TRACK FINDING IN GAMMA CONVERSIONS IN CMS

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A track finding algorithm has been developed for reconstruction of e^+e^- pairs. It combines the information of the electromagnetic calorimeter with the information provided by the Tracker. Results on reconstruction efficiency of converted photons, as well as on fake rate are shown for single isolated photons and for photons from $H \to \gamma\gamma$ events with pile-up events at 10^{33} cm^{-2} s^{-1} LHC luminosity.

1. Introduction

The need for high granularity and an adequate number of measurements along the charged particle trajectories, in order to obtain excellent momentum resolution and pattern recognition in the congested environment of LHC events, has lead to a CMS Tracker design having an unprecedented large area of silicon detectors with a very large number of front-end readout channels. The resulting amount of material is large and comprises active layers, support structures, general services as well as an impressive cooling system.

The relatively massive Tracker results in a large probability of photon conversion and electron bremsstrahlung radiation in the Tracker volume. The fraction of photons converting in the Tracker material, integrated over the acceptance, has been estimated from a simulated sample of single photons with $P_T = 35$ GeV (Fig. 1). The number of gamma conversions in CMS is not negligible and it is important to reconstruct the e^+e^- tracks. Major examples of the use of track reconstruction of gamma conversions are:

Photons from neutral pion decays constitute a very large background to prompt photons. In the case of converted photons the rejection of the background using the electromagnetic shower shape becomes ineffective. The information added by dedicated track finding improves the available rejection factor. Moreover the information from the tracks can be used to refine the electromagnetic energy clustering in the ECAL hence improving the energy measurement.

Gamma conversion reconstruction is also a tool for electron reconstruction validation, i.e. asymmetric conversions occurring very early in the Tracker are unwanted background to genuine electrons.

The reconstruction of conversion vertices provides, once the reconstruction efficiency is taken into account, a "radiography" of the Tracker and allows the mapping of the material with data.

This paper summarizes the work described in Ref.[1;2]. A detailed description of the CMS Electromagnetic Calorimeter and of the Pixel and Silicon Strip Tracker is provided in Ref.[3] and Ref.[4;5] respectively.

2. Electron-positron pair track reconstruction

CMS track reconstruction is divided into four separate steps; a) trajectory seed generation; b) trajectory building (i.e. seeded pattern recognition); c) trajectory cleaning which resolves ambiguities and d) trajectory smoothing (i.e. the final track fit).

In CMS, the standard seed and track finding algorithm (Chapter 14, Sec.4.1 of Ref.[6]) was developed and optimized for tracks originating from the primary interaction vertex, with pattern recognition starting from track seeds built in the pixel detector. For electron tracks, instead, the match between a super-cluster energy deposit in the ECAL and hits in the pixel detector is used for building seeds (Ref.[7]).

Neither of these approaches are suitable for tracks originating from vertices that are significantly displaced with respect to the primary vertex such as those from converted photons. Different seed finding and pattern recognition algorithms are necessary.

Recently, after a major re-working of the CMS Reconstruction software took place (Ref.[8]), additional track seed finding methods were developed which no longer rely on the Pixel information. However they were developed for general usage and do not combine information from ECAL for specific conversion reconstruction.

This paper describes the combination of an inward ECAL seeded track finding method with a subsequent outward track finding step.

2.1. Inward Tracking

The electron bending in the CMS 4 Tesla magnetic field and the large emission probability of bremsstrahlung photons in the Tracker material leads to a spray of energy in the ECAL extending mainly in the transverse plane. When dealing with single, high-energy electrons the electron energy is collected by clusters of clusters extended along a road called super-clusters (SC). Different clustering algorithms (Ref.[7]) are used for the ECAL barrel and endcaps. The same clustering procedure is applied here when dealing with converted photons.

The initial assumption is made that the bulk of energy arising from converted photons is contained in one super-cluster, however allowance is made for tracks falling outside its boundaries. The energy of the sub-clusters within a SC and the magnetic field are used to give a first rough estimate of a trajectory path, assuming that the initial photon vertex is the origin of the reference frame. Compatible hits are then sought for in the three outermost layers of Tracker. If compatible hits are found they are used to re-evaluate the seed parameters releasing the initial hypothesis on the initial vertex. Seeds are built out of pairs of hits and used for pattern recognition, trajectory building and final fitting proceeding inward in the Tracker, using the Kalman Filter formalism (Ref. [9]).

