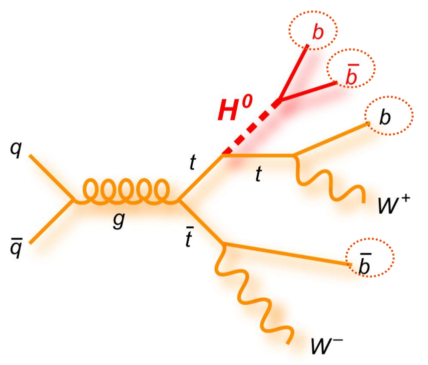
Measurement of the *b*-tagging performance of the ATLAS detector

The aim of *b*-tagging is to identify jets originating from the fragmentation of *b*-quarks. In ATLAS, different *b*-tagging algorithms are used to identify *b*-jets. The measurement of their efficiency and mistag rate in data is a crucial step for any physics analysis using *b*-tagging.

The importance of *b*-tagging

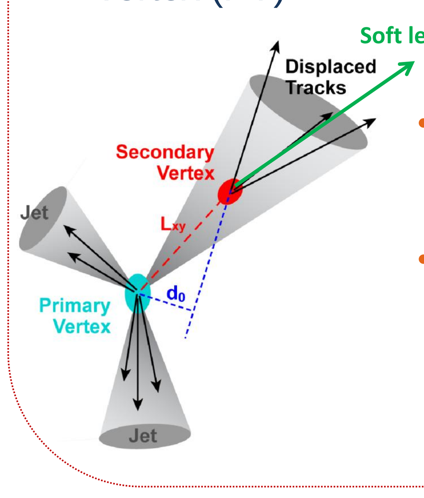


The knowledge of the *b*-tagging performance is crucial for:

- search for a light Higgs boson
- $t\bar{t}$ cross section measurement
- search for SUSY, 4th generation…
- suppression of background…

The *b*-hadrons properties

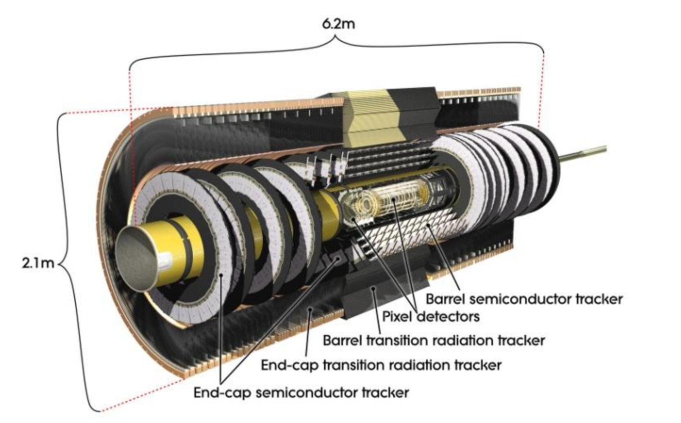
- Long lifetime : a *b*-hadron in a jet of p_T=50 GeV flies ~ 3mm in Rφ before decaying
- Displaced secondary vertex (SV) from primary vertex (PV)



- Large transverse impact parameter d_0 of tracks in jets from the SV
- Semileptonic decay (~40% of *b*-jets): $BR(b \to l\nu X)$ + $BR(b \to c/(\bar{c}) \to l\nu X)$ = 11% + 10% (l=e, μ)

The ATLAS inner detector

is the most important detector used for the identification and reconstruction of secondary vertices from *b*-hadrons

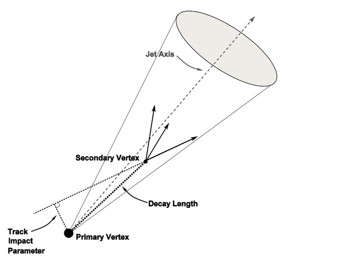


- very high granularity
  → very high resolution
- 3-dimensional vertexing capabilities

The performance of *b*-tagging relies heavily on the performance of the inner detector

- Pixel : ~ 80 million channels, **~96.9%** operational!
- SCT : 6.3 million channels, **~99.1%** operational!
- TRT : 350 000 channels, **~97.5%** operational!

