Theory predictions of single top-quark t-channel production

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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

BERGISCHE UNIVERSITÄT WUPPERTAL

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"Physics at the Terascale"
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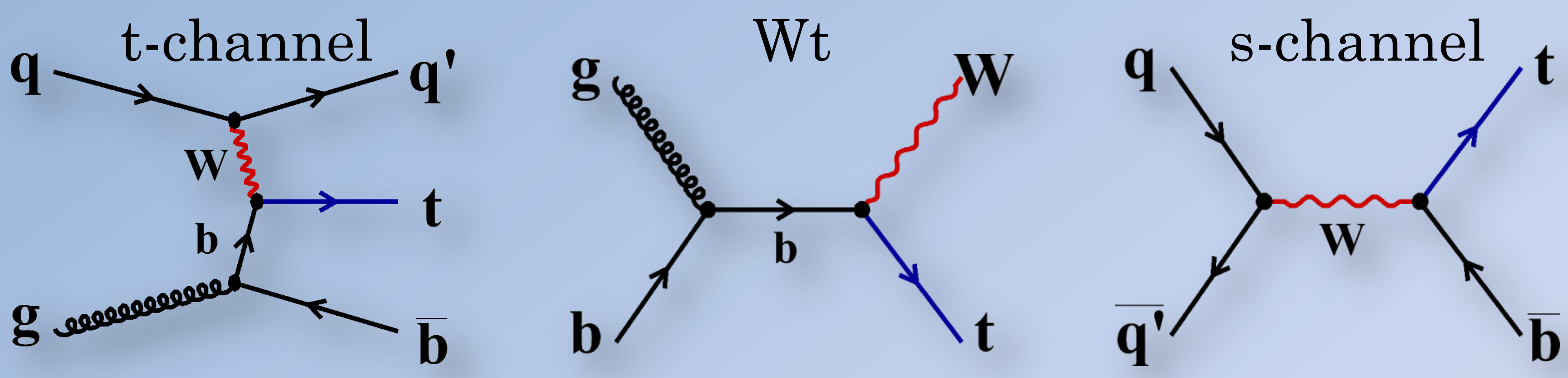
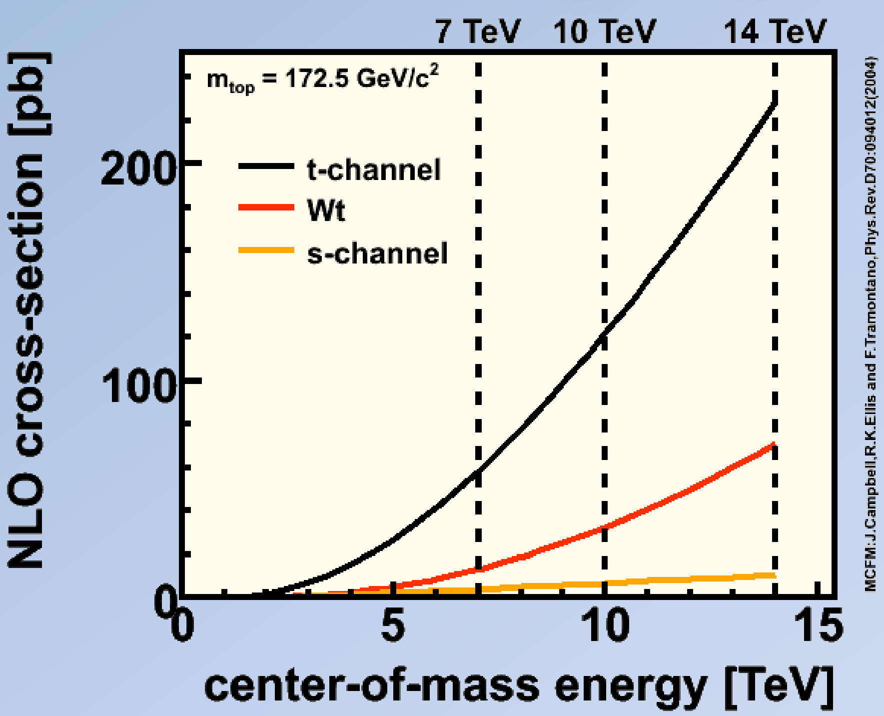
Production of single top quark events



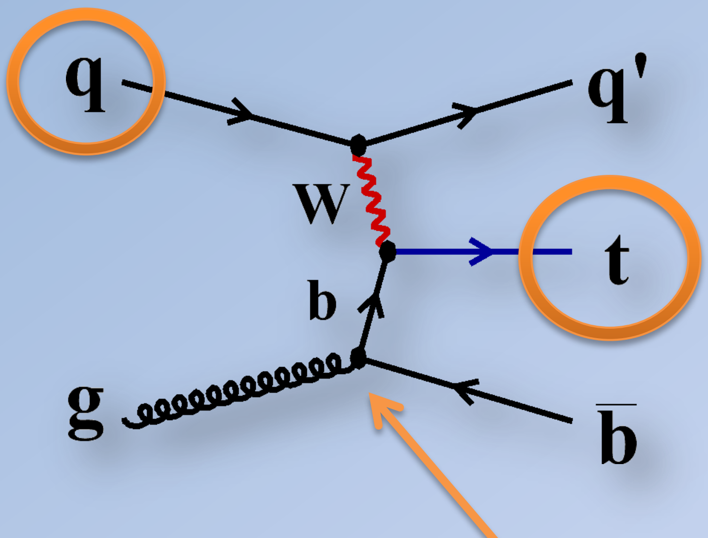


Cross section	7 TeV m_t=172.5 GeV	8 TeV m_t=172.5 GeV
t – channel	64.6 ± 2.4 pb	87.8 ± 3.4 pb
Wt	15.7 ± 1.1 pb	22.4 ± 1.5 pb
s – channel	4.6 ± 0.2 pb	5.6 ± 0.2 pb

Calculations by N. Kidonakis:
Phys.Rev.D83 (2011) 091503, Phys.Rev.D82 (2010) 054018,2010, Phys.Rev.D81 (2010) 054028
at NLO + NNLL resummation

What can we learn about PDFs?

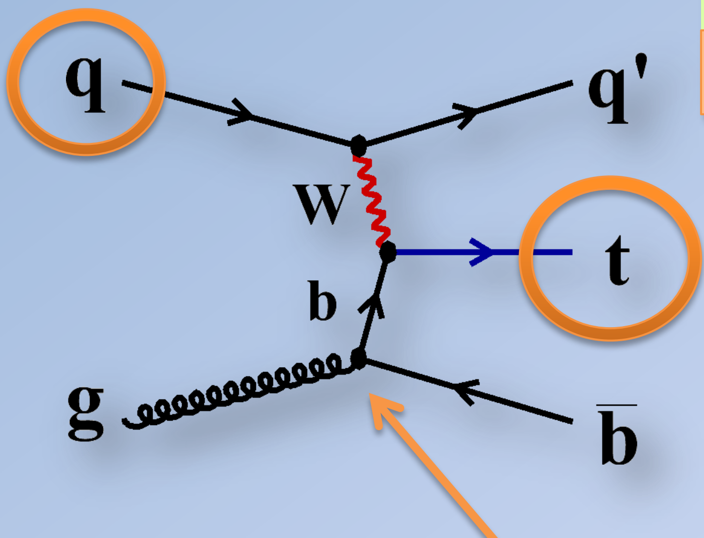
The charge of the top quark is connected to the type of the incoming light-flavour quark



Kinematic of the top quark might depend on the PDFs.

Test of the b-quark PDF

What can we learn about PDFs?



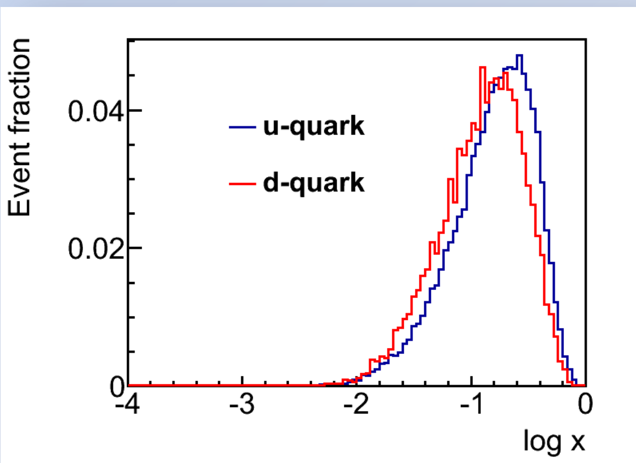
The charge of the top quark is connected to the type of the incoming light-flavour quark

Measure cross-section ratio top-quark/top-antiquark production

Unfold light quark distribution

Kinematic of the top quark might depend on the PDFs.

Unfold top quark pT and rapidity



Test of the b-quark PDF

Measure total cross section

Unfold b-jet p_T and rapidity

What can we learn about PDFs?

