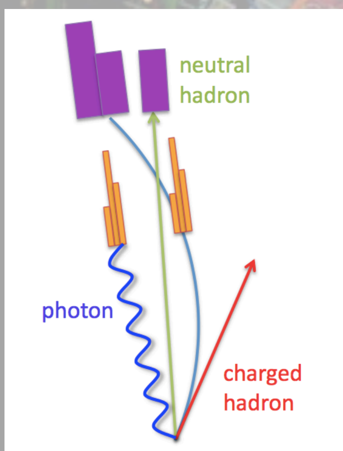
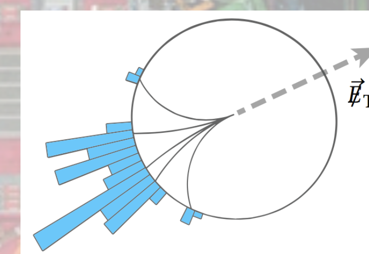
LHCP2020: The Eighth Annual Conference on Large Hadron Collider Physics (LHCP2020)

CMS: Jet and missing ET reconstruction





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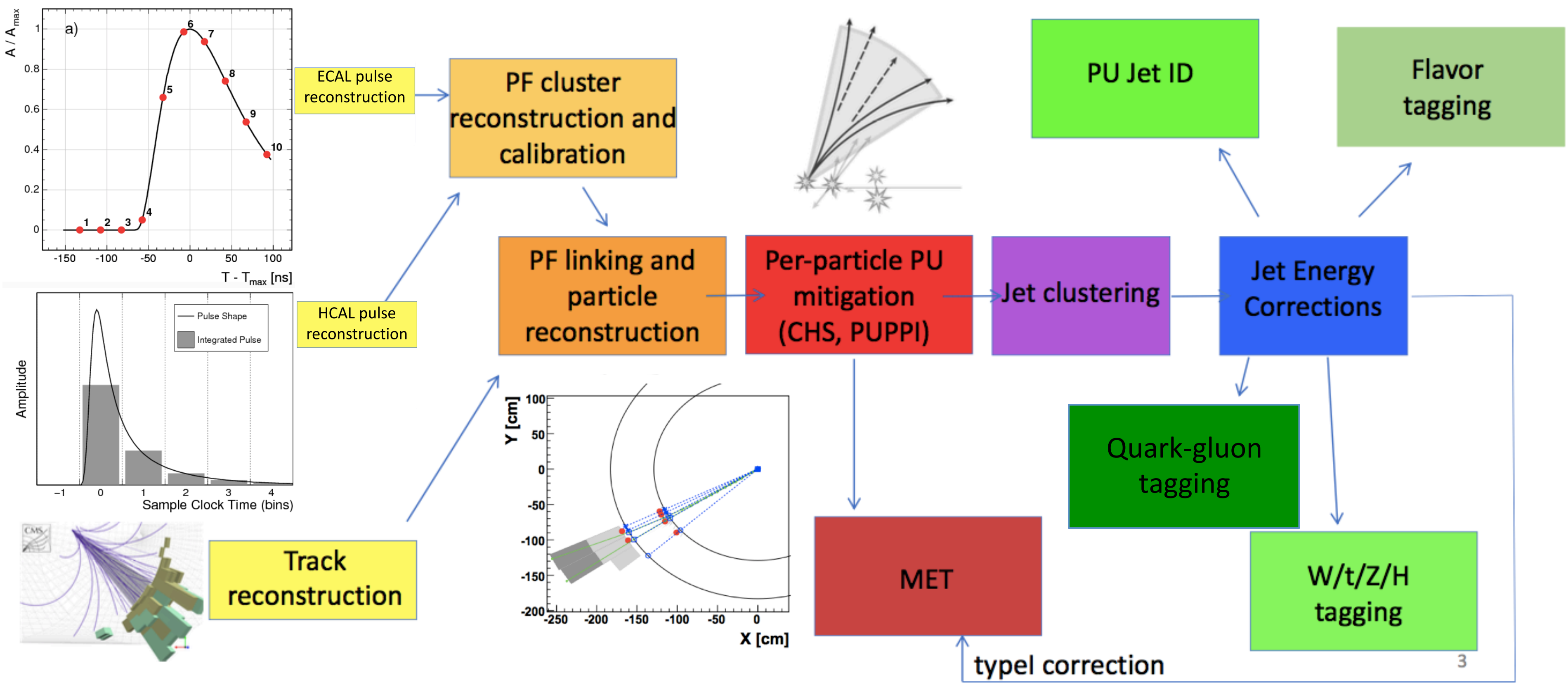
On behalf of the CMS Collaboration

25-30 May 2020

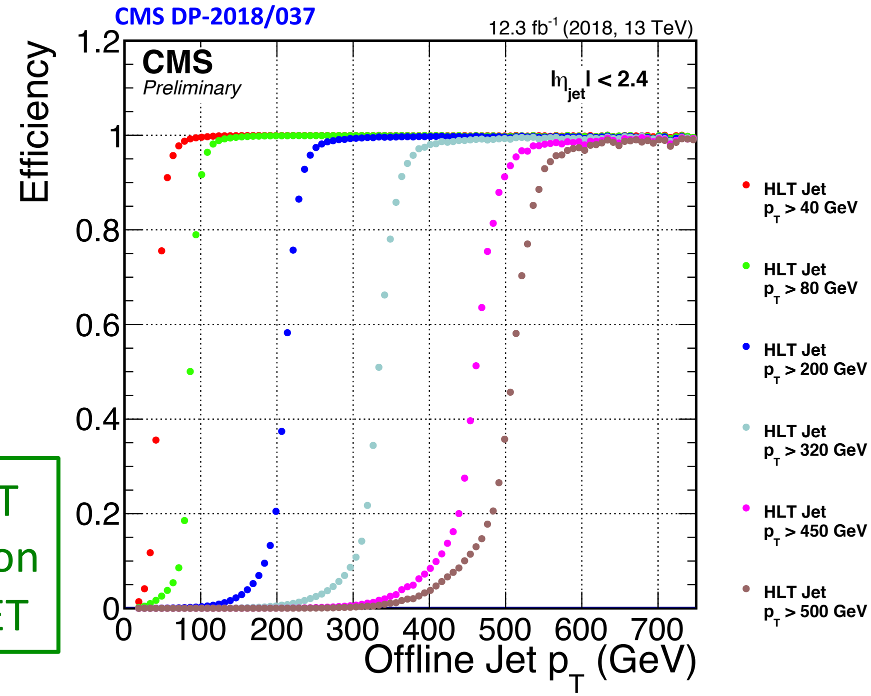
Jets reconstruction at CMS experiment

- Jets at CMS clustered using the anti-k_T algorithm (mostly using the R = 0.4, 0.8)
- Particle-level jets: stable and visible particles in gen.evt; Calo jets: from energy deposits in calorimeter towers; Particle Flow jets: by clustering PF candidates; PF + CHS(Charged Hadron Subtraction) and Pile Up Per Particle ID (PUPPI) jets

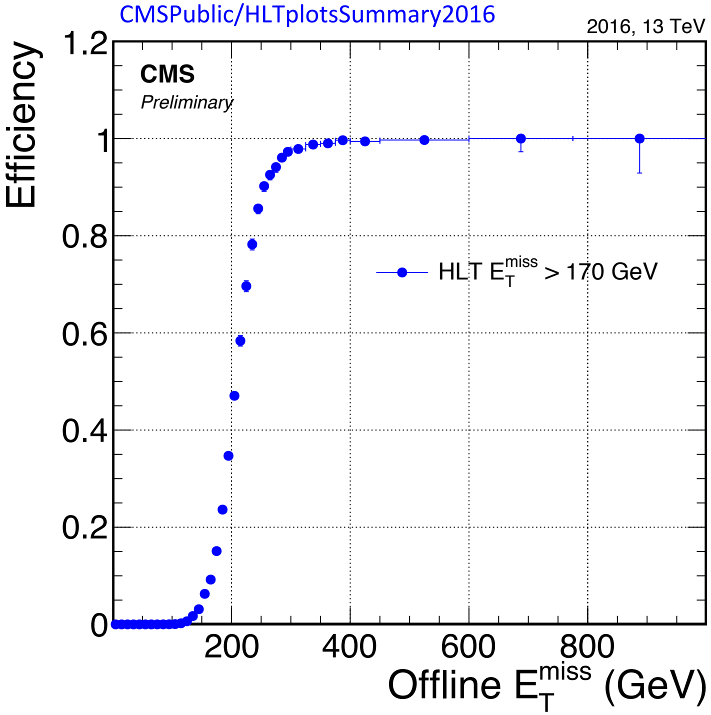


Jet and M(issing)ET reconstruction at HLT

- The adapted jet and MET reco runs at HLT level and is speed/performance optimized
- Particle Flow@HLT x100 faster than offline
- At the HLT tracking reduced to 3 iterations
- L1L2L3 JEC derived for HLT (only from MC)



