HEP Student Seminar (30th April 2018, DESY Hamburg)

Search with Bottom Tagged Jets in ATLAS

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ATLAS EXPERIMENT

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Introduction

- Jets originated from b-quarks play an important role in a wide range of physics programs at ATLAS
- Therefore understanding the performance of the bottom tagging (b-tagging) is very critical
- b-tagging can be sensitive to more exotic signatures such as long-lived decays

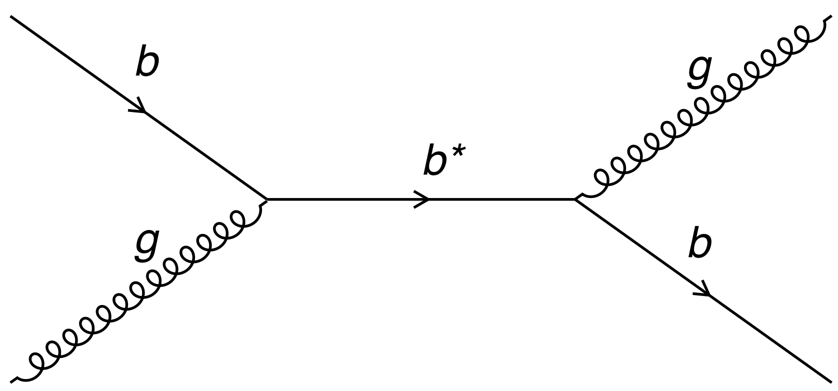
Di-b-jet Resonance Search
High pT b-tagging Calibration
pT_{rel} b-tagging Calibration
LLP Re-interpretation with B-tagging

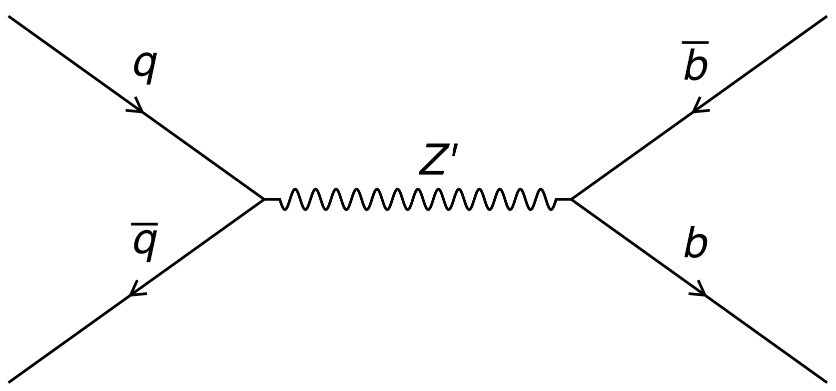
A personal story about these topics I am working on

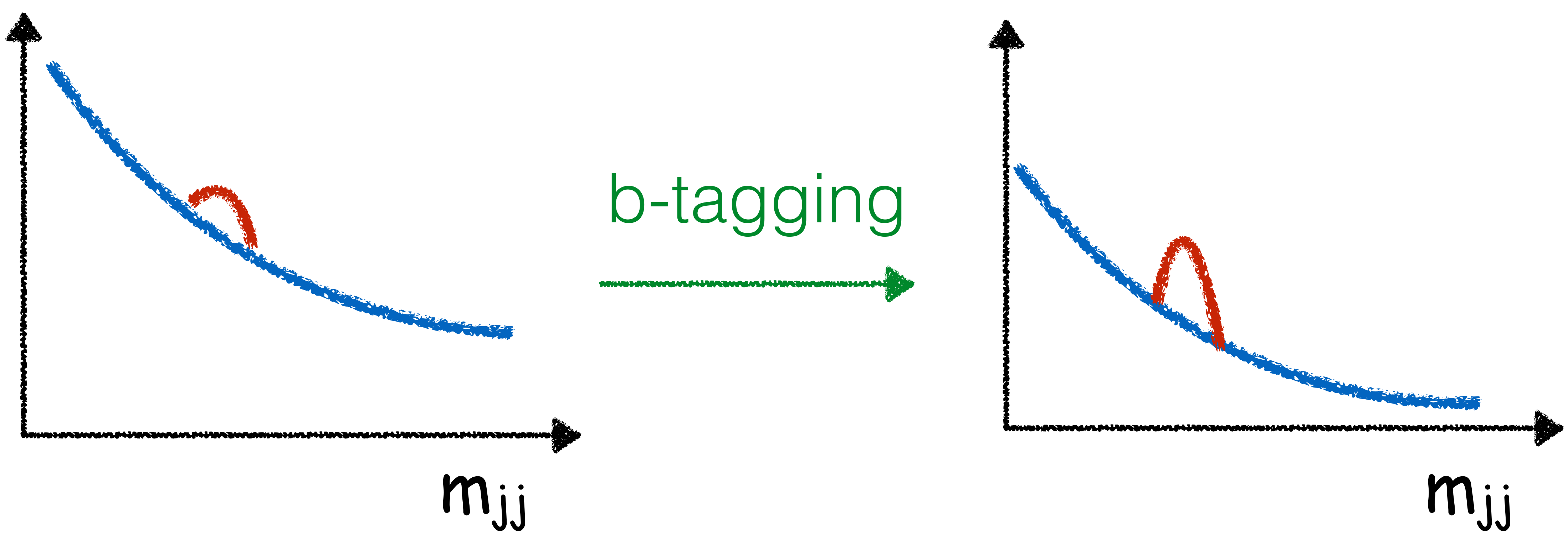
Hopefully it will give you a perspective on how topics in various groups are connected

Di-b-jet Resonance Search

- The sensitivity to BSM particles that preferentially decay to $b\bar{b}$ or bg can be increased by applying b-tagging





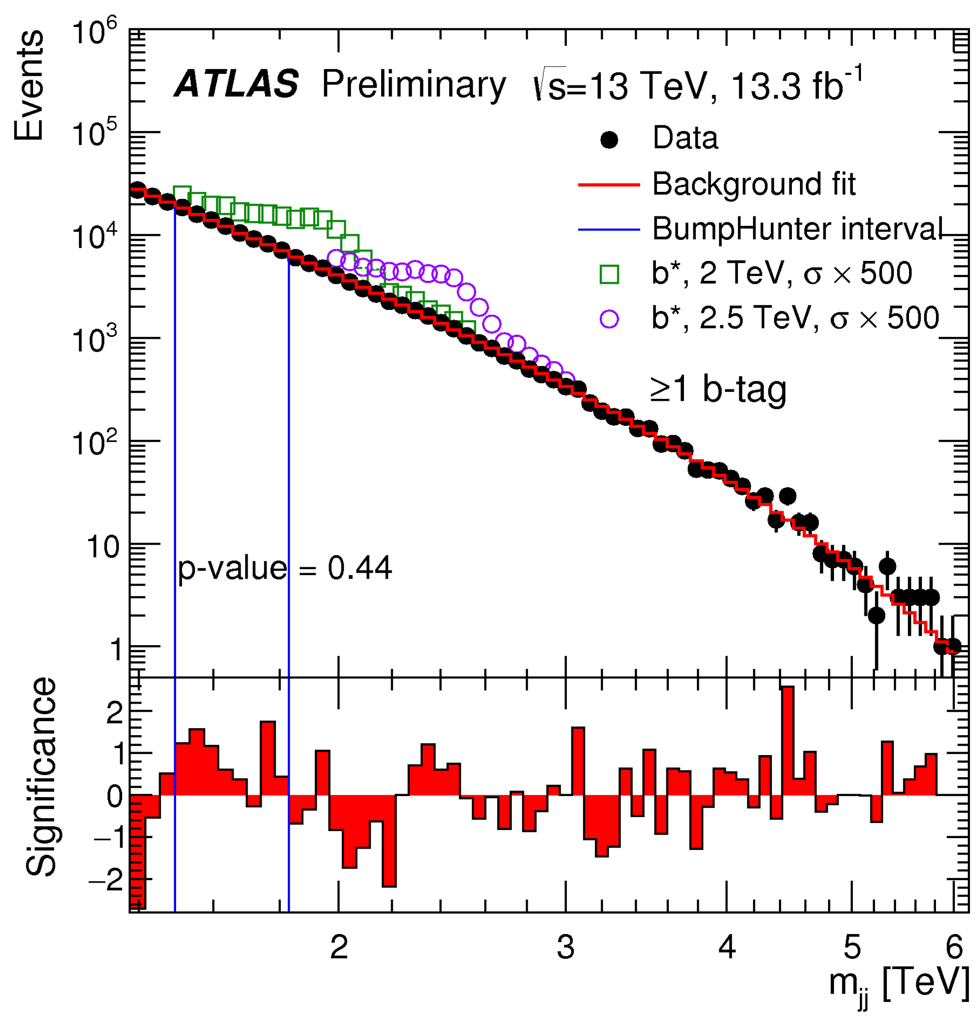


Analysis Strategy

- Perform an inclusive search in six steps:
  1. Apply a proper trigger to collect data
  2. Select well reconstructed jets
  3. B-tagging at least one or two jets
  4. Obtain a data-driven background estimation
  5. Check if there are significant deviations
  6. Interpretation: b* and Z' models, Gaussian shaped resonances
- We will see search results using full 2015 + partial 2016 data
- We will discuss a new background modeling method applied in the full 2015 + 2016 search

