First results from inclusive jet measurement with Ultra-Legacy Run 2 data

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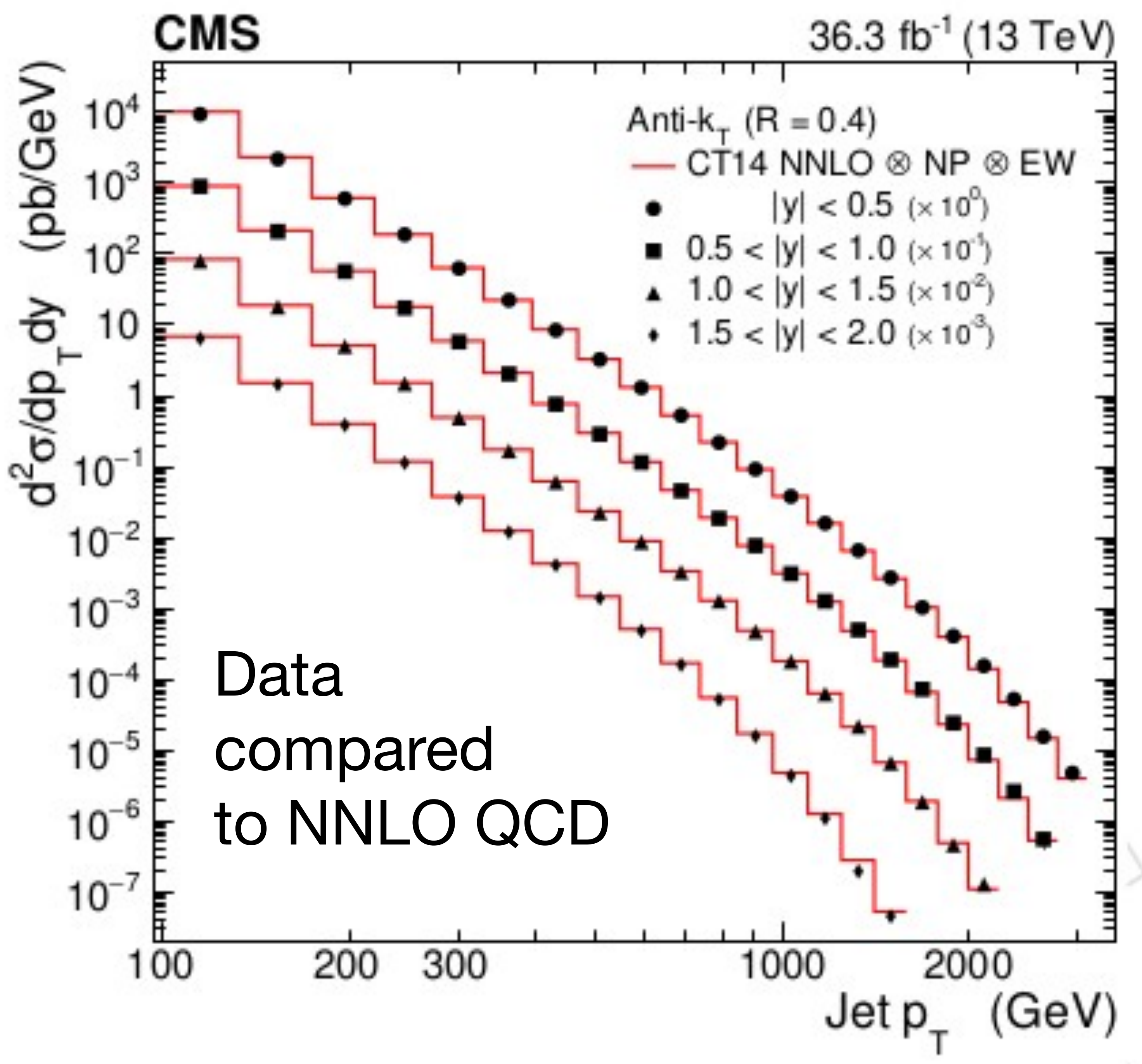
HELMHOLTZ

Definition of observables & Motivation

- **Cross section measurement of inclusive jets**
  - ***Inclusive jets:*** for each jet of each event, we fill p_T and y histograms

$$\frac{d^2\sigma}{dp_T dy} = \frac{N^{eff}_{jets}}{\mathscr{L} * \Delta p_T * \Delta y}$$



JHEP 02 (2022) 142

- **Goal:**
  - QCD test: **comparison** of differential cross sections **to theory predictions**
  - **Fit** $PDFs$ and α_S

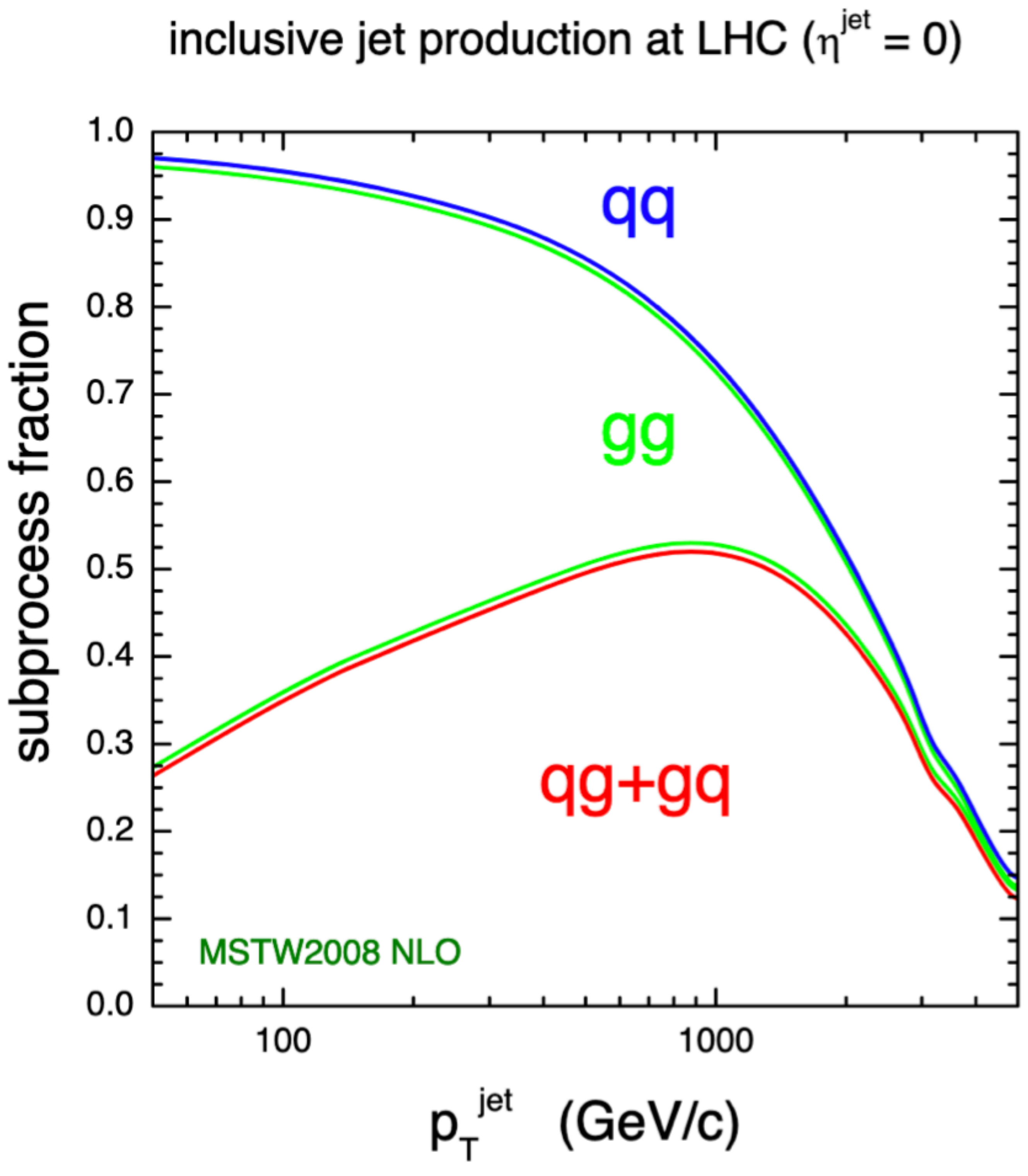
- **Full Run2:**
  - **Higher** accumulated **luminosity** → opens up new corners of phase space
  - **Final scale factors** & more **refined corrections** → improved precision

