# Mueller Navelet jet and jet gap jet studies

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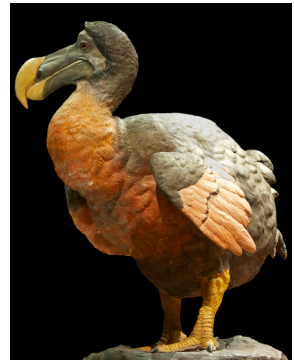
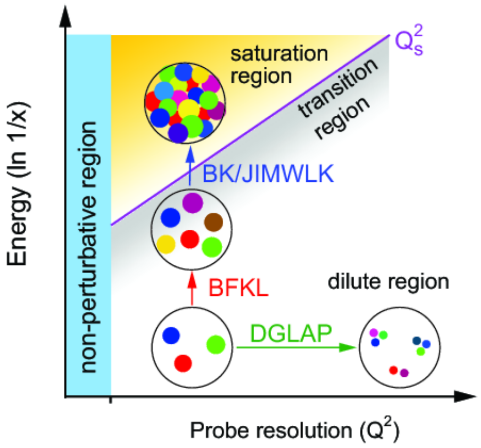


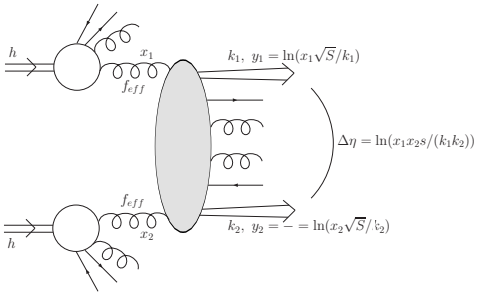
- BFKL dynamics
- Mueller Navelet jets
- Jet gap jet
- Work in collaboration with C. Baldenegro, M. Kampshoff, P. Gonzalez, M. Klasen, A. Sabio Vera, G. Chachamis

# Looking for BFKL resummation /saturation effects




- DGLAP (Dokshitzer Gribov Lipatov Altarelli Parisi): Evolution in resolution $Q^2$, resums terms in $\alpha_S \log Q^2 \rightarrow$ resolving "smaller" partons at high $Q$
- BFKL (Balitski Fadin Kuraev Lipatov (BFKL): Evolution in energy $x$, resums terms in $\alpha_S \log 1/x \rightarrow$ Large parton densities at small $x$
- Saturation region at very small $x$
- Important to understand QCD evolution, parton densities
- Important for cosmic ray physics: understand forward physics

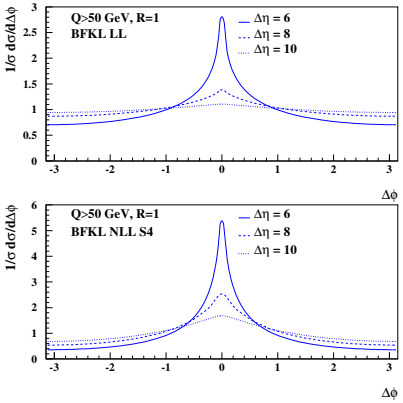
# Looking for BFKL resummation effects at hadron colliders



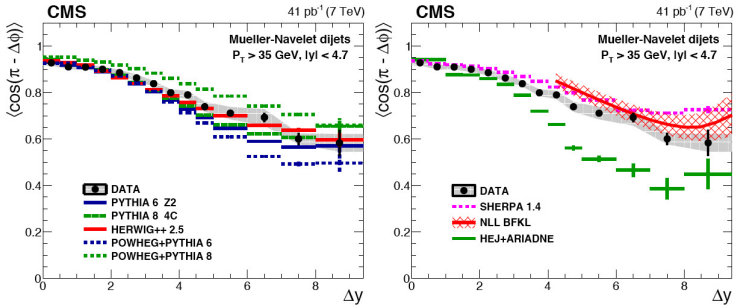

- Mueller Navelet jets: Look for dijet events separated by a large interval in rapidity
- If jets have similar $p_T$, DGLAP cross section suppressed because of the $k_T$ ordering of the gluons emitted between the two jets
- BFKL cross section enhanced: gluon emissions possible because of large rapidity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

# Mueller Navelet jets: $\Delta\Phi$ dependence

- $1/\sigma d\sigma/d\Delta\Phi$ spectrum for BFKL NLL as a function of $\Delta\Phi$ for different values of $\Delta\eta$, scale dependence: $\sim$20%
- Stronger decorrelation for BFKL prediction than for DGLAP
- C. Marquet, C.Royon, Phys. Rev. D79 (2009) 034028

