WORKSHOP ON TOP QUARK MASS MEASUREMENTS

RELATION BETWEEN TOP QUARK MSR MASS AND THE MC MASS PARAMETER

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Top quark mass interpretation

- The physical mass of the top quark is that found in the Lagrangian. However, MC top quark mass has much lower uncertainties.
  - **Want to understand how the MC mass relates to the physical mass.**
  - **Test the relation between the two mass parameters:**

$$m_t^{MC} = m_t^{theo} + \Delta_{t,MC}$$

- The ambiguity in interpreting direct mass measurements within a field-theoretical renormalisation scheme can be reduced through dedicated 'calibration' studies.

➡ Is m_t^{MC} only effective in matching experimental data, using mass parameters that don't directly correspond to fundamental QCD parameters?

➡ Or, if closely aligned with QCD, can m_t^{MC} represent the physical mass in a given scheme of the top quark as in the QCD Lagrangian.

Analysis Goal

- **The interpretation of the top mass in an MC generator, in terms of a renormalised mass in the MSR scheme:**

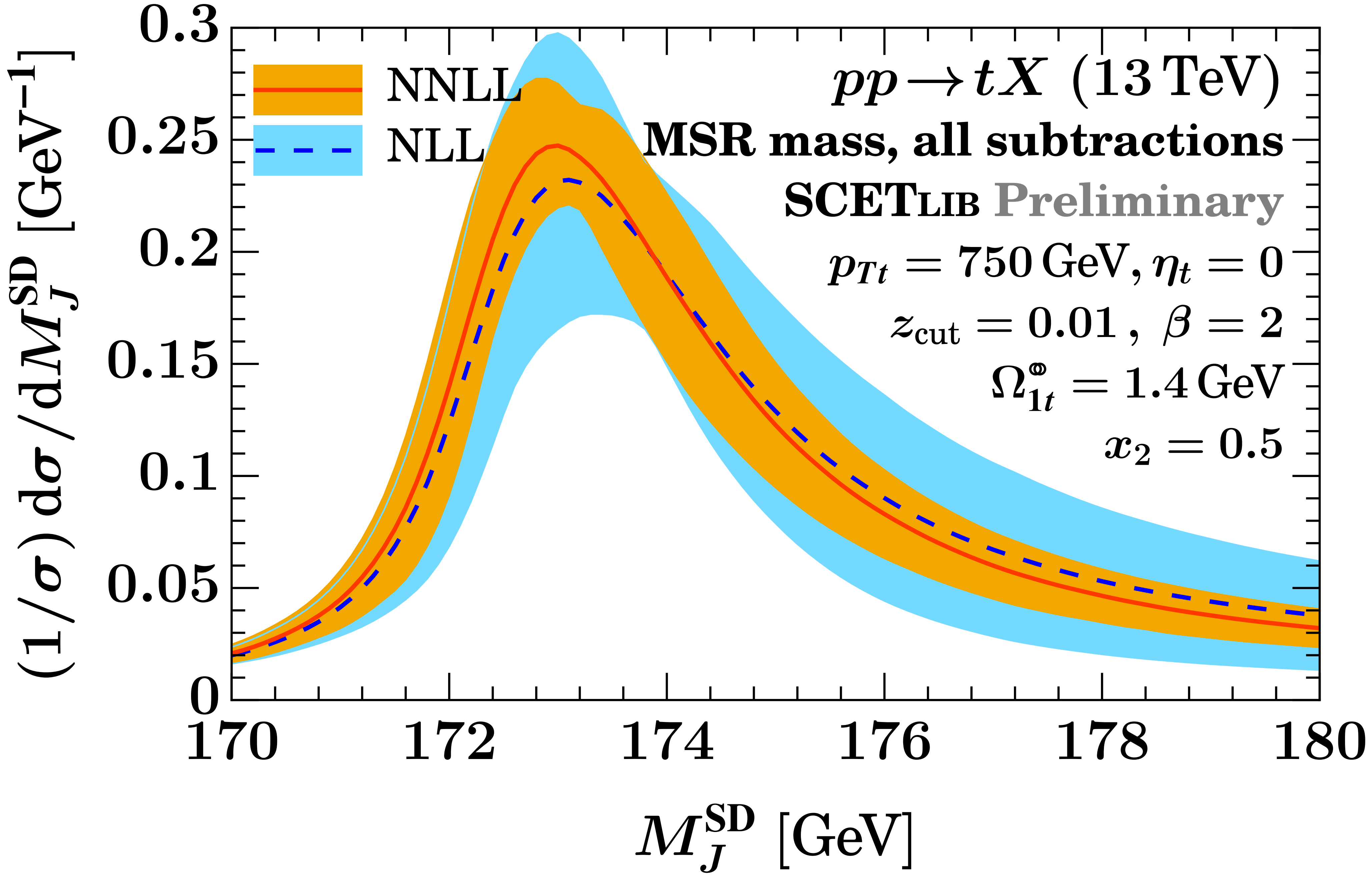
$$\mathbf{m_t^{MC} = m_t^{MSR}(R = 3GeV) + \Delta m_t^{MSR}}$$

- Calibration performed with **NNLL calculation** compared against **Pythia MC** predictions with NNPDF3.0 NLO PDF set and A14 set of tuned parameters.

m_t^{MC} **is set to 172.5 GeV.**

Theoretical scheme

- Continuation of the top mass interpretation with NLL accuracy found at ATL-PHYS-PUB-2021-034.
- Using SCET-based calculation with NNLL accuracy
  - Improved perturbative stability.
  - Renormalon subtraction - increased stability in peak of differential cross-section of jet mass. Renders the first-moment non-perturbative correction renormalon free.
- Model uses three parameters, $\mathbf{m_t}^{MSR}$, $\mathbf{\Omega_1^{had}}$, and $\mathbf{x_2}$ associated with **first-** and **second-moment non-perturbative corrections.**

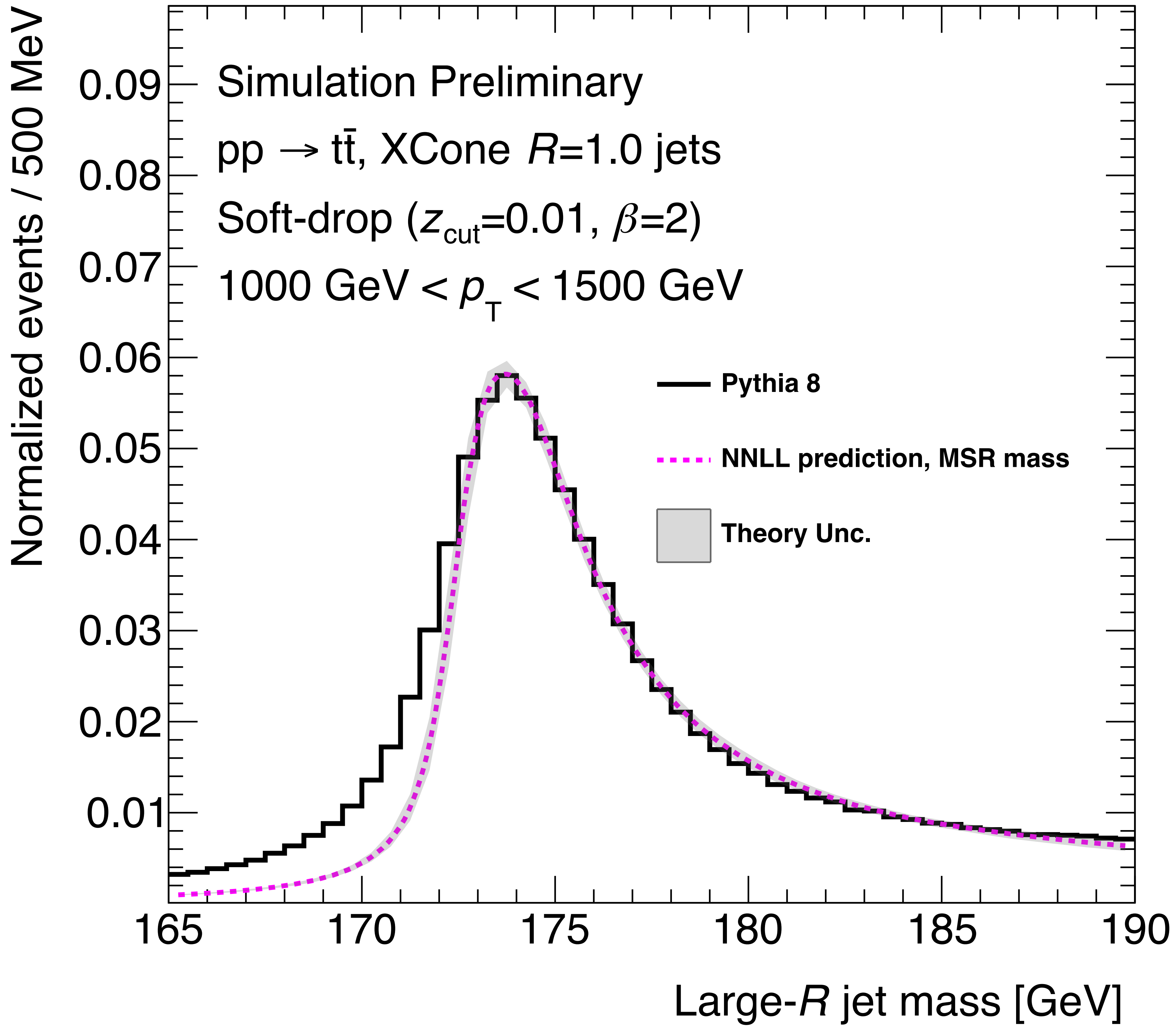


MANTRY, MICHEL, PATHAK, STEWART PRELIMINARY

Fitting Details

- Idea is to obtain **value of parameters in NNLL theory** calculation that **best describe MC prediction.**

