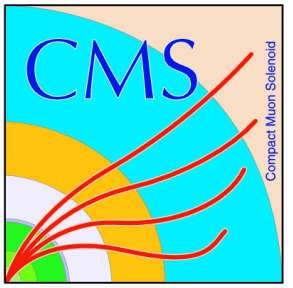


CMS triggers with boosted objects or jet substructure

BOOST2015: 7th International Workshop on Boosted Object Phenomenology, Reconstruction and Searches in HEP

August 13th, 2015

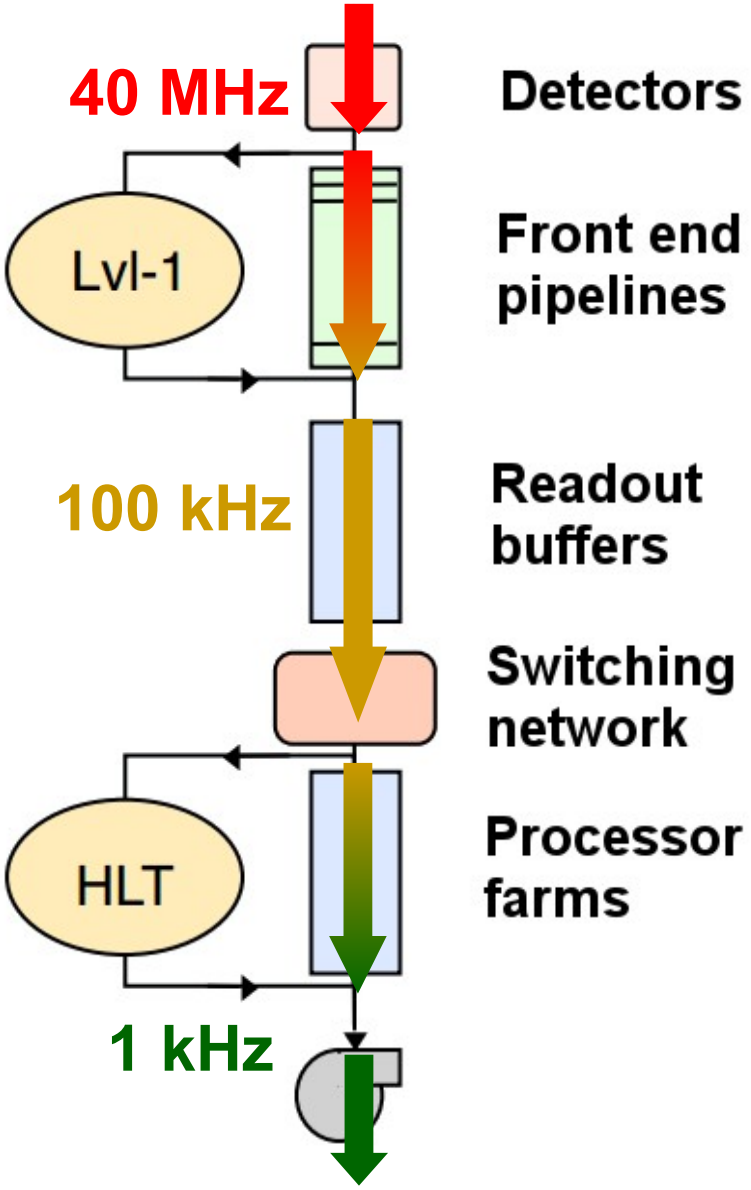
Dylan Rankin *(Boston University)*
on behalf of the CMS Collaboration

Introduction

- Jet substructure tools have become part of a broad array of new physics searches
  - Resonances decaying to t/H/W/Z ($Z' \rightarrow t\bar{t}$, single vector-like quarks)
  - Boosted resonances (RPV Stop)
- Substructure is a critical element of these searches (and many others)
- If our trigger system does not also take advantage of these tools, we risk losing a large fraction of the signal events
- By utilizing jet substructure in triggers, we are able to improve acceptance for a wide range of different signals

CMS Trigger

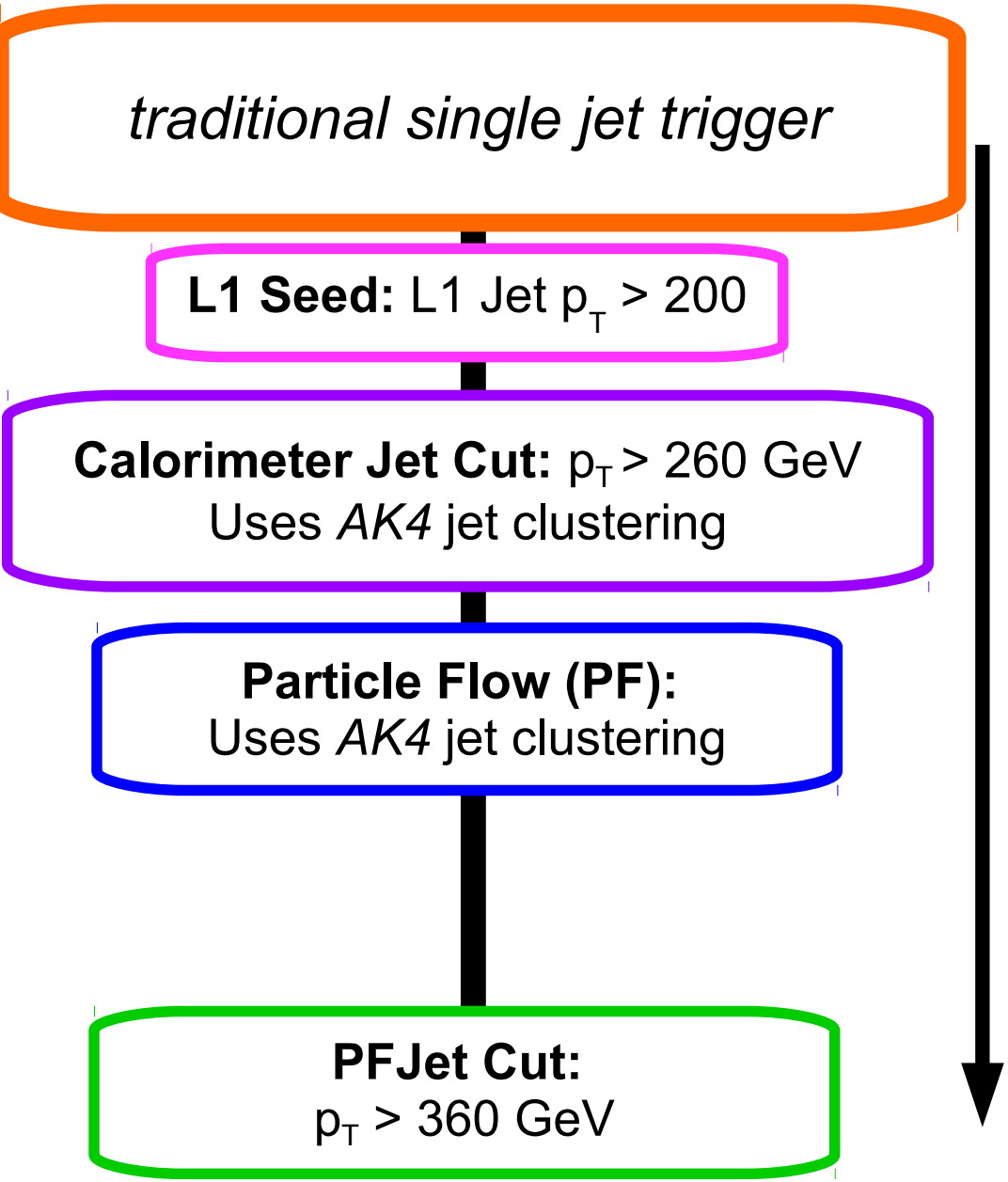
- CMS uses a two-level trigger system
  - Level 1 (L1) is hardware-based, uses limited detector information, 4 μs latency
  - **High Level Trigger** (HLT) is entirely software-based, uses full detector information, 200 ms latency
    - Uses same software framework as offline
- Any event which is rejected is lost ***forever***!



