CutLang v2

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CutLang v1

arXiv:1801.05727

https://cutlang.hepforge.org

- arXiv paper: internals, user manual, how to run examples etc.
- Web page: user manual, examples & source code tgz:

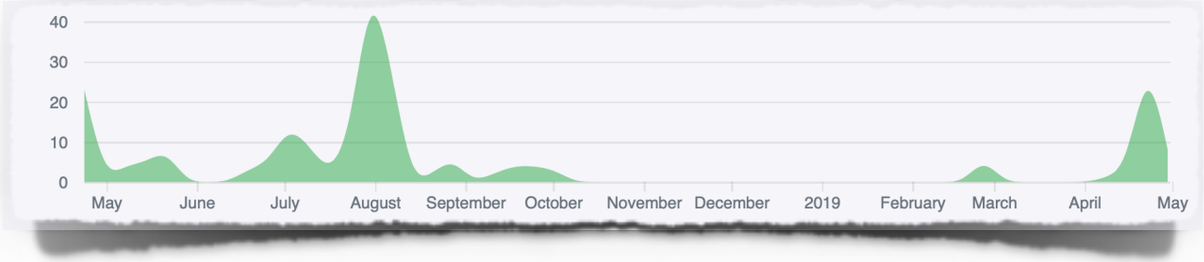
Introducing CutLang v2

- Analysis description language (ADL) and runtime interpreter
  - Human readable text file to describe the whole analysis
  - Run time interpretation of the ADL file: *No compiling!*
    - ADL: [initializations] [definitions] [objects] [definitions] commands

- Works with multiple input data formats
  - Currently available data formats: LVL0, ATLAS OpenData, CMS OpenData, Delphes, LHCO, FCC, CMSNANOAOD,….
    - more can be easily added…

CutLang implementation

- *Modest* requirements:
  - Pure C++ classes, on top of ROOT LorentzVectors and histograms
  - Linux or Mac, C++ (gcc4.x)
    - ROOT6
    - yacc & lexx (NEW)
- Additional tools to help the analyst and the advisor
  - All definitions, cuts and object selections are saved into the output ROOT file
  - Shell & Python scripts for plotting & addition of “user functions” being updated
- The project is opensource and lives on github
  - https://github.com/unelg/CutLang.git



Syntax

- The execution order is top to bottom.
- Most mathematical functions are available
  - sin(), cos(), tan(), abs(), sqrt(), ^, *, /, +, -, interval inclusion and exclusion
- There are few keywords (and their synonyms):
  - events are selected using **select** (or **cmd**)
  - additional constants, functions and particles are constructed using **define** (or **def**)
  - histograms are booked, and filled with **histo**
  - independent algorithms are declared using **region** (or **algo**)
  - new particle objects are defined using **object** (or **obj**)
  - predefined particles are: **ELE**CTRON, **MUO**N, **TAU**, **PHO**TON, **JET**, **F**AT**JET**, **MET**
    - particles are already sorted in decreasing transverse momentum order
  - predefined particle attributes and functions are: charge mass, energy, transverse momentum, total momentum, pseudorapidity, angular distances,…
  - units are in GeV, comment character is #

particle notation

- On the blackboard, we write

jet_1

  - When you type it in latex it is jet_1
  - CL understands *particleName_index* notation:

Highest Pt object	Second Highest Pt object
ELE_0	ELE_1
MUO_0	MUO_1

- On the computer, we write

```
jet[3]
```

  - CL understands *particleName*[*index*] notation:

```
muonsVeto[0]
photons[0]
```

functions & attributes

- Is pseudo rapidity or transverse momentum a property of a particle? of the addition of many particles? is it an attribute? is it a function?

- DO I CARE? no.
  - I only care about the result of my analysis

- However, when I speak or write I might say either of
  - “the mass of a particle set” m ( )
  - “the particle set’s mass” { }m ← more natural in Turkish

- CL understands both notations

Meaning	Operator	Operator
Mass of	`m( )`	`{ }m`
Charge of	`q( )`	`{ }q`
Phi of	`Phi( )`	`{ }Phi`
Eta of	`Eta( )`	`{ }Eta`
Absolute value of Eta of	`AbsEta( )`	`{ }AbsEta`
Pt of	`Pt( )`	`{ }Pt`

A very simple example

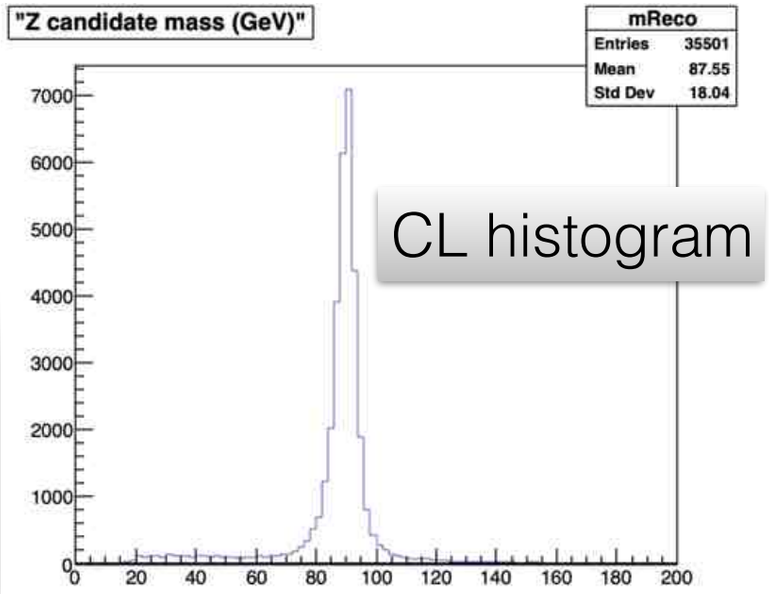
- reconstruct Z boson candidate from the first two electrons $Z \to \ell\ell \quad \ell = e, \mu$
- histogram the mass of the candidate

user's ADL file

```
region   test
  select      ALL                 # to count all events
  select      Size (ELE) >= 2     # events with 2 or more electrons
  histo       mReco, "Z candidate mass (GeV)", 100, 0, 200, {ELE_0 ELE_1}m
```

CL output

```
            test    Based on 125000 events:
                          ALL :      1 +-          0 evt:   125000
                 Size (ELE) >= 2 :  0.284 +-   0.00128 evt:    35501
[Histo] Z candidate mass (GeV) :      1 +-          0 evt:    35501
     --> Overall efficiency  =   28.4 % +-  0.128 %
```



CL histogram

A very simple example

- Additional constraint

$$Z \to \ell\ell \quad \ell = e, \mu$$

  - the Z candidate should be neutral (q=0)

user's ADL file

```
region   test
  select      ALL                 # to count all events
  select      Size (ELE) >= 2  # events with 2 or more electrons
  histo       h1mReco, "Z candidate mass (GeV)", 100, 0, 200, {ELE_0 ELE_1}m
  select      {ELE[0] ELE[1] }q == 0    # Z is neutral
  histo       h2mReco, "Z candidate mass (GeV)", 100, 0, 200, {ELE_0 ELE_1}m
```

CL output

```
            test    Based on 125000 events:
                            ALL :      1 +-          0 evt:   125000
               Size (ELE) >= 2 :  0.284 +-   0.00128 evt:    35501
[Histo] Z candidate mass (GeV) :      1 +-          0 evt:    35501
        {ELE[0] ELE[1] }q == 0 : 0.9595 +-   0.00105 evt:    34063
[Histo] Z candidate mass (GeV) :      1 +-          0 evt:    34063
     --> Overall efficiency  =   27.3 % +-  0.126 %
```