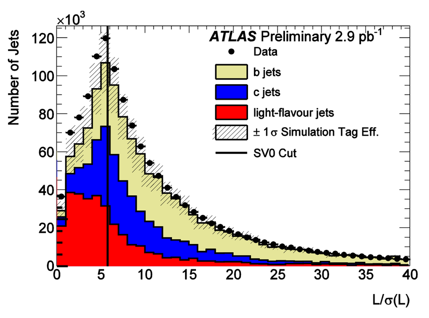
Early *b-tagging* algorithms SV0 and JetProb



The SV is reconstructed from tracks with a large impact parameter significance with respect to the primary vertex.

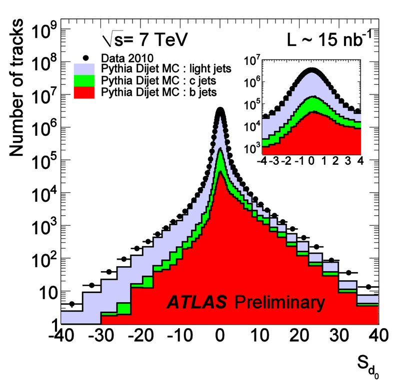
The **SV0 tagging algorithm** relies on reconstructed secondary vertices from the tracks associated to jets.

→ uses of the signed decay length significance $L/\sigma(L)$.



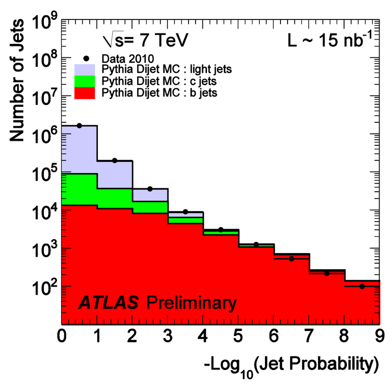
$L/\sigma(L)$ distribution for all reconstructed SV data events (black points). Superimposed, the expectation from simulated events.

The **JetProb tagging algorithm** Uses the signed transverse impact parameter significance (S_{d_0}) of charged tracks.



→computes the probability for each track and combines them into a jet probability to originate from the primary vertex using S_{d_0}.

The jet probability to be compatible with a light jet for data (black points). Superimposed, the expectation from simulated events



Both algorithms, JetProb and SV0, have been commissioned, calibrated and are being used in ATLAS physics analyses.

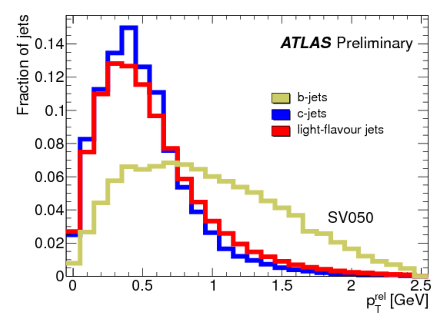
Measurement of the *b*-tagging efficiency

2 methods based on jets containing muons

The p_T^{rel} method:

p_T^{rel} is the transverse momentum of a muon with respect to the jet axis.

Very good discriminating power!



Using the p_T^{rel} distribution fit to data, the *b*-tagging efficiency is the ratio between

the number of ***b*-tagged *b*-jets** and the number of ***b*-jets**

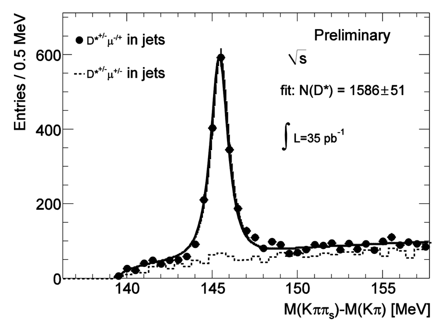
The $D^*\mu$ method:

A pure sample of *b*-jets can be selected by reconstructing the semi-leptonic decay of *b*-hadrons to $D^*\mu$ final states:

$b \to X \mu D^{*+} \to X \mu D^0 (\to K^- \pi^+) \pi^+$

→ high *b*-jet purity (~93%)

→ direct access to *b*-tagging efficiency



The reconstructed mass difference $m(D^*)$-$m(D^0)$.

