Pileup mitigation in jets with CMS

Ksenia de Leo, Anna Benecke, Andreas Hinzmann, Roman Kogler

University of Hamburg

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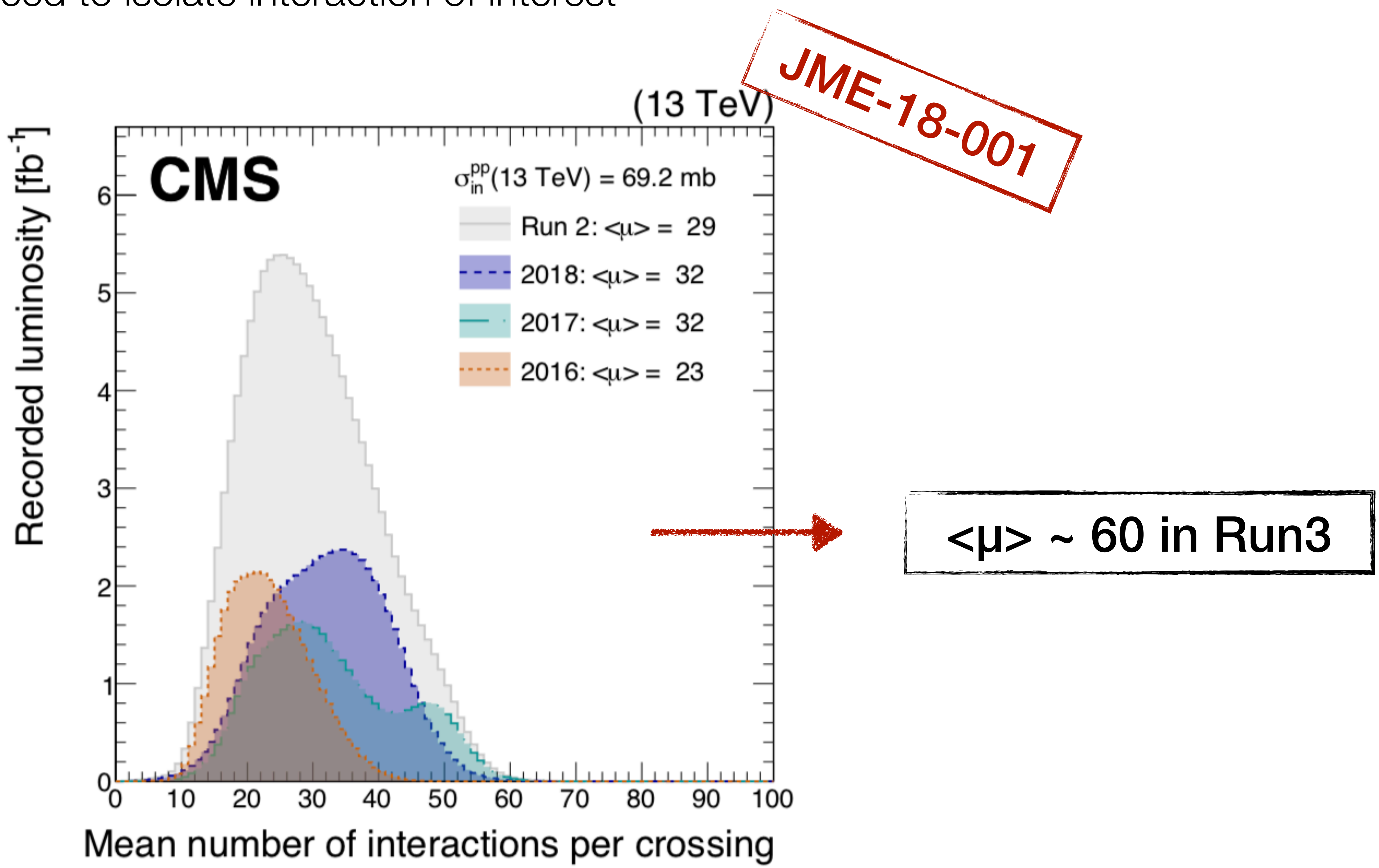
Pileup in Run2

- In each bunch crossing: **main interaction** + additional collisions (**pileup**)
- Need to isolate interaction of interest



Pileup Mitigation Techniques

- Charged Hadron Subtraction **CHS**
- Pileup Per Particle Identification **PUPPI**
- Pileup Jet ID: reject PU jets (applied on CHS)

CHS

- **Charged particles** associated to PU vertex are removed from jets
- All **neutral particles** are kept
- Additional correction on jets to treat neutral PU

PUPPI Algorithm

- Each particle is assigned a weight **$0<w<1$**:
  - 0 it is most probably originating from PU
  - 1 it is most probably originating from LV
- Weight applied to 4-momentum of the particle
- **Charged particles** are given a weight of **0 or 1** based on the track-vertex association (fromPV and d_Z variable)
- For **neutral particles** the weight is calculated based on surrounding particles and charged PU distribution in the event

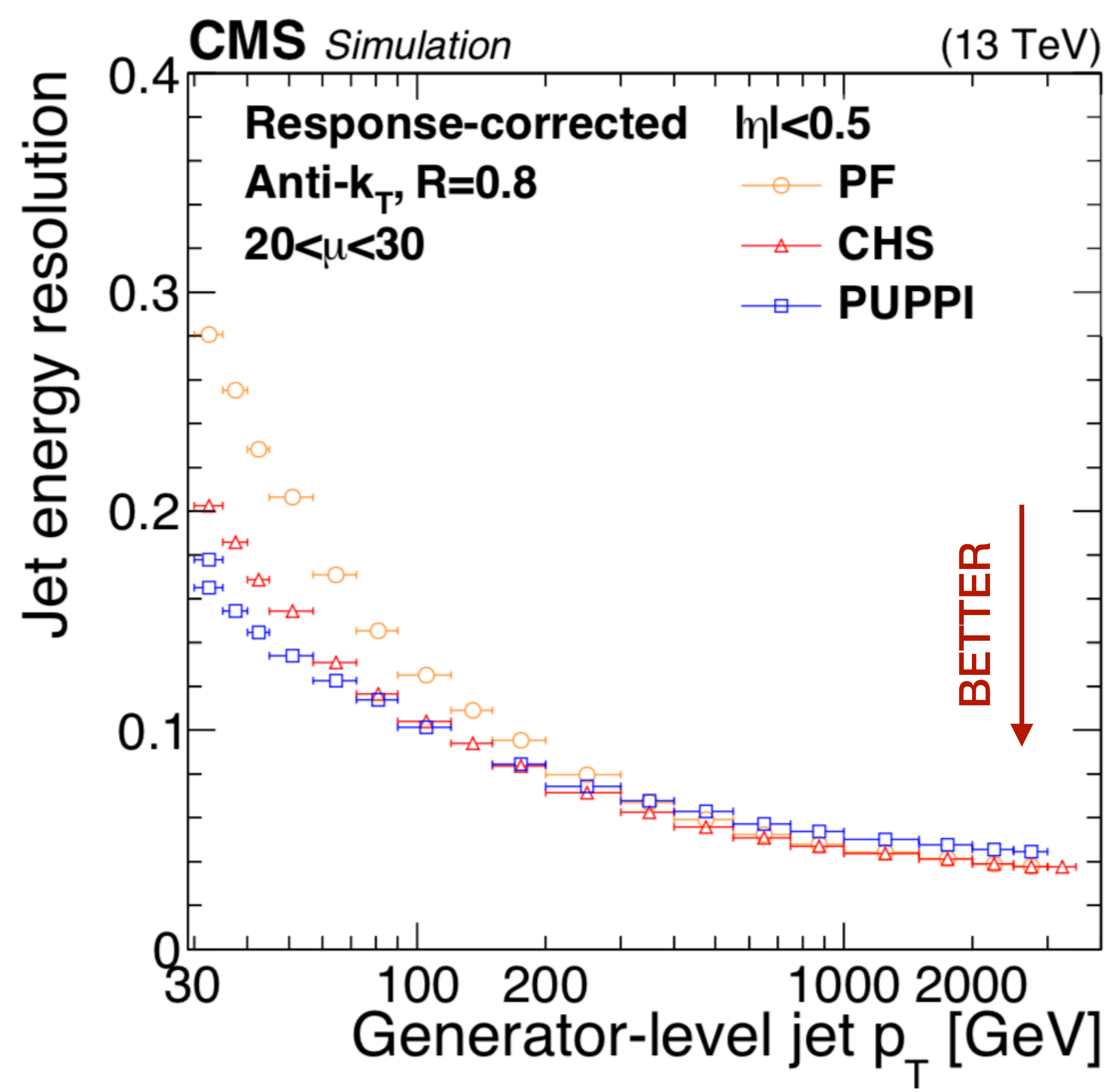
PUPPI Algorithm

- PUPPI shows very good performance **(JME-18-001)**: jets, MET, lepton isolation, jet substructure…

→ **goal**: PUPPI as default algorithm in Run3

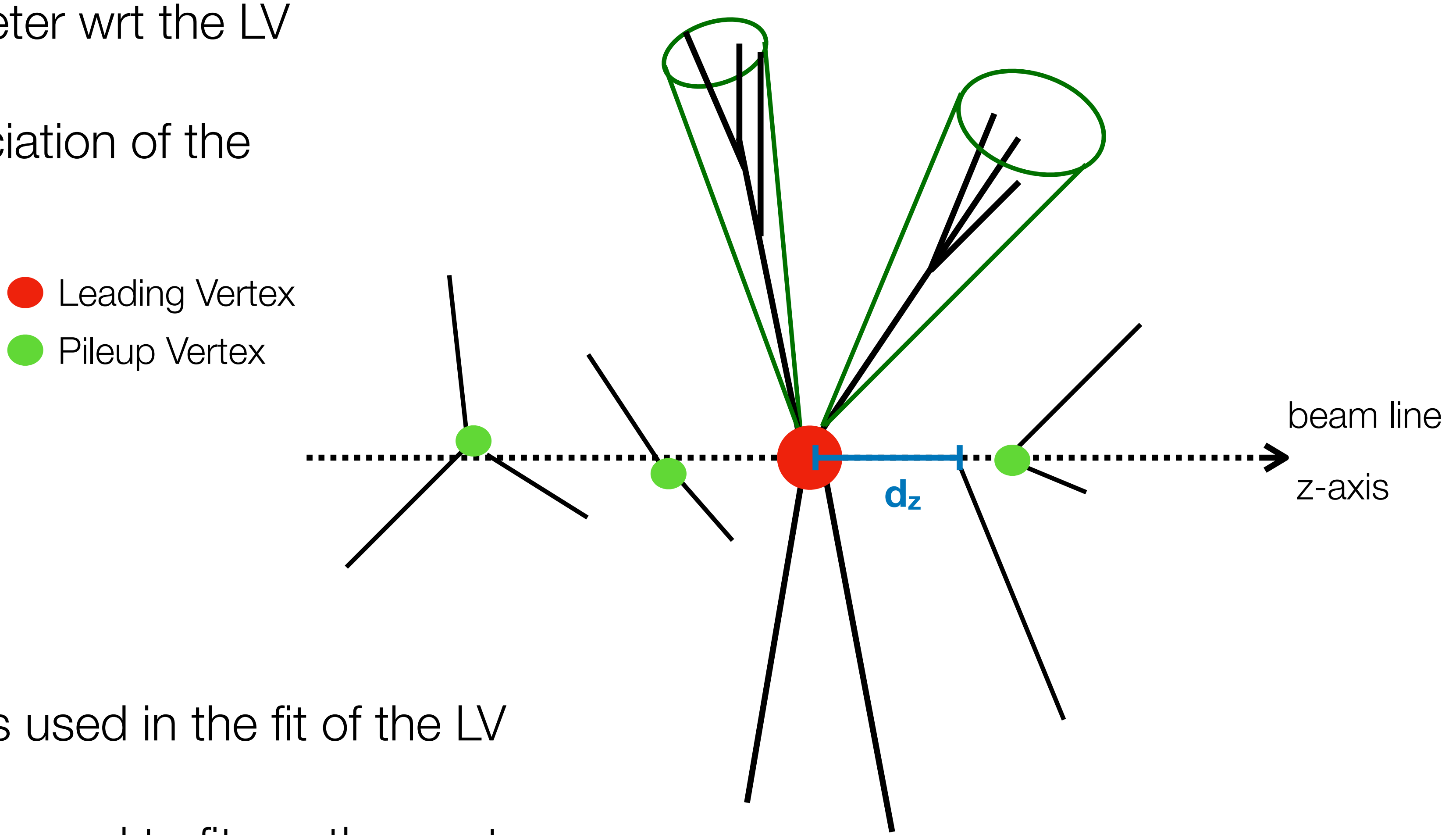
- Improvements: JER at high p_T

At **low p_T** PUPPI shows better performance than CHS, but worse performance at **high p_T**



fromPV & d_Z

- Some charged particles are rejected because of the **fromPV** and **d_Z** variables
- **d_Z** is the transverse impact parameter wrt the LV
- **fromPV** tells how tight is the association of the particle to the LV



- Four values between 3 and 0:

vertex association
  - **fromPV=3** the track is used in the fit of the LV
  - **fromPV=0** the track is used to fit another vertex

no vertex association
  - **fromPV=2** the track is not used in the fit of any vertex and is close in z to the LV
  - **fromPV=1** the track is close in z to another vertex

fromPV & d_Z in CHS and PUPPI

- In CHS the charged particles with **fromPV>0** are kept
- In PUPPI:
  - charged particles from a PU vertex are assigned a weight w=0 and are removed ▹ **fromPV>0** as in CHS
  - charged particles from the LV are assigned a weight w=1 ▹ **fromPV=3**
  - no vertex association, w=1 if **d_Z<0.3** cm, w=0 otherwise ▹ **fromPV=1, 2** & **d_Z<0.3** cm

PROBLEM ➜ charged particles at high p_T are ***not well assigned to the vertex***

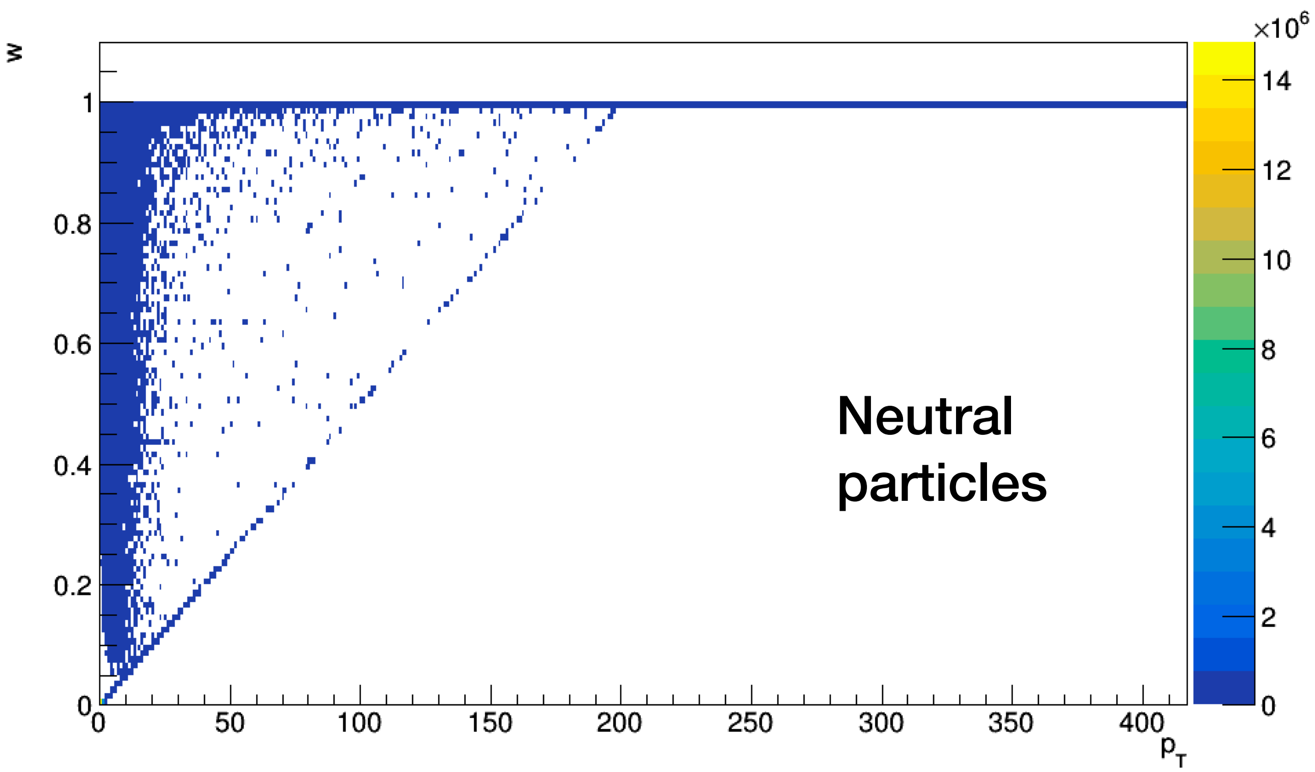
- In the following we will work only with charged particles with **fromPV=1 & 2**

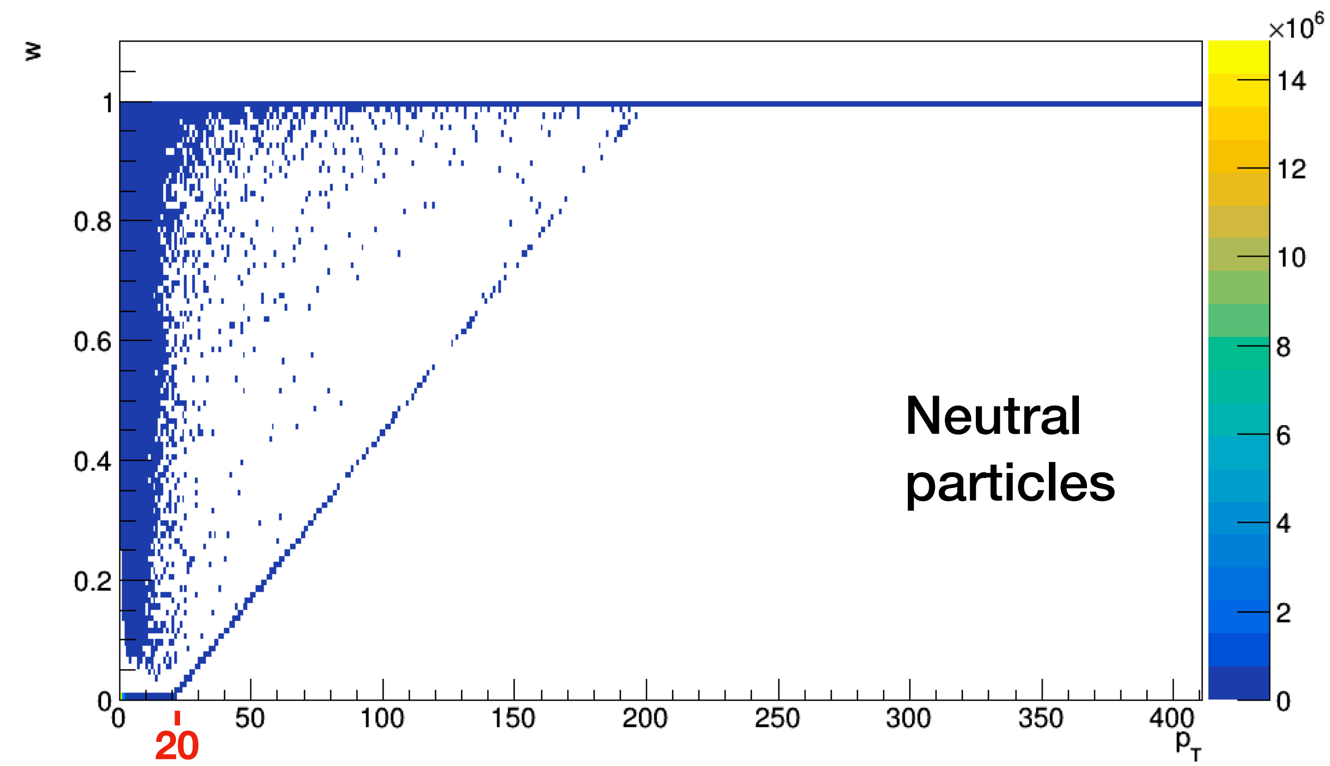
PUPPI tune v13 beagle

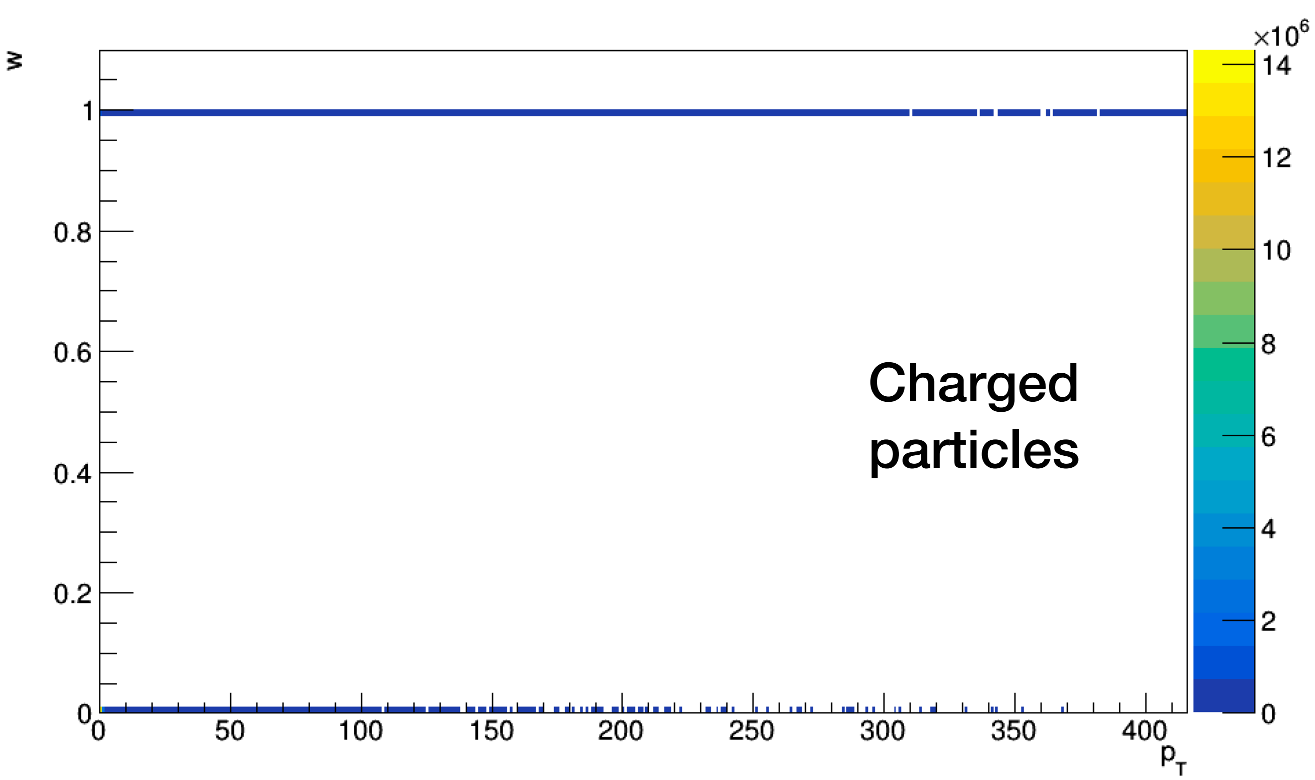
- **Wrong track-vertex association** at high p_T → remove d_Z cut and introduce p_T and η cuts
- Charged particles:
  - **p_T** protection at p_T = 20 GeV. **Below 20 GeV** particles are treated as neutrals ($0<w<1$), **above 20 GeV** all particles with no vertex assignment are kept
  - In 2017/2018 phase-1 pixel: more charged hadrons in **$|\eta|> 2.5$**, but **no track-vertex association** (fromPV=1 or 2)
  - Strategy: for $|\eta|> 2.5$ keep all the charged particles not associated to a PU vertex
- Neutral particles:
  - Linear **p_T** protection between 20 and 200 GeV

