Top Pair Production at 1.4TeV

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Motivation

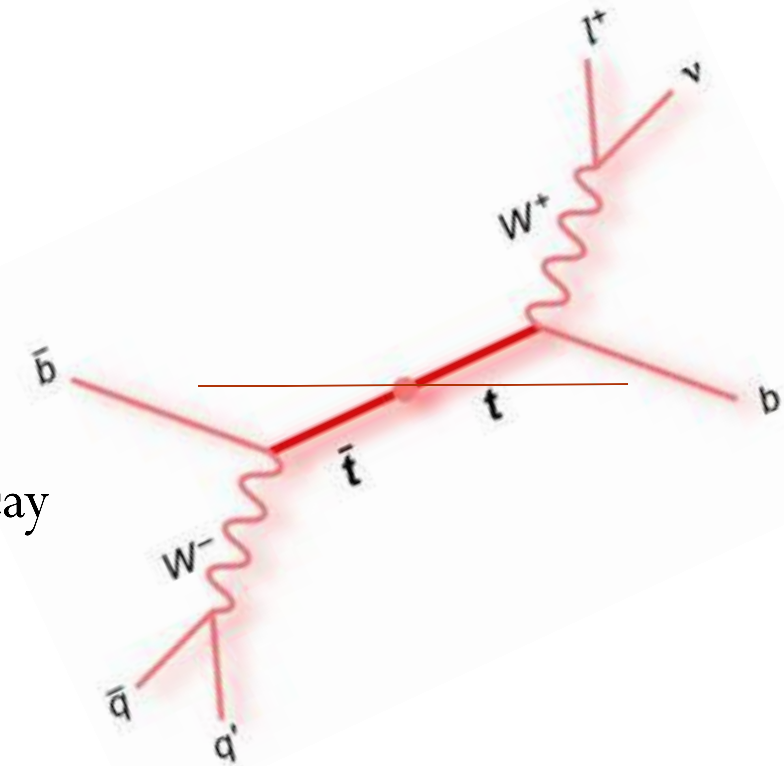
- $t\bar{t}$ production, examine directly coupling of t to Z, γ
- Sub-percent precision on anomalous EW couplings
  - Greater sensitivity to new physics than from direct searches

$$\Gamma_{\mu}^{t\bar{t}X}(k^2, q, \bar{q}) = ie\left\{\gamma_\mu (F_{1V}^X(k^2) + \gamma_5 F_{1A}^X(k^2)) - \frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\nu (iF_{2V}^X(k^2) + \gamma_5 F_{2A}^X(k^2))\right\}$$

- Extraction of form factors needs input from multiple measurements, e.g. cross-section, asymmetries, …
  - See Ignacio Garcia's talk for details

Analysis Strategy

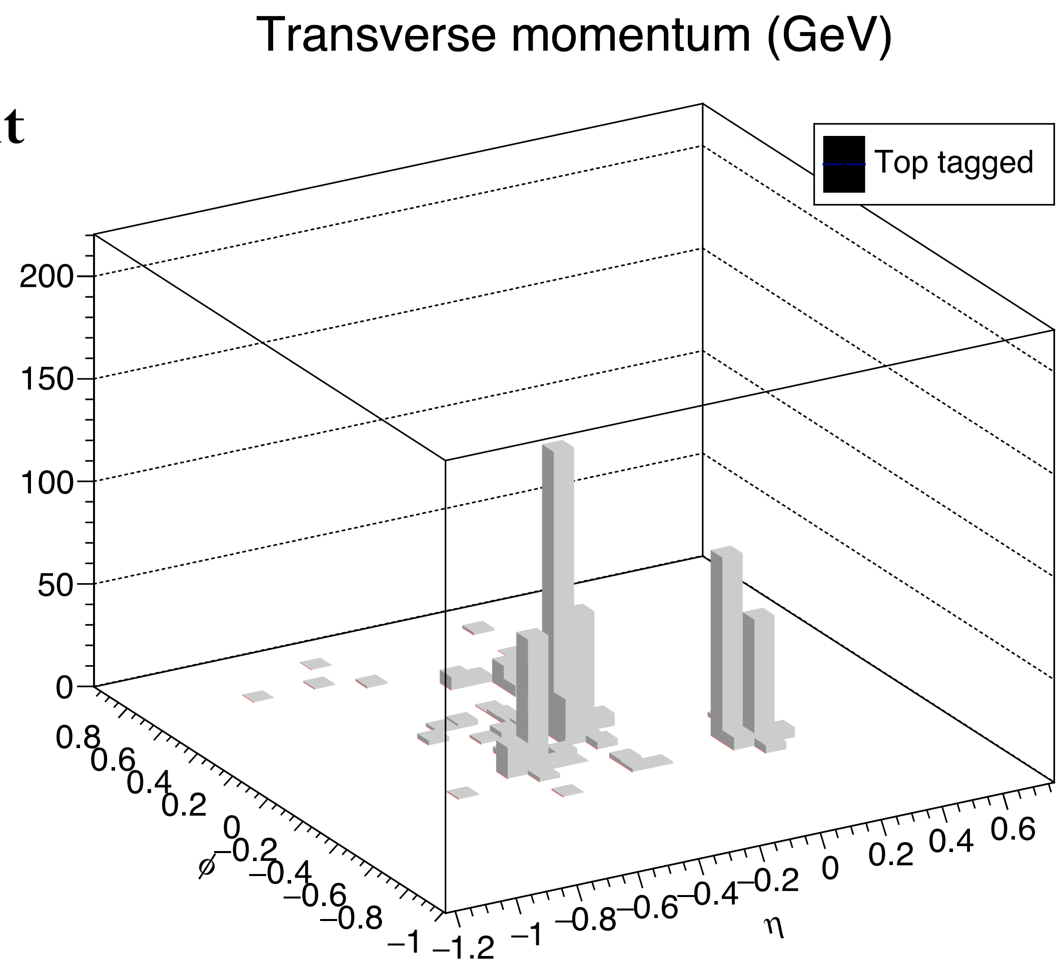
- Semileptonic $t\bar{t}$ decays
  - Ideal for measuring A_{FB}
- Charge tagging from leptonic decay
- Production angle from hadronic decay provides good resolution on the top



- Traditionally, use b-tag to identify events
  - Less effective at 1.4TeV – highly boosted decay systems
- Two alternative approaches investigated
  - "Top tagger"- Rickard Ström
  - "Jet substructure"- Alasdair Winter ← Focus of this talk

