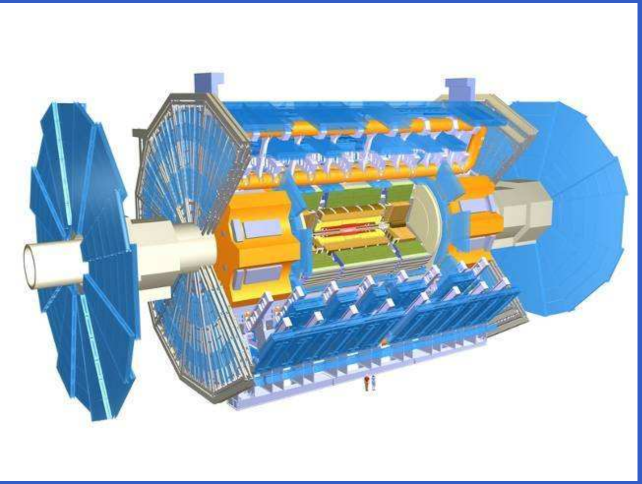
Trigger Strategies for the Charged Higgs Boson (with emphasis on ATLAS)



Chris Potter [for the ATLAS Collaboration]

McGill University, Montreal, Canada

Generic H^+ Trigger Strategy

- The trigger strategy for a search for rare phenomena demands the
  - highest possible signal efficiency with respect to the offline-selected events
  - while keeping the overall trigger rates within acceptable bounds

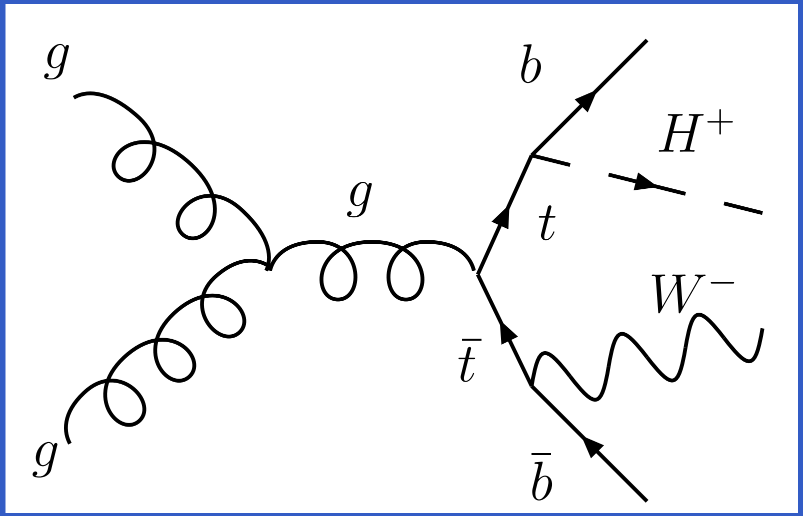
  To this end, we do the following:
- Use unprescaled single object signatures with the lowest threshold when possible. Single object triggers (as opposed to multiple objects AND-ed together) simplify measuring trigger efficiencies from data and applying them to simulation. Prescaled signatures are useless for triggering on rare phenomena since they are inefficient by design.
- Optimize the double object thresholds when double object signatures are necessary. When it is not possible to use single object triggers, one should use the unprescaled double object signatures which maximize the signal efficiency while keeping the rates within reasonable bounds.
- Use the most realistic overall trigger rate estimates possible. When data comes, we will know how to optimize the menu.
- Monitor the performance of the trigger algorithms in the signal simulation closely. Anomalous behavior of triggers in signal simulation should be corrected immediately.

The resulting trigger should be inclusive, to trigger on unknown phenomena, and robust against increasing luminosity.

Lesson from the Tevatron: $H^+ \to t\bar{b}$ Search at DZero

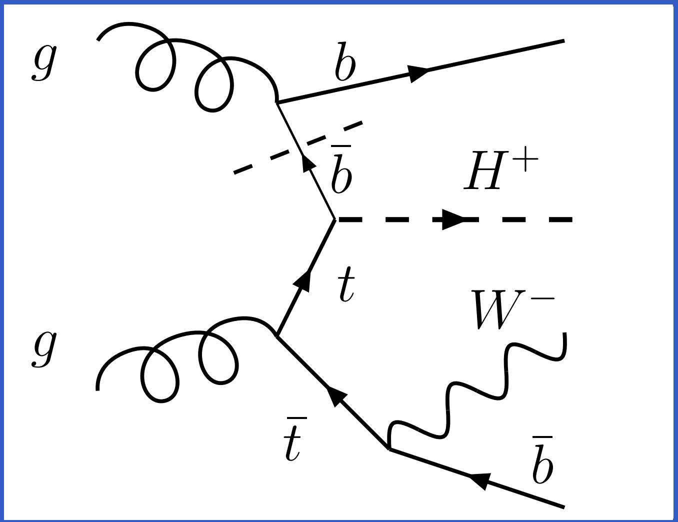
- “Search for charged Higgs bosons decaying to top and bottom quarks in ppbar collisions”, FERMILAB-PUB-08-229-R (arXiv:0807.0859) submitted to PRL. This search for $qq' \to H^+$ production used the single top search infrastructure and the ℓ+jet(s) trigger signature.
- In the e+2jets channel, require one e with $p_T > 15$ GeV plus two jets with rising p_T thresholds to maintain background rejection and bandwidth budget:
  - $p_T^{j1} > 15$ GeV and $p_T^{j2} > 15 GeV$
  - $p_T^{j1} > 20$ GeV and $p_T^{j2} > 20 GeV$
  - $p_T^{j1} > 25$ GeV and $p_T^{j2} > 20 GeV$
  - $p_T^{j1} > 30$ GeV and $p_T^{j2} > 30 GeV$
- In the μ+jet channel, require one μ and one jet with thresholds:
  - $p_T^{\mu} > 0$ GeV and $p_T^{j} > 20$ GeV
  - $p_T^{\mu} > 0$ GeV and $p_T^{j} > 25$ GeV
  - $p_T^{\mu} > 3$ GeV and $p_T^{j} > 30$ GeV
  - $p_T^{\mu} > 3$ GeV (isolated) and $p_T^{j} > 25$ GeV
  - $p_T^{\mu} > 3$ GeV and $p_T^{j} > 35$ GeV
- As instantaneous luminosity increases, the thresholds and isolation criteria will necessarily have to tighten to maintain reasonable trigger rates.