The average radiation energy loss (bremsstrahlung) experienced by electrons traversing the Tracker material is described by the Bethe-Heitler parametrization (Ref. [10,11]). With the Kalman filter (which is a linear least-squares estimator), the radiation energy loss is taken into account at each propagation step by correcting the track momentum by an amount corresponding to the predicted mean value of the energy loss and by increasing the track momentum variance with the predicted variance of the energy loss under the assumption that its distribution is Gaussian.

2.2. Outward Tracking

The two oppositely charged tracks with the largest number of hits reconstructed with the inward tracking are used in turn, independently from one another, as the basis for the outward seed and track finding procedure. If only one track was found it is used by default. Given an inward track, its innermost hit is assumed to be the e^+e^- vertex and is used as the starting point for seed finding of the other conversion arm.

The first hypothesis of the outgoing track is made based on the presence of a basic cluster within a suitable ϕ range from the presumed conversion vertex and the fact that the two tracks must be parallel at the vertex. Pairs of hits compatible with the estimated track path are sought in the next two layers moving outwards along the helix. These pairs are used as seeds for the forward trajectory building. After this step, trajectories are cleaned according to the number of shared hits and smoothed with the backward fit to obtain the parameters of the tracks at their innermost state. The description given in Sec. 2.1 concerning the treatment of radiation energy losses applies here.

The two sets of tracks reconstructed in the inward and outward tracking procedures are merged together. All combinations of oppositely charged tracks are fitted to a common vertex and are considered as possible converted photon candidates.

2.3. Results

The algorithmic efficiency was measured normalizing the number of reconstructed conversions to the simulated conversions with the vertex located before the third-outermost Tracker layer ($R \leq 85$ cm). Figure 2 shows the efficiency as a function of the radius and of η; the total efficiency is broken down into two contributions arising from candidates with two reconstructed tracks and those with only one track.

At this point it is important to check that the photon momentum measured from the tracks matches the energy collected in the ECAL supercluster. The ratio P_T(tracks)/E_T(SC) is shown in Fig. 3 for signal and background (dark grey) from fake pairs. The fraction of fake pairs was measured in a sample of Higgs-to-two-photon decays with low LHC luminosity (10^{33} cm^{-2} s^{-1}) pile-up events; it amounts to about 5%, easily reducible with a cut on P_T(tracks)/E_T(SC). Finally the position of the fitted conversion vertices is shown in Fig. 4. It is worth emphasizing that the results presented here were obtained with a non-final simulation of the Tracker material and are likely to change in a future update.

3. Conclusions

A baseline reconstruction method for converted photons in CMS has been described. It gives very encouraging results. This tracking method, designed specifically for reconstruction of converted photons has recently been ported to the new CMS Software environment (CMSSW) (Ref. [8]), where the final Tracker geometry description is being finalized.

