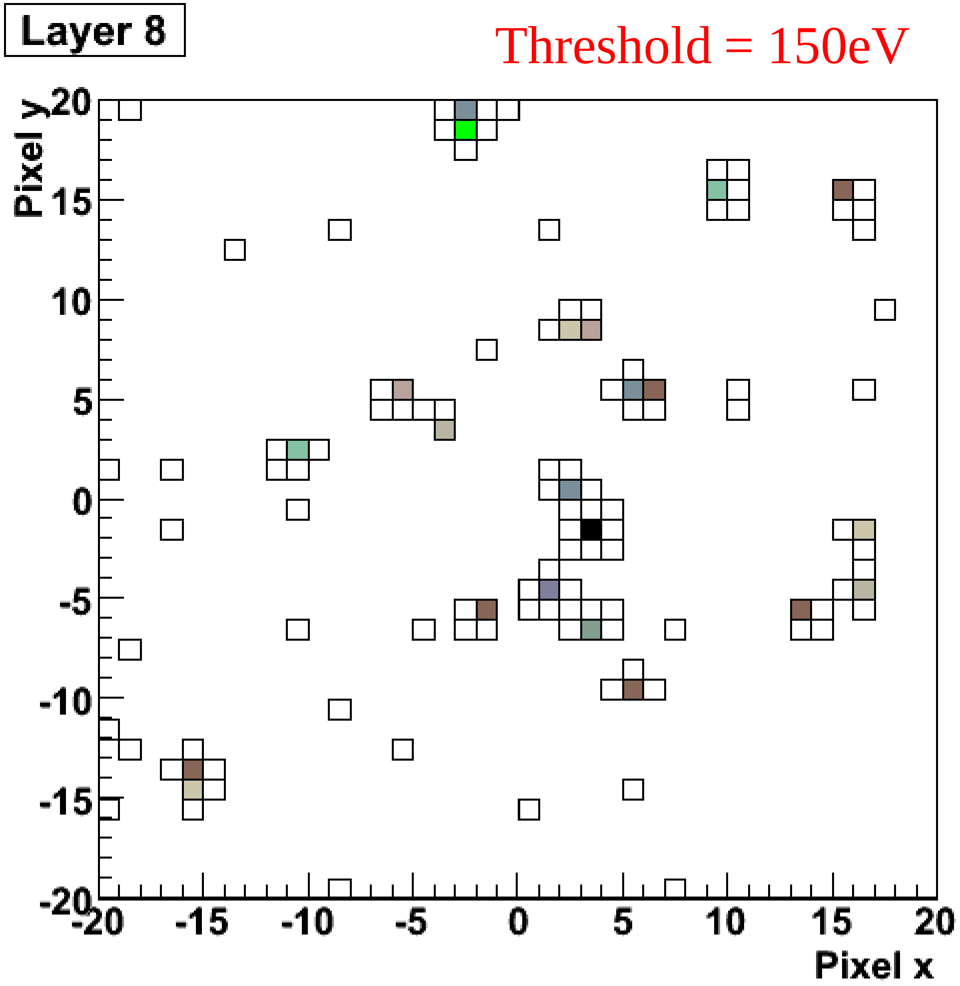


Compare with original particles



- Single particle can result in ~1-4 pixels being above threshold
  - All neighbouring
- Call each isolated group a "cluster"
- Count clusters not pixels to estimate particle number
- PROBLEM: close-by particles give larger clusters
  - Estimate particles in a cluster by $1+N_8$
  - N_8 = number of pixels with all 8 neighbours also hit

Depends on threshold and noise values



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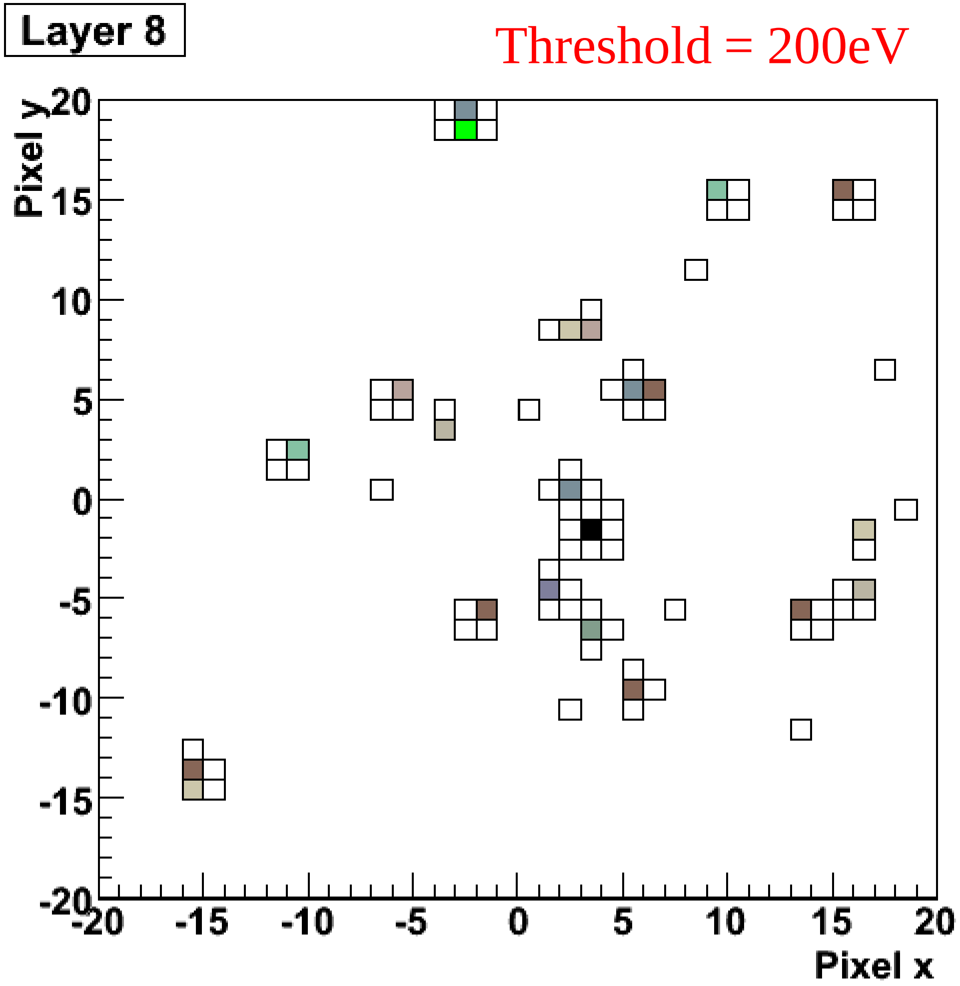

