Experimental study of Quark and Gluon jets in proton-proton collisions

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Motivation

Jets are objects produced in hard scatterings of colliding particles. Experimentally we can observe jets as showers of high momentum particles. The character of these showers is determined by the fragmentation properties of the original parton – quark or gluon. In QCD, quarks and gluons carry a different color factors [1]. This factor is proportional to the probability of a parton to radiate a soft gluon. **Gluons have a higher color factor and as such are believed to form**

$$\underbrace{\textit{Higher multiplicity} \quad \textit{Broader} \quad \textit{Softer}}_{\textit{jets}}$$

Apart from these differences, the **gluons are expected to contribute mainly to the baryon production, whereas quarks give rise to meson**[2]. Of course, all these differences must me demonstrated in the particle spectra observed in an experiment. Previous experiments with e^+e^- [3] and $p\bar{p}$ [4] collisions studying the properties of different parton types have qualitatively proven the expectations in charged multiplicity and fragmentation distributions. However, the identified hadron spectra inside such jets are still waiting to be measured and new excellent PID capability detectors at LHC give a promising outlook for this topic.

From the heavy-ion perspective, the study of fragmentation properties of quarks and gluons becomes important for understanding unexpected observation from RHIC explained by different phenomenological models (coalescence [5], jet flavor conversion [6]), which incorporate the above mentioned differences.

Experimental treatment of quark and gluon jets

The experimental treatment of quarks and gluons in proton-proton and heavy-ion collisions seems challenging since we only can observe the final state hadrons together with the underlying event.

Problems:

- Jet-definition through jet-finding algorithm
- Prior expectations bias our selection
- Cannot use MC

Solution:

Focus on clean production channels

Quarks: *gamma-jet*
Gluons: *multi-jet events*

Simulation details:

In order to study the performance and possibilities to distinguish between quark and gluon jets we have used a MC simulation:

- Pythia 6.4, ***Perugia0*** [7]
- **pp@7TeV**
- *1M events* ***QQ*** ($qq \to qq$, $q\bar{q} \to q\bar{q}$, $gg \to qq$),
- *1M events* ***GG*** ($q\bar{q} \to gg$, $gg \to gg$),
- *1M events* ***QG*** ($qg \to qg$),
- *1M events* ***γ-jets*** ($gq \to \gamma\, q$)

Since the cross-section of the jet production strongly depends on jet energy, the jet production was performed in 10 p_T^{Hard} bins and the spectra scaled with cross-section

p_T^{Hard} = {[5;11], [11;21], [21;36], [36;57], [57;84], [84;117], [117;156], [156;200], [200;249], [249;-1]}

Method description:

1st step: We apply the jet-finding algorithm and for each jet we determine the energy dependence of the cut-variable. In our case this is the ΔR(90%). We fit this dependence and obtain calculated variable as function of jet energy:

$$\Delta R(90\%)_{calc} \begin{cases} \nearrow \; pol1 = A+BxE \\ \searrow \; exp = exp(A+BxE) \end{cases}$$

R = 0.7

E interval	Fit. fction	A	B	χ^2/Ndf	Prob
(35;75)	*pol1*	*0.3913 +/- 0.0159*	*-0.002424 +/- 0.000309*	*0.6188/2*	*0.733*
(65;155)	*exp*	*-1.316 +/- 0.035*	*-0.002666 +/- 0.000297*	*3.658/7*	*0.8183*

R = 0.4

E interval	Fit. fction	A	B	χ^2/Ndf	Prob
(25;85)	*exp*	*-1.59 +/- 0.02*	*-0.006556 +/- 0.000465*	*3.138/4*	*0.535*
(85;155)	*exp*	*-1.878 +/- 0.049*	*-0.002438 +/- 0.000401*	*3.97/5*	*0.5537*

