TECHNISCHE UNIVERSITÄT DRESDEN
Fakultät Physik Institut für Kern- und Teilchenphysik

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

Combining ttjets and ttbb MC

Higgs Toppings, May 2018, Benasque

Frank Siegert

in collaboration with

Stefan Höche (SLAC) & Johannes Krause (TU Dresden),
and Judith Katzy & Chris Pollard (DESY)

Disclaimer

- This talk is meant to be a teaser to start discussions. I will
  - explore the necessity to go beyond standalone ttbb@NLO,
  - identify open questions related to that,
  - give some answers, but not necessarily all or final!

- Huge effort and progress on NLO+PS ttbb 4F calculations
  - I will take them for granted and simply apply them here.
  - some of the following is related to ttbb 4F discussions; it affects particularly the configurations which cause large differences in ttbb 4F generators

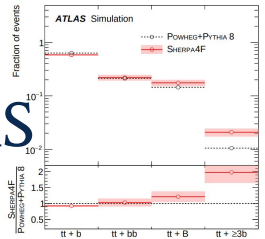
More discussions on those in next talk!

Motivation

- tt+HF modelling in ATLAS and CMS based on NLO tt + parton shower
- Theory predictions for NLO ttbb + PS available, but used only for:
  - reweighting HF fractions (ATLAS)
  - cross-checks (CMS)
- Reasons for discrepancy?
  1. ttbb more “complicated” evgen
  2. ttbb is not inclusive!
     need inclusive description to define all HF categories, including light/charm
  3. ?

ATLAS

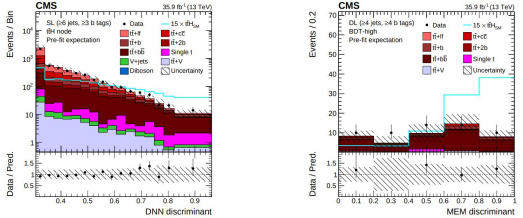
- Nominal $t\bar{t}+$jets MC sample : Powheg+Pythia8
  - A14 tune, $\alpha_S(ISR) = \alpha_S(FSR) = 0.127$ (see ATL-PHYS-PUB-2014-021)
  - h_{damp}=1.5 m_{top} (optimised on 8 TeV data, see ATL-PHYS-PUB-2016-020)
  - normalised to NNLO+NNLL prediction 831.76 pb^{-1}
- $t\bar{t}+\geq 1b$, $t\bar{t}+\geq 1c$ fractions taken from PP8, also when comparing to other samples
  - but are let free-floating in the fit
- $t\bar{t}+\geq 1b$ sub-categories fractions reweighted to Sherpa 4FS $t\bar{t}+b\bar{b}$
  - except $t\bar{t}+b$(*MPI*/*FSR*) which isn't included in Sherpa 4FS $t\bar{t}+b\bar{b}$



CMS

$t\bar{t}$ + jets Modelling

- Inclusive POWHEG+PYTHIA8 $t\bar{t}$ NLO simulation
  - CUETP8M2T4 tune, NNPDF3.0
- Normalised to NNLO+NNLL cross section of 832 pb
- Events split into the 5 $t\bar{t}+X$ processes

