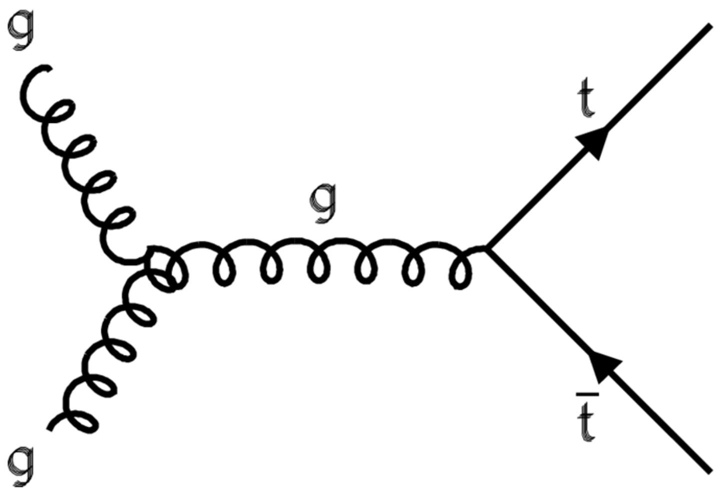
Recent PDF results from top quark pair and single top t-channel differential cross sections in CMS

DIS 2019 workshop, 8-12 April, Torino, Italy

Olaf Behnke (DESY), on behalf of the CMS collaboration

Covered CMS top quark cross section results

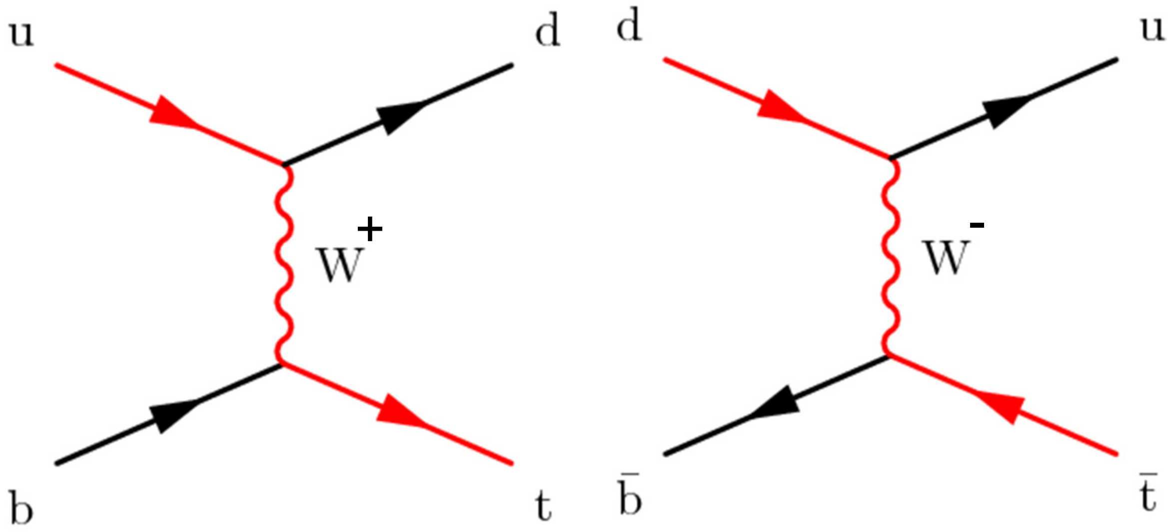
Top quark pair ($t\bar{t}$)



→ Sensitive to g(x), α_s and m_t

- TOP-17-001: inclusive
- TOP-18-004: triple differential

t-channel single Top



→ Sensitive to u/d ratio

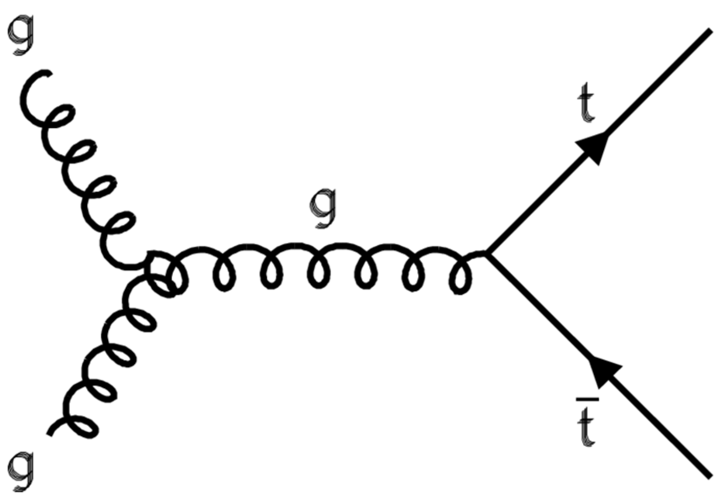
- TOP-17-011: inclusive
- TOP-17-023: differential

All analyses:

- 2016 data at 13 TeV with L~36 fb^{-1}
- Using only leptonic top decays ($t \to bW \to bl\nu$)

Covered CMS top quark cross section results

Top quark pair ($t\bar{t}$)



→ Sensitive to g(x), α_s and m_t

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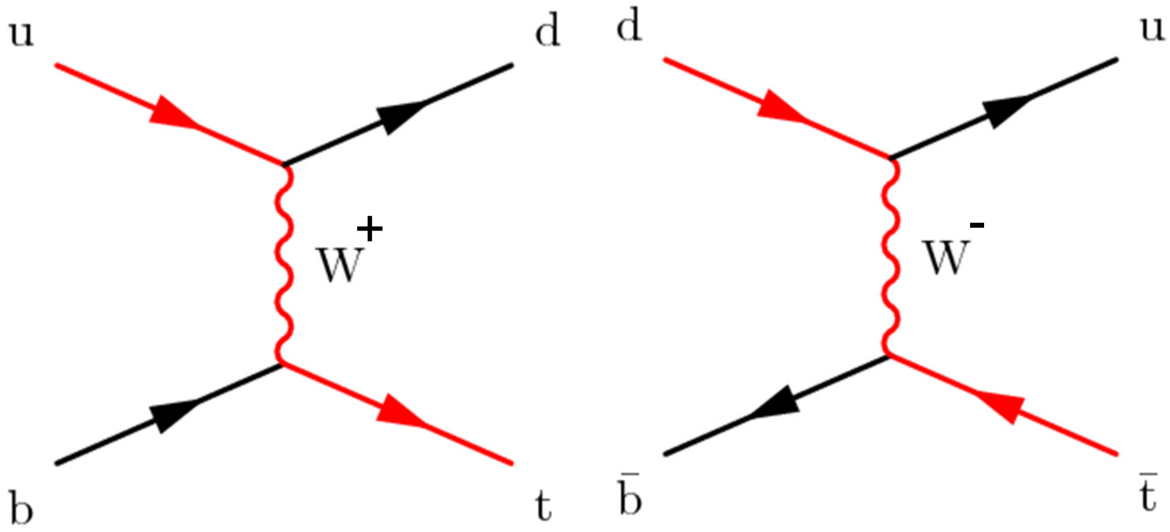
More measurement details in talk "Top pairs at the LHC", Sergio Grancagnolo, WG5, Apr 9

t-channel single Top



→ Sensitive to u/d ratio

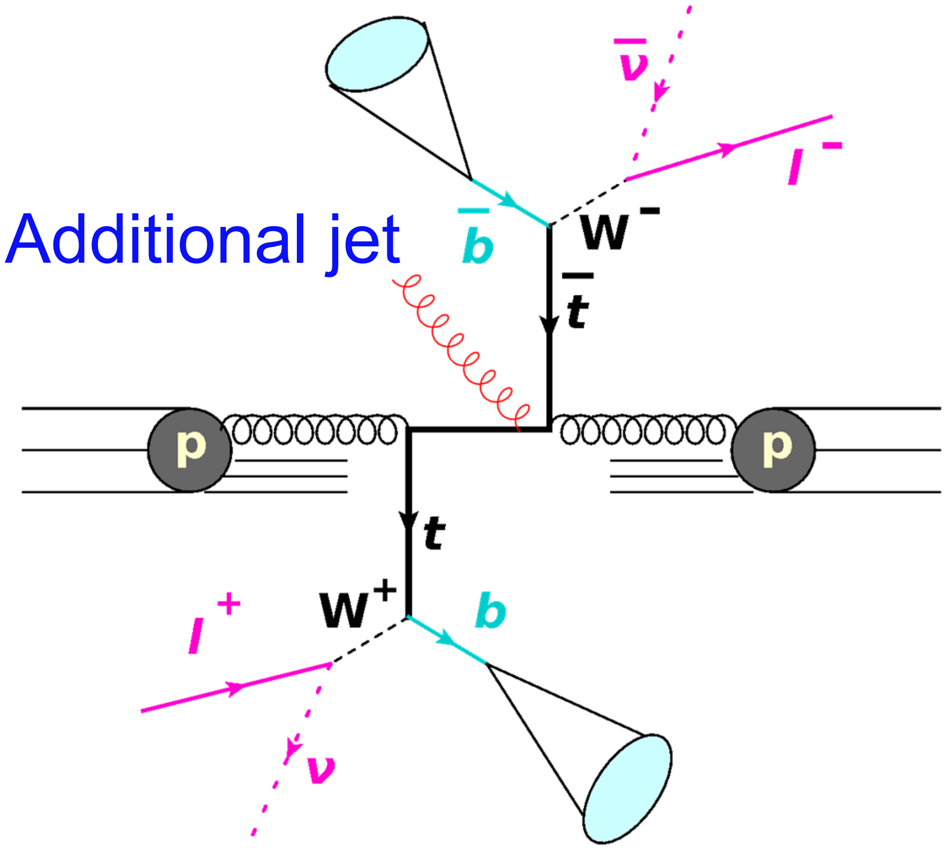
- TOP-17-011: inclusive
- TOP-17-023: differential

at 13 T
lepton

More measurement details in talk "Single top production at the LHC", Achim Geiser, WG5, Apr 9

Inclusive $t\bar{t}$ cross section $\sigma_{t\bar{t}}$

TOP-17-001, [1812.10505]



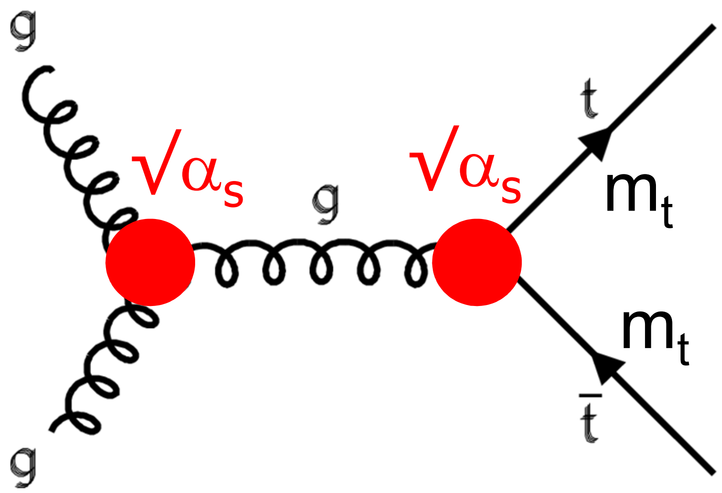
- $\sigma_{t\bar{t}}$ is extracted from template fit to final state distributions
- Simultaneous fit of $\sigma_{t\bar{t}}$ and MC mass parameter m_t^{MC} to 3D distribution: [#b-jets, #additional jets, m_{lb}^{min}]

→ Result:

$$\sigma_{t\bar{t}} = 815 \pm 2\,(\text{stat}) \pm 29\,(\text{syst}) \pm 20\,(\text{lumi})\,\text{pb}$$ → ~4% unc.

