Performance of b-jet identification in ATLAS.

HEP Student Seminars

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HELMHOLTZ | GEMEINSCHAFT

DESY

Disclaimer: biased choices in the topics

- I recall some jet physics basics and define some kinematics required to understand the content of the talk
- I spend a bit of time to describe the idea of the most basic identification algorithms and on which detector measurements they rely on
- I spend a bit of time to give a rough idea on how we cross check / calibrate the algorithm performance with real collision data

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- I do not explain the latest algorithm developments and most fancy techniques
- I do not cover c- and τ lepton (to hadrons)-tagging
- I do not address the issue of b-tagging at very high $p_{\mathrm{T}}^{\mathrm{jet}}$ (i.e. beyond the $t\bar{t}$ kinematic reach)

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if you need more info:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/FlavourTaggingPublicResultsCollisionData

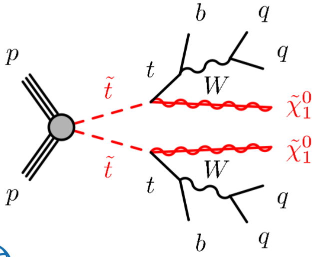
Why b-jet identification so important for ATLAS?

- Identifying the jets originating from the hadronization of a *b*-quark (*b*-tagging) is essential to many ATLAS physics analysis:

Top Physics / New Phenomena

→ top precision cross section measurement

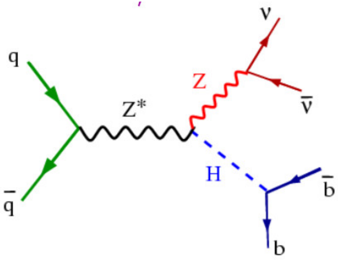
→ high mass stop SUSY searches



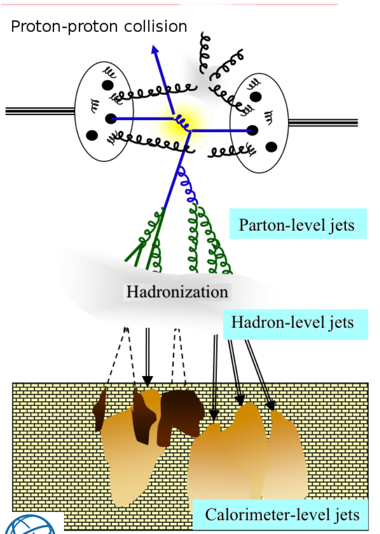
Higgs Physics

→ observation of $b\bar{b}$ decay mode

→ direct measurement of top-Higgs couplings (ttH production)



What's a hadronic jet?



- Perturbative QCD, very small timescales
  $\rightarrow$ **coloured final state objects**

- Partons can be grouped together via a clustering algorithm
  $\rightarrow$ **definition of "parton-level" jets**

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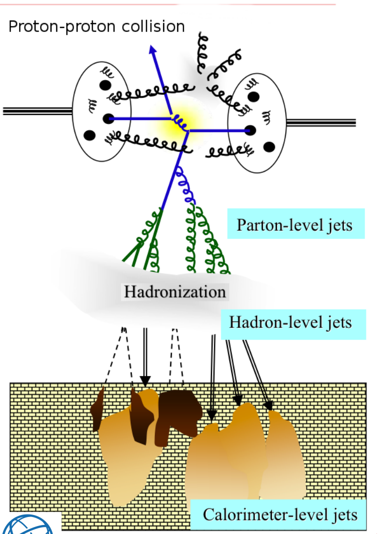

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  → **hadronization (non-perturbative)**
  → other non-perturbative effects
  → **definition of "particle-level" jets**

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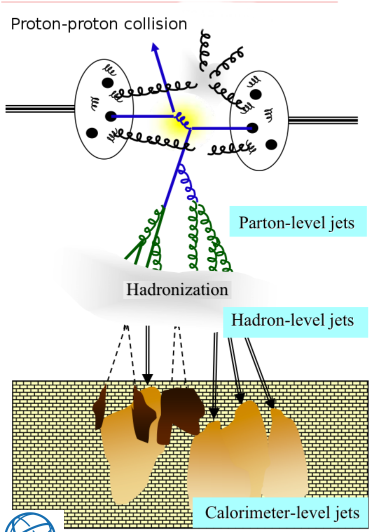

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- Hadrons cannot be reconstructed individually in the detector
  → experimentally, clustering based on **calorimeter energy deposits**

What's a hadronic b-jet?

