A Search for Heavy Resonances in the e^+e^- Final State

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Introduction

- High energy electrons are relatively easy to identify at hadron colliders
- UA1 and UA2 made the first observations of the Standard Model $W^{+/-}$ and Z^0 bosons with only a few events containing high energy electrons
- The LHC will operate at a centre of mass energy of 14 TeV, an order of magnitude greater than previously available.
- Can we expect to see new physics in the first LHC data by utilizing such a distinct signature?

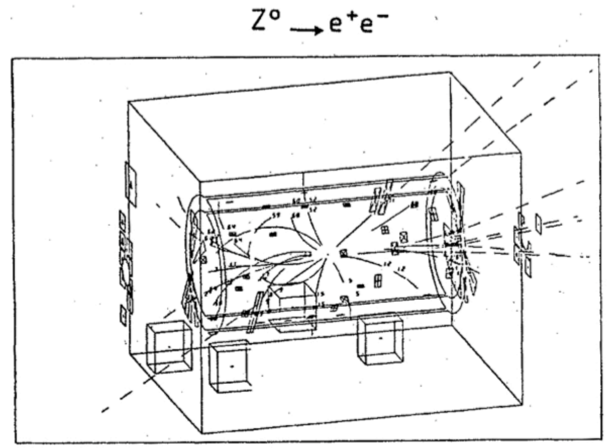


FIG. 25. Event display. All reconstructed vertex-associated tracks and all calorimeter hits are displayed.

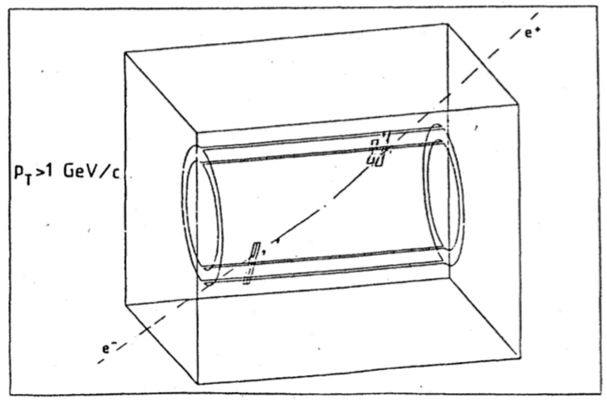
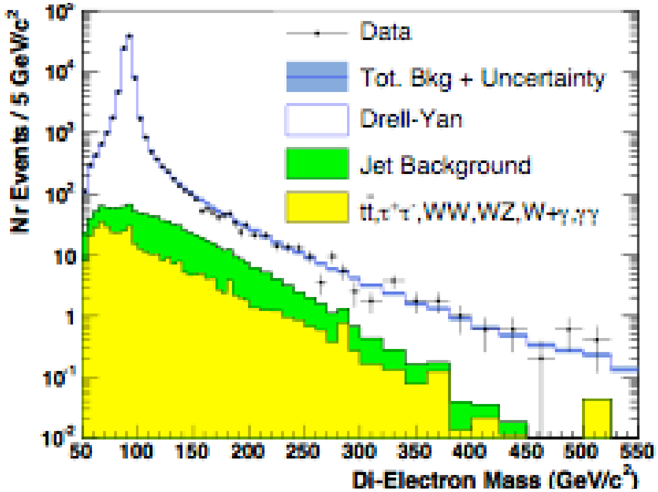


FIG. 26. The same as Fig. 25, but thresholds are raised to $p_T > 2$ GeV/c for charged tracks and $E_T > 2$ GeV for calorimeter hits. Only the electron pair survives these mild cuts.

Top right, All reconstructed tracks and calorimeter hits. Bottom right, tracks with p_T > 2 GeV and calorimeter hits with E_T > 2 GeV. "Experimental observation of lepton pairs of invariant mass around 95 GeV/c^2 at the CERN SPS" *Physics Letters B*, *July 1983*, *Pages 398-410*

Heavy Resonances

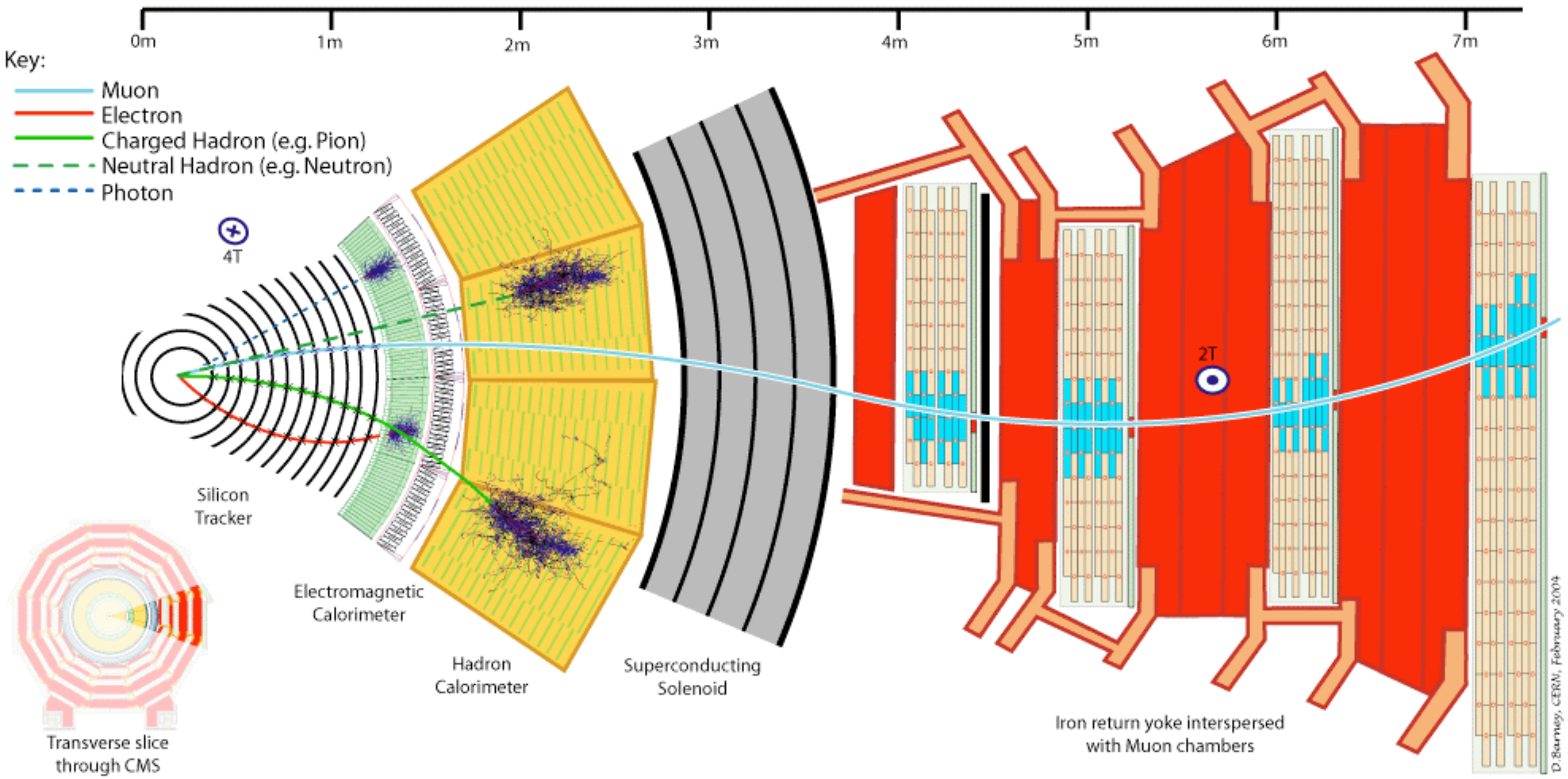
- Many models of physics Beyond the Standard Model predict an excess in the di-electron channel, notably E_6 SSM and RS graviton models
- I tend to take the definition of Rizzo (hep-ph/0610104v1)
  - To an experimenter, a Z' is a resonance, which is more massive than the SM Z, observed in the Drell-Yan process $pp \rightarrow l^+l^- + X$, where $l = e, \mu$



From PRL 99, 171802 (2007) Figure 1.
No events observed above 550 GeV.