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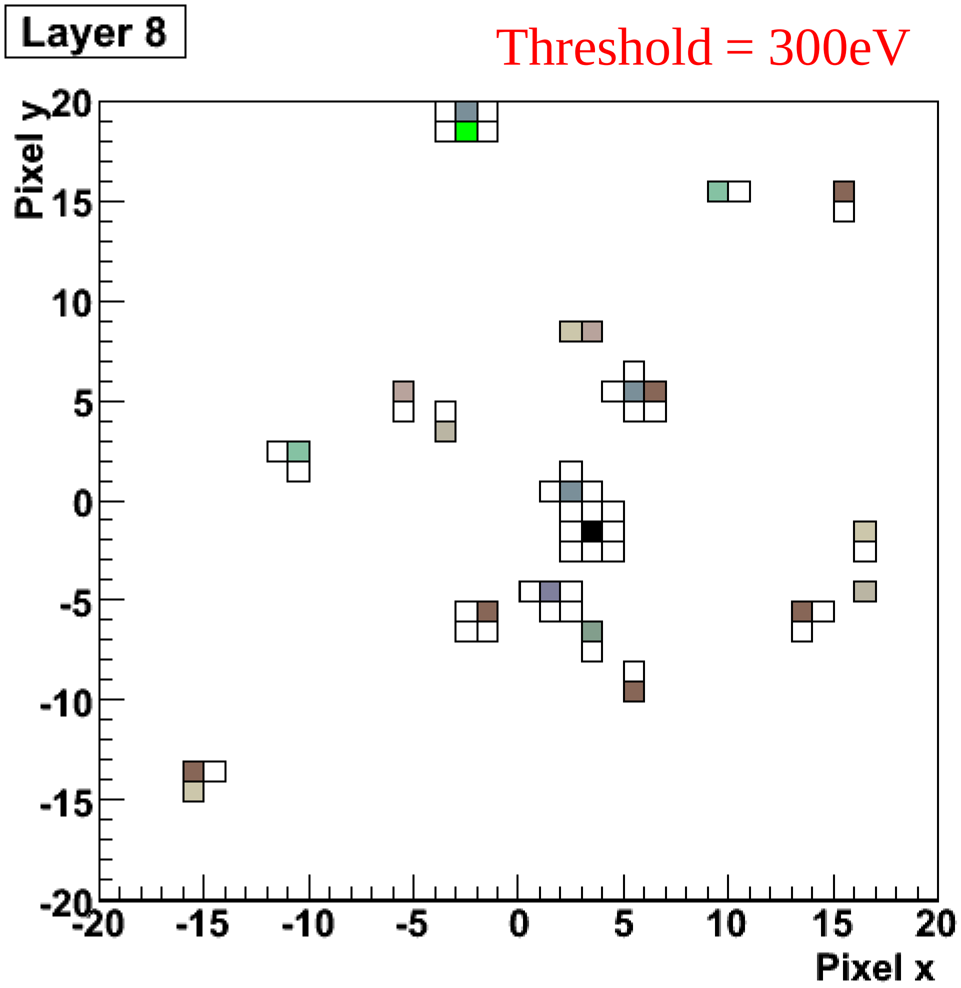

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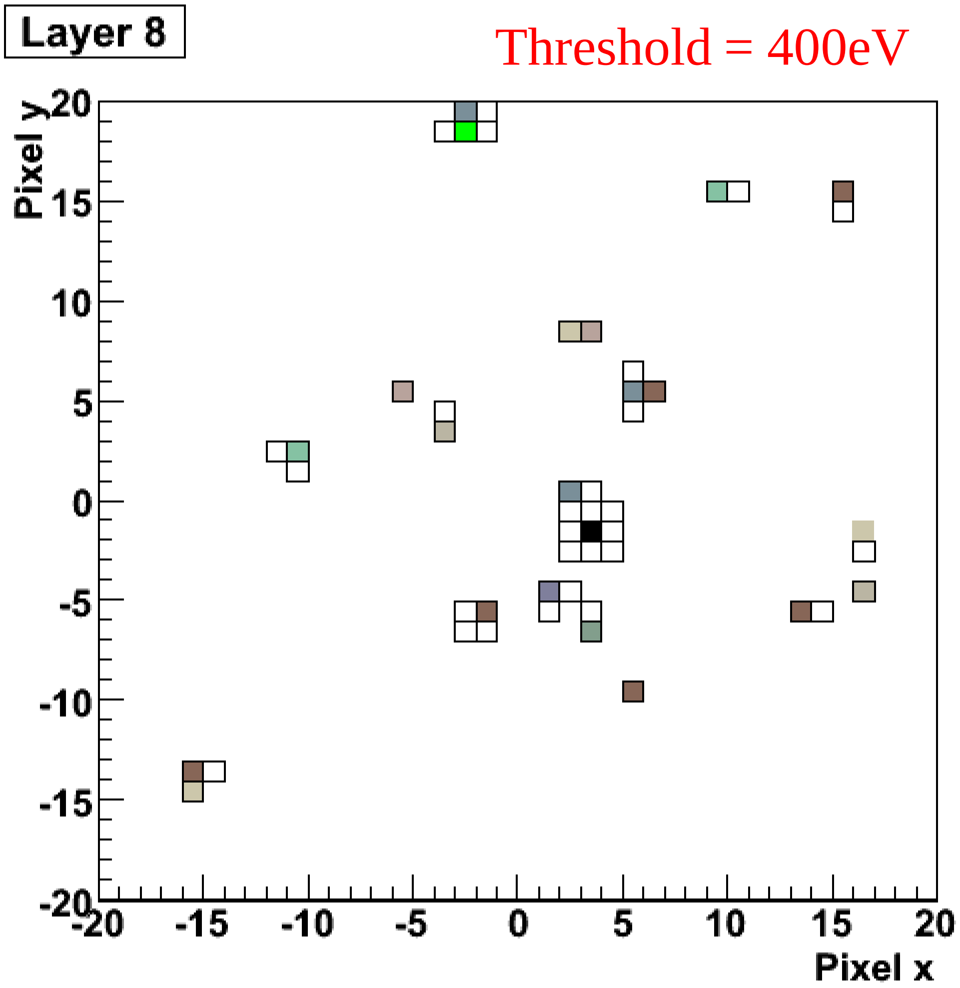

