Latest and greatest of flavour tagging

Janik von Ahnen

Krisztian Peters, Marco Rimoldi, Chris Pollard
Loic Valery, Jonathan Burr

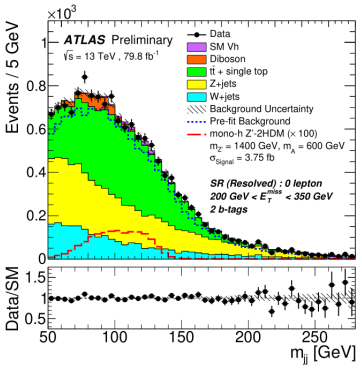
November 28, 2019

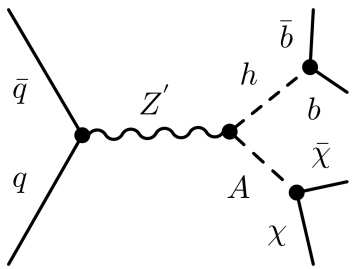
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

ATLAS
EXPERIMENT

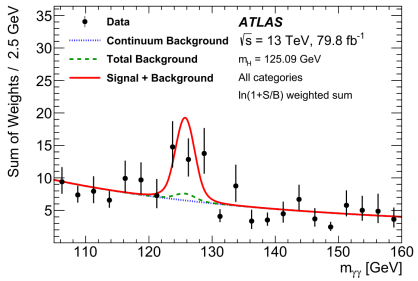
Why are *b*-jets interesting?

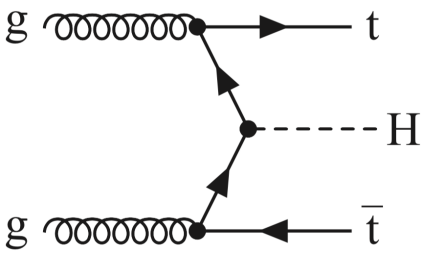
Hbb+MET



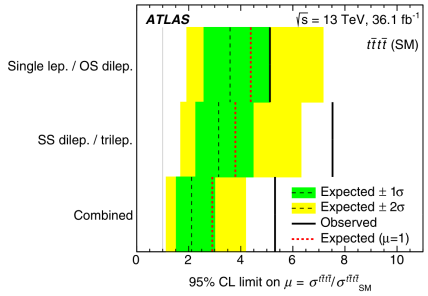


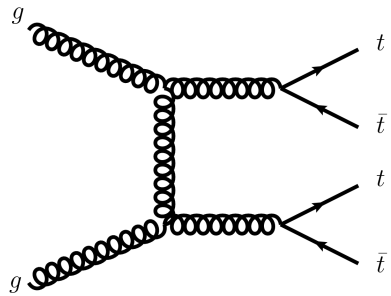
ttH



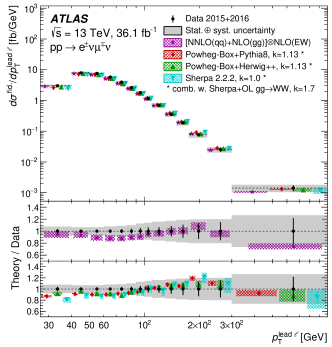


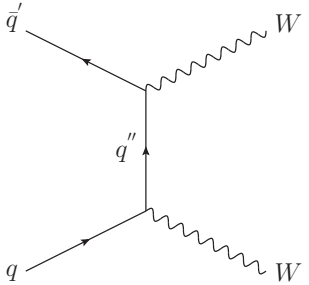
4 tops





WW

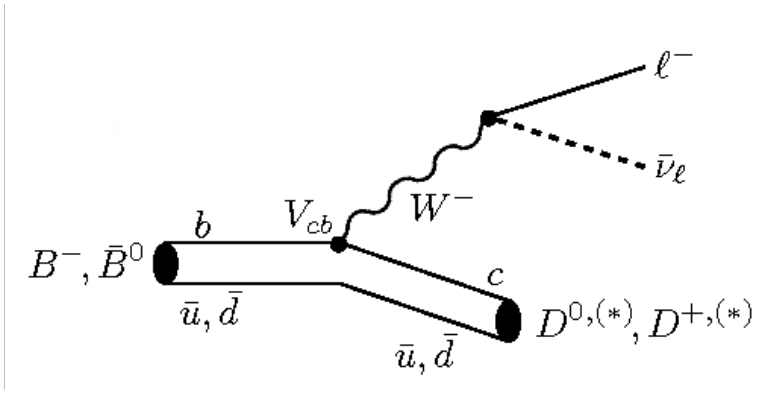


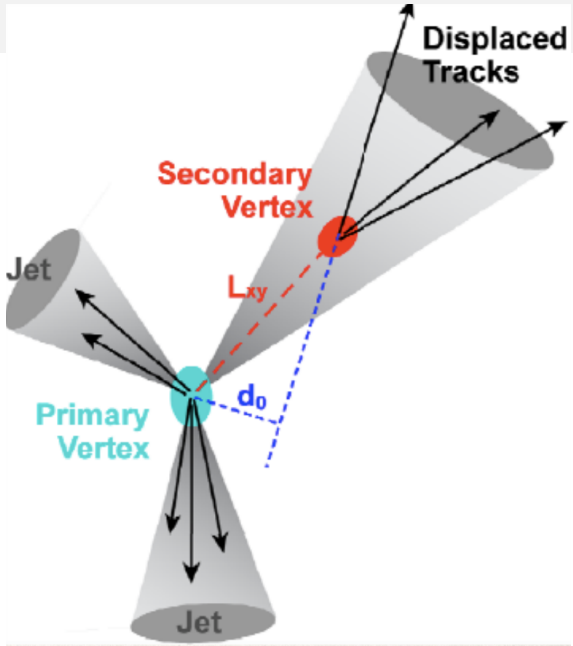


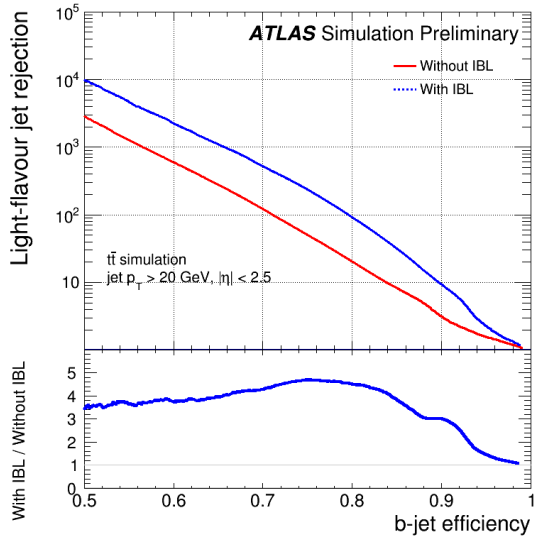
What are *b*-jets?

Key properties:

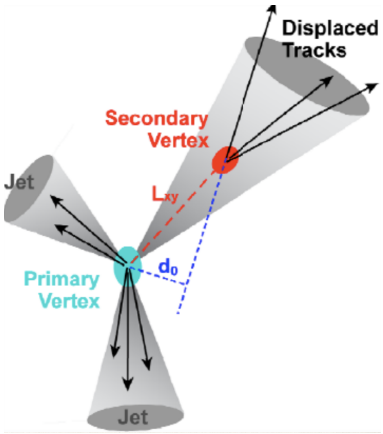
- Significant *b*-hadron lifetime (∼1.5 ps)
  $\Longrightarrow$ secondary vertex
- Significant *b*-hadron mass
- Can contain leptons
- Contains ∼80 % of the intial *b*-hadron energy

