Towards a realistic Si digitization for the μ-collider detector

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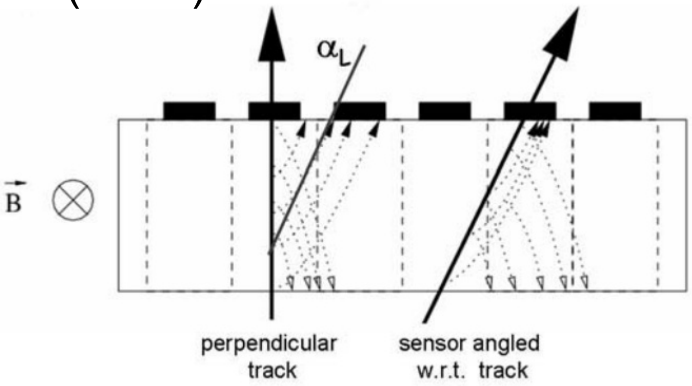
Pixel digitization

- Baseline starting model from CMS pixel digitization (Twiki)
- Main effects included so far:
  - Split of G4 charge (1 value per volume per particle) into e^- – holes creation along particle path with energy deposition fluctuations
  - Lorentz angle effects
  - Diffusion of charge when drifting
  - Front-End (FE) electronics threshold and noise (on signal)

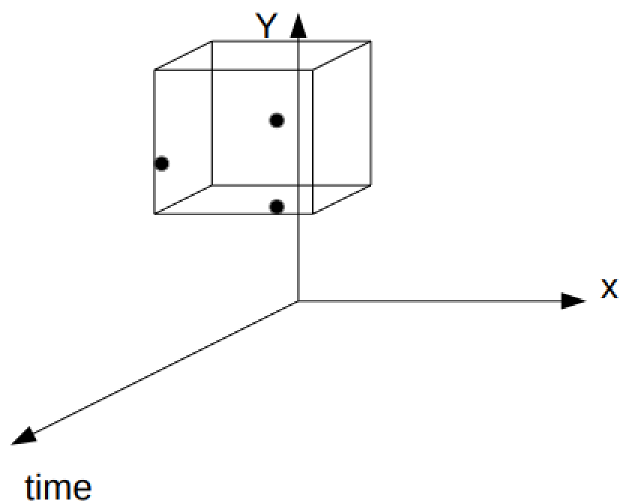


- Main effects not yet included (very much ok for a start):
  - Discretization of measured charge (finite resolution, 4 bits in current FE chips)
  - Threshold dispersion (not all pixels can be tuned exactly at the same thr)
  - Parametrized time measurement digitization → right now just true G4 timing
  - Main branch adopts a simplified approach with 1 Geant4 deposit creating 1 cluster of pixels → no overlap of particles on the same hit is simulated
    - Ok for initial studies, its importance should be studied eventually

Code status

- Digitization code on github (branch `master`)
  - Contains the fully validated code **used in this presentation**
  - Branch `sidigi-dev` of LCTuple packages to include detailed cluster and individual pixel hit information, when enabled (see full diff on github)

- Digitization code has also an `experimental` branch
  - Split digitization and cluster reconstruction properly
    → allows multiple particle to create merged pixel clusters
  - Implements multi-threaded space-time based clustering!



- Simulated hits are placed in space and time
- We can take a slice of space and time, with simulated hits sorted according to the time
- The volume of space-time is partitioned according to the ladders (multi threading)
- All the simulated hits in a ladder must be aggregated with a suitable algorithm