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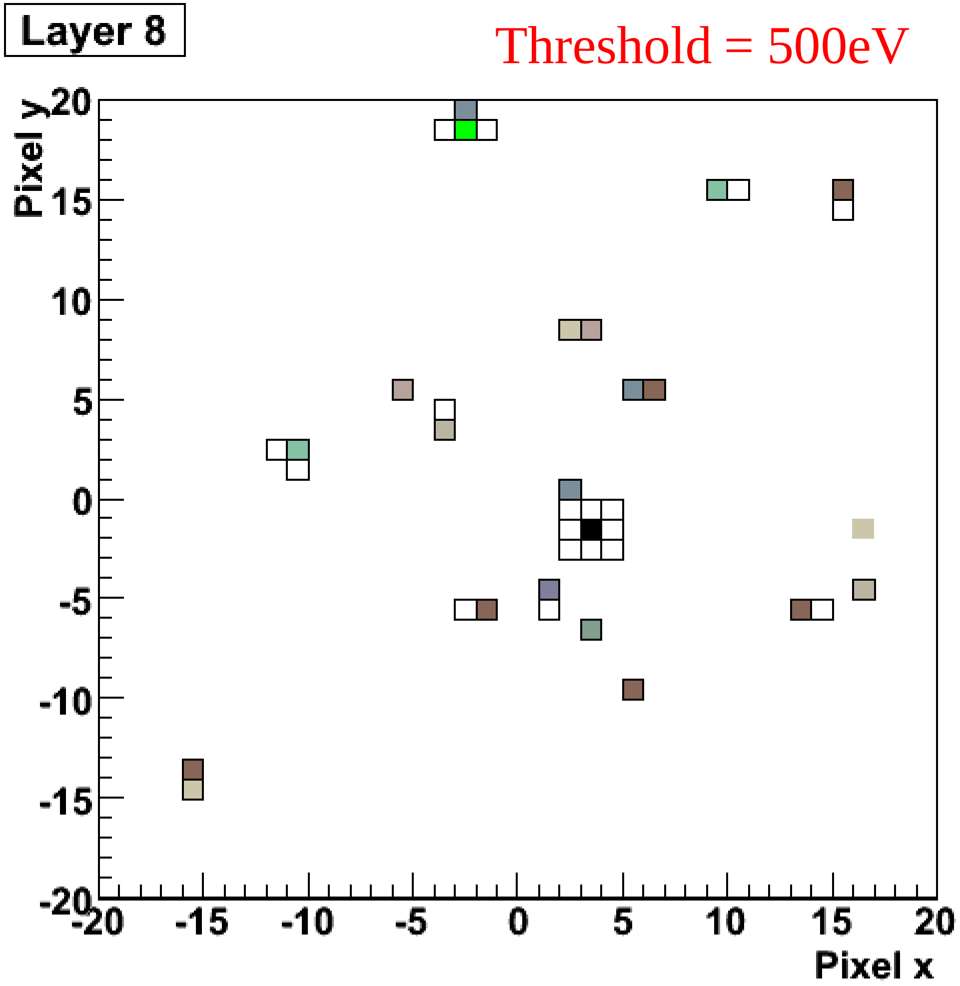