For theorists:

1. **fixed-order QCD computation:**
   no jets, only limited number of partons
2. **+ parton shower:**
   parton-level jet with *b*-quark as highest p_T parton with $p_T > X$ GeV
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   particle-level jet including at least one b-hadron

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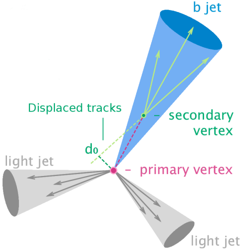
For experimentalists:

1. **long-lifetime of b-hadrons:**
V_{cb} small $\rightarrow$ decay length $\sim$ 450 μm
2. **large mass of b-hadrons:** few GeV

$\rightarrow$ presence of displaced tracks

$\rightarrow$ presence of secondary vertices
(B $\rightarrow$ C $\rightarrow$ light)

$\rightarrow$ peculiar topology
(more and higher energy tracks, etc)



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in ATLAS, "true" b-jet in simulation: calorimeter-level jet with at least one b-hadron ($\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$)

Experimental identification of b-jets rely strongly on detector tracking performance

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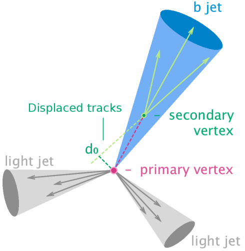
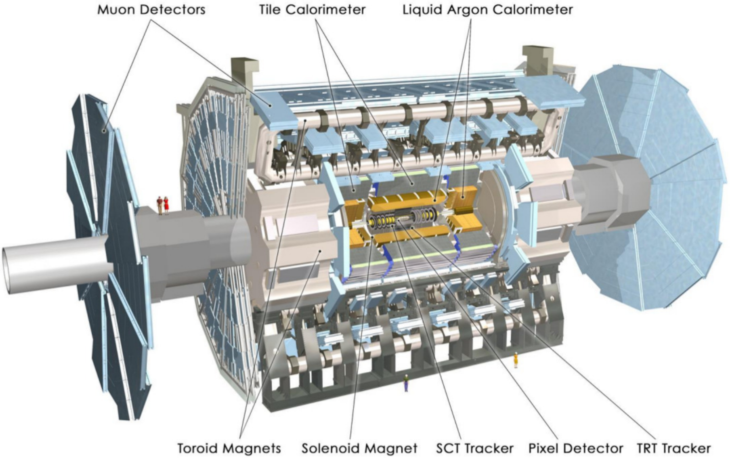


Jets and b-jet identification in ATLAS



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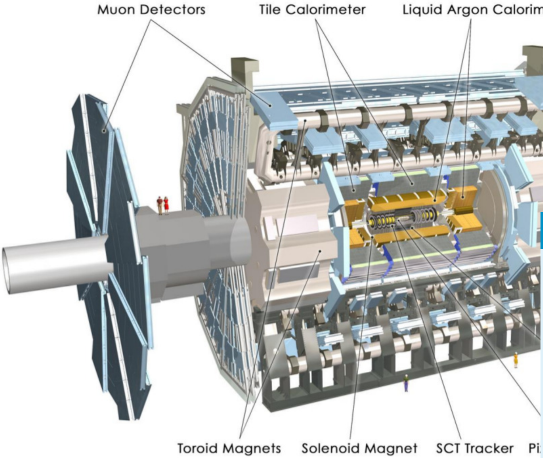

Inner detector

- $B = 2$ T
- Non-destructive detection of charged particles
- trajectories, p_{T}
- **Primary (PV) and secondary vertices (SV) reconstruction**
- **Track impact parameters**
- track momentum (angular) resolution decreases (increases) with p_{T}