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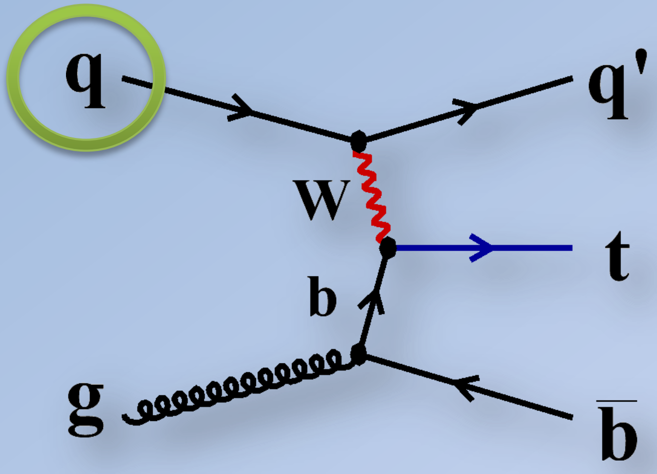
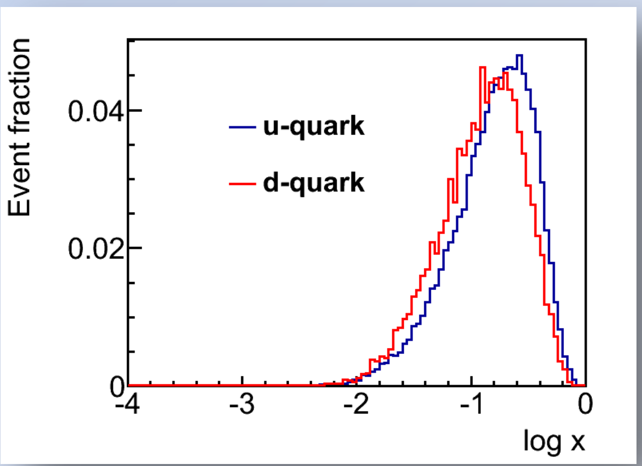
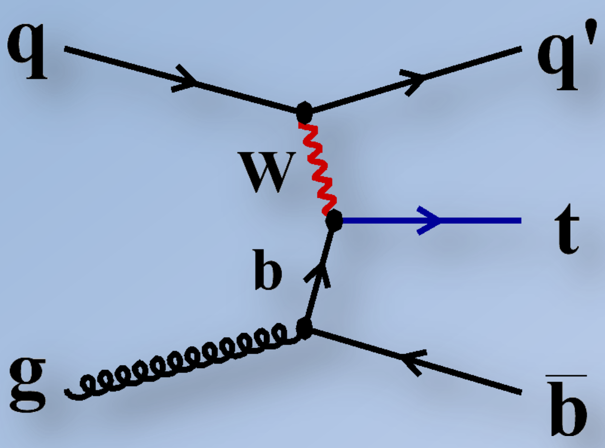
Measure cross-section ratio top-quark/top-antiquark production





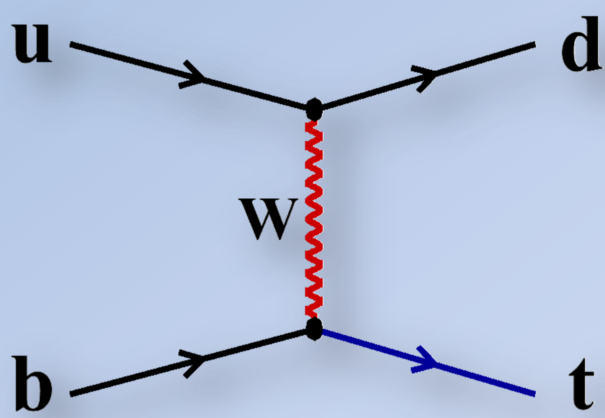
t-channel single top quark production

light quark jet



second b-quark / spectator b

2 → 3:
- Production in the 4 flavour scheme
- Massive b quarks in the final state



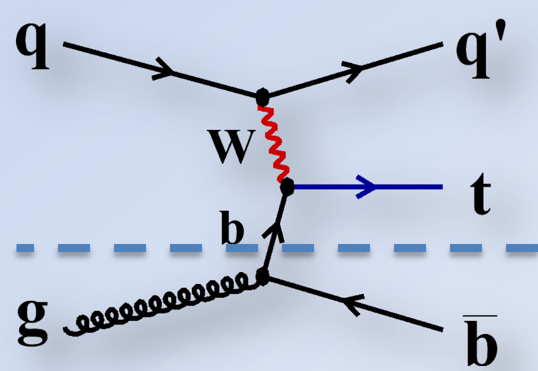
2 → 2:
- Production in the 5 flavour scheme
- Second b quark produced through DGLAP backward evolution
  → second b quark massless

Calculation of theory predictions

Author	Precision	Scheme	PDF(s)	Free parameters
Kidonakis (only values, no code)	NLO+NNLL	5-flavour	MSTW2008	m_{top}, $\sqrt{s}$
Hathor (private version)	NLO	5-flavour	LHAPDF	scales, $\sqrt{s}$, m_{top}
MCFM (publically available)	NLO	4- / 5- flavour	LHAPDF	All

Strategy

- Sanity checks:
  - Compare MCFM with Hathor
  - Compare MCFM/Hathor with Kidonakis
- Produce all PDF variations with Hathor/MCFM
  - Calculate uncertainties using Hathor
  - Calculate dependencies on $\sqrt{s}$, α_s etc. using Hathor



Settings for MCFM

Used Version
- 6.5

Processes
- $2 \to 2$: 161 / 166
- $2 \to 3$: 231 / 236

Used settings
- $\sqrt{s} = 7$ TeV
- Quark masses
  - $m_{top} = 172.5$ GeV,
  - $2 \to 2$: $m_b = 0$ GeV
  - $2 \to 3$: $m_b = 4.7$ GeV
- No cuts on jets
- All others: default settings

Fac. / Renorm scales
- $2 \to 2$: m_{top}
- $2 \to 3$: Light quark line: $m_{top}/2$
  Heavy quark line: $m_{top}/4$

Choice from:
J. M. Campbell et. al Phys. Rev. Lett. 102 (2009) 182003

Stat. Uncertainty
- $2 \to 2$: 0.1%
- $2 \to 3$: 0.3%

Better precision would just mean more CPU …

Values from MCFM

PDF	$\sigma(t)$ [pb]	$\sigma(\bar{t})$ [pb]	R_t	$\sigma(t)$ [pb]	$\sigma(\bar{t})$ [pb]	R_t
	$2 \to 2$			$2 \to 3$		
CT10	41.0	21.3	1.93	39.3	20.4	1.93
CT10f4				41.2	21.6	1.91
CT10nlo	41.0	21.3	1.92	39.2	20.4	1.92
CT10w	40.4	21.8	1.86	38.8	20.9	1.86
CT10wf4				40.7	22.0	1.85
MSTW2008nlo68cl	42.3	22.4	1.89	40.1	21.2	1.89
MSTW2008nlo68cl_nf4				40.1	21.3	1.88
abm11_5n_nlo	45.2	22.0	2.06	39.6	19.1	2.07
abm11_4n_nlo				39.6	19.2	2.07
GJR08VFnloE	42.2	22.5	1.87	38.3	20.4	1.88
GJR08FFnloE				40.5	20.6	1.96
HERAPDF15NLO	42.0	21.2	1.98	40.3	20.4	1.98
NNPDF23_nlo_as_0119	42.4	22.7	1.87	40.2	21.6	1.86

Comparison between MCFM & Hathor ($2 \rightarrow 2$)

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 NLO+NNLL (MSTW2008nnlo):

$\sigma(t) = 42.1$ pb

$\sigma(\bar{t}) = 22.4$ pb

$R_t = 1.88$

Calculation of uncertainties

Statistical uncertainty

- from integration , limited by used CPU time
- $2 \rightarrow 2$: 0.1%, $2 \rightarrow 3$: 0.3%
- $\rightarrow$ 0.2% for R_t

Scale uncertainty

- Following Olness et el. arXiv:0907.5052
- Scan μ_r,μ_f plane between ½ and 2 x nominal
- Use difference between min and max to nominal, respectively.
  $\rightarrow$ in the future maybe use "restricted scale variations"

$2 \rightarrow 2$ vs. $2 \rightarrow 3$

- Use difference between the two calculations

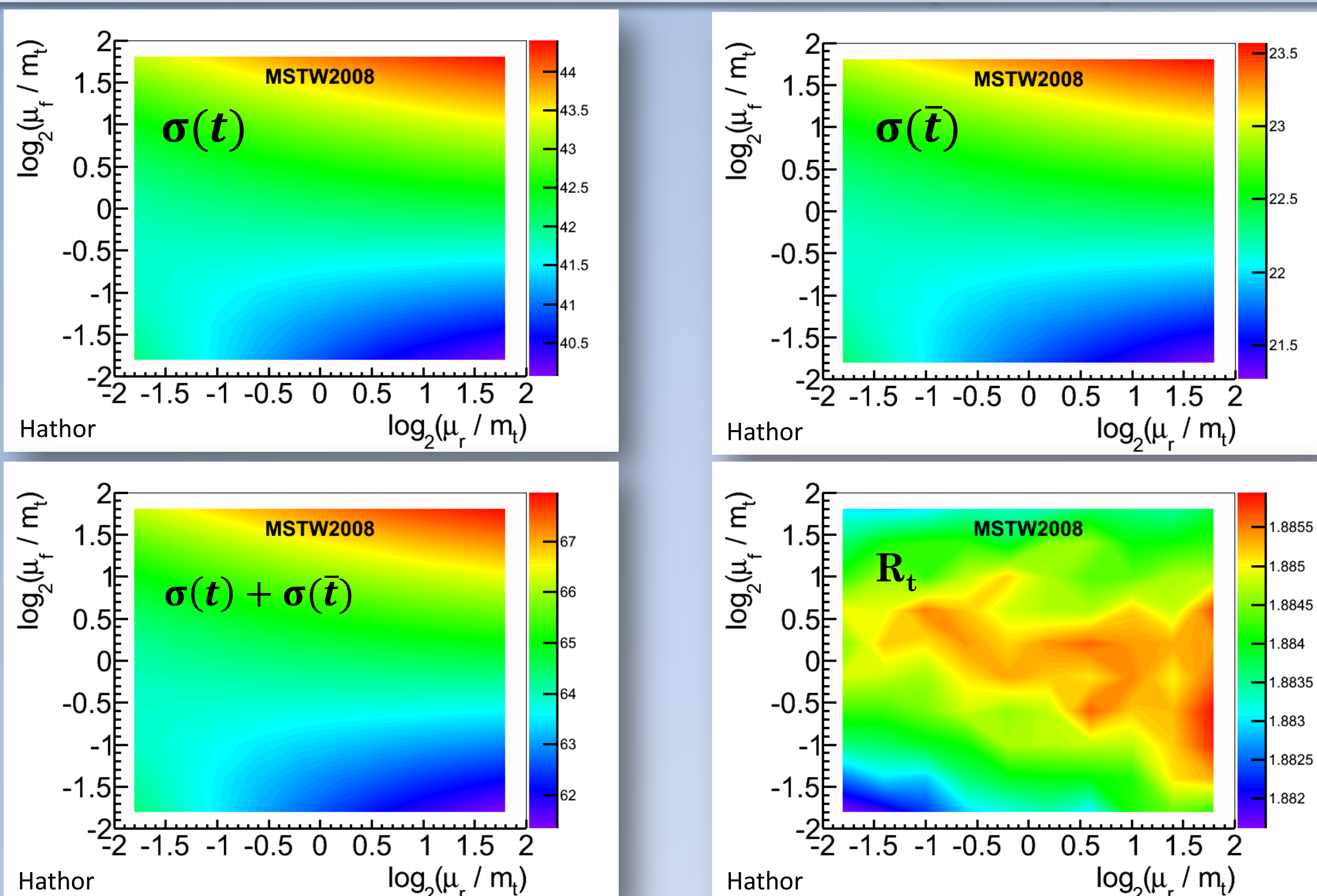
PDF internal uncertainties

- Calculations are done according to respective recommendations
  - NNPDFs: Use RMS of replicas
  - All others use symmetric or asymmetric Hessian approach