Dominant H^+ Production in the MSSM at the LHC



Light H^+, $H^+ \to \tau^+\nu$.

- Final state depends on W and τ decays.
- Possible final states: $2b + 2\ell + 3\nu$, $2b + 1\ell + 2\nu + \tau_{had}$, $2b + 1\ell + 2\nu + 2j$ and $2b + \tau_{had} + 1\nu + 2j$.
- Heavy $H^+ \to \tau^+\nu$ final states same as for light H^+.



Heavy H^+, $H^+ \to t\bar{b}, \tau^+\nu$.

- $H^+ \to t\bar{b}$ final state depends on W^+ and W^- decays.
- $H^+ \to t\bar{b}$ possible final states: $4b + 2\ell + 2\nu$, $4b + 1\ell + 1\nu + 2j$, $4b + 4j$
- Heavy $H^+ \to \tau^+\nu$ final states same as for light H^+.

LHC Signal Channels and Trigger Objects

Production and Decay	Branching Ratio	ATLAS/CMS Studied	Trigger Objects
$t\bar{t} \longrightarrow 2bW_{lep}\tau_{lep}\nu$	0.076	NO/NO	j,b, e, mu, E_T^{miss}
$t\bar{t} \longrightarrow 2bW_{lep}\tau_{had}\nu$	0.140	YES/YES	j,b, e, mu, tau, E_T^{miss}
$t\bar{t} \longrightarrow 2bW_{had}\tau_{lep}\nu$	0.276	YES/NO	j,b, e,mu,E_T^{miss}
$t\bar{t} \longrightarrow 2bW_{had}\tau_{had}\nu$	0.508	YES/NO	j,b, tau,E_T^{miss}
$tbH^+ \longrightarrow 4bW_{lep}W_{lep}$	0.046	NO/NO	j,b, e,mu,E_T^{miss}
$tbH^+ \longrightarrow 4bW_{lep}W_{had}$	0.338	YES/YES	j,b, e,mu,E_T^{miss}
$tbH^+ \longrightarrow 4bW_{had}W_{had}$	0.611	NO/NO	j,b
$tbH^+ \longrightarrow 2bW_{lep}\tau_{lep}\nu$	0.076	NO/NO	j,b,e,mu,E_T^{miss}
$tbH^+ \longrightarrow 2bW_{lep}\tau_{had}\nu$	0.140	NO/NO	j,b,e,mu,tau,E_T^{miss}
$tbH^+ \longrightarrow 2bW_{had}\tau_{lep}\nu$	0.276	NO/NO	j,b,e,mu,E_T^{miss}
$tbH^+ \longrightarrow 2bW_{had}\tau_{had}\nu$	0.508	YES/YES	j,b,tau,E_T^{miss}

ATLAS and CMS H^+ Trigger Studies (Light H^+)

- CMS Light $H^+ \to \tau^+\nu$: CMS Note 2006/056 (M. Baarmand, M. Hashemi, A. Nikitenko)
  - Final state $2bW_{lep}\tau_{had}\nu$. Single lepton trigger at HLT: $p_T > 29$ GeV for electrons and $p_T > 19$ GeV for muons. Isolation for muons.
  - HLT and L1 rates at 2×10^{33} luminosity (from CMS TS-2007/005, M. Hashemi PhD):

Object	Threshold [GeV]	HLT Rate [Hz]
e	29	33
μ	19	25

  - L1 and HLT gives efficiencies $0.48 - 0.50$ for $m_{H^+} = 150 - 170$ GeV.
- ATLAS Light $H^+ \to \tau^+\nu$: CERN-OPEN-2008-020, to appear (ATLAS)
  - Final states $2bW_{lep}\tau_{had}$, $2bW_{had}\tau_{had}$ and $2bW_{had}\tau_{lep}$. Signatures considered are single lepton, E_T^{miss} and combinations of the two.
  - Trigger rate estimates:

10^{33} Signature	Rate [Hz]
e25i+xe30	10 ± 10
mu20+xe30	20 ± 15

  - Signal efficiencies for L1 and HLT are $0.35 - 0.61$ for three final states and $m_{H^+} = 130$ GeV.