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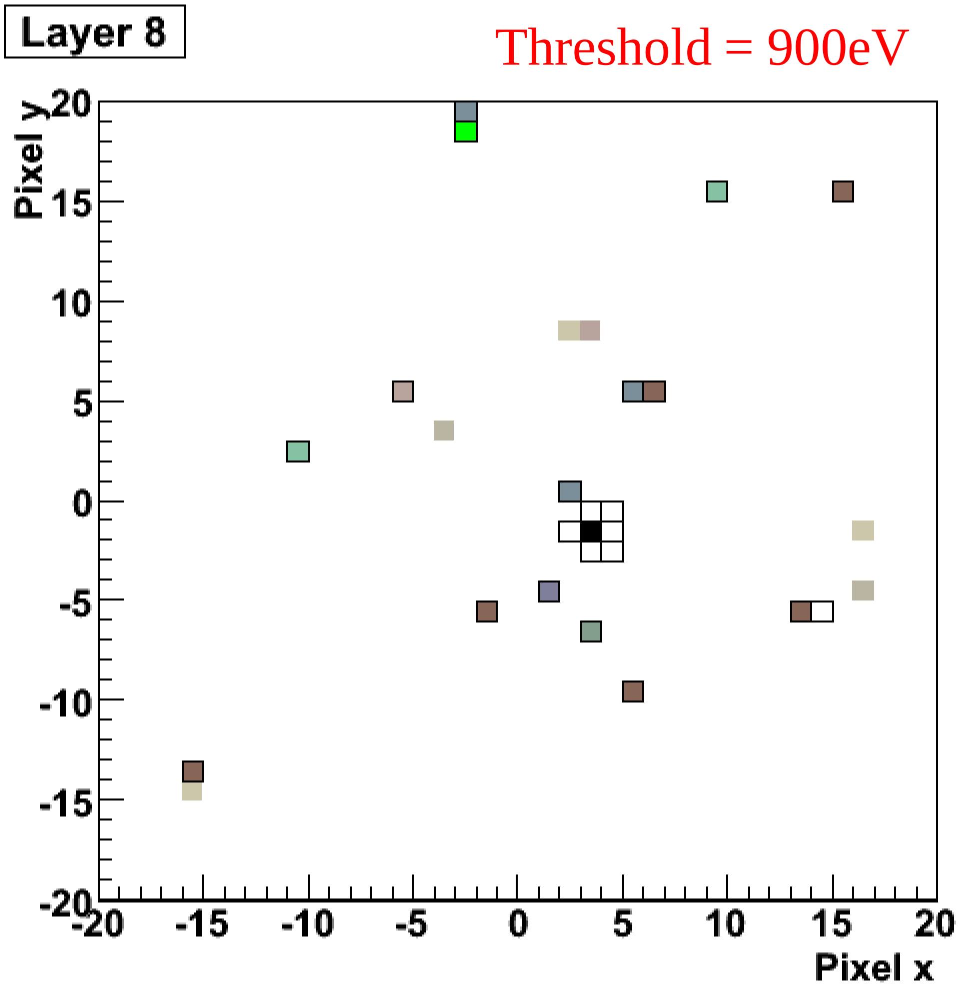
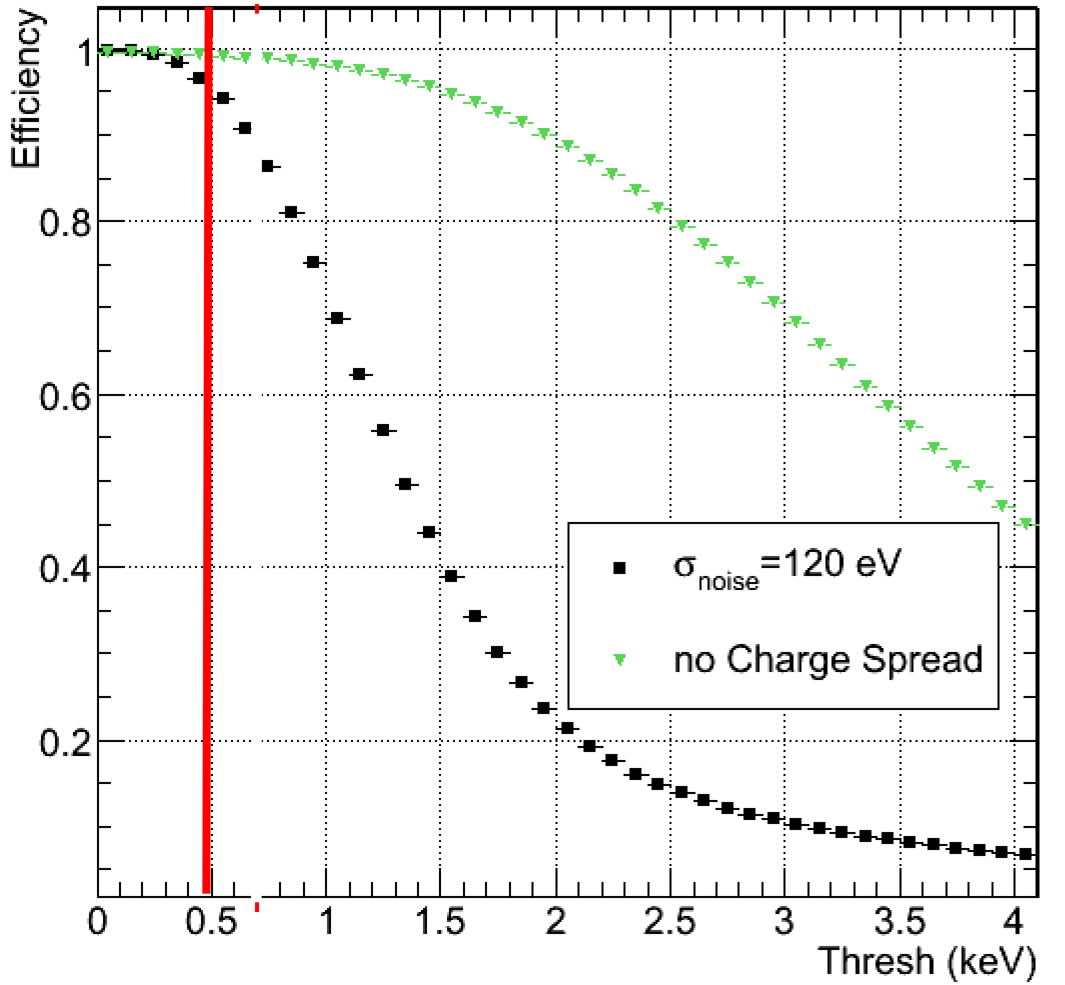


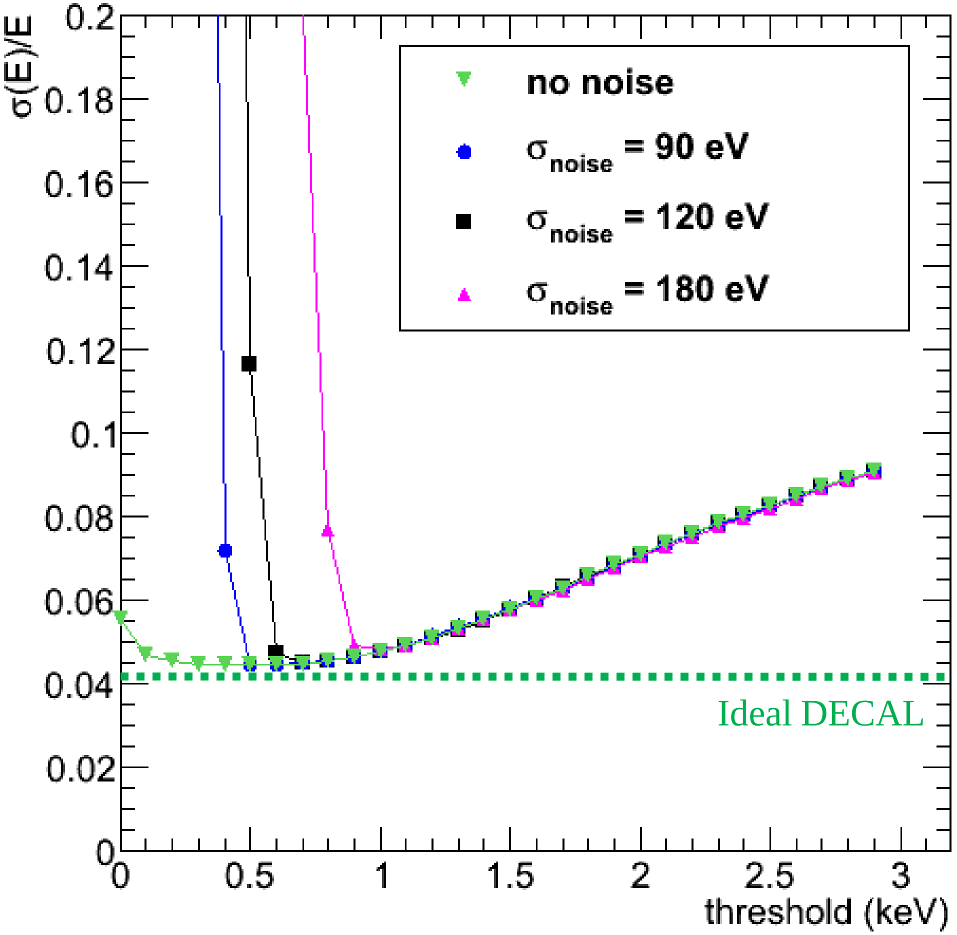
Efficiency for MIPs

- Expect ~95% efficiency
- Perfectly OK for a DECAL
- Not so good for a tracker!