Full 2015 + Partial 2016 Results: >= 1 b-tag

- A search is done using partial 2016 data corresponding to an integrated luminosity of 13.3 fb^{-1}
  - Use single jet trigger (m_{jj} > 1.4 TeV)
  - $f(x) = p_1(1-x)^{p_2}(x)^{p_3}$ is applied in the background fit



- No evidence of significant localized excess over the background estimate
- The most discrepant interval is 1.5–1.8 TeV with a p-value of 0.44

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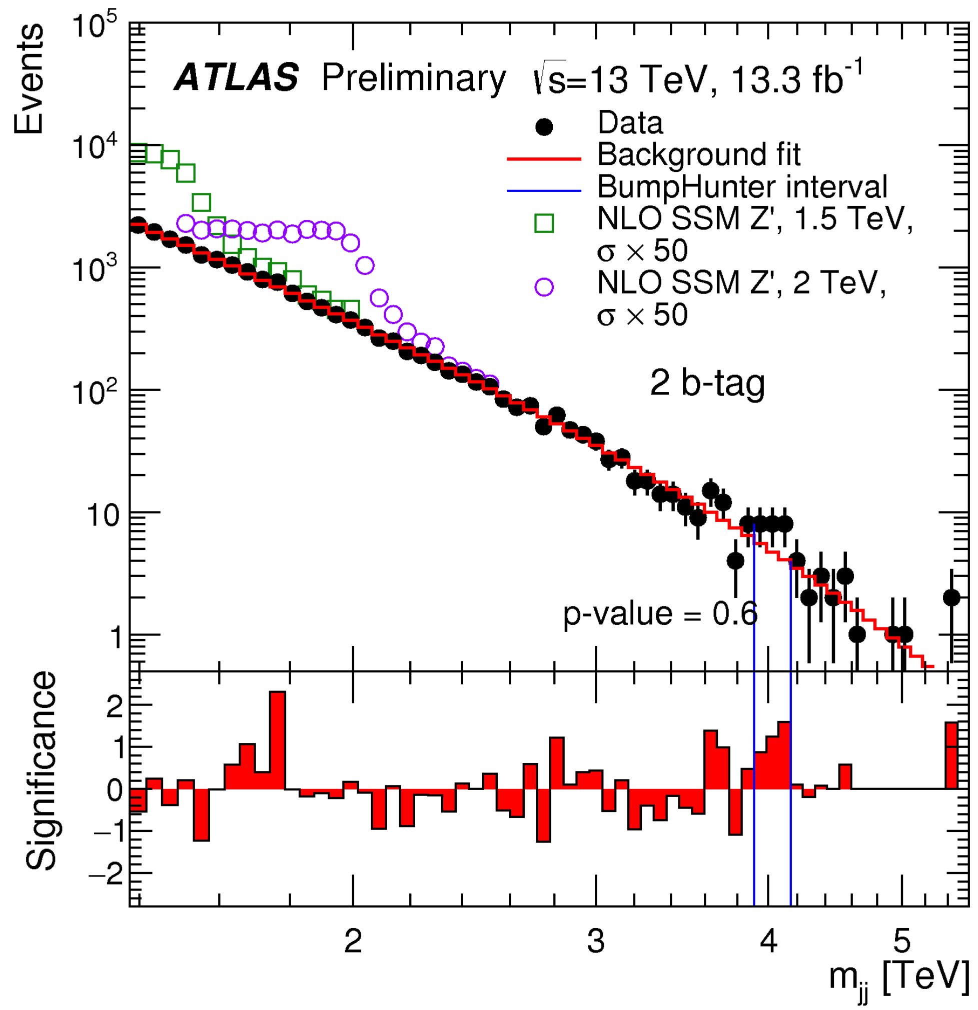
Full 2015 + Partial 2016 Results: == 2 b-tag

- A search is done using partial 2016 data corresponding to an integrated luminosity of 13.3 fb^{-1}
  - Use single jet trigger ($m_{jj} > 1.4$ TeV)
  - $f(x) = p_1(1-x)^{p_2}(x)^{p_3}$ is applied in the background fit



- No evidence of significant localized excess over the background estimate
- The most discrepant interval is 3.9–4.2 TeV with a p-value of 0.60

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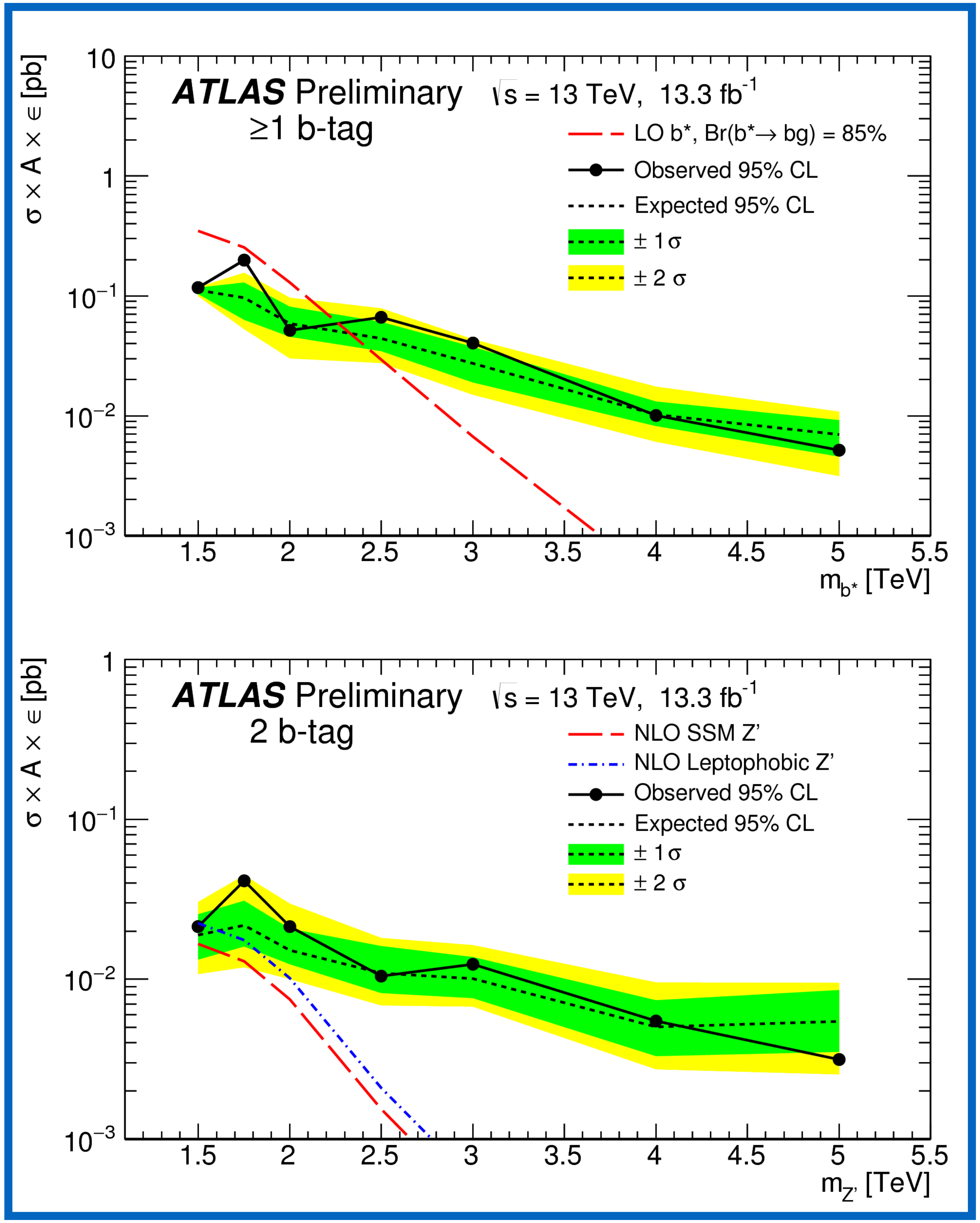
Full 2015 + Partial 2016 Results: Interpretation