ATLAS and CMS H^+ Trigger Studies (Heavy $H^+ \to \tau^+\nu$)

- CMS Heavy $H^+ \to \tau^+\nu$: CMS Note 2006/100 (R. Kinnunen)
  - Final state $2bW_{had}\tau_{had}$. Single τ-jet trigger at L1, in HLT require $E_T^{miss} > 67$ GeV, isolation and leading track $p_T > 25$ GeV.
  - No trigger rate estimates.
  - L1 and HLT gives efficiencies $0.09 - 0.41$ for $m_{H^+} = 170 - 600$ GeV.
- ATLAS Heavy $H^+ \to \tau^+\nu$: CERN-OPEN-2008-020, to appear (ATLAS)
  - Final state $2bW_{had}\tau_{had}$ (same as CMS). Possible triggers are τ-jet plus E_T^{miss} and τ-jet plus E_T^{miss} plus three jets.
  - L1 and HLT rate estimates:

10^{31} Signature	Rate [Hz]	10^{33} Signature	Rate [Hz]
tau20i+xe30	5.8 ± 0.8	tau35i+xe50	< 10
tau15i+xe20+3j18	5.4 ± 0.8	tau35i+xe40+3j18	< 10

  - L1 and HLT signal efficiencies $0.21 - 0.39$ for $m_{H^+} = 170 - 600$ GeV.

ATLAS and CMS H^+ Trigger Studies (Heavy $H^+ \to t\bar{b}$)

- CMS Heavy $H^+ \to t\bar{b}$: CMS Note 2006/109 (S. Lowette and J. D'Hondt)
  - Final state $4bW_{lep}W_{had}$. Single lepton trigger at HLT: $p_T > 29$ GeV for electrons and $p_T > 19$ GeV for muons.
  - HLT and L1 rates at 2×10^{33} luminosity (from CMS TS-2007/003, S. Lowette PhD):

Object	Threshold [GeV]	HLT Rate [Hz]
e	29	23.5
μ	19	25.8

  - L1 and HLT give efficiencies 0.16 for $m_{H+} = 260 - 500$ GeV.
- ATLAS Heavy $H^+ \to t\bar{b}$: CERN-OPEN-2008-020, to appear (ATLAS)
  - Final state $4bW_{lep}W_{had}$. Single lepton trigger in combination with E_T^{miss}.
  - L1 and HLT rate estimates:

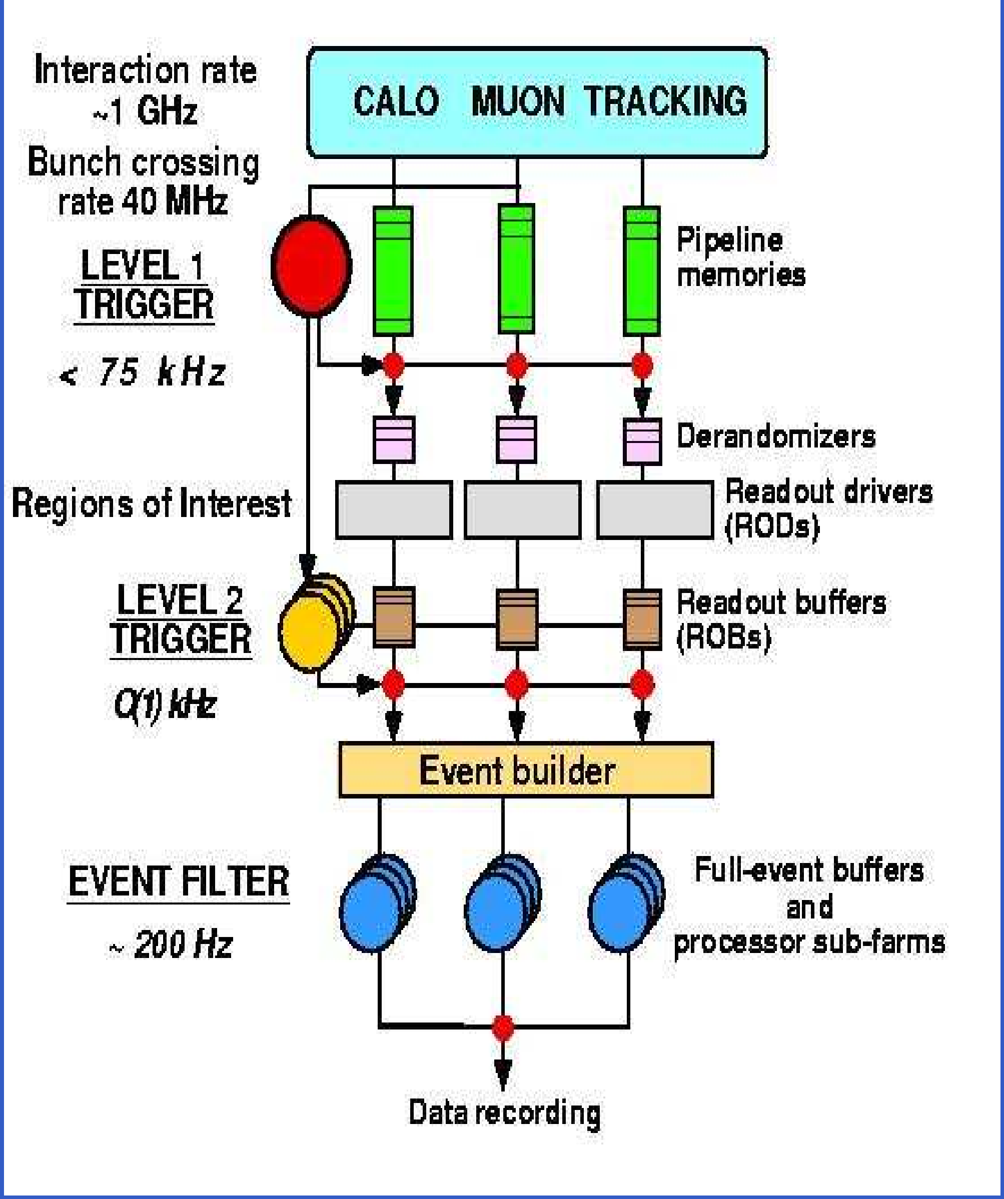
10^{33} Signature	Rate [Hz]
e25i+xe30	10 ± 10
mu20+xe30	20 ± 15

