Measurement of mass dependence of the transverse momentum of Drell Yan lepton pairs

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on behalf of the CMS collaboration

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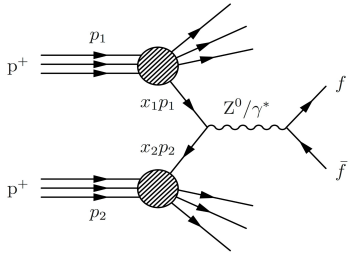
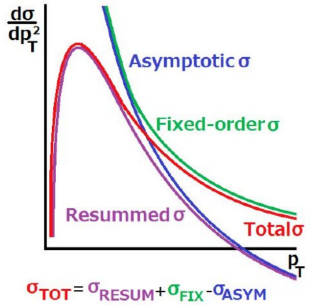
Introduction and motivation

- Measurements of the DY process in hadron collision - insight into the partonic structure and evolution of PDFs
- The transverse momentum of the Z boson understanding of the production of heavy states:

  ⇒ **Low p_T** - requires soft gluon resummation; sensitive to intrinsic p_T of colliding partons: transverse-momentum-dependent (TMD) PDF

  ⇒ **High p_T**: dominated by fixed order perturbative QCD





Differential cross sections in the dilepton transverse momentum $p_T(ll)$, and in the lepton angular variable φ^* are measured for different values of the dilepton mass, m_{ll} (50 GeV - 1 TeV)

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Analysis overview

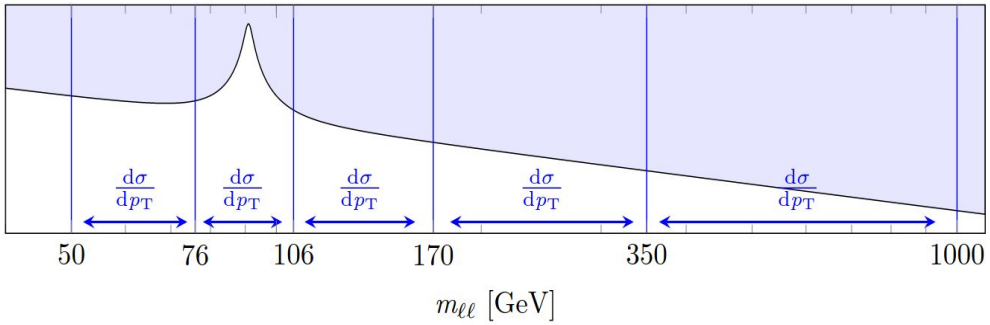
- Measuring the $p_T(ll)$ spectrum in a wide m_{ll} range tests the validity of the resummation approach and the precision of different predictions
- The kinematic quantity φ^*, derived from these lepton angles, is measured
- The DY process in the presence of one jet is a complementary way to investigate the initial-state QCD radiations

13 TeV, 36.3 fb^{-1}

φ^* variable:

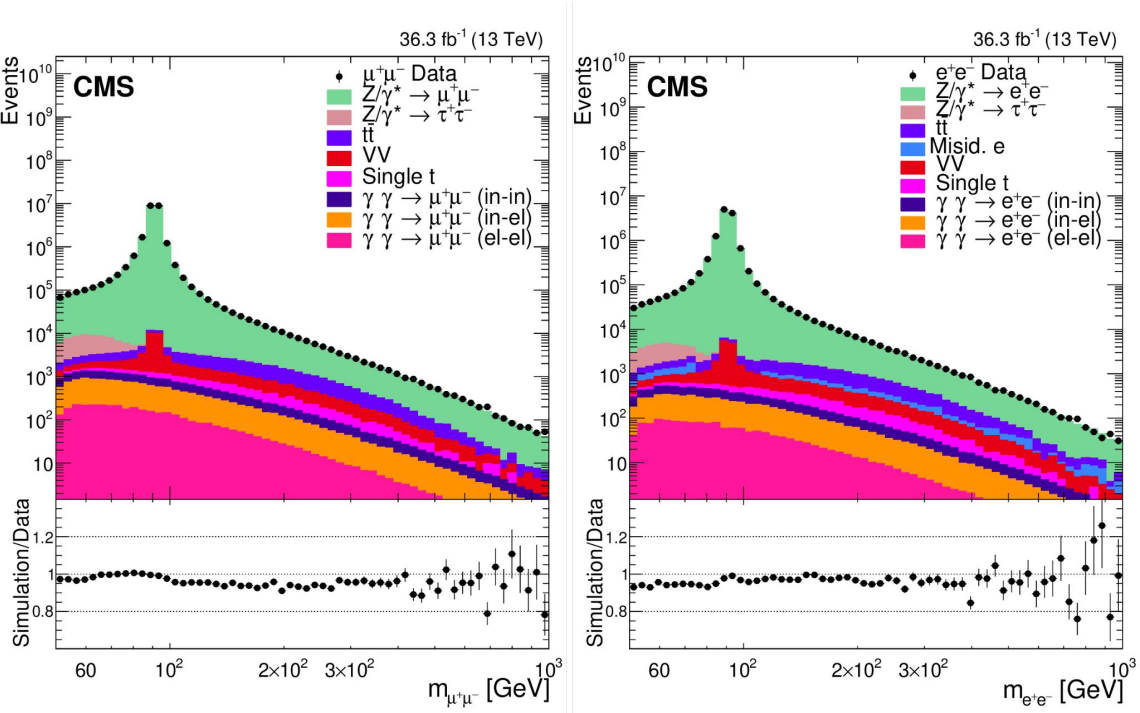
$$\varphi^*_\eta \equiv \tan\left(\frac{\pi - \Delta\varphi}{2}\right) \sin(\theta^*_\eta)$$

where: $\cos(\theta^*_\eta) = \tanh\left[(\eta^- - \eta^+)/2\right]$



- $p_T(ll)$ and φ^* are measured in five invariant mass bins
  - $p_T(ll)$ for ≥ 1 jet in the lower four bins
- Cross section ratio to the one at Z peak
  - reduced uncertainty
  - probes of evolution between different scales

Background estimation



Monte-Carlo based:

- **tt and single top**
  - → contribute at **high mass**
  - → reduced by the **b veto**
- **γγ → l^+l^- (in-in, in-el, el-el)**
  - → significant at very **low p_T**
- **Z/γ* → $\tau^+\tau^-$**
  - → dominant at **low mass**
- **Dibosons (VV)**
  - → WW, ZW, ZZ

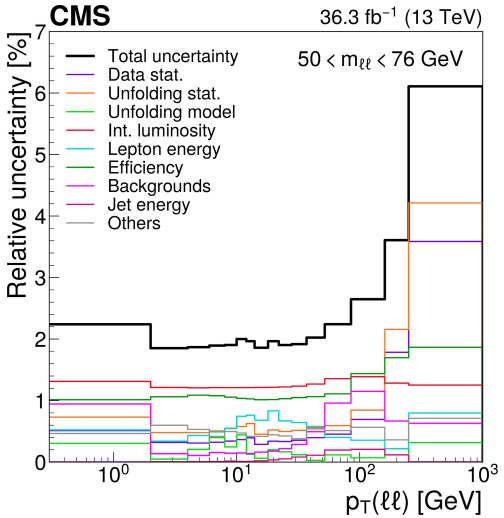
Data-driven:

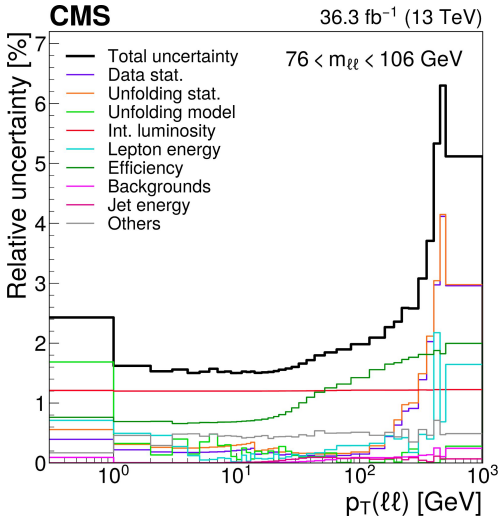
- **Misidentified electrons**
  - → Estimation based on e^+e^+ and e^-e^- events

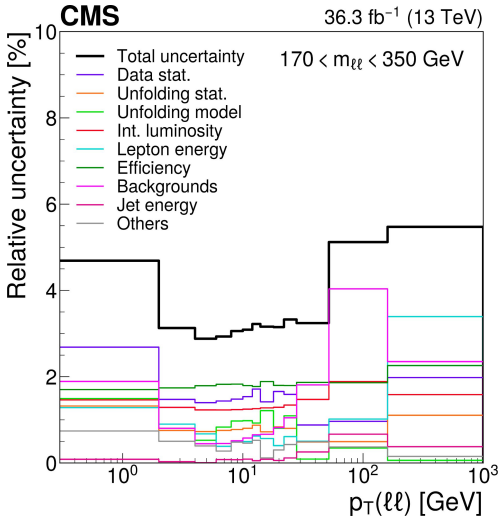
➢ Good description of the data is obtained

Systematic uncertainty

- In inclusive case - **total uncertainty at the level of 1.5-2% around Z peak**
  - → **Luminosity** uncertainty is dominant, follow by the **efficiency**
  - → **Unfolding statistic** is dominant in high p_T region