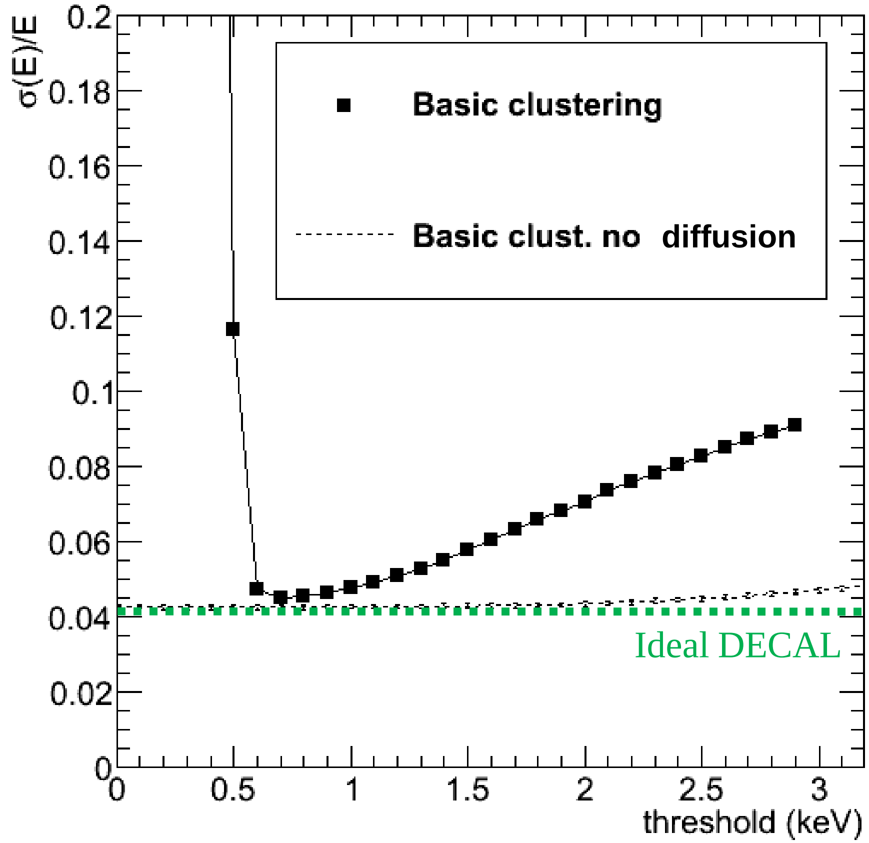
Resolution effect of noise

- Choosing threshold ~500eV gives same resolution as with no noise
  - Close to ideal resolution of Lecture 1: ~10% worse
- Following plots with noise of 120eV
  - Pessimistic: actual measured noise is 70eV



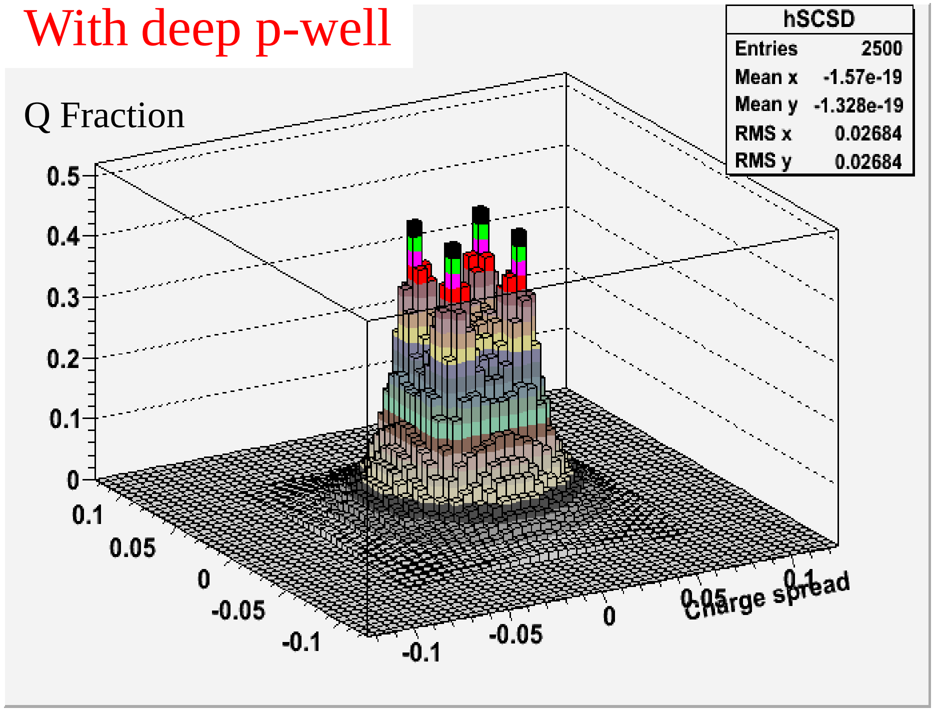
Resolution effect of charge diffusion

- With no charge diffusion, signal is ~3 times bigger; threshold cut has almost no effect over this range
- With charge diffusion and correct threshold, resolution is only slightly degraded
- Small disagreements of charge diffusion modelling not significant