A very simple example

- Additional constraint

$$Z \to \ell\ell \quad \ell = e, \mu$$

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  select      {ELE[0] ELE[1] }q == 0    # Z is neutral
  histo       h2mReco, "Z candidate mass (GeV)", 100, 0, 200, {ELE_0 ELE_1}m
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[Histo] Z candidate mass (GeV) :      1 +-          0 evt:    34063
     --> Overall efficiency  =   27.3 % +-  0.126 %
```

2 electron combination is often used, why not to give it a name like Zreco?

A very simple example

- introducing definitions

$$Z \to \ell\ell \quad \ell = e, \mu$$

user's ADL file

```
define Zreco : ELE[0] ELE[1]

region   test
  select      ALL                 # to count all events
  select      Size (ELE) >= 2  # events with 2 or more electrons
  histo       h1mReco, "Z candidate mass (GeV)", 100, 0, 200, {Zreco}m
  select      {Zreco}q == 0    # Z is neutral
  histo       h2mReco, "Z candidate mass (GeV)", 100, 0, 200, m(Zreco)
```

CL output

```
            test    Based on 125000 events:
                           ALL :      1 +-          0 evt:   125000
               Size (ELE) >= 2 :  0.284 +-   0.00128 evt:    35501
[Histo] Z candidate mass (GeV) :      1 +-          0 evt:    35501
                 {Zreco}q == 0 : 0.9595 +-   0.00105 evt:    34063
[Histo] Z candidate mass (GeV) :      1 +-          0 evt:    34063
     --> Overall efficiency  =   27.3 % +-  0.126 %
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A very simple example

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user's ADL file

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define Zreco : ELE[0] ELE[1]

region   test
  select      ALL                 # to count all events
  select      Size (ELE) >= 2  # events with 2 or more electrons
  histo       h1mReco, "Z candidate mass (GeV)", 100, 0, 200, {Zreco}m
  select      {Zreco}q == 0    # Z is neutral
  histo       h2mReco, "Z candidate mass (GeV)", 100, 0, 200, m(Zreco)
```

CL output

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            test    Based on 125000 events:
                          ALL :      1 +-          0 evt:   125000
               Size (ELE) >= 2 :  0.284 +-   0.00128 evt:    35501
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[Histo] Z candidate mass (GeV) :      1 +-          0 evt:    34063
     --> Overall efficiency  =   27.3 % +-  0.126 %
```

Are these electrons inside the inner tracker?

A simple example

- introducing derived objects

$$Z \to \ell\ell \quad \ell = e, \mu$$

```
define Zreco : ELE[0] ELE[1]

object goodEle : ELE
  select  Pt(ELE_)         >   10
  select abs({ELE_}Eta)    <   2.4
  select     {ELE_}AbsEta ][  1.442 1.556

define goodZreco : goodEle[0] goodEle[1]

region   test
  select      ALL                # to count all events
  select      Size(ELE)      >= 2  # events with 2 or more electrons
  select      Size(goodEle) >= 2  # events with 2 or more electrons
  histo       h1mReco,      "Z candidate mass (GeV)", 100, 0, 200, {Zreco}m
  histo       h1mgoodReco, "Z candidate mass (GeV)", 100, 0, 200, {goodZreco}m
  select      {Zreco}q == 0       # Z is neutral
  select      {goodZreco}q == 0   # Z is neutral
  histo       h2mReco     , "Z candidate mass (GeV)", 100, 0, 200, m(Zreco)
  histo       h2mgoodReco, "Z candidate mass (GeV)", 100, 0, 200, m(goodZreco)
```

Derived objects

- Further cleaning or refining can be achieved using derived objects
  - Derived objects can be used to derive further refined objects
    - JETS —> goodJETs —> cleanJETs —> verycleanJets …
  - Multiple selection criteria can be applied
  - If all members of a particular class (e.g. jets) are considered, a _ sign is needed
  - The criteria selection line can contain at most 2 different type of objects (e.g. j & p)
  - The whole criteria returns a boolean for the considered pair (j_i and p_j)

```
# jets - no photon
object AK4jetsNOpho : AK4jets
  select dR(AK4jets_, photons_ ) >=0.4 OR {photons_}Pt/{AK4jets_}Pt ][ 0.5 2.0
```

- Analysis algorithms can use the original objects or derived objects

A simple example

- introducing derived objects

$$Z \to \ell\ell \quad \ell = e, \mu$$

```
define Zreco : ELE[0] ELE[1]

object goodEle : ELE
  select Pt(ELE_)        >   10
  select   {ELE_}AbsEta <   2.4
  select   {ELE_}AbsEta ][  1.442 1.556

define goodZreco : goodEle[0] goodEle[1]

region   test
  select      ALL                 # to count all events
  select      Size(ELE)     >= 2  # events with 2 or more electrons
  select      Size(goodEle) >= 2  # events with 2 or more electrons
  histo       h1mReco,     "Z candidate mass (GeV)", 100, 0, 200, {Zreco}m
  histo       h1mgoodReco, "Z candidate mass (GeV)", 100, 0, 200, {goodZreco}m
  select      {Zreco}q == 0       # Z is neutral
  select      {goodZreco}q == 0   # Z is neutral
  histo       h2mReco     , "Z candidate mass (GeV)", 100, 0, 200, m(Zreco)
  histo       h2mgoodReco, "Z candidate mass (GeV)", 100, 0, 200, m(goodZreco)
```

this is not fair, Zreco's charge should not impact goodZreco selection.

A simple example

- introducing multiple regions or algorithms

$$Z \to \ell\ell \quad \ell = e, \mu$$

```
define Zreco : ELE[0] ELE[1]

object goodEle : ELE
  select Pt(ELE_)        >   10
  select   {ELE_}AbsEta <   2.4
  select   {ELE_}AbsEta ][  1.442 1.556

define goodZreco : goodEle[0] goodEle[1]

algo        preselection
  select      ALL                 # to count all events
  select      Size(ELE)      >= 2  # events with 2 or more electrons

algo        testA
  preselection
#  histo       h1mReco,      "Z candidate mass (GeV)", 100, 0, 200, {Zreco}m
  select      {Zreco}q == 0        # Z is neutral
  histo       h2mReco     , "Z candidate mass (GeV)", 100, 0, 200, m(Zreco)

algo        testB
  preselection
  select      Size(goodEle) >= 2  # events with 2 or more electrons
#  histo       h1mgoodReco, "Z candidate mass (GeV)", 100, 0, 200, {goodZreco}m
  select      {goodZreco}q == 0   # Z is neutral
  histo       h2mgoodReco, "Z candidate mass (GeV)", 100, 0, 200, m(goodZreco)
```

Running with multiple regions

- A user defined region can contain another one
  - e.g. SignalRegion containing preselection
- All regions are processed in parallel and saved as TDirectories in the output ROOT file

```
TFile**         histoOut-ex5.root
 TFile*         histoOut-ex5.root
  KEY: TDirectoryFile   preselection;1  preselect
  KEY: TDirectoryFile   testA;1 testA
  KEY: TDirectoryFile   testB;1 testB
```

```
root [2] testA->cd()
(bool) true
root [3] .ls
TDirectoryFile*         testA   testA
 KEY: TText     CLA2cuts;1
  select      ALL
  select      Size(ELE)     >= 2
  select      {Zreco}q == 0
  histo       h2mReco    , "Z candidate mass (GeV)", 100, 0, 200, m(Zreco)
  select      ALL

 KEY: TText     CLA2defs;1
define Zreco : ELE[0] ELE[1]
define goodZreco : goodEle[0] goodEle[1]

 KEY: TText     CLA2Objs;1
object goodEle : ELE
  select   Pt(ELE_)       >   10
  select abs({ELE_}Eta )  <   2.4
  select     {ELE_}AbsEta ][  1.442 1.556

 KEY: TH1F      eff;1   selection efficiencies
 KEY: TNtuple   rntuple;1       run info
 KEY: TH1D      h2mReco;1       "Z candidate mass (GeV)"
```

