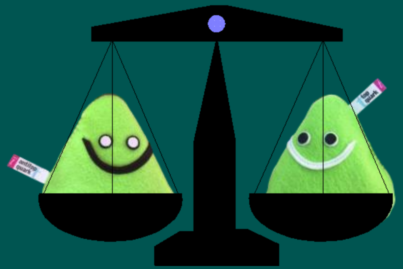
Institute of Particle Physics and Accelerator Technologies

State Research Programme

Jet flavor studies in CMS and flavor-antiflavor uncertainties for the top vs anti-top mass measurement



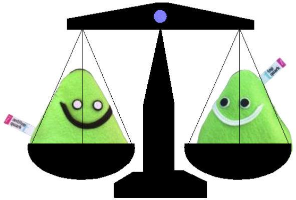
For the 3rd CERN Baltic Conference

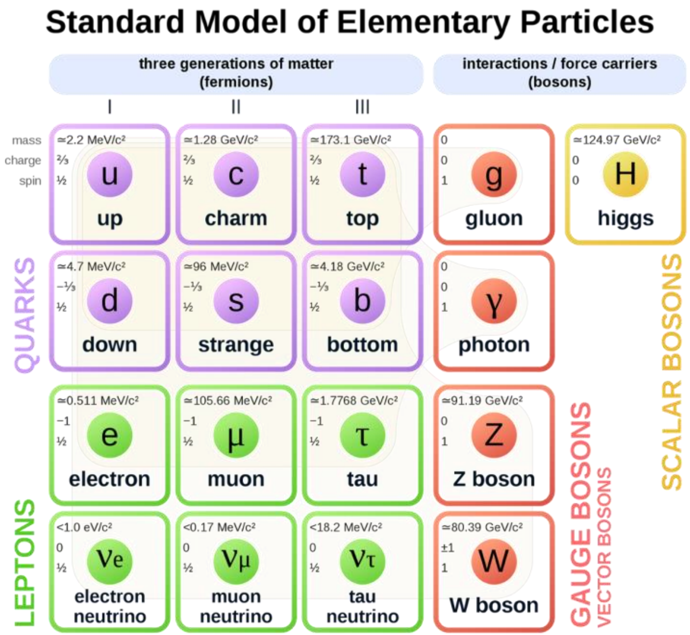
Kārlis Dreimanis, Markus Seidel,
<u>Andris Potrebko</u>

10.10.2023

Introduction

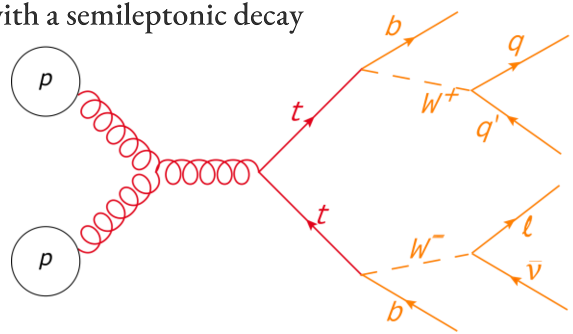
Top quark – the heaviest elementary particle in the Standard Model.





$t\bar{t}$ lepton+jets decay channel allows to measure m_t separately from $m_{\bar{t}}$.

Top-quark pair process with a semileptonic decay



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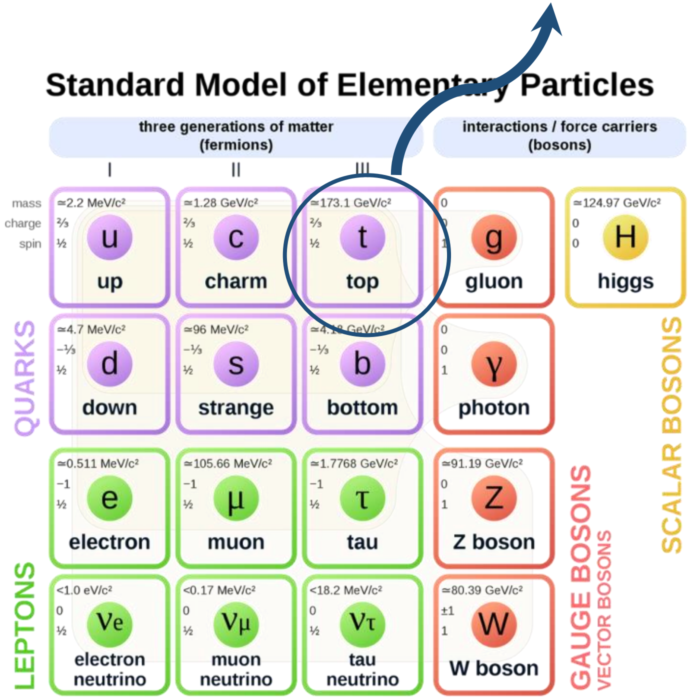

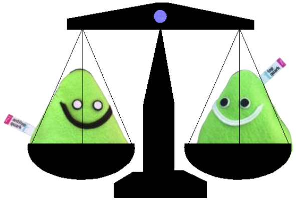

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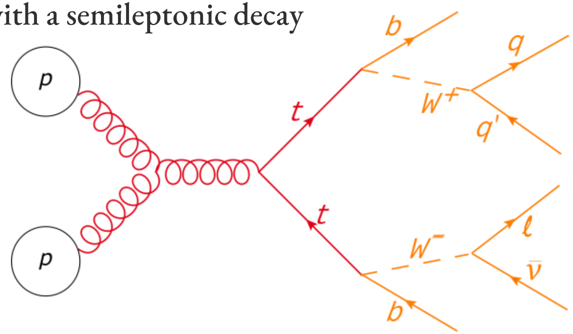

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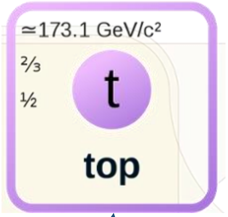

