Impact of CMS ECAL anomalous signals on jet reconstruction

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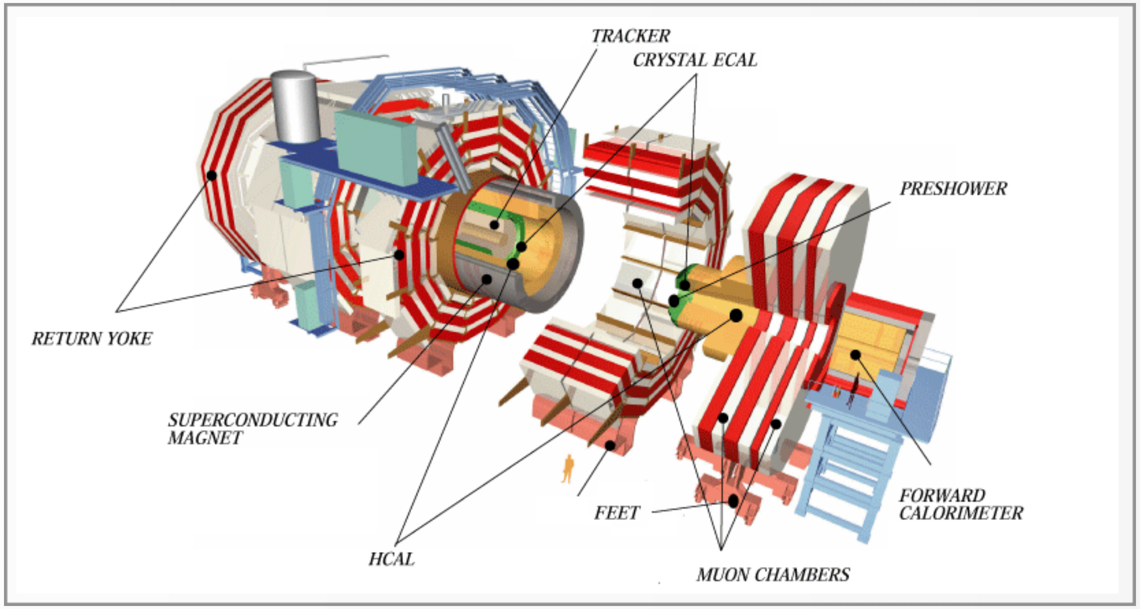
”The worthwhile problems are the ones you can really solve or help solve, the ones you can really contribute something to. ... No problem is too small or too trivial if we can really do something about it.”

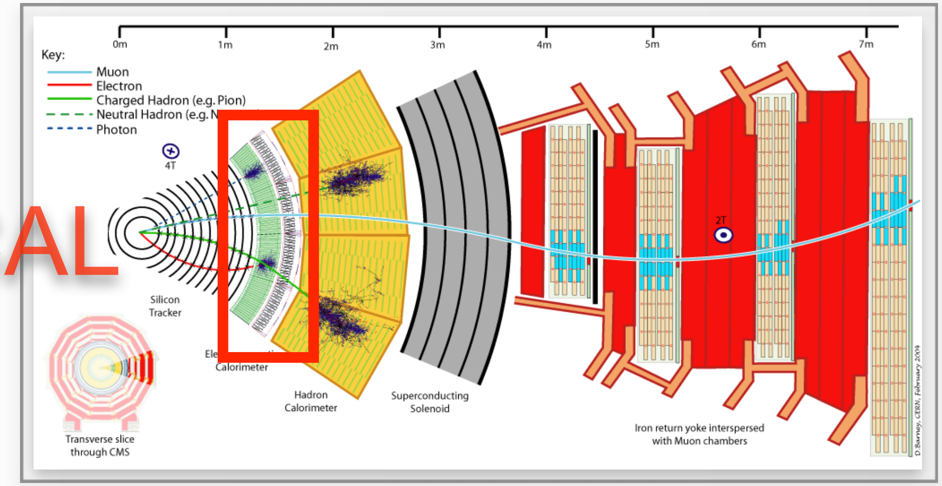
- R. P. Feynman

CMS - Compact Muon Solenoid

- Total weight
  - 12 500 tones
- Overall diameter
  - 15.0 m
- Overall length
  - 21.50 m
- Magnetic field
  - 4 Tesla

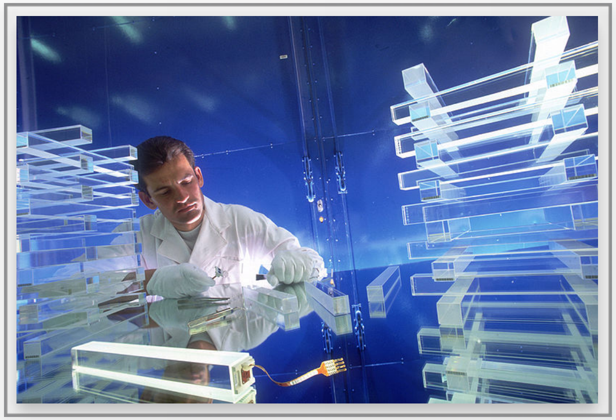


ECAL



CMS Electromagnetic Calorimeter (ECAL)

- Measures energies of electrons and photons.
- High accuracy.
- Ideal for stopping high energy particles.
- Made from crystals of lead tungstate ($PbWO_4$).
- Backed by silicon APD's
  - APD - Avalanche Photo Diode
  - Converts light to electricity very efficiently.
- Number of crystals in ECAL
  - Barrel: 61,200
  - Endcap: 7,324



CMS Trigger system

- The Level 1 (L1) trigger is a hardware trigger close to the detector, consisting of super fast electronics.
- The High Level Trigger (HLT) is a software trigger.
- The trigger system reduces the number of events from about 40 million per second (40 MHz) to ~ 100 per second.
- RAW data from CMS would be ~ 40 terabytes per second.
- After the trigger roughly 100 MB per second remain.

Overview

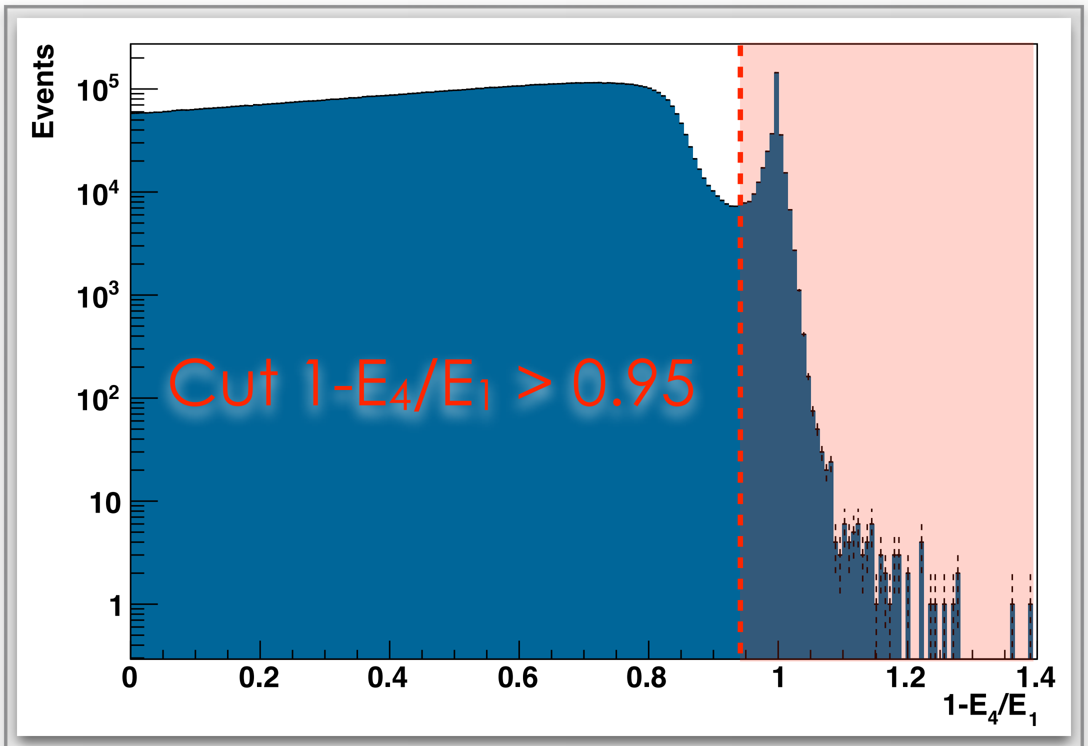
- *"Impact of CMS ECAL anomalous signals on jet reconstruction"*
    - **ECAL** - Electromagnetic Calorimeter
    - **Anomalous signals** - High energy deposits in ECAL Barrel region, "SPIKES".
    - **Jets** - Narrow cone of hadrons and other particles produced by the hadronization of a quark or a gluon.
    - **RecHit** - reconstructed hit in the detector.
- Anomalous signals are filtered
    - At trigger level (L1 and HLT).
    - In offline data reconstruction.
- In 2011
    - An additional filter algorithm will be implemented at trigger level.
- Goal of my project
    - Measure how many anomalous signals contribute to the jet reconstruction.
    - Determine the efficiency of the cleaning algorithm used in trigger electronics.