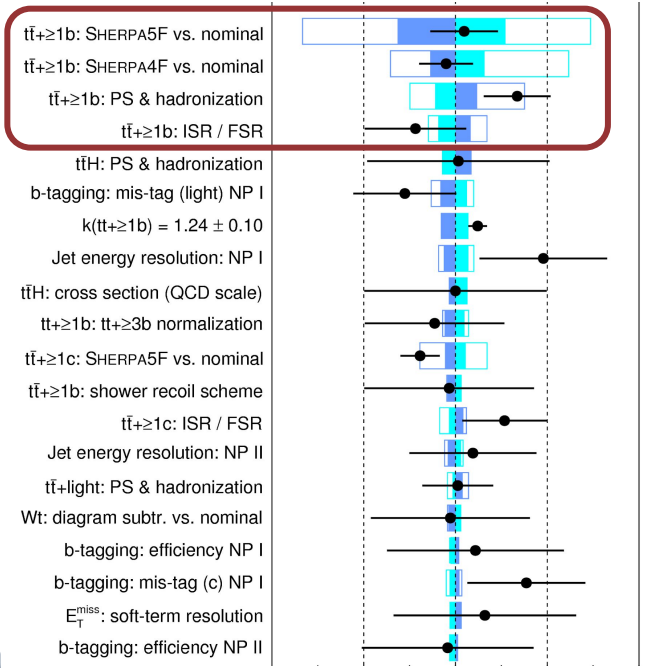


Shape and normalisation from POWHEG+PYTHIA8

Impact

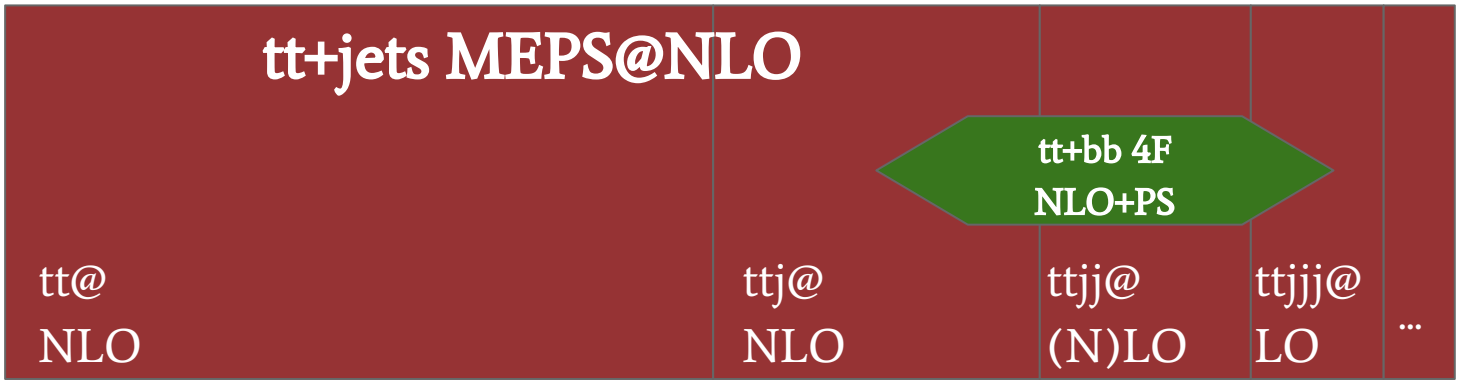
Why ~~listen to this talk~~combine tt+jets ⊕ ttbb?

- Largest uncertainties affected by separation into tt (5F) and ttbb (4F)
- Unc's not only large, but also hard to debate with or improve by theorists!
- Parts of unc's are nominal MC stats → improvable by using dedicated ttbb within a combined ttjets+ttbb?
- Theoretical impact:
  - better description of additional jet activity
  - better access to multi-scale configurations with relatively soft g→bb?



Combining X+bb and X+jets in the Sherpa MC

aka "A Critical Appraisal of Heavy Flavour Overlap Removal"



[Höche, Krause, FS in prep]

Three main steps:

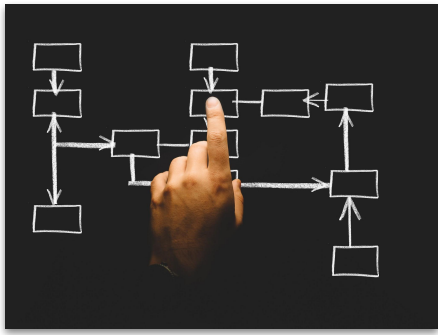
1. HF Overlap removal
2. Embedding ttbb as merged contribution
3. Matching 4F/5F in PDFs and α_s

IMPACT

COMPLEXITY

Step 1: Heavy Flavour Overlap Removal

- HFOR used before in experiments in simplified form
  - dR(b,b)>0.4 → keep from ttbb ME
  - dR(b,b)<0.4 → keep from tt ME + bb from PS
- Here: from multi-leg merging prescription
  - Cluster full event at PS level using "reverse shower"
  - Look at **leading two emissions**
    - » Heavy Flavour → keep from **ttbb NLO+PS** simulation
    - » Light Flavour → keep from **tt+jets MEPS@NLO**



⇒ Sub(sub)leading g→bb splittings not from ttbb ME, but from ttjjjj ME or from PS. Open question: Good or Bad?