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References

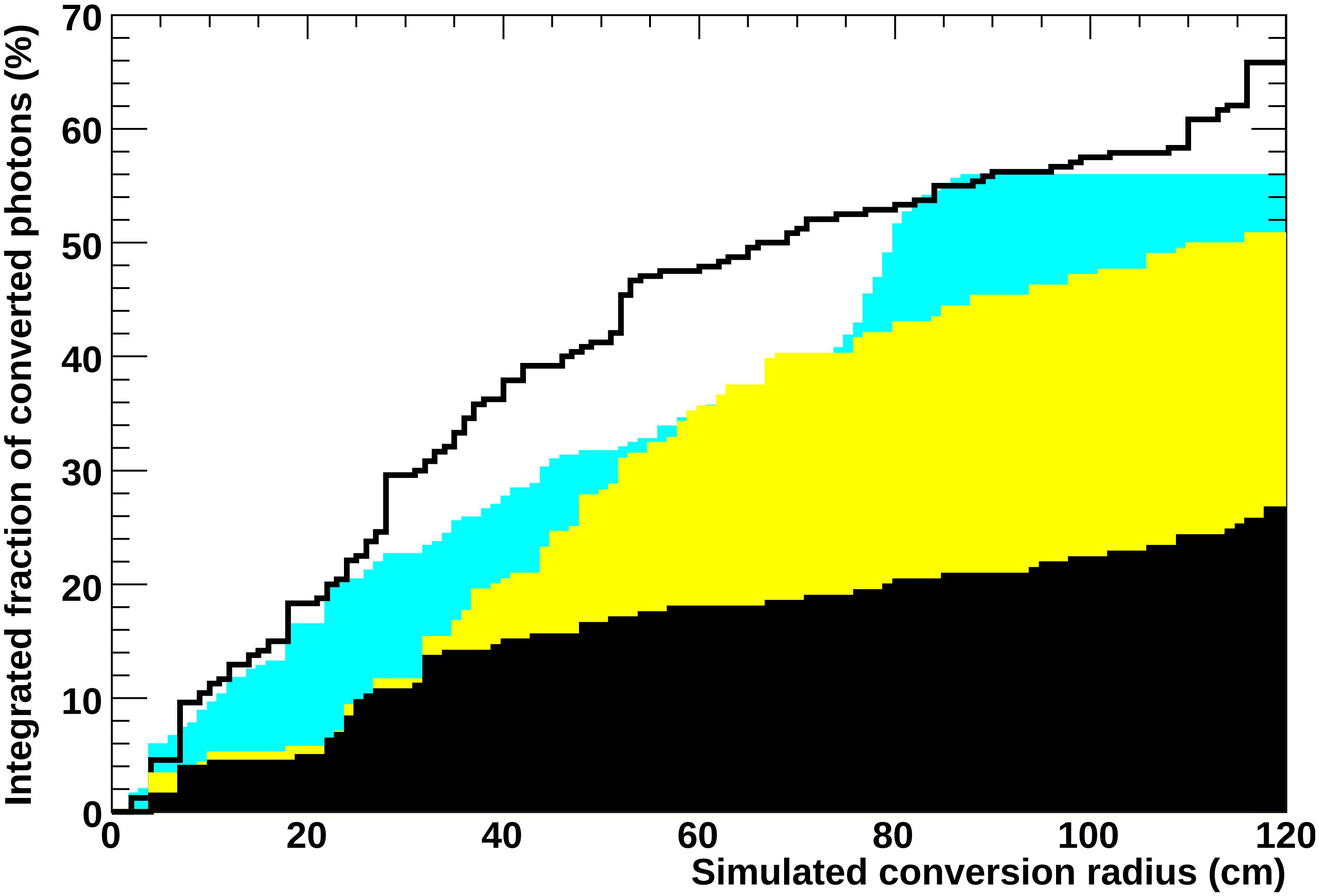
1. N. Marinelli, Track finding and identification of converted photons, CMS Note 2006/005.
2. The CMS Collaboration CMS – Detector performance and software, Physics Technical Design Report Vol. 1, CERN/LHCC 2006-001, CMS TDR 8.1 (2006).
3. The CMS Collaboration, The Electromagnetic Calorimeter Project, Technical Design Report, CERN/LHCC 97-33, CMS TDR 4.
4. The CMS Collaboration, The Tracker Project, Technical Design Report, CERN/LHCC 98-6, CMS TDR 5.
5. The CMS Collaboration, The Tracker Project, Technical Design Report, CERN/LHCC 2000-016, CMS TDR 5, Addendum 1 (2000).
6. The CMS Collaboration, The Trigger and data acquisition project , Vol 2 Technical Design Report, CERN/LHCC 2002-026, CMS TDR 6.2; Track reconstruction in the CMS tracker, W. Adam, B. Mangano, T. Speer, T. Todorov, CMS NOTE 2006-041.
7. Electron reconstruction in CMS, S. Baffioni et al., CMS NOTE 2006/040.
8. CMSSW, The CMS Software for Simulation and Reconstruction, https://twiki.cern.ch/twiki/bin/view/CMS/SWGuideFrameWork; https://twiki.cern.ch/twiki/bin/view/CMS/Reco.
9. R. Fruhwirth, Nucl. Instrum. and Methods A 262, 444 (1987).
10. H. Bethe and W. Heitler, Proc. R. Soc. London A 146 (1934) 83.
11. D. Stampfer, M. Regler and R. Fruhwirth, Comp. Phys. Comm. 110 (1994) 157.
12. The CMS Collaboration, The CMS High Level Trigger, The CMS Trigger and Data Acquisition Group, hep-ex/0512077.

