Novel approach to measure quark/gluon jets at the LHC

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2.8.2023

Outline:

1. Introduction
2. Theory
3. Results
4. Conclusion

Back-up

Introduction:

- SM searches: often signature for a BSM signals: many quark, backgrounds: QCD gluons
    - 8-jet Gluino event: $pp \rightarrow \tilde{g}\tilde{g}$ and each $\tilde{g}$ decays to 4 quarks:

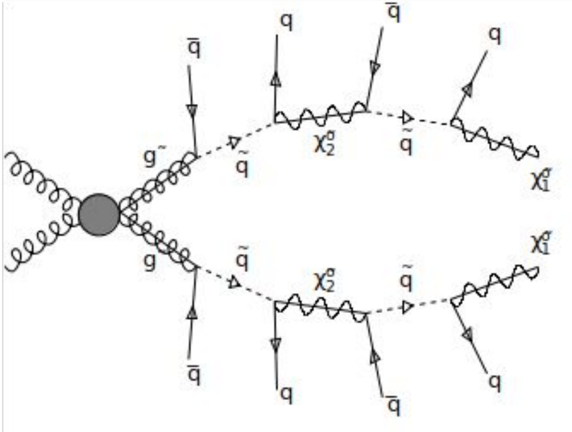
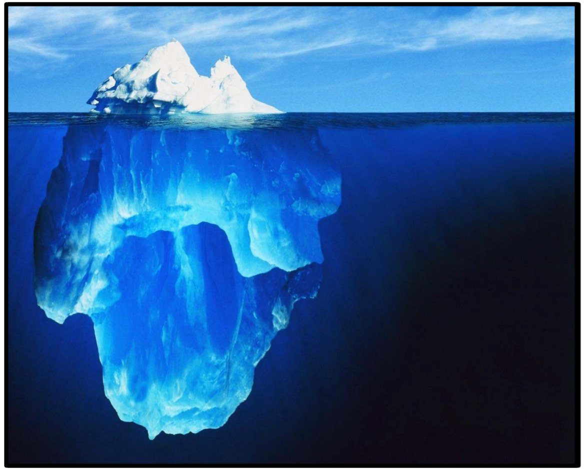
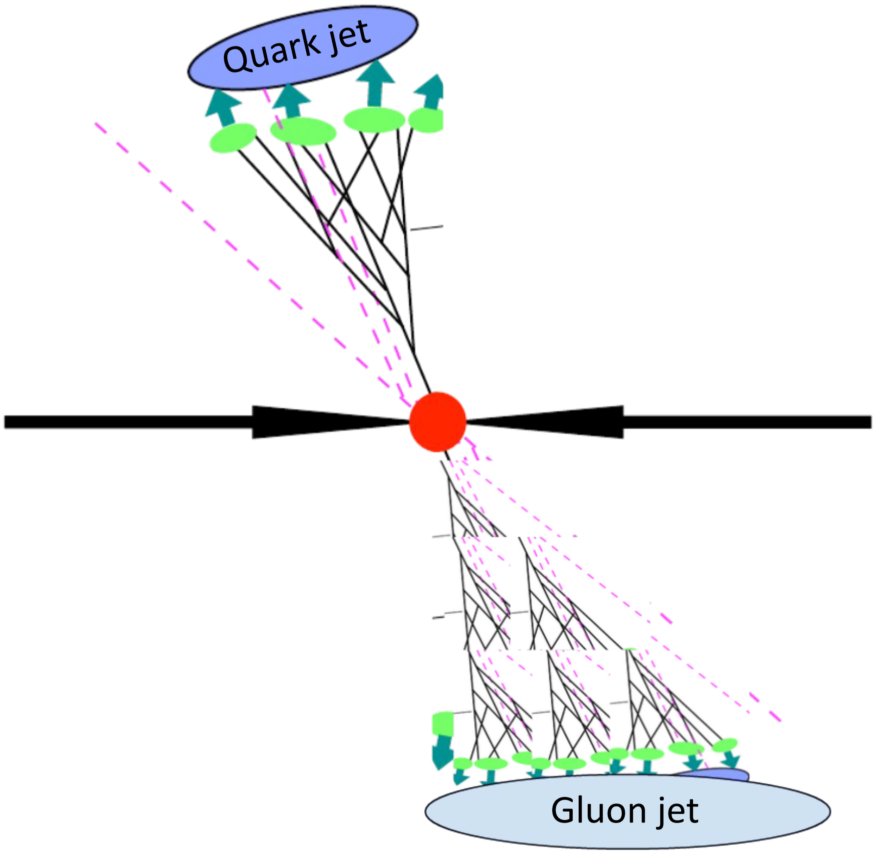


Fig. From J. Gallicchio and M. D. Schwartz, Phys. Rev. Lett.107 (2011)



    - Higgs $H^+ \rightarrow c\bar{s}$ (for charged Higgs mass between τ and t mass)
    - Measure *Z′* coupling to hadrons (or find a leptophobic *Z′*/*W′*)

Introduction:



2. Theory

[Gras, Hoeche, Kar, Larkoski, Lönnblad, Plätzer, AS, Skands, Soyez, Thaler, JHEP 1707 (2017) 091]

Cartoon:

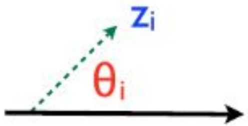
Quark: $C_F = 4/3$ vs. Gluon: $C_A = 3$

Probe radiation pattern with
e.g. Generalized Angularities

$$\lambda^\kappa_\beta = \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\beta$$

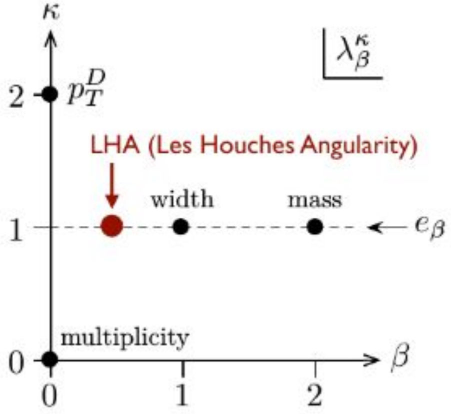
momentum fraction

angle to recoil-free axis



$(\lambda^\kappa_\beta)_{\text{quark}} < (\lambda^\kappa_\beta)_{\text{gluon}}$

(except p_T^D)



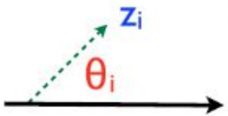
[Larkoski,Salam,Thaler,13]
[Larkoski,Thaler,Waalewijn,14]

Theory:

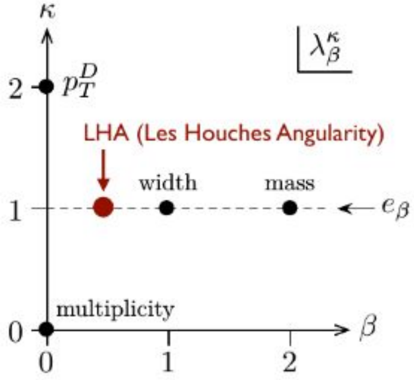
Probe radiation pattern with e.g. Generalized Angularities

$$\lambda^{\kappa}_{\beta} = \sum_{i \in \text{jet}} z_i^{\kappa} \theta_i^{\beta}$$

momentum fraction — angle to recoil-free axis

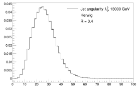


$(\lambda^{\kappa}_{\beta})_{\text{quark}} < (\lambda^{\kappa}_{\beta})_{\text{gluon}}$

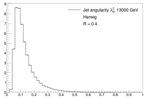


[Larkoski,Salam,Thaler,13]
[Larkoski,Thaler,Waalewijn,14]

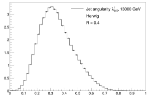
λ^0_0 - multiplicity



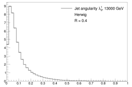
λ^2_0 - p_T^D



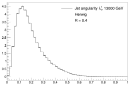
$\lambda^1_{0.5}$ - LHA (Les Houches Angularity)

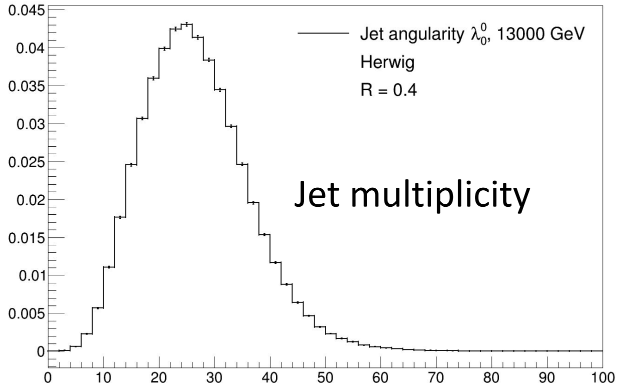


λ^1_2 - Mass



λ^1_1 - Width

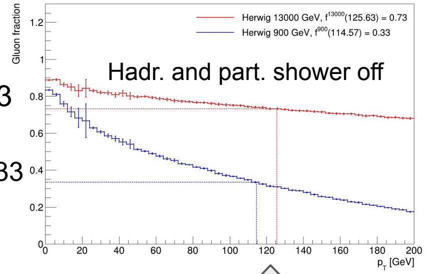




Theory:

$f^{13000} = 0.73$

$f^{900} = 0.33$



Each angularitity λ is composed of gluon λ_g and quark λ_q angularities

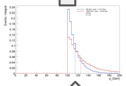
$$\boxed{\lambda = f\,\lambda_g + (1 - f)\,\lambda_q}$$

where

f ... gluon fraction

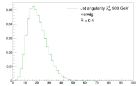
$(1 - f)$ ... quark fraction

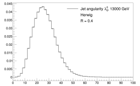
taken from simulation



$p_T^{cut} = 100$ GeV

Let’s write equations for measurement at energy 900 GeV and 13 000 GeV
(with the same event selection)





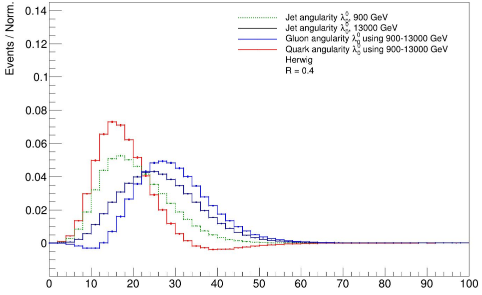
$$\lambda^{900} = f^{900}\,\lambda_g + (1 - f^{900})\lambda_q$$

$$\lambda^{13000} = f^{13000}\,\lambda_g + (1 - f^{13000})\lambda_q$$

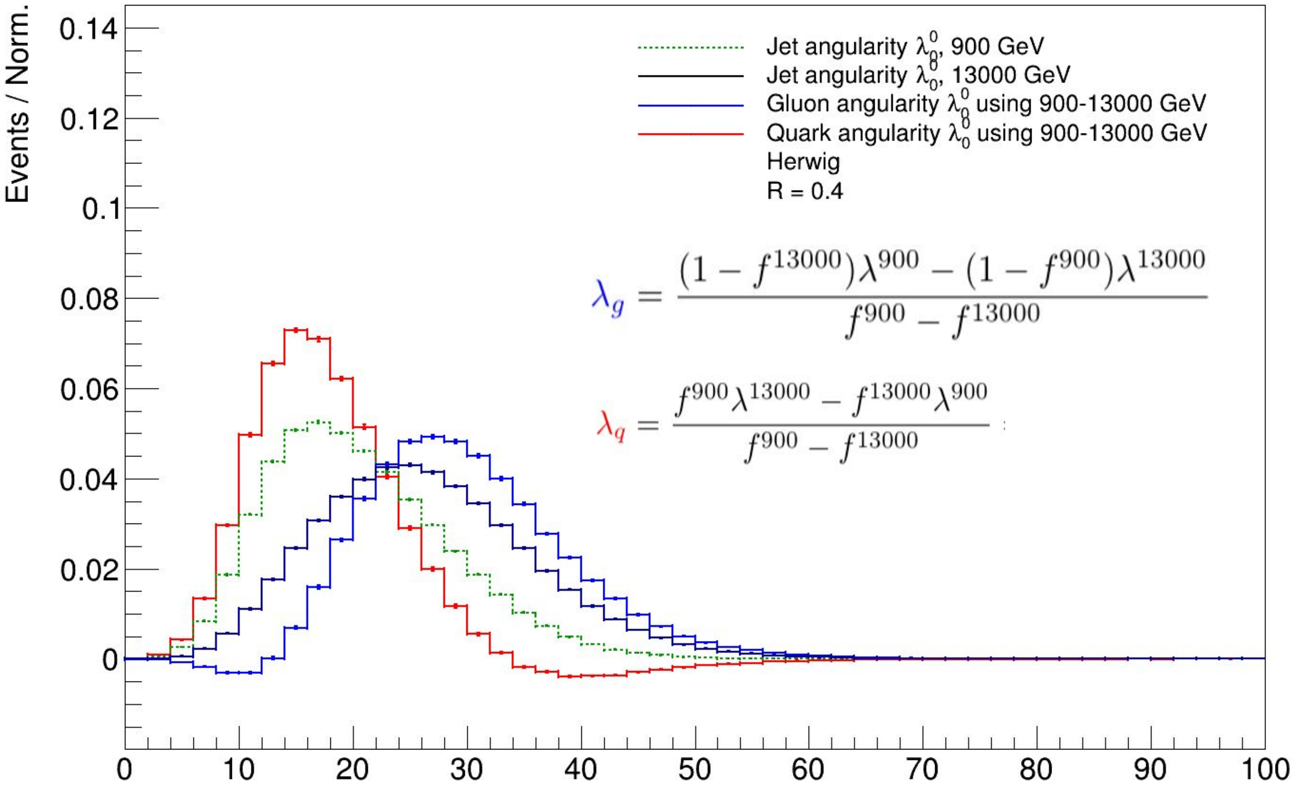
Assuming λ_g and λ_q are energy independent.

$$\lambda_g = \frac{(1 - f^{13000})\lambda^{900} - (1 - f^{900})\lambda^{13000}}{f^{900} - f^{13000}}$$

$$\lambda_q = \frac{f^{900}\lambda^{13000} - f^{13000}\lambda^{900}}{f^{900} - f^{13000}}$$