- m_t^{MSR}, Ω_1^{had}, and x_2 varied:
  - Best fit of MC-to-theory distributions found for variations of the three parameters.
  - χ^2 minimisation fit applied to the three parameters to find the global minimum.
  - **This is how we extract the top quark MSR mass.**

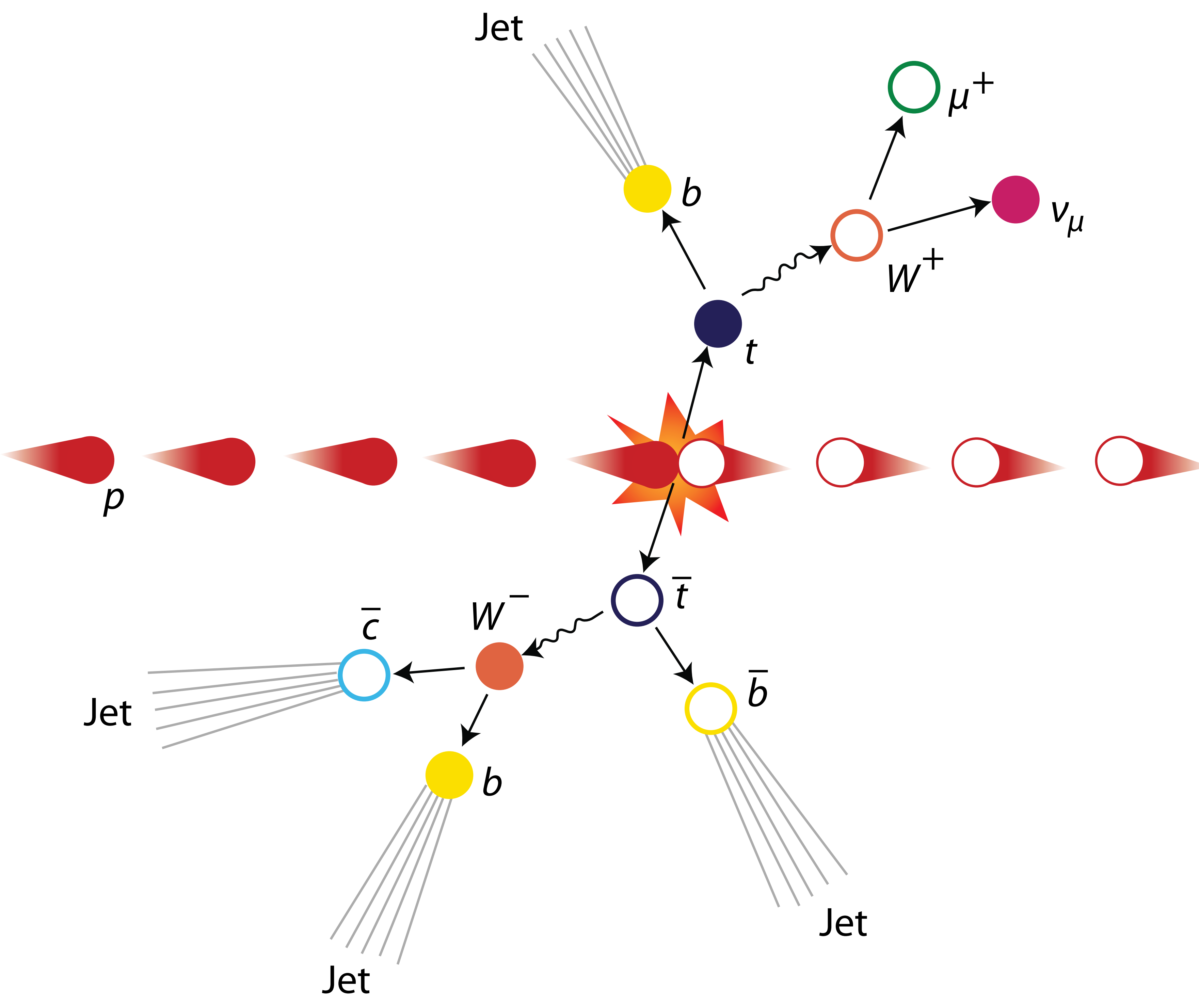


Jet building

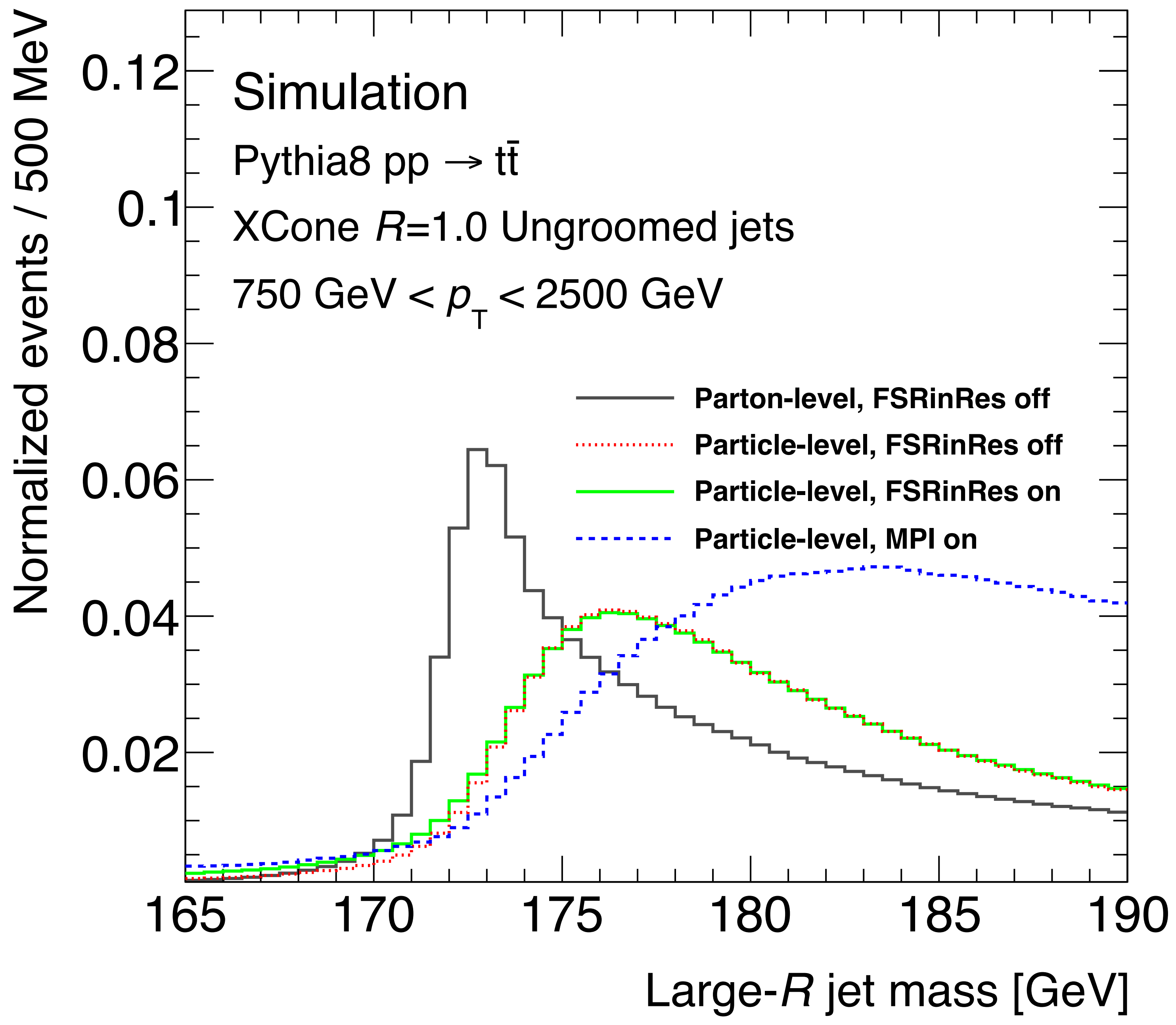
- Focus on particle-level hadronic top quark decay in $pp \to t\bar{t}$ processes.
  - Top mass determined by fitting large-R jet mass containing hadronic top.
  - Mass reconstructed using information from decay products of top quark within large-R jet.
- Boosted jet: Inclusive treatment of decay products.
  - **Four orthogonal jet p_T bins**:

$p_T^{jet} \in \{750, 1000, 1500, 2000, 2500\}$GeV.

- Large-R jets built with:
  - **XCone** jet algorithm with **R = 1**.
    - Jet algorithm minimising N-jettiness. Useful filtering out unwanted jets in densely populated events (useful in boosted regime where signal jets may partially overlap.)
  - **Soft-drop light grooming** applied to remove soft-wide radiation ($z_{cut} = 0.01, \beta = 2$).
    - Considerably reduces UE impact. Shift of ~5 GeV down to ~1 GeV.



