Towards a realistic Si digitization for the μ-collider detector

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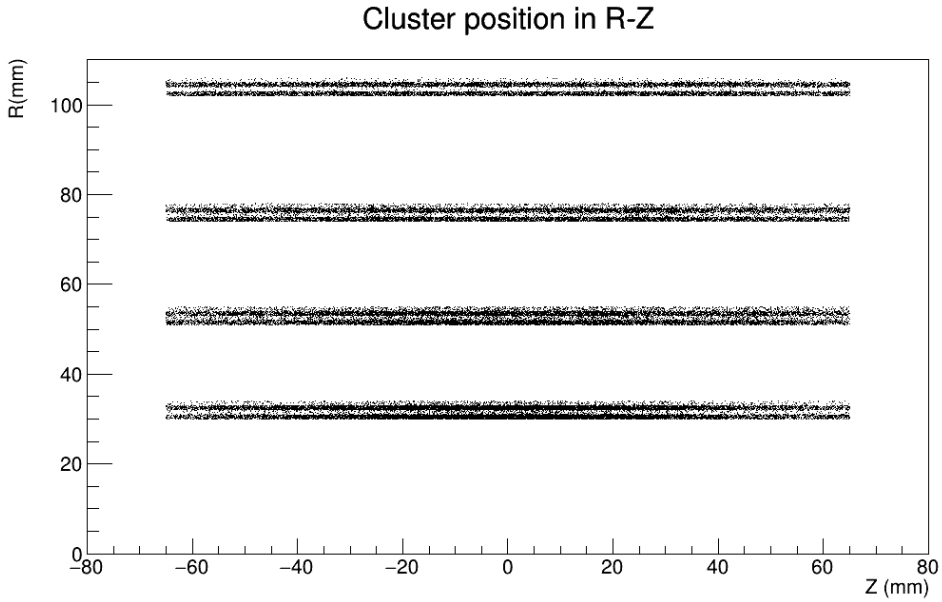
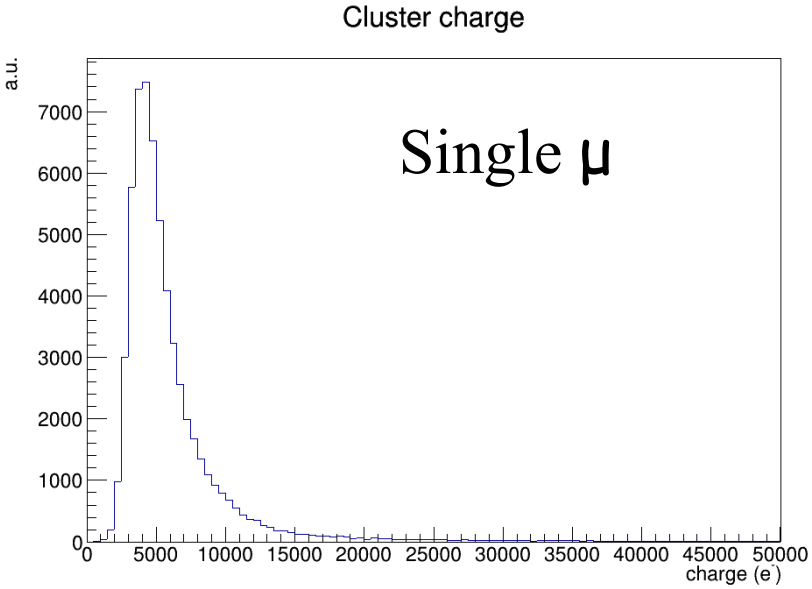
Reminder

- First validation of realistic silicon digitization (see later for TODO items)
  - Only vertex detector barrel considered so far (highest density)





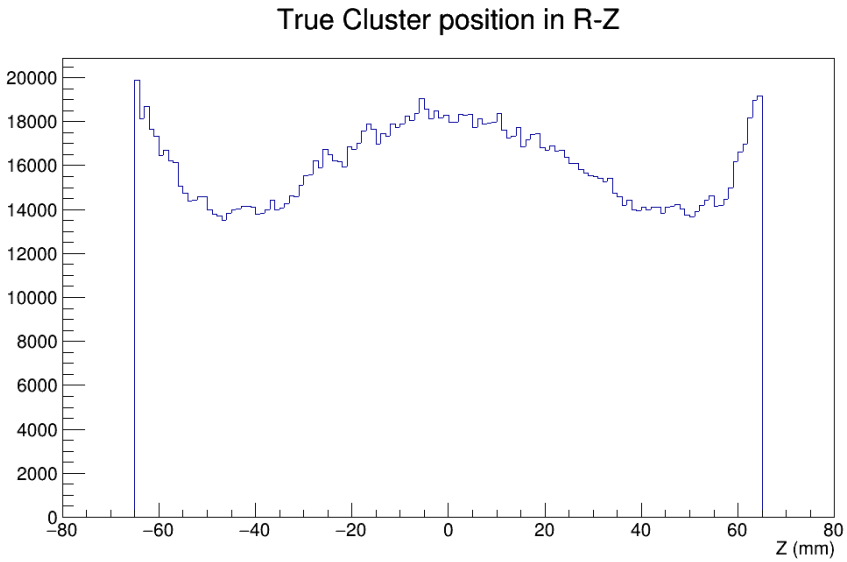
- Using two main samples:
  - Single muon E = 10 GeV (uniform in theta in the VXD barrel)
  - Same as above + BIB (now @ 100%)