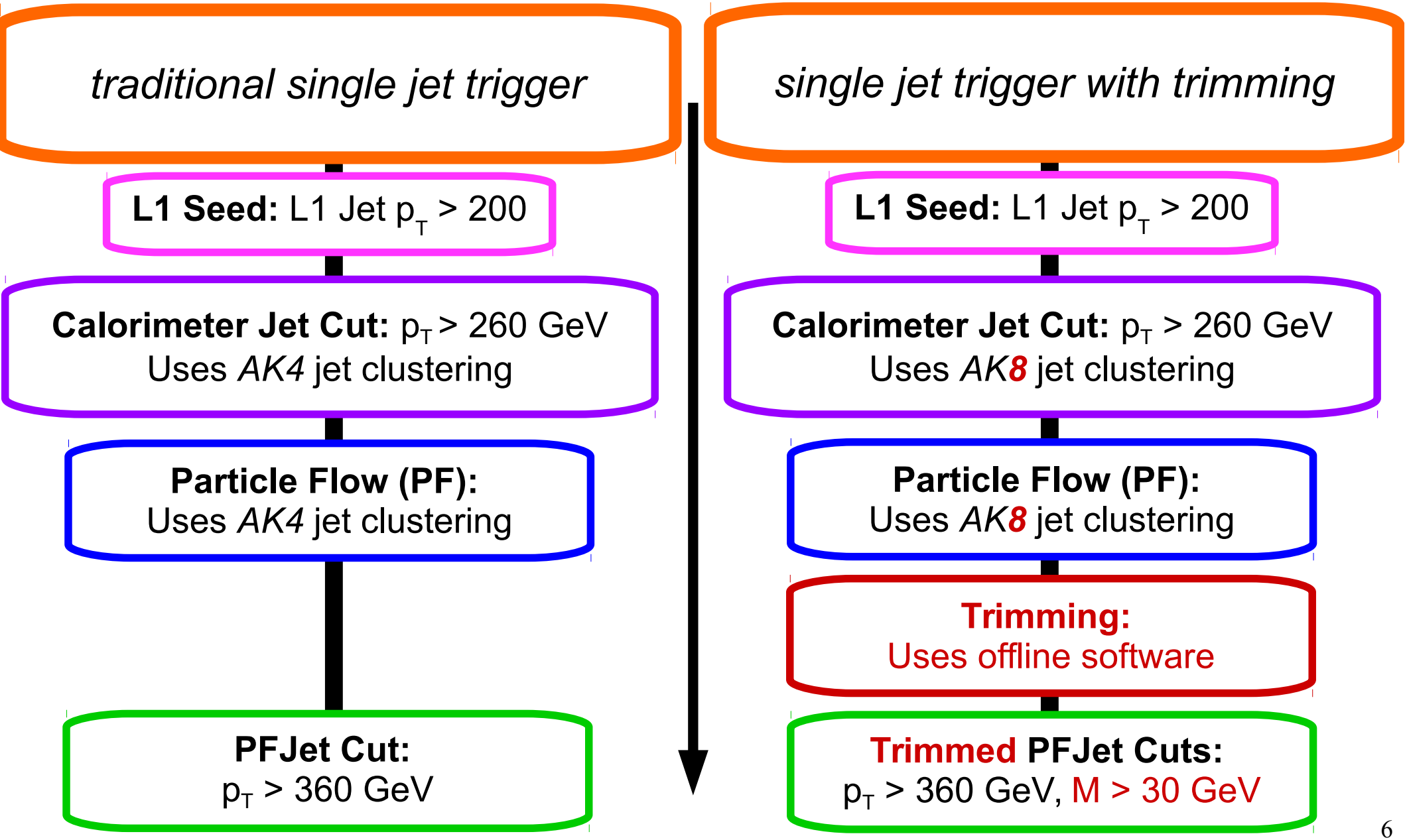
Substructure Triggers

- CMS has developed a set of different substructure based triggers
  - Single jet
  - H_T
  - Dijet
- These build off traditional hadronic trigger logic
- Use AK8 jets and a requirement on the trimmed jet mass
- Trimming is chosen because it is relatively simple among substructure algorithms
  - $R_{sub} = 0.1$, $f_{cut} = 0.03$

