Experimental study of Quark and Gluon jets in pp collisions at LHC energies

- *Quark/Gluon jet differences*
- *Motivation to study them separately*
- *Separation method*
- *Possibility to use multi-jet and gamma-jet events*

Zimányi

WINTER SCHOOL ON

HEAVY ION PHYSICS

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Sona Pochybova[1,2]

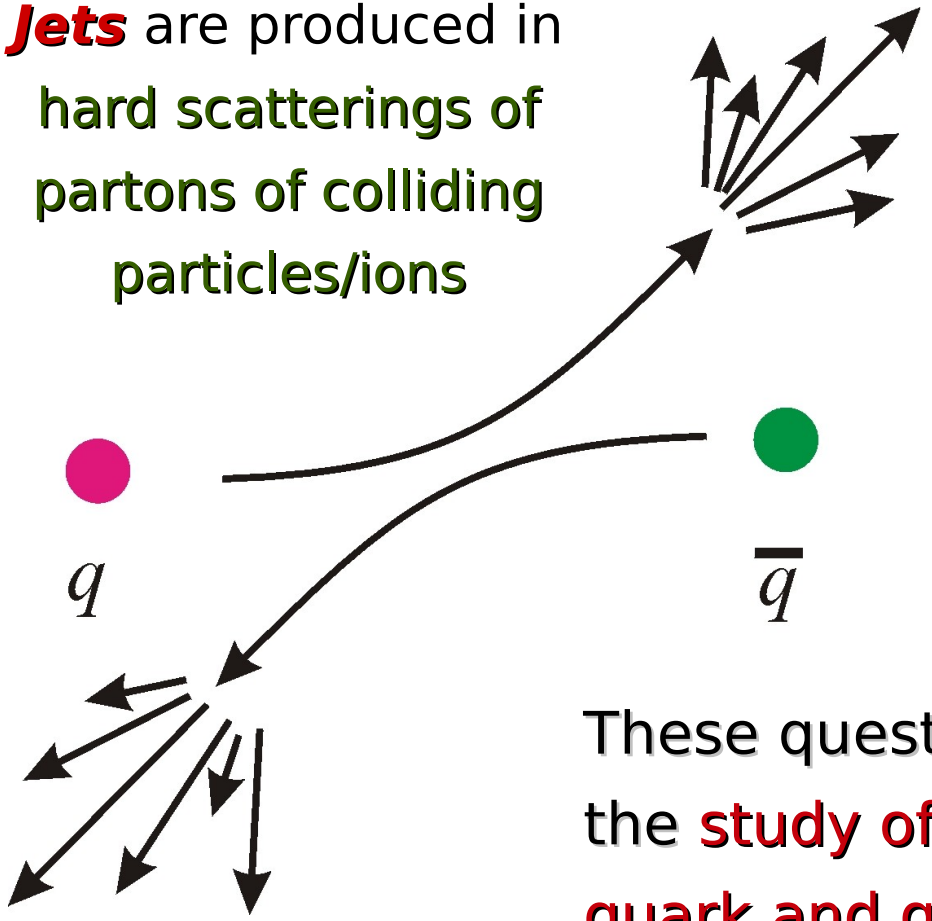
sona.pochybova@cern.ch

[1] ELTE, Budapest, Hungary

[2]MTA KFKI RMKI, Budapest, Hungary

Introduction

Jets are produced in **hard scatterings of partons of colliding particles/ions**



Emerging from the very early stages of collisions they are ideal to study

Early stages of collisions
Hadronisation processes
Particle production

These questions can be addressed through the study of fragmentation properties of quark and gluon jets

Quark and Gluon Jets

Quark and gluon jet carry different colour factors

$$\frac{C_A}{C_F}=\frac{9}{4}=2{,}25\,(Q\to\infty)$$

The colour factors are proportional to the **probability a parton radiates soft gluon**

Gluons branch more easily and are expected to form

Higher multiplicity jets

Broader jets

Jets with softer fragmentation function

Quark and Gluon Jets

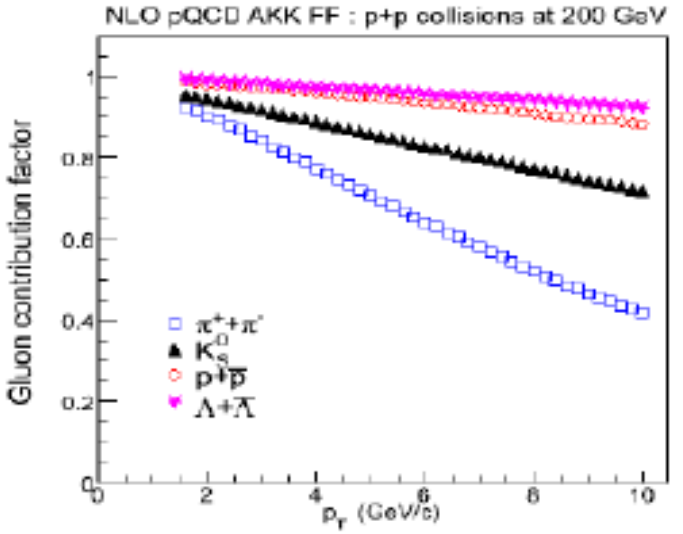
Particle production differences:

Gluons

Baryon production

Quarks

Meson production



S. Albino, B.A. Kniehl, and G. Kramer - NPB 725 (2005) 181

Higher multiplicity jets

Broader jets

Jets with softer fragmentation function

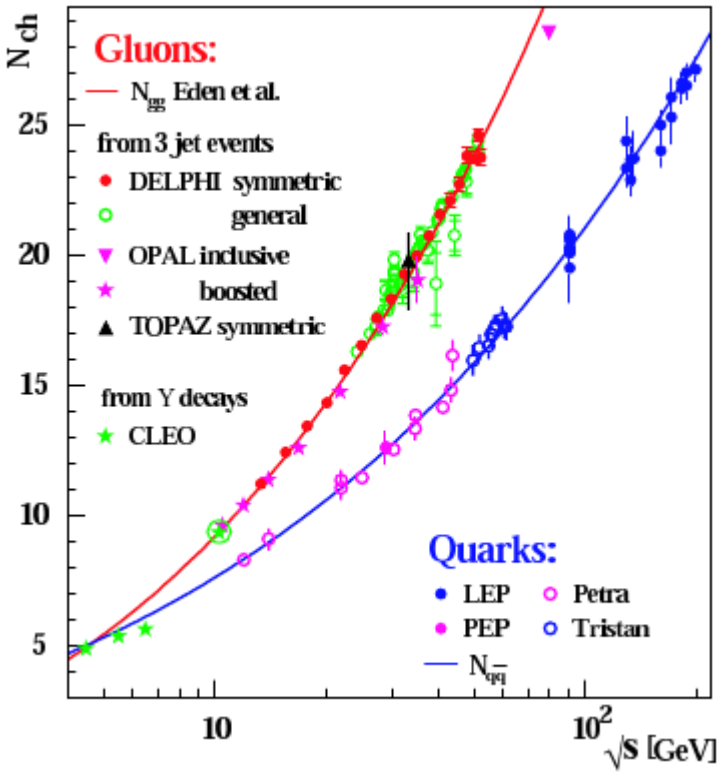
- *The differences in the frag. properties of q/g jets must naturally be represented in the experimentally studied variables*
  - identified hadron spectra, multiplicity, R(AA)

- *Variables connected to jet-properties study*
  - Jet-shape, charged multiplicity
  - Fragmentation functions
  - Identified hadron spectra

Historical outlook

- First studies looking at properties of jets were conducted in e^+e^- (LEP)

Acta Phys.Polon.B36:433-440,2005.



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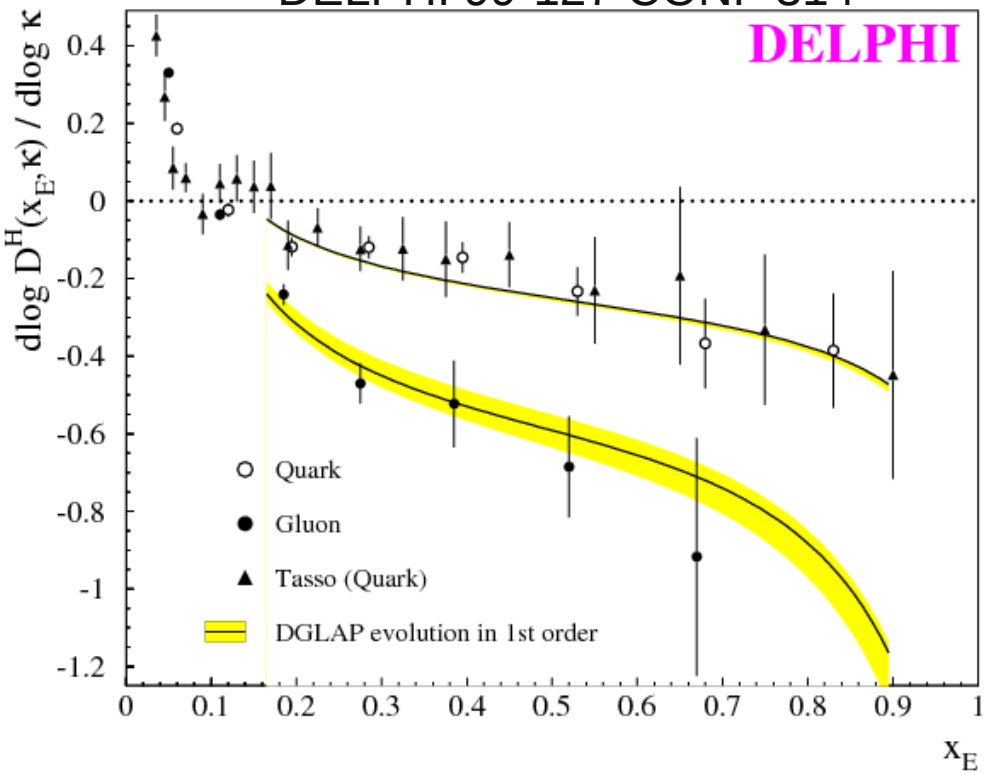
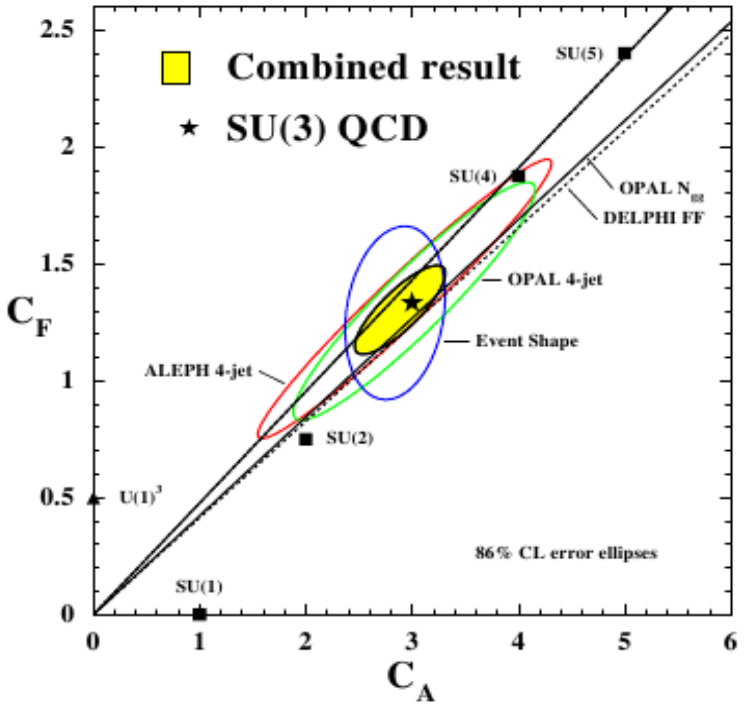