- Z ′ with a mass below 923 GeV and the RS graviton with a mass below 807 GeV ($k/M_{pl} = 0.1$) both excluded at the 95% confidence level in 1.3 fb^{-1} of CDF di-electron data (PRL 99, 171802 (2007))
- At the LHC we can expect ~ 50 events in 0.1 fb^{-1} (1 TeV SSM Z')
  - Will we be able to find them?

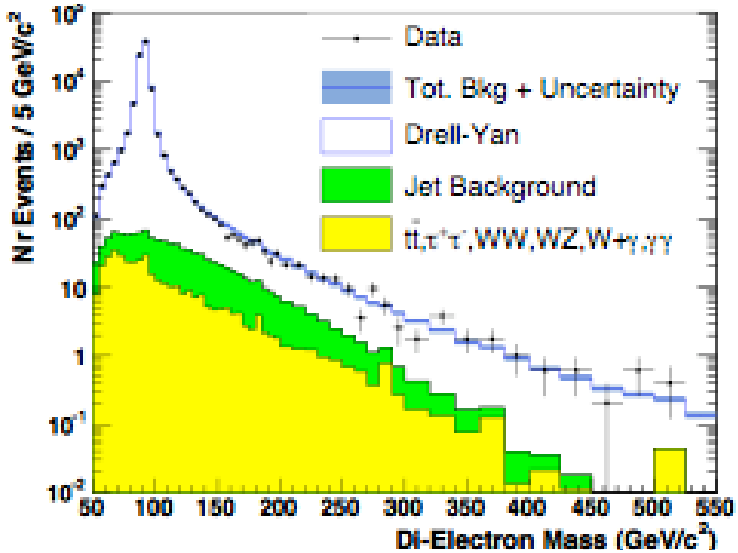
The CMS Detector



Analysis Strategy

- Design an analysis starting from the trigger selecting from three available electromagnetic triggers with no isolation criteria at Level1
  - SingleElectronRelaxed (18)
  - HighEt (80)
  - VeryHighEt (200)

- Utilize robust offline reconstruction and choose cut variables to reject background while retaining good behavior on signal events
- Use the low E_T trigger threshold to include the Z pole in the analysis as a control region, as has been used at CDF (right)

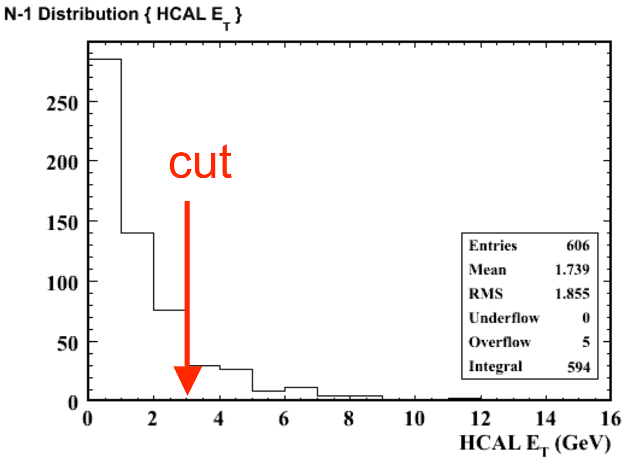


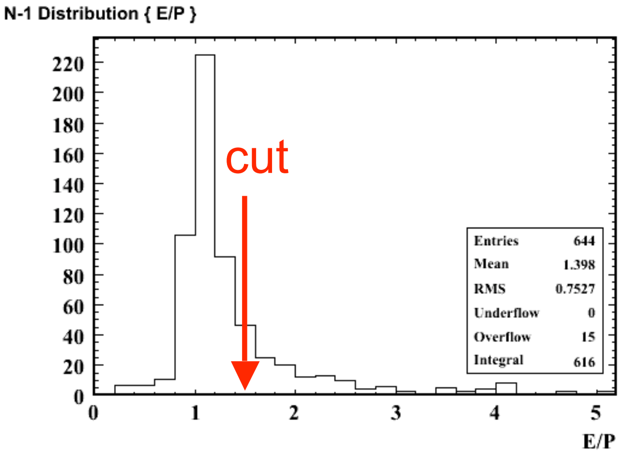
From PRL 99, 171802 (2007) (**CDF**)
Figure 1. No events observed above 550 GeV.

Triggering Issues

N-1 Efficiencies

	W->enu	Z->ee	Z'1000	Z'3000
Et > 18 GeV	0.94 ± 0.0036	0.95 ± 0.0046	1.00 ± 0	1.00 ± 0
H < 3 GeV	0.99 ± 0.0013	0.99 ± 0.0021	0.86 ± 0.013	0.25 ± 0.017
> 0 PixMatch	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
E/P < 1.5 (2.45)	0.85 ± 0.0053	0.89 ± 0.0066	0.80 ± 0.015	0.81 ± 0.03
TrackIso < 0.06	0.97 ± 0.0028	0.98 ± 0.0030	1.00 ± 0.0020	1.00 ± 0





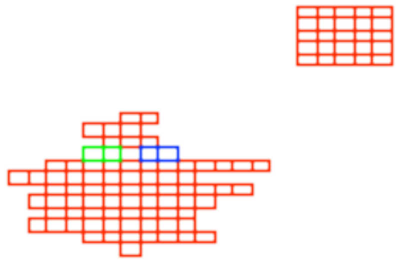
- Improve high energy trigger performance by scaling 'bad' filters with energy. H→H/E, E/P → |1/E-1/p|

Cumulative Efficiency

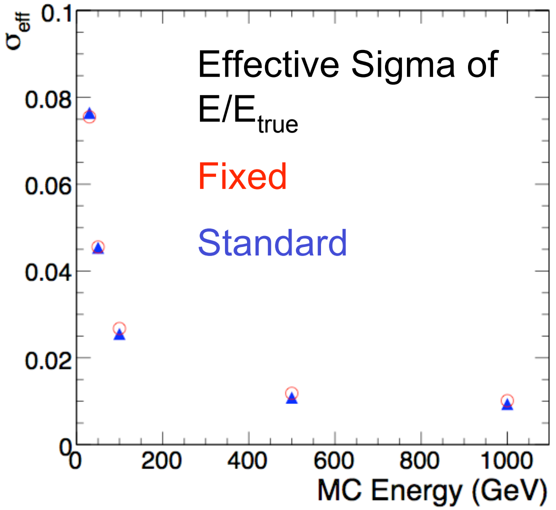
	W->enu	Z->ee	Z'1000	Z'3000
Before fixes	0.64 ± 0.020	0.77 ± 0.10	0.70 ± 0.011	0.23 ± 0.011
After fixes	0.71 ± 0.019	0.82 ± 0.009	0.95 ± 0.005	0.96 ± 0.0052

