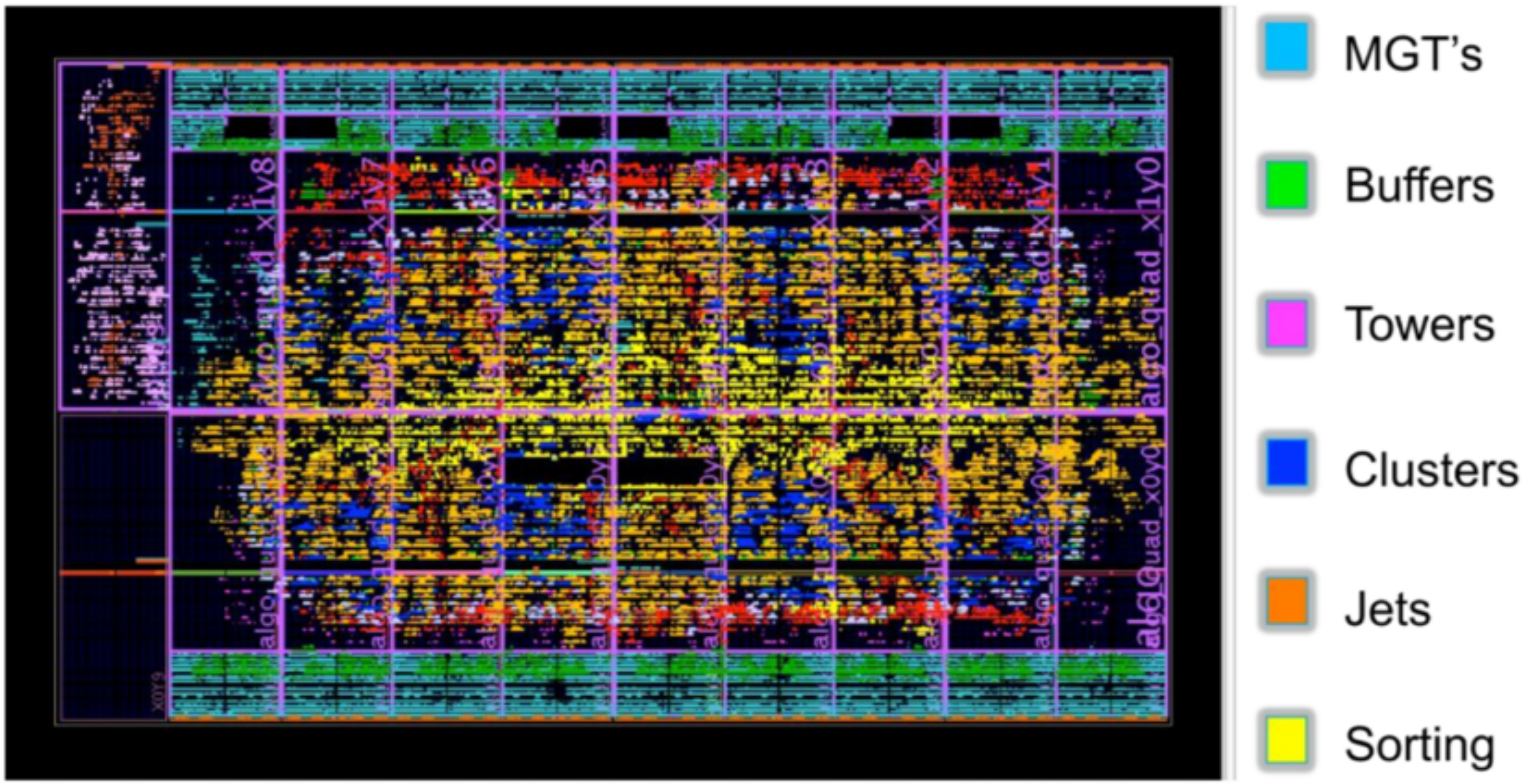
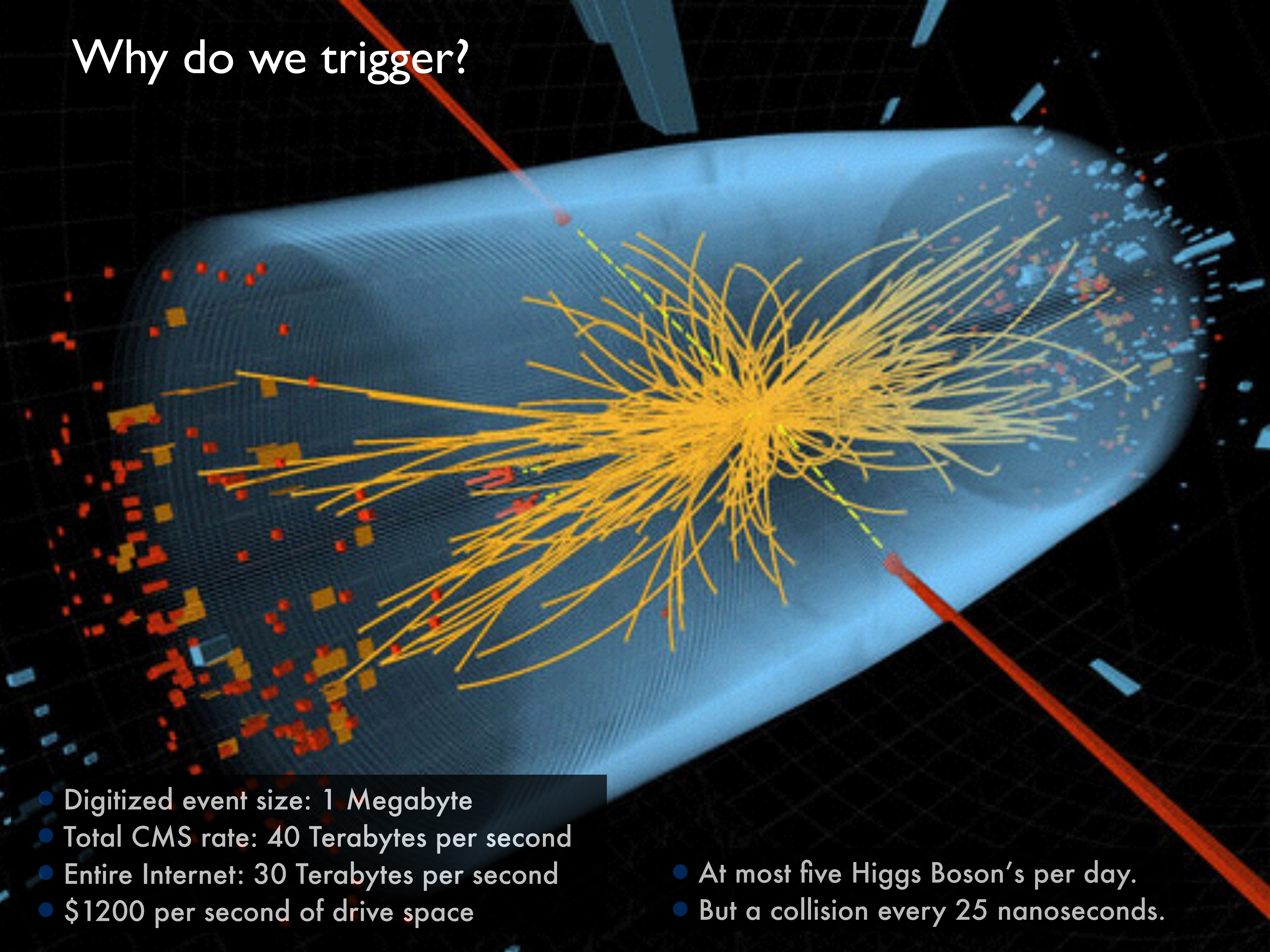
The role of the CMS calorimeter trigger for the study of the Higgs sector and other searches for new resonances during the LHC Run II.

Michael Mulhearn for the CMS collaboration



MP7 firmware floor plan

Why do we trigger?



- Digitized event size: 1 Megabyte
- Total CMS rate: 40 Terabytes per second
- Entire Internet: 30 Terabytes per second
- $1200 per second of drive space

- At most five Higgs Boson's per day.
- But a collision every 25 nanoseconds.

The Analysis Team's Perspective

The perfect trigger:

Has 100% efficiency.
Has a rate equal to the offline selection.
Has a trigger object exactly the same as offline.