Jets as a probe of QCD

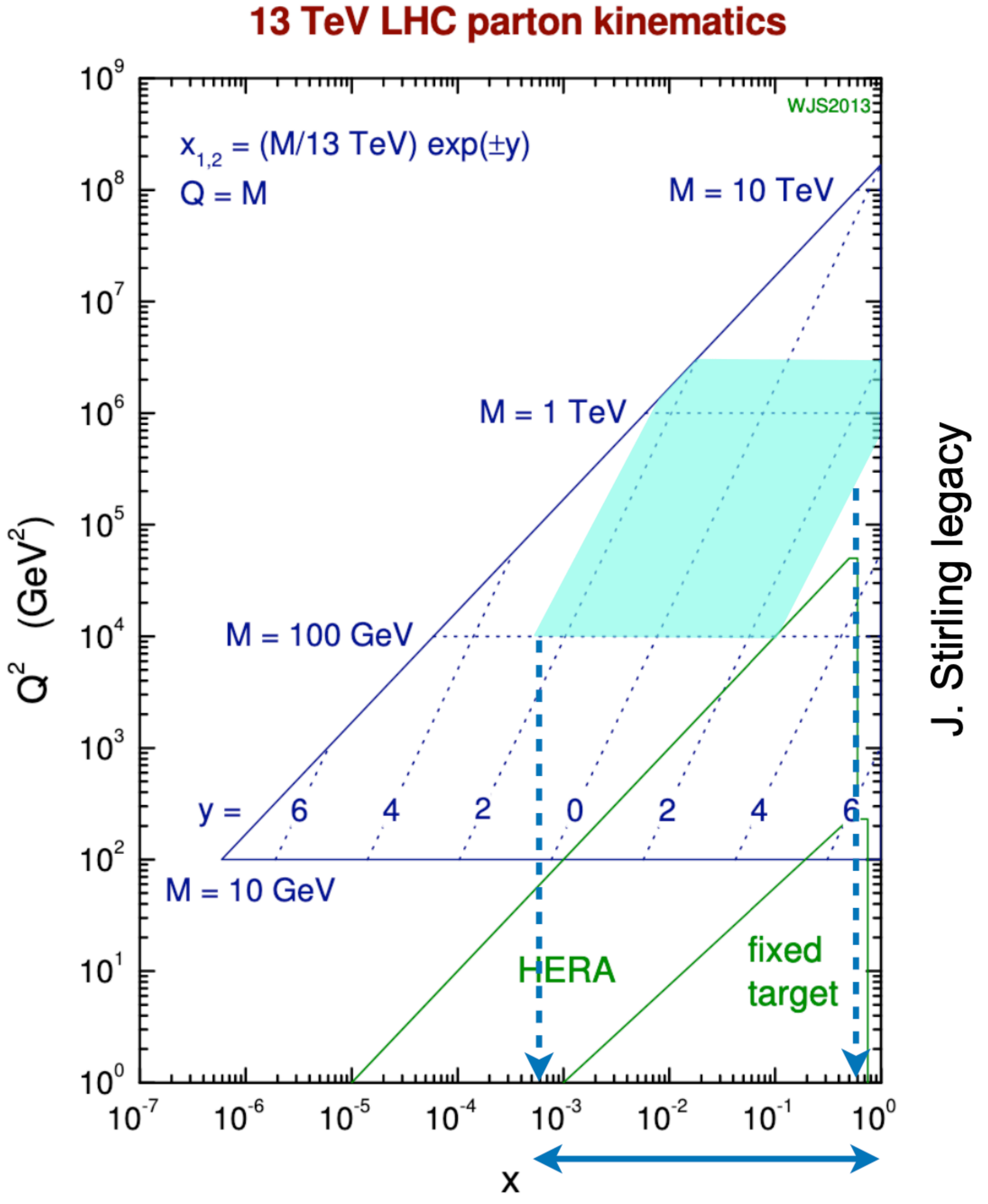
- Jet production is a **flagship SM measurement:**
  - Sensitive to α_S and gluon distribution at high momentum fraction x:

$$\sigma_{pp\to jet+X} = \sum_{ij} \underbrace{f_i(x_1,\mu_F)f_j(x_2,\mu_F)}_{\text{PDFs}} \times \sigma_{ij}\left(x_1, x_2, \alpha_S(\mu), \frac{Q^2}{\mu_R}, \frac{Q^2}{\mu_F}\right)$$

    - Improve **PDFs** precision at high x
    - **Extract α_S**



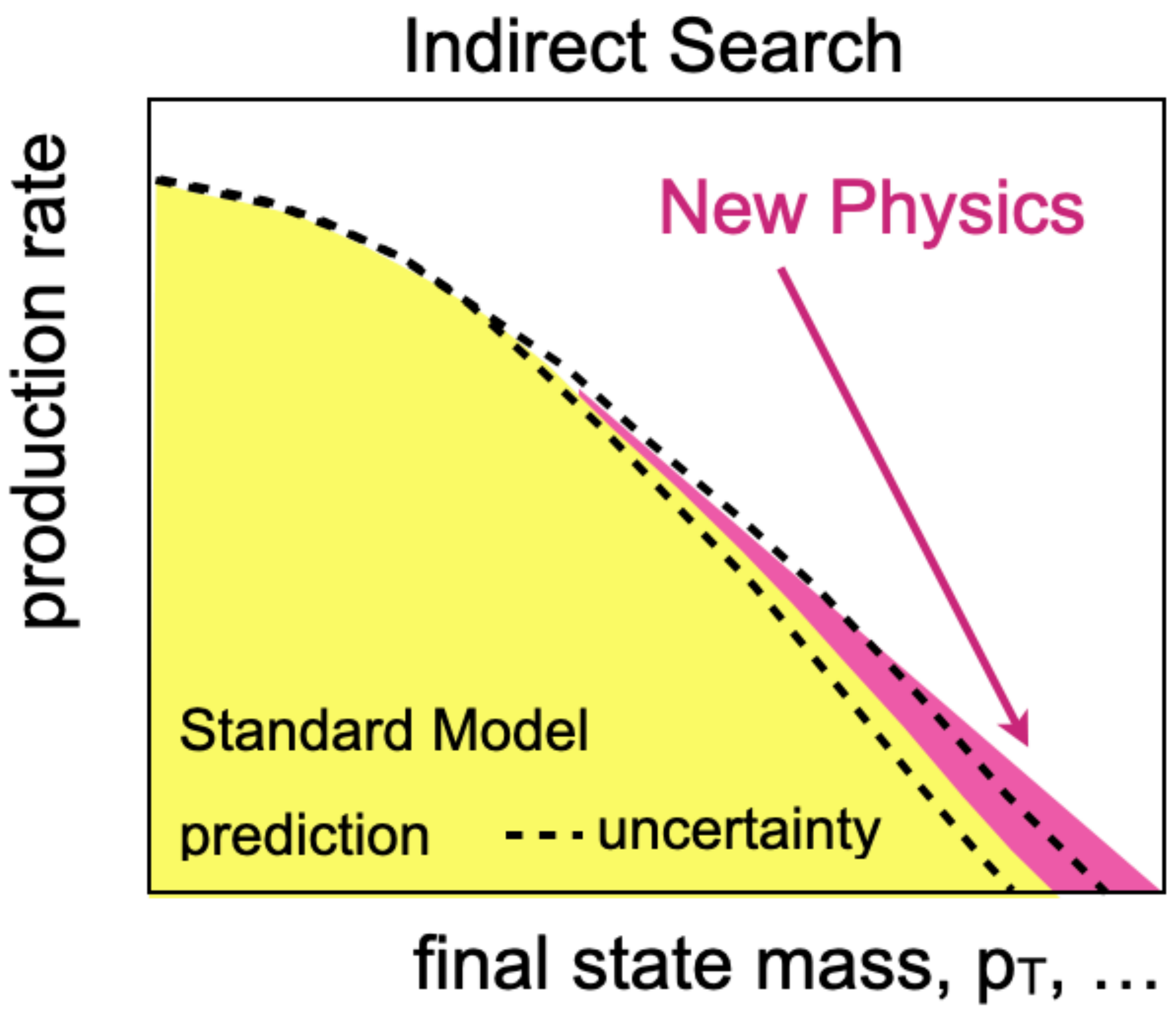
gg fusion dominant
qq and qg at high-p_T



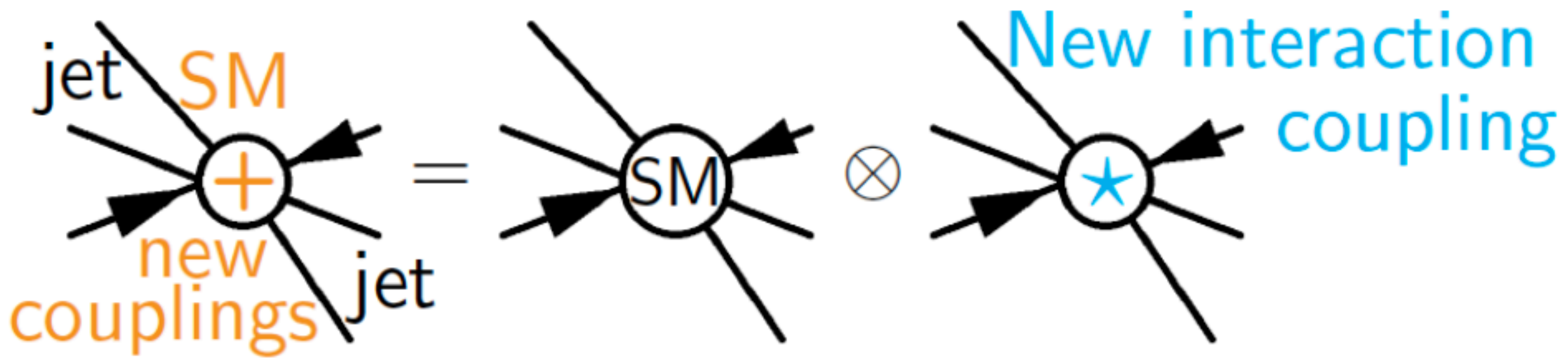
x and Q^2 ranges probed by jet production at LHC

Jets as a probe of new physics

- Perform indirect **beyond SM searches** → jets at high-pT



- **New phenomena** described in **Effective Field Theory (EFT):**
  - **4-quark "contact interactions" (CI)**



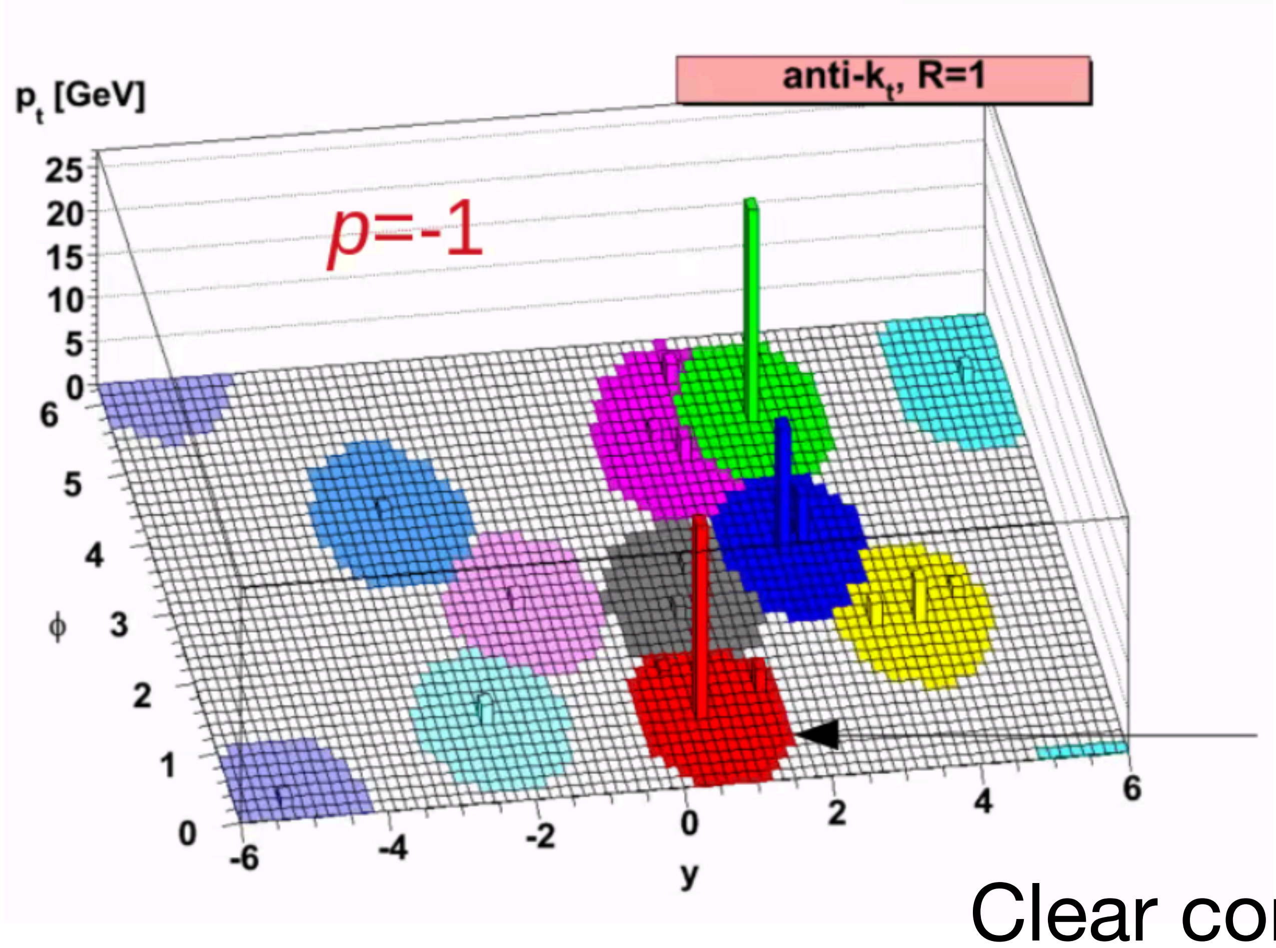
$$L_{SMEFT} = L_{SM} + \frac{2\pi}{\Lambda^2} \sum_n c_n O_n$$

