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L1Calo at High Luminosity

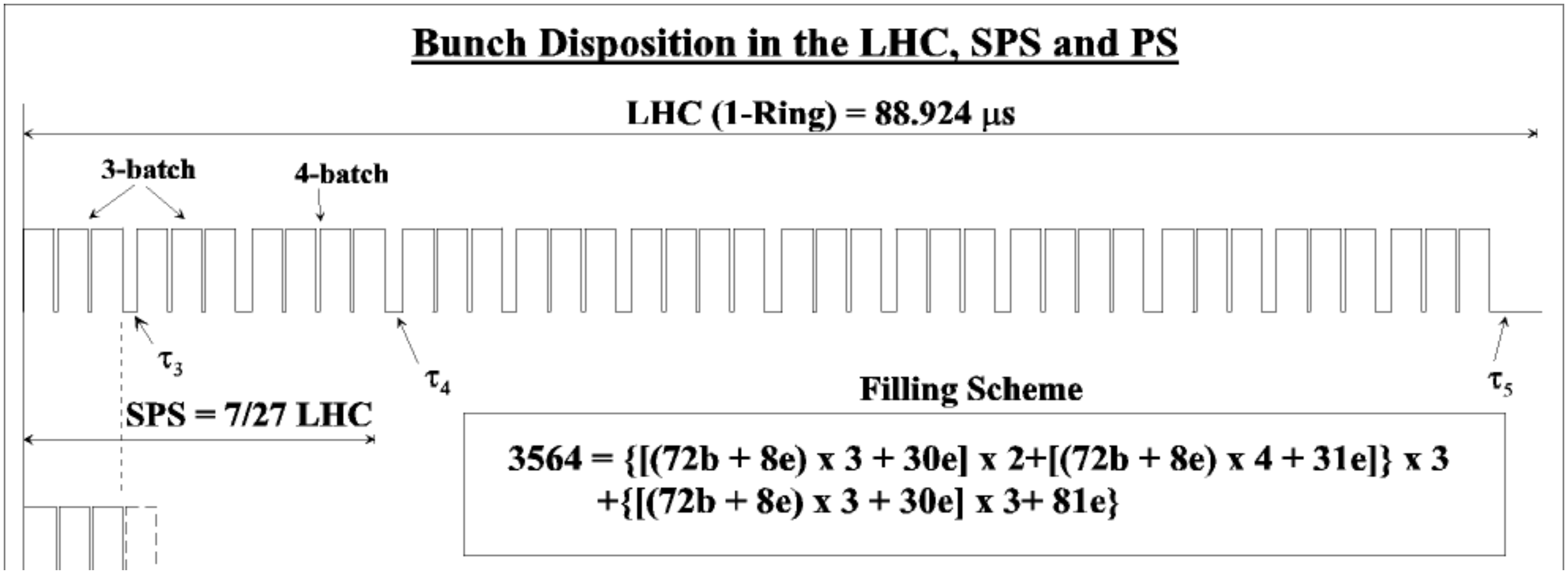
Up to $3x10^{34}$ $cm^{-2}s^{-1}$

Aims of the Study

- Predict what will happen to the existing L1Calo trigger as luminosity is increased
- Simulations up to and beyond design luminosity
  - Ended up going up to 3E34 for this iteration of the analysis
- Investigate quantities at the trigger tower level…
  - Peak-finding efficiency
  - Effect of noise cut
  - Tower multiplicity/occupancy
  - Energy resolution (or deltas)
- …and at the ROI level…
  - Trigger rates
  - Efficiency turn-on curves
  - Energy resolutions
- Understand all this within different bunch structures and L1Calo noise thresholds
  - 25ns, 50ns and 150ns spacing
  - Position in bunch train
  - Noise thresholds of 2, 4 and 10 (old LUT strategy)

Bunch Structures

- Simulating the full LHC bunch structure
- Taken from http://sl.web.cern.ch/SL/sli/cycles.htm



- 25ns spacing has 2808/3564 filled bunches
- For 50ns spacing, just removed every other filled bunch (leaving 1404 filled)
- For 150ns spacing, removed 5 out of every 6 (leaving 468 filled)
  - End of 2010 proton physics was with 150ns spacing

Simulating Pileup

- $\sqrt{s}$ = 14TeV
- Vary the bunch-instantaneous luminosity by changing the mean of the poisson-distributed number of collisions.
  - Mean of 23 collisions per filled bunch = 1E34
- This mean has been used in production samples with bunch spacing of 25ns. Using the filling scheme shown on last slide, then this assumes:

$$L = 1 \times 10^{34} cm^{-2} s^{-1} = \frac{23 \times (2808/3564)}{(25ns) \times \sigma_{ND}}$$

$$\Rightarrow \sigma_{ND} = 72.5mb$$

- But the Minbias sample used is from pythia, which reports a cross section of **54.7mb**. For design luminosity (1E34), this gives a mean of **17.25 collisions per bunch**
- Latest minbias analyses suggest pythia cross sections are consistent with data, so keep in mind luminosities quoted in this talk are probably upper estimates

Simulating Pileup (2)

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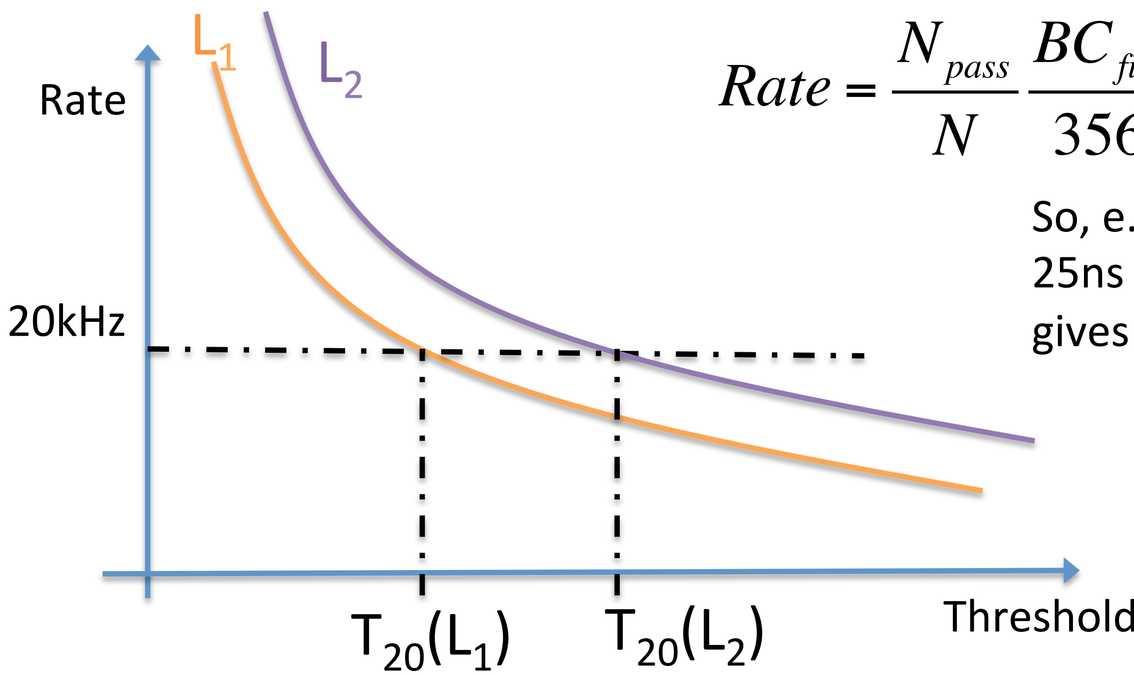
- Used a dataset of 1Million minbias events as non-diffractive minbias pileup
  - mc10_14TeV.105001.pythia_minbias.merge.HITS.e663_s1107_s1109/
- When estimating trigger rates, a sample of empty events are used as the "signal" event: all signals are due to the minbias pileup
- For the ROI efficiency studies (later in talk), the signal events were not empty, so one minbias pileup event was subtracted from the central (triggered) bunch crossing, to maintain the same mean number of collisions
  - Assumes the signal event is part of the minbias non-diffractive cross section
- Cavern, beam halo and beam gas contributions are neglected
  - See slides 5 and 6 of James Koll's talk (http://indico.cern.ch/getFile.py/access?contribId=7&sessionId=1&resId=0&materialId=slides&confId=126214)
- Simulated pileup in bunch crossings from -23 to +7 bunches:

Trigger rate studies

- Want to determine threshold, as a function of luminosity, that gives a fixed trigger rate for a given trigger type
- Trigger types investigated: EM, EMI, TAU, TAUI, JET4, JET8, TE, XE
  - EMI isolation cuts were: EMIsol=4, HadIsol=3, HadCore=2
  - TAUI isolation cuts were: EMIsol=6
- For each trigger type, plot trigger rate as a function of threshold, and read off the threshold that gives the desired rate (in this study, that is **20kHz**)

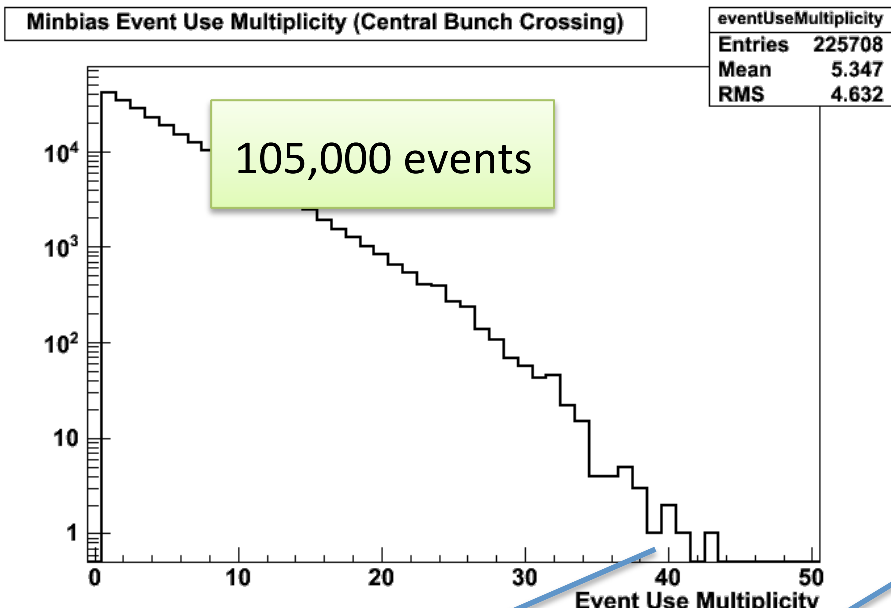


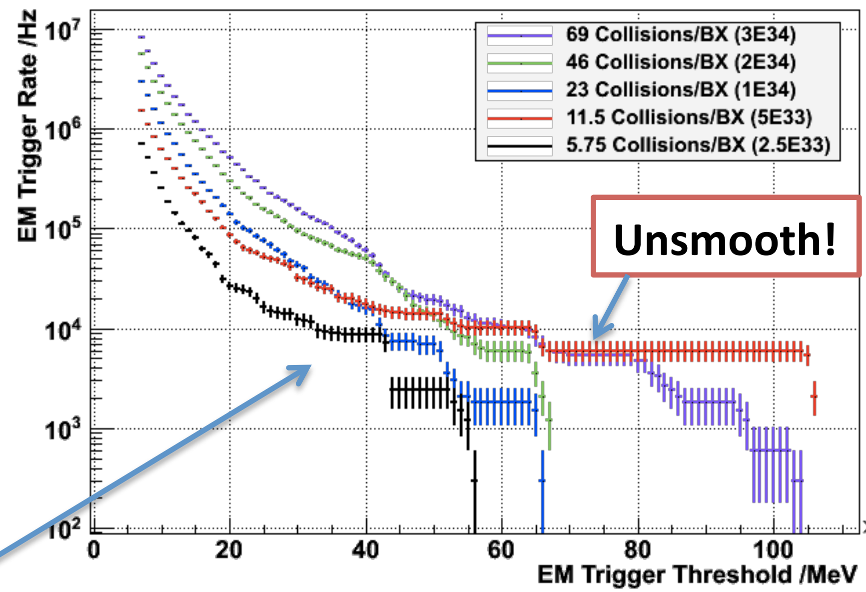
$$Rate = \frac{N_{pass}}{N}\frac{BC_{filled}}{3564}\times 40\,MHz$$

So, e.g., N=100,000 with 25ns structure (Bc_{filled}=2808) gives N_{pass}≈63 for 20kHz

Why in-house MC sample production?

- Production samples have no bunch structure (and only 25ns spacing)
- The production minbias pileup samples are susceptible to biases being introduced that significantly affects the rates we are interested in
  - Underlying event reuse mechanism driven by a random number generator, which causes some events to appear in the central bunch crossing more than others





If these events have a high energy ROI in them, they will dominate the rate calculation at low rates

Other reasons for custom MC samples

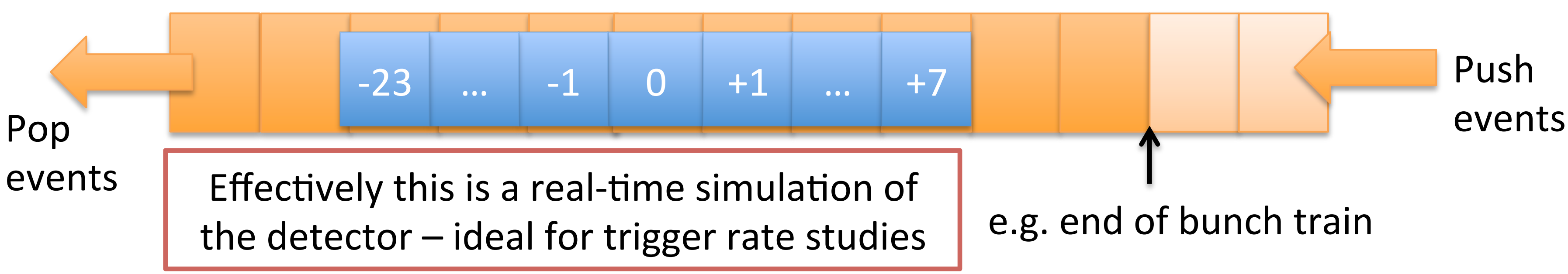
- Simulation "window" in production samples of -32 to +4 does not cover the full L1Calo simulation range
  - Not expected to cause a significant difference in results
- Production samples have not yet implemented latest FCAL calibration fix

The “Stepping Cache” solution

- Event reuse random mechanism was disabled (ReadDownScaleFactor=1)
- This still doesn’t guarantee every event gets its turn in the central bunch crossing, because the events get assigned randomly to the bunch crossings in the simulation “window”
  - Event reuse is inevitable (e.g. 100,000 events of 23 collisions per crossing with a simulation window 31 crossings long, would mean we need to pileup a total of 71.3Million events, but we only have a million available in the dataset)
  - One event could, by chance, be selected for the central crossing every time it was reused

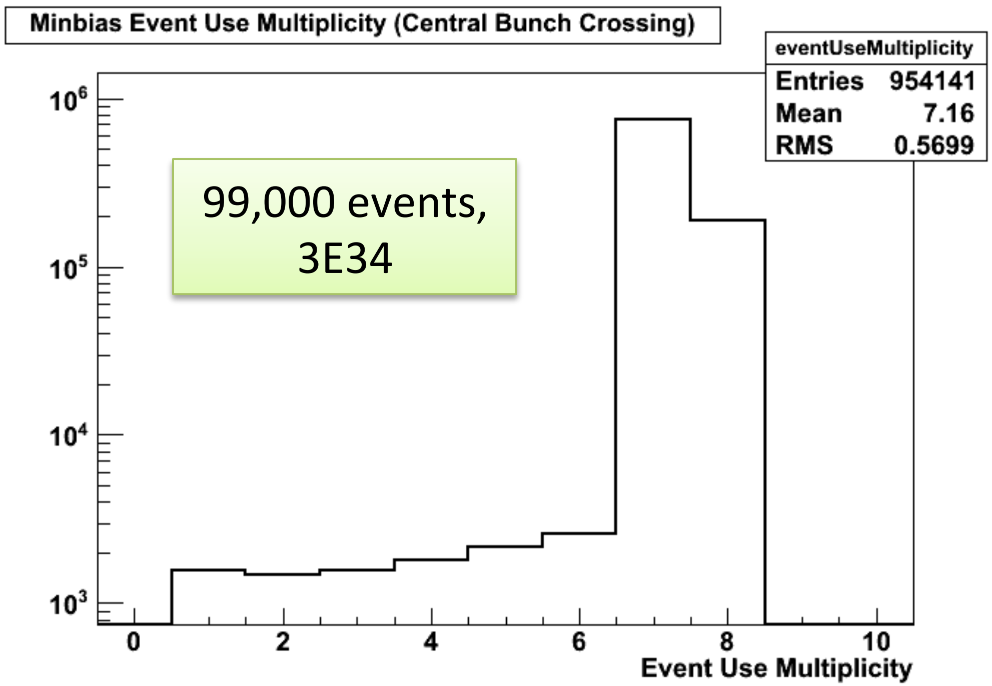
Solution

- Created code that effectively puts the events on a conveyor belt, which slides underneath the simulation window. If grid jobs are carefully constructed, events will all get used approximately the same number of times.
  - Doesn’t apply to signal event, but this is ok in the case of empty signal events



The “Stepping Cache” solution (2)

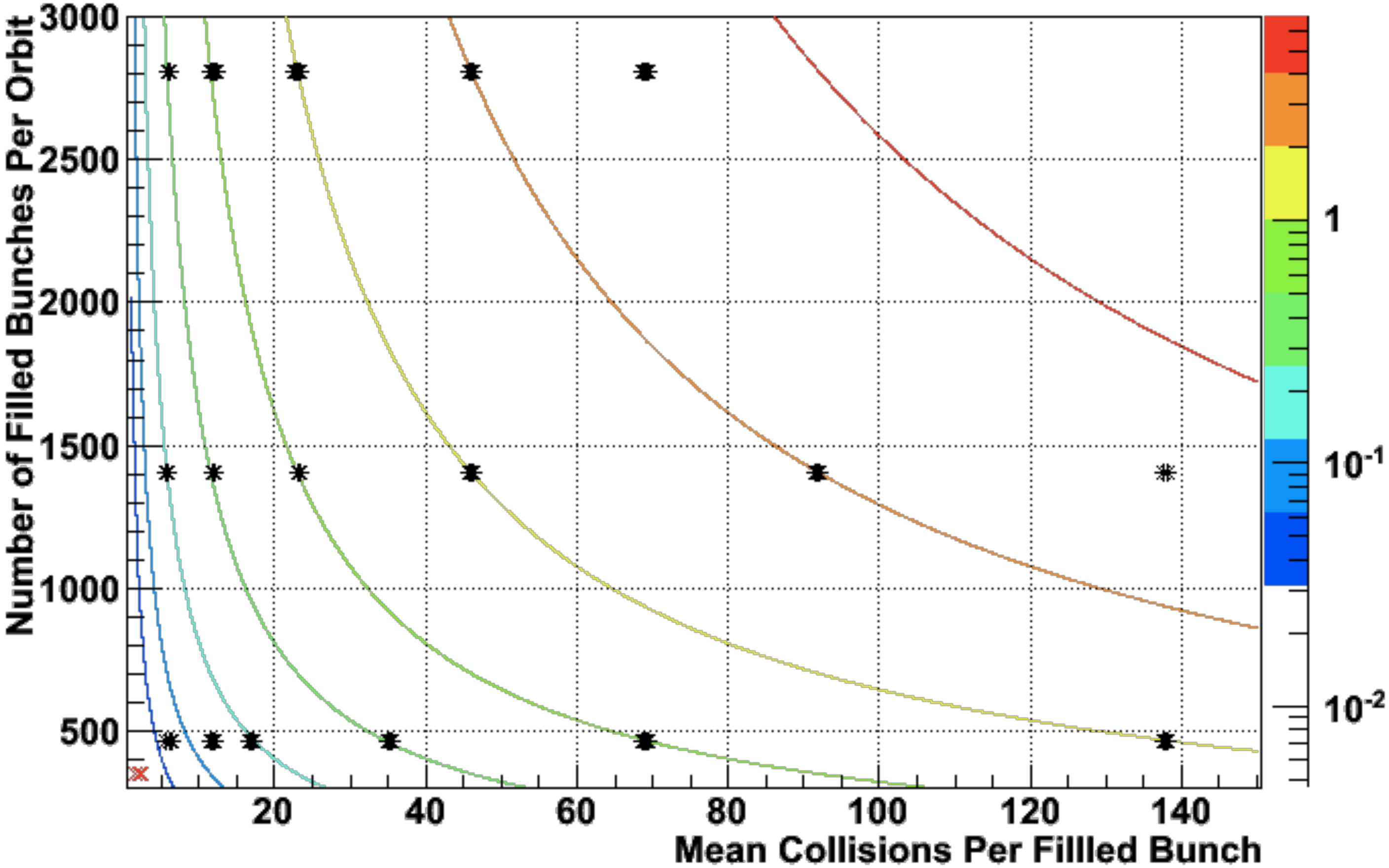
- Solution ensures the minbias events are “proportionally represented” in the pileup sample
- At the highest luminosities (3E34), it is still possible that a few underlying events will dominate the rates – so keep an eye out for the unsmooth structure appearing in rate plots. Rates at these points should not be taken as reliable