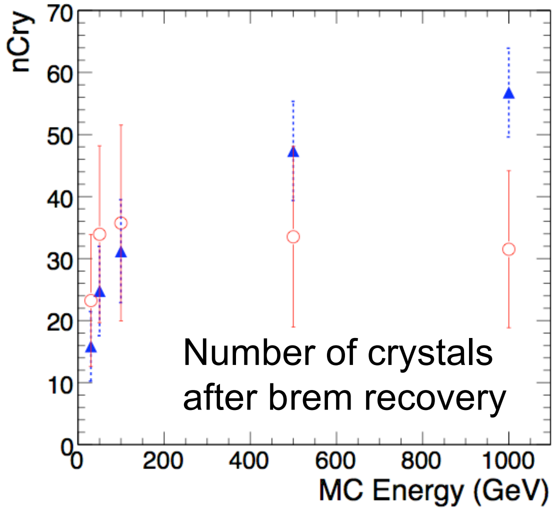
Reconstruction Issues

- Reconstructing energy deposits in the the ECAL over two orders of magnitude with consistent behavior is hard even though we know the EM shower shape is independent of energy
- I have studies a simplified algorithm utilizing fixed size clusters centered on local maxima of energy
- To recover the emission of photons due to bremsstrahlung a dynamic window in the ϕ direction is used



Above, a map of crystals used by the Island and constant size algorithms on a 2 TeV shower



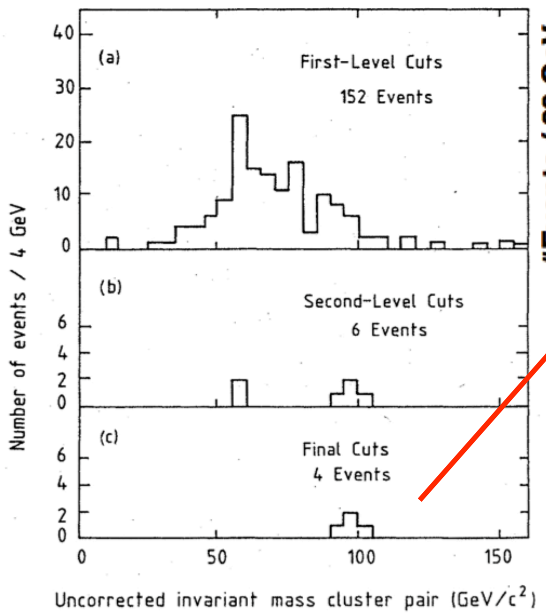


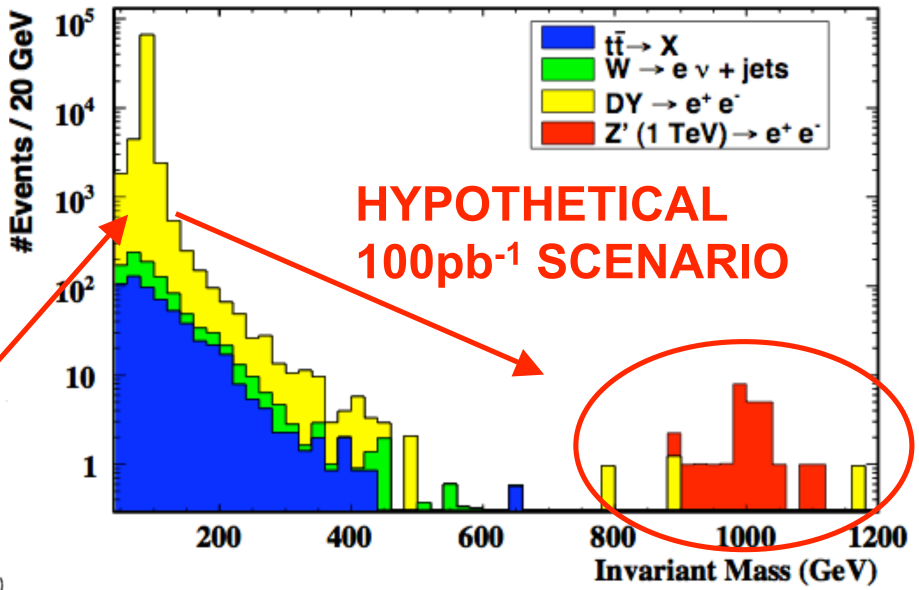
Left, clustering resolution of standard Island algorithm (blue) compared with constant size algorithm (red)

Right, number of crystals used in standard Island algorithm (blue) and constant size algorithm (red)

Outlook

- In July 1983 UA1 published *"Experimental observation of lepton pairs of invariant mass around 95 GeV/c² at the CERN SPS collider"*
- Are we prepared to observe high energy electrons if they are present in the first LHC data?
- With the triggering, reconstruction and data driven techniques discussed the outlook is good



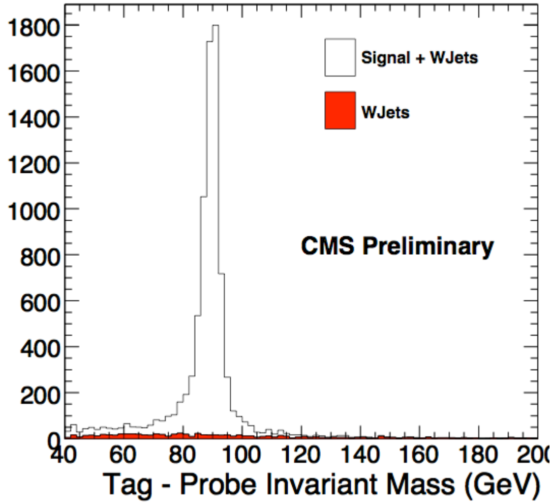


Left, from *Physics Letters B*, *July 1983*, *Pages 398-410 Figure 1*

Right, expected number of events from various sources for a hypothetical 100 pb⁻¹ scenario with a 1 TeV SSM Z' using the trigger described earlier

BACKUP

Efficiency Measurements



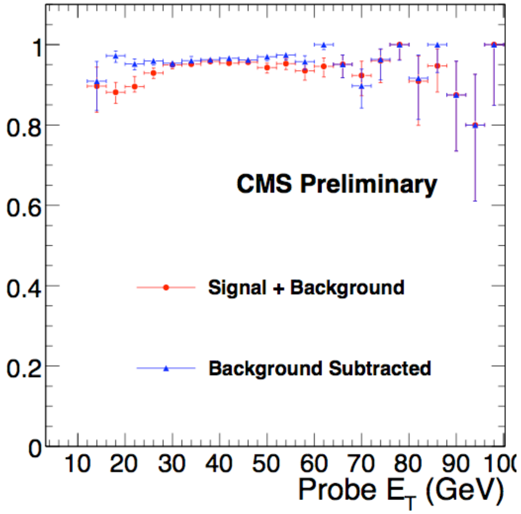


Table 2: Background Estimate for Electron Preselection Efficiency Calculation

Method	Region	N^{PASS}	N_B^{PASS}	N^{TOTAL}	N_B^{TOTAL}
Same-sign	EB	3820 ± 61.8	7 ± 3.7	3969 ± 63.0	49.7 ± 10.0
	EE	1563 ± 39.5	0 ± 1	1710 ± 41.4	14.7 ± 5.4
Side-band	EB	3822 ± 61.8	32.0 ± 5.7	3971 ± 63.0	45.9 ± 6.8
	EE	1564 ± 39.5	10.7 ± 3.3	1711 ± 41.4	17.0 ± 4.2
MC truth	EB	-	25	-	59
	EE	-	5	-	19

- To make a high energy search believable the Standard Model control region must be understood.
- Extensive work with the “Tag and Probe” method in CMS AN 2007/019
- Clearly statistical precision only achievable at the Z pole
  - Essential to use well behaved cut criteria

