Development of charm quark tagger for supersymmetric particle search at the CMS detector

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• Supersymmetry (SUSY)

• Large Hadron Collider (LHC) and Compact Muon Solenoid (CMS)

• Objects and Event Reconstructions

• Charm quarks tagger

• Conclusions
One interesting search channel is $\tilde{t} \rightarrow c + \tilde{\chi}_1^0$.

Charm quark will be detected as a jet in the detector and LSP will be invisible to our detector.

In order to find the supersymmetric top particle in this channel, it is important to identify the charm quark jet and precisely measure the missing energy from detector.
Large Hadron Collider (LHC)

- 27 km in circumference
- To collide rotating beams of protons or heavy ions
- Maximum energy of proton-proton collisions at $\sqrt{s} = 14$ TeV and $4 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- In 2011, collision at $\sqrt{s} = 7$ TeV and $4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- In 2012, collision at $\sqrt{s} = 8$ TeV and $7.7 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- In 2015, expect collision at $\sqrt{s} = 13$ TeV and $22.8 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
Compact Muon Solenoid (CMS)

CMS Detector

**Pixels Tracker**
- Pixels: (100 x 150 μm$^2$)
  - ~1m$^2$: ~66M channels
- Microstrips (80-160μm)
  - ~200m$^2$: ~9.6M channels

**Crystal Electromagnetic Calorimeter (ECAL)**
- ~76k scintillating PbWO$_4$ crystals

**Preshower**
- Silicon strips
  - ~16m$^2$: ~137k channels

**Hadron Calorimeter (HCAL)**
- Brass + plastic scintillator
  - ~7k channels

**Superconducting Solenoid**
- Niobium-titanium coil carrying ~18000 A

**Steel Return Yoke**
- ~13000 tonnes

**Forward Calorimeter**
- Steel + quartz fibres
  - ~2k channels

**Muon Chambers**
- Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
- Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

**Total weight**: 14000 tonnes
**Overall diameter**: 15.0 m
**Overall length**: 28.7 m
**Magnetic field**: 3.8 T
The tracker can reconstruct the paths of high-energy muons, electrons and hadrons (particles made up of quarks) as well as see tracks coming from the decay of relatively long lived particles such as “b quarks” and “c quarks”.

These paths can be traced back to the interaction point (or primary vertex) of the event.

The interaction point that misplaces from beam line (or secondary vertex) is the indication of b and c quarks.
• Because of QCD confinement, particles carrying a color charge, such as quarks, cannot exist in free form.

• A high-energy quark (or gluon or anti-quark) is transformed into a spray of hadrons (particles made from quarks, antiquarks and gluons).

• This spray is called a “jet” which can be detected
Missing Transverse Energy

- Since the actual collisions take place at the parton level (quark, anti-quark, or gluon), thus we do not know the actual colliding energy of the partons.

- However, the plane that perpendicular to the incoming particles, transverse plane, has zero momentum before the collision, so after the collision the sum of outgoing momenta have to be zero.

- We defined momentum measured of outgoing particles as “$p_T$“ or the “transverse momentum”

- If the sum of momenta after collision is not zero, any net momentum in the transverse plane is called “Missing Transverse Energy (MET)”. 

- MET is the indication of the non-detectable particles such as standard model neutrino and physics beyond standard model particle, lightest supersymmetric particle (LSP)
Event at CMS

Muon:
- $p_T = 64.4$ GeV/c
- $\eta = 0.29$

Jet:
- $p_T = 61.7$ GeV/c
- $\eta = 1.38$

Jet:
- $p_T = 135.9$ GeV/c
- $\eta = 0.79$

Jet:
- $p_T = 51.5$ GeV/c
- $\eta = -0.12$

Missing $E_T$:
- $65.9$ GeV

CMS

Run: 163480
Event: 81224410
Identification ("tagging") of jets originating from the hadronization of c quarks (c jets).

Due to the sizable life-time, the decay of the J/ψ meson (c and anti c) and D mesons (c or anti-c and light or anti-light quark) are characterized by displaced tracks with a large impact parameter (IP) and a displaced secondary vertex (SV), with a large flight distance.

C-tagger is a new topic studied at CMS. Started in 2013.

C-tagger is a sub group under the well established b-tagger group.

The method and software is based on the b-tag algorithm. The goal of the c-tag development group is to provide a c-tag algorithm for analyzes in Run-II (2015).

As of now, there are 7 people from 4 institutes.
C-quark Jets Tagger at CMS (II)

Jet Cone ("iterative cone 0.5" calorimeter jet in CMSSW)

- b-hadrons:
  - $\tau \approx 1.5$ ps, $c\tau \approx 450$ $\mu$m
  - at $p = 20$ GeV $\rightarrow$ dist $\approx 1.8$ mm
  - $m_b \approx 4.2$ GeV
  - high track multiplicity

- c-hadrons:
  - $D^+: \approx 312$ $\mu$m, $D^0: \approx 123$ $\mu$m
  - $m_c \approx 1.9$ GeV
  - can produce a secondary vertex or an additional tertiary vertex in a b-jet
We are using the newly developed b-tag code that using BTagAnalyzer with Toolkit for Multivariate Data Analysis (TMVA).

There are two more setups that are currently developing by our c-tag colleagues.

The goal is to find the best c-tag setup or mixing these setups together.
• Starting with well defined QCD or ttbar simulation, modified BTagAnalyzer produces a set of variables needed for c-tag purpose such as jet $p_T$, jet $\eta$, and secondary vertex information.

• Since this is done on simulation, we can match jets with the mother parton.
• Jets are independent for the $p_T$ and $\eta$.

• TagVarExtractor eliminate the bias due to the restricted size of the sample.
C-Tagger Procedures (II)

• The number of track associated with the secondary vertex (vertexNtracks) and the signed transverse impact parameter significance (trackSip2dSig) are shown.

• The clear distinctions between signal (c jets) and background (light quark and gluon jets) can be seen.

• This signatures are our tools to discriminate c jets from other jets.
• TMVA is the statistical method that will tell us that this kind of jet are c jet or not.

• In the end we will have the discriminator data base to use with real data recorded at the CMS.
C-Tagger Procedures (IV)

- The last step is to understand the performance of our c-tag setup.

- So we can go back to find the way to improve the efficiency of c-tag.
Status, Plans, and Conclusions

Status:

• Step 1 and Step 2 are done. We are successfully modified BTagAnalyzer and TagVarExtractor for c-tag purpose.

• Since each frameworks are using different definitions and algorithms to calculate the related variables, currently we are working with other teams to find the sources of discrepancies of each framework and how to optimize the selections for the c-tag purpose.

Plans:

• TMVA is newly implement at CMS, thus we are working closely with experts to understand and maximize the efficiency of c-tag.

• In the end, we will finalized the best method that can be used at the CMS for Run-II in 2015.

Conclusion:

• For the first time c-tagger is studied at the CMS.

• C-tagger will be one of the crucial elements for new physics search such as supersymmetric top.

• Also, it can be benefit for Standard Model precision measurement.
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