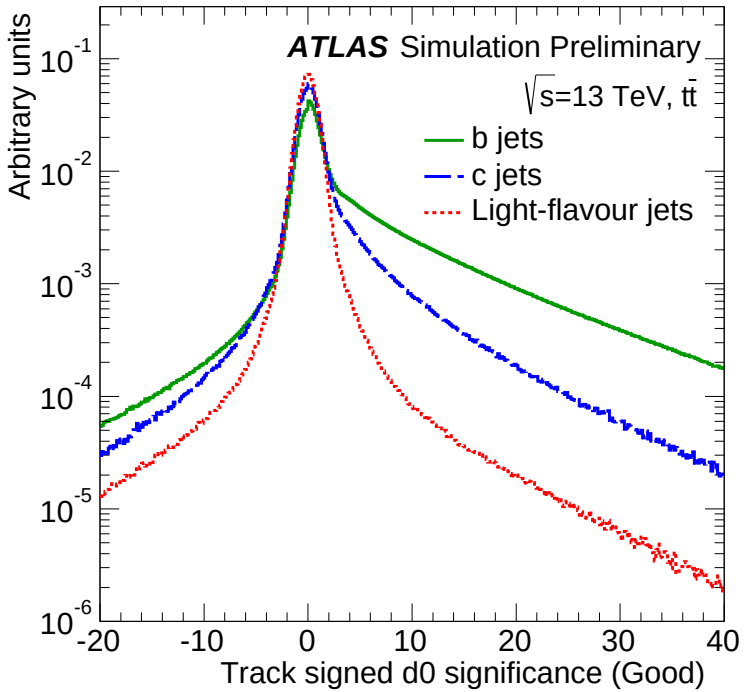




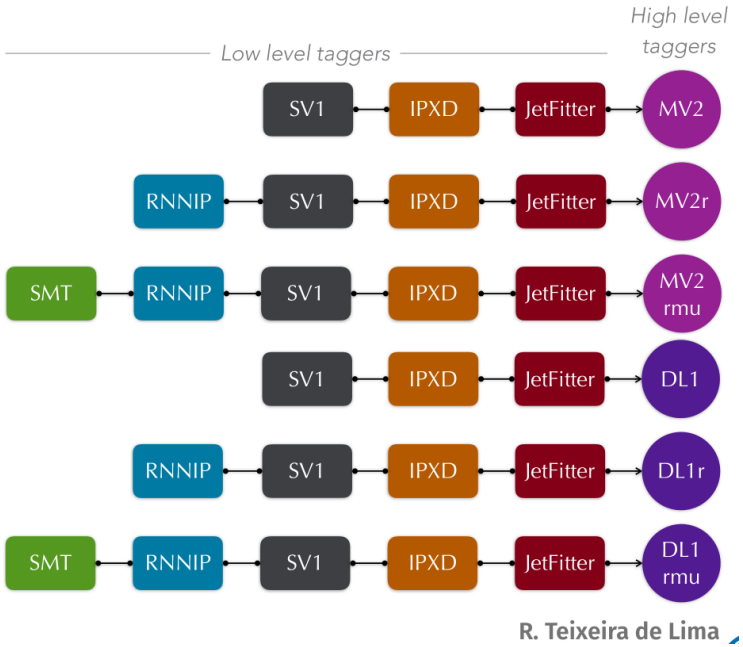


b-jet identification algorithms





- MV2: Based on BDT
- DL1: Feed-forward Neural Network

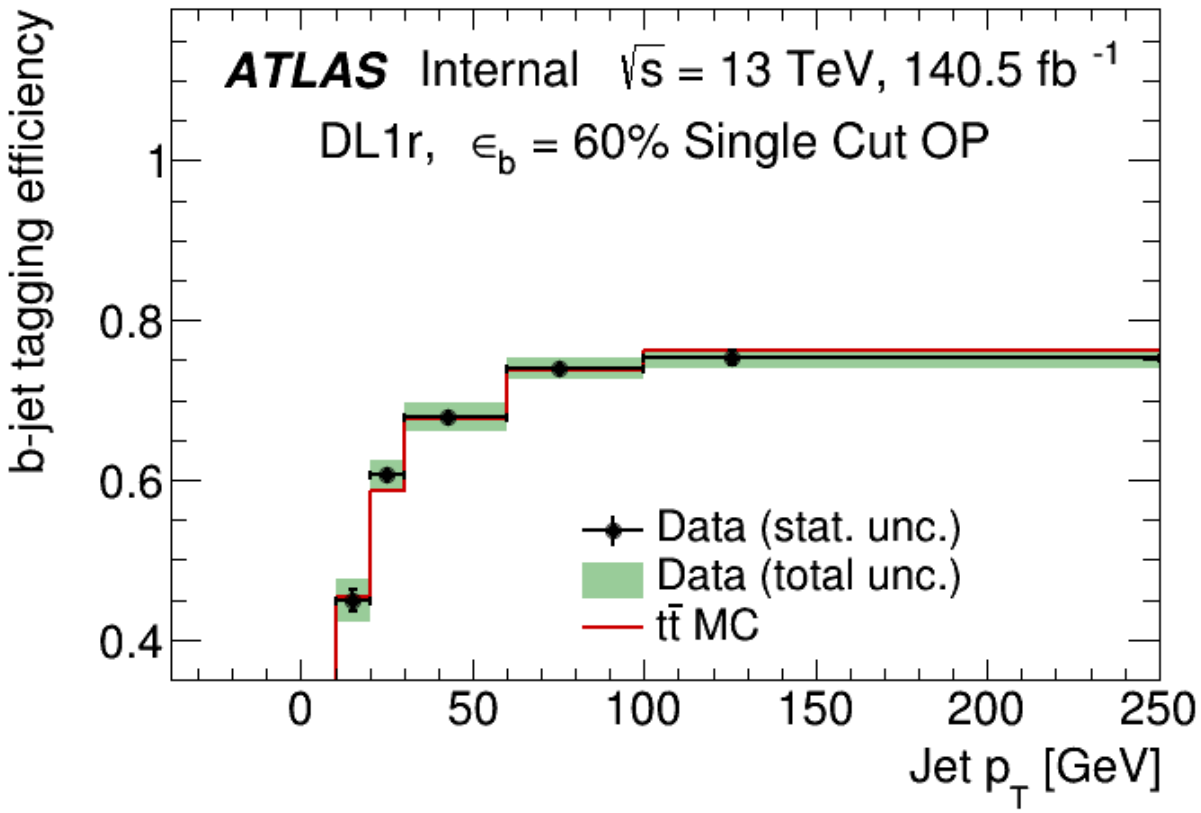


Calibration of *b*-tagging algorithms

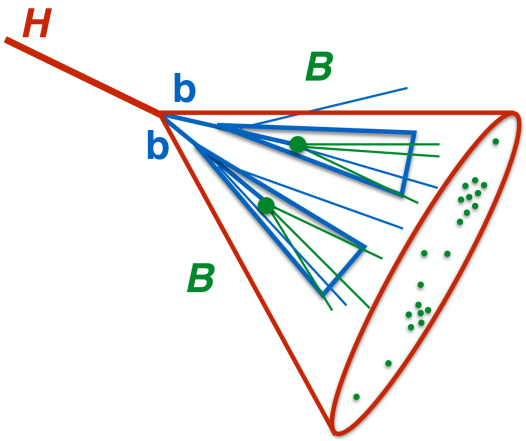
- MC modeling is not perfect
- *b*-taggers make heavy use of correlations
- Measure *b*-tagging efficiency in data

Scale Factor (SF):

$$SF = \frac{\epsilon_{data}}{\epsilon_{MC}}$$



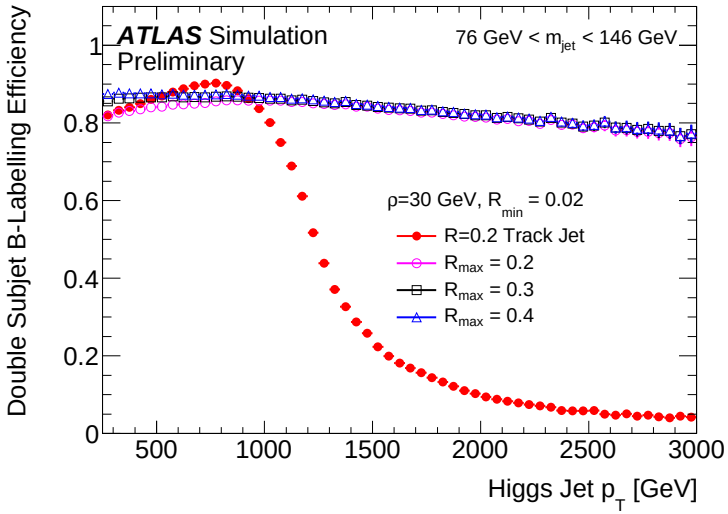
What are variable-R track jets?

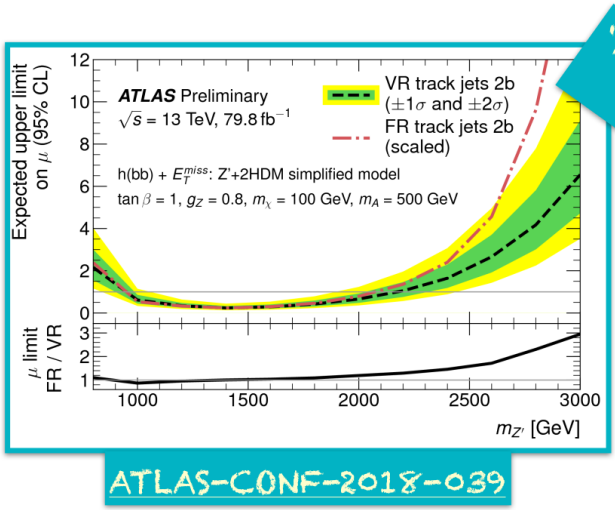


- Clustering tracks of the inner detector with anti-k_t

$$R \to R_{eff}(p_T) = \frac{\rho}{p_T}$$

- $\rho = 30\text{GeV}, R_{min} = 0.02, R_{max} = 0.4$

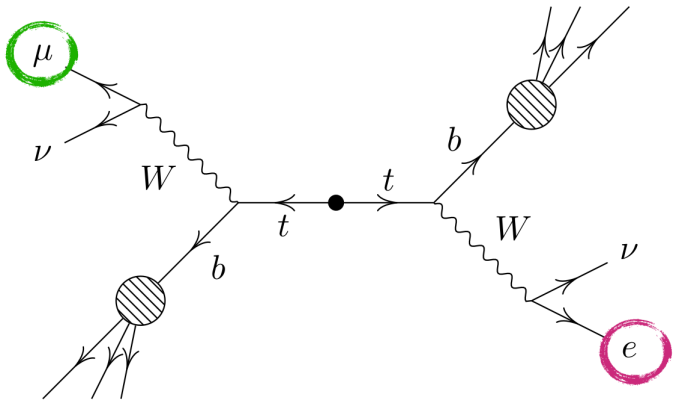


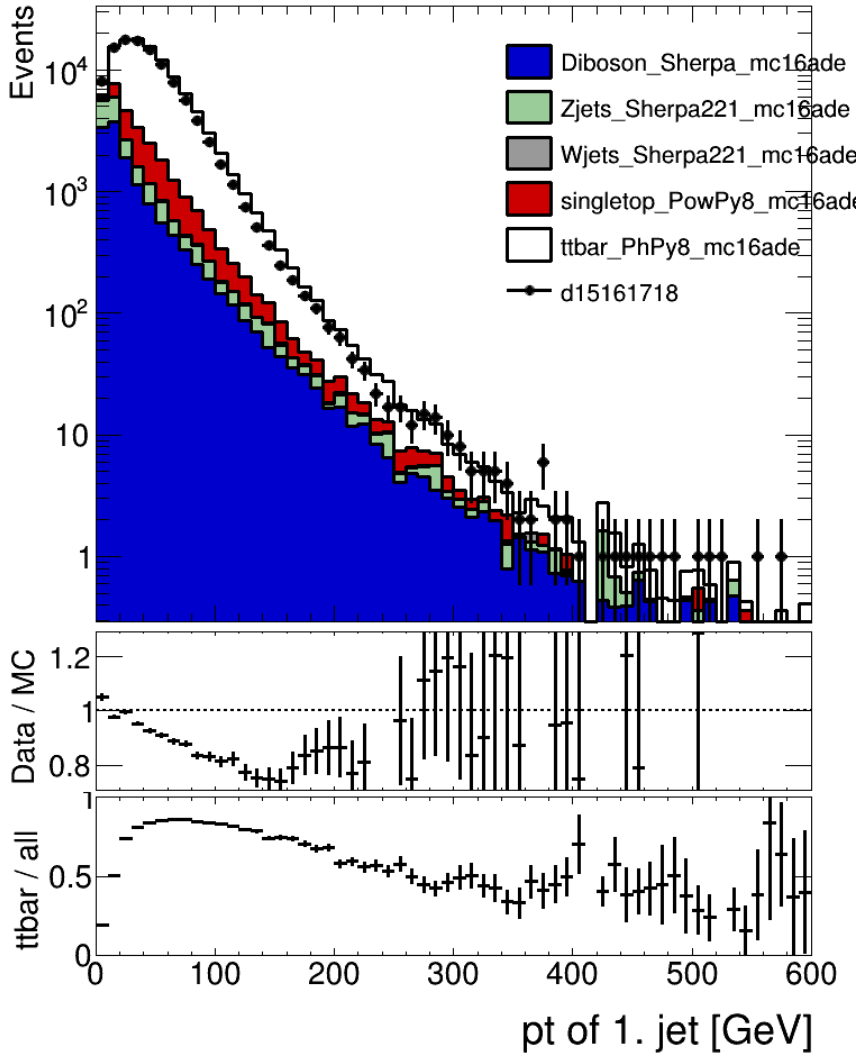


*Also interesting for low p_T since EMTopo jets can only be reconstructed down to ∼20 GeV

