Effective field theory for generic jet hierarchies

Piotr Pietrulewicz

based on arXiv:1601.05088 and w.i.p.
in collaboration with Frank Tackmann and Wouter Waalewijn

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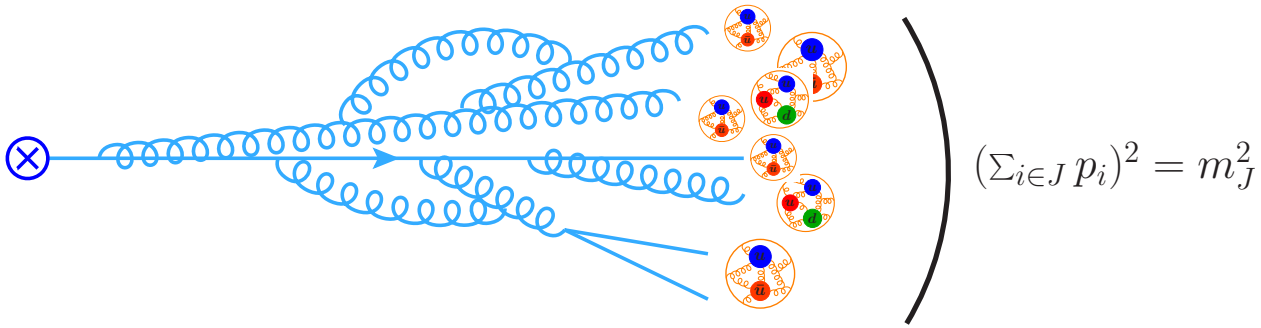
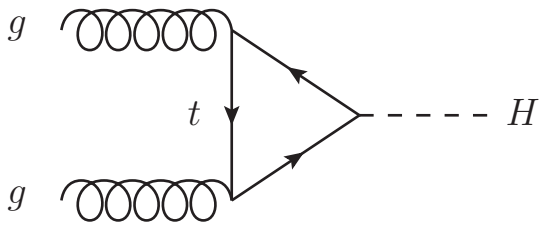
Jet processes at colliders

- quarks and gluons not directly observable
  $\rightarrow$ description of (restricted) QCD final state at colliders via jet observables

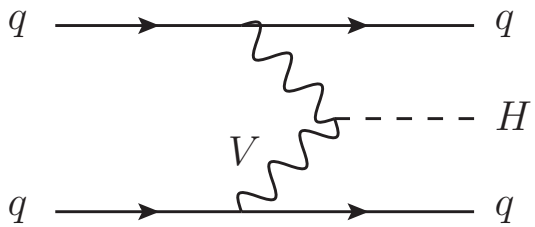


- jet binning relevant, e.g. in Higgs production

0 jets: ggF



2 quark jets: VBF



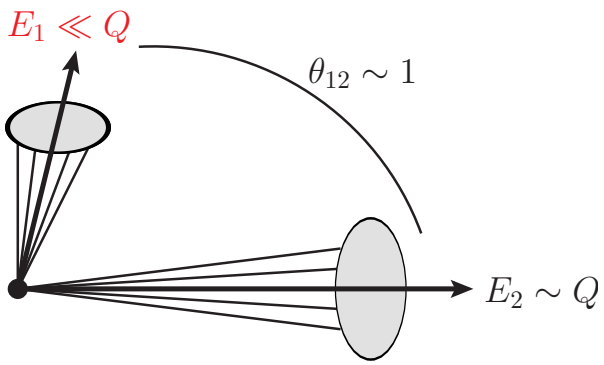
- typical characteristics of jets: hierarchy $|\vec{p}_i^{\perp}| \ll E_J$, $m_J \ll E_J$
  $\rightarrow$ multiple physical scales
  $\rightarrow$ large logarithms, e.g. $\sim \alpha_s \ln^2(m_J/E_J)$, in fixed-order (FO) perturbation theory
  $\Rightarrow$ FO calculations are necessary, but often not sufficient for precision analyses