Qualitative differences were observed

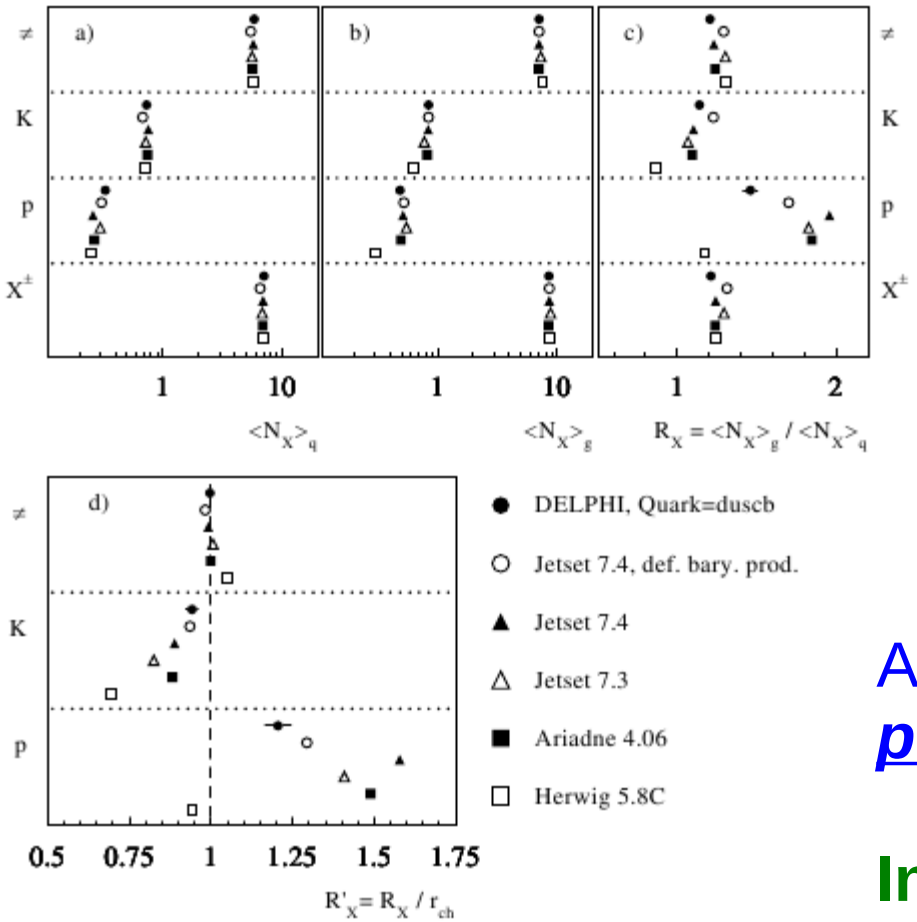
Nucl.Phys.Proc.Suppl.133:36-46,2004
arXiv:hep-ex/0309070v2

- **4-jet events**
  - Angles between 2-momenta planes
- **Event shape**
  - Thrust
- **Q/G separation**
  - 3-jet events



The results of the methods have been combined to average C_A and C_F

$$\overline{C}_A = 2.89 \pm 0.03(\text{stat.}) \pm 0.21(\text{syst.})$$
$$\overline{C}_F = 1.30 \pm 0.01(\text{stat.}) \pm 0.09(\text{syst.})$$



http://arXiv.org/abs/hep-ex/0106063v1

Identified particles in Q/G jets have been measured as well.

Relative proton abundance in gluon jets has been observed

All measurements at LEP have been ***performed in vacuum***

In hadron-hadron and heavy-ion collisions we face the challenge to test QCD in a dense environment.

Int.J.Mod.Phys.A20:3723-3725,2005.

PhD. Thesis of Takuma Horaguchi

TEVATRON

- Jets identified in di-jet and γ-jet events based on the expected fraction of gluon jets at certain di-jet invariant mass
- Multiplicities were compared

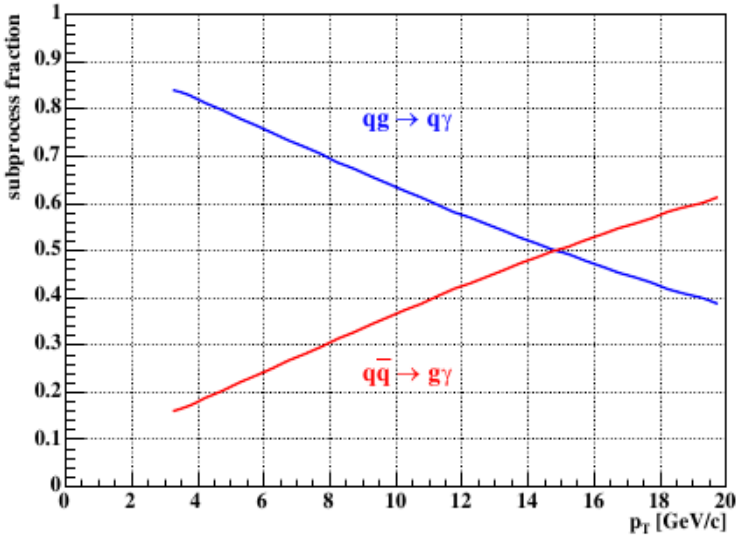


Figure 2.11: The fraction of $gq \to \gamma q$ and $q\bar{q} \to \gamma g$ as function of p_T in $p + \bar{p}$ at $\sqrt{s} = 200$GeV.