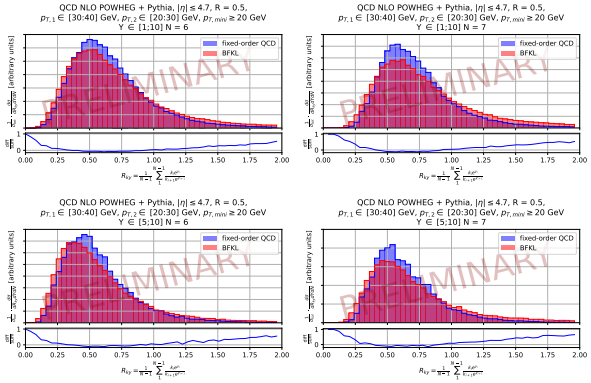


# Mueller Navelet jets: $\Delta\Phi$ dependence: CMS measurements




- CMS measurement: Azimuthal decorrelation between jets at 7 TeV: JHEP 08 (2016) 139
- BFKL NLL leads to a good description of data but also PYTHIA/HERWIG after MPI tuning...: Redo measurement at 13 TeV, and measure ratio of 13 to 7 TeV
- More differential observables needed or completely new ideas

# Mueller Navelet processes: Looking for less inclusive variables



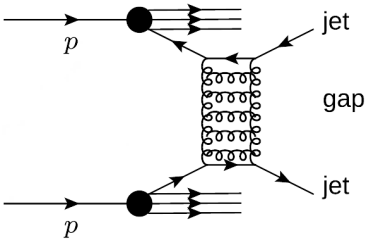

- Looking for multiple gluon emission along ladder characteristic of BFKL

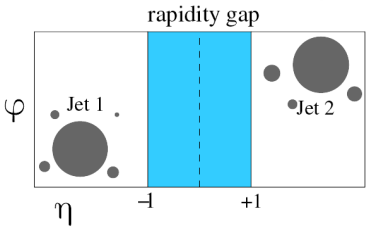
- Fixed-order NLO + PS and BFKL at NLL are in agreement in phase-space control region
- Comparison between BFKL-ex MC (A. Sabio Vera, G. Chachamis) and usual QCD MC to find best possible variables (M. Kampshoff, M. Klasen, J. Salomon, C. Baldenegro, CR)
- As example:

$$< p_T > = \frac{1}{N} \Sigma_1^N p_{T_i}$$

$$< R_{ky} > = \frac{1}{N+1} \Sigma_1^{N+1} \frac{k_i e^{y_i}}{k_{i-1} e^{y_{i-1}}}$$

# Another observable: Gap between jets



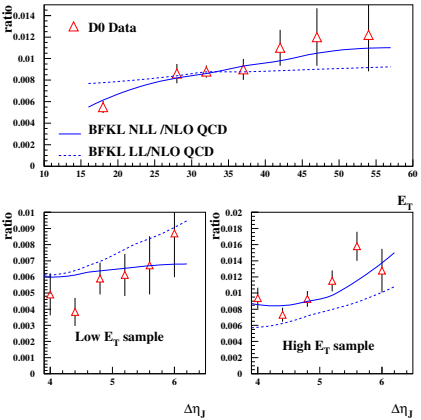

- Looking for a gap between two jets: Region in rapidity devoid of any particle production, energy in detector
- Exchange of a BFKL Pomeron between the two jets: two-gluon exchange in order to neutralize color flow
- In practice, we request no track between the two jets

# Comparison with D0 data

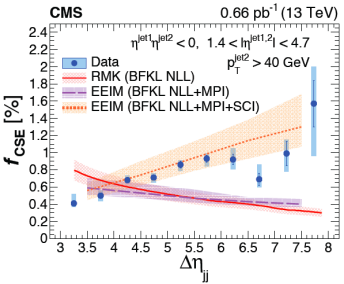
- D0 measurement: Jet gap jet cross section ratios as a function of second highest $E_T$ jet, or $\Delta\eta$ for the low and high $E_T$ samples, the gap between jets being between -1 and 1 in rapidity
- Comparison with BFKL formalism:

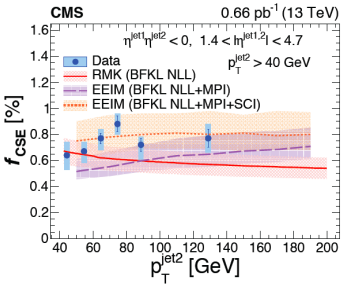
$$R = \frac{BFKL\ NLL\ Herwig}{Dijet\ Herwig} \times \frac{LO\ QCD\ NLOJet}{NLO\ QCD\ NLOJet}$$

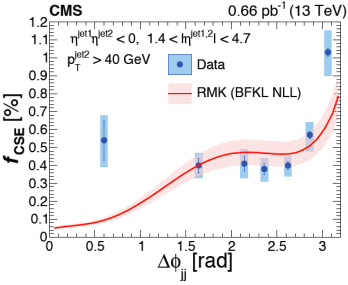
- Reasonable description using BFKL NLL formalism



# Jet gap jet fraction at the LHC (CMS)

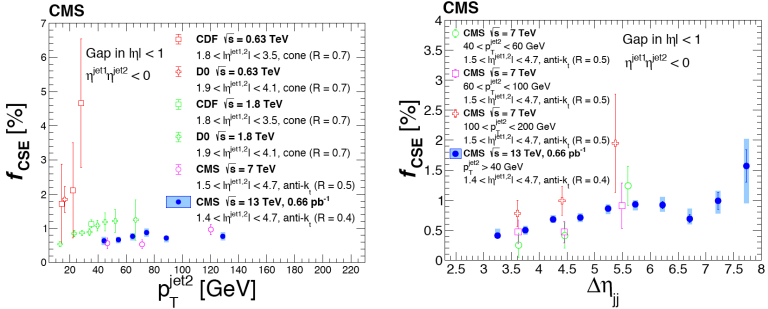


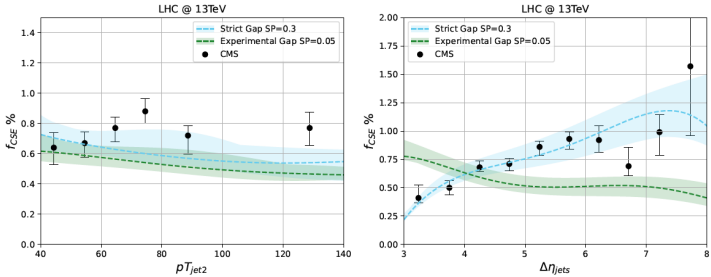

- Measurement of fraction of jet gap jet events as a function of jet $\Delta\eta$, $p_T$ (the gap being defined as no track above 200 MeV in $-1 \leq \eta \leq 1$)
- Comparison with BFKL NLL calculation (including LO coupling to protons (impact factor): Differences between prediction and measurement in $\Delta\eta$ observable
- What is going on between 2 TeV and 13 TeV ????

# Comparison with previous experiments



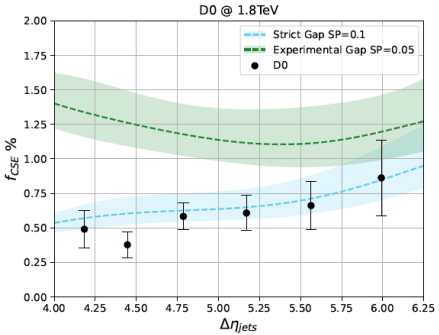

- Jet gap jet measurements at 4 different $\sqrt{S}$: 0.63 TeV, 1.8 TeV, 7 TeV, 13 TeV
- For the first time, measurement at high $\Delta\eta_{jj}$, important to probe BFKL
- Usually suppression of cross section as a function of $\sqrt{S}$ (survival probability): **No further suppression within uncertainties between 7 and 13 TeV!**

# Jet gap jet fraction: sensitivity to gap definition at 13 TeV



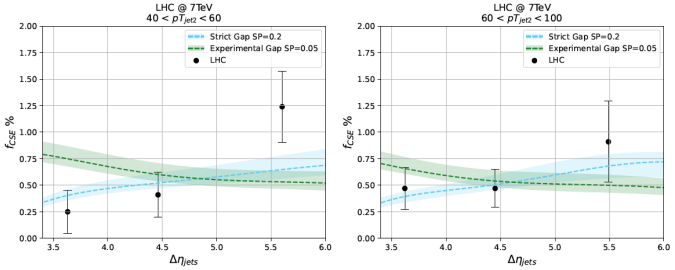

- Difference between "theory" gap definition (no particle above 5 MeV in the gap + ISR from pythia) and "experimental" (no charged particle agove 200 MeV): Theory gap prediction agrees with data
- Inclusive QCD simulated with POWHEG+PYTHIA8 (NLO+PS) and jet gap jet simulation is a new implementation in PYTHIA8 (we have access to all the MPI/UE/ISR effects that were not present in Herwig 6.5)
- Work in collaboration with P. Gonzales, M. Klasen, M. Kampshoff, C. Baldenegro, C.R.

