HCAL Anomalous Events

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ASC TF

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Introduction

Anomalous events studied and characterized in CRAFT08, CRAFT09, and TB

HE/HB dominated by anomalous electronic noise

Ion feedback, HPD discharge, RBX electronics noise

HF dominated by anomalous interactions

Observed muon interactions in PMT windows in the Test Beam data

Software framework and filters developed to flag/remove anomalous rechits

More details can be found in:

CFT-09-019 ***Accepted by JINST***

"Identification and Filtering of Uncharacteristic Noise in the CMS Hadron Calorimeter"

CFT-09-009 ***Accepted by JINST***

"Performance of the CMS hadron calorimeter with cosmic ray muons and LHC beam data"

Now looking at first collisions

Noise rates in HE/HB look as expected

HF more complicated - ***indications of additional contributions***

Introduction

HF Noise Filters Working Group

Optimize filters to reject HF PMT Hit events

http://indico.cern.ch/conferenceDisplay.py?confId=85887

HF Noise Sources Working Group

Understand sources of HF PMT Hit events

http://indico.cern.ch/conferenceDisplay.py?confId=85878

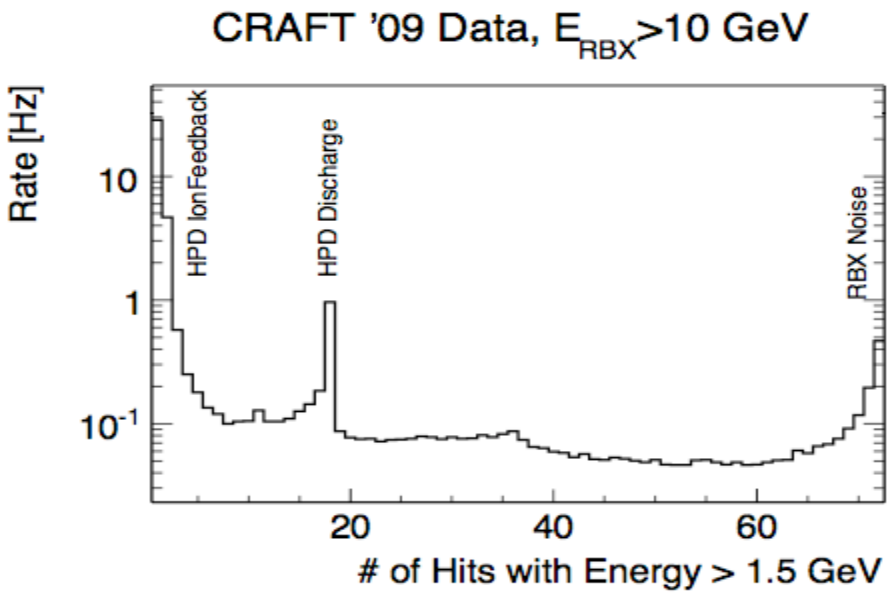
Group reports presented in the DPG meeting of March 13

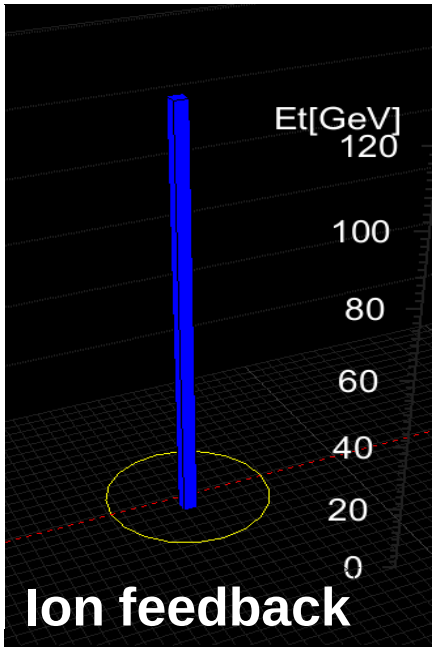
http://indico.cern.ch/conferenceDisplay.py?confId=85629

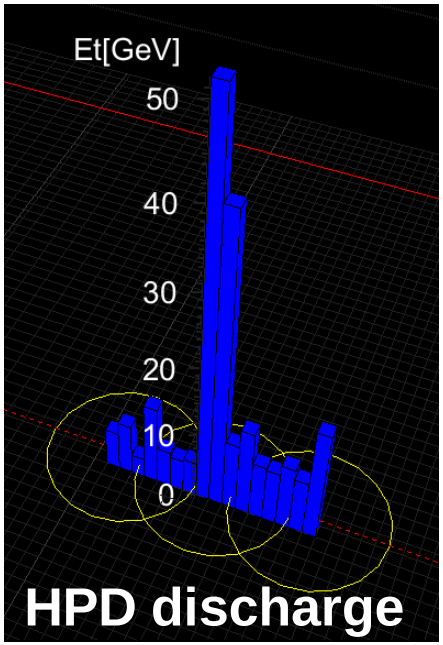
Contributions from many people

I. Vodopiyanov, D. Ferencek, F. Santanastasio, J. Temple, T. Yetkin, E. Yazgan, S. Kunori, Kai Yi, Yi Chen, B. Bilki, S. Banerjee, N. Akchurin, V. Gavrilov, F. Chlebana

HPD and RBX Noise







HPD Ion Feedback **(1-9 hits/RBX)**

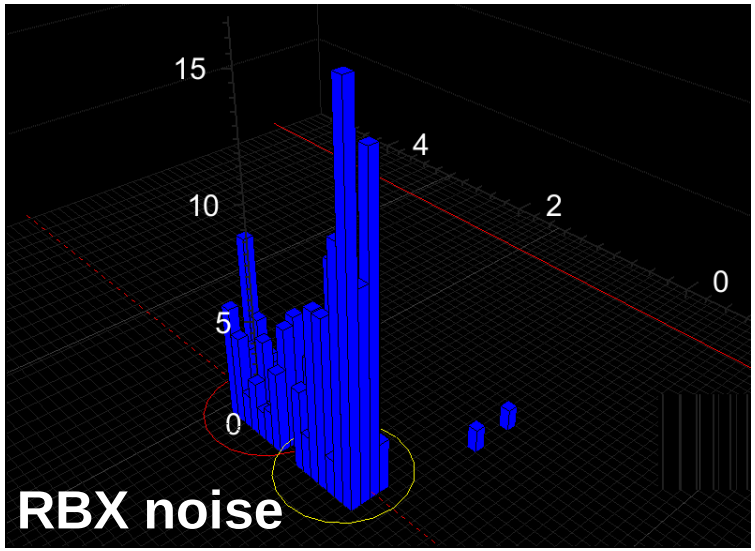
Emission of electrons (thermal, photoelectric,…) which feedback into the HPD resulting in avalanche and a high signal

HPD Discharge **(10-18 hits/RBX)**

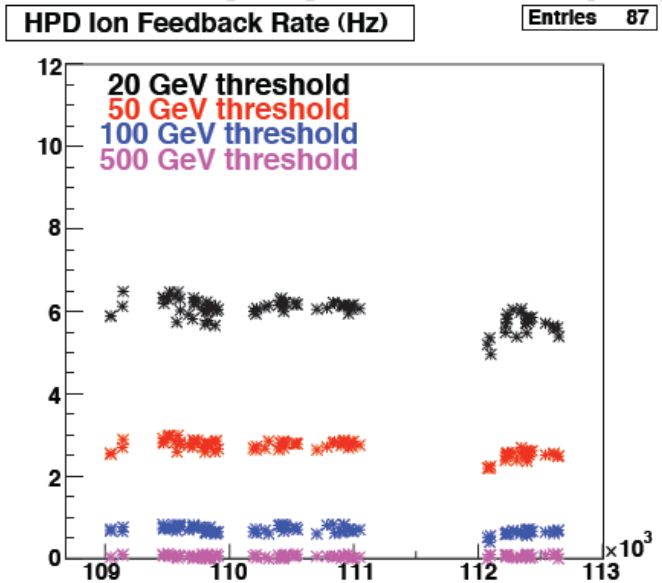
Possibly related to electrical discharge emanating from the wall of the HPD

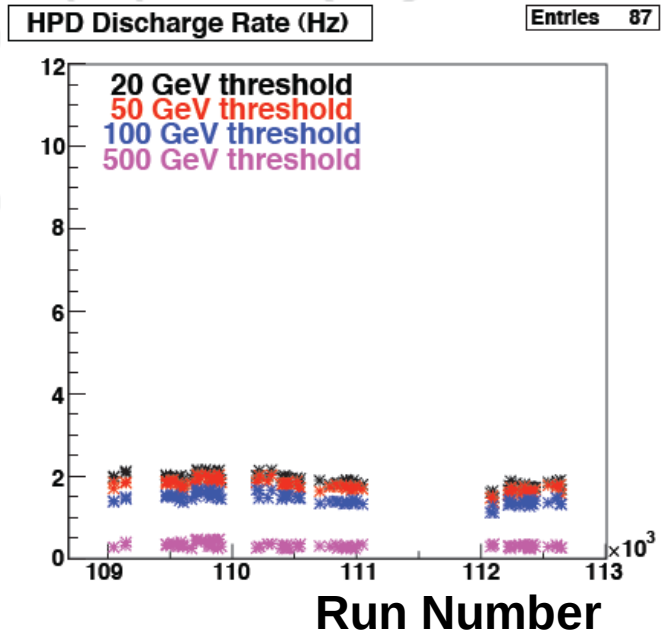
RBX Noise **(19-72 hits/RBX)**

Anomalous noise characterized by high multiplicity in all four HPDs in a RBX



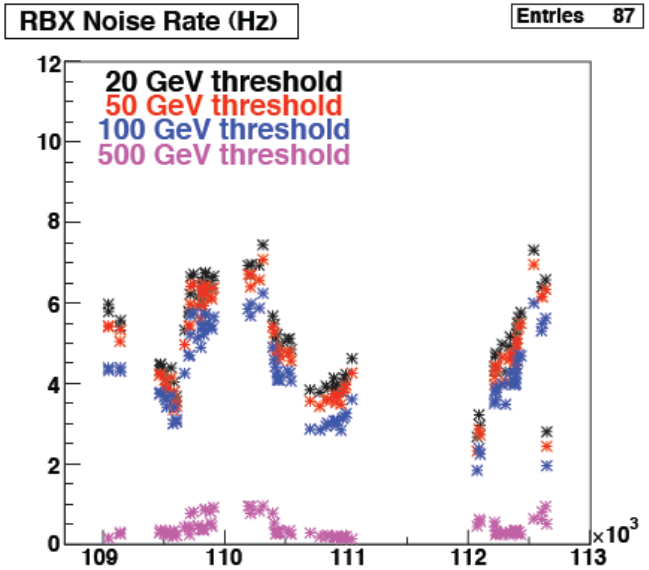
Noise Rate as a Function of Run Number





Ion feedback and HDP discharge rates are constant

RBX noise rate can very by a factor of 2



Total rate of HPD and RBX noise is

~10-20 Hz for E > 20 GeV
for all 288 HPDs

Rate is random
→ overlap with physics expected to be low

HB/HE Noise Rates

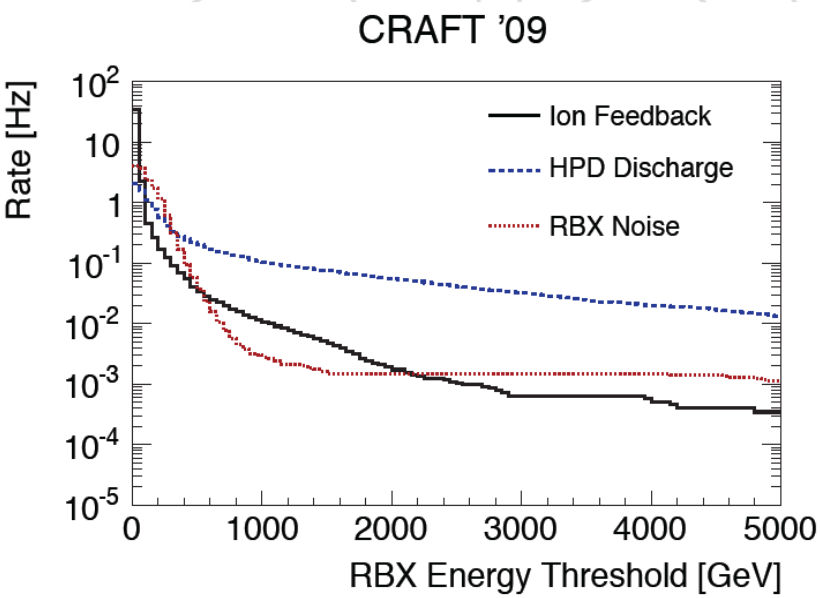
Noise rate not a problem at L1, but may be an issue at HLT

Filters to identify HPD/RBX noise use *pulse shape, timing, and hit multiplicity*

Ready to be applied at the HLT for the Jet and MET paths if needed

1E31 Menu ($\sqrt{s}$ =10 TeV)

Trigger	Prescale	Noise Rate (Hz)	Physics Rate (Hz)
Jet 15	×10000	$\sim 1.3 \times 10^{-3}$	1.34 ± 0.33
Jet 30	×5000	$\sim 1.5 \times 10^{-3}$	1.17 ± 0.31
Jet 50	×200	$\sim 25 \times 10^{-3}$	1.84 ± 0.39
Jet 80	×20	~ 0.12	1.42 ± 0.34
Jet 110	×1	~ 1.3	7.11 ± 0.77
Jet 180	×1	~ 0.60	1.17 ± 0.31
MET 20	×2000	$\sim 5.0 \times 10^{-3}$	0.17 ± 0.12
MET 35	×20	~ 0.37	0.33 ± 0.17
MET 60	×1	~ 5.1	~ 0.5
MET 100	×1	~ 2.2	~ 0.0



Noise rates in table not gated by trigger

Scale = (4 TS x Bunches) / Total buckets

Total buckets = 3564

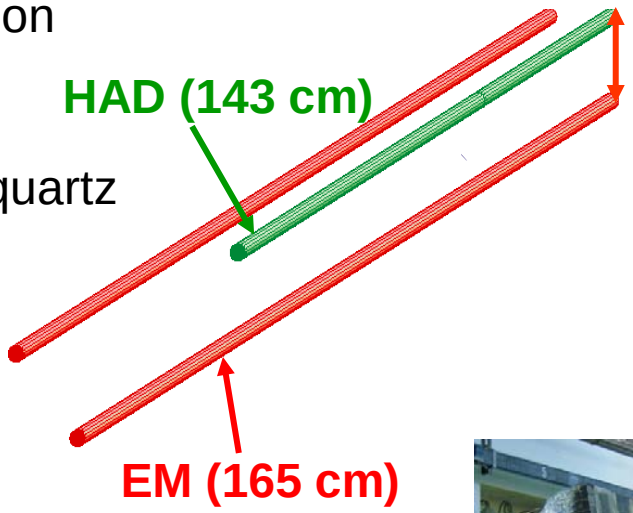
Bunches	Scale Factor	MET100
43	0.048	~0.1 Hz
156	0.175	~0.4 Hz
936	1.000	~2.2 Hz

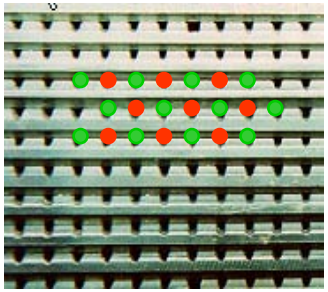
Forward Calorimeter (HF)

HF is located about 11 m from the interaction point, covers 3 < |η| < 5 with depth 10 λ_{int}

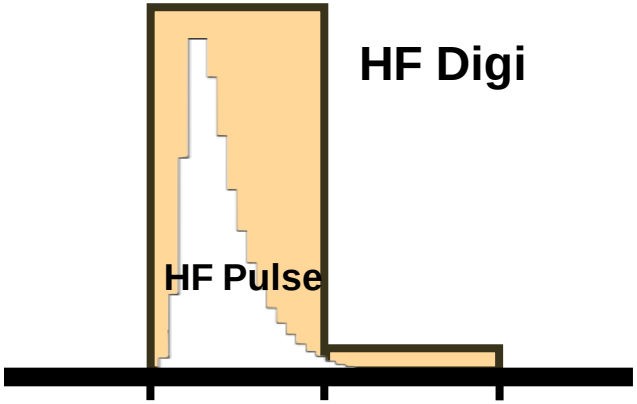
Consists of iron absorber embedded with quartz fibers parallel to the beam direction in a 5x5 mm matrix

Charged particles from showers produce Cherenkov light

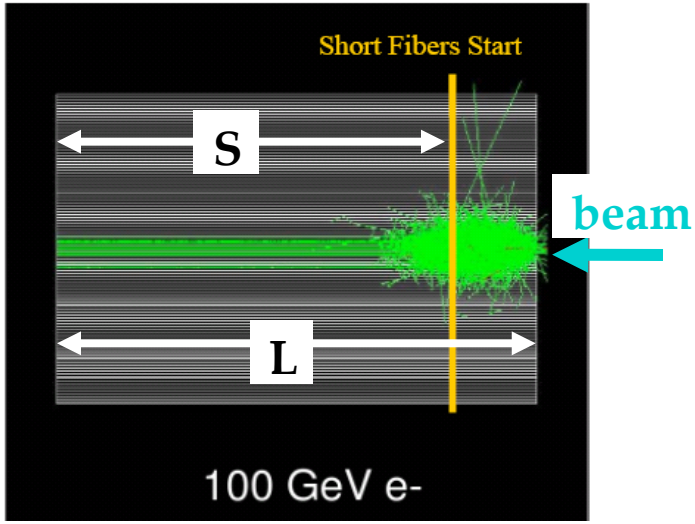




HF signal generation and collection is very fast ~10 ns



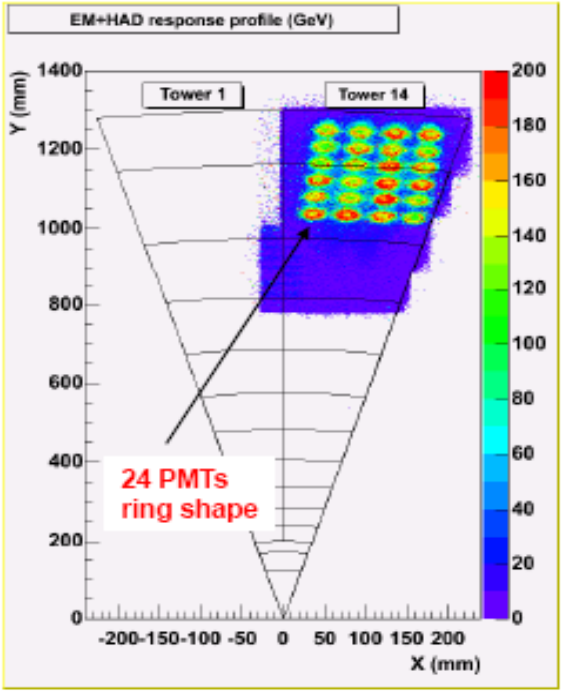
25 ns time samples



20° wedges

HF PMT Window Hits

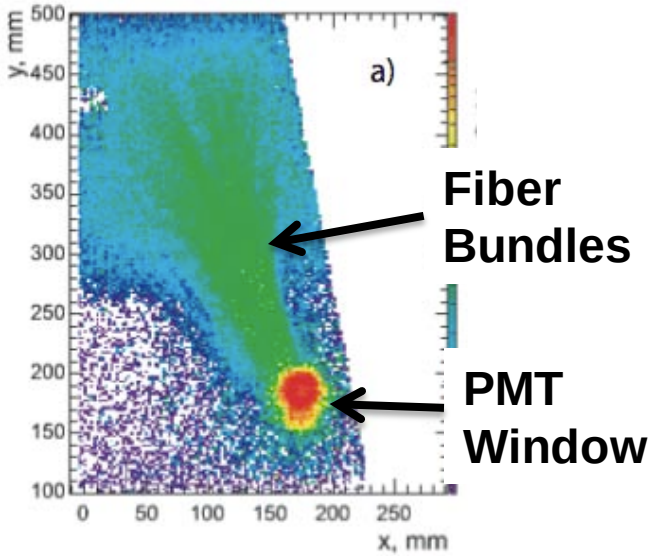
150GeV Muon / Wedge 2-6

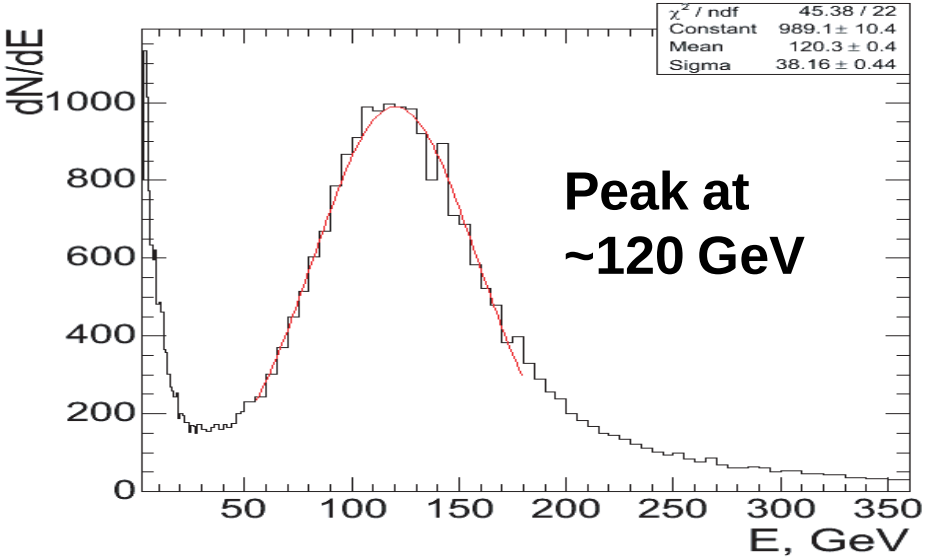


TB2004 elog 3601 Aug. 2, 2004

In the test beam data, we observed anomalous signals in HF L or S sections from particles interacting in the PMT window.