- In DY+≥1 jets - total uncertainty is ~10% level
  - → dominant uncertainty from **jet energy scale** correction

Theoretical predictions

MADGRAPH_aMC@NLO FxFx

- Interfaced with PYTHIA8 using the CUETP8M1 Tune
- Matrix element at NLO for up to 2 partons
- NNPDF3.0 NLO PDF

MiNNLO

- PYTHIA8 for the parton showers based on the CP5 tune
- Matrix element at NNLO
- NNPDF3.1 NNLO PDF
- Sudakov form factors are used to interpolate between the scale

CASCADE

- Parton Branching TMD
- PYTHIA6
- Z+0j or Z+1j at NLO

ARTEMIDE

- Analytical prediction
- N^3LL + NNLO TMD
- QED FSR based on PYTHIA8

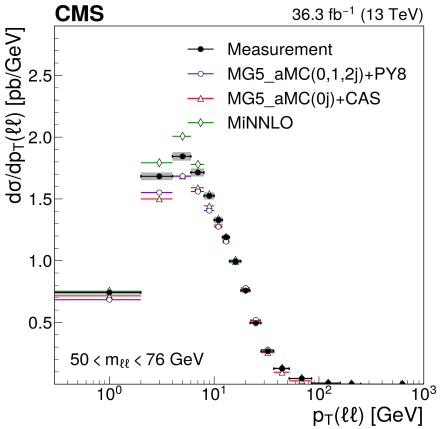
GENEVA τ

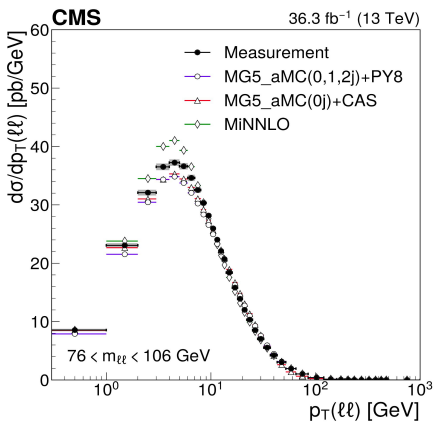
- higher-order resummation with a DY calculation at NNLO
- 0-jettiness variable τ_0 resumation - NNLL' τ + NNLO
- PYTHIA8 parton shower, tune CUETP8M1
- PDF4LHC15 NNLO

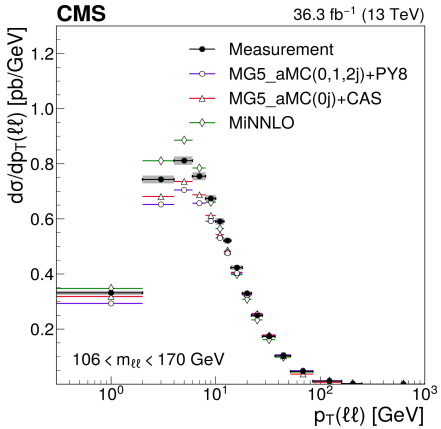
GENEVA q_T

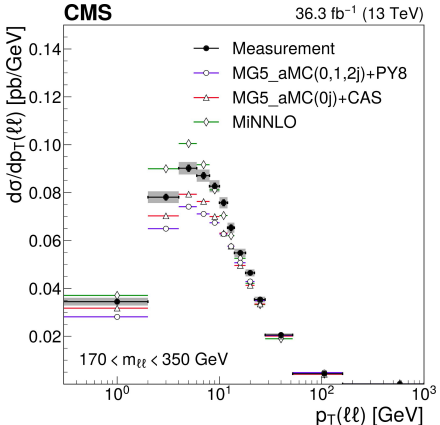
- q_T resummation at N^3LL in the Radish formalism + NNLO
- PYTHIA8 parton shower, tune CUETP8M1
- PDF4LHC15 NNLO

