**8th International Workshop on High pT Physics at LHC 2012**

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# *"Quark" and "Gluon" jet identification in pp collisions at LHC energies*

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# Quark and Gluon Jets

Quark and gluon jet carry different colour factors

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

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

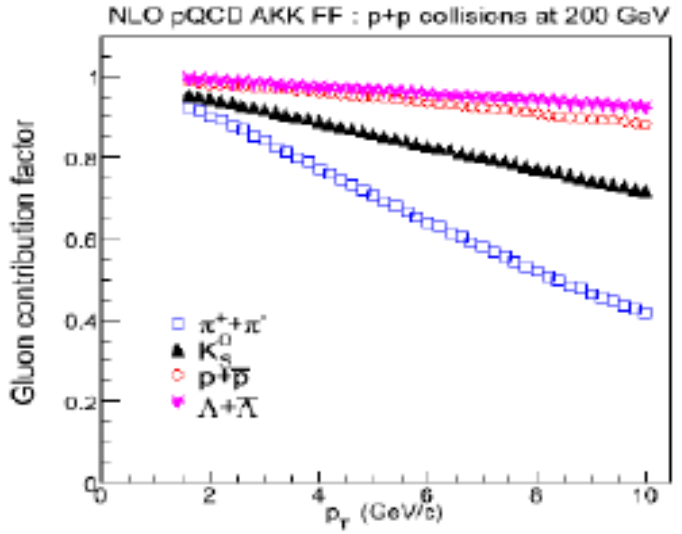
**Particle production differences:**

**Gluons**

***Baryon production***

**Quarks**

***Meson production***




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

**Higher multiplicity jets**

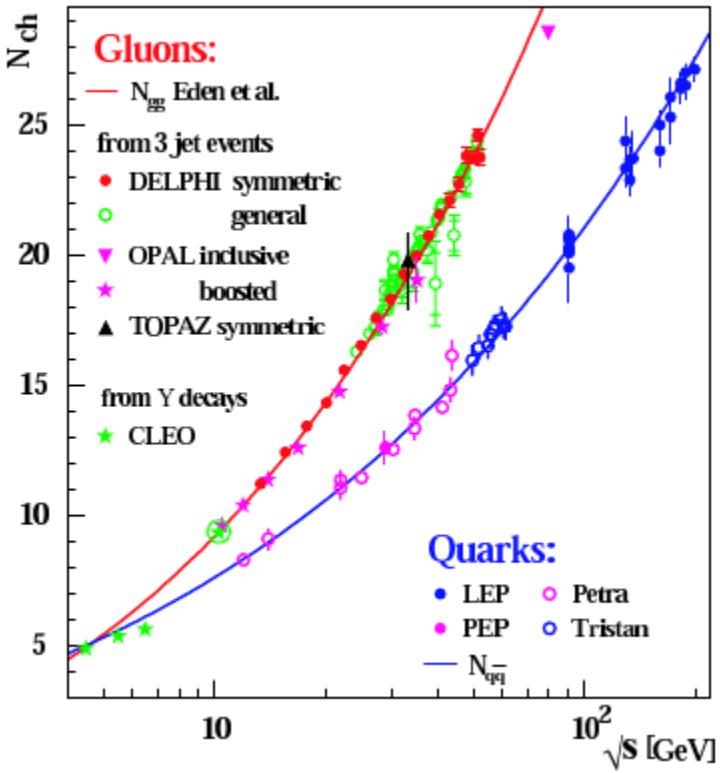
**Broader jets**

**Jets with softer fragmentation function**

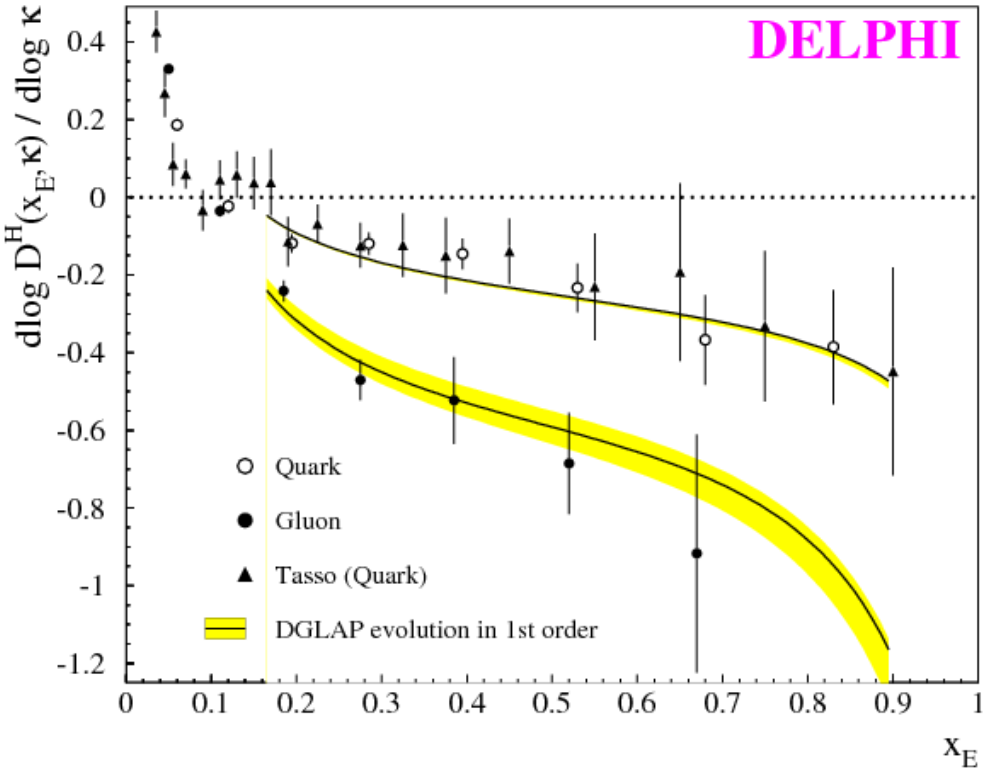
# History of studying Quark and Gluon jets