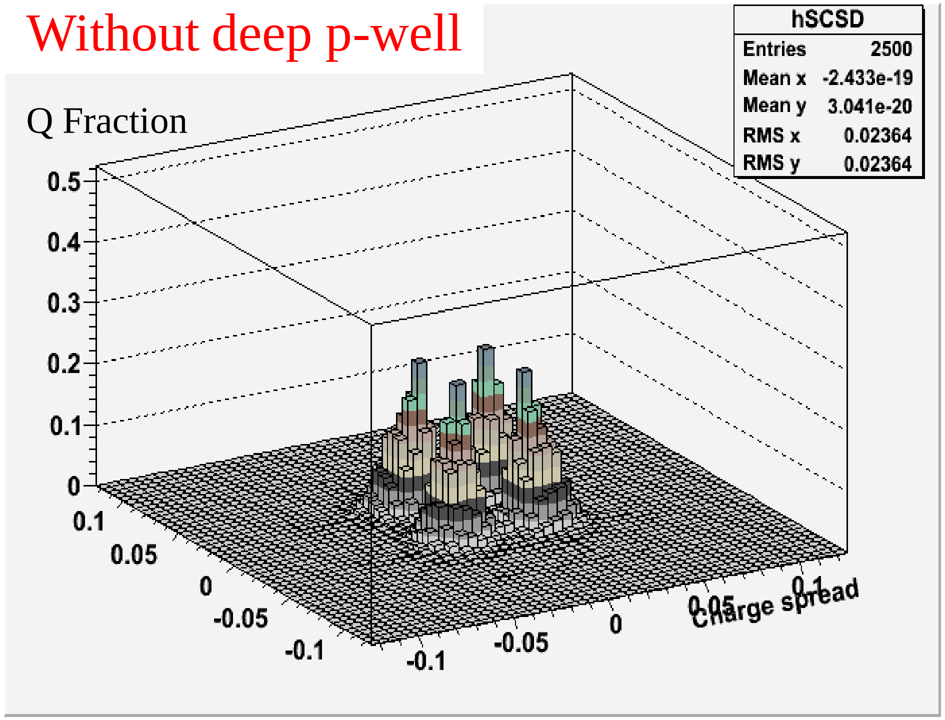


Resolution with and without deep p-well

With deep p-well



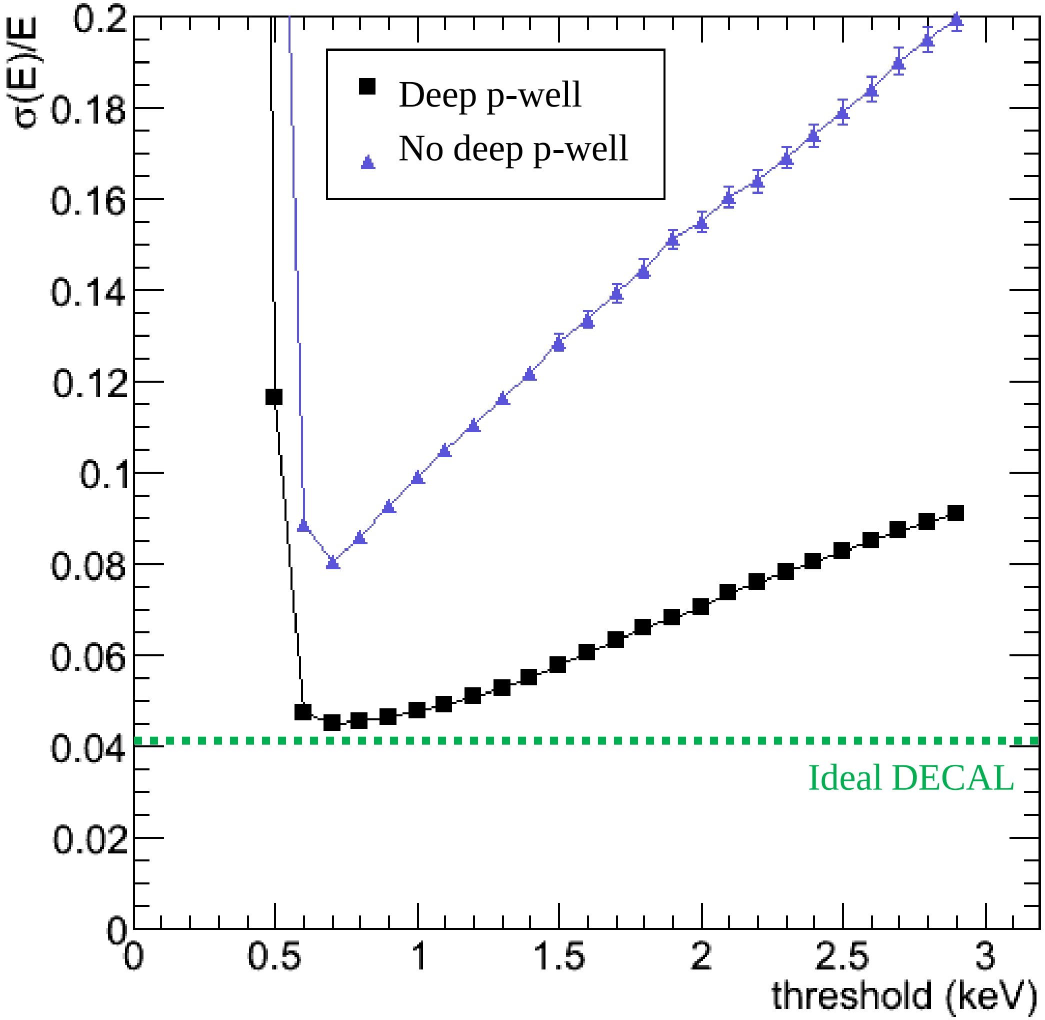
Without deep p-well



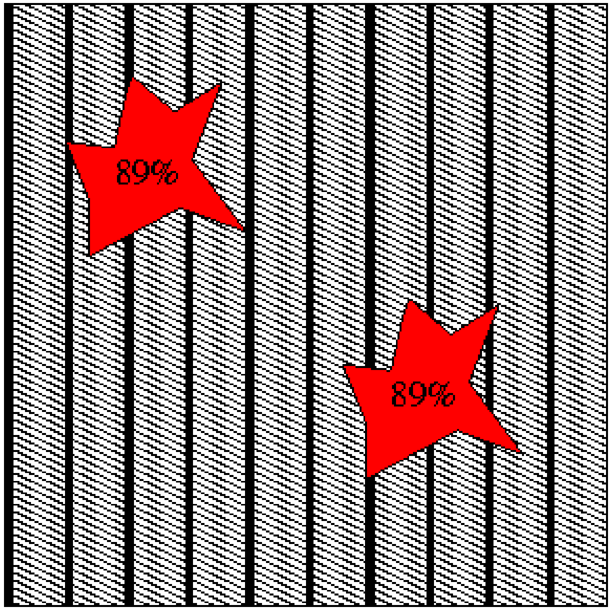
- Without deep p-well, a lot of charge is lost to circuit n-wells
  - Average signal is ~25% of deep p-well case