c_n: Wilson Coefficient (= effective coupling)
Λ: energy scale of new physics
O_n: 6-dimension operators

- Check BSM effects are not absorbed into $PDFs$ → **fit the $PDFs$ simultaneously with σ_{SMEFT}**

Goal of the measurement

- **Goal:** Measure inclusive jet double differential cross section
  - **Full Run2:** 2016-17-18 samples
    - $L = 138\, fb^{-1}, \sqrt{s} = 13 TeV$
  - **Anti-k_t** clustering algorithm with **R = 0.4** (& **R = 0.8**)



Clear cones

- **Datasets (latest reconstructions):**
  - **Data:** */JetHT/Run201*UL*/MINIAOD & /ZeroBias/Run201*-UL*/MINIAOD*
  - **MC (Pythia Flat sample):** */QCD_Pt-15to7000_TuneCP5_Flat_13TeV_pythia8/RunIISummer20UL*MiniAOD*

Calibration procedure in a nutshell

- **Event selection at detector and hadron level:**
  - Rapidity region: |y| < 3.0
  - Jet p_T >~ 30 GeV
- **Event-by-event or jet-by-jet corrections**

- **Monte Carlo (MC):**
  1. **Jet veto maps** & **Missing Energy Transverse (MET)** filters
  2. **JET** corrections (jet energy scale and jet energy resolution smearing)
  3. **Pile-up correction:** work in progress

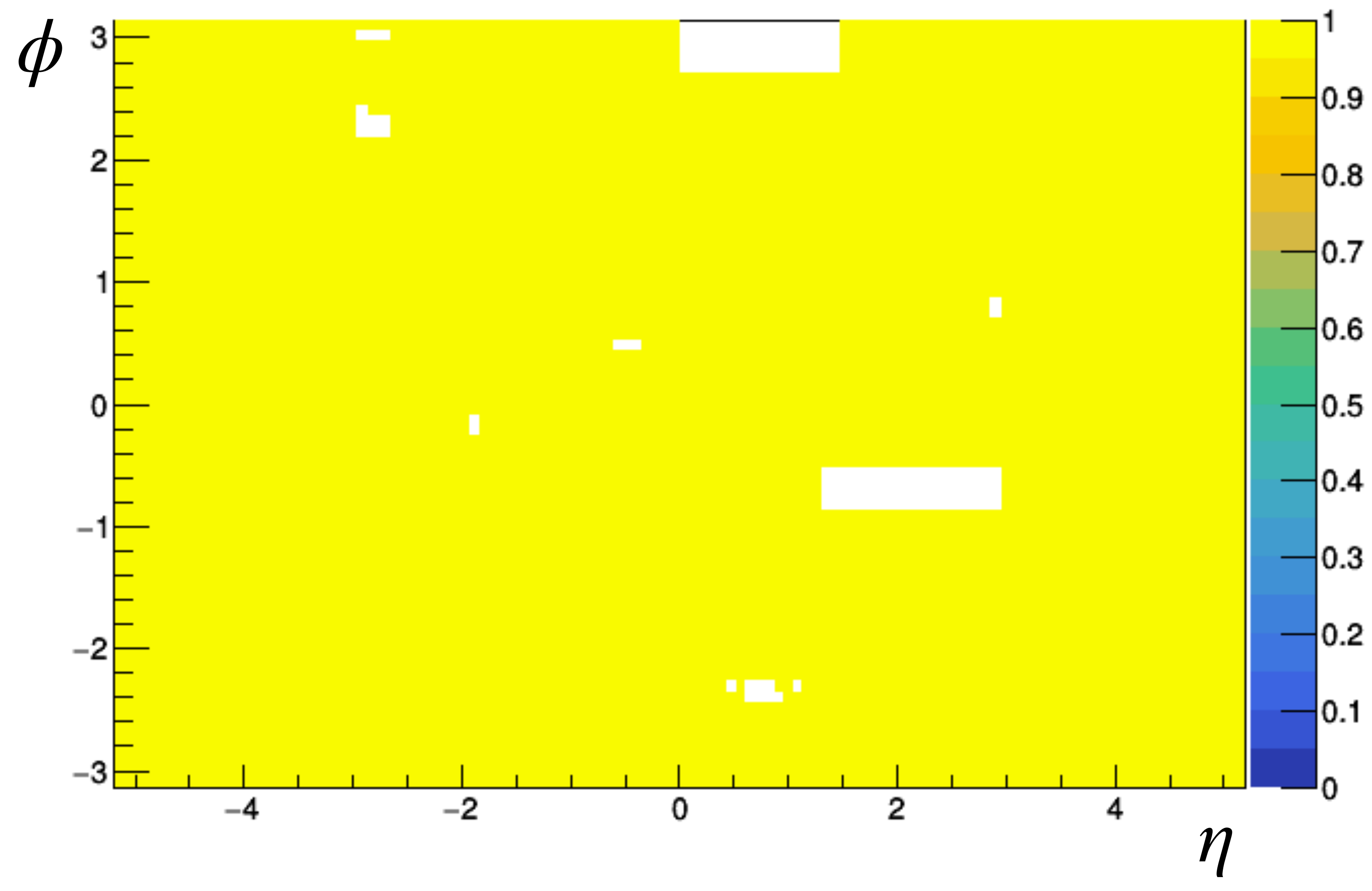
- **Data:**
  1. **Jet veto maps** & **MET** filters
  2. **Jet energy scale** corrections
  3. **Prefiring weight correction** (2016-2017)

1. Jet veto maps & MET filters

✓ **Jet veto maps:**

- **Certain detector regions damaged** (not well simulated) → excluded both from data and MC
- **Jet veto maps** describe regions with an **excess** of jets in data
- If a region have an excess of jets in one era → jets in this region removed from whole year

2017 jet veto map



✓ **MET filters:**

- MET ⟶ 0 for pure QCD jet measurement
- MET **mostly** arising from **experimental effects**
- Series of **selections** based on MET

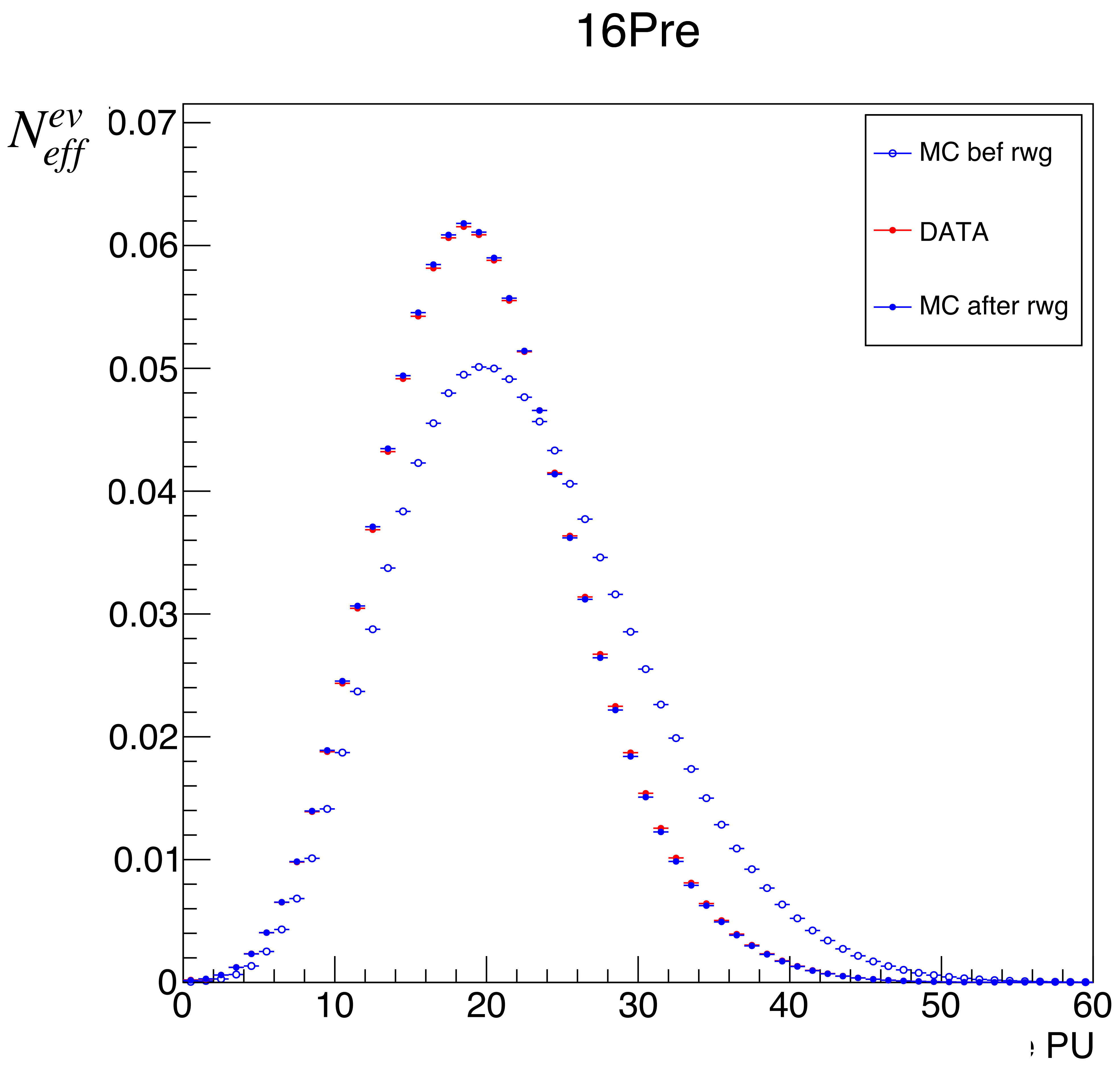
Missing Energy Transverse (MET)

$$E_T^{miss} = |p_T^{miss}|$$

3. Pile-up corrections (for MC)

- **Pile-up profile corrections:** MC usually produced with slightly overestimated PU