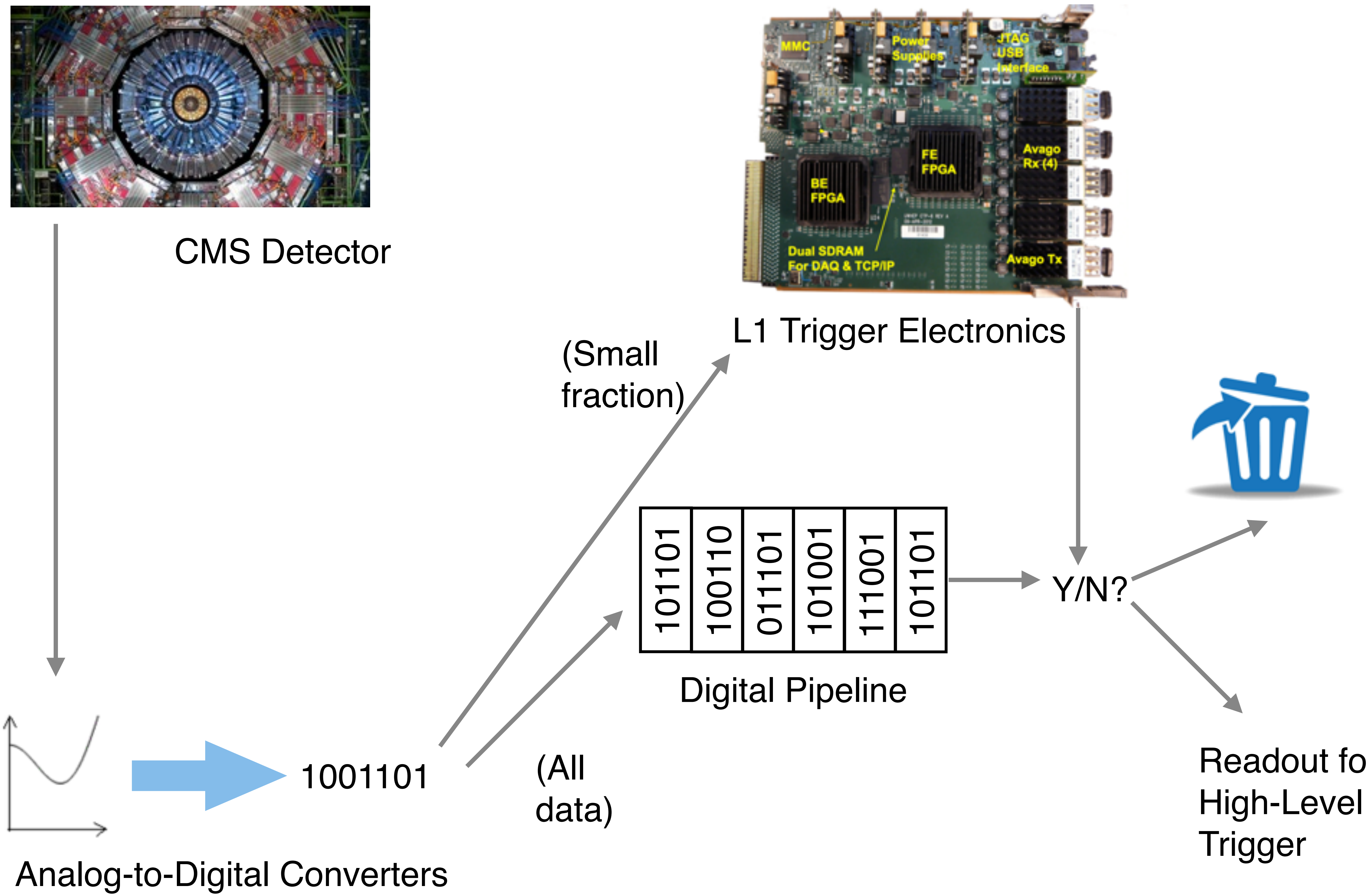
In short, the perfect trigger is *invisible*.

