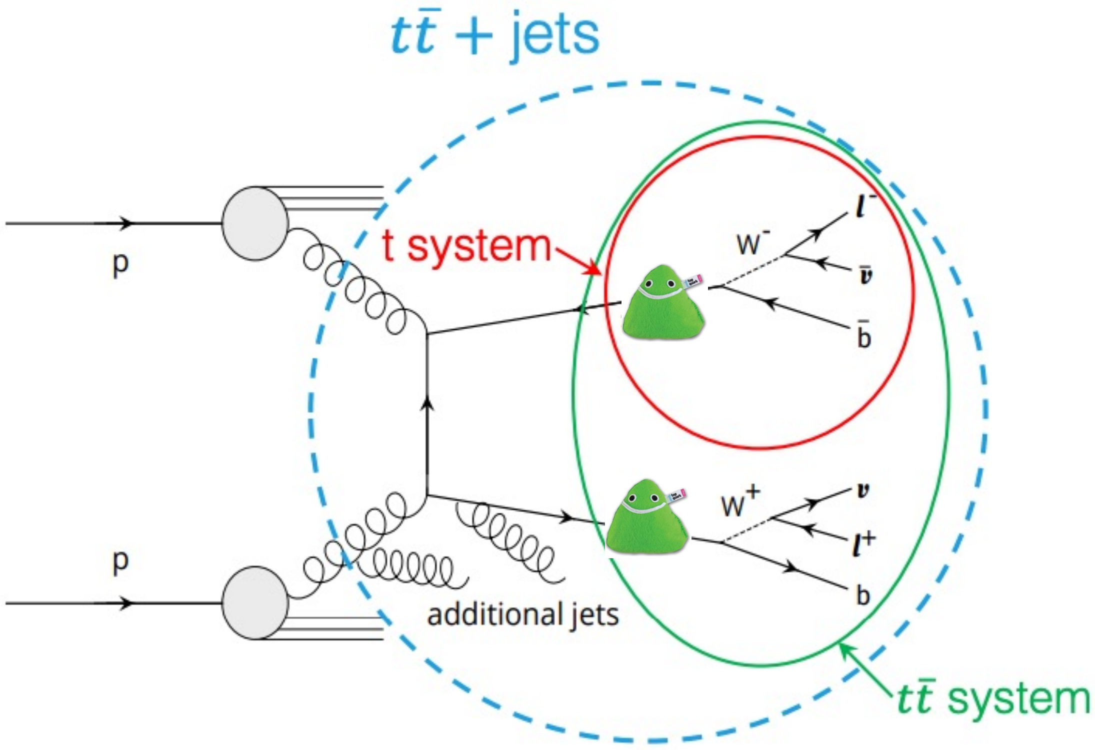


Measurements of differential cross sections for the production of top quark pairs in pp collisions at $\sqrt{s}$ = 13 TeV with the CMS experiment

CMS-PAS-TOP-20-006

The 15th International Workshop on Top Quark Physics (TOP 2022)

Henriette Petersen

On behalf of the CMS Collaboration

Analysis overview

Differential cross sections performed with full Run 2 data:

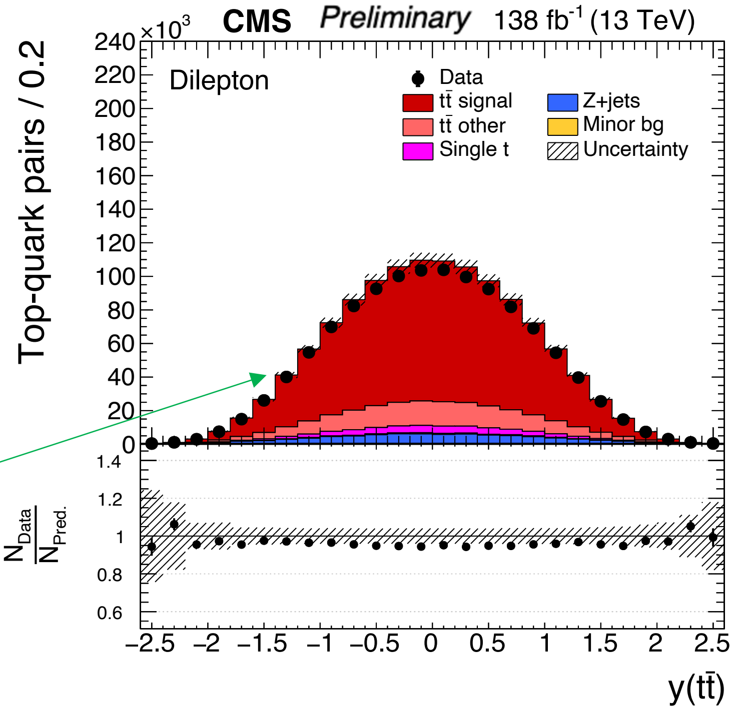
- Study details of $t\bar{t}$ production dynamics in different phase space regions.
- Compare to state of the art Standard Model predictions: window to new physics.

Study kinematical distributions and topologies of following objects

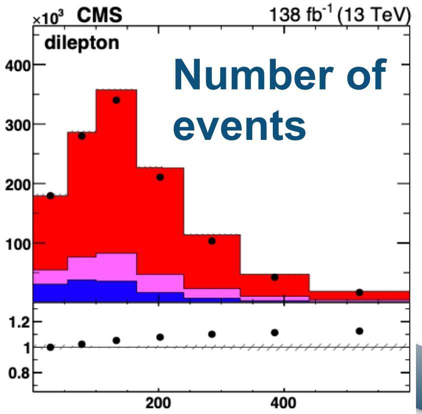
- t, $\bar{t}$ and $t\bar{t}$
- Leptons and b-jets
- Additional jet multiplicity

$t\bar{t}$ decays to prompt $e^{\pm}e^{\mp}$, $\mu^{\pm}\mu^{\mp}$ and $e^{\pm}\mu^{\mp}$ final states:

- Dilepton and single lepton triggers.
- Two high p_{T} leptons.
- Two high p_{T} jets ($\geq$ 1 b-tag).



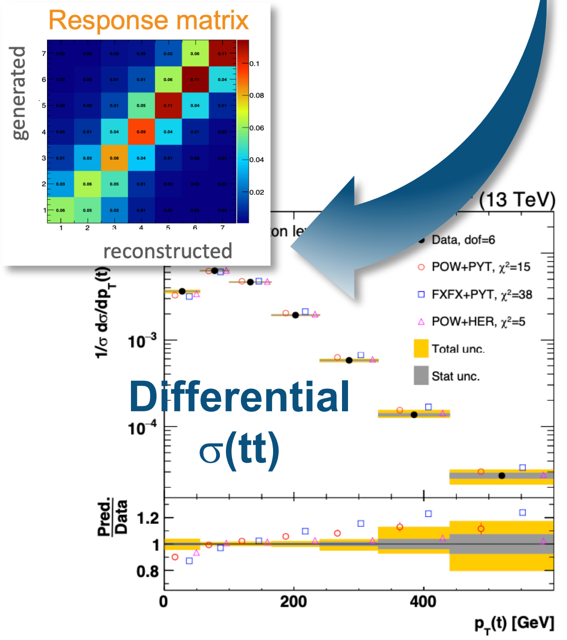
1 million $t\bar{t}$ events after full selection in Run 2! Unprecedented precision.



Channels and years combined at detector level!

