$\overline{\text{MS}}$ top-quark mass in the global ABMPtt/ABGMZ25 PDF fits

Sergey Alekhin[1], Maria Vittoria Garzelli[1], Sven-Olaf Moch[1], Sasha Zenaiev[1,2]

[1] Hamburg University, II. Institute for Theoretical Physics

[2] Taras Shevchenko National University of Kyiv

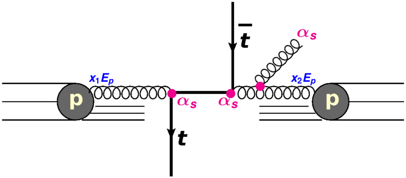
Alekhin, Garzelli, Moch, Zenaiev arXiv:2510.21435

Alekhin, Garzelli, Moch, Zenaiev EPJ C 85 (2025) 162 [arXiv:2407.00545]

Garzelli, Mazzitelli, Moch, Zenaiev JHEP 05 (2024) 321 [arXiv:2311.05509]

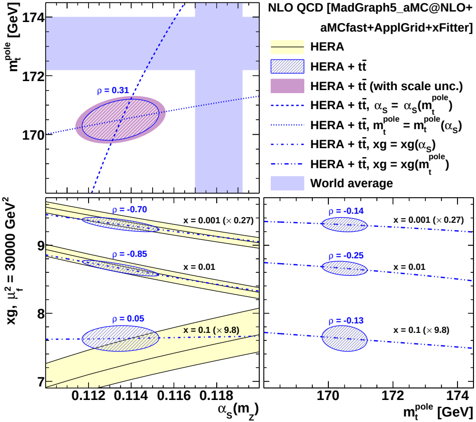
Workshop on top quark mass measurements
11 Nov 2025

Why study $t\bar{t}$ production?



- m_t provides a hard scale
  $\Rightarrow$ ultimate probe of pQCD
  (NLO, aNNLO, NNLO, ...)
- Produced mainly via gg
  $\Rightarrow$ constrain gluon PDF at high x
- Production sensitive to α_s and m_t
- May provide insight into possible new physics

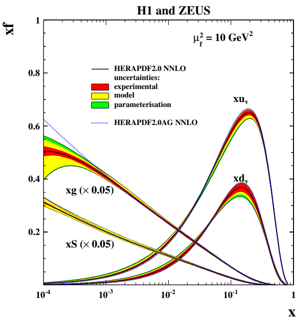
CMS TOP-18-004 [EPJ C80 (2020) 7]

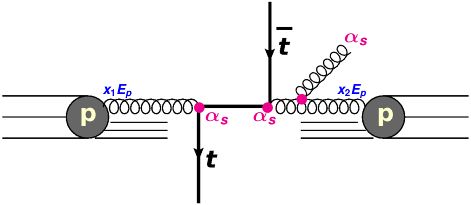


- 1D: probe of $t\bar{t}$ dynamics, extract one input
- 2D: probe of correlations, access to two inputs
- 3D: simultaneous extraction of PDFs, α_s, m_t^{pole} possible (currently at NLO)
  - extended to $\overline{MS}$, MSR schemes in JHEP 04 (2021) 043 [Garzelli, Kemmler, Moch, SZ]

Proton PDFs

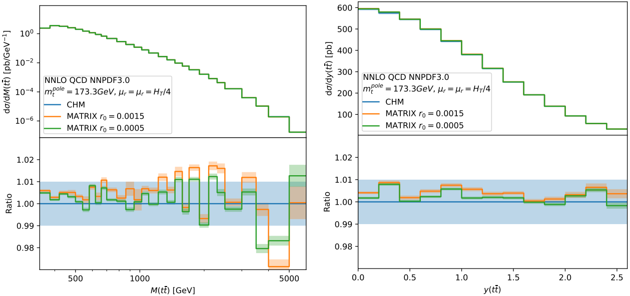
- Parton distribution functions (PDFs) cannot be computed perturbatively and must be extracted from data: *ep* DIS, DY etc.
- In this work we focus on gluon PDF: it is a challenge because it is constrained by DIS data (backbone of PDF fits) only indirectly
  - especially at large x (important for BSM searches at LHC)
  - in addition, g is strongly correlated with α_S
- Processes to constrain g:
  - heavy-quark production: NNLO, but depend on m_Q
  - jet production: larger dependence on NNLO scale choice
- We focused on double-differential $t\bar{t}$ LHC data $d^2\sigma/M(t\bar{t})y(t\bar{t})$:
  - $M(t\bar{t}) \approx \sqrt{sx_1x_2}$ provides sensitivity to m_t and PDFs
  - $y(t\bar{t}) \approx \frac{1}{2}\ln\frac{x_1}{x_2}$ is sensitive especially to PDFs





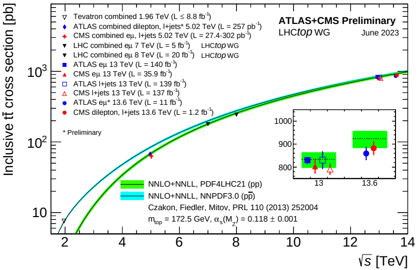
Theoretical calculations and scope of our work

- NNLO calculations for total and fully differential $t\bar{t}$ (q_T subtraction) are publicly available with MATRIX framework [Catani et al. PRD99 (2019) 5, 051501] [Catani et al. JHEP 07 (2019) 100]
  - fully differential NNLO calculations were also published in [Czakon, Heymes, Mitvo JHEP 04 (2017) 071] [CHM], but no public code available (apart from the HighTEA datbase)



- We have interfaced MATRIX $t\bar{t}$ to PineAPPL interpolation library: **no NNLO/NLO K-factors**
- Using LHC $t\bar{t}$ data only, one can focus e.g. on extracting m_t [Garzelli, Mazzitelli, Moch, Zenaiev JHEP 05 (2024) 321 [arXiv:2311.05509]]
- Using more data (HERA, Tevatron, LHC) one can do a global PDF+α_S+m_t fit with enhnced senitivity to m_t [Alekhin, Garzelli, Moch, Zenaiev EPJ C 85 (2025) 162 [arXiv:2407.00545]]

$t\bar{t}$ data used in this analysis



Selection of data:

- all measurements of total $\sigma(t\bar{t})$:
  - 10 data points, including recently combined CMS+ATLAS cross section at 7 and 8 TeV
- differential measurements $\frac{1}{\sigma(t\bar{t})}\frac{d\sigma(t\bar{t})}{dO}$ which satisfy following criteria:
  - as function of $M(t\bar{t})$ (if available, 2D $M(t\bar{t})$ and $y(t\bar{t})$)
  - unfolded to parton level (no cuts on p_T, y of leptons or jets): no LHCb data
  - normalized cross sections (to avoid unknown correlation with total $\sigma(t\bar{t})$ and to reduce unknown correlations between different data sets)
  - bin-by-bin correlations are available
  - for the moment only Run-2 2D data included in the PDF fit (besides the total $t\bar{t}$ x-section data)