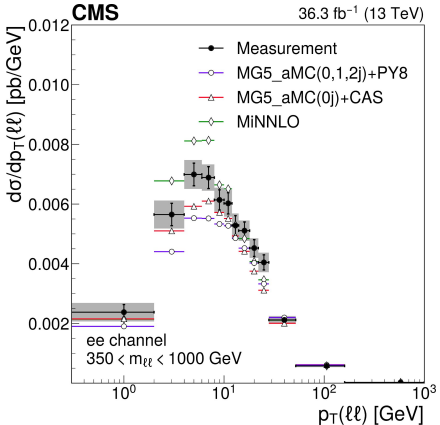
p_T results





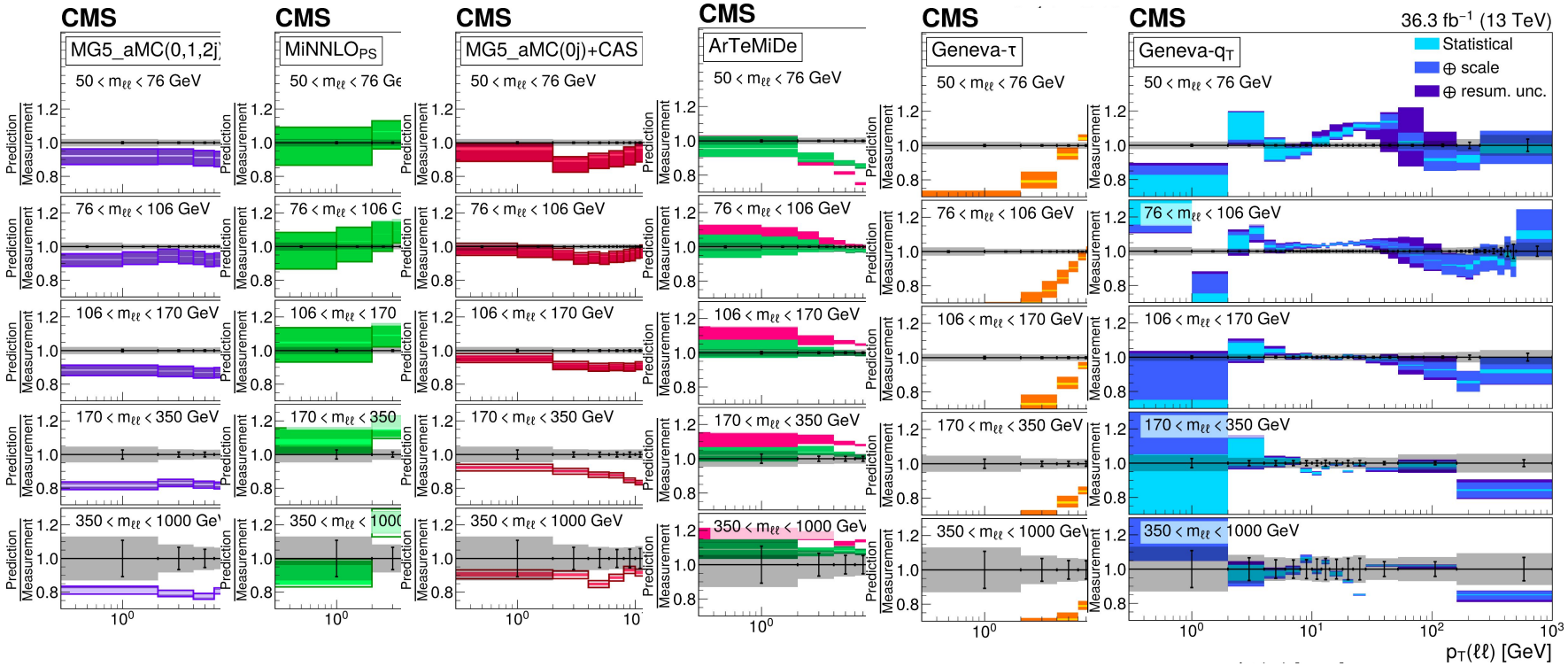






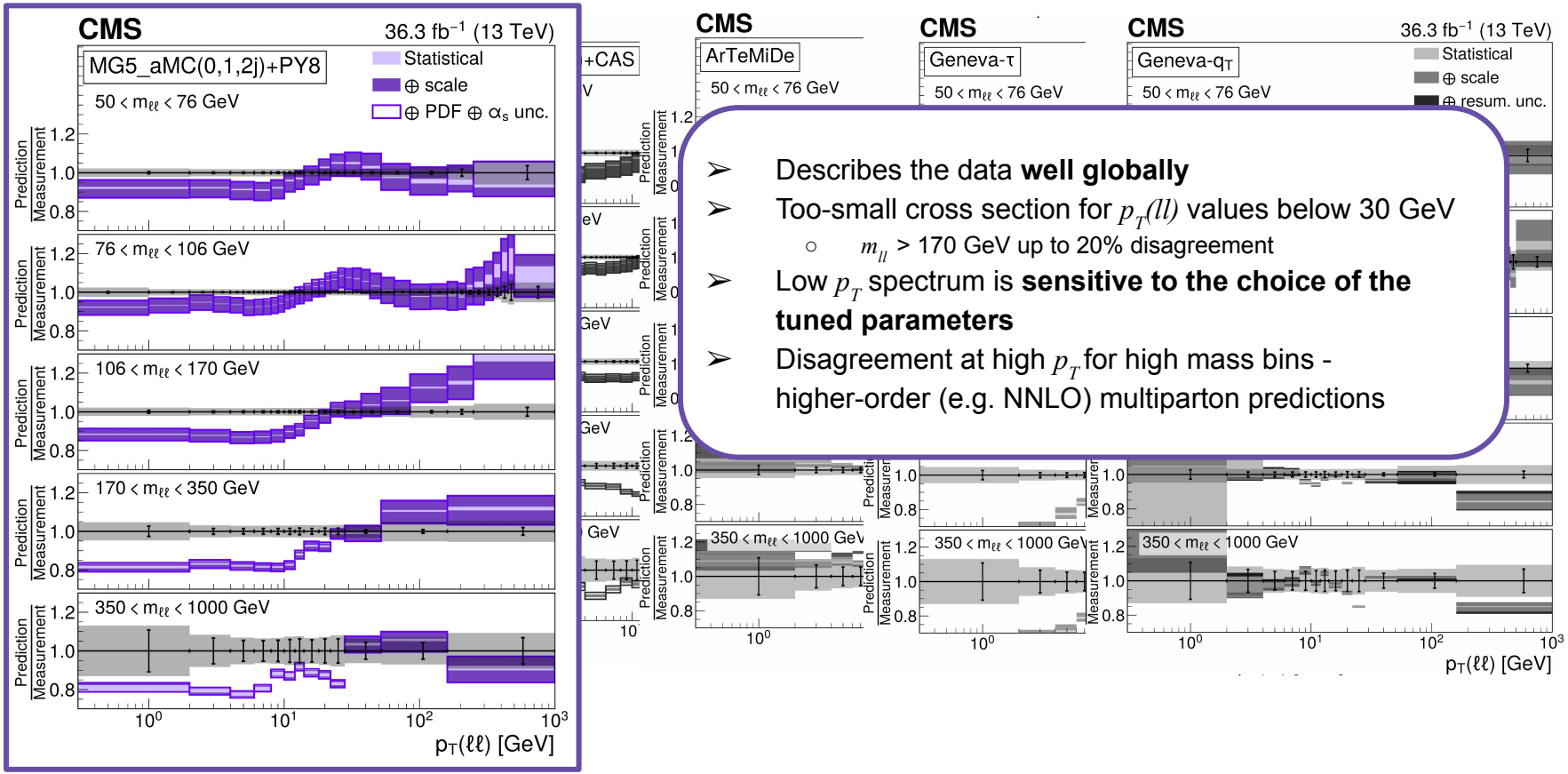
- Highest mass range is based on the electron channel only
- The variation of the dilepton invariant mass does not have a visible effect on the peak position (around 5 GeV)

p_T results



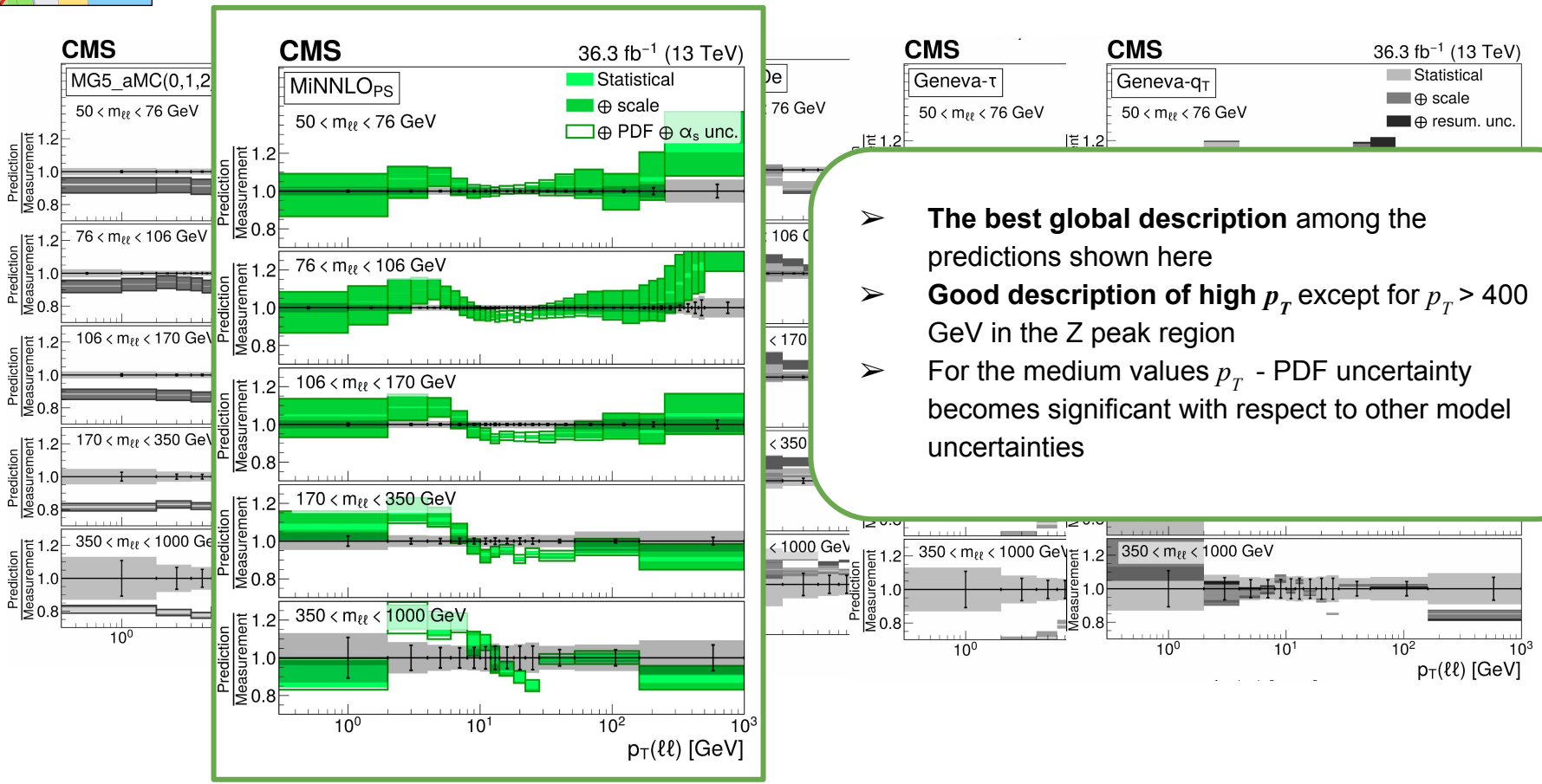
- Different level of agreement for different theoretical predictions

p_T results



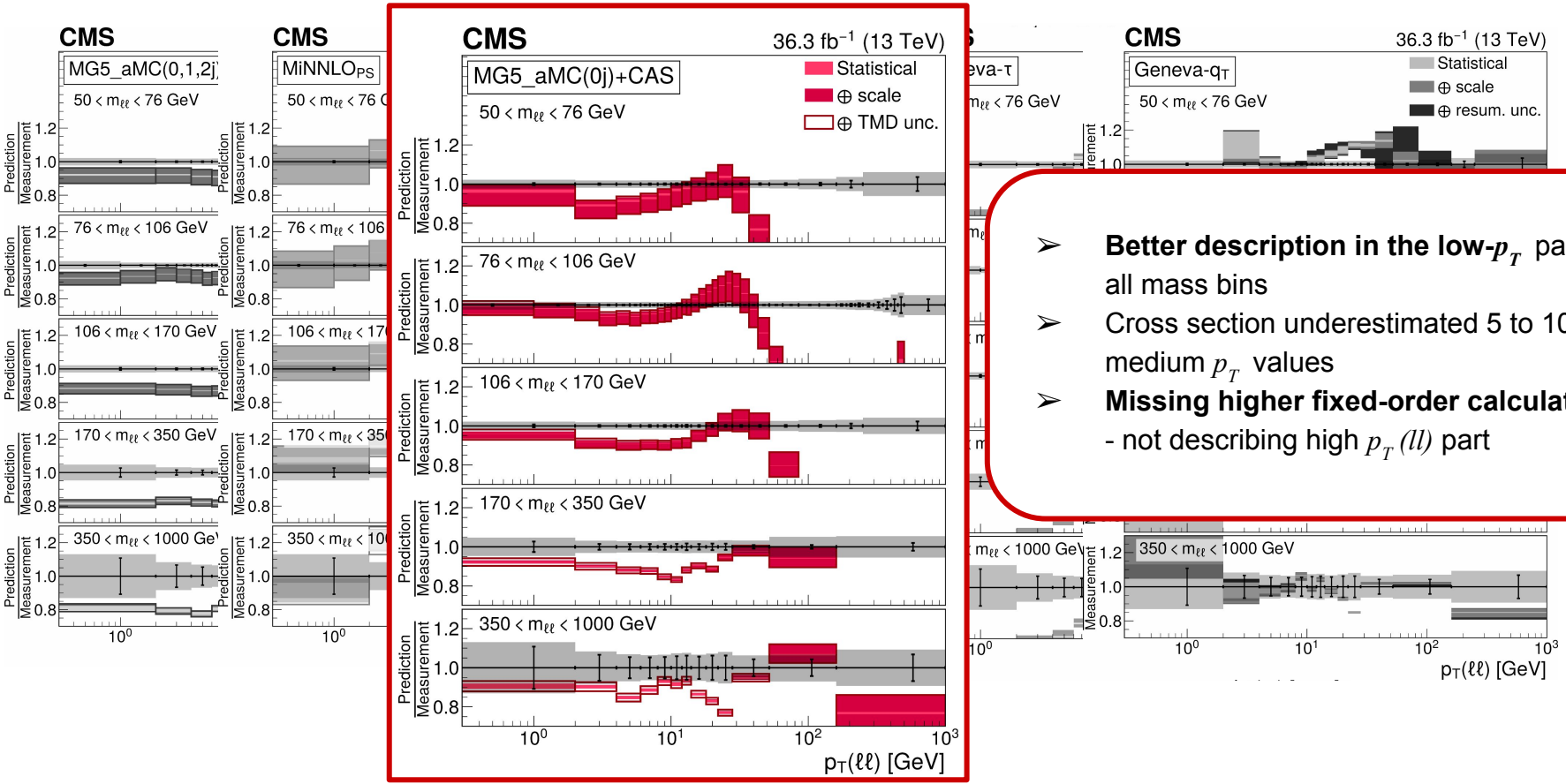
- Describes the data **well globally**
- Too-small cross section for $p_T(ll)$ values below 30 GeV
  - m_{ll} > 170 GeV up to 20% disagreement
- Low p_T spectrum is **sensitive to the choice of the tuned parameters**
- Disagreement at high p_T for high mass bins - higher-order (e.g. NNLO) multiparton predictions

