Studies of color reconnection and fragmentation with the CMS

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Zimányi Winter School

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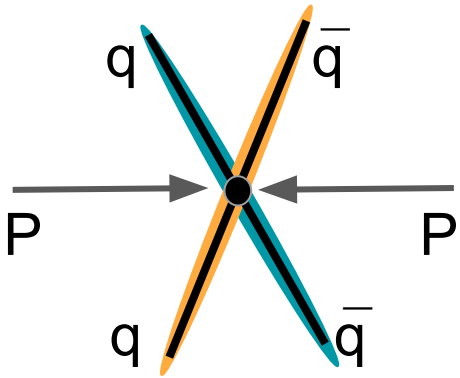
Outline

- Description of color reconnection
- Jet properties affected by the color reconnection scheme
- Main motivation: ALEPH measurements on this topic
- Studied color reconnection approaches
- Results from CMS recorded proton-proton collisions

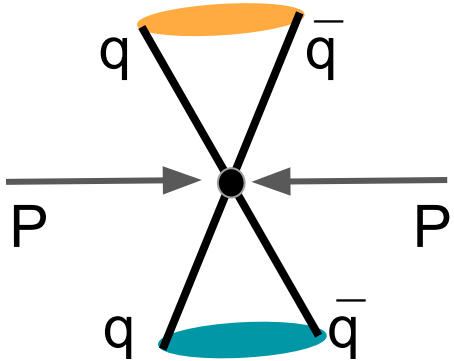
Color reconnection

- Color flux tube rearrangement instead of simple planar color flow
  - What is the effect on the final state?
- Obtained shorter strings → energetically favourable configuration

Planar color flow



Rearranged structure



- Particles are created along the strings
  - Model prediction: number of particles created ~ length of the string

Lower multiplicity in the final state, particles carrying more p_T

Stefan Gieseke et al ”Colour reconnections in Herwig++” arXiv:1206.0041

Color reconnection for jets

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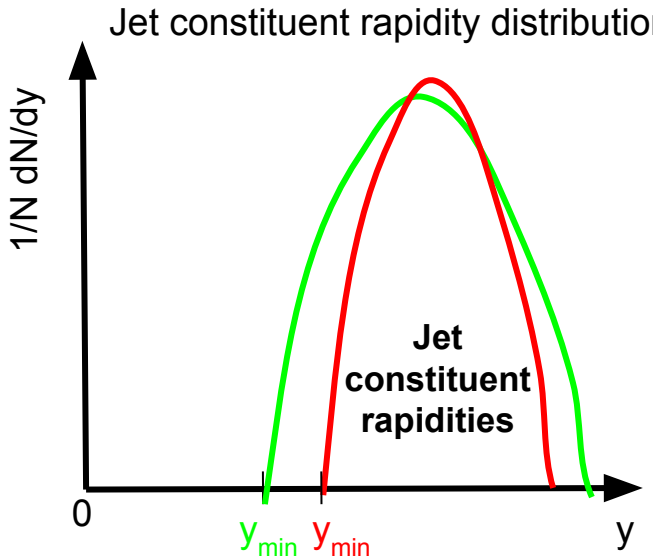
Planar color flow

Rearranged structure

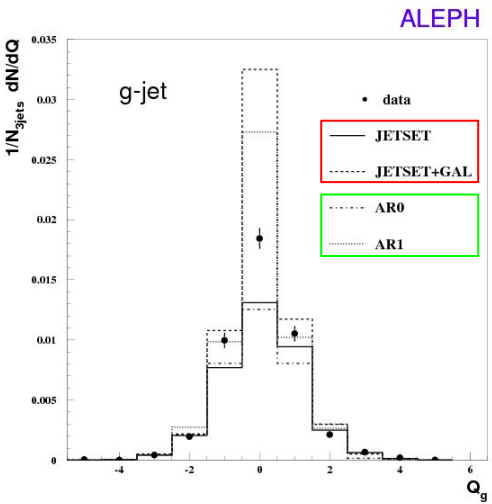


- Unique parameter for jets: minimum rapidity value found among the jet constituents
  - y_{min} also called rapidity gap in this context
  - Large y_{min} → expectation: narrow jets due to CR

