Monte Carlo modelling issues in top physics

[SM@LHC 2013 conference – Albert-Ludwigs-Universität Freiburg]

Jan Winter

– MPP Munich –

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

→ ***mainly discussed in context with AFB.***

- *Colour coherence effect.*
- *Inclusion of top quark decays.*

Monte Carlos for top physics

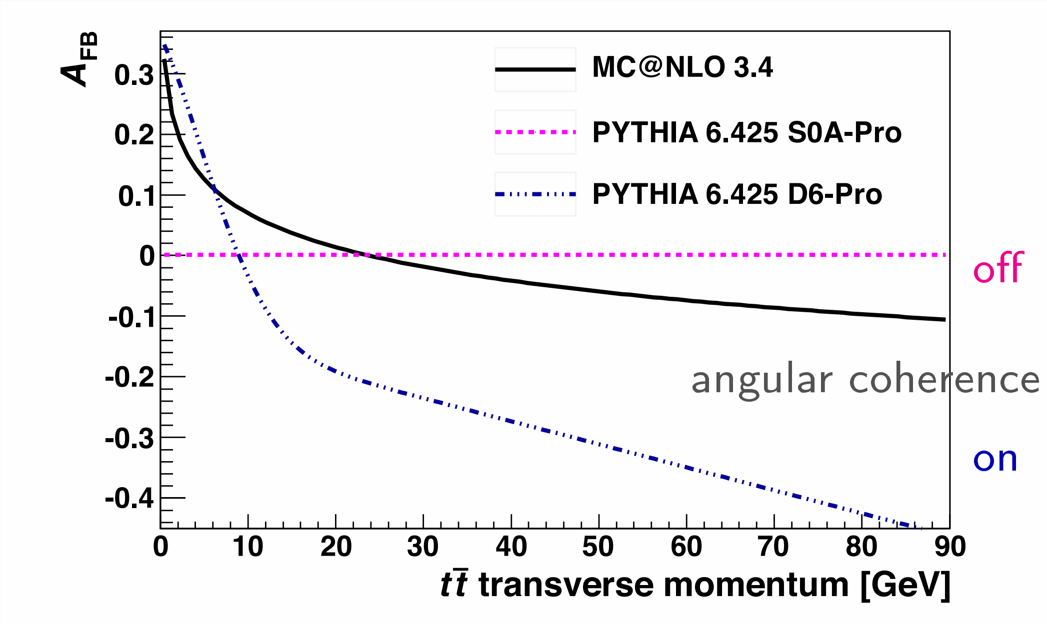
- Standard nowadays is NLO+PS for single top quark, top quark pair and associated production.
  - PowhegBox (and interface to showers). [NASON ET AL.]
  - MC@NLO and aMC@NLO (and interface to showers). [FRIXIONE ET AL.]
  - Sherpa with virtual corrections from BlackHat/GoSam/OpenLoops etc. [KRAUSS ET AL.]
- A number of questions can be asked.
  - Status of validation
  - Level of agreement in differential distributions (Do we understand differences?)
  - Comparison to fixed, higher-order calculations
  - Comparison to merging approaches, MEPS@(N)LO and MENLOPS
  - Assessment of uncertainties
  - Treatment of top quark mass
  - Treatment of top quark decays
  - Treatment of parton showers
  - ...
- Here I will only be able to discuss last few points.

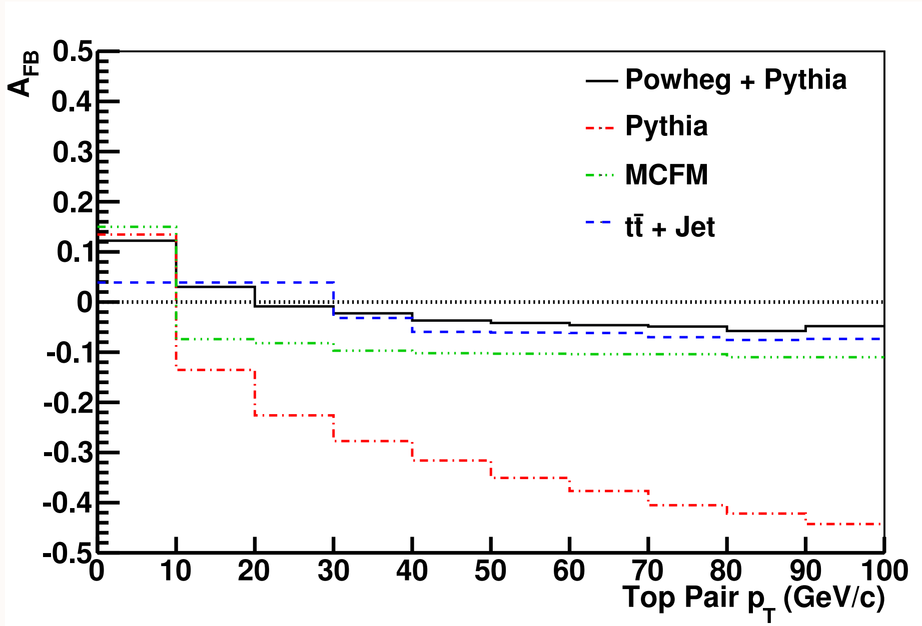
A new benchmark observable for Monte Carlos ?

[PLOTS BELOW FROM CDF – ARXIV:1211.1003]

➡ ***"Observation" first made by DØ.***

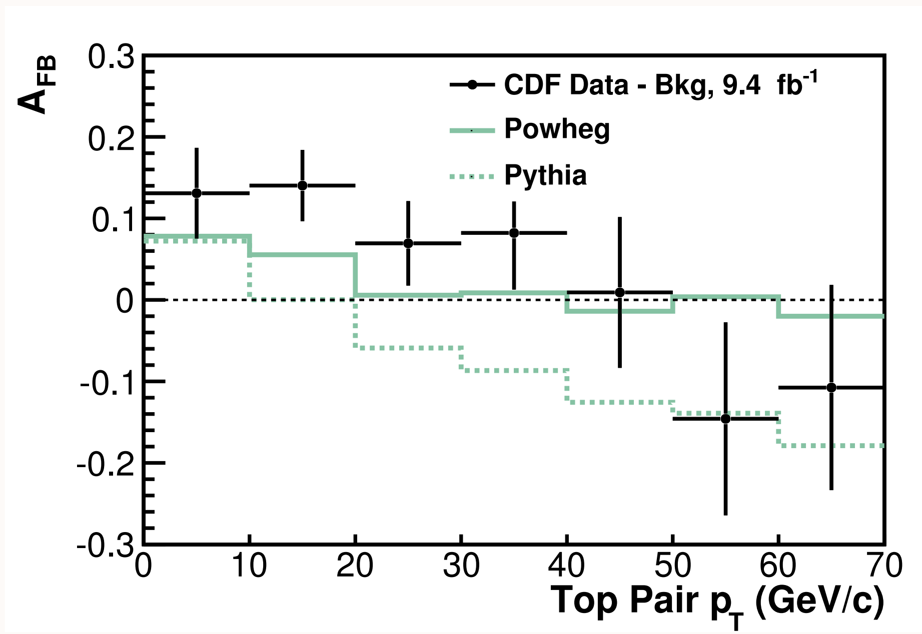
[PLOT UPPER LEFT FROM DØ – ARXIV:1107.4995]





- coherent shower Monte Carlos (MCs) contain/enhance asymmetry
- rapidity difference: $\Delta y = y_t - y_{\bar{t}}$

$$A_{\rm FB}(O) = \frac{\left.\frac{d\sigma}{dO}\right|_{\Delta y>0} - \left.\frac{d\sigma}{dO}\right|_{\Delta y<0}}{\left.\frac{d\sigma}{dO}\right|_{\Delta y>0} + \left.\frac{d\sigma}{dO}\right|_{\Delta y<0}}$$



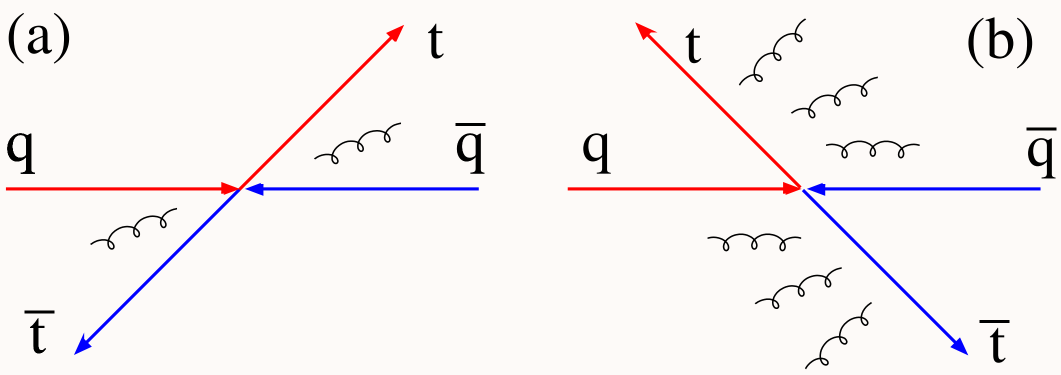
Colour coherence effect

In LO $q\bar{q} \to t\bar{t}$, there are (IF) colour flows from incoming quark to top quark and vice versa.

