Mueller Navelet and Mueller Tang processes at the LHC

Christophe Royon
University of Kansas, Lawrence, USA
ISMD 2023, Gyöngyös, Hungary

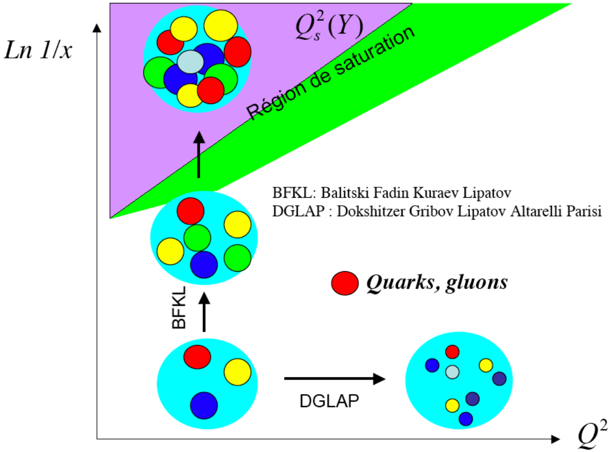
August 21-26 2023

Contents

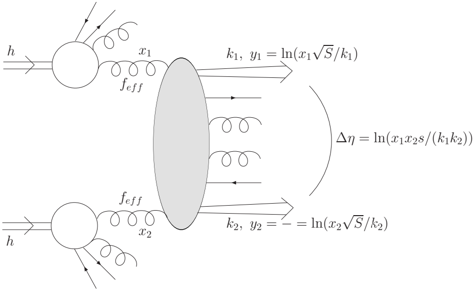
- BFKL formalism
- Mueller Navelet processes at the LHC: new observables
- Jet gap jet measurements at the LHC: CMS results and dependence on ISR
- Jet gap jet cross sections including NLO impact factors

Looking for BFKL/saturation effects

Looking for BFKL/CGC effects at LHC/EIC in dedicated final states

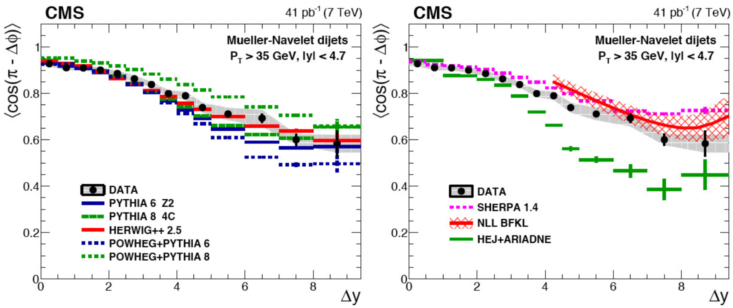


Looking for BFKL resummation effects at hadron colliders



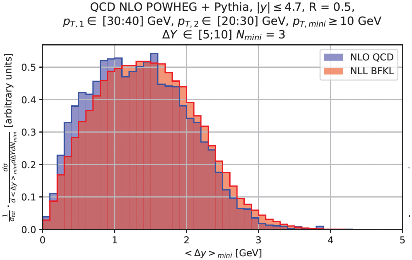
- Mueller Navelet jets: Look for dijet events separated by a large interval in rapidity
- If jets have similar p_T, DGLAP cross section suppressed because of the k_T ordering of the gluons emitted between the two jets
- BFKL cross section enhanced: gluon emissions possible because of large rapidity interval
- Study the $\Delta\Phi$ between jets dependence of the cross section as an example

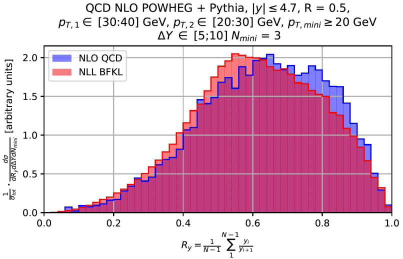
Mueller Navelet jets: ΔΦ dependence: CMS measurements



- CMS collaboration: Azimuthal decorrelation between jets at 7 TeV: J. High Energy Phys. 08 (2016) 139
- BFKL NLL leads to a good description of data but also PYTHIA/HERWIG after MPI tuning...
- More differential observables needed or completely new ones