2 methods based on top-quark pair events

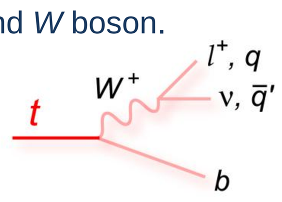
The *tag counting* method:

The top quark decays in ~99% of the cases into a *b*-quark and *W* boson.

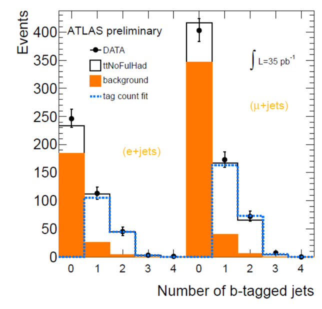
→*tt* events → enriched *b*-jets data sample

→count the number of events with 0,1,2 or 3 *b*-tagged jets

→measure the *b*-tagging efficiency using a likelihood fit

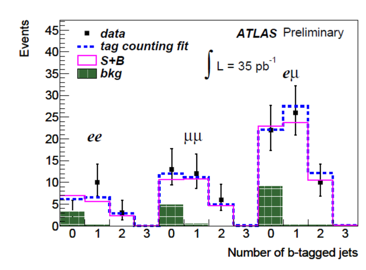


The fitted *b*-tagged jet multiplicity



lepton+jets channel

di-leptonic channel



The kinematic selection method:

→at least one jet in the event *b*-tagged with the SV0 algorithm.

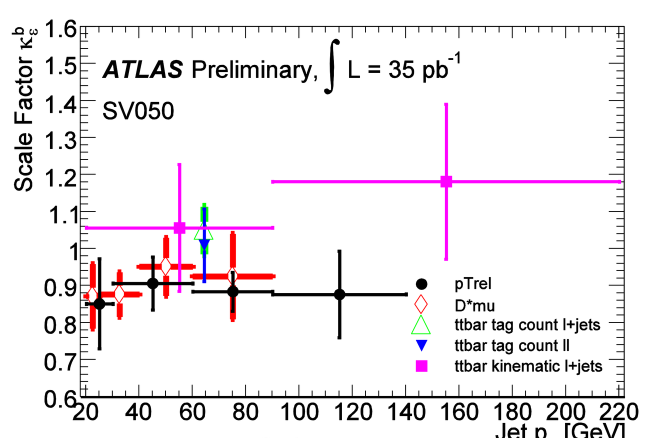
→two samples are formed:

→ ***L234 and L1*** : *different* jet is required to be *b*-tagged in each sample

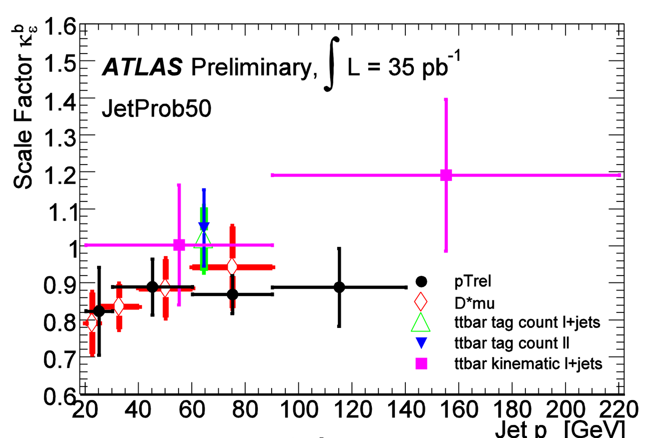
→the two samples are combined for the *b*-tagging efficiency measurement.

