, lepton isolation and missing ET

Pileup mitigation techniques for jets in CMS

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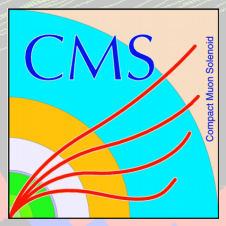


Fermilab

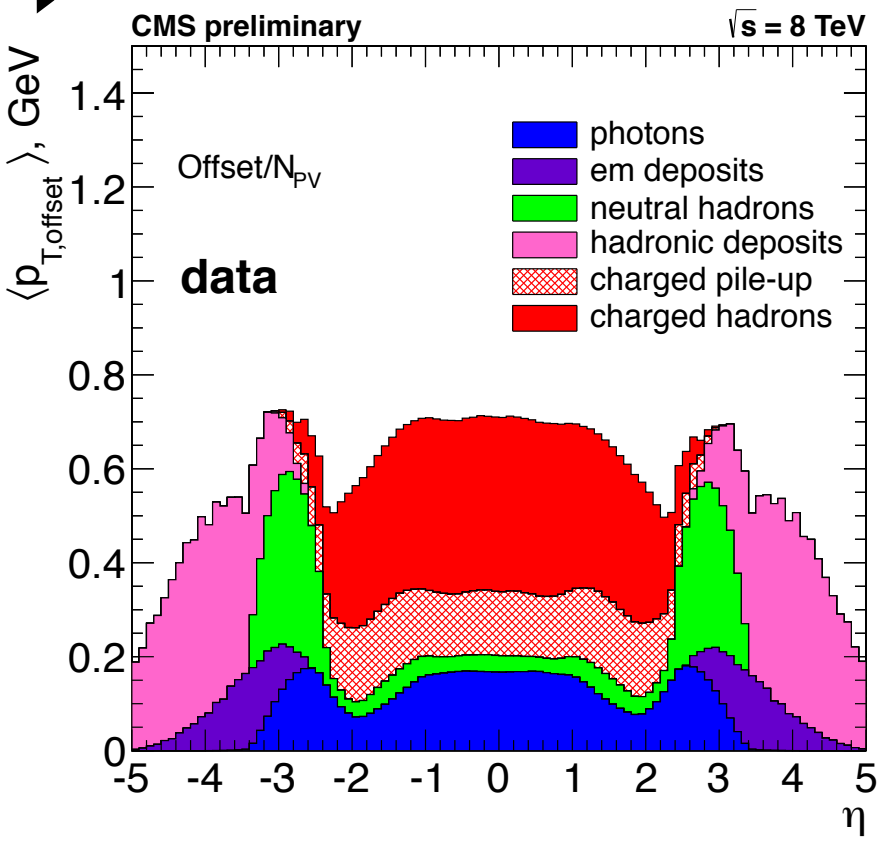
More data !! and more pileup…

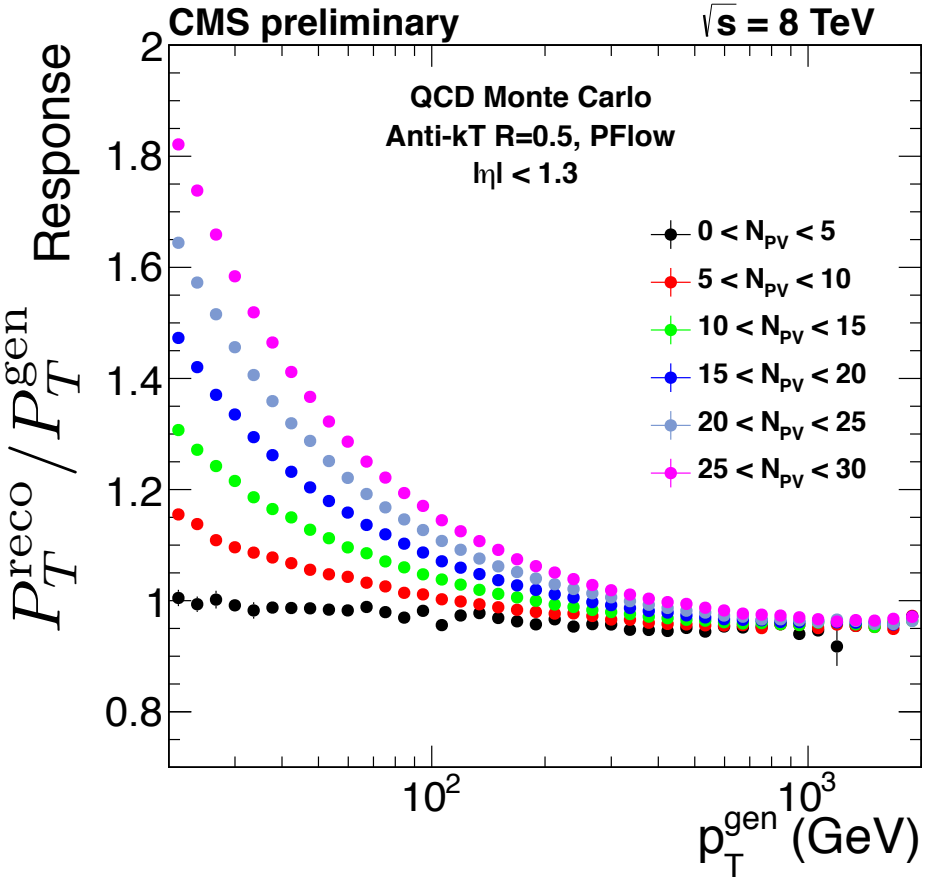
- We are excited for 13 TeV data, but **high statistics data do not come free**…
- High luminosity operation of the LHC provides us more data, but collision conditions with **O(50) pileup are one of our major concerns**…
- We can, however, **mitigate the impact by using full granularity of the detector and characteristic of pileup.**
- In CMS, various sophisticated techniques to fight against pileup have been proposed and studied.

Now, we need to understand them in more detail to ensure the performance for Run-2 analyses.

