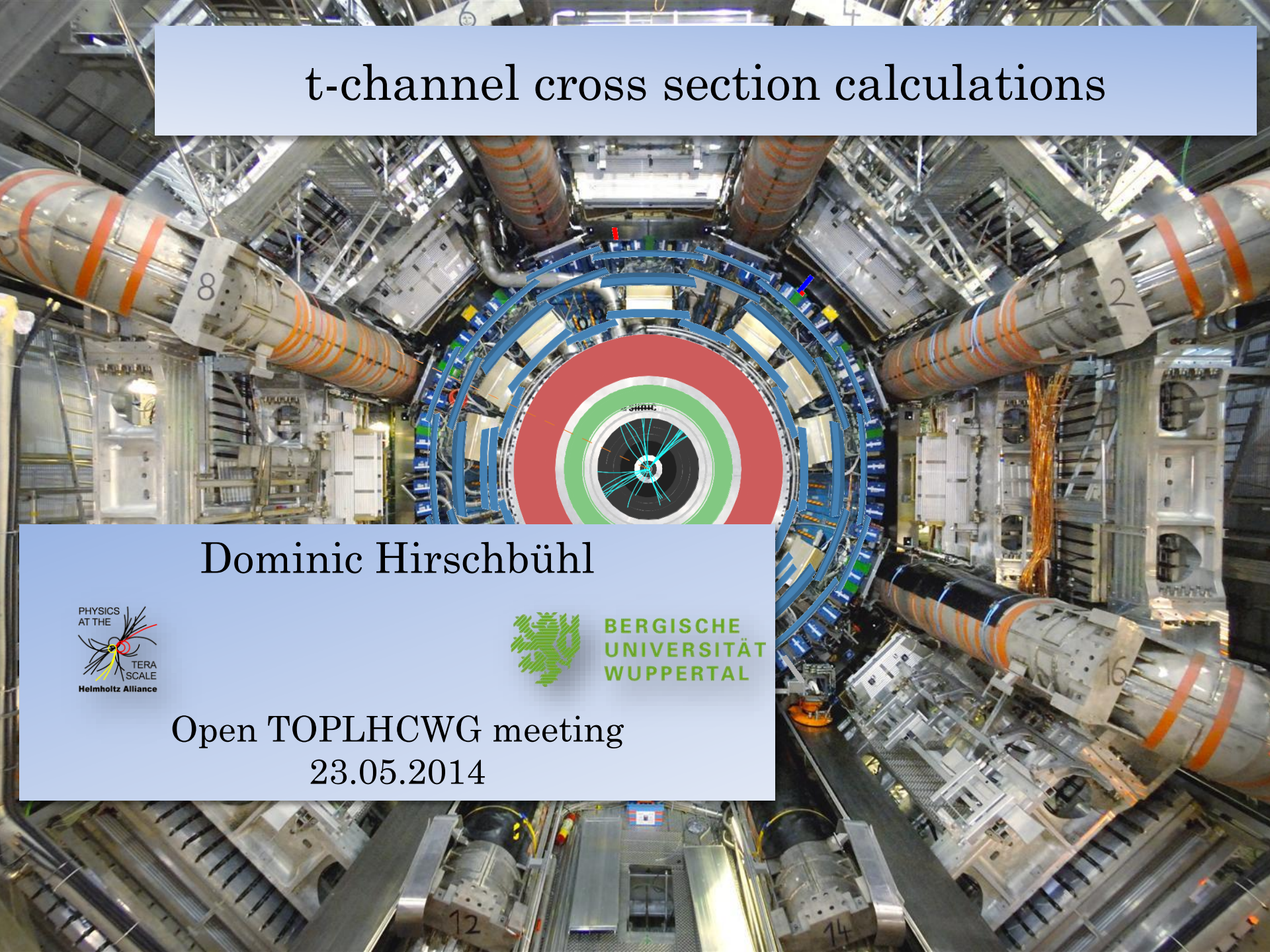
t-channel cross section calculations



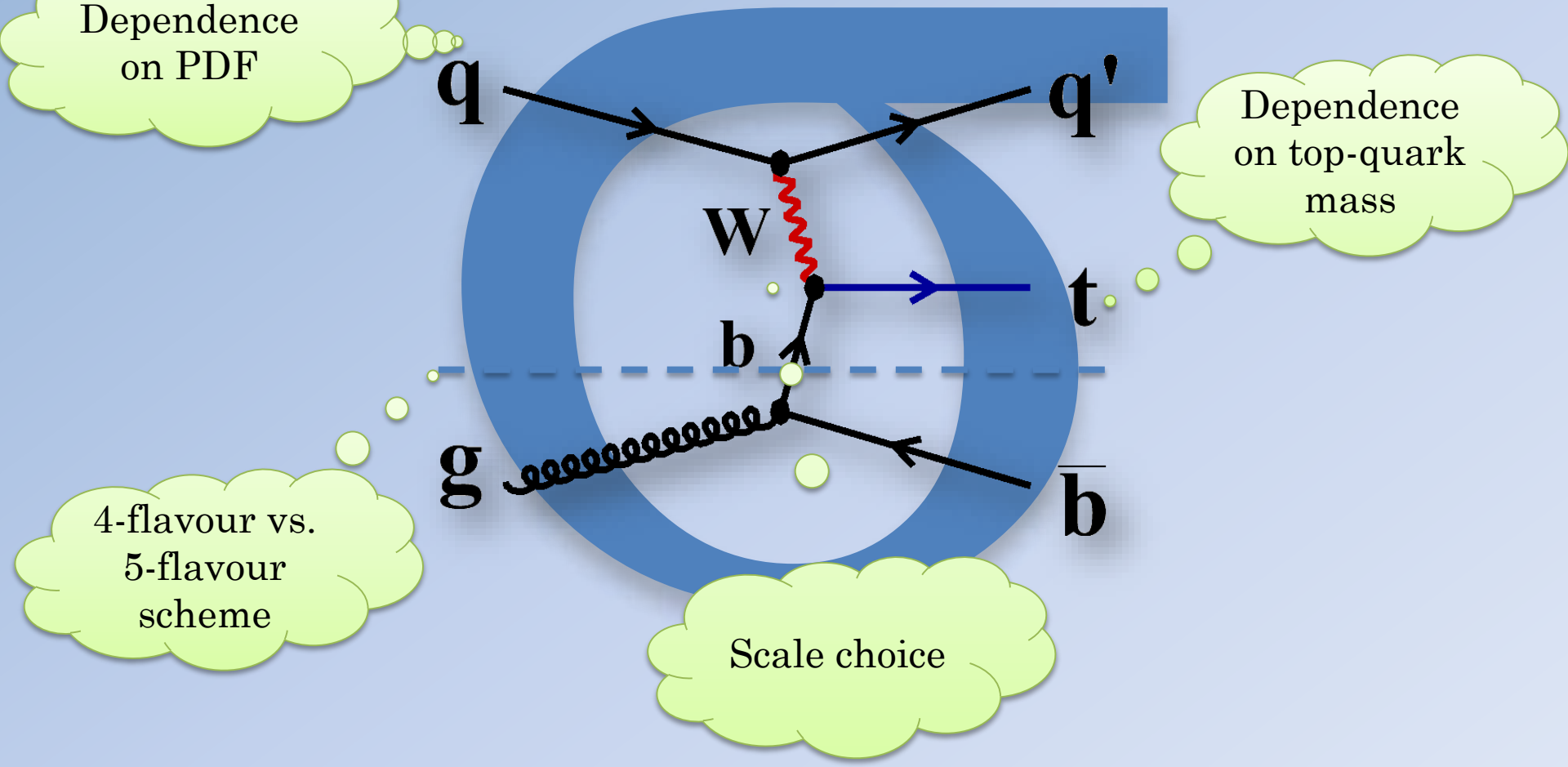
Dominic Hirschbühl

PHYSICS AT THE TERA SCALE Helmholtz Alliance

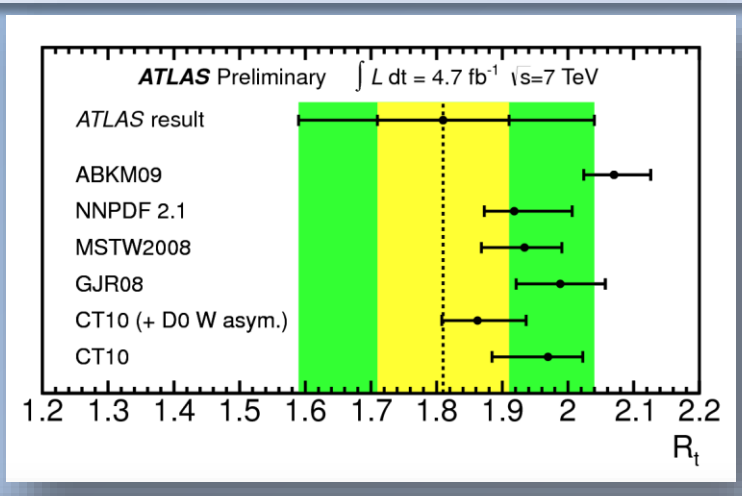
BERGISCHE UNIVERSITÄT WUPPERTAL

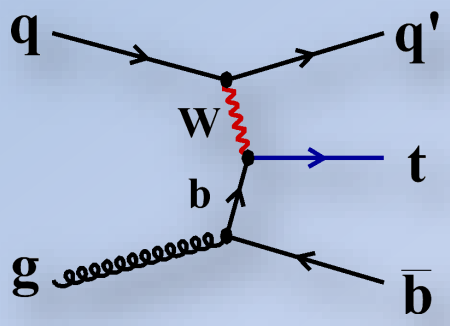
Open TOPLHCWG meeting
23.05.2014

Introduction

