Novel approach to measure quark/gluon jets at the LHC

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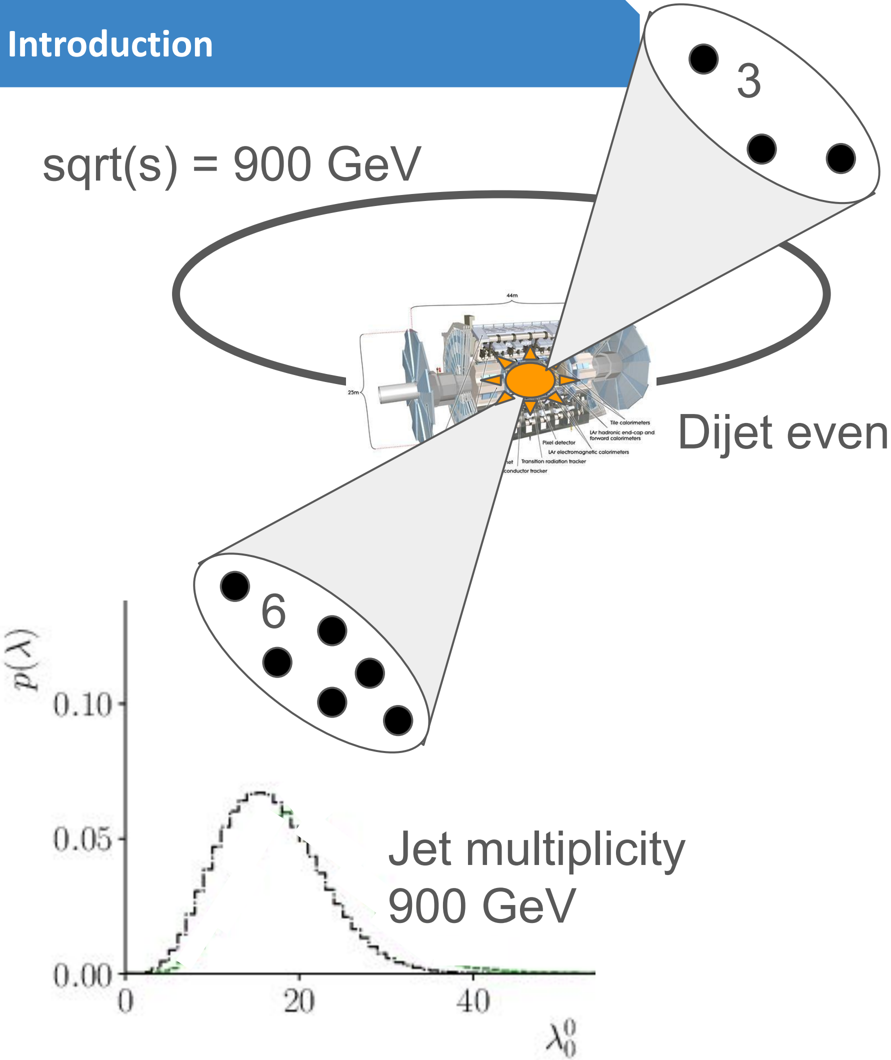
11.1.2024

Outline:

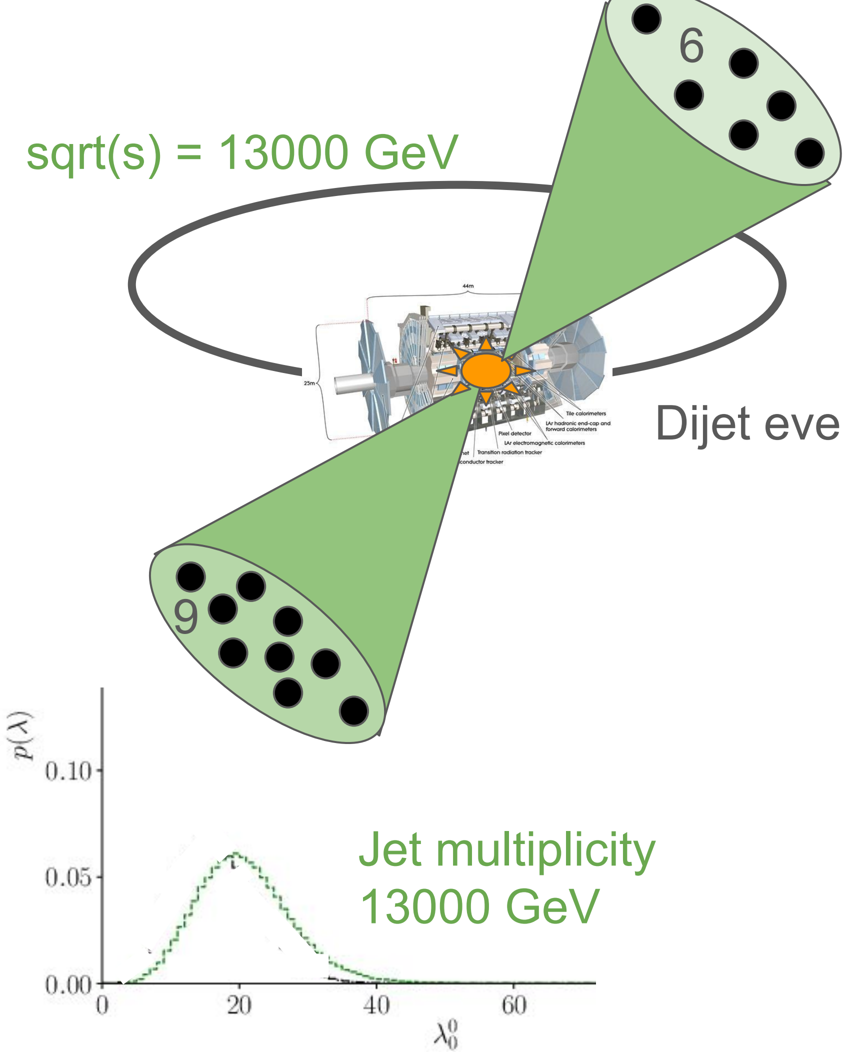
Introduction



sqrt(s) = 900 GeV

Dijet events

Jet multiplicity
900 GeV

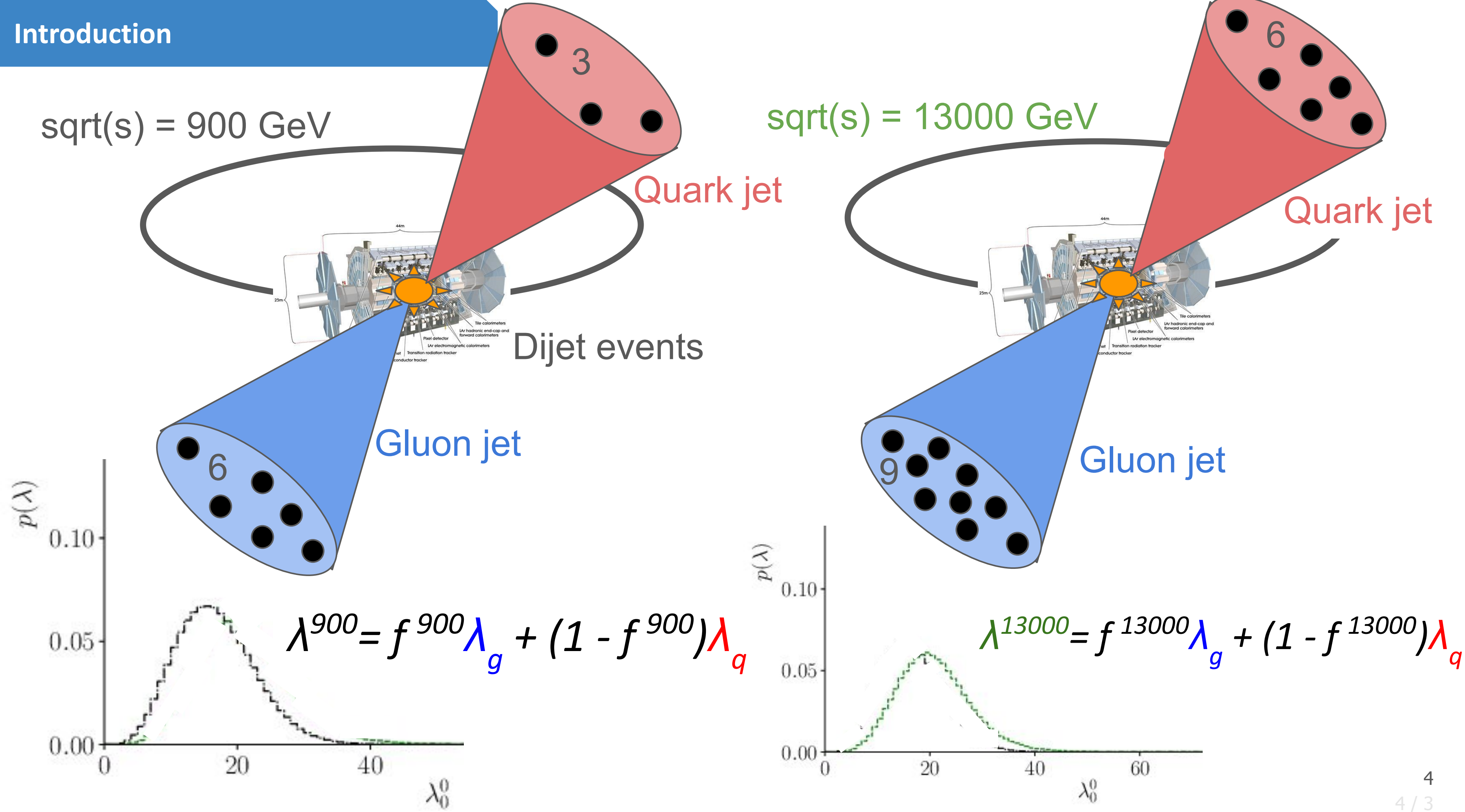


sqrt(s) = 13000 GeV

Dijet events

Jet multiplicity
13000 GeV

Introduction



sqrt(s) = 900 GeV

Quark jet

Dijet events

Gluon jet

sqrt(s) = 13000 GeV

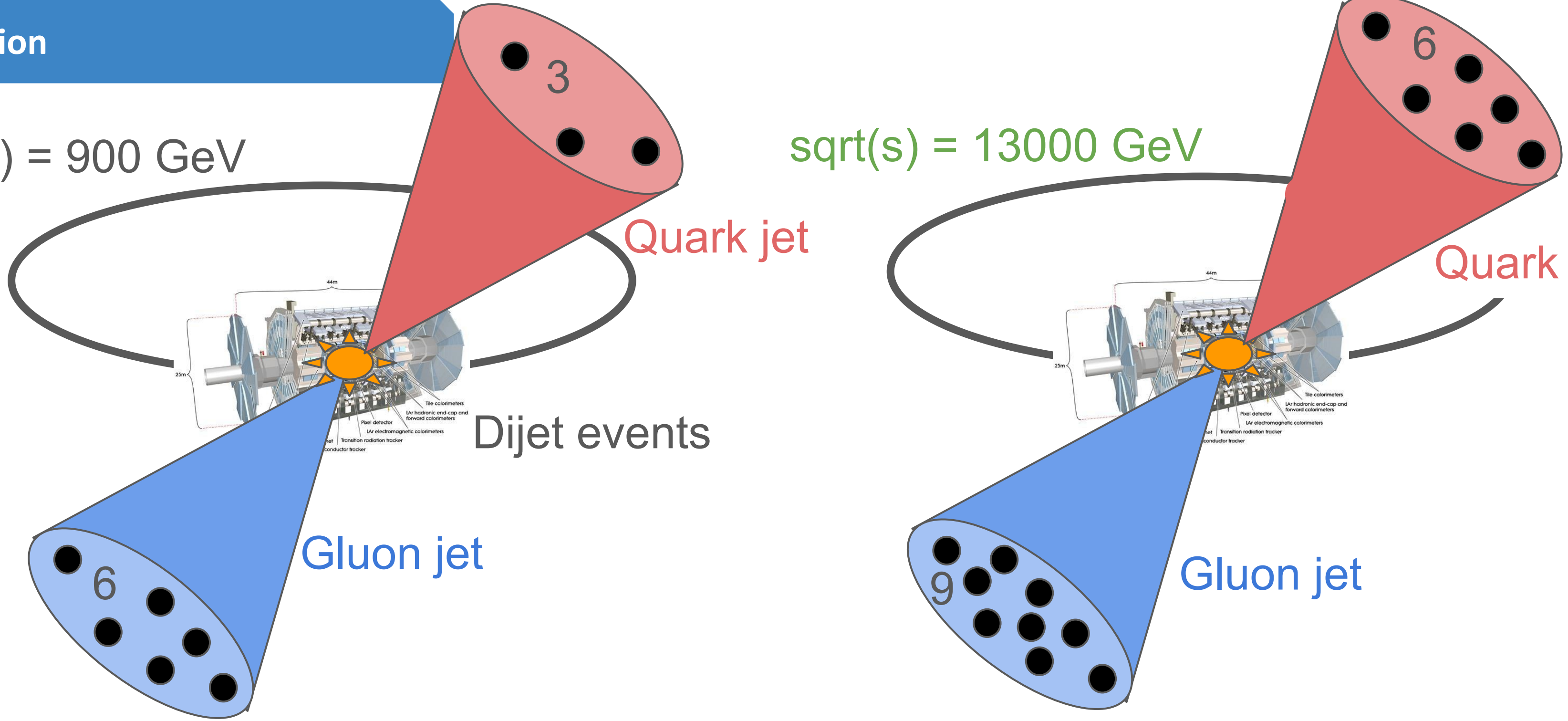
Quark jet

Gluon jet

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

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

Introduction



sqrt(s) = 900 GeV

Quark jet

Dijet events

Gluon jet

sqrt(s) = 13000 GeV

Quark jet

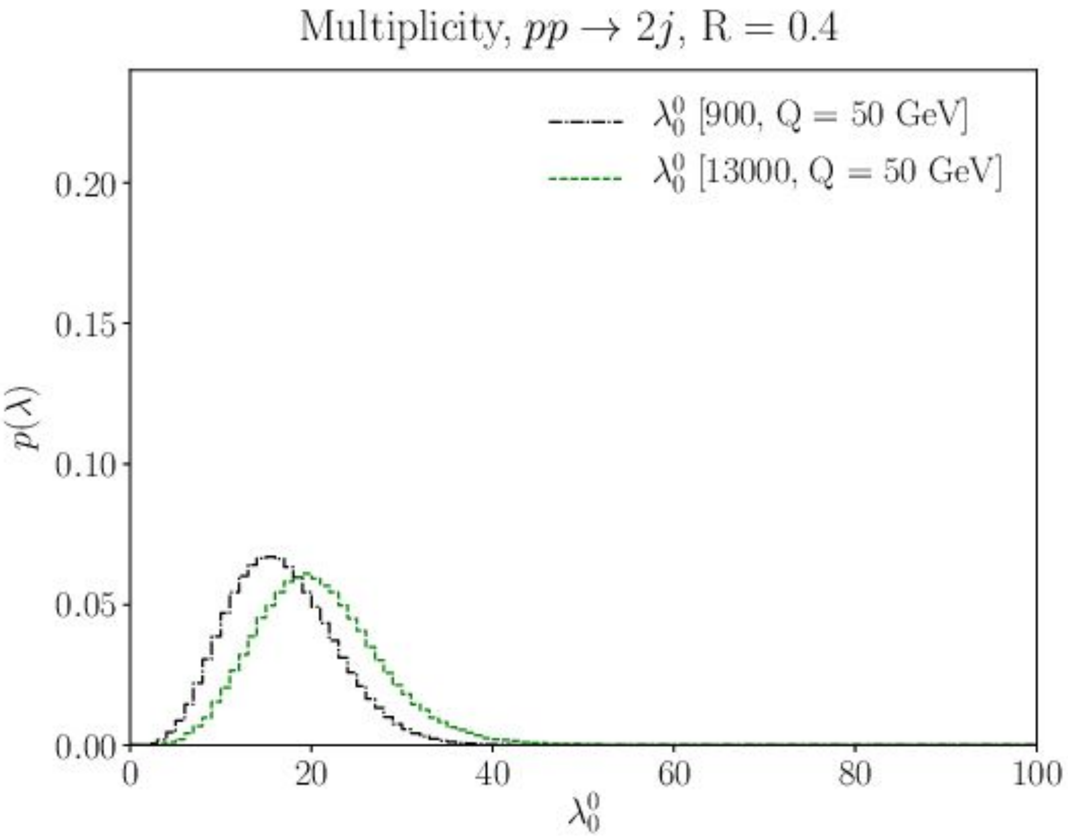
Gluon jet

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

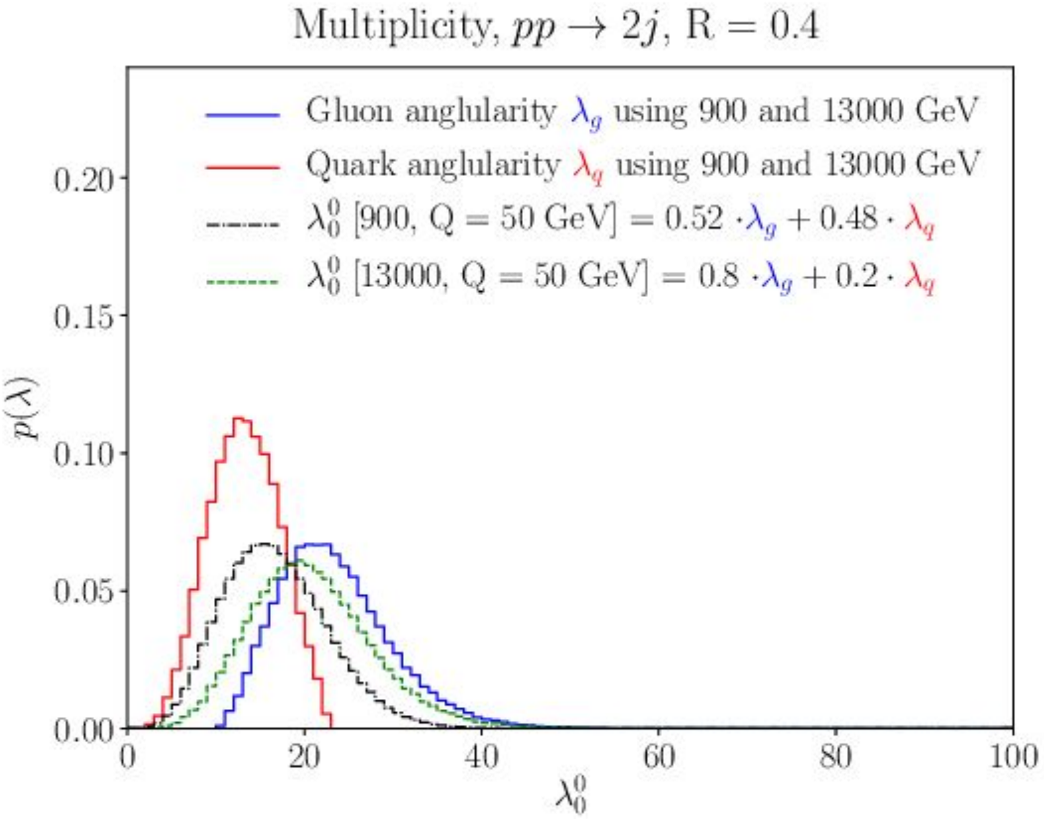
$$\lambda^{13000} = f^{13000}\lambda_g + (1 - f^{13000})\lambda_q$$