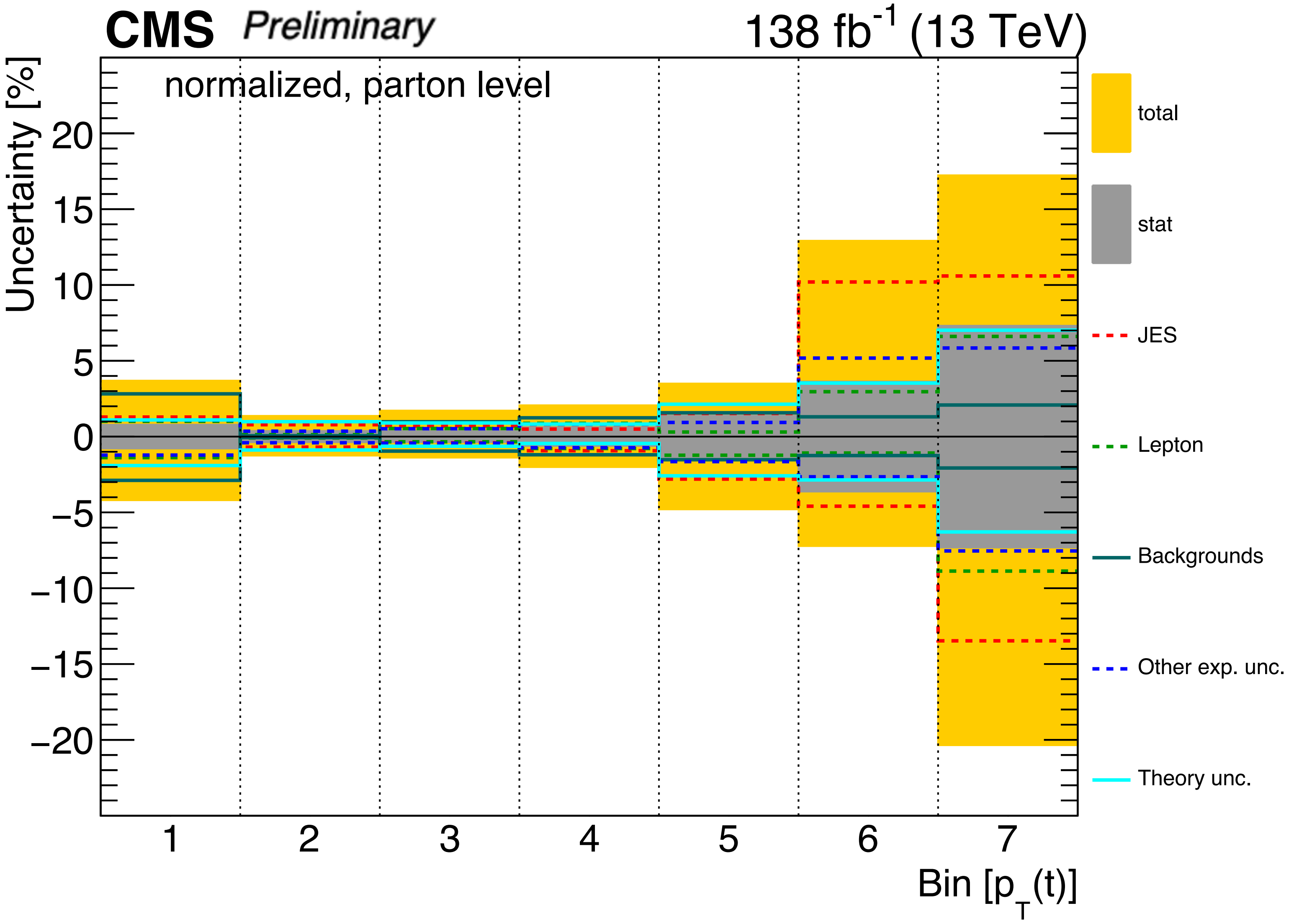
Δ^X_i = bin width for variable X

$$\frac{d\sigma_i}{dX} = \frac{\mathrm{unfold}(s_i^X - b_i^X)}{\Delta_i^X \cdot \int \mathcal{L}dt}$$



Uncertainty contributions in unfolded cross sections

- Systematics dominated
- Experimental uncertainties are larger than theory uncertainties:
  - main sources: Jet energy scale, lepton efficiency and background normalization
- Total uncertainties are in 2 – 20% range
- Overall uncertainty reduced by a factor of ~2 w.r.t. previous measurements



p_{T} of top and $t\bar{t}$

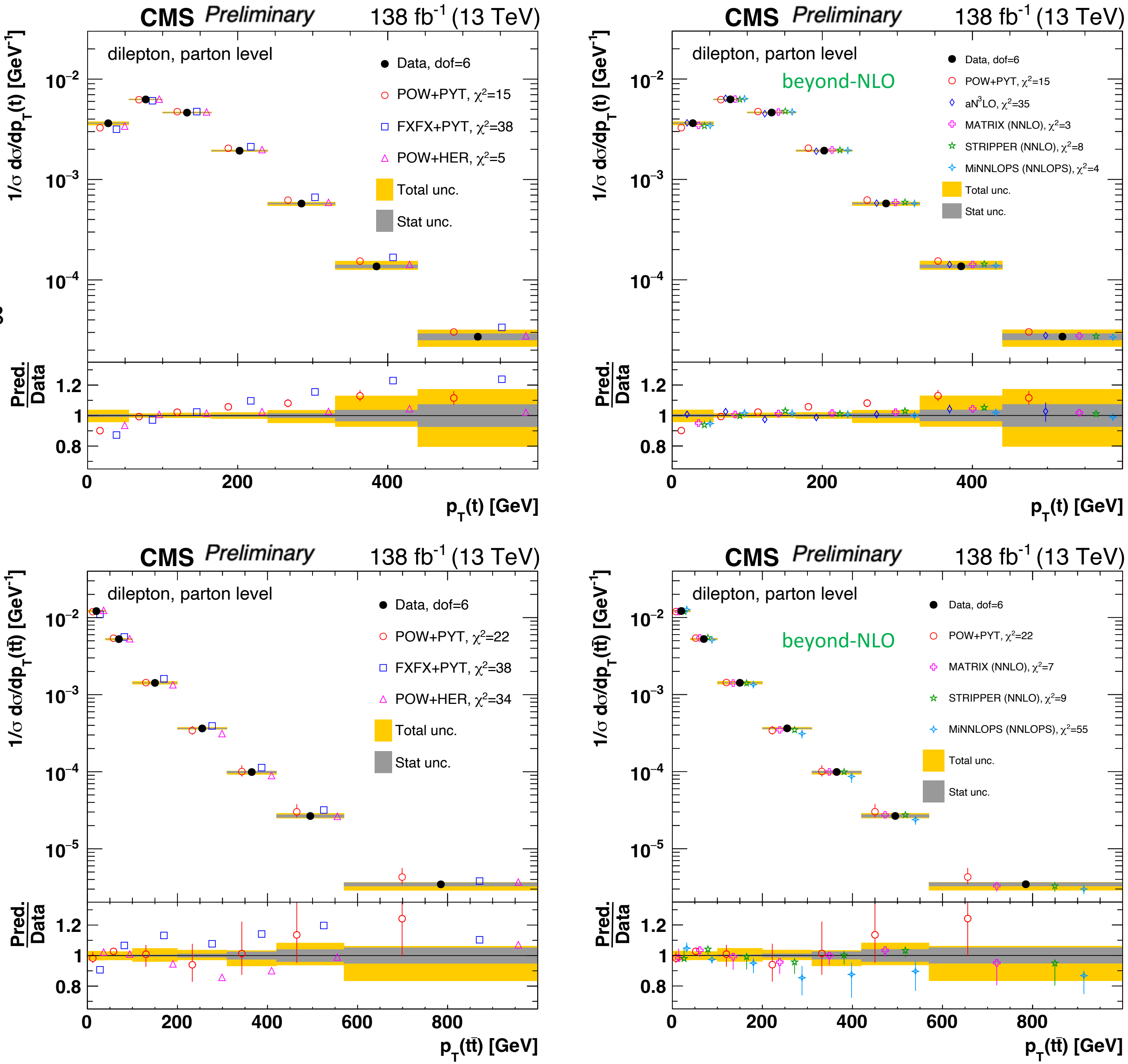
Left: comparison to different MC at NLO QCD:

- ○ POW+PYT → PowhegV2+Pythia8
- □ FXFX+PYT → MG5_aMC@NLO[FxFx] +Pythia8
- △ POW+HER → PowhegV2+Herwig7

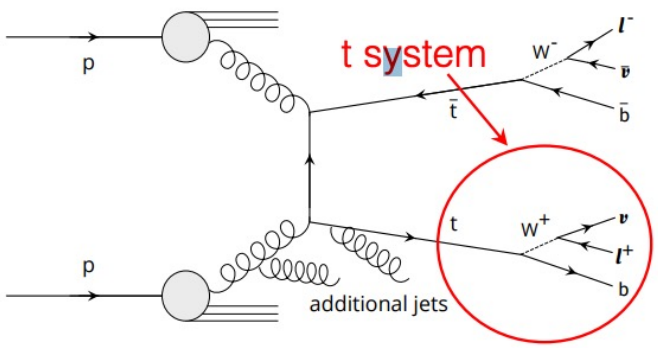
Right: comparison to beyond-NLO QCD (when available):

