On the low p_t cutoff for minijet production

Sergey Ostapchenko
Hamburg University

MPILHC-2022
Madrid, November 14-18, 2022

Why the low p_t cutoff?

- General purpose MC generators necessarily involve both perturbative & nonperturbative physics

Why the low p_t cutoff?

- General purpose MC generators necessarily involve both perturbative & nonperturbative physics
  - Q_0^2-cutoff - just a border between the respective treatments (minimal parton virtuality for pQCD being applicable)
  - in principle, should be a technical parameter

Why the low p_t cutoff?

- General purpose MC generators necessarily involve both perturbative & nonperturbative physics
  - Q_0^2-cutoff - just a border between the respective treatments (minimal parton virtuality for pQCD being applicable)
  - in principle, should be a technical parameter
- but: choice of Q_0^2 impacts strongly the predictions (e.g. for $\sigma_{pp}^{\mathrm{tot/inel}}$ or for N_{pp}^{ch})

Why the low p_t cutoff?

- General purpose MC generators necessarily involve both perturbative & nonperturbative physics
  - Q_0^2-cutoff - just a border between the respective treatments (minimal parton virtuality for pQCD being applicable)
  - in principle, should be a technical parameter
- but: choice of Q_0^2 impacts strongly the predictions (e.g. for $\sigma_{pp}^{\mathrm{tot/inel}}$ or for N_{pp}^{ch})
  - (mini)jet production explodes at small p_t
  - but: soft physics knows nothing about this cutoff

Why the low p_t cutoff?

- General purpose MC generators necessarily involve both perturbative & nonperturbative physics
  - Q_0^2-cutoff - just a border between the respective treatments (minimal parton virtuality for pQCD being applicable)
  - in principle, should be a technical parameter
- but: choice of Q_0^2 impacts strongly the predictions (e.g. for $\sigma_{pp}^{\mathrm{tot/inel}}$ or for N_{pp}^{ch})
  - (mini)jet production explodes at small p_t
  - but: soft physics knows nothing about this cutoff
- $\Rightarrow$ there should be a perturbative mechanism damping jet production in the small p_t limit

Energy-dependent Q_0^2-cutoff: what physics is behind?

- Many MC generators employ s-dependent Q_0^2-cutoffs
  - for a fixed Q_0^2, steep low-x rise of the gluon density leads to a too rapid increase of $\sigma_{pp}^{\rm tot/inel}$ & $N_{pp}^{\rm ch}$
  - $\Rightarrow$ *ad hoc* parametrizations for $Q_0^2(s)$: fitting $N_{pp}^{\rm ch}$ & $\sigma_{pp}^{\rm tot/inel}$

Energy-dependent Q_0^2-cutoff: what physics is behind?

- Many MC generators employ s-dependent Q_0^2-cutoffs
  - for a fixed Q_0^2, steep low-x rise of the gluon density leads to a too rapid increase of $\sigma_{pp}^{\text{tot/inel}}$ & N_{pp}^{ch}
  - $\Rightarrow$ *ad hoc* parametrizations for $Q_0^2(s)$: fitting N_{pp}^{ch} & $\sigma_{pp}^{\text{tot/inel}}$
  - usually interpreted as 'saturation effects'

Energy-dependent Q_0^2-cutoff: what physics is behind?

- Many MC generators employ s-dependent Q_0^2-cutoffs
  - for a fixed Q_0^2, steep low-x rise of the gluon density leads to a too rapid increase of $\sigma_{pp}^{\rm tot/inel}$ & $N_{pp}^{\rm ch}$
  - $\Rightarrow$ *ad hoc* parametrizations for $Q_0^2(s)$: fitting $N_{pp}^{\rm ch}$ & $\sigma_{pp}^{\rm tot/inel}$
  - usually interpreted as 'saturation effects'

But: min-bias pp interactions are dominated by peripheral collisions

- at large b: low parton density
- $\Rightarrow$ hard to expect strong effects of parton saturation

Energy-dependent Q_0^2-cutoff: what physics is behind?

- Many MC generators employ s-dependent Q_0^2-cutoffs
  - for a fixed Q_0^2, steep low-x rise of the gluon density leads to a too rapid increase of $\sigma_{pp}^{\mathrm{tot/inel}}$ & N_{pp}^{ch}
  - $\Rightarrow$ *ad hoc* parametrizations for $Q_0^2(s)$: fitting N_{pp}^{ch} & $\sigma_{pp}^{\mathrm{tot/inel}}$
  - usually interpreted as 'saturation effects'

Also: the recipee doesn't look like parton saturation

- standard PDFs employed in MC generators
- rather, parton scattering rate is damped at higher and higher q^2, with increasing s

Energy-dependent Q_0^2-cutoff: what physics is behind?

- Many MC generators employ s-dependent Q_0^2-cutoffs
  - for a fixed Q_0^2, steep low-x rise of the gluon density leads to a too rapid increase of $\sigma_{pp}^{\mathrm{tot/inel}}$ & N_{pp}^{ch}
  - $\Rightarrow$ *ad hoc* parametrizations for $Q_0^2(s)$: fitting N_{pp}^{ch} & $\sigma_{pp}^{\mathrm{tot/inel}}$
  - usually interpreted as 'saturation effects'

Also: the recipee doesn't look like parton saturation

- standard PDFs employed in MC generators
- rather, parton scattering rate is damped at higher and higher q^2, with increasing s

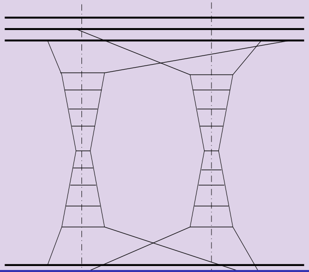
NB: s-dependence of $\sigma_{pp}^{\mathrm{tot/inel}}$ much less restrictive than $N_{pp}^{\mathrm{ch}}(s)$!

MPIs & generalized parton distributions (GPDs)

- Usual PDFs $f_I(x, Q^2)$ insufficient to describe MPIs
  - multiparton GPDs $F^{(n)}_{I_1 \ldots I_n}(x_1, \ldots, x_n, \vec{b}_1, \ldots, \vec{b}_{n-1}, Q_1^2, \ldots)$ required

E.g., $F^{(2)}$ for double parton scattering (production of 2 dijets)

$$\sigma_{pp}^{\text{4jet(DPS)}}(s, p_{\text{t}}^{\text{cut}}) = \frac{1}{2} \int dx_1^+ dx_2^+ dx_1^- dx_2^- \int_{p_{\text{t}_1}, p_{\text{t}_2} > p_{\text{t}}^{\text{cut}}} dp_{\text{t}_1}^2 \, dp_{\text{t}_2}^2 \sum_{I_1, I_2, J_1, J_2} \frac{d\sigma_{I_1 J_1}^{2\to 2}}{dp_{\text{t}_1}^2} \frac{d\sigma_{I_2 J_2}^{2\to 2}}{dp_{\text{t}_2}^2}$$
$$\times \int d^2\Delta b \, F_{I_1 I_2}^{(2)}(x_1^+, x_2^+, \mu_{\text{F}_1}^2, \mu_{\text{F}_2}^2, \Delta b) \, F_{J_1 J_2}^{(2)}(x_1^-, x_2^-, \mu_{\text{F}_1}^2, \mu_{\text{F}_2}^2, \Delta b)$$



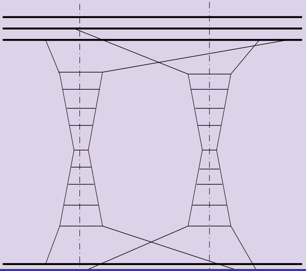
MPIs & generalized parton distributions (GPDs)

- Usual PDFs $f_I(x, Q^2)$ insufficient to describe MPIs
  - multiparton GPDs $F^{(n)}_{I_1 \ldots I_n}(x_1, \ldots, x_n, \vec{b}_1, \ldots, \vec{b}_{n-1}, Q_1^2, \ldots)$ required

E.g., $F^{(2)}$ for double parton scattering (production of 2 dijets)

$$\sigma_{pp}^{\text{4jet(DPS)}}(s, p_{\text{t}}^{\text{cut}}) = \frac{1}{2} \int dx_1^+ dx_2^+ dx_1^- dx_2^- \int_{p_{\text{t}_1}, p_{\text{t}_2} > p_{\text{t}}^{\text{cut}}} dp_{\text{t}_1}^2 \, dp_{\text{t}_2}^2 \sum_{I_1, I_2, J_1, J_2} \frac{d\sigma^{2\to 2}_{I_1 J_1}}{dp_{\text{t}_1}^2} \frac{d\sigma^{2\to 2}_{I_2 J_2}}{dp_{\text{t}_2}^2}$$
$$\times \int d^2\Delta b \, F^{(2)}_{I_1 I_2}(x_1^+, x_2^+, \mu_{\text{F}_1}^2, \mu_{\text{F}_2}^2, \Delta b) \, F^{(2)}_{J_1 J_2}(x_1^-, x_2^-, \mu_{\text{F}_1}^2, \mu_{\text{F}_2}^2, \Delta b)$$