Single Jet Trigger



Single Jet Trigger

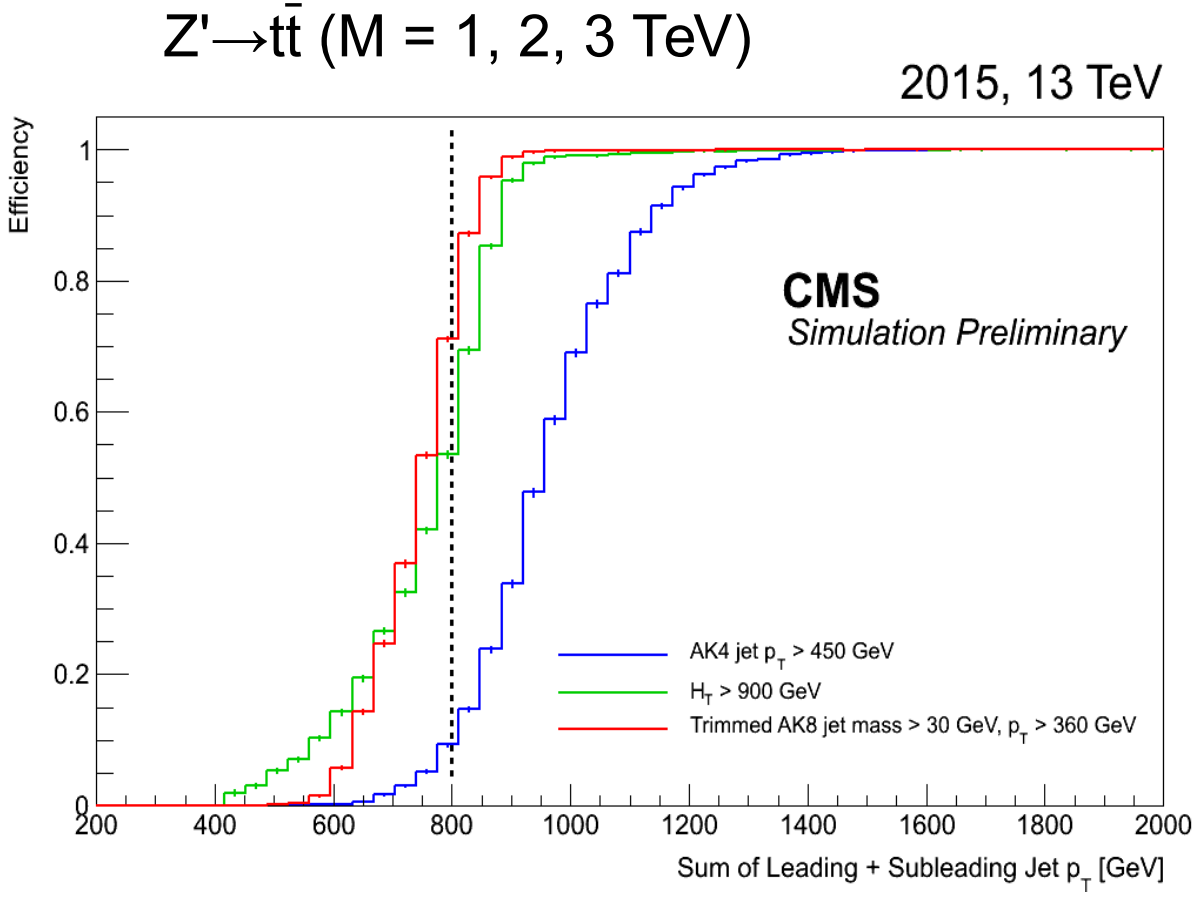


Rates and Timing

- Trigger development must balance three needs:
  - Increase efficiency, reduce rate, reduce timing
- Efficiency
  - Will show that substructure triggers have significantly improved efficiency with respect to more traditional hadronic triggers
- Rate
  - Trimmed jet mass requirement helps to reject large amount of QCD background events; keeps rate low
- Timing
  - By running trimming algorithm after making a very loose selection on calorimeter quantities, most events are rejected before trimming is ever applied; keeps timing low

Single Jet Trigger Efficiency

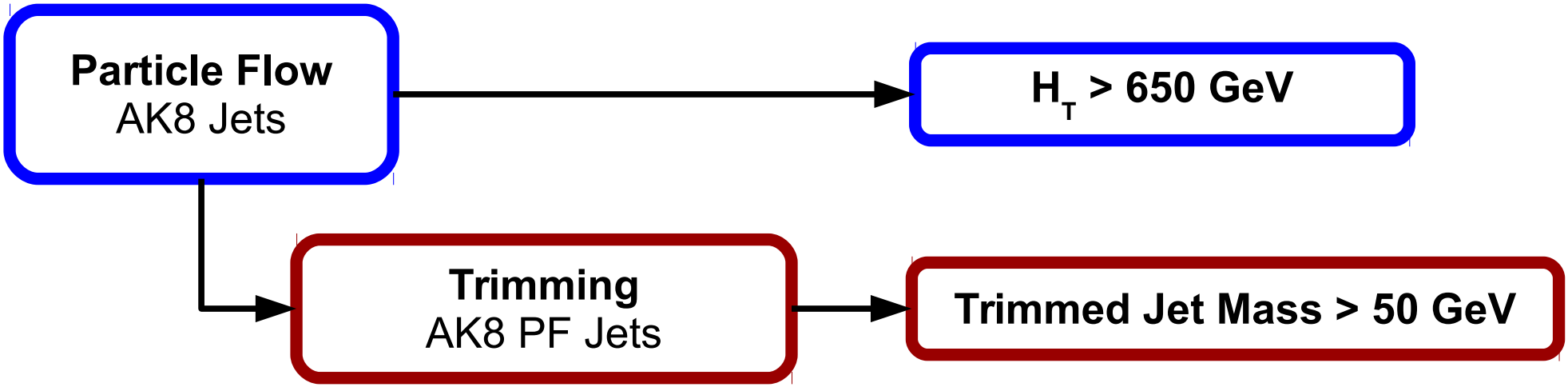
$$\text{Efficiency} = \frac{\text{Offline Selection \&\& Trigger}}{\text{Offline Selection}}$$



- Offline selection: 2 AK8 jets with pruned mass > 50 GeV, pT > 200 GeV
- Very large improvement over traditional AK4 single jet trigger
- Sharper turn-on compared to H_T trigger (main alternative)

Trimmed H_T Trigger

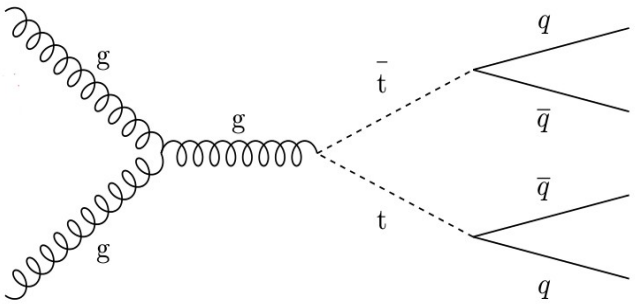
- Can apply basic strategy of single jet trigger to H_T trigger
- Start from traditional hadronic trigger (H_T)
- Change AK4 clustering to AK8, addition of trimmed jet mass requirement
- **AK8 PF H_T > 650 GeV, Trimmed Jet Mass > 50 GeV**

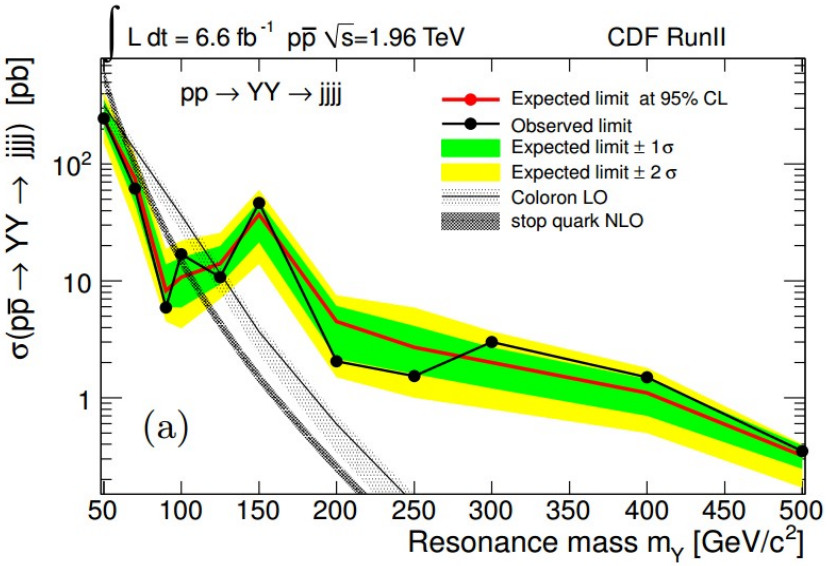


RPV Stop

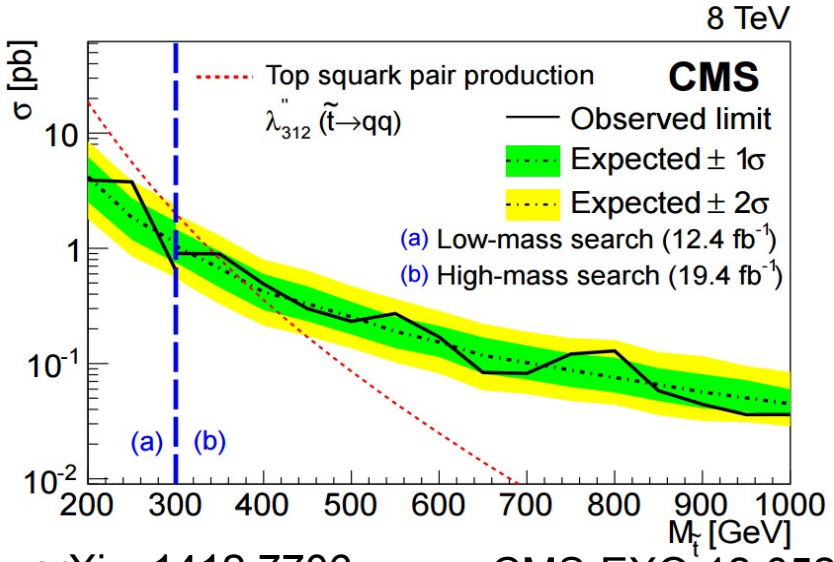
- There is an unexplored window in dijet resonances around 100 GeV
- CDF limits extend below 100 GeV, Run 1 CMS limits extend above 200 GeV
  - Run 1 search relied on resolved jets (no substructure techniques)
- Lower mass resonances are very difficult to trigger on (low hadronic activity)
- By requiring resonance to be boosted, jet mass requirement can greatly improve ability to trigger