- ◇ aN^{3}LO N. Kidonakis.
- ✚ MATRIX (NNLO) M. Grazzini et al.
- ☆ STRIPPER (NNLO) M. Czakon et al.
- ✦ MiNNLOPS (NNLOPS)

Monni et al., results provided by S. Amoroso

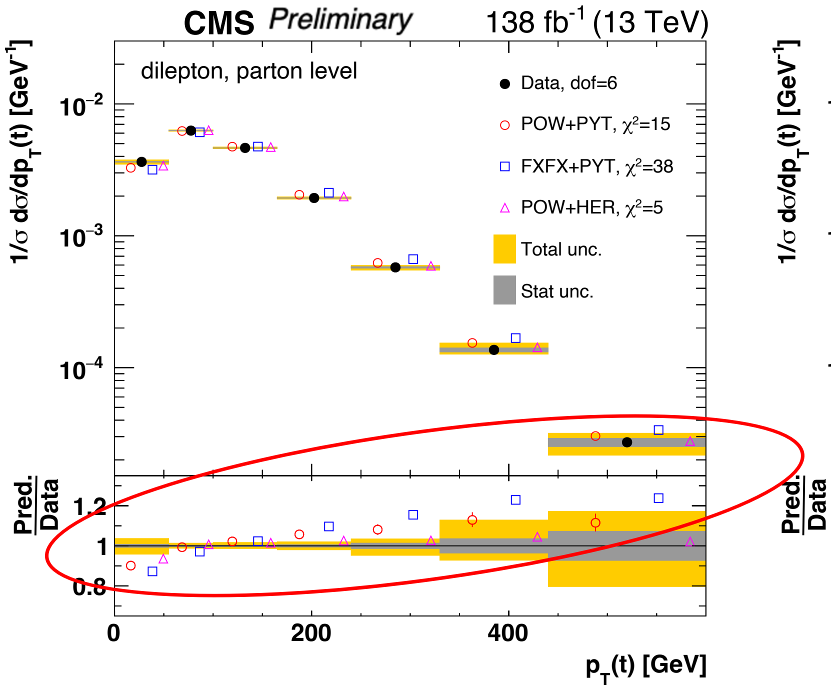


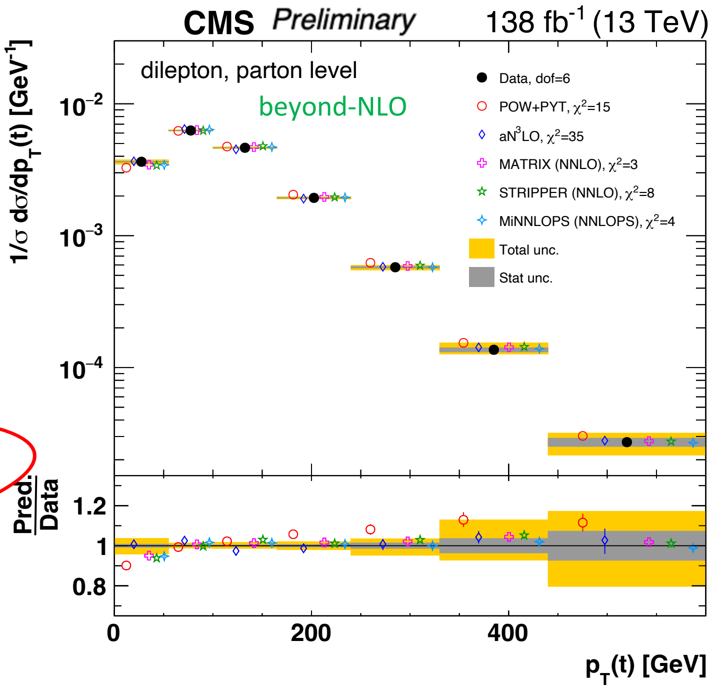
p_{T} of top and $t\bar{t}$

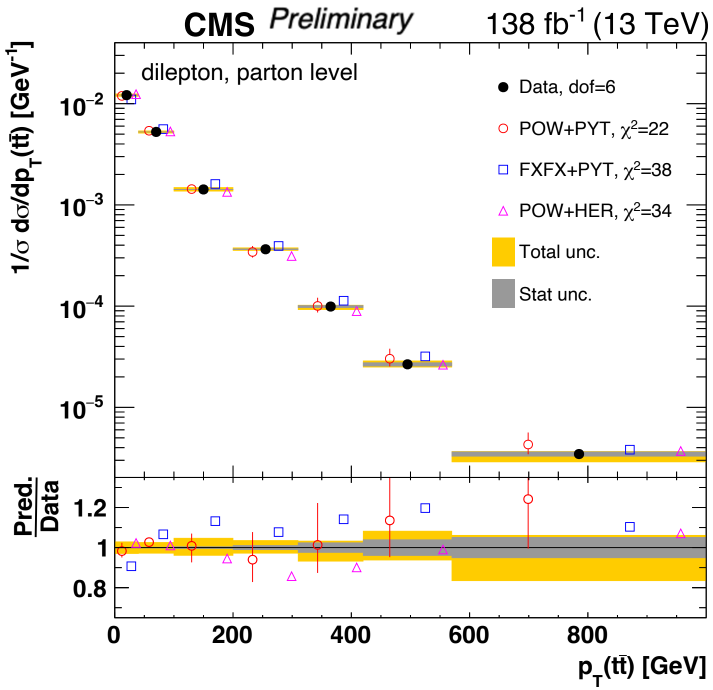


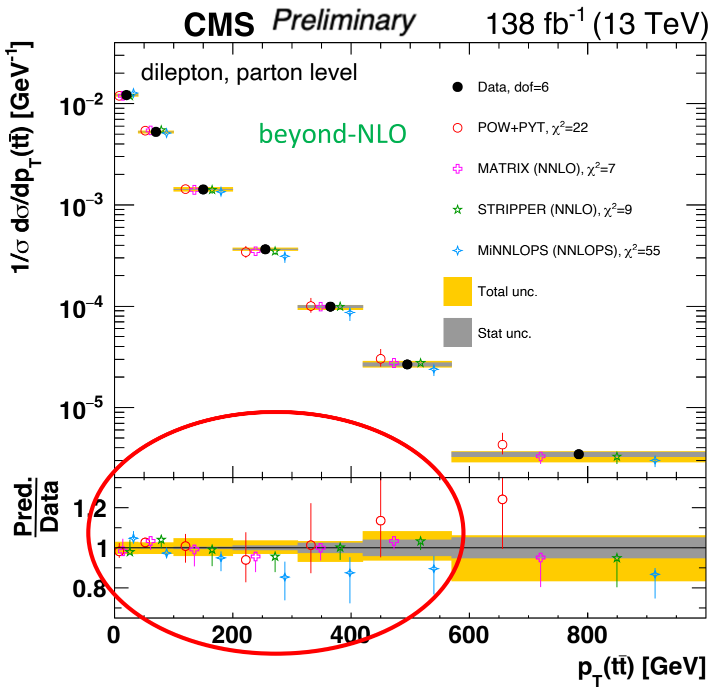
- The 'POW+PYT' and 'FXFX+PYT' models predict harder $p_{\mathrm{T}}(t)$.

- $p_{\mathrm{T}}(t\bar{t})$ directly sensitive to additional gluon radiation.
  - All models exhibit slight modulation.