https://twiki.cern.ch/twiki/bin/view/CMSPublic/HLTplotsSummary2016

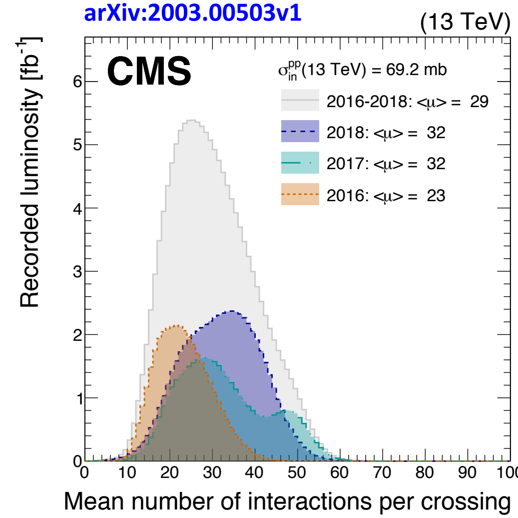


Efficient HLT reconstruction of jets & MET

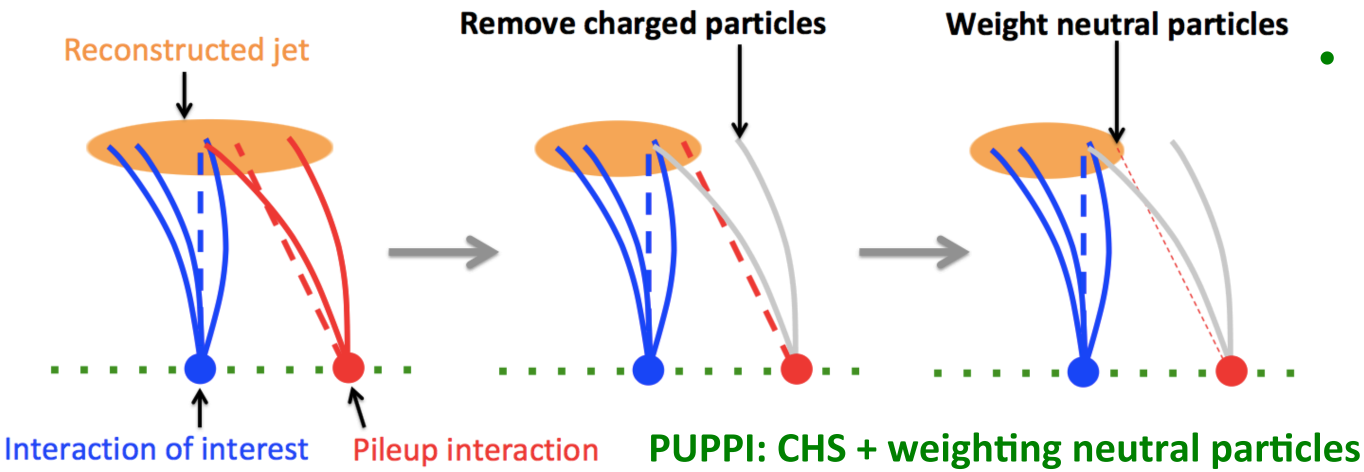
- The jet HLT efficiency as a function of the offline jet p_T, measured using the single - muon sample
- The E_T^{miss} trigger efficiency as a function of offline E_T^{miss}, measured using the single-electron sample

Pileup mitigation techniques at CMS

- Pile-up became an ever growing challenge in LHC physics
- The LHC Run 2: ~29 interactions/evt (Run 3 exp up to 50)



- Charged hadrons subtraction (CHS) algo uses the tracking info to remove particles associated to the pileup vertices



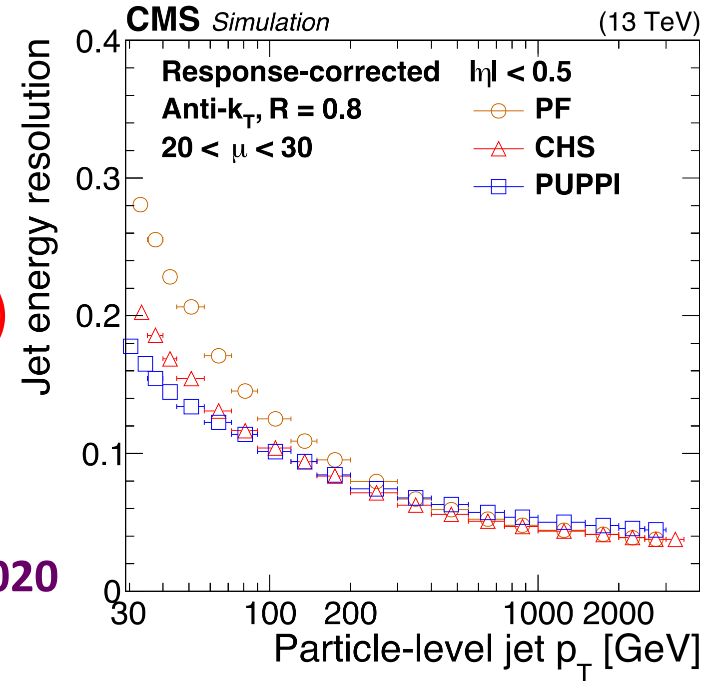
- Pile Up Per Particle ID (PUPPI) use distribution of neighboring particles to estimate probability of neutral particles to originate from pileup

- After CHS some PU jets remain -> PU Jet ID: MVA to reject jets from pileup particles

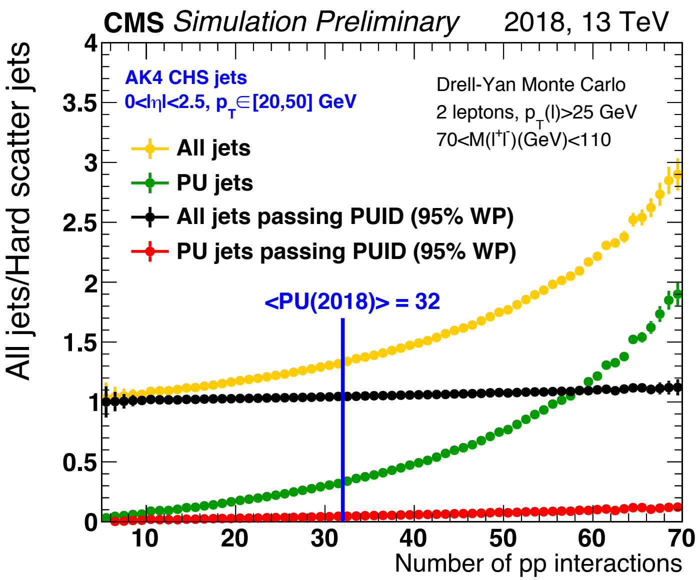
Pileup mitigation techniques: performance

- Jet energy resolution as function of ptcl-level jet pT for PF, PF+CHS & PUPPI jets in QCD MC
- PUPPI has better performance than PF (+CHS) (neutral PU ptcl. contribute more to AK8 jets)