SCET for jet physics

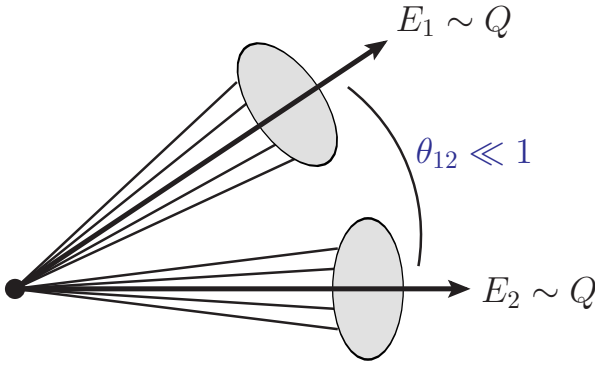
Soft-Collinear Effective Theory (SCET) [Bauer, Fleming, Pirjol, Stewart (2001)]

$\rightarrow$ factorizes cross section and "resums" logarithms via RGE

- standard SCET: hierarchy between jet resolution variable (e.g. m_J or $p_T^{\rm veto}$) and partonic c.m. energy Q
  $\rightarrow$ resummation of $\ln(m_J/Q)$, $\ln(p_T^{\rm veto}/Q)$
- SCET$_+$: additional hierarchies in jet energies and/or angles between the jets
  [Bauer, Tackmann, Walsh, Zuberi (2011); Larkoski, Moult, Neill (2015); P.P., Tackmann, Waalewijn (2016)]



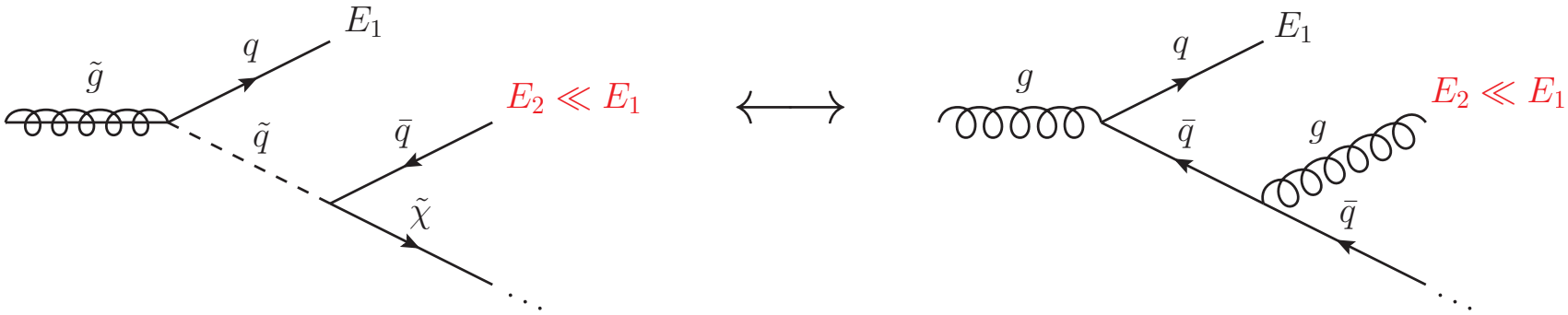
$\rightarrow$ resummation of $\ln(E_1/Q)$



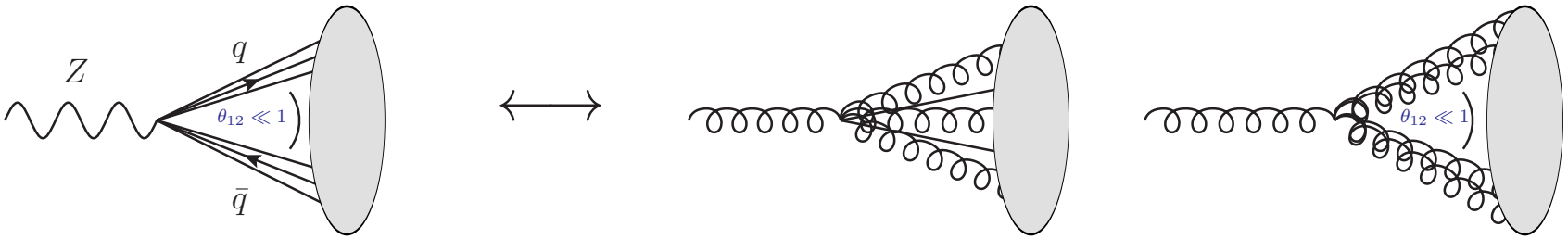
$\rightarrow$ resummation of $\ln\theta_{12}$

Where are jet hierarchies important?