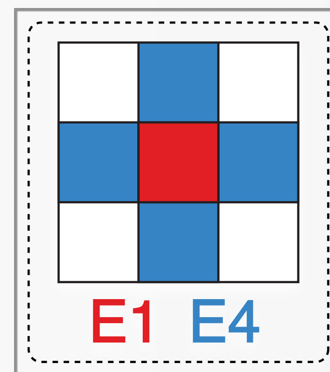
Spike phenomenology

- Isolated high energy deposits in ECAL Barrel (EB)
  - Occur at a rate proportional to the intensity of the proton beams.
  - Produced by ionization of the APD's by particles created in pp collisions.
  - Presents issues for *triggering* CMS at *high luminosity*.
  - Produce large *missing transverse energy* (MET), elimination improves the tails in MET distributions.
- Spike properties
  - Shower shape inconsistent with that expected from an average electromagnetic shower.
    - Cut on topology ("Swiss-cross" variable).
  - Reconstructed time distribution anomalous, appear as early signals.
    - Cut on timing.

Topological "Swiss-cross" variable

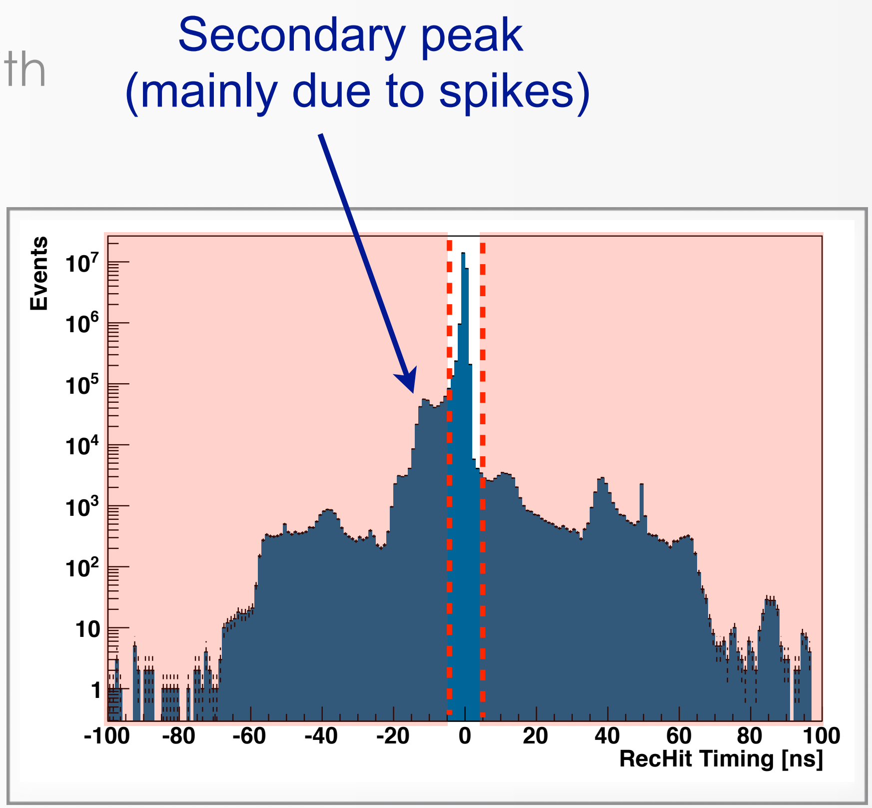
- Identify spikes where most energy is confined to a single crystal.
- Compare the energy in one crystal (E_1) to the sum of the four adjacent crystals (E_4) in η and ϕ.
- Swiss-cross variable defined as: $1\text{-}E_4/E_1$
- The figure shows this variable for jet trigger data with $\sqrt{s}$ = 7 TeV, for all RecHit p_T above 5 GeV.