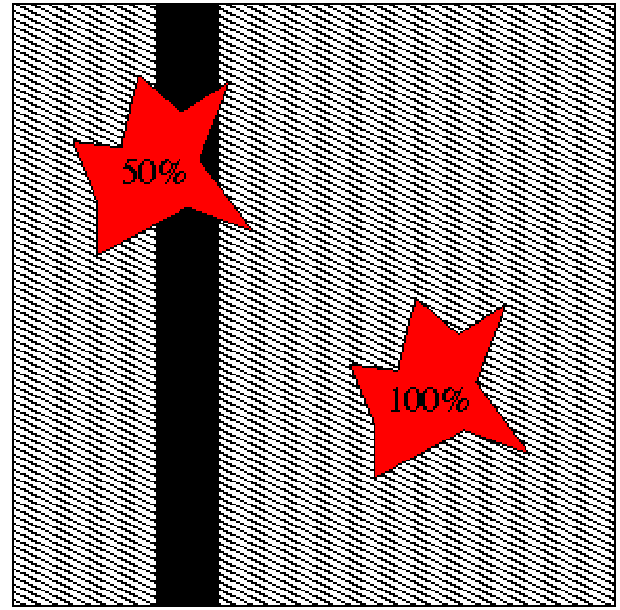
Resolution with and without deep p-well

- Without deep p-well, approximately only ¼ of number of pixel hits seen
- Contributes as √N so gives factor of two worse resolution
- Deep p-well essential



Resolution effect of dead areas



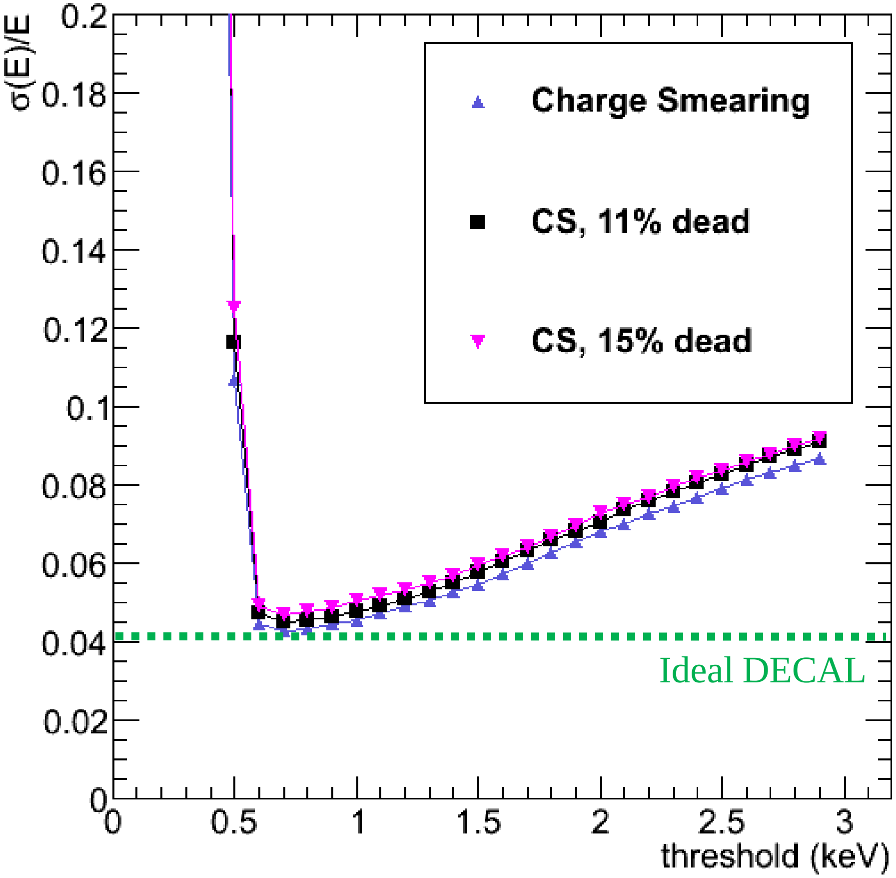


- Small frequent dead areas reduce the number of pixels hit for all showers by the same amount
- Gives $\sqrt{N}$ fluctuations to all showers

- Large infrequent dead areas lose many hits for some showers and none for others
- Gives big fluctuations for some fraction of showers

