Universität Hamburg
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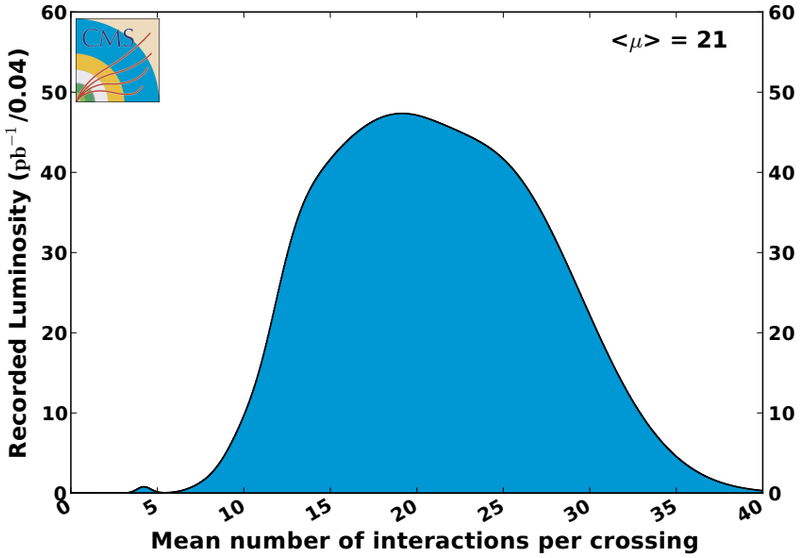
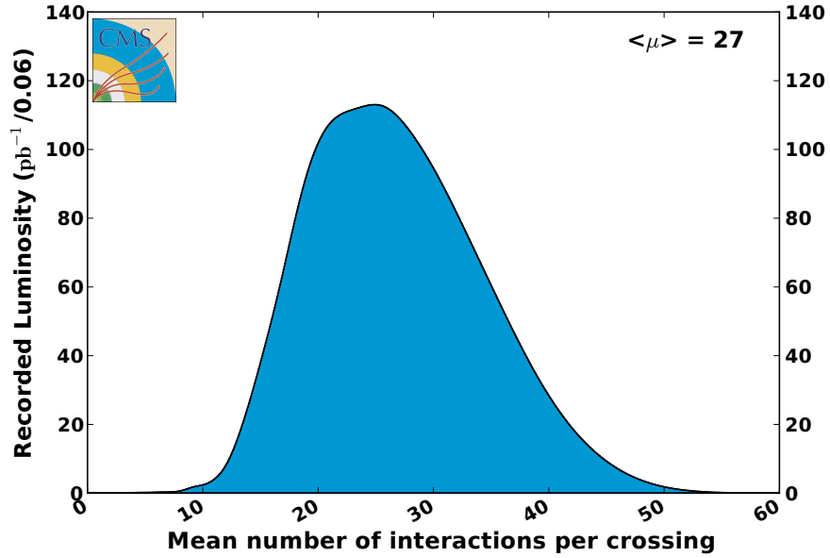
Pileup Mitigation in CMS

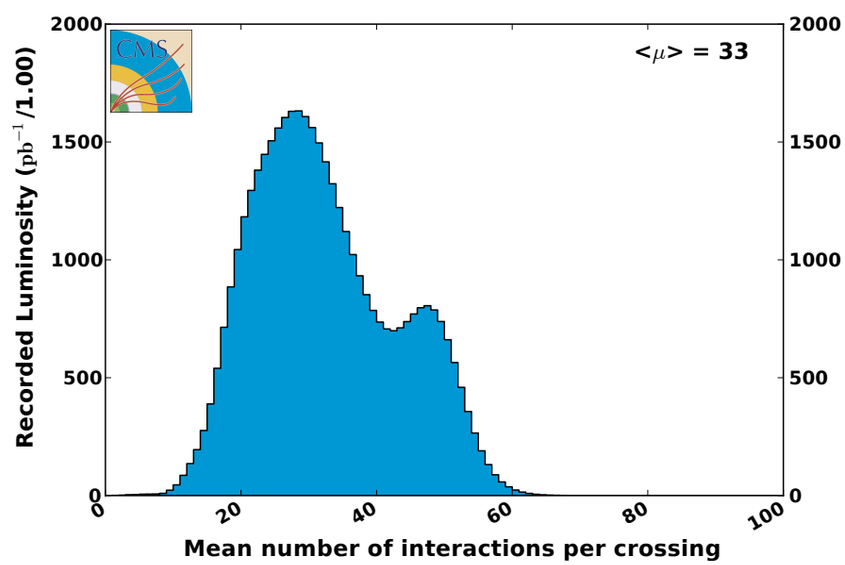
Anna Benecke
For the CMS Collaboration

More Data, More Pileup

CMS Public Lumi Results

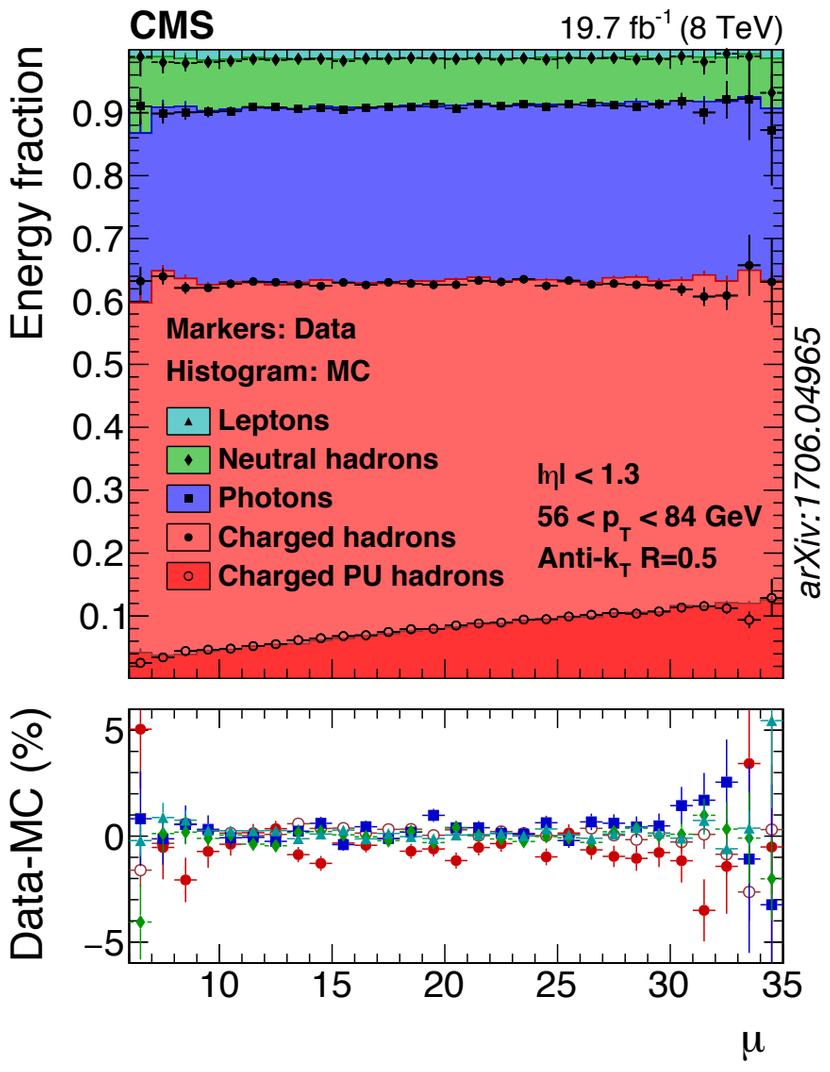


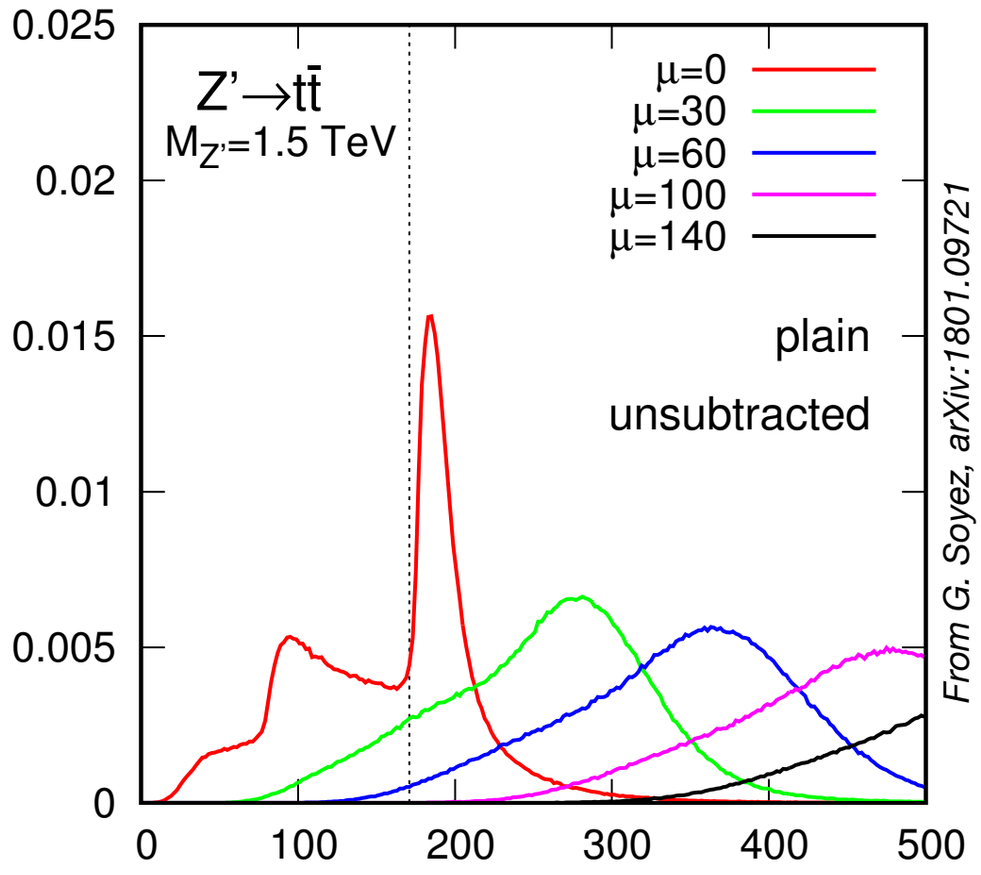




Pileup increased from 2016 to 2017 and is planned to be around 140-200 for the HL-LHC

The Problem with Pileup





(a) raw, ungroomed jets

PU affects jet substructure, jet counting, lepton isolation…

Pileup Mitigation Techniques & more

CHS, Pileup Jet ID, PUPPI

Performance of PUPPI vs CHS

HCAL Out Of Time PU

Update on CS in PbPb collisions

Upgrades of CMS Tracker

Pileup Mitigation Techniques

Charged Hadron Subtraction (CHS)

- **Removes charged particles associated to PU vertex, but no neutral particles**
- **Correct jet quantities for neutral PU**

Pileup Jet ID

- **Problem: pileup can generate additional “PU” jets**
- **Solution: Multi-variant technique to reject PU jets applied on CHS**

PileUp Per Particle Identification

- **Calculate weight for each particle based on the shape of charged PU**
- **Remove particles rather than correct jet quantities for consistent event interpretation**

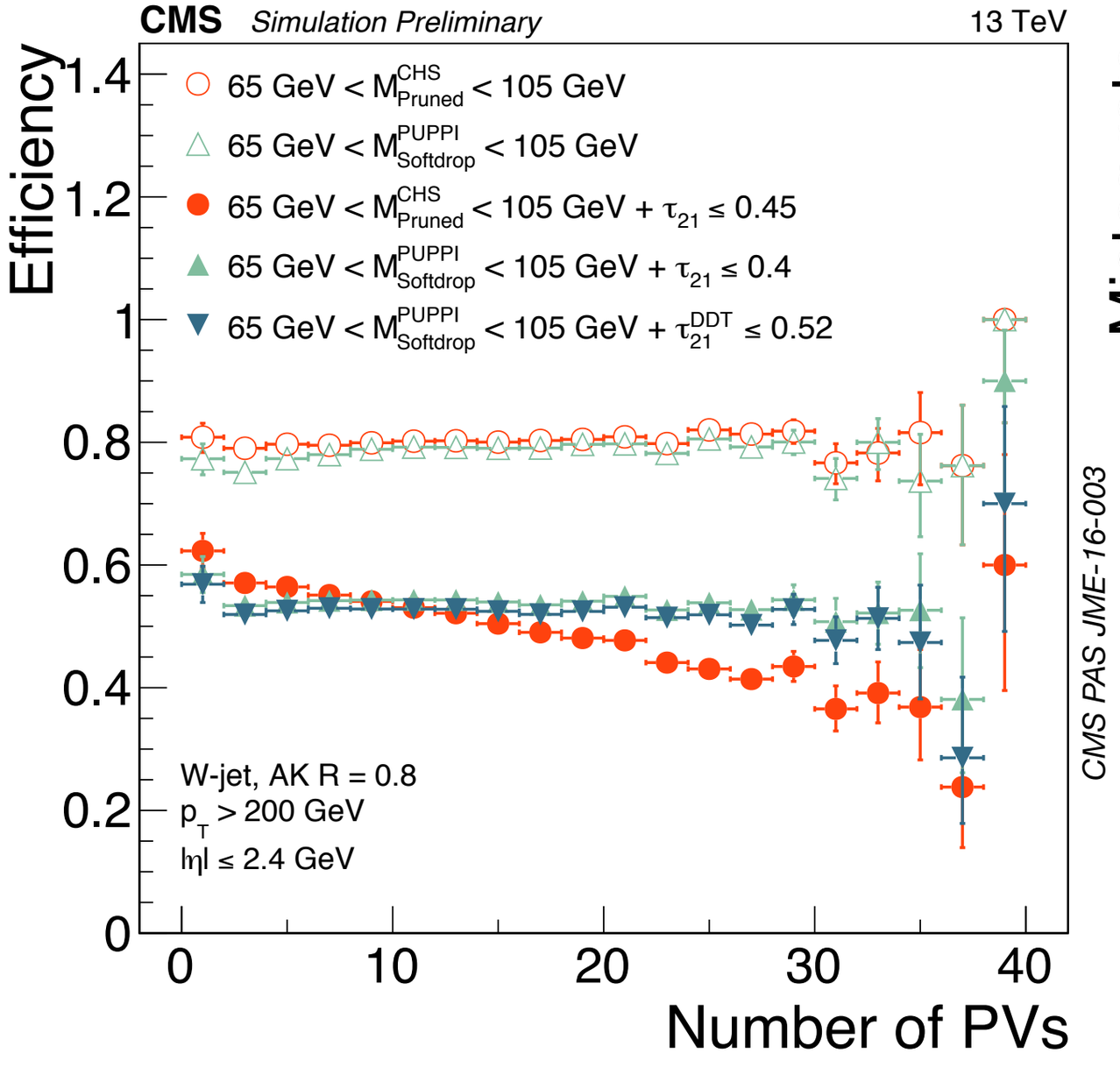
Performance of CHS vs PUPPI

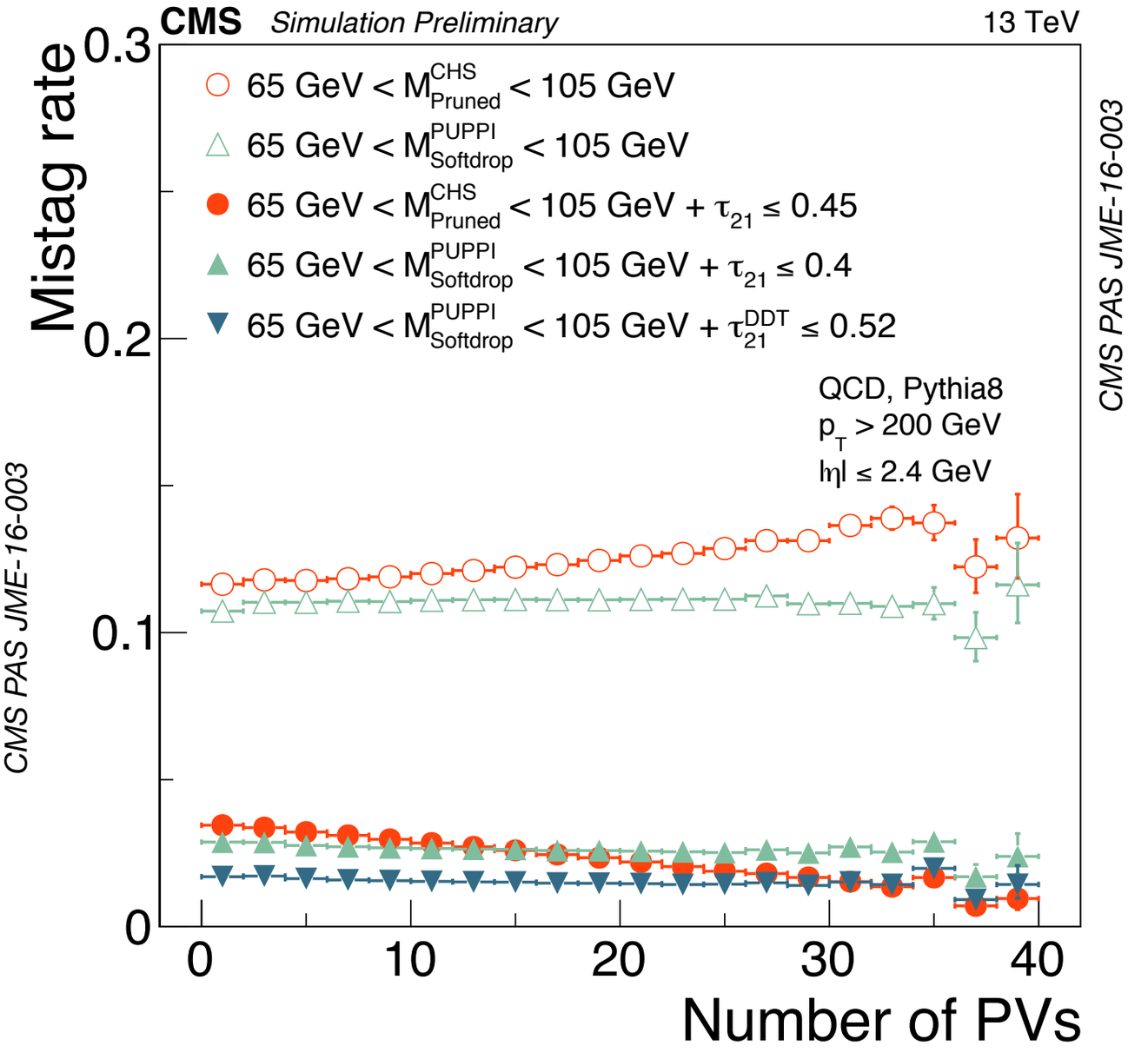
1. Aim: identify highly boosted objects
→ good mass and substructure resolution