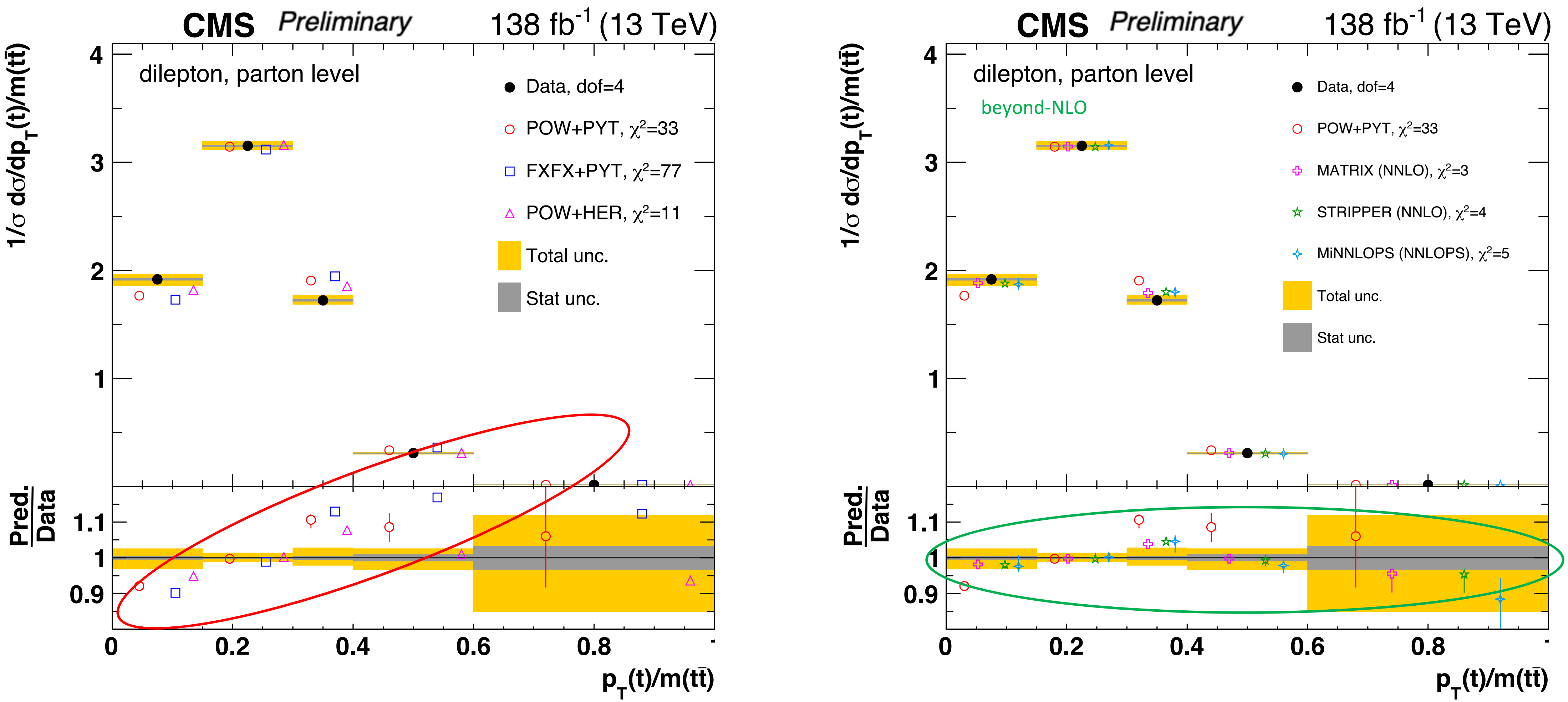






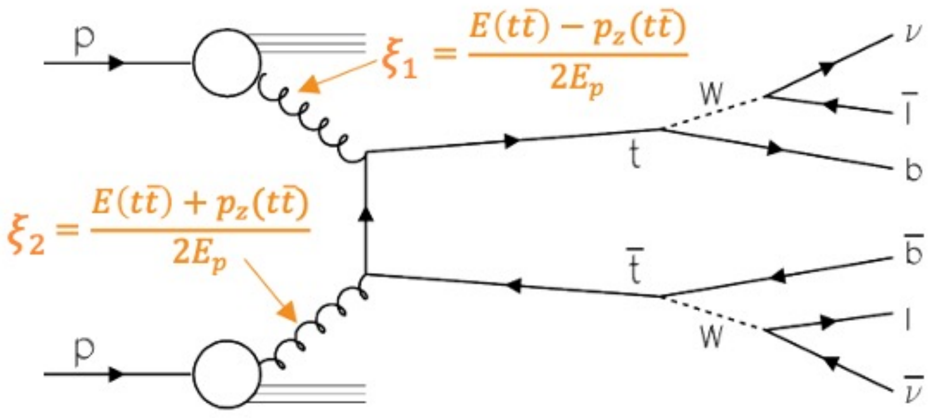


New ratio observable: $p_{\mathrm{T}}(t)/\mathrm{m}(t\bar{t})$



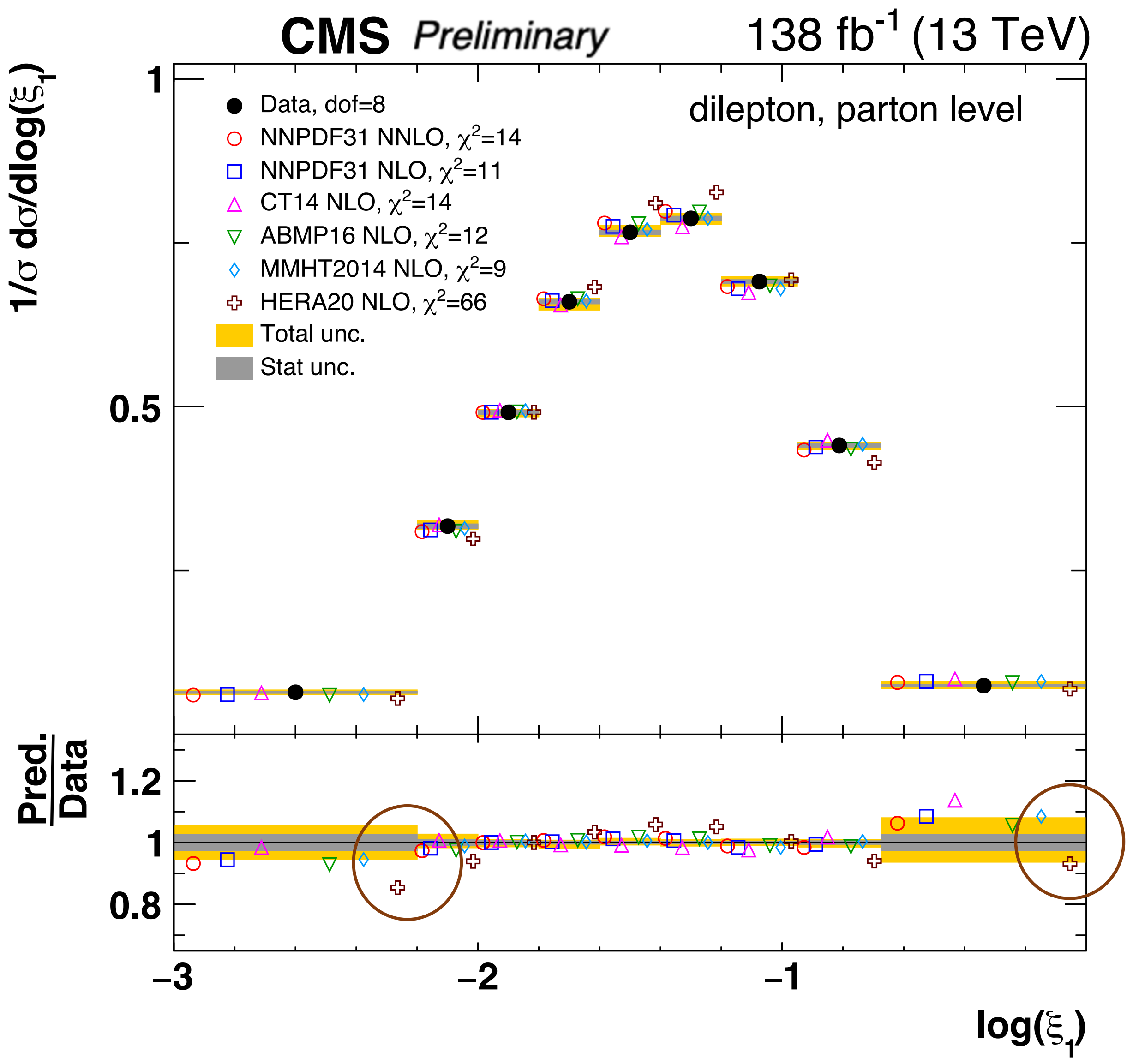
- The 'POW+PYT' and 'FXFX+PYT' models predict harder spectra than in data.
- Good description of data from predictions at beyond-NLO precision.