- QCD background to SUSY cascade $\rightarrow$ strong ordering in energy



- jet substructure: discrimination of EW jets from QCD jets $\rightarrow$ hierarchy in angle

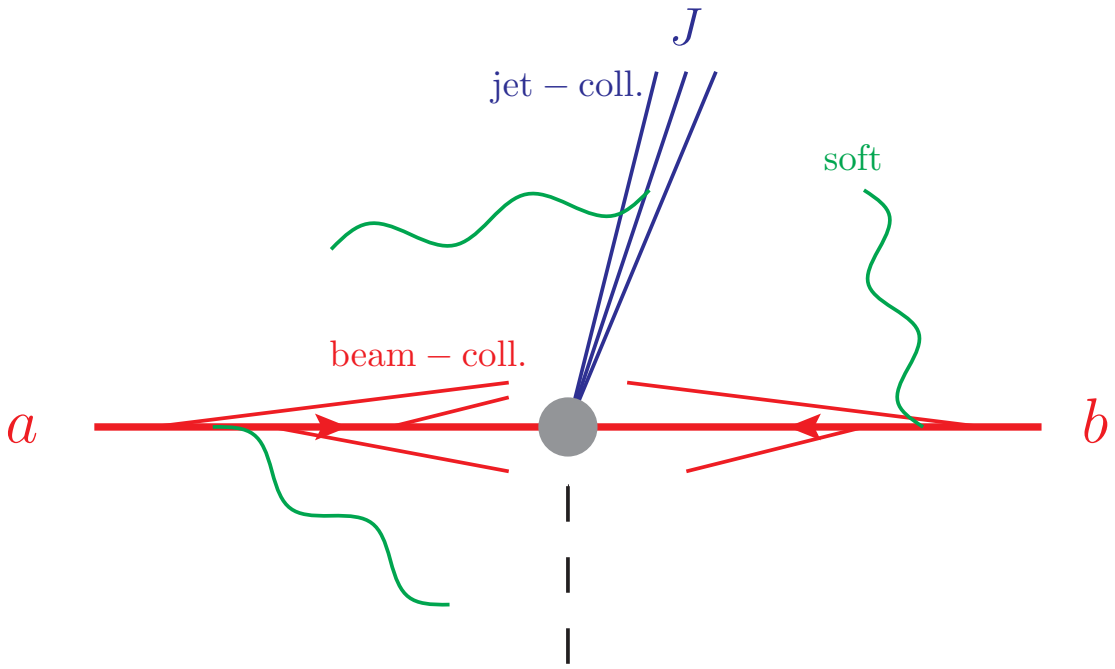


2 prong 1 prong 2 prong

- precision predictions for H+1,2,... jets (in the following: $pp \rightarrow H + 1$ jet)

No additional kinematic hierarchies

hard jet: $E_J \sim Q \sim m_H$
jet far away from the beam: $\theta_{aJ} \sim \theta_{bJ} \sim 1$

