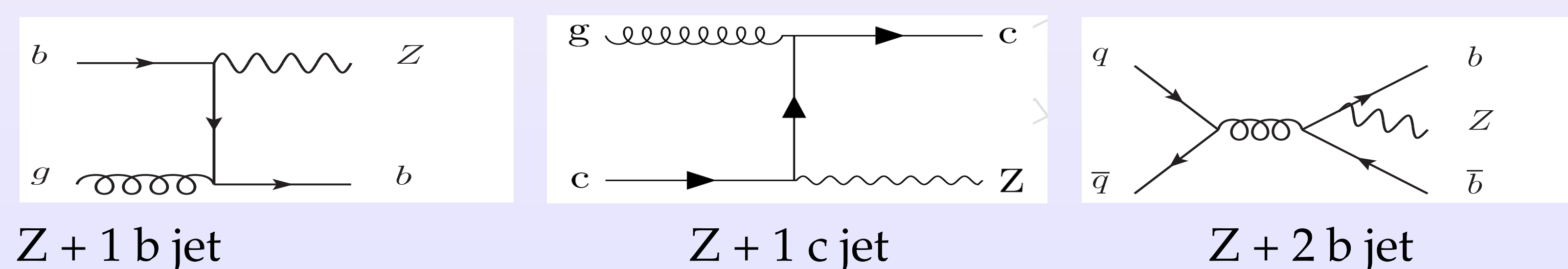


## Physics motivation

The cross section measurements of  $Z (\rightarrow ll, ll=\mu\mu/ee) + \geq 1$  b jet [1],  $Z + \geq 1$  c jet [2], & cross section ratio measurements of  $Z +$  b jet &  $Z +$  c jet w.r.t  $Z +$  jets ( $R(b/j)$  &  $R(c/j)$ ) [3] at 13 TeV are presented

- Measurements of  $Z +$  heavy-flavor (bottom (b), charm (c)) jets ( $Z +$  HF jets) are important to test electroweak & pQCD
- **Study at particle- & parton-level is a good approach to be compared against different hadronization-fragmentation processes**
- It also provides information on the b & c quark parton distribution functions (PDFs)
- Important background in many SM processes & BSM searches