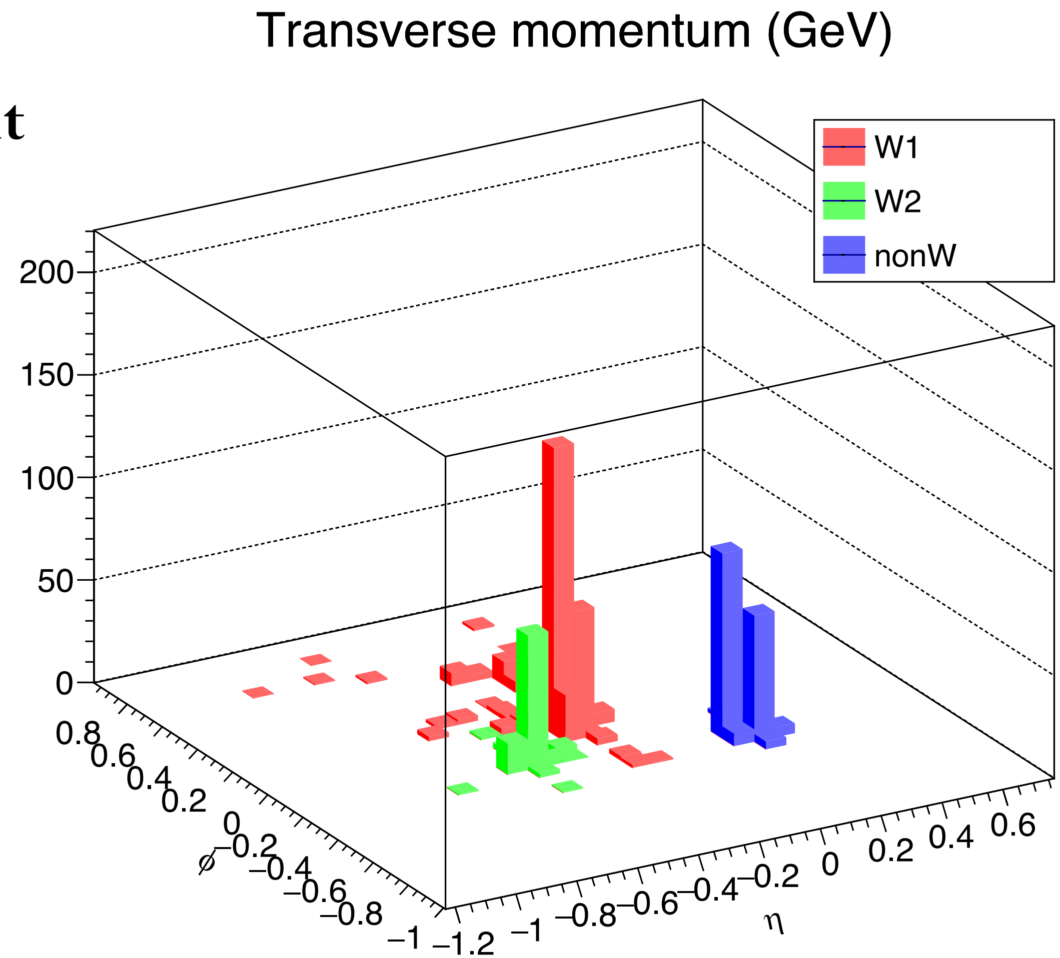
Top tagged system

Typical event

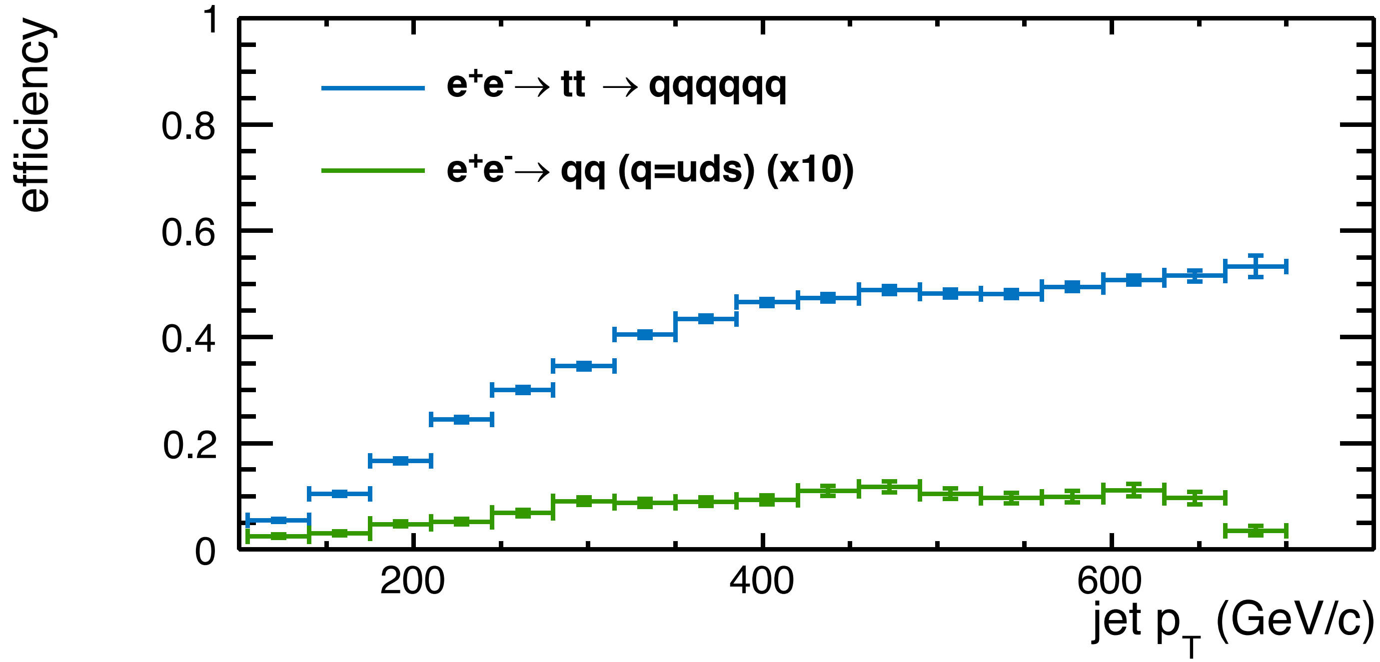


Identified W and b-jet systems

Typical event

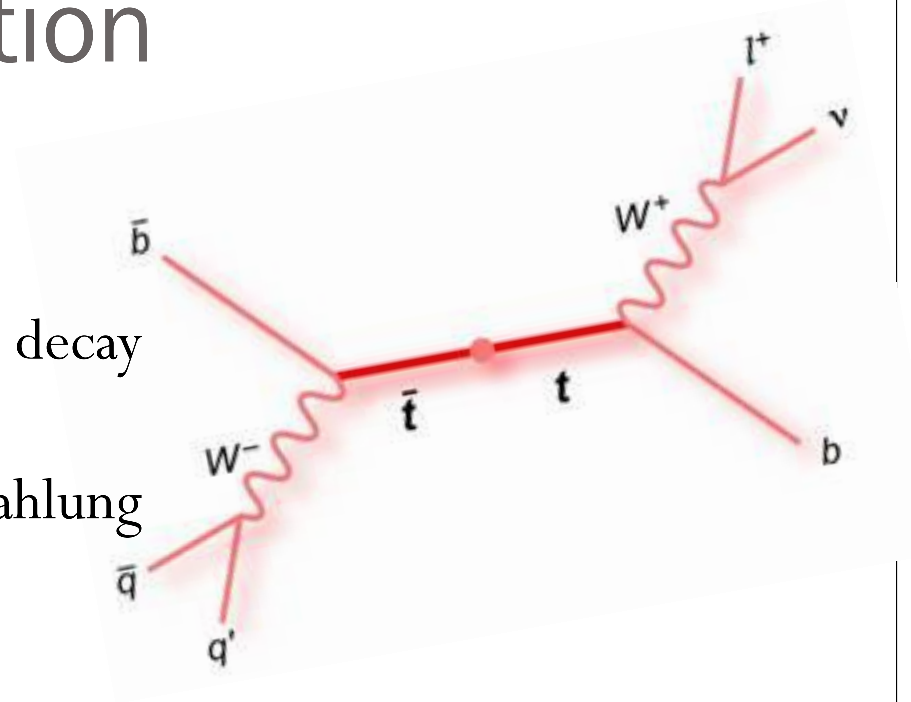


Efficiency for top tagger



Event Reconstruction

- 7 objects to be reconstructed:
  - 2 b-jets from initial top decays
  - 2 quarks-jets from hadronic W decay
  - Charged lepton and neutrino
  - Photon(s) from ISR/Beamsstrahlung



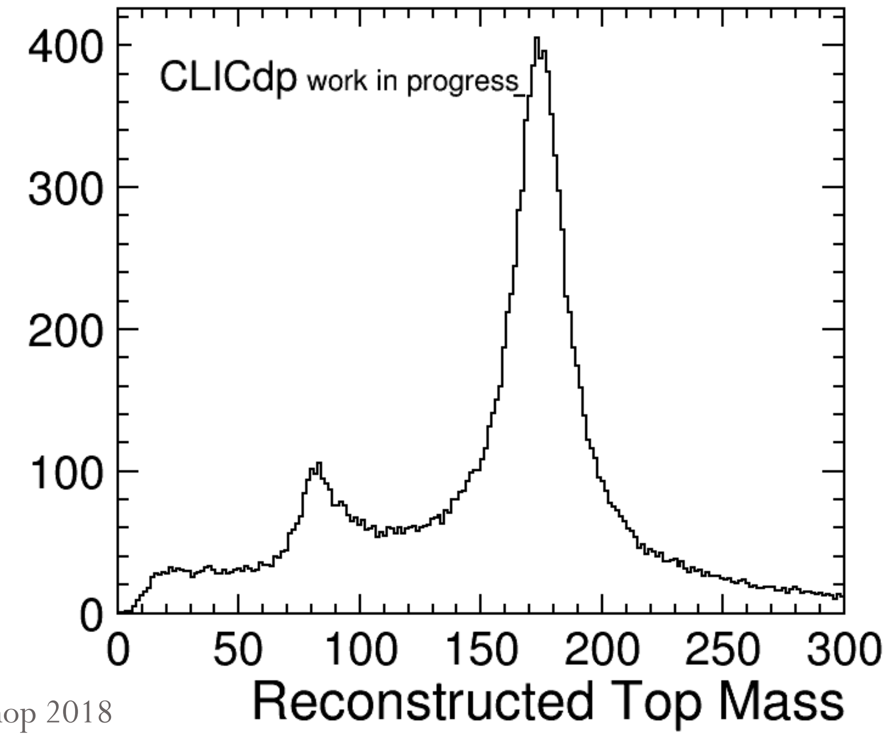
- For $\sqrt{s} \gg$ threshold
  - top decay products highly collimated
  - Harder to resolve individual quark jets
- Approach used, cluster PFOs into "fat" jets
  - hadronic top and the b-jet from the leptonic side
- Use large ISR/BS to measure differential in $\sqrt{s'}$