$gg \rightarrow \tilde{t}\,\tilde{t} \rightarrow qqqq$ *(light quarks)*





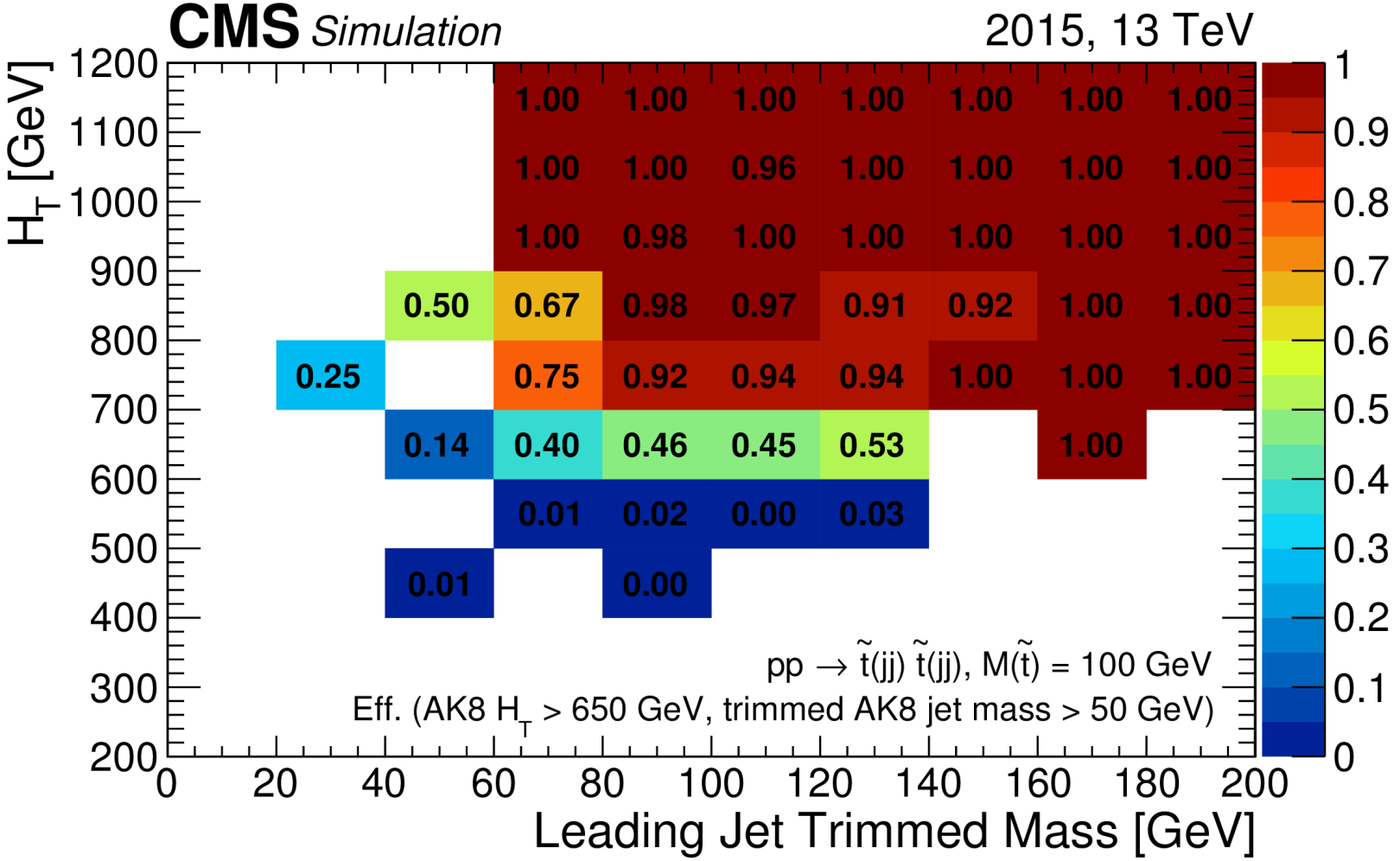
arXiv: 1303.2699



arXiv: 1412.7706

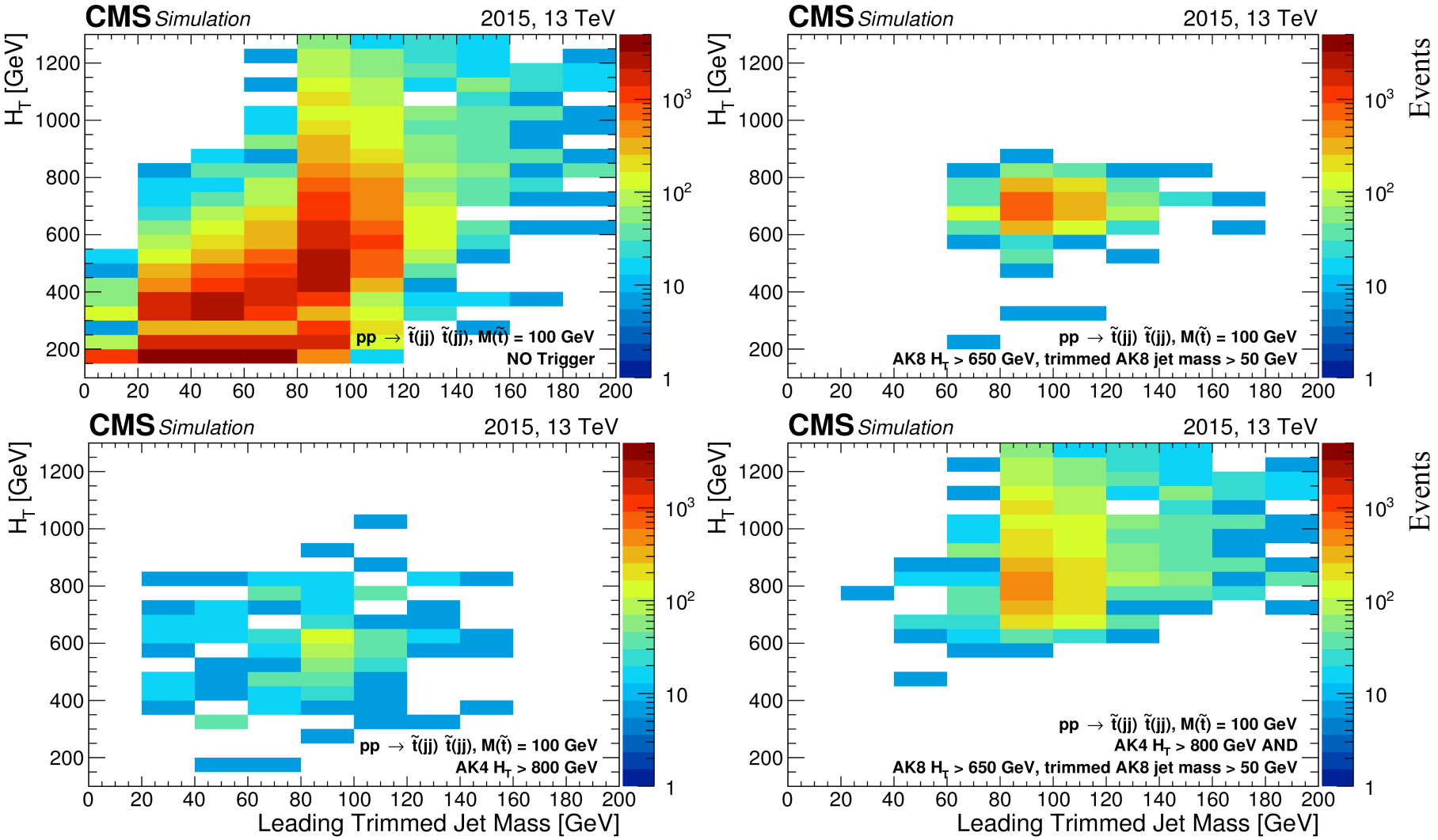
CMS-EXO-12-052

Trimmed H_T Trigger



- 2D efficiency curve shown for 100 GeV RPV Stop
- Offline selection: at least 2 AK8 jets p_T > 150 GeV
- Turn-ons as expected in H_T and trimmed jet mass, fully efficiency in plateau

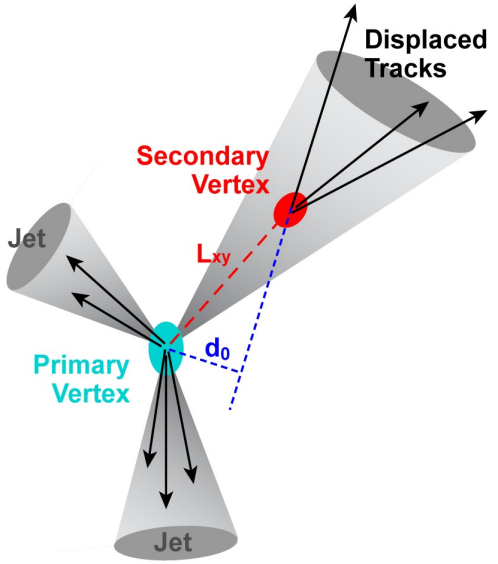
Trimmed H_T Trigger



- Signal distribution of 100 GeV RPV Stop
  - Clockwise from top left: No trigger, AK8HT+trim mass, AK8HT+trim mass AND AK4HT, AK4HT