The Analysis Team's Perspective

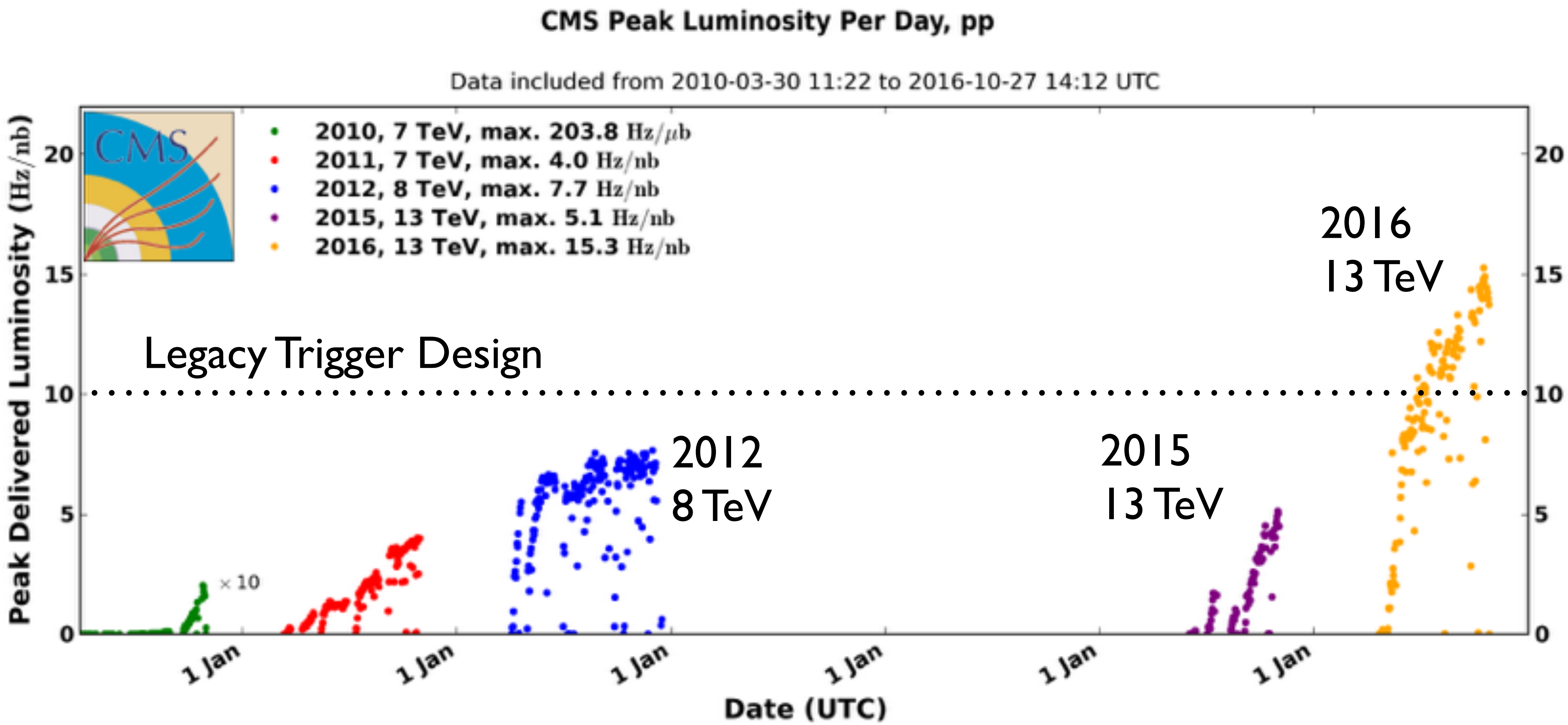
Karri Ramo

We can only disappoint you…

CMS Data Acquisition



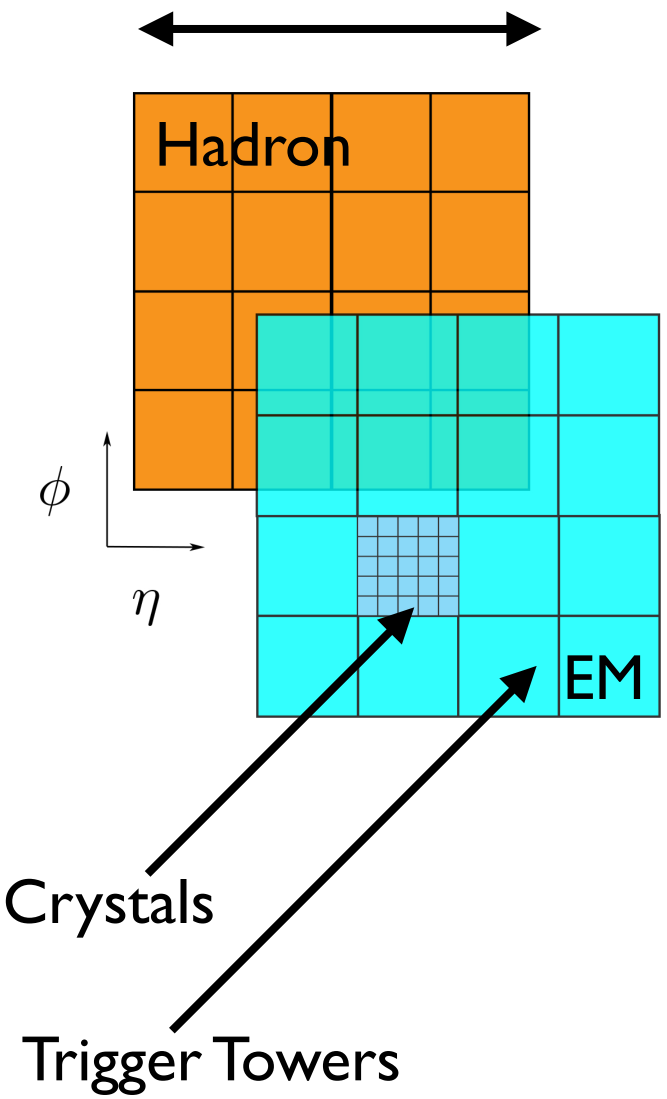
The Level-1 Trigger Upgrade



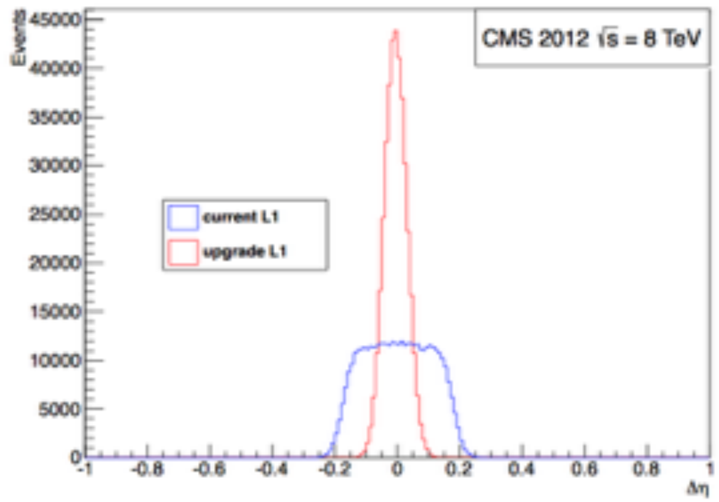
- Upgrades to the LHC were (correctly) predicted to overwhelm legacy trigger by 2016.
- A partial upgrade in 2015 provided much improved trigger even before it was needed.
- Calorimeter trigger upgrade highlights include:
  - Improved electromagnetic object (photon or electron) shape and isolation.
  - Subtract bias in energy of calorimeter objects due to pile-up
  - Improved tau algorithm using a smaller, optimized shape.
- Muon and Global trigger was upgraded as well (but not covered in this talk)

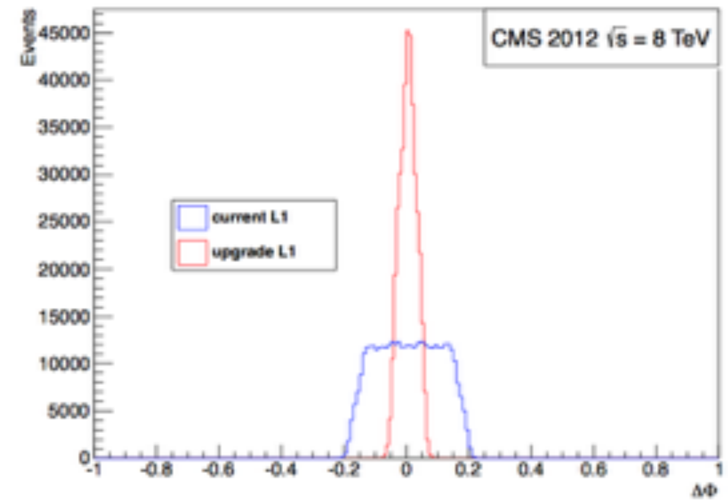
Resolution Improvements

Legacy Region Resolution

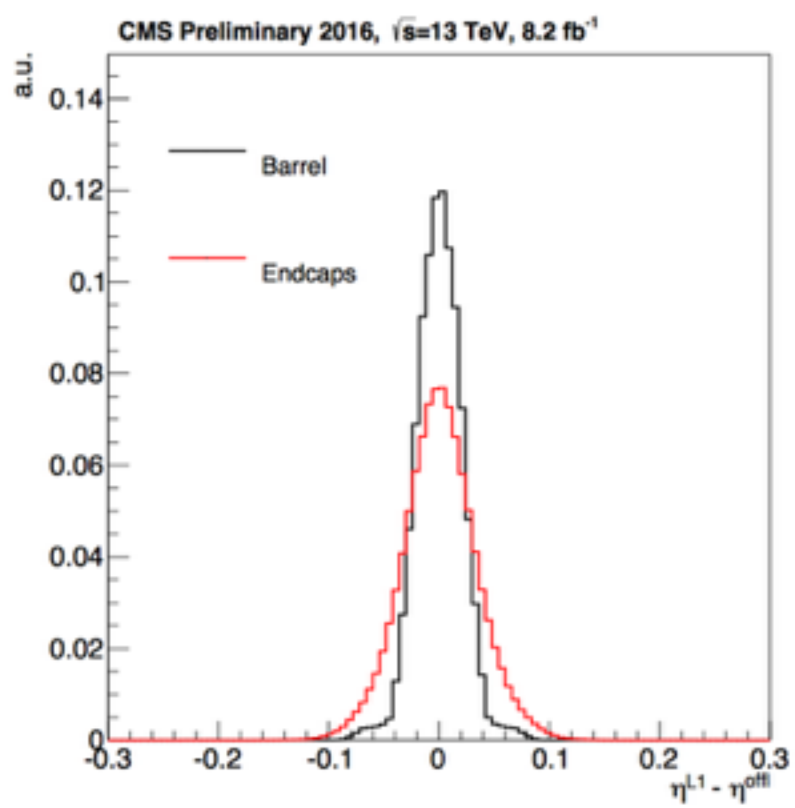


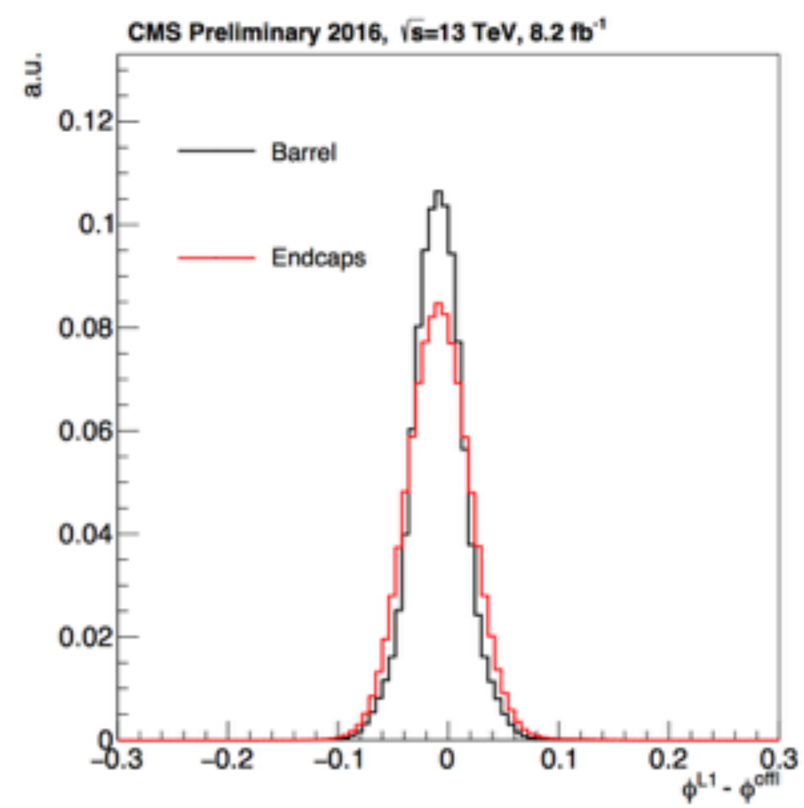
Promised in TDR:





Delivered in 2016:

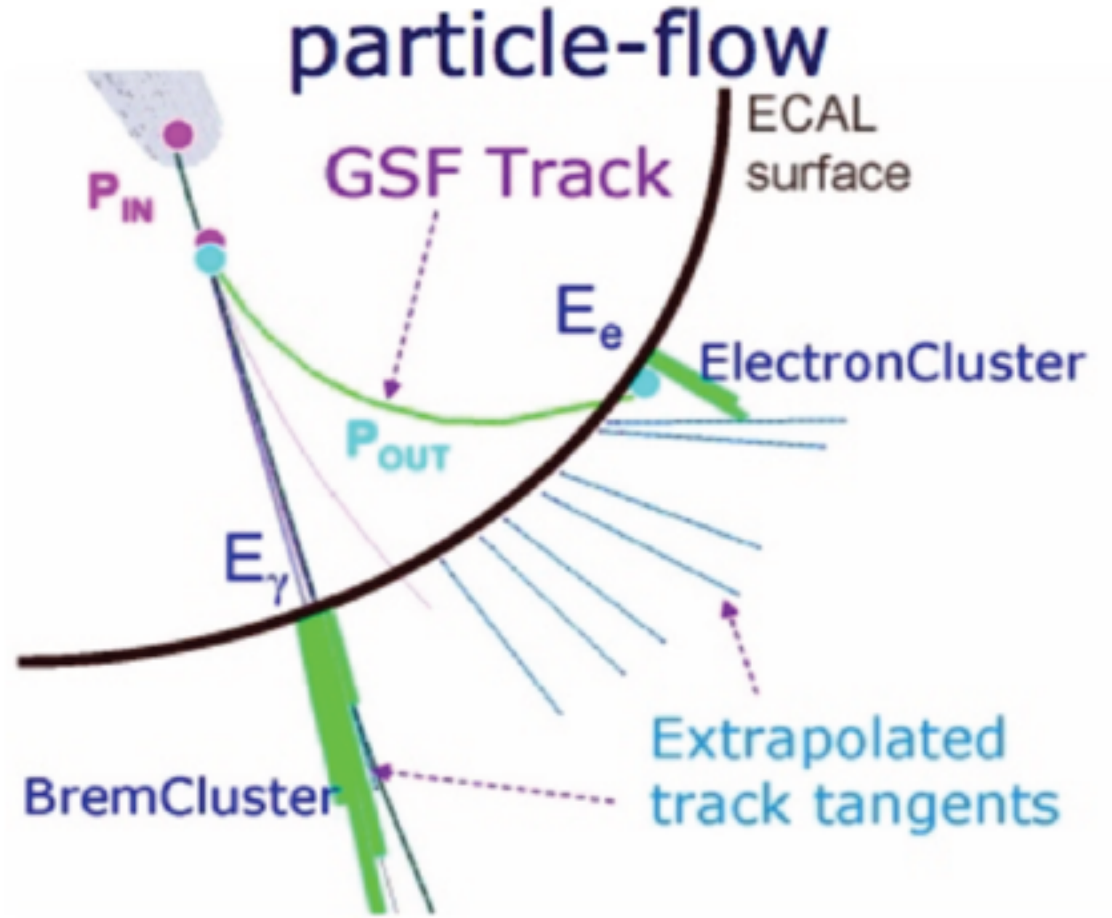




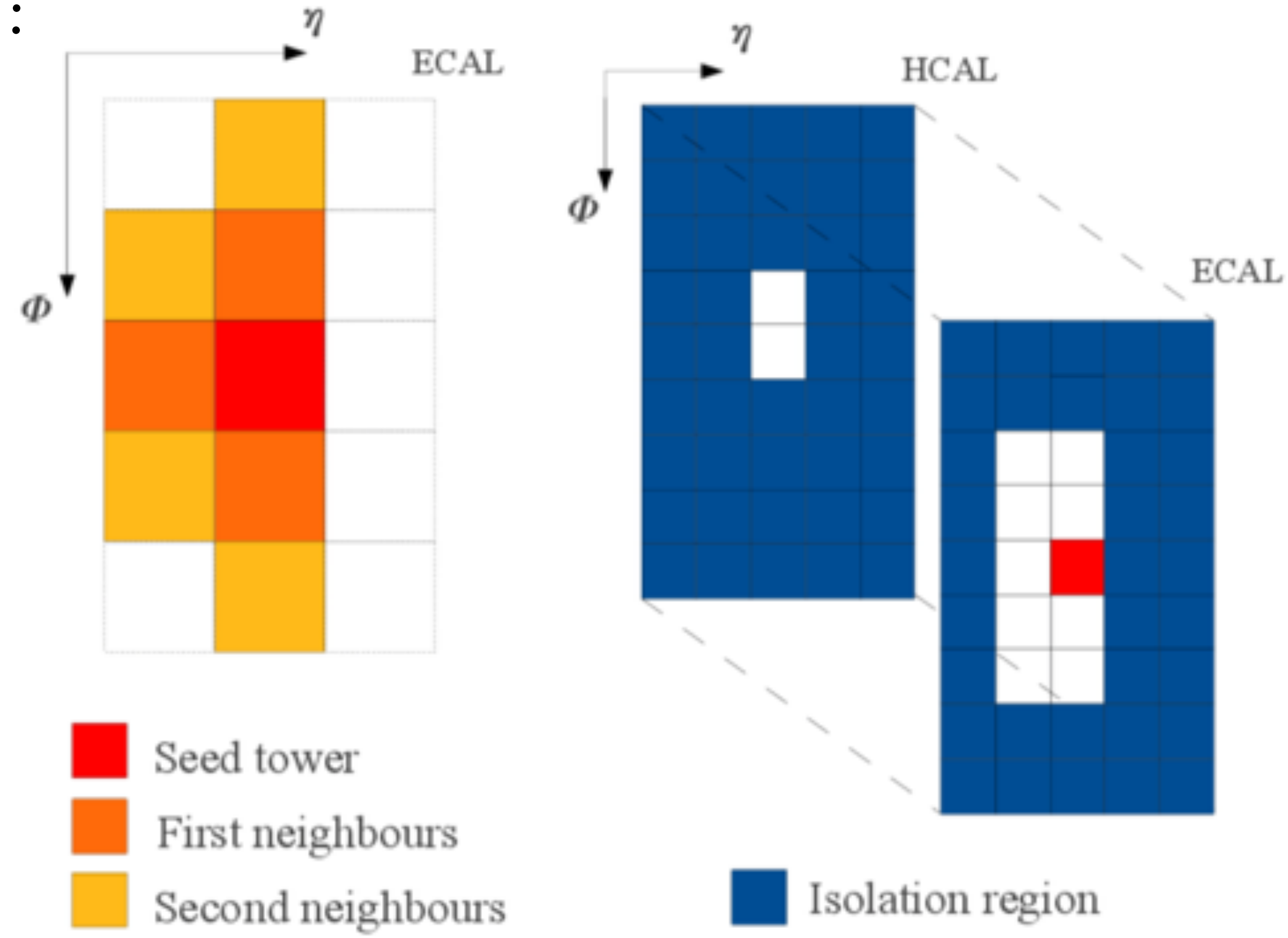
Improves invariant mass triggers, and object matching in higher level trigger.

Electromagnetic Object

Offline:



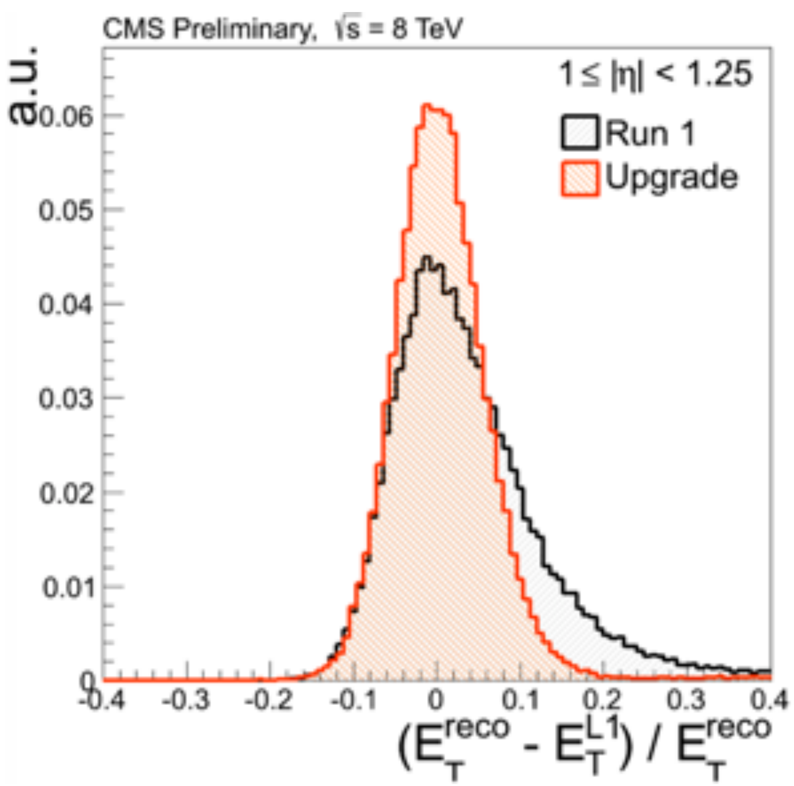
LIT:



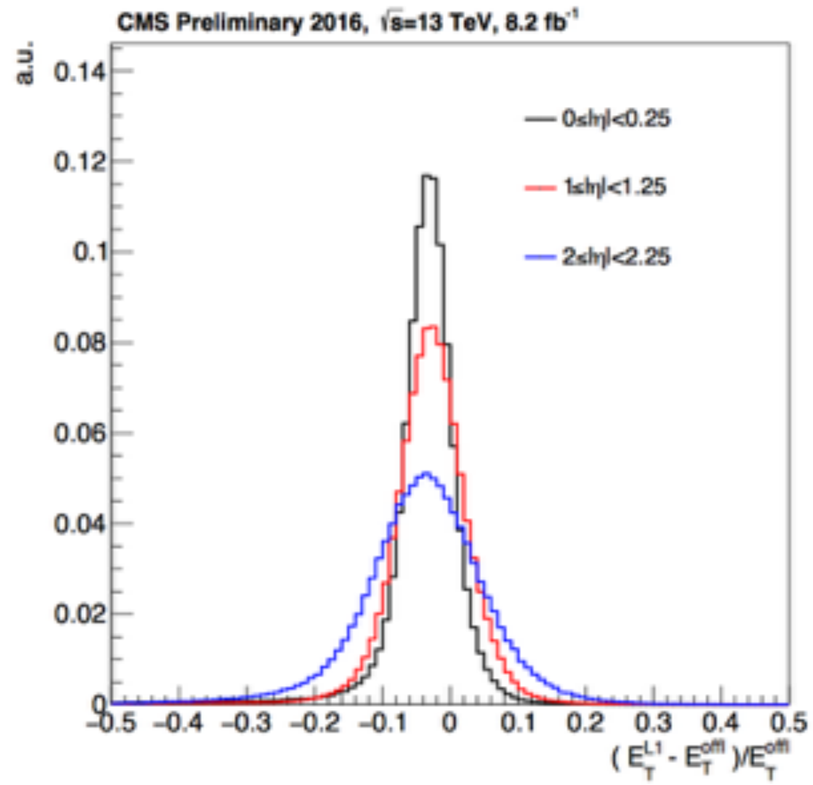
- Offline Gaussian Sum Filter track associated with EM clusters for electron and bremsstrahlung.
- Trigger EM candidates are calorimeter only, but new extended clustering includes bremsstrahlung.
- Isolation requirements are tuned as a function of pile-up.