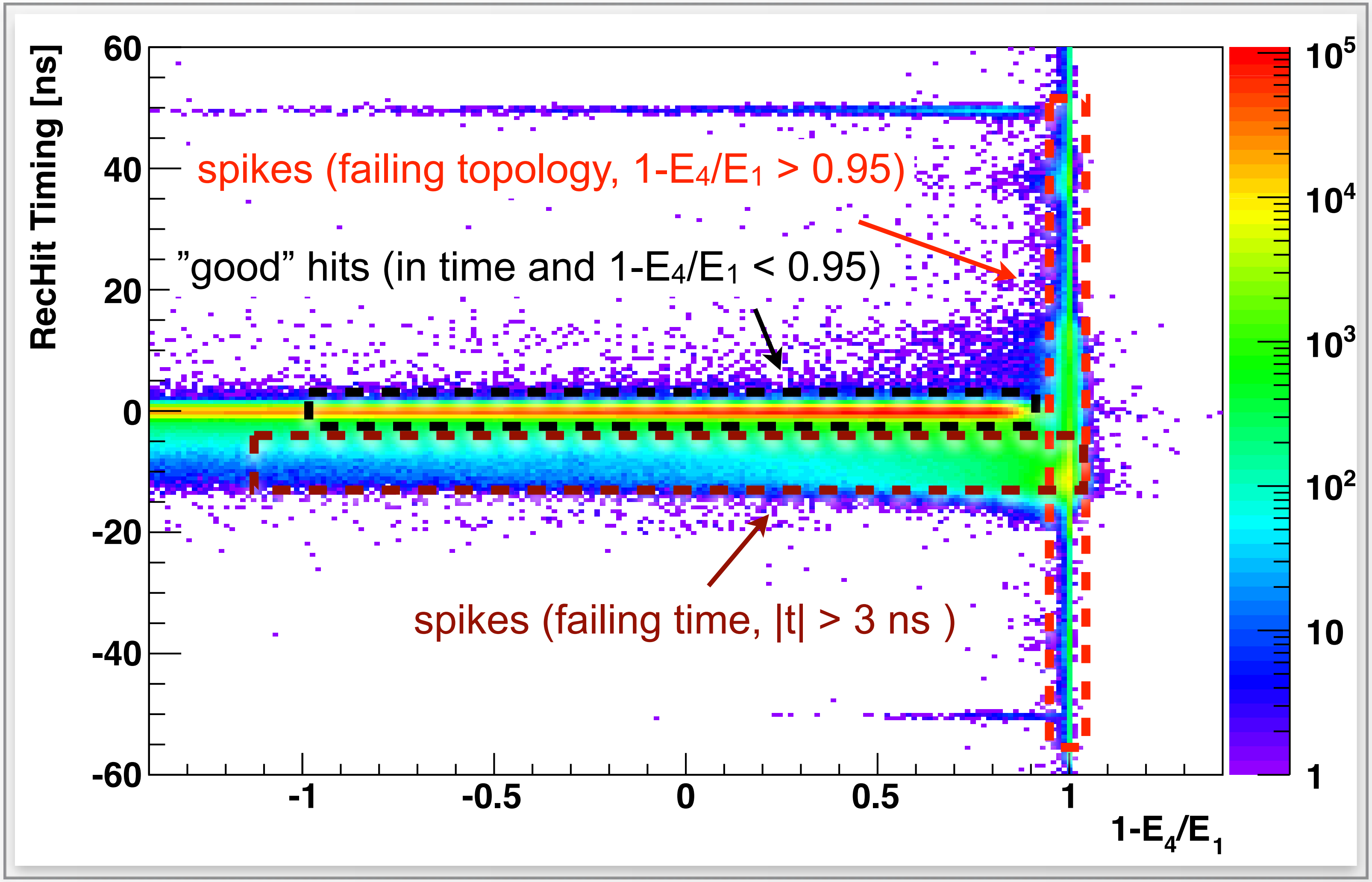
Timing variable

- The figure shows the distribution of RecHit timing for jet trigger data with √s = 7 TeV, for all RecHit p_T above 5 GeV.
- A relativistic particle produced at the interaction point will be reconstructed with an average time of zero.
- The peak at zero is due to prompt electromagnetic showers.
- The secondary peak at ~ -10 ns is due to spikes.
- The long tail is mainly caused by neutrons hitting the APD's.
- The additional bumps at ± 50 ns etc, are a consequence of the previous and next beam crossings.