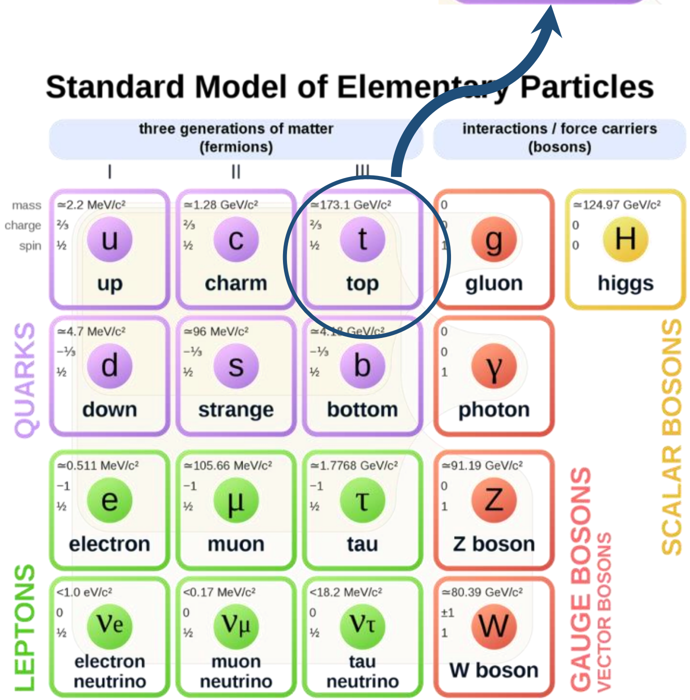

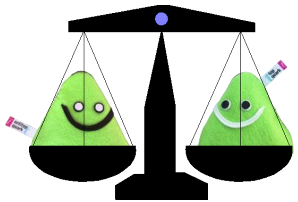

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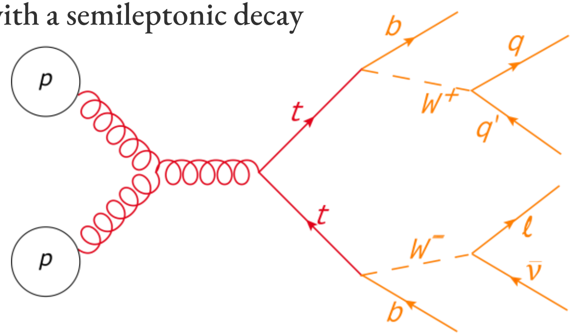

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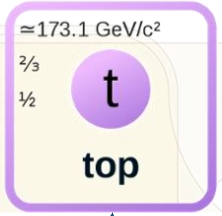

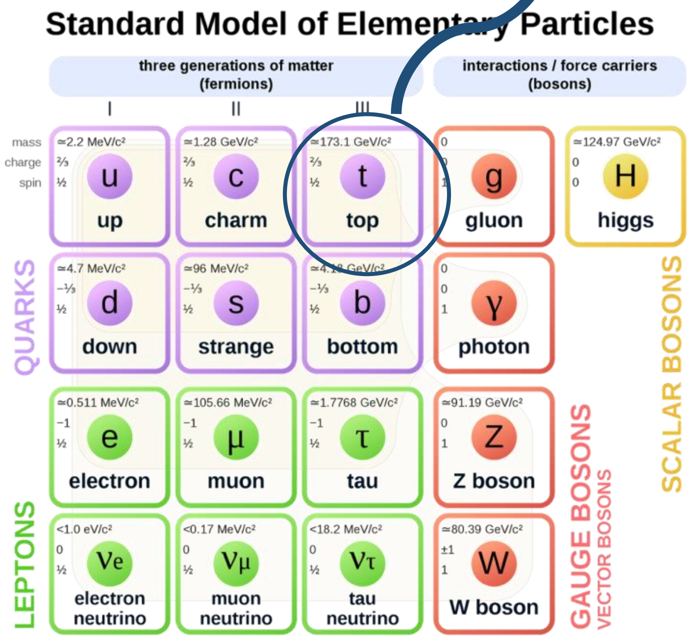

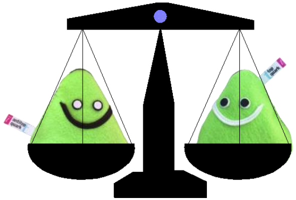

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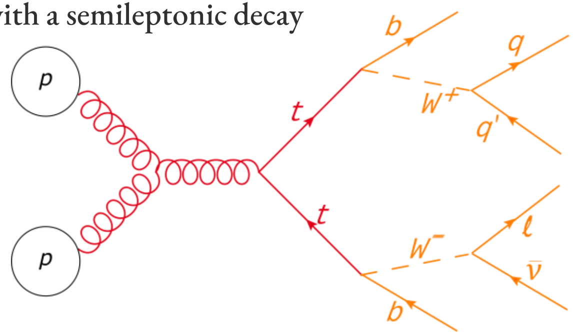
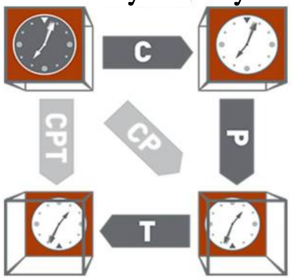


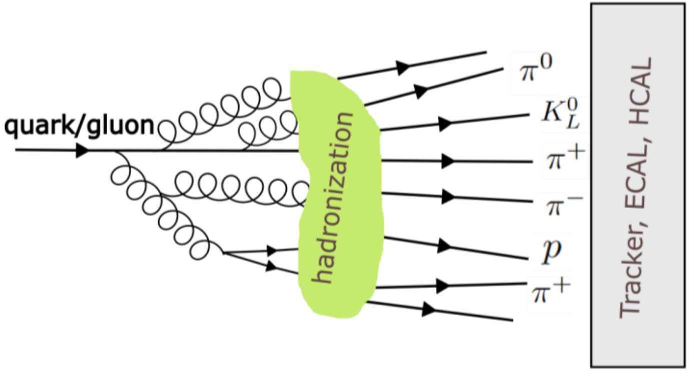
$\Delta m_t = m_t - m_{\bar{t}}$ analysis allows to probe the CPT symmetry.

CMT symmetry



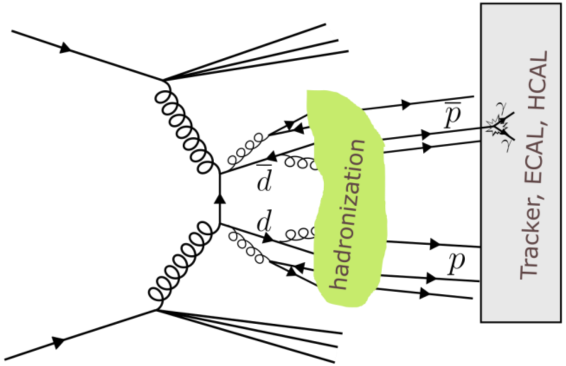
Δm_t measurement requires a good understanding of the differences of the bottom and antibottom quark responses in CMS.

