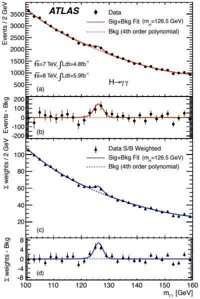
top tagging and jet substructure

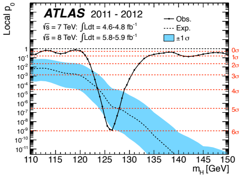
Michihisa Takeuchi

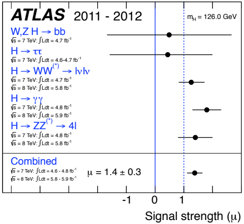
King's College London (Universität Heidelberg)

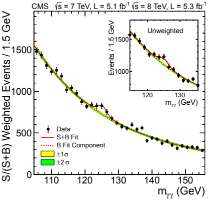
23th Oct. 2012

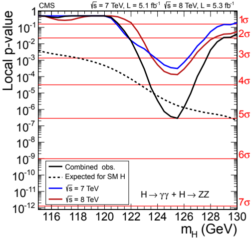
Higgs like particle found!

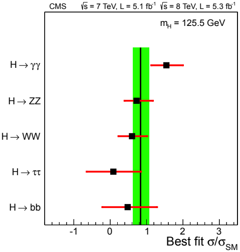












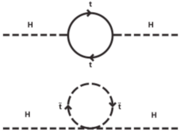
Michihisa Takeuchi

Top at the LHC

closest to new physics → probe for new physics

– fine tuning problem

→ cancellation via top partner



– Tevatron anomalies (A^t_{FB}, single top etc.)

– copiously produced via strong interaction at LHC

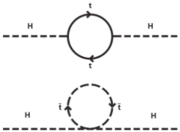
7TeV LHC $\sim 800,000\ t\bar{t}$

Tevatron $\sim 40,000\ t\bar{t}$

→ precision physics

Top at the LHC

closest to new physics → probe for new physics



- fine tuning problem

  → cancellation via top partner
- Tevatron anomalies (A^t_{FB}, single top etc.)
- copiously produced via strong interaction at LHC

  7TeV LHC $\sim 800,000\ t\bar{t}$

  Tevatron $\sim 40,000\ t\bar{t}$ → precision physics

HEPTopTagger: hadronic top $t \to 3j$

- full momentum reconstruction possible in principle

  → important beyond discovery
- top against 10^3 larger QCD, how to identify?

  $\sigma_{tt}^{14\text{TeV}} = 918$ pb $\leftrightarrow \sigma_{3j}^{14\text{TeV}} \sim 2 \cdot 10^6$ pb
- take 3 jets with simple m_t, m_W condition

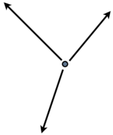
  → large QCD combinatorial BG kill us

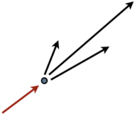
Boosted Tops at the LHC

top jet

- top at rest $\rightarrow$ separate 3 jets
- boosted top $\rightarrow$ massive jet

$$R \sim 2m/p_T$$

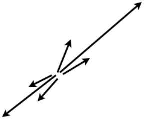




QCD jet

- 2 jet events dominate QCD
- soft-collinear nature in its substructure
- take massive jet & look into jet substructure

combinatorics significantly reduced

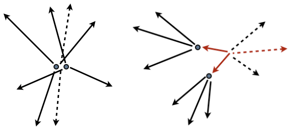


Boosted Tops at the LHC

top as a probe

– new physics search with $\not{E}_T$

→ need recoil



· top at rest: not useful

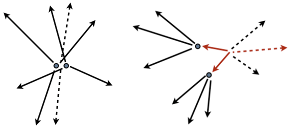
· boosted tops: carry information on dark matter

better S/B (cf. M_{T2} end point.)

Boosted Tops at the LHC

top as a probe

– new physics search with $\not{E}_T$
  $\rightarrow$ need recoil



· top at rest: not useful

· boosted tops: carry information on dark matter

better S/B (cf. M_{T2} end point.)

top taggers

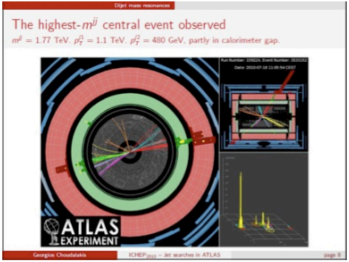
several top taggers available: focus on $p_T > 500$ GeV.

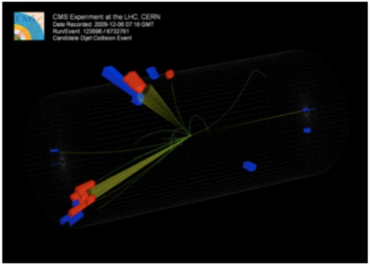
[Kaplan, Rehermann, Schwartz, Tweedie] [Thaler, Wang] [Almeida, Lee, Perez, Sterman, Sung]

Jet substructure

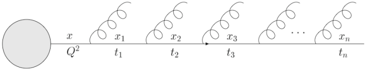
What is a jet?

Jet = collimated hadronic activity in the detector





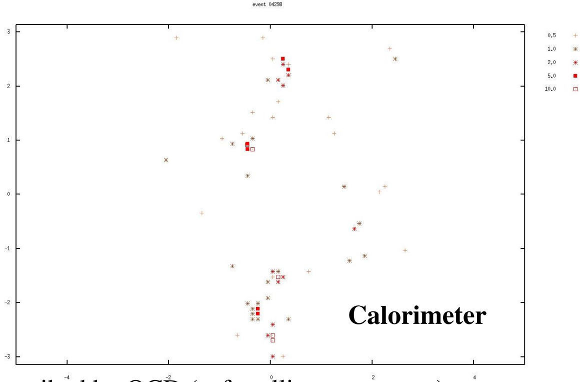
well described by QCD (soft-collinear property)



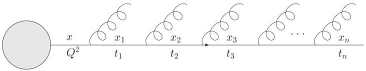
$$Q^2 > t_1 > t_2 > \dots$$
$$t = E_1 E_2 (1 - \cos\theta)$$

$\longrightarrow$ parton shower $\longrightarrow$

What is a jet?



well described by QCD (soft-collinear property)



$\longrightarrow$ parton shower $\longrightarrow$

$\longleftarrow$ clustering $\longleftarrow$

$Q^2 > t_1 > t_2 > \dots$

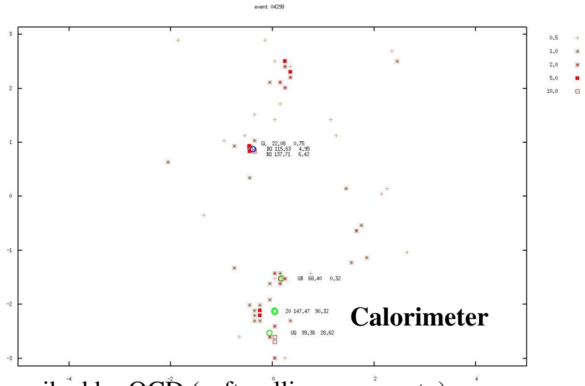
$t = E_1 E_2 (1 - \cos\theta)$

parton-hadron mapping

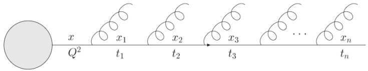
need jet definition

$\rightarrow$ cone, clustering

What is a jet?