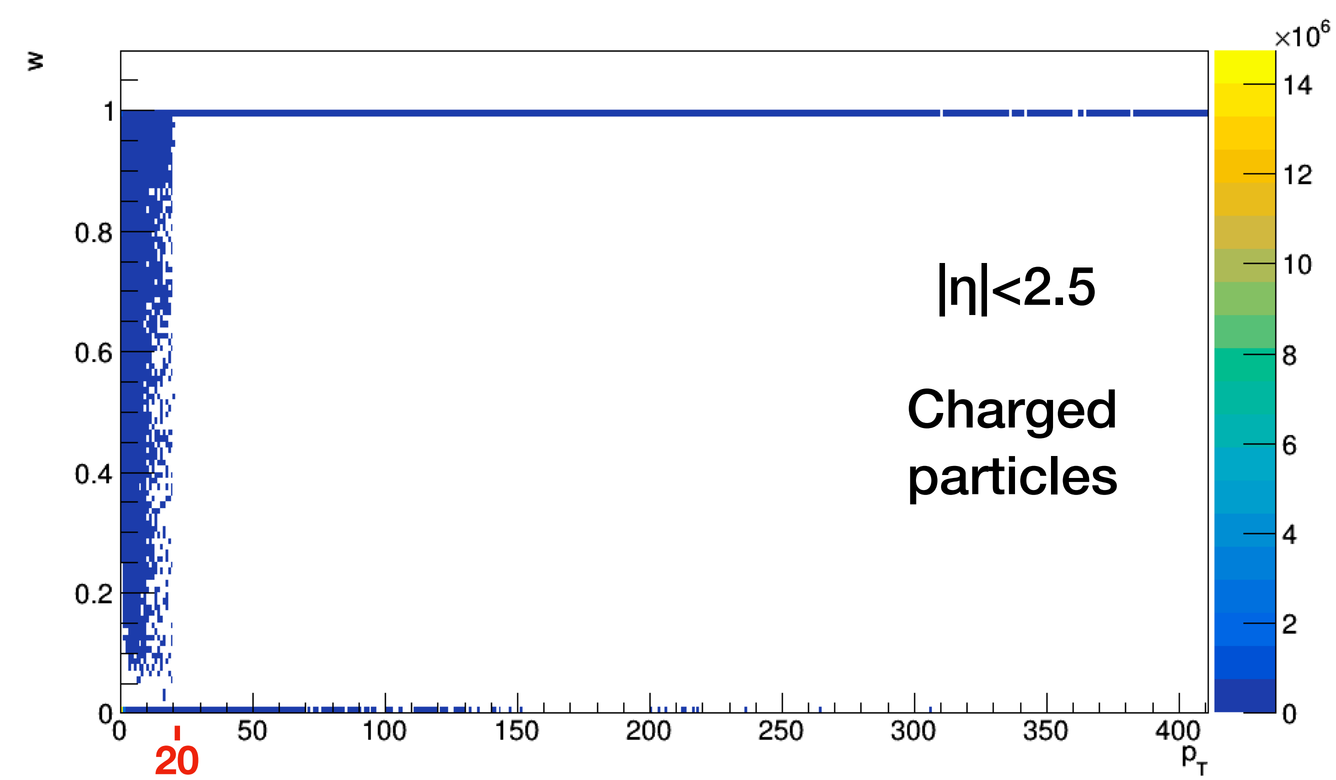
weight vs p_T

PUPPI default | **PUPPI v13 beagle**





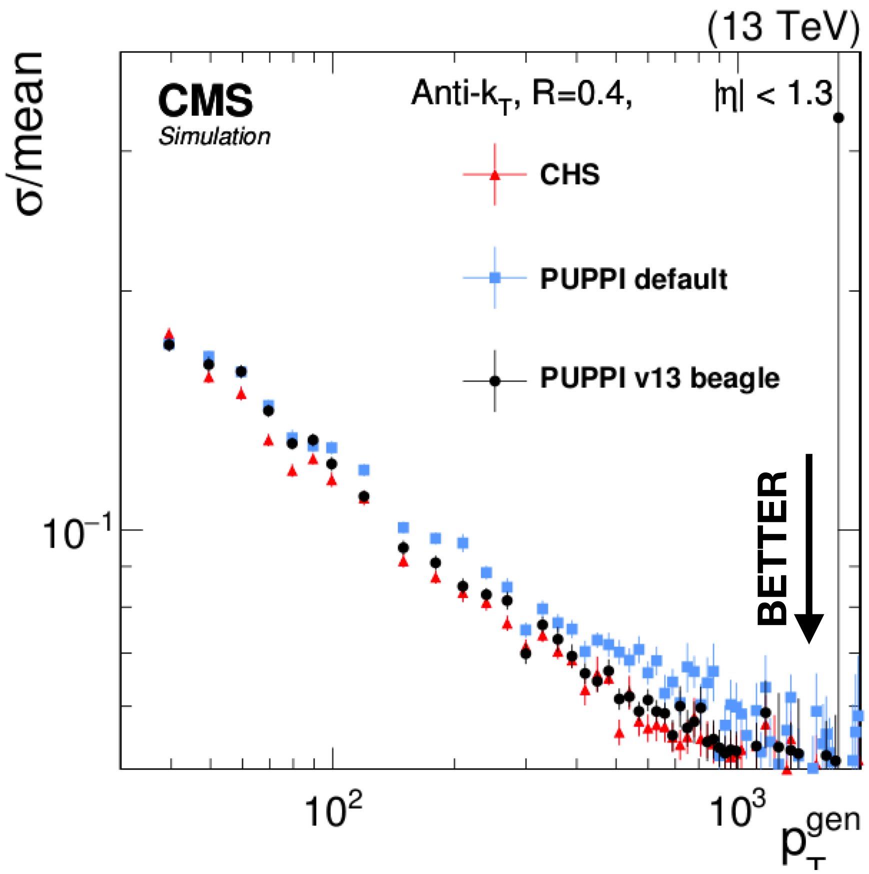


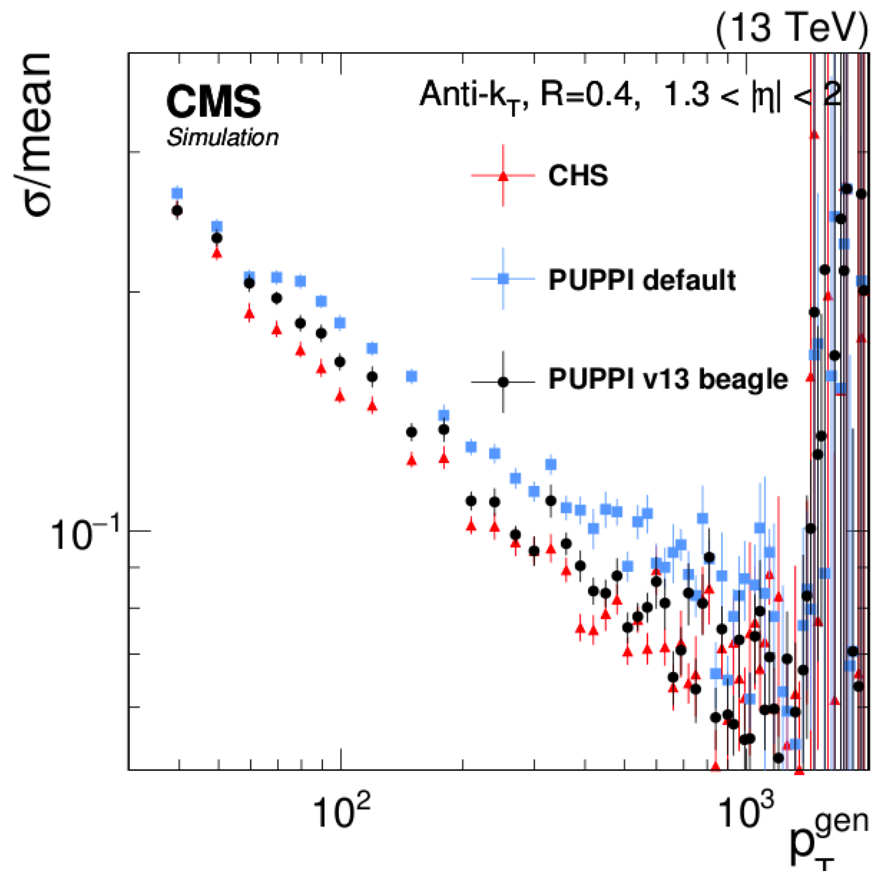


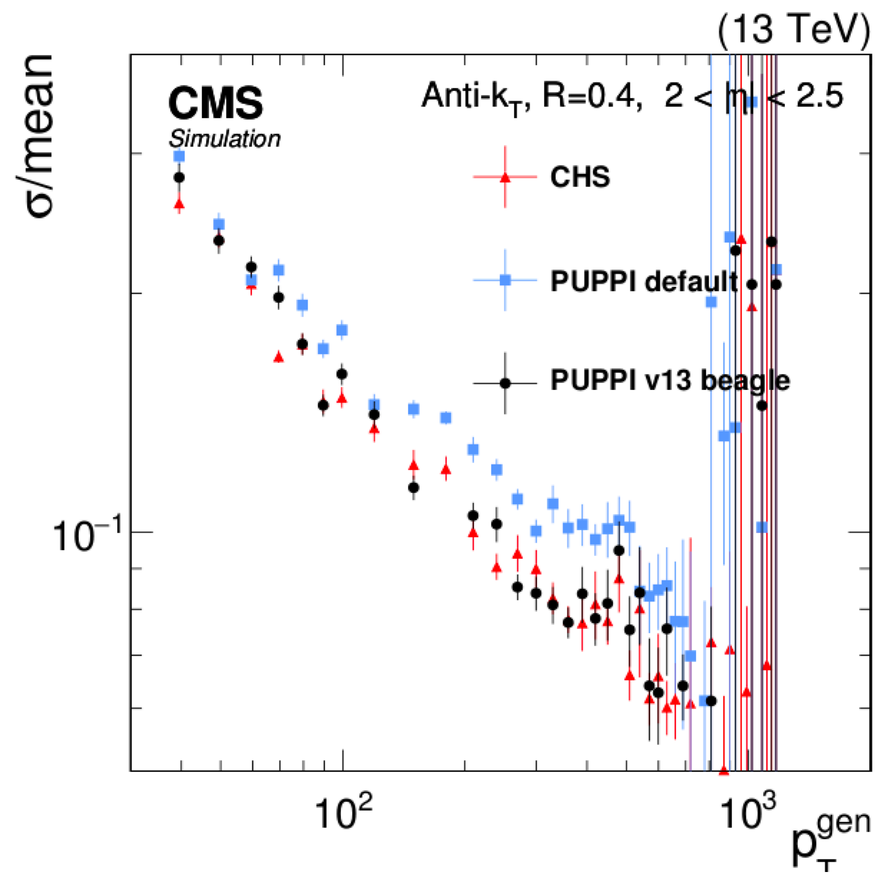
sample: QCD 2018

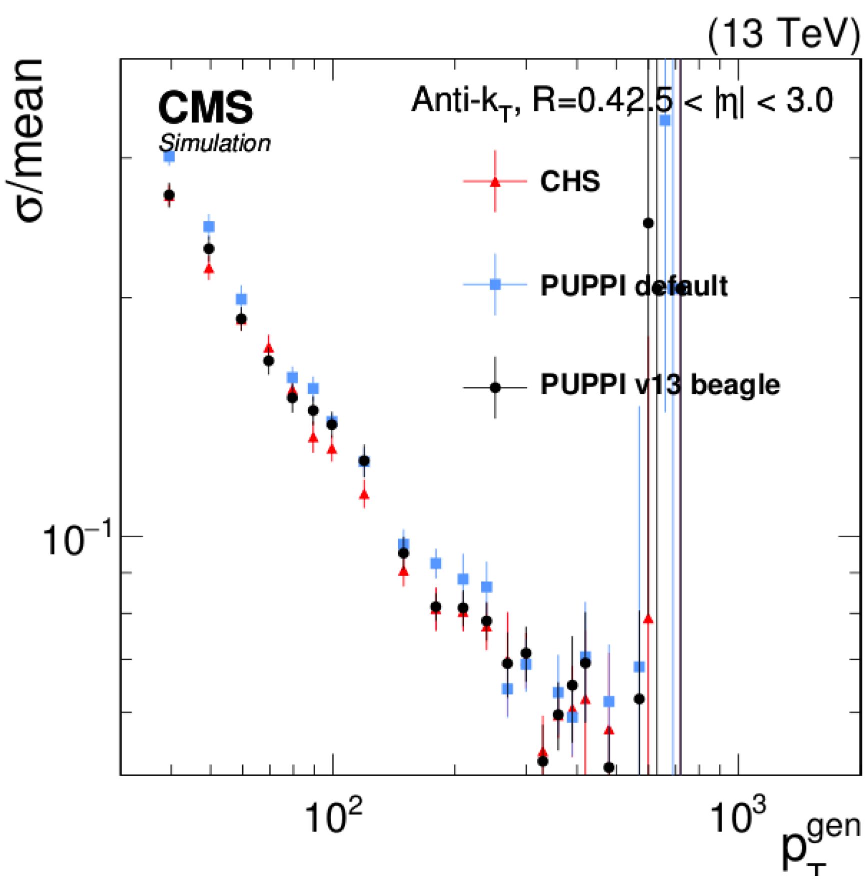
JER 2017 - Ak4 PU>50

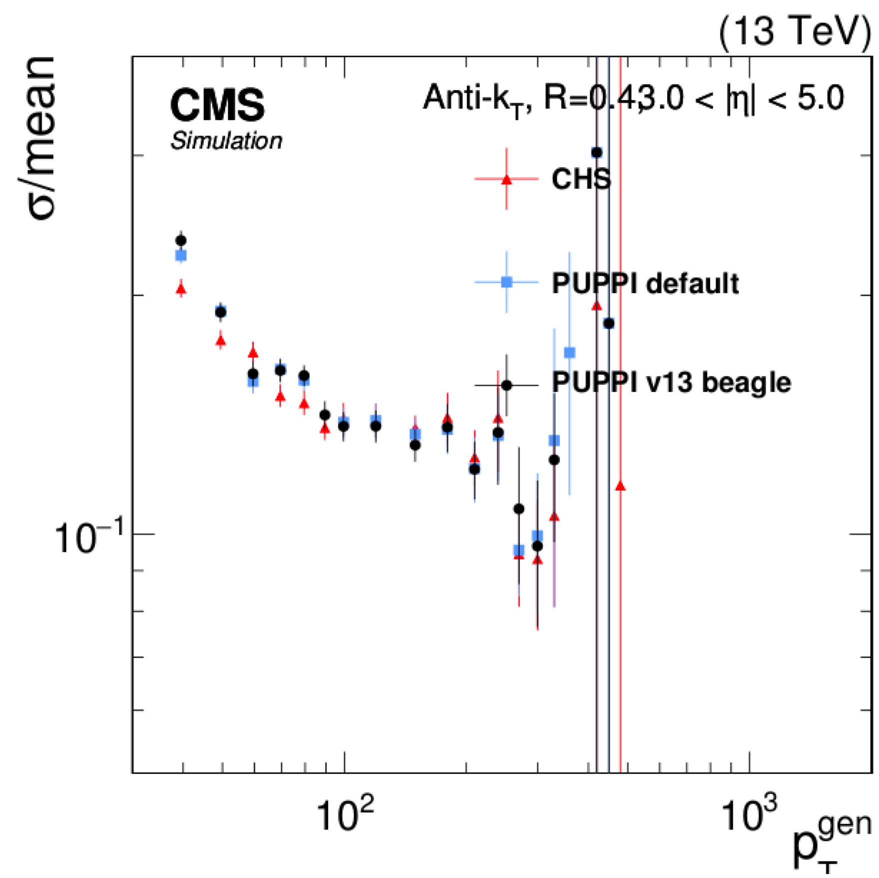
QCD sample







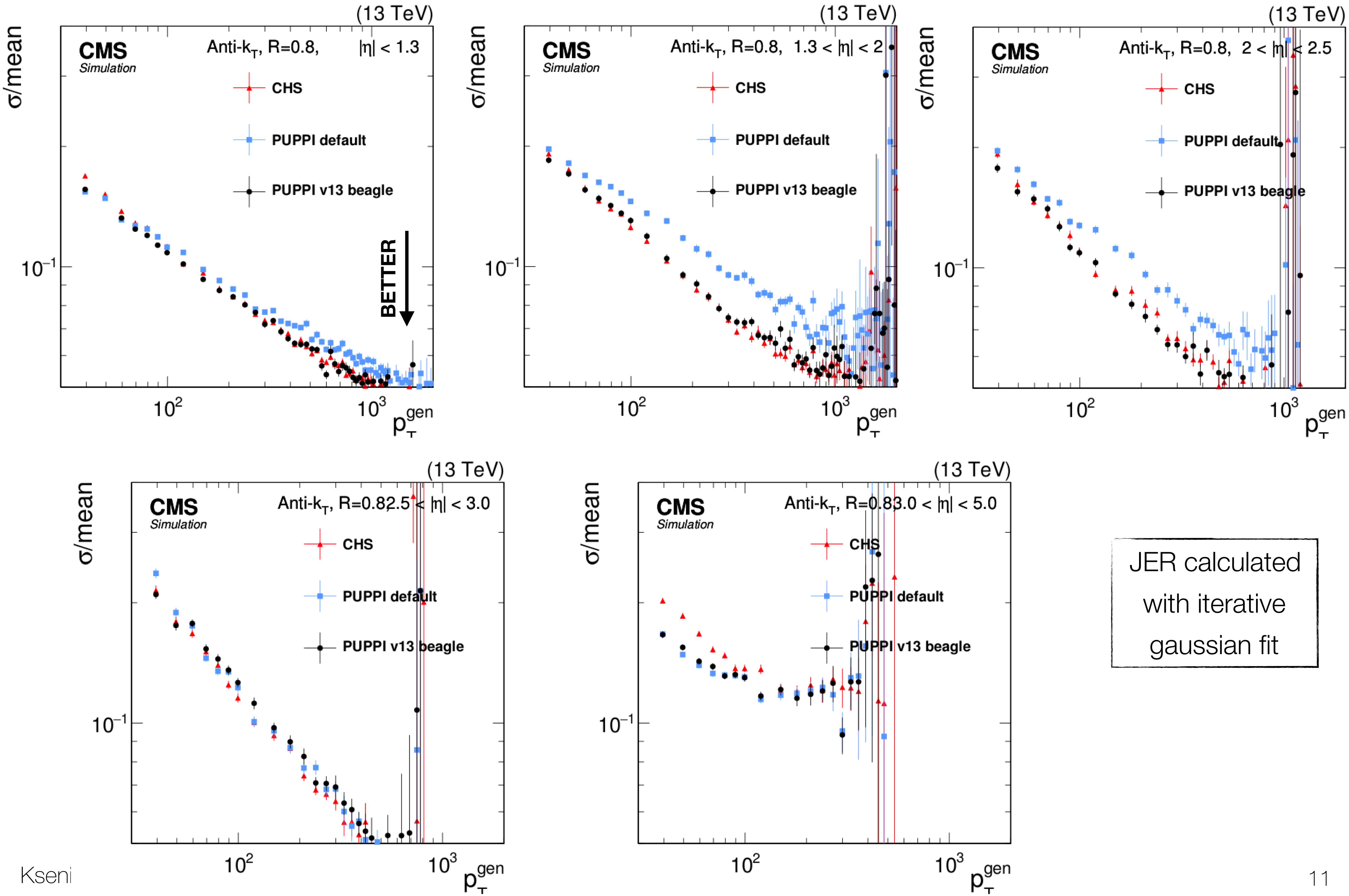




JER calculated with iterative gaussian fit

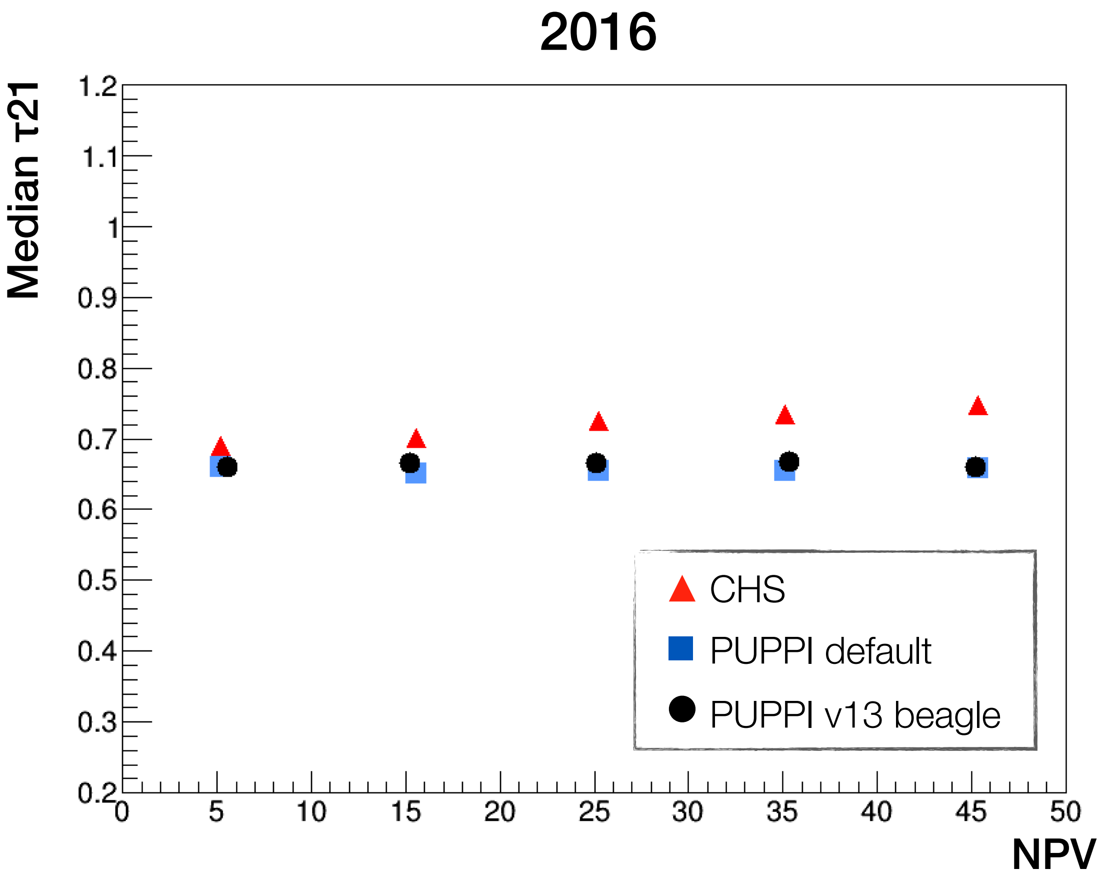
JER 2017 - Ak8

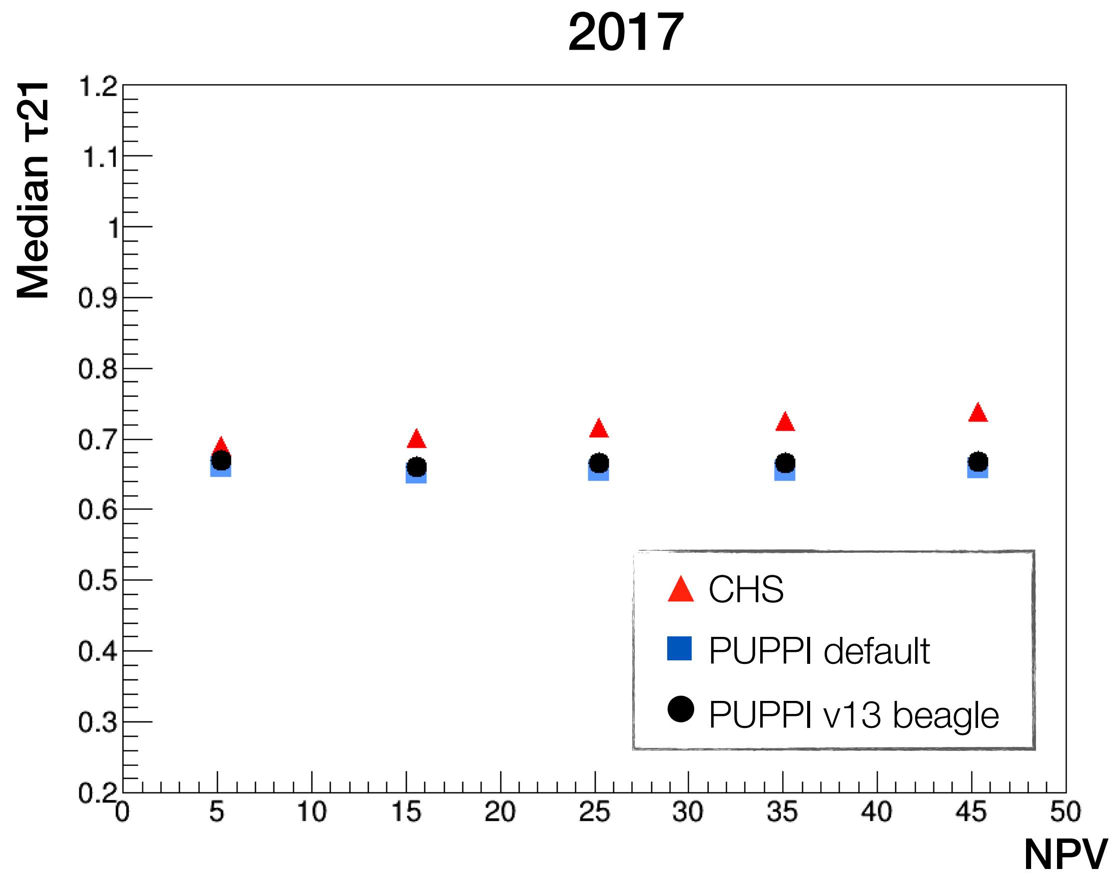
QCD sample

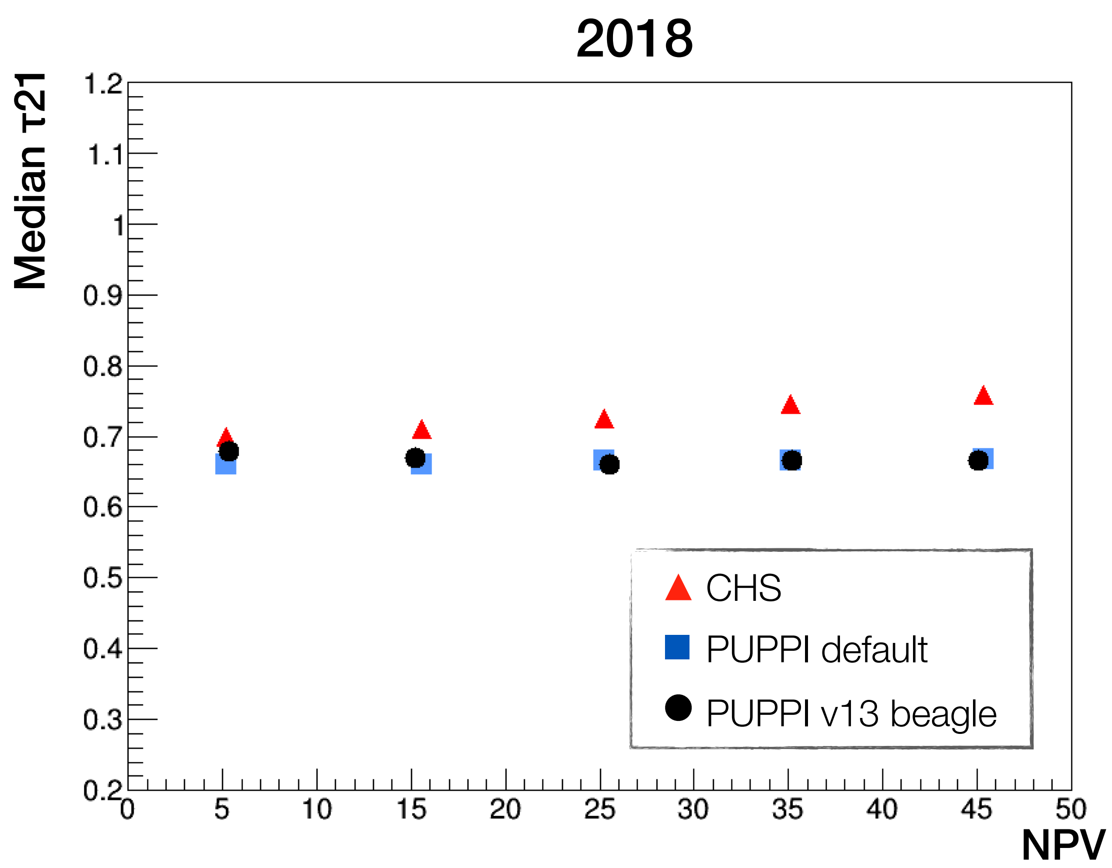


JER calculated with iterative gaussian fit

Median τ21







QCD sample

Median τ21 leading Ak8 jet

400 < p_T < 600 GeV

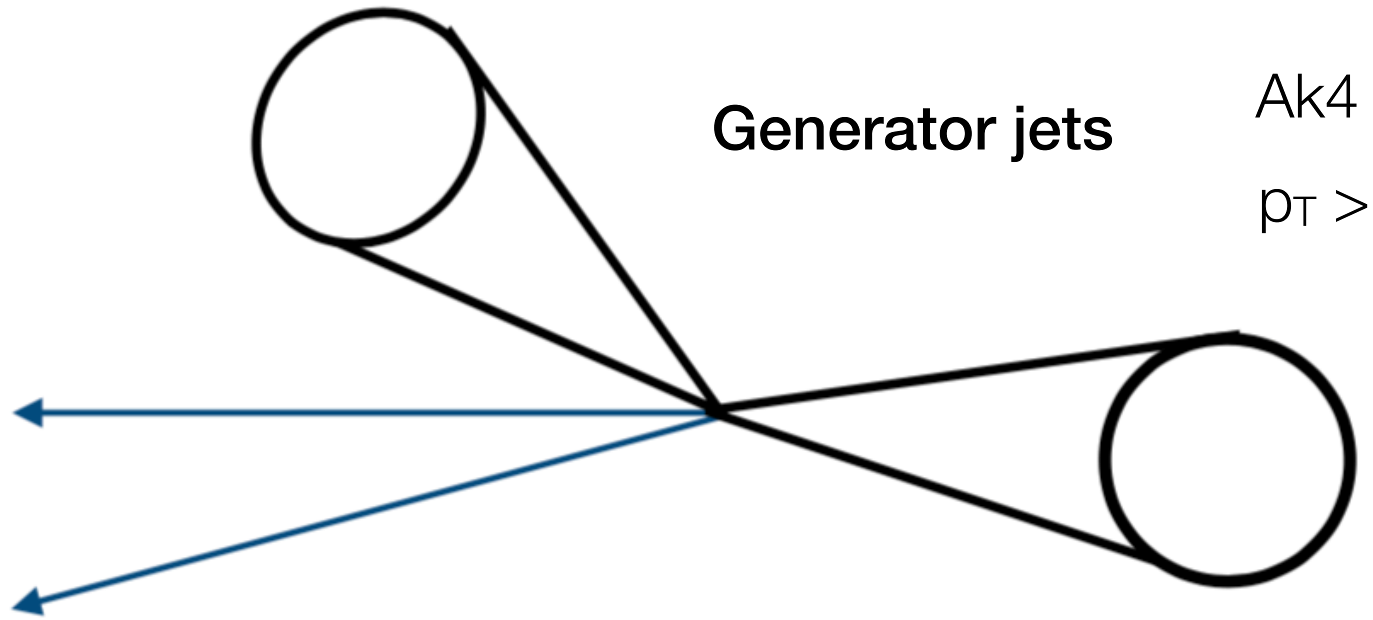
no SoftDrop Mass cut

Efficiency & Purity

Efficiency and Purity

Z + Jets

MC studies



Generator jets

Ak4 jets with

$p_T > 20$ GeV

muons

2 muons with $p_T > 20$ GeV,

70 GeV < $M_{\mu\mu}$ < 110 GeV

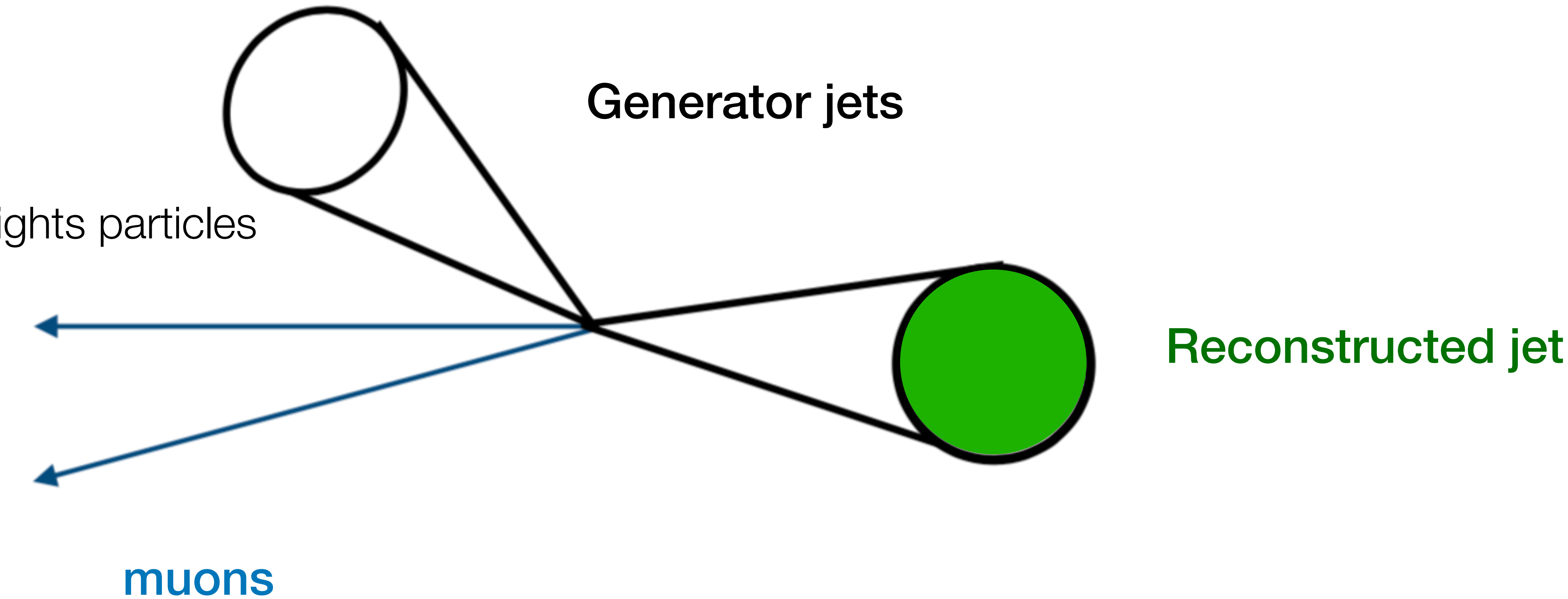
Jets overlapping with muons removed

Efficiency and Purity

Efficiency

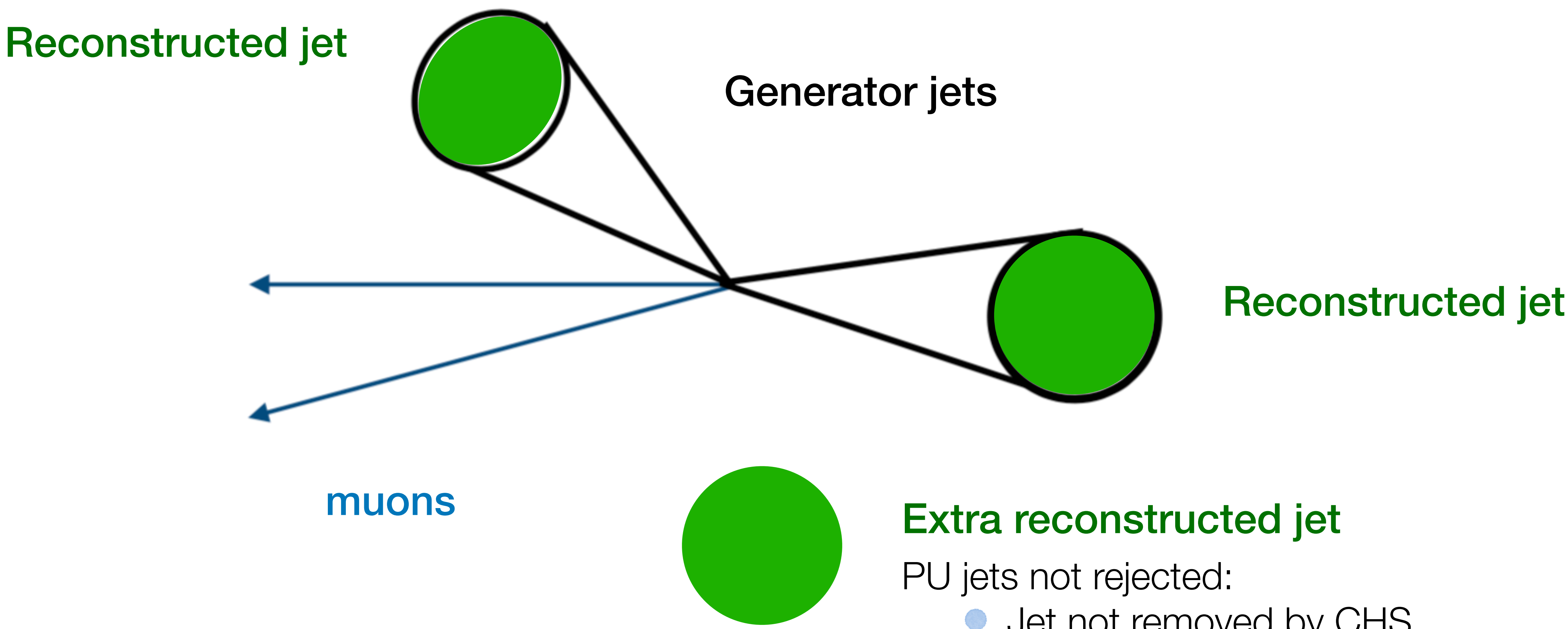
Not reconstructed or rejected jet

- Pileup Jet ID
- PUPPI down-weights particles



Efficiency and Purity

Purity

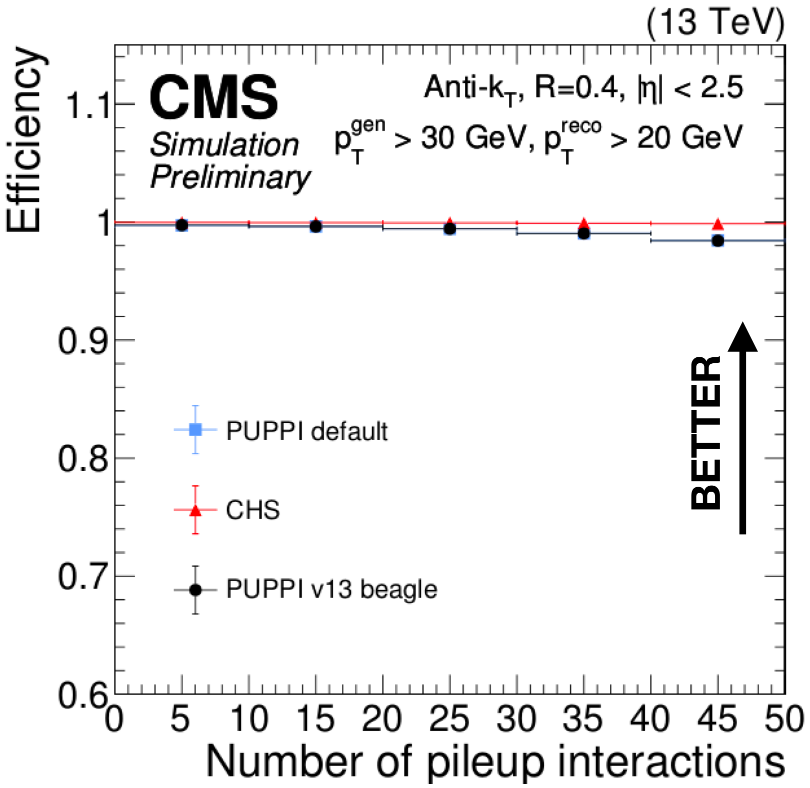


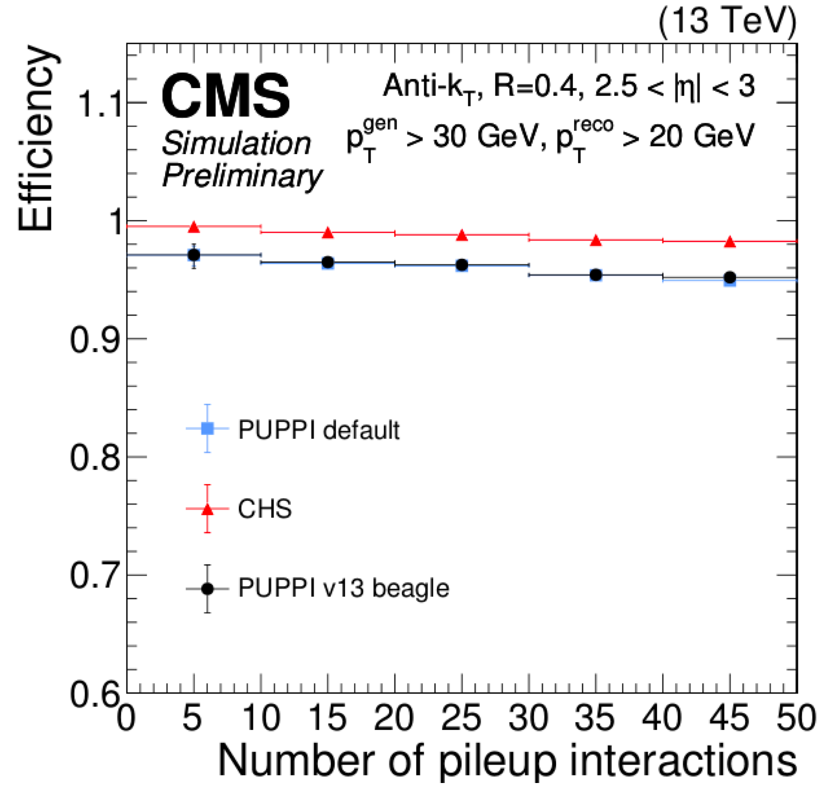
PU jets not rejected:

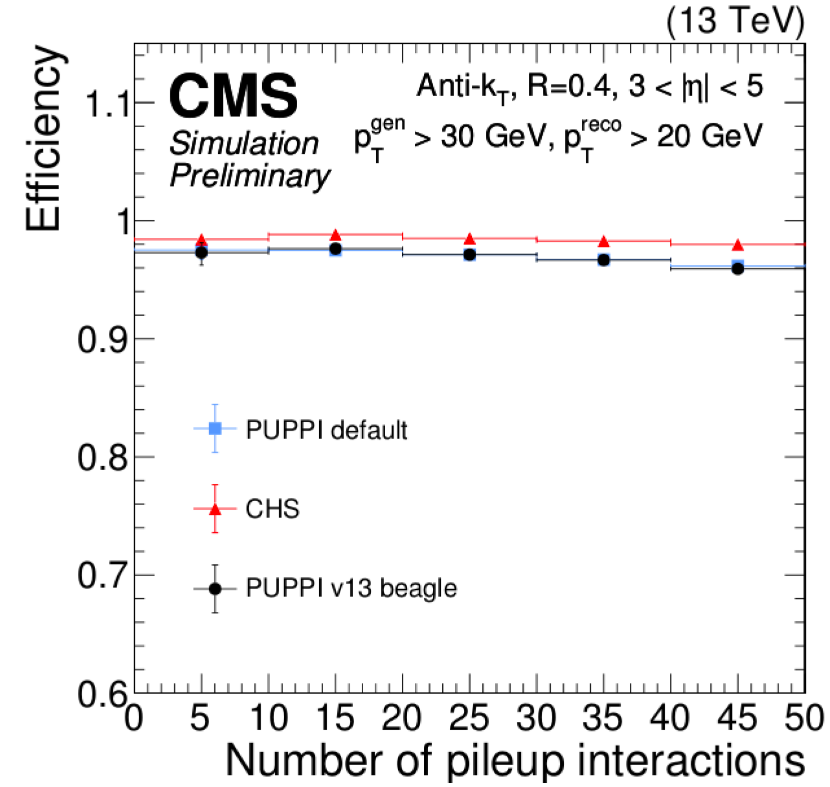
- Jet not removed by CHS
- Particles not removed by PUPPI