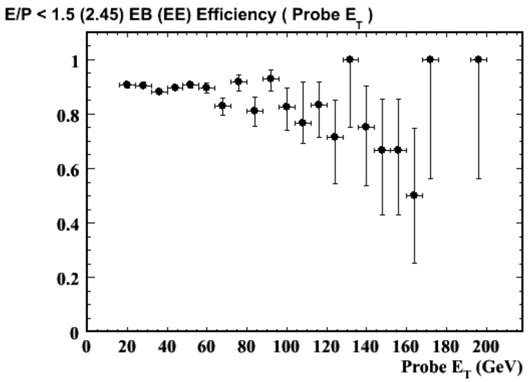
E/P → | 1/E – 1/p |

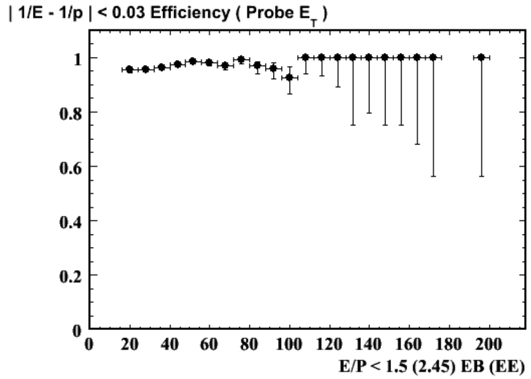
The efficiency of E/P behaves poorly as a function of ET (top right)

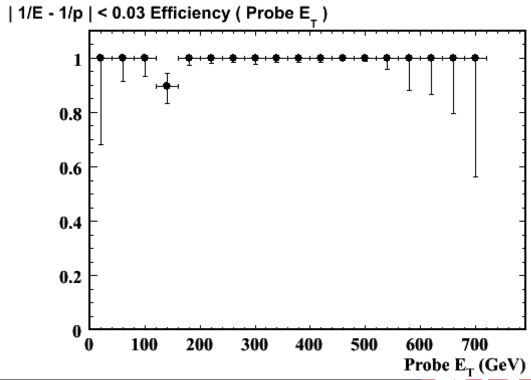
| 1/E – 1/p | presents a method to relax the cut as a function of E and was used in the H → WW analysis CMS Note 2006/047.

Applied with a looser threshold than offline of 0.03 increases the event efficiency and gives better efficiency as a function of ET

Figures Z → ee (middle right) and Z'(1000) → ee (bottom right)





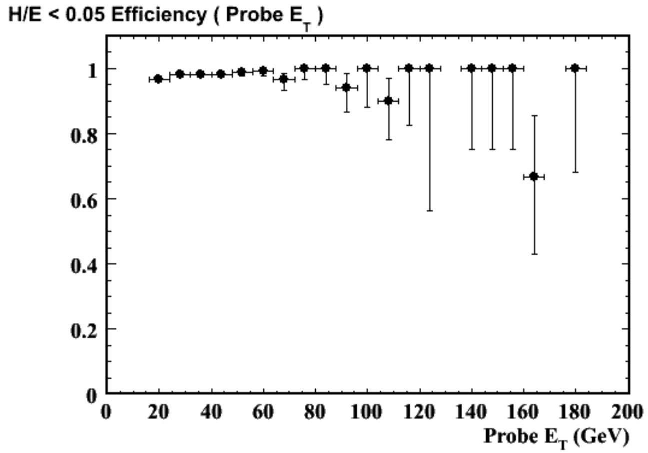


N-1 Efficiencies

	W->enu	Z->ee	Z'1000	Z'3000
E/P < 1.5 (2.45)	0.85 ± 0.0053	0.89 ± 0.0066	0.80 ± 0.015	0.81 ± 0.03
|1/E–1/p| < 0.03	0.95 ± 0.0032	0.97 ± 0.021	1 ± 0.0023	0.99 ± 0.0069

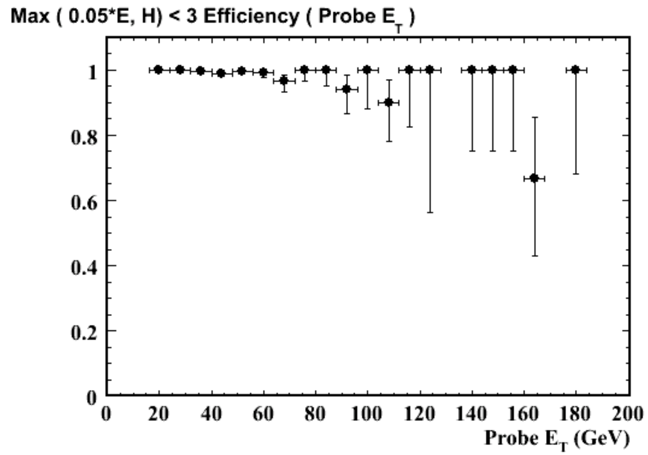
H → H/E

Adjusting HCAL isolation to scale with energy as H/E has already been presented (http://indico.cern.ch/conferenceDisplay.py?confId=16637 M. Mozer) with H/E < 0.05



N-1 Efficiencies

	W->enu	Z->ee	Z'1000	Z'3000
H < 3 GeV	0.99 ± 0.0013	0.99 ± 0.0021	0.86 ± 0.013	0.25 ± 0.017
H/E < 0.05	0.98 ± 0.0023	0.98 ± 0.0030	0.99 ± 0.0046	0.96 ± 0.0076



To resolve the slight drop in low energy efficiency (top right) the condition may be changed (bottom right) such that

(0.05E || H) < 3

If required this or condition can be implemented in two paths

Efficiencies of mods

N-1 Efficiencies

	W->enu	Z->ee	Z'1000	Z'3000
H < 3 GeV	0.99 ± 0.0013	0.99 ± 0.0021	0.86 ± 0.013	0.25 ± 0.017
H/E < 0.05	0.98 ± 0.0023	0.98 ± 0.0030	0.99 ± 0.0046	0.96 ± 0.0076

N-1 Efficiencies

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Cumulative Efficiency

	W->enu	Z->ee	Z'1000	Z'3000
Before fixes	0.64 ± 0.020	0.77 ± 0.10	0.70 ± 0.011	0.23 ± 0.011
After fixes	0.71 ± 0.019	0.82 ± 0.0092	0.95 ± 0.0054	0.96 ± 0.0052

Conclusions on mods

Considering the N-1 efficiency of the filters in the relaxed trigger with the modifications described previously the high energy behaviour is improved while maintaining efficiency at least as good is the unmodified case at low energy. Computing the total cumulative efficiency before and after all fixes I find the same

	W->enu	Z->ee	Z'1000	Z'3000
Before fixes	0.64 ± 0.020	0.77 ± 0.10	0.70 ± 0.011	0.23 ± 0.011
After fixes	0.71 ± 0.019	0.82 ± 0.0092	0.95 ± 0.0054	0.96 ± 0.0052

Using mc-onsel-120_PU_Minbias-OSFDefault-v5 (L1 skimmed) data at Wisconsin I compute a trigger rate of 8.40 ± 1.83 Hz compared to 8.5 Hz from jets for the standard non isolated single electron trigger documented in https://twiki.cern.ch/twiki/bin/view/CMS/SWGuideEgammaHLT.

This is the first step in the development and full validation of an improved isolated single electron HLT. The next step will be the inclusion of this trigger as a CAND trigger.