arXiv:2003.00503v1



CMS DP-2020/020

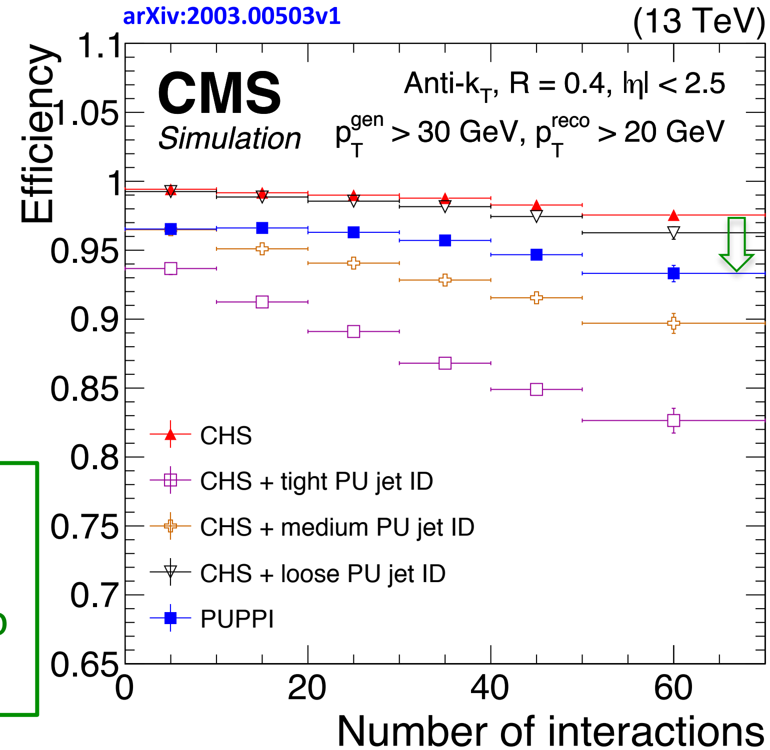


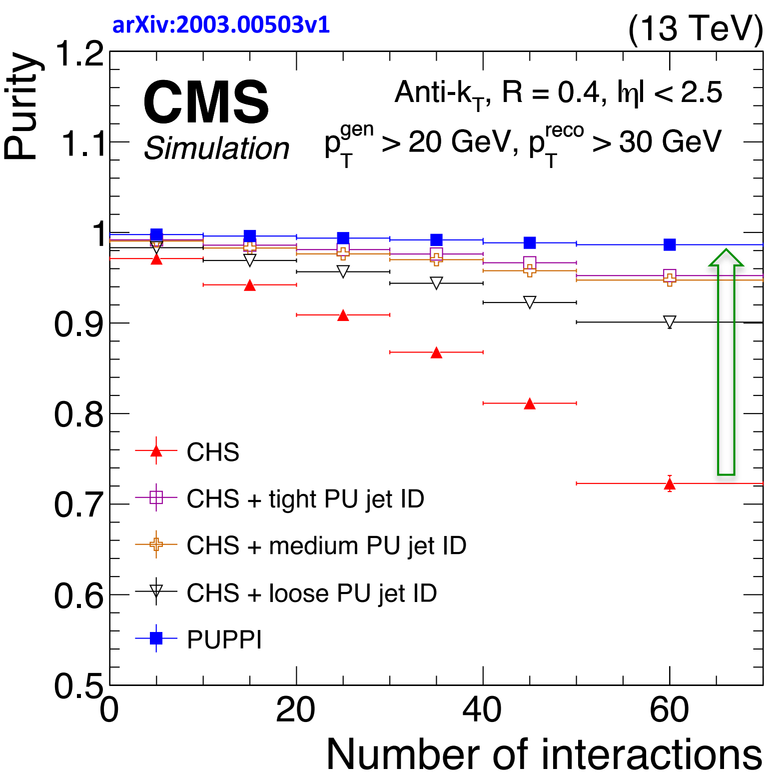
< --- NEW for LHCP 2020

- Ratio of the total number of jets with |η| < 2.5 p_T > 20 GeV over the corresponding number of hard scatter jets before and **after** applying the PU ID WP corresponding to the 95% efficiency
- Ratios for PU jets before and after the PU jet ID

Pileup mitigation: efficiency and purity

- Measured in MC: CHS (+PU JetID) vs PUPPI
- **Efficiency** defined as a fraction of particle-level jets with p_T > 30 GeV matched (ΔR < 0.4) with reconstruction jets of p_T>20 GeV



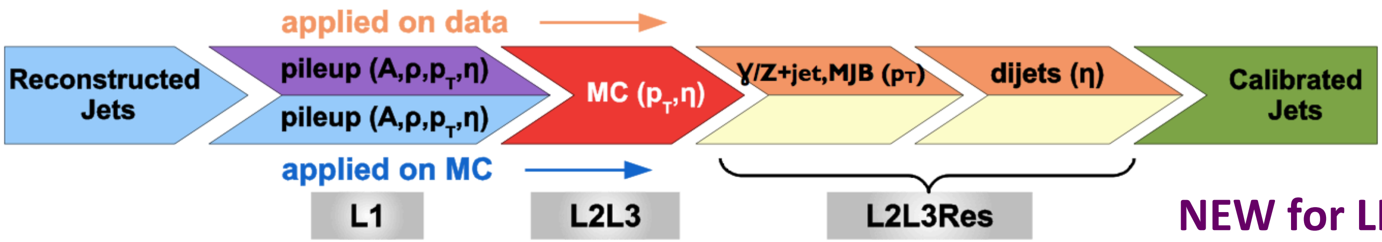


CHS efficiency over 95%, but purity drops to 70% in barrel

- **Purity**: fraction of reco-level jets (p_T>30 GeV) matched (ΔR<0.4) with generator jets (p_T>20 GeV) from main interaction
- PUPPI has an improved efficiency and purity overall perform. in cent. region

Jet energy corrections (JEC) at CMS

- JEC procedure: a factorized approach to correct the jets to particle jet level

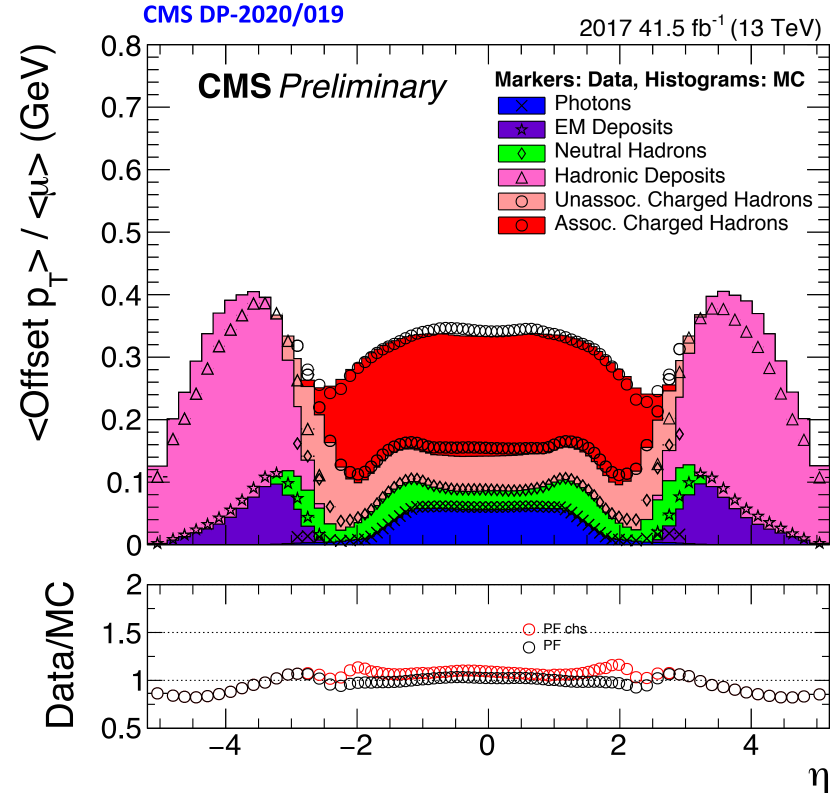


$$\frac{<p_T^{RECO}>}{<p_T^{ptcl}>}(p_T^{ptcl}, \eta, \mu) = 1$$

NEW for LHCP 2020 ---v

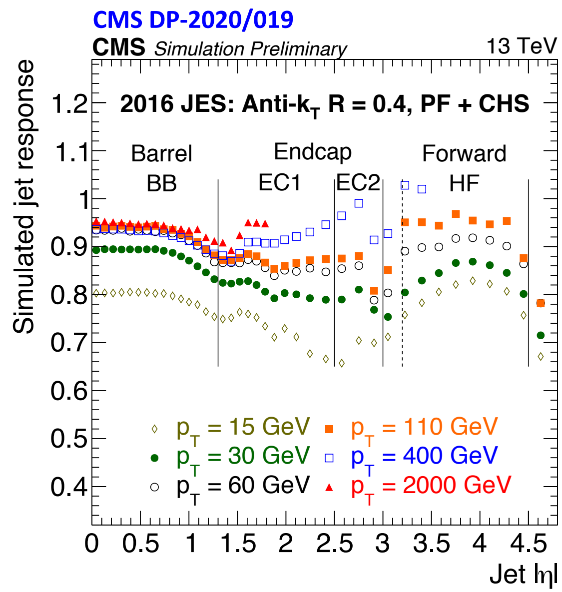
- Pileup correction in order to account for offset energy coming from pileup
- Correction to the particle level jet vs p_T and η obtained from MC simulation
- Small residual corrections to data for pileup, relative vs η, absolute vs p_T -> full physics analysis to derive residuals