- b* model is excluded at 95% CL for masses up to 2.3TeV in the >=1 b-tag channel
- Leptophobic Z'->bb with SM couplings is excluded at 95% CL for masses up to 1.5 TeV in the ==2 b-tag channel

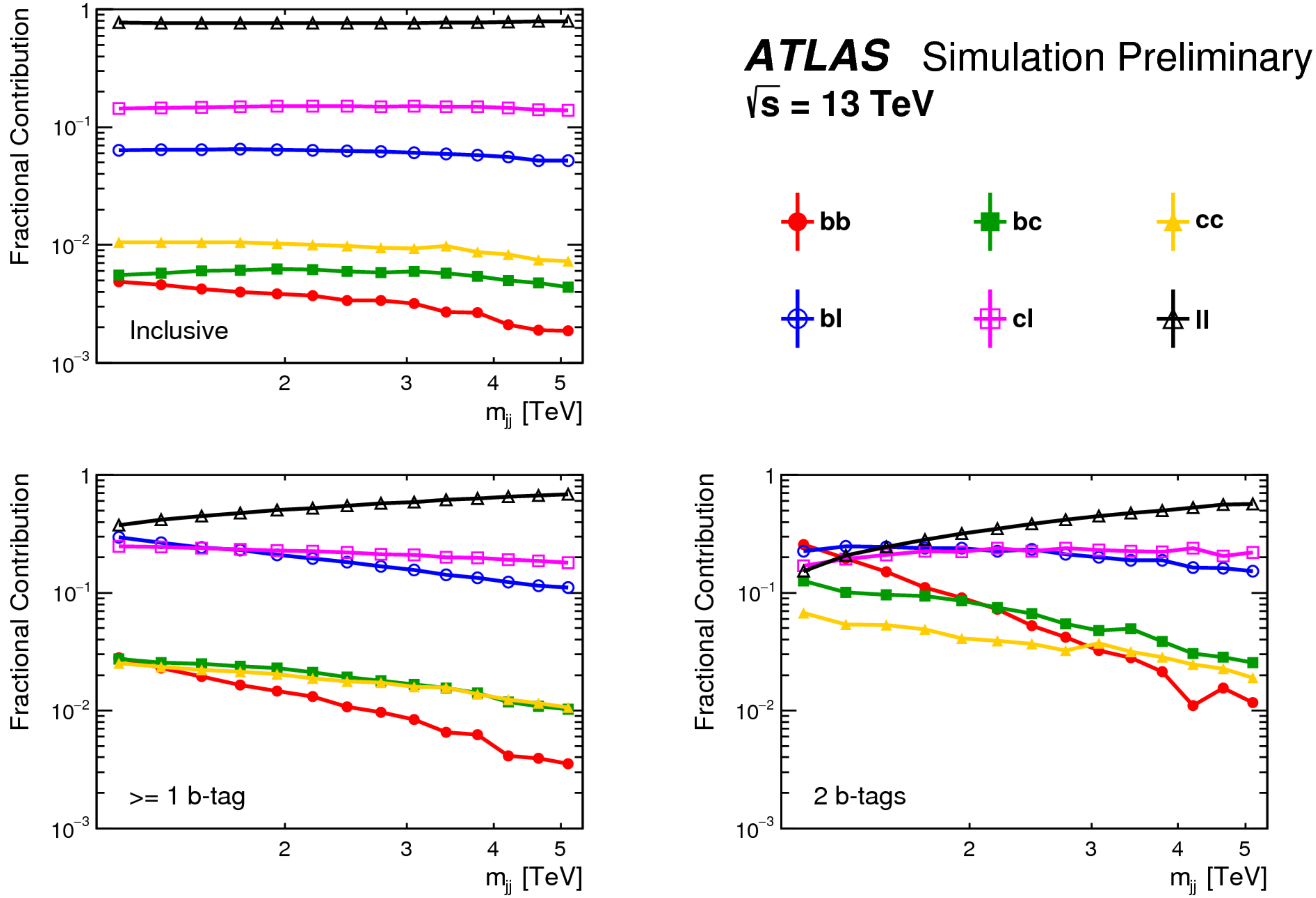
b-tagging Efficiency Measurement

- The di-b-jet resonance search has a main challenge:
  - Non-analytical structures in the mass spectrum created by the b-tagging
- Want to measure the b-tagging efficiencies to model/ understand these non-analytical structures
  - 2D sideband scaling — method applied in the di-b-jet search
  - High-pT b-tagging calibration
  - pT_{rel} b-tagging Calibration

