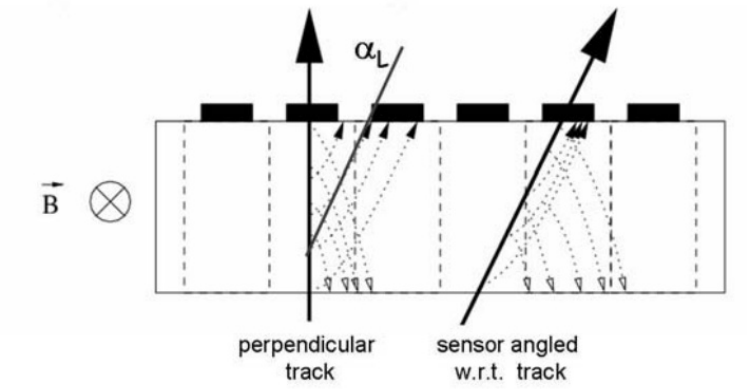
# Towards a realistic Si digitization for the μ-collider detector

**Simone**

# Pixel digitization

- Starting from Paolo's implementation of CMS pixel digitization (Twiki)
- Main effects included so far:
  - Split of G4 charge into $e^-$ – holes creation along particle path with energy deposition fluctuations
  - Lorentz angle
  - Diffusion of charge when drifting
  - FE electronics threshold and noise (on signal)



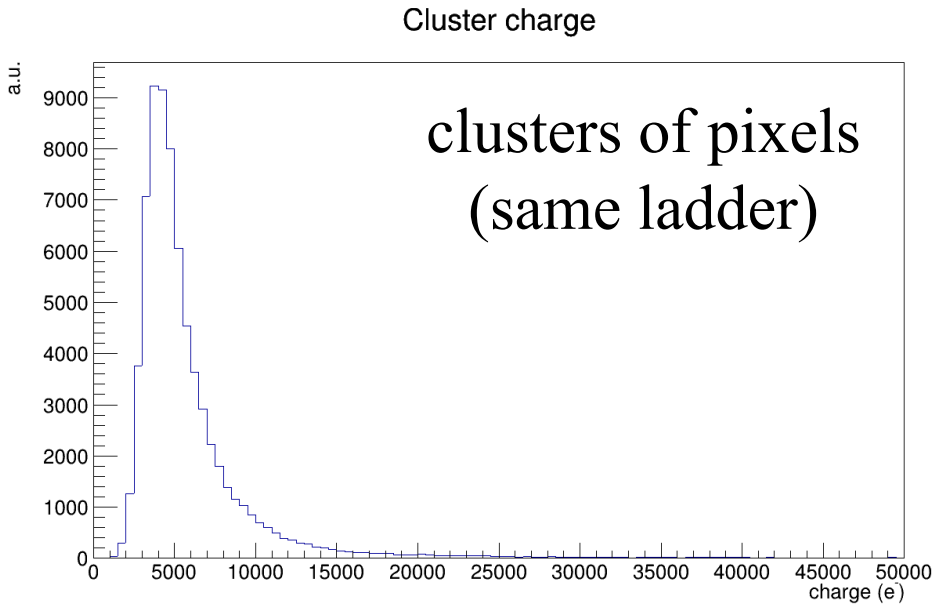

- Main effects not yet included (very much ok for a start):
  - Threshold dispersion (not all pixels can be tuned exactly at the same thr)
  - Parametrized time measurement digitization
  - Right now multiple G4 deposits creates different clusters → no overlap of particles on the same hit is simulated

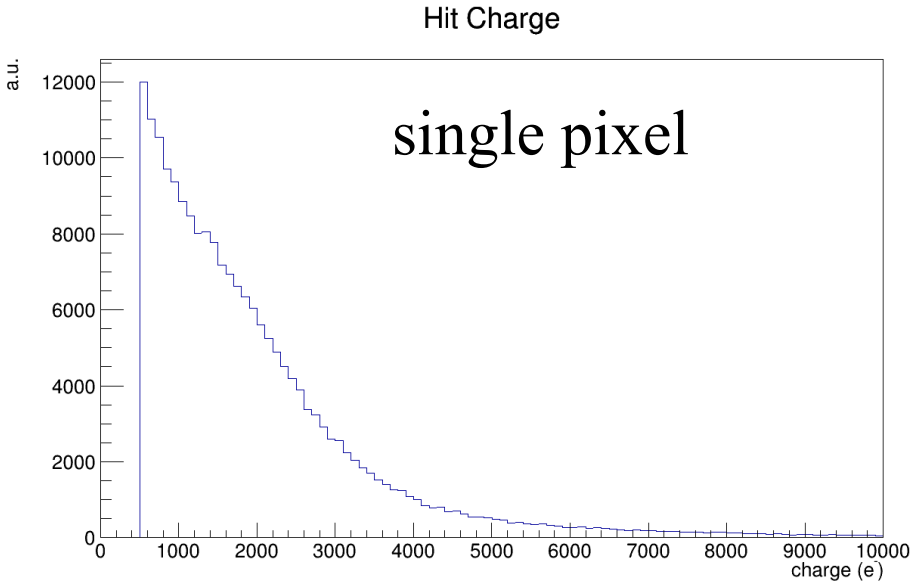
- Code: Branch 'lbldev' of MuonCVXDDigitiser and branch 'sidigi-dev' of LCTuple packages
  - Mostly working out of the box, just quite a bit of debugging for – in the end - some small fixes and tuning of parameters required!
  - See full diff on github