Table 1: Fit functions and their parameters for reconstructed jes

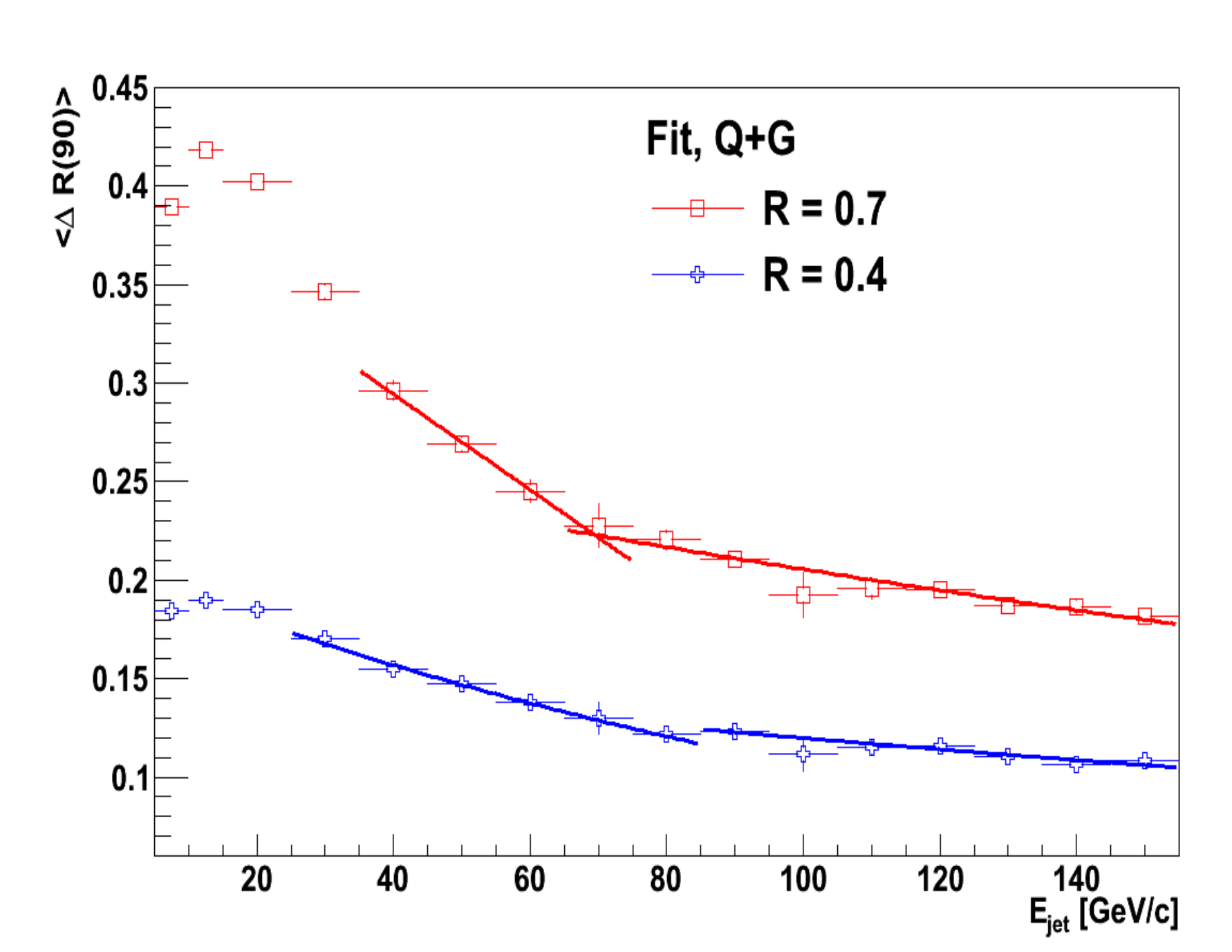


Fig. 1: ΔR(90%) as a function of jet energy.

2nd step: From the reconstructed gamma-jet we select leading jets and from multi-jet events other than the two leading ones. For the selected jets we measure the ΔR(90%) and compare it to the calculated one obtained from the fit in 1st step:

$$DR = \Delta R(90\%)_{calc} - \Delta R(90\%)_{measured}$$

And determine the cut:

R = 0.7

E interval	Quark DR	Gluon DR
(35;75)	*0.15*	*0.00*
(65;155)	*0.10*	*0.05*

R = 0.4

E interval	Quark DR	Gluon DR
(25;85)	*0.15*	*0.10*
(85;155)	*0.05*	*0.00*

Table 2: DR cuts for quark and gluon jets

Then we apply these cuts to the two leading jets in an event.