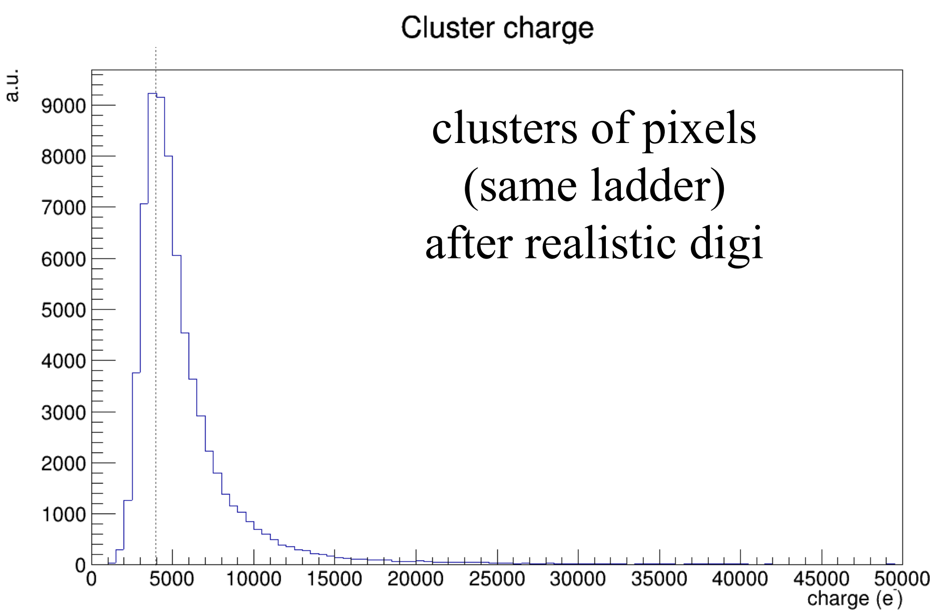
Digitization parameters / changes

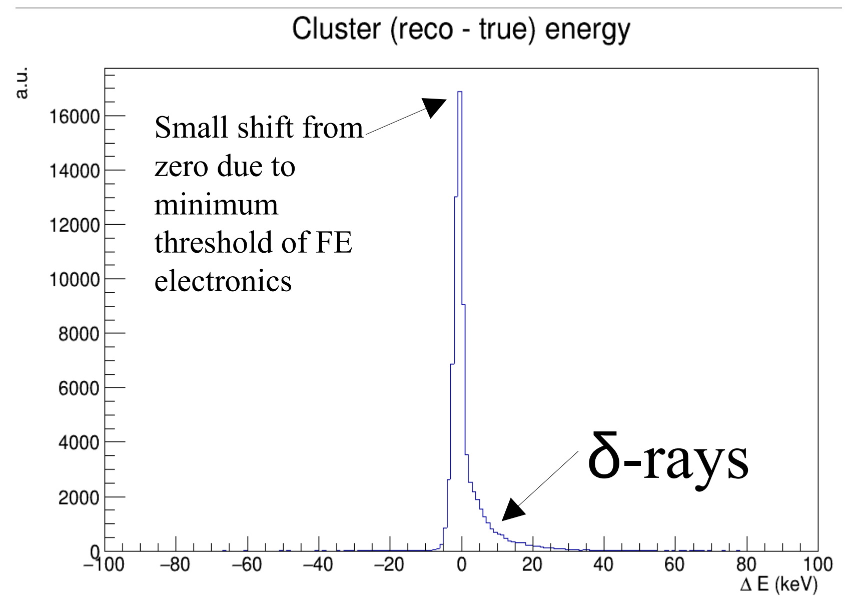
- Diffusion formula/parameter changed compared to original model
  - Replaced with something I'm more familiar with (and widely used in literature)
- Default FE electronics threshold and noise set to something more in-line with modern FE pixel electronics (and a bit beyond that)
  - this is necessary 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
- In the future, study performance dependence to determine technology requirements!
- Main parameters for reference:

Parameter	**Branch: master**	**Notes**
Threshold	500 e^-	Consistent with a bit beyond state-of-art electronics
Diffusion	0.07	Assuming reasonable operating depletion voltages
Electronic noise	80 e^-	Consistent with a bit beyond state-of-art electronics
Lorentz angle	0.8	To be x-checked
Cut on δ rays	30 keV	Speed vs accuracy
Segment length	5 μm	Speed vs accuracy

Validation

- Simple muon gun with E = 10 GeV, only spanning VXD BARREL
- Only running VXD barrel digitization, save results and modified LCTuple to store detailed information on individual pixel hits and clusters of them
- ✅ Roughly speaking expecting Landau with most probable value of ~4ke$^-$ per minimum-ionizing particle (as the 10 GeV muon is)
  - One e-hole pair requires ~3.6 eV of ionization energy loss, ~80 e$^-$-hole pairs / μm
- ✅ Energy reconstructed from deposited charge vs true G4 deposit