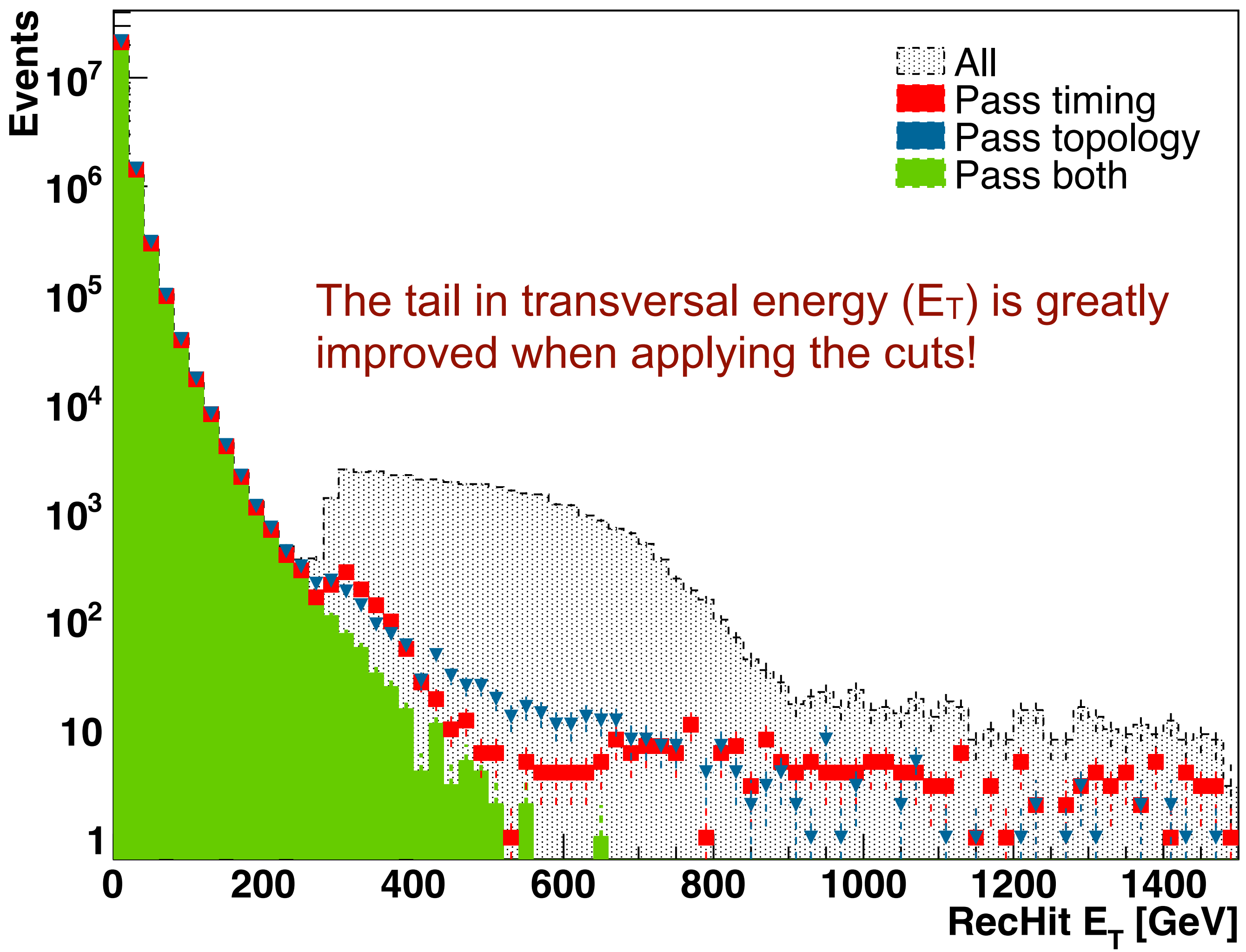


Cut |t| > 3 ns

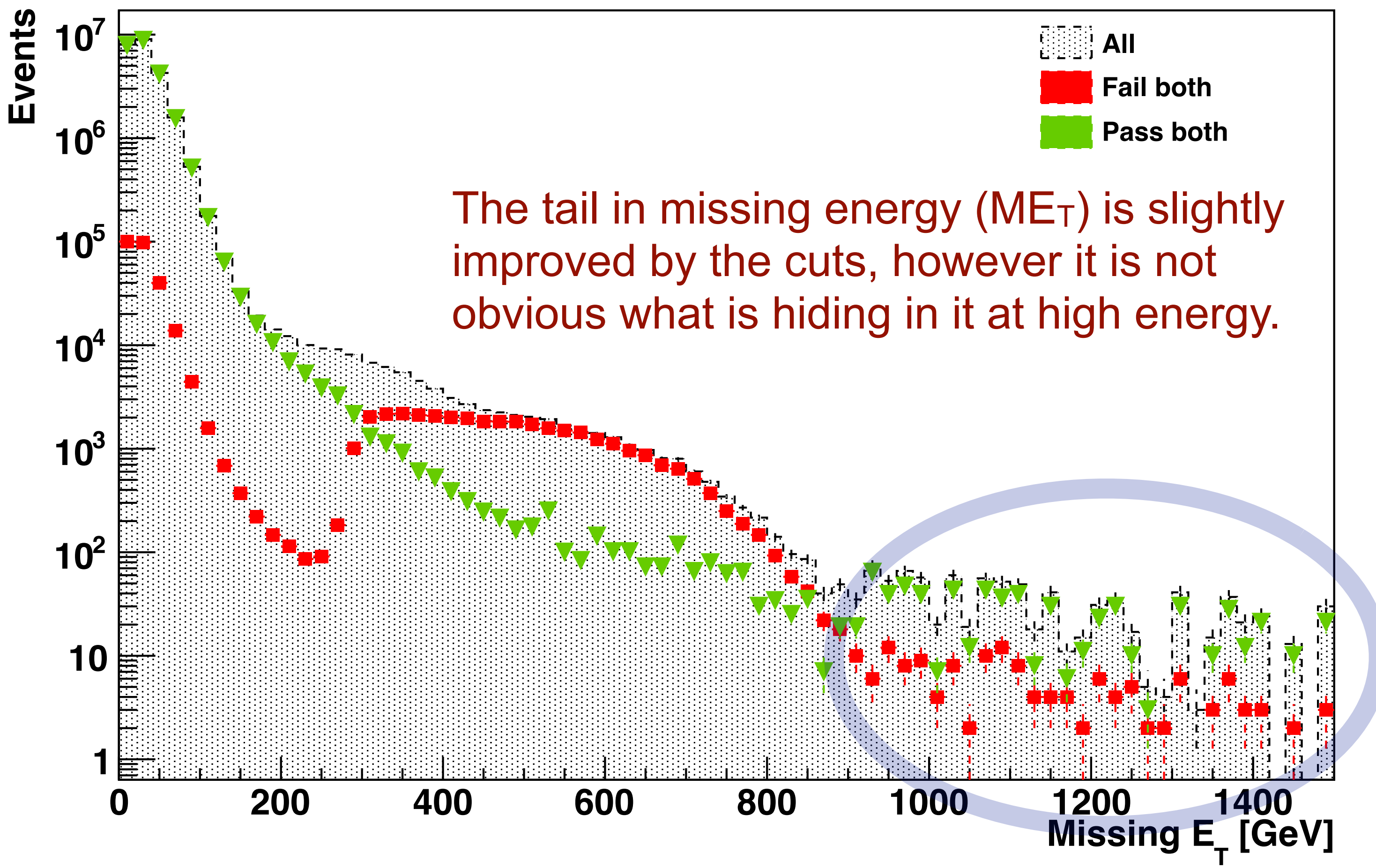
Time and Topology



Efficiency of Time and Topology



Missing E_T



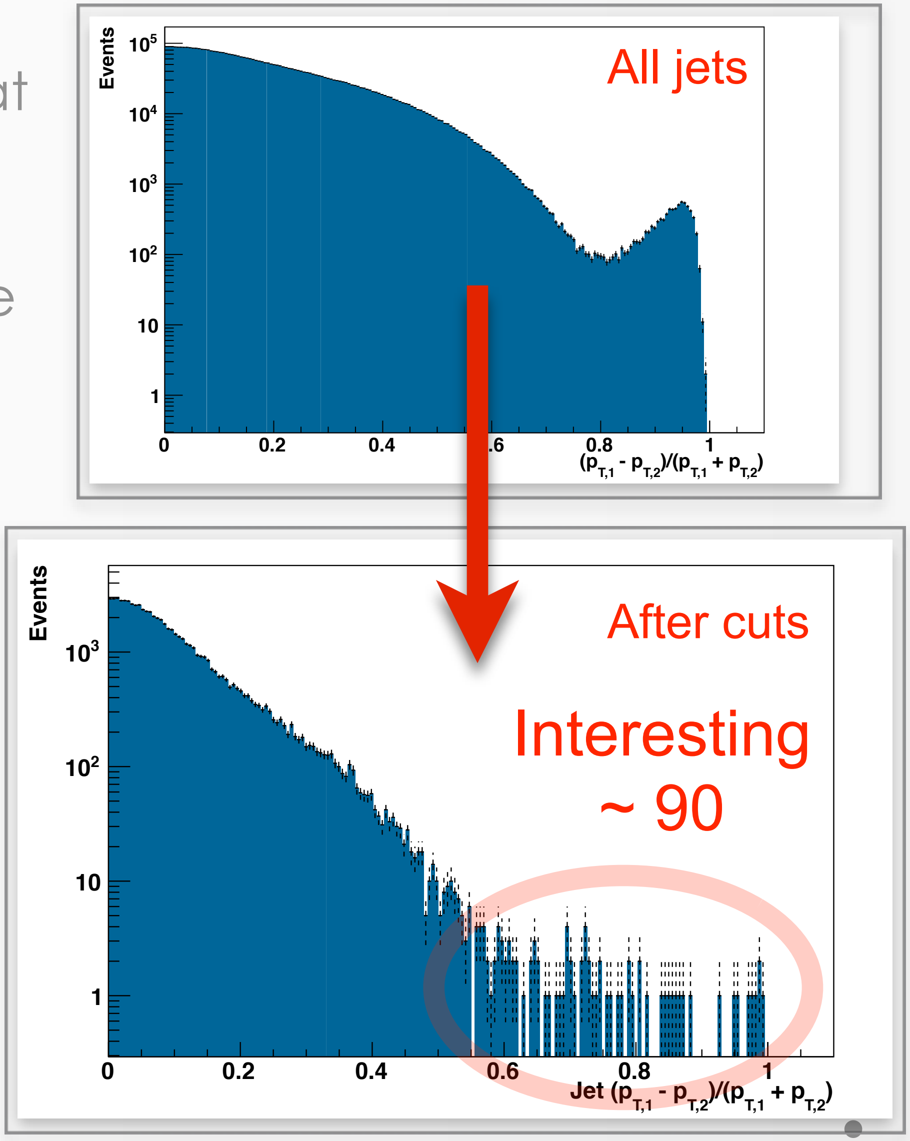
Events
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0
200
400
600
800
1000
1200
1400
Missing E_T [GeV]
All
Fail both
Pass both
The tail in missing energy (ME_T) is slightly improved by the cuts, however it is not obvious what is hiding in it at high energy.