b-tagging calibration

Main Challenge: Non-analytical Structures in Background

- Flavor composition + pT dependent b-tagging efficiency/ fake-rate



Main Challenge: Non-analytical Structures in Background

- Flavor composition + pT_{rel} dependent b-tagging efficiency/ fake-rate

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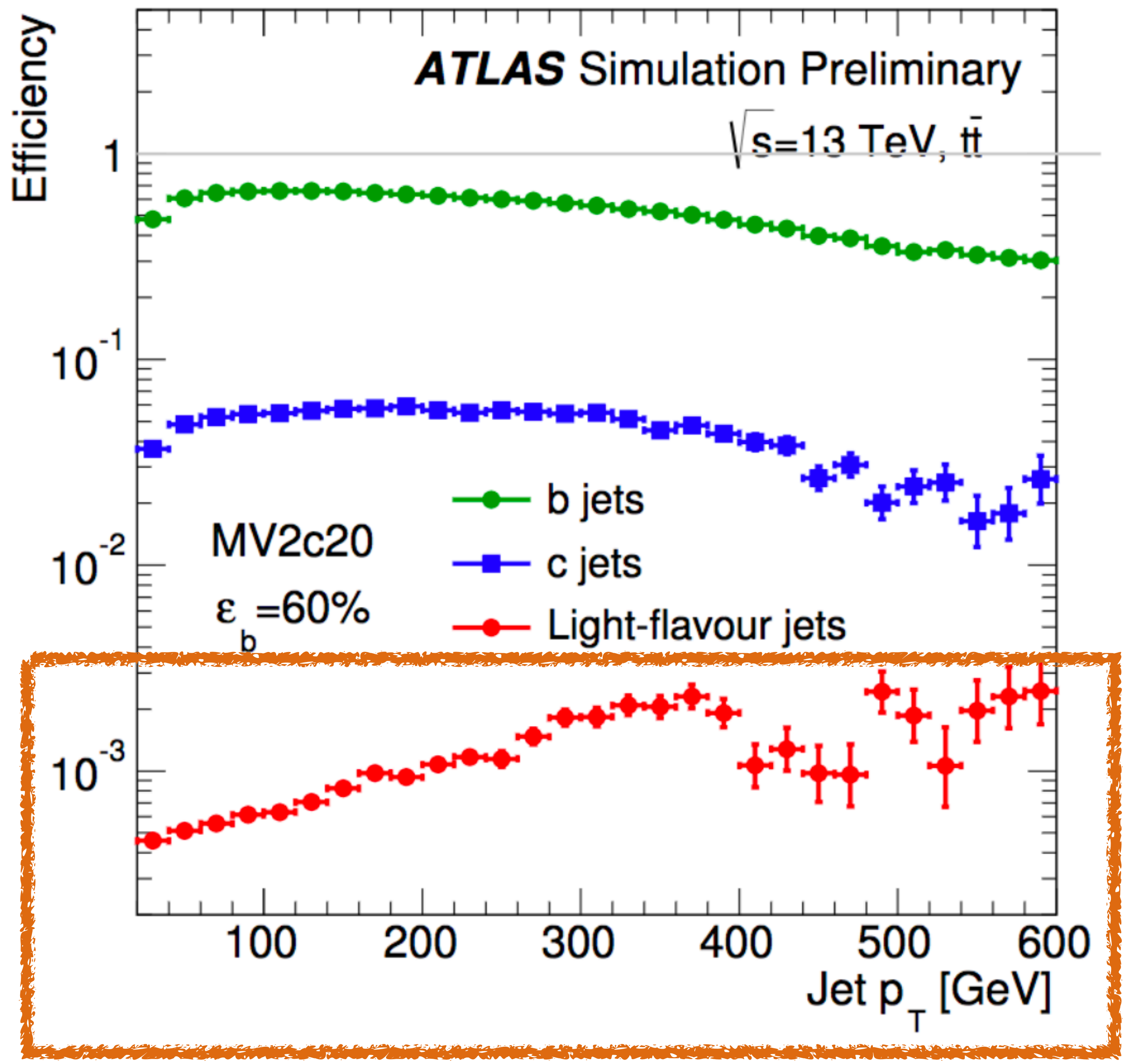
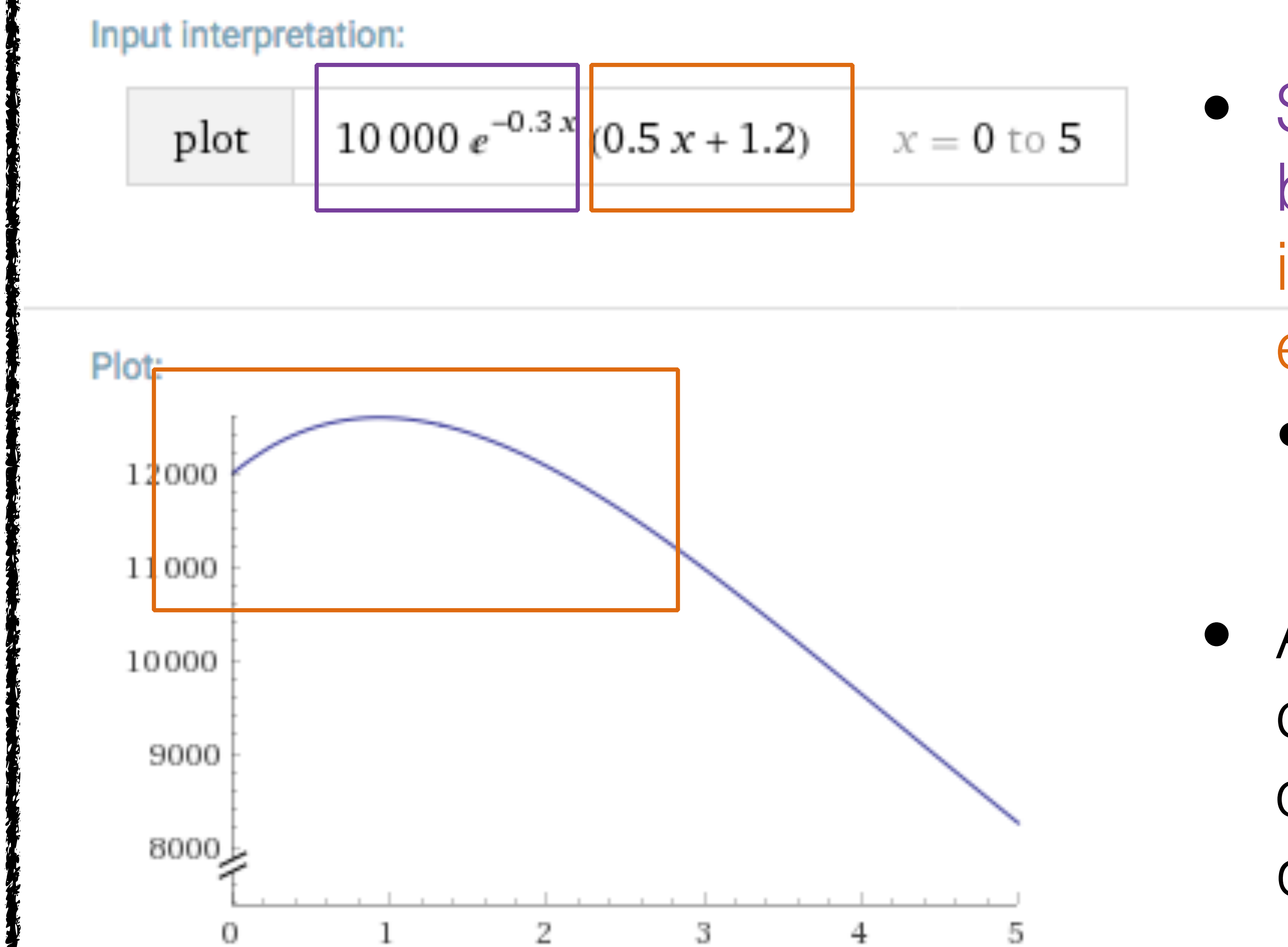


- The b-tagging efficiency/fake rate is not flat w.r.t jet pT
- Smoothly falling background + increasing tagging efficiency
  - May create bump like structures

Main Challenge: Non-analytical Structures in Background

- Flavor composition + pT dependent b-tagging efficiency/ fake-rate



- Smoothly falling background + increasing tagging efficiency
  - May create bump like structures
- After summing up all components the overall effect can be quite complex

A non-realistic illustration via Wolfram Alpha

Main Challenge: Non-analytical Structures in Background

- The structures are not analytical
  - Functions like $f(x) = p_1(1-x)^{p_2}(x)^{p_3}$ is not able to describe the structures
  - Adding more free parameters do not bring significant improvements $f(x) = p_1(1-x)^{p2}(x)^{p3+p_4 lnx+p_5(lnx)^2}$
- A Sliding Window Fit (SWiFt) method can help with this situation (It is a method applied in the Di-jet resonance search: PRD.96.052004)
- But today I want to introduce another modeling method developed
  - 2D sideband data scaling

2D Sideband Data Scaling

A tagged $|y^*| > 0.8$	**B** tagged $|y^*| < 0.8$
C untagged $|y^*| > 0.8$	**D** untagged $|y^*| < 0.8$

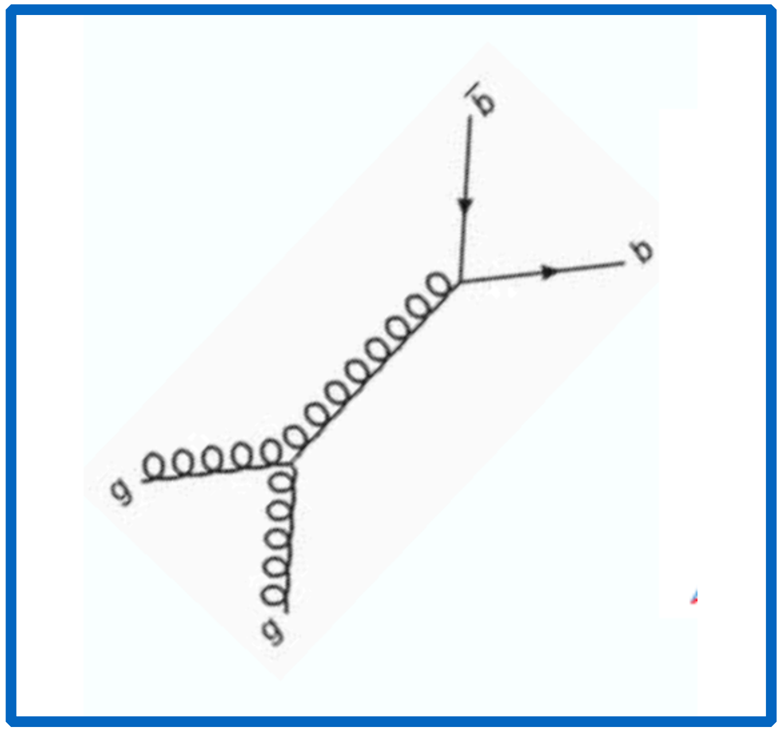
- Two sidebands data scaling method
- Obtain per jet tagging efficiencies in $|y^*|$ inverted regions (A and C)
- Calculate event level tagging efficiencies
- Scale untagged (D) region to tagged region (B)

