YSF: Measurements of differential top quark pair production cross sections as a function of kinematic event variables at 13 TeV at CMS

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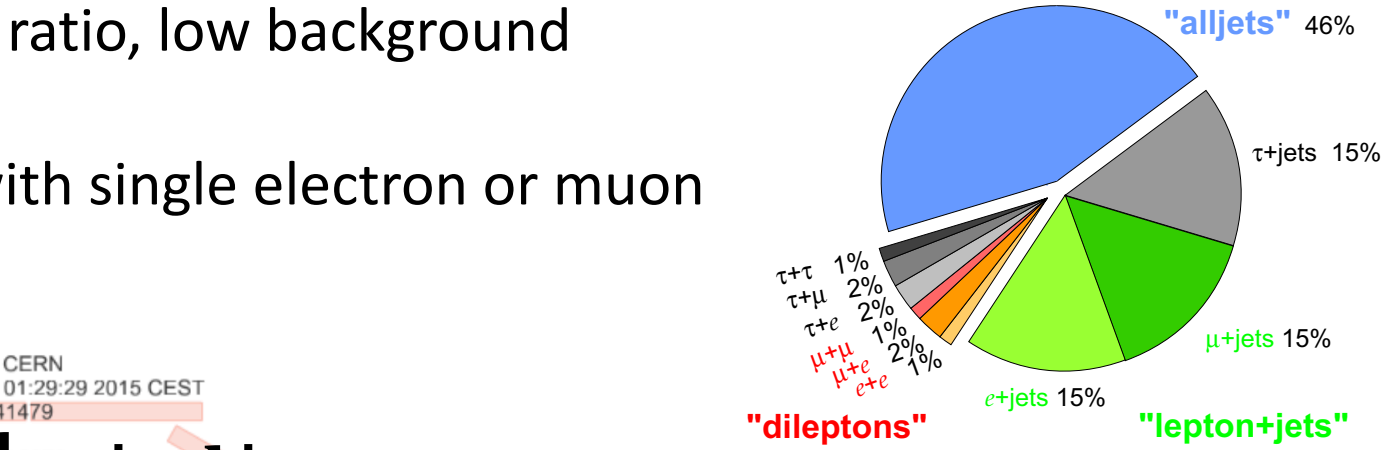
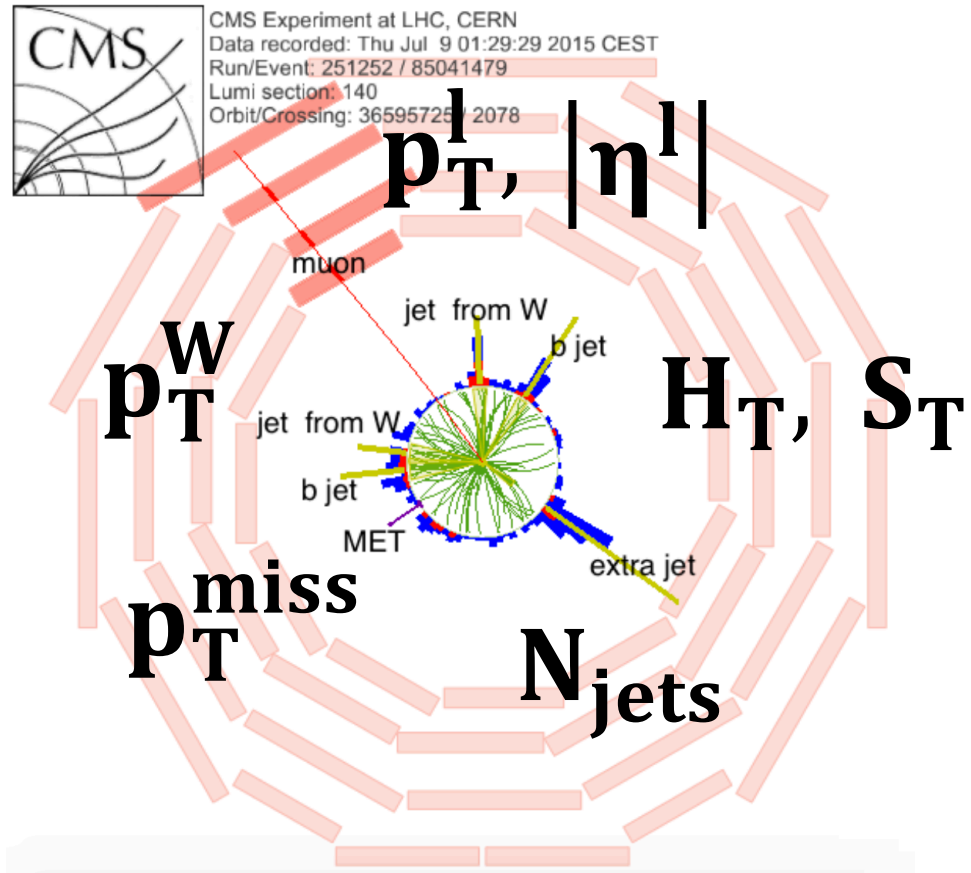
Single lepton decay channel