Lepton Finding

- Identify **1** charged lepton/event, **exclude** from fat-jet clustering
- Five stage approach based on Particle-ID and isolation
  - Cluster all PFOs into **5 jets** using ee kt algorithm
  - Take **e, μ candidates >10GeV** from Pandora PID
  - Ratio of energy each **candidate/jet** it is clustered into
    - → isolation metric
  - Most isolated candidate selected as lepton from W decay
  - Relax candidate energy as necessary
- **Charge tagging** efficiencies/event
  - **96%** muons, **93%** electron

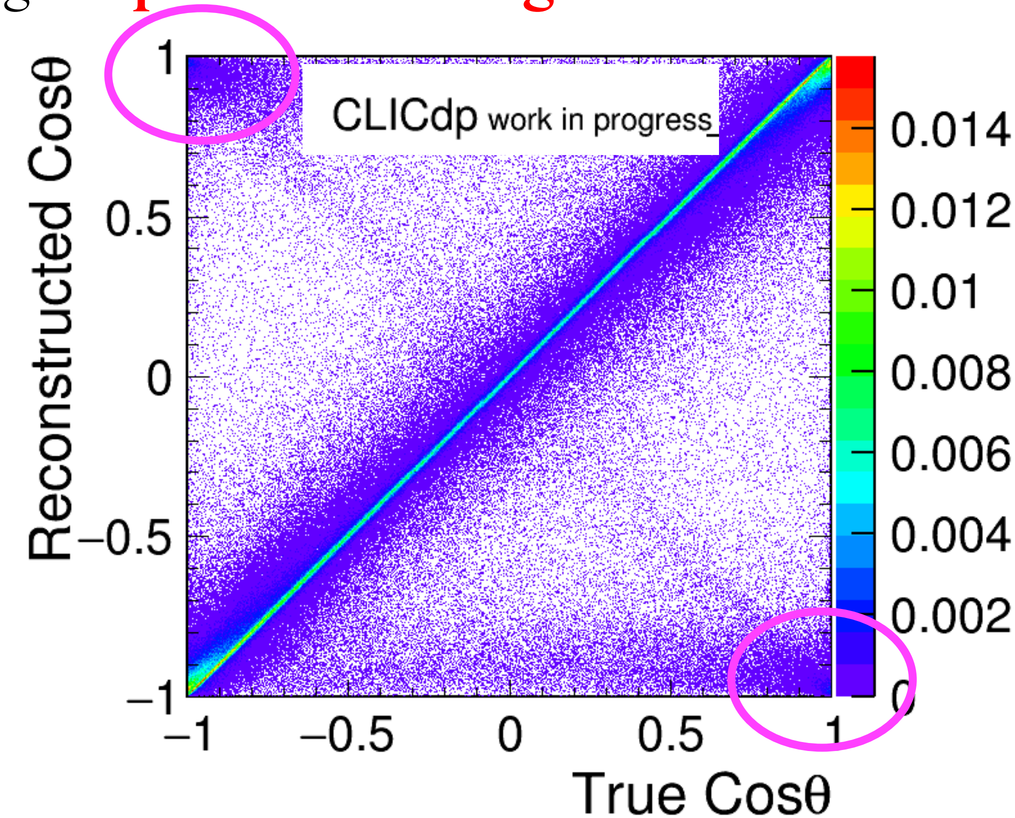
Fat Jet Reconstruction

- Remaining PFOs are clustered into **two fat jets** using Valencia Algorithm with R=1.5, β=1, γ=1
- **Higher** energy assigned as **hadronic** top decay
- Other fat jet considered the **b-jet** from the **leptonic** decay



Fat Jet Performance

- Fat jet gives **production angle** for each event



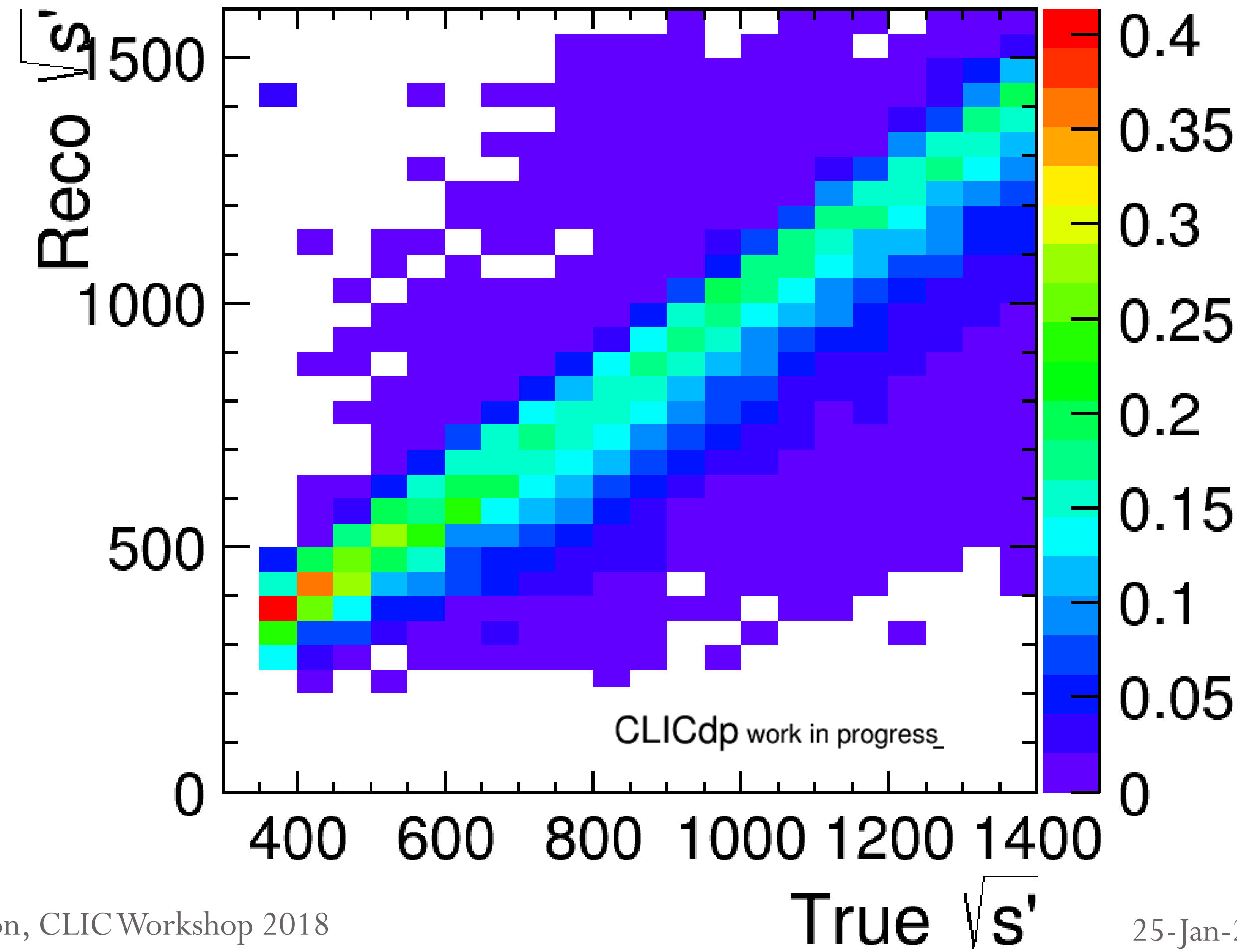
- Angle **flipped by π** where fat jet energy unreliable for the choosing hadronic top
- Artefact of **detector acceptance** near acceptance limits

$\sqrt{s'}$ Reconstruction

- Associate missing energy with photon(s) and neutrino
- Use constrained kinematic fit - MarlinKinFit v00-03
- 5 fit objects: lepton, neutrino, 2 fat jets, photon
- 6 constraints: total four momentum, W mass, $\Delta M_{top-antitop}$
- Resolution parameters
  - $\sigma_{Jet\ Energy} = 35\%\sqrt{E}$
  - $\sigma_{EM\ Energy} = 20\%\sqrt{E}$
  - $\sigma_{\theta/\varphi} = 10\%$
- $\sqrt{s'} = E_{Top} + E_{antitop}$

$\sqrt{s'}$ Reconstruction

- Reconstructed $\sqrt{s'}$ reproduces true distribution
  - Resolution ~75GeV



Event Selection

Pre-selection
- obvious backgrounds
(97% Sig.Efficiency)

