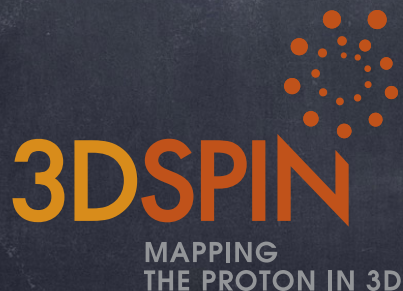


A neither complete  
nor exhaustive  
review of something

giuseppe bozzi  
(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



# SCET

- effective field theory: high energy d.o.f. integrated out, soft and collinear d.o.f. decouple

$$A^\mu \rightarrow A_s^\mu + A_c^\mu + A_{\bar{c}}^\mu + \dots$$

$$\psi \rightarrow \psi_s + \psi_c + \psi_{\bar{c}} + \dots$$

$$\mathcal{L} = \mathcal{L}_s + \mathcal{L}_c + \mathcal{L}_{\bar{c}} + \dots$$

$$(DY) \quad \sigma \sim \text{Beam}(\mu, \nu) \otimes \text{Beam}(\mu, \nu) \otimes \text{Soft}(\mu, \nu) \otimes \text{Hard}(\mu, Q)$$

- 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,  $e^+e^- \rightarrow$  hadrons)

$$(DY) \quad \sigma \sim f(x, k_T^2, \mu^2) \otimes f(x, k_T^2, \mu^2) \otimes Hard$$

- same divergencies  $\rightarrow$  same RG evolutions as SCET

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

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

$$f(x, k_T^2, \mu^2) \otimes f(x, k_T^2, \mu^2) \otimes Hard \sim Beam \otimes Beam \otimes Soft \otimes Hard$$

- Common form (CSS)

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



# 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

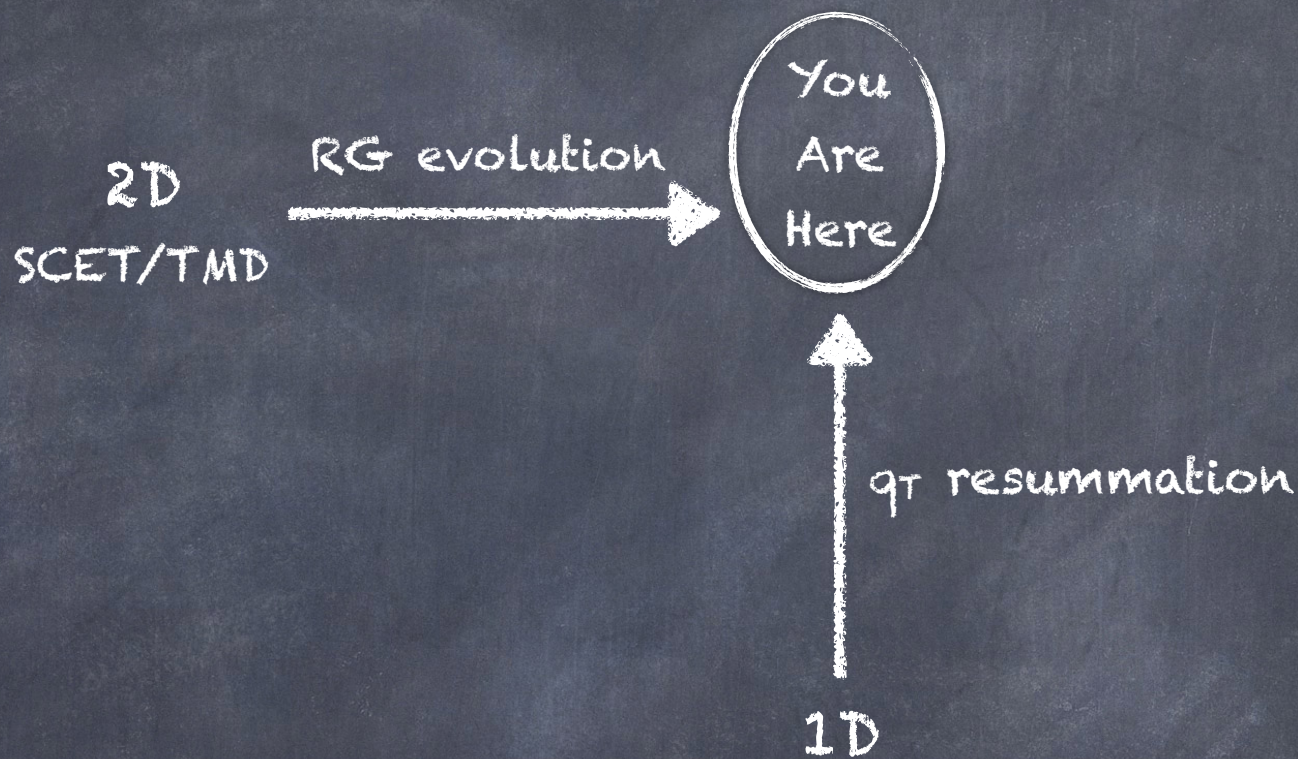
- dynamical ( $|M_{n\text{-gluons}}| \sim |M_{1\text{-gluon}}|^n$ ) and kinematical ( $PS_{n\text{-gluons}} \sim \prod_n PS_{1\text{-gluon}}$ ) factorisation properties of QCD

- 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:



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

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  $\rightarrow$  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, ReSolve
- 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

⊙  $q_T$ -space: low- $q_T$  cutoff

⊙  $b_T$ -space needs either a "freezing"/"saturation" of  $b$  (MANY CHOICES for " $b_*$ ") 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  $q_T$

⊙ 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 ( $\int \frac{d\sigma}{dq_T} dq_T = \sigma$ ), i.e. modified logs (damping function and NP may spoil it!)

⊙ lepton cuts