Kinematic **event** variables

- High branching ratio, low background
- Select events with single electron or muon





- Variables defined with respect to the whole event
- No top quark reconstruction
  - No uncertainty from reconstruction

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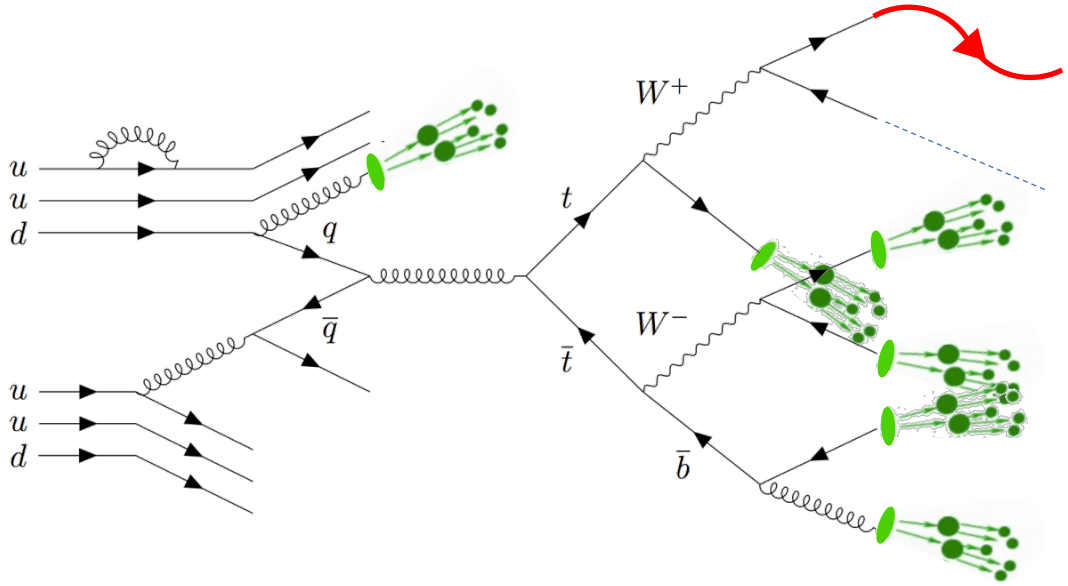
Single lepton decay channel