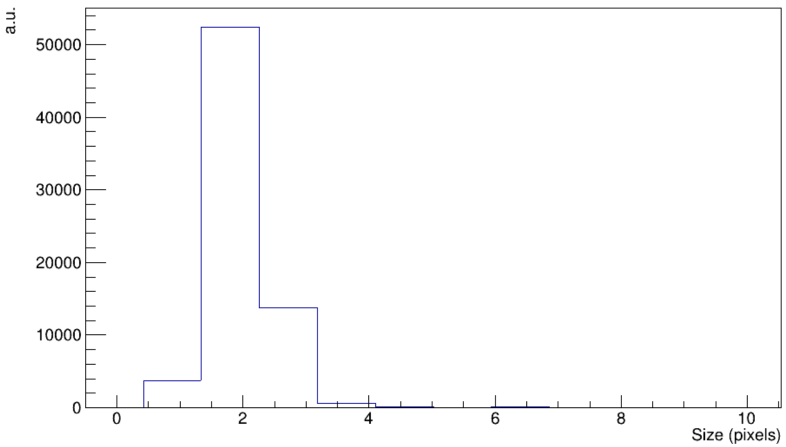




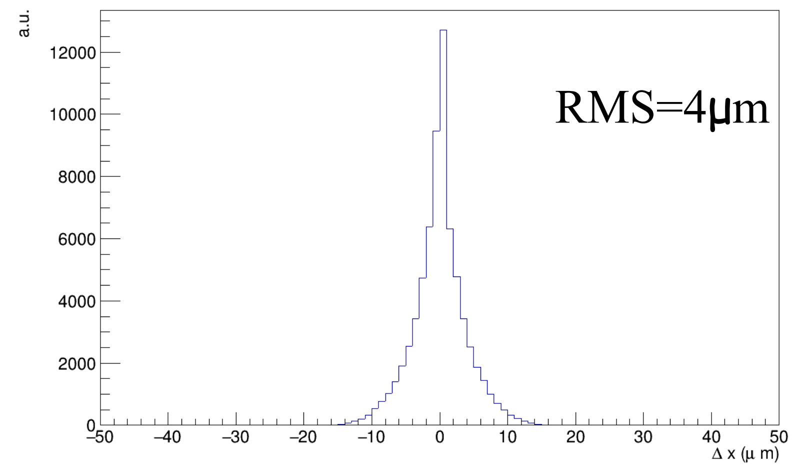
Position determination

- Simple averaging of individual hits positions (note: 25 µm * sqrt(12) ~ 7 µm)
  - Future: use charge information of external pixels for slightly better accuracy
- Note: current smearing-based method assumed 5µm

