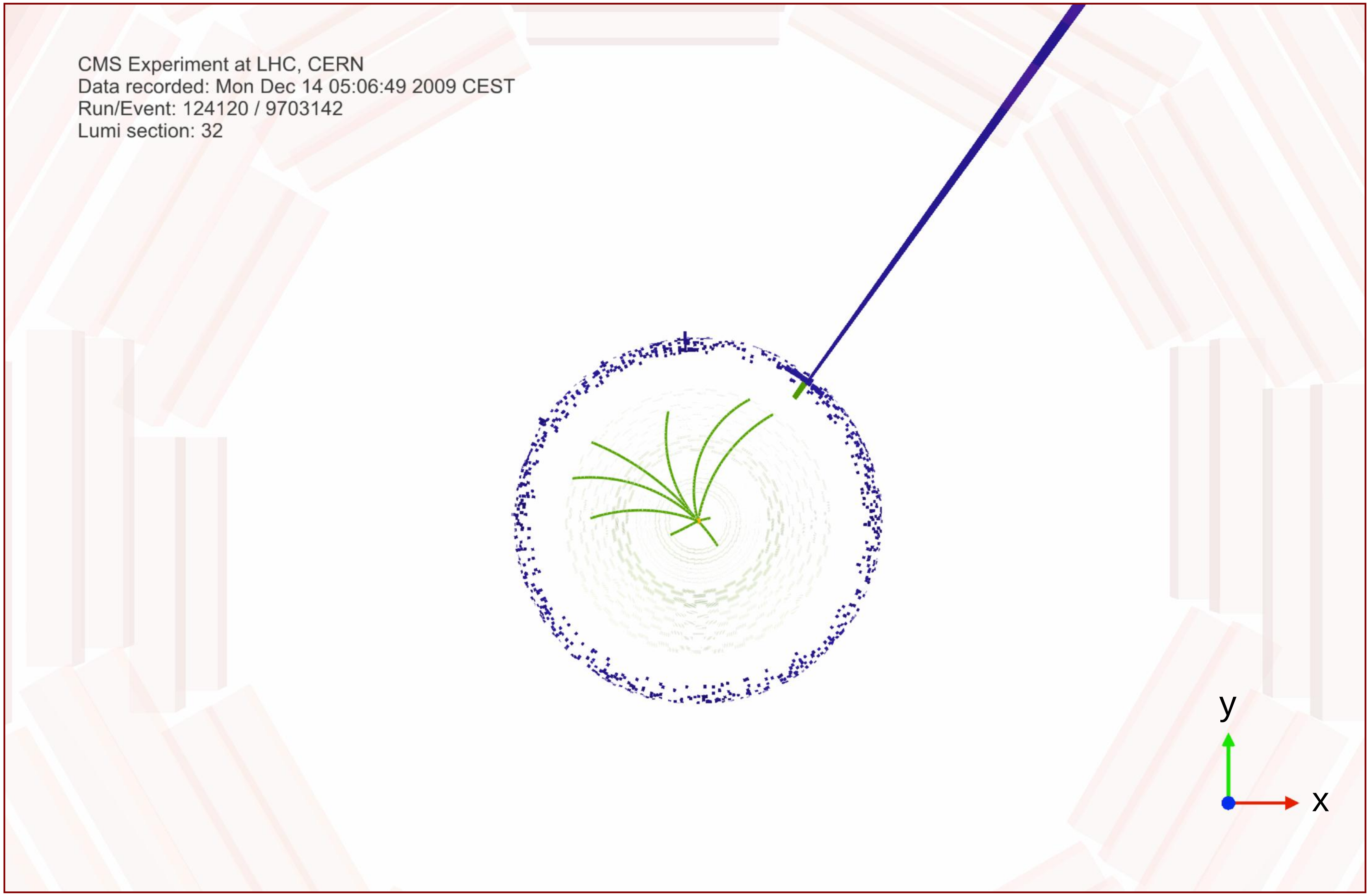
ECAL Spike plots for approval

1. Updates to existing approved plots

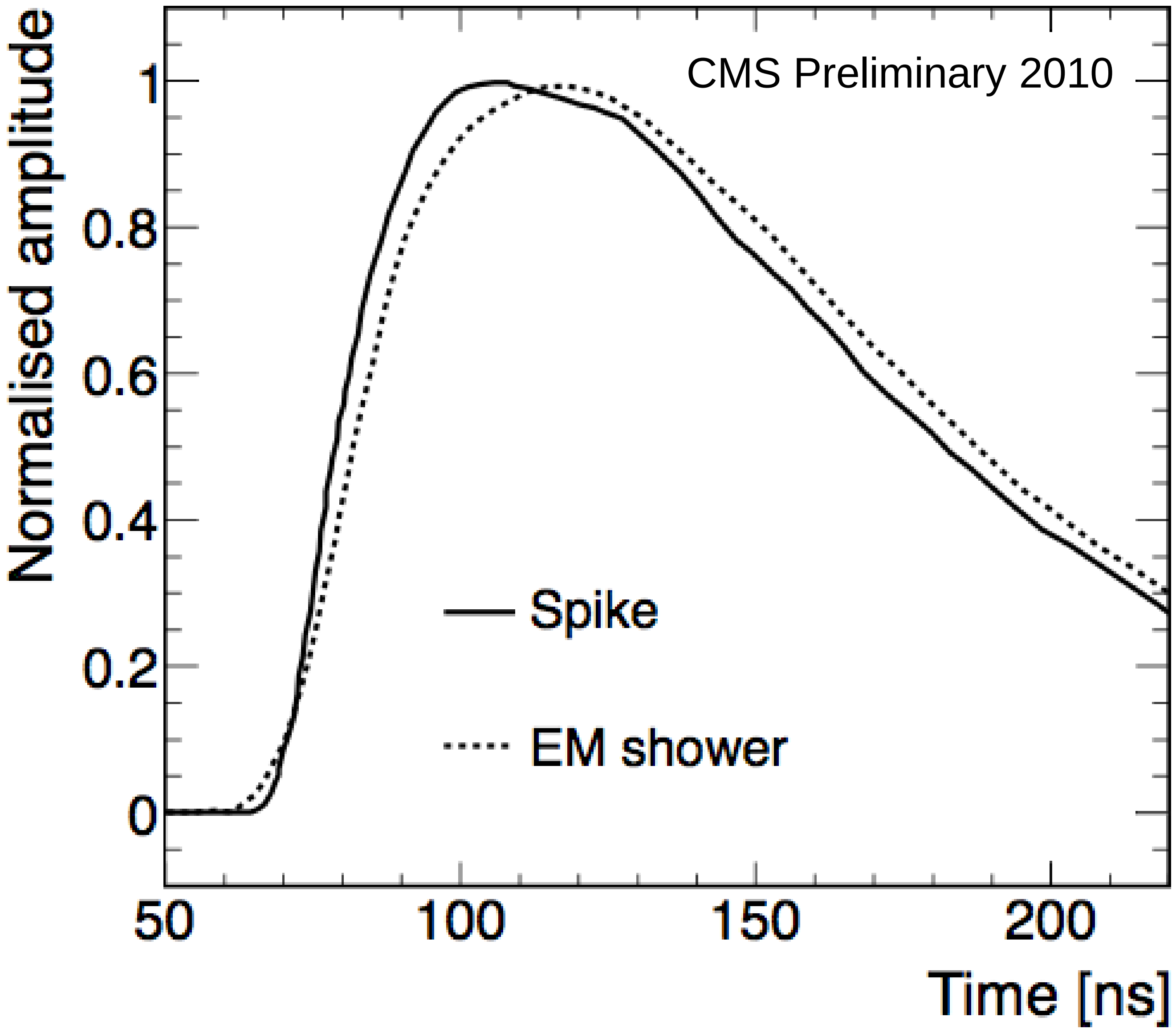
Spike Event Display



Caption

- CMS Event Display of a pp collision event (sqrt(s)=2.36 TeV), showing an isolated ECAL spike simulating a 600 GeV transverse energy deposit. (scintillation light in $PbWO_4$ ~4.5 p.e./MeV)
- The CMS detector is shown in x,y projection. The outlines of the CMS tracker and muon chambers are shown. The purple histogram shows the ECAL energy deposits (length proportional to the energy of the reconstructed signals);
- The defining signature of a spike in the ECAL is the presence of an isolated, high energy deposit.