- standard simplification:
  neglect multiparton correlations
- $F^{(n)}_{I_1 \ldots I_n}(x_1, \ldots x_n, \vec{b}_1, \ldots \vec{b}_{n-1}, Q_1^2, \ldots)$
  $\to \int d^2 b_n \, G_{I_n}(x_n, \vec{b}_n, Q_n^2)$
  $\times \prod_{i=1}^{n-1} G_{I_i}(x_i, \vec{b}_i + \vec{b}_n, Q_i^2)$



MPIs & generalized parton distributions (GPDs)

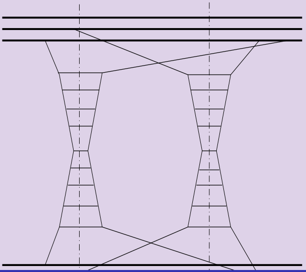
- Usual PDFs $f_I(x, Q^2)$ insufficient to describe MPIs
  - multiparton GPDs $F^{(n)}_{I_1 \ldots I_n}(x_1, \ldots, x_n, \vec{b}_1, \ldots, \vec{b}_{n-1}, Q_1^2, \ldots)$ required

E.g., $F^{(2)}$ for double parton scattering (production of 2 dijets)

$$\sigma^{\mathrm{4jet(DPS)}}_{pp}(s, p_{\mathrm{t}}^{\mathrm{cut}}) = \frac{1}{2}\int dx_1^+ dx_2^+ dx_1^- dx_2^- \int_{p_{\mathrm{t}_1}, p_{\mathrm{t}_2} > p_{\mathrm{t}}^{\mathrm{cut}}} dp^2_{\mathrm{t}_1}\, dp^2_{\mathrm{t}_2} \sum_{I_1, I_2, J_1, J_2} \frac{d\sigma^{2\to 2}_{I_1 J_1}}{dp^2_{\mathrm{t}_1}} \frac{d\sigma^{2\to 2}_{I_2 J_2}}{dp^2_{\mathrm{t}_2}}$$

$$\times \int d^2\Delta b\, F^{(2)}_{I_1 I_2}(x_1^+, x_2^+, \mu^2_{\mathrm{F}_1}, \mu^2_{\mathrm{F}_2}, \Delta b)\, F^{(2)}_{J_1 J_2}(x_1^-, x_2^-, \mu^2_{\mathrm{F}_1}, \mu^2_{\mathrm{F}_2}, \Delta b)$$

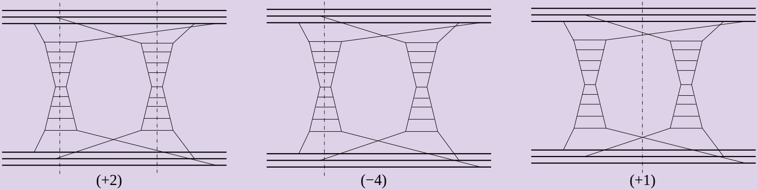
- standard simplification: neglect multiparton correlations
- $F^{(n)}_{I_1 \ldots I_n}(x_1, \ldots x_n, \vec{b}_1, \ldots \vec{b}_{n-1}, Q_1^2, \ldots)$ $\rightarrow \int d^2 b_n\, G_{I_n}(x_n, \vec{b}_n, Q_n^2)$ $\times \prod_{i=1}^{n-1} G_{I_i}(x_i, \vec{b}_i + \vec{b}_n, Q_i^2)$
- $\Rightarrow \sigma^{\mathrm{4jet(DPS)}}_{pp}(s, p_{\mathrm{t}}^{\mathrm{cut}}) =$ $\frac{1}{2}\int d^2 b\, [G_I \otimes \sigma^{2\to 2} \otimes G_J]^2$



Total/inelastic cross sections & multiple scattering

Relation to $\sigma_{pp}^{\mathrm{tot/inel}}$: from AGK cutting rules

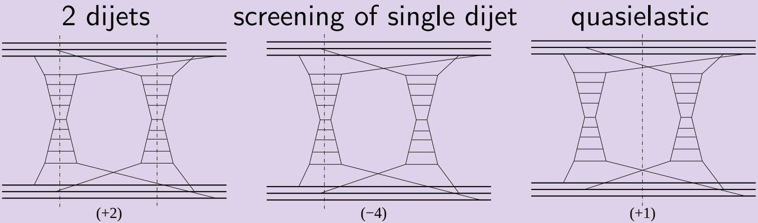
2 dijets — screening of single dijet — quasielastic



- partial contributions of the 3 processes: (+2):(-4):(+1)

Total/inelastic cross sections & multiple scattering

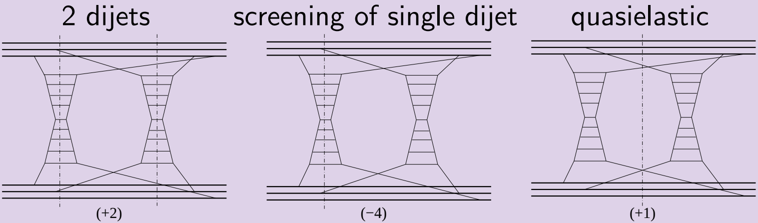
Relation to $\sigma_{pp}^{\mathrm{tot/inel}}$: from AGK cutting rules



- partial contributions of the 3 processes: (+2):(-4):(+1)
- $\Rightarrow \Delta^{(2)}\sigma_{pp}^{\mathrm{tot/inel}} = -\frac{1}{2}\sigma_{pp}^{\mathrm{4jet(DPS)}}$ (similarly for $n > 2$ dijets)

Total/inelastic cross sections & multiple scattering

Relation to $\sigma_{pp}^{\mathrm{tot/inel}}$: from AGK cutting rules

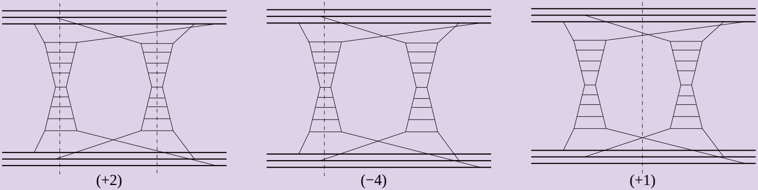


- partial contributions of the 3 processes: (+2):(-4):(+1)
- $\Rightarrow \Delta^{(2)}\sigma_{pp}^{\mathrm{tot/inel}} = -\frac{1}{2}\sigma_{pp}^{\mathrm{4jet(DPS)}}$ (similarly for $n > 2$ dijets)
- higher MPI rate $\Rightarrow$ stronger inelastic screening

Total/inelastic cross sections & multiple scattering

Relation to $\sigma_{pp}^{\mathrm{tot/inel}}$: from AGK cutting rules

2 dijets — screening of single dijet — quasielastic



- partial contributions of the 3 processes: (+2):(-4):(+1)
- $\Rightarrow \Delta^{(2)}\sigma_{pp}^{\mathrm{tot/inel}} = -\frac{1}{2}\sigma_{pp}^{\mathrm{4jet(DPS)}}$ (similarly for $n > 2$ dijets)
- higher MPI rate $\Rightarrow$ stronger inelastic screening

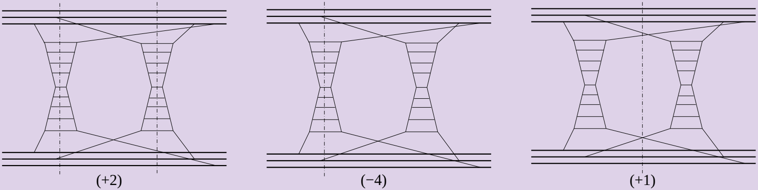
$\Rightarrow$ usual 'minijet' ansatz (neglecting the 'soft' contribution)

- $\sigma_{pp}^{\mathrm{inel}}(s) = \int d^2b \left[1 - \exp(-2\chi_{pp}^{\mathrm{jet}}(s,b,p_{\mathrm{t}}^{\mathrm{cut}}))\right]$
- $\chi_{pp}^{\mathrm{jet}}(s,b,p_{\mathrm{t}}^{\mathrm{cut}}) = \frac{1}{2}\sum_{I,J} G_I \otimes \sigma_{IJ}^{2\to 2} \otimes G_J$