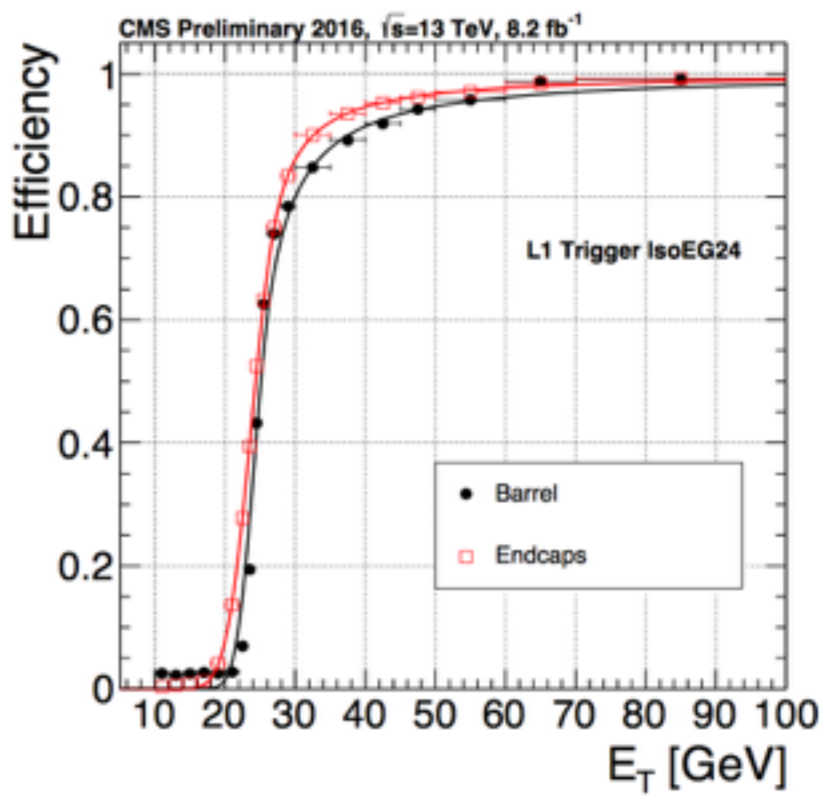
EM Performance

Expected improvement:

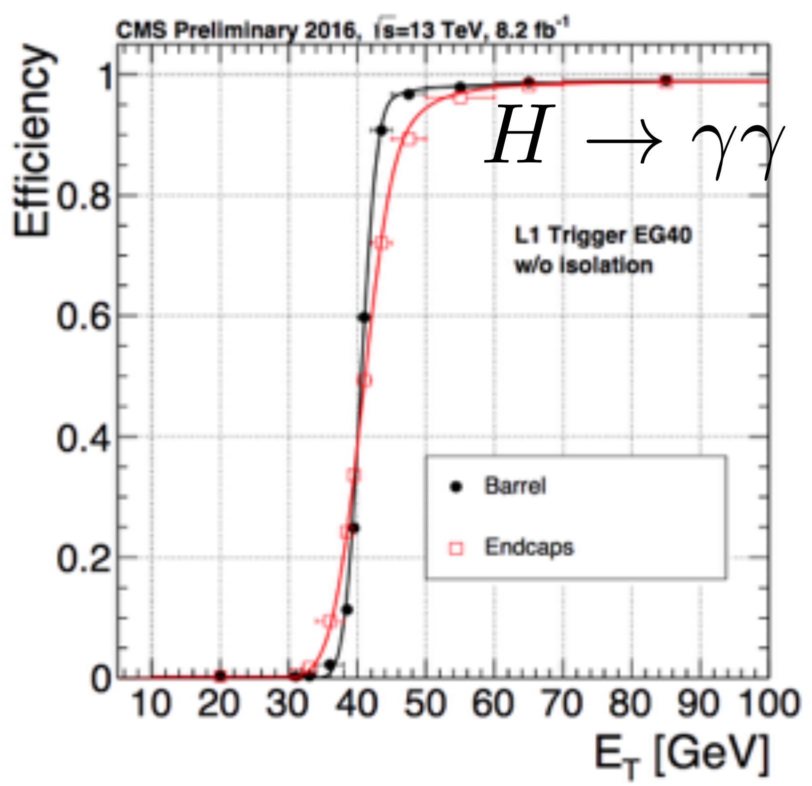


Delivered in 2016:



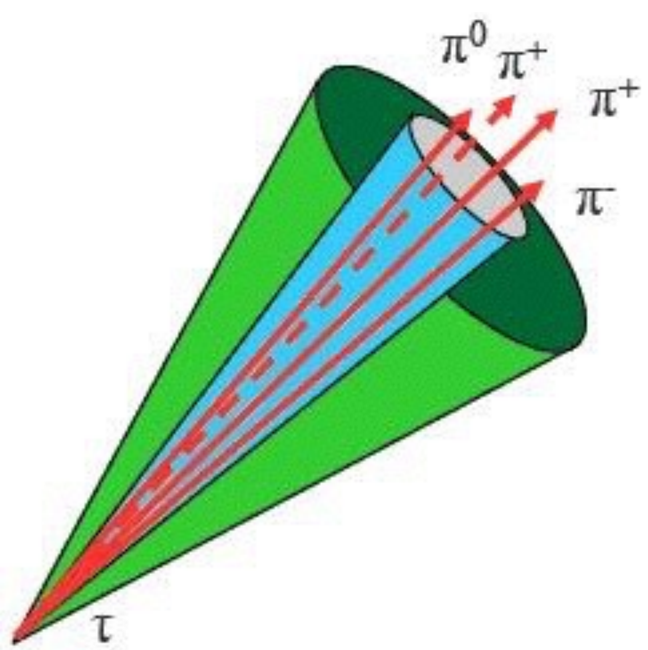


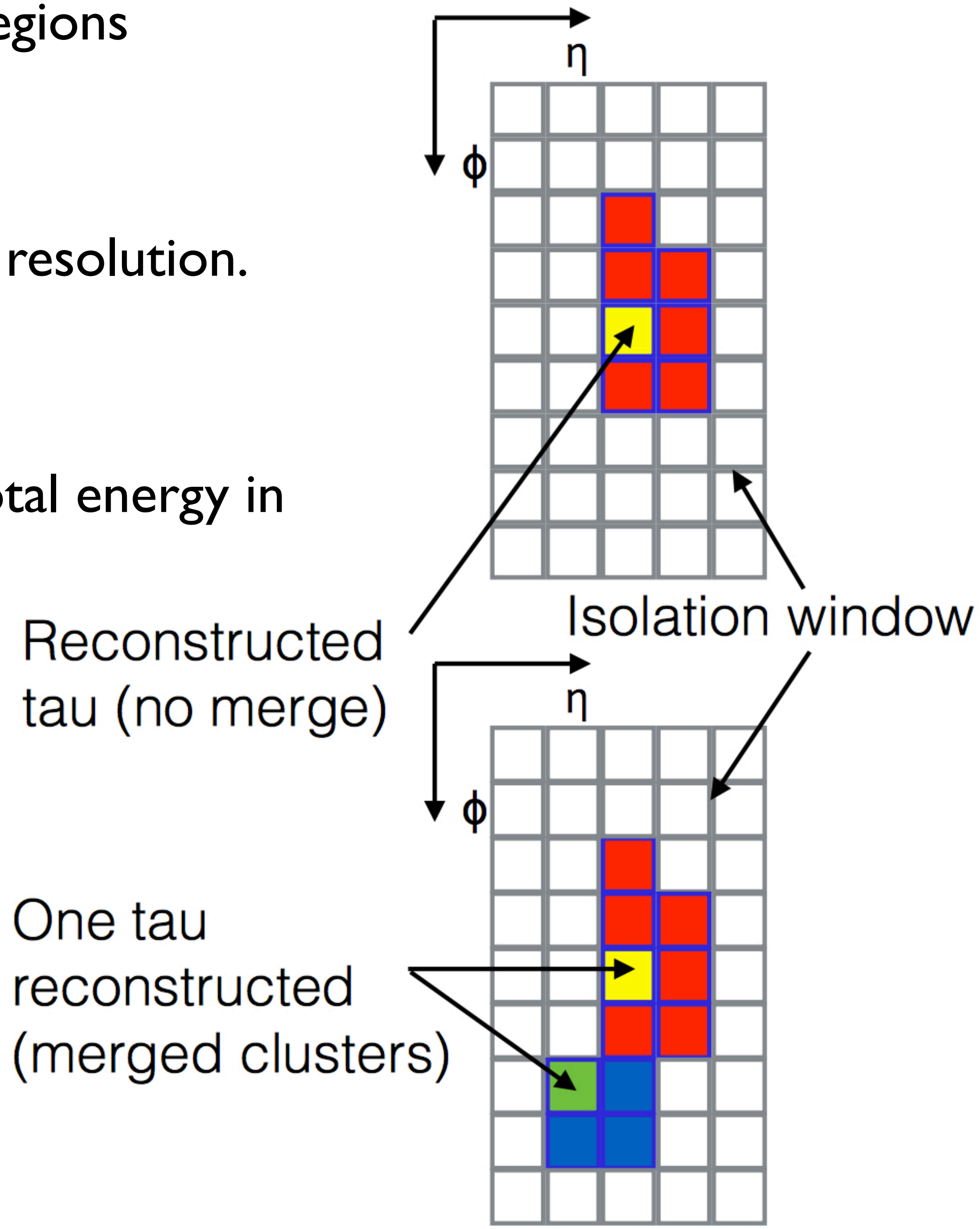
- Resolutions are from comparison with offline.
- Efficiency estimated from tag-and-probe method using $Z \to ee$ events.
- Different isolation requirements are applied to barrel and end cap regions.
- Thresholds shown are typical unprescaled thresholds up to ICHEP.