- (Extra: caution with b's from "FSR" in top decay products!)

Step 2: Embedding ttbb as merged contribution

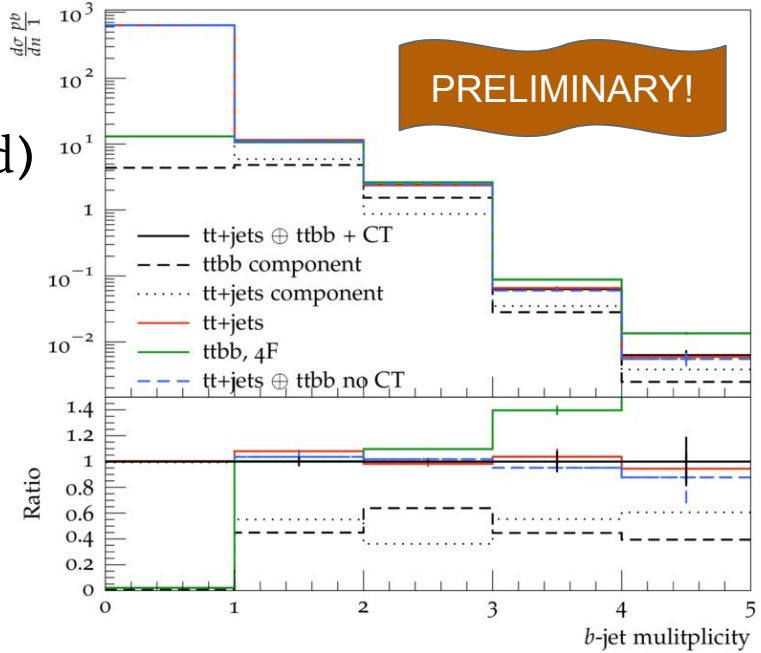
- ttj(j(...)) matrix elements in **tt+jets MEPS@NLO** undergo special treatment:
  - clustering to get scale hierarchy of ME emissions ("shower history")
  - core scale based on 2→2 process
  - application of $\alpha_S(\mu_R^2) \rightarrow \alpha_S(p_T^2)$ reweighting for each emission
  - application of Sudakov factors $\Delta(t_1, t_2)$ along internal lines for correct resummation properties
- Same procedure applied to **ttbb NLO+PS** massive calc'n
  - (but no event veto if shower produces hard emission)
  - remains separate standalone ttbb NLO+PS sample, but generated as if within multi-leg merged approach

Step 3: Matching 4F/5F in PDFs and α_S

- For consistent combination with tt+jets we produce the massive **ttbb NLO+PS** with a 5F PDF
  - m_b mismatch with massive NLO matrix elements
    → recycle ideas from FONLL [Forte, Napoletano, Ubiali 2016], but extend them to a parton shower picture
  - Basic idea: subtract from **tt+jets MEPS@NLO** the 4F prediction in $m_b \to 0$ limit by appropriate vetoes and counterterms
    - » Leading Log matching term automatically contained in tt+jets PS simulation through overlap removal veto, remaining terms by explicit counterterms as event weights
- Additional counter-terms for mismatch between α_S evolution with $m_b = 0$ and virtuals with $m_b \neq 0$

Application and results for ttbb

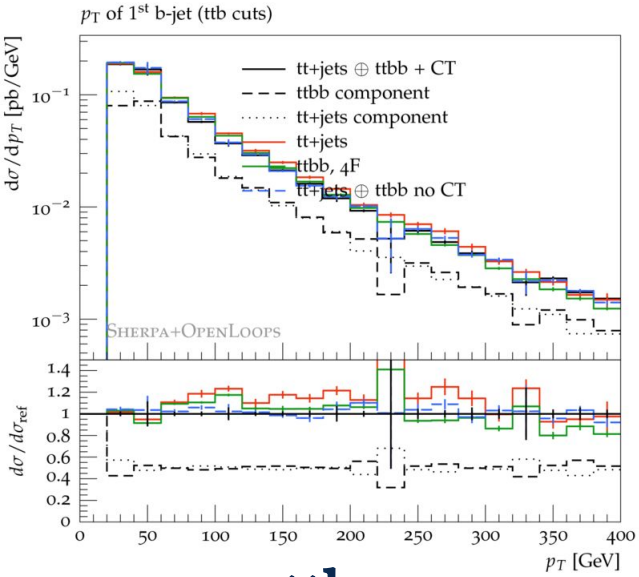
- Comparison of different Sherpa+OpenLoops predictions in typical ttb(b) regions and observables
  - combined tt+jets ⊕ ttbb
    - » ttbb sub-component (dashed)
    - » tt+jets sub-component (dotted)
  - tt+jets MEPS@NLO (5F) (tt+0,1j@NLO+2,3j@LO)
  - ttbb NLO+PS (4F)
  - for education: full result without counterterms in dashed blue
- NNPDF3.0 (N)NLO PDF sets