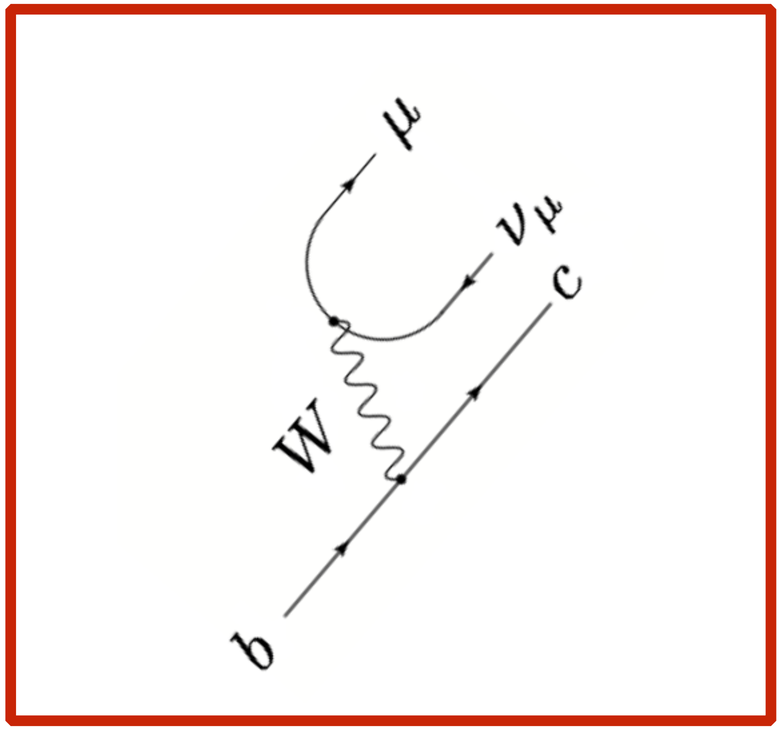
Equivalently a b-tagging efficiency measurement!

Note: y^* is the rapidity difference between two jets divided by 2. s-channel events are populated at small $|y^*|$ while t-channel events are populated at large $|y^*|$

b-tagging Efficiency Measurement at high pT

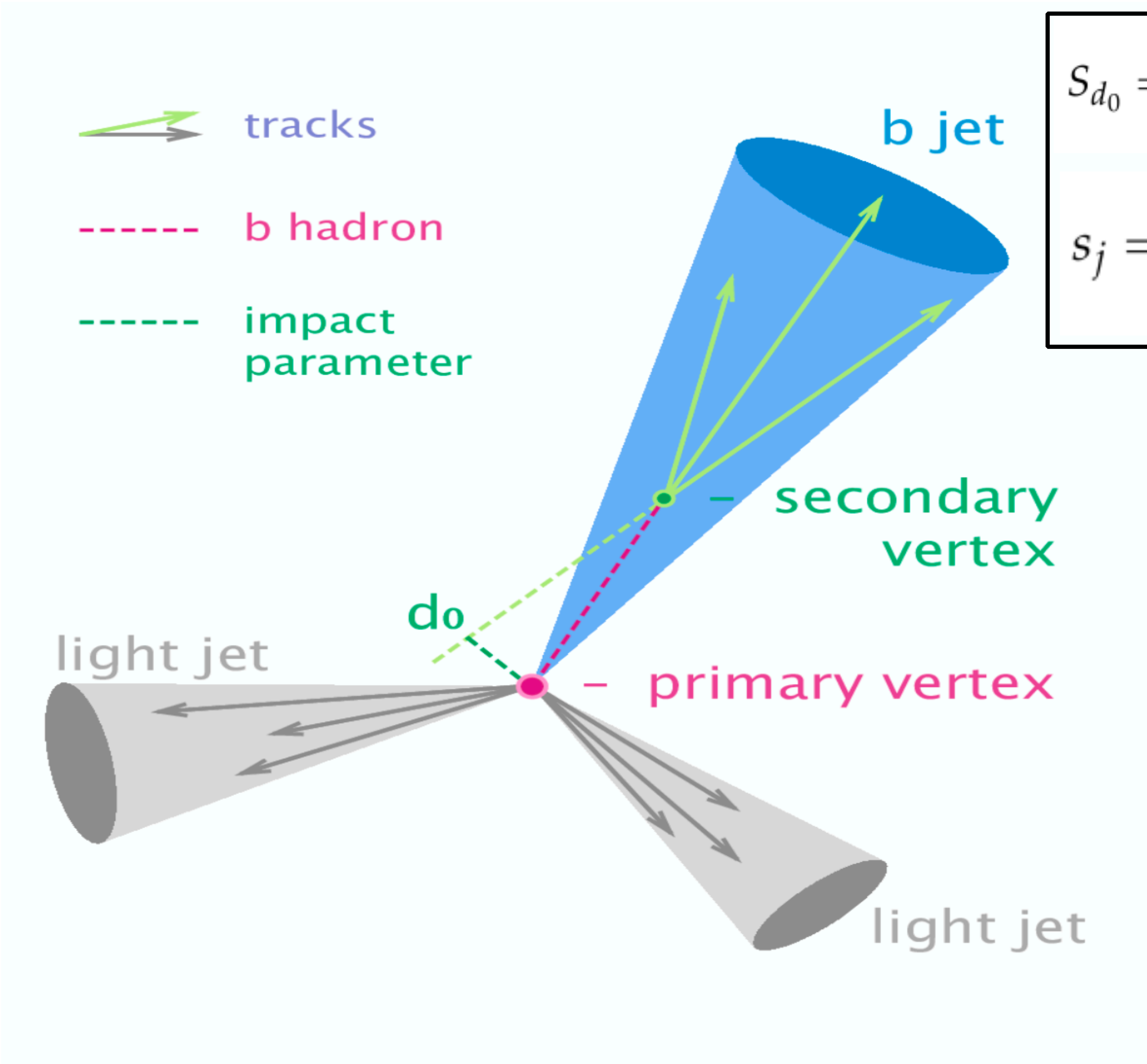
- As seen in the di-b-jet resonance search, a good understanding of the b-tagging efficiency at high pT in data is extremely useful
- This is the main task of the high-pT b-tagging calibration
  - Must relay on $b\bar{b}$ events to cover the high pT regime
  - Use gluon-splitting or muon channel semi-leptonic decay to enhance the b-fraction





b-tagging Efficiency Measurement at high pT

- Calibration strategy:
  - Define a discriminating variable — S_{d0}



$$S_{d_0} = \left|\frac{d_0}{\sigma_{d_0}}\right| \cdot s_j$$

$$s_j = \mathrm{sign}\left[\sin\left(\arctan(\frac{p_y(j)}{p_x(j)} - \phi(t)\right) \cdot d_0\right]$$

- Tracks in jets originated from b-quarks are likely to have positive/large S_{d0}

b-tagging Efficiency Measurement at high pT

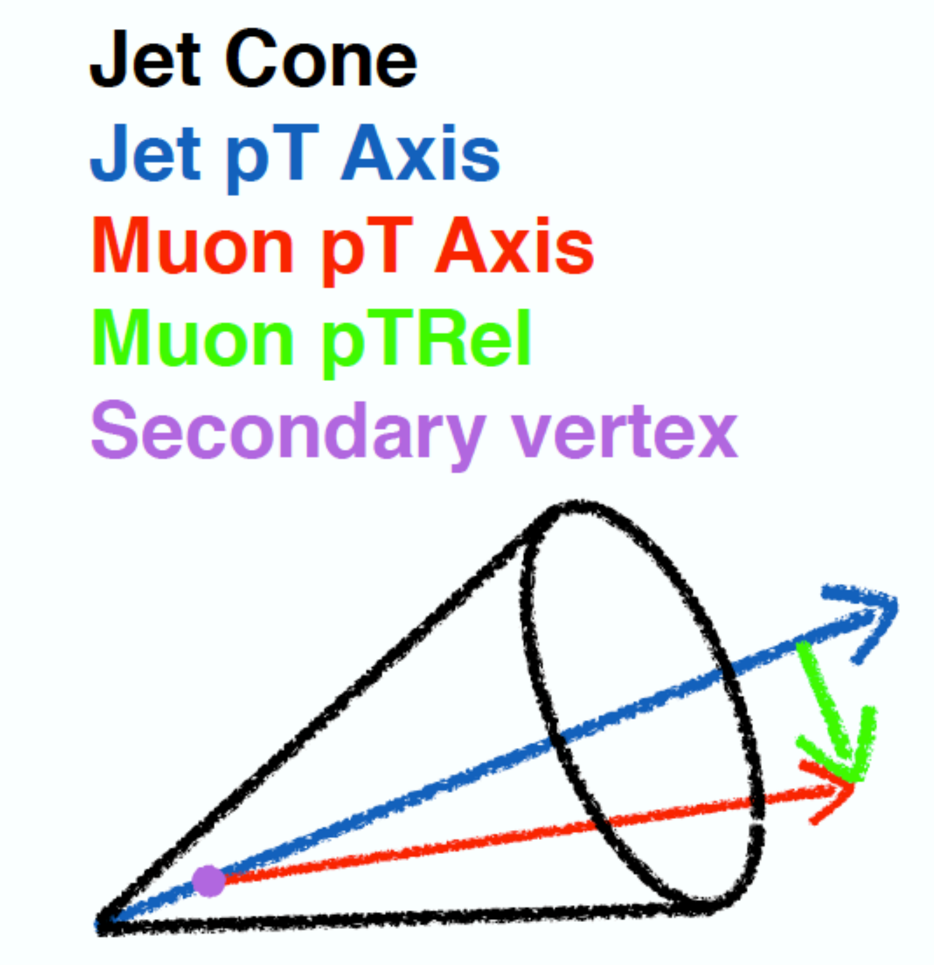
- Calibration strategy:
  - Define a discriminating variable — S_{d0}
  - Produce S_{d0} templates for jets with different flavors, bottom (b), charm (c) and light (l)
  - Apply the b-enhanced selections in data
  - Perform a template fit to data before and after applying b-tagging to obtain the fraction of b's
  - Extract the b-tagging efficiency using number of events and the fractions
  - Compare the efficiencies measured in data with the those in MC

