# Charged particle spectra at 13TeV Unfolding

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# **Responce** Matrices

- Matching Reco-Gen
  - pT:  $\Delta R = \sqrt{(\Delta \eta^2 + \Delta \varphi^2)} < 0.04$
  - Eta:  $\Delta R = \sqrt{(\Delta p_T^2 + \Delta \varphi^2)} < 0.07$
  - Multiplicity: Same event selection

Events must have the same event selection at Gen and Detector level.

Initial binning:

- pT [0.5, 50] GeV with 0.1 bin width
- η [-2.4, 2.4] with 0.2 bin width
- Multiplicity [1, 100] with 1 bin width

# Rebinning

For each distributions there are several RM's involved for its unfolding and Systematic uncertainties determination.

- Nominal Selection (exactly 1 vertex and HFcut 5GeV) ----- (1)
- For HF (event selection) systematics:
  - Variation UP (HFcut 6GeV) ------(2)
  - Variation DOWN (HFcut 4GeV) ------ (3)
- For PU systematics:
  - At Least 1 vertex ------ (4)

# Rebinning

They have to be populated enough along the full phase space for the Unfolding procedure.

**Condition**: to have at least certain number of entries along each Gen bin

All the RM's are scanned simultaneously and the **maximum common value** of all RM's with the Initial Binning is kept and from that value the rest of the RM is rebinned doubling the last bin binwidth.

The process is **repeated iteratively** until covering all the populated phase space.

# RM normalised by rows -> fraction Gen particles(per bin) in Reco bins



Unfolding is not needed

p⊤ is diagonal Above 70% stays in the diagonal

High M -> Low M



#### Response Matrix: $p_{T}$ for Inelastic Gen $p_{_{T}}$ 0.9 0.8 12 0.7 0.6 0.5 0.4 0.3 0.2 0.1 14 8 10 12 Reco p<sub>-</sub> Response Matrix: $\mathbf{p}_{_{T}}$ for SD minus Gen $p_{_{\rm T}}$ 0.9 12 0.8



Response Matrix:  $p_{T}$  for NSD

CUETP8M1



Response Matrix:  $\mathbf{p}_{_{T}}$  for SD plus



### RM for transverse momentum distributions in different event selections

#### CUETP8M1 RM for Leading transverse momentum distributions in different event selections









Response Matrix:  $p_{\tau}$  for NSD (leading)



Response Matrix: p<sub>r</sub> for SD plus (leading)



### RM for Multiplicity distributions in different event selections

#### **Response Matrix: Multiplicity for Inclusive**



#### **Response Matrix: Multiplicity for SD**



**Response Matrix: Multiplicity for Inelastic** 



#### **Response Matrix: Multiplicity for SD minus**



Response Matrix: Multiplicity for NSD

CUETP8M1



#### **Response Matrix: Multiplicity for SD plus**



# Comparison at detector level













## Multiplicity distributions (Log scale)

Iterations of unfolding and Folding Back

# Folding Back

$$N_{det}^{i} = \sum_{j=1}^{N_{bins}} rac{P^{ij} \cdot N_{unfold}^{j} \cdot (1 - Miss)}{1 - Fake^{i}}$$

The quality of the backfolding is estimated by evaluating:

$$\chi^{2} = \sum_{i=1}^{Nbins} \left( \frac{X_{det} - X_{fold}}{\sqrt{\sigma_{det}^{2} + \sigma_{fold}^{2}}} \right)^{2}$$

\* DAS school: Inclusive Jets Exercise

Pseudorapidity (Inclusive event selection)

#### (13 TeV) (13 TeV) (13 TeV) (1/N ) dN /dη events 4.5 5 4 $(1/N_{events}) dN_{ch}/d\eta$ CMS CMS CMS Inclusive selection Inclusive selection Inclusive selection • data • data data Preliminarv Preliminary Preliminarv all systematics all systematics all systematics $N_{ch} \ge 1$ in $|\eta| < 2.4$ — PYTHIA8 CUETM1 – – PYŤHIA8 CUETM1 $N_{ab} \ge 1$ in $|\eta| < 2.4$ — PYTHIA8 CUETM1 $N_{\perp} \ge 1$ in $|\eta| < 2.4$ $p_{m} > 0.5 \text{ GeV}$ ----- EPOS LHC $p_{m} > 0.5 \text{ GeV}$ ----- EPOS LHC $p_{m} > 0.5 \text{ GeV}$ ----- EPOS LHC **5** iterations **10 iterations 1** iteration 3.5 3.5 3.5 ........ 3 2.5 2.5 2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 -2 -1.5 -1 -0.5 0 0.5 1 2 15 2 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 n n