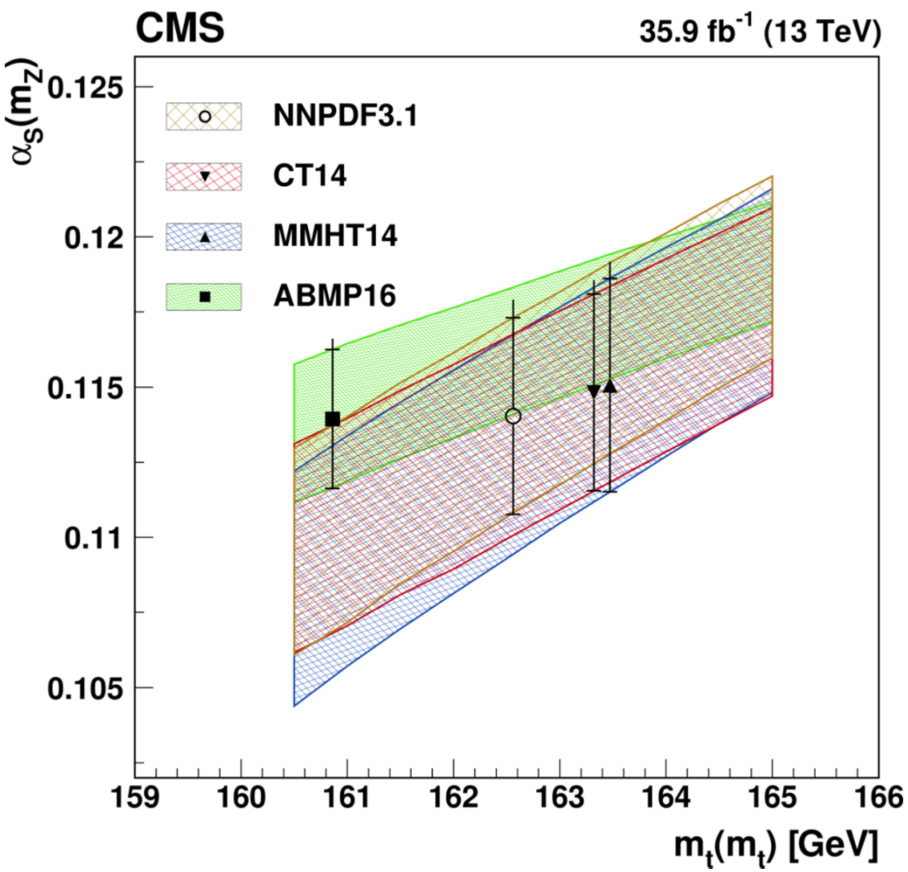
$$m_t^{\text{MC}} = 172.33 \pm 0.14\,(\text{stat})\,^{+0.66}_{-0.72}\,(\text{syst})\,\text{GeV}$$

Use measured $\sigma_{t\bar{t}}$ to extract α_s vs $m_t(m_t)$



- Fit NNLO prediction (HATHOR) to $\sigma_{t\bar{t}}$
- NNLO prediction
  - ↗ with growing $\alpha_s(m_Z)$
  - ↘ with growing $m_t(m_t)$

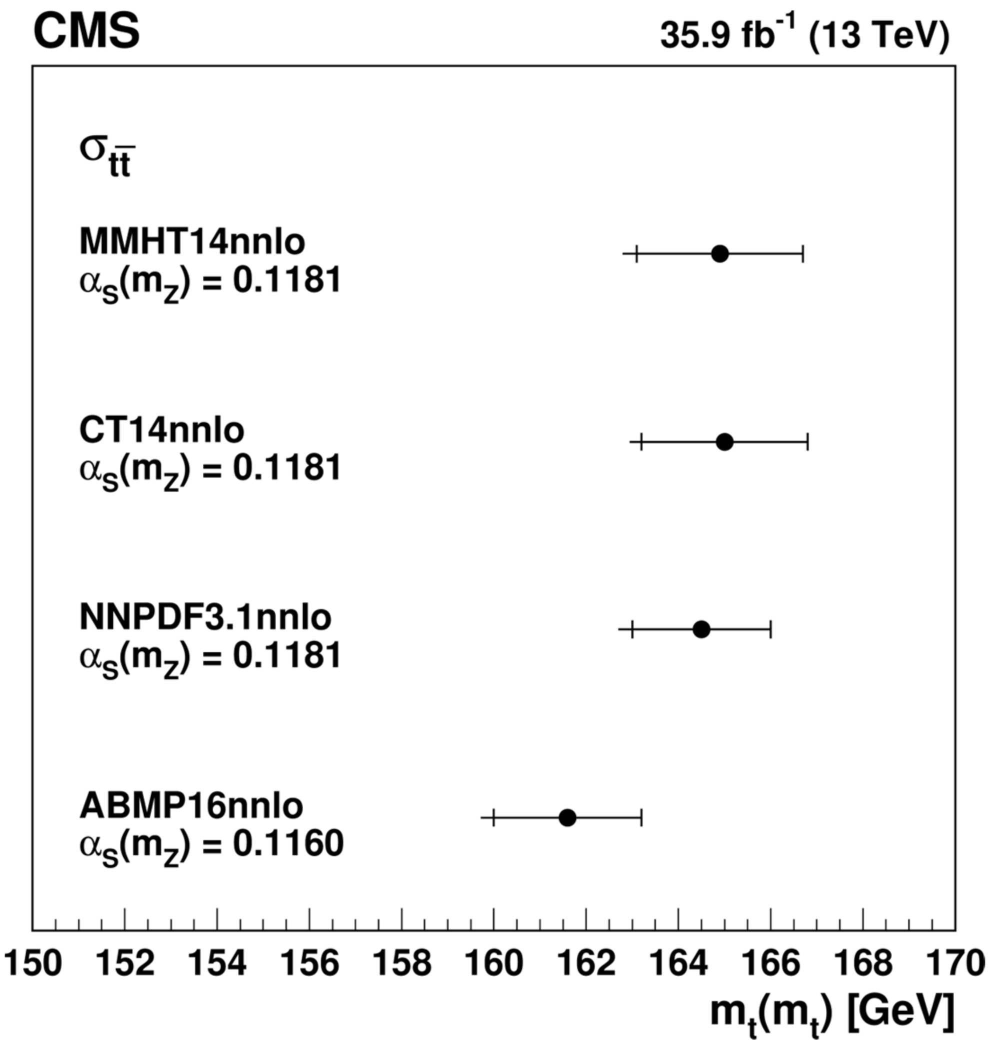
⇒ Fit $\alpha_s(m_Z)$ value vs $m_t(m_t)$ value, for 4 PDFs



→ ~3% precision for $\alpha_s(m_Z)$ at any $m_t(m_t)$, ~similar uncertainty contributions from measured $\sigma_{t\bar{t}}$ and PDFs

Use measured $\sigma_{t\bar{t}}$ to extract $m_t(m_t)$ and m_t^{pole}

- Fix $\alpha_s(m_Z)$ to value used in PDF and vary within uncertainty



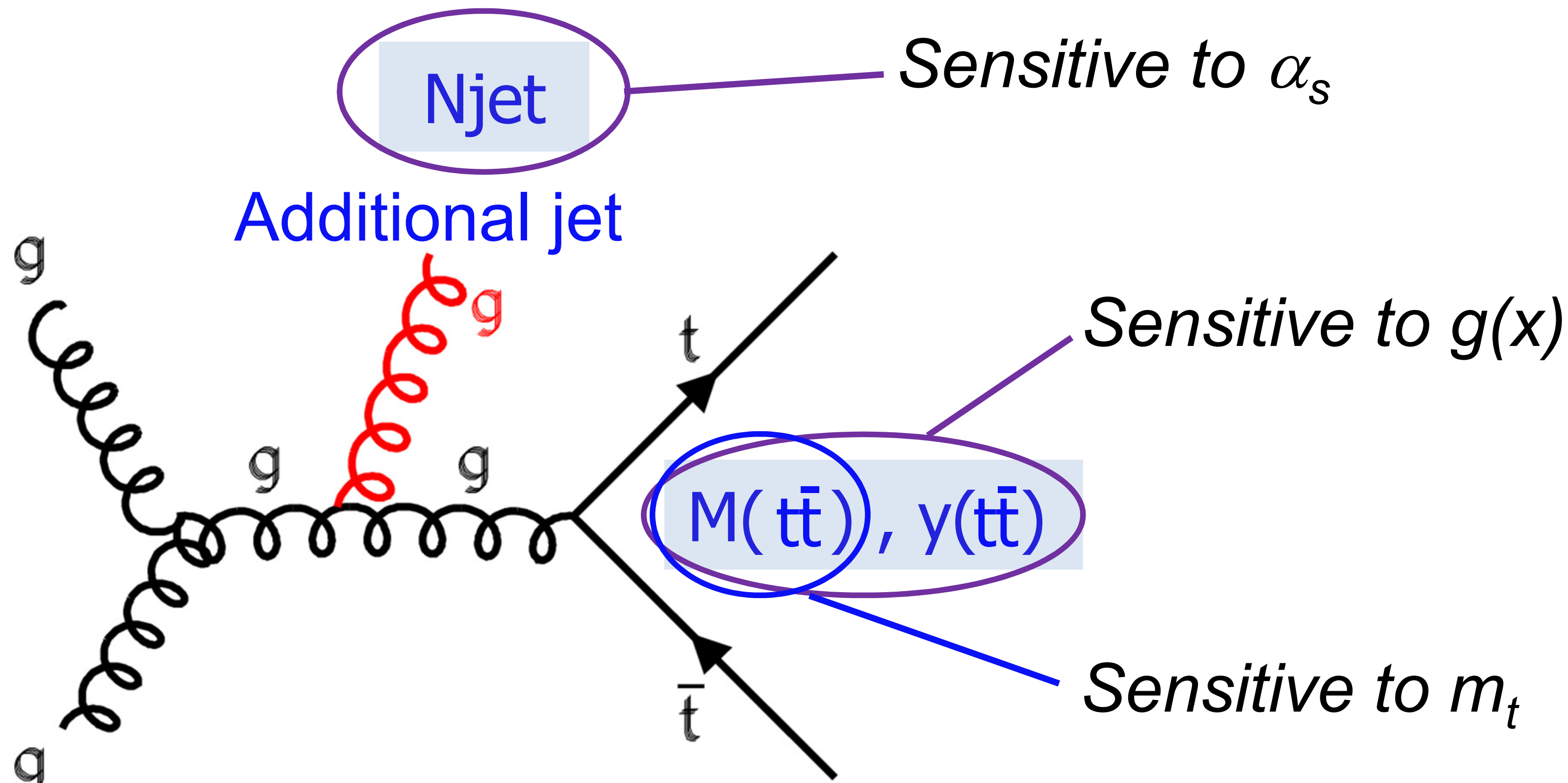
PDF set	m_t^{pole} [GeV]
ABMP16	169.9 ± 1.8 (fit + PDF + α_S) $^{+0.8}_{-1.2}$ (scale)
NNPDF3.1	173.2 ± 1.9 (fit + PDF + α_S) $^{+0.9}_{-1.3}$ (scale)
CT14	173.7 ± 2.0 (fit + PDF + α_S) $^{+0.9}_{-1.4}$ (scale)
MMHT14	173.6 ± 1.9 (fit + PDF + α_S) $^{+0.9}_{-1.4}$ (scale)

