Measurements with b-jets and b-tagging

G. Watts (UW/Seattle)

November 12, 2012

CHICAGO Workshop on LHC Physics in the Higgs Era

THE UNIVERSITY OF CHICAGO
THE ENRICO FERMI INSTITUTE

b-Tagging

The LHC program requires us to address bottom quarks as a unique object

Signals	Low mass Higgs, SUSY high tan β, etc.
Backgrounds	W+jets, Z, and $t\bar{t}$

This is not black-box object ID

➡ The identification algorithms are getting quite complex

➡ Their calibration are full blown analyses in their own right (and take quite a bit of time)

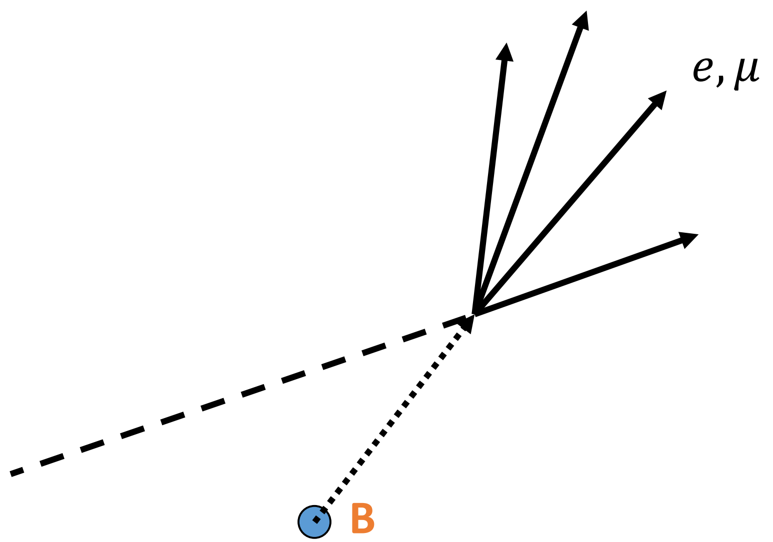
Anatomy of a *b*-quark

~20% of decays are semileptonic

Decays via the Weak Force

Anatomy of a *b*-quark

Semileptonic Decays



Electron

- Electron embedded in jet extraordinarily difficult

Muon

- MIP in calorimeter, easy to identify in muon chambers, even low p_T

Used heavily in calibration
Less so in analysis

Semileptonic Tagging

Muon, $p_T > 3$ GeV, $\eta < 2.5$ (Binary Decision)