**Unfolded distributions** 

Unfolding starts to degenerate with the number of iterations for highly diagonal RMs



Transverse momentum (Inclusive event selection)

#### (13 TeV) (13 TeV) (13 TeV) <sup>45</sup> dp/ 40 T dN /dp /dp /dp /dp /dp /dp 32 30 CMS CMS CMS Inclusive selection Inclusive selection Inclusive selection • data data data Preliminarv Preliminarv Preliminary all systematics all systematics all systematics $N_{ch} \ge 1$ in |m| < 2.4— PYŤHIA8 CUETM1 — – PYŤHIA8 CUETM1 $N_{\perp} \ge 1$ in $|\eta| < 2.4$ PYŤHIA8 CUETM1 $N_{\perp} \ge 1$ in $|\eta| < 2.4$ (1/N) 30 30 (11/N) 30 ----- EPOS LHC ----- EPOS LHC ----- EPOS LHC p > 0.5 GeVp > 0.5 GeVp > 0.5 GeV25 25 25 **1** iteration **5** iterations **10 iterations** 20 20 20 15 15 15 10 10 10 5 5 5 0.5 1.5 2 2.5 3 3.5 0.5 2 2.5 3 1.5 2 2.5 3 4.5 5 1.5 3.5 4.5 5 0.5 3.5 4.5 5 4 1 p<sub>\_</sub> [GeV] p<sub>\_</sub> [GeV] p\_ [GeV]

### **Unfolded distributions**

Degeneration as increasing number of iterations



Leading transverse momentum (Inclusive event selection)

#### (13 TeV) (13 TeV) (13 TeV) (1/N (1/N ) dN /dp (1/N ) (1/N (1/N (1/N (1/N (1/N / dp ( CMS CMS .dp/ CMS Inclusive selection Inclusive selection Inclusive selection ్<sub>చర</sub>్ data Preliminarv data Preliminarv data Preliminary all systematics all systematics all systematics — PYŤHIA8 CUETM1 $N_{\perp} \ge 1$ in $|\eta| < 2.4$ $N_{ch} \ge 1$ in $|\eta| < 2.4$ — – PYŤHIA8 CUETM1 $1 \ge 1$ in $|\eta| < 2.4$ PYTHIA8 CUETM1 (11N events) 0.7 ----- EPOS LHC ----- EPOS LHC p > 0.5 GeV----- EPOS LHC p > 0.5 GeV> 0.5 GeV 0.6 **1** iteration 0.6 **5 iterations** 0.6 0 iterations 0.5 0.5 0.5 0.4 0.4 0.4 0.3 0.3 0.3 0.2 0.2 0.2 0. 0.1 0.1 2.5 3 3.5 4 2.5 3 3.5 1.5 2 4.5 1.5 2 1.5 2.5 3 3.5 0.5 0.5 4 4.5 0.5 2 4.5 5 1 1 1 4 leading charged particle p\_ [GeV] leading charged particle p\_ [GeV] leading charged particle p\_ [GeV]

## **Unfolded distributions**

Degeneration as increasing number of iterations







### Multiplicity distributions (Inclusive event selection)



Backfolding





Backfolding



# Comparison Bin-By-Bin vs Unfolding







### Transverse momentum

### **Bin By Bin**

Unfolding 1 iteration









# Multiplicity distributions

# **Bin By Bin**











Additional Material





6

Λ

8

2

12

Reco p<sub>-</sub>

10

# RM for transverse momentum distributions in different event selections



**EPOS** 



Response Matrix:  $\textbf{p}_{\tau}$  for SD plus



### RM for Multiplicity distributions in different event selections

#### **Response Matrix: Multiplicity for Inclusive**



#### **Response Matrix: Multiplicity for SD**



**Response Matrix: Multiplicity for Inelastic** 



#### **Response Matrix: Multiplicity for SD minus**



**Response Matrix: Multiplicity for NSD** 

**EPOS** 



#### **Response Matrix: Multiplicity for SD plus**