well described by QCD (soft-collinear property)



$\longrightarrow$ parton shower $\longrightarrow$

$\longleftarrow$ clustering $\longleftarrow$

$Q^2 > t_1 > t_2 > \ldots$

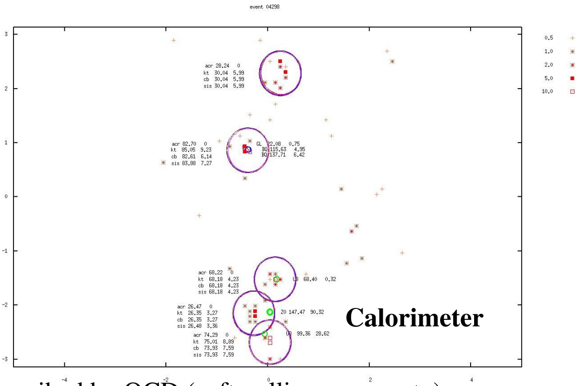
$t = E_1 E_2 (1 - \cos\theta)$

parton-hadron mapping

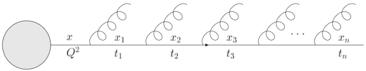
need jet definition

$\rightarrow$ cone, clustering

What is a jet?



well described by QCD (soft-collinear property)



$$Q^2 > t_1 > t_2 > \dots$$

$$t = E_1 E_2 (1 - \cos\theta)$$

$\longrightarrow$ parton shower $\longrightarrow$

$\longleftarrow$ clustering $\longleftarrow$

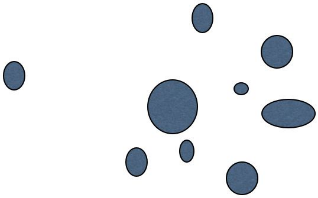
parton-hadron mapping

need jet definition

$\rightarrow$ cone, clustering

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

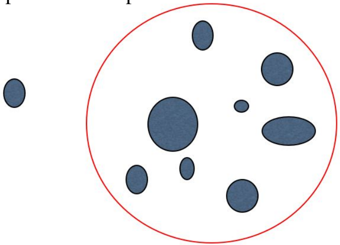
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

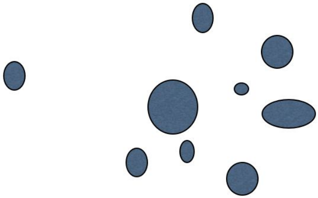
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

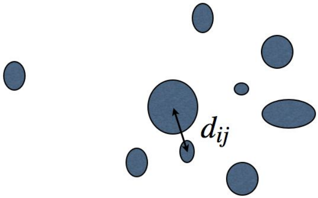
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

– R: jet size $\quad d_{ij} > R$

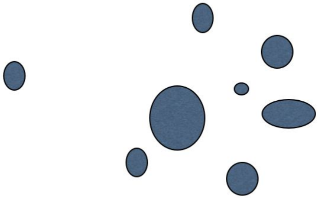
Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

– R: jet size $\quad d_{ij} > R$

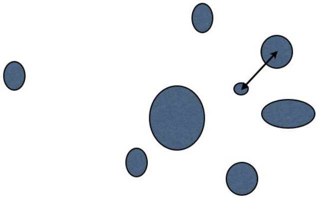
Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

– R: jet size $\quad d_{ij} > R$

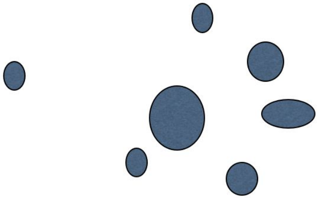
Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

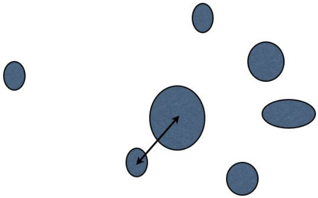
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

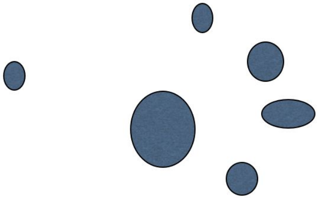
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

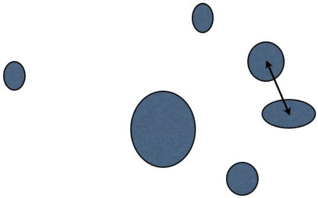
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

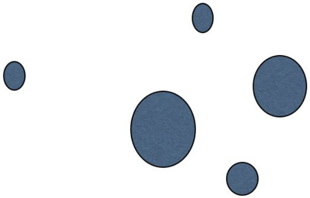
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

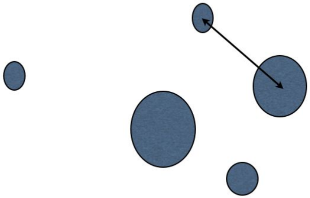
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

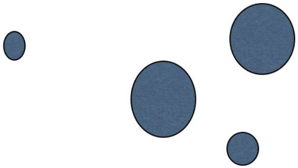
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

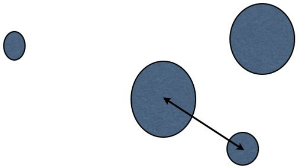
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

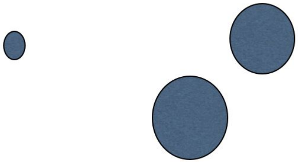
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

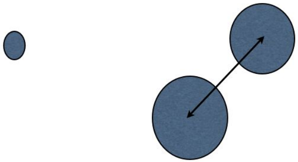
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

– R: jet size $\quad d_{ij} > R$

Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.

d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

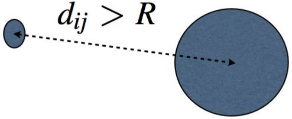
  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.



d_{ij}: distance measure

- R: jet size $\quad d_{ij} > R$

  Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

  kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

  anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

Michihisa Takeuchi

Introduction

Boosted Top

Jet substructure

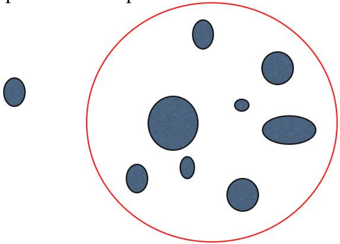
HEPTopTagger

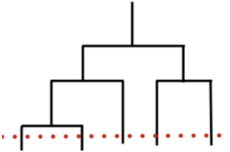
Applications

Summary

clustering algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij} is smallest recombine i and j, if d_{iB} is smallest call i as a jet.
3. repeat step 1-2 until no particles left.





d_{ij}: distance measure

– R: jet size $\quad d_{ij} > R$

Cambridge/Aachen $\quad d_{ij} = \Delta R_{ij}^2/R^2, \quad d_{iB} = 1$

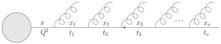
kT $\quad d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^2$

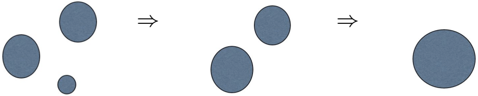
anti-kT $\quad d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}^2/R^2, \quad d_{iB} = p_{Ti}^{-2}$

Jet substructure

clustering

- collinear singularity of QCD → naturally collects FSR
- collects decay products from boosted object
- collects ISR and UE at the same time