# Validation

- Simple muon gun with $p_T$ = 10 GeV, only spanning VXD BARREL
- Only running VXD barrel digitization so far, save results and modified LCTuple to store detailed information on individual pixel hits and clusters of them

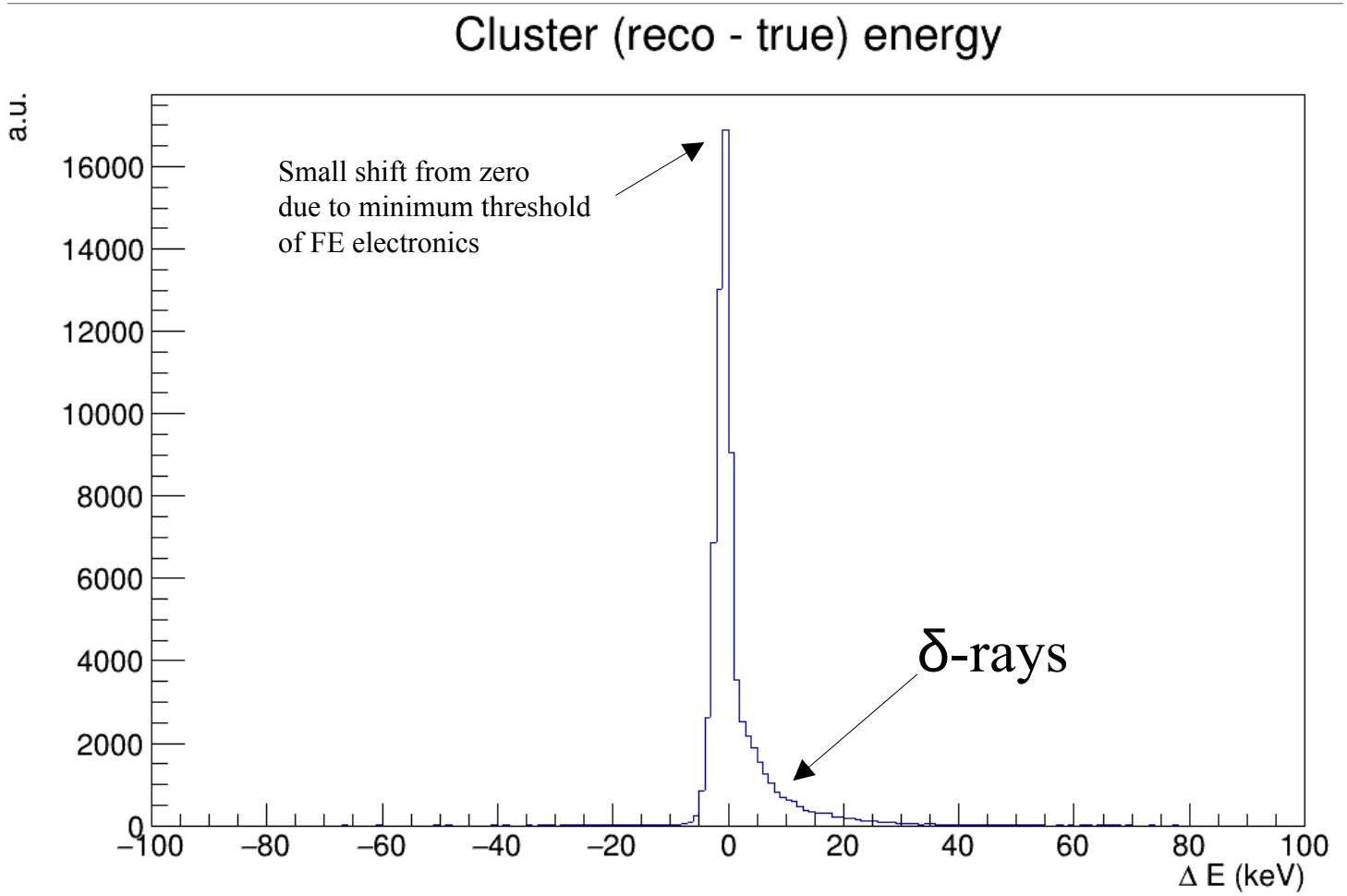
- Roughly speaking expecting ~4ke$^-$ of signal per minimum-ionizing particle (as the 10 GeV muon is), equivalent to ~15keV of deposited E