- Generate enough events in each sample to ensure that 20kHz rate results from **no fewer than 50 events** – adequate statistics to use errors of binomial proportion

Minbias Samples Produced

- Plot shows contours of Luminosity (z-axis in units of $10^{34}cm^{-2}s^{-1}$)
- Black dots are samples produced, red x is approximately the situation at the end-of-2010 proton running (but with different cross-section)



Tower Level Analysis – some details

- FCAL settings (determined by auto calibration in simulation):
  - EMB = [1,4,9,5,1] dropBits=4
  - EMEC = [1,4,9,5,1] dropBits=4
  - FcalE = [0,3,14,4,0] dropBits=4
  - Tile = [1,8,15,10,4] dropBits=5
  - Hec = [0,9,15,11,6] dropBits=5
  - FcalH = [0,3,11,6,0] dropBits=4

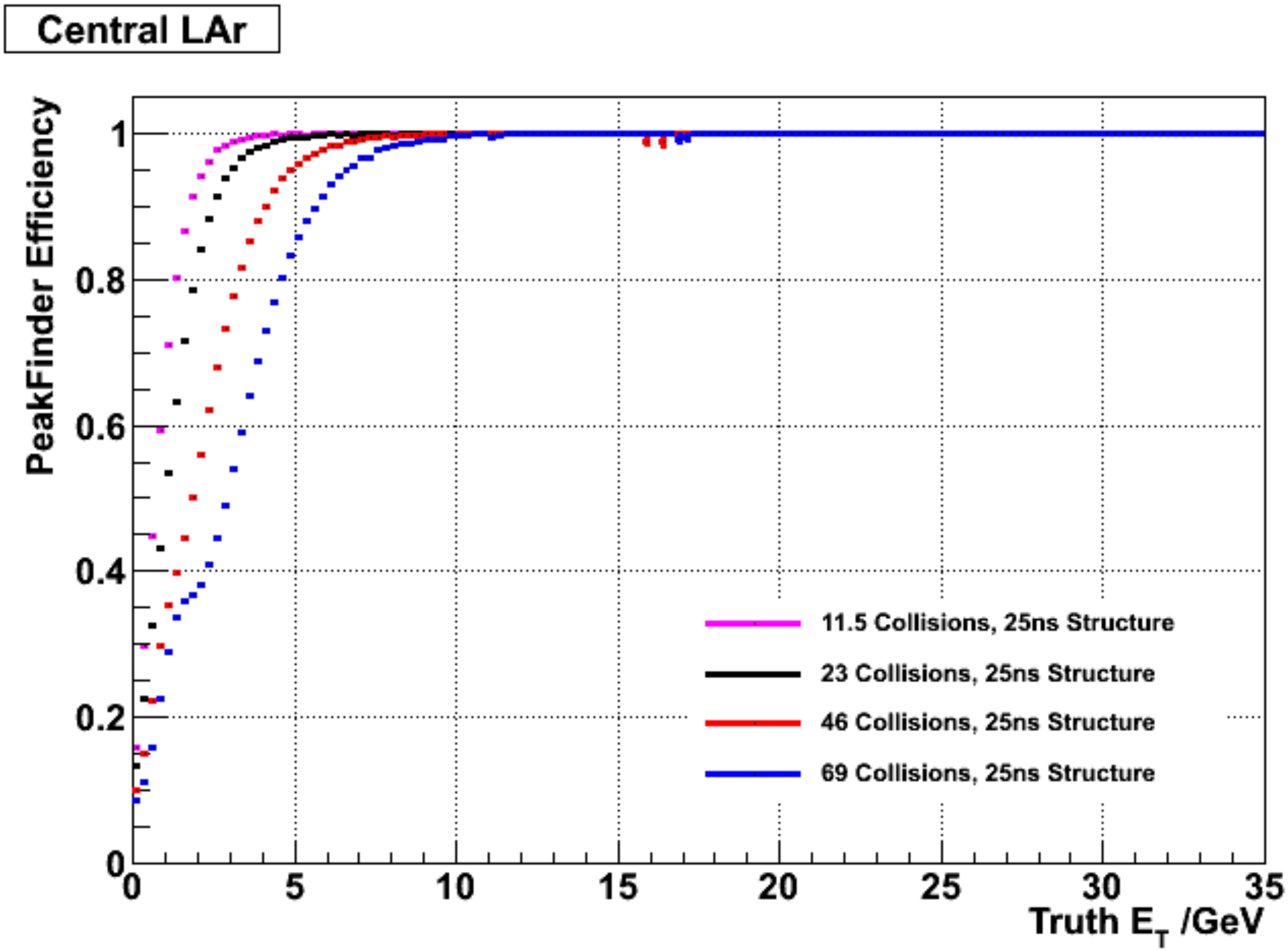
- Peakfinder Efficiency (as function of Truth ET) = fraction of Truth ET deposits that have successful BCID decision (3^{rd} bit = 1)
  - These efficiencies are independent of the noise cut

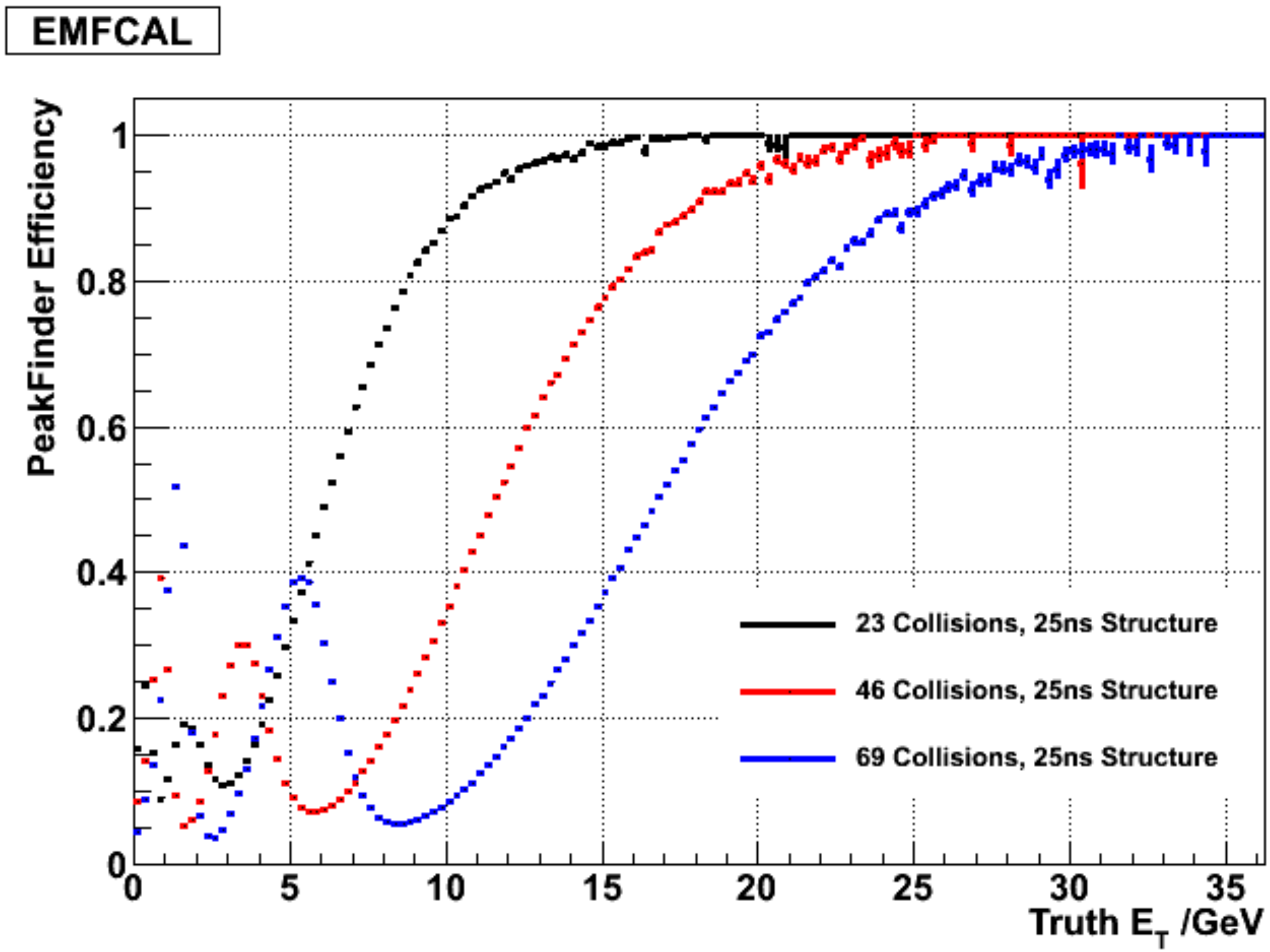
<u>A Note About "Truth ET"</u>

- This is not the same as the calorimeter cell ET. It is approximately the same but for a further discussion of the definition of this value, see the backup slides

Central Lar Peak Finding Efficiency

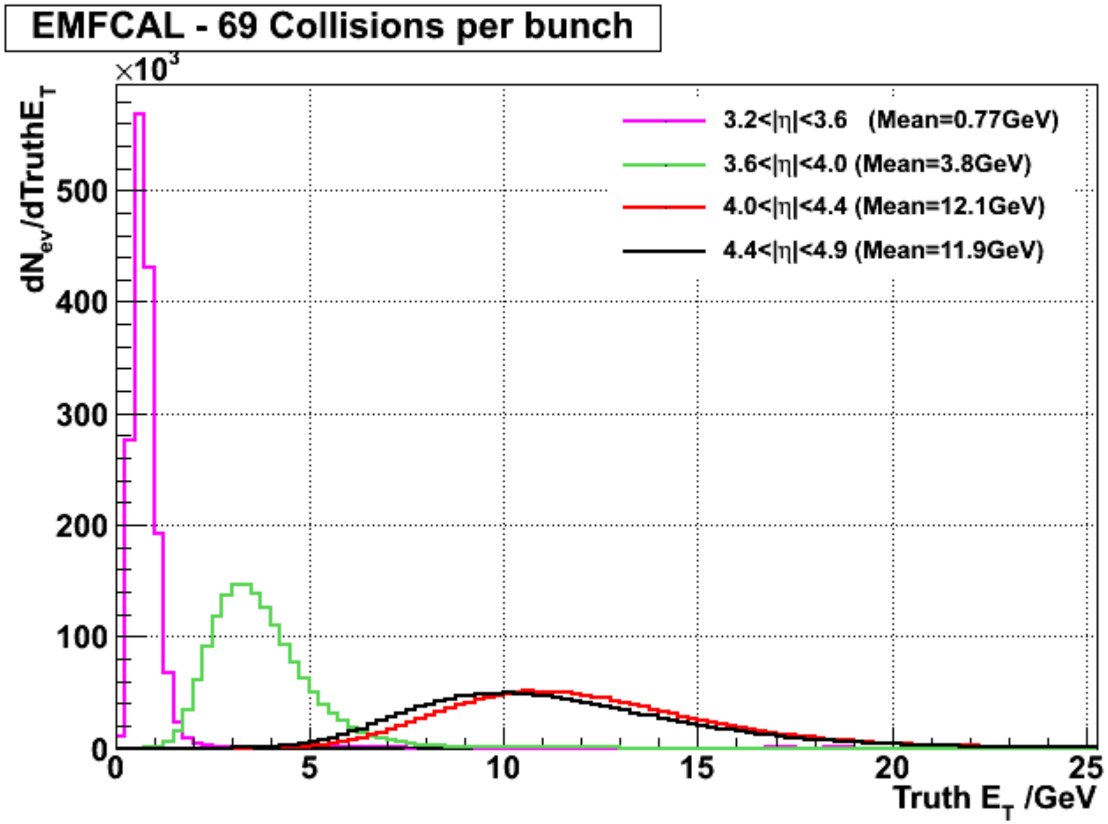
Central LAr = EM Barrel + EMEC + HEC




EMFCAL
PeakFinder Efficiency
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
Truth E_T /GeV
23 Collisions, 25ns Structure
46 Collisions, 25ns Structure
69 Collisions, 25ns Structure

Understanding the Peakfinder EMFCAL "wiggle"

- Answer lies in the Truth ET distribution for this partition
  - TruthET distribution is bunch-structure and noise cut independent, only depends on number of collisions per bunch (i.e. the bunch-instantaneous luminosity)



- EMFCAL TruthET is overcalibrated relative to CaloET (see backup slides), so situation wont be quite this bad if we get the calibration right. But we are already seeing signs in data that FCAL occupancy is getting high

Summary of Peakfinder Efficiencies

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- Position of turn-on curve is dominated by the mean of the energy distribution
- This distribution is determined by the number of collisions per filled bunch
- Bunch structure also influences turn-on curve
  - The larger the bunch spacing, the better the peak finding

- Table of 90% peakfinder efficiency **TruthET** energies (25ns/50ns):

# Collisions	Central LAr	Tile	EMFCAL	HadFCAL
5.75	1.5 / 1.5	1.6 / 1.6	4.0 / 2.6	2.3 / 1.8
11.5	1.8 / 1.6	1.7 / 1.7	6.2 / 4.5	3.5 / 2.6
23	2.6 / 2.0	1.7 / 1.7	10.5/ 7.3	5.5 / 4.3
46	4.1 / 3.2	1.7 / 1.7	18.0/ 12.5	9.0 / 7.2
69	5.8 / ----	1.8 / ----	25.0/ ---	13.0/ ---
92	--- /5.6	--- / 1.8	--- / 22.0	--- / 13.0
138	--- /7.8	--- / 2.0	--- / 31	--- / 17.8

Tower Multiplicity and Occupancy

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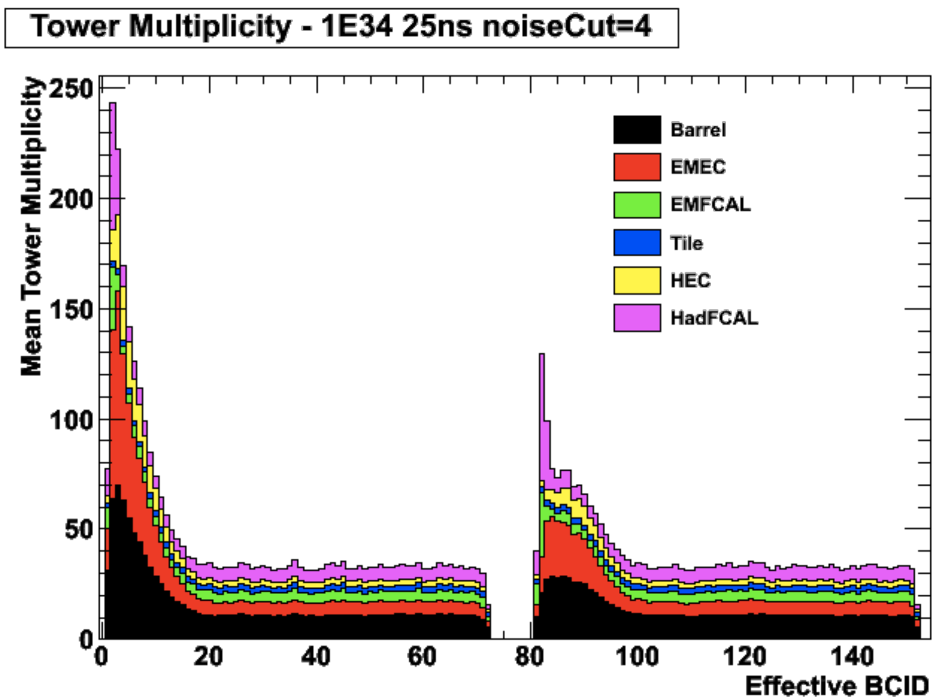
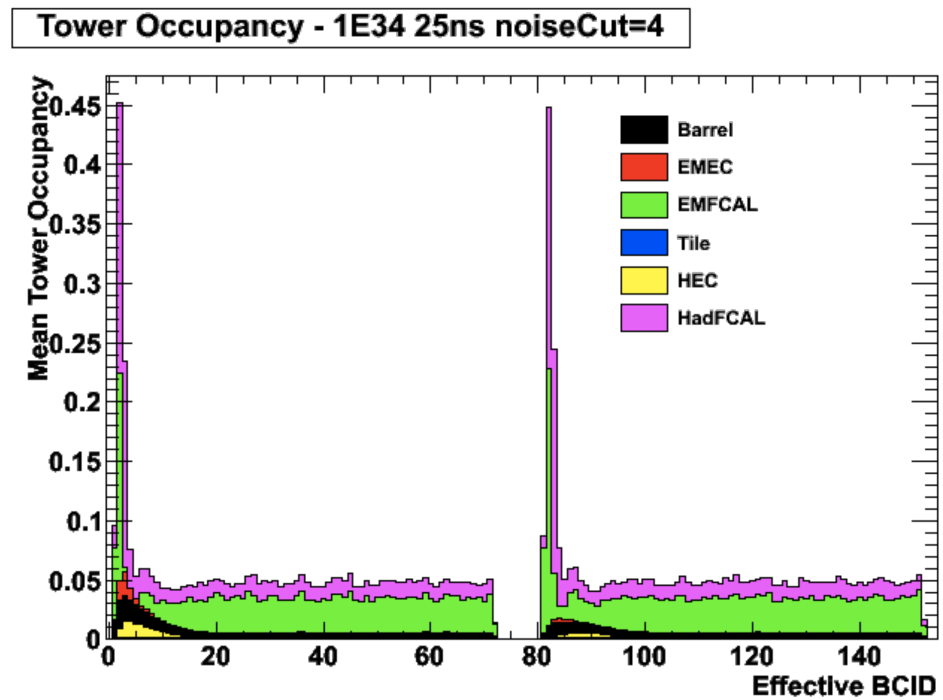
- Look at multiplicity and occupancy through the bunch train
  - The gap in the plot is the “small” gap between neighbouring trains. The first train is the train you get after a “large” gap between trains. See the bunch structure slide from earlier.