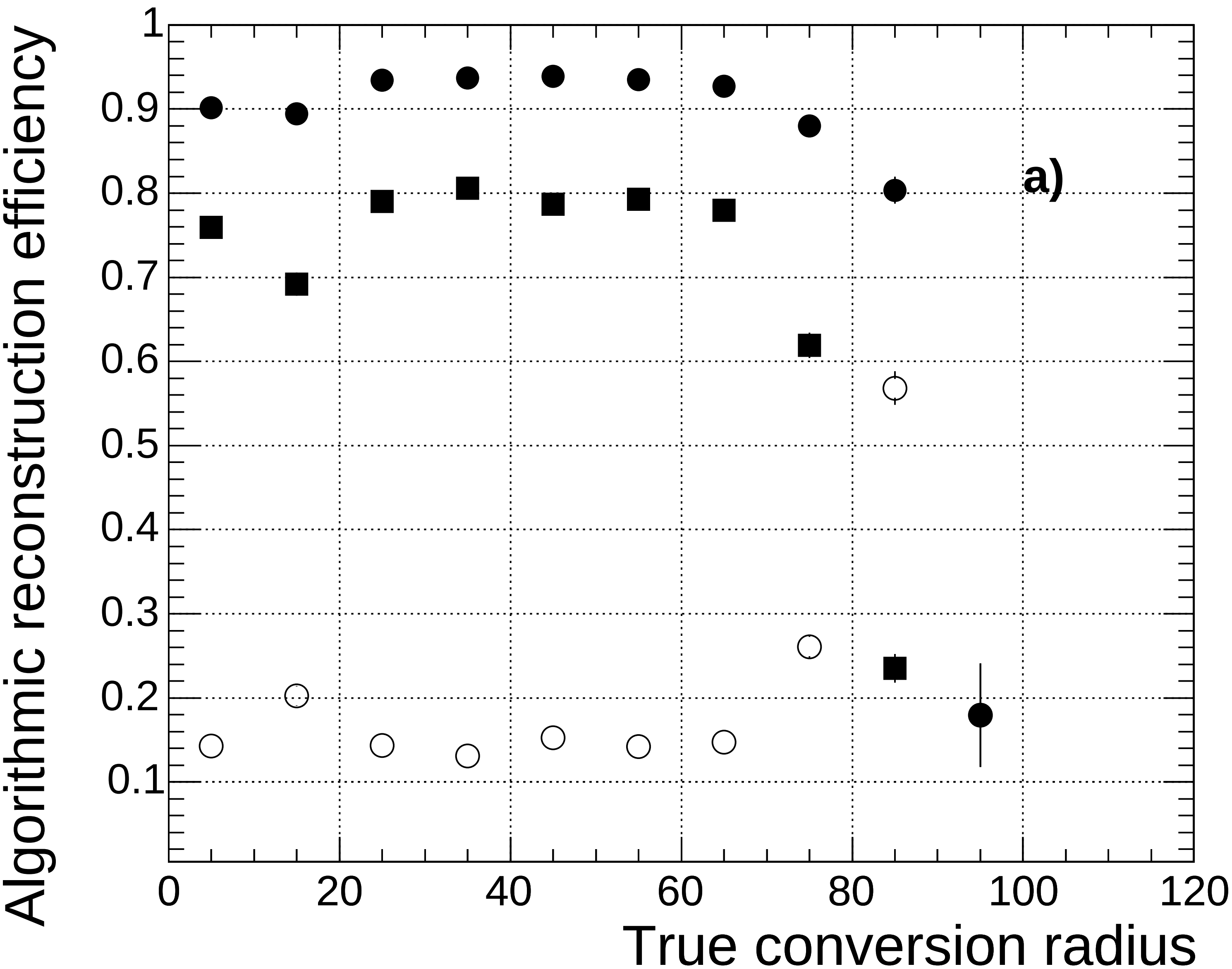
Fig. 1. Fraction of photons converting in the Tracker, integrated over all radii. The four histograms correspond to 0.1 slices in η around $|\eta| = 0.2$ (black), $|\eta| = 0.9$ (light grey), $|\eta| = 2.0$ (dark grey) and $|\eta| = 1.2$ (hollow).