  - Signal efficiencies $0.61 - 0.75$ for $m_{H+} = 200 - 600$ GeV.

The ATLAS Trigger

- The ATLAS trigger is designed to reduce the bunch crossing rate of 40 MHz down to 200 Hz.
- This is achieved through a system based on three online selection levels (LVL1 in hardware, LVL2 and EF in software).
- The ATLAS trigger includes functionality for identifying electrons, muons, hadronically decaying taus, jets, b-jets and E_T^{miss} allowing for a robust and flexible trigger menu.

See ATLAS trigger talks from F. Winkelmeier and R. Brenner.



ATLAS H^+ Trigger Menu

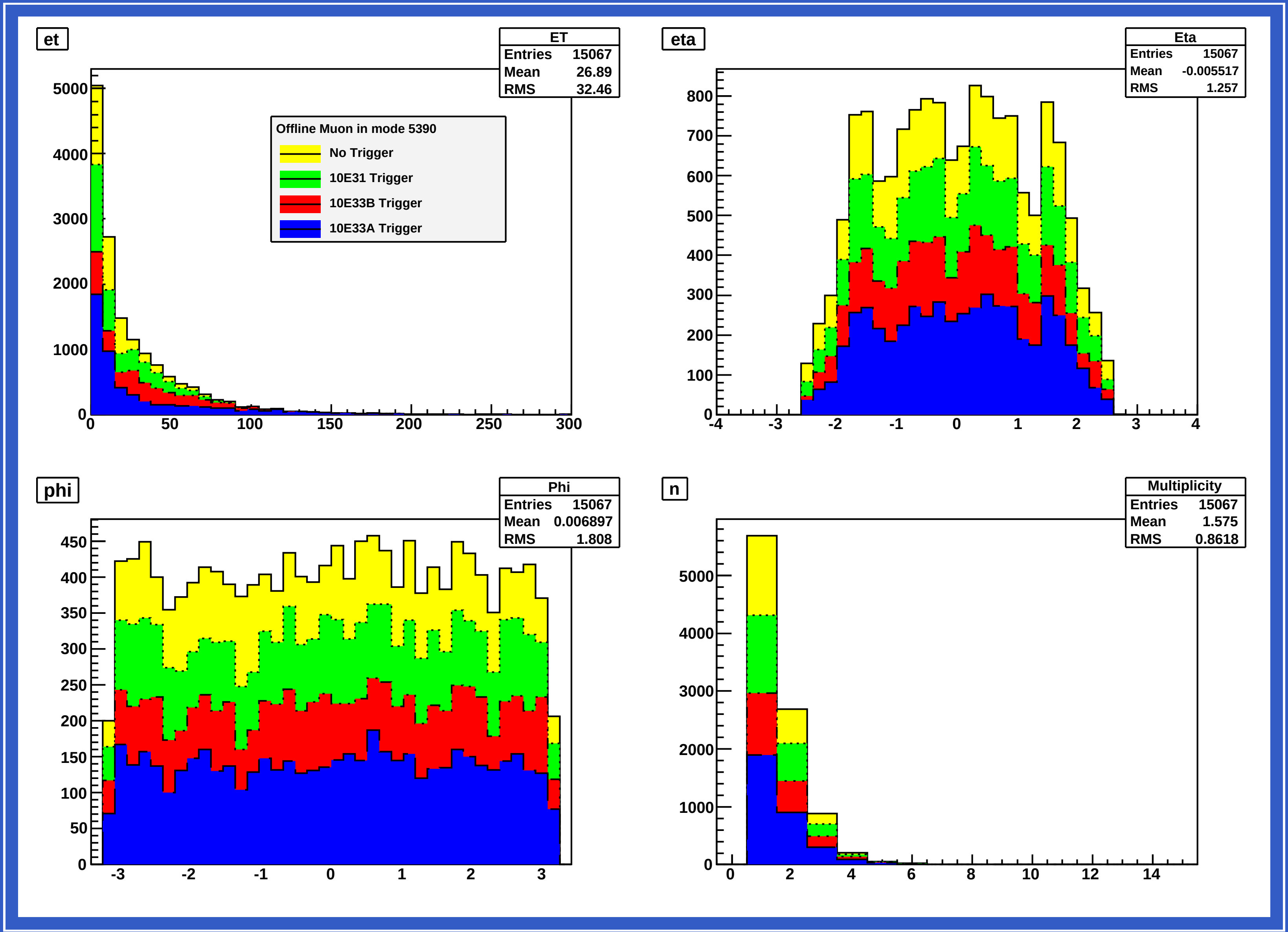
Considerations for each channel:

- The $tbH^+ \to 4bW_{lep}W_{had}$, $t\bar{t} \to 2bW_{lep}\tau_{had}\nu$ and $t\bar{t} \to 2bW_{had}\tau_{lep}\nu$ analyses can reliably depend on electron and muon signatures at lower luminosities.
- At higher luminosities, these single-object triggers may have thresholds which are too high for these signal modes, and consequently double-object triggers will have to be employed.
- The $tbH^+_{400} \to 2bW_{had}\tau_{had}\nu(p)$ and $\bar{t}bH^+_{130} \to 2bW_{had}\tau_{had}\nu$ analyses will require hadronic tau and missing E_T signatures.
- Multiple jet triggers ($3j$ and $4j$), as well as b-tag triggers, may also prove useful for all of these analyses, though unprescaled jet triggers will necessarily have fairly high thresholds.
- Since the unprescaled single tau and E_T^{miss} signatures have thresholds which are simply too high to retain even a modest signal efficiency, these modes will require double-object triggers.

Proposed trigger menus one for low luminosity running ($\mathcal{L} = 10^{31}$ cm^{-2} s^{-1}) and two for high luminosity running ($\mathcal{L} = 10^{33}$ cm^{-2} s^{-1}):

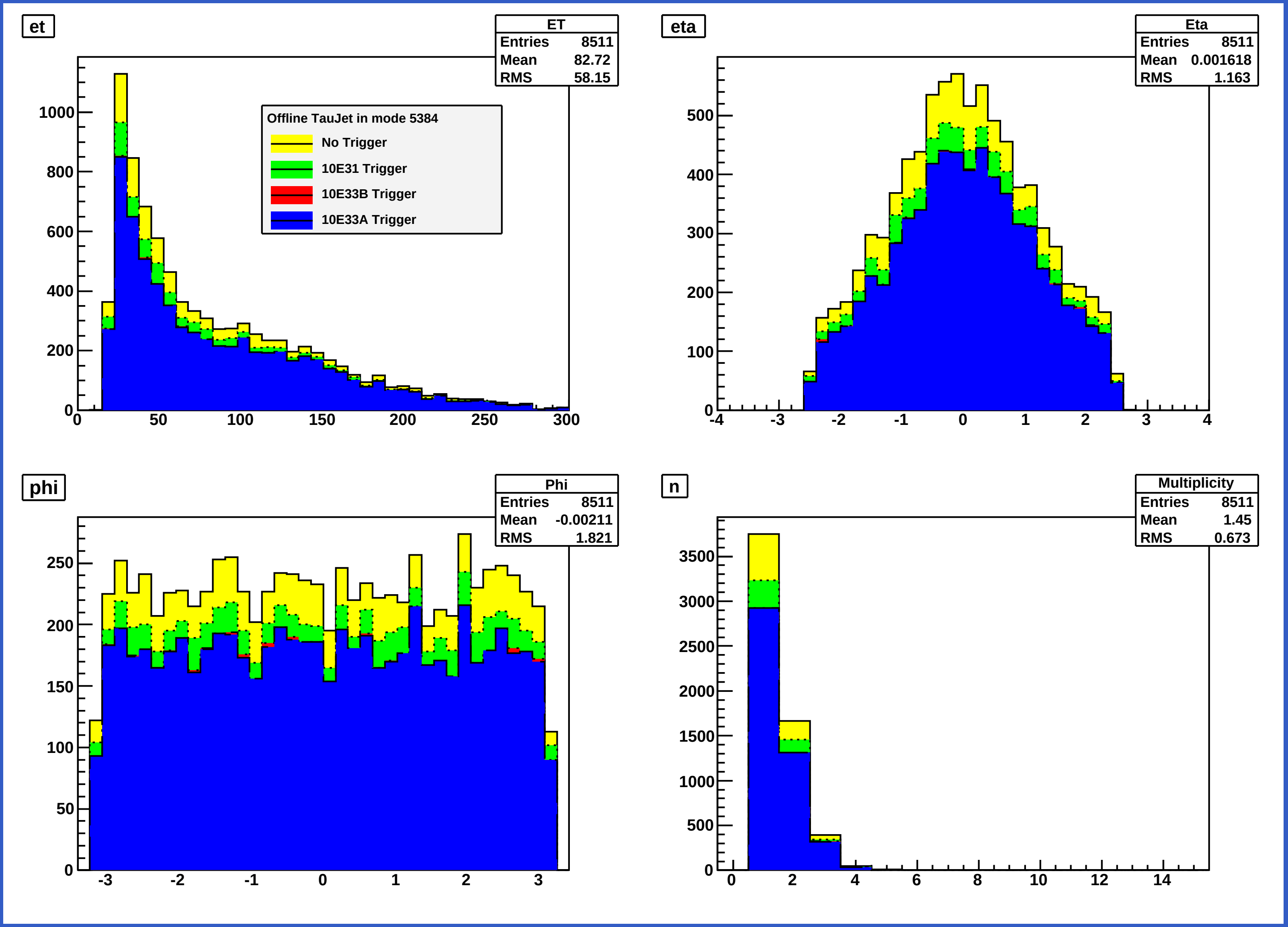
- 10^{31} Menu: xe70 OR e25i tight OR mu20 OR tau20i+xe30 OR tau15i+xe20+3j18
- $10^{33}A$ Menu: xe80 OR e55 OR mu40 OR tau35i+xe50 OR tau35i+xe40+3j18
- $10^{33}B$ Menu: xe80 OR e25i+xe30 OR mu20+xe30 OR tau35i+xe50 OR tau35i+xe40+3j18