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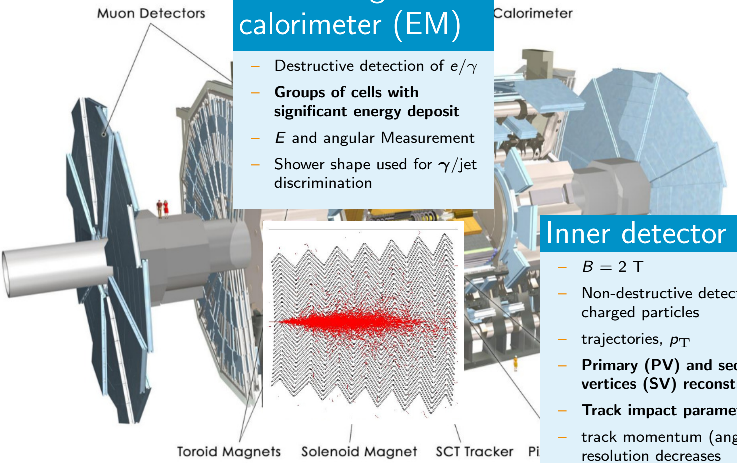

Electromagnetic calorimeter (EM)

- Destructive detection of e/γ
- **Groups of cells with significant energy deposit**
- E and angular Measurement
- Shower shape used for γ/jet discrimination

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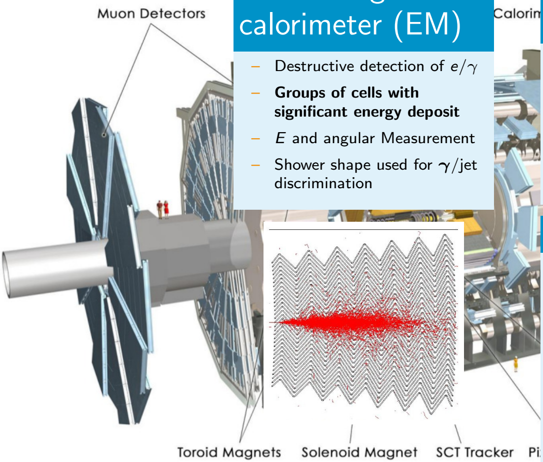

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Jets and b-jet identification in ATLAS

Muon spectrometer

- $B = 0.5$ T (mean)
- Muon detection
- **Not used in "classic" b-tagging algorithms**

Electromagnetic calorimeter (EM)

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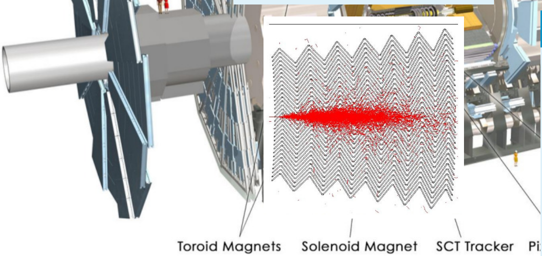

“Low-level” b-tagging algorithms in ATLAS

Impact parameter-based algorithm: IP2D/IP3D $\rightarrow$ **used at LEP**

- $\mathbf{d_0}$: “distance of closest approach between the track and the primary vertex (PV) in the transverse plane”
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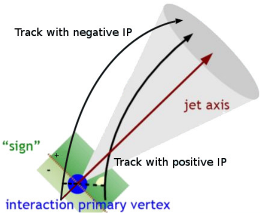

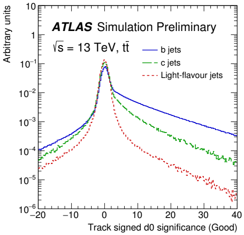

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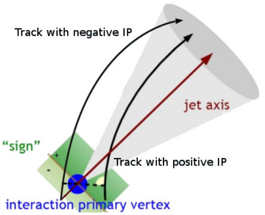

