Jets separated by a large rapidity gap at the Tevatron and the LHC

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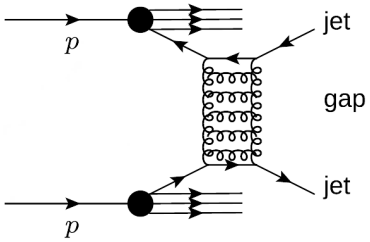
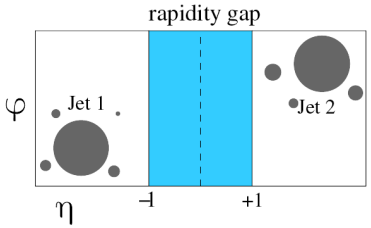
- C. Baldenegro, P. Gonzalez Duran, M. Klasen, C. Royon, J. Salomon, JHEP 08 (2022) 250

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

BFKL formalism

- BFKL jet gap jet cross section: integration over ξ, p_T performed in Herwig event generation

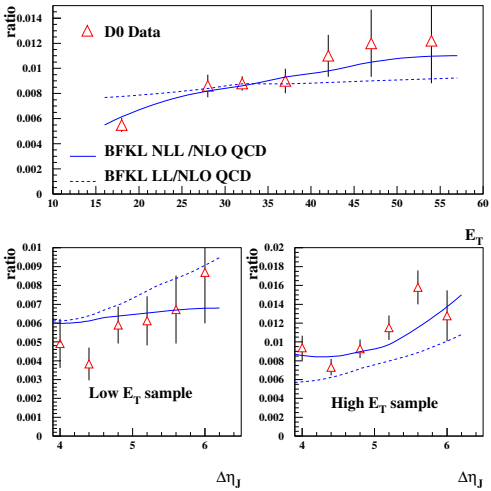
$$\frac{d\sigma^{pp\to XJJY}}{dx_1 dx_2 dp_T^2} = \mathcal{S}\frac{f_{eff}(x_1,p_T^2)f_{eff}(x_2,p_T^2)}{16\pi}\left|A(\Delta\eta,p_T^2)\right|^2$$

  where S is the survival probability (0.1 at Tevatron, 0.03 at LHC)

$$A = \frac{16N_c\pi\alpha_s^2}{C_F p_T^2}\sum_{p=-\infty}^{\infty}\int\frac{d\gamma}{2i\pi}\frac{[p^2-(\gamma-1/2)^2]}{[(\gamma-1/2)^2-(p-1/2)^2]}\frac{\exp\left\{\frac{\alpha_S N_C}{\pi}\chi_{eff}\Delta\eta\right\}}{[(\gamma-1/2)^2-(p+1/2)^2]}$$

- α_S: 0.17 at LL (constant), running using RGE at NLL
- BFKL effective kernel χ_{eff}: determined numerically, solving the implicit equation: $\chi_{eff} = \chi_{NLL}(\gamma, \bar{\alpha}\ \chi_{eff})$
- S4 resummation scheme used to remove spurious singularities in BFKL NLL kernel
- Implementation in Monte Carlo: needed to take into account: jet size and gap size smaller than $\Delta\eta$ between jets

Comparison with D0 data

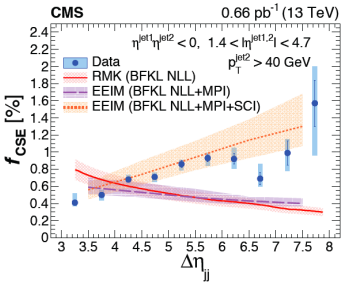


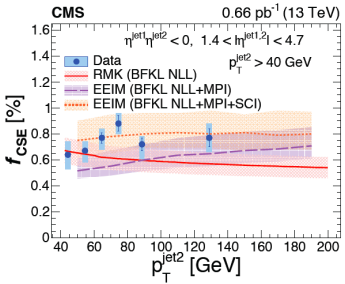
- D0 measurement: Jet gap jet cross section ratios, gap between jets being between -1 and 1 in rapidity
- Comparison with BFKL formalism:

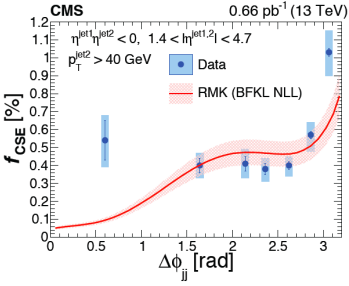
$$Ratio = \frac{BFKL\ NLL\ Herwig}{Dijet\ Herwig} \times \frac{LO\ QCD\ NLOJet++}{NLO\ QCD\ NLOJet++}$$

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

LHC: Measurement of jet gap jet fraction (CMS)

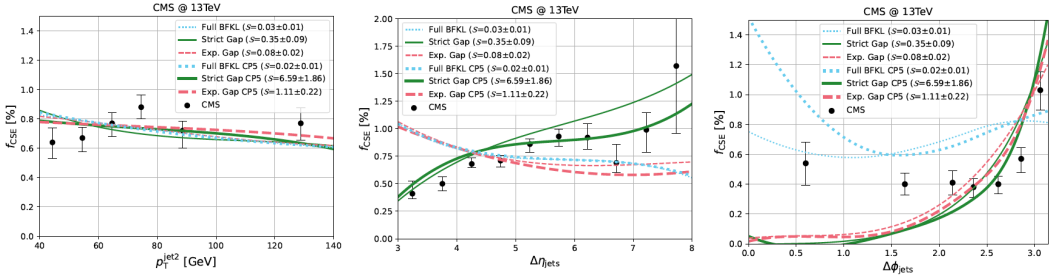






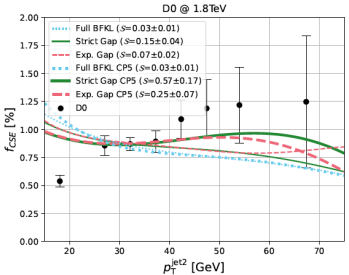
- Measurement of fraction of jet gap jet events as a function of jet $\Delta\eta$, p_T, $\Delta\Phi$ (Phys.Rev.D 104 (2021) 032009)
- Comparison with NLL BFKL (with LO impact factors) as implemented in PYTHIA, and soft color interaction based models (Ingelman et al.)
- Disagreement between BFKL and measurements ($\Delta\eta$ dependence): What is going on?

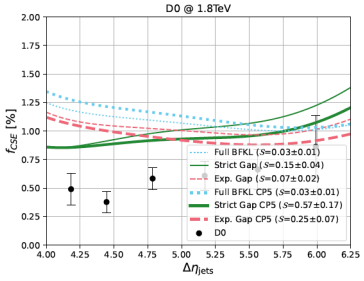
Jet gap jet measurements at the LHC (CMS@13 TeV)

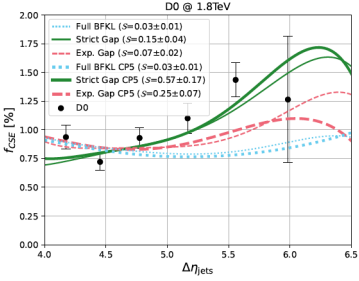


- Implementation of BFKL NLL formalism in Pythia and compute jet gap jet fraction
- Dijet cross section computed using POWHEG and PYTHIA8
- Three definitions of gap: theory (pure BFKL), experimental (no charged particle above 200 MeV in the gap $-1 < \eta < 1$) and strict gap (no particle above 1 MeV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

Jet gap jet measurements at the Tevatron (D0)