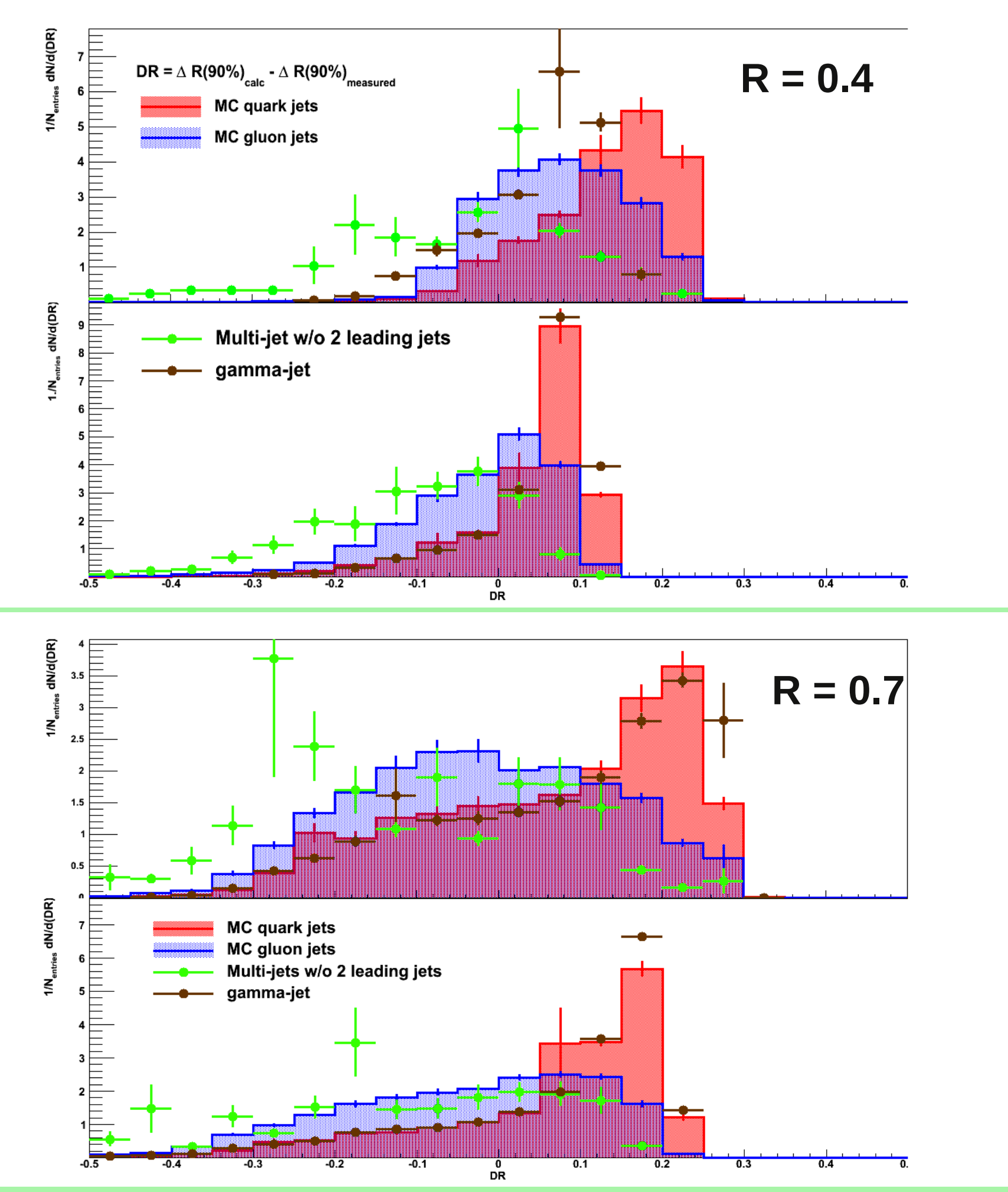


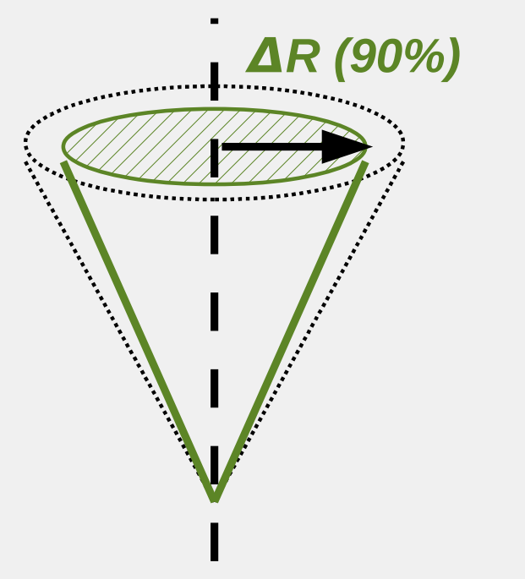
Fig. 2: DR variable distribution for quark and gluon jets

Jet definition:

The jets were reconstructed using the **anti-kT jet finding algorithm** [8]. We used two R-parameter values **(0.4, 0.7)**. A jet was accepted if it lied in **|η| < 0.5** and contained at least **3 charged particles**.

Cut variable:

- ***ΔR(90%)***
- “jet-shape like” variable
- size of sub-cone containing 90% of jet's energy



Performance:

$$Eff = \frac{\sum (Q_{cut} \wedge Q_{MC})}{\sum Q_{MC}} \qquad Pur = \frac{\sum (Q_{cut} \wedge Q_{MC})}{\sum Q_{cut}}$$

In case of quarks, the purity of the selection visibly rises with energy and the performance in general gets better.