→ **Correction applied to match data PU profile**



3. Prefiring weight correction

✓ **Prefiring study**

- It affects only 2016-2017

- Certain jets in the forward region (**2.0 < $|\eta|$ < 3.0**) wrongly considered by Level-1 trigger as belonging to the previous bunch crossing:

  - **Rule:** No two consecutive bunch crossings can both fire the trigger!

  - **Consequences:**
    - If **some jets** of the event **affected** by prefiring issue → **event discarded**
    - Confusion only at trigger level → apply a **weight to compensate for the efficiency loss**

Prefiring calibration maps

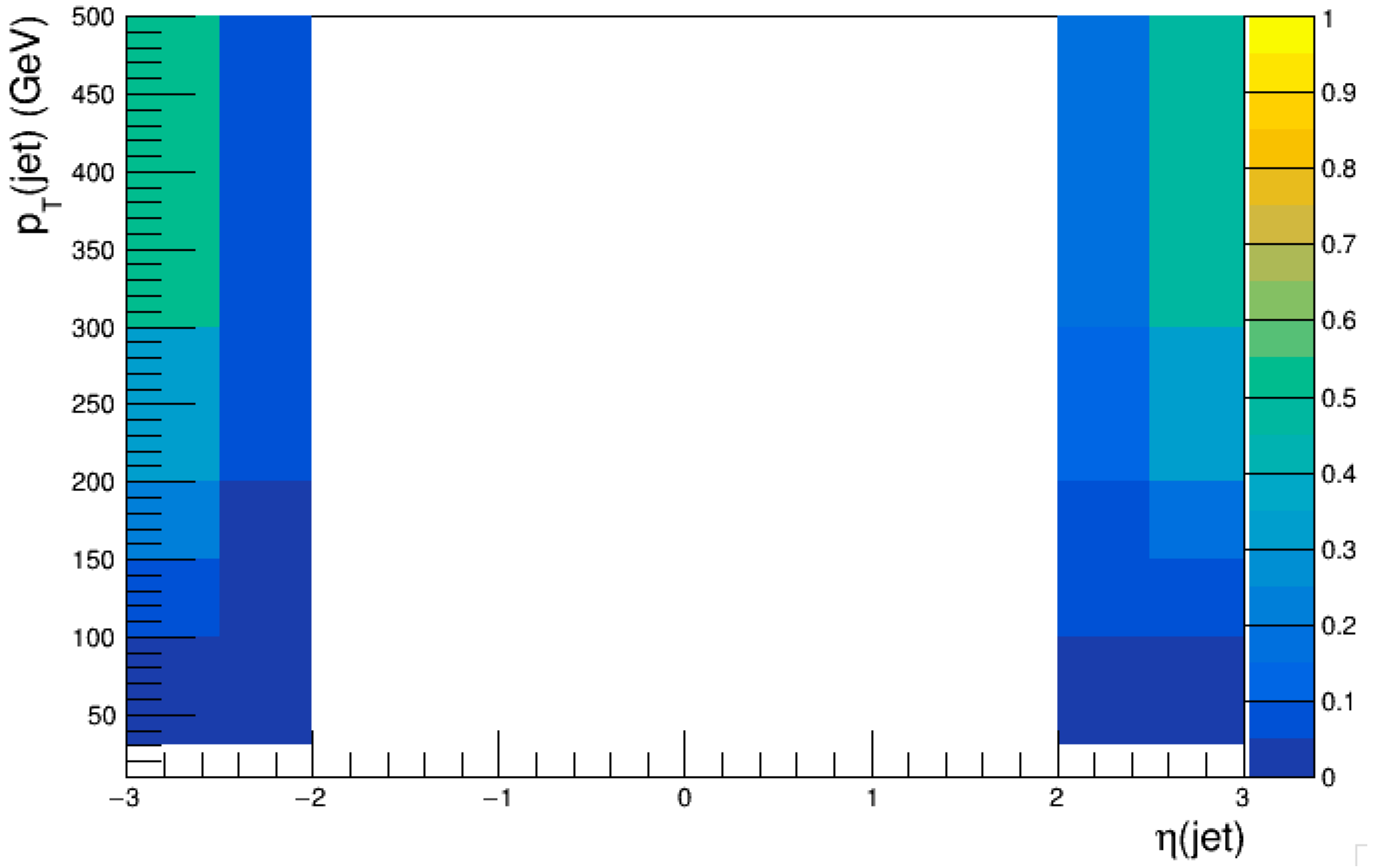
$$W = 1 - prob_{pref}$$

NB w for only one jet, if more jets probabilities have to be combined

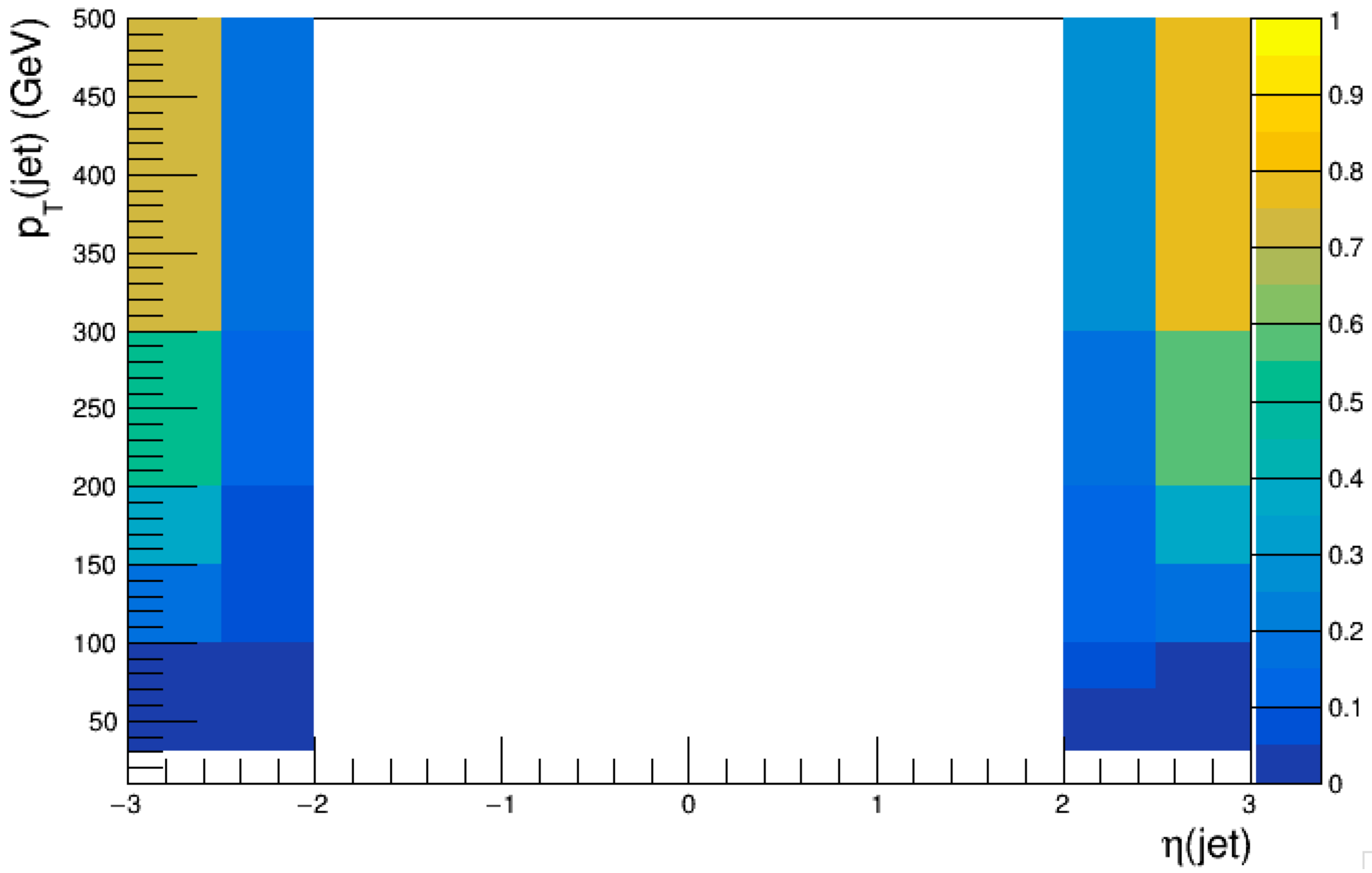
- **Two possibilities:**

  1. **Average probability map**
     - BUT: time dependence is not accounted for
  2. **Maps for different eras:**
     - BUT: only limited statistics available for each era

