A neither complete nor exhaustive review of something

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(with the invaluable help of Valerio Bertone and Miguel Echevarria)
Disclaimer

Just a few slides to stimulate discussion and try to anticipate possible future steps for our benchmark

Kind of bird-eye view of different formalisms, without many technical details and with some “dictionary” included

Please forgive and point out any omission/mistake/inaccuracy: slides are meant to be continuously (even real-time!) updated
effective field theory: high energy d.o.f. integrated out, soft and collinear d.o.f. decouple

\[ A^\mu \rightarrow A^\mu_s + A^\mu_c + A^\mu_{\bar{c}} + \ldots \]
\[ \psi \rightarrow \psi_s + \psi_c + \psi_{\bar{c}} + \ldots \]
\[ \mathcal{L} = \mathcal{L}_s + \mathcal{L}_c + \mathcal{L}_{\bar{c}} + \ldots \]

\[ \sigma \sim \text{Beam}(\mu, \nu) \otimes \text{Beam}(\mu, \nu) \otimes \text{Soft}(\mu, \nu) \otimes \text{Hard}(\mu, Q) \]

Beam function directly related to collinear PDF \((C \times f)\)

two non-physical scales for renormalisation of UV \((\mu)\) and rapidity \((\nu)\) divergences

\(\nu\) arises from distinguishing soft modes from collinear modes (connected by Lorentz boost), just as \(\mu\) arises from distinguishing different virtualities

each function has its own RG evolution: \(\frac{d \ln X}{d \ln \mu} = \Gamma_X\) with \(X = B, H, S\) leading to resummed predictions and customary formula (next slide)
TMD

- 2D factorisation theorem (SIDIS, DY, e⁺e⁻ → hadrons)

\[ \sigma \sim f(x, k_T^2, \mu^2) \otimes f(x, k_T^2, \mu^2) \otimes \text{Hard} \]

- same divergencies → same RG evolutions as SCET

\[ f(x, k_T^2, \mu^2) \sim \text{Beam} \otimes \sqrt{\text{Soft}} \]

- For the Drell-Yan process, SCET and TMD are equivalent

\[ f(x, k_T^2, \mu^2) \otimes f(x, k_T^2, \mu^2) \otimes \text{Hard} \sim \text{Beam} \otimes \text{Beam} \otimes \text{Soft} \otimes \text{Hard} \]

- Common form (CSS)

\[ \sigma \sim [C \otimes f(x)] \text{Hard} [C \otimes f(x)] \exp(S) \exp(S_{NP}) \]
**qt resummation**

- **1D (collinear) factorisation theorem**

\[ \sigma \sim f(x, \mu^2) \otimes f(x, \mu^2) \otimes \text{Hard} \]

- Resummation (i.e. factorisation and exponentiation) of soft-gluon emissions to all orders

- Dynamical (\(|M_{n-\text{gluons}}| \sim |M_{1-\text{gluon}}|^n\)) and kinematical (\(\text{PS}_{n-\text{gluons}} \sim \prod_n \text{PS}_{1-\text{gluon}}\)) factorisation properties of QCD

- Identical formula as in the previous slide

\[ \sigma \sim [C \otimes f(x)] \text{Hard} [C \otimes f(x)] \exp(S) \exp(S_{NP}) \]
For hadroproduction of colourless final states:

\[ \sigma \sim \left[ C \otimes f(x) \right] \text{Hard} \left[ C \otimes f(x) \right] \exp(S) \exp(S_{NP}) \]

- 2D SCET/TMD
- RG evolution
- q_{T} resummation
- 1D

1st order OPE for TMD operator/
Collinear emissions
("matching"/"Wilson"/
"collinear"/"boundary")

("Sudakov": soft emissions
contains "cusp"/"A"
and "non-cusp"/"B"
anomalous dimensions)

necessary input:
RG evol. eq. needs initial condition
(to be determined from data)
Parton Branching

- parton-shower based: evolution equation with Sudakov factor denoting probability of no-(resolvable)branching

- difference w.r.t. customary parton-shower: forward evolution (from hadron scale to hard scale) instead of backward evolution

- angular-ordered emissions from initial parton → non-ordered emissions give subleading logs

- possible to prove formal equivalence with $b$-space formalism at various accuracies
Codes

- SCET: SCETlib, CuTe
- TMD: ResBos2, NangaParbat
- $q_T$ resummation: DYRes/DYTURBO, ReResolve
- shower-like: RadISH, PartonBranching

Basic ingredients (A,B,C functions) common to all codes.

Main differences in:
- working space for resummation/evolution ($b_T$ or $q_T$)
- dealing with NP-physics (prescription/cutoff and intrinsic-${k_T}$)
- matching with fixed order at intermediate $q_T$
Differences

NP-physics (1): avoiding the Landau pole

- $q^2$-space: low-$q^2$ cutoff
- $b_T$-space needs either a “freezing”/“saturation” of $b$ (MANY CHOICES for “$b_\ast$”) or a “minimal prescription” (suitable integration path in complex-$b$ plane)

NP-physics (2): intrinsic-$k_T$ effects

- NP form factor to be determined from data, in principle kinematics- and flavour-dependent
- Matching with fixed order at intermediate $q^2$
  - Multiplicative $\sigma_{res}\left[\frac{\sigma_{fix}}{\sigma_{res}}\right]_{expanded}$ or additive $\sigma_{res} + \sigma_{fix} - \sigma_{asy}$
  - Damping function to switch off resummation/evolution (MANY choices)
  - Unitarity enforcing ($\int \frac{d\sigma}{dq_T} = 0$), i.e. modified logs (damping function and NP may spoil it!)
- Lepton cuts