High Energy Factorization plus Parton Showers

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Work in collaboration with
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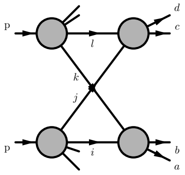
What is Double Parton Scattering ?

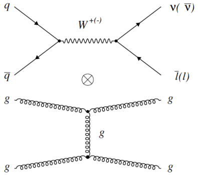
Introducing Double Parton Scattering



Two hard scatterings in the same hadron-hadron collision

 # scatterings > 2 not covered here

DPS in CGC ⇒ A. Kovner's talk



$$\sigma^D = \sum_{i,j,k,l} \mathcal{S}^{ij}_{kl} \int \Gamma_{ij}(x_1, x_2, b; t_1, t_2)\, \Gamma_{kl}(x'_1, x'_2, b; t_1, t_2)\, \hat{\sigma}(x_1, x'_1)\, \hat{\sigma}(x_2, x'_2)\, dx_1 dx_2 dx'_1 dx'_2 d^2 b$$

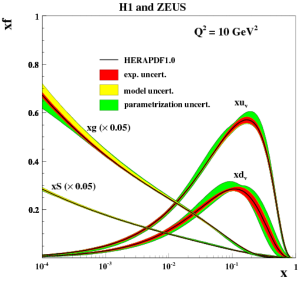
Usual assumption : $\Gamma_{ij}(x_1, x_2, b; t_1, t_2) = D^{ij}_h(x_1, x_2; t_1, t_2)\, F^{ij}(b) = D^{ij}_h(x_1, x_2; t_1, t_2)\, F(b)$

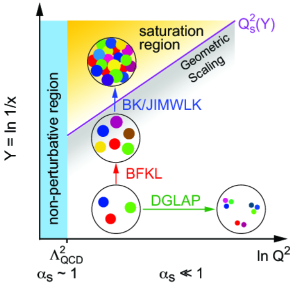
- Longitudinal correlations, most often ignored or assumed to be negligible, especially at small x : $D^{ij}_h(x_1, x_2; t_1, t_2) = D^i(x_1; t_1)\, D^j(x_2; t_2)$
- Transverse correlation, assumed to be independent of the parton species, taken into account via $\sigma_{eff}^{-1} = \int d^2 b\, F(b)^2 \approx (15mb)^{-1}$ (CDF, D0, LHCb . . .)

The so-called *pocket formula*: $\sigma^D = \dfrac{1}{\sigma_{eff}} \sum_{A,B} \dfrac{\sigma^A \sigma^B}{1 + \delta_{AB}}$

Paver, Treleani, Nuovo Cim. A70 (1982) 215, Mekhfi, Phys. Rev. D32 (1985) 2371.
Diehl, Ostermeier, Schäfer, Gaunt, Plößl, Schönwald
JHEP 1203 (2012) 089, JHEP 1601 (2016) 076, arXiv:1702.06486

Hunting for Double Parton Scattering: an acrobatics game





1. We do not know how to fully treat double parton correlations.
2. Too high x's miss DPS, too small x's hit the UE region. We cannot cleanly study DPS in the highly perturbative regime.
3. DPS is still power-suppressed w.r.t usual Single Parton Scattering: $\frac{\sigma_{DPS}}{\sigma_{SPS}} \sim \frac{\Lambda^2}{Q^2}$

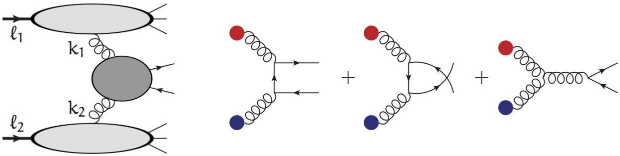
How these issues are addressed:

1. **NP correlations are a second order effect at the pheno state of the art level. Community is working on them to (also) better constrain σ_{eff} from theory.**
2. **The kinematic window opened by the LHC allows to go for relatively small-x at intermediate energies ⇒ High Energy Factorization**
3. **Not absolute rates, but rather the shape of carefully selected observables.**

High Energy Factorization and amplitudes

High Energy Factorization: more degrees of freedom

High Energy Factorization *(Catani,Ciafaloni,Hautmann, 1991 / Collins,Ellis, 1991)*



$$\sigma_{h_1,h_2\to q\bar{q}} = \int d^2k_{1\perp}\,d^2k_{2\perp}\,\frac{dx_1}{x_1}\,\frac{dx_2}{x_2}\,f_g(x_1,k_{1\perp})\,f_g(x_2,k_{2\perp})\,\hat{\sigma}_{gg}\,(m,x_1,x_2,s,k_{1\perp},k_{2\perp})$$

where the f_g's are the gluon densities, obeying **BFKL, BK, CCFM** equations.
Non negligible transverse momentum is associated to small x physics.