An example $Z \to \ell\ell \quad \ell = e, \mu$

- Introducing optimizers
  - if there are more than 2 electrons, search all possible combinations to find the “best” candidate

```
define Zreco : ELE[0] ELE[1]

object goodEle : ELE
  select Pt(ELE_)        >   10
  select   {ELE_}AbsEta <   2.4
  select   {ELE_}AbsEta ][  1.442 1.556

define goodZreco : goodEle[-1] goodEle[-1]

algo BestZ
  select      ALL                     # to count all events
  select      Size(goodEle) >= 2      # events with 2 or more electrons
  select      {goodZreco}m ~= 91.2    # find the pair yielding mass closest to Z
  select      {goodZreco}q == 0       # Z is neutral
  histo       hZRecoB, "Z candidate mass (GeV)", 100, 0, 200, m(goodZreco)
```

We use negative indices if they are to be determined at run time, using a criterion, such as: **~=**

Repeating the same negative value helps speeding up since $e_i\ e_j = e_j\ e_i$

User (external) functions

- User defined selection functions are somewhat difficult to incorporate into an interpreter

- Currently we define a user function type and compile it in.
  - CLv2 will provide the means to do this automatically
  - Currently Razor functions are pre-integrated:

```
std::vector<TLorentzVector> fmegajets(std::vector<TLorentzVector> myjets);
double fMR(std::vector<TLorentzVector> j);
double fMTR(std::vector<TLorentzVector> j, TVector2 amet);
double fMTR2(std::vector<TLorentzVector> j, TLorentzVector amet);
```

- Simple functions can be interpreted using CL math functions

```
    return sqrt( 2 * lepton.Pt() * pfmet.Pt() * ( 1 - cos( pfmet.Phi() - lepton.Phi() )));
```

```
define MTe : sqrt( 2*{electronsVeto_0}Pt *MET*(1-cos( {METLV_0}Phi - {electronsVeto_0}Phi )))
define MTm : sqrt( 2*{muonsVeto_0}Pt *MET*(1-cos( {METLV_0}Phi - {muonsVeto_0}Phi )))
define mZ : 91.187
```

First reactions

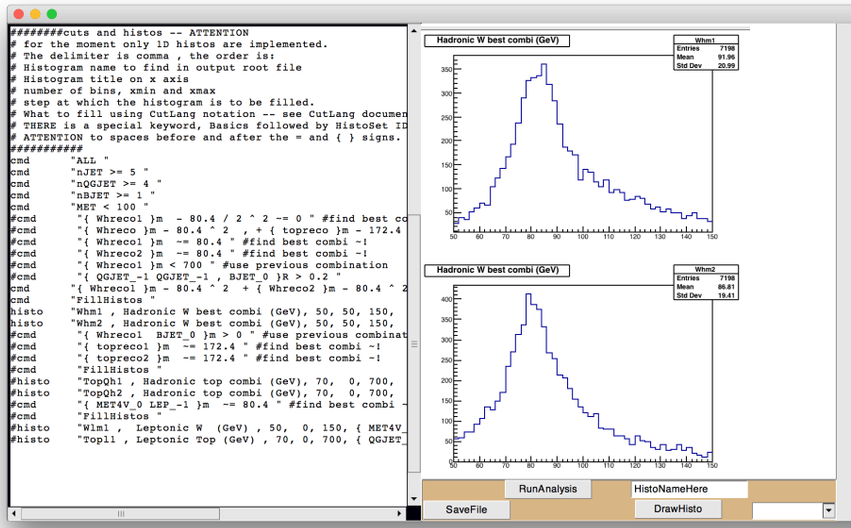
- An earlier version of CutLang is being used in an ATLAS Exotics analysis, the feedback is so far positive:

- Students
  - Very happy not to deal with C++ syntax, pointers, ROOT etc.
  - Very easy to keep track of various analysis variations such as control regions, cut optimizations etc.
  - Very easy to test ideas, disable a cut or swap two cuts, add a histogram etc.

- Advisors
  - Can follow easily what the students are doing
  - Analysis algorithms, object definition thresholds are automatically synchronized to program output
  - Full algorithm including thresholds is saved into output ROOT files

OutLook

- compatibility between CutLang and LHADA is nearly achieved via ADL



- A CutLang Gui is underway
  - edit config file, run, look at histograms…
- Improve CutLang documentation & training guide including a wiki page
- More work on CutLang v2
  - 2D histograms…
  - SORT, COMBInation, PERMutation…
  - multithreaded version
  - …

We will have a CERN summer student to work on some of these. CutLang needs you!

thank you for your attention

backup slides

- reference guide
- ttbar reconstruction
- example analyses
- speed issues

reference guide

- The Objects

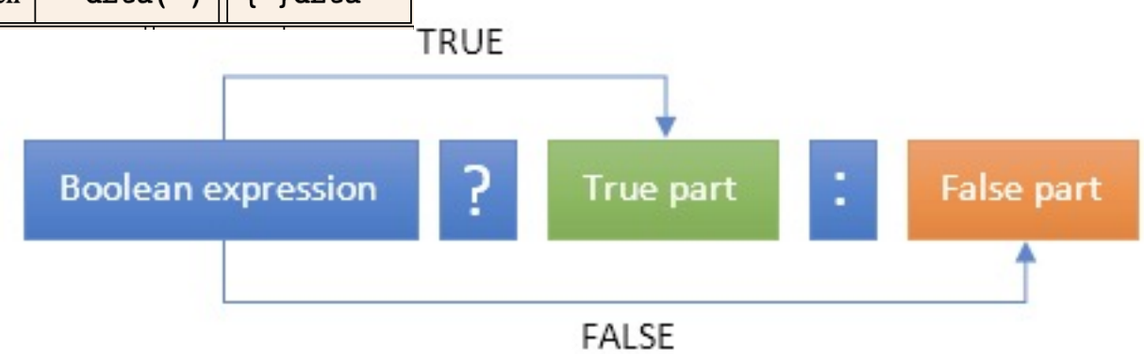
Name	Keyword	Highest Pt object	Second Highest Pt object	$j+1^{th}$Highest Pt object
Electron	ELE	ELE_0	ELE_1	ELE_j
Muon	MUO	MUO_0	MUO_1	MUO_j
Tau	TAU	TAU_0	TAU_1	TAU_j
Lepton	LEP	LEP_0	LEP_1	LEP_j
Photon	PHO	PHO_0	PHO_1	PHO_j
Jet	JET	JET_0	JET_1	JET_j
Fat Jet	FJET	FJET_0	FJET_1	FJET_j
b-tagged Jet	BJET	BJET_0	BJET_1	BJET_j
light Jet	QGJET	QGJET_0	QGJET_1	QGJET_j
neutrino	METV	METV_0	METV_1	METV_j

- Functions

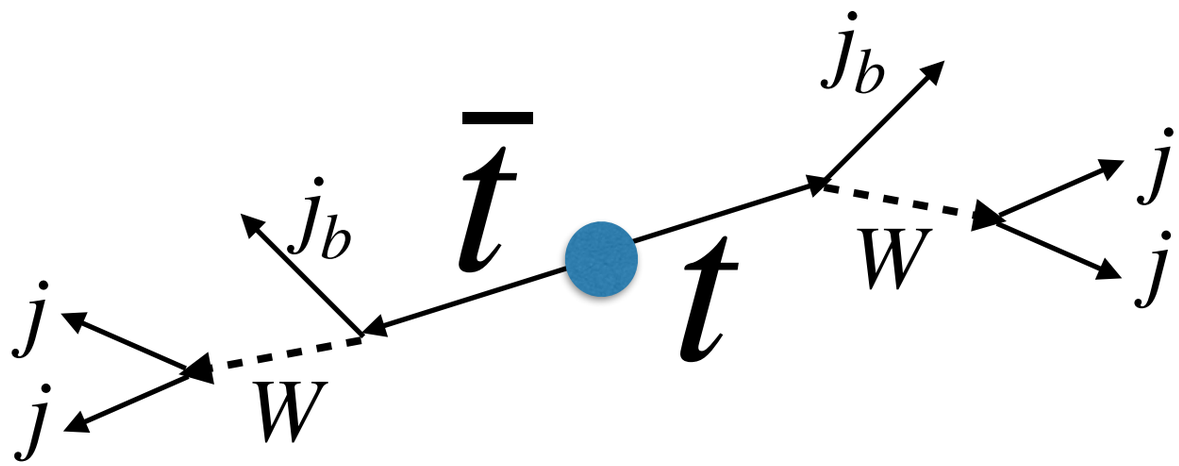
Meaning	Operator
number of	Size( )
tangent	tan()
sinus	sin()
cosinus	cos()
absolute value	abs()
square root	sqrt()
in the interval	[ ]
not in the interval	][
as close as possible	~=
as far away as possible	!=
usual meaning	+-/*
to the power	^