b-tagging efficiency calibration for VR-track jets

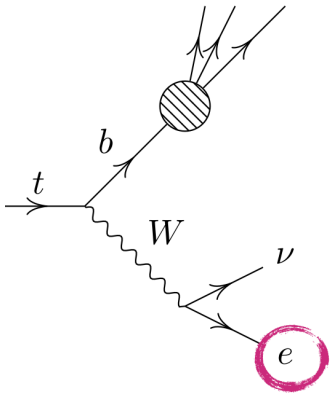
- Goal: Select a sample with high fraction of b-jets without applying b-tagging (avoid bias)
- $\Longrightarrow$ di-leptonic (e-mu) $t\bar{t}$



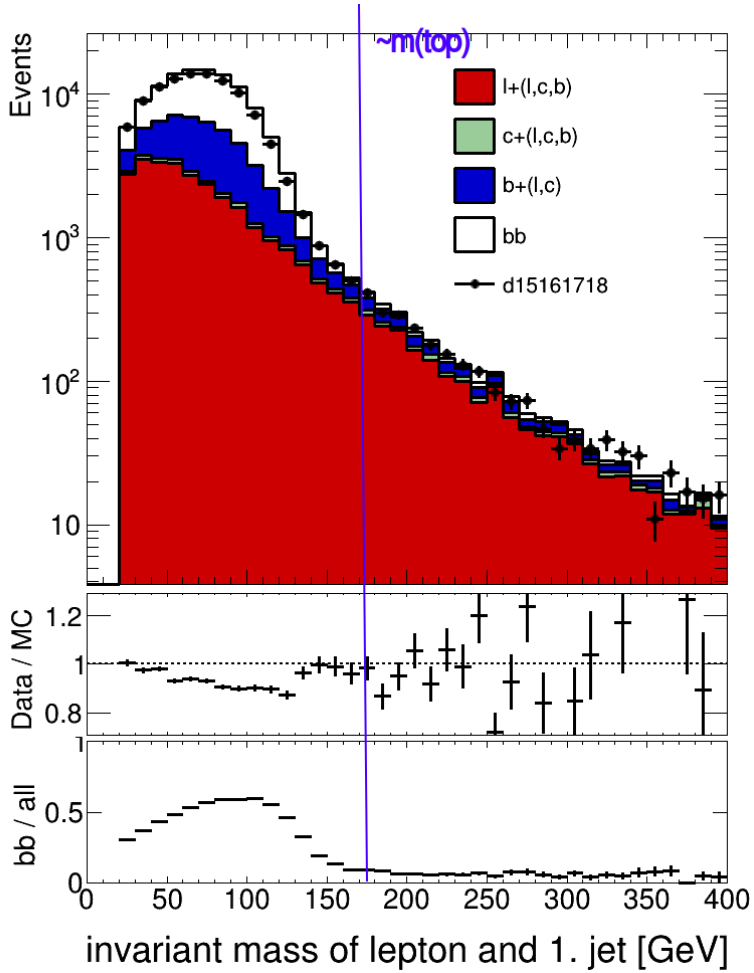


New sideband-fit method

- Uncertainy on background (i.e. non b-jets) is large
  $\Longrightarrow$ Use SR/CRs based on $m_{j,l}$



- The fit extracts the b-tagging efficiency in data

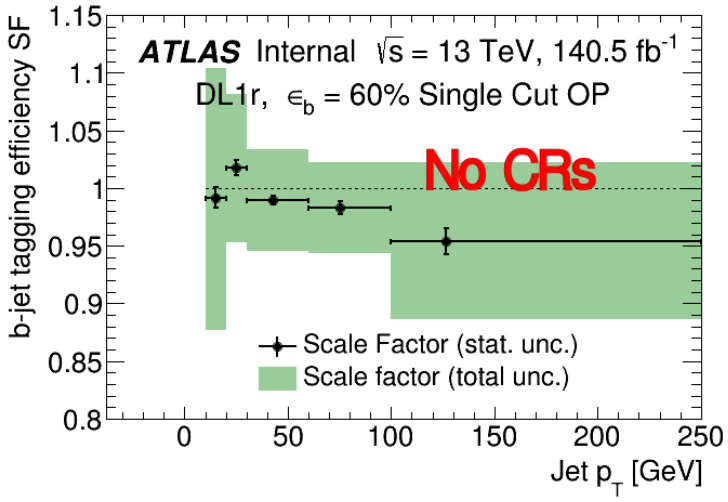


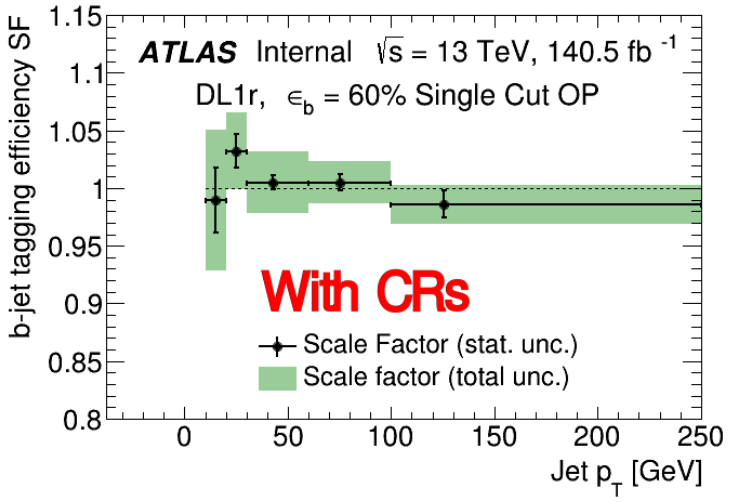
New sideband-fit method

- Statistical uncertainty increases in the sideband-fit due to addition of CRs

SFs with modeling uncertainties (i.e. flavour composition uncertainty):

$$SF = \frac{\epsilon_{data}}{\epsilon_{MC}}$$



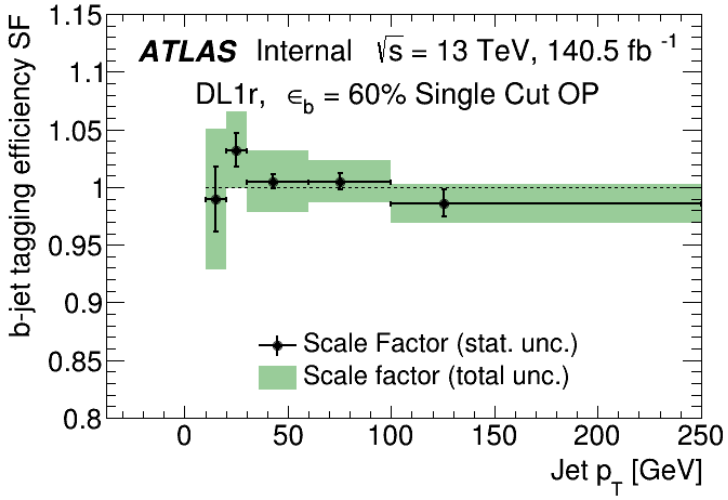


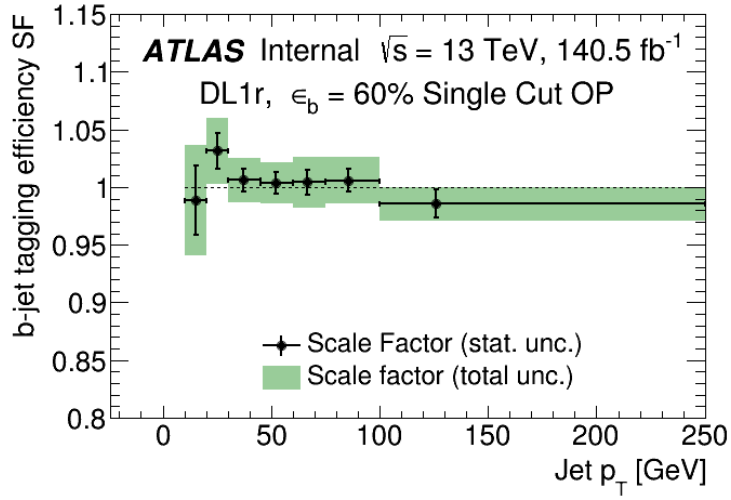
New fit method reduces the modeling uncertainty by a factor ∼2!