Occupancy should be worse for larger bunch spacings

Baseline Shift in the Bunch Train

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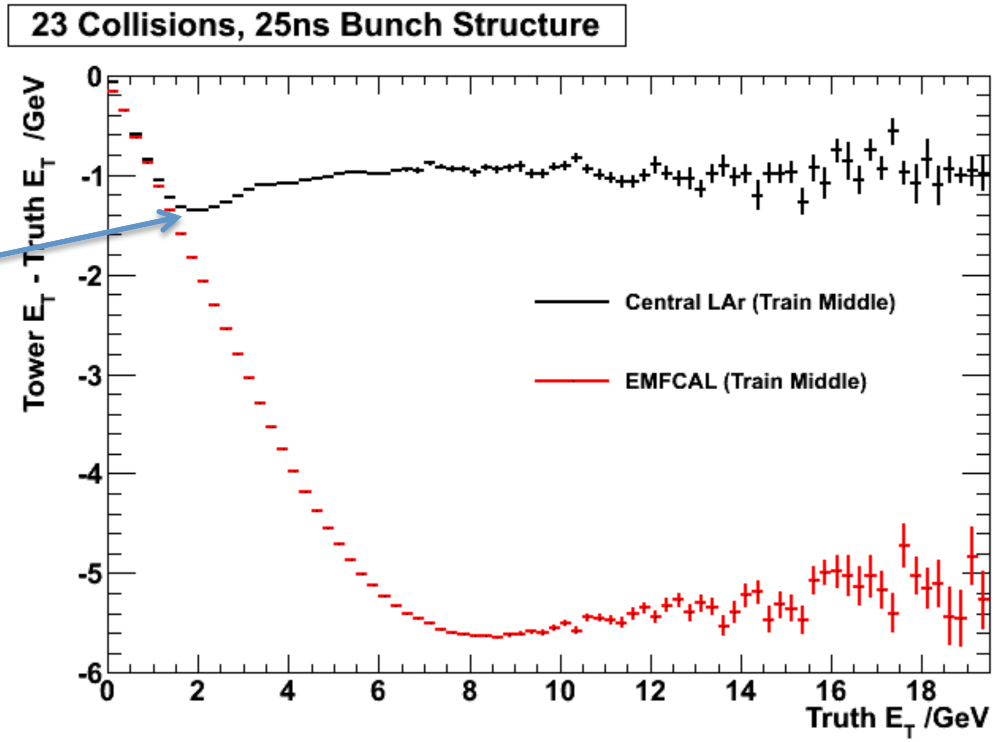
- Throughout the bunch train, a negative baseline shift is observed across L1Calo
  - Biggest in the FCAL

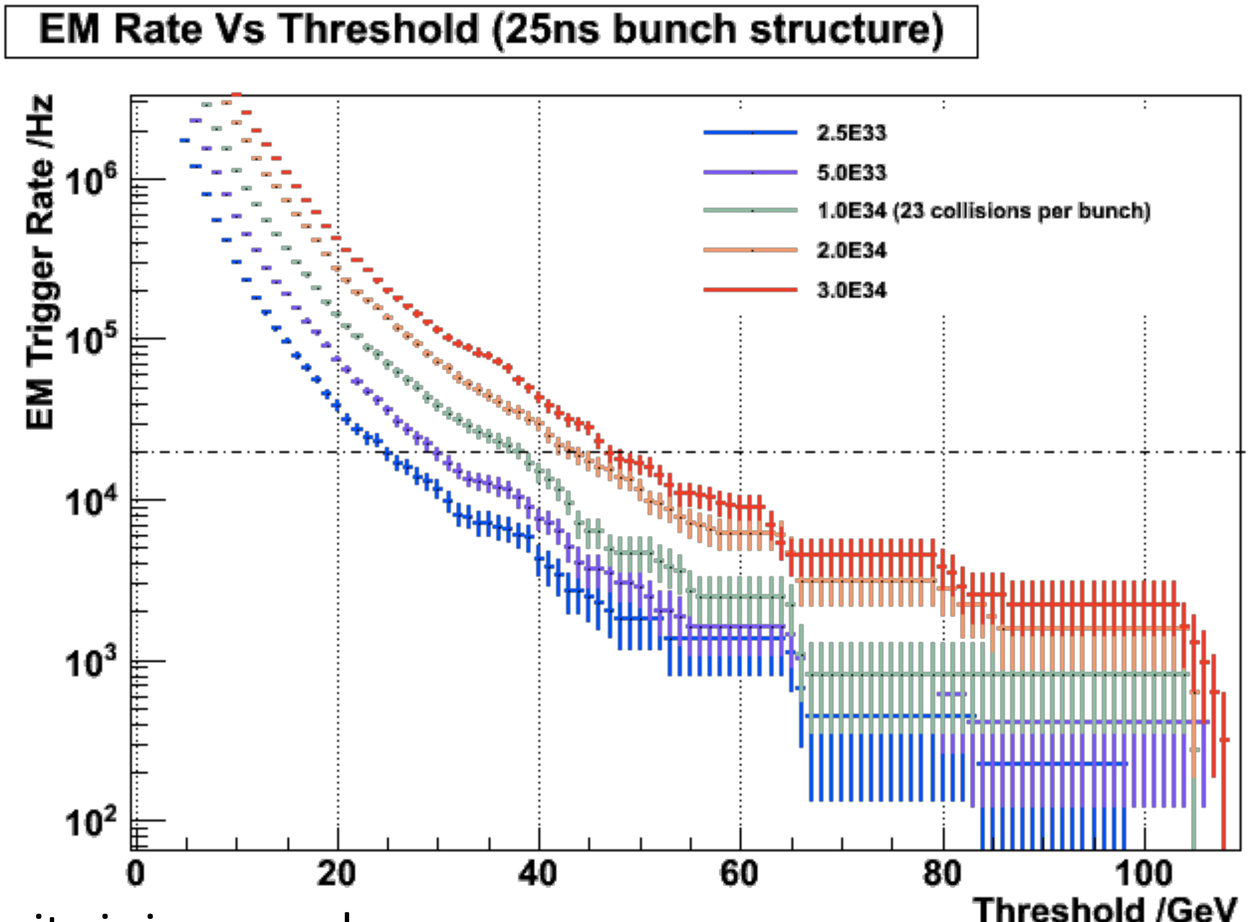
Minimum is due to NoiseCut (=4 in this plot)



- Have found that the normalized pulse shapes used in the simulation integrate to slightly less than zero.
  - E.g. EMFCAL integrates to -0.12. The lowest energy LAr shape integrates to -0.83!!!!
- This, combined with the average energy deposited per filled bunch, can explain the observed baseline shift

ROI Analysis – EM Trigger

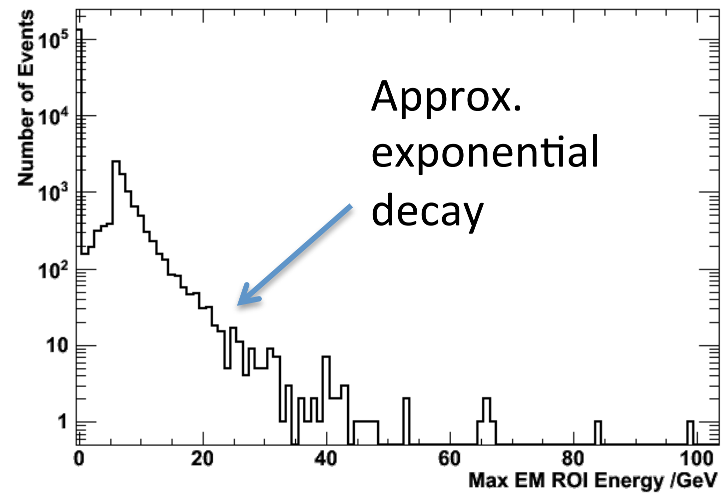
- Plot includes only NoiseCut=4 samples, with 25ns bunch structure



- As luminosity is increased:
  – Shape of plots are approximately preserved
  – Rates at a fixed threshold appear to scale linearly with the luminosity (will confirm this in a couple of slides)

Understanding EM Rate vs Threshold

- Focus on just the EM ROI for a moment…
- Each underlying minbias event has some (or none) RoI associated to it, which we will assume are independent of each other.
- So each underlying collision event can have an associated "Max Energy ROI".
- If we doubled the number of collisions per BC and simulated the same number of events, the number of events in the tail of the distribution should approximately double
  - Small chance that two of the high-energy Max ROI events go in to the same bunch crossing



- As Luminosity increases:
  - Events start to migrate to the right of the distribution. The further to the left of the distribution, the more likely they are to migrate (biggest probability of event combining with an event containing a higher energy max ROI)
  - **If the luminosity doubles, then the number of events in the tail of the distribution will double (to a very good approximation)**
- At some point along the energy spectrum there is a transition from this linear behaviour with luminosity to non-linear behaviour.

Understanding EM Rate vs Threshold (2)

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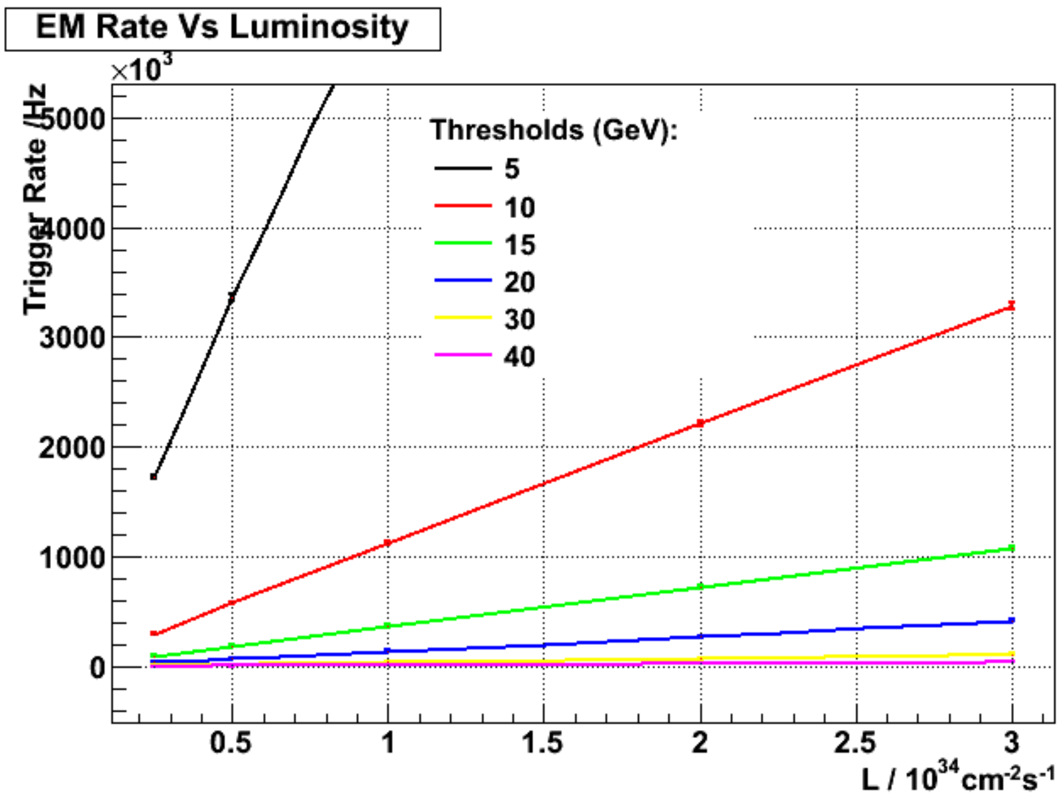
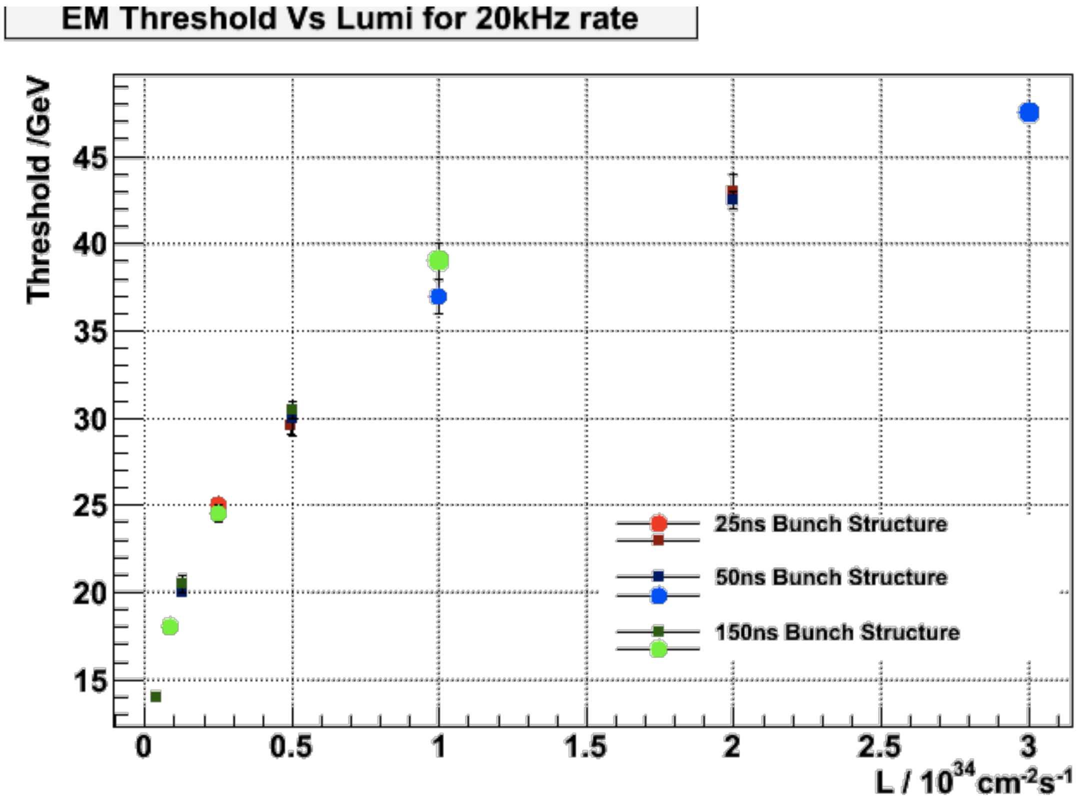
- The rate at a given threshold is proportional to the integration under the Max ROI Energy distribution, from the threshold energy up to infinity
- So doubling the luminosity doubles the integral
  - **i.e. rate at a fixed threshold scales with luminosity**

$$Rate = \frac{N_{pass}}{N}\frac{BC_{filled}}{3564} \times 40\,MHz$$



Threshold vs Luminosity – EM Trigger

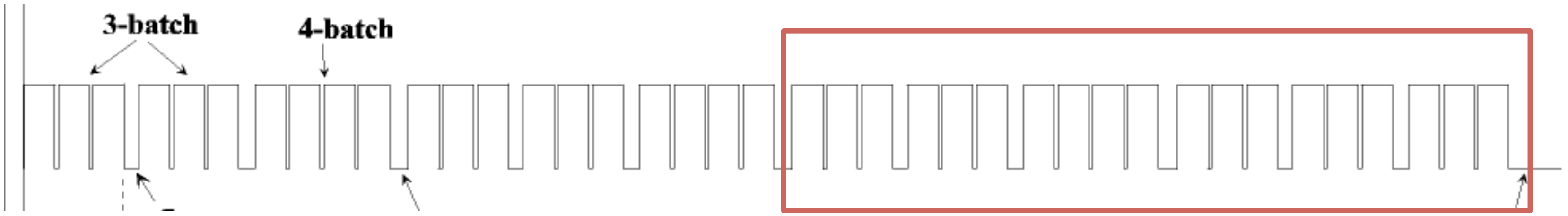
- For fixed 20kHz rate, plot threshold vs luminosity for the different bunch structures.



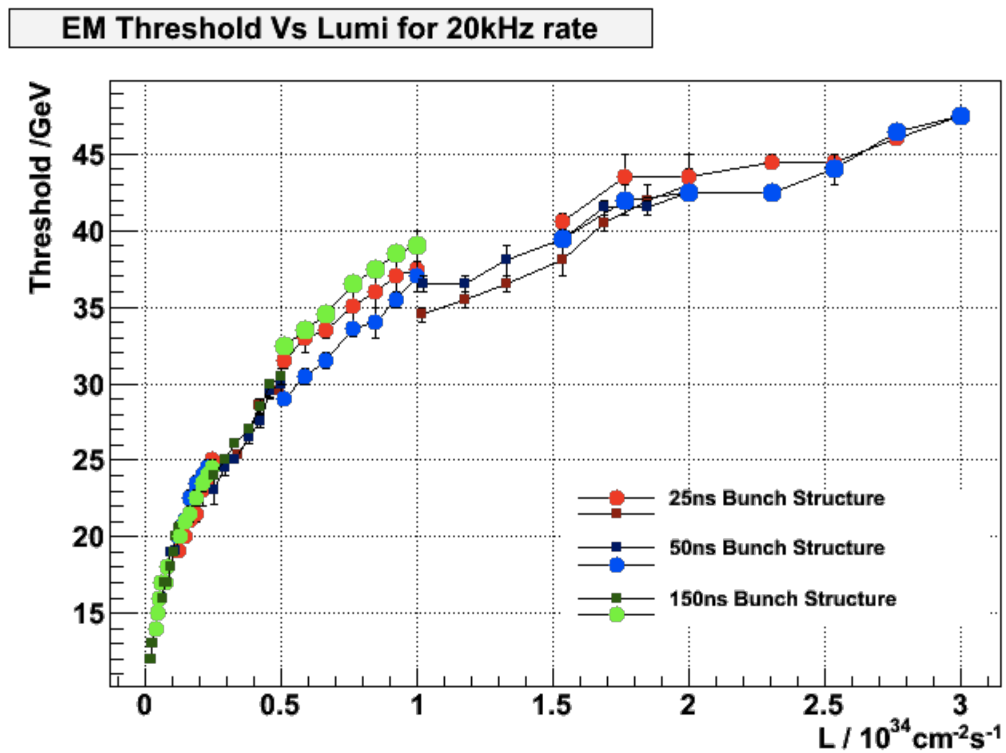
- Bunch structure does not significantly alter the threshold required for 20kHz EM rate.