→ extract $m_t(m_t)$ with ~1.6 GeV unc.
→ Pole mass unc. larger, reason can be the slower convergence of the perturbative series compared to $\overline{MS}$ scheme $m_t(m_t)$

Triple differential cross section $d^3\sigma_{t\bar{t}}$

CMS-PAS-TOP-18-004

Use kinematical & topological observables to extract theory parameters

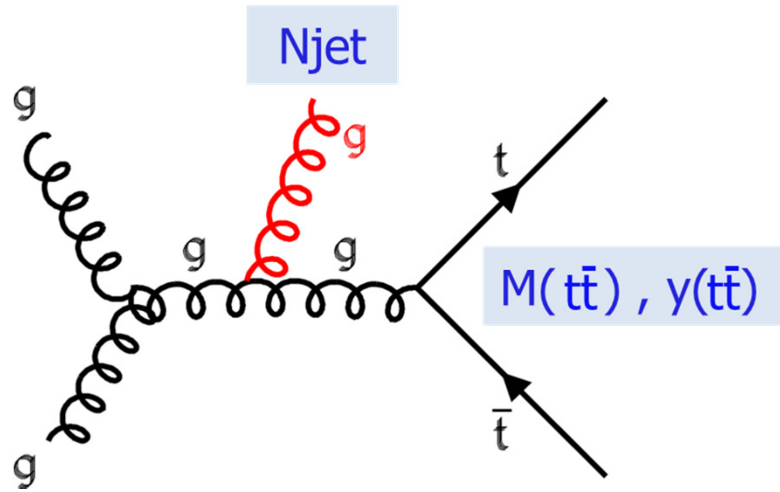


→ First ever 3D measurement of $\sigma_{t\bar{t}}$ vs [Njet, M($t\bar{t}$), y($t\bar{t}$)]

Analysis:

- New kinematic reconstruction without top mass constraints
- Regularised unfolding with TUnfold

NLO calculation for $d^3\sigma_{t\bar{t}}$



- Fixed order NLO predictions using MadGraph5_aMC@NLO+aMCfast+ApplGrid+xFitter
- $\sigma_{t\bar{t}}$ vs [Njets, M($t\bar{t}$), y($t\bar{t}$)] calculations:

Mangano, Nason, Ridolfi, NPB 373 (1992) 295

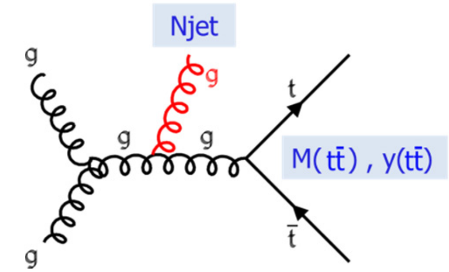
Dittmaier, Uwer, Weinzierl, PRL 98 (2007) 262002

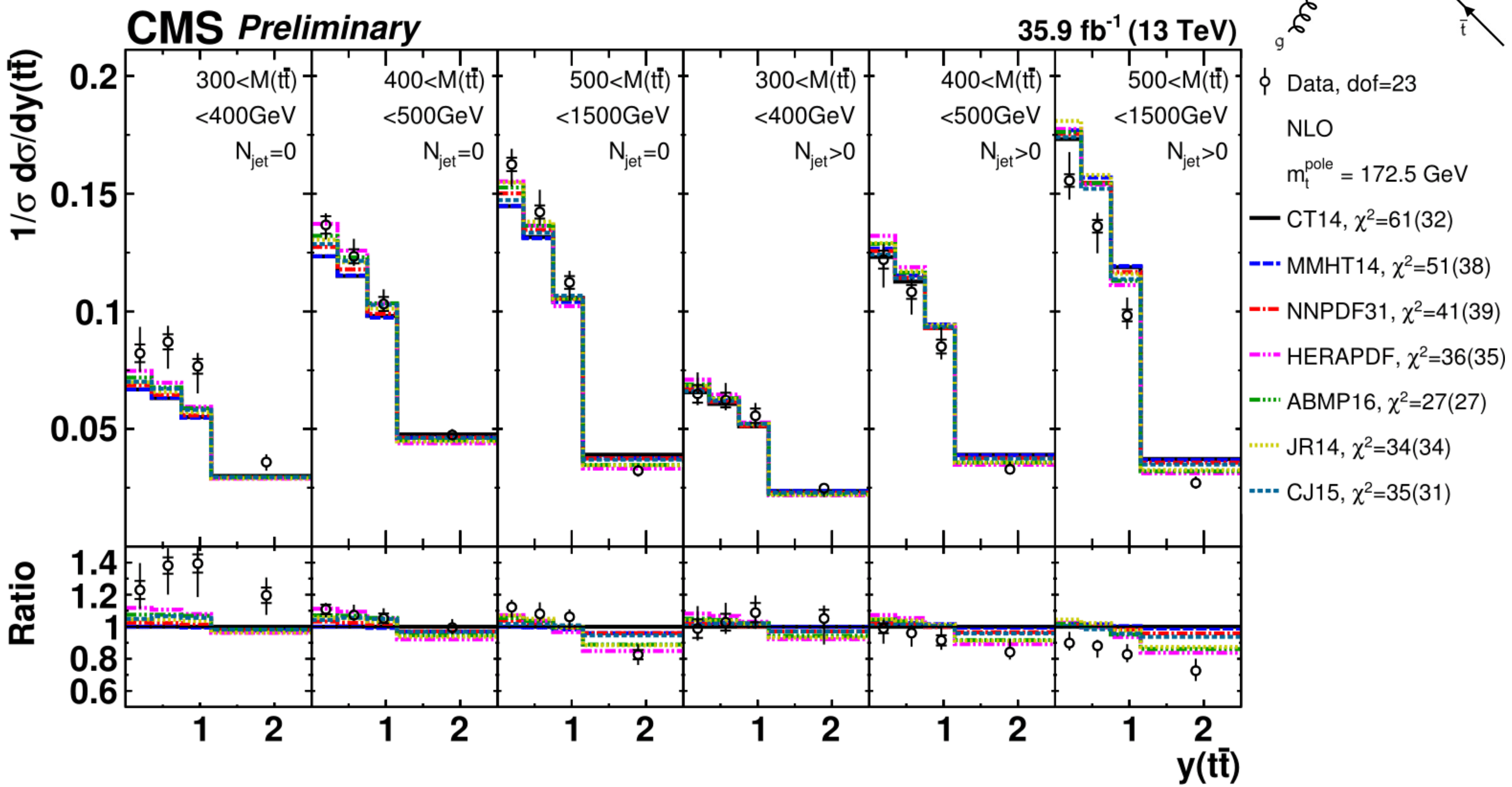
  - $\sigma^{NLO}(\text{Njets}=0) = \sigma^{NLO}(t\bar{t}) - \sigma^{NLO}(t\bar{t}+1\text{jet})$
  - $\sigma^{NLO}(\text{Njets}>0) = \sigma^{NLO}(t\bar{t}+1\text{jet})$

Details

- $\mu_r = \mu_f = H'/2$, $H' = \Sigma_i m_{T,i}$, sum is over all final state partons
  - μ_r, μ_f varied by factor 2 (6 variations in total)
- $m_t^{pole} = 172.5 \pm 1$ GeV
- PDFs and α_s from several groups via LHAPDF, vary α_s ±0.001 for uncertainties
- Multiplied with non-perturbative corrections (<5%) from parton to particle level