For gluons, the purity slightly decreases towards higher energies. But thanks to gluon dominance in the sample, we still reach high values of purity

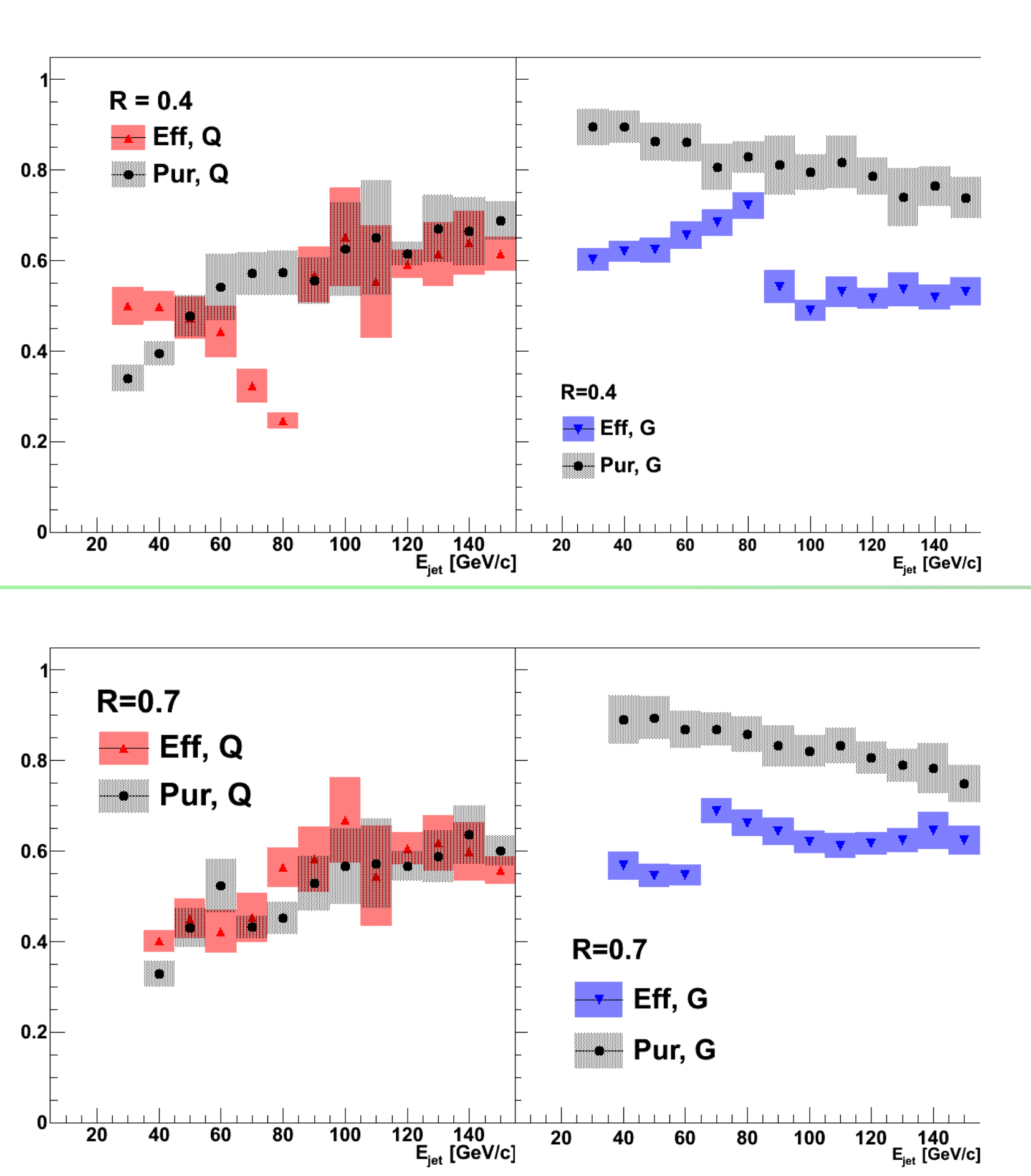


Fig. 3: Efficiency and purity for the samples of selected quark and gluon jets

Discussion

We presented a possibility to **distinguish between quark and gluon jets experimentally**. The main advantage of this method lies in the fact, that the cut on the variable introduced can be calibrated on real data **without the necessity to rely on MC information**. This way, our selection is not biased by our prior expectations about the differences of quark and gluon jets.

However, the method needs to be fine-tuned especially in the region of lower energy jets. As can be seen in Fig. 2, the cut based on gamma-jet and multi-jet events selects harder jets as quarks and softer jets for gluons, which we need to be aware of and apply a more detailed treatment of this region.

The performance of the method was determined by the efficiency and purity of the identification of the two leading jets. As can be seen in Fig. 3, for quarks it achieves efficiency and purity up to 60% in the higher energy interval. For gluons, efficiency of the selection is better (constant, 60% for higher energy interval), although the purity drops slightly with energy. The rise of purity for quarks and the drop for gluons is however expected since quarks are to form harder jets than gluons.

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