Difficulties of pileup

PT offset / unit area / # of vertices

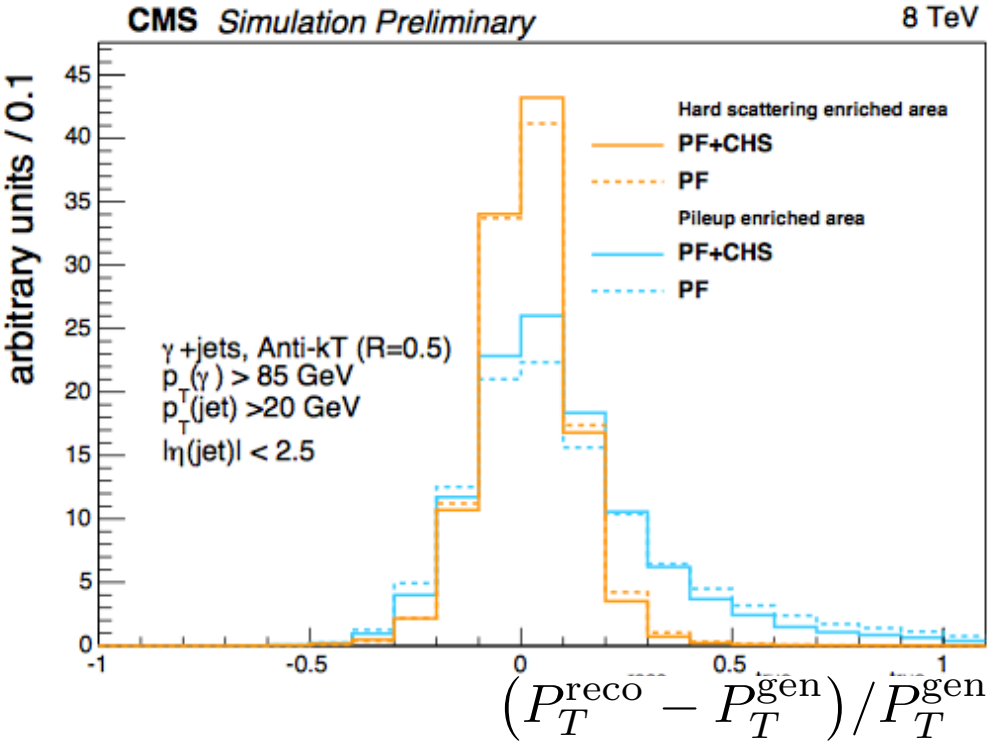


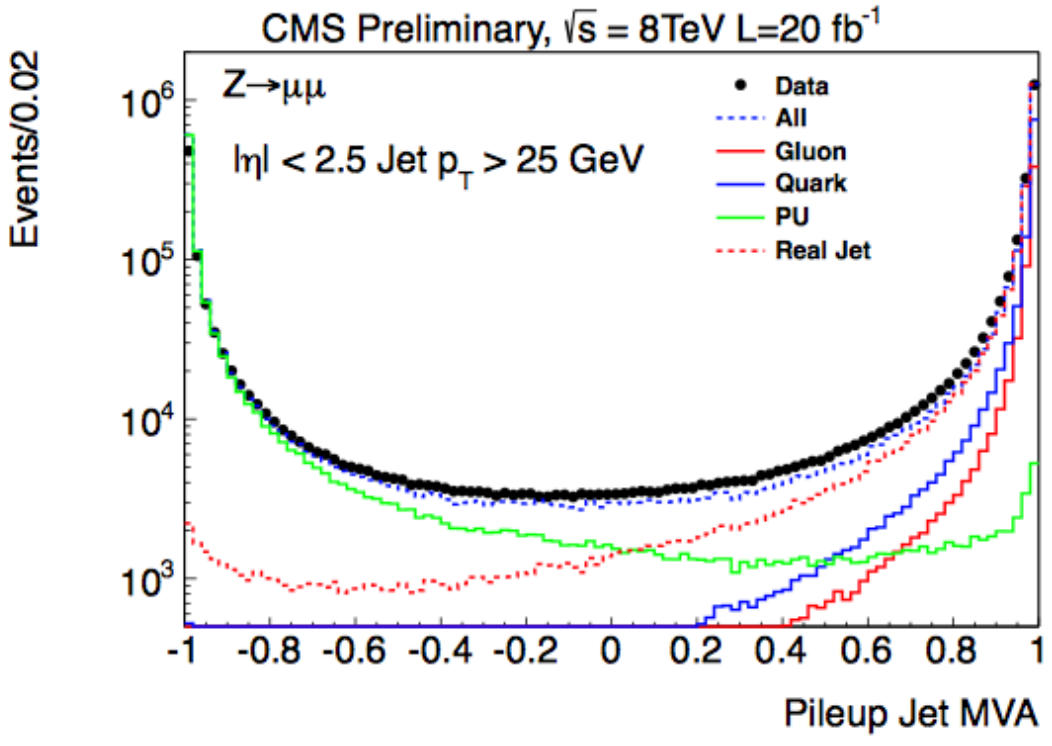


Run-1 experience : roughly speaking, 0.7 GeV /η /ϕ /# of vertices.
Ak5 jets with pileup of 25 (17 vertices) = 10 GeV offset.
The average scale can be corrected but the resolution can not be recovered,
which affect the performance of Jet PT/mass, sub-structure, isolation and missing ET.

Standard tools to fight against pileup

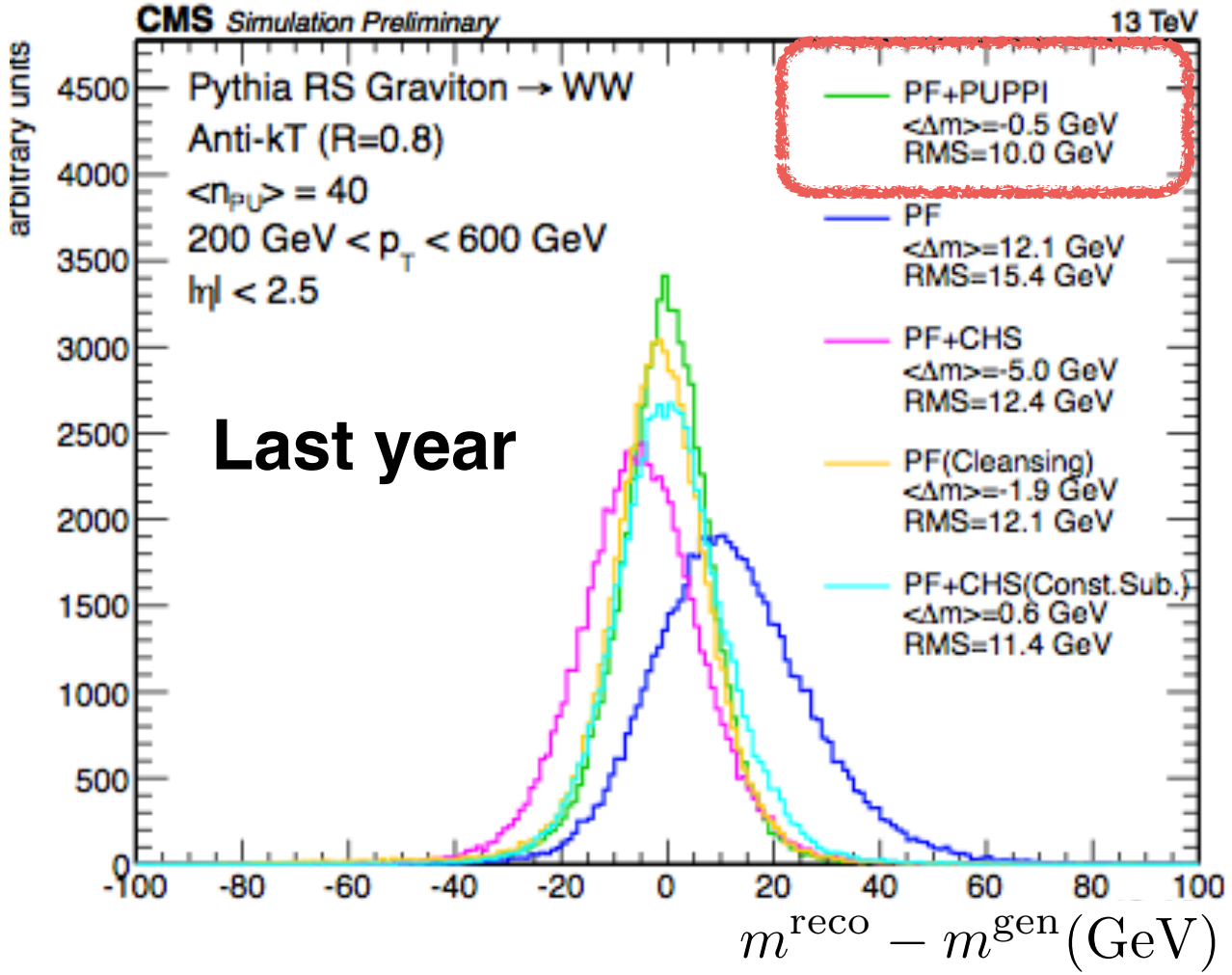
- CMS has developed and implemented various techniques :
  - Timing of calorimeter @ hardware level, effective to remove out-of-time pileup.
  - Subtracting pileup contribution in average from jets and lepton isolation.
  - **Charge Hadron Subtraction**(**CHS**) removes charged particles associated with pileup vertices from reconstructing physics objects.
  - Pileup Jet ID : Remove jets from pileup using tracking information and jet shape.





Recently developed tools

In addition to CHS, various sophisticated techniques have been also studied.



We have continued the development of one of the more promising technique '*PUPPI*' for run-2 analyses.