EM Trigger

- Can, to some extent, simulate the intermediate luminosities by throwing away bunch trains from the end of the structure…



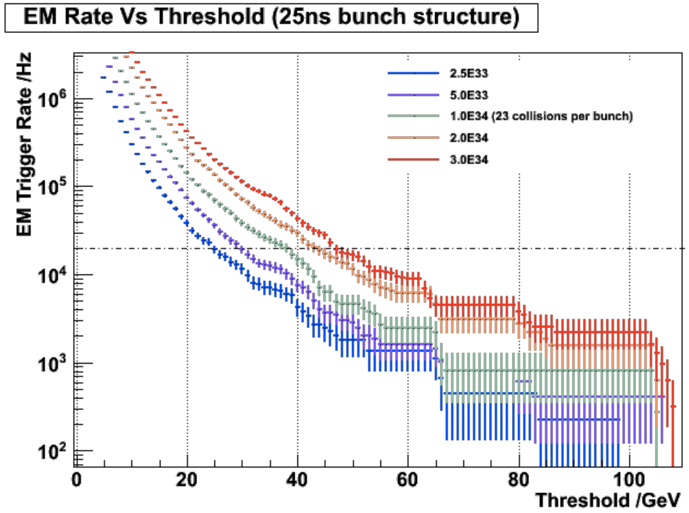
- Gives 6 additional points per sample – going down to approximately half the luminosity of the sample. See plot ->
- The samples “joining up” is confirmation that the rate at fixed threshold is linear with respect to luminosity (when changing the number of collisions)



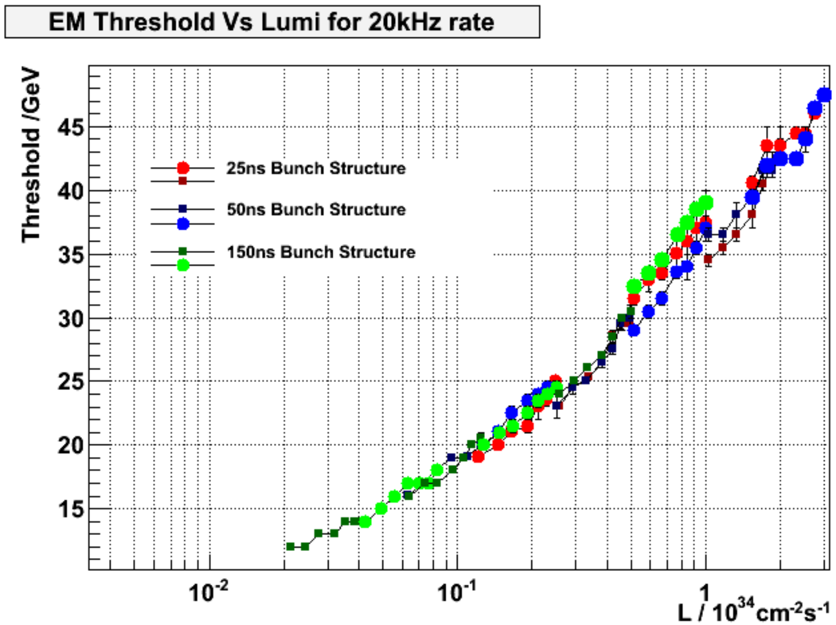
- Then repeat all this with NoiseCut 2 and 10….

Understanding the EM Threshold evolution

- Evolution is approximately logarithmic
- In the case where rate vs threshold is exponentially decaying function, then threshold evolution at fixed rate is logarithmic (see me for maths)
- **The shape of the rate vs threshold plot influences the evolution of the threshold vs luminosity**

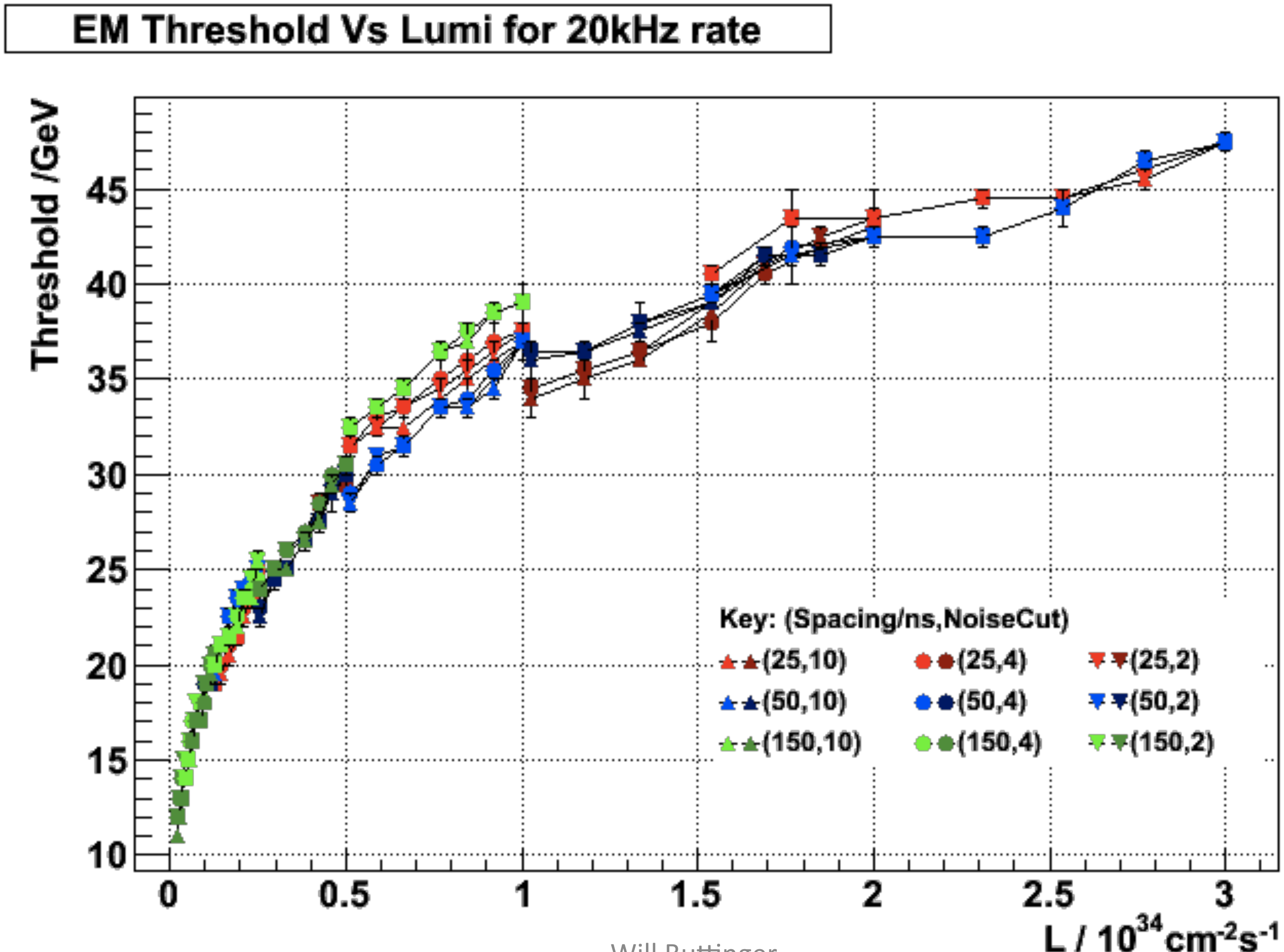


- Slightly faster than logarithmic increase is observed (see plot to right), due to the slightly faster than exponential decay of rate vs threshold.



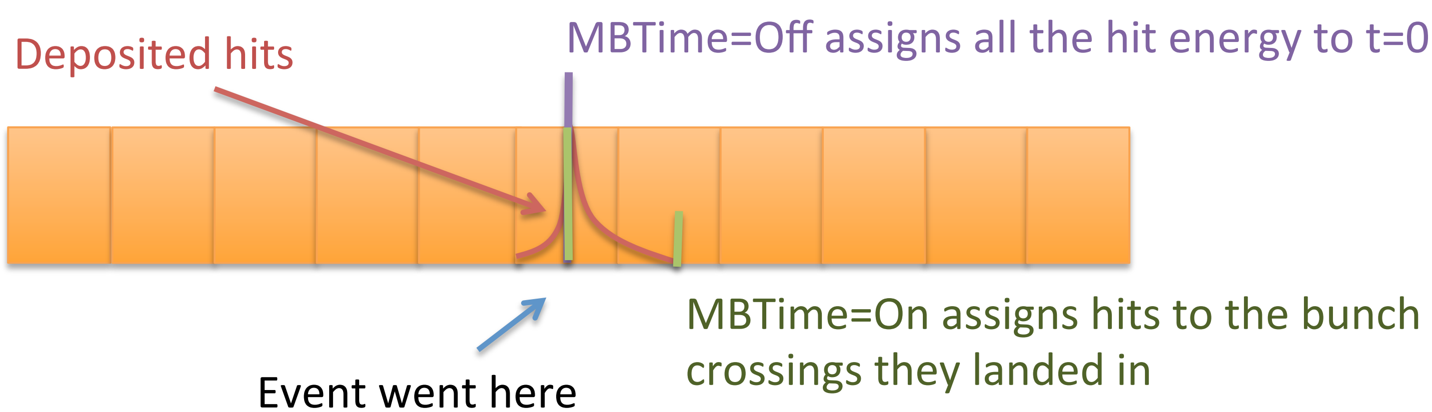
EM Trigger – All the noise cuts

- Noise cuts do not significantly change the threshold-vs-luminosity for the EM trigger
  - Thresholds are already so high that suppressing up to 2.5GeV towers wont reduce EM ROI with these energies



The MC Strikes Back – the MBTime feature

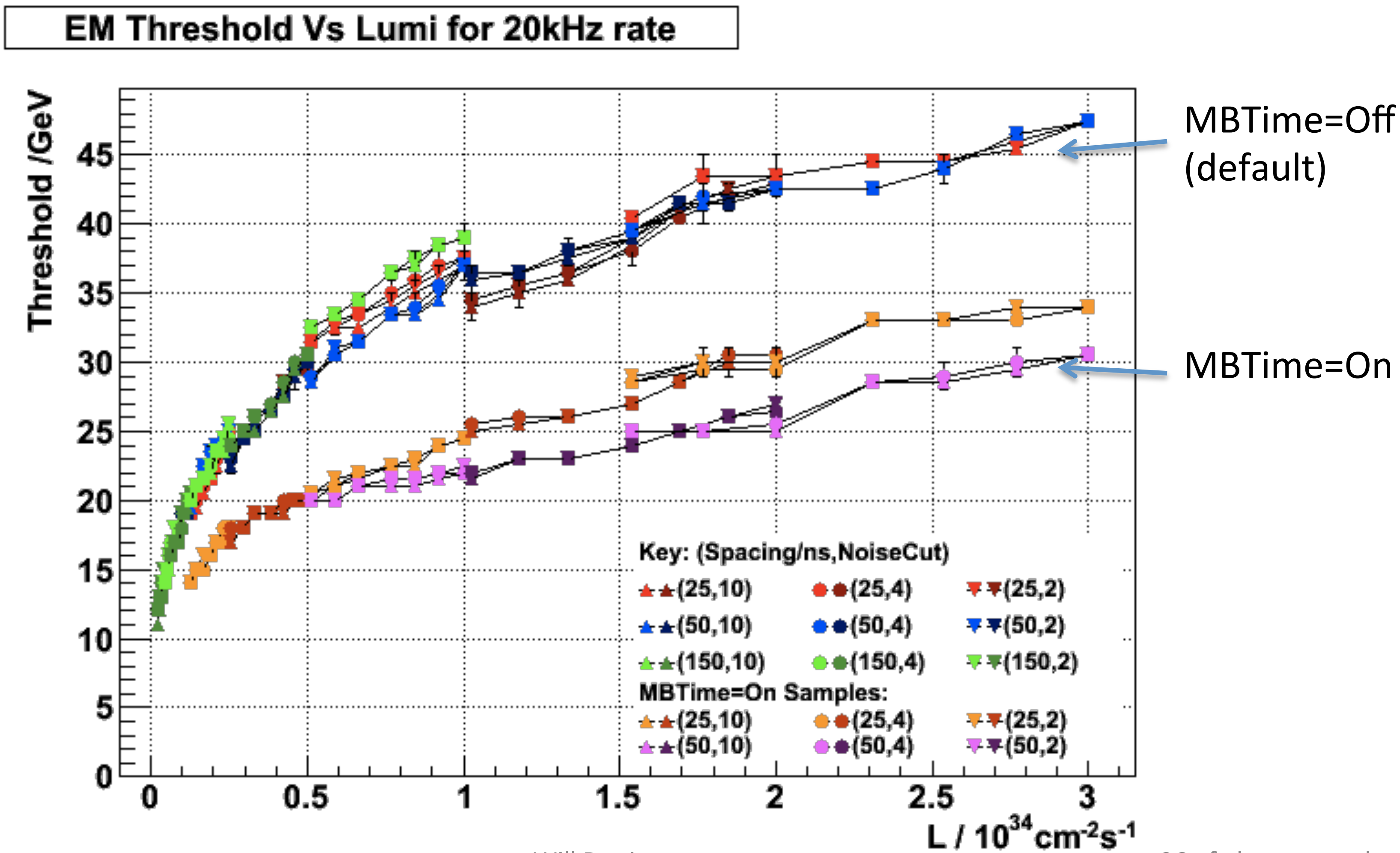
- **This only affects the LAr**
- An event in the underlying minbias sample will contain a list of calorimeter cell hits. Each hit has a time associated to it, relative to the time of the interaction and adjusted for distance of the hit from the origin – time of flight
- For any given cell, would expect most of the energy to be deposited close to t=0



- By default (I believe to speed up processing time), the timing of the hits are ignored in the simulation, all the times of hits of the minbias event get set to the time of the centre of the bunch crossing that the event has been assigned to
  - E.g. an event that gets put in bunch crossing +1 will have all it's hit times set to +25ns
- But the feature can be enabled so that the hit timings are preserved and the energy deposits could be spread over more than one bunch crossing
- If most of the energy deposit is made close to t=0, this shouldn't make much of a difference to the energy of the ROIs
  - Maybe occasionally would lose 1GeV to neighbouring bunches

The effect of the MBTime feature

- Turns out that enabling the feature to keep this timing significantly changes the scale (and to some extent, the shape) of the rate-vs-threshold plot at a given luminosity.
- This significantly alters the the threshold-vs-luminosity plots



Validating the simulation

- To have confidence in the threshold vs luminosity plots, we need to validate the rate-vs-threshold plot
  – The shape of this plot determines the evolution of the threshold vs luminosity, and the scale of the rate determines the absolute scale on the threshold plot.
- Need to also decide what to do about this MBTime feature
  – Should it be on or off? On sounds more "realistic", but that's not a sufficient argument
- Test all of this by comparing to real data, but will have to do this at 7TeV

7TeV – Run 167776

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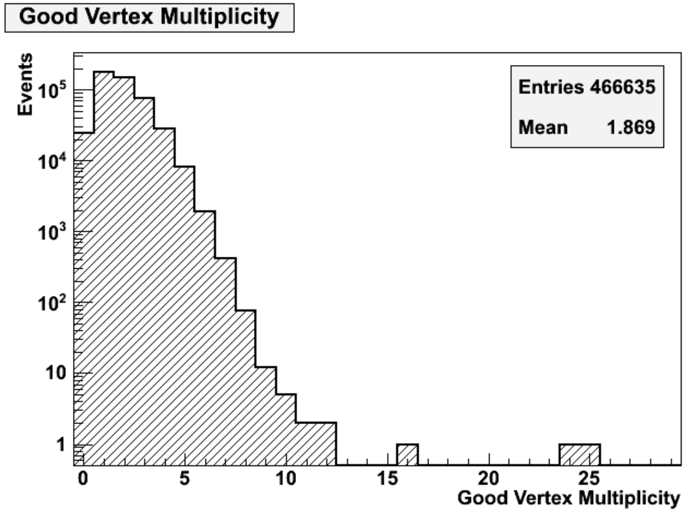
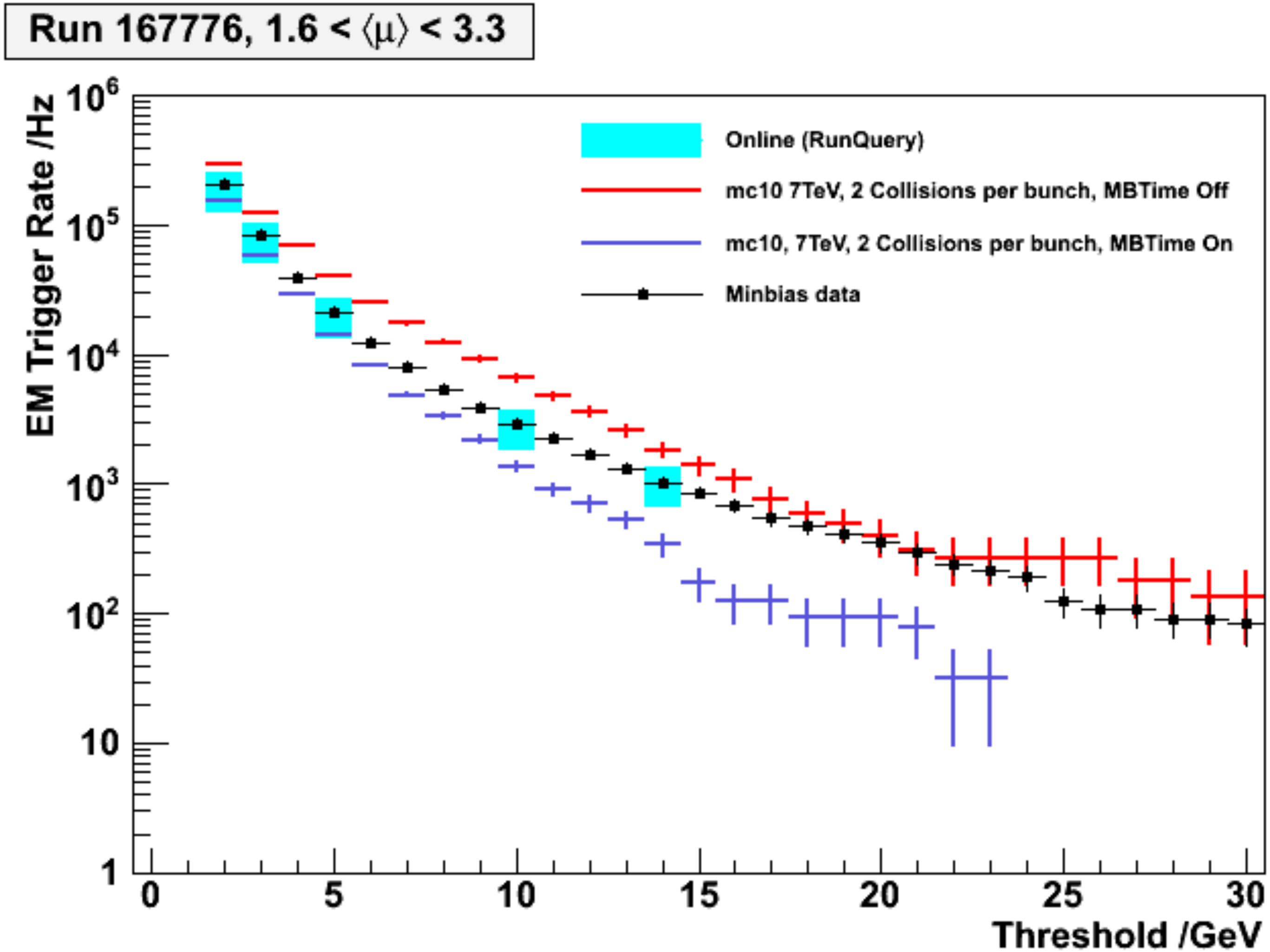
- Online Luminosity (during stable beams) was from 178.9 – 87.5 x10^{30} $cm^{-2}s^{-1}$
  - Lumiblocks 124 to 546 inclusive
- If we take the cross section given in the mc sample (48mb), this corresponded to between 2.1 and 1.0 mean collisions per filled bunch (348 filled bunches)
  - Cross section estimate by pythia a lower estimate?
- The online <μ> was 3.3 to 1.6 (will include some amount of diffractive)
- Made a minbias data sample by selecting on EF_mbMbts_1_eff, EF_mbLucid_eff or EF_mbZdc_eff
  - Counted "good vertices": number of primary vertices with at least three reconstructed tracks
- **Mean of 2.0 collisions per filled bunch seems a reasonable simulation attempt**



7Tev – Run 167776

- MBTime-On too low (but in the band), MBTime-Off too high (but good at high threshold?)
  - What's really bothering us is that this simulation feature makes such a big difference!



Why does the MBTime feature make a big difference?