# Validation

- Energy reconstructed from deposited charge vs true G4 deposit



# Digitization parameters / changes

- Diffusion formula/parameter did not make much sense
  - Replaced with something I'm more familiar with (and widely used in literature); made diffusion z-dependent as should be
- Tuned FE electronics threshold and noise to something more in-line with modern FE pixel electronics (and a bit beyond that)
  - this is necessary since the super-thin (50μm thickness vs 100-250μm used for LHC/HL-LHC detectors) silicon sensors in our simulation
  - Note: thin sensors useful for accurate time measurements as well

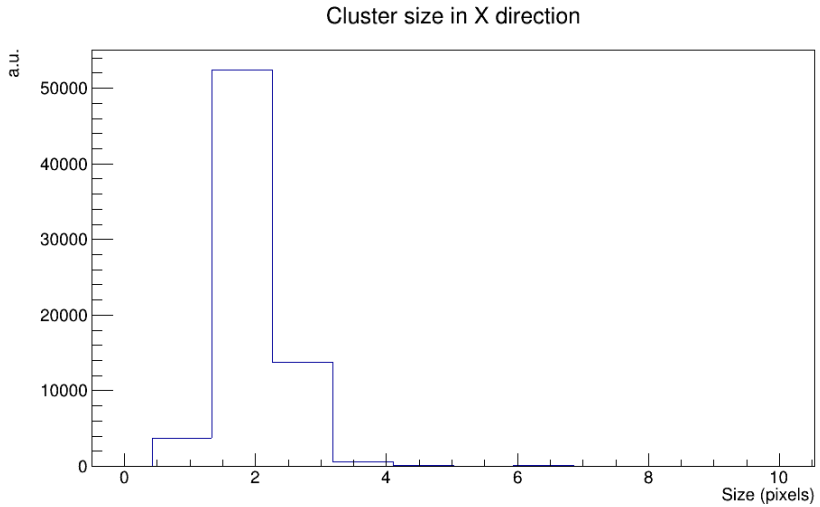
| Parameter | Old default | Branch: lbldev | Notes |
|---|---|---|---|
| Threshold | 200 $e^-$ | 500 $e^-$ | Old not consistent with other settings and very aggressive |
| Diffusion | 2μm | 0.07 | DIFFERENT computation |
| Electronic noise | 100 $e^-$ | 80 $e^-$ | |
| Lorentz angle | 0.8 | 0.8 | Haven't checked yet |
| Cut on δ rays | 30 keV | 30 keV | |
| Segment length | 5 μm | 5 μm | |
| "Width of cluster" | 3 | | Not used anymore |