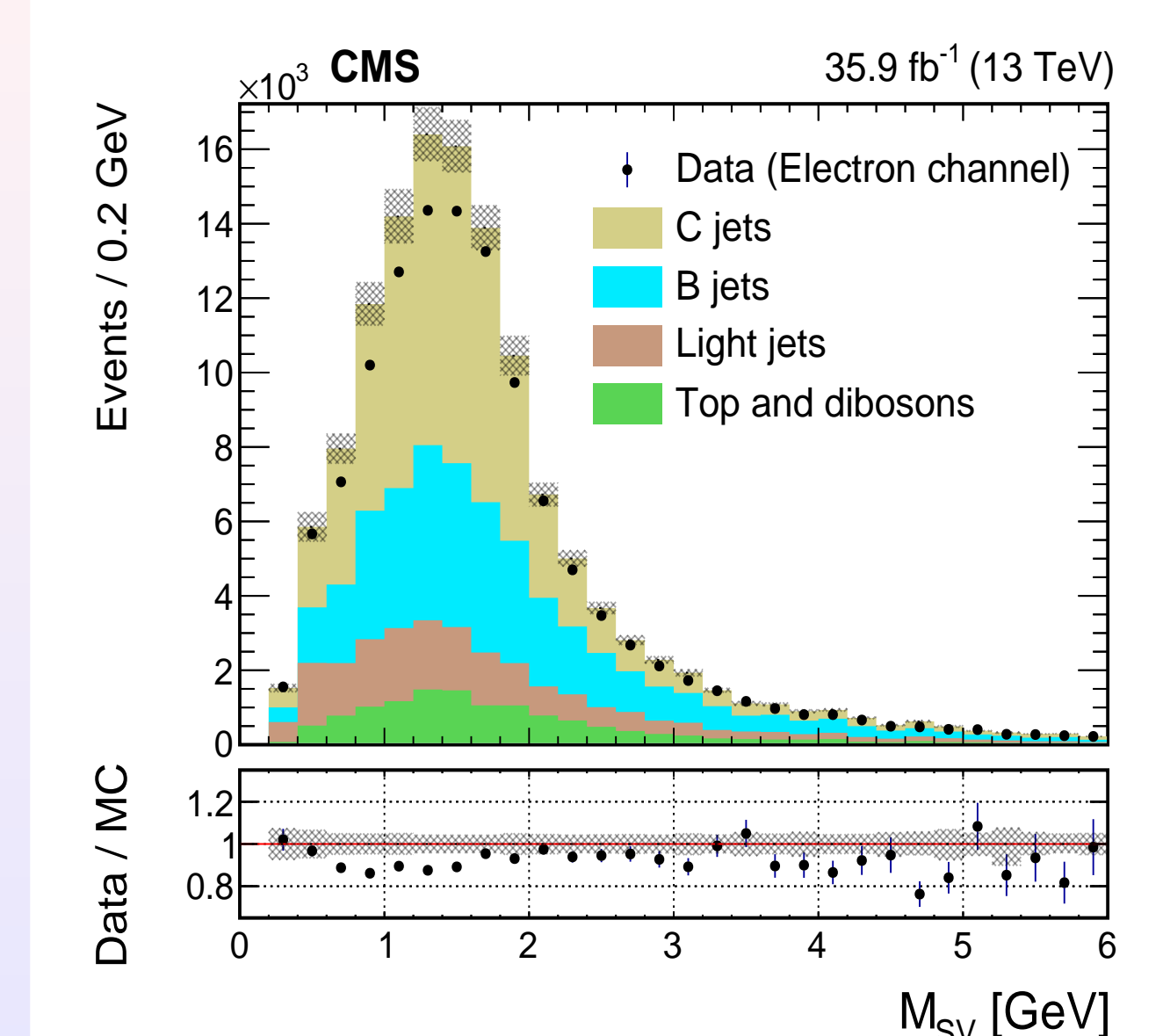


## Event selection

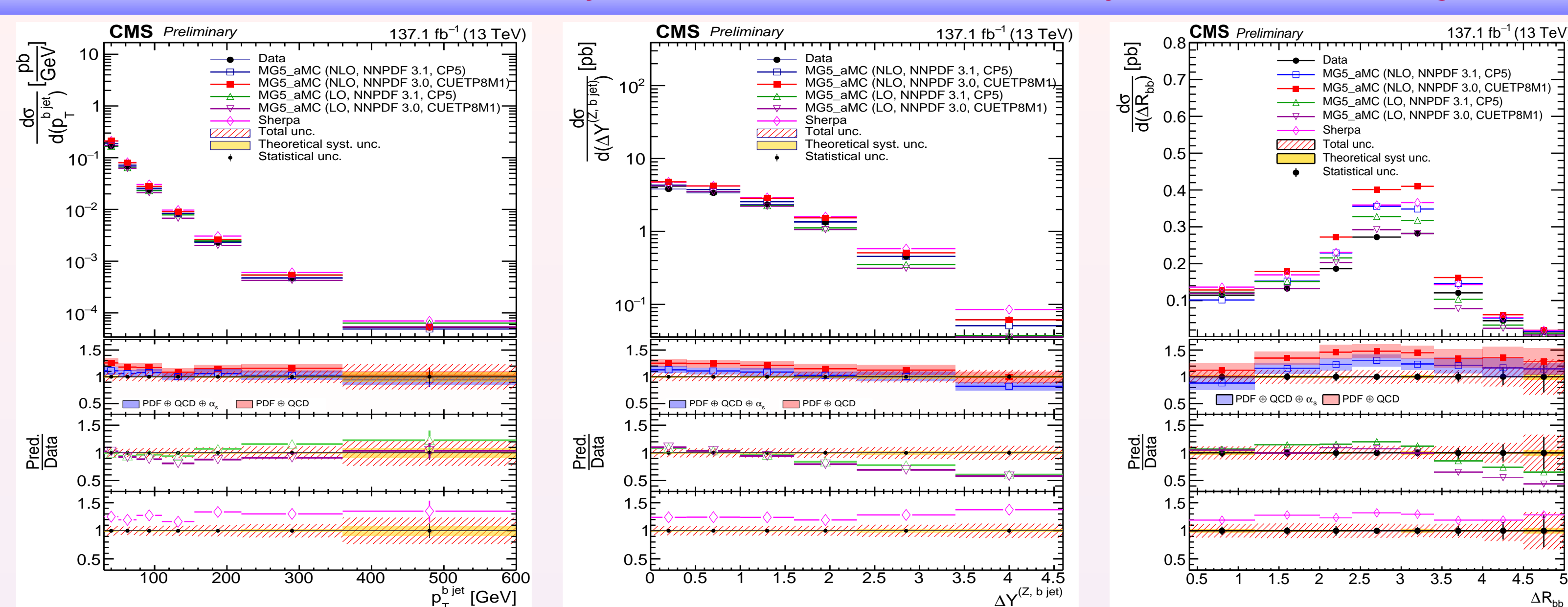
- $Z(ll)$ :  $71 < M_{ll} < 111$  GeV,  $|\eta(ll)| < 2.4$
- particle-level jets:  $p_T > 30$  GeV,  $|\eta(jet)| < 2.4$
- $Z(ll) + \geq 1$  b jet:  $p_T^{miss} < 50$  GeV
- $Z(ll) + \geq 1$  b/c jet: b/c jets are selected with deepCSV tight b/c-tag discriminators,