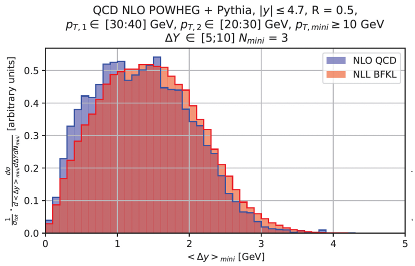
Mueller Navelet processes: Looking for less inclusive variables

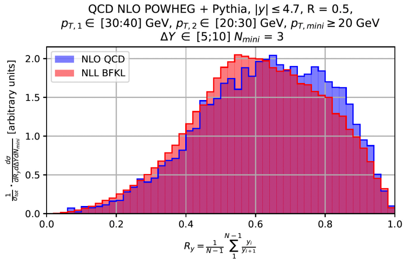




- Looking for multi-gluon emission along ladder, characteristic of BFKL NLL/DGLAP NLO
- Comparison between BFKL-ex MC and usual QCD NLO MC to compare both approaches (M. Kampshoff, A. Sabio Vera, G. Chachamis, C. Baldenegro, CR in preparation)
- We first require two forward jets with $5 < |\Delta Y| < 10$, $30 < p_{T_1} < 40$ GeV, $20 < P_{T_2} < 30$ GeV

Mueller Navelet processes: Looking for less inclusive variables





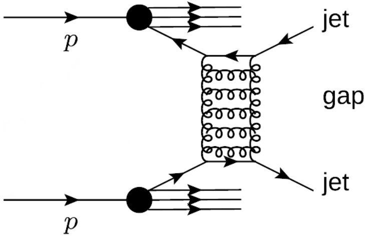
- We define as $y = 0$ the rapidity of the mini-jet closest to the MN jet and N is the number of mini-jets above 20 GeV (or 10 GeV) emitted between the two MN jets
- Rapidity of emitted mini-jets

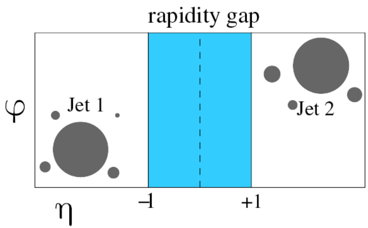
$$< \Delta y_{mini} > = \frac{1}{N-1}(y_N - y_1)$$

$$< R_y > = \frac{1}{N-1}\Sigma_1^{N-1}\frac{y_i}{y_{i+1}}$$

- Similar distributions for both approaches (R_y slightly higher for NLO QCD): test of gluon emission as predicted by QCD

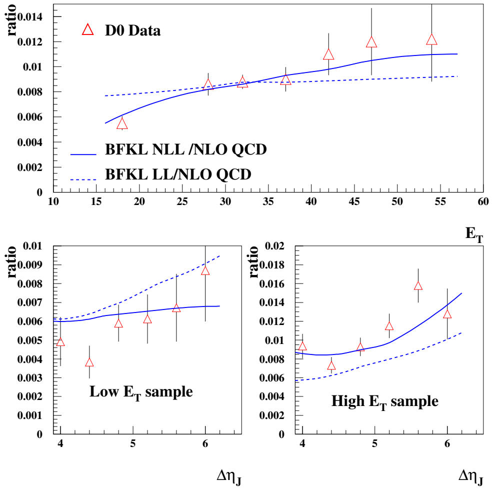
Mueller Tang: Gap between jets at the Tevatron and the LHC





- Looking for a gap between two jets: Region in rapidity devoid of any particle production, energy in detector
- Exchange of a BFKL Pomeron between the two jets: two-gluon exchange in order to neutralize color flow
- Method to test BFKL resummation: Implementation of BFKL NLL formalism in HERWIG/PYTHIA Monte Carlo

Comparison with D0 data

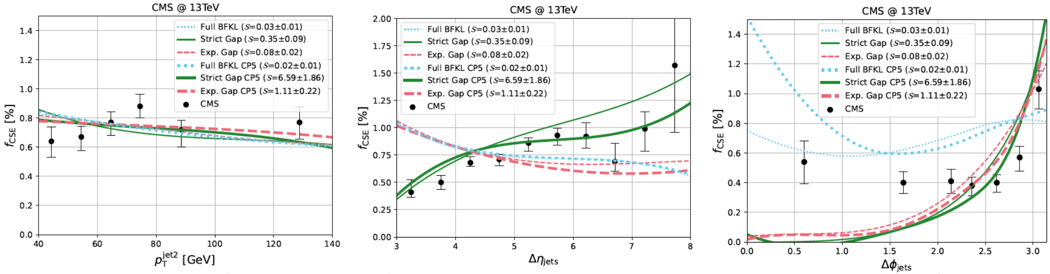


- D0 measurement: Jet gap jet cross section ratios, gap between jets being between -1 and 1 in rapidity
- Comparison with BFKL formalism:

$$Ratio = \frac{BFKL\ NLL\ Herwig}{Dijet\ Herwig} \times \frac{LO\ QCD\ NLOJet++}{NLO\ QCD\ NLOJet++}$$