Eur.Phys.J. C53, 139-166 (2008)

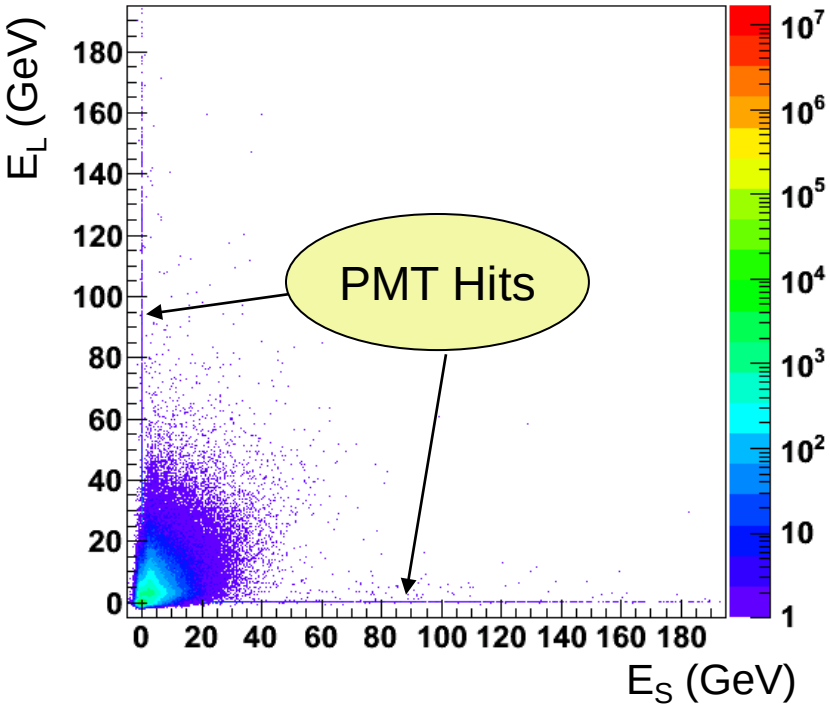




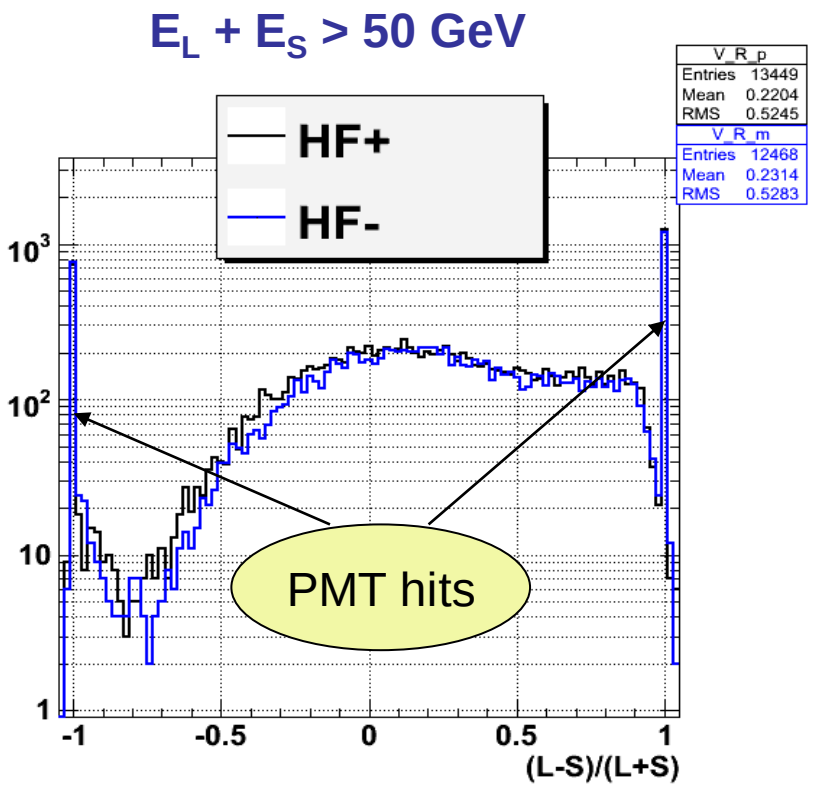
TB calibration for 100 GeV electrons set so L energy = 100 GeV; L+S = 130 GeV

For current calibration peak would occur at 120 / (130/100) = 92 GeV

Algorithm 1



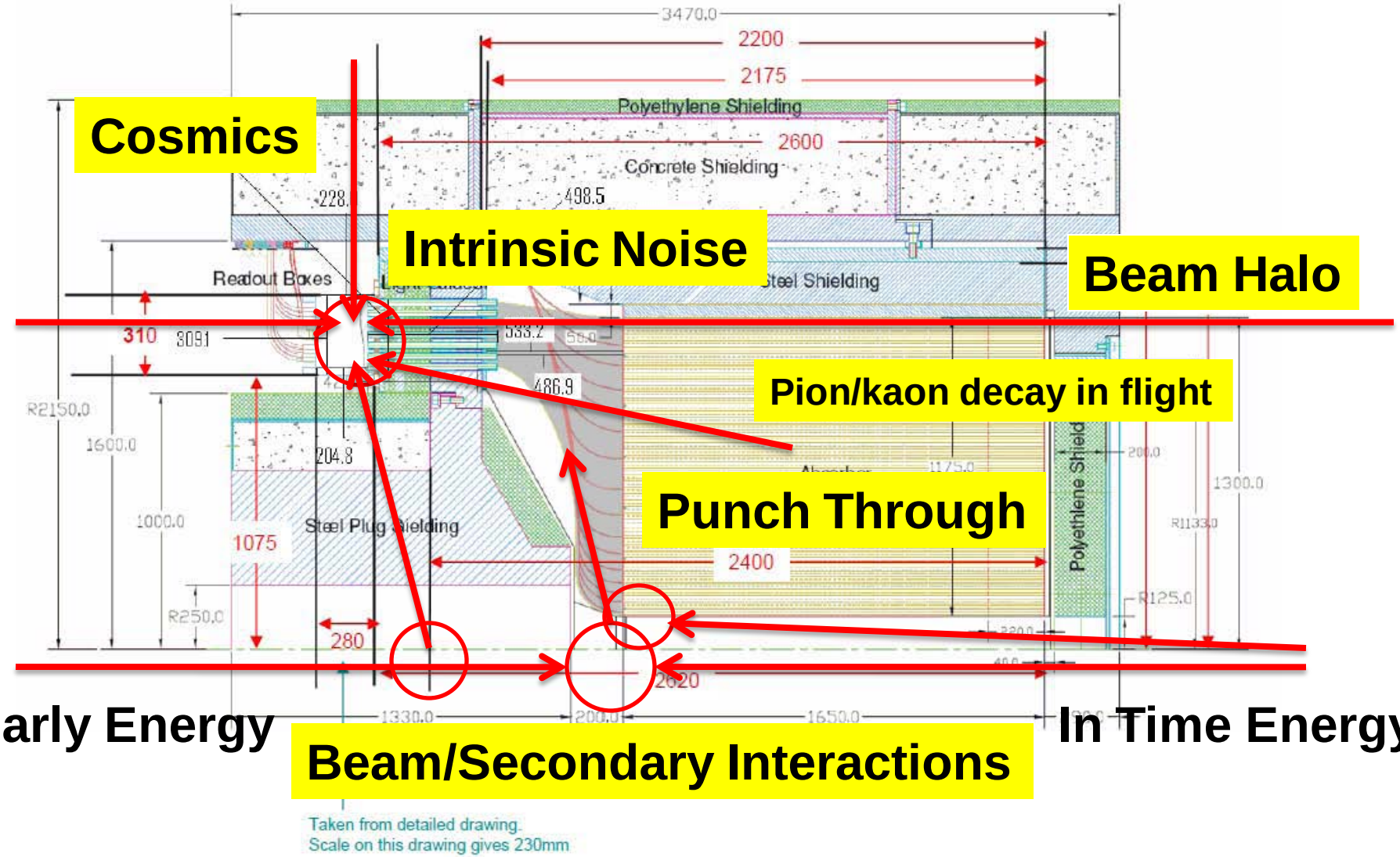
Identify HF PMT hit events by looking at the ratio R=(L-S)/(L+S) and require *E* or E_T > E_Th



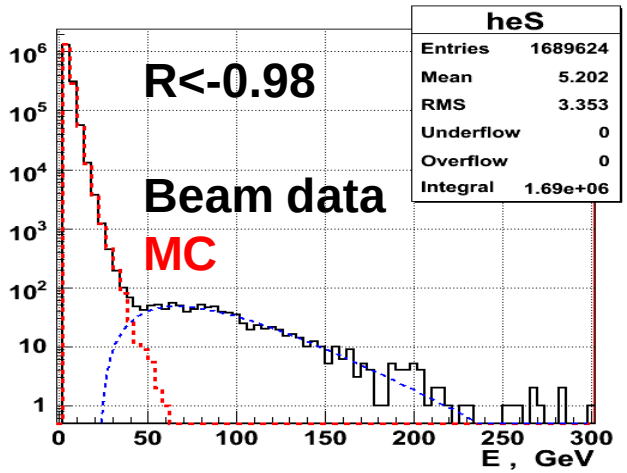
Particles travelling through HF and hitting the PMT window would produce signals a few ns (~3-5 ns) earlier than signals produced by energy loss within HF

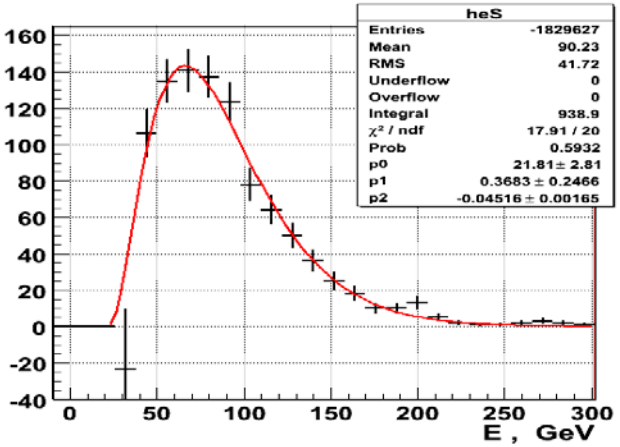
Need to have a very precise phase alignment for HF in order to be able to use timing information to identify punch through

Possible Sources of HF Anomalous Signals

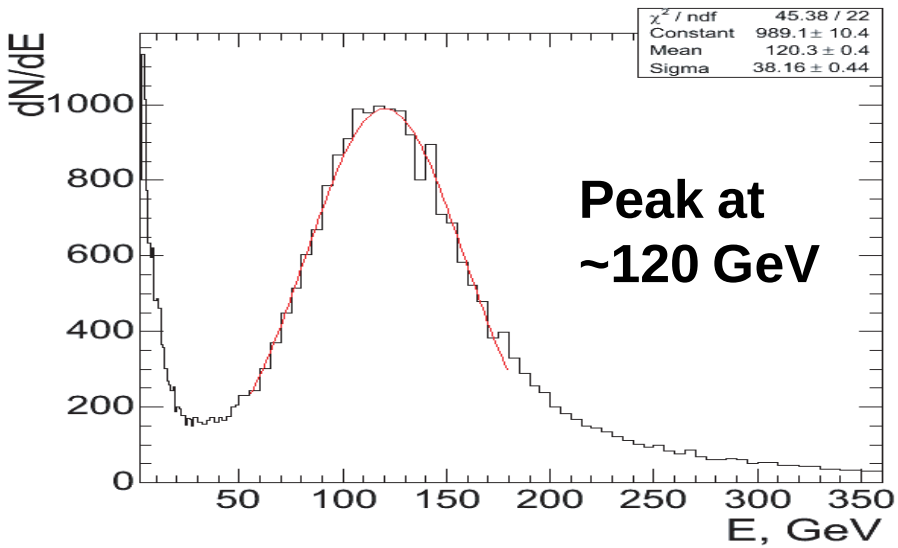


HF PMT Window Events





Eur.Phys.J. C53, 139-166 (2008)



Spectra of PMT Hit events does not extend to very high energies

Forward region → Low ET

TB calibration for 100 GeV electrons set so L energy = 100 GeV; L+S = 130 GeV

For current calibration peak would occur at 120 / (130/100) = 92 GeV

Number of HF PMT Hits per Event

	Random Triggers	Single beam (450 GeV)	Two "non-colliding" beams (450 GeV)	Collision (900 GeV)	Collision (2360 GeV)
N_{ev} selected	1408372	1855746	1908061	164703	9685
# PMT Hits	70	89	80	1058	79
# PMT Hits / event	$(5.0 \pm 0.6) \times 10^{-5}$	$(4.8 \pm 0.5) \times 10^{-5}$	$(4.2 \pm 0.5) \times 10^{-5}$	$(6.4 \pm 0.2) \times 10^{-3}$	$(8.1 \pm 0.9) \times 10^{-3}$

Rate of HF PMT Hits for random triggers, single, and two "non-colliding" beams is similar

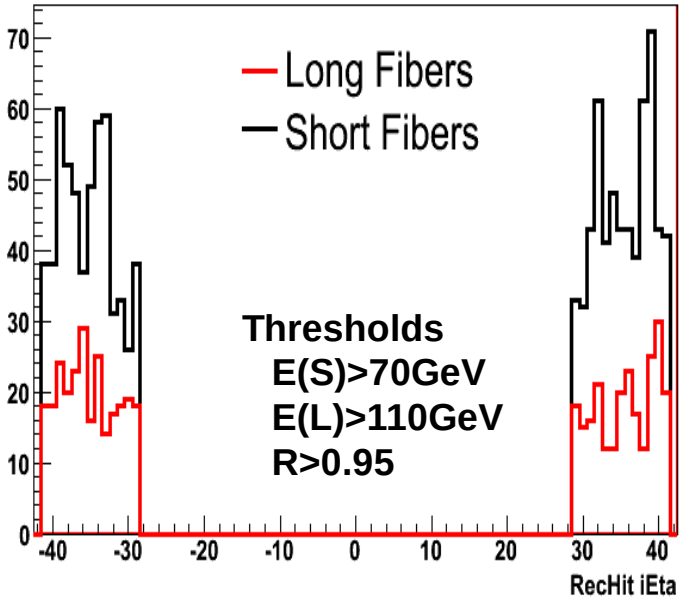
No significant contribution from Beam Halo

Due to intrinsic noise and possibly cosmics

Rate of HF PMT Hits ~130 times larger during 900 GeV collisions than for random, single beam, or "non-colliding" beams

With the limited statistics at 2360 GeV, rate of HF PMT Hits in the single collision run at 2360 GeV is 25% larger than 900 GeV collisions

Eta distribution of PMT hits (mostly single hit)

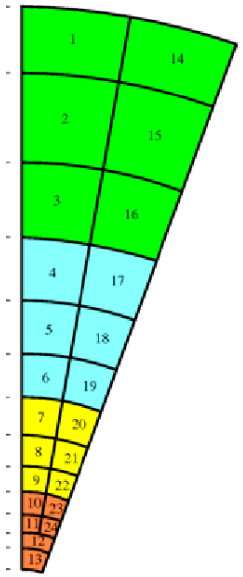


No strong eta dependence

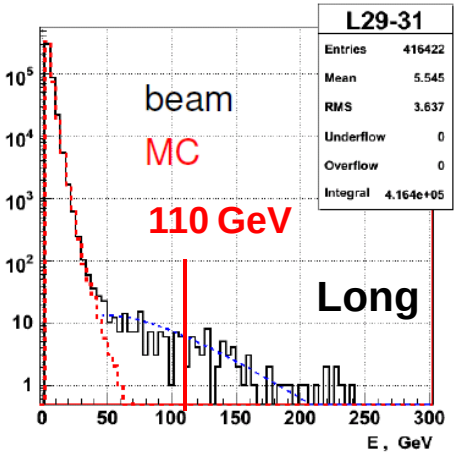
Consistent with light source from PMT glass window (not fibers)

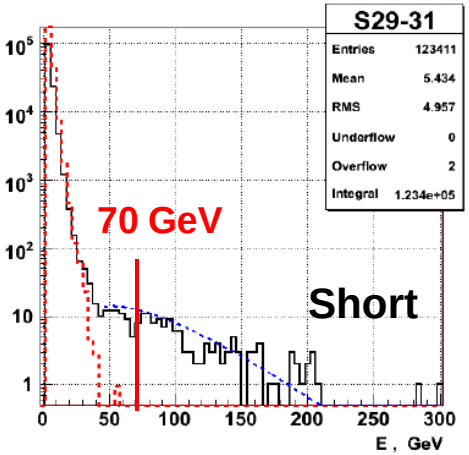
High E thresholds were used to avoid contamination of real signal at high eta

N. of fibers.	
iη	N
41:	45
40:	42
39:	30
38:	41
37:	59
36:	85
35:	120
34:	171
33:	242
32:	346
31:	491
30:	696
29:	594

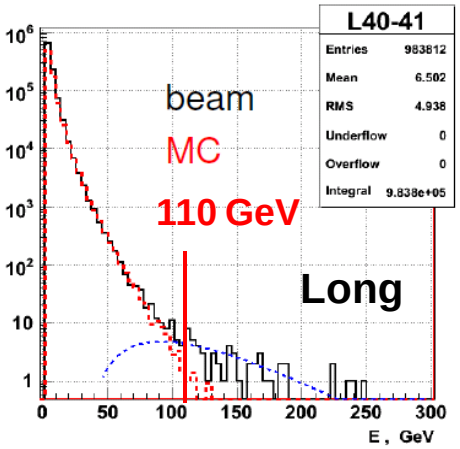


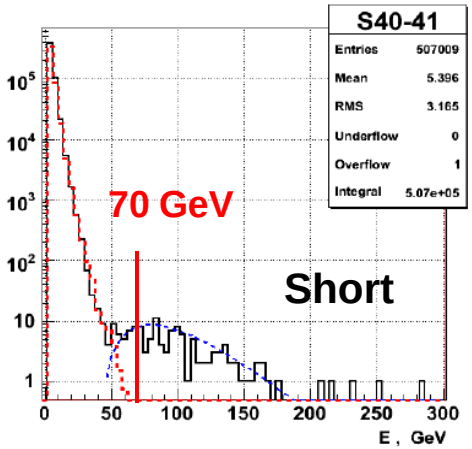
Low eta (iEta 29-31)





High eta (iEta 40-41)





G4 Simulation Results *(Very preliminary)*

900 GeV min-bias 100k events simulated

65606 events after cut on particle energy flow to HF (*)

(*) HFM>10GeV and HFP>10GeV (|η| = 3.1-4.0).

(energy scale not perfect at his stage)

MC PMT hits (E>50GeV) 3.9 PMT hits/1k events

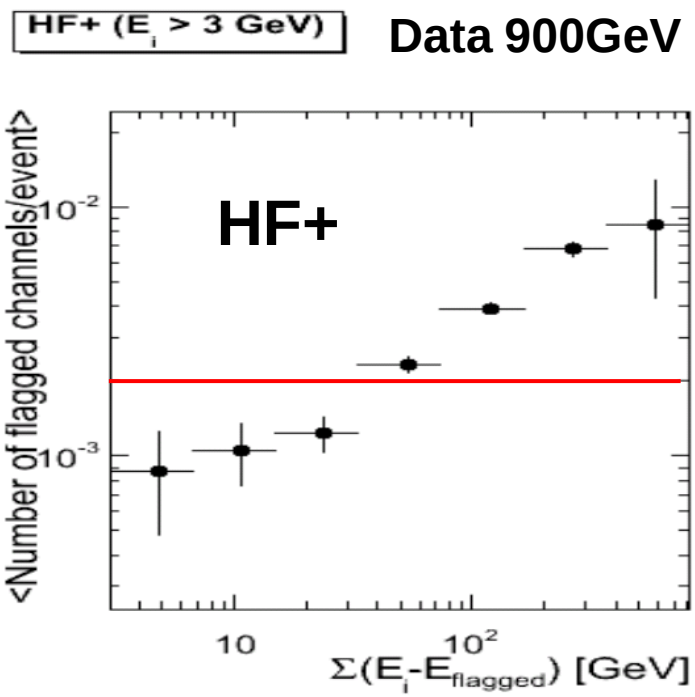
- 58% pion/kaon decay in flight to muon
- 30% hadron punch through
- 12% unknown *(available in next version)*

7 TeV min-bias 20k events

14410 events after cut on energy flow to HF(*)

MC PMT hits (E>50GeV) 5.9 PMT hits/1k events

- 53% pion/kaon decay in flight to muon
- 32% hadron punch through
- 15% unknown *(available in next version)*



<Data> ~ 6.4×10^{-3} hits/evt

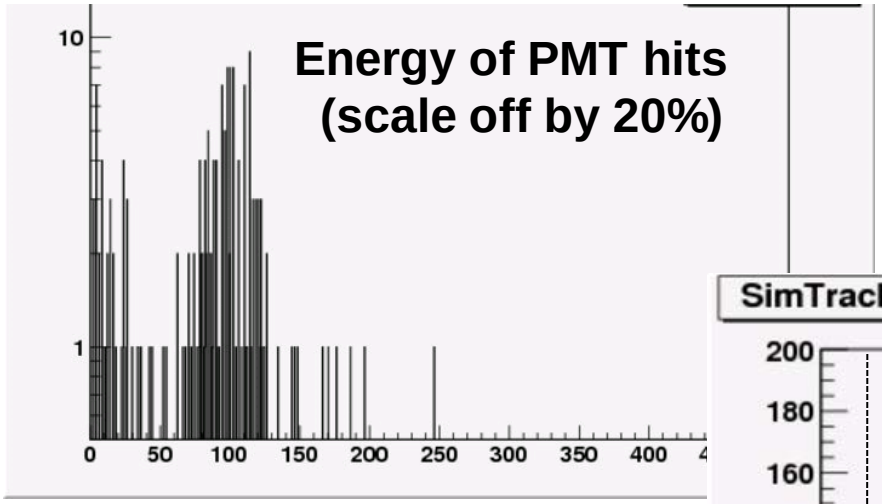
<MC> ~ 3.9×10^{-3} hits/evt

Simulation of BSC trigger not used (yet)

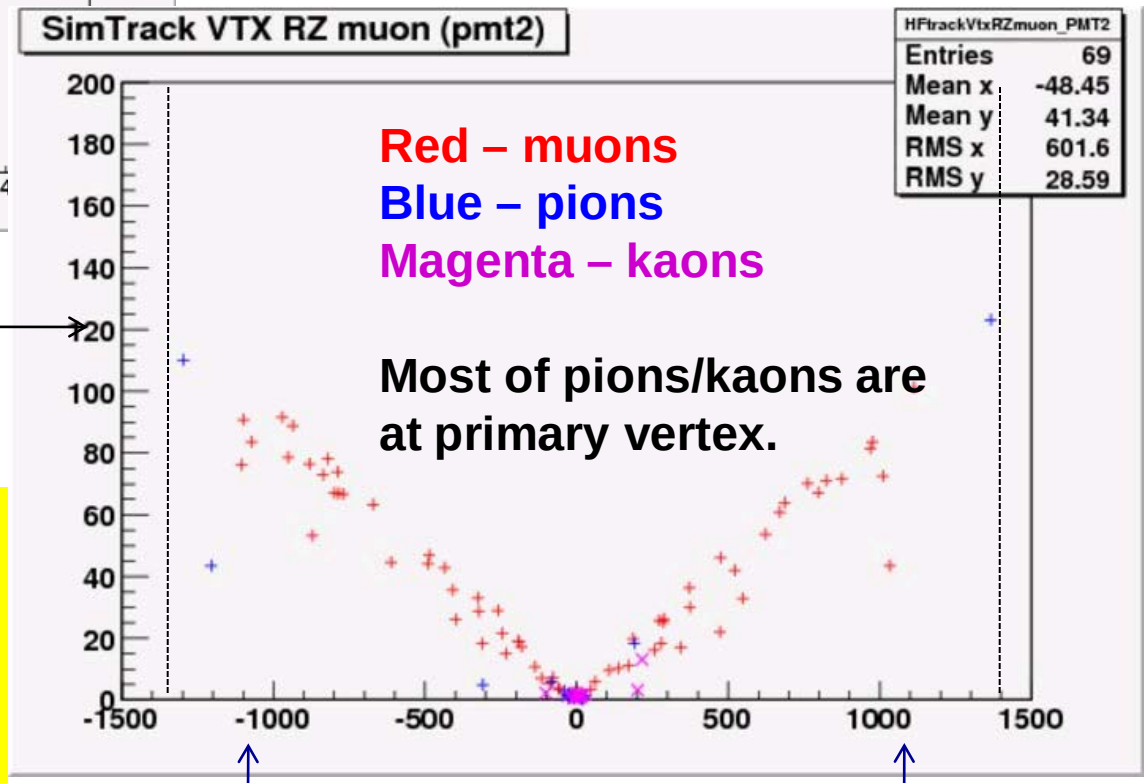
No signal simulation for HF body (yet)