PUPPI to fight against pileup

Brief overview : how PUPPI works

PUPPI in **top quark tagging**

PUPPI **QCD jet reconstruction performance**

Application to **muon isolation**

Application to **missing ET**

Test with more severe pileup condition — **PUPPI in HL-LHC operation**

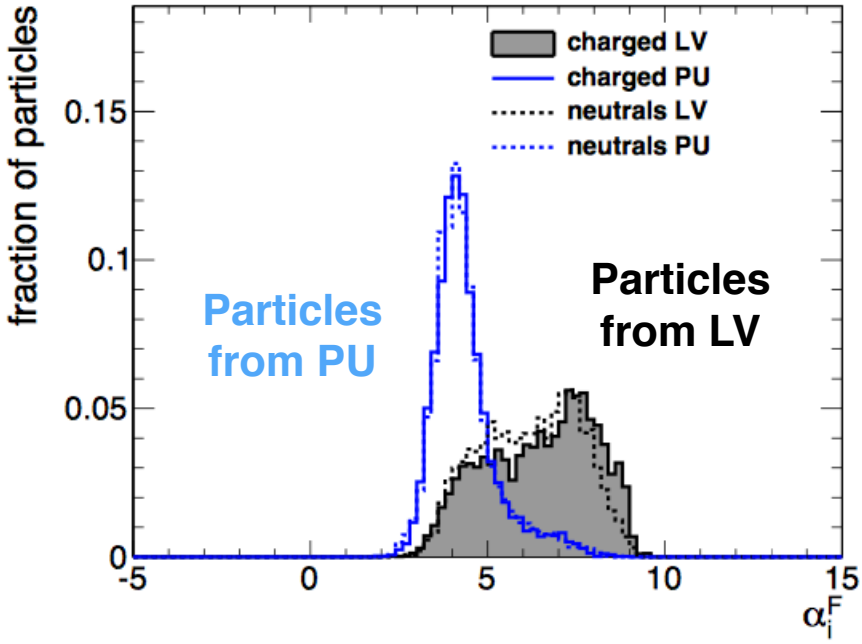
How PUPPI works

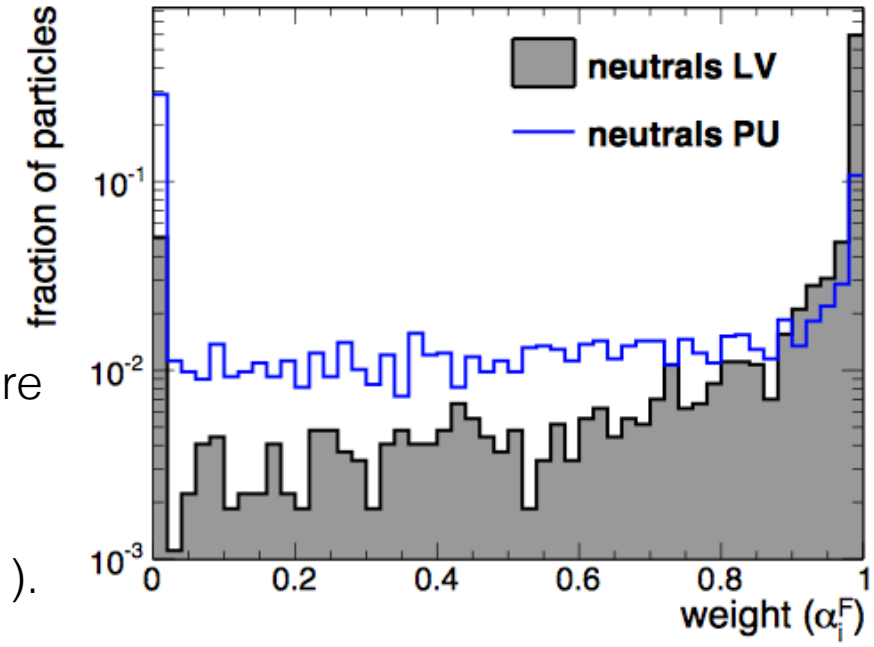
- **PileUp Per Particle Identification** (**PUPPI**)
- It takes as input particle flow objects (charged/neutral hadrons, photon and charged leptons)
  - and it gives weight for each of them.
- Defines ***α*** of each particle (*i*)
  using other particles (*j*) around it.
  For example

$$\alpha_i = \log \sum_{j \in \text{event}} \frac{P_T^j}{\Delta R_{ij}} \Theta(R_{\min} < \Delta R_{ij} < R_0)$$

PT sum weighted with distance

Step function to take into account only particles around it.

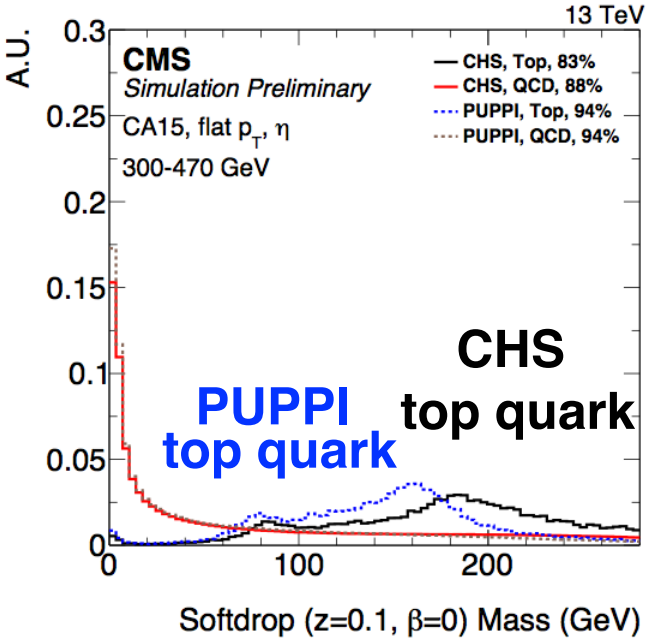


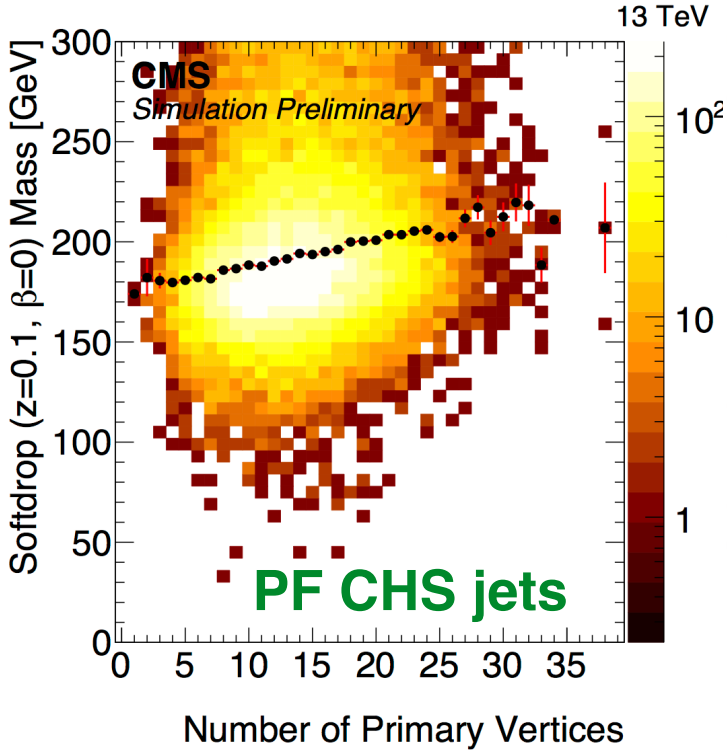


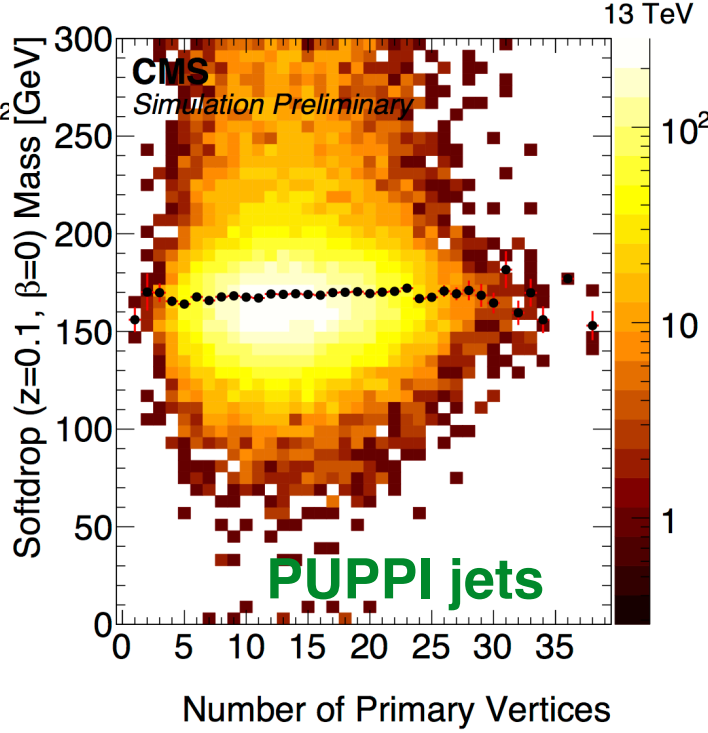
- Transforms the distribution of ***α*** in a **weight**
  (1 for particle from LV, 0 for particles from PU)
- This weight can be also defined at large rapidities where there is no coverage from the tracker.
- Then, jet reconstruction algorithm can run on the particles with the **weight** (but PUPPI is not only for jet.).

Pileup mitigation in top quark tagging

Top quark tagging is a technique to identify jets from top quark decays. It works for boosted jet and exploits the mass of jet and also three sub-jets in a top quark decay : $t \to bW \to bqq$