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

Introduction



Introduction



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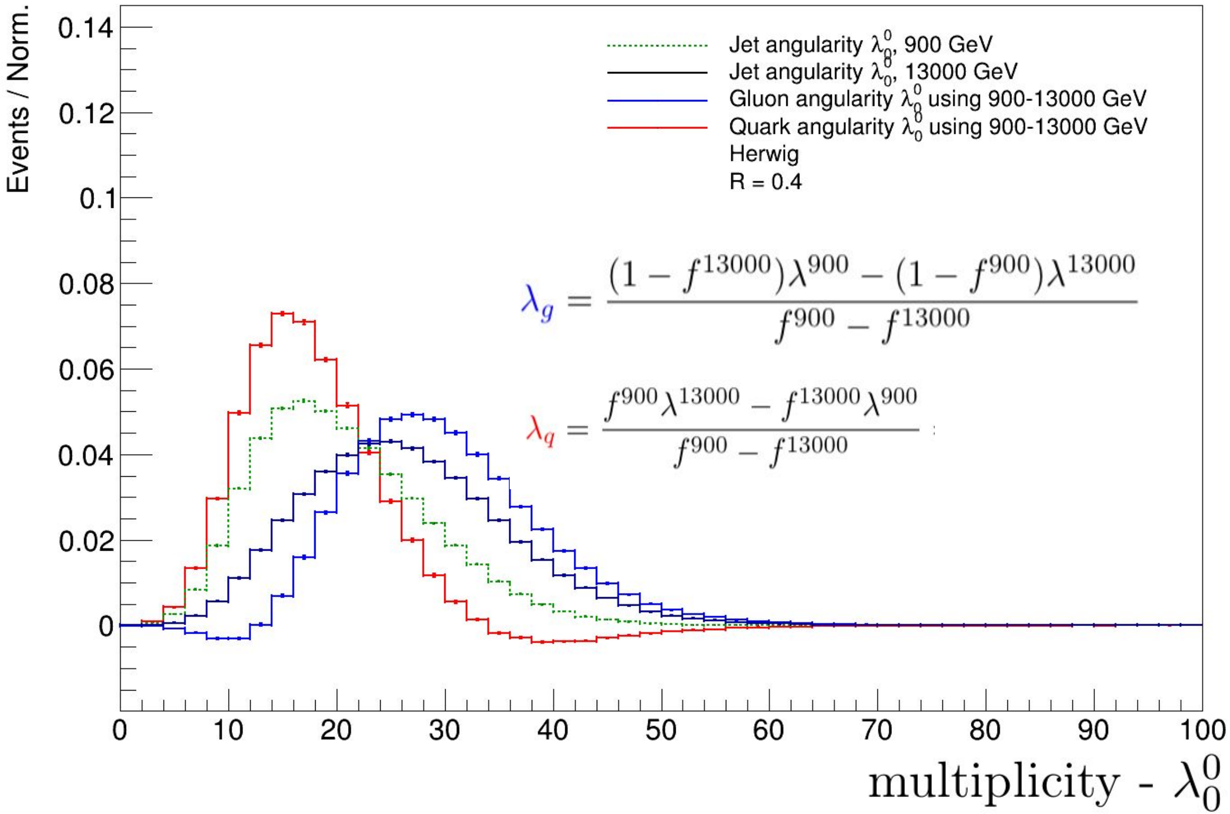
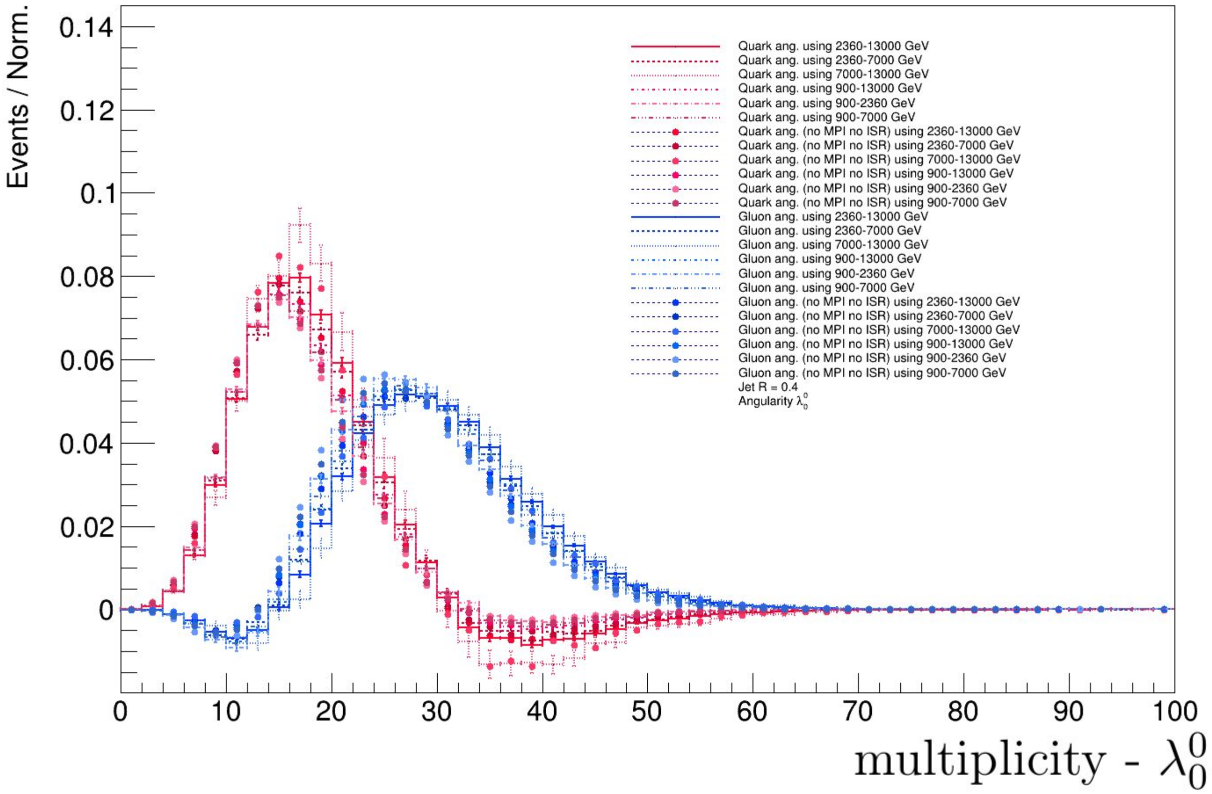


$$\lambda_g = \frac{(1-f^{13000})\lambda^{900} - (1-f^{900})\lambda^{13000}}{f^{900} - f^{13000}}$$

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

Introduction

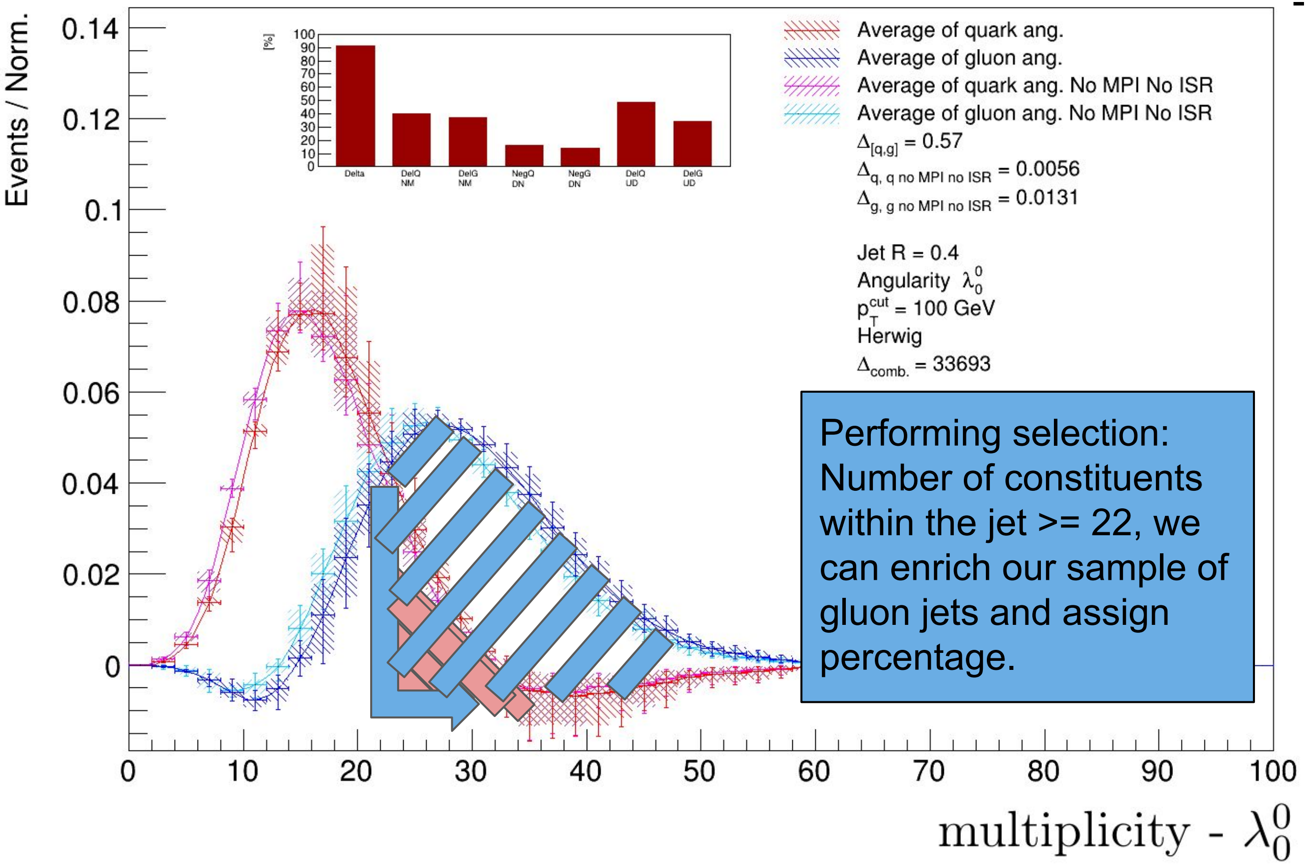
Let's use more 6 energy combinations:
900-2360, 900-7000, 900-13000, 2360-7000, 2360-13000, 7000-13000 GeV



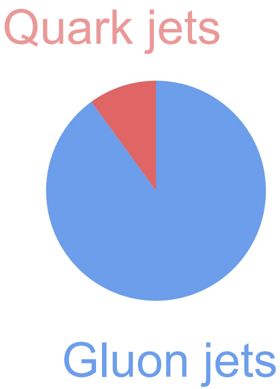
Dotted lines test the robustness to Multi Parton Interactions MPI and Initial State Radiation ISR

Motivation

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



Performing selection: Number of constituents within the jet >= 22, we can enrich our sample of gluon jets and assign percentage.



Motivation

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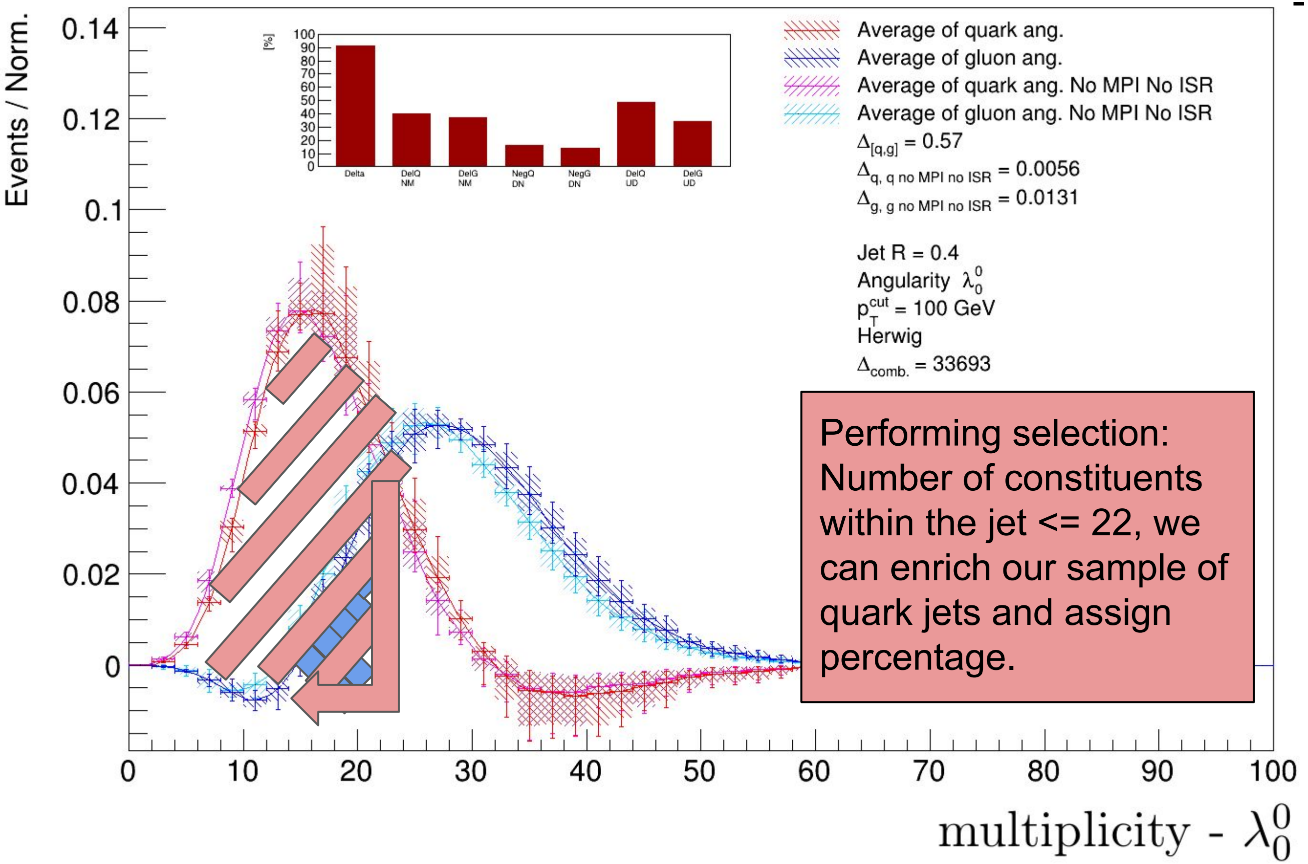
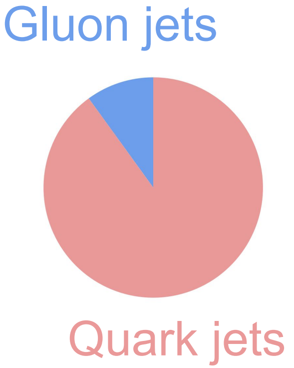


Performing selection: Number of constituents within the jet <= 22, we can enrich our sample of quark jets and assign percentage.