Tau Algorithm

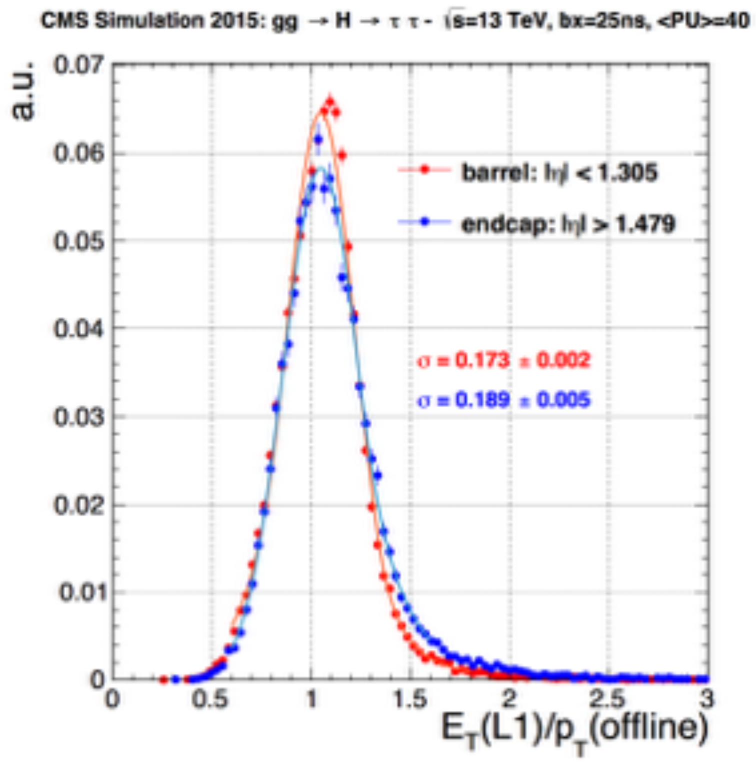
- Run 1 Taus were limited by 4x4 trigger tower (TT) regions
  - area too large, plus a flat cut on isolation.
  - terrible performance at high pile-up
- Upgrade algorithm uses dynamic clustering at full TT resolution.
- Dynamic clustering to better match tau shape.
- Cluster merging to handle multiple particle decays
- Isolation calculated from ratio clustered energy to total energy in the 5x9 window around the seed tower.
  - Thresholds depend on pile-up, Et, and eta.



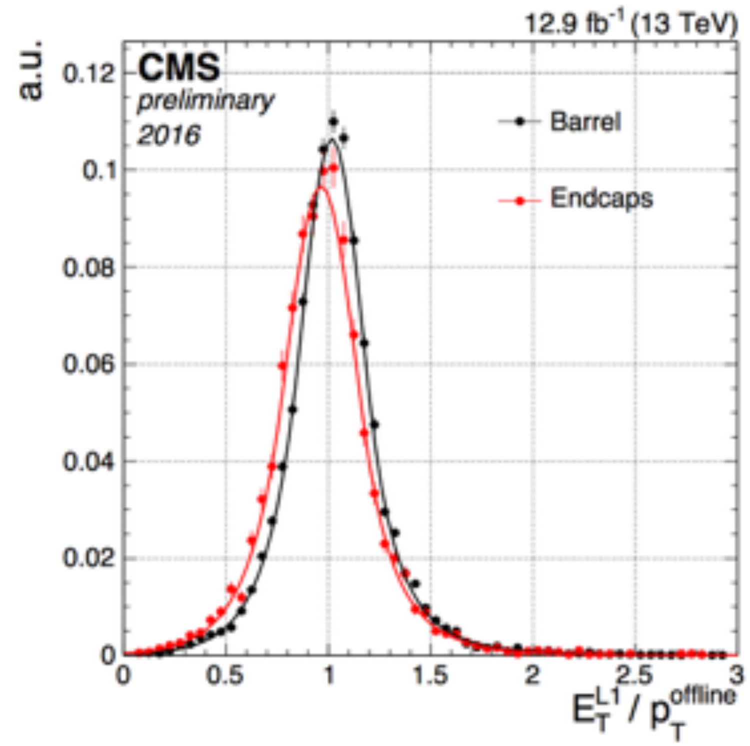


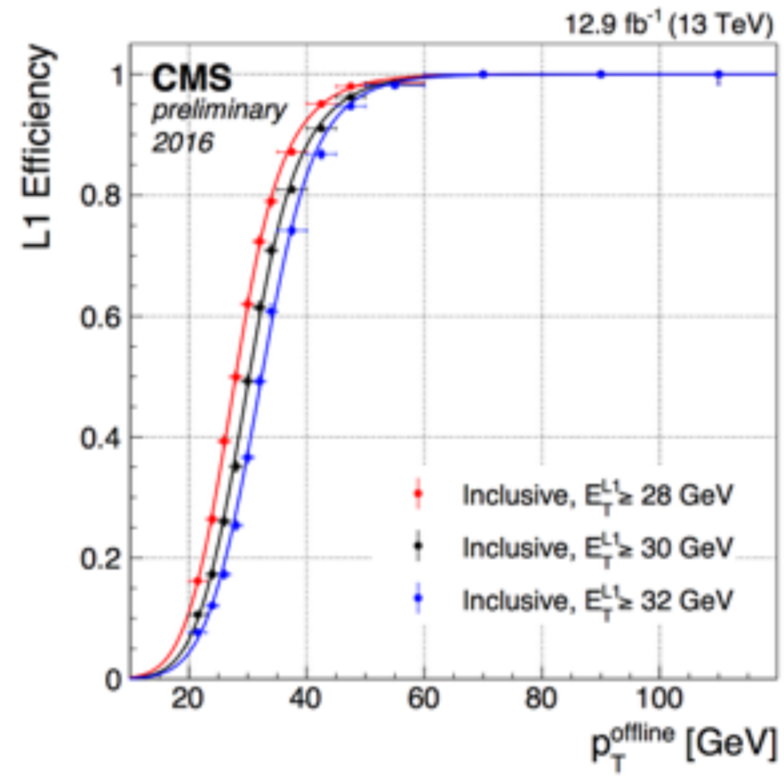
Tau Algorithm and Performance

Expected:

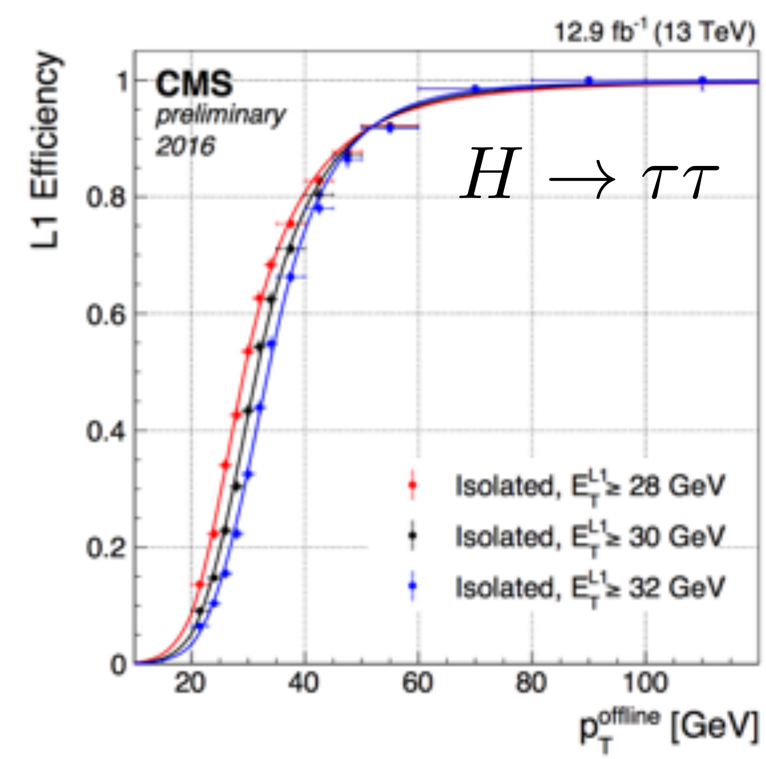


Delivered in 2016:

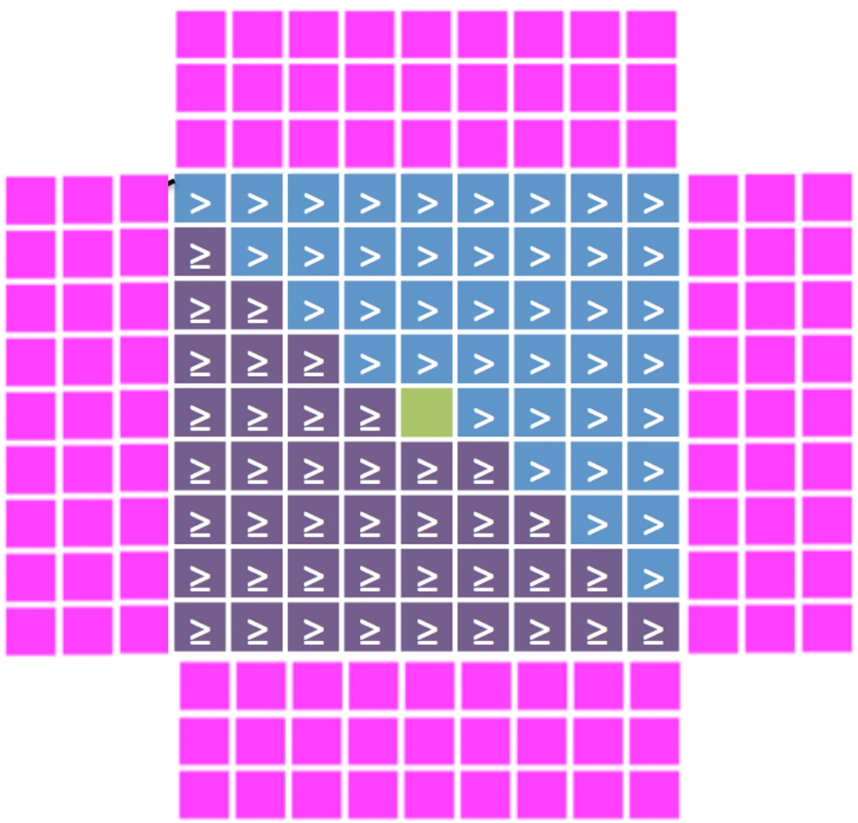


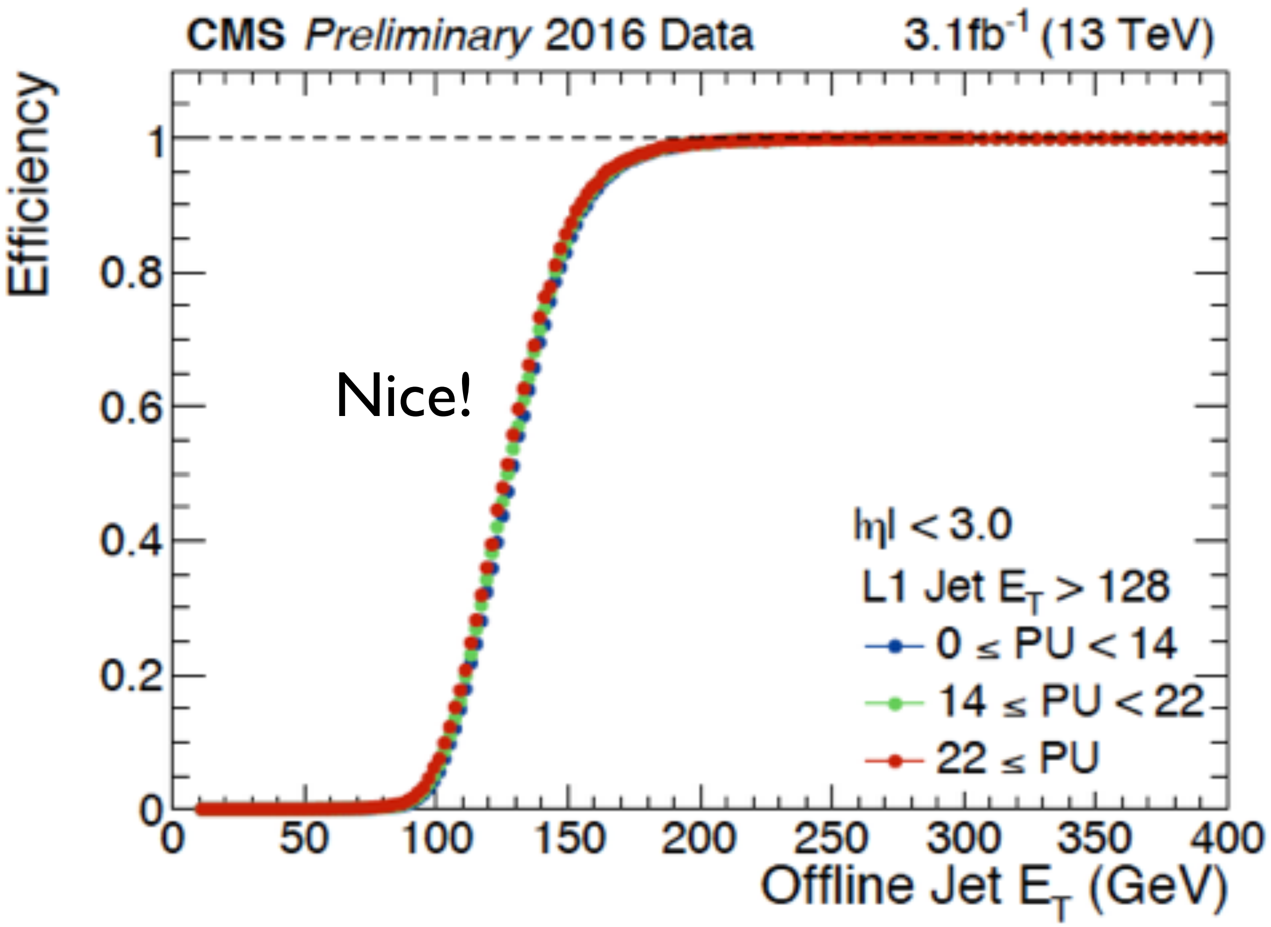


- Efficiency from $Z \to \tau\tau$ by tag and probe.
- The tag tau decays to a muon, firing muon trigger.
- The probe tau decays hadronically.
- Satisfies baseline $H \to \tau\tau$ selection:
  - both taus are well identified and isolated
  - $m(\not{E}_{\rm T}, \mu) < 30\ {\rm GeV}$ to suppress W+jets.



