Target fragment substructure and its Soft Collinear Effective Theory

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CFNS Ad-hoc workshop: Target fragmentation and diffraction with novel processes

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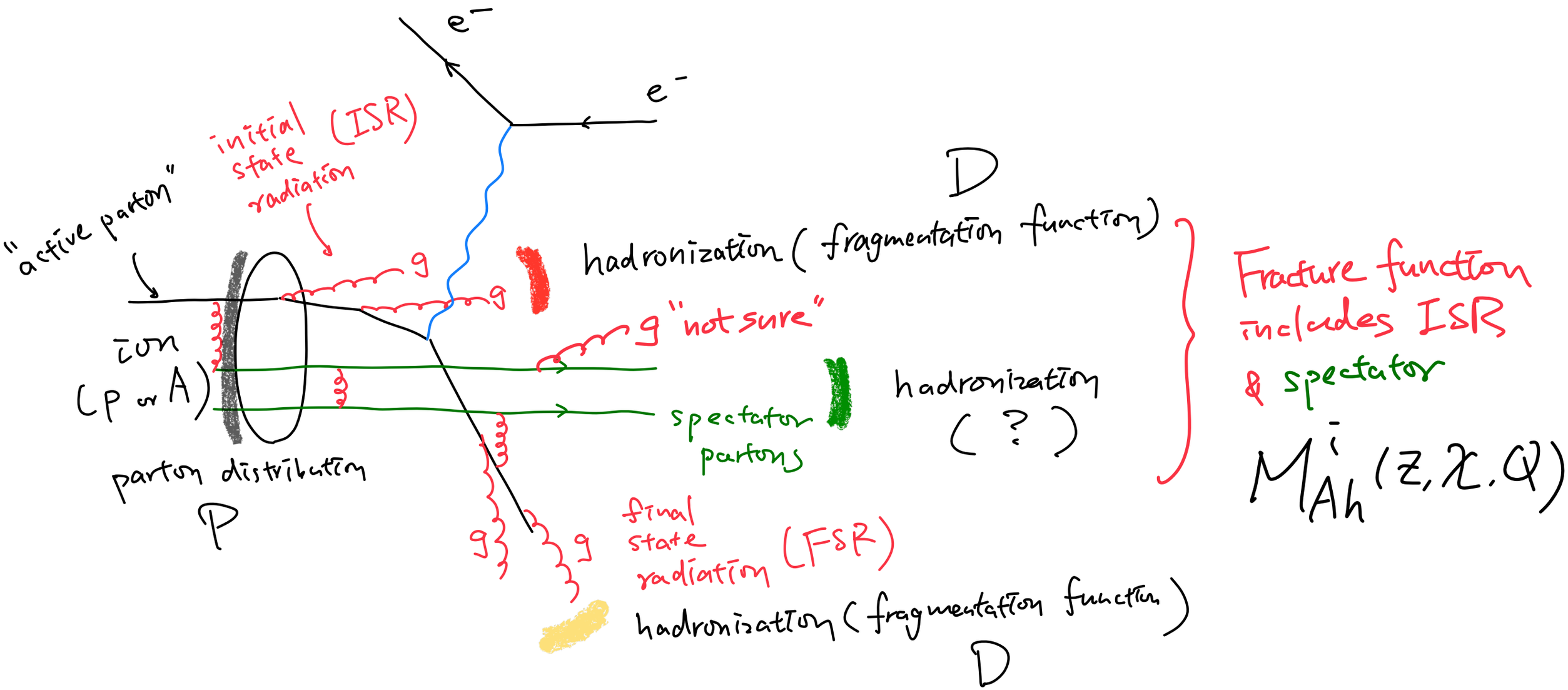
Outline

- Target fragment and initial state radiation
  - Quantification of its substructure
  - Fracture (fragmentation + structure) function
- SCET and “Beam function”
- “Beam fracture function”

Disclaimer: there is no proof of factorization in this talk!