2 . Aim: identify prompt muons
→ PU hard isolation criteria

3. Aim: search for invisible particles
→ Good E_T^{miss} reconstruction

W-Tagging


CMS Simulation Preliminary 13 TeV
Efficiency
65 GeV < M^CHS_Pruned < 105 GeV
65 GeV < M^PUPPI_Softdrop < 105 GeV
65 GeV < M^CHS_Pruned < 105 GeV + τ21 ≤ 0.45
65 GeV < M^PUPPI_Softdrop < 105 GeV + τ21 ≤ 0.4
65 GeV < M^PUPPI_Softdrop < 105 GeV + τ21^DDT ≤ 0.52
W-jet, AK R = 0.8
p_T > 200 GeV
|η| ≤ 2.4 GeV
Number of PVs
CMS PAS JME-16-003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65 GeV < M^CHS_Pruned < 105 GeV
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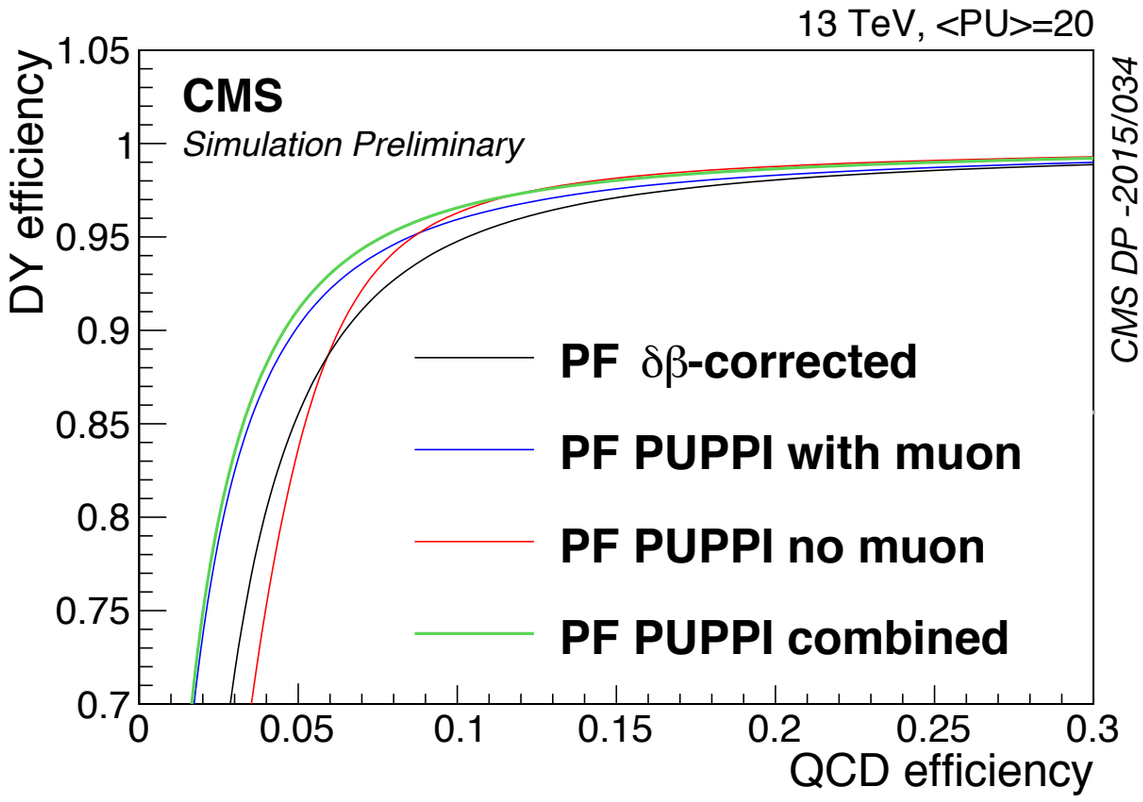
65 GeV < M^PUPPI_Softdrop < 105 GeV + τ21 ≤ 0.4
65 GeV < M^PUPPI_Softdrop < 105 GeV + τ21^DDT ≤ 0.52
QCD, Pythia8
p_T > 200 GeV
|η| ≤ 2.4 GeV
Number of PVs
CMS PAS JME-16-003

Muon Isolation



PF $\delta\beta$ corrected

Estimates contribution of neutral particles from PU based on contribution of charged particles from PU

PF PUPPI with muon

Isolation calculated with PUPPI weights

PF PUPPI no muon

PUPPI weight calculated without prompt muons as input

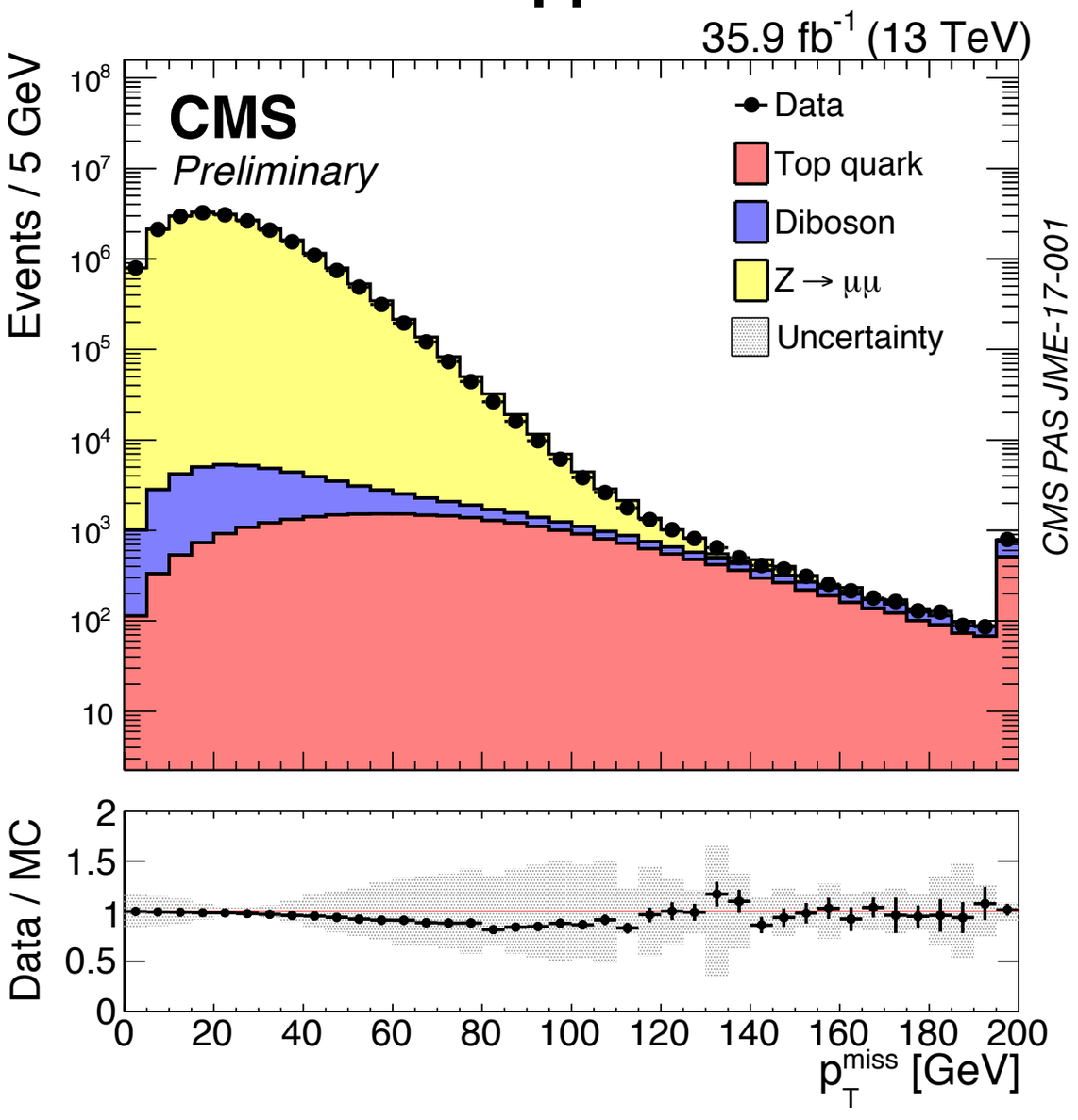
PF PUPPI combines

Average of PF PUPPI with muon and PF PUPPI no muon

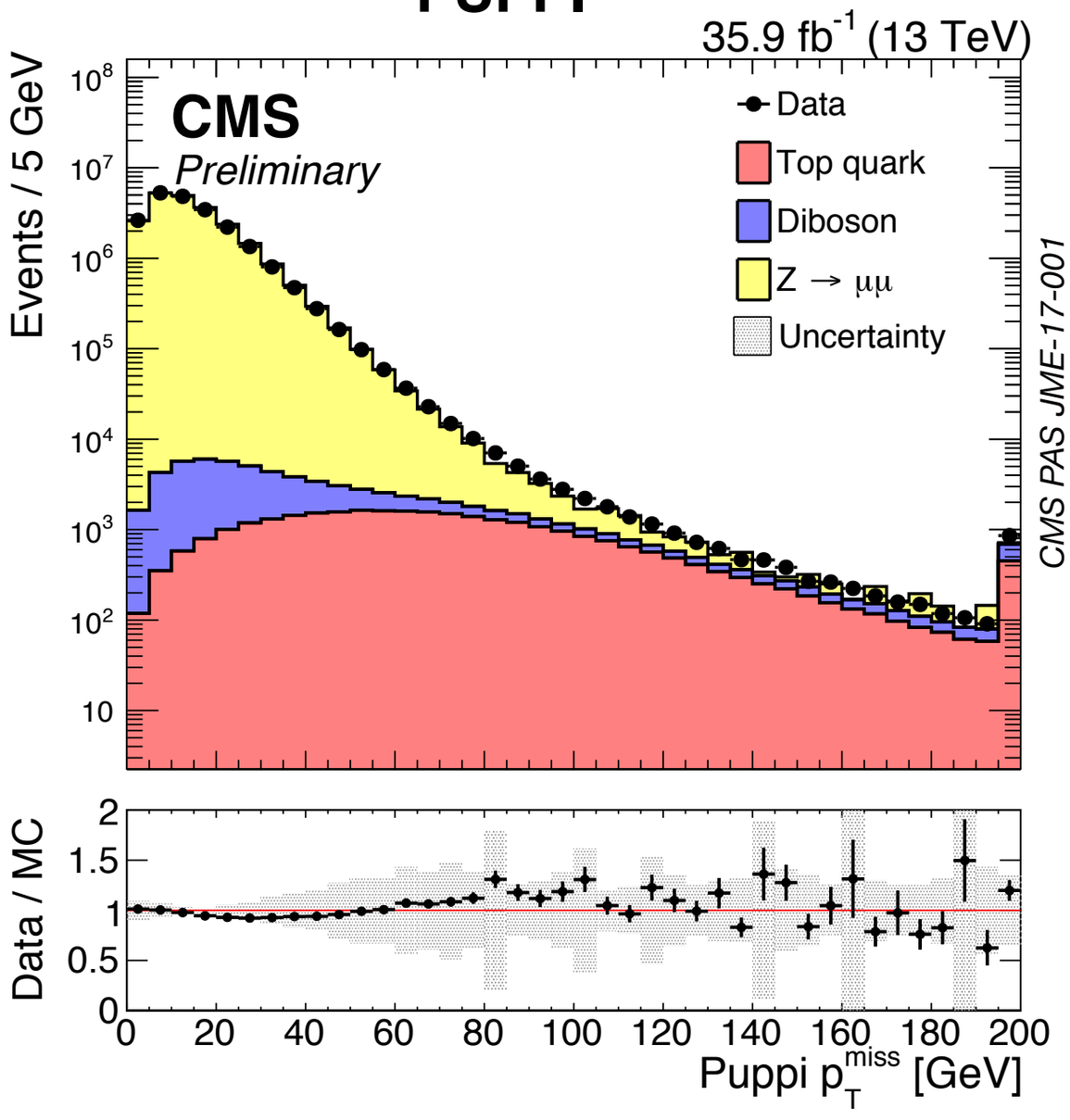
NEW

E_T^{miss} Reconstruction

PF



PUPPI

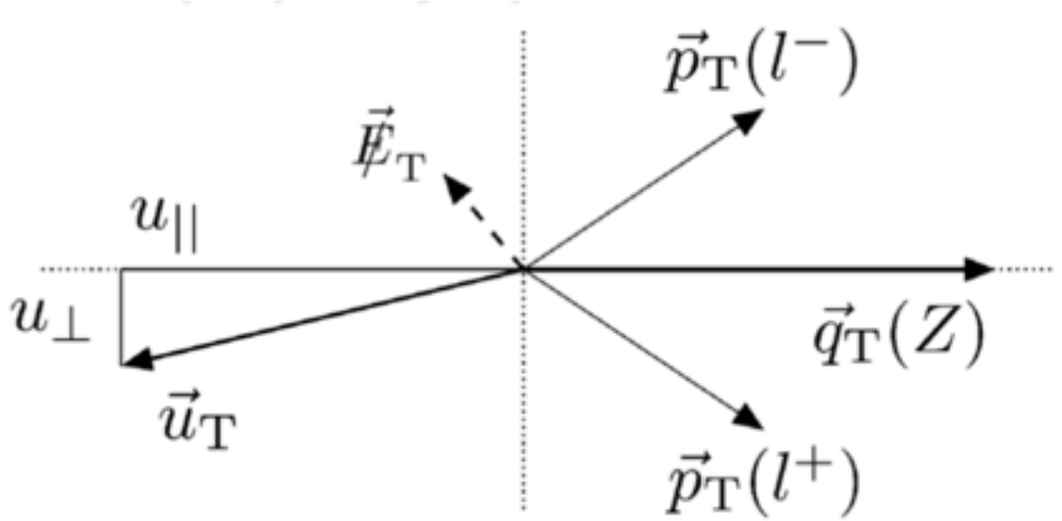


E_T^{miss} Reconstruction

Z + jets Events used for detector response measurement

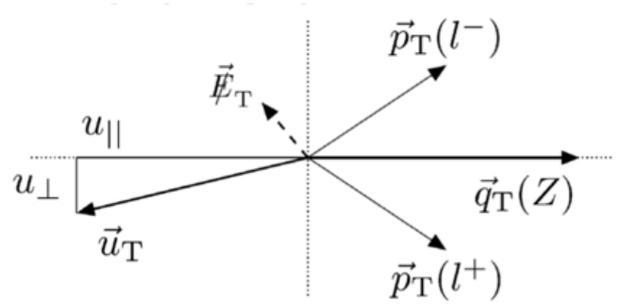
- **No real E_T^{miss}**
- **Hadronic recoil projected onto Z boson momentum**

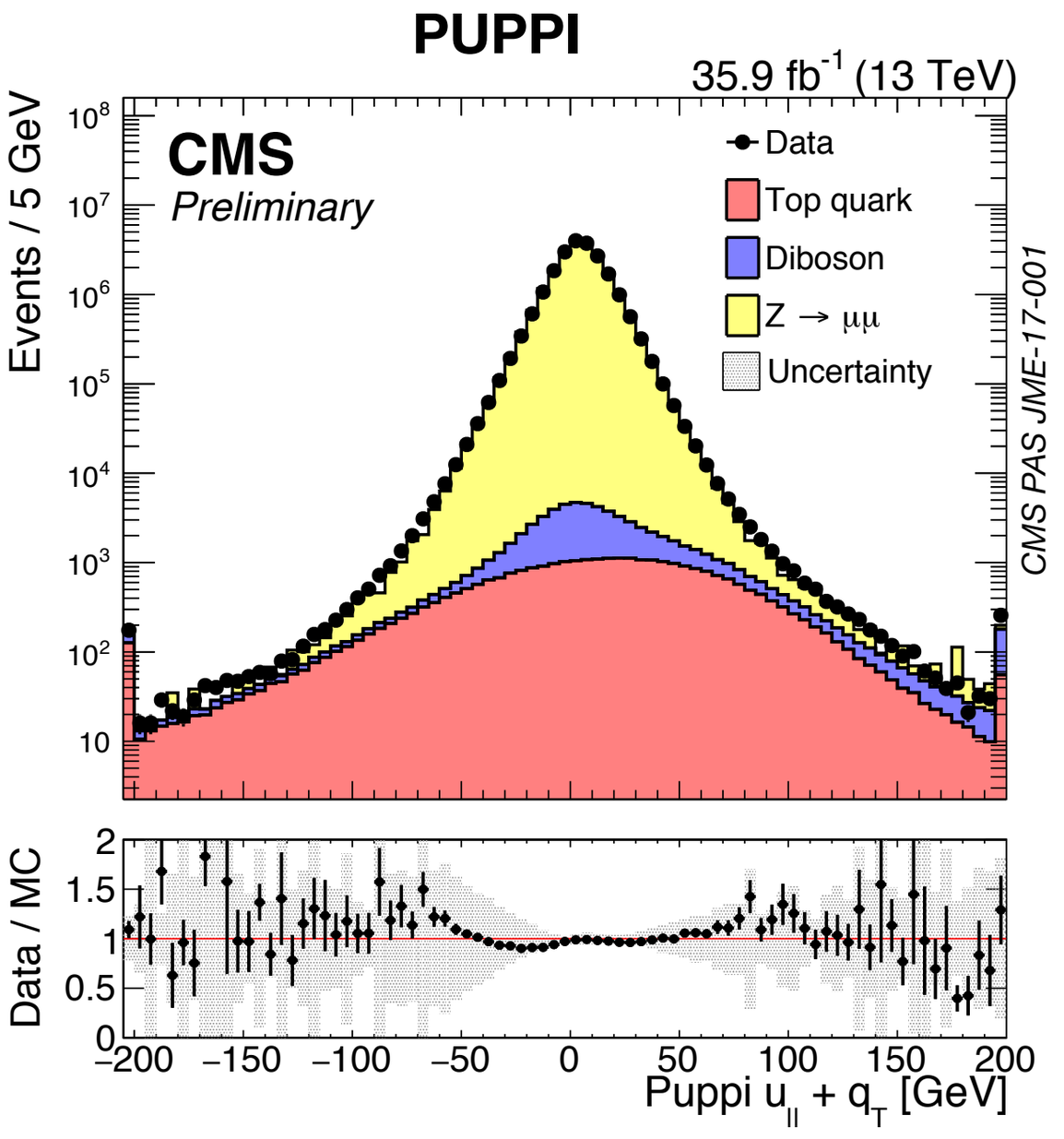
W (l ν) + jets Events with real E_T^{miss}