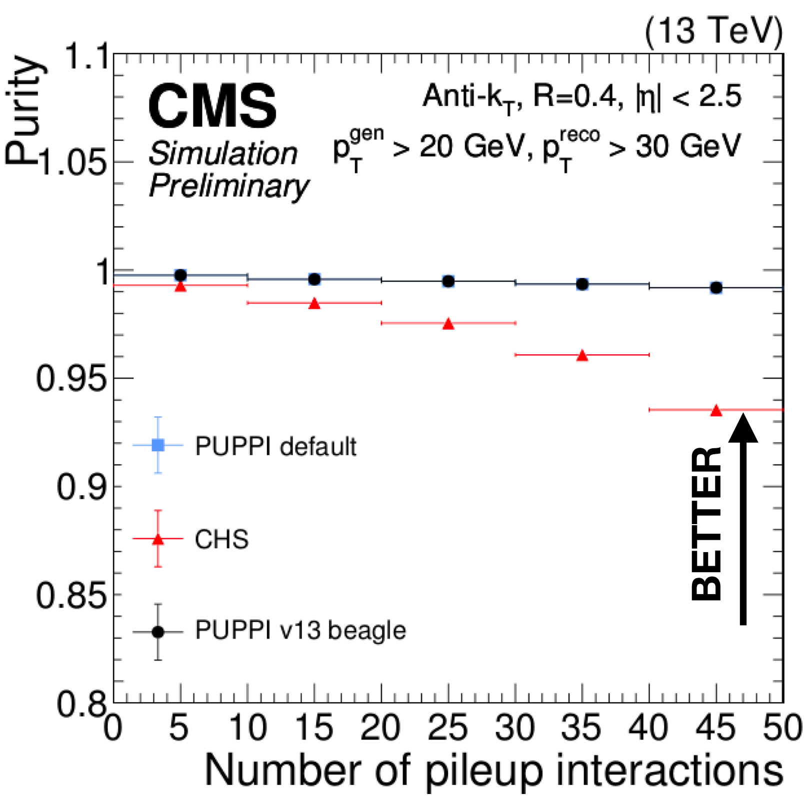
Efficiency & Purity - 2016

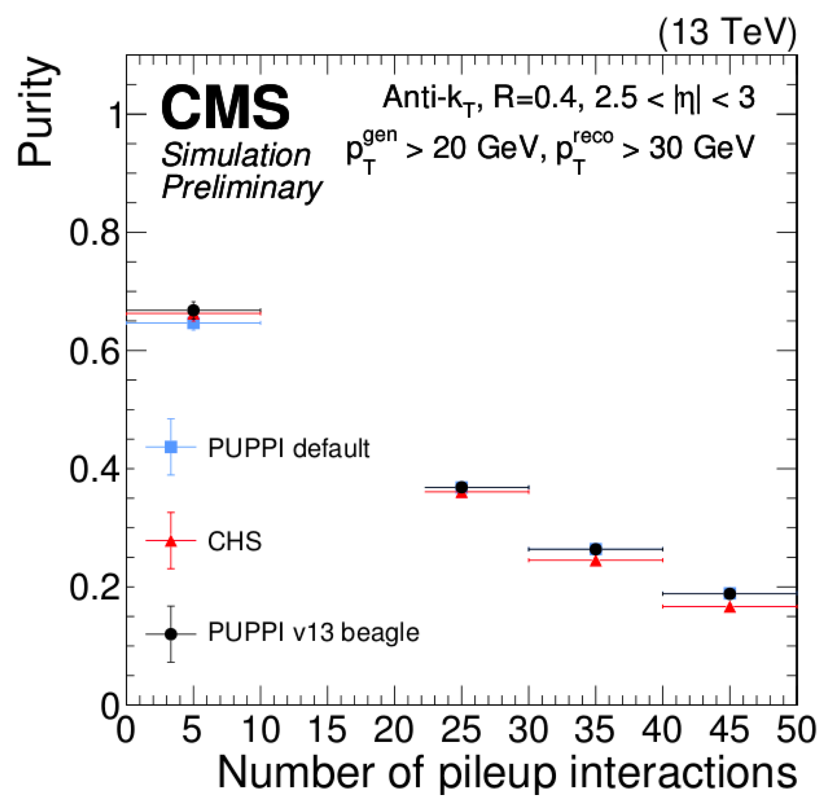
DY sample

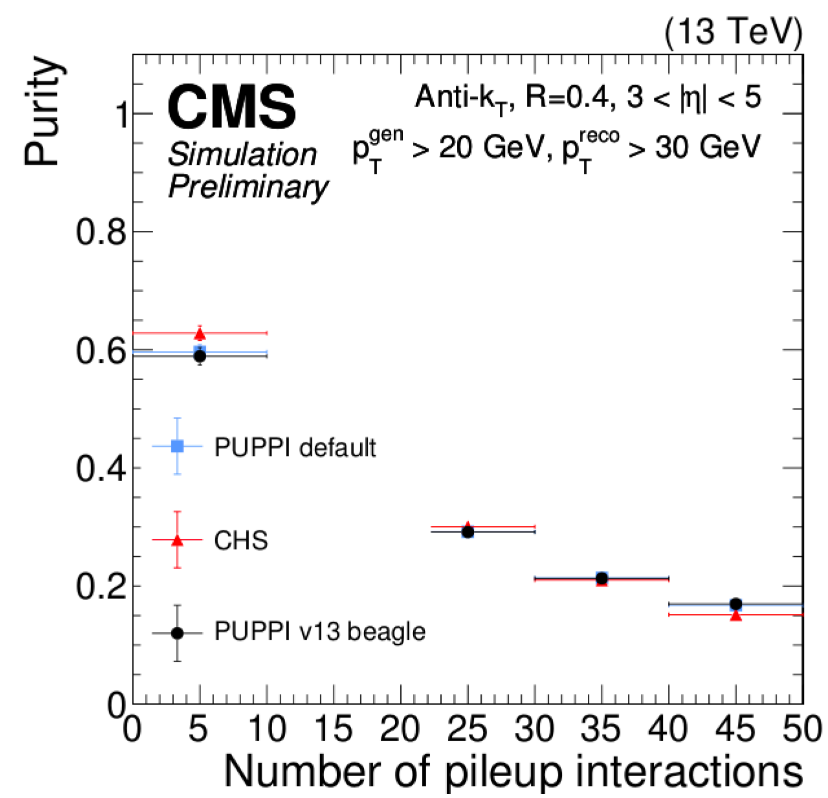






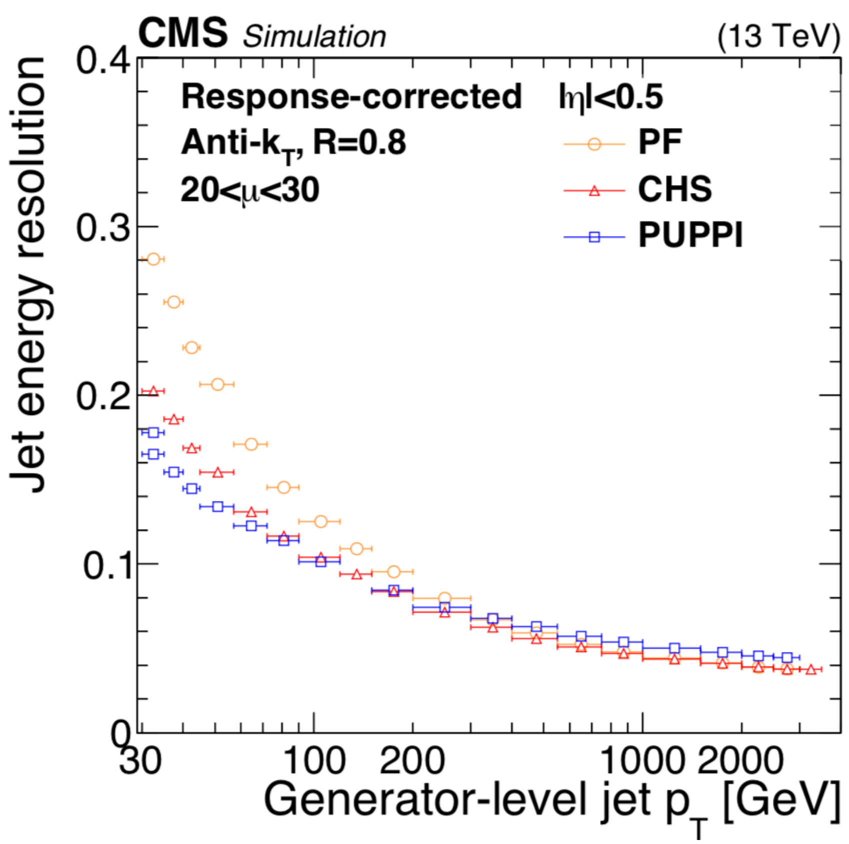


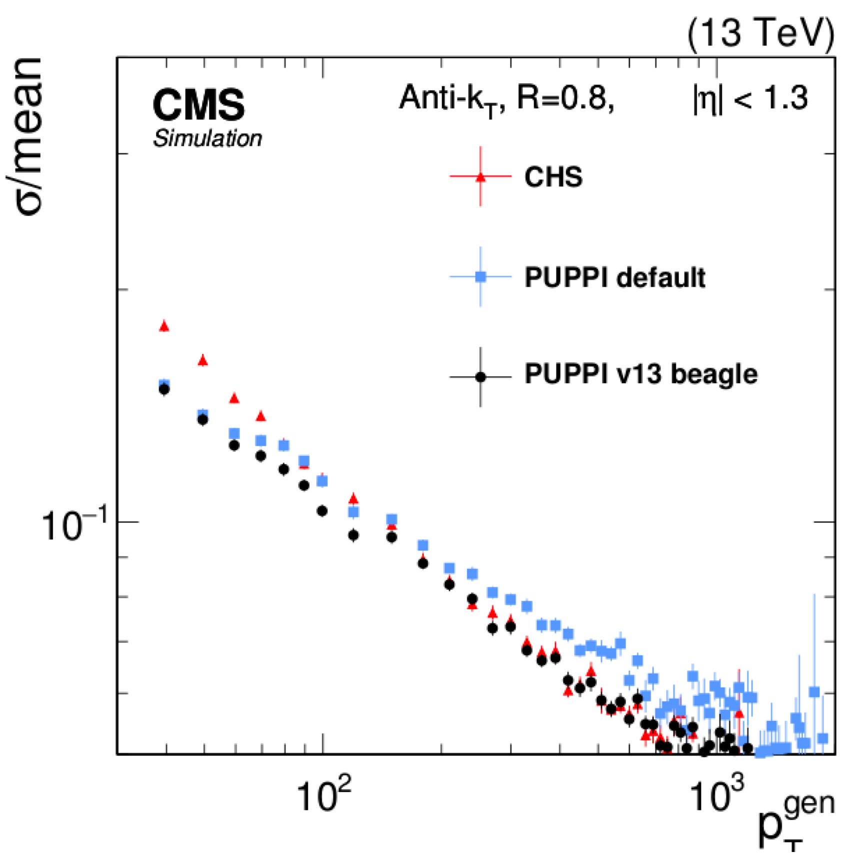




Summary

- Pileup mitigation in jets
- PUPPI shows very good performance → standard algorithm in Run3
- Improvements: **JER** at high p_T
- New tune **PUPPI v13 beagle** and preliminary validation





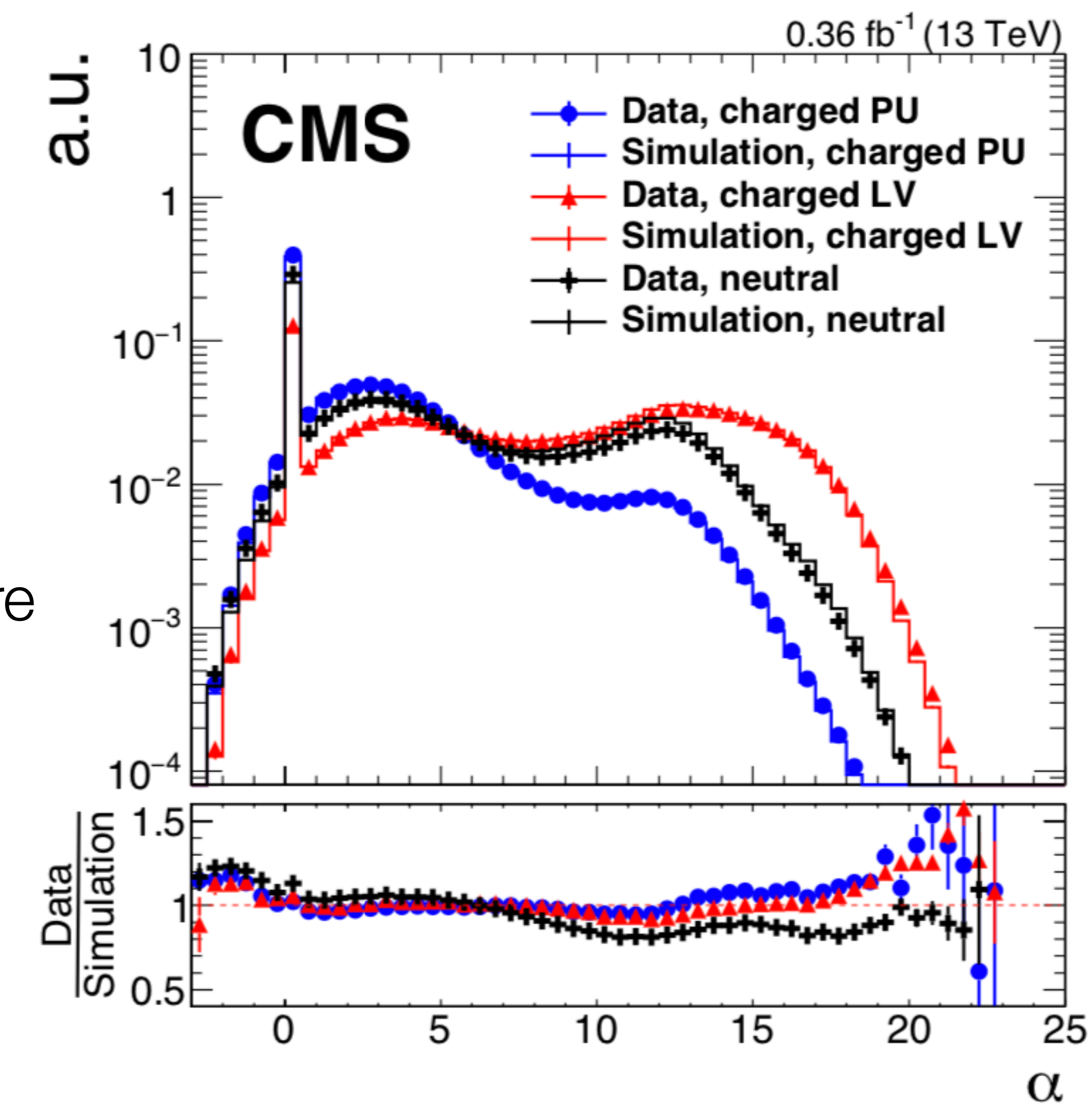
BACKUP

PUPPI details - 1

- Define α variable for neutral particle *i*:

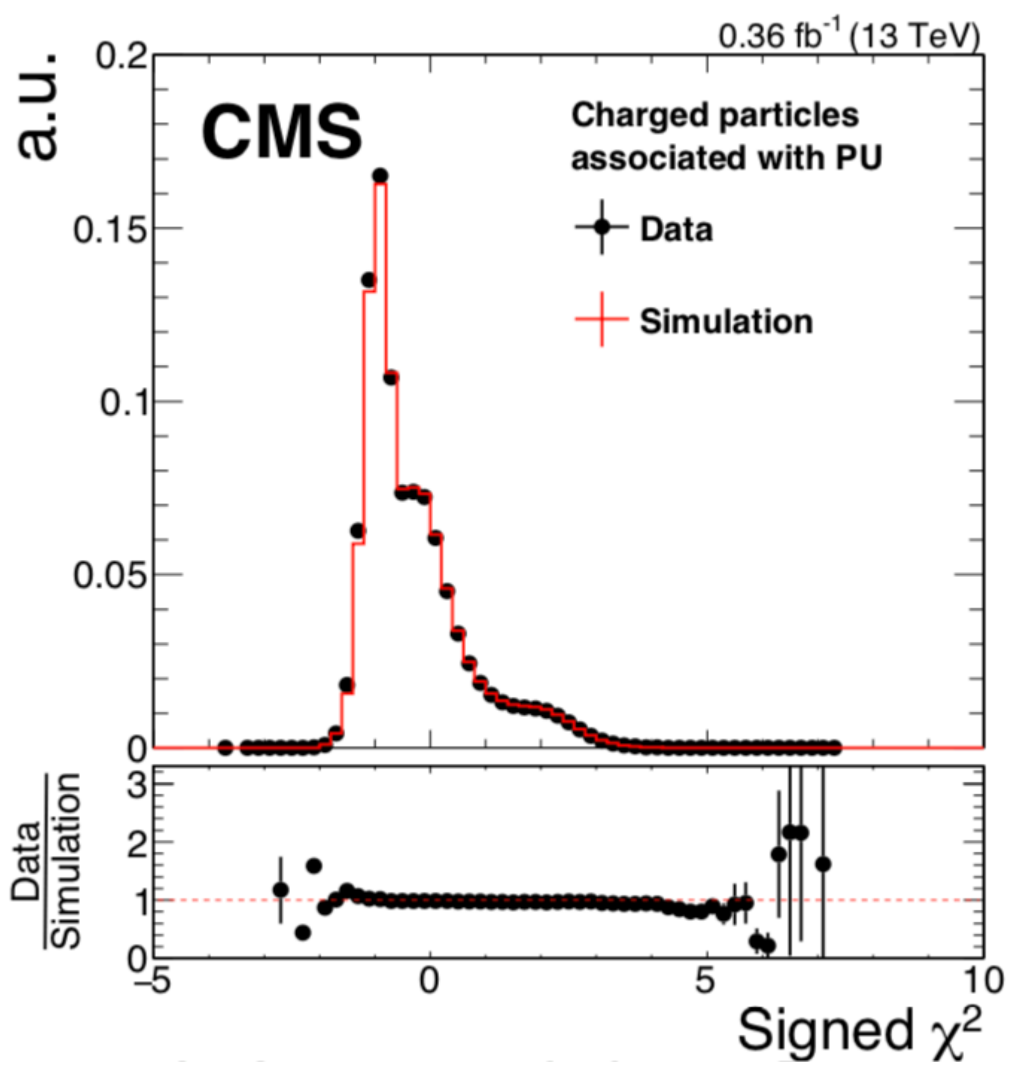
$$\alpha_i = \log \sum_{j \neq i, \Delta R_{ij} < R_0} \left(\frac{p_{Tj}}{\Delta R_{ij}} \right)^2 \begin{cases} \text{for } |\eta_i| < 2.5, & j \text{ are charged particles from LV,} \\ \text{for } |\eta_i| > 2.5, & j \text{ are all kinds of reconstructed particles} \end{cases}$$

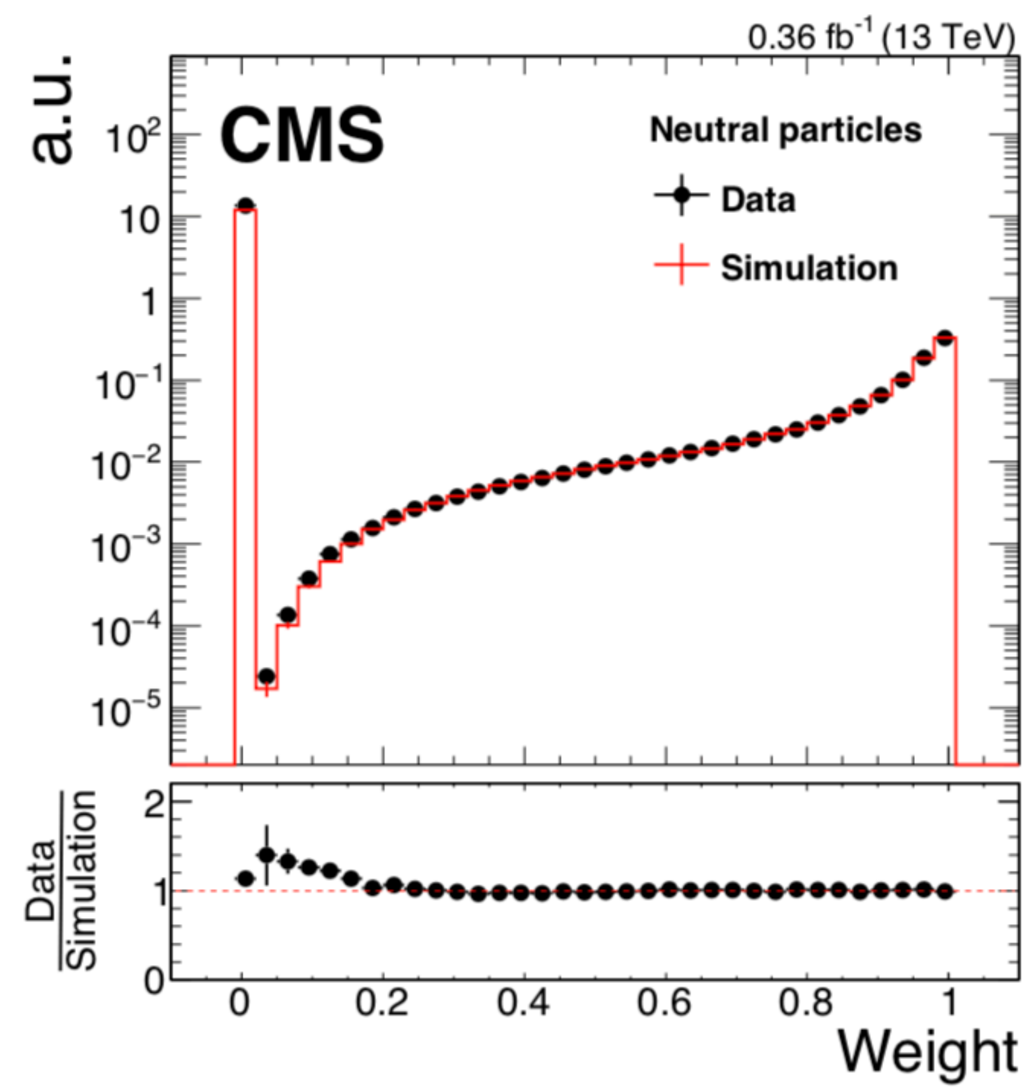
- Suppose neutral PU same shape as charged PU
- Calculate α distribution of charged PU, extract median $\overline{\alpha}_{PU}$ and root-mean-square RMS_{PU} of the distribution



PUPPI details - 2

- For each particle *i* calculate: $$\chi_i^2 = \frac{(\alpha_i - \bar{\alpha}_{PU})|\alpha_i - \bar{\alpha}_{PU}|}{RMS_{PU}^2}$$
- Assign a weight w_i: $$w_i = F_{\chi^2, NDF=1}(\chi_i^2)$$





PUPPI details - 3

- Remove particles with $w_i < 0.01$
- Keep only neutral particles that fulfil:

$$w_i \times p_{T,i} > (A + B \times NPV) \text{ GeV}$$

- A, B: tunable parameters
- NPV: number of primary vertices

How PUPPI can treat Charged Particles

Properties	from LV	from PU	α_{PU} calculation	α_i calculation	weight	note
1	✓			✓	1	Charged LV
2		✓	✓		0	Charged PU
0				✓	0 to 1	Neutrals

Tune v13

- In 2017 and 2018 the **v13 beagle** tune shows a **worse** performance in the region **|η|> 2.5**
- More charged hadrons in |η|> 2.5, but **no track-vertex association**: the particles get a value of fromPV=1 or 2
- Strategy: in |η|> 2.5 keep all the charged particles with fromPV=1,2,3

pT cut	**pT < 20 GeV**		**pT > 20 GeV**	
eta cut	**|η| < 2.5**	**|η| > 2.5**	**|η| < 2.5**	**|η| > 2.5**
v13 beagle	**N**	**N**	**LV**	**LV**
v13 new PR 2017	**N**	**LV**	**LV**	**LV**

A charged particle not associated to any vertex can be treated as:
1 Charged LV (LV) 2 Charged PU (PU) 0 Neutral (N)

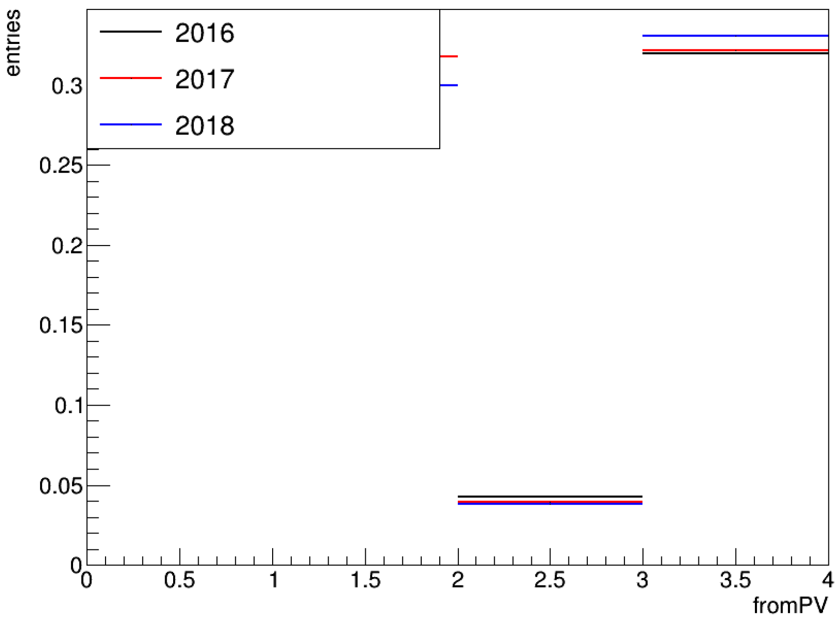
QCD Dataset

Year	DAS	CMSSW release	Notes
2016v2	/QCD_Pt-15to7000_TuneCUETP8M1_Flat_13TeV_pythia8/RunIISummer16MiniAODv2-PUFlat0to70_magnetOn_80X_mcRun2_asymptotic_2016_TrancheIV_v4-v1/MINIAODSIM	production: 80X reconstruction: 80X	
2017v2	/QCD_Pt-15to7000_TuneCUETP8M1_Flat_13TeV_pythia8/RunIIFall17MiniAODv2-FlatPU0to70_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	production: 92X reconstruction: 94X	• More particles at low p_T • Phase-1 pixel: more charged particles in $\|\eta\| > 2.5$
2018	/QCD_Pt-15to7000_TuneCP5_Flat_13TeV_pythia8/RunIIAutumn18MiniAOD-FlatPU0to70RAW_102X_upgrade2018_realistic_v15_ext2-v1/MINIAODSIM	production: 102X reconstruction: 102X	• More particles at low p_T • Phase-1 pixel: more charged particles in $\|\eta\| > 2.5$
UL2017	/QCD_Pt-15to7000_TuneCP5_Flat2018_13TeV_pythia8/RunIISummer19UL17MiniAOD-FlatPU0to70_106X_mc2017_realistic_v6-v3/MINIAODSIM	production: 106X reconstruction:106X	Coming soon
UL2018	/QCD_Pt-15to7000_TuneCP5_Flat2018_13TeV_pythia8/RunIISummer19UL18MiniAOD-pilot_106X_upgrade2018_realistic_v11_L1v1-v3/MINIAODSIM	production: 106X reconstruction:106X	Coming soon