Proton momentum fraction

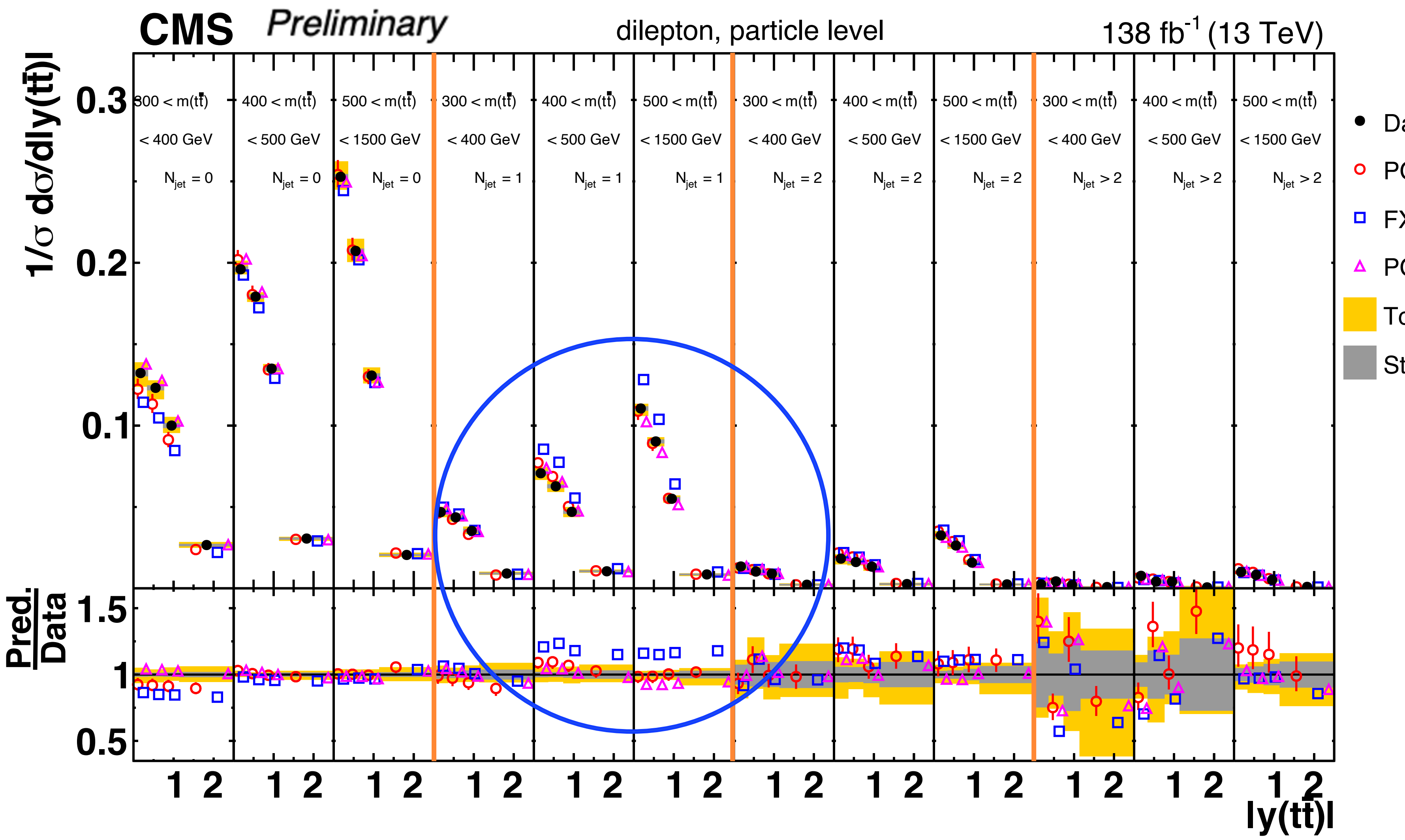


- Sensitive to gluon momentum density fractions up to ~ 0.2.

- The HERAPDF2.0 NLO prediction undershoots the data in outer regions of $\log(\xi_1)$.



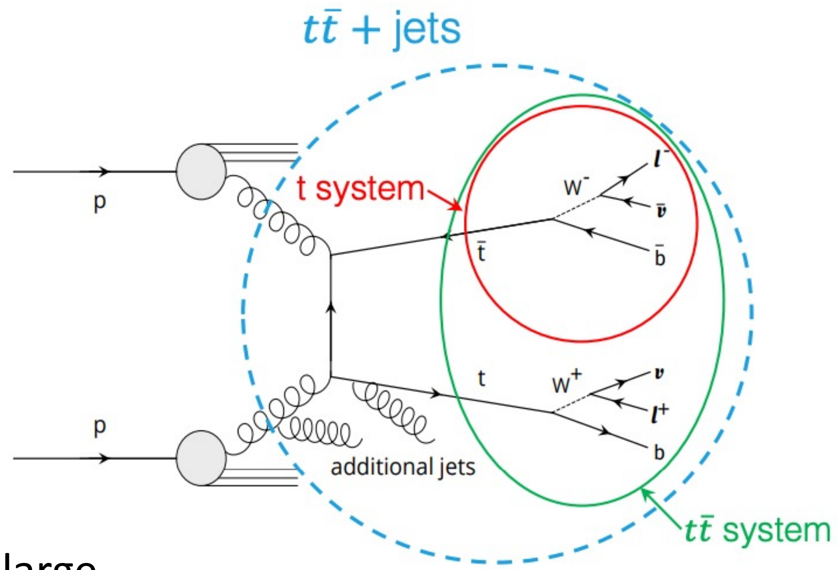
$t\bar{t}$ kinematics and extra jets multiplicity: $[n_{\mathrm{jet}}^{0,1,2,3+}, \mathrm{m}(t\bar{t}), \mathrm{y}(t\bar{t})]$



- ➢ Measure in 4 N_{jet} bins for first time.
- ➢ FXFX+PYT has poor description for $N_{\mathrm{jet}} = 1$ in all rapidity bins at $\mathrm{m}(t\bar{t}) > 500$ GeV.