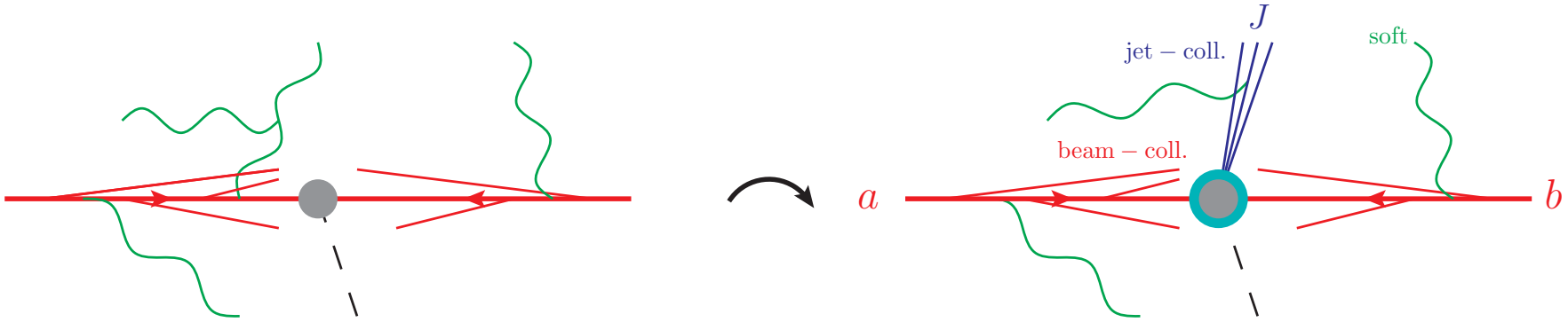


Factorization formula: $\mathrm{d}\sigma_{\mathrm{SCET}} \sim H_1 \times (B_a \times B_b \times J) \otimes S_1$

- H_1: hard function: partonic short distance interaction
- $B_{a,b}$: beam functions: parton distributions & initial state collinear radiation
- J: jet function: final state collinear radiation
- S_1: soft function: wide-angle soft radiation

Soft jet

soft jet: $E_J \ll Q \sim m_H$
jet far away from the beam: $\theta_{aJ} \sim \theta_{bJ} \sim 1$

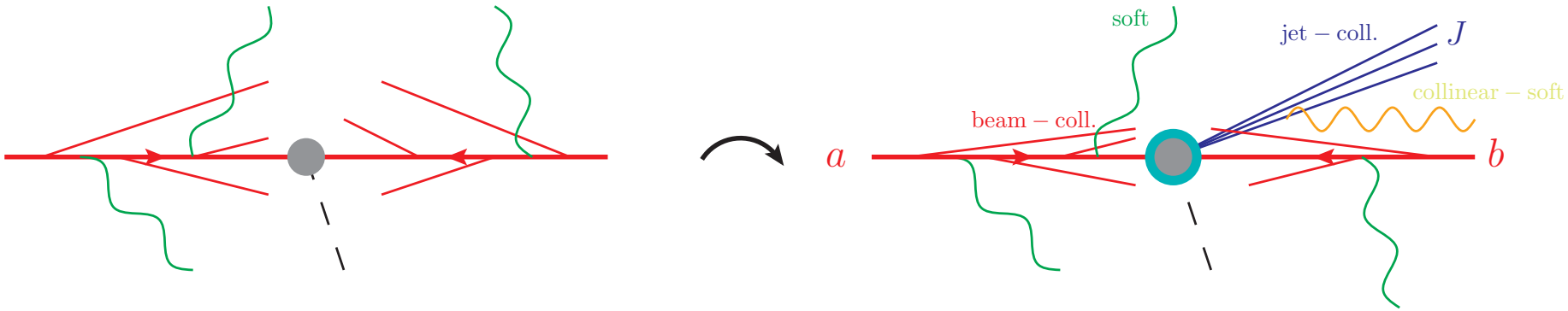


Factorization formula: $\mathrm{d}\sigma_s \sim H_0 \times H_s \times (B_a \times B_b \times J) \otimes S_1$

- final state collinear modes are now softer
- refactorization of the hard function: $H_1 \to H_0 \times H_s$