p_T results



- **The best global description** among the predictions shown here
- **Good description of high p_T** except for p_T > 400 GeV in the Z peak region
- For the medium values p_T - PDF uncertainty becomes significant with respect to other model uncertainties

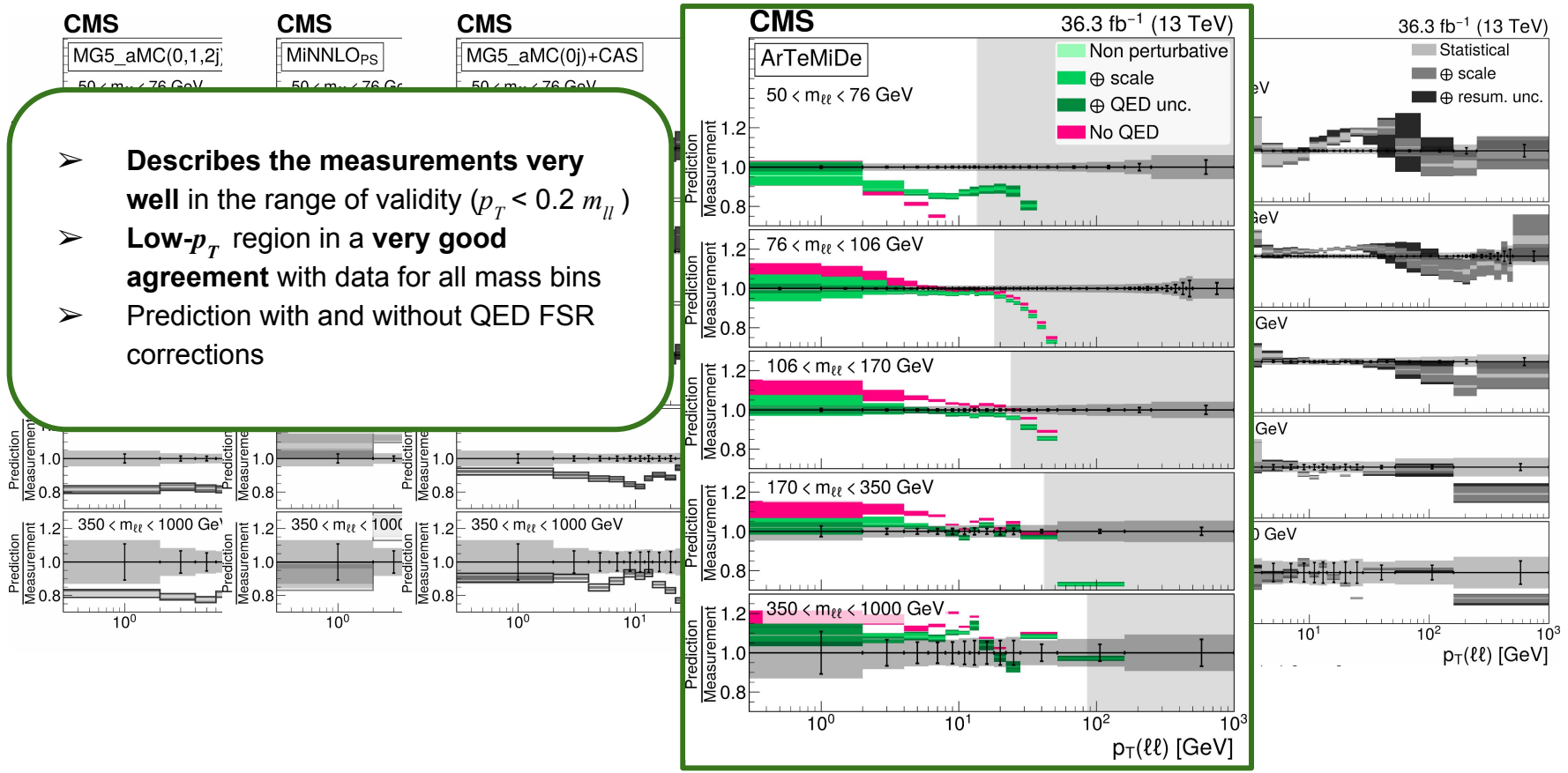
p_T results



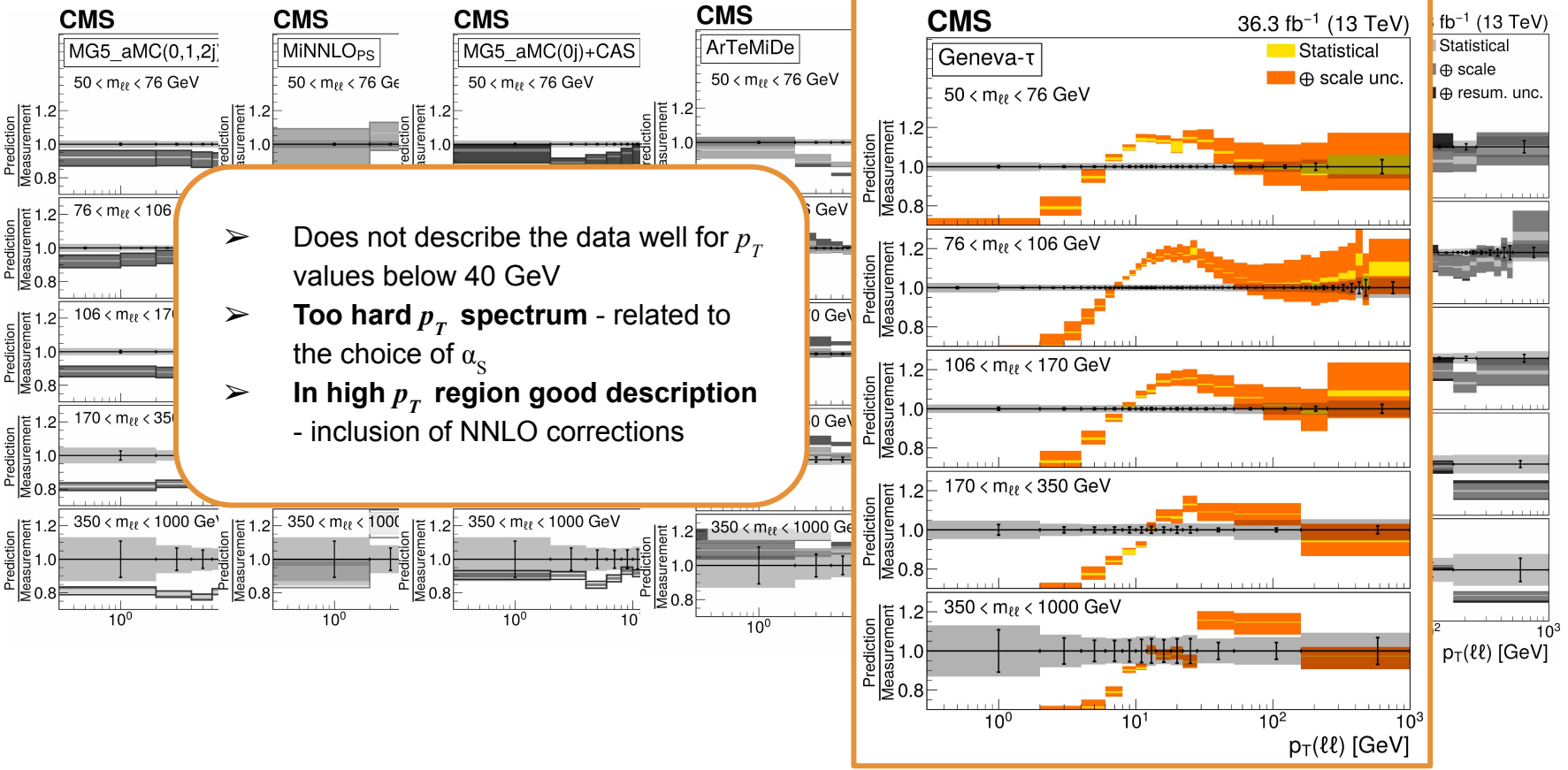
- **Better description in the low-p_T** part in all mass bins
- Cross section underestimated 5 to 10% for medium p_T values
- **Missing higher fixed-order calculations** - not describing high p_T *(ll)* part

p_T results

- **Describes the measurements very well** in the range of validity ($p_T < 0.2\ m_{ll}$)
- **Low-p_T** region in a **very good agreement** with data for all mass bins
- Prediction with and without QED FSR corrections