Spike pulse shape

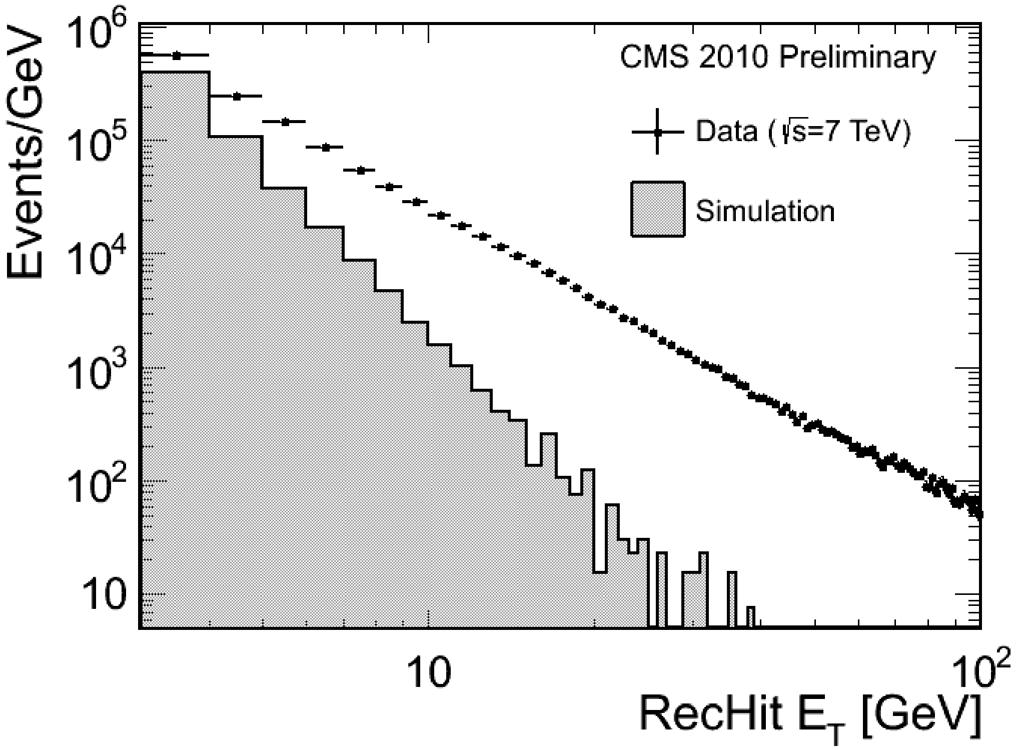


Caption

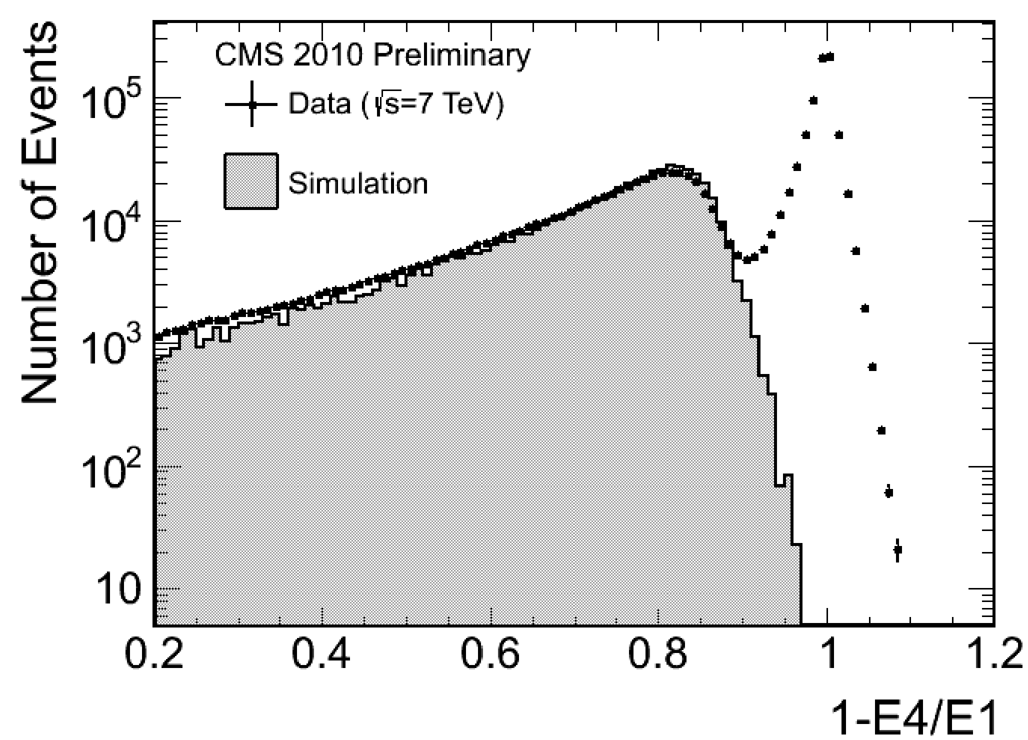
- Oversampled pulse shape (normalised signal amplitude versus time) for spike (solid line) and electromagnetic (dashed line) energy deposits measured from CMS data
- The rise time of the electronic pulse is consistent with an instantaneous signal from the APD, and not from the typical scintillation light signal in the crystal.
- Update of an already approved plot, now in CMS standard plot style:

http://cms-project-ecal-p5.web.cern.ch/cms-project-ECAL-P5/approved/Spike2.php

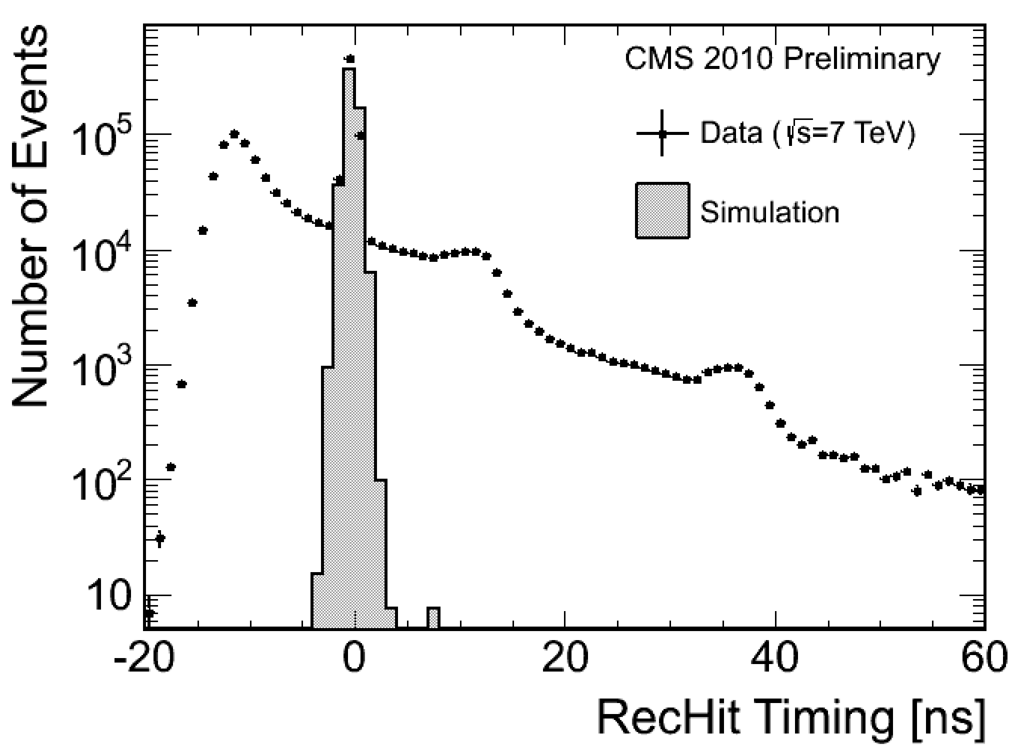
Spike characteristics



a)



b)



c)