More data $\Longrightarrow$ More bins

Last binning was used for 80 fb^{-1} but now we have 140 fb^{-1}

$\Longrightarrow$ We can use a finer binning (N_{bins} : 5 $\rightarrow$ 7)



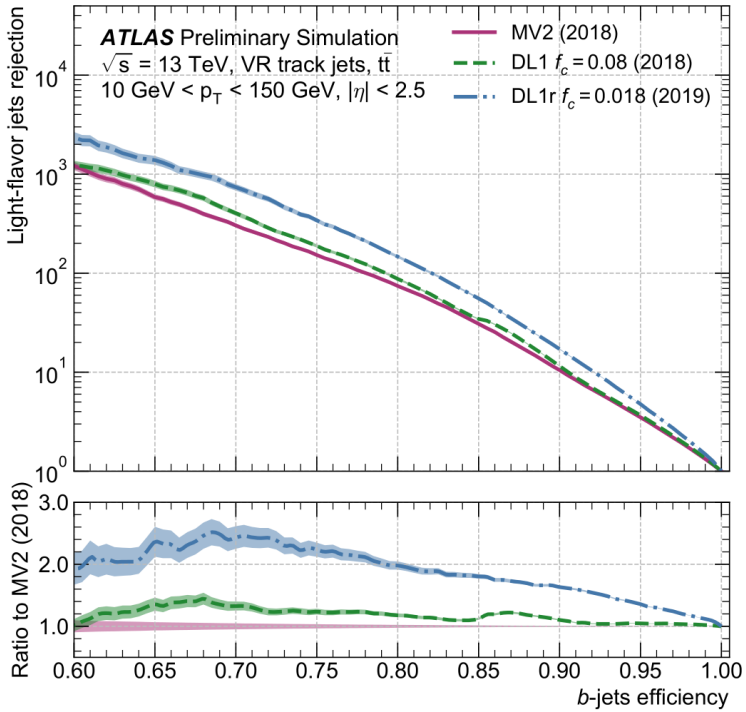


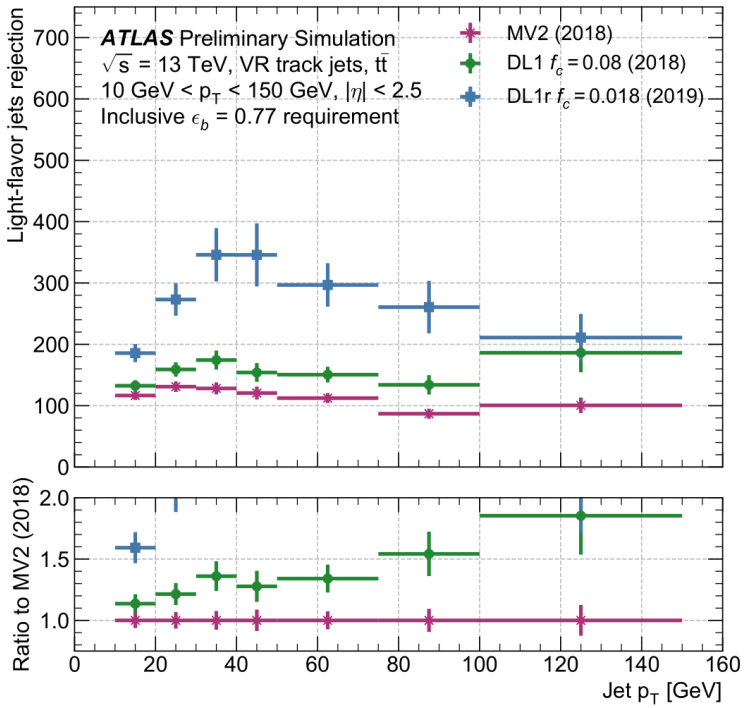
More bins reduce the total uncertainty!

- ~2% uncertainty on SFs $\Longrightarrow$ precision measurement!

Retraining campaign

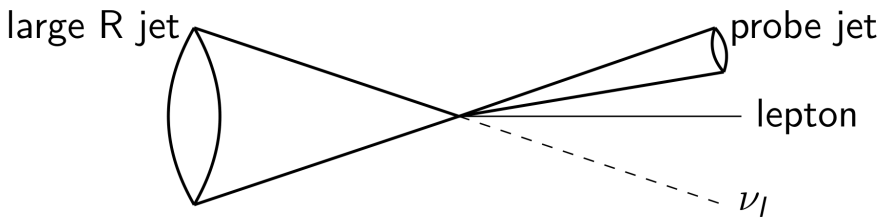
The *b*-tagging algorithms have been improved and retrained for the VR-track jets (previous: MV2, future: DL1r)





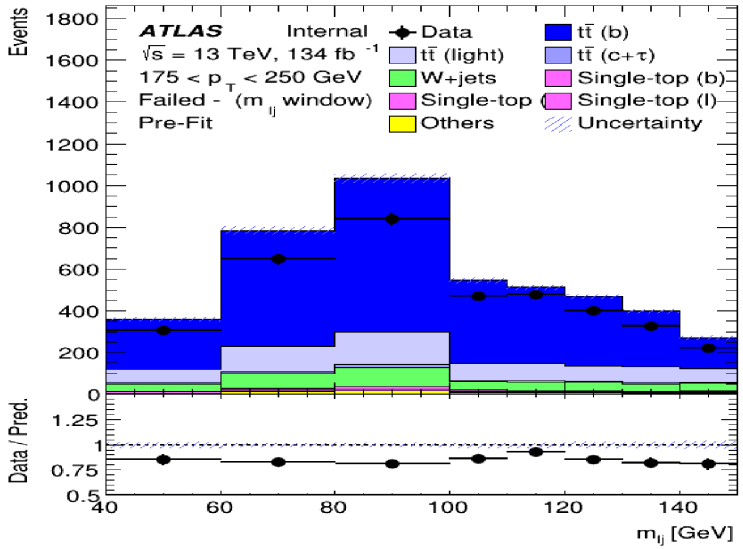
Significant improvement for all *b*-tag efficiencies!

High-p_T b-jet calibration (Loic Valery + students)

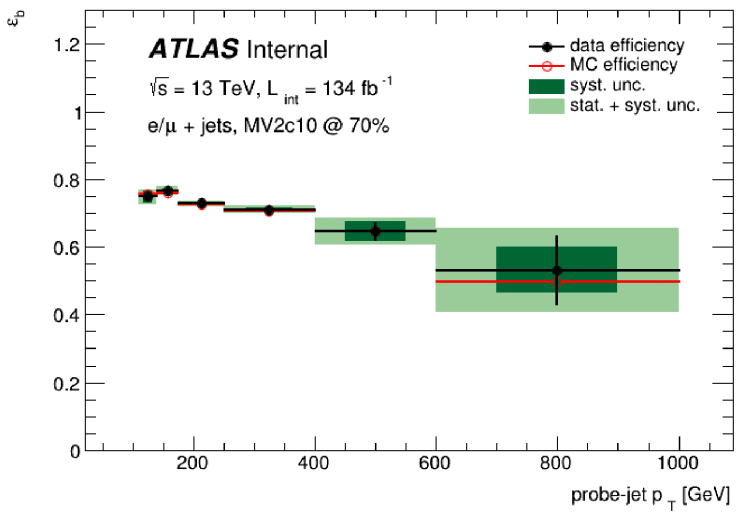


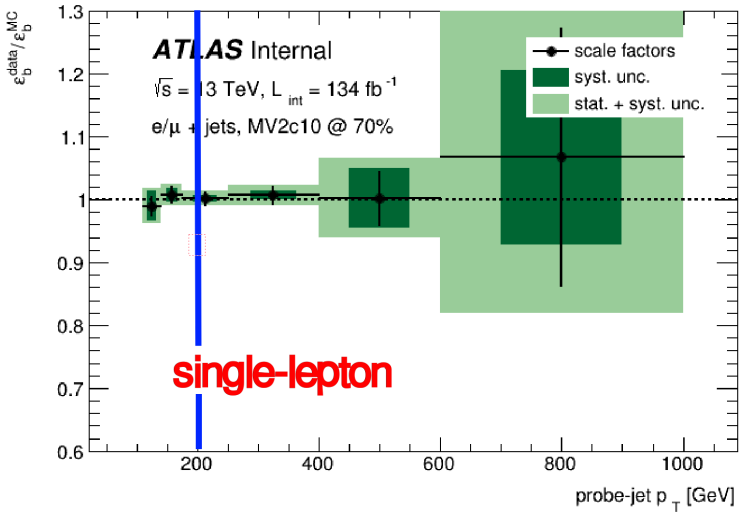
- Calibration using di-leptonic $t\bar{t}$ is limited by statistics at high p_T

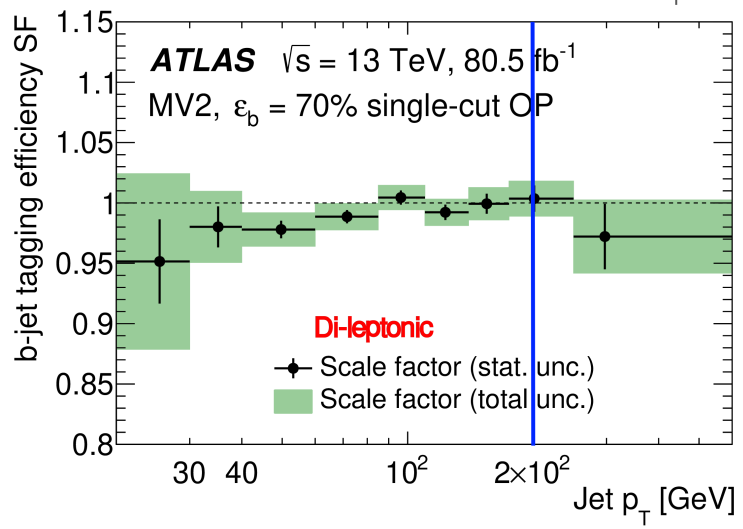
- Single-lepton $t\bar{t}$ events have a higher branching ratio



High-p_T b-jet calibration (Loic Valery + students)