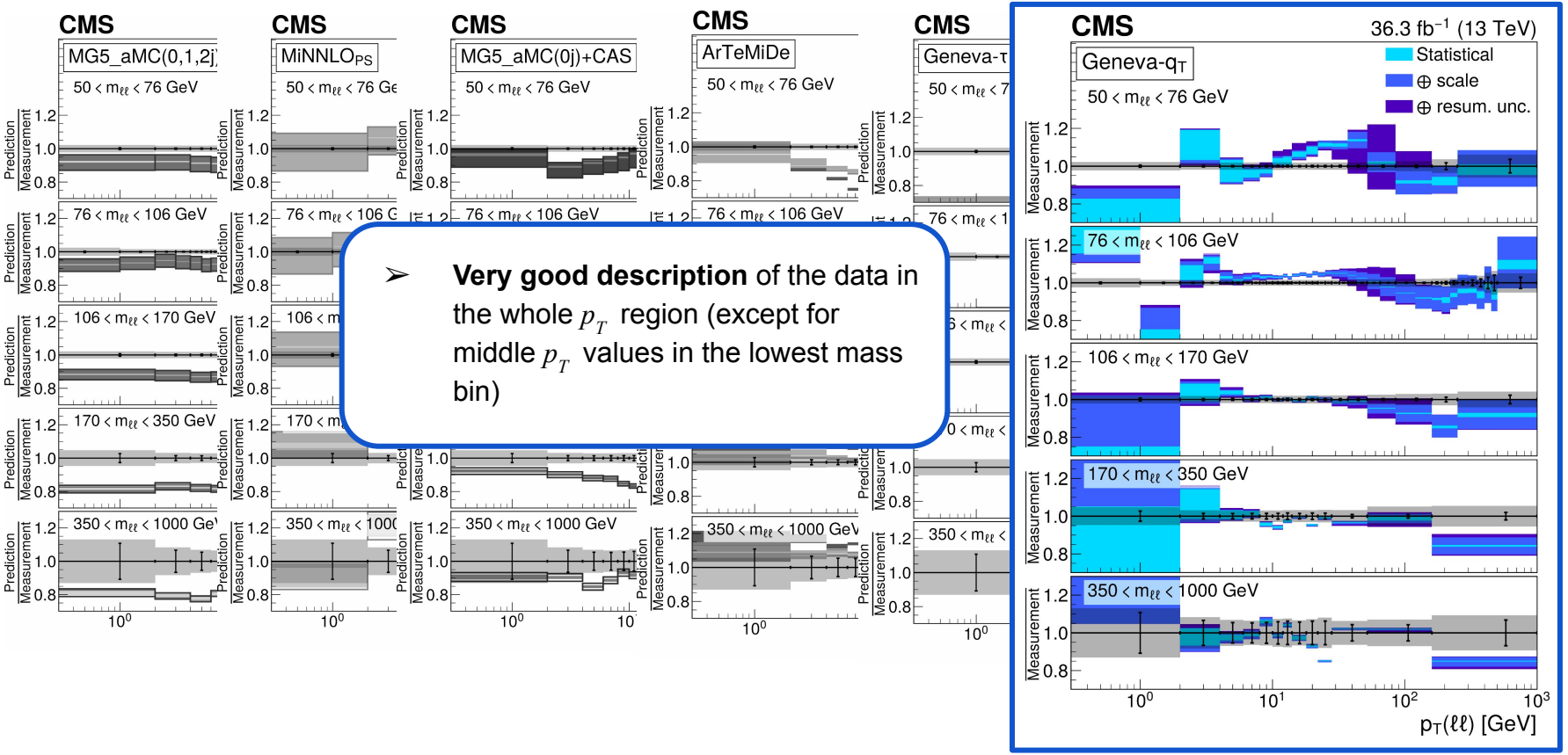


p_T results



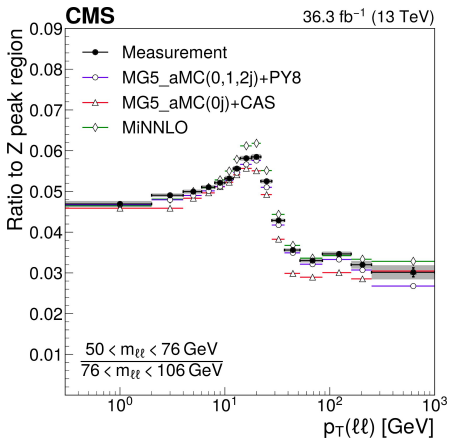
- Does not describe the data well for p_T values below 40 GeV
- **Too hard p_T spectrum** - related to the choice of α_S
- **In high p_T region good description** - inclusion of NNLO corrections

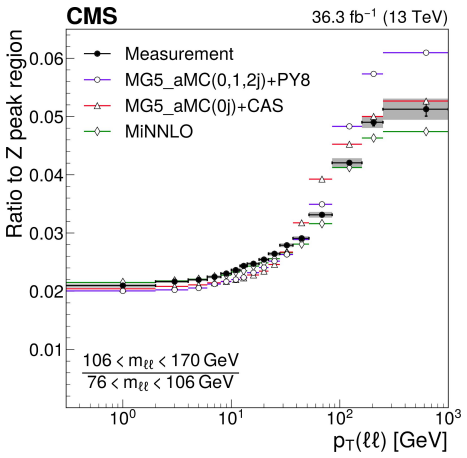
p_T results

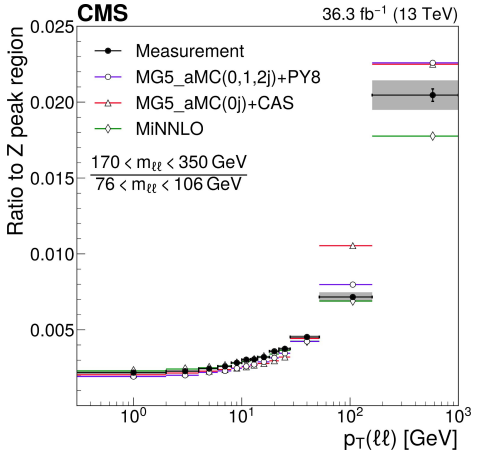


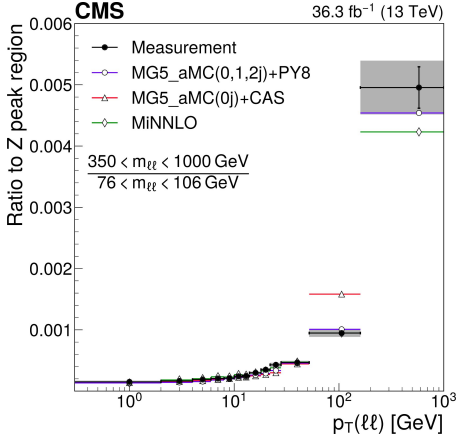
➢ **Very good description** of the data in the whole p_T region (except for middle p_T values in the lowest mass bin)

Ratio of cross section to Z peak



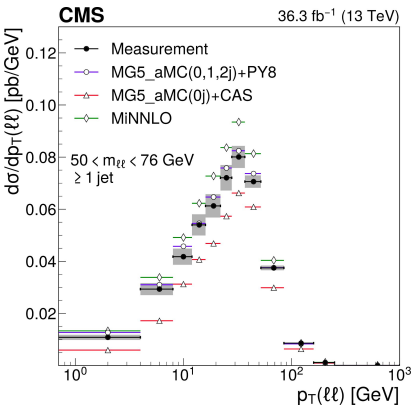


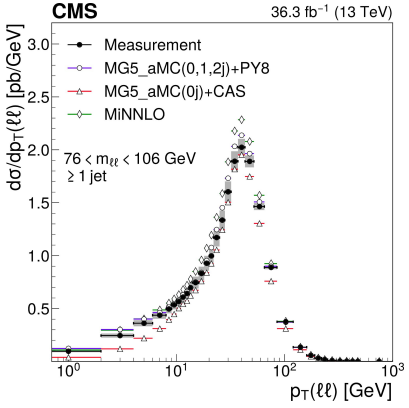


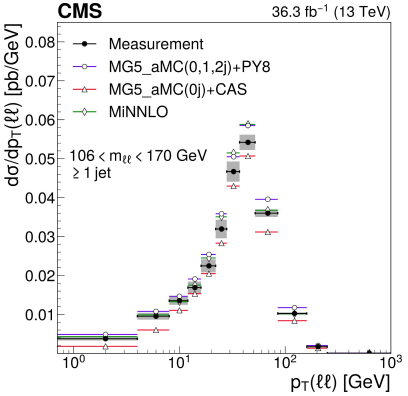


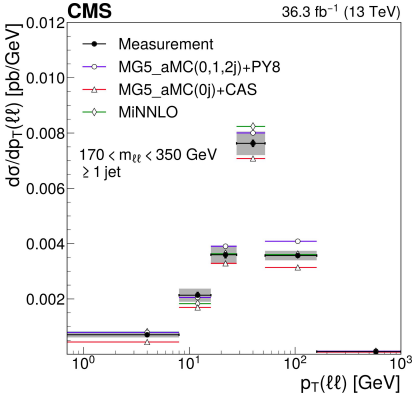
- Increase of m_{ll} results in a broader distribution for p_T *(ll)* values above the peak
- The rising ratio for the lowest m_{ll} range up to a p_T *(ll)* value of 20 GeV is due to QED radiative effects on the final-state leptons