Summary

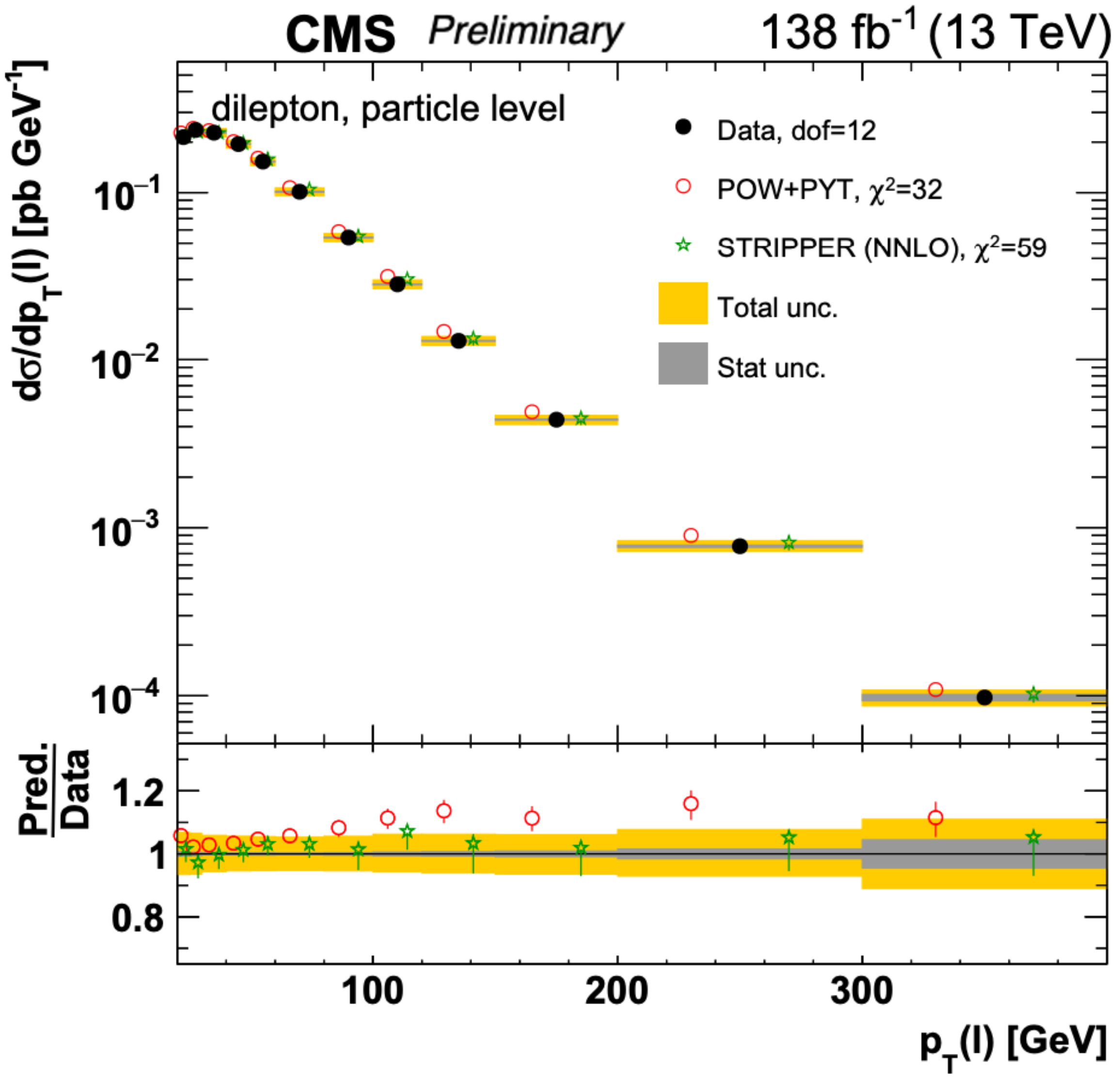
- Presented measurements of differential $t\bar{t}$ cross sections in the dilepton channel using full Run 2 data:
  - Comprehensive set of observables of $t\bar{t}$, t, $\bar{t}$, their decay products (leptons and b-jets), and the additional jet multiplicity in the event.
  - Several new observables measured for the first time ever.
  - Total uncertainties are reduced by a factor $\sim$2.
- Comparison of results with predictions:
  - No single model at NLO or beyond-NLO precision provides a good description of the data in all measured cross sections.
  - beyond-NLO theory predictions provide
    - similar or improved descriptions of the data, e.g. for $p_{\mathrm{T}}(t)$.
    - exceptions are e.g. $p_{\mathrm{T}}(t\bar{t})$, where theory scale uncertainties are large.



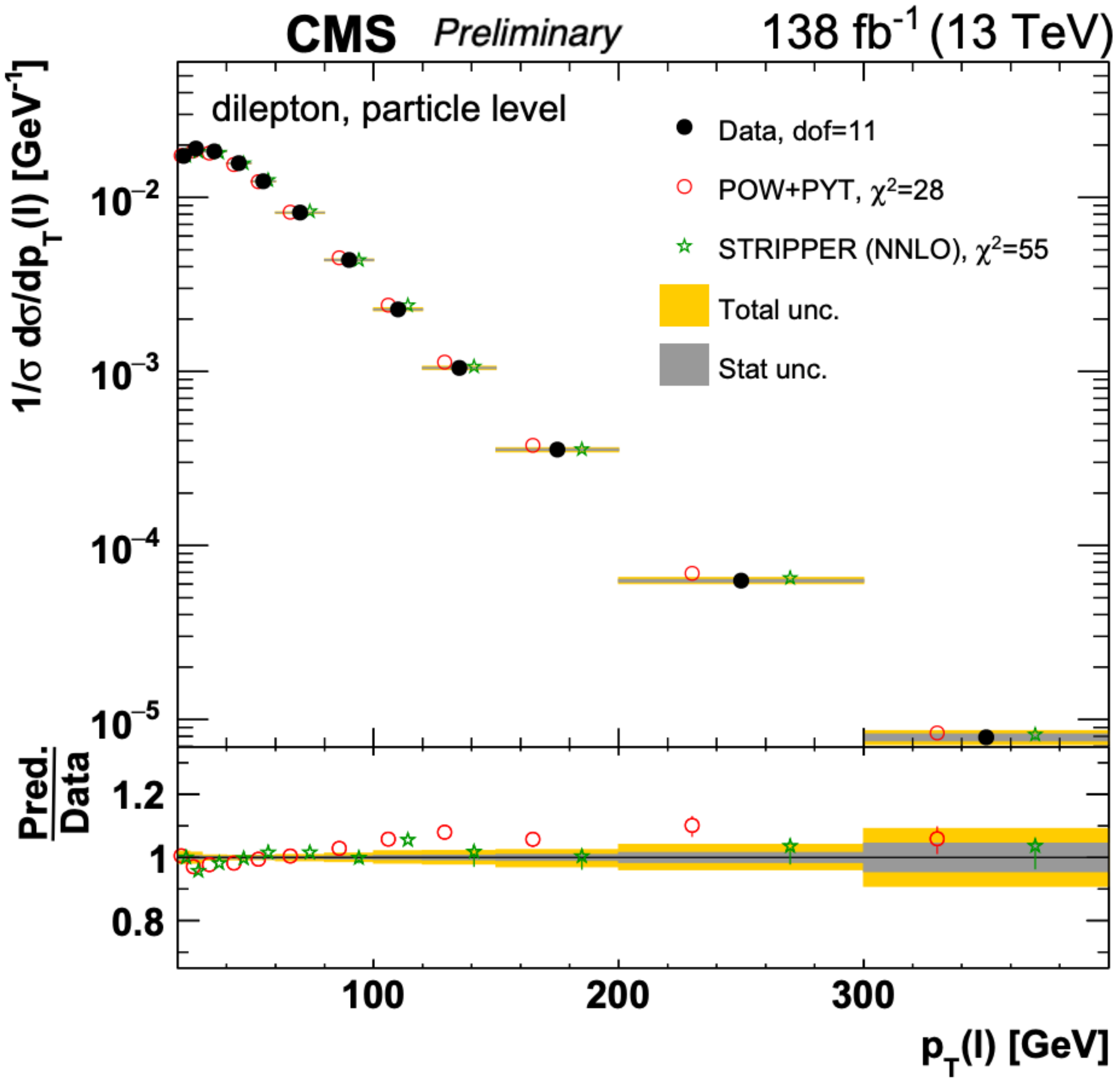
All results are featured in the preliminary result CMS-PAS-TOP-20-006!