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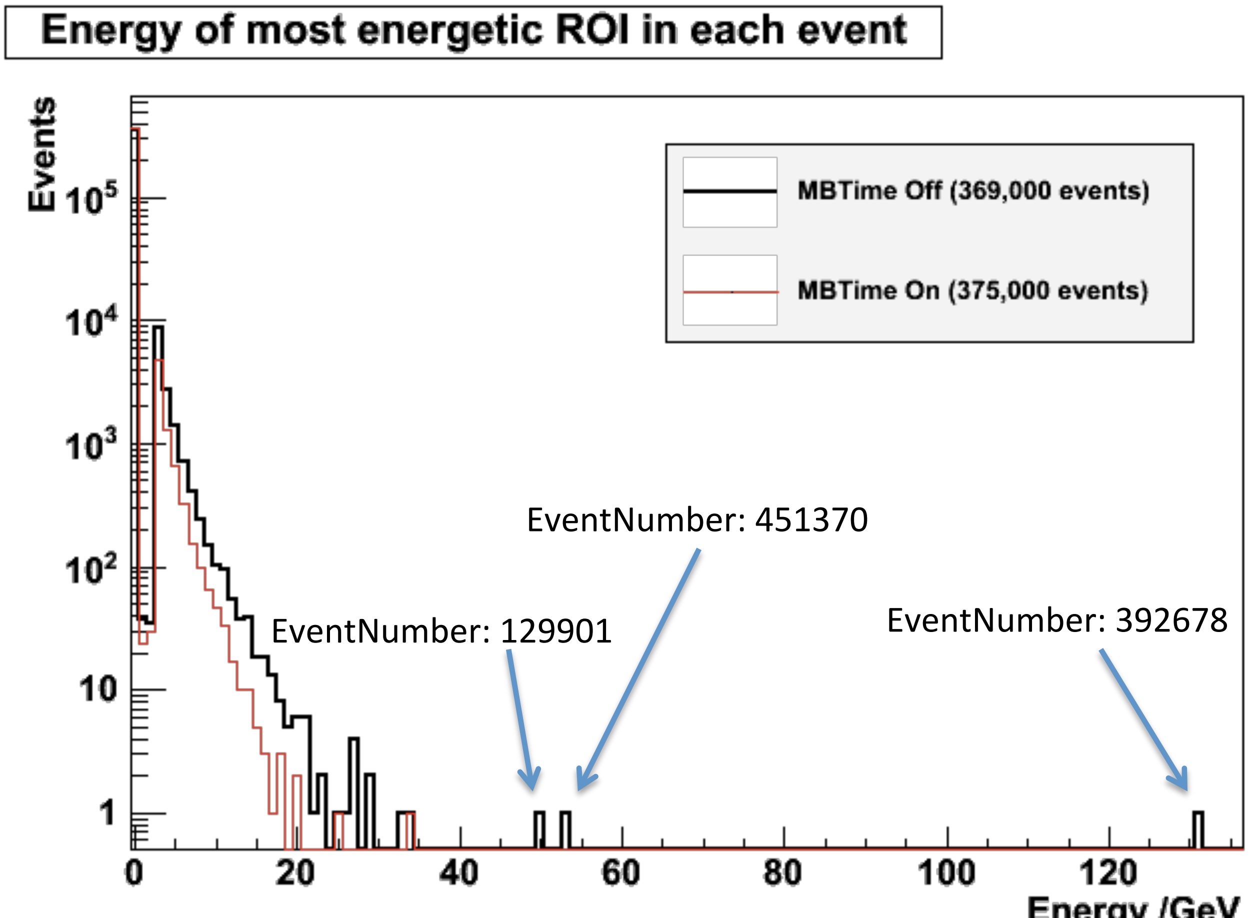
- Produced sample with MBTime On and MBTime Off for the mc10_7TeV sample:
  - Mc10_7TeV.105001.pythia_minbias.merge.HITS.e577_s964_s952/
- Passed the events individually through the "pileup" simulation
  - Signal was neutrino events, minbias was actually the "cavern", but simulated just central bunch crossing, with cavern collisions = 1 and readdownscale=1



EventNumbers are coming from minbias sample

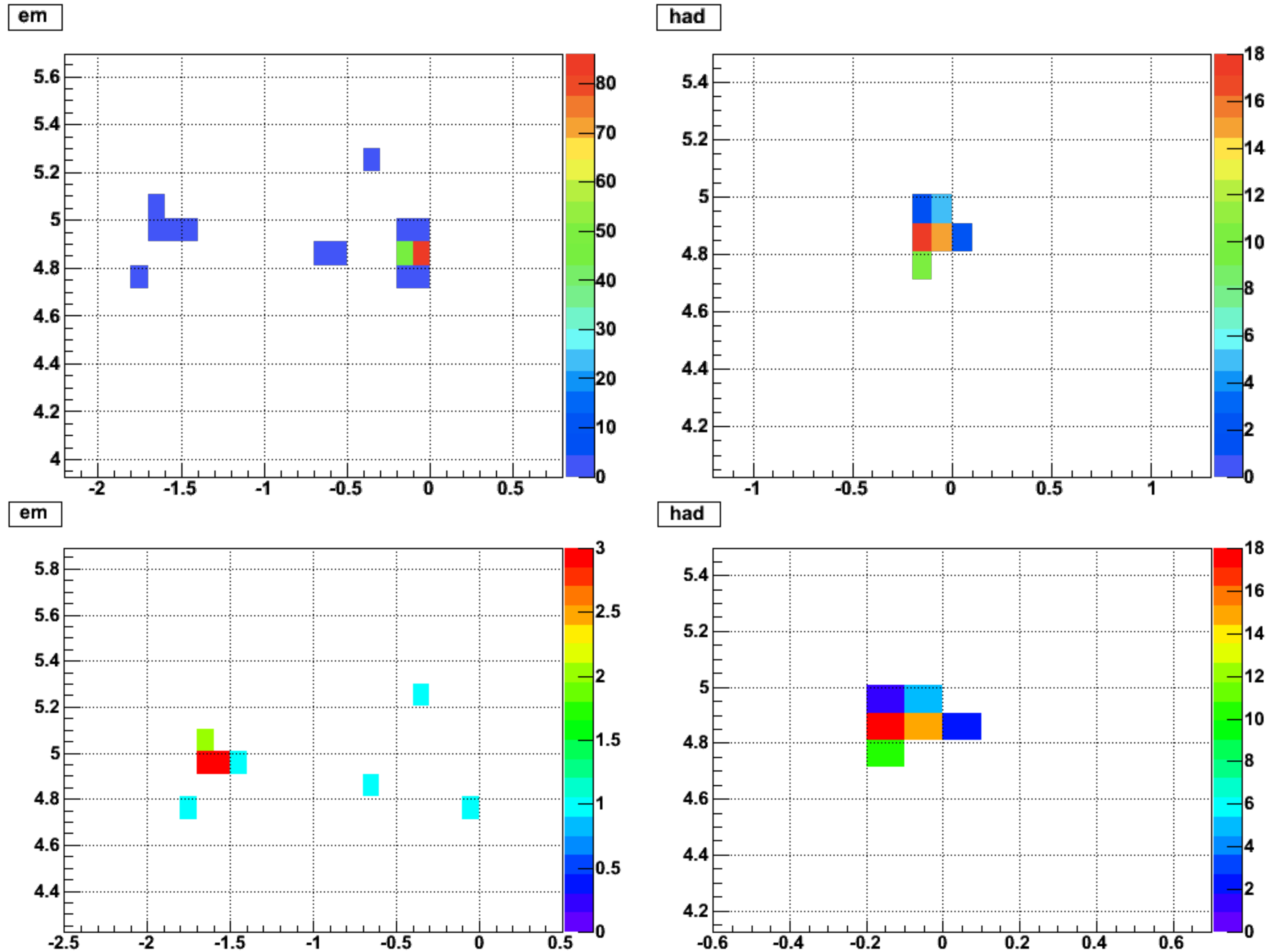
HitMaps

- Found the three labeled events in both datasets, look at the hitmaps

<u>EventNumber: 392678</u>

MBTime Off

MBTime On



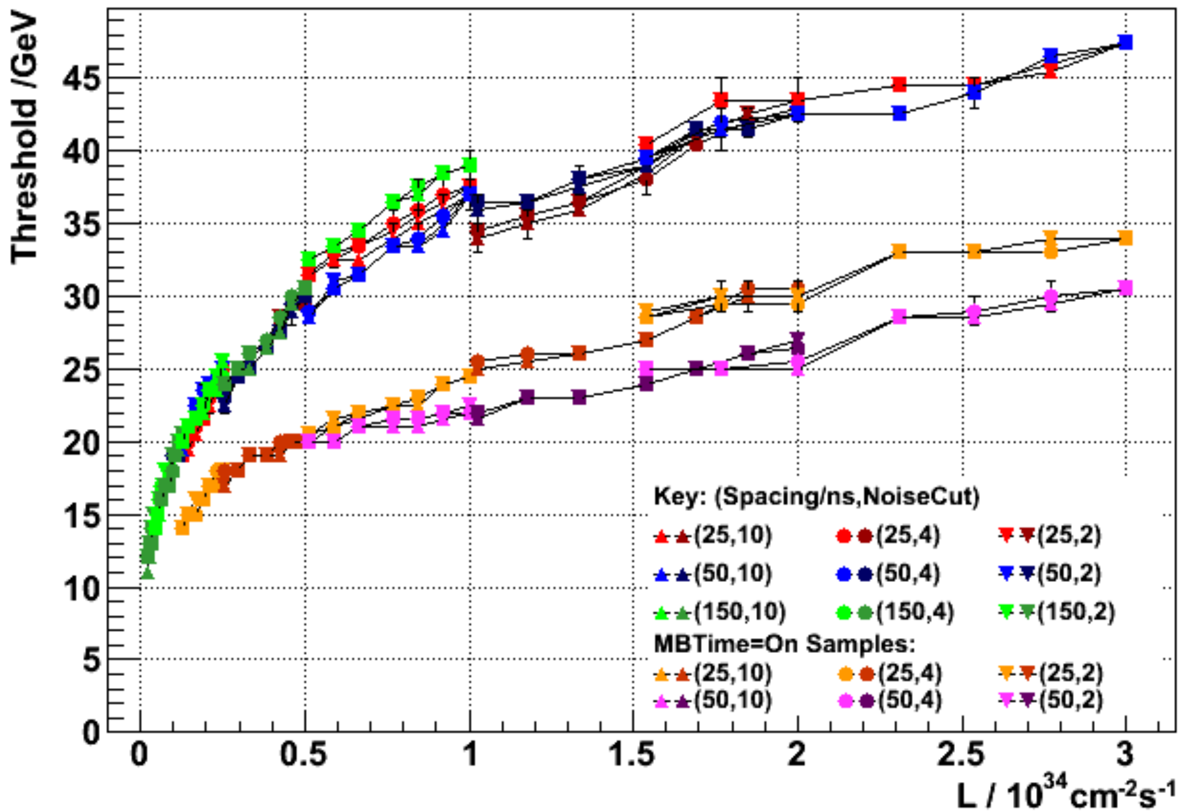
Summary of MBTime investigation

- "Disappearing" energy would not be too much of a problem as long as it **ALL** reappears in **one** of the other bunch crossings
  - As long as this was a "filled" bunch crossing that will be given a chance to trigger
- When only some of the energy disappears, we've spread the ROI around, and this can significantly change the shape and scale of the rate vs threshold plot for the sample

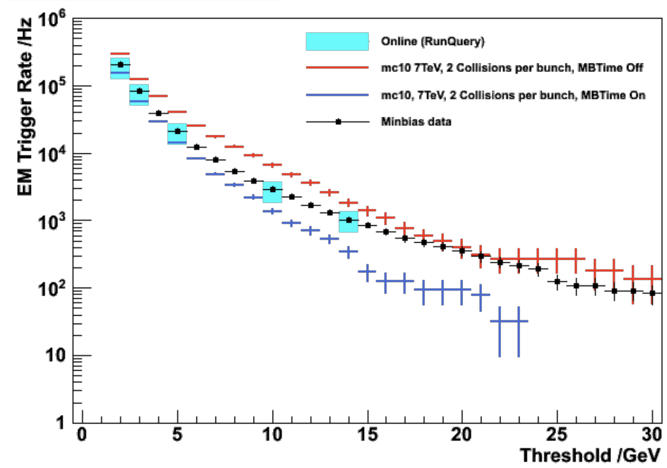
- I am wondering if the deposits in the tilecal are significant here?
  - The biggest energy difference was for the biggest tilecal deposit?
- Hadronic interactions leading to delayed hits in the LAr?
  - Investigations are ongoing, and in communication with LAr simulation expert

EM Trigger

EM Threshold Vs Lumi for 20kHz rate



Run 167776, 1.6 < ⟨μ⟩ < 3.3



EM Rate Vs Threshold (25ns bunch structure)

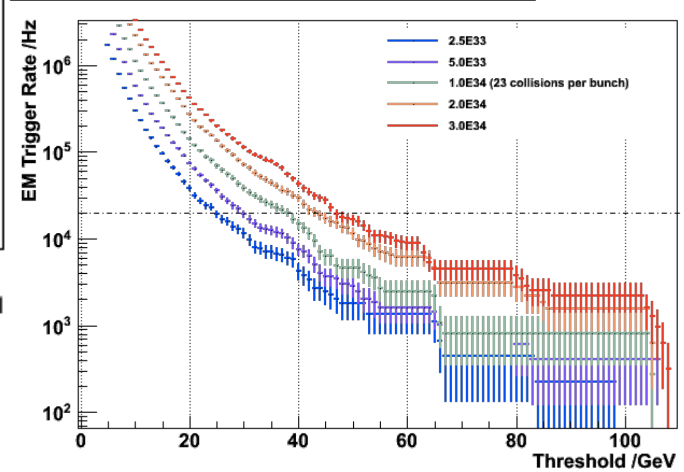


Table of approximate thresholds (in GeV) for 20kHz

L /10^{34} cm^{-2}s^{-1}	MBTime On	MBTime Off
0.5	20	30
1.0	20-25	35-40
3.0	30-35	45-50

Isolated EM Trigger

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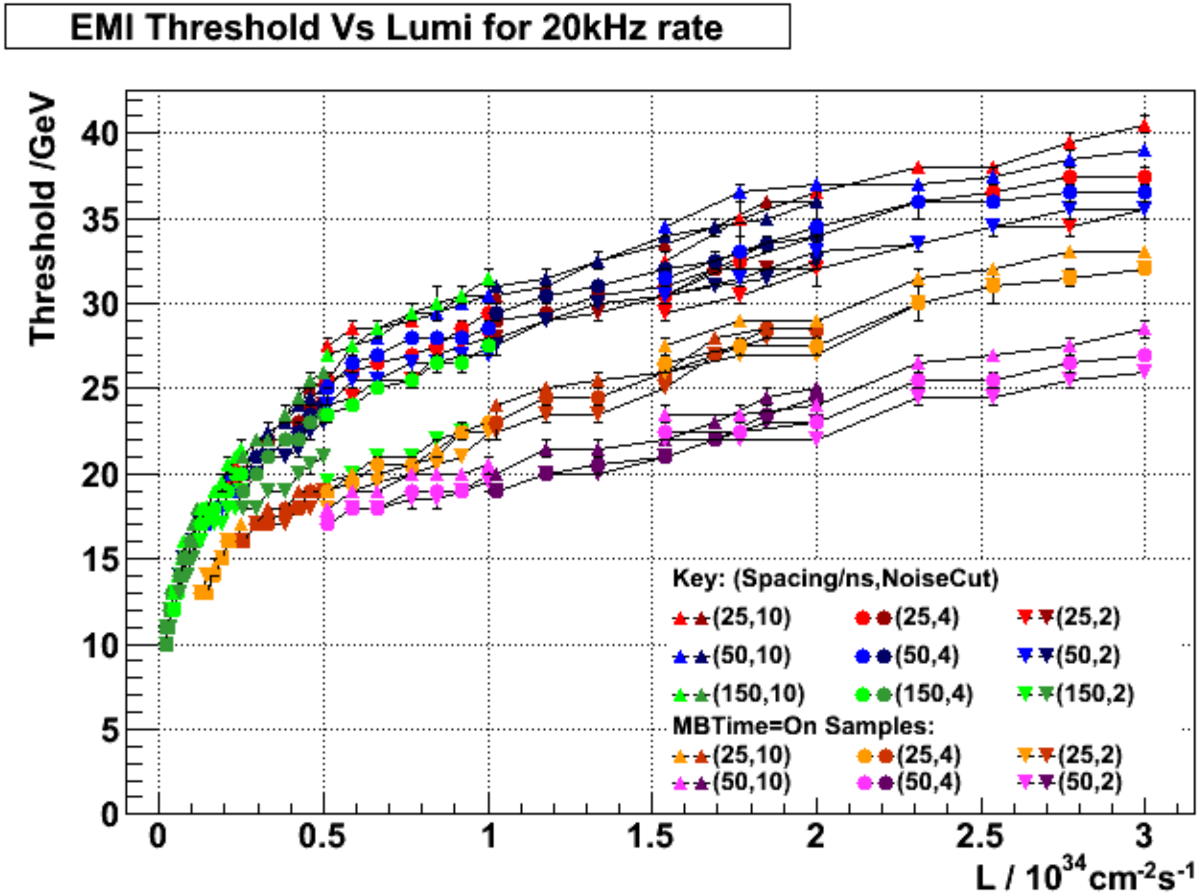

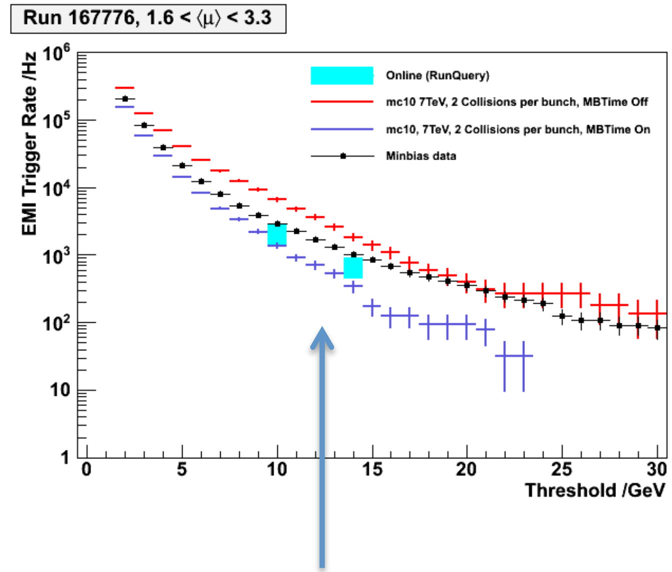

Data-vs-mc used slightly too high isolation cut, hence higher rates than Online – mentally shift the histograms down a bit

Table of approximate thresholds (in GeV) for 20kHz

$L / 10^{34}$ $cm^{-2}s^{-1}$	MBTime On	MBTime Off
0.5	17-20	23-28
1.0	19-25	26-31
3.0	25-33	35-40