1. Flavor-dependent Jet Energy Correction (JEC) and uncertainty studies for CMS Run 2



11 minutes

2. Quark-antiquark jet uncertainty



5 minutes

3. Conclusion

2 minutes

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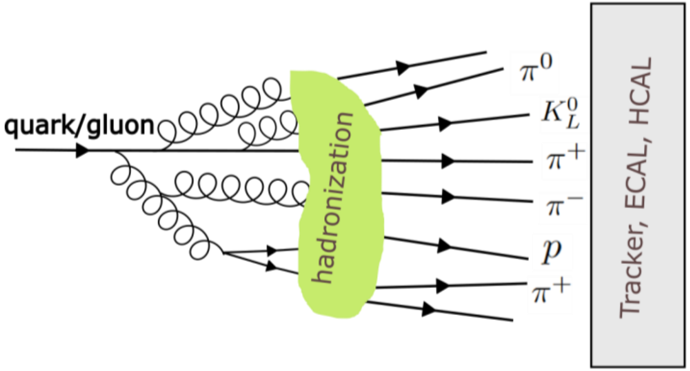

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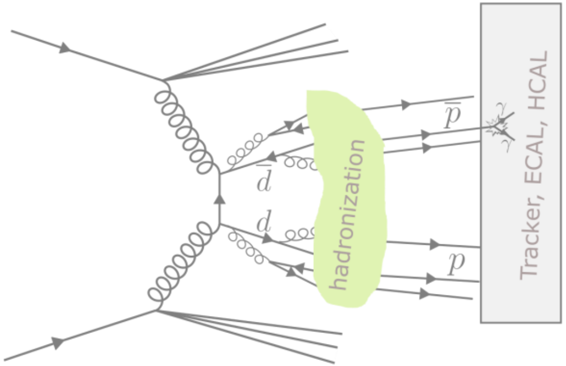


5 minutes

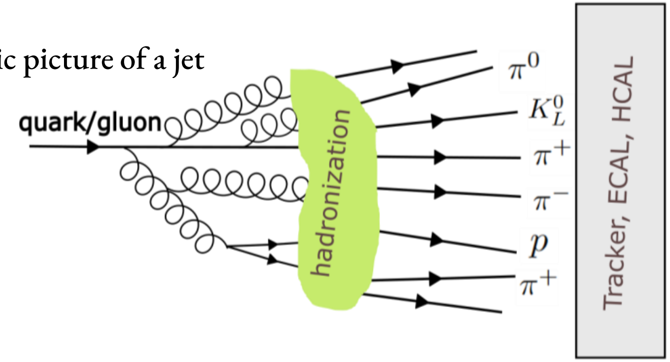
3. Conclusion

2 minutes

Jets are collimated sprays of particles

- Confinement: only particles in color singlet state are observed in nature.
- Hadronization: (non-perturbative) formation of hadrons out of quarks and gluons.

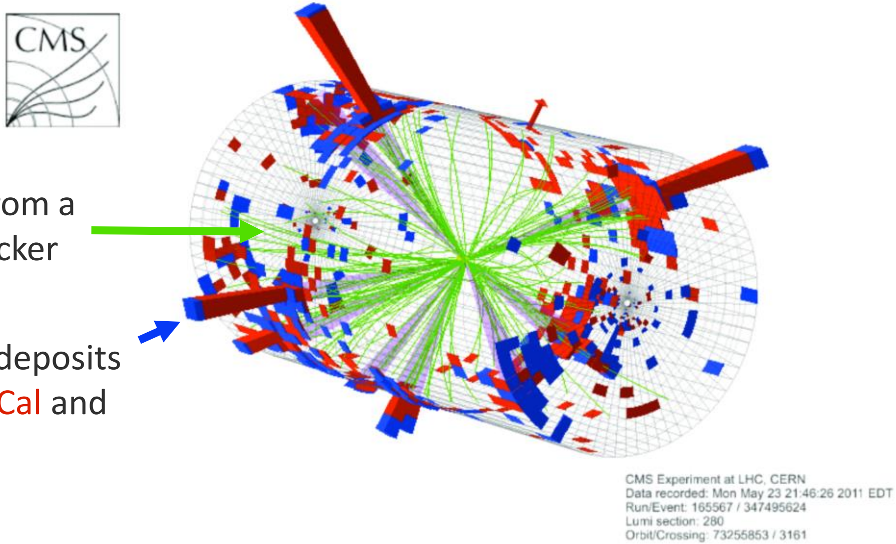
Schematic picture of a jet



- Calo jets: only calorimeter response used.
- PF jets: Particle Flow (PF) hadrons are clustered ⇒ information from multiple subdetectors is combined.

see, poster on PF by D. Osīte and C. Diaz

A multijet event in CMS



"Cluster" algorithm family:

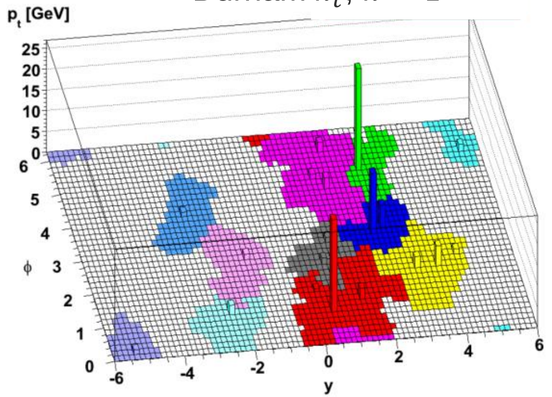
Sequentially combine particles based on the distance measure (starting with the smallest).

$$d_{ij} = \min(p_{T,i}^{2k}, p_{T,j}^{2k}) \frac{\Delta_{ij}^2}{R^2}$$

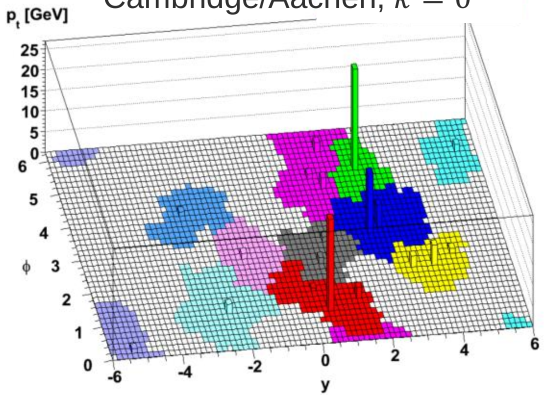
- Δ_{ij}^2 → Distance between particles i and j
- $p_{T,i}^{2k}$ → Transverse momentum, p_T, of the particle i
- R^2 → Jet radius (maximum distance)

In CMS, jets are typically clustered with anti-k_t with R=0.4, boosted jets with R=0.8.