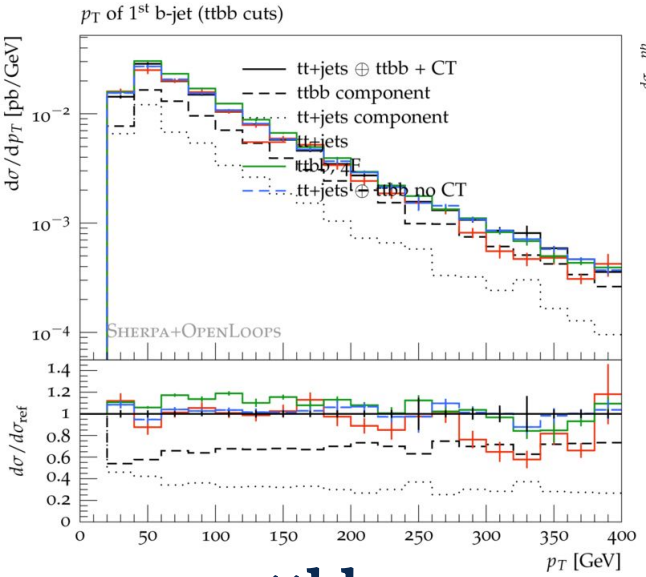
[Katzy, Krause, Pollard, FS in prep]

PRELIMINARY!