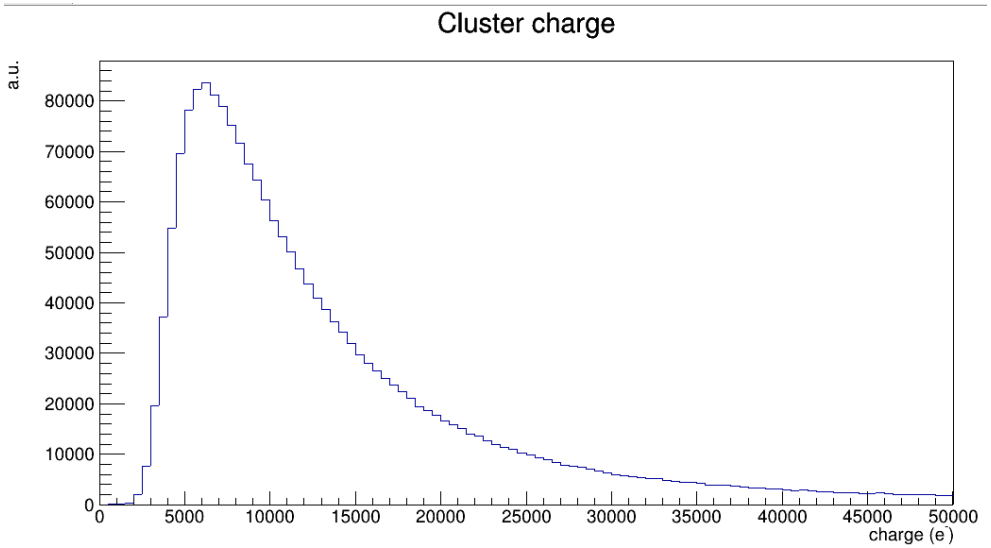
BIB overlay

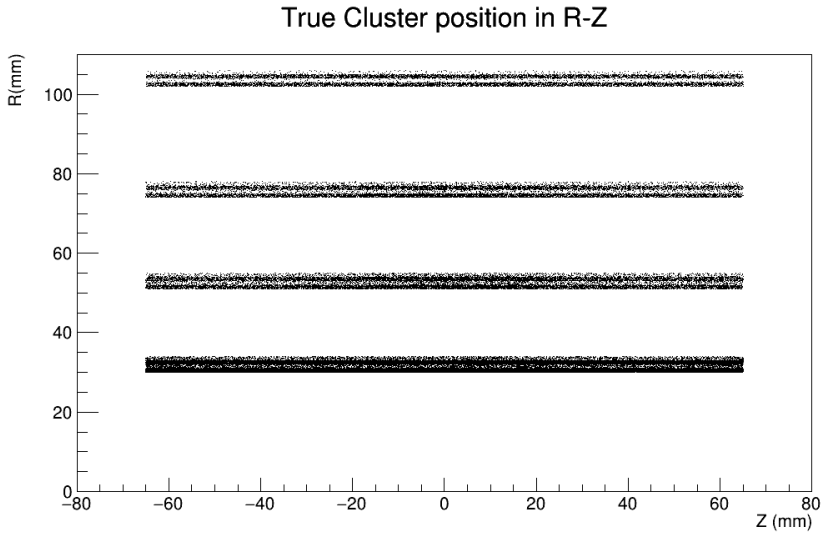
- Moved to new BIB files from Massimo
- Fix to Overlay module for truth info:
  - Allows to strip MCParticle but store momentum of particle on truth hits that is needed for digi (also resets MCParticle pointer that otherwise becomes invalid)
- Caveat: Overlay module select random files one after the other
  - Need to merge mu+/mu- BIB files such that each file has one complete BIB event OR have only one input BIB event (thanks to Karol for digging into this!)
  - Corollary: using only a fraction of BIB actually gives an heavy-biased BIB distribution
- Other changes:
  - LCTuple: allows to store hits information (PR in progress)