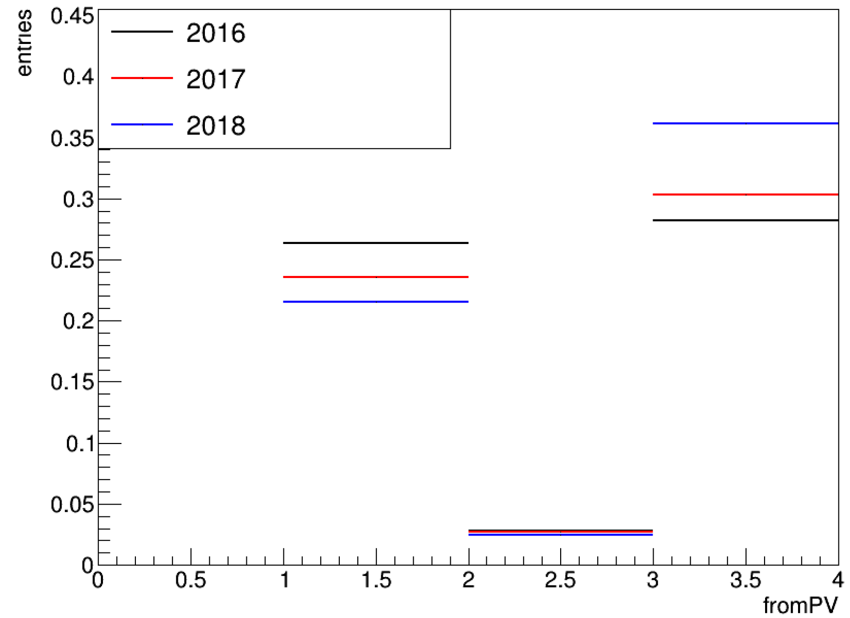
PR tune v13 beagle

fromPV - p_T < 20 GeV

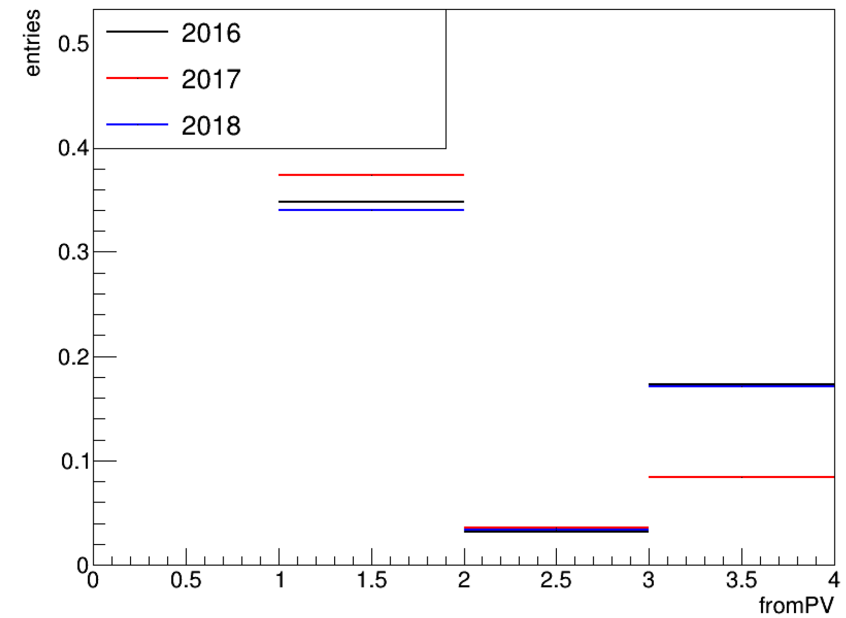
0 < |η| < 1.3



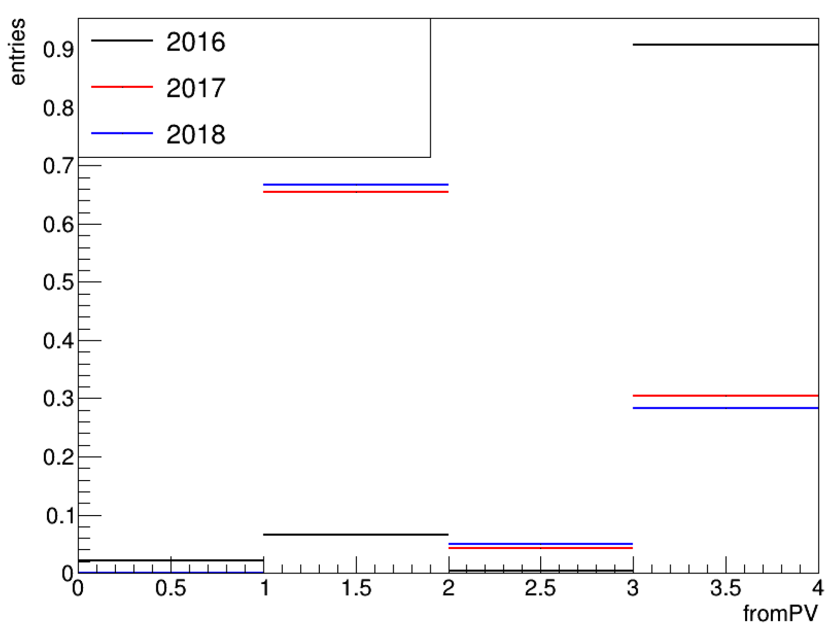
1.3 < |η| < 2



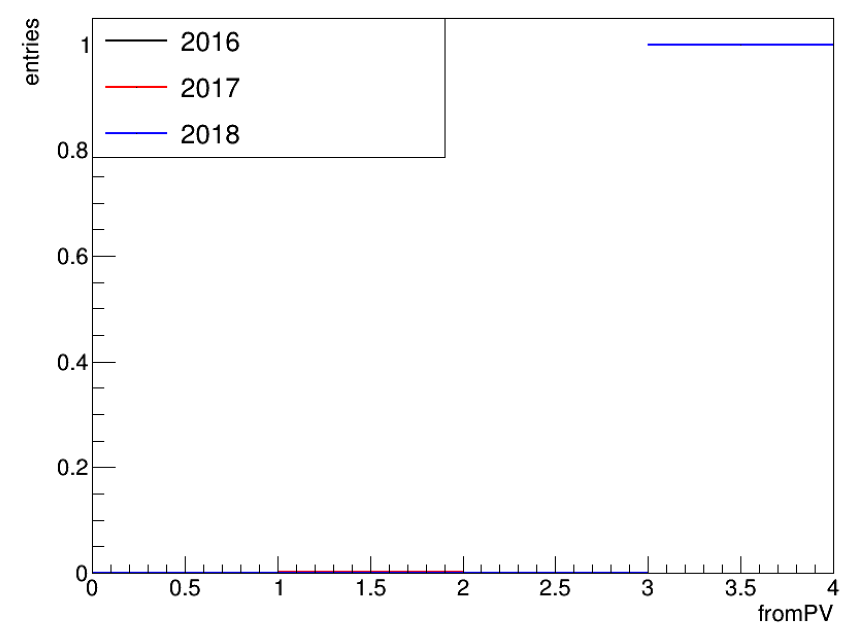
2 < |η| < 2.5



2.5 < |η| < 3

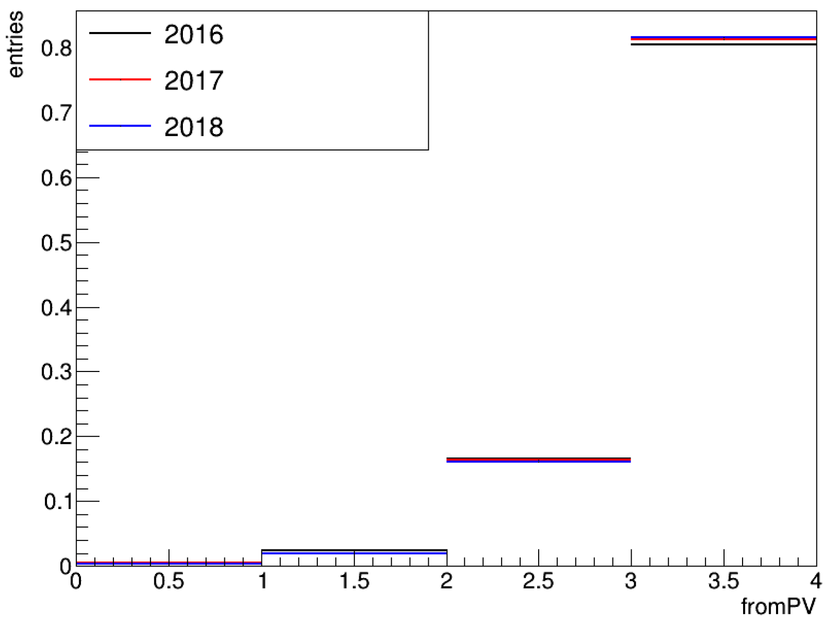


3 < |η| < 10

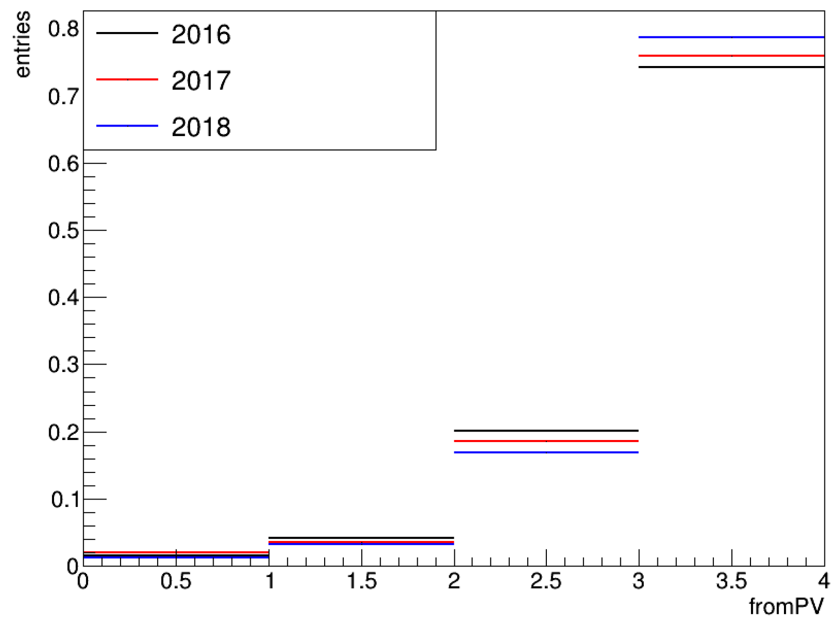


fromPV - p_T > 20 GeV

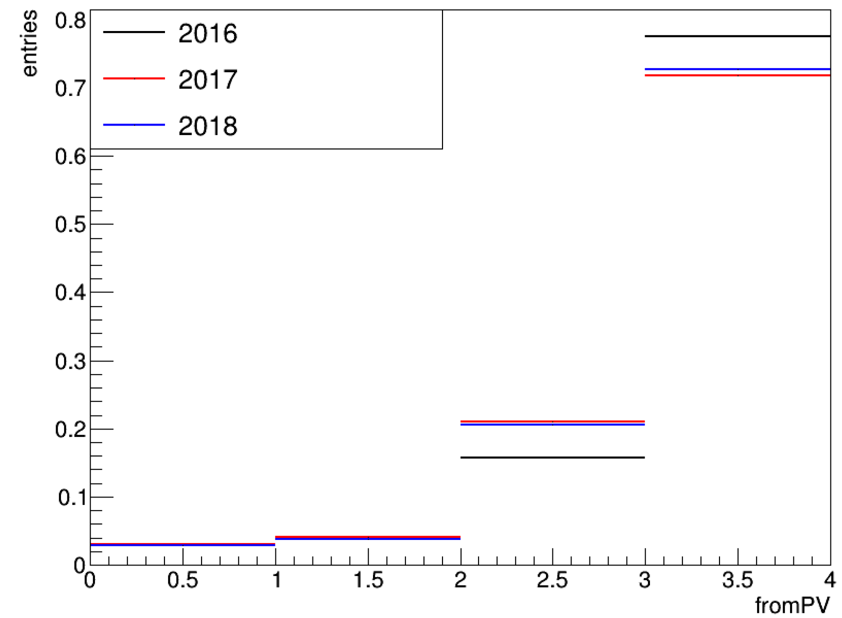
0 < |η| < 1.3



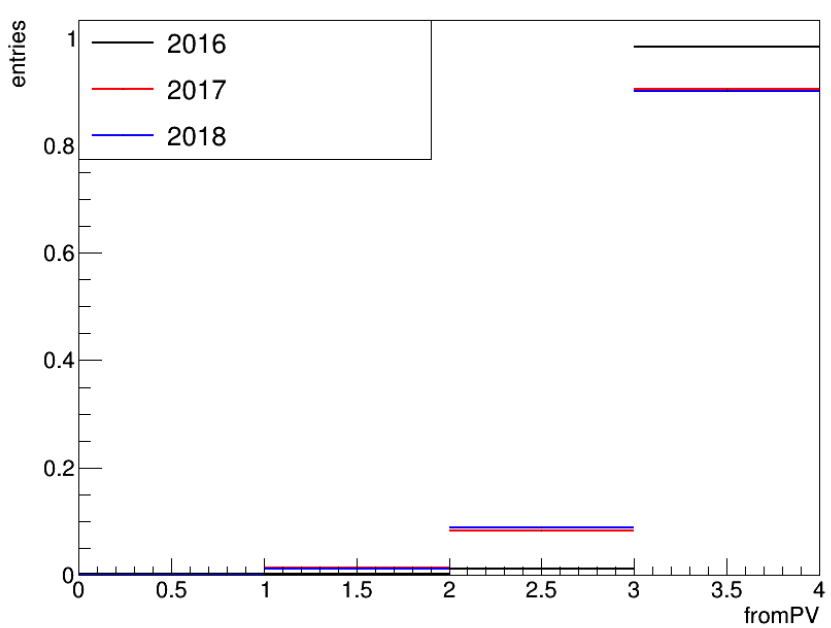
1.3 < |η| < 2



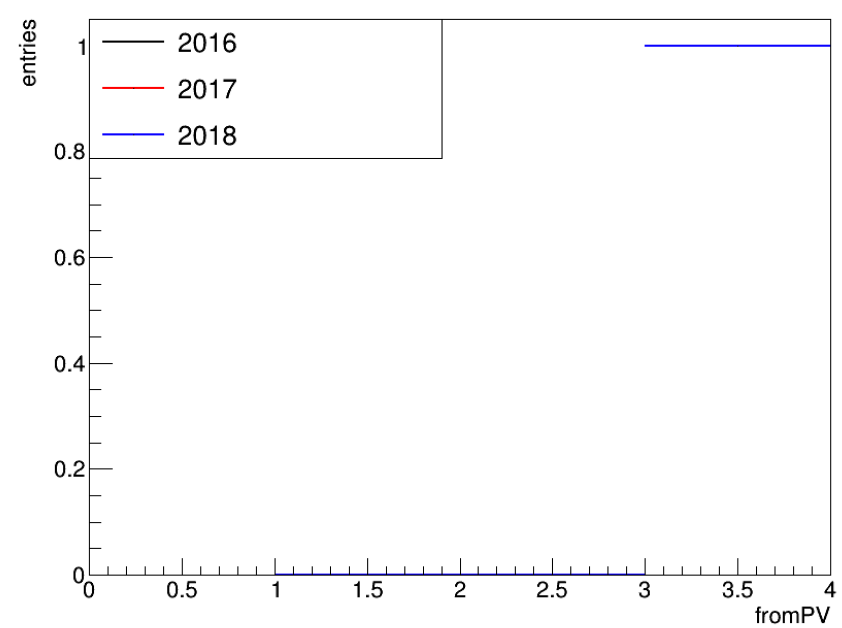
2 < |η| < 2.5



2.5 < |η| < 3

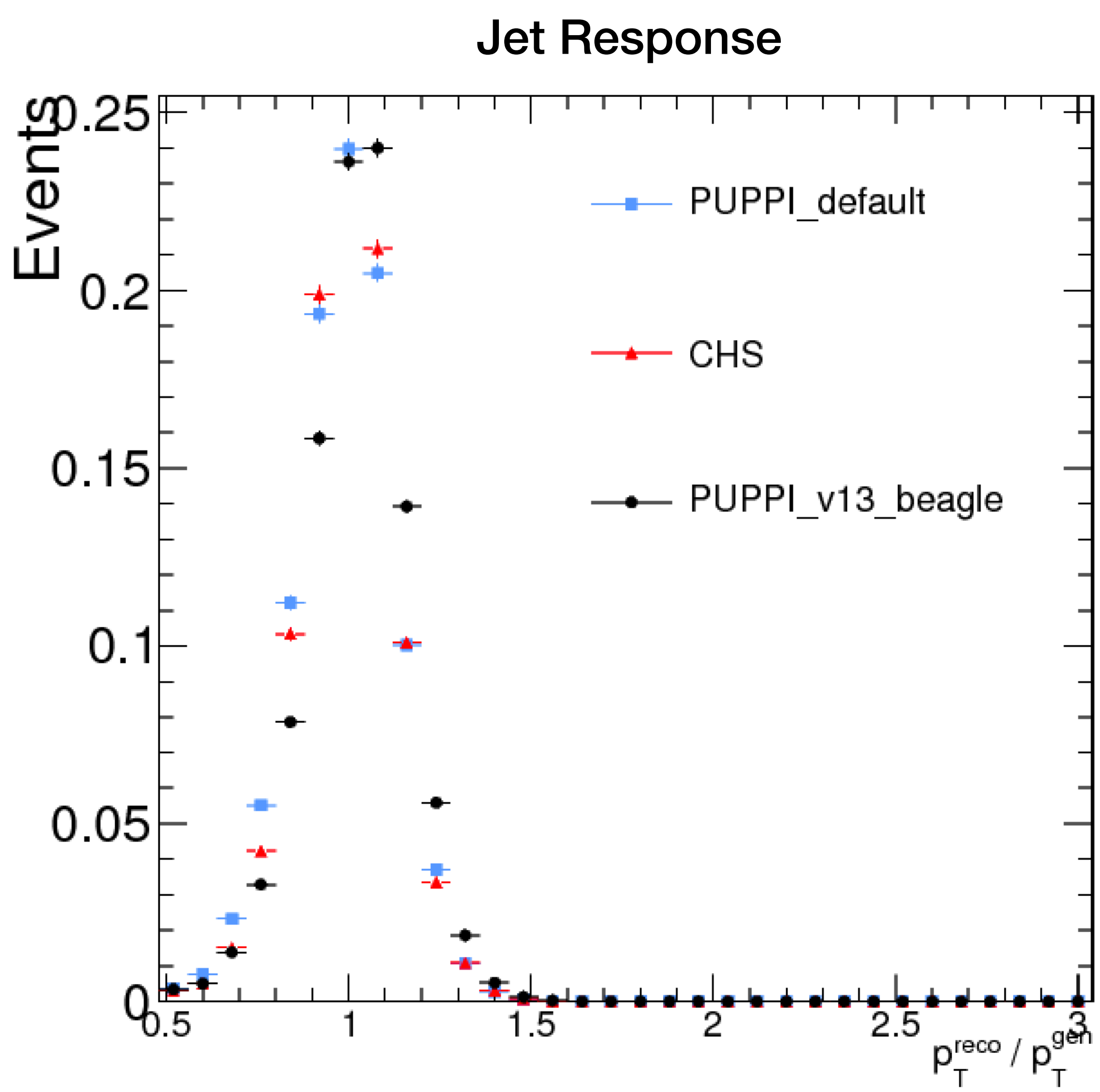


3 < |η| < 10



JER calculation

- Response distribution: p_T $^{(recojets)}$/p_T $^{(genjets)}$
- Iterative Gaussian fit in the range [*mean* - 1.5σ, *mean* + 1.5σ]
- JER = σ/*mean*

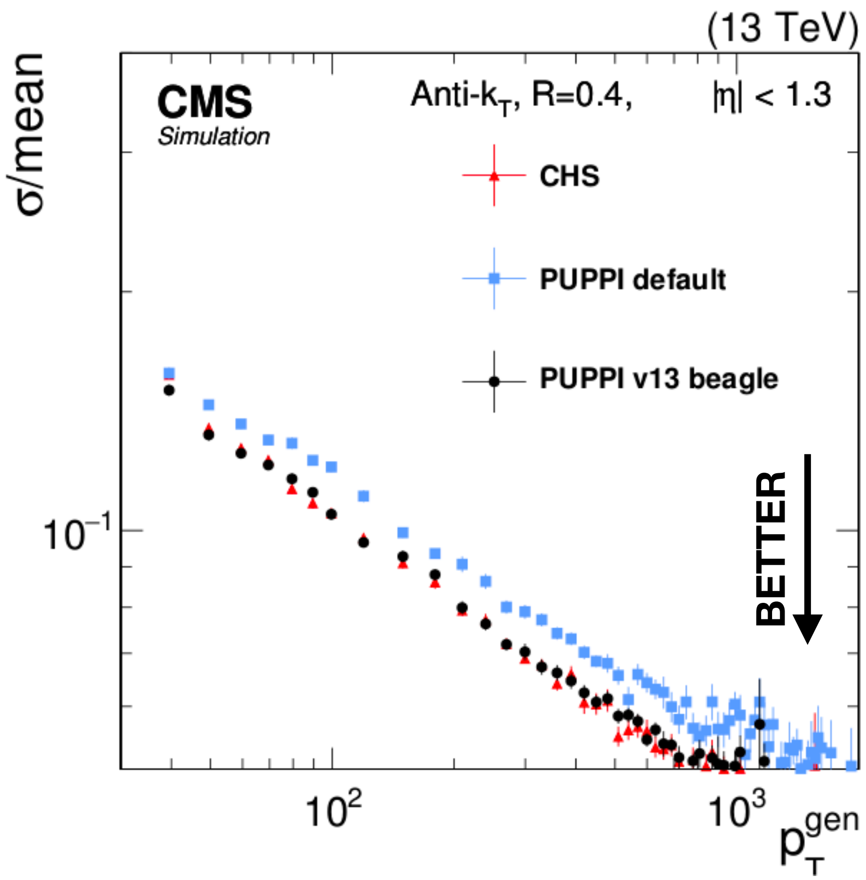


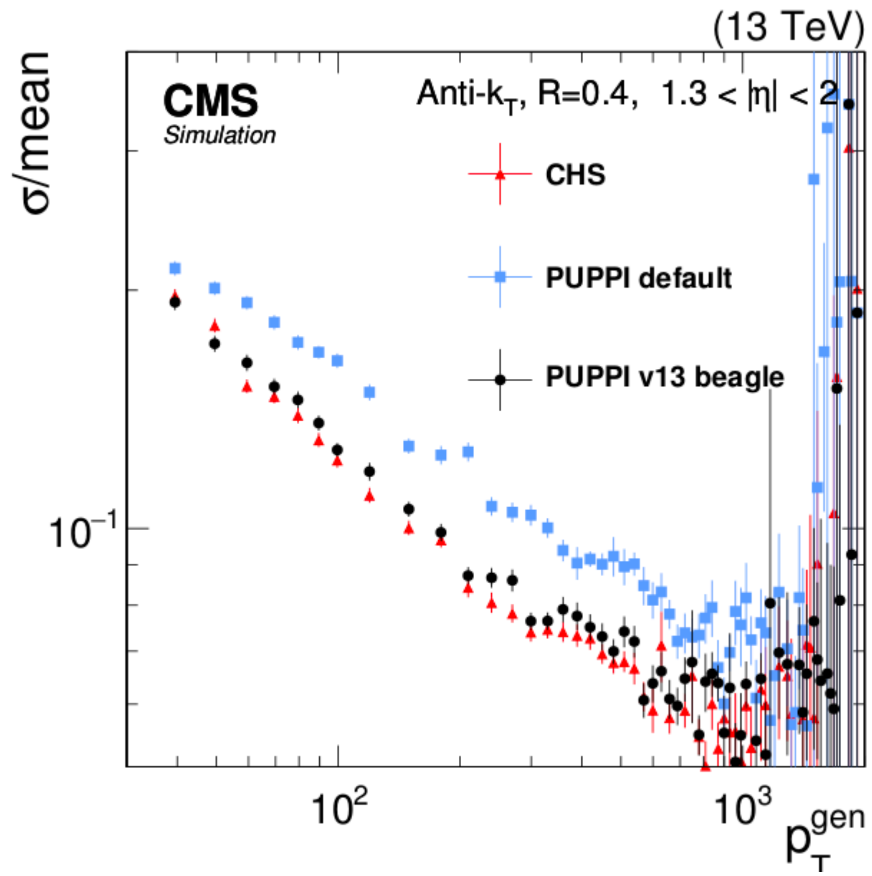
0 < |η| < 1.3
80 < jet p_T < 90 GeV

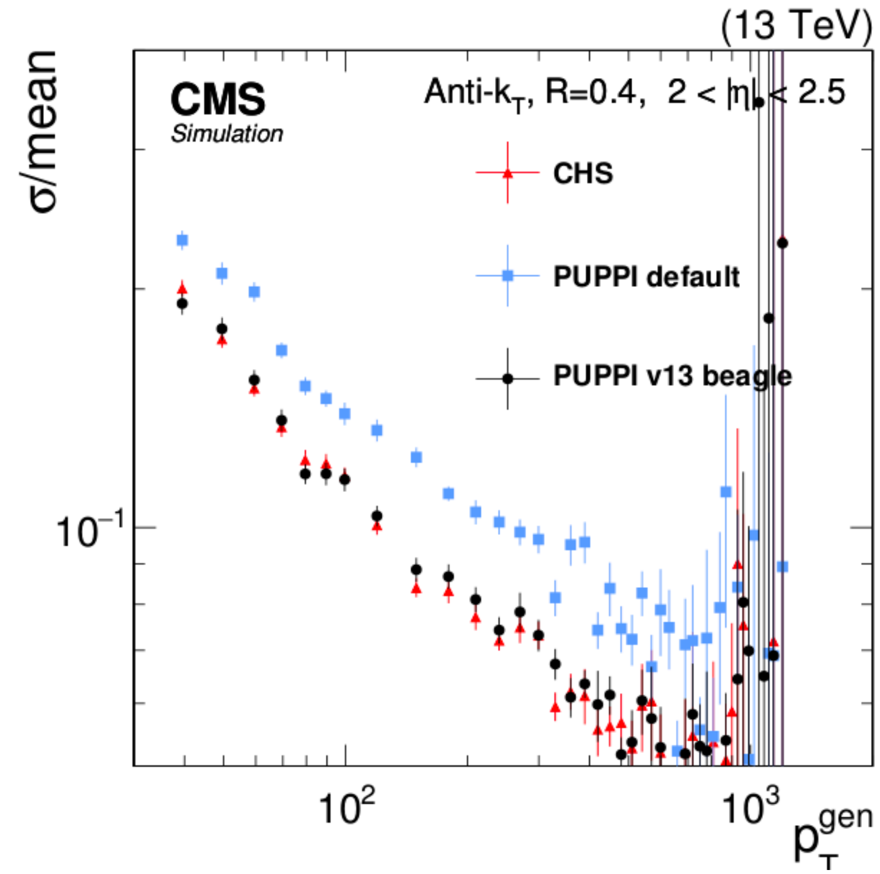
JER Ak4 Jets

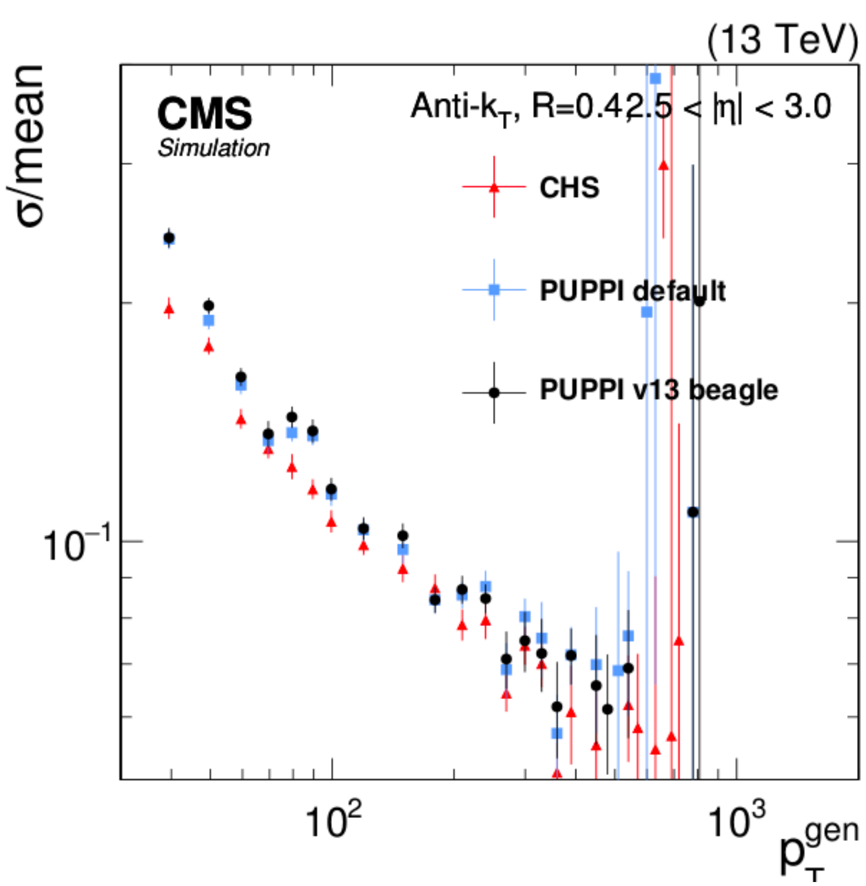
JER 2016 - Ak4

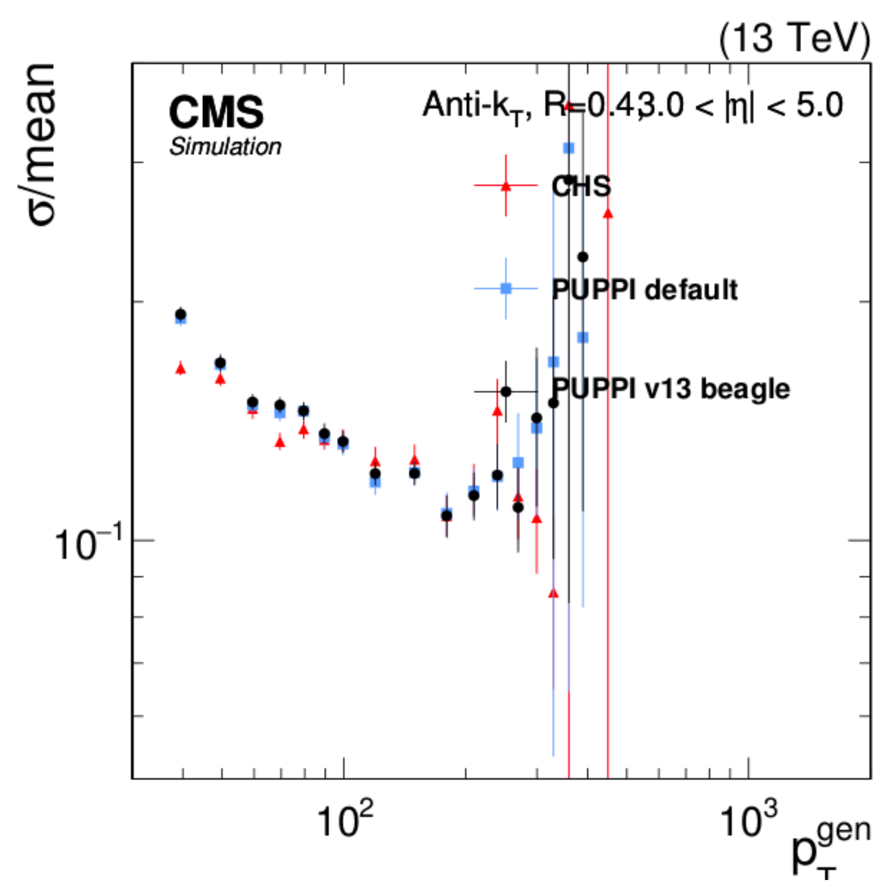
QCD sample







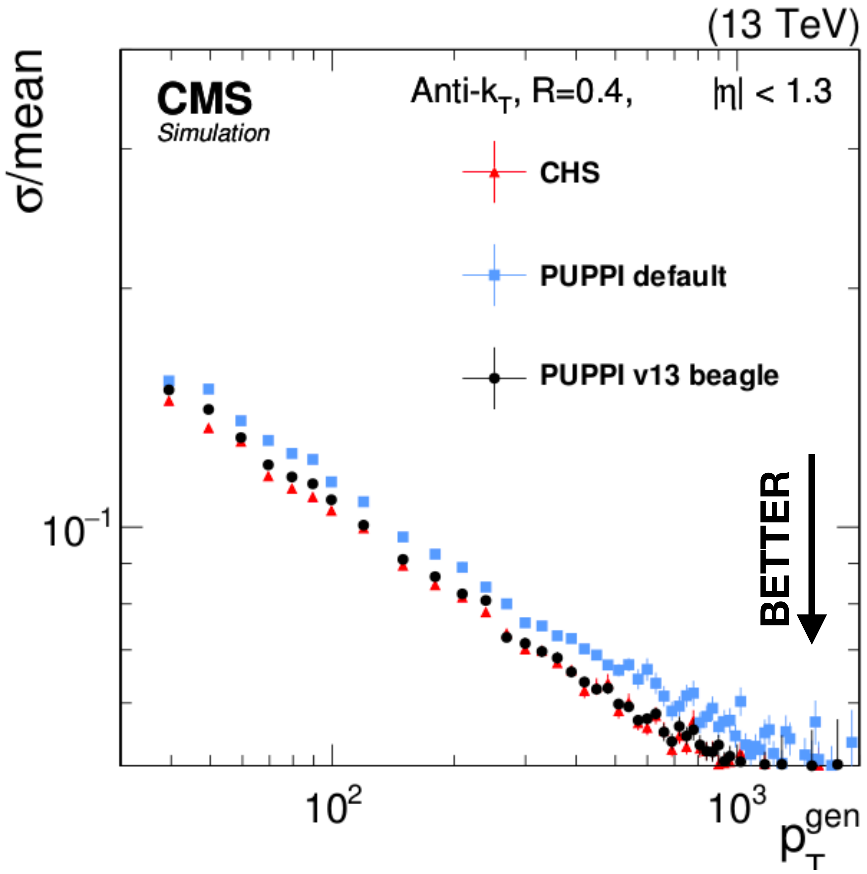


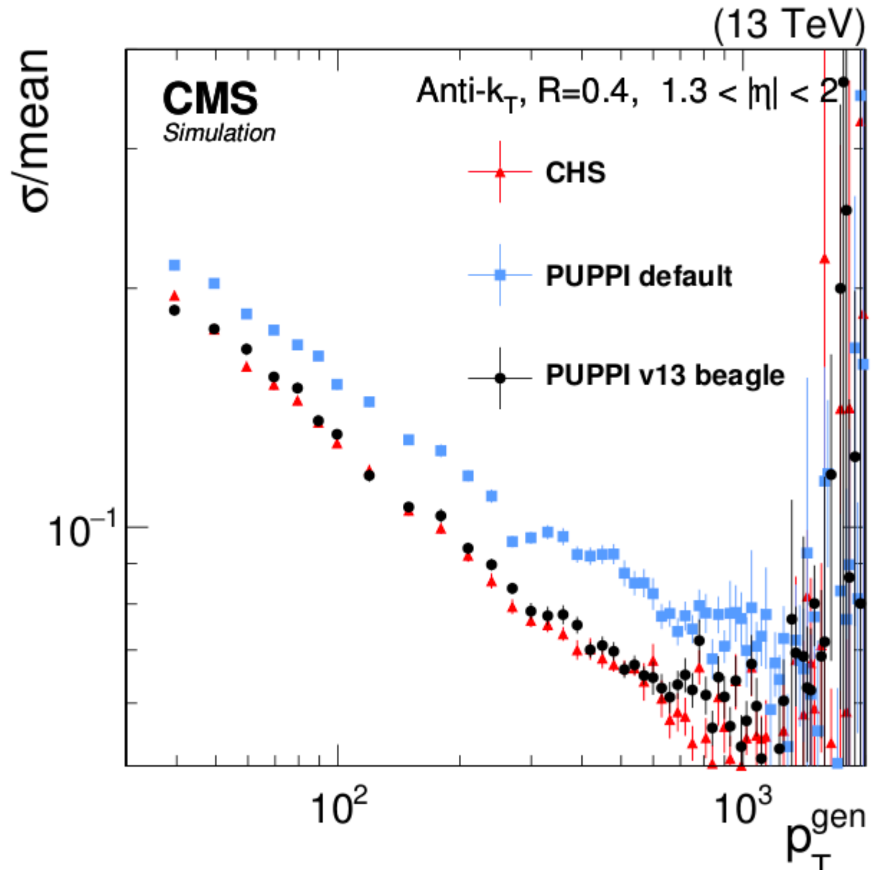


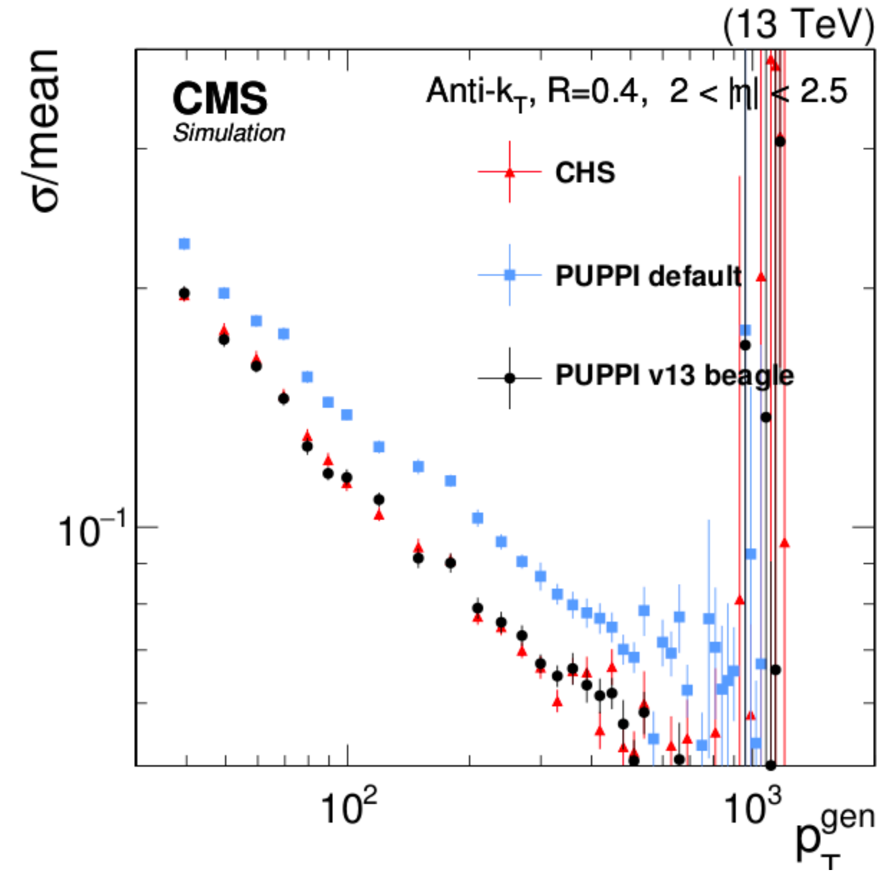
JER calculated with iterative gaussian fit