# Jet gap jet fraction: sensitivity to gap definition at 1.8 TeV



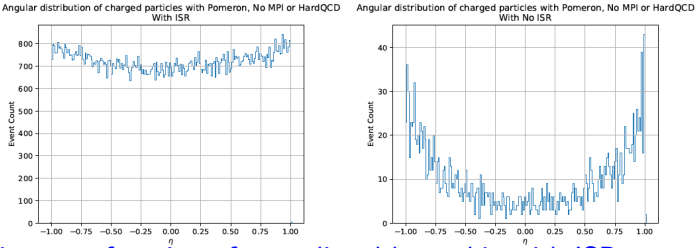

- Difference between "theory" gap definition (no particle above 5 MeV in the gap + ISR from pythia) and "experimental" gap at 1.8 TeV
- We reproduce the comparison between the D0 result and the BFKL NLL calculation
- Good agreement between BFKL calculation and measurement (also true with CDF data)

# Jet gap jet fraction: sensitivity to gap definition at 7 TeV



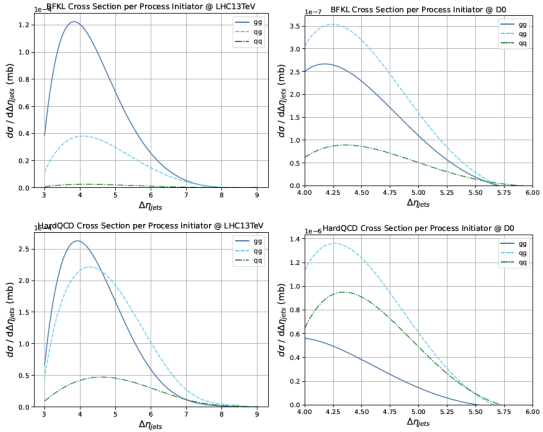

- Conclusions are still true at 7 TeV: better description using theoretical gap
- However, differences between theoretical and experimental gaps much smaller at 7 TeV

# Jet gap jet fraction: particles emission in pythia (ISR)



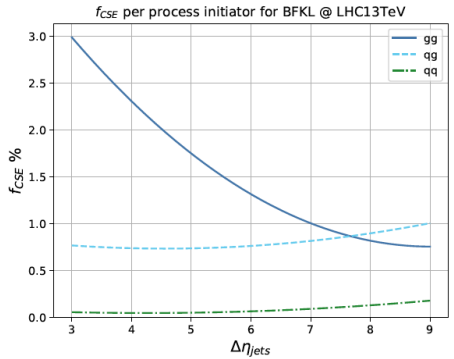

- Particle emission as a function of $\eta$ predicted by pythia with ISR on or off
- ISR generates more color charges in the forward region (collinear emissions) and it is more likely to get color strings connecting the forward and backward systems
- These strings reconnect with the Lund color strings, and lead to hadron production in the gap region
- Process challenges color string framework of Pythia8. If we trust the BFKL calculation, then tuning is needed, would be also interesting to see what Herwig++ predicts

# Jet gap jet fraction: why a difference between 2 and 13 TeV?



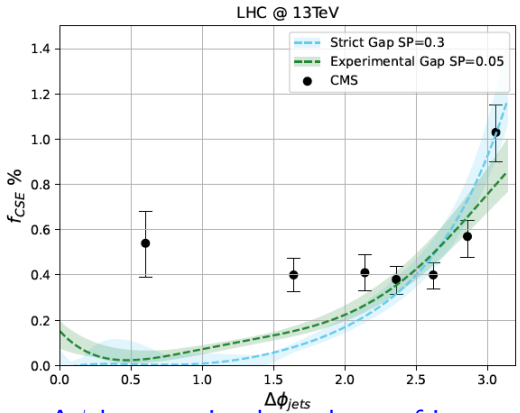

- Differences between 2 and 13 TeV?
- Quark gluon fraction of events at 13 TeV (left) and 1.8 TeV (right) for BFKL (top) and LO QCD (bottom)
- BFKL events are more gluon-like and differences due to PDFs
- More color charges produced in the forward/backward region in Pythia at high $\sqrt{s}$, so more likely to produce particles in the gap region