Total/inelastic cross sections & multiple scattering

Relation to $\sigma_{pp}^{\mathrm{tot/inel}}$: from AGK cutting rules

2 dijets   screening of single dijet   quasielastic



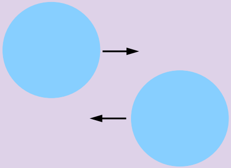
- partial contributions of the 3 processes: (+2):(-4):(+1)
- $\Rightarrow \Delta^{(2)}\sigma_{pp}^{\mathrm{tot/inel}} = -\frac{1}{2}\sigma_{pp}^{\mathrm{4jet(DPS)}}$ (similarly for $n > 2$ dijets)
- higher MPI rate $\Rightarrow$ stronger inelastic screening

NB: inclusive jet cross section – unmodified by such MPIs

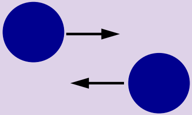
- e.g., summary contribution of the 3 processes:
  $2 * (+2) + 1 * (-4) + 0 * (+1) = 0$
- $\Rightarrow$ collinear factorization preserved: $\frac{d\sigma_{pp}^{\mathrm{jet}}}{dp_t^2} = \sum_{I,J} f_I \otimes \frac{d\sigma_{IJ}^{2\to 2}}{dp_t^2} \otimes f_J$

Main message: to reduce $\sigma_{pp}^{tot/inel}$, enhance MPIs

Simpliest way to regulate the rise of σ_{pp}^{tot}: denser parton 'packing'



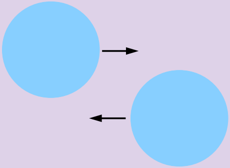
- larger proton size
  $\Rightarrow$ larger σ_{pp}^{tot}
- smaller parton density
  $\Rightarrow$ smaller MPI rate



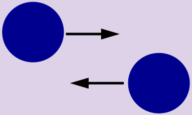
- smaller proton size
  $\Rightarrow$ smaller σ_{pp}^{tot}
- larger parton density
  $\Rightarrow$ larger MPI rate

Main message: to reduce $\sigma_{pp}^{tot/inel}$, enhance MPIs

Simpliest way to regulate the rise of σ_{pp}^{tot}: denser parton 'packing'



- larger proton size
  $\Rightarrow$ larger σ_{pp}^{tot}
- smaller parton density
  $\Rightarrow$ smaller MPI rate

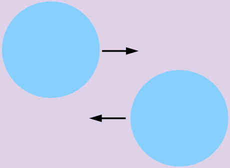


- smaller proton size
  $\Rightarrow$ smaller σ_{pp}^{tot}
- larger parton density
  $\Rightarrow$ larger MPI rate

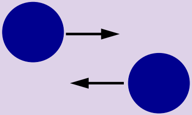
- in reality, not a solution:
  proton size is constrained by data on $B_{pp}^{el}(s) \propto \langle b^2(s) \rangle$
- moreover, b-dependence of the gluon GPD is constrained by data on J/ψ photoproduction *[Frankfurt & Strikman, 2002]*

Main message: to reduce $\sigma_{pp}^{\mathrm{tot/inel}}$, enhance MPIs

Simpliest way to regulate the rise of $\sigma_{pp}^{\mathrm{tot}}$: denser parton 'packing'



- larger proton size
  $\Rightarrow$ larger $\sigma_{pp}^{\mathrm{tot}}$
- smaller parton density
  $\Rightarrow$ smaller MPI rate



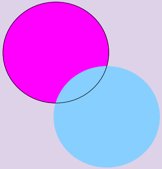
- smaller proton size
  $\Rightarrow$ smaller $\sigma_{pp}^{\mathrm{tot}}$
- larger parton density
  $\Rightarrow$ larger MPI rate

- in reality, not a solution:
  proton size is constrained by data on $B_{pp}^{\mathrm{el}}(s) \propto \langle b^2(s) \rangle$
- moreover, b-dependence of the gluon GPD is constrained by data on J/ψ photoproduction *[Frankfurt & Strikman, 2002]*

Realistic option: introduce parton 'clumps'

What is wrong with the uncorrelated parton picture?

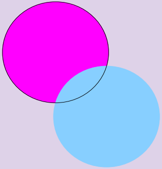
- double (multiple) hard scattering results from independent cascades
  - $\Rightarrow$ mostly in central collisions (too low parton density at large b)



Realistic option: introduce parton 'clumps'

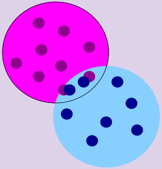
What is wrong with the uncorrelated parton picture?

- double (multiple) hard scattering results from independent cascades
  - $\Rightarrow$ mostly in central collisions (too low parton density at large b)



How multiparton correlations help?

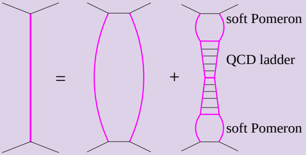
- one has to create parton 'clumps' to enhance peripheral multiple scattering (without changing the transverse profile)
  - can be done via 'soft' & 'hard' parton splitting mechanisms



Hard processes in the RFT framework [QGSJET(-II), EPOS]

'Semihard Pomeron' scheme *[Drescher, Hladik, SO, Pierog & Werner, 2001]*

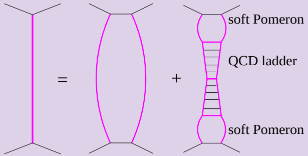
- soft Pomeron description for nonperturbative physics
- $\left|p_t^2\right| < Q_0^2 \Rightarrow$ soft Pomeron
- $\left|p_t^2\right| > Q_0^2 \Rightarrow$ DGLAP



Hard processes in the RFT framework [QGSJET(-II), EPOS]

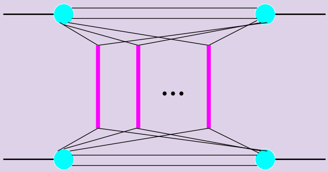
'Semihard Pomeron' scheme *[Drescher, Hladik, SO, Pierog & Werner, 2001]*

- soft Pomeron description for nonperturbative physics
- $\left|p_t^2\right| < Q_0^2 \Rightarrow$ soft Pomeron
- $\left|p_t^2\right| > Q_0^2 \Rightarrow$ DGLAP



RFT scheme based on a 'general Pomeron' (soft + semihard)

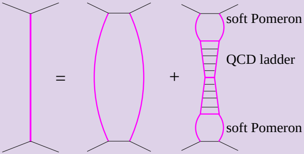
- regarding jet production: similar to the 'minijet' approach
- parton GPDs at the Q_0^2 scale: described by soft Pomeron



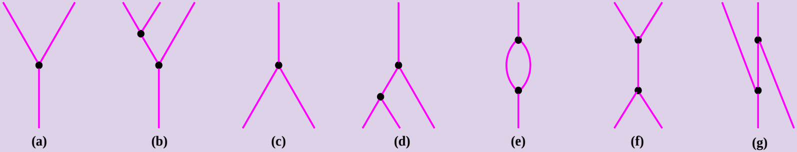
Hard processes in the RFT framework [QGSJET(-II), EPOS]

'Semihard Pomeron' scheme *[Drescher, Hladik, SO, Pierog & Werner, 2001]*

- soft Pomeron description for nonperturbative physics
- $\left|p_t^2\right| < Q_0^2 \Rightarrow$ soft Pomeron
- $\left|p_t^2\right| > Q_0^2 \Rightarrow$ DGLAP



Real change due to Pomeron-Pomeron interactions (scattering of intermediate partons off the proj./target hadrons & off each other)

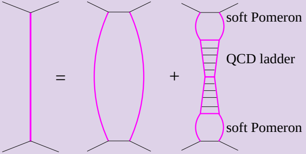


thick lines = Pomerons = 'elementary' parton cascades

Hard processes in the RFT framework [QGSJET(-II), EPOS]

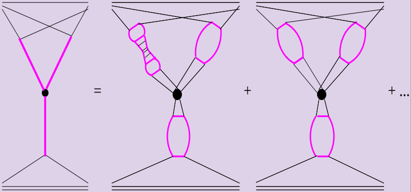
'Semihard Pomeron' scheme *[Drescher, Hladik, SO, Pierog & Werner, 2001]*

- soft Pomeron description for nonperturbative physics
- $|p_t^2| < Q_0^2 \Rightarrow$ soft Pomeron
- $|p_t^2| > Q_0^2 \Rightarrow$ DGLAP



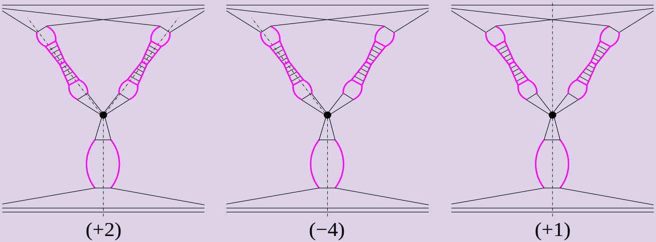
Pomeron-Pomeron interaction: a closer look