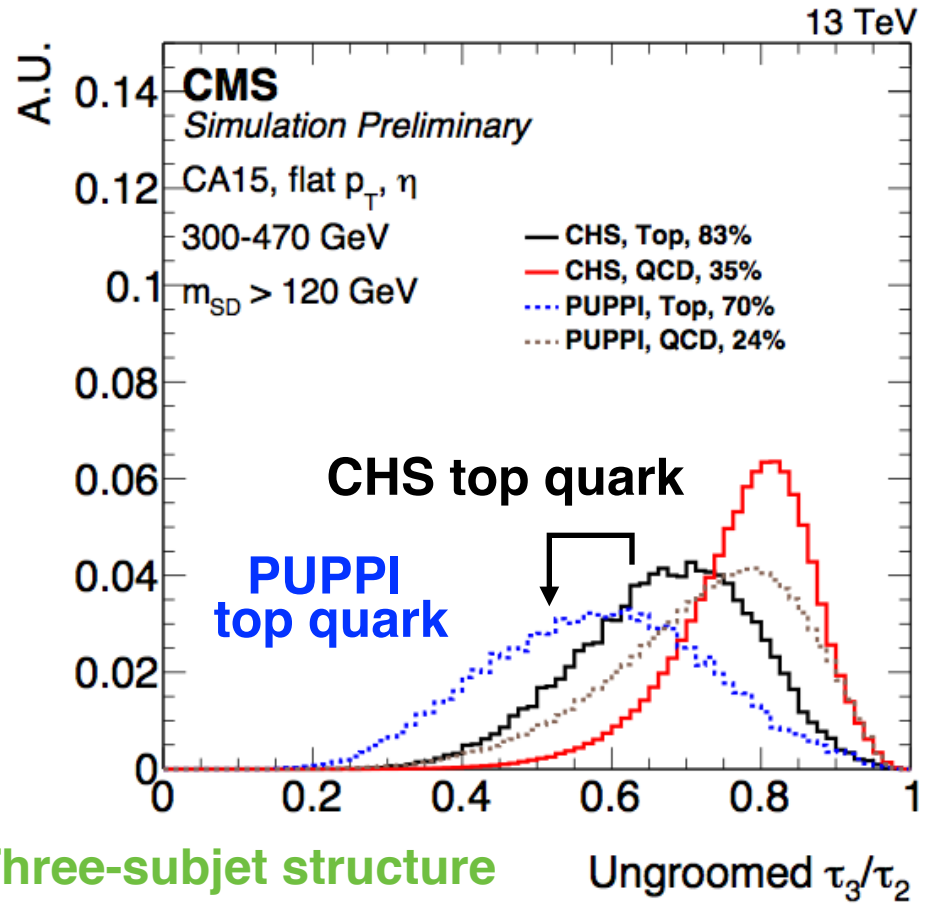


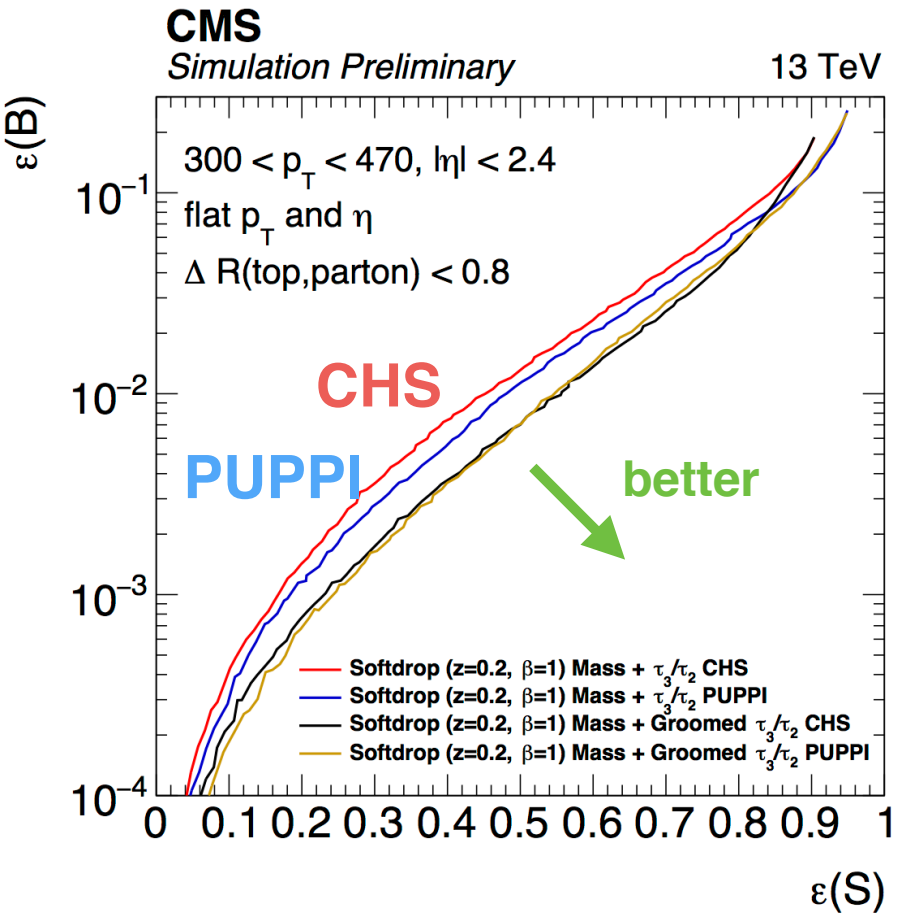




PUPPI considerably reduces pileup dependence.

Pileup mitigation in top quark tagging

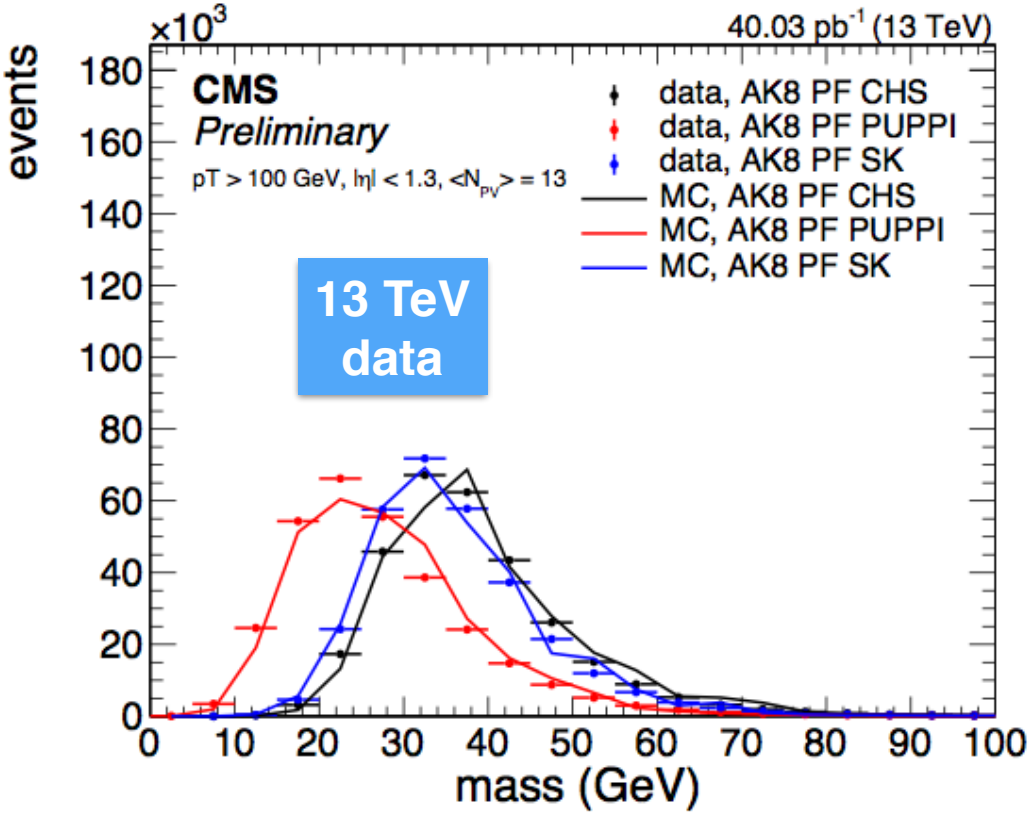


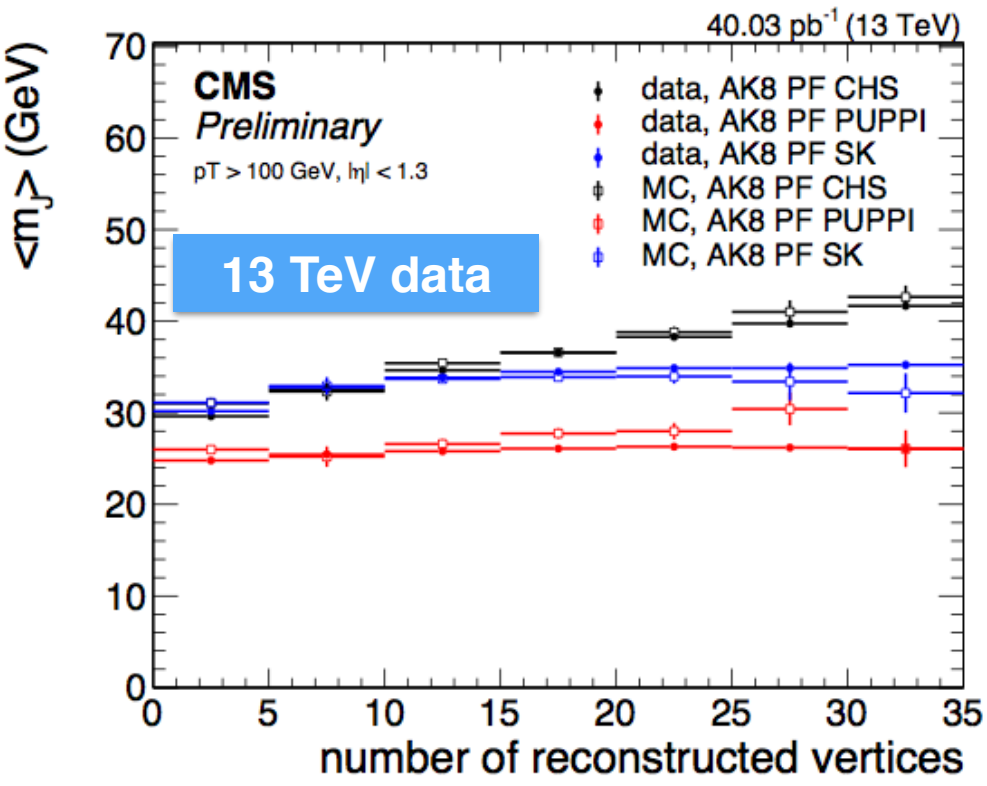


PUPPI reduce pileup dependence and improves the reconstruction of the three sub-jet structure without ruining the performance.