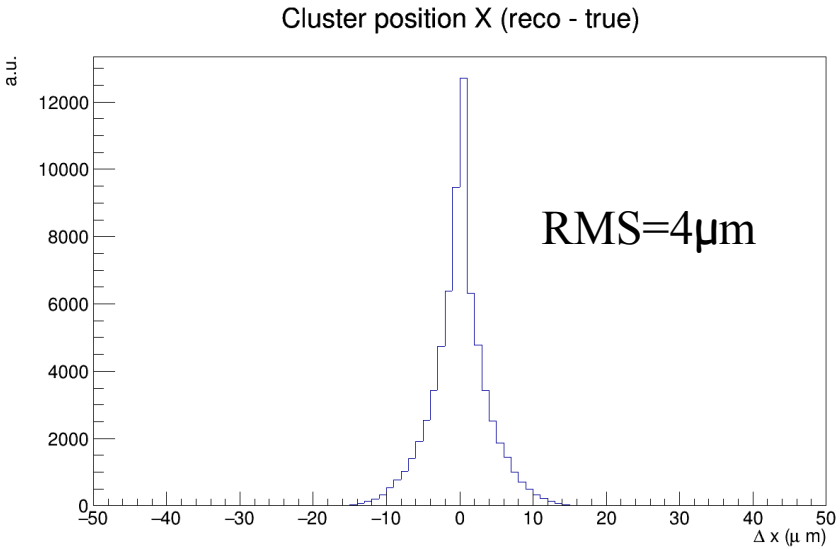
# Reconstruction of clusters

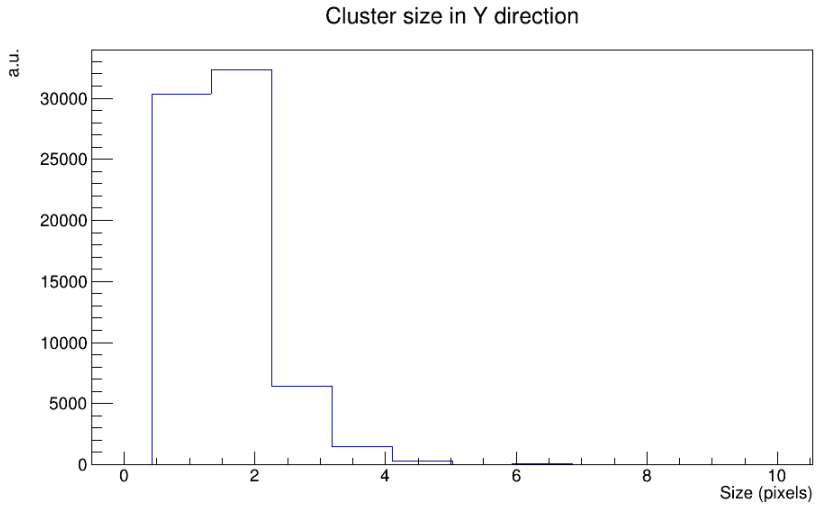
- Pixel clusters formation:
  - Wish: use pixel hits above threshold to form cluster of contiguous hits
  - Right now: one true energy deposit → one cluster, no check if hits contiguous (so-called broken clusters are accepted so far)
- Position determination:
  - Master: use charge-weighted average of all pixels' positions in the cluster
  - New: use simple average of all pixels in the cluster (it's actually better!)
  - Wish: use charge-weighted average with calibrated constants of only the most external pixel hits in a cluster
    - Why? It avoids being sensitive to the large charge deposit fluctuations in the central pixels that see a full path length and only introduce a large noise in the averaging procedure