$N_g/N_q = r = 1.6 \pm 0.2$

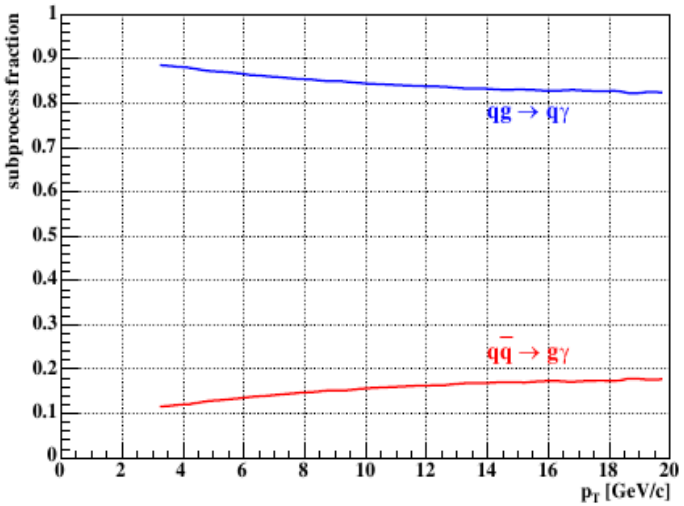
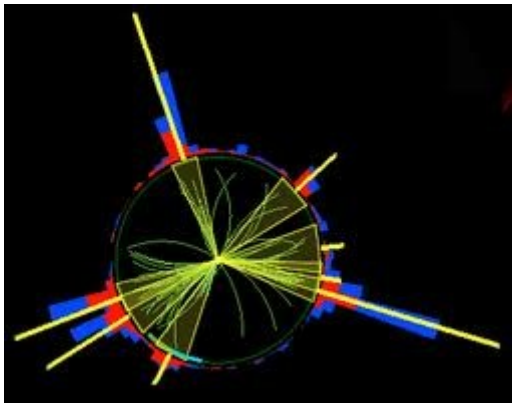


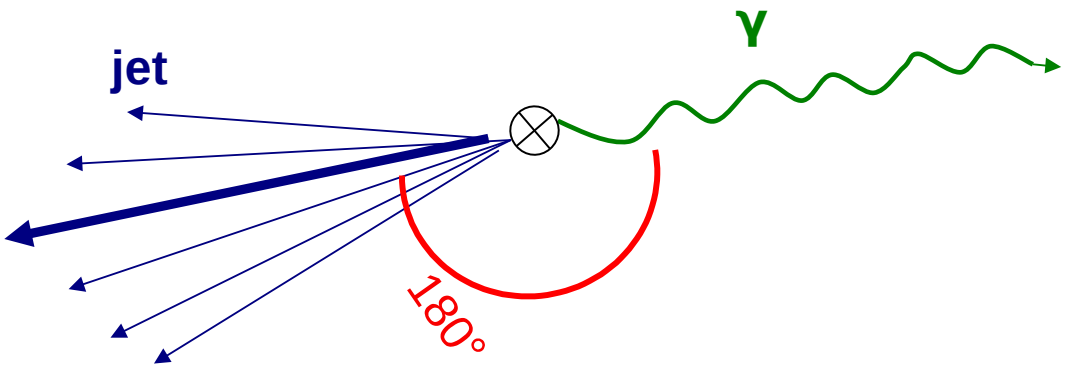
Figure 2.10: The fraction of $gq \to \gamma q$ and $q\bar{q} \to \gamma g$ as function of p_T in $p + p$ at $\sqrt{s} = 200$GeV.

Method sensitive to misidentification. High fraction of gluon jets both in di-jet and γ-jet events in proton-antiproton col.

How to ID the different partons?

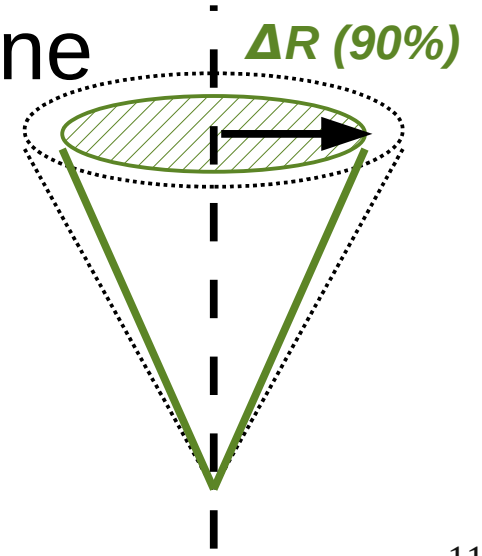
- Use their properties
- Separate “clean” production channels for the production of Q/G
  - G: Multi-jet events
  - Q: gama-jet