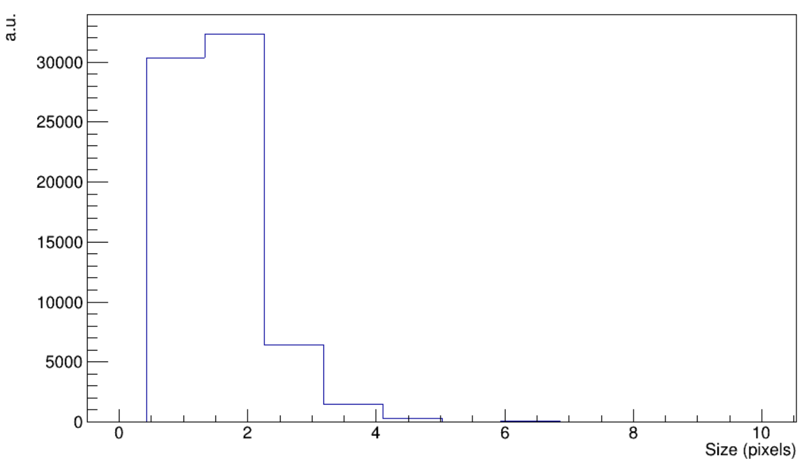
Cluster size in X direction



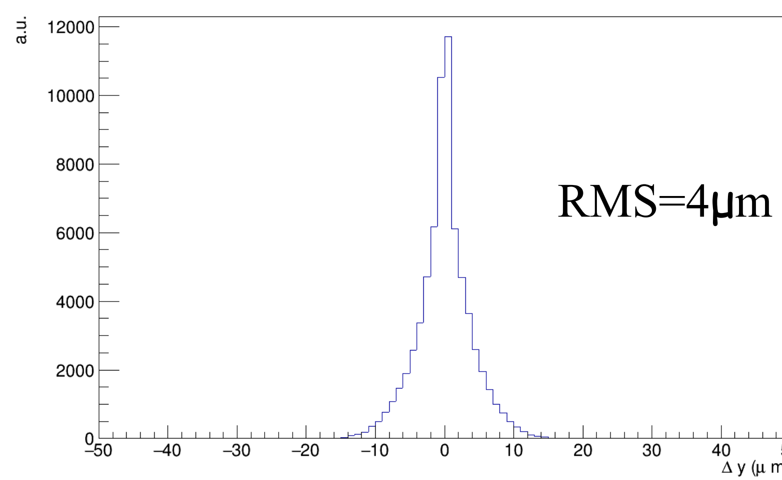
Cluster position X (reco - true)