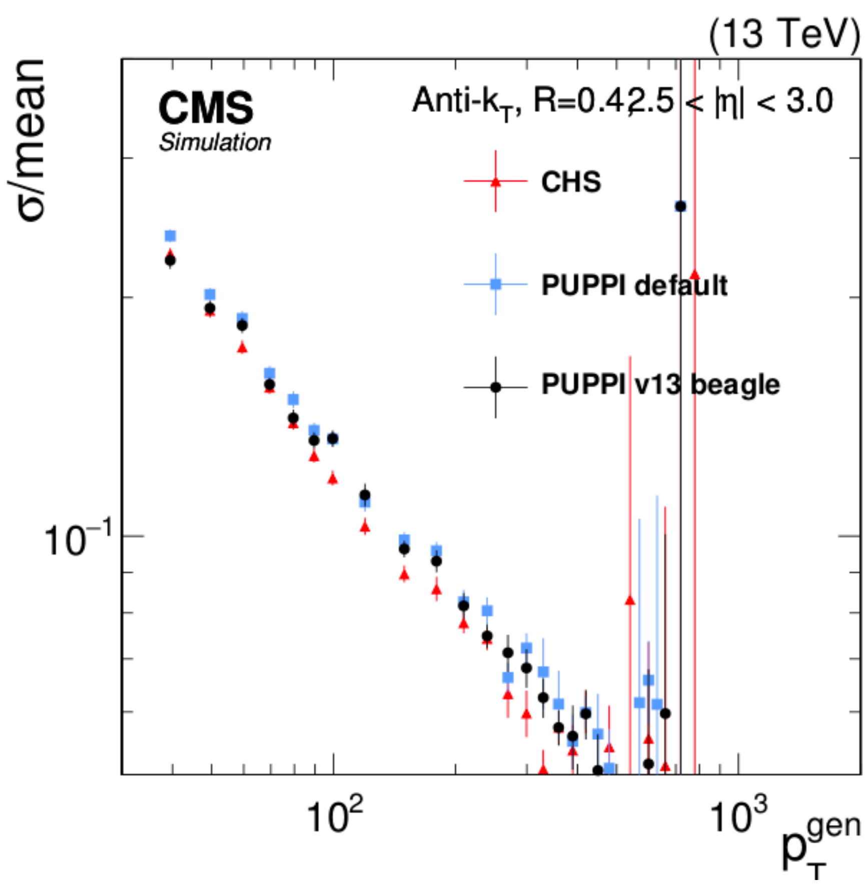
JER 2017 - Ak4

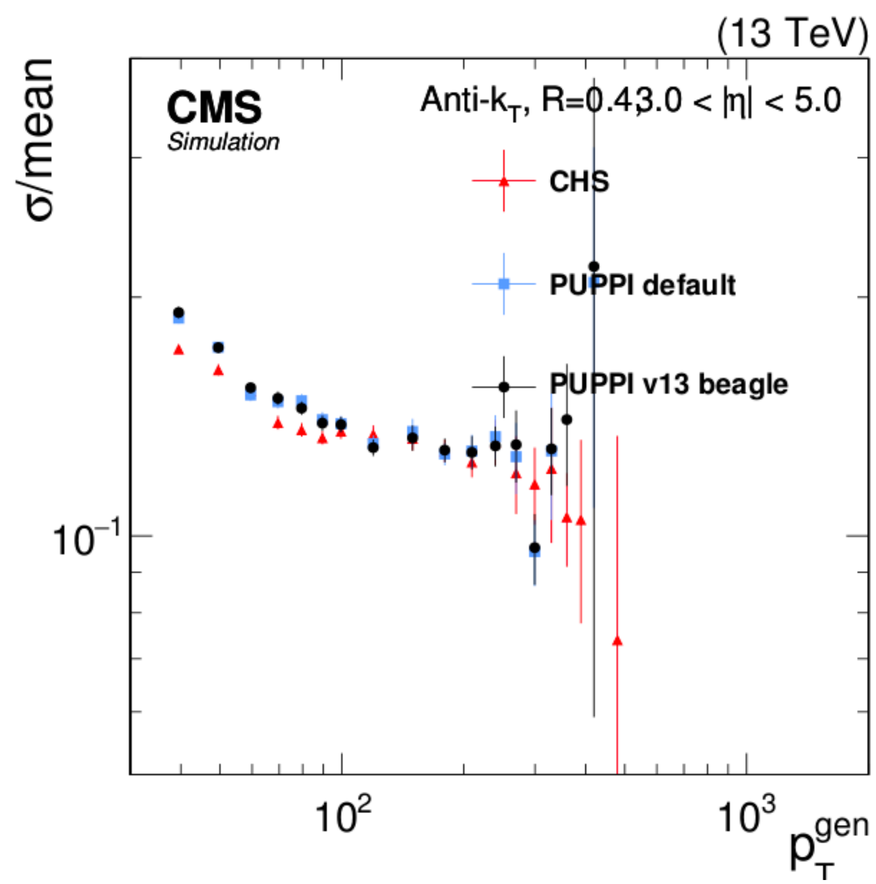
QCD sample







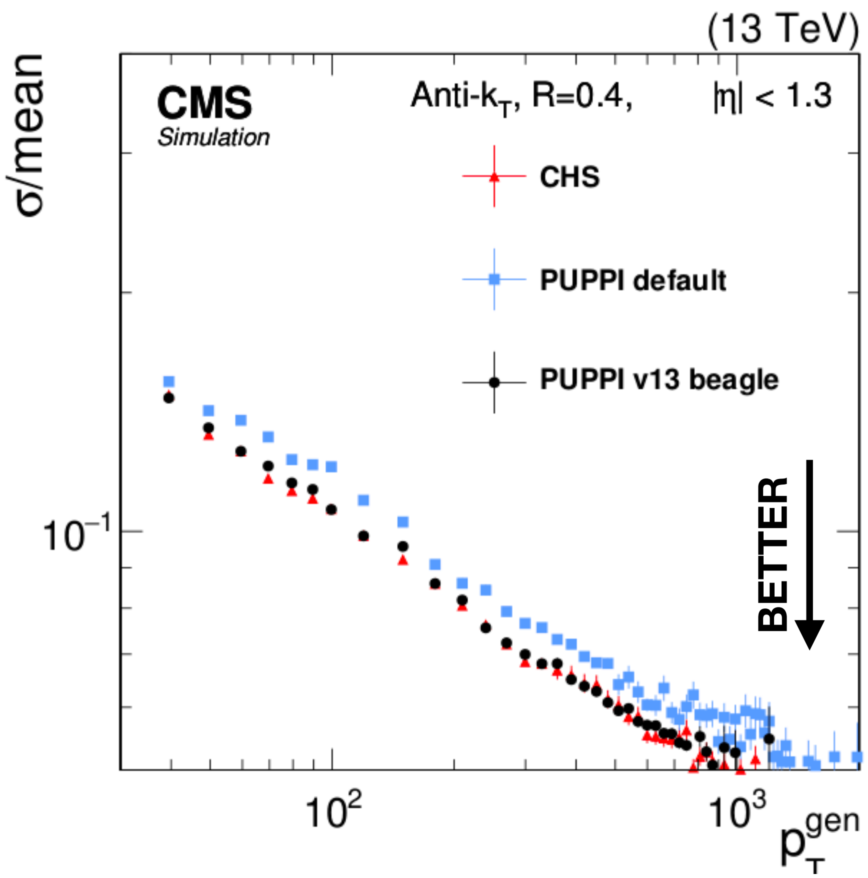


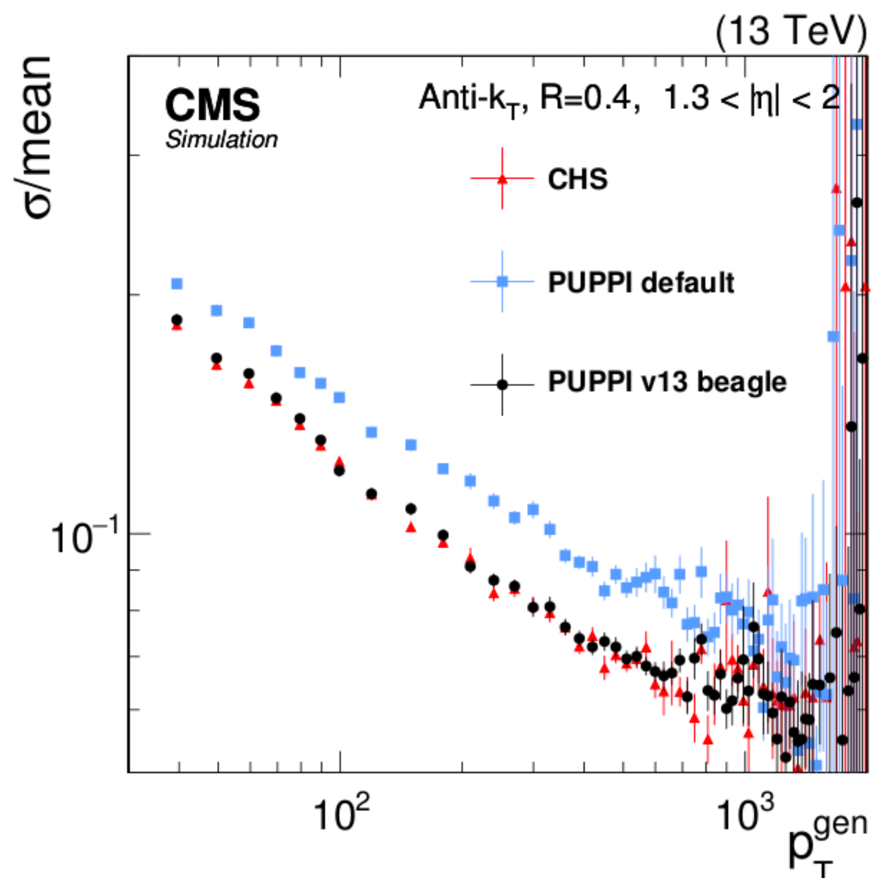


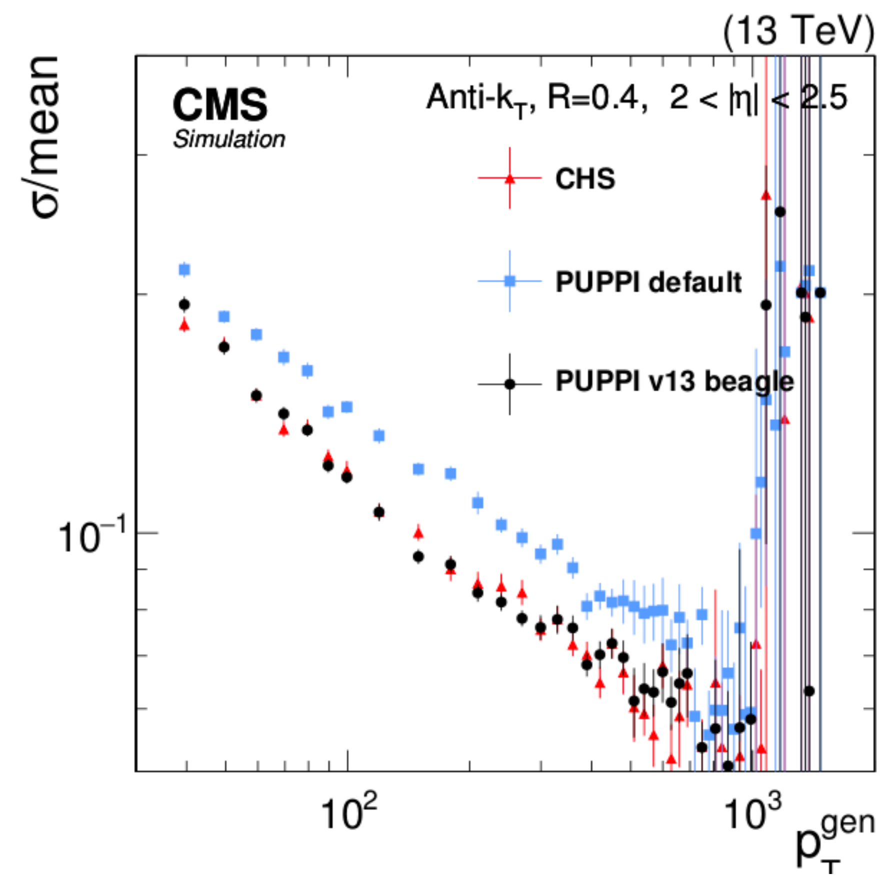
JER calculated with iterative gaussian fit

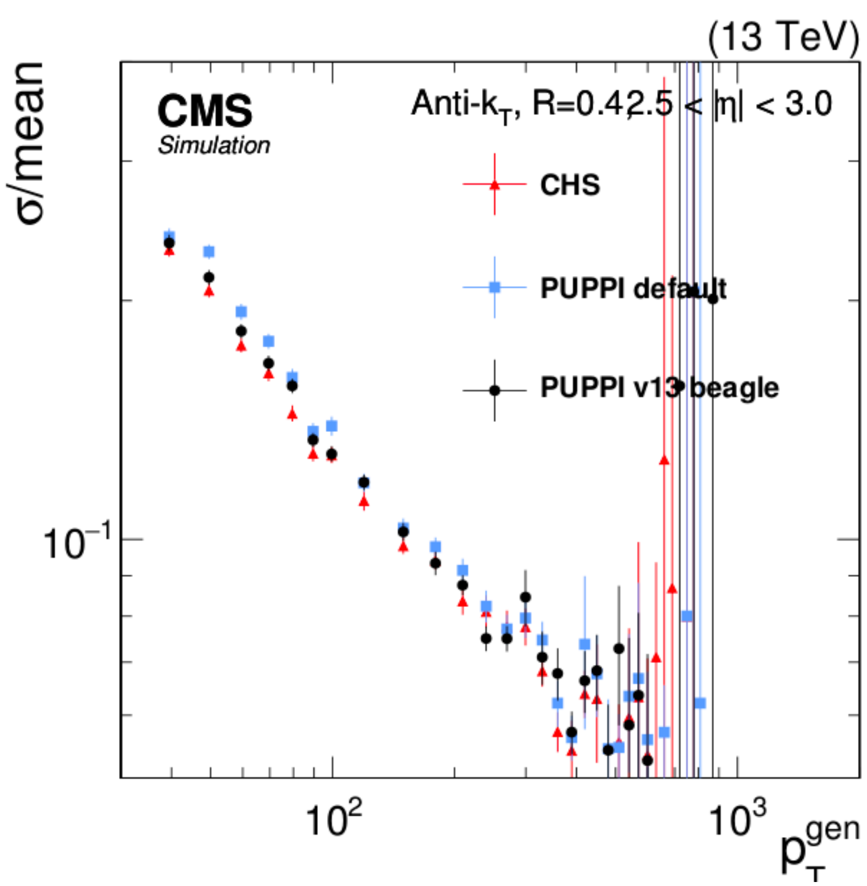
JER 2018 - Ak4

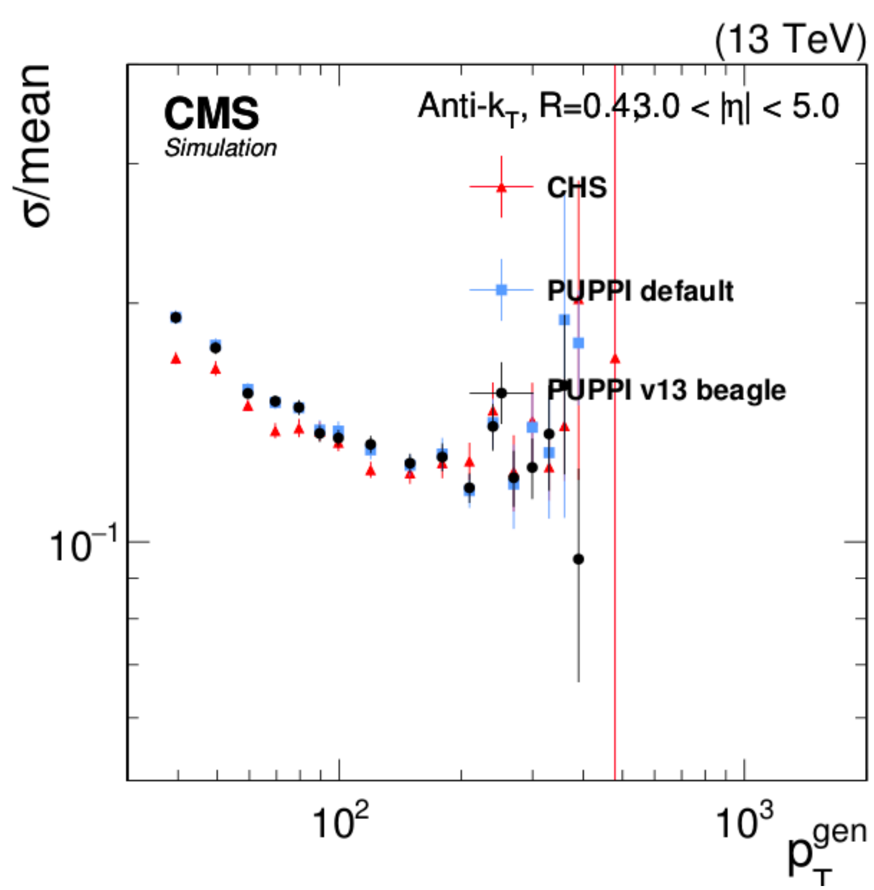
QCD sample







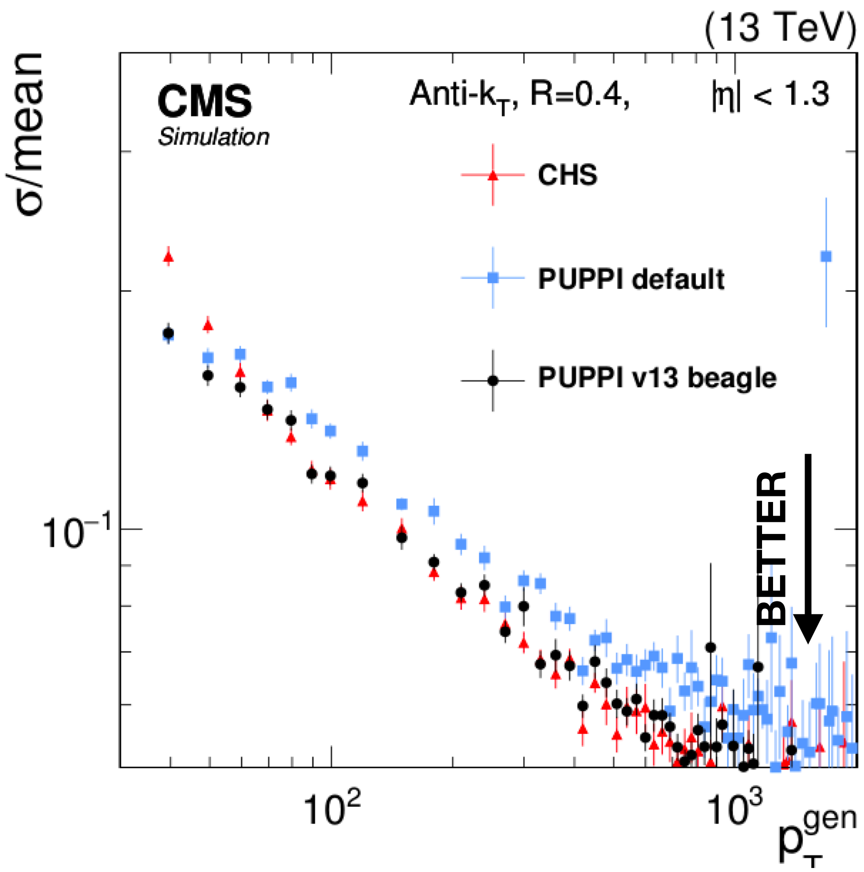


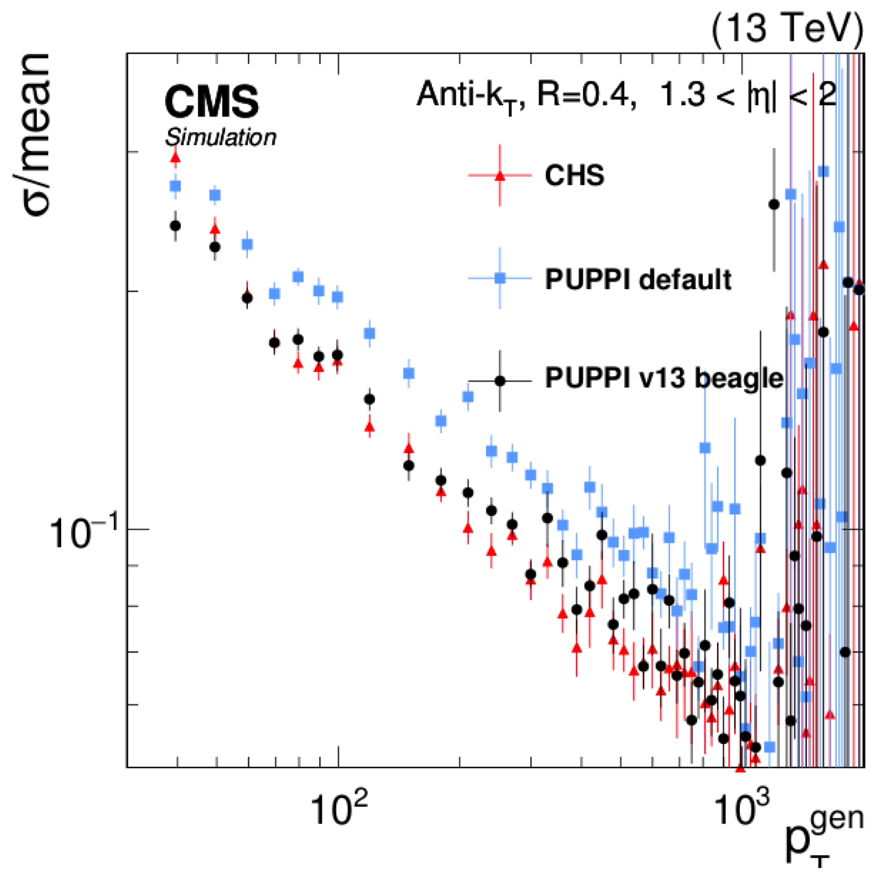


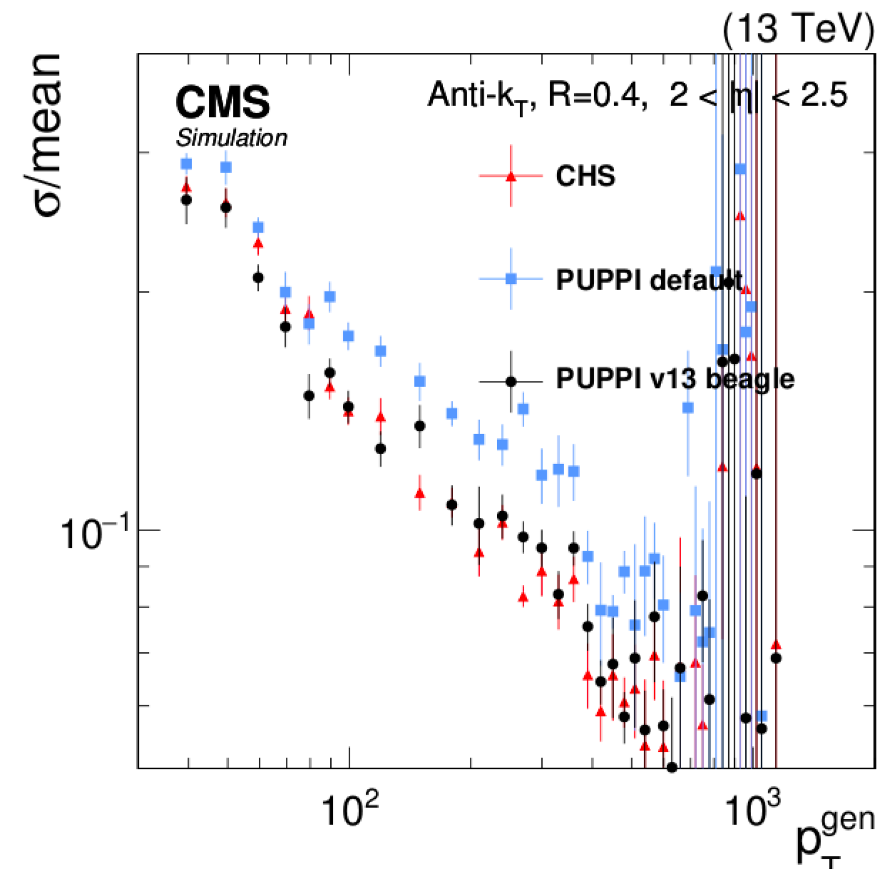
JER calculated with iterative gaussian fit

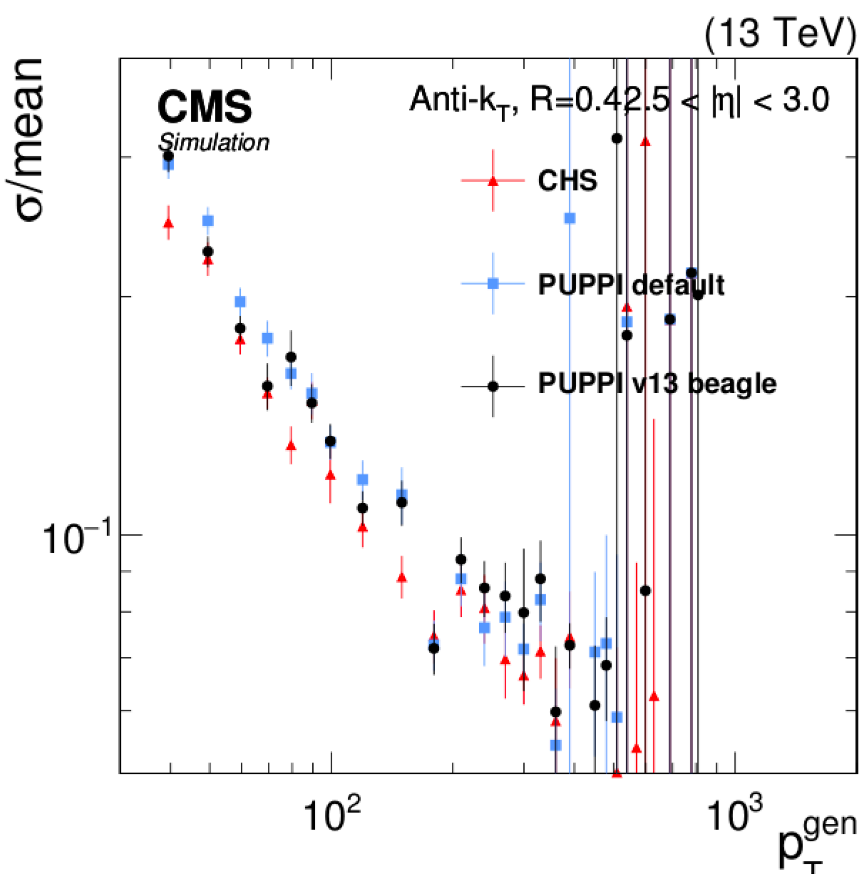
JER 2016 - Ak4 PU>50

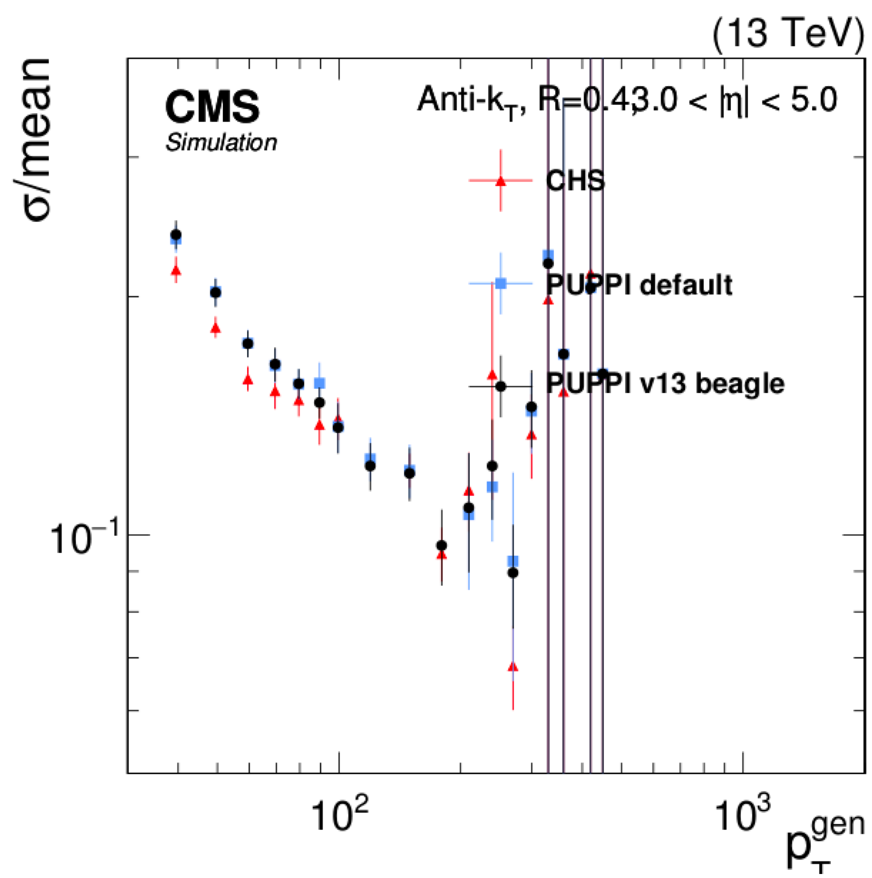
<u>QCD sample</u>







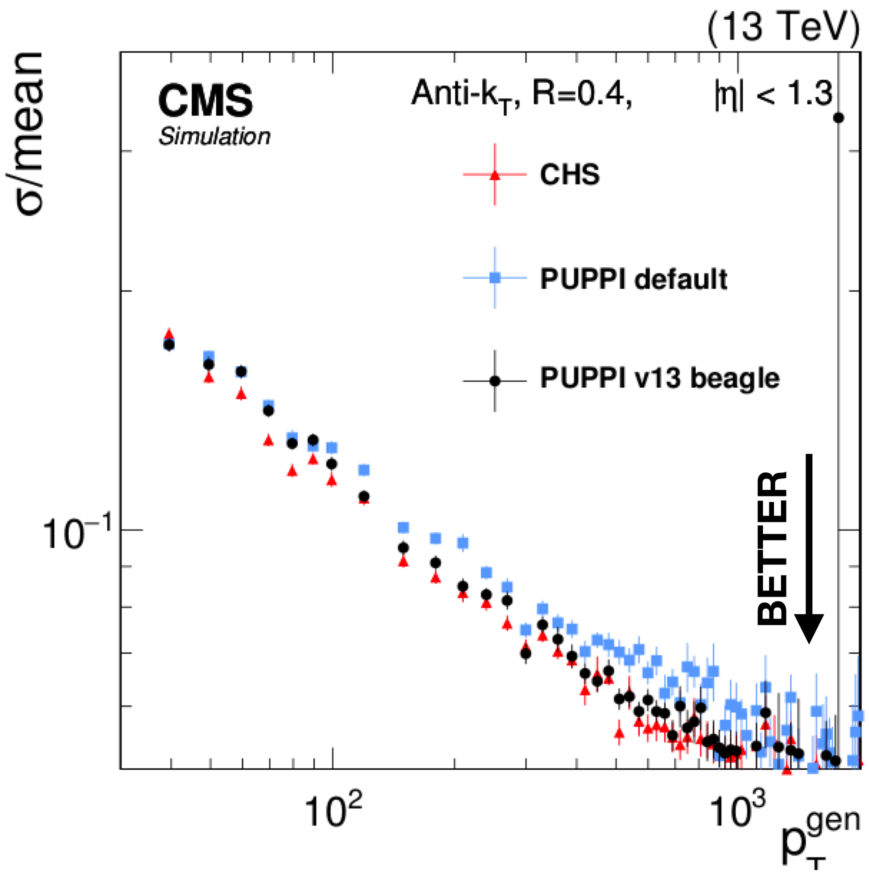


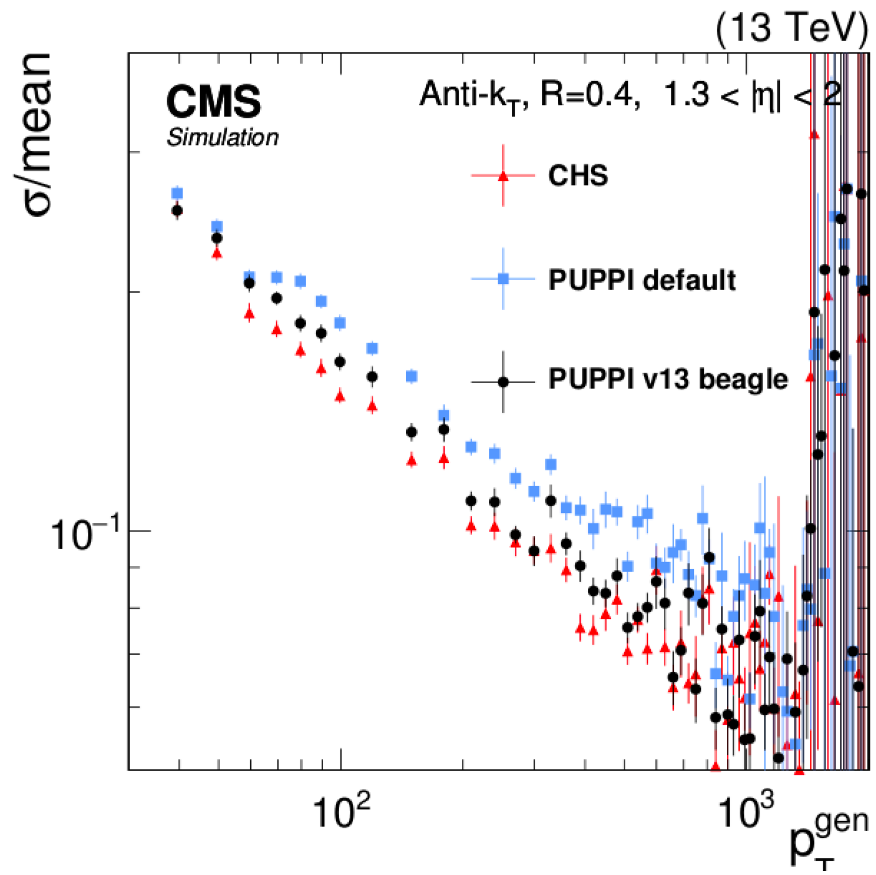


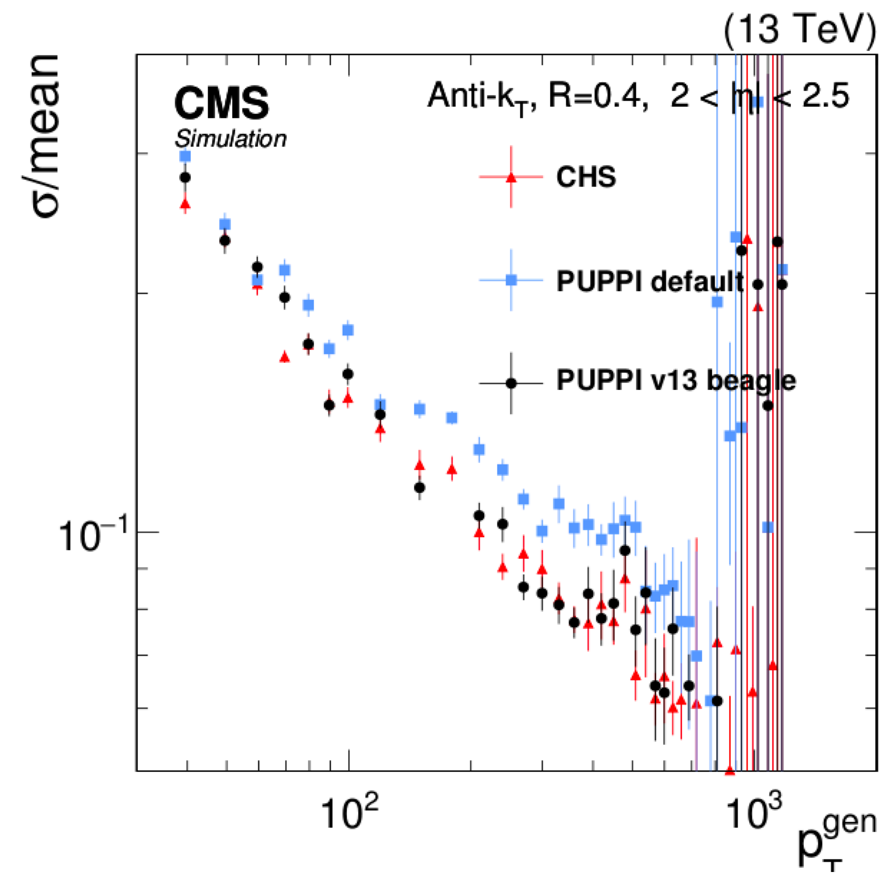
JER calculated with iterative gaussian fit