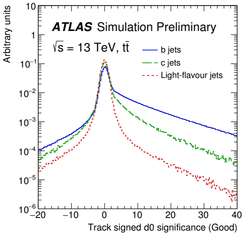

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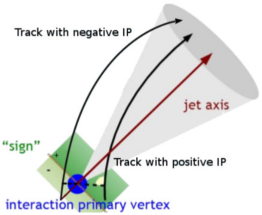

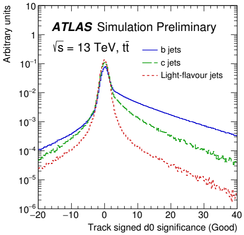

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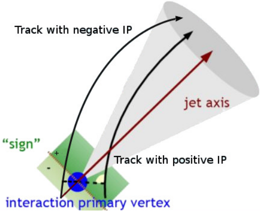
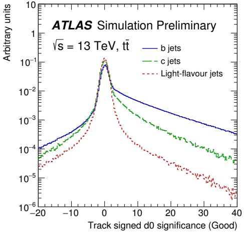
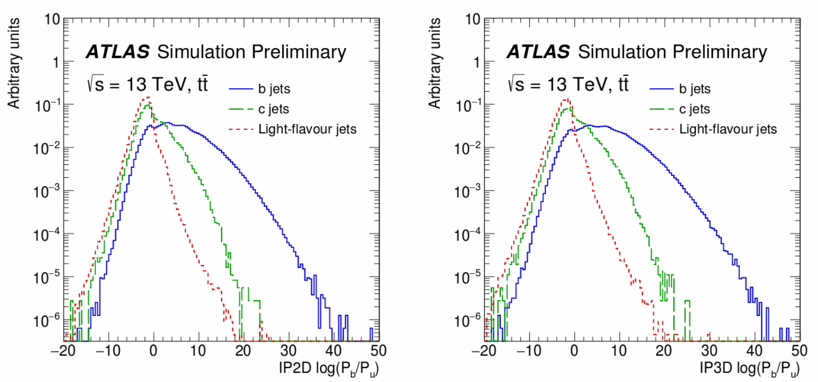
- IP2D → d_0 templates (x,y)
  IP3D: → d_0,z_0 + correlations (3D)





IP2D/IP3D discriminants

$\log(P_b/P_u)$ log-likelihood discriminant for IP2D (left) and IP3D (right)

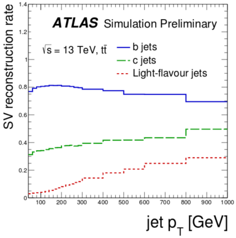


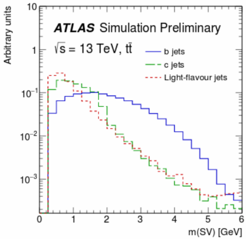
→ $\log(P_c/P_u)$ and $\log(P_b/P_c)$ also defined

“Low-level” b-tagging algorithms in ATLAS

Inclusive secondary vertex reconstruction: SV1

- All track pairs within a jet are tested for a two-track vertex hypothesis, final fit includes all tracks from 2-trk vertices
  $\rightarrow$ 1 (or 0) “inclusive” vertex reco per jet





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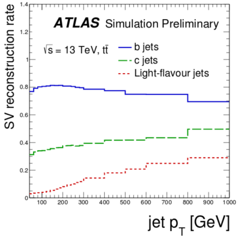

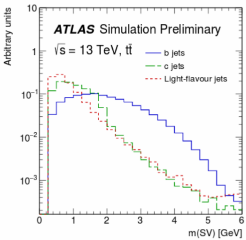

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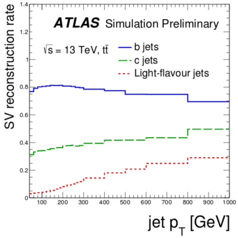
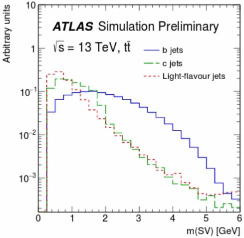
- Rate for light increases as a function of $p_{\mathrm{T}}^{\mathrm{jet}}$ (more tracks, more material interactions)