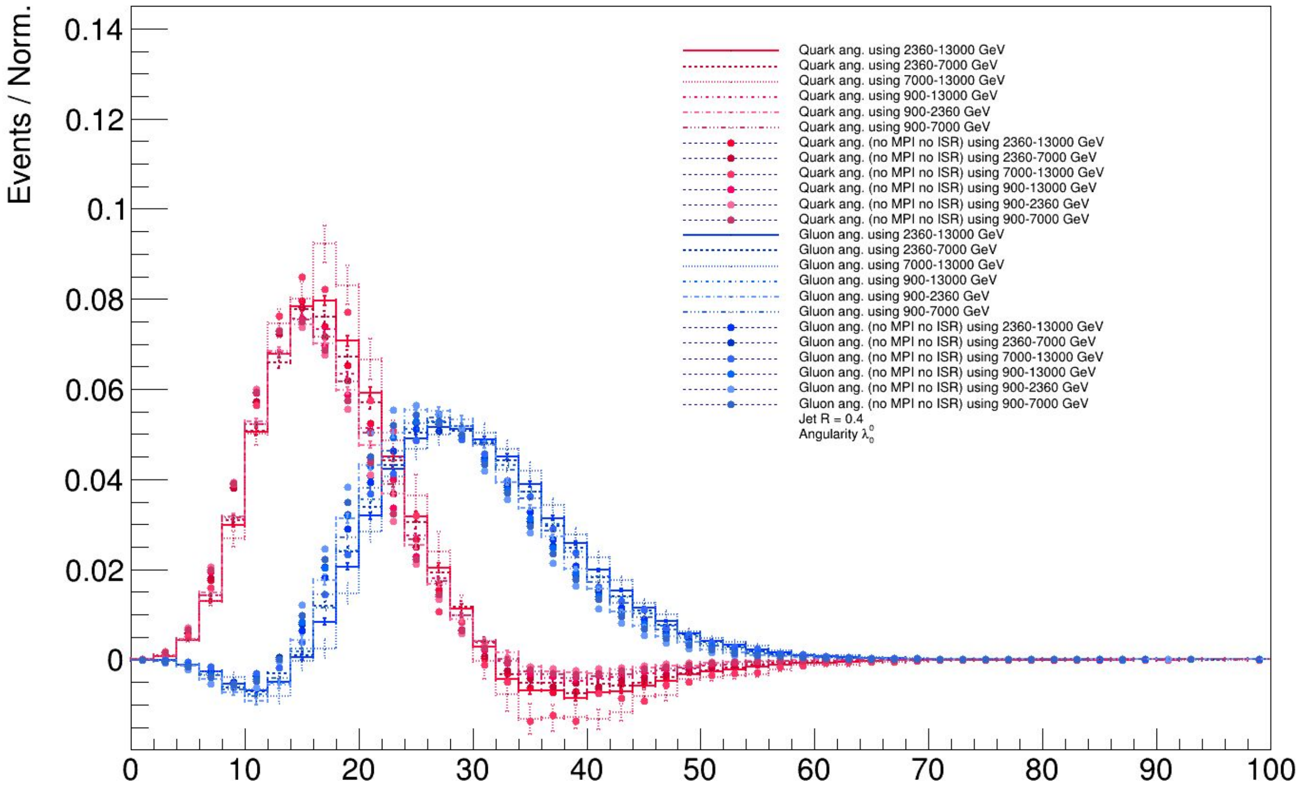


Theory:



Events / Norm.
Jet angularity λ_0^0, 900 GeV
Jet angularity λ_0^0, 13000 GeV
Gluon angularity λ_0^0 using 900-13000 GeV
Quark angularity λ_0^0 using 900-13000 GeV
Herwig
R = 0.4
$$\lambda_g = \frac{(1-f^{13000})\lambda^{900} - (1-f^{900})\lambda^{13000}}{f^{900} - f^{13000}}$$
$$\lambda_q = \frac{f^{900}\lambda^{13000} - f^{13000}\lambda^{900}}{f^{900} - f^{13000}}$$
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
10
20
30
40
50
60
70
80
90
100

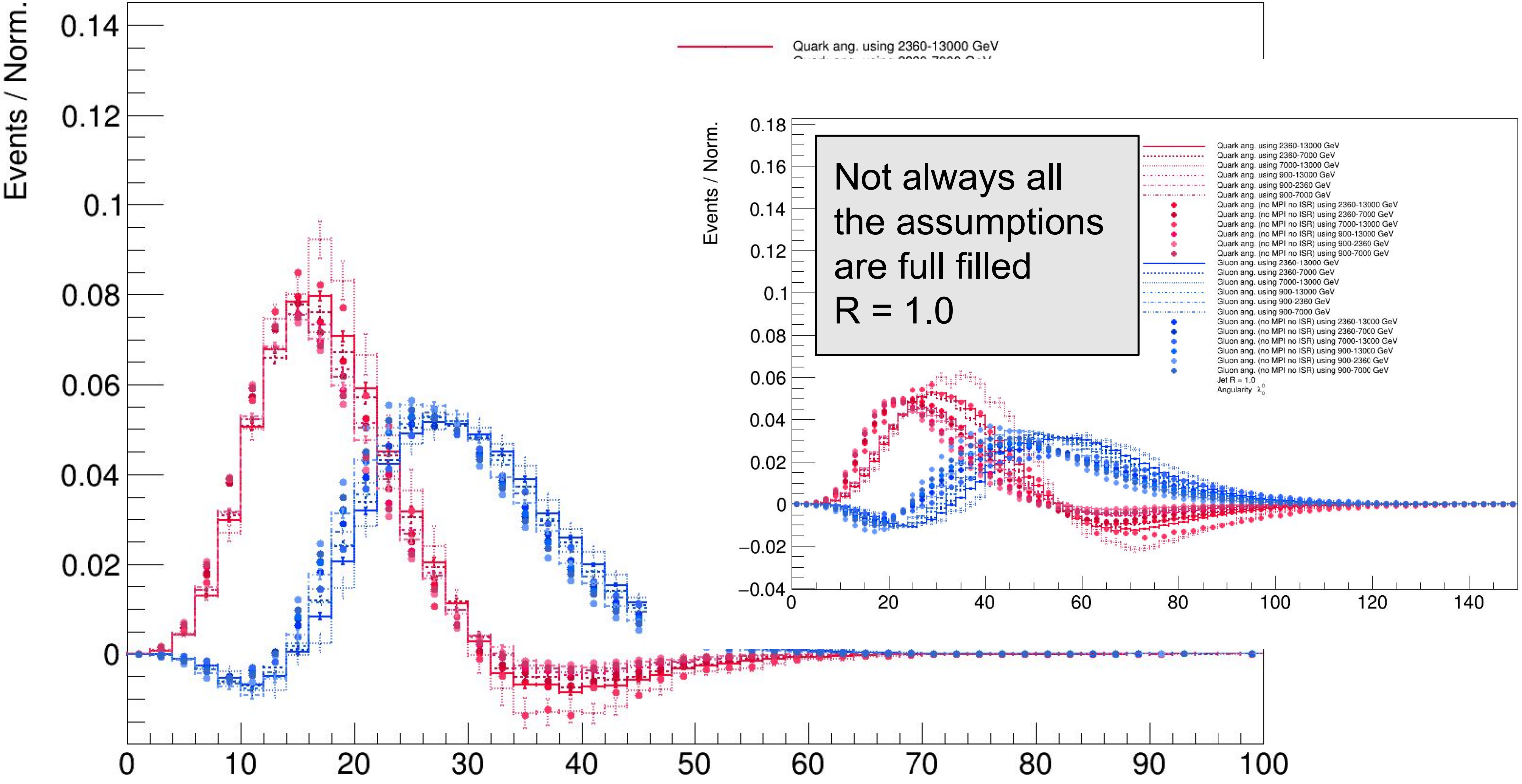
Let's use more 6 energy combinations:
900-2360, 900-7000, 900-13000, 2360-7000, 2360-13000, 7000-13000 GeV



Dotted lines test the robustness to Multi Parton Interactions MPI and Initial State Radiation ISR

Theory:

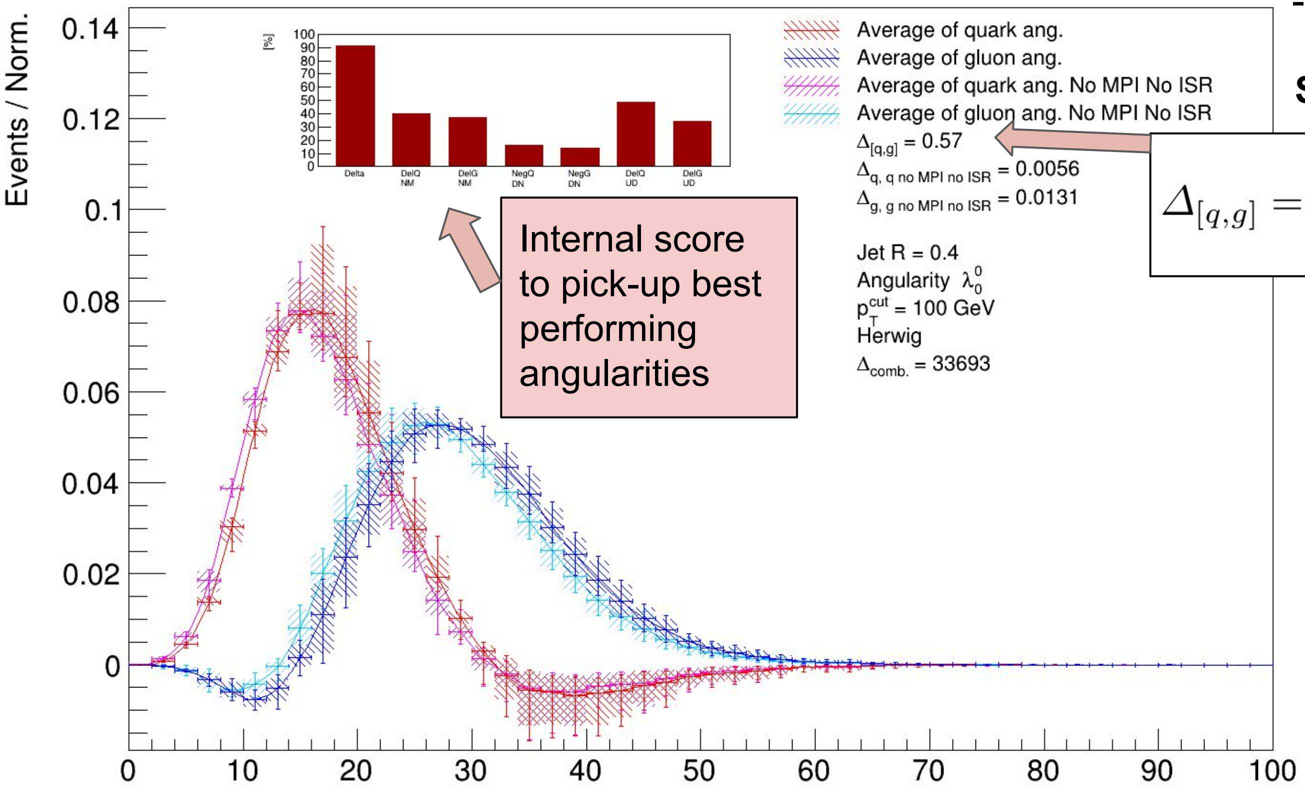
Let’s use more 6 energy combinations:
900-2360, 900-7000, 900-13000, 2360-7000, 2360-13000, 7000-13000 GeV



Dotted lines test the robustness to Multi Parton Interactions MPI and Initial State Radiation ISR

Theory:

Simplified averaged plot over 6 energy combinations: - filled area (energy comb. variation),
- ticks - stat. Unc.



Internal score to pick-up best performing angularities

Separation power:

$$\Delta_{[q,g]} = \frac{1}{2}\sum_{i=1}^{N}\frac{(\lambda_{q_i}-\lambda_{g_i})^2}{\lambda_{q_i}+\lambda_{g_i}}$$

3. Results

Results:

Selection of dijet events:

$N^{jets} = 2$
veto neutrinos

$p_T \text{ sublead} / p_T \text{ lead} > 0.8$

We considered all combinations of:

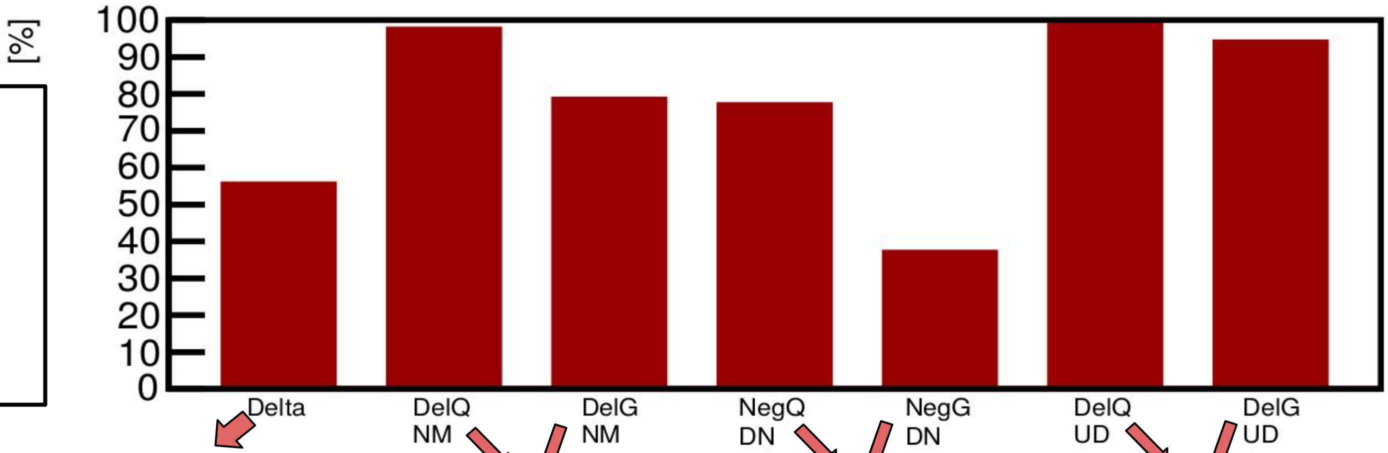
– 5 – angularities λ_0^0, $\lambda_{0.5}^1$, λ_1^1, λ_0^2, λ_2^1
– 2 – using groomed (MMDT) / not groomed jets
– 5 – jet radii $R = 0.2, 0.4, 0.6, 0.8, 1.0$
– 4 – regions - dijet average $p_T^{\text{cut}} = 50$ GeV, 100, 200, and 400 GeV

$(p_T \text{ lead} + p_T \text{ sublead})/2 > p_T^{\text{cut}}$

– 2 – quark/gluon
– 2 – MPI and ISR switched on/off
– 6 – energy combinations: 900–2360, 900–7000, 900–13000, 2360–7000, 2360–13000, 7000–13000 GeV
– 2 – event generators Herwig and Pythia

Results:

Each column represents percentile of given feature of all our studied plots.



