

# Higher Order QCD Radiation in Top Pair Production with the CMS Detector

Preliminary Results

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DESY

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## ① Analysis on Generator Level

Parton Evolution

Transverse Momentum of the  $t\bar{t}$  System

## ② Analysis on Detector Level

Selection and Reconstruction of the  $t\bar{t}$  System

Transverse Momentum of the Reconstructed  $t\bar{t}$  System

## QCD radiation in $t\bar{t}$ events

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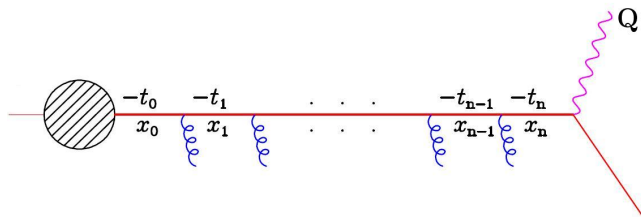
## Conditions

- High top mass
  - High centre-of-mass energy at LHC ( $\sqrt{s} = 14\text{TeV}$  for this study)
- ⇒ Large available phase space for radiation
- Fully perturbative description available
  - Clear identification of top pair events possible

# Parton Evolution

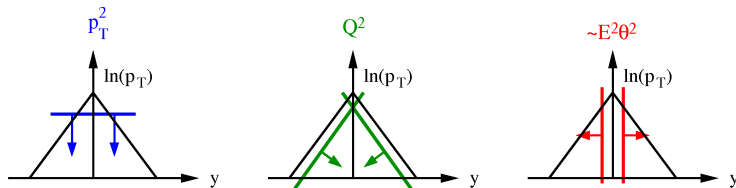
## Evolution

- Initial state: spacelike evolution to the hard scale
- Final state: timelike evolution from the hard scale
- Based on DGLAP equations
- Perturbative evolution in scale  $t$
- Different choices for  $t$  possible



- $t$ : evolution scale
- $x$ : momentum fraction

# Evolution Variables



## Phase space description

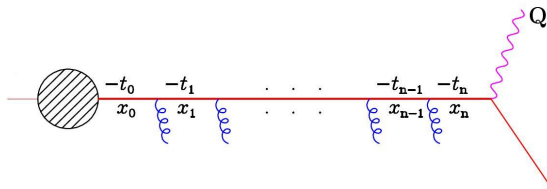
- Available phase space represented by triangle in transverse momentum  $p_T$  and rapidity  $y$
- Evolution starts at an upper scale (details on next slide)

## Possible choices for evolution scale $t$

- Ordering in transverse momentum:  $p_T^2$
- Ordering in virtuality:  $Q^2$
- Angular ordering:  $\sim E^2\theta^2$

# Phase Space Boundaries

How to match the parton shower to the hard interaction?  
At which scale has the evolution to stop?

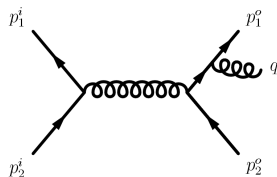
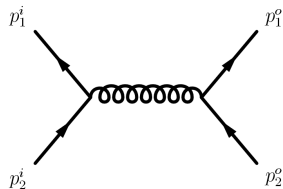


## Boundary choices for initial state

- Standard shower: starting scale set by factorization scale:  $t_{max} \sim t_{hard}$
- Power shower: whole available phase space is exploited:  $t_{max} \sim \sqrt{s}$



# Matrix Element Matching



## Matching real emission matrix elements with parton shower

- Hard emissions calculated on matrix element level
- Parton shower accounts for remaining soft contributions
- Matching procedure to avoid double counting
- MC@NLO: Modified subtraction scheme
- ALPGEN: Matching with special veto algorithm (MLM matching)

# Generators

## HERWIG

- Angular ordered parton shower
- HERWIG6 and HERWIG++

## PYTHIA

- $Q^2$  and  $p_T^2$  ordered parton showers
- Power and standard shower option
- PYTHIA6 and PYTHIA8

## ALPGEN

- Real higher order matrix elements
- Events can be processed further by HERWIG6 and PYTHIA6