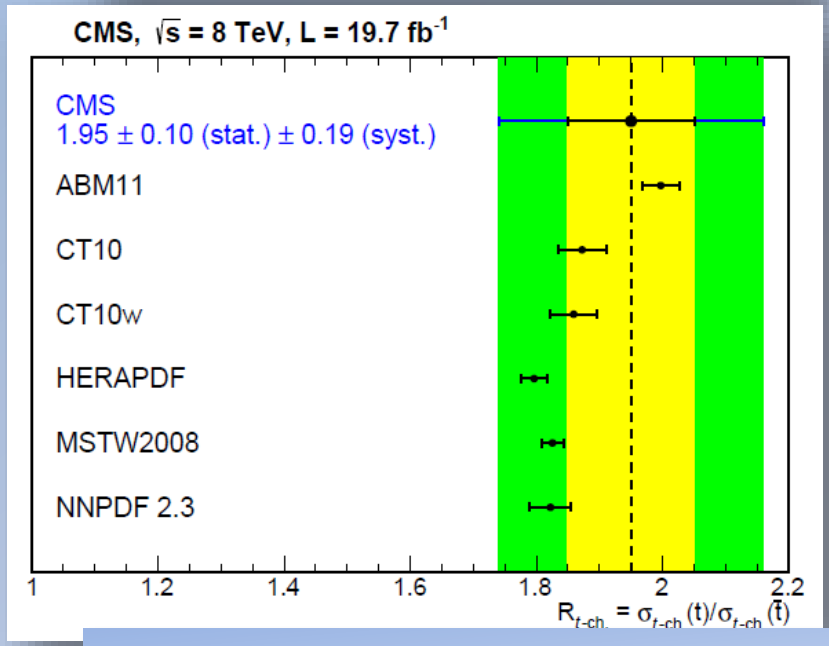


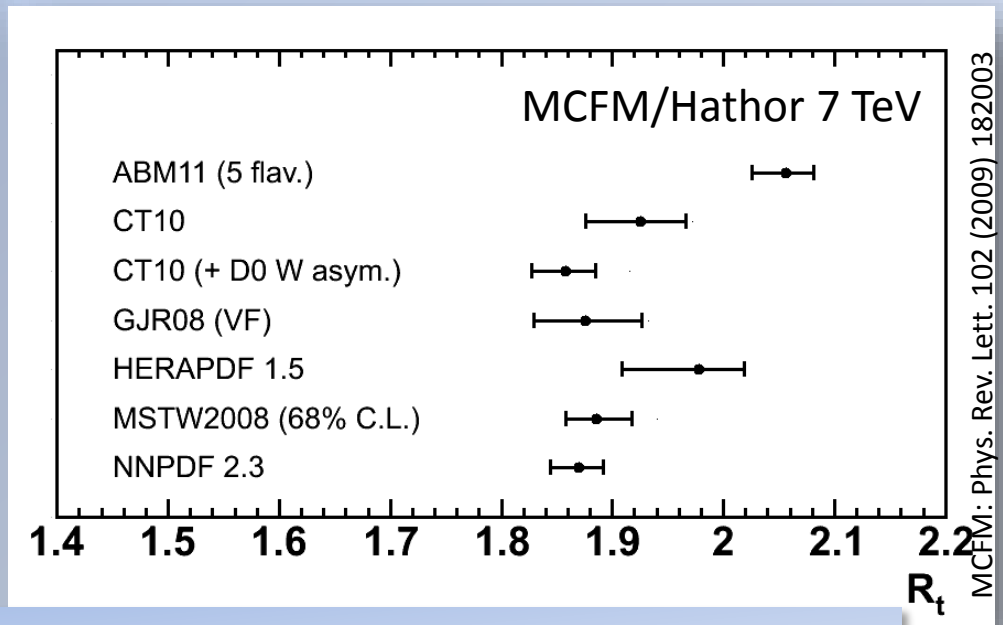
Introduction / Motivation





$$R_t = \frac{\sigma(t)}{\sigma(\bar{t})}$$





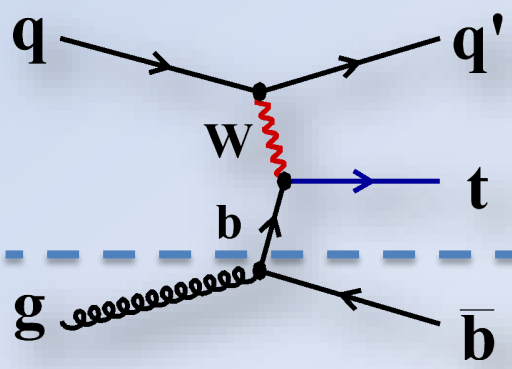
CMS & ATLAS do the calculation differently
→ has nothing to do with the experiment, needs to be harmonized

Available calculations

Author	Order	Schema	PDF	Free parameters
Brucherseifer, Caola, Melnikov arXiv:1404.7116	NNLO	5-flavour	MSTW2008	---
Kidonakis (only values, no code)	NLO+NNLL	5-flavour	MSTW2008	m_{top},√s
Hathor 2.0* (based on MCFM)	NLO	5-flavour	LHAPDF	$m_{top,}$ scales, √s
MCFM PRL 102 (2009) 182003	NLO	4- / 5- flavour	LHAPDF	mtop, scales, √s, etc.
aMC@NLO / POWHEG_BOX	NLO	4- / 5- flavour	LHAPDF	$m_{top,}$ scales, √s, etc.