- basic assumption: multi-$\mathbb{P}$ vertices – dominated by soft ($|q^2| < Q_0^2$) parton processes
- generates parton 'clumping' *[SO & Bleicher, 2016]*



Parton 'clumping' due to 'soft parton splitting'

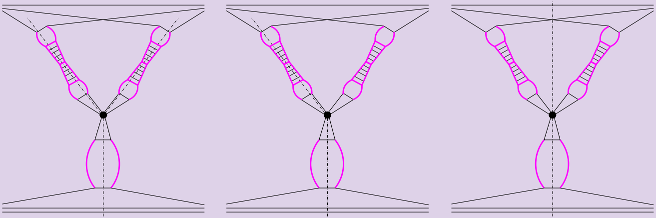
E.g., double dijet production from soft Pomeron splitting



- small slope for soft Pomeron:
  ⇒ two hard processes are closeby in b-space
  - ≡ having a parton 'clump' in the target proton

Parton 'clumping' due to 'soft parton splitting'

E.g., double dijet production from soft Pomeron splitting

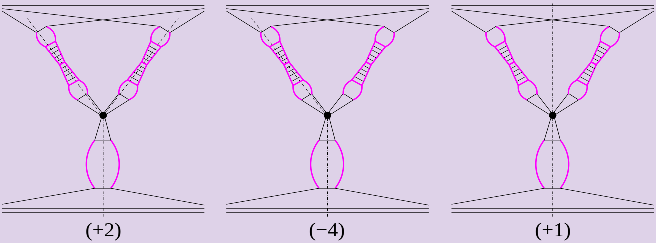


(+2) (−4) (+1)

- small slope for soft Pomeron:
  $\Rightarrow$ two hard processes are closeby in b-space
  - $\equiv$ having a parton 'clump' in the target proton
- $\Rightarrow$ enhanced MPI rate in peripheral collisions

Parton 'clumping' due to 'soft parton splitting'

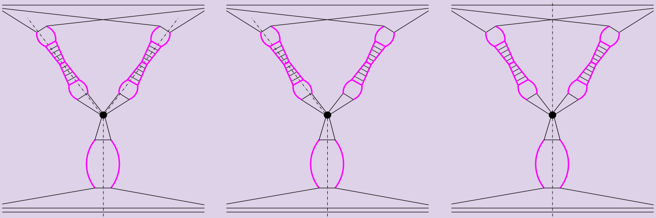
E.g., double dijet production from soft Pomeron splitting



- small slope for soft Pomeron:
  $\Rightarrow$ two hard processes are closeby in b-space
  - $\equiv$ having a parton 'clump' in the target proton
- $\Rightarrow$ enhanced MPI rate in peripheral collisions
- adding two other contributions $\Rightarrow$ negative correction to $\sigma_{pp}^{\rm tot}$

Parton 'clumping' due to 'soft parton splitting'

E.g., double dijet production from soft Pomeron splitting

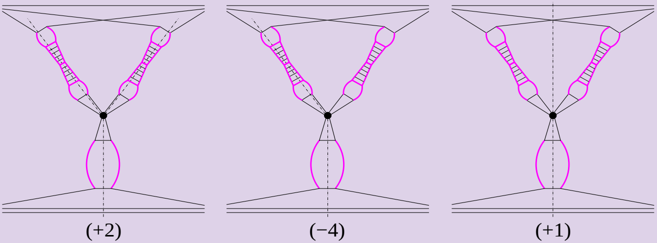


(+2) (−4) (+1)

- small slope for soft Pomeron:
  $\Rightarrow$ two hard processes are closeby in b-space
  - $\equiv$ having a parton 'clump' in the target proton
- $\Rightarrow$ enhanced MPI rate in peripheral collisions
- adding two other contributions $\Rightarrow$ negative correction to σ_{pp}^{tot}
- NB: no impact on inclusive jet cross section
  $[2*(+2)+1*(-4)+0*(+1)=0]$

Parton 'clumping' due to 'soft parton splitting'

E.g., double dijet production from soft Pomeron splitting



- small slope for soft Pomeron:
  $\Rightarrow$ two hard processes are closeby in b-space
  - $\equiv$ having a parton 'clump' in the target proton

Generic property: thanks to AGK cancellations, collinear factorization preserved for inclusive jet cross section

$$\frac{d\sigma_{pp}^{\rm jet}}{dp_t^2} = \sum_{I,J} f_I \otimes \frac{d\sigma_{IJ}^{2\to 2}}{dp_t^2} \otimes f_J$$

How to tame the low p_t jet production?

Collinear factorization: $d\sigma_{pp}^{\mathrm{jet}}/dp_t^2 = \sum_{I,J} f_I \otimes \frac{d\sigma_{IJ}^{2\to 2}}{dp_t^2} \otimes f_J$

- low-p_t rise of jet production projects itself on the multiplicity: $N_{pp}^{\mathrm{ch}}(s,Q_0) \propto \langle n_{pp}^{\mathrm{jets}}(s,p_\mathrm{t} > Q_0)\rangle = \sigma_{pp}^{\mathrm{jet}}(s,p_\mathrm{t} > Q_0)/\sigma_{pp}^{\mathrm{inel}}(s)$
    - $\Rightarrow N_{pp}^{\mathrm{ch}}$ explodes for decreasing Q_0

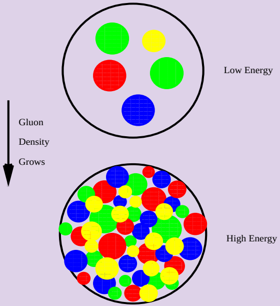
How to tame the low p_t jet production?

Collinear factorization: $d\sigma_{pp}^{\mathrm{jet}}/dp_t^2 = \sum_{I,J} f_I \otimes \frac{d\sigma_{IJ}^{2\to 2}}{dp_t^2} \otimes f_J$

- low-p_t rise of jet production projects itself on the multiplicity: $N_{pp}^{\mathrm{ch}}(s,Q_0) \propto \langle n_{pp}^{\mathrm{jets}}(s,p_\mathrm{t} > Q_0)\rangle = \sigma_{pp}^{\mathrm{jet}}(s,p_\mathrm{t} > Q_0)/\sigma_{pp}^{\mathrm{inel}}(s)$
  - $\Rightarrow N_{pp}^{\mathrm{ch}}$ explodes for decreasing Q_0

Can only be cured by parton saturation?

- parton emission at low x & low q^2: compensated by fusion of partons



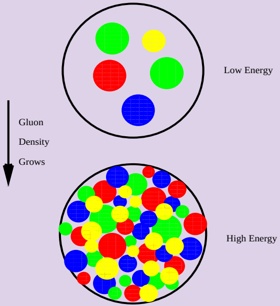
How to tame the low p_t jet production?

Collinear factorization: $d\sigma_{pp}^{\mathrm{jet}}/dp_t^2 = \sum_{I,J} f_I \otimes \frac{d\sigma_{IJ}^{2\to 2}}{dp_t^2} \otimes f_J$

- low-p_t rise of jet production projects itself on the multiplicity: $N_{pp}^{\mathrm{ch}}(s,Q_0) \propto \langle n_{pp}^{\mathrm{jets}}(s,p_\mathrm{t} > Q_0)\rangle = \sigma_{pp}^{\mathrm{jet}}(s,p_\mathrm{t} > Q_0)/\sigma_{pp}^{\mathrm{inel}}(s)$
  - $\Rightarrow N_{pp}^{\mathrm{ch}}$ explodes for decreasing Q_0

Can only be cured by parton saturation?

- parton emission at low x & low q^2: compensated by fusion of partons
- nobody doubts the mechanism
  but does it play the main role here?



How to tame the low p_t jet production?

Saturation: a picture of a crowded bus in mind

- one often speaks about 'unitarity': impossible to squeeze too many partons in a small volume

How to tame the low p_t jet production?

Saturation: a picture of a crowded bus in mind

- one often speaks about 'unitarity': impossible to squeeze too many partons in a small volume
- but: partons are not observable

How to tame the low p_t jet production?

Saturation: a picture of a crowded bus in mind

- one often speaks about 'unitarity': impossible to squeeze too many partons in a small volume
- but: partons are not observable

Observable are (hard) interactions of partons

- here same argument applies: not too many boxing pairs at the same ring

How to tame the low p_t jet production?