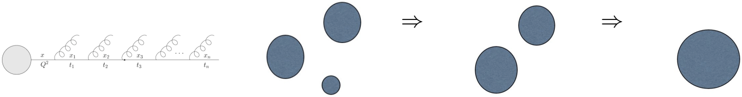




Jet substructure

clustering

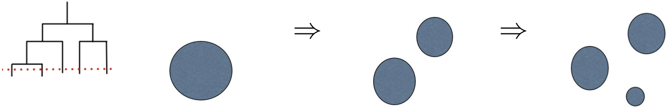
- collinear singularity of QCD → naturally collects FSR
- collects decay products from boosted object
- collects ISR and UE at the same time



undoing clustering

- expect: clustering history ∼ shower history
- no soft-collinear singularity for decay of boosted object → mass drop, p_T drop

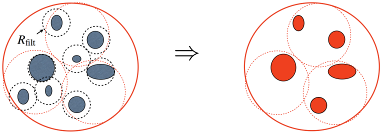
$j = j_1 + j_2$, $\boxed{m_j \gg m_{j1}, m_{j2} \text{ (massive particle)}} \leftrightarrow \boxed{m_j \sim m_{j1} \gg m_{j2} \text{ (QCD)}}$

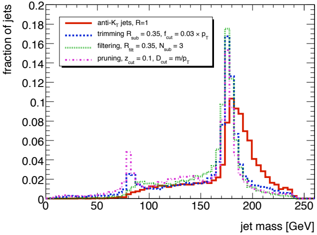


Jet filtering

Filtering [Butterworth et al.]

- effect of pile-up, underlying events $\sim R^2$
- reduce effective area with smaller R_{filt} and n_{filt}
- recombine the constituents with smaller R_{filt}, for example $R_{\text{filt}} = 0.2$
- take only first hardest n_{filt} subjets (discard others)





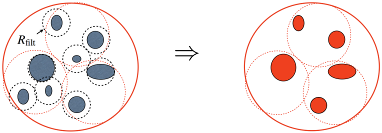
- $R_{\text{filt}} = \min\{0.3, R_{ij}/2\}$

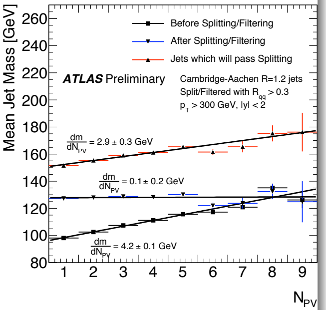
  $n_{\text{filt}} = 5\ (t \to bWg \to bgjjg)$

Jet filtering

Filtering [Butterworth et al.]

- effect of pile-up, underlying events $\sim R^2$
- reduce effective area with smaller $R_{\rm filt}$ and $n_{\rm filt}$
  - recombine the constituents with smaller $R_{\rm filt}$, for example $R_{\rm filt} = 0.2$
  - take only first hardest $n_{\rm filt}$ subjets (discard others)





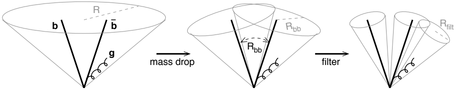
- $R_{\rm filt} = \min\{0.3, R_{ij}/2\}$

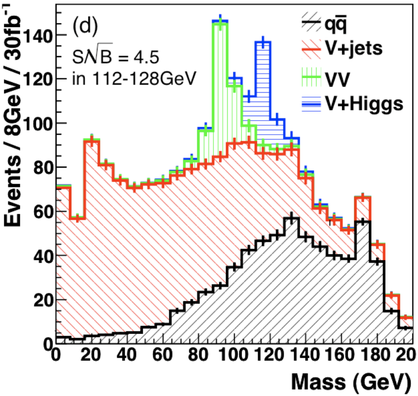
  $n_{\rm filt} = 5 \; (t \to bWg \to bgjjg)$

Boosted Higgs

[Butterworth et al. Phys.Rev.Lett. 100 (2008) 242001]

– fat jet with jet substructure





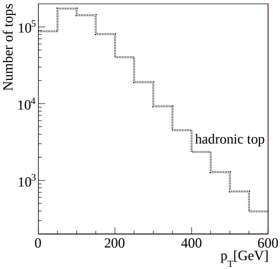
Moderately Boosted Tops at the LHC

top p_T distribution

- $p_T > 500$ GeV: not many in SM

$$\sigma_{>200\text{GeV}} \sim 50\sigma_{>500\text{GeV}}$$

- need top tagger valid down to low p_T range → testable



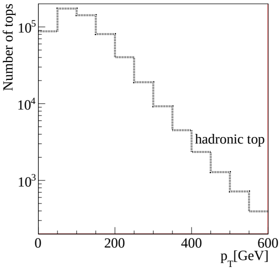
Moderately Boosted Tops at the LHC

top p_T distribution

- $p_T > 500$ GeV: not many in SM

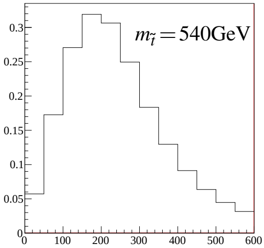
$$\sigma_{>200\text{GeV}} \sim 50\sigma_{>500\text{GeV}}$$

- need top tagger valid down to low p_T range → testable



- light top partners also provide tops in the same range

we focus on $p_T > 200$GeV
→ need fat jet with $R = 1.5$



HEPTopTagger [JHEP 1010:078,2010. arXiv:1006.2833 T. Plehn, M. Spannowsky, D. Zerwas, MT] [Phys.Rev. D85 (2012) 034029, arXiv:1111.5034]

1. fat jets – C/A with $R = 1.5$, $p_T^{\text{fatjet}} > 200$ GeV

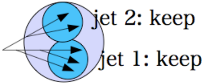
HEPTopTagger

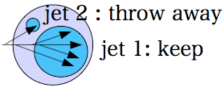
[JHEP 1010:078,2010. arXiv:1006.2833 T. Plehn, M. Spannowsky, D. Zerwas, MT]
[Phys.Rev. D85 (2012) 034029, arXiv:1111.5034]

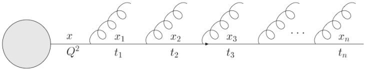
1. **fat jets** – C/A with $R=1.5$, $p_T^{\text{fatjet}} > 200$ GeV
2. **find subjets by mass drop criterion**

$j = j_1 + j_2$

$m_j \gg m_{j1}, m_{j2}$ (decay) $\leftrightarrow$ $m_j \sim m_{j1} \gg m_{j2}$ (QCD)

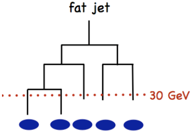






soft-collinear singularity

– keep j_1 and j_2 for $m_{j_1} < 0.8 m_j$ until $m_j < 50$ GeV



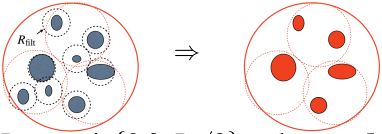
HEPTopTagger [JHEP 1010:078,2010. arXiv:1006.2833 T. Plehn, M. Spannowsky, D. Zerwas, MT] [Phys.Rev. D85 (2012) 034029, arXiv:1111.5034]

1. **fat jets** – C/A with $R = 1.5$, $p_T^{\text{fatjet}} > 200$ GeV
2. **find subjets by mass drop criterion**
   – keep j_1 and j_2 for $m_{j_1} < 0.8 m_j$ until $m_j < 50$ GeV
3. **take 3 subjets with best filtered mass**
   – $|m_{jjj}^{\text{filt}} - m_t| < 25$ GeV $\rightarrow$ top candidate

filtering [Butterworth et al.]