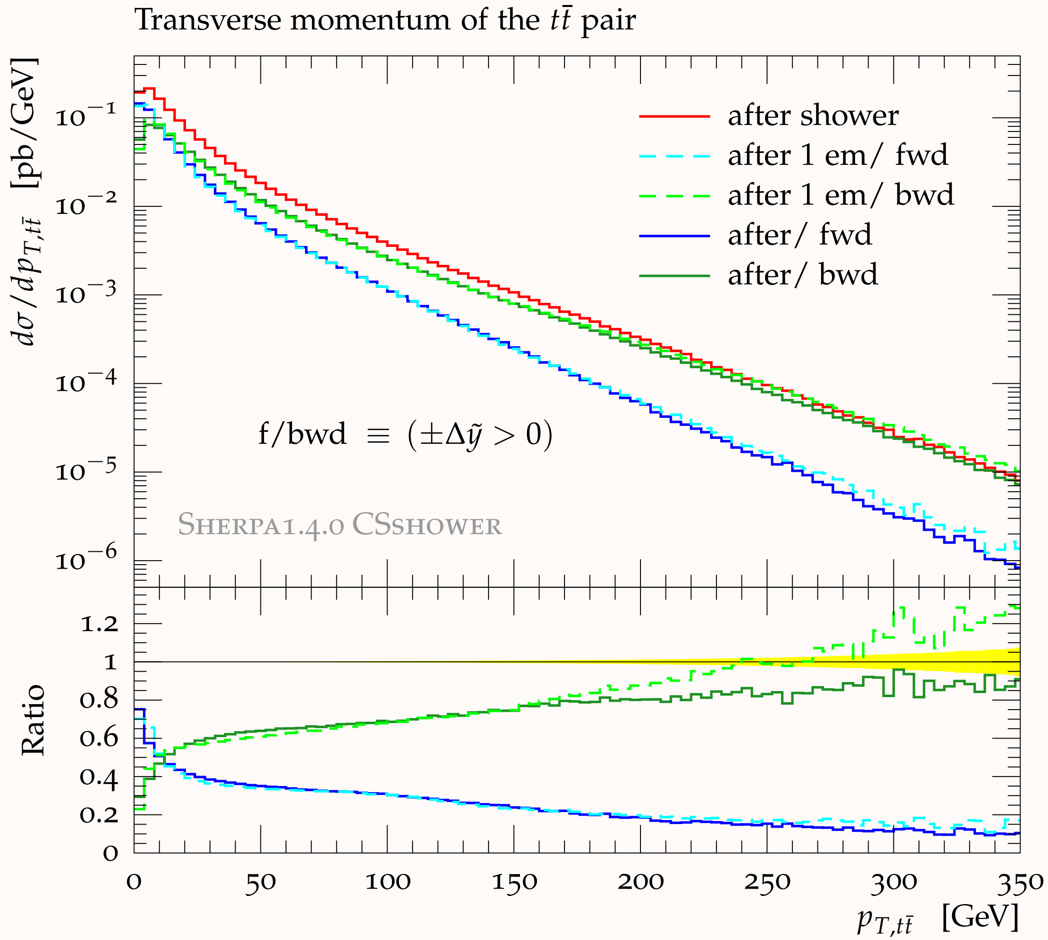
"Forward" dipoles – less space space for emission, less likely to radiate.

"Backward" dipoles – more violent acceleration of colour, hence more QCD radiation.

- (a) Forward configuration



- (b) Backward configuration



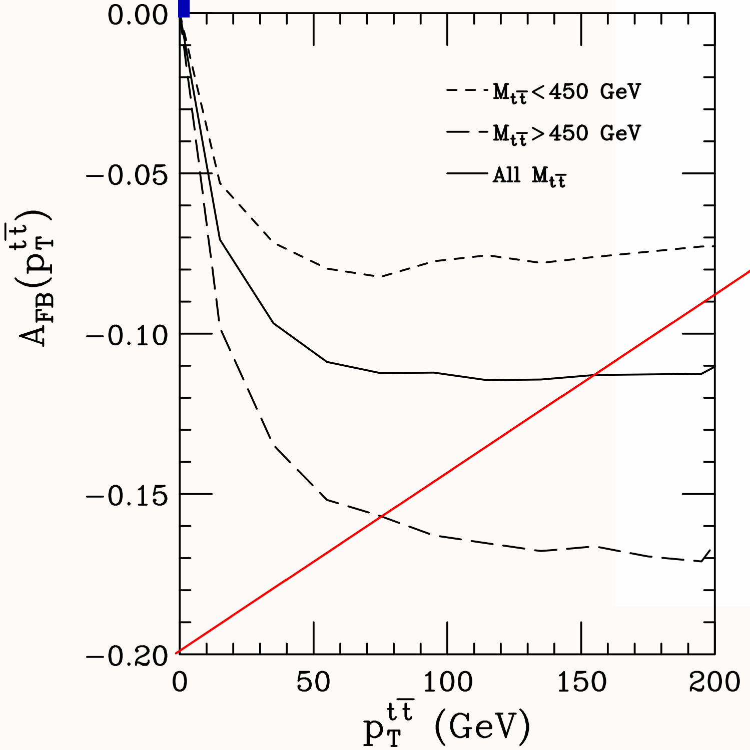
- Colour coherence (leads to angular ordering)
  ➡ asymmetric real emission
- Extra emission (confined to cone as large as θ_{ini})
  ➡ more recoil for backward top pairs

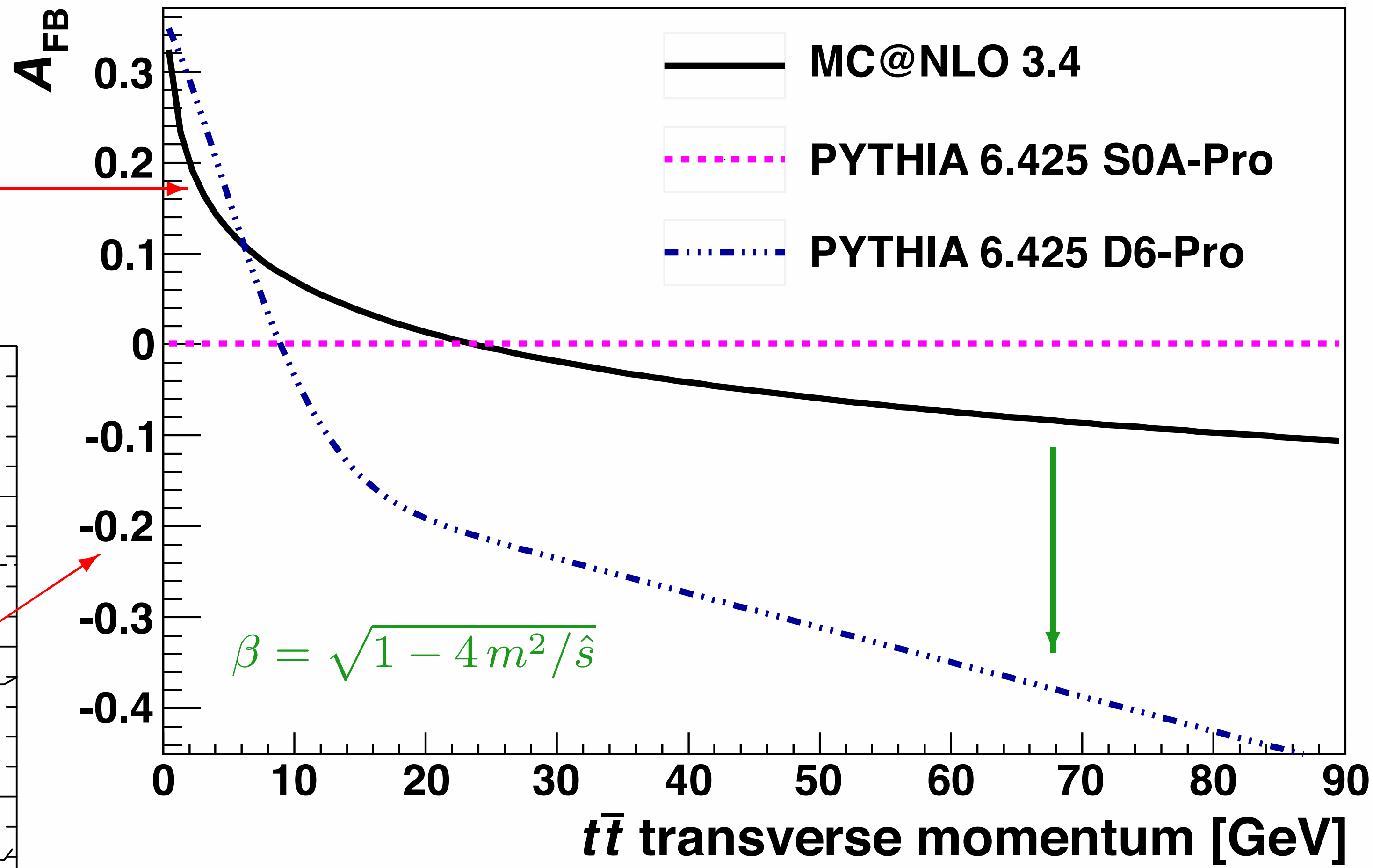
Comparison with fixed order

[PLOT FROM DØ – ARXIV:1107.4995]

[FO USING MCFM]

- Sudakov suppression yields "pT smearing"





$$\frac{p_T}{\hat{\sigma}_B}\frac{d\hat{\sigma}_A}{dp_T} = \frac{\alpha_S}{\pi}\frac{(N^2-4)}{N}F(\beta, p_T)$$

- coherent-branching showers work well in soft limit: real emission approximated by "Born × dip.-rad. functions $W_{ij} \times 2\,C_F$"
- LO MCs replace (N^2-4) by $(N^2-1) \Rightarrow$ 60% overestimate
- And, $F(\beta, p_T)$ underestimated by $F(\beta, 0) = -4\,\beta - \beta^3 - \ldots$