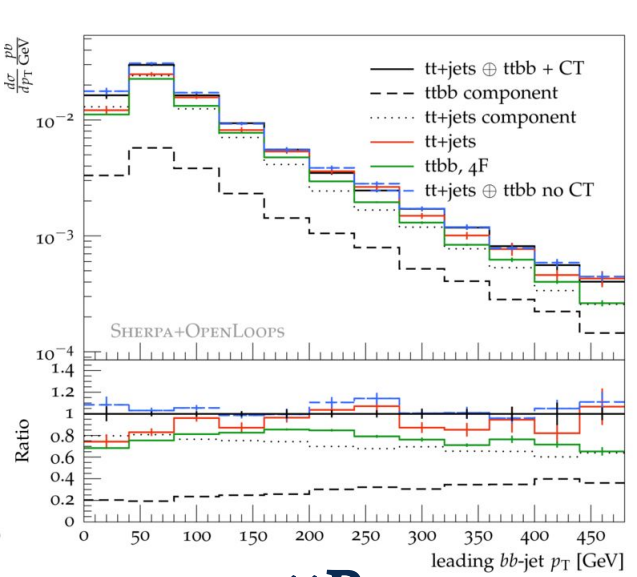
Leading HF jet



ttb



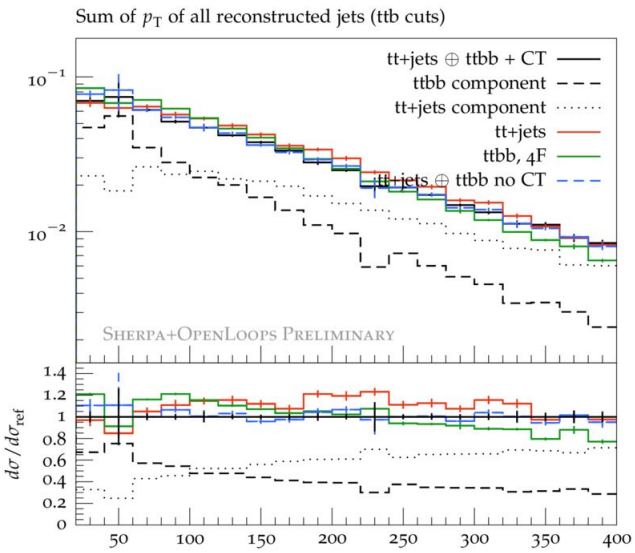
ttbb



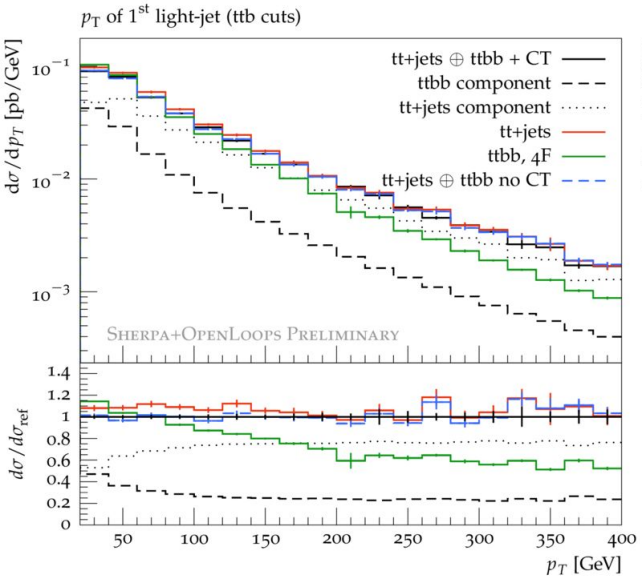
ttB

PRELIMINARY!