- AK8HT+trim mass trigger significantly more efficient than traditional H_T trigger

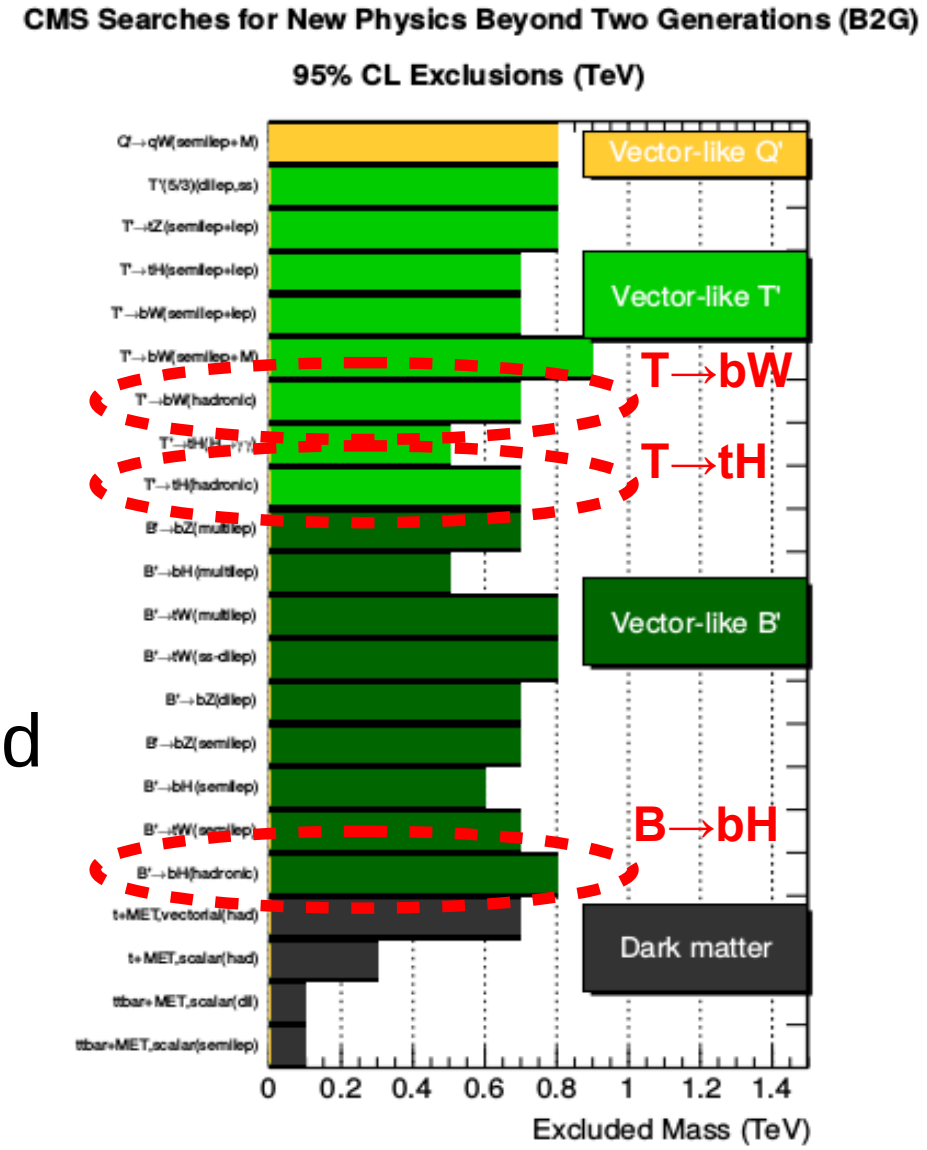
Further Substructure Triggers

- Cannot lower trigger thresholds indiscriminately
- B-tagging is an effective handle on large QCD background which dominates LHC environment
- Using previous two triggers as a base, developed two additional substructure triggers
  - AK8HT+trim mass+b-tag
    - **AK8 PF H_T > 600 GeV, Trimmed Jet Mass > 50 GeV, ≥1 Loose b-tag**
  - Dijet+trim mass+b-tag
    - **AK8 PFJet p_T > 250, 200 GeV, Trimmed Jet Mass > 30 GeV, ≥1 Loose b-tag**