Quality Cuts
- poorly reconstructed
(37 % Sig.Efficiency)

High Energy BDT
identify **high** $\sqrt{s'}$ topology

Low Energy BDT
identify **low** $\sqrt{s'}$ topology

BDT response 1

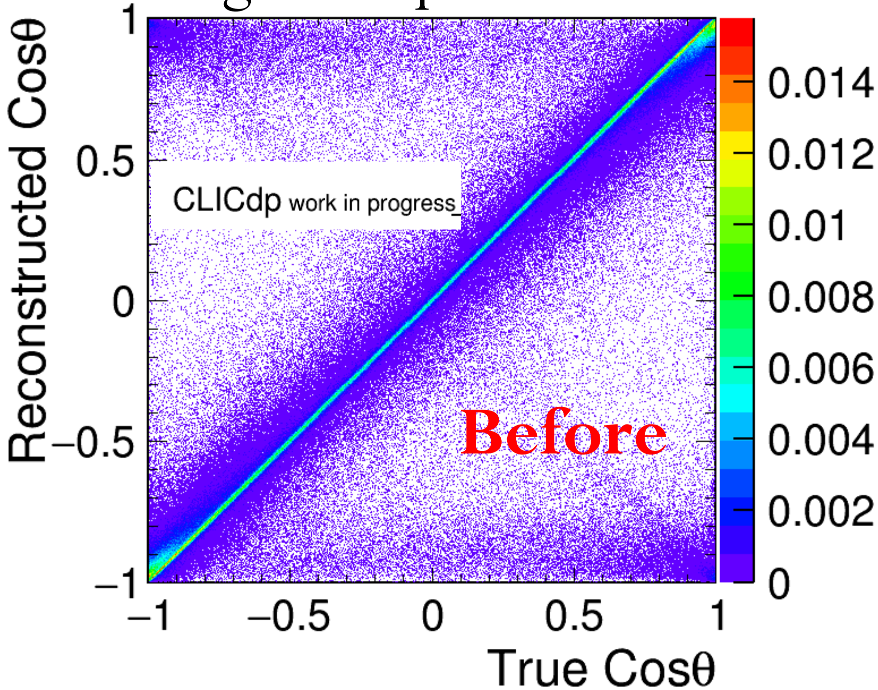
BDT response 2

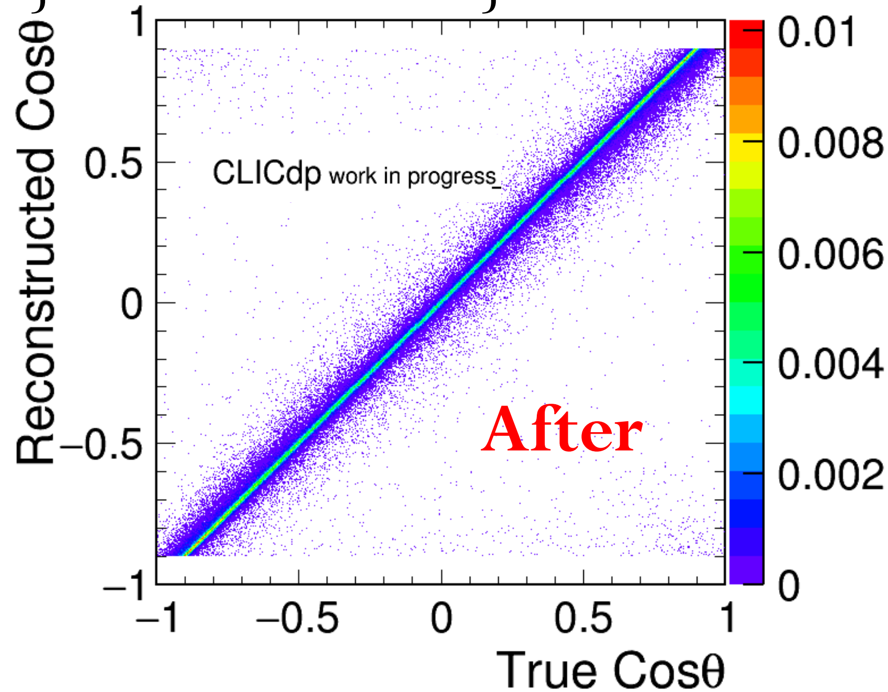
Final Selected Events

Overall signal Efficiency 31%
Purity 62%

Quality Cuts

- Remove events where reconstruction fails
- Cut on angular acceptance ($|\mathrm{Cos}\theta_{Top}|<0.9$), lepton charge, top mass, event kinematics, jet resolution parameters, angular separation of W and b jets within the fat jet



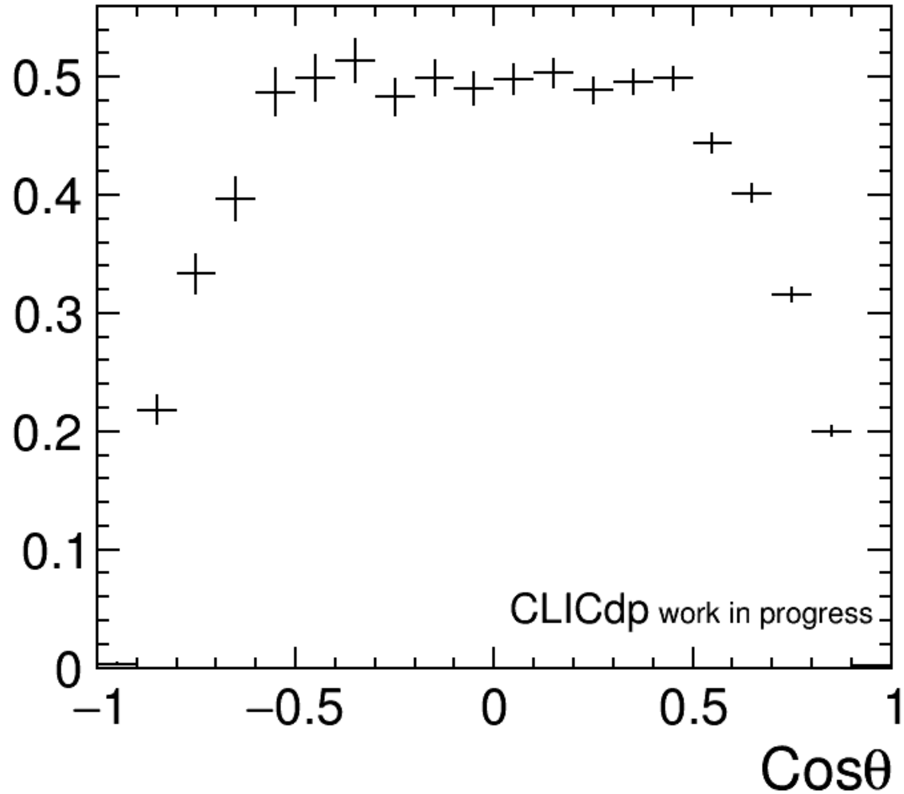


MVA Selection

- 2 BDTs to classify events
  - highly boosted topology (E>1350GeV)
  - lower energy events (E<1350GeV)
- Inputs include
  - kinematics of the tops, lepton and b jet
  - number of e/μ candidates with E>30GeV
  - event shape and b-tagging information
- Several jet substructure variables also used
  - NSubjettiness
  - Jet multiplicity
  - Angles between subjets when reclustering the fat jet into 3 subjets (kt algorithm, R=0.3)

Process	Cross section (fb)	Selection Efficiency (%)	Events for 1.5ab^{-1} (x10^{3})
ee→tt→qqqqlv, l=e/u/τ (includes leptonic τ decays)	51.2	31.6	24.3
ee→tt→qqqqτv, (only includes hadronic τ decays)	14.0	10.1	2.1
ee→qqqqlv, single top	46.3	8.9	6.2
ee→qqqqlv, no top	30.8	1.2	0.54
qqqqqq	113	0.5	0.76
qq	4840	0.02	1.5
qqvv	1400	0.0026	0.05
qqlv	6980	0.0024	0.25
qqll	2680	0.0039	0.16
qqqq	2300	0.014	0.47
qqqqll	71.7	0.091	0.1
qqqqvv	24.7	0.12	0.05

Signal Efficiency, E>1200 GeV



- Uniform ~50% efficiency in central region
- Reduced efficiency in forward region
  - Poor reconstruction of signal events
  - More forward peaked backgrounds