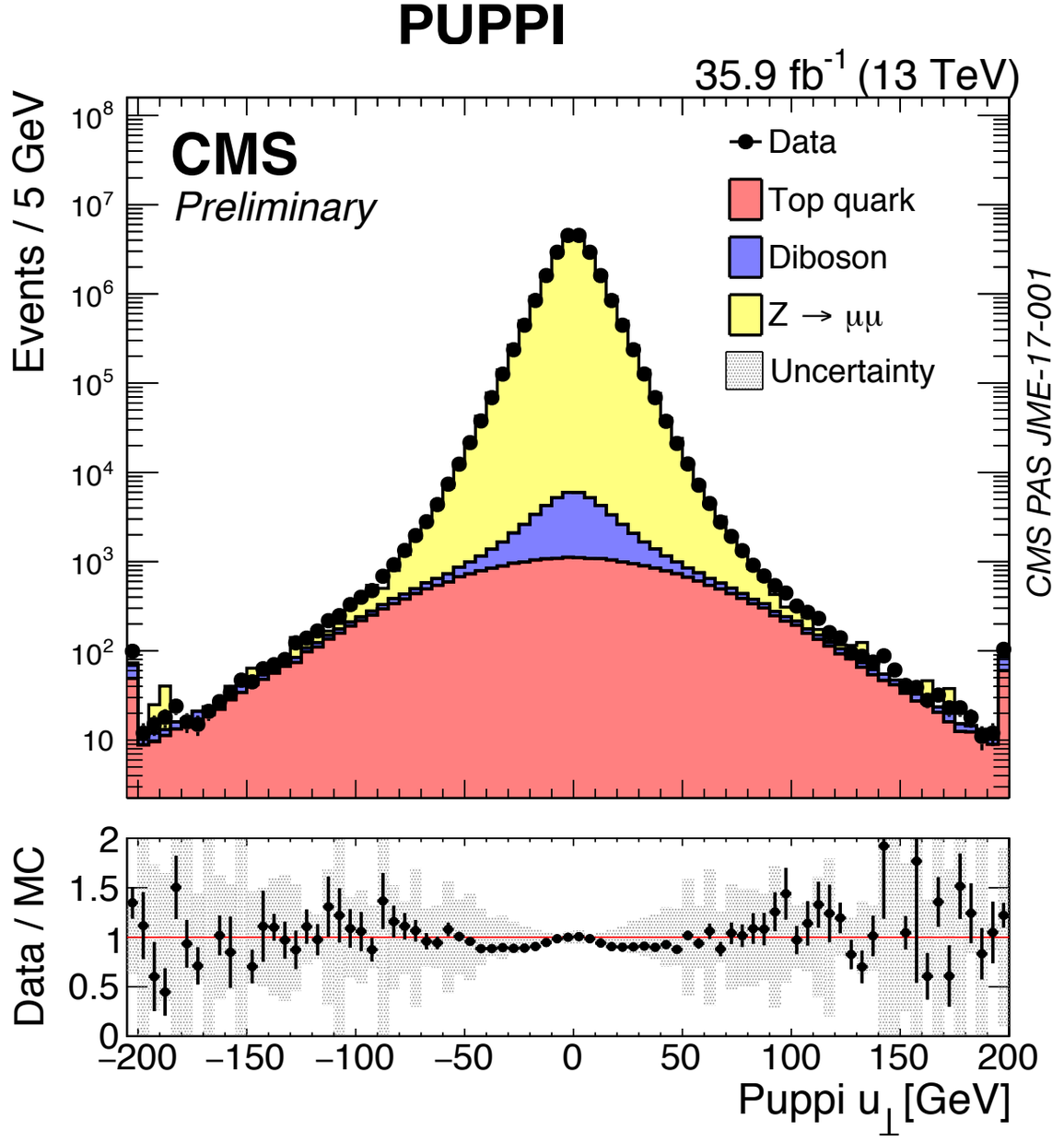


NEW

E_T^{miss} Reconstruction

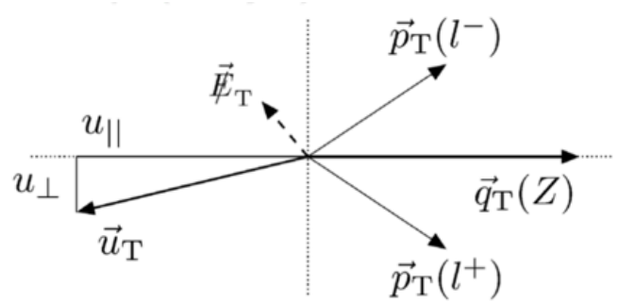


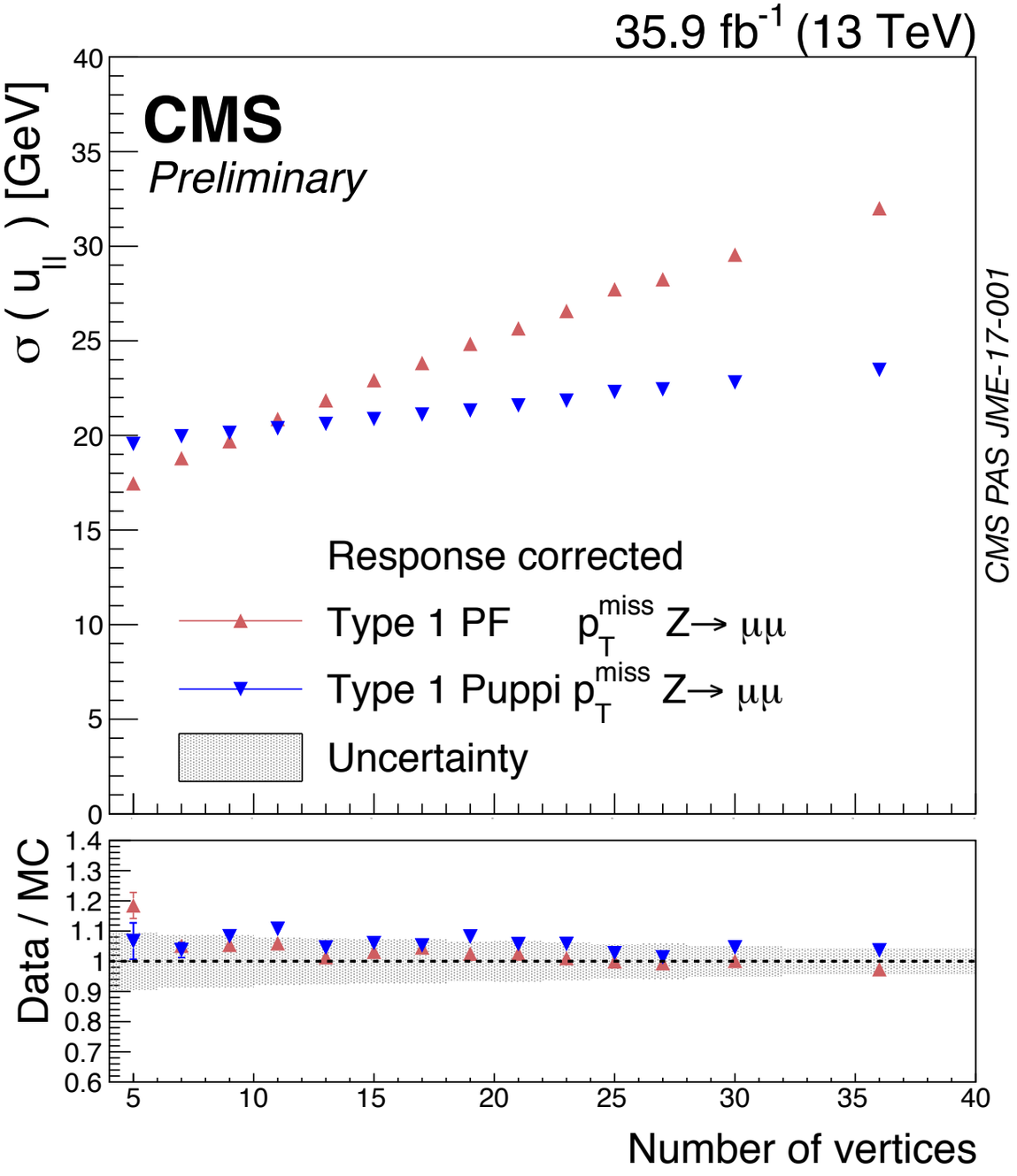


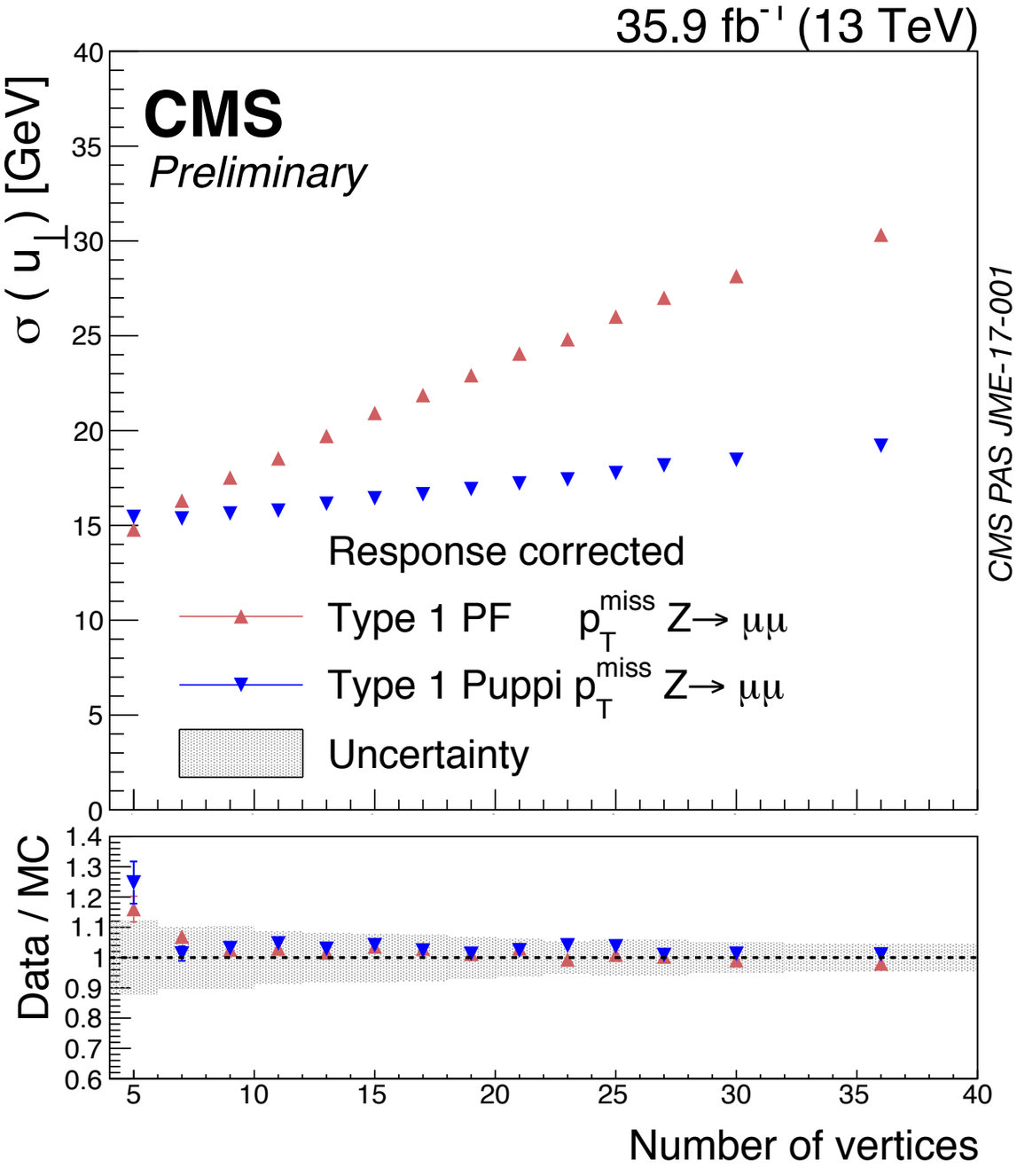


NEW

E_T^{miss} Reconstruction



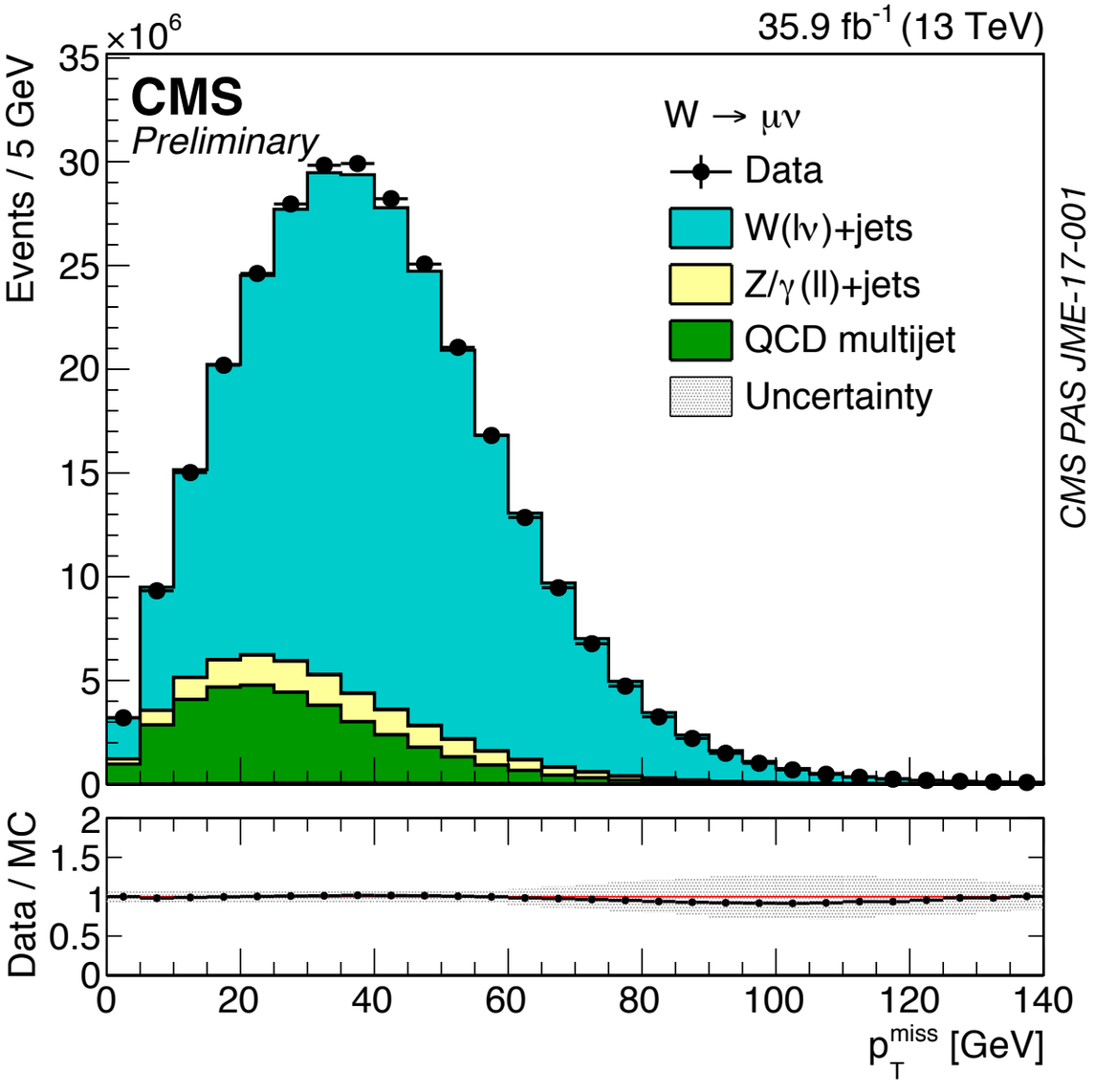




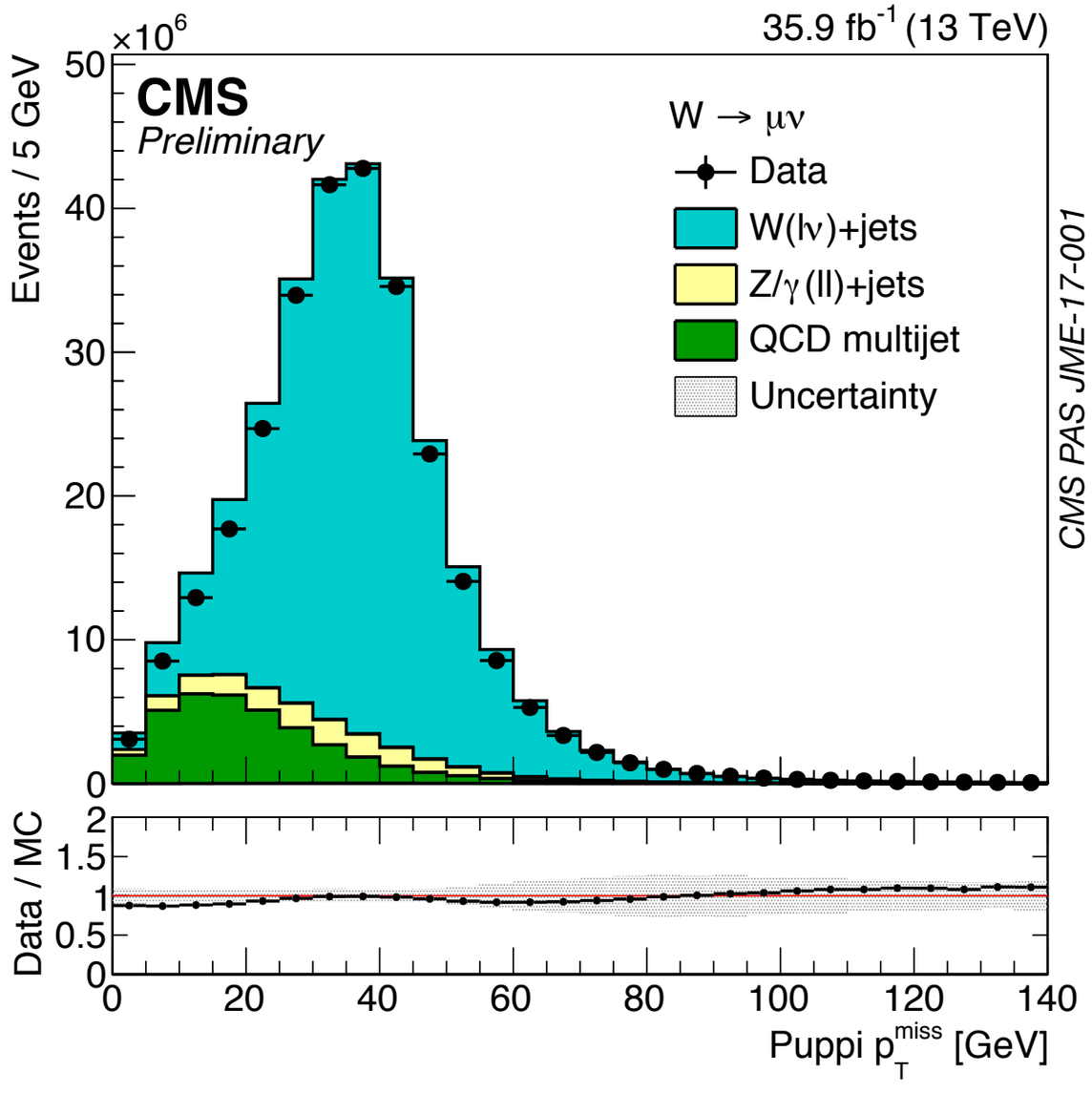
NEW

E_T^{miss} Reconstruction

PF

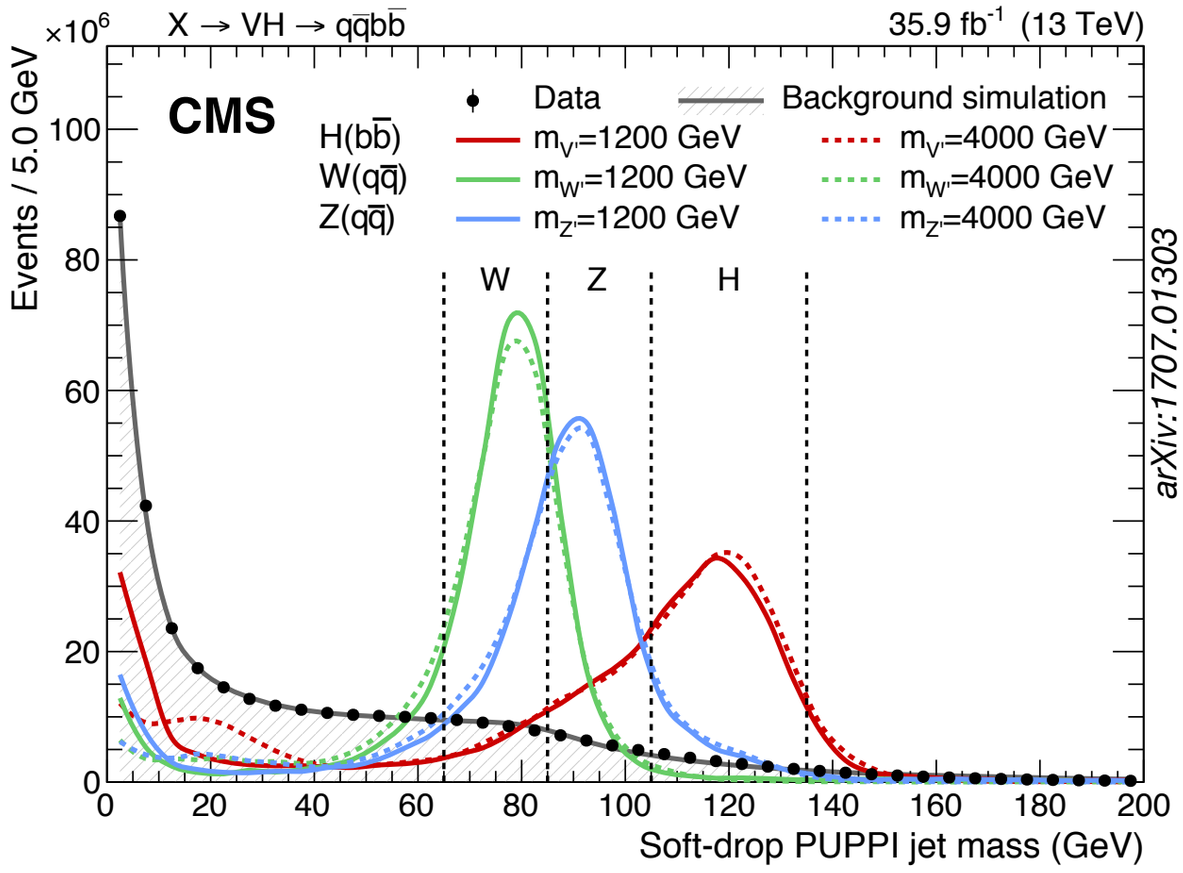


PUPPI



PUPPI in CMS Analyses

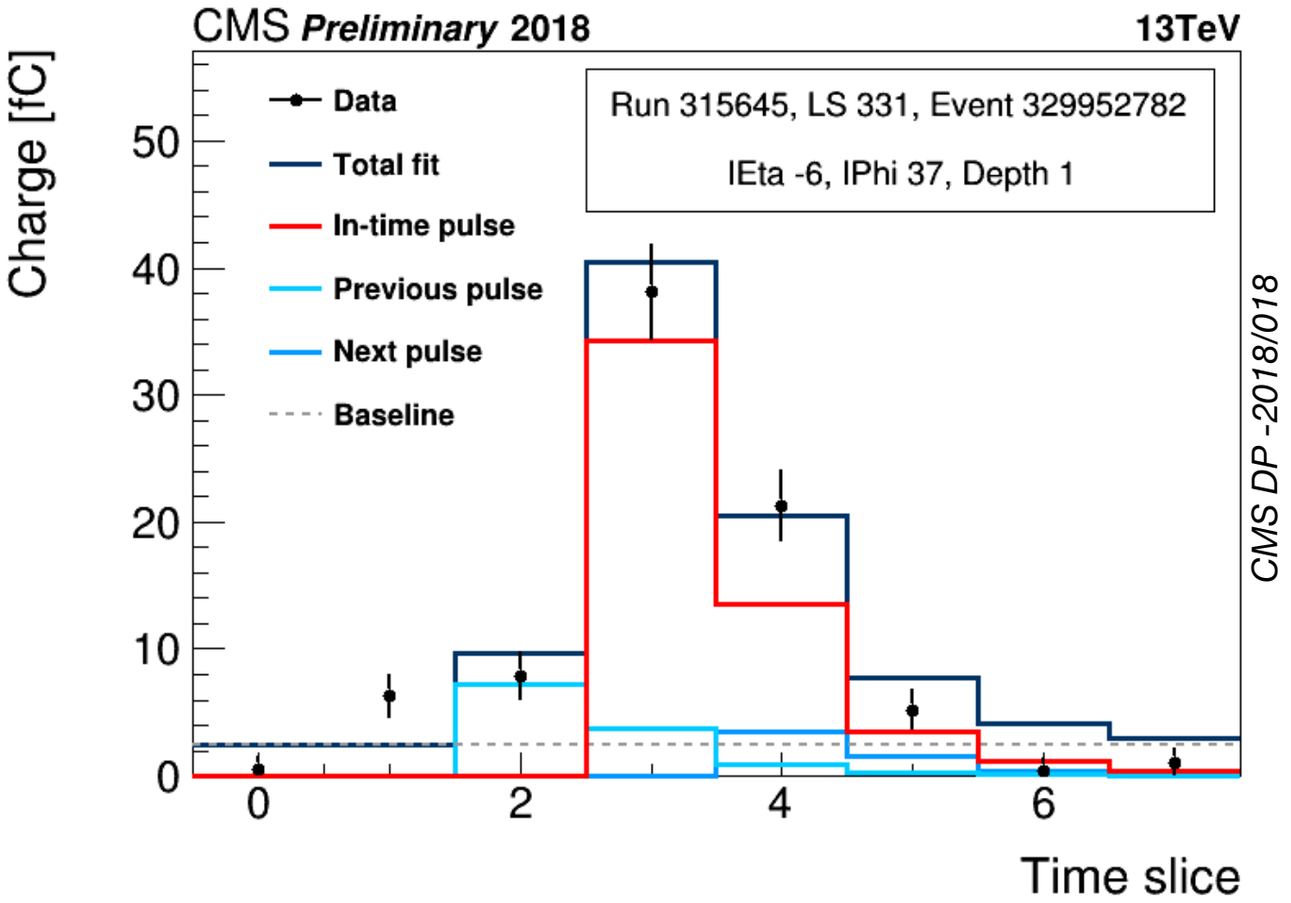
- DM+top, EXO-16-051
- DM+H(bb), EXO-16-012
- H(bb)+jet, HIG-17-010
- H(bb)+gamma resonances, EXO-17-019
- X→ZV, B2G-17-005
- X→VV, B2G-17-001
- X→VH, B2G-16-003, B2G-17-002