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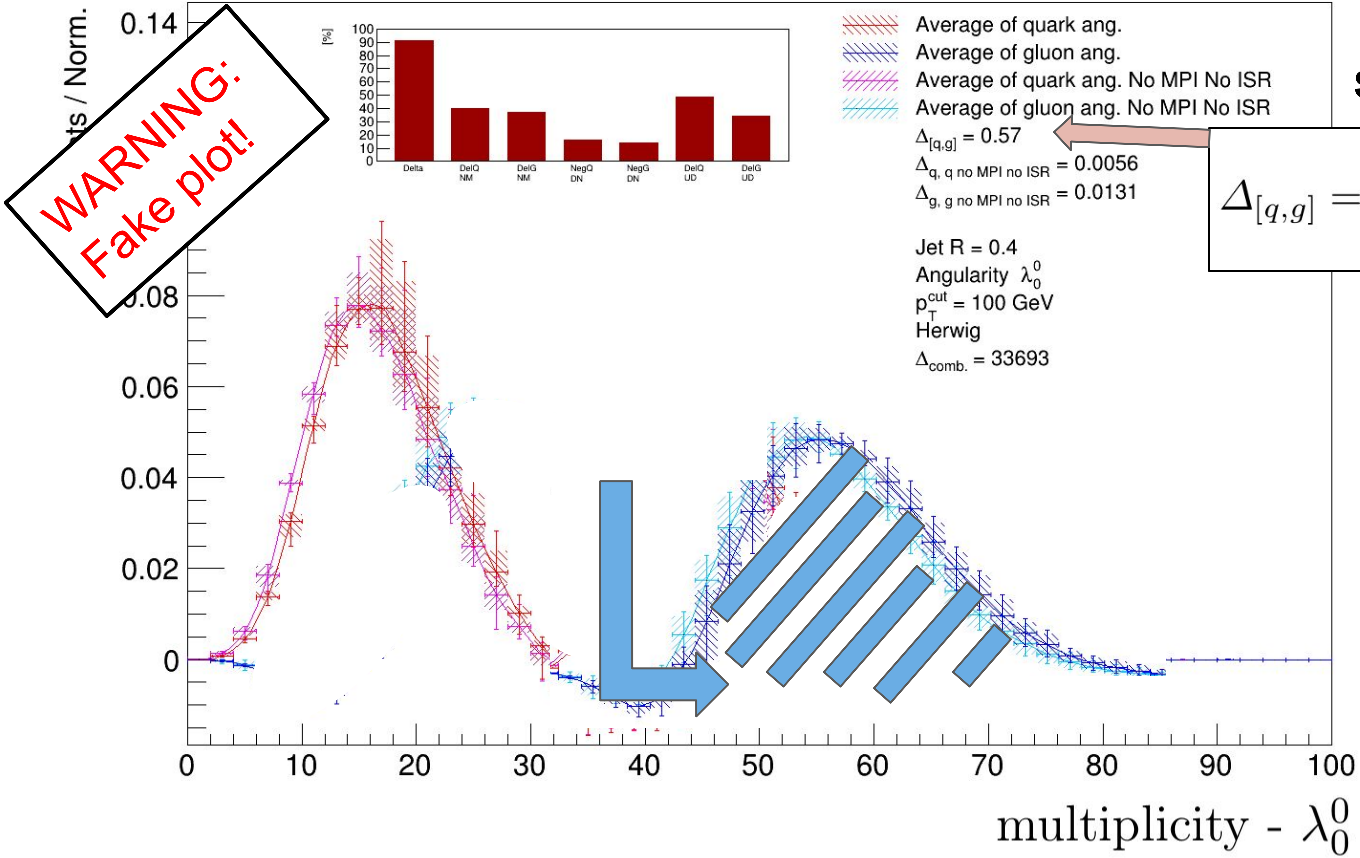


Separation power:

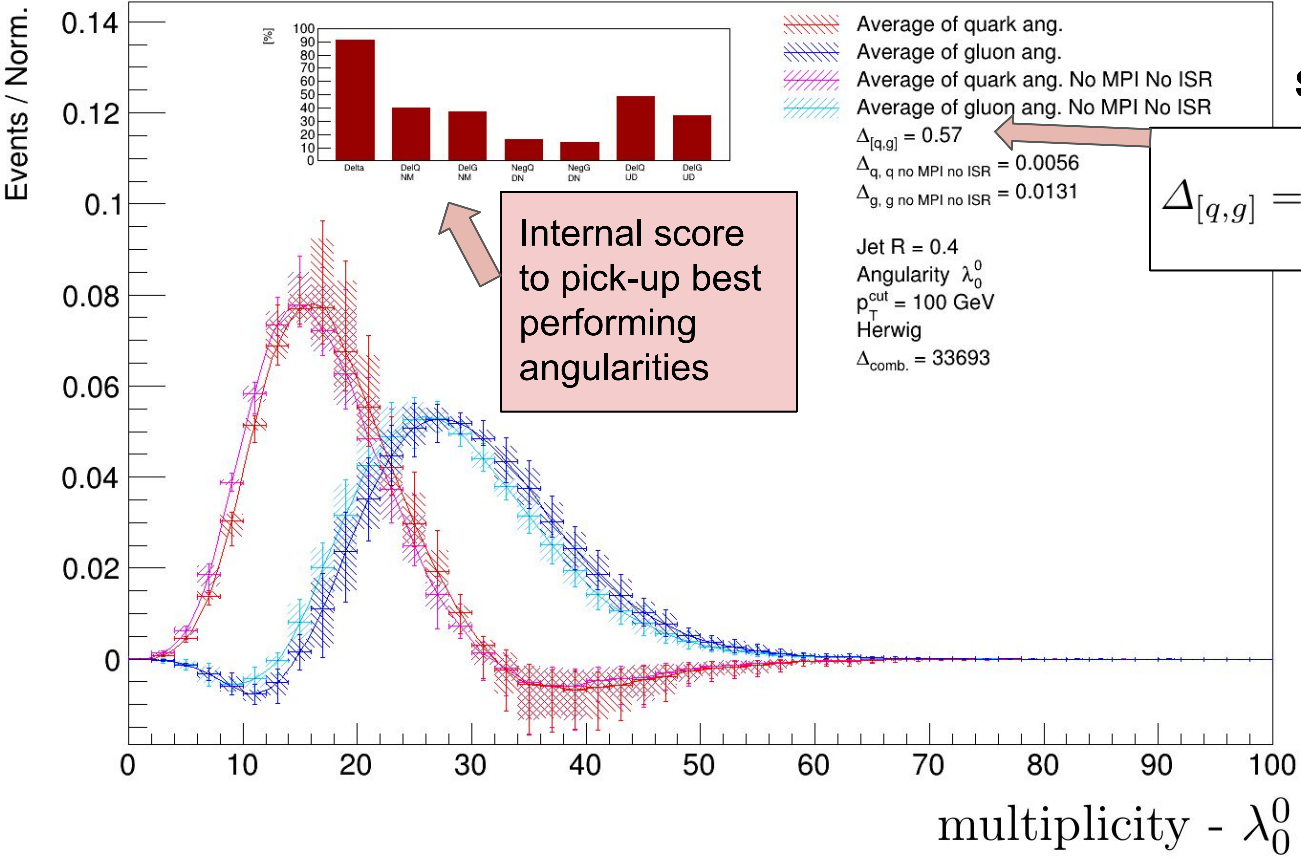
$$\Delta_{[q,g]} = \frac{1}{2}\sum_{i=1}^{N}\frac{(\lambda_{q_i} - \lambda_{g_i})^2}{\lambda_{q_i} + \lambda_{g_i}}$$

Aim is to find variable with highest separation power

Gluon jets

Motivation

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

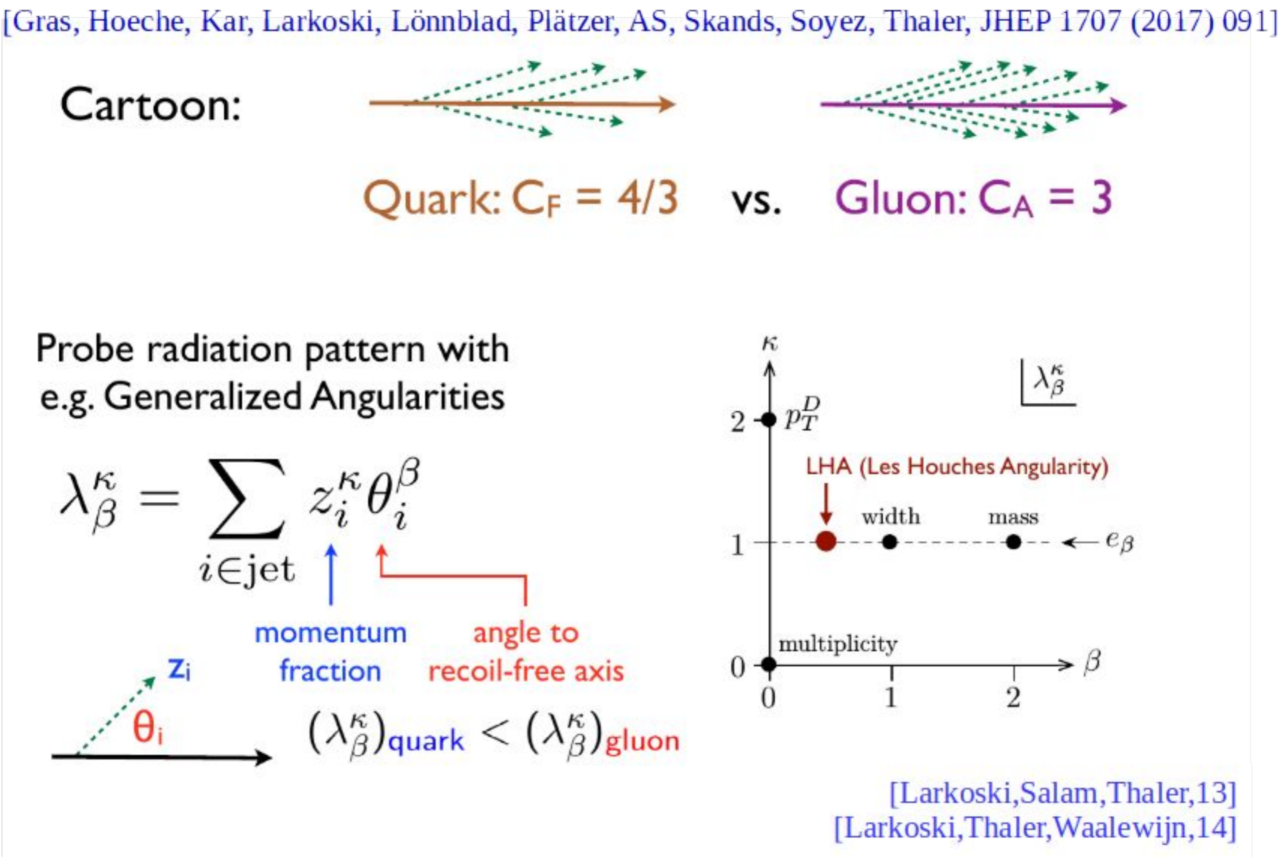


Internal score to pick-up best performing angularities

Separation power:

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

Result



[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

$$\lambda_\beta^\kappa = \sum_{i \in \text{jet}} \underset{\uparrow}{z_i^\kappa}\,\underset{\uparrow}{\theta_i^\beta}$$

momentum fraction

angle to recoil-free axis

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

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

multiplicity - λ_0^0

p_T^D - λ_0^2,

LHA - $\lambda_{0.5}^1$,

width - λ_1^1, and

mass - λ_2^1.

Results:

Selection of dijet events:

$N^{jets} = 2$
veto neutrinos

$p_{T\ \mathrm{sublead}}/p_{T\ \mathrm{lead}} > 0.8$

We considered all combinations of:

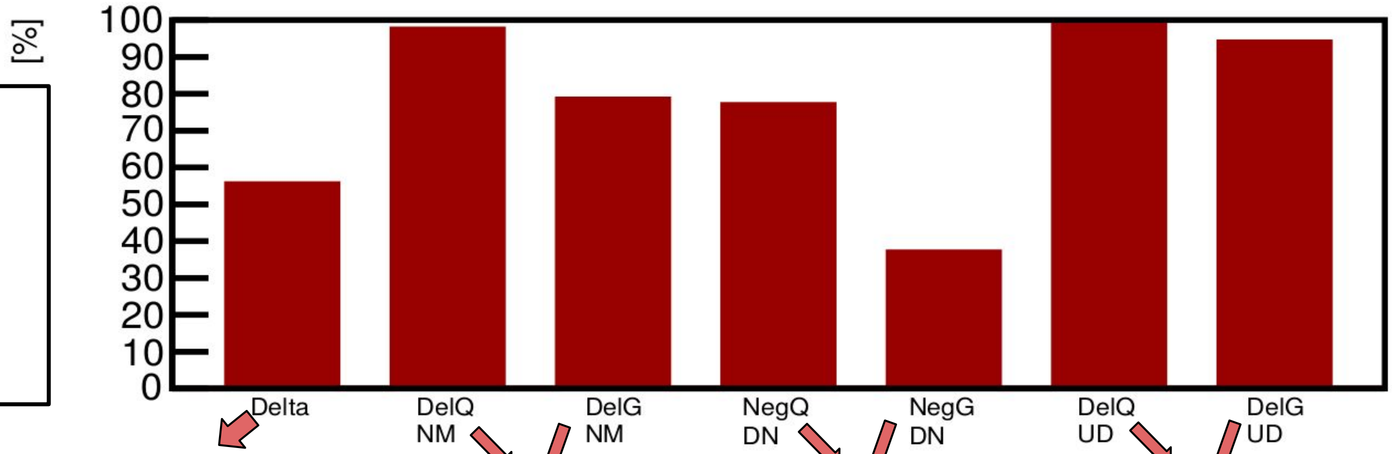
- 5 – angularities λ_0^0, $\lambda_{0.5}^1$, λ_1^1, λ_0^2, λ_2^1
- 2 – using groomed (MMDT) / not groomed jets
- 5 – jet radii $R = 0.2, 0.4, 0.6, 0.8, 1.0$
- 4 – regions - dijet average $p_T^{\mathrm{cut}} = 50$ GeV, 100, 200, and 400 GeV

$(p_{T\ \mathrm{lead}} + p_{T\ \mathrm{sublead}})/2 > p_T^{\mathrm{cut}}$

- 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**

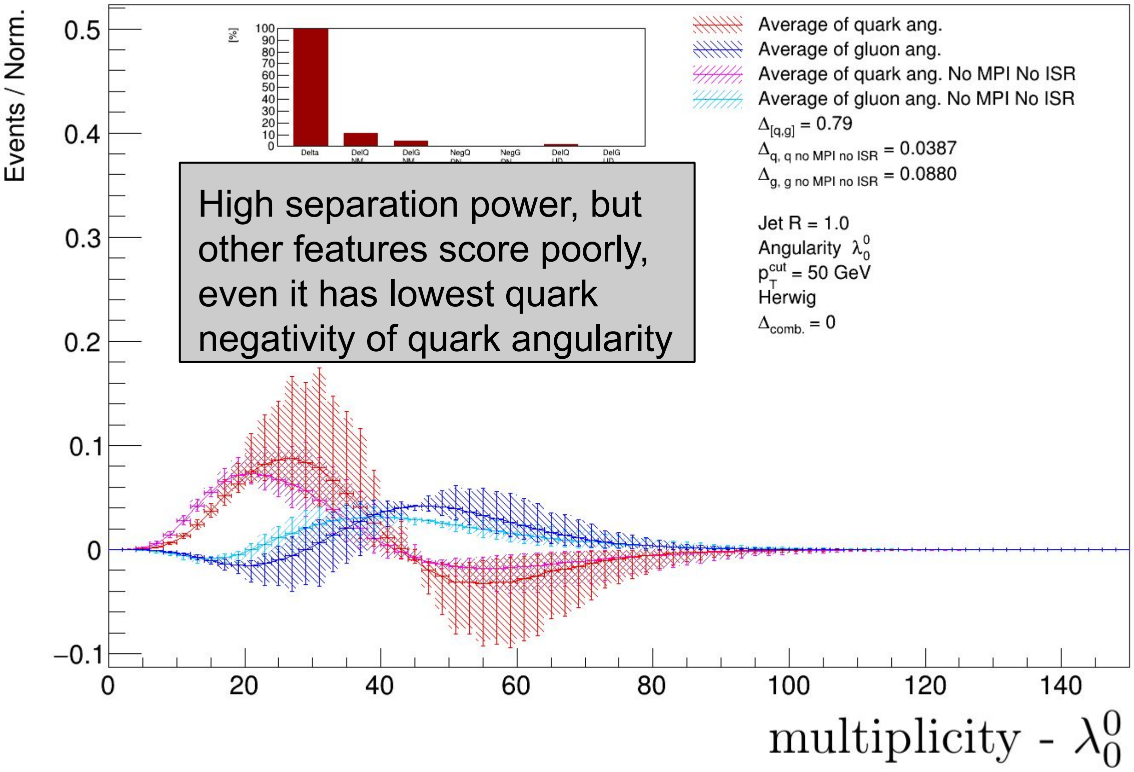
Combining all columns gives us our internal score :

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

min-max 0-41447

Results:

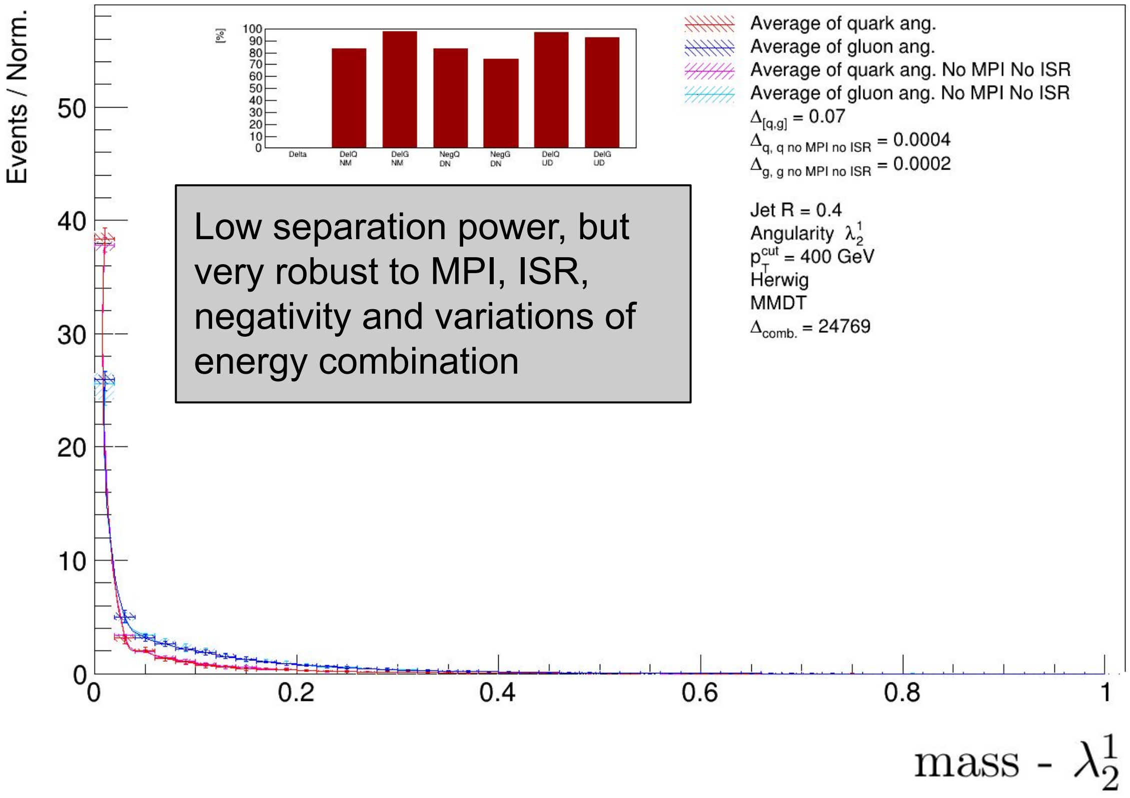
Why we looking into other features then separation power (bad examples):