Meaning	Operator	Operator
Mass of	m( )	{ }m
Charge of	q( )	{ }q
Phi of	Phi( )	{ }Phi
Eta of	Eta( )	{ }Eta
Absolute value of Eta of	AbsEta( )	{ }AbsEta
Pt of	Pt( )	{ }Pt
Pz of	Pz( )	{ }Pz
Energy of	E( )	{ }E
Momentum of	P( )	{ }P
Angular distance between	dR( )	{ }dR
Phi difference between	dPhi( )	{ }dPhi
Eta difference between	dEta( )	{ }dEta

- The ternary function in C notation



$t\bar{t}$ Reconstruction example



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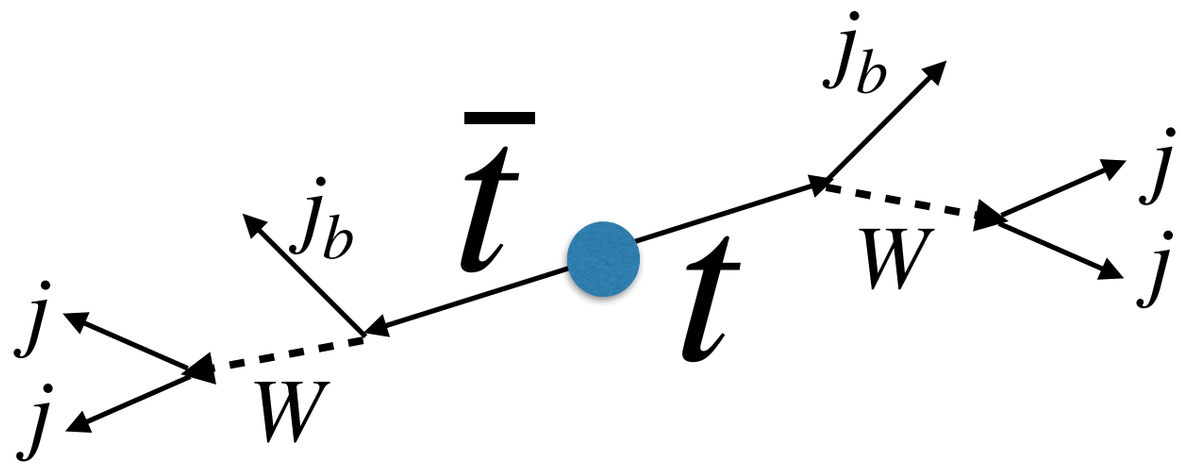
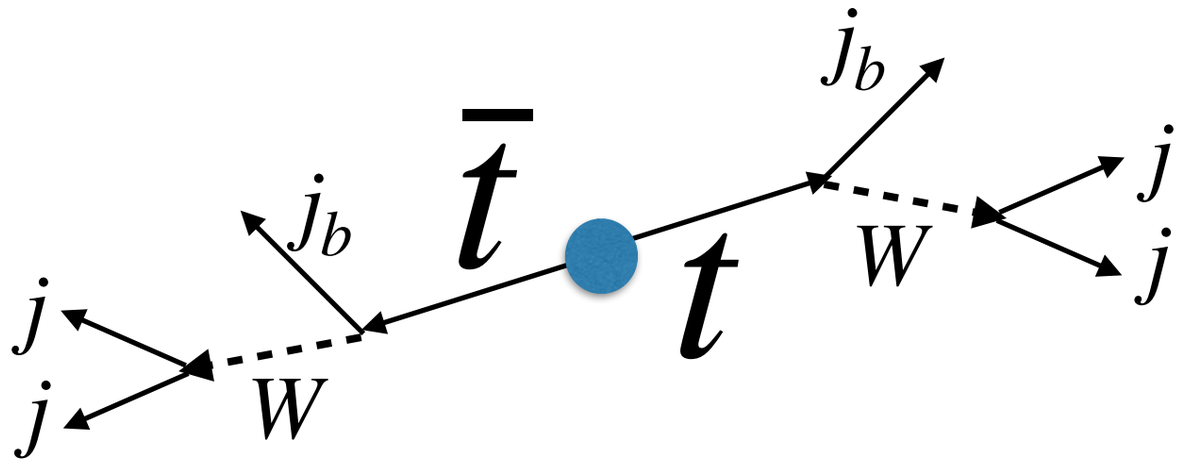


$$t \to Wb \to jjj_b$$

$t\bar{t}$ Reconstruction example

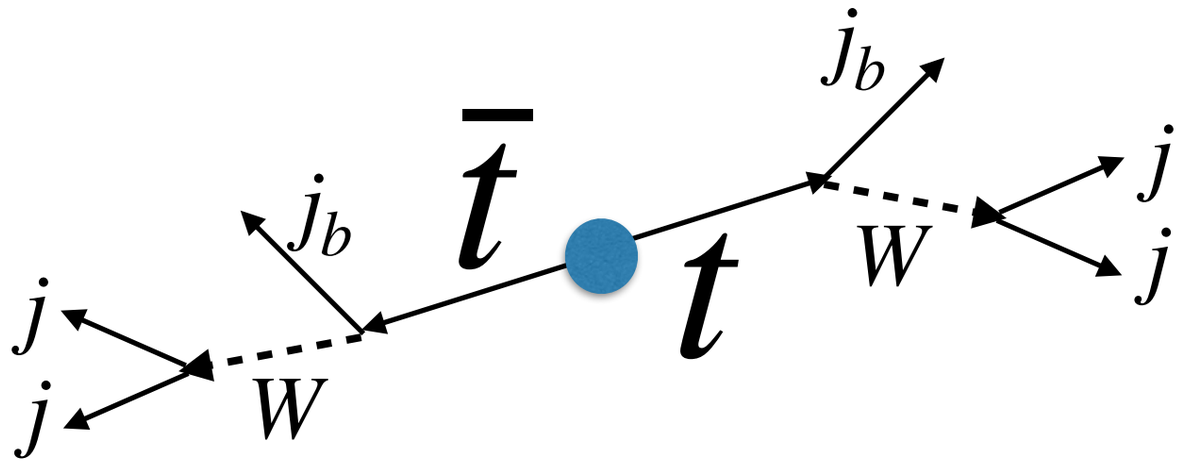


$$t \to Wb \to jjj_b$$

There are 6 jets in the event <u>of which 2 can be b-tagged</u>

+ LOTS of *other jets* from spectator quarks and QCD effects

$t\bar{t}$ Reconstruction example



$$t \to Wb \to jjj_b$$

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Which one is which?