- X→tt, B2G-17-017
- Low mass X→bb, EXO-17-024
- Low mass X→qq, EXO-16-030
- ISR X→qq, EXO-17-001
- SUSY with boosted tops, SUS-16-050
- …..



Lots of analyses using PUPPI

NEW

HCAL Out Of Time PU (OOTPU)



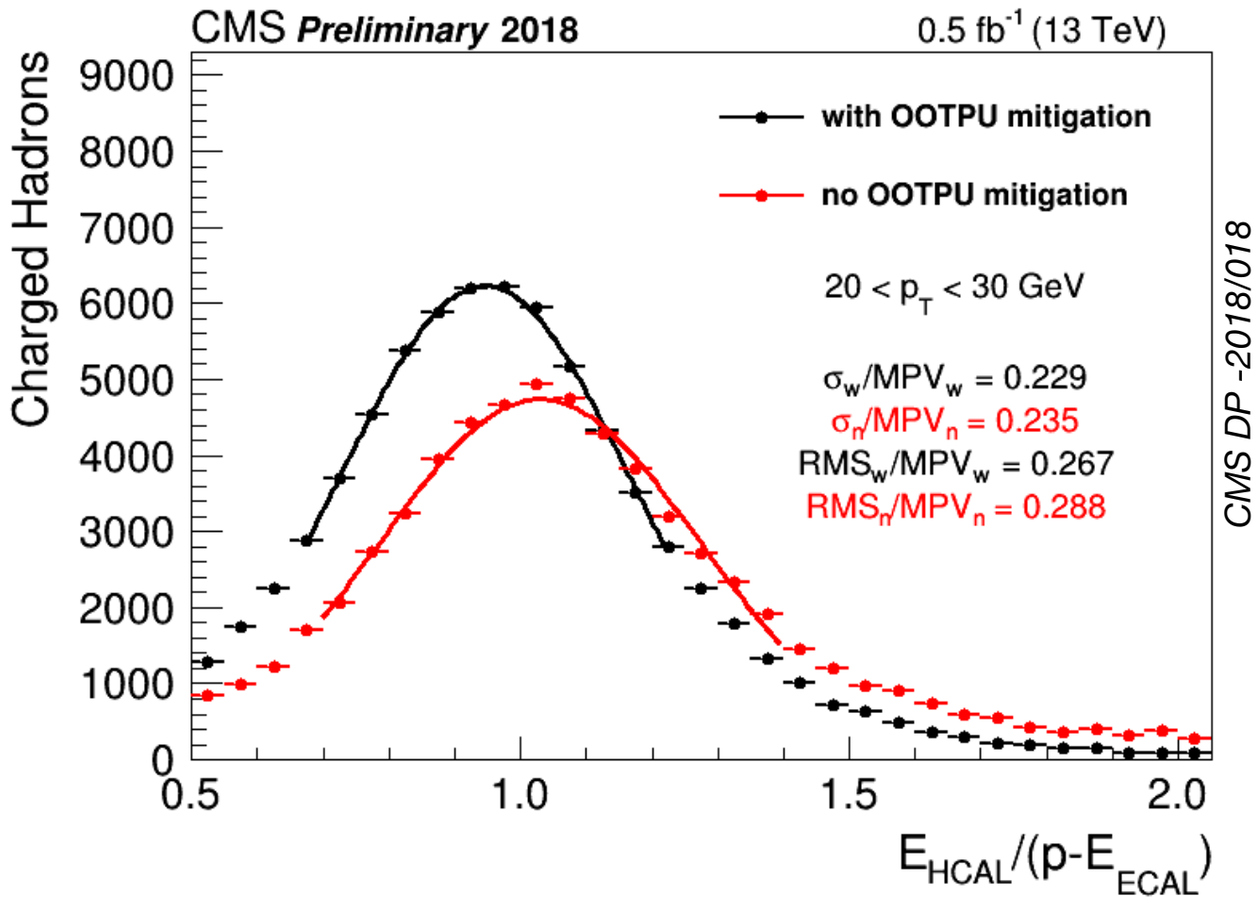
- **Signal from HCAl consist of several events**

- **No OOTPU:**
  Uses sum of charge in the triggered and next samples corrected by an additional containment factor to account for the pulse tail

- **With OOTPU:**
  Fits up to three pulses in triggered, previous, and next bunch crossings with variable amplitude

NEW

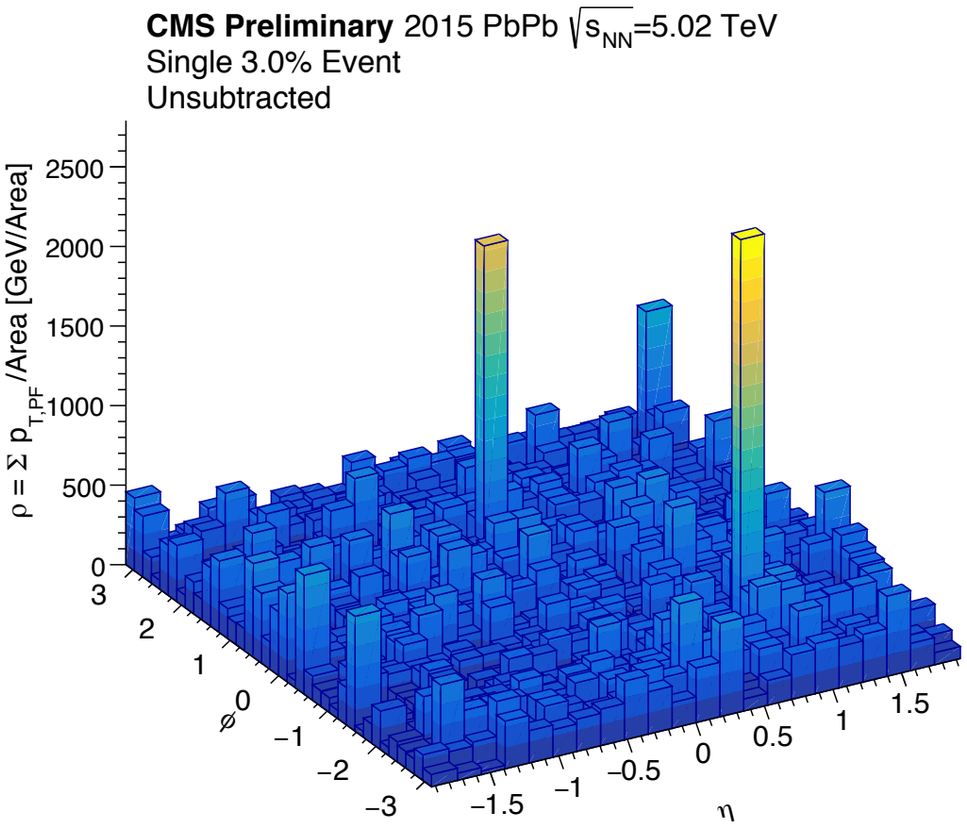
HCAL Out Of Time PU (OOTPU)