TOP-18-004: $d^3\sigma_{t\bar{t}}$ vs NLO, different PDFs

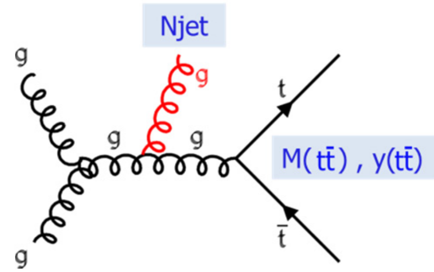


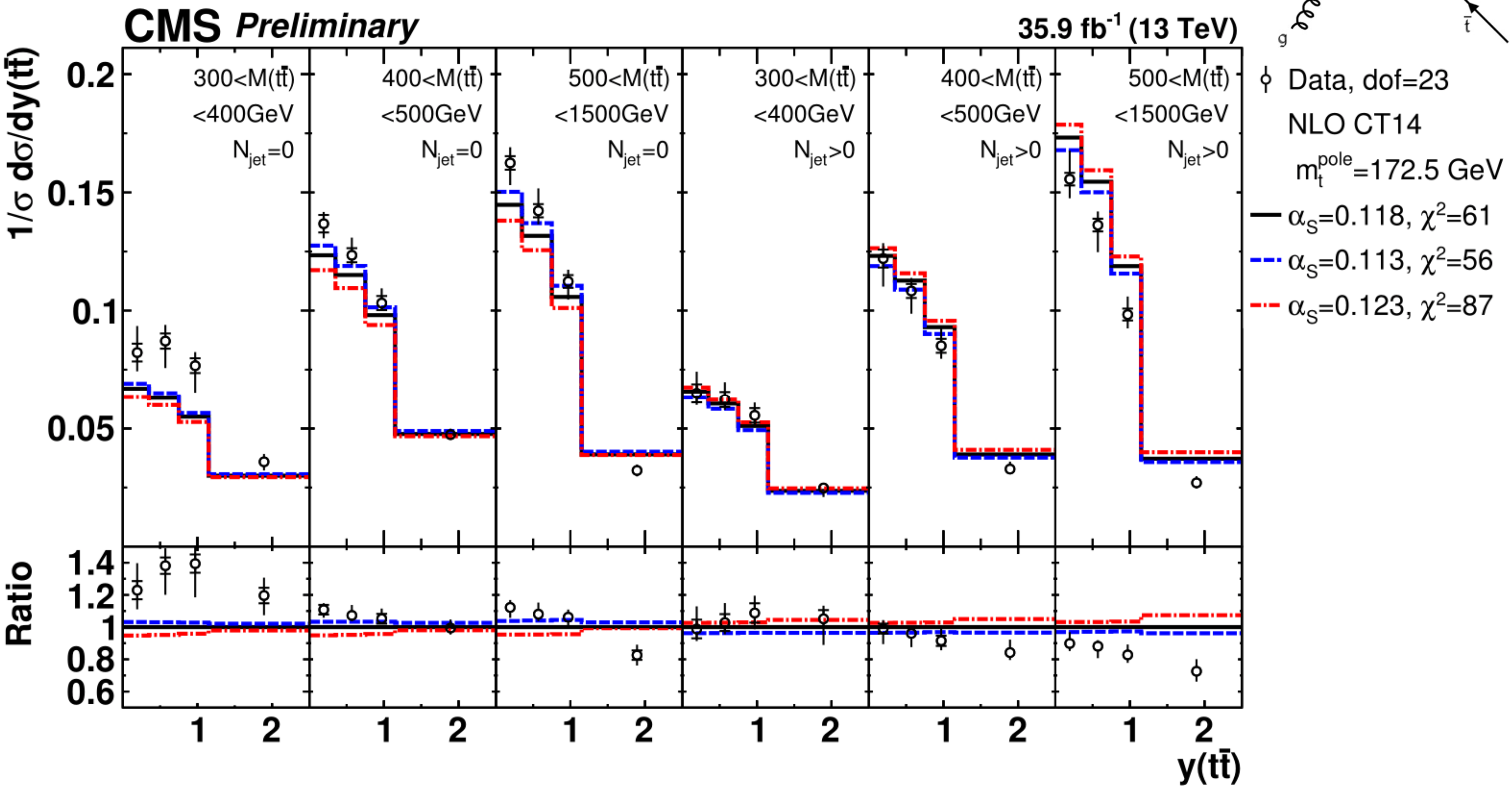


→ Description depends on PDFs → sensitivity

→ PDFs already using older $t\bar{t}$ data: MMHT2014, NNPDF3.1, ABMP16

TOP-18-004: $d^3\sigma_{t\bar{t}}$ vs NLO, different α_s

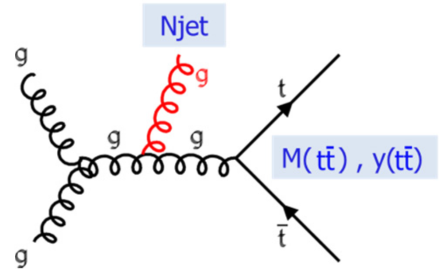




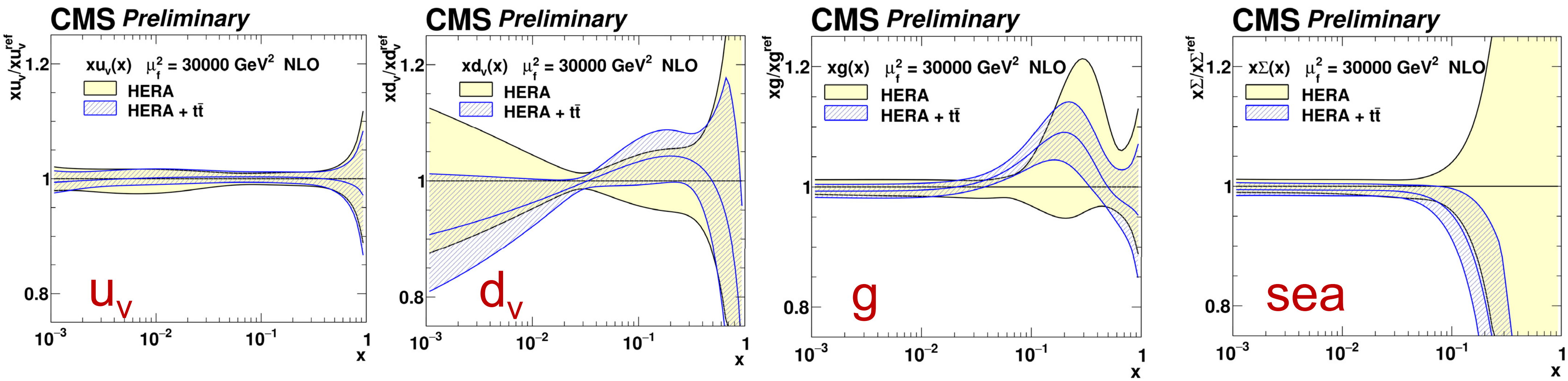
→ α_s sensitivity comes from different Njet bins

→ Indirect sensitivity from [M($t\bar{t}$),y($t\bar{t}$)] via sensitivity to PDFs

TOP-18-004: simultaneous PDF, α_s and m_t^{pole} extraction



- Using HERA DIS data [1506.06042] or HERA DIS + our new $d^3\sigma_{t\bar{t}}$ data
- Use xFitter-2.0.0, HERAPDF2.0 settings, HERA-only fit α_s = 0.1135 ±0.0016



→ Reduced g uncertainty at high x

$$\alpha_s(m_Z) = 0.1135 \pm 0.0016(\text{fit})^{+0.0002}_{-0.0004}(\text{model})^{+0.0008}_{-0.0001}(\text{param})^{+0.0011}_{-0.0005}(\text{scale}) = 0.1135^{+0.0021}_{-0.0017}(\text{total}),$$

$$m_t^{pole} = 170.5 \pm 0.7(\text{fit}) \pm 0.1(\text{model})^{+0.0}_{-0.1}(\text{param}) \pm 0.3(\text{scale})\ \text{GeV} = 170.5 \pm 0.8(\text{total})\ \text{GeV}$$

→ Two SM parameters determined precisely, weak correl. (ρ=0.3)

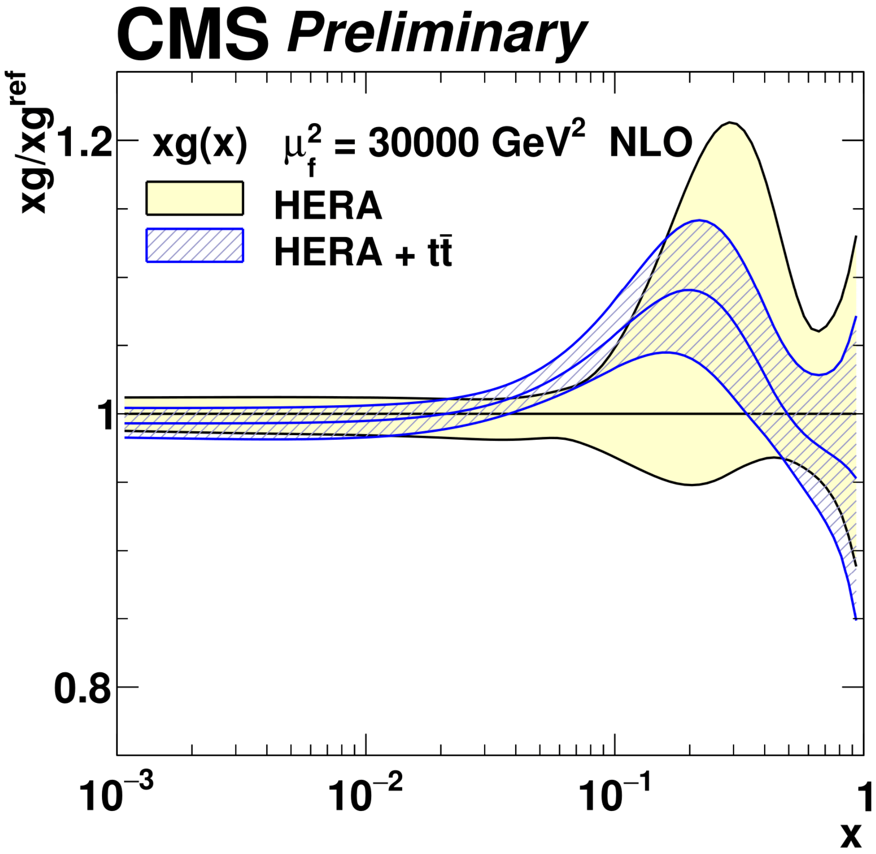
xg(x) with using different CMS data sets

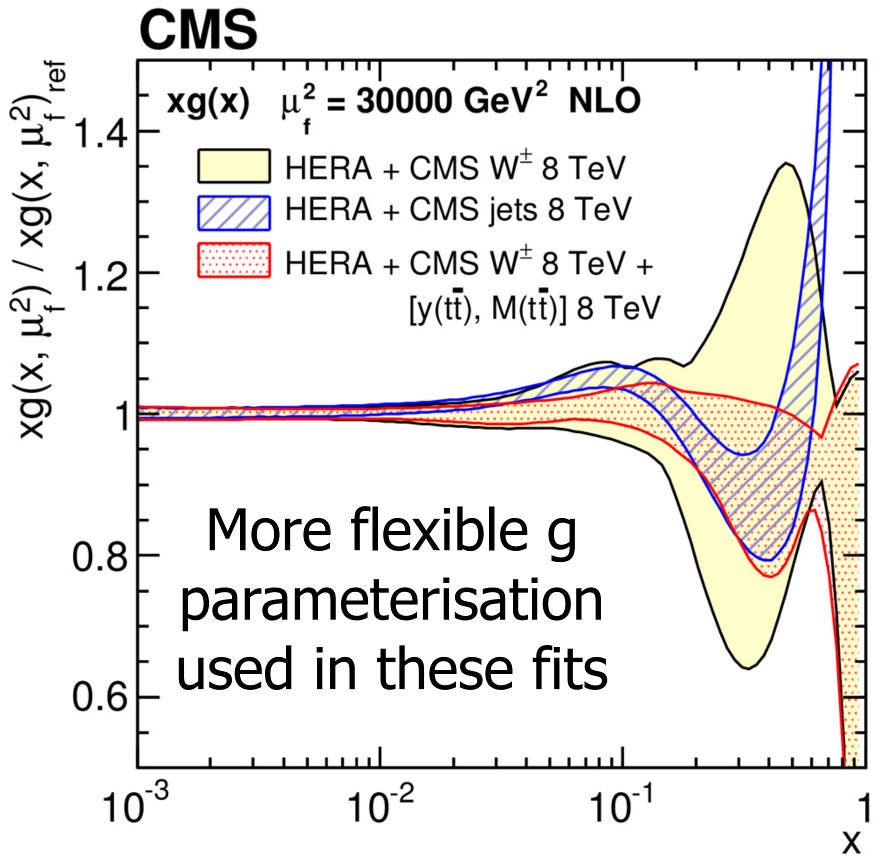
CMS-PAS-TOP-18-004:

- HERA
- HERA + $d^3\sigma_{t\bar{t}}$

TOP-14-013 EPJ C77 (2017) 459:

- HERA + CMS W EPJ C76 (2016) 469
- HERA + CMS jets JHEP 03 (2017) 156
- HERA + CMS W + $d^2\sigma_{t\bar{t}}$





→ ~similar improvements adding $d^3\sigma_{t\bar{t}}$ (RUN II) or $d^2\sigma_{t\bar{t}}$ (RUN I)

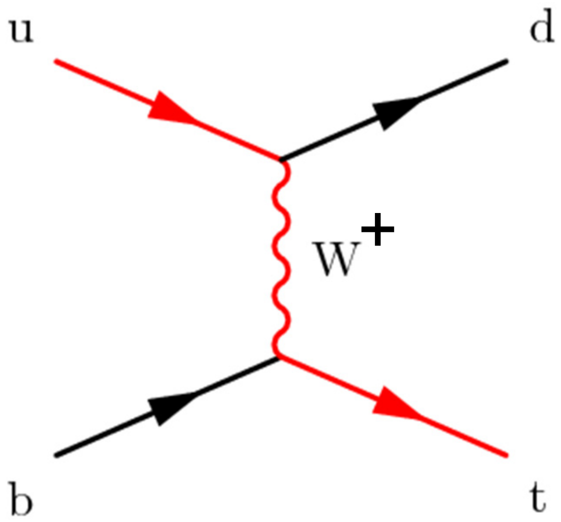
→ should fit to all data simultaneously!

t-channel single top production

TOP-17-011 [1812.10514]

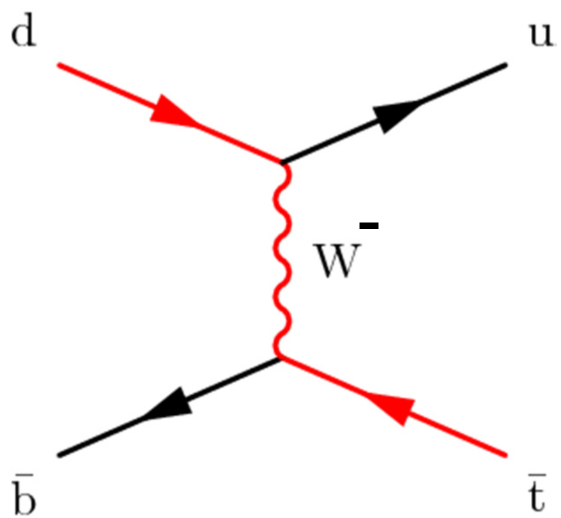
Analysis:

- Use #jets, #b-jets +BDTs → isolate signal



Result:

$$\sigma_{t-ch,t} = 136 \pm 1\,(\mathrm{stat}) \pm 22\,(\mathrm{syst})\,\mathrm{pb}$$