Cluster size in Y direction

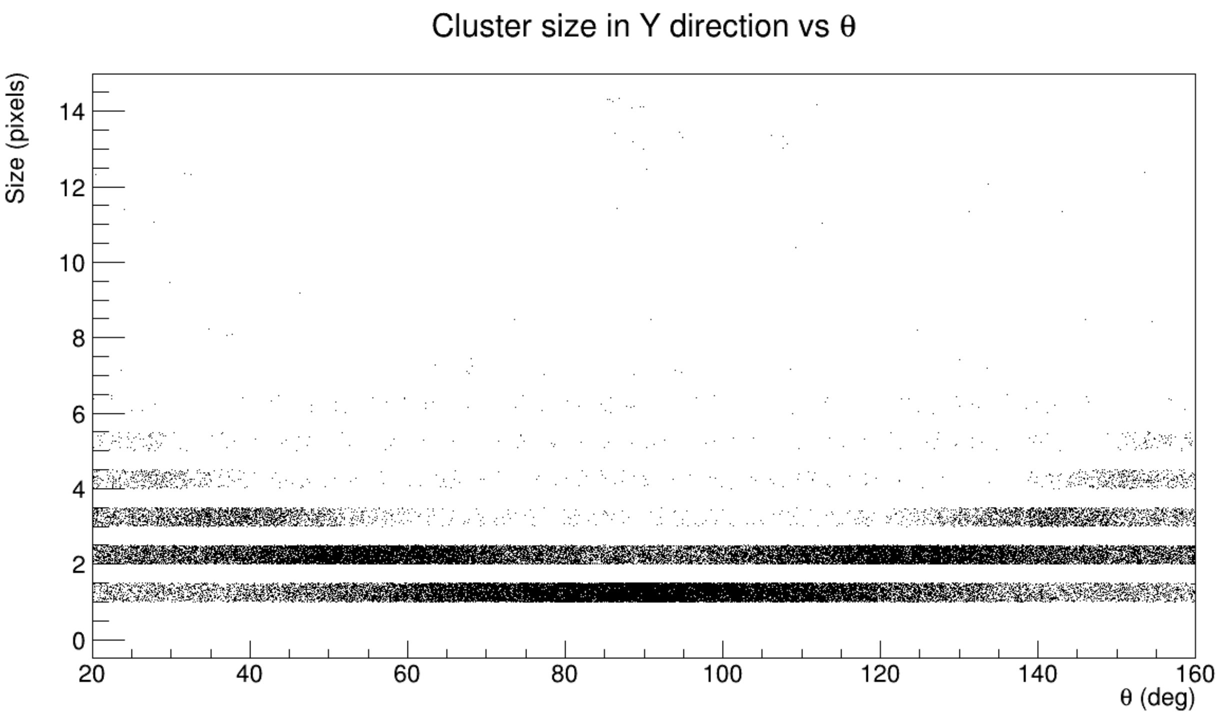


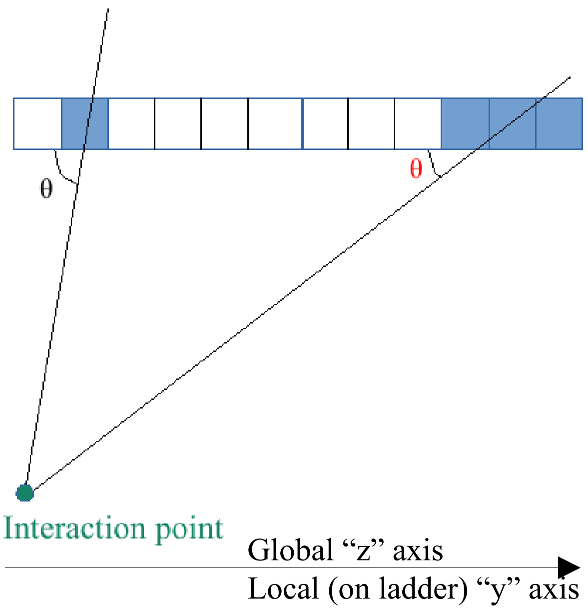
Cluster position Y (reco - true)



Hits filtering

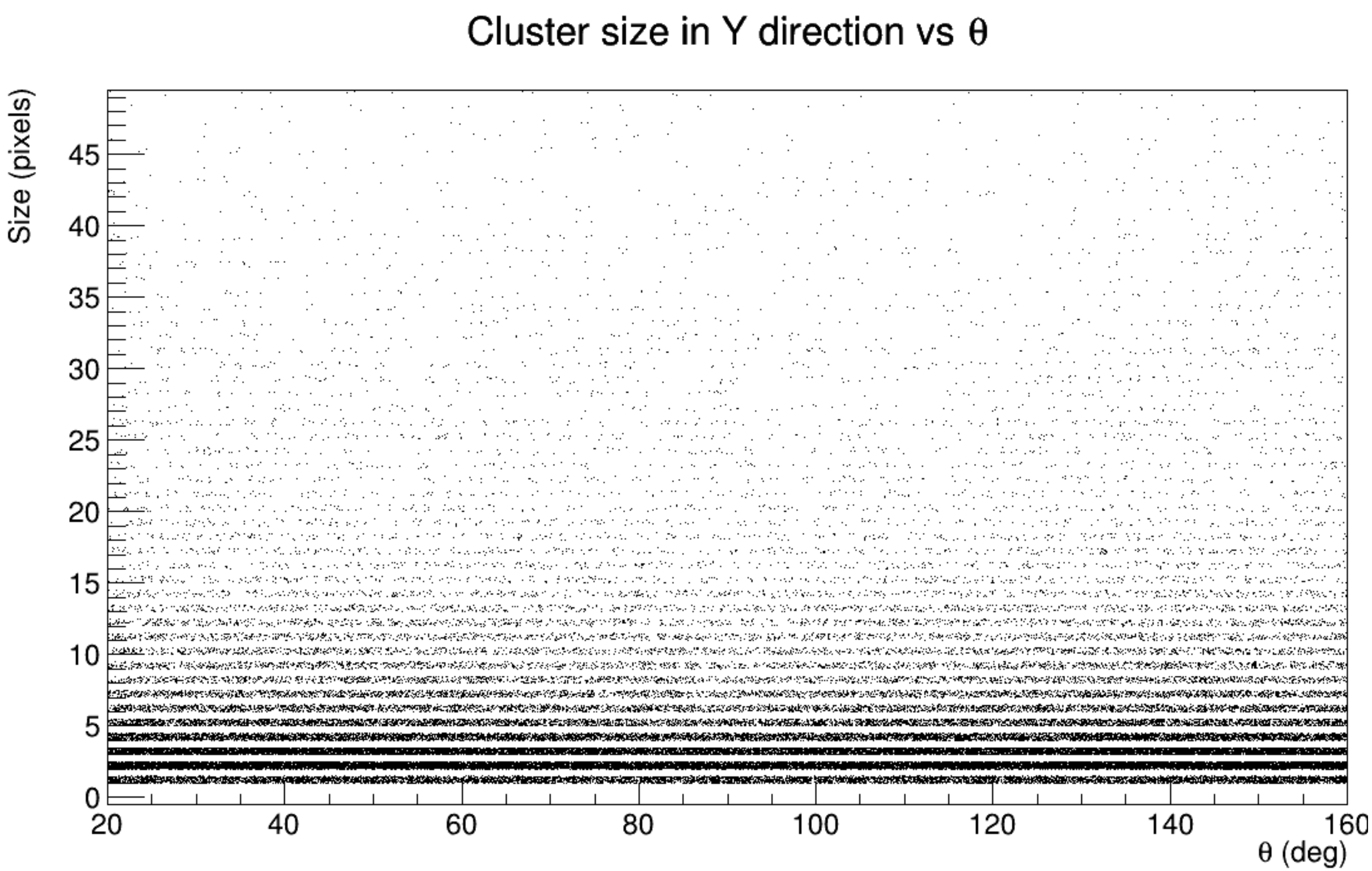
- Ultimately, would like to study discrimination based on released energy and cluster shapes of signal vs beam-induced background
- Below, the clear correlation of size vs theta for prompt muons
  - Simple geometrical effect: larger incidence angle on sensor → longer path
  - Expect BIB to be quite different (see next)