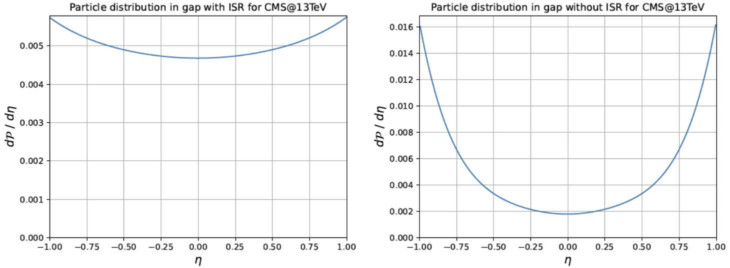
- Reasonable description using BFKL NLL formalism
- O. Kepka, C. Marquet, C. Royon, Phys. Rev. D 83 (2011) 034036

Jet gap jet measurements at the LHC (CMS@13 TeV)



- Implementation of BFKL NLL formalism in Pythia and compute jet gap jet fraction
- Dijet cross section computed using POWHEG and PYTHIA8
- Three definitions of gap: theory (pure BFKL), experimental (no charged particle above 200 MeV in the gap $-1 < \eta < 1$) and strict gap (no particle above 1 MeV in the gap region) (C. Baldenegro, P. Gonzalez Duran, M. Klasen, C. Royon, J. Salomon, JHEP 08 (2022) 250); CMS data: Phys.Rev.D 104 (2021) 032009
- Two different CMS tunes: CP1 without MPI, CP5 with MPI

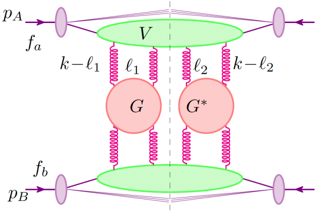
Charged particle distribution



- Disitribution of charged particles from PYTHIA in the gap region $-1 < \eta < 1$ with ISR ON (left) and OFF (right)
- Particles emitted at large angle with $p_T > 200$ MeV from initial state radiation have large influence on the gap presence or not, and this on the gap definition (experimental or strict)

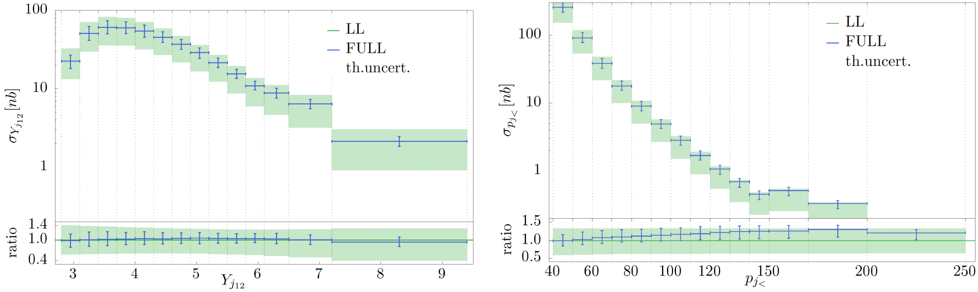
Jet gap jet: Full NLO BFKL calculation including NLO impact factor

- Combine NLL kernel with NLO impact factors (Hentschinski, Madrigal, Murdaca, Sabio Vera 2014)



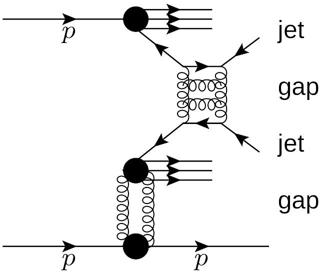
- Gluon Green functions in red
- Impact factors in green
- Will lead to an improved parametrisation to be implemented in HERWIG/PYTHIA
- D. Colferai, F. Deganutti, T. Raben, C. Royon, ArXiv 2304.09073