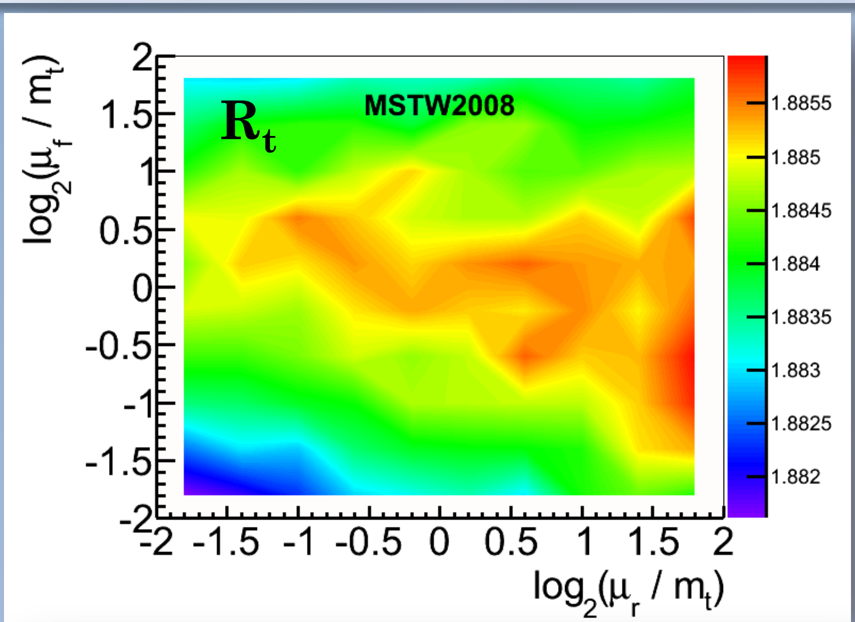
Uncertainty on α_s

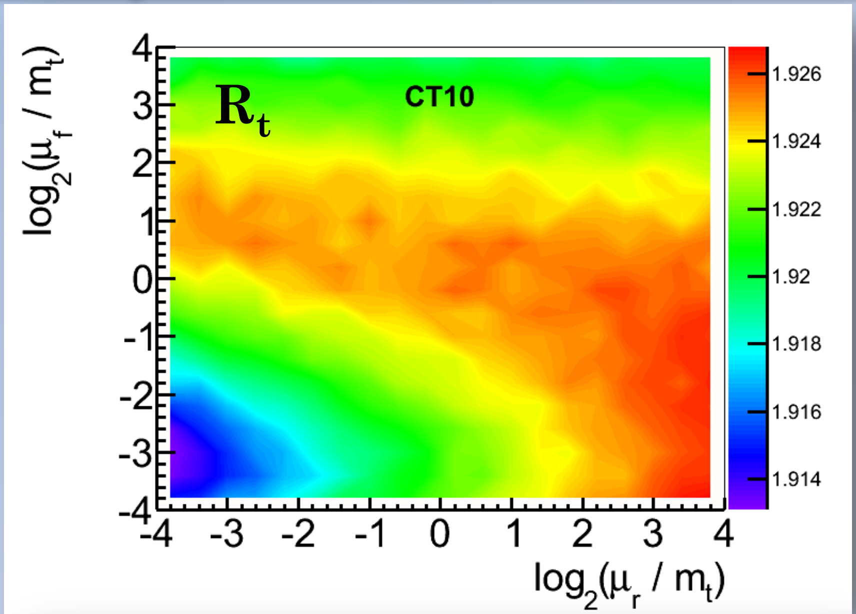
- $\pm$ 0.002 or correlated with PDF unc. (MSTW)

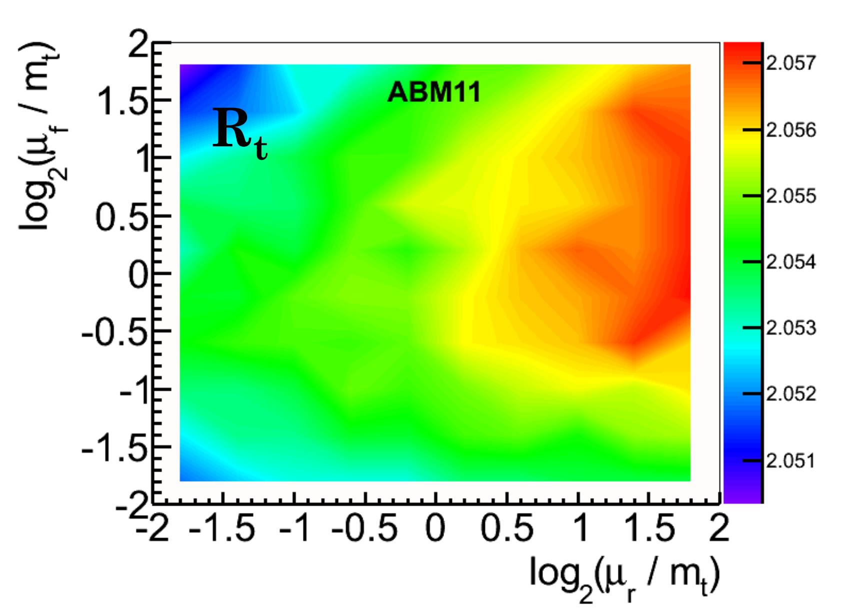
Scan of ren. / fac. scales ($2 \to 2$)