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

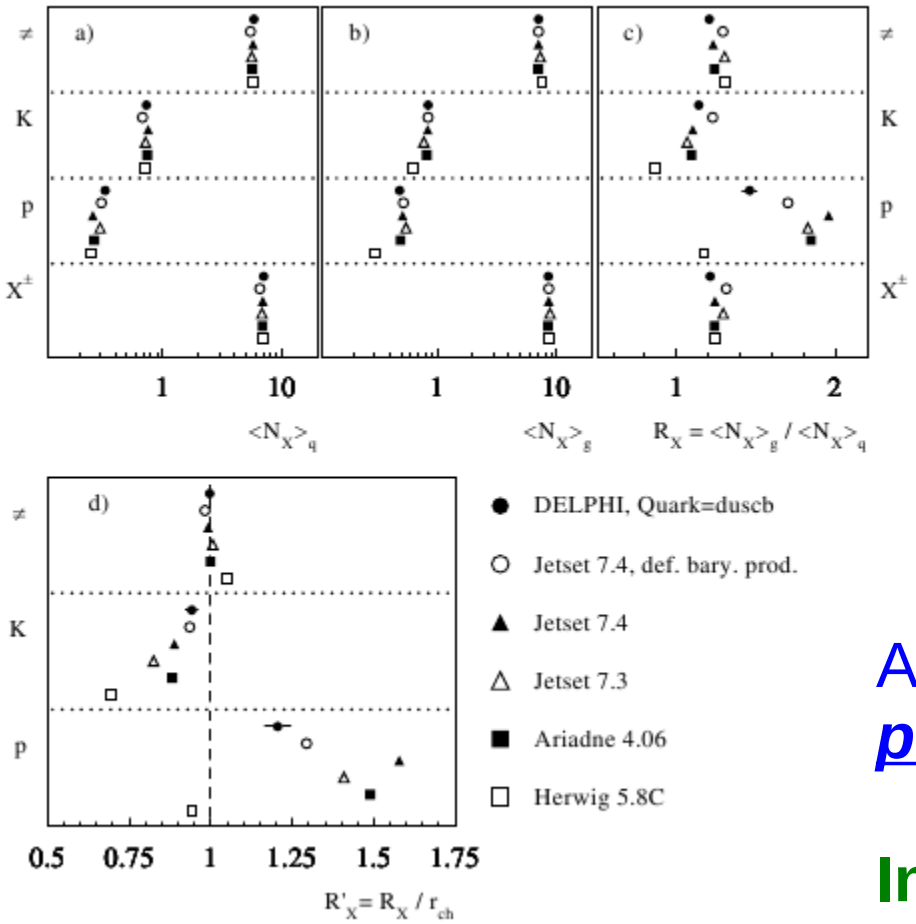
Acta Phys.Polon.B36:433-440,2005.




DELPHI 99-127 CONF 314




*Qualitative differences were observed*




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

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

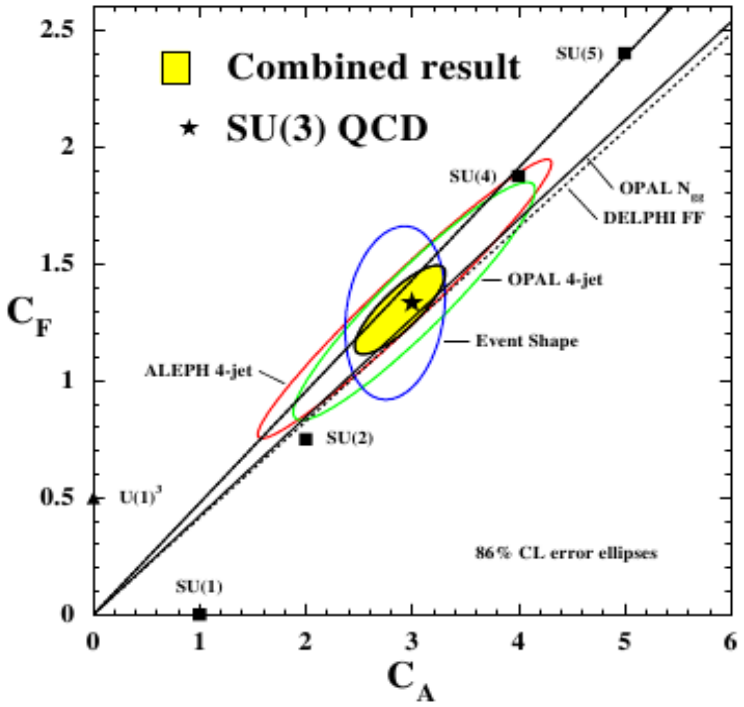
**Relative proton abundance in gluon jets has been observed**

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**.