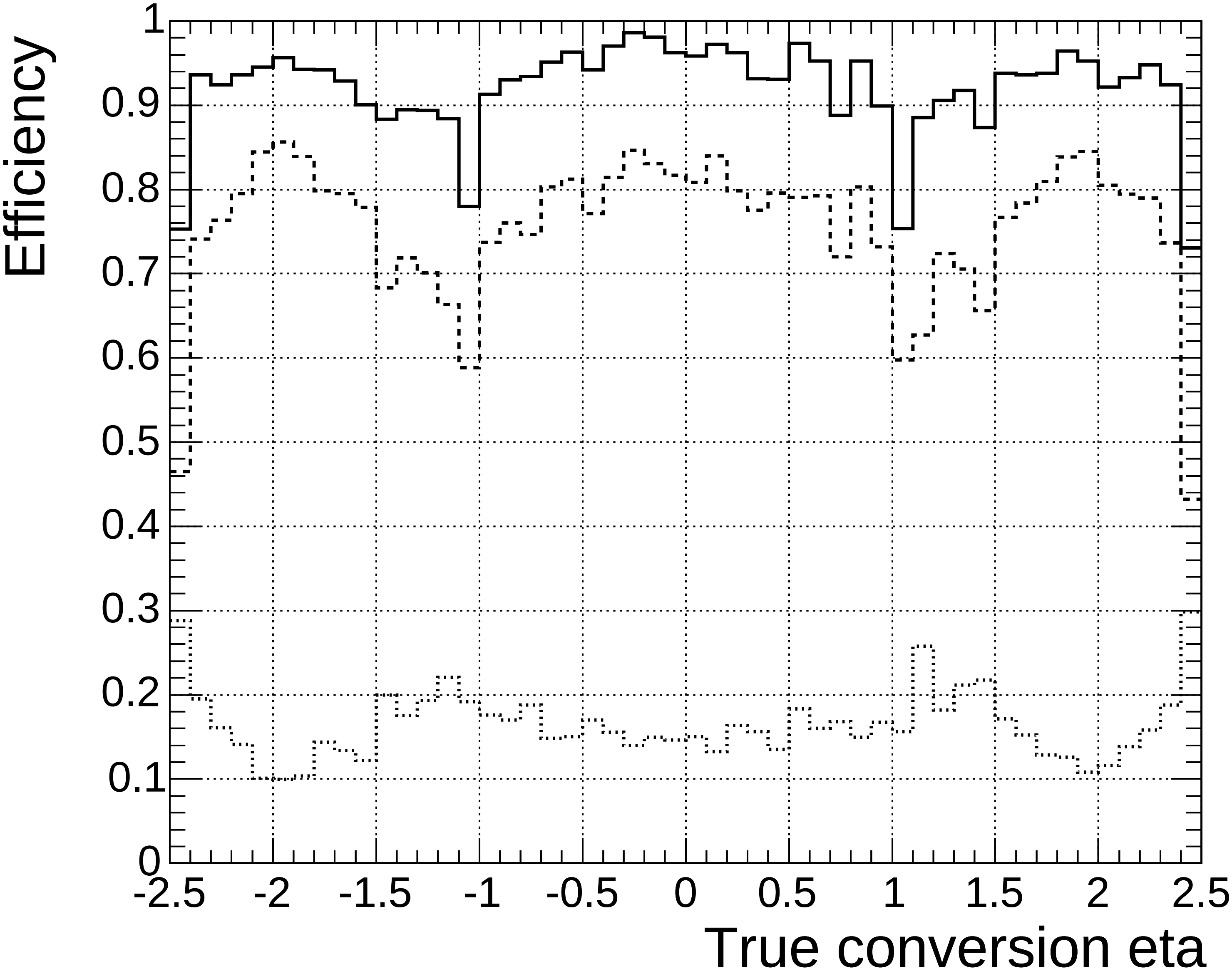
Fig. 2. Reconstruction efficiency measured with single photons with fixed $P_T = 35$ GeV/c as a function of the simulated conversion-point position. (left) Total (black dots), two-tracks (black squares) and single track (open dots); (right) Total (solid line), two-tracks (dashed line) and single track (dotted line).