See Ted's talk and the references within: Trentadue & Veneziano
Berera & Soper
Collins
Graziani, Trentadue & Veneziano
and more

A schematic picture of target fragmentation for DIS

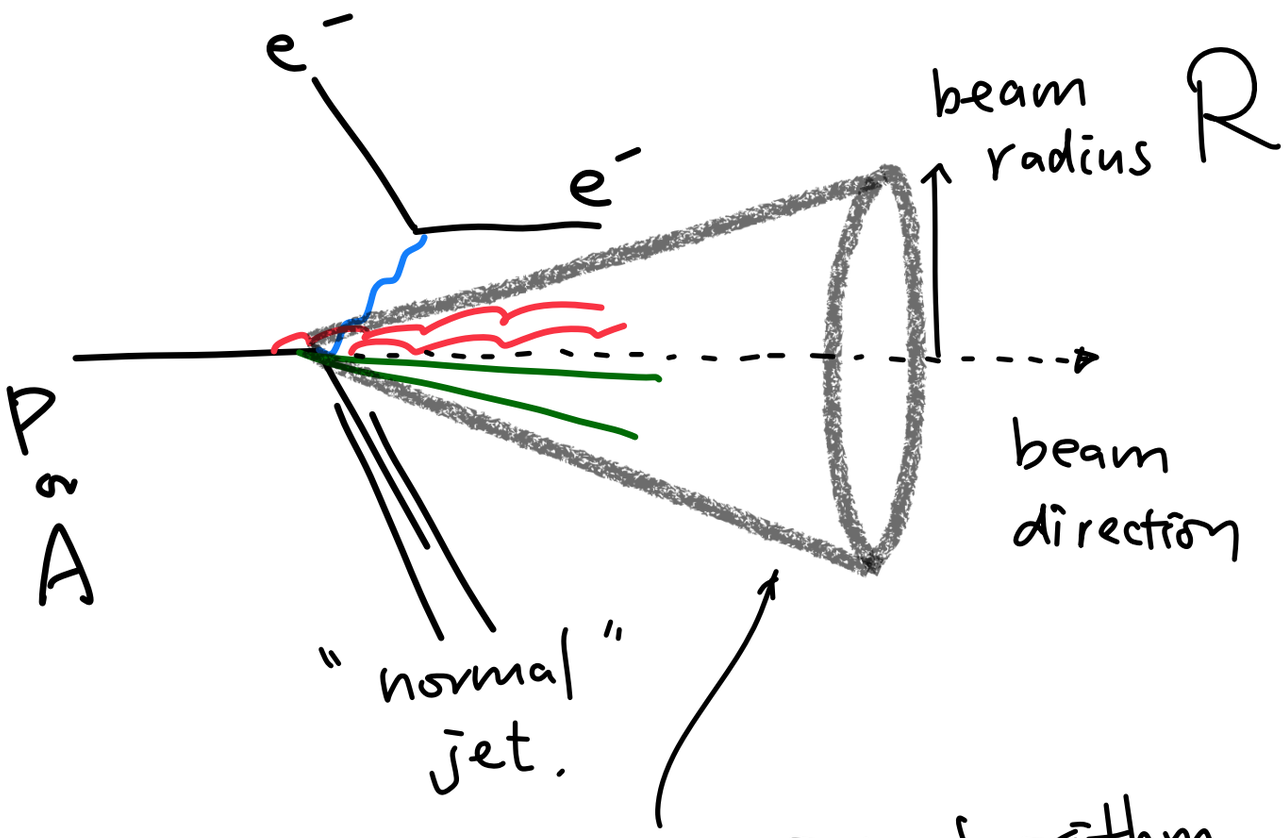


- Trentadue & Veneziano '94, target fragments include ISR and spectator contributions, advocated to be not naturally separable.
- However, ISR can have large transverse momenta and fake as ISR jets