p_T results DY+≥1 jets



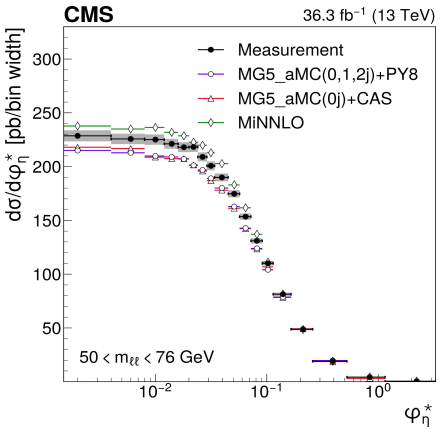


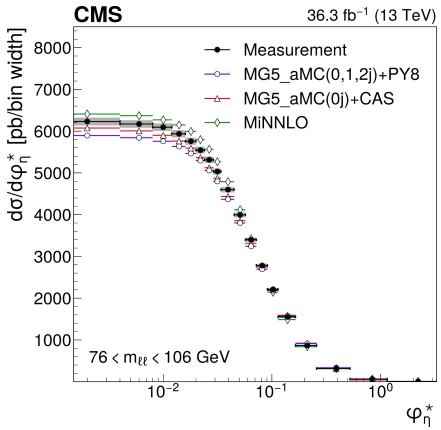


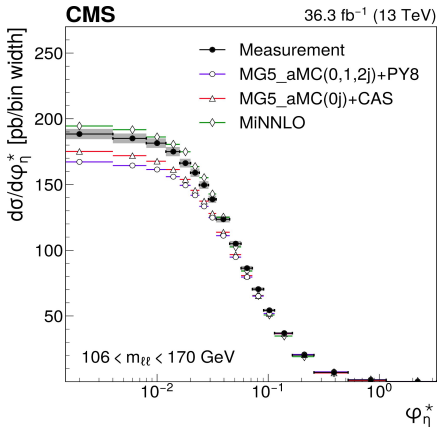


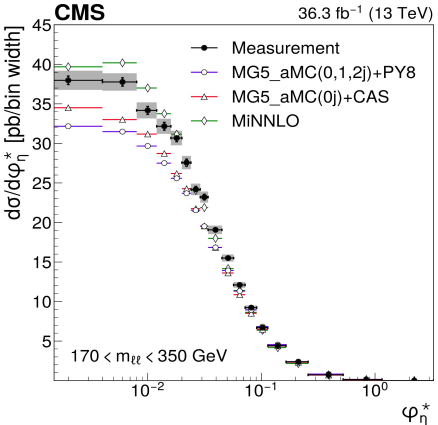
- The peak is shifted towards larger p_T *(ll)* values corresponding to the jet selection threshold (30 GeV here) regardless of the m_{ll}
- The distributions become broader for p_T *(ll)* values larger than the peak for increasing m_{ll}