PUPPI performance with 13 TeV data

Performance of PUPPI jet was tested with **13 TeV pp collision data (40/pb)**





Good agreement between data and MC in all the methods.
PUPPI provides stable performance with respect to the number of pileups.

Pileup mitigation of muon isolation

- In general, energy deposits around μ (typically dR<0.4) are used to distinguish prompt ones from hadron origin ones.
- Most common isolation definition during Run-1 (*"δβ-corrected"*) is :

$$\mathrm{Iso}_{\delta\beta} = \Big(\sum_{CH} P_T + \max(\sum_{NH} P_T + \sum_{PH} P_T - 0.5\sum_{PU} P_T, 0)\Big)/P_T^{\mu}$$

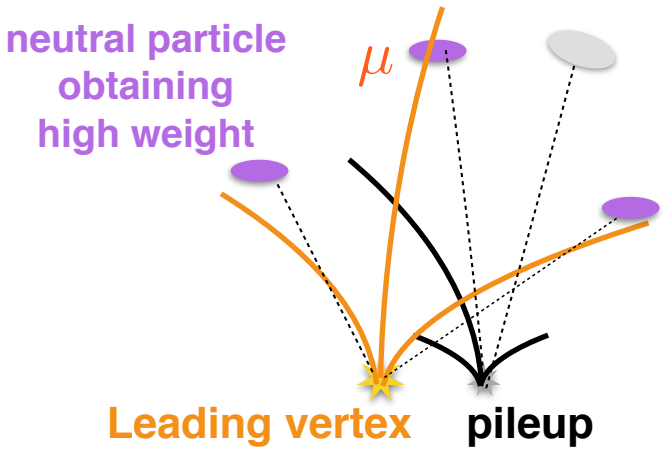
  - PT sum of **charged hadrons** from LV arounds the muon
  - As **neutral component**, add following if it is grater than 0 :
    - "PT sum of neutral hadrons and photons arounds the muon"
      minus "estimated contribution from PU neutral particles (*δβ*)"
      - *δβ* = **0.5** x "PT sum of **charged hadrons from PU**"

        0.5 comes from the ratio between charged/neutral particles in isospin limit.
  - PU contribution is removed in average.
- Introduce PUPPI weight **ω** to calculate the isolation.

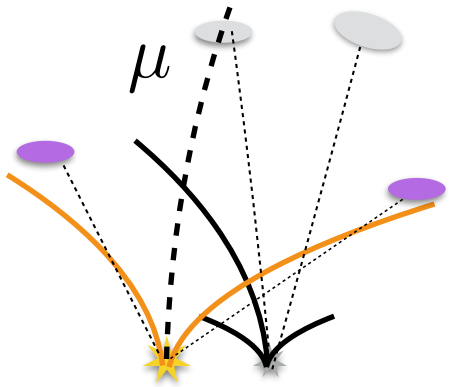
$$\mathrm{Iso}_{\mathrm{PUPPI}} = (\sum_{\mathrm{CH}} \omega^i P_T^i + \sum_{\mathrm{NH}} \omega^i P_T^i + \sum_{\mathrm{PH}} \omega^i P_T^i)/P_T^{\mu}$$

Pileup mitigation of muon isolation

- **PF PUPPI** weighted isolation ("**with muon**")
  - Straightforward application. Use weight that PUPPI calculates.
  - Concern : Existence of muon increases weights of neutral particles around it.
    - As the result, PU dependence in variable will remain.



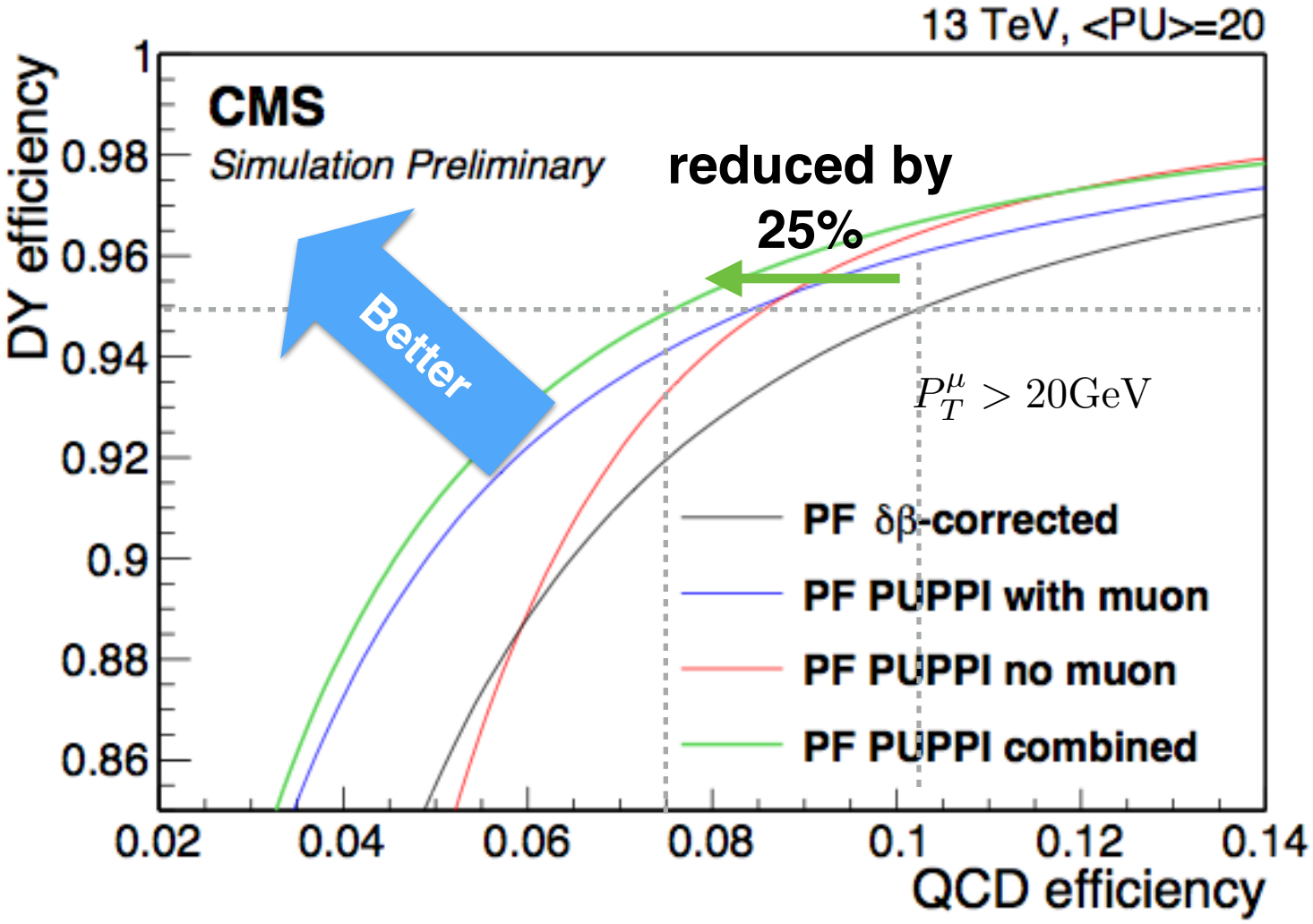
- **PF PUPPI** calculated with **no muons**
  - Based on the hypothesis that muons are prompt, computes particle weights **excluding muons** from PUPPI input.



- **PF PUPPI combined** : the simplest combination
  - average of the two isolations.