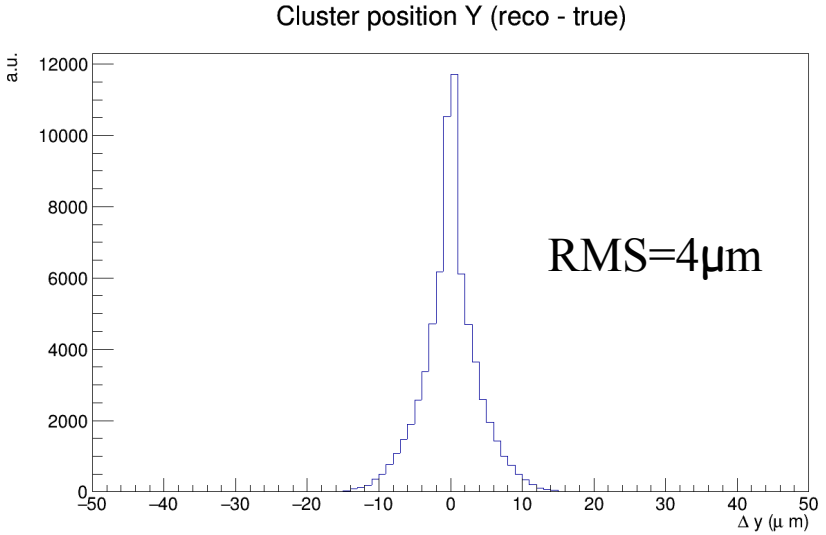
# Position determination

- Test with simple averaging of hits positions
  - Note: 25 µm * sqrt(12) ~ 7 µm



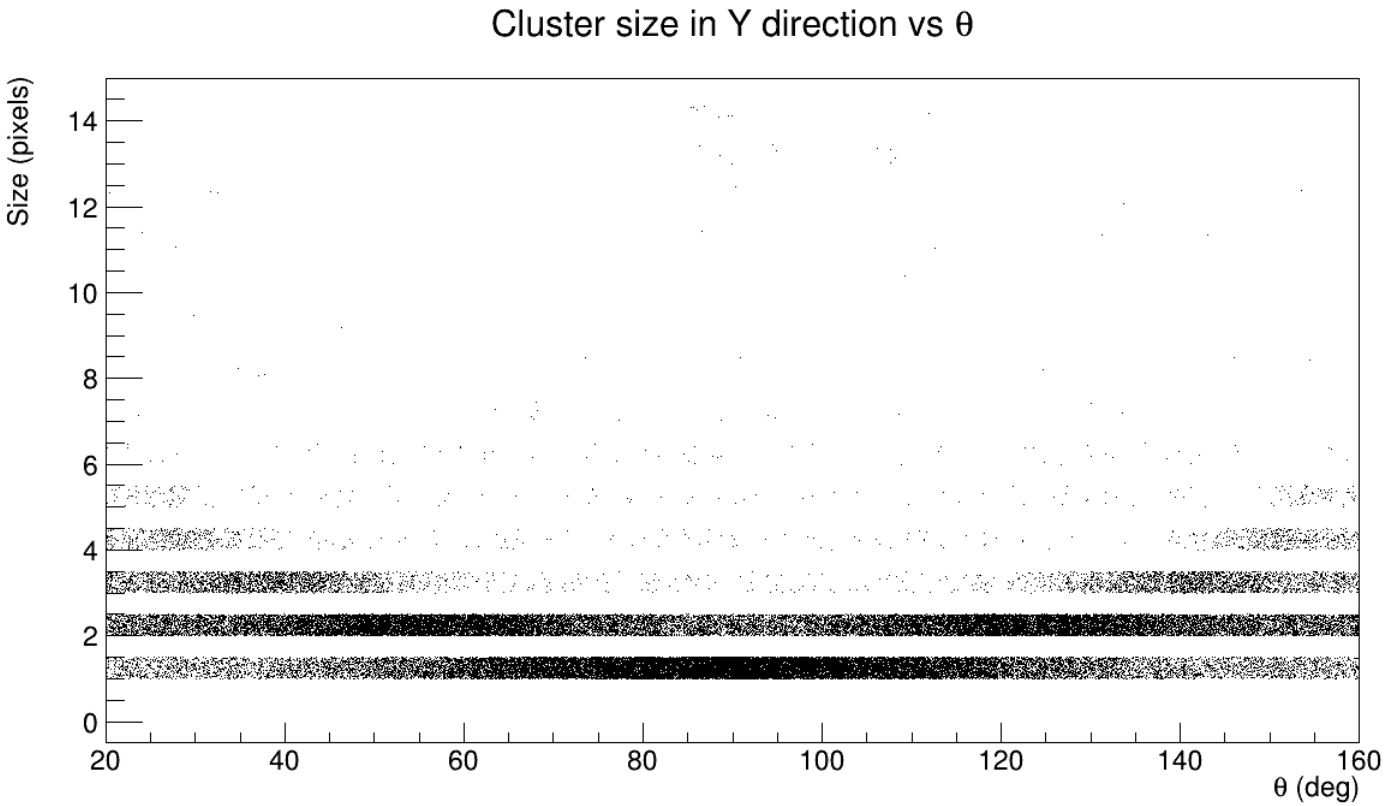



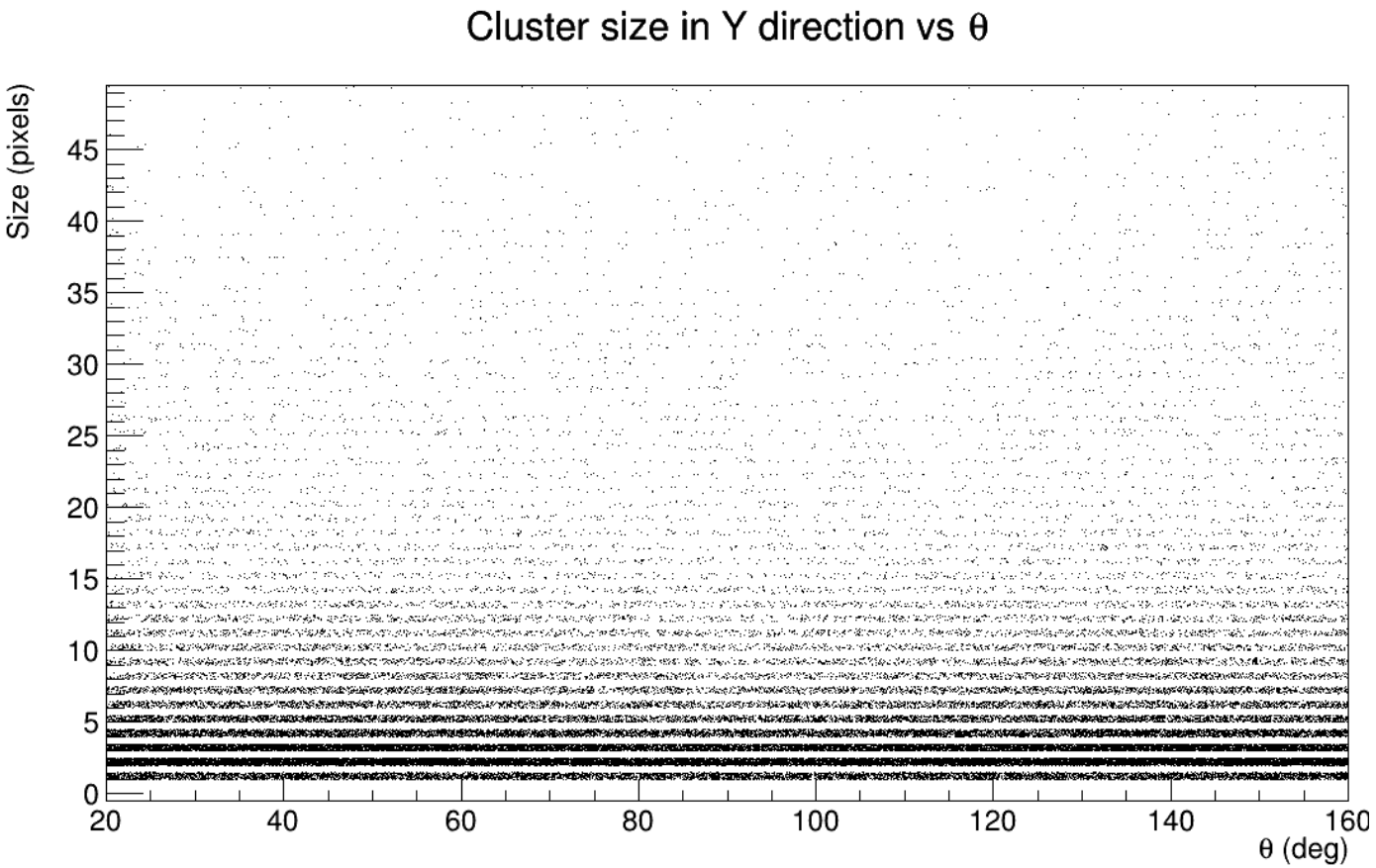
# Hits filtering

- Ultimately, would like to study discrimination based on released energy and cluster shapes of signal vs beam background