BIB simulation

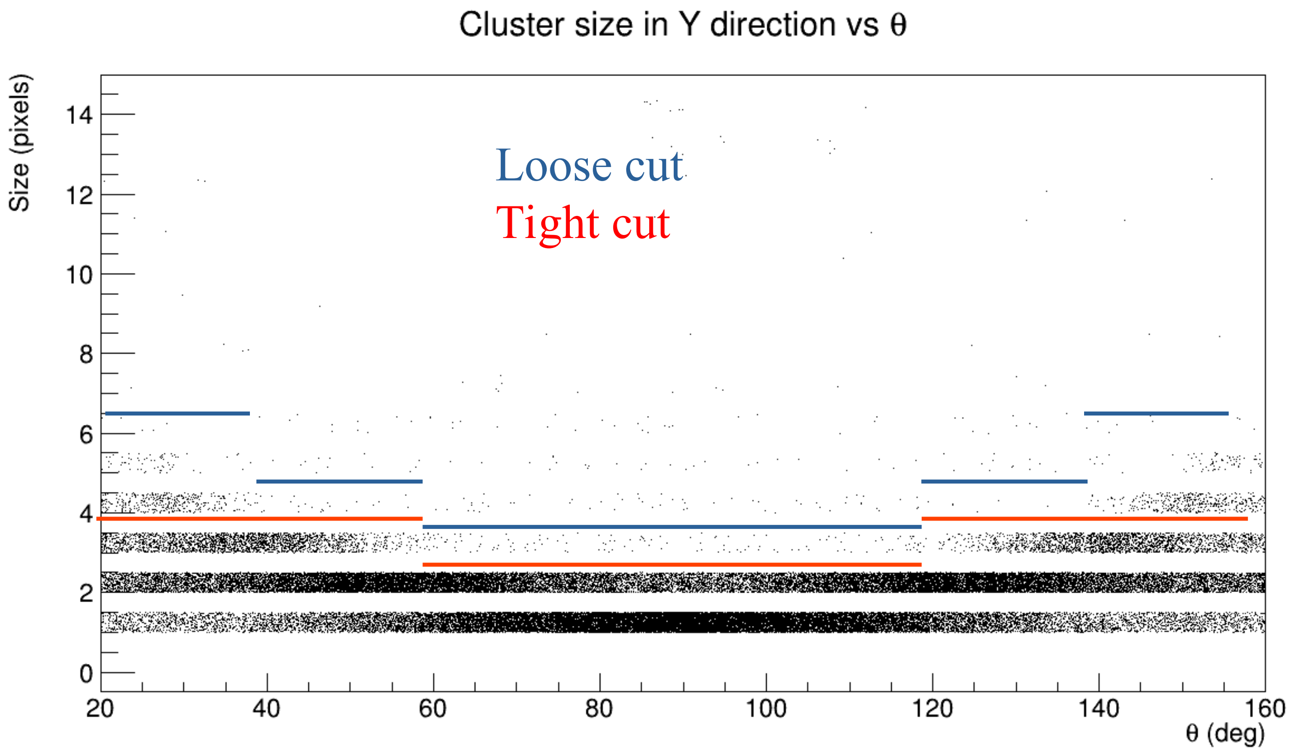
- 100 single-μ events, 30 BIB bkg events (1% BIB)
  - Interested in BIB distribution overall, does not matter if digitized in single or multiple events at this stage (over multiple events requires less RAM)