Jet close to a beam

hard jet: $E_J \sim Q \sim m_H$
jet close to beam a: $\theta_{aJ} \ll 1$

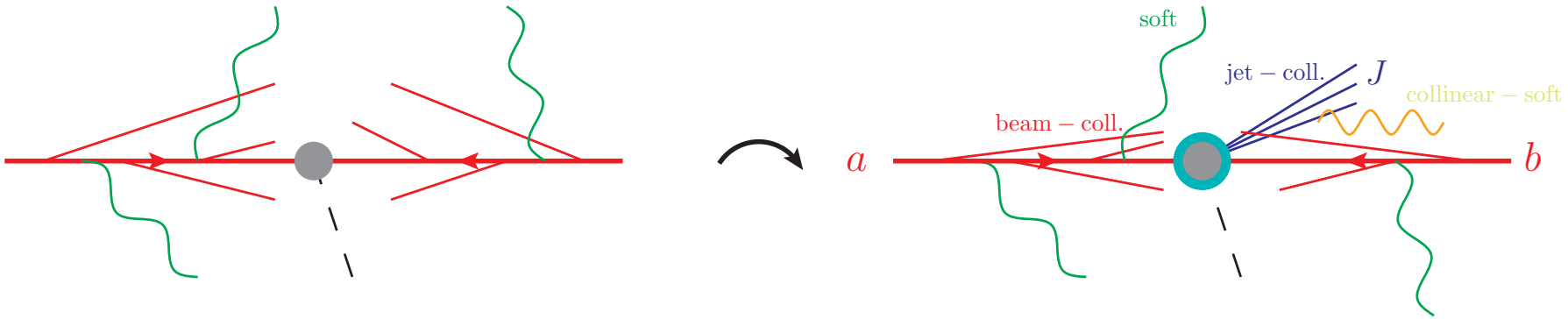


Factorization formula: $\mathrm{d}\sigma_c \sim H_0 \times H_c \times (B_a \times B_b \times J) \otimes S_c \otimes S_0$

- refactorization of the hard function: $H_1 \to H_0 \times H_c$
- refactorization of the hard function: $S_1 \to S_c \otimes S_0$

Soft jet close to a beam

soft jet: $E_J \ll Q \sim m_H$
jet close to beam a: $\theta_{aJ} \ll 1$



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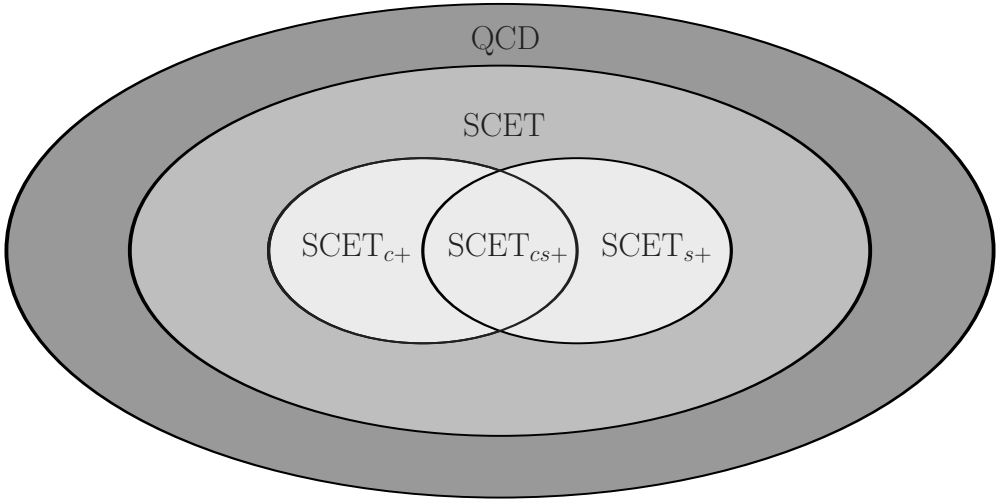
Result with full fixed-order content & log-resummation

- fixed order content of the theories:



- diff. cross section resumming all kinematic logs with full fixed-order content:

$$\mathrm{d}\sigma = \mathrm{d}\sigma_{cs} + \mathrm{d}\sigma_s^{nons} + \mathrm{d}\sigma_c^{nons} + \mathrm{d}\sigma_{\mathrm{SCET}}^{nons} + \mathrm{d}\sigma_{\mathrm{QCD}}^{nons}$$

$\rightarrow$ $\mathrm{d}\sigma_{cs}$: resums all logs incl. $\ln(E_J/m_H)$, $\ln\theta_{aJ}$

$\rightarrow$ remaining corrections add "nonsingular" perturbative fixed-order content without associated resummations, e.g. $\mathrm{d}\sigma_c^{nons} = \mathrm{d}\sigma_c - \mathrm{d}\sigma_{cs}|_{E_J \sim m_H}$

Summary

- jets (and/or vetoed jets) are omnipresent at hadron colliders
- precise theory predictions for exclusive, multi-differential cross sections required
- here: EFT framework for generic kinematic hierarchies between jets (SCET$_+$)
  $\rightarrow$ systematic resummation of logarithms between jet energies and angles
  $\rightarrow$ can be easily combined with corresponding fixed-order corrections
- in general (for $pp \rightarrow N$ jets):
  $\rightarrow$ spin and color correlations
  $\rightarrow$ proliferation of possible hierarchies (strongly and not strongly ordered)
- applications: jet binning, parton showers, jet substructure, ...