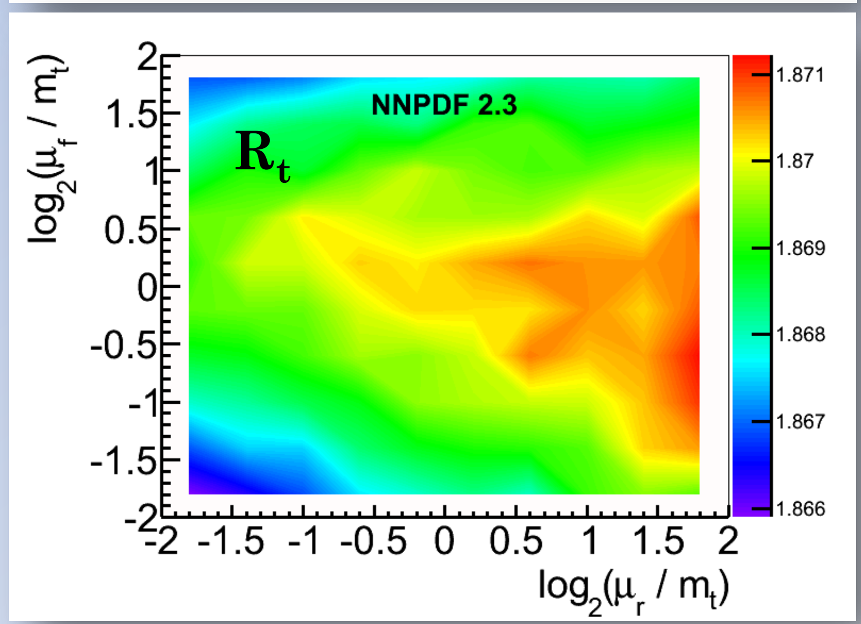


Scale scans for R_t $(2 \rightarrow 2)$

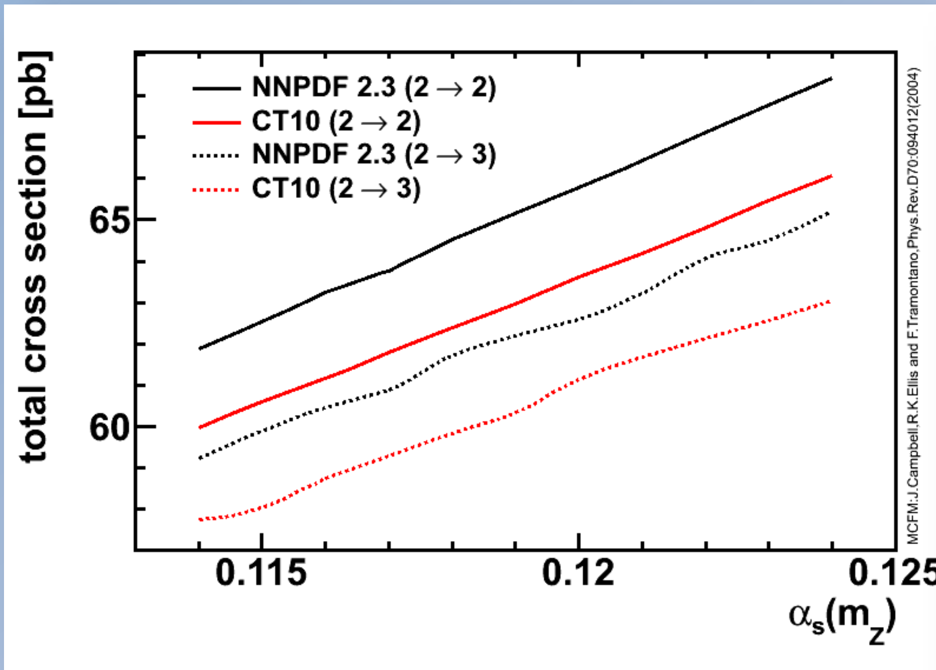


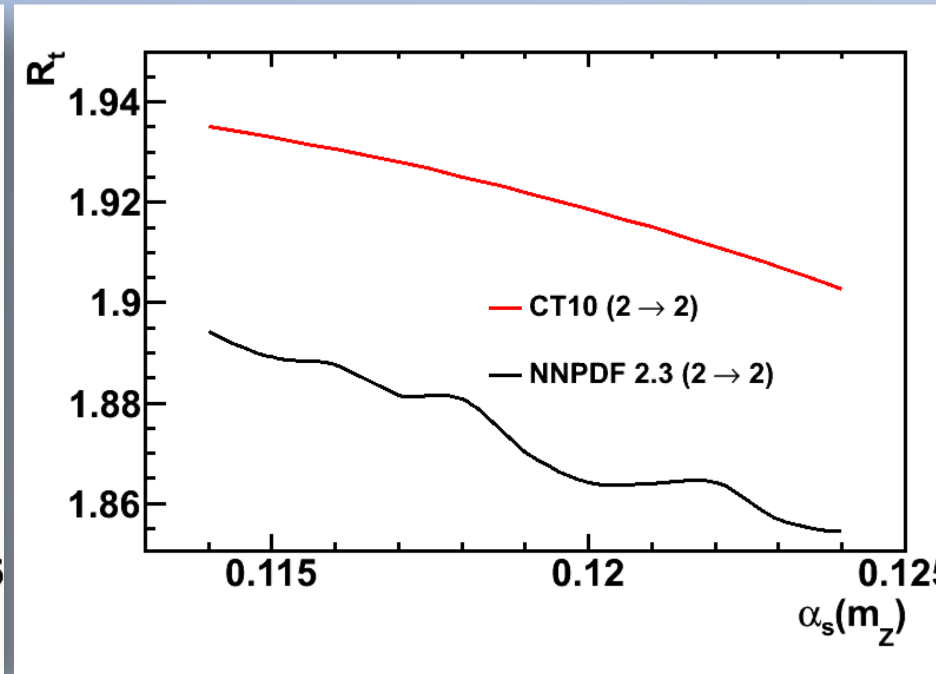






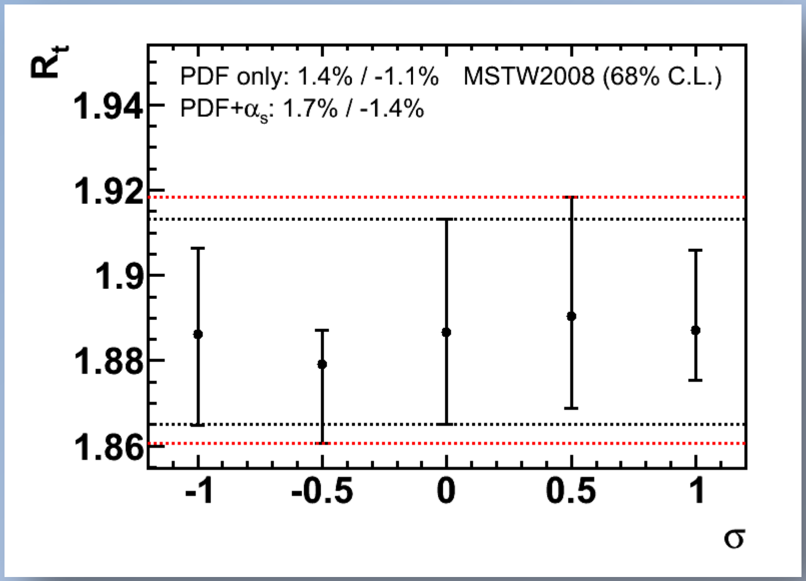
α_s dependence for σ and R_t

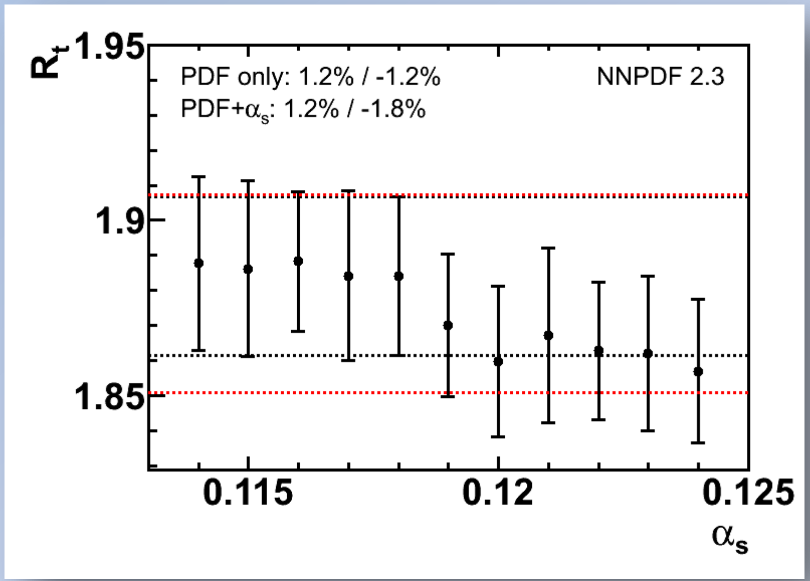




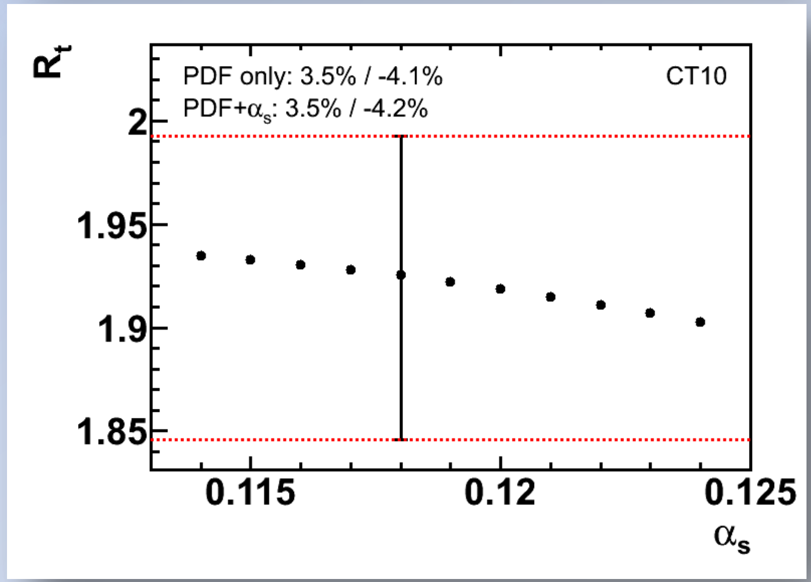
- Stronger dependence on cross section than for R_t
- Dependence similar for 2→3 and 2→2 process
  → Uncertainty can be calculated using 2→2 process

α_s dependence





- Following respective recommendations
- ± 0.002
- correlated with PDF unc. (MSTW)



Summary of theory predictions

PDF set	R_t	scale unc.	PDF unc.	α_s	4- / 5-flavour
ABM11 (5 flav.)	2.06	-0.2% / 0.1%	-1.2% / 0.9%	-0.9% / 0.8%	± 0.7%
CT10	1.93	-0.2% / 0.1%	-4.1% / 3.5%	-0.4% / 0.3%	± 0.3%
CT10 (+ D0 W asym.)	1.86	-0.2% / 0.1%	-2.7% / 2.3%	-0.4% / 0.4%	± 0.1%
GJR08 (VF)	1.88	-0.1% / 0.1%	-2.5% / 2.7%	—	± 0.2%
HERAPDF 1.5	1.98	-0.1% / 0.1%	-3.5% / 2.0%	-0.2% / 0.2%	± 0.1%
MSTW2008 (68% C.L.)	1.89	-0.2% / 0.0%	-1.4% / 1.7%		± 0.3%
NNPDF 2.3	1.87	-0.2% / 0.1%	-1.1% / 1.1%	-1.3% / 0.2%	± 0.3%