TAU Trigger

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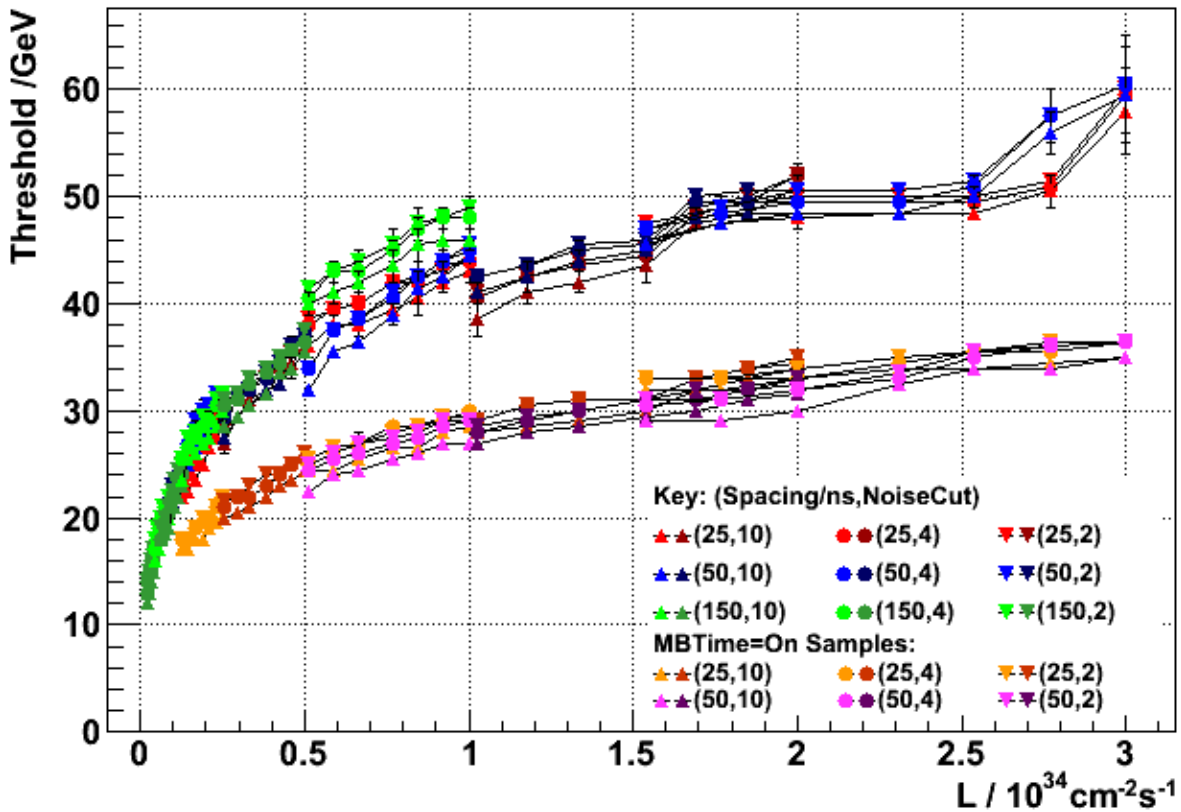
TAU Threshold Vs Lumi for 20kHz rate



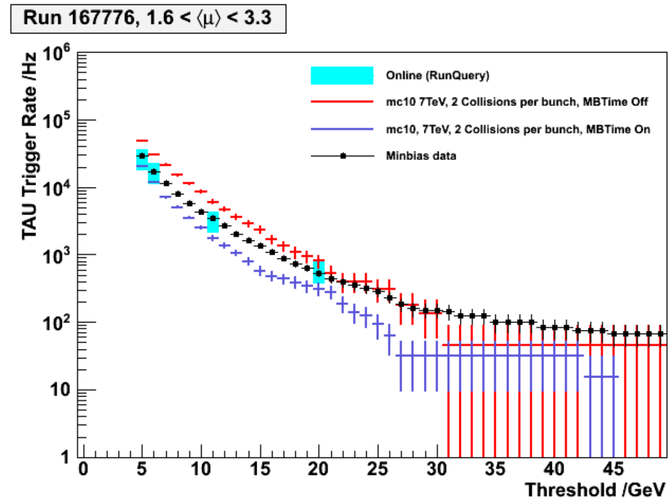


Table of approximate thresholds (in GeV) for 20kHz

L /10^{34} cm^{-2}s^{-1}	MBTime On	MBTime Off
0.5	23-27	35-40
1.0	25-30	40-45
3.0	33-37	55-65

Isolated TAU Trigger

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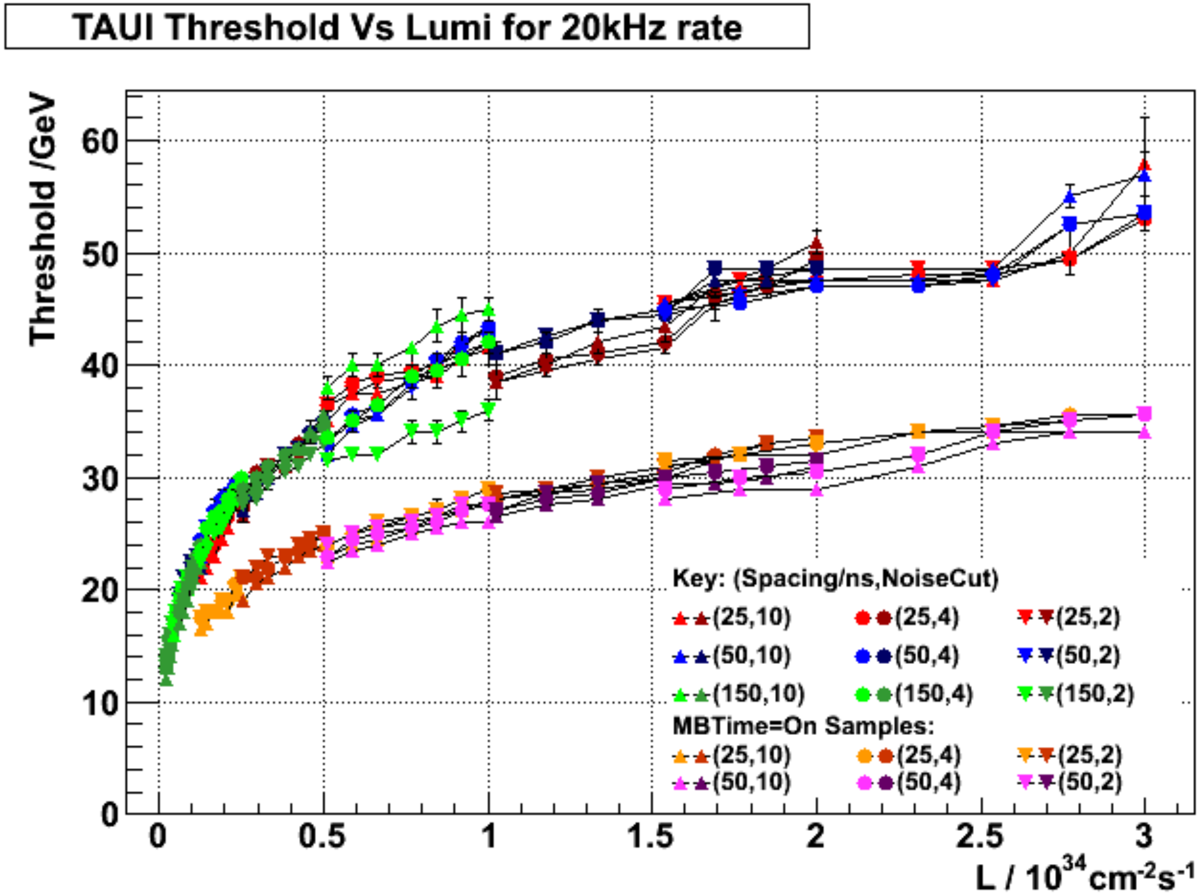

Hadronic isolation only starts to provide improvements at highest luminosities (3E34)

Table of approximate thresholds (in GeV) for 20kHz

L /10^{34} cm^{-2}s^{-1}	MBTime On	MBTime Off
0.5	23-27	35-40
1.0	25-30	40-45
3.0	33-37	55-60

JET4 Trigger

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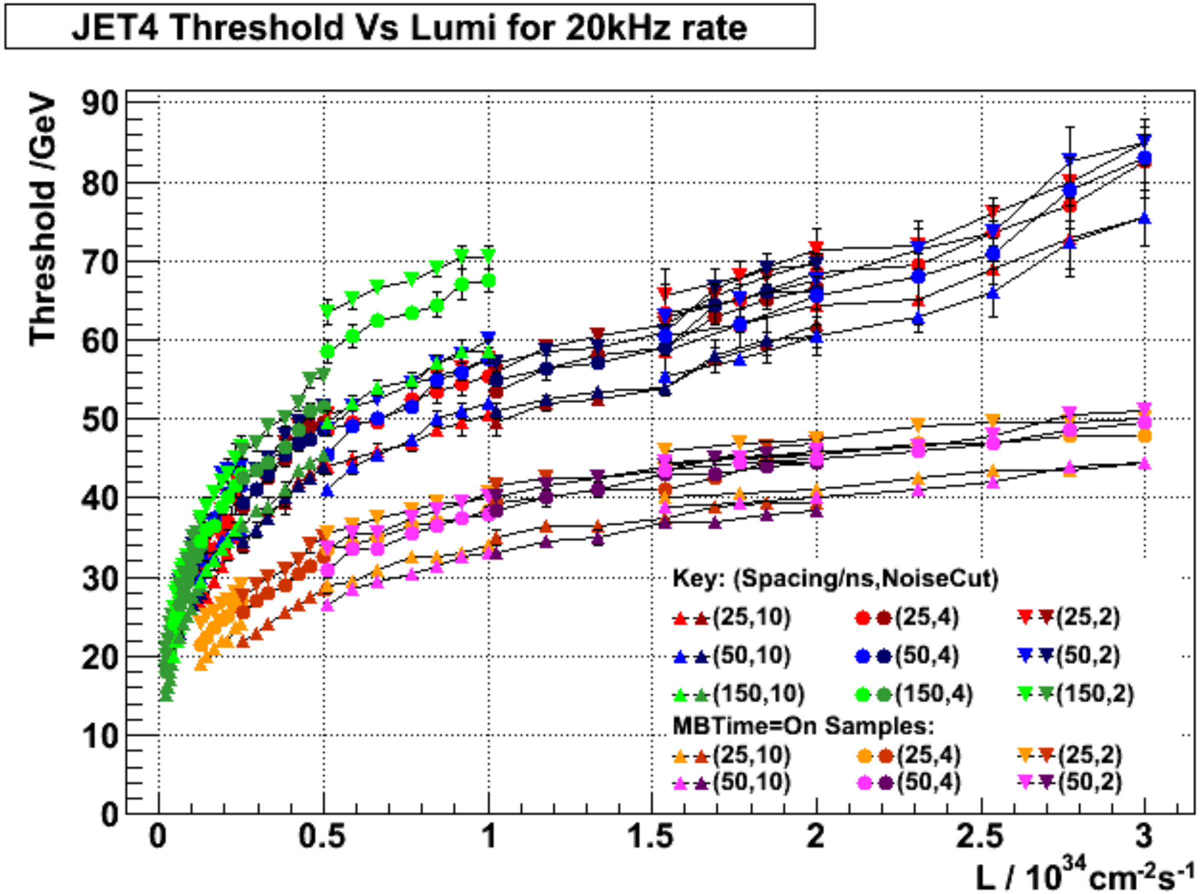

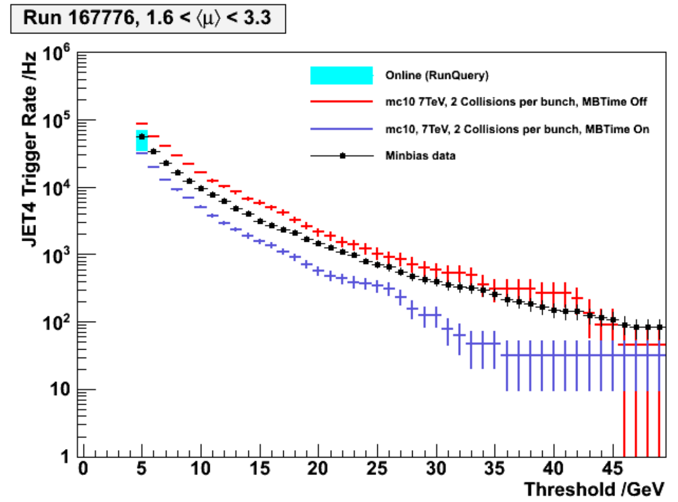

Table of approximate thresholds (in GeV) for 20kHz

$L\ /10^{34}\ cm^{-2}s^{-1}$	MBTime On	MBTime Off
0.5	25-35	40-50
1.0	30-40	50-60
3.0	40-50	75-85

JET8 Trigger

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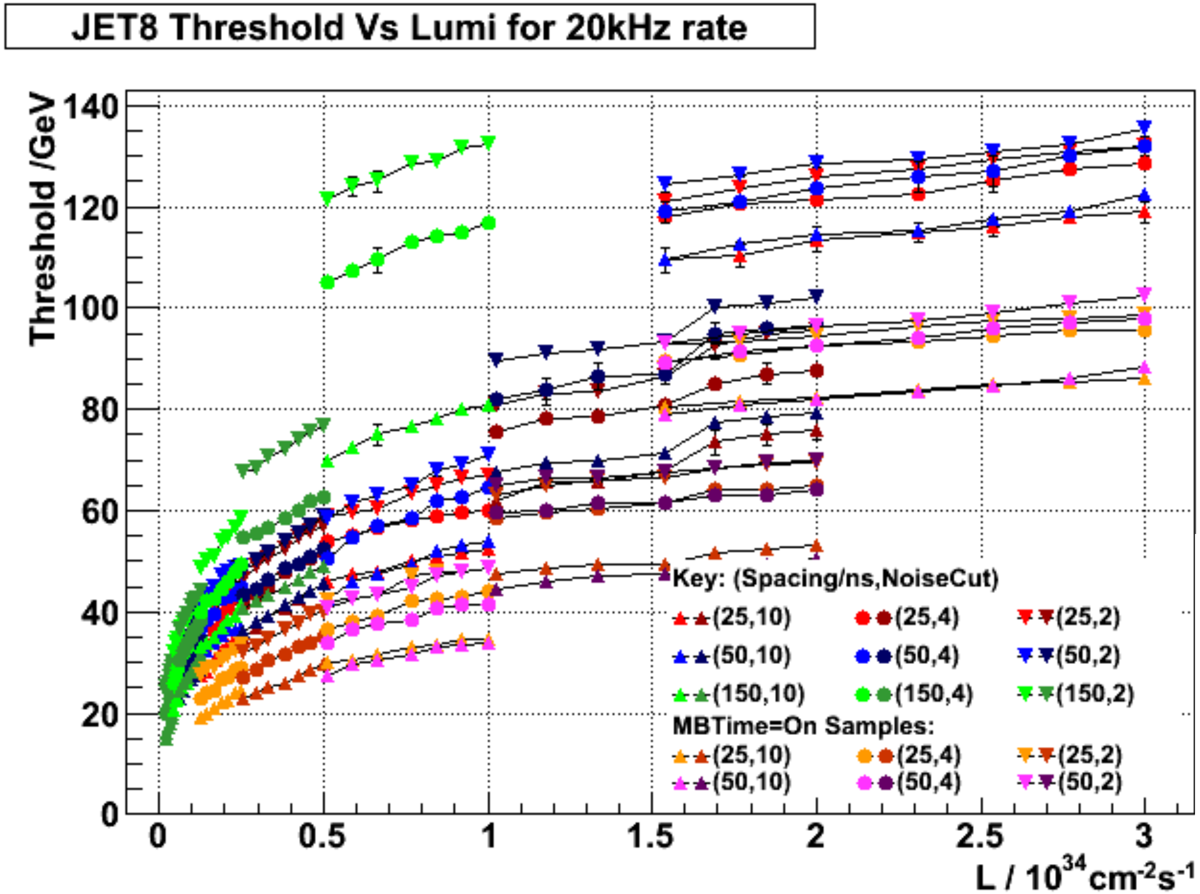

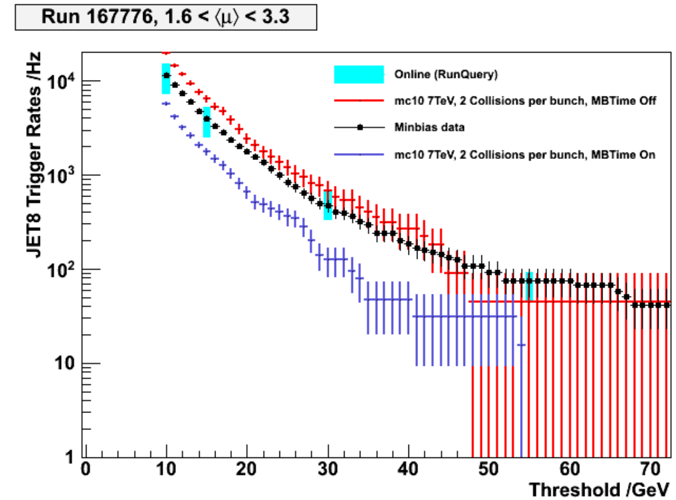

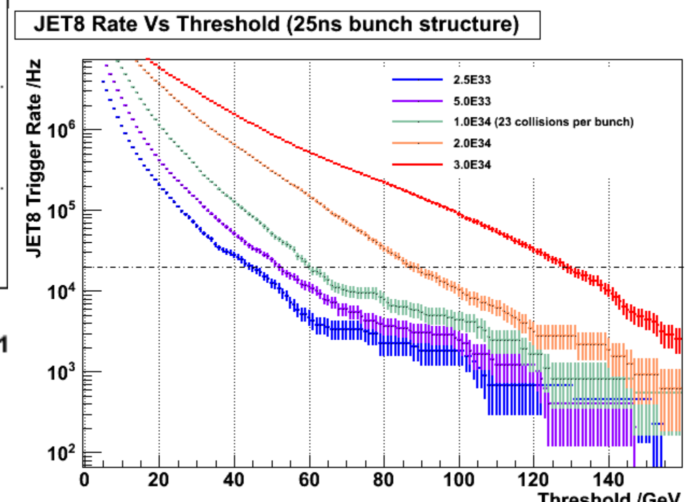

- Samples no longer “join up”
  - Rate vs Threshold plot is changing shape
  - Rate at fixed threshold no longer scales linearly with luminosity at these high thresholds
- These thresholds have entered the “pileup” regime
  - Significant production of “fake” ROI passing these thresholds

JET8 Trigger – simplified (just end points of samples)