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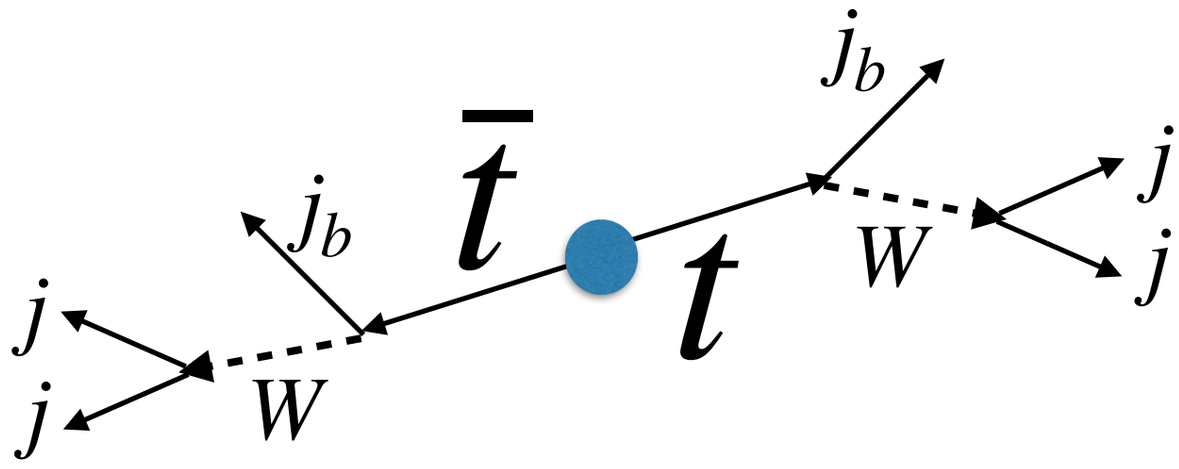


$$t \to Wb \to jjj_b$$

There are 6 jets in the event <u>of which 2 can be b-tagged</u>

+ LOTS of *other jets* from spectator quarks and QCD effects

Which one is which?

with the χ^2 defined as:

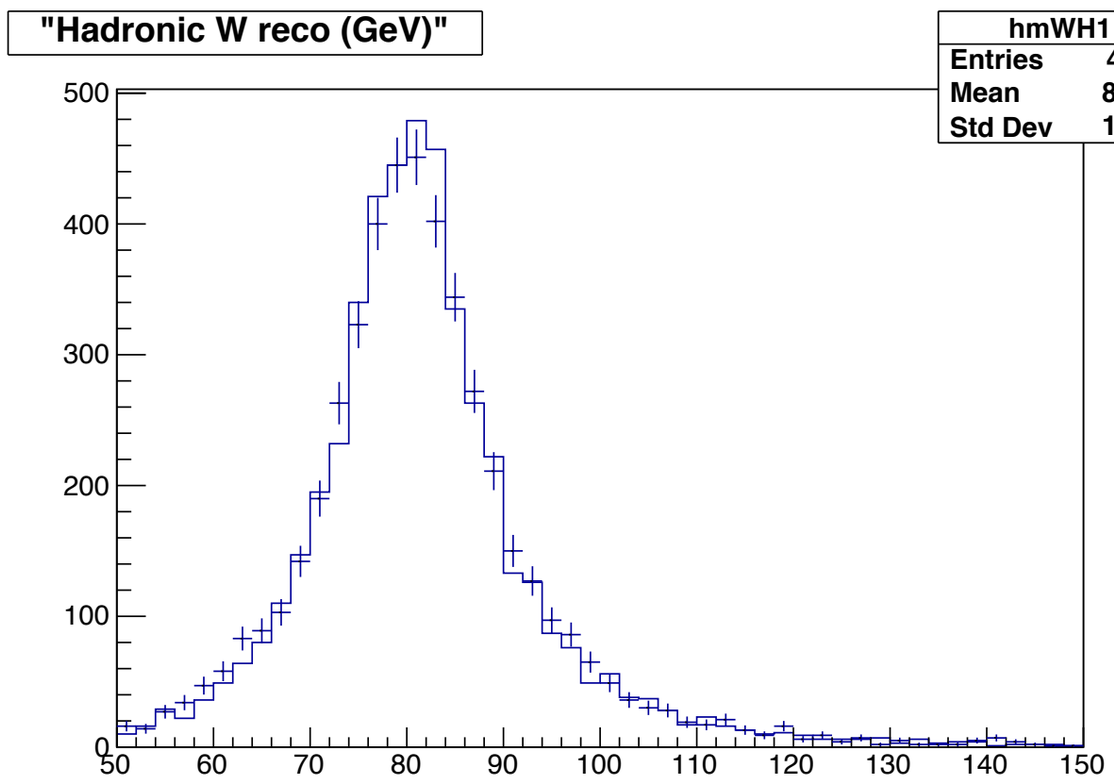
$$\chi^2 = \frac{(m_{b_1 j_1 j_2} - m_{b_2 j_3 j_4})^2}{\sigma^2_{\Delta m_{bjj}}} + \frac{(m_{j_1 j_2} - m_W^{\mathrm{MC}})^2}{\sigma^2_{m_W^{\mathrm{MC}}}} + \frac{(m_{j_3 j_4} - m_W^{\mathrm{MC}})^2}{\sigma^2_{m_W^{\mathrm{MC}}}}.$$

$t\bar{t}$ Reconstruction example

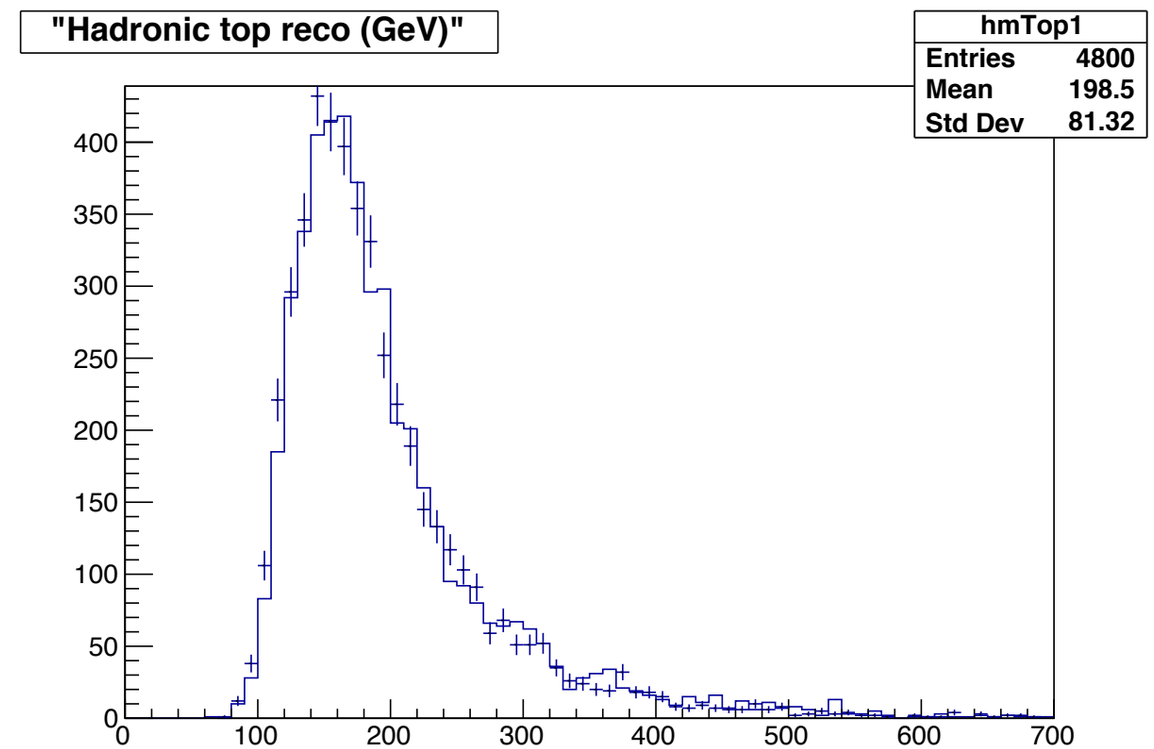
```
define   WH1  : JET[-1] JET[-1]
define   WH2  : JET[-3] JET[-3]
###      chi2 for W finder
define   Wchi2 : (({WH1}m - 80.4)/2.1)^2 + (({WH2}m - 80.4)/2.1)^2

## top quarks without b tagging
define   Top1 : WH1 JET[-2]
define   Top2 : WH1 JET[-4]
define   mTop1 : m(Top1)
define   mTop2 : m(Top2)
###      chi2 for top finder
define   topchi2 : ((mTop1 - mTop2)/4.2)^2

algo besttop
  select   ALL                    # to count all events
  select   Size(JET) >= 6         # at least 6 jets
  select   MET < 100              # no large MET
  select   Wchi2 + topchi2 ~= 0   # find the tops and ws
  histo    hmWH1 , "Hadronic W reco (GeV)", 50, 50, 150, m(WH1)
  histo    hmWH2 , "Hadronic W reco (GeV)", 50, 50, 150, m(WH2)
  histo    hmTop1 , "Hadronic top reco (GeV)", 70, 0, 700, mTop1
  histo    hmTop2 , "Hadronic top reco (GeV)", 70, 0, 700, mTop2
```