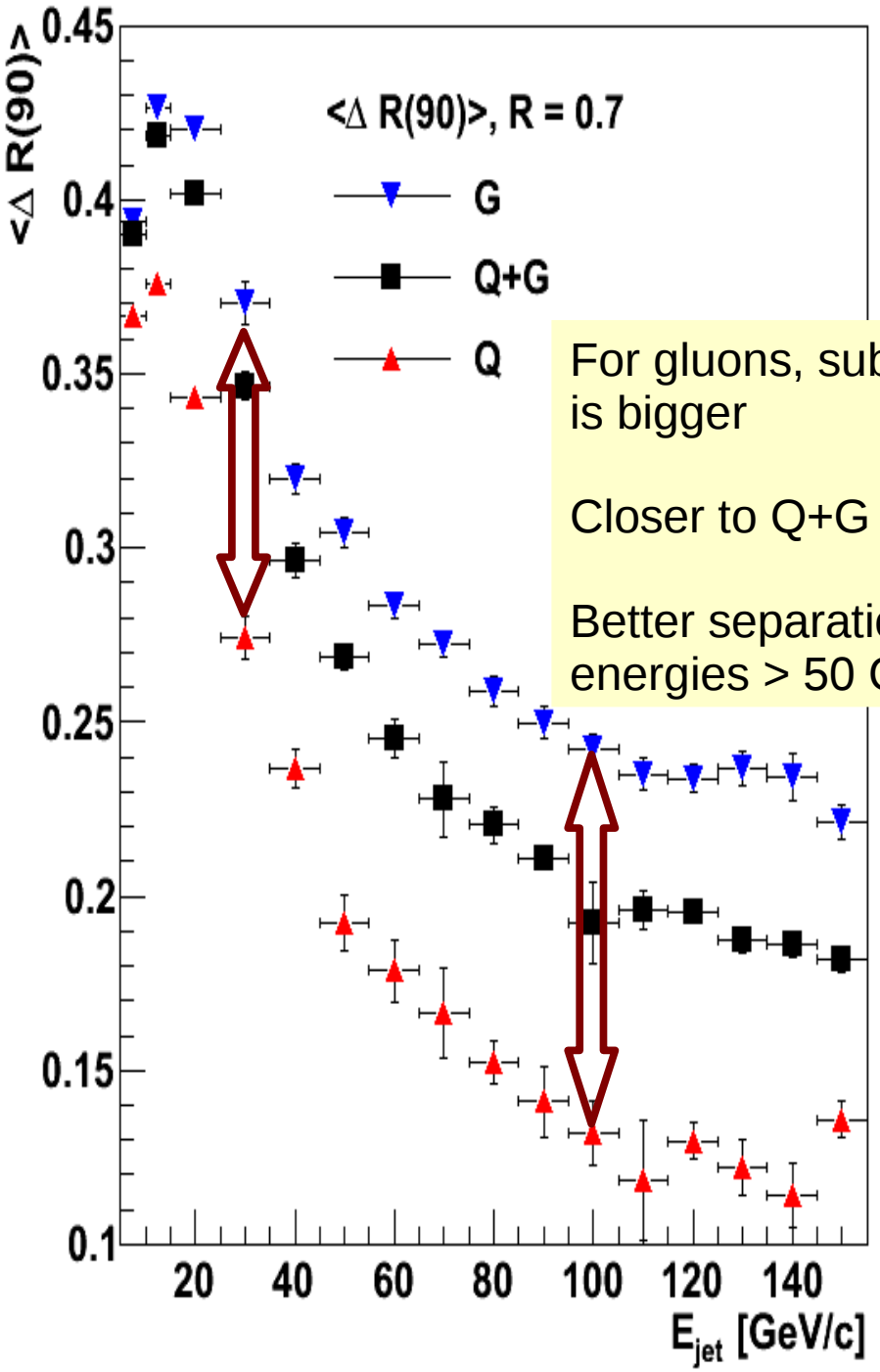


What we did

- Pythia 6, Perugia-0, pp@7TeV
- ***QQ, GG, QG, γ-jets*** channels, each 1M events
- anti-kT algorithm, R = {0.4, 0.7}
- |η| < 0.5, at least 3 charged particles
- Variables: **ΔR(90%)**; size of sub-cone containing 90% of jet's energy



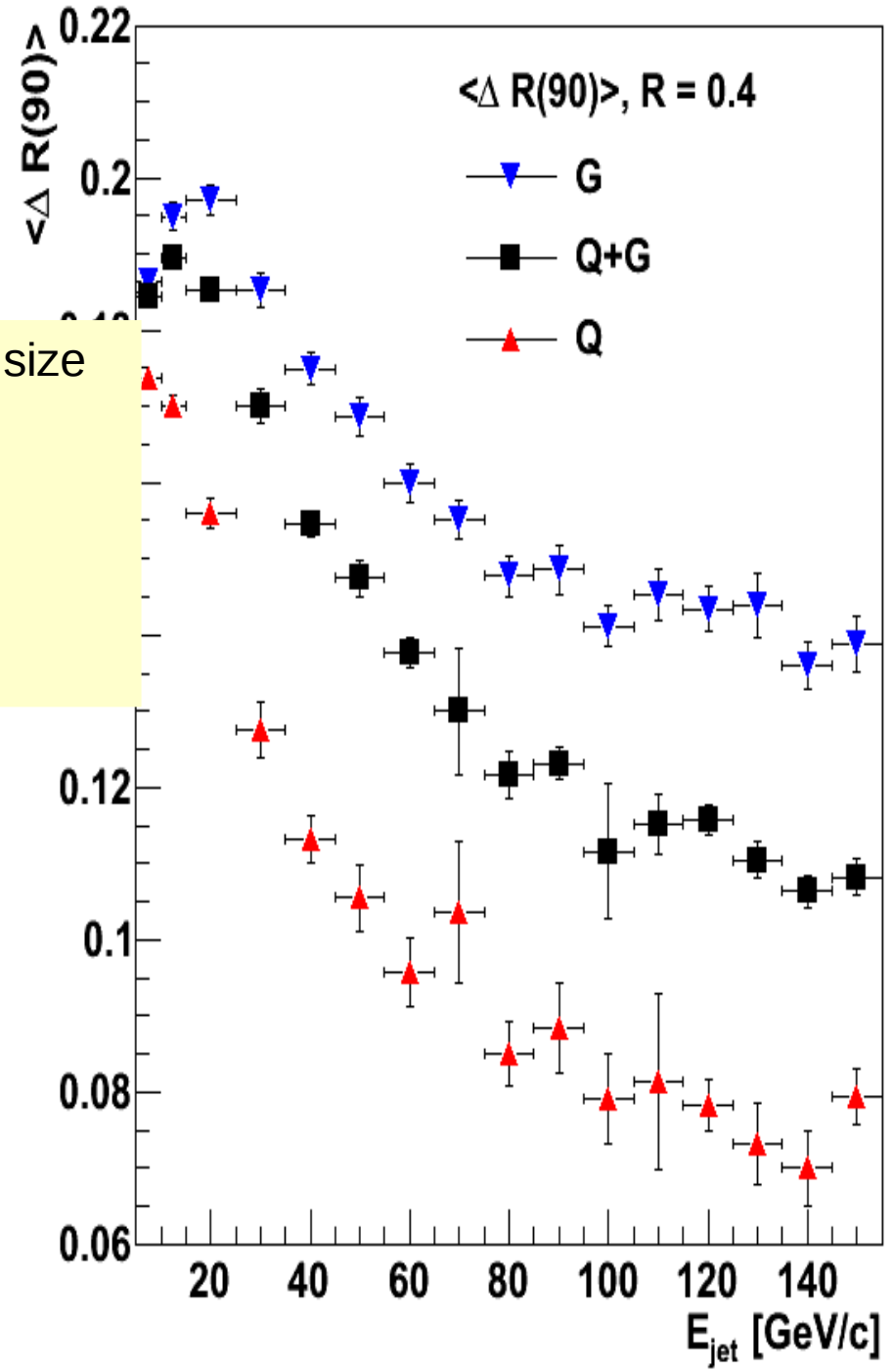
1st step: **extract the distribution of the variable and fit to obtain ΔR(90%)**