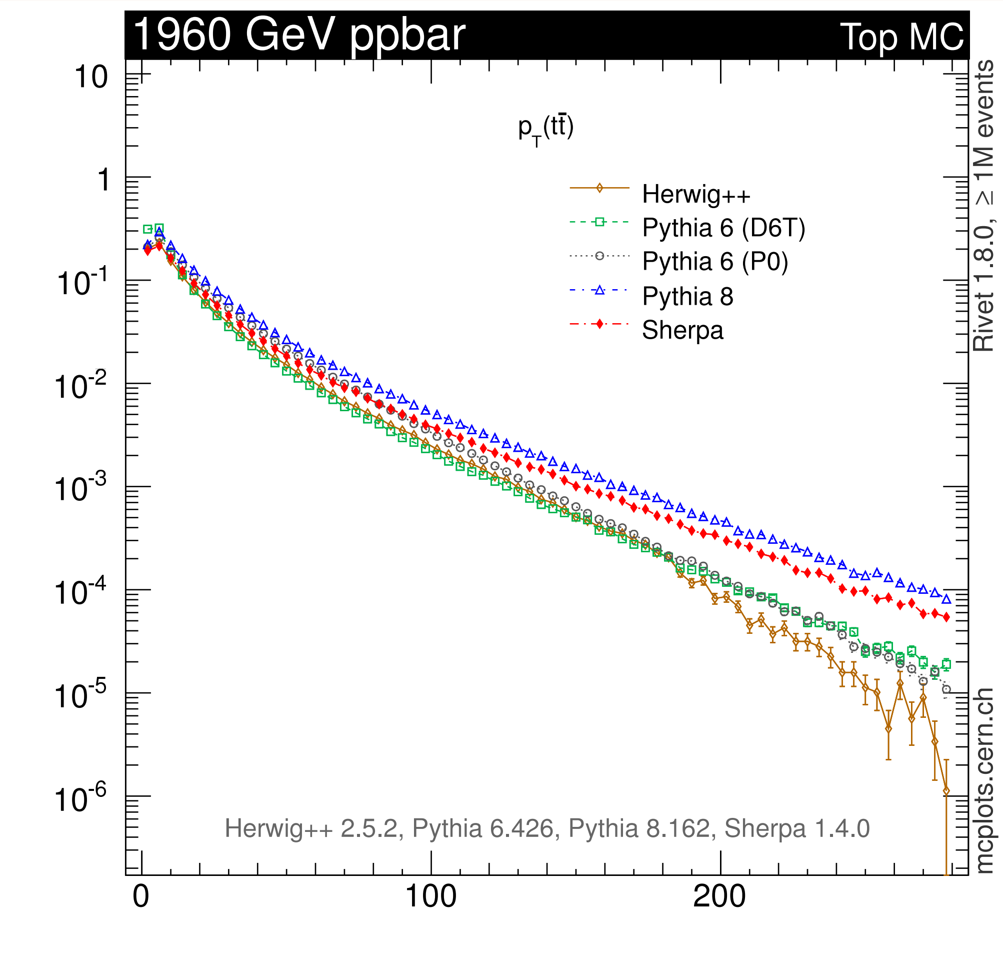
Differential asymmetry produced by LO generators

[Skands, Webber, Winter, JHEP 07 (2012) 151 (arXiv:1205.1466)]

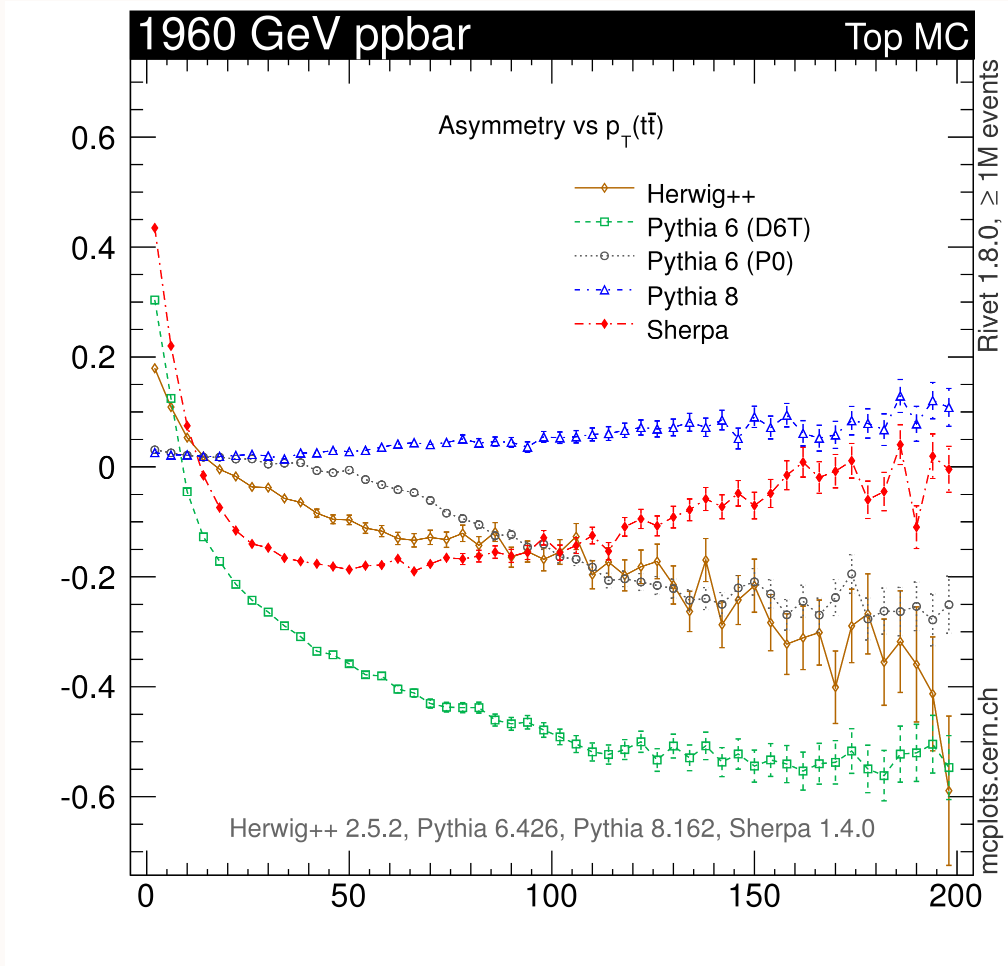
QCD coherence built in for Herwig++ and Sherpa, Pythia 6 has options with varying amounts of coherence.

➡ Pythia 8 version used here does not have QCD coherence implemented

LO $q\bar{q}, gg \to t\bar{t}$ production and showering



Asymmetry as function of the top-pair p_T



- $p_{T,t\bar{t}}$ differential cross section distribution

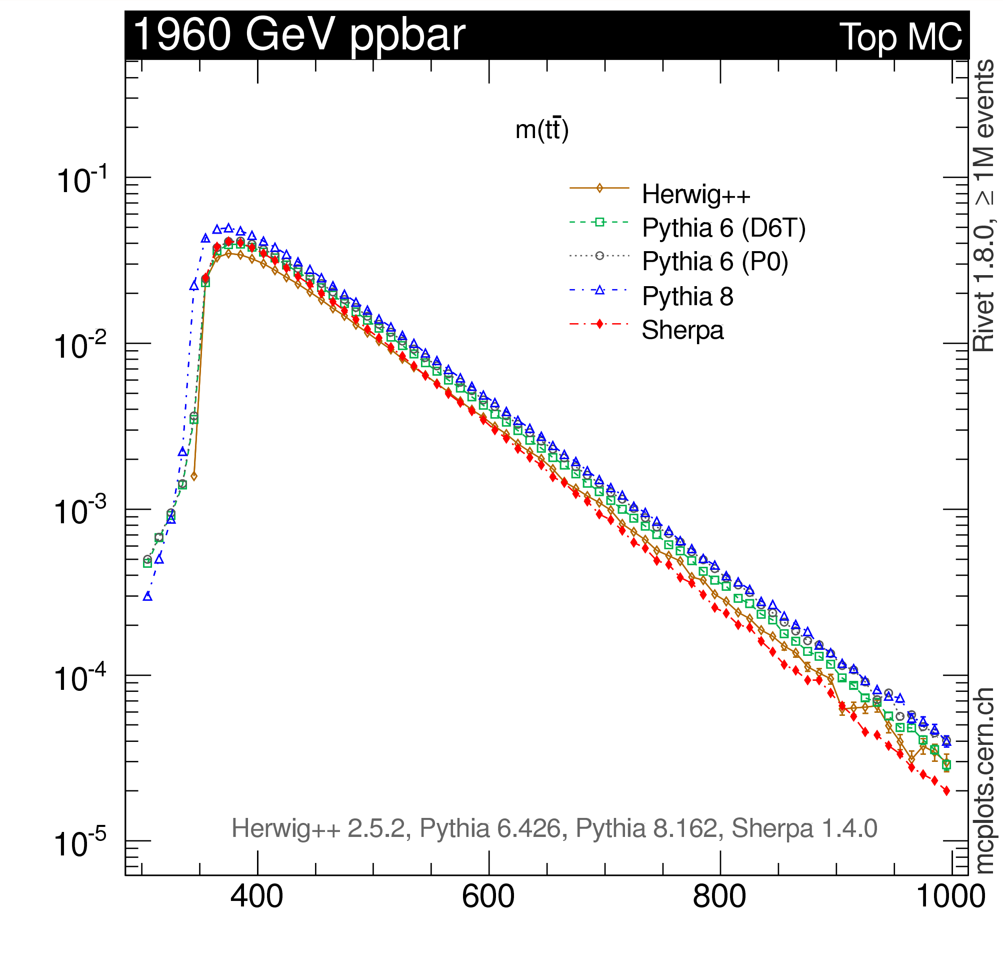
Differential asymmetry produced by LO generators