No light guide and no gap between HF wedges in MC geometry

Simulation of PMT Hit Events



Production point of particles hitting PMT windows



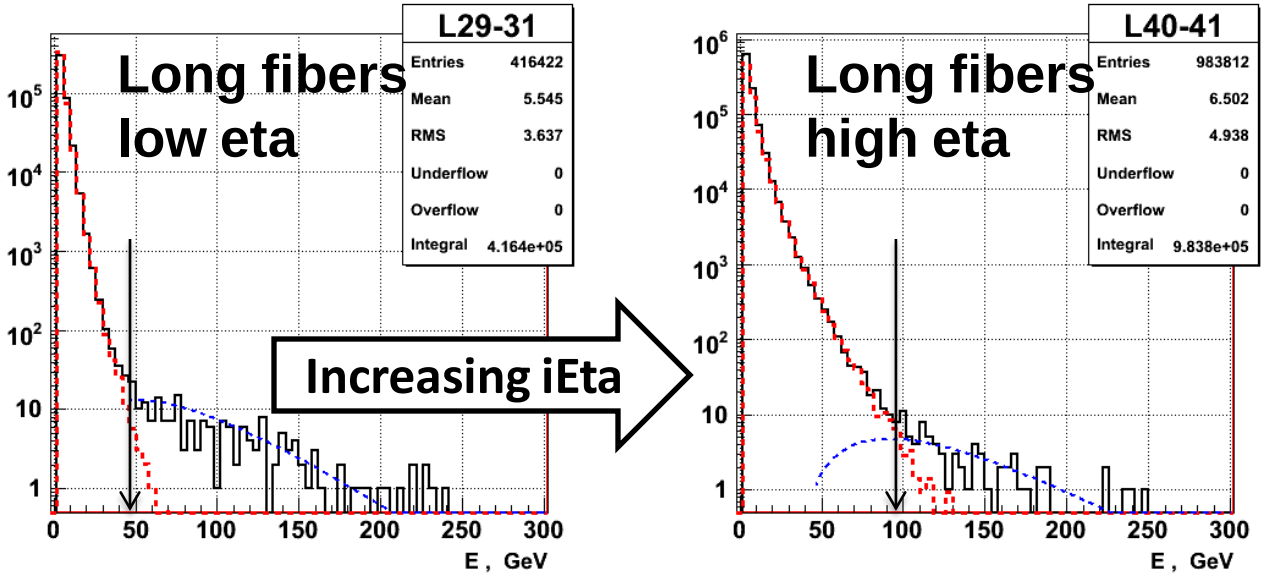
PMT Windows (120 cm)

Majority of HF PMT Hits can be explained by muons from particles that decay in flight and hadronic shower punch through that interacts in the PMT window

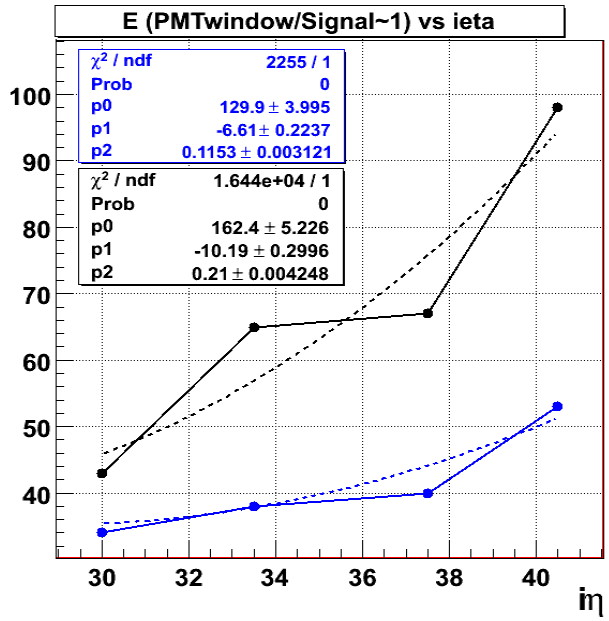
Front face of HF (-11m)

Front face of HF (11m)

Algorithm 2



Use a sliding energy threshold to improve filter efficiency



Polynomial Energy Threshold (PET)

R = (L-S)/(L+S)

E > E_Th(iEta)

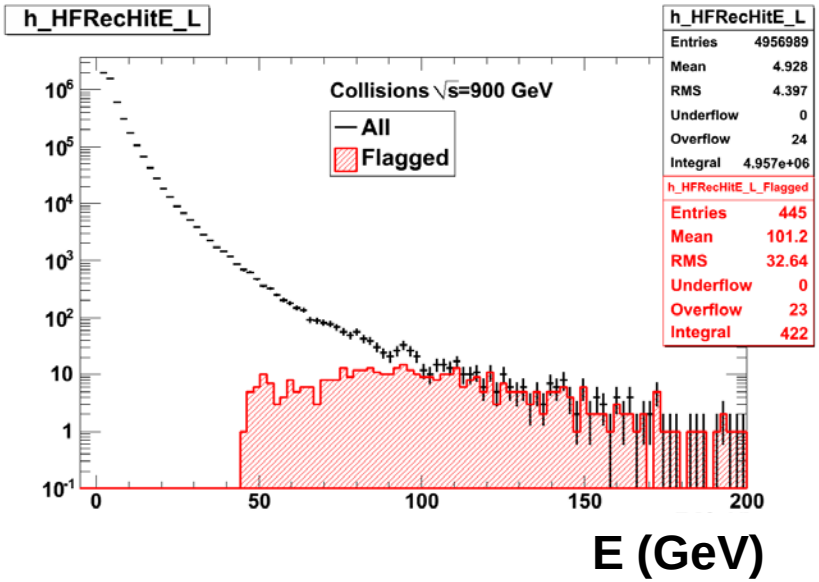
E_Th(iEta) optimized using

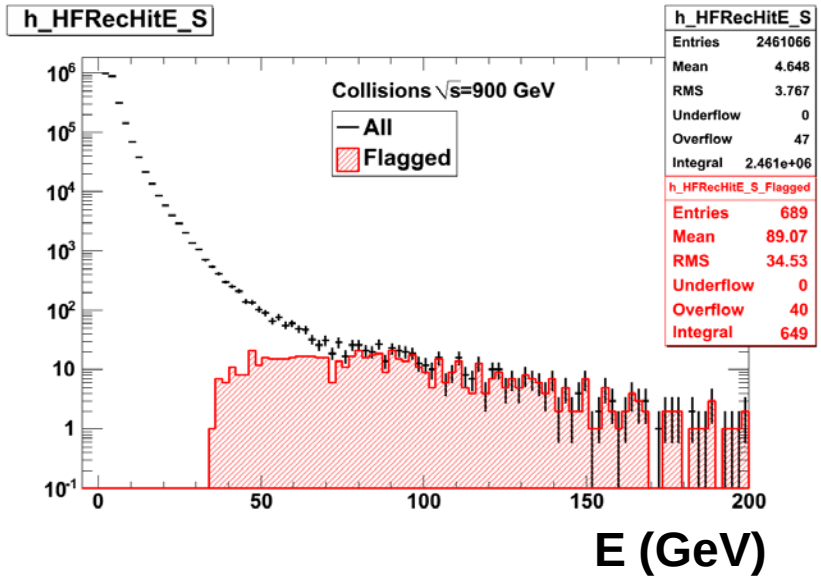
900 GeV MinBias MC and

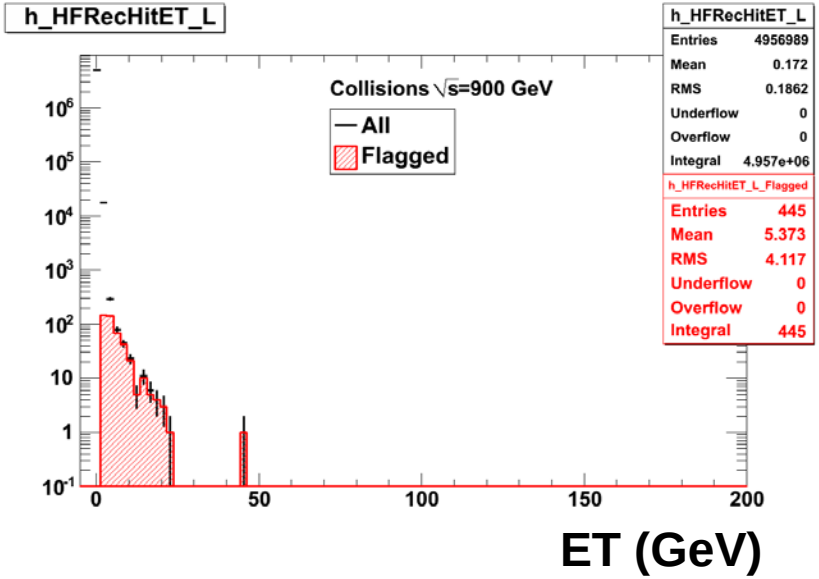
900 GeV collision data

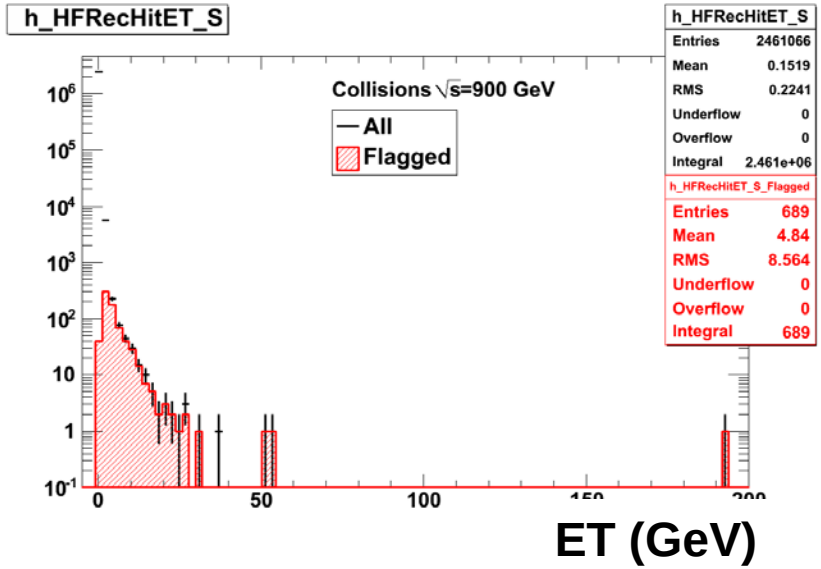
Set threshold where physics = noise rate

Algorithm 2: 900 GeV Collision Data

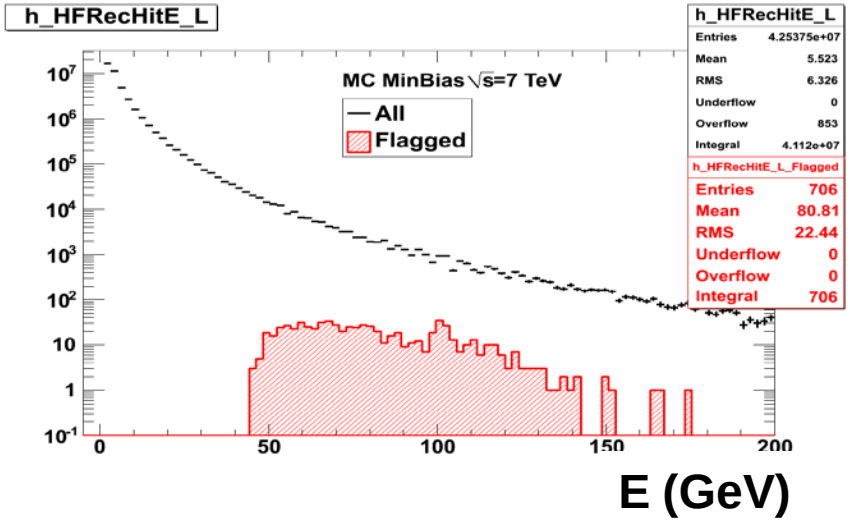


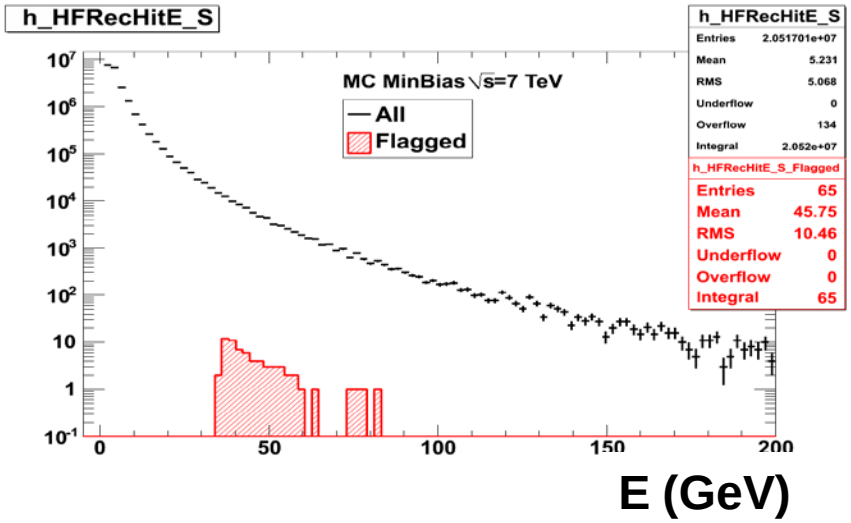


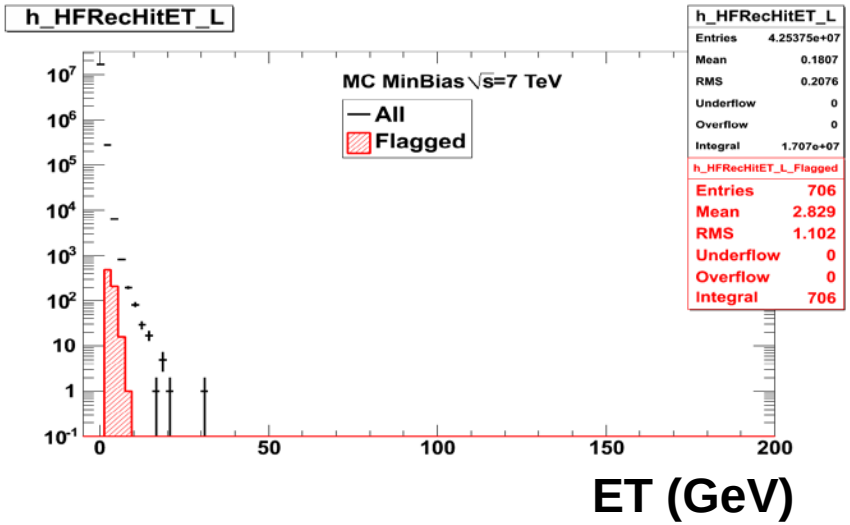


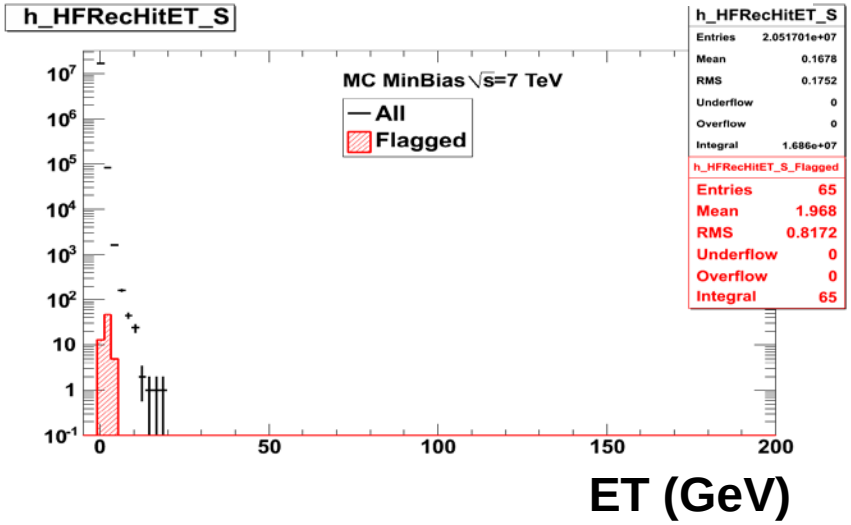


Algorithm 2: 7 TeV MC Min Bias







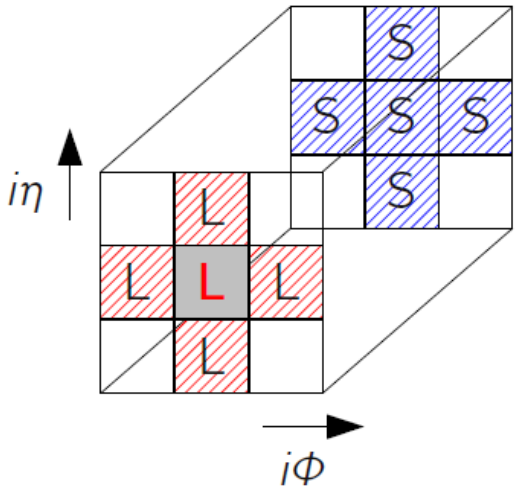


E_T of flagged rechits is very small…

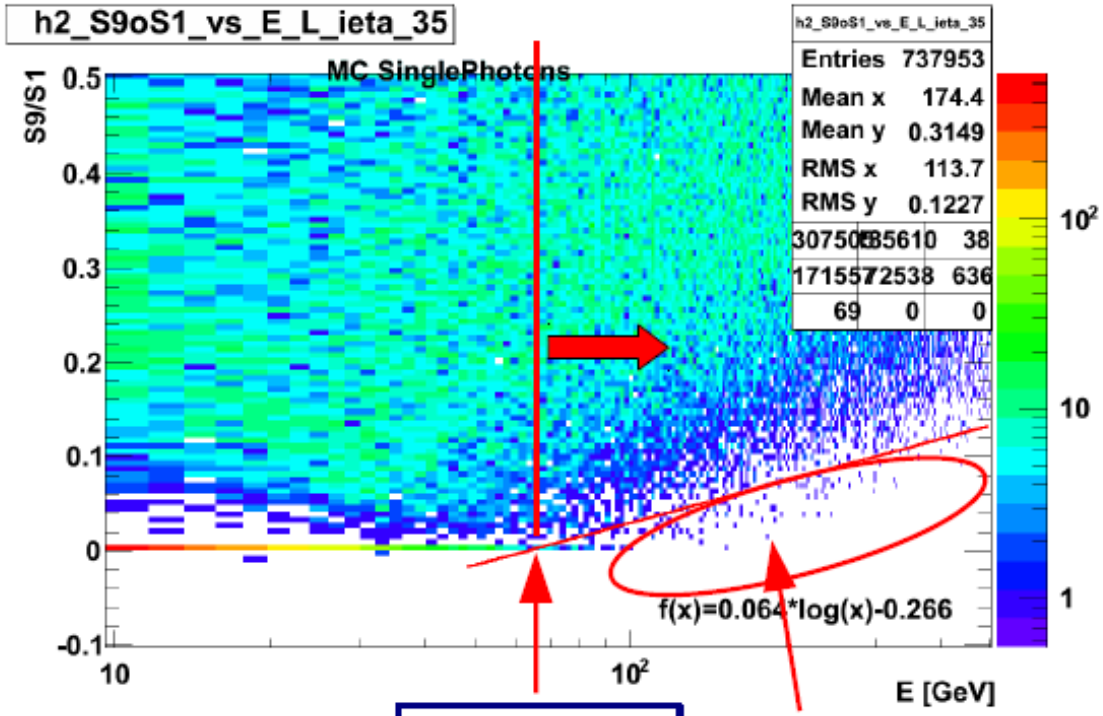
Algorithm 3

Introduce isolation to make the algorithm "safer"

E > E_PET(iEta)
S9/S1 < f(E, iEta)



$$\left(\frac{S9}{S1}\right)_L = \frac{S + L_{(4)} + S_{(4)}}{L}$$

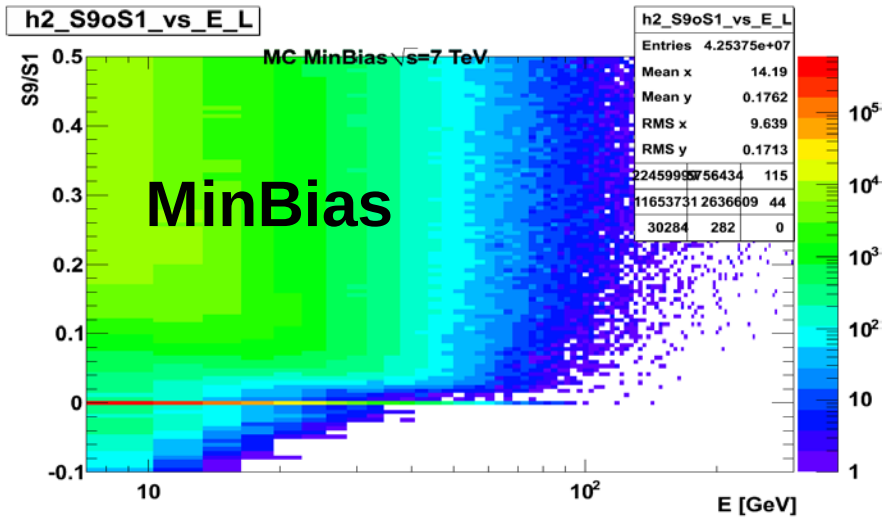


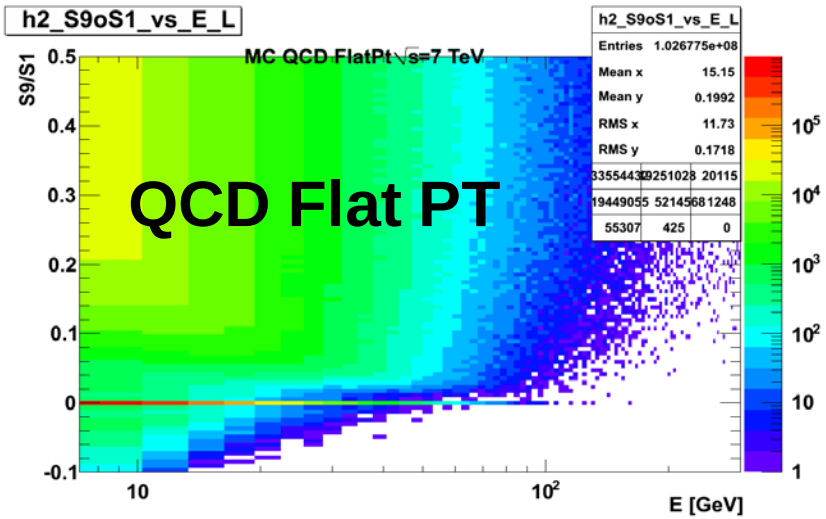
$E_{PET}(35)$ cut

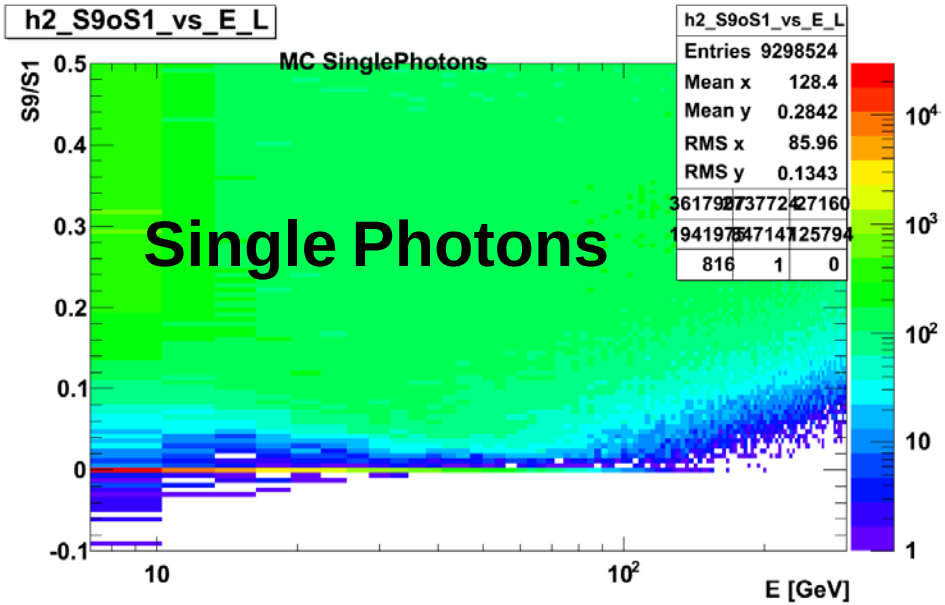
Flagged RecHits are those below the cut line

Slope optimized such that only 0.1% of the simulated photons above the E_PET(iη) threshold is flagged