Saturation: a picture of a crowded bus in mind

- one often speaks about 'unitarity': impossible to squeeze too many partons in a small volume
- but: partons are not observable

Observable are (hard) interactions of partons

- but: one may have arbitrary many virtual boxers at the ring, if they don't fight (no problem with unitarity)

How to tame the low p_t jet production?

Saturation: a picture of a crowded bus in mind

- one often speaks about 'unitarity': impossible to squeeze too many partons in a small volume
- but: partons are not observable

Observable are (hard) interactions of partons

- but: one may have arbitrary many virtual boxers at the ring, if they don't fight (no problem with unitarity)
- is there a mechanism which can prevent partons from 'fighting each other'?

Dynamical higher twist effects as a potential solution?

Power corrections may fit in the demand...

- can (in principle and to some extent) be treated perturbatively
- come into play at relatively small p_t (suppressed as $1/(p_\mathrm{t}^2)^n$)

Dynamical higher twist effects as a potential solution?

Power corrections may fit in the demand...

- can (in principle and to some extent) be treated perturbatively
- come into play at relatively small p_t (suppressed as $1/(p_\mathrm{t}^2)^n$)

How to proceed in practice?

- basic theoretical approach dates 40 years back *[Shuryak & Vainstein, 1981; Jaffe & Soldate, 1981; Ellis, Furmański & Petronzio, 1982]*
- contributions involve many unknown mutiparton correlators
- generally can't be treated probabilistically

Dynamical higher twist effects as a potential solution?

Power corrections may fit in the demand...

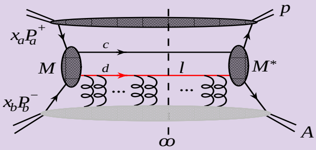
- can (in principle and to some extent) be treated perturbatively
- come into play at relatively small p_t (suppressed as $1/(p_\mathrm{t}^2)^n$)

How to proceed in practice?

- basic theoretical approach dates 40 years back *[Shuryak & Vainstein, 1981; Jaffe & Soldate, 1981; Ellis, Furmański & Petronzio, 1982]*
- contributions involve many unknown mutiparton correlators
- generally can't be treated probabilistically

Promising: coherent multiple scattering in pA *[Qiu & Vitev, 2004, 2006]*

- A-enhanced jet suppression at low p_t & low x in pA



Dynamical higher twist effects as a potential solution?

Power corrections may fit in the demand...

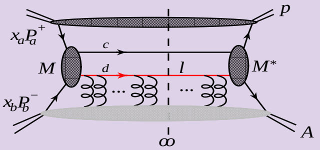
- can (in principle and to some extent) be treated perturbatively
- come into play at relatively small p_t (suppressed as $1/(p_t^2)^n$)

How to proceed in practice?

- basic theoretical approach dates 40 years back *[Shuryak & Vainstein, 1981; Jaffe & Soldate, 1981; Ellis, Furmański & Petronzio, 1982]*
- contributions involve many unknown mutiparton correlators
- generally can't be treated probabilistically

Promising: coherent multiple scattering in pA *[Qiu & Vitev, 2004, 2006]*

- A-enhanced jet suppression at low p_t & low x in pA
- is it applicable/relevant for pp?



Dynamical higher twist effects as a potential solution?

Power corrections may fit in the demand...

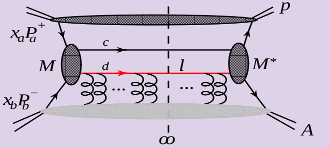
- can (in principle and to some extent) be treated perturbatively
- come into play at relatively small p_t (suppressed as $1/(p_\mathrm{t}^2)^n$)

How to proceed in practice?

- basic theoretical approach dates 40 years back *[Shuryak & Vainstein, 1981; Jaffe & Soldate, 1981; Ellis, Furmański & Petronzio, 1982]*
- contributions involve many unknown mutiparton correlators
- generally can't be treated probabilistically

Promising: coherent multiple scattering in pA *[Qiu & Vitev, 2004, 2006]*

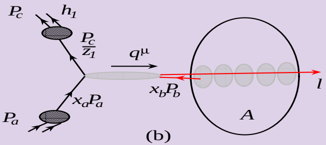
- A-enhanced jet suppression at low p_t & low x in pA
- is it applicable/relevant for pp?
- is a probabilistic treatment (MC implementation) possible?



'Breit' frame: 'head-on' collision with the virtual gluon

- $q^\mu = n^\mu \frac{(p_b \cdot q)}{p_b^+} - x_\mathrm{B}\, p_b^\mu$

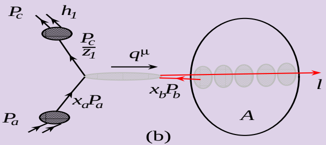
  $(x_\mathrm{B} = -\frac{q^2}{2(p_b \cdot q)},\ p_b^+ = (p_b \cdot n),\ n^2 = 0)$
- low-x parton scattered back



Coherent multiple scattering on soft gluons *[Qiu & Vitev, 2004, 2006]*

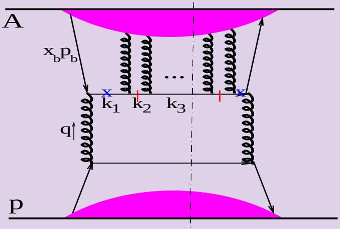
'Breit' frame: 'head-on' collision with the virtual gluon

- $q^\mu = n^\mu \frac{(p_b \cdot q)}{p_b^+} - x_B\, p_b^\mu$
  $(x_B = -\frac{q^2}{2(p_b \cdot q)},\ p_b^+ = (p_b \cdot n),\ n^2 = 0)$
- low-x parton scattered back



Collinear expansion: $\hat{k}_i = \gamma^+ \frac{(p_b \cdot q)}{p_b^+} + \hat{p}_b],(x_b + \sum_{j=1}^{i-1} x_{g_j} - x_B)$

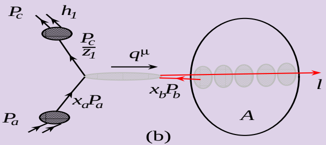
- $\Rightarrow$ sequence of pole (X) and contact (|) propagators (in axial ($A^+ = 0$) gauge)



Coherent multiple scattering on soft gluons *[Qiu & Vitev, 2004, 2006]*

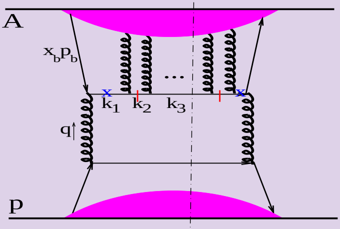
'Breit' frame: 'head-on' collision with the virtual gluon

- $q^\mu = n^\mu \frac{(p_b \cdot q)}{p_b^+} - x_B \, p_b^\mu$
  $(x_B = -\frac{q^2}{2(p_b \cdot q)},\ p_b^+ = (p_b \cdot n),\ n^2 = 0)$
- low-x parton scattered back



Collinear expansion: $\hat{k}_i = \gamma^+ \frac{(p_b \cdot q)}{p_b^+} + \hat{p}_b], (x_b + \sum_{j=1}^{i-1} x_{g_j} - x_B)$

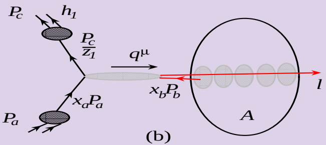
- $\Rightarrow$ sequence of pole (X) and contact (|) propagators (in axial ($A^+ = 0$) gauge)
- contact terms $(\frac{\pm i x_B \hat{p}_b}{q^2})$: no propagation in LC^- direction



Coherent multiple scattering on soft gluons *[Qiu & Vitev, 2004, 2006]*

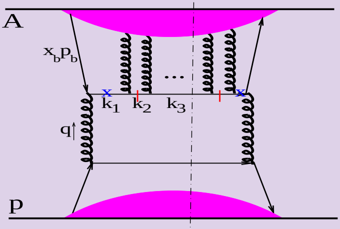
'Breit' frame: 'head-on' collision with the virtual gluon

- $q^\mu = n^\mu \frac{(p_b \cdot q)}{p_b^+} - x_B\, p_b^\mu$
  $\left(x_B = -\frac{q^2}{2(p_b \cdot q)},\; p_b^+ = (p_b \cdot n),\; n^2 = 0\right)$
- low-x parton scattered back



Collinear expansion: $\hat{k}_i = \gamma^+ \frac{(p_b \cdot q)}{p_b^+} + \hat{p}_b], (x_b + \sum_{j=1}^{i-1} x_{g_j} - x_B)$

- $\Rightarrow$ sequence of pole (X) and contact (|) propagators (in axial ($A^+ = 0$) gauge)
- contact terms $\left(\frac{\pm i x_B \hat{p}_b}{q^2}\right)$: no propagation in LC$^-$ direction
- pole terms $\left(\frac{\pm i\gamma^+}{2p^+(x_b + \sum_{j=1}^{i-1} x_{g_j} - x_B) \pm i\varepsilon}\right)$: propagation over long distances