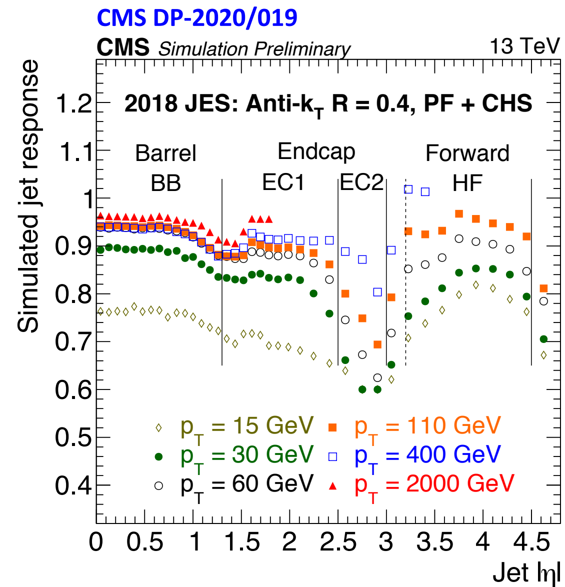
CMS DP-2020/019

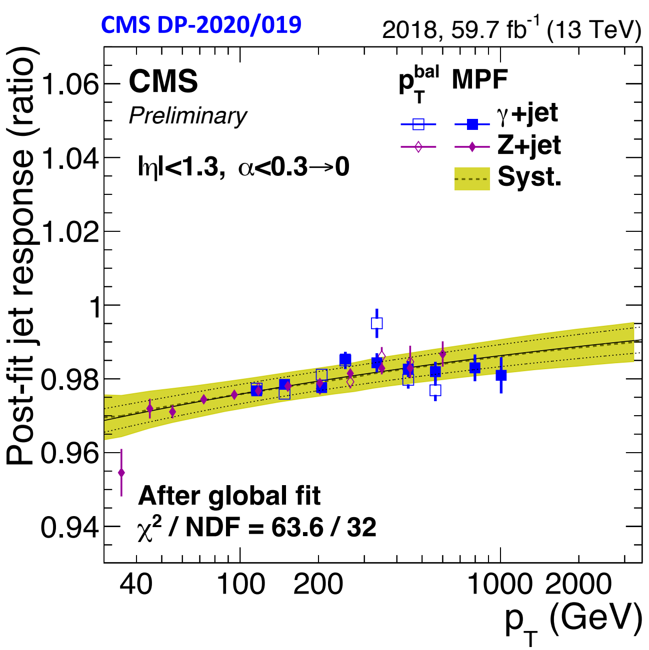


Jet energy corrections: performance

- Jet response, $\langle p_T^{RECO} \rangle / \langle p_T^{ptcl} \rangle$, corrections in bins of p_T^{jet}, $|\eta_{jet}|$
- Stable in the barrel (BB) region
- N. had. resp. 0.6, 15% of p_T^{ptcl}
- Stronger depend. in EC and HF
- EC2-> calorimeter degradation





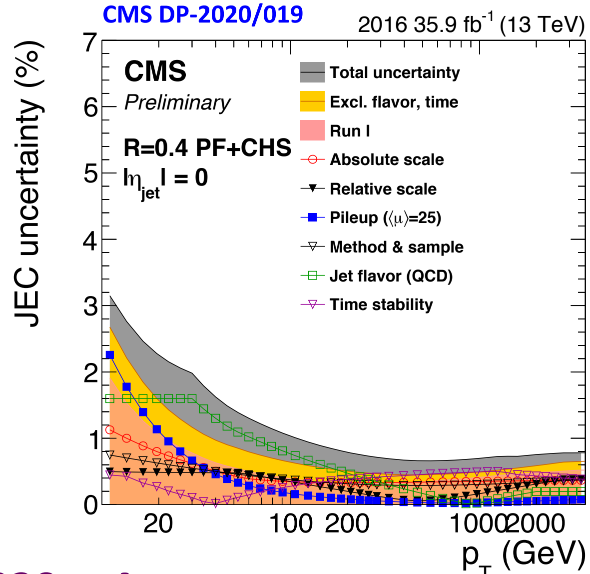


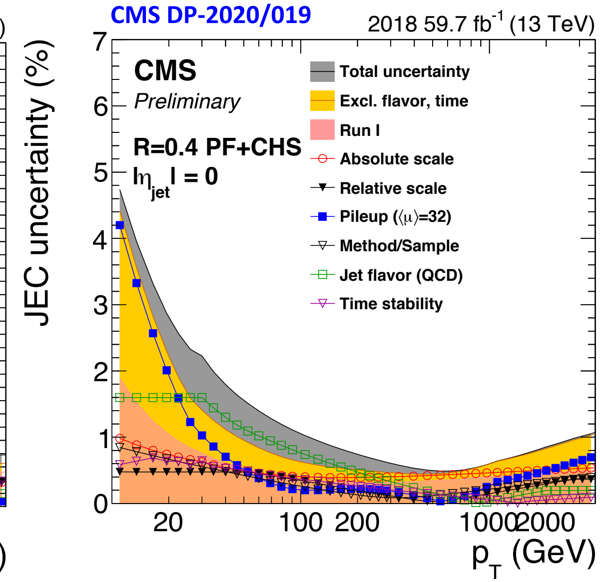
< --- NEW for LHCP 2020 ---^

- Data-to-simulation comparison for the jet response dependence on the jet p_T
- Combination of γ + jet, Z + jet & Multijet (2016)
- Yellow band indicates absolute scale uncertainty

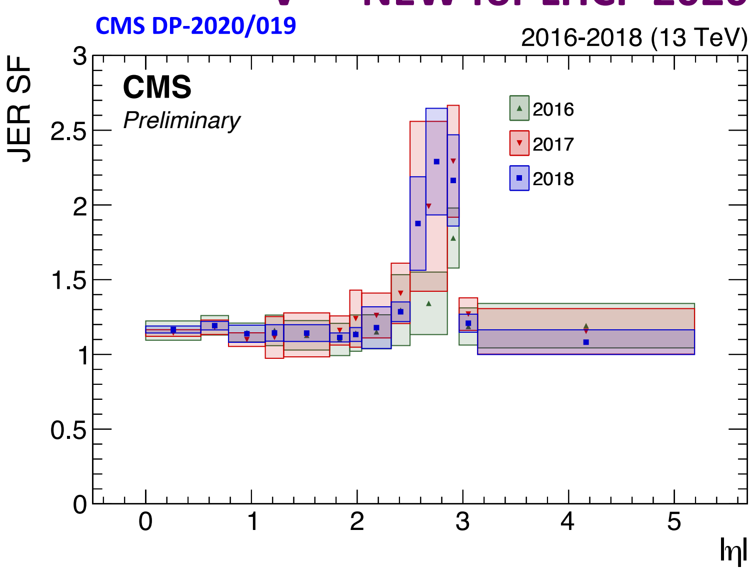
Jet energy (scale) uncertainties and resolution

- The Jet Energy Scale (JES) uncertainty sources and total as function of jet p_T
- Run I result without the flavour and time sources is shown for comparison





v --- NEW for LHCP 2020 ---^



- Jet Energy Resolutions (JER) measured in dijet and Z/γ + jet simulated events vs p_T^{ptcl}, η and μ and data to MC scale factors from di-jet applied in addition
- SFs of 1.1-1.2, larger in the EC-HF transition region of $|\eta| \in [2.5, 3]$

MET reconstruction, cleaning and performance

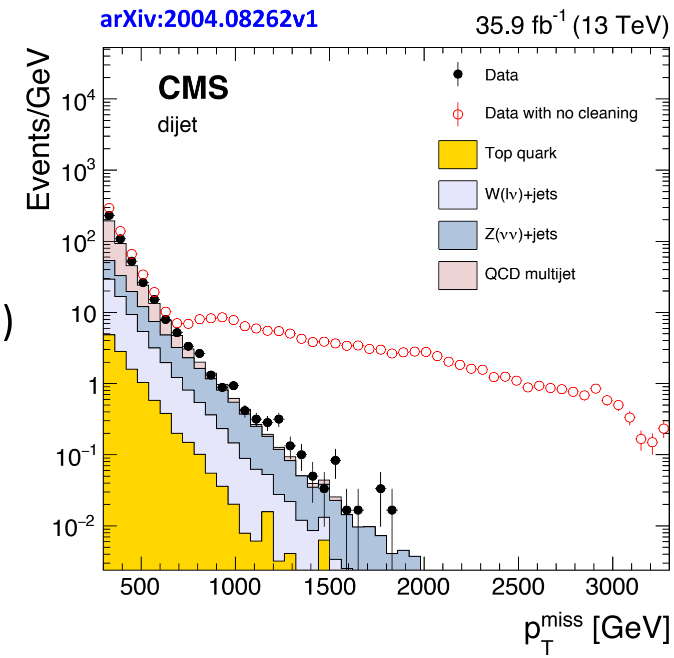
- PF/PUPPI MET definition:

	PF	PF + Puppi
$\vec{p}_T^{miss} =$	$-\sum_{i\in PF} \vec{p}_T^{\,i}$	$-\sum_{i\in PF} w^i \vec{p}_T^{\,i}$

- Jet energy corrections propagated p_T^{miss} (Type-I MET) ->

$$\vec{p}_T^{\,miss} = \vec{p}_T^{\,miss,\,raw} - \sum_{jets}\left(\vec{p}_{T,\,jet}^{\,corr} - \vec{p}_{T,\,jet}\right)$$ p_T(jet) > 15(10) GeV/Run 2(1)