High separation power, but other features score poorly, even it has lowest quark negativity of quark angularity

Results:

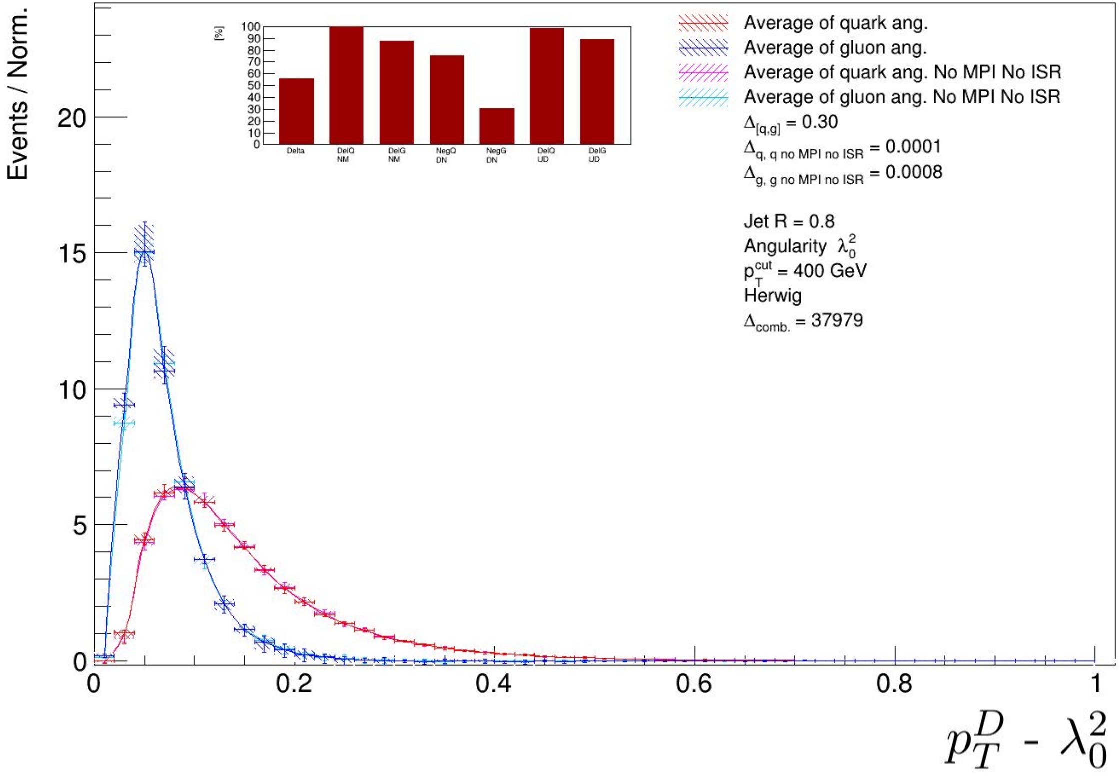
Why we looking into other features then separation power (bad examples):



Low separation power, but very robust to MPI, ISR, negativity and variations of energy combination

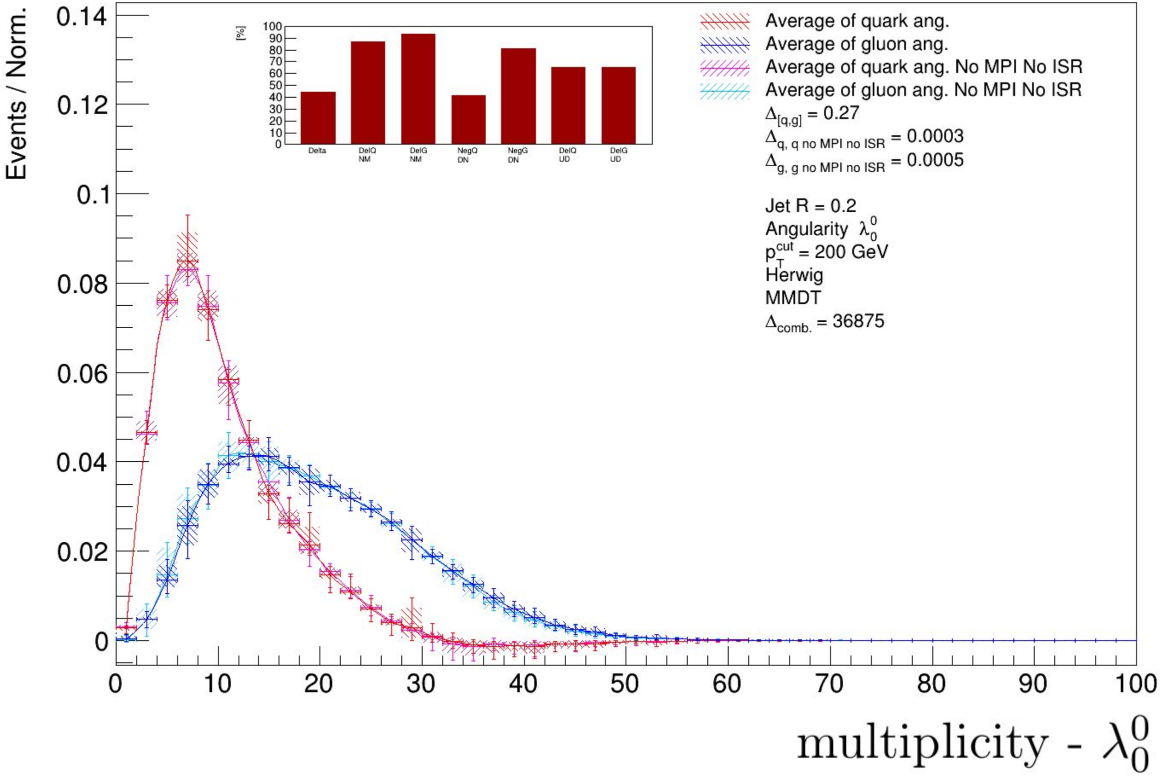
Results:

Best performing angularities: p_T^D



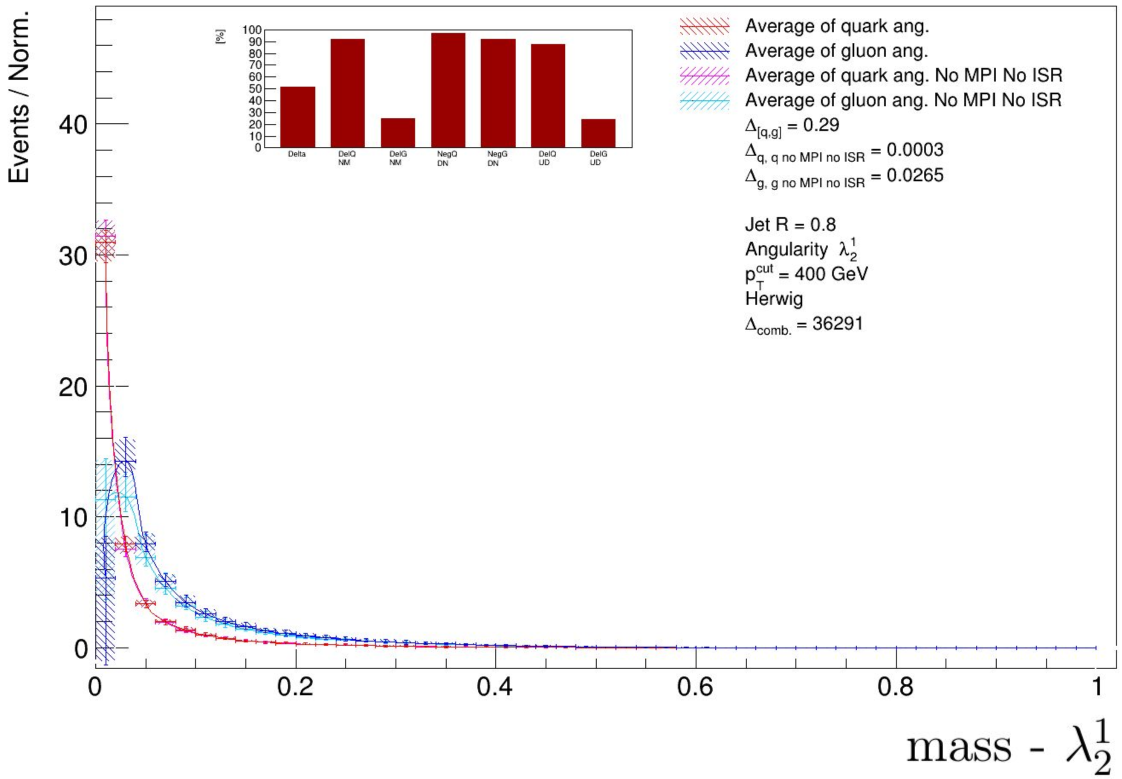
Results:

Best performing angularities: Multiplicity



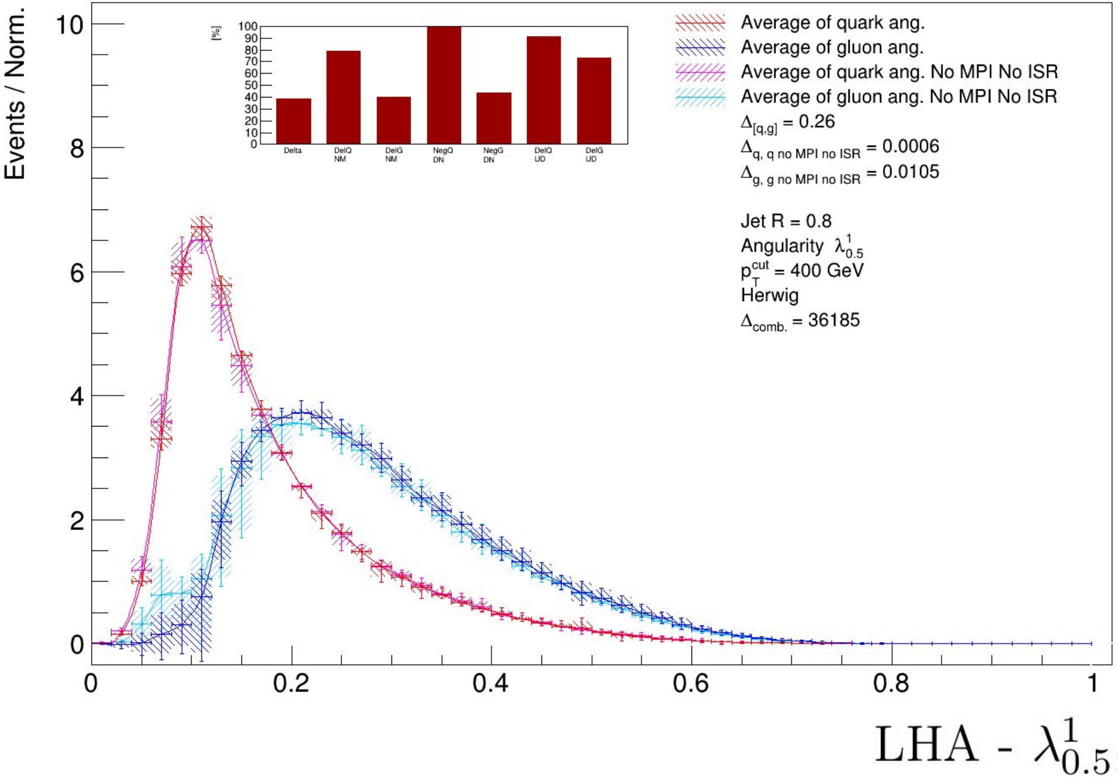
Results:

Best performing angularities: Mass



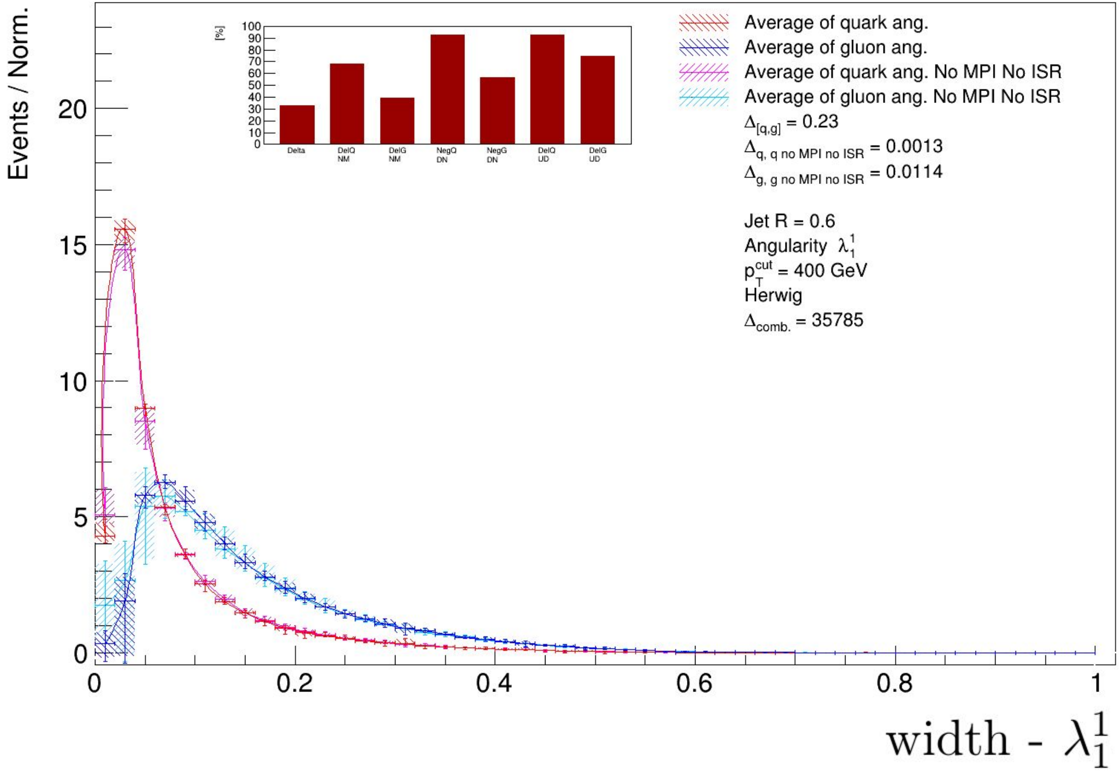
Results:

Best performing angularities: LHA



Results:

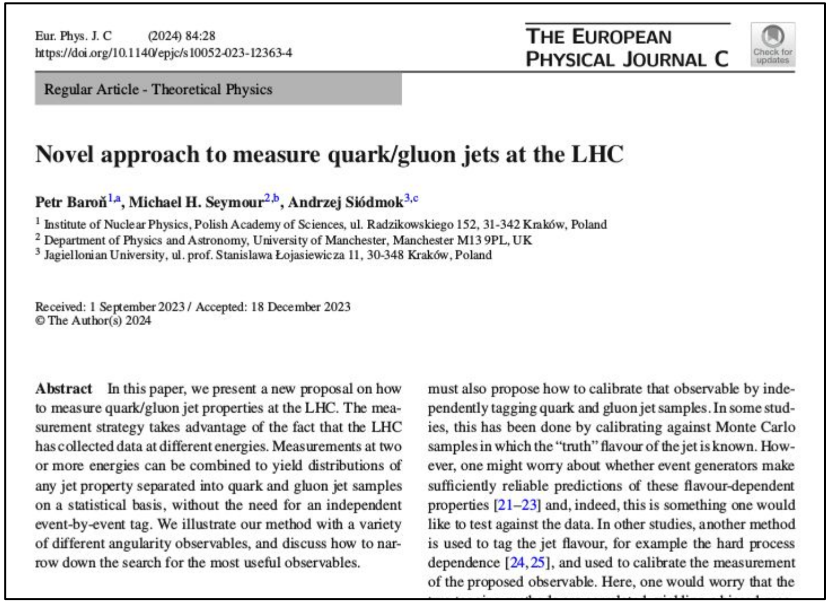
Best performing angularities: Width



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://doi.org/10.1140/epjc/s10052-023-12363-4



Eur. Phys. J. C (2024) 84:28
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THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Novel approach to measure quark/gluon jets at the LHC

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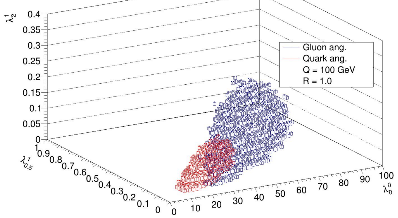
[1] Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, 31-342 Kraków, Poland
[2] Department of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK
[3] Jagiellonian University, ul. prof. Stanislawa Łojasiewicza 11, 30-348 Kraków, Poland

Received: 1 September 2023 / Accepted: 18 December 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.