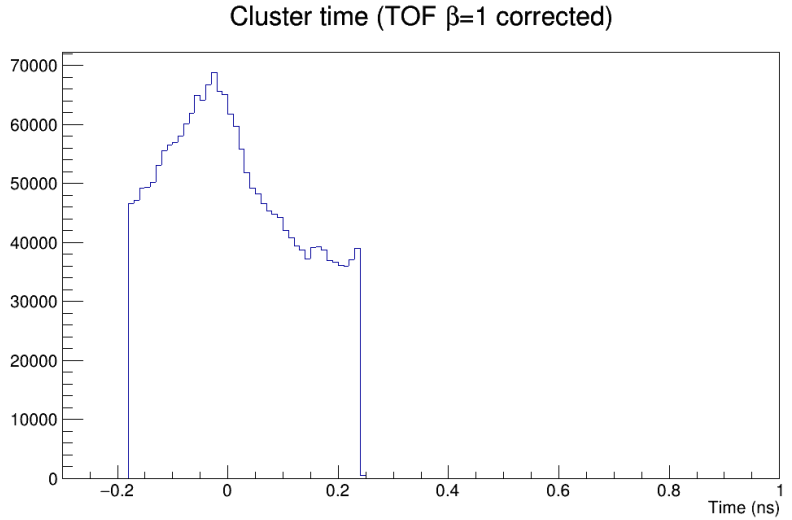
Additional BIB validation

- Checked that BIB is reasonably symmetric in Z









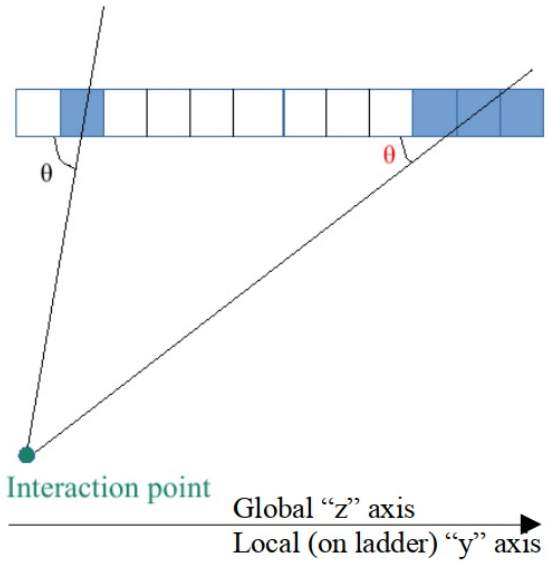
Prompt vs BIB separation

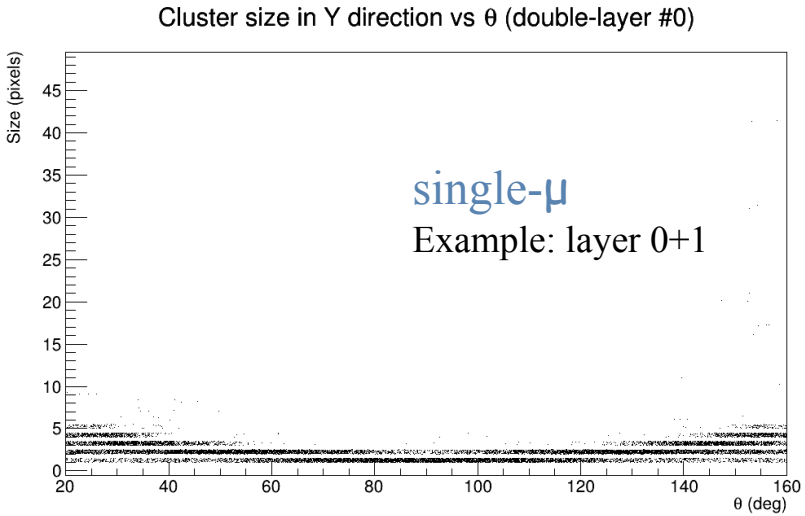
- New: added timing cuts to hits before considering size-Y vs theta separation

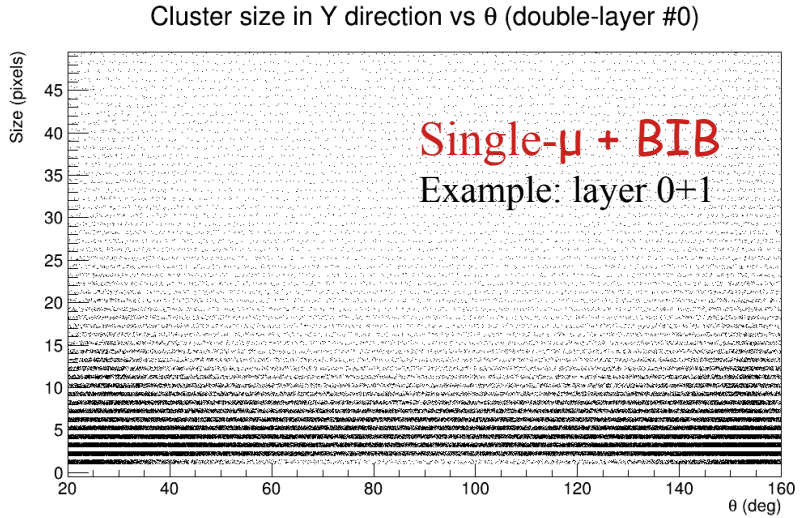
```
<parameter name="Collection_IntegrationTimes" type="StringVec" >

  VertexBarrelCollection -0.18 0.24
  VertexEndcapCollection -0.18 0.24
```