, with the χ^2 defined as:

$$\chi^2 = \frac{(m_{b_1 j_1 j_2} - m_{b_2 j_3 j_4})^2}{\sigma^2_{\Delta m_{bjj}}} + \frac{(m_{j_1 j_2} - m_W^{\mathrm{MC}})^2}{\sigma^2_{m_W^{\mathrm{MC}}}} + \frac{(m_{j_3 j_4} - m_W^{\mathrm{MC}})^2}{\sigma^2_{m_W^{\mathrm{MC}}}}.$$



reconstructed W bosons



reconstructed top quarks

Razor boost example 1/2

```
# arxiv:1710.11188, CMS SUSY stop (resolved and boosted)

#info analysis
# Details about experiment
#  experiment CMS
#  id SUS-16-050
#  publication Phys.Rev. D97 (2018) no.1, 012007
#  sqrtS 13.0
#  lumi 35.9
#  arXiv 1710.11188
#  hepdata https://www.hepdata.net/record/ins1633588
#  doi 10.1103/PhysRevD.97.012007

### OBJECT SELECTIONS

# AK4 jets
object AK4jets : JET
  select {JET_}Pt > 30
  select {JET_}AbsEta < 2.4

# AK8 jets
object AK8jets : FJET
  select {FJET_}Pt > 200
  select {FJET_}AbsEta < 2.4

# b-tagged jets - loose
object bjetsLoose : AK4jets
  select {AK4jets_}btagDeepB > 0.152

# b-tagged jets - medium
object bjetsMedium : AK4jets
  select {AK4jets_ }btagDeepB > 0.4941

# b-tagged jets - tight
object bjetsTight : AK4jets
  select {AK4jets_}btagDeepB > 0.8001

# W jets - mass-tagged
object WjetsMasstag : AK8jets
  select {AK8jets_}msoftdrop [] 65 105

# W jets - W-tagged
object Wjets : WjetsMasstag
  select {WjetsMasstag_}tau2  <= 0.2
  select {WjetsMasstag_}tau2 / {WjetsMasstag_}tau1 <= 0.4

```

```
# W jets - anti-tagged
object WjetsAntitag : WjetsMasstag
  select {WjetsMasstag_}tau2 / {WjetsMasstag_}tau1 > 0.4

# top jets - mass-tagged
object topjetsMasstag : AK8jets
  select {AK8jets_}Pt > 400
  select {AK8jets_}msoftdrop [] 105 210

# top jets - mass-tagged, subjet b-antitagged
object topjetsMasstag0b : topjetsMasstag
  select {topjetsMasstag_}btagDeepB < 0.1522

# top jets - top-tagged, subjet b-tagged
object topjets : topjetsMasstag
  select {topjetsMasstag_}btagDeepB >= 0.1522
  select {topjetsMasstag_}tau3 / {topjetsMasstag_}tau2 < 0.46

# top jets - anti-tagged
object topjetsAntitag : topjetsMasstag
  select {topjetsMasstag_}btagDeepB < 0.1522
  select {topjetsMasstag_}tau3 / {topjetsMasstag_}tau2 >= 0.46

# muons - veto
object muonsVeto : MUO
  select {MUO_}Pt > 5
  select {MUO_}AbsEta < 2.4
  select {MUO_}softId == 1
  select {MUO_}miniPFRelIsoAll < 0.2
  select abs({MUO_}dxy) < 0.2  ## how to take the abs of this
  select abs({MUO_}dz) < 0.5   ## and this?

# muons - select
object muonsSel : MUO
  select {MUO_}Pt > 10
  select {MUO_}AbsEta < 2.4
  select {MUO_}miniPFRelIsoAll < 0.15
  select abs({MUO_}dxy) < 0.05
  select abs({MUO_}dz) < 0.1

# electrons - veto
object electronsVeto : ELE
  select {ELE_}Pt > 5
  select {ELE_}AbsEta < 2.5
  select {ELE_}miniPFRelIsoAll < 0.1
  select abs({ELE_}dxy) < 0.05
```

```
  select abs({ELE_}dz) < 0.1

# electrons - select
object electronsSel : ELE
  select {ELE_}Pt > 10
  select {ELE_}AbsEta < 2.5
  select {ELE_}AbsEta  ][ 1.442 1.556
  select {ELE_}miniPFRelIsoAll < 0.1
  select abs({ELE_}dxy) < 0.05
  select abs({ELE_}dz) < 0.1

# taus - veto
object tausVeto : TAU
  select {Tau_}Pt > 18
  select {Tau_}AbsEta < 2.5
  select {Tau_}dMVAnewDM2017v2 >= 4

# photons - select
object photons : PHO
  select {PHO_}Pt > 5
  select {PHO_}AbsEta < 2.5

# jets - no photon
object AK4jetsNOpho : AK4jets
  select dR(AK4jets_, photons_ ) >=0.4 OR {photons_}Pt/{AK4jets_}Pt ][ 0.5 2.0
#  reject dR(AK4jets_, photons) < 0.4 AND photons.pt/j.pt [] 0.5 2.0

### EVENT VARIABLES
object megajets : AK4jets
  select fmegajets(AK4jets) == 2

object megajetsNOpho : AK4jetsNOpho
  select fmegajets(AK4jetsNOpho) == 2

def newdefinitions ### this comment with a dummy ID has to sit right after obje
define MR : fMR(megajets)
define Rsq : (fMTR(megajets, MET) / MR )^0.5
define dphimegajets : dPhi(megajets_0, megajets_1)
define dphimegajetsNOpho : dPhi(megajetsNOpho_0, megajetsNOpho_1)

define METLVe   : METLV_0 electronsVeto_0
define METLVm   : METLV_0 muonsVeto_0
define METLVee  : METLV_0 electronsVeto_0  electronsVeto_1
define METLVmm  : METLV_0 muonsVeto_0  muonsVeto_1
define METLVpho : METLV_0 photons_0
```

```

define R2e : (fMTR(megajets, METLVe) / MR)^0.5
define R2m : (fMTR(megajets, METLVm) / MR)^0.5
define R2ee : sqrt(fMTR(megajets, METLVee) / MR)
define R2mm : sqrt(fMTR(megajets, METLVmm) / MR)
define MR0pho : fMR(megajetsNOpho)
define R2pho : sqrt(fMTR(megajetsNOpho, METLVpho) / MR0pho)
define MTe : sqrt( 2 * {electronsVeto_0}Pt * MET * ( 1 - cos( {METLV_0}Phi - {electronsVeto_0}Phi ) ) )
define MTm : sqrt( 2 * {muonsVeto_0}Pt * MET * ( 1 - cos( {METLV_0}Phi - {muonsVeto_0}Phi ) ) )
define mZ : 91.187
```

