# Hard color-singlet exchange in dijet events at √s = 13 TeV with CMS and TOTEM

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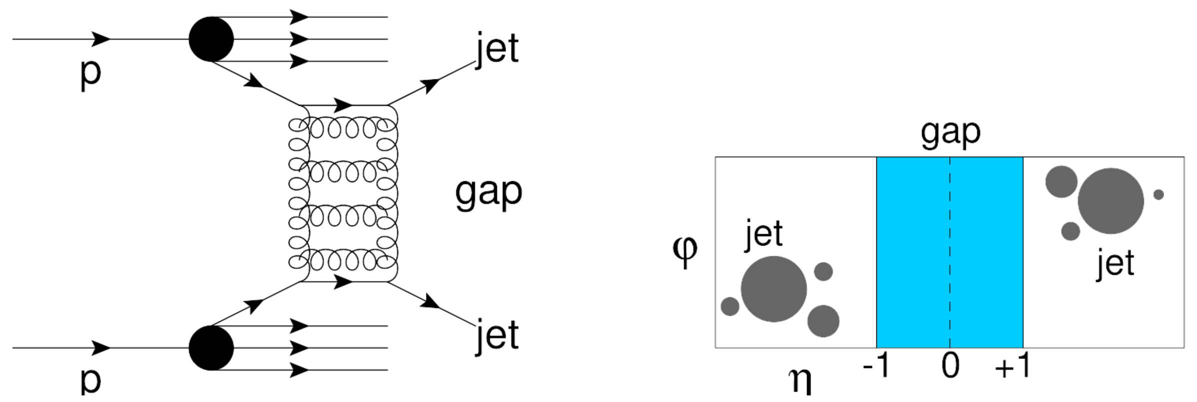
**CMS-TOTEM Collaborations [1, 2]**, poster based on *Phys. Rev. D* 104, 032009 (2021), arXiv:2102.06945

## Hard color-singlet exchange dijets

Events where the two highest-pT jets are separated by a pseudorapidity interval void of particles (*pseudorapidity gap*) are consistent with *t*-channel hard color-singlet exchange between partons (two-gluon exchange at LO in pQCD). These are known as **jet-gap-jet** or **Mueller-Tang[3]** jets.




At large Δηjj ≡ |ηjet1−ηjet2|, it is expected that the hard color-singlet exchange should be described by t-channel two-gluon ***ladder*** exchange (perturbative pomeron), which is described by the Balitsky-Fadin-Kuraev-Lipatov (BFKL) **[4, 5, 6]** equation of pQCD. The latter resums logarithms of energies to all orders in αS of the form $(\alpha_S \ln|s/|t||)^n$ with $\alpha_S \ln(s/|t|) \lesssim 1$ and n = 1, 2, 3, …, and where *s* and *t* are the squares of the center-of-mass energy and four-momentum transfer of the 2→2 process.

***Hence, jet-gap-jet events can be used to test the high-energy limit of QCD.***

## Data Analysis

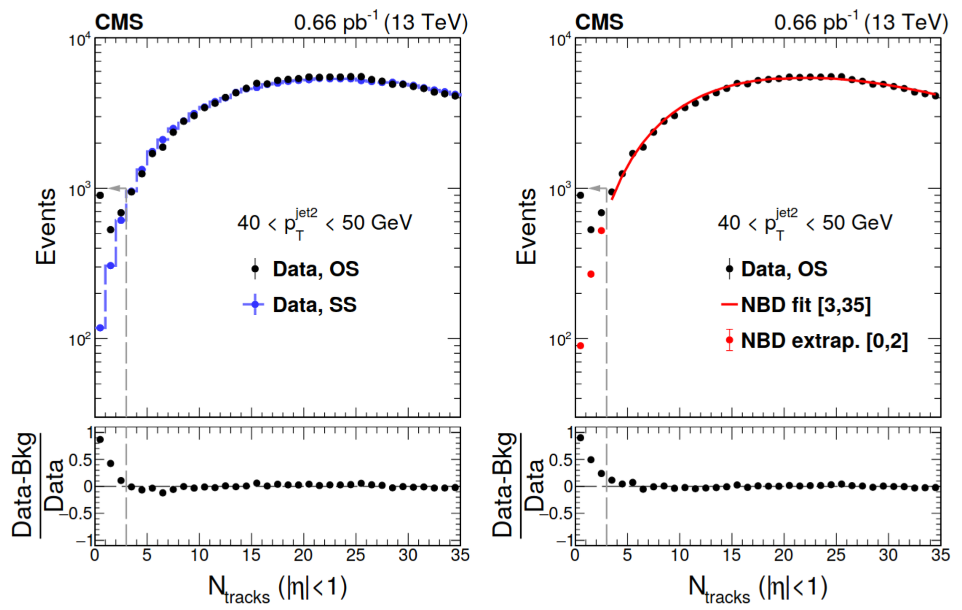
The analysis is based on a low pileup 2015 LHC run with (mostly) single proton-proton collisions per bunch crossing. Low pileup is necessary to suppress forward pileup jets and to observe clean pseudorapidity gaps.