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2 → 2 vs. 2 → 3

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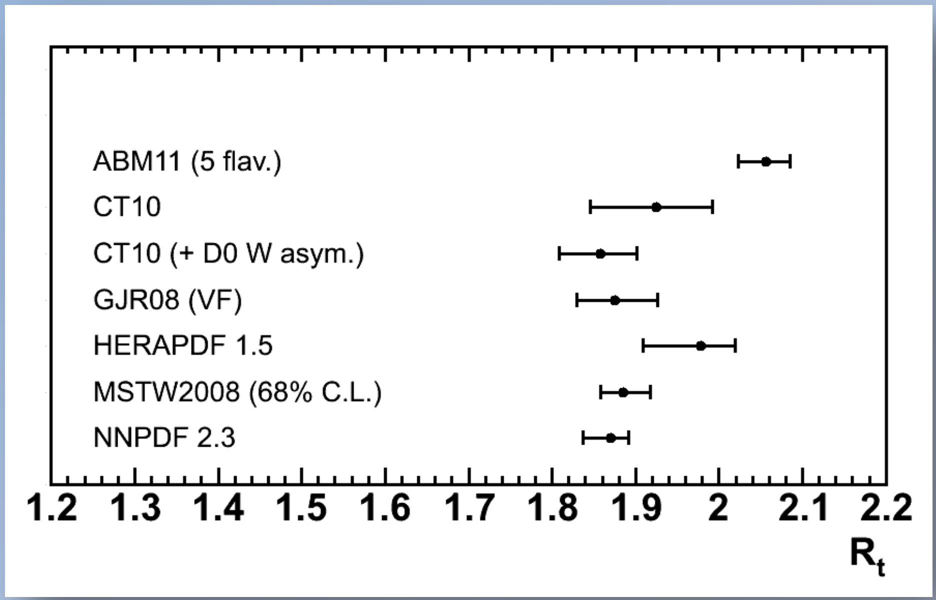
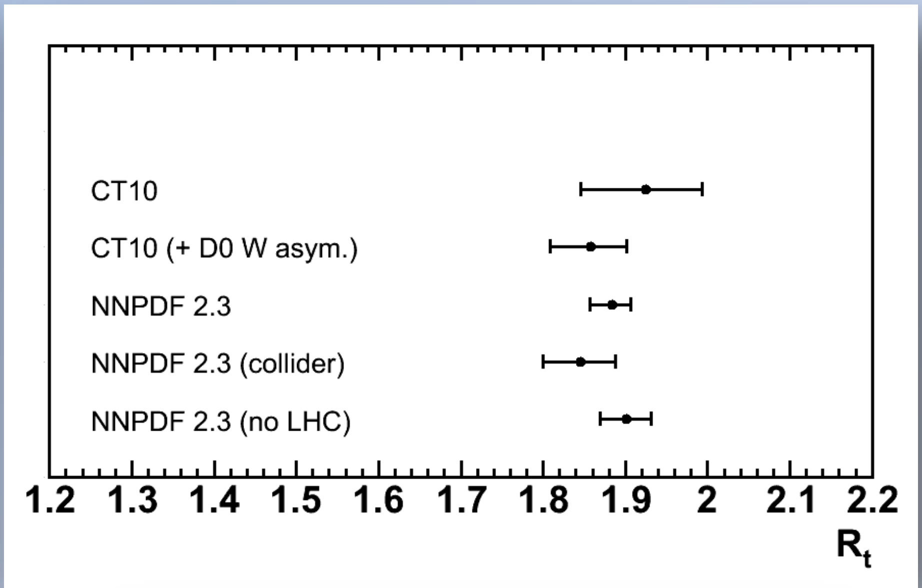
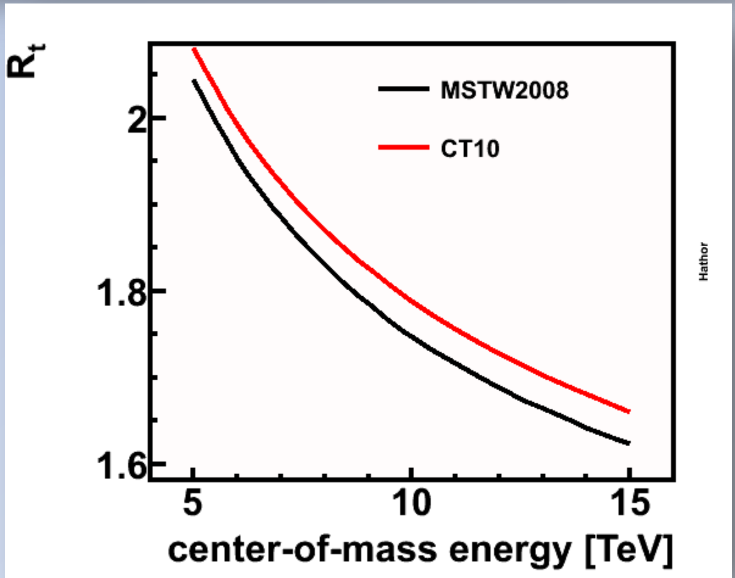
Summary of theory predictions



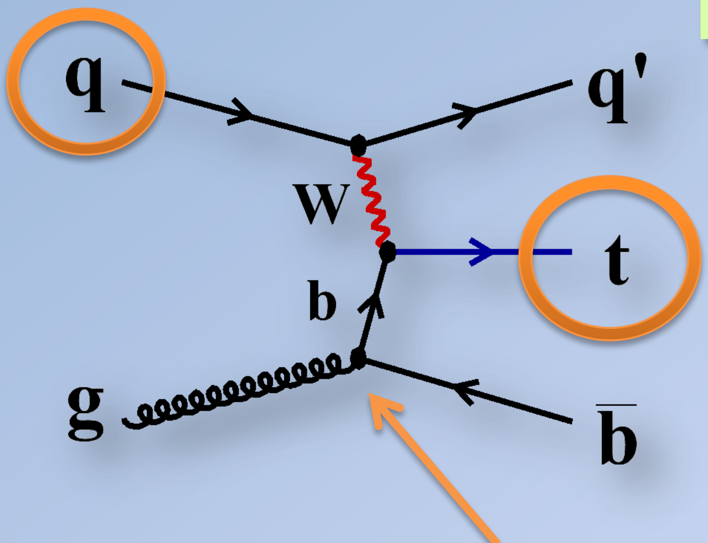


- Different PDFs predict different values for R_t
- Uncertainties dominated by PDF internal uncertainties

- Also different behavior for s dependence



What can we learn about PDFs?



The charge of the top quark is connected to the type of the incoming light-flavour quark

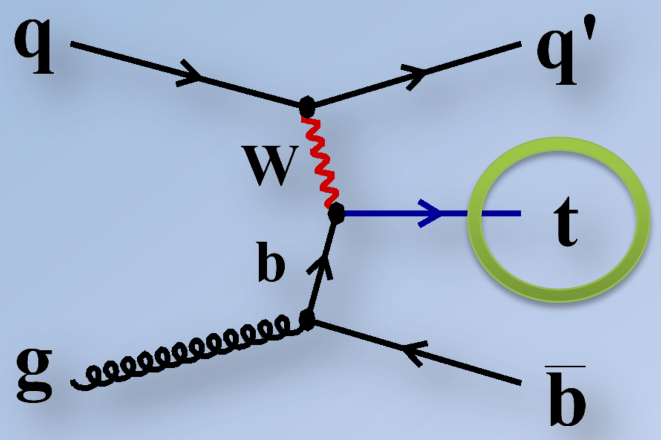
Measure cross-section ratio top-quark/top-antiquark production → see Wolfgangs talk!

Kinematic of the top quark might depend on the PDFs.

Unfold top quark pT and rapidity

Test of the b-quark PDF

Kinematic of top quark



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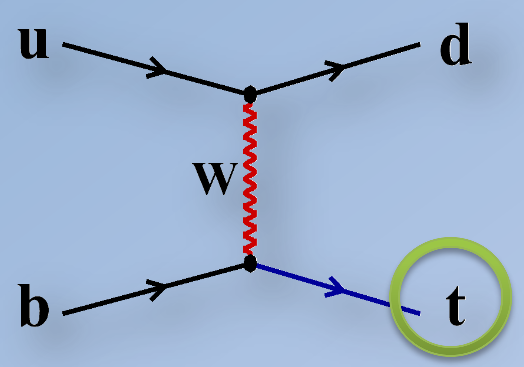
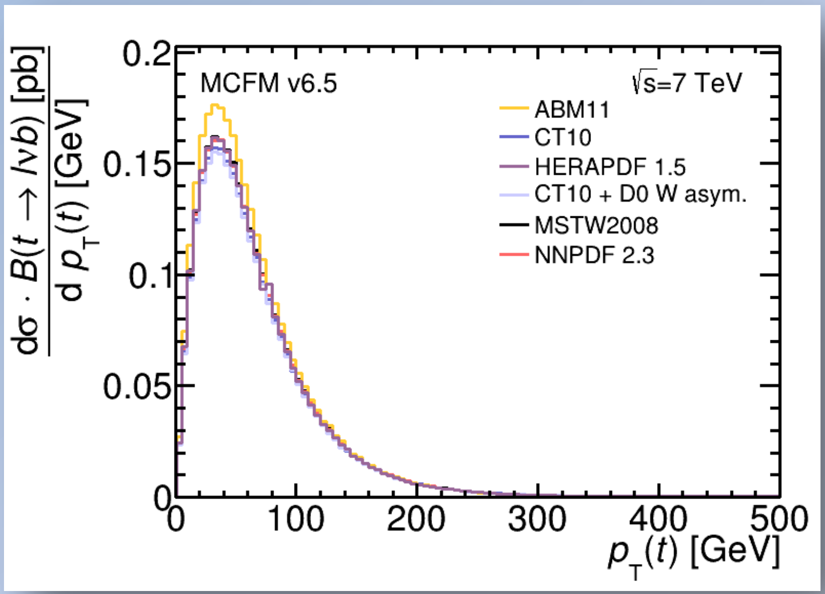
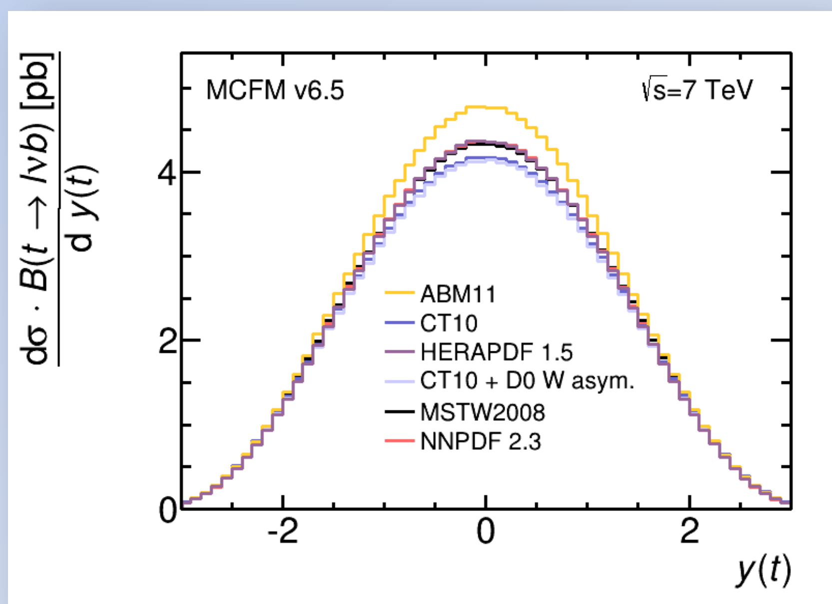


Used settings:

- Calculations are done using MCFM (v6.5)
- Same settings as for Rt calculations
- Only done for 2→2 (less CPU intensive)
- PDF internal uncertainties calculated by very small (not included in plots)
- Calculated p_T and y of top quark and top antiquark separately