## MC@NLO

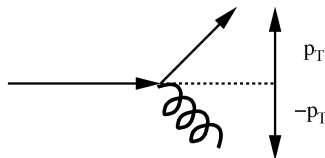
- Full NLO matrix elements
- Events can be processed further by HERWIG6

## Steering parameters

- Evolution scale
- Upper phase space limit

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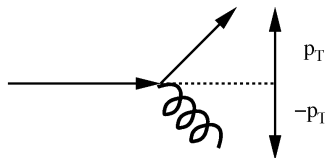
## Radiation effects

- Transverse momentum of the  $t\bar{t}$  system
- Radiation causes additional jets

# Generator Analysis

## Steering parameters

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## Radiation effects

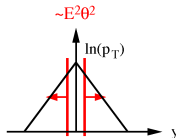
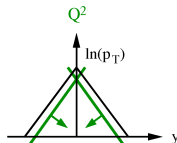
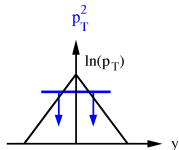
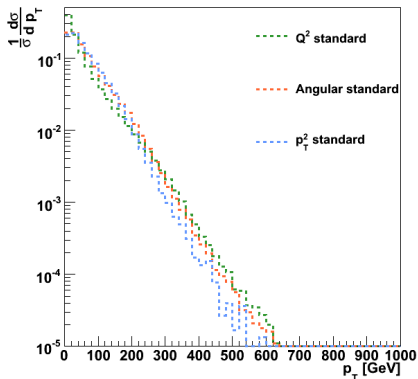
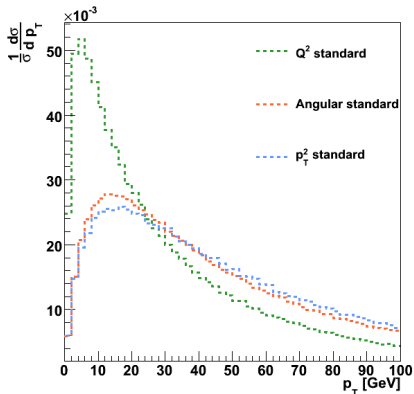
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## Observable

- Differential cross section: transverse momentum spectrum of the  $t\bar{t}$  system

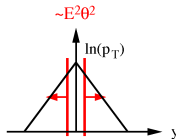
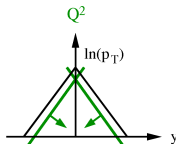
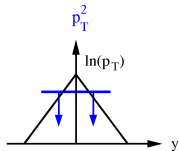
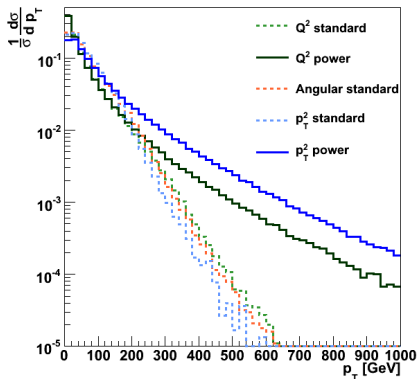
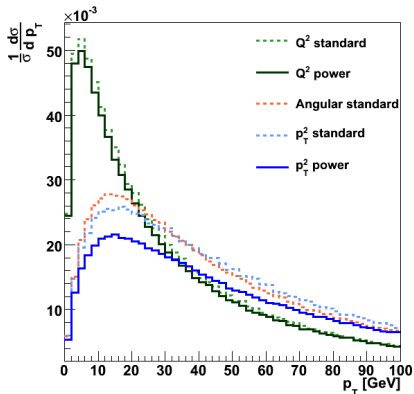
# Transverse Momentum of the $t\bar{t}$ System

Influence of evolution scale and available phase space:



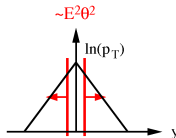
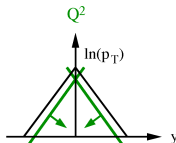
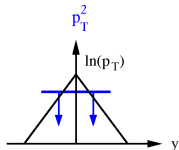
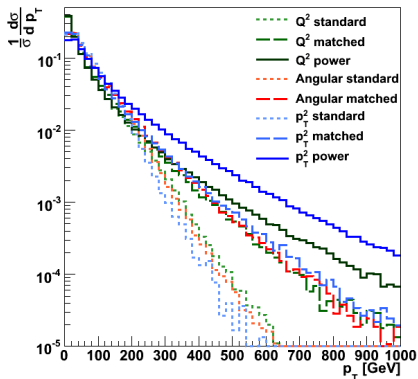
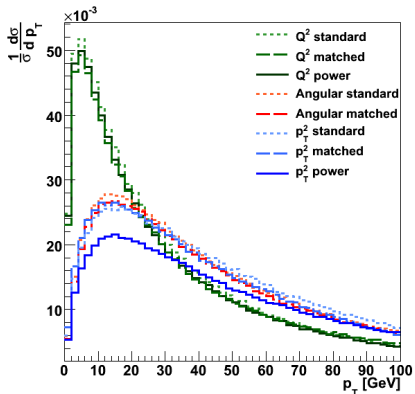
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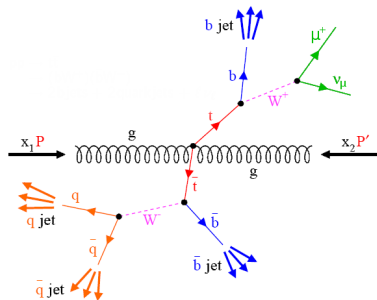
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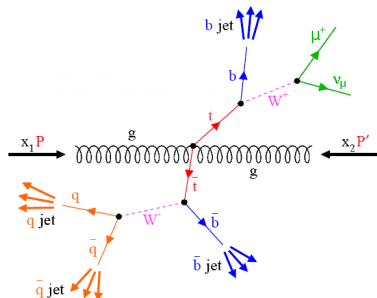
# Semi-muonic $t\bar{t}$ Decay Channel



## Partonic final state

- One muon
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## Reconstructed Objects

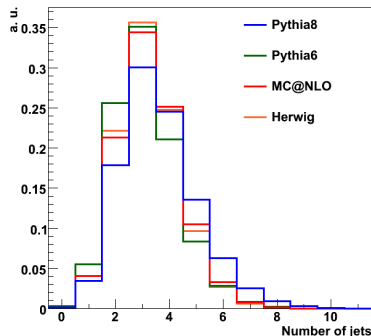
- Muons with additional isolation criterion
- Jets with  $k_T$  algorithm with  $R = 0.4$
- Track based b-tag
- Missing transverse energy  $\cancel{E}_T$

Analysis performed for  $7 \text{ fb}^{-1}$  at low luminosity phase at  $\sqrt{s} = 14 \text{ TeV}$

## Preselection cuts

- Exactly one isolated muon with  $p_T > 30$  GeV in  $|\eta| < 2.4$
- At least four jets with  $p_T > 25$  GeV in  $|\eta| < 2.4$
- At least three jets with  $p_T > 35$  GeV in  $|\eta| < 2.4$
- Cut on highest b-tag

N-1 plot for number of jets with  $p_T > 35$  GeV:



Jet multiplicities depend on generator settings

## Reconstruction

- All events passing the preselection are reconstructed
- Reconstruction via kinematic fit

# Reconstruction and Selection

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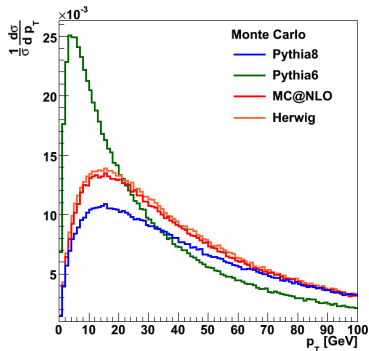
Total number of background events: 9540

Selected signal events:

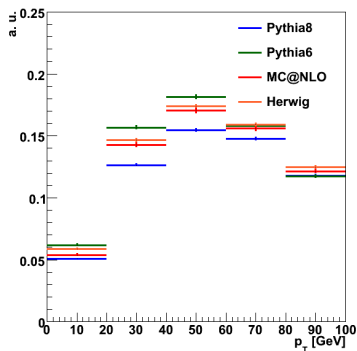
Generator	Selected Events	Efficiency	S/B Ratio
HERWIG	57927	0.062	6.1
MC@NLO	57765	0.061	6.1
PYTHIA6	49256	0.052	5.2
PYTHIA8	61018	0.065	6.4