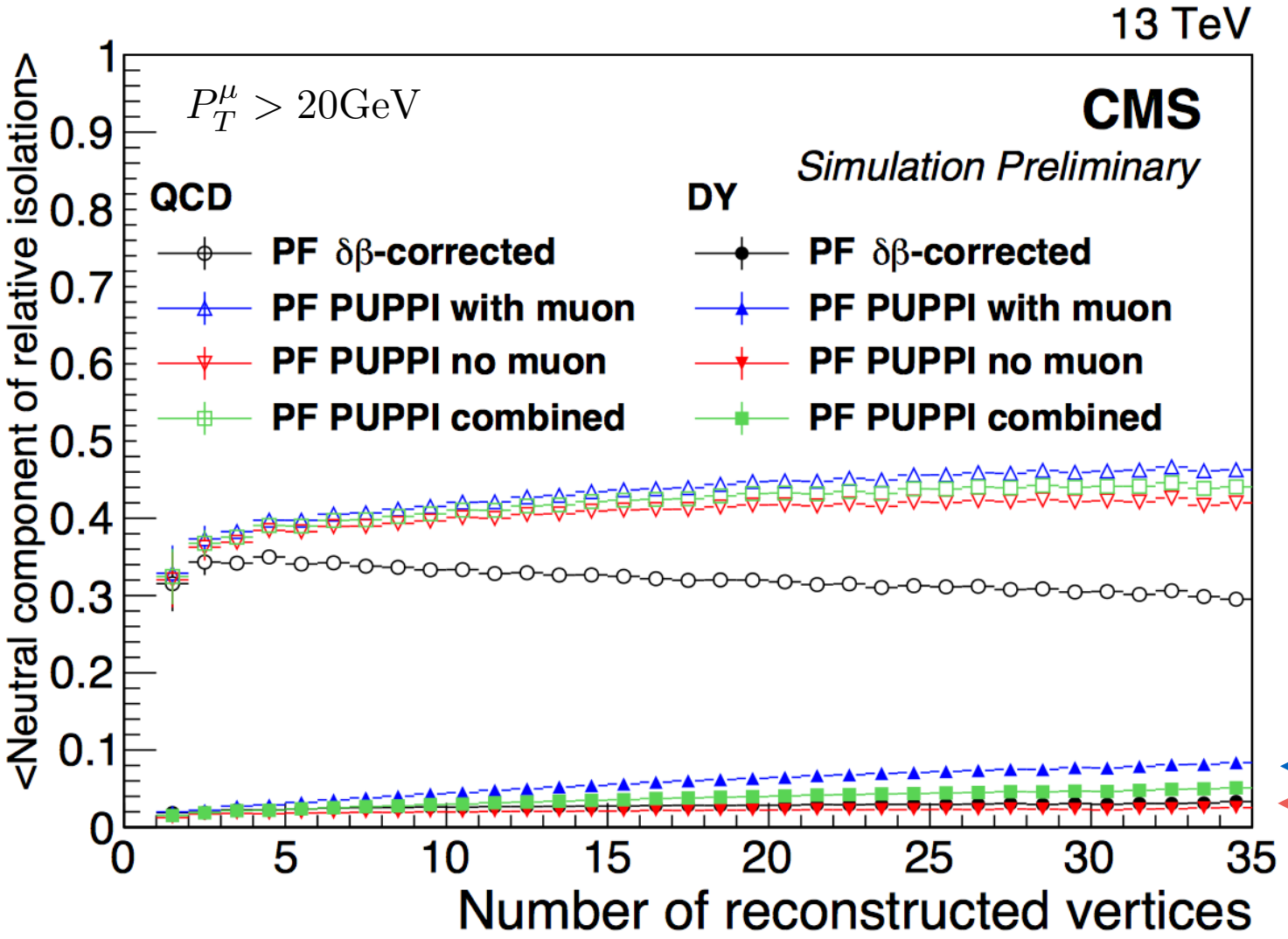
Muon isolation ROC curve

Isolation efficiency with respect to tightly identified muons in DY and QCD (13 TeV, <PU>=20).



Compared to **delta beta corrected**, **PUPPI technique provides up-to 25% less background**(QCD muons) @ 95% efficiency point.

Neutral component of muon isolation

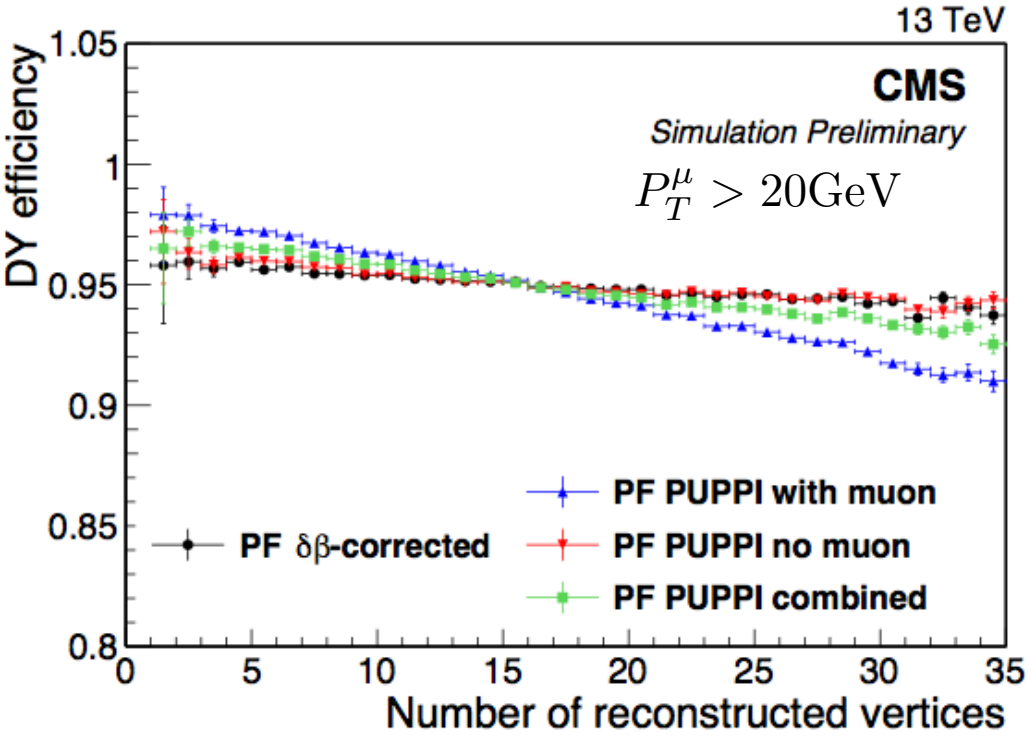


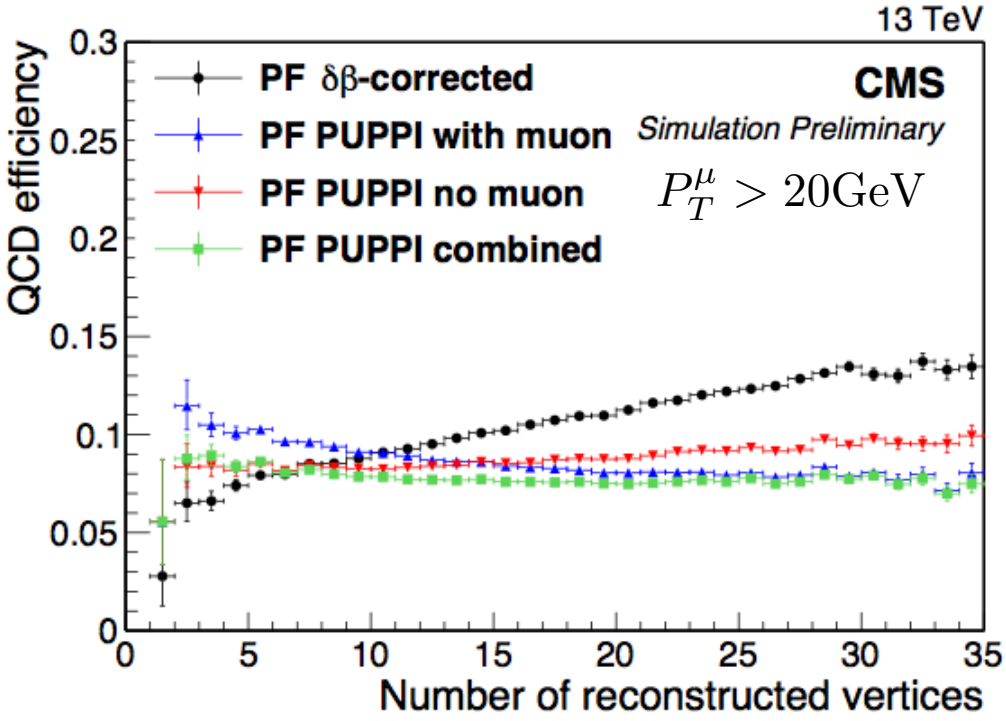
As expected,pileup dependence of prompt muon isolation remains in **PUPPI with muon.**

As designed, **PUPPI no muon** provides stable isolation value for prompt muon.