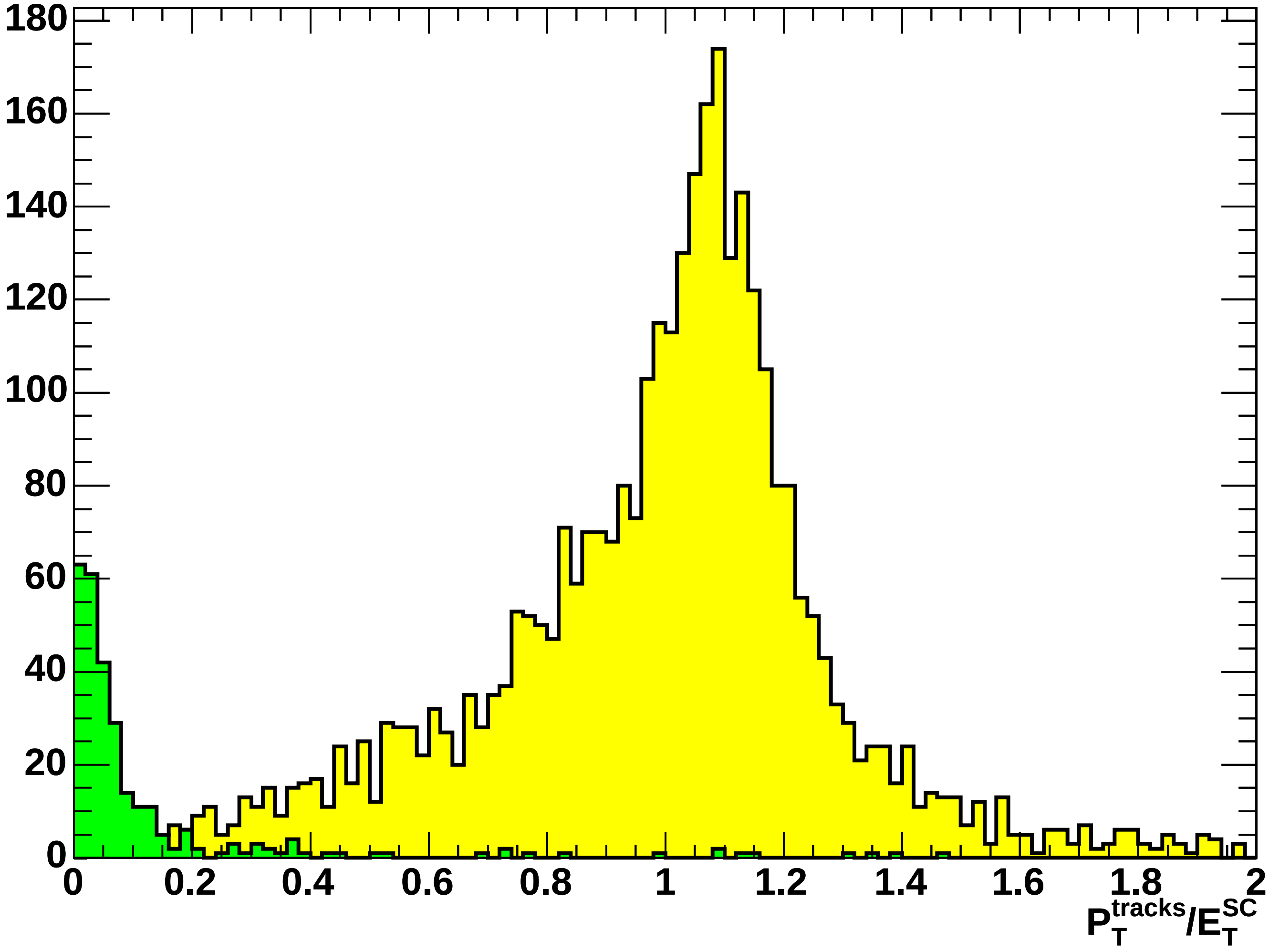
Fig. 3. The ratio $P_T(\text{tracks})/E_T(\text{SC})$ for reconstructed converted photons in a sample of $H \rightarrow \gamma\gamma$ events with low luminosity pile-up. The dark grey histogram shows the contribution from fake pairs.