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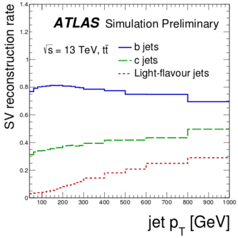
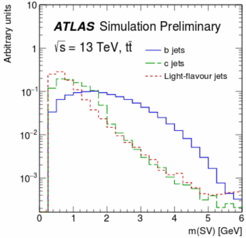
- **8 SV properties are used as discriminants**

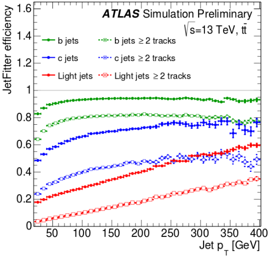




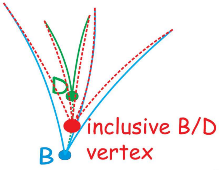
"Low-level" b-tagging algorithms in ATLAS

Decay chain multi-vertex reconstruction: JetFitter → **ATLAS specificity**

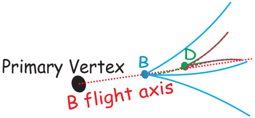
- J. Phys. Conf. Ser. 119 (2008) 03203
- exploits the topological structure of weak *b*- and *c*-hadron decays to reconstruct the full b-hadron decay chain



What SV1 does:



What JetFitter tries:

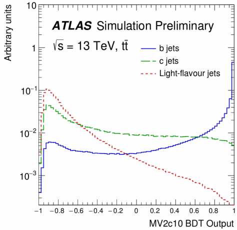


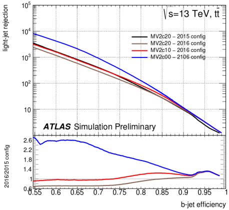
8 quantities reconstructed by JetFitter are used as discriminants

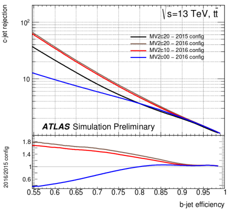
“High-level” b-tagging algorithm in ATLAS

$p_{\mathrm{T}}^{\mathrm{jet}} + \eta^{\mathrm{jet}}$ + 3 (IP2D/IP3D) + 8 (SV1) + 8 (JF) variables used as input to a boosted decision tree: **MV2 (multi-variate discriminant)**

- Algorithm learns how to identify *b*-jets, trained on $t\bar{t}$ simulated MC sample
- Provide a weight within [-1,1] telling you how likely the jet to be a *b*-jets
- Performance quantified in ROC curve: **signal efficiency vs background rejection**
- MV2 is the main tagger used by ATLAS







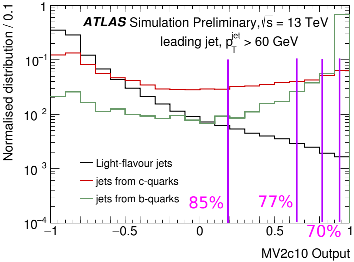
Quantification and calibration of *b*-tagging performance

- **Tagger working points (WP) defined as a certain cut on the BDT output**

  $\rightarrow$ select a certain point on the ROC curves

- **"fixed-cut working points"**
  $\rightarrow$ constant cut value on the BDT output

- WP name gives b-efficiency observed in a $t\bar{t}$ simulated sample, ex: 85% WP



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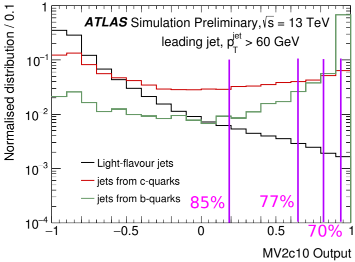

- **Strong reasons to believe simulation is not perfect**
  - **for signal (i.e. true b-jets): theory modeling effects.** Uncertainty in b-fragmentation function, underlying event (non-perturbative), ..., also pileup
  - **for background (i.e. non-b jets): detector effects.** Non-perfect tracker geometry, dead pixels, fake tracks from random hits, material interactions, ..., also pileup