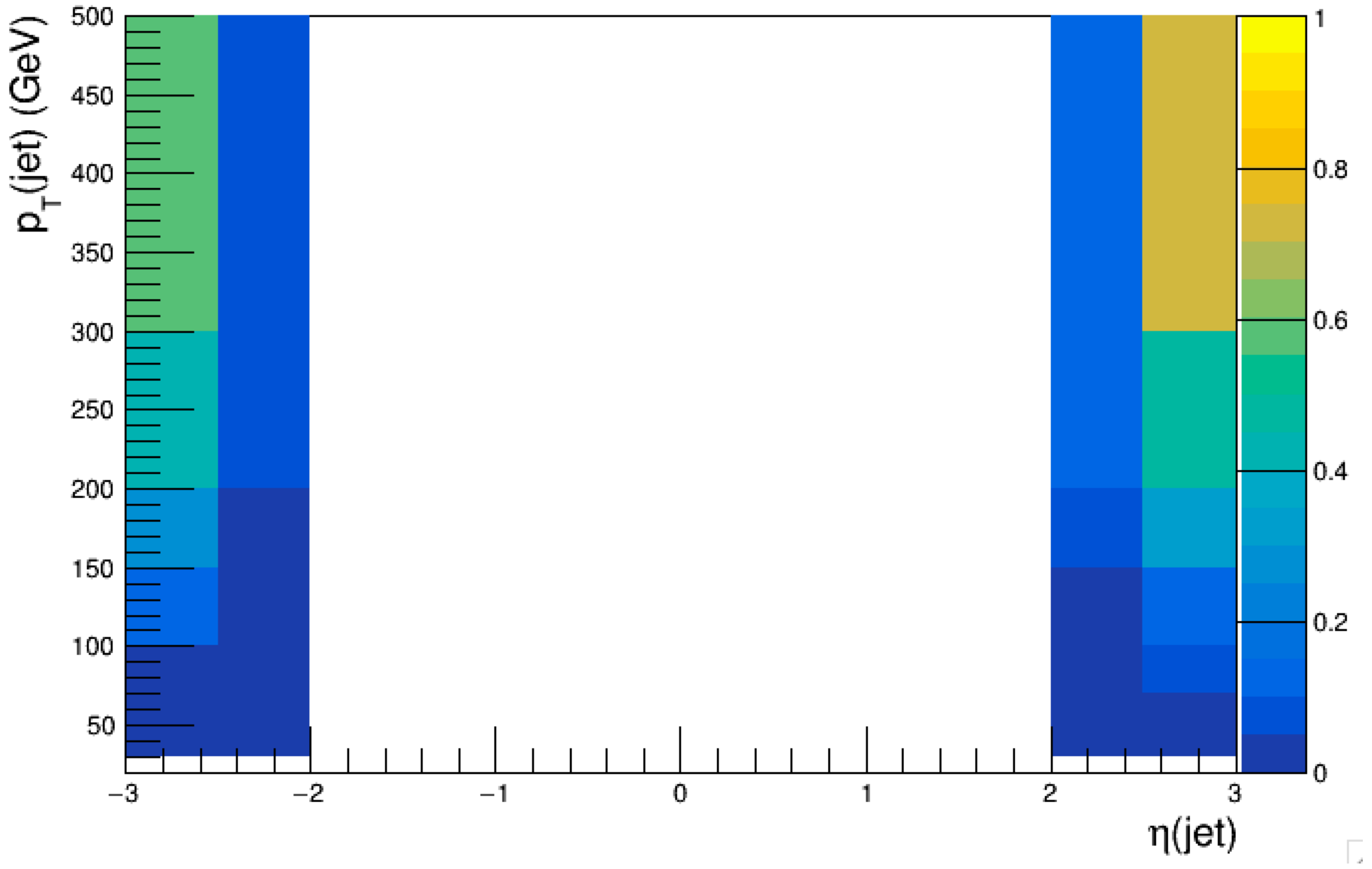
Average 2016



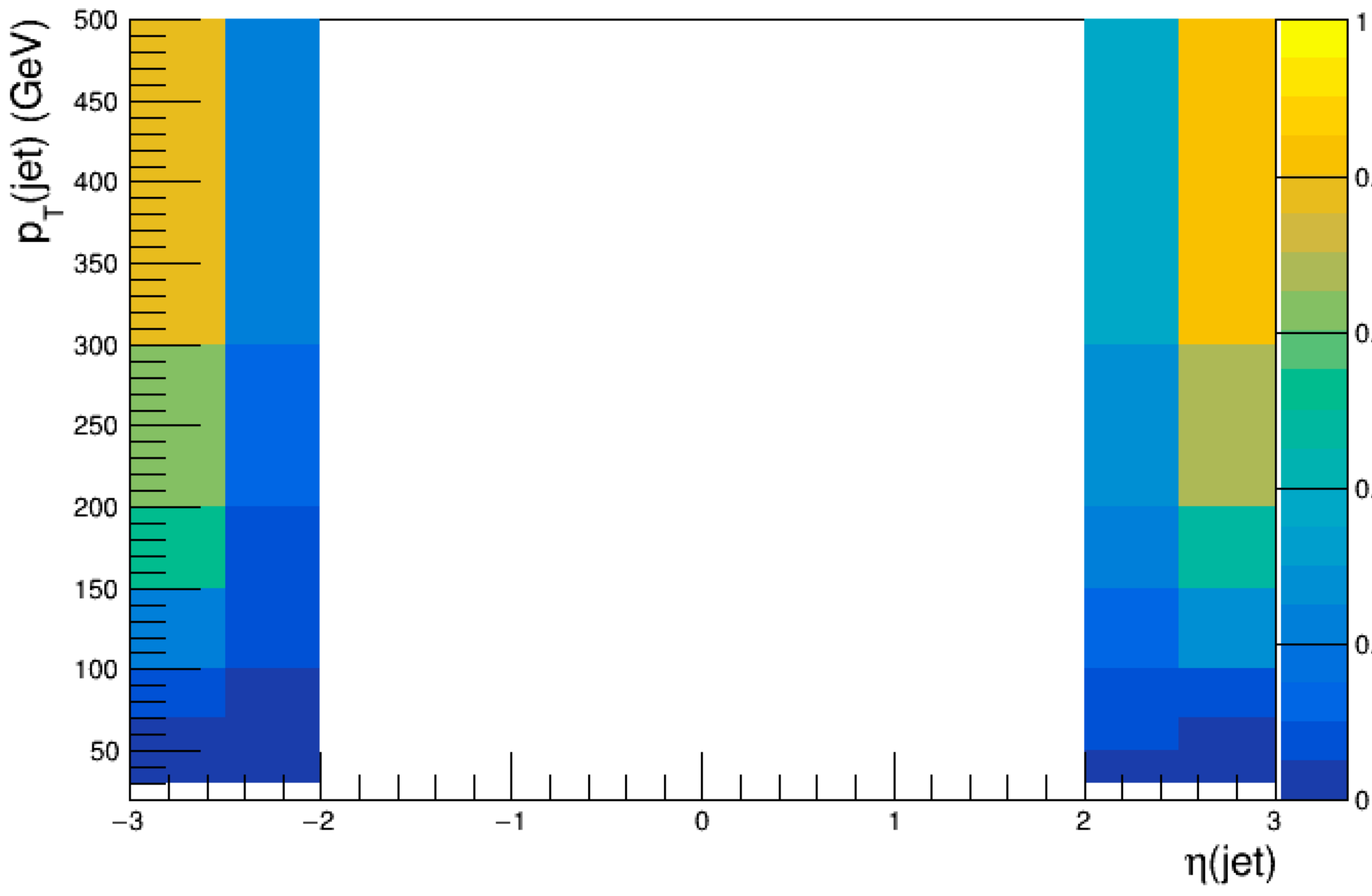
Average 2017



MapsPerEra 2017 era B



MapsPerEra 2017 era F



- **Corrections applied on data:**
  - inverse of weight w

Trigger strategy for data samples

- **Prescaled single-jet triggers:** at least one jet with p_T^{jet} at the High Level Trigger (HLT) larger than a certain threshold is required in the event
  - AK4 HLT_PFJet_* with * = 40,60,80,140,200,260,320,400,450, (500) for 2016 (2017-18)
    - $\rightarrow$ **to collect enough events down to low p_T**
    - Triggers have **increasing prescales as a function of p_T**

- **Trigger strategy:**
  - Triggering on leading jet present in |y|<2.5
  - Normalising event by event with prescales, with turn-on points at nearly 100% of efficiency
  - **+ ZeroBias trigger for $|y| > 2.5$ or p_T < lowest jet trigger threshold**

Trigger methods

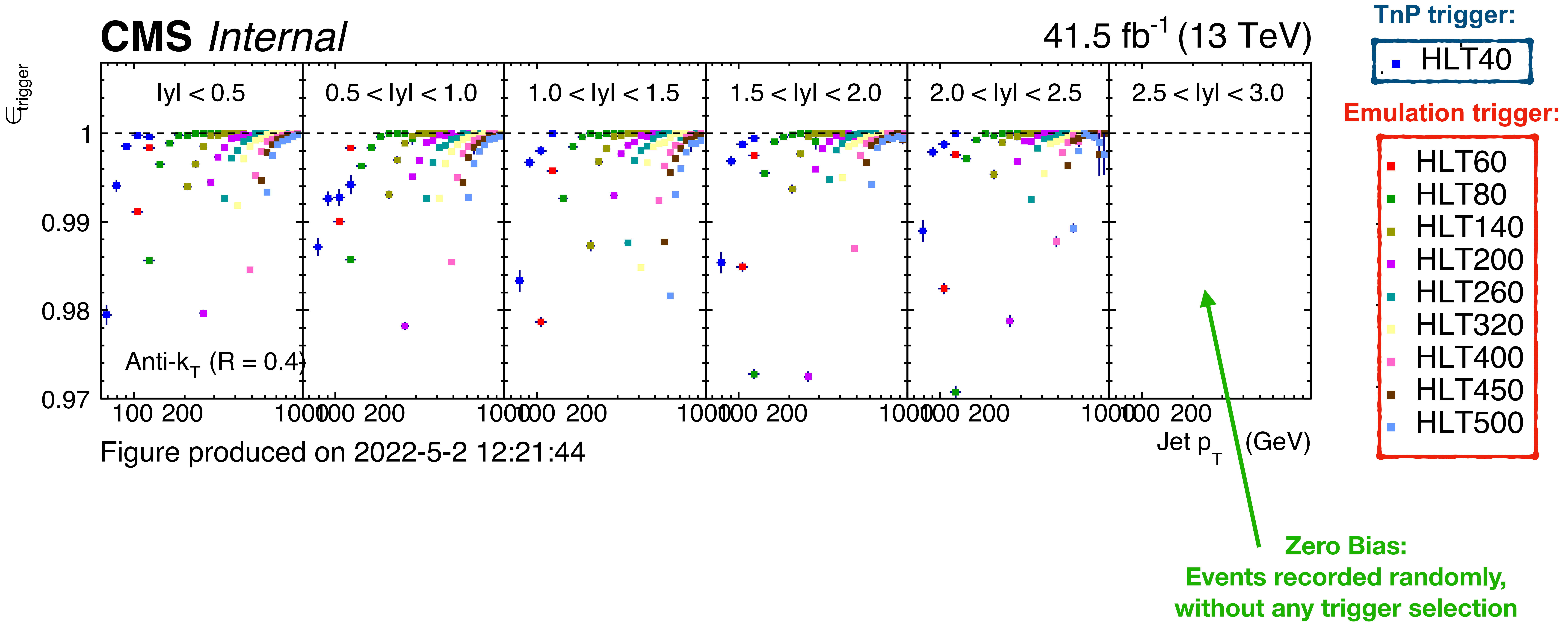
- **Emulation trigger:**
  - ~ Reference trigger method, whereas test trigger is emulated instead of directly checked if it has fired
    - **Check when a trigger of higher-adjacent th fired,** using previous th trigger as reference