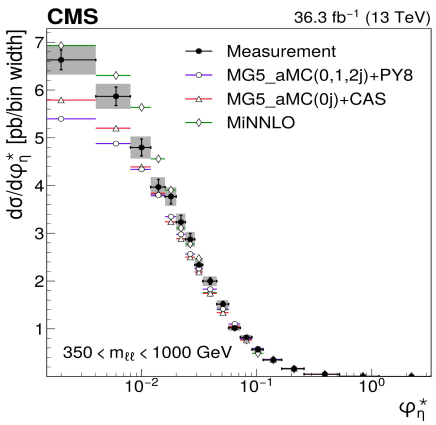
φ^* results





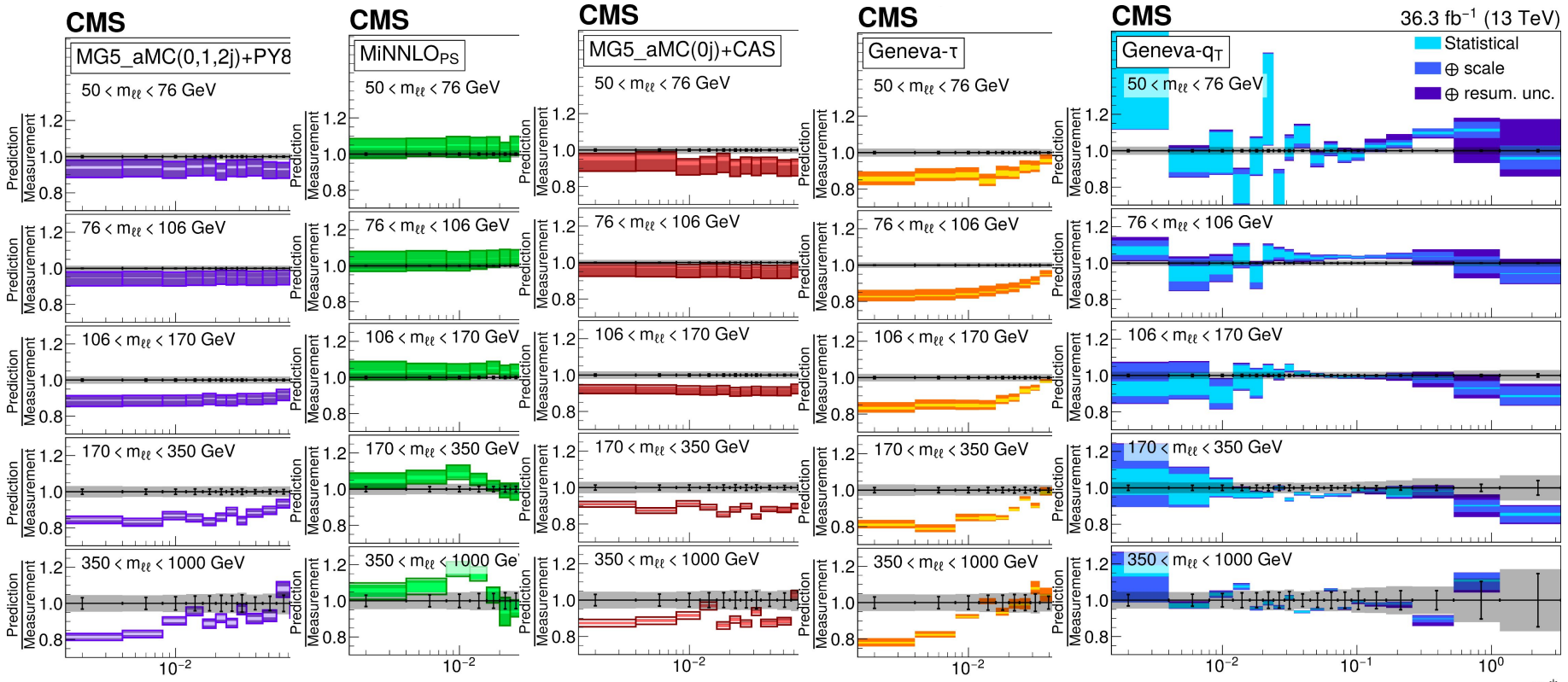




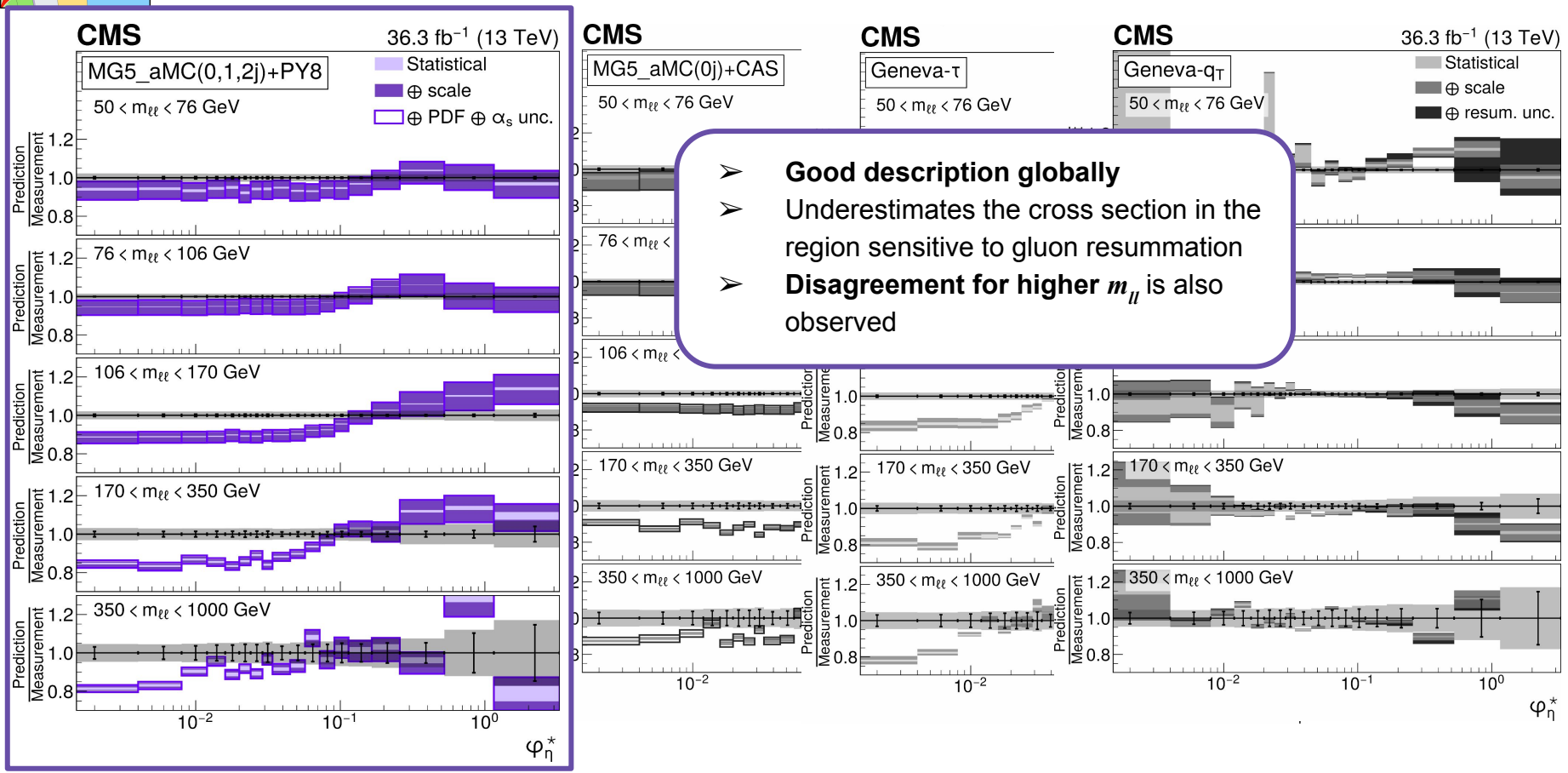


- At small values, the φ^* distributions contain a plateau whose length decreases with increasing m_{ll}
- φ^* distributions fall more rapidly with increasing m_{ll}

φ^* results

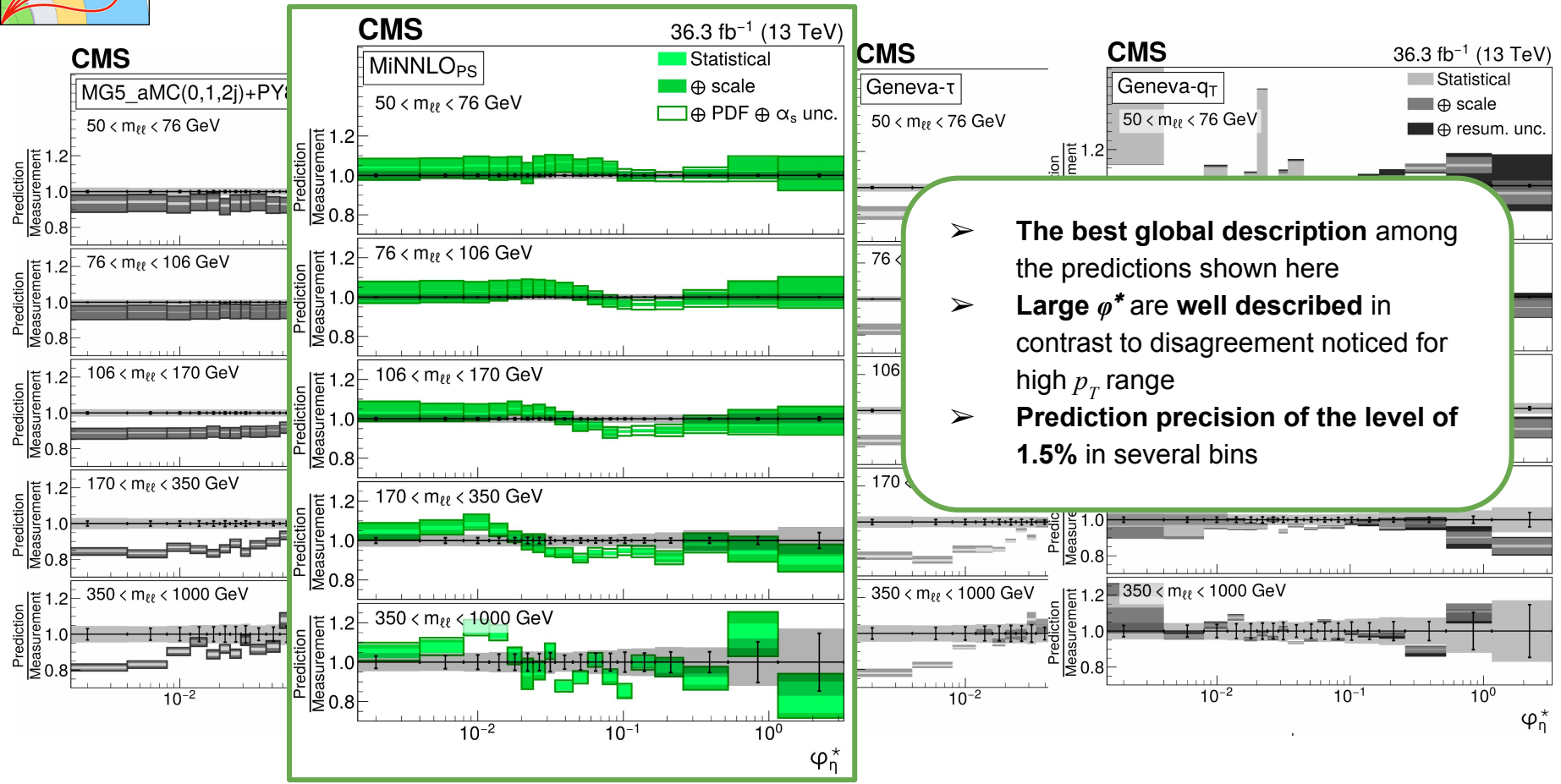


φ^* results



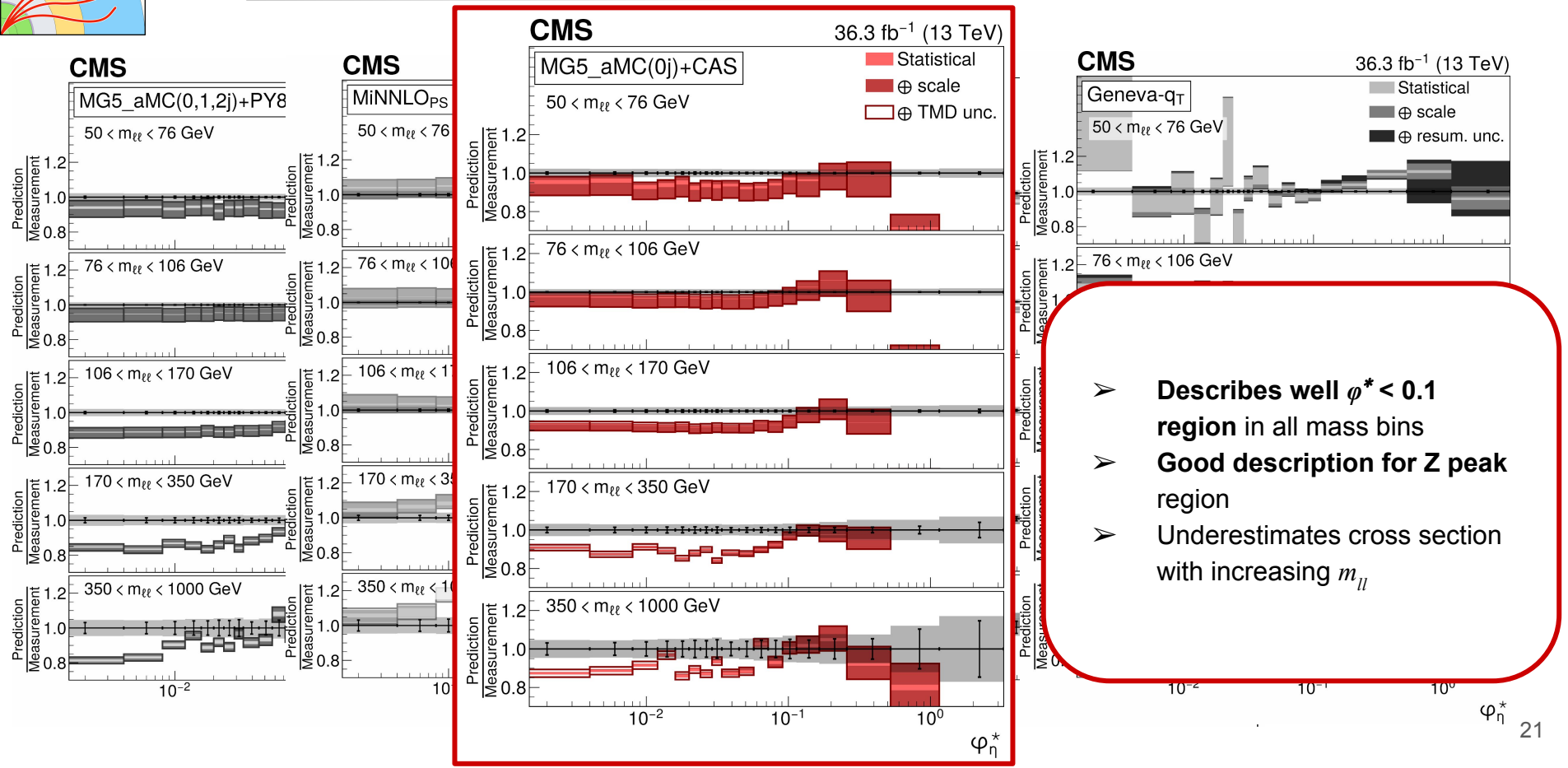
- **Good description globally**
- Underestimates the cross section in the region sensitive to gluon resummation
- **Disagreement for higher m_{ll}** is also observed