Spikes embedded in jets

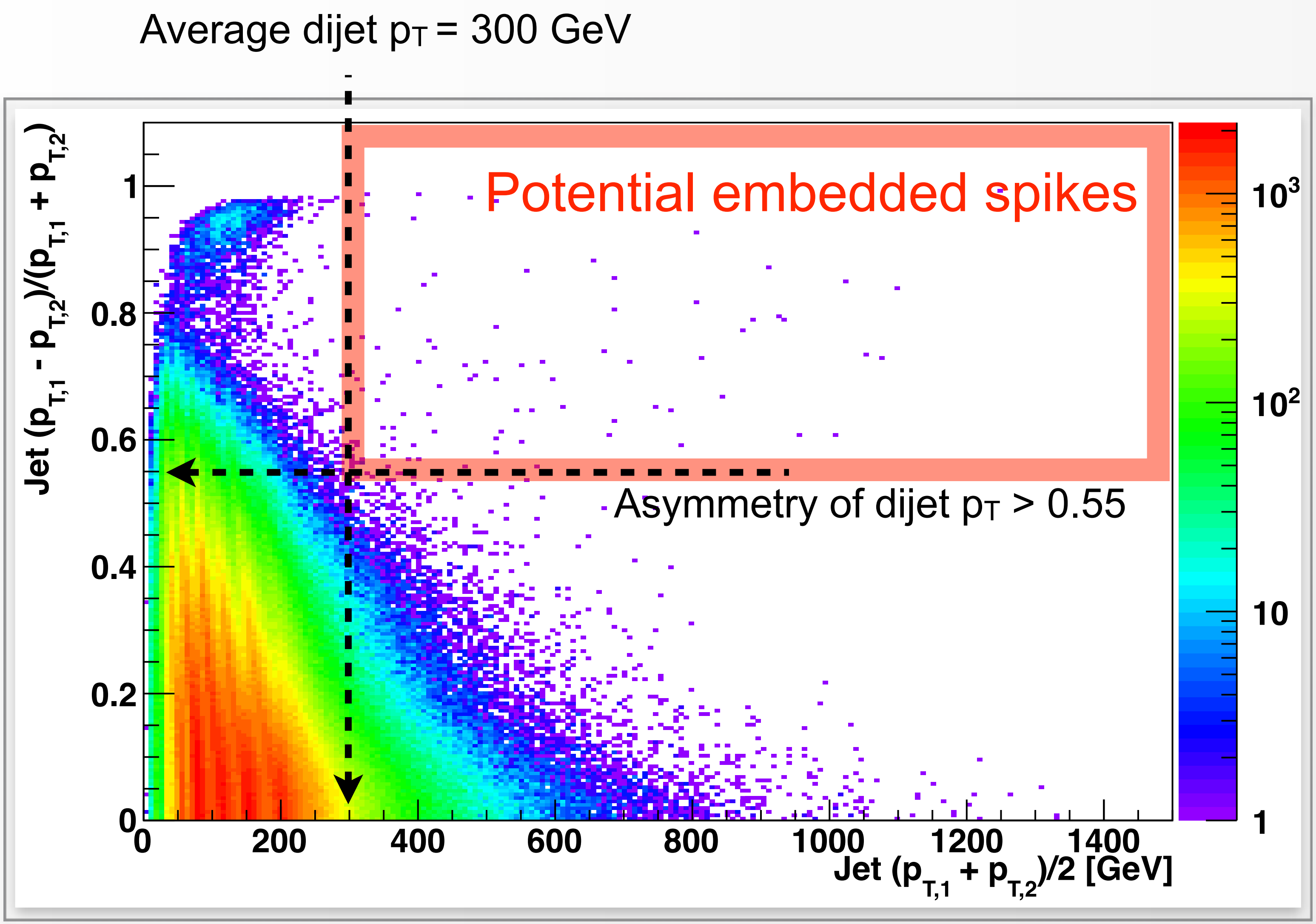
- The combined timing and topological cuts are very effective in identifying and removing spikes.
- But, are these cuts enough?
  1. Are there any spikes embedded in jets not cleaned by the topological (Swiss-cross) cut?
  2. Are there also such spikes not cleaned by the timing cut?
- Analysis:
  1. Look at asymmetry of leading dijet p_T.
  2. Identify actual spikes embedded in jets.
  3. Look at spike candidates matched with jets.
  4. Hits passing both time and topology.

Asymmetry of leading dijet p_T

- **Idea:** Among two high energy asymmetric jets, is it possible that one contains a spike?
  - Indeed it is (next slide)!
- Apply cuts as, then examine the events to look for spike in jet candidates.
  - $E_T > 5$ GeV
  - $(p_{T,1} + p_{T,2})/2 > 300$ GeV
  - $p_{T,3} < 50$ GeV
  - $|\eta| < 1.3$ (both jets)
  - $dR = \sqrt{(\Delta\eta^2 + \Delta\phi^2)} < 1$ (both jets)
- The few events with $(p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2}) >\sim 0.55$ are to be examined (see snapshots of event display on the next slide).

