Improved calorimeter reconstruction at Muon Collider

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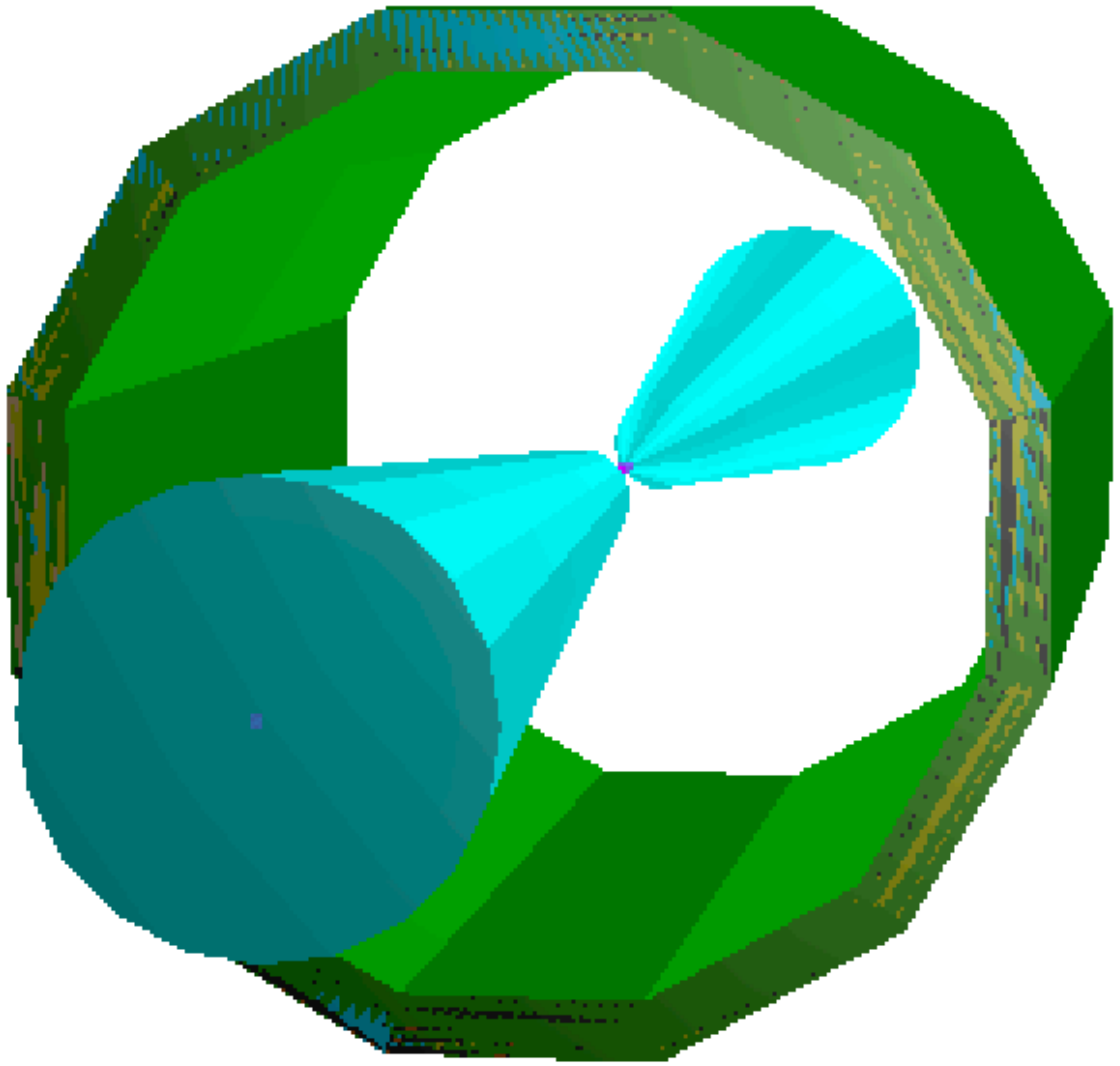
Detector performance and MDI meeting, 11/4/2023

Introduction

- In this talk: **photon reconstruction with the PbF_2 semi-homogeneous calorimeter Crilin**
- An optimized strategy for BIB mitigation has been defined
- The integration time is discussed for the first time with the full simulation
- Results are compared with the photon reconstruction configuration reported in the EPJC paper: https://arxiv.org/pdf/2303.08533.pdf where the W-Si calorimeter designed by CLIC is used