$$\epsilon = \frac{N(test\ emulated\,|\,ref\ fired)}{N(ref\ fired)}$$

- **Tag and Probe method (TnP):**
  - Using events with di-jet final state and checking when only one or both should have fired the trigger
    - For first threshold: **HLT40**
    - **Cross-check** and to **estimate uncertainties**

$$\epsilon = \frac{N(probe\,|\,tag)}{N(tag)}$$

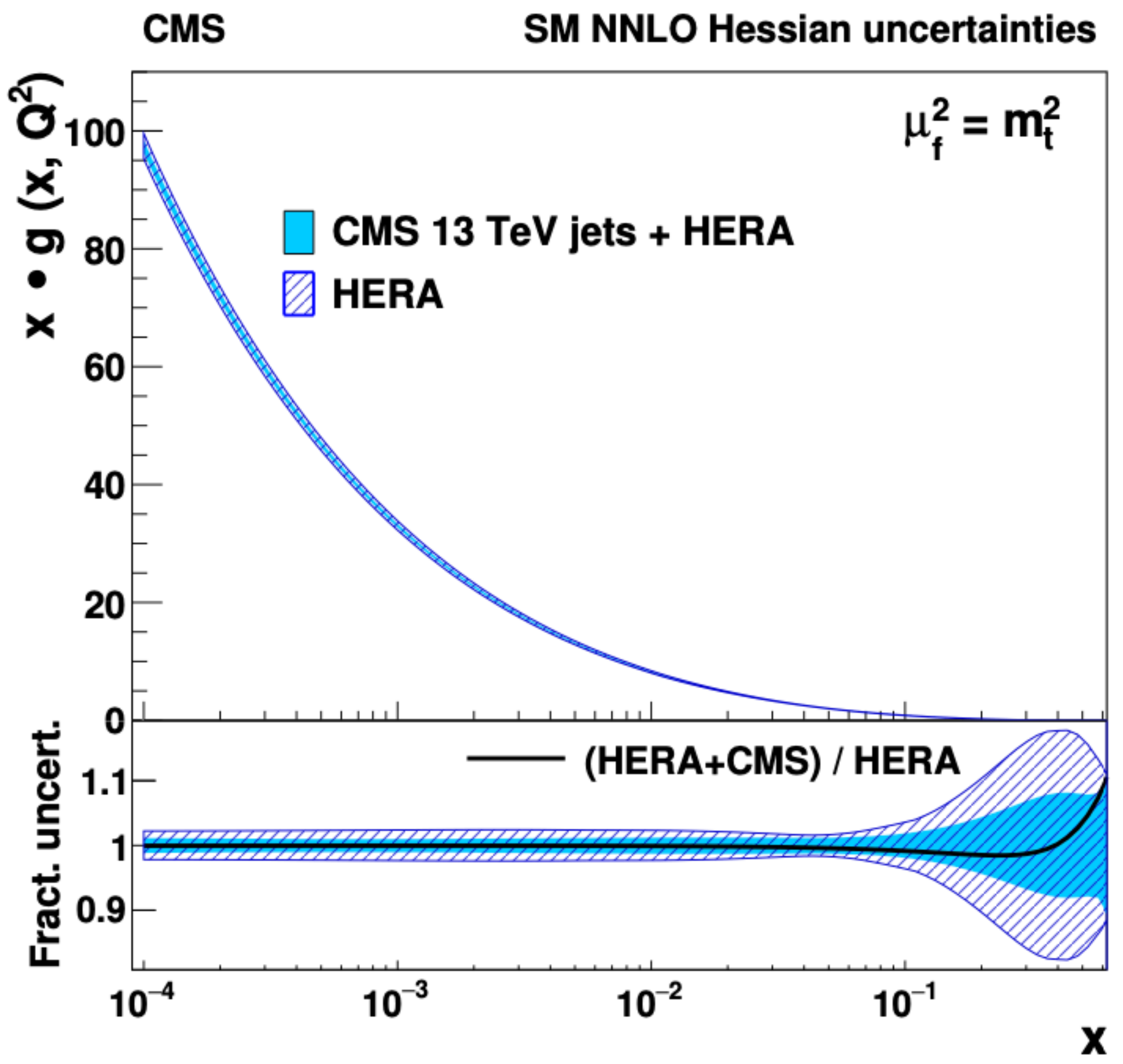
Emulation and TnP trigger efficiency curves for 2017 data



Interpretation

- **Inclusive jets** powerful tool to **constraint α_S, PDFs** and to search for **new physics:** see recent measurement (JHEP 2022, 142 (2022))

1. **Our measurement at 13 TeV will improve uncertainties respect to previous measurements:**
   - **Statistics** (not very important) due to higher accumulated luminosity
   - **Systematics** (very important) due to:
     - Most recent sample reconstruction
     - Most recent scale factors
     - More refined corrections



JHEP 2022, 142 (2022)

2. **Combine new measurement with ones of Run1 at 7, 8 TeV to improve:**

   → PDF constraints, sensitive to different x-range & Q^2

   → α_S and contact interaction precision

Summary and conclusion

- **Presented first look at inclusive jets full Run2 data in CMS:**
  - Jet veto maps & MET filters, Prefiring corrections investigated
  - PU corrections: work in progress

- **Prospects:**
  - Comparison with predictions
  - Perform the unfolding
  - Check compatibility with theory (and correlation with dijet mass)
  - Interpretation: extract most precise measurement of α_S

Thank you

Backup

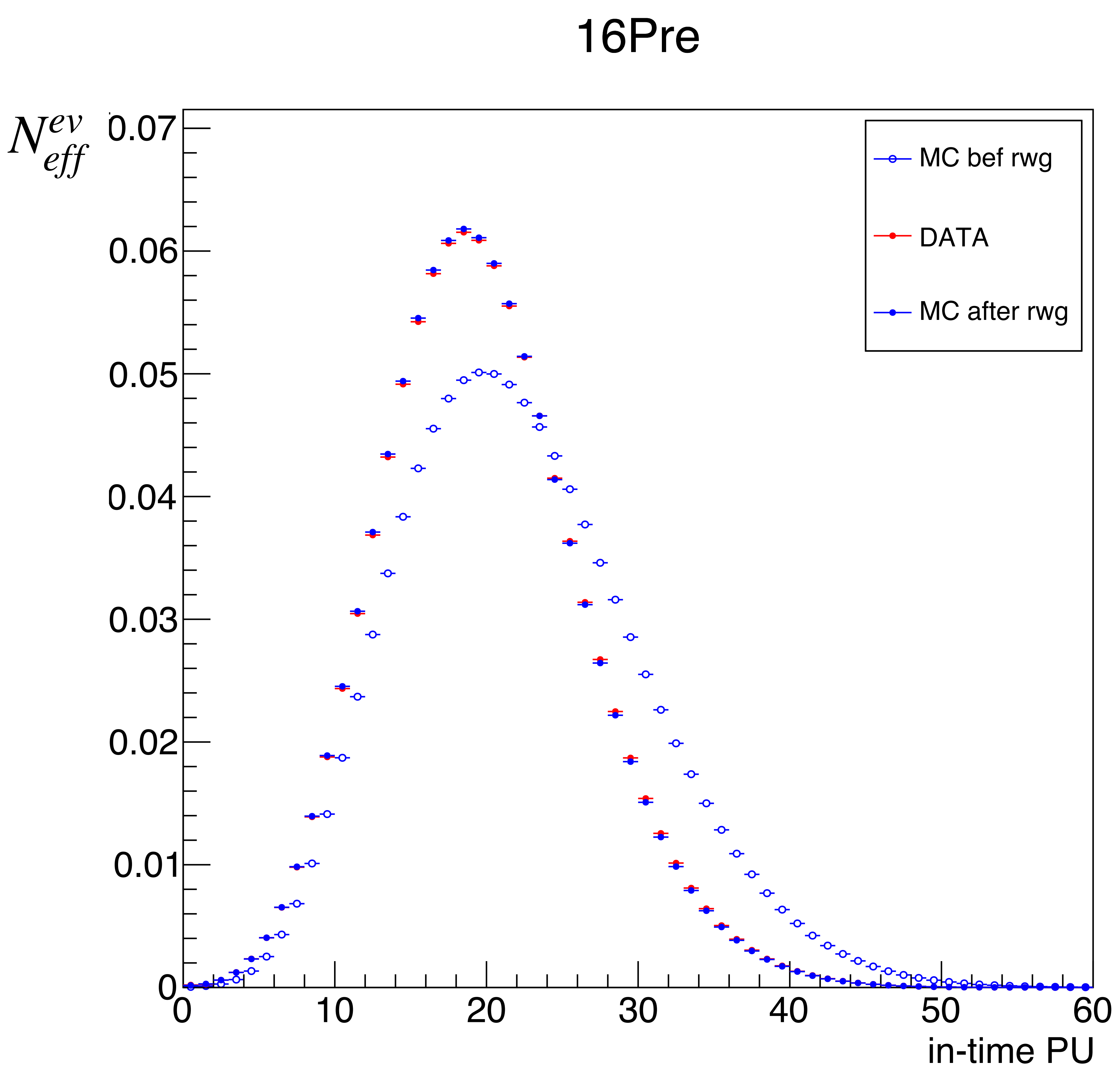
3. Pile-up corrections (for MC)