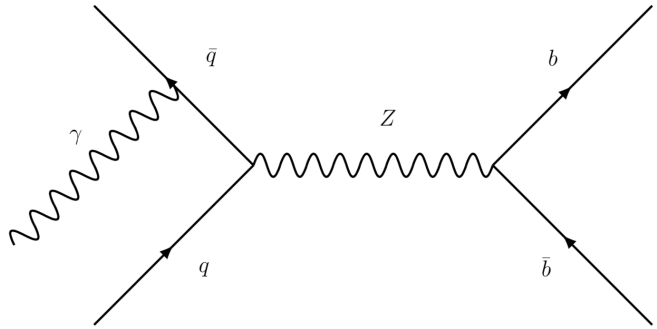


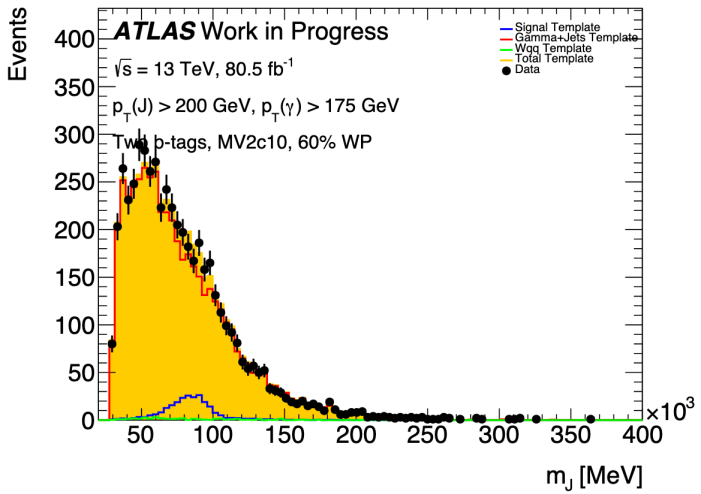
- Good data/MC agreement
- Uncertainties can be competitive to those derived in di-leptonic $t\bar{t}$
  $\Longrightarrow$ These could be combined in the future

Calibration can reach very high p_T!

Z+γ (Jonathan Burr + students)

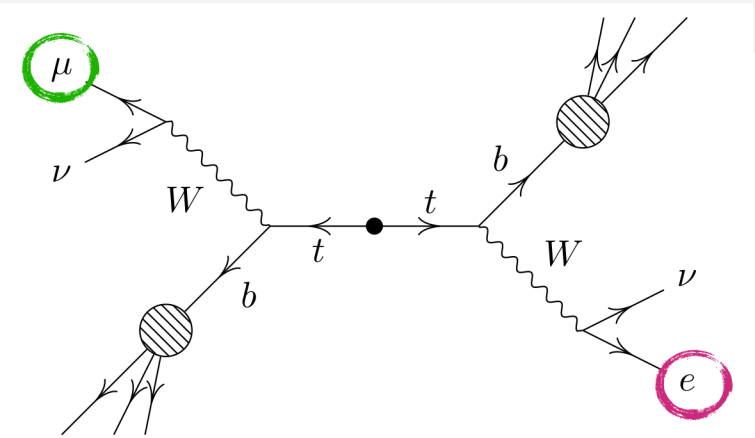
- **Motivation**: Many analysis rely on identifying Higgs bosons (also X$\to b\bar{b}$)
- **Target**: measure tagging efficiency of Z$\to b\bar{b}$
- Z$\to b\bar{b}$ is very similar to H$\to b\bar{b}$ but has a much higher cross section
- Use Z($\to b\bar{b}$)γ events to calibrate a true double b-tagger (expected uncertainty $\sim$20 %)
- **Status**: Fitting strategy being developed using MC-based templates



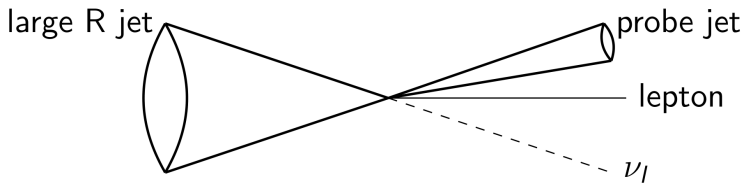


Summary

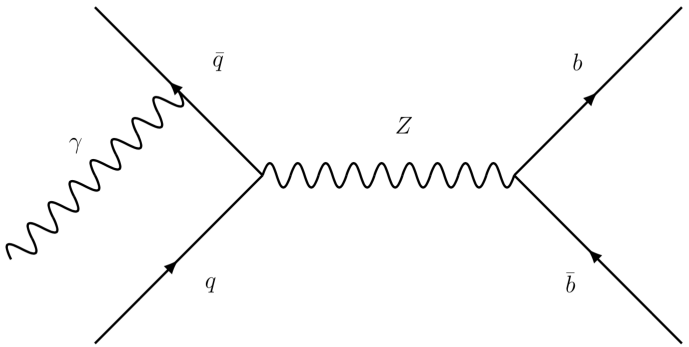
- b-tagging efficiency calibration for VR track jets using di-leptonic $t\bar{t}$ events