- Below, the clear correlation of size vs theta for prompt muons
  - Expect BIB to be quite different (both in shape as well as in E released)



# BIB simulation

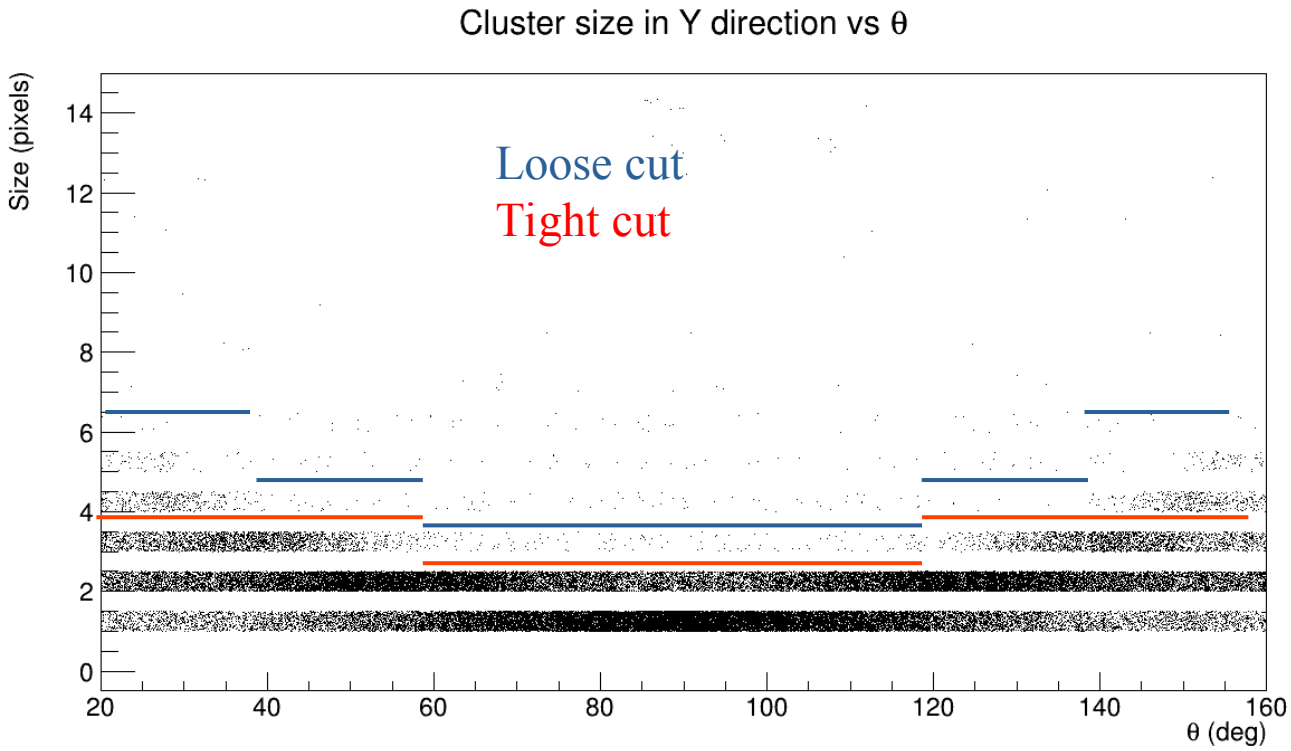
- 100 single-μ events, 30 BIB bkg events (1% BIB)
  - Interested in BIB distribution overall, does not matter if digitized in single or multiple events at this stage (over multiple events requires less RAM)