# Jet gap jet fraction: quark and gluon components




- Gap fraction for BFKL events for different quark gluon components as a function of $\Delta\eta$
- Same conclusion as before: we are dominated by gluon-like events as predicted
- Due to PDF dependence for jets with large $\Delta\eta$

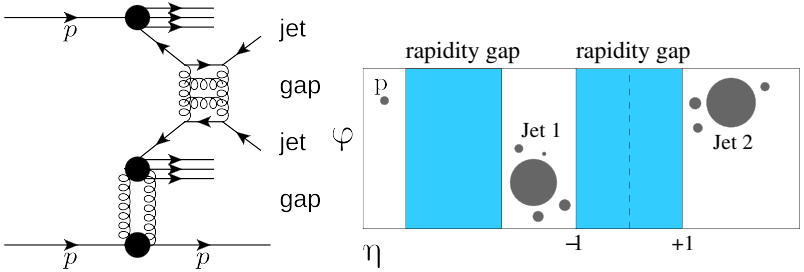
# Jet gap jet at 13 TeV: a puzzling result




- $\Delta\phi$ between jet dependence of jet gap jet results

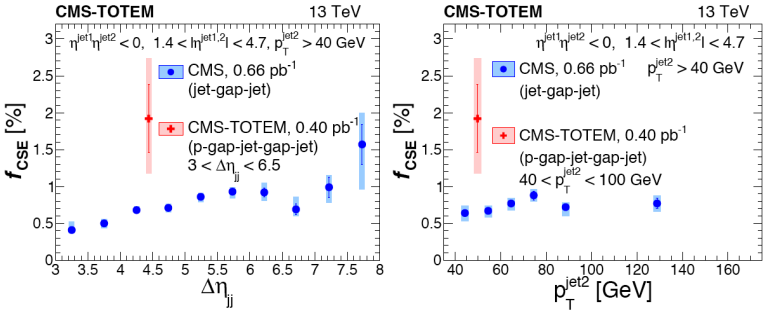
- Discrepancy at small $\Delta\phi$ not well understood
- NLO impact factor calculation in progress (F. Deganutti and D. Colferai) will not modify this result by a large amount
- Is it because we have a mixture of Mueller Navelet and jet gap jet events? When $|\Delta\eta_{jet}| >> |\Delta\eta_{gap|}$ there is enough phase space for multi-gluon emission to occur, and we see dijet decorrelation as predicted by BFKL for MN jets, we see *JET-MN gluon emission-gap-MN gluon emission-JET*

# Jet gap jet events in diffraction




- TOTEM roman pots detectors on both sides of CMS allow to measure intact protons in the final state
- Subsample of gap between jets events requesting in addition at least one intact proton on either side of CMS
- **Jet gap jet events in diffraction were observed for the 1st time by CMS-TOTEM!**

# First observation of jet gap jet events in diffraction




- First observation: 11 events observed with a gap between jets and at least one proton tagged with $\sim 0.7$ pb$^{-1}$
- Leads it very clean events for jet gap jets since MPI are suppressed and might be the "ideal" way to probe BFKL: suppresses radiation by definition
- Would benefit from more stats and a dedicated trigger requesting an intact proton in the final state, probably $>10$ pb$^{-1}$ needed, 100 for DPE

# Conclusion

- Mueller Navelet jets: Larger decorrelation expected for BFKL formalism
- Mueller Navelet jets: not enough discrimination to observe clearly BFKL resummation effects $\rightarrow$ Looking for less inclusive variables more sensitive to BFKL dynamics
- Jet gap jets:
  - NLL BFKL cross section implemented in PYTHIA (Kernel), LO impact factors
  - Fair description of D0 (and CDF), CMS data using the theory gap definition
  - Full NLL calculation including NLO impact factors in progress and small changes expected due to NLO impact factors
  - Pythia produces too much radiation, what about herwig?
- Jet gap jet events in diffraction: clean tests of BFKL, modulo the survival probability (and its dependence on kinematics)