S9/S1 vs E for Long Fibers

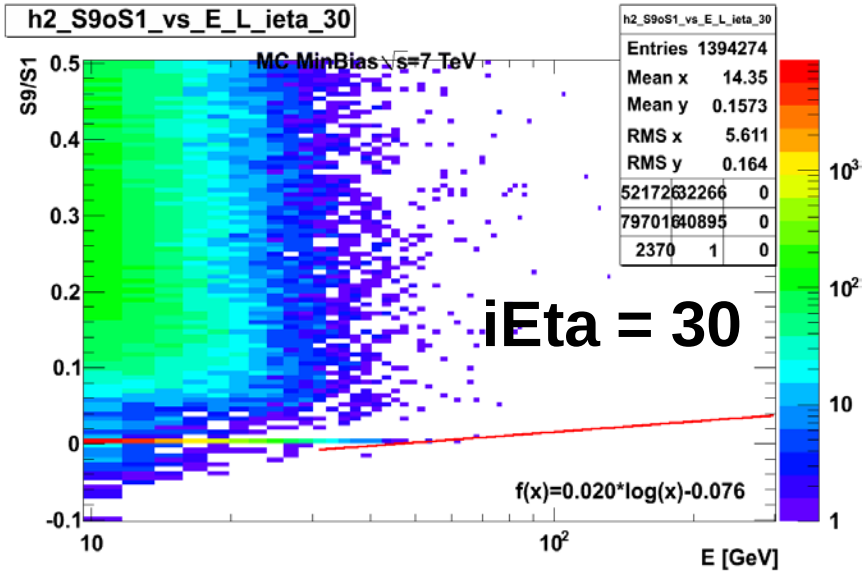


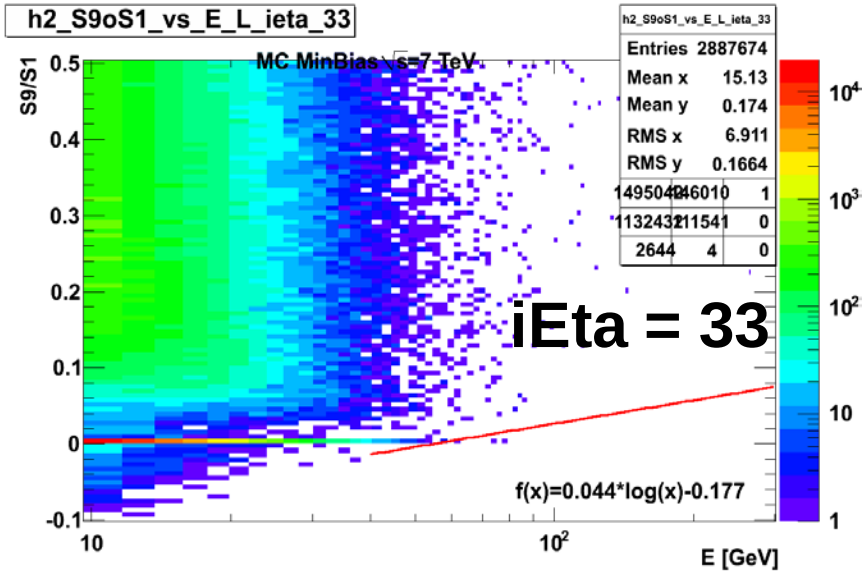


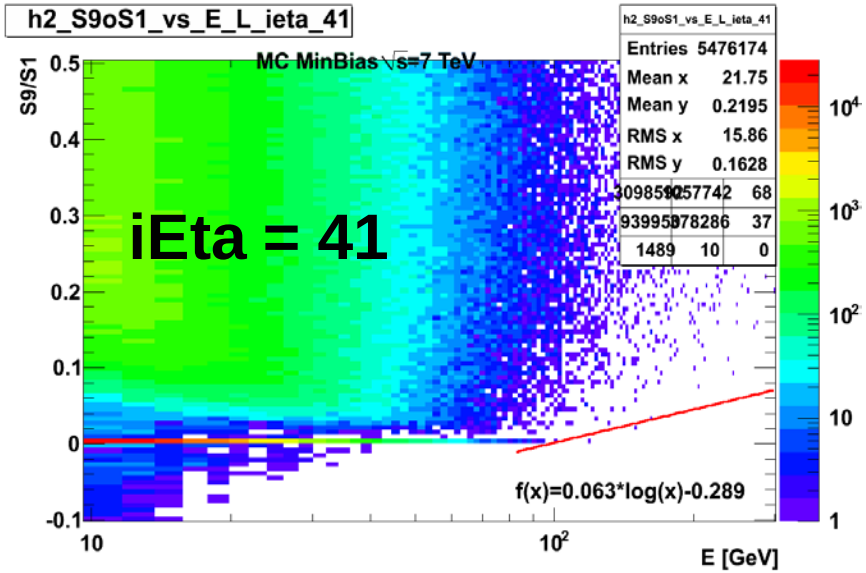


Optimize S9/S1 cut using the single photon sample
representing the worst case

MinBias MC for 7 TeV



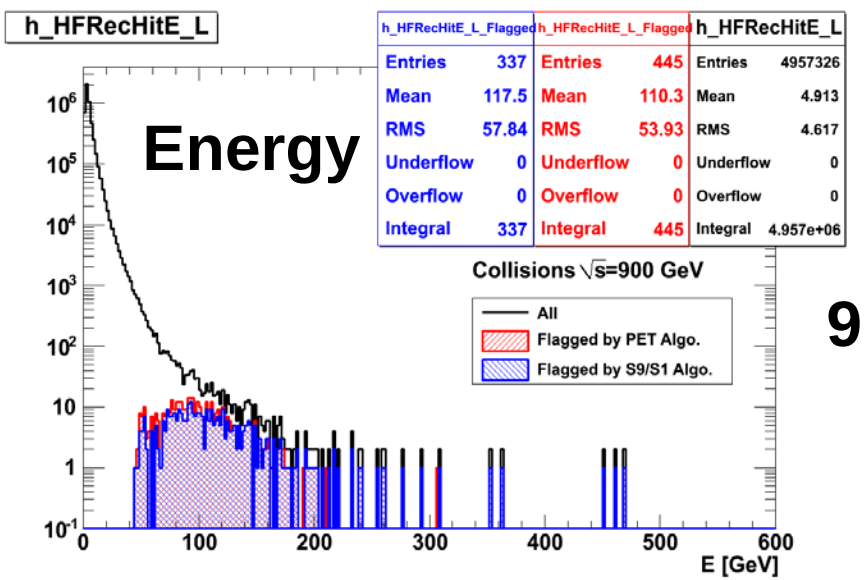




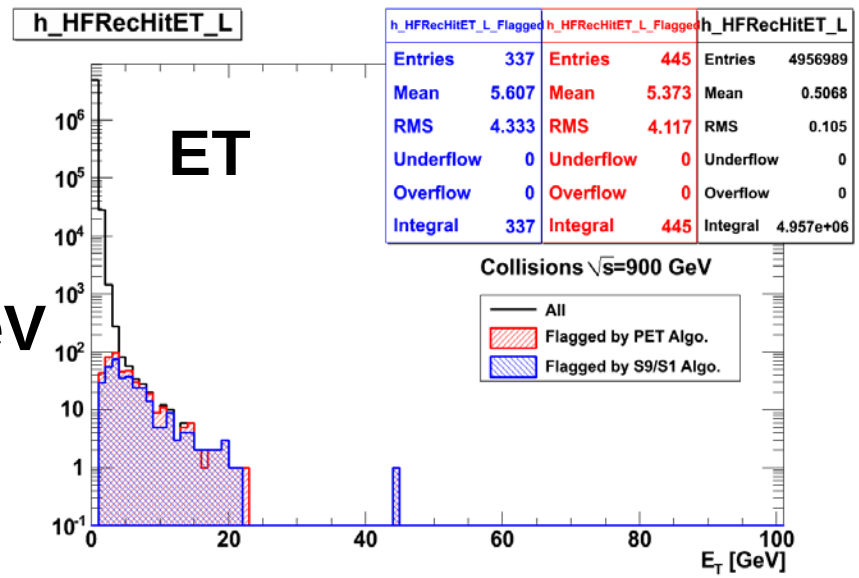
S9/S1 cut optimized for single photon events as a function of iEta

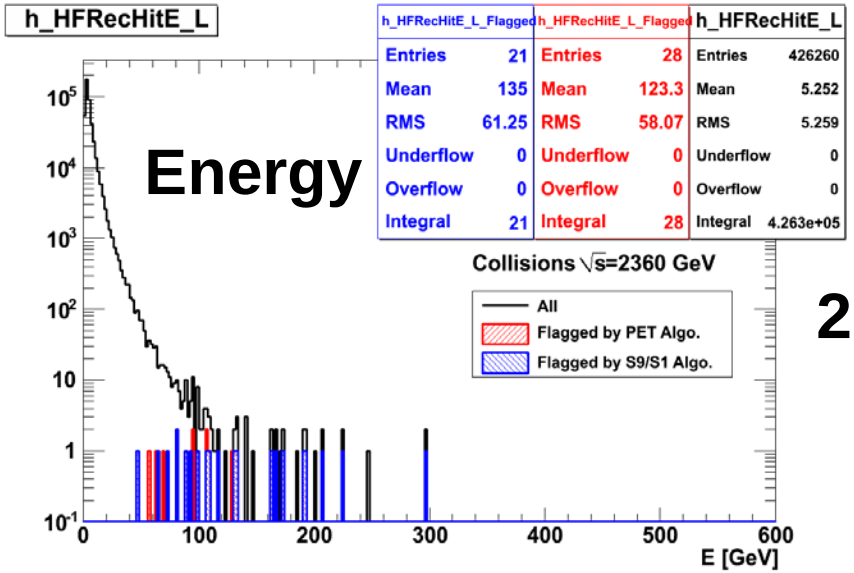
Cut line shown for 7 TeV MinBias MC

Comparison of PET and S9/S1 in Data

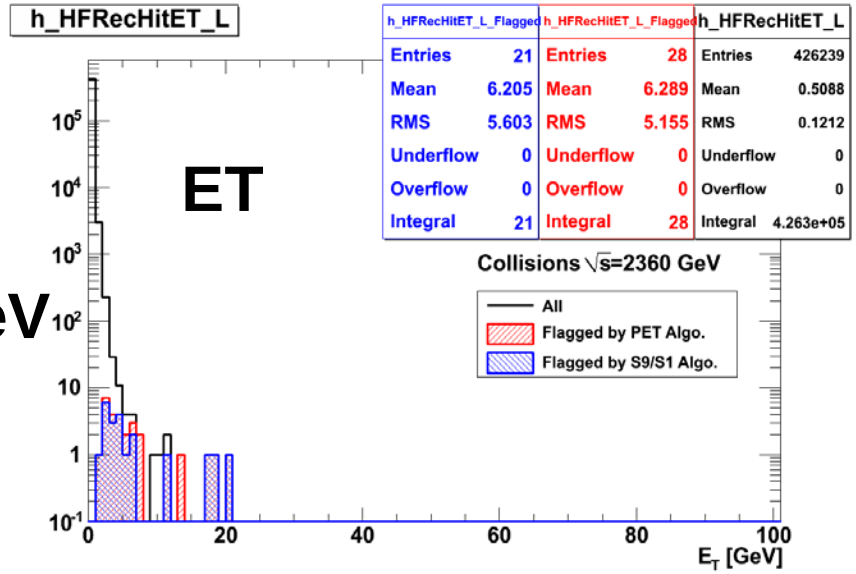


900 GeV

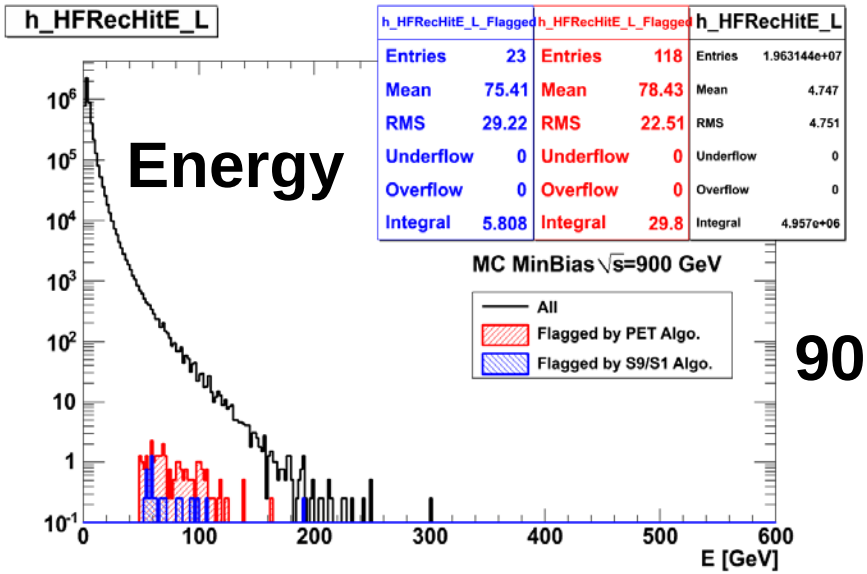




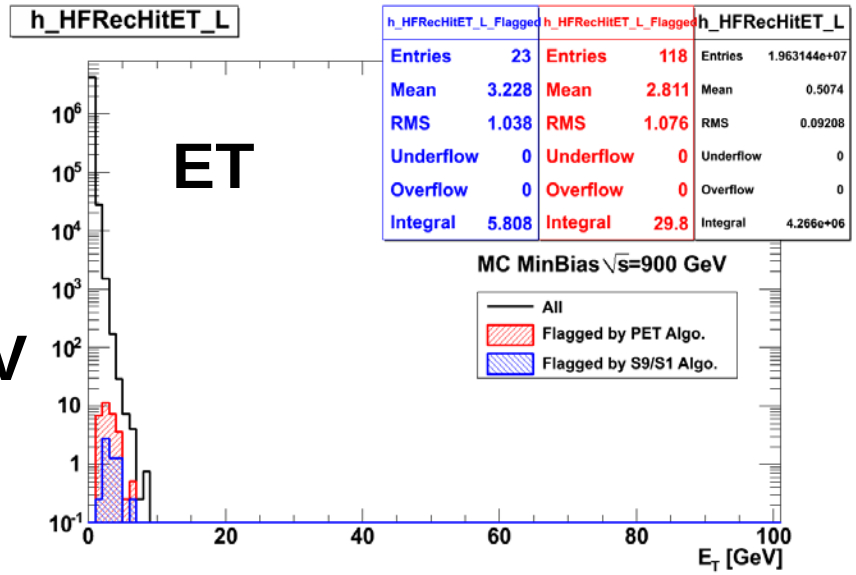
2.36 TeV

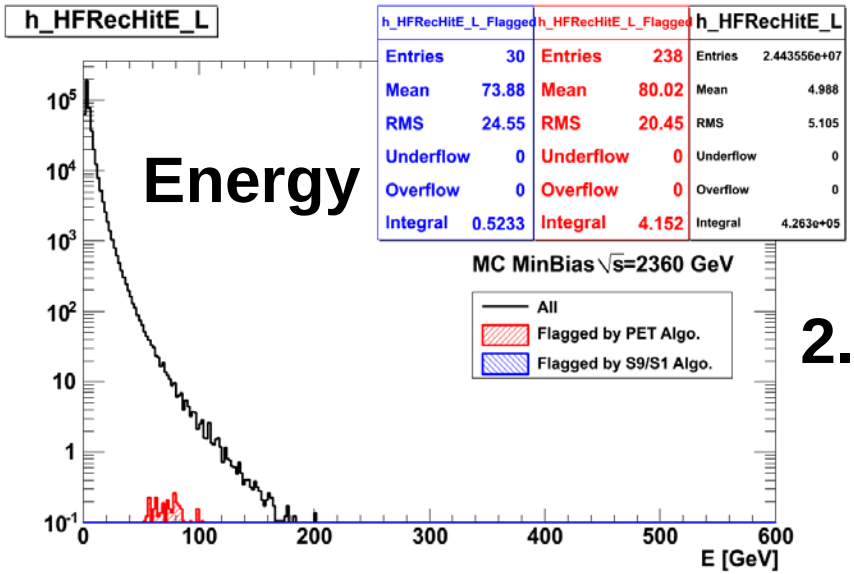


Comparison of PET and S9/S1 in MC MinBias

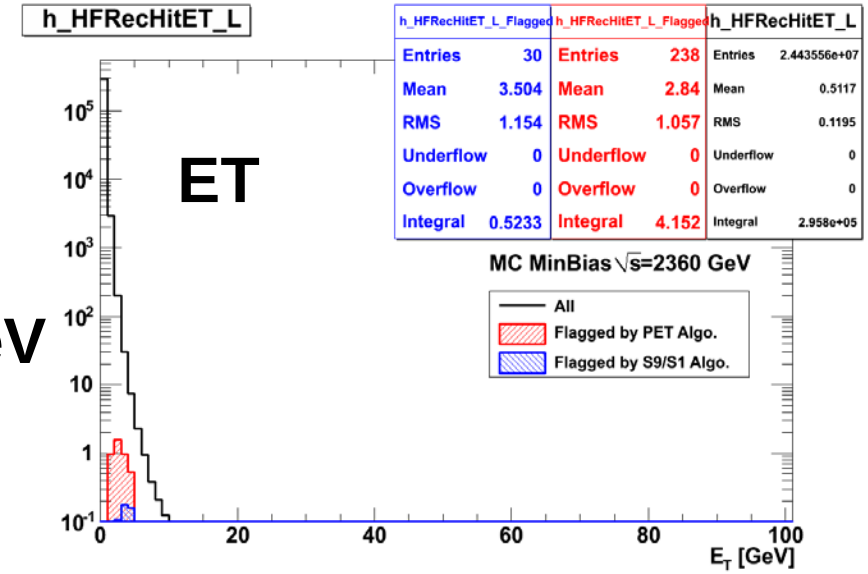


900 GeV





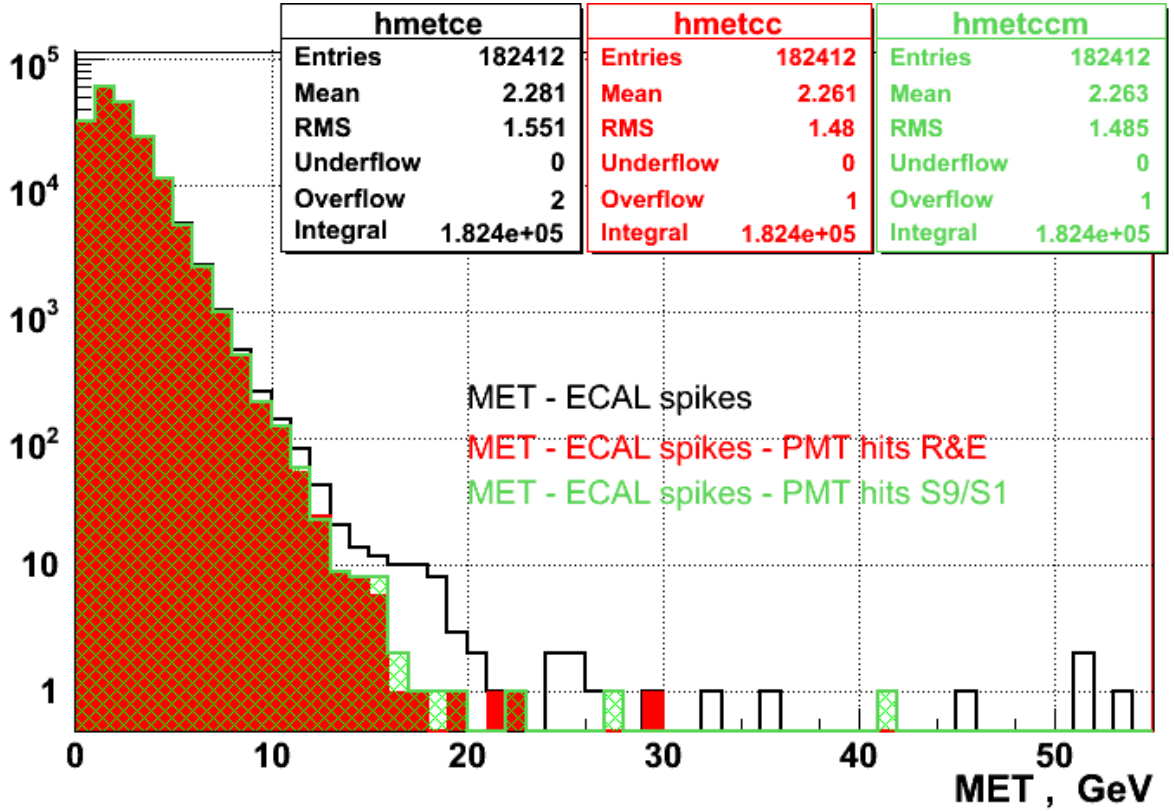
2.36 TeV



Cleanup Performance for PET and S9/S1

ECAL spikes are cleaned using the selection defined on the "recipes" twiki
Crystals with ET>5 GeV and E(four neighbors)/E<0.05

HB and HE noise events were removed using the method described on
https://twiki.cern.ch/twiki/bin/viewauth/CMS/HcalNoiseInfoLibrary

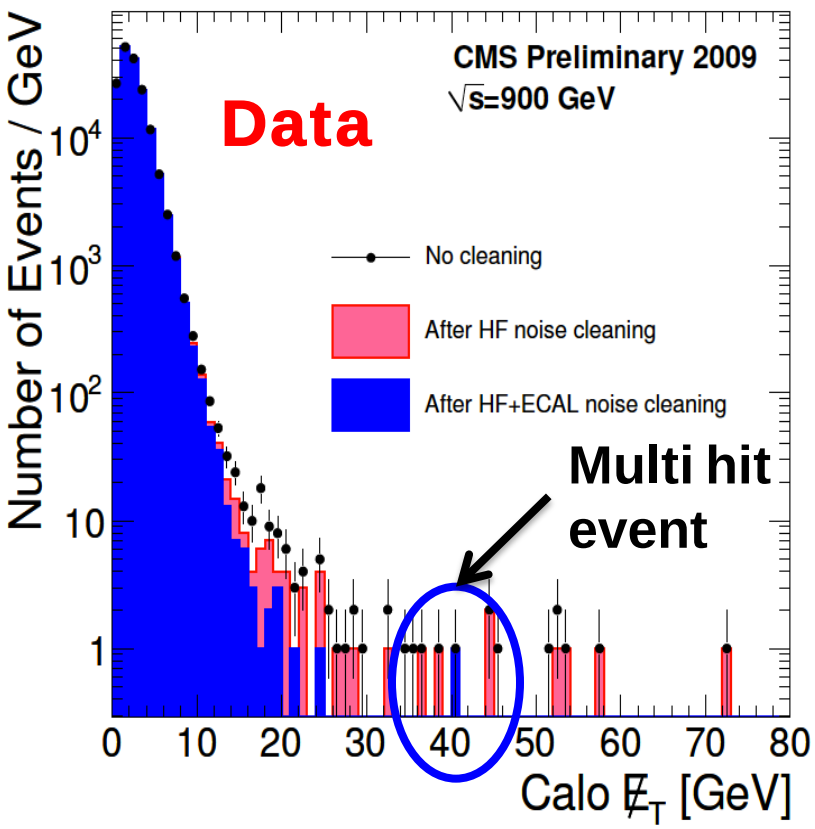


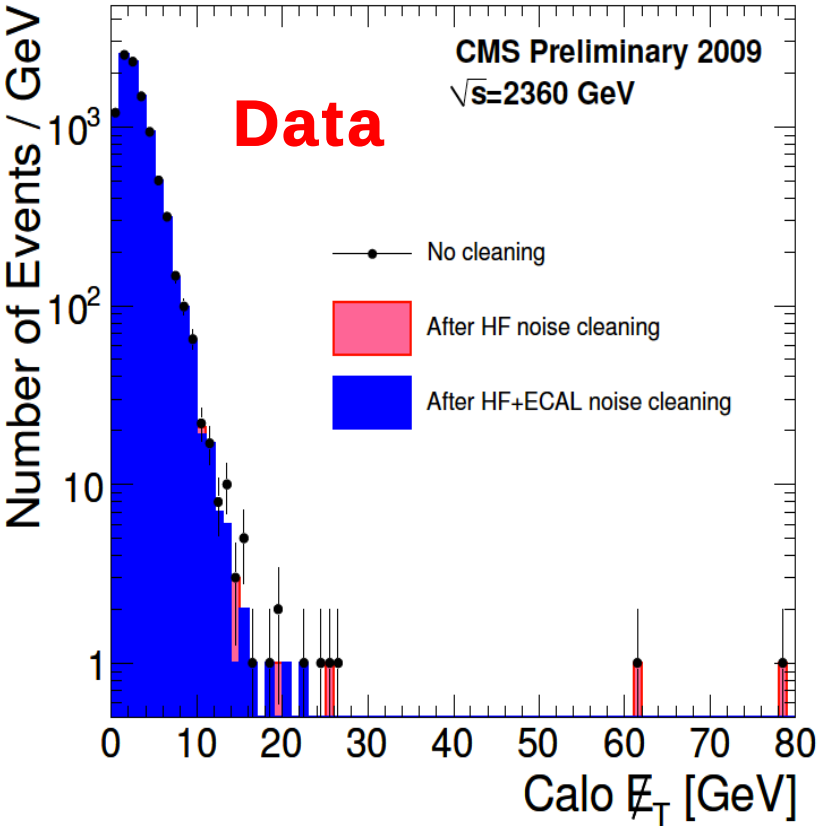
A few outliers due to multihit events

Calorimeter Missing E_T

From PAS JME-10-002 "Missing ET in 0.9 and 2.36 TeV pp Collisions"