In **separation between Q/G jets** about 55 % of variations have lower performance

Separation power between noMPI variations - **robustness to noMPI no ISF**

Negativity (percentage of negative area to whole area) **negative bins**

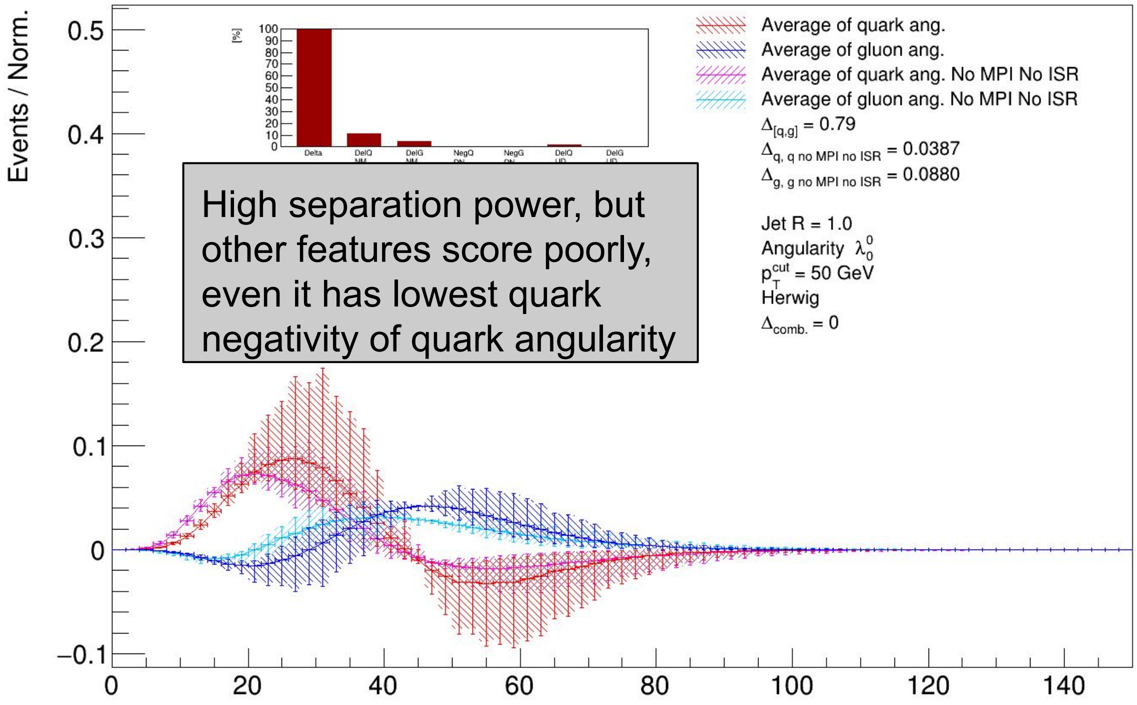
Separation power to UP and DOWN energy combination variations **robustness to different energy combination used**

Combining all columns gives us our internal score :

$$\Delta_{\mathrm{comb}} = 1000 \cdot \ln\left[1 + (\mathrm{Delta})^3 \cdot (\mathrm{DelQ\ NM}) \cdot (\mathrm{DelG\ NM}) \cdot (\mathrm{NegQ\ DN}) \cdot (\mathrm{NegG\ DN}) \cdot (\mathrm{DelQ\ UD}) \cdot (\mathrm{DelG\ UD})\right]$$

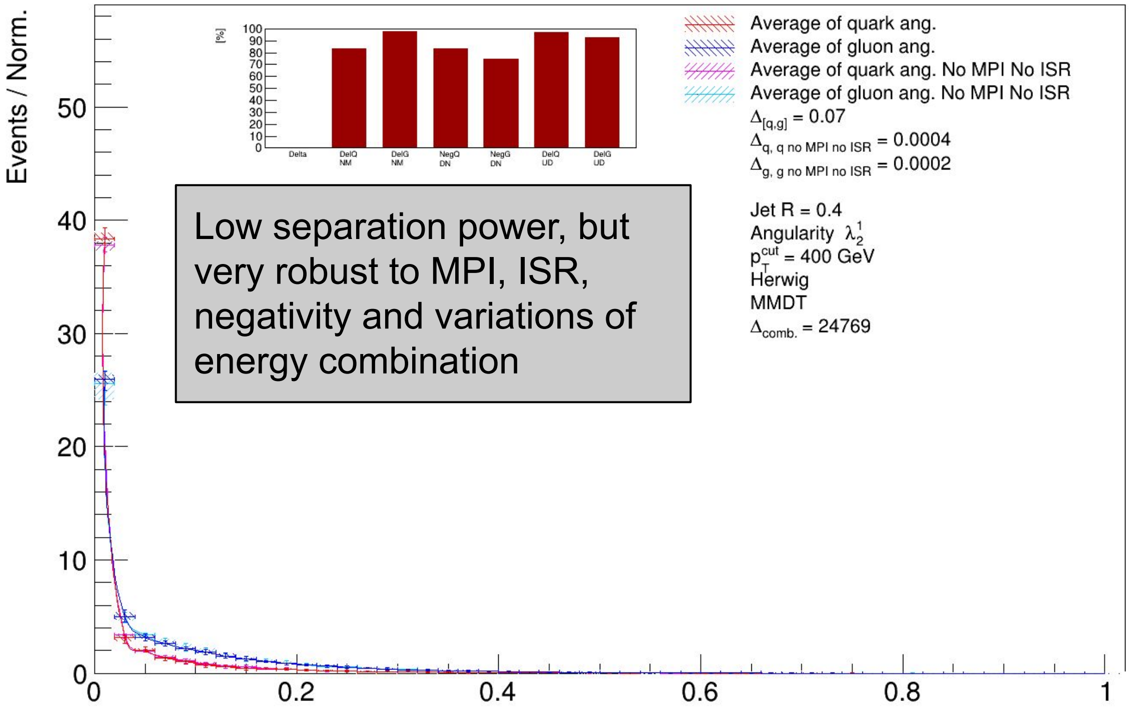
min-max
0-41447

Why we looking into other features then separation power (bad examples):



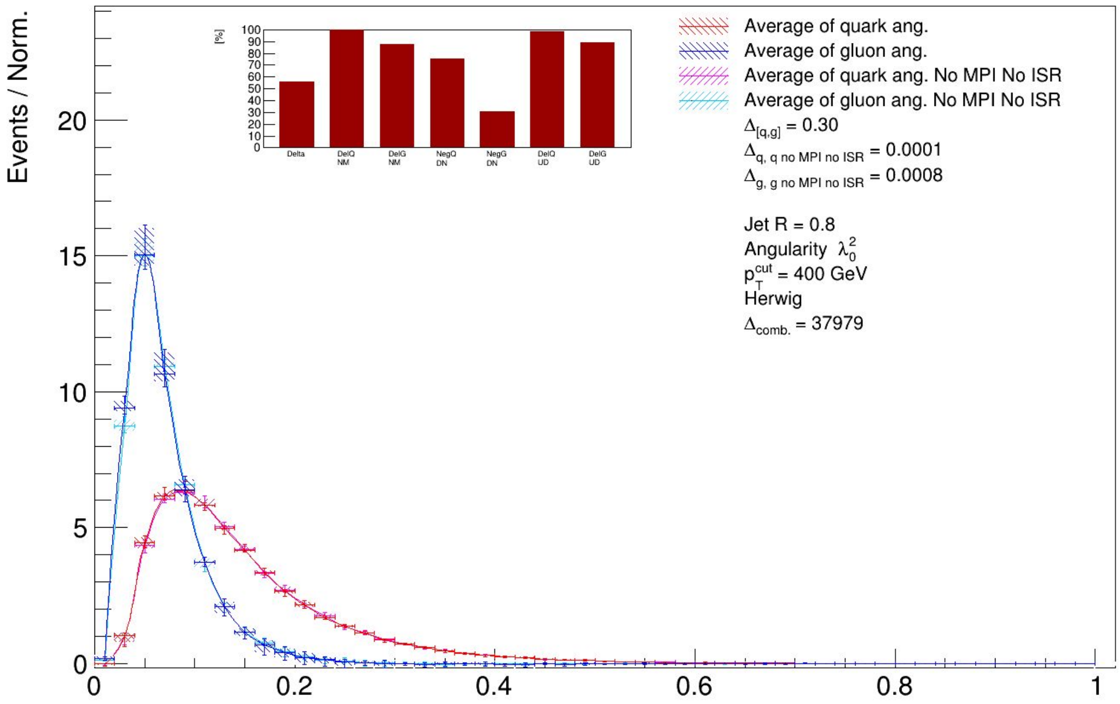
Results:

Why we looking into other features then separation power (bad examples):



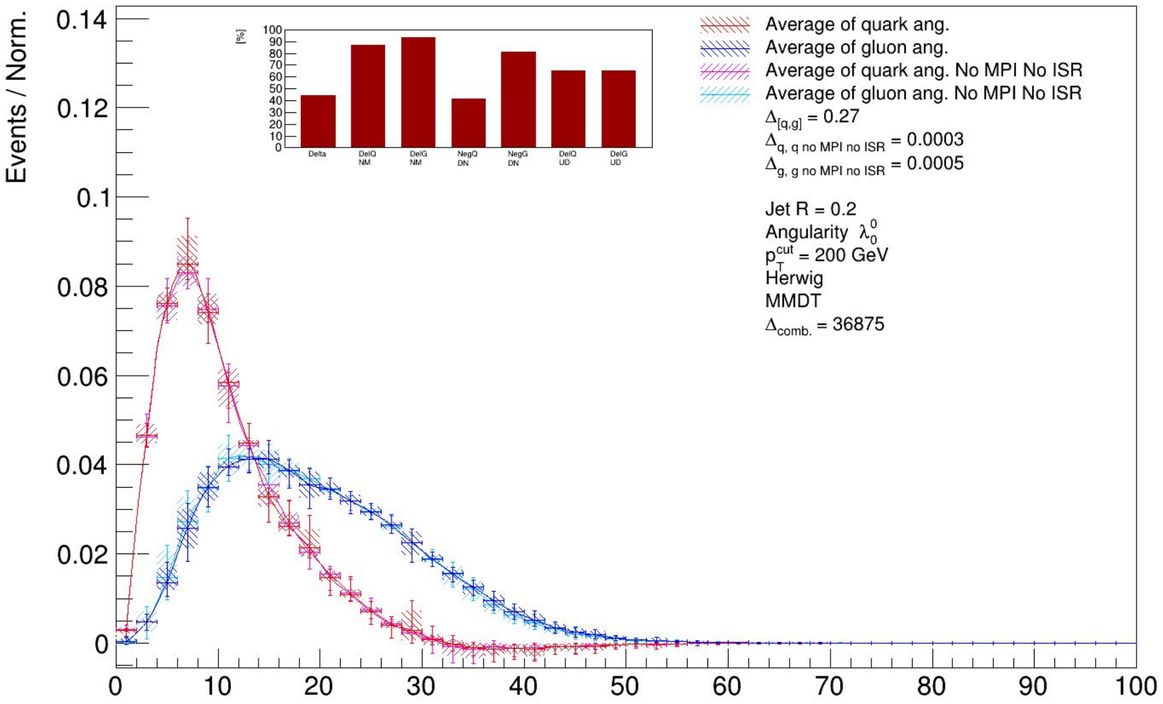
Results:

Best performing angularities: p_T^D

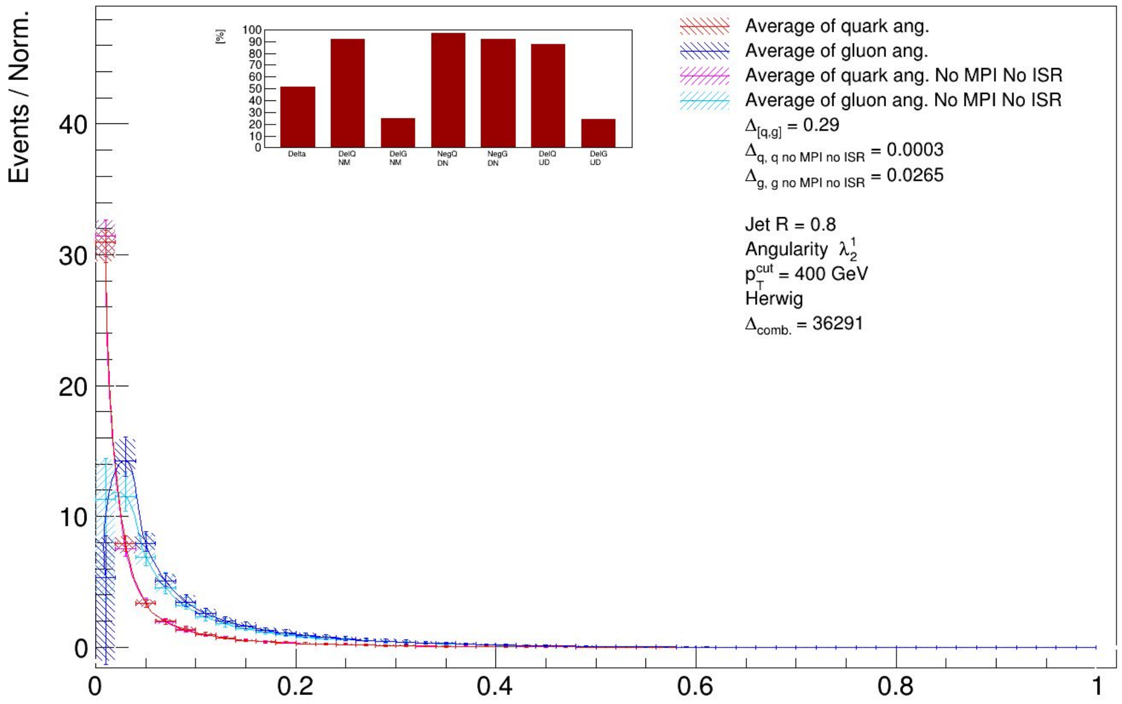


Results:

Best performing angularities: Multiplicity

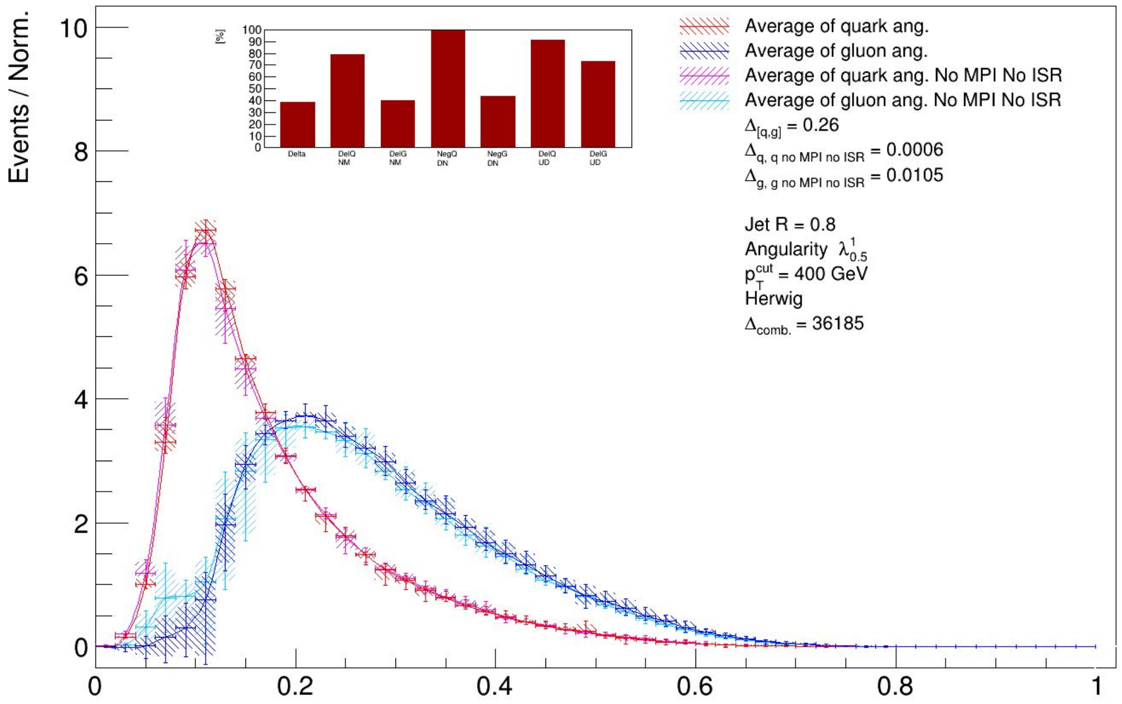


Best performing angularities: Mass



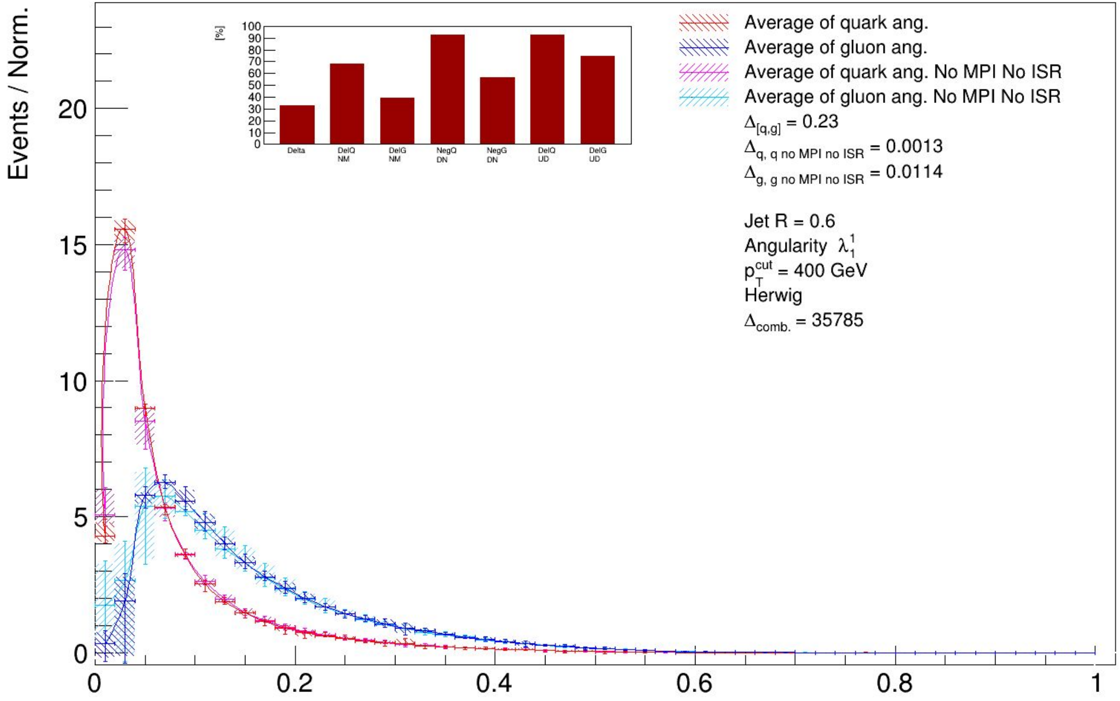
Results:

Best performing angularities: LHA



Results:

Best performing angularities: Width

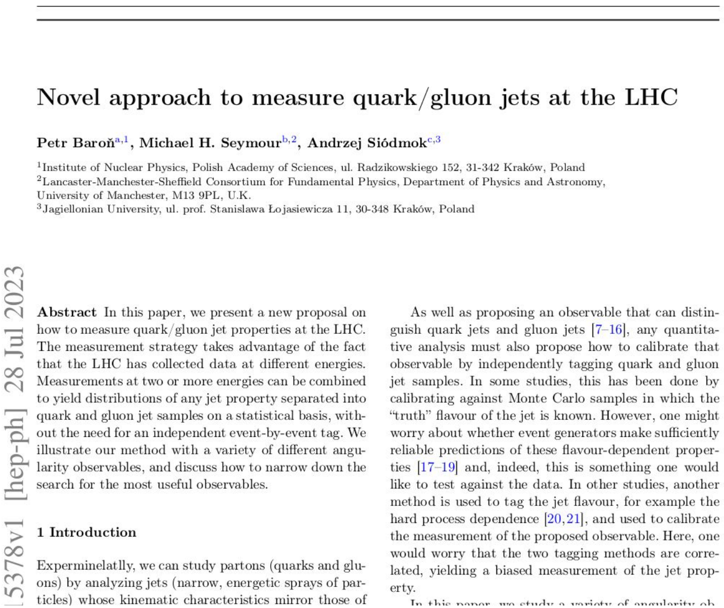


4. Conclusion

Conslution:

- Main idea it that properties of jets of a given flavour and transverse momentum, are almost entirely independent of the jet's production mechanism.
  Thus, the energy-dependence can be used to extract the flavour-dependent properties on a statistical basis.
- We proposed selection of best performing angularities
- More details: https://arxiv.org/abs/2307.15378

- Plans:
  - Multidim angularities (2D, 3D) with machine learning approach to enhance separation power
  - Derive jet topics: https://arxiv.org/abs/1802.00008 since all ingredients should be in place
  - Perform measurement - we will be happy to contribute:-)



Novel approach to measure quark/gluon jets at the LHC

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[1]Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, 31-342 Kraków, Poland
[2]Lancaster-Manchester-Sheffield Consortium for Fundamental Physics, Department of Physics and Astronomy, University of Manchester, M13 9PL, U.K.
[3]Jagiellonian University, ul. prof. Stanislawa Łojasiewicza 11, 30-348 Kraków, Poland

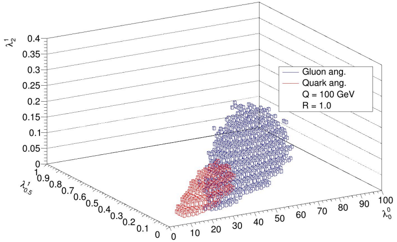
5378v1 [hep-ph] 28 Jul 2023

Abstract In this paper, we present a new proposal on how to measure quark/gluon jet properties at the LHC. The measurement strategy takes advantage of the fact that the LHC has collected data at different energies. Measurements at two or more energies can be combined to yield distributions of any jet property separated into quark and gluon jet samples on a statistical basis, without the need for an independent event-by-event tag. We illustrate our method with a variety of different angularity observables, and discuss how to narrow down the search for the most useful observables.

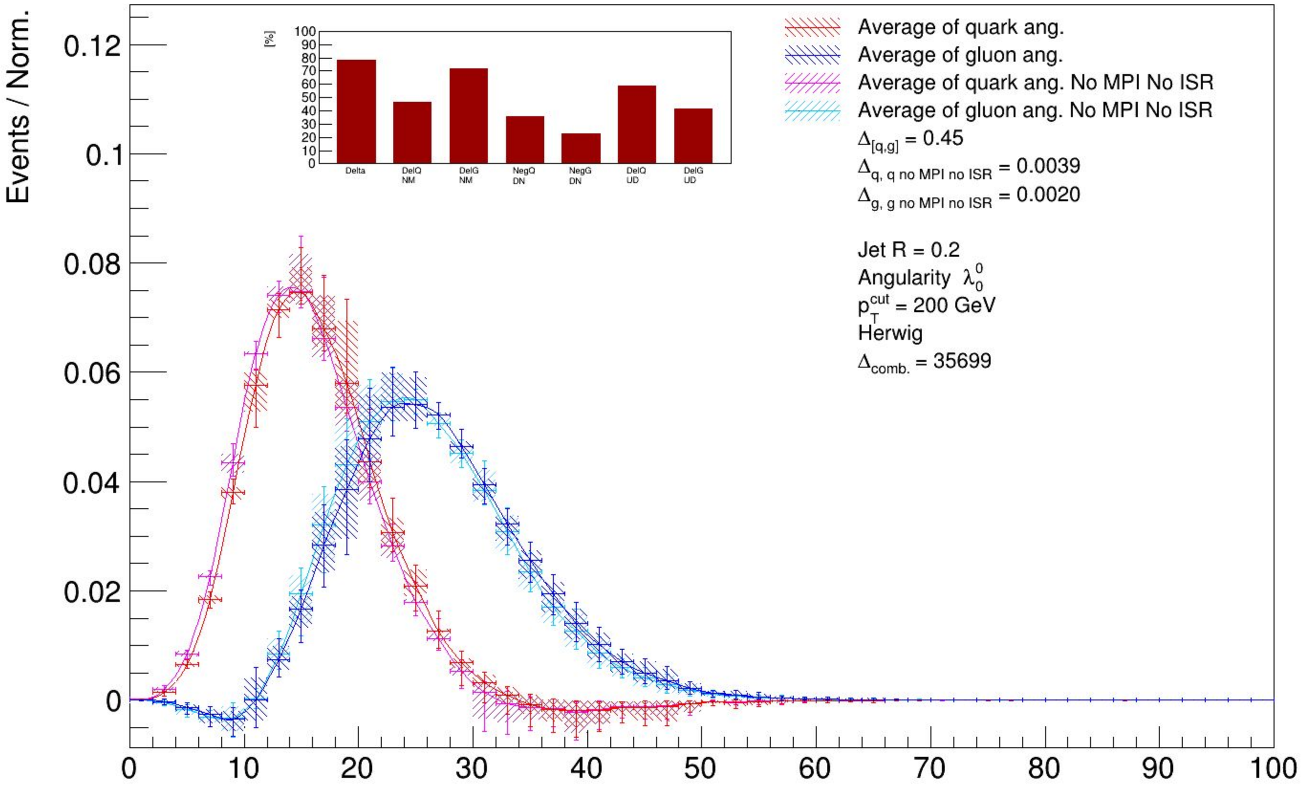
1 Introduction

Experminelatlly, we can study partons (quarks and gluons) by analyzing jets (narrow, energetic sprays of particles) whose kinematic characteristics mirror those of

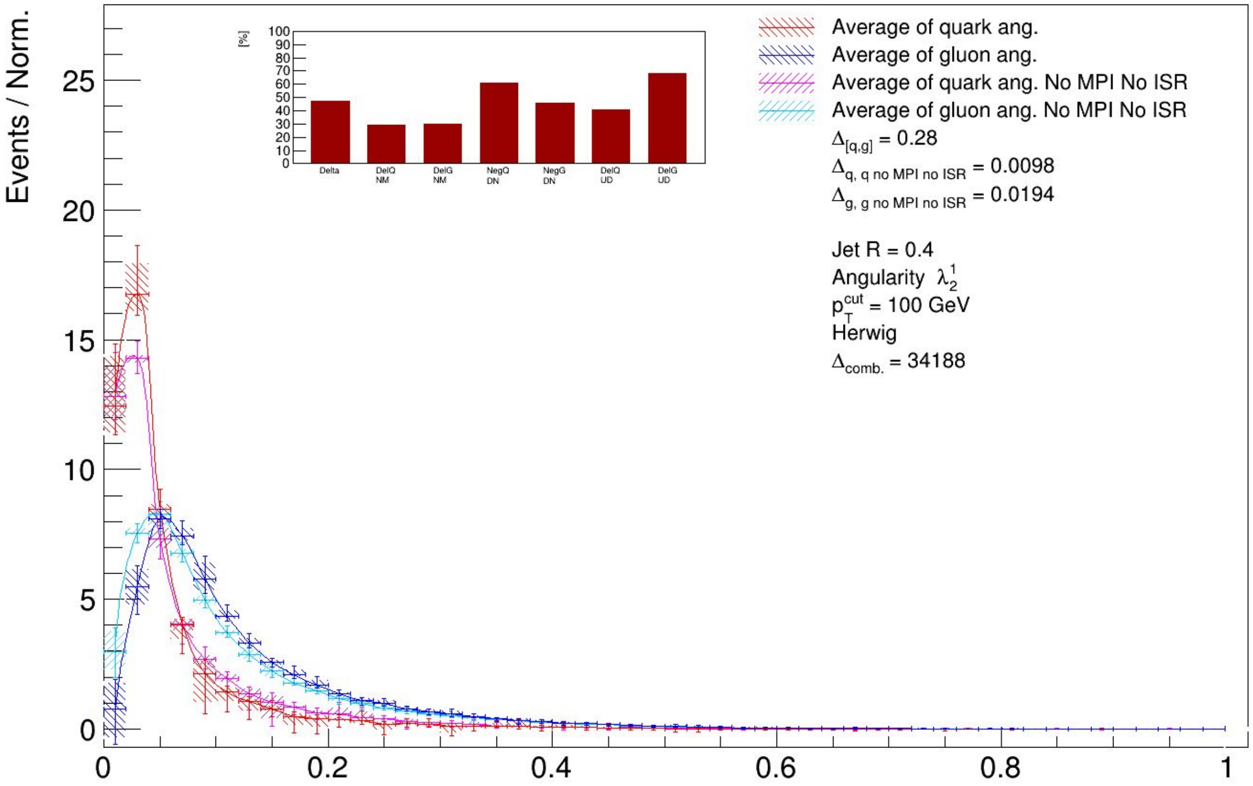
As well as proposing an observable that can distinguish quark jets and gluon jets [7–16], any quantitative analysis must also propose how to calibrate that observable by independently tagging quark and gluon jet samples. In some studies, this has been done by calibrating against Monte Carlo samples in which the "truth" flavour of the jet is known. However, one might worry about whether event generators make sufficiently reliable predictions of these flavour-dependent properties [17–19] and, indeed, this is something one would like to test against the data. In other studies, another method is used to tag the jet flavour, for example the hard process dependence [20,21], and used to calibrate the measurement of the proposed observable. Here, one would worry that the two tagging methods are correlated, yielding a biased measurement of the jet property.