$\sigma(t\bar{t})$

Experiment	decay channel	dataset	luminosity	$\sqrt{s}$
ATLAS & CMS	combined	2011	5 fb^{-1}	7 TeV
ATLAS & CMS	combined	2012	20 fb^{-1}	8 TeV
ATLAS	dileptonic, semileptonic	2011	257 pb^{-1}	5.02 TeV
CMS	dileptonic	2011	302 pb^{-1}	5.02 TeV
ATLAS	dileptonic	2015-2018	140 fb^{-1}	13 TeV
ATLAS	semileptonic	2015-2018	139 fb^{-1}	13 TeV
CMS	dileptonic	2016	35.9 fb^{-1}	13 TeV
CMS	semileptonic	2016-2018	137 fb^{-1}	13 TeV
ATLAS	dileptonic	2022	11.3 fb^{-1}	13.6 TeV
CMS	dileptonic, semileptonic	2022	1.21 fb^{-1}	13.6 TeV

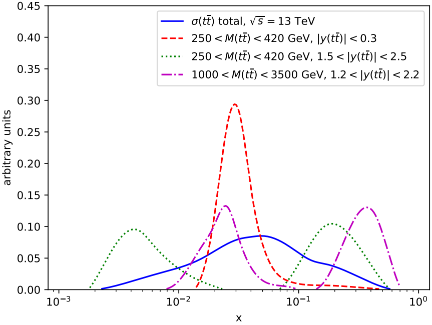
$\frac{1}{\sigma(t\bar{t})}\frac{d\sigma(t\bar{t})}{dO}$

Experiment	decay channel	dataset	luminosity	$\sqrt{s}$	observable(s)	n
CMS	semileptonic	2016–2018	137 fb^{-1}	13 TeV	$M(t\bar{t})$, $\|y(t\bar{t})\|$	34
CMS	dileptonic	2016	35.9 fb^{-1}	13 TeV	$M(t\bar{t})$, $\|y(t\bar{t})\|$	15
ATLAS	semileptonic	2015–2016	36 fb^{-1}	13 TeV	$M(t\bar{t})$, $\|y(t\bar{t})\|$	19
ATLAS	all-hadronic	2015–2016	36.1 fb^{-1}	13 TeV	$M(t\bar{t})$, $\|y(t\bar{t})\|$	10
CMS	dileptonic	2012	19.7 fb^{-1}	8 TeV	$M(t\bar{t})$, $\|y(t\bar{t})\|$	15
ATLAS	semileptonic	2012	20.3 fb^{-1}	8 TeV	$M(t\bar{t})$	6
ATLAS	dileptonic	2012	20.2 fb^{-1}	8 TeV	$M(t\bar{t})$	5
ATLAS	dileptonic	2011	4.6 fb^{-1}	7 TeV	$M(t\bar{t})$	4
ATLAS	semileptonic	2011	4.6 fb^{-1}	7 TeV	$M(t\bar{t})$	4

Kinematic region probed by $t\bar{t}$, DY and Higgs production

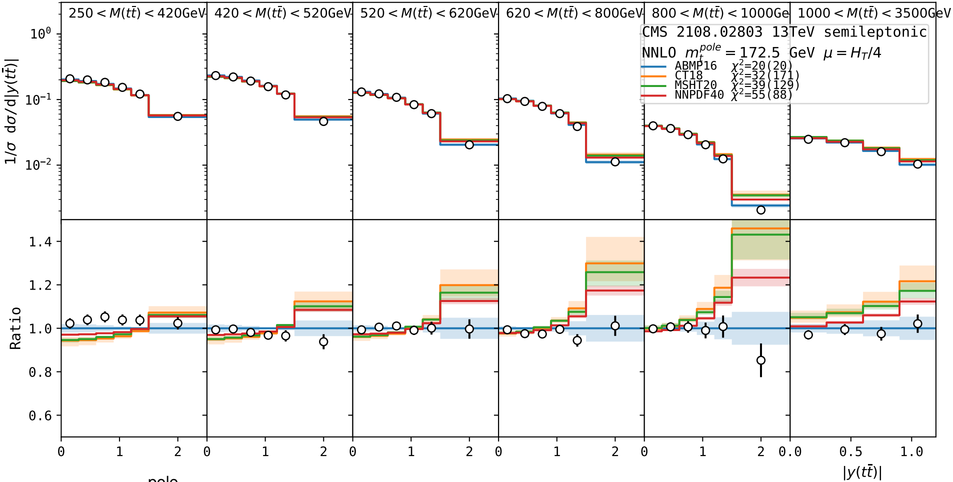
$$\text{LO: } x_{1,2} = (M(t\bar{t})/\sqrt{s}) \exp\left[\pm y(t\bar{t})\right]$$

- Double-differential $t\bar{t}$ @ 13 TeV probes $0.002 \lesssim x \lesssim 0.7$
  - *gg* contributes $\approx 90\%$
- E.g. Higgs production at the LHC probes $x \sim m_H/\sqrt{s} \sim 0.01$ which is well covered by differential $t\bar{t}$ data
- Energy scales m_H, M_W, M_Z and m_t are similar
- DY production at the LHC probes a similar region $x \sim m_{W,Z}/\sqrt{s}$
  - sensitive to quark PDFs mostly



Sensitivity to PDFs: CMS 2108.02803 vs NNLO predictions

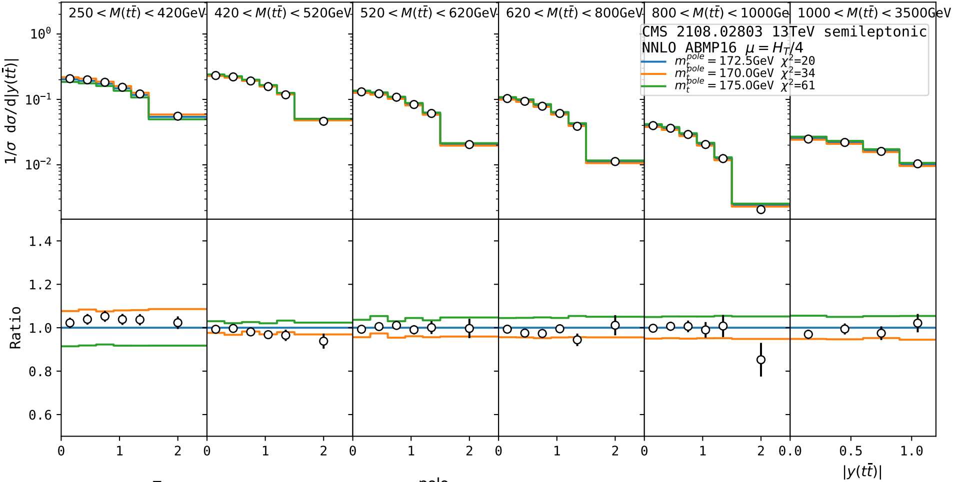
Garzelli, Mazzitelli, Moch, Zenaiev JHEP 05 (2024) 321