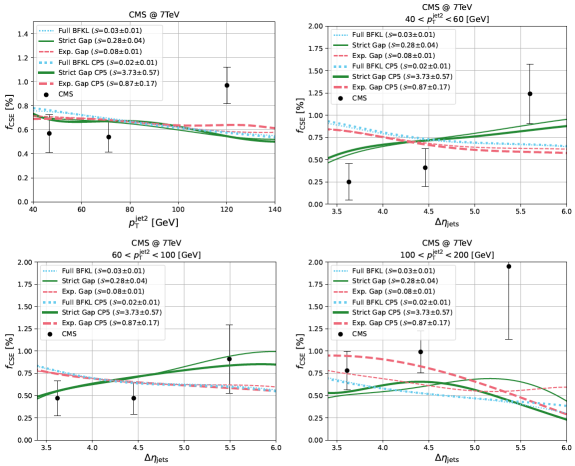






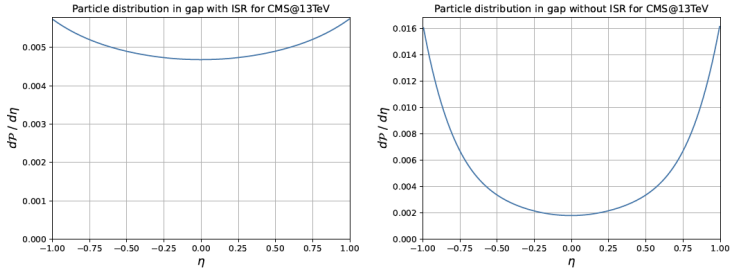
- Better agreement with the strict gap definition
- Fair agreement with the experimental gap definition since the differences between strict and experimental predictions are now that large compared to results at LHC energies
- Why such a large difference at the LHC?

Jet gap jet measurements at the LHC (CMS@7 TeV)



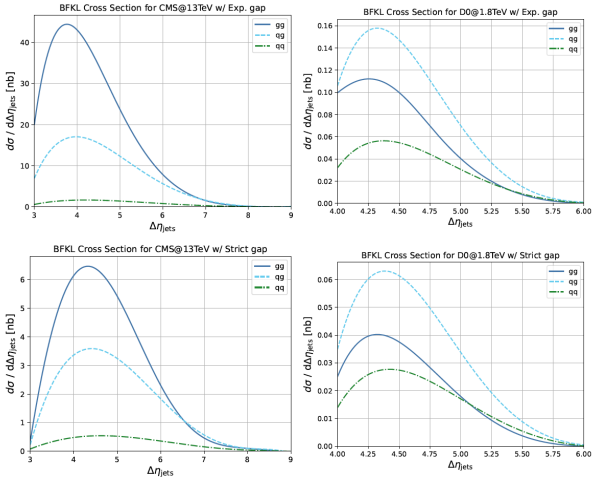
- Good agreement between CMS measurement at 7 TeV and experimental/strict gap definitions
- Slightly better agreement with strict gap definition for $\Delta\eta$ distribution
- Large uncertainties on measurements (mainly statistical)

Charged particle distribution



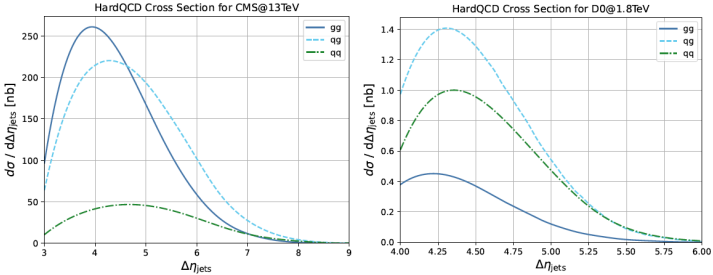
- Disitribution of charged particles from PYTHIA in the gap region $-1 < \eta < 1$ with ISR ON (left) and OFF (right)
- Particles emitted at large angle with $p_T > 200$ MeV from initial state radiation have large influence on the gap presence or not, and this on the gap definition (experimental or strict)

BFKL cross sections: gg, qg or qq processes?



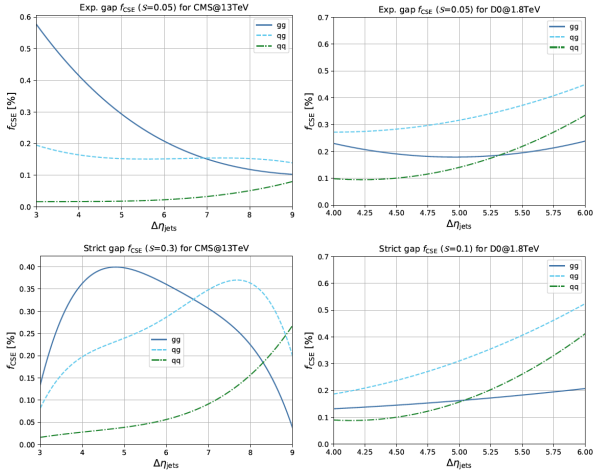
- Better understanding of BFKL and NLO QCD event production
- Events predicted by BFKL dynamics using the experimental and strict gap definitions: are they more gg, qg or qq events
- Tevatron energies: quark gluon induced process
- LHC energies: gluon gluon process

Hard QCD cross sections: gg, qg or qq processes?