Possibly suitable to the smaller-x window opened up by the LHC, especially for intermediate energy events.

The initial state kinematic is exact.

Progress to connect TMD evolution and low-x evolution (this approach)

Applies if $s >> P_\perp^2 >> \Lambda^2$

Momentum parameterization:

$$k_1^\mu = x_1\,l_1^\mu + k_{1\perp}^\mu \quad , \quad k_2^\mu = x_2\,l_2^\mu + k_{2\perp}^\mu$$

$$l_i^2 = 0, \quad l_i\cdot k_i = 0, \quad k_i^2 = -k_{i\perp}^2, \quad i = 1,2$$

Novel results and Tools in High Energy Factorization QCD for hadron-hadron collisions

- With growing number of legs, it is necessary to figure out practical ways to compute amplitudes efficiently. A promising possibility is the BCFW (Britto-Cachazo-Feng-Witten) recursion relation, originally discovered for on-shell QCD amplitudes and extended to off-shell gluon amplitudes in *A. van Hameren, JHEP 1407 (2014) 138*
- A general analysis extending the modified BCFW to amplitudes with fermion pairs has been developed in *A. van Hameren, MS JHEP 1507 (2015) 010* and *A. van Hameren, K. Kutak, MS, JHEP 1702 (2017) 009*
- Numerical implementation and cross-checks are done and always successful. A program exists implementing Berends-Giele recursion relation, *A. van Hameren, M. Bury, Comput.Phys.Commun. 196 (2015) 592-598*
- **The big player for phenomenology: *KaTie***, a parton level event generator for k_T-dependent initial states *A. van Hameren, arXiv:1611.00680*. Once interfaced with the **AvHlib** library by the same author and supplied with the desired TMDs, it can compute cross sections in HEF for any process in the Standard Model, providing automatised phase space optimisation (**KALEU**). Published papers: Kutak, Maciula, Szczurek, MS, van Hameren, JHEP 1604 (2016) 175, Phys.Rev. D94 (2016) no.1, 014019....

What is the most natural next step ?

- Loop calculations for hadron-hadron too demanding so far (but A. van Hameren is on the hunt $\Rightarrow$ **see P. Kotko's talk**)
- What is the next best thing that we can do without loops: LO + PS, just as it is done in the ordinary collinear Monte Carlo programs: Pythia, Herwig, Sherpa.
- **CASCADE** already on the market (by Hannes Jung). Previous scope: CCFM (only-gluons) angular-ordered parton showers; mostly developed for DIS and some $pp(\bar{p}) \to X$ processes.

THE IDEA:

use KaTie to produce LHE files in full HEF kinematics and feed them into CASCADE

Difference w.r.t. ordinary collinear generators:

The exact kinematics of the initial state kills the need to perform initial state boosts and rotations in order to accommodate for the initial state transverse momentum.

Instead, this comes for free and in a fully gauge invariant way from the hard matrix element in High Energy Factorization.

Adding Parton Showers to High Energy Factorization: When KaTie met CASCADE

Matching the hard off-shell matrix elements with parton showers:

- **KaTie** (A. van Hameren) : arXiv:1611.00680 Monte Carlo program for tree-level calculations of *any process within the Standard Model*; initial-state partons either on-shell or off-shell.
- u **and** d initial state quarks, final states with all the $N_f = 5$ lightest flavours, massless quark approximation.
- **Martin-Ryskin-Watt prescription** to generate the k_T-dependence from the collinear set CT10nlo
- **CASCADE-2.4.07**: Comput.Phys.Commun. 143 (2002) 100-111 . All-flavour TMD evolution, no coherence assumption, backward evolution of the initial state k_T.
- Hadronization performed via **Pythia 6**
- jets are reconstructed via the anti-k_T algorithm with **FastJet**: Eur.Phys.J. C72 (2012) 1896

Comparing integrated MRW and collinear PDFs

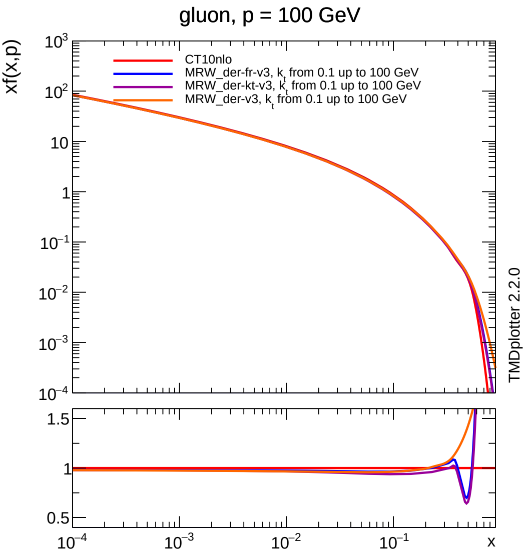
Martin, Ryskin and Watt on the prescription for obtaining unintegrated PDFs and its extension to NLO:

**Phys.Rev. D70 (2004) 014012, Erratum: Phys.Rev. D70 (2004) 079902
Eur.Phys.J. C66 (2010) 163-172**

**Idea: hard k_T emissions can come from the showering.
Not the same ordering as in the DGLAP framework:
angular ordering instead**

$$\int \mathbf{d^2k_T}\, \mathcal{F}(\mathbf{x}, \mathbf{k}_\perp, \mu) = \mathbf{f}(\mathbf{x}, \mu) \Rightarrow$$

Mismatch limited to a region which contributes very little to the cross section for 4 jets.



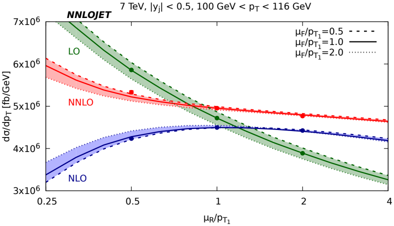
Phenomenological results and the scale choice problem

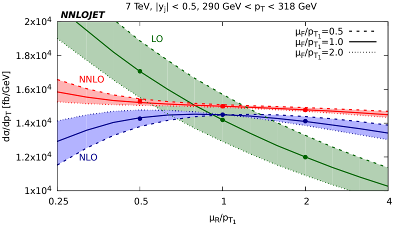
The problem of scale choice: simply stated, very puzzling

$$\sigma = \sum_{ab} \int_{\zeta_a}^{1} dx_a \int_{\zeta_b}^{1} dx_b \, f_a(x_a, \mu_F) \, , f_b(x_b, \mu_F) \, \sigma_{ab}(\alpha_s(\mu_R^2), \mu_R^2)$$

How to choose the renormalization and factorization scale optimally ?

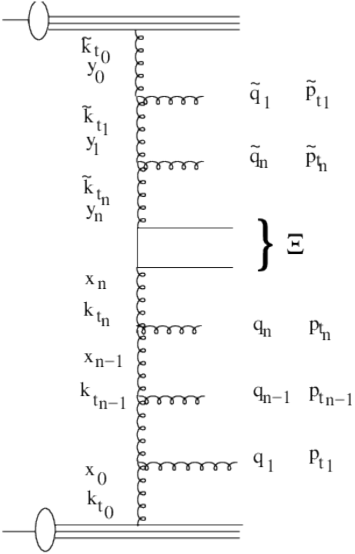
Better question: what is a reliable estimate of the theoretical uncertainty ?





- With many NNLO calculations, interesting debate was sparked.
- The inclusive jet NNLO calculation ($\mu_R = \mu_F = p_T$) (Currie,Glover,Pires, Phys.Rev.Lett. 118 (2017) no.7, 072002) has some tension with the NLO result.
- The NNLO dijet calculation does not present the same kind of problem (Gehrmann, Glover et al, arXiv:1705.10271)

A natural scale choice for angular-ordered evolution: example for quark-quark scattering: Eur.Phys.J. C70 (2010)



$$p_q + p_{\bar{q}} = \Upsilon(p^{(1)} + \Xi p^{(2)}) + Q_t$$

$$Y = \frac{1}{2}\log\left(\frac{E+p_z}{E-p_z}\right) = \frac{1}{2}\log\left(\frac{1}{\Xi}\right)$$

$$\begin{aligned} E &= E_q + E_{\bar{q}}\,, p_z = p_{q\,z} + p_{\bar{q}\,z} \\ &\Rightarrow E + p_z = \Upsilon\sqrt{s}\,, E - p_z = \Upsilon\Xi\sqrt{s} \end{aligned}$$

Gluon cascade momenta

$$\begin{aligned} p_i &= \upsilon_i(p^{(1)} + \xi_i p^{(2)}) + p_{ti}\,, \\ \xi_i &= \frac{p_{ti}^2}{s\upsilon_i^2}\,, \upsilon_i = (1-z_i)x_{i-1}\,, x_i = z_i x_{i-1} \end{aligned}$$