A_{FB} Extraction

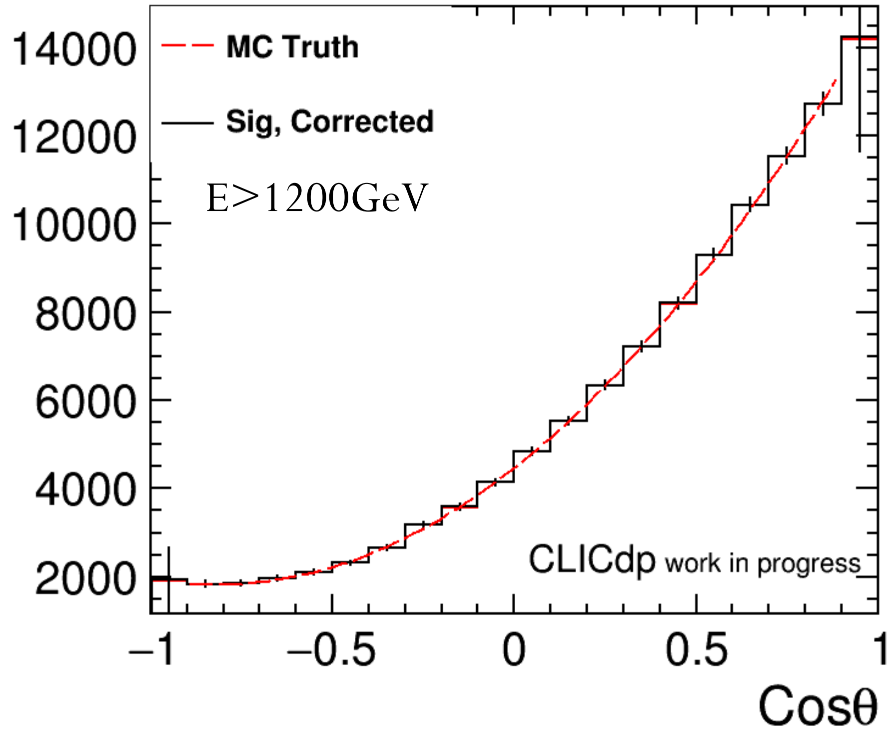
- A_{FB} extracted using[1]

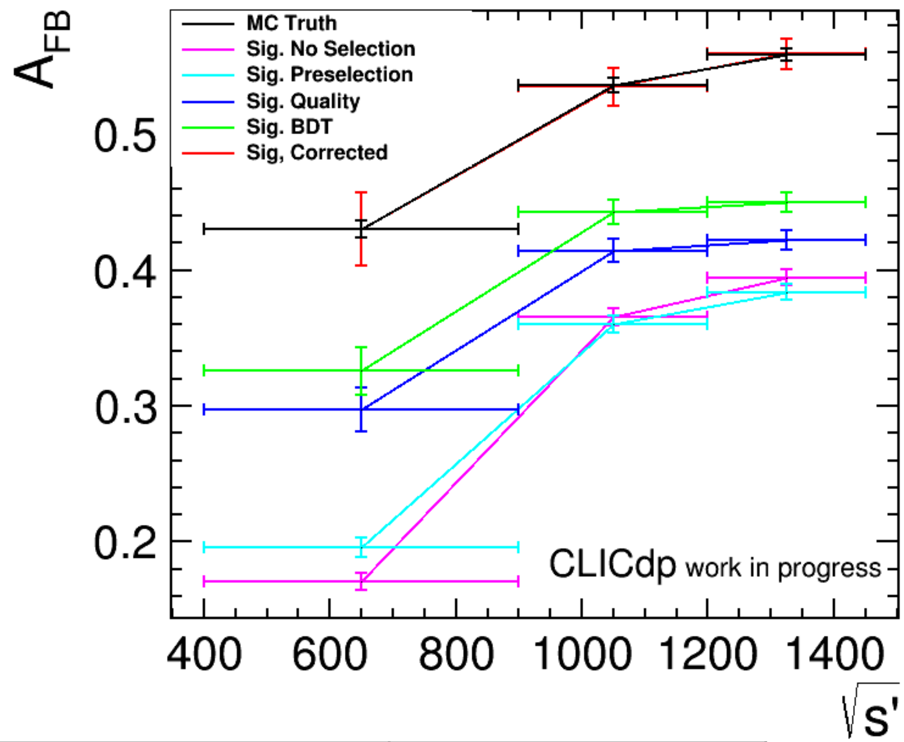
$$\frac{d\sigma}{dCos\theta} = \frac{3}{8}(1+\cos^2\theta)\sigma_U + \frac{3}{4}(\sin^2\theta)\sigma_L + A_{\mathrm{FB}}\cos\theta\,\sigma_{Tot}$$

[J. Jersak, E. Laermann and P.M. Zerwas, *Phys. Lett*. **98** B (1981) 363 and *Phys*. Rev. D **25** (1982) 1218]

- σ_U, σ_L, σ_{Tot} are unpolarised, longitudinally polarised and total cross-sections
- Before fitting, signal corrected for efficiency bin-by-bin in cosθ
- Use k=2 folding, evaluate the signal efficiency in statistically independent samples
- Stat. uncertainty evaluated assuming background subtraction from MC
  - Assign systematic from uncertainty in normalisation and shape

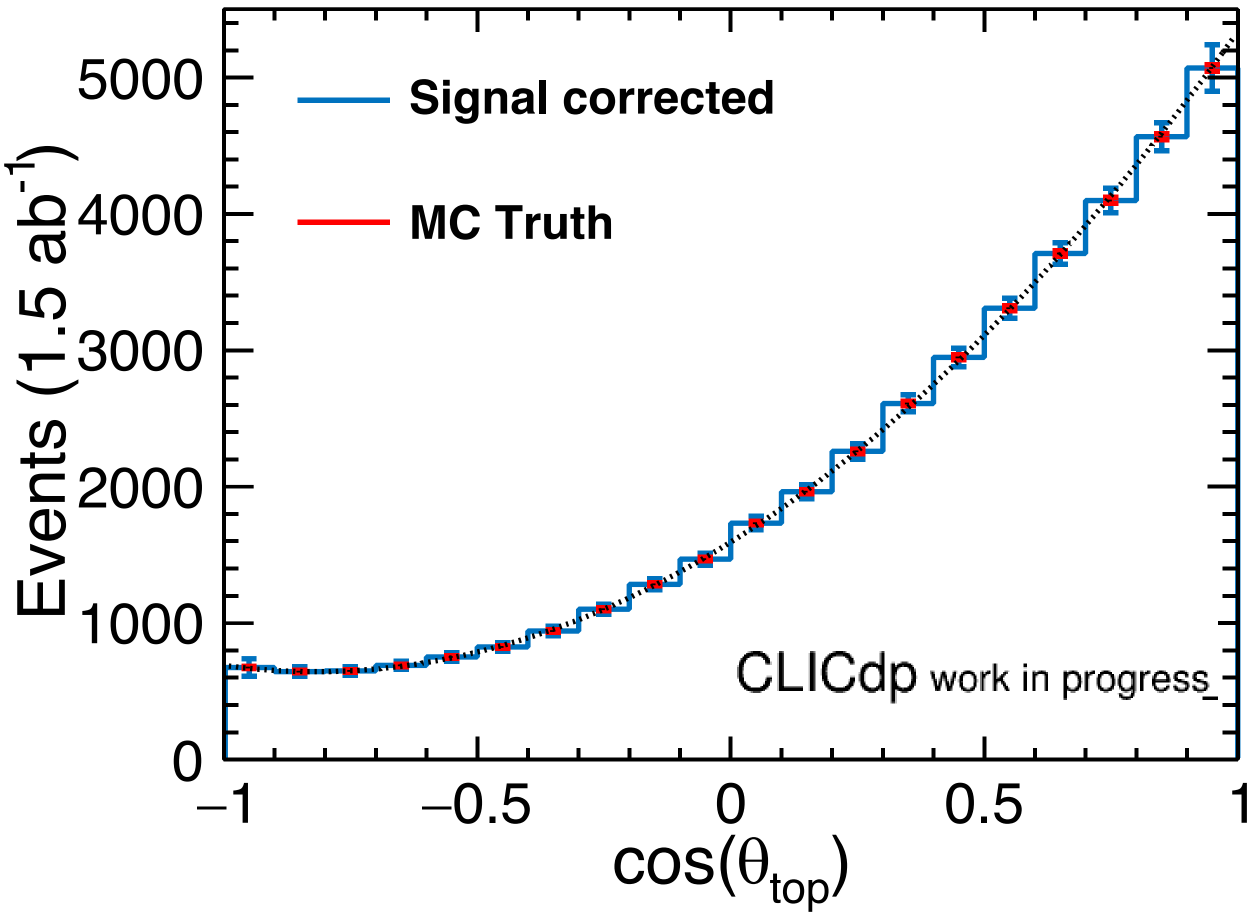
Fit results





Energy (GeV)	A_{FB} (True)	A_{FB} (Reco)	σ (Reco, fb)
400-900	0.430	0.430 +/- 0.027	13.6 +/- 1.3
900-1200	0.536	0.535 +/- 0.014	14.9 +/- 0.7
>1200	0.559	0.559 +/- 0.011	22.7 +/- 0.9