Proposal:

- Use MCFM / Hathor for cross sections and uncertainties
  - Hathor used to speed up scale variations and PDF uncertainties
- Make cross checks with aMC@NLO/POWHEG-BOX



* https://www.physik.hu-berlin.de/pep/tools/hathor.html

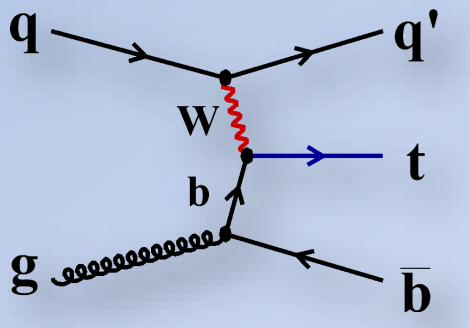
Status Quo

	ATLAS	CMS
Calculation method		
Incl. σ	Kidonakis	Kidonakis
R_t	MCFM/Hathor 5-flavour scheme	POWHEG-BOX 4-or 5-flavour scheme
m_{top}	172.5 GeV	173 GeV
Considered uncertainties for R_t		
Statistical uncertainty	✓	✓
Scale uncertainties	✓ x0.5 / x2	✓ x0.5 / x2
PDF uncertainty	✓	✓
α_s (combined with PDF)	✓	x
2→3 vs. 2→2	✓	x
m_{top}	x	✓ ± 1 GeV

Should use consistent theory values (and uncertainties) not only for $\boldsymbol{R_t}$ but also for $\boldsymbol{\sigma(tq), \sigma(\bar{t}q), \sigma(tq + \bar{t}q)}$

General settings

- Center of mass energies
  - $\sqrt{s}$ = 7 / 8 / 13 / 14 TeV



- Quark masses
  - m_{top} = 172.5 GeV,
  - $2 \rightarrow 2$: m_b = 0 GeV
  - $2 \rightarrow 3$: m_b = 4.7 GeV

- No cuts on jets

- Factorization / Renormalization scales
  - $2 \rightarrow 2$: m_{top}
  - $2 \rightarrow 3$: Light quark line: $m_{top}/2$
    Heavy quark line: $m_{top}/4$

} Used in MCFM

or

$4 \cdot \sqrt{p_T(b) + m_b}$ → Used in aMC@NLO/POWHEG-BOX

- Uncertainty calculation following the $t\bar{t}$ NNLO examples, see Maria's talk:
  https://indico.cern.ch/event/280522/session/1/contribution/4/material/slides/0.pdf

Comparison between MCFM & Hathor (2 →2)

PDF	$\sigma(t)$ [pb]	$\sigma(\bar{t})$ [pb]	R_t	$\sigma(t)$ [pb]	$\sigma(\bar{t})$ [pb]	R_t
	MCFM			Hathor		
CT10	41.0	21.3	1.93	41.0	21.3	1.93
CT10nlo	41.0	21.3	1.92	41.0	21.4	1.92
CT10w	40.4	21.8	1.86	40.4	21.9	1.85
MSTW2008nlo68cl	**42.3**	**22.4**	**1.89**	**42.3**	**22.4**	**1.89**
NNPDF22_nlo_100	42.6	22.6	1.89	42.6	22.7	1.88
abm11_5n_nlo	45.2	22.0	2.06	45.3	22.0	2.06
GJR08VFnloE	42.2	22.5	1.87	42.2	22.5	1.87
HERAPDF15NLO	42.0	21.2	1.98	41.8	21.1	1.98

Kidonakis (MSTW2008nnlo):
$\boldsymbol{\sigma(t)}$ = 42.1 pb
$\boldsymbol{\sigma(\bar{t})}$ = 22.4 pb
$\boldsymbol{R_t}$ = 1.88
→ Very close to NLO calculation

Calculation of uncertainties

Statistical uncertainty
- from integration < 0.1%

Scale uncertainty
- Using restricted independent scale variation
- Take enevelope of all variations

μ_r	μ_f
0.5	0.5
0.5	1
1	0.5
1	1
2	1
1	2
2	2

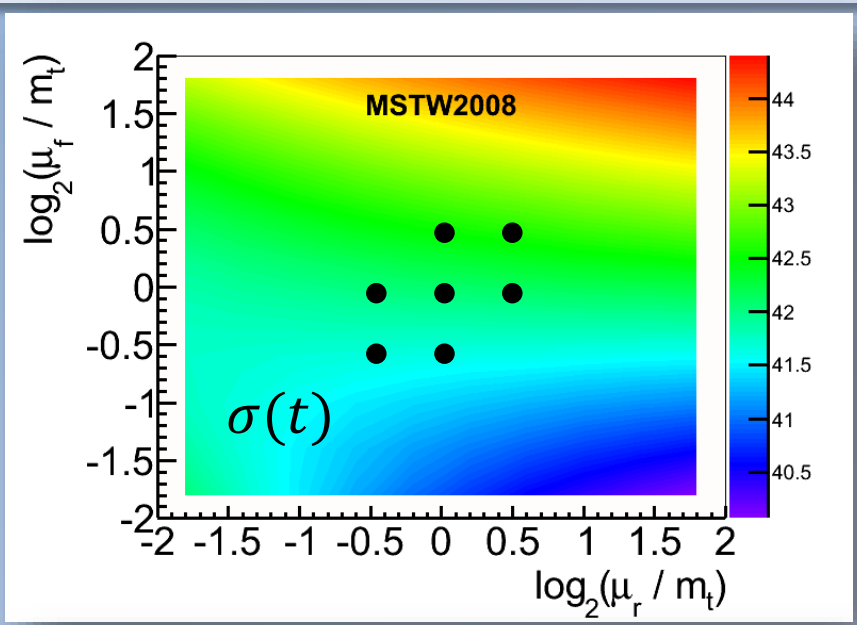
PDF internal uncertainties (@ 68% C.L.)
- Doing the calculations according to respective recommendations
  - NNPDFs: Use RMS of replicas
  - All others use symmetric or asymmetric Hessian approach
- Use LHAPDF recommendation for combination