- High-p_T calibration with tag & probe in semi-leptonic $t\bar{t}$

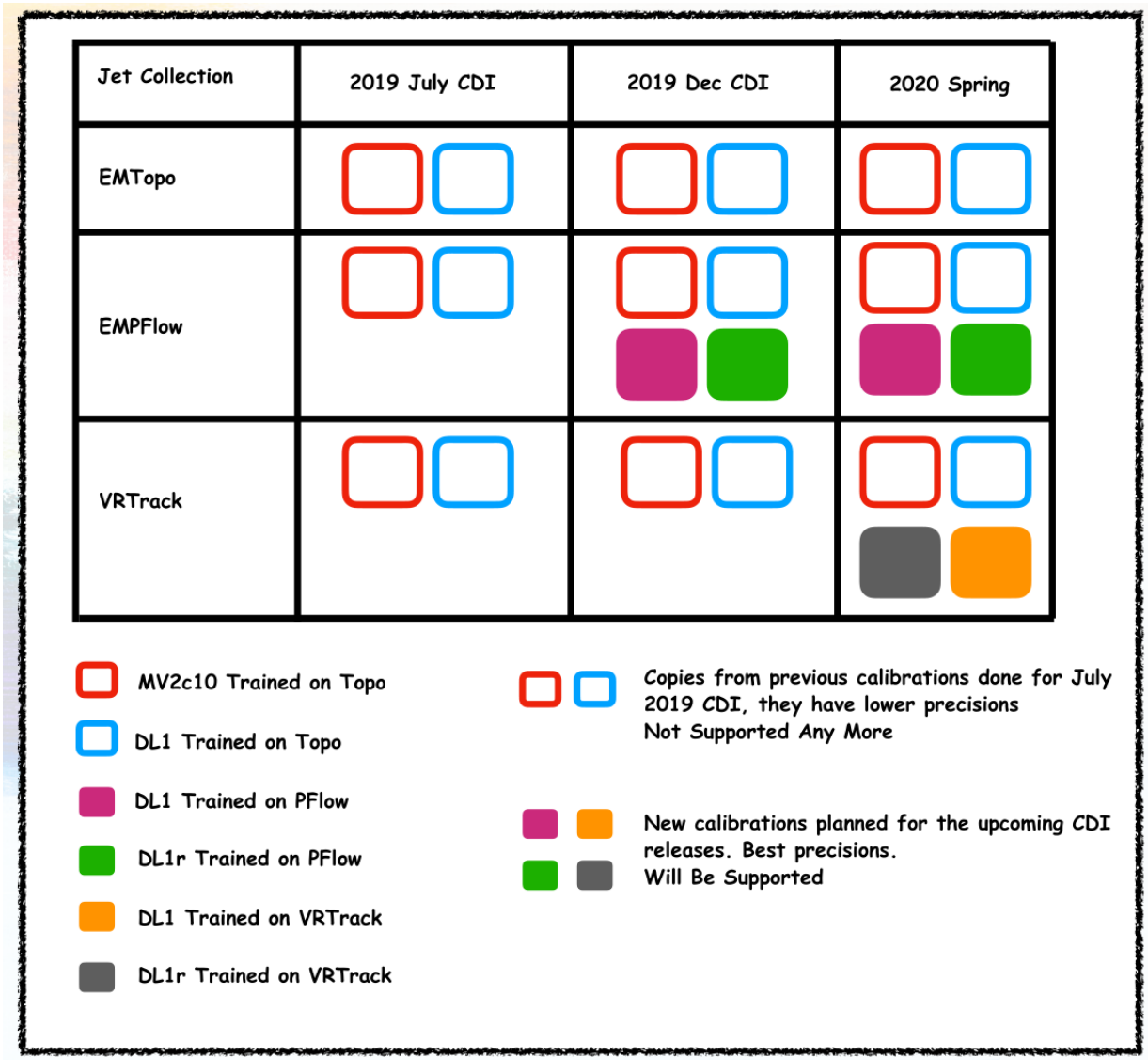


- Double b-tagging calibration for boosted environments with Z+γ



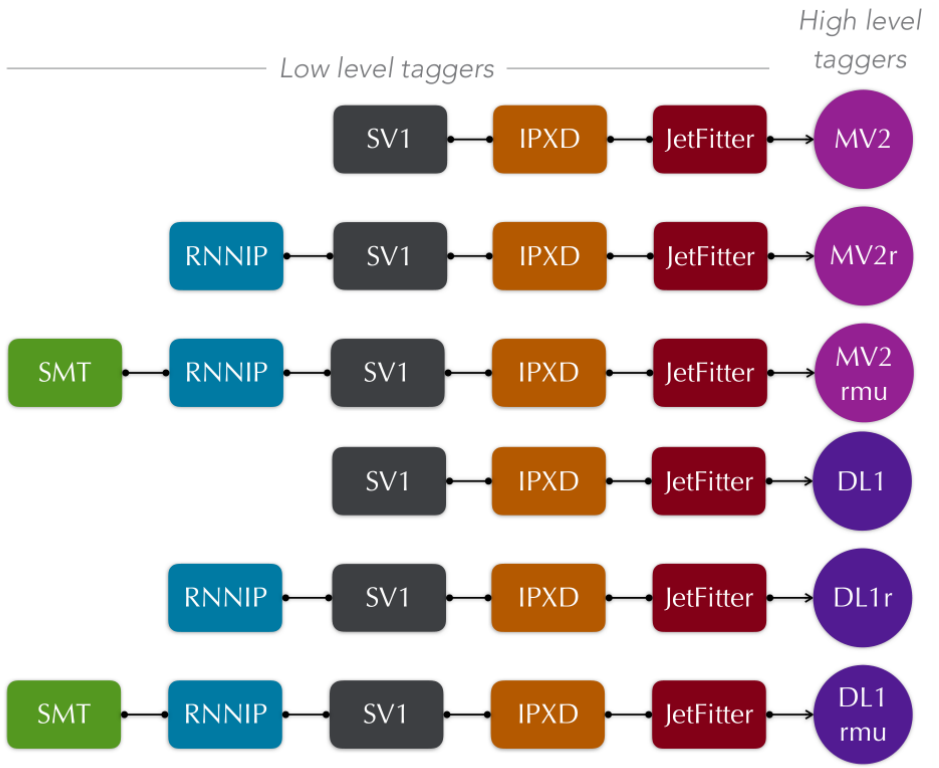
Backup

Retraining campaign



More on retraining campaig

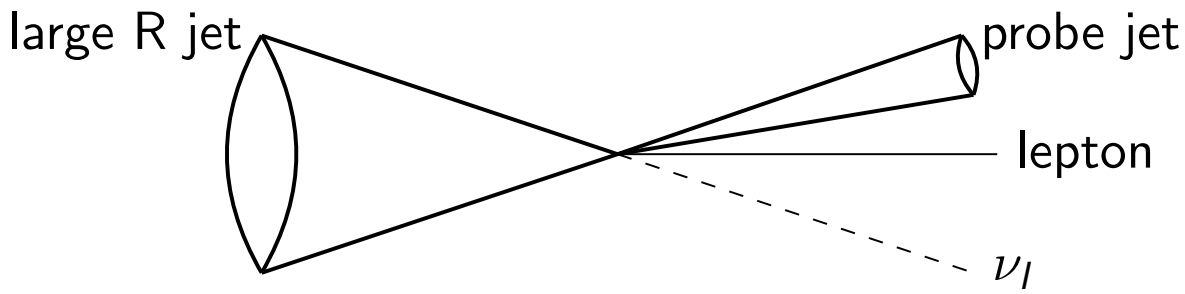
- Particle Flow jets:
  - SMT, RNNIP, MV2 and DL1 are being retrained
- Variable Radius track jets
  - RNNIP, MV2 and DL1 are being retrained
- Only machine learning-based taggers are retrained
- All trainings performed on (extended) hybrid samples



R. Teixeira de Lima

Event selection

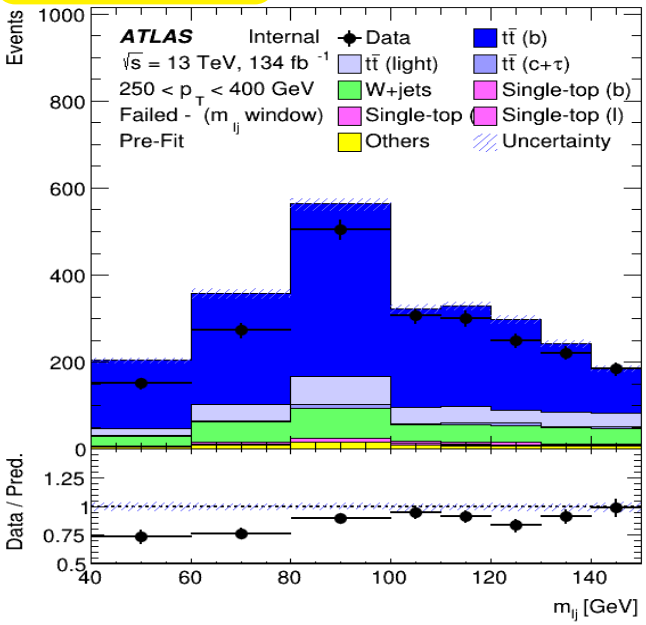
- Boosted topology
  - Large R Jet $p_T > 300\,\text{GeV}$
  - Large R jet mass $> 100\,\text{GeV}$
  - Lepton $p_T > 70$ GeV
  - MET $> 70\,\text{GeV}$
  - $|\Delta\phi(t_{\text{had}}, t_{\text{lep}})| > 1$
  - At least one of the small R Jets matched to the large R Jet has to be b-tagged at 77% WP
- Probe jet: the jet closest to the lepton



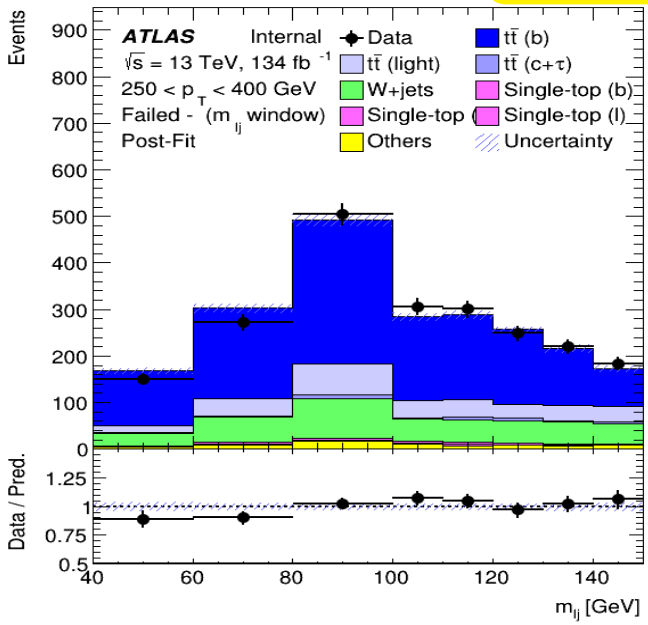
Fit Strategy

- Fit on m_{lj} or $m_{large-Rjet}$ spectrum for each p_T bin for events that pass/fail b-tagging requirement on the probe jet, done with ▸ TRExFitter
- b-tagging efficiency, signal normalisation and background normalisation are left as free parameters