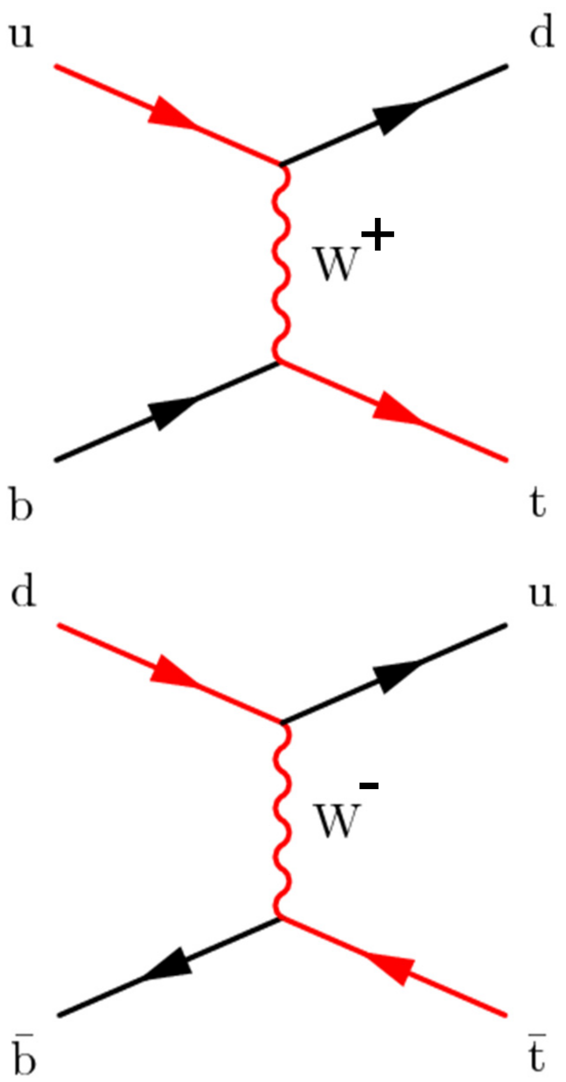
Result:

$$\sigma_{t-ch,\bar{t}} = 82 \pm 1\,(\mathrm{stat}) \pm 14\,(\mathrm{syst})\,\mathrm{pb}$$

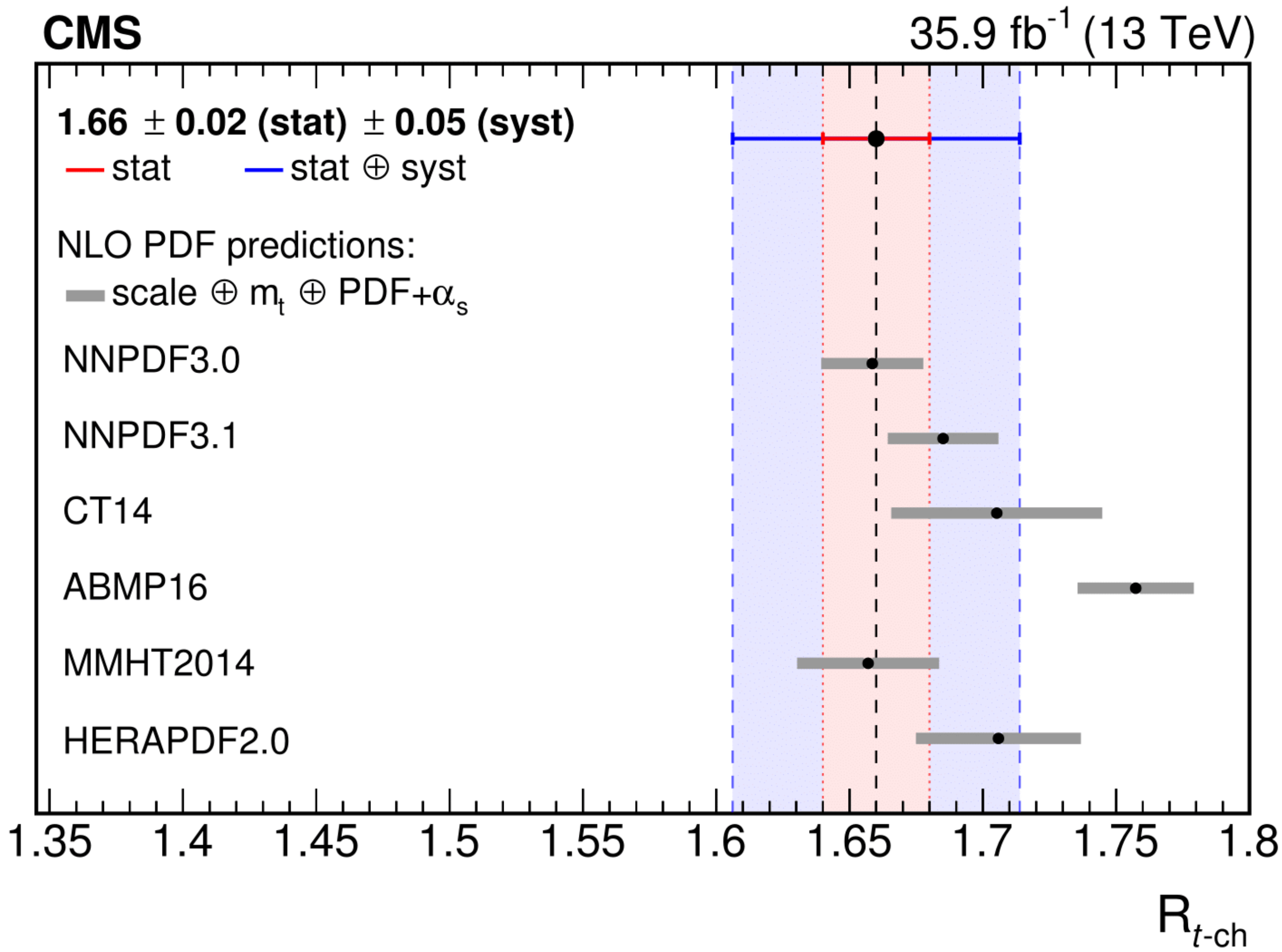
t/t̄ Ratio:

$$R_{t-ch} = 1.66 \pm 0.02\,(\mathrm{stat}) \pm 0.05\,(\mathrm{syst})$$

t-channel single top production: $t/\bar{t}$ ratio



Compare $R_{t\text{-ch}}$ to NLO calculation (HATHOR 5FS)



→ Predictions with different PDF sets: *most* describe data well

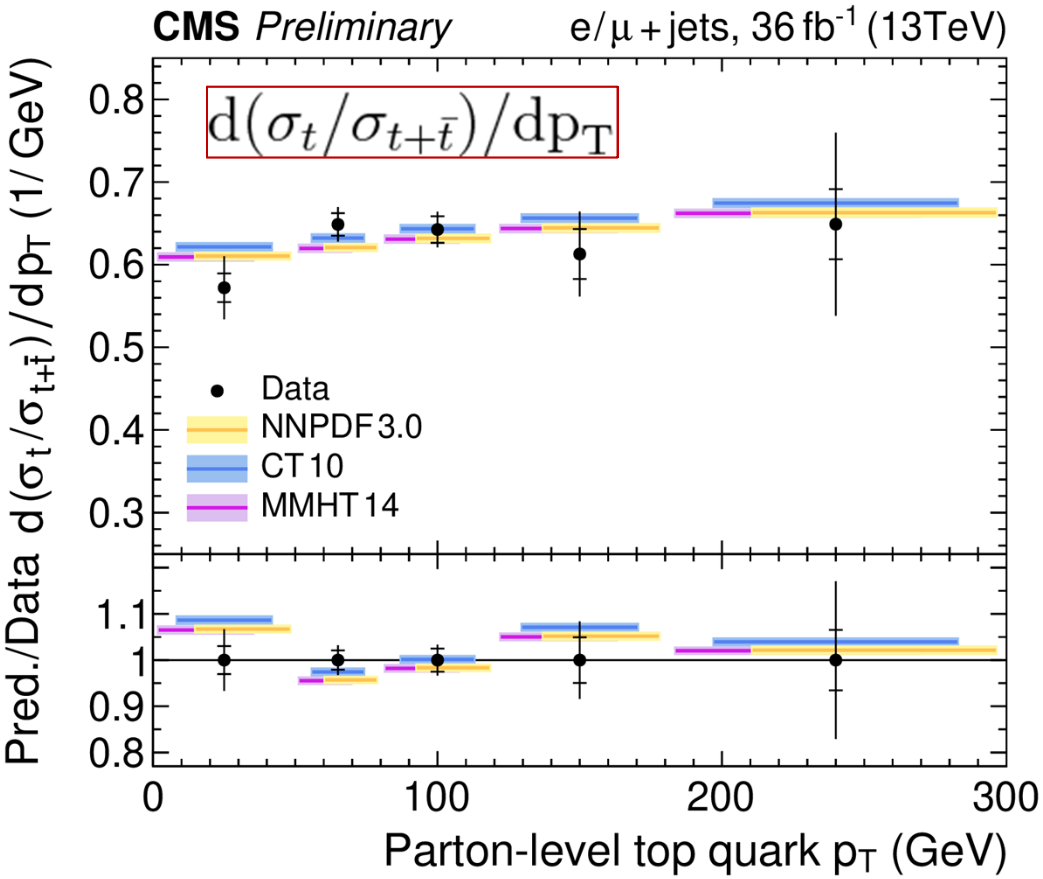
Differential t-channel single top

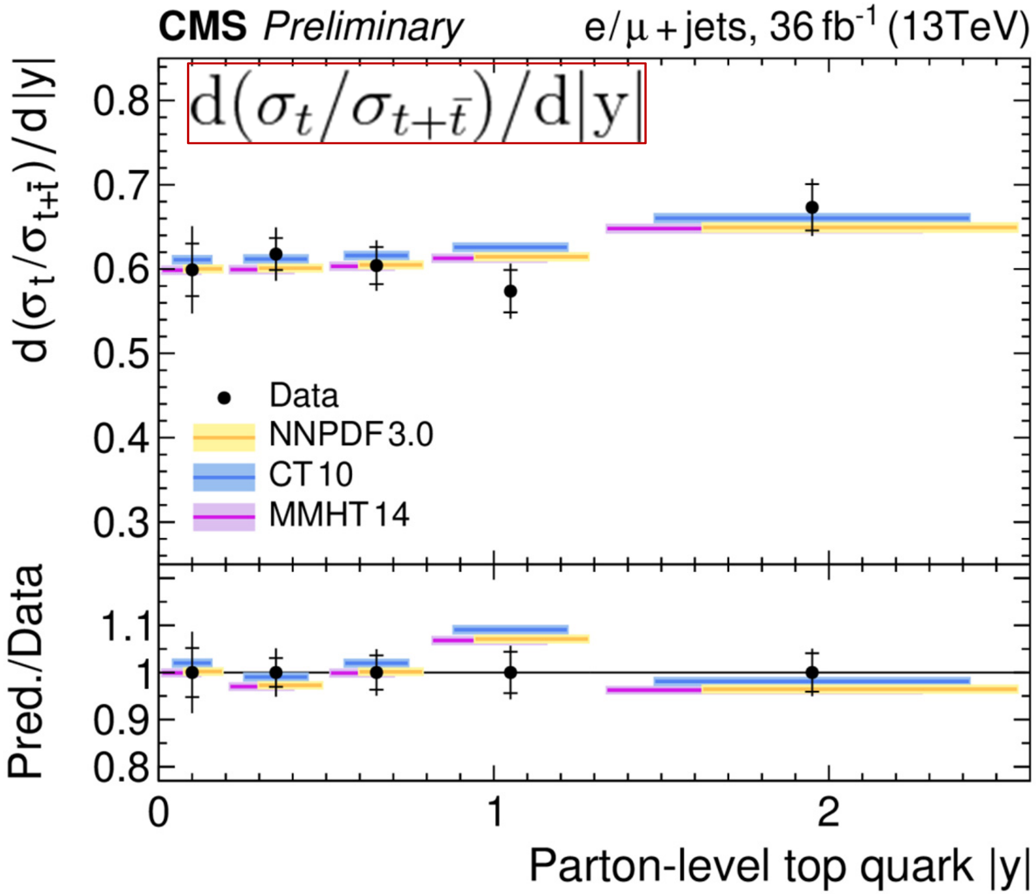
CMS-PAS-TOP-17-023

Analysis:

- Fit signal yields to $m_T(W)$ & BDT distributions in regions of #jets and #b-jets; unfold cross sections (Tunfold)

POWHEG NLO with different 4FS PDFs vs data:

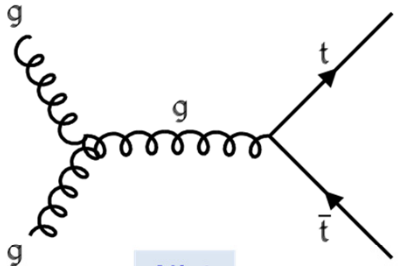


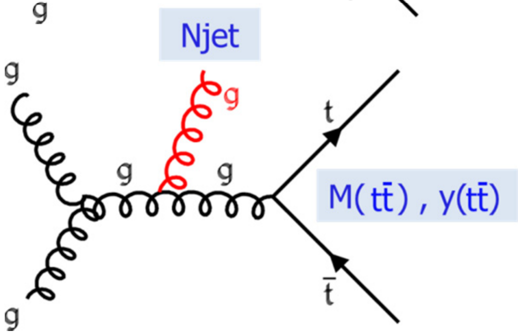


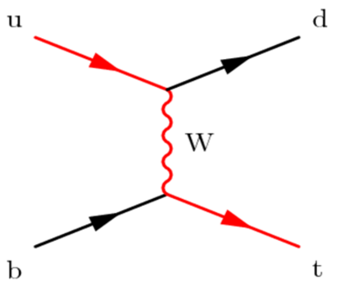
→ *For all 3 PDF sets* predictions agree with the data

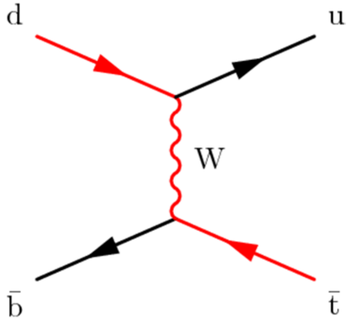
Conclusions

4 CMS measurements covered using data at 13 TeV, L~36 fb^{-1}







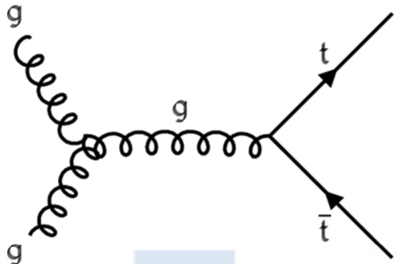
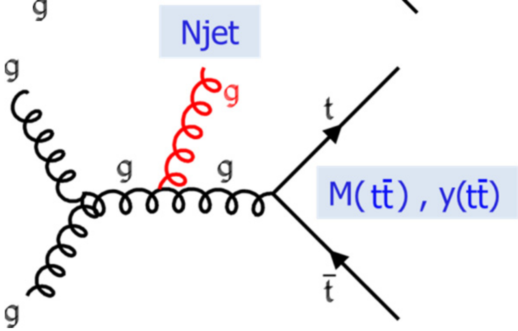


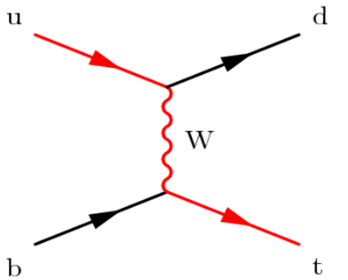
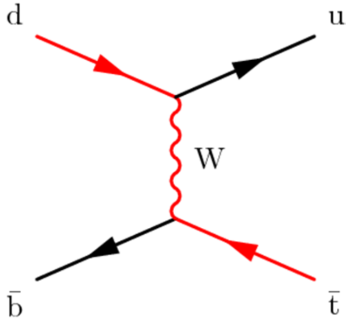
Measurement	Exp. Unc.	Theory	Results
TOP-17-001 $\sigma_{t\bar{t}}$	~4%	NNLO	Different PDFs agree $\alpha_s(m_Z)$ [~3%], $m_t(m_t)$ [~1.6GeV], m_t^{pole} [~2 GeV]
TOP-18-004 $d^3\sigma_{t\bar{t}}$; $d^2\sigma_{t\bar{t}}$	~10%	NLO	Constrain g(x) at high x, $\alpha_s(m_Z)$ [~2%], m_t^{pole} [~0.8GeV]
TOP-17-011 $R_{t\text{-}ch} = \sigma_t / \sigma_{\bar{t}}$	~3%	NLO	Different PDFs agree with data
TOP-17-023 $\mathrm{d}(\sigma_t/\sigma_{t+\bar{t}})$	~5%	NLO	Different PDFs agree with data

Conclusions

Some remarks on the future:

4 CMS measurements covered using data at 13 TeV, L~36 fb^{-1}

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TOP-17-011 $R_{t\text{-}ch} = \sigma_t / \sigma_{\bar{t}}$	~3%	NLO	Different PDFs agree with data
TOP-17-023 $d(\sigma_t/\sigma_{t+\bar{t}})$	~5%	NLO	Different PDFs agree with data

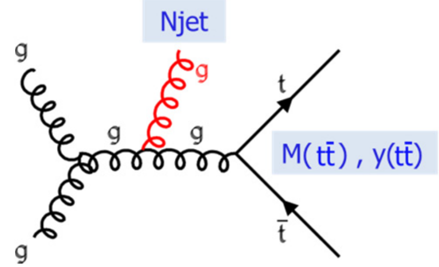
Challenge to improve syst. with full RUN II data