Trigger Rates/Eff (1_6_7)

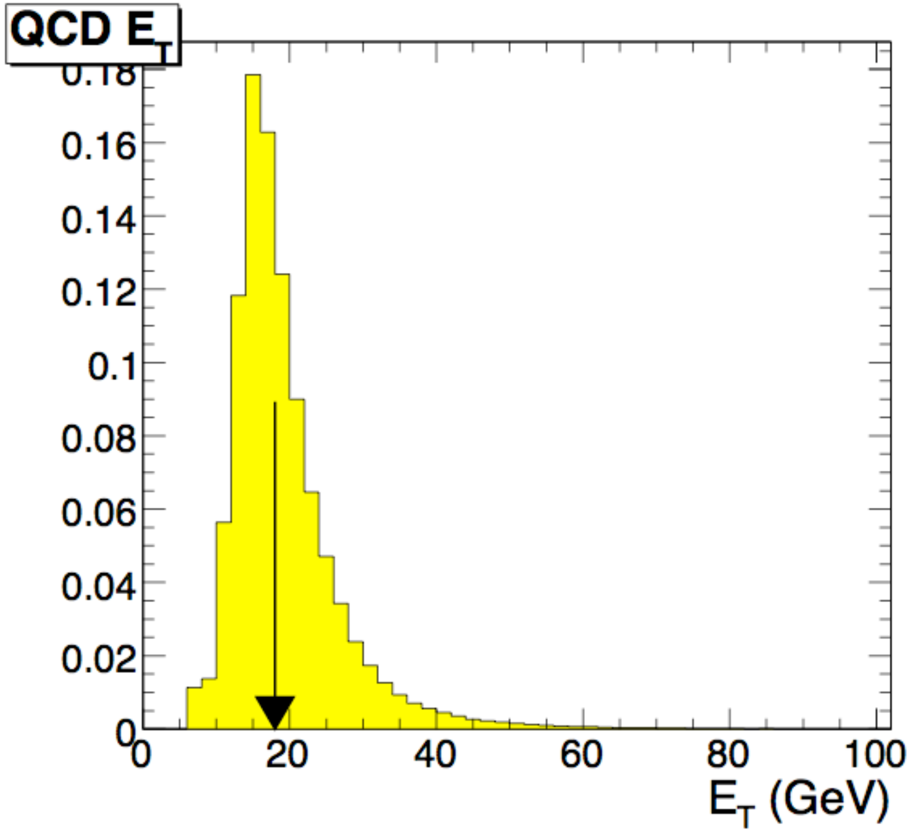
cuts	$W \to e\nu$	$Z \to e^+e^-$	DY(200)	DY(500)	Z′(1TeV)	Z′ (4TeV)	QCD [Hz]
Et >18GeV	91.7%	95.7%	99.5%	99.9%	99.9%	100.0%	628.9
H/E < 0.05 | H < 3 GeV	98.7%	99.5%	99.4%	99.6%	99.7%	99.3%	483.5
> 0 Pixel Match	89.0%	95.0%	97.5%	98.6%	98.6%	98.8%	43.8
|1/E - 1/P| < 0.03	94.7%	97.7%	98.9%	99.5%	99.6%	99.6%	34.8
TrackIso < 0.06	96.9%	98.2%	99.2%	99.7%	99.8%	99.8%	9.1
final numbers	73.9%	86.9%	94.7%	97.3%	97.7%	97.6%	9.1

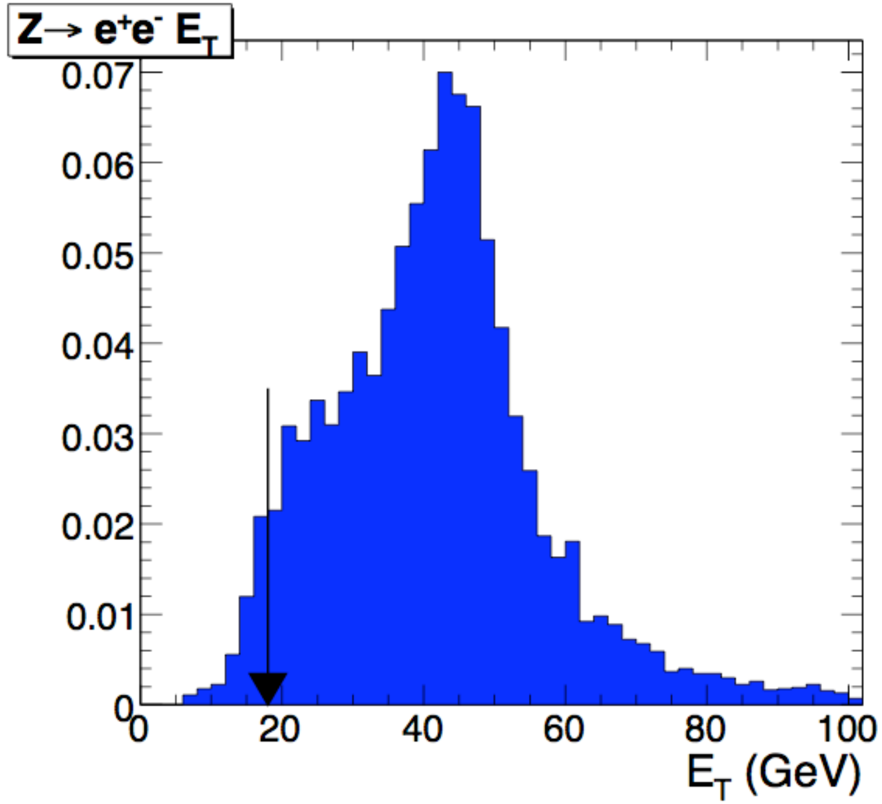
Table 10: sequential, Relaxed with 1/E - 1/p

cuts	$W \to e\nu$	$Z \to e^+e^-$	DY(200)	DY(500)	Z′(1TeV)	Z′ (4TeV)
Et >18 GeV	93.6%	95.7%	99.6%	100.0%	100.0%	100.0%
H/E < 0.05 | H < 3 GeV	99.5%	99.6%	99.5%	99.6%	99.6%	99.1%
> 0 Pixel Match	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
|1/E - 1/P| < 0.03	95.0%	97.6%	99.0%	99.6%	99.7%	99.7%
TrackIso < 0.06	97.0%	98.2%	99.2%	99.7%	99.8%	99.9%