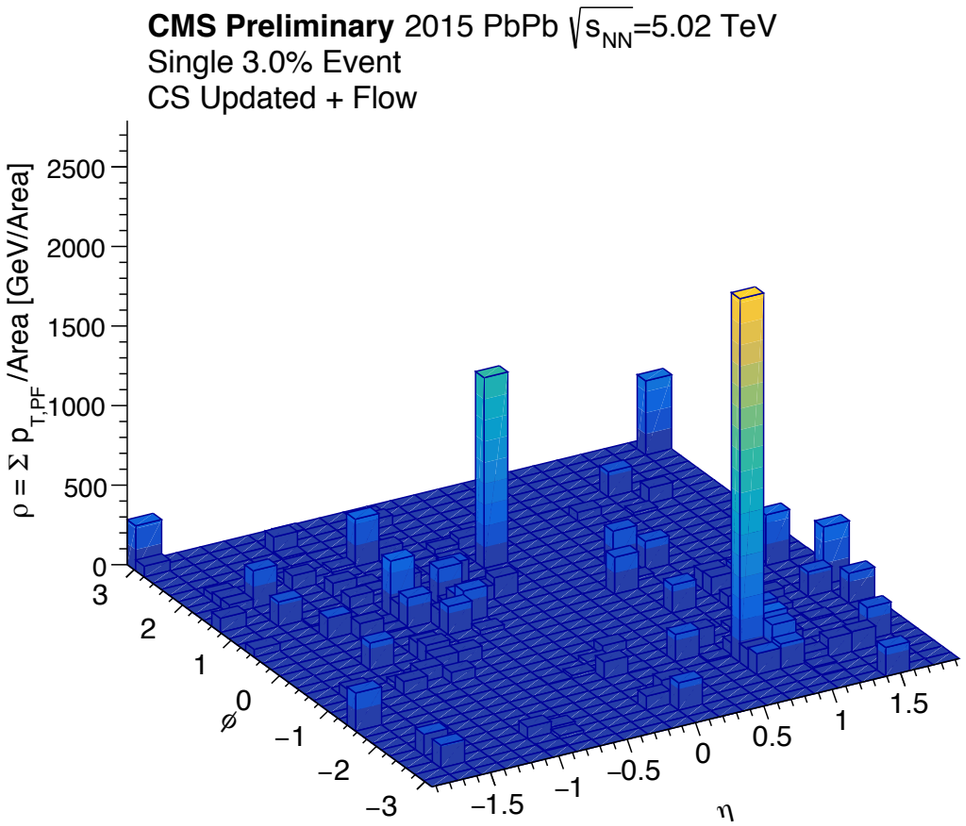


no OOTPU scenario has long tail with ratio of HCAL energy to track momentum above 2.0 due to pileup contributions

NEW

Update of CS in Pb-Pb collision





CMS DP -2018/024

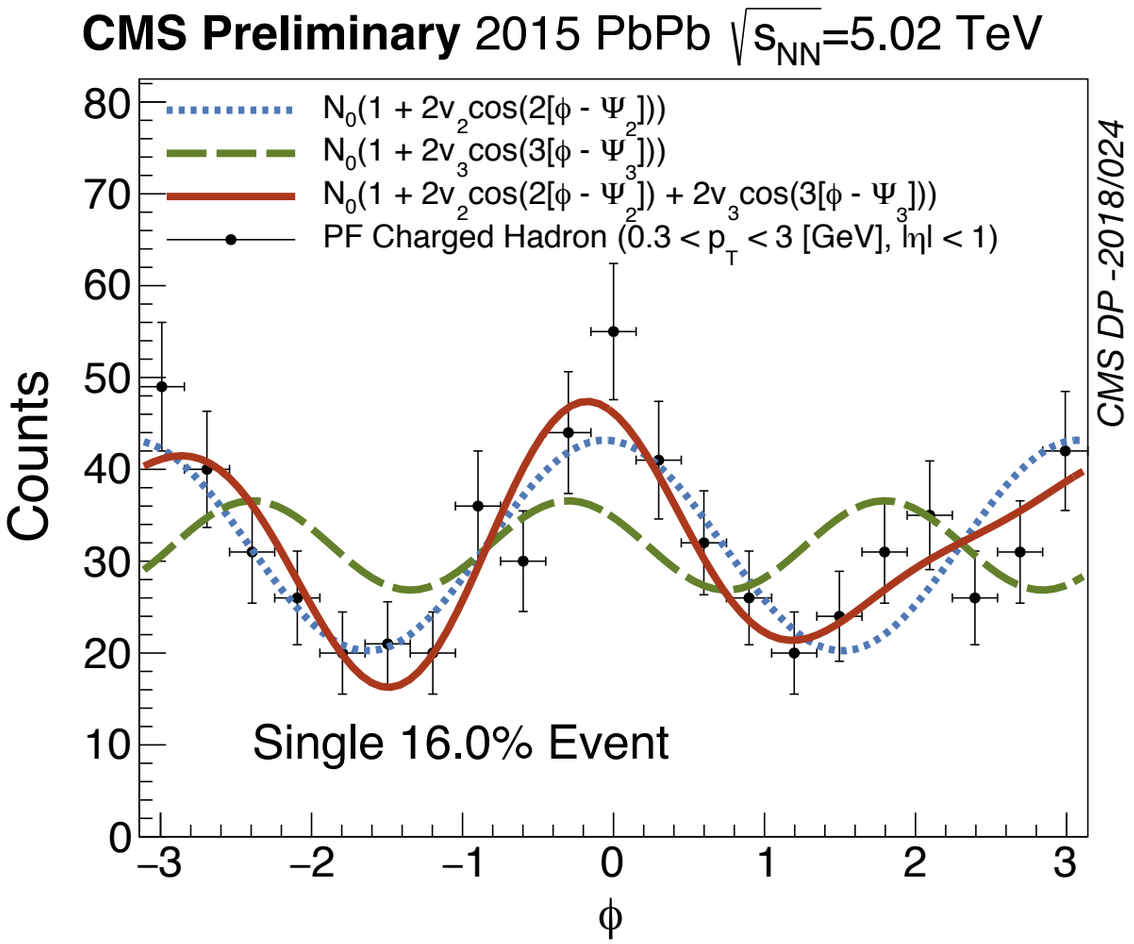
Extracting ρ from an iterative pedestal subtraction

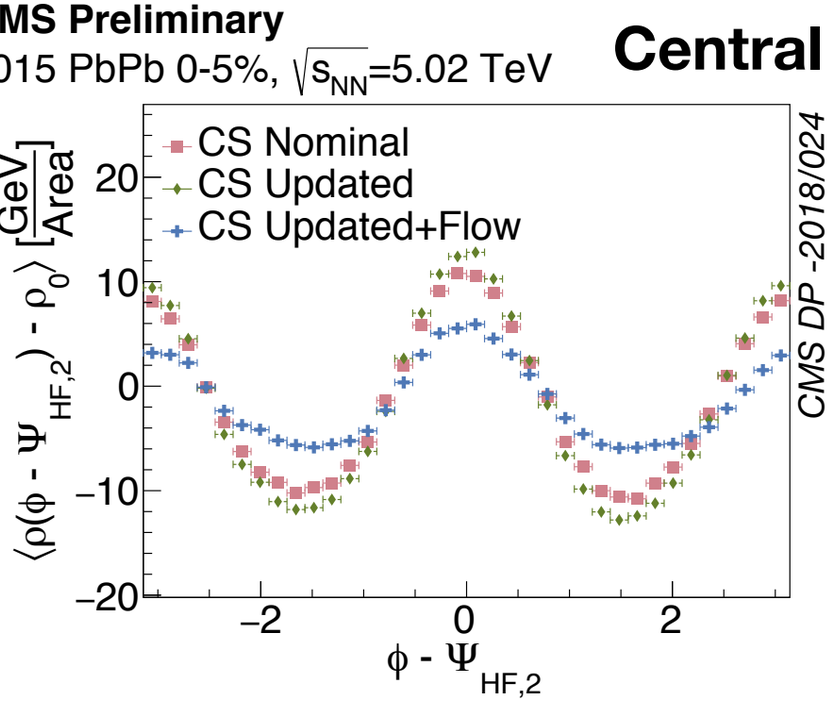
ρ is plugged into the constituent subtraction (CS)

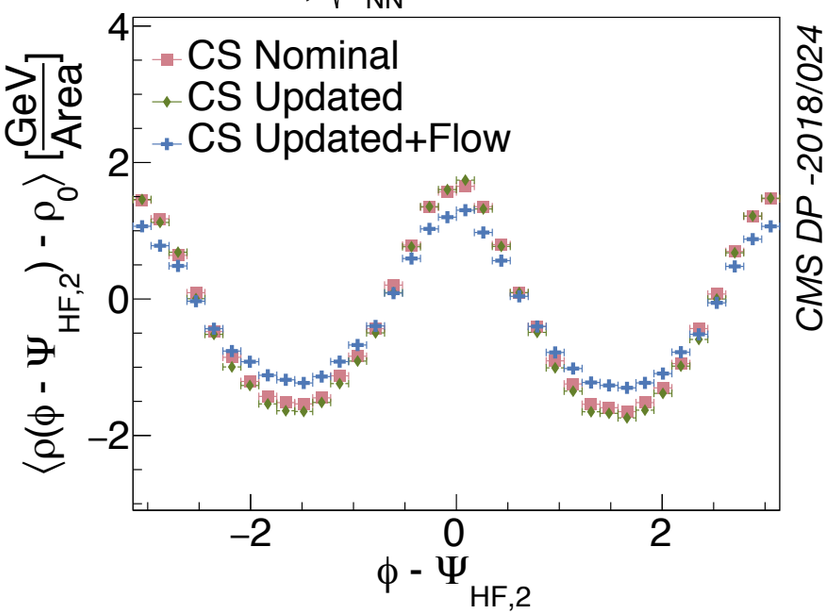
On top add modulation of underlying event

NEW

Update of CS in Pb-Pb collision







HL- LHC Upgrade

Instantaneous peak luminosity	$7.5 \times 10^{34} cm^{-2} s^{-1}$
Average collision per bunch crossing	$140 - 200$
Center of mass energy	$\sqrt{s} = 14$**TeV**

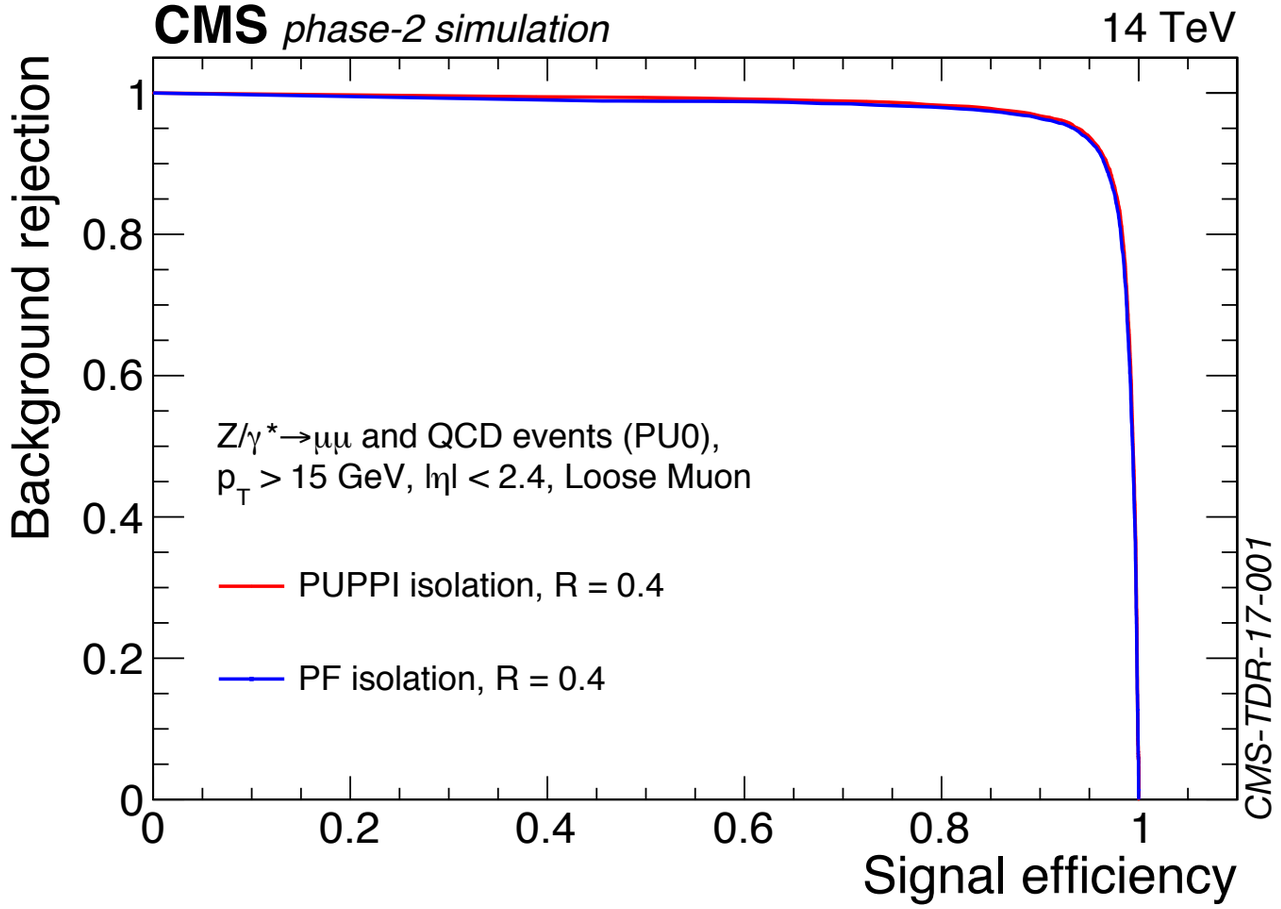
Aim: study highly boosted objects while PU increases

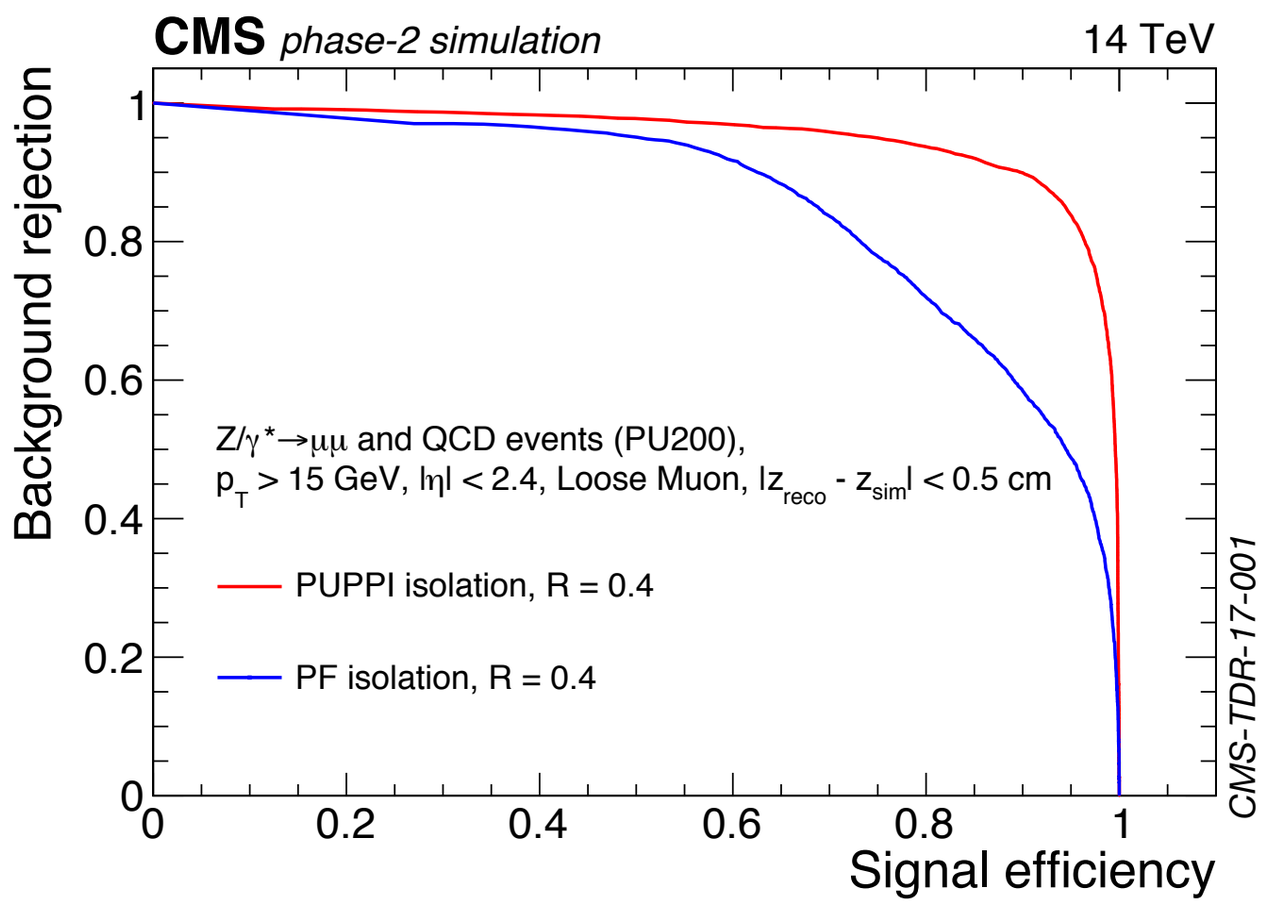
CMS Tracker Upgrade

- **Higher granularity**
- **Increase forward acceptance**
- **Increase radiation hardness**
- **And more**