- **Pile-Up (PU) cleaning:** remove MC events at very low p_T where pileup jets with high p_T contribute with large weight

  → **artificial effect**, only due to our way of generating pile-up

- **Pile-up profile corrections:** MC usually produced with slightly overestimated PU

  → **Correction applied to match data PU profile**



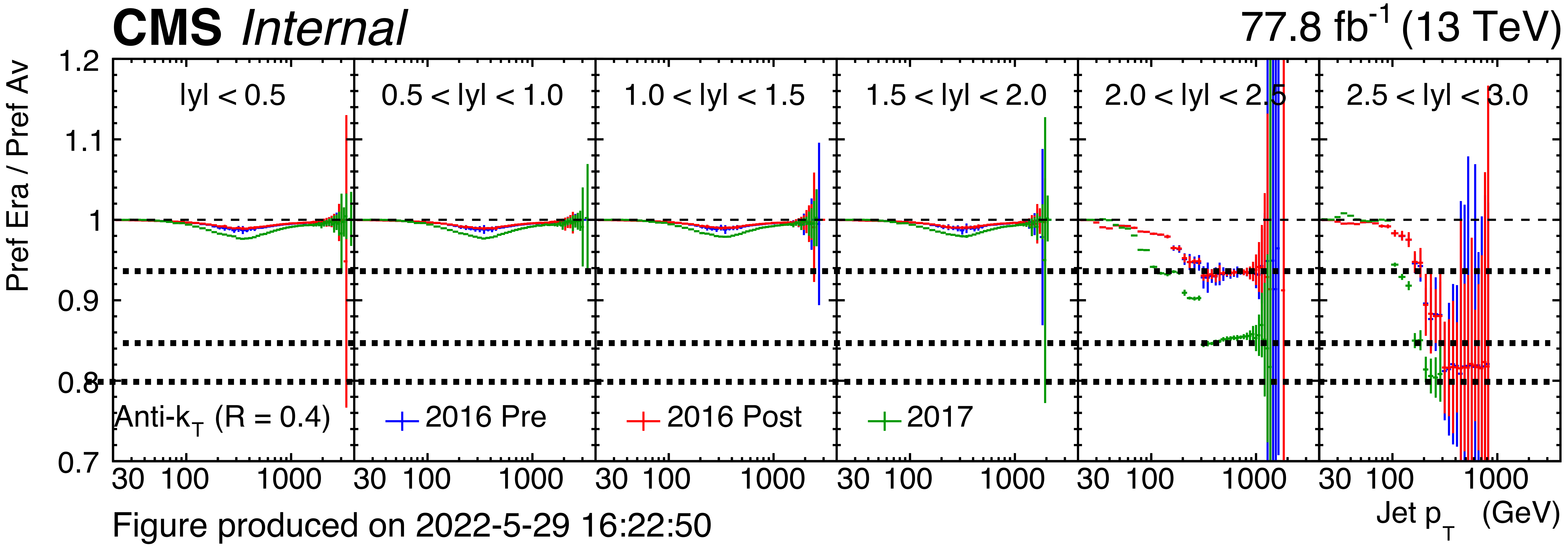
Prefiring Results

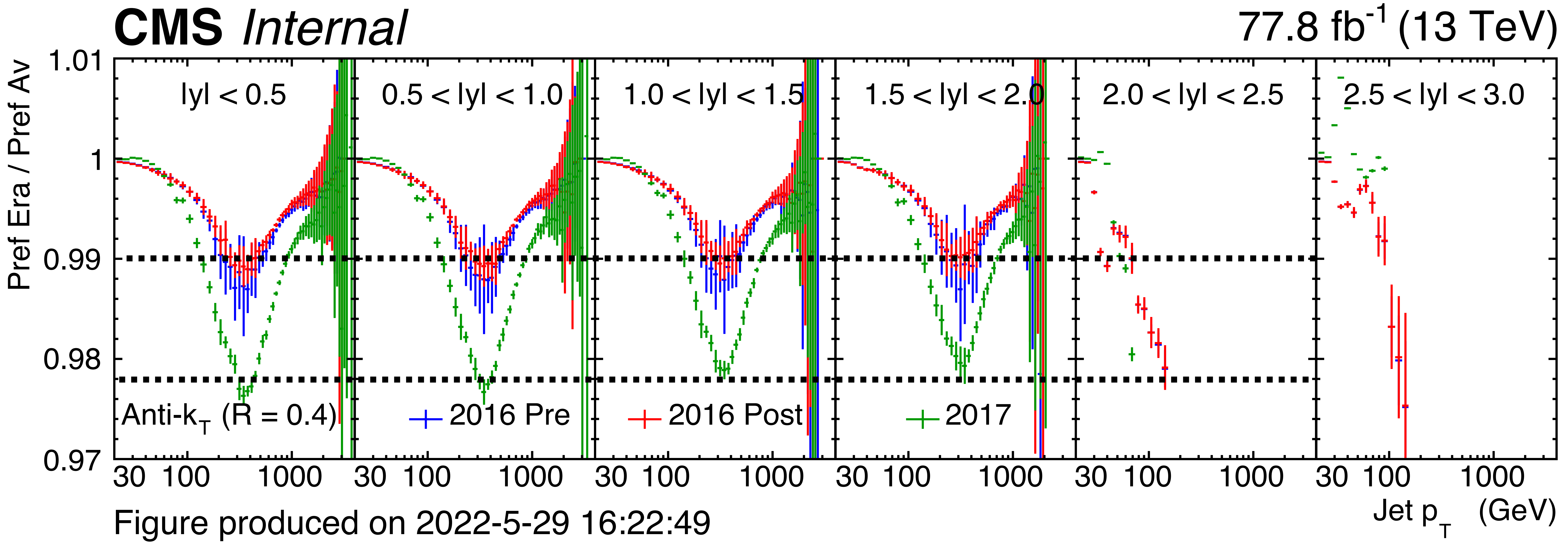
Differences for 16/17:

- 1-4 rap bins: **~1-2%**
- 5 rap bin: **~5/15%**
- 6 rap bin: **~20%**

Remark:

- Map per Era correction smaller than Average map correction



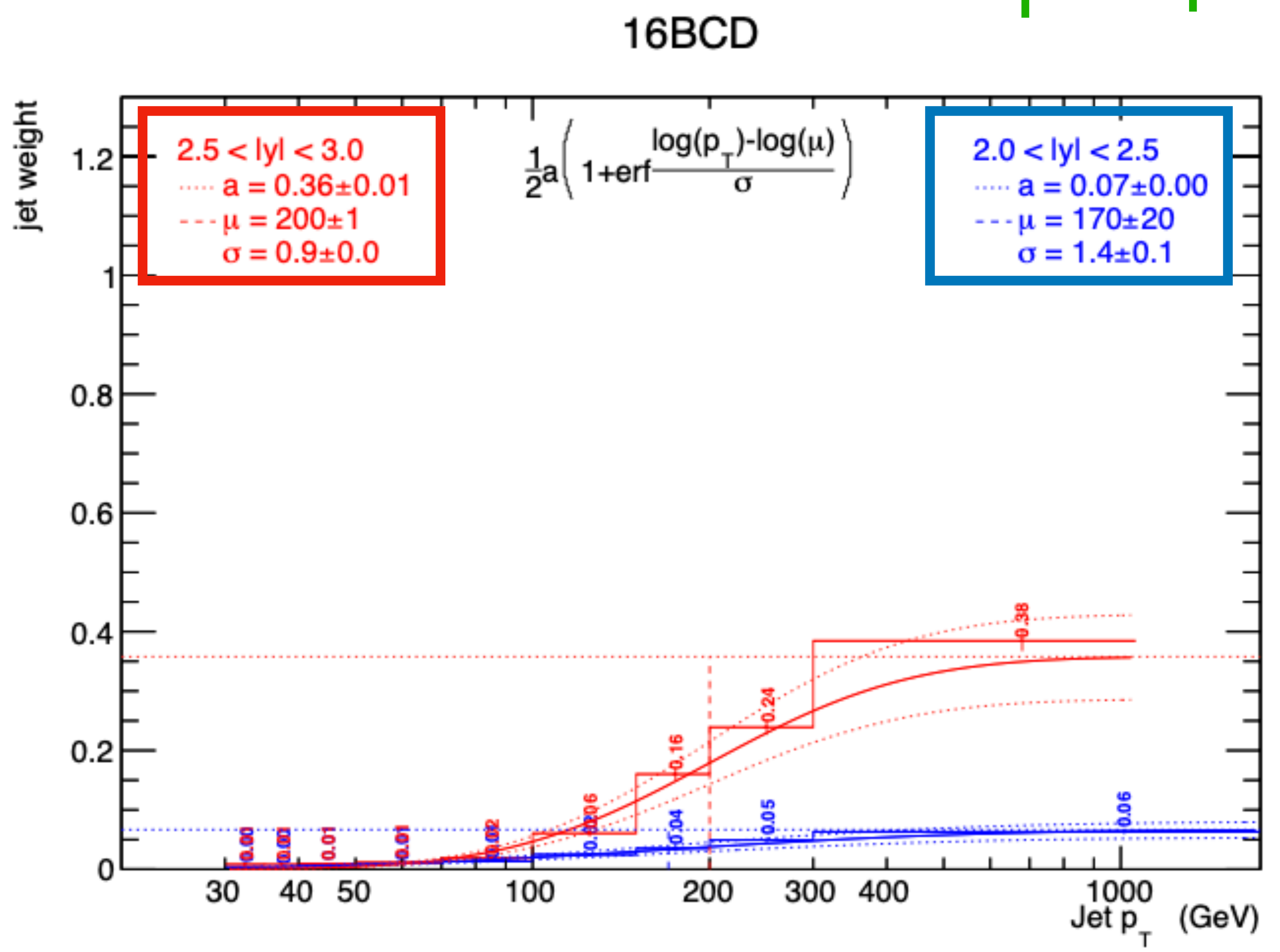


Conclusion prefiring study

- **Improve the correction** w.r.t. the official recommendations, as:
  - One single correction not enough to cover the various effects
  - Correction binning coarser than measurement's one

$$\frac{1}{2}a\left(1 + erf\,\frac{logp_T - log\mu}{\sigma}\right)$$

- **Next step:** smooth function of maps per era (continuous in p_T)
  - To avoid edge effects
  - To ensure smoothness of final results



- Preliminary study done, but in the future:
  - Try to derive again maps
  - Try to derive smooth function directly from data