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



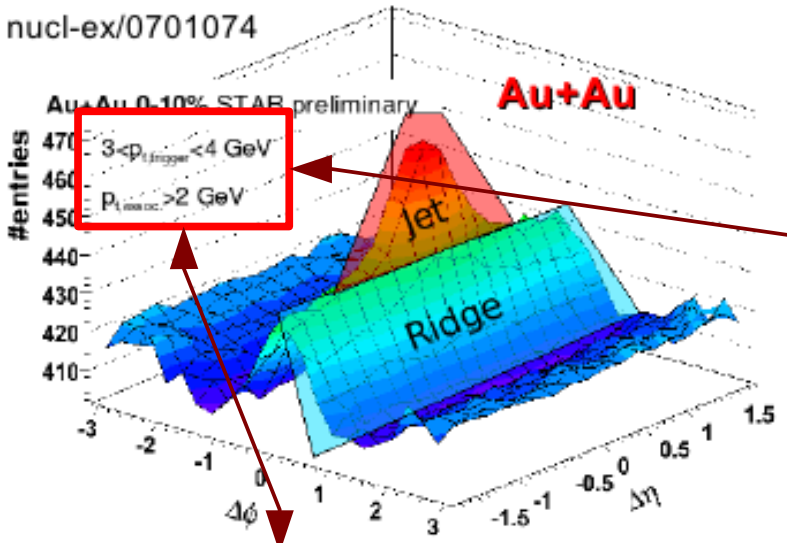

*The results of the methods have been combined to average $C_A$ and $C_F$*

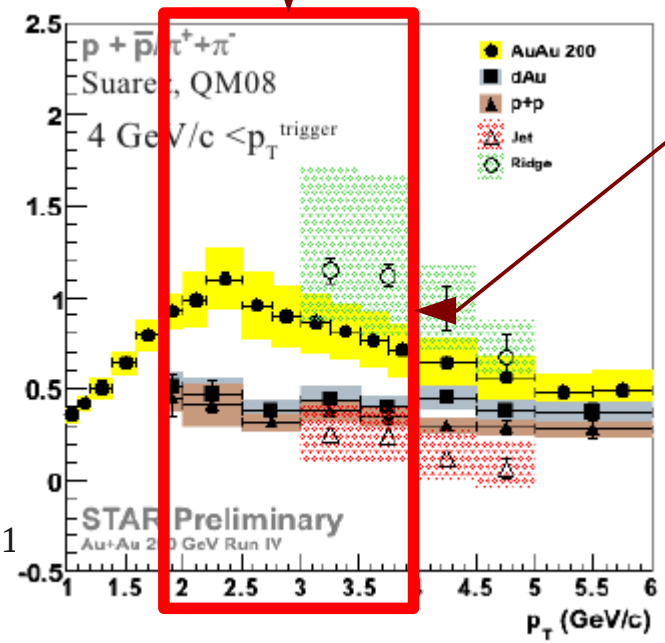
$$\overline{C}_A = 2.89 \pm 0.03(\text{stat.}) \pm 0.21(\text{syst.})$$
$$\overline{C}_F = 1.30 \pm 0.01(\text{stat.}) \pm 0.09(\text{syst.})$$

- *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)

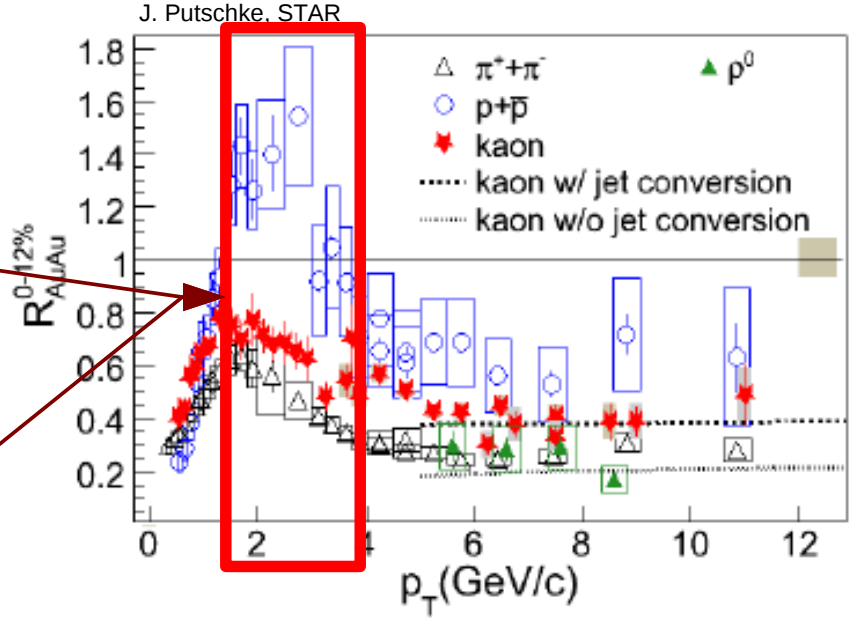
- *Variables connected to jet-properties study*
  - Jet-shape, charged multiplicity
  - Fragmentation functions
  - Identified structure of jets
  - “ridge”