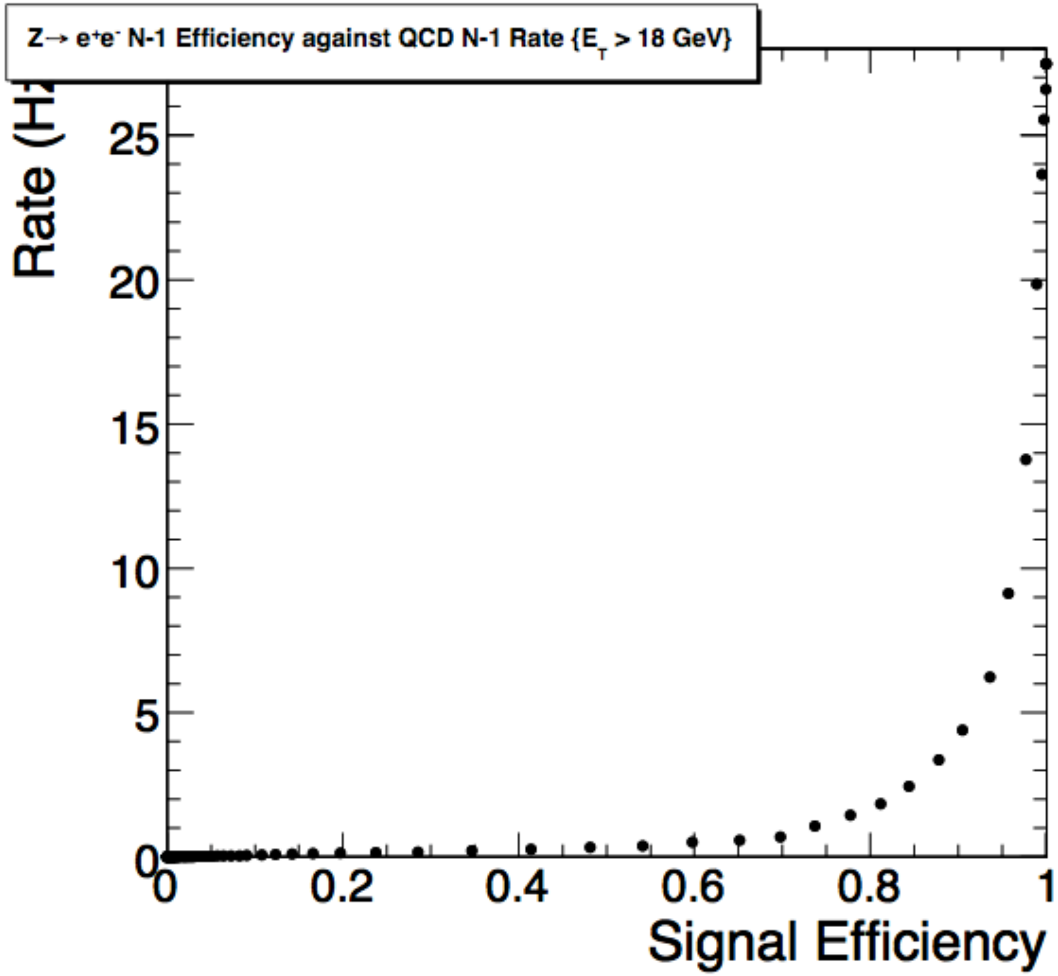
Table 11: n-1, Relaxed with 1/E - 1/p

More Trigger Backup





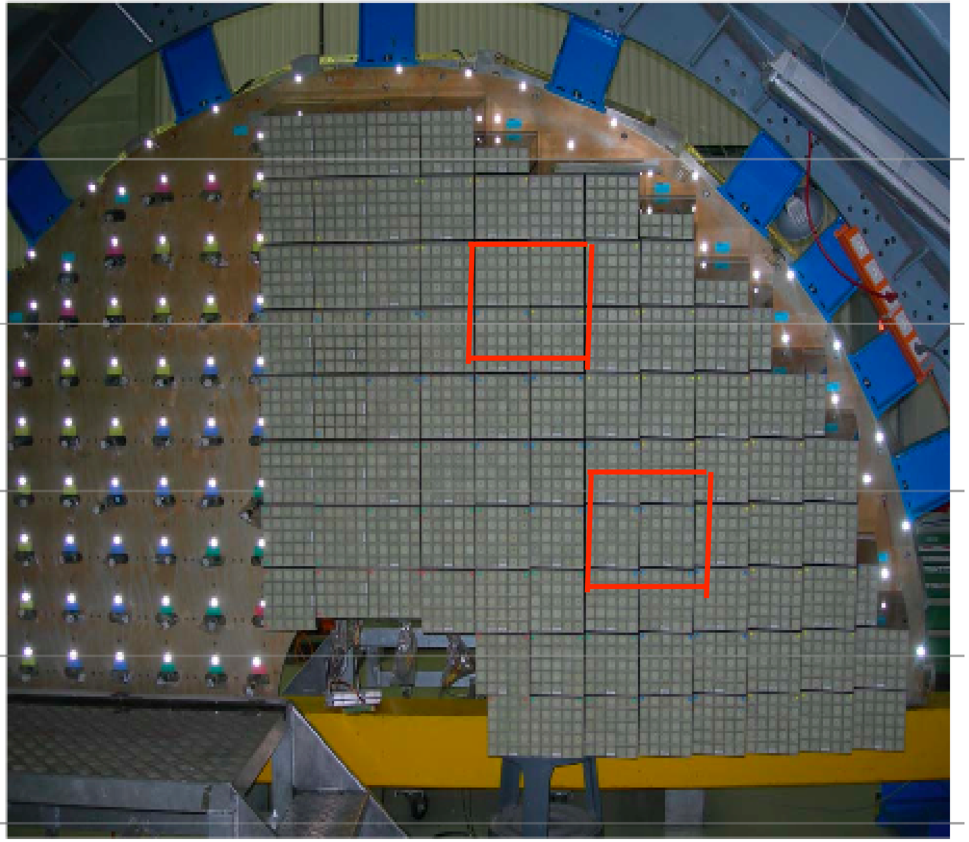
More Trigger Backup



RS Graviton Definitions

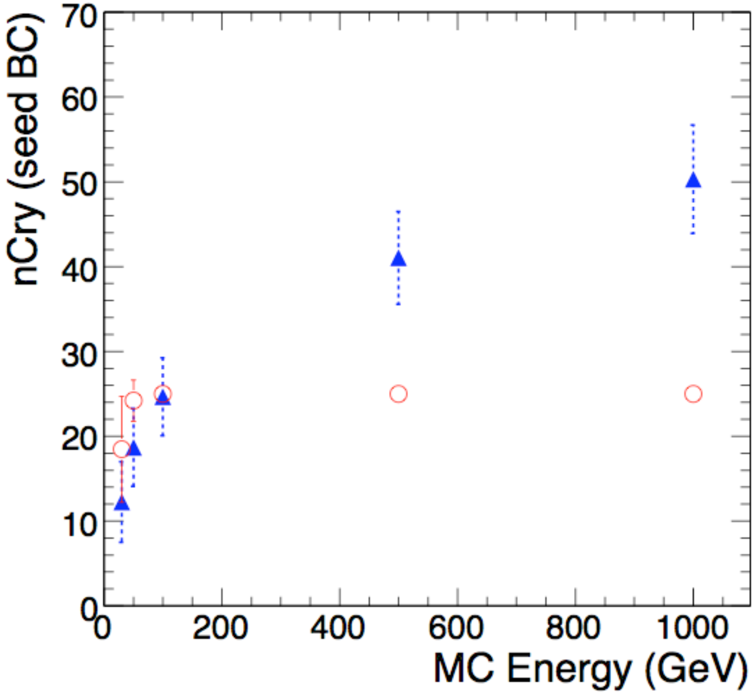
- $k/\bar{M} = 0.1$ for the CDF limits

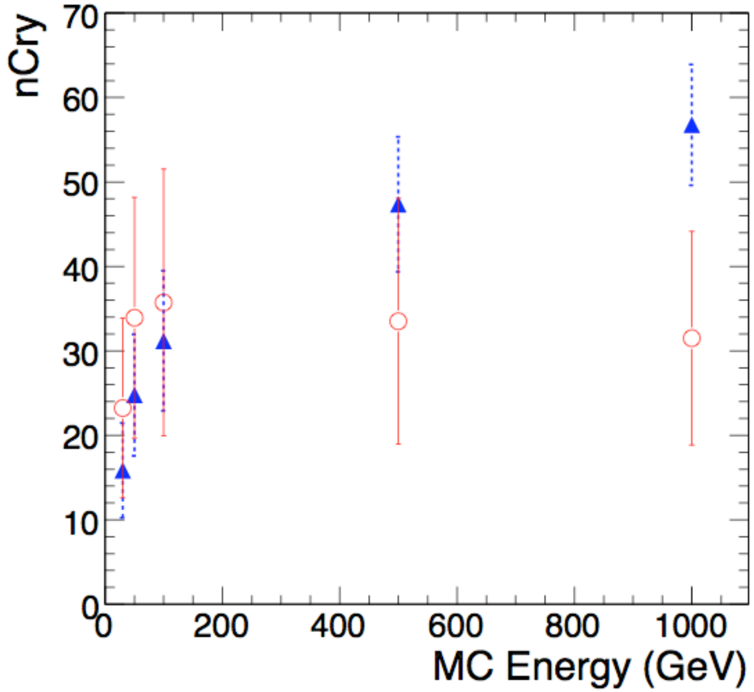
An ECAL Endcap (almost)