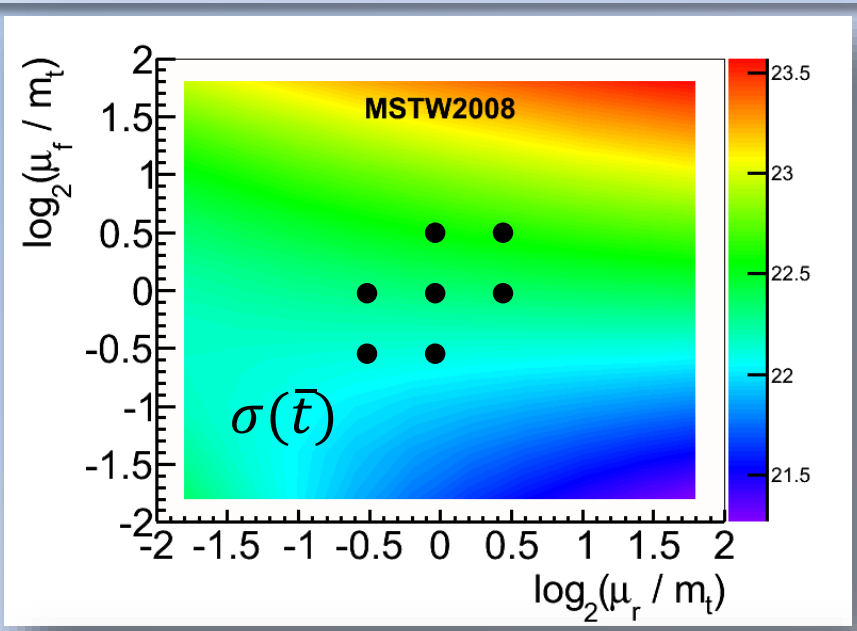
α_s uncertainty
- Use combined with internal PDF where applicable
- ± 0.002 difference in α_s as uncertainty on α_s
  $\rightarrow$ divide by 1.645 to get 68% C.L.

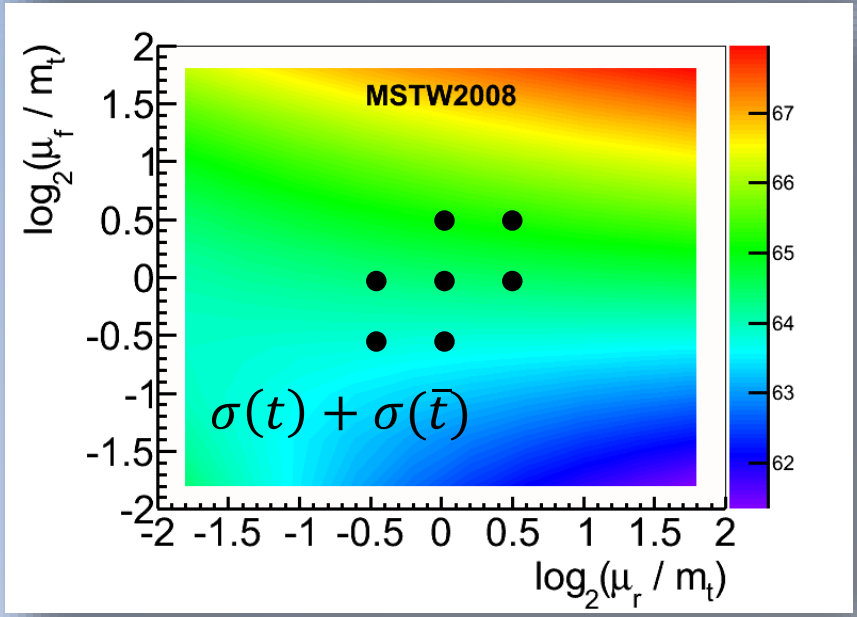
$2 \rightarrow 2$ vs. $2 \rightarrow 3$ (To be discussed)
- Use difference between the two calculations