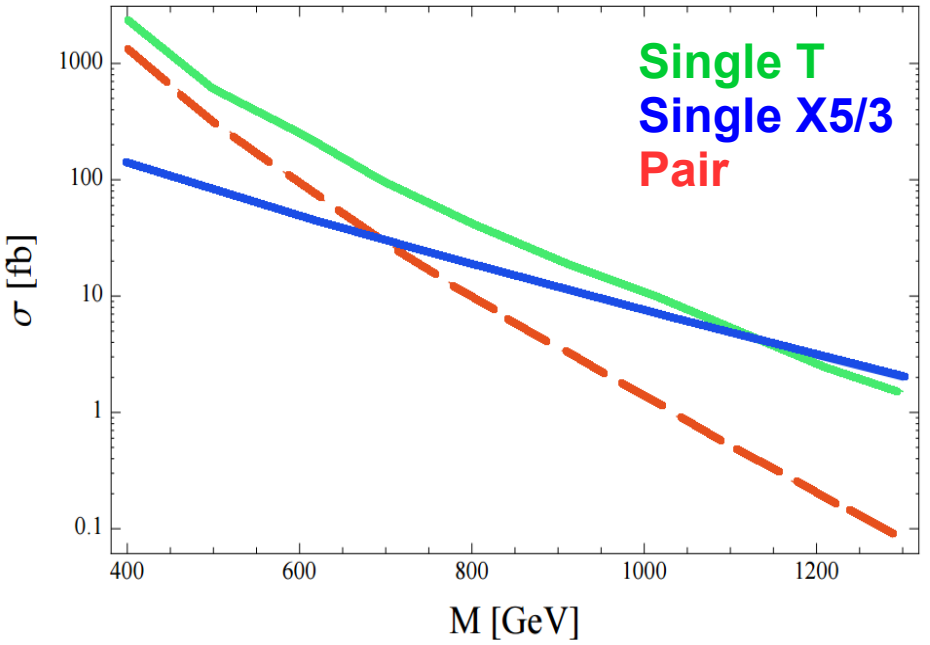
Vector-Like Quarks

- Many BSM theories predict additional generations of quarks
- Heavy vector-like quark searches offer broad range of decay modes/search strategies
- Hadronic channel is dominated by large QCD backgrounds
- Current exclusion limits are ~700 GeV



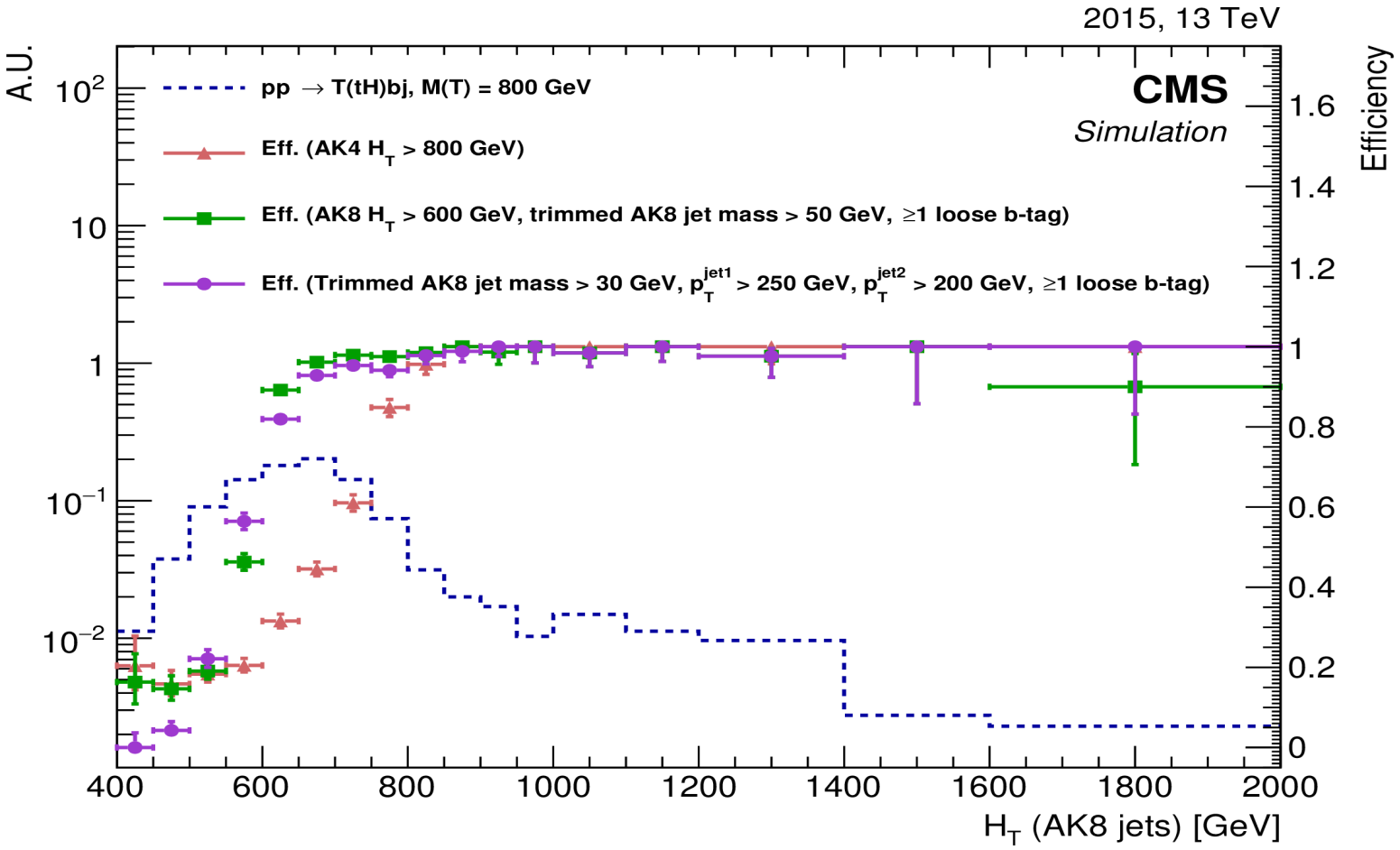
Single Vector-like Quarks

- Run 1 searches focused on pair-production
- Single production is difficult to study (small hadronic activity), but is dominant production for higher masses
- Can use substructure triggers to recover large amount of acceptance for multiple signals
  - **T → tH, T → bW, B → tW**