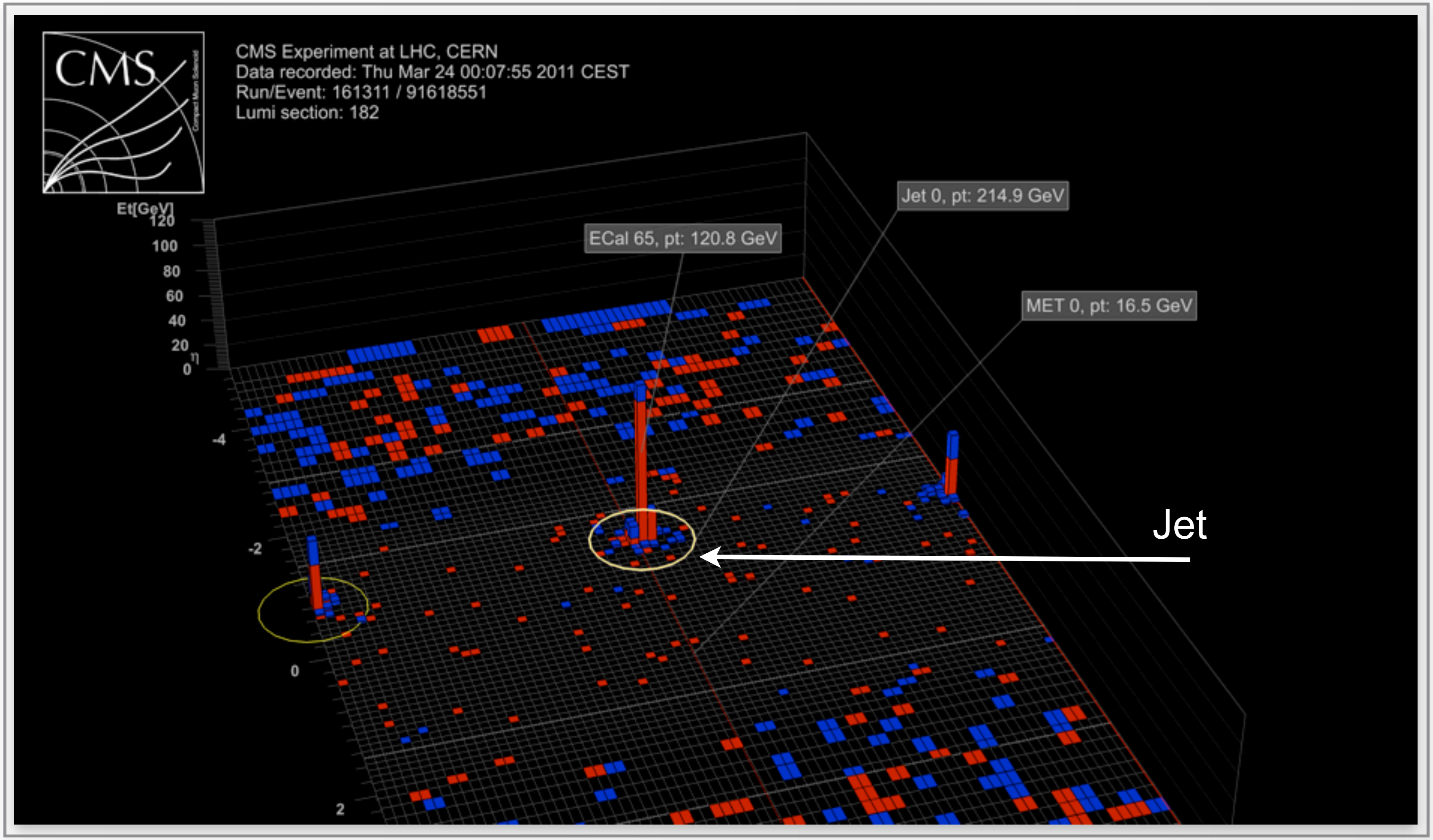


Asymmetry of leading dijet p_T



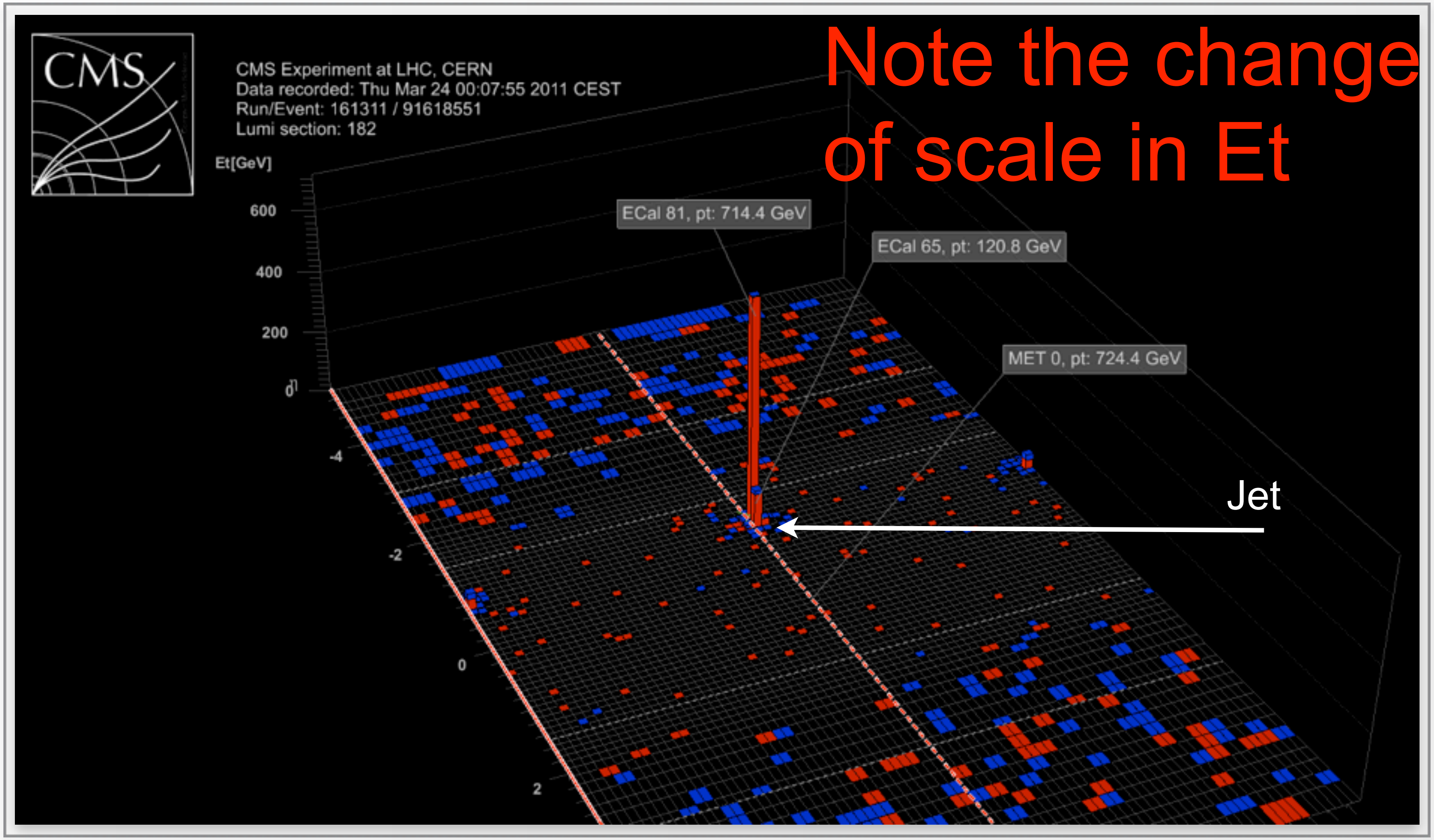
Embedded spikes

- Default reconstruction of typical event (red box on previous slide).



Embedded spikes

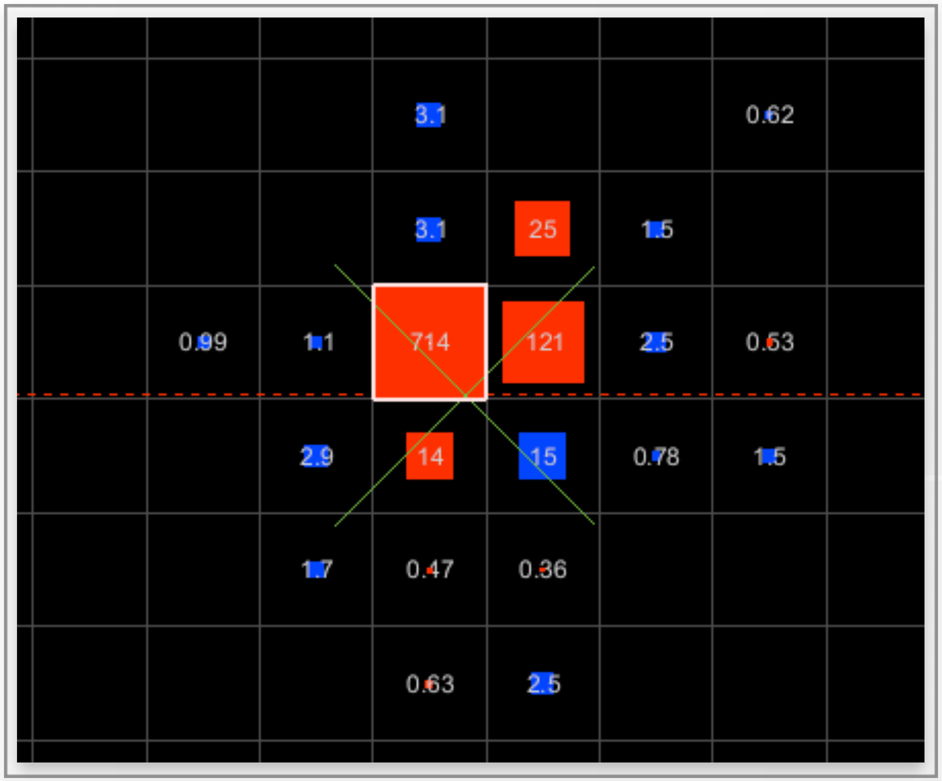
- Same event but with spike cleaning (timing) undone.

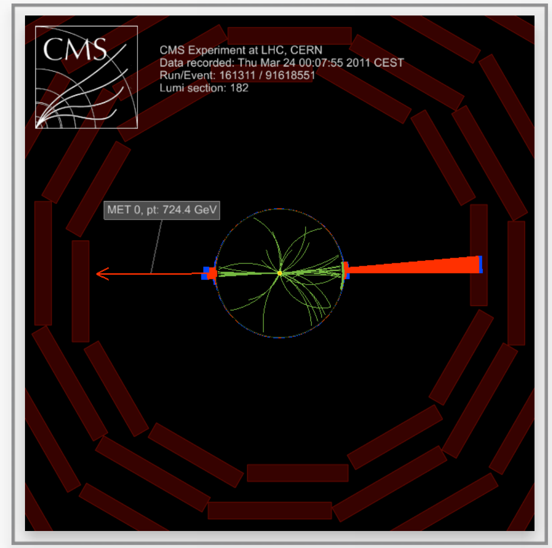


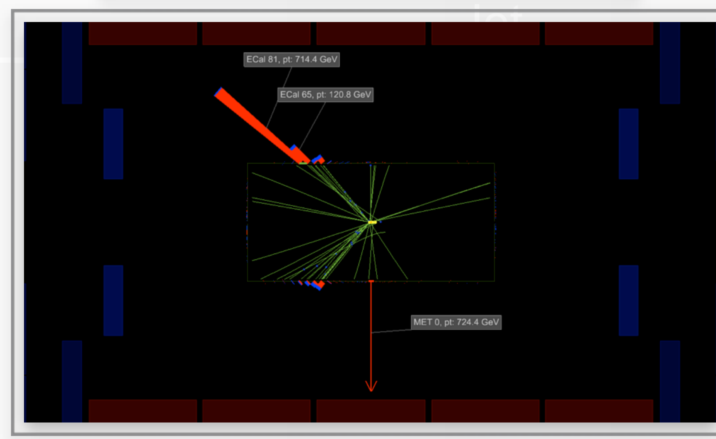
Embedded spikes

This spike was out of time, but not identified by the topological cut:

$1\text{-}E_4/E_1 > 1\text{-}121/714 = 0.83 < 0.95$





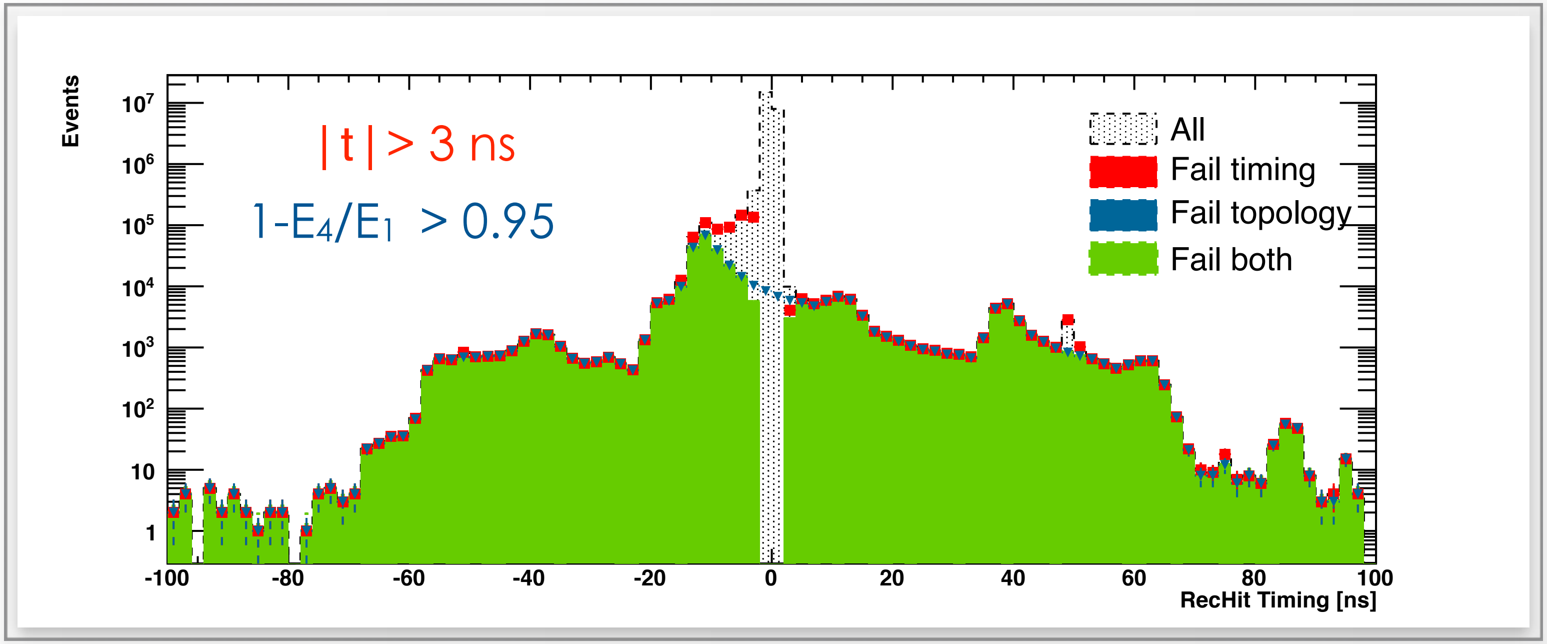


Spike candidates matched with jets

- For RecHit p_T > 30 GeV, spike candidates are matched with jets according to:

$$\sqrt{((\Delta\eta)^2 + (\Delta\phi)^2)} = \Delta R < 0.1$$

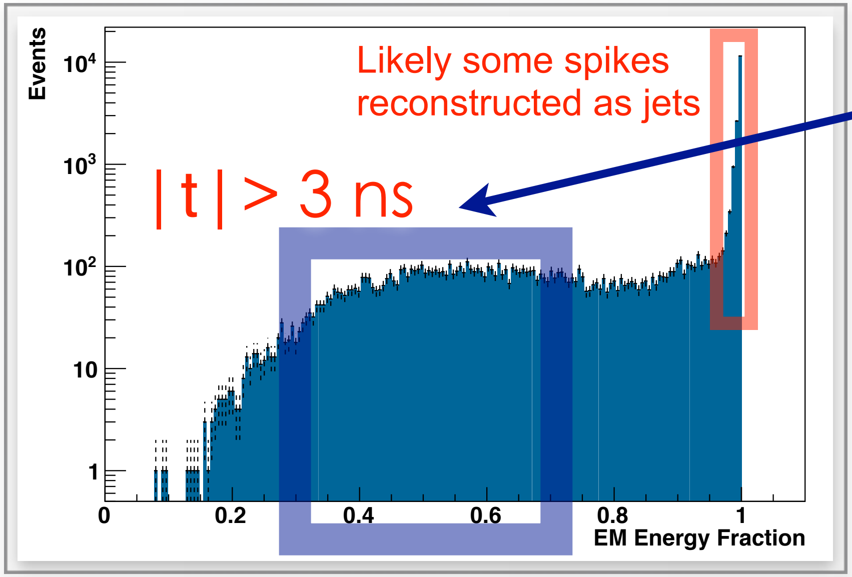
- A spike candidate is either |t| > 3 ns or $1-E_4/E_1 > 0.95$.
- Each variable was checked independently.
- The RecHit timing for both cuts is shown below.



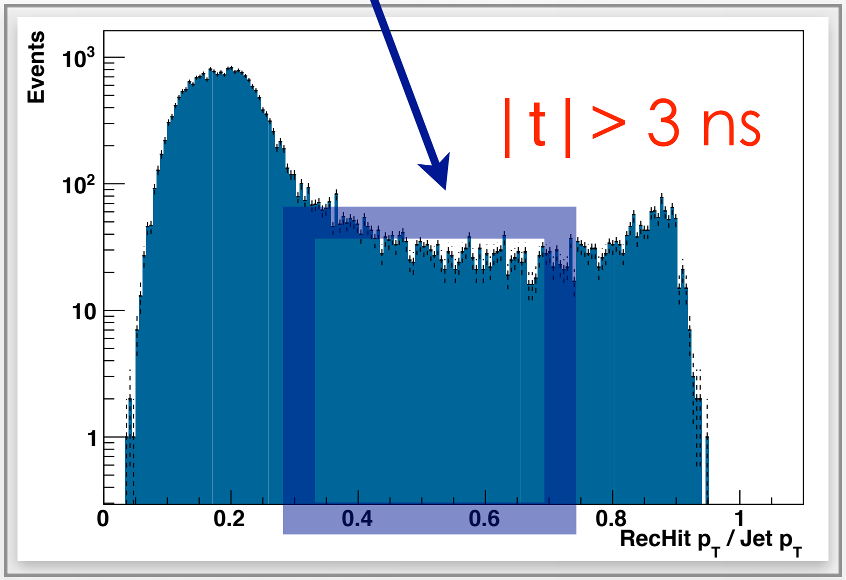
Spike candidates matched with jets

Two representative plots for spike candidates failing time matched with jets (lots of different correlation plots were made).

Potentially interesting!