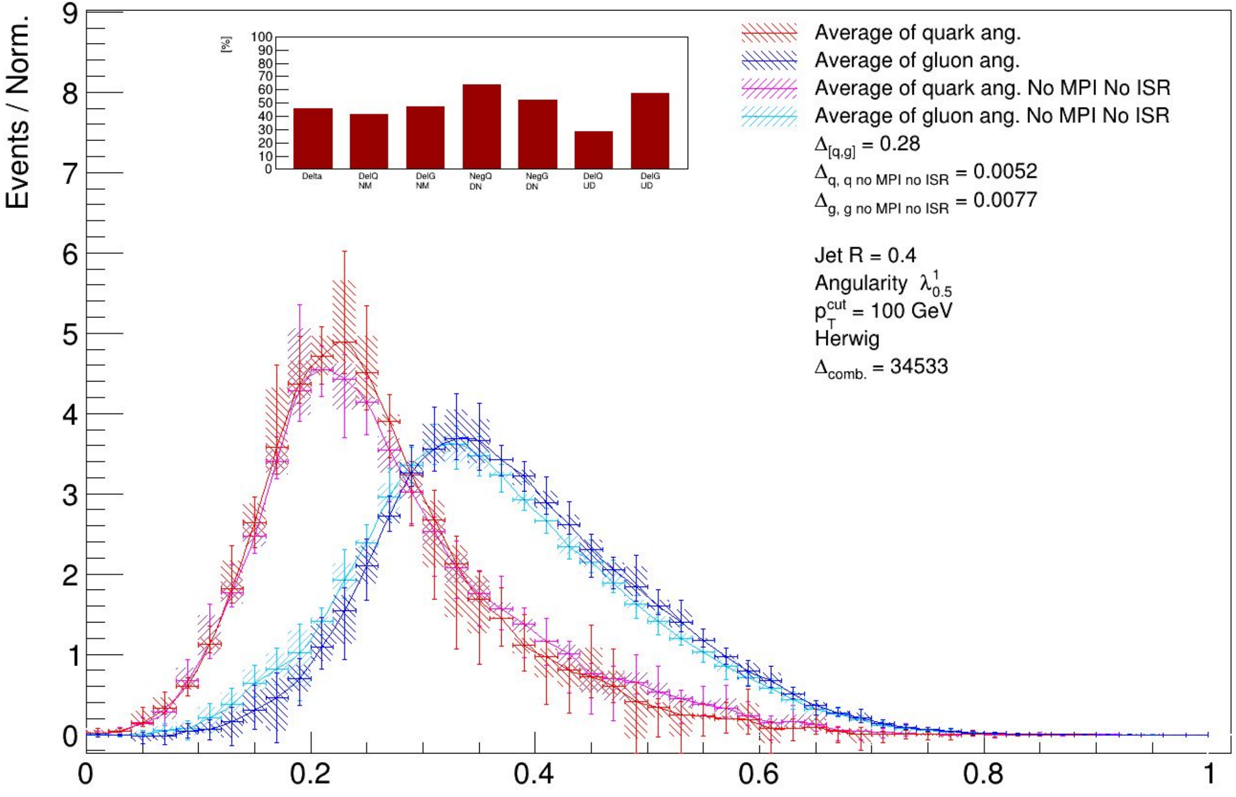
Wild cards (chosen by “eye”): multiplicity



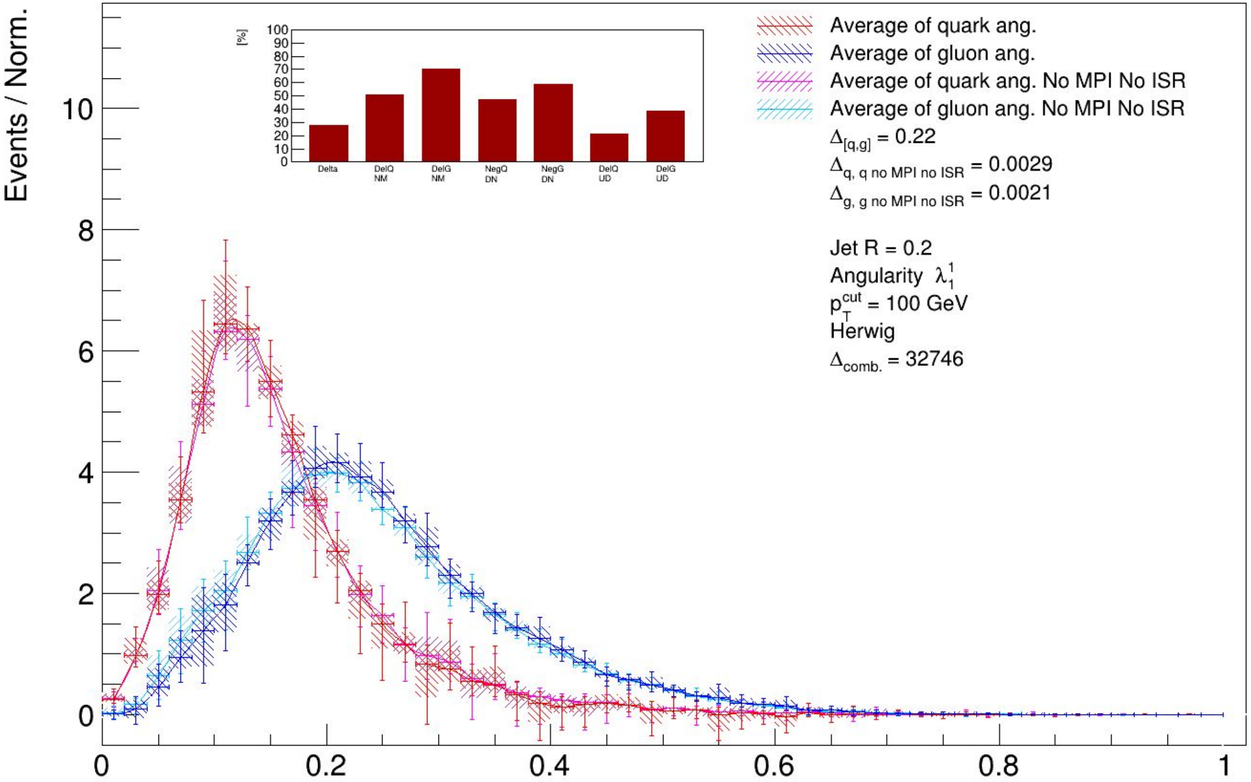
Wild cards (chosen by “eye”): mass



Wild cards (chosen by “eye”): LHA



Wild cards (chosen by “eye”): width



Back-up

Herwig vs Pythia

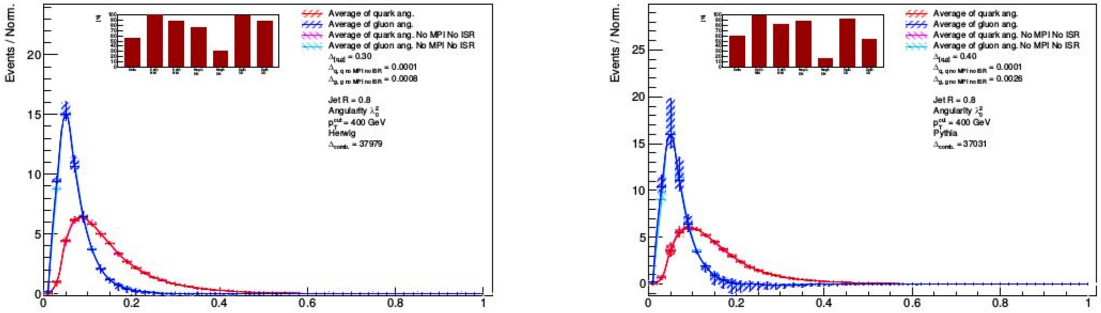


Fig. 17 Quark and gluon averaged angularities λ_0^2, $R = 0.8$ with highest score $\Delta_{\mathrm{comb}} = 37979$ using HERWIG event generator (left) and $\Delta_{\mathrm{comb}} = 37031$ using PYTHIA event generator (right), with $p_T^{\mathrm{cut}} = 400$ GeV, using the average of 6 energy combinations 900–2360, 900–7000, 900–13000, 2360–7000, 2360–13000, 7000–13000 GeV.

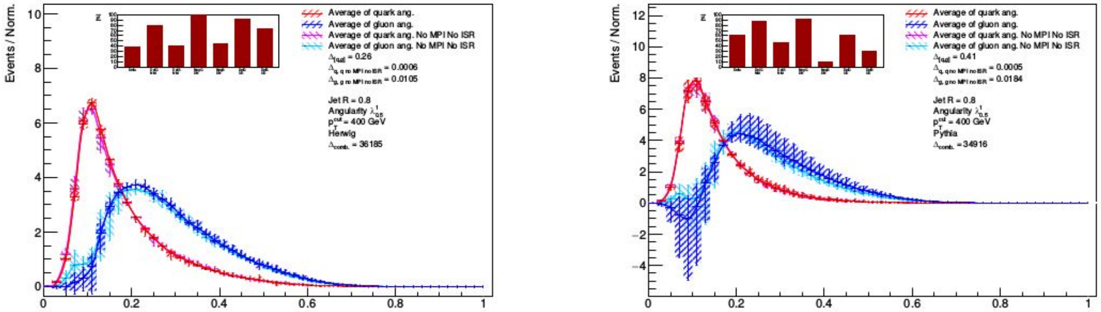
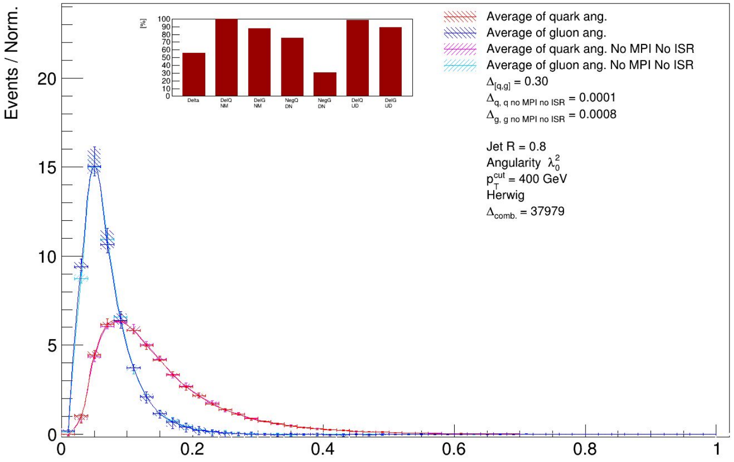
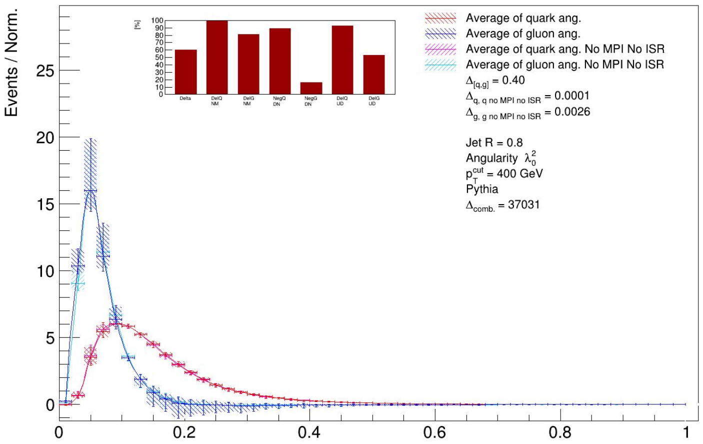


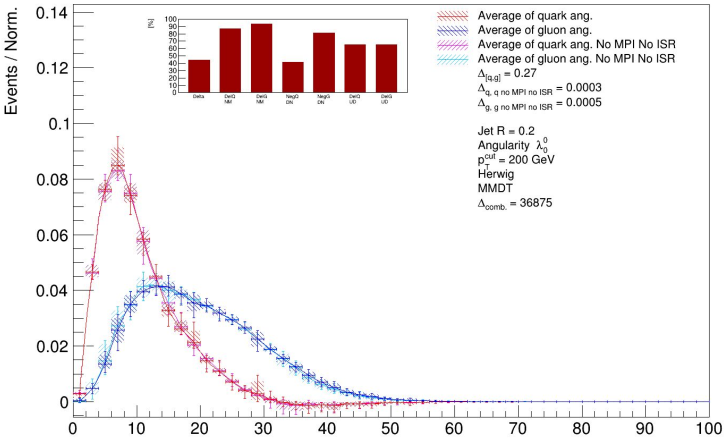
Fig. 18 Quark and gluon averaged angularities MMDT $\lambda_{0.5}^1$, $R = 0.8$ with score $\Delta_{\mathrm{comb}} = 36185$ using HERWIG event generator (left) and $\Delta_{\mathrm{comb}} = 34916$ using PYTHIA event generator (right), with $p_T^{\mathrm{cut}} = 400$ GeV, using the average of 6 energy combinations 900–2360, 900–7000, 900–13000, 2360–7000, 2360–13000, 7000–13000 GeV.

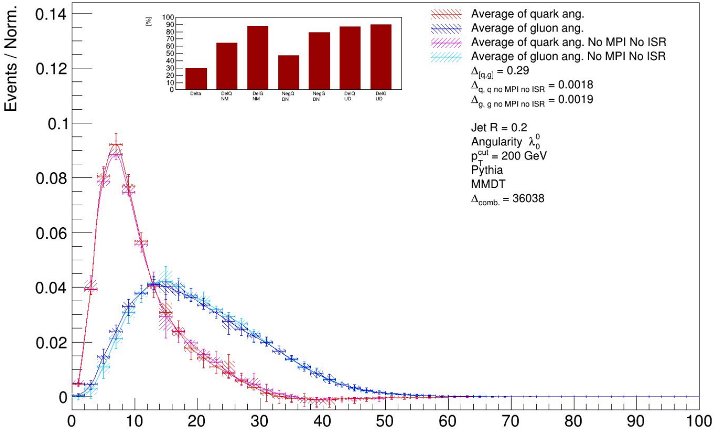
Best performing angularities: p_T^D



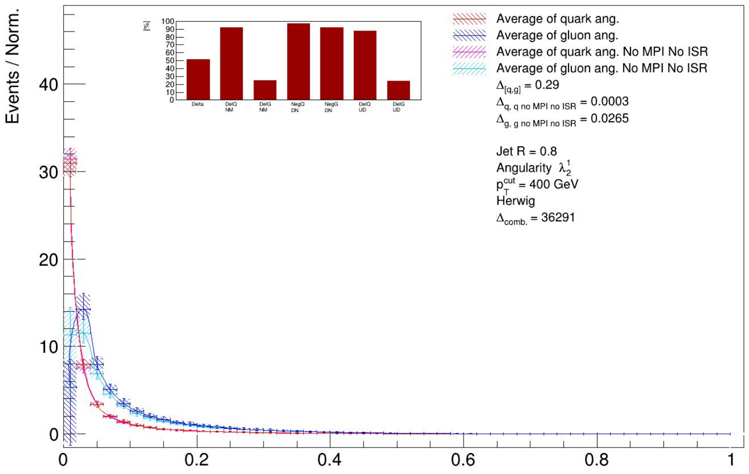


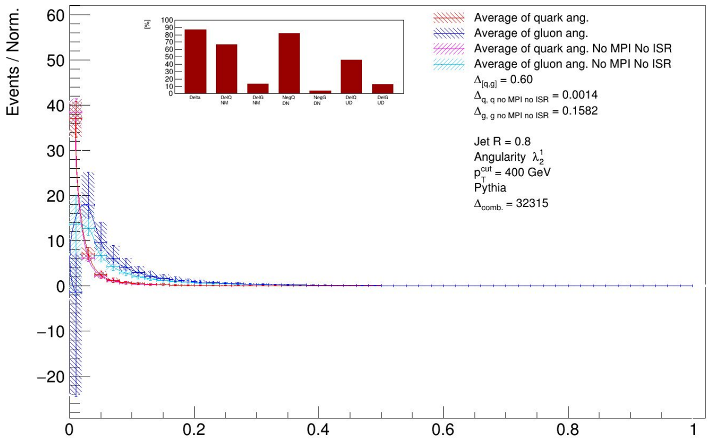
Best performing angularities: Multiplicity