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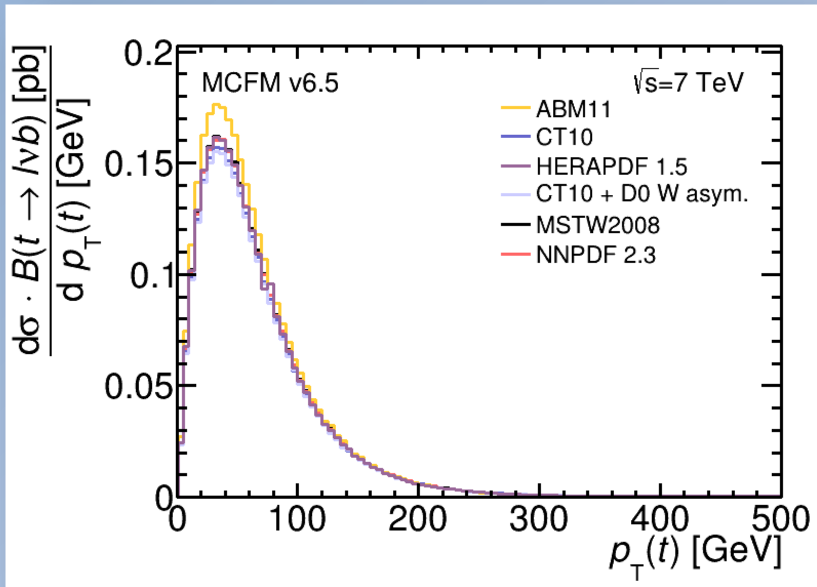
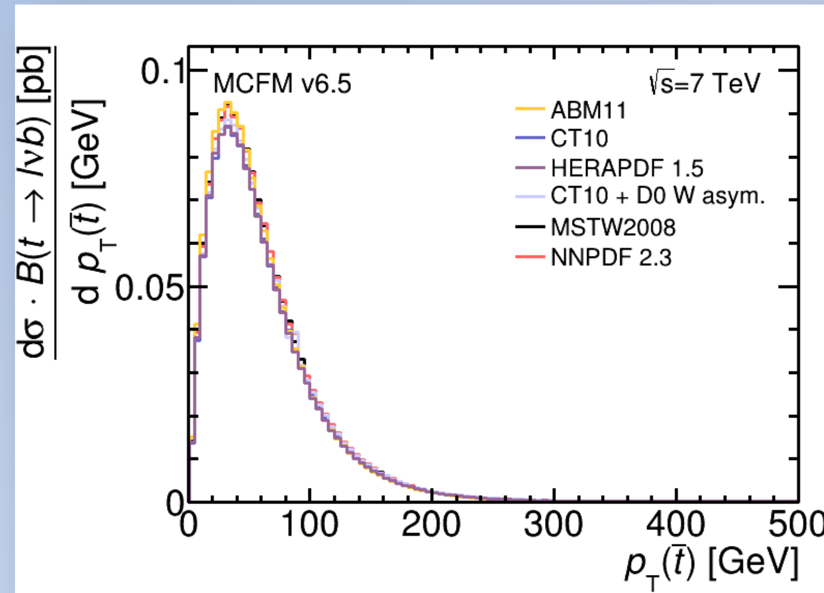
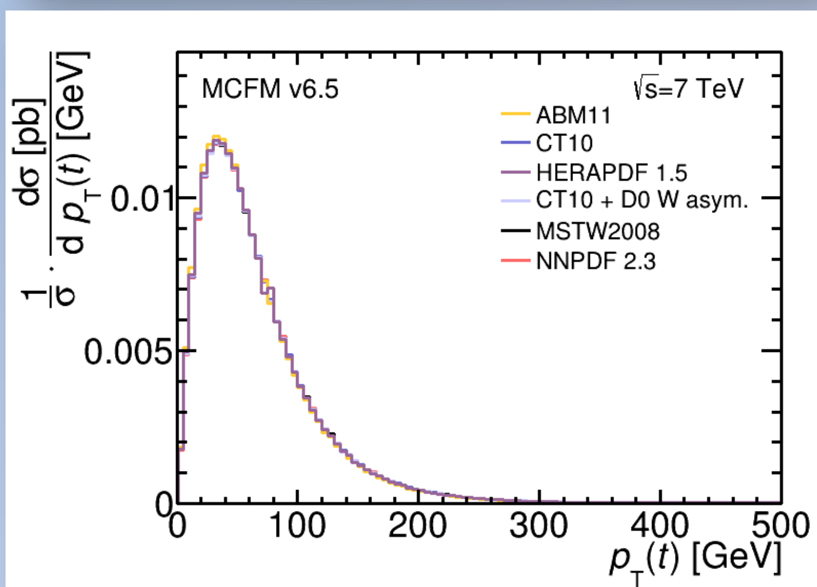
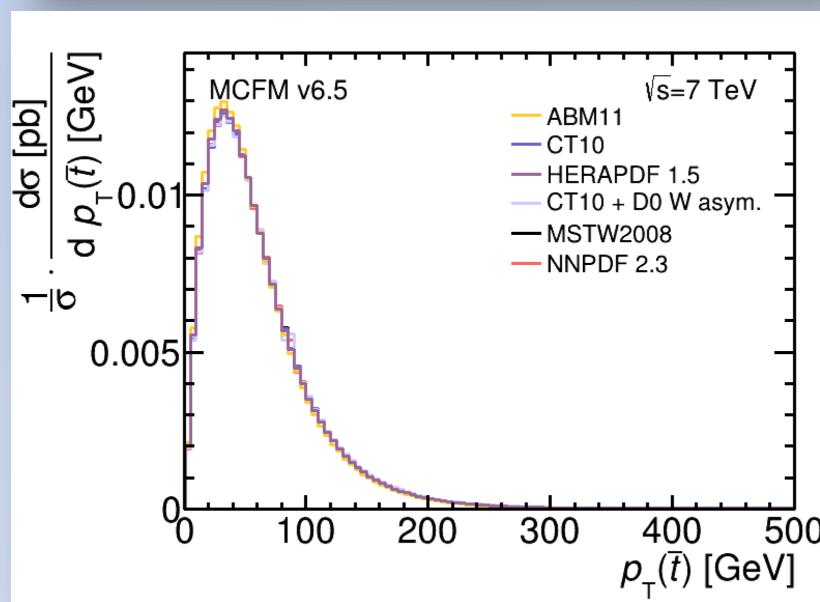
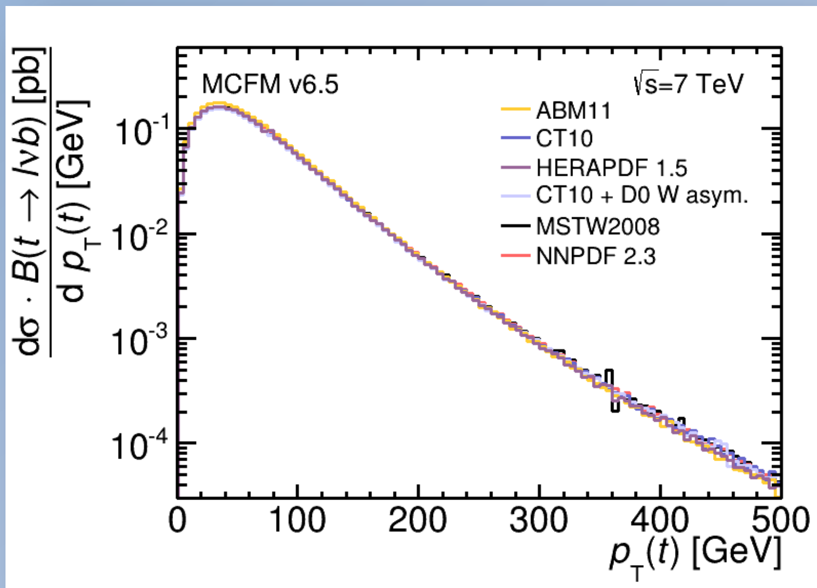