- Fixed $m_t^{pole} = 172.5$ GeV (not always consistent with PDF sets), $\mu_r = \mu_f = H_T/4$
- Reported χ^2 values with (and without) PDF uncertainties
- All PDF sets describe data reasonably well, with best description by ABMP16
  - CT18, MSHT20 and NNPDF40 show clear trend w.r.t data at high $y(t\bar{t})$ (large x)

Sensitivity to m_t^{pole}: CMS 2108.02803 vs NNLO predictions

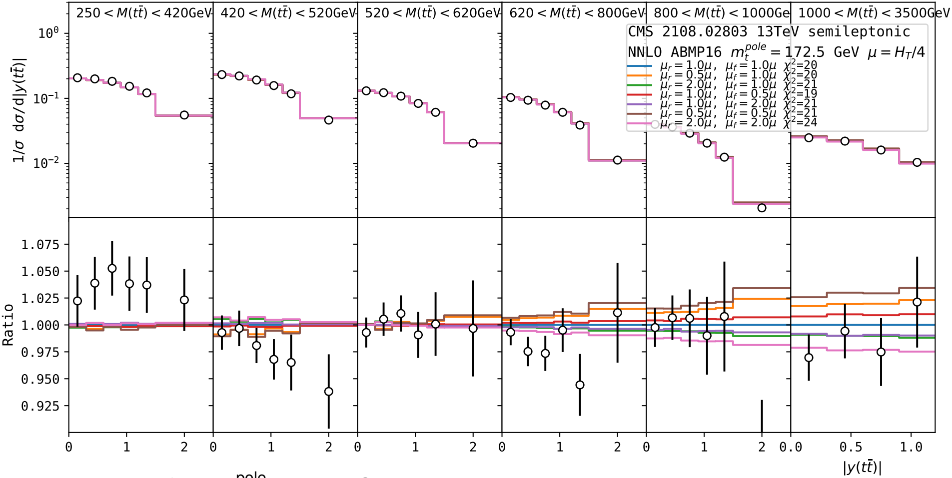
Garzelli, Mazzitelli, Moch, Zenaiev JHEP 05 (2024) 321



- Low $M(t\bar{t})$: strong dependence on m_t^{pole} via threshold effects
- Possible bound state effects near the $t\bar{t}$ production threshold ('toponium') are not yet included: see Garzelli et al., PLB 866 (2025) 139532 [arXiv:2412.16685]

NNLO scale variation uncertainties

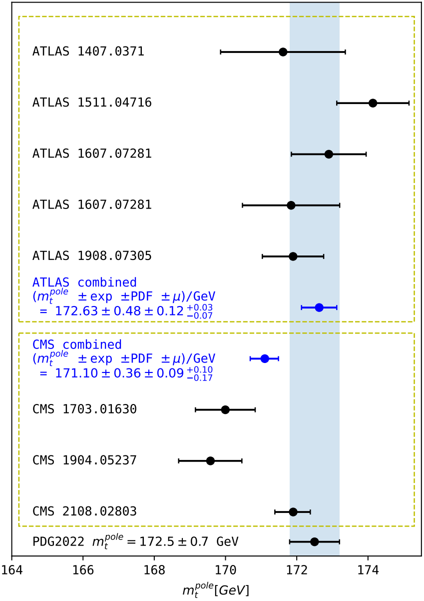
Garzelli, Mazzitelli, Moch, Zenaiev JHEP 05 (2024) 321



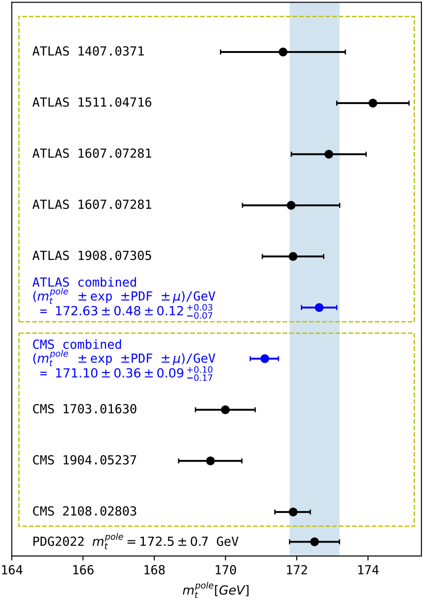
- ABMP16, fixed $m_t^{\text{pole}} = 172.5$ GeV
- Scale variations with $\mu_0 = H_T/4$ for normalised differential cross sections $< 1\%$ at low $M(t\bar{t})$ (largest cancellation), reach $\approx 4\%$ at high $M(t\bar{t})$ (for the total cross section: $^{+3\%}_{-5\%}$)

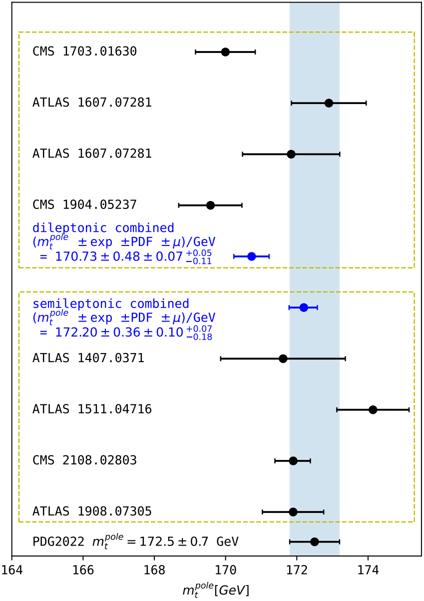
  $\rightarrow$ **these data are useful to provide constraints on m_t and PDFs**

Extraction of m_t^{pole} using ABMP16 JHEP 05 (2024) 321 [arXiv:2311.05509]

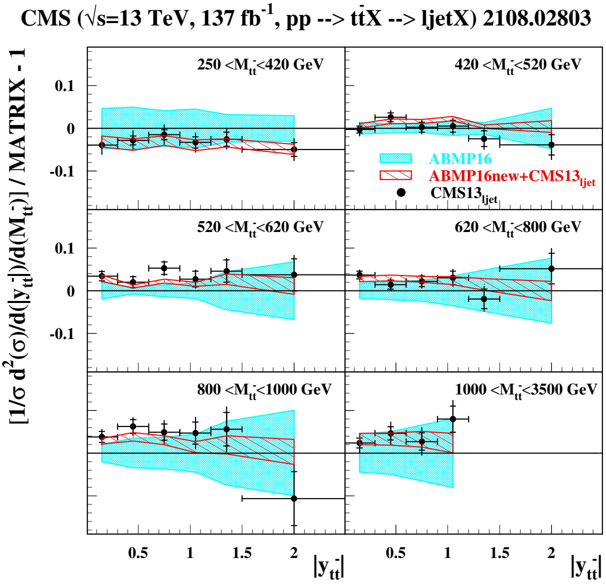


Extraction of m_t^{pole} using ABMP16 JHEP 05 (2024) 321 [arXiv:2311.05509]