– effect of pile-up, underlying events $\sim R^2$

– reduce effective area with smaller R_{filt} and n_{filt}



– $R_{\text{filt}} = \min\{0.3, R_{ij}/2\}$ and $n_{\text{filt}} = 5$ $(t \rightarrow bWg \rightarrow bgjjg)$

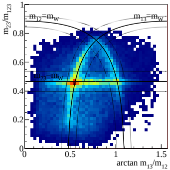
HEPTopTagger [JHEP 1010:078,2010. arXiv:1006.2833 T. Plehn, M. Spannowsky, D. Zerwas, MT] [Phys.Rev. D85 (2012) 034029, arXiv:1111.5034]

1. **fat jets** – C/A with $R = 1.5$, $p_T^{\text{fatjet}} > 200$ GeV
2. **find subjets by mass drop criterion**
   – keep j_1 and j_2 for $m_{j_1} < 0.8 m_j$ until $m_j < 50$ GeV
3. **take 3 subjets with best filtered mass**
   – $|m_{jjj}^{\text{filt}} - m_t| < 25$ GeV $\rightarrow$ top candidate
4. **check mass ratios**
   – 3 subjets: $p_1, p_2, p_3 \rightarrow m_{12}, m_{13}, m_{23}$
   – $m_t^2 = m_{123}^2 = m_{12}^2 + m_{13}^2 + m_{23}^2 \rightarrow$ 2D mass ratios

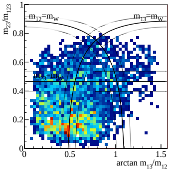
HEPTopTagger [JHEP 1010:078,2010. arXiv:1006.2833 T. Plehn, M. Spannowsky, D. Zerwas, MT] [Phys.Rev. D85 (2012) 034029, arXiv:1111.5034]

1. **fat jets** – C/A with $R = 1.5$, $p_T^{\text{fatjet}} > 200$ GeV
2. **find subjets by mass drop criterion**
   – keep j_1 and j_2 for $m_{j_1} < 0.8 m_j$ until $m_j < 50$ GeV
3. **take 3 subjets with best filtered mass**
   – $|m_{jjj}^{\text{filt}} - m_t| < 25$ GeV $\to$ top candidate
4. **check mass ratios**
   – 3 subjets: $p_1, p_2, p_3 \to m_{12}, m_{13}, m_{23}$
   – $m_t^2 = m_{123}^2 = m_{12}^2 + m_{13}^2 + m_{23}^2 \to$ 2D mass ratios

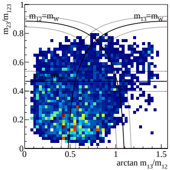
$m_{23} \downarrow 0$
$0 \leftarrow m_{13}$
$m_{12} \to 0$



$t\bar{t}$



W+jets



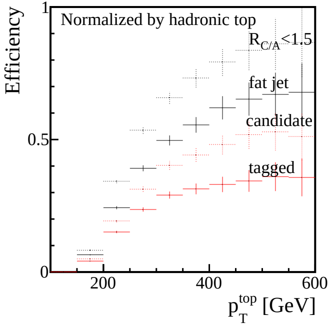
QCD

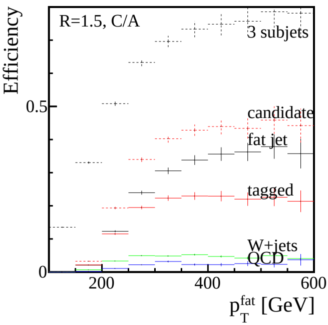
– W mass condition, soft-collinear cut $\to$ tagged top

– no b-tag information

HEPTopTagger [JHEP 1010:078,2010. arXiv:1006.2833 T. Plehn, M. Spannowsky, D. Zerwas, MT]

efficiency





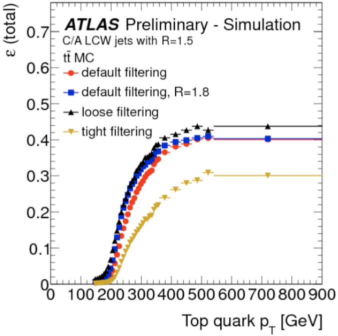
– efficiency $\sim$ 30% for hadronic tops, 2 $\sim$ 4% mis-tag rate

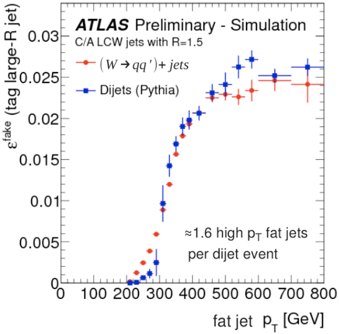
– momentum well reconstructed

– validation with ATLAS experimentalists in Heidelberg

[G. Kasieczka, S. Schätzel, A. Schöning]

Validation by ATLAS [ATLAS-CONF-2012-065]



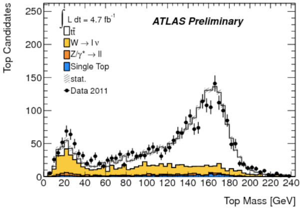


– efficiency $\sim 30\%$ for hadronic tops, $2 \sim 4\%$ mis-tag rate

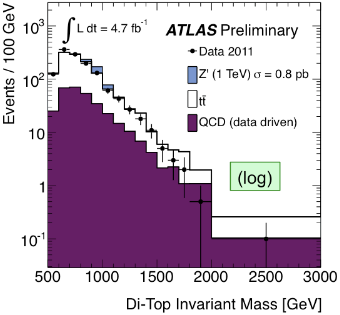
– validation by ATLAS experimentalists in Heidelberg

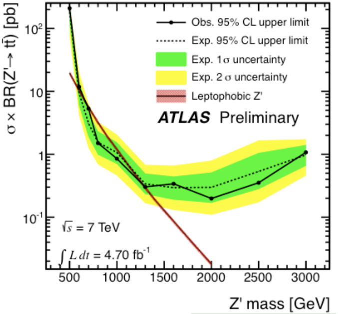
[G. Kasieczka, S. Schätzel, A. Schöning]

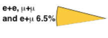
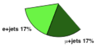
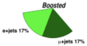
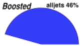
– data well described by MC



Z' search with HEPTopTagger by ATLAS [ATLAS-CONF-2012-065]





				
Article/ Note	**arXiv: 1205.5371**	**arXiv: 1205.5371**	**arXiv: 1207.2409**	**ATLAS-CONF-2012-102**
Integrated Luminosity	2 fb^{-1}	2 fb^{-1}	2 fb^{-1}	4.7 fb^{-1}
Z' limits $\Gamma/m = 1.2\%$	-	0.5-0.88 TeV	0.6-1.15 TeV	0.7-1.3 TeV
KKG limits $\Gamma/m = 15.3\%$	0.5-1.08 TeV	0.5-1.13 TeV	0.6-1.5 TeV	0.7-1.5 TeV

– Extended reach with boosted tops

Improving HEPTopTagger

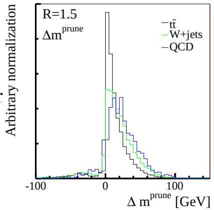
[Phys.Rev. D85 (2012) 034029, arXiv:1111.5034]
[T. Plehn, M. Spannowsky, MT]

different algorithms (kt, C/A, anti-kt)

- better subjet reconstruction with kT in high p_T
  $\rightarrow$ better ϵ_{tag} with worse rejection for BG

additional pruning [Ellis et al.]