Lots of material in front of muon chambers…
CMS Calib uses $p_T > 7$ GeV

Calibration

- Muon ID
- Trust Monte Carlo

Used by CMS in their high mass Higgs search

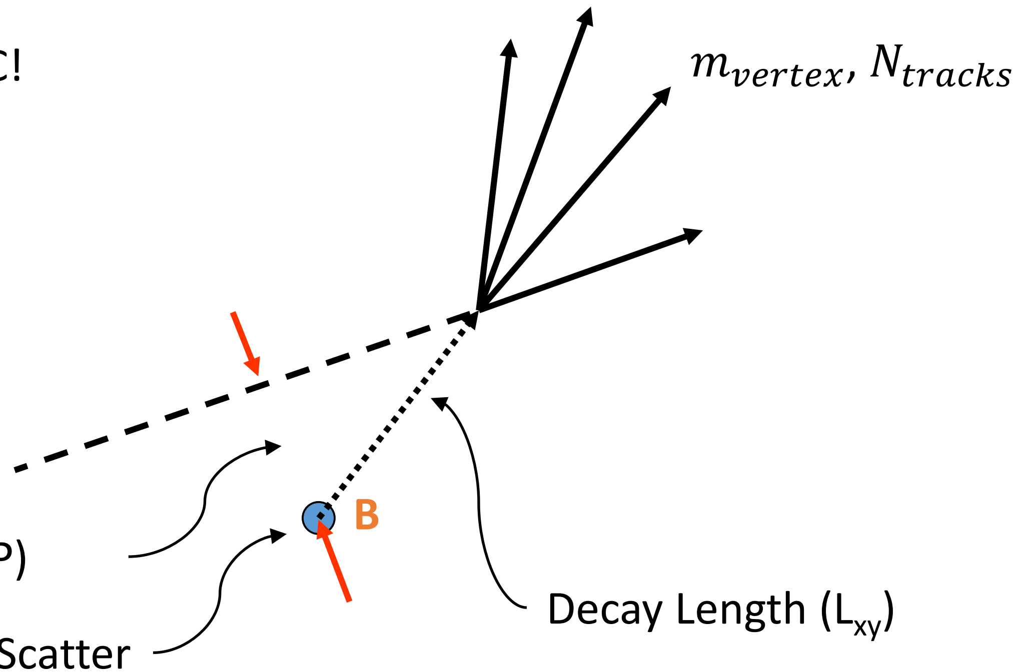
$H \to ZZ \to \ell\ell\nu\nu$

Used with regular b-tagging as a veto

Anatomy of a *b*-quark

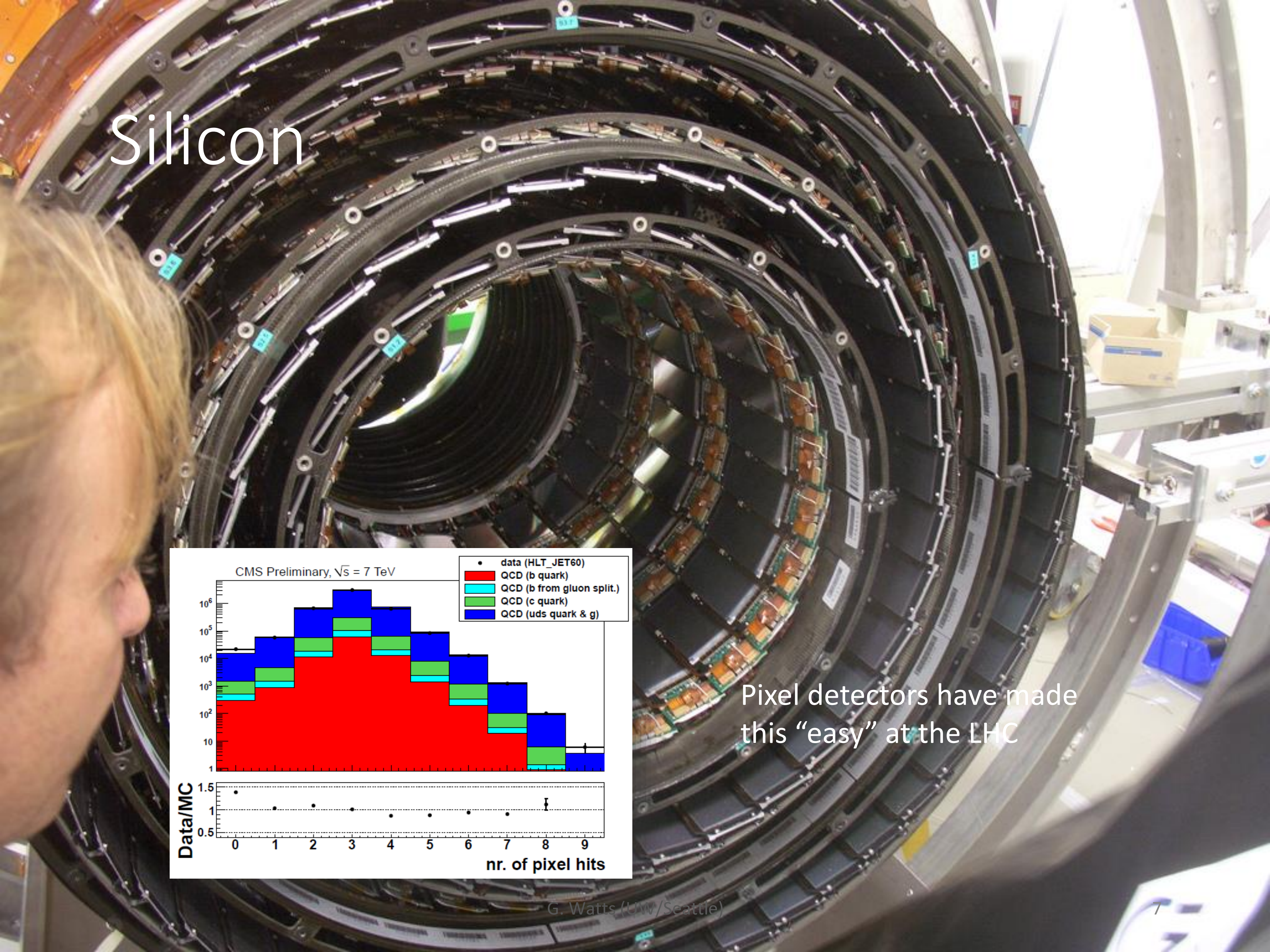
$c\tau \approx 450\mu m$

➡ ≈ 5 mm at the LHC!



Algorithms tuned to take advantage of one or more of these features

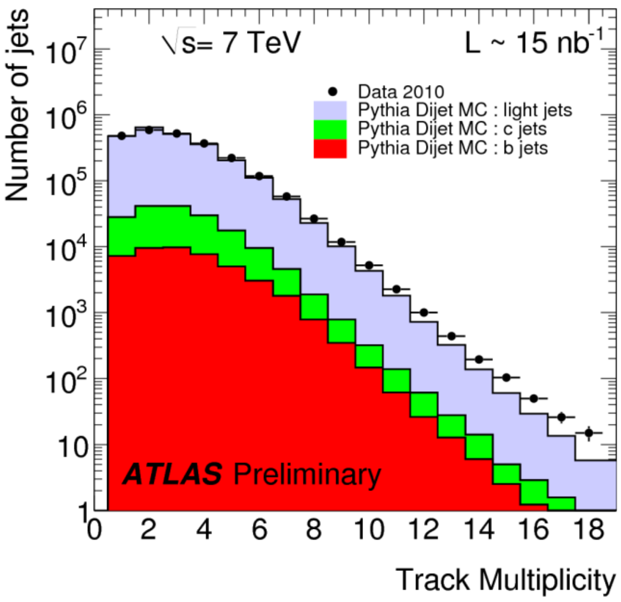
Silicon



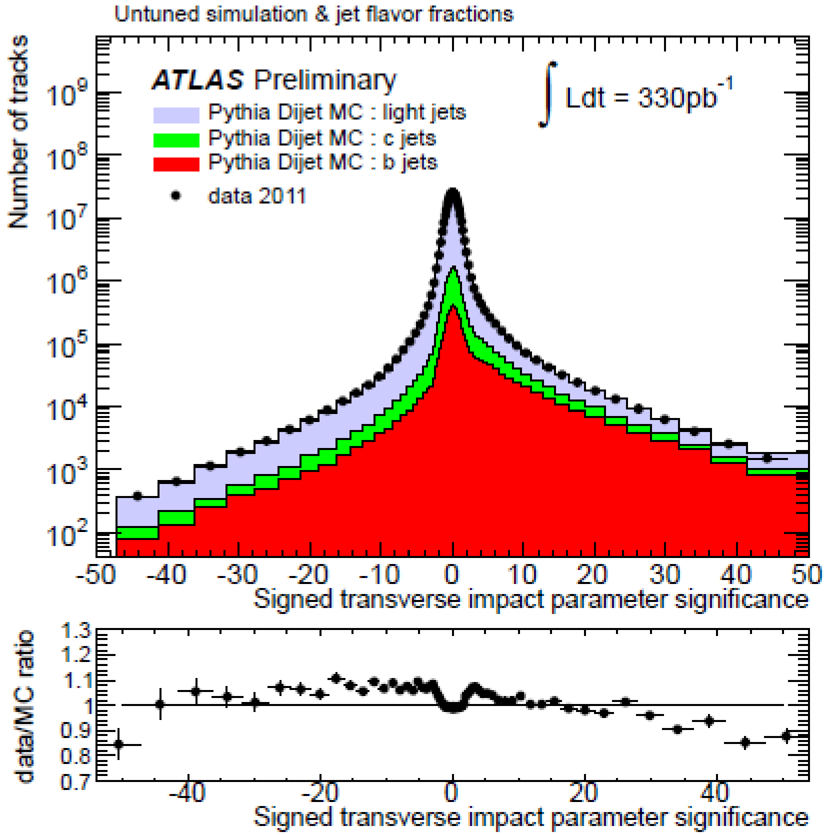
Pixel detectors have made this “easy” at the LHC