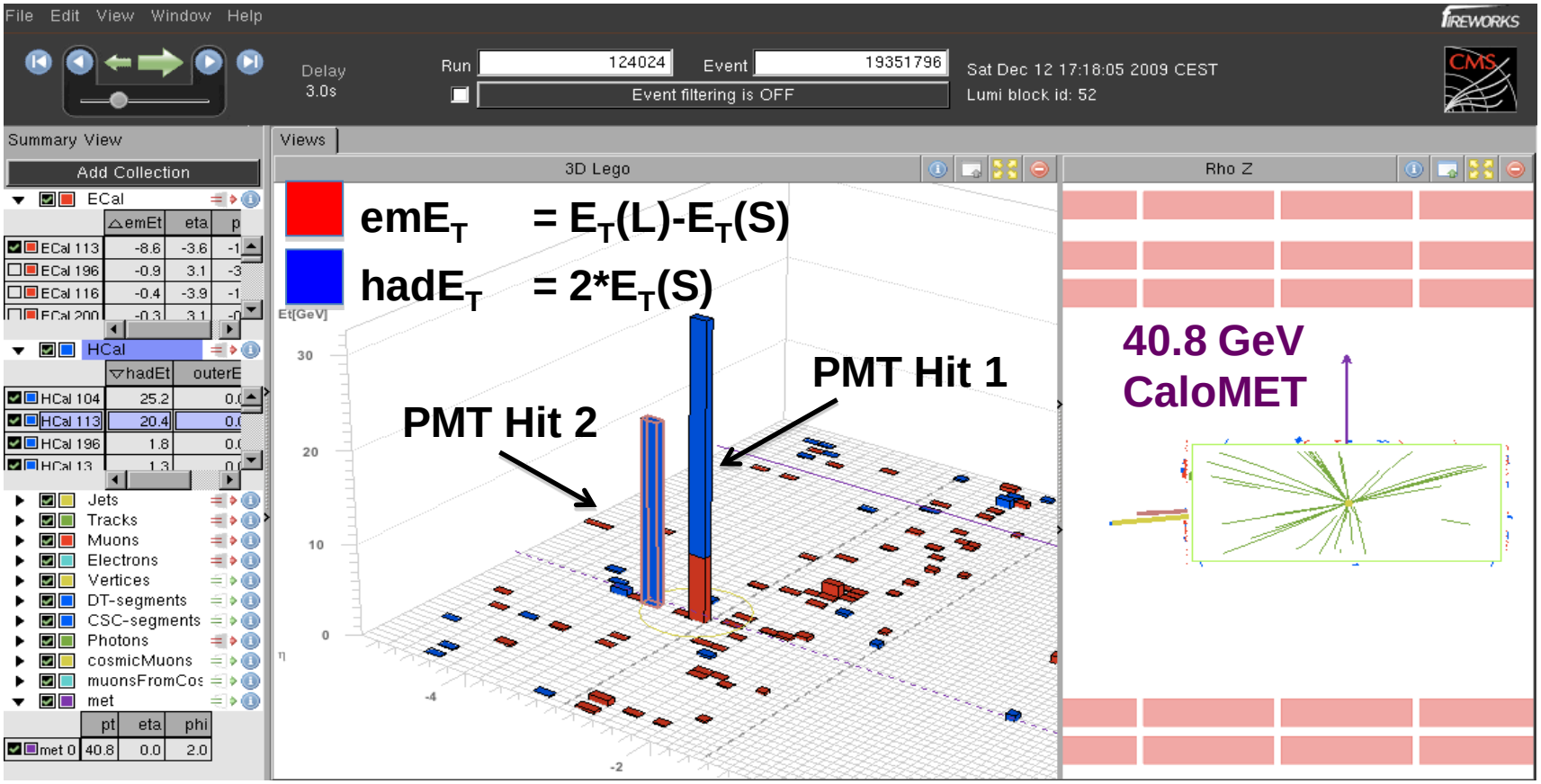
<u>Algorithm 1 is already being used by the physics groups</u>





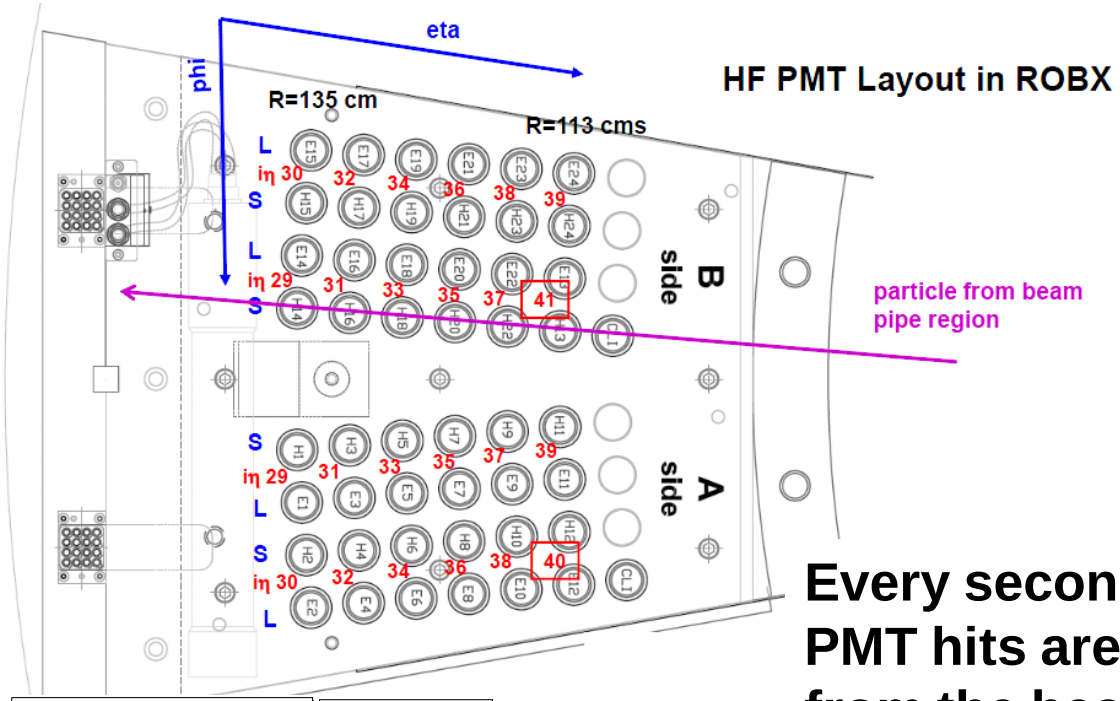
Multihit Event

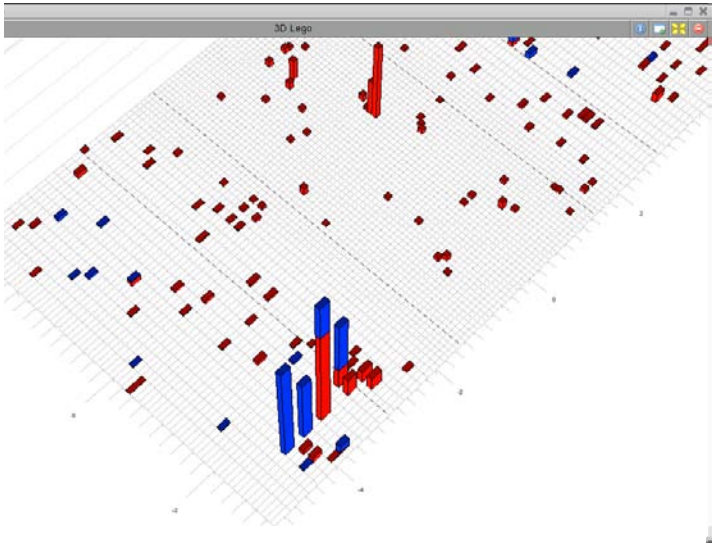
Multihit event were one hit is identified depending on the choice of algorithm



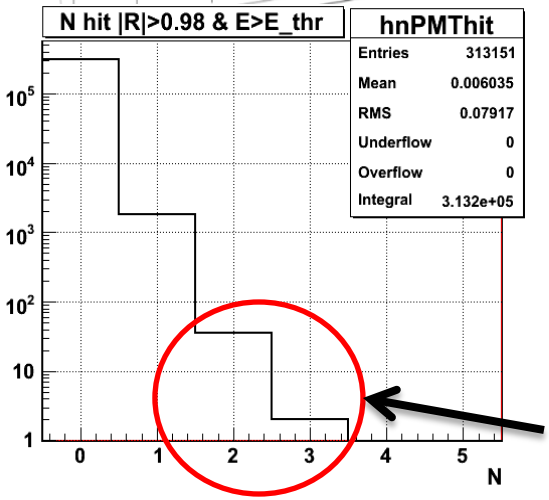
Event display view being developed to show energy in the HF Long and Short sections

HF Multihit Events





Every second channel pattern suggests PMT hits are produced by particles from the beam pipe going through *fiber bundles at light guide, fibers, or PMT*

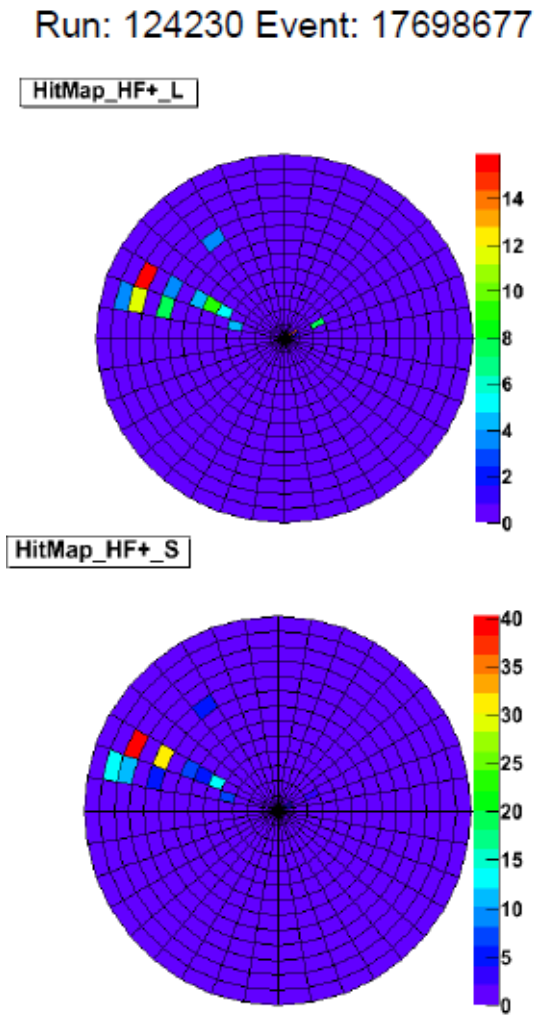


(L-S)/(L+S) filter does not select all multi hit events since there is some energy in both L and S sections

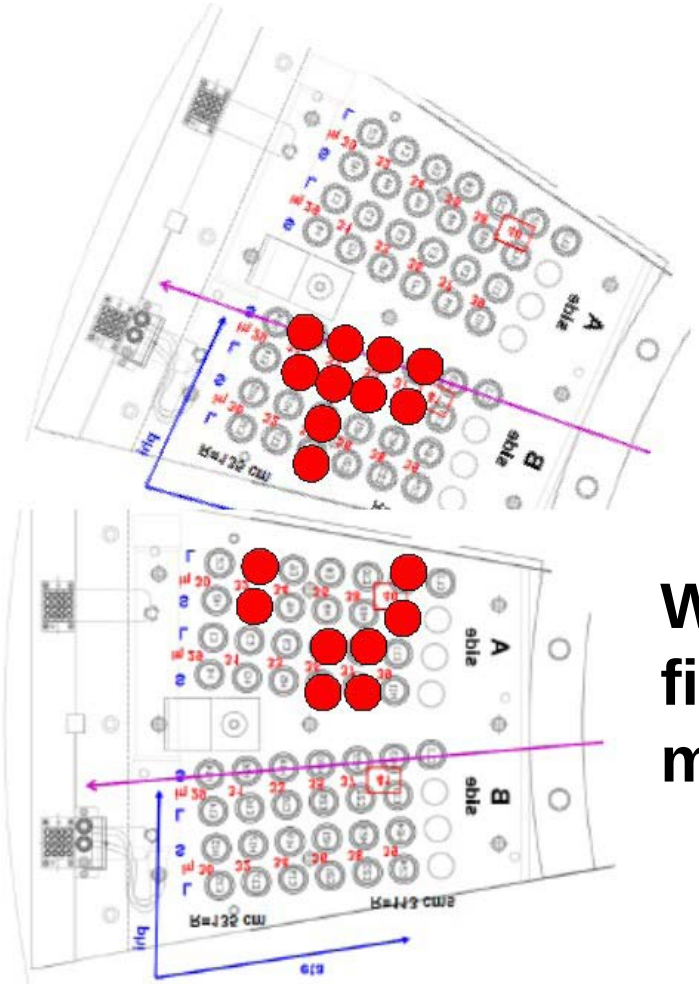
Rate of multi-hit events is low *need to monitor this as the beam intensity increases…*

Possible Punch Through Signature

Radial pattern



Cluster-like



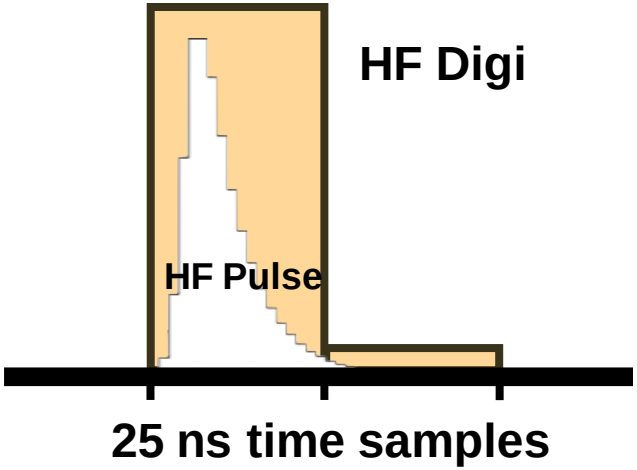
Will need to develop filters to identify multihit events…

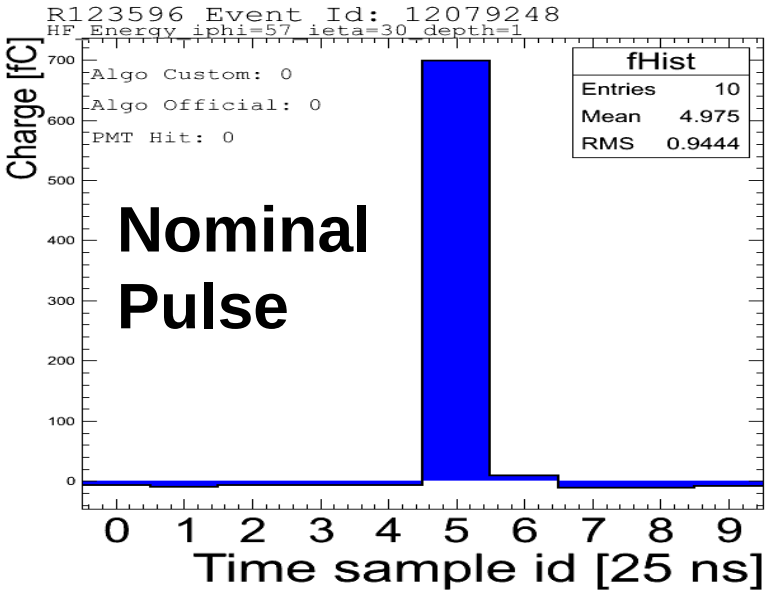
Pulse Shape

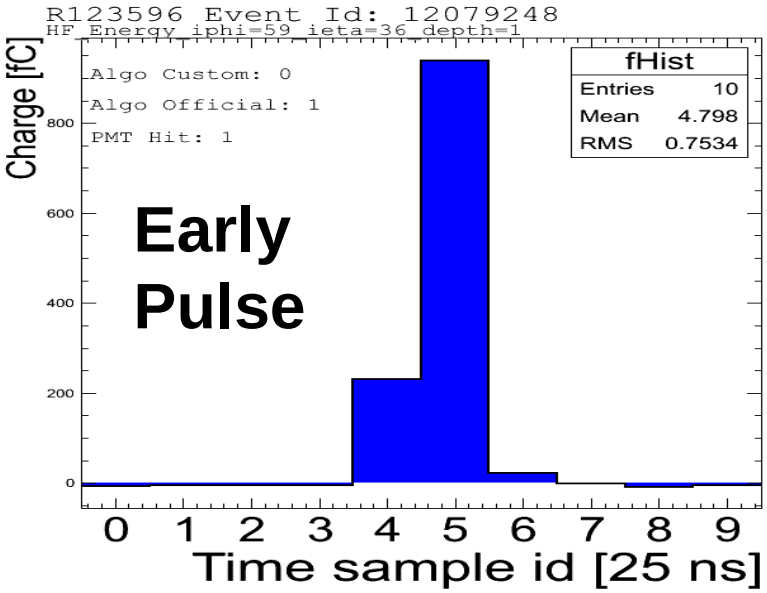
Particles hitting the PMT window can arrive ~5 ns earlier than the light signal from showing particles in HF

We can align the HF signal to the front edge of the TS

Plan to use the 900 GeV data to do a time scan







HF PMT Upgrade

Thin window replacement PMTs

The Research of Proposal 09.02 for upgrade of the HF PMTs was approved by CMS UMB

Raw signal through the window is at least 2-5 times lower than that of the existing PMT consistent with the glass thickness profiles of the PMTs

Multi channel readout for the Fibers would allow elimination of HF PMT anomalous signals

CMS DN 2009/011, CMS DN 2009/012
CMS NOTE 2010/003 (to be submitted to JINST)

Also looking at the development of "Anti-Cherenkov" PMTs

CMS IN-2009/028

Filtering Events

General framework exists to flag/remove rechits identified as having anomalous signals

Filters exist and rechits are being flagged

- **Pulse shape, RBX/HPD, HF (L,S),…**
- **Improvements to filters need to be migrated to CMSSW**
- ***Filters need to be tuned and studied by Physics Groups***

Modular design allowing new filters to be added

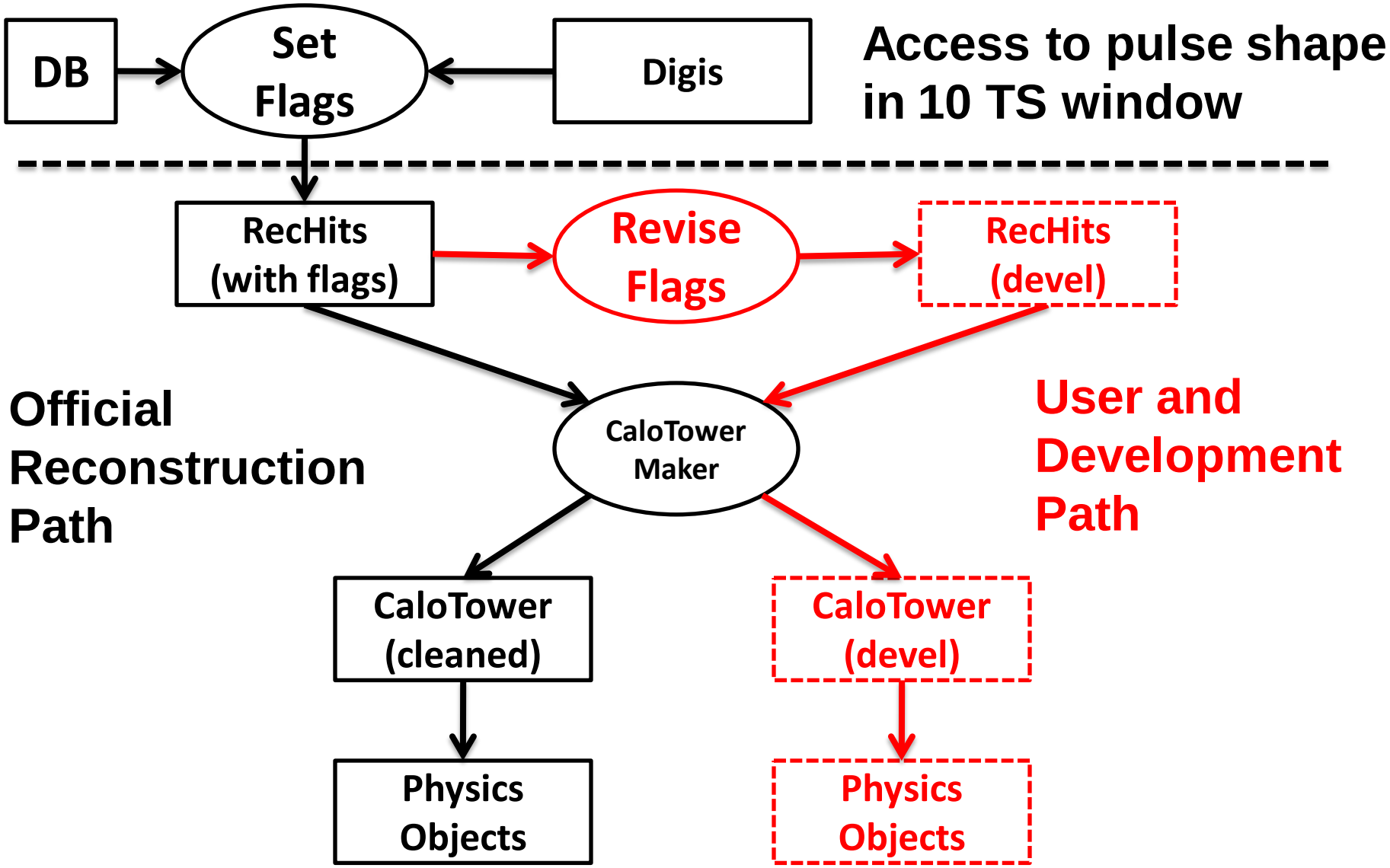
User framework to allow testing of new filter ideas

- ***Migrate new ideas into the default cleanup***

Noise summary object is saved in the data to identify HPD/RBX noise

- **Can be used to flag/reject events identified as having significant noise**
- ***RBX/HPD noise overlap with physics will be very low…***