Jet building



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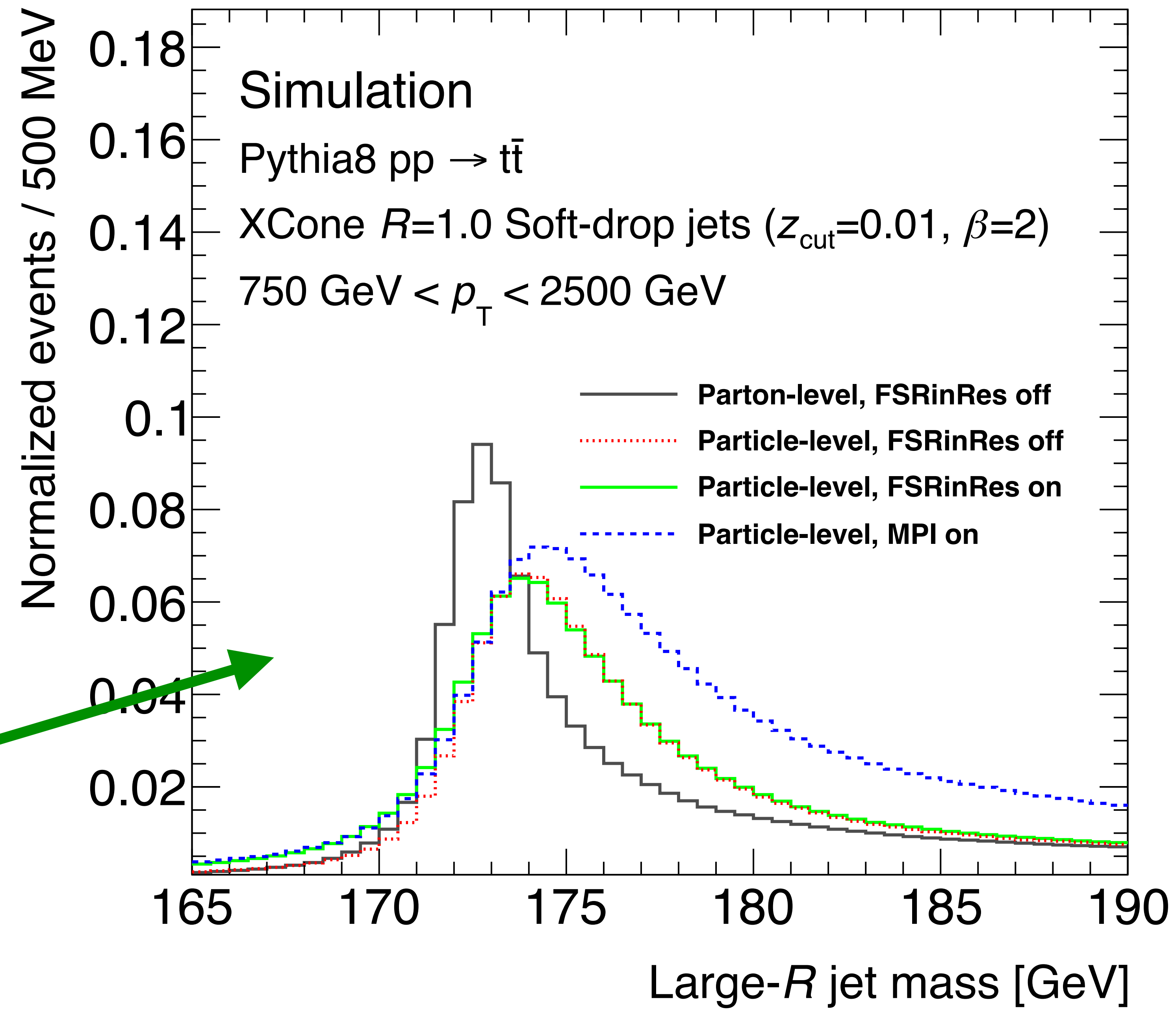


Uncertainties

- Uncertainties are applied to account for:
  - **Estimation of perturbative uncertainty in calculation.**
  - **Fitting methodology (FSR estimation not present in calculation).**
  - p_T **influence of large-R jet.**
  - **UE not yet present in the calculation.**

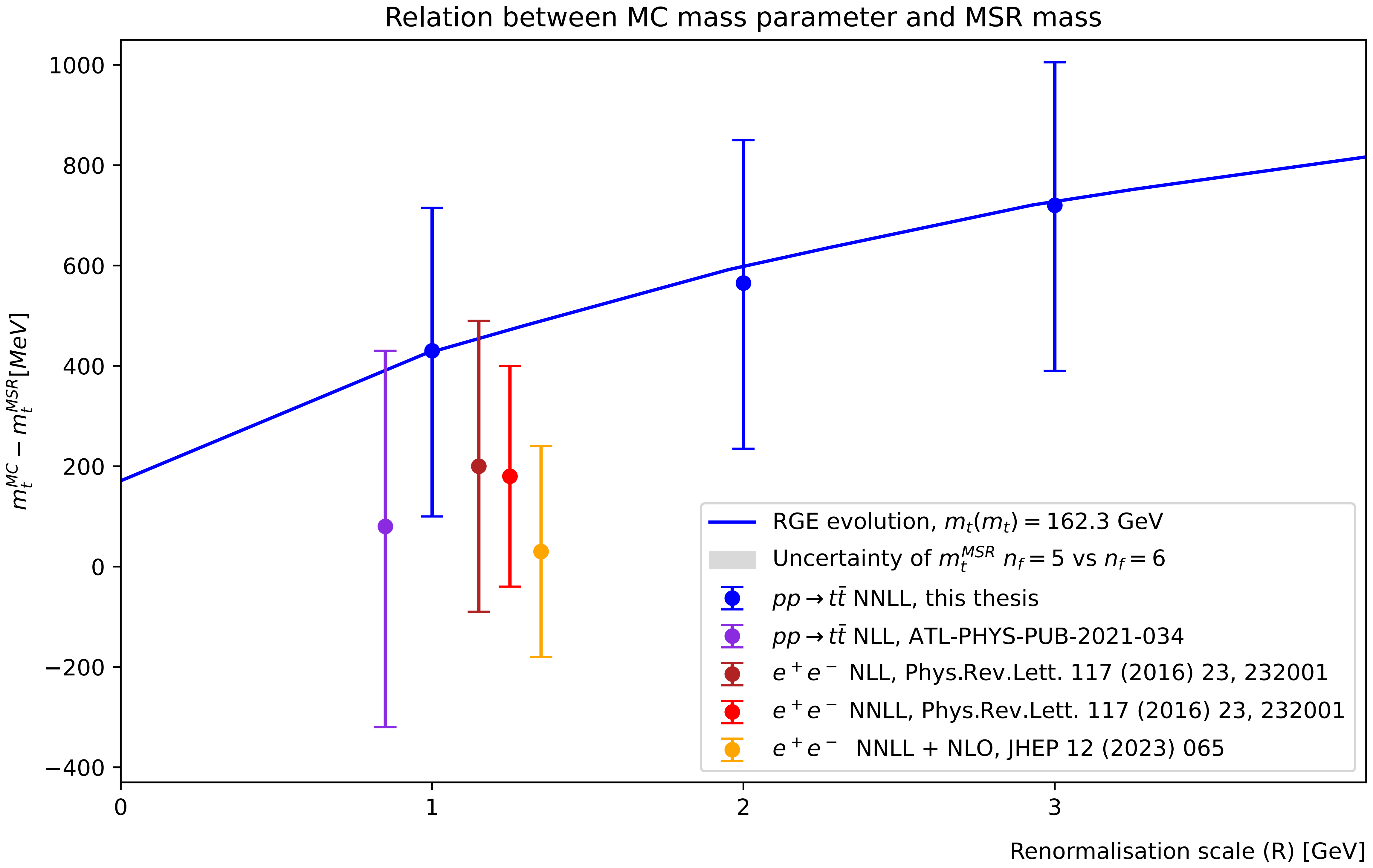
	Uncertainty [MeV]
Theoretical	+110/-200
Fitting	+/- 215
Kinematic range	+63/-84
Underlying event	+137/-122
Total	**+285/-330**

Result

Mass relation of:

$$\Delta^{MSR} = m_t^{MC} - m_t^{MSR}(R = 3 \text{ GeV}) = 720^{+285}_{-330} \text{ MeV}$$

- Uncertainties decreased significantly from previous relation with pp processes.
- Optimised R value and improved NNLL calculation.



- Comparisons with previous top quark mass interpretations in pp and e^+e^- collision regimes.
  - All results compatible within uncertainties.