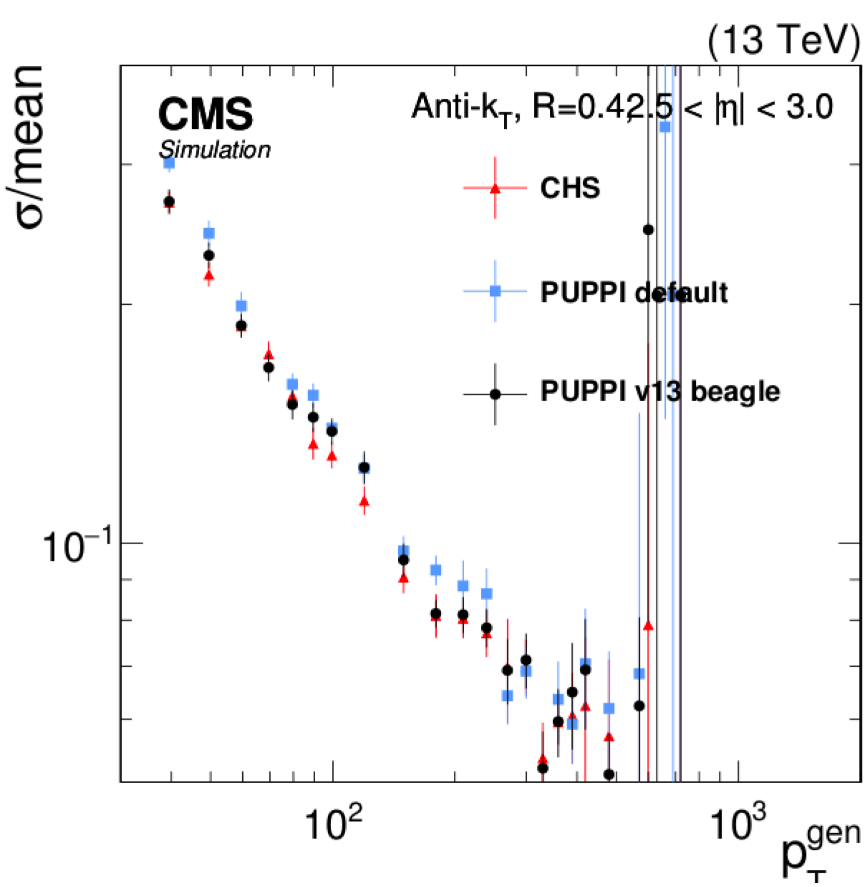
JER 2017 - Ak4 PU>50

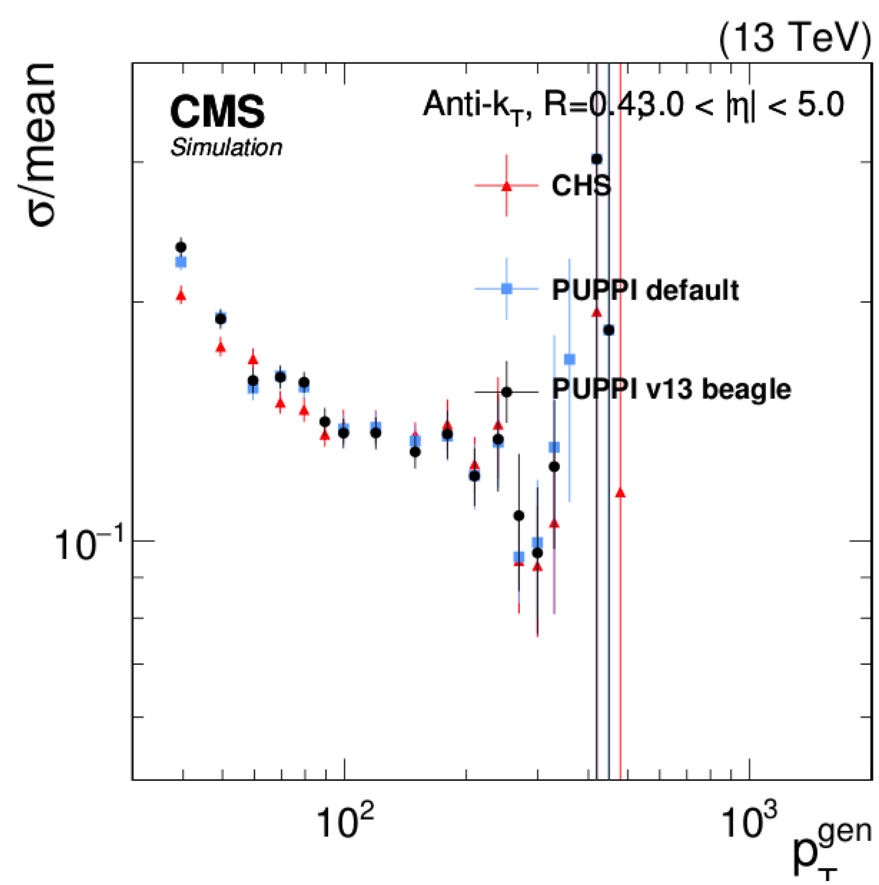
QCD sample







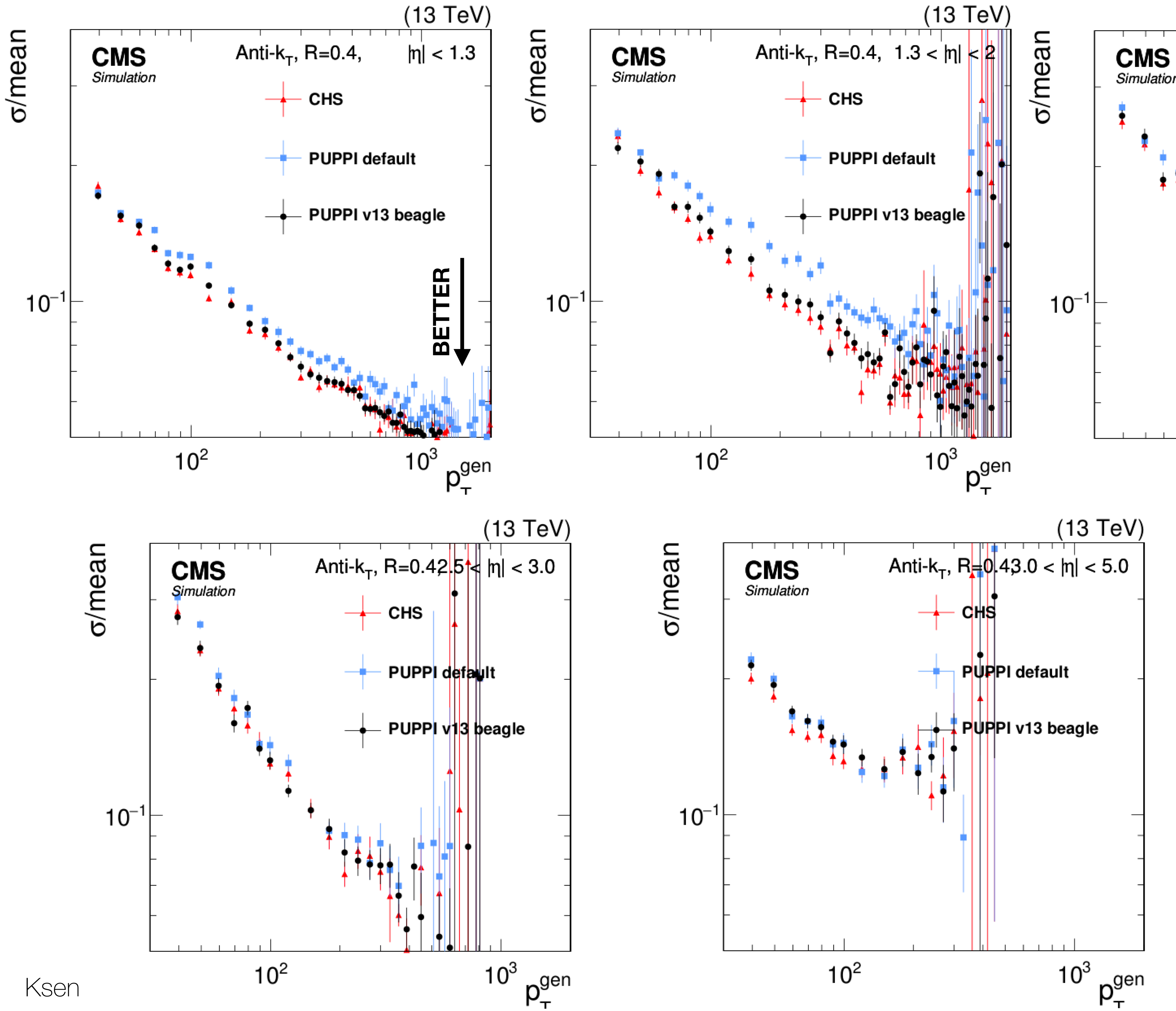




JER calculated with iterative gaussian fit

JER 2018 - Ak4 PU>50

QCD sample

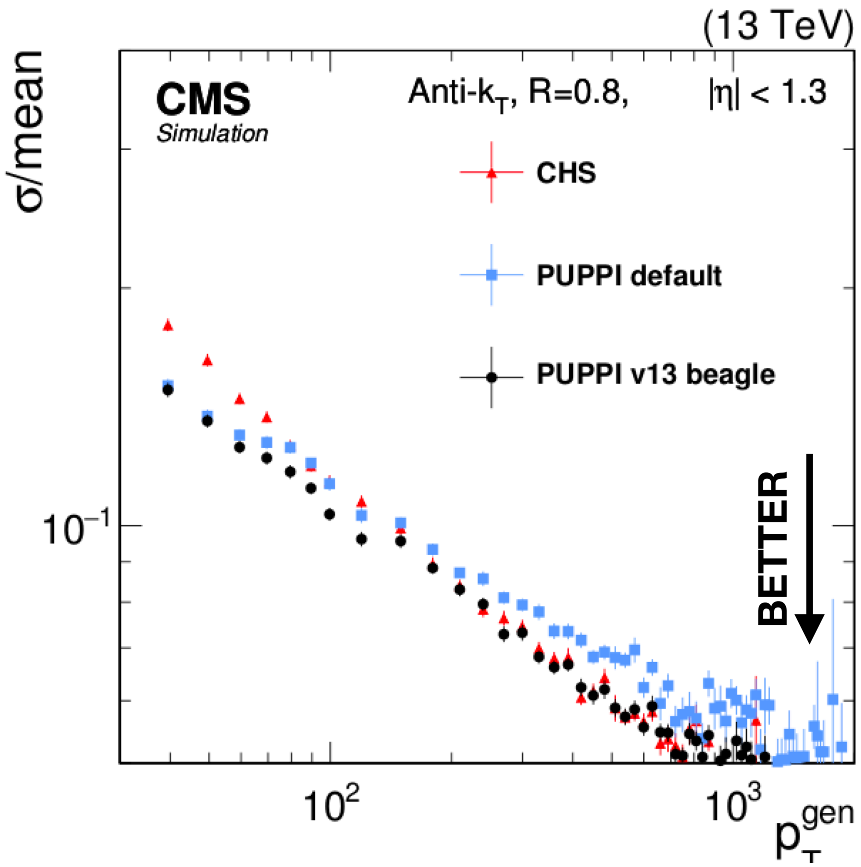


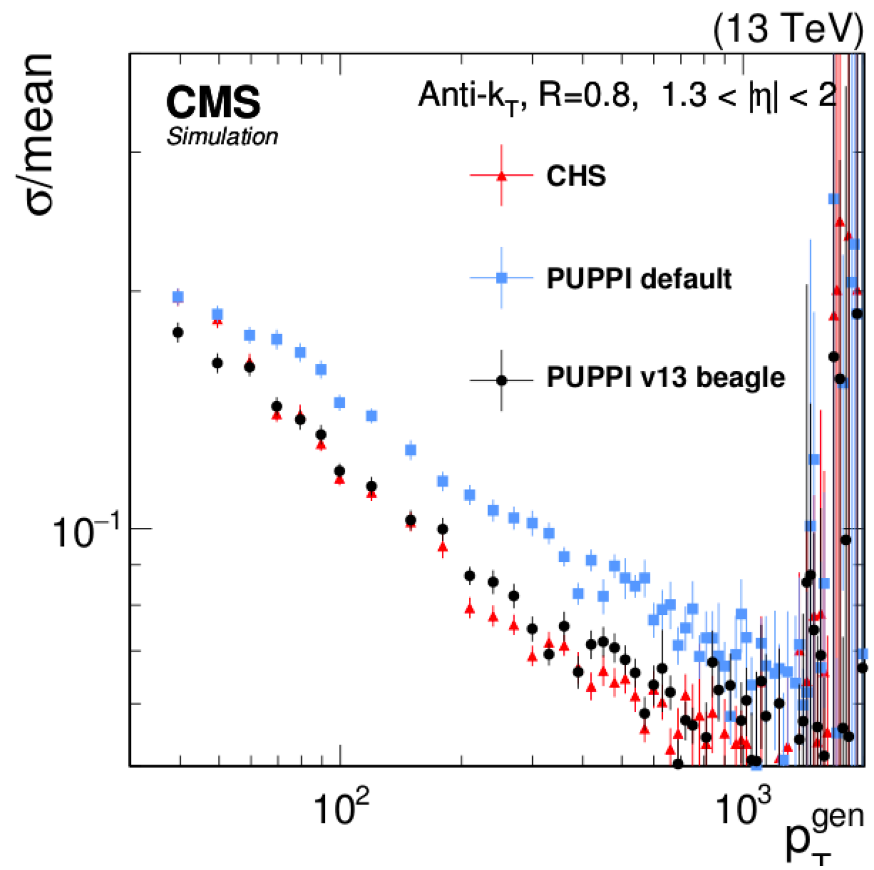
JER calculated with iterative gaussian fit

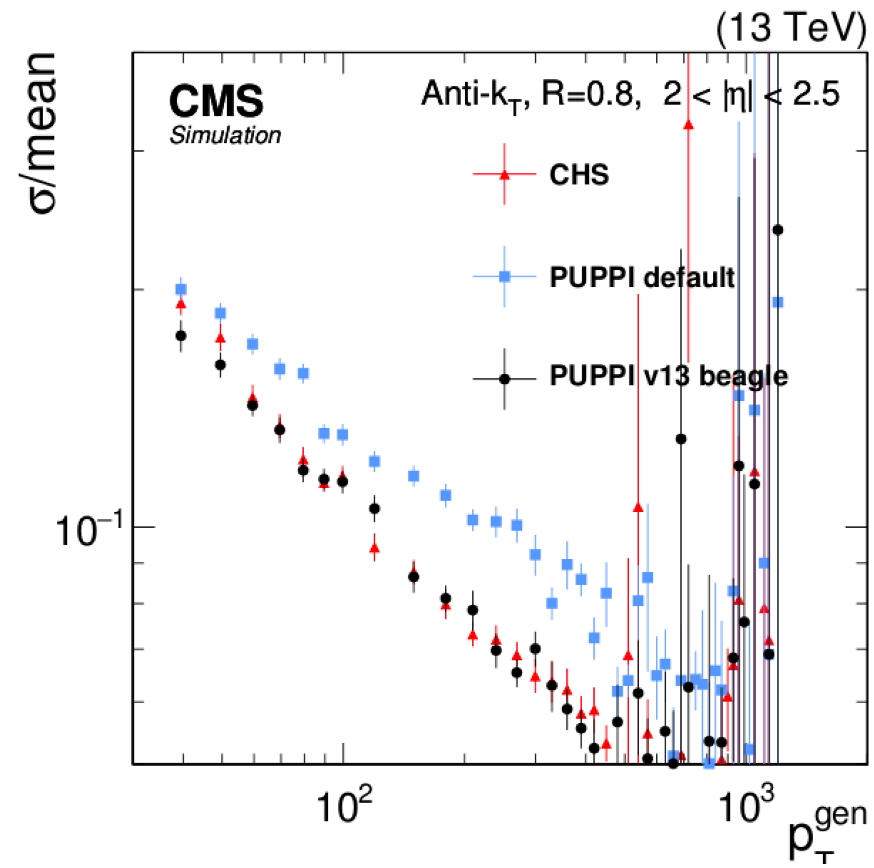
JER Ak8 Jets

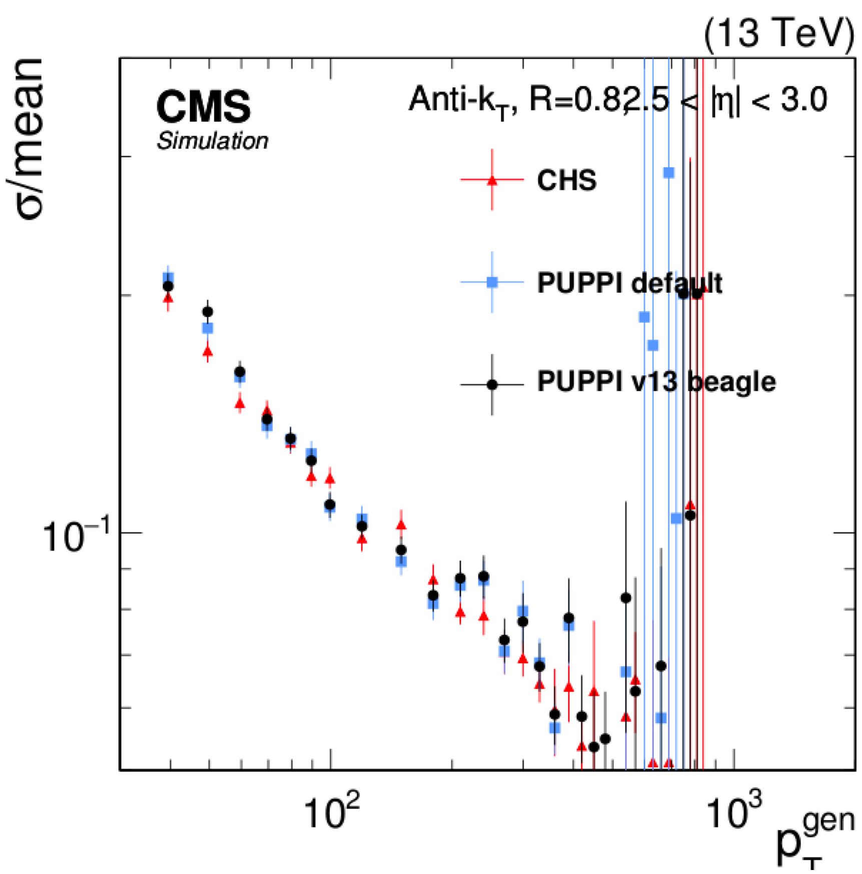
JER 2016 - Ak8

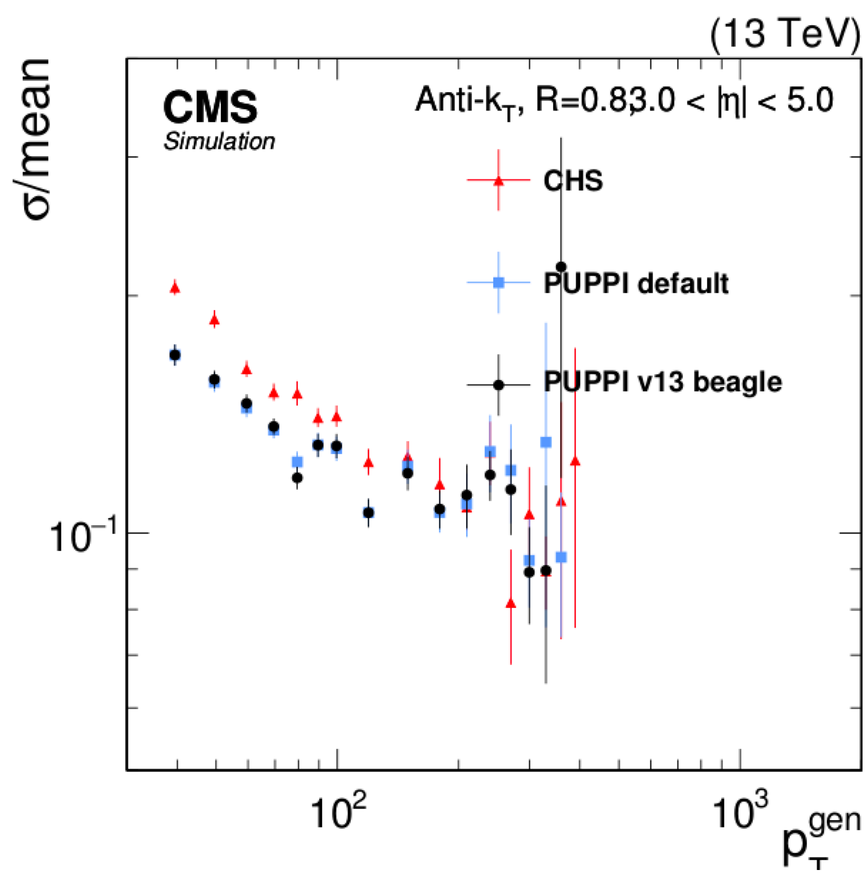
<u>QCD sample</u>







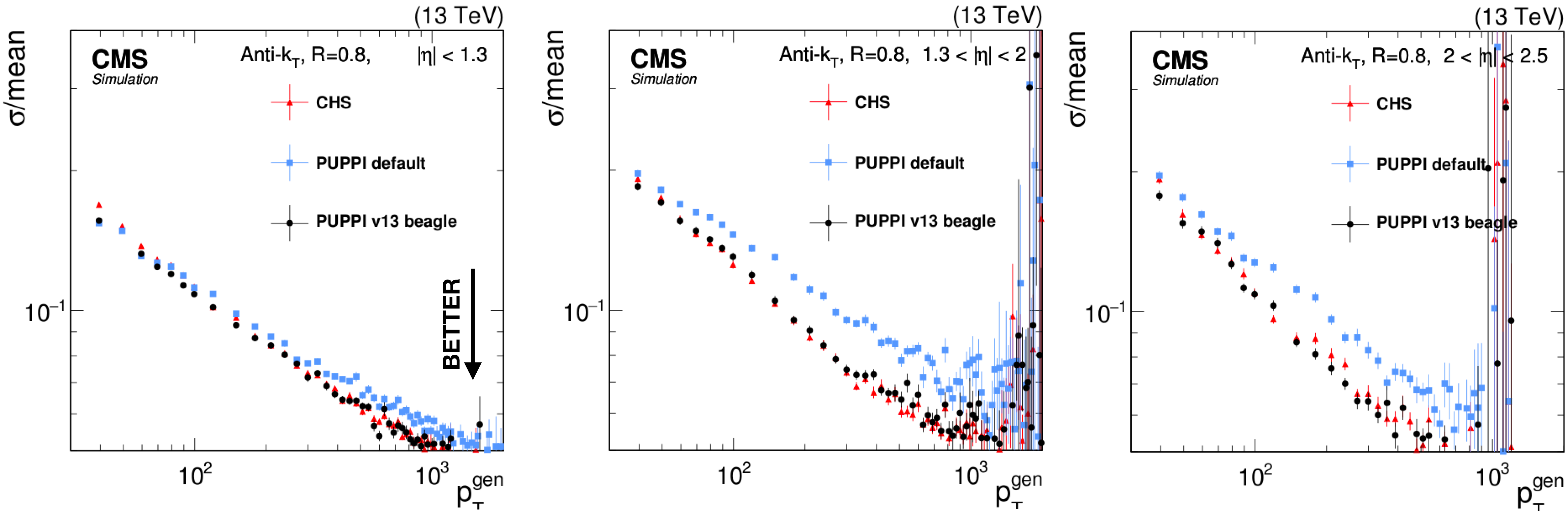


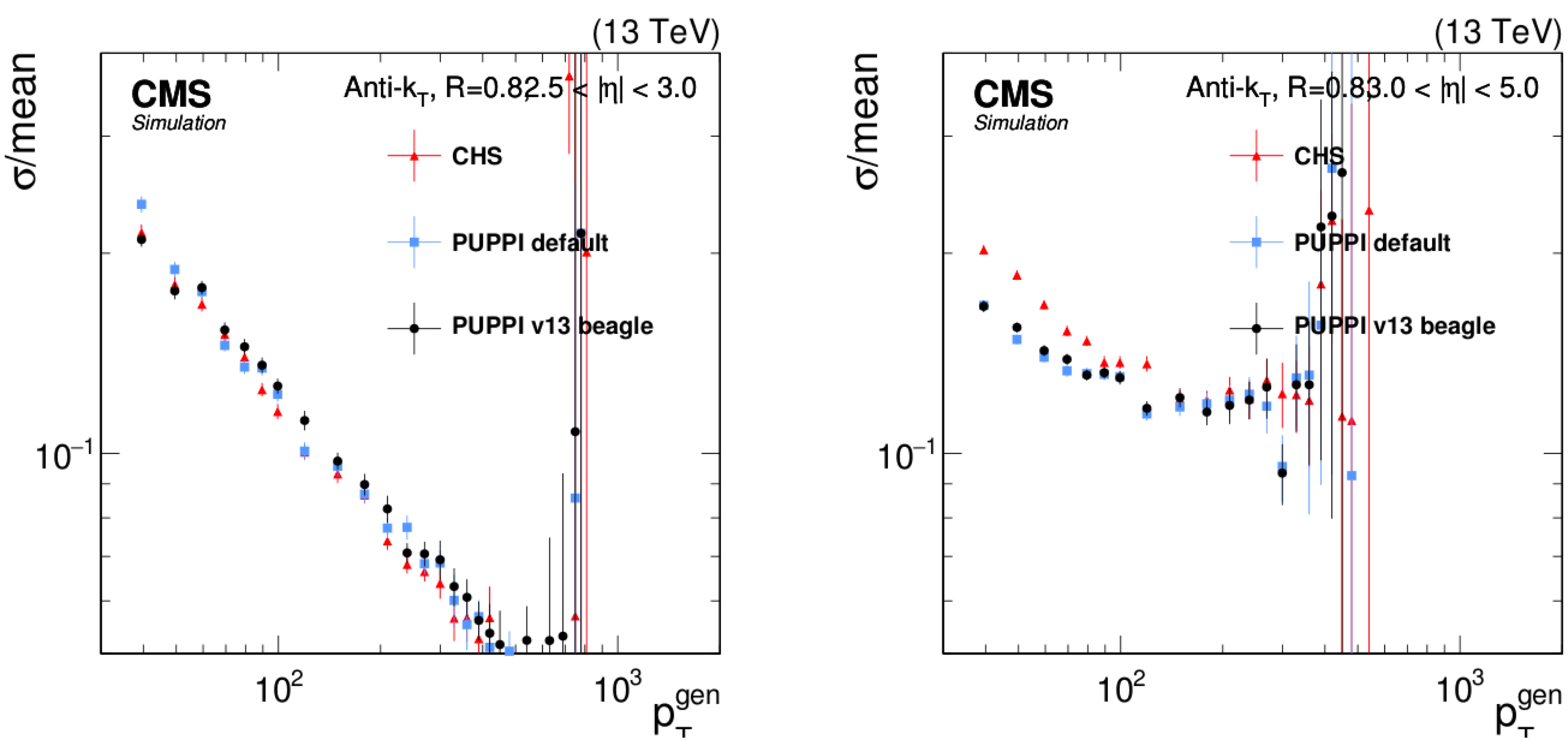


JER calculated with iterative gaussian fit

JER 2017 - Ak8

<u>QCD sample</u>

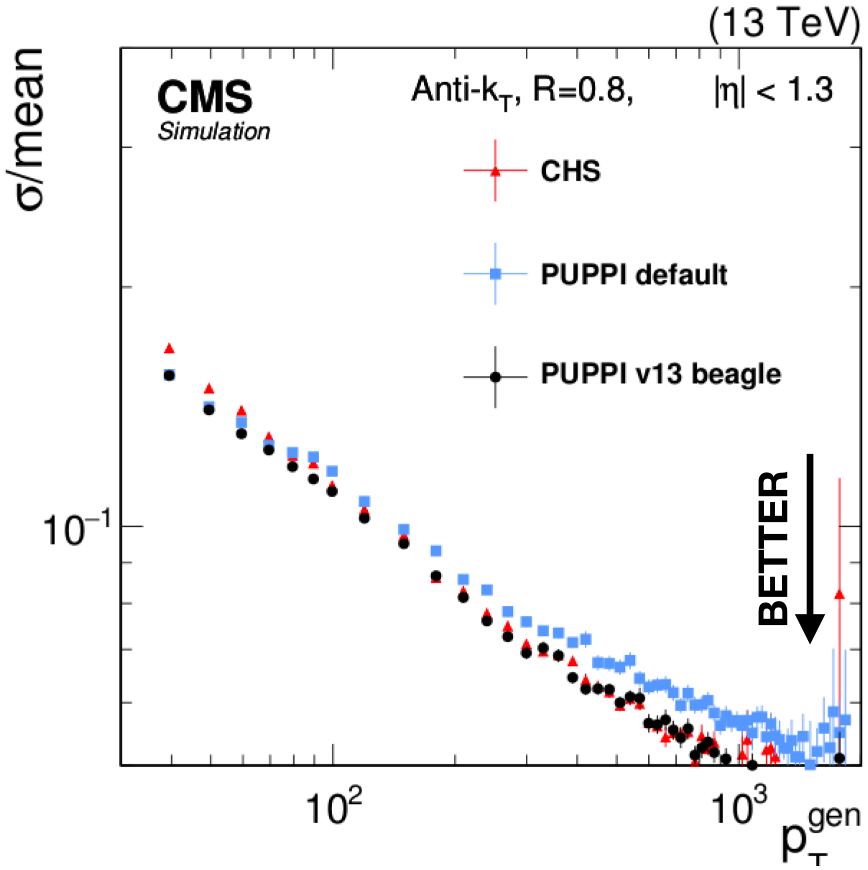


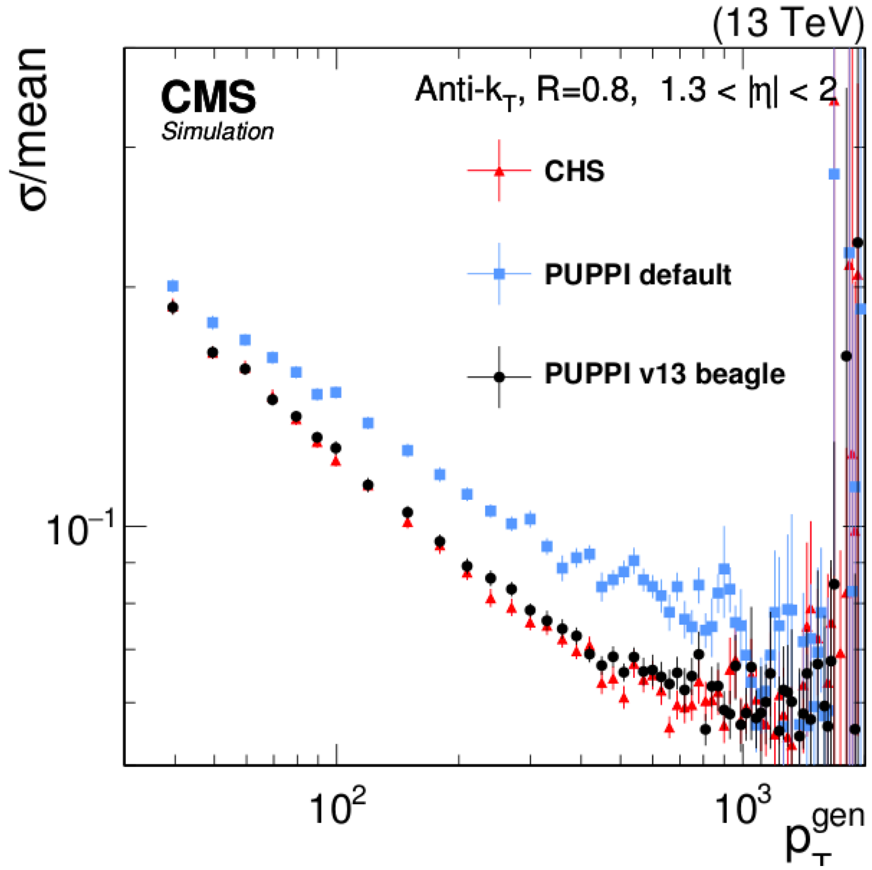


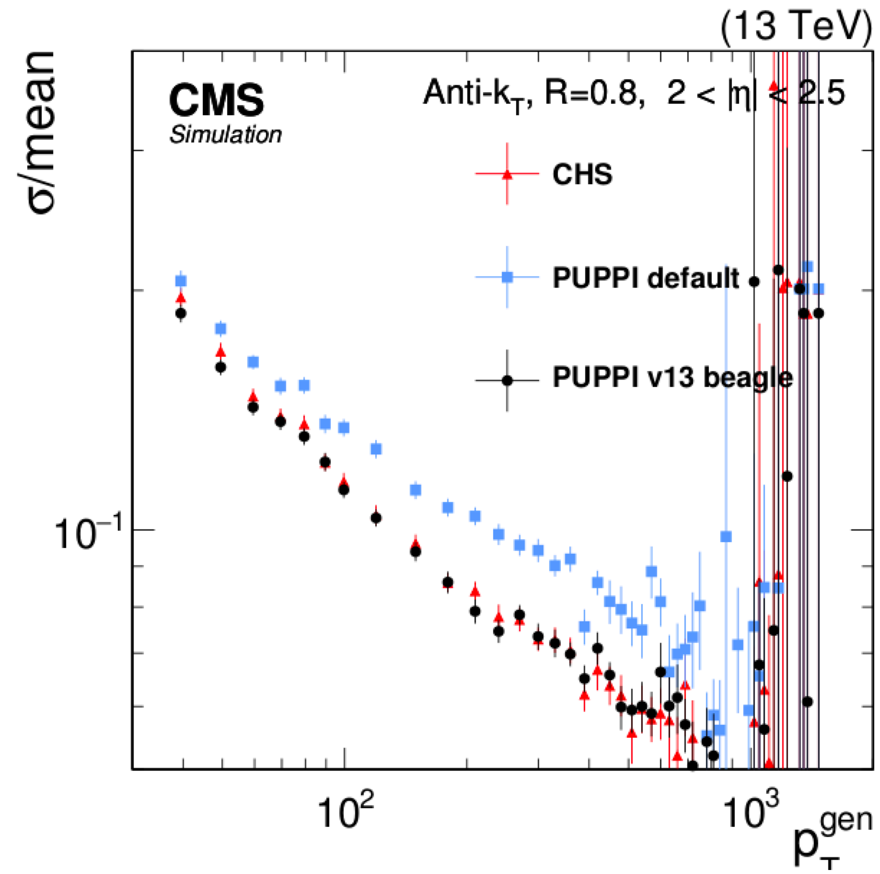
JER calculated with iterative gaussian fit