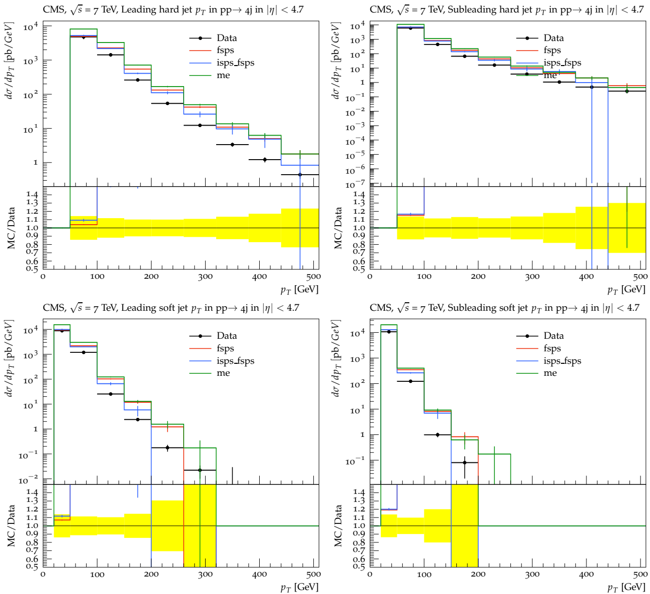
Angular ordered region:

$$\xi_0 < \xi_1 < \cdots < xi_n < \Xi$$

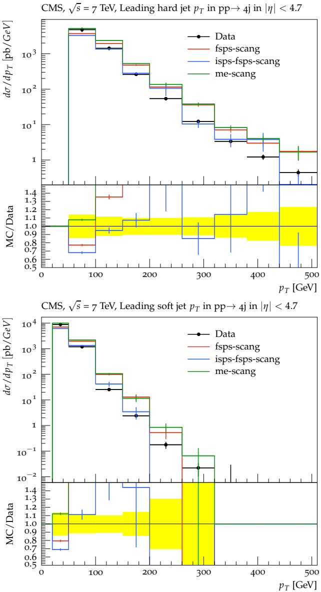
$$z_{i-1}q_{i-1} < q_i\,, q_i = x_{i-1}\sqrt{s\xi_i} = \frac{p_{ti}}{1-z_i}$$

$$\mu^2 \equiv Q^2 = \Upsilon^2\,\Xi\,s = \hat{s} + Q_t^2 = (p_q + p_{\bar{q}})^2 + Q_t^2$$

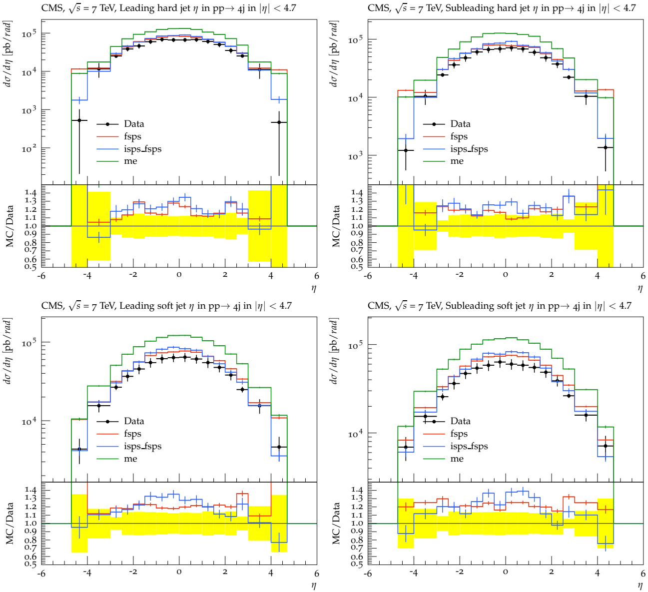
4 jets with ordinary scale choice, **no tuning**: p_T spectra



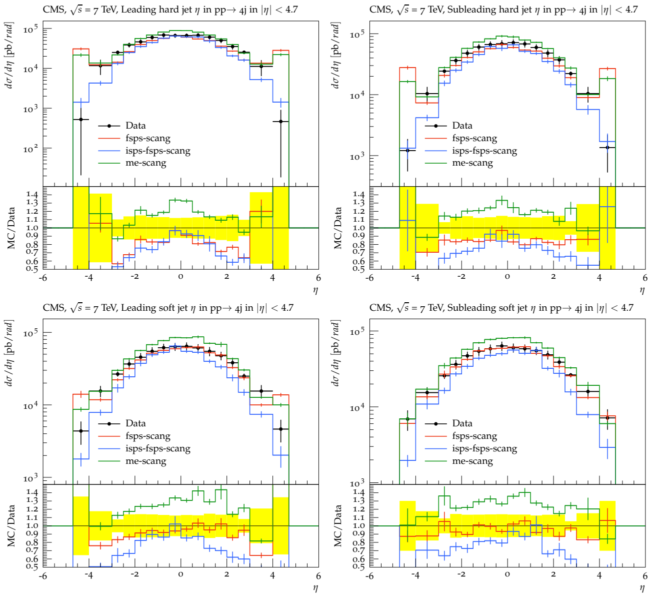
4 jets with "angular" scale choice, **no tuning**:: p_T spectra