Update to Theory

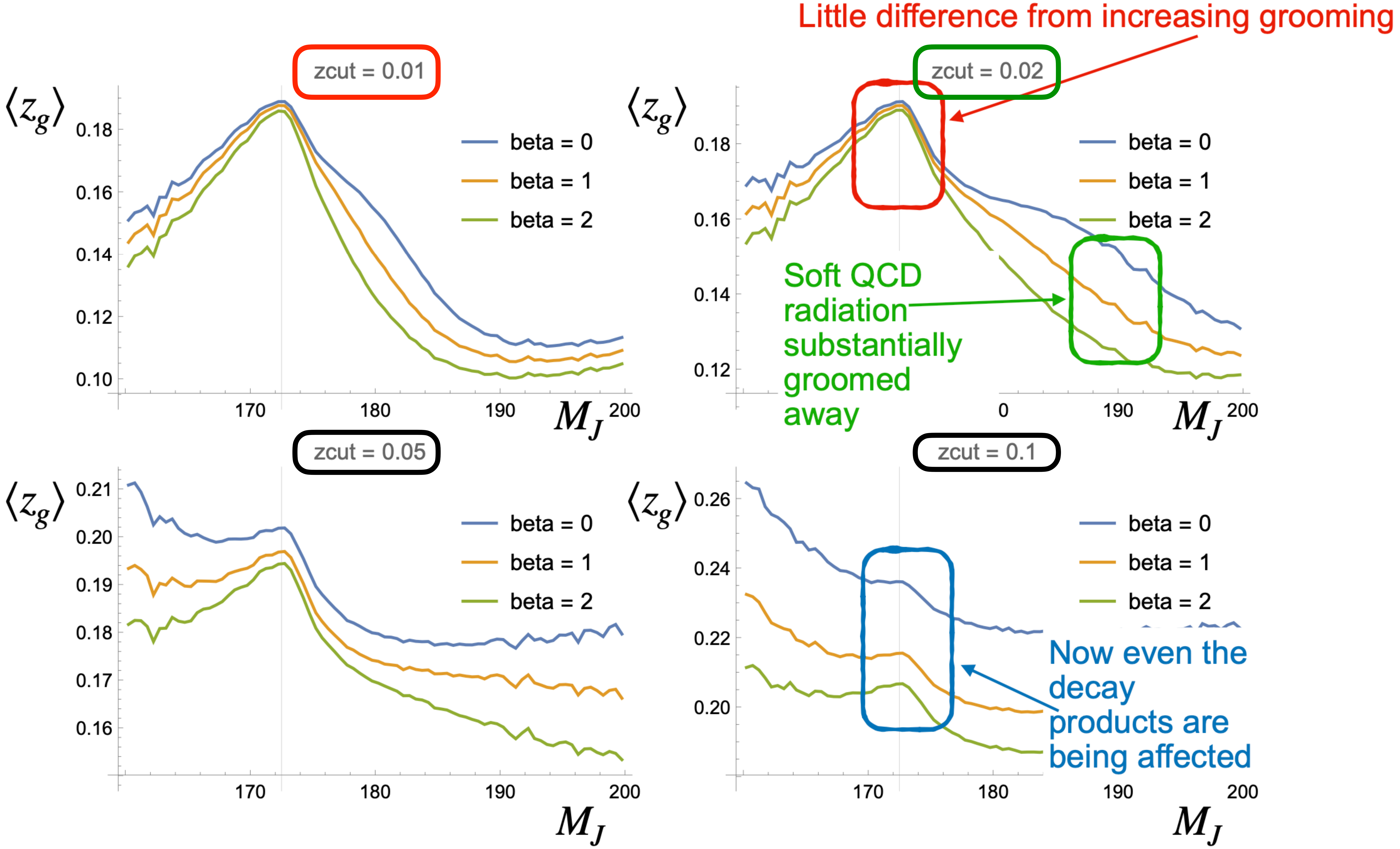
- **Can work with more aggressive grooming:**

Old: $z_{cut} = 0.01, \beta = 2$

$\rightarrow$ New: $z_{cut} = 0.02, \beta = 0$

New grooming works?

Seems the decay products protect the ultra-collinear radiation.



Peak position dependence

- Peak position in new grooming scheme:

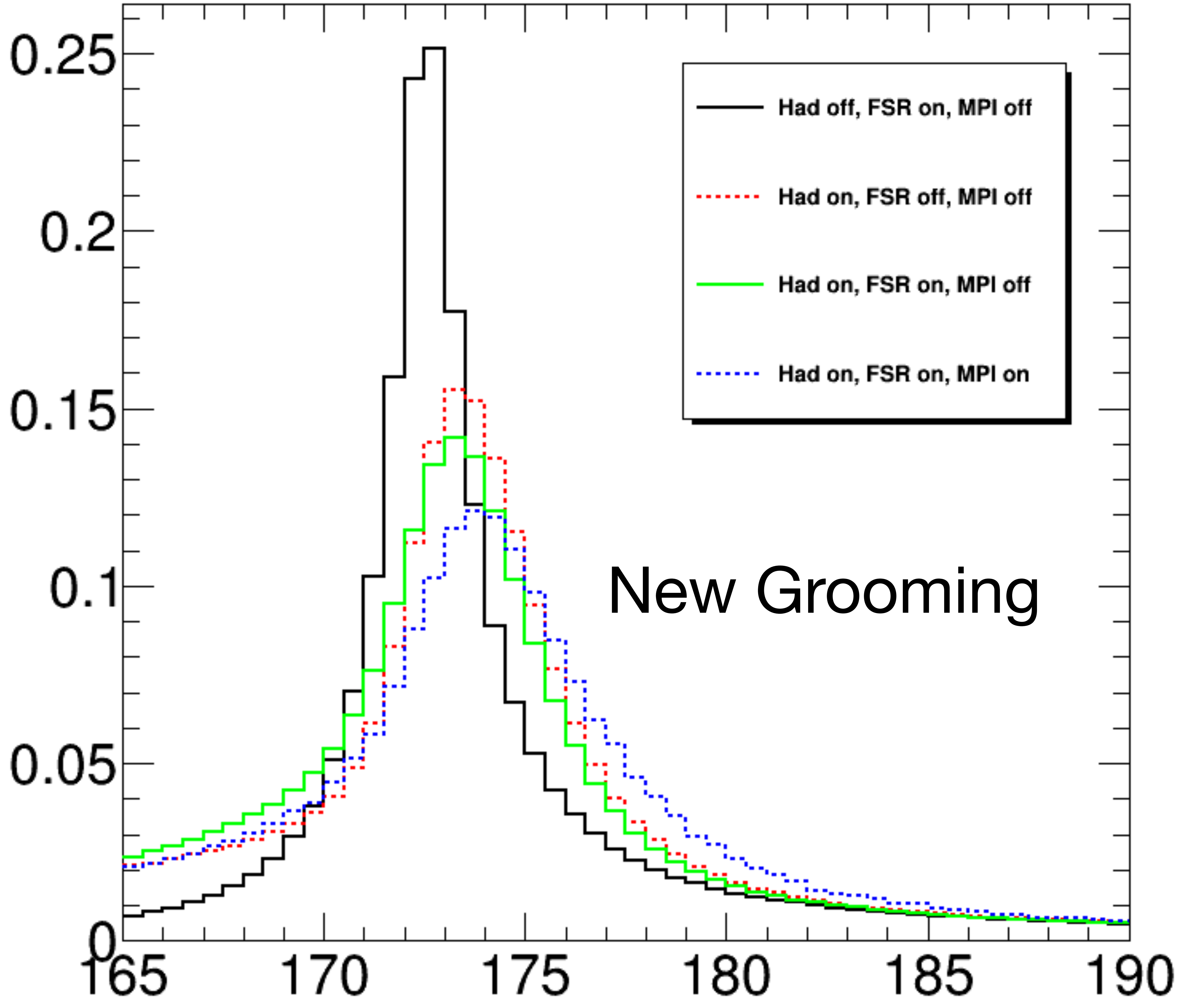
$$M_J^{Peak} \sim m_t + \Gamma_t(1 + \alpha_s \ldots) + h \times \Omega_1 + \left\langle R_d^4 \right\rangle_{M_J} \Lambda_{UE}$$

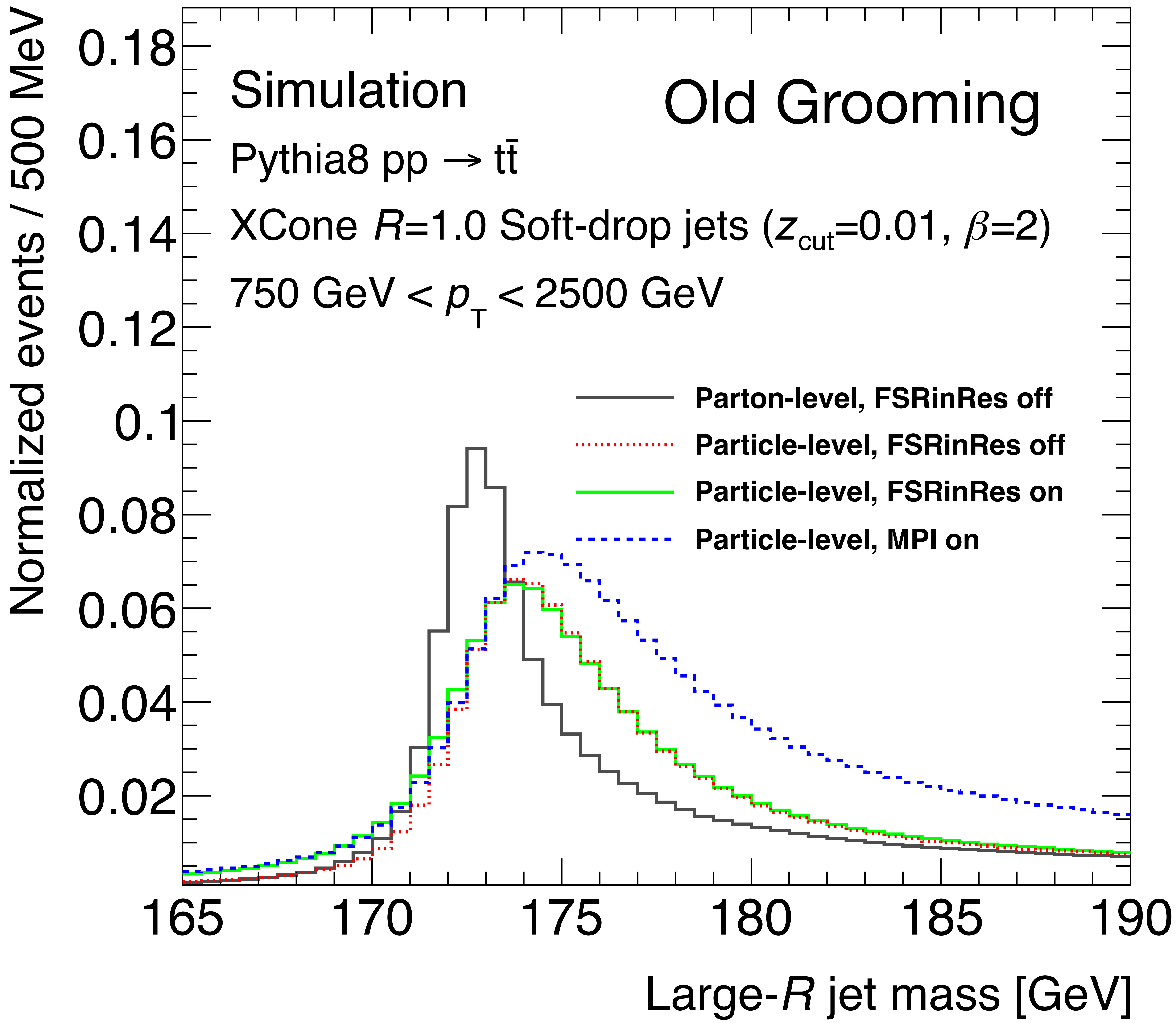
- No p_T dependence, only dependence on h, defined as $R_d = \frac{m_t}{p_T} h$
    - Possibility to bin in h instead of p_T.
    - Underlying event contribution Λ_{UE} depends on p_T. Can disentangle underlying event by considering different p_T bins.