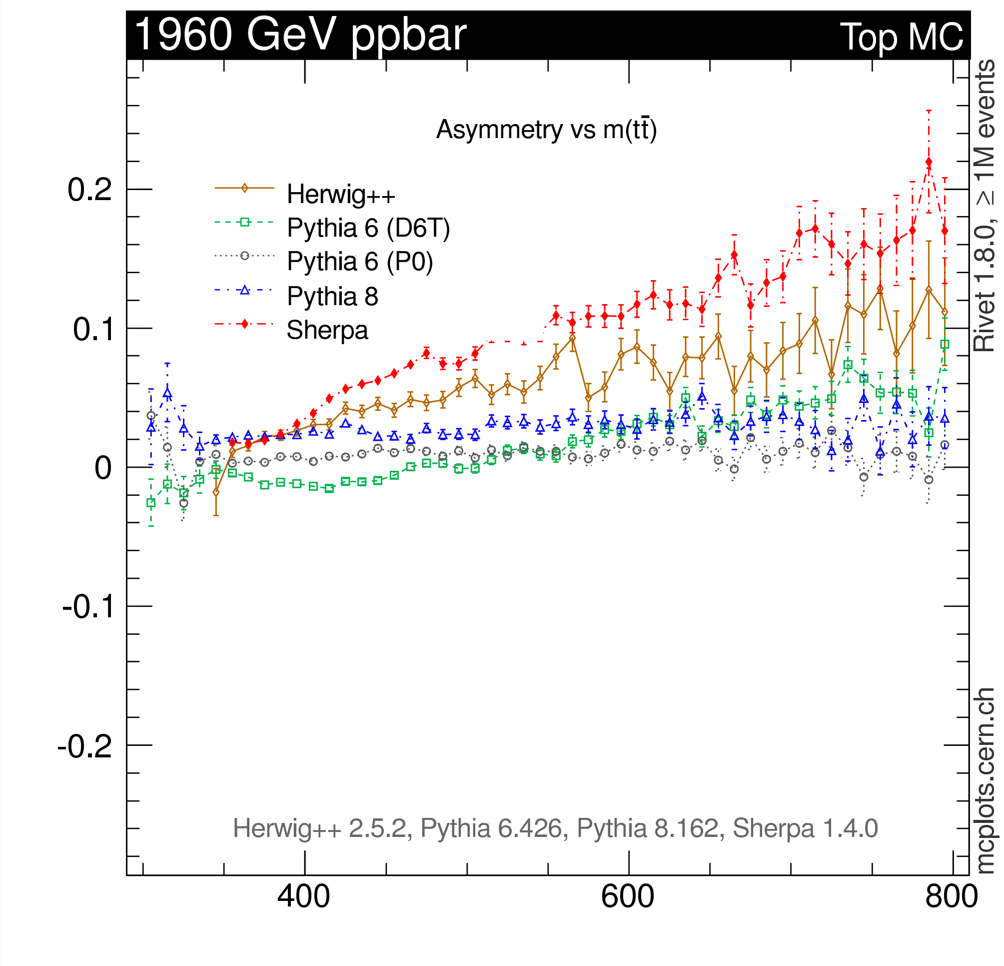
[Skands, Webber, Winter, arXiv:1205.1466]

➡ mass dependence driven by dependence on Δy and $\Delta\phi$, Sudakov region applies over entire mass range

$$m_{t\bar{t}}^2 \;=\; m_t^2 + m_{\bar{t}}^2 + 2\,E_{T,t}E_{T,\bar{t}}\,\cosh\Delta y - 2\,p_{T,t}p_{T,\bar{t}}\,\cos\Delta\phi$$

Asymmetry as a function of the pair mass





- $m_{t\bar{t}}$ differential distribution

Differential asymmetry produced by LO generators

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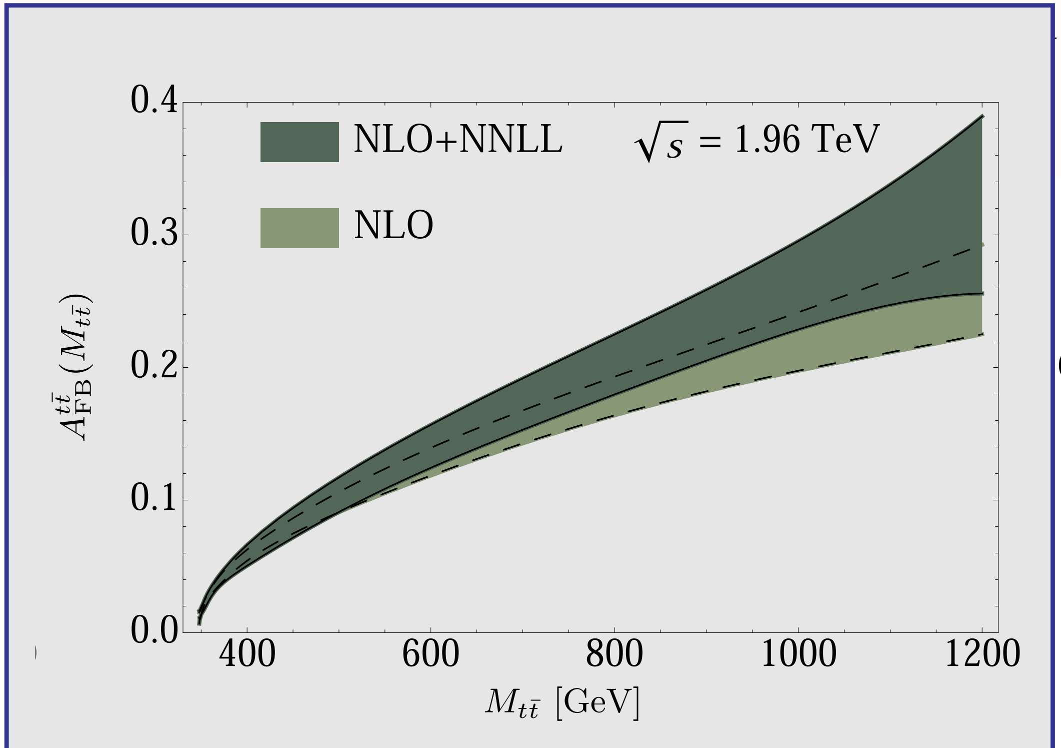
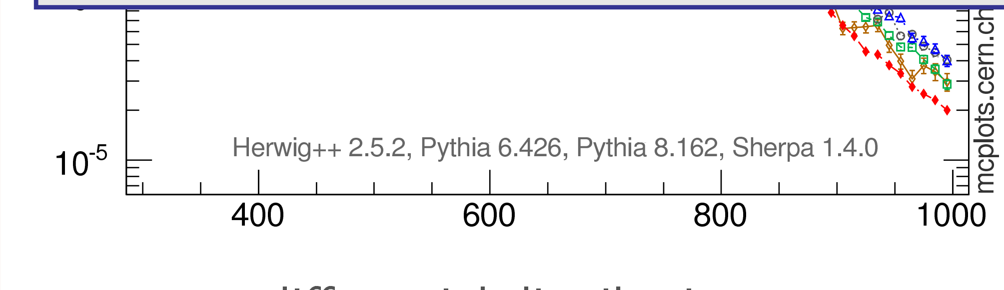
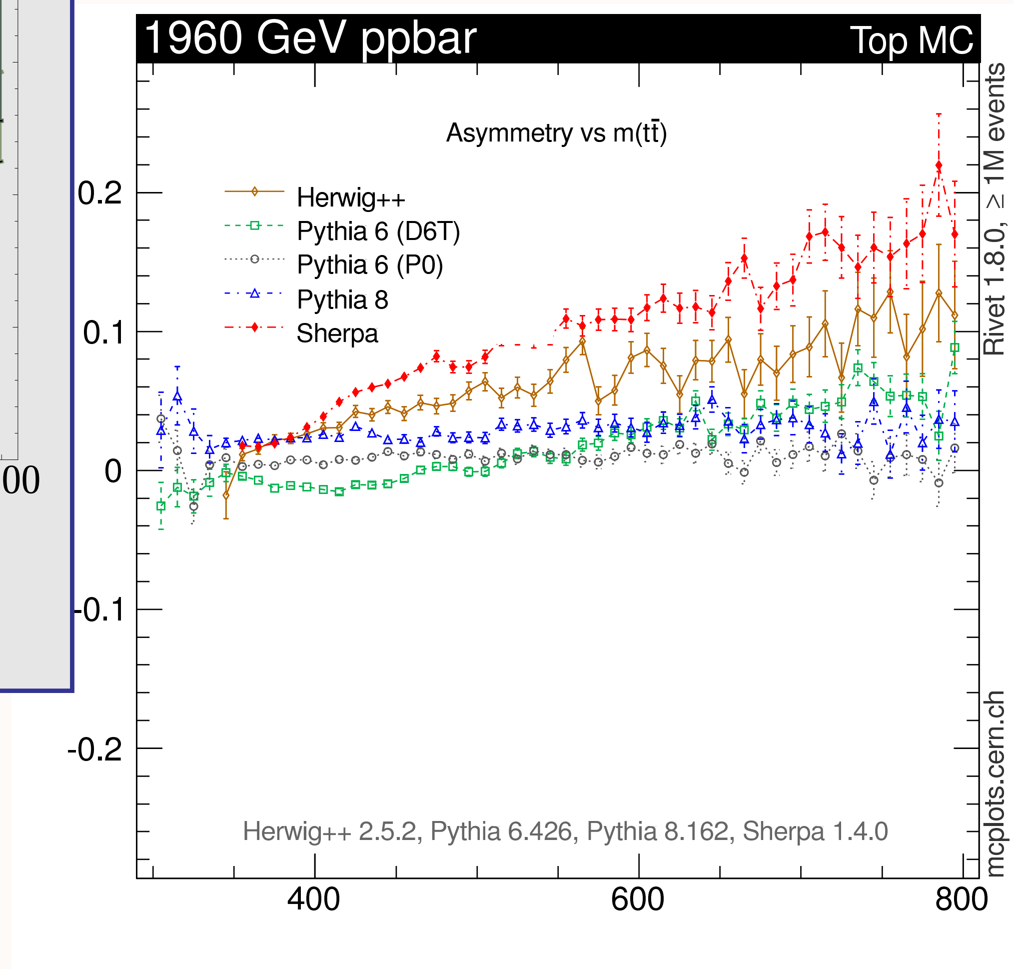
$\cos\Delta\phi$