Offline event selection:

- Particle-flow, anti-kT jets with R = 0.4.
- Two highest pT jets have pTjet > 40 GeV each.
- At most one primary vertex, nPV ≤ 1.
- Leading two jets must have 1.4 <|ηjet| < 4.7 and ηjet1 ηjet2 < 0
→ **Favors *t*-channel exchanges.**

## Background control

The pseudorapidity gap is defined **as the absence of charged particle tracks between the jets**, Ntracks. Each charged particle has pT>200 MeV in |η| < 1.




Color-exchange dijet events (**background**) dominate at large Ntracks → Use as control region to estimate their fluctuations at low Ntracks . Two data-based approaches:

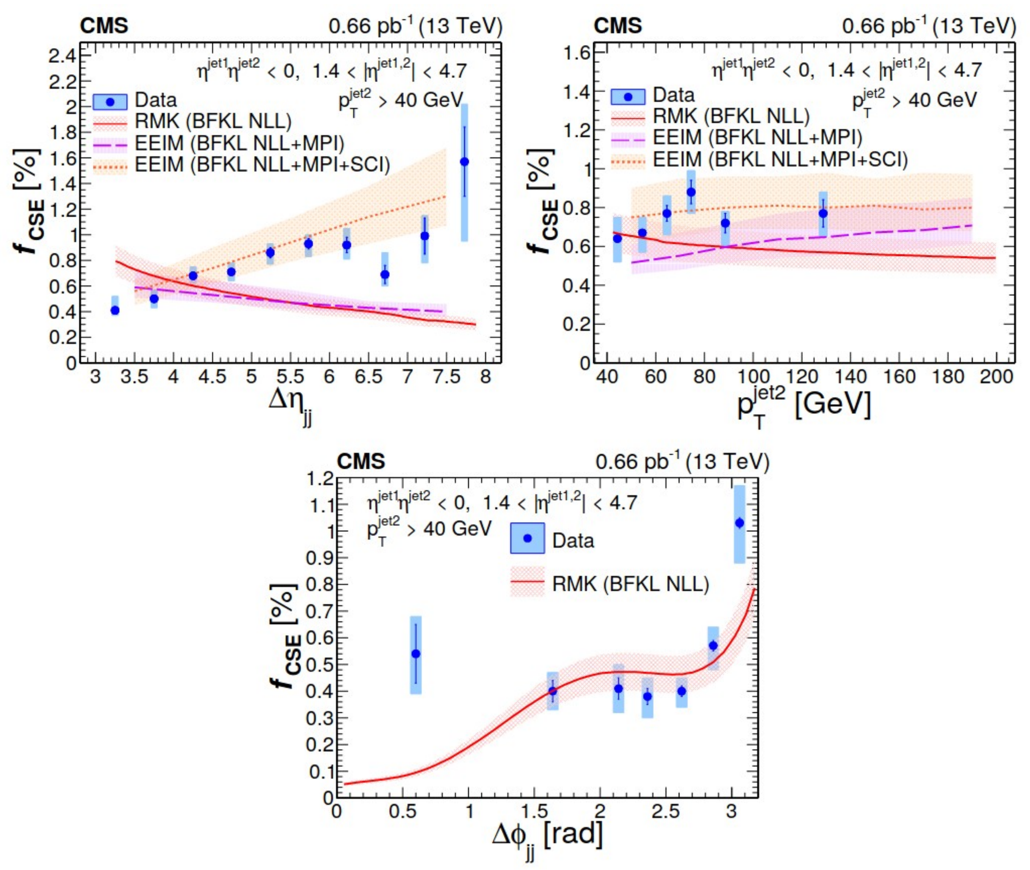
**Control dijet sample:** two jets on the same-side (SS) of the CMS detector, ηjet1 ηjet2 > 0. Normalize to events with jets in opposite sides (OS) of CMS, η jet1 η jet2 < 0, in Ntracks > 3.