Offline Muon Distributions in Signal Simulation



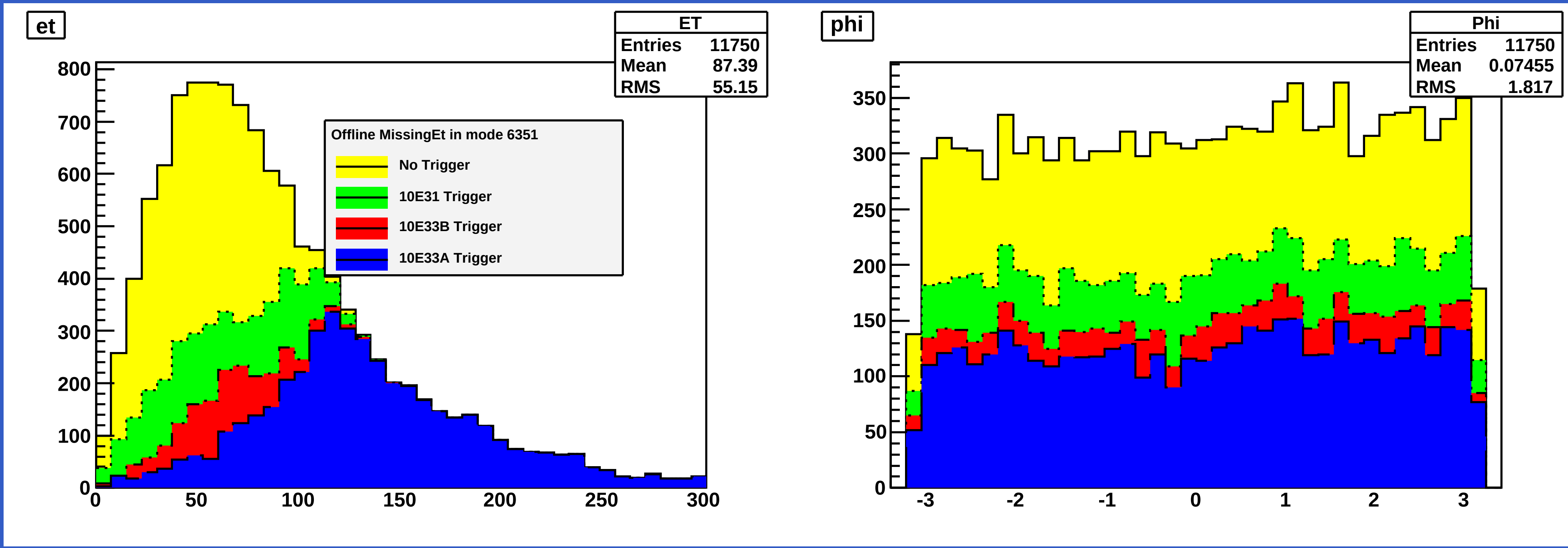
Heavy H^{+}_{250} with final state $4bW_{lep}W_{had}$ *offline* muon distributions before and after applying the trigger menus. Plotted are η, ϕ, E_T and multiplicity. No bias, other than threshold effects, is evident after applying the trigger menu.

Offline Tau Distributions in Signal Simulation



Heavy H^{+}_{400} with final state $2bW_{had}\tau_{had}\nu$ *offline* tau distributions before and after applying the 10^{31}, $10^{33}A$ and $10^{33}B$ trigger. Plotted are η, ϕ, E_T and multiplicity. No bias, other than threshold effects, is evident after applying the trigger menu.

Offline E_T^{miss} Distributions in Signal Simulation



Light H^+ with final state $2bW_{had}\tau_{lep}\nu$ *offline* E_T^{miss} distributions before and after applying the 10^{31}, $10^{33}A$ and $10^{33}B$ trigger. Plotted are E_T and ϕ. No bias, other than threshold effects, is evident after applying the trigger menu.