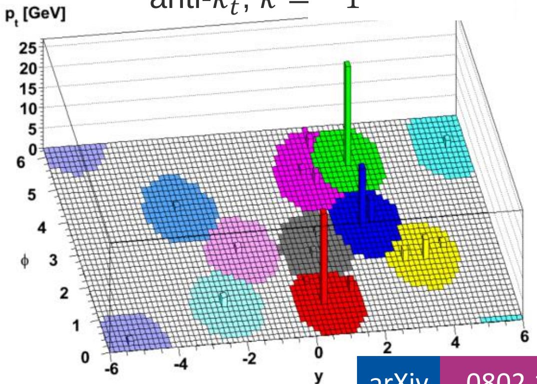
Durham k_t, $k = 1$



Cambridge/Aachen, $k = 0$



anti-k_t, $k = -1$



arXiv 0802.1189

Jets require calibration

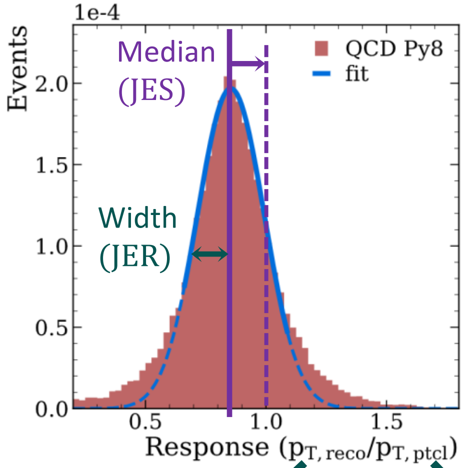
Jet p_T: typically, different from the generated/true p_T:

- Pileup
- Non-linear calorimeter response
- Out-of-cone radiation

Jet p_T response distribution is used in the MC-truth driven corrections.

JES = jet energy scale

JER = jet energy resolution



measured p_T (detector simulation)

true (generated/ particle-level) p_T

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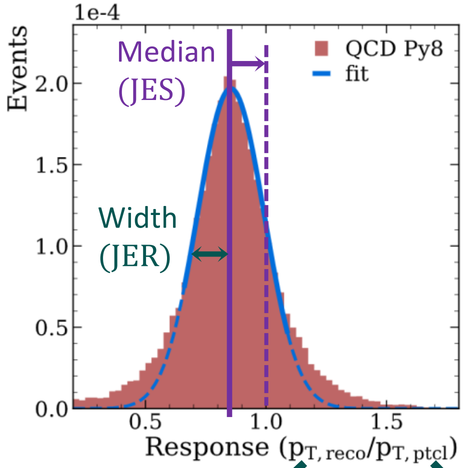

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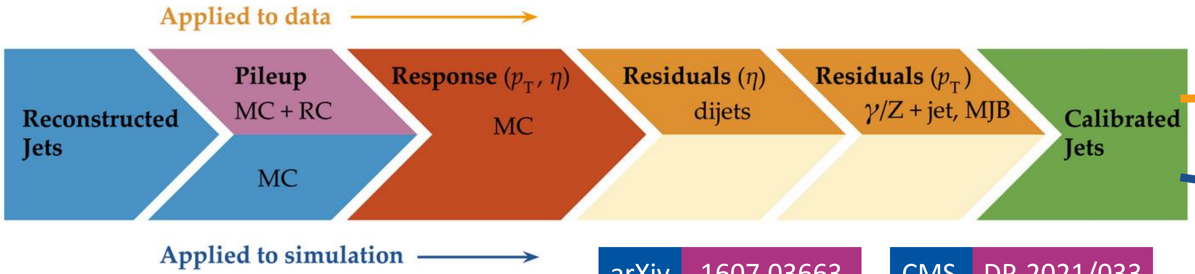
CMS jet correction strategy: factorized in steps



Optional → Flavor-dependent correction (MC)

Mandatory → Uncertainties incl. jet-flavor uncertainty

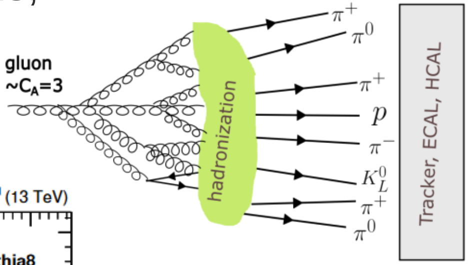
arXiv 1607.03663 CMS DP-2021/033

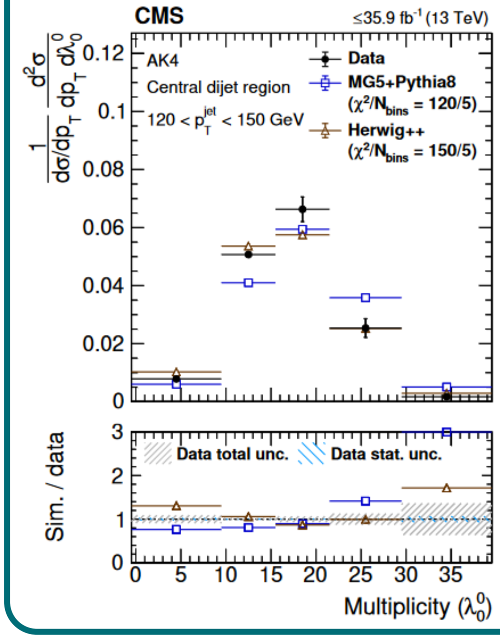
Jets of different flavors behave differently