Update to Theory

- **Can work with more aggressive grooming:**
  - Old: $z_{cut} = 0.01, \beta = 2 \quad \rightarrow \quad$ New: $z_{cut} = 0.02, \beta = 0$
- **Can perform calibration with new grooming scheme.**
  - Currently, only possible with pole mass, without gap subtraction.
  - MSR with gap subtraction numerically too difficult to implement at the moment.
  - Should be possible to disentangle first moment non-perturbative correction from underlying event contribution.

Comparisons





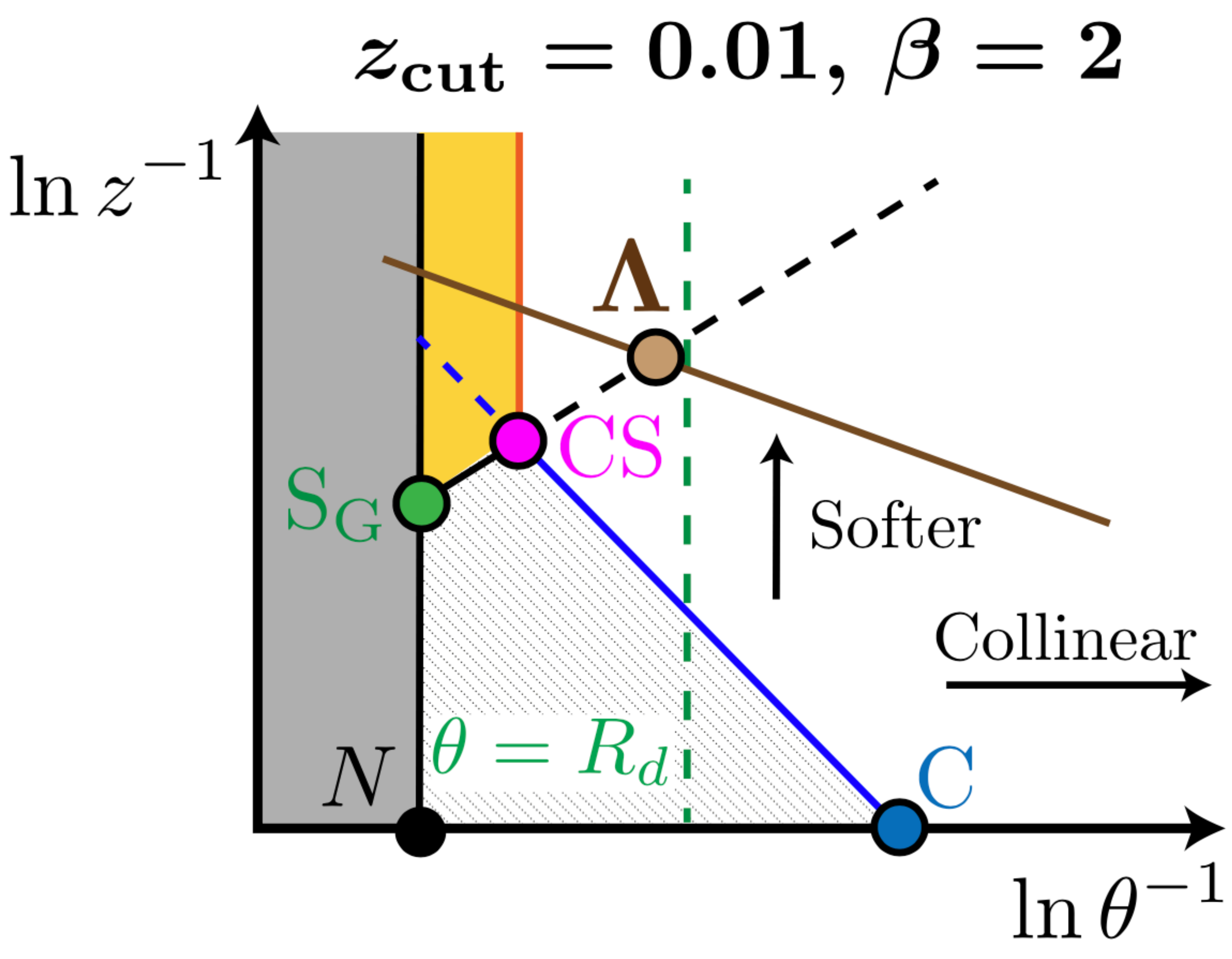
Conclusion

- In the future we need:
  - More studies into fit ranges.
  - Comparison of results with previous grooming scheme (pole mass).
  - Consideration of UE.
  - $e^+e^- \to t\bar{t}$ results.