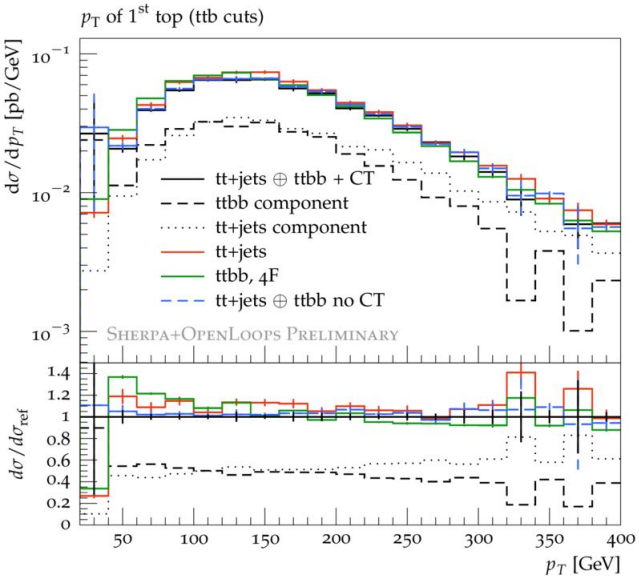
ttb region



H_T



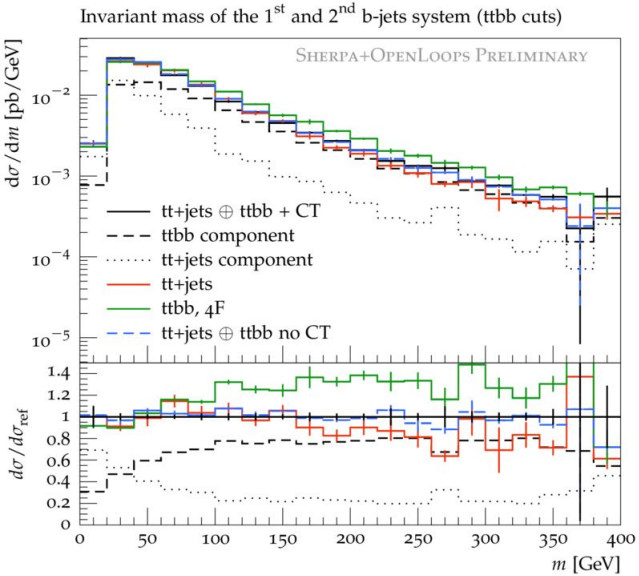
$p_{T,j1}$



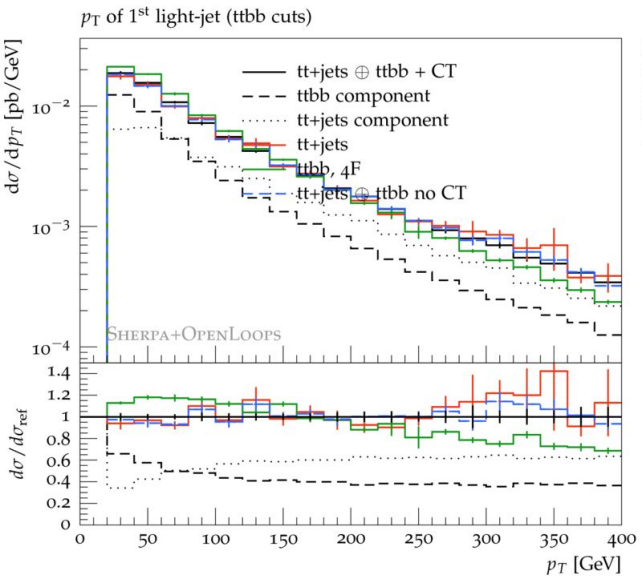
$p_{T,top1}$

PRELIMINARY!

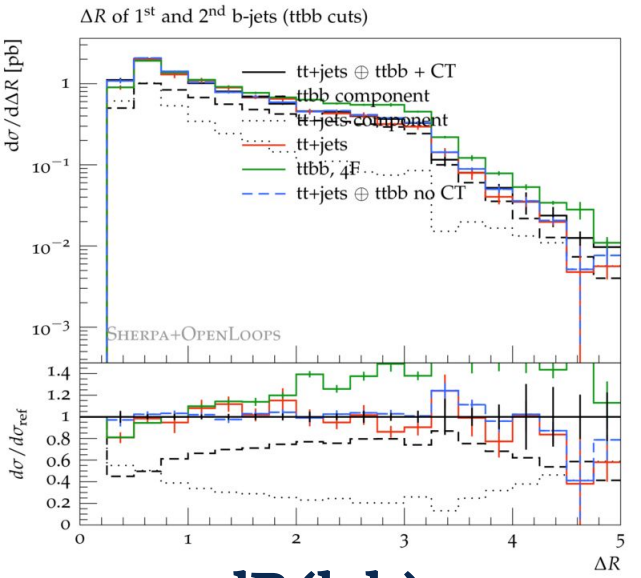
ttbb region



m_{bb}



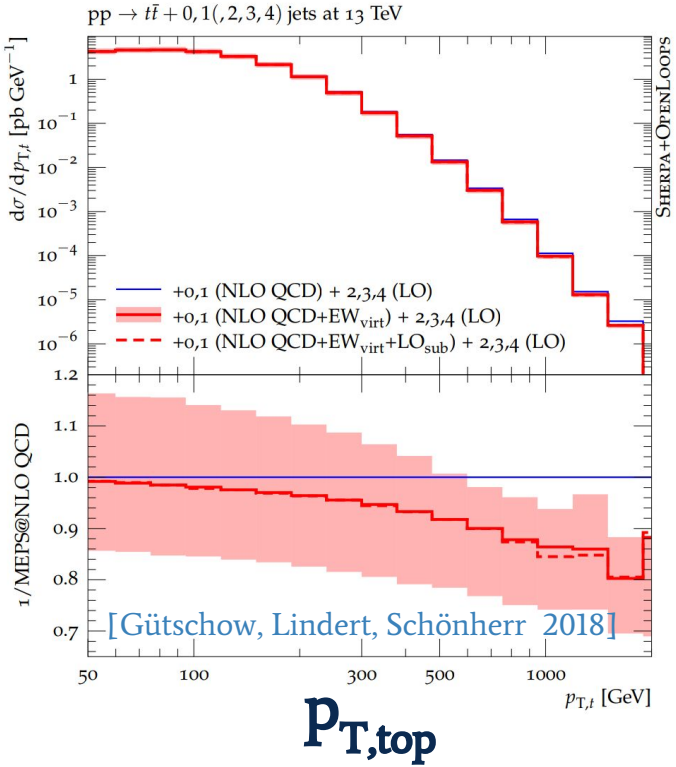
$p_{T,j1}$



dR(b,b)