4 jets with ordinary scale choice, **no tuning**:: rapidity spectra



4 jets with "angular", **no tuning**:: rapidity spectra



DPS for 4-jets: the case of the CMS data

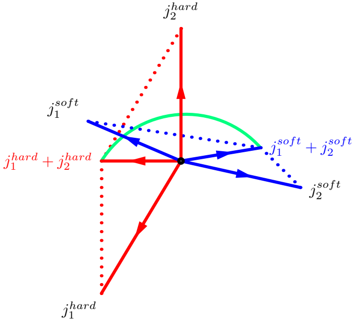
$p_T(1,2) \geq 50\,\text{GeV}\,,\; p_T(3,4) \geq 20\,\text{GeV}\,,\; |\eta| \leq 4.7\,,\; I$

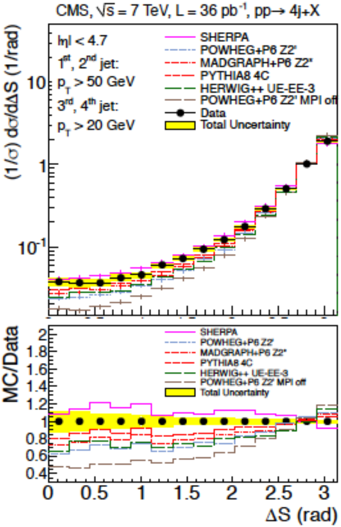
$$\Delta S = \arccos\left(\frac{\vec{p}_T(j_1^{\text{hard}}, j_2^{\text{hard}}) \cdot \vec{p}_T(j_1^{\text{soft}}, j_2^{\text{soft}})}{|\vec{p}_T(j_1^{\text{hard}}, j_2^{\text{hard}})| \cdot |\vec{p}_T(j_1^{\text{soft}}, j_2^{\text{soft}})|}\right)$$

$\vec{p}_T(j_i, j_k) \equiv p_{T,i} + p_{T,j}$

Expected to be flat for DPS

Not well described by available tools

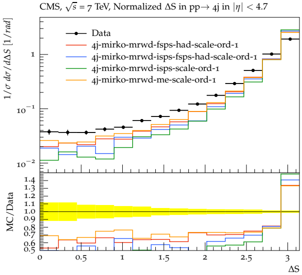


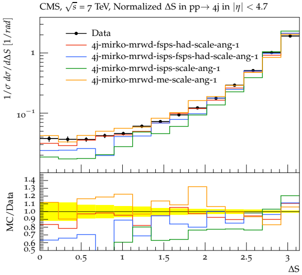


ΔS: HEF with MRW plus showers

$$\Delta S = \arccos\left(\frac{\vec{p}_T(j_1^{\text{hard}}, j_2^{\text{hard}})\cdot \vec{p}_T(j_1^{\text{soft}}, j_2^{\text{soft}})}{|\vec{p}_T(j_1^{\text{hard}}, j_2^{\text{hard}})|\cdot|\vec{p}_T(j_1^{\text{soft}}, j_2^{\text{soft}})|}\right),$$

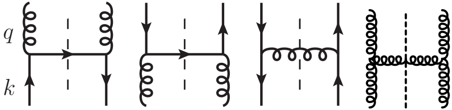
- Pure tree level: K. Kutak, R. Maciula, MS, A. Szczurek, A. van Hameren, JHEP 1604 (2016) 175
- Jets equally hard or harder than those from the hard matrix element can come from the showering.
- The predictions without parton showers roughly agrees with the data
- Once we include showers and full remnant treatment, we see that we recover a similar result as in the collinear case.
- We conclude that, in this ME+PS scenario, High energy Factorization seems to suggest the need for MPI's .





What will be next: going beyond CCMF

Improving the CCFM evolution: splitting functions à la Curci-Furmanski-Petronzio: Hentschinski et al, JHEP 1601 (2016) 181



Real contributions to generalised TMD à la Curci-Furmanski-Petronzio

- If light-cone gauge $\Rightarrow$ collinear singularities only from upper propagators
- Divergences isolated by the use of suitable projectors in spin and momentum space.
- Checked equivalence between Lipatov's vertices and spinor helicity formalism in the cases above.

$$\Gamma'^{\,\mu}_{q^*g^*q}(q,k,p') = i\,g\,t^a\,d^{\mu\lambda}(k)\left(\gamma_\lambda - \frac{n_\lambda}{k\cdot n}\,\not{q}\right)$$

$$\Gamma'^{\,\mu}_{g^*q^*q}(q,k,p') = i\,g\,t^a\,d^{\mu\lambda}(q)\left(\gamma_\lambda - \frac{p_\lambda}{p\cdot q}\,\not{k}\right)$$

$$\Gamma^{\mu}_{q^*q^*g}(q,k,p') = igt^a\left(\gamma^\mu - \frac{p^\mu}{p\cdot p'}\not{k} + \frac{n^\mu}{n\cdot p'}\not{q}\right)$$