Caption

- **(a) The energy distribution of the highest rechit in Minimum Bias data and Monte Carlo events**. A lower threshold of 3 GeV is applied to the transverse energy of the rechit, and ***the two distributions are normalised to the total number of events below (1-E4/E1)<0.9***. There is a clear excess of high energy hits in the data distribution, due to spikes. These anomalous signals dominate the rechit spectrum at high energies - above 20 GeV over 98% of the rechits are due to spikes - and are a major source of missing transverse energy in CMS triggered events. The spike energy distribution extends up to the ECAL saturation energy of ~ 1.7 TeV.

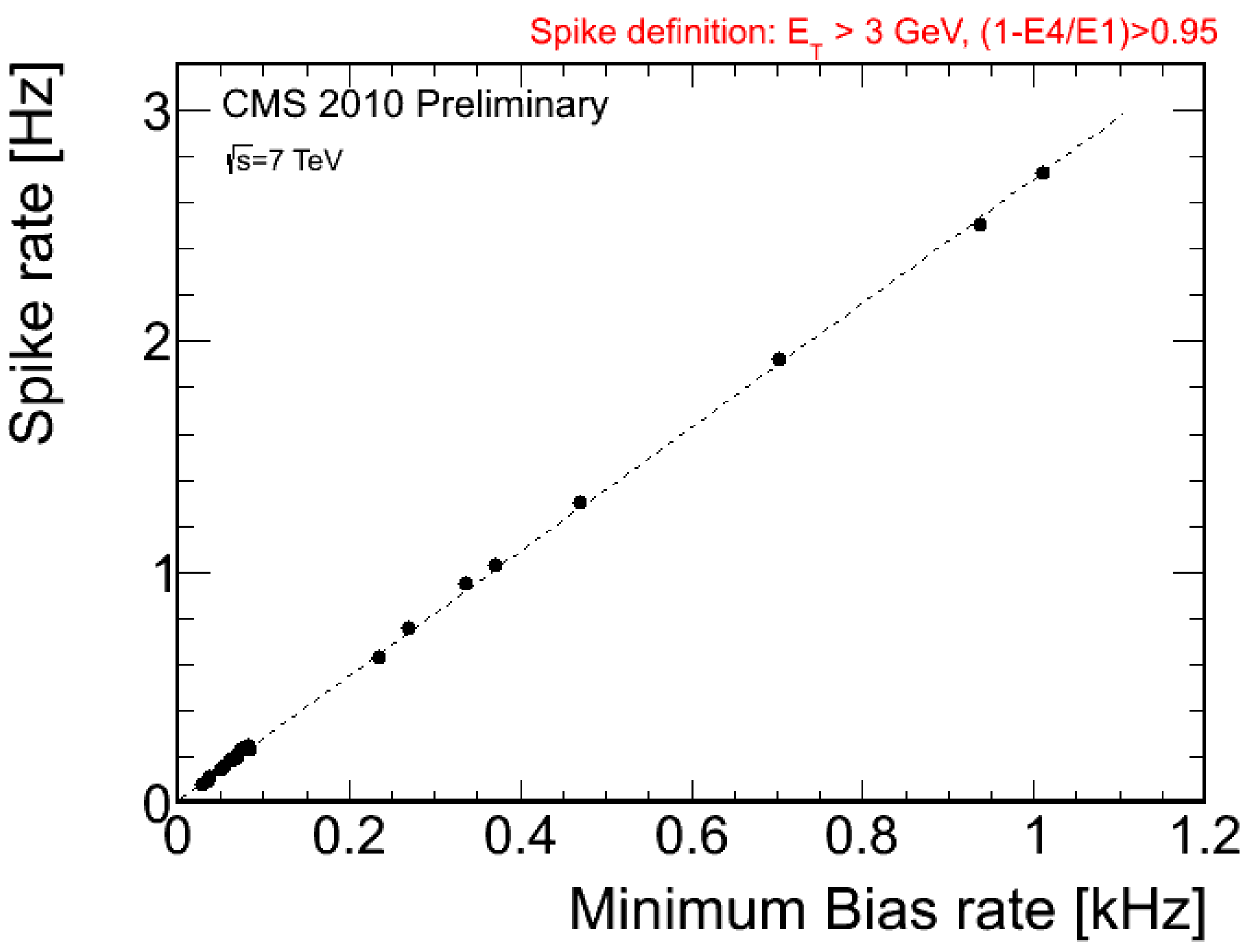
- **(b) Distribution of the RecHit timing for Minimum Bias data and Monte Carlo**, plotted for the highest energy rechit in each event, requiring a minimum rechit transverse energy of 3 GeV. The timing distribution for Minimum Bias data is clearly inconsistent with the Monte Carlo distribution (hatched). The peak at zero is due to prompt electromagnetic showers, and is modelled by the Monte Carlo. The secondary peak at −10 ns is due to spikes. The origin of the 10 ns difference can be understood by comparing the pulse shape of 'normal' (Swiss-cross< 0.95) and 'spike' (Swiss-cross> 0.95) RecHits. The faster pulse rise time for the spike RecHits is due to the lack of a scintillation component (80% of light emitted in 25 ns), since the spikes are produced by particles directly interacting in the APD. Since the time reconstruction algorithm compares this pulse to the expected shape, this faster rise time results in an apparent 'early' reconstructed time for the pulse.