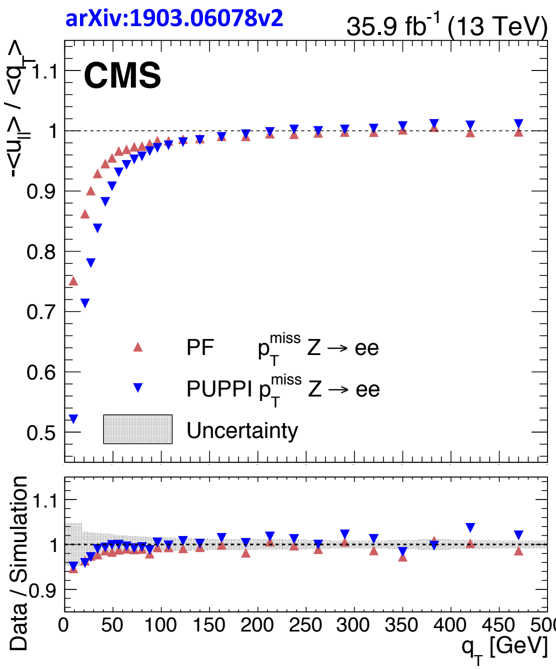
- Anomalous MET events -> mostly due to detector noise

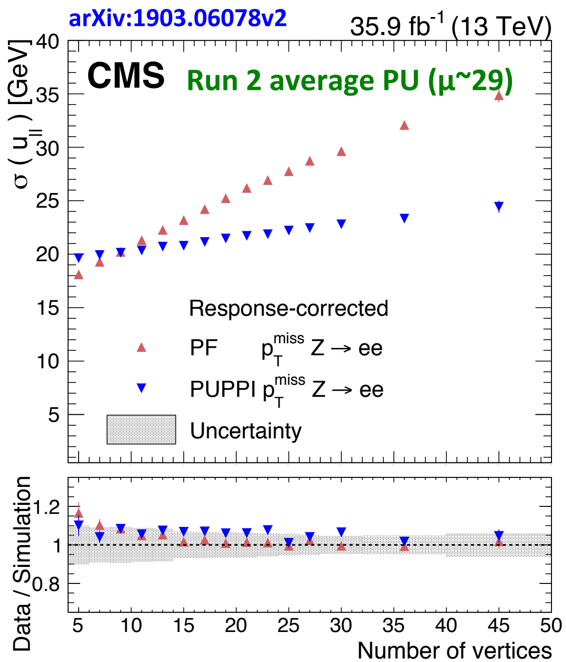


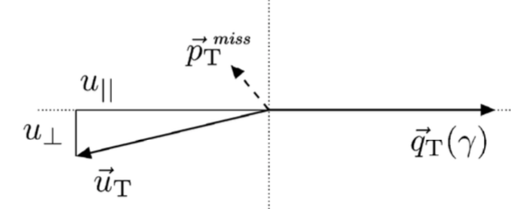
Response ~1 for q_T>100 GeV

PUPPI MET has **20% better resolution** for avg. Run 2 PU

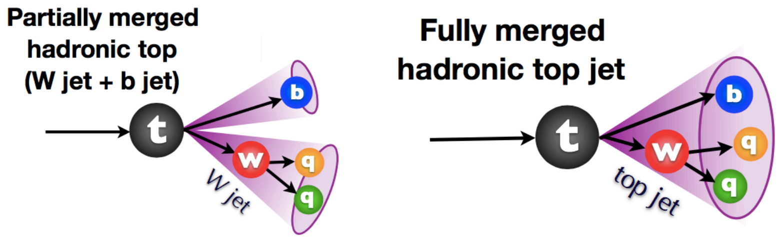
Stable performance vers PU







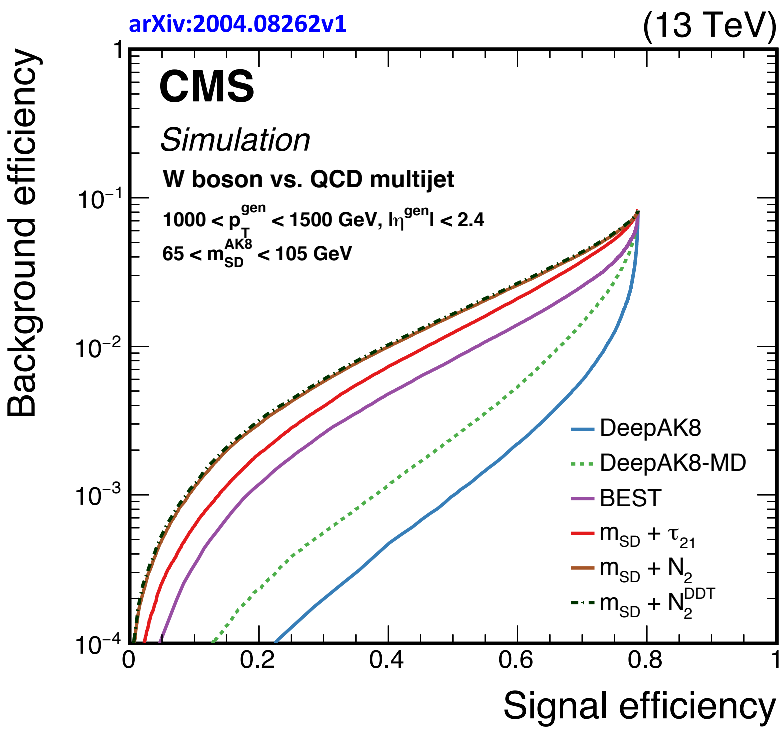
Standard and ML heavy object tagging



- Standard heavy object taggers-> groomed mass & N-subjettiness

Algorithm	p_T (jet) [GeV]	t quark	W boson	Z boson	Higgs boson	decay modes
$m_{SD} + \tau_{32}$	400	✓				
$m_{SD} + \tau_{32} + b$	400	✓				
$m_{SD} + \tau_{21}$	200		✓	✓		
HOTVR	200	✓				
$N_3 -$ BDT (CA15)	200	✓				
$m_{SD} + N_2$	200		✓	✓	✓	
BEST	500	✓	✓	✓	✓	
ImageTop	600	✓				
DeepAK8	200	✓	✓	✓	✓	✓
Jet mass decorrelated algorithms						
$m_{SD} + N_2^{DDT}$	200		✓	✓	✓	
double–b	300			✓	✓	
ImageTop–MD	600	✓				
DeepAK8–MD	200	✓	✓	✓	✓	✓

arXiv:2004.08262v1



Machine-learning based taggers -> large performance improvements vs non− ML

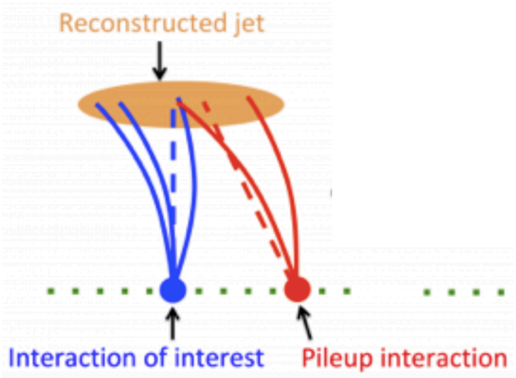
ML : N_3-BDT, BEST, ImageTop & DeepAK8

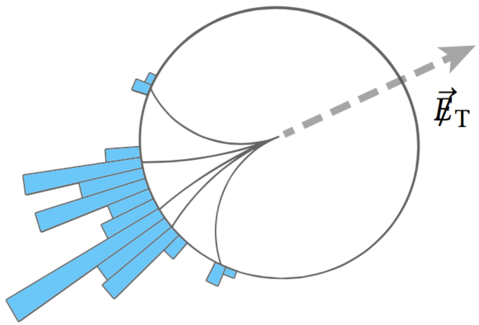
NEW for LHCP: DeepAK8-DDT, ParticleNet

Talk on boosted objects by Pantelis Kontaxakis

Summary and Outlook

- Demonstrated the ability to deal with the pileup conditions expected in Run 3 with mitigation techniques exercised in Run 2