Tagging Algorithms

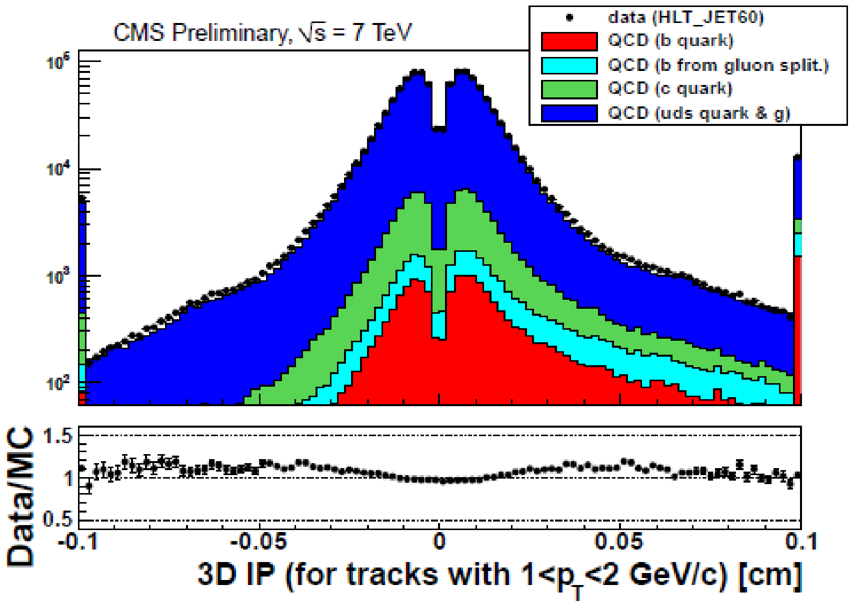
- Tracks
  - Count the number of tracks in a jet
  - Cuts on impact parameter
  - Highly efficient
- Vertex Reconstruction
  - Fit the tracks looking for a displaced vertex
  - Efficiency has relatively low plateau
  - Many variations
- Combined
  - Use elements of both
  - Recovers some of the efficiency
  - Often use MVA techniques



Must Understand Tracking!



ATLAS



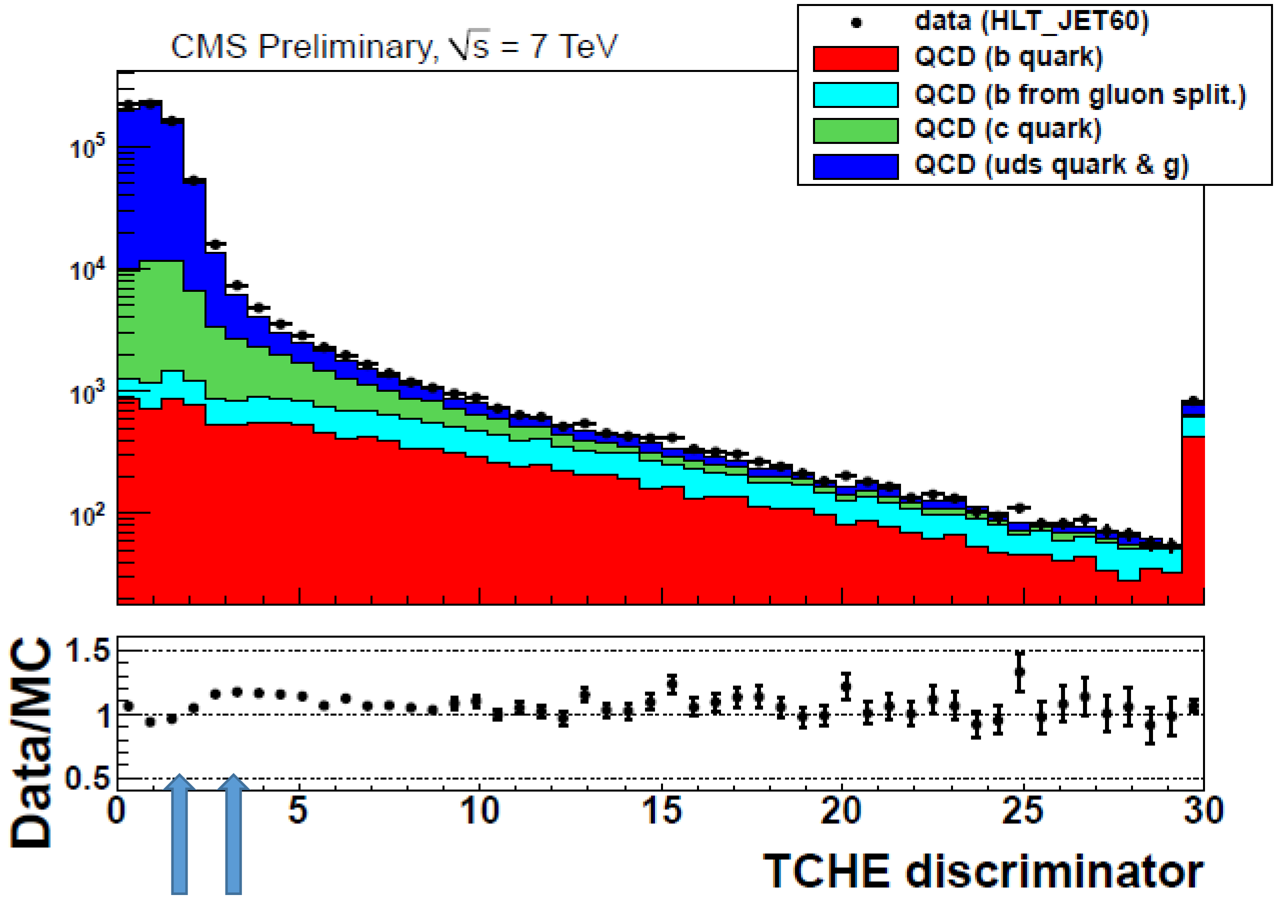
CMS Low p_T
(agreement just
as good at high p_T)

Counting Tracks

Long, rich, history (CSIP, JLIP, etc.)

CMS Track Counting (TC) Algorithm
Many variations on a theme

- Ranks tracks by IP significance
- 2nd highest track is the discrimination variable



Loose, Medium Operating Points

Simple taggers, easy to understand, good for early data!