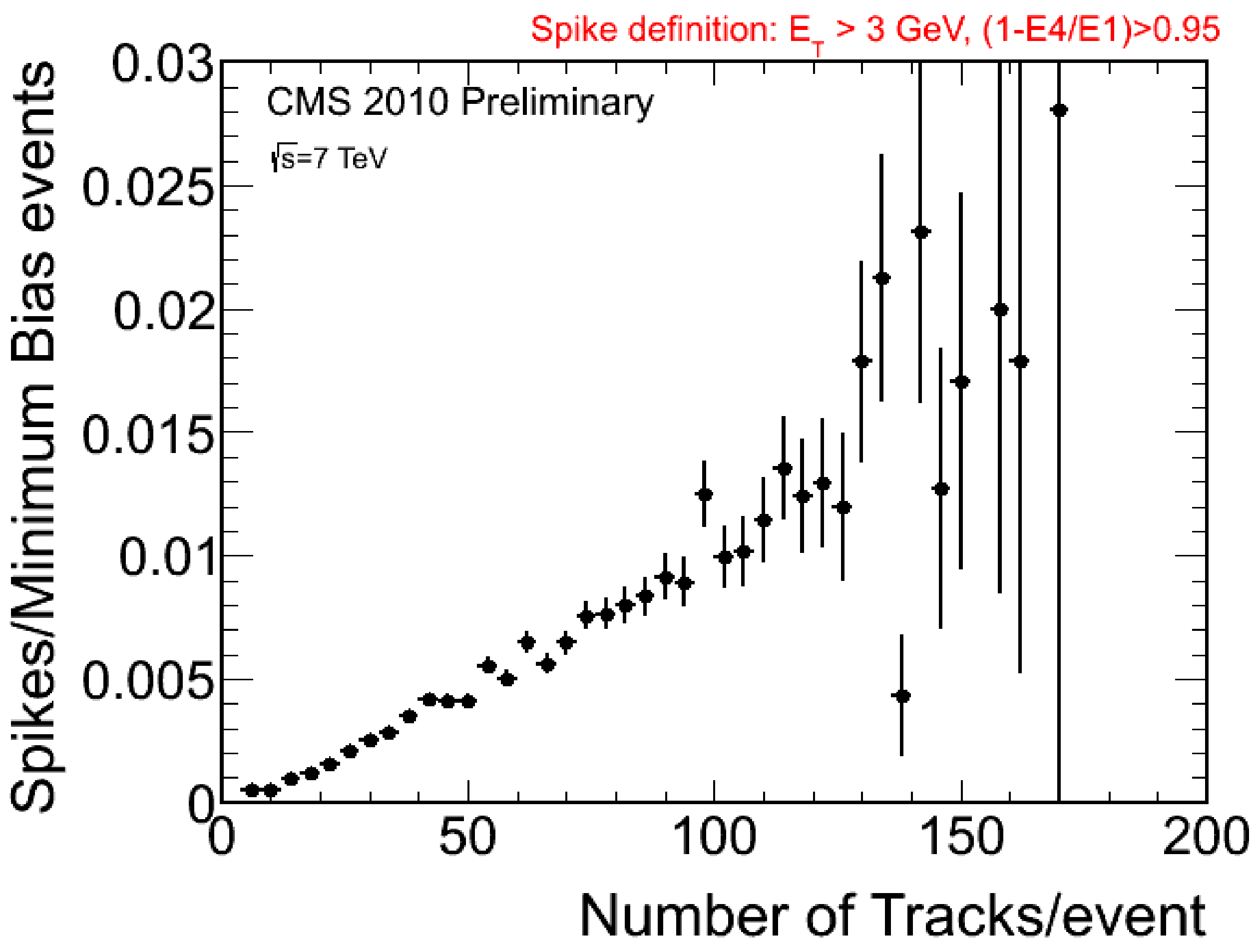
- (c) **The distribution of the "Swiss-cross" variable (1 − *E4/E1*) for data and Monte Carlo** minimum bias events. The data distribution (points), is normalised to the same number of events as the Monte Carlo (hatched) below a Swiss-cross value of 0.9. It shows good agreement with the shape of the Monte Carlo distribution below this value. However, there is a significant second peak at 1.0, due 9 to spikes, not present in the default Monte Carlo simulation. A cut on the Swiss-cross variable at 0.95 is efficient at removing spikes. For a EM shower that is well-centered on a crystal, one expects approximately 80% of the shower energy in the central crystal, and ~ 20% of the energy in the four adjacent crystals. The Monte Carlo distribution therefore shows a peak at approximately 0.8 in the Swiss-cross variable, with a tail extending to low values and a relatively sharp cut-off above 0.95.