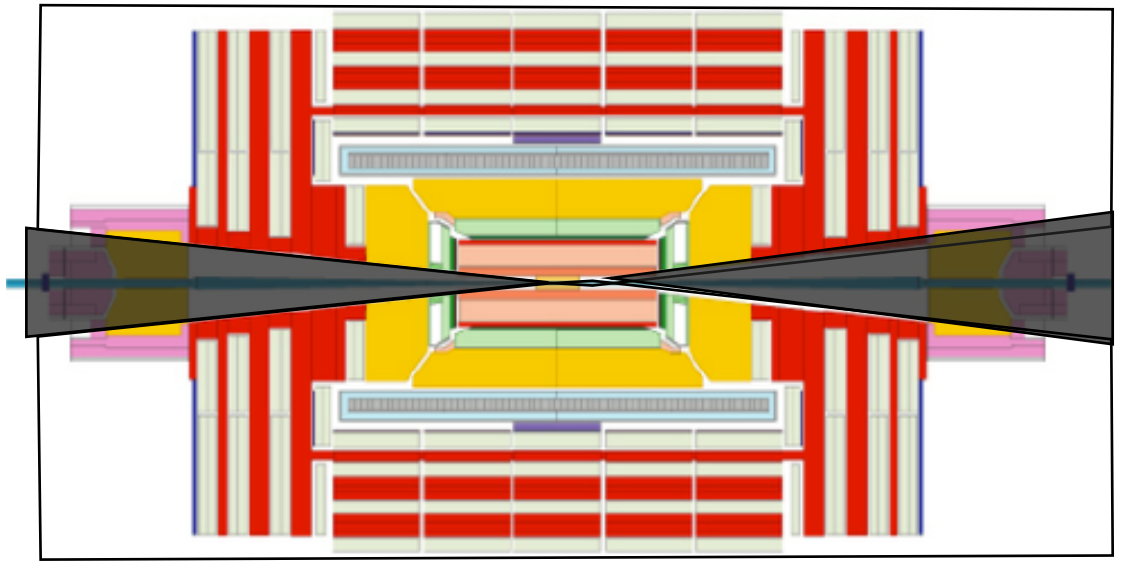
Kinematic **event** variables

Particle level

Visible phase space

- With respect to stable objects detectable by CMS
  - Electrons and muons,
  - Hadrons clustered into jets
  - Missing p_{T}





- A phase space as close as possible to reconstruction level

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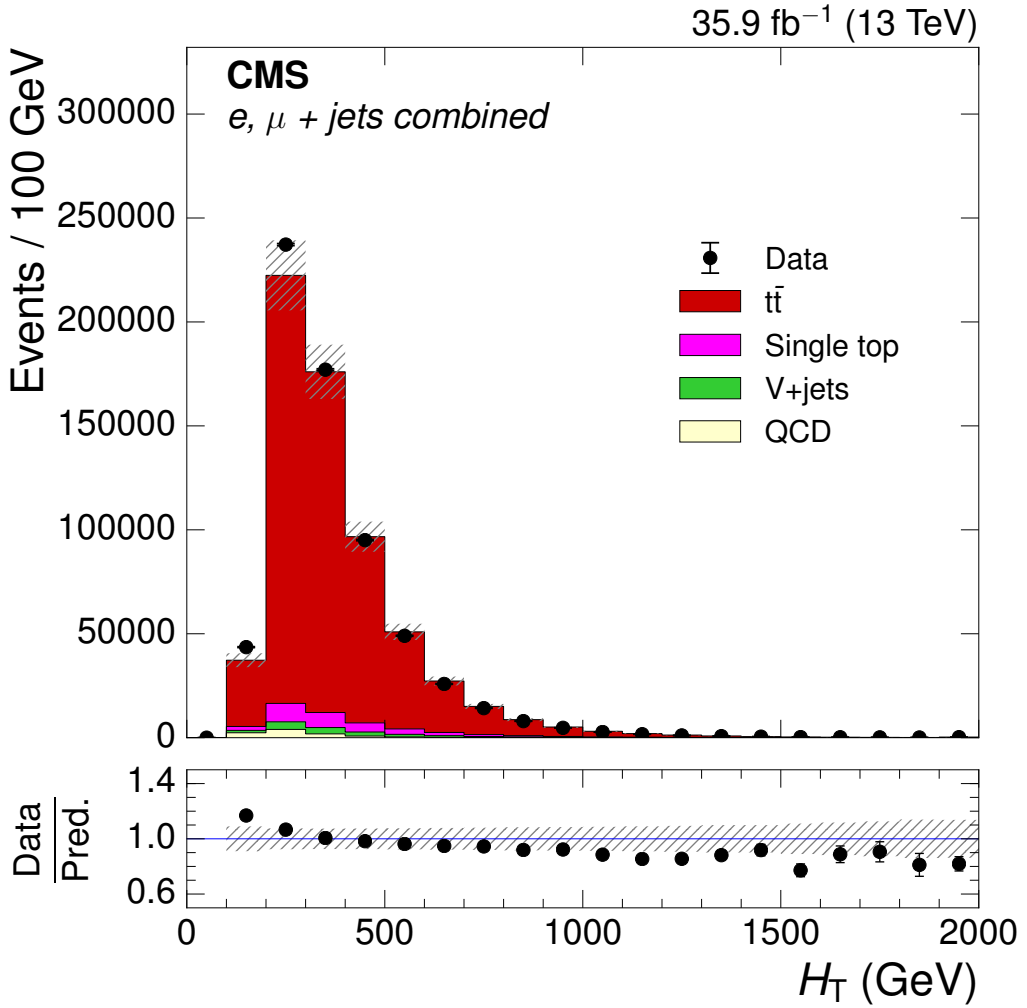
Cross section process

Estimate the reconstructed $t\bar{t}$ yield by **subtracting background estimates**:

- single top quark
- vector boson + jets
- data driven QCD

Binning scheme is chosen to be wider than resolution of data

Data is **smeared** by CMS and contains **acceptance inefficiencies** – must be **unfolded**



Use unfolded yields to calculate **absolute** and **normalised** cross sections

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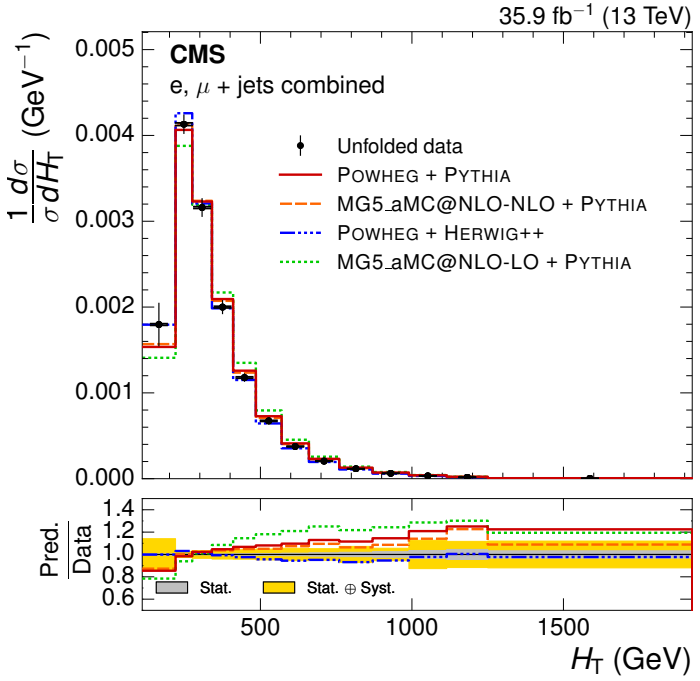
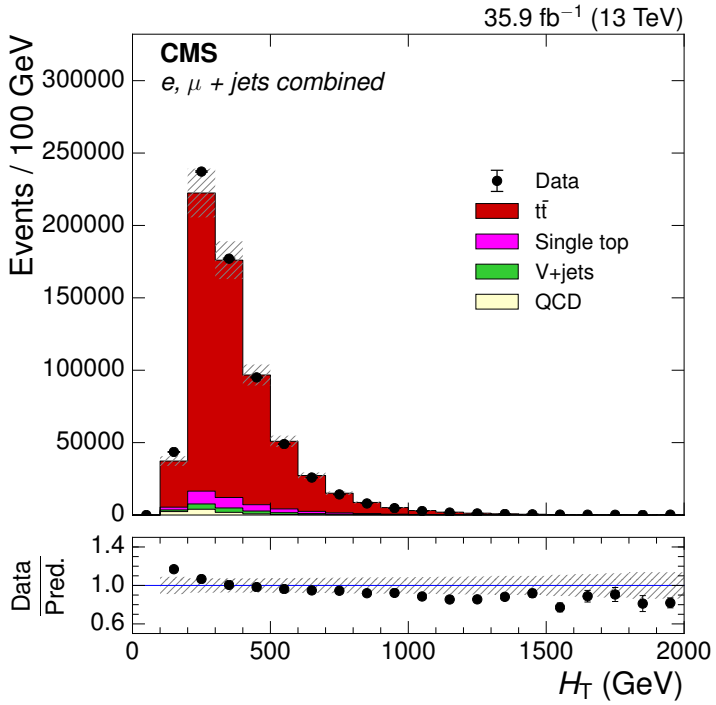
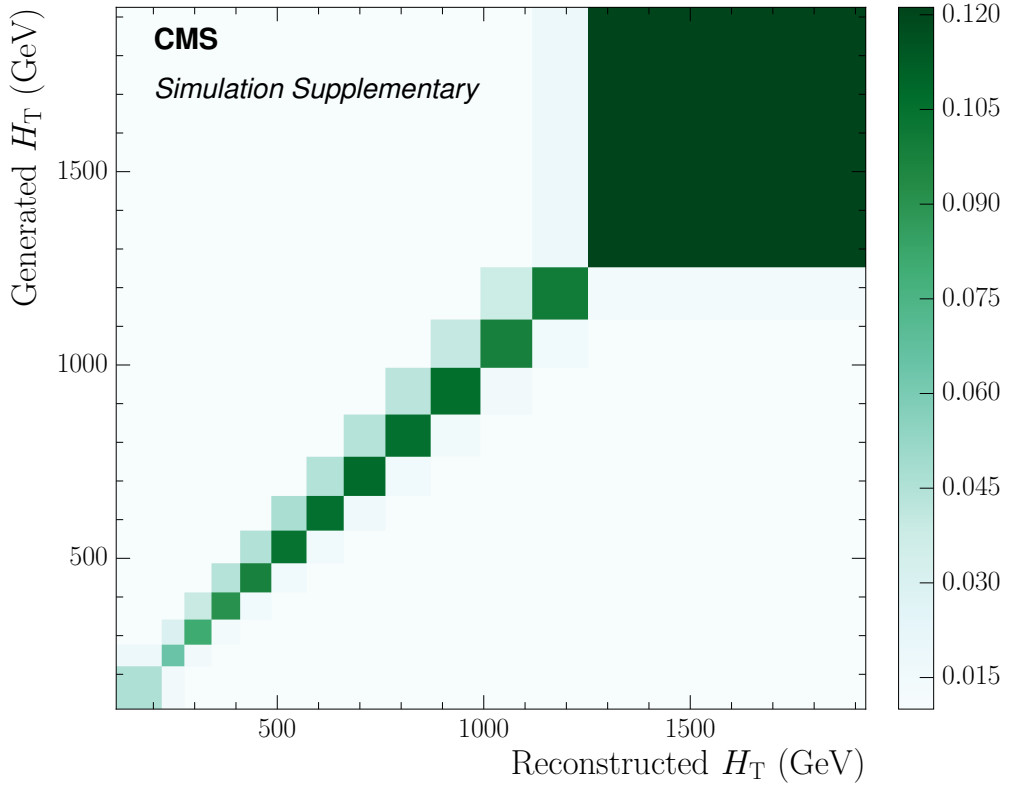
Cross section process