ATLAS H^+ Trigger Menu Rate Estimates

10^{31} Signature	Rate/Hz	10^{33} Signature	Rate/Hz
xe70	0.2 ± 0.1	xe80	< 10
e25i tight	0.7 ± 0.3	e55	10 ± 10
		e25i+xe30	10 ± 10
mu20	1.7 ± 0.4	mu40	10 ± 10
		mu20+xe30	20 ± 15
tau20i+xe30	5.8 ± 0.8	tau35i+xe50	< 10
tau15i+xe20+3j18	5.4 ± 0.8	tau35i+xe40+3j18	< 10

The proposed trigger menus and estimated rates for $\mathcal{L} = 10^{31}$ cm^{-2} s^{-1} and $\mathcal{L} = 10^{33}$ cm^{-2} s^{-1}. Rates are only preliminary estimates obtained with high statistics, fully simulated minimum-bias events.

Proposed trigger menus one for low luminosity running ($\mathcal{L} = 10^{31}$ cm^{-2} s^{-1}) and two for high luminosity running ($\mathcal{L} = 10^{33}$ cm^{-2} s^{-1}):

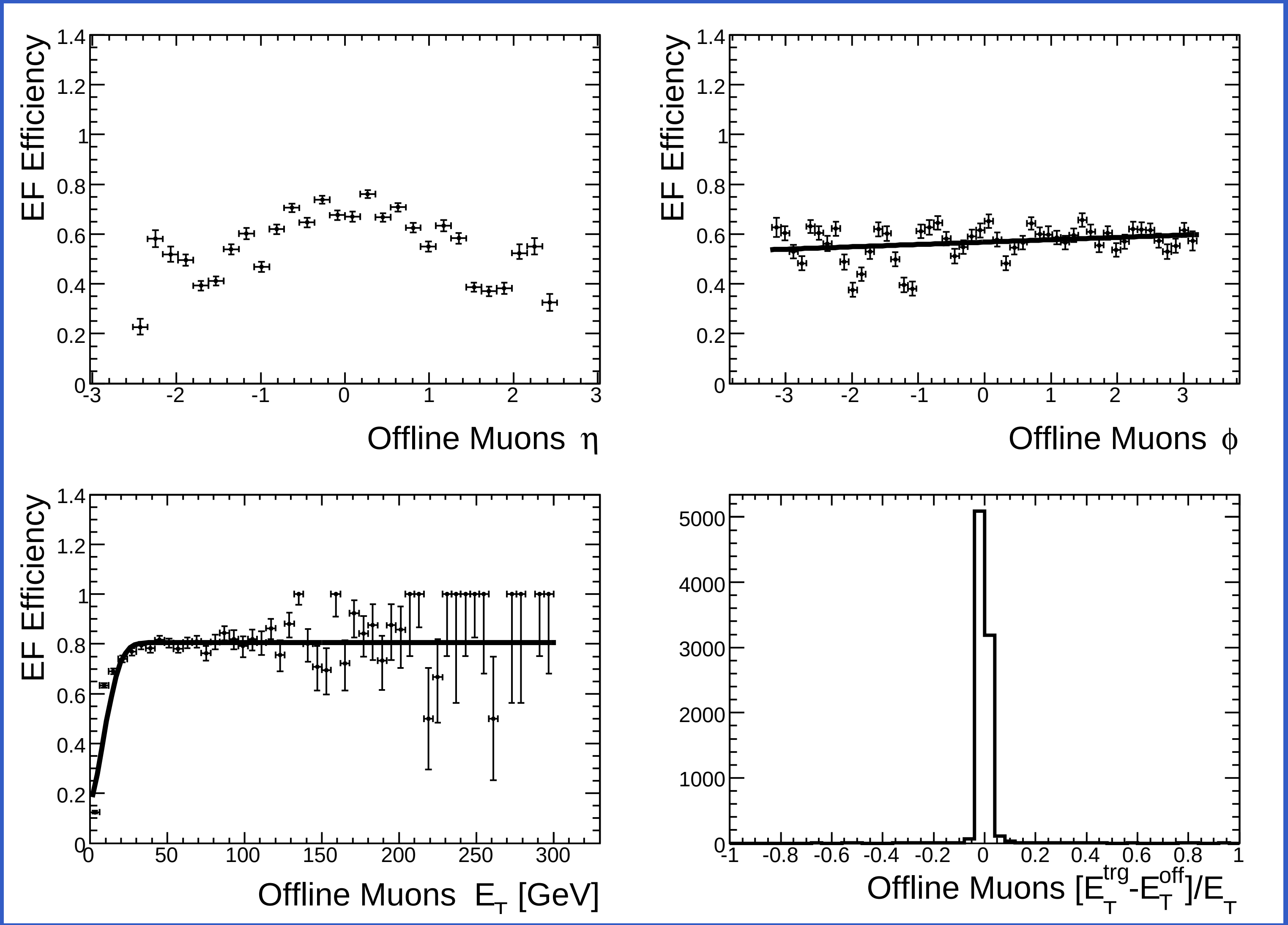
- 10^{31} Menu: xe70 OR e25i tight OR mu20 OR tau20i+xe30 OR tau15i+xe20+3j18
- $10^{33}A$ Menu: xe80 OR e55 OR mu40 OR tau35i+xe50 OR tau35i+xe40+3j18
- $10^{33}B$ Menu: xe80 OR e25i+xe30 OR mu20+xe30 OR tau35i+xe50 OR tau35i+xe40+3j18