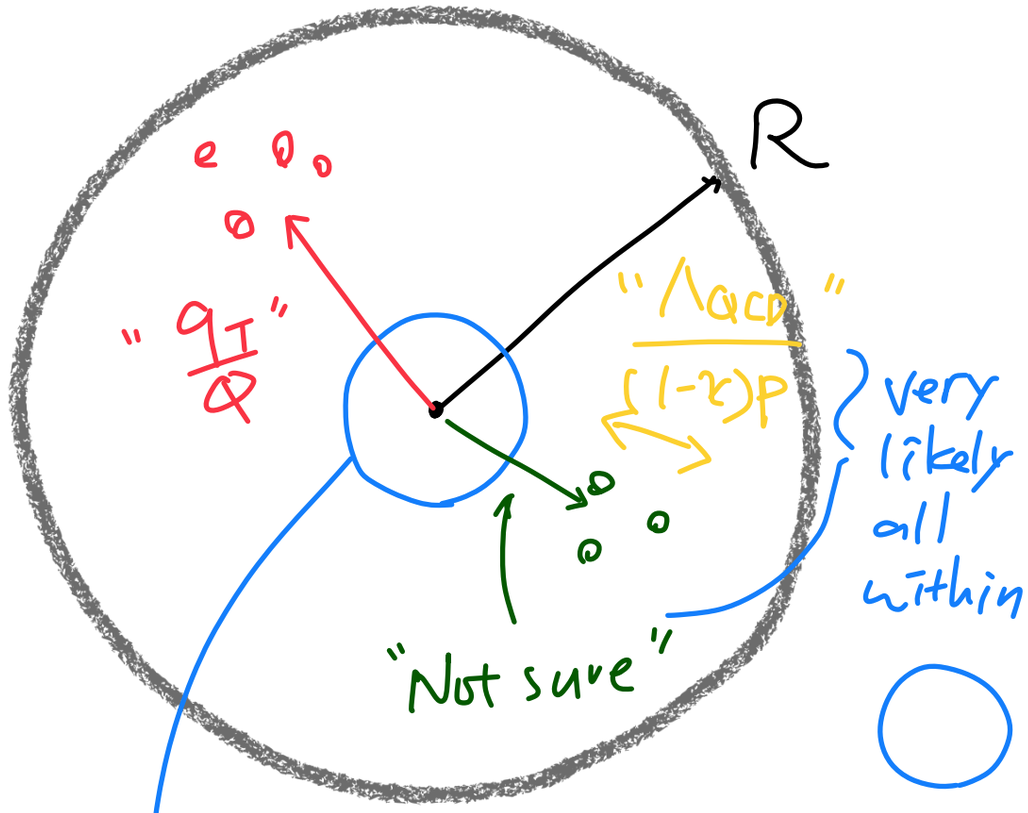
I think the caveat is that, if only looking at longitudinal momenta, both can be soft or hard.

← may be too much of an extreme case.

Measurement of target fragments



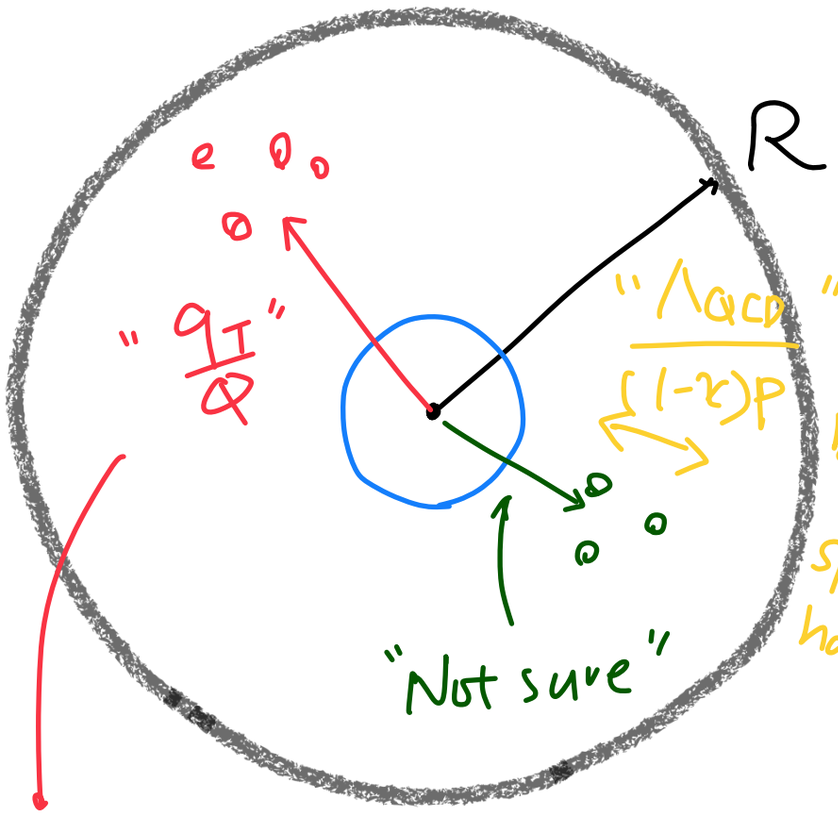
Defined using a jet algorithm. For the purpose of this talk, just use a cone to enclose the beam, with a radius optimally depending on x and Q^2.