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 [21–23] 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 [24,25], and used to calibrate the measurement of the proposed observable. Here, one would worry that the

- Plans:
  - Multidim angularities (2D, 3D) with machine learning approach to enhance separation power
  - Perform measurement at LHC



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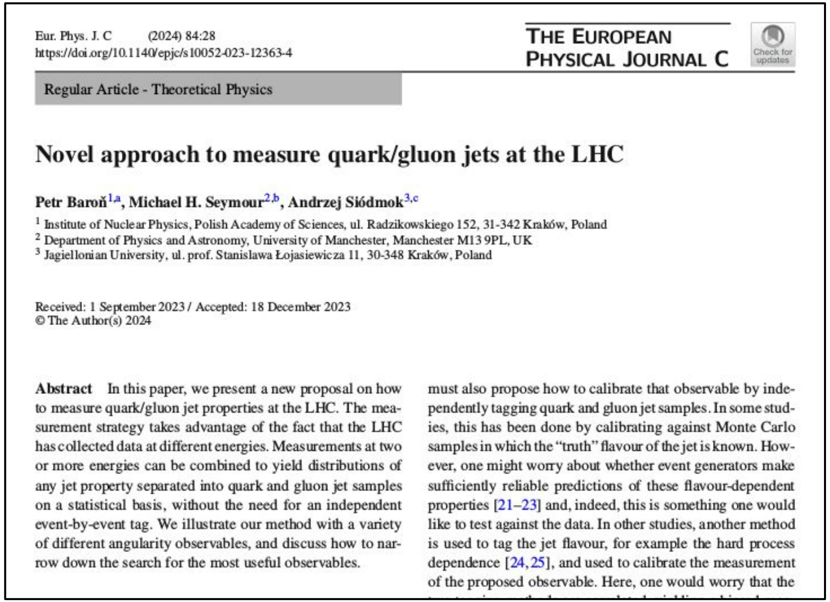

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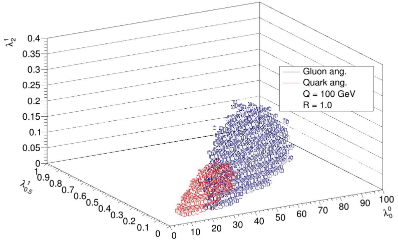
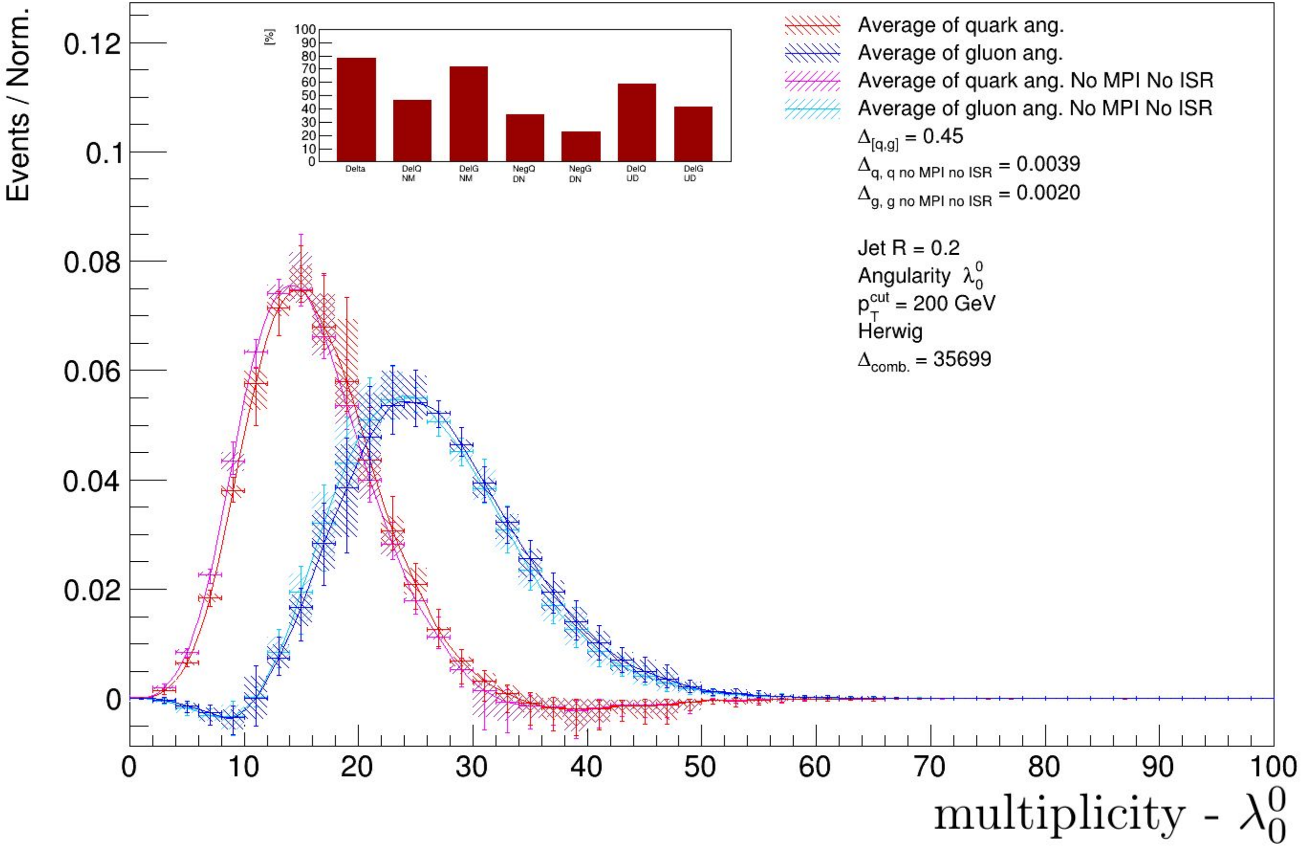


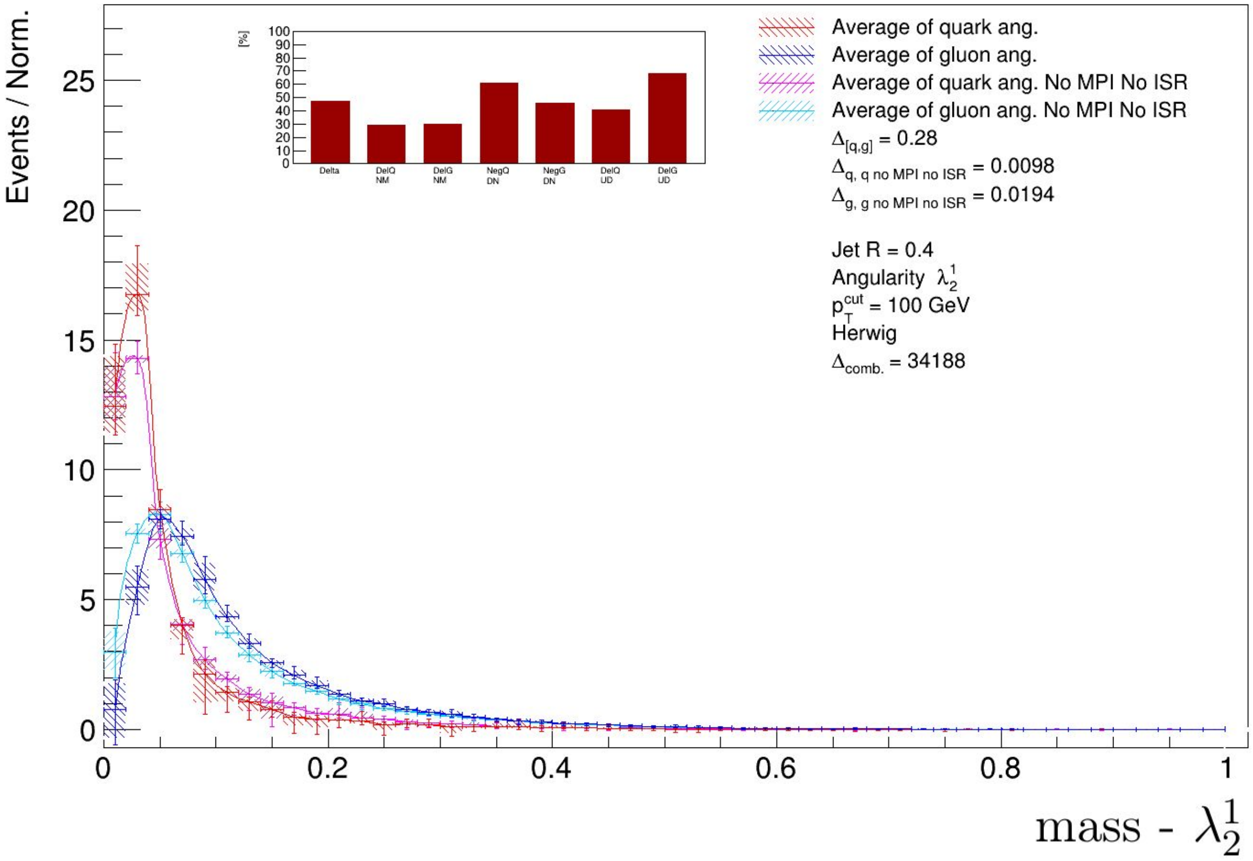
Thank you!