- $Z(ll) + \geq 1$  HF jets cross section ratio: particle (parton)-level jets:  $p_T > 30$  (15) GeV,  $p_T^{miss} < 40$  GeV, b jets are selected with deepCSV medium b-tag discriminator
- deepCSV discriminators: **combined tracks & secondary vertex (SV) characteristics using machine learning techniques**

## Background estimation

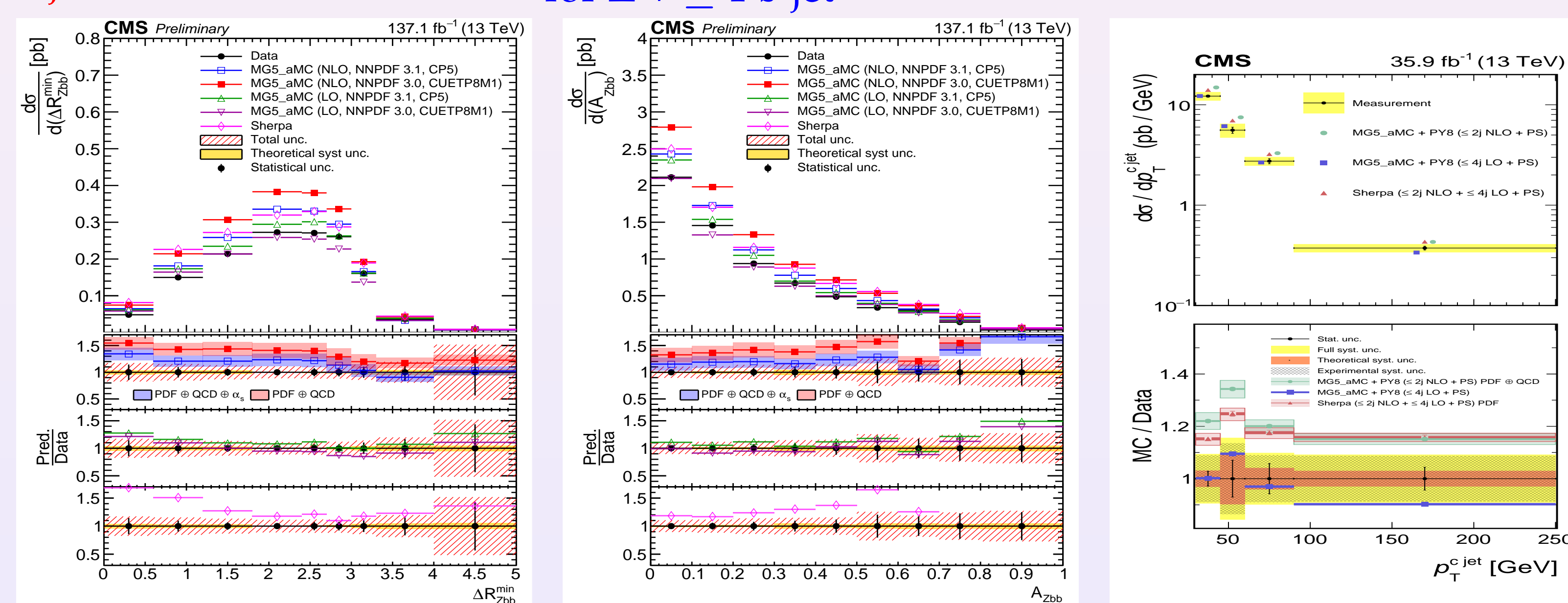
The dominant background contributions are extracted by fitting templates of SV mass distribution obtained from Drell-Yan simulation for  $Z +$  c jet analysis, & validated with different data driven methods for  $Z +$  HF jets cross section ratio analysis.