Unfolding







A map between object reconstruction and particle level

Unfolded using the regularised **TUnfold** algorithm

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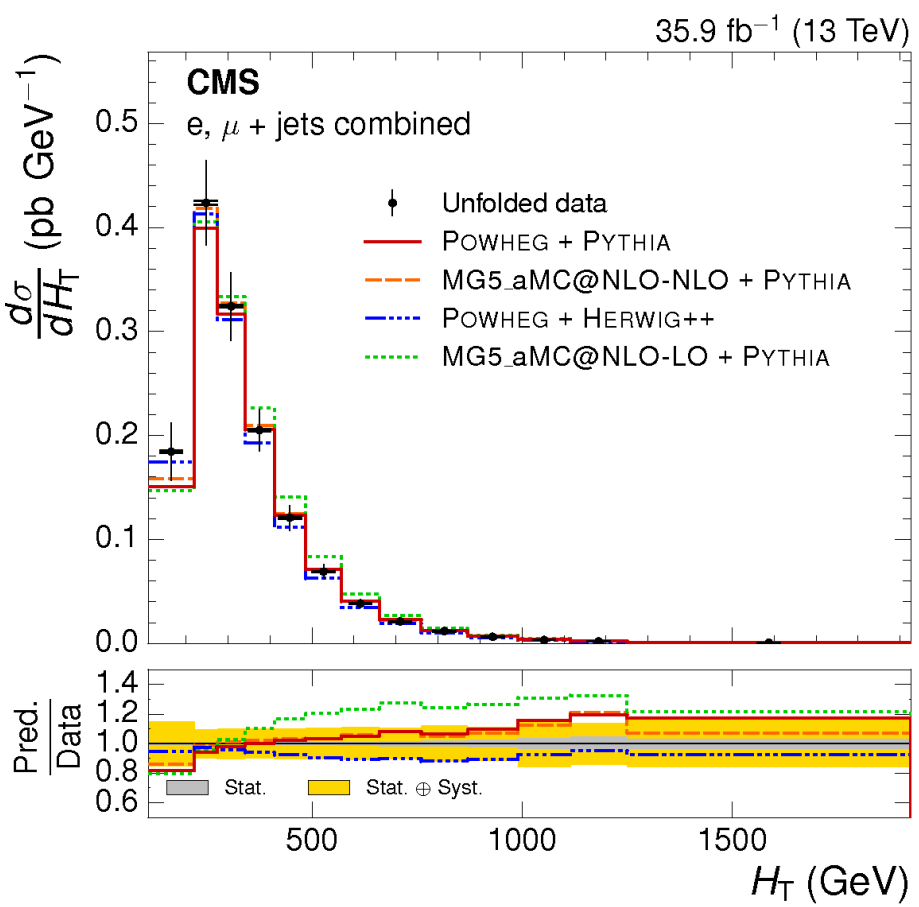
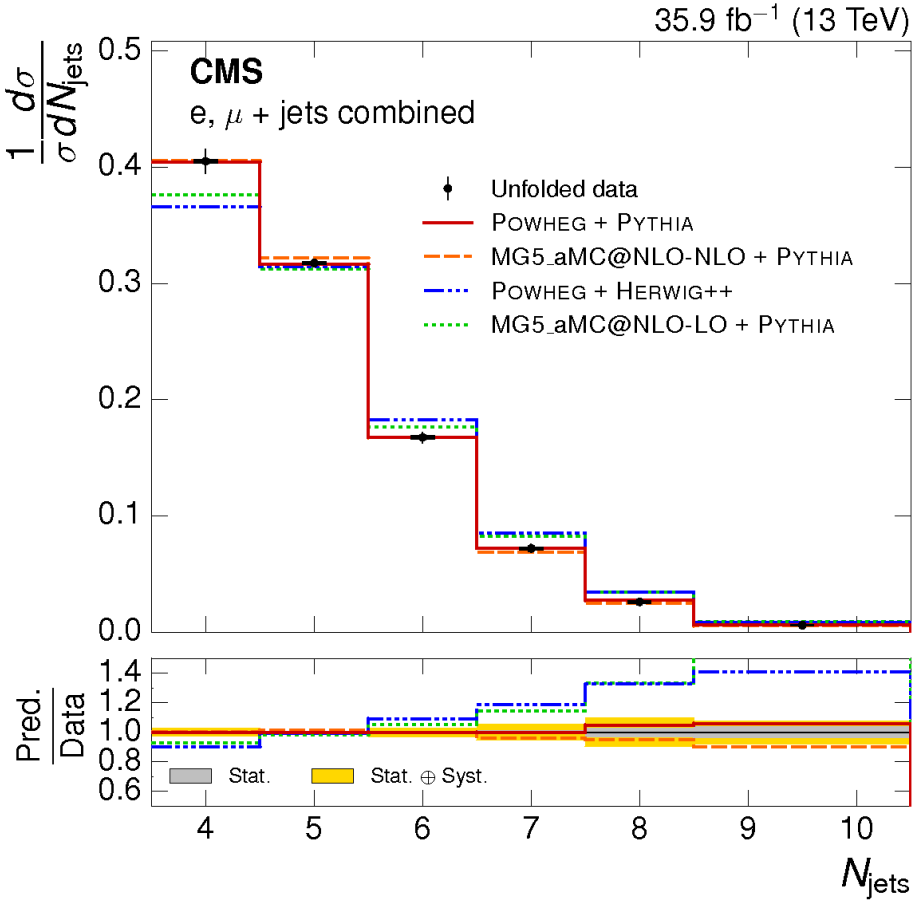
Cross section process

Unfolding

Results





Compare four simulations of $t\bar{t}$ production

- POWHEG + PYTHIA
- POWHEG + HEWRIG++
- MG5_aMC@NLO-NLO (uses FxFx matching)
- MG5_aMC@NLO-LO (uses MLM matching)

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Cross section process

Unfolding

Results

Perform **goodness-of-fit** tests

- POWHEG + PYTHIA is generally consistent with data and differences are covered by theoretical uncertainties in the model.
- MG5_aMC@NLO-NLO + PYTHIA and POWHEG + HERWIG++ are at least as consistent.
- MG5_aMC@NLO-LO + PYTHIA is not consistent
- No generator accurately describes all event variables studied

	POWHEG+PYTHIA		With MC theoretical uncertainties	
	χ^2/ndf	p-value	χ^2/ndf	p-value
N_{jets}	2 / 5	0.84	1.8 / 5	0.88
H_{T}	28 / 12	<0.01	4.9 / 12	0.96
S_{T}	22 / 12	0.04	4.2 / 12	0.98
$p_{\text{T}}^{\text{miss}}$	11 / 5	0.06	2.9 / 5	0.72
p_{T}^{W}	16 / 6	0.01	2.5 / 6	0.87
p_{T}^{ℓ}	25 / 16	0.08	14 / 16	0.60
$\lvert\eta^{\ell}\rvert$	19 / 7	<0.01	15 / 7	0.03