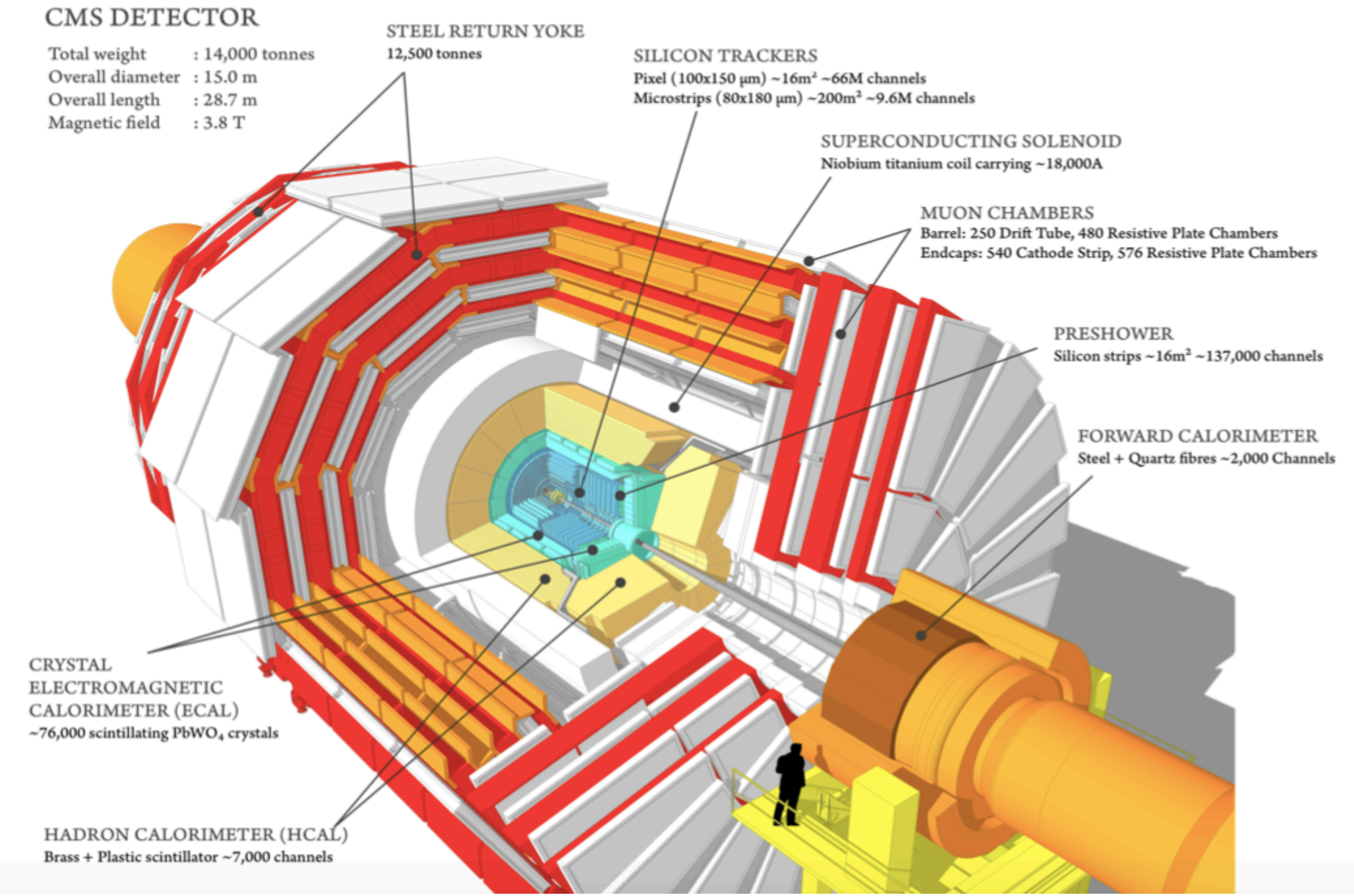


- Significant gain in MET performance using the new PU mitigation techniques (PUPPI)
- Further evolving boosted object taggers

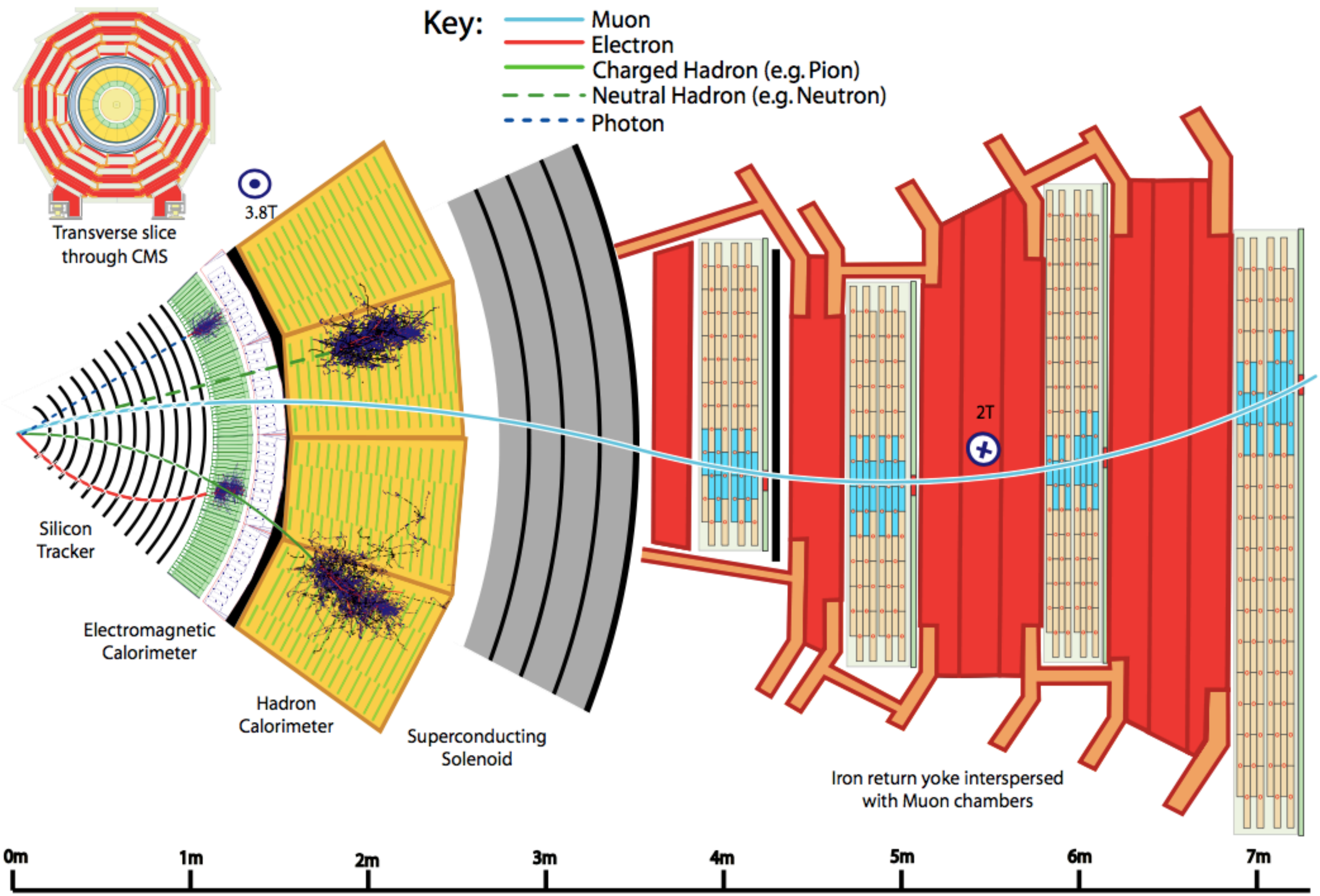
Identification of heavy, energetic, hadronically decaying particles using machine-learning techniques (arXiv:2004.08262v1)
Pileup mitigation at CMS in 13 TeV data (arXiv:2003.00503v1)
Performance of missing transverse momentum in pp collision at 13 TeV (arXiv:1903.06078v2)
Performance of the pile up jet identification in CMS for Run 2 (CMS DP-2020/020)
Jet energy scale and resolution performance with 13 TeV data collected by CMS in 2016-2018 (CMS DP-2020/019)
Mitigation of anomalous missing transverse momentum measurements in data collected by CMS at √s=13 TeV during the LHC Run 2 (CMS DP-2020/018)
Identification of highly Lorentz-boosted heavy particles using graph neural networks and new mass decorrelation techniques (CMS DP-2020/002)
Jet trigger performance in 2018 at 13 TeV (CMS DP-2018/037) **^--- New for LHCP 2020**
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsJME

Backup Slides

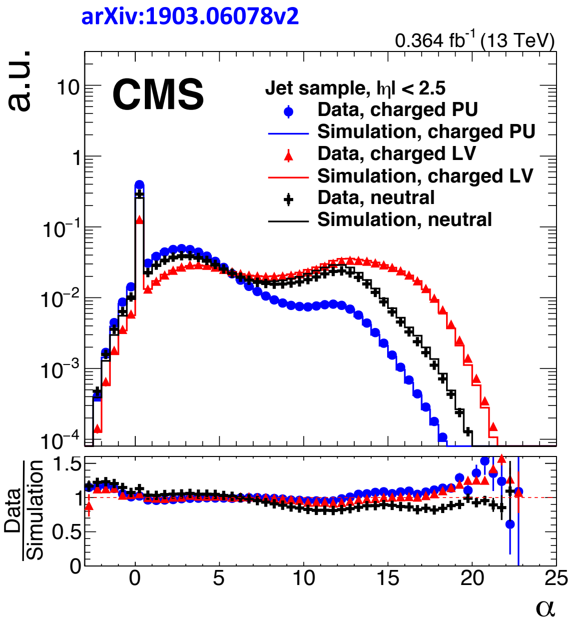
The CMS detector at CERN

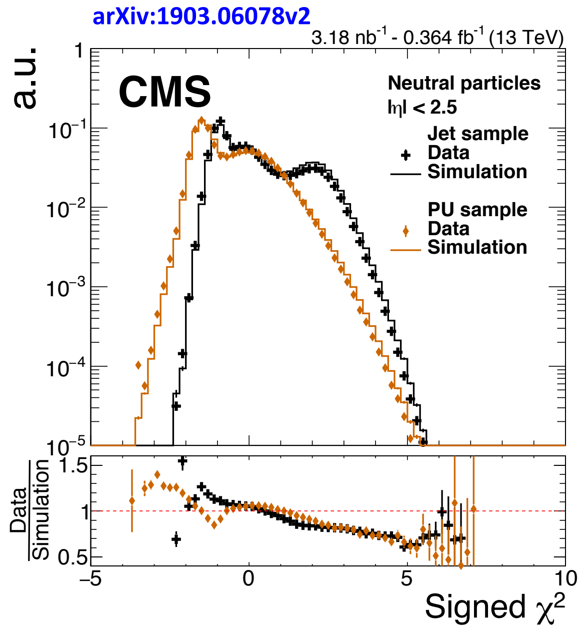


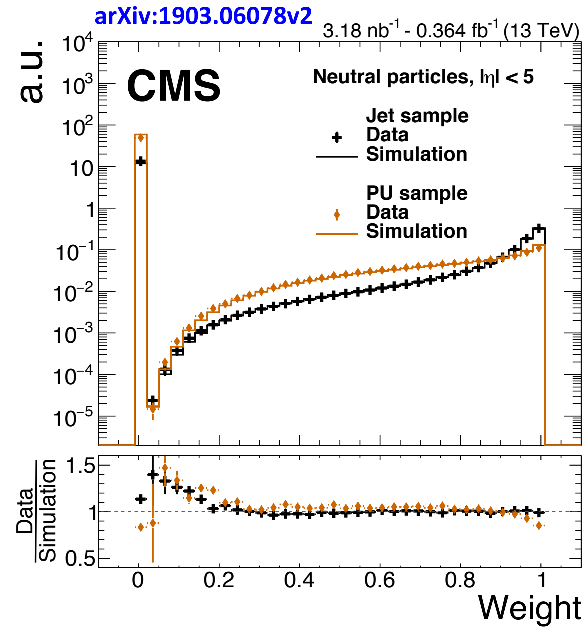
Particles in the CMS detector



Pileup mitigation tehniques at CMS





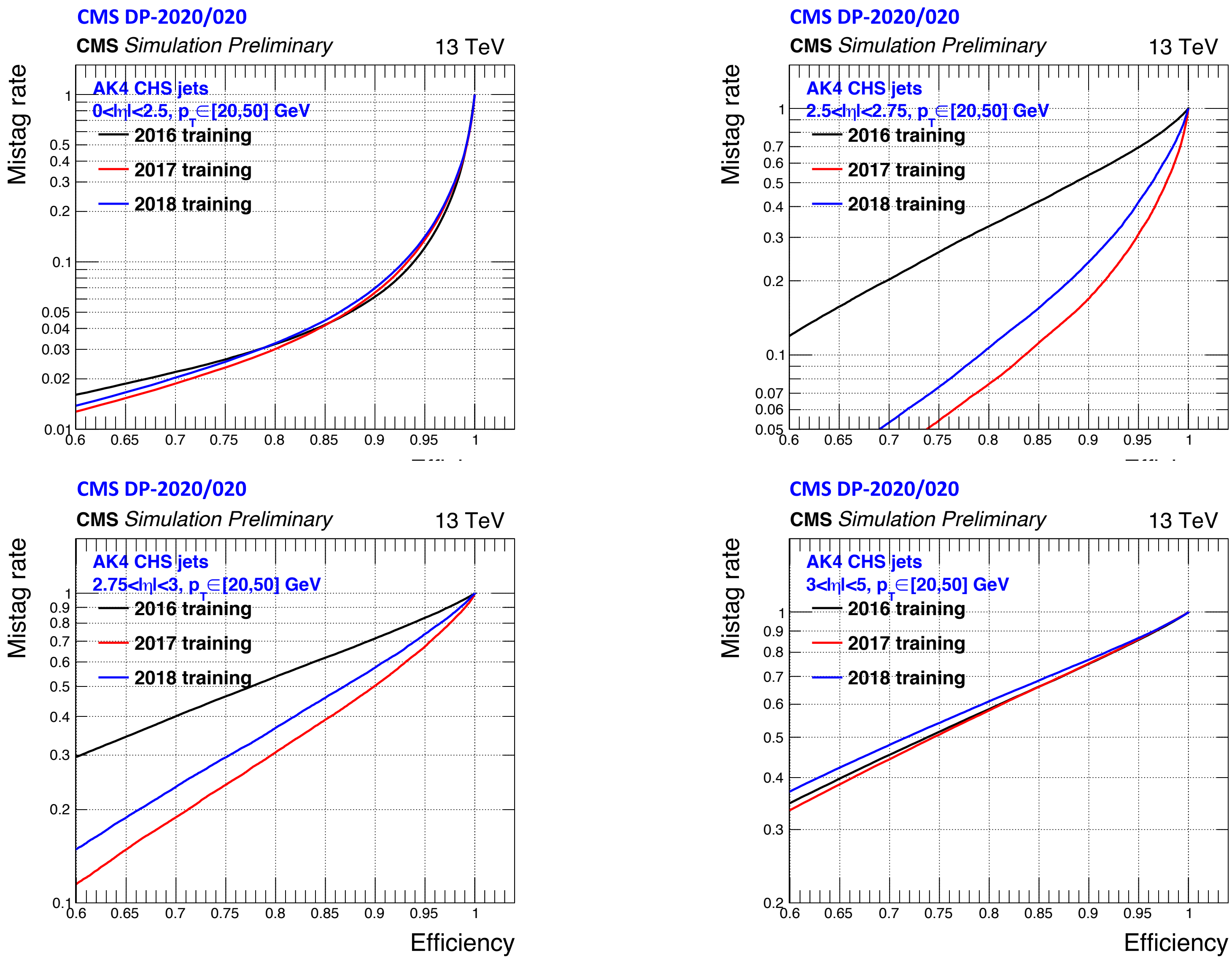


$$\alpha_i = \log \sum_{j \neq i, \Delta R_{ij} < 0.4} \left(\frac{p_{\mathrm{T}j}}{\Delta R_{ij}} \right)^2 \begin{cases} \text{for } |\eta_i| < 2.5, & j \text{ are charged PF candidates from PV} \\ \text{for } |\eta_i| > 2.5, & j \text{ are all kinds of reconstructed PF candidates} \end{cases}$$

$$\chi_i^2 = \frac{(\alpha_i - \overline{\alpha}_{\mathrm{PU}})^2}{\mathrm{RMS}_{\mathrm{PU}}^2}$$ - to determine the probability that the PF candidate is from pile-up

$$w_i = F_{\chi^2, \mathrm{NDF}=1}(\chi_i^2)$$ - the weight being zero (one) if the PF candidate is from pileup (PV)

Pileup mitigation tehniques at CMS (NEW)