Gluon jets:

More, softer hadrons,

lower response





Dijet sample:

mostly gluon enriched;
larger multiplicity

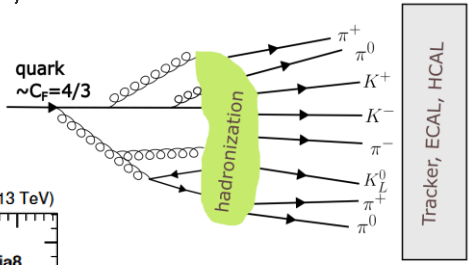
$\langle \lambda_0^0 \rangle \equiv \langle n \rangle \approx 20$

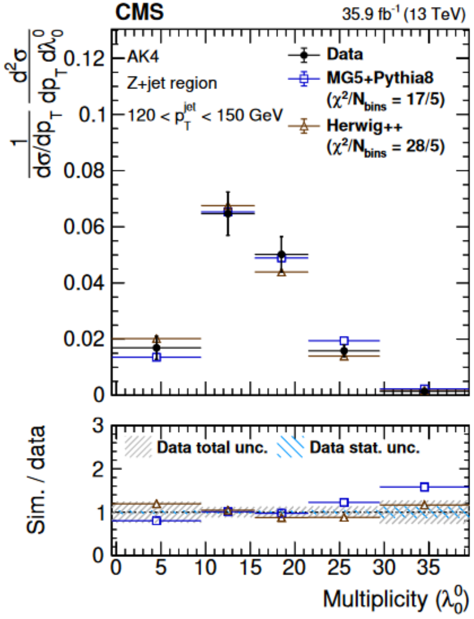
arXiv 2109.03340

Quark jets:

Less, harder hadrons,

higher response





Z+jet sample:

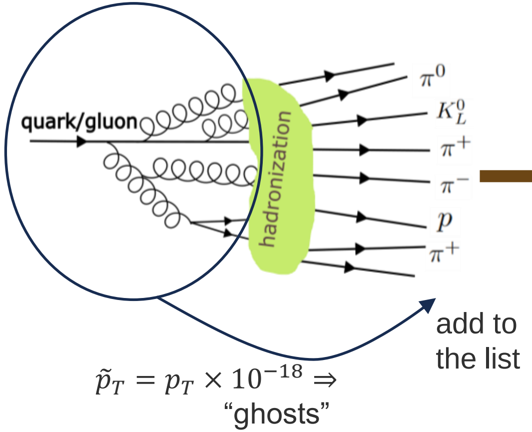
Mostly quark enriched;
smaller multiplicity

$\langle \lambda_0^0 \rangle \equiv \langle n \rangle \approx 15$

arXiv 2109.03340

Jet flavor assignment

MC flavor assignment: "ghost clustering"



Anti-kT algorithm: R=0.4

Jet flavor:

flavor of the hardest parton clustered in the jet

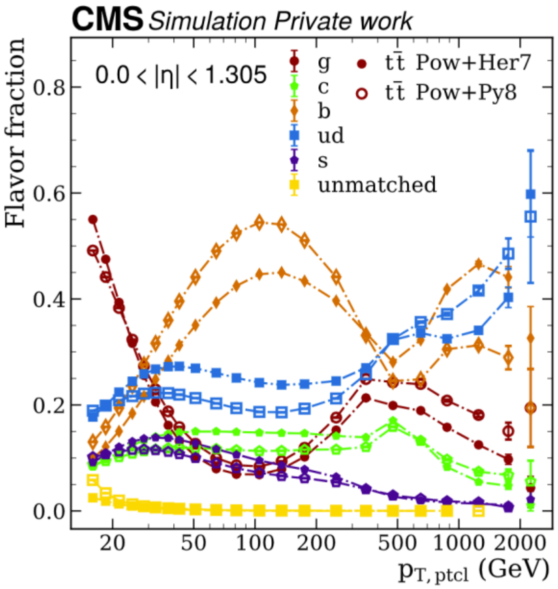
1. Physics partons, all partons from the matrix element to the hadronization, are added as "ghosts" (scaled by a small number) to the list of stable hadrons;
2. The jet clustering is repeated together with the ghost partons;
3. Flavor of the hardest parton is assigned to the jet (bottom/charm are given priority).

More precise than ΔR matching (hardest parton within the cone) for non-conical jet shapes.

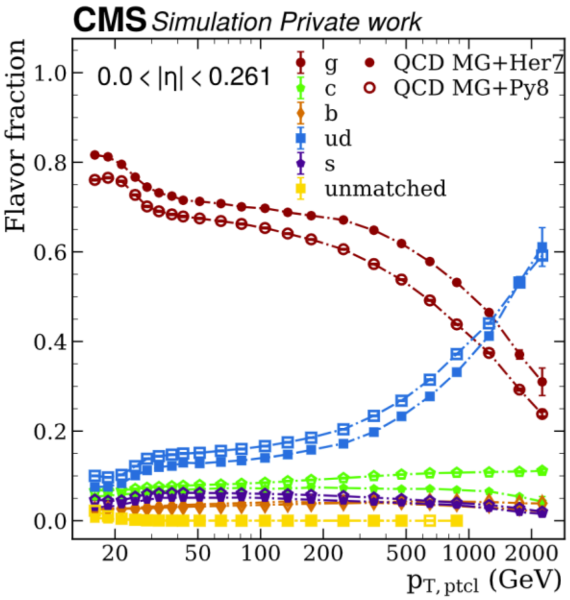
Different physics processes have different flavor mixes

- Three different samples with three distinct flavor mixes.
- All showered with both Pythia 8 and Herwig 7 generators.