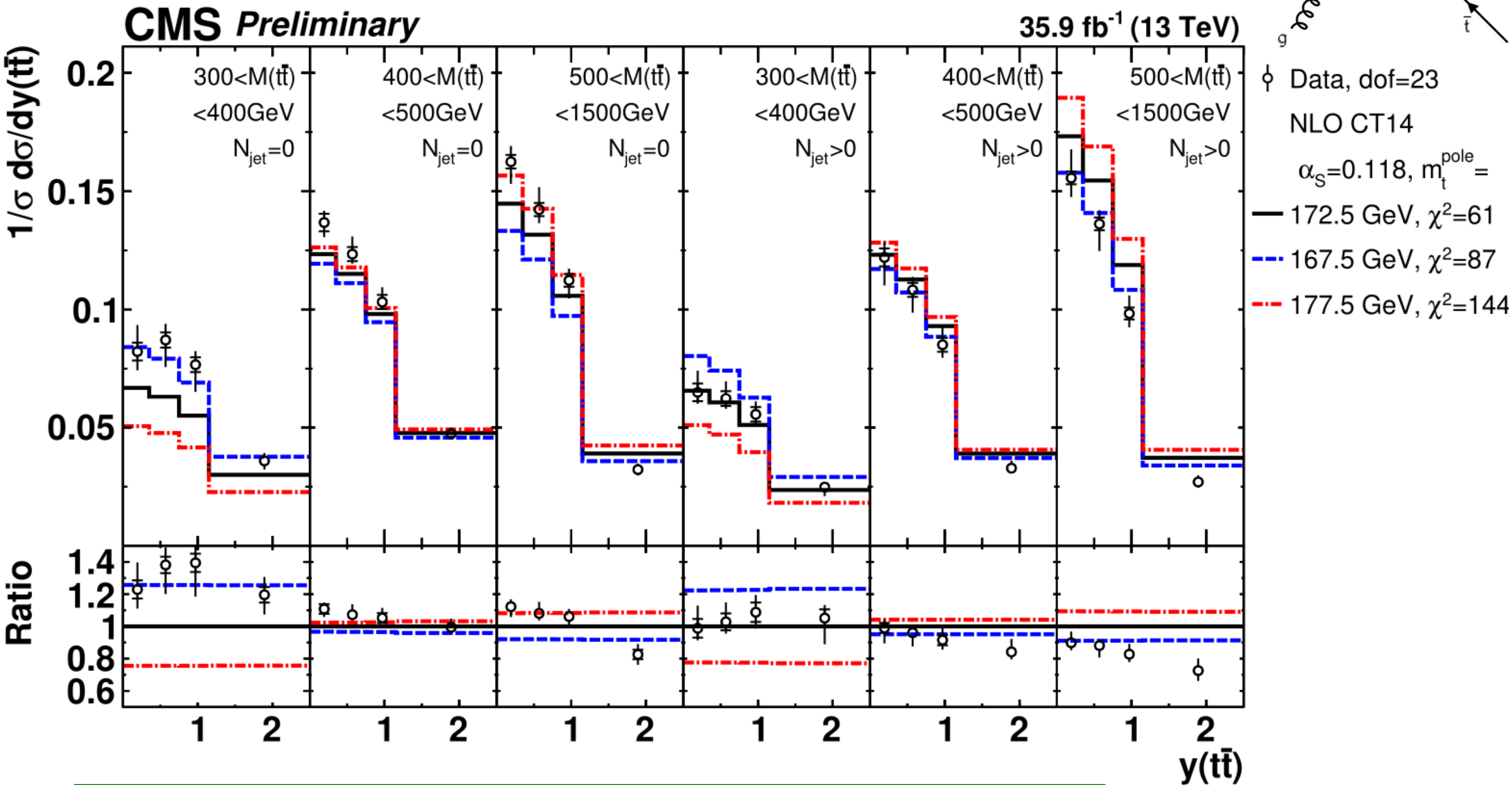
Need publicly available NNLO tool

Expect more precise + more differential results with full RUN II data

Backup slides

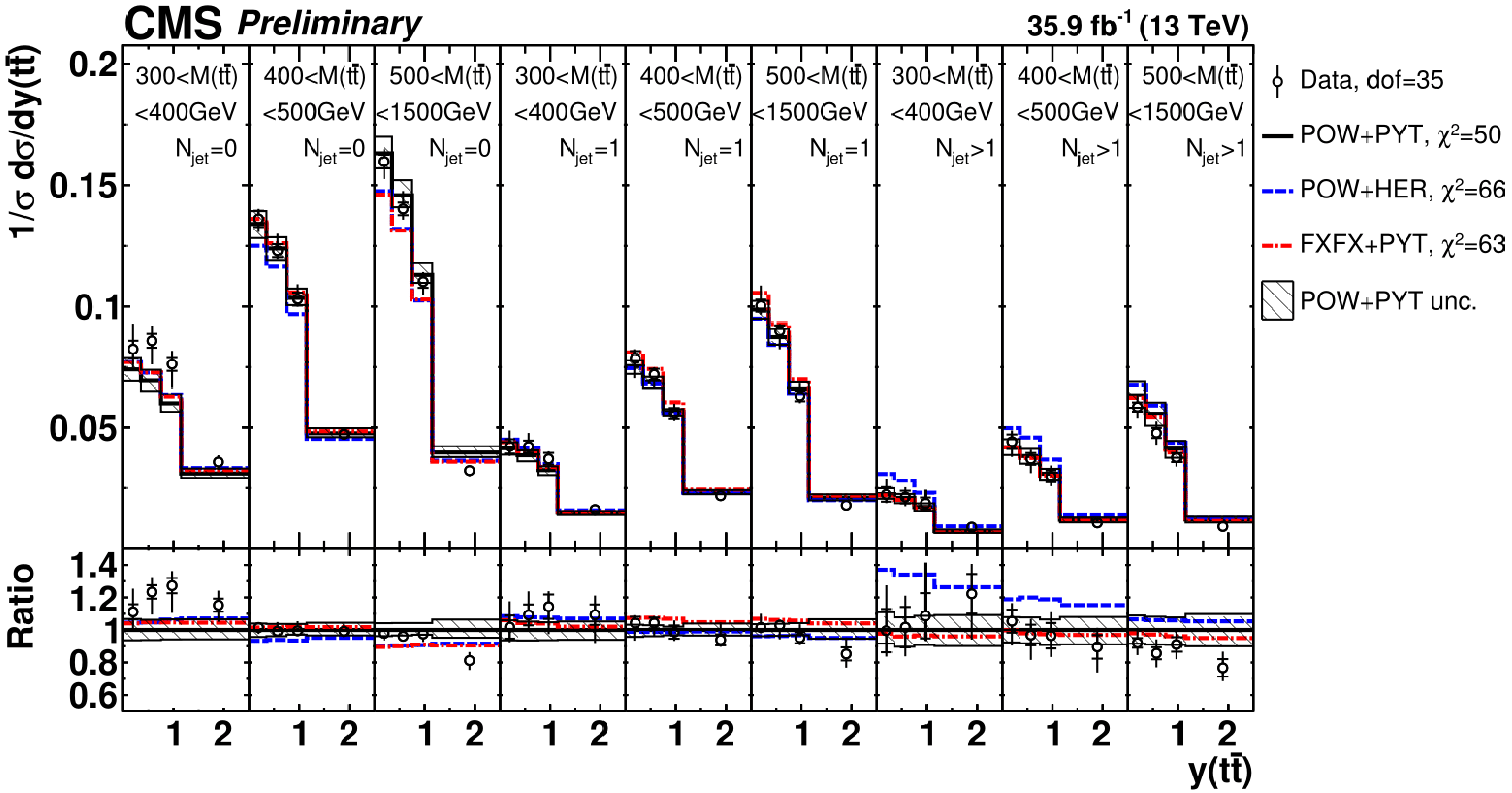
TOP-18-004: $d^3\sigma_{t\bar{t}}$ vs NLO, different m_t^{pole}





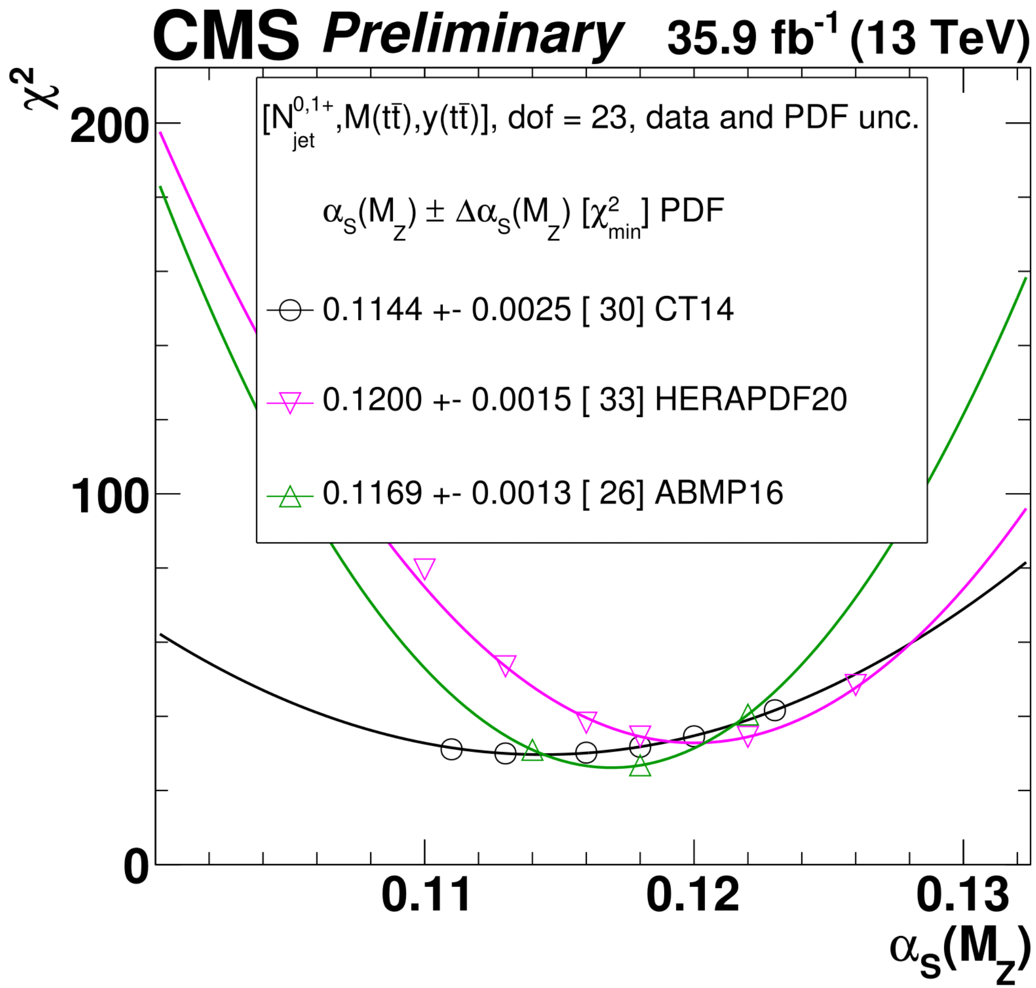
→ m_t^{pole} sensitivity mainly from first $m(t\bar{t})$ bin

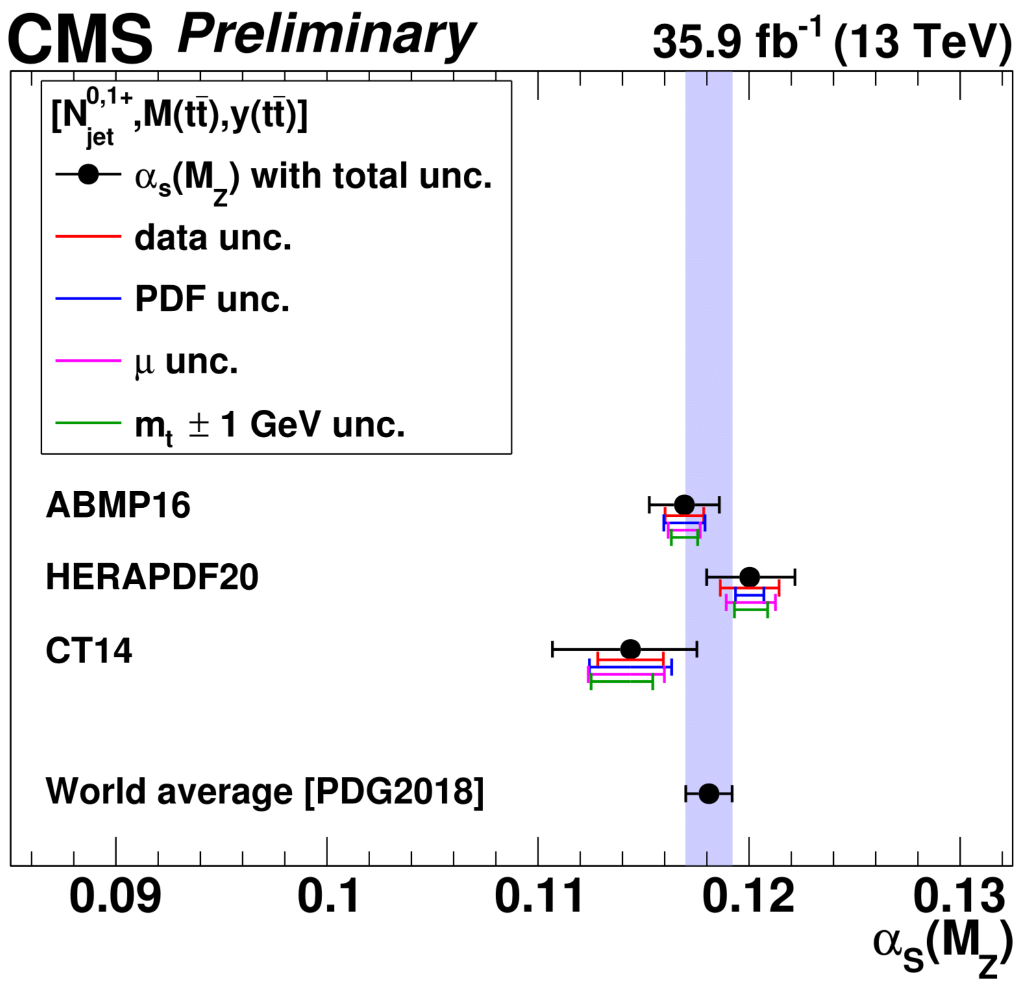
TOP-18-001 $d^3\sigma_{tt}$ vs NLO MC predictions