Muon isolation behavior with pileup

Each isolation at working point of efficiency = 95%





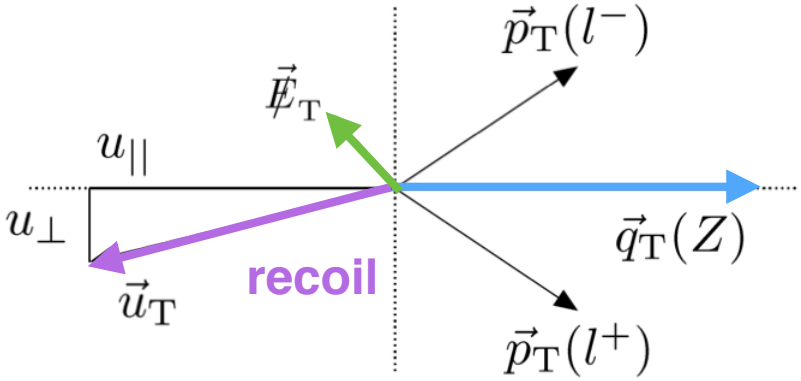
Comparing the stability with pileup for prompt and non-prompt muons, PUPPI no muon performs best. PUPPI combined inherits the characteristic.

Pileup mitigation of Missing ET

Missing ET can benefit from PUPPI technique.

Performance was evaluated from resolution of “recoil” momentum in DY events.

- Missing ET calculated in |η|<3.0 (HF calorimeter is being calibrated.)
- Charged leptons (=**Z boson**) are measured precisely.
- Intrinsically no **missing ET** source.
- Ideally, sum of other activities (**recoil**) should balance with Z boson.

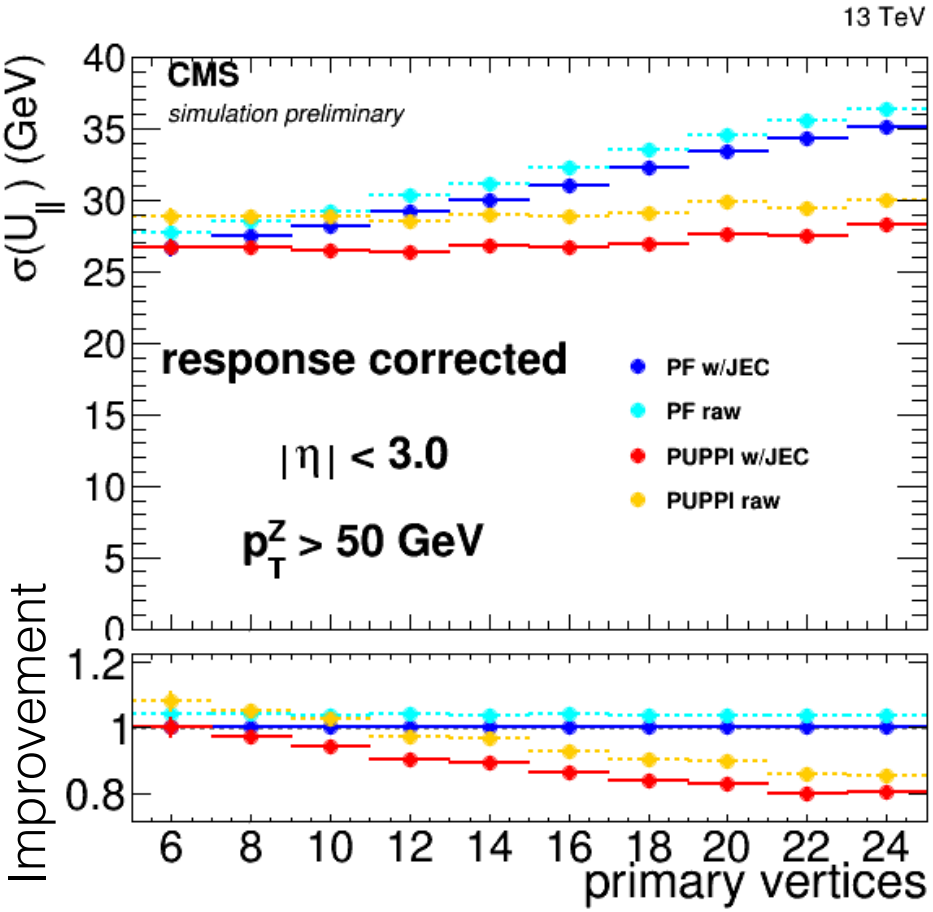


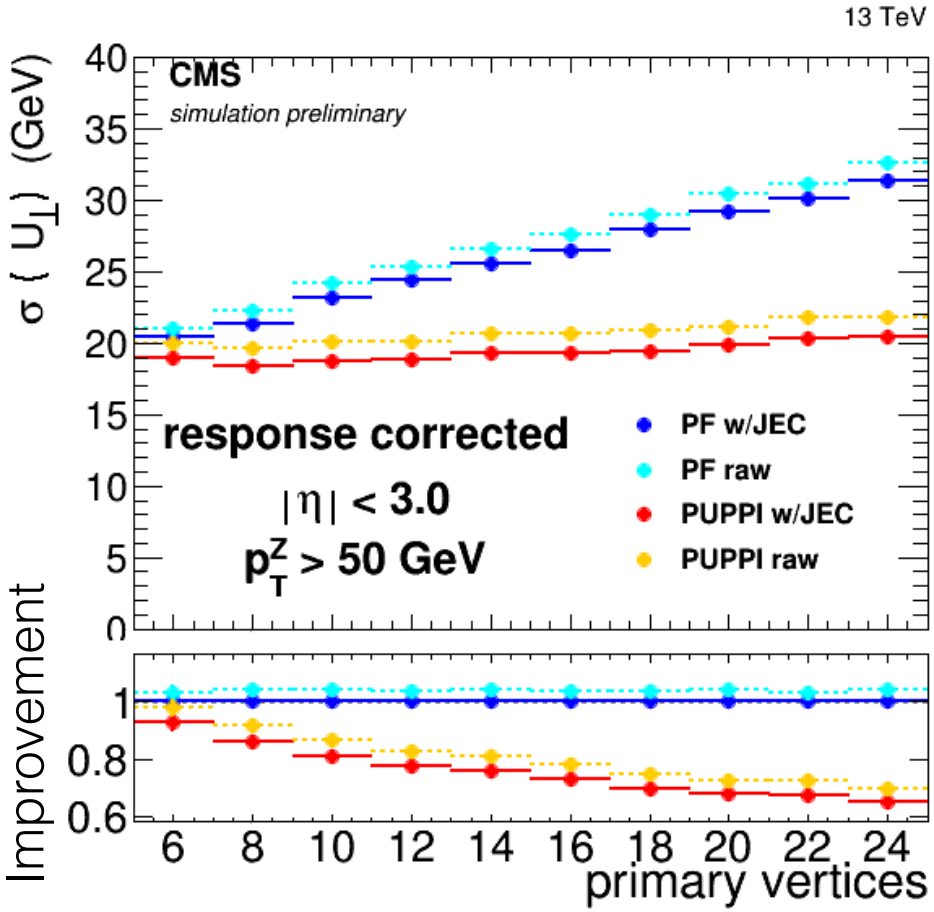
We evaluated the performance of recoil measurement in two directions.

- **Perpendicular** to Z boson : tends to be affected by **pileup**
- **parallel** to Z boson : tends to be affected by **energy scale**

Muons were removed from PUPPI weight calculation,
which prevents pileup dependence as we saw in muon isolation calculation.