## Results: $Z + \geq 1$ b jet [1] & $Z + \geq 1$ c jets [2] analysis

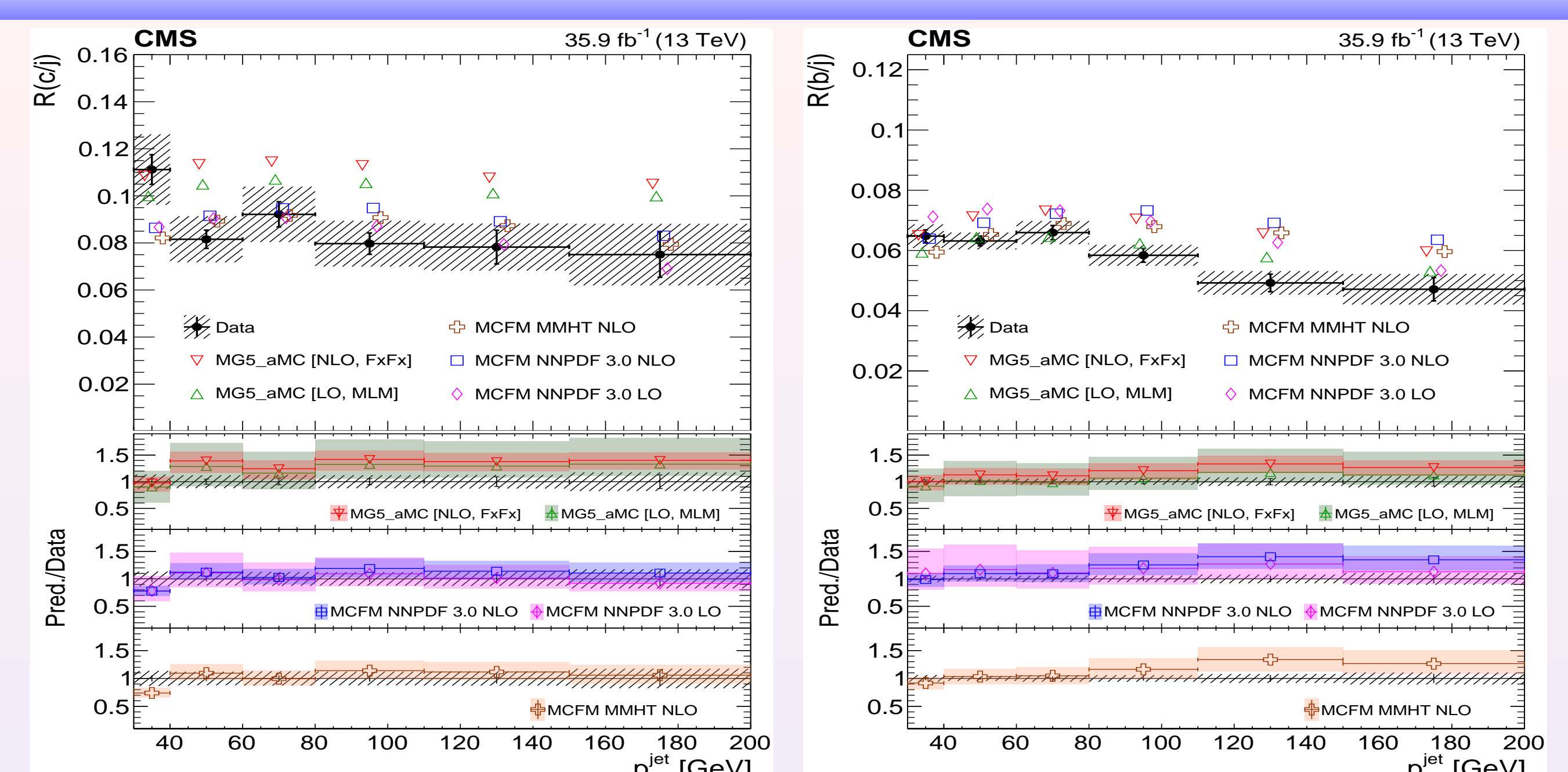


Leading b jet  $p_T$  for  $Z + \geq 1$   $\Delta Y(Z, bjet)$  ( $Y \rightarrow$  rapidity) b jet  
 $\Delta R_{bb}$  for  $Z + \geq 2$  b jet  
 for  $Z + \geq 1$  b jet



- $\Delta R_{Zbb}^{min}$  for  $Z + \geq 2$  b jet
- $\Delta R, \Delta Y \rightarrow$  agreement improved significantly with MG5\_aMC at next-to-leading-order (NLO) w.r.t leading-order (LO) in high regions
- $A_{Zbb} \rightarrow$  sensitive to extra emission of gluon at final state. If no extra gluon radiation, then  $A_{Zbb} \sim 0$ .
- SHERPA: provides good description of distributions shapes
- **$Z + \geq 1/2$  b jets results: use of more up-to-date PDFs (NNPDF 3.1), & underlying event tune (CP5), results in better agreement**

## Results: $Z +$ HF cross section ratio [3]



Measured differential cross section ratio (left)  $R(c/j)$  & (right)  $R(b/j)$  as a function of  $p_T^{jet}$  compared at particle-(parton)-level with MG5\_aMC (MCFM) predictions.

- $R(c/j) \rightarrow$  MG5\_aMC NLO overestimating the data, while MCFM LO & NLO describing well
- $R(b/j) \rightarrow$  All predictions describing well the data within 10%, except higher  $p_T^{jet}$  where NLO predictions deviate upto 20–30%

## Conclusion

- All NLO prediction PDFs overestimate the b/c quark content & will be useful in improving the the existing constraints in simulation of the b/c-quark PDF
- Provide valuable inputs for tuning & constraining model parameters of advanced parton shower Monte Carlo programs

## References

- [1] CMS Collaboration, "Measurement of  $Z+b$  jets cross section in proton-proton collisions at  $\sqrt{s} = 13$  TeV", CMS Physics Analysis Summary, CMS-PAS-SMP-20-015 (2021)
- [2] CMS Collaboration, "Measurement of differential cross sections for Z bosons produced in association with charm jets in pp collisions at  $\sqrt{s} = 13$  TeV", JHEP 04 (2021) 109, arXiv:2012.04119, doi:10.1007/JHEP04(2021)109
- [3] CMS Collaboration, "Measurement of the associated production of a Z boson with charm or bottom quark jets in proton-proton collisions at  $\sqrt{s} = 13$  TeV TeV", Phys. Rev. D 102 (2020) 032007, arXiv:2001.0689, doi:10.1103/PhysRevD.102.032007