# Recent studies connected to Q/G jet fragmentation




arXiv:0908.1766 (August 2009)
J. Putschke, STAR

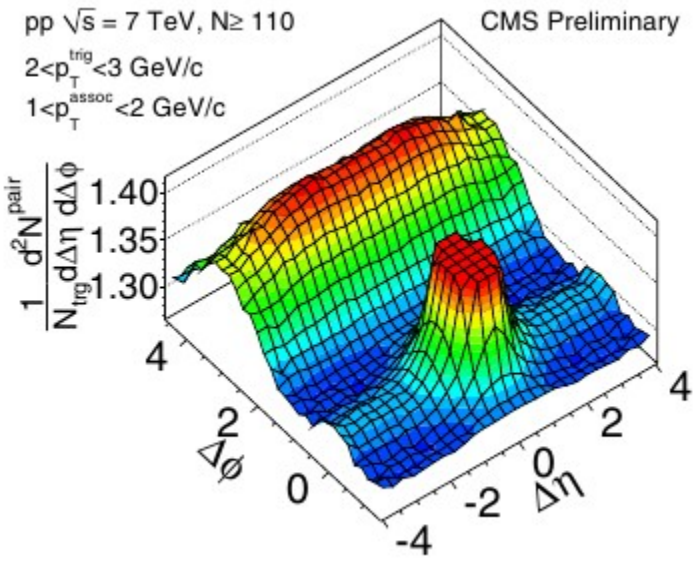


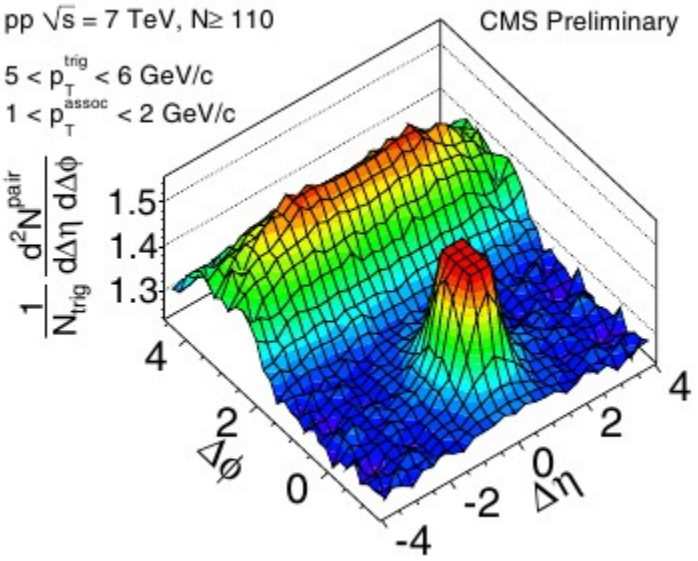

**p/π ratio in ridge consistent w/ bulk and above 1**

**In the same pT region, were the ridge is measured we observe enhancement of protons**

***Ridge was not observed in pp***

J. Phys. G: Nucl. Part. Phys. 38 (2011) 124051



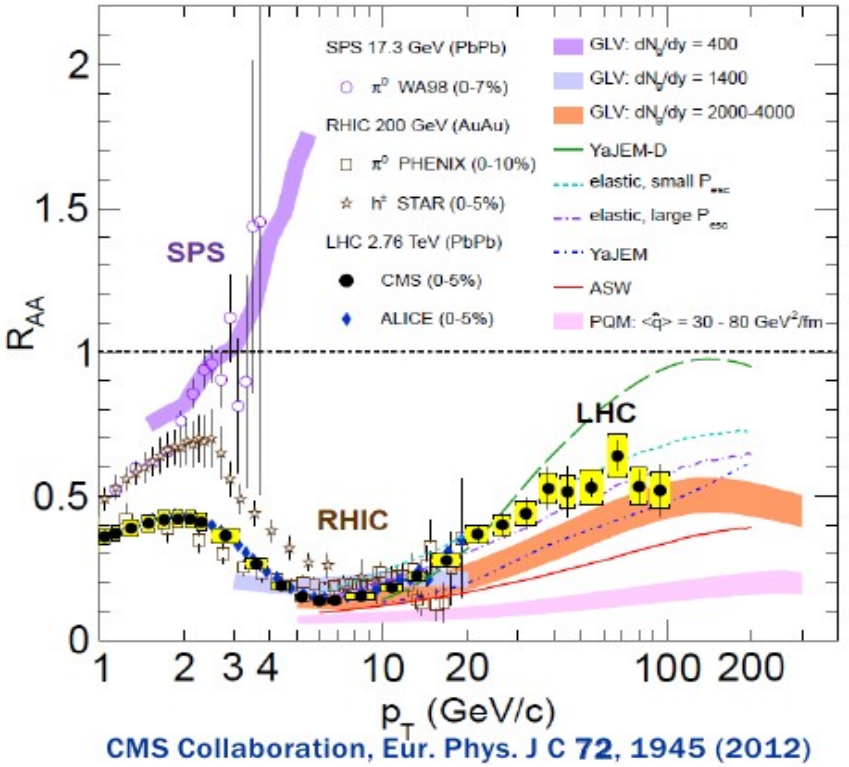




**Ridge observed in pp at CMS**
**Implications for R_AA ?**

**We see that proton Raa seems to be smaller than the one measured at RHIC**

***Ridge observed in pp changes the spectra in the appropriate momentum region and makes the R_AA smaller.***

***!!! necessary to quantify to what extent and what is the particle content of the ridge in order to understand R_AA***




CMS Collaboration, Eur. Phys. J C **72**, 1945 (2012)

# What causes the ridge in pp

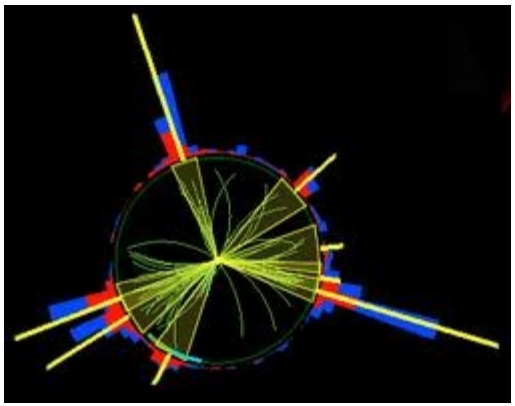
- *Collective phenomena? "Explosive" pp collisions?*
- **Let's think about something else**
  - RHIC -> LHC : Quark -> Gluon (both for pp and PbPb)
  - Gluon = ***higher multiplicity, more protons, softer particles***
  - multi-jet events – ***gluon enhanced events, higher multiplicity***
- *Ridge in STAR: medium makes jets softer, gluon-like ?*