Development Framework to Treat Noise



Cleanup Roadmap

Provide safe cleanup (S9/S1) to be applied to CaloTower

User framework available to test more aggressive cleanup

Can undo any cleanup and produce "unclean" CaloTower

Migrate any improvements for the filters into the default cleanup

Reprocess data to make default cleaned CaloTower available

As occupancy increases we can relax the isolation criteria (PET)

May be able to use HF pulse shape to identify early arriving signals

Expect time scan to be done with 900 GeV Data

Need to adjust global phase several weeks after 7 TeV running

Long term mitigation plan

Plan to replace PMTs with ones less sensitive to window interaction

May add multiple readout channels / fiber

Summary

RBX/HPD noise is random, overlap with physics is expected to be low

Use noise summary to remove events

A flexible software framework exists that allows flagging bad rechits and eventually their removal from CaloTower

Filters to remove HF PMT hits have been optimized and characterized

E_T from HF PMT hits is low

User framework to test new filters is under development and we will have the ability to undo any cleaning applied to CaloTower

MC simulation and event characteristics suggest that the HF PMT events are due to particles hitting the PMT window originating from decays in flight and hadronic shower punch through

Mitigation plan: software filter, pulse shape, replace PMT

Material for Approval

Anomalous HCAL Signals

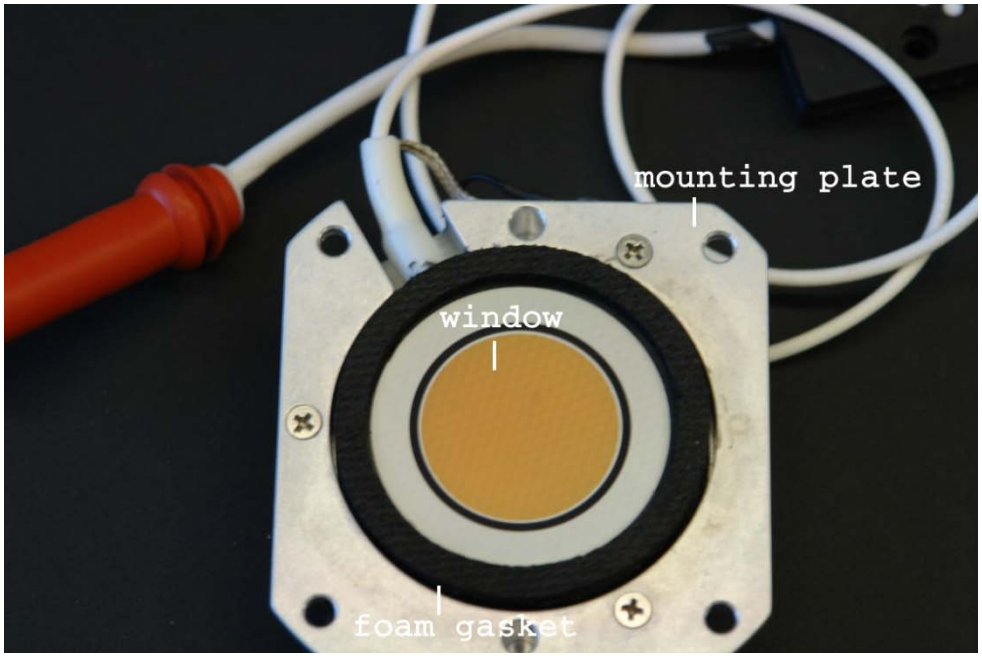
Two Classes

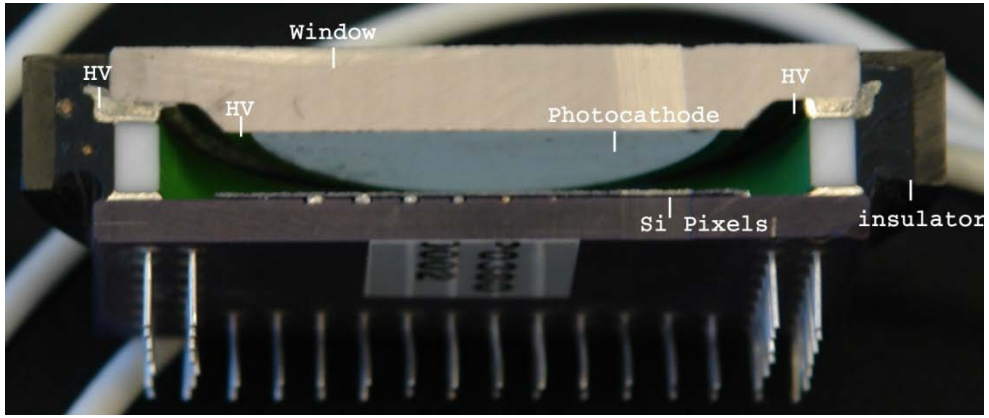
1) Electronics noise from the Hybrid Photo Diode, HPD, (18 cells) and Readout BoX, RBX, (4 HPDs) in the Hadronic Barrel and Endcap calorimeters

2) PMT window Cherenkov interactions in the Forward Calorimeters

- ¼ photoelectrons per GeV
- Window thickness of 1mm glass in the center increasing to 6.1mm on the edges

Hybrid PhotoDiode (HPD)





PMT Window Geometry

HPD and RBX Noise

HPD Ion Feedback

Photoelectron induced libration of ions from the silicon diode that accelerate across the HV gap and interact with photocathode to liberate additional photoelectrons (signals from 3-5 GeV in Energy)
~1 HPD channel participates

HPD Discharge

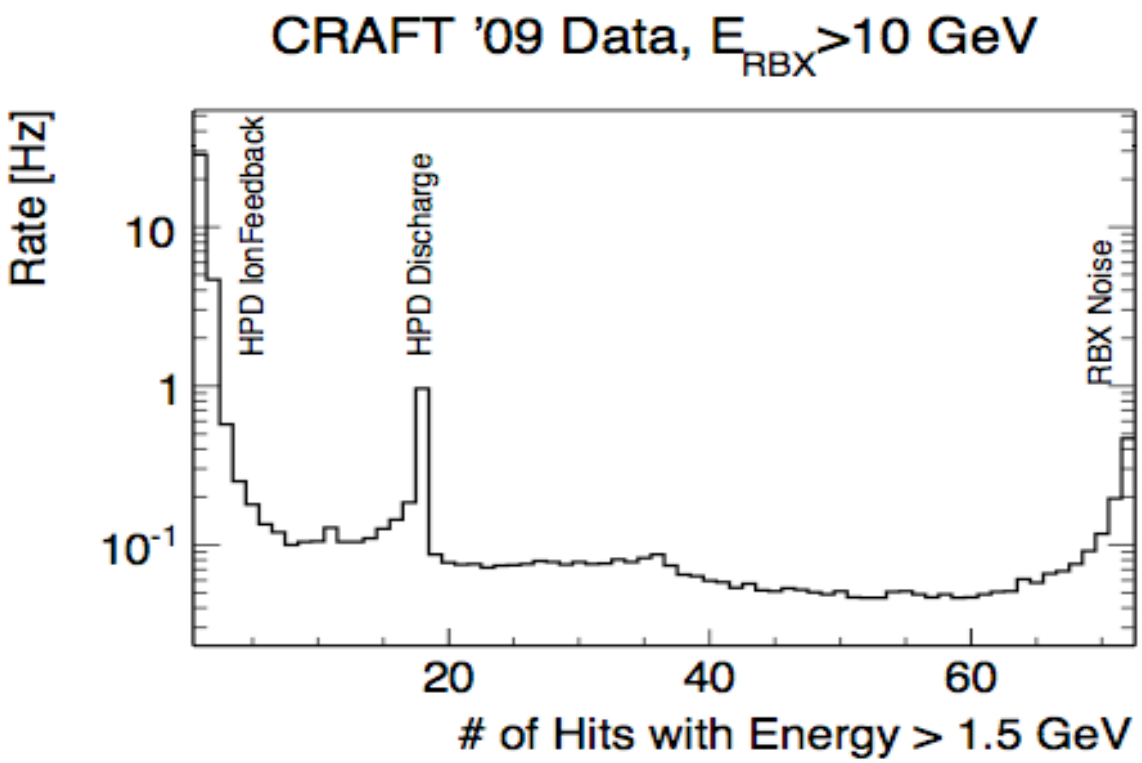
HPD photocathode operates at -8kV with discharge occurring across sidewall or sidewall covering within vacuum
up to 18 HPD channels participates

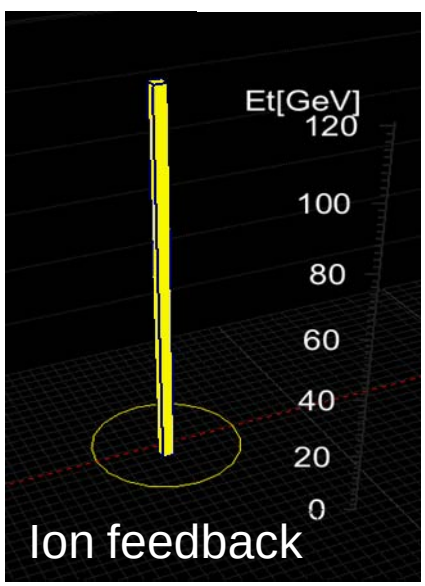
RBX Noise

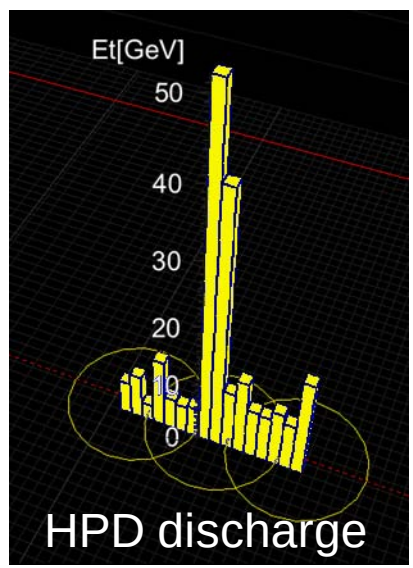
Source unknown, likely to be external noise source that couples to HV
many channels across whole RBX (up to 72) participate

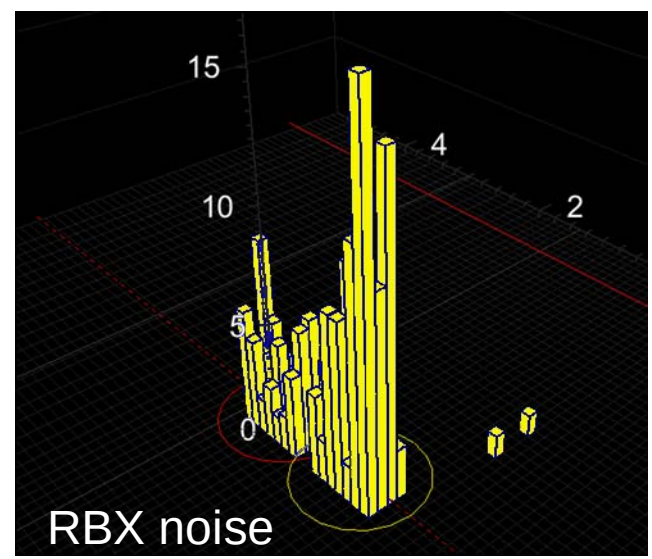
Total rate of HPD and RBX is ~10-20 Hz for E>20 GeV (total rate contribution from the OR of all 288 HPDs)

HPD and RBX noise is random and the overlap with physics is very low


CRAFT '09 Data, E_{RBX}>10 GeV
Rate [Hz]
10
1
10^{-1}
HPD Ion Feedback
HPD Discharge
RBX Noise
20
40
60
# of Hits with Energy > 1.5 GeV


Et[GeV]
120
100
80
60
40
20
0
Ion feedback


Et[GeV]
50
40
30
20
10
0
HPD discharge


15
10
5
0
4
2
RBX noise

HF PMT Window Hits

In the test beam data, we observed signals from interactions in the PMT windows and in the fiber bundles for both types of fibers (Long – full length of calorimeter and Short – all but the first 25 radiation lengths (EM portion) of the HF calorimeter)

Test Beam Data and PMT Window measurements are published in

Eur. Phys.J. C53, 139-166 (2008)

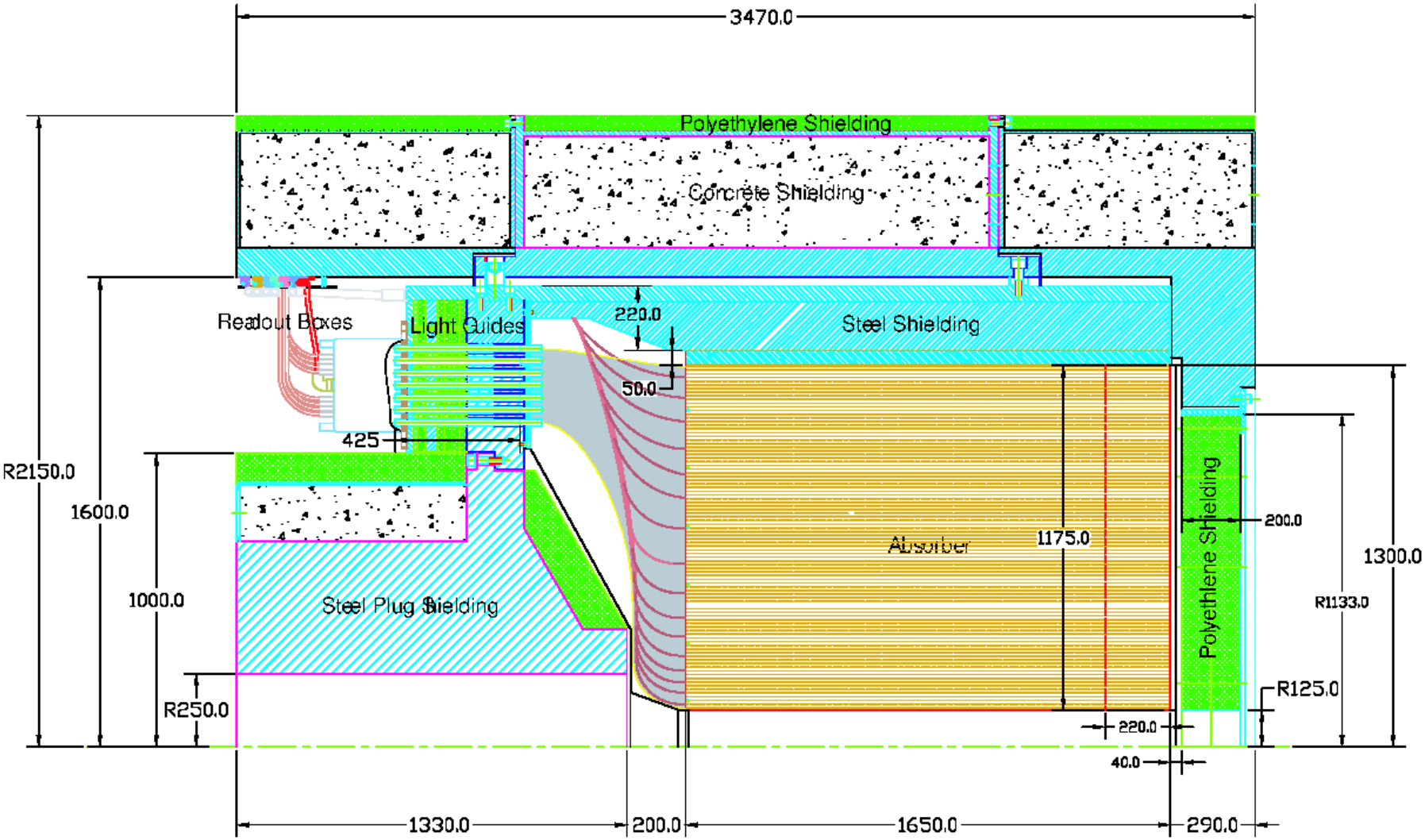
Most of the HF PMT hits can be filtered based on a signal seen in one fiber in a cell but not the other by forming the discriminating variable $(E_L-E_S)/(E_L+E_S)$

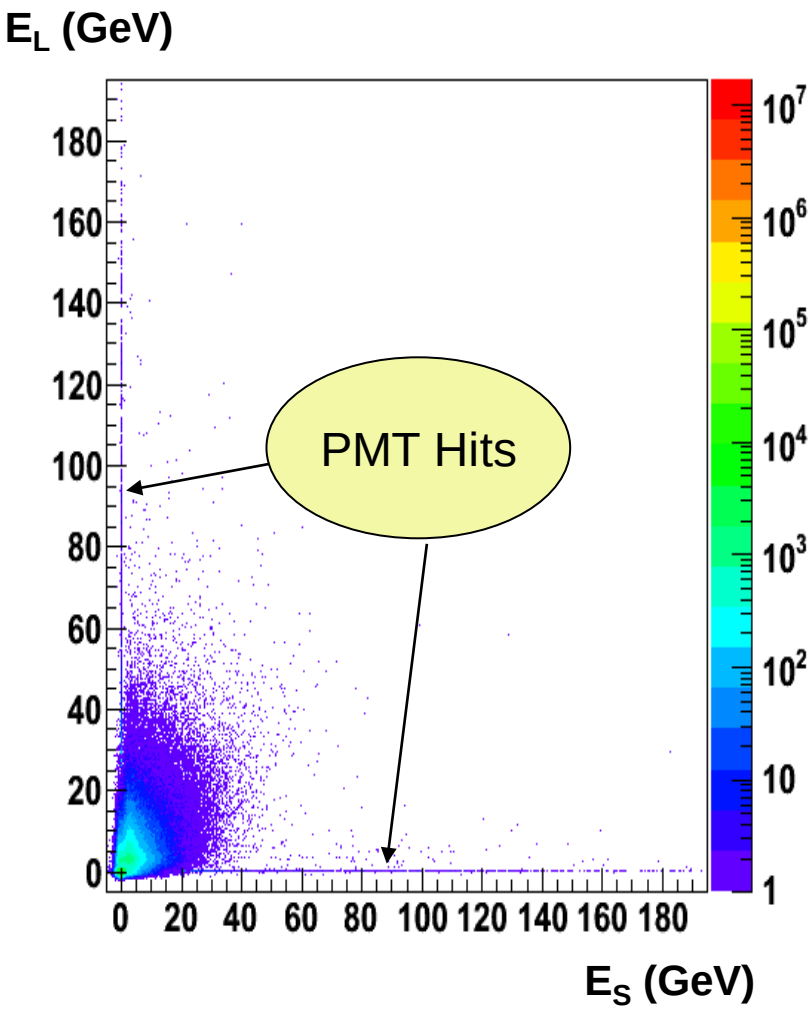
Rates observed in 2009 collision data (min bias)

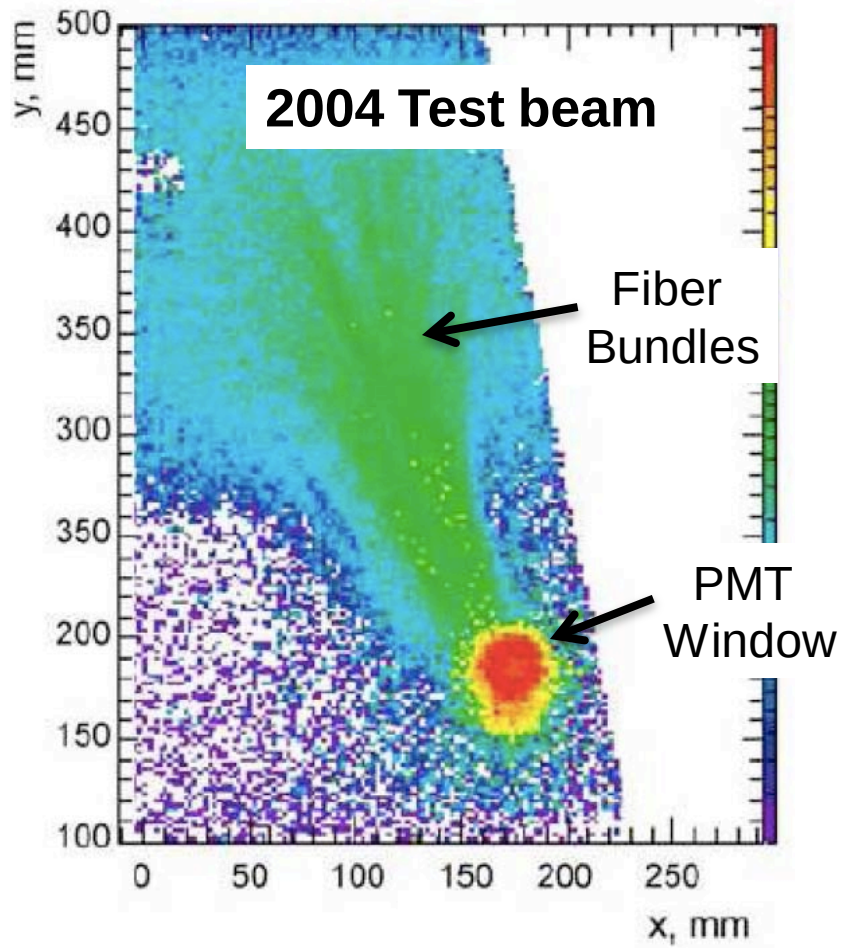
~6×10^{-3} per event identified for 900 GeV data
~8×10^{-3} per event identified for 2.36 TeV data

Determined for ~1720 PMTs

Dominant sources in the data are muons from decays in flight and hadron shower punch through

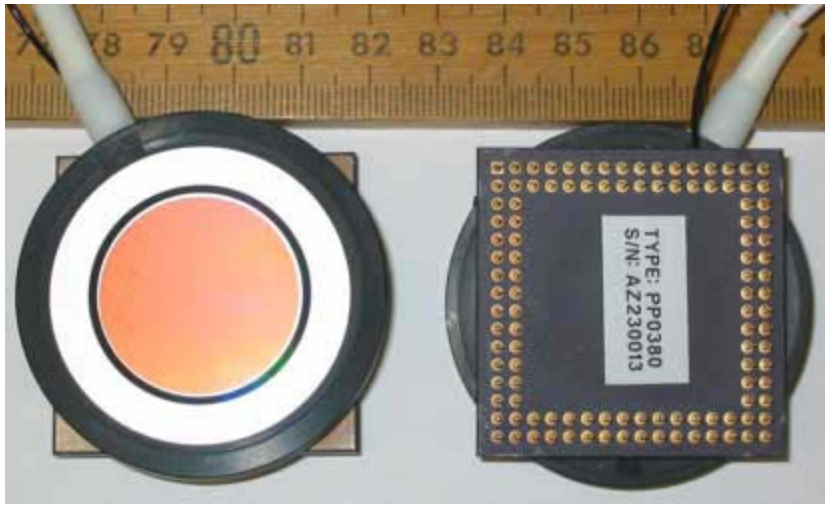

3470.0
Polyethylene Shielding
Concrete Shielding
Readout Boxes
Light Guides
220.0
Steel Shielding
50.0
425
R2150.0
1600.0
1000.0
Steel Plug Shielding
Absorber
1175.0
200.0
Polyethylene Shielding
1300.0
R1133.0
R125.0
R250.0
220.0
40.0
1330.0
200.0
1650.0
290.0

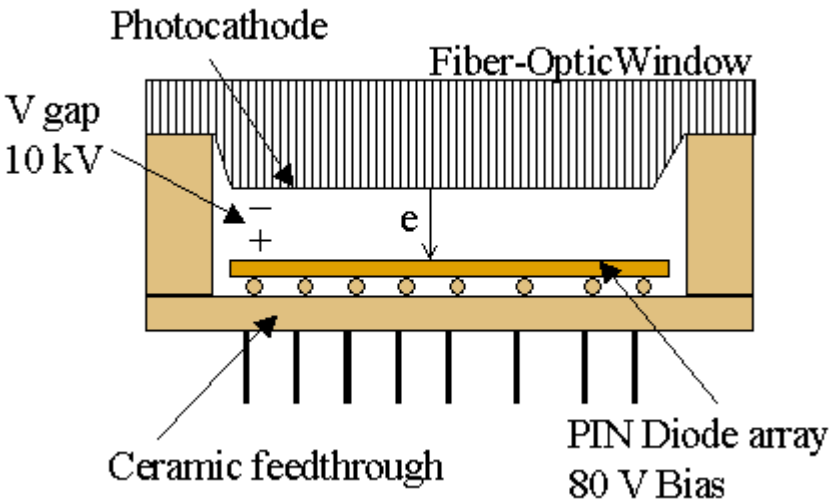

E_L (GeV)
PMT Hits
E_S (GeV)