**Negative binomial distribution (NBD) function:** Fit data with NBD in 3 ≤ Ntracks ≤ 35, extrapolate down to Ntracks = 0.

**Clear excess of events at Ntracks = 0.** These are the signal jet-gap-jet events.

## Results on jet-gap-jet

We extract the fraction of dijet events produced by color-singlet exchange, fCSE.



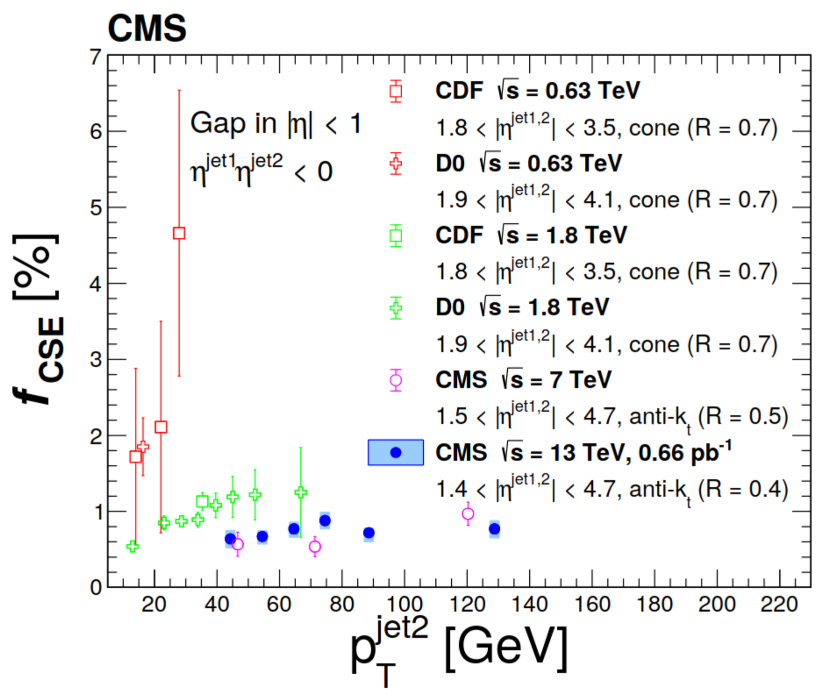

**Color-singlet exchange dijets represent about 0.6% of the inclusive dijet cross section** for the probed phase-space. The fCSE grows with Δηjj, is uniform in pTjet2, and maximizes at Δφjj ≡ |φ jet1−φjet2| = π.

We make a comparison with calculations based on the BFKL framework with next-to-leading logarithmic (NLL) resummation and LO impact factors:

- **Royon, Marquet, Kepka (RMK)** predictions (*Phys. Rev. D* 83.034036 (2011), arXiv:1012.3849), with survival probability $|S|^2$ = 0.1.
- **Ekstedt, Enberg, Ingelman, Motyka ( EEIM )** predictions (*Phys. Lett. B* 524:273 and arXiv:1703.10919) with **multiple parton interactions** (MPI) to simulate $|S|^2$ , also be supplemented with **soft-color interactions** (SCI) .

*Challenging to describe theoretically all aspects of the measurement simultaneously.*

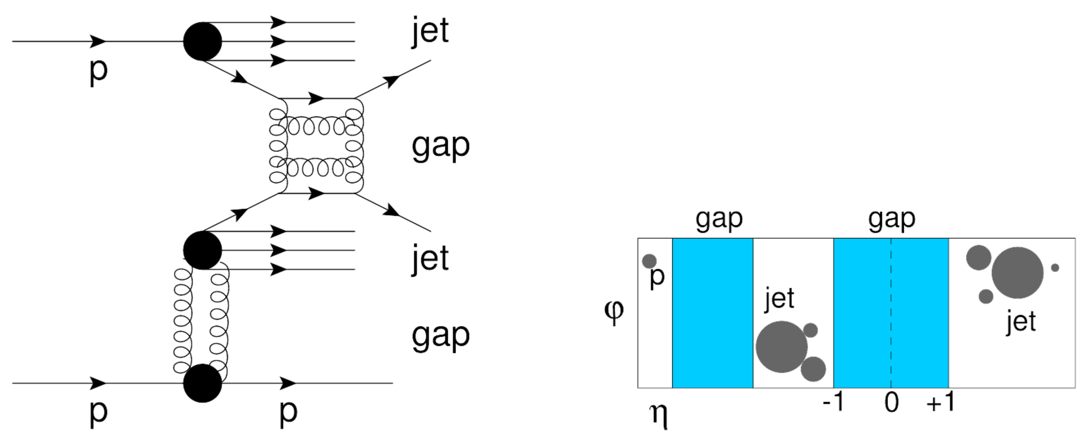
## Comparison to previous measurements




We compared our results to previous measurements at lower √s. Generally, the fCSE is expected to decrease with increasing √s, due to an increase in spectator parton activity with √s.