# Transverse Momentum of the Reconstructed $t\bar{t}$ System

Generator input:



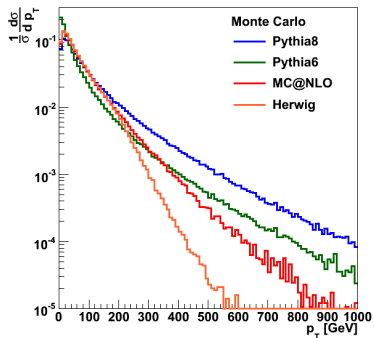
Fitted result with statistical uncertainties:



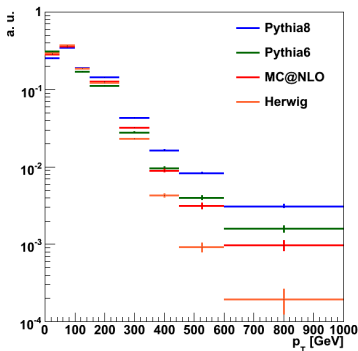
- Spectra severely distorted: migration and bias
- Relative number of entries correlated with input
- Different models can be distinguished in peak region

# Transverse Momentum of the Reconstructed $t\bar{t}$ System

Generator input:



Fitted result with statistical uncertainties:



- Relative number of entries clearly correlated with input
- Different models can be distinguished in tail



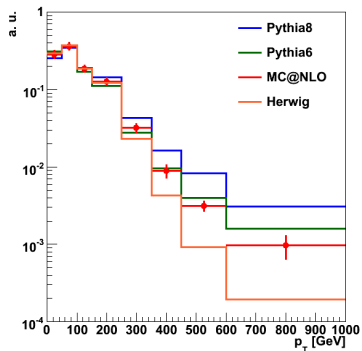
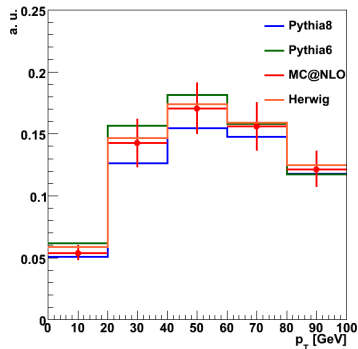
# Signal with Combined Uncertainties

- Jet energy scale,  $\cancel{E}_T$ , b-tagging and background uncertainties included
- Combined systematic uncertainty around 15% for all generators

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Only MC@NLO signal is shown with combined systematic and statistical errors:



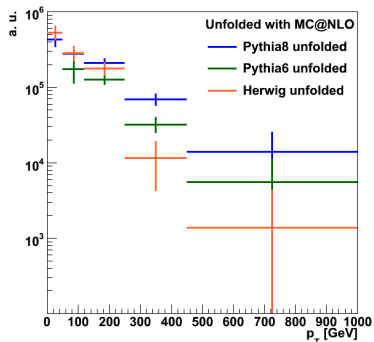
# Unfolding

- Undo migration
- Correct for limited acceptance in certain regions

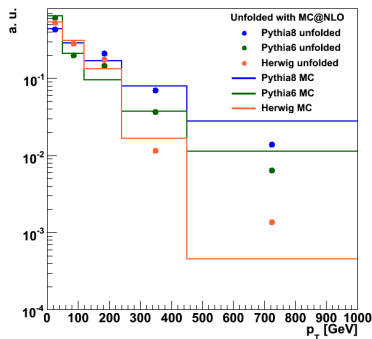
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Unfolded result:



Comparison with generator level:



- Here migration matrix computed with MC@NLO

## Generator level

- Transverse momentum of the  $t\bar{t}$  system sensitive to radiation
- Peak region shows dependence on evolution scale
- Tail sensitive to upper phase space limit

## Detector level

- Selection dependence on jet multiplicity
- $t\bar{t}$   $p_T$  distribution distorted
- Different models can be distinguished
- Unfolding of distributions can be accomplished