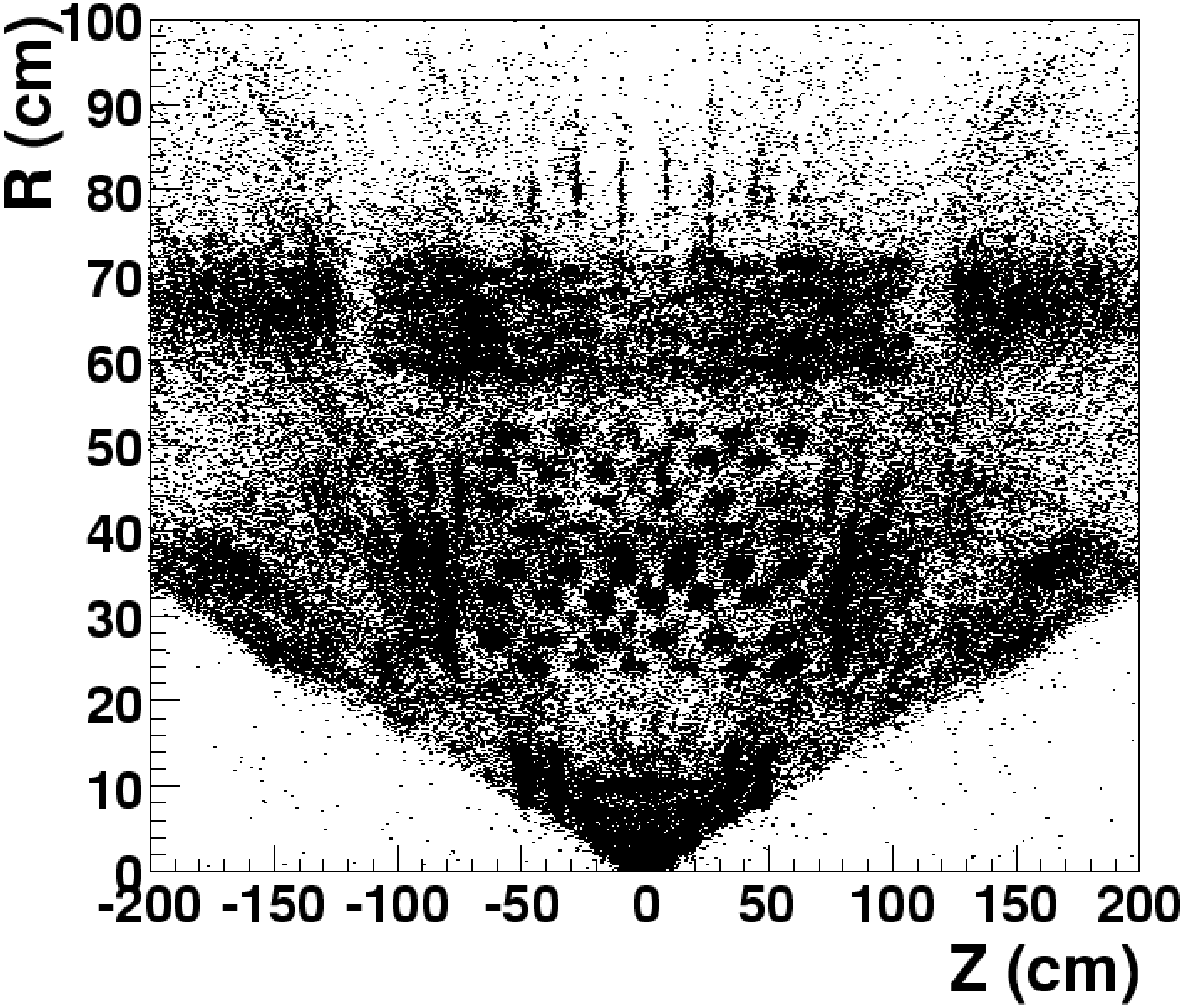
Fig. 4. Reconstructed converted photon vertices.