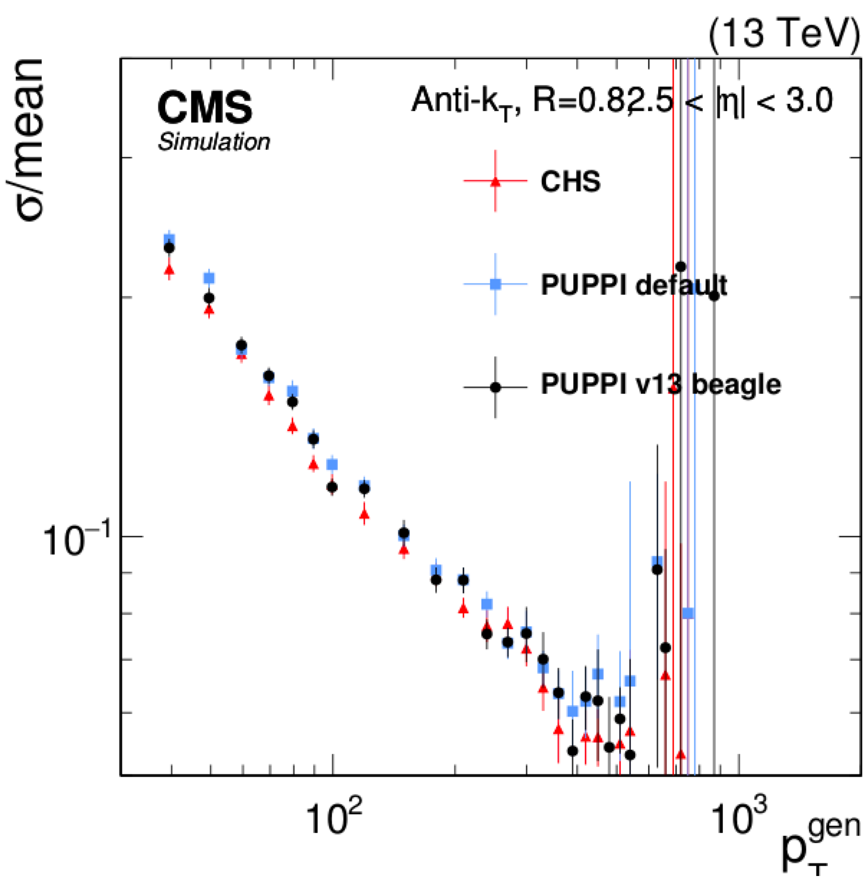
JER 2018 - Ak8

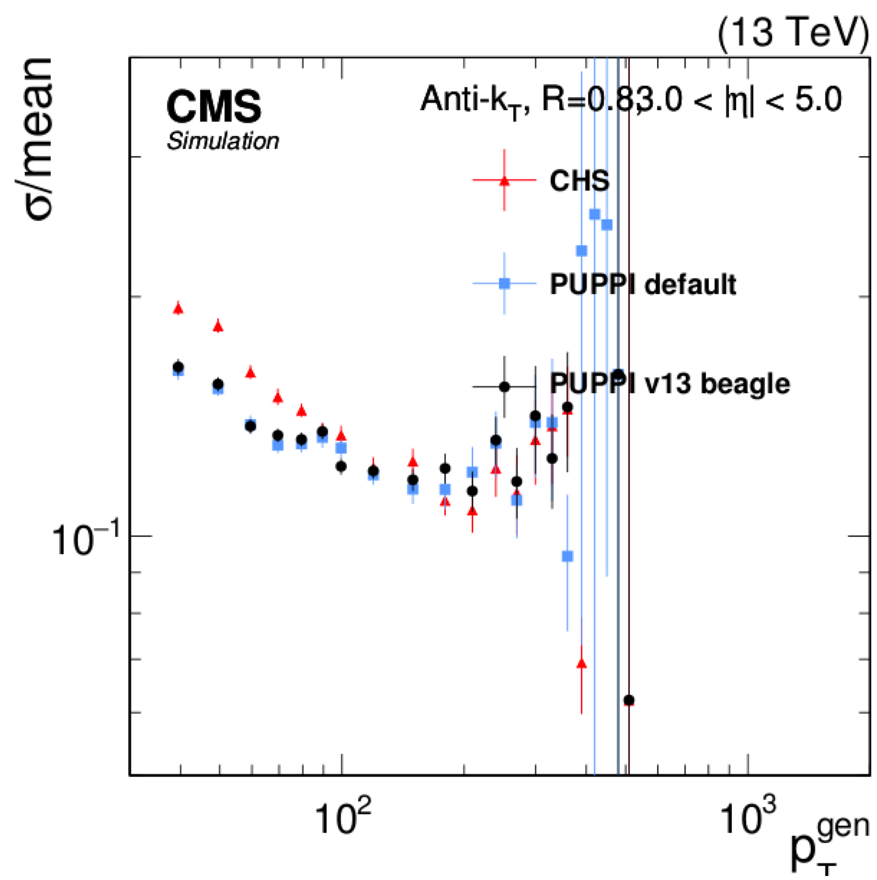
QCD sample







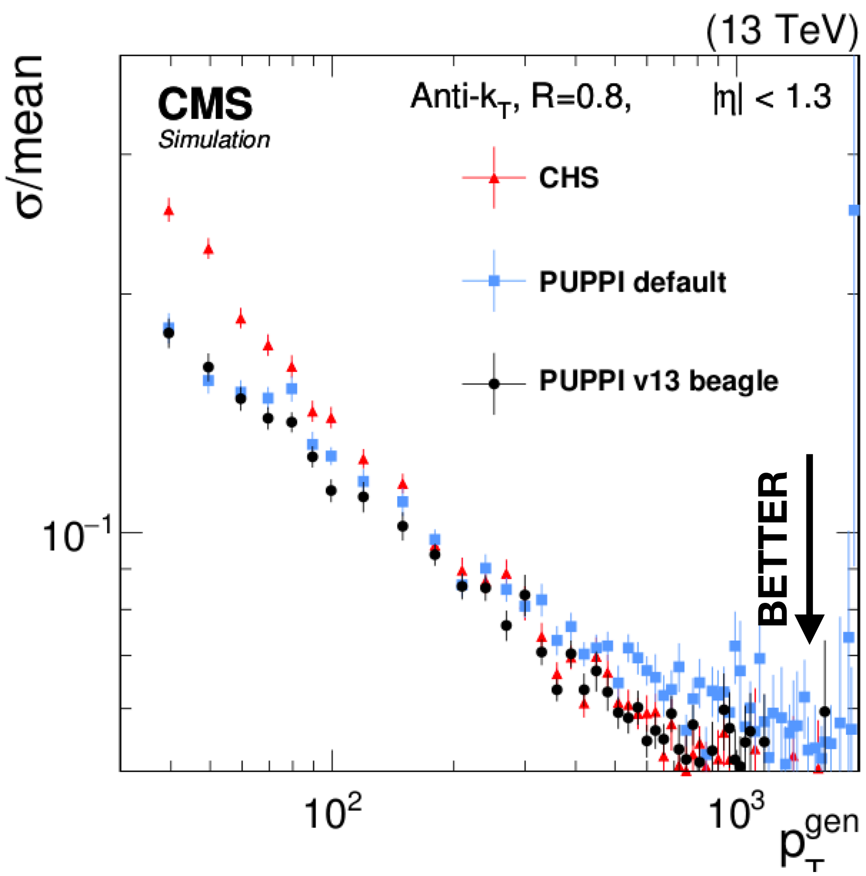


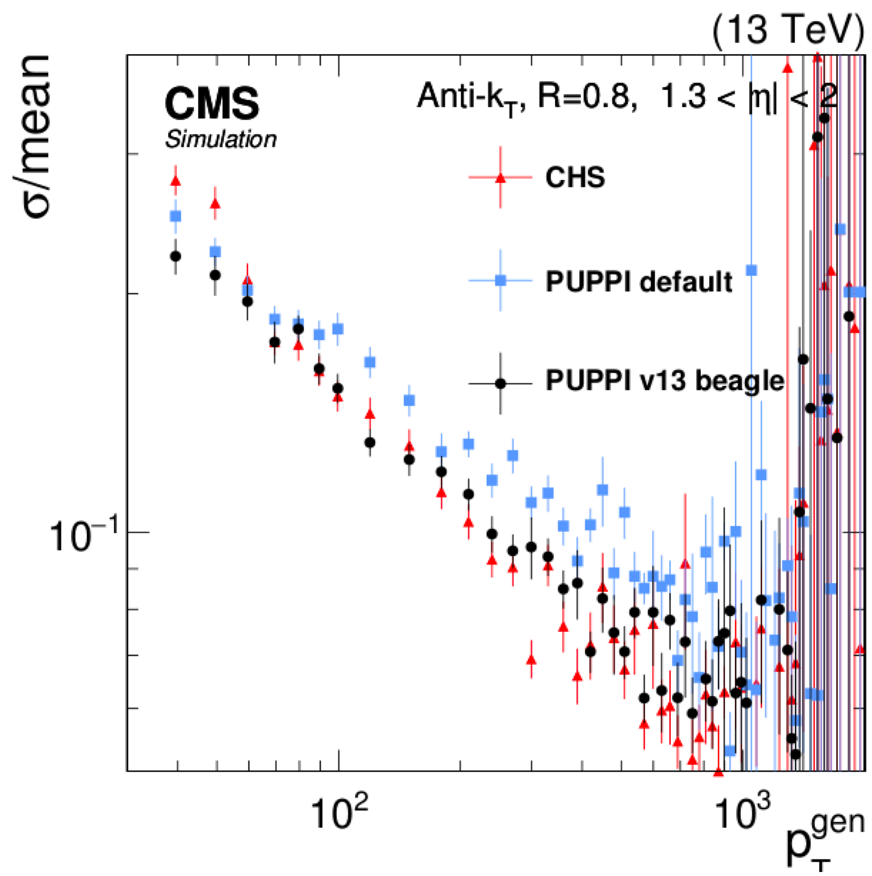


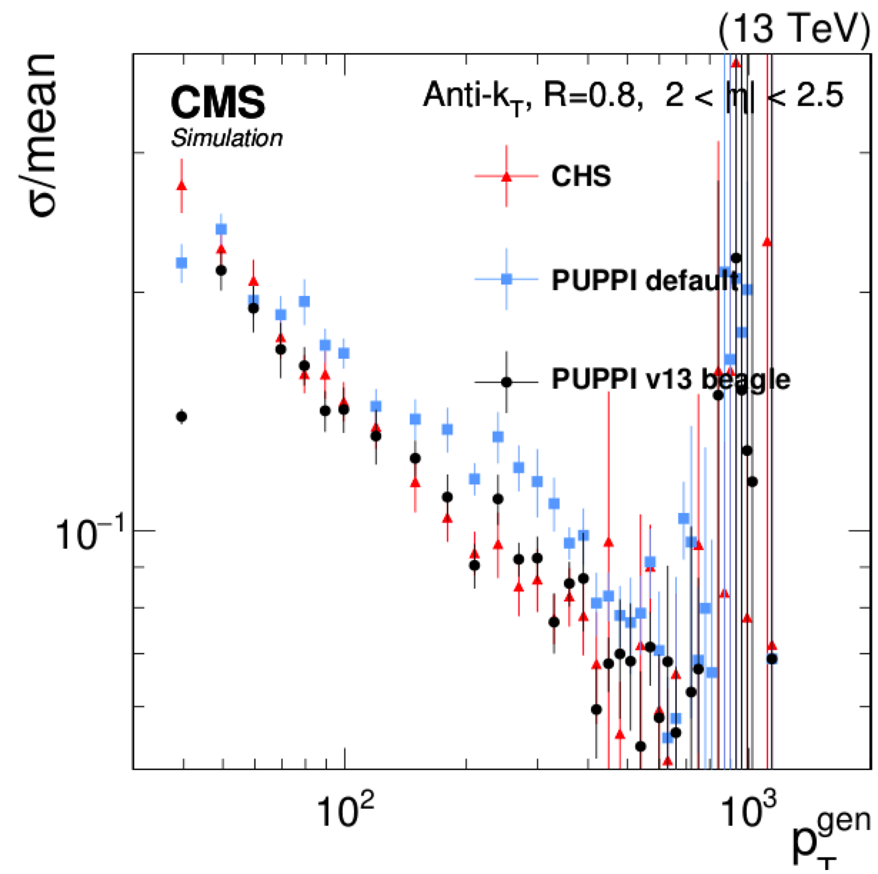
JER calculated with iterative gaussian fit

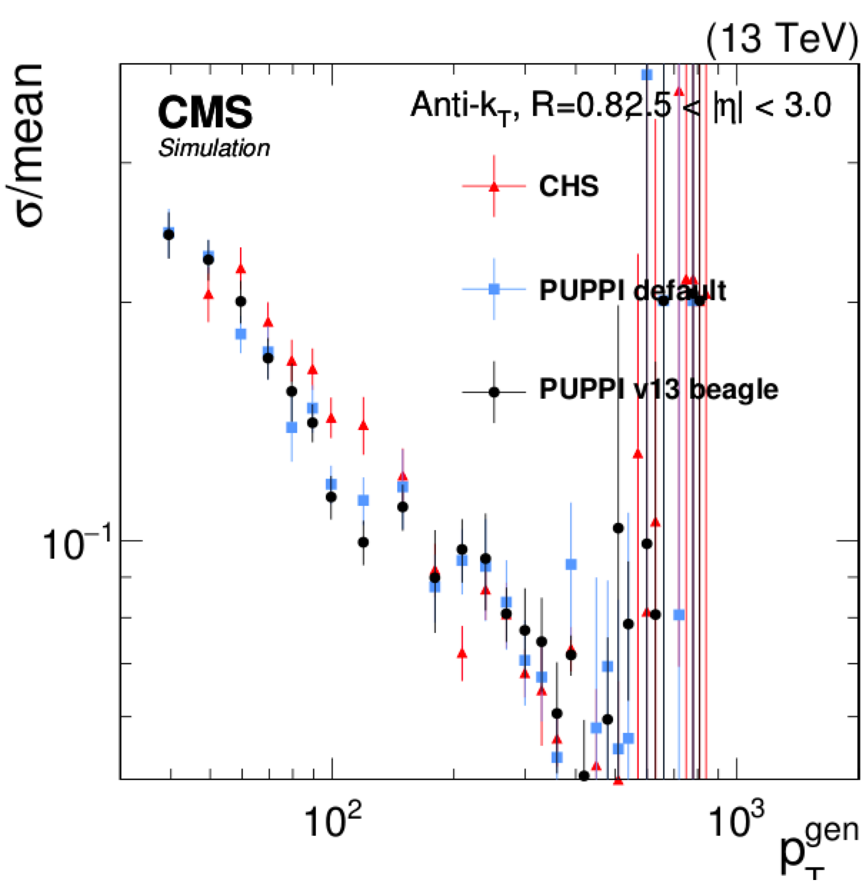
JER 2016 - Ak8 PU>50

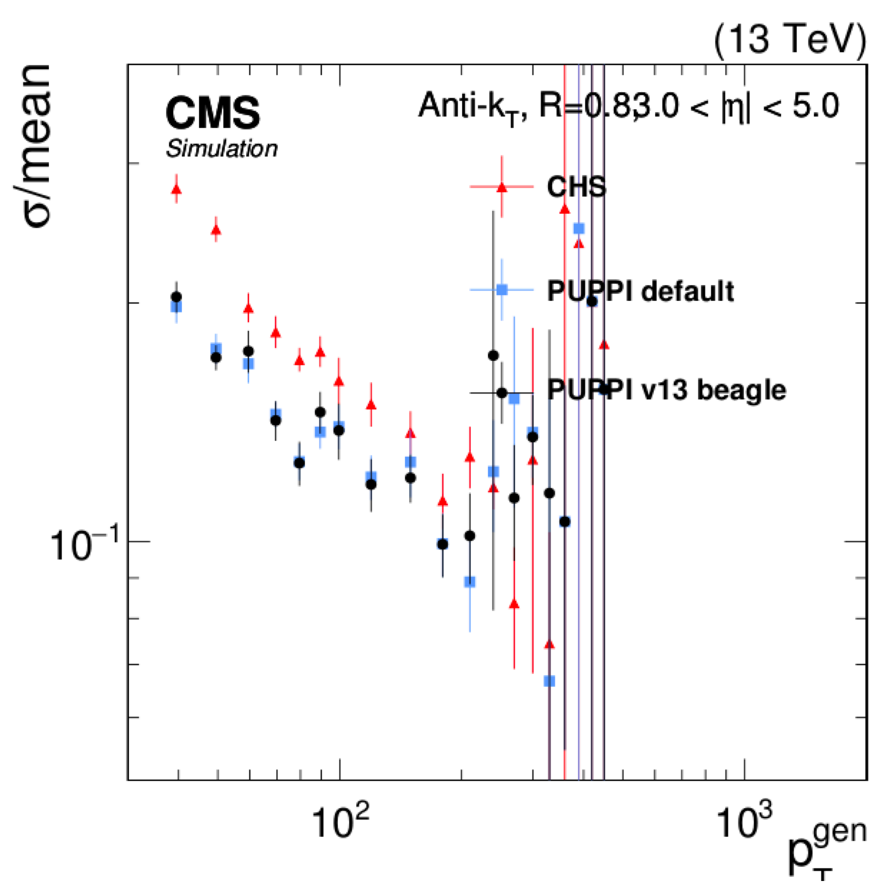
QCD sample







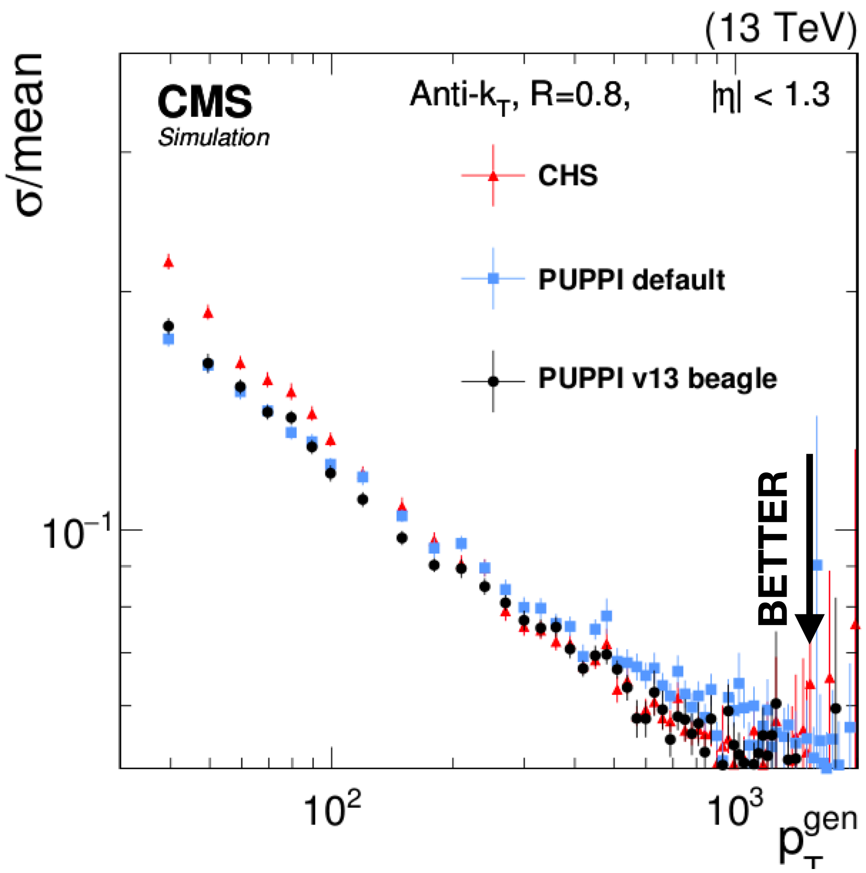


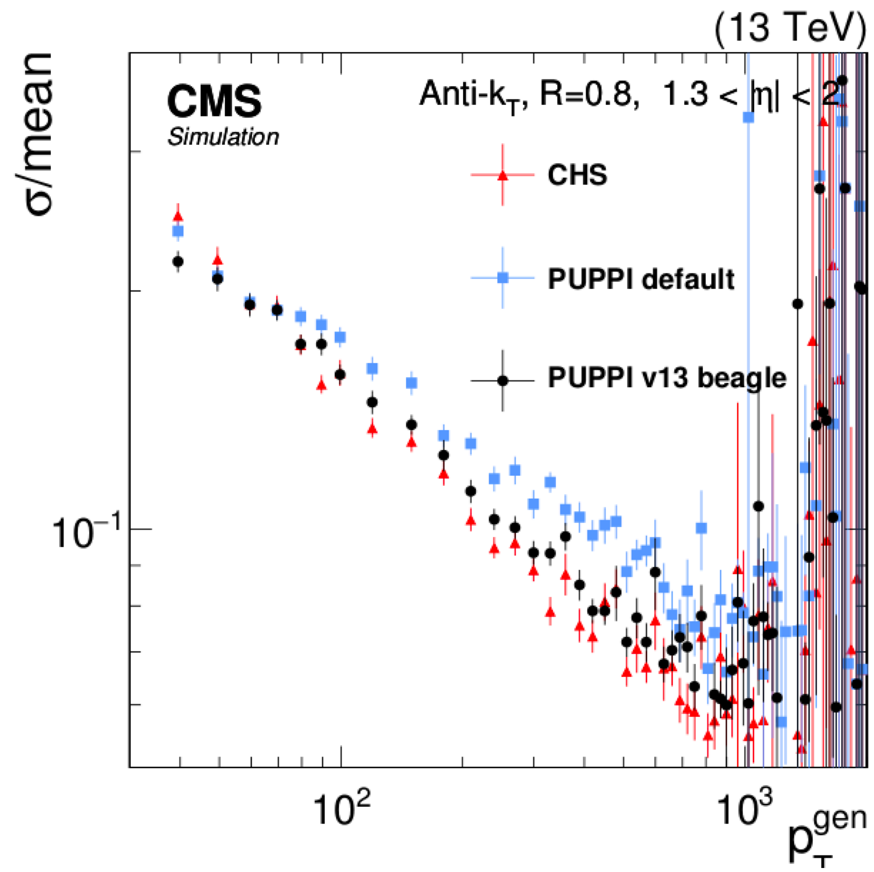


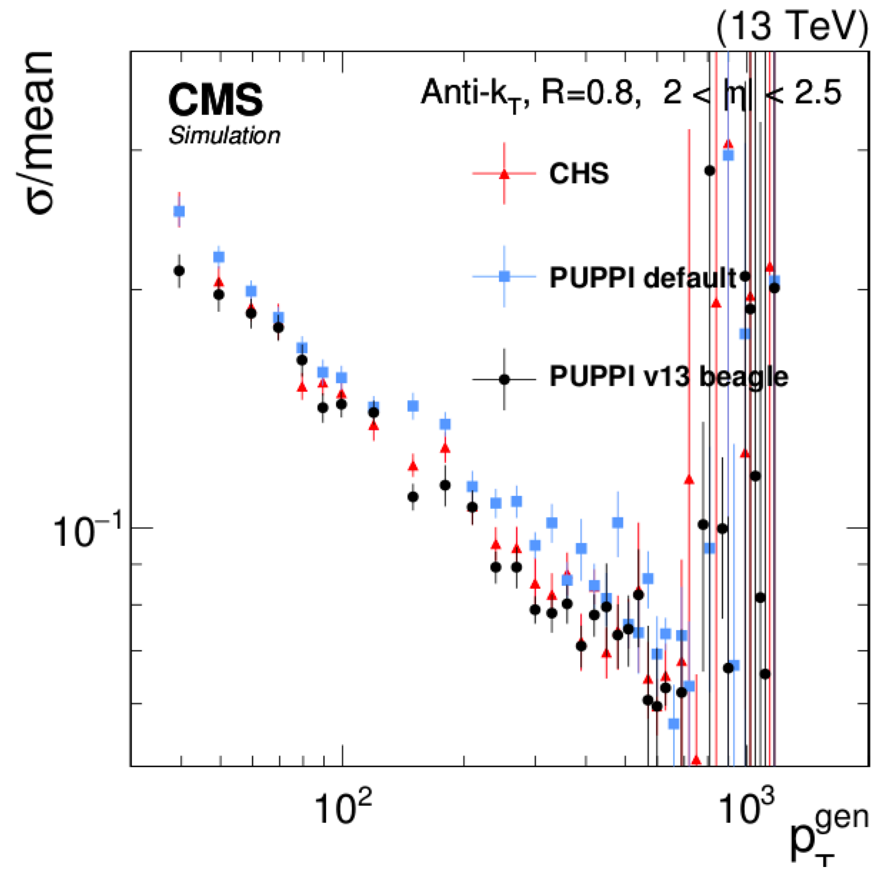
JER calculated with iterative gaussian fit

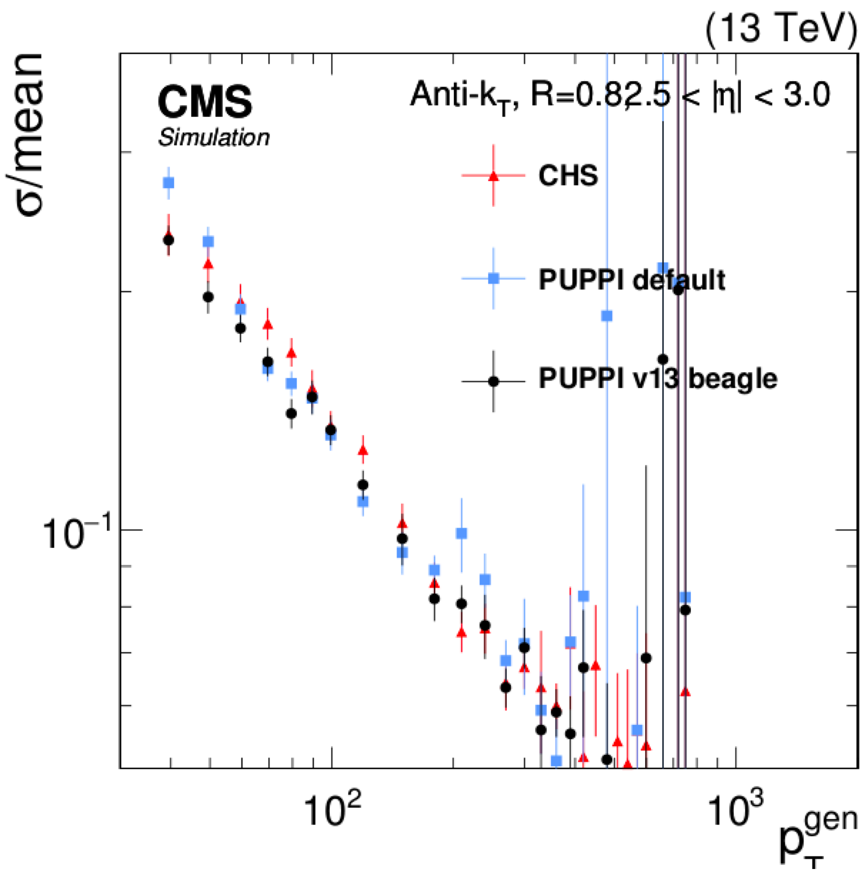
JER 2017 - Ak8 PU>50

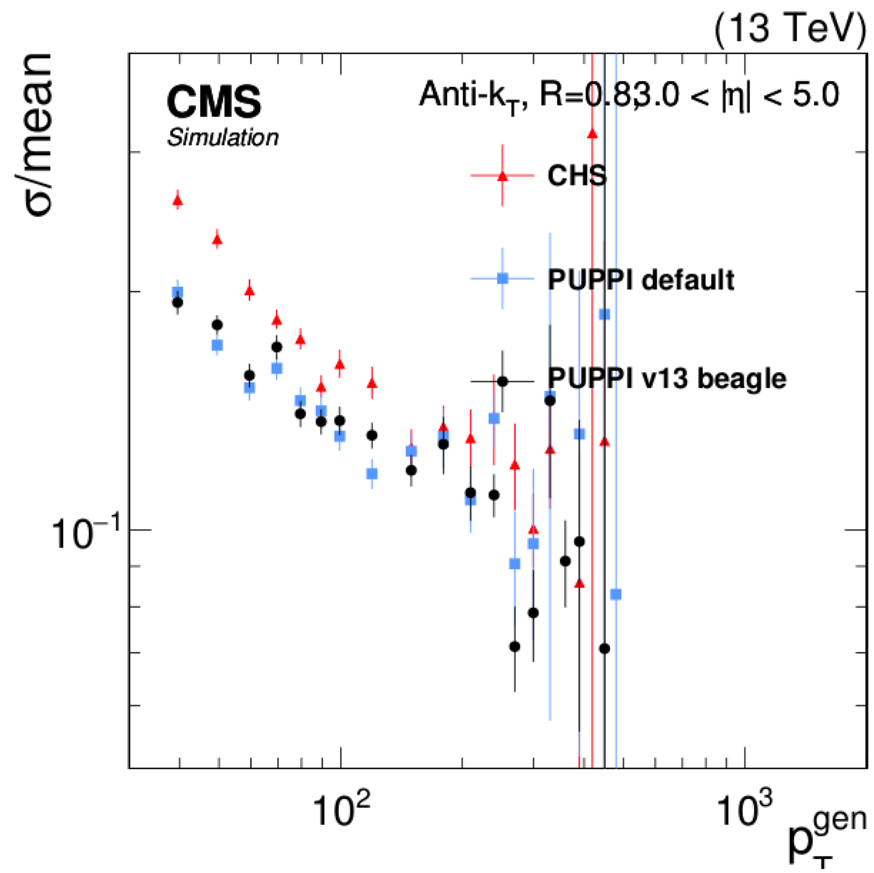
QCD sample







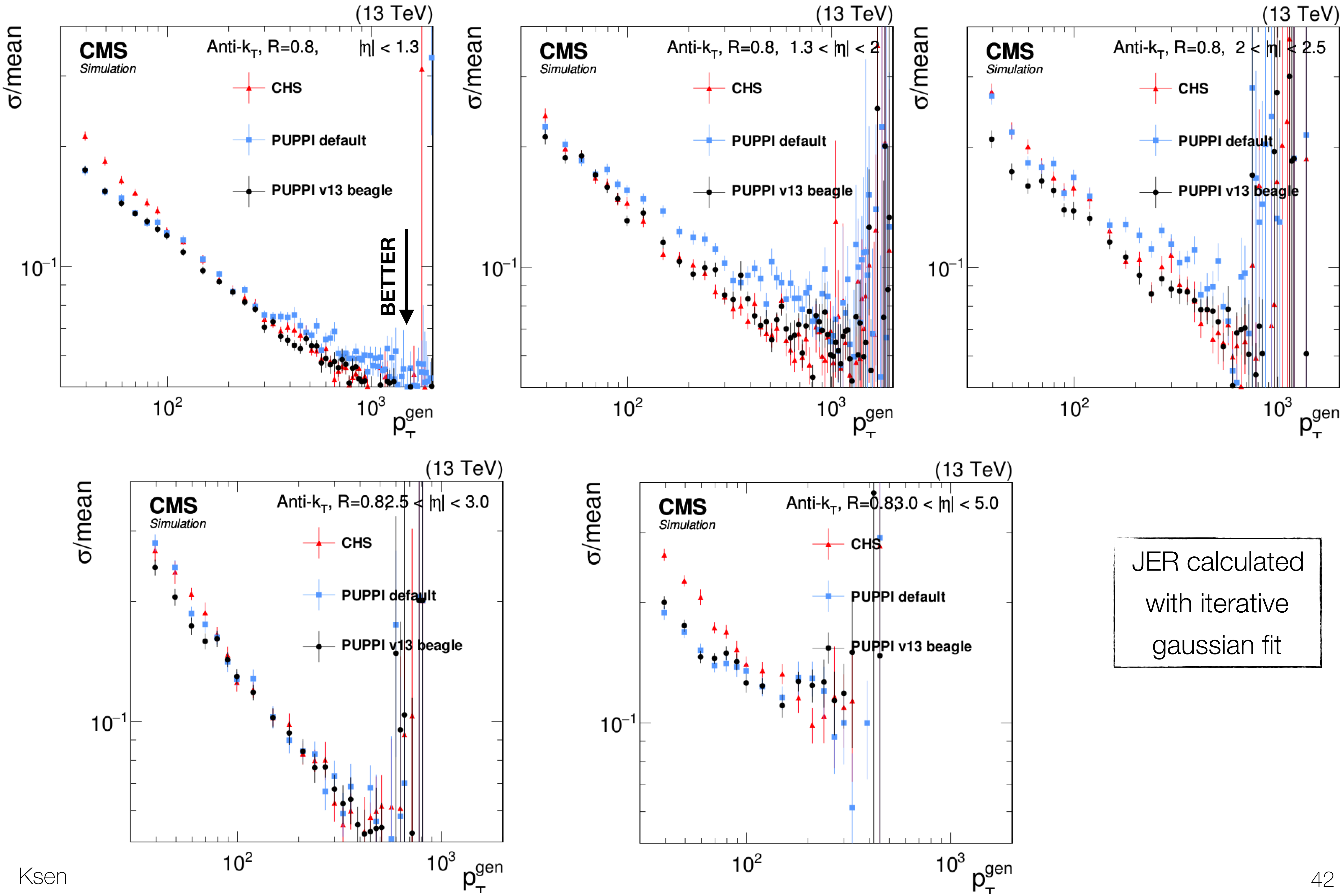




JER calculated with iterative gaussian fit

JER 2018 - Ak8 PU>50

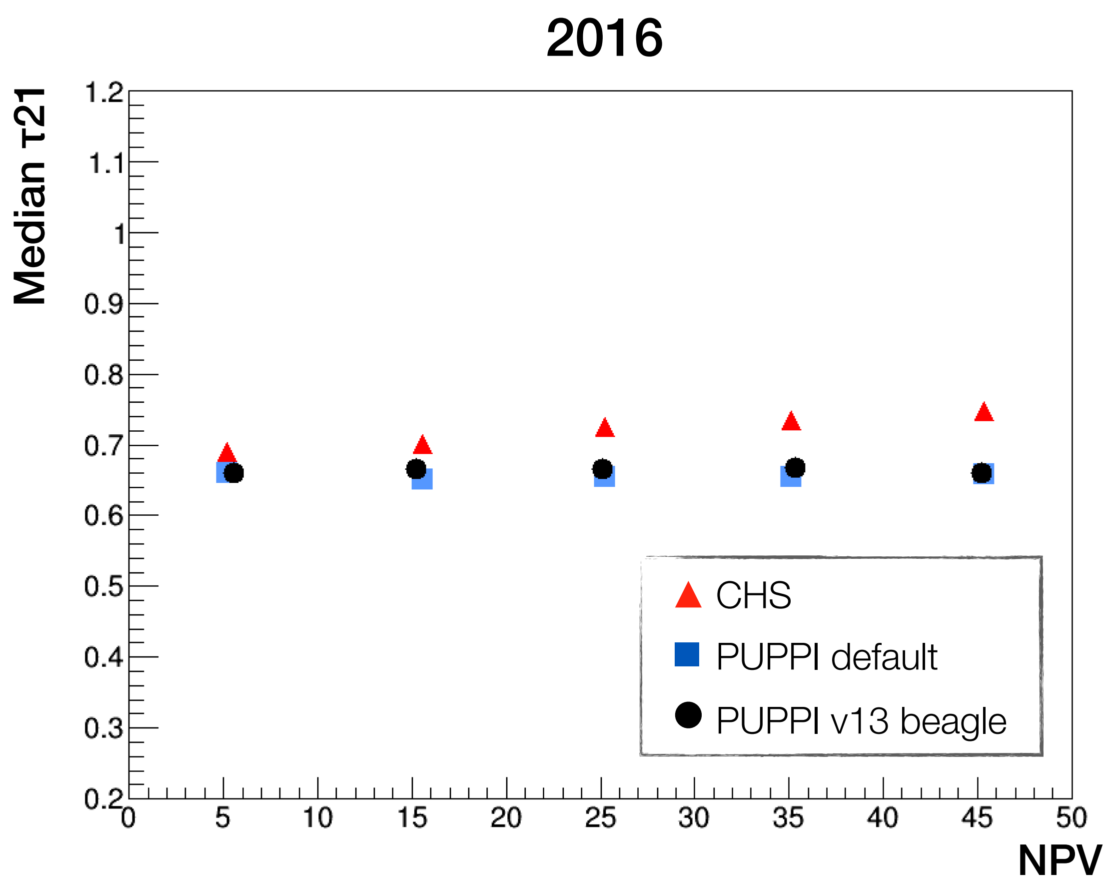
QCD sample

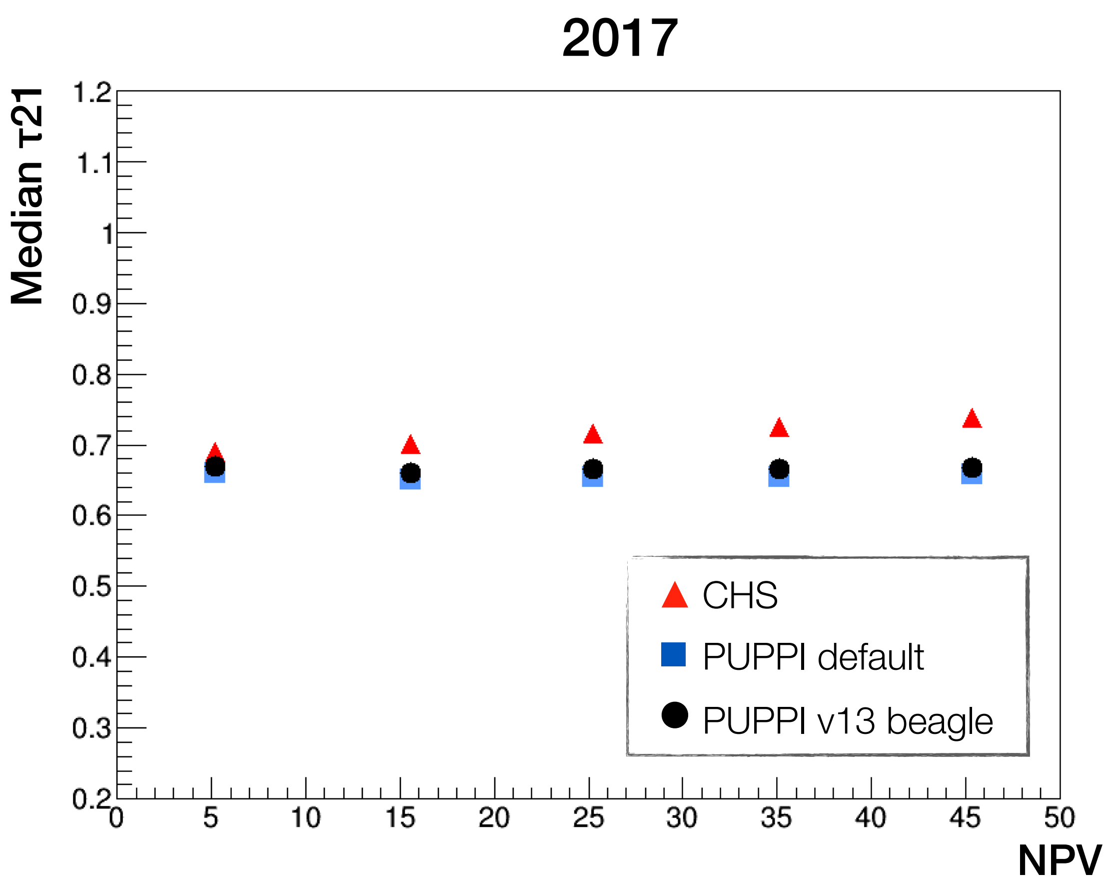


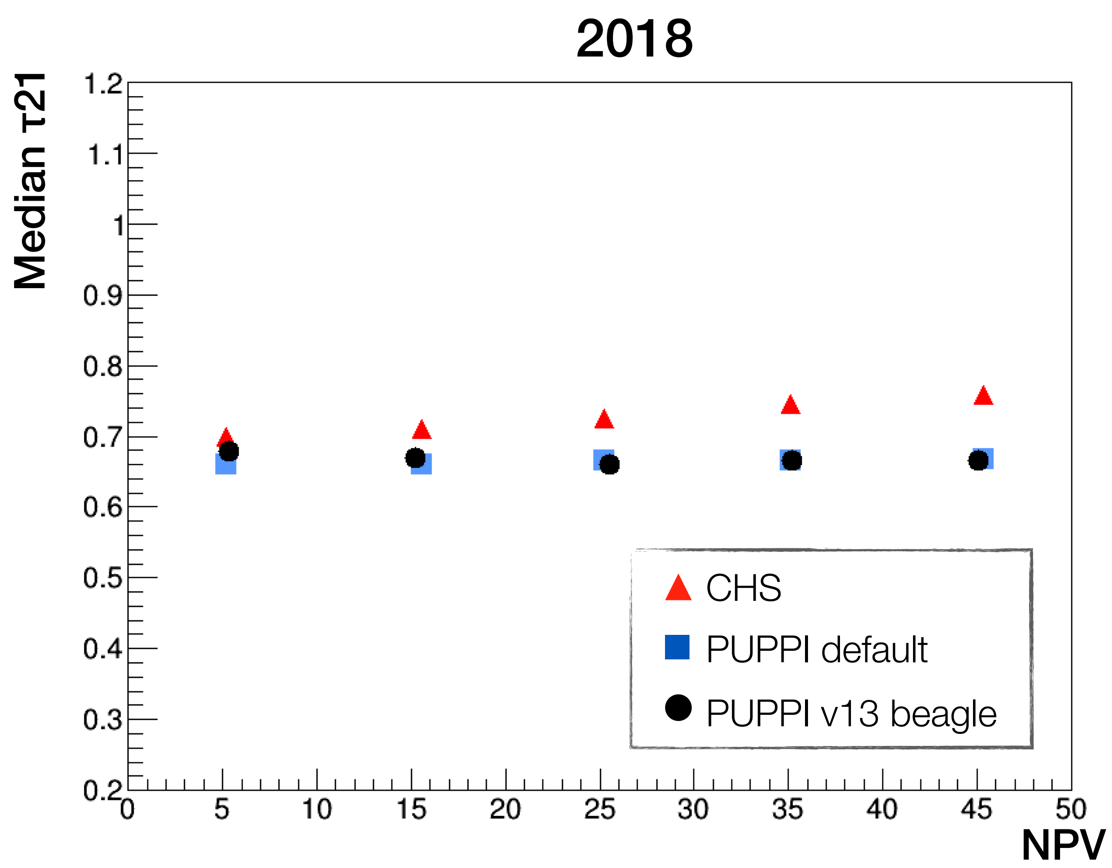
JER calculated with iterative gaussian fit