10^{33} B Menu Efficiencies in Signal Simulation

Mode	xe80	e25i+ xe30	mu20i+ xe30	tau35i+ xe50	tau35i+ xe40+3j20	H^+ 1E33B
Before Offline Selection						
$tbH^+_{400} \rightarrow 2bW_{had}\tau_{had}\nu$	0.69	0.01	0.03	0.36	0.35	0.78
$\bar{t}bH^+_{130} \rightarrow 2bW_{had}\tau_{had}\nu$	0.25	0.01	0.02	0.11	0.14	0.35
$tbH^+_{250} \rightarrow 4bW_{lep}W_{had}$	0.19	0.17	0.25	0.07	0.10	0.49
$\bar{t}bH^+_{130} \rightarrow 2bW_{had}\tau_{lep}\nu$	0.34	0.09	0.14	0.06	0.07	0.47
$\bar{t}bH^+_{130} \rightarrow 2bW_{lep}\tau_{had}\nu$	0.29	0.21	0.24	0.23	0.24	0.61
After Offline Selection						
$tbH^+_{400} \rightarrow 2bW_{had}\tau_{had}\nu$	0.96	0.00	0.02	0.58	0.57	0.97
$\bar{t}bH^+_{130} \rightarrow 2bW_{had}\tau_{had}\nu$	0.16	0.00	0.06	0.31	0.36	0.45
$tbH^+_{250} \rightarrow 4bW_{lep}W_{had}$	0.23	0.25	0.37	0.10	0.14	0.63
$\bar{t}bH^+_{130} \rightarrow 2bW_{had}\tau_{lep}\nu$	1.00	0.14	0.18	0.14	0.14	1.00
$\bar{t}bH^+_{130} \rightarrow 2bW_{lep}\tau_{had}\nu$	1.00	0.25	0.62	0.50	0.38	1.00

Estimated trigger efficiencies for selected signal samples. Efficiency *before offline selection* indicates the efficiency with respect to all signal simulation events, while *after offline selection* means with respect only to those signal simulation events which survive offline selection. The rightmost column indicates the efficiency for all signatures OR-ed together.

Trigger Efficiency wrt Offlne (Turnon Curves)



Heavy H^+_{250} with final state $4bW_{lep}W_{had}$ trigger μ efficiencies with respect to the corresponding offline object versus η, ϕ, and E_T. Resolution is also plotted. Note that the ϕ efficiency for muons drops slightly on either side of $\phi = -\pi/2$ due to the muon spectrometer feet.

Trigger Object Efficiency, Purity and Resolution

Trig. Object	$\Delta^{max} R$	Efficiency	Purity	E_T Resolution	E_T Offset
Electron: $H^+_{90} \rightarrow \tau_{had}\nu$	0.02	0.99	0.22	0.01	-0.02
Muon: $H^+_{250} \rightarrow t\bar{b}$	0.02	0.81	0.94	0.03	-0.001
Muon: $H^+_{130} \rightarrow \tau_{lep}\nu$	0.02	0.78	0.97	0.02	-0.001
Tau Jet: $H^+_{130} \rightarrow \tau_{had}$	0.1	0.93	0.29	0.07	-0.03
Jet: $H^+_{130} \rightarrow \tau_{had}$	0.1	0.89	0.80	0.10	-0.15
E_T^{miss}: $H^+_{250} \rightarrow t\bar{b}$	0.4	0.99	0.81	0.28	-0.16
E_T^{miss}: $H^+_{130} \rightarrow \tau_{lep}\nu$	0.4	0.98	0.97	0.20	-0.19
E_T^{miss}: $H^+_{130} \rightarrow \tau_{had}$	0.4	0.97	0.98	0.18	-0.21

- $\Delta R \equiv \sqrt{\Delta\phi^2 + \Delta\eta^2}$, and a trigger object is *matched* to an offline object if $\Delta R < \Delta^{max} R$.
- $\Delta^{max} R$ is chosen to correspond closely with a typical resolution.
- Efficiencies and purities are the fitted plateau values.
- The E_T resolution is defined for matched trigger objects: the RMS of $(E_T^{trg} - E_T^{off})/E_T^{trg}$.
- The E_T offset for matched trigger objects is the mean of the $(E_T^{trg} - E_T^{off})/E_T^{trg}$.

Conclusions

- The trigger strategy for any search for rare phenomena demands the highest possible signal efficiency with respect to the offline-selected events while keeping the overall trigger rates within acceptable bounds.
- At the Tevatron, with increasing instantaneous luminosity came the need to raise E_T thresholds and tighten isolation requirements.
- At the LHC, CMS and ATLAS trigger strategies are broadly similar. The CMS studies rely more on single lepton triggers while ATLAS uses single lepton trigger in combination with E_T^{miss} to keep within a bandwidth budget.
- A coarsely optimized high luminosity ($\mathcal{L} = 10^{33}$ cm^{-2} s^{-1}) running has been identified and studied for the ATLAS H^+ search.
- The trigger selection imposes no observed biases on the offline distributions apart from threshold effects. The expected trigger signature efficiencies and resolution with respect to offline objects are good, though E_T^{miss} needs improvement.
- The expected trigger rates and overall signal efficiencies for the menu are acceptable, and we will be able to optimize the menu after taking data with collisions.