φ^* results



- **The best global description** among the predictions shown here
- **Large φ^*** are **well described** in contrast to disagreement noticed for high p_T range
- **Prediction precision of the level of 1.5%** in several bins

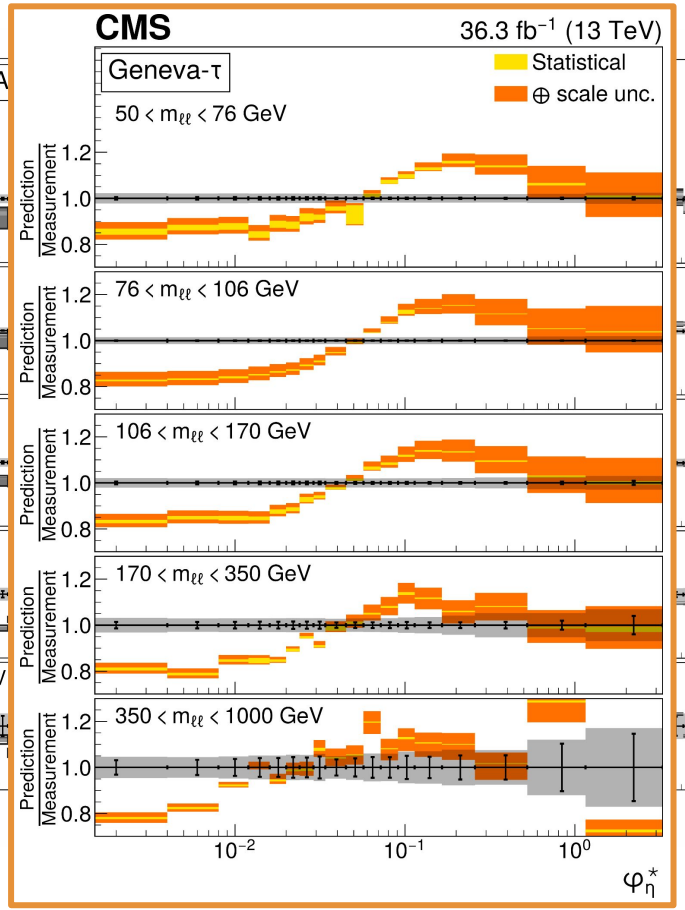
φ^* results

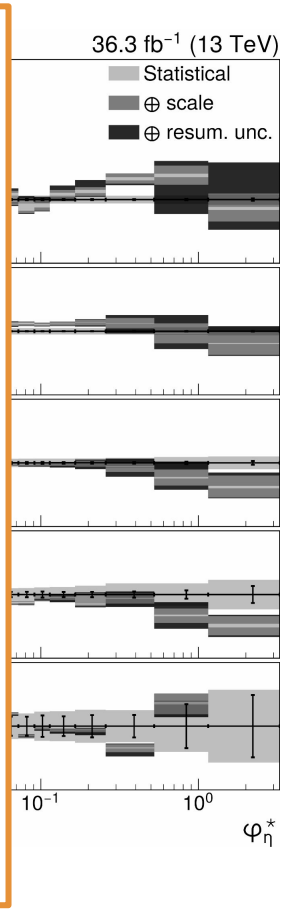


- **Describes well $\varphi^* < 0.1$ region** in all mass bins
- **Good description for Z peak** region
- Underestimates cross section with increasing m_{ll}

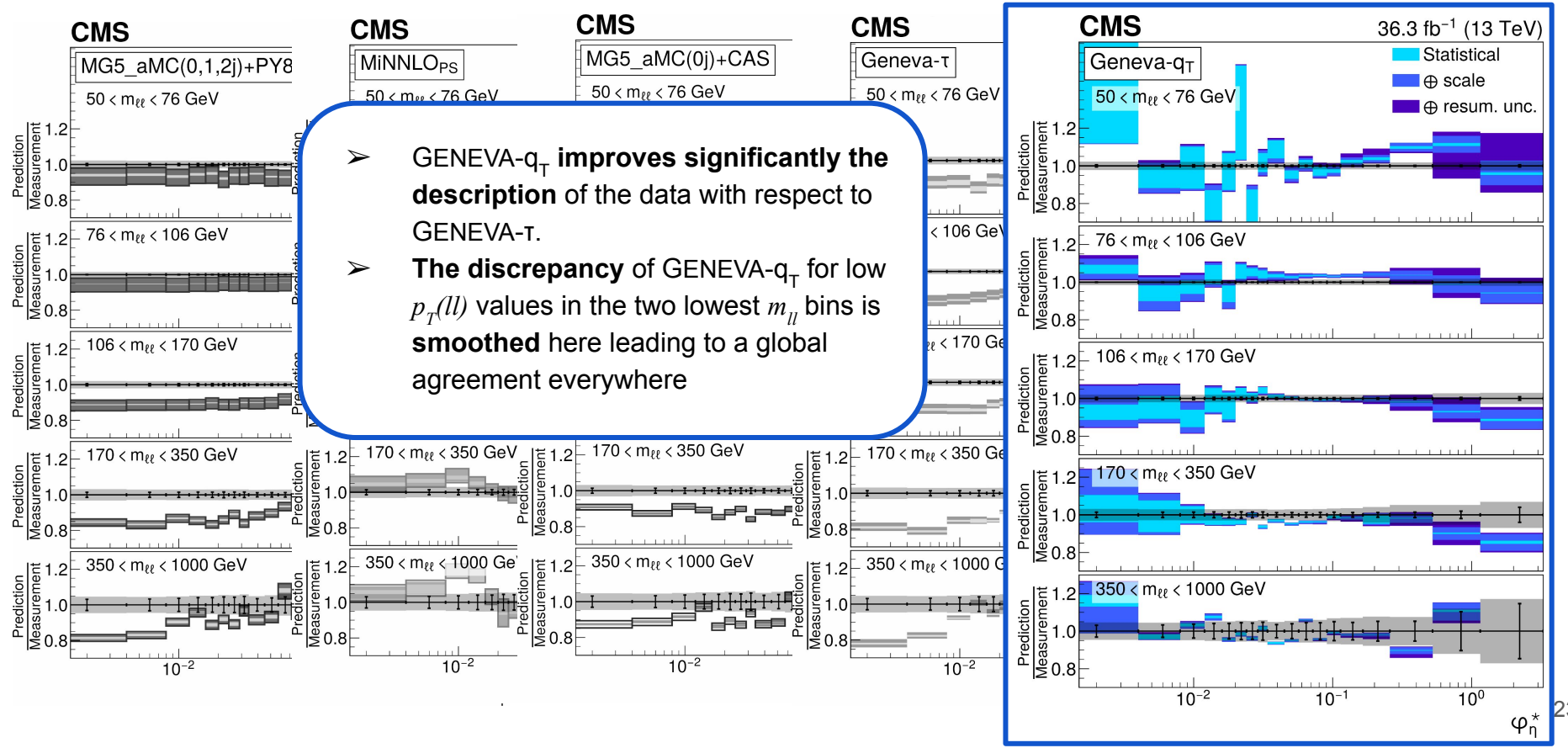
φ^* results

- GENEVA predictions provide a **good description** of the measurements
- Precise shape in φ^* is not well reproduced by GENEVA-τ
- **The scale dependence is well described** over the large range covered by the present measurement





φ^* results



- GENEVA-q_T **improves significantly the description** of the data with respect to GENEVA-τ.
- **The discrepancy** of GENEVA-q_T for low $p_T(ll)$ values in the two lowest m_{ll} bins is **smoothed** here leading to a global agreement everywhere

Summary

- The differential cross section of the dilepton p_T from the Drell-Yan process has been measured in a wide mass range
  - additional measurements for φ^*, DY+≥1 jets events, and the ratio to Z peak results
- Comparisons of the measurements to six predictions using different treatments of soft initial-state QCD radiations performed

➢ The measurements of Drell–Yan cross section in a wide range in dilepton masses allows to probe the interplay between the transverse momentum and the mass scales of the process

➢ Theoretical predictions individually describe the measurements well in the regions they were designed for

→ No model is able to reproduce all dependencies over the complete covered range