Back-up

Lepton p_T

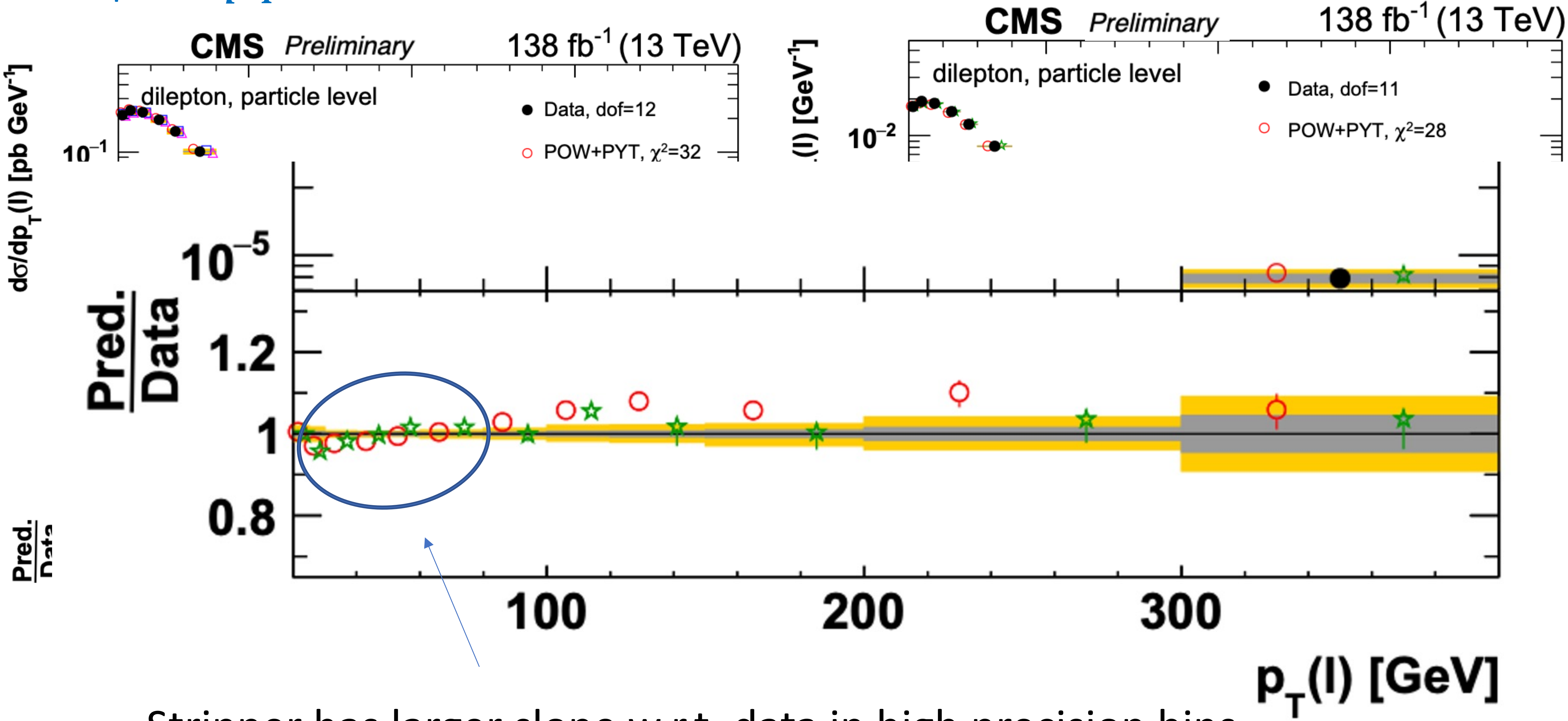


CMS Preliminary
138 fb-1 (13 TeV)
dilepton, particle level
Data, dof=12
POW+PYT, χ2=32
STRIPPER (NNLO), χ2=59
Total unc.
Stat unc.
dσ/dpT(l) [pb GeV-1]
Pred./Data
pT(l) [GeV]



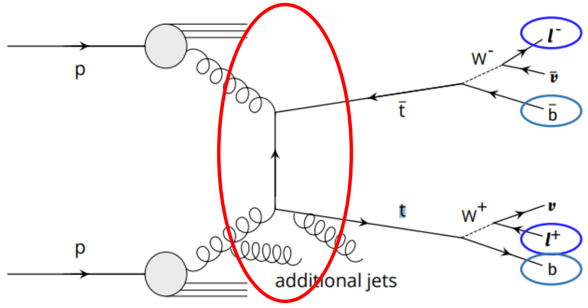
CMS Preliminary
138 fb-1 (13 TeV)
dilepton, particle level
Data, dof=11
POW+PYT, χ2=28
STRIPPER (NNLO), χ2=55
Total unc.
Stat unc.
1/σ dσ/dpT(l) [GeV-1]
Pred./Data
pT(l) [GeV]

Lepton p_{T}



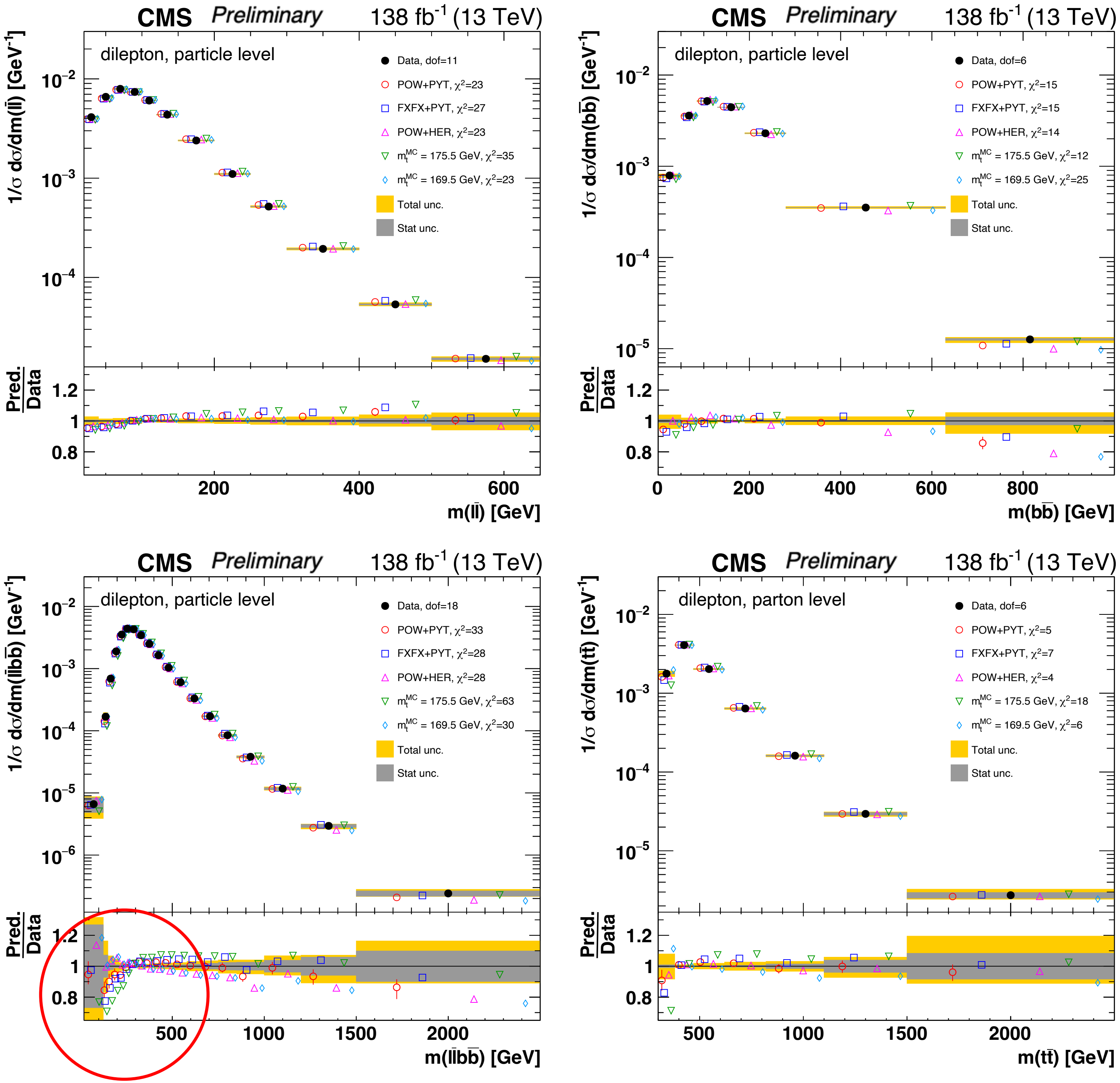
Stripper has larger slope w.r.t. data in high precision bins.