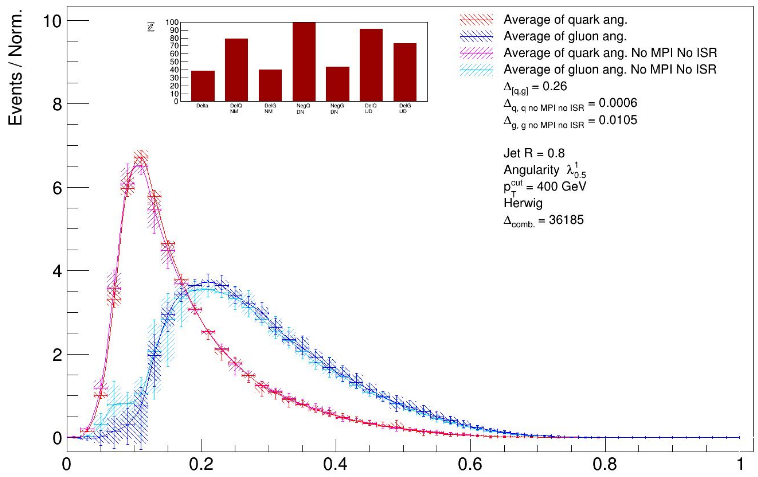
Best performing angularities: Mass

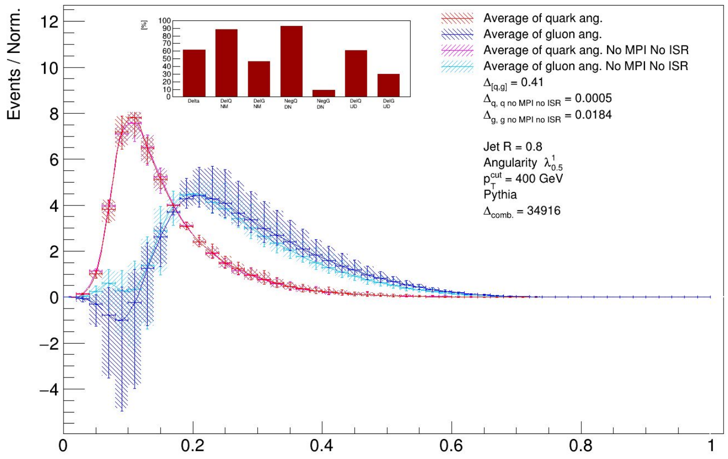




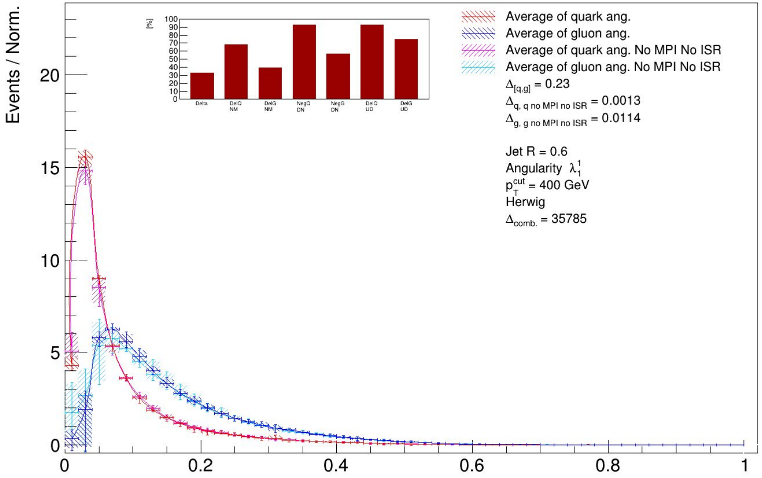
Results:

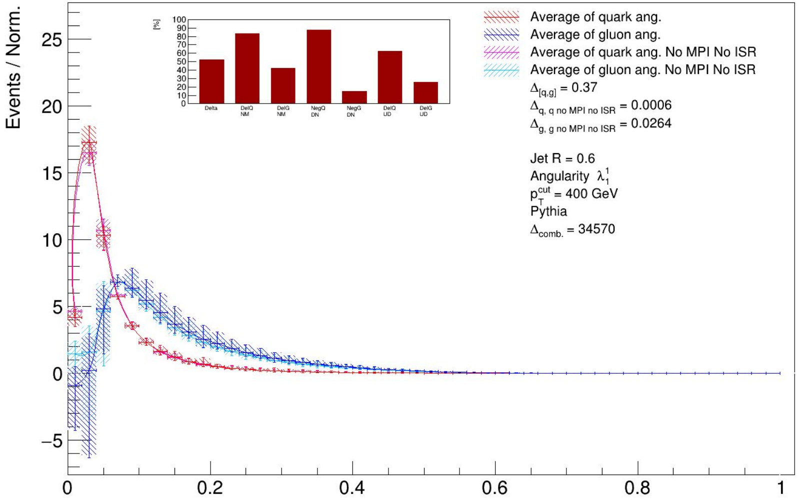
Best performing angularities: LHA



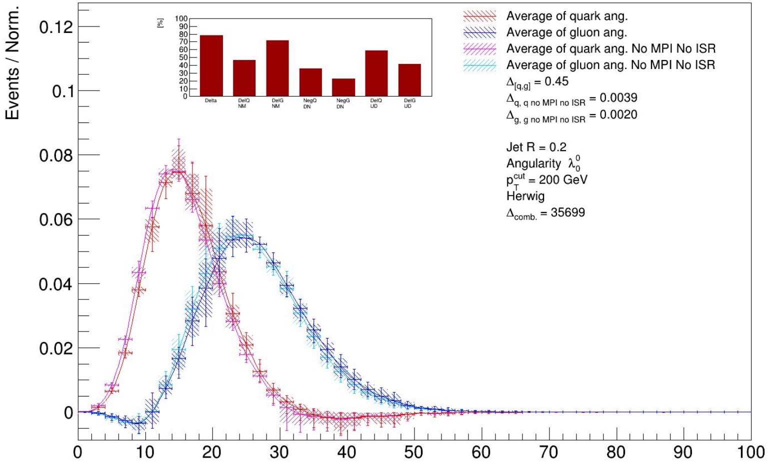


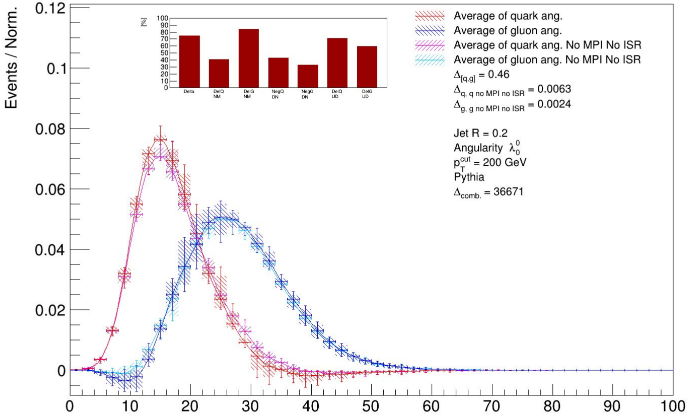
Best performing angularities: Width



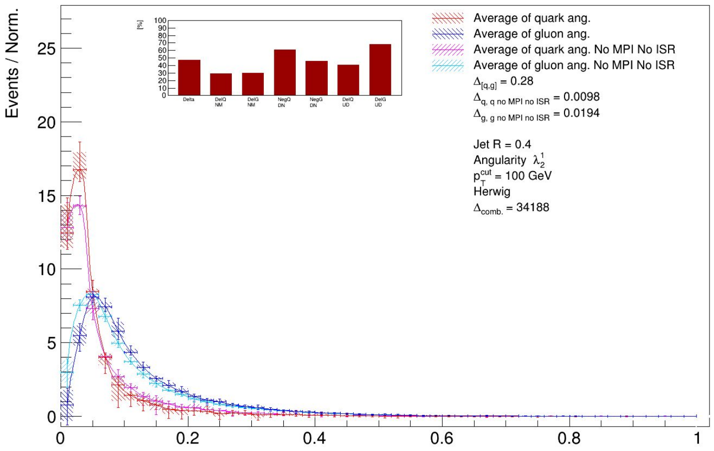


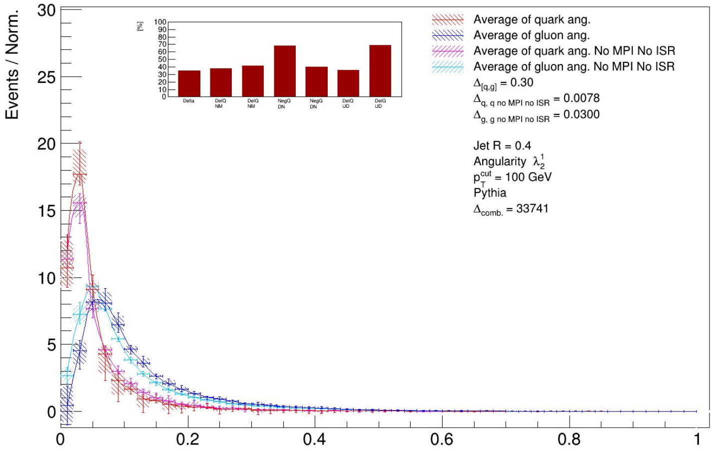
Wild cards (chosen by “eye”): multiplicity