Light-cone gauge propagator

$$d^{\alpha\beta}(p) = -g^{\alpha\beta} + \frac{p^\alpha n^\beta + p^\beta n^\alpha}{p\cdot n}$$

$$p\cdot n \neq 0\,,\; n^2 = 0$$

$$\Gamma^{\mu_1\mu_2\mu_3}_{g^*g^*g}(q,k,p') = f^{abc}\left\{\frac{\mathcal{V}^{\lambda\kappa\mu_3}_{ggg}(q,k,p')}{\sqrt{2}}\,d^{\mu_1}{}_\lambda(q)\,d^{\mu_2}{}_\kappa(k) + d^{\mu_1\mu_2}(k)\,\frac{q^2 q_\parallel^{\mu_3}}{2\,q_\parallel\cdot k} - d^{\mu_1\mu_2}(q)\,\frac{k^2 k_\parallel^{\mu_3}}{2\,k_\parallel\cdot q}\right\}$$

What will be next: improving the CCFM evolution

Available 'till 1 month ago: real contributions to the angular averaged P_{qg} , P_{gq} , P_{qq} TMD splitting functions: gauge invariant and correct DGLAP limits

$$P_{qg}^{(0)}\left(z, \frac{\mathbf{k}^2}{\tilde{\mathbf{q}}^2}, \epsilon\right) = T_R \left(\frac{\tilde{\mathbf{q}}^2}{\tilde{\mathbf{q}}^2 + z(1-z)\,\mathbf{k}^2}\right)^2 \left[z^2 + (1-z)^2 + 4z^2(1-z)^2 \frac{\mathbf{k}^2}{\tilde{\mathbf{q}}^2}\right]$$

$$P_{gq}^{(0)}\left(z, \frac{\mathbf{k}^2}{\tilde{\mathbf{q}}^2}, \epsilon\right) = C_F \left[\frac{2\tilde{\mathbf{q}}^2}{z|\tilde{\mathbf{q}}^2 - (1-z)^2\mathbf{k}^2|} - \frac{\tilde{\mathbf{q}}^2(\tilde{\mathbf{q}}^2(2-z) + \mathbf{k}^2 z(1-z^2)) - \epsilon z(\tilde{\mathbf{q}}^2 + (1-z)^2\mathbf{k}^2)}{(\tilde{\mathbf{q}}^2 + z(1-z)\mathbf{k}^2)^2}\right]$$

$$P_{qq}^{(0)}\left(z, \frac{\mathbf{k}^2}{\tilde{\mathbf{q}}^2}, \epsilon\right) = C_f \left(\frac{\tilde{\mathbf{q}}^2}{\tilde{\mathbf{q}}^2 + z(1-z)\mathbf{k}^2}\right) \left[\frac{\tilde{\mathbf{q}}^2 + (1-z^2)\mathbf{k}^2}{(1-z)|\tilde{\mathbf{q}}^2 - (1-z)^2\mathbf{k}^2|} + \frac{z^2\tilde{\mathbf{q}}^2 - z(1-z)(1-3z+z^2)\mathbf{k}^2 + (1-z)^2\epsilon(\tilde{\mathbf{q}}^2 + z^2\mathbf{k}^2)}{(1-z)(\tilde{\mathbf{q}}^2 + z(1-z)\mathbf{k}^2)}\right]$$

Trickier in the gluon case: requires modification of the prescription to extract collinear singularities; check not only DGLAP, but also BFKL limit ! ✓

Virtual contributions: in axial gauge and for off-shell vertices, they possibly imply computing integrals with more than one linear denominator.

To be provided: virtual P_{gg} and P_{qq}

Hentschinski, Kusina, Kutak, MS, in preparation

Conclusions

Summary and perspectives

- We have a complete framework for the evaluation of cross sections from amplitudes with off-shell quarks and TMDs. Results (.lhe files) from KaTie are fed into to the (new) CASCADE parton shower Monte Carlo.
- The angular-ordering prescription seems to do well in the description of inclusive jet data. We must still improve the showers and tune our framework, but the results are encouraging.
- Soon release of a paper on single inclusive jet production and the general technical framework. Results on multi-jets will come later. **The first TMD Monte Carlo framework for hadron-hadron collisions is being born.**
- All-flavour, gauge invariant TMD splitting functions reproducing the correct DGLAP and (for gluons) BFKL limits are emerging from a parallel program. The virtual corrections are the next challenge to be solved.