Thanks for listening

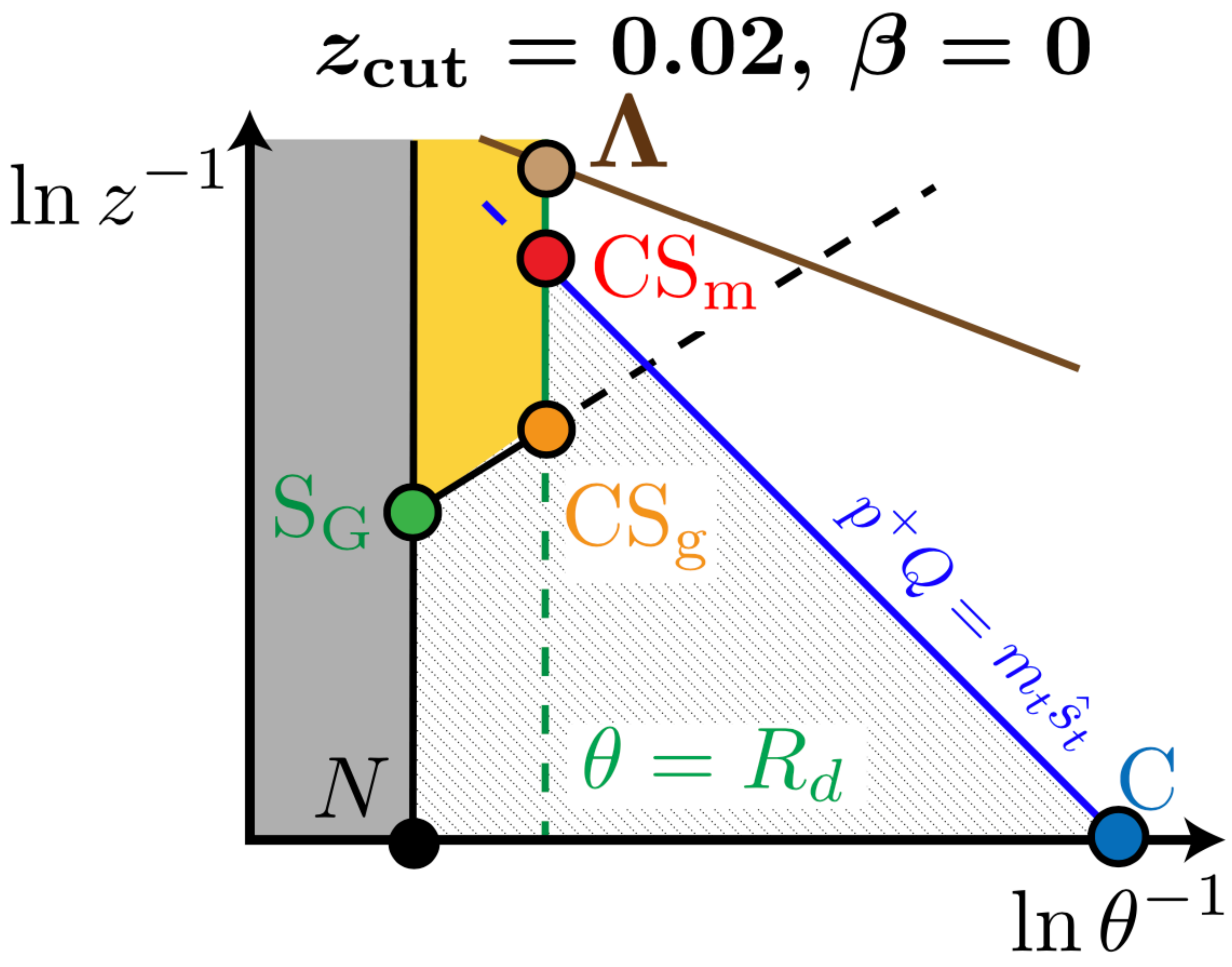
Backup - Changes in theory

Old Grooming Scheme



Soft drop outcome like light quark jets for $R_g > R_d$

New Grooming Scheme

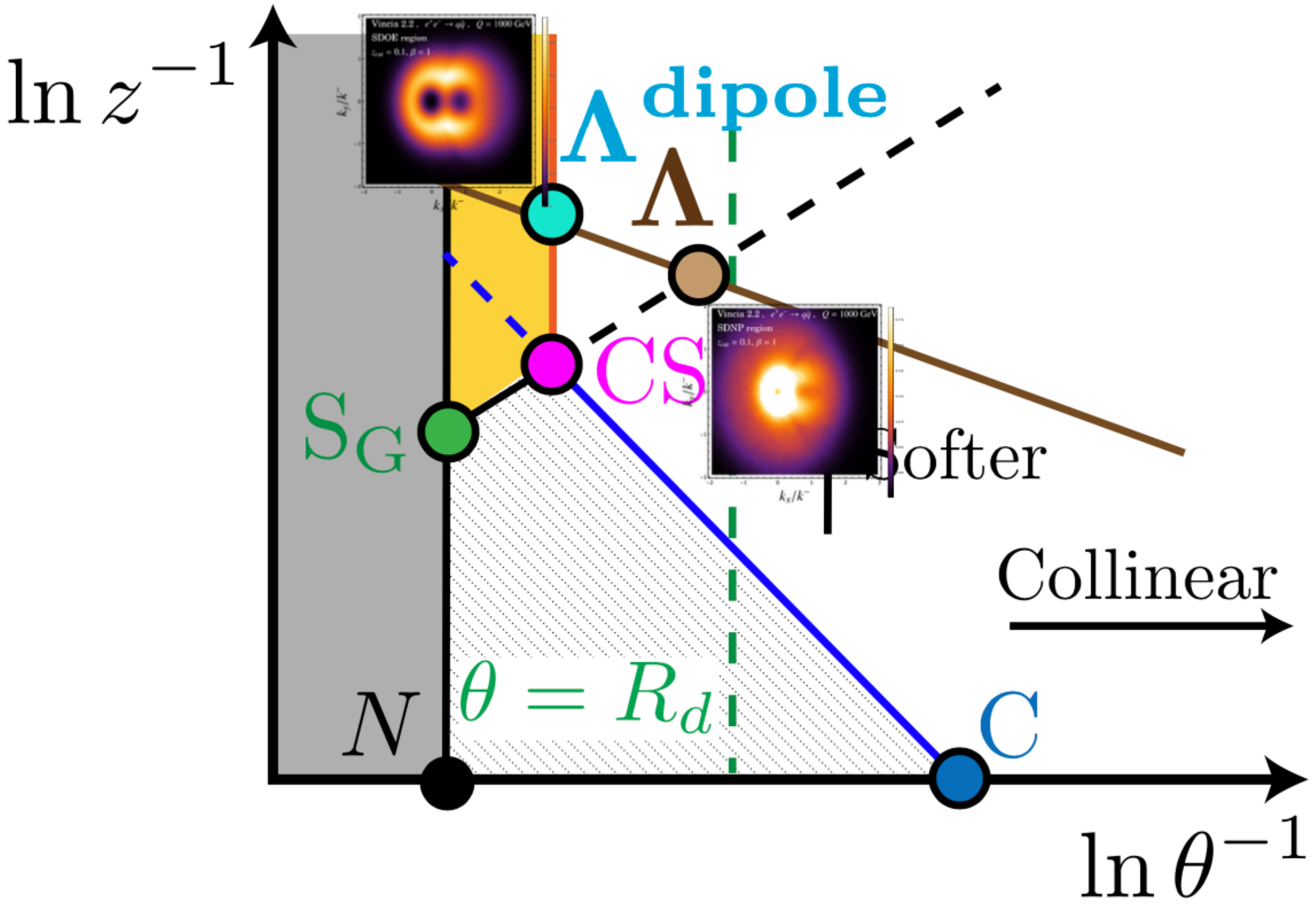


Soft drop halted by decay products at $\theta = R_d$

Backup - Changes in theory

Old Grooming Scheme

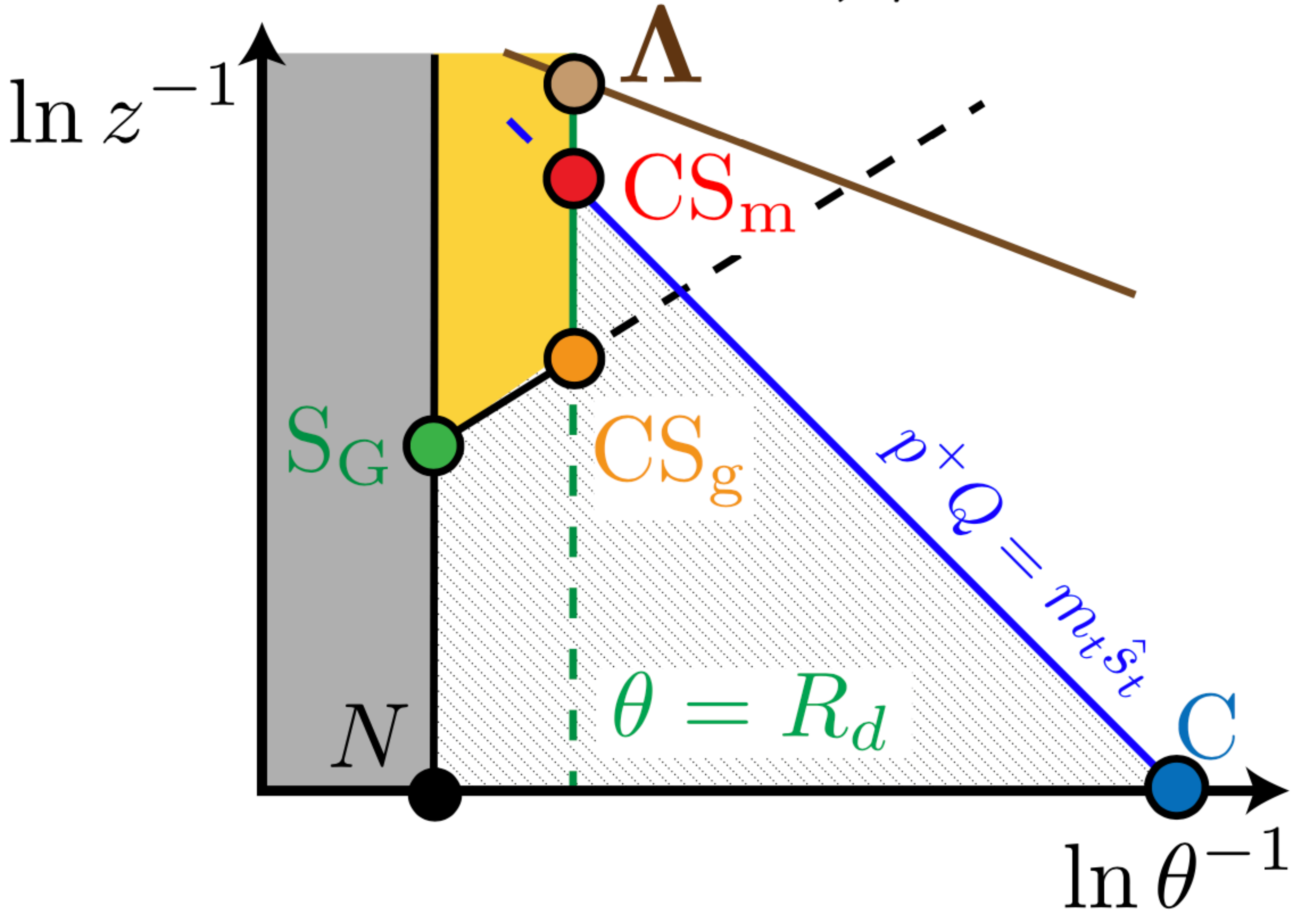
$$z_{\mathrm{cut}} = 0.01,\ \beta = 2$$



Hadronization corrections associated with soft drop are complicated: Λ^{dipole} merges with Λ as we reduce the jet mass