- veto recombination $z = \frac{\min\{p_{Ti}, p_{Tj}\}}{|\vec{p}_{Ti} + \vec{p}_{Tj}|} < z_{\text{cut}}$
- pruned mass $\Delta m^{\text{pruned}} = m^{\text{pruned}} - m^{\text{filter}}$
- $\epsilon_{\text{tag}}/\epsilon_{\text{mis}}$ rate improves factor 2
  with $\Delta m^{\text{pruned}} < 15$ GeV



b-tag information

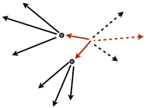
- not help to use b-tag information in selecting subjets
- without b-tag, 77% top tag already select $j_b = b$
- only BG has factor $3 \times \epsilon_b^{\text{mis}}$
- use b-tag after top tag

Applications

Scalar Top Pairs at 14 TeV

hadronic mode [T. Plehn, M. Spannowsky, MT, D. Zerwas]

- $\tilde{t}_1\tilde{t}_1^* \to (t\tilde{\chi}_1^0)(\bar{t}\tilde{\chi}_1^0)$: $m_{\tilde{t}1} = 100$ GeV
- main BG: $t\bar{t}$+jets, W+jets and QCD



events in 1 fb^{-1}	$\tilde{t}_1\tilde{t}_1^*$					$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\ \mathrm{fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	390	440	490	540	640					390	
$p_{T,j} > 200$ GeV, ℓ veto	447	292	187	124	46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$\sim 10^{-5}$	
$\not{E}_T > 150$ GeV	234	184	133	93	35	2245	$2.4 \cdot 10^5$	1710	2240	$\sim 10^{-3}$	
first top tag	91	75	57	42	15	743	7590	90	114	0.01	
second top tag	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	0.07	
b-tag for 1$^{\mathrm{st}}$ top tag	7.4	6.3	5.0	3.8	1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.34	5.0
$m_{T2} > 250$ GeV	5.0	4.9	4.2	3.2	1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	1.0	7.1

W+jets, Z+jets negligible with 2 top tag

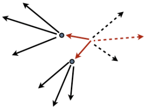
QCD negligible with additional b-tag

$t\bar{t}$ reduced with m_{T2} cut

Scalar Top Pairs at 14 TeV

hadronic mode [T. Plehn, M. Spannowsky, MT, D. Zerwas]

- $\tilde{t}_1 \tilde{t}_1^* \to (t\tilde{\chi}_1^0)(\bar{t}\tilde{\chi}_1^0)$: $m_{\tilde{t}1} = 100$ GeV
- main BG: $t\bar{t}$+jets, W+jets and QCD

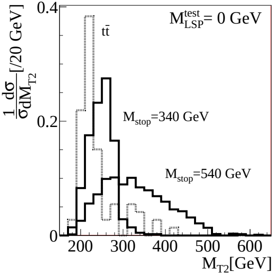


events in 1 fb^{-1}	$\tilde{t}_1\tilde{t}_1^*$					$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\ \mathrm{fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	390	440	490	540	640					390	
$p_{T,j} > 200$ GeV, ℓ veto	447	292	187	124	46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$\sim 10^{-5}$	
$\not{E}_T > 150$ GeV	234	184	133	93	35	2245	$2.4 \cdot 10^5$	1710	2240	$\sim 10^{-3}$	
first top tag	91	75	57	42	15	743	7590	90	114	0.01	
second top tag	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	0.07	
b-tag for 1st top tag	7.4	6.3	5.0	3.8	1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.34	5.0
$m_{T2} > 250$ GeV	5.0	4.9	4.2	3.2	1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	1.0	7.1

W+jets, Z+jets negligible with 2

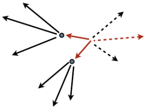
QCD negligible with additional b

$t\bar{t}$ reduced with m_{T2} cut



Scalar Top Pairs at 14 TeV

hadronic mode [T. Plehn, M. Spannowsky, MT, D. Zerwas]



- $\tilde{t}_1\tilde{t}_1^* \to (t\tilde{\chi}_1^0)(\bar{t}\tilde{\chi}_1^0)$: $m_{\tilde{t}1} = 100$ GeV
- main BG: $t\bar{t}$+jets, W+jets and QCD

events in 1 fb^{-1}	$\tilde{t}_1\tilde{t}_1^*$					$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\ \text{fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	390	440	490	540	640					390	
$p_{T,j} > 200$ GeV, ℓ veto	447	292	187	124	46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$\sim 10^{-5}$	
$\not{E}_T > 150$ GeV	234	184	133	93	35	2245	$2.4 \cdot 10^5$	1710	2240	$\sim 10^{-3}$	
first top tag	91	75	57	42	15	743	7590	90	114	0.01	
second top tag	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	0.07	
b-tag for 1st top tag	7.4	6.3	5.0	3.8	1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.34	5.0
$m_{T2} > 250$ GeV	5.0	4.9	4.2	3.2	1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	1.0	7.1

$$S/B = 1, S/\sqrt{B} > 5 \text{ at 14 TeV with } 10\text{fb}^{-1}$$

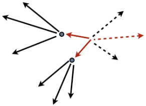
- stop mass from $m_{T2}(m_{\tilde{\chi}_1^0})$ endpoint [C. G. Lester, D. J. Summers]

  like sleptons or sbottoms

Scalar Top Pairs at 14 TeV

hadronic mode [T. Plehn, M. Spannowsky, MT, D. Zerwas]

- $\tilde{t}_1 \tilde{t}_1^* \rightarrow (t\tilde{\chi}_1^0)(\bar{t}\tilde{\chi}_1^0)$: $m_{\tilde{t}1} = 100$ GeV
- main BG: $t\bar{t}$+jets, W+jets and QCD



events in 1 fb^{-1}	$\tilde{t}_1\tilde{t}_1^*$					$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\text{ fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	390	440	490	540	640					390	
$p_{T,j} > 200$ GeV, ℓ veto	447	292	187	124	46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$\sim 10^{-5}$	
$\not{E}_T > 150$ GeV	234	184	133	93	35	2245	$2.4 \cdot 10^5$	1710	2240	$\sim 10^{-3}$	
first top tag	91	75	57	42	15	743	7590	90	114	0.01	
second top tag	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	0.07	
b-tag for 1st top tag	7.4	6.3	5.0	3.8	1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.34	5.0
$m_{T2} > 250$ GeV	5.0	4.9	4.2	3.2	1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	1.0	7.1

$$S/B = 1, S/\sqrt{B} > 5 \text{ at 14 TeV with 10fb}^{-1}$$

- stop mass from $m_{T2}(m_{\tilde{\chi}_1^0})$ endpoint [C. G. Lester, D. J. Summers]
  like sleptons or sbottoms