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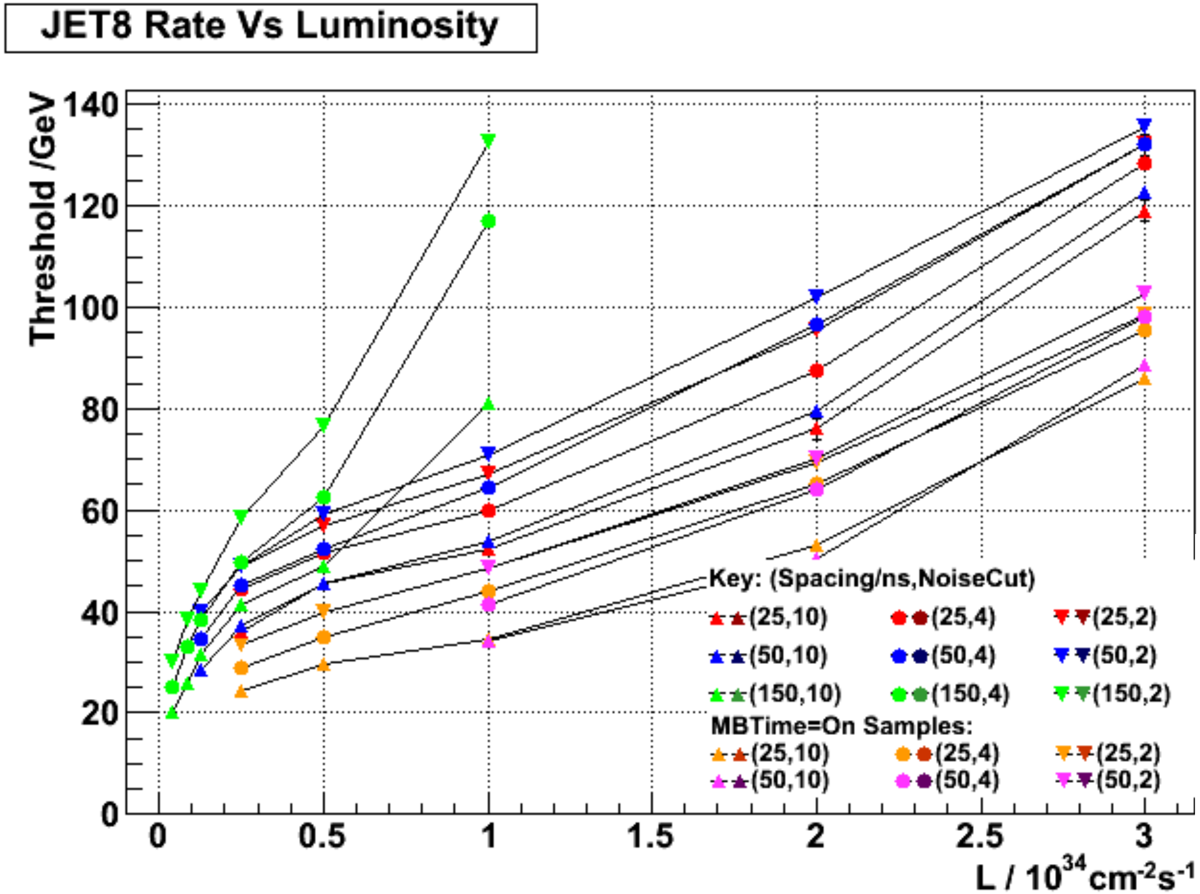
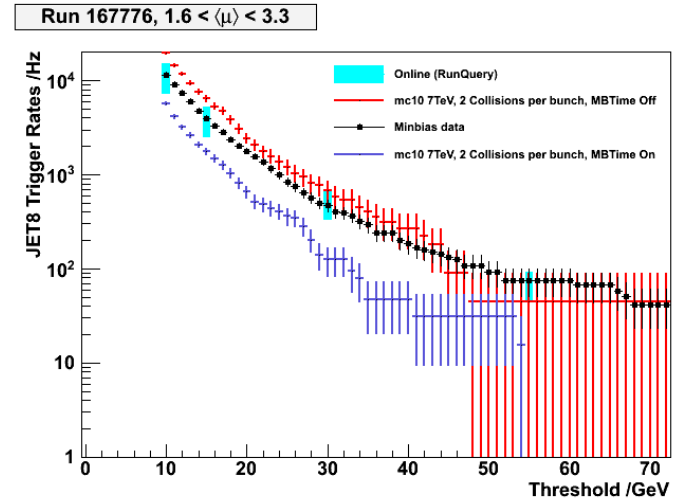




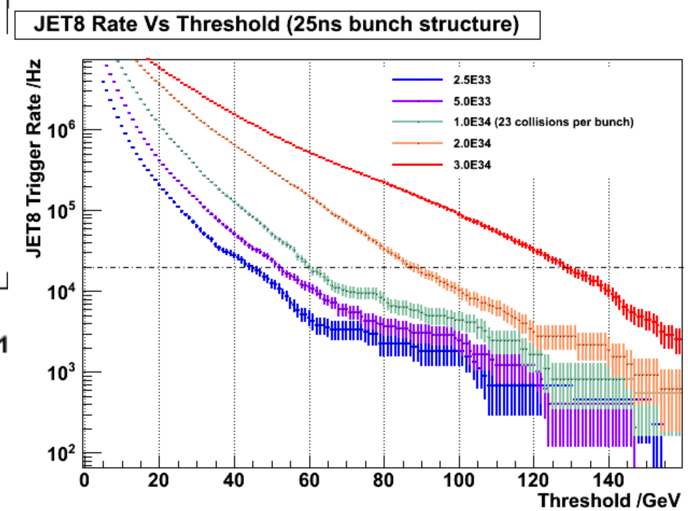
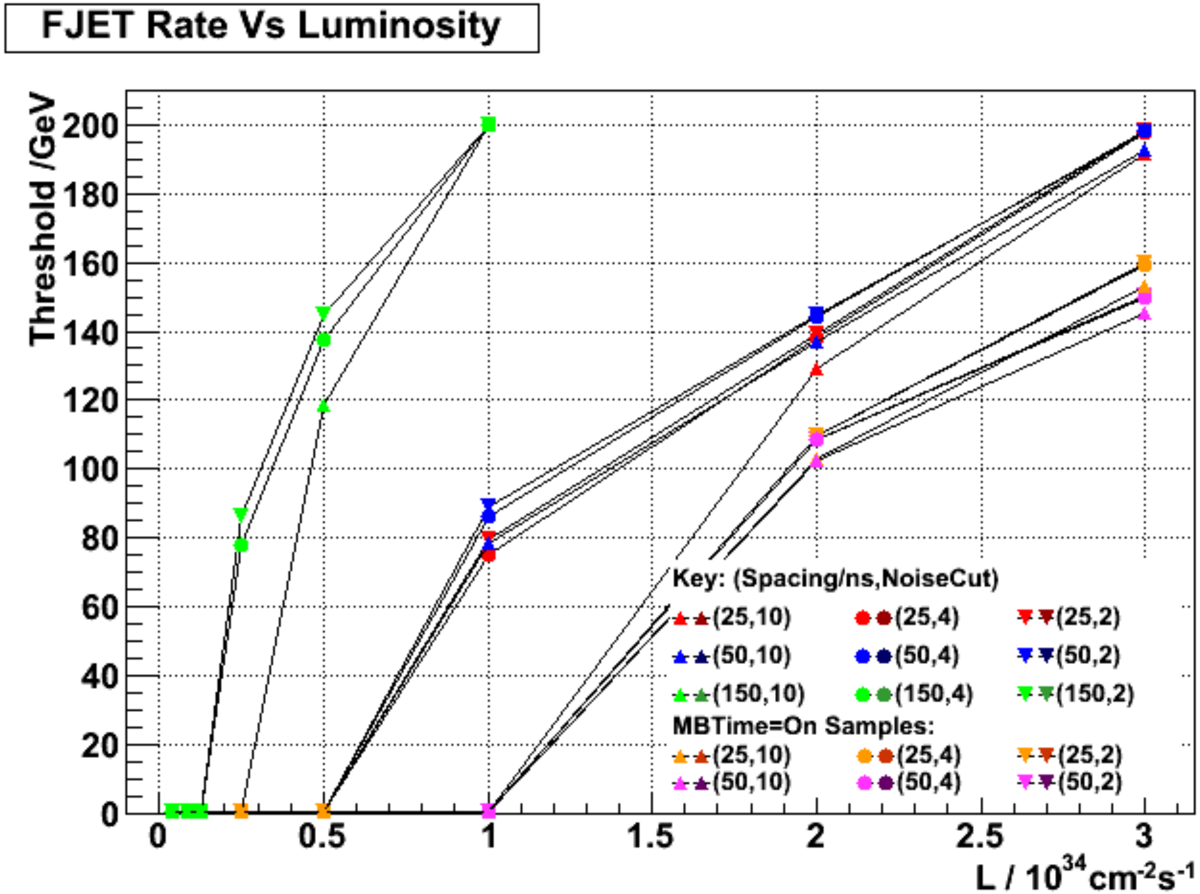


Table of approximate thresholds (in GeV) for 20kHz

L /10^{34} cm^{-2}s^{-1}	MBTime On	MBTime Off
0.5	25-40	45-60
1.0	30-50	50-70
3.0	85-100	120-140

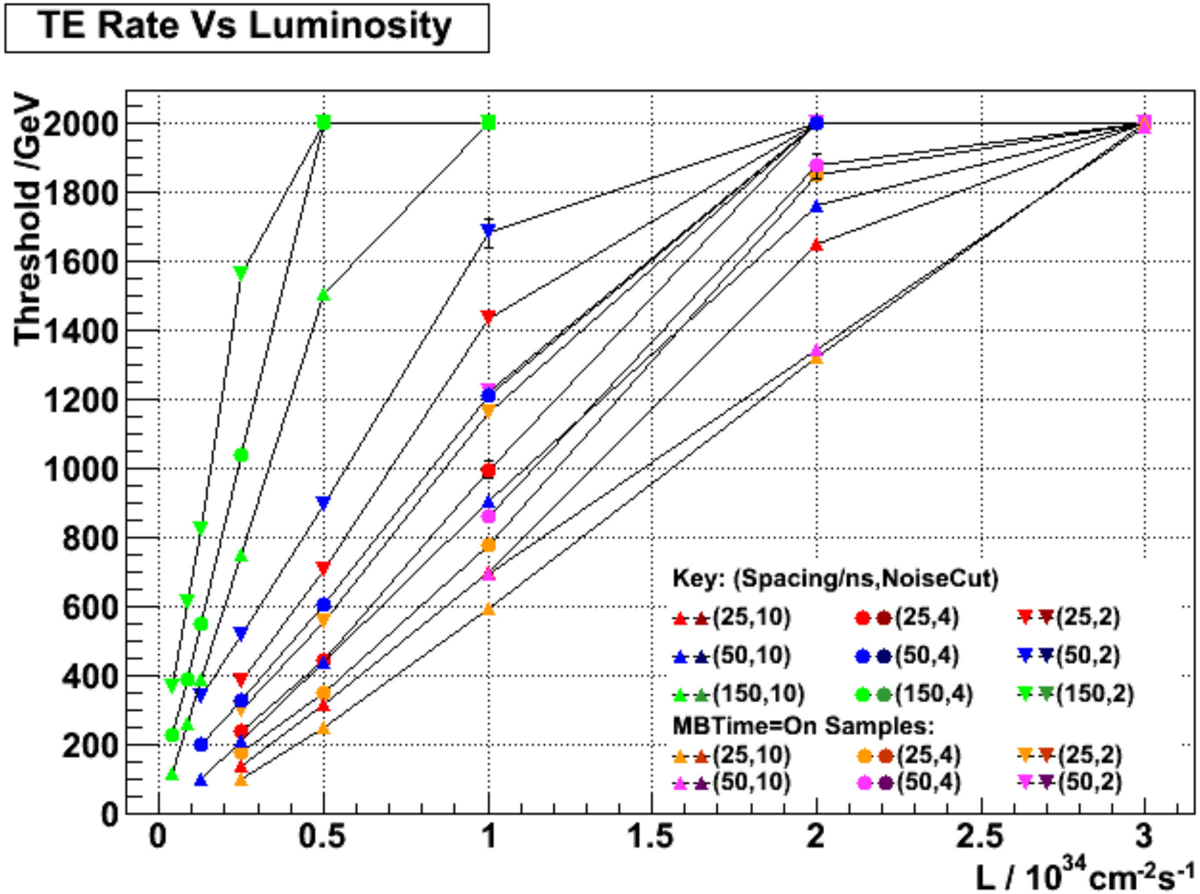
Forward/Backward Jets Trigger



Lowest luminosity values unavailable due to lowest Forward/backward jet trigger in menu being a 70GeV threshold

Table of approximate thresholds (in GeV) for 20kHz

$L / 10^{34}\ cm^{-2}s^{-1}$	MBTime On	MBTime Off
0.5	<70	<70
1.0	<70	70-90
3.0	140-160	190-200



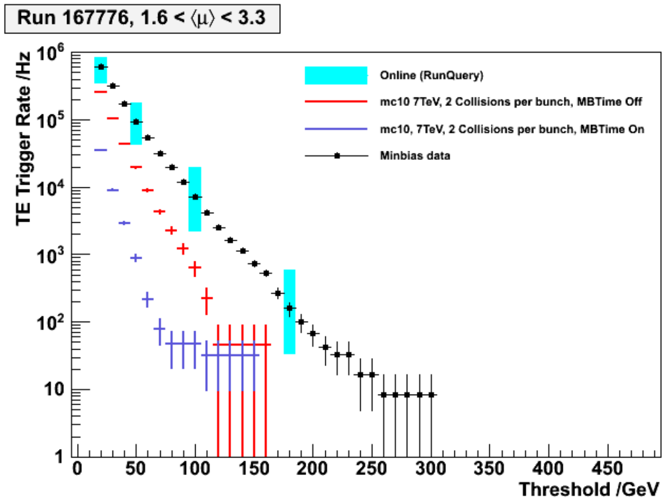
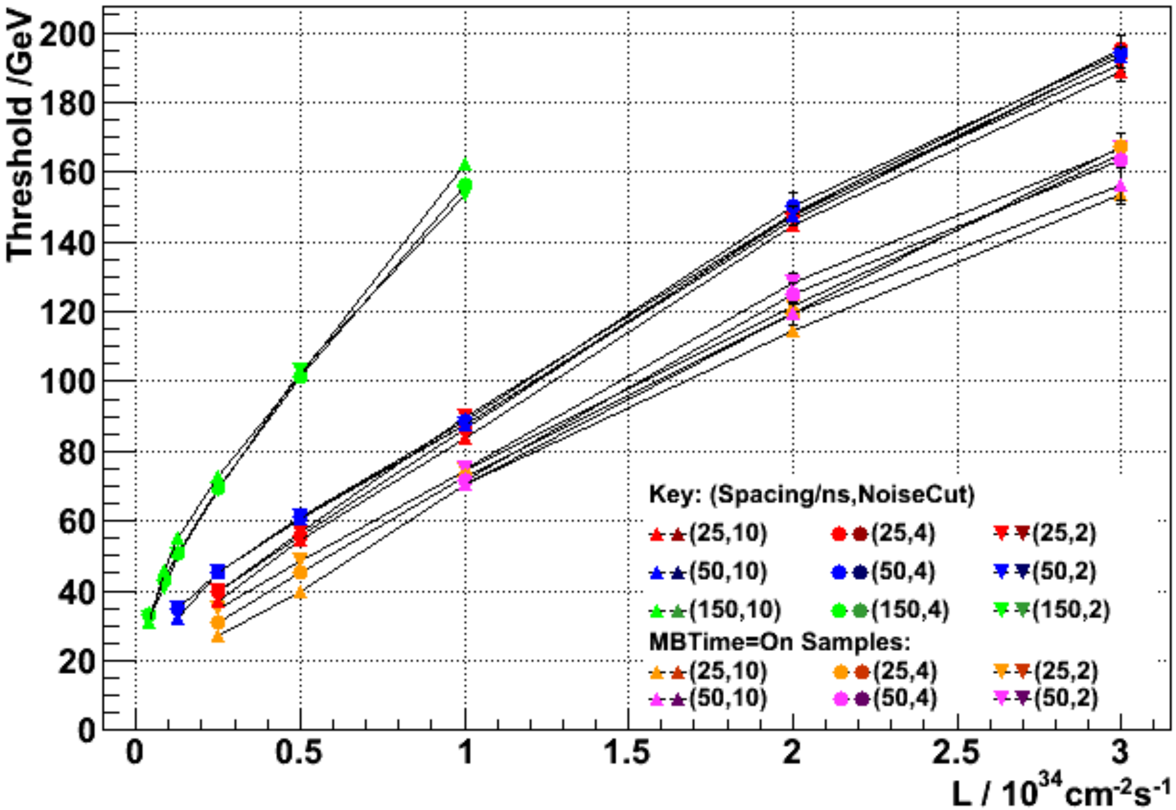


Table of approximate thresholds (in GeV) for 20kHz

L $/10^{34}$ cm^{-2}s^{-1}	MBTime On	MBTime Off
0.5	200-600	300-900
1.0	600-1200	900-1700
3.0	>2000	>2000

Missing Energy Trigger

XE Rate Vs Luminosity



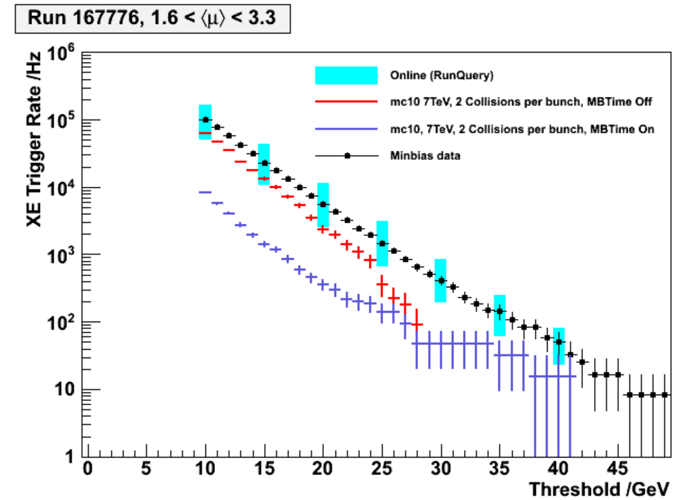


Table of approximate thresholds (in GeV) for 20kHz

L /10^{34} cm^{-2}s^{-1}	MBTime On	MBTime Off
0.5	40-50	50-60
1.0	70-80	80-90
3.0	150-170	185-200

A quick look at Efficiency Studies

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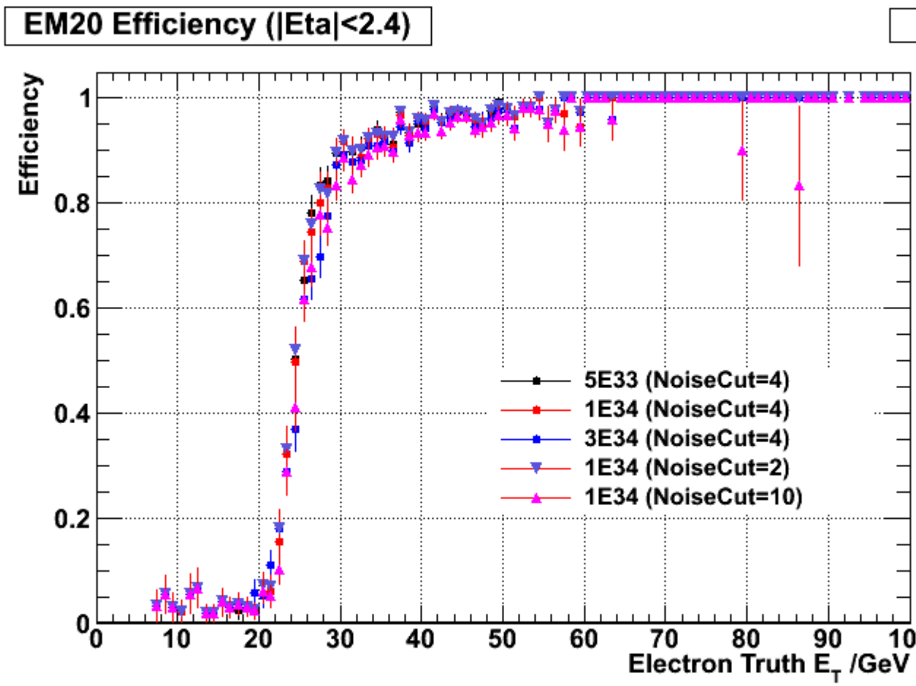
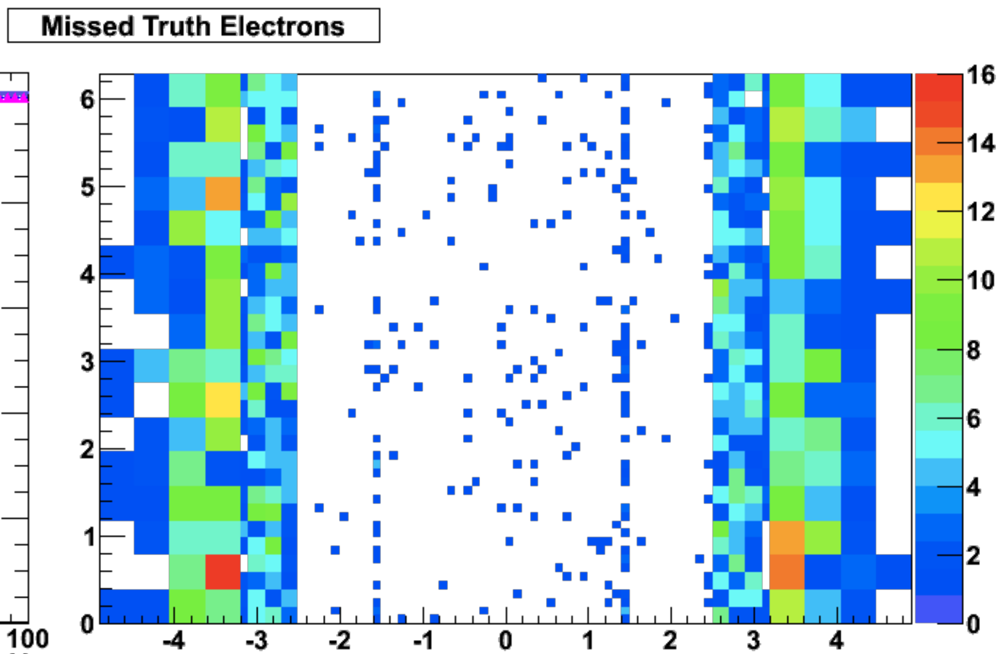
- Delta R matching ROI to Truth Electrons
  - |Eta| < 2.4
  - ΔR < 0.15
- Using a sample of 7TeV Z->ee events (just needed a sample of truth electrons)
  - mc10_7TeV.106046.PythiaZee_no_filter.simul.HITS.e574_s1023/