Masses of decay particle systems

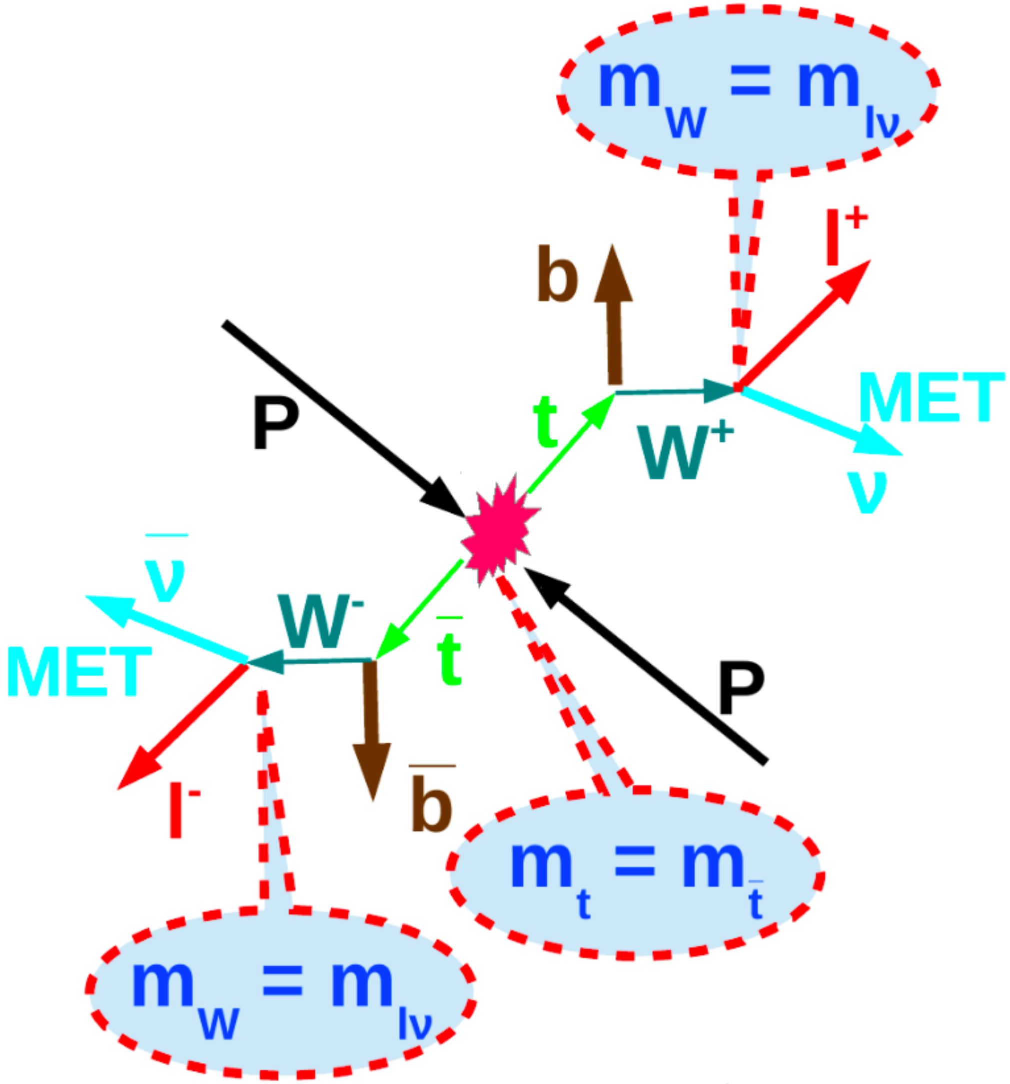


$m(t\bar{t}) > 2m_t$

- Study sensitivity to the top mass from proxies for $t\bar{t}$ mass system.
- Comparison to $m_t^{\mathrm{MC}} = 175.5$ GeV and $m_t^{\mathrm{MC}} = 169.5$ GeV:
  - $\mathrm{m}(l\bar{l}b\bar{b})$ exhibits best sensitivity.



Kinematic reconstruction



- Input: leptons, jets, **MET**
- Unknowns: $\mathbf{p}_\nu$, $\mathbf{p}_{\bar{\nu}}$ (6)
- Constraints:
  - m_t, $m_{\bar{t}}$ (2)
  - m_{W^+}, m_{W^-} (2)
  - $(\mathbf{p}_\nu + \mathbf{p}_{\bar{\nu}})_T$ = **MET** (2)

Kinematic reconstruction

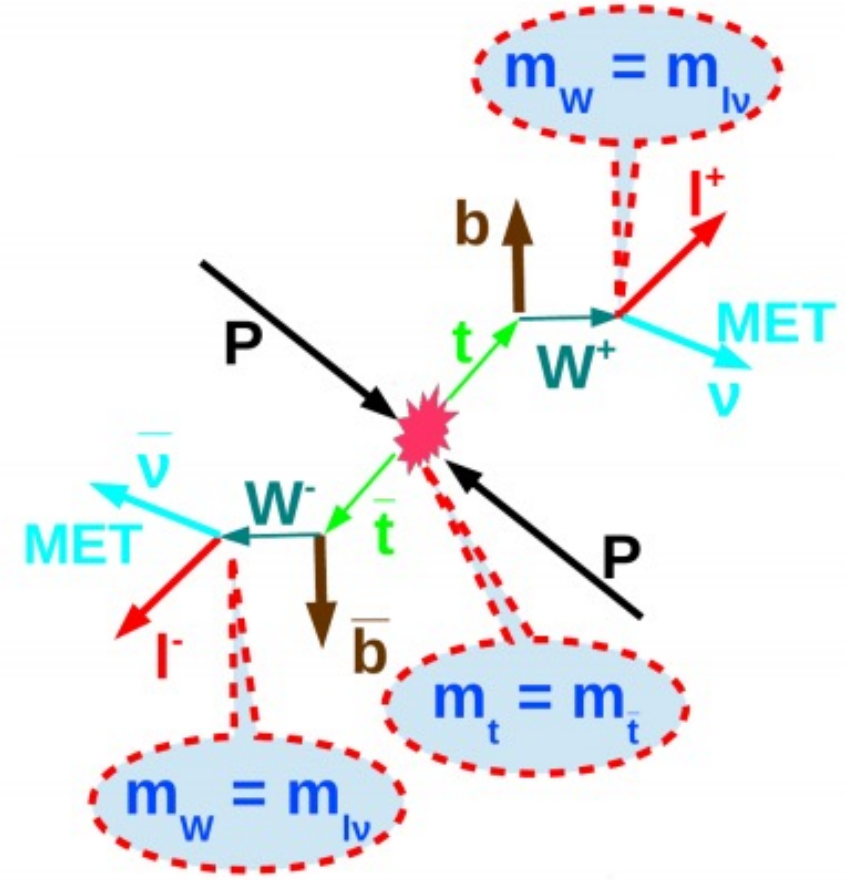
with additional details for loose kinematic reconstruction

Loose kinematic reconstruction

- No constraint on top mass
- Mass onset is accessible
- Can only reconstruct $t\bar{t}$ system

- Kinematic requirements:

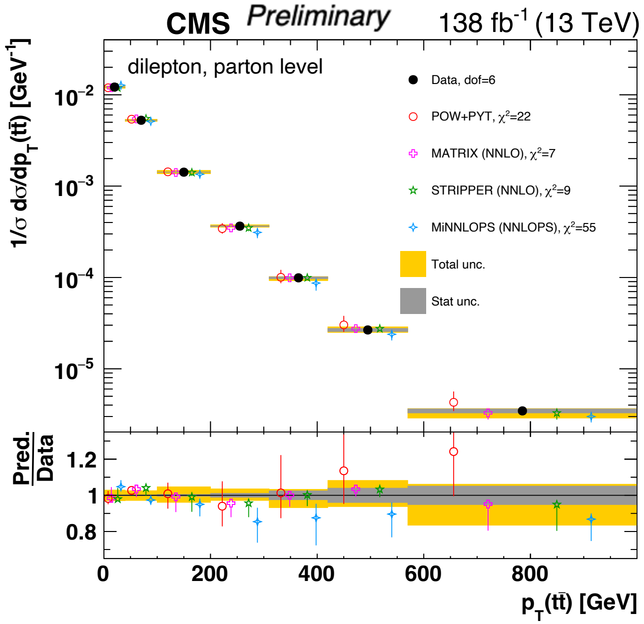
$$p_{x,y}(\nu\bar{\nu}) = \text{MET}_{x,y}$$
$$p_z(\nu\bar{\nu}) = p_z(l\bar{l}),\ E_z(\nu\bar{\nu}) = E_z(l\bar{l})$$
$$M(\nu\bar{\nu}) \geq 0,\ M(\nu\bar{\nu}l\bar{l}) \geq 2M_W$$



Comparisons to recent measurements from CMS and ATLAS

- No single model at NLO or beyond-NLO precision provides a good description of the data in all measured cross sections.
- Discrepancies between the predictions and data are enhanced in the double-differential measurements.

$p_{\mathrm{T}}(t\bar{t})$



$p_{\mathrm{T}}(l)$