Used in 2011 CMS $H \rightarrow ZZ \rightarrow \ell\ell qq$

Secondary Vertex Finding

ATLAS: Basic Kalman Fitter
CMS: Adaptive Vertex Fitter

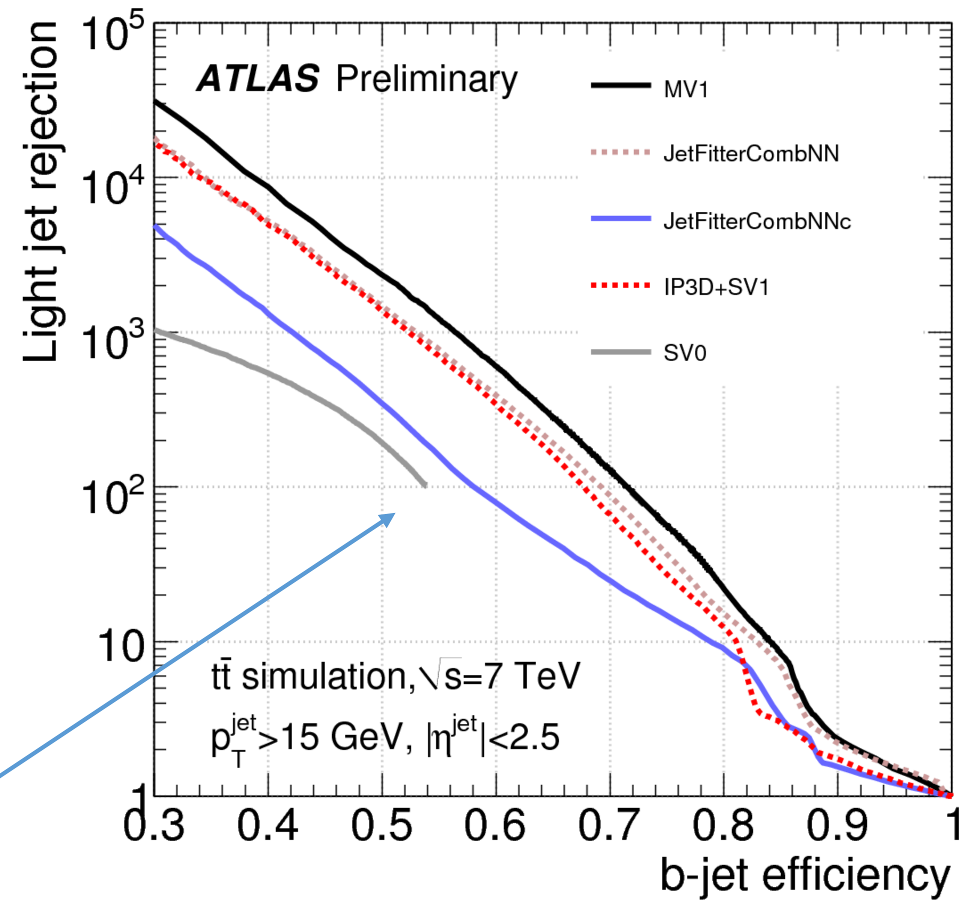
Typical Tracks:

$p_T > 0.5,1$ GeV
Require inner layer hits

Reject 2 track vertices consistent with Λ^0, K_S^0, conversions

Purity is great!

Efficiency can be a problem!



Used in early data…

Combined Algorithms

Attempt to combine the best of both worlds.

These are the algorithms used by most analyses

Combination techniques: likelihood, NN, BDT, etc. → The input variables

CMS (likelihood) - CSV

- Vertex Type
- 2D L_{xy} significance
- IP Significance of all tracks
- Vertex Mass
- N_{tracks} in vertex and jet
- Ratio of energy of tracks in vertex to tracks in jet
- The η of the tracks
- 2D IP significance of first non-charm track

ATLAS (NN) – MV1

- Uses only outputs of other tagging algorithms
- IP3D – track based algorithm
- SV1 – Secondary vertex finding algorithm
- JetFitterCOMBNN

↑ ATLAS has really converged on this one algorithm

Charm

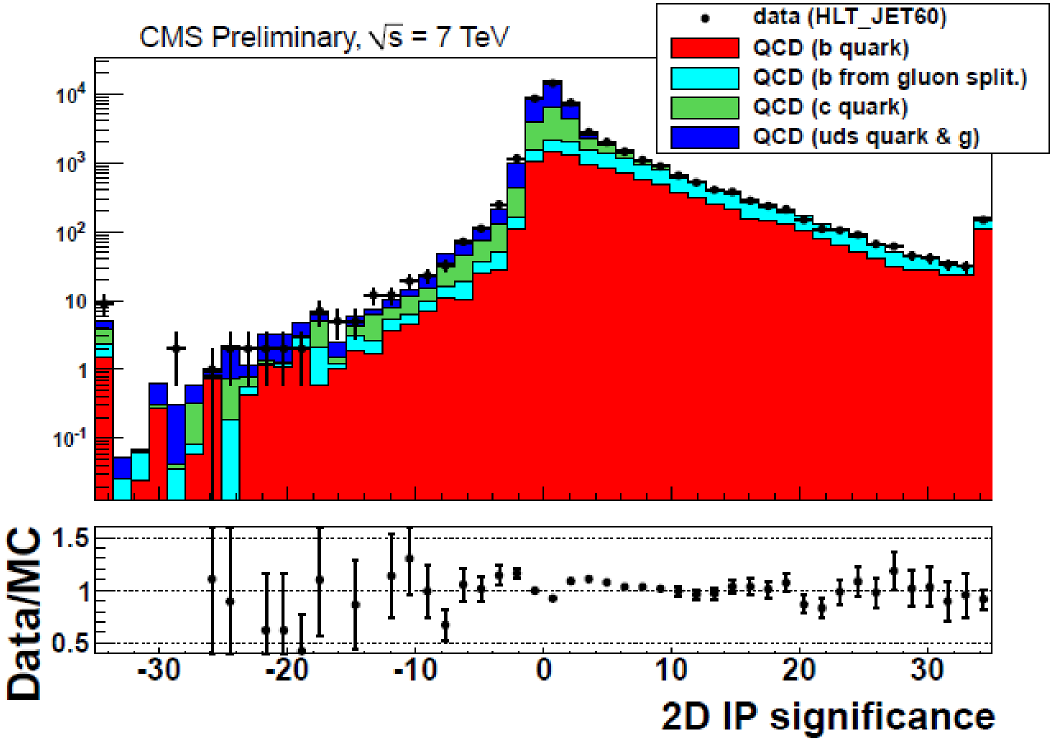
Charm mesons also decay by the weak force
Typical tag rates are 15-20% of bottom tag rates

Can be a significant background in W+jets, etc.