[Ahrens et al. Phys.Rev. D84 (2011) 074004]



Asymmetry as a function of the pair mass



- $m_{t\bar{t}}$ differential distribution

Inclusive asymmetry produced by LO generators

Model	Version [tune]	Inclusive	$m_{t\bar{t}}$/GeV < 450	$m_{t\bar{t}}$/GeV > 450	$p_{T,t\bar{t}}$/GeV < 50	$p_{T,t\bar{t}}$/GeV > 50
HERWIG++	2.5.2 [def]	3.9	2.7	6.0	5.8	−14.3
PYTHIA 6	6.426 [def]	−0.1	−0.8	1.2	2.5	−42.5
PYTHIA 6	6.426 [D6T]	−0.2	−1.1	1.2	3.2	−43.4
PYTHIA 6	6.426 [P0]	0.8	0.7	1.1	1.8	−8.6
PYTHIA 8	8.163 [def]	2.5	2.4	2.8	2.4	4.8
SHERPA	1.4.0 [def]	5.5	3.5	9.2	8.7	−15.4
SHERPA	1.3.1 [def]	6.3	3.3	12.1	9.6	−15.8
QCD	LO	6.0	4.1	9.3	7.0	−11.1

- different recoil strategies implemented in the different models
- recoil effects are $\sim$ leading wrt. LO asymmetry (eval. by MCFM)

- ***If shower kinematics allow for migrations, a net inclusive asymmetry can be generated.***
- showers are unitary, preserving the total inclusive cross section (LO)
- BUT asymmetry is not protected by unitarity $\Rightarrow$ migration from $\Delta y > 0$ to $\Delta y < 0$ and v.v.

$$A_{\rm FB}^{\rm (cut)} = \frac{\sigma^{\rm (cut)}\big\rfloor_{\Delta y>0} - \sigma^{\rm (cut)}\big\rfloor_{\Delta y<0}}{\sigma^{\rm (cut)}}$$

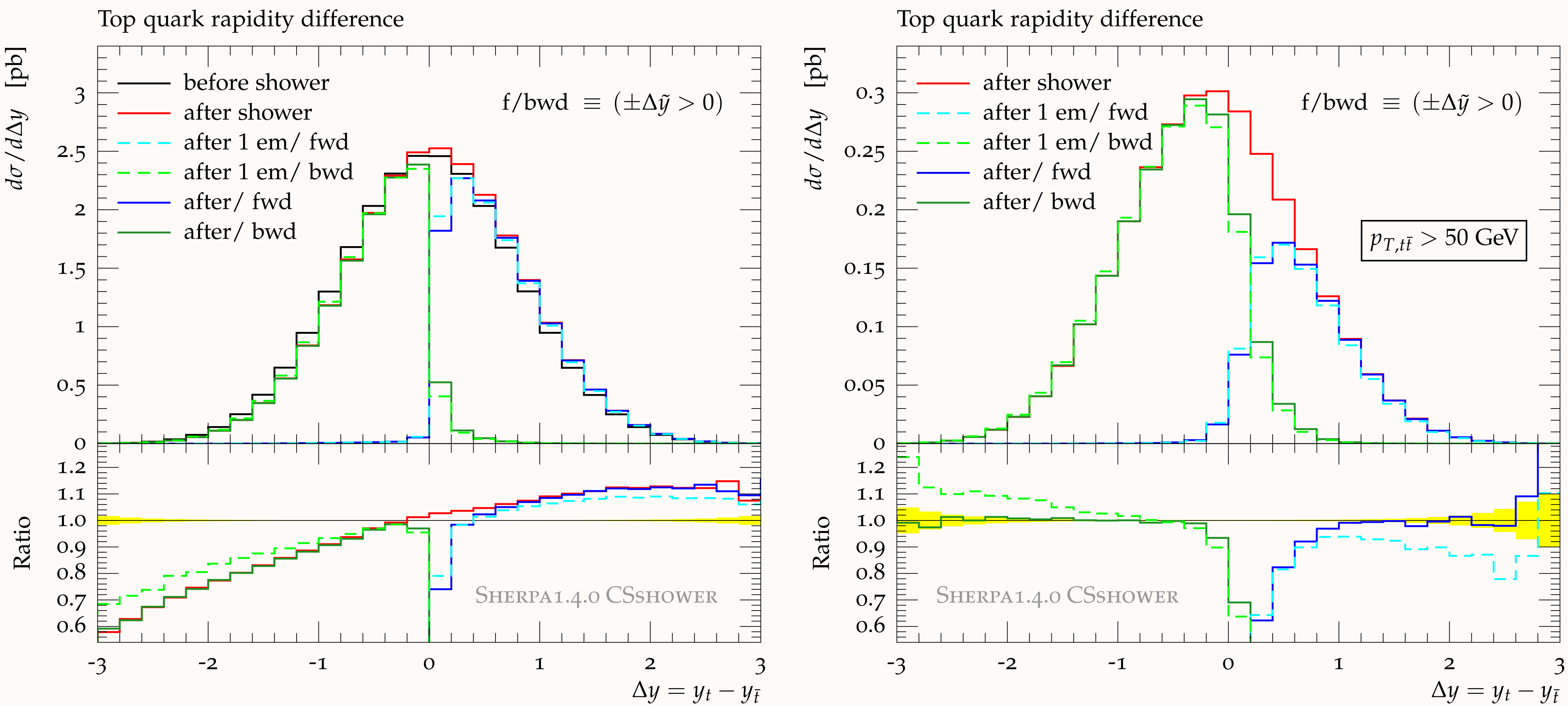
Longitudinal recoil effects – migration

[Skands, Webber, Winter, arXiv:1205.1466]

Simple dipole picture where gluon emission on average stretches IF dipole can give $\Delta y = \Delta\tilde{y} + \epsilon$ $(\epsilon > 0)$.

➡ migration is small, local, favouring $- \to +$ direction; largest effect already after 1st emission

radiation imbalance wins over more severe migration



- Δy distribution for various LO $\Delta\tilde{y}$ generation and shower modes

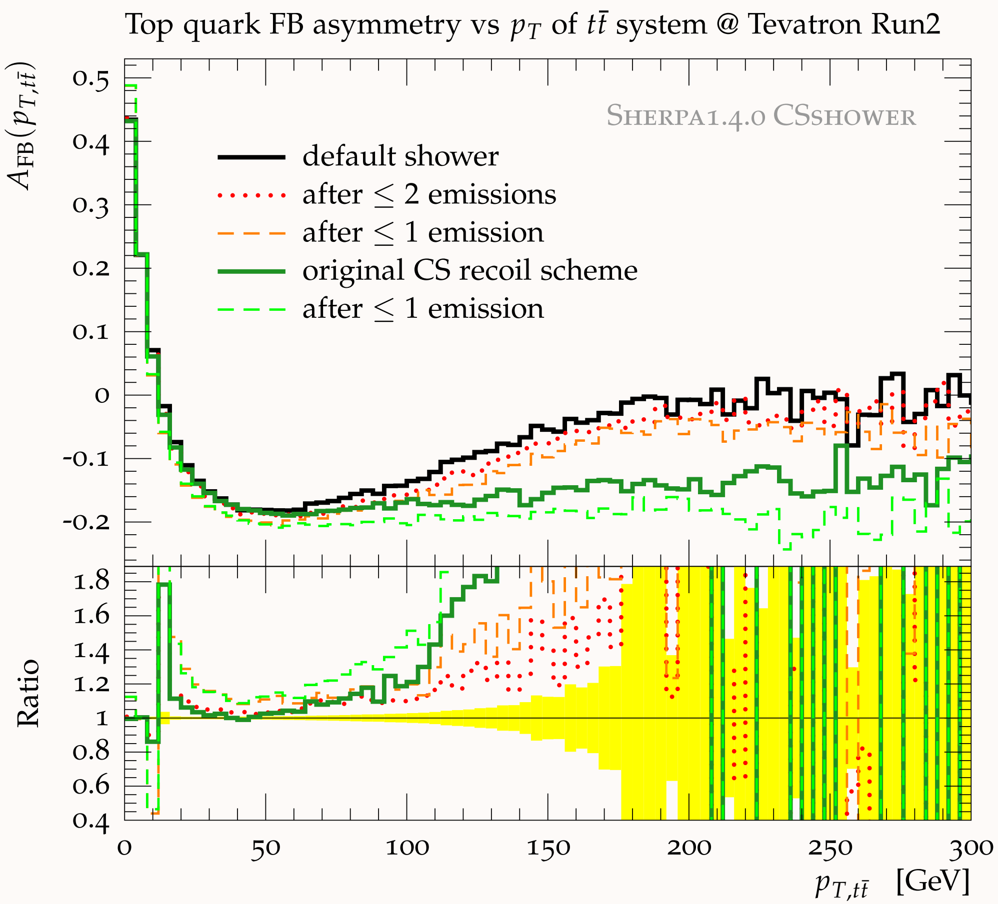
Different recoil-scheme options in Sherpa