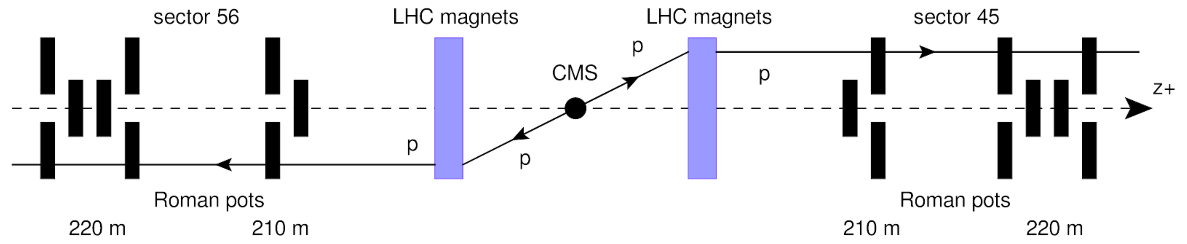
Within the uncertainties, fCSE **stops decreasing with √s at LHC energies**, in contrast to trend observed at lower energies 0.63 TeV→ 1.8 TeV→7 TeV.

## Jet-gap-jet with an intact proton




We can better understand the role of the spectator parton activity in the destruction of the central gap in jet-gap-jet events ***with a forward intact proton***. The proton remains intact due to the a color-singlet exchange object (pomeron exchange).

The intact protons are detected in the Roman Pot (RP) detectors of the TOTEM experiment, which are located at about 210 m w.r.t. IP5.



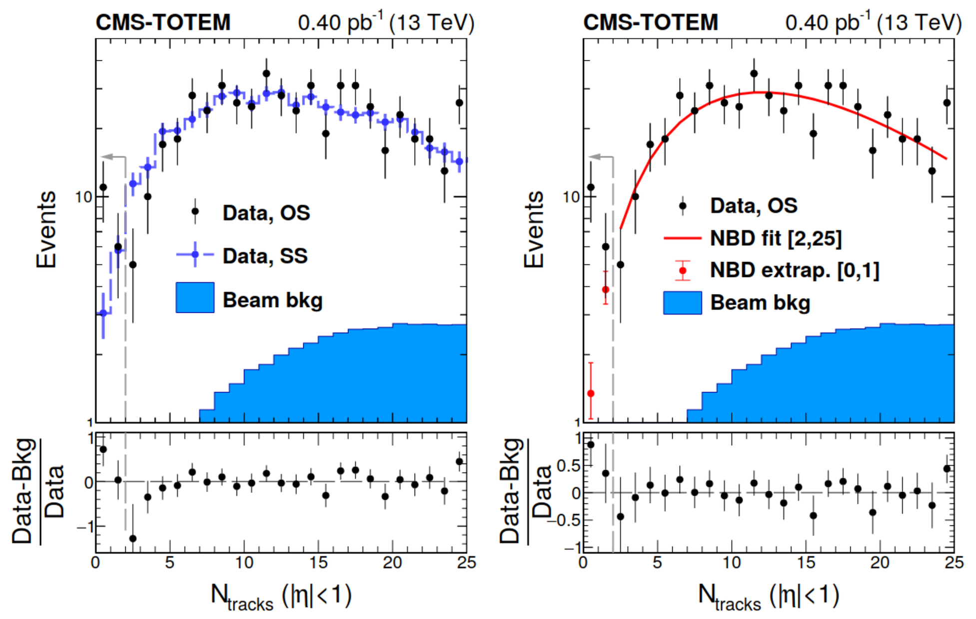

Schematic diagram of CMS-TOTEM configuration during the common run.

**Same dijet and central gap denitions as with CMS-only analysis.**

Intact proton requirements:

- The fraction of beam energy lost by the proton, ξp(RP), must be ξp(RP) < 0.2.
- The four-momentum transfer square at the proton vertex must be −4 < t < −0.025 GeV2, where t = ( pf−pi ) 2 of the proton.