Razor boost example 2/2

```
# EVENT SELECTION
# Boosted categories

# Boost pre-selection cuts
region preselection
  select ALL   # This is only to see the initial event count
  select Size(AK4jets) >= 3
  select Size(AK8jets) >= 1
  select Size(megajets) == 2
  select MR > 800
  select Rsq > 0.08

region WcategorySR
  preselection
  select Size(electronsVeto) + Size(muonsVeto) == 0
  select Size(tausVeto) == 0
  select Size(bjetsMedium) >= 1
  select Size(Wjets) >= 1
  histo hWjPT, "Wjets Pt GeV", 10, 0, 500, {Wjets_0}Pt
  select Size(Wjets) >= 1
  select dphimegajets < 2.8

region WcategoryCRQ
  preselection
  select Size(electronsVeto) + Size(muonsVeto) == 0
  select Size(tausVeto) == 0
  select Size(WjetsAntitag) >= 1
  select Size(bjetsLoose) == 0
  select dphimegajets >= 2.8

region WcategoryCRT
  preselection
  select Size(electronsVeto) + Size(muonsVeto) == 1
  select Size(bjetsLoose) >= 1
  select Size(Wjets) >= 1
  select dphimegajets < 2.8
  select Size(muonsVeto) == 1 ? MTm < 100 : MTe < 100

region WcategoryCRW
  preselection
  select Size(muonsVeto) + Size(electronsVeto) == 1
  select Size(bjetsLoose) == 0
  select Size(WjetsMasstag) >= 1
  select dphimegajets < 2.9
  select Size(muonsVeto) == 1 ? MTm [] 30 100 : MTe [] 30 100

region WcategoryCRL
  select Size(AK4jets) >= 3
  select Size(AK8jets) >= 1
  select Size(megajets) == 2
  select MR > 800
  select Size(muonsVeto) + Size(electronsVeto) == 1
  select Size(muonsVeto) == 1 ? R2m > 0.08 : R2e > 0.08
  select Size(bjetsLoose) == 0
  select Size(WjetsMasstag) >= 1
  select dphimegajets < 2.10
  select Size(muonsVeto) == 1 ? MTm [] 30 100 : MTe [] 30 100

region WcategoryCRZ
  select Size(AK4jets) >= 3
  select Size(AK8jets) >= 1
  select Size(megajets) == 2
  select MR > 800
  select (Size(muonsSel) == 2 AND Size(electronsVeto) == 0) OR (Size(electronsSel) == 2 AND Size(muonsVeto) == 0)
  select Size(muonsSel) == 2 ? {muonsSel_0}q + {muonsSel_1}q == 0 : {electronsSel_0}q + {electronsSel_1}q == 0
  select Size(muonsSel) == 2 ? Abs({muonsSel_0 muonsSel_1}m - mZ) < 10 : Abs({electronsSel_0 electronsSel_1}m - mZ) < 10
  select Size(muonsSel) == 2 ? R2mm > 0.08 : R2ee > 0.08
  select Size(WjetsMasstag) >= 1
  select dphimegajets < 2.8

region WcategoryCRG
  select Size(photons) > 0
  select Size(AK4jetsNOpho) >= 3
  select Size(AK8jets) >= 1
  select Size(electronsVeto) + Size(electronsVeto) == 0
  select Size(tausVeto) == 0
  select Size(megajetsNOpho) == 2
  select MR0pho > 800
  select R2pho > 0.08
  select Size(WjetsMasstag) >= 1
  select dphimegajetsNOpho < 2.8

# # Top category signal and control regions
region TopcategorySR
  preselection
  select Size(electronsVeto) + Size(muonsVeto) == 0
  select Size(tausVeto) == 0
  select Size(topjets) >= 1
  select dphimegajets < 2.8

region TopcategoryCRQ
  preselection
  select Size(electronsVeto) + Size(muonsVeto) == 0
  select Size(tausVeto) == 0
  select Size(topjetsAntitag) >= 1
  select Size(bjetsLoose) == 0
  select dphimegajets >= 2.8

region TopcategoryCRT
  preselection
  select Size(electronsVeto) + Size(muonsVeto) == 1
  select Size(bjetsLoose) >= 1
  select Size(topjets) >= 1
  select dphimegajets < 2.8
  select Size(muonsVeto) == 1 ? MTm < 100 : MTe < 100

region TopcategoryCRW
  preselection
  select Size(muonsVeto) + Size(electronsVeto) == 1
  select Size(bjetsLoose) == 0
  select Size(topjetsMasstag0b) >= 1
  select dphimegajets < 2.8
  select Size(muonsVeto) == 1 ? MTm [] 30 100 : MTe [] 30 100

region TopcategoryCRL
  select Size(AK4jets) >= 3
  select Size(AK8jets) >= 1
  select Size(megajets) == 2
  select MR > 800
  select Size(muonsVeto) + Size(electronsVeto) == 1
  select Size(muonsVeto) == 1 ? R2m > 0.08 : R2e > 0.08
  select Size(bjetsLoose) == 0
  select Size(topjetsMasstag0b) >= 1
  select dphimegajets < 2.10
  select Size(muonsVeto) == 1 ? MTm [] 30 100 : MTe [] 30 100

region TopcategoryCRZ
  select Size(AK4jets) >= 3
  select Size(AK8jets) >= 1
  select Size(megajets) == 2
  select MR > 800
  select (Size(muonsSel) == 2 AND Size(electronsVeto) == 0) OR (Size(electronsSel) == 2 AND Size(muonsVeto) == 0)
```


```
  select (Size(muonsSel) == 2 AND Size(electronsVeto) == 0) OR (Size(electronsSel) == 2 AND Size(muonsVeto) == 0)
  select Size(muonsSel) == 2 ? {muonsSel_0}q + {muonsSel_1}q == 0 : {electronsSel_0}q + {electronsSel_1}q == 0
  select Size(muonsSel) == 2 ? Abs({muonsSel_0 muonsSel_1}m - mZ) < 10 : Abs({electronsSel_0 electronsSel_1}m - mZ) < 10
```


```
  select Size(muonsSel) == 2 ? R2mm > 0.08 : R2ee > 0.08
  select Size(topjetsMasstag) >= 1
  select dphimegajets < 2.8

region TopcategoryCRG
  select Size(photons) > 0
  select Size(AK4jetsNOpho) >= 3
  select Size(AK8jets) >= 1
  select Size(electronsVeto) + Size(electronsVeto) == 0
  select Size(tausVeto) == 0
  select Size(megajetsNOpho) == 2
  select MR0pho > 800
  select R2pho > 0.08
  select Size(topjetsMasstag) >= 1
  select dphimegajetsNOpho < 2.8
```

```
#  experiment ATLAS
#  id SUSY-2013-15
#  publication Eur. Phys. J. C(2016) 76: 392
#  sqrtS 13.0
#  lumi 3.2
#  arXiv 1605.03814
```

Compatibility

	Rivet			MadAnalysis 5			CheckMATE
Description	#evt	tot.eff	rel.eff	#evt	tot.eff	rel.eff	tot.eff
2jl cut-flow	31250	1	-	31250	1	-	
Pre-sel+MET+pT1	28592	0.91	0.91	28626	0.92	0.92	
Njet	28592	0.91	1	28625	0.92	1	
Dphi_min(j,MET)	17297	0.55	0.6	17301	0.55	0.6	
pT2	17067	0.55	0.99	17042	0.55	0.99	
MET/sqrtHT	8900	0.28	0.52	8898	0.28	0.52	
m_eff(incl)	8896	0.28	1	8897	0.28	1	
2jm cut-flow	31250	1	-	32150	1	-	1
Pre-sel+MET+pT1	28472	0.91	0.91	28478	0.91	0.91	0.91
Njet	28472	0.91	1	28477	0.91	1	0.91
Dphi_min(j,MET)	22950	0.73	0.81	22889	0.73	0.8	0.73
pT2	22950	0.73	1	22889	0.73	1	0.73
MET/sqrtHT	10730	0.34	0.47	10710	0.34	0.47	0.33
m_eff(incl)	10630	0.34	0.99	10609	0.34	0.99	0.32
2jt cut-flow	31250	1	-	31250	1	-	
Pre-sel+MET+pT1	28592	0.91	0.91	28626	0.92	0.92	
Njet	28592	0.91	1	28625	0.92	1	
Dphi_min(j,MET)	17297	0.55	0.6	17301	0.55	0.6	
pT2	17067	0.55	0.99	17042	0.55	0.99	
MET/sqrtHT	5083	0.16	0.3	5098	0.16	0.3	
Pass m_eff(incl)	4861	0.16	0.96	4889	0.16	0.96	