Template Fit Method!

b-tagging Efficiency Measurement via pT_{rel}

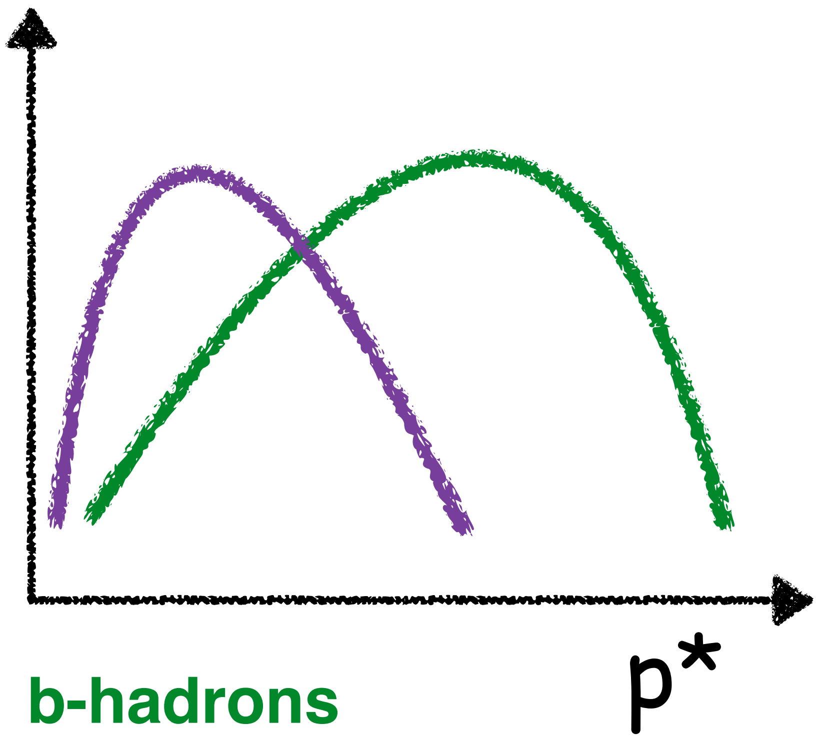
- A different b-tagging efficiency calibration method using template fit and $b\bar{b}$ events!
- B-hadrons are unique
  - Relatively longer lifetime — secondary vertex
  - Relatively heavier mass — other interesting kinematic properties: pT_{rel}

$$p_T^{rel} = \sqrt{\vec{p}_\mu^{\,2} - \left(\frac{\vec{p}_{jet} \cdot \vec{p}_\mu}{|p_{jet}|} \right)^2}$$



b-tagging Efficiency Measurement via pT_{rel}

- Muons have harder pT in the rest frame of b-hadron (p*)



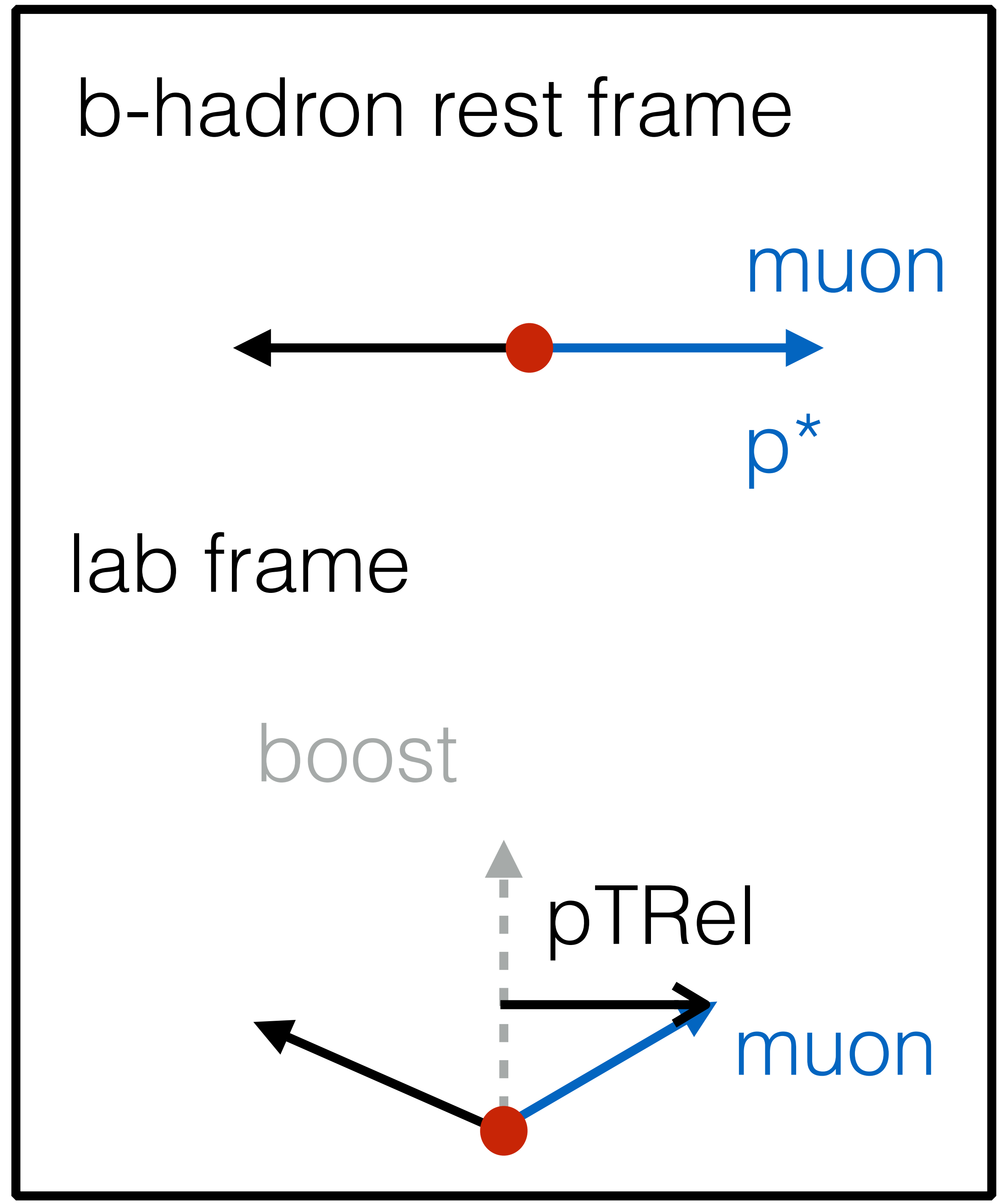
b-hadrons
c-hadrons

Massless two-body decay:

$(P,\vec{P}) + (P,-\vec{P}) = M_{b/c}$

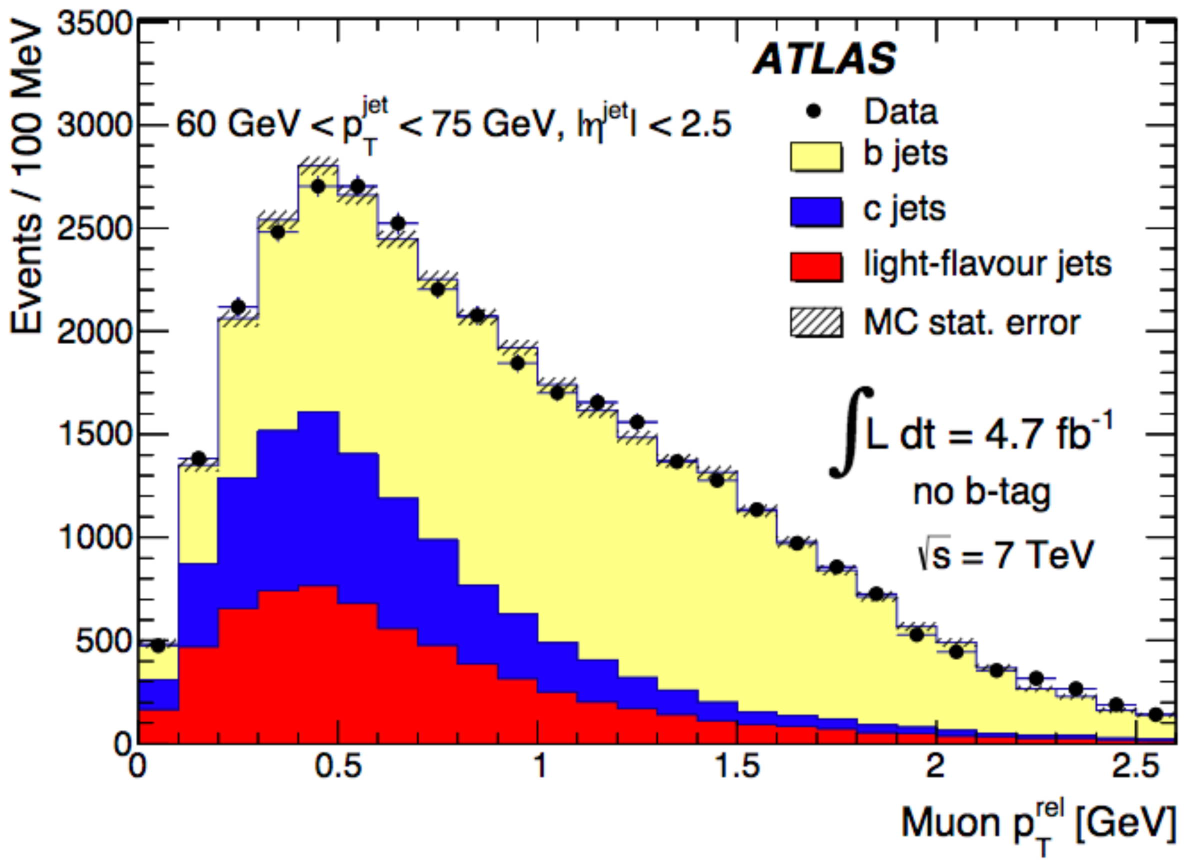
$P = 0.5 * M_{b/c}$

$p^* \sim M_{b/c}$

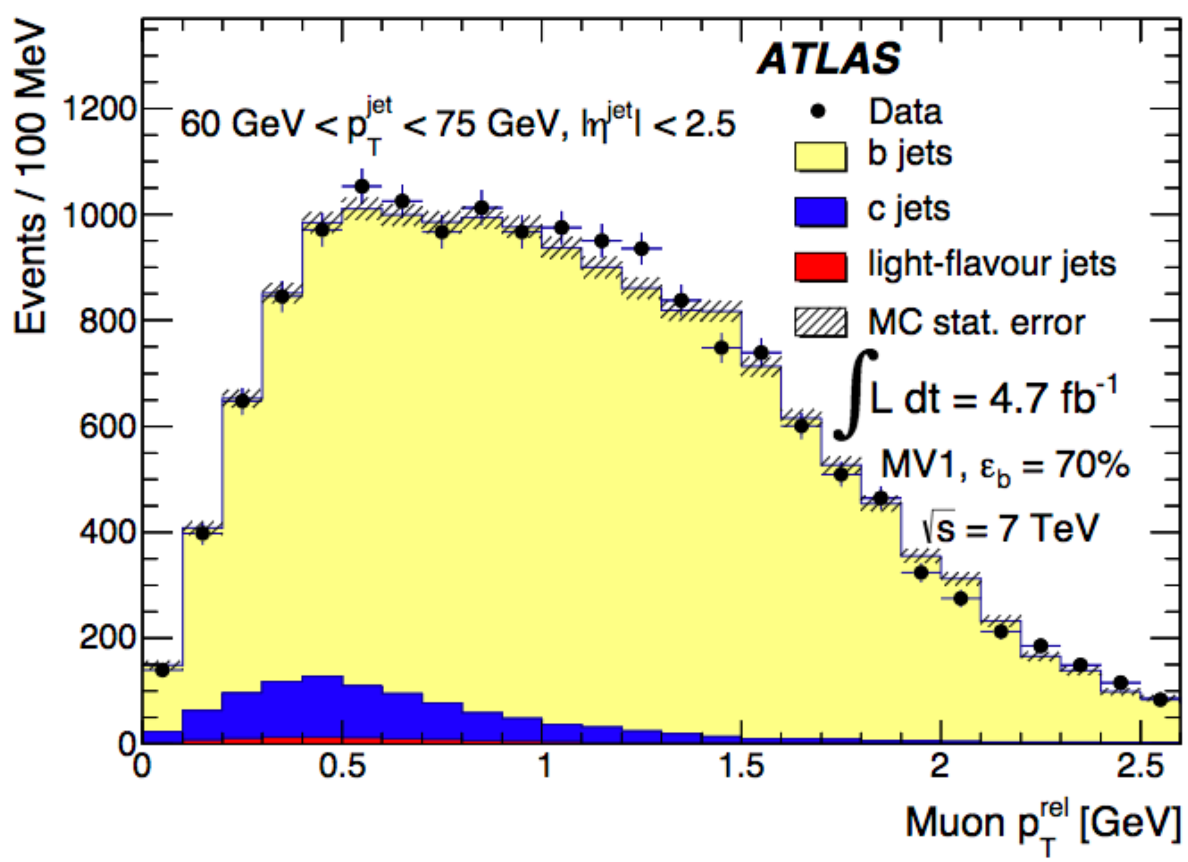


b-tagging Efficiency Measurement via pT_{rel}

- Fit the pT_{rel} templates to data before/after b-tagging and obtain the b-tagging efficiencies



post-fit before b-tagging



post-fit after b-tagging

- $N_b = N_{data}$ * b-fraction (from template fit)

Performance of b-jet identification in ATLAS

b-tagging Efficiency Measurement via pT_{rel}

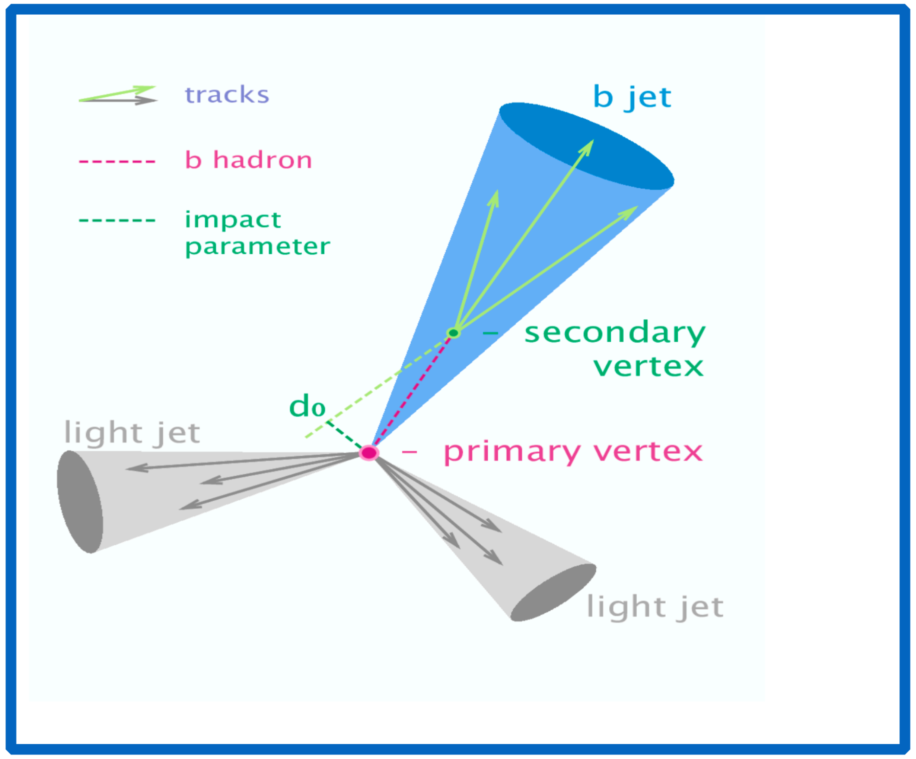
- pT_{rel} calibrates the b-tagging efficiency via $b\bar{b}$ events
- It is an orthogonal approach to the nominal $t\bar{t}$ based calibration
- Analyses using top may prefer pT_{rel} calibration to avoid possible biases
  - Top R_b measurement