measured wrt jet axis

Motivation from ALEPH results

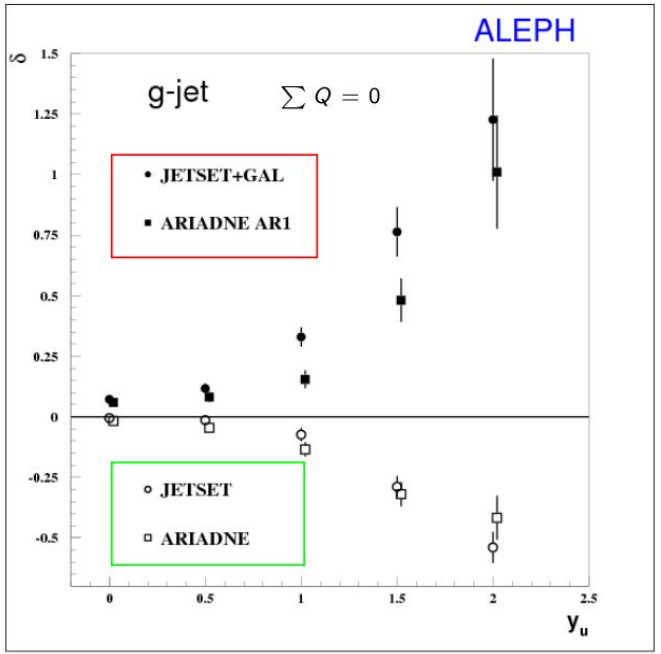
- Color reconnection in gluon jets from e^-e^+ collisions previously studied by LEP detectors
- One of the measured properties: sum charge of jet constituents wrt minimal rapidity
  - Significant differences between predicted <u>neutral jet rates</u>



$$r(0) = \frac{N(Q_j{=}0, y_{min})}{N_{3j}} \qquad \delta = \frac{r_{MC}(0) - r_{data}(0)}{r_{data}(0)}$$

models with CR predict more jets with neutral sum charge

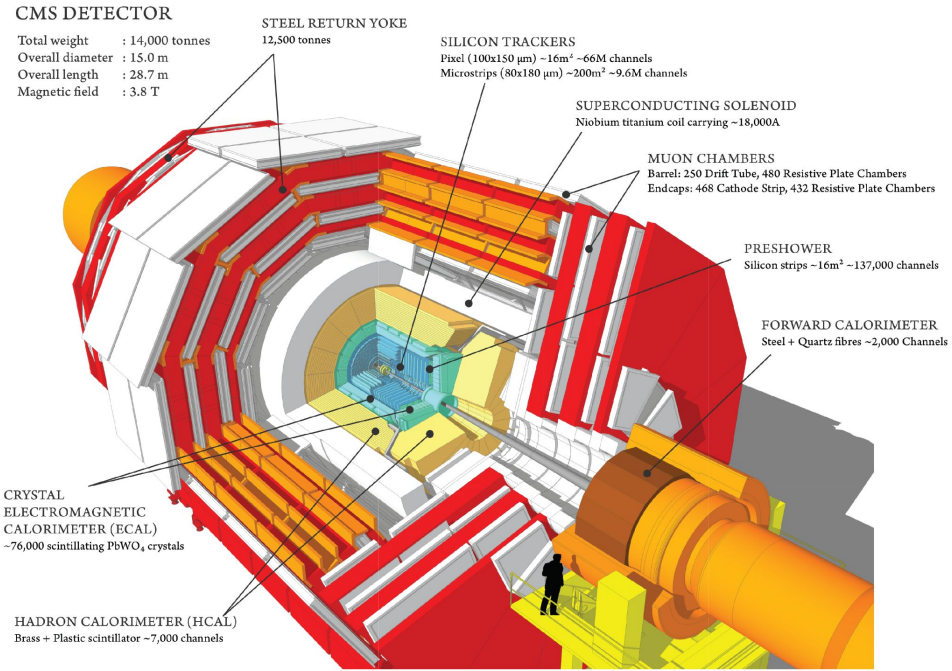
models not considering CR underestimate the measured rate