Summary and perspectives

- We have a complete framework for the evaluation of cross sections from amplitudes with off-shell partons and TMDs. Results (.lhe files) from KaTie are fed into to the (new) CASCADE parton shower Monte Carlo.
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Happy 5778 year
and thank you so much, Cracow !!!

Backup slides

DPS effects in collinear and HEF: the problem of asymmetric cuts

DPS effects are expected to become significant for lower cuts on the final state transverse momenta, like the ones of the CMS collaboration
Phys.Rev. D89 (2014) no.9, 092010

$$p_T(1,2) \geq 50\,\text{GeV}\,, \quad p_T(3,4) \geq 20\,\text{GeV}\,, \quad |\eta| \leq 4.7\,, \quad R = 0.5$$

CMS collaboration :	$\sigma_{tot} = 330 \pm 5\,(\text{stat.}) \pm 45\,(\text{syst.})\; nb$
LO collinear factorization :	$\sigma_{SPS} = 697\; nb\,, \quad \sigma_{DPS} = \mathbf{125\,nb}\,, \quad \sigma_{tot} = 822\; nb$
LO HEF k_T-factorization :	$\sigma_{SPS} = 548\; nb\,, \quad \sigma_{DPS} = \mathbf{33\,nb}\,, \quad \sigma_{tot} = 581\; nb$

In HE factorization DPS gets suppressed and does not dominate at low p_T

Counterintuitive result from well-tested perturbative framework
$\Rightarrow$ phase space effect ?

Higher order corrections to 2-jet production

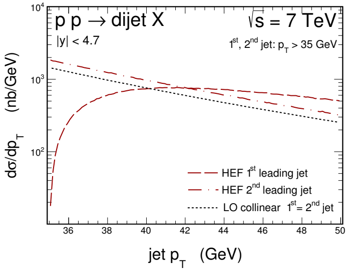


Figure: The transverse momentum distribution of the leading (long dashed line) and subleading (long dashed-dotted line) jet for the dijet production in HEF.

NLO corrections to 2-jet production suffer from instability problem when using symmetric cuts: Frixione, Ridolfi, Nucl.Phys. B507 (1997) 315-333

Symmetric cuts rule out from integration final states in which the momentum imbalance due to the initial state non vanishing transverse momenta gives to one of the jets a lower transverse momentum than the threshold.

ATLAS data vs. theory (nb) @ LHC7 for 2,3,4 jets. Cuts are defined in Eur.Phys.J. C71 (2011) 1763; theoretical predictions from Phys.Rev.Lett. 109 (2012) 042001

#jets	ATLAS	LO	NLO
2	$620 \pm 1.3^{+110}_{-66} \pm 24$	$958(1)^{+316}_{-221}$	$1193(3)^{+130}_{-135}$
3	$43 \pm 0.13^{+12}_{-6.2} \pm 1.7$	$93.4(0.1)^{+50.4}_{-30.3}$	$54.5(0.5)^{+2.2}_{-19.9}$
4	$4.3 \pm 0.04^{+1.4}_{-0.79} \pm 0.24$	$9.98(0.01)^{+7.40}_{-3.95}$	$5.54(0.12)^{+0.08}_{-2.44}$

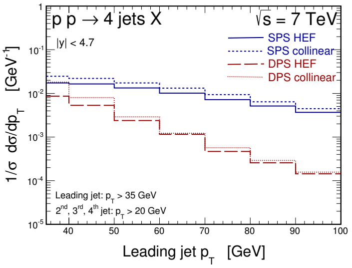
Reconciling High Energy and Collinear Factorization : asymmetric p_T cuts

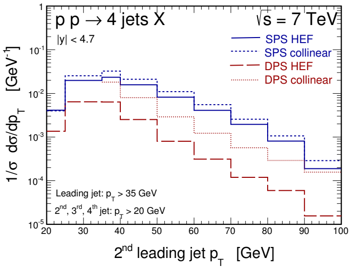
In order to open up wider region of soft final states and thereof expected that the DPS contribution increases

$p_T(1) \geq 35\text{GeV}\,, \quad p_T(2,3,4) \geq 20\text{ GeV}\,, |\eta| < 4.7\,, \quad \Delta R > 0.5$

LO collinear factorization : $\sigma_{SPS} = 1969\, nb\,, \quad \sigma_{DPS} = 514\, nb\,, \quad \sigma_{tot} = 2309\, nb$

LO HEF k_T-factorization : $\sigma_{SPS} = 1506\, nb\,, \quad \sigma_{DPS} = 297\, nb\,, \quad \sigma_{tot} = 1803\, nb$





DPS dominance pushed to even lower p_T but restored in HE factorization as well
Next natural step: fully asymmetric cuts !