Uniform vs theta and longer clusters from BIB

Simple size Y selection vs theta

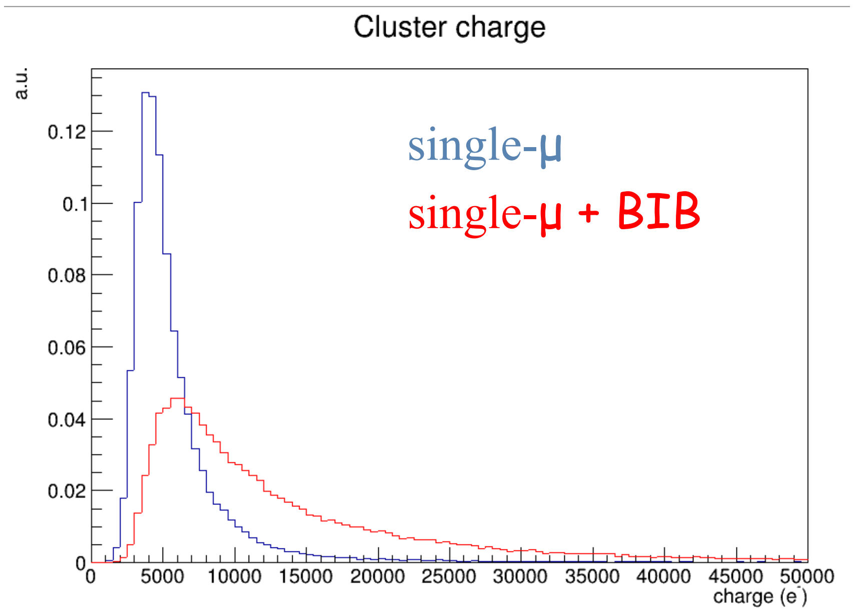
Cut Efficiency	Loose	Tight
Single muon	99.4%	75.0%
Single muon + BIB	63.5%	42.9%

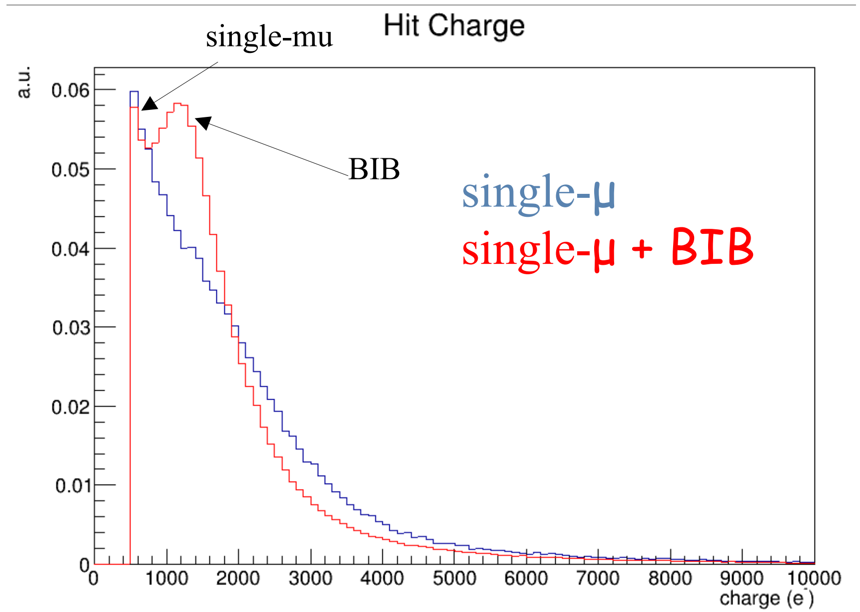


Note: single-muon is uniform in cos(theta)

More discrimination..