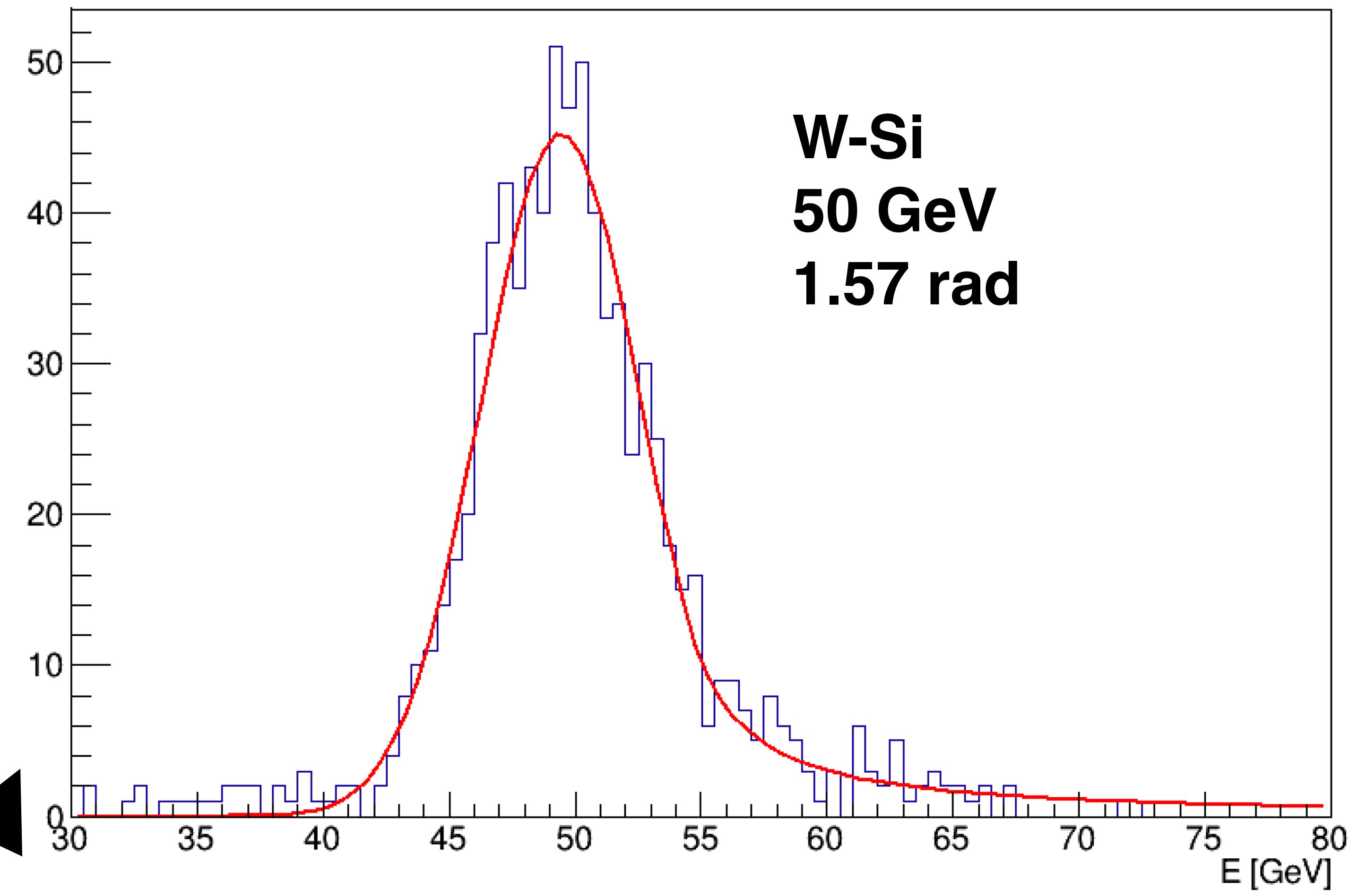
Detector

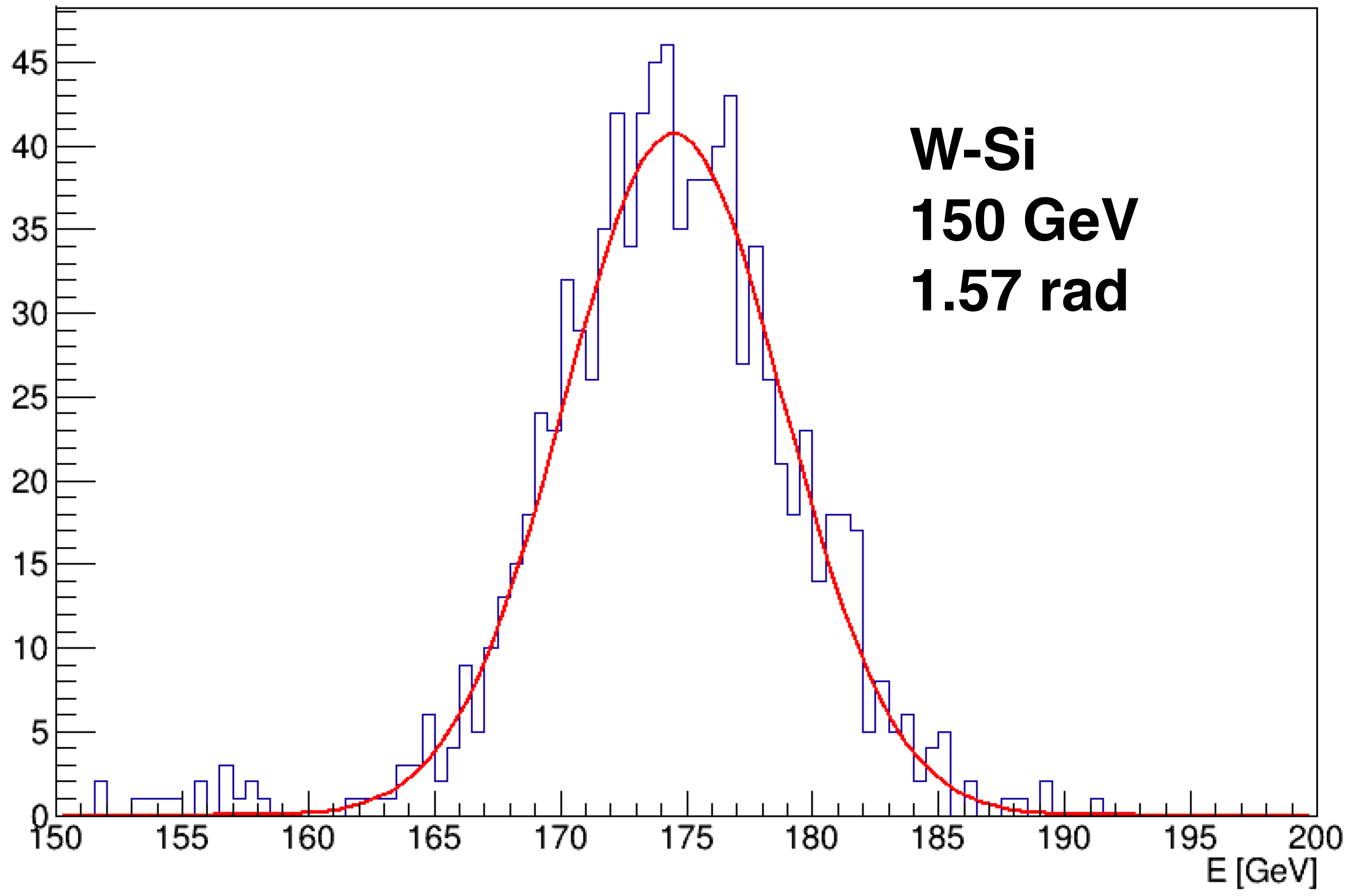
- The **ECAL barrel** with Crilin technology has been implemented in the Muon Collider simulation framework
- As for the other detectors, the implementation is done with the DD4HEP interface to Geant4
- **It is longer than previous studies**: from 40 mm length cell to 45 mm, to increase the number of X_0 (from 18.8 to 21.5)
- 5 layers of 45 mm length, 10 X 10 mm^2 cell area. Dodecahedra geometry
- In each cell: 40 mm PbF_2 + 3 mm SiPM + 1 mm electronics + 1 mm air



Methods

- The procedure in applied to both Crilin ECAL and W-Si ECAL
- Photon gun at 8 different energies * 3 angles wrt z-axis:
  - 10,25,50,75,100,125,150,175 GeV
  - 1.05, 1.31, 1.57 rad
- 1000 signal events per point. 1 full BIB bunch-crossing at 1.5 TeV for Crilin, 1000 BIB bunch-crossing for W-Si
- Simulation with ddsim of both signal and BIB
- Signal+BIB overlay with Marlin
- Digitization+Clustering with Marlin: DDCalo_Digi + PandoraPF
- A calibration function is applied (explained later)
- For each energy point, the cluster energy distribution is fitted with a double-side Crystal Ball: <E> and σ are extracted

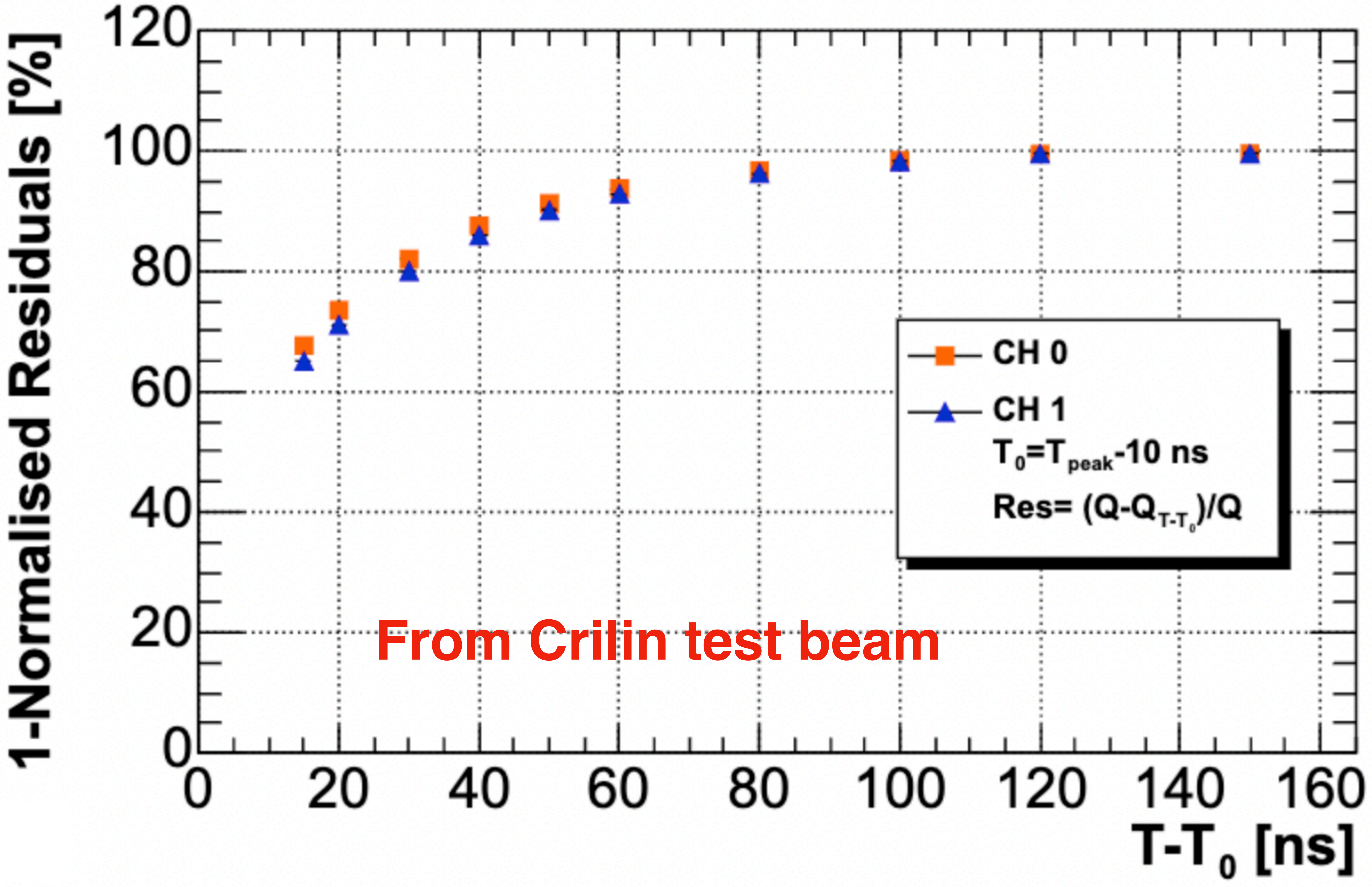




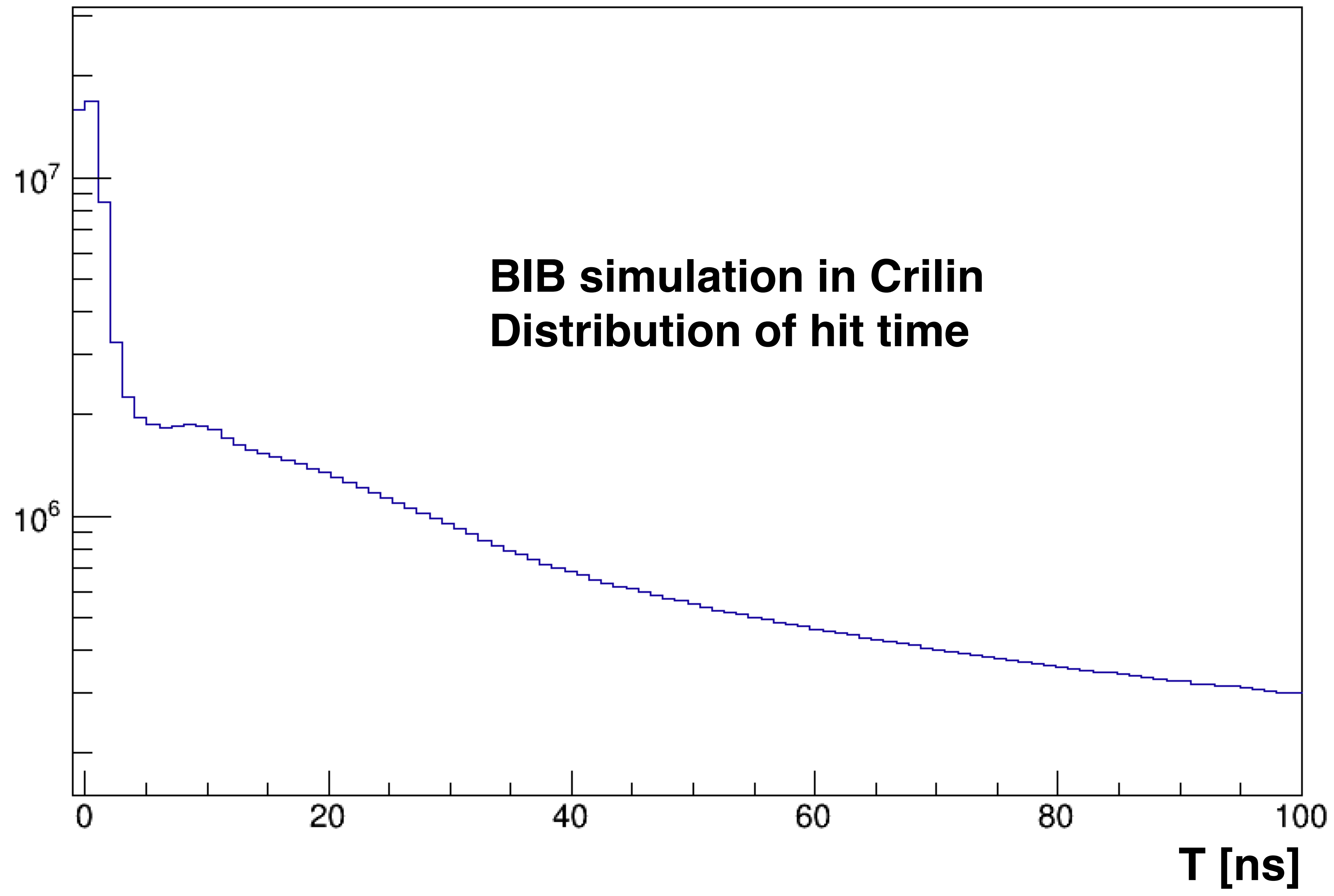
Integration time

- The integration time has two main effects

The fraction of signal charge collected



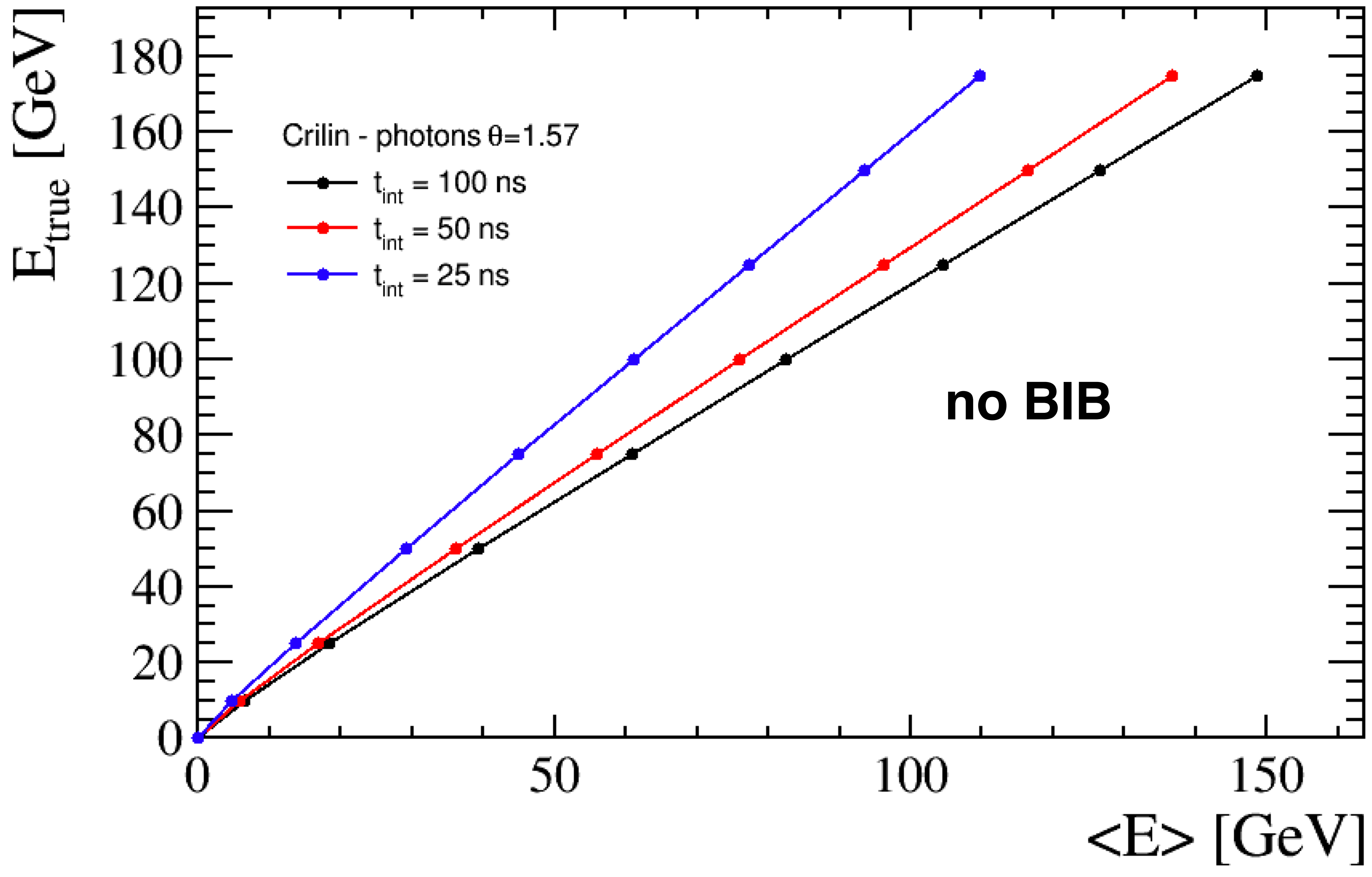
The amount of integrated BIB energy



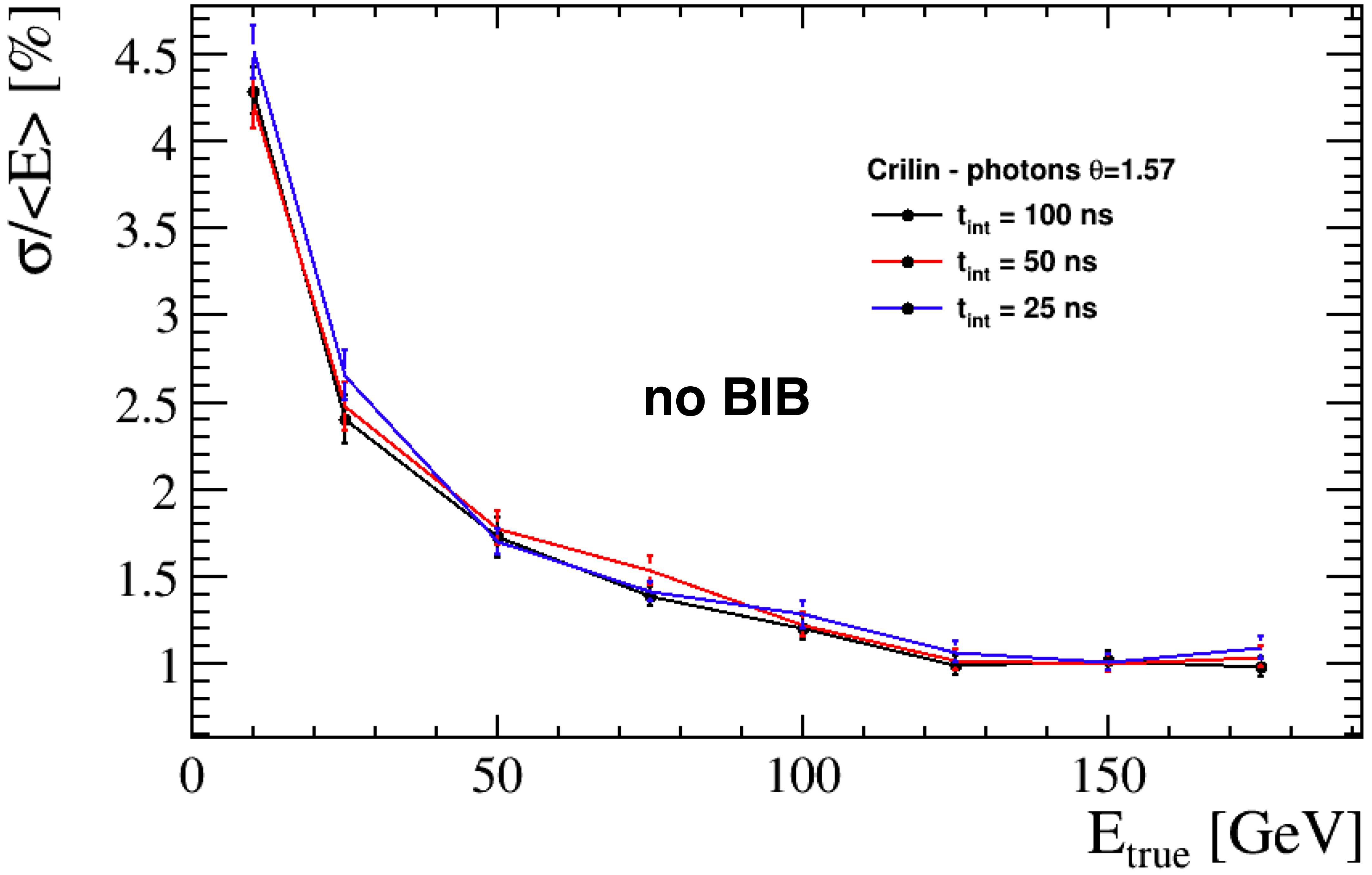
I have implemented these two effects in DDCaloDigi processor (for Crilin)

Integration time (signal)

Calibration curves: true photon energy as a function of the peak <E>

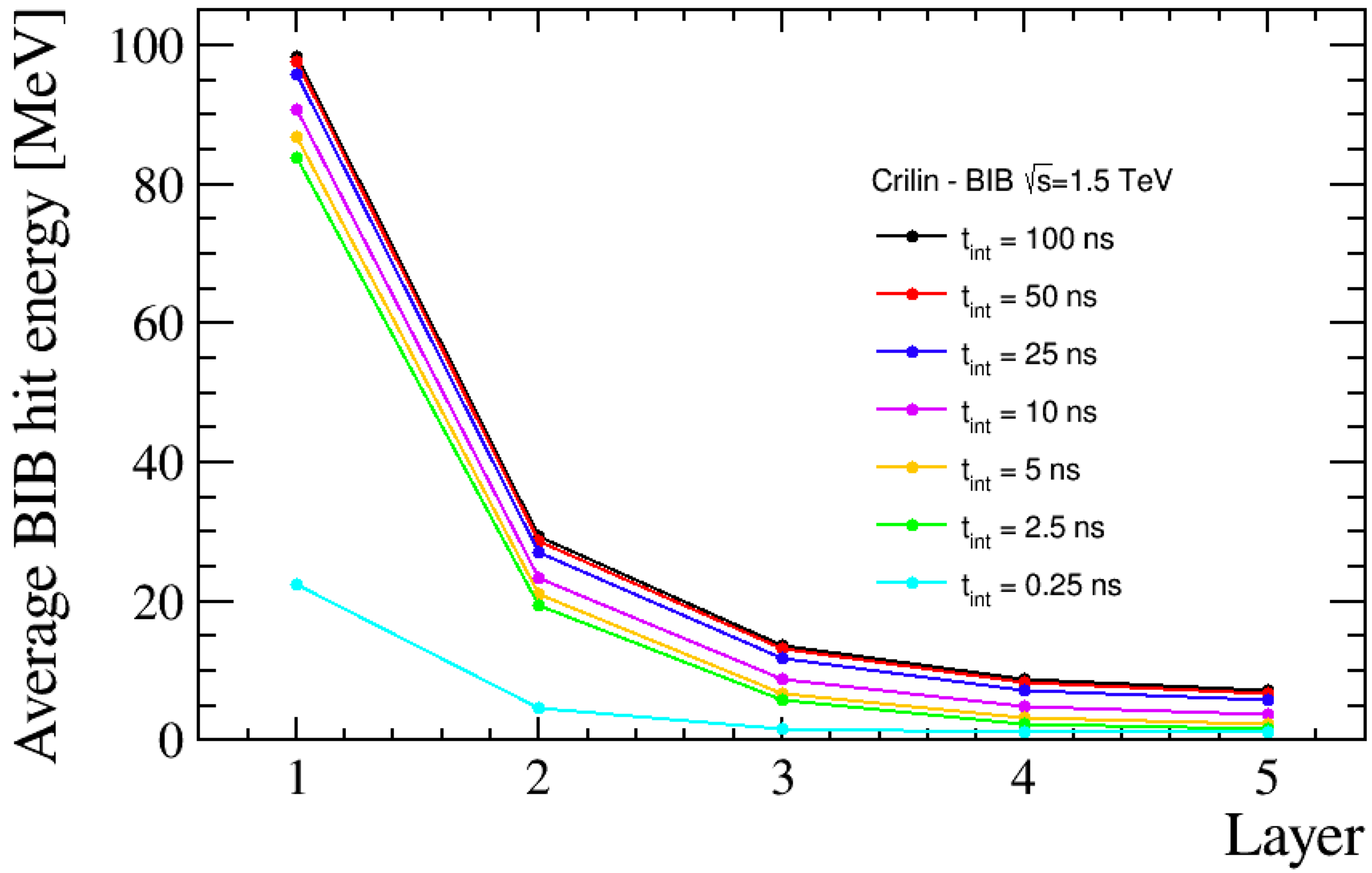


Peak resolution after calibration



After the calibration there is no significant impact on the resolution (no BIB)

Integration time (BIB)



Hits per layer (100 ns) = 17696,18306,18924,19550,19766

Hits per layer (50 ns) = 17696,18306,18924,19536,19752

Hits per layer (25 ns) = 17696,18306,18924,19506,19692

Hits per layer (2.5 ns) = 17696,18305,18485,16927,13922

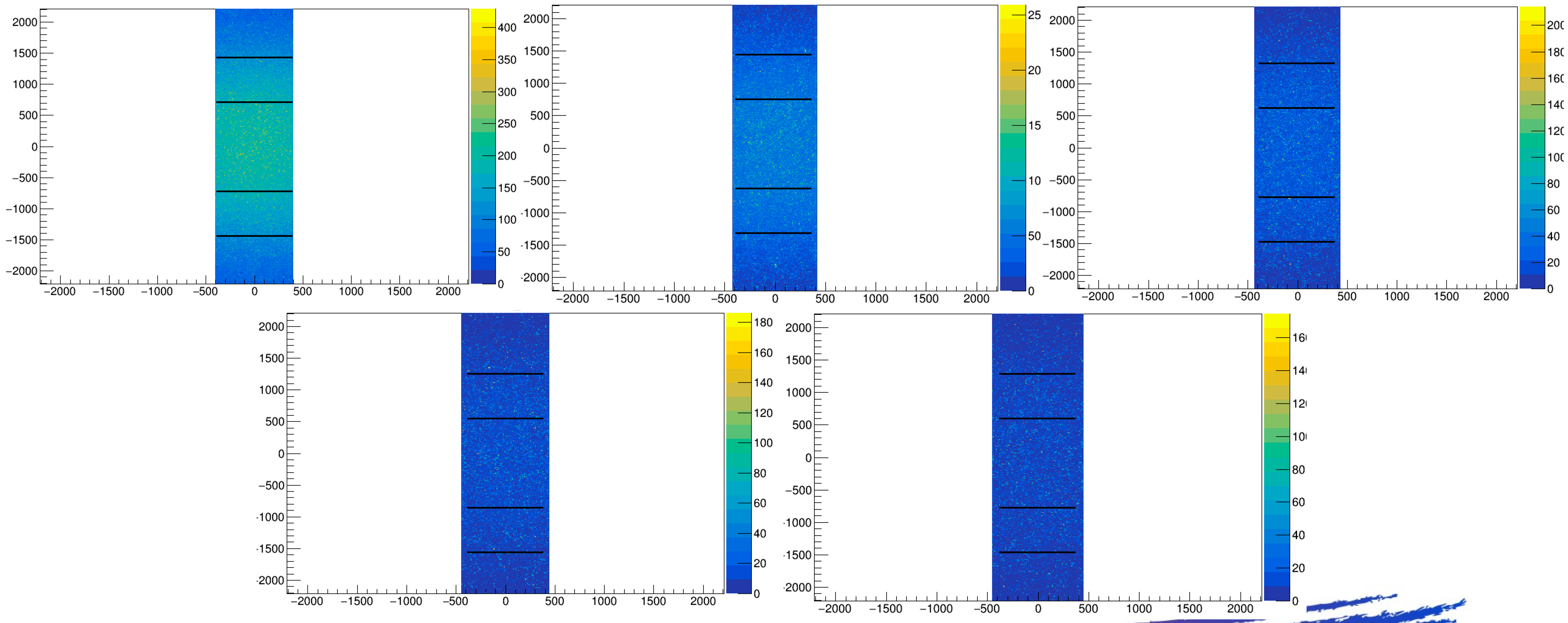
Using 0.25 ns as integration time in the Overlay processor to speed-up the reconstruction leads to an underestimation of the BIB energy

In this study integration time = 25 ns

BIB

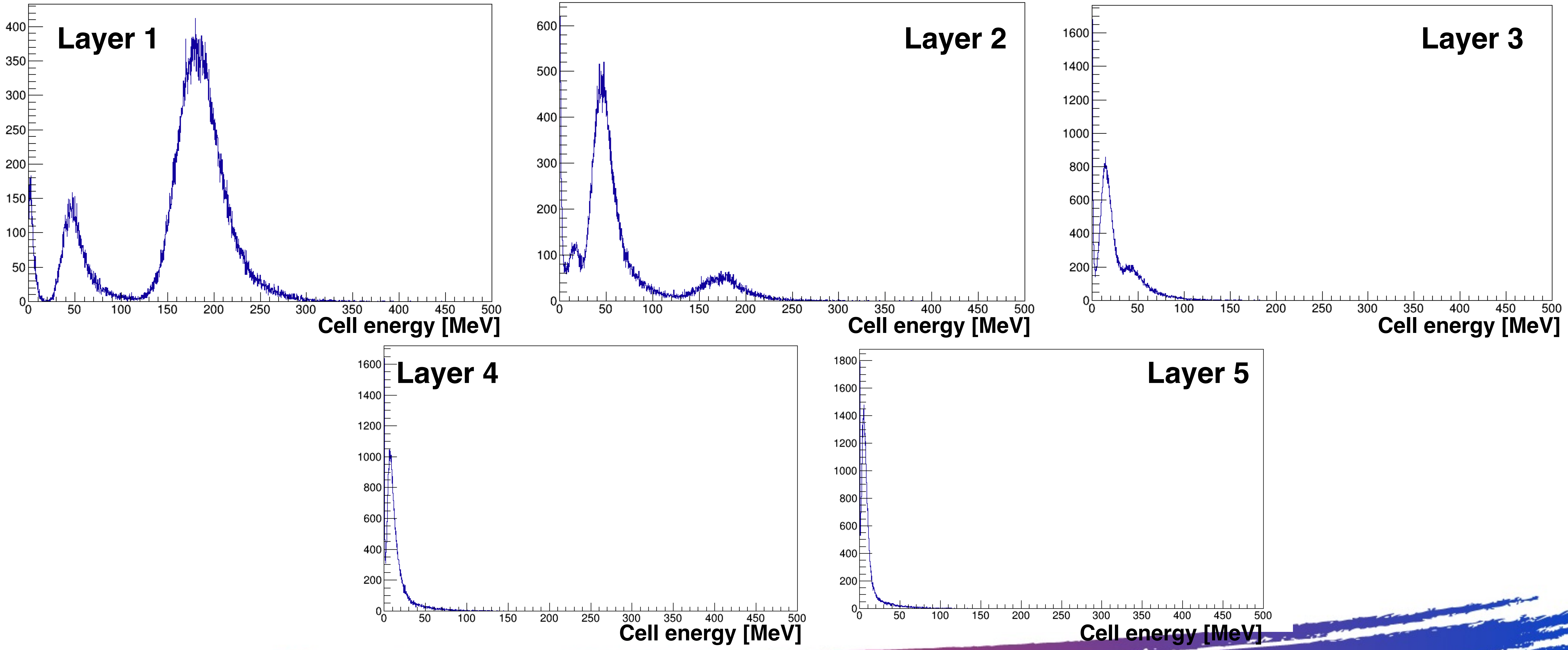
Thresholds

- **Each layer is divided in five regions along z to determine thresholds**



Thresholds

- In each cell the energy of many BIB hits is integrated: cell energy distributions are not trivial
- In this slide the cell energy distributions for the BIB are obtained in the central z region
- It is clear that we have to take profit of the segmentation



Thresholds

- Thresholds are defined as

$$E_{th}(L,Z) = < E_{BIB} > (L,Z) + N \cdot STD_{BIB}(L,Z)$$

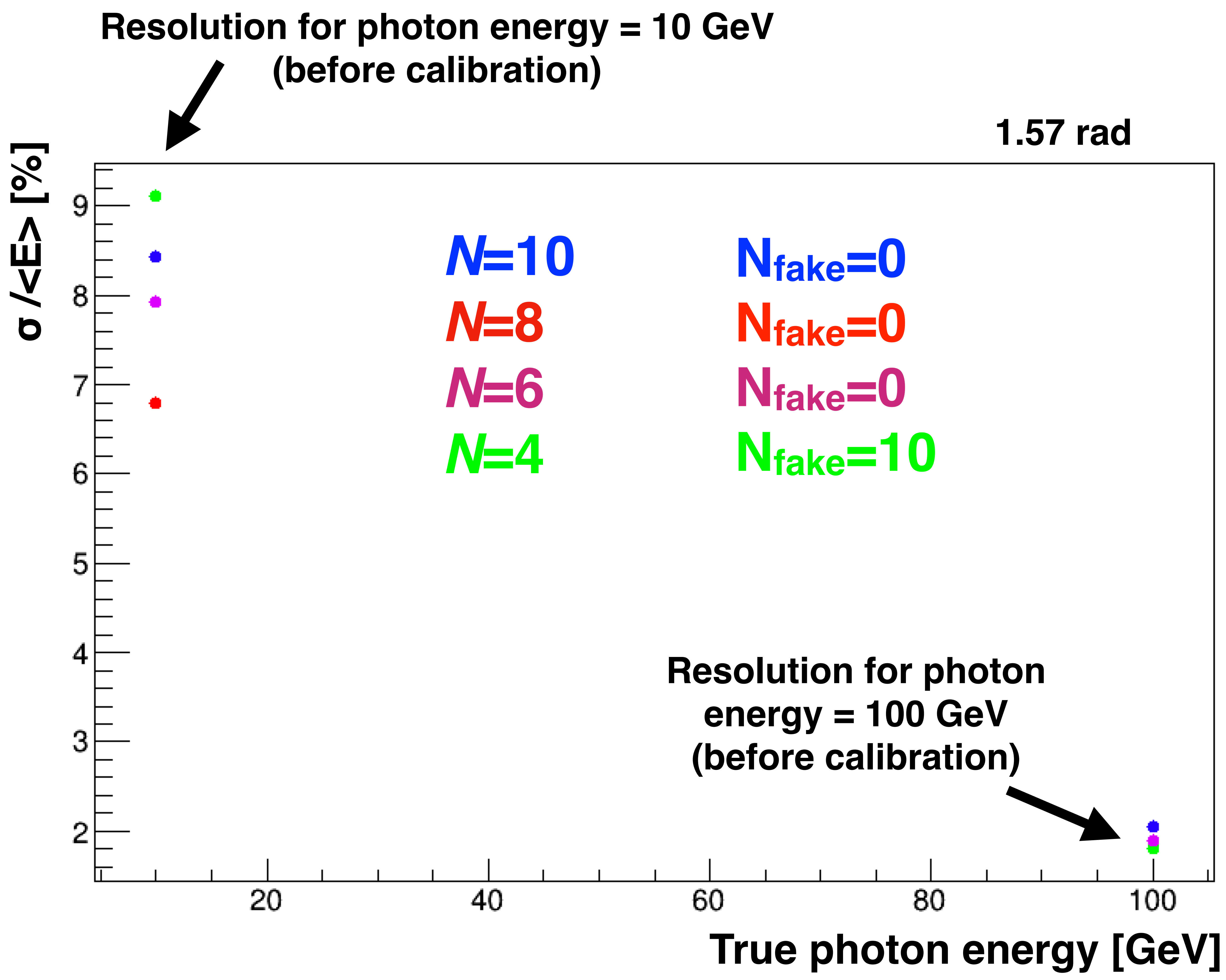
Where ***<E_{BIB}>(L,Z)*** is the average and ***STD_{BIB}(L,Z)*** is the standard deviation of BIB cell energy in **layer *L*** and **region *Z***

N is a parameter to be tuned with Signal+BIB

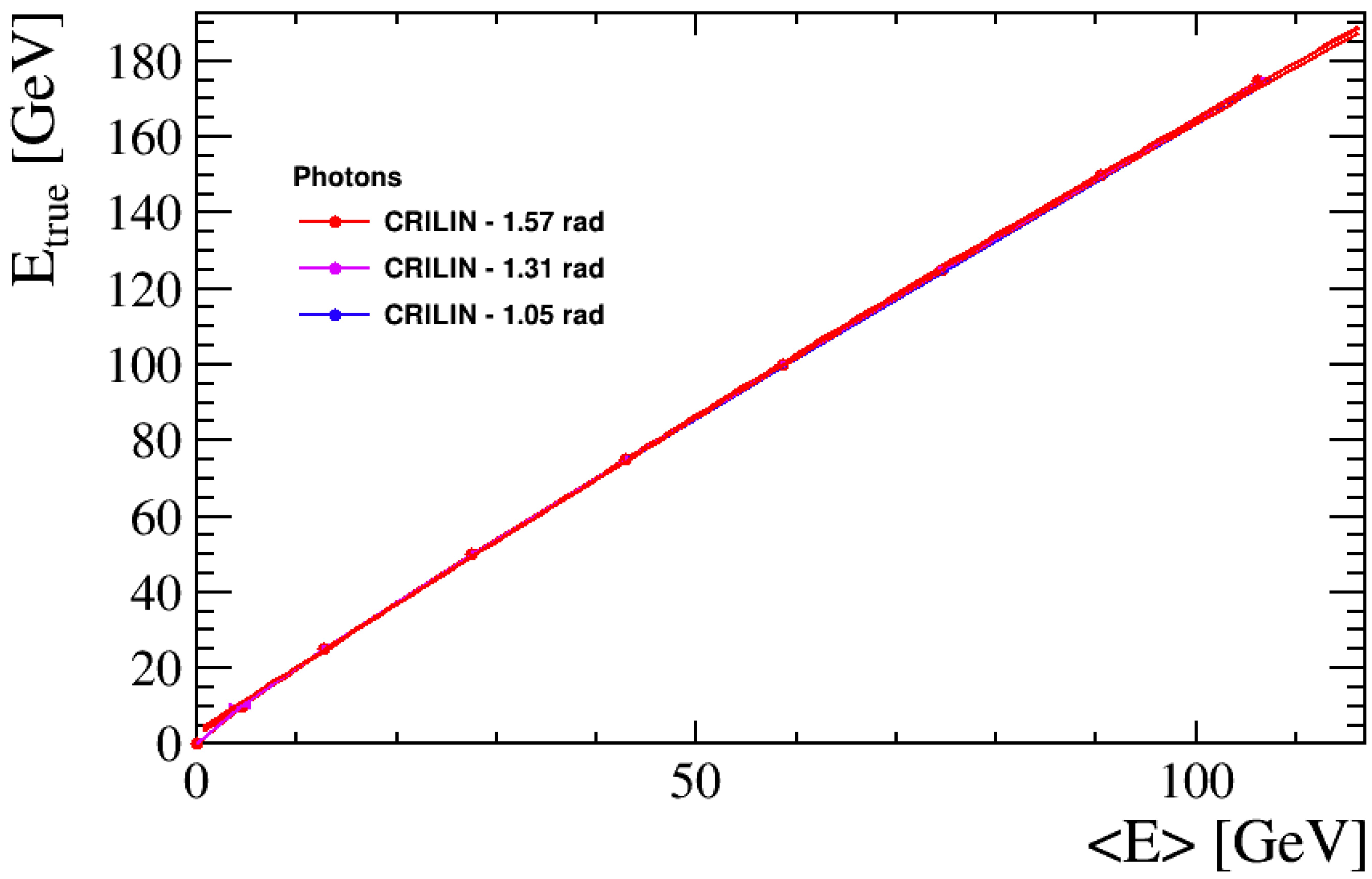
- Lower *N* means higher efficiencies and fake rate

- Not-trivial relation between *N* and peak resolution

***N* = 7 is used**

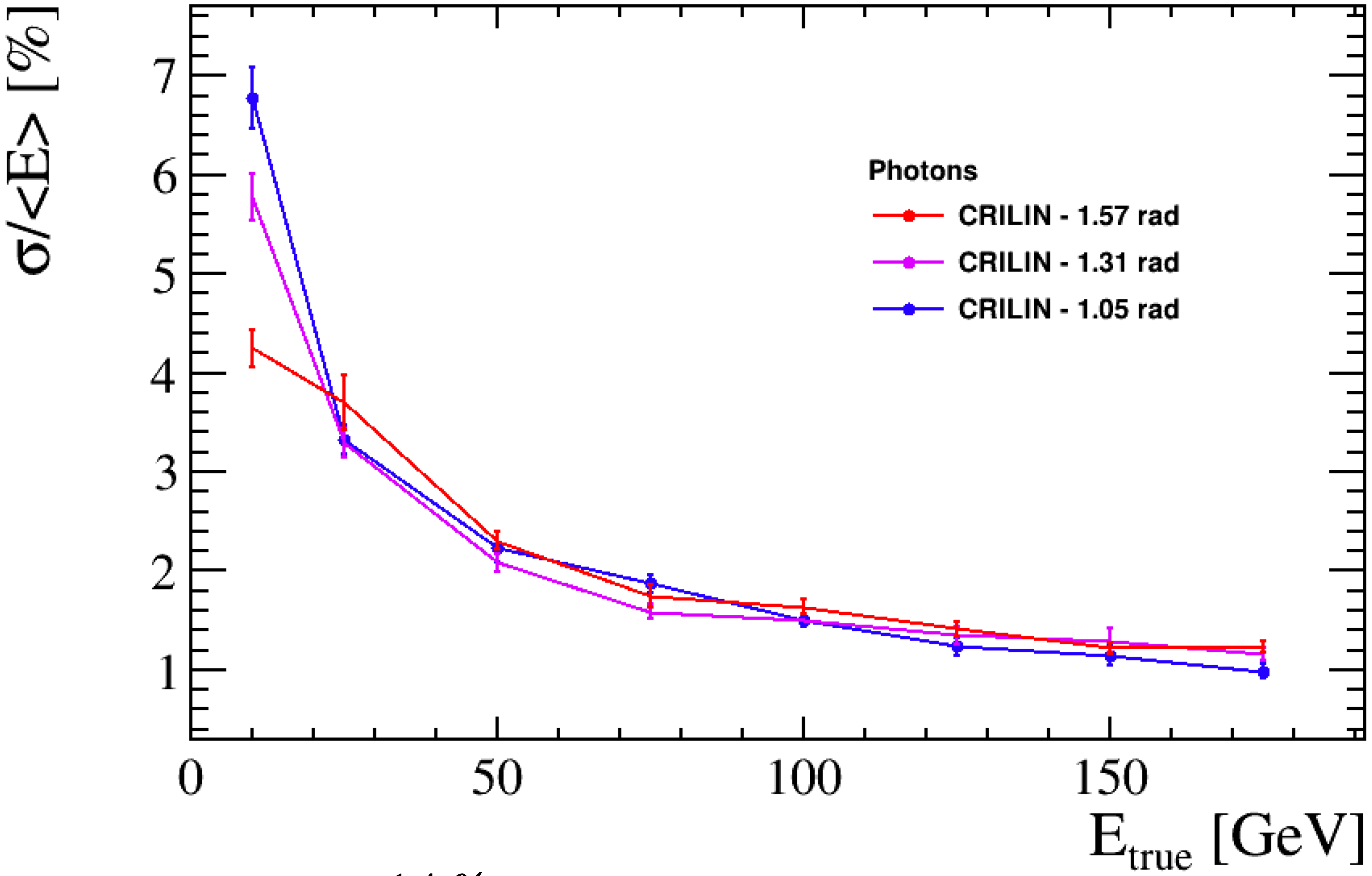


Calibration curves

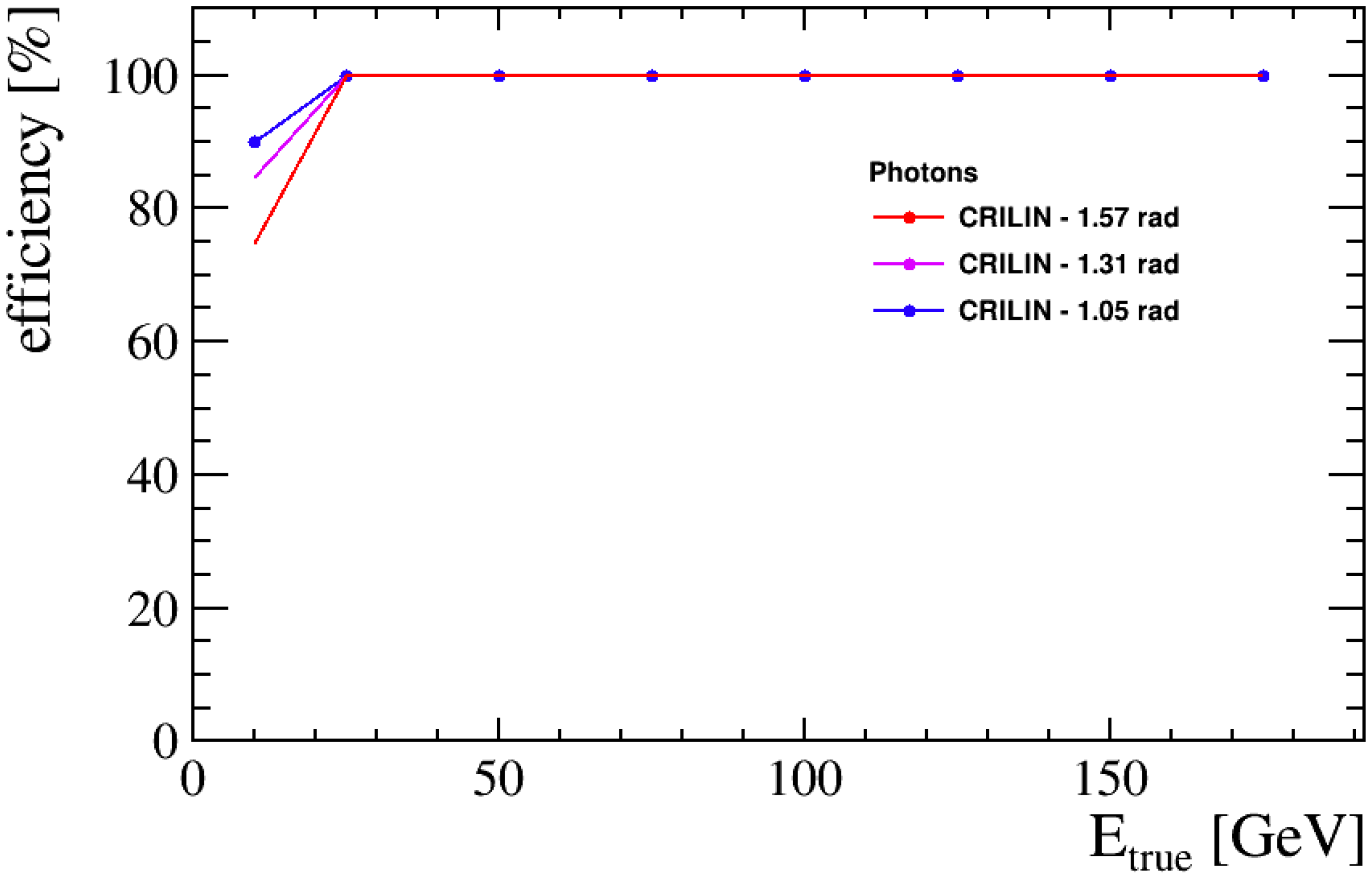


Calibration curves obtained at different angles are compatible

Crilin performance

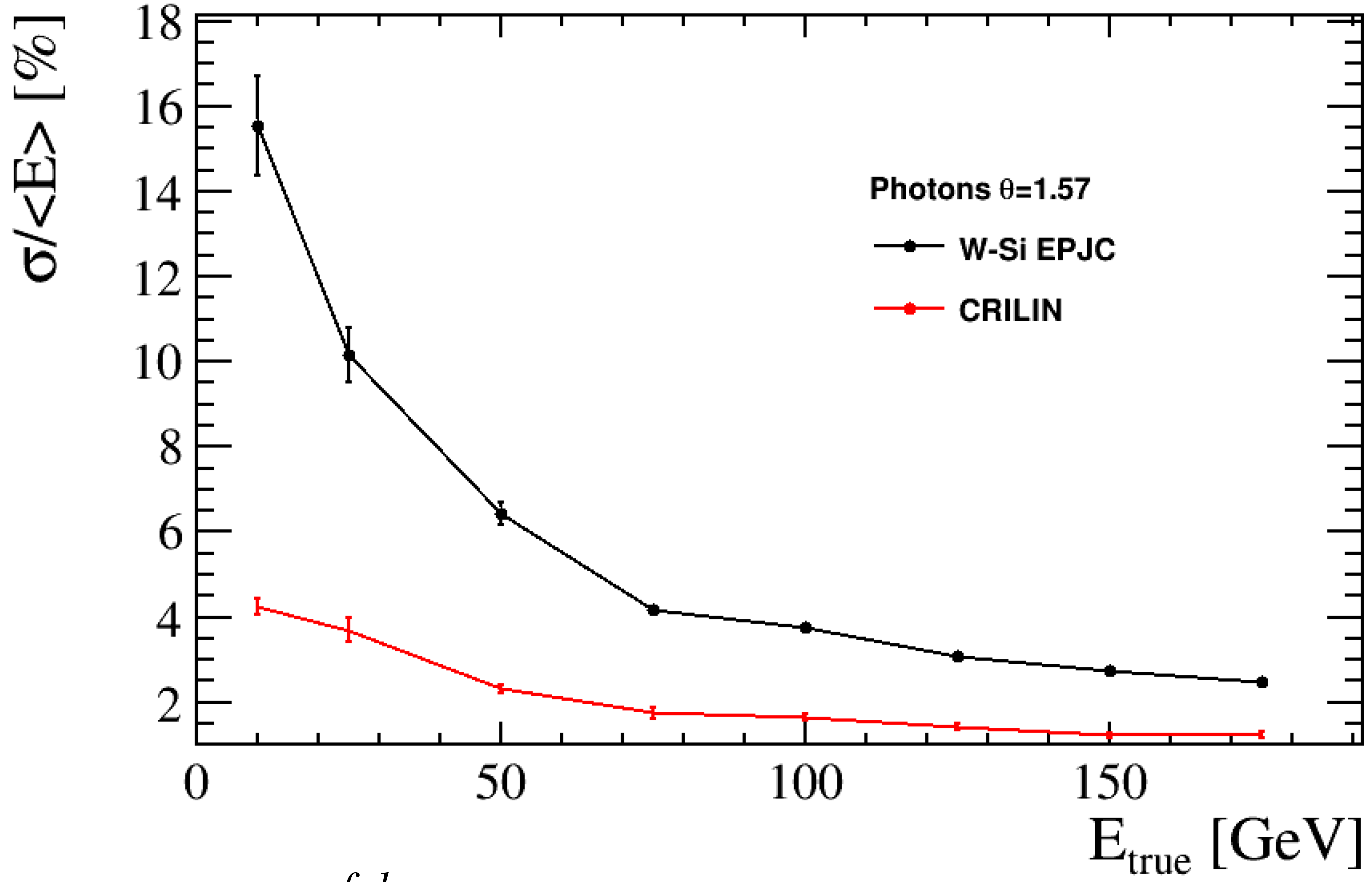


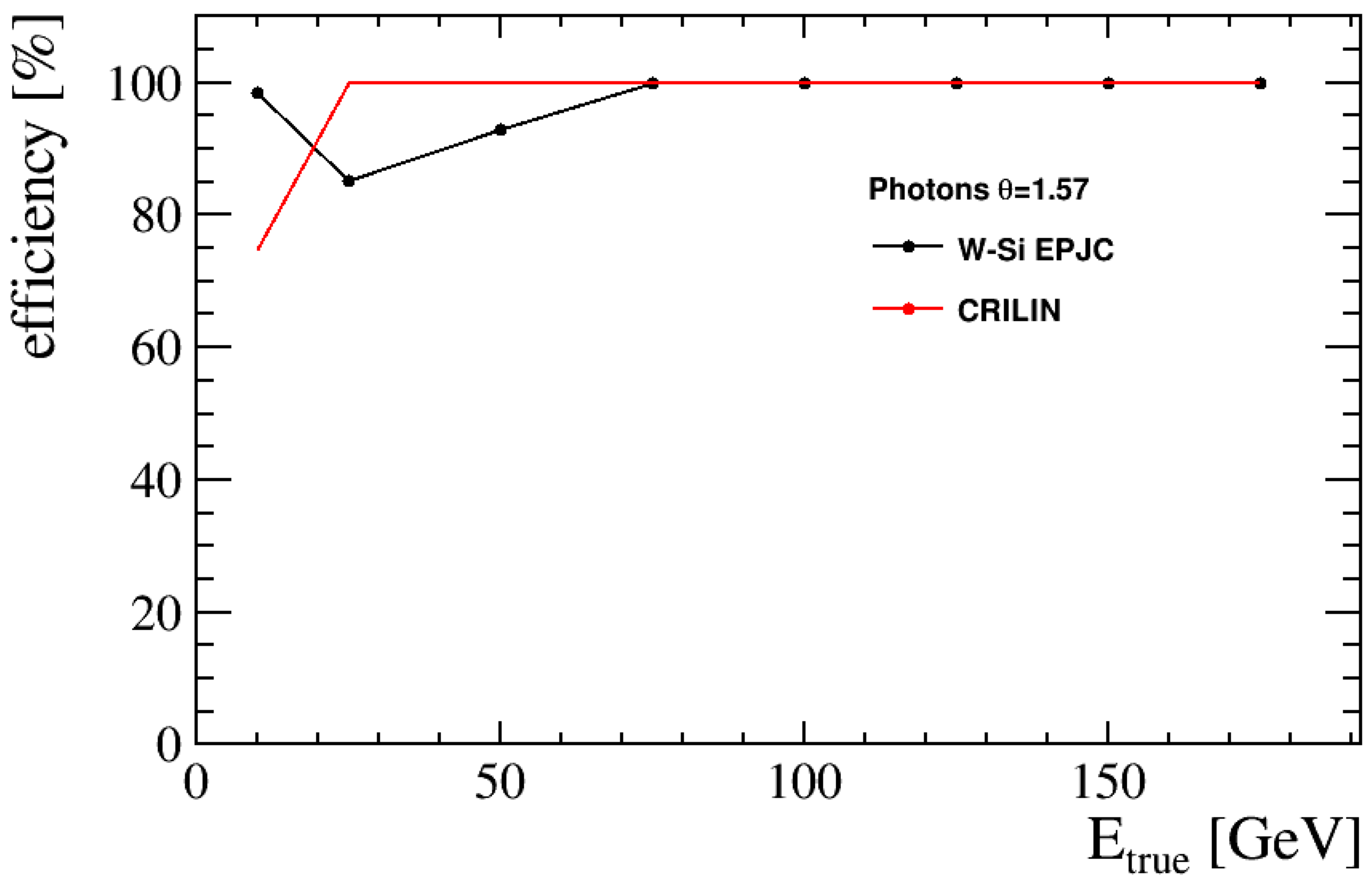
$$\frac{\sigma}{E} \simeq \frac{14\,\%}{\sqrt{E}}$$ for theta = 1.57



$N^{fake}_{CRILIN} \simeq 0$ number of fake clusters per event

Crilin performance





$N^{fake}_{CRILIN} \simeq 0$

$N^{fake}_{W-Si} \simeq 60$

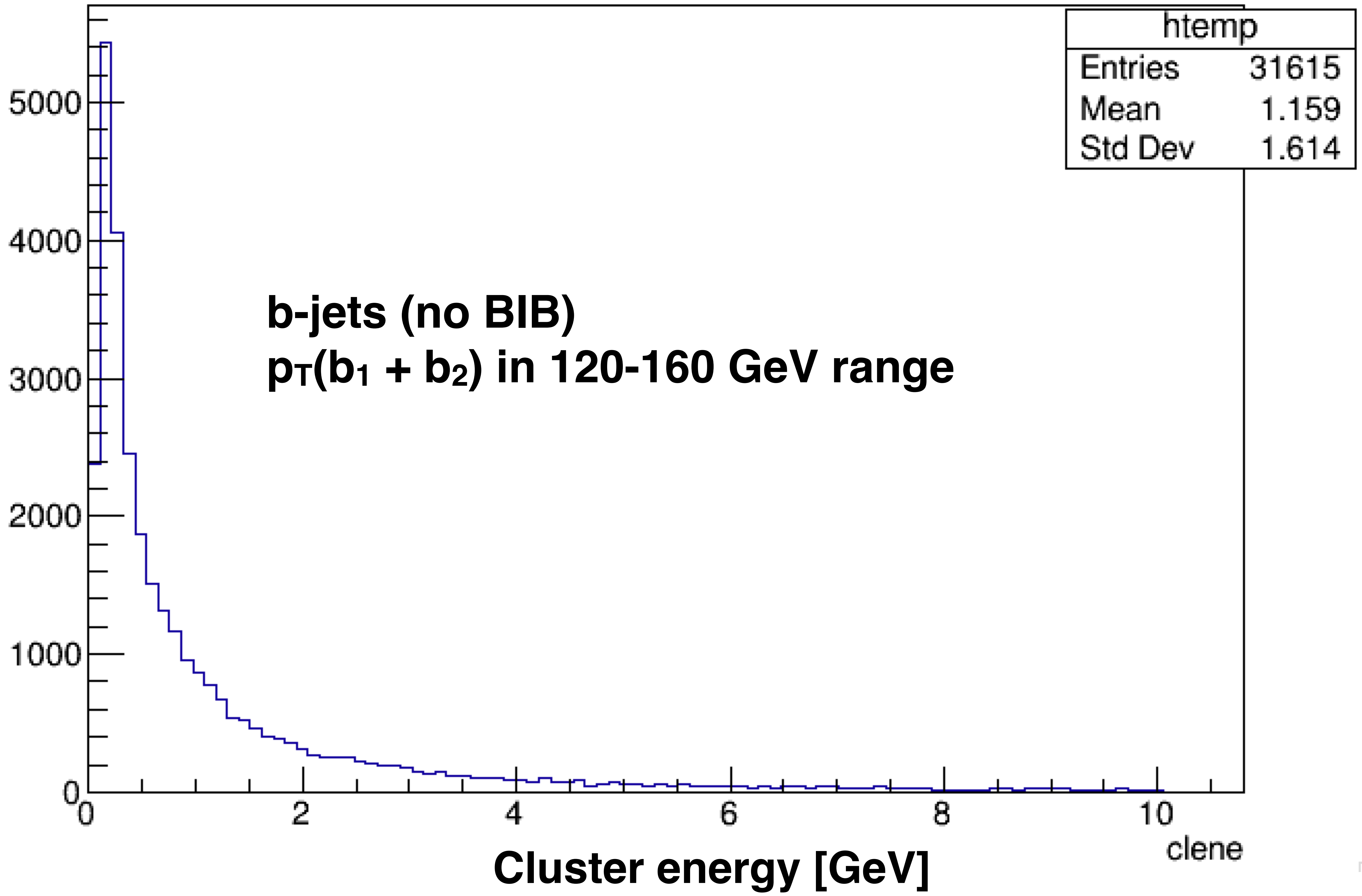
W-Si: 40 layers, 2 MeV threshold in each cell

Jet reconstruction

- Typical energy of clusters produced by jet fragmentation is lower than 10 GeV

- Optimization shown in this talk does not work in this range, thresholds tuned for 10 GeV photons eliminate the jet signal

- However the same strategy can be applied in this energy range -> work on-going



Discussion

- This talk does not demonstrate that Crilin is better than W-Si: the message is that **with a proper reconstruction strategy we can mitigate the impact of the BIB, and obtain the target performance**
- However Crilin is particularly suited for this mitigation strategy: having thicker layers, the BIB energy is integrated in large volumes, reducing the statistical fluctuations of the average energy
- Moreover Crilin has just 5 layers wrt to 40 layers of the W-Si calorimeter, less readout channels and it costs a factor 10 less
- **The same strategy is being applied to the jet reconstruction**: different energy range than >10 GeV photons
- Prospects: test Crilin as Endcap ECAL

Thanks for your attention!

Backup