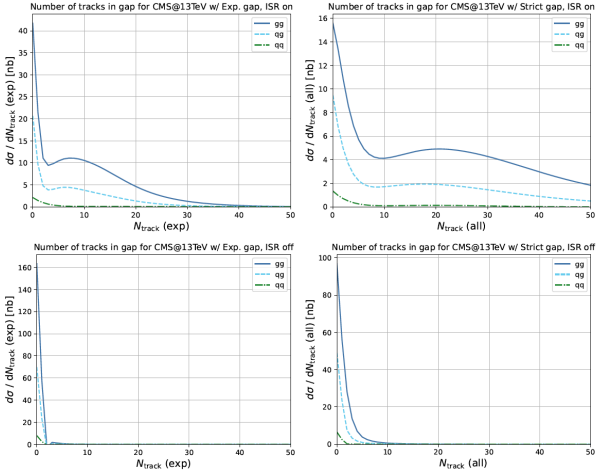


- Better understanding of BFKL and NLO QCD event production
- Events predicted by NLO QCD dynamics using the experimental and strict gap definitions: are they more gg, qg or qq events
- Tevatron energies: quark gluon induced process
- LHC energies: gluon gluon process except at large $\Delta\eta$, quark gluon

Jet gap jet fraction: gg, qg or qq processes?

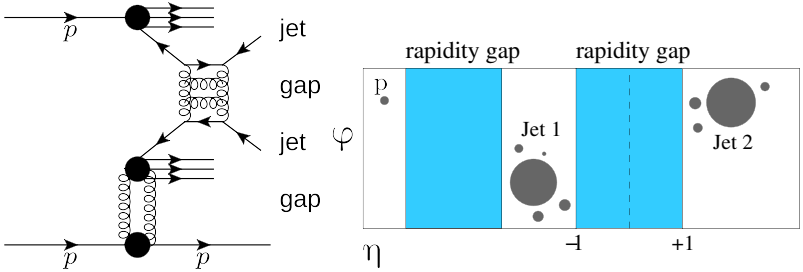


- Jet gap jet ratios predicted by BFKL and NLO QCD dynamics using the experimental and strict gap definitions: are they more gg, qg or qq events
- Tevatron energies: quark gluon induced process
- LHC energies: gluon gluon process except at large $\Delta\eta$, quark gluon, but shapes very different for strict and experimental gap definitions



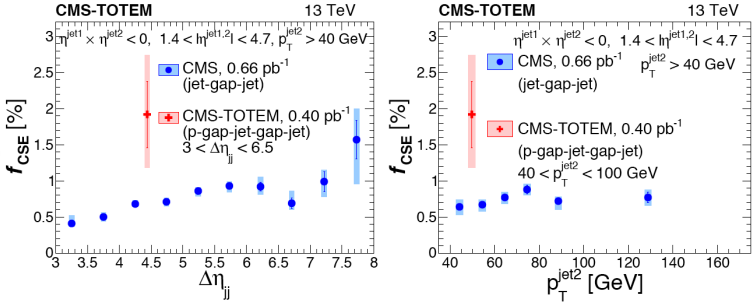
- Number of particles emitted in the gap region $-1 < \eta < 1$ with $p_T > 200$ MeV from PYTHIA with ISR ON (top) and OFF (bottom)
- The number of particles is much larger for *gg* processes, and then for *qg* processes, and obviously with ISR ON
- The ISR emission from PYTHIA is too large at high angle and must be further tuned for jet gap jet events: Use for instance $J\Psi$-gap-$J\Psi$ events which is a *gg* dominated process

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



- Jet gap jet events: powerful test of BFKL resummation C. Marquet, C. Royon, M. Trzebinski, R. Zlebck, 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

- Measurement of jet gap jet fraction of events at the Tevatron (1.96 TeV) and at the LHC (7 and 13 TeV)
- 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 $J\Psi$-gap-$J/|Psi$ events