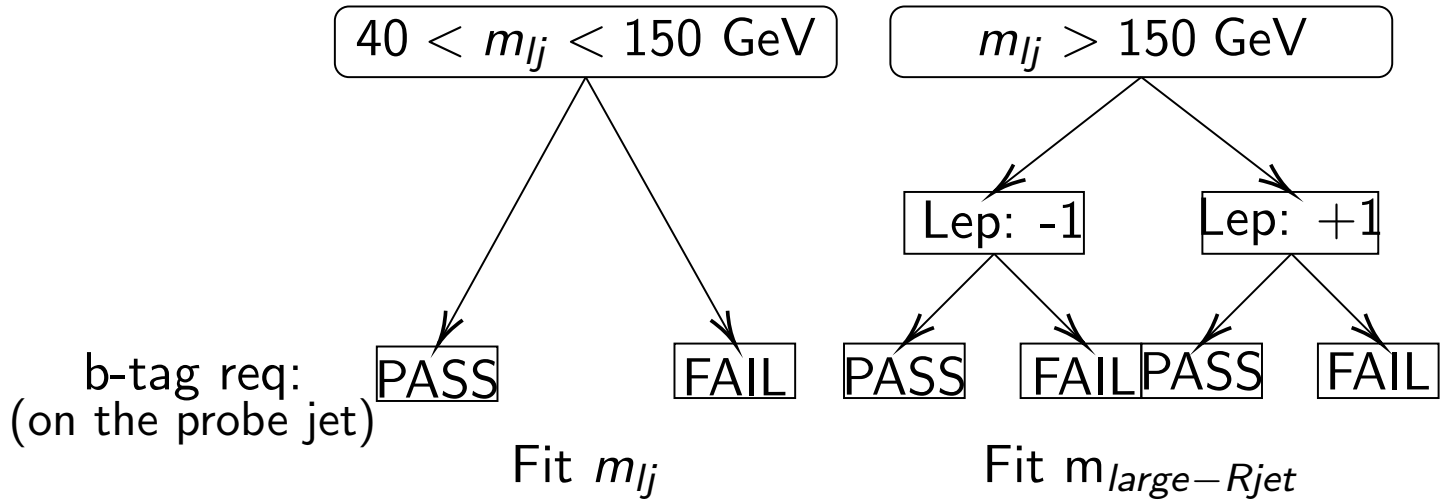
Pre-fit, 70%

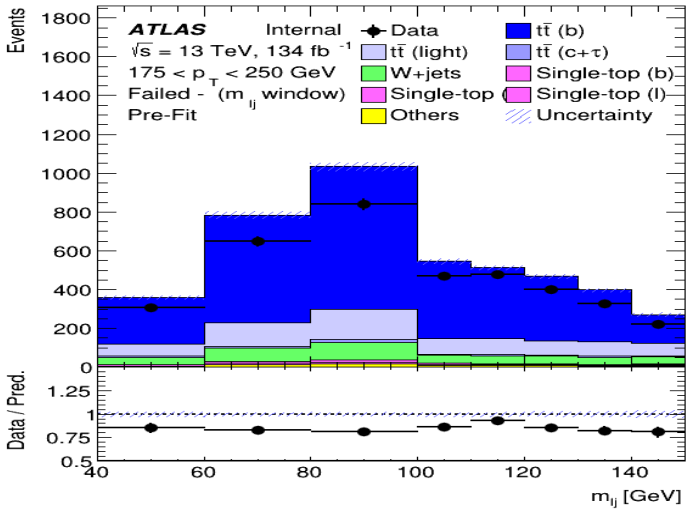


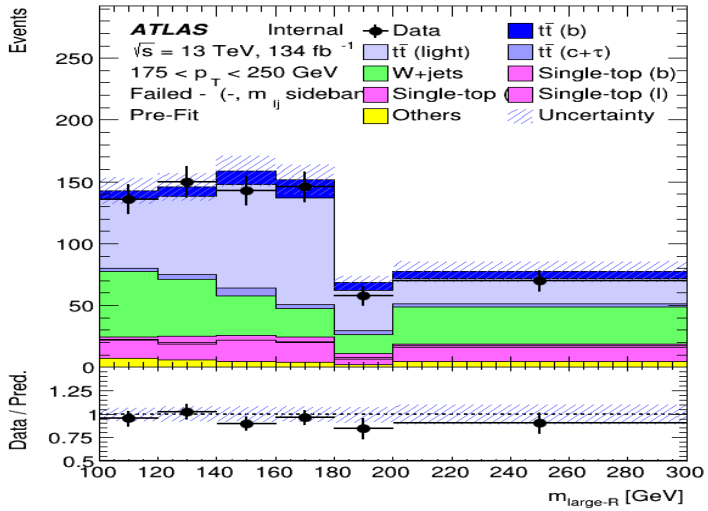
Post-fit, 70%



Fit Strategy - Regions Definition



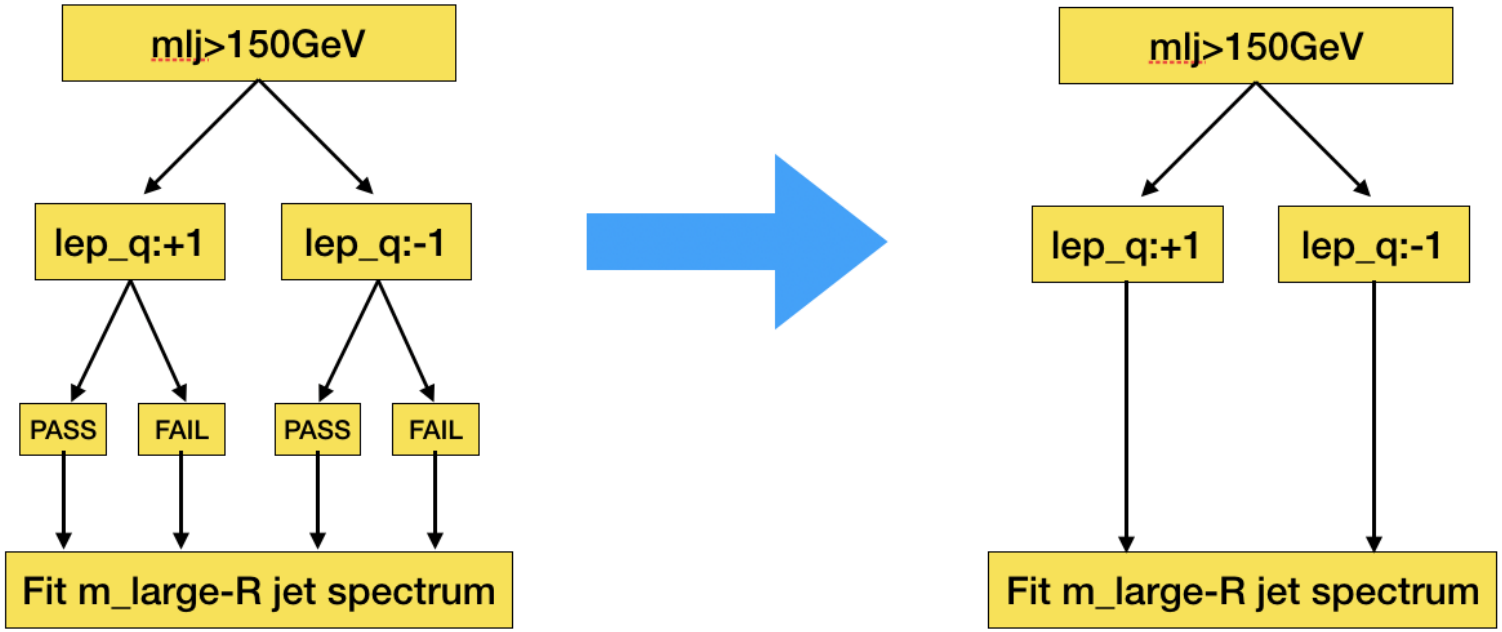




Fit Strategy - Fit Parameter

- b-tagging efficiency
  - Efficiency in "PASS" region
  - Inefficiency in "FAIL" region
- Free floating parameter
  - $t\bar{t}(b)$: signal
  - $t\bar{t}(c/l)$: for the probe jets coming from radiation
  - W+jets: different process
- Constrained parameter
  - Single-top
  - Other backgrounds
  - Gaussian constraint (50%)

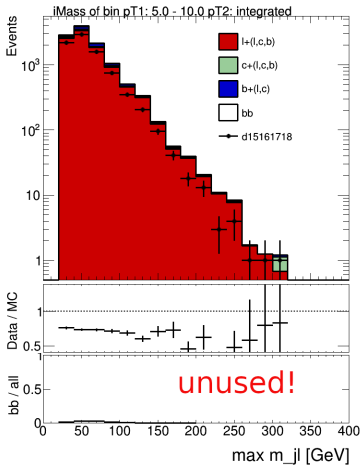
Region Merging



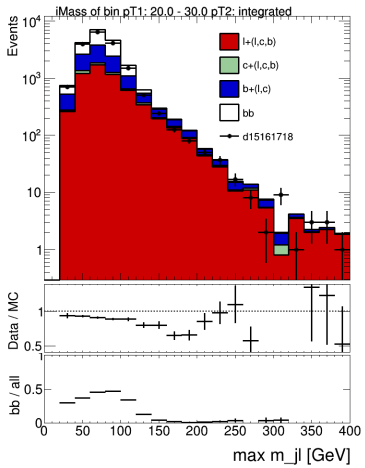
- Increase the number of events in $m_{large-R\ jet}$ by:
  - Merging the PASS/FAIL regions
    - Should not affect the efficiency due to the low signal
    - Could help to better discriminate the background against the signal
    - Merged regions are background enriched