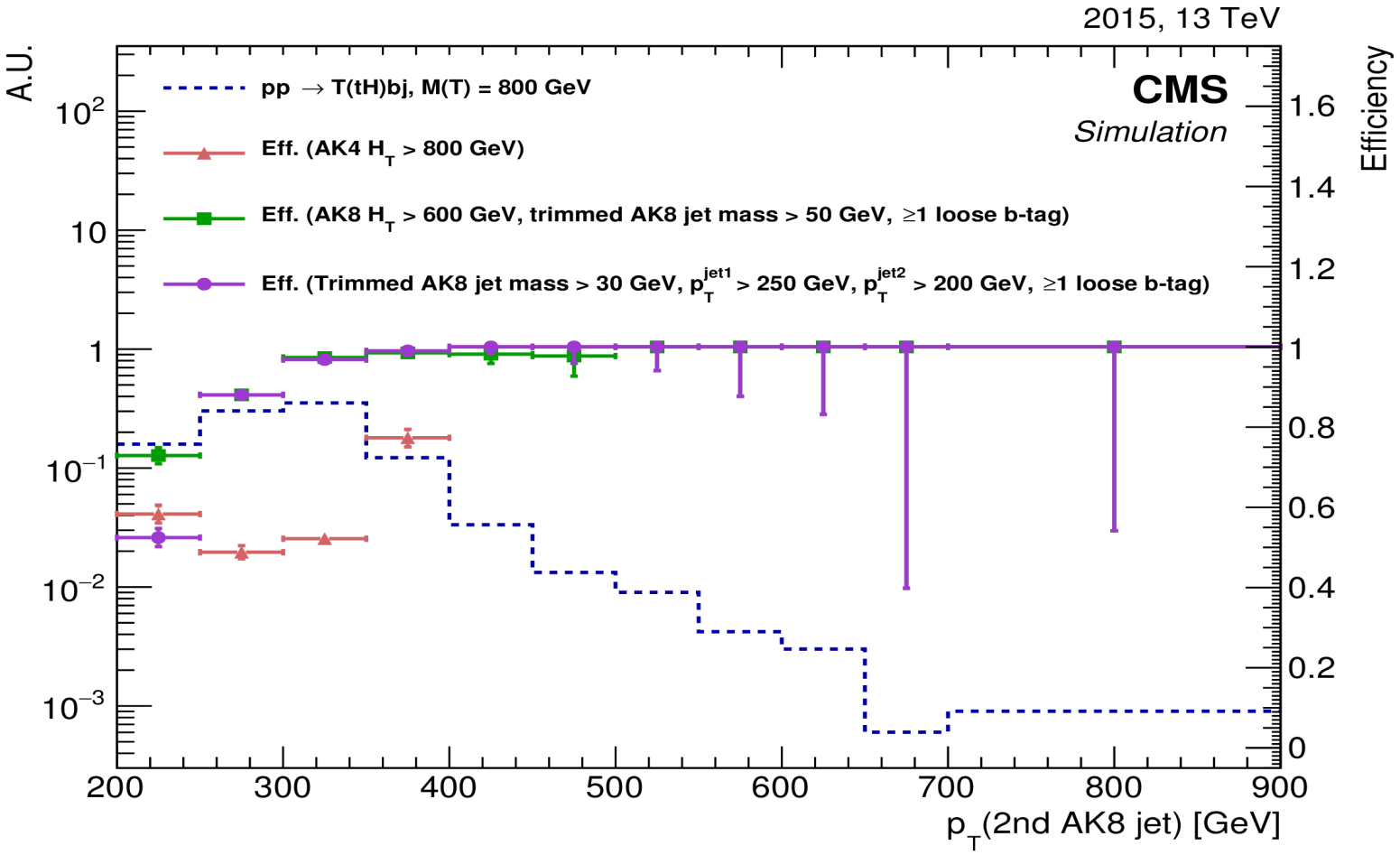
De Simone, Matsedonskyi, Rattazzi, Wulzer
arXiv: 1211.5663

T → tH, M(T)=800 GeV



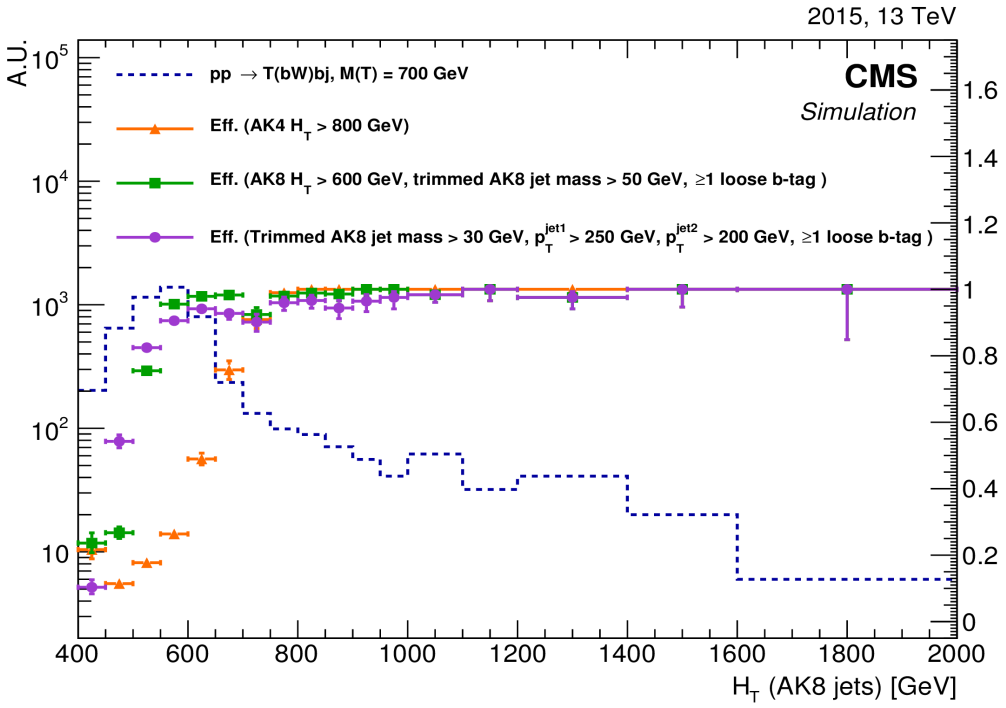
- Offline selection: 2 AK8 jets with soft-drop mass > 50 GeV, pT > 300, 250 GeV, either 3 loose b-tags OR 1 medium b-tag
- Two substructure triggers turn on sharper and 150 GeV sooner than traditional AK4 H_T trigger
- Soft-drop mass > 50 GeV is in plateau of both substructure efficiency curves
- Gained acceptance is significant, peak of signal distribution is only captured by substructure triggers