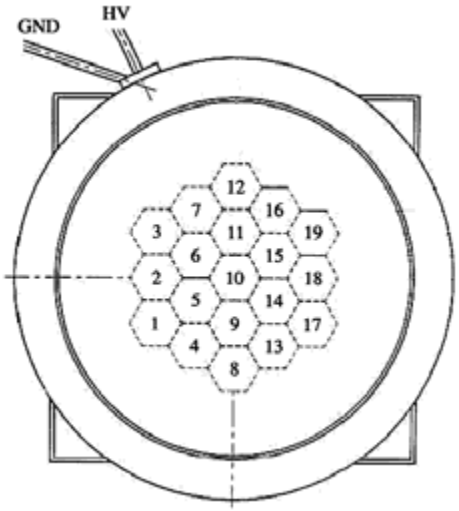

2004 Test beam
Fiber Bundles
PMT Window
y, mm
x, mm

Bonus Material

Hybrid Photo Diode (HPD)







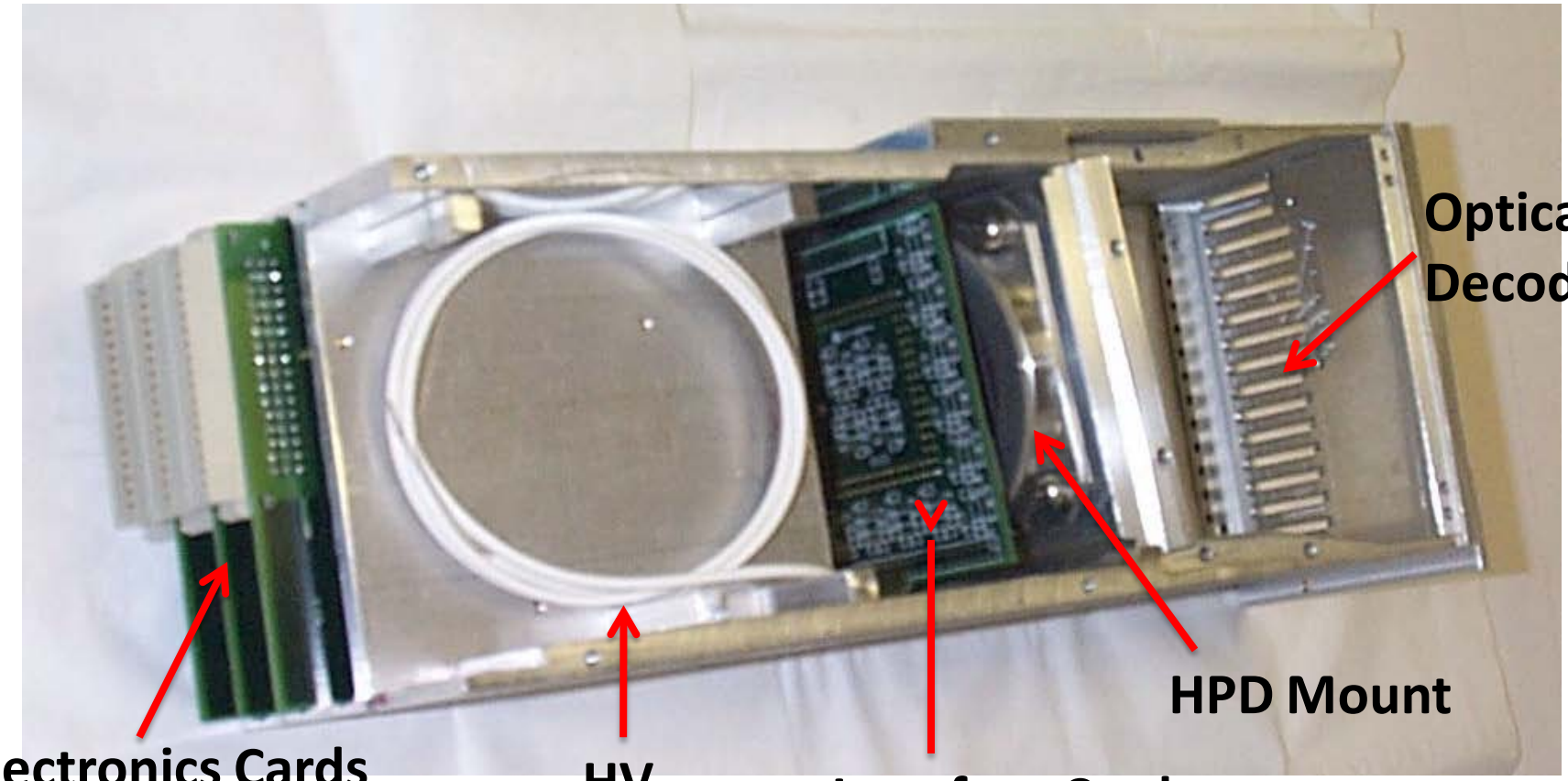
Hybrid Photo Diode photon transducer used for HB, HE, HO.

Fiber optic front window, conventional photocathode, pixelated diode

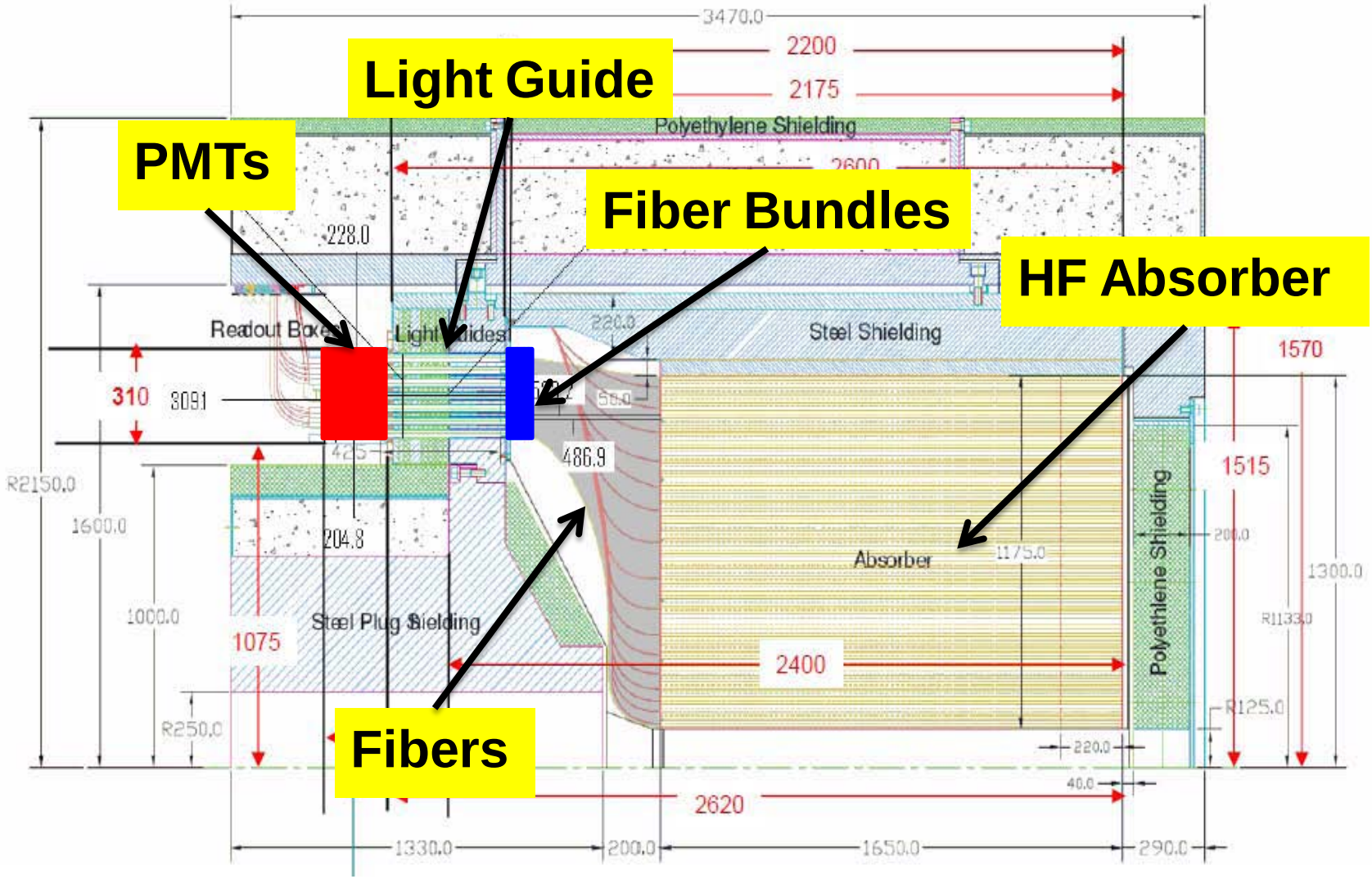
19 channels/device
(one channel used for calibration)

Readout Module

The readout module (RM) integrates the HPD, front end electronics, and digital optical drivers



Anatomy of the Hadronic Forward Calorimeter



Summary of Current Algorithms

Algorithm 1) ***HCAL DPG, tcMET***

R = |L-S|/(L+S) > R_Th

E or Et > E_Th

Original algorithm

E, ET thresholds were too low

Algorithm 2) ***HCAL DPG***

Polynomial Energy Threshold (PET)

R = (L-S)/(L+S)

E > E_Th(iEta)

Optimization of E threshold

Algorithm 3) ***PFlow, HCAL DPG***

Short: S/L

Long: S9/S1

Simple cuts (Algorithm 1) were removing energy in physics MC

Isolation criteria introduced by PFlow

CaloTower vs RecHit

CaloTower in HF has EM and HAD sections defined as:

EM	**=**	**L - S**		
HAD	**=**	**2S**		
Tot	**=**	**EM + HAD**	**=**	**L + S**

Tower iEta = 29 contains EndCap cells

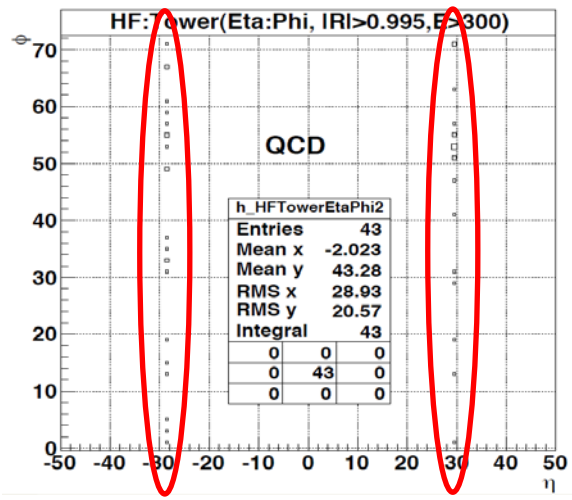
Hot/Dead rechits are removed from CaloTower

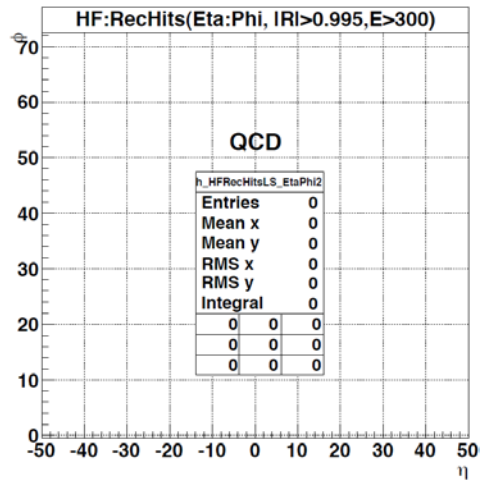
The list of Hot/Dead channels will change

Need to apply the cleanup at the RecHit level

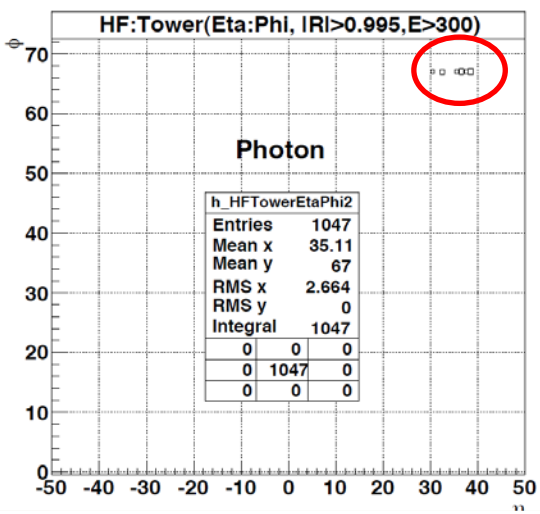
CaloTower vs RecHit

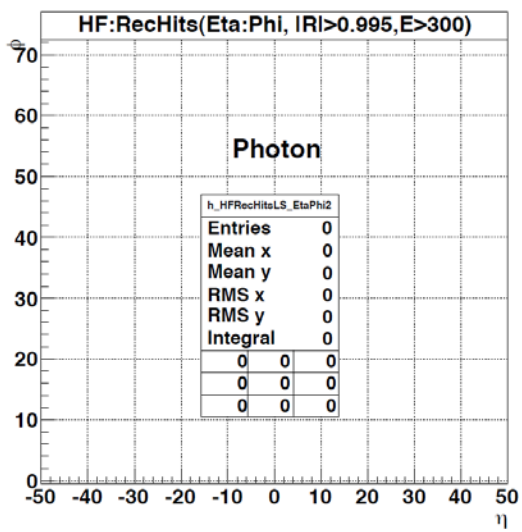
CaloTower based flagging **RecHit based flagging**





CaloTower iEta=29 includes energy from HE





iPhi=67 *included* crystals that are flagged as hot and dropped when constructing CaloTower

Detail of Fiber Bundles

HE Signal Around PMT Hits

We found PMT hits:

HEM 2006 events

HEP 2033 events

If PMT hits were created by beam halo muons, we expect signal in HE. HE energy in two depths in ieta-22-25 are summed up in one (five) phi slices around PMT hits.

Since halo muons do not follow the projective HE tower geometry, energy may spread to three cells. With zero suppression, it is hard to see clean signal. Although this analysis is not optimized to see such small signal, we do not observe many muon hits in HE.

May indicate many PMT hits are not due to halo muons

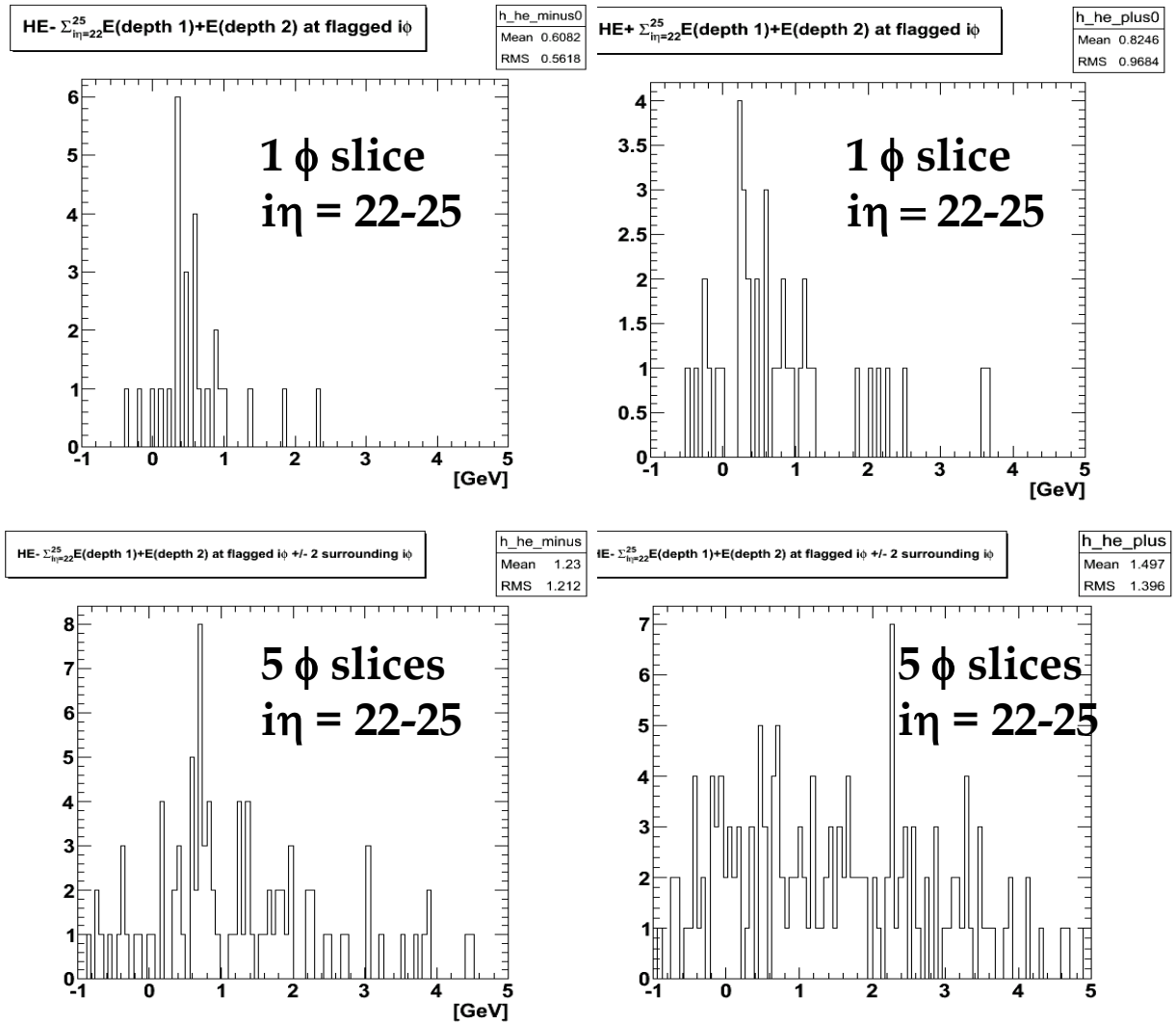
HE hits:

HEM 28 (99) events

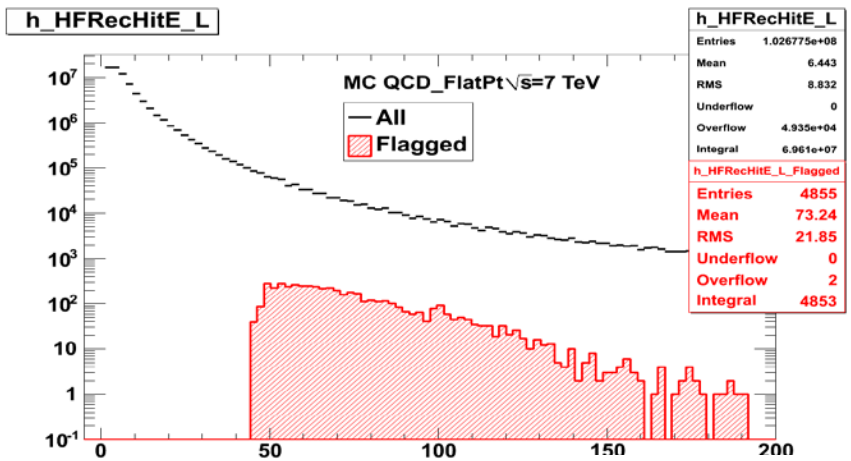
HEP 42 (180) events

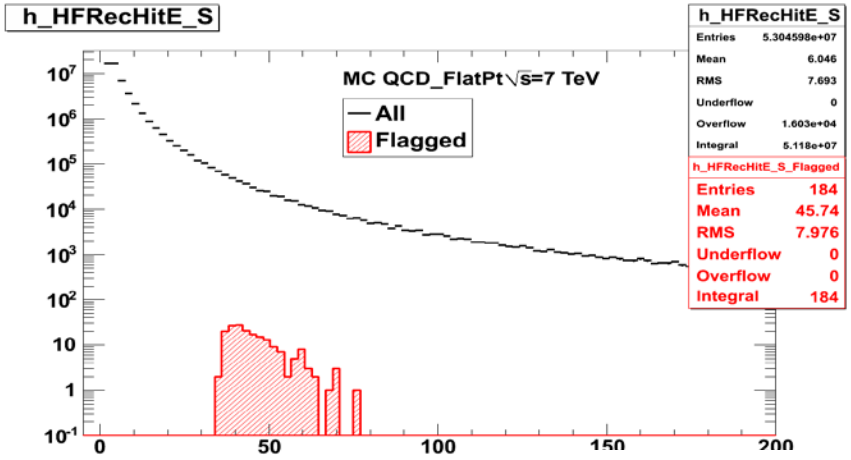
in 1 (5) phi slices and ieta=22-25

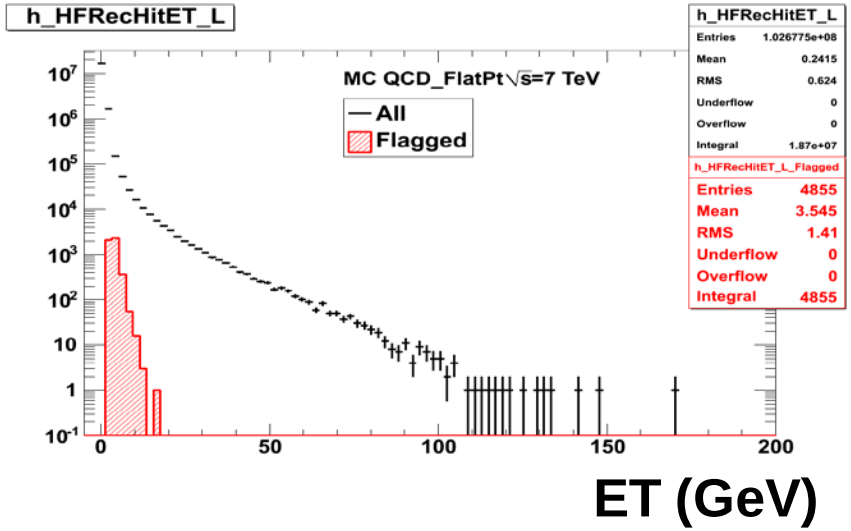
HEM **HEP**

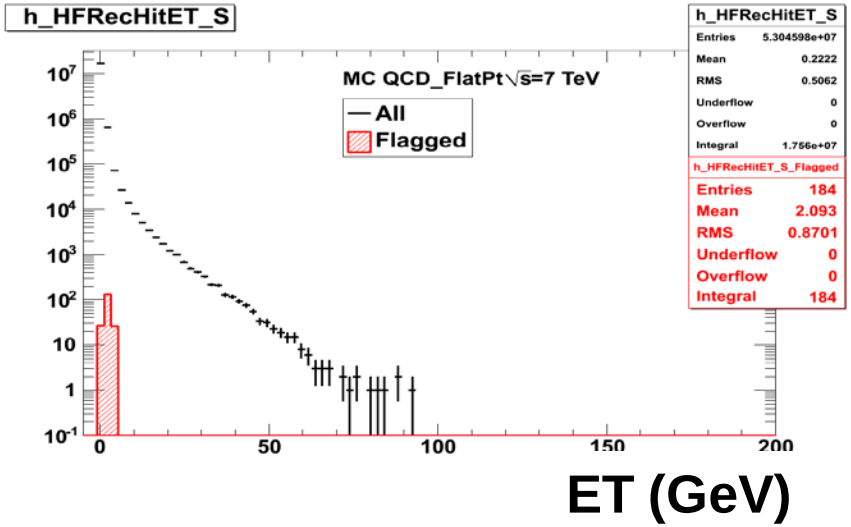


Algorithm 2: 7 TeV MC QCD Flat Pt



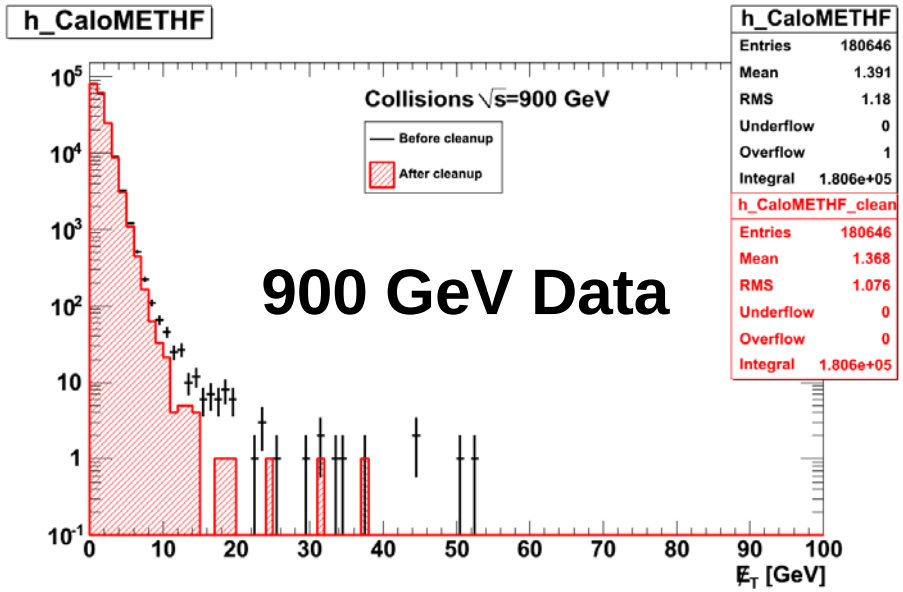


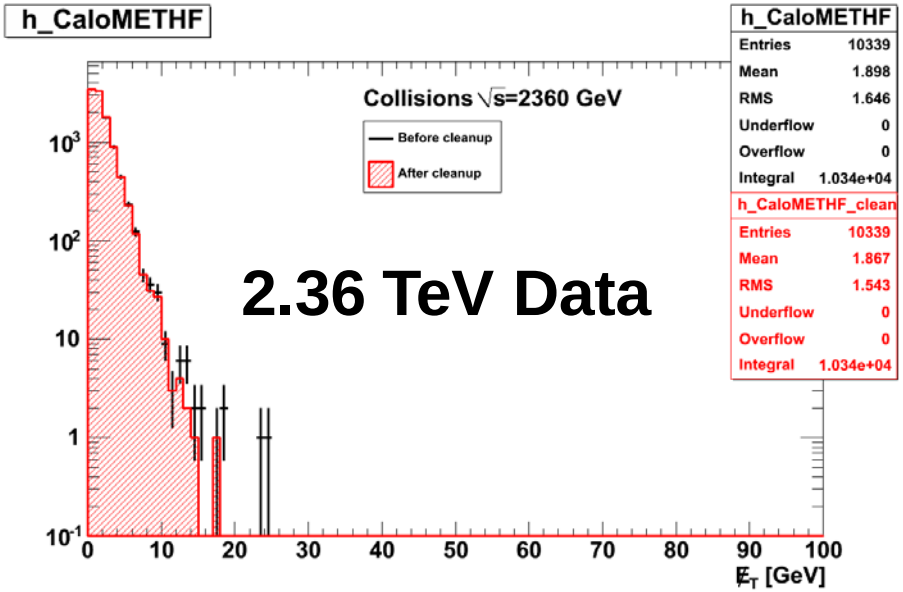


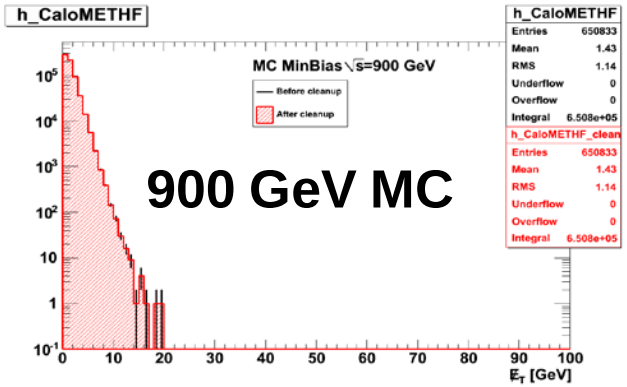


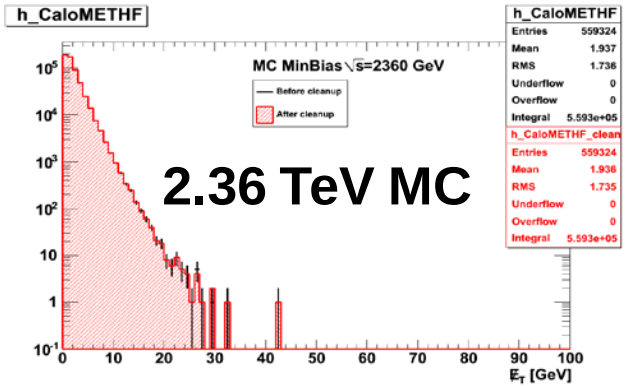
E_T of flagged rechits is very small…

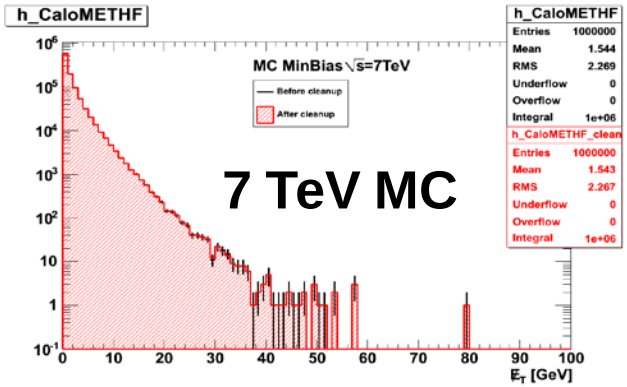
CaloMET for HF











The PET algorithm is effective at removing HF PMT Hits

Falsely flags *some* energy, E_T of misflagged rechits is small

Expected HF PMT Hit Rate at 7 TeV

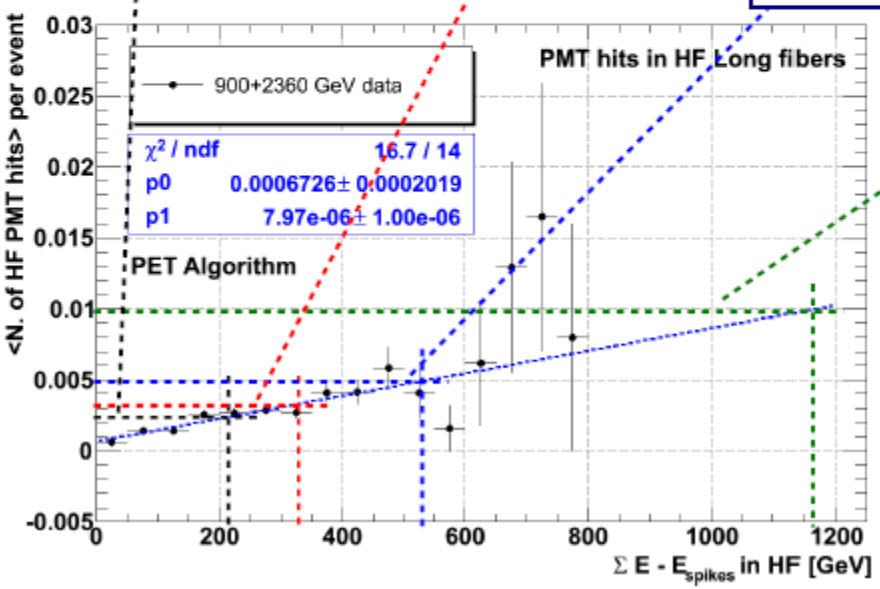
900 GeV MinBias
<SumE in HF> = 208.4 GeV
<N. PMT hits/evt.>:
"Expected" ~2.3×10^{-3}
Observed ~$(2.5\pm0.1)\times10^{-3}$

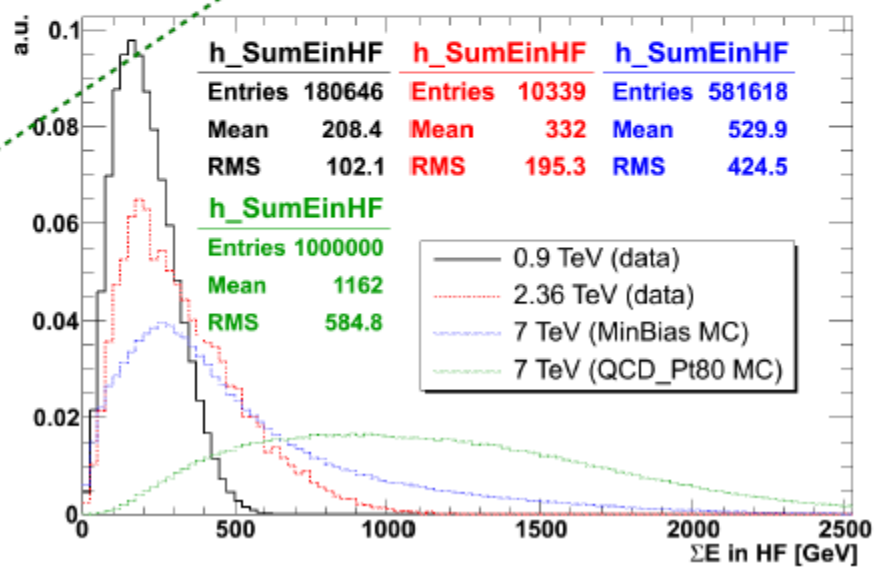
2.36 TeV MinBias
<SumE in HF> = 332 GeV
<N. PMT hits/evt.>:
"Expected" ~3.3×10^{-3}
Observed ~$(2.7\pm0.5)\times10^{-3}$

7 TeV MinBias
<SumE in HF> = 529.9 GeV
<N. PMT hits/evt.>:
"Expected" ~4.9×10^{-3}

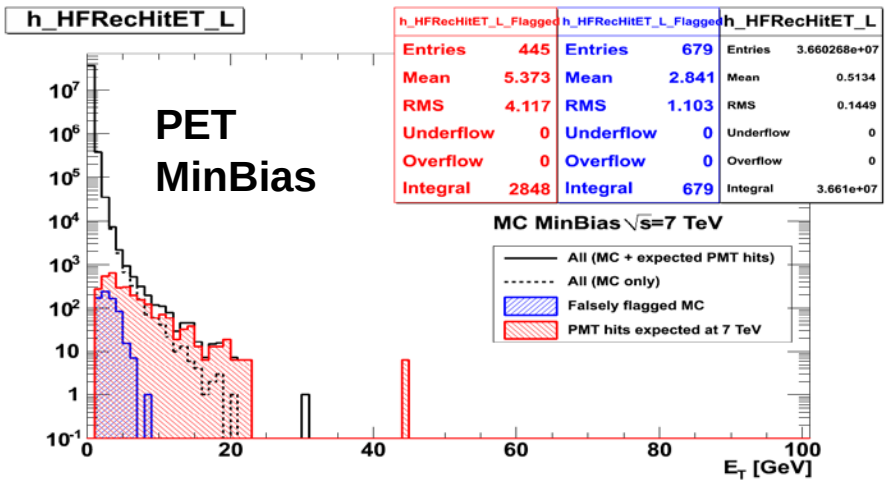
7 TeV QCD Pt80
<SumE in HF> = 1162 GeV
<N. PMT hits/evt.>:
"Expected" ~9.9×10^{-3}

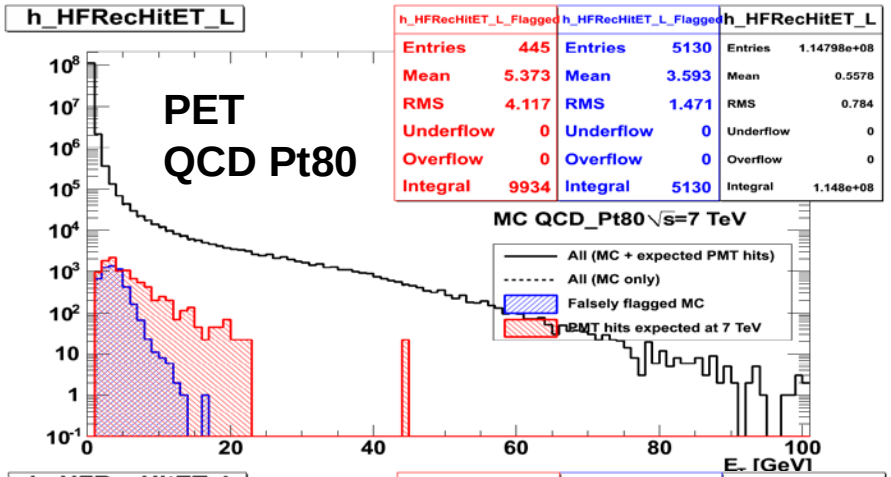
This approach can in principle be used to estimate the rate of HF PMT hits in a generic sample with a given average sum of energy in HF. Similar linear dependence also observed for the S9/S1 algorithm

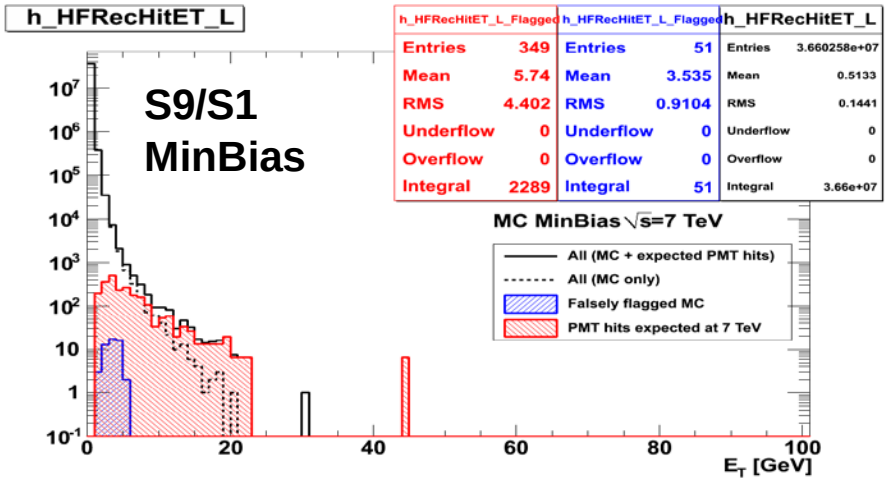


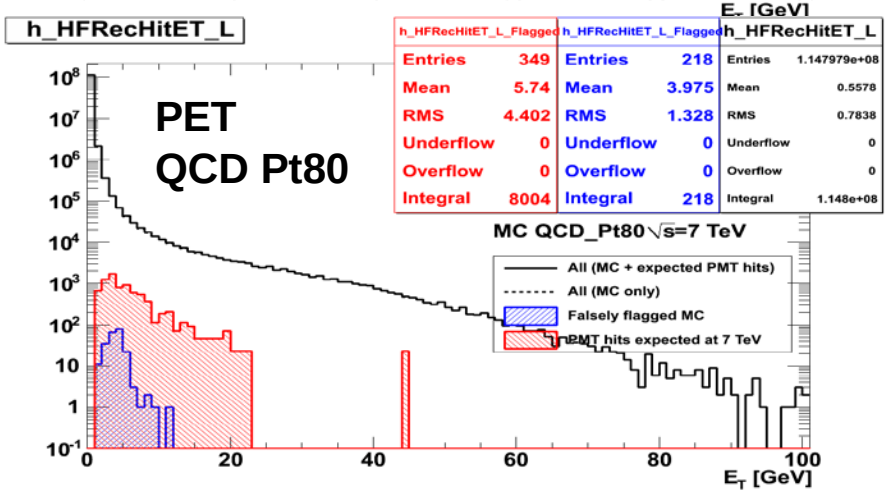


Extrapolation to 7 TeV





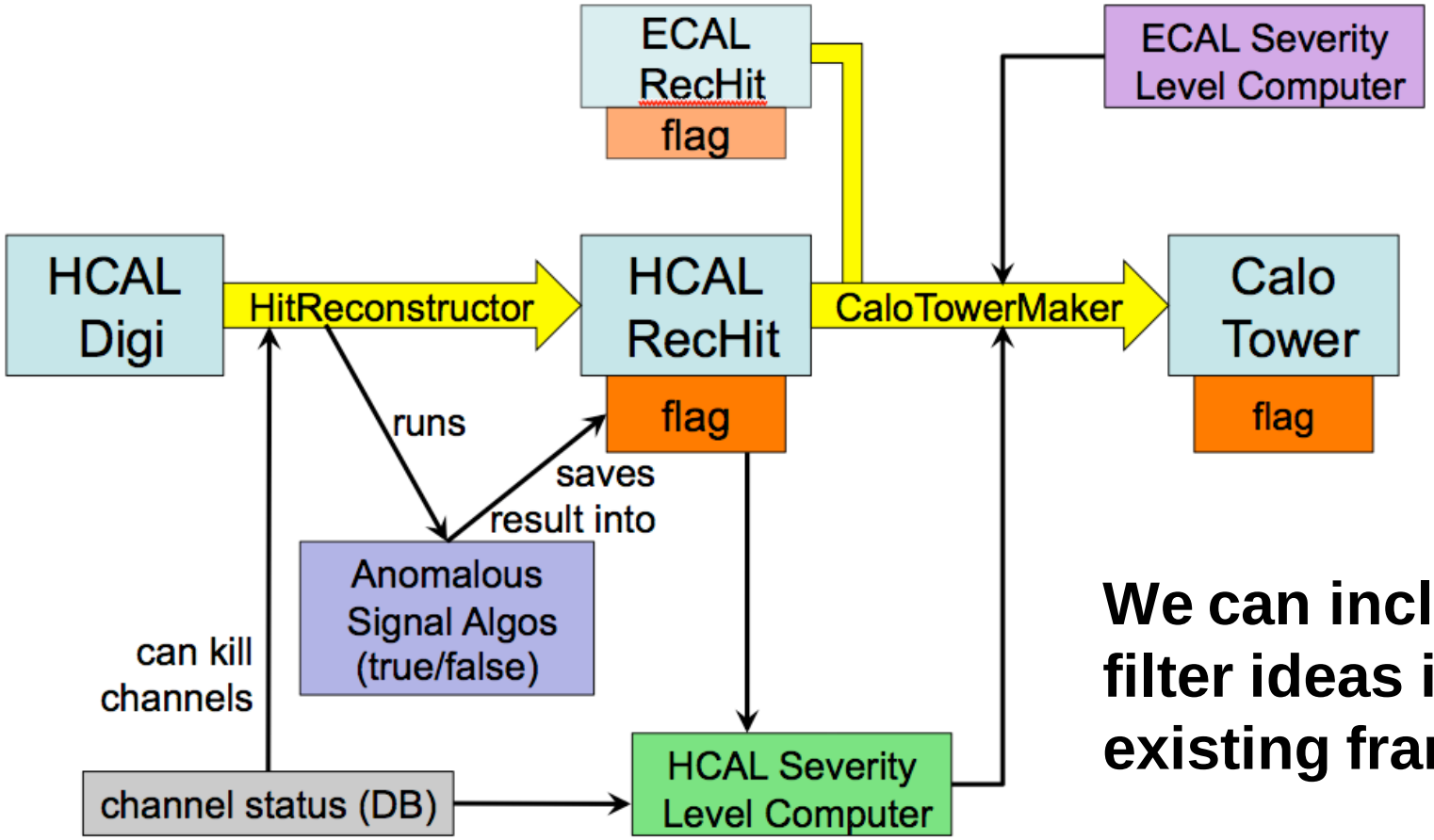




Shape of the *E_T spectrum taken from the 900 GeV data* and assumed not to change significantly at 7 TeV
PMT hit rate extrapolated to 7 TeV by scaling by HF energy

Framework to Treat Noise

We have a well developed software framework to run Anomalous Signal Filters; Flag RecHit; Remove/Count bad RecHits from CaloTower



We can include new filter ideas into existing framework

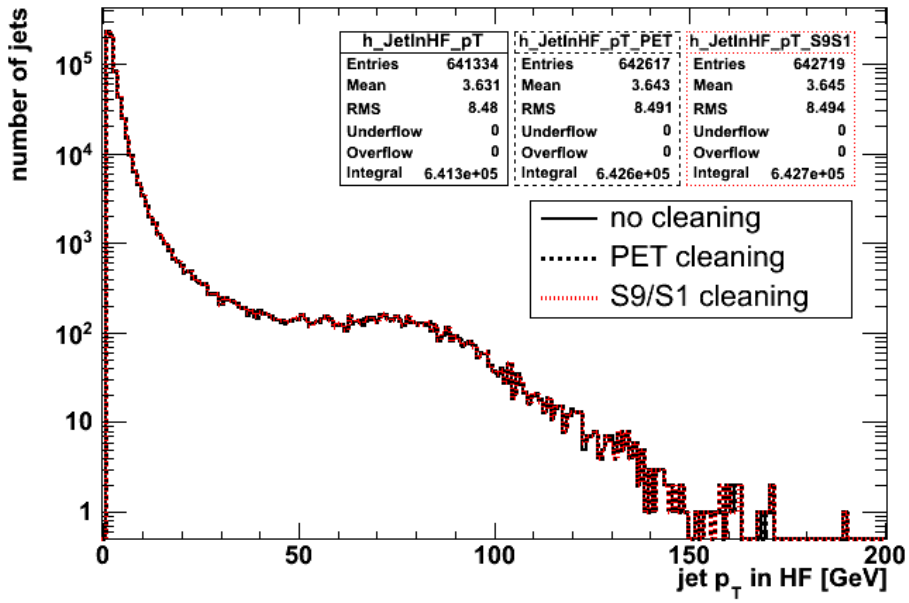
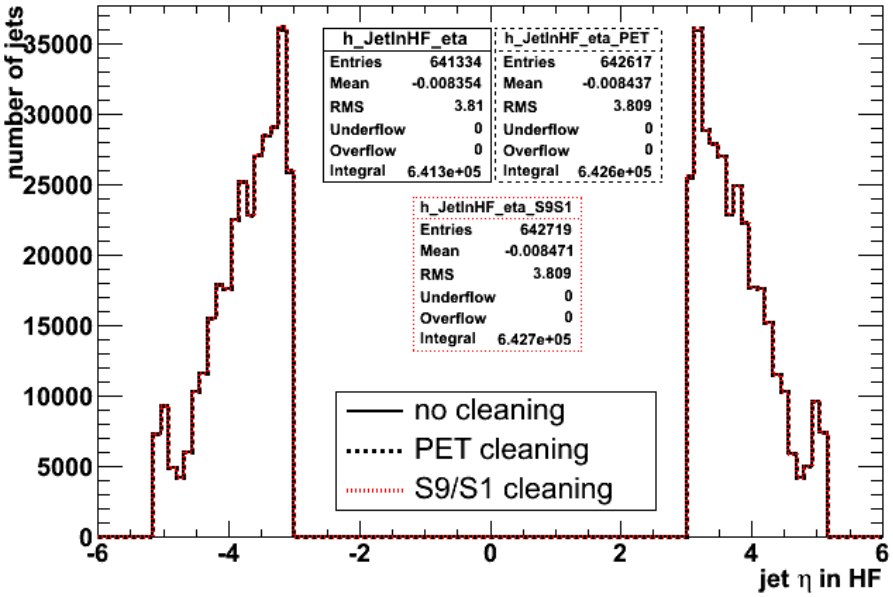
User Framework to Test Filters

We are running algorithms to flag bad rechits

Several algorithms available and being optimized

Ready to provide a default cleaned CaloTower

User framework to apply new filters is being developed

Currently PET and S9/S1 is available

Config file allows easy changing of thresholds