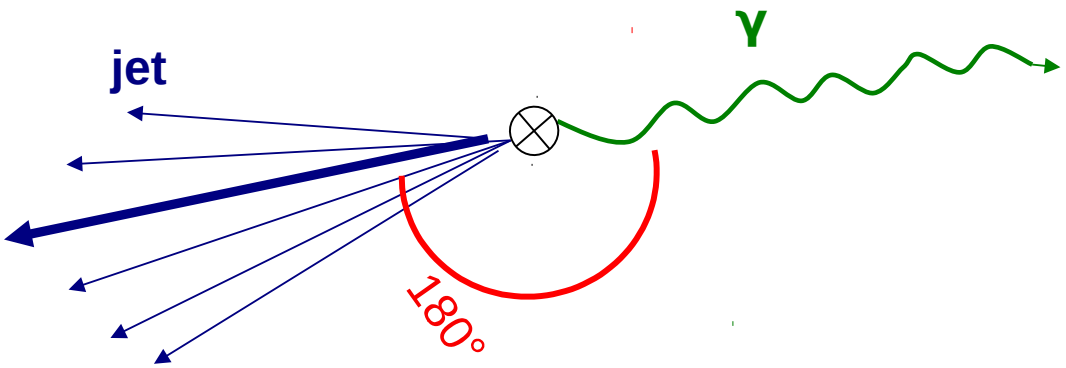
## MAIN GOAL

***What is the experimentally observable jet(jet-event)-property that is connected to its baryon and meson content, so we will be able to quantify their contribution to the observed spectra and distributions. This is crucial for pp and HI collisions, since we have an interplay of different factors and to see the nuclear effects we should first try to estimate the effects of jet-fragmentation on the spectra in pp, which we obviously do not fully understand.***

# How to ID the different partons?

- Use their properties to calibrate cuts
- Separate “clean” production channels for the production of Q/G
  - **G: 3-jet events**
  - **Q: gama-jet**





# Gamma-jet events

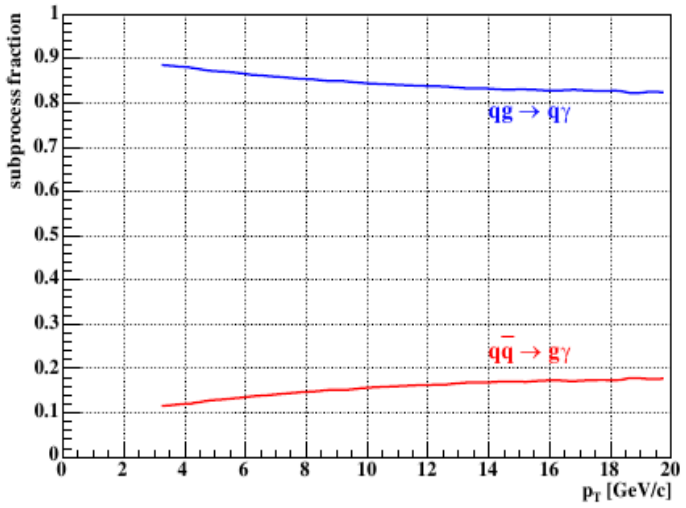



Figure 2.10: The fraction of $gq \to \gamma q$ and $q\bar{q} \to \gamma g$ as function of $p_T$ in $p+p$ at $\sqrt{s} = 200\text{GeV}$.

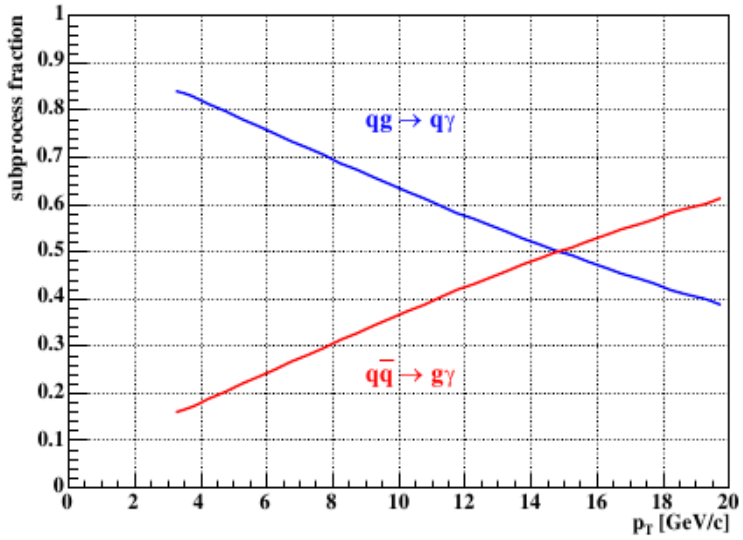
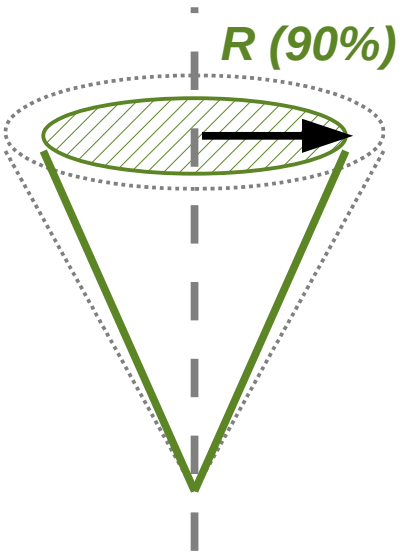