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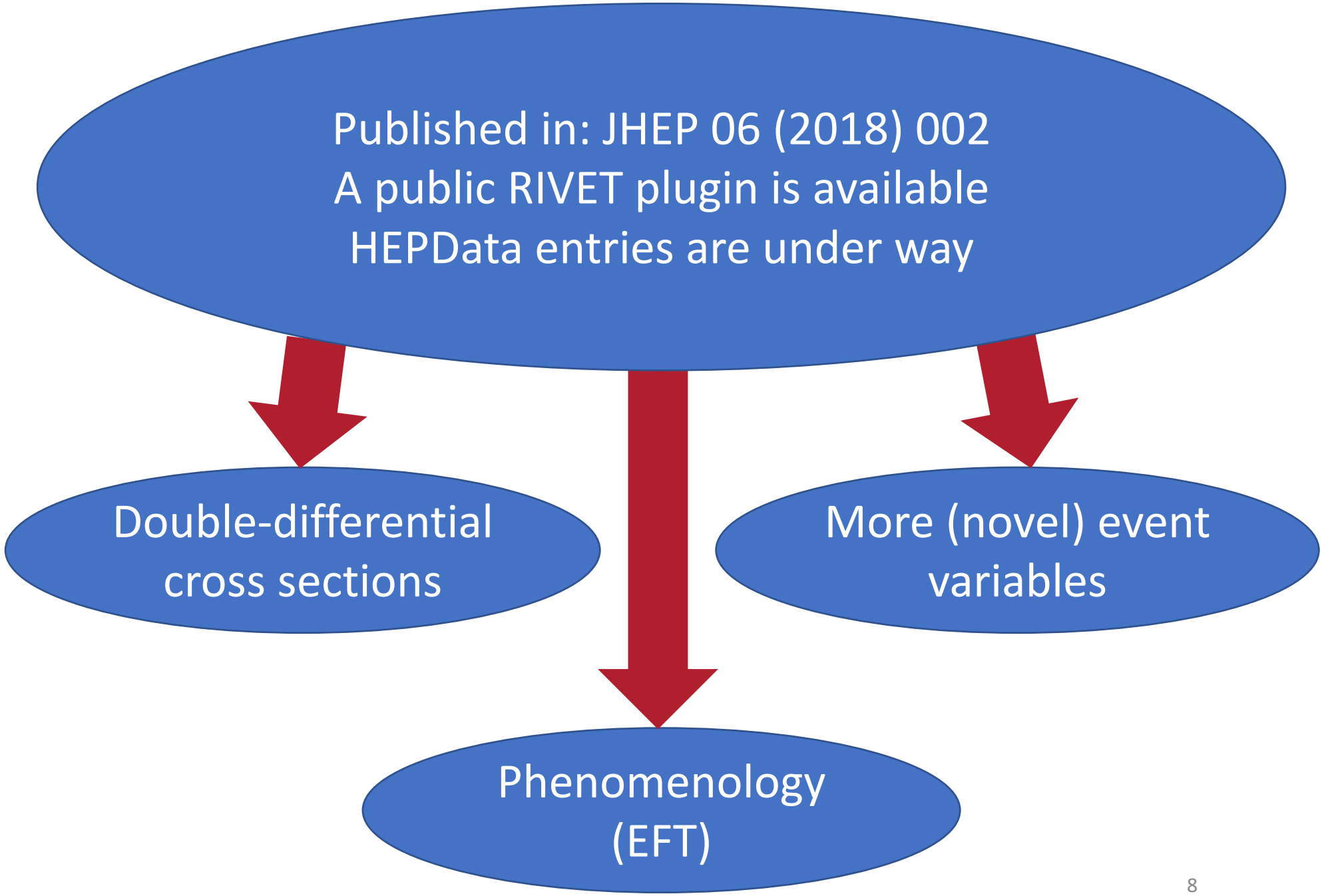
Cross section process

Unfolding

Results

Next?



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Backup

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Why measure top quark cross sections?