From top tagger



Systematic uncertainties

- Fit results assume residual backgrounds are modelled with arbitrarily small uncertainty
- Estimate systematic from limited knowledge of **accepted** background cross sections
- Evaluate impact in worst case scenario- correlated shift in all backgrounds
  - To do – artificially **introduce** asymmetry to **shape of background**

Assumed uncertainty on **background normalisation (%)**	**Systematic uncertainty A_{FB} for E>1.2TeV (%)**
2.5	0.6
5	**1.2**
7	1.8
10	2.4

- **LEP-2** indicative **normalisation uncertainty** on 4-jet background in WW→4q was **5%**
- Even with this **conservative** estimate of background uncertainty **statistical** uncertainty on A_{FB} ~2% dominates

Summary & Outlook

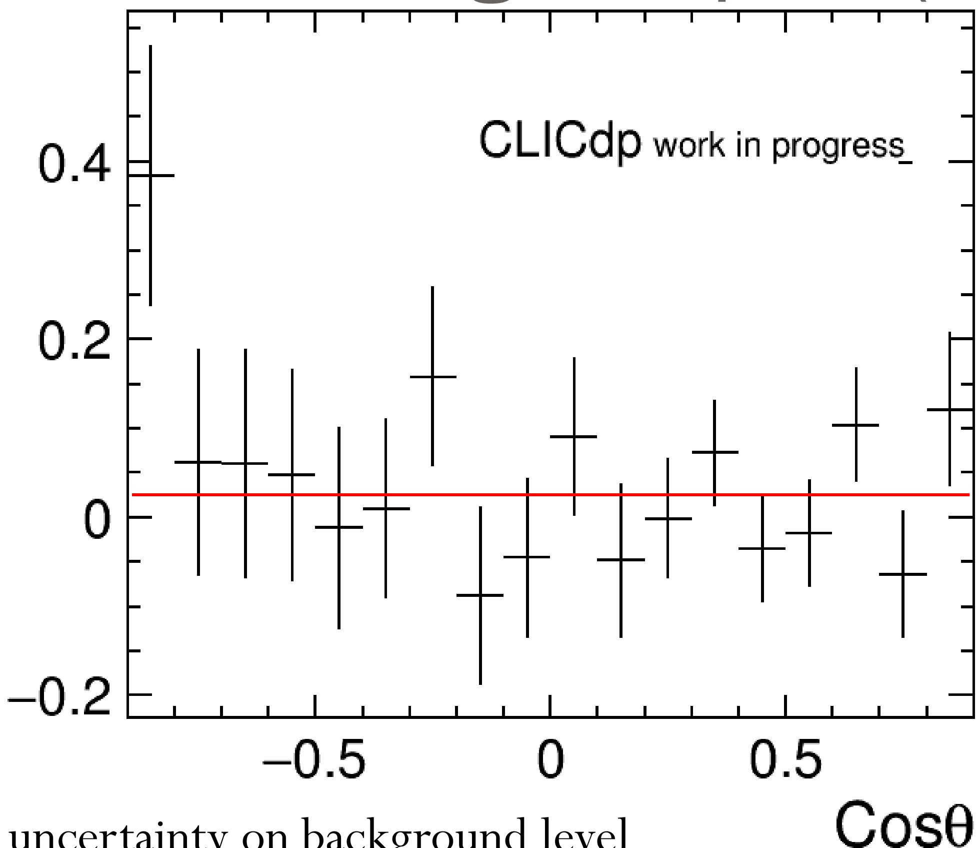
- Two analyses developed in parallel
  - 3 TeV, 1.4 TeV and 1.4 TeV (radiative)
- Statistical uncertainty of ~2% on A_{FB} at 1.4 TeV (1.5ab^{-1})
  - Both analyses consistent at 1.4 TeV ☺
- First look at systematics (background normalisation)
  - Precision of A_{FB} ~dominated by statistical uncertainty
- Other potential systematics
  - Luminosity
  - Background shape
  - Beam polarisation
- Next: Finish paper draft + publish

Backup Slides

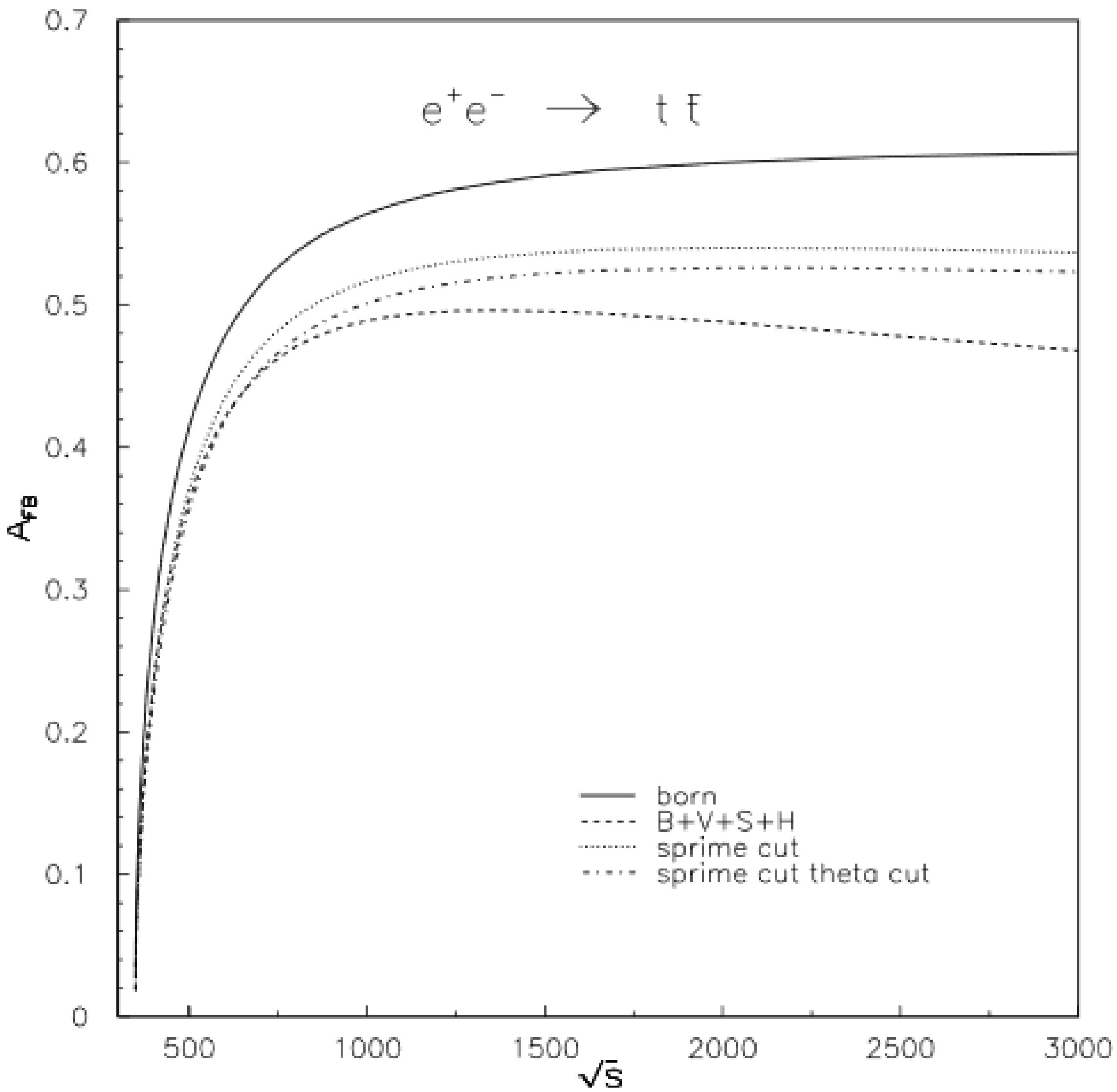
Signal Efficiency Correction

1. Split events into two samples- A and B
2. Train BDTs with sample A and test with B
3. Evaluate signal efficiencies in both cosθ and energy post event selection using sample B
4. Train new BDTs with sample B and test with A
5. Evaluate AFB for sample A
6. Use results of step 3 to correct AFB measurement by performing bin by bin scaling by efficiency

Difference between background training and testing samples (%)



- Large uncertainty on background level
- Limited by MC sample size
- Can always generate more events to reduce purely statistical uncertainty
- Consider background uncertainties as a systematic effects