Specific algorithms have been designed to identify jets containing only charm

CMS

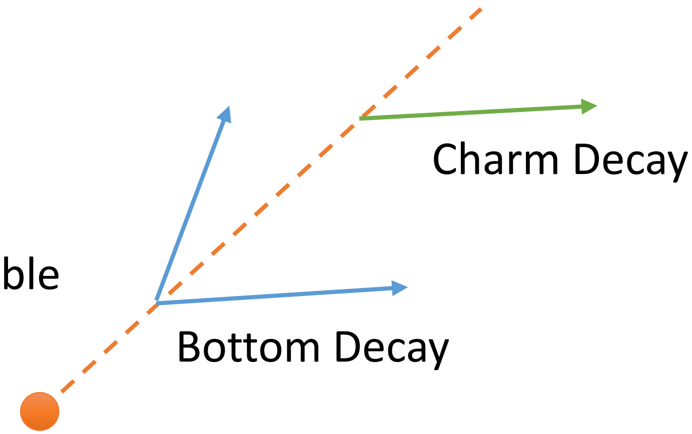
- Rank tracks in a vertex by IP significance
- One track at a time add to a vertex
- First track where $m_{vertex} >$ 1.5 GeV is likely due to a bottom quark
- Combine likelihoods to reject charm in CSV