- Separated size cuts in theta ranges and layers
  - Note: theta calculated from vector "reconstructed cluster position" – "Int. point"







Separation power

- Cuts chosen to retain high efficiency for prompt particles “by eye”

loose/tight cut size-Y <= X/Y	Layer 0,1	Layer 2,3	Layer 4,5	Layer 6,7
$0<\theta^*<30°$	2/2	2/2	2/2	3/2
$30<\theta^*<50°$	3/3	3/3	3/3	3/2
$50<\theta^*<70°$	6/5	4/4	3/3	4/2
$70<\theta^*$	--/5	--/5	--/3	--/3

- Performance in single muon and BIB for Loose/Tight cuts:

Cut Efficiency	Loose	Tight
Single muon	99.7%	99.6%
Single muon + BIB	55.2%	43.7%

— Main difference from last time:
  - New BIB files, and fixed overlay “random file” selection
  - Applying tight timing cuts before evaluating these efficiencies
  - New granularity of size-Y cuts

TODO

- Today: some additional separation power studies and small fixes

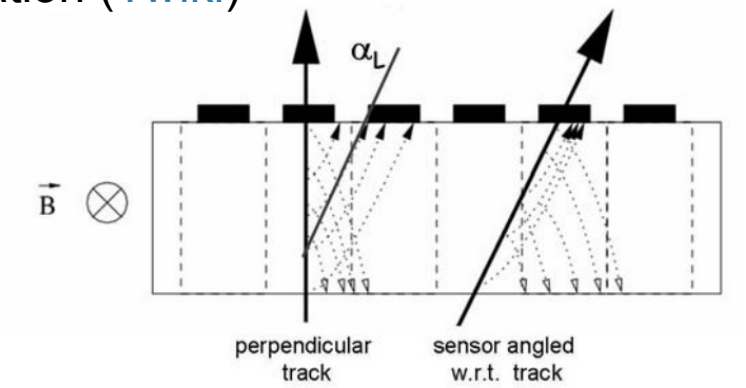
- Work-in-progress / important todo in digi:
  - Discretization of measured charge (finite resolution, 4 bits in current FE chips) [Elodie]
  - Threshold dispersion (not all pixels can be tuned exactly at the same thr) [Elodie]
  - Parametrized time measurement digitization → right now just true G4 timing [Elodie/Simone]
  - 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 [Paolo/Alessio]

- Work-in-progress / important todo in separation power studies:
  - Use additional information (size X, energy?) [Rohit]
  - Test with different particles (protons, …) [Rohit]
  - Test with realistic beamspot [Rohit/Simone]
  - Test with non-prompt particles (e.g. for b-hadron decay) [Rohit/Simone]
  - Implement tool for filtering hits [Simone/Rohit]
  - Prepare reco steering file with realistic digi in VXD + hits filtering option [Simone]

BACKUP

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)

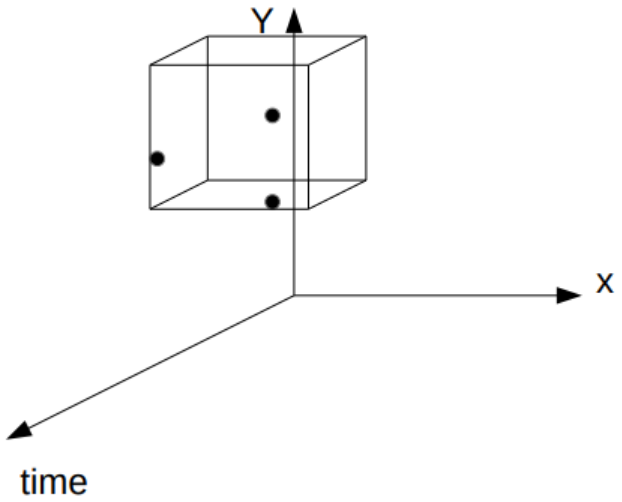


- Main effects not yet included (very much ok for a start):
  - Discretization of measured charge (finite resolution, 4 bits in current FE chips)
  - Threshold dispersion (not all pixels can be tuned exactly at the same thr)
  - Parametrized time measurement digitization → right now just true G4 timing
  - 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