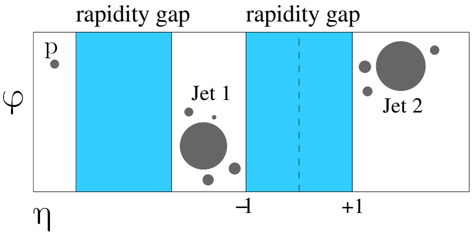
Effect of NLO impact factor on jet gap jet cross section: final results



- Higher cross section by 20% at high p_T and small effect on the y dependence
- Total uncertainties are much smaller at NLO: 15-20%

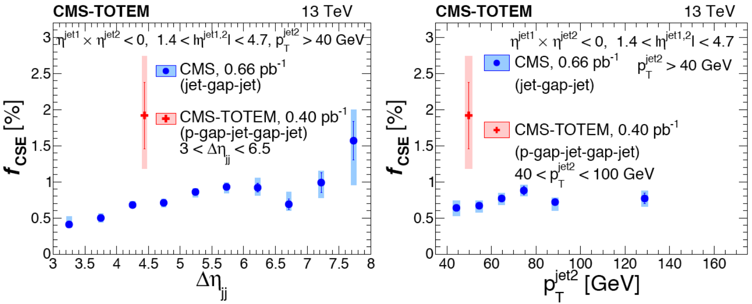
Another kind of events: Jet gap jet events in diffraction (CMS/TOTEM)





- Jet gap jet events: powerful test of BFKL resummation C. Marquet, C. Royon, M. Trzebinski, R. Zlebcík, Phys. Rev. D 87 (2013) 3, 034010
- Subsample of gap between jets events requesting in addition at least one intact proton on either side of CMS
- **Jet gap jet events were observed for the 1st time by CMS!** (Phys.Rev.D 104 (2021) 032009)

First observation of jet gap jet events in diffraction (CMS/TOTEM)

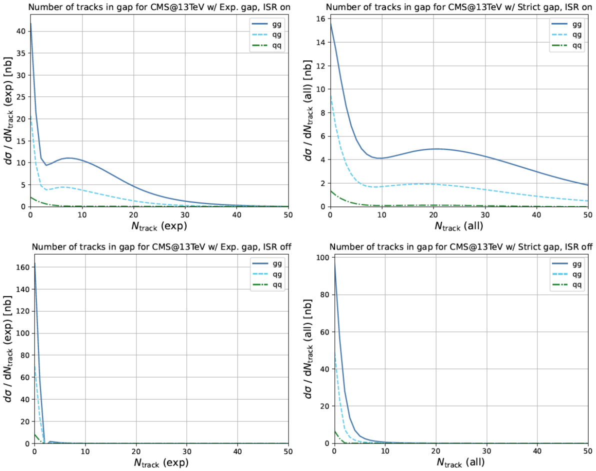


- First observation: 11 events observed with a gap between jets and at least one proton tagged with ~ 0.7 pb^{-1}
- Leads to very clean events for jet gap jets since MPI are suppressed and might be the "ideal" way to probe BFKL
- Would benefit from more stats >10 pb^{-1} needed, 100 for DPE

Conclusion

- New variables to probe QCD dynamics: mini-jets emission between Mueller Navelet jets
- Measurement of jet gap jet fraction at Tevatron and LHC: Agreement of BFKL calculation and measurement at the Tevatron, but apparent disagreement at 13 TeV
- BFKL predictions very sensitive to Initial State Radiation as described in PYTHIA especially for gg interaction processes: Too much ISR at high angle predicted by PYTHIA, should be tuned further using for instance J/Ψ-gap-J/Ψ events
- First calculation of Mueller Tang processes including NLO impact factors: Higher cross section by 20% at high p_T and small effect on the y dependence

$N_{particle}$



- Number of particles emitted in the gap region $-1 < \eta < 1$ with $p_T > 200$ MeV from PYTHIA with ISR ON (top) and OFF (bottom)
- Number of particles much larger for *gg* processes, gluons radiate more
- Tevatron/LHC energies: mainly quark gluon/gluon gluon induced processes, so more radiation at LHC
- ISR emission from PYTHIA too large at high angle and must be further tuned for jet gap jet events: Use for instance J/Ψ-gap-J/Ψ events which is a *gg* dominated process