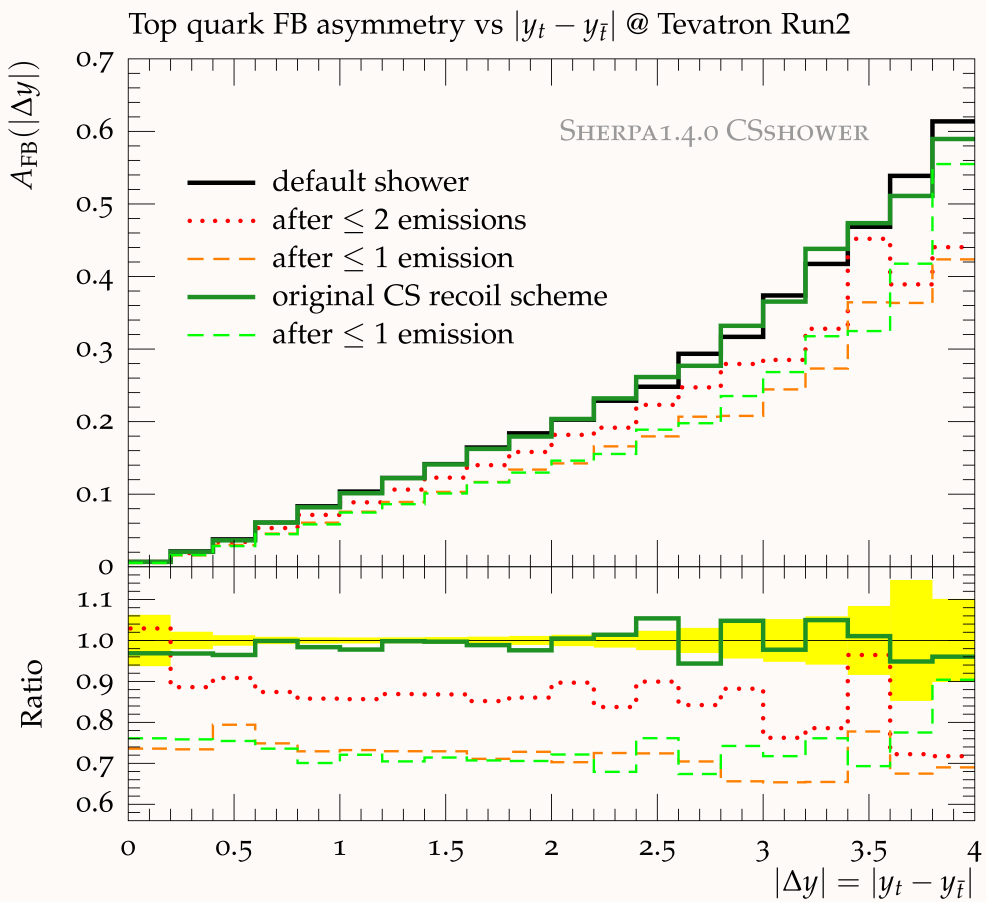
[SKANDS, WEBBER, WINTER, ARXIV:1205.1466]

Sherpa's CSshower provides two options for treating the recoils. ⇒ Recoil options affect high p_T.

➡ original CS scheme treats recoils more locally, IF dipole is decoupled from rest of event

longitudinal recoil treatment is effectively the same





- Asymmetry versus $p_{T,t\bar{t}}$
- Asymmetry versus $|\Delta y|$

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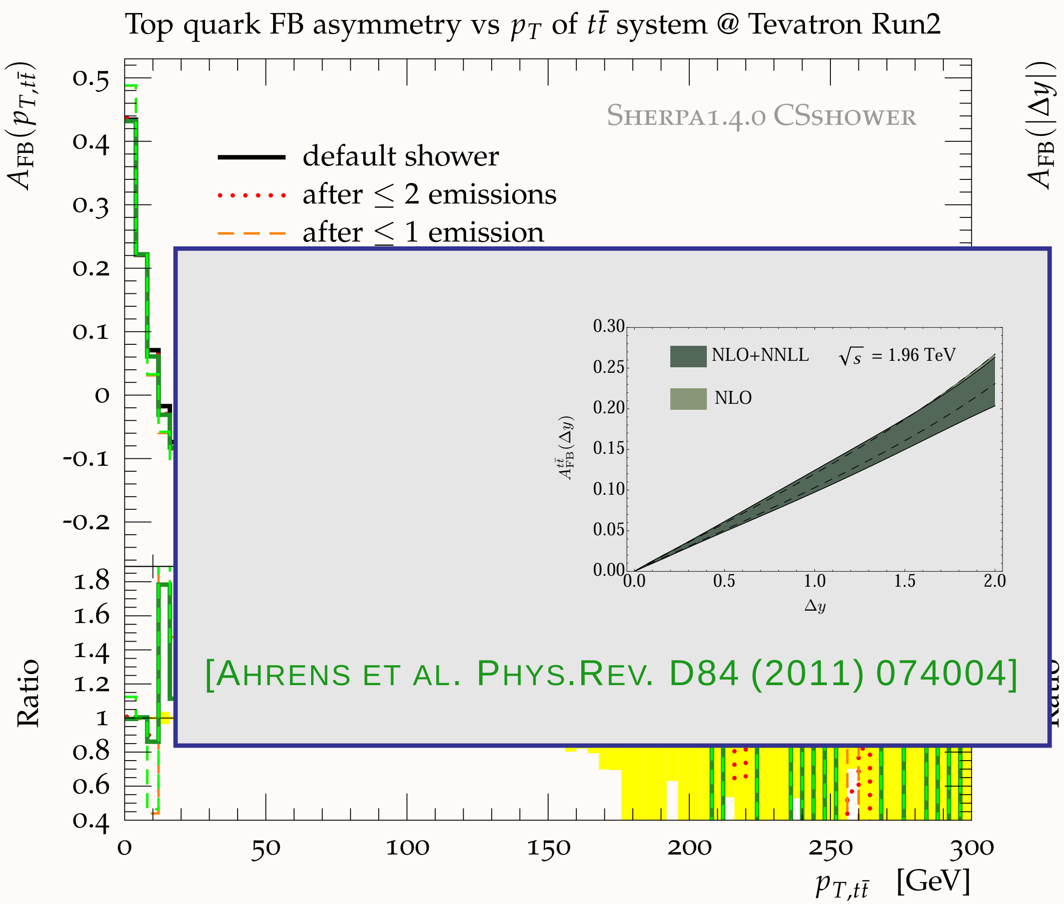
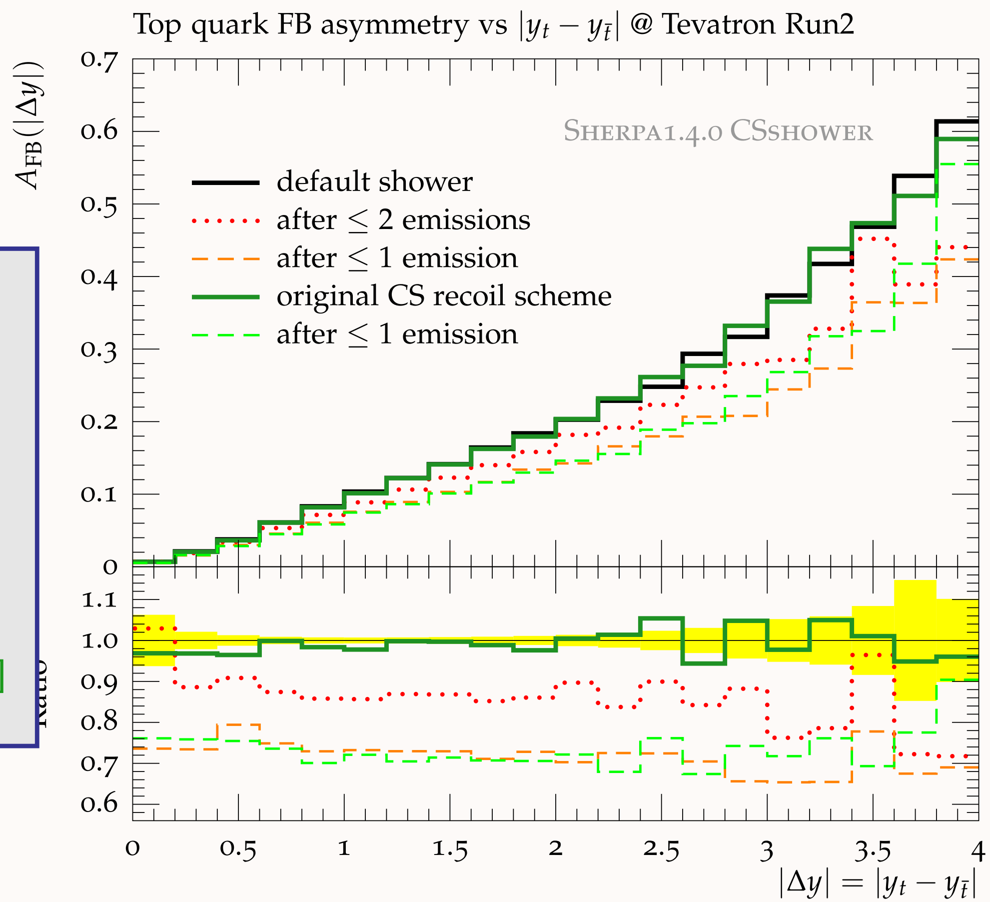


[AHRENS ET AL. PHYS.REV. D84 (2011) 074004]