New Grooming Scheme

$$z_{\mathrm{cut}} = 0.02,\ \beta = 0$$

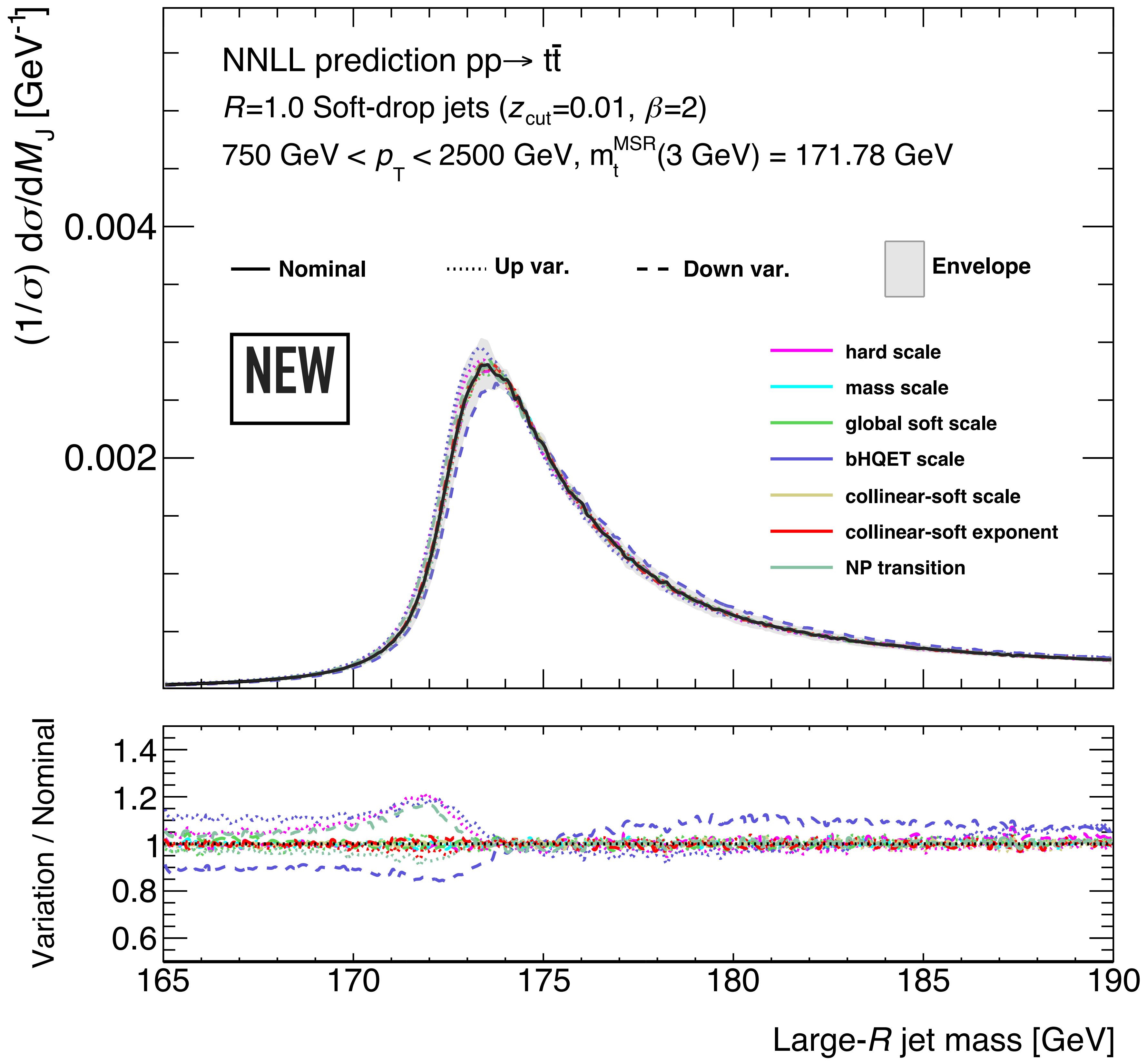


Hadronization corrections are identical to ungroomed jets (but not the same size!): Λ stays that way.

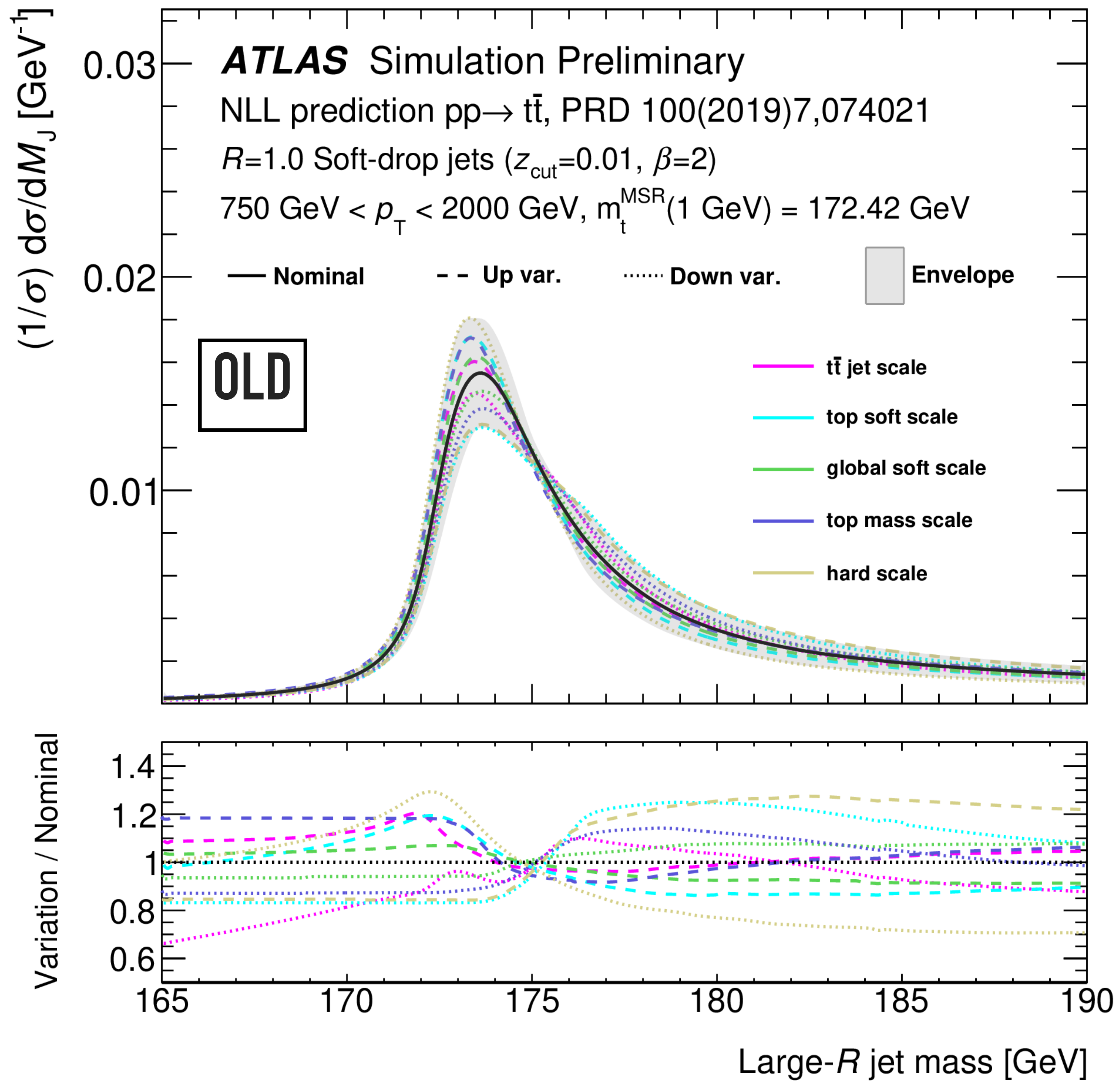
THEORETICAL UNCERTAINTIES

- Theoretical uncertainty determined by jet mass dependent renormalisation scales that to estimate the perturbative uncertainty.

Scale variations on these dependencies measured and compared to central value.



Scale variations lead to +110 MeV and -200 MeV shifts.

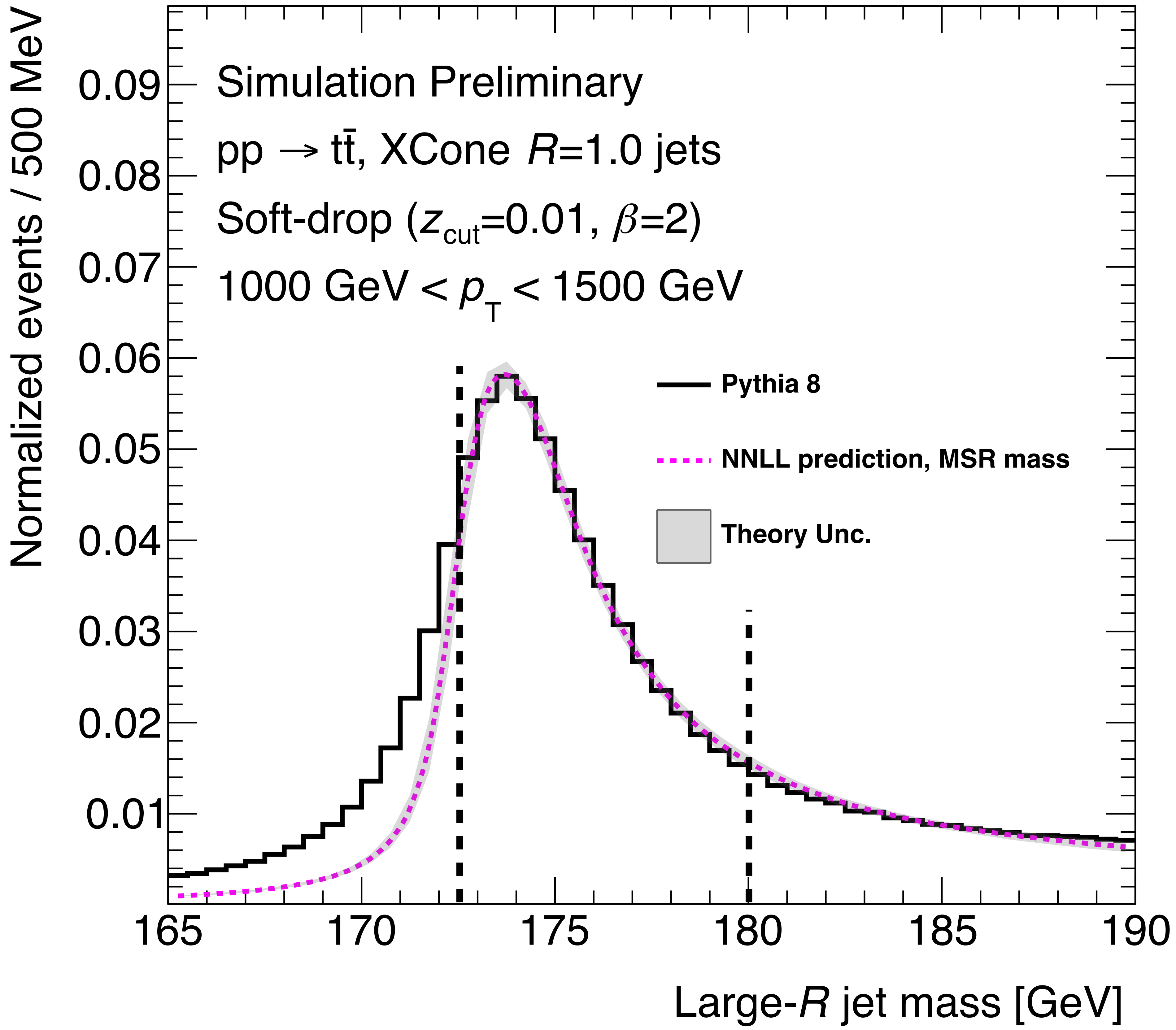


Big decrease from previous that was +230 MeV and - 310 MeV.