mlj-max distributions

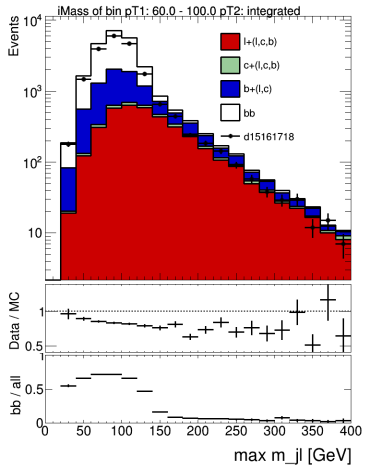
5-10 GeV



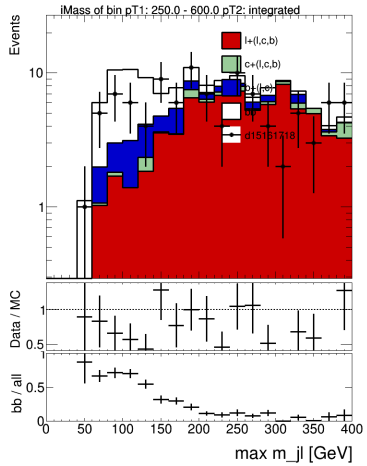
20-30 GeV



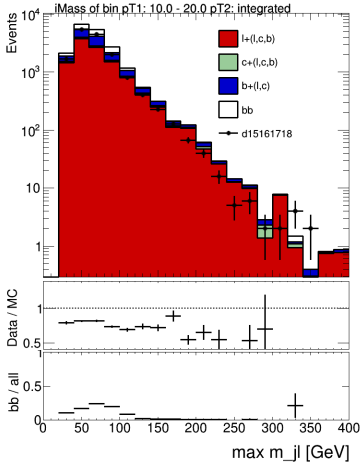
60-100 GeV



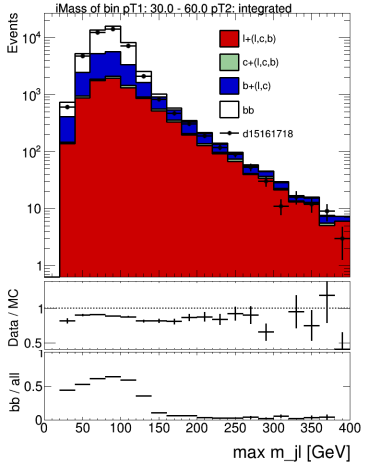
250-600 GeV



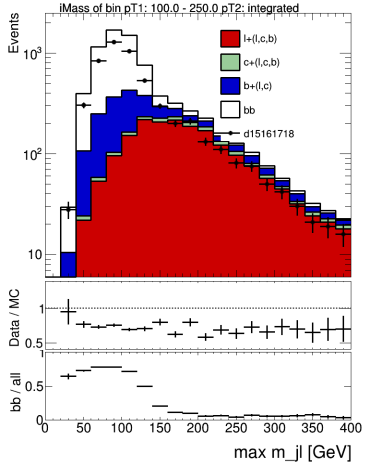
10-20 GeV



30-60 GeV

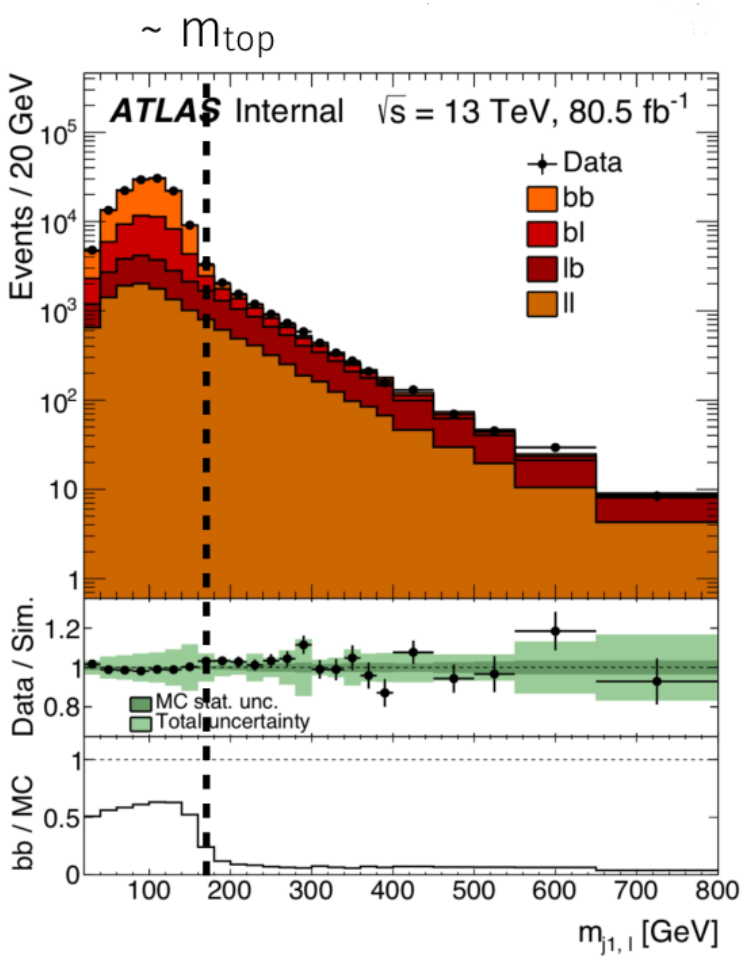


100-250 GeV

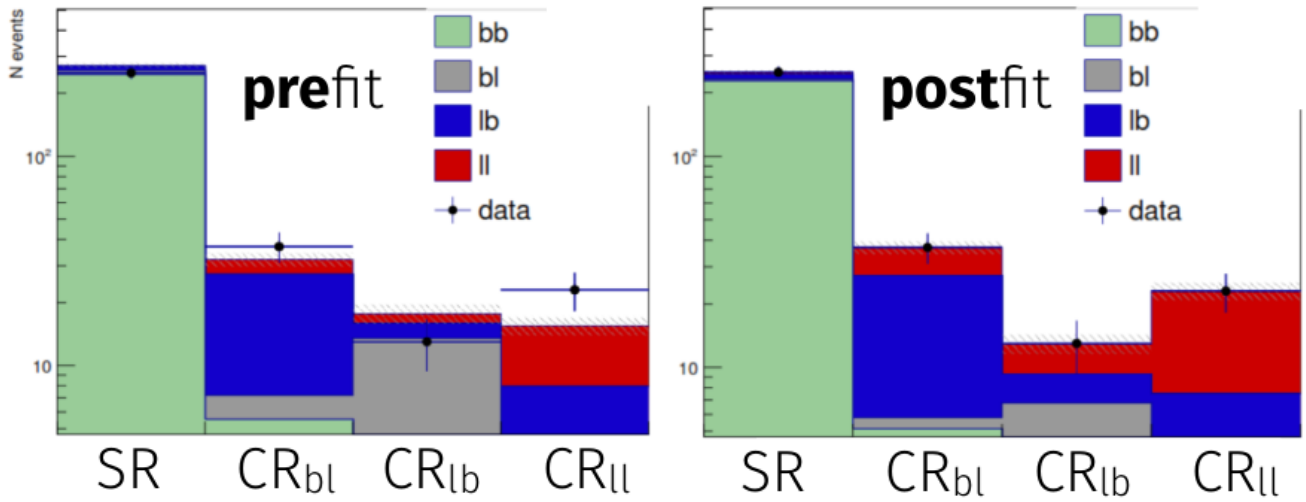


Previous *b*-jet efficiency calibration (mlj cut fit)

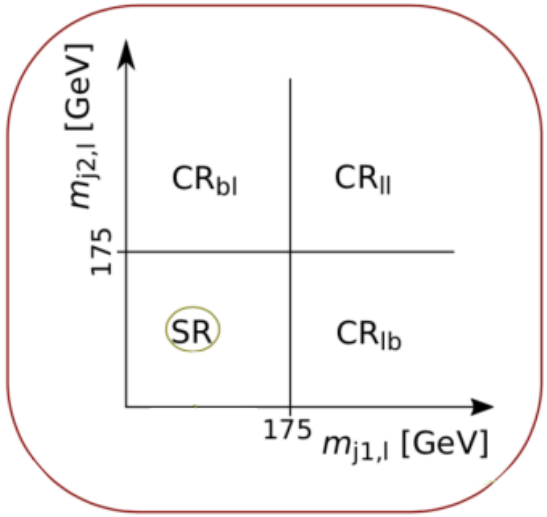
- *b*-tagging efficiency is determined by perfomring a combinatorial likelihood fit.
- The likelihood function is the product of per event based likelihood functions.
- The relative fractions of flavours (bb, bl, ll) are taken from MC.



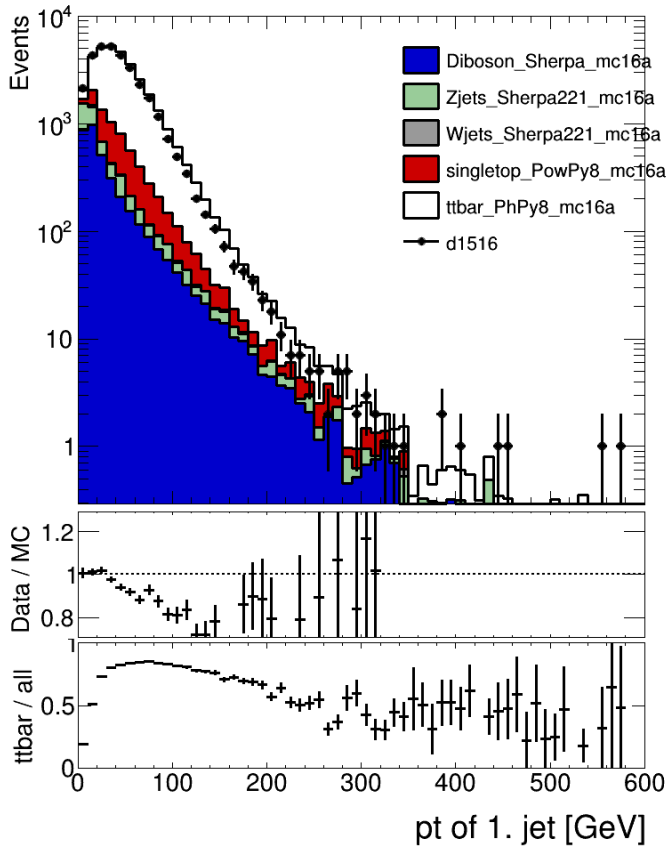
New sideband-fit method



- The flavour composition has been the biggest systematic uncertainty in previous calibration due to the big uncertainties in the $t\bar{t}$ modelling



Reminder: Deriving rewighting factors

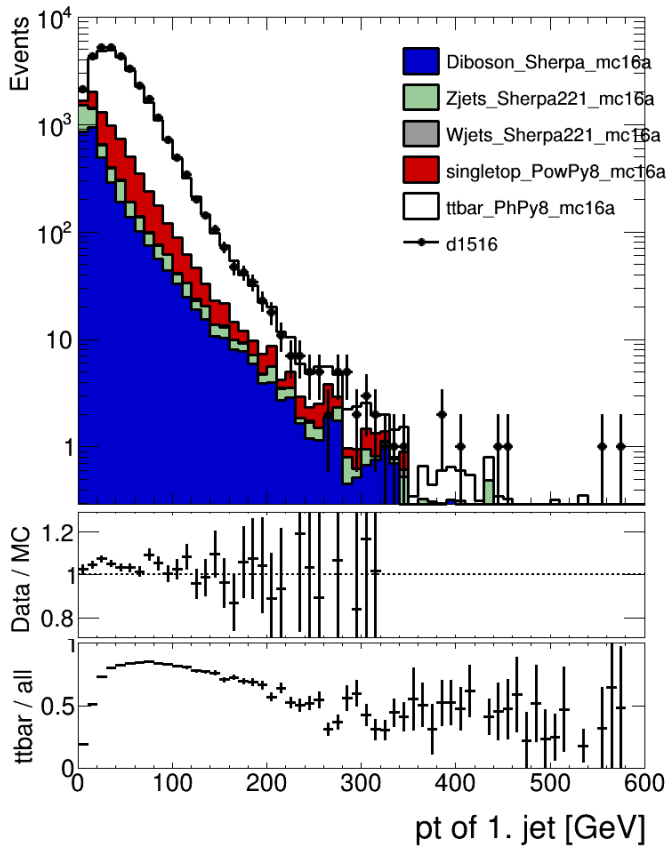


Steps:

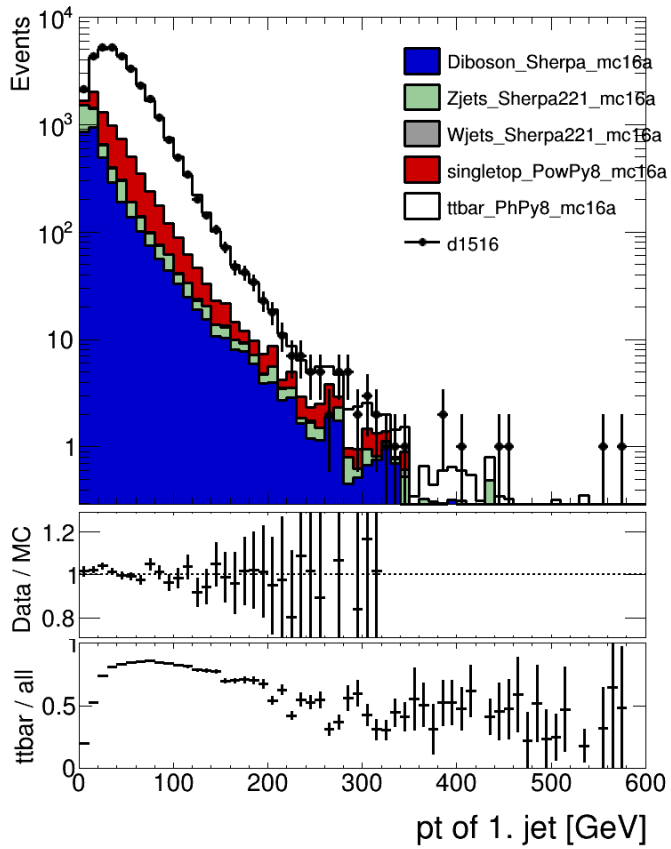
- Fit the Data/MC slope up to 150 GeV (linear fit)
- Take Data/MC ratio as weight for events from $150 - 250$ GeV (in 10 GeV bins)
- Add these weights to all events before applying mlj-cut

pt reweighting with new factors

Old factors



New factors



Q: Should this be done per campaign or just once for the combination?