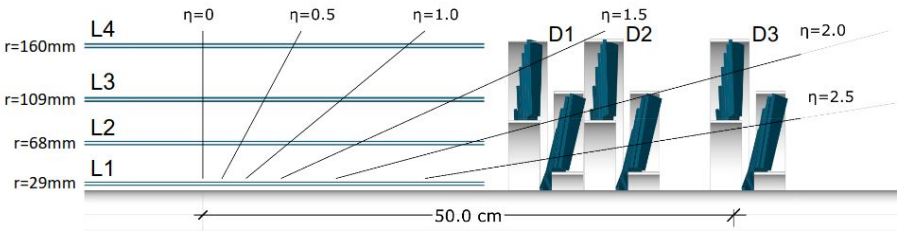


The ALEPH Collaboration "Test of colour reconnection models using three-jet events in hadronic Z decays" Eur. Phys. J. C 48, 685-698 (2006)

Proton-proton collisions in CMS

- Different conditions: more complex systems from pp collisions
- General purpose detector system
- Objects fit into the tracker volume (|η| < 2.5)

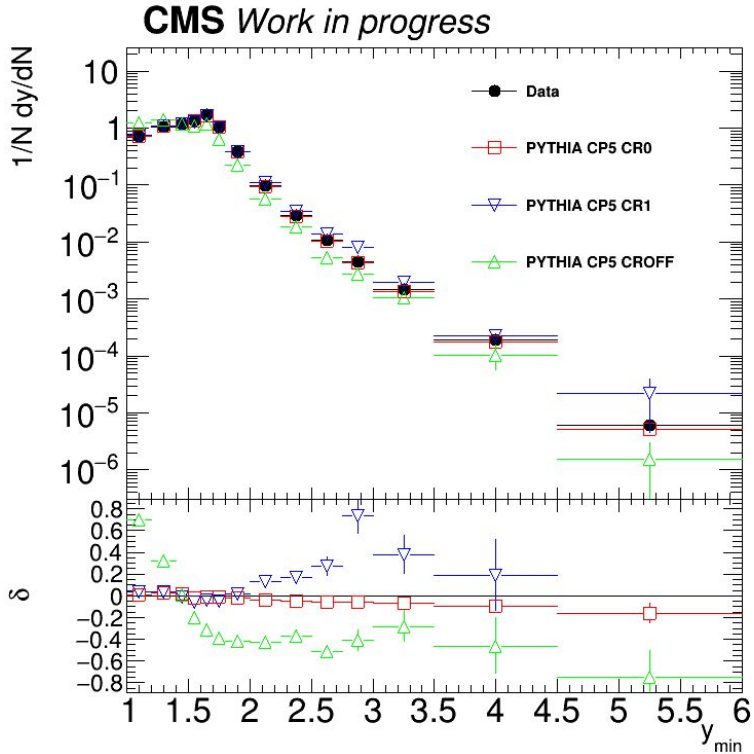




The Tracker Group of the CMS Collaboration “The CMS Phase-1 Pixel Detector Upgrade” arXiv:2012.14304

Minimum rapidity found in jets from pp collisions

- Anti-k_t jets with R=0.4, kinematic cuts in the backup
- Narrow jets with large rapidity gaps are rather suppressed



Default CR (CR0): reconnection probability depends on the p_T of the partons.

'Newer scheme' (CR1): QCD sum rules are also taken into account. Predicts more narrow jets.

CROFF: CR0 tunes, but the whole CR process is excluded. Significantly lower number of jets with high gap.