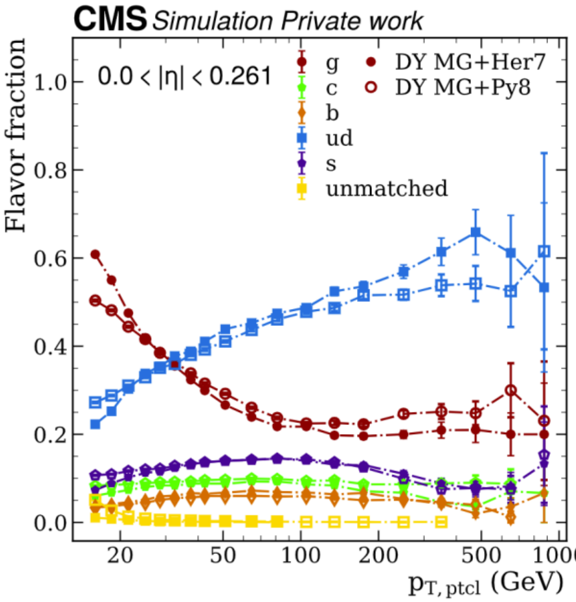
$t\bar{t}$: bottom enriched



QCD (dijet): gluon enriched



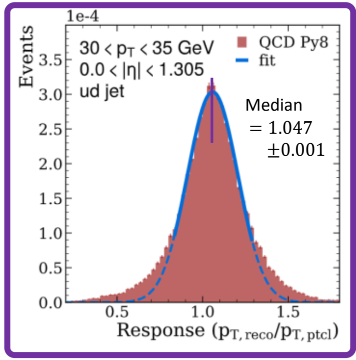
DY(Z+Jets): quark enriched

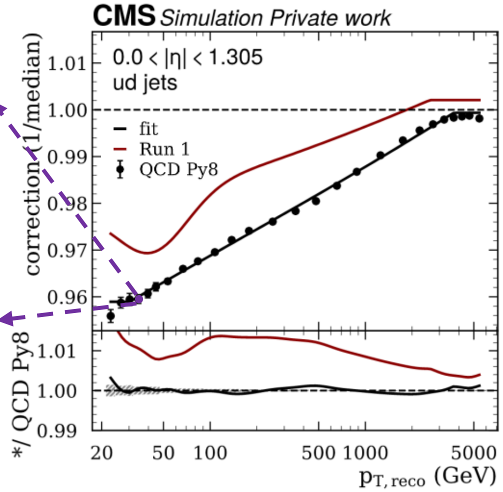


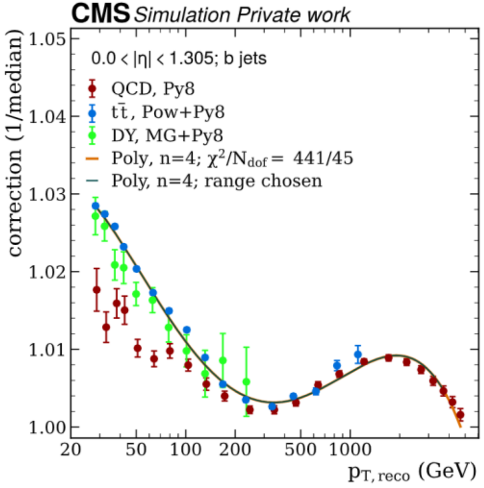
Flavor-dependent jet energy correction: results

Large differences w.r.t Run 1 (QCD):

- Pythia 6 vs Pythia 8
- Different flavor definitions
- Reduced statistical uncertainties

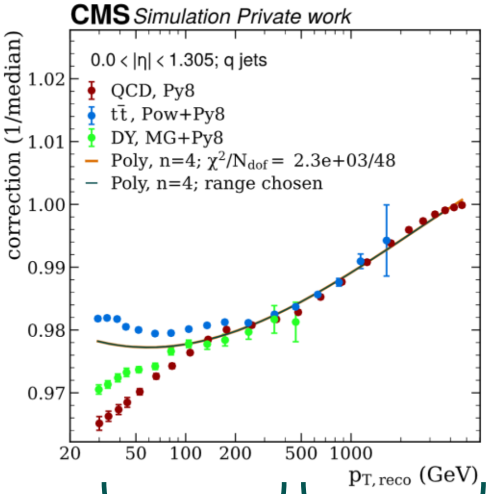






Mostly jets from $t\bar{t}$

Mostly jets from QCD



Benefits from DY

Mostly jets from QCD again

The final flavor correction in Run 2:

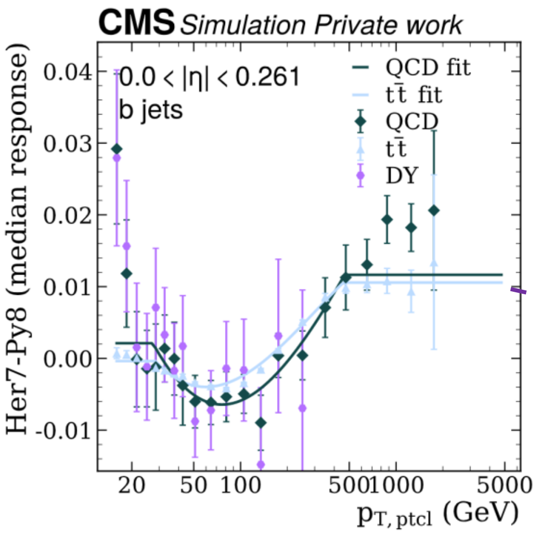
- Obtained from a simultaneous fit of several physics processes
- Slight differences (at low p_T) between different event topologies

Jet flavor uncertainty: results

Uncertainty of jet flavor mismodelling.

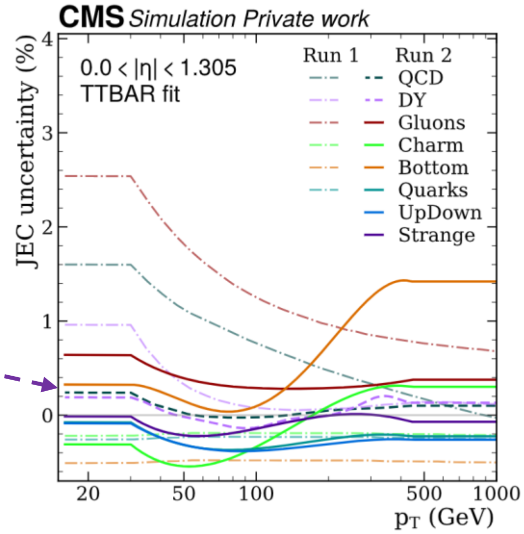
Estimated in Monte-Carlo data using:

Pythia8 (p_T-ordered shower) vs Herwig7 (angular-ordered shower)



Normalized to the reference point of the global fit to obtain the uncertainty.