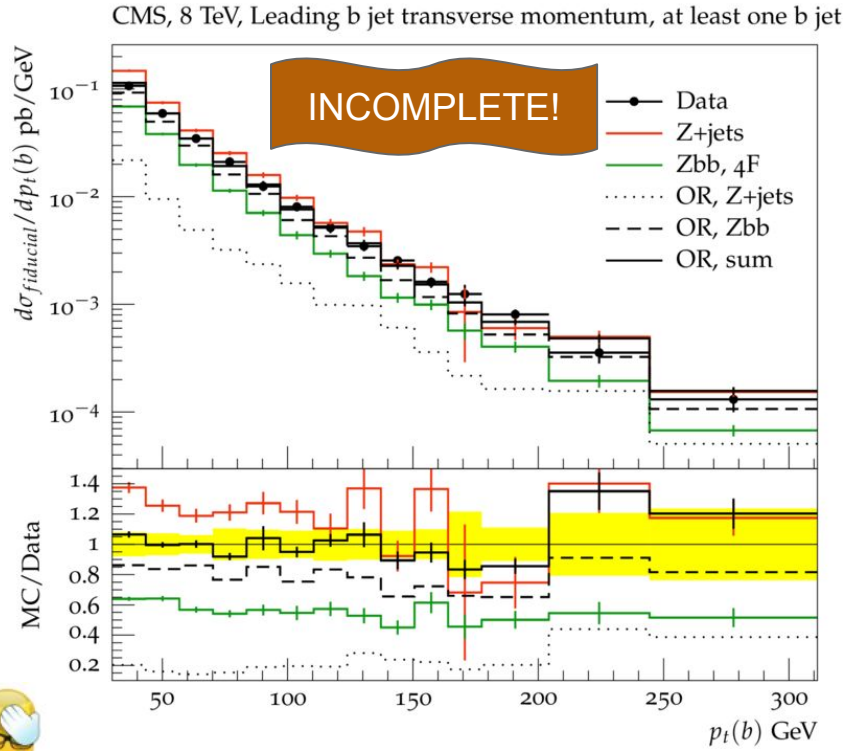
Remarks

- Only plots with stable tops here, but unstable tops available as well.
- Keep in mind importance of NLO EW for general tt observables
  - We'll probably not have them for ttbb anytime soon?
  - Extend EW_{virt} approach to combined ttjj/ttbb sample?
- ttcc would still come from tt+jets... still better than from PS, but how to ensure sufficient MC statistics?



Bonus: Application to Zbb/Zjets

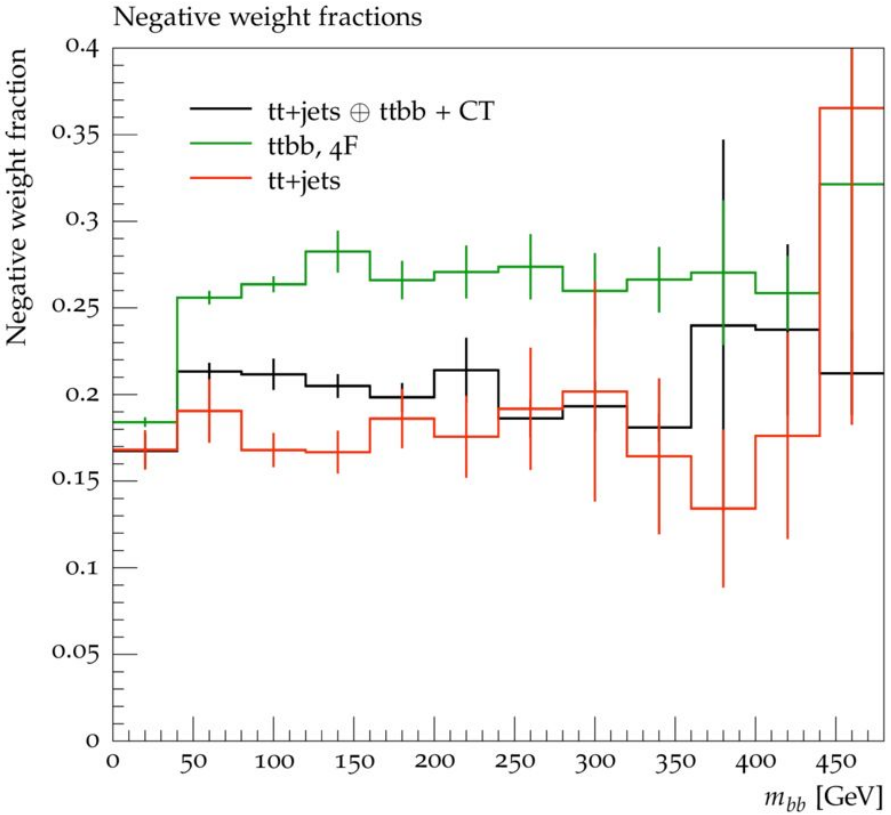
- Identical algorithm applied to Z+jets ⊕ Zbb
- Caveat: 4F/5F matching terms beyond LL not applied yet
  ⇒ prediction incomplete
  - first attempt at including them shows 20% deviations
    → debugging!
- Comparing incomplete predictions to CMS 8 TeV data looks promising though...