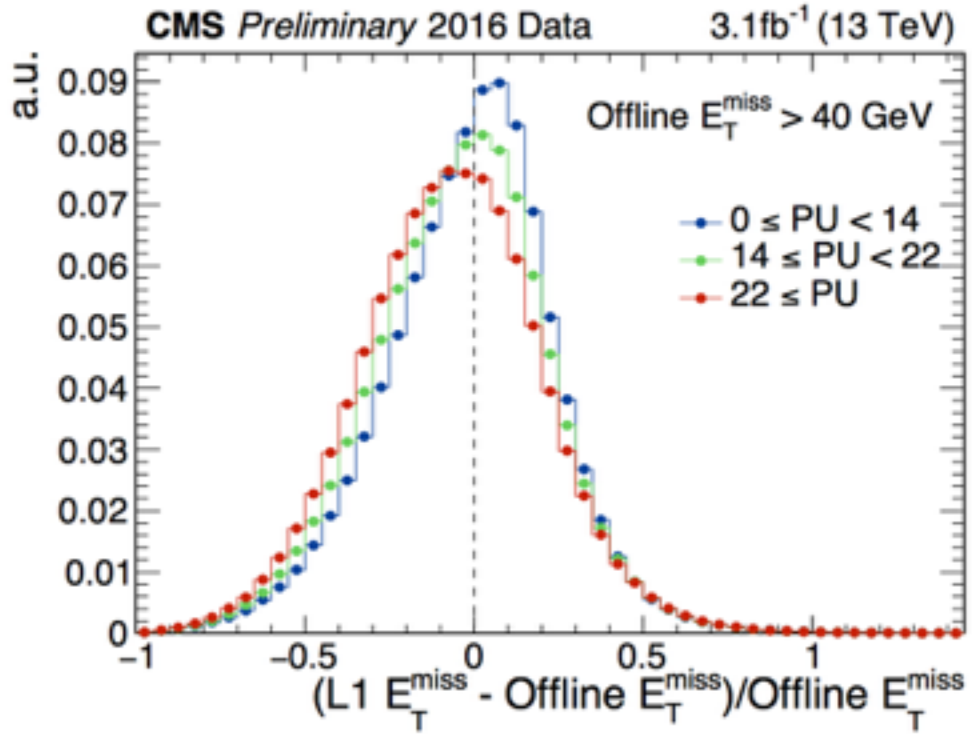
Jet Algorithm and Performance

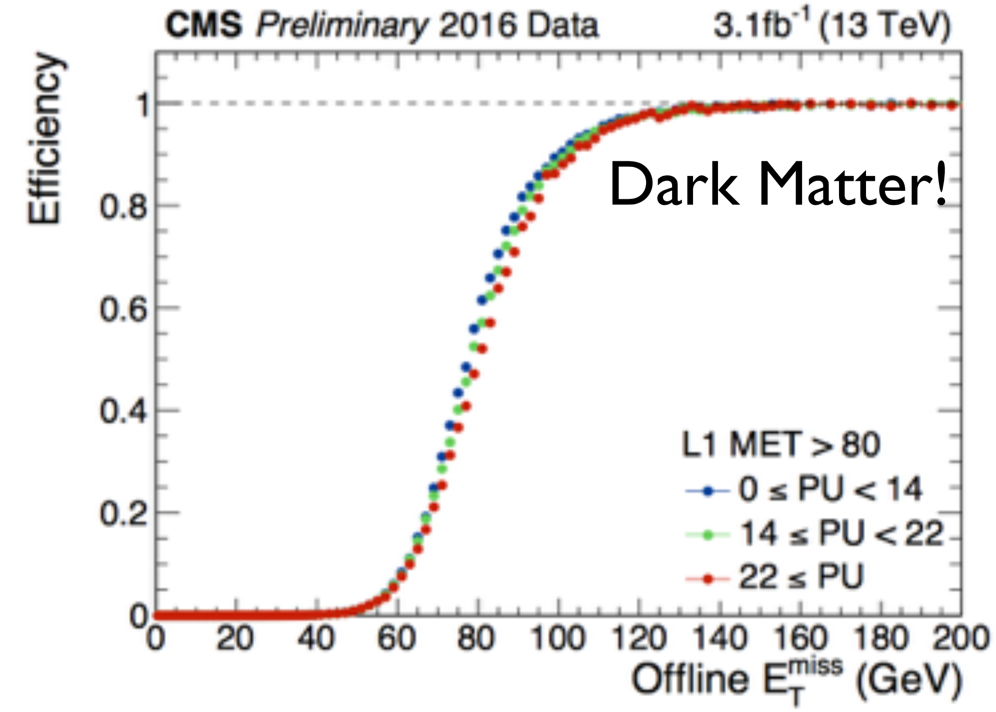


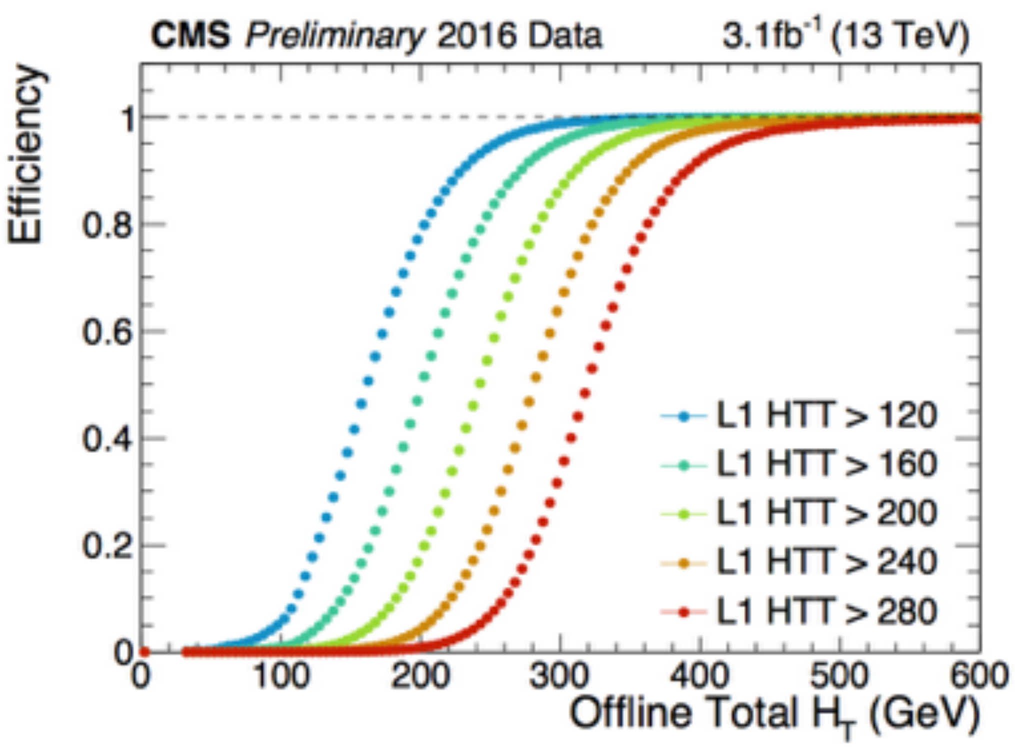


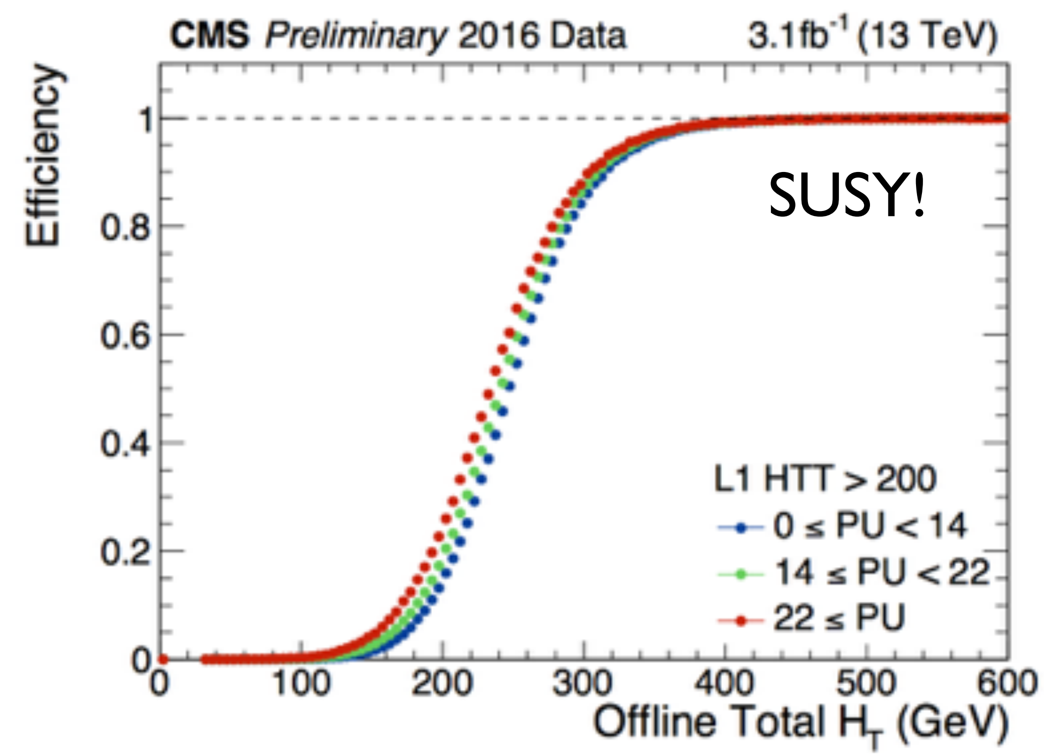
- Jet selection based on local maximum in sliding 9x9 window
- Pile-up estimated from sum in outer "chunky-donut" region, scaled to 9x9 area.
- Jet ET is inner sum minus the pile-up estimation.
- Decent stability wrt pile-up but does begin to deteriorate at PU ~ 50.

Sum Performance









Recent Analysis featuring Calorimeter Trigger

Analysis	Note	Offline Requirement [GeV]	Trigger Efficiency	Trigger Systematic
$H \to \gamma\gamma$	HIG-16-20	$\gamma > 30, 20$	95%	$< 0.1\%$
$\phi^{++}\phi^{--} \to 4\ell$	HIG-16-36	$e > 23, 12$	-	$2 - 6\%$
		$\tau > 35, 35$	-	$2 - 6\%$
$H \to \tau\tau$	HIG-16-37	$\tau > 40, 40$	-	7%
		$\tau > 30, e > 26$	-	-
$X \to ZV \to \ell\ell qq$	B2G-16-22	$e > 105$	-	6-8%
$X \to VV/qV$	B2G-16-21	$H_{\mathrm{T}} > 800$	99%	
		$H_{\mathrm{T}} > 650$ $j > 360$	99%	
$ZX \to \ell\ell + \not{E}_{\mathrm{T}}$	EXO-16-38	$e > 23, 12$	-	4%
$t + \not{E}_{\mathrm{T}}$	EXO-16-40	$\not{E}_{\mathrm{T}} > 250$	99%	-
$\ell + \not{E}_{\mathrm{T}}$	SUS-16-31	$\not{E}_{\mathrm{T}} > 220$	98%	-

Conclusion

- Completely new trigger for CMS installed and commissioned just in time for the 2016 Run.
- The system has been operating stably and has already provided a trove of data that we are just beginning to search through.
- "You'll be AMAZED to hear what my collaborator's asked me."

Further Reading

- Trigger Upgrade TDR
- Run I Trigger
- These Result
- Algorithm performance for Taus, Electrons, Jets and Sums.

- Related Conference notes:
  - Run II trigger, Calo Trigger, Upgrades.
  - Run II Trigger, Installation and Commissioning.

- Many thanks to our funding agency, the US DOE.