Uniform vs theta and longer clusters from BIB

# Simple size Y selection vs theta

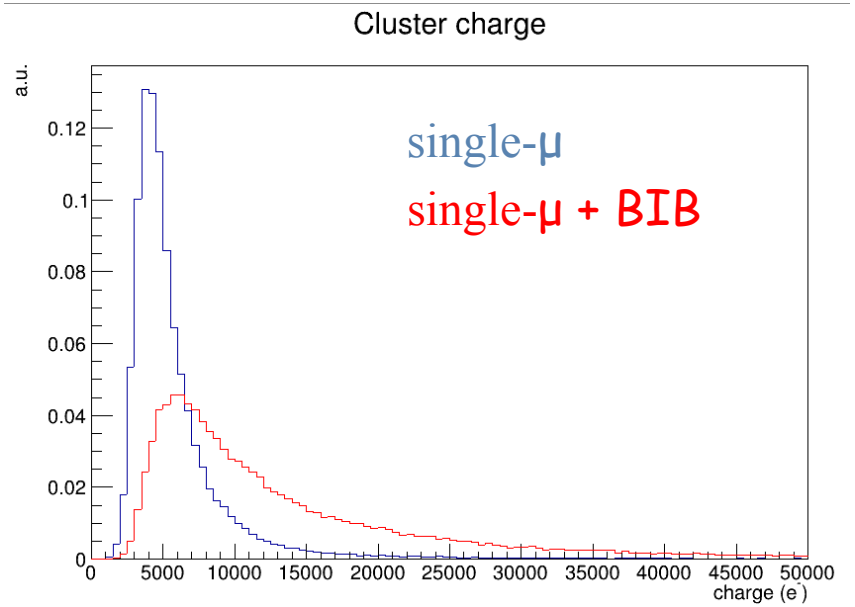
| Cut Efficiency | Loose | Tight |
|---|---|---|
| Single muon | 99.4% | 75.0% |
| Single muon + BIB | 63.5% | 42.9% |

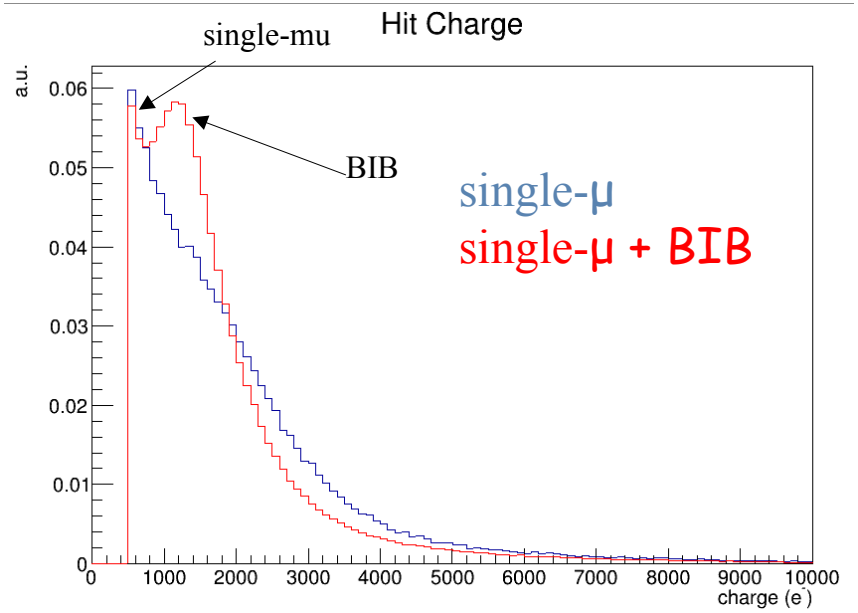



Note: single-muon is uniform in cos(theta)