Charm

ATLAS

Cascade charm/bottom decay reconstruction



Fit to a single line hypothesis

Single track vertices are possible

NN to aggregate the final values

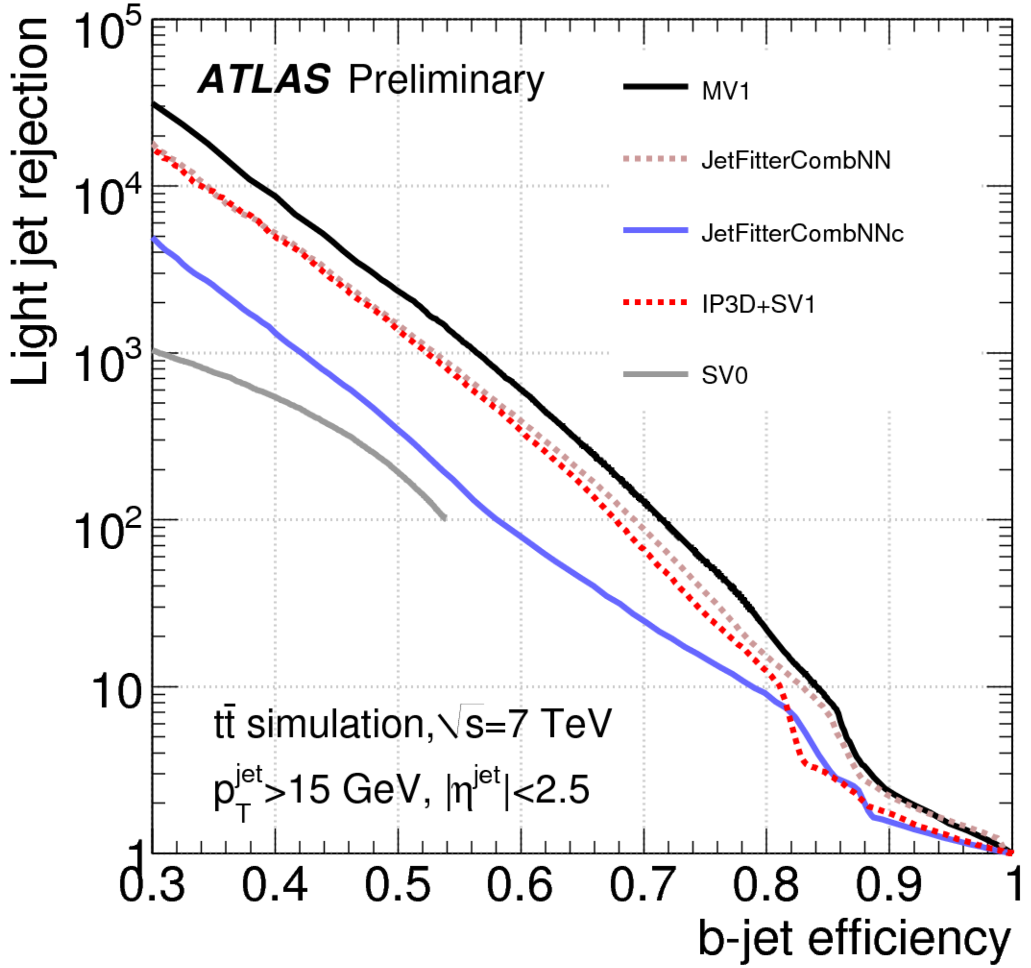
IP3D is also added in

The "JetFitterCOMB" algorithm

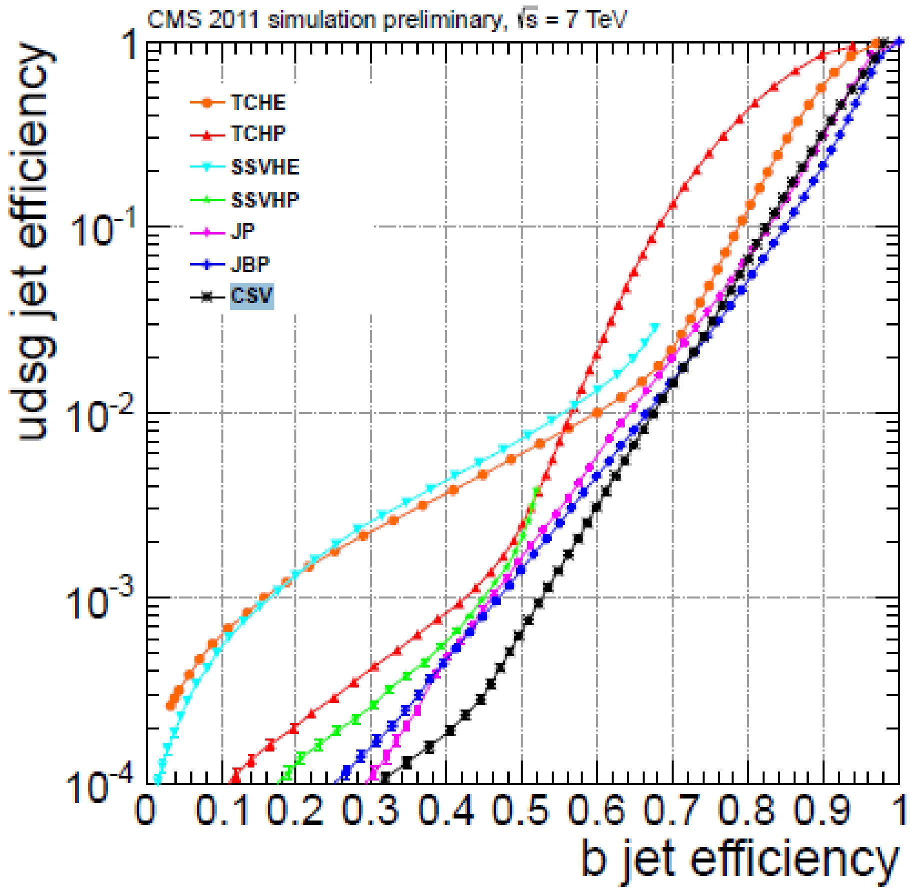
An input to the MV1

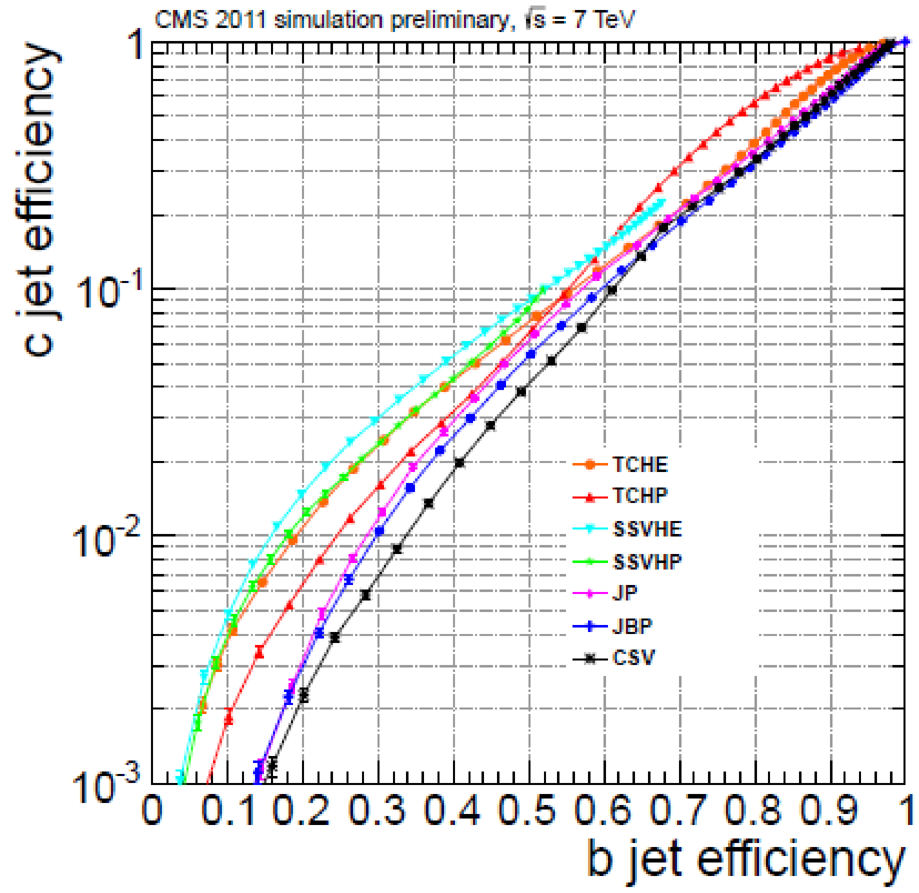
JetFitterCOMBNNc is a variant tuned to reject charm

Performance



Performance





Calibration

There is no clean sample of jets known to be bottom quarks!

$$Z \rightarrow e^{+}e^{-}$$

The QCD background is just too great!

Two bottom quark rich samples are used instead ← Errors driven by statistics and ability to determine *b*-fraction

QCD dijet events ← Hard because the *b* fraction is unknown

$t\bar{t}$ Production ← Hard because it's… top.

Calibration ⇒ Scale Factor and Systematic Error

The techniques matter

From the 2011 ATLAS $VH \rightarrow Vb\bar{b}$ Analysis

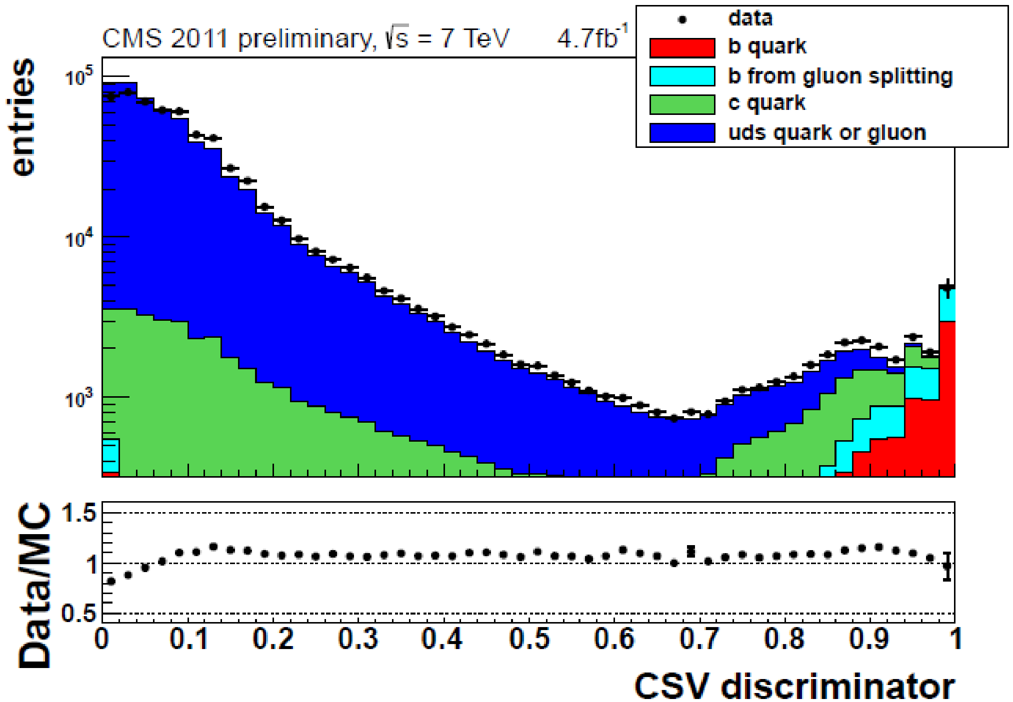
(used dijet calibration only)