NEW

Muon Isolation @ HL-LHC

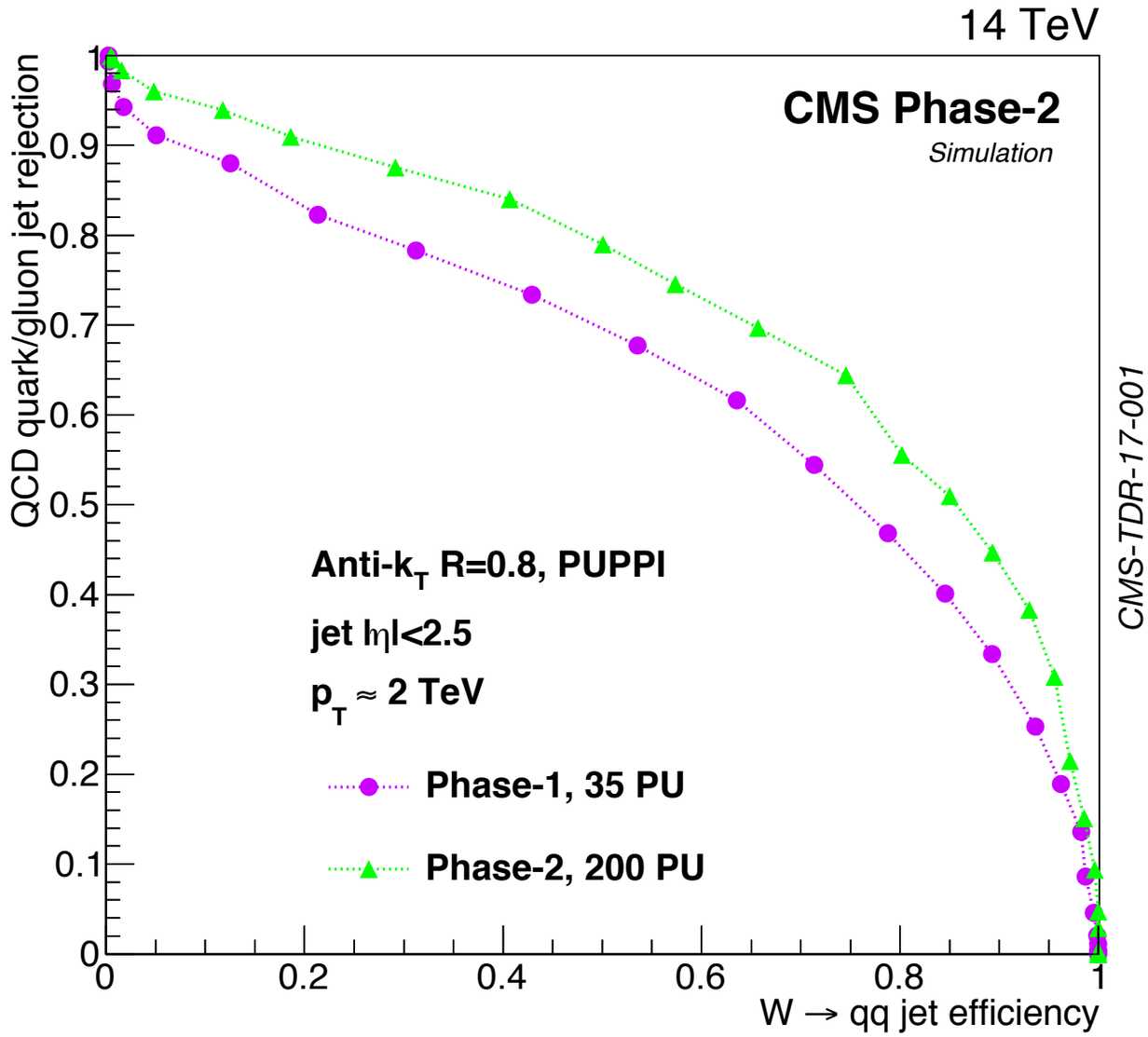




PUPPI shows a robust performance also for PU of 200

NEW

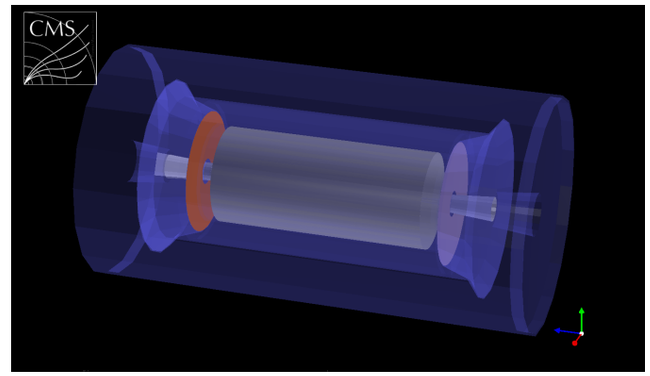
Jet Substructure @ HL-LHC



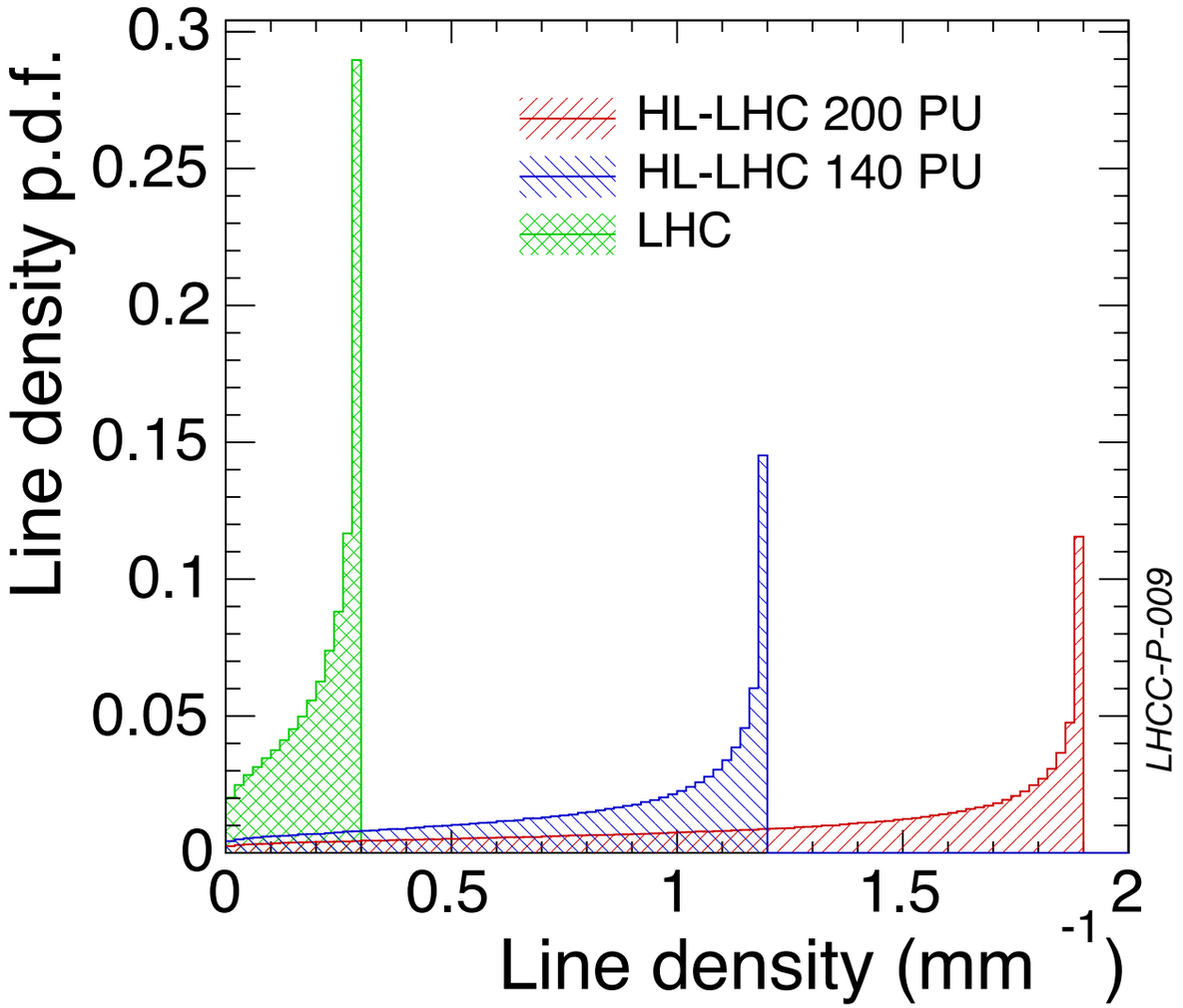
Higher granularity improves jet substructure with increasing PU

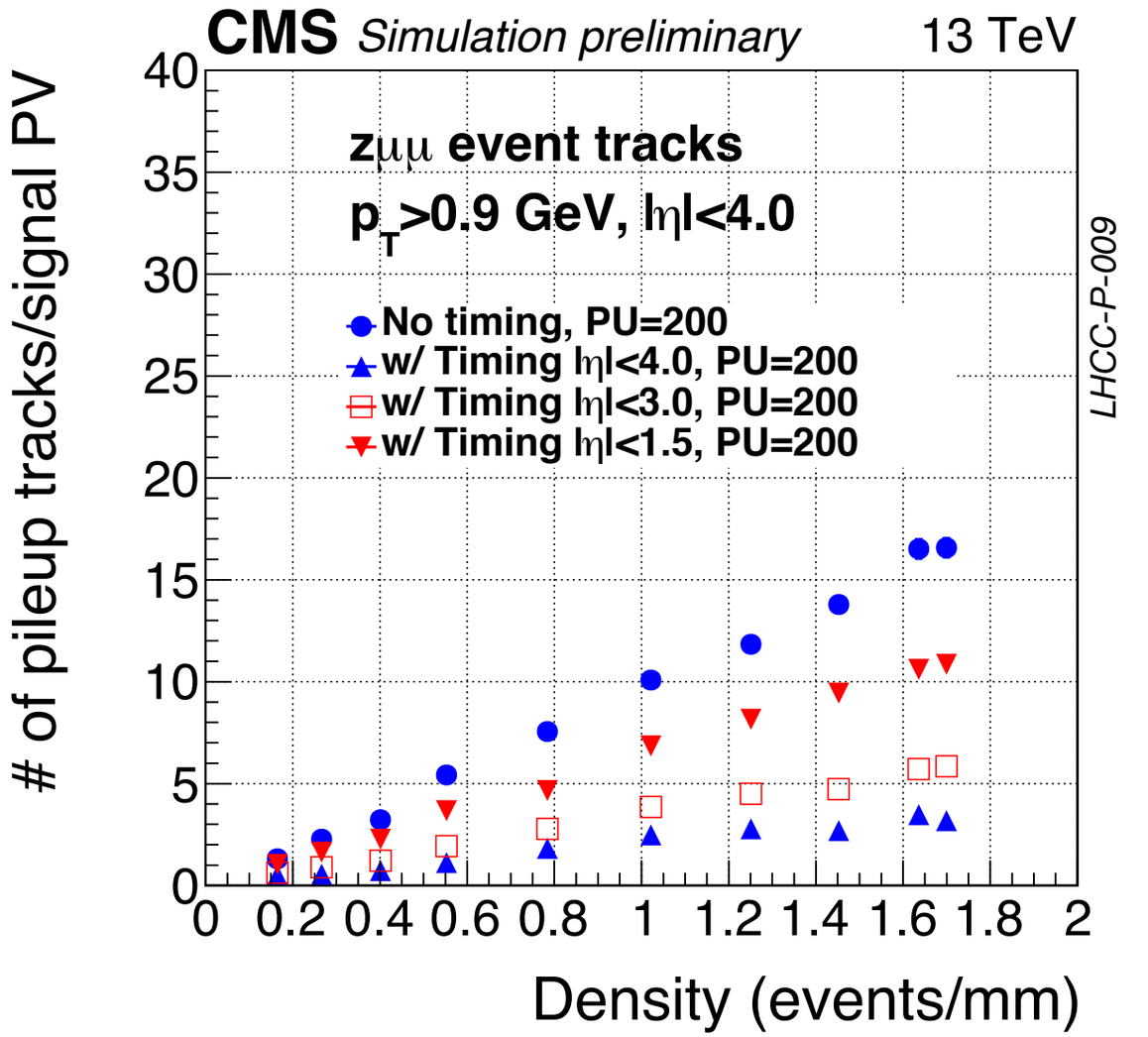
NEW

Timing Detector



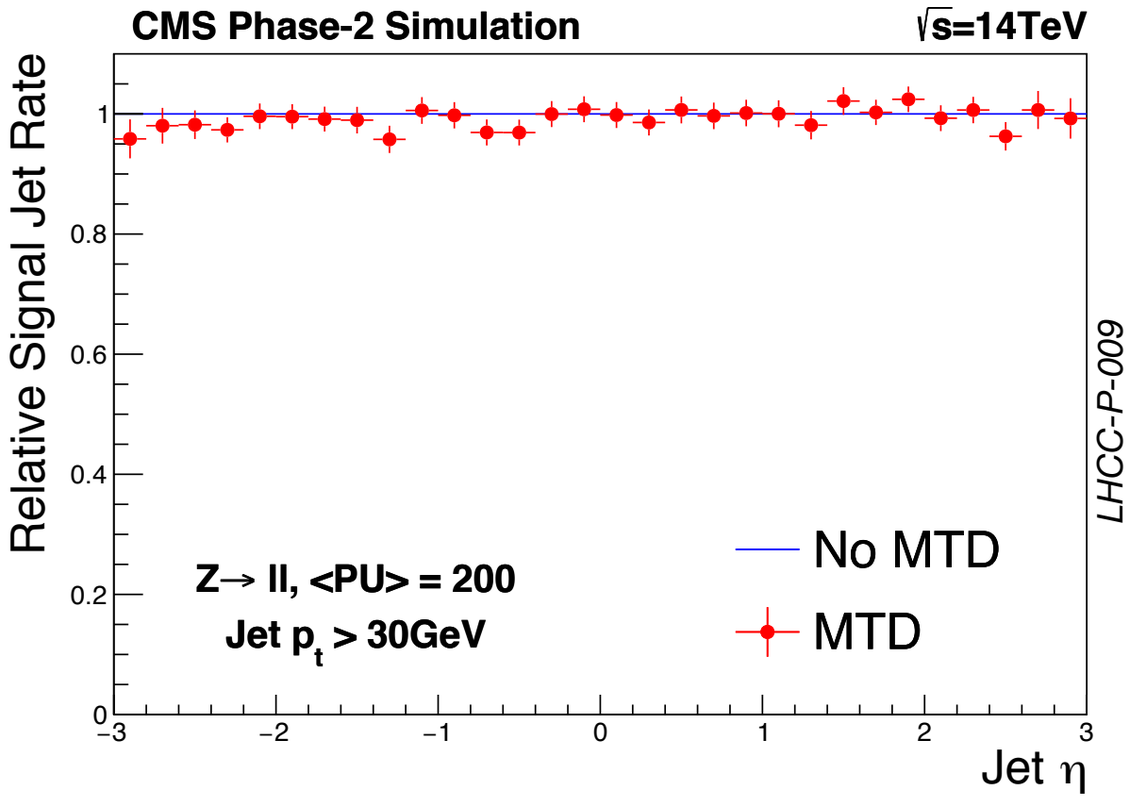
Sensitive to minimum ionising particles
Placed between tracker and ECAL