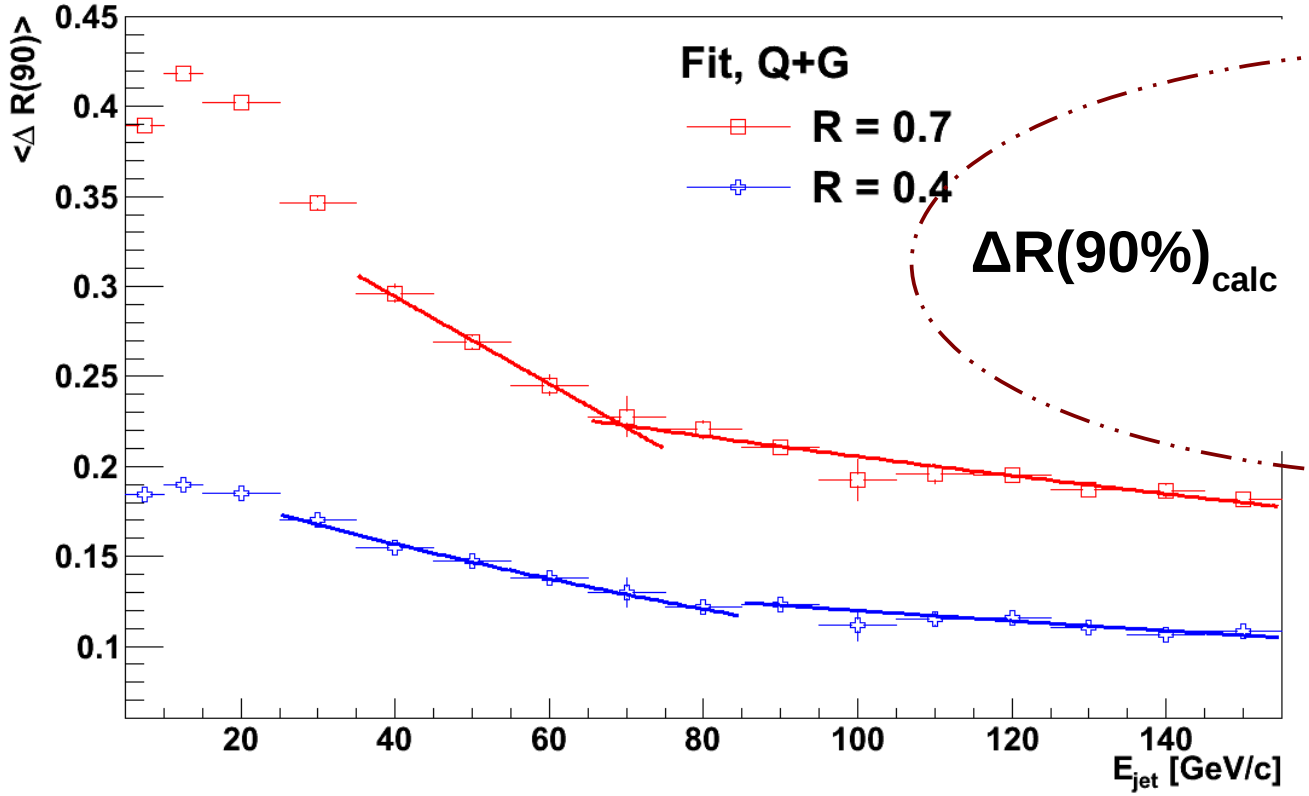


For gluons, sub-cone size is bigger

Closer to Q+G

Better separation at energies > 50 GeV/c





$\Delta R(90\%)_{calc}$

Fit fctions:

pol1 = A+BxE

exp = exp(A+BxE)

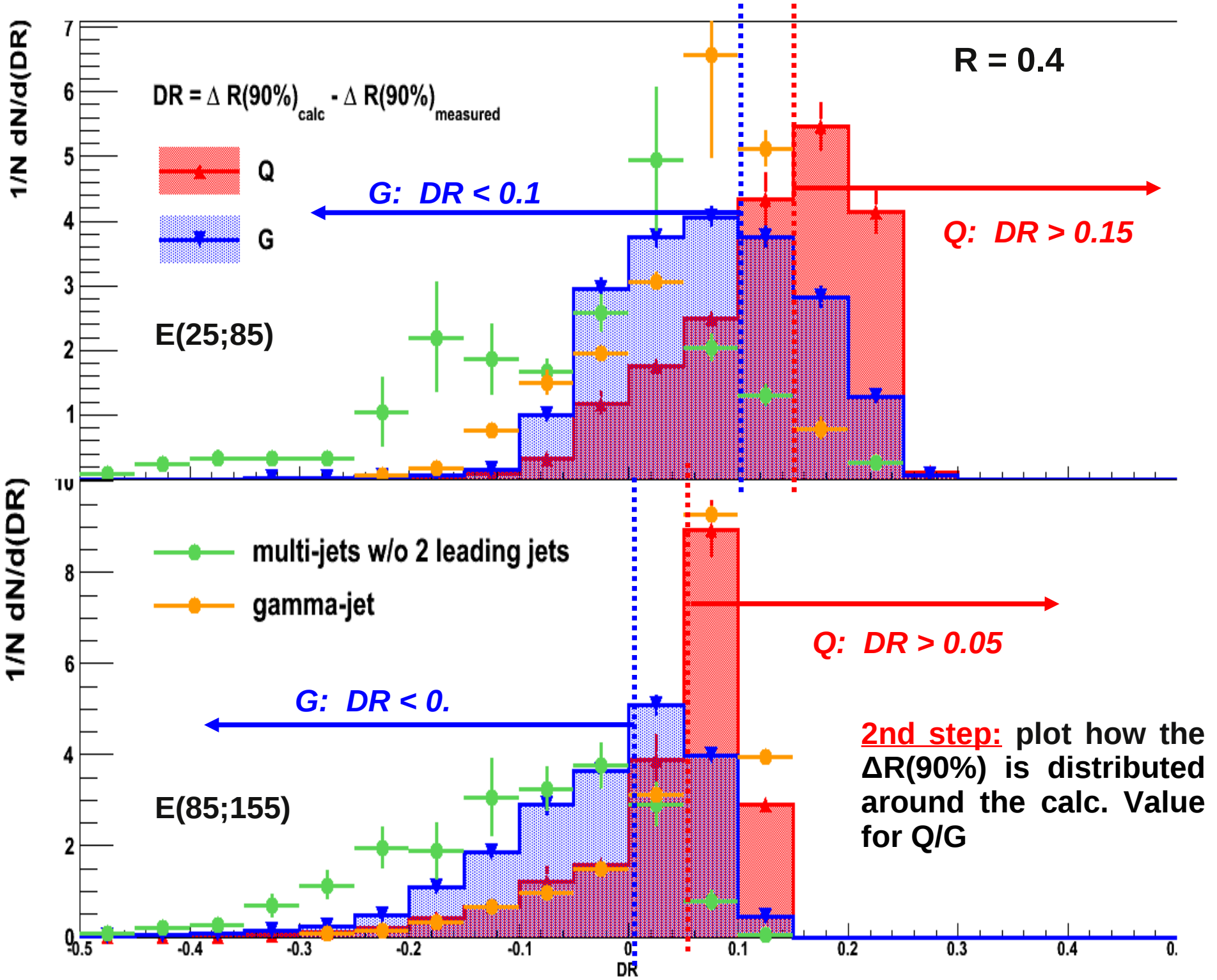
We get the variable as function of jet energy