Bin	$ZH \rightarrow \ell^+\ell^- b\bar{b}$ p_T^Z[GeV]				$WH \rightarrow \ell\nu b\bar{b}$ p_T^W[GeV]				$ZH \rightarrow \nu\bar{\nu}b\bar{b}$ E_T^{miss}[GeV]		
	0-50	50-100	100-200	>200	0-50	50-100	100-200	>200	120-160	160-200	>200
Components of the Signal Systematic Uncertainties [%]											
B-tag Eff	10	11	13	16	10	11	13	15	13	16	21
JES/MET	6.5	4.6	4.0	3.7	6.7	6.8	7.8	4.7	11.0	5.4	9.9
Leptons	1.1	1.5	1.5	3.6	3.2	4.2	5.0	5.5	-	-	-
Luminosity	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Pile Up	0.7	1.2	2.4	3.4	1.4	3.9	3.2	3.4	0.5	0.8	2.1
Theory	5	5	5	5	13	13	13	13	13	13	13
Total Signal	13.6	13.3	14.9	18.3	18.5	19.4	21.4	21.5	21.8	21.7	26.8

We expect dijet to be most powerful at low jet p_T, and $t\bar{t}$ calibration at high jet p_T

Operating Points

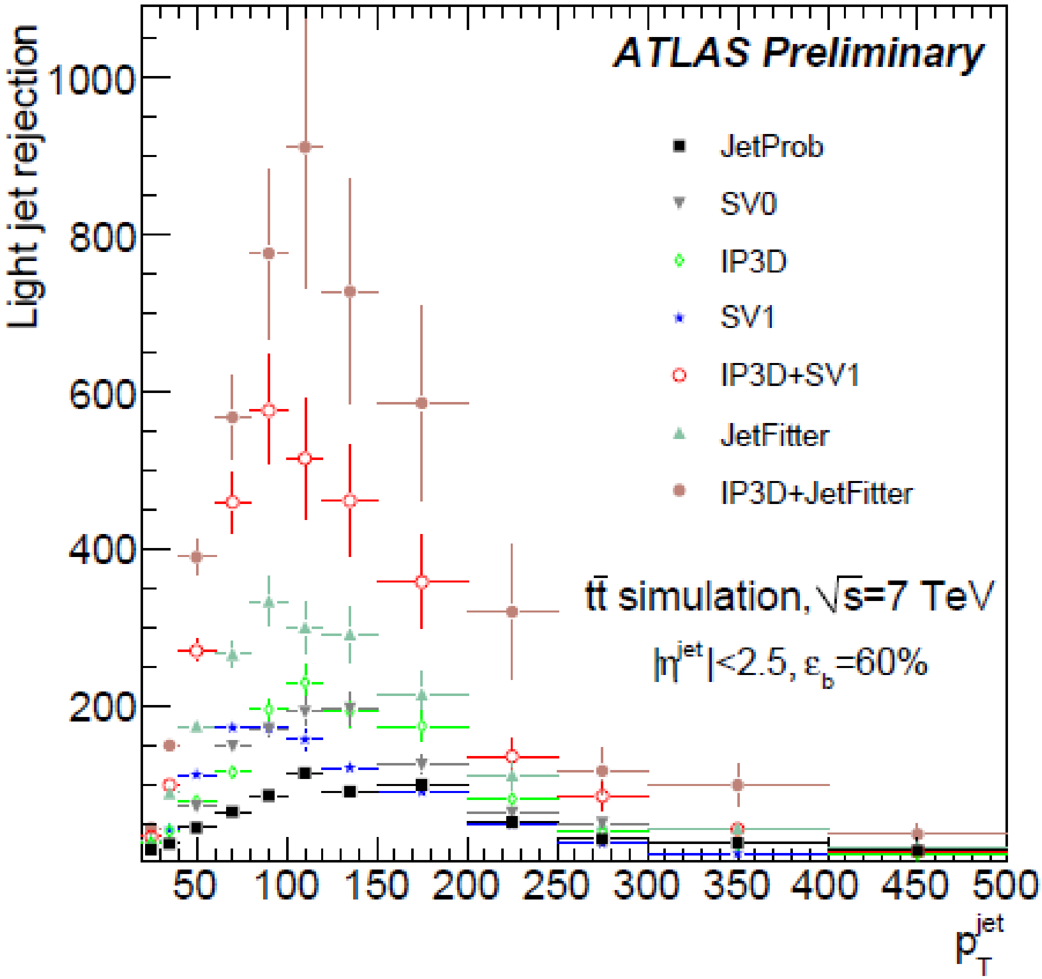
Most tagging algorithms produce a continuous output



Why not use as MVA input?

(CDF has already done this in most recent SM WH results)