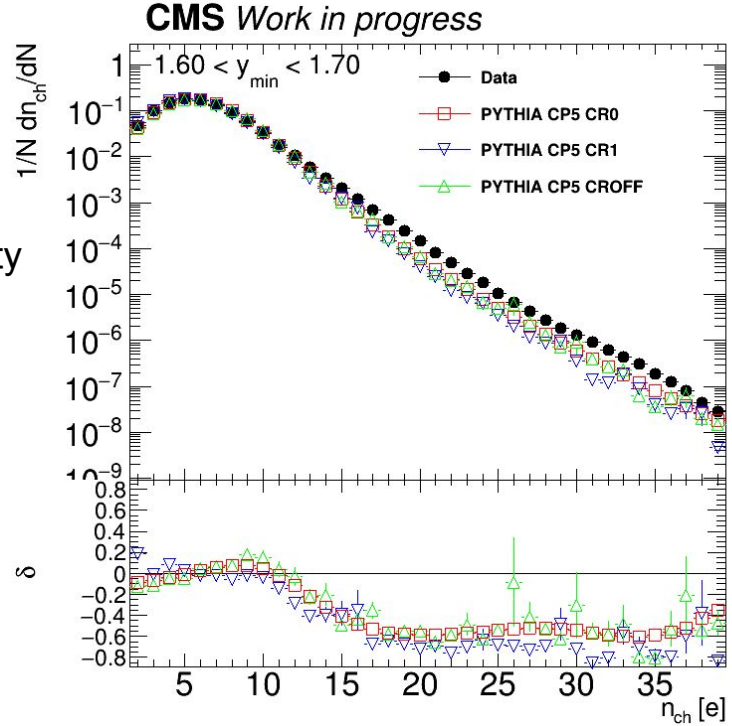
$$\delta = \frac{r_{MC} - r_{data}}{r_{data}}$$ relative model-data difference

T. Sjostrand et al. "An Introduction to PYTHIA 8.2" Comput. Phys. Commun. 191 (2015) 159

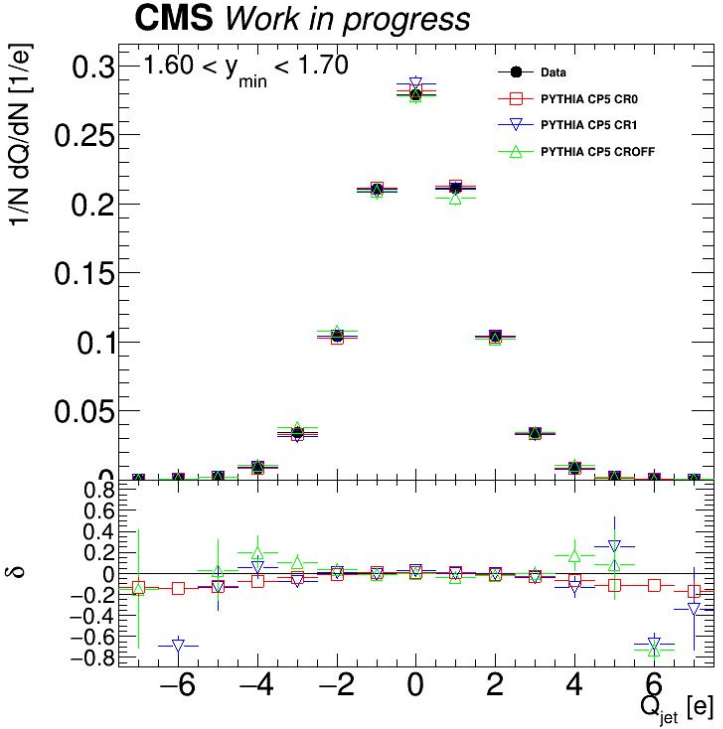
Examined jet properties

- Interesting properties for the all the different y_{min} windows:
  - number of charged particles in jets (n_{ch})
  - sum charge distribution (Q_{Jet})