J. Fleisher et al, 2003, https://arxiv.org/pdf/hep-ph/0302259.pdf

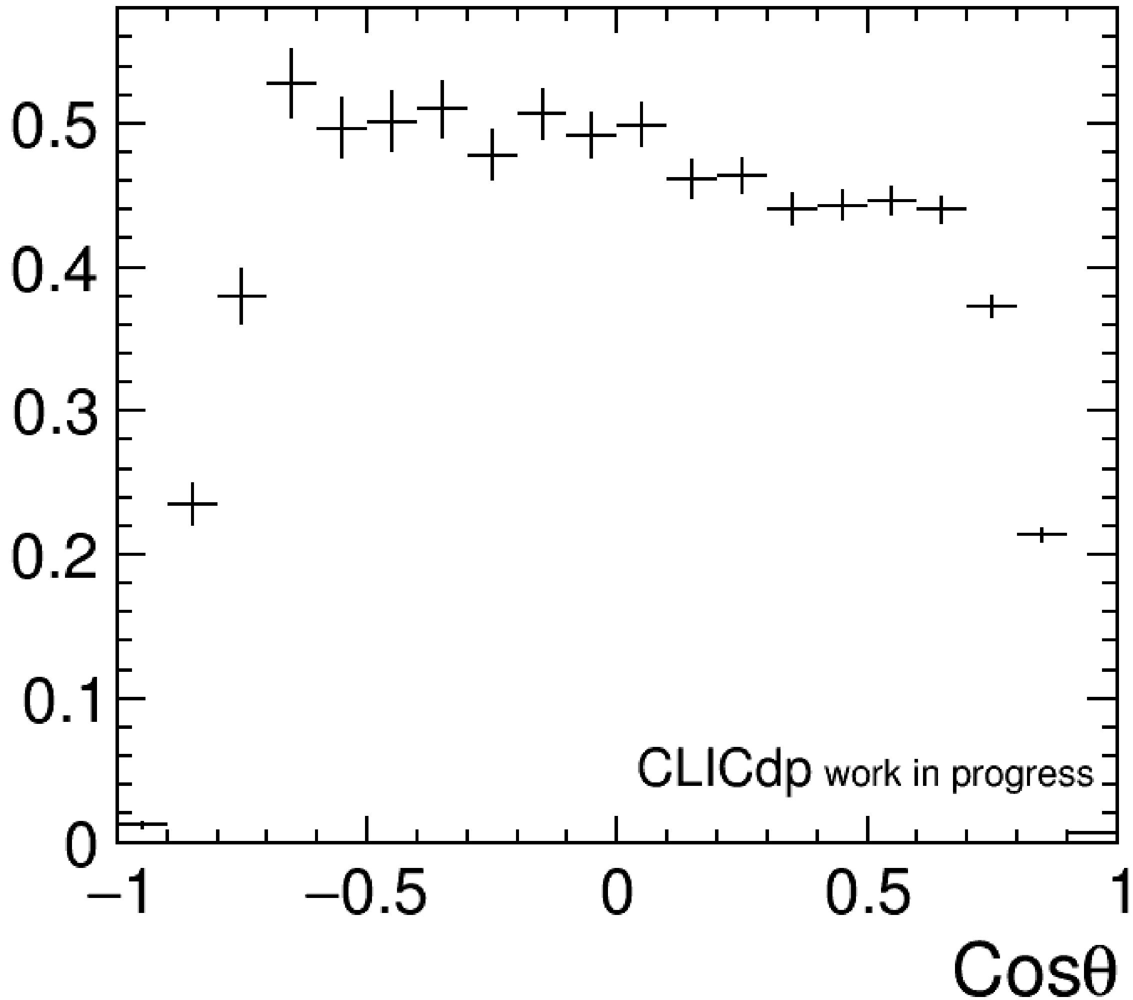
Quality Cuts

- Preselection Cuts (pre-existing to remove background events):
  - Visible Pt>200 GeV
  - Hadronic Top Energy>100 GeV
  - Leptonic B Jet Pt>20 GeV
  - $-\log(y_{23})<7$ && $-\log(y_{34})<9$
  - $|(\text{Top } \cos\theta)|<0.9$
- Quality Cuts:
  - Hadronic Top Mass>100 GeV
  - Hadronic Top Pt>100 GeV
  - Leptonic B Jet Mass<100 GeV
  - 0.2<Collinearity of highest and next highest energy subjets<0.8
  - -log(Y23)>3
  - Pz Constraint from fit<100 GeV
- Currently use same cuts across full energy range
  - Scope to further optimise as some variables are energy dependent

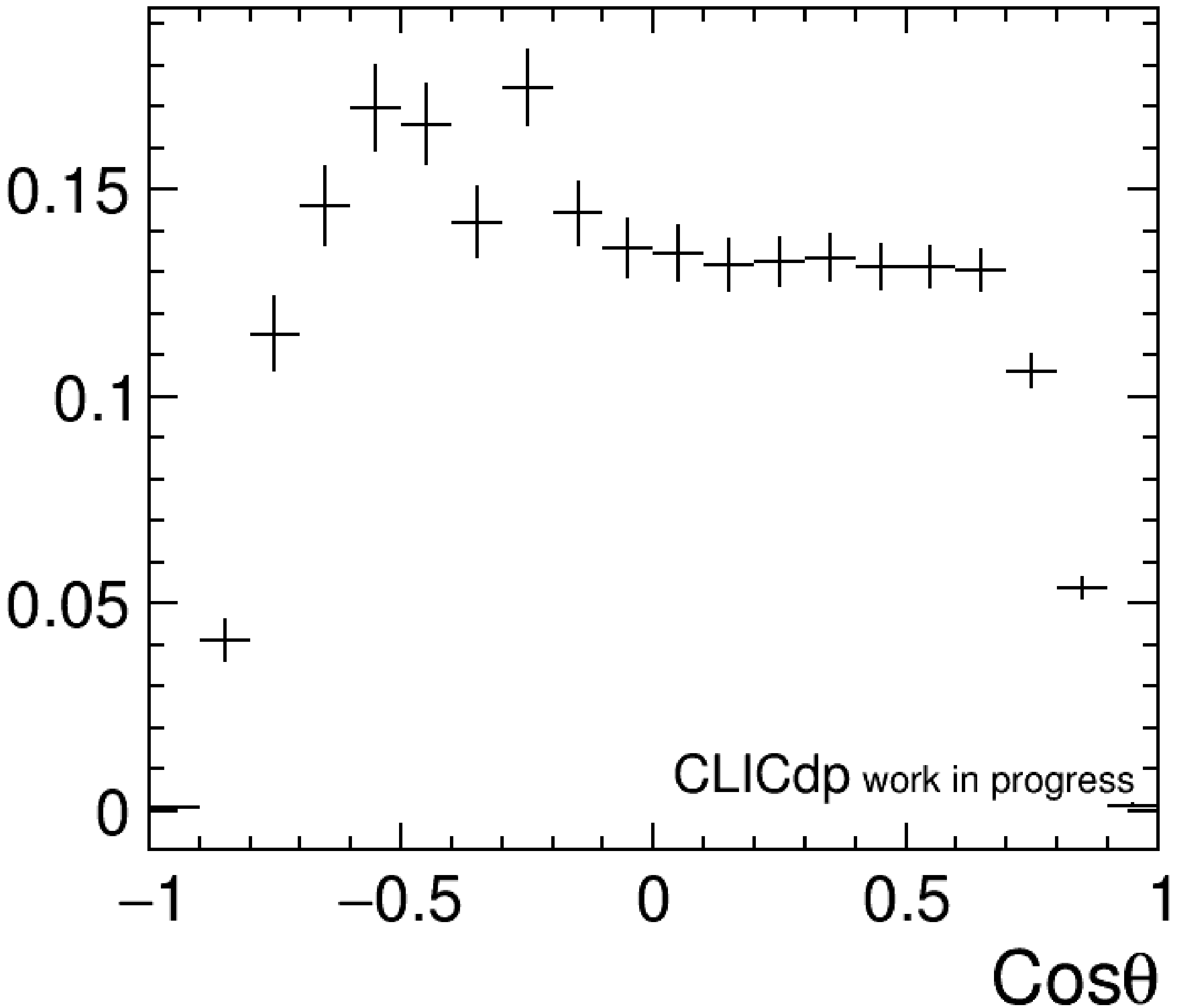
Variables currently used to train BDT

- Visible Energy and Pt
- Hadronic Fat Jet Energy and Pt
- Leptonic Fat Jet Mass
- Leptonic 1SubJettiness, 1SubJettiness/2SubJettiness
- Relative angle of the 3 subjets within hadronic fat jet
- Isolated lepton Energy, Pt and total momentum
- N Lepton candidates with E>30GeV
- Angular separation between lepton and hadronic fat jet
- $-\log(y_{23})$
- Major thrust
- Leptonic Top Energy
- Highest and next to highest btags