Wild cards (chosen by “eye”): multiplicity

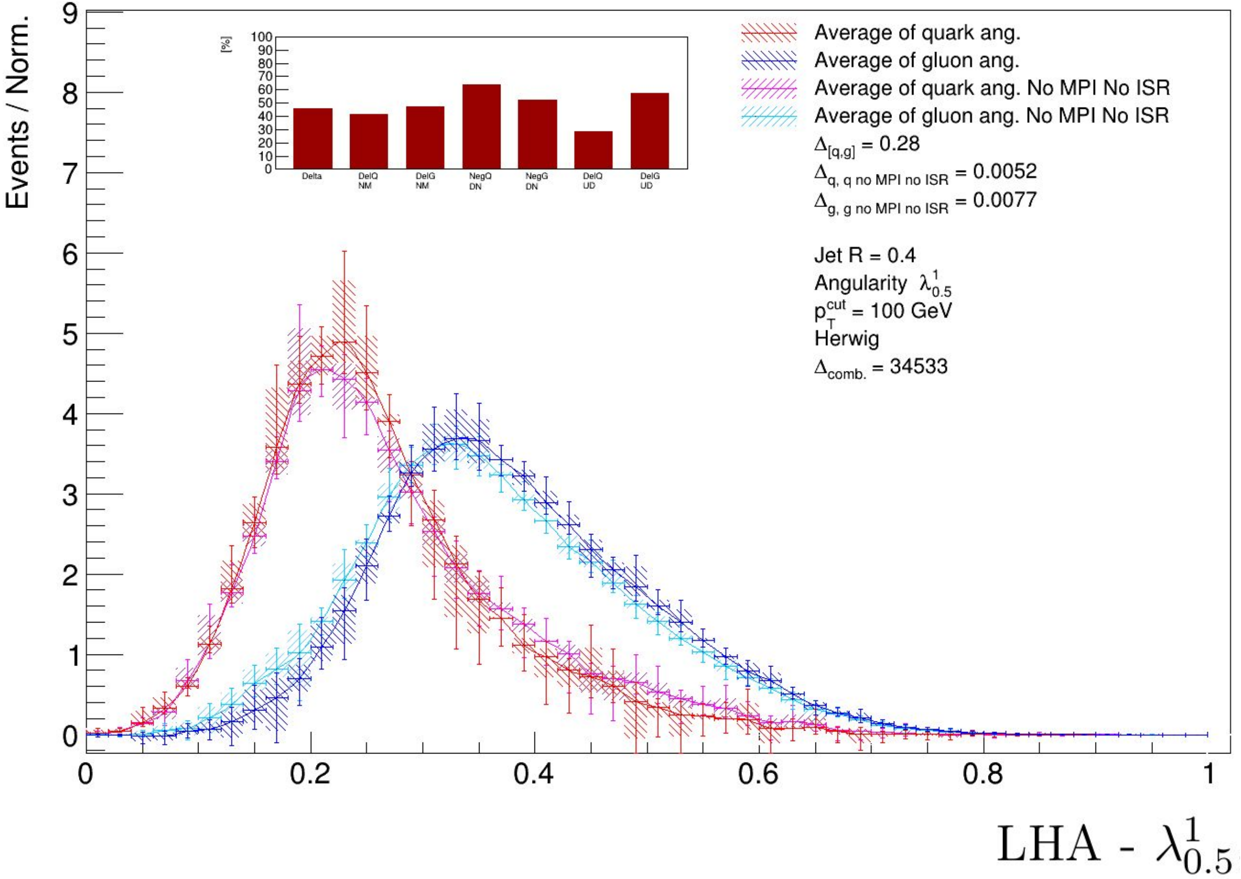


Back-up

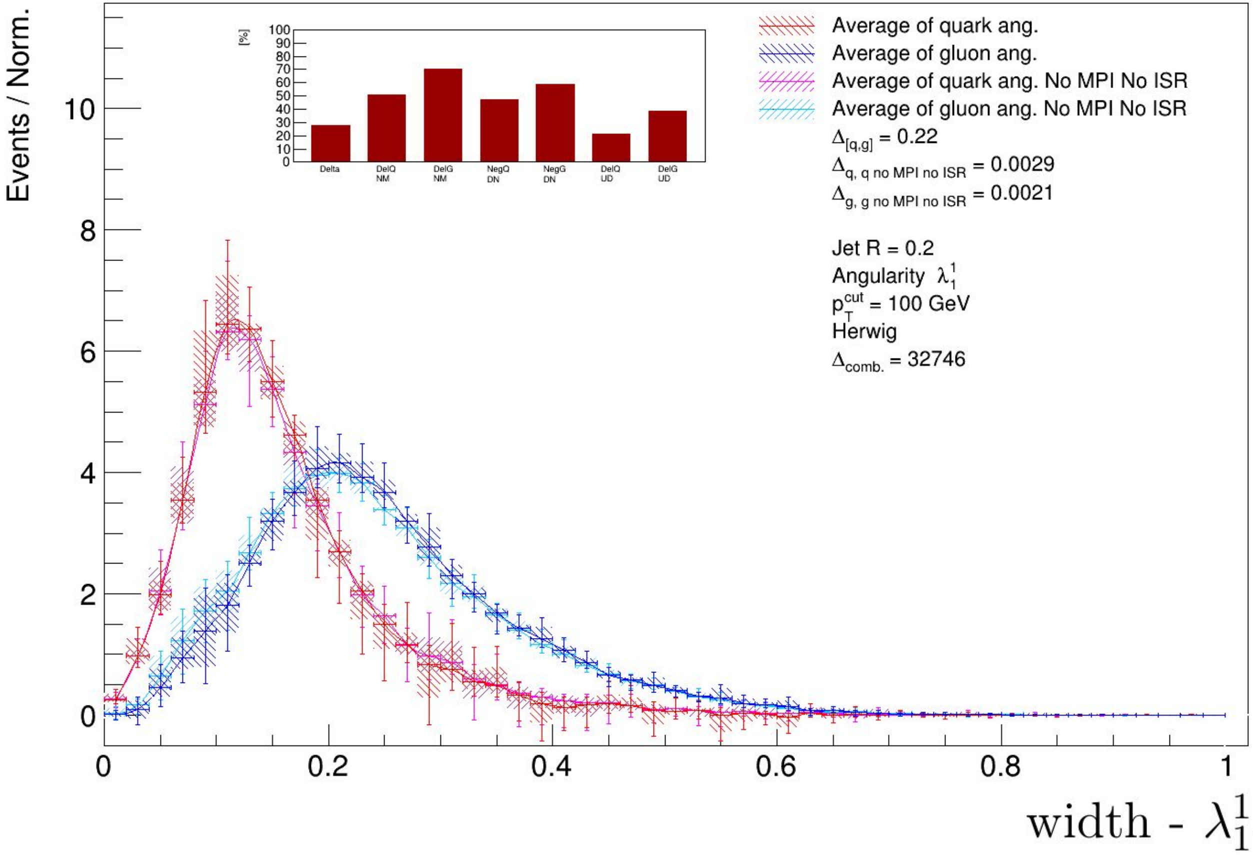
Wild cards (chosen by “eye”): mass



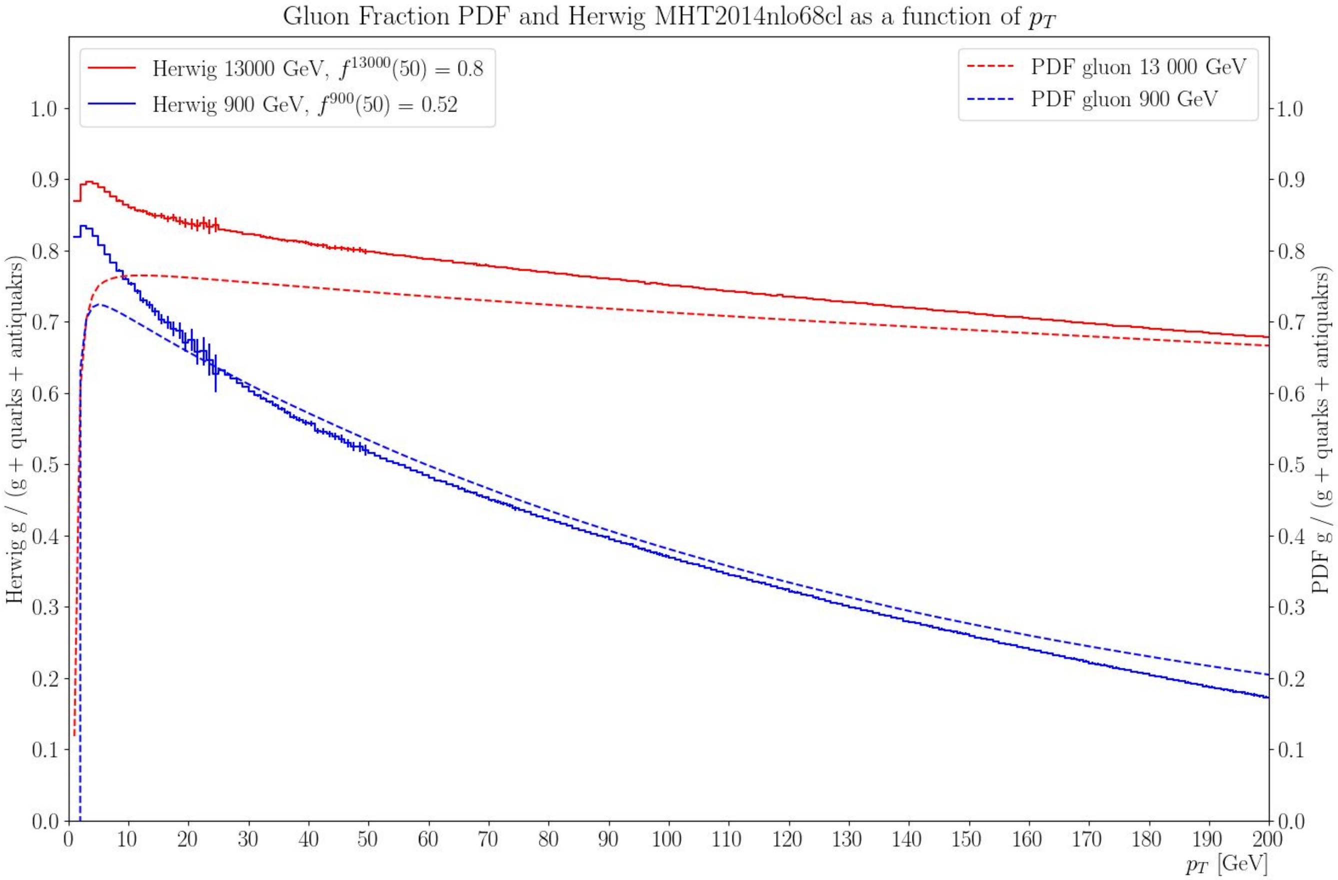
Wild cards (chosen by “eye”): LHA



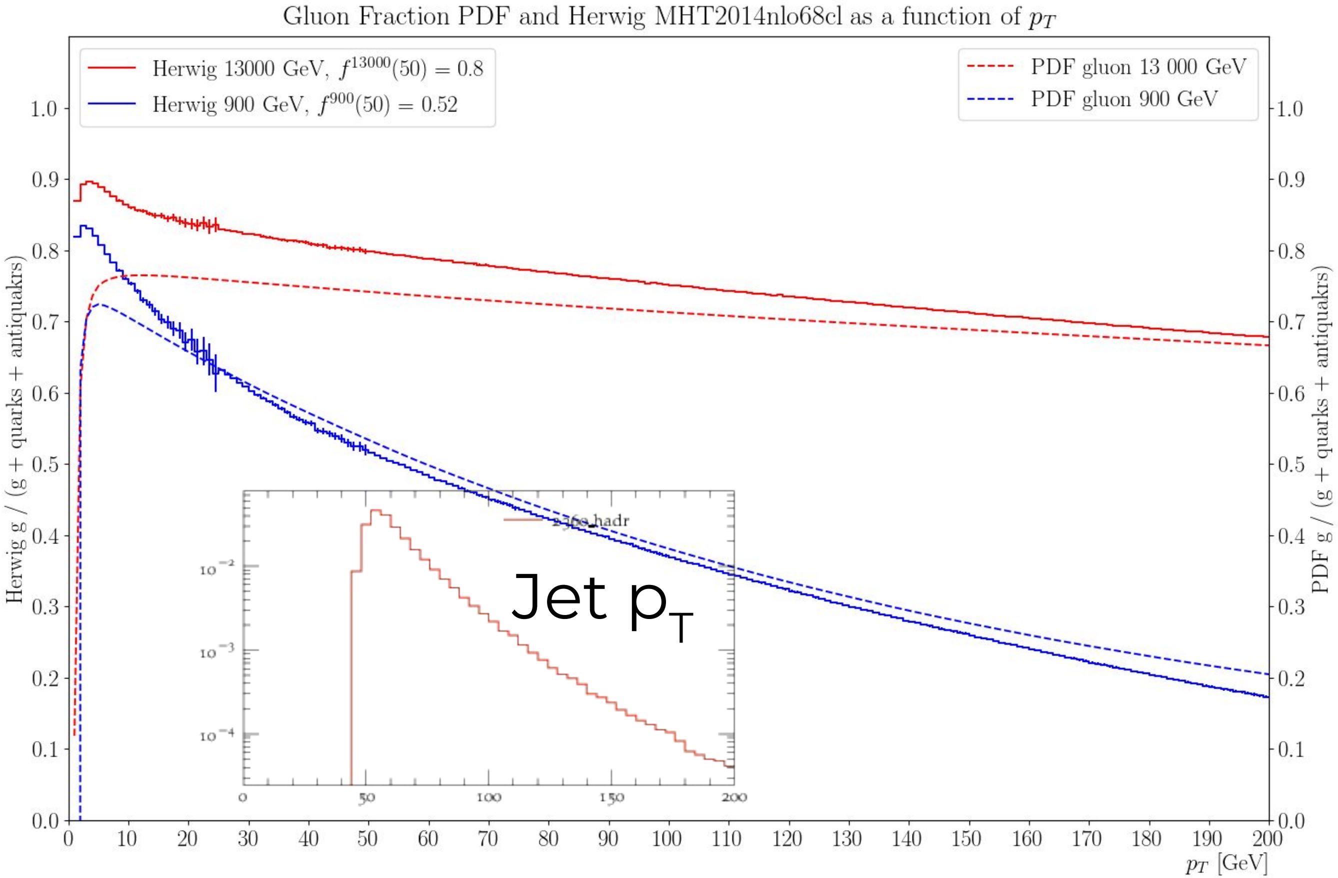
Wild cards (chosen by “eye”): width



Back-up

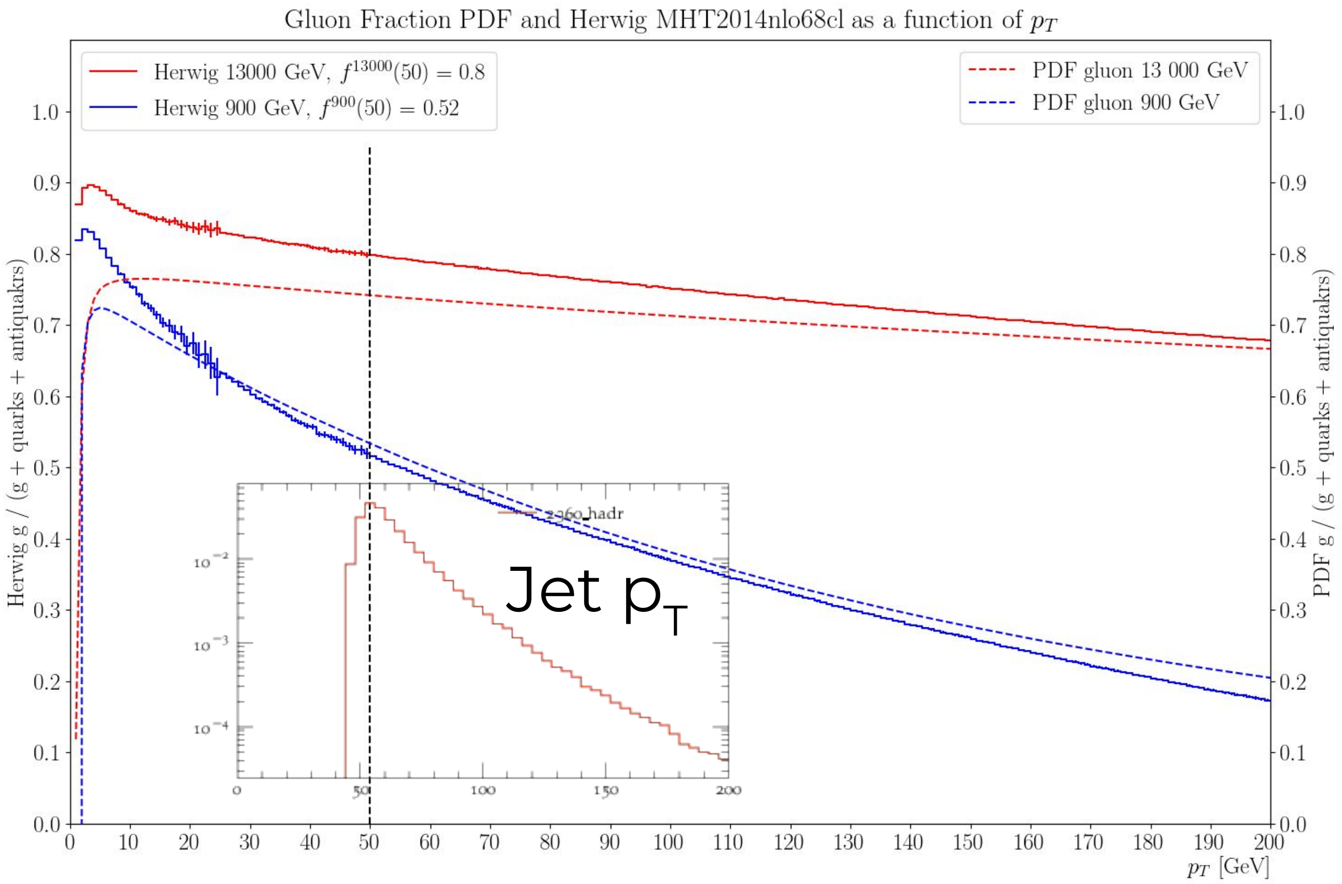

Gluon Fraction PDF and Herwig MHT2014nlo68cl as a function of p_T
Herwig 13000 GeV, $f^{13000}(50) = 0.8$
Herwig 900 GeV, $f^{900}(50) = 0.52$
PDF gluon 13 000 GeV
PDF gluon 900 GeV
Herwig g / (g + quarks + antiquakrs)
PDF g / (g + quarks + antiquakrs)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
p_T [GeV]

Back-up



Jet p_T

Back-up



Jet p_T

Back-up

Matching to the truth parton level by minimal dR

- Black lines

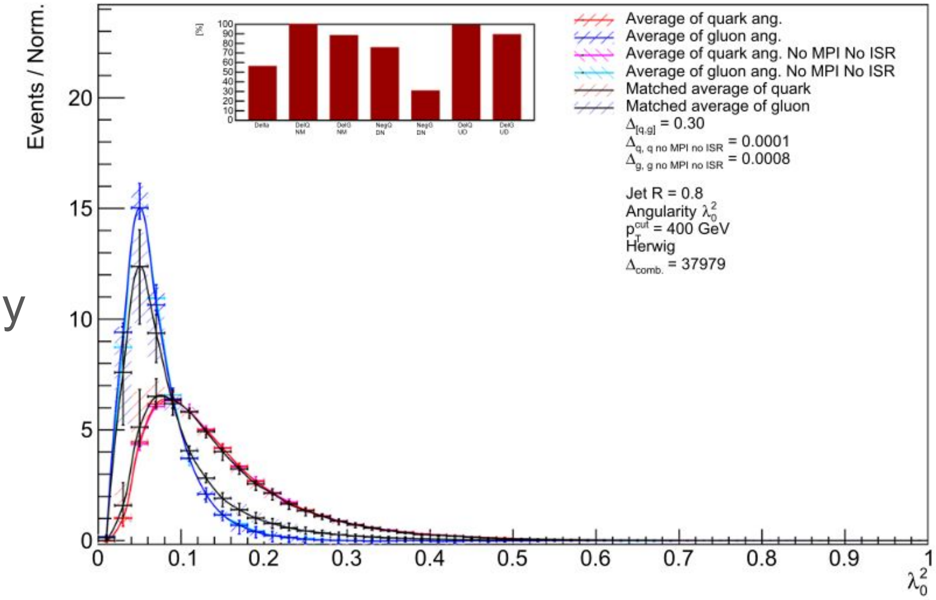


Fig. 19 Quark and gluon averaged angularities λ_0^2, $R = 0.8$ with highest score $\Delta_{\text{comb}} = 37979$. Using HERWIG event generator, with $p_T^{\text{cut}} = 400$ GeV, using the average of 6 energy combinations 900–2360, 900–7000, 900–13000, 2360–7000, 2360–13000, 7000–13000 GeV

Back-up

Matching to the truth parton level by minimal dR

- Black lines

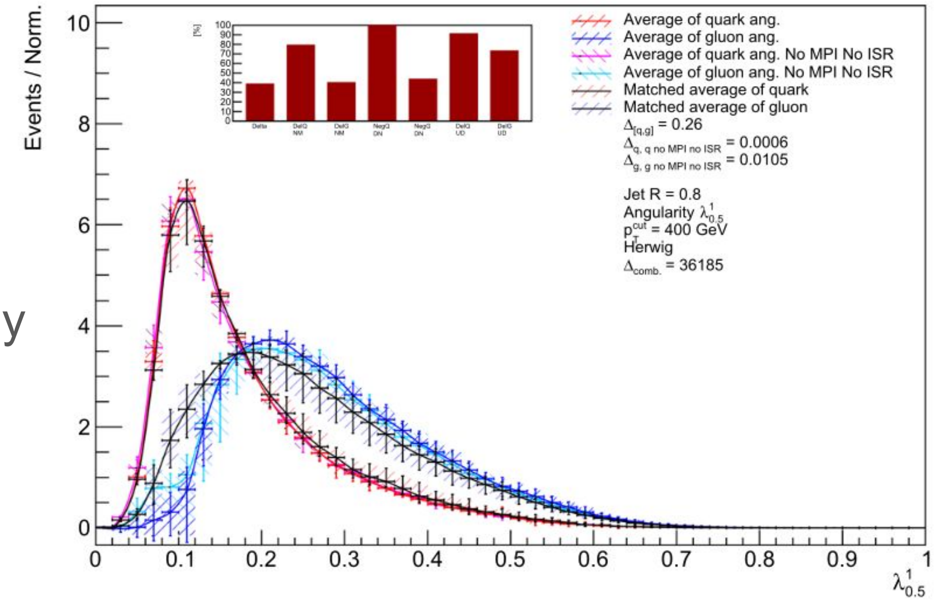
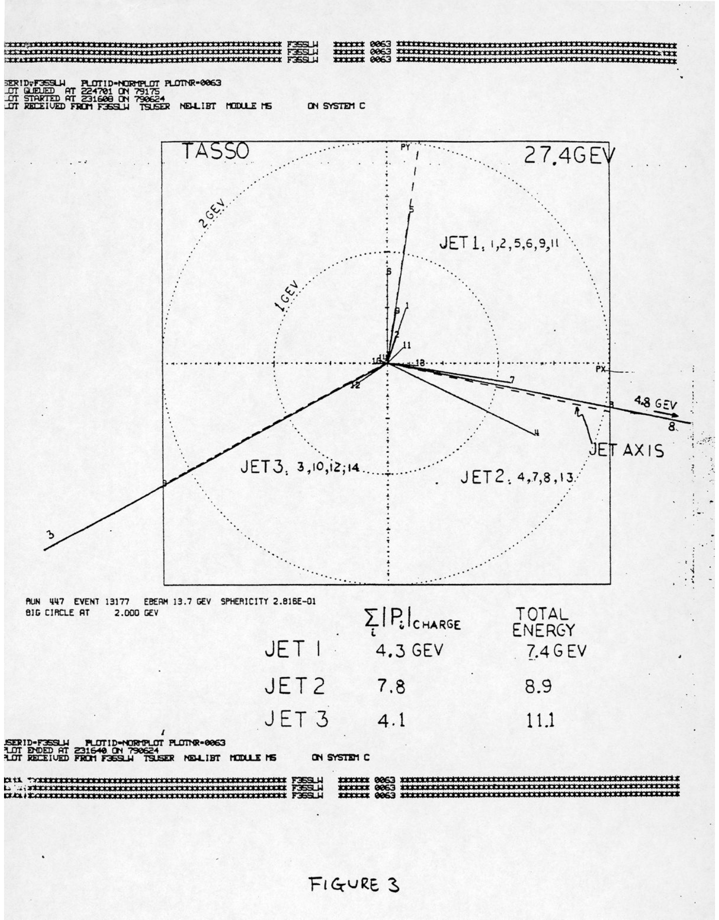


Fig. 22 Quark and gluon averaged angularities MMDT $\lambda^1_{0.5}$, $R = 0.8$ with score $\Delta_{\text{comb}} = 36185$. Using HERWIG event generator, with $p_T^{\text{cut}} = 400$ GeV, using the average of 6 energy combinations 900–2360, 900–7000, 900–13000, 2360–7000, 2360–13000, 7000–13000 GeV

Back-up



```
SERID=F35SLW   PLOTID=NORMPLOT PLOTNR=0063
LOT QUEUED  AT 224701 ON 79175
LOT STARTED AT 231608 ON 790624
LOT RECEIVED FROM F35SLW  TSUSER  NEWLIBT  MODULE M5       ON SYSTEM C
```

```
RUN  447  EVENT 13177   EBEAM 13.7 GEV  SPHERICITY 2.816E-01
BIG CIRCLE AT      2.000 GEV
```

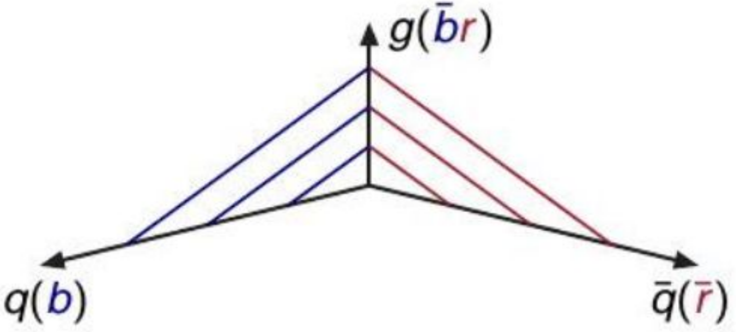
	$\sum_i \lvert P_i \rvert_{CHARGE}$	TOTAL ENERGY
JET 1	4.3 GEV	7.4 GEV
JET 2	7.8	8.9
JET 3	4.1	11.1

```
USERID=F35SLW   PLOTID=NORMPLOT PLOTNR=0063
PLOT ENDED AT 231640 ON 790624
PLOT RECEIVED FROM F35SLW  TSUSER  NEWLIBT  MODULE M5       ON SYSTEM C
```

FIGURE 3

This collision event recorded in **1979**, provided the first evidence of the gluon.