Due to detector limitation, there might be an inner region within which the information is harder to be obtained (need ZDC...)

So do some collinear drop. Chien & Stewart, 1907.11107

Sensitivity to ISR



- There have been IRC safe observables indirectly or directly probing the ISR.
  - Drell-Yan p_T
  - Dijet or boson+jet momentum imbalance q_T
  - Beam thrust
  - Jet veto
- ISR contributions captured by "beam function"

Mantry & Petriello 0911.4135 and more

"nuclear breakup"

"spectator hadronization"

classic

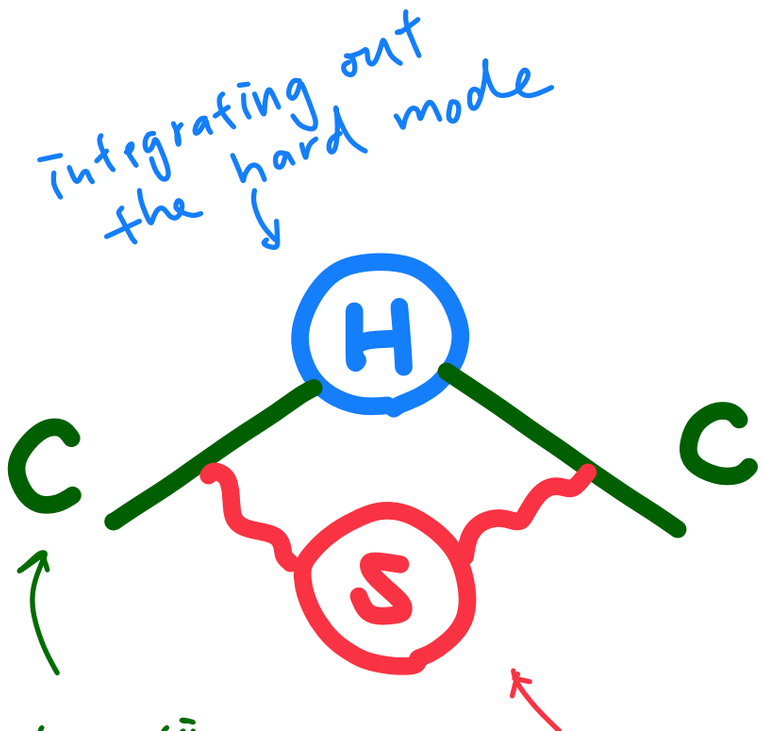
thrust around the beam axis you can think of τ_t as the mass of the beam.

This is the ratio between q_T: momentum imbalance between e and leading jet.

Q: some hard energy, may be the DIS Q, or just the ISR energy.

Beam functions were introduced in the framework of Soft-Collinear Effective Theory (SCET), but it is a collinear object physically regularized by perturbative measurement.

Soft Collinear Effective Theory



A very quick description about SCET at leading power.

$$d\sigma = H \; C \; C \; S \; \delta(\mathcal{O} - \mathcal{O}(p_c, p_s))$$

- H: hard function
- $C\,C$: Collinear function — Can be PDF, beam function, Jet function
- S: soft fuction
- $\delta(\mathcal{O} - \mathcal{O}(p_c, p_s))$: measurement fn. of observable $\mathcal{O}$ depending on the IR leading region.