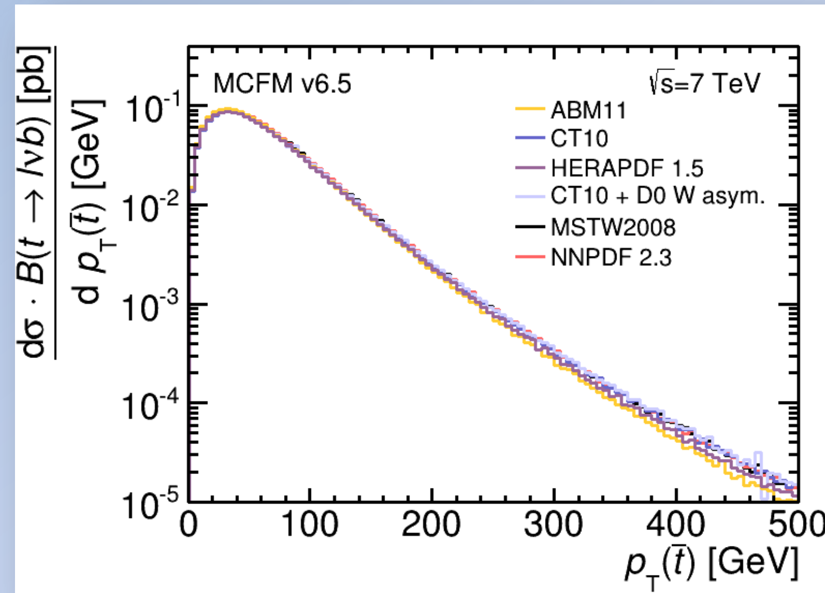


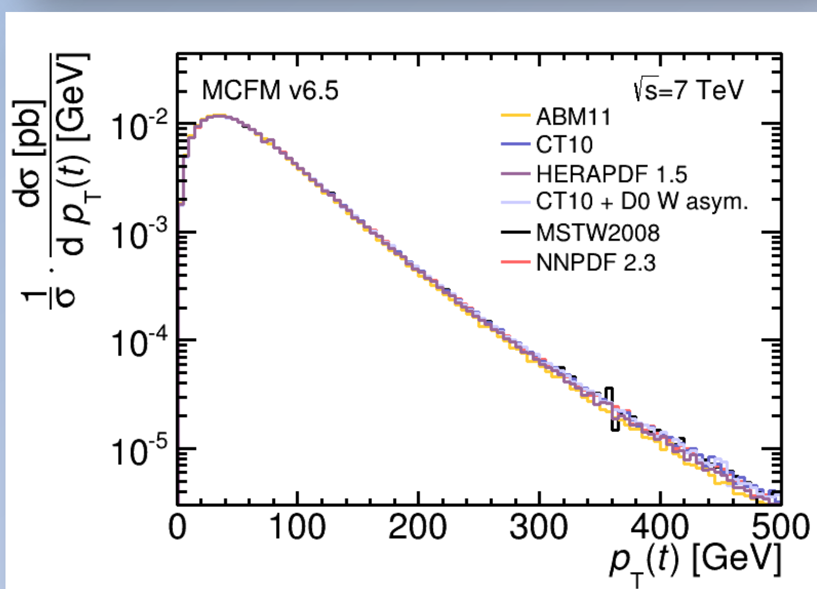


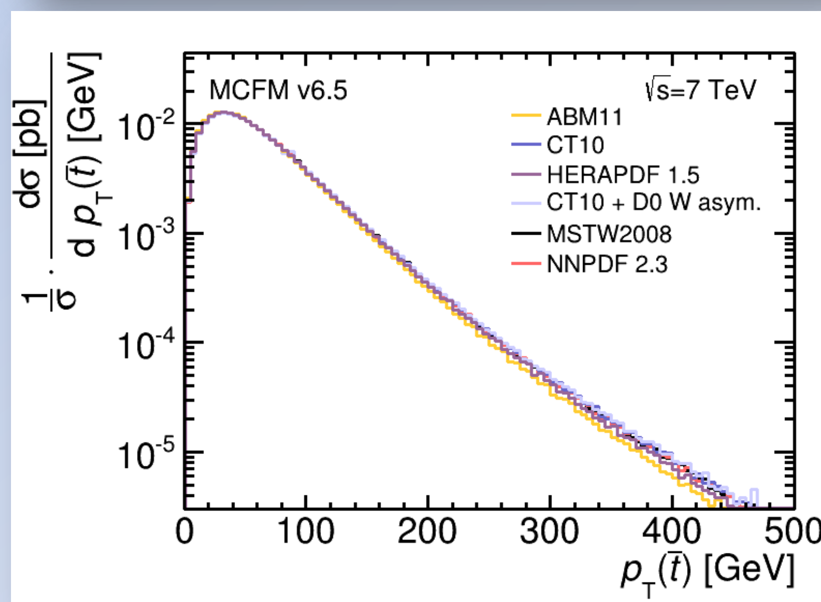


Kinematic of top quark









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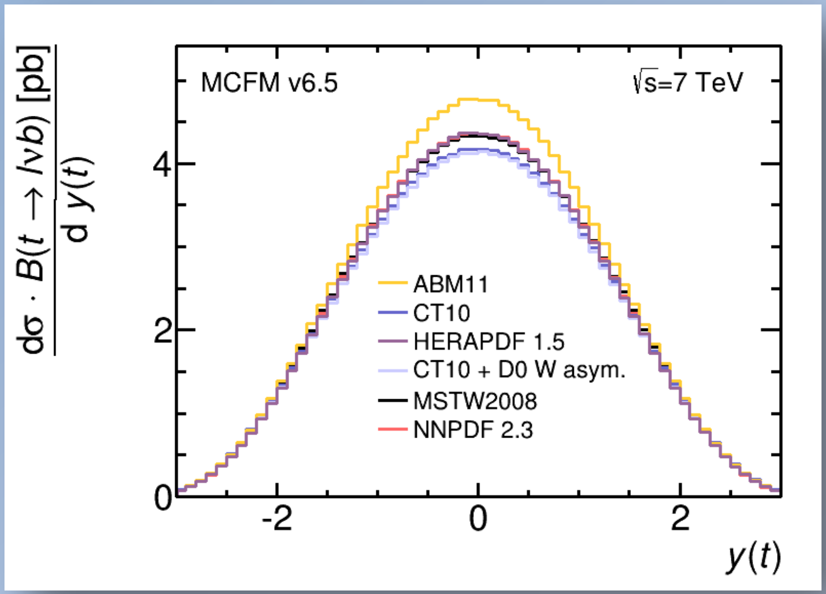

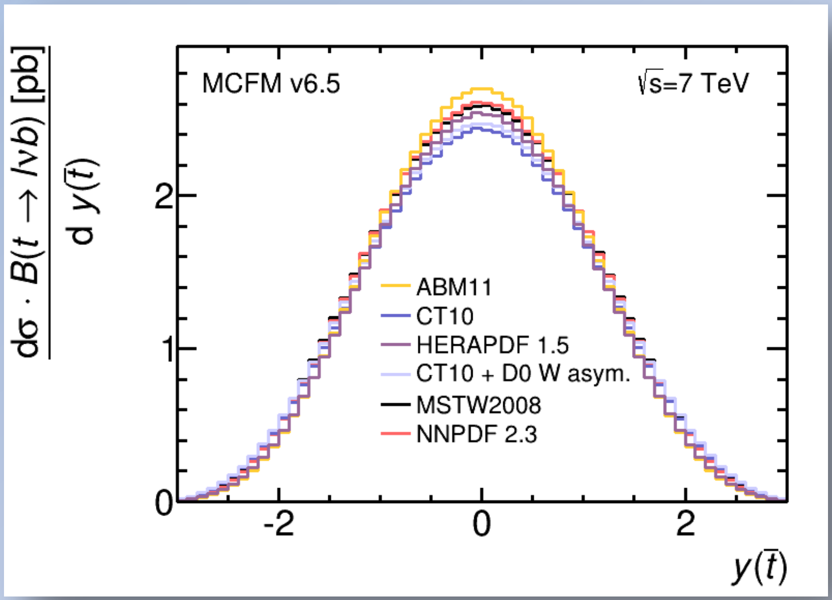

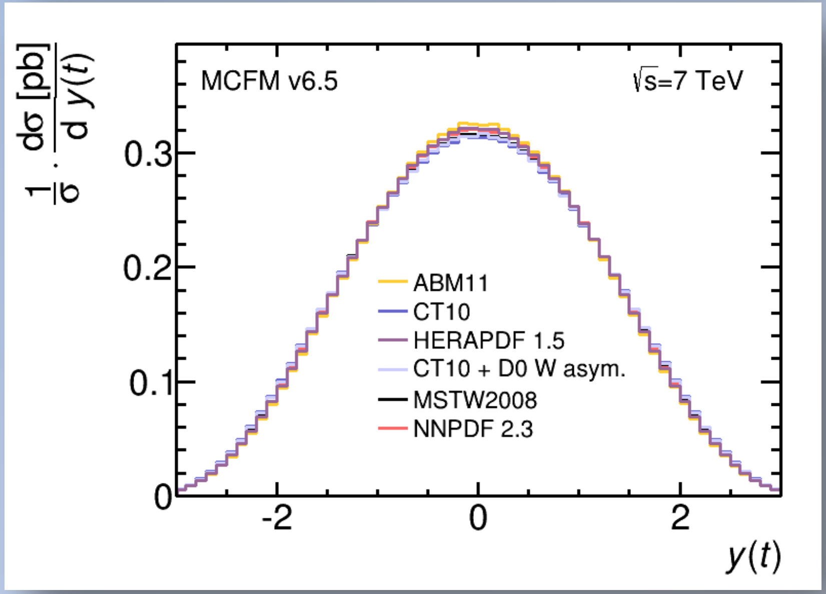

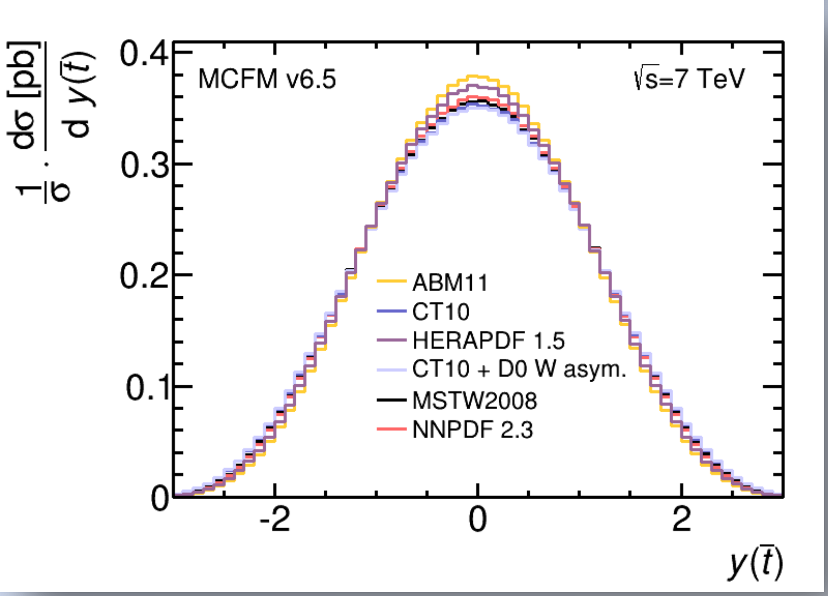

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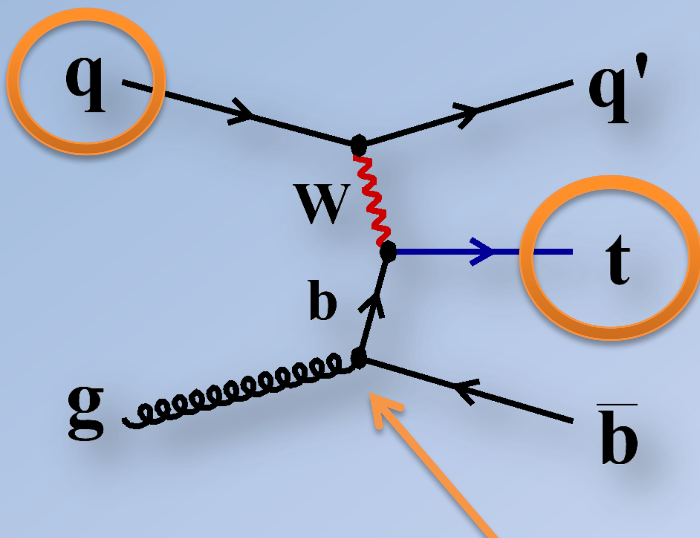
Measure cross-section ratio top-quark/top-antiquark production → see Wolfgangs talk!