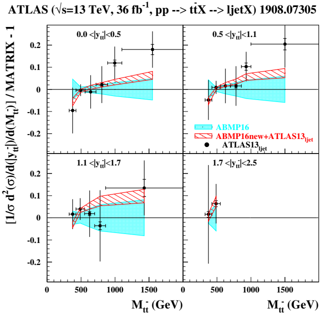


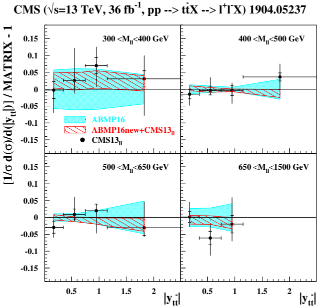


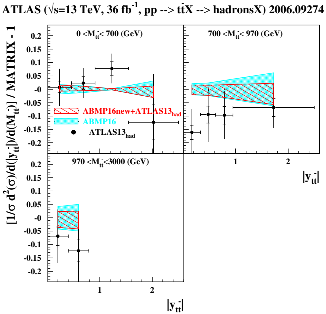
CMS 2108.02803 in ABMP16 PDF fit



→ these data are in good agreement with NNLO theoretical predictions and put significant constraints on the PDFs



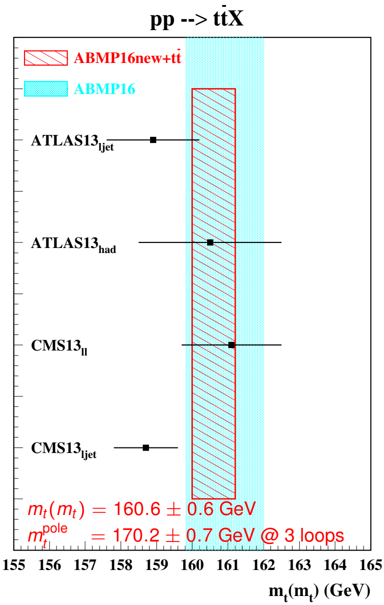




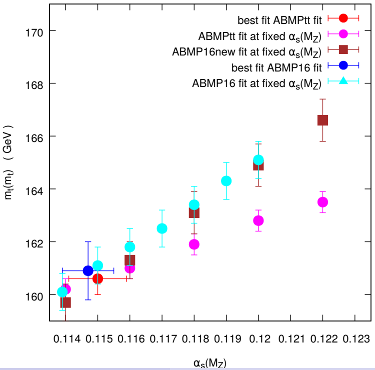
→ all data are in agreement with NNLO theoretical predictions and put significant constraints on the PDFs

. . . although ATLAS dileptonic vs. semileptonic data sets have somewhat different trends at large $M(t\bar{t})$

$m_t(m_t)$ and α_s in ABMP16 PDF fit



- Overall, good agreement among $m_t(m_t)$ extracted from different data sets
- Good agreement with ABMP16 fit and $\sim 50\%$ **reduced uncertainty on** $m_t(m_t)$
- ABMP16new: consistent with ABMP16, but with extra iteration for DY data
- Positive corr. between α_s and $m_t(m_t)$ reduced with $t\bar{t}$ differential data (and single t data)



χ^2 for different variants of the ABMPtt fit

Experiment	Data set	$\sqrt{s}$ (TeV)	Reference	NDP	χ^2		
					I	II	III
ATLAS	$ATLAS\,13_{ljet}$	13	[25]	19	34.2	27.2	–
	$ATLAS\,13_{had}$	13	[26]	10	11.8	12.1	–
CMS	$CMS\,13_{ll}$	13	[24]	15	21.1	–	19.9
	$CMS\,13_{ljet}$	13	[22]	34	42.2	–	40.8

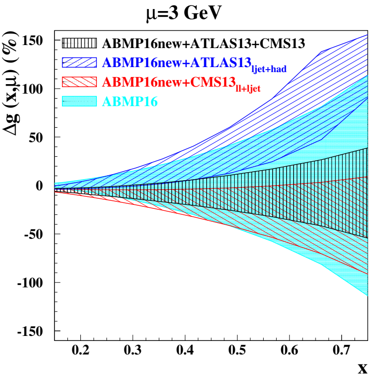
I: both ATLAS and CMS

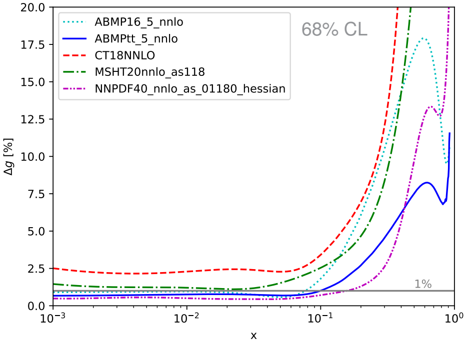
II: only ATLAS

III: only CMS

$\rightarrow$ **Overall good description of data with NNLO theoretical predictions, but some tension between ATLAS and CMS differential $t\bar{t}$ data is noticeable**

Fitted gluon PDF

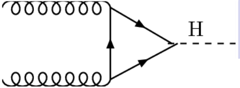




- Significant reduction of the gluon PDF uncertainty once differential $t\bar{t}$ data are included
- The fitted gluon PDF is consistent with ABMP16
- Fitted $\alpha_S(M_Z) = 0.1150 \pm 0.0009$ in ABMPtt (vs fixed $\alpha_S(M_Z) = 0.118$ in other fits)

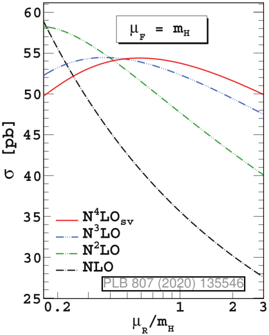
$\rightarrow$ **we have confirmed ABMP16 gluon and α_S with new data**