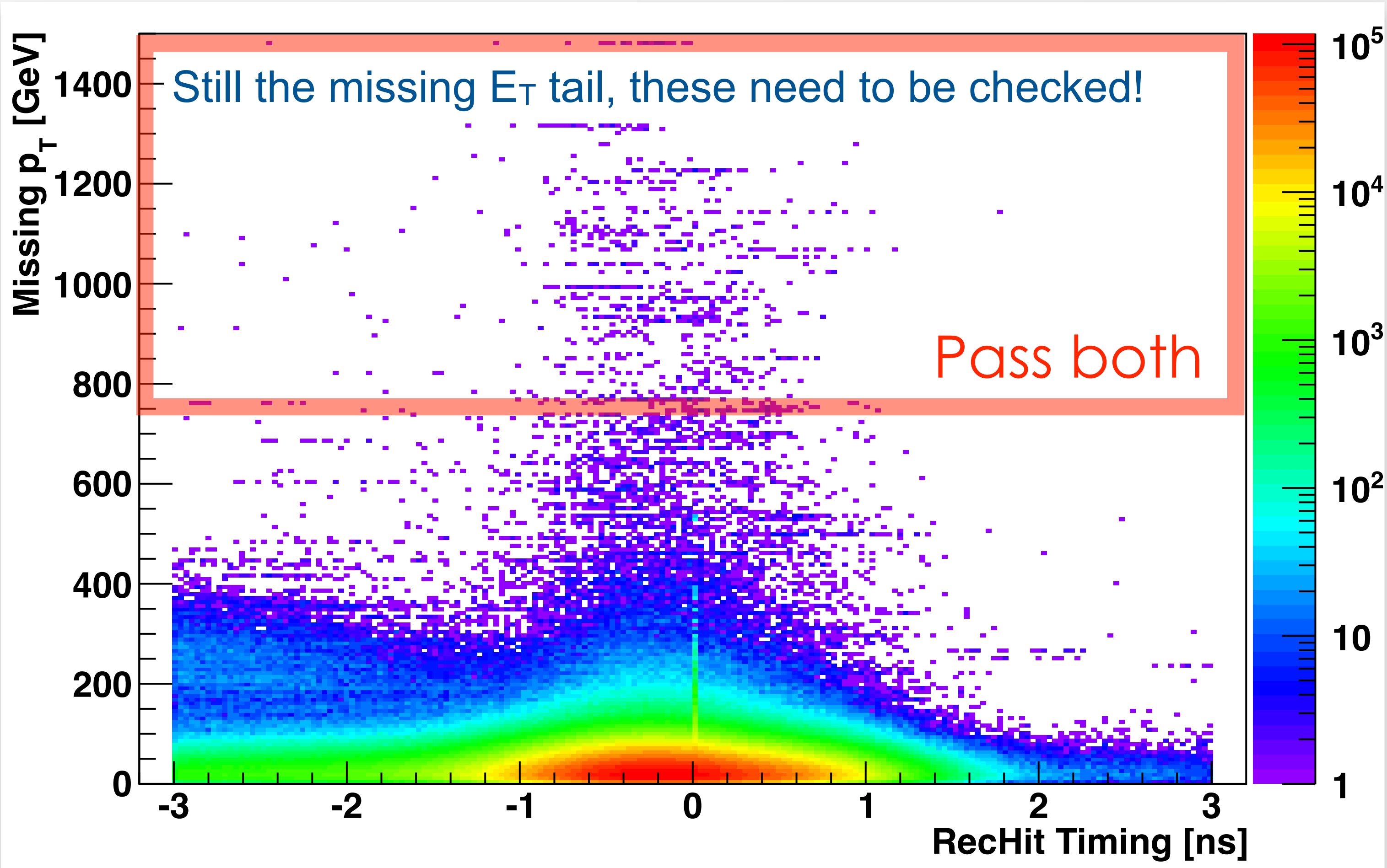


Electromagnetic energy fraction of jets matched with spike candidates.



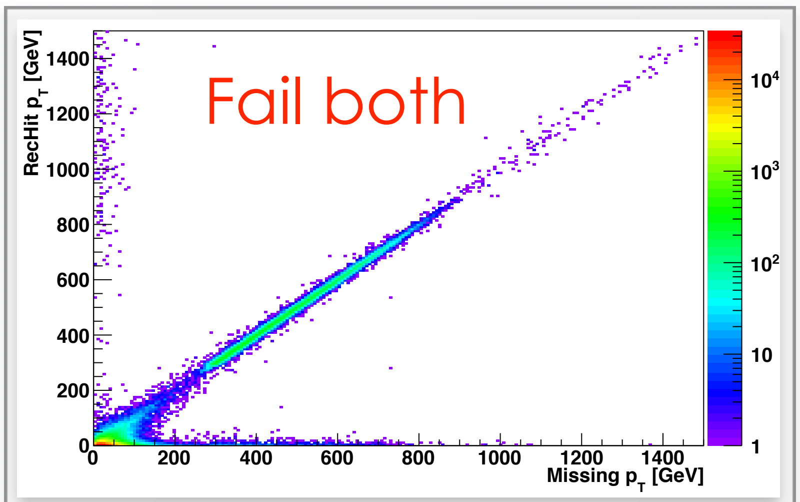
E_T spike candidate / E_T jet

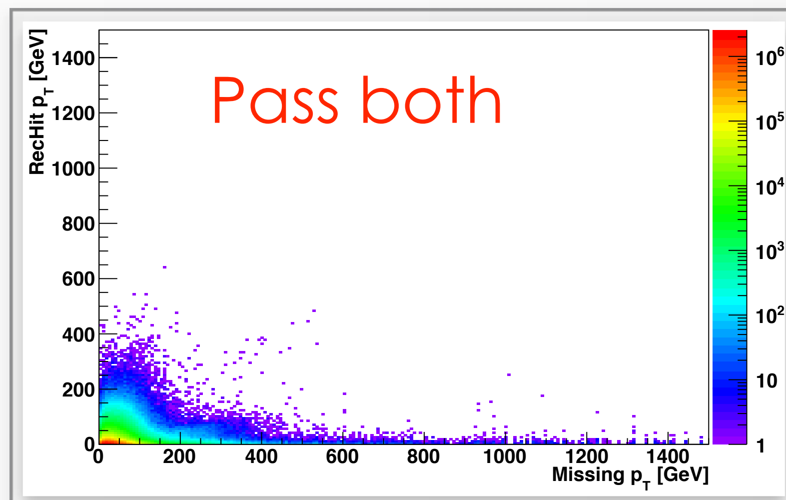
Passing both time and topology



Passing both time and topology

- Most of the high energy missing E_T disappears when applying both cuts (right plot).
- Remaining missing E_T corresponds to low RecHit p_T.
- This is indeed very nice, since it strongly implies that there are no high energy spikes after the time and topology cuts have been applied.





Conclusion

- Spikes occur in the ECAL Barrel region.
- Filtering already implemented is very efficient.
- The existence of spikes embedded in jets has been verified.
- There is still some work left quantifying the result.
- At the end of the day: How many anomalous signals contribute to the jet reconstruction?
    - The probability of this is given by the number of anomalous signals fully embedded in a jet.
    - The key question is if this is number is large enough to be significant.

Prospects

- Quantify the result!
- Over-efficiency of triggers (L1 and HLT).
- Look for spikes in other types of data than jets, e.g. electron, photon reconstruction.

For anyone reading this online, please don't hesitate to email me if you have questions: j.mr.olsson@gmail.com

Thanks!

- CERN Summer Student Program for everything.
- Caltech CMS group for having me, it has been great.
- My two supervisors Artur Apresyan and Adi Bornheim for all their help and support.
- Professors Harvey Newman and Maria Spiropulu for their kind advice.
- All great friends I've made here.

- You guys, thanks for coming this morning!

An awesome summer!

Thanks to you all :)