Slight differences for different event topologies, e.g., $t\bar{t}$: busier with jets and has jets from a color singlet.



Quarks split into (kaon rich) Strange and UpDown.

Improvement w.r.t. Run 1 (Herwig++ vs Pythia 6).

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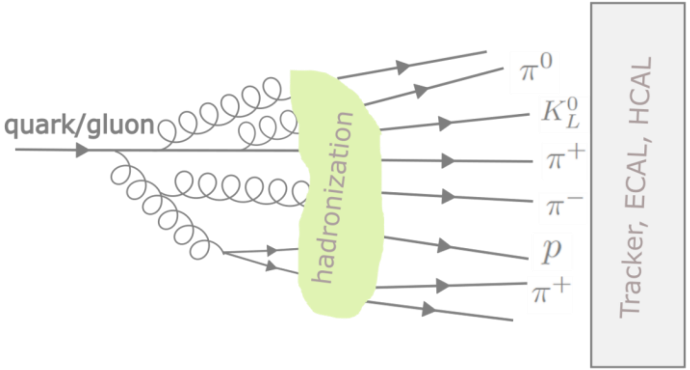
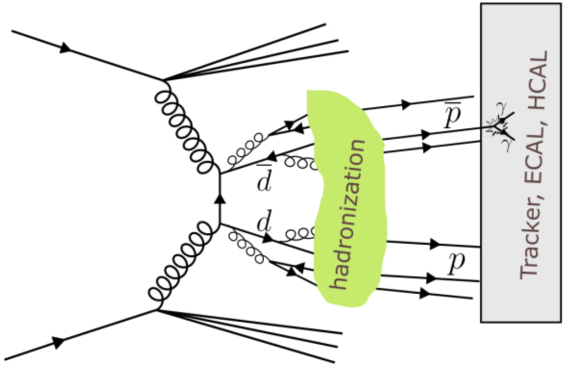


11 minutes

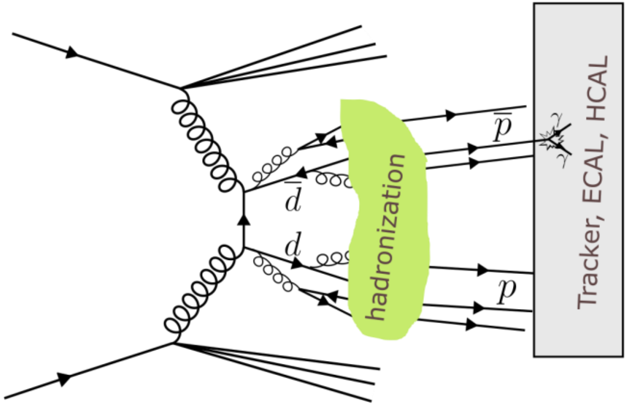
2. Quark-antiquark jet uncertainty



5 minutes

3. Conclusion

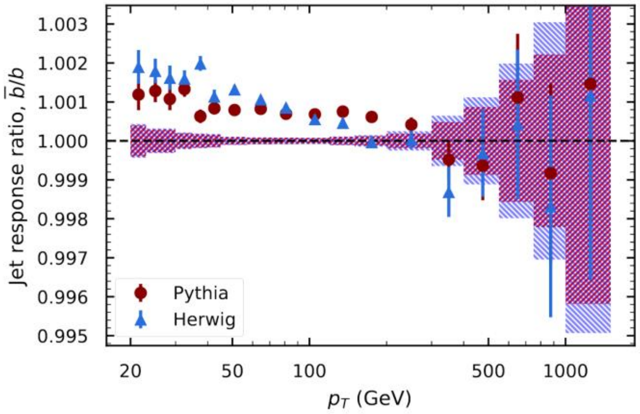
2 minutes



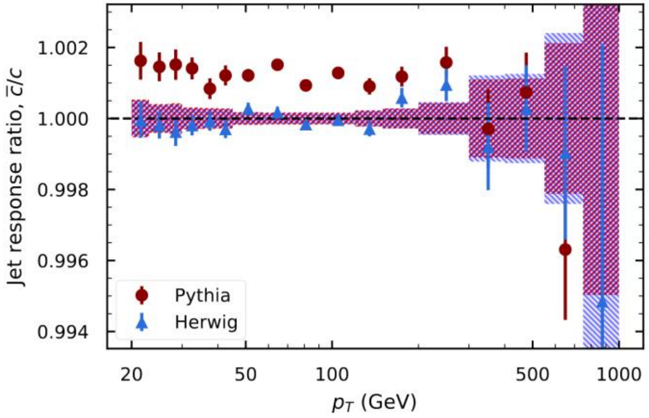
anti-quark jets: larger antiparticle content
⇒ annihilation ⇒ O(0.1%) larger response.

Herwig: predicts such an effect only for b-jets.

The ratio of jet energy responses for $\overline{b}$-jet and b-jet at *0<|η|<1.3*

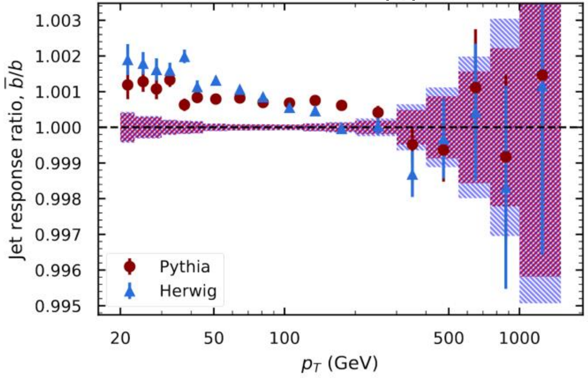


The ratio of jet energy responses for $\overline{c}$ -jet and c-jet at *0<|η|<1.3*