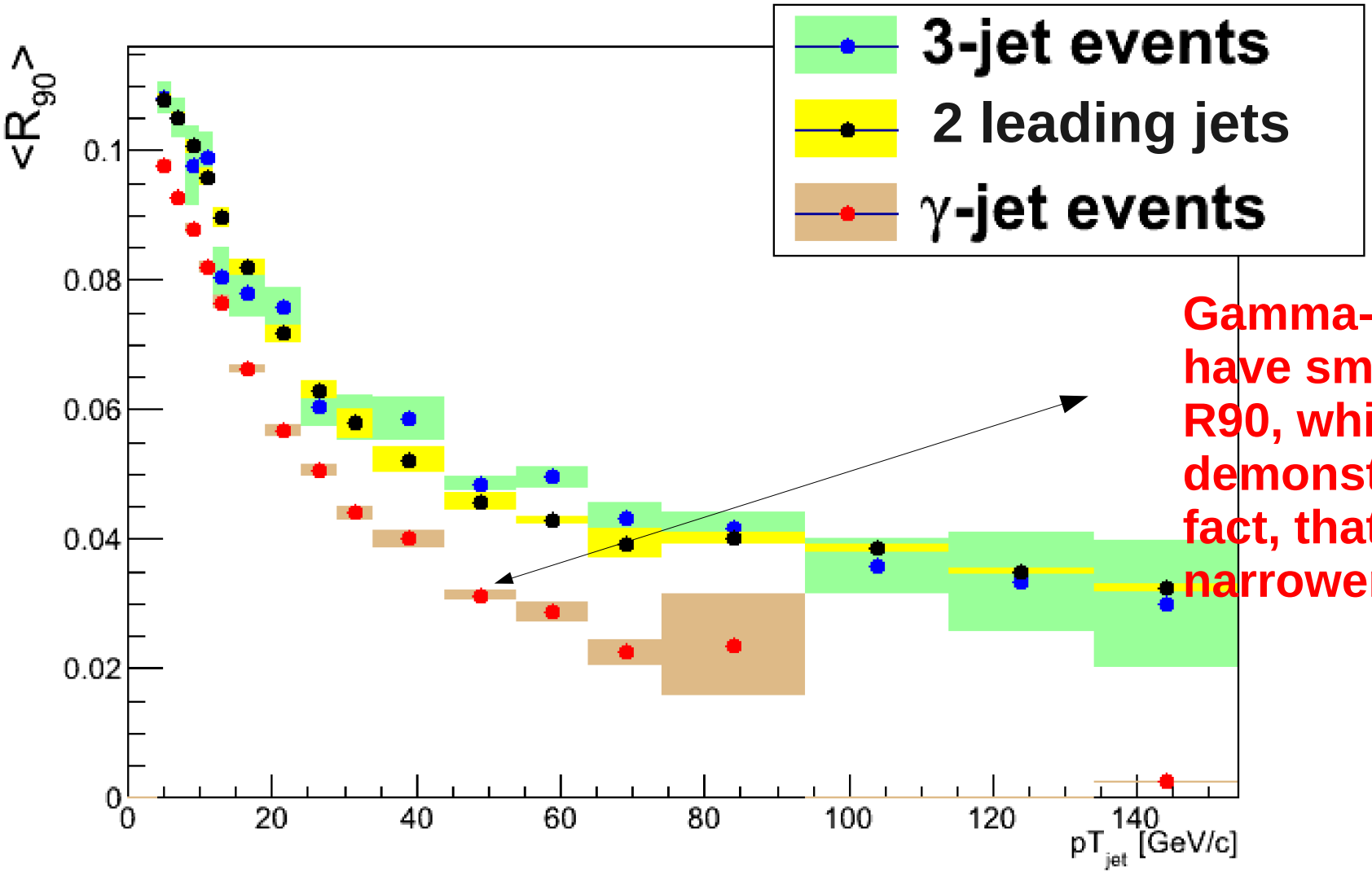

Figure 2.11: The fraction of $gq \to \gamma q$ and $q\bar{q} \to \gamma g$ as function of $p_T$ in $p+\bar{p}$ at $\sqrt{s} = 200\text{GeV}$.

**Gamma-jets** – ***Compton scattering, quark/a-quark anihilation -> source of QUARK jets***

**LHC – pp collisions – low fraction of annihilation process in the whole pT range (high gluon density in colliding partons, low probability of anihilation)**

- Pythia 6, Perugia-0, pp@7TeV
- ***Jet-jet***
  - ***10 Milion events***
- ***γ-jet events***
  - ***1 Milion events***
- *anti-kT algorithm, R = 0.4*
- |η| < 0.5, at least 3 charged particles
- Variables: **R(90%)**; ***size of sub-cone containing 90% of jet's energy***






Gamma-jet events have smaller average R90, which is the demonstration of the fact, that quarks are narrower than gluons

3-jet events practically overlap with the jet-jet distribution – gluon dominated sample