Application: Higgs x-section with modern PDFs



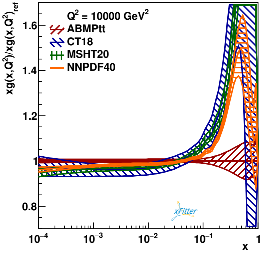
PDF Name	N2LO	N3LO	N4LOsv
ABMP16	$(45.4 \pm 4.6)^{+0.7}_{-0.7}$	$(49.6 \pm 2.6)^{+0.8}_{-0.8}$	$(50.8 \pm 1.9)^{+0.9}_{-0.9}$
ABMPtt	$(45.0 \pm 4.6)^{+0.6}_{-0.6}$	$(49.2 \pm 2.6)^{+0.7}_{-0.7}$	$(50.4 \pm 1.9)^{+0.8}_{-0.8}$
CT18NNLO	$(47.4 \pm 5.1)^{+1.3}_{-1.7}$	$(52.0 \pm 2.9)^{+1.4}_{-1.9}$	$(53.4 \pm 2.1)^{+1.5}_{-1.9}$
MMHT2014nnlo68cl	$(47.7 \pm 5.1)^{+0.6}_{-0.8}$	$(52.3 \pm 2.9)^{+0.7}_{-1.0}$	$(53.8 \pm 2.2)^{+0.7}_{-1.0}$
MSHT20nnlo_as118	$(47.4 \pm 5.1)^{+0.5}_{-0.6}$	$(52.0 \pm 2.9)^{+0.6}_{-0.6}$	$(53.4 \pm 2.1)^{+0.6}_{-0.6}$
NNPDF40_nnlo_as_01180	$(47.8 \pm 5.1)^{+0.3}_{-0.3}$	$(52.4 \pm 2.9)^{+0.3}_{-0.3}$	$(53.8 \pm 2.2)^{+0.3}_{-0.3}$
PDF4LHC21_40	$(47.6 \pm 5.1)^{+0.8}_{-0.8}$	$(52.3 \pm 2.9)^{+0.9}_{-0.9}$	$(53.7 \pm 2.2)^{+0.9}_{-0.9}$
MSHT20an3lo_as118	$(45.0 \pm 4.8)^{+0.8}_{-0.7}$	$(49.4 \pm 2.8)^{+0.9}_{-0.8}$	$(50.7 \pm 2.0)^{+0.9}_{-0.8}$

Table 1: Higgs cross-section along with the absolute error obtained from seven-point scale variation around $(\mu_R{}^c, \mu_F{}^c) = (1,1)m_H$ as well as intrinsic PDF uncertainty using LHAPDF. $\sqrt{S} = 14$ TeV, α_S from LHAPDF (NNLO value).



- Das, Moch, Vogt, Phys.Lett.B 807 (2020) 135546:
  - N4LOsv: soft virtual ggF corrections at 4 loops
  - N3LO: effective theory for $m_t \gg m_H$
  - N2LO: full theory for $m_H \lesssim m_t$
  - $\rightarrow$ apparent convergence of perturbative series
- N4LOsv estimates missing higher-order corrections: 2%
- Larger differences originate from PDF + α_S sets:

  7% (1995) $\rightarrow$ 12% (2020) $\rightarrow$ **7% (2024)** $\rightarrow$ **???**



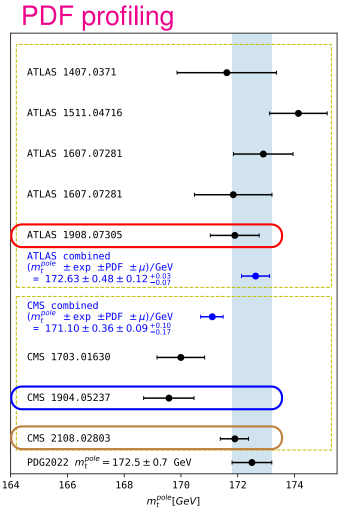
PineAPPL grids for 2D $t\bar{t}$ & xFitter

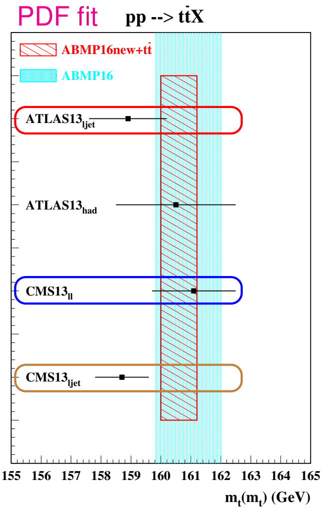
- PineAPPL grids store genuine NNLO predictions with their exact PDFs, α_S, $\mu_{r,f}$ dependence
  - 2×10^{11} events (5×10^{12} weights): 2M CPU hours, or 3 months of real time
  - numerical uncertainty in bins $\lesssim$ few ‰
  - the grids were produced for $165 \leq m_t^{pole} \leq 177.5$ GeV with 2.5 GeV step
  - all grids occupy 6 GB
- fine binning in $M(t\bar{t})$ abd $y(t\bar{t})$ which is suitable for all existing Run 1 and 2 ATLAS and CMS measurements at parton level via re-binning
  - can be used at another $\sqrt{s}$ and for another (slightly) different binning via intepolation

  $\rightarrow$ hopefully, can be used for Run-3 measurements
- **our grids are publicly available via Ploughshare + xFitter example how to use them:**
  - `https://gitlab.cern.ch/fitters/xfitter`
  - not affected by the rapidity distribution feature, which affected official MATRIX and was fixed only very recently

CMS	pp nnlo	13 TeV	ttbar-mt1650	MATRIX	xFitter	2108.02803	xfitter-cms-ttbar-mt1650-arxiv-2108.02803
CMS	pp nnlo	13 TeV	ttbar-mt1675	MATRIX	xFitter	2108.02803	xfitter-cms-ttbar-mt1675-arxiv-2108.02803
CMS	pp nnlo	13 TeV	ttbar-mt1700	MATRIX	xFitter	2108.02803	xfitter-cms-ttbar-mt1700-arxiv-2108.02803
CMS	pp nnlo	13 TeV	ttbar-mt1725	MATRIX	xFitter	2108.02803	xfitter-cms-ttbar-mt1725-arxiv-2108.02803
CMS	pp nnlo	13 TeV	ttbar-mt1750	MATRIX	xFitter	2108.02803	xfitter-cms-ttbar-mt1750-arxiv-2108.02803
CMS	pp nnlo	13 TeV	ttbar-mt1775	MATRIX	xFitter	2108.02803	xfitter-cms-ttbar-mt1775-arxiv-2108.02803