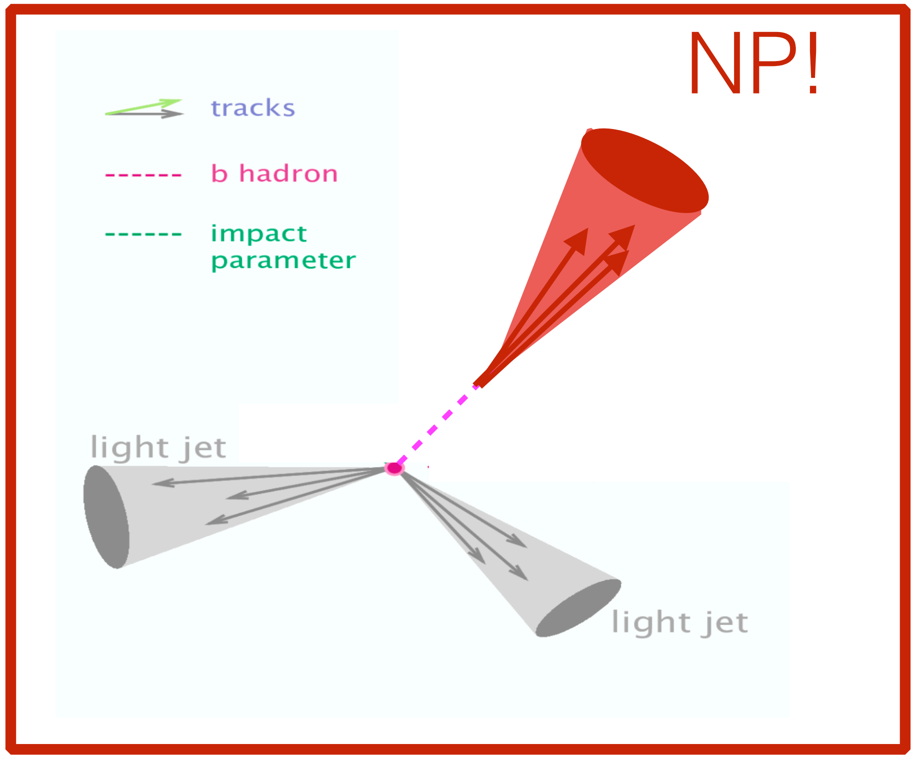
$$R_b = \frac{BR(t \to Wb)}{BR(t \to Wq)} = \frac{|V_{tb}|^2}{\Sigma_q |V_{tq}|^2}$$

$t\bar{t}$ calibration uses this

b-Hadrons are Relatively Long-lived

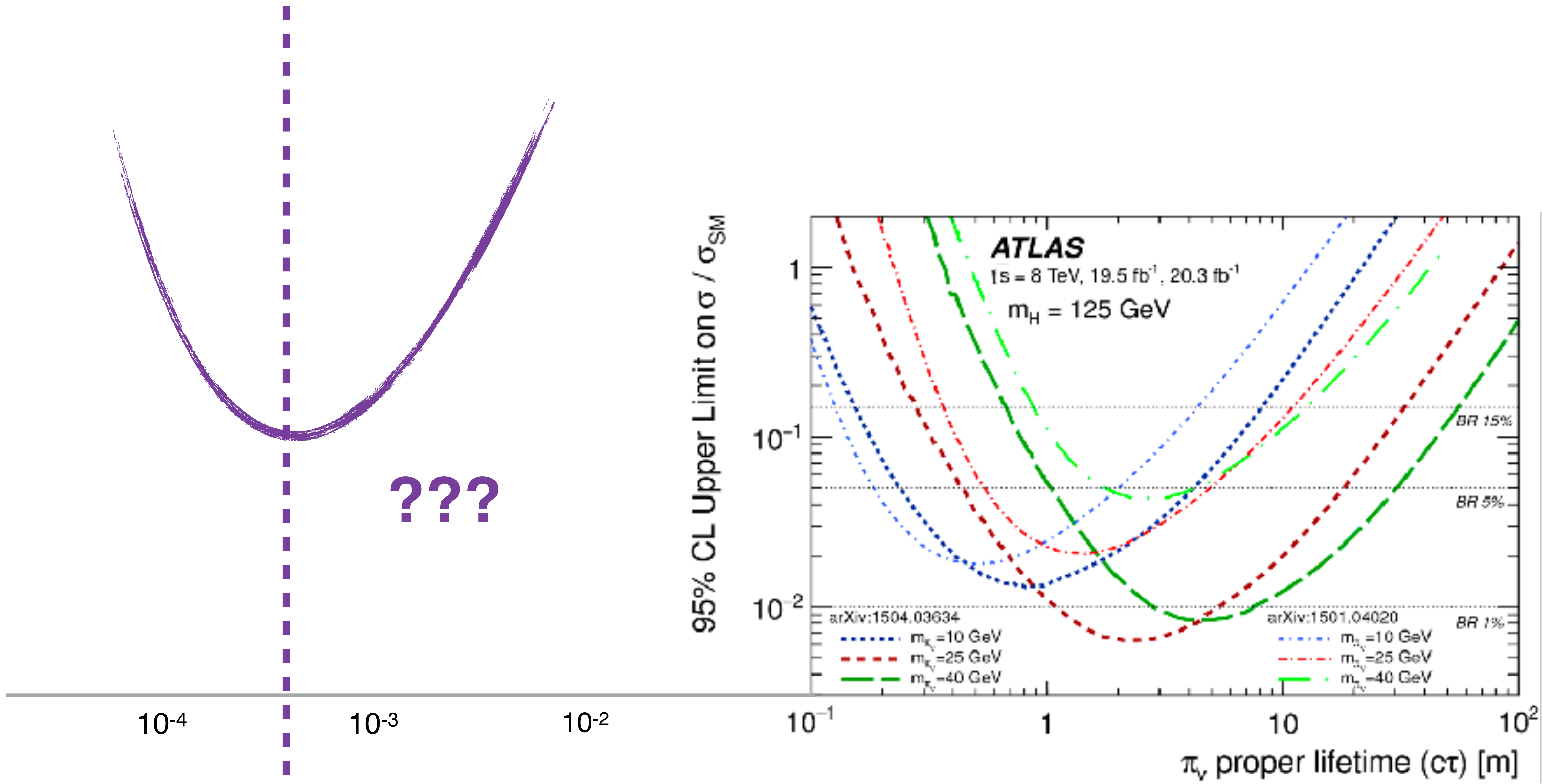
- B-hadrons are unique
  - Relatively longer lifetime — secondary vertex
  - Relatively heavier mass — other interesting kinematic properties: pT_{rel}
- If new particles have similar lifetimes as the b-hadrons and interact with the materials normally
  - b-tagging algorithms should also be sensitive!





b-Hadrons are Relatively Long-lived

- It is worth probing. Traditional searches with b-tagging can probe a large parameter space



b-hadron lifetime

Conclusion

- b-tagging is a very rich topic!
- Analyses and calibrations have common interests and many techniques can be shared
- b-tagging should be sensitive to LLP with a certain lifetime
- Stay tuned for the new results!

Thank you!