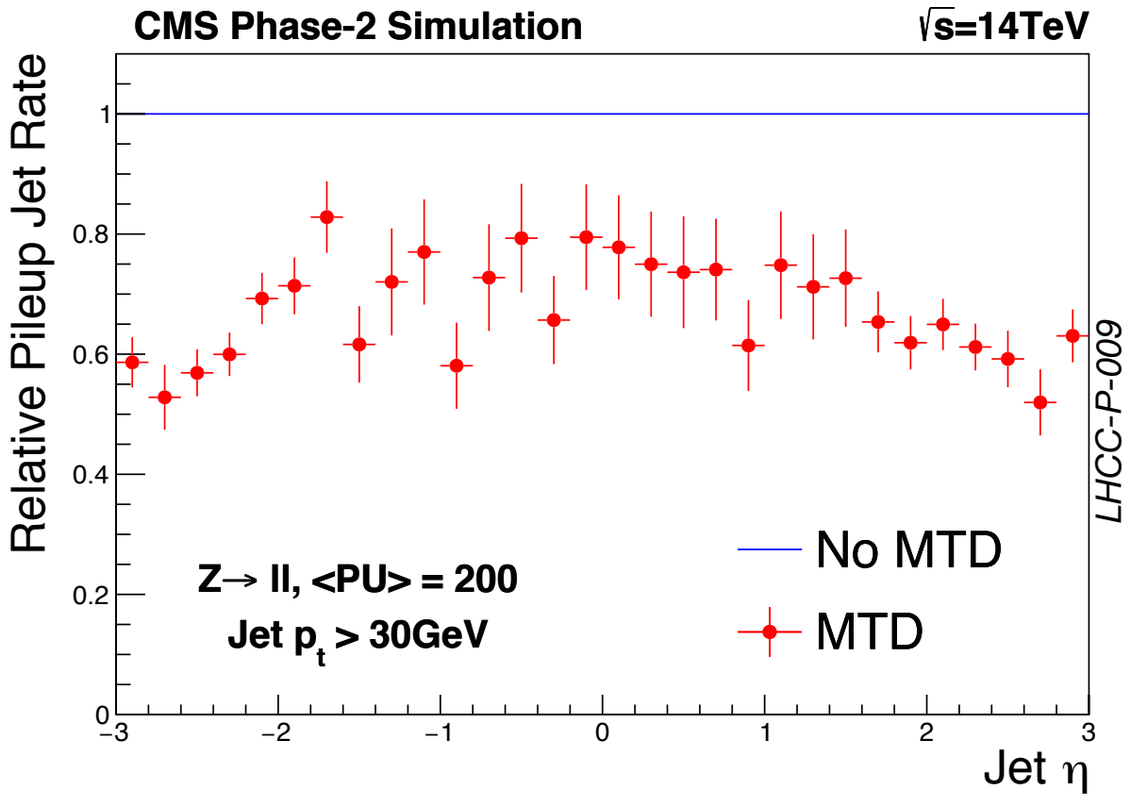




NEW

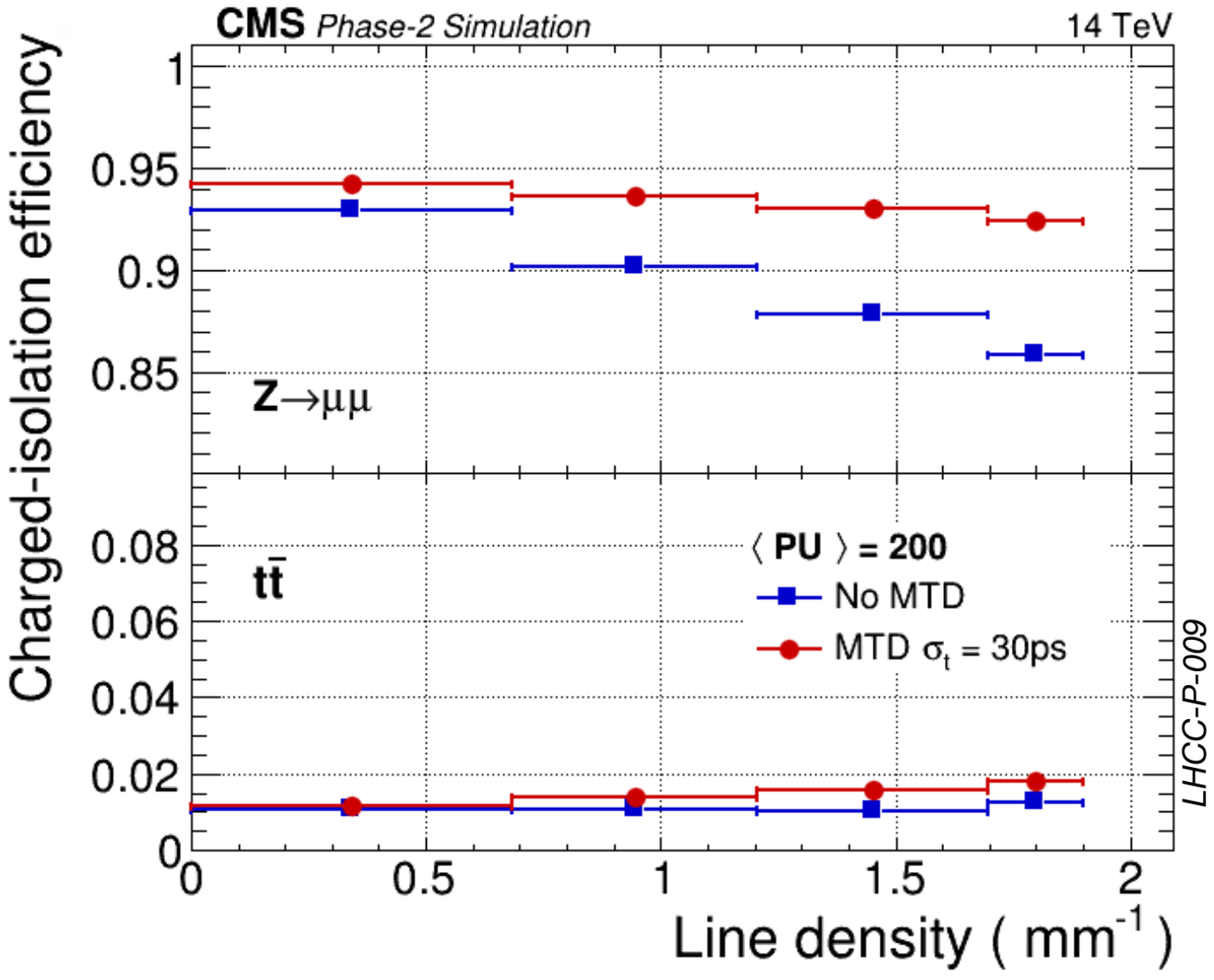
PU jets with Timing Detector

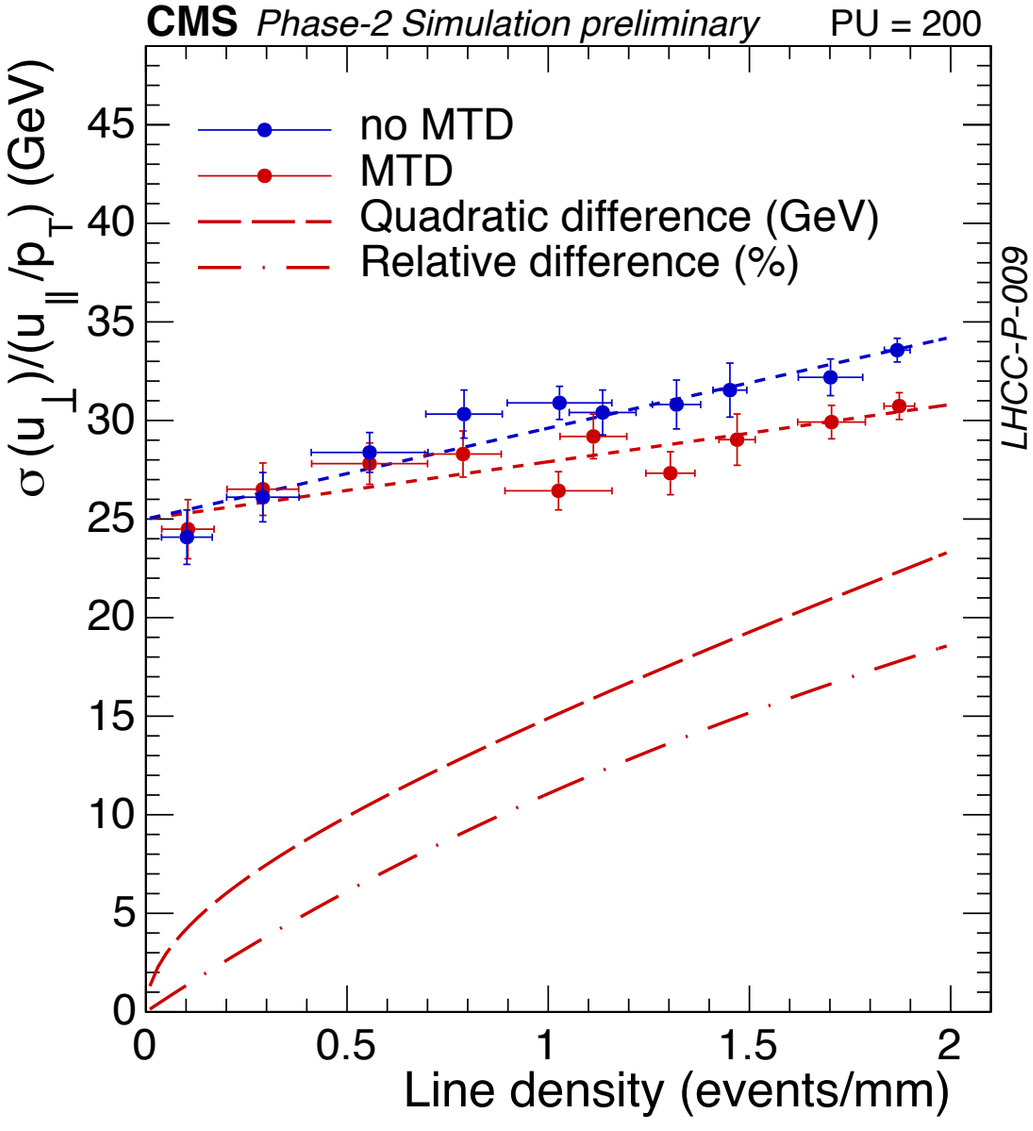




NEW

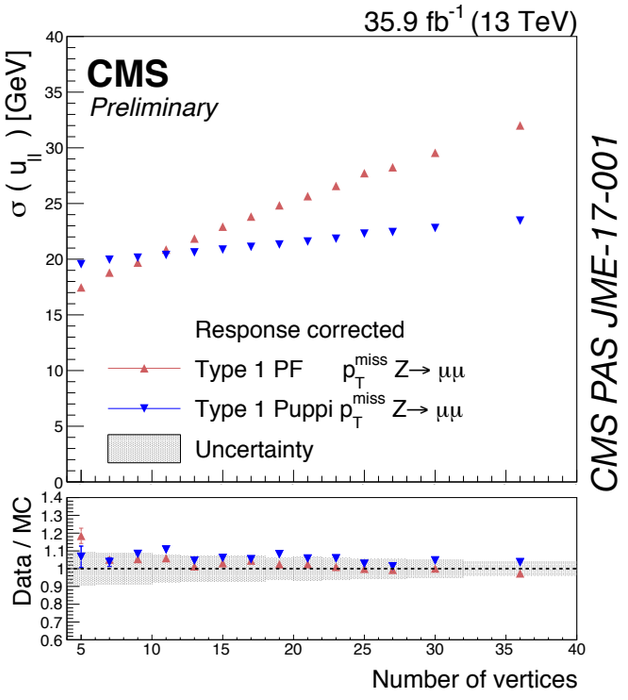
Muon Isolation & E_T^{miss} with Timing Detector

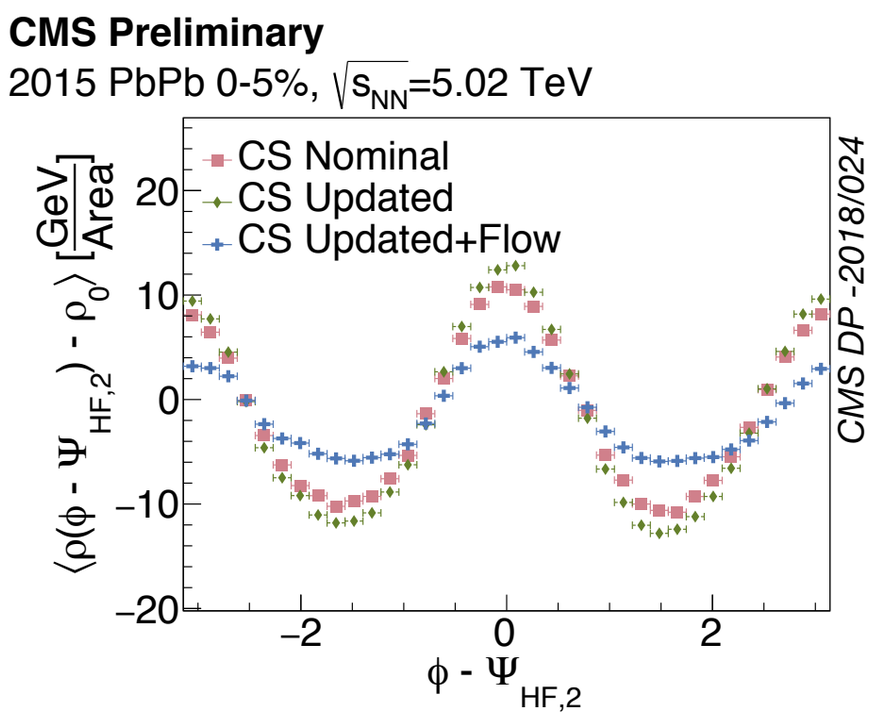




Summary

- **CHS and Pileup Jet ID reliable under current PU situation**
- **PUPPI shows good performance also for high PU**
- **HCAL OOTPU mitigation increase resolution**
- **CS+Flow in PbPb collision reduces “PU” significantly**
- **HL-LHC Tracker upgrade maintains performance at PU of 140-200**
- **Timing detector improves pileup mitigation techniques**





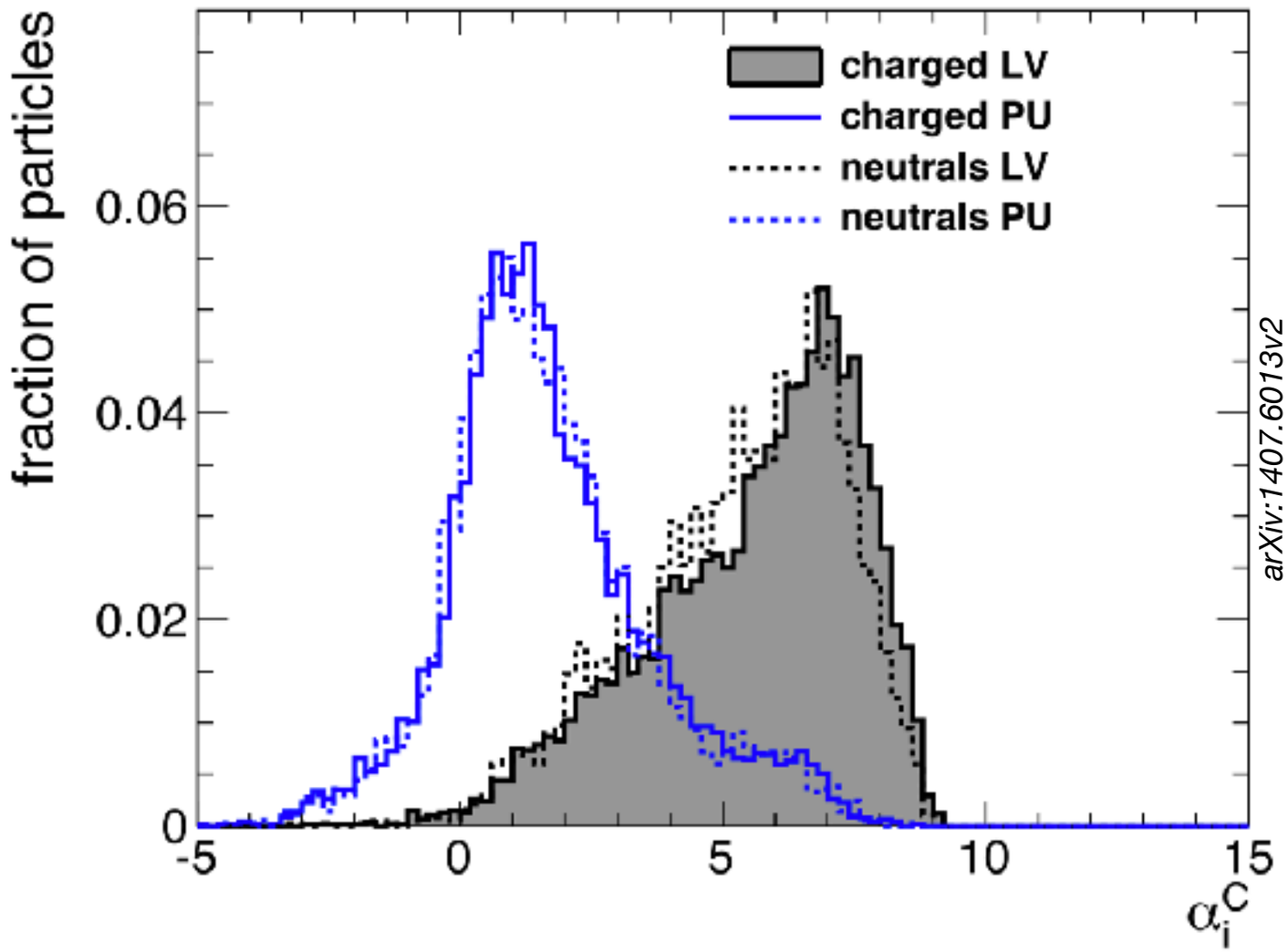
Backup

1. Define local shape α for charged pileup

$$\alpha_i = \log \sum_{j \in \text{event}} \frac{p_{Tj}}{\Delta R_{ij}} \times \Theta(R_{\min} \leq \Delta R_{ij} \leq R_0)$$

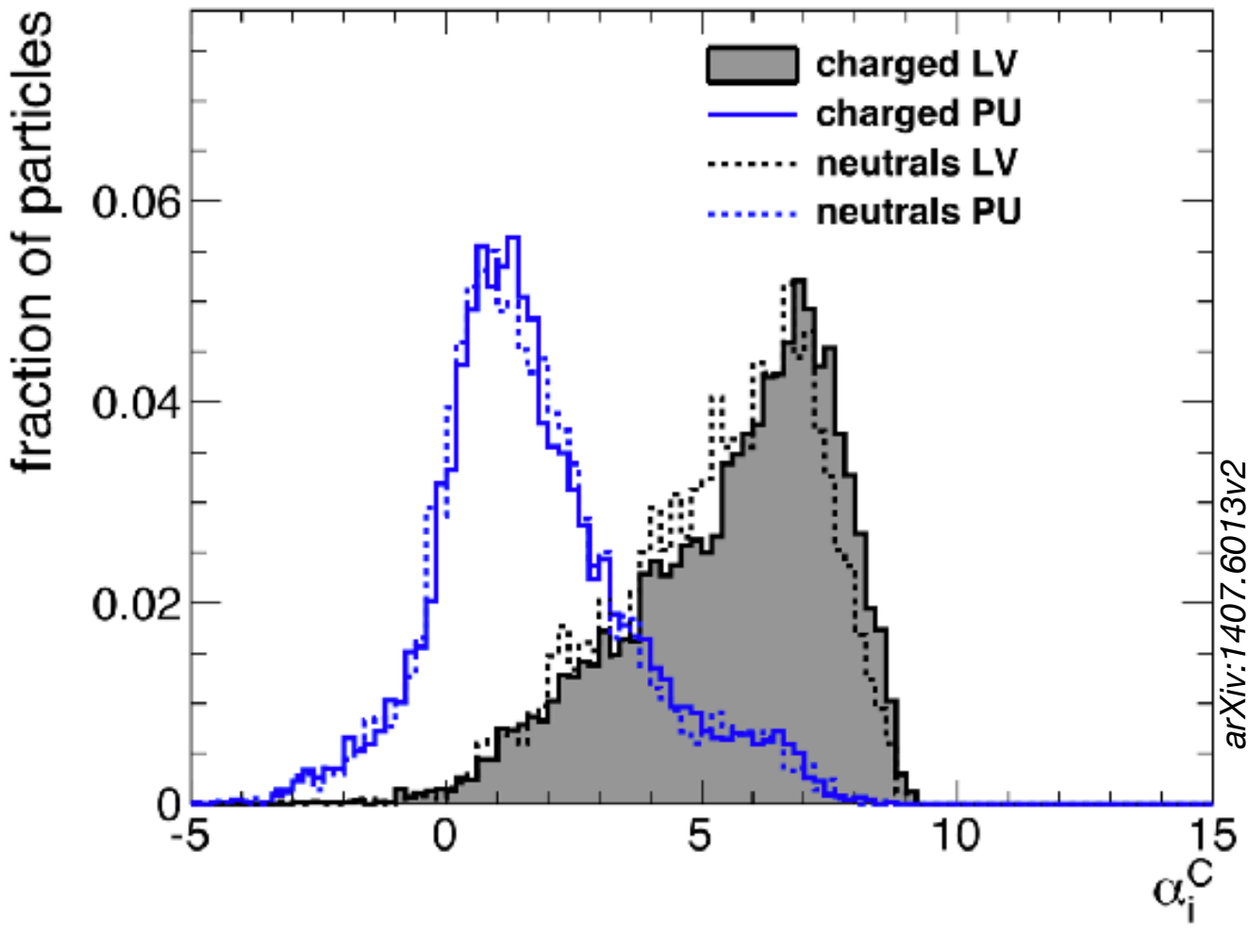
Regulator for collinear splitting of particle i (0.02)

Only particles within R0 are used to calculate the shape (0.3)