FITTING DETAILS

- Idea is to obtain **value of parameters in NNLL theory** calculation that **best describe MC prediction.**
- **Decay product FSR effects are not yet included in calculation.**
  - In grooming procedure, theory does not accurately describe the low-mass tail present in the generator prediction.
  - Must restrict fit range to avoid the low jet-mass tail, that would bias the extracted top mass to lower values.

➡ **Fit range set to 172.5-180 GeV.**



- Perform a **fit range study.**
  - Measure the top quark mass value at 172-180 GeV and 173-180 GeV

➡ Estimate an uncertainty: **±215 MeV**.

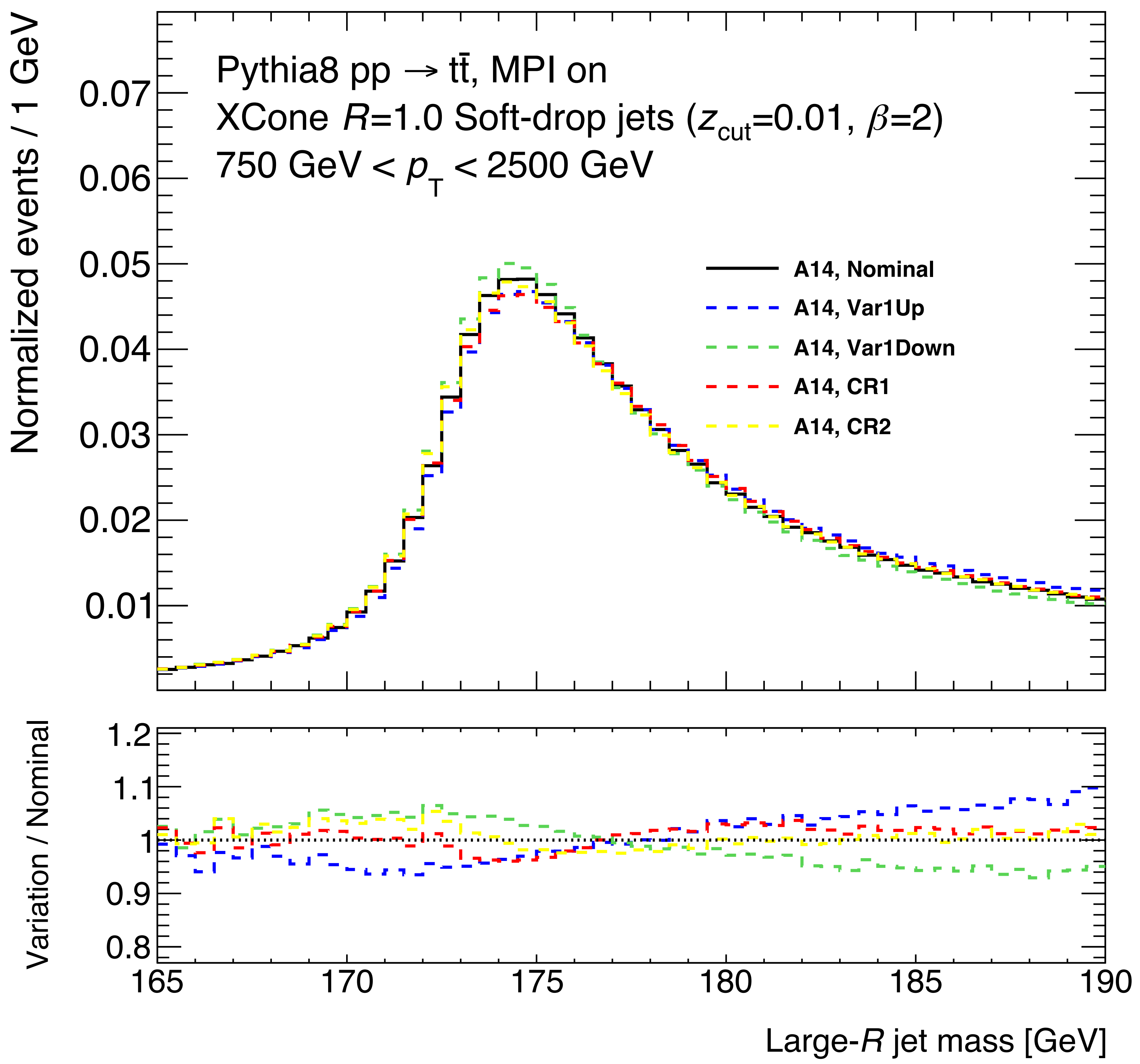
FITTING DETAILS

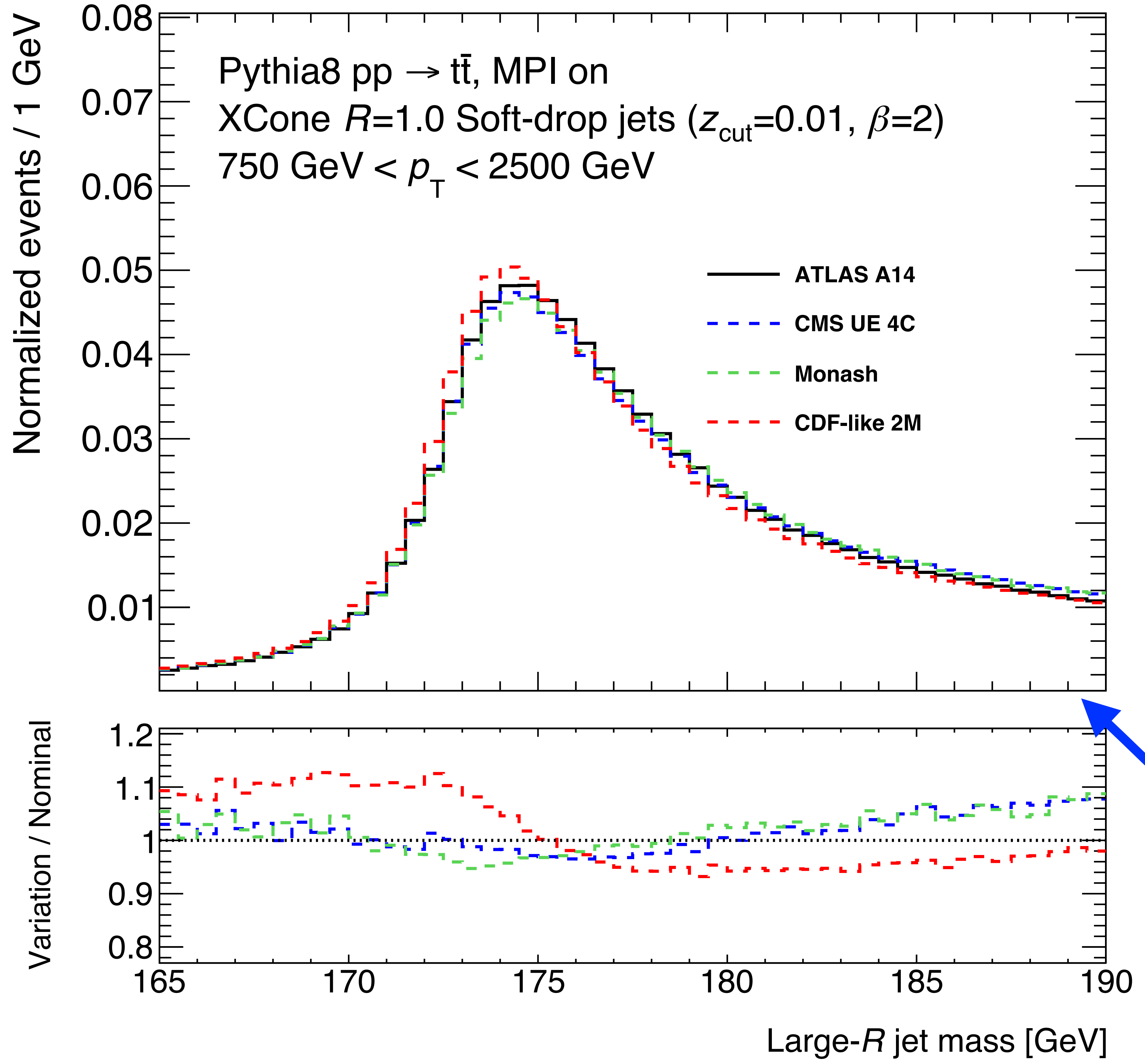
- Need to cover any bias of the influence of the kinematic ranges on the mass relation.
  - **Impact of the choice of large-R jet p_T is evaluated.**
  - **Compare fits on sub-sets of three p_T intervals for all permutations of the set of the 4 p_T bins.**
  - **Maximum variation taken as the uncertainty.**

→ Uncertainty calculated as $^{+63}_{-83}$ MeV.

UNDERLYING EVENT UNCERTAINTIES

- **Underlying event is not currently included in the calculation.**





- UE must be estimated through simulation parameter changes in MC-to-MC fits.
  - Comparing nominal MPI-on Pythia against A14 eigentune variations (coverage of UE variations modelling uncertainties).

    →Uncertainty of -122 MeV and +137 MeV.

  - Extend to inclusion of MPI-on Pythia against different tunes based on other detectors to evaluate the effect.