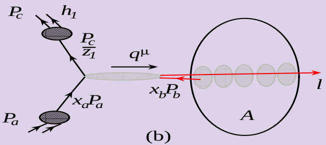


Coherent multiple scattering on soft gluons *[Qiu & Vitev, 2004, 2006]*

'Breit' frame: 'head-on' collision with the virtual gluon

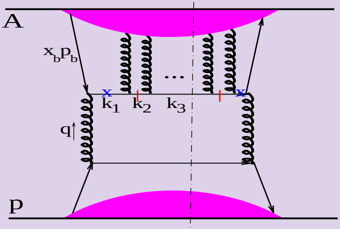
- $q^\mu = n^\mu \frac{(p_b \cdot q)}{p_b^+} - x_B\, p_b^\mu$

  $(x_B = -\frac{q^2}{2(p_b \cdot q)},\ p_b^+ = (p_b \cdot n),\ n^2 = 0)$
- low-x parton scattered back



Collinear expansion: $\hat{k}_i = \gamma^+ \frac{(p_b \cdot q)}{p_b^+} + \hat{p}_b],(x_b + \sum_{j=1}^{i-1} x_{g_j} - x_B)$

- $\Rightarrow$ sequence of pole (X) and contact (|) propagators (in axial ($A^+ = 0$) gauge)
- contact terms $(\frac{\pm i x_B \hat{p}_b}{q^2})$: no propagation in LC$^-$ direction
- pole terms $(\frac{\pm i \gamma^+}{2p^+(x_b + \sum_{j=1}^{i-1} x_{g_j} - x_B) \pm i\varepsilon})$: propagation over long distances



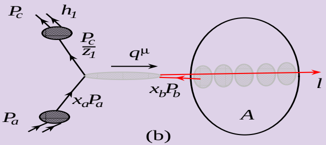
- $\Rightarrow$ multiple coherent scattering on correlated virtual gluon

Coherent multiple scattering on soft gluons *[Qiu & Vitev, 2004, 2006]*

'Breit' frame: 'head-on' collision with the virtual gluon

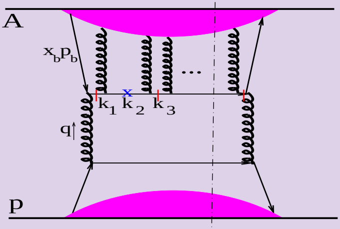
- $q^\mu = n^\mu \frac{(p_b \cdot q)}{p_b^+} - x_B\, p_b^\mu$

  $(x_B = -\frac{q^2}{2(p_b \cdot q)},\ p_b^+ = (p_b \cdot n),\ n^2 = 0)$
- low-x parton scattered back



Alternative: contact term between scattered parton & 1st gluon

- ⇒ 1st gluon belongs to the same nucleon
- ⇒ subdominant contribution (no A-enhancement)



Coherent multiple scattering on soft gluons [Qiu & Vitev, 2004, 2006]

Power corrections to $d\sigma_{pp}^{\text{jet}}/dp_t^2 = \sum_{I,J} f_I \otimes \frac{d\sigma_{IJ}^{2\to 2}}{dp_t^2} \otimes f_J$

$$f_I(x, Q^2) \to f_I(x, Q^2) + \sum_{n=1}^{\infty} \frac{(-x C_I \pi^2 \alpha_s / Q^2)^n}{n!} \frac{d^n T_I^{(n+1)}(x)}{d^n x}$$

- $C_q = 4/3, \ C_g = 3$

$$T_q^{(2)}(x) = \int \frac{dy^-}{4\pi} \frac{dy_{g_1}^- \, dy_{g_2}^-}{2\pi} e^{ip^+ xy^-} \Theta(y_{g_2}^-), \Theta(y_{g_1}^- - y^-)$$
$$\times d_{\alpha\beta}^{\perp} \langle p | \overline{\psi}(0) \gamma^+ F_+^{\alpha}(y_{g_2}^-) F_+^{\beta}(y_{g_1}^-) \psi(y^-) | p \rangle$$

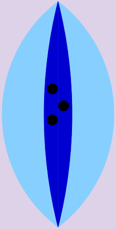
$$T_g^{(2)}(x) = \int \frac{dy^-}{4\pi} \frac{dy_{g_1}^- \, dy_{g_2}^-}{2\pi} e^{ip^+ xy^-} \Theta(y_{g_2}^-), \Theta(y_{g_1}^- - y^-)$$
$$\times d_{\alpha\beta}^{\perp} d_{\mu\nu}^{\perp} \langle p | F_+^{\mu}(0) \gamma^+ F_+^{\alpha}(y_{g_2}^-) F_+^{\beta}(y_{g_1}^-) F_+^{\nu}(y^-) | p \rangle$$

- higher powers - inserting more gluon pairs

Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

Is the approach of Qiu & Vitev applicable/relevant for pp?

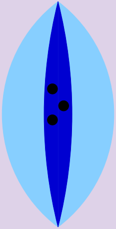
- Lorentz contraction acts differently on partons of different momenta
  - valence quarks: contained in a narrow 'pancake'
  - low-x gluons & sea quarks: spread over large distances $\propto 1/(xp)$



Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

Is the approach of Qiu & Vitev applicable/relevant for pp?

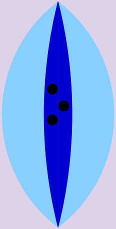
- Lorentz contraction acts differently on partons of different momenta
  - valence quarks: contained in a narrow 'pancake'
  - low-x gluons & sea quarks: spread over large distances $\propto 1/(xp)$
- $\Rightarrow$ space-time picture - similar to pA (AA)



Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

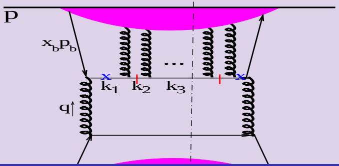
Is the approach of Qiu & Vitev applicable/relevant for pp?

- Lorentz contraction acts differently on partons of different momenta
  - valence quarks: contained in a narrow 'pancake'
  - low-x gluons & sea quarks: spread over large distances $\propto 1/(xp)$
- $\Rightarrow$ space-time picture - similar to pA (AA)



Dominant power corrections: expected from same kinds of graphs

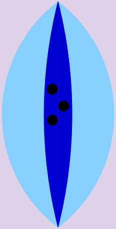
- pole contribution for k_1: the struck low-x parton fully probes the gluon 'cloud'
  - $\Rightarrow$ scatters coherently on correlated gluon pairs



Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

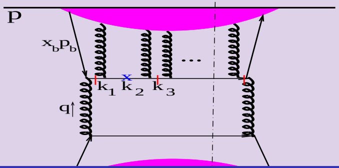
Is the approach of Qiu & Vitev applicable/relevant for pp?

- Lorentz contraction acts differently on partons of different momenta
  - valence quarks: contained in a narrow 'pancake'
  - low-x gluons & sea quarks:
    spread over large distances $\propto 1/(xp)$
- $\Rightarrow$ space-time picture - similar to pA (AA)



Contact term between the struck parton & 1st gluon: subdominant

- the struck low-x parton probes a tiny fraction of the gluon 'cloud'



Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

One needs a model for multi-parton correlators $T_q^{(n)}$, $T_g^{(n)}$

$$
\begin{aligned}
T_q^{(2)}(x) &= \int \frac{dy^-}{4\pi} \frac{dy_{g_1}^- \, dy_{g_2}^-}{2\pi} e^{ip^+ x y^-} \, \Theta(y_{g_2}^-), \Theta(y_{g_1}^- - y^-) \\
&\times \langle p | \overline{\psi}(0) \gamma^+ F_+^{\alpha}(y_{g_2}^-) F_{\alpha}^+(y_{g_1}^-) \psi(y^-) | p \rangle
\end{aligned}
$$

Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

One needs a model for multi-parton correlators $T_q^{(n)}$, $T_g^{(n)}$

$$
\begin{aligned}
T_q^{(2)}(x) \quad &= \quad \int \frac{dy^-}{4\pi} \frac{dy^-_{g_1}\, dy^-_{g_2}}{2\pi}\, e^{ip^+ xy^-}\, \Theta(y^-_{g_2}), \Theta(y^-_{g_1} - y^-) \\
&\times \quad \langle p | \overline{\psi}(0)\, \gamma^+\, F_+^{\alpha}(y^-_{g_2})\, F_{\alpha}^{+}(y^-_{g_1})\, \psi(y^-) | p \rangle
\end{aligned}
$$

- formally $T_q^{(2)}(x) \propto \lim_{x_g \to 0} x_g\, F_{qg}^{(2)}(x, x_g, \Delta b = 0)$

Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

One needs a model for multi-parton correlators $T_q^{(n)}$, $T_g^{(n)}$

$$
\begin{aligned}
T_q^{(2)}(x) &= \int \frac{dy^-}{4\pi} \frac{dy^-_{g_1}\, dy^-_{g_2}}{2\pi} e^{ip^+ xy^-}\, \Theta(y^-_{g_2}), \Theta(y^-_{g_1} - y^-) \\
&\times \langle p|\overline{\psi}(0)\gamma^+ F^{\alpha}_{+}(y^-_{g_2}) F^{+}_{\alpha}(y^-_{g_1}) \psi(y^-)|p\rangle
\end{aligned}
$$

- formally $T_q^{(2)}(x) \propto \lim_{x_g \to 0} x_g F_{qg}^{(2)}(x, x_g, \Delta b = 0)$
  - interpreting $T_q^{(2)}(x)$ as ${}^{(2)}$GPD (DPD) $F_{qg}^{(2)}$?
  - what to use for x_g and Q_g^2?

Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

One needs a model for multi-parton correlators $T_q^{(n)}$, $T_g^{(n)}$

$$T_q^{(2)}(x) = \int \frac{dy^-}{4\pi} \frac{dy_{g_1}^- \, dy_{g_2}^-}{2\pi} e^{ip^+ xy^-} \Theta(y_{g_2}^-), \Theta(y_{g_1}^- - y^-) \times \langle p | \bar{\psi}(0) \gamma^+ F_+^{\alpha}(y_{g_2}^-) F_{\alpha}^+(y_{g_1}^-) \psi(y^-) | p \rangle$$

- formally $T_q^{(2)}(x) \propto \lim_{x_g \to 0} x_g F_{qg}^{(2)}(x, x_g, \Delta b = 0)$
  - interpreting $T_q^{(2)}(x)$ as $^{(2)}$GPD (DPD) $F_{qg}^{(2)}$?
  - what to use for x_g and Q_g^2?
- $x_g \sim \langle k_\perp^2 \rangle / (x^- s)$, with $k_\perp^2 \sim \Lambda_{\mathrm{QCD}}^2$?

Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

One needs a model for multi-parton correlators $T_q^{(n)}$, $T_g^{(n)}$

$$T_q^{(2)}(x) = \int \frac{dy^-}{4\pi} \frac{dy_{g_1}^- \, dy_{g_2}^-}{2\pi} e^{ip^+ xy^-} \Theta(y_{g_2}^-), \Theta(y_{g_1}^- - y^-)$$
$$\times \langle p | \bar{\psi}(0) \gamma^+ F_+^{\alpha}(y_{g_2}^-) F_{\alpha}^+(y_{g_1}^-) \psi(y^-) | p \rangle$$

- formally $T_q^{(2)}(x) \propto \lim_{x_g \to 0} x_g F_{qg}^{(2)}(x, x_g, \Delta b = 0)$
  - interpreting $T_q^{(2)}(x)$ as ${}^{(2)}$GPD (DPD) $F_{qg}^{(2)}$?
  - what to use for x_g and Q_g^2?
- $x_g \sim \langle k_\perp^2 \rangle / (x^- s)$, with $k_\perp^2 \sim \Lambda_{\mathrm{QCD}}^2$?
- 'brute force': $Q_g^2 \to Q_0^2$, $x_g \to Q_0^2/(x^- s)$

Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

One needs a model for multi-parton correlators $T_q^{(n)}$, $T_g^{(n)}$

$$T_q^{(2)}(x) = \int \frac{dy^-}{4\pi} \frac{dy_{g_1}^- \, dy_{g_2}^-}{2\pi} e^{ip^+ xy^-} \Theta(y_{g_2}^-), \Theta(y_{g_1}^- - y^-) \times \langle p|\bar{\psi}(0)\gamma^+ F_+^{\alpha}(y_{g_2}^-) F_{\alpha}^+(y_{g_1}^-) \psi(y^-)|p\rangle$$

- formally $T_q^{(2)}(x) \propto \lim_{x_g \to 0} x_g F_{qg}^{(2)}(x, x_g, \Delta b = 0)$
  - interpreting $T_q^{(2)}(x)$ as $^{(2)}$GPD (DPD) $F_{qg}^{(2)}$?
  - what to use for x_g and Q_g^2?
- $x_g \sim \langle k_\perp^2 \rangle / (x^- s)$, with $k_\perp^2 \sim \Lambda_{\mathrm{QCD}}^2$?
- 'brute force': $Q_g^2 \to Q_0^2$, $x_g \to Q_0^2/(x^- s)$
- $\Rightarrow$ $T_q^{(2)}(x) \to K_{\mathrm{HT}}\, x_g F_{qg}^{(2)}(x, x_g, \mu_{\mathrm{F}}^2, Q_0^2, \Delta b = 0)$
  $T_g^{(2)}(x) \to K_{\mathrm{HT}}\, x_g F_{gg}^{(2)}(x, x_g, \mu_{\mathrm{F}}^2, Q_0^2, \Delta b = 0)$

Coherent multiple scattering on soft gluons: application to pp & MC implementation *[SO & Bleicher, 2019]*

Lowest power correction to $\sigma_{pp}^{\mathrm{jet}}$

$$\Delta^{(2)} \frac{d\sigma_{pp}^{\mathrm{jet}}}{dp_t^2} = \sum_{I,J} \int dx^+ dx^- \, \frac{K_{\mathrm{HT}}\, \pi^2 \alpha_s}{\hat{t}} \frac{d\sigma_{IJ}^{2\to 2}}{dp_t^2}$$

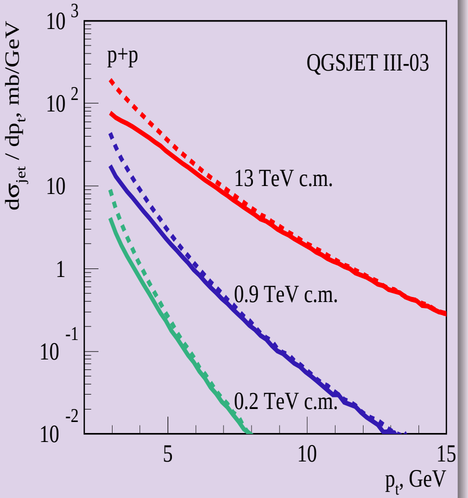
$$\times \left[C_I x_g^+ F_{Ig}(x^+, x_g^+, \mu_{\mathrm{F}}^2, Q_0^2, \vec{0}) \, f_J(x^-, \mu_{\mathrm{F}}^2) + C_J x_g^- F_{Jg}(x^-, x_g^-, \mu_{\mathrm{F}}^2, Q_0^2, \vec{0}) \, f_I(x^+, \mu_{\mathrm{F}}^2) \right]$$

- $x_g^{\pm} = Q_0^2 / (x^{\mp} s)$
- higher powers - similarly
- corrections vanish for high p_t

Numerical results

HT effects: impact on (mini)jet rate

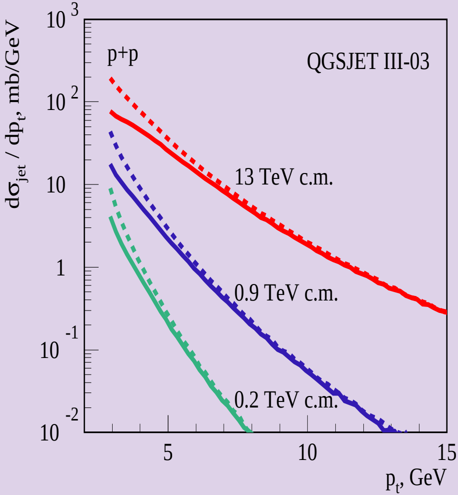
- (mini)jet production suppressed at low p_t
- the effect fades away at high p_t
- stronger impact at higher energies



- $K_{HT} = 4$, $Q_0^2 = 2$ GeV^2 ($\mu_F^2 = p_t^2/4 \Rightarrow p_{t,cut}^2 = 8$ GeV^2)

HT effects: impact on (mini)jet rate

- (mini)jet production suppressed at low p_t
- the effect fades away at high p_t
- stronger impact at higher energies