Pileup mitigation of Missing ET



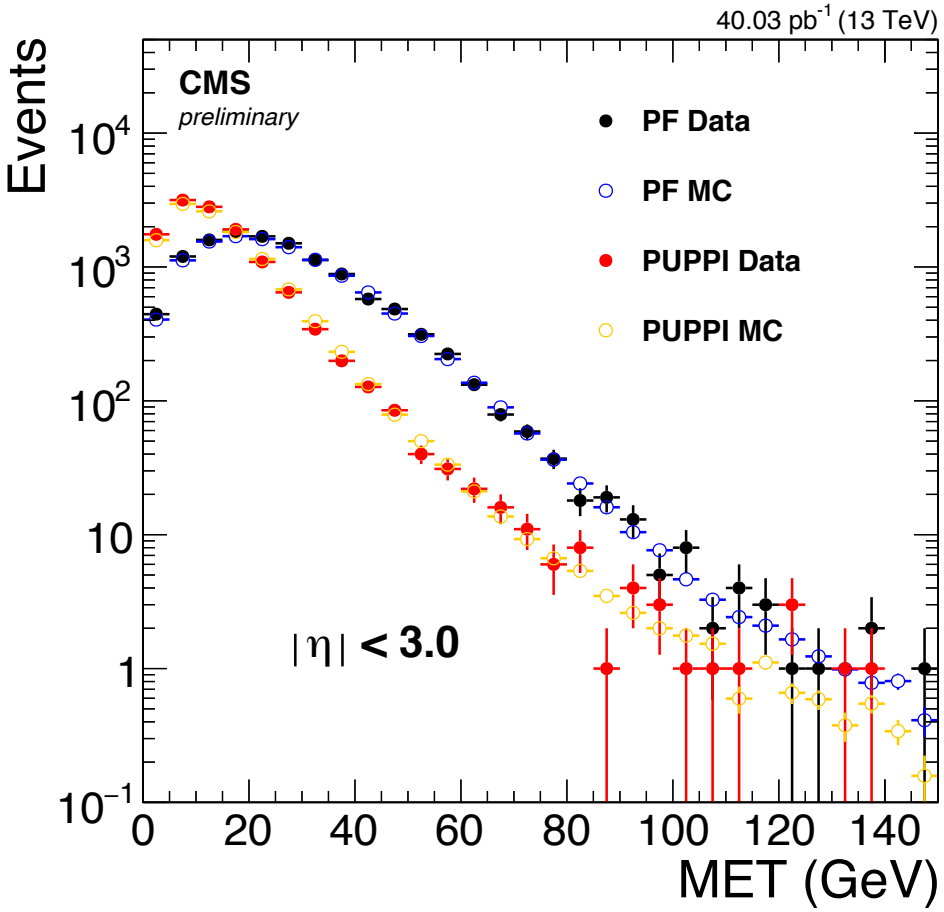


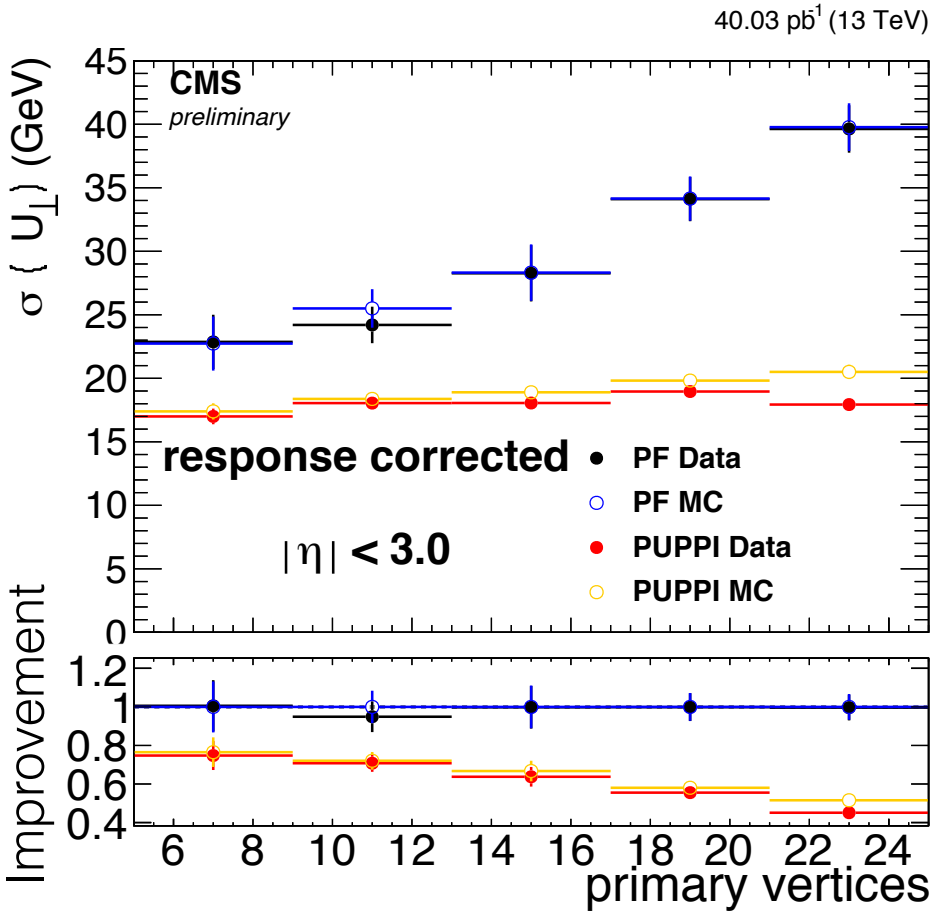
PUPPI provides **better resolution**,
and it is **stable with respect to pileup**.

Pileup mitigation of Missing ET

the first missingET performance study with 13 TeV data

Performance was evaluated with DY events.



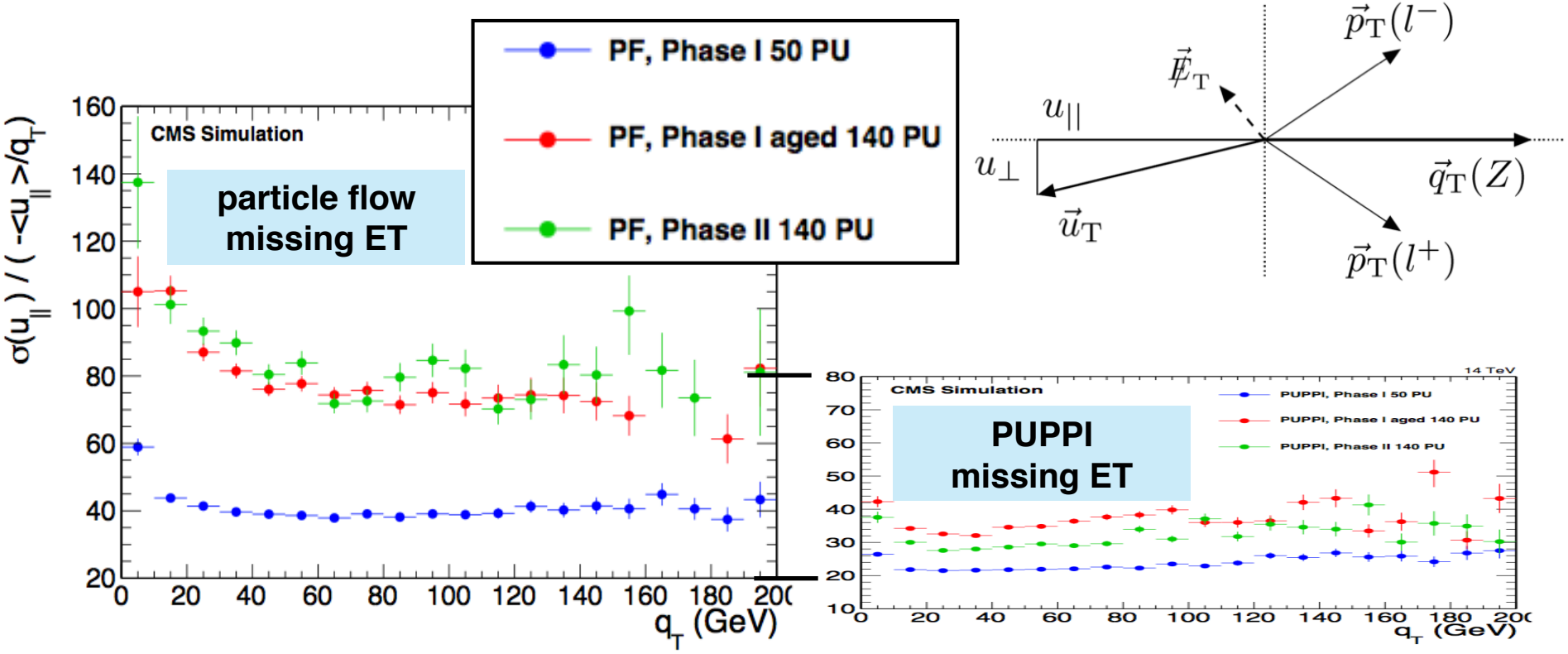


Good agreement between data and MC was seen in both.

The stable performance of PUPPI was confirmed with data.

PUPPI for HL-LHC

In HL-LHC operation, we expect events with pileup of 200.
In order to execute physics analyses, we will upgrade detector,
and also can profit from pileup mitigation techniques.



PUPPI keeps working up to events with <pileup>=150.

Summary

- At high luminosity operation of LHC, one of the keys for successful physics analyses is how much we can mitigate the degradation of the performance due to pileup.
- The use of the PUPPI technique has been extended to multiple physics objects.
  - For **top quark tagging, jet reconstruction, muon isolation and missing ET, PUPPI works better than others**.
    - **Better resolution, and more independent from pileup**.
    - **The performance of PUPPI has been studied with 13 TeV data** for the jet reconstruction and missing ET.
      - **These are the first CMS results with 13 TeV data for missing ET performance.**
  - While those tests are with the number of pileup of ~20, we have started looking into PUPPI in HL-LHC condition and it performs well for missing E_T.

Now we have a promising weapon for Run-2 analyses and beyond in our hand.

CMS result references

- *DP 2015/XXX (plots for page 8 -18)*
  - *the wiki page will be appear soon.*
- *"Technical Proposal for the Phase-II Upgrade of the CMS Detector"* CERN-LHCC-2015-010
  - *http://cds.cern.ch/record/2020886*
- *"Study of Pileup Removal Algorithms for Jets" CMS PAS JME-14-001*
  - *http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/JME-14-001/index.html*
- *"Pileup Jet Identification" CMS PAS JME-13-005*
  - https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsJME13005/JME-13-005-pas.pdf
- "JEC performance plots for 2012" DP-2012/012
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsJME2012JEC