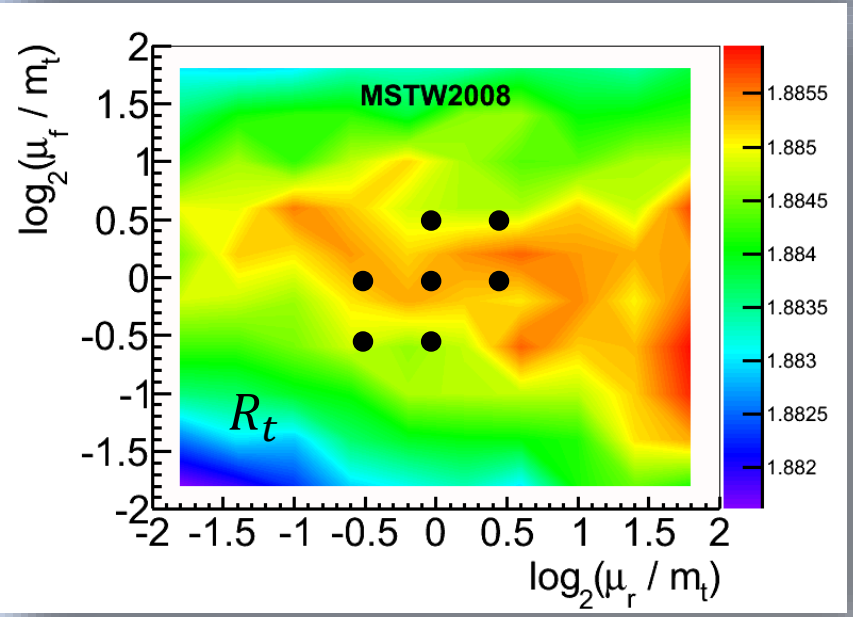
Uncertainty on m_{top} (Only for interpretations?)