- Efficiency of EM20 trigger relatively unaffected by increasing luminosity and noise cuts. Missed electrons are going into the overlap region.
- A similar analysis is underway with jets (formed from Truth AntiKt4)

Summary

- ROI understood to belong to two regions of the energy spectrum
  - The "independent" regime where linear behaviour with respect to luminosity observed
    - energies are high enough that virtually all the ROIs are "real" ROIs coming from the underlying minbias events
    - It is rare to produce significant "fake" ROIs are this energy, from overlap of lower energy ROIs
  - The "pileup" regime, where non linear behaviour with respect to luminosity is observed
    - Energy is low enough that fake ROIs are present
    - ROIs are common enough in pileup that they start to overlap to change energies
- In the independent regime, the shape and scale of the rate-vs-threshold plot will govern the evolution of threshold required for fixed rate as luminosity is increased

- Data vs MC shows we are unable still to reproduce online trigger rates accurately
  - Investigating the MBTime feature of LAr
  - Would be good to get the pulse shapes right too
- The 2011 data should help test the higher collision rate MC

Summary (2)

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- I think we have our best picture yet of what will happen to the existing trigger at high luminosity. Table below shows range (in limited precision) of thresholds covered by the variety of noise cuts and 25ns and 50ns bunch structures.
  - Have just estimated these from plots – please see relevant slide for actual numbers
- **Keep in mind that the luminosities given are probably upper estimates**

Approximate thresholds required to give Trigger Rate of 20kHz for each Trigger Type

Trigger Type	$0.5 * 10^{34} cm^{-2} s^{-1}$	$1.0 * 10^{34} cm^{-2} s^{-1}$	$3.0 * 10^{34} cm^{-2} s^{-1}$
EM	20-30	20-40	30-50
EMI	20-30	20-30	25-45
TAU	20-40	25-45	35-65
TAUI	20-40	25-45	35-60
JET4	25-50	30-60	40-85
JET8	25-60	30-70	85-140
FJET	<70	<90	140-200
TE	200-900	600-1700	>2000
XE	40-60	70-90	150-200

BACKUP SLIDES

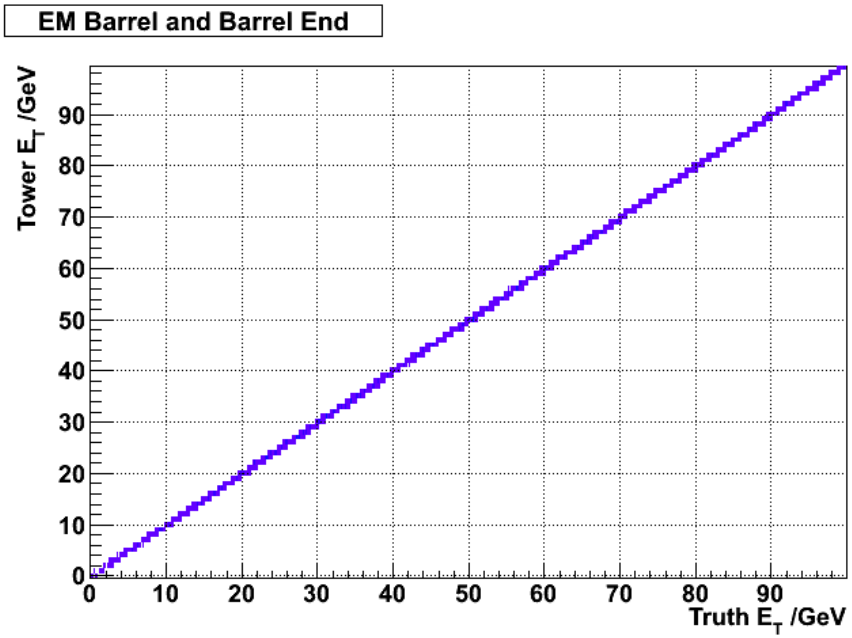
Truth Energy

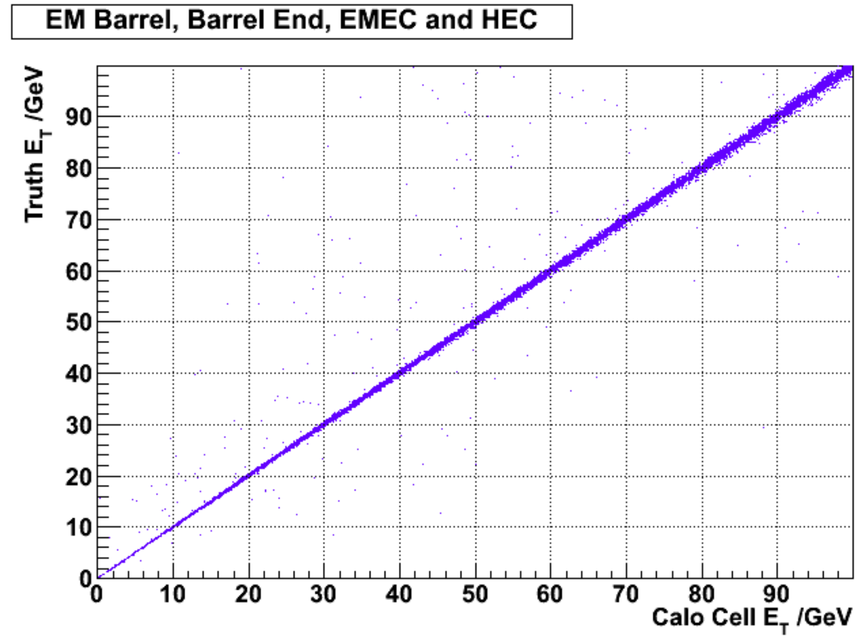
- A quantity extracted from within the L1Calo simulation that "represents" the energy deposited in the trigger tower during the central bunch crossing
- This is **not** the same as the energy measured by summing up the Calo Cell energies of the cells associated to the trigger tower…
- The truth energy is the effective energy that the L1Calo simulation is told about, to use for scaling up normalized pulse shapes in order to simulate the detector response.
  - Can also be thought as an energy that depends on the receiver gains
- This study uses an auto-calibration of L1Calo FIR filters and LUT slopes, the truth energy equals the L1Calo preprocessor output under "ideal conditions" (see next few slides)

- Advantages:
  - Calo Energy is dependent on the calorimeter performance, which may change at high luminosity. Truth Energy is more consistent
  - Truth Energy not subject to same mis-calibration problems in fcal as calo cell energy is…

Truth Energy – EM Barrel

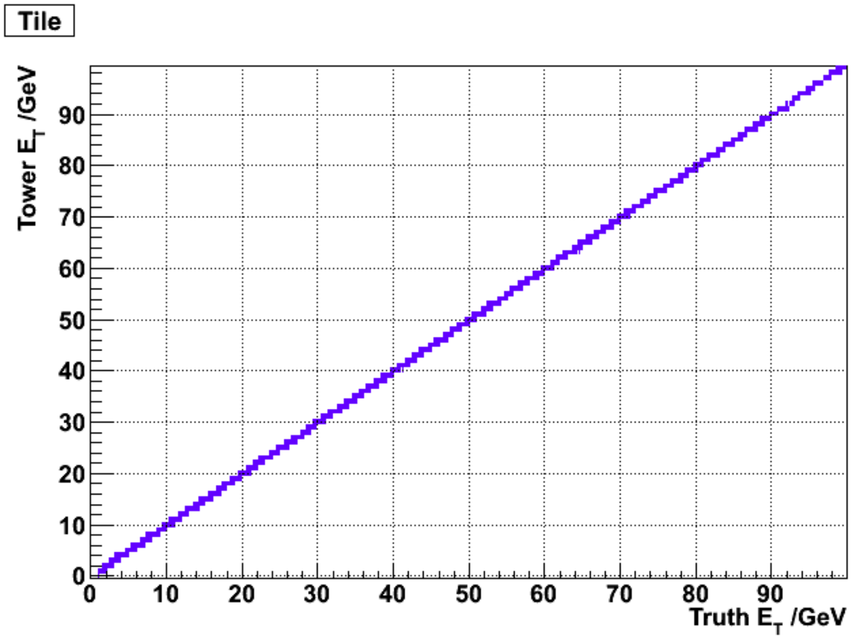
- Flooded simulation with perfectly timed-in hits in a custom "Calibration mode", with a simulation window of only one bunch crossing

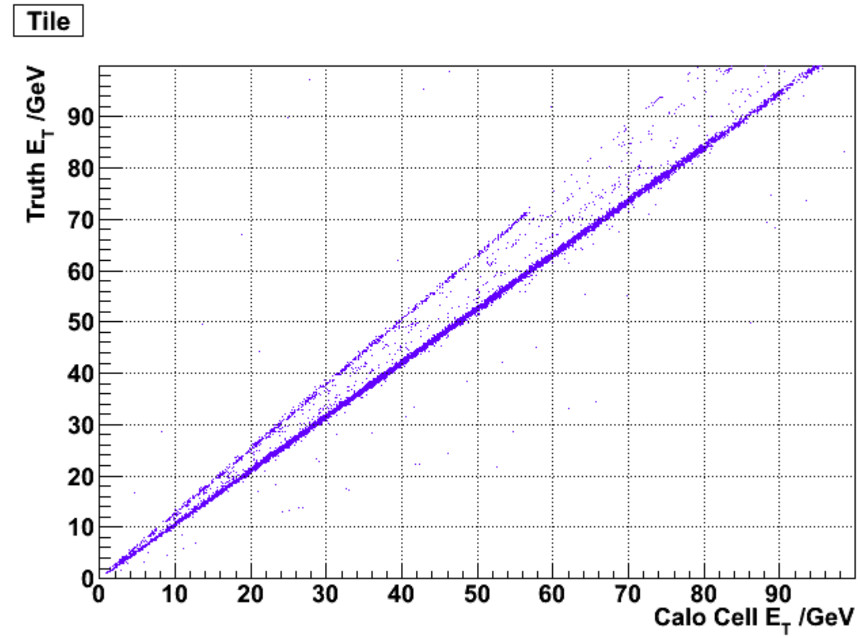




Truth Energy – Tile

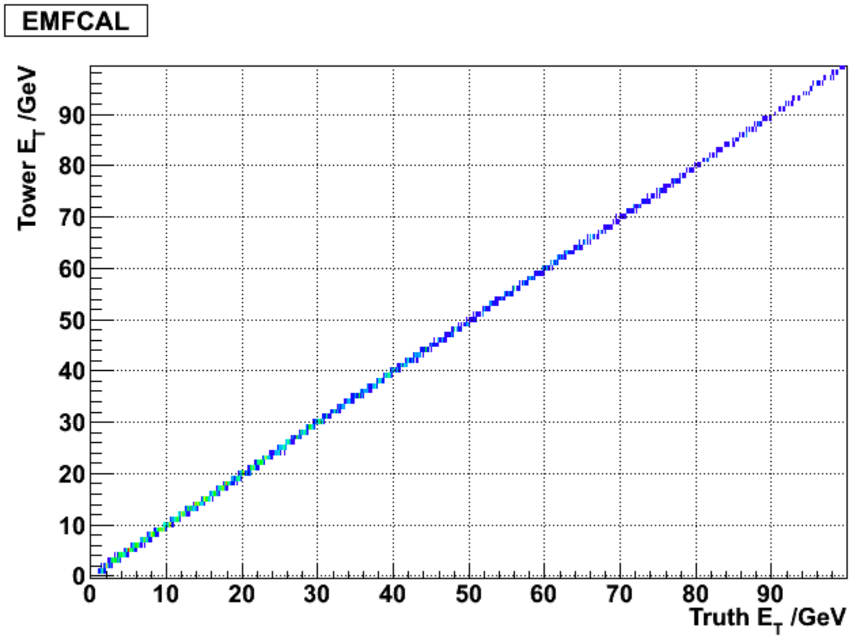
- Flooded simulation with perfectly timed-in hits in a custom "Calibration mode", with a simulation window of only one bunch crossing

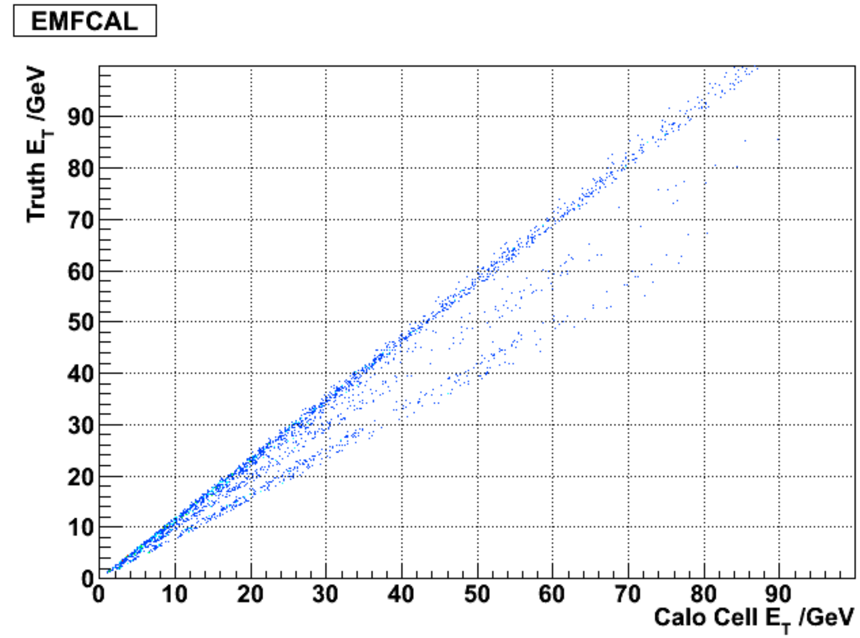




Truth Energy – EMFCAL

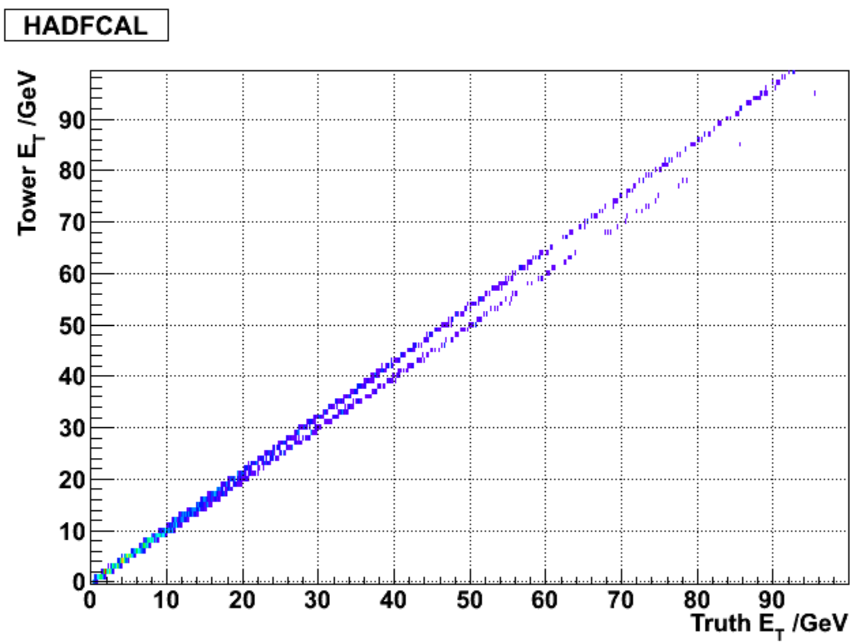
- Flooded simulation with perfectly timed-in hits in a custom “Calibration mode”, with a simulation window of only one bunch crossing

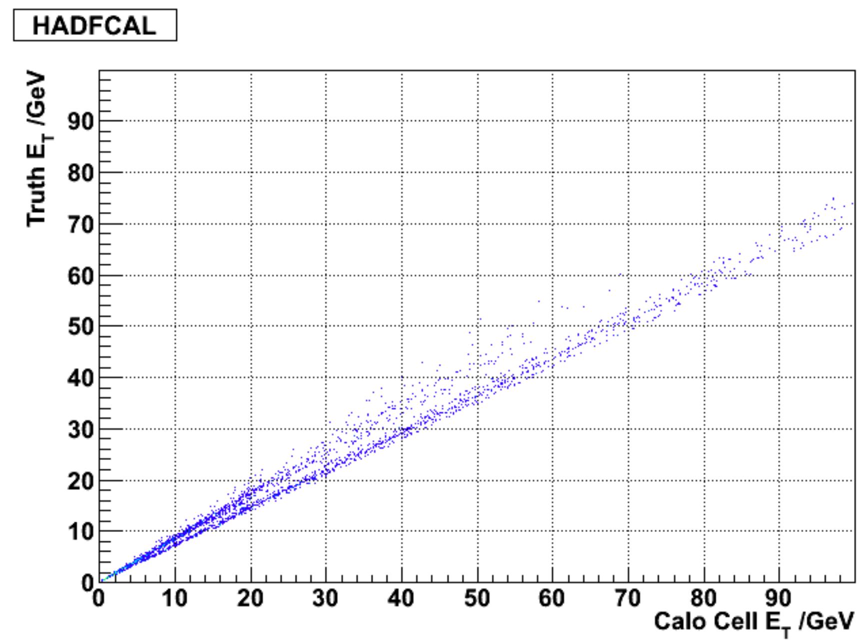




Truth Energy – HadFCAL

- Flooded simulation with perfectly timed-in hits in a custom "Calibration mode", with a simulation window of only one bunch crossing





- HadFCAL is only place where Truth Energy ≠ Tower Energy (in calibration mode)
  - Due to pulse shape simulation using two different pulses for FCAL2 and FCAL3, but L1Calo preprocessor auto-configuration uses only one of the pulses

Old comparison between MSU and Cambridge samples

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- The most significant disagreements appear after curves become unsmooth