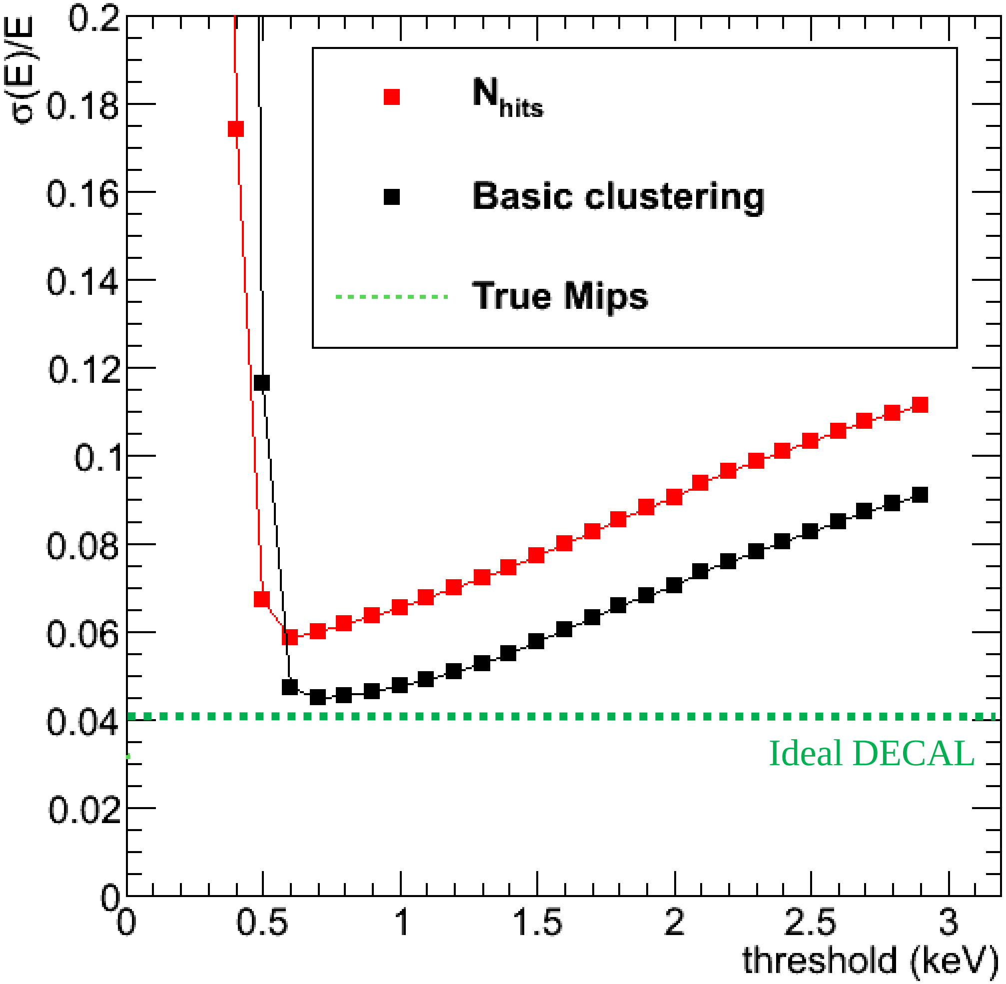
Resolution effect of dead areas

- Dead memory storage pixels on TPAC1 give 11% dead area
  - Strips of 250μm wide
  - One strip every 2.35mm
- Small(ish) compared to EM shower so goes as √N
  - ~5% degradation
- Also shown is 15% dead area
  - Includes estimates 4% extra dead area from sensor edges

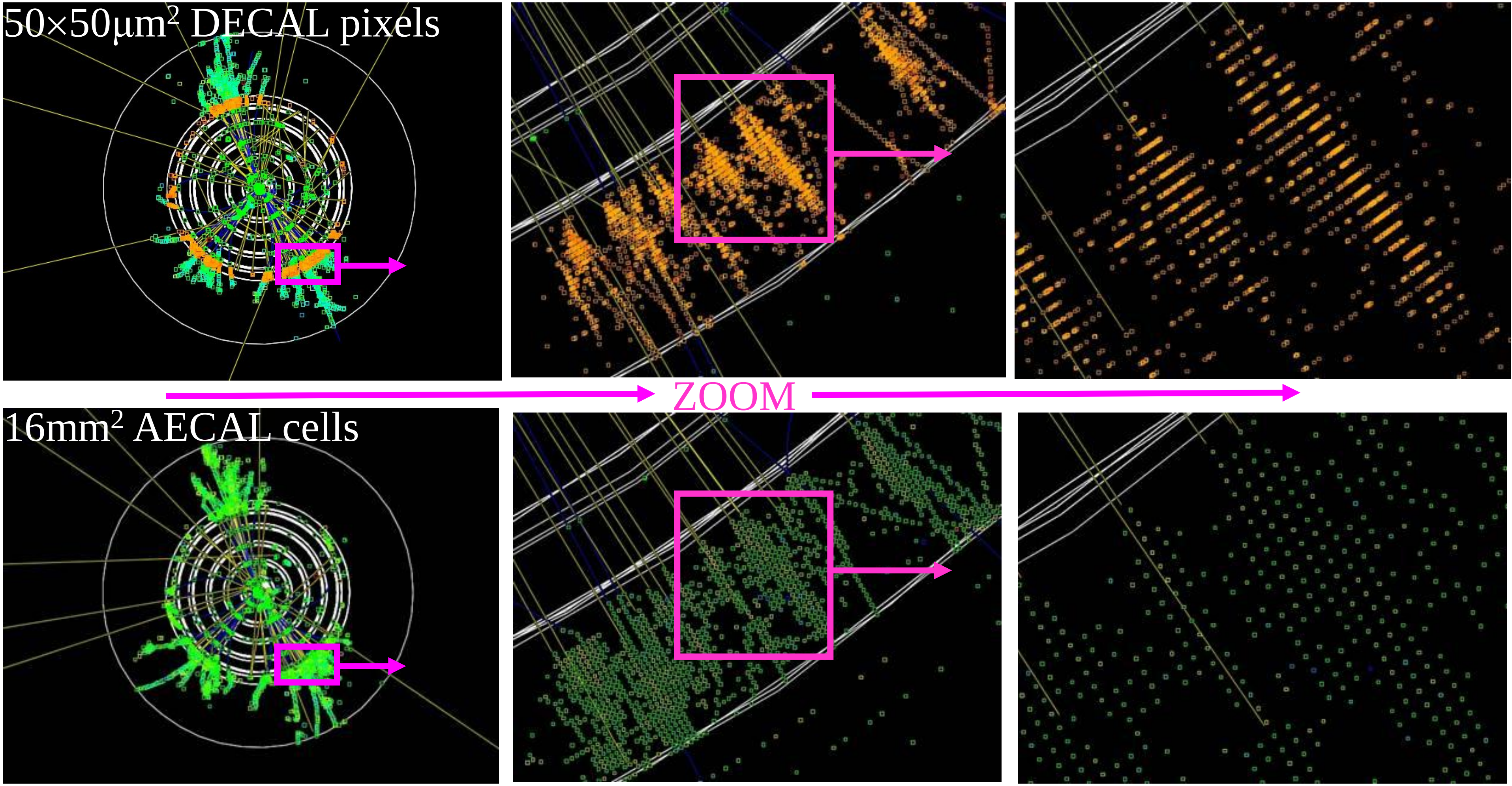


Resolution effect of clustering

- Charge diffusion means one MIP can (usually) give between 1 and 4 pixel hits
  - Ruins resolution if counting pixels with no clustering
- Basic clustering using $1+N_8$ essential to achieve good resolution
- Scope to play with clustering algorithms and improve further?



Effect on Particle Flow?



Remember...

- Most of this is purely simulation
  - Almost definitely wrong!
- Could be many "real detector" problems not yet found; we have heard about
  - Guard rings, temperature dependence, fibre-PMT alignment, sparking, electromagnetic pickup, etc, etc...
  - We don't know what the DECAL problems will be yet
- No detailed measurement of shower density at very small granularity
  - GEANT4 not tested at 50μm so core density may be much higher
  - GEANT4 may not give right number of low energy (~keV) photons
- We MUST do these measurements to take this concept seriously

Future measurements

- Next version of TPAC1 being made now
  - Due within one week
- Must do beam test this summer to measure hit densities in showers
  - Carefully compare against GEANT4
- TPAC1 only ~1×1cm^2
  - Cannot see whole shower or measure energy resolution
- Design larger version, TPAC2, size ~2.5×3cm^2, and make ~20 layer DECAL in 2010
  - Find out if concept really works!
  - (Funding permitting ☹)