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Test of the b-quark PDF

Measure total cross section

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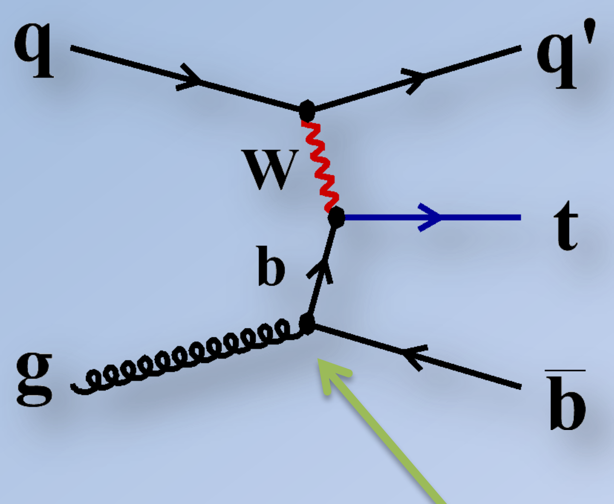


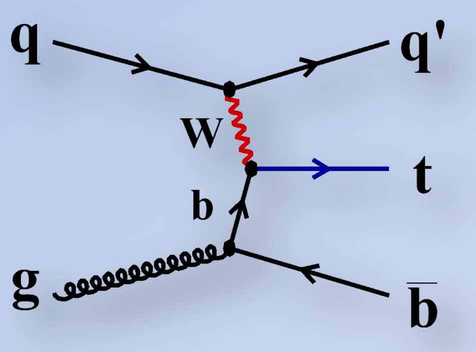
No predictions for different PDFs concering b-quark PDF yet
→ Study of different event generators
→ Study acceptance differences on truth quantities

Test of the b-quark PDF

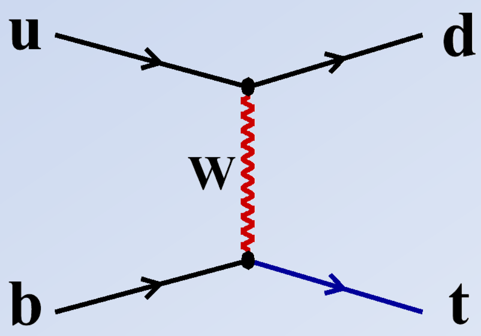
Measure total cross section

Available event generators

- **4 flavour (2 → 3) NLO**
  - aMC@NLO + MadSpin
    - + Herwig++
    - + fHerwig → disfavored for the future
    - + Pythia8 → very soon
  - Powheg + MadSpin
    - + Pythia6 → disfavored for the future
    - + Pythia8 / Herwig++
    - + fHerwig → disfavored for the future



- **Matched samples for 2 → 2 (LO) and 2 → 3 (LO) process**
  - Matching using p_T of second b (Comphep)
  - **ACOT method (AcerMC) → default in ATLAS**



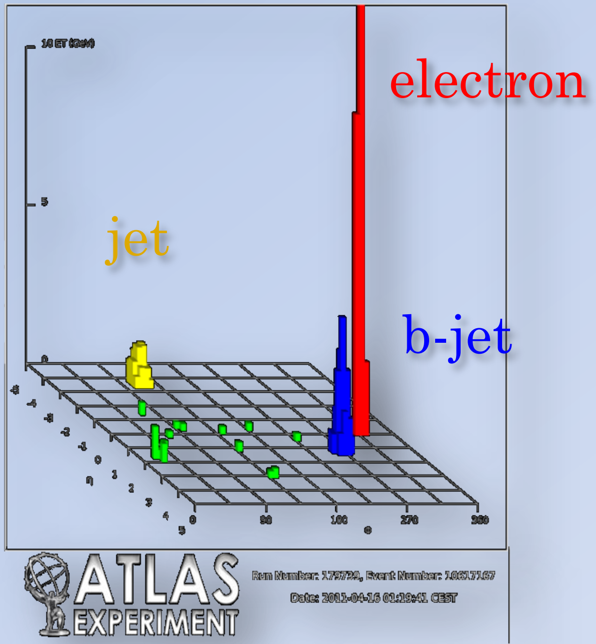
- **5 flavour (2 → 2) NLO**
  - Powheg
    - + **Pythia 6 → default in CMS**
    - + Pythia 8 / Herwig++
  - aMC@NLO
    - + Herwig++ / Pythia8

Parameters used in the generation / selection

2→3 NLO (aMC@NLO or Powheg)
- PDF: CT10f4
- Scale: $\mu = 4 \cdot m_T(b)$

2→2 & 2→3 matched (AcerMC)
- PDF: MRSTLO**
- Scale: $\mu = m_{top}$ = 172.5 GeV (fixed scale)

2→2 NLO (Powheg)
- PDF: CT10
- Scale: $\mu = m_{top}$ = 172.5 GeV (fixed scale)



Electron / Muon:
- Exactly one electron or muon with $p_T > 25$ GeV, $|\eta| < 2.5$

Missing transverse momentum
- fourvector sum of all neutrinos, $E_T^{Miss} > 25$ GeV

Jets: (Fastjet 3.0.4 , anti-k_t with R=0.4)
- $p_T > 30$ GeV , $|\eta| < 4.5$
- Ghost b-tagging using b-hadrons with b_{eff}=0.5, mistag rate 0.2%
- Exactly one b-tag

Anti-QCD cut
- $m_T(W) > 50$ GeV

Comparison of acceptance

	acc.	AcerMC rel. diff.	
aMC@NLO 2->3 + fHerwig	5.83%	+12.1%	
aMC@NLO 2->3 + Herwig++ (CTEQ6l1)	5.43%	+4.4%	
aMC@NLO 2->3 + Herwig++ (MRSTLO**)	5.41%	+4.4%	
Powheg 2->3 + Pythia6	5.80 %	+11.5%	
Powheg 2->3 + Pythia8	6.14 %	+18.0%	
AcerMC+Pythia6 μ=172.5 GeV	5.20%		
Powheg 2->2 + Pythia6	5.75%	+10.6%	

AcerMC has much lower acceptance than all other generators
→ maybe too high scale (μ = 172.5 GeV is default)

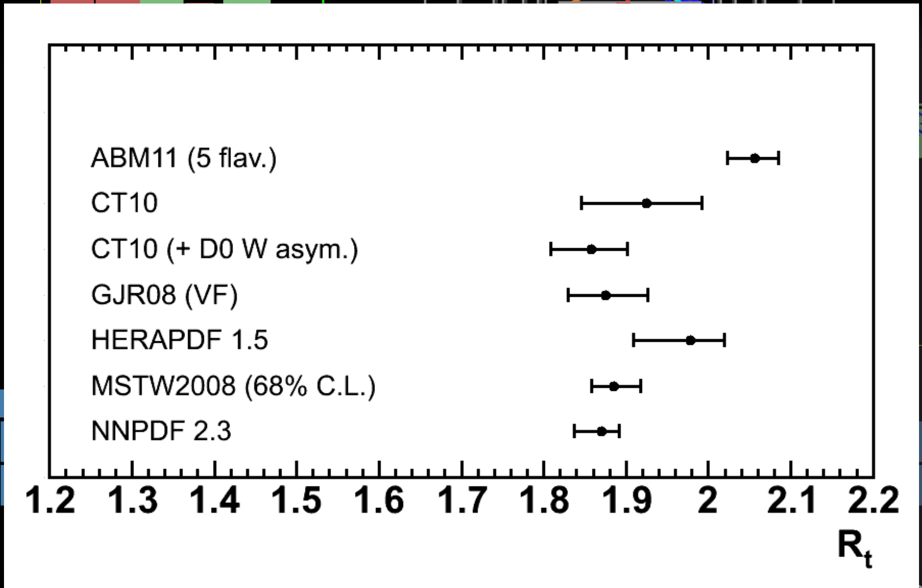
Comparison of acceptance

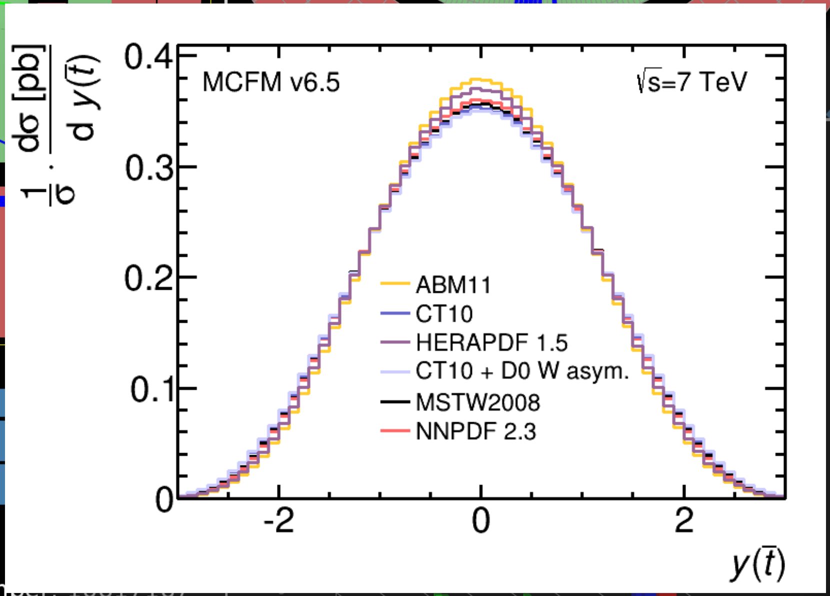
	acc.	AcerMC (175) rel. diff.	AcerMC(60) rel. diff
aMC@NLO 2->3 + fHerwig	5.83%	+12.1%	-0.1%
aMC@NLO 2->3 + Herwig++ (CTEQ6l1)	5.43%	+4.4%	-7.8%
aMC@NLO 2->3 + Herwig++ (MRSTLO**)	5.41%	+4.4%	-7.8%
Powheg 2->3 + Pythia6	5.80 %	+11.5%	-1.5%
Powheg 2->3 + Pythia8	6.14 %	+18.0%	+4.2%
AcerMC+Pythia6 μ=172.5 GeV	5.20%		-11.7%
AcerMC+Pythia6 μ=60 GeV	5.89%	+13.3%	
Powheg 2->2 + Pythia6	5.75%	+10.6%	-2.4%

→ Lower scale for AcerMC increases acceptance significantly

Summary / Conclusion

- Ratio of top-quark over top-antiquark t-channel single top quark production shows – significant – differences between different PDFs
- Differential top pT and y distributions don't show big differences
- Investigations on most suitable event generator on-going





EXPERIMENT

Date: 2011-04-16 01:19:41 CEST