number of charged constituents



sum charge



normalized to unity per y_{min} window

$$\delta = \frac{r_{MC} - r_{data}}{r_{data}}$$

relative model-data difference

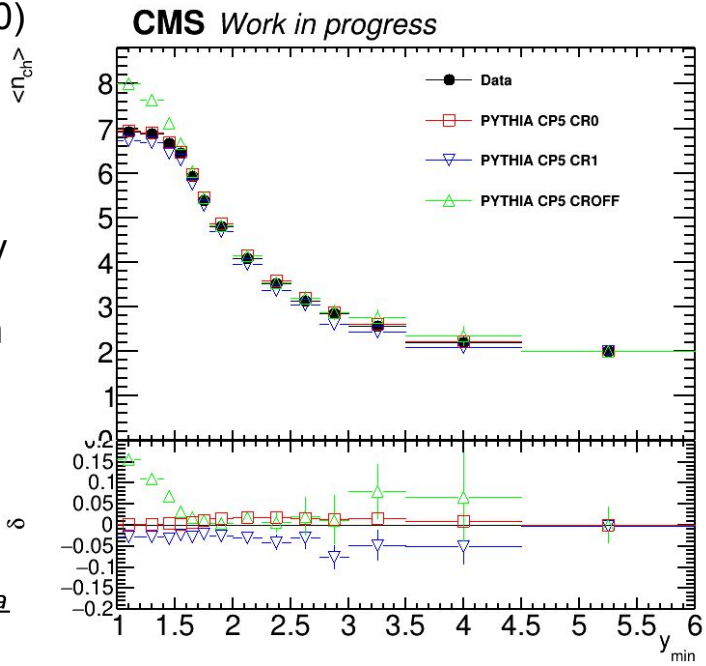
Summary plots

- Significant difference between the model predictions
- Main properties for each min rapidity region:

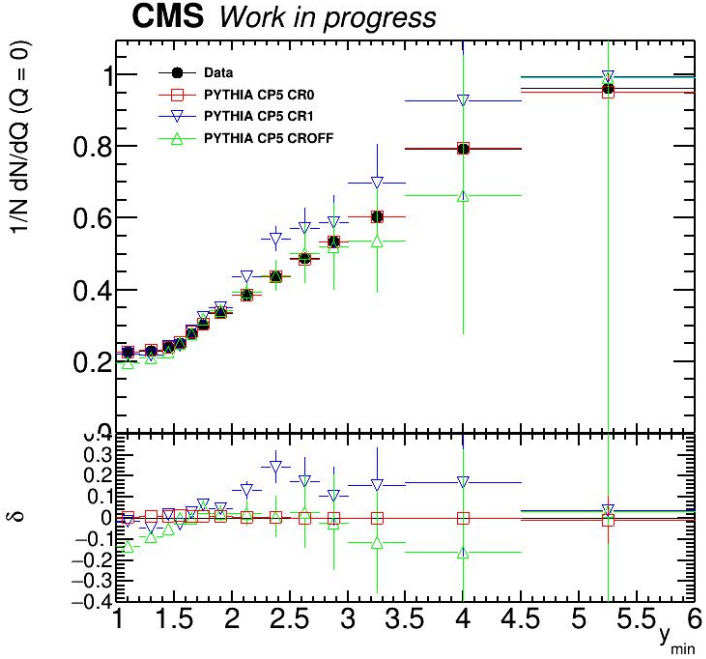
CROff highest charged multiplicity

CR1 larger fraction of neutral jets

average number of charged constituents <n_{ch}> 0)



fraction of neutral jets 1/N dN/dQ (Q = 0)



$$\delta = \frac{r_{MC} - r_{data}}{r_{data}}$$

relative model-data difference

Conclusion and further plans

- Colour reconnection sensitive properties of jets found
- Feasibility studies: CMS recorded pp data can be used
- Increase the statistics for non-standard MC samples
- Extend the study to include other CR approaches (e.g. gluon-move scheme in Pythia, Herwig++, etc)

Backup

Overview of pp analysis properties

Ultralegacy pp runs from 2017	294927-306462, Era B-E, 31.7 fb^{-1}
MC used for the analysis	Official ultralegacy campaign (tune: CP5CR0) + two private MC samples (tunes: CP5CR1; CP5CROff)
Triggers to collect data	Particle Flow AK4 jet triggers with proper weights and 99% efficiency cuts
Reconstructed objects	Pile-up cleared AK4 slimmedJetsPuppi $p_T > 30$ GeV, $\|\eta\| < 2$, containing at least two tracks Tracks, $p_T > 0.2$ GeV (pions, leptons) Neutral constituents, $p_T > 0.2$ GeV (photons, kaons)
Generator level objects	GenJets (AK4) $p_T > 20$ GeV, $\|\eta\| < 2$, at least two charged particles Charged constituents $p_T > 0.2$ GeV Neutral constituents $p_T > 0.2$ GeV