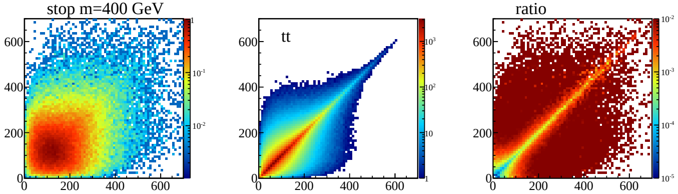
semi-leptonic mode [JHEP 1105 (2011) 135 [arXiv:1102.0557], T. Plehn, M. Spannowsky, MT]

boosted leptonic top $S/B \sim 2, S/\sqrt{B} > 5$ at 14 TeV with 10fb^{-1}

Scalar Top Pairs at 8TeV [arXiv:1205.2696 T. Plehn, M. Spannowsky, MT]

- $\sigma^{8\text{TeV}} \sim \frac{1}{10}\sigma^{14\text{TeV}}$: both for $t\bar{t}$ and $\tilde{t}_1\tilde{t}_1^*$
- 2 boosted tops: not enough signal left

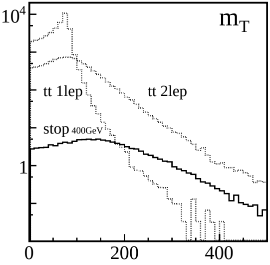
  $S/B \sim 0.8, S/\sqrt{B} \sim 1.5$ (two top tag)
- $t\bar{t}$: dominant background at the end



- 1 boosted top and 1 non-boosted top
  - hadronic mode: 1 hadronic top-tag + b-jet + $\not{E}_T$
  - semi-leptonic mode: 1 hadronic top-tag + ℓ, $\not{E}_T$

Scalar Top Pairs at 8TeV [arXiv:1205.2696 T. Plehn, M. Spannowsky, MT]

– semi-leptonic mode: 1 hadronic top-tag + $\ell, \not{E}_T$



$t\bar{t} \to t_h + b\ell\nu$

negligible with $m_T(\ell, \not{E}_T) > 150$ GeV

$t\bar{t} \to b\bar{b} + \tau_h\ell + 2\nu$

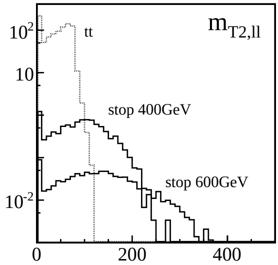
fake hadronic top tag with ISR or τ_h

$\to$ subjet id: b-tag, τ_h rejection.

$\sqrt{s} = 8$ TeV, $R = 1.5$	$\tilde{t}1\tilde{t}1^*$						$t\bar{t}$	S/B	$S/\sqrt{B}_{10\text{fb}-1}$
$m_{\tilde{t}}$[GeV]	350	400	450	500	600	700		400	
cross section [fb]	760	337	160	80.5	23.0	7.19	$2.34 \cdot 10^5$		
$n_\ell = 1$, $\not{E}_T > 100$ GeV, $n_{\text{fat}} \geq 1$	104.37	61.49	34.81	19.54	6.28	2.11	5631		
$n_{\text{tag}} = 1$	13.09	9.02	5.80	3.60	1.33	0.50	788.79		
$m_T > 150$ GeV	4.63	4.27	3.25	2.19	0.94	0.38	3.28	1.0	6.5
$j_b = b$	1.47	1.38	1.06	0.70	0.31	0.13	0.63	2.1	5.4
$(j_b, j_{W1}, j_{W2}) = (b, j, j)$	1.33	1.27	0.96	0.65	0.29	0.12	0.50	2.4	5.5
$(j_b, j_{W1}, j_{W2}) = (b, j, j)$, reject τ_h	1.20	1.16	0.88	0.60	0.27	0.11	0.25	4.1	6.9

Scalar Top Pairs at 8TeV [arXiv:1205.2696 T. Plehn, M. Spannowsky, MT]

– di-lepton mode



$t\bar{t} \to b\bar{b} + \ell\ell + 2\nu$

negligible with $m_{T2}^{\ell\ell} > 100$ GeV

$$m_{T2} = \min_{\not{E}_T\ split} \left[\max\{m_T^{\ell_1}, m_T^{\ell_2}\} \right]$$

$\sqrt{s} = 8$ TeV	$\tilde{t}1\tilde{t}1^*$						$t\bar{t}$	$t\bar{t}Z$	S/B	$S/\sqrt{B}_{10\mathrm{fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	350	400	450	500	600	700			400	
$n_\ell = 2$	30.98	14.27	7.07	3.58	1.04	0.33	7650.88	n.a.		
$\not{E}_T > 100$GeV	19.04	9.99	5.40	2.94	0.91	0.30	1312.74	0.35		
$m_{T2}^{\ell\ell} > 100$ GeV	6.05	4.30	2.70	1.65	0.56	0.20	0.65	0.09	5.8	16
$m_{T2}^{\ell\ell} > 150$ GeV	0.81	1.21	1.06	0.81	0.34	0.14	0.00	0.02	60	27

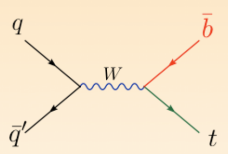
Scalar Top Pairs at 8TeV [arXiv:1205.2696 T. Plehn, M. Spannowsky, MT]

For scalar top mass 400 GeV for 10 fb^{-1}

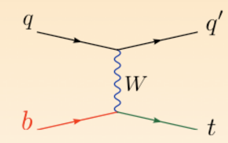
- fully hadronic mode: statistically limited
  $S/B \sim 0.8, S/\sqrt{B} \sim 1.5$ (two top tag)
  $S/B \sim 1, S/\sqrt{B} \sim 3$ (one top tag)
- semi-leptonic mode:
  $S/B \sim 4, S/\sqrt{B} \sim 7$
- di-lepton mode: not conclusive
  $S/B \sim 6, S/\sqrt{B} \sim 16$
  95% C.L. exclusion up to ~ 600 GeV

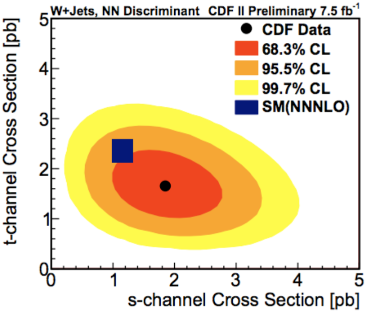
Single tops at 8TeV [arXiv:1207.4787 F. Kling, T. Plehn, MT]

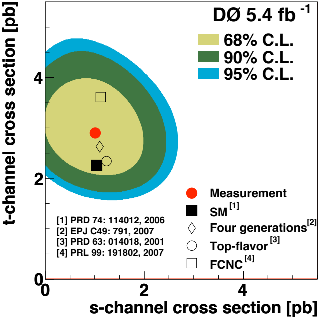
s-channel:



t-channel:



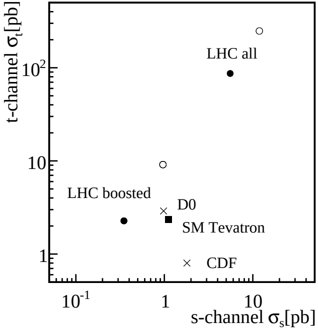


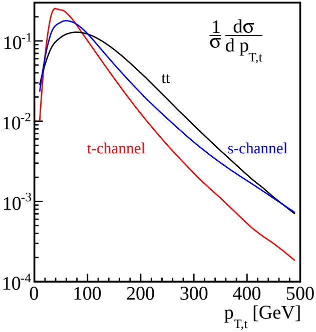


– 3σ level contradiction between CDF and D0

Single tops at 8TeV

[arXiv:1207.4787 F. Kling, T. Plehn, MT]