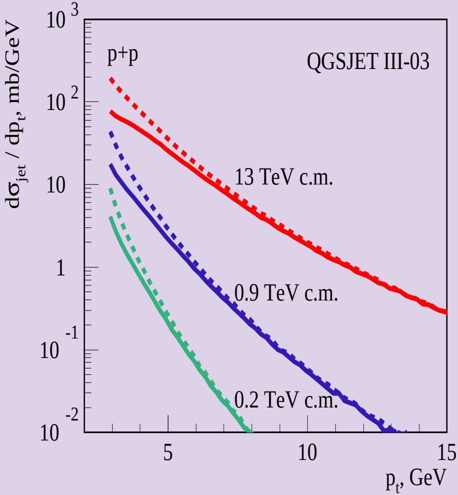


- $K_{HT} = 4$, $Q_0^2 = 2$ GeV^2 ($\mu_F^2 = p_t^2/4 \Rightarrow p_{t,cut}^2 = 8$ GeV^2)

Numerical results

HT effects: impact on (mini)jet rate

- (mini)jet production suppressed at low p_t
- the effect fades away at high p_t
- stronger impact at higher energies

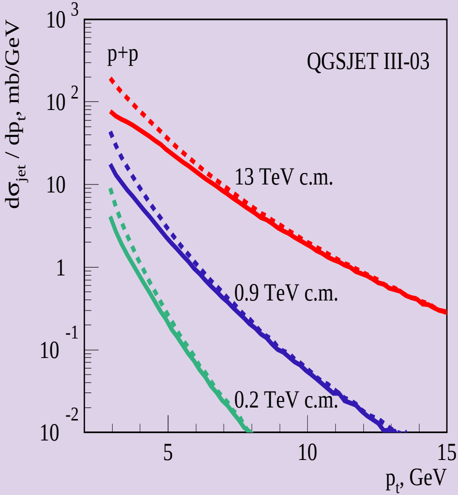


- $K_{\rm HT} = 4$, $Q_0^2 = 2\ {\rm GeV}^2$ ($\mu_F^2 = p_t^2/4 \Rightarrow p_{t,\rm cut}^2 = 8\ {\rm GeV}^2$)

Numerical results

HT effects: impact on (mini)jet rate

- (mini)jet production suppressed at low p_t
- the effect fades away at high p_t
- stronger impact at higher energies
- $\Rightarrow$ qualitatively similar to s-dependent Q_0-cutoff

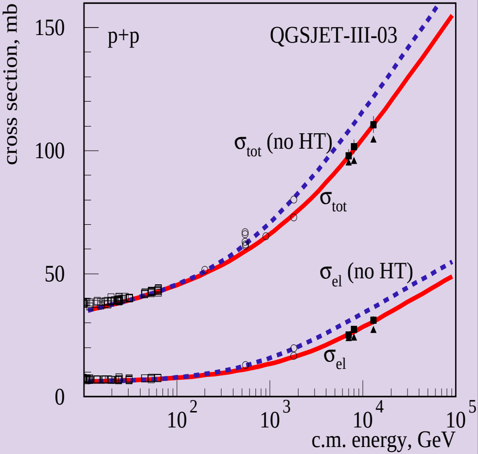


- $K_{HT} = 4$, $Q_0^2 = 2$ GeV^2 ($\mu_F^2 = p_t^2/4 \Rightarrow p_{t,cut}^2 = 8$ GeV^2)

Numerical results

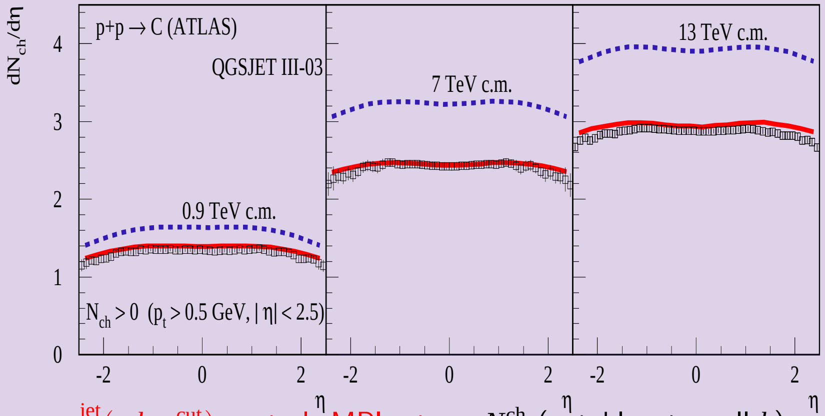
HT effects: sizable impact on $\sqrt{s}$-dependence of $\sigma_{pp}^{tot/el}$

- taming the $\sqrt{s}$-rise of $\chi_{pp}^{jet}(s,b,p_t^{cut})$ $\Rightarrow$ of the proton 'blackness'



Numerical results

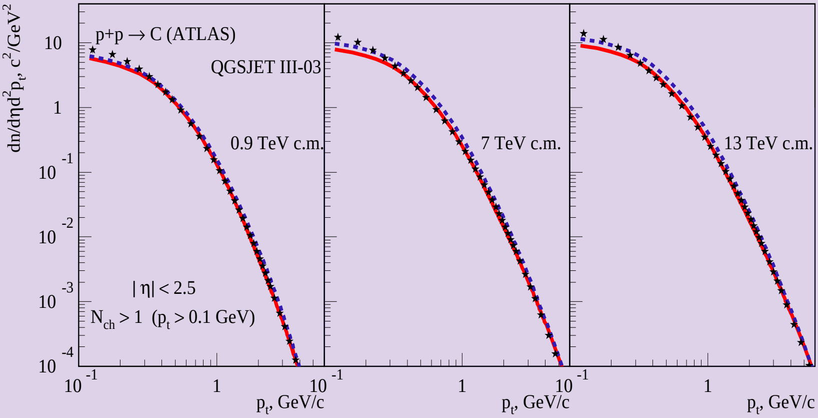
Stronger impact on $\sqrt{s}$-dependence of $dN^{ch}_{pp}/d\eta$ $(N_{ch}(p_t > 0.5) \geq 1)$



- $\chi^{jet}_{pp}(s, b, p^{cut}_t)$ controls MPI rate $\Rightarrow N^{ch}_{pp}$ (notably, at small b)

Numerical results

$\sqrt{s}$-dependence of dN^{ch}_{pp}/dp_t



- reduction of low p_t production due to the minijet suppression
- the effect is somewhat masked by soft production

Outlook

1. (Mini)jet production at (moderately) low p_t may be suppressed by power corrections
2. Phenomenological implementation in QGSJET-III of the approach of Qiu & Vitev:
   - tames the energy-rise of both $\sigma_{pp}^{\mathrm{tot/inel}}$ and N_{pp}^{ch}
   - qualitatively resembles the effect of an s-dependent p_t-cutoff for minijet production
   - however, a dynamical treatment: e.g. a stronger suppression at small b
   - the strength of the effects is governed by the low-x behavior of the gluon GPD

Outlook

1. (Mini)jet production at (moderately) low p_{t} may be suppressed by power corrections
2. Phenomenological implementation in QGSJET-III of the approach of Qiu & Vitev:
   - tames the energy-rise of both $\sigma_{pp}^{\mathrm{tot/inel}}$ and N_{pp}^{ch}
   - qualitatively resembles the effect of an s-dependent p_{t}-cutoff for minijet production
   - however, a dynamical treatment: e.g. a stronger suppression at small b
   - the strength of the effects is governed by the low-x behavior of the gluon GPD

Outlook

1. (Mini)jet production at (moderately) low p_t may be suppressed by power corrections
2. Phenomenological implementation in QGSJET-III of the approach of Qiu & Vitev:
   - tames the energy-rise of both $\sigma_{pp}^{tot/inel}$ and N_{pp}^{ch}
   - qualitatively resembles the effect of an s-dependent p_t-cutoff for minijet production
   - however, a dynamical treatment: e.g. a stronger suppression at small b
   - the strength of the effects is governed by the low-x behavior of the gluon GPD

Outlook

1. (Mini)jet production at (moderately) low p_t may be suppressed by power corrections
2. Phenomenological implementation in QGSJET-III of the approach of Qiu & Vitev:
   - tames the energy-rise of both $\sigma_{pp}^{\mathrm{tot/inel}}$ and N_{pp}^{ch}
   - qualitatively resembles the effect of an s-dependent p_t-cutoff for minijet production
   - however, a dynamical treatment: e.g. a stronger suppression at small b
   - the strength of the effects is governed by the low-x behavior of the gluon GPD

Outlook

1. (Mini)jet production at (moderately) low p_t may be suppressed by power corrections
2. Phenomenological implementation in QGSJET-III of the approach of Qiu & Vitev:
   - tames the energy-rise of both $\sigma_{pp}^{tot/inel}$ and N_{pp}^{ch}
   - qualitatively resembles the effect of an s-dependent p_t-cutoff for minijet production
   - however, a dynamical treatment: e.g. a stronger suppression at small b
   - the strength of the effects is governed by the low-x behavior of the gluon GPD