2. New plots

shown previously at ECAL DPG/ASC task force meetings

Spike rate vs minbias collisions rate, vs number of tracks





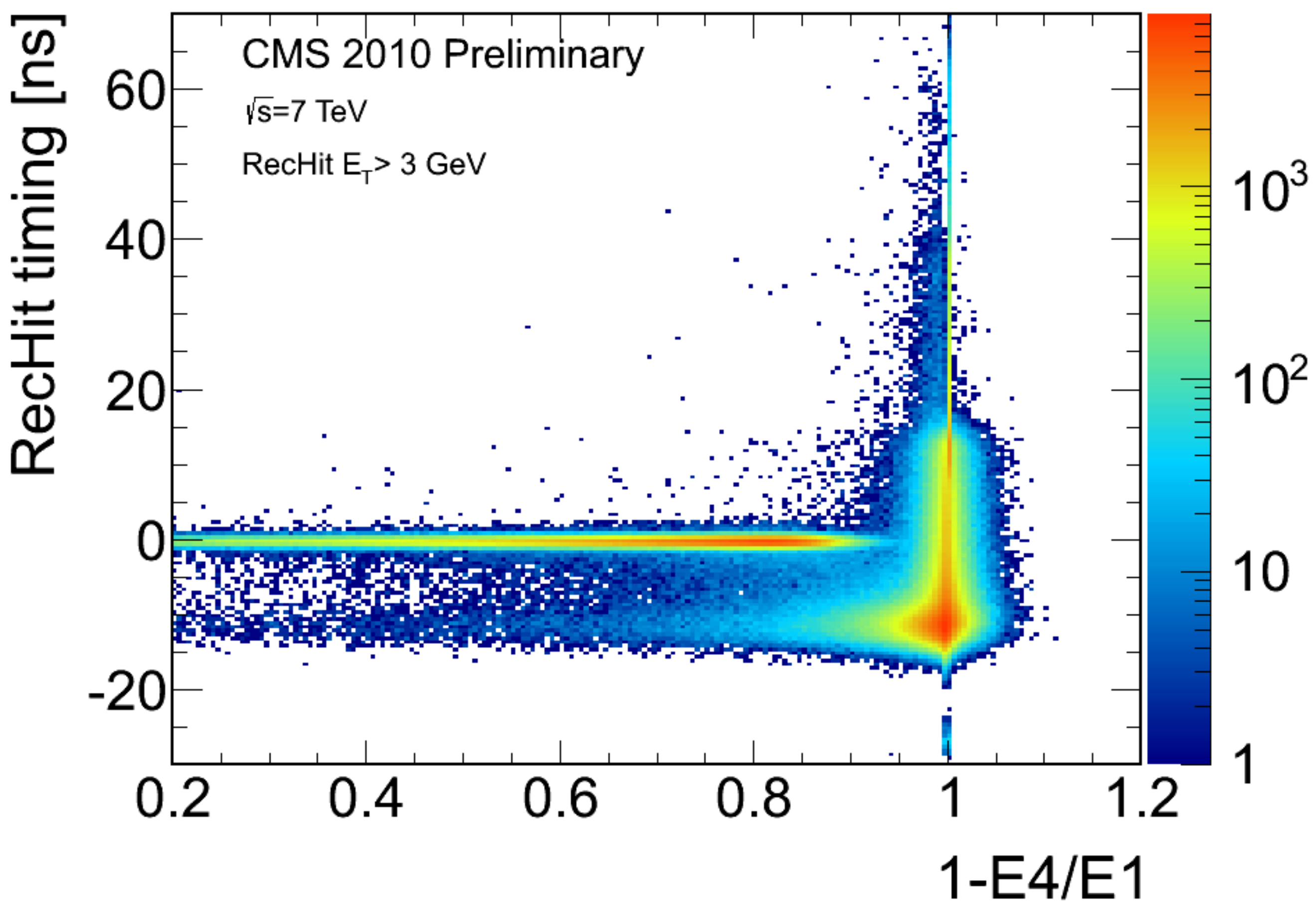
Caption

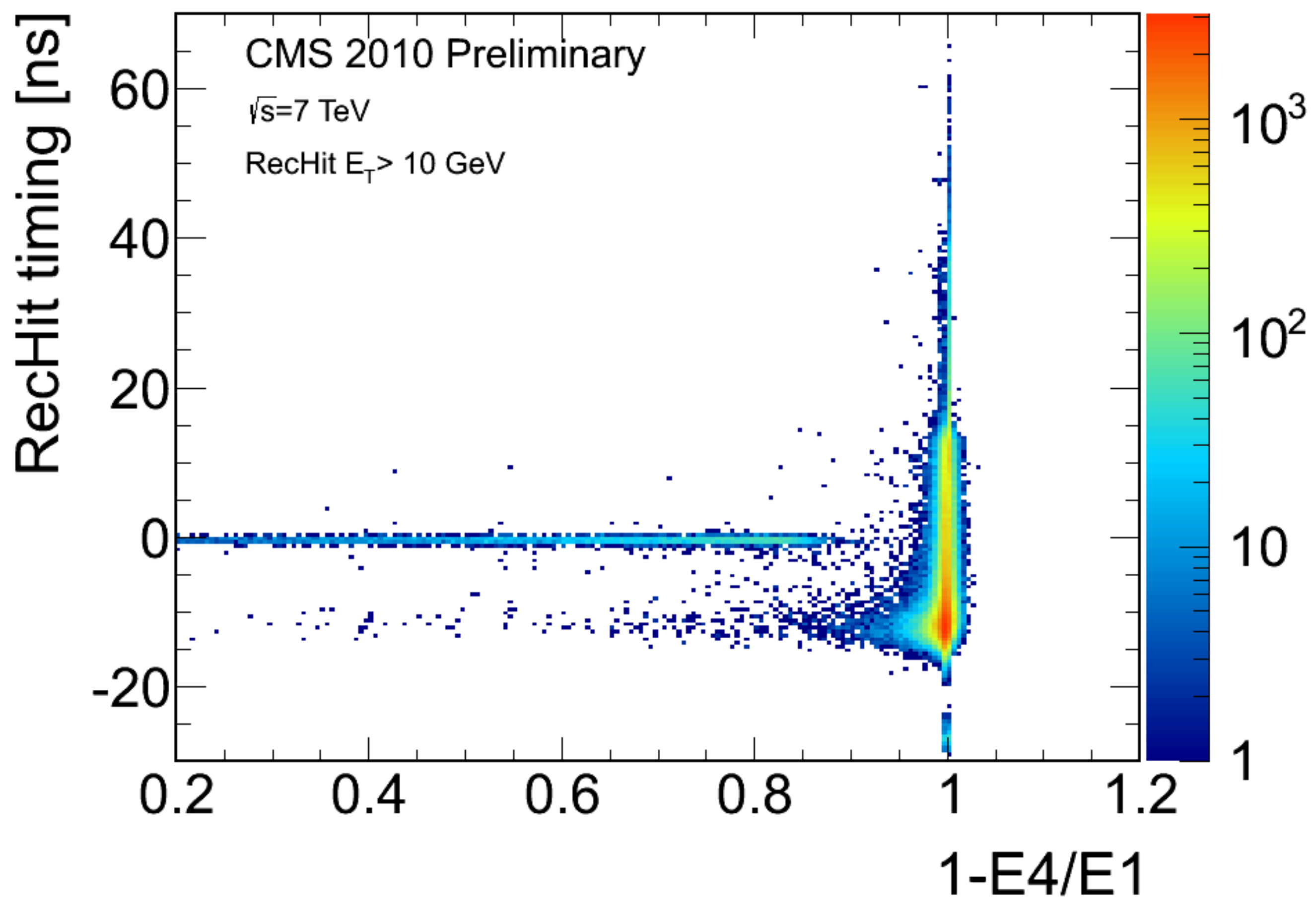
- (Left) Spike rate versus Minimum Bias trigger rate (technical bit 41) for early 7 TeV data. The dashed line is a straight line fit to the data points, with a gradient of 2.7×10^{-3} spikes per Minimum Bias event.
- (Right) Probability to observe a spike per minimum bias event as a function of the number of reconstructed charged tracks.
  - track quality cuts: abs(vtx_z)<15cm && vtx_isfake==0 && vtx_ndof>5
- Spikes are defined as ECAL energy deposits (RecHits) with $E_T > 3$ GeV and (1-E4/E1)>0.95
- ***The rate of spikes in CMS is proportional to the minimum bias collisions rate, and to the number of charged tracks per event***

CM energy [TeV]	Spikes/MinBias event
0.9	$(1.666 \pm 0.089)\times10^{-3}$
2.36	$(1.811 \pm 0.342)\times10^{-3}$
7.0	$(2.697 \pm 0.005)\times10^{-3}$

Average spike rates per Minimum Bias event (technical bit 41) as a function of LHC centre-of-mass energy. Spikes are defined as RecHits with 3 GeV and (1-E4/E1)>0.95.

Swiss-cross vs timing





Caption

- The two-dimensional distribution of the reconstructed signal timing (in ns) vs the Swiss-cross variable (1-E4/E1) for two rechit transverse energy thresholds. Only the most energetic rechit in each event is plotted.

- Since the swiss-cross and rechit time variables relate to independent properties of the event (the energy deposition in the affected channel relative to its neighbours, and the pulse shape of the anomalous energy deposit) they should be independent variables to first order.

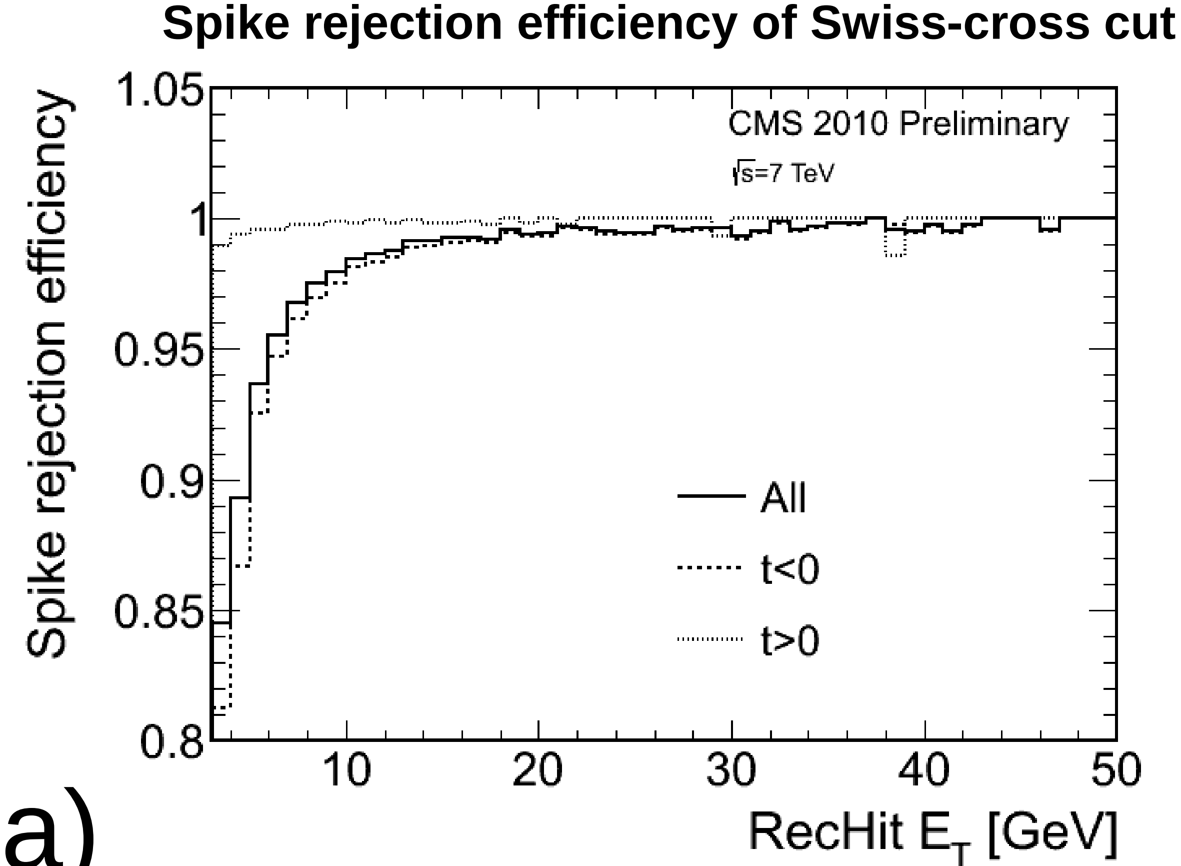
- Three specific regions may be identified:

  - ***non-spike rechits:*** Swiss-cross < 0.95; |time| < 3 ns

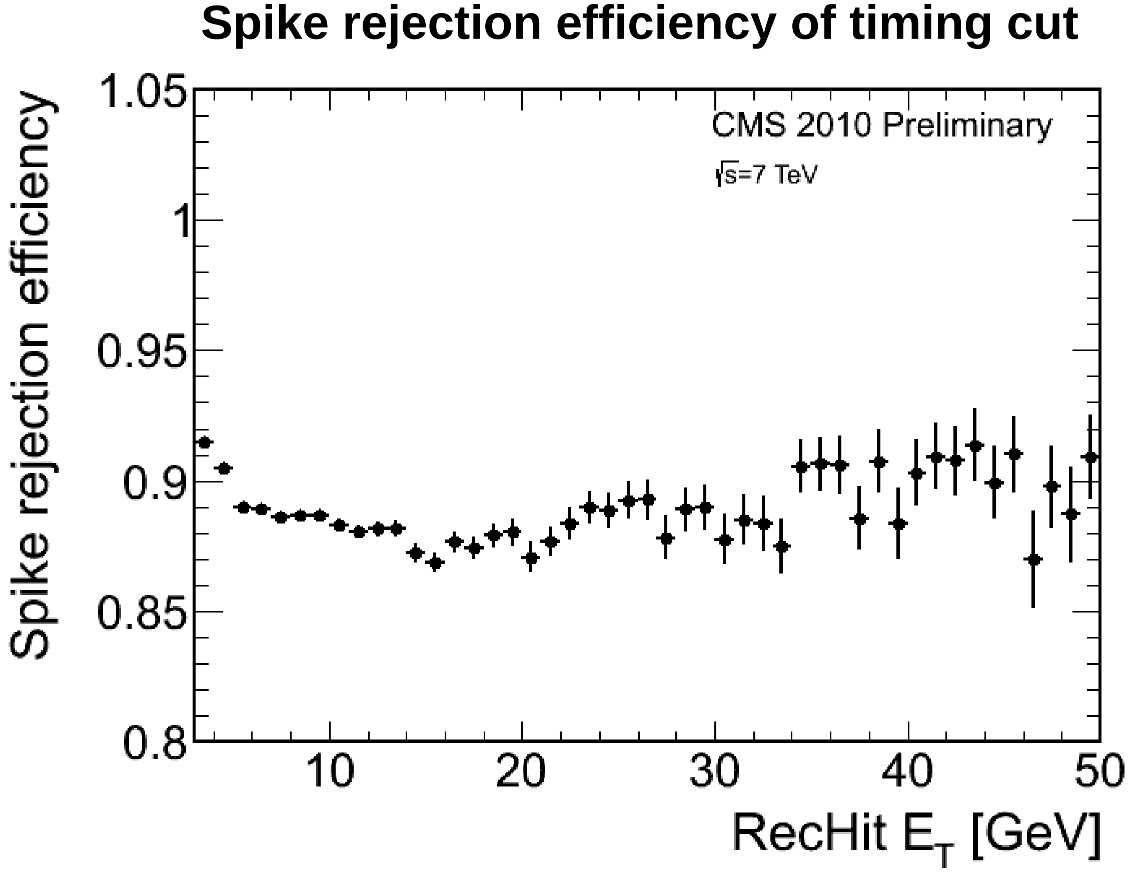
  - ***isolated spikes:*** Swiss-cross > 0.95

  - ***non-isolated spikes:*** Swiss-cross < 0.95; |time| > 3 ns

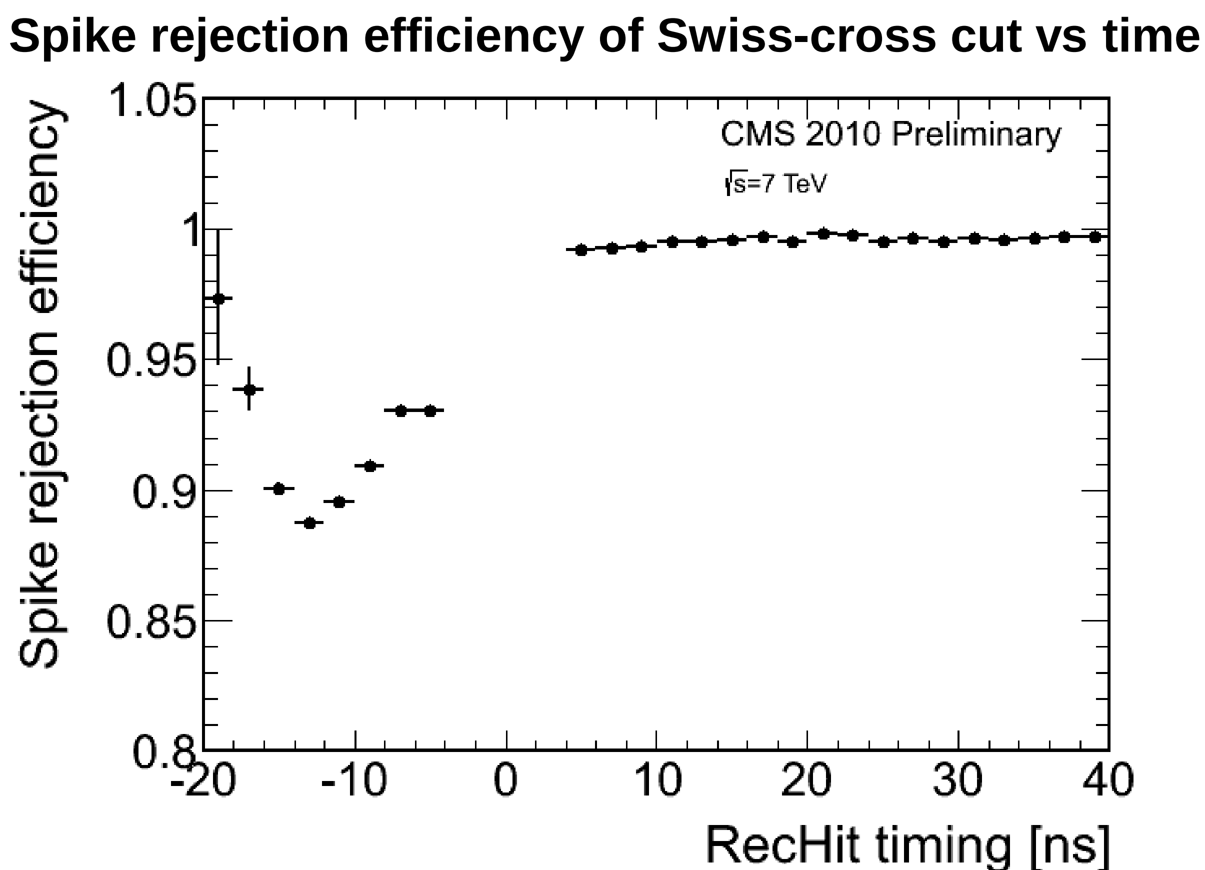
Efficiency of spike cleaning cuts



a)



b)