## Background control




**The beam background** (consisting of beam-halo particles or pileup protons paired with uncorrelated dijets) is estimated from the data.

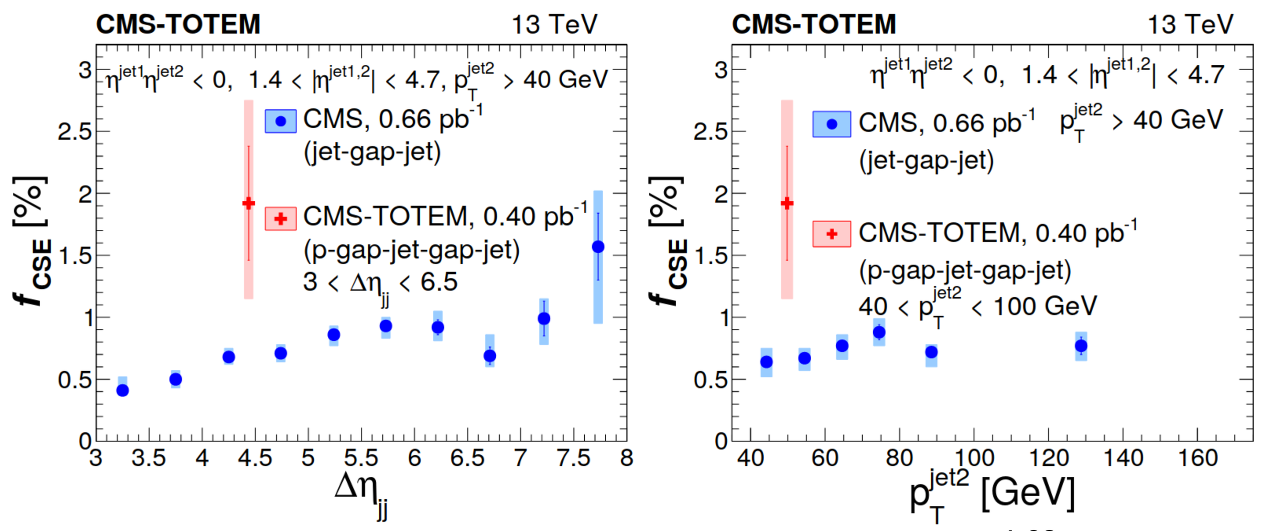
Similar techniques to estimate the background from fluctuations in Ntracks from standard diffractive dijet events:

**Control dijet sample:** Two jets in same side w.r.t. fixed η region. The η interval is adjusted to account for the intrinsic longitudinal boosts of single-diffractive dijets.

**NBD approach:** NBD is fit in 2 < N tracks < 25, and extrapolated down to Ntracks = 0.

**Clear excess of events at Ntracks = 0.** These are the signal p-jet-gap-jet events.

## Results on jet-gap-jet with an intact proton




The fCSE fraction in p-gap-jet-gap-jet study is $2.91 \pm 0.70\ (\text{stat.})^{+1.08}_{-1.01}$ (syst) times larger than the one in inclusive dijet, for similar dijet kinematics.

Lower spectator parton activity in events with intact protons → **Better chance of central gap surviving the collision.**

***First observation of this process!***

## Summary

- **Unique opportunity to probe BFKL dynamics in jet production at the CERN LHC.**
- About 0.6% of dijet events are produced by hard color-singlet exchange.
- **No further suppression between 7 and 13 TeV results is observed.**
- The BFKL NLL calculations with LO impact factor are not able to describe all aspects of the measurement simultaneously. Description improves with SCI and MPI supplemented to the calculation.
- First study of jet-gap-jet events with an intact proton allows for the possibility of future dierential measurements with larger luminosity.
- Hard color-singlet exchange fraction fCSE in events with at least one intact protons is larger the one in standard jet-gap-jet events.

## References

[1] CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

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[3] A. H. Mueller and W. K. Tang, “High energy parton-parton elastic scattering in QCD”, *Phys. Lett. B* 284 (1992) 123, doi:10.1016/0370-2693(92)91936-4.

[4] E. A. Kuraev, L. N. Lipatov, and V. S. Fadin, “The Pomeranchuk singularity in nonabelian gauge theories”, Sov. Phys. JETP 45 (1977) 199.

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[6] L. N. Lipatov, “The bare pomeron in quantum chromodynamics”, Sov. Phys. JETP 63 (1986) 904.