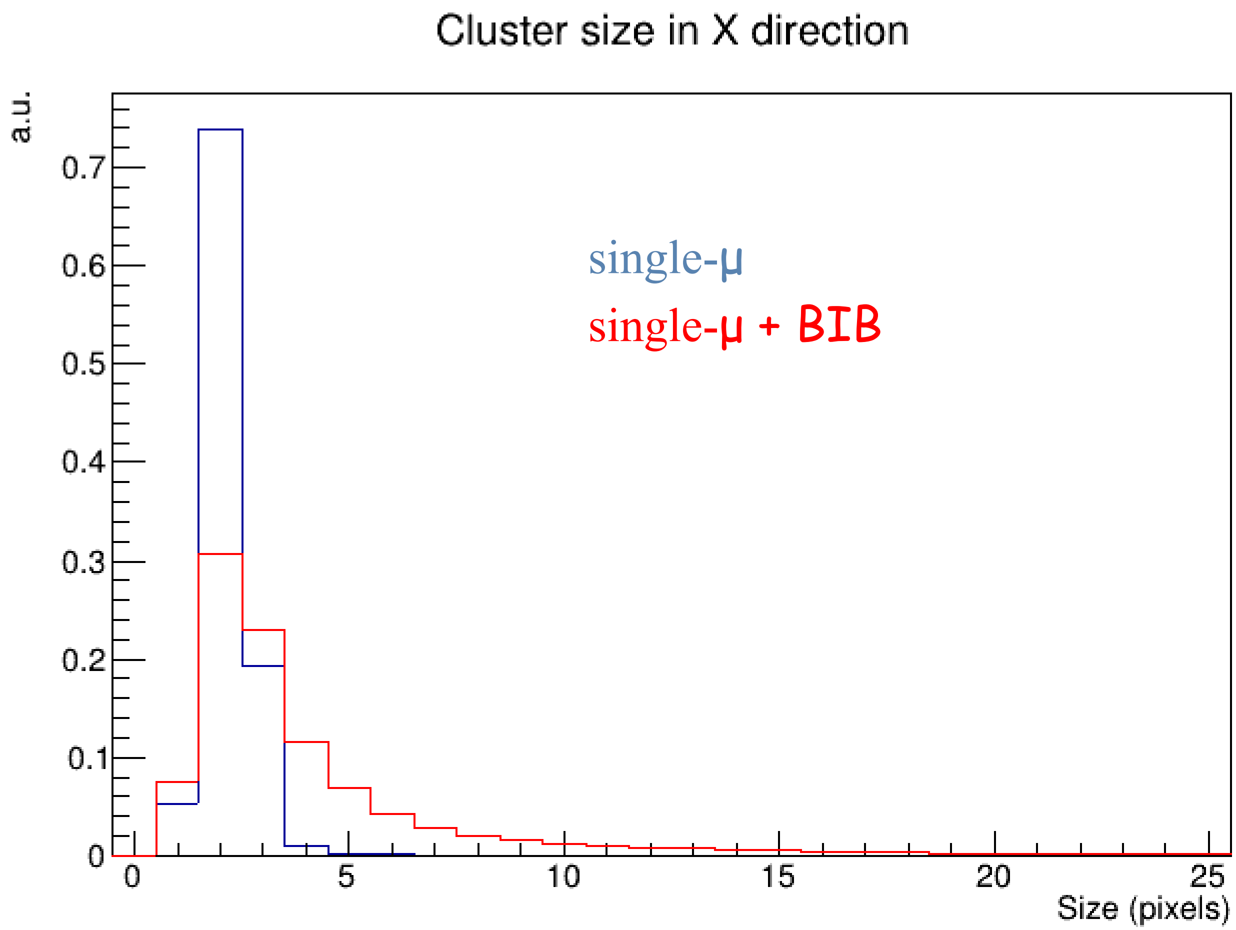
- Some discrimination also from deposited energy, however:
  - Not enough for a plain cut
  - Need to be careful to not penalize low-βγ particles
- Still, could be a useful quantity in pre-tracking filtering for a first pass
  - TODO: will explore combining this and size information in a smarter way





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 developments to the digitization code as e.g.:
  - Realistic charge measurement resolution, implement threshold dispersion
  - Implement digitization of time measurement (parametric)
  - Run/validate realistic digi for VXD endcap as well
  - Create new job config and evaluate running time on BIB to propose a viable config
  - … and much more
- Main message:
  promising additional separation power from cluster shapes
- Two more people ramping up at LBL (Elodie – postdoc – and Rohit – undergraduate student) will help in the development and studies

Backup

- Single pixel collected charge above threshold (500 e^-)