Importance of non-linear effects





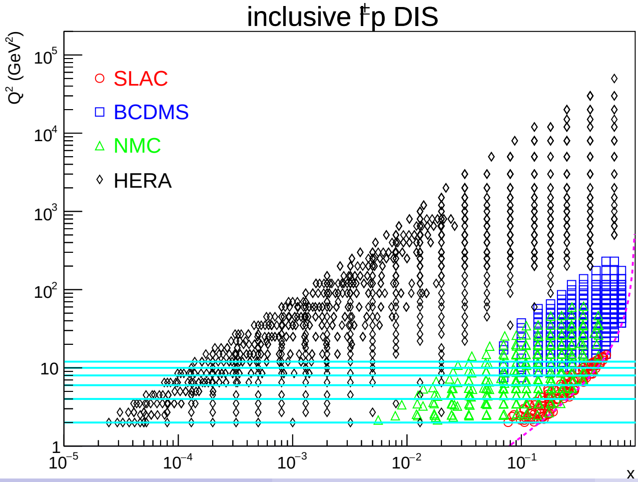
- PDF profiling: linearised problem + assume perfect data/theory compatibility
- Sometimes there are large differences between central values and uncertainties
- NNLO/NLO K-factors are also linearisation (neglect dependence of NNLO/NLO on PDFs)

Discussion of uncertainty treatment

- Experimental uncertainties:
  - only two data sets (CMS dilepton Run 1, CMS dilepton Run 2) report source by source systematic uncertainties
  - all other data sets report covariance matrices: it is even not possible to separate systematic correlation from statistical (unfolding)
  - for some data sets (ATLAS l+jet Run 2, ATLAS dilepton Run 1 (8 TeV)), covariance matrices are not singular as they should be for normalised x-sections (one degree of freedom is lost): numerical inaccuracy?
  - **we tried to minimize the impact of the lack of experimental systematic correlations by using the total x-section and normalised differential x-sections: many systematic uncertainties cancel for normalised x-sections, but:**
    - $\rightarrow$ please always report covariance matrix from unfolding and source by source systematic uncertainties
    - $\rightarrow$ please specify the sign of systematic variation (e.g. scale varied up or down)
    - $\rightarrow$ if some systematics is calculated as envelope of several variations, please report every variation
    - $\rightarrow$ for covariance matrix, please do some basic consistency checks (positive definiteness, singularity if normalised x-sections etc.)
    - $\rightarrow$ if possible, provide statistical correlations between various 1D cross sections (ATLAS l+jet Run 2, but with some caveat: see talk by Taras Sliusar)
- **Work in progress** on producing ntuple with $t\bar{t}$ events which will enable quick computation of **any distribution** at NNLO with a small numeric uncertainty

ABGMZ25: global PDF+α_S+m_t fit of high energy data arXiv:2510.21435

- NNLO QCD + **LO QED** PDF evolution
- Updated data sets: latest HERA charm+beauty & LHC total $t\bar{t}$ and DY data
- More flexible PDF parameterization
- Discarded higher-twist effects by using **higher energy HERA data with virtuality** $Q^2 > 10$ **GeV**^{2}



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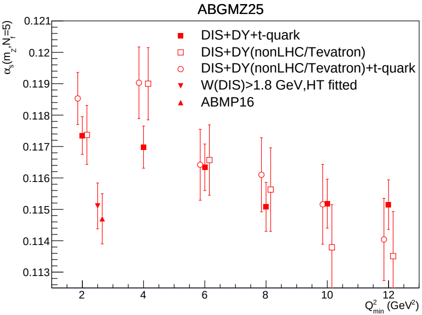
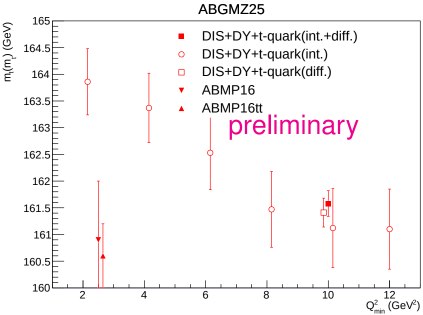




- $Q^2 \geq 10$ GeV^2: higher-twist effects are suppressed
- $\alpha_S(M_Z) = 0.1152 \pm 0.0008$
- $m_t(m_t) = 161.1 \pm 0.7$ GeV

Summary and outlook

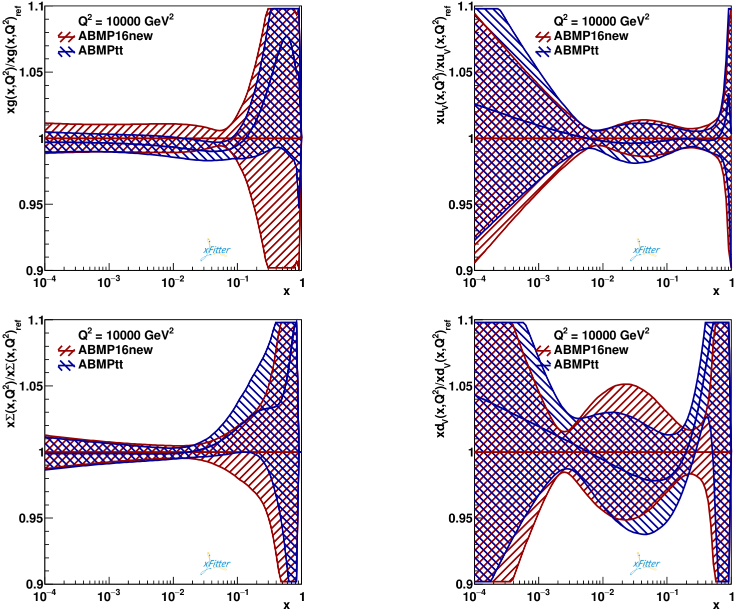
- ABMPtt NNLO fit includes latest ATLAS and CMS data on $t\bar{t}$ production
  - EPJ C 85 (2025) 162 [arXiv:2407.00545]
  - done at exact NNLO for $t\bar{t}$ (no K factors etc.)
  - uncertainty on $m_t(m_t)$ and gluon PDF is reduced by up to a factor of 2 w.r.t ABMP16
  - our PDFs and theory grids used for this work are available
    https://lhapdf.hepforge.org/lhapdf5/pdfsets
    https://ploughshare.hepforge.org
    https://gitlab.cern.ch/fitters/xfitter
- New ABGMZ25 QCD+QED NNLO fit was recently completed:
  - arXiv:2510.21435
  - PDF grids etc. will be released soon with a follow up paper