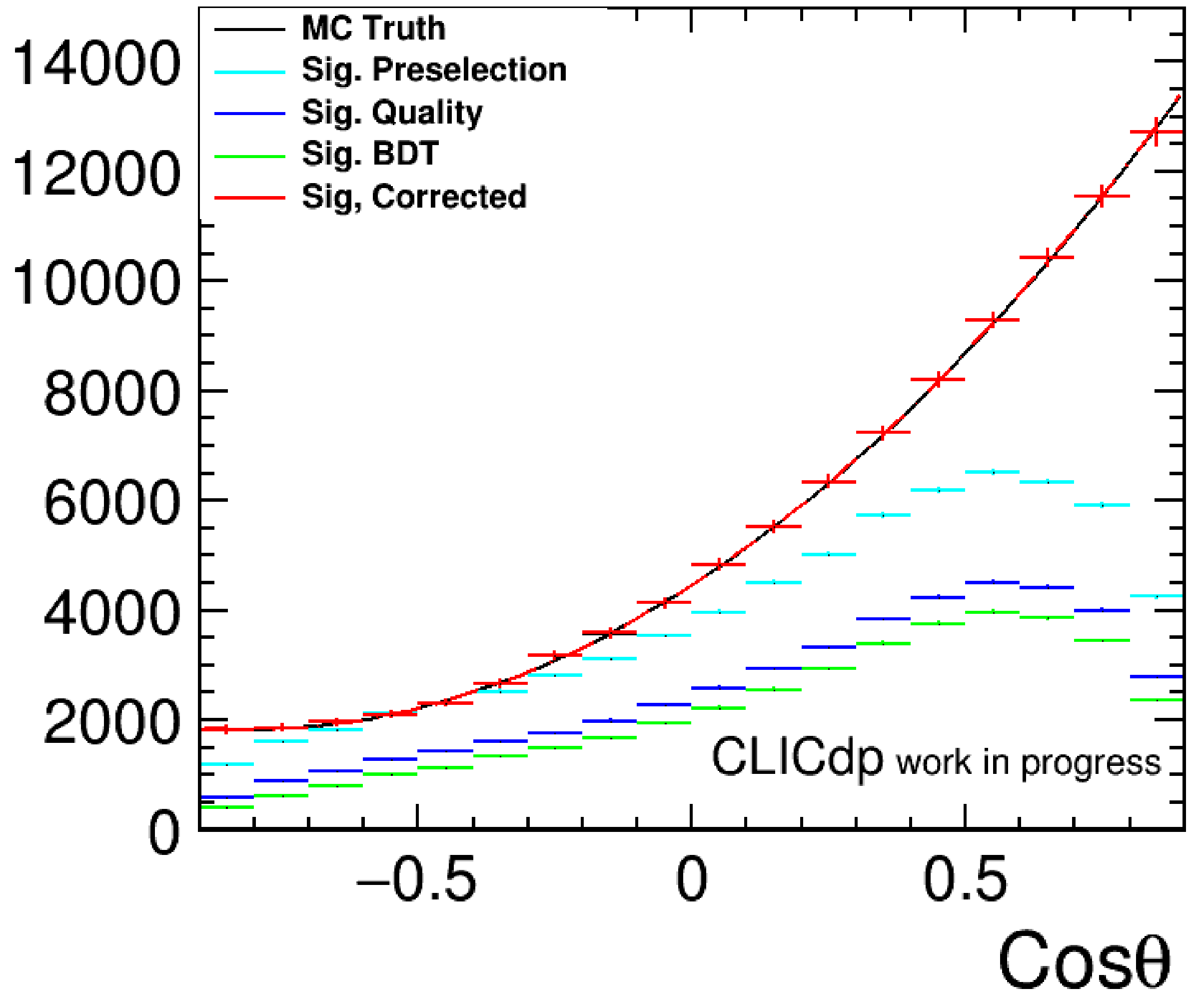
Signal Efficiency, 900GeV<E<1200GeV



Signal Efficiency, 400GeV<E<900GeV



Theta Distribution After each Stage of cuts at E>1.2TeV



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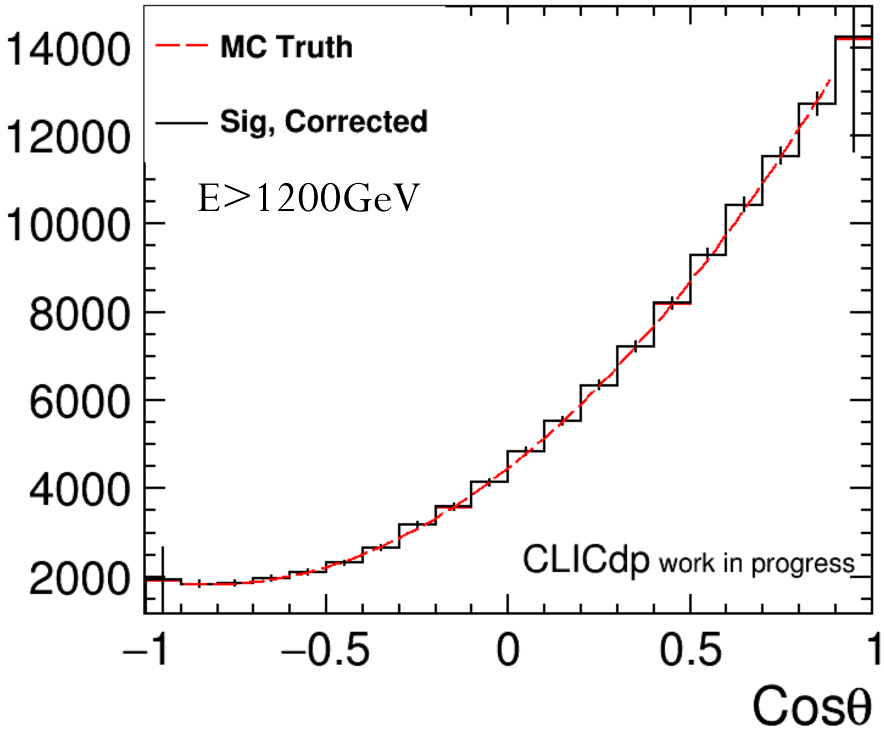

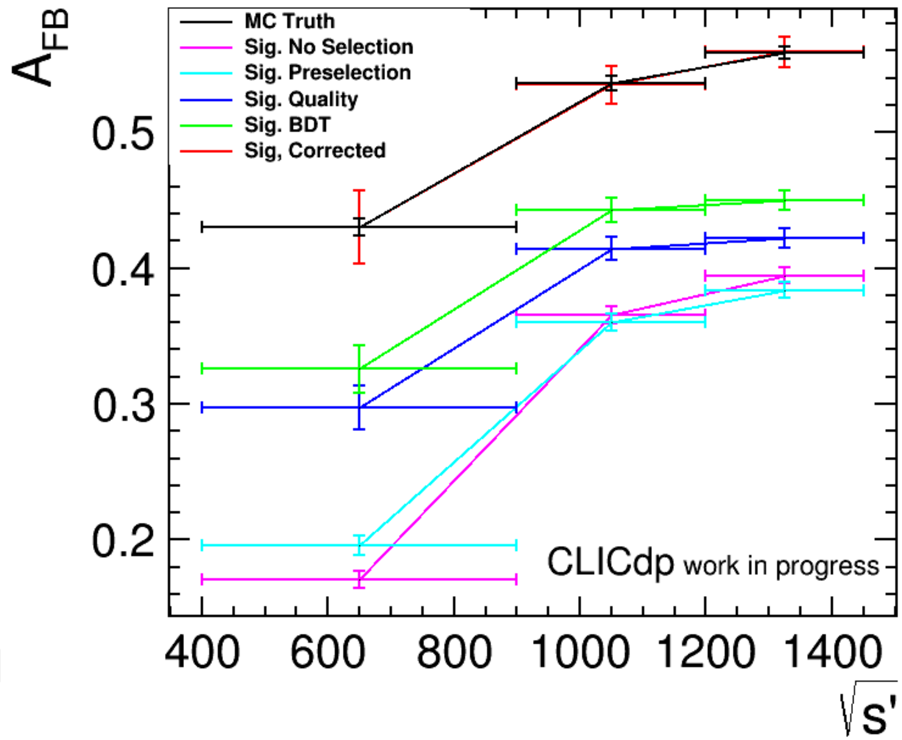

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