- Sensitive to higher order cross sections
  - Precision test of perturbative QCD
- Sensitive to the proton parton distribution functions
- Lots of soft QCD radiation produced
  - Test the modelling of parton shower
- Sensitive to new physics beyond the standard model
  - Either through production, decay or couplings
- Large background to many new physics searches and rare standard model searches

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Cross section definition

Normalised cross section:

$$\frac{1}{\sigma_{t\bar{t}}^{vis}}\frac{d\sigma_{t\bar{t}}^{i}}{dX} = \frac{1}{\sum_j N_{t\bar{t}}^{j}}\frac{N_{t\bar{t}}^{i}}{\Delta X^{i}}$$

Absolute cross section:

$$\frac{d\sigma_{t\bar{t}}^{i}}{dX} = \frac{N_{t\bar{t}}^{i}}{\mathcal{L}\Delta X^{i}}$$

$N_{t\bar{t}}$: N events

ΔX : Binwidth

$\mathcal{L}$: Luminosity

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Cross section definition

Goodness-of-fit

Normalised

	POWHEG+PYTHIA		With MC theoretical uncertainties	
	χ^2/ndf	p-value	χ^2/ndf	p-value
N_{jets}	2.0 / 5	0.85	1.5 / 5	0.91
H_{T}	26 / 12	< 0.01	4.8 / 12	0.97
S_{T}	22 / 12	0.04	4.2 / 12	0.98
$p_{\text{T}}^{\text{miss}}$	11 / 5	0.06	2.9 / 5	0.72
p_{T}^{W}	16 / 6	0.01	2.5 / 6	0.87
p_{T}^{ℓ}	24 / 16	0.09	14 / 16	0.63
$\lvert\eta^{\ell}\rvert$	19 / 7	< 0.01	15 / 7	0.04

	POWHEG+HERWIG++		MG5_aMC@NLO-NLO+PYTHIA		MG5_aMC@NLO-LO+PYTHIA	
	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value
N_{jets}	38 / 5	< 0.01	9.5 / 5	0.09	78 / 5	< 0.01
H_{T}	23 / 12	0.03	11 / 12	0.52	160 / 12	< 0.01
S_{T}	21 / 12	0.04	11 / 12	0.57	110 / 12	< 0.01
$p_{\text{T}}^{\text{miss}}$	1.3 / 5	0.93	5.9 / 5	0.31	23 / 5	< 0.01
p_{T}^{W}	0.81 / 6	0.99	8.9 / 6	0.18	30 / 6	< 0.01
p_{T}^{ℓ}	11 / 16	0.82	16 / 16	0.44	37 / 16	< 0.01
$\lvert\eta^{\ell}\rvert$	19 / 7	< 0.01	24 / 7	< 0.01	30 / 7	< 0.01

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Cross section definition

Goodness-of-fit

Absolute

	POWHEG+PYTHIA		With MC theoretical uncertainties	
	χ^2/ndf	p-value	χ^2/ndf	p-value
N_{jets}	2.2 / 6	0.90	1.7 / 6	0.95
H_{T}	23 / 13	0.05	4.3 / 13	0.99
S_{T}	19 / 13	0.11	4.7 / 13	0.98
$p_{\text{T}}^{\text{miss}}$	13 / 6	0.05	3.1 / 6	0.80
p_{T}^{W}	17 / 7	0.02	2.7 / 7	0.91
p_{T}^{ℓ}	20 / 17	0.28	14 / 17	0.68
$\lvert\eta^{\ell}\rvert$	16 / 8	0.04	15 / 8	0.06

	POWHEG+HERWIG++		MG5_aMC@NLO-NLO+PYTHIA		MG5_aMC@NLO-LO+PYTHIA	
	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value
N_{jets}	39 / 6	< 0.01	12 / 6	0.07	93 / 6	< 0.01
H_{T}	21 / 13	0.07	10 / 13	0.66	150 / 13	< 0.01
S_{T}	18 / 13	0.17	9.3 / 13	0.75	110 / 13	< 0.01
$p_{\text{T}}^{\text{miss}}$	1.5 / 6	0.96	6.6 / 6	0.36	26 / 6	< 0.01
p_{T}^{W}	0.90 / 7	1.00	9.2 / 7	0.24	33 / 7	< 0.01
p_{T}^{ℓ}	11 / 17	0.87	15 / 17	0.58	36 / 17	< 0.01
$\lvert\eta^{\ell}\rvert$	17 / 8	0.04	23 / 8	< 0.01	31 / 8	< 0.01

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Cross section definition

Goodness-of-fit

Unregularised

Also performed cross section measurements using unregularised unfolding

- Chi2 | NDF values fluctuate up and down by small amounts
- No effect on leptonic variables
- No conclusions are altered with respect to the regularised case

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