$+$ correction of order $\mathcal{O}\left(\frac{\text{low scale}}{\text{high scale}}\right)$

* The low scale is induced by the measurement, say qT.
  beam thrust, jet veto, etc.

Beam function

In SCET, collinear sectors are described by what is call "collinear jet field"

χ_n and $\mathcal{B}^{\mu}_{n\perp}$, each invariant under collinear gauge transformation

χ_n ↑ quark jet field = $W_n^\dagger \xi_n$ (collinear Wilson line; quark field)

$\mathcal{B}^{\mu}_{n\perp}$ ↑ gluon jet field = $\frac{1}{g}[W_n^\dagger i D^{\mu}_{n\perp} W_n]$ (covariant derivative)

Schematically, quark beam function for transverse momentum distribution (q_T, say) for proton would be

$$\mathcal{B}_i(x, k_T) = \langle P | \bar{\chi}_n \delta(\underbrace{\text{longitudinal momentum fraction } x, \text{ perturbative } p_T}_{\text{constraining collinear d.o.f.}}) \chi_n | P \rangle$$

Beam function and PDF

If the perturbative scale induced by the measurement is much larger than Λ_{QCD}, the through operator product expansion, beam functions can be related to the standard parton distribution function.

$$B_i(x, k_T) = \sum_j \int_x^1 \frac{d\xi}{\xi} \underbrace{I_{ij}\left(\frac{x}{\xi}, k_T\right)}_{\text{perturbatively calculable matching coefficient}} \underbrace{f_j(\xi)}_{\text{PDF}} \left[1 + \mathcal{O}\left(\frac{\Lambda_{QCD}}{k_T}\right)\right]$$

SCET resums logarithmically enhanced contribution through renormalization group evolution, and is quite systematic.

So when Christian asked me if SCET is useful for describing target fragmentation, my first thought was that if there is perturbative evolution then the answer is yes.

Jet-like fracture function

Some words about Ceccopieri & Trentadue (0705.2326) before moving on to further SCET discussion:

Jet calculus was applied to ISR, and a jet-like fracture function $M_{\bar{q}}^{\bar{i}}(x, Q^2, z, t)$

this z is now for a jet instead of a hadron

this t is specifically the virtuality, but it is an IR scale between Λ_{QCD} and Q.

so need a jet definition

As far as I can tell, $M_{\bar{q}}^{\bar{i}}$ promoter $M^{\bar{i}}$ to be a bit more IRC safe so that we don't have too many more nonperturbative objects to introduce.

Beam fracture function

A natural step, to me, is to study what I call "beam fracture function", some combination of the idea of beam function and fracture function. Physically, having a perturbative scale q_T (say) is useful because it gives us a chance to disentangle ISR and spectator hadronization

↖ may be the conventional gluon fragmentation

↖ new NP object.

SOME POSSIBLE FACTORIZATION

So may be

$$\mathcal{B}_i^{Ah}(x,z,k_T) = \sum_j \int_x^1 \frac{d\xi}{\xi} \mathcal{I}_{ij}\left(\frac{x}{\xi},k_T\right) \underbrace{M_j^{Ah}(x,z)}_{\text{which can be further factorized.}} + \mathcal{O}\left(\frac{\Lambda_{QCD}}{k_T}\right)$$

Match to D, P and $D_{spectator}$ ←

Outlook

- Suggest to measure simultaneously electron-jet momentum imbalance and forward hadrons
- Beam thrust is affected by underlying event significantly at hadron collider, so DIS beam thrust might give a direct, clean probe of ISR.
- Transverse momentum distribution (TMD) and spin dependence of target fragments are natural objects to explore.

In some sense fracture function should be factorizable in some kinematic regim because ISR's partonic origin is from gluons, and spectator partons give other contributions. If we want to write down the operator definition of fracture function, we need to deal with this issue.

Thank you