– small $\bar{q}$ and large $g \to b\bar{b}$

$\to \sigma_t \sim 16\sigma_s$ at LHC

8 TeV: $p_{T,t}^{min}$	0	100	200	300	400	500
σ_s [fb]	5548	1784	349	86.4	26.5	9.54
σ_t [fb]	86829	18167	2273	409.2	95.7	26.0
$\sigma_{t\bar{t}}$ [fb]	234731	137274	34640	7560	1850	519
σ_s/σ_t(%)	6.4	9.8	15.4	21.1	27.7	36.7
$\sigma_s/\sigma_{t\bar{t}}$(%)	2.36	1.29	1.00	1.14	1.43	1.83

σ_s/σ_t improves

in boosted regime

$\to$ top tagger

Single tops at 8TeV [arXiv:1207.4787 F. Kling, T. Plehn, MT]

– no lepton, 2 fat jets

– one top tag

– Δm^{prune}, b-tag in top tag

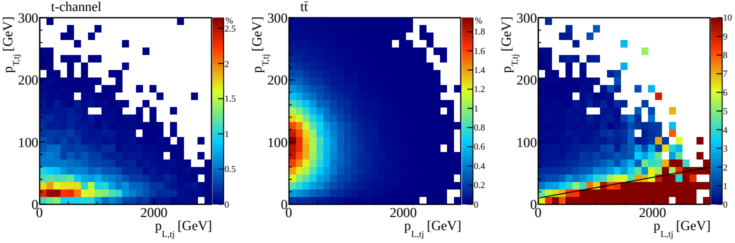
$\rightarrow t\bar{t}$ becomes main BG

8 TeV: rates in fb	t-ch.	s-ch.	$t\bar{t}$	tW	QCD	W+jets	S/B	$S/\sqrt{B}$
0. cross section	$8.72 \cdot 10^4$	$5.55 \cdot 10^3$	$2.34 \cdot 10^5$	$4.06 \cdot 10^4$	$6.58 \cdot 10^8$	$1.57 \cdot 10^6$	–	–
1. $n_\ell = 0$, 2 fat-j	$1.57 \cdot 10^3$	230	$1.88 \cdot 10^4$	$1.63 \cdot 10^3$	$6.67 \cdot 10^6$	$4.81 \cdot 10^4$	0.0002	1.9
2. one top tag	204	28.2	3070	227	$6.38 \cdot 10^4$	1297	0.003	2.5
3. Δm^{prune} cut	110	13.9	1421	102	$9.71 \cdot 10^3$	530	0.009	3.2
4. b-tag in top tag	44.3	5.29	524	37.4	97.1	5.30	0.07	5.4

Single tops at 8TeV

[arXiv:1207.4787 F. Kling, T. Plehn, MT]

– *tj*-system momentum



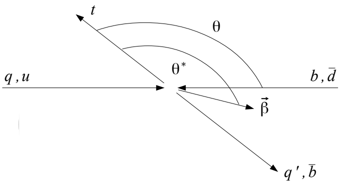
$$p_{T,tj} < \frac{p_{L,tj}}{60} + 10 \;\; \text{GeV} \quad \text{to reduce } t\bar{t}$$

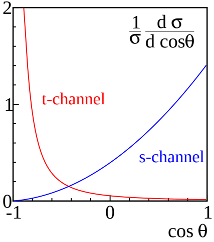
8 TeV: rates in fb	t-ch.	s-ch.	$t\bar{t}$	tW	QCD	W+jets	S/B	$S/\sqrt{B}$
0. cross section	$8.72\cdot10^4$	$5.55\cdot10^3$	$2.34\cdot10^5$	$4.06\cdot10^4$	$6.58\cdot10^8$	$1.57\cdot10^6$	–	–
1. $n_\ell = 0$, 2 fat-j	$1.57\cdot10^3$	230	$1.88\cdot10^4$	$1.63\cdot10^3$	$6.67\cdot10^6$	$4.81\cdot10^4$	0.0002	1.9
2. one top tag	204	28.2	3070	227	$6.38\cdot10^4$	1297	0.003	2.5
3. Δm^{prune} cut	110	13.9	1421	102	$9.71\cdot10^3$	530	0.009	3.2
4. b-tag in top tag	44.3	5.29	524	37.4	97.1	5.30	0.07	5.4
5. p_{tj} cut	15.3	1.34	11.1	1.12	12.4	1.27	0.57	9.3

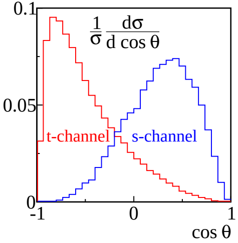
Single tops at 8TeV

[arXiv:1207.4787 F. Kling, T. Plehn, MT]

– top production angle distribution





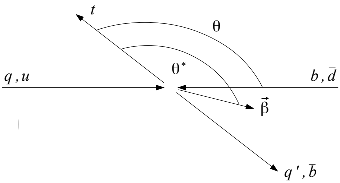


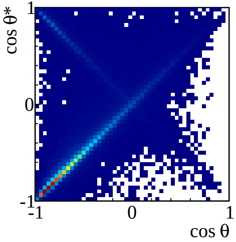
8 TeV: rates in fb	t-ch.	s-ch.	$t\bar{t}$	tW	QCD	W+jets	S/B	$S/\sqrt{B}$
0. cross section	$8.72\cdot10^4$	$5.55\cdot10^3$	$2.34\cdot10^5$	$4.06\cdot10^4$	$6.58\cdot10^8$	$1.57\cdot10^6$	–	–
1. $n_\ell = 0$, 2 fat-j	$1.57\cdot10^3$	230	$1.88\cdot10^4$	$1.63\cdot10^3$	$6.67\cdot10^6$	$4.81\cdot10^4$	0.0002	1.9
2. one top tag	204	28.2	3070	227	$6.38\cdot10^4$	1297	0.003	2.5
3. Δm^{prune} cut	110	13.9	1421	102	$9.71\cdot10^3$	530	0.009	3.2
4. b-tag in top tag	44.3	5.29	524	37.4	97.1	5.30	0.07	5.4
5. p_{tj} cut	15.3	1.34	11.1	1.12	12.4	1.27	0.57	9.3

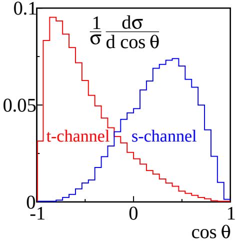
Single tops at 8TeV

[arXiv:1207.4787 F. Kling, T. Plehn, MT]

– top production angle distribution



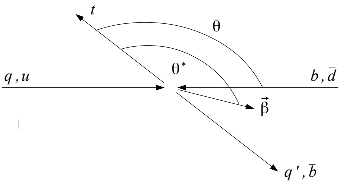


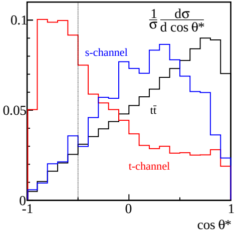


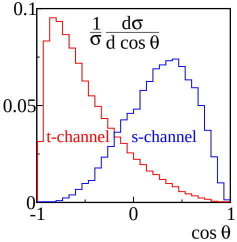
8 TeV: rates in fb	t-ch.	s-ch.	$t\bar{t}$	tW	QCD	W+jets	S/B	$S/\sqrt{B}$
0. cross section	$8.72\cdot10^4$	$5.55\cdot10^3$	$2.34\cdot10^5$	$4.06\cdot10^4$	$6.58\cdot10^8$	$1.57\cdot10^6$	–	–
1. $n_\ell = 0$, 2 fat-j	$1.57\cdot10^3$	230	$1.88\cdot10^4$	$1.63\cdot10^3$	$6.67\cdot10^6$	$4.81\cdot10^4$	0.0002	1.9
2. one top tag	204	28.2	3070	227	$6.38\cdot10^4$	1297	0.003	2.5
3. Δm^{prune} cut	110	13.9	1421	102	$9.71\cdot10^3$	530	0.009	3.2
4. b-tag in top tag	44.3	5.29	524	37.4	97.1	5.30	0.07	5.4
5. p_{tj} cut	15.3	1.34	11.1	1.12	12.4	1.27	0.57	9.3