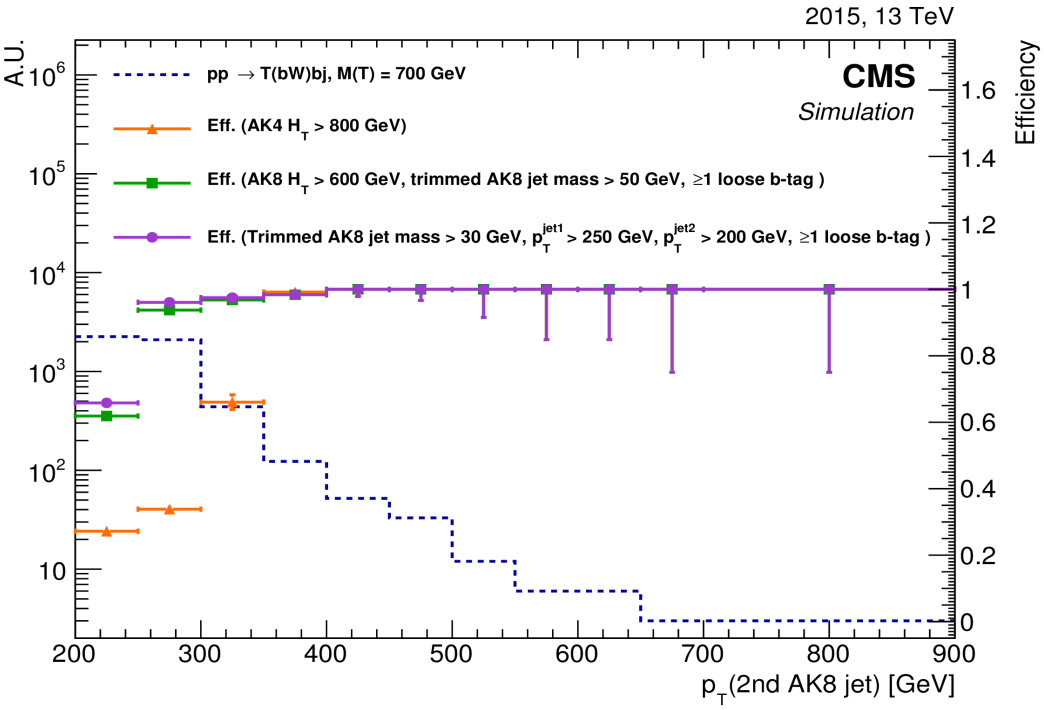
T → tH, M(T)=800 GeV



- Offline selection: 2 AK8 jets with soft-drop mass > 50 GeV, leading jet pT > 300 GeV, H_T > 700 GeV, either 3 loose b-tags OR 1 medium b-tag
- Two substructure triggers turn 100 GeV sooner than traditional AK4 H_T trigger
- Gained acceptance is significant, peak of signal distribution is only captured by substructure triggers

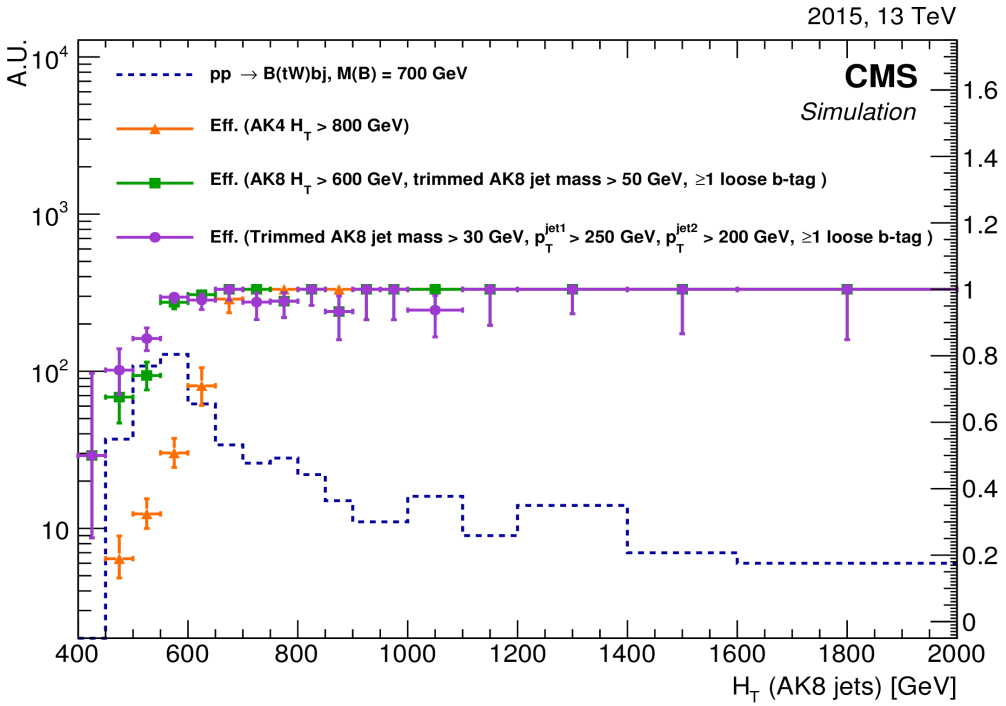
T → bW, M(T)=700 GeV

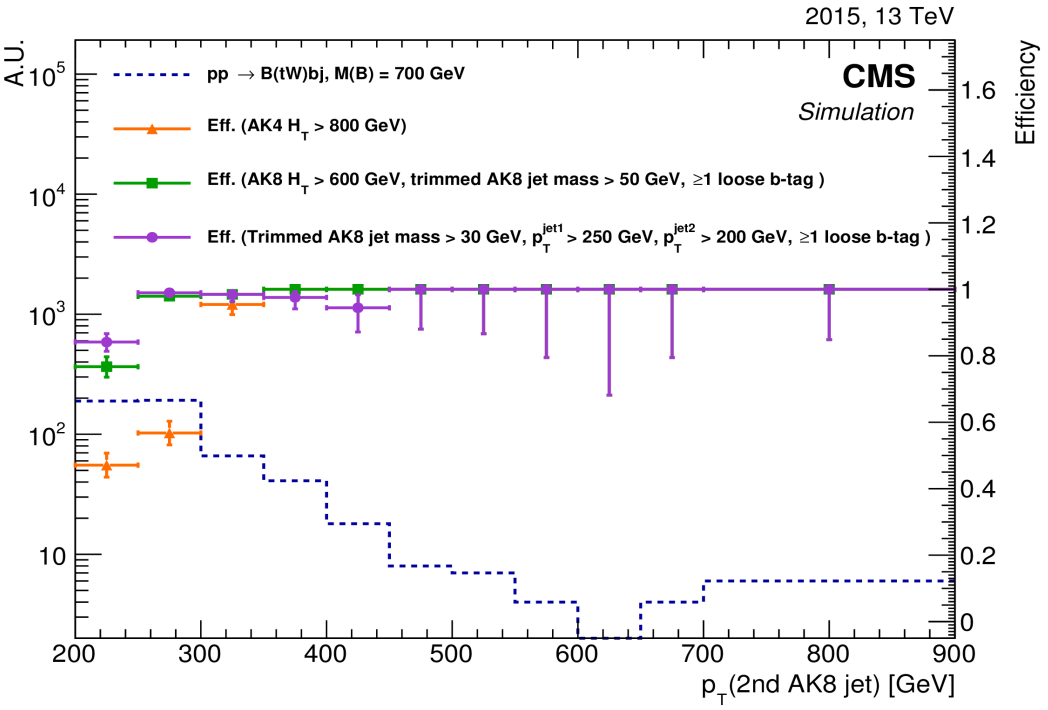




- Offline selection: 1 AK8 jet with trimmed mass > 60 GeV, pT > 200 GeV, 1 medium b-tag
- Two substructure triggers turn on sharper and 50-150 GeV sooner than traditional AK4 H_T trigger
- Trimmed mass > 60 GeV is in plateau of both substructure efficiency curves
- Peak of signal distribution almost triggered by substructure triggers, traditional AK4 H_T triggers only on tail of signal distribution

B → tW, M(B)=700 GeV





- Offline selection: 2 AK8 jets with pT > 200 GeV, trimmed mass > 50, 100 GeV, 1 medium b-tag
- Two substructure triggers turn on 50-100 GeV sooner than traditional AK4 H_T trigger
- Gained acceptance is significant, peak of signal distribution is only captured by substructure triggers

Conclusion

- CMS has developed an inclusive set of hadronic triggers which utilize jet substructure
- Shown that it is viable to implement substructure algorithm (trimming) online
- These triggers improve the acceptance/efficiency for a wide range of different signals
  - RPV Stop, Z', vector-like quarks shown in this talk
  - Many more signals/searches which will benefit
- Plots (11-12, 16-19) to appear soon in DP note
  - DP 2015/XXX