Median tau21

Median τ21







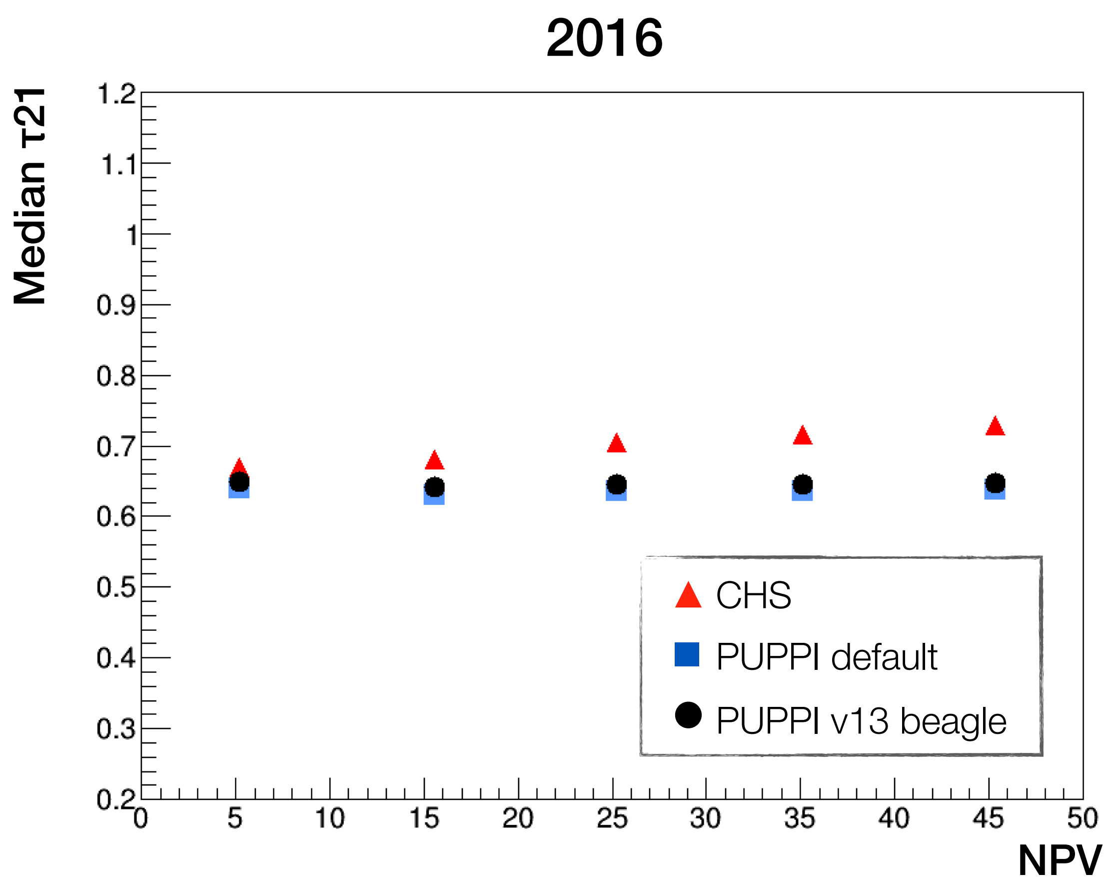
<u>**QCD sample**</u>

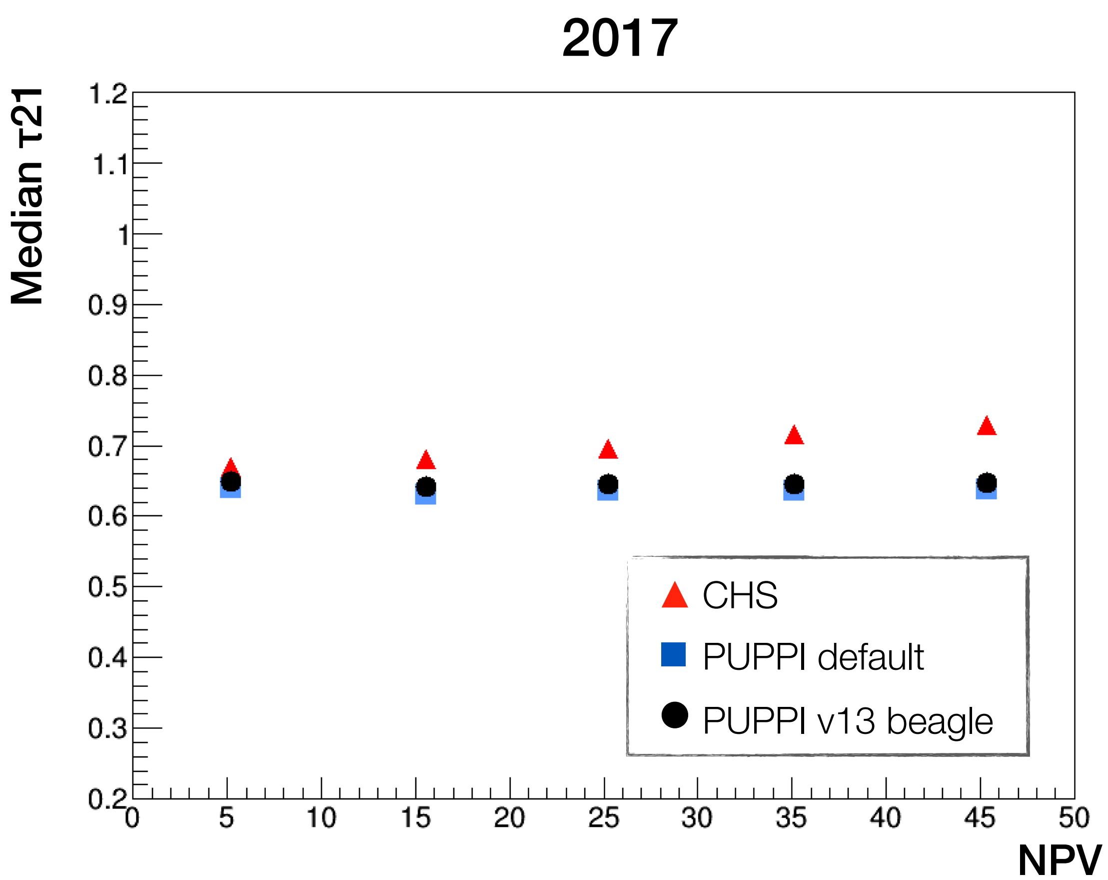
Median τ21 leading Ak8 jet

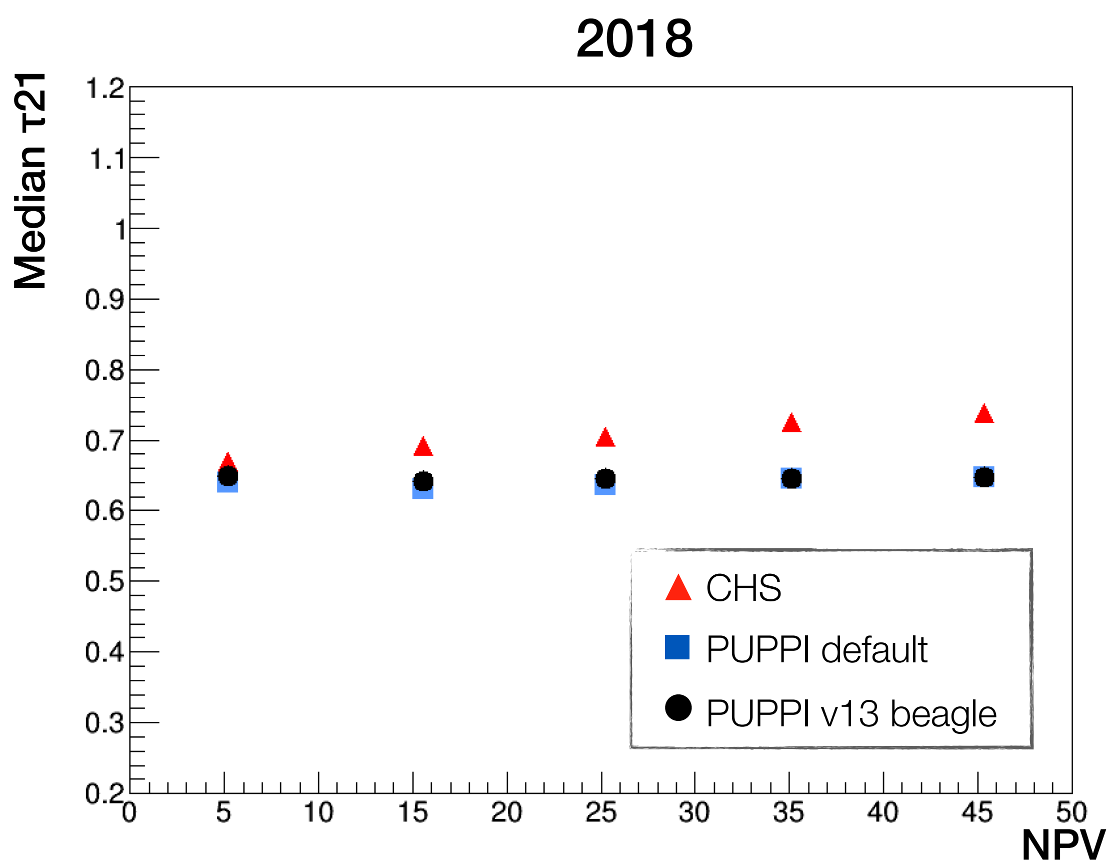
400 < p_T < 600 GeV

no SoftDrop Mass cut

Median τ21







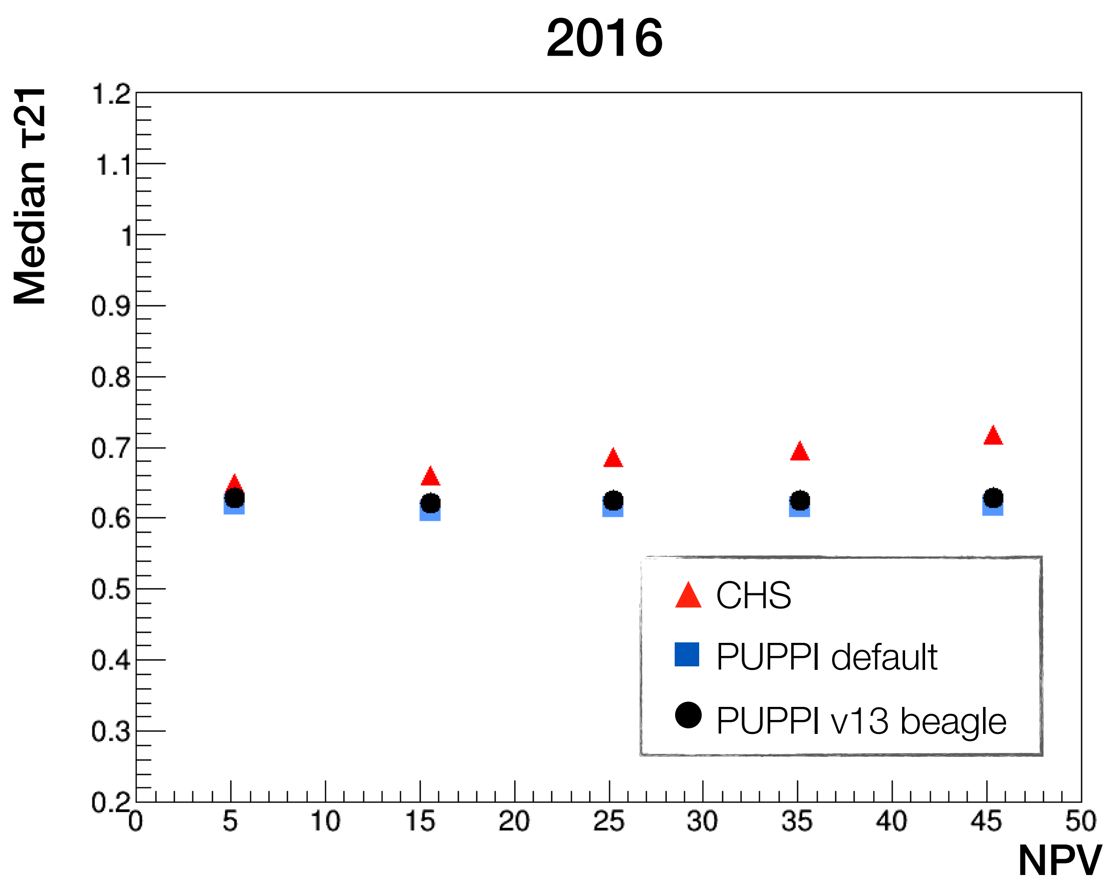
QCD sample

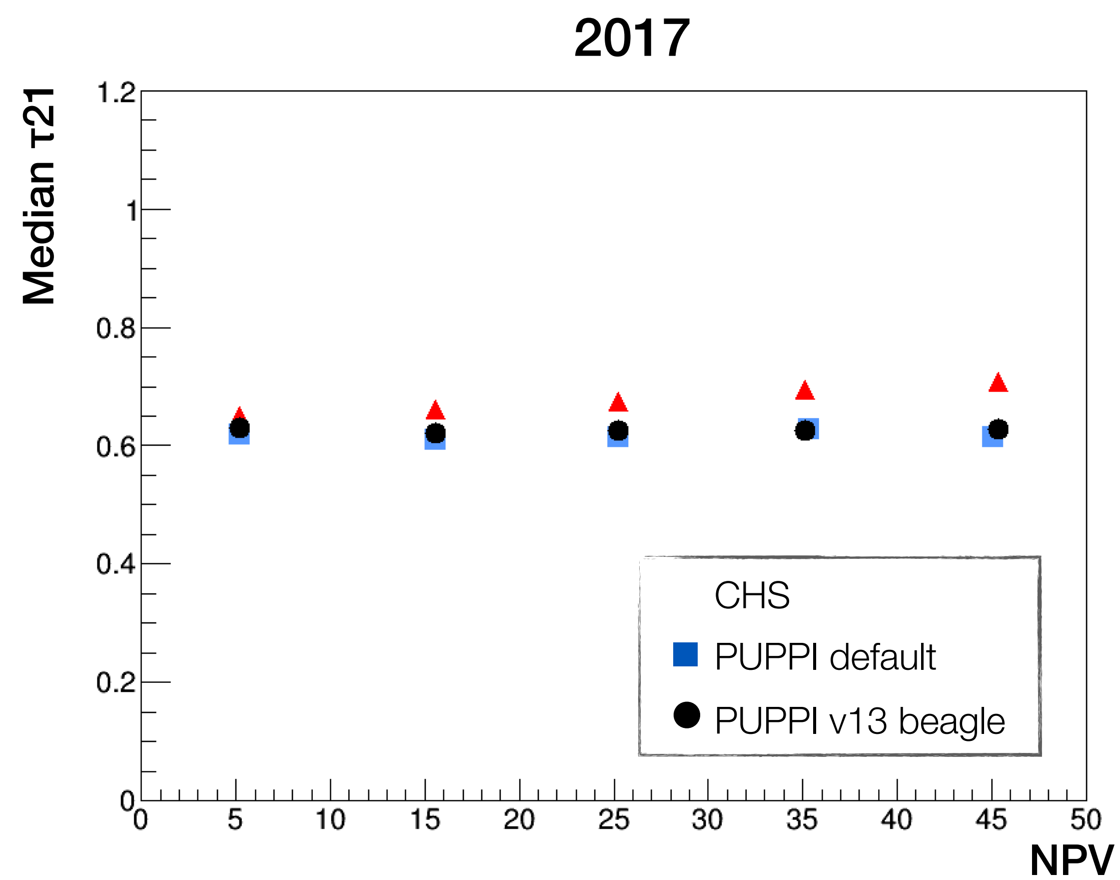
Median τ21 leading Ak8 jet

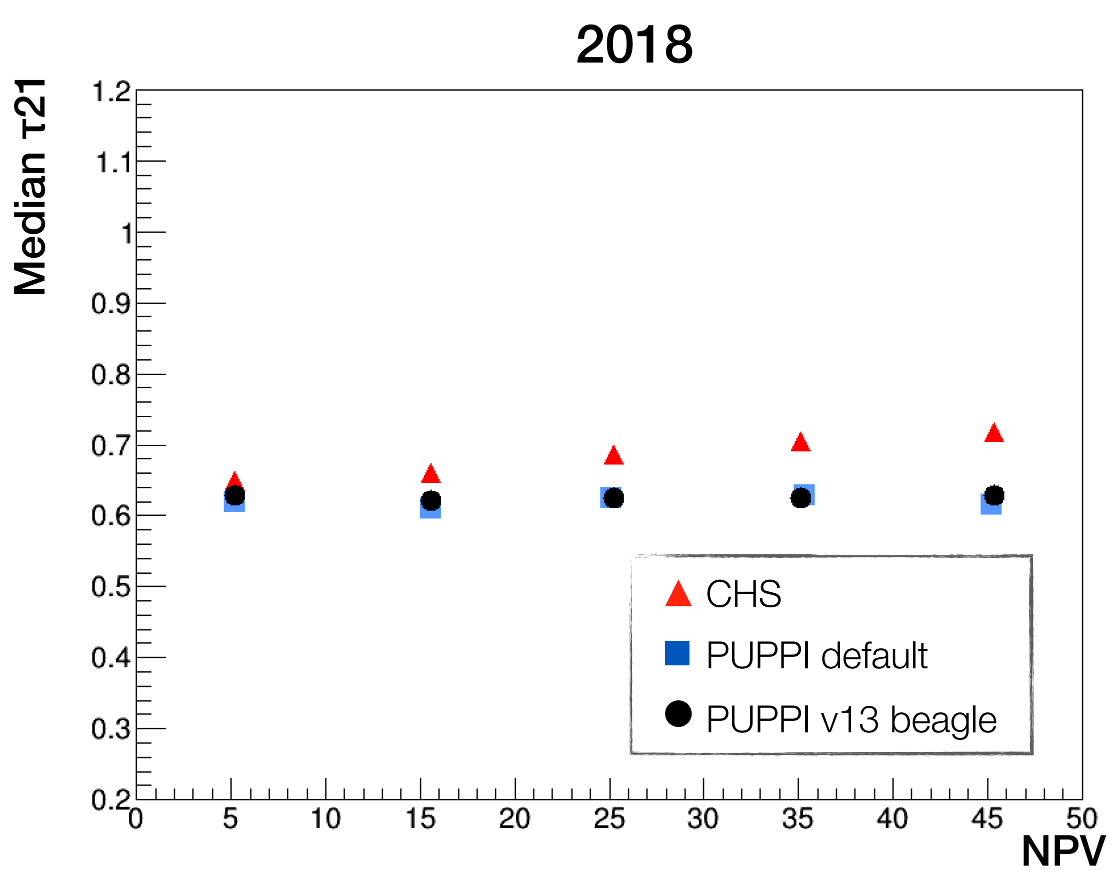
$600 < p_T < 800$ GeV

no SoftDrop Mass cut

Median τ21







<u>QCD sample</u>

Median τ21 leading Ak8 jet

800 < p_T < 1000 GeV

no SoftDrop Mass cut

Efficiency and Purity: calculation

Efficiency

- $p_T^{genjets} > 30$ GeV, $p_T^{recojets} > 20$ GeV
- Fill histogram with N_{PV} for each genjet
- Match each genjet to a recojet
- Fill histogram for each matched genjet with N_{PV}
- Divide the histograms

Purity

- $p_T^{recojets} > 30$ GeV, $p_T^{genjets} > 20$ GeV
- Fill histogram with N_{PV} for each recojet
- Match each recojet to a genjet
- Fill histogram for each matched recojet with N_{PV}
- Divide the histograms

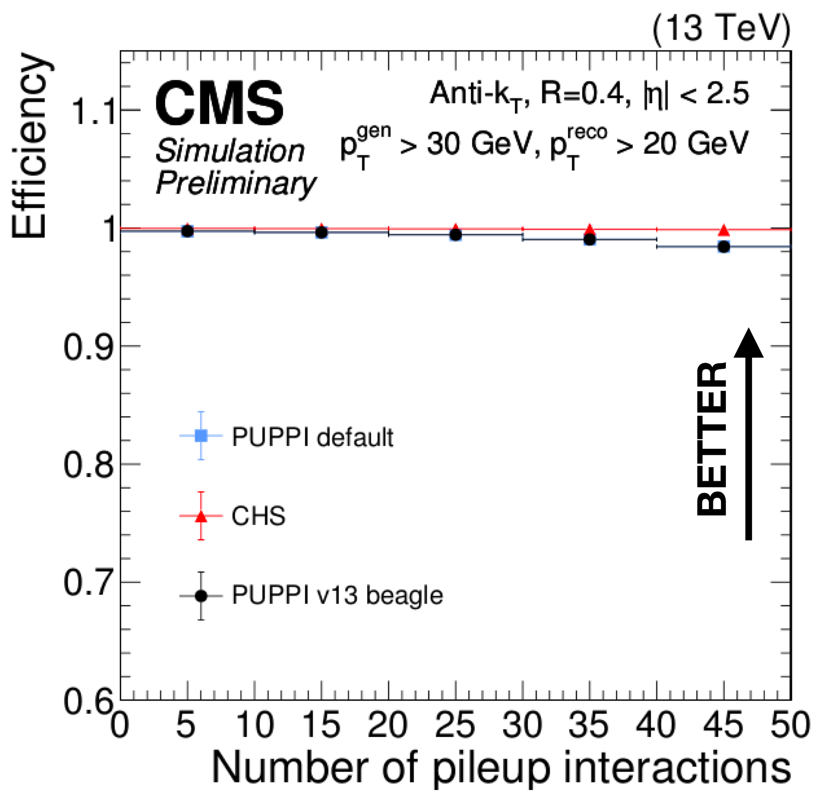
DY Dataset

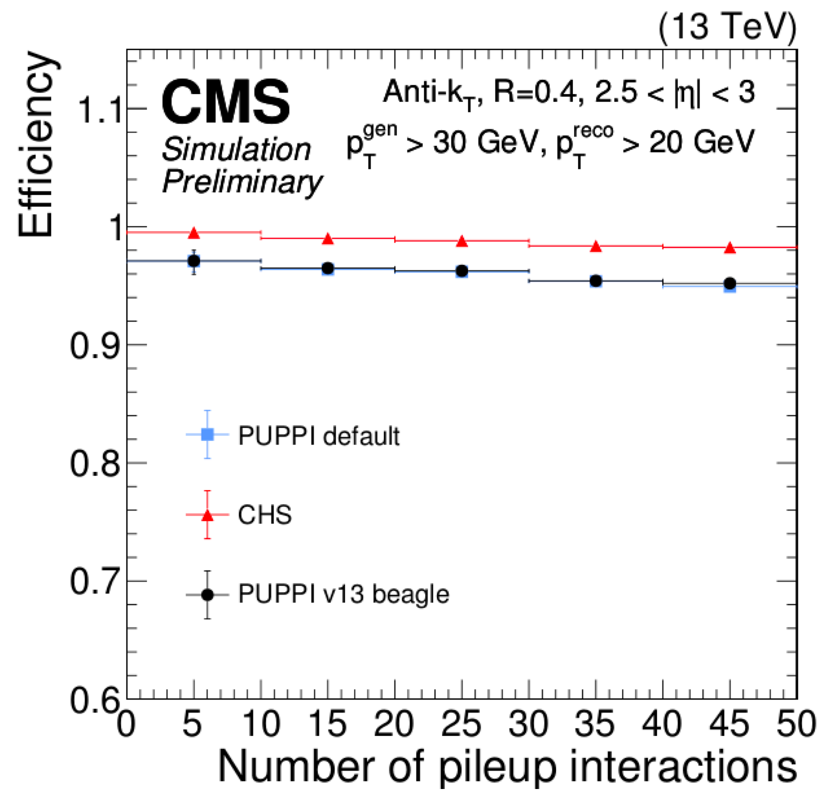
Year	DAS	CMSSW production release	Note
2016v3	/DYJetsToLL_M-50_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIISummer16MiniAODv3-PUMoriond17_94X_mcRun2_asymptotic_v3_ext1-v2/MINIAODSIM	production: 80X reconstruction: 94X	Version v3, in QCD sample 2016 version v2
2017v2	/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_new_pmx_94X_mc2017_realistic_v14-v1/MINIAODSIM	production: 92X reconstruction: 94X	
2018	/DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	production: 102X reconstruction: 102X	Coming soon

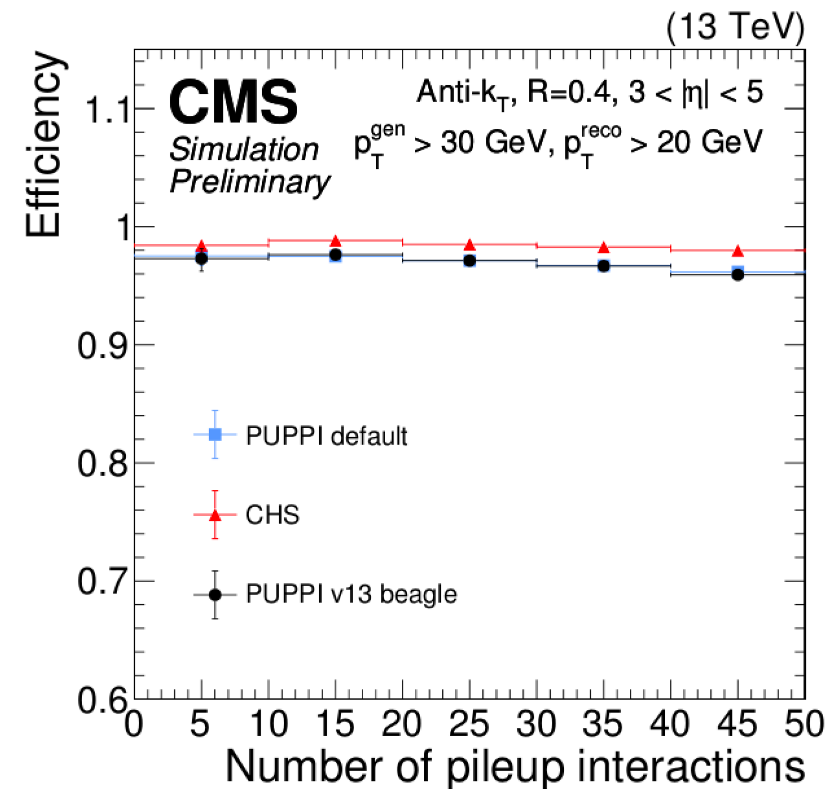
PR tune v13 beagle

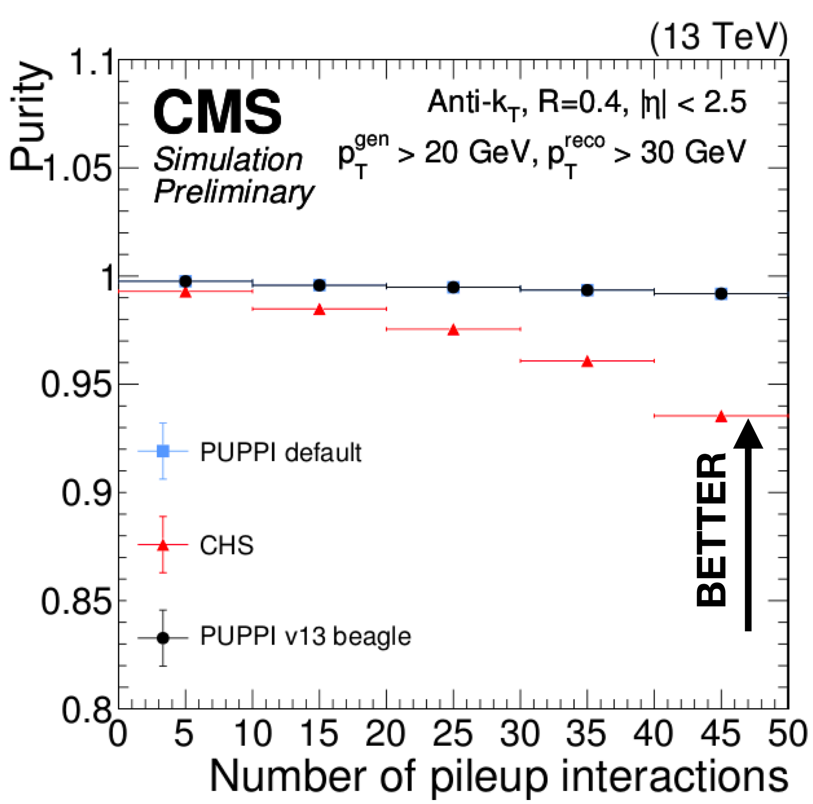
Efficiency & Purity - 2016

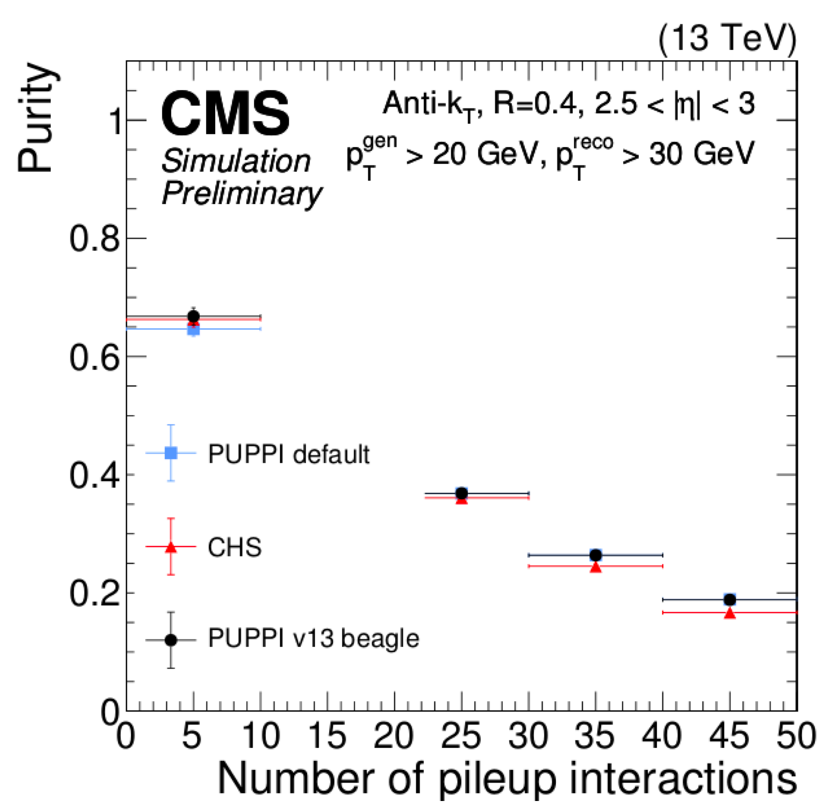
<u>DY sample</u>

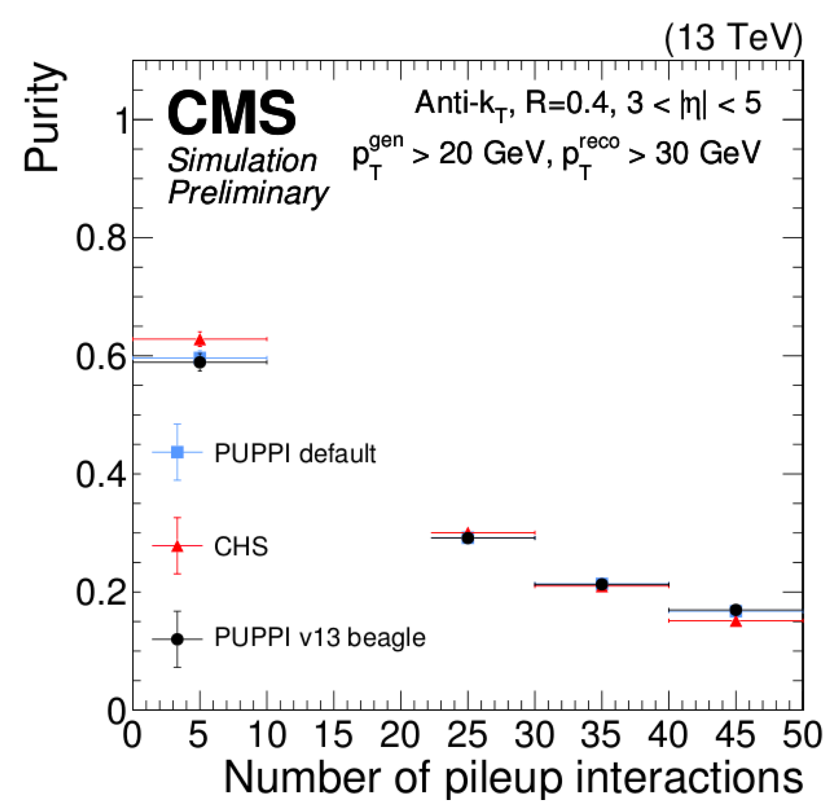












Efficiency & Purity - 2017

DY sample