R = 0.7

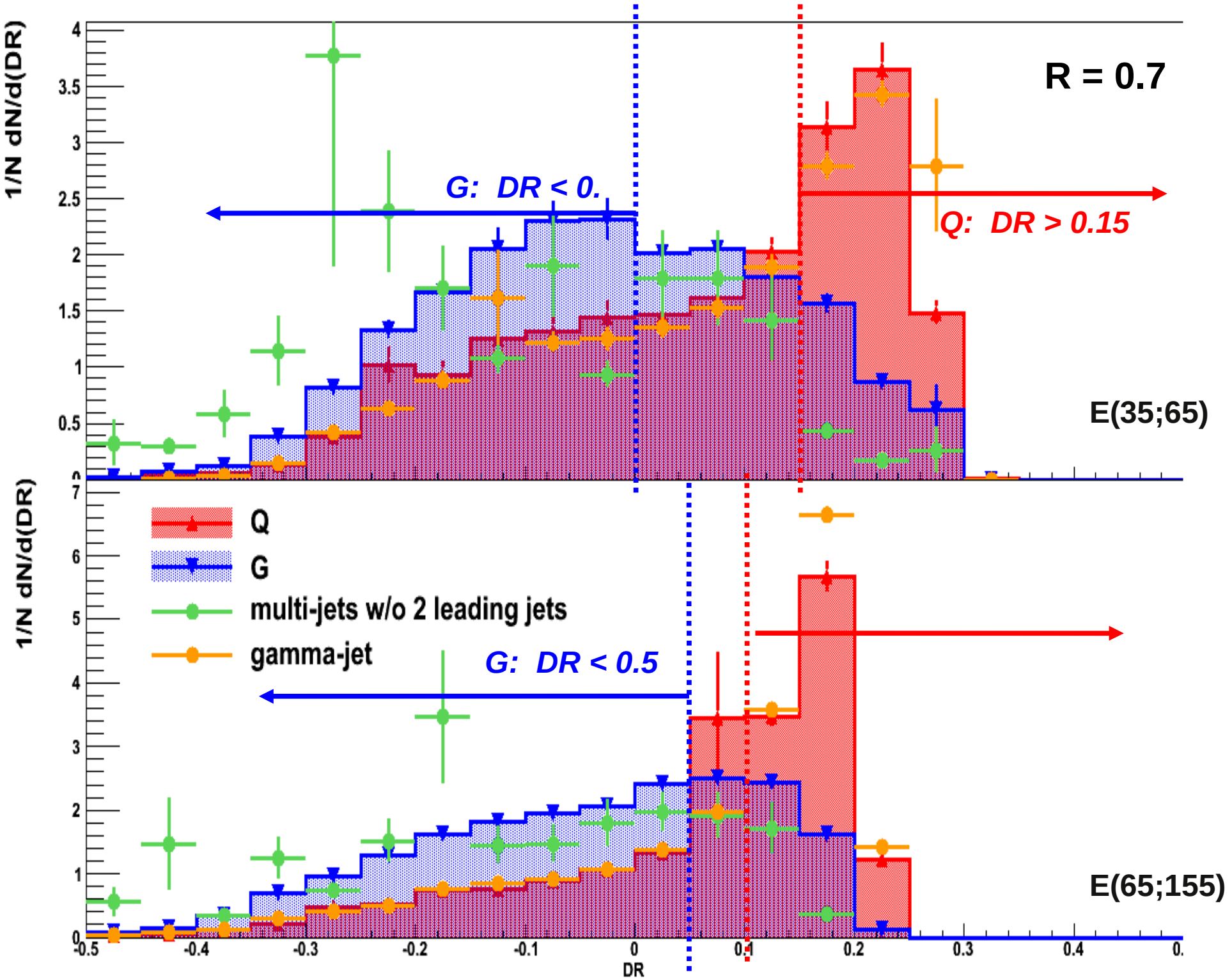
E interval	Fit. fction	A	B	χ^2/Ndf	Prob
(35;75)	*pol1*	*0.3913 +/- 0.0159*	*-0.002424 +/- 0.000309*	*0.6188/2*	*0.733*
(65;155)	*exp*	*-1.316 +/- 0.035*	*-0.002666 +/- 0.000297*	*3.658/7*	*0.8183*