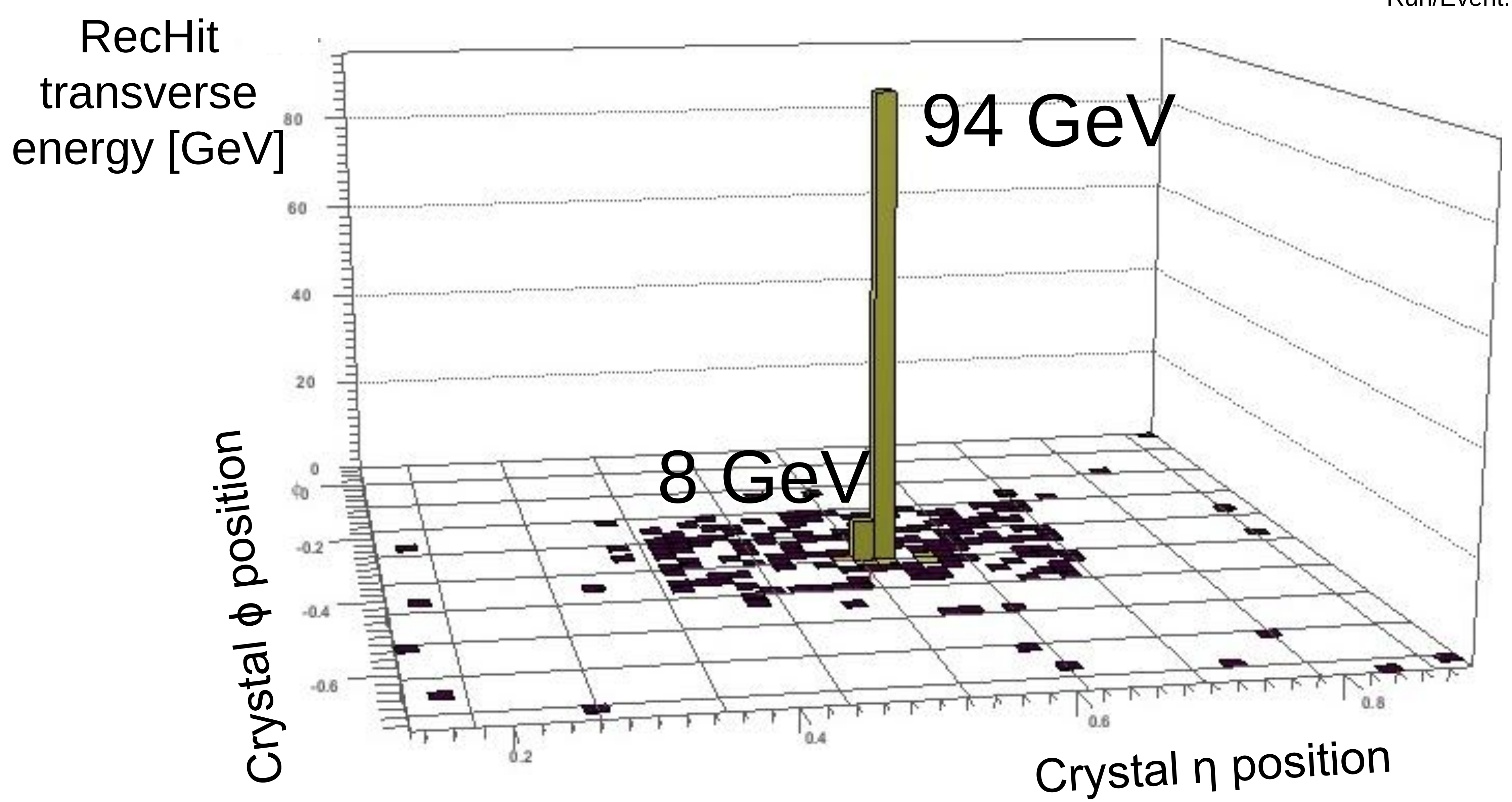
c)

Caption

- Data-driven estimate of the spike rejection efficiency of the Swiss-cross and timing cuts using Minimum Bias events. Define two control regions, assuming that the timing and Swiss-cross variables are independent:
  - **Time-selected: |T| > 3 ns, RecHit E_T > 3 GeV.** ***Use this to compute the efficiency of the Swiss-cross cut.***
  - **Topology-selected: $1 - E4/E1 > 0.95$, RecHit E_T > 3 GeV.** ***Use this to compute the efficiency of the timing cut.***
- a) The efficiency of the Swiss-cross cut ($1 - E4/E1 < 0.95$) plotted as a function of rechit transverse energy. The Swiss-cross cut is very efficient at high RecHit E_T (better than 99% for $E_T > 10$ GeV. There is a reduction in efficiency at the lowest rechit energies due to noise. For a 3 GeV spike at $\eta = 0$, a Swiss-cross value of 0.95 corresponds to 150 MeV in the adjacent four crystals, which is an approximately 2 standard deviation upward fluctuation in the noise (single channel noise is approximately 40 MeV). In addition, there is a reduction in efficiency for rechits with $T < 0$. This is due to the phenomenon of non-isolated spikes, which are more prevalent for negative T.
- b) The efficiency of the timing cut plotted as a function of rechit transverse energy. The efficiency of this cut is approximately 90%, independent of RecHit transverse energy. The inefficiency is due to spikes that fall within the ±3 ns timing window around zero.
- c) The Swiss-cross efficiency as a function of RecHit time. One can again see the reduction in efficiency for rechits with $T < 0$, due to non-isolated spikes.

Double spike

CMS Experiment at LHC, CERN
Data recorded: Tue Jul 15 00:55:42 2010 CEST
Run/Event: 139458/163767467
Lumi section:151