Recorded as event 13177 of run 447 of the TASSO experiment at the Deutsches Elektronen-Synchrotron (DESY), the graphic shows three jets of particles produced in an electron-positron collision.



Back-up

Quark - Gluon Separation in Three Jet Events

Hans Peter Nilles (SLAC), K.H. Streng (SLAC) (Aug 1, 1980)

Published in: *Phys.Rev.D* 23 (1981) 1944

A Monte Carlo Program for Quark and Gluon Jet Generation

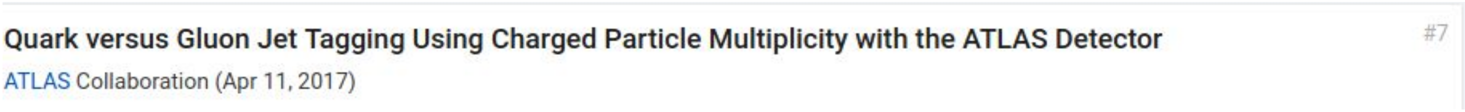
Torbjorn Sjostrand (Lund U., Dept. Theor. Phys.) (Apr 1, 1980)

Quark and gluon jet separation: Conventional and neural network methods

Z. Fodor (Eotvos U.) (Jul, 1991)

Published in: *Conf.Proc.C* 910725V1 (1991) 438 • Contribution to: Joint International Lepton Photon Symposium at High Energies (15th) and European Physical Society Conference on High-energy Physics, 438

⋮



Quark versus Gluon Jet Tagging Using Charged Particle Multiplicity with the ATLAS Detector

ATLAS Collaboration (Apr 11, 2017)

Back-up

BSM searches: often signature for a BSM signals: many quark, backgrounds: QCD gluons

- 8-jet Gluino event: $pp \to \tilde{g}\tilde{g}$ and each $\tilde{g}$ decays to 4 quarks:

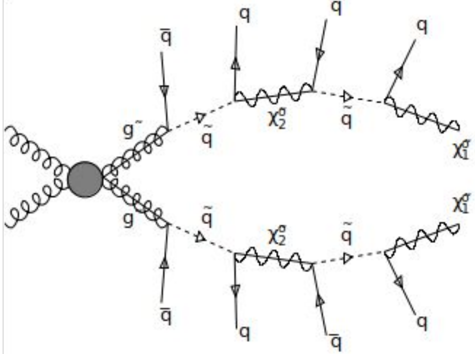


Fig. From J. Gallicchio and M. D. Schwartz, Phys. Rev. Lett.107 (2011)

- Higgs $H^+ \to c\bar{s}$ (for charged Higgs mass between τ and t mass)
- Measure Z' coupling to hadrons (or find a leptophobic Z'/W')

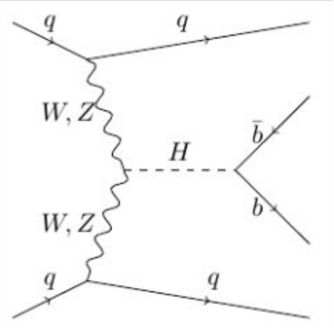
Back-up

Interesting standard model physics also tends to be quark-heavy

Examples:

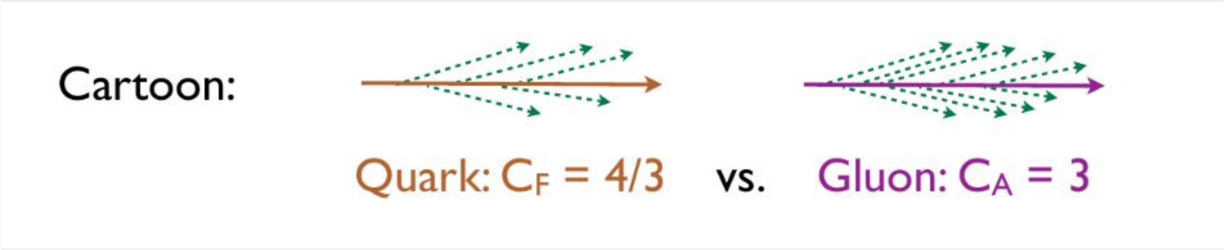
- W's decaying hadronically (no b's!): $W^+ \to u\bar{d}$ or $c\bar{s}$
- Tops ($t\bar{t} \to b\bar{b}$ + 0, 2, or 4 light quarks)
- Vector Boson Scattering/Fusion (forward 'tag' jets are quarks)

QCD background: mainly composed by gluons
Signal: mainly composed by quarks



Back-up

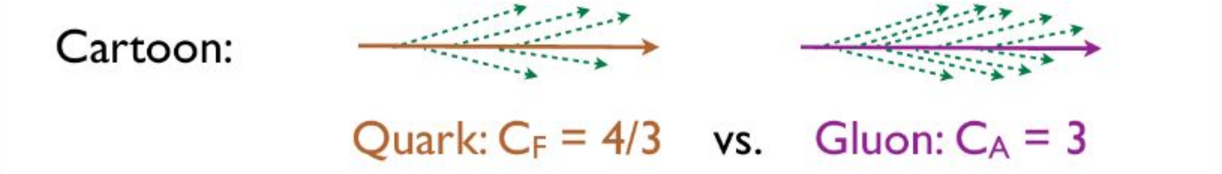
Gluon has a greater effective color charge (squared) than quark:



Expectation:

- Gluon will radiate more
- Gluon will radiate wider
- Multiple radiation → effect will exponentiate

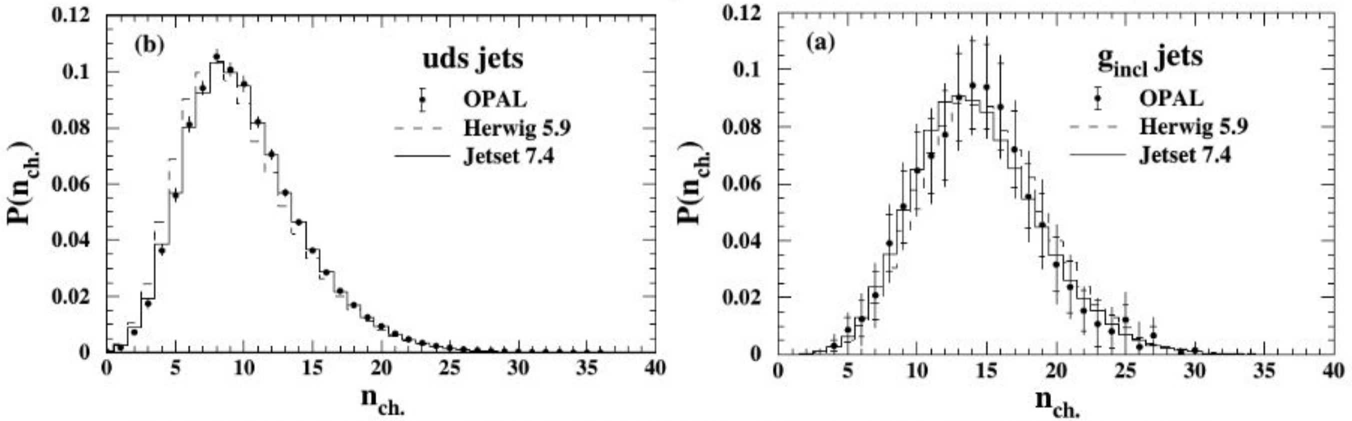
Back-up



Cartoon:

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

Gluon will radiate more, gluon will radiate wider $\frac{\langle N_g \rangle}{\langle N_q \rangle} = \frac{C_A}{C_F}$ = 3/(4/3)=9/4 = 2.25

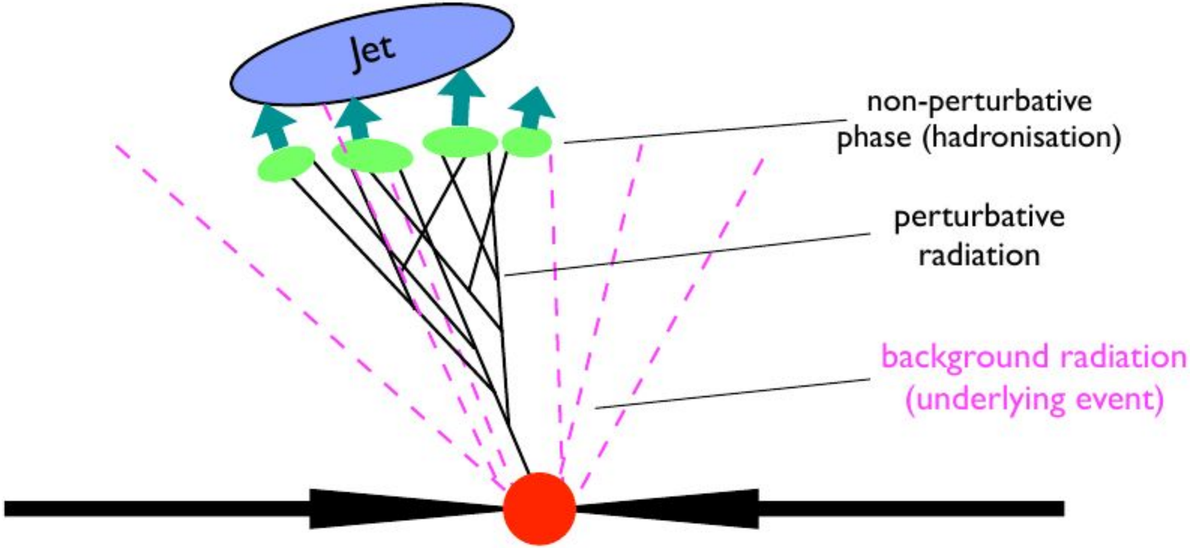


"Multiplicity distributions of gluon and quark jets and tests of QCD analytic predictions"
[hep-ex/9708029]

13.82
Sig 4.37
14

Mean 10.6
Sig 4.297
8.5

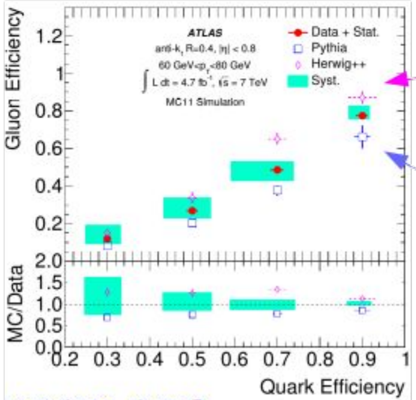
Back-up



- hadronisation: $-\Lambda / R$
- MPI: $+\Lambda * R^2$

Back-up

Efficiency is simply the ratio of the number of jets selected by a discriminant over the total number in the sample.



Herwig++ is too pessimistic, Quark and gluon jets looks more the same than in the data.

Pythia is too optimistic, Quark and Gluon jets are too different compared to data.

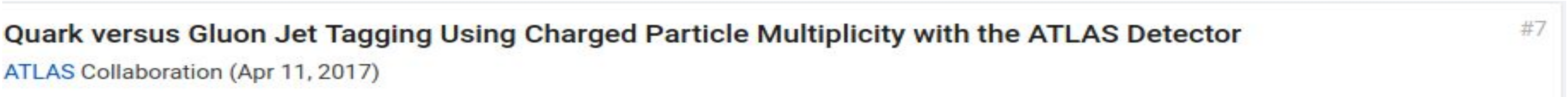
[ATLAS, Eur. Phys. J. C (2014) 74]

Conclusion:

"A detailed study of the jet properties reveals that quark-and gluon-jets look more similar to each other in the data than in the Pythia 6 simulation and less similar than in the Herwig++ simulation."

Problem: Q/G jets LHC data show discrepancy with the predictions from MC generators

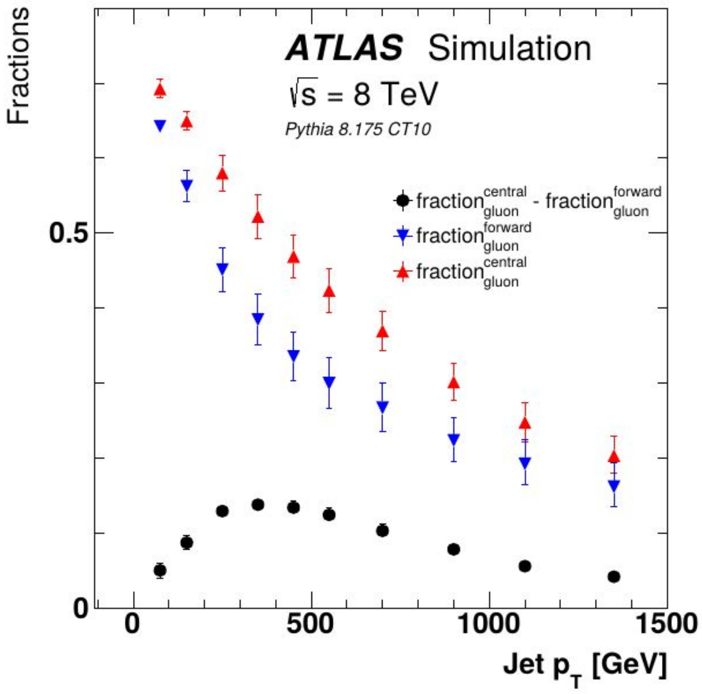
Back-up



Quark versus Gluon Jet Tagging Using Charged Particle Multiplicity with the ATLAS Detector

ATLAS Collaboration (Apr 11, 2017)

#7

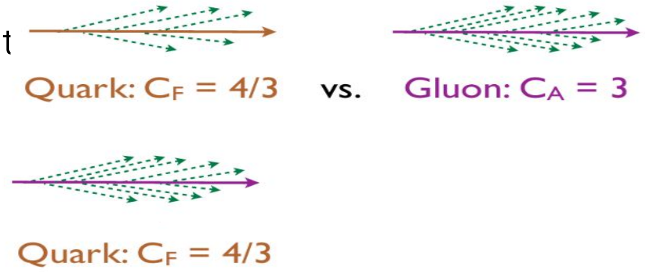


Using phase space cuts, for example:

- Pt - jet transverse momentum
- η - jet rapidity (central/forward)

But then we will have quark and gluon sample jets with different (Pt, η).

Same Pt



But hight Pt Q will radiate more and look like a G

Can we find a way to get enhanced Q/G with the same Pt, η?