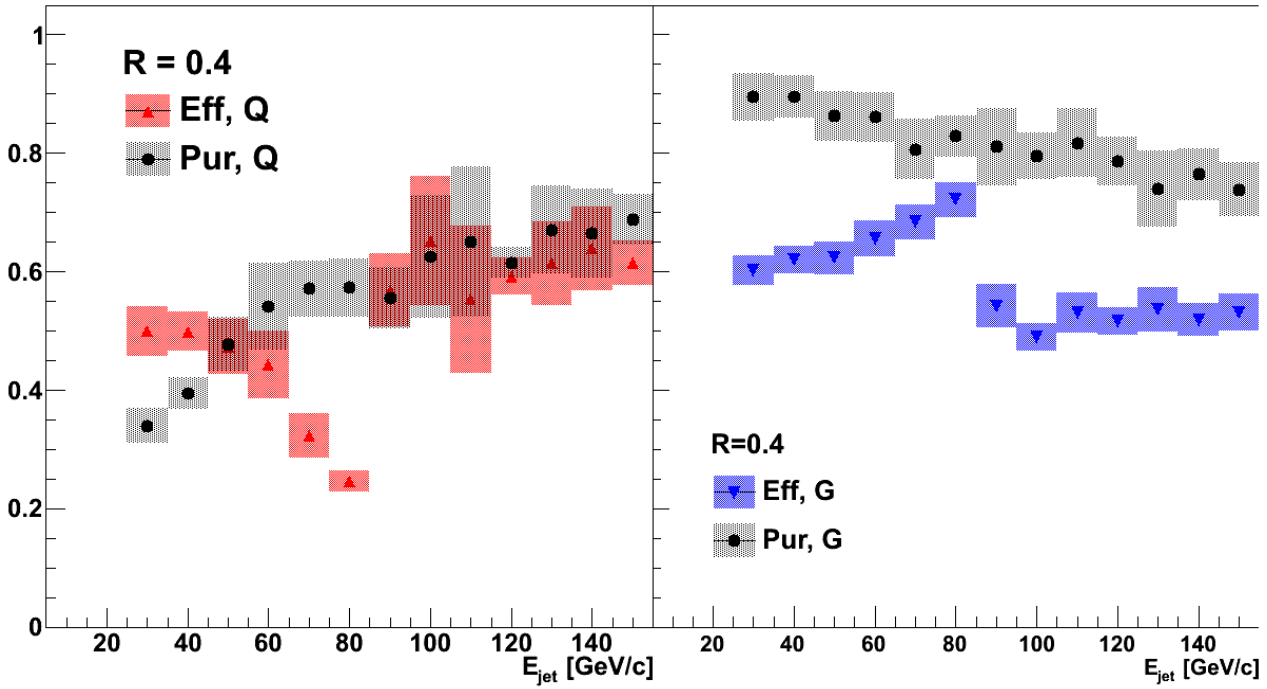
R = 0.4

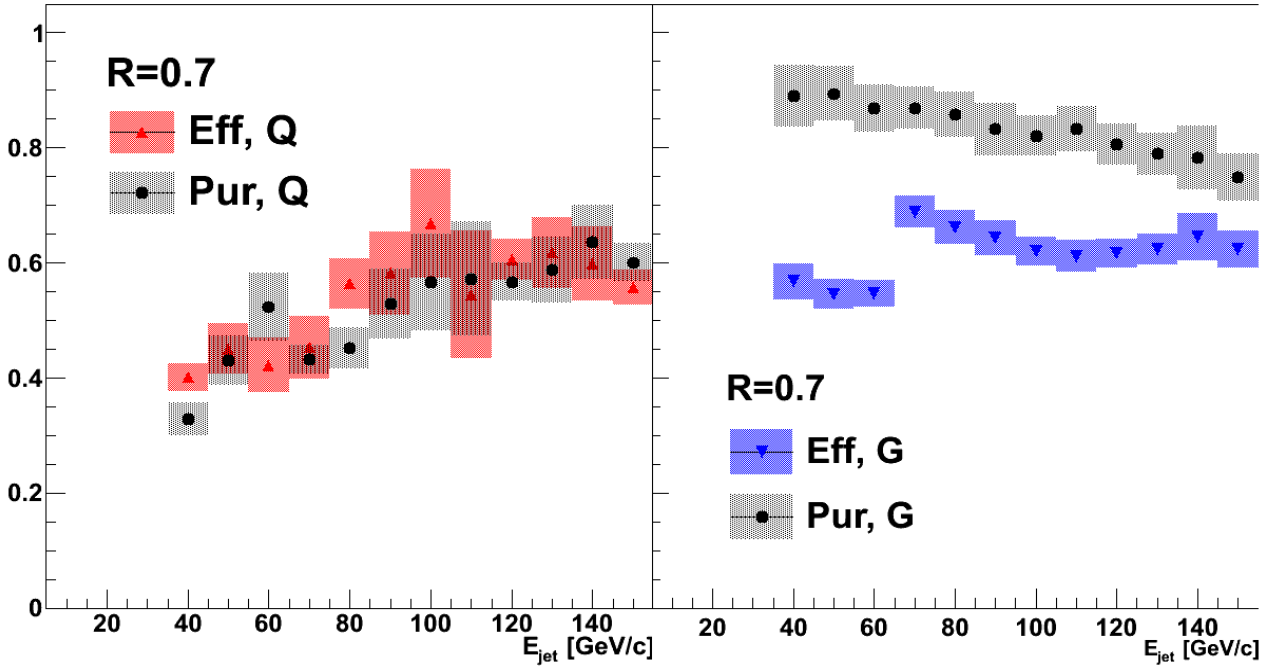
E interval	Fit. fction	A	B	χ^2/Ndf	Prob
(25;85)	*exp*	*-1.59 +/- 0.02*	*-0.006556 +/- 0.000465*	*3.138/4*	*0.535*
(85;155)	*exp*	*-1.878 +/- 0.049*	*-0.002438 +/- 0.000401*	*3.97/5*	*0.5537*



2nd step: plot how the ΔR(90%) is distributed around the calc. Value for Q/G


R = 0.7
G: DR < 0.
Q: DR > 0.15
E(35;65)
1/N dN/d(DR)
Q
G
multi-jets w/o 2 leading jets
gamma-jet
G: DR < 0.5
E(65;155)
DR





Performance

Apply the cuts on the two reconstructed leading jets.

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.

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

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

Summary

- **We introduced a method that can be used to identify Q/G jets in pp collisions**
- Although we showed a MC study, **experimental data offers an opportunity to define cuts using the "clean" production channels** of Quark and Gluon jets – ***multi-jets events, gamma-jet***
- Such approach allows to **study the properties of leading jets based on the parton type in various topologies**

Next steps...

1) Fine tune method on data from LHC.
2) Study properties of such identified jets
   - Identified hadron spectra
   - Charged multiplicity
3) Investigate possibility to ID jets in HI
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Thank you!