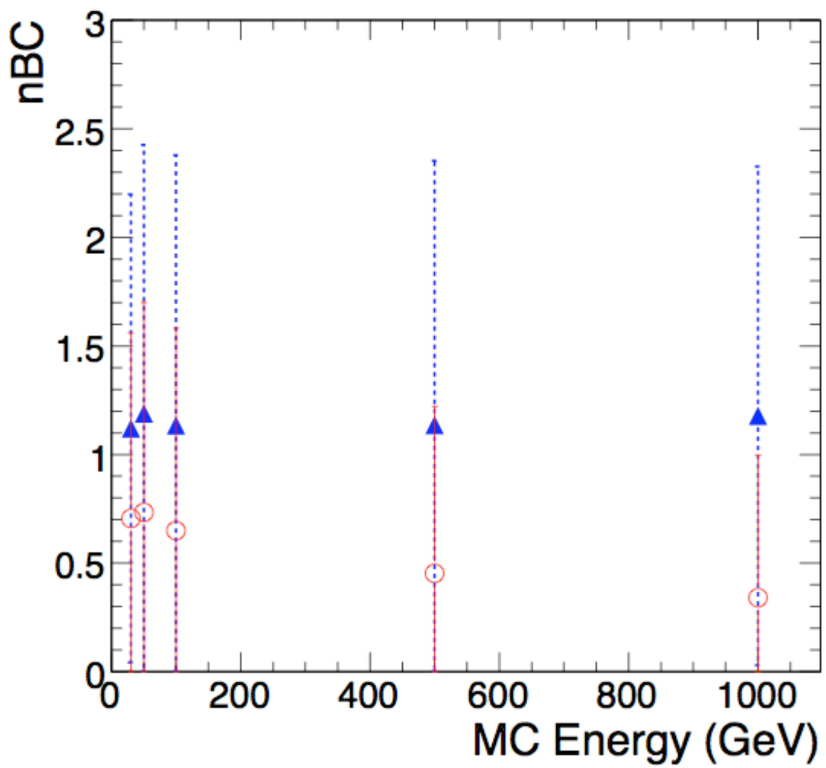
93 SCs on Dee1 (60%)