Flavor vs antiflavor: MC driven

The ratio of jet energy responses for $\bar{b}$-jet and b-jet at $0<|\eta|<1.3$



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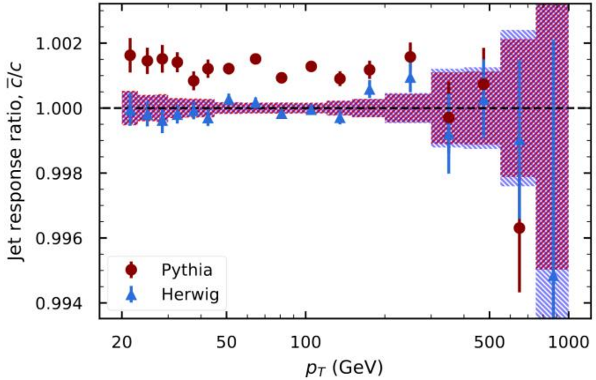
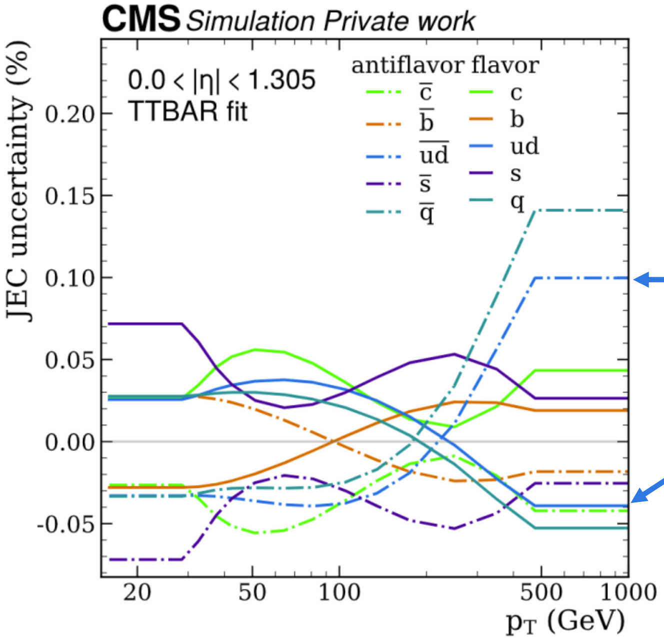


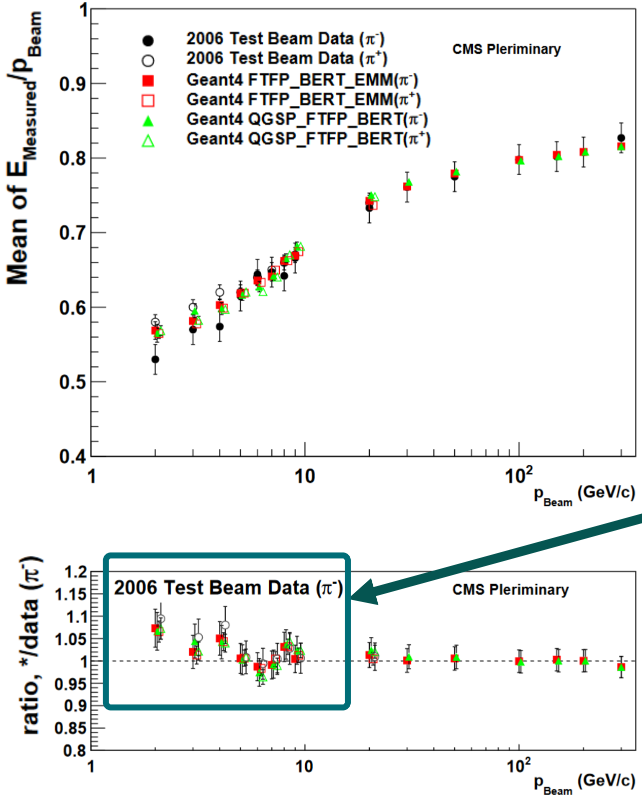
Improved approach for the b vs $\bar{b}$ uncertainty vs Run 1.



Slightly asymmetric for ud jets due to more ud jets than $\overline{ud}$ jets in pp collisions.

Flavor vs antiflavor: hadron-detector interaction

π^+ vs π^- difference in the CMS HCAL test beam



Larger response for π^+ than for π^-.

Not accounted for by the detector simulation (using the Geant4 program).

Work plan:

Before the Particle Flow hadron calibration:

$$E_{Meas,\pi^-}(p_T) \rightarrow E_{Meas,\pi^-}(p_T) \cdot C(p_T)$$

↓

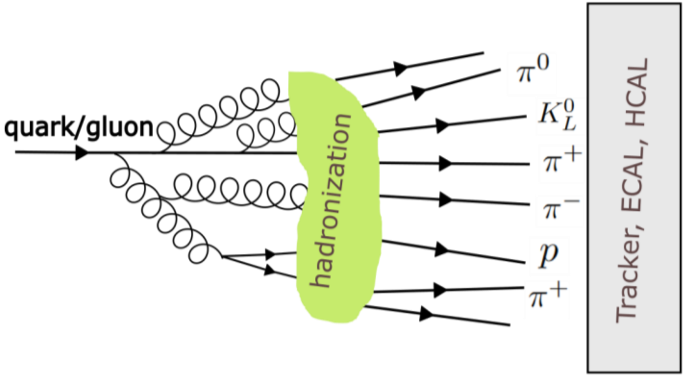
Full event reconstruction

↓

Uncertainty from comparing the corrected vs the original sample using the JEC framework

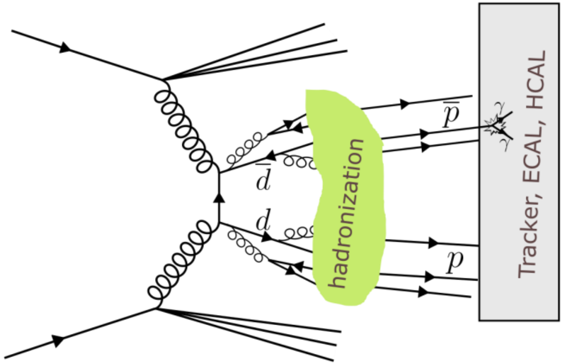
Summary of the presentation

1. Flavor-dependent Jet Energy Correction (JEC) and uncertainty studies for CMS Run 2



- Updated flavor uncertainties will be highly beneficial to the $t\bar{t}$ and dijet measurements.

2. Quark-antiquark jet uncertainty



- Two sources of b-vs-$\bar{b}$ uncertainty is to be used in the t-vs-$\bar{t}$ mass measurement.