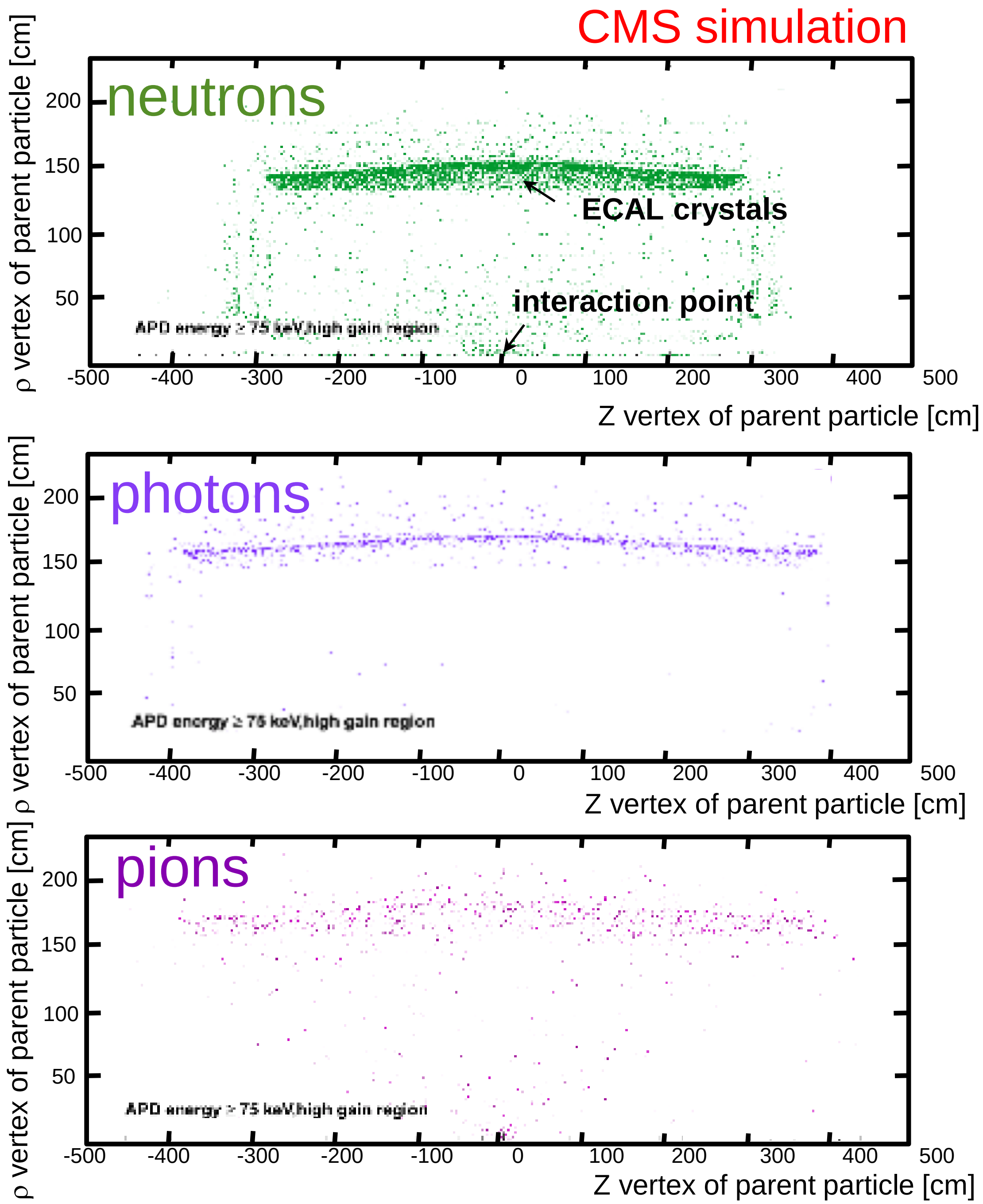


Caption

- A class of non-isolated events with two high energy adjacent crystals has been identified from scans of high MET events. An example is shown in the event display, which shows the transverse energy of ECAL energy deposits for a LHC collisions event at sqrt(s)=7 TeV.
- In this event, 100 GeV is shared between two crystals, with very little surrounding activity. Both crystals are significantly out-of-time, suggesting a spike-related origin for the two hits. The energy deposition is also inconsistent with the shape expected from an electromagnetic shower.
- Such “double spike” events are believed to be caused by particles produced in hadronic showers during LHC collisions that induce anomalous signals in neighbouring APDs.

APD Monte Carlo: location of spike progenitors

CMS detector view

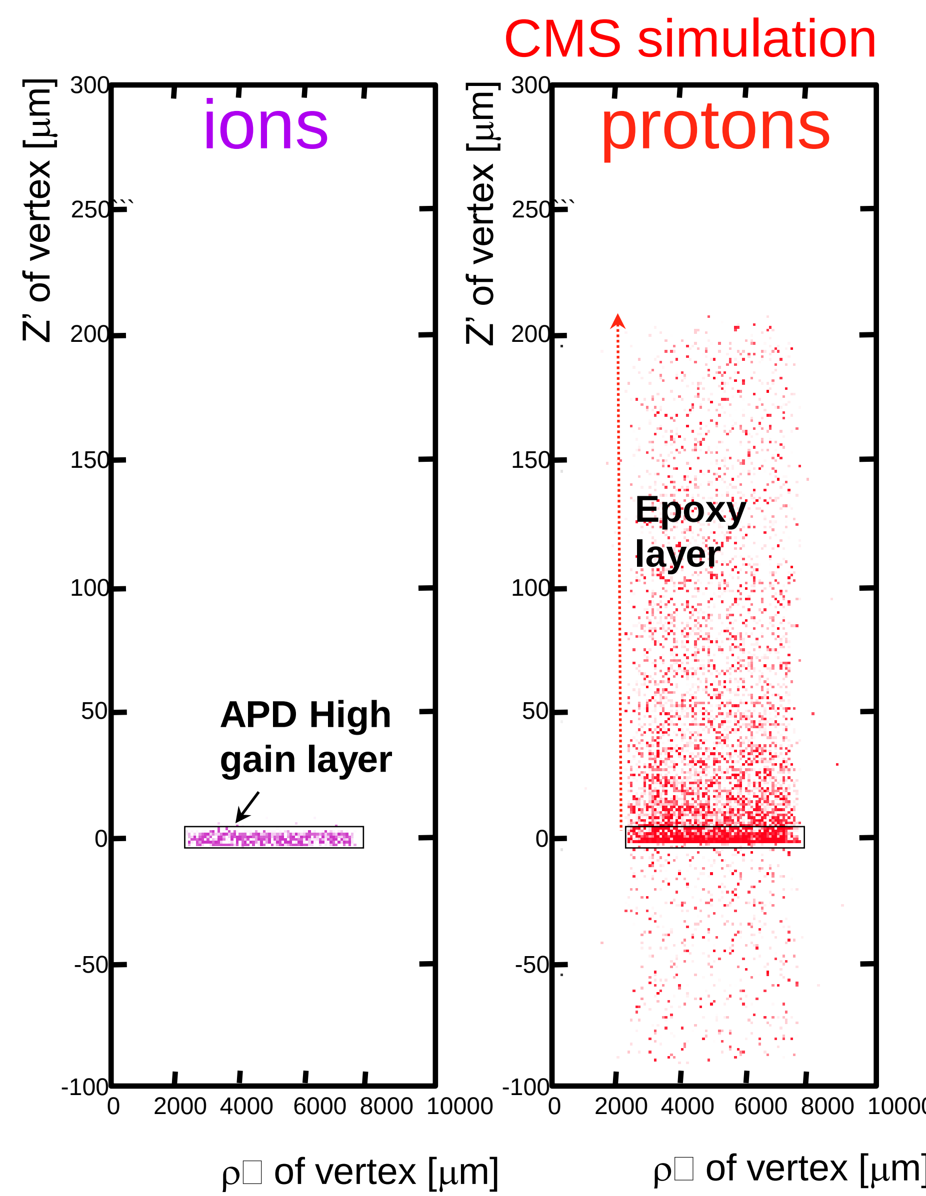


Origin of parent particle

z - distance along beam axis

ρ - distance perpendicular to beam axis

ECAL APD view



Origin of particle hitting APD

ρ' - distance along APD

z' - distance perpendicular to APD axis

Caption

- A detailed model of the APD structure has been implemented in the CMS Monte Carlo simulation
- The simulation (using Geant 4) is used to further understand the origin of spikes and their rates in CMS.
- The simulations show that direct ionization of the APD by protons/ions produced in pp collisions can produce large apparent energy signals after amplification (direct ionization produces ~2.8×10^5 e/MeV, c.f. ~4 p.e./MeV for scintillation light in $PbWO_4$)
- The plots show the location in CMS of the particles produced in CMS collisions that are the progenitors of the APD (spike) hits in the simulation:
  - pions are produced both at pp interaction point and close to APDs
  - photons are produced close to APDs
  - neutrons are produced in PbWO4 crystals
  - Protons are produced in epoxy close to APD.
  - Ions are produced in APD high gain layer
- The simulation results (and laboratory measurements) indicate that a significant fraction of the anomalous signals are produced by np scattering in the protective epoxy coating of the APD, and the resulting proton directly ionizing the APD active volume.