Preliminary assessments of the potential of various asymmetric cuts

Below, HEF predictions with **DLC2016** without PS for 4 jets (no b-tagging).
Experimentally ideal: using track-jets, in order to optimally deal with high pile-up
$\Rightarrow R = 0.4\,, |\eta| < 2.1$.
(P. Van Mechelen, H. Van Haevermaet, M. Pieters, private communication)

Competing effects at work :

1. The lower the highest cut, the more DPS we can see (see PDFs)
2. As the spread in transverse momentum between jets wides up, the phase space is reduced
3. One has to be careful to impose an asymmetry in $p_t \geq 5$ GeV, in order to tame extra logarithms *Alioli, Andersen, Oleari, Re, Smillie, Phys.Rev. D85 (2012) 114034*

- $p_T(1) \geq 40\ GeV\,, p_T(2) \geq 30\ GeV\,, p_T(3) \geq 20\ GeV\,, p_T(4) \geq 10\ GeV$
  $\sigma_{SPS} = 2132 nb\,, \sigma_{DPS} = 240 nb \Rightarrow f_{DPS} \simeq\ 0.11$
- $p_T(1) \geq 40\ GeV\,, p_T(2) \geq 25\ GeV\,, p_T(3) \geq 25\ GeV\,, p_T(4) \geq 10\ GeV$
  $\sigma_{SPS} = 1571 nb\,, \sigma_{DPS} = 151 nb \Rightarrow f_{DPS} \simeq 0.10$
- $p_T(1) \geq 35\ GeV\,, p_T(2) \geq 20\ GeV\,, p_T(3) \geq 15\ GeV\,, p_T(4) \geq 10\ GeV$
  $\sigma_{SPS} = 4654 nb\,, \sigma_{DPS} = 922 nb \Rightarrow f_{DPS} \simeq 0.19$
  Not very different for equal cuts on the second and third jet:
  lower highest cut is the dominant effect !
  Better to stick to 3 instead of 4 different cuts because of point 3.

Pinning down double parton scattering: $\Delta\phi_3^{min}$ - azimuthal separation

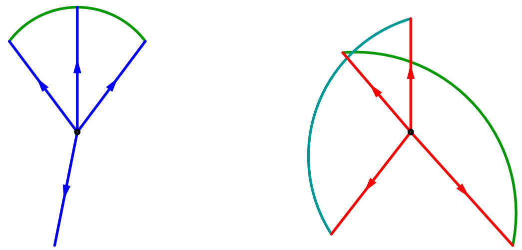


Figure: Left: typical 4-particle final state topology associated with SPS. Right: typical 4-particle final state topology generated by DPS. No way, in the latter case, to get a $\Delta\phi_{\mathbf{3}}^{min}$ below

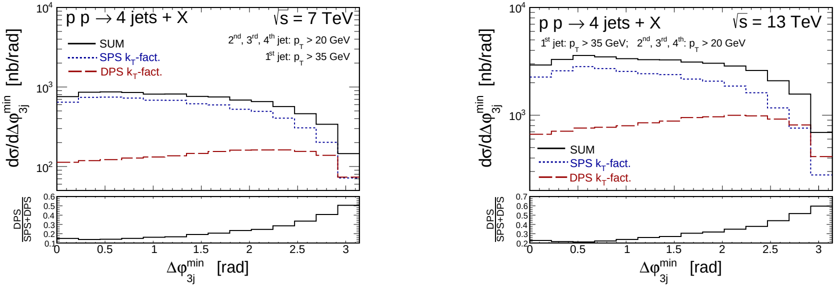
Minimum total distance in azimuthal angle between triplets of jets:

$$\Delta\phi_{\mathbf{3}}^{min} = min_{i,j,k[\mathbf{1},\mathbf{4}]} \left(\left|\phi_i - \phi_j\right| + \left|\phi_j - \phi_k\right|\right) \;, \quad i \neq j \neq k$$

Almost back-to-back topologies clearly favour high values of this variable !
$\Rightarrow$ DPS is expected to push up the cross section in the high-$\Delta\Phi_3^{min}$ region

Pinning down double parton scattering: $\Delta\phi_3^{min}$ - azimuthal separation

K. Kutak, R. Maciula, MS, A. Szczurek, A. van Hameren
Phys.Rev. D94 (2016) no.1, 014019



- Definition: $\Delta\phi_3^{min} = min_{i,j,k[1,4]}\left(|\phi_i - \phi_j| + |\phi_j - \phi_k|\right)\ , \quad i \neq j \neq k$
- Proposed by ATLAS in *JHEP 12 105 (2015)* for high p_T analysis
- High values favour DPS, because there is no way to construct a low value from a (nearly) back-to-back configuration.
- For $\Delta\phi_3^{min} \geq 2\pi/3$ the total cross section is heavily affected by DPS at 13 TeV.