Interpretation

- **Inclusive jets** powerful tool to **constraint α_S, PDFs** and to search for **new physics**

1. **Our measurement at 13 TeV will improve uncertainties respect to previous measurements:**
   - **Statistics** (not very important) due to higher accumulated luminosity
   - **Systematics** (very important) due to most recent sample reconstruction and more refined corrections

2. **Combine new measurement with ones of Run1 at 7, 8 (and 2.76) TeV to improve:**

   → PDF constraints

   → α_S and contact interaction precision

   1. **Preliminary study at NNLO:** →
      1. **FastNLO grid at NLO + QCD k-factors**
      2. **Previous analysis** (done with 2016 EOY)

Work in Progress

Data at 13 TeV	Data at 7+13 TeV
α_S: 0.1170 ± 0.0014	α_S: 0.1180 ± 0.0011
Total χ^2: 1321 / 1118 (~1.18)	**Total** χ^2: 1491 / 1251 (~1.19)

✓ **Only Fit uncertainties** (Hessian method): statistics and systematics of data and fitted PDF parameter uncertainties

‼ Not model and PDF parametrisation uncertainties

Fit setup Xfitter

Interpretation

- + 7-13 TeV Inclusive jet cross-section datasets

- Data divided in **~20 bins of pT** (~[97GeV, 3103GeV]) **in 4 bins of rapidity** (|y|<0.5, 0.5<|y|<1, 1<|y|<1.5, 1.5<|y|<2)

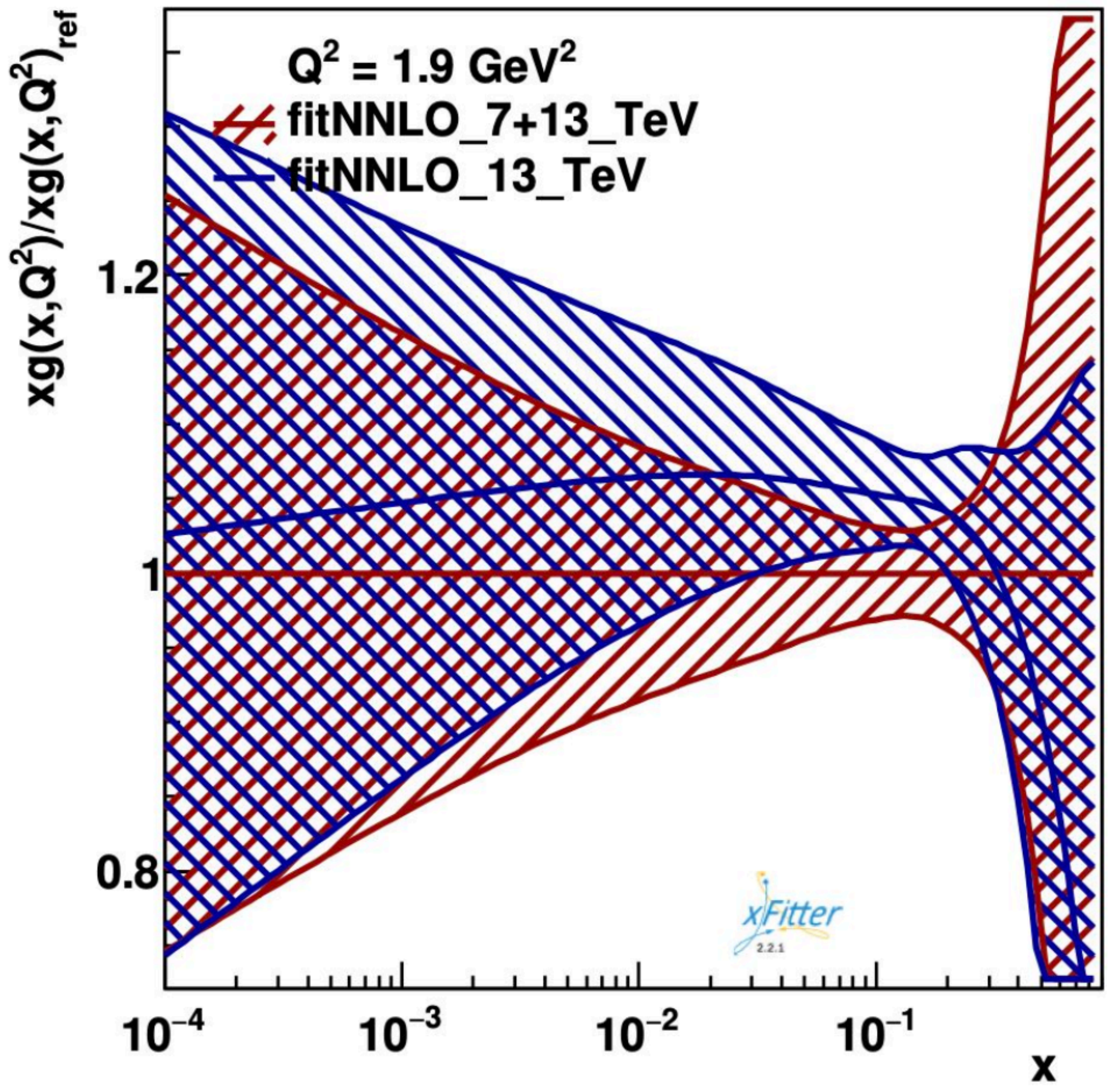
- Starting energy scale: **Q0 = 1.9 GeV**

- PDF parametrization: **p**arametrization scans following the approach of the HERAPDF2 paper

- **TheorExpr = 'F*kF*NP*EW'** (FastNLO, QCD kFactor, non perturbative correction, ew correction) defines the factors that goes into cross section computation
    - For 7 TeV data, QCD and EW factors are taken from repository NNPDF, computed by NNLOJET at HThat QCD scale

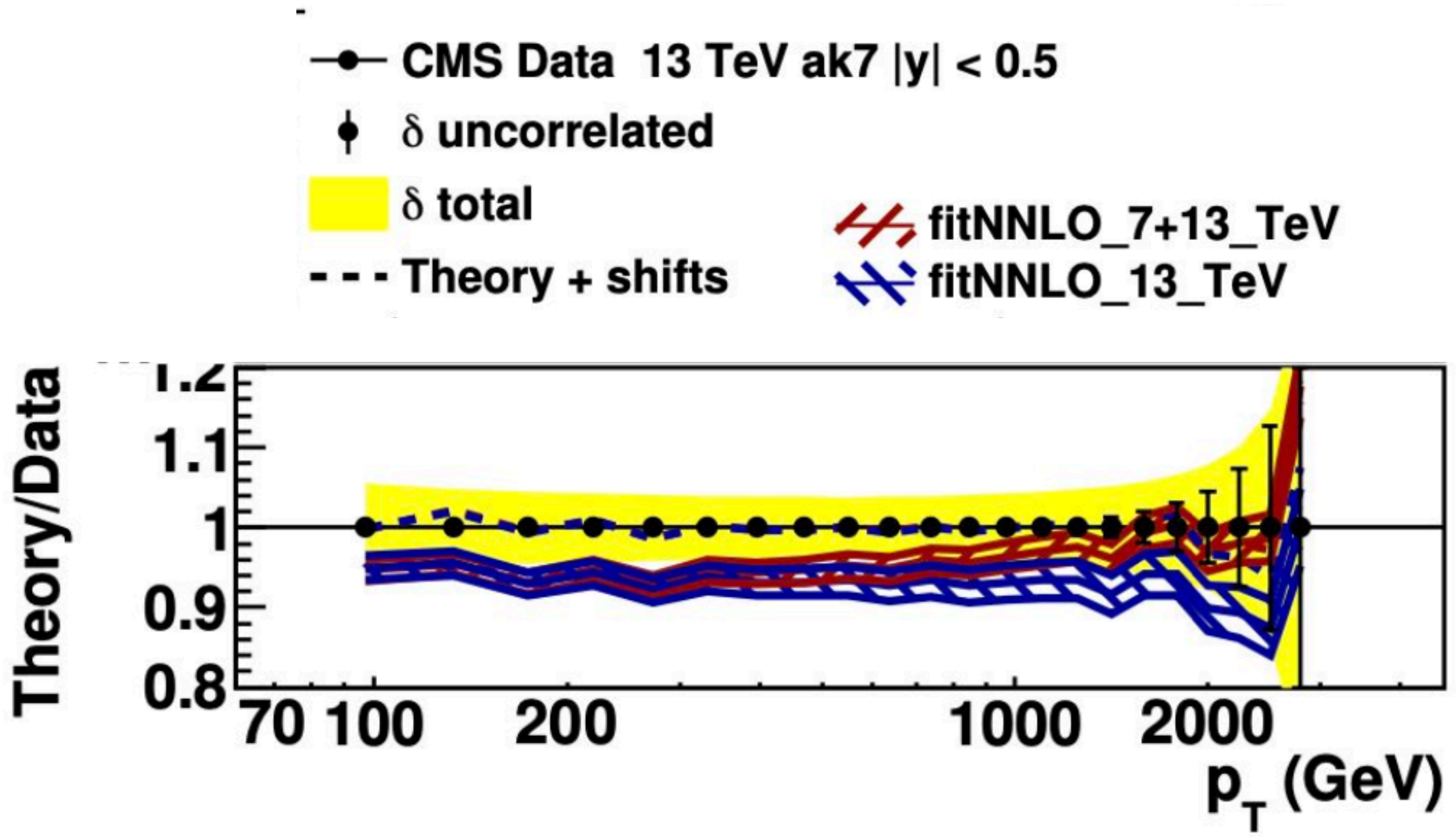
Interpretation

- **Goal:** fit of $PDFs$ and α_S at NNLO
- **Data:**
  - HERA I+II Dis datasets
  - Inclusive jet cross-section datasets at 7+8+13 TeV (R=0.7)



- Now: only 7+13 TeV, with FastNLO grid at NLO

- $TheorExpr = F_{NLO} * k_F^{QCD} * NP * EW$ defines the factors that goes into cross section computation



- Next step: → Grid at NNLO

$$TheorExpr = F_{NNLO} * NP * EW$$

Fit Results

Interpratation

- Change in the central value of α_S
- Uncertainty reduction of α_S variable
- Good reduced χ^2

Data at 13 TeV	Data at 7+13 TeV
α_s: 0.1170 ± 0.0014	**α_s:** 0.1180 ± 0.0011
Total χ^2: 1321 / 1118 (~1.18)	**Total χ^2:** 1491 / 1251 (~1.19)