Scale scans cross sections

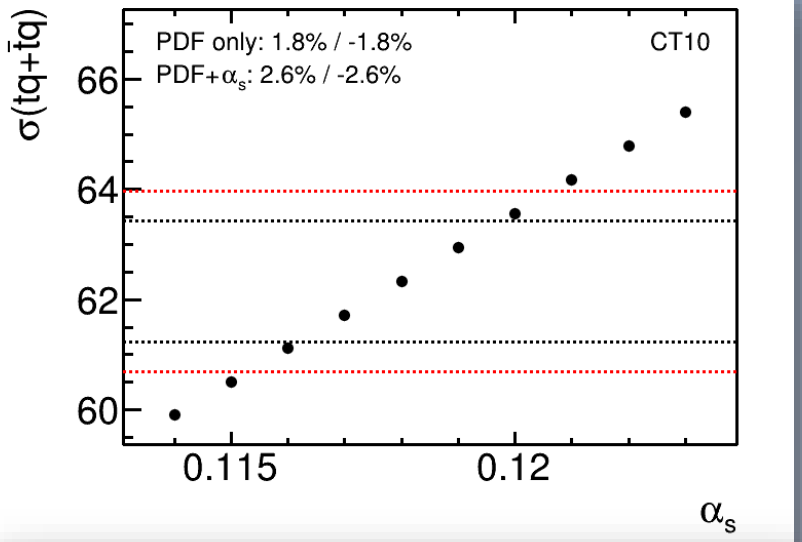


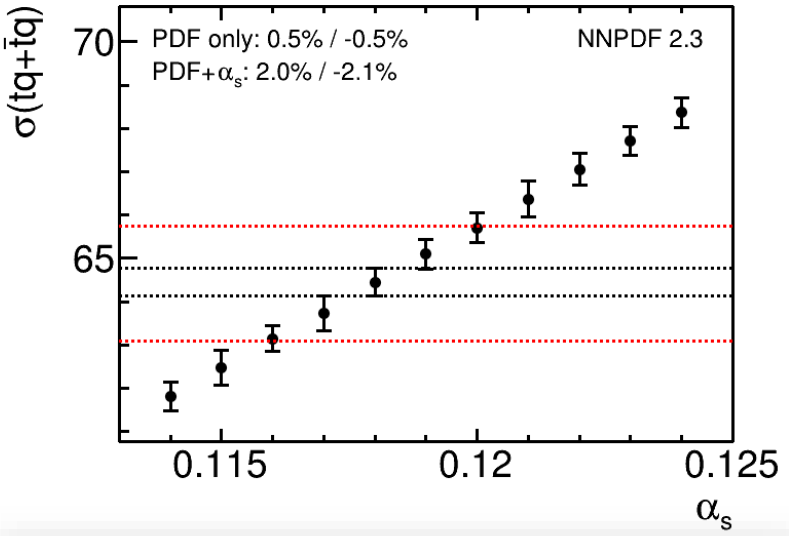


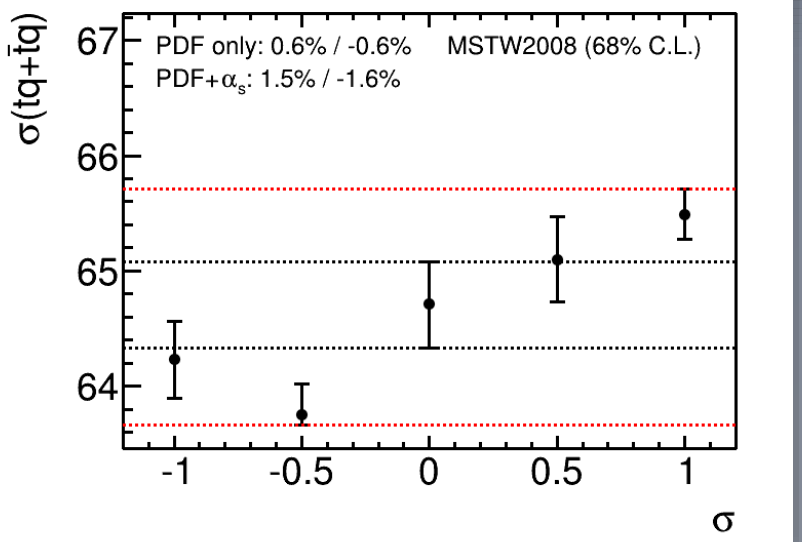


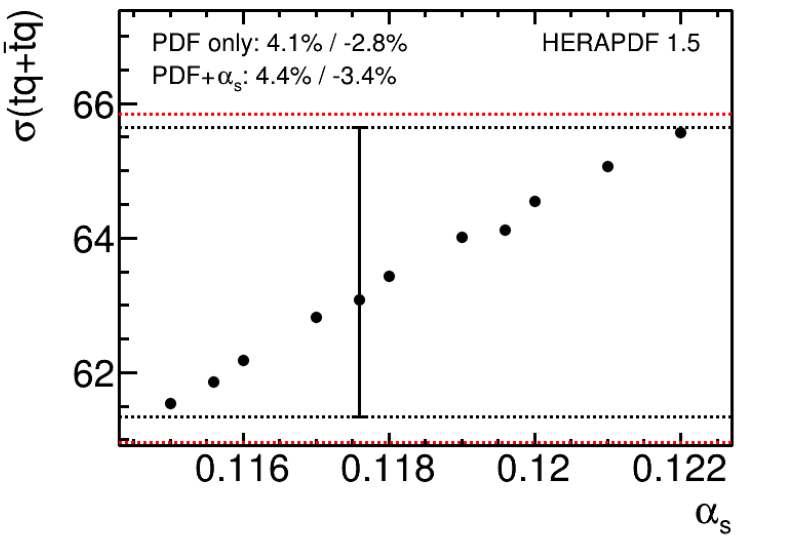


α_s dependence







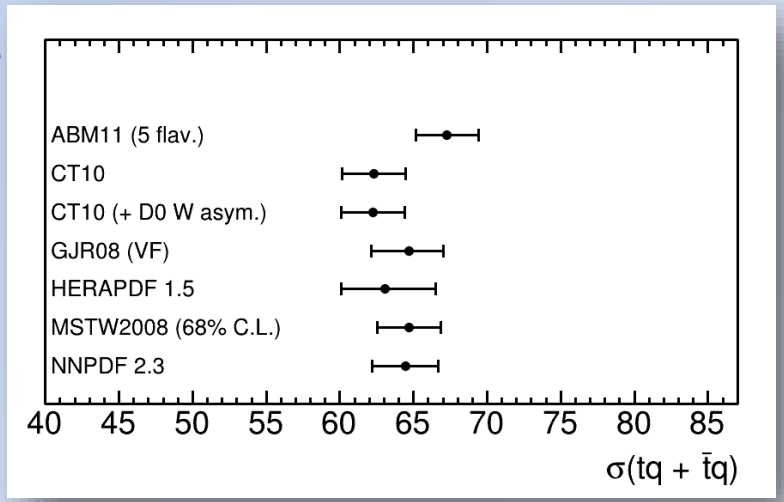


Black line: PDF uncertainty
Red line: Combined α_s and PDF uncertainty

Calculation of uncertainties - $\sigma(tq + \bar{t}q)$

PDF	$\sigma(\bar{t}q)$ [pb]	Stat.	Scale		PDF + α_s		$2\rightarrow2$ $2\rightarrow3$
ABM11	**67.3**	± 0.1 %	-2.6%	2.6%	-1.7%	1.9%	12.6%
CT10	**62.3**	± 0.1 %	-3.1%	3.1%	-1.6%	1.6%	4.3%
CT10w	**62.3**	± 0.1 %	-3.0%	3.0%	-1.6%	1.6%	4.2%
GJR08	**64.7**	± 0.1 %	-3.1%	3.1%	-2.4%	1.7%	9.2%
HERAPDF 1.5	**63.1**	± 0.1 %	-3.3%	3.3%	-3.4%	4.4%	3.8%
MSTW2008	**64.7**	± 0.1 %	-3.0%	3.0%	-1.6%	1.5%	5.2%
NNPDF 2.3	**64.5**	± 0.1 %	-3.3%	3.3%	-2.1%	2.0%	4.0%

Scale uncertainty very similar between PDF sets
Comparison between 2→2 and 2→3 would add a sizable uncertainty.