Performance & Calibration



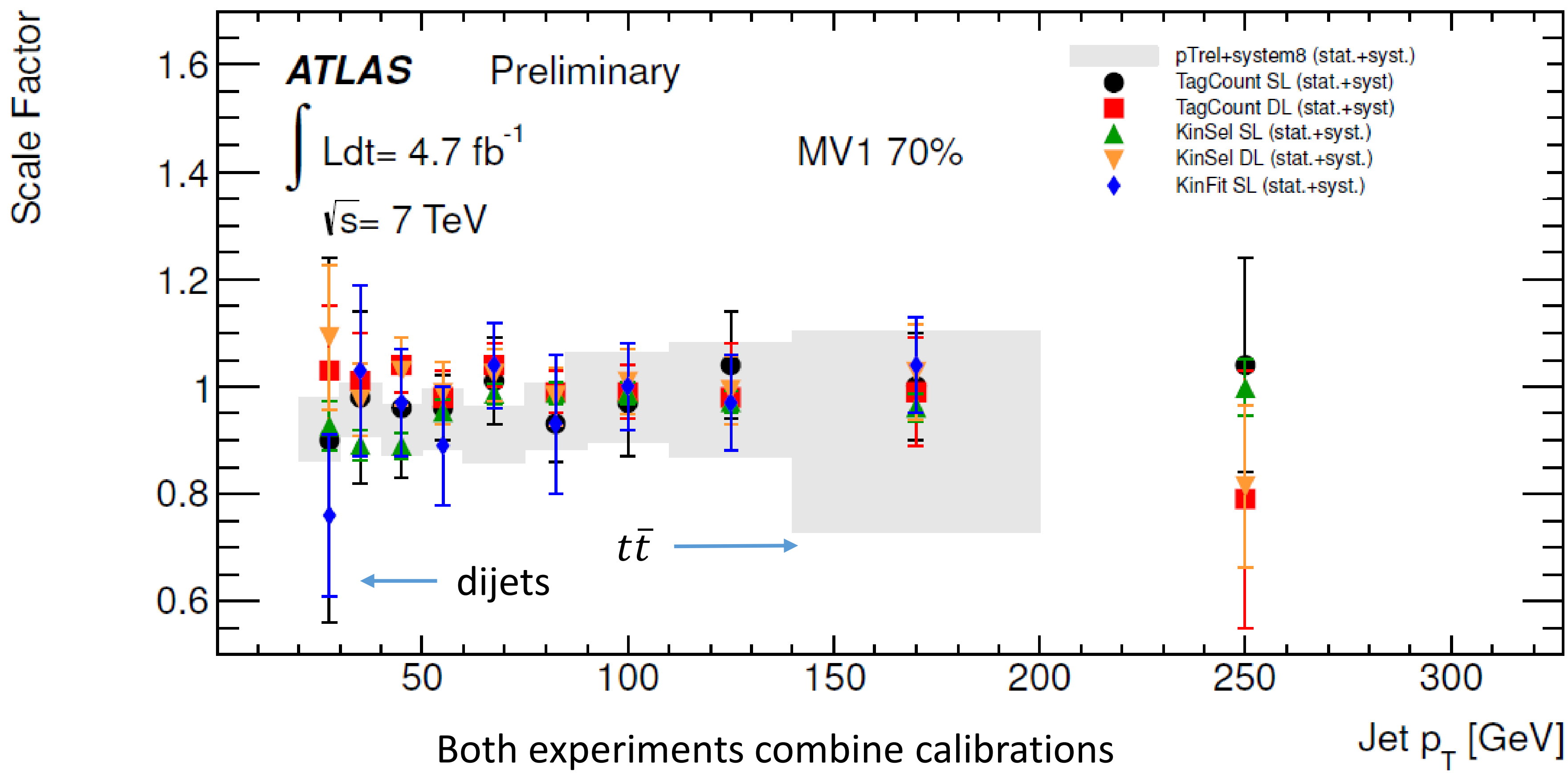
Performance is a function of at least p_T, η (binned)

Add another axis: tag discrimination variable

Statistics are low!

Calibrate in terms of Operating Points $\epsilon_b > X$

Calibration Results



Both experiments combine calibrations

Using *b*-tagging

Straight Forward Search

- Require at least 1 (2) jets to be tagged
- Relatively high efficiency with 2 tags

Many of the early searches used this technique

Search with binning by N_{tagged}

- Split analysis: 0 tags, 1 tag, 2 tags
- Spliting by $S/\sqrt{B}$
- Tag requirements often different

Will we do better with continuous tagging?

Using *b*-tagging

Veto

Use a high efficiency operating point & algorithm

Used to suppress a background containing heavy flavor.

In $H \rightarrow ZZ \rightarrow llqq$ suppresses $Z \rightarrow b\bar{b}$ background

In $H \rightarrow \tau\tau$ used to suppress $t\bar{t}$ backgrounds

Using b-tagging

CMS $VH \rightarrow Vb\bar{b}$ uses b-tagging to improve the mass resolution

Events are chosen using standard search techniques

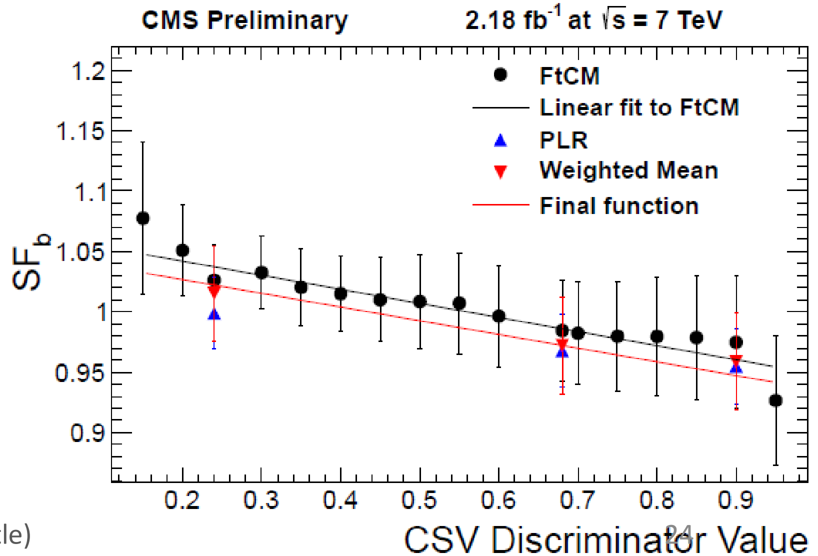
1 Use a Boosted Decision Tree to improve the bottom jet energy resolution

- Properties of a found secondary vertex
- Properties of the tracks (IP, etc.)
- Jet Energy related variables

15% increase in mass resolution

2 Final Discriminate

- CSV max and min value for b-tagged jet
- Calibration done at many points enables this



Conclusions: Future

- Better Combinations
  - Both experiments have some techniques that might benefit each other
- Calibration Improvements
  - High luminosity and statistics $t\bar{t}$ should shrink the b-tagging error
  - Direct calibration of charm and tau backgrounds instead of Monte Carlo ratios
- Continuous Tagging
  - Using the output of a combined b-tagging algorithm directly as input
  - Final variable fit for analysis ordered in significance
- Better Treatment of systematic errors
  - Errors are being driven further into the analysis
  - Common errors like Jet Energy Scale need to be varied in common
  - Technically challenging
- High p_T Tagging
  - Efficiency turnover occurs around 200 GeV
  - Calibration is very difficult due to statistics
- Other types of taggers?
  - ATLAS has a double-bottom quark tagger ($g \to b\bar{b}$)

Conclusions

- The 2012 $t\bar{t}$ calibration should be stunning
  - And its effect should be obvious in the HCP results
- b-tagging continues to evolve
  - Many possible improvements
  - We are still a good way from the point of diminishing returns
    - Though we try…
- Challenge: are there ways to use b-tagging in analysis with more than a highly tuned MVA?
- How much will we improve on this as opposed to getting read for new data ($\sqrt{N}$)
- I didn't mention high tan β bottom quark searches
  - Their use of b-tagging is similar to the SM analyses
  - See Keith's talk tomorrow