# More discrimination..

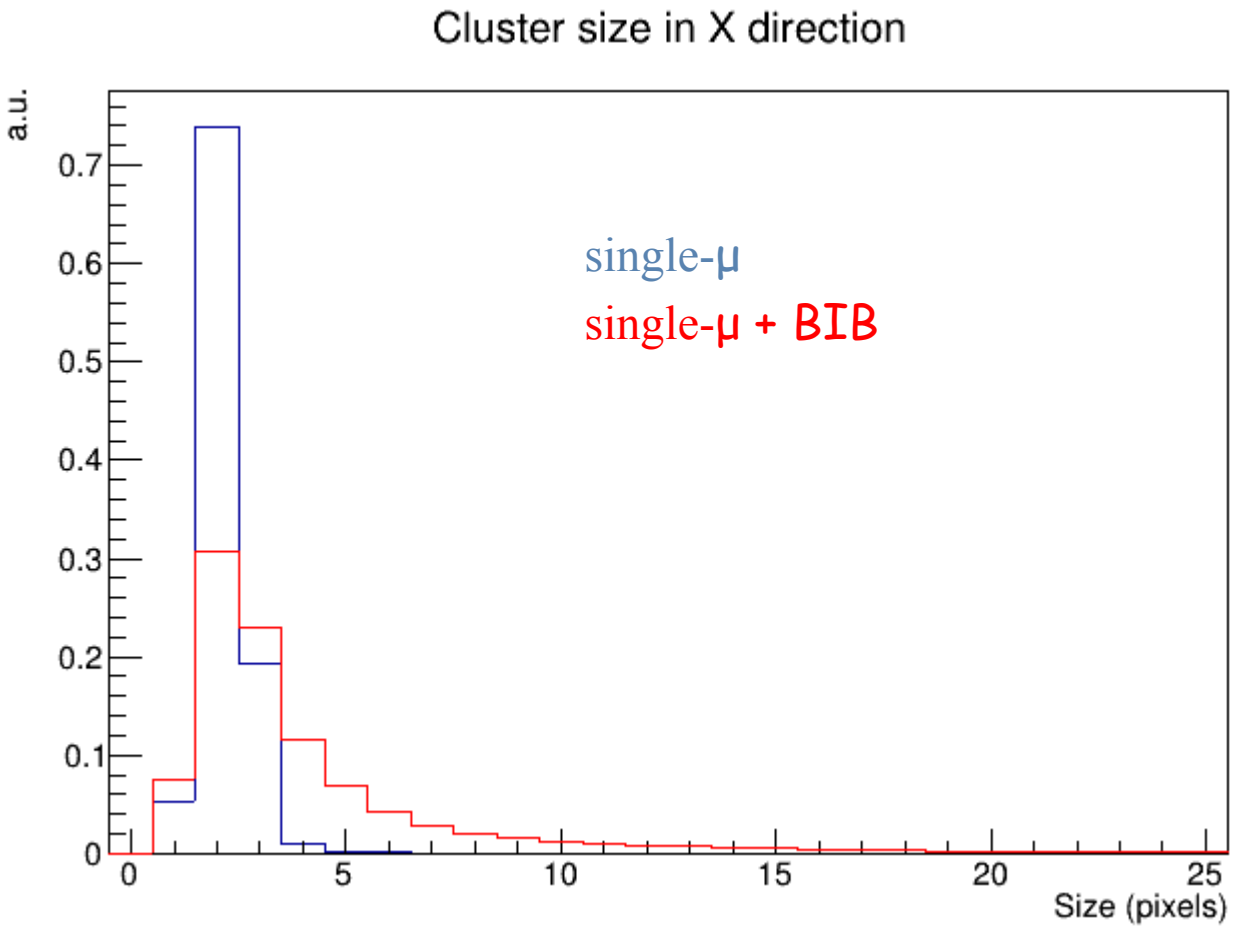
- Some discrimination also from deposited energy, however:
  - Not enough for a plain cut
  - Need to be careful to not penalize low-βγ particles
- Still, could be a useful quantity in pre-tracking filtering for a first pass
  - TODO: will explore combining this and size information in a smarter way



# Even more...

- Some discrimination also on size X
  - Unphysically long clusters for BIB...



# Future TODO

- Determine cluster energy/shape discrimination (better..)
- Further tune some of the parameters and study what is nice vs required → requirements for R&D
- A few further tweaks to the digitization:
  - Implement threshold dispersion
  - Implement time digitization
  - Include noisy pixels (small effect though but easy)
- Run/validate realistic digi for VXD endcap as well, create new job config and evaluate running time on BIB
- Change logic to separate digitization and cluster reconstruction
  - Allow to mix different energy deposits (SimHits) in the same pixel(s)
  - Mostly relevant if someone wants to study dense environments (e.g. core of jets)
- Change and tune position determination algorithm