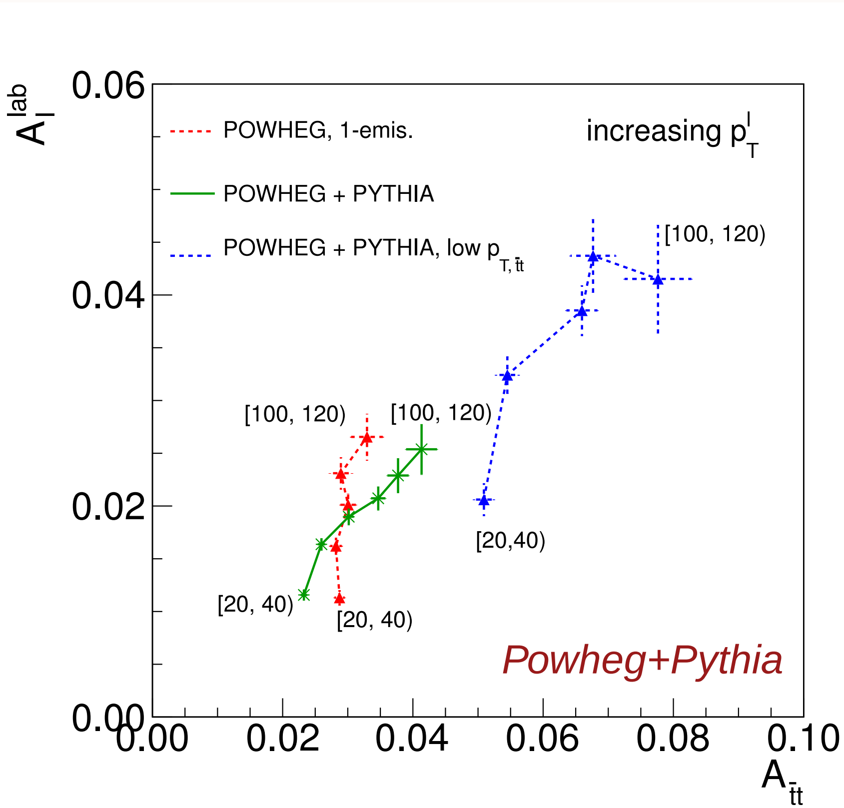


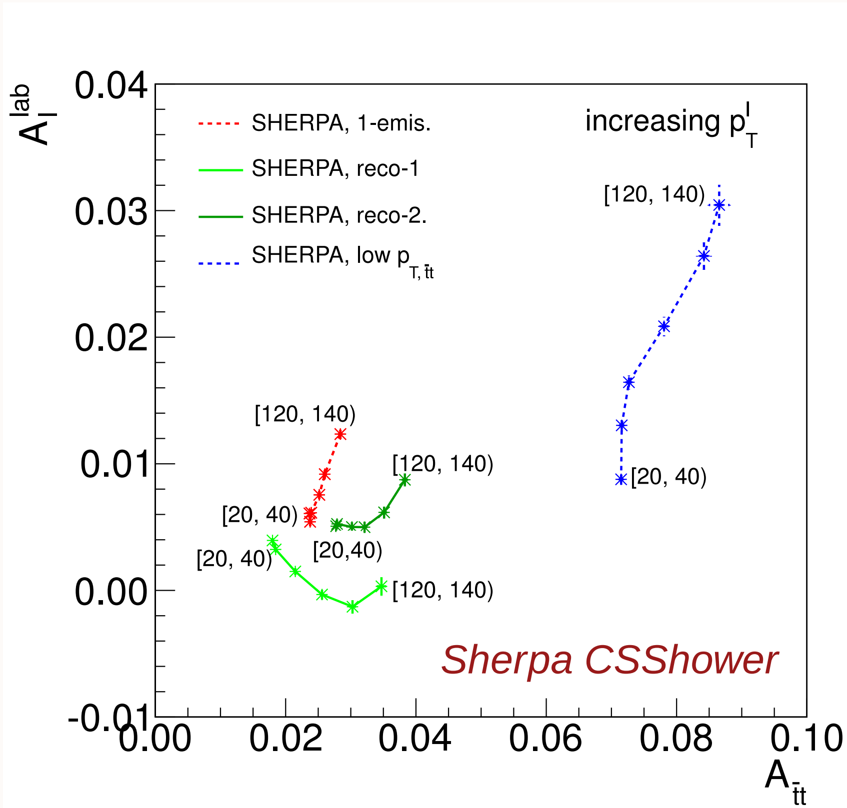
- Asymmetry versus $p_{T,t\bar{t}}$
- Asymmetry versus $|\Delta y|$

Asymmetry from the lepton perspective

[Falkowski, Mangano, Martin, Perez, Winter, arXiv:1212.4003]

- consider top quark $A_{t\bar{t}}$ and lepton-based A_ℓ at the same time (as a function of $p_{T,\ell}$)
- gain extra handles in your analyis: exploit correlation of asymmetries, make use of "no or less" need for top quark reconstruction $\Rightarrow$ Correlation is robust, but modelling of $p_{T,t\bar{t}}$, hence $A_{t\bar{t}}(p_{T,t\bar{t}})$ turns out to be crucial. Just colour coherence alone as in Sherpa's shower is not sufficient.
- BSM predictions are very different but should come with warning label: LO+PS accuracy only.





CDF-like cuts

blue: $p_{T,t\bar{t}} < 10$ GeV

for Powheg, CDF-like reconstruction

for Sherpa, jet-combinatorial (short lines) and naive ($b\bar{b}+2j$) reconstruction

➡ Important for such a study, the reliable treatment of top quark decays.

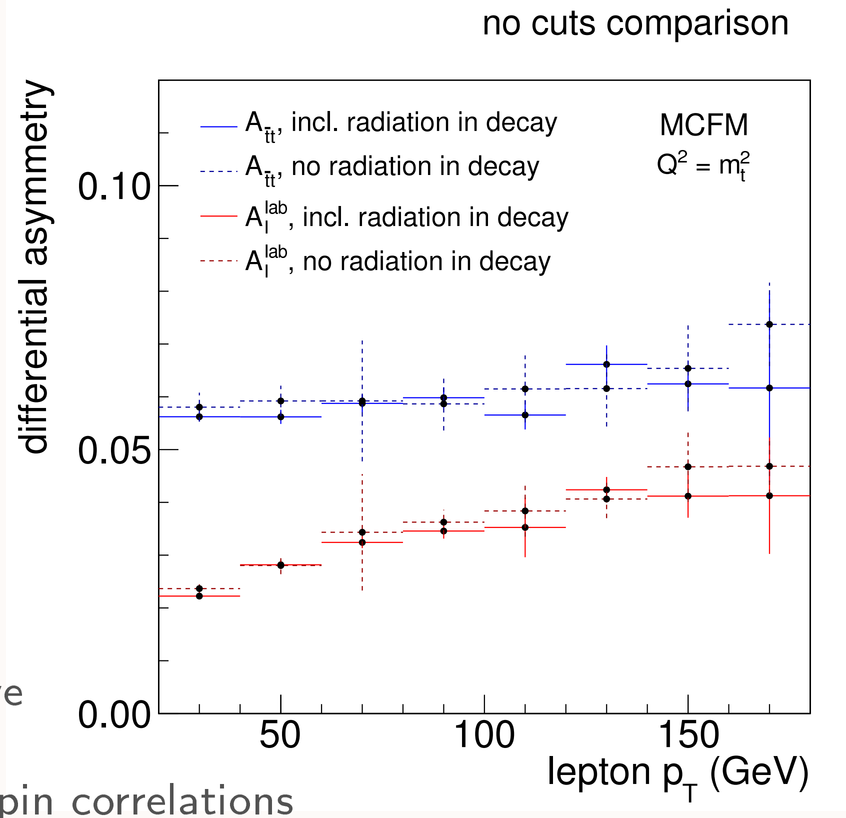
Top quark decays included

Effect of radiation in decays

- using MCFM [CAMPBELL, ELLIS, ARXIV:1204.1513]
- top production in pole approximation (allows for NLO)
- all spin correlations kept in tree, real and virtual MEs

→ in our study, corrections on $A_{t\bar{t}}$, A_ℓ turn out to be small

- how does it compare to full $WWb\bar{b}$ computation
  [DENNER ET AL, ARXIV:1012.3975, ARXIV:1204.1513]
  [BEVILACQUA ET AL, ARXIV:1012.4230]
  effects Γ_t/m_t or $\alpha_s\Gamma_t/m_t$ suppressed if sufficiently inclusive



- LO Sherpa showering includes top quark off-shellness and spin correlations
- NLO+PS, here Powheg, generate un-decayed top quark pairs and introduce the decay spin correlation by reweighting (approximate spin correlation mechanism)

$$\frac{d\sigma(\bar{e},\nu,b;e,\bar{\nu},\bar{b},[p])}{d\Phi_{\rm dec}d\Phi_{t\bar{t}[p]}} = \frac{d\sigma^{\rm NLO+PS}(t;\bar{t},[p])}{d\Phi_{t\bar{t}[p]}} \times \underbrace{\frac{\frac{d\sigma^{\rm Tree}(\bar{e},\nu,b;e,\bar{\nu},\bar{b},[p])}{d\Phi_{\rm dec}d\Phi_{t\bar{t}[p]}}}{\frac{\sigma^{\rm Tree}(t,\bar{t},[p])}{d\Phi_{t\bar{t}[p]}}}}_{\text{Integrates to 1 in } d\Phi_{\rm dec}}$$

[FRIXIONE ET AL, HEP-PH/0702198]

➡ Full validation between approaches should be done to assess differences.