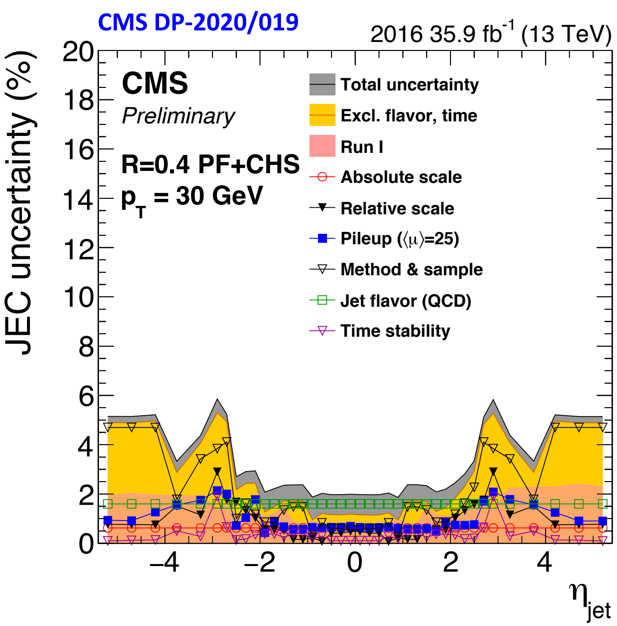


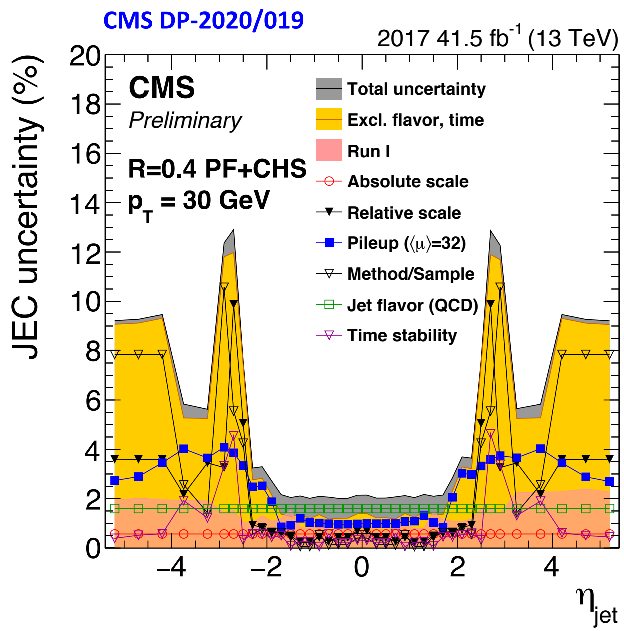
Pileup Jet ID: input variables

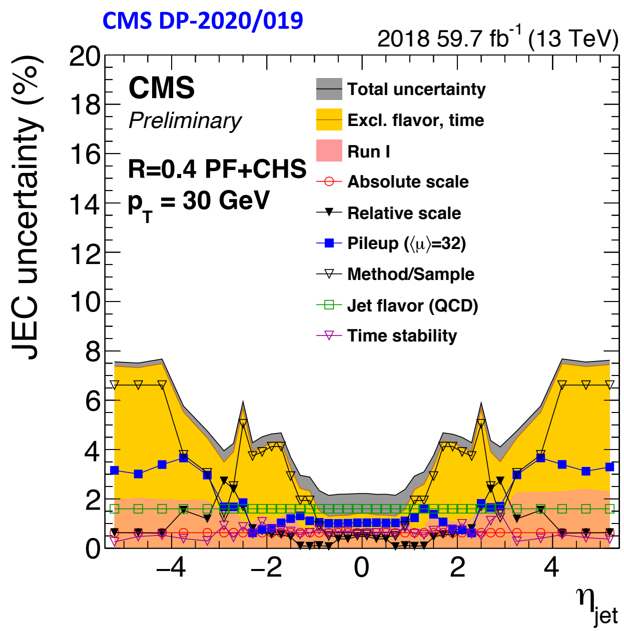
arXiv:2003.00503v1

Input variable	Definition
β	Fraction of p_{T} of charged particles associated with the LV, defined as $\sum_{i\in\mathrm{LV}} p_{\mathrm{T},i} / \sum_i p_{\mathrm{T},i}$ where i iterates over all charged PF particles in the jet
N_{vertices}	Number of vertices in the event
$\langle\Delta R^2\rangle$	Square distance from the jet axis scaled by p_{T}^2 average of jet constituents: $\sum_i \Delta R^2 p_{\mathrm{T},i}^2 / \sum_i p_{\mathrm{T},i}^2$
$f_{\mathrm{ring}X}$, $X = 1, 2, 3$, and 4	Fraction of p_{T} of the constituents ($\sum p_{\mathrm{T},i} / p_{\mathrm{T}}^{\mathrm{jet}}$) in the region $R_i < \Delta R < R_{i+1}$ around the jet axis, where $R_i = 0, 0.1, 0.2$, and 0.3 for $X = 1, 2, 3$, and 4
$p_{\mathrm{T}}^{\mathrm{lead}} / p_{\mathrm{T}}^{\mathrm{jet}}$	p_{T} fraction carried by the leading PF candidate
$p_{\mathrm{T}}^{\mathrm{l.\,ch.}} / p_{\mathrm{T}}^{\mathrm{jet}}$	p_{T} fraction carried by the leading charged PF candidate
$\lvert\vec{m}\rvert$	Pull magnitude, defined as $\lvert(\sum_i p_{\mathrm{T}}^i \lvert r_i\rvert \vec{r}_i)\rvert / p_{\mathrm{T}}^{\mathrm{jet}}$ where $\vec{r}_i$ is the direction of the particle i from the direction of the jet
N_{total}	Number of PF candidates
N_{charged}	Number of charged PF candidates
σ_1	Major axis of the jet ellipsoid in the η-ϕ space
σ_2	Minor axis of the jet ellipsoid in the η-ϕ space
$p_{\mathrm{T}}^{\mathrm{D}}$	Jet fragmentation distribution, defined as $\sqrt{\sum_i p_{\mathrm{T},i}^2} / \sum_i p_{\mathrm{T},i}$

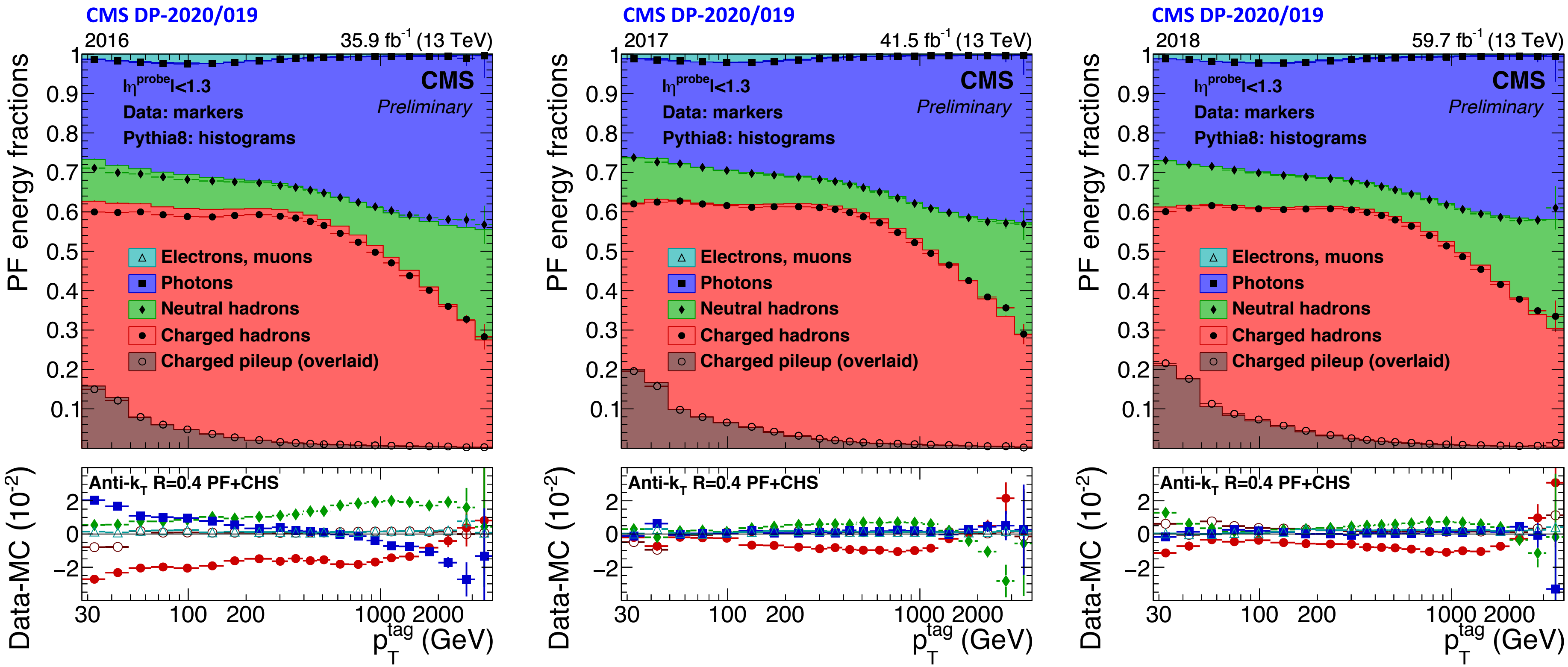
Jet energy scale uncertainties







Jet PF composition



Jet PF composition studied from dijet events using fully corrected jets.

Cross-check comparison between data and simulation for monitoring the stability of JES.

All categories considered: Photons, Leptons, Neutral and Charged Hadrons.

Fraction of energy removed by CHS before jet clustering is overlaid.

An event rejected by the HCAL noise filter

CMS DP-2020/018