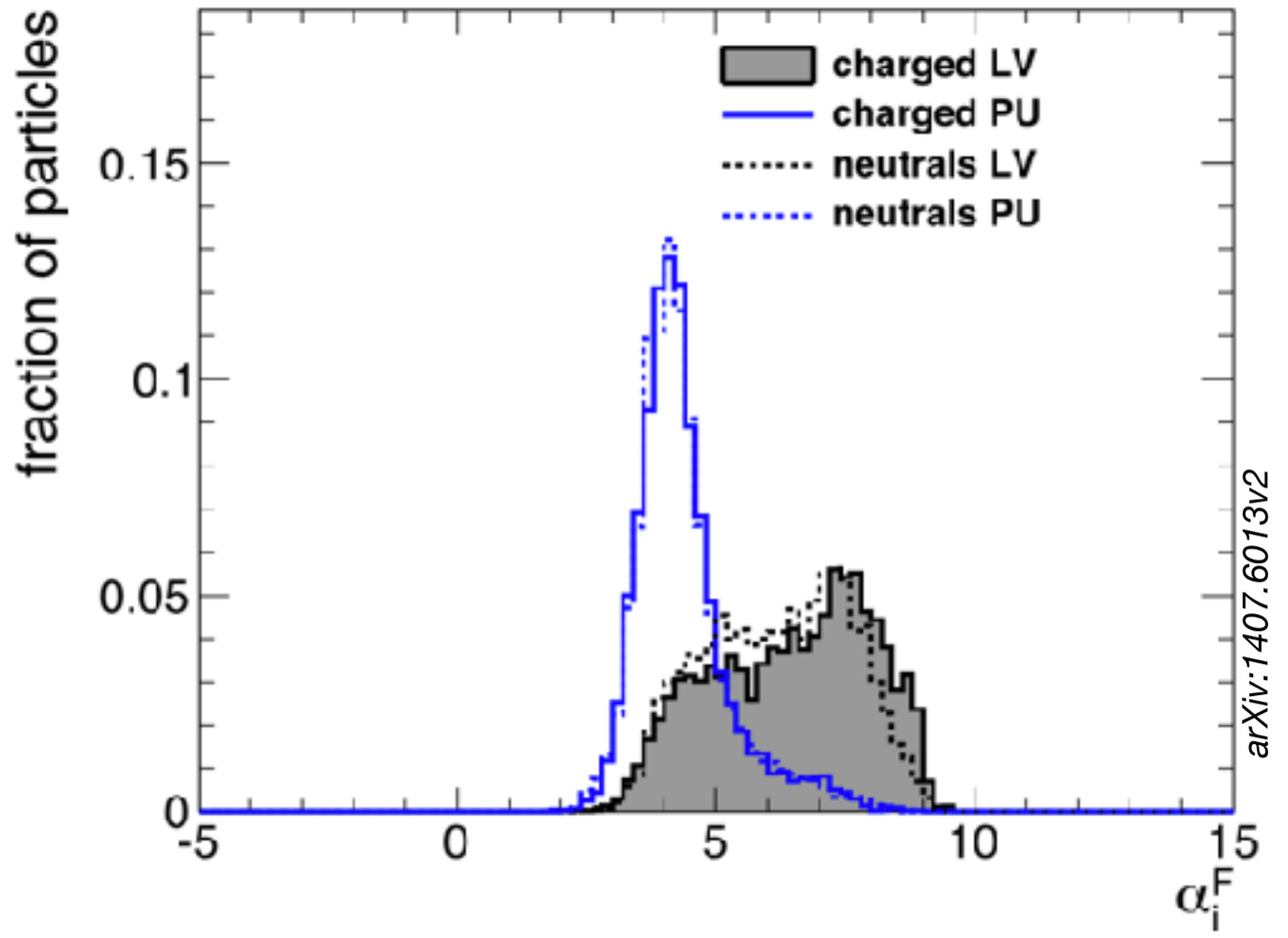


2. Assume charged pileup has the same shape as neutral pileup

Central

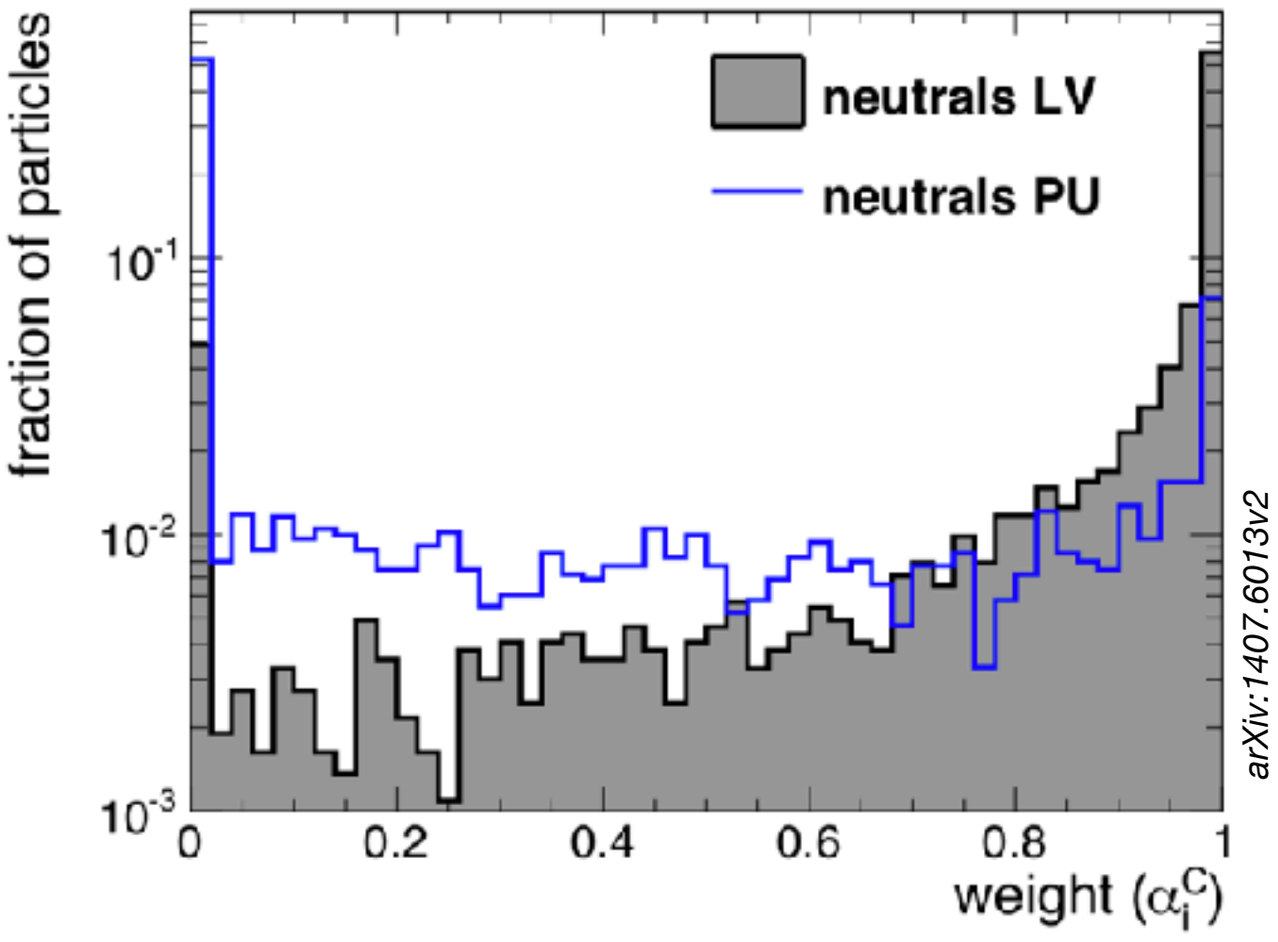


Forward

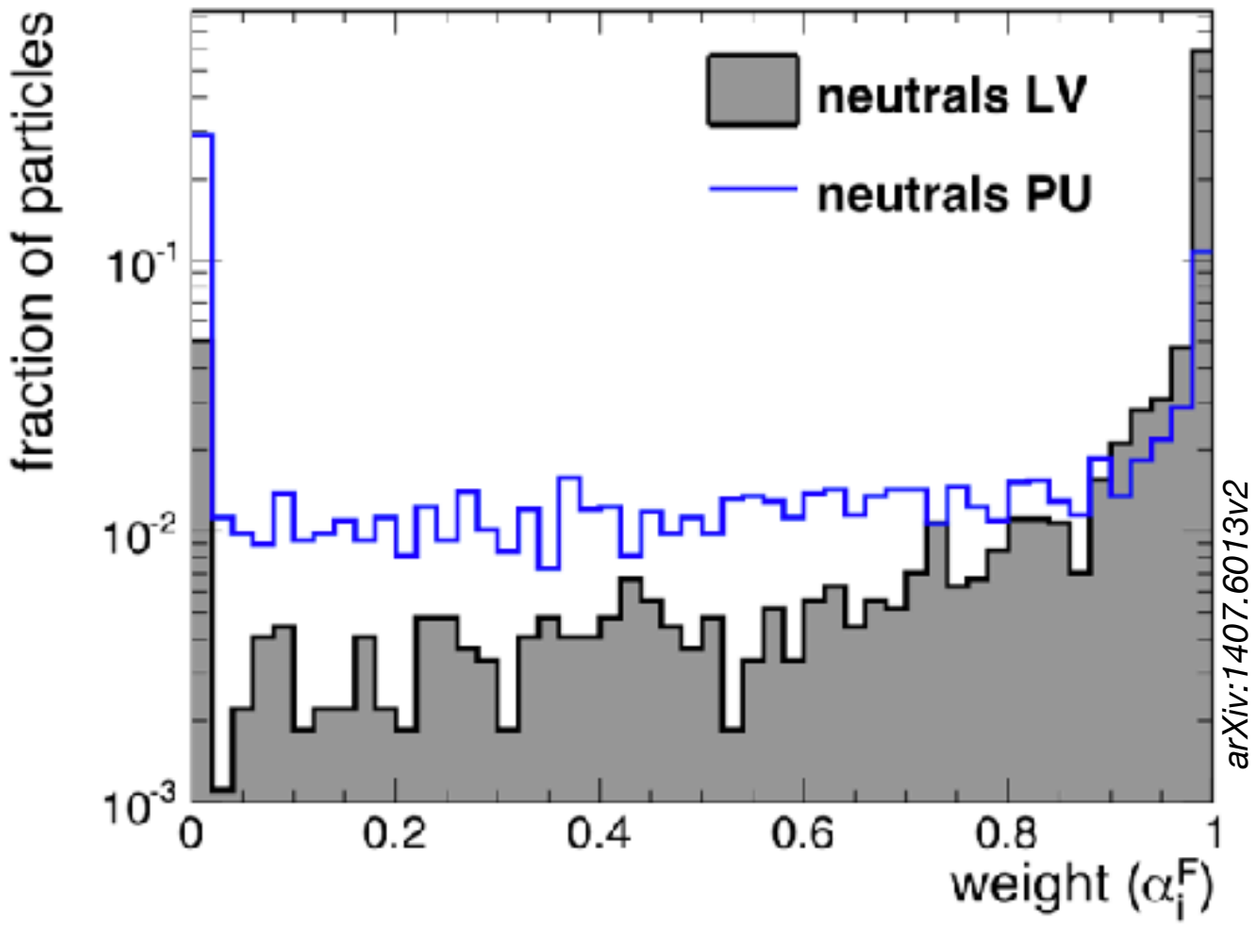


3. Use α on an event-by-event basis to calculate weight

Central

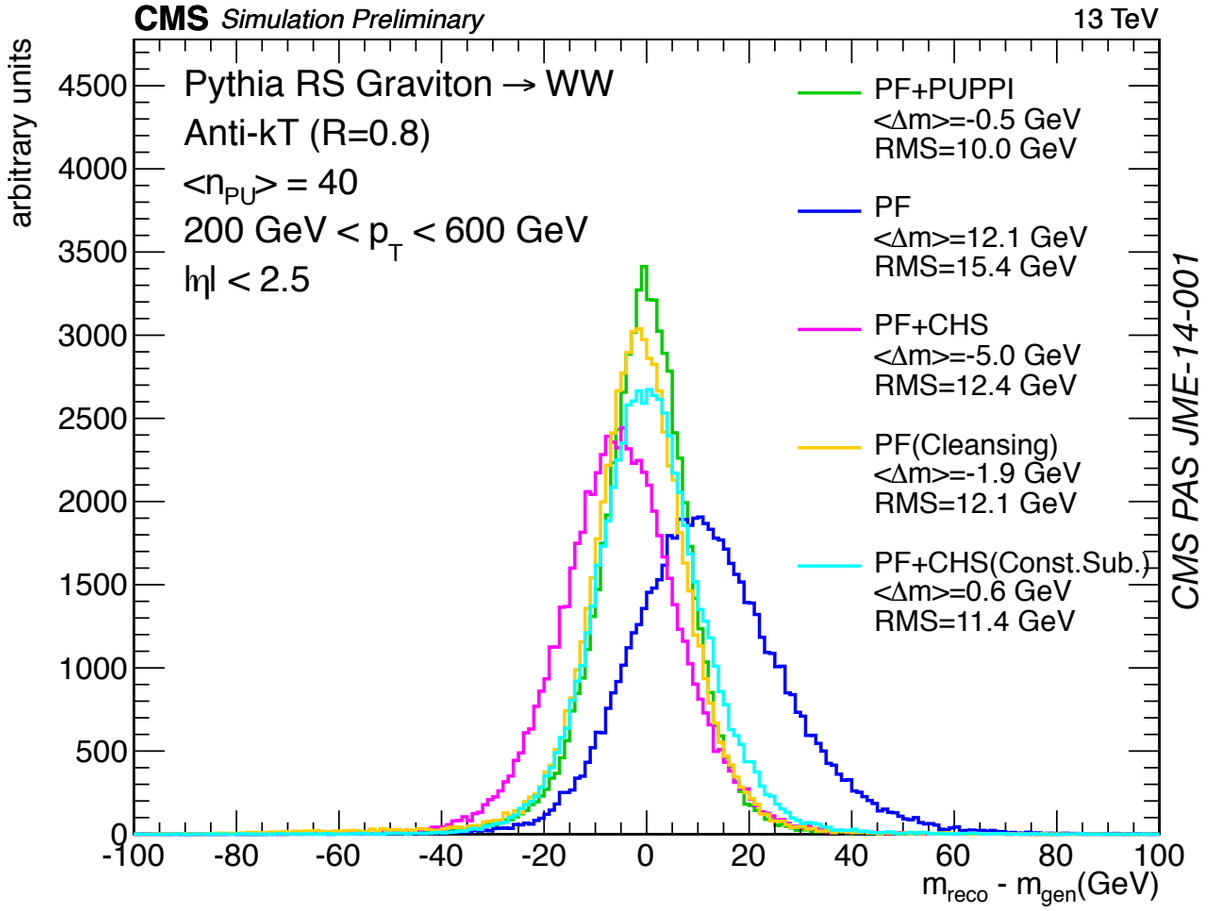


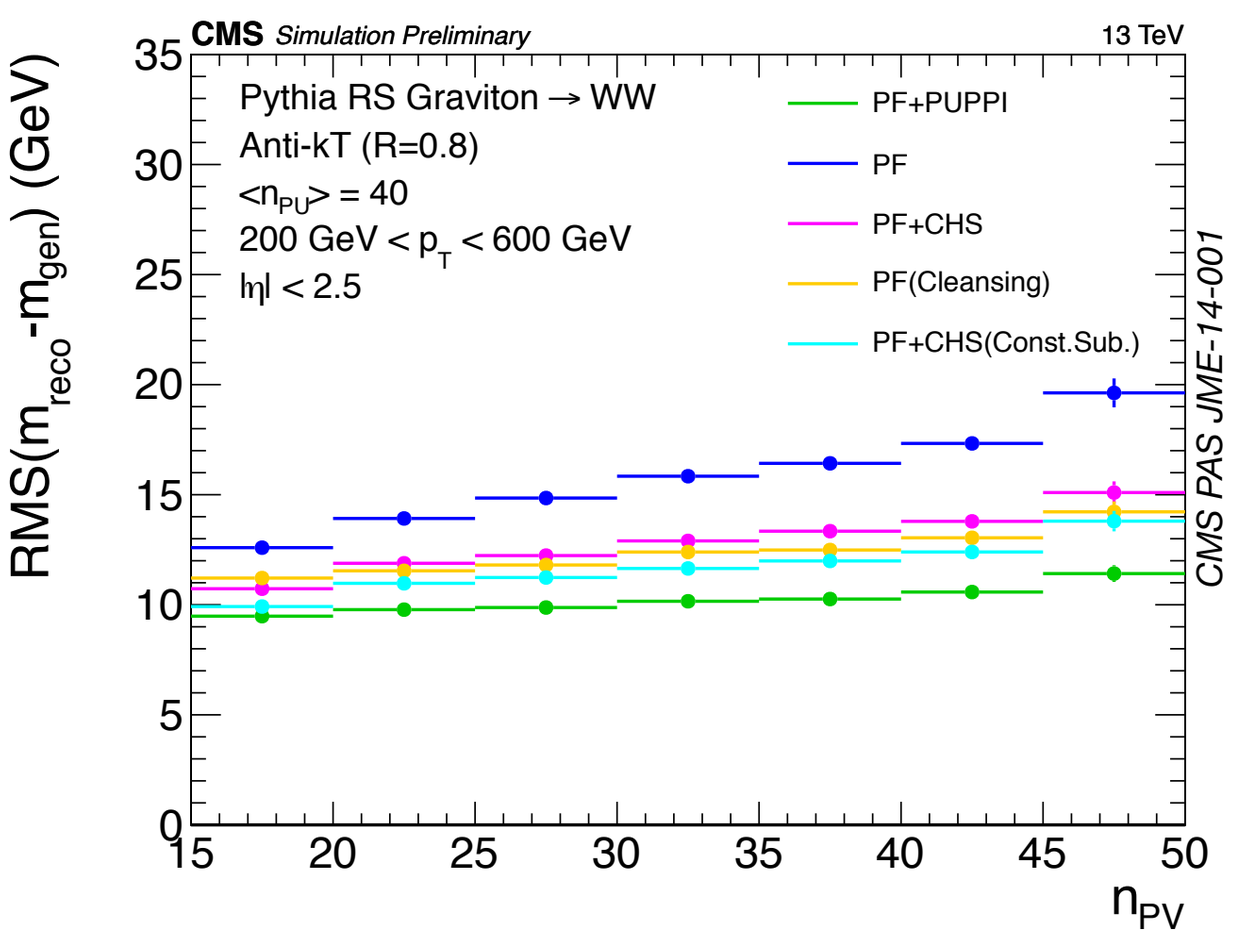
Forward



Pileup → **Hard scattering**

Mass Resolution





PUPPI outperformance CHS in mass resolution