"Final value" using MSTW2008:
NLO using MCFM/Hathor:

$$\sigma(tq + \bar{t}q) = 64.7 \pm 1.9\ (\text{scale}) \pm 1.0\ (\text{PDF})\ \text{pb}$$

Compared to NLO+NNLL:

$$\sigma(tq + \bar{t}q) = 64.5^{+2.5}_{-0.3}\ (\text{scale}) \pm 1.2\ (\text{PDF})\ \text{pb}$$

Conclusion

Need to harmonize cross section prediction for single top processes between ATLAS and CMS
→ Most important for R_t prediction

Suggestion to use NLO calculation also for inclusive cross sections for all three single top processes
→ Can either use MCFM/Hathor or aMC@NLO or POWHEG-BOX

Uncertainty calculation following the $t\bar{t}$ examples
→ maybe add 2→2 vs. 2→3 in case of t-channel

Need to agree on all parameters
→ e.g. m_{top} = 172.5 GeV and world average?

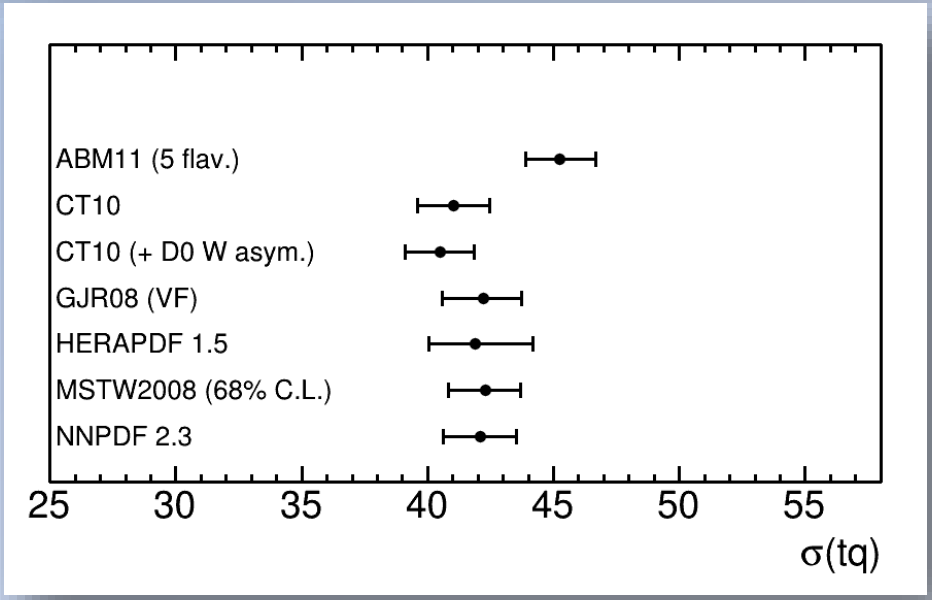
Provide analytic formula / parameterization for the top mass dependence

Make nice common cross section summary figures

Backup

Calculation of uncertainties - $\sigma(tq)$

PDF set	$\sigma(tq)$	scale unc.	PDF unc.	α_s	4- / 5-flavour
ABM11 (5 flav.)	45.25	-2.6% / 2.6%	-0.9% / 1.4%	-1.1% / 1.1%	± 12.4%
CT10	41.02	-3.1% / 3.1%	-1.3% / 1.3%	-1.1% / 1.1%	± 4.1%
CT10 (+ D0 W asym.)	40.48	-3.0% / 3.0%	-1.2% / 1.1%	-1.1% / 1.1%	± 4.2%
GJR08 (VF)	42.21	-3.1% / 3.1%	-2.4% / 1.9%	0.0% / 0.0%	± 9.2%
HERAPDF 1.5	41.90	-3.2% / 3.2%	-2.3% / 4.0%	-1.9% / 1.7%	± 3.8%
MSTW2008 (68% C.L.)	42.28	-2.9% / 2.9%	-1.7% / 1.6%	0.0% / 0.0%	± 5.1%
NNPDF 2.3	42.08	-3.2% / 3.2%	-0.6% / 0.6%	-1.2% / 1.0%	± 4.3%



Calculation of uncertainties - $\sigma(\bar{t}q)$

PDF set	$\sigma(\bar{t}q)$	scale unc.	PDF unc.	α_s	4- / 5-flavour
ABM11 (5 flav.)	22.01	-2.6% / 2.6%	-1.4% / 1.8%	-1.6% / 1.7%	± 13.0%
CT10	21.31	-3.1% / 3.1%	-1.8% / 2.0%	-1.3% / 1.3%	± 4.5%
CT10 (+ D0 W asym.)	21.78	-3.0% / 3.0%	-1.5% / 1.5%	-1.3% / 1.4%	± 4.1%
GJR08 (VF)	22.50	-3.2% / 3.2%	-3.3% / 2.4%	0.0% / 0.0%	± 9.3%
HERAPDF 1.5	21.18	-3.3% / 3.3%	-5.2% / 4.3%	-2.1% / 1.5%	± 3.9%
MSTW2008 (68% C.L.)	22.43	-3.0% / 3.0%	-1.9% / 1.9%	0.0% / 0.0%	± 5.4%
NNPDF 2.3	22.37	-3.3% / 3.3%	-1.0% / 1.0%	-1.4% / 1.5%	± 3.4%