Backup

PRELIMINARY!

Negative weight fractions



Relevant settings: ttbb standalone

```
PP_HPSMODE=4
CSS_IS_AS_FAC=1.0
EXCLUSIVE_CLUSTER_MODE=1

PDF_SET NNPDF30_nlo_as_0118_nf_4
MASSIVE[5]=1
CSS_KMODE=34

SCALES VAR{H_TM2/4}{sqrt(MPerp(p[2])*MPerp(p[3])*MPerp(p[4])*MPerp(p[5]))}{H_TM2/4}

Process 93 93 -> 6 -6 5 -5
Order (*,0)
NLO_QCD_Mode MC@NLO
ME_Generator Amegic; RS_ME_Generator Comix; Loop_Generator OpenLoops
```

Relevant settings: ttbb component

```
PP_HPSMODE=4
CSS_IS_AS_FAC=1.0
EXCLUSIVE_CLUSTER_MODE=1

PDF_SET NNPDF30_nnlo_as_0118
MASSIVE[5]=1
SHERPA_LDADD=ALPHAS_Hook;
USERHOOK = ALPHAS;

SCALES METS{MU_F2}{MU_R2}{MU_Q2};
CORE_SCALE VAR{sqr(172.5)+0.5*(PPerp2(p[2])+PPerp2(p[3]))};

Process 93 93 -> 6 -6 5 -5
Order (*,0)
CKKW sqr(1000);
NLO_QCD_Mode MC@NLO
ME_Generator Amegic; RS_ME_Generator Comix; Loop_Generator OpenLoops
```

Relevant settings: ttjets standalone

```
PP_HPSMODE=4
CSS_IS_AS_FAC=1.0
EXCLUSIVE_CLUSTER_MODE 1;

PDF_SET NNPDF30_nnlo_as_0118

SCALES METS{MU_F2}{MU_R2}{MU_Q2};
CORE_SCALE VAR{sqr(172.5)+0.5*(PPerp2(p[2])+PPerp2(p[3]))};

NJET:=3; LJET:=2,3; QCUT:=20.;

Process : 93 93 ->  6 -6 93{NJET};
Order (*,0);
NLO_QCD_Mode MC@NLO {LJET}; CKKW sqr(QCUT/E_CMS);
ME_Generator Amegic {LJET}; RS_ME_Generator Comix {LJET}; Loop_Generator OpenLoops;
```

Relevant settings: ttjets component

```
PP_HPSMODE=4
CSS_IS_AS_FAC=1.0
EXCLUSIVE_CLUSTER_MODE 1;

PDF_SET NNPDF30_nnlo_as_0118
SHERPA_LDADD=FUSING_Hook
USERHOOK = FUSING_HOOK
FUSING_PDF_CORRECTION 1

SCALES METS{MU_F2}{MU_R2}{MU_Q2};
CORE_SCALE VAR{sqr(172.5)+0.5*(PPerp2(p[2])+PPerp2(p[3]))};

NJET:=3; LJET:=2,3; QCUT:=20.;

Process : 93 93 ->  6 -6 93{NJET};
Order (*,0);
NLO_QCD_Mode MC@NLO {LJET}; CKKW sqr(QCUT/E_CMS);
ME_Generator Amegic {LJET}; RS_ME_Generator Comix {LJET}; Loop_Generator OpenLoops;
```