Single tops at 8TeV [arXiv:1207.4787 F. Kling, T. Plehn, MT]

– top production angle distribution





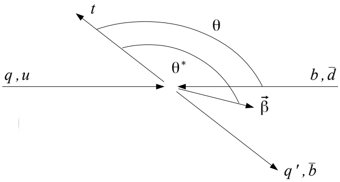


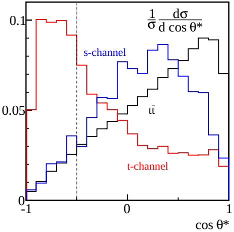
8 TeV: rates in fb	t-ch.	s-ch.	$t\bar{t}$	tW	QCD	W+jets	S/B	$S/\sqrt{B}$
0. cross section	$8.72 \cdot 10^4$	$5.55 \cdot 10^3$	$2.34 \cdot 10^5$	$4.06 \cdot 10^4$	$6.58 \cdot 10^8$	$1.57 \cdot 10^6$	–	–
1. $n_\ell = 0$, 2 fat-j	$1.57 \cdot 10^3$	230	$1.88 \cdot 10^4$	$1.63 \cdot 10^3$	$6.67 \cdot 10^6$	$4.81 \cdot 10^4$	0.0002	1.9
2. one top tag	204	28.2	3070	227	$6.38 \cdot 10^4$	1297	0.003	2.5
3. Δm^{prune} cut	110	13.9	1421	102	$9.71 \cdot 10^3$	530	0.009	3.2
4. b-tag in top tag	44.3	5.29	524	37.4	97.1	5.30	0.07	5.4
5. p_{tj} cut	15.3	1.34	11.1	1.12	12.4	1.27	0.57	9.3

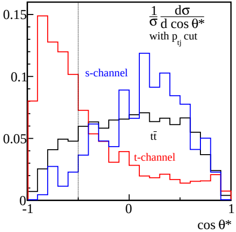
Michihisa Takeuchi

Single tops at 8TeV [arXiv:1207.4787 F. Kling, T. Plehn, MT]

– top production angle distribution







8 TeV: rates in fb	t-ch.	s-ch.	$t\bar{t}$	tW	QCD	W+jets	S/B	$S/\sqrt{B}$
0. cross section	$8.72\cdot10^4$	$5.55\cdot10^3$	$2.34\cdot10^5$	$4.06\cdot10^4$	$6.58\cdot10^8$	$1.57\cdot10^6$	–	–
1. $n_\ell = 0$, 2 fat-j	$1.57\cdot10^3$	230	$1.88\cdot10^4$	$1.63\cdot10^3$	$6.67\cdot10^6$	$4.81\cdot10^4$	0.0002	1.9
2. one top tag	204	28.2	3070	227	$6.38\cdot10^4$	1297	0.003	2.5
3. Δm^{prune} cut	110	13.9	1421	102	$9.71\cdot10^3$	530	0.009	3.2
4. b-tag in top tag	44.3	5.29	524	37.4	97.1	5.30	0.07	5.4
5. p_{tj} cut	15.3	1.34	11.1	1.12	12.4	1.27	0.57	9.3
6. $\cos\theta^* < -0.5$	8.6	0.07	1.58	0.14	3.3	0.21	1.62	11.8

$\rightarrow S/B > 1$, $S/\sqrt{B} > 10$ for 10fb^{-1}

Single tops at 8TeV [arXiv:1207.4787 F. Kling, T. Plehn, MT]

s-channel: need additional cuts for recoil jet

– $\cos\theta^* > -0.5$

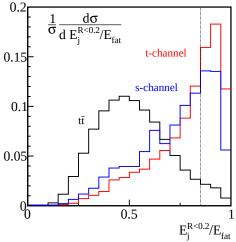
8 TeV: rates in fb	t-ch.	s-ch.	$t\bar{t}$	tW	QCD	W+jets	S/B	$S/\sqrt{B}$
1-5. one top tag, b-tag, p_{tj} cut	15.3	1.34	11.1	1.12	12.4	1.27	–	–
6. $\cos\theta^* > -0.5$	6.75	1.27	9.52	0.97	9.06	1.06	0.05	1.2

Single tops at 8TeV

[arXiv:1207.4787 F. Kling, T. Plehn, MT]

s-channel: need additional cuts for recoil jet

- $\cos\theta^* > -0.5$
- *b*-tag in recoil jet
- $E_j^{R<0.2}/E_{\text{fat}} > 0.85$ and $m_j < 65$ GeV
- $\not{p}_T < 40$ GeV



8 TeV: rates in fb	t-ch.	s-ch.	$t\bar{t}$	tW	QCD	W+jets	S/B	$S/\sqrt{B}$
1-5. one top tag, b-tag, p_{tj} cut	15.3	1.34	11.1	1.12	12.4	1.27	–	–
6. $\cos\theta^* > -0.5$	6.75	1.27	9.52	0.97	9.06	1.06	0.05	1.2
7. b-tag in recoil jet	0.07	0.64	1.94	0.18	0.09	0.01	0.28	2.1
8. $E_j^{R<0.2}/E_{\text{fat}}$, $m_j < 65$ GeV	0.04	0.35	0.11	0.02	0.03	–	1.75	3.9
9. $\not{p}_T < 40$ GeV	0.04	0.32	0.07	0.02	0.03	–	2.00	4.0

$\rightarrow S/B = 2,\ S/\sqrt{B} = 4$ for 25fb^{-1}

Summary

HEPTopTagger available on http://www.thphys.uni-heidelberg.de/∼plehn/

- moderate p_T tops (> 200GeV) $\rightarrow$ testable in SM
- fat jets kill combinatorics
- jet substructure
  thrown information $\rightarrow$ use all available infomation
- momentum well reconstructed
- general idea: tops at LHC identified just like bottoms

Applications

- stop pairs at 14 TeV (2 boosted tops)
  $S/B \sim 1$(hadronic), $S/B \sim 2$(semi-leptonic), with $S/\sqrt{B} > 5$
- stop pairs at 8 TeV with 10fb^{-1}
  hadronic: $S/B \sim 1, S/\sqrt{B} \sim 1.5$
  semi-leptonic: $S/B \sim 4, S/\sqrt{B} \sim 7$
  di-leptonic: $S/B \sim 6, S/\sqrt{B} \sim 16$
- single tops at 8 TeV
  t-channel: $S/B > 1, S/\sqrt{B} \sim 12$ for 10 fb^{-1}
  s-channel: $S/B \sim 2, S/\sqrt{B} \sim 4$ for 25 fb^{-1}