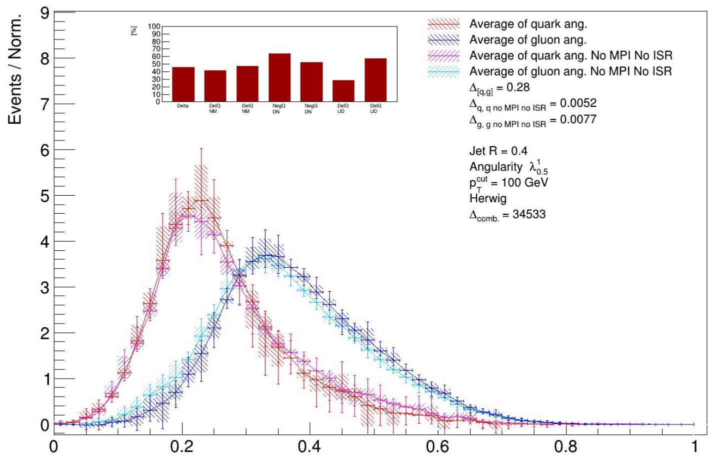


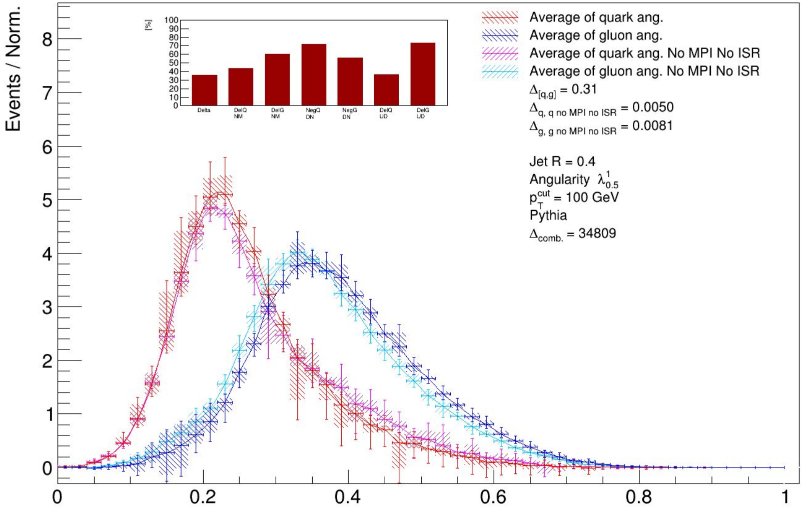
Wild cards (chosen by "eye"): mass



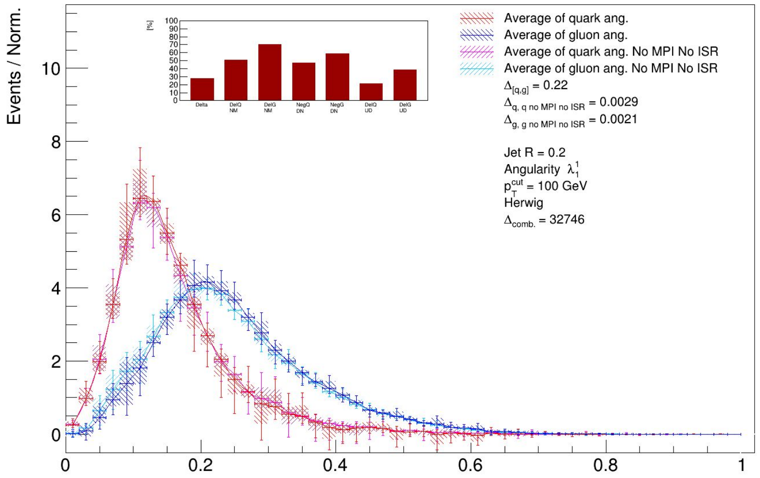


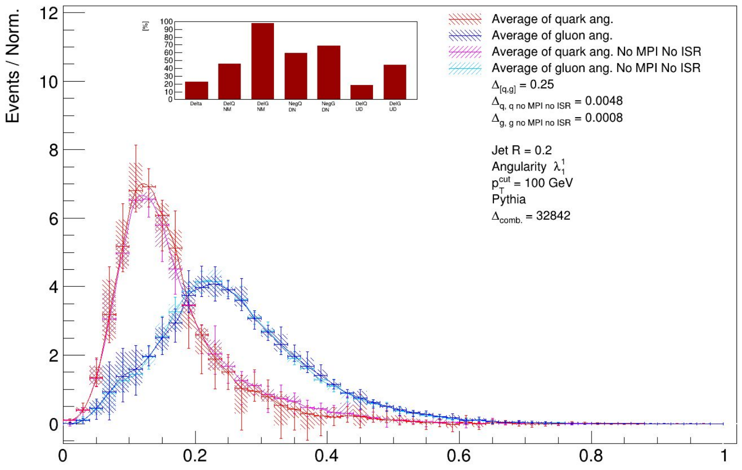
Wild cards (chosen by “eye”): LHA

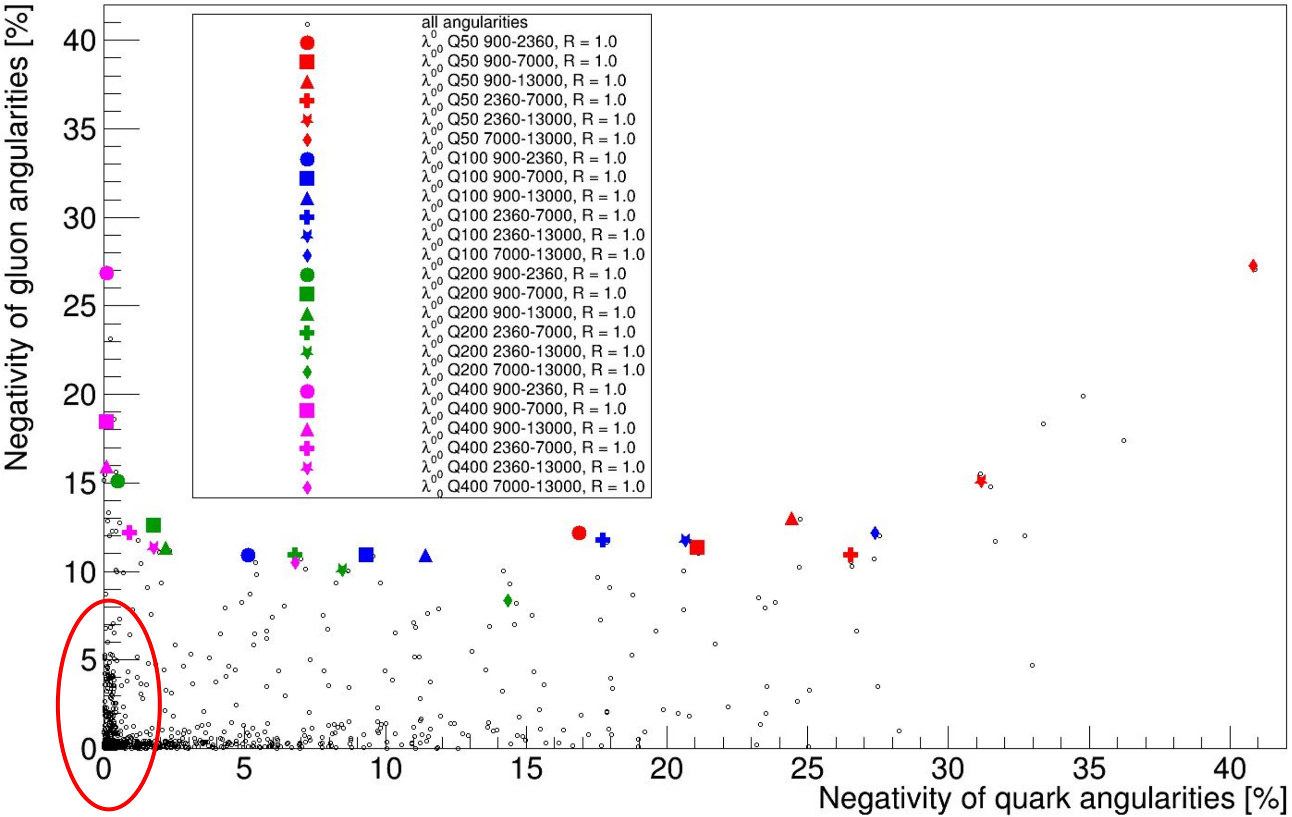


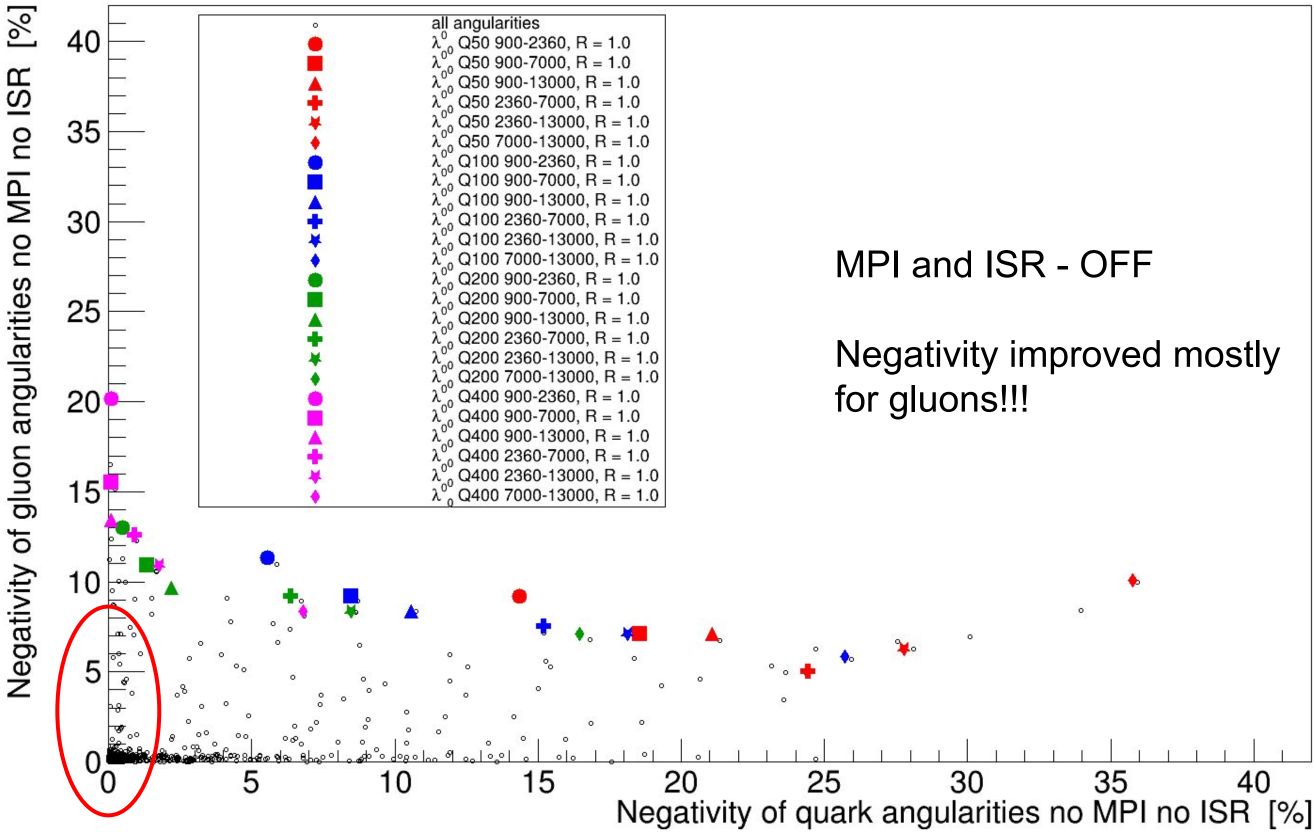


Wild cards (chosen by "eye"): width



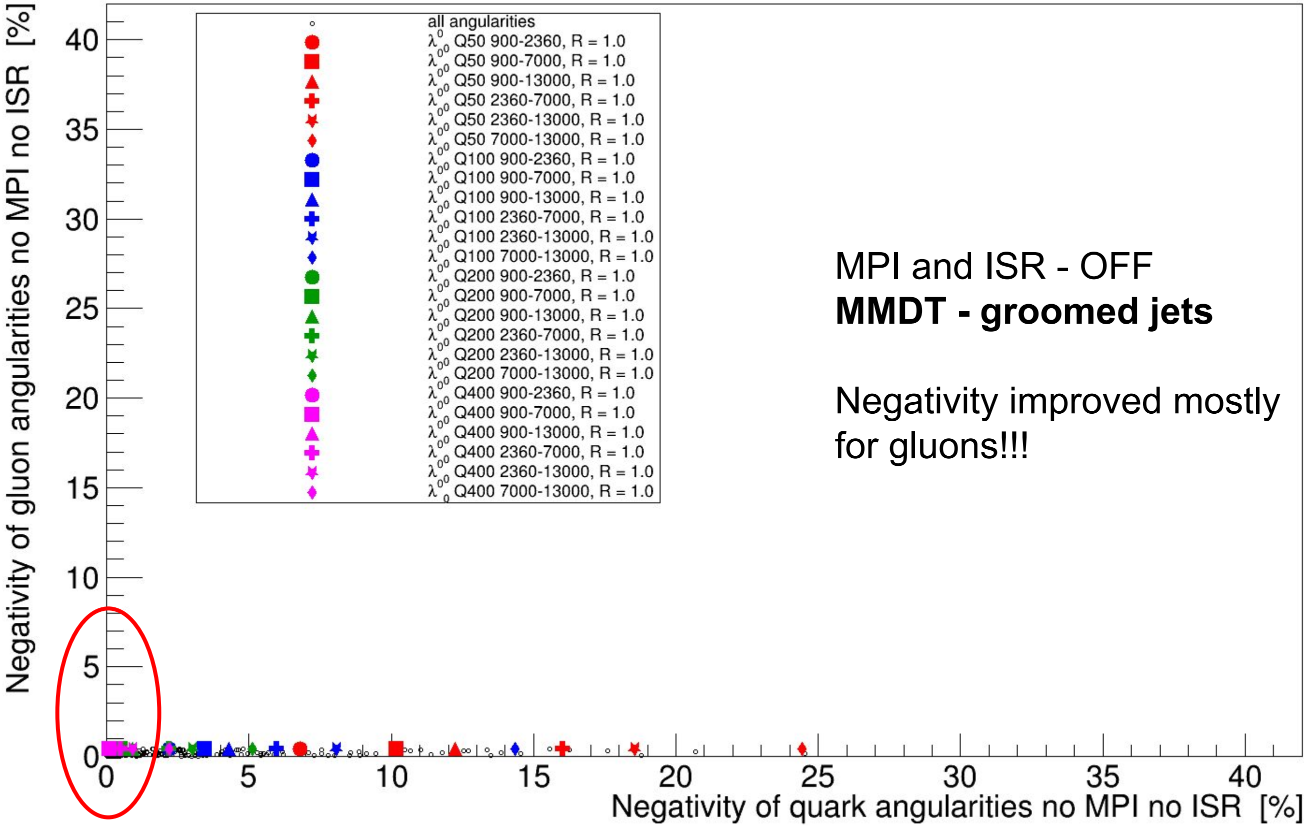



all angularities
λ^0_0 Q50 900-2360, R = 1.0
λ^0_0 Q50 900-7000, R = 1.0
λ^0_0 Q50 900-13000, R = 1.0
λ^0_0 Q50 2360-7000, R = 1.0
λ^0_0 Q50 2360-13000, R = 1.0
λ^0_0 Q50 7000-13000, R = 1.0
λ^0_0 Q100 900-2360, R = 1.0
λ^0_0 Q100 900-7000, R = 1.0
λ^0_0 Q100 900-13000, R = 1.0
λ^0_0 Q100 2360-7000, R = 1.0
λ^0_0 Q100 2360-13000, R = 1.0
λ^0_0 Q100 7000-13000, R = 1.0
λ^0_0 Q200 900-2360, R = 1.0
λ^0_0 Q200 900-7000, R = 1.0
λ^0_0 Q200 900-13000, R = 1.0
λ^0_0 Q200 2360-7000, R = 1.0
λ^0_0 Q200 2360-13000, R = 1.0
λ^0_0 Q200 7000-13000, R = 1.0
λ^0_0 Q400 900-2360, R = 1.0
λ^0_0 Q400 900-7000, R = 1.0
λ^0_0 Q400 900-13000, R = 1.0
λ^0_0 Q400 2360-7000, R = 1.0
λ^0_0 Q400 2360-13000, R = 1.0
λ^0_0 Q400 7000-13000, R = 1.0
Negativity of gluon angularities [%]
Negativity of quark angularities [%]
0
5
10
15
20
25
30
35
40



MPI and ISR - OFF

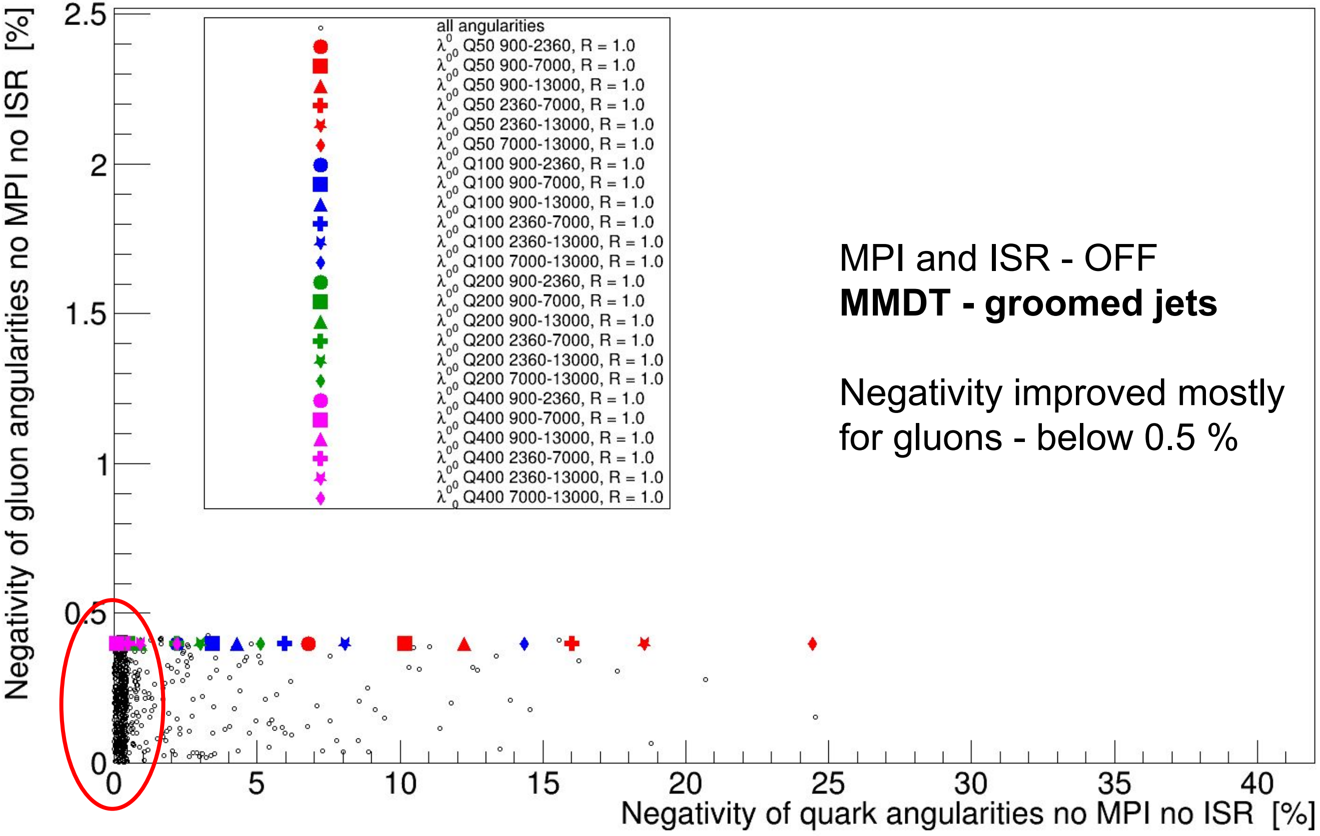
Negativity improved mostly for gluons!!!