Back-up

Herwig vs Pythia

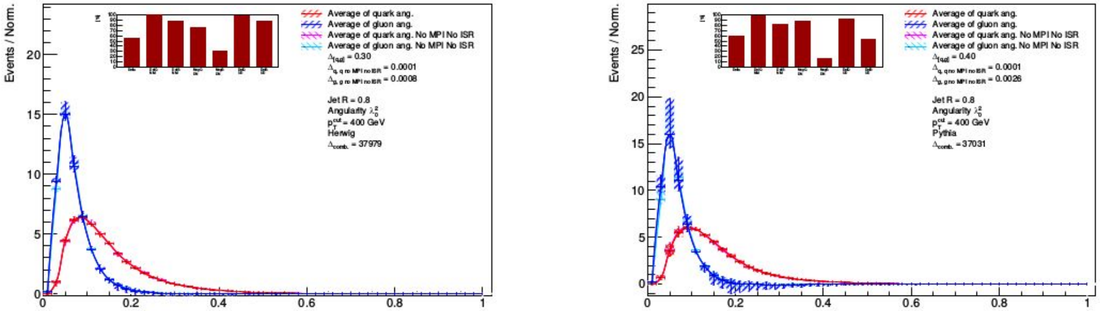


Fig. 17 Quark and gluon averaged angularities λ_0^2, $R = 0.8$ with highest score $\Delta_{\mathrm{comb}} = 37979$ using HERWIG event generator (left) and $\Delta_{\mathrm{comb}} = 37031$ using PYTHIA event generator (right), with $p_T^{\mathrm{cut}} = 400$ GeV, using the average of 6 energy combinations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

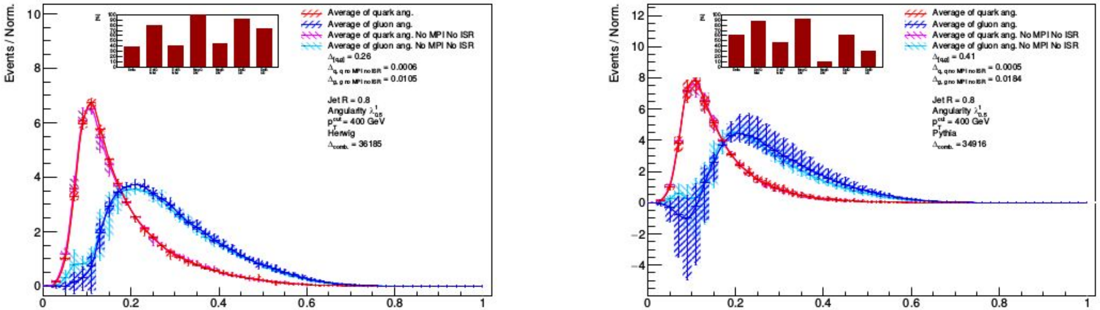
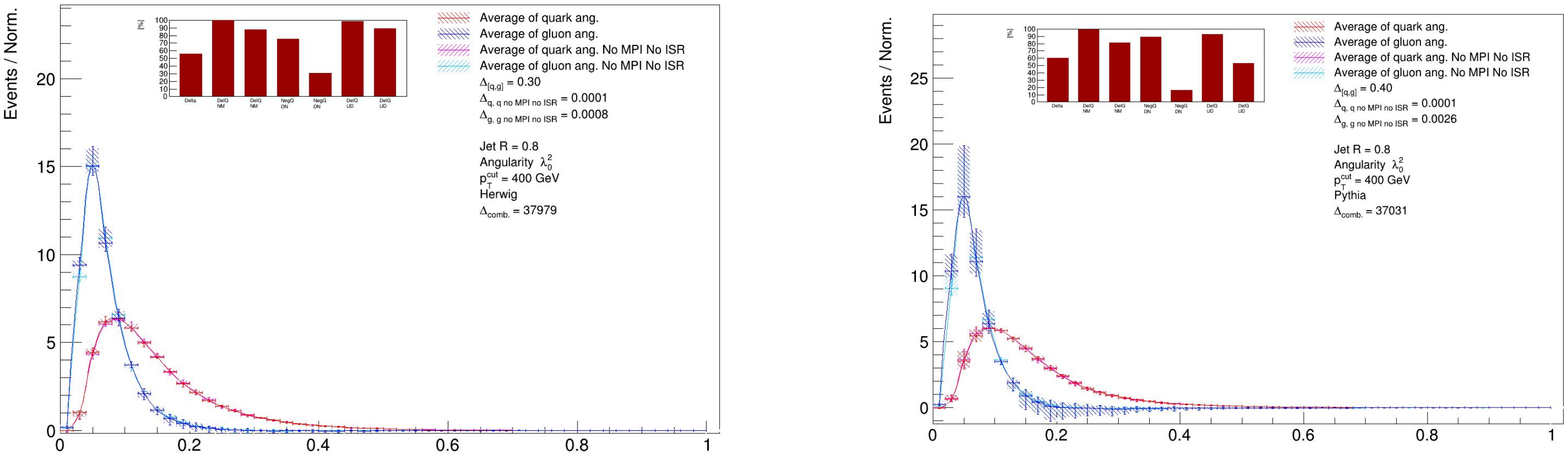


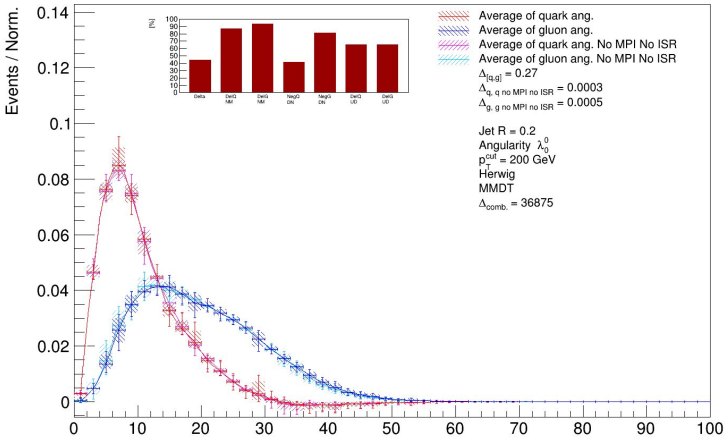
Fig. 18 Quark and gluon averaged angularities MMDT $\lambda_{0.5}^1$, $R = 0.8$ with score $\Delta_{\mathrm{comb}} = 36185$ using HERWIG event generator (left) and $\Delta_{\mathrm{comb}} = 34916$ using PYTHIA event generator (right), with $p_T^{\mathrm{cut}} = 400$ GeV, using the average of 6 energy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

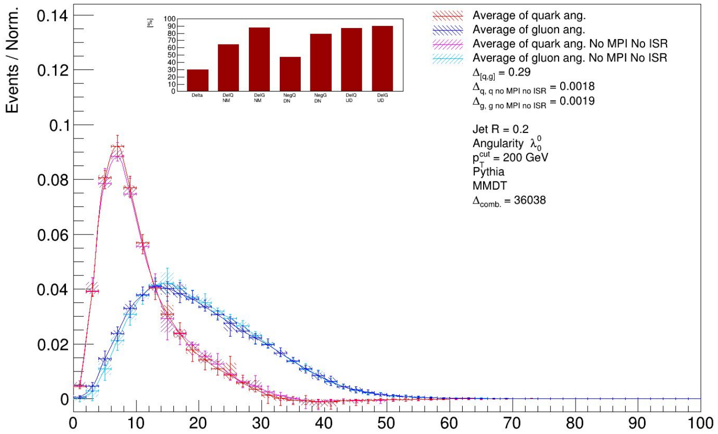
Back-up

Best performing angularities: p_T^D



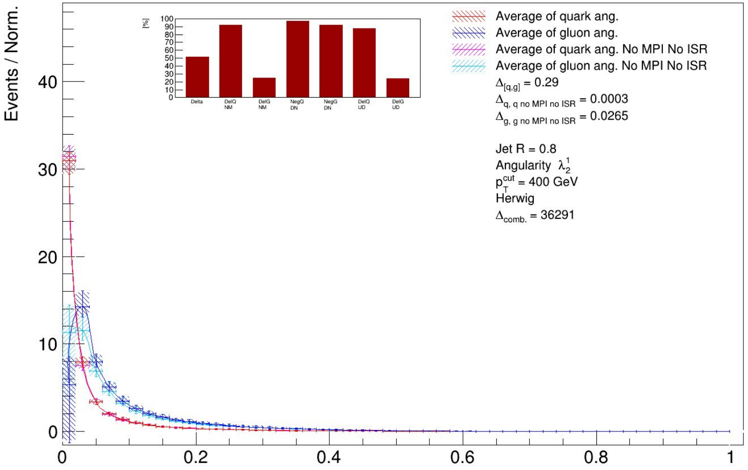
Best performing angularities: Multiplicity

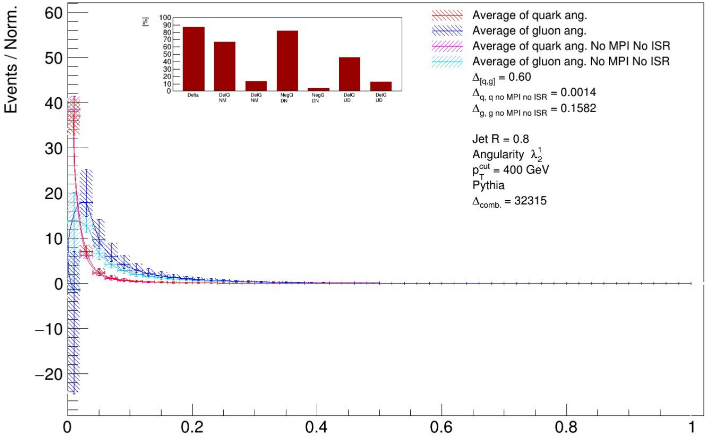




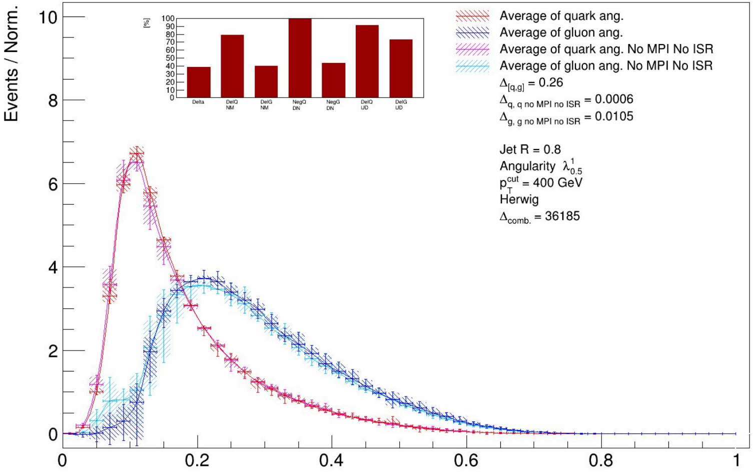
Back-up

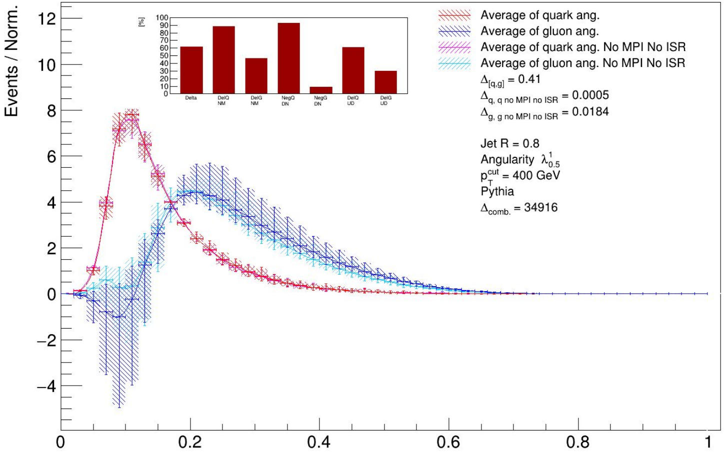
Best performing angularities: Mass





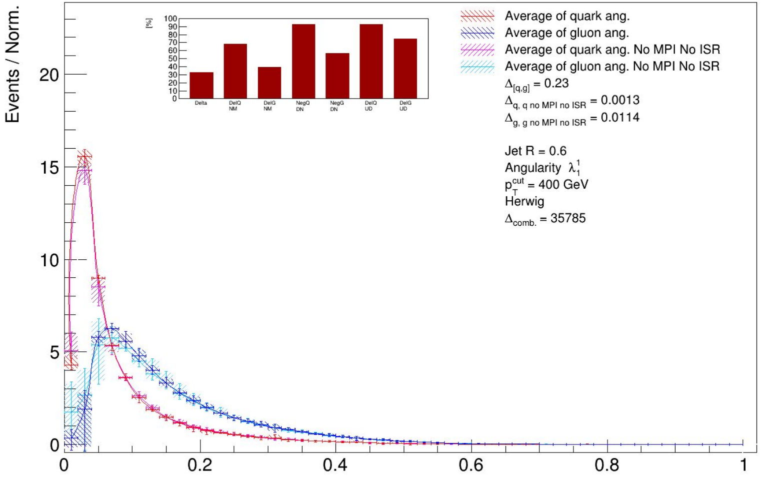
Best performing angularities: LHA

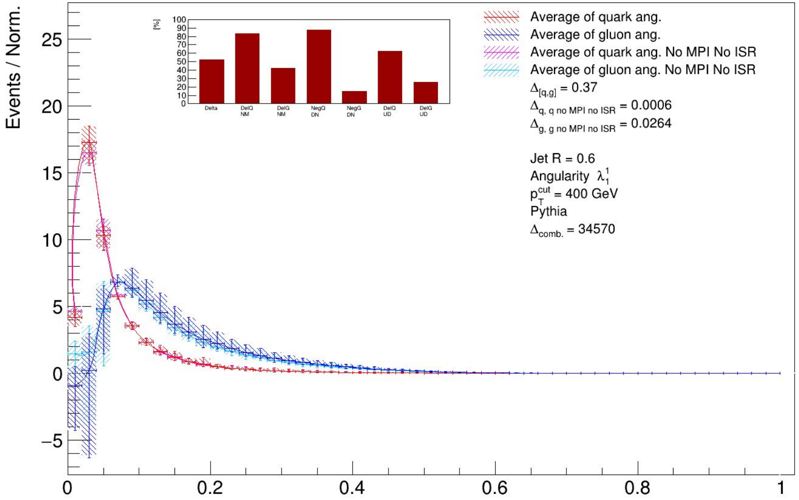




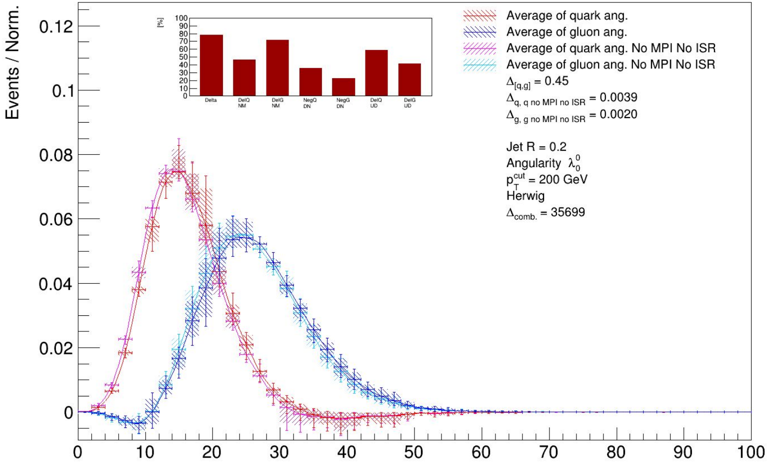
Back-up

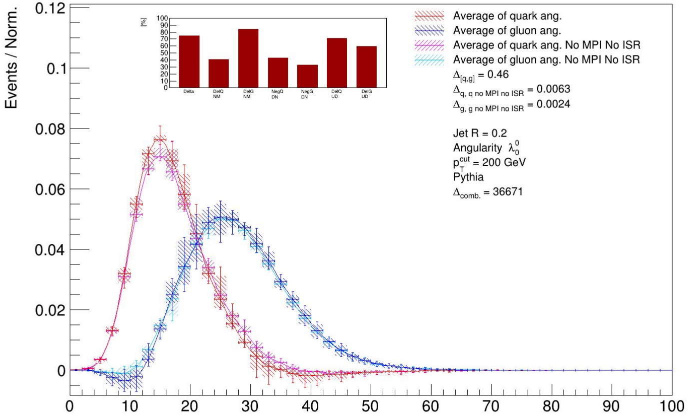
Best performing angularities: Width



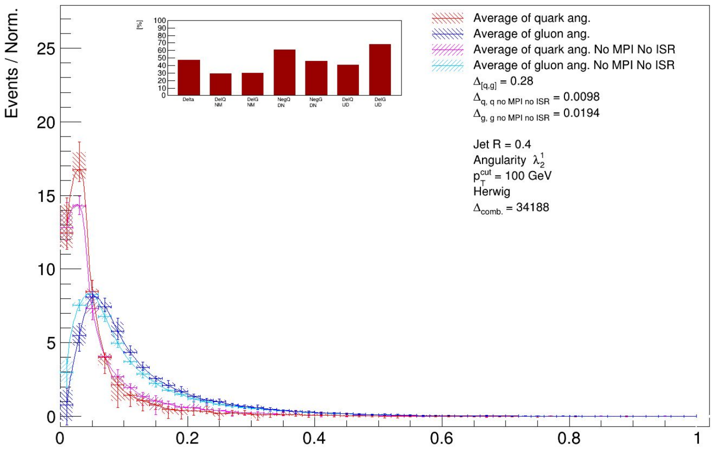


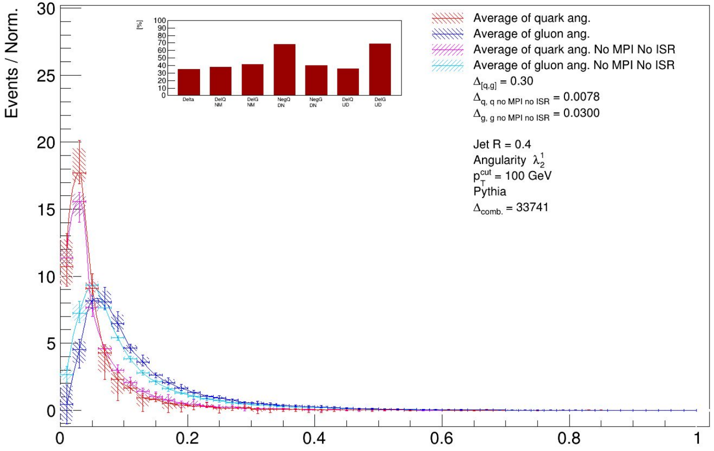
Wild cards (chosen by “eye”): multiplicity



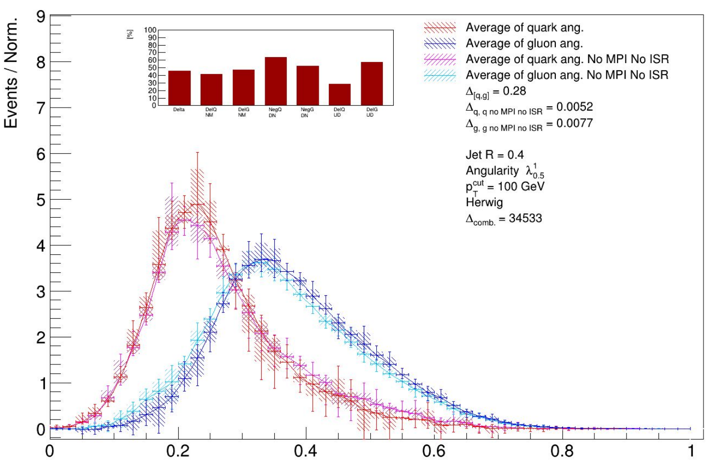