Endcap Clustering

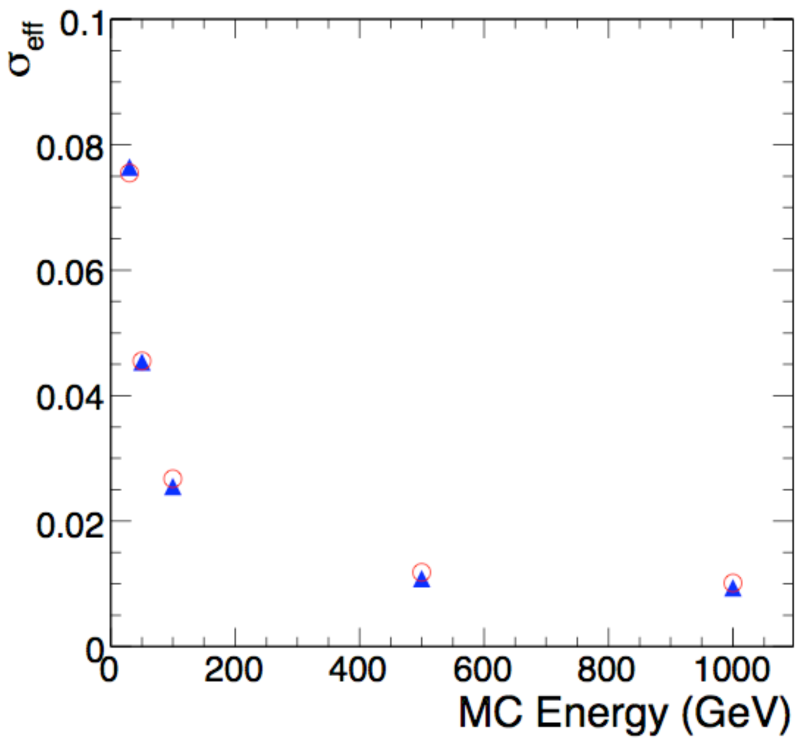


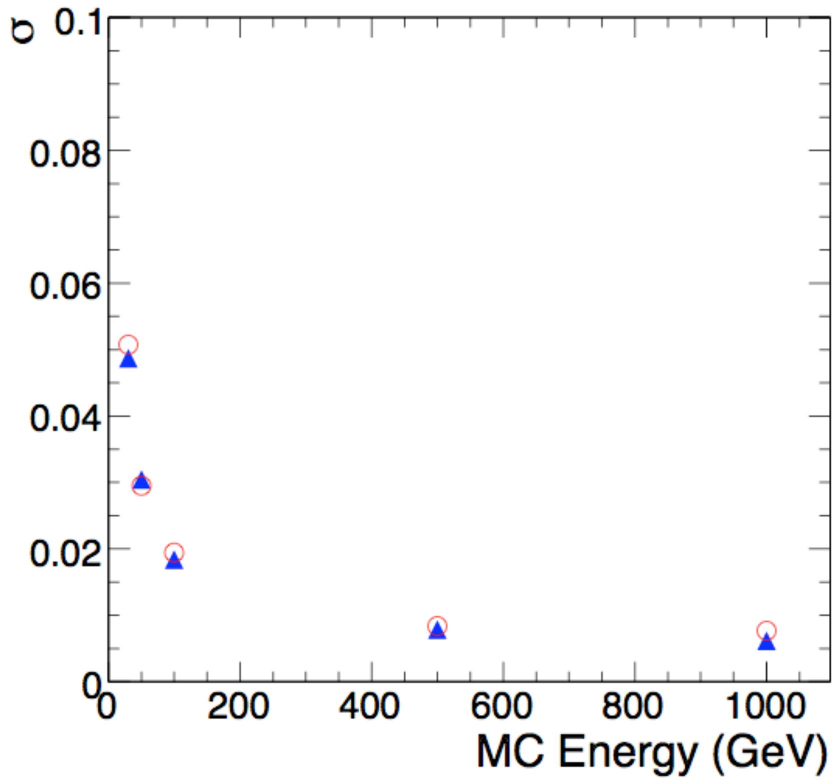


Endcap Clustering II



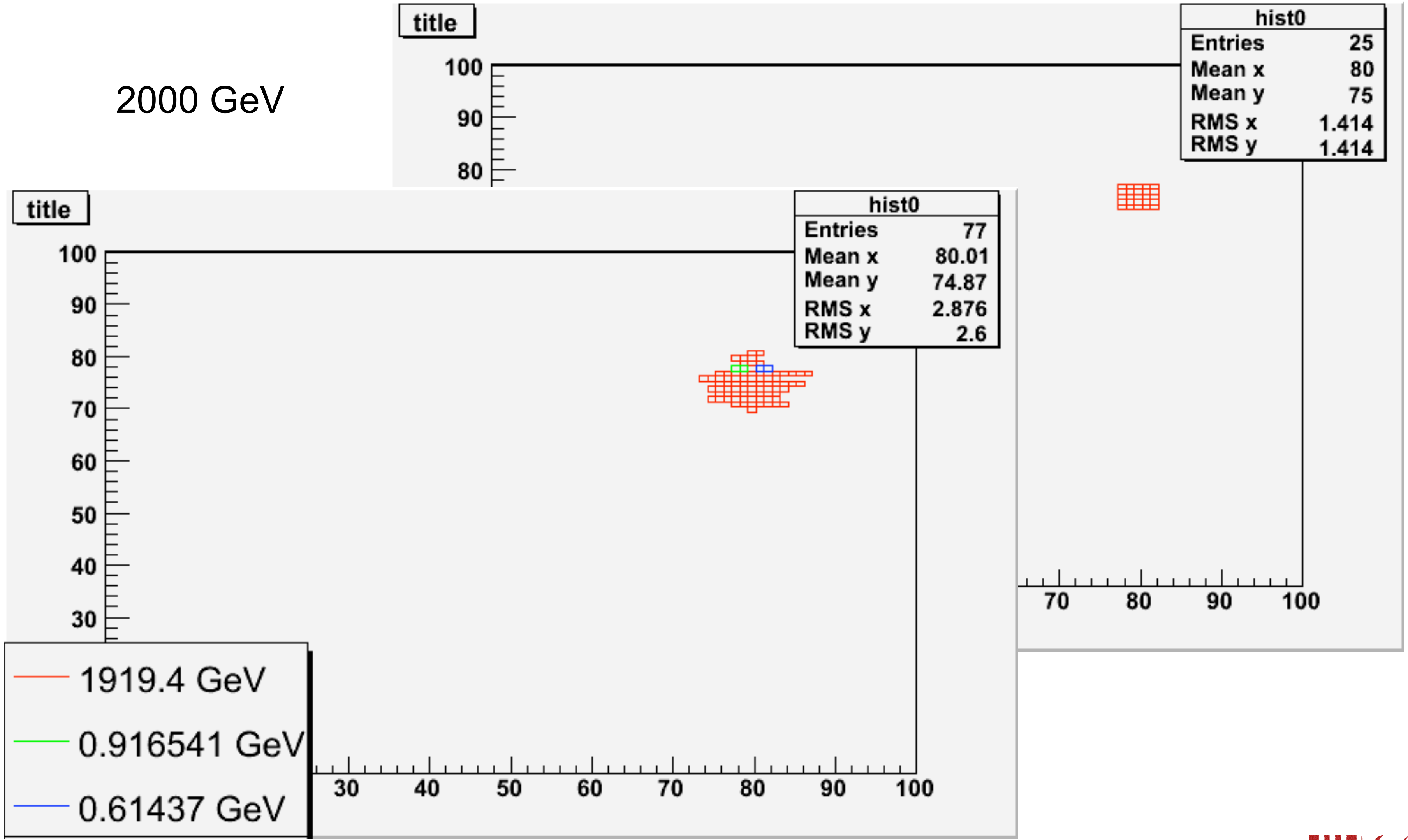
Endcap Clustering III





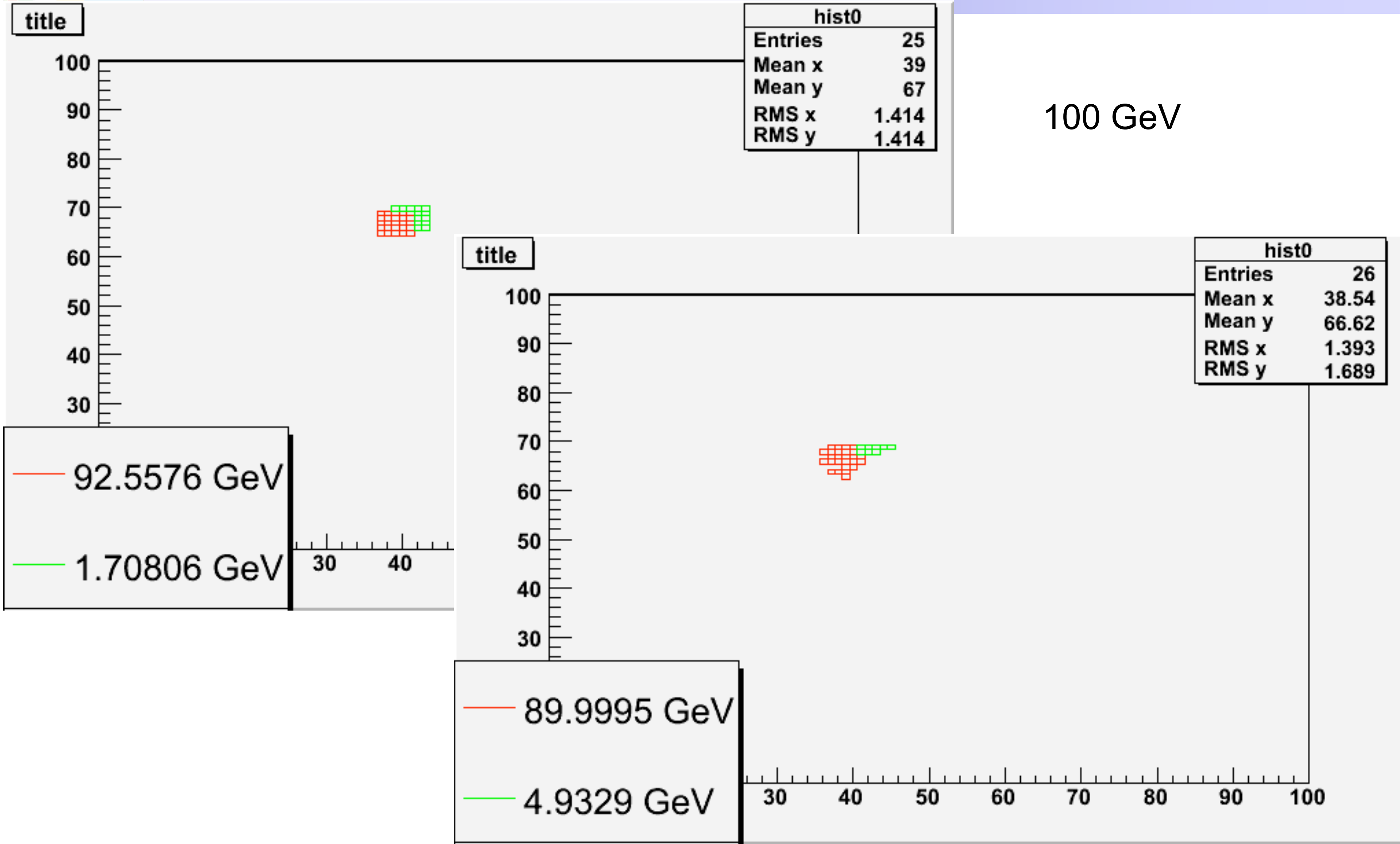
Endcap Clustering IV

2000 GeV



Endcap Clustering V

100 GeV



Offline Selection

Official HEEP Selection v1.1 (Current Version)

Variable	Barrel	Endcap
Et	> 20 GeV	> 20 GeV
Eta ^{sc}	absValue < 1.4442	1.560 < absValue < 2.5
classification	< 40	≥100
Delta Eta_in	absValue < 0.005	absValue < 0.007
Delta Phi_in	absValue < 0.09	absValue < 0.092
HoE	<0.05	<0.08
Sigma Eta Eta	<0.011	<0.0275
EM Isolation	<6+0.01*Et	<6+0.01*Et
Had Isolation	<4+0.005*Et	<4+0.005*Et
Track Isol: Nr Tracks	< 4	<4
Track Isol: Trk Pt /Et^{sc}	<0.2	<0.2