Category	L234 sample		L1 sample	
	e+jets	μ+jets	e+jets	μ+jets
W+jets	8.1	19.1	7.2	15.1
Z+jets	0.6	1.2	0.7	1.3
single top	4.2	5.8	3.8	5.4
$t\bar{t}$	70.6	100.7	65.0	91.9
QCD	12.1	8.8	11.7	7.7
MC total & QCD	95.5	135.7	88.4	121.4
data	87	137	96	126

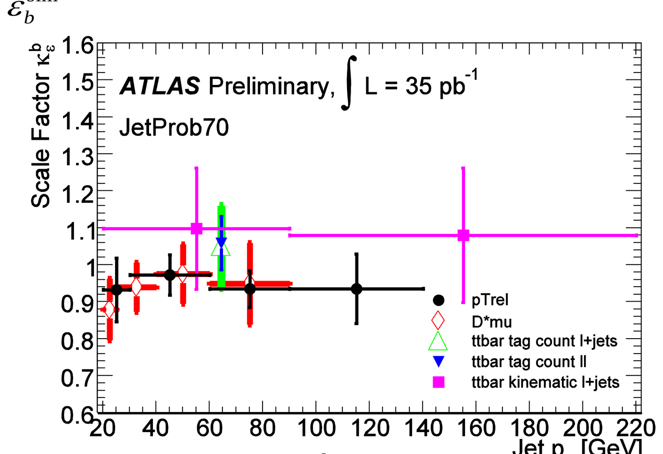
The measurements of the *b*-tagging efficiency are provided in terms of scale factors that correct the *b*-tagging performance in simulation to what is observed in data. All four methods described above have compatible results! $\kappa_{\epsilon_b}^{\text{data/sim}} = \epsilon_b^{\text{data}} / \epsilon_b^{\text{sim}}$



$\epsilon_b^{\text{SV0}} = 50\%$



$\epsilon_b^{\text{JetProb}} = 50\%$



$\epsilon_b^{\text{JetProb}} = 70\%$

Measurement of the mistag rate

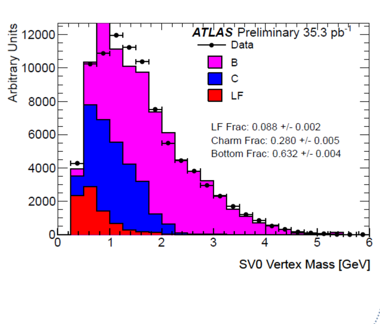
The mistag rate is the rate by which light-flavour jets are identified as *b*-jets by a b-tagging algorithm.

The *SV0 mass fits* method:

→discriminating variable : the invariant mass of the tracks associated to the reconstructed SV

→get the sample composition before and after applying the *b*-tagging using the *b*- and *c*-tagging efficiencies

$$\epsilon_l = \frac{N_l^{tag}}{N_l} = \frac{N_l^{tag}}{N_{\text{data}} - \frac{N_b^{tag}}{\epsilon_b} - \frac{N_c^{tag}}{\epsilon_c}}$$

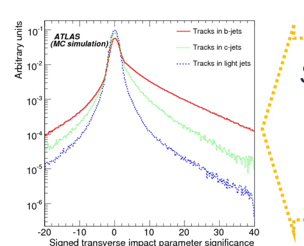


The *negative tag* method:

→finite resolution of the ID

→S_{d_0} and $L/\sigma(L)$ are expected to be symmetric around 0 for light-jets

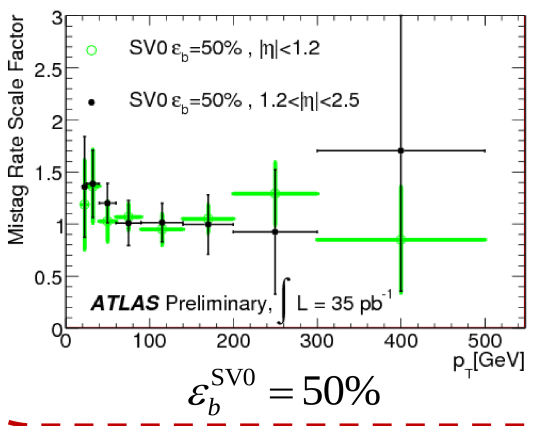
With proper corrections for the long-lived particle component of the mistag rate using simulation