Outlook

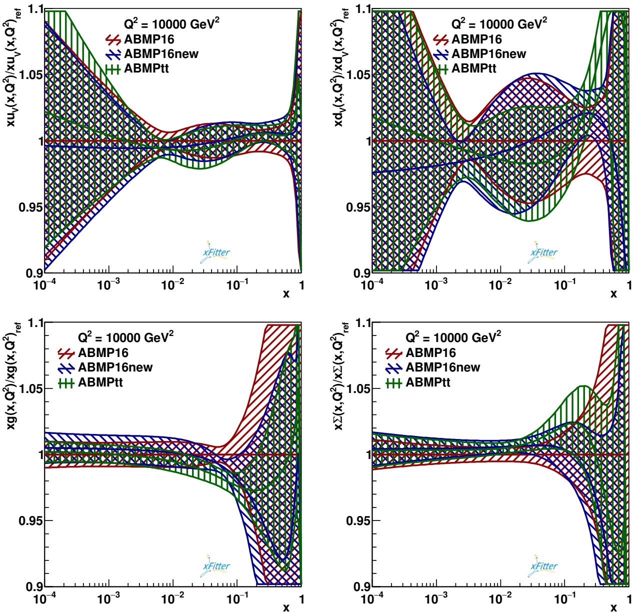
- Differential measurements of $t\bar{t}$ production seem to show some tension
  - ATLAS+CMS effort on combining differential $t\bar{t}$ data will be useful
  - more information on experimental correlations should be reported
- LHCb covers a complementary kinematic region sensitive to higher x, but no measurements unfolded to parton level (without cuts p_T, y of decay products) were done
  - would be useful to have such measurements from LHCb
- It would be very nice to have NNLO differential calculations for $t\bar{t}$+jets
  - would allow direct constraints on α_S

BACKUP

ABMPtt PDFs at $\mu \sim m_t$

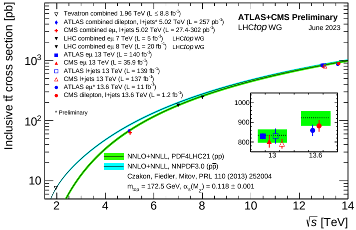


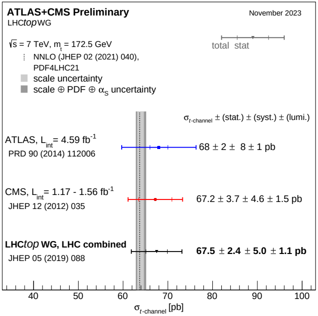
ABMPtt vs ABMP16



Experiment	Process	Reference	NDP	χ^2
DIS				
HERA I+II	$e^{\pm}p \to e^{\pm}X$	[4]	1168	1510
	$e^{\pm}p \to \overset{(-)}{\nu}X$			
BCDMS	$\mu^{+}p \to \mu^{+}X$	[61]	351	411
NMC	$\mu^{+}p \to \mu^{+}X$	[60]	245	343
SLAC-49a	$e^{-}p \to e^{-}X$	[54, 62]	38	59
SLAC-49b	$e^{-}p \to e^{-}X$	[54, 62]	154	171
SLAC-87	$e^{-}p \to e^{-}X$	[54, 62]	109	103
SLAC-89b	$e^{-}p \to e^{-}X$	[56, 62]	90	79
DIS heavy-quark production				
HERA I+II	$e^{\pm}p \to e^{\pm}cX$	[63]	52	62
H1	$e^{\pm}p \to e^{\pm}bX$	[15]	12	5
ZEUS	$e^{\pm}p \to e^{\pm}bX$	[16]	17	16
CCFR	$\overset{(-)}{\nu}p \to \mu^{\pm}cX$	[64]	89	62
CHORUS	$\nu p \to \mu^{+}cX$	[18]	6	7.6
NOMAD	$\nu p \to \mu^{+}cX$	[17]	48	59
NuTeV	$\overset{(-)}{\nu} \to \mu^{+}cX$	[64]	89	49
DY				
FNAL-605	$pCu \to \mu^{+}\mu^{-}X$	[67]	119	165
FNAL-866	$pp \to \mu^{+}\mu^{-}X$	[68]	39	53
	$pD \to \mu^{+}\mu^{-}X$			
Top-quark production				
ATLAS, CMS	$pp \to tqX$	[27–32]	10	2.3
CDF&DØ	$\bar{p}p \to tbX$	[53]	2	1.1
	$\bar{p}p \to tqX$			
ATLAS, CMS	$pp \to t\bar{t}X$	[33–52]	23	13
CDF&DØ	$\bar{p}p \to t\bar{t}X$	[53]	1	0.2

$t\bar{t}$ and single top LHC data have been updated to latest LHCTOPWG:



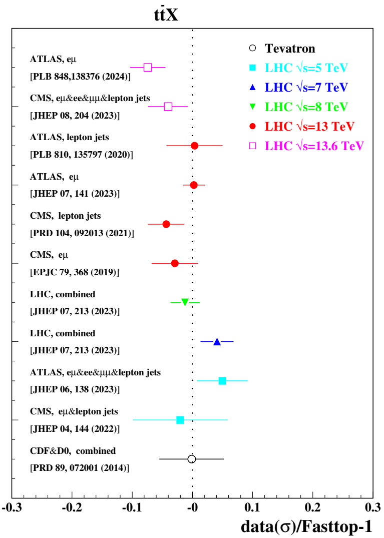


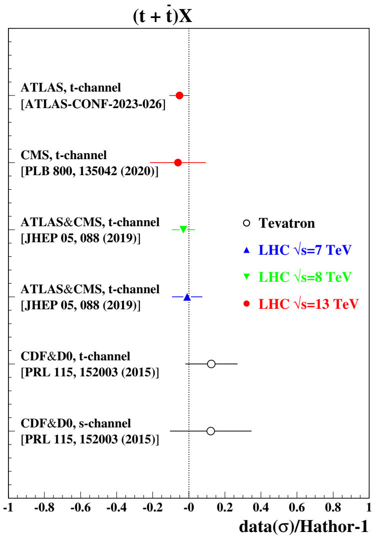
Experiment		ATLAS		CMS		DØ		LHCb		
$\sqrt{s}$ (TeV)		7	13	7	8	1.96		7	8	
Final states		$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ (asym)	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ (asym)	$W^+ \to e^+\nu$ $W^- \to e^-\nu$ (asym)	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ $Z \to \mu^+\mu^-$	$Z \to e^+e^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ $Z \to \mu^+\mu^-$
Cut on the lepton P_T		$P_T^l > 20$ GeV	$P_T^e > 25$ GeV	$P_T^\mu > 25$ GeV	$P_T^\mu > 25$ GeV	$P_T^\mu > 25$ GeV	$P_T^e > 25$ GeV	$P_T^\mu > 20$ GeV	$P_T^e > 20$ GeV	$P_T^\mu > 20$ GeV
Luminosity (1/fb)		0.035	0.081	4.7	18.8	7.3	9.7	1	2	2.9
Reference		[66]	[26]	[24]	[25]	[23]	[22]	[19]	[21]	[20]
NDP		30	6	11	22	10	13	31	17	32
χ^2	present analysis [a]	31.0	9.2	22.4	16.5	17.6	19.0	45.1	21.7	40.0
	CJ15 [6]	–	–	–	–	20	29	–	–	–
	CT14 [7]	42	–	– [b]	–	–	34.7	–	–	–
	JR14 [8]	–	–	–	–	–	–	–	–	–
	`HERAFitter` [197]	–	–	–	–	13	19	–	–	–
	MMHT14 [9]	39	–	–	–	21	–	–	–	–
	NNPDF3.0 [10]	35.4	–	18.9	–	–	–	–	–	–

[a] The ABM12 [1] analysis has used older data sets from CMS and LHCb.
[b] For the statistically less significant data with the cut of $P_T^\mu > 35$ GeV the value of $\chi^2 = 12.1$ was obtained.