MPI and ISR - OFF
MMDT - groomed jets

Negativity improved mostly for gluons!!!

ZOOMED



MPI and ISR - OFF
MMDT - groomed jets

Negativity improved mostly for gluons - below 0.5 %

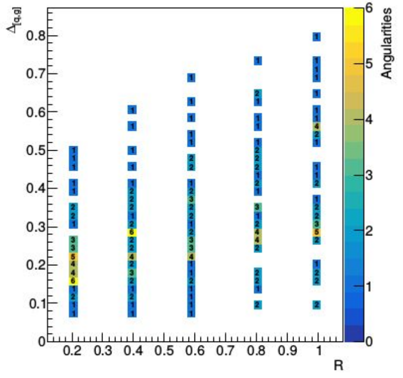


Fig. 19 First column scatter plot of $\Delta_{[q,g]}$ as a function of jet radius.

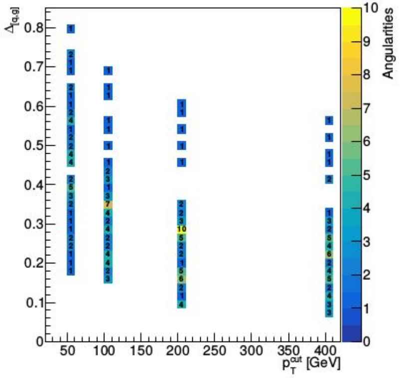


Fig. 21 First column scatter plot of $\Delta_{[q,g]}$ as a function of $p_T^{\rm cut}$.

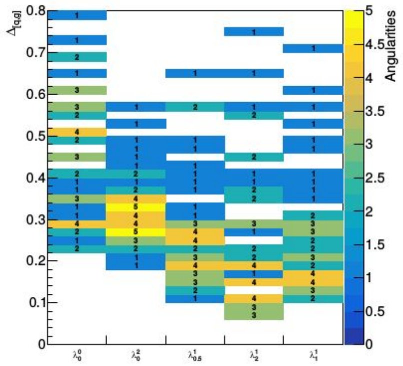


Fig. 20 First column scatter plot of $\Delta_{[q,g]}$ as a function of jet angularity.

Back-up

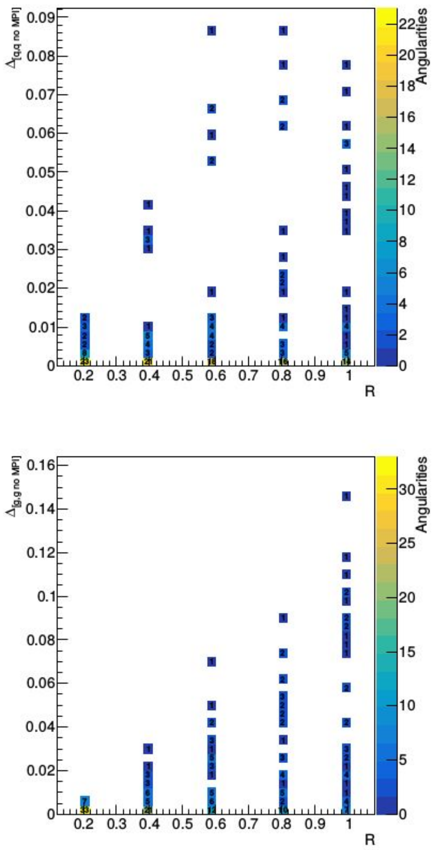


Fig. 22 Second/third column quark $\Delta_{[q,q\ \mathrm{noMPI}]}$ (top) and gluon $\Delta_{[g,g\ \mathrm{noMPI}]}$ (bottom) as a function of jet radius.

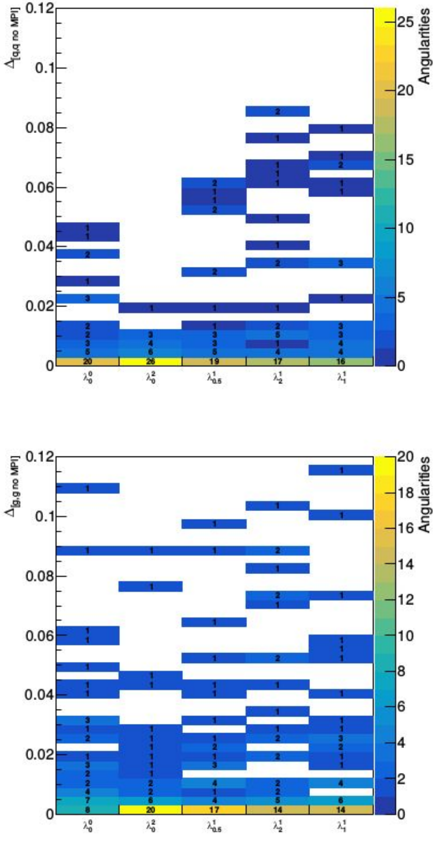


Fig. 23 Second/third column quark $\Delta_{[q,q\ \mathrm{noMPI}]}$ (top) and gluon $\Delta_{[g,g\ \mathrm{noMPI}]}$ (bottom) as a function of angularities.

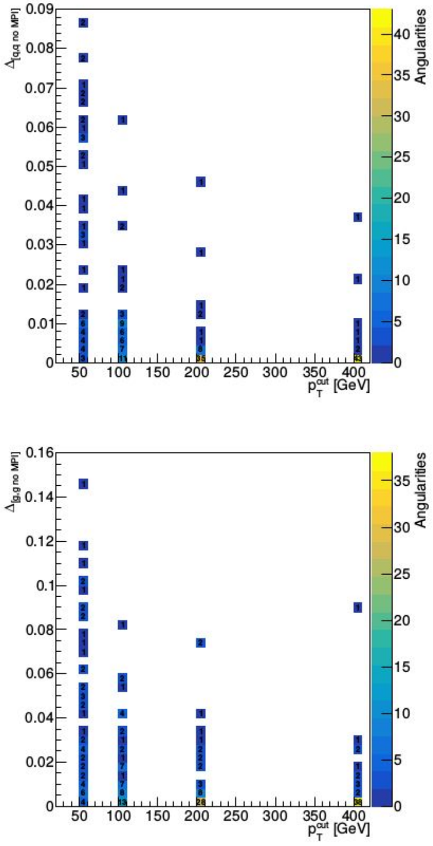


Fig. 24 Second/third column quark $\Delta_{[q,q \text{ noMPI}]}$ (top) and gluon $\Delta_{[g,g \text{ noMPI}]}$ (bottom) as a function of p_T^{cut}.

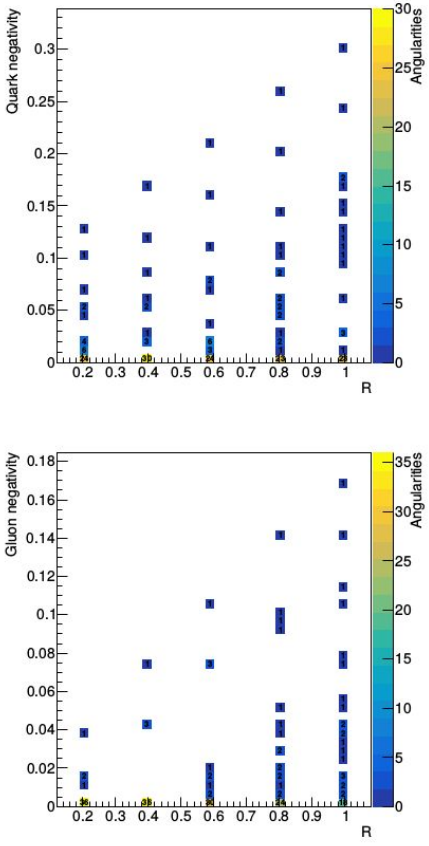


Fig. 25 Fourth/fifth column quark (top) and gluon negativity (bottom) as a function of jet radius.

Back-up

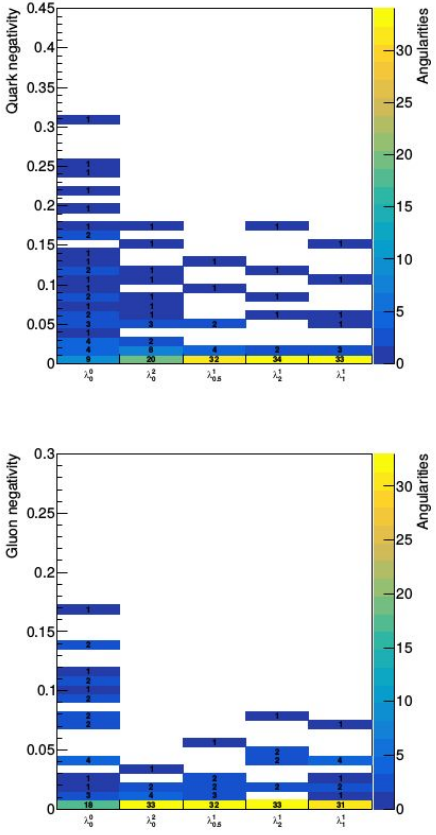


Fig. 26 Fourth/fifth column quark (top) and gluon negativity (bottom) as a function of angularities.

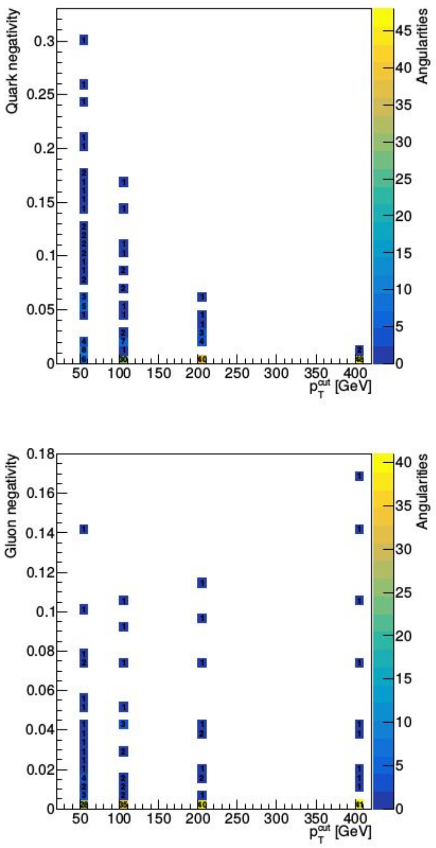


Fig. 27 Fourth/fifth column quark (top) and gluon negativity (bottom) as a function of $p_T^{\rm cut}$.

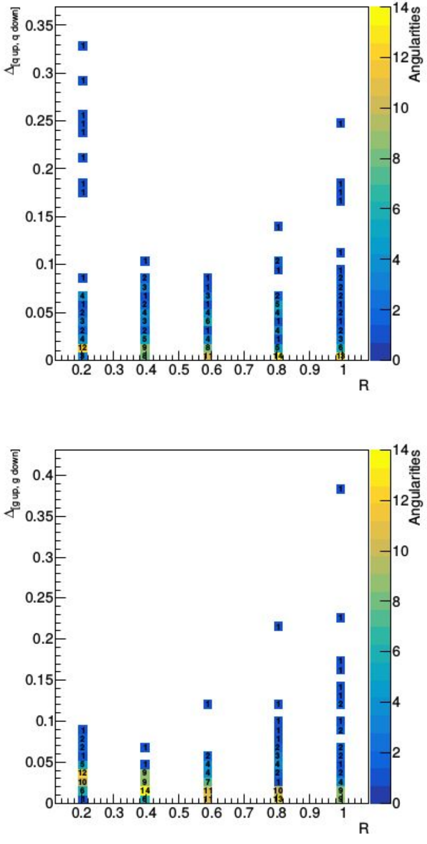


Fig. 28 Sixth/Seventh column quark $\Delta_{[q\ down, q\ up]}$ (top) and gluon $\Delta_{[g\ down, g\ up]}$ (bottom) as a function of jet radius.

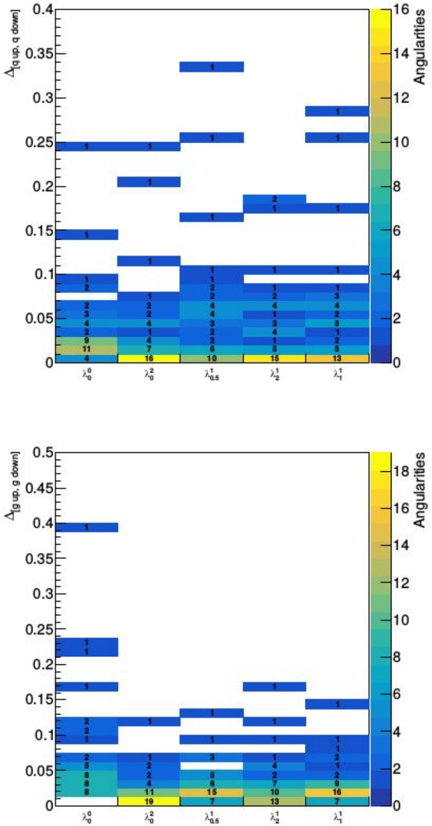
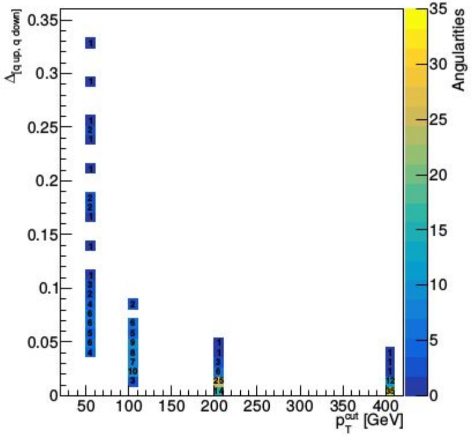


Fig. 29 Sixth/Seventh column quark $\Delta_{[q\ down, q\ up]}$ (top) and gluon $\Delta_{[g\ down, g\ up]}$ (bottom) as a function of angularities.

Back-up



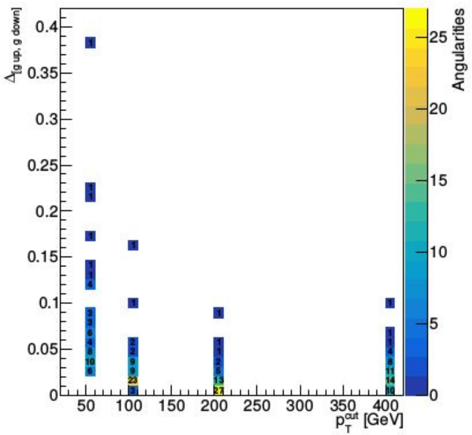


Fig. 30 Sixth/Seventh column quark $\Delta_{[q\ \mathrm{down}, q\ \mathrm{up}]}$ (top) and gluon $\Delta_{[g\ \mathrm{down}, g\ \mathrm{up}]}$ (bottom) as a function of p_T^{cut}.