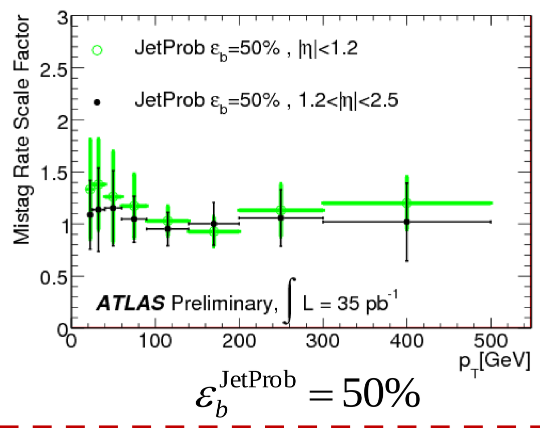
S_{d_0} for different jet flavours in simulated events

→determine the light-flavour mistag probability using the negative part of S_{d_0} or $L/\sigma(L)$.

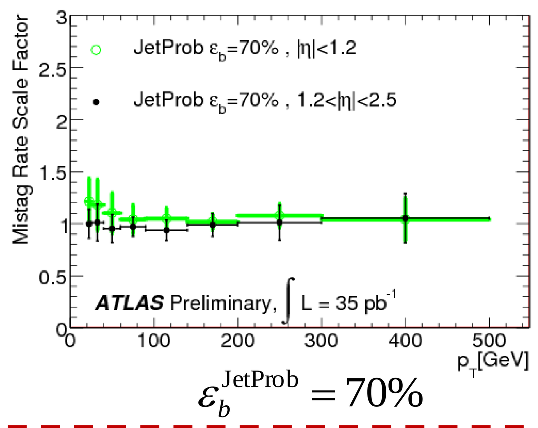
The combined results for scale factors the two methods are presented in the plots below for SV0 and JetProb.



$\epsilon_b^{\text{SV0}} = 50\%$



$\epsilon_b^{\text{JetProb}} = 50\%$

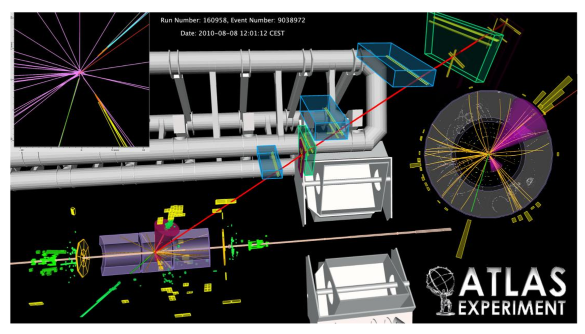


$\epsilon_b^{\text{JetProb}} = 70\%$

ATLAS event display with 2 *b*-tagged jets

Event display of a top pair di-lepton candidate with two *b*-tagged jets

The two *b*-tagged jets are shown by the purple cones.



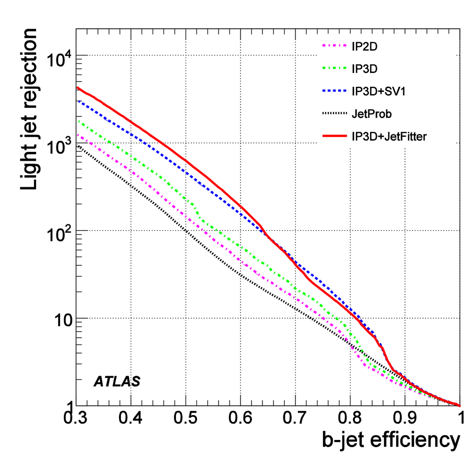
The secondary vertices are indicated by the orange ellipses.

Advanced *b*-tagging algorithms

Much better *b*-tagging performance can be achieved by more sophisticated algorithms!

→currently under commissioning.

→ expected to be calibrated very soon for future physics analyses which will improve ATLAS physics discovery potential!



ATLAS has an excellent *b*-tagging performance which has been measured in data as input to physics analyses. Rejection of *light*-jets (for same *b*-tagging efficiency) is expected to increase by up to a factor of ~6 with the use of the advanced taggers, which will improve greatly ATLAS physics reach!

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Nancy Tannoury, on behalf of the ATLAS Collaboration