TABLE VI: Compilation of precise data on W- and Z-boson production in pp and $p\bar{p}$ collisions and the χ^2 values obtained for these data sets in different PDF analyses using their individual definitions of χ^2. The NNLO fit results are quoted as a default, while the NLO values are given for the CJ15 [6] and `HERAFitter` [197] PDFs. Missing table entries indicate that the respective data sets have not been used in the analysis.

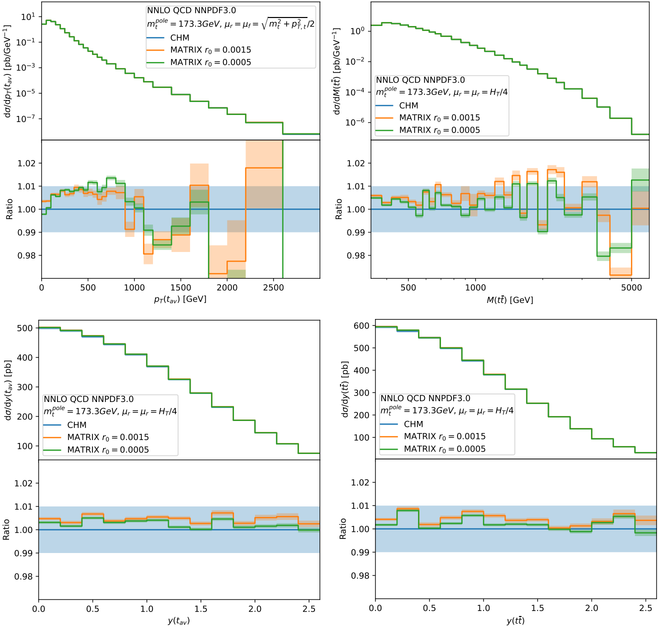
$\sigma(t\bar{t})$ and single t in ABMP16 PDF fit





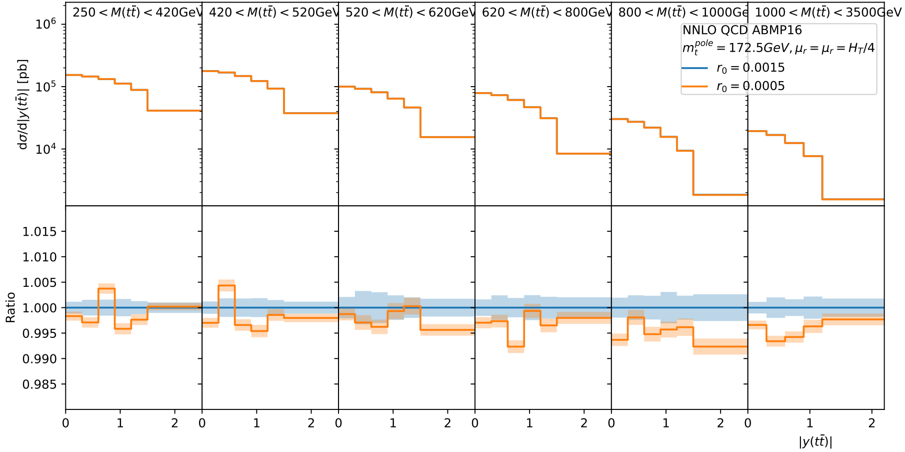
- good description of total $t\bar{t}$ and single t data
- single t data provide additional constraint on m_t (less correlated with g and α_S)

Variation of r cut, validation vs JHEP 04 (2017) 071 by Czakon et al. [CHM]

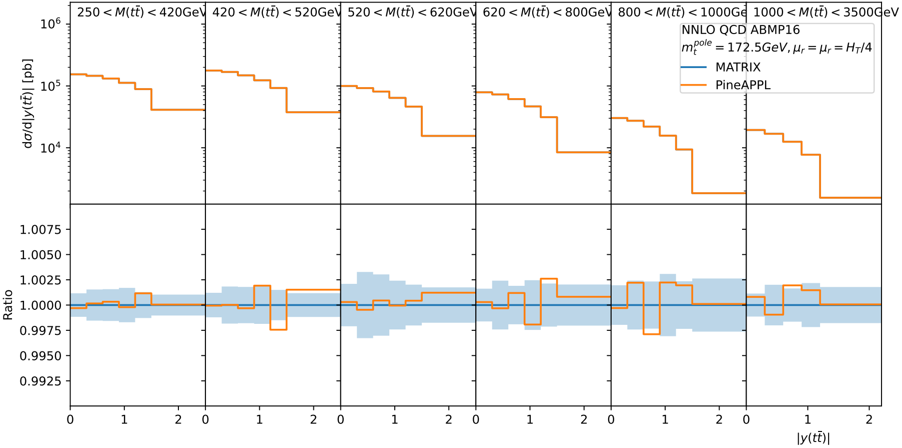


Good agreement $< 1\%$

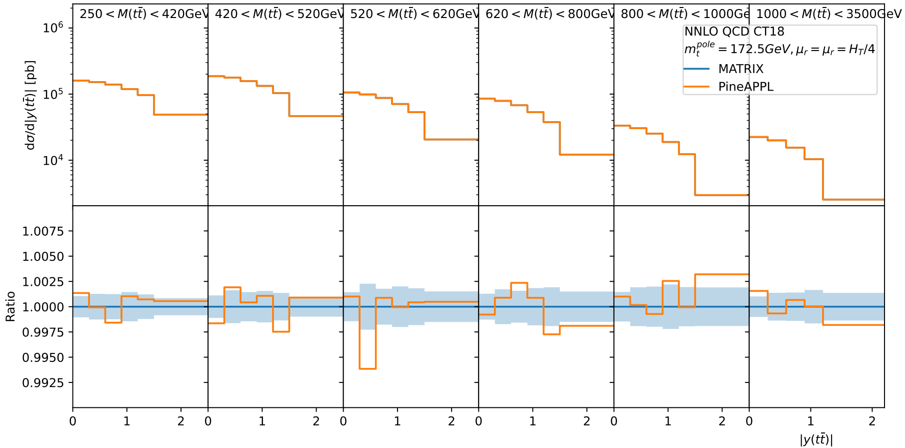
r cut variation in bins of TOP-20-001



PineAppl vs MATRIX in bins of TOP-20-001 [ABMP16]



PineAppl vs MATRIX in bins of TOP-20-001 [CT18]



- grids were produced with ABMP16

MATRIX vs HighTEA