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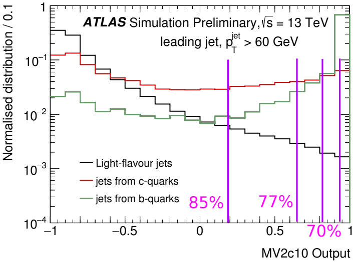

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→ **last topic:** measurement of b-tagging performance in collision data **(calibration)**

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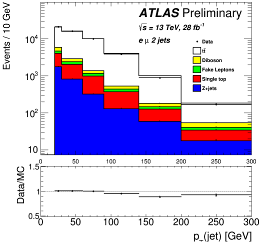
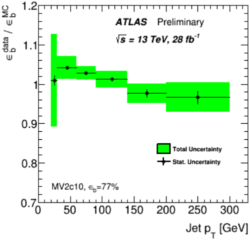
- exactly 2 jets required to limit combinatorics to bb, bl, lb, ll





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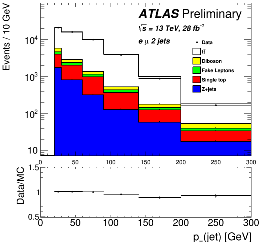
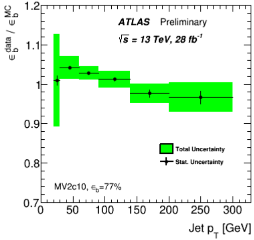
- flavour fractions and light mistag rate taken from simulation, **b-efficiency fitted from data (likelihood)**
- uncertainty $\sim$ few %, b-jet kinematic range limited by top mass





b-tagging efficiency measurements for c-jets (fake rate)

- no public plots released yet at $\sqrt{s} = 13$ TeV but will be very soon!
- main calibration analysis based on ttbar events in semi leptonic decays, i.e. one W$\rightarrow$ $l\nu$ and one W$\rightarrow$ cs
- 1 lepton + 4 jets (including 2 b-tagged jets)
- likelihood fit of the c-mistag rate. **Much higher background than for b-calibration**
- **results depend significantly on b and light calibration precision**

b-tagging efficiency measurements for light-jets (fake rate)

- sample of true light-jet **before and after** any tagging needed
- not achievable by regular di-jet selection: $\sim$ 2% (5%) b-(c-)jet bef tag ... x10 after.

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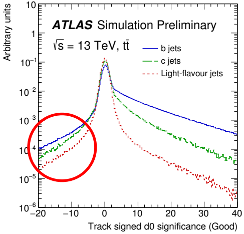

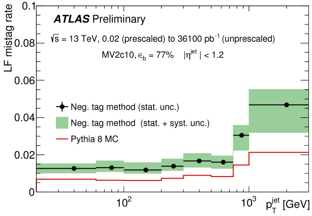

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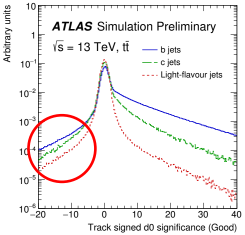

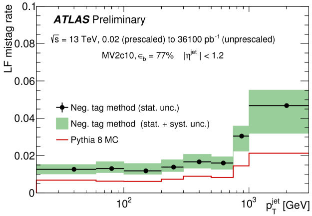

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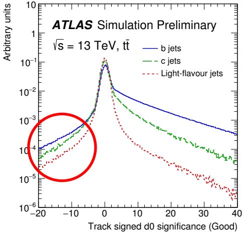

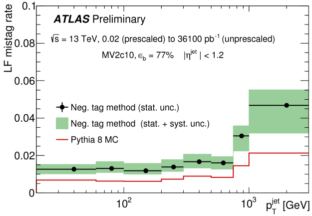

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- **Examples of challenges for b-tagging at the LHC (not developed here)**
  - b-tagging beyond the $t\bar{t}$ kinematic reach: algorithm & calibration
  - calibration of fake rates for very tight working points

Performance of b-jet identification in ATLAS.

Back-up slides

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