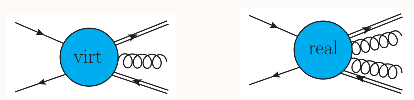
One more jet included (at NLO)

[Melnikov, Scharf, Schulze, arXiv:1111.4991]

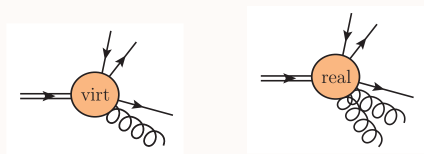
Effect of radiation in decays

- prediction based on the narrow width approximation with the NLO QCD corrections to both production and decay
- in general more complicated pattern of corrections and larger effects due to radiation in decay

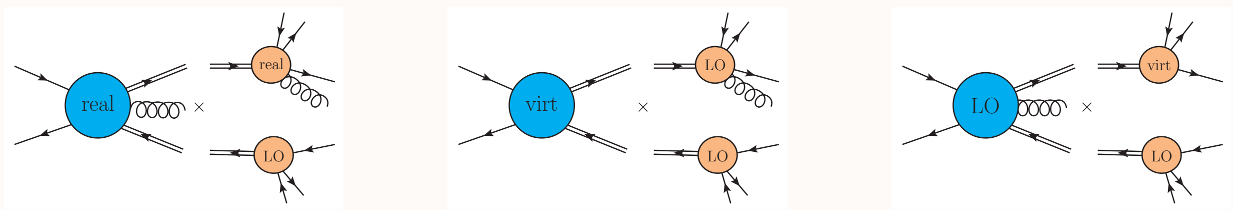
→ for example, the negative forward–backward asymmetry given at LO receives fairly sizeable positive corrections



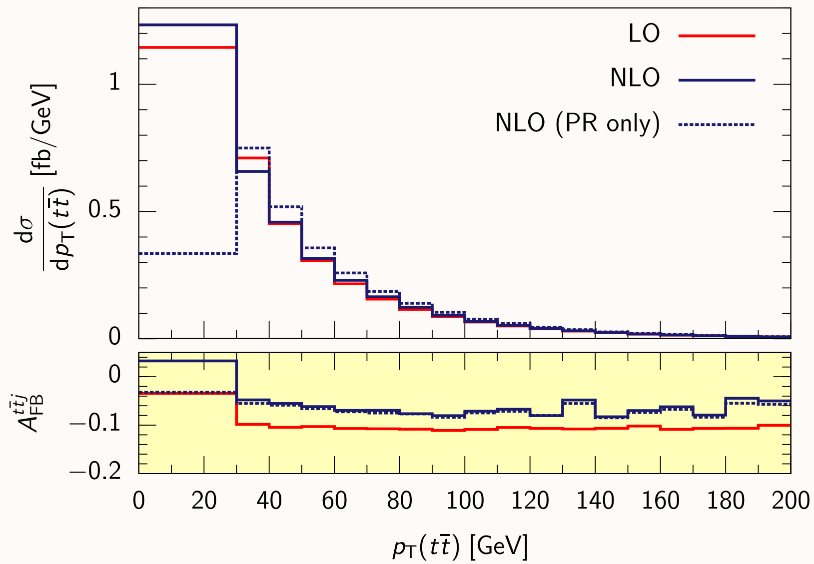
(a) jet emission in production

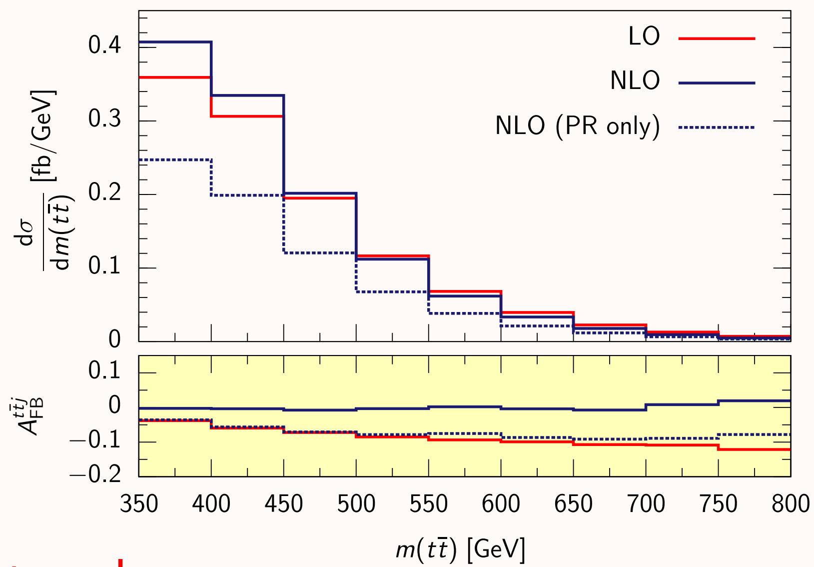


(b) jet emission in decay



(c) mixed contribution



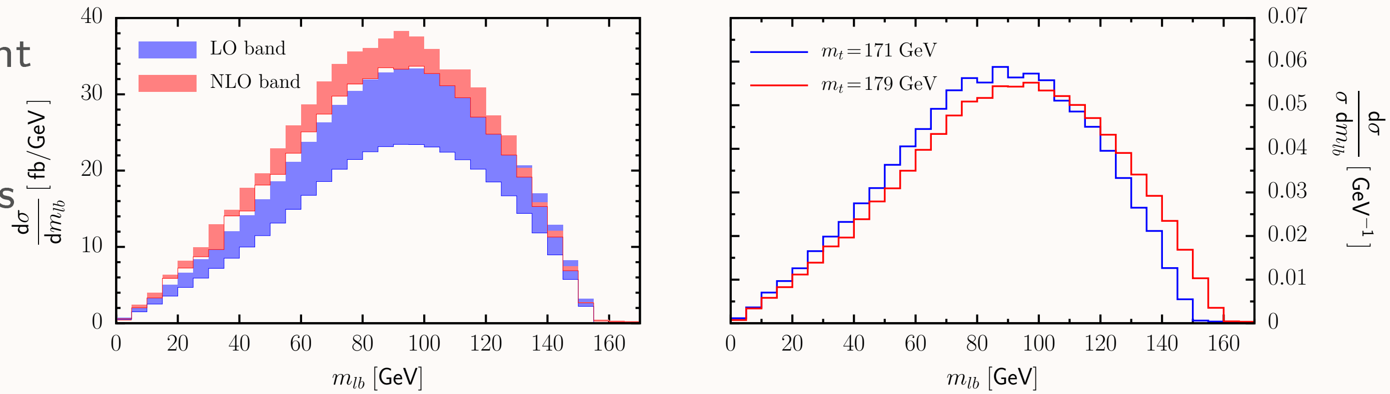


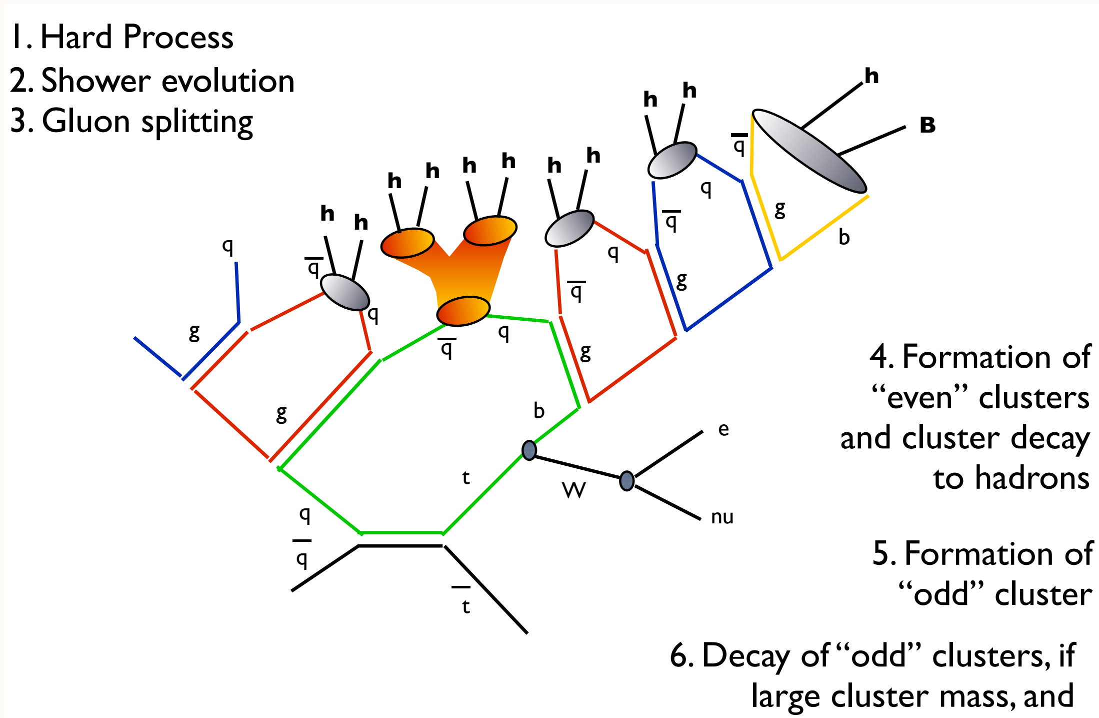
➡ How do we match NLO calculations as such to parton showers.

Quick note: top quark mass determination

[From Biswas, Melnikov, Schulze, arXiv:1006.0910]

- accurate and reliable measurement of top quark mass is important
- precisely measured in experiments but we have trouble to relate this mass parameter to a top quark mass we can control
- several proposals to extract it from kinematic distributions describable with pQCD (renormalization schemes can be switched)
  → S. Moch's talk
- this still requires object identification, i.e. non-perturbative corrections have to be estimated
- preliminary studies by M. Mangano indeed point to $\mathcal{O}(1)$ GeV effects





[From M. Mangano]

Summary & Implications

- Monte Carlo LO event generators can produce significant (differential and inclusive) asymmetries where none were previously expected.
  - One needs to be aware of that for the interpretation of experimental data.
  - Monte Carlo estimates of corrections to asymmetries could be affected by this.
  - Model-dependent corrections!?
- Asymmetries in Monte Carlos arise from valid physics built into generators with coherent parton or dipole showering.
- While not quantitatively correct in every detail, important features are captured by coherent showering approximation.
  - unequal Sudakov factors for forward and backward top production
  - migration of recoiling tops between hemispheres (Use (N)LO for A_{FB} to optimize recoils?)
  - from modelling point of view we are safe since standard is NLO+PS
  - but shall we neglect contributions from secondary emissions?
- Inclusion of top quark decays complicates the picture, more checks and work needed.