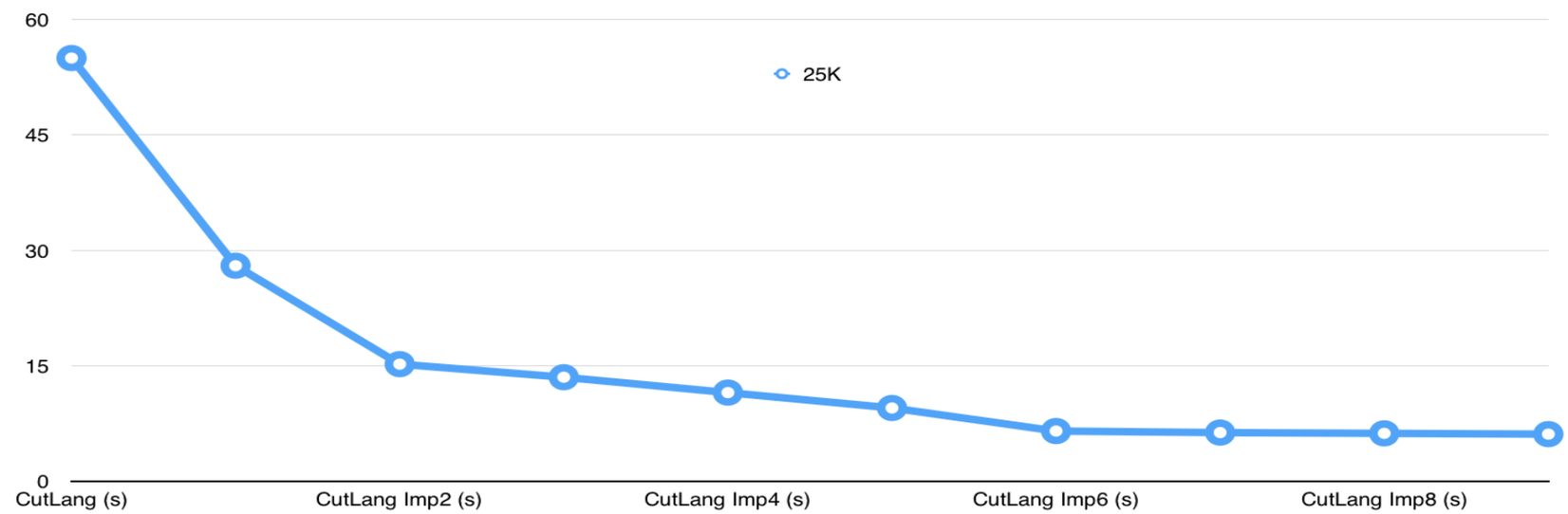
CutLang

#evt	total eff.	rel. eff.
31250	1.000	-
28431	0.91	0.91
28430	0.91	1.00
16661	0.53	0.59
16381	0.52	0.98
8159	0.26	0.50
8156	0.26	1.00
31250	1.000	-
28301	0.91	0.91
28300	0.91	1.00
22441	0.72	0.79
22441	0.72	1.00
10043	0.32	0.45
9896	0.32	0.99
31250	1.000	-
28431	0.91	0.91
28430	0.91	1.00
16661	0.53	0.59
16381	0.52	0.98
4375	0.14	0.27
4132	0.13	0.94

Debugging & speeding

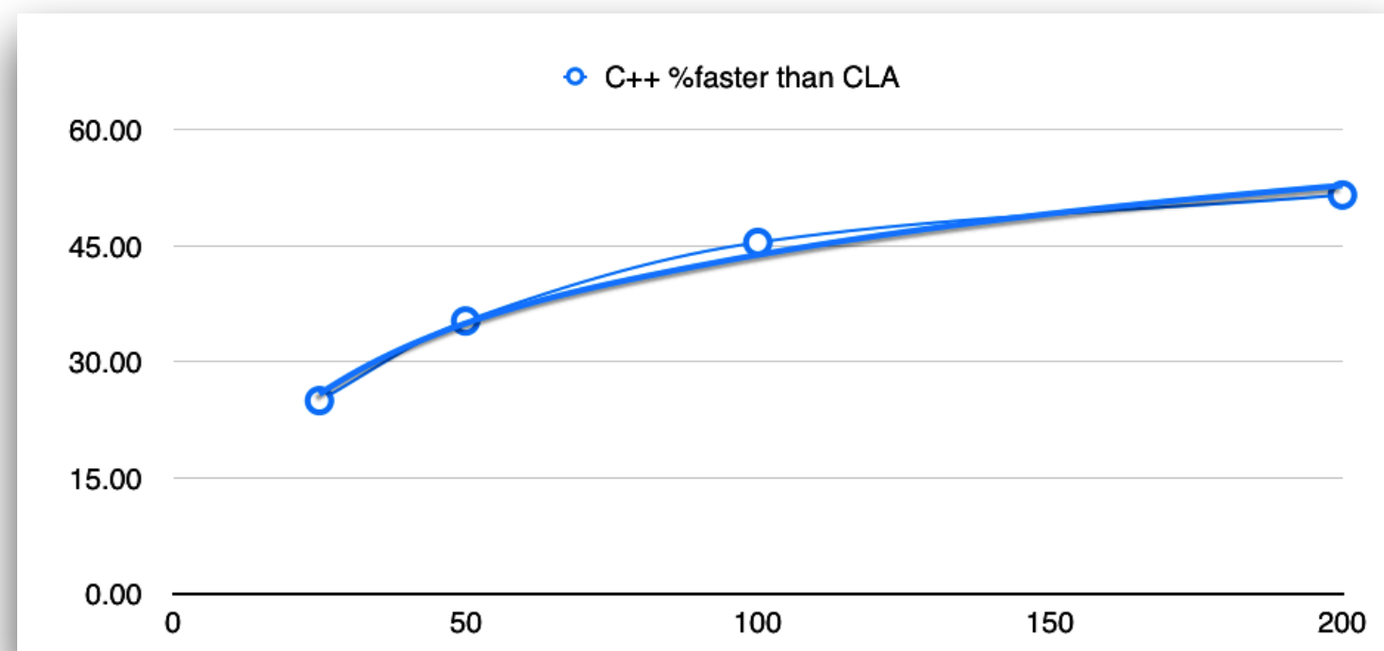
ATLAS hadronic ttbar tests

	25K	50K	100K
Sezen (s)	12	24	45.7
Sezen imp (s)	3.1	4.7	7.9
CutLang (s)	55	106	210
CutLang Imp (s)	28	55	108
CutLang Imp2 (s)	15.2	29	56.2
CutLang Imp3 (s)	13.5	25.8	49.7
CutLang Imp4 (s)	11.5	21.6	41.9
CutLang Imp5 (s)	9.5	17.5	33.5
CutLang Imp6 (s)	6.5	11.5	21.6
CutLang Imp7 (s)	6.3	11.1	20.8
CutLang Imp8 (s)	6.2	11.0	20.4
CutLang Imp9 (s)	6.1	10.9	20.1
ratio best	1.9677419	2.319148	2.54430
%slow	103.226	136.170	163.291
%faster	49.180	56.881	60.697
	25	50	100



ATLAS wz tests e- channel

	500K
Sezen (s)	6.3
CutLang Imp (s)	6.9
ratio	1.10
%faster	8.70



For example, the one step and two step top quark reconstructions requiring one line and two lines to implement in the *CutLang* language take about 40 to 70 lines of standard analysis code in C++.