*How is the average value influenced by the quark and gluon jets?*

**ΔR = R90 - <R90>**

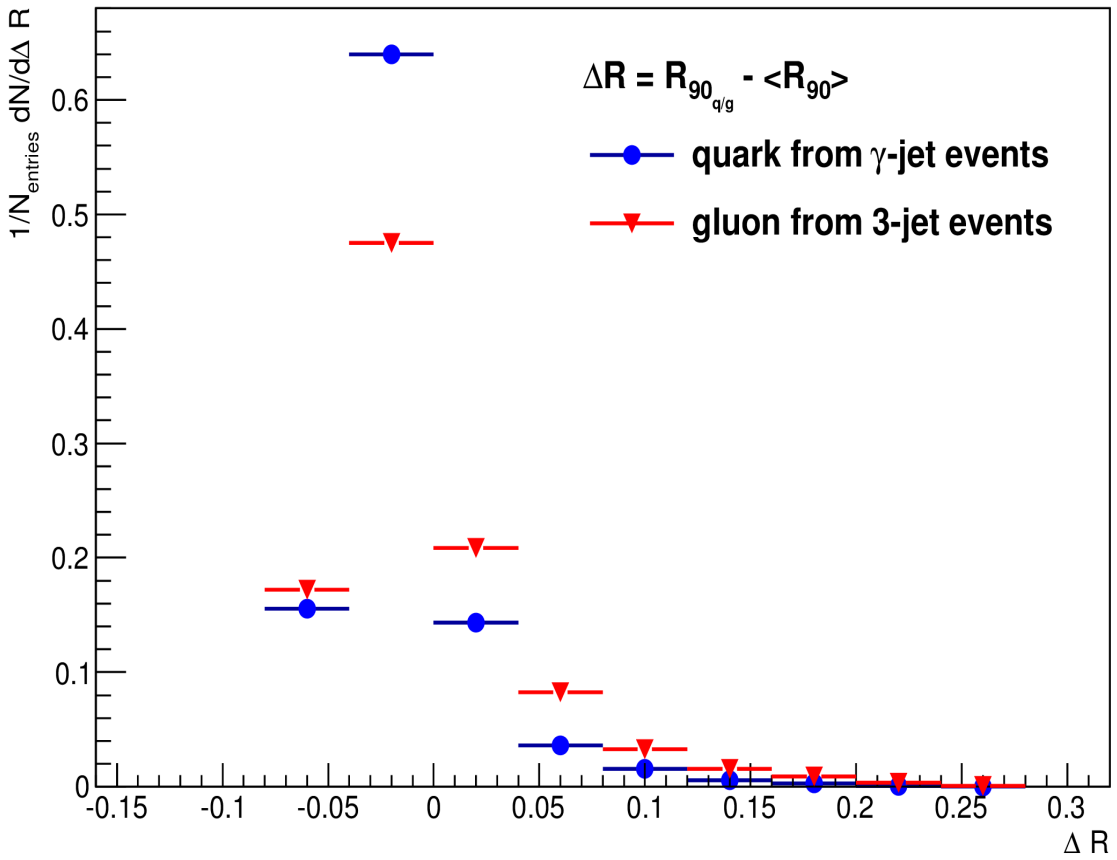
***We select bin:***

**Jet pT = (34;44)**

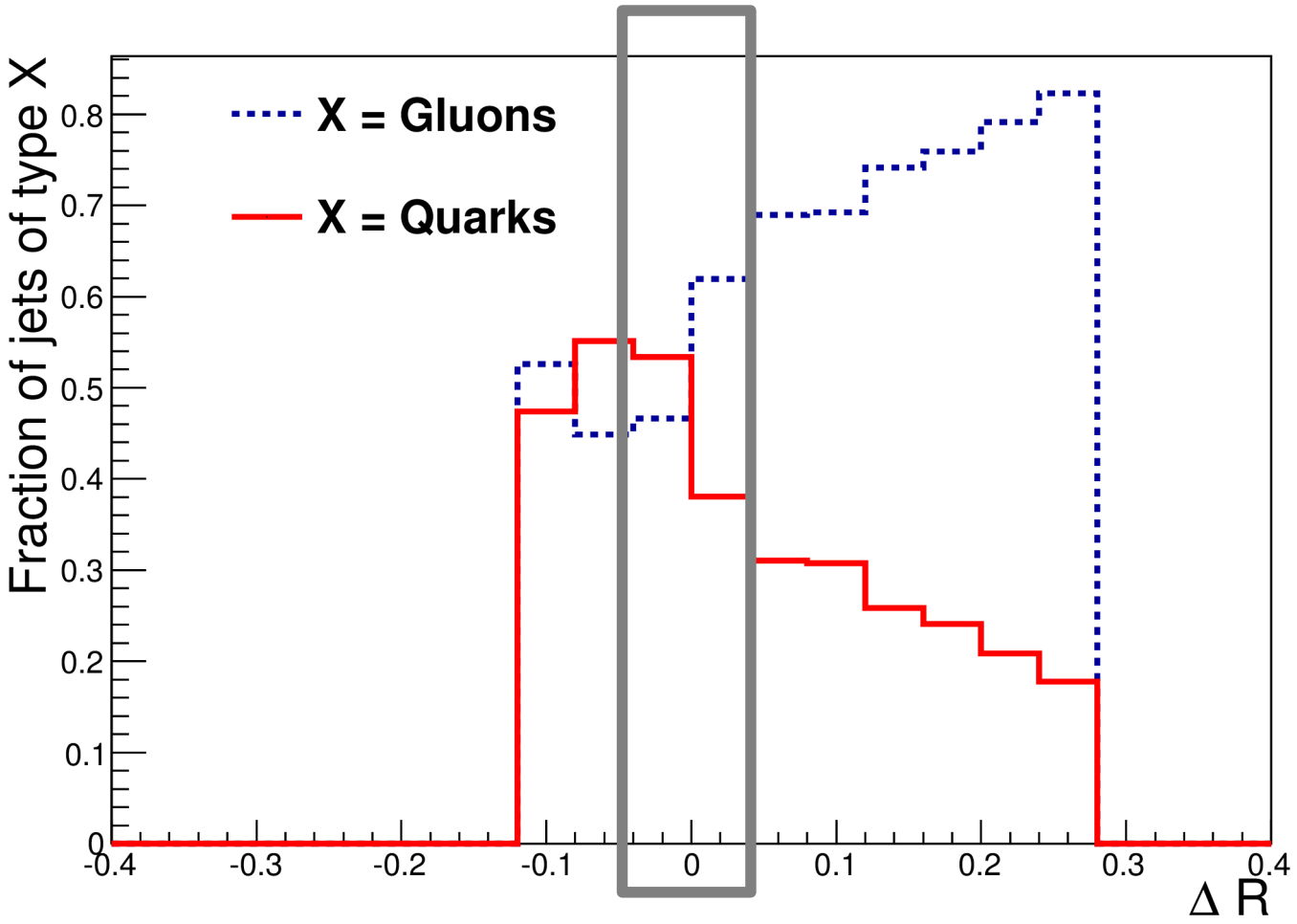
***Determine cut:***

**Q: ΔR = (-0.04, 0)**

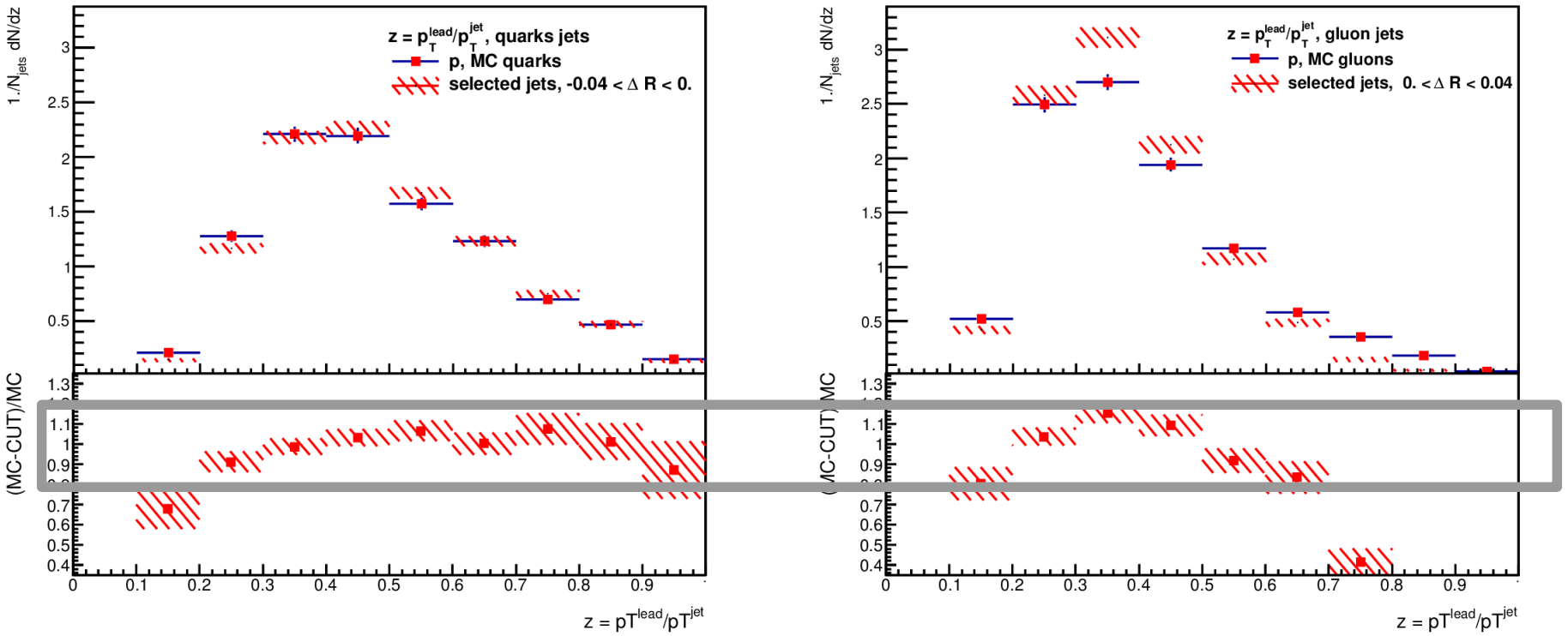
**G: ΔR = (0., 0.04)**




**We see that the distributions overlap but we can identify the regions were quark/gluon dominates**




**Whereas the gluons are dominating the positive side of the distribution, the quarks dominate the negative values of ΔR. However, the *"quark sector" is highly contaminated by gluons.***




**The selected quarks are compared to MC quarks and gluons. We see that *even we have high contamination in our selection, we selected "quark-like" and "gluon-like" jets.***

**Interesting observation which complements the previous overlapping distribution. Quarks fragment as gluons and vice versa**

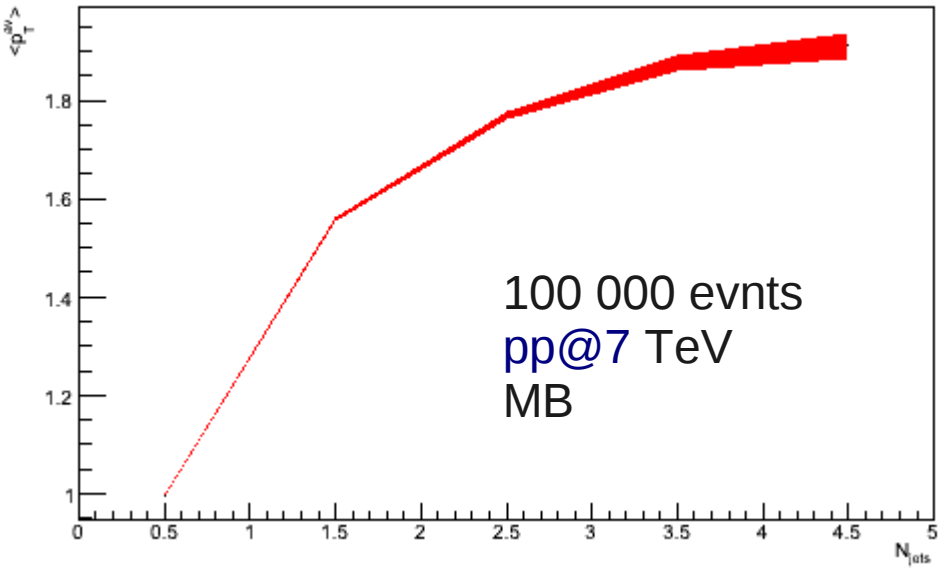
# Summary

- Seems we cannot distinguish q/g jets on jet-by-jet basis, rather we select ***"quark-like"*** and ***"gluon-like"*** jets
- We can study structural properties of these jets, such as FFs and particle spectra and their ratios
- The reference samples of quarks and gluons from γ-jet and 3-jet events are essential

# Closing remarks

- QCD structure I – discussion session on Friday
  - Jet-finding algorithms and problems w/ them
  - Possibility – tag events w/ hard scattering combining info about jet-content with info about <pT> in event
  - This way we can see the “hard” part of the spectra on subtracting events we tag as soft from those, we tag as hard

# Closing remarks




Jets contribute to increasing average pT

As compared to average pT as a function of N_{parts} with jets we increase the average momentum to higher values.

Even the presence of hard scattering in an event increases the av. momentum