→ Only 'POW-PYT' is in satisfactory agreement with the data

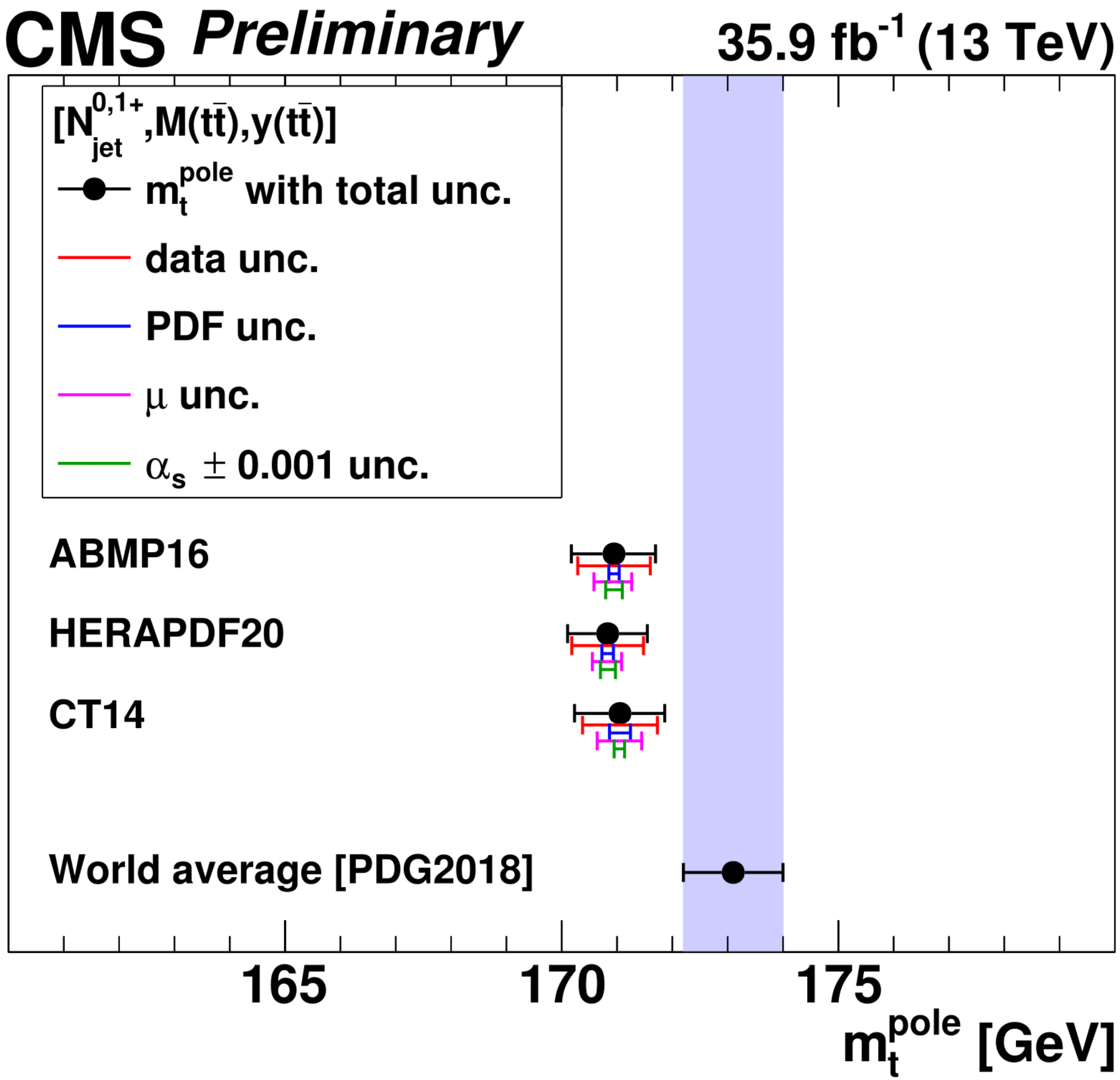
TOP-18-001: α_s extraction





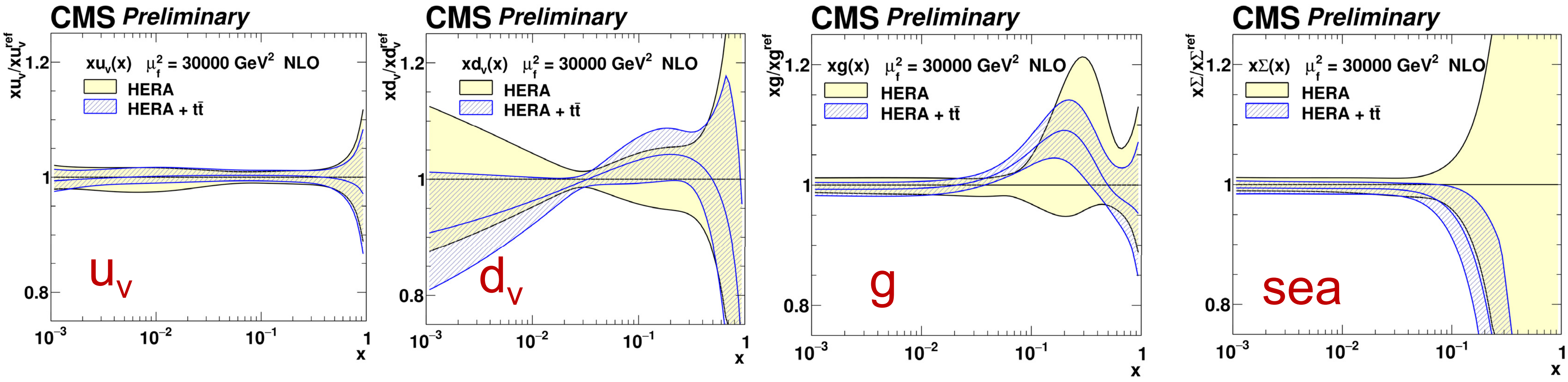
→ Precise determination of α_s, at NLO QCD

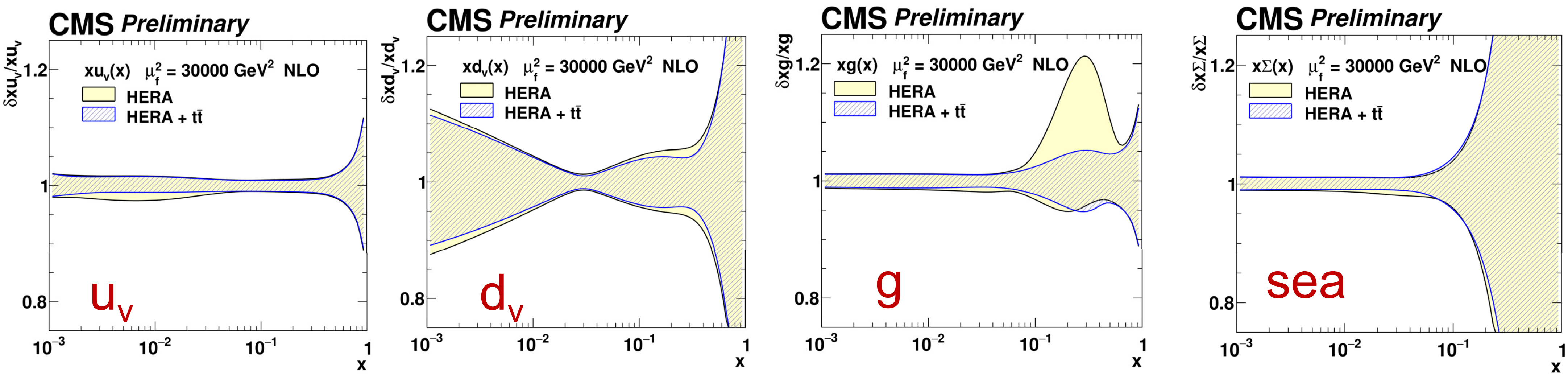
TOP-18-001: m_t^{pole} extraction



→ Precise determination of m_t^{pole}, at NLO QCD

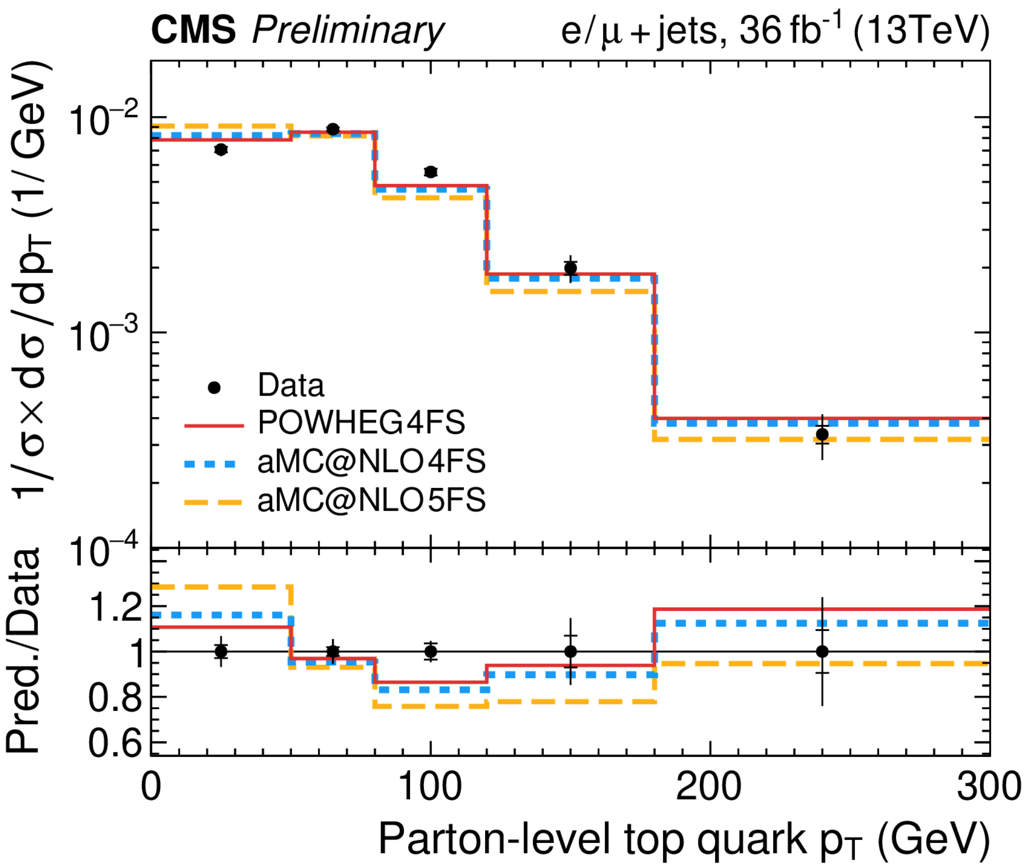
TOP-18-004: simultaneous α_s, m_t^{pole}, PDF extraction

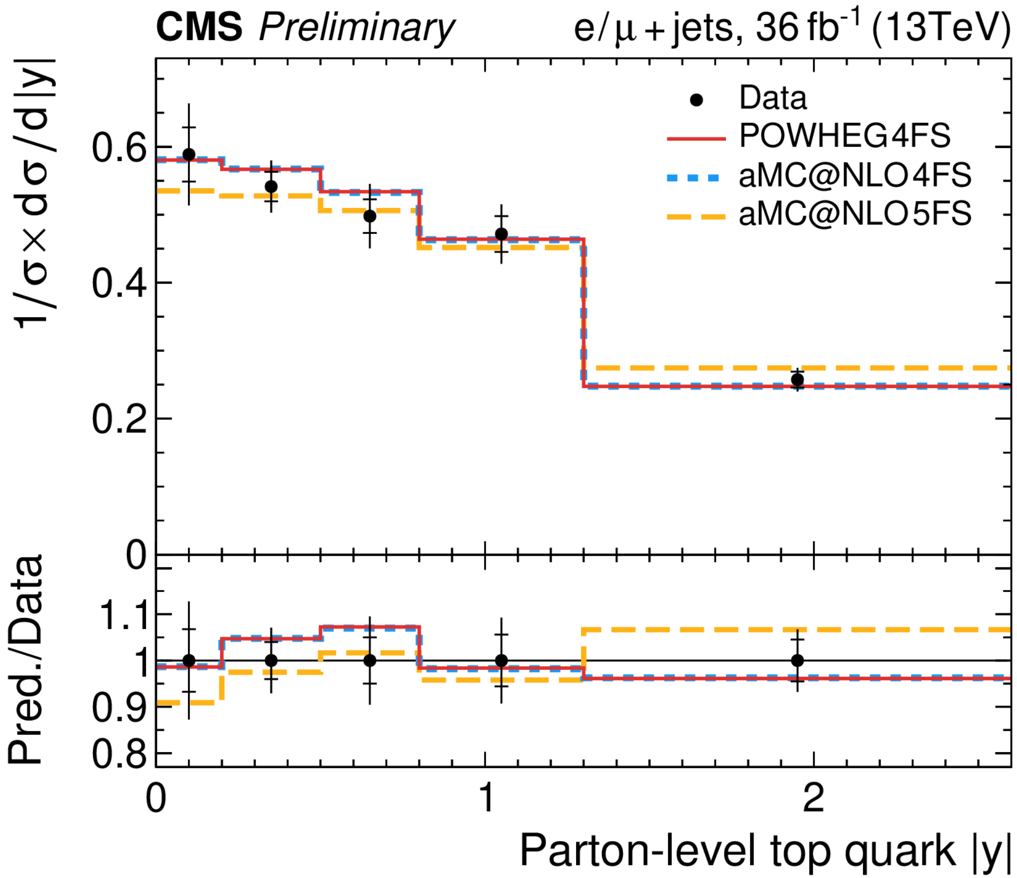




PDF Uncertainty improvements

TOP-17-023: differential t-channel single t production





→ Slightly better description by aMC@NLO4FS than aMC@NLO5FS