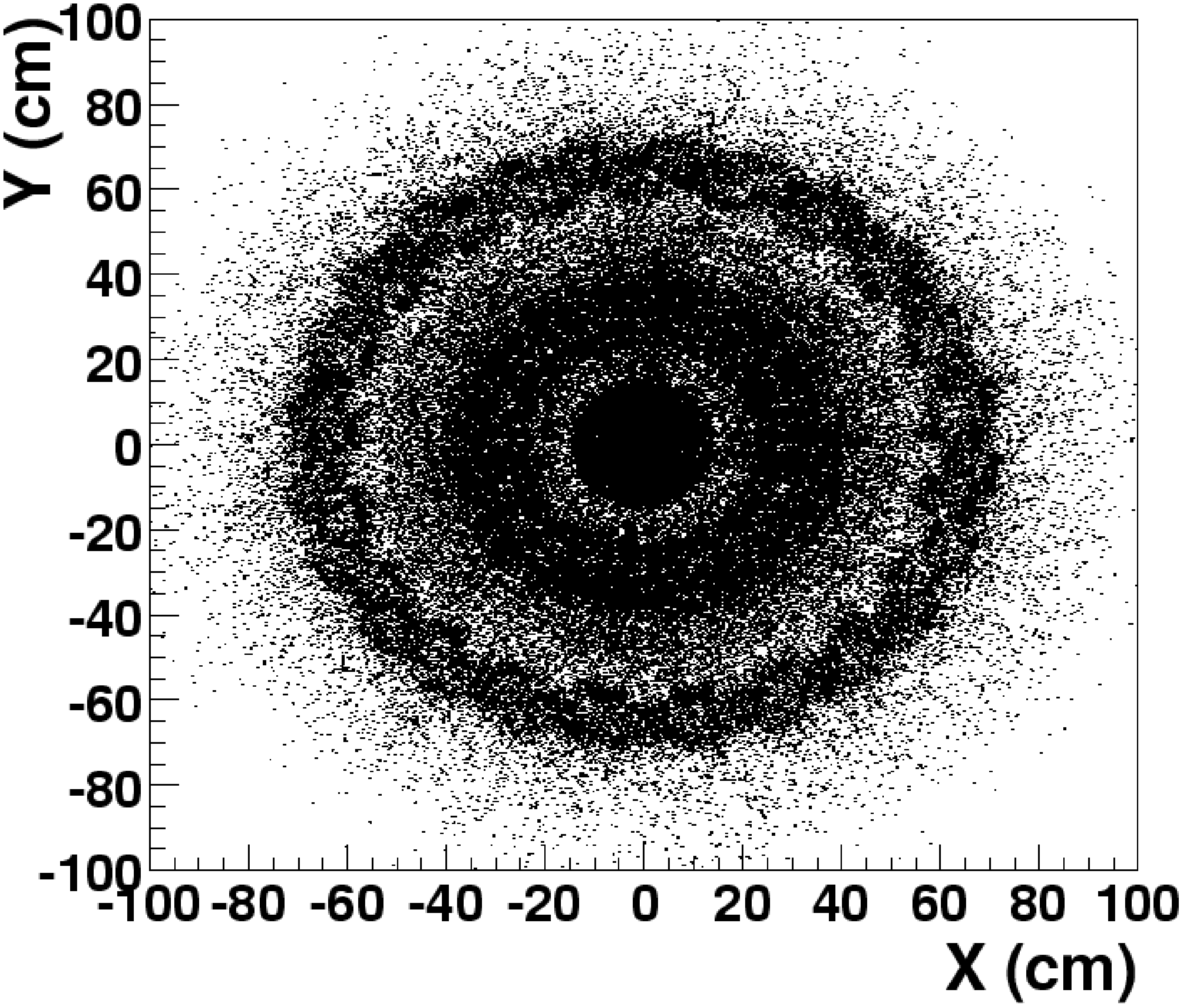

Integrated fraction of converted photons (%)
Simulated conversion radius (cm)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120


Algorithmic reconstruction efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
120
True conversion radius
a)


Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
True conversion eta


180
160
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
P_T^{tracks}/E_T^{SC}


R (cm)
100
90
80
70
60
50
40
30
20
10
0
-200
-150
-100
-50
0
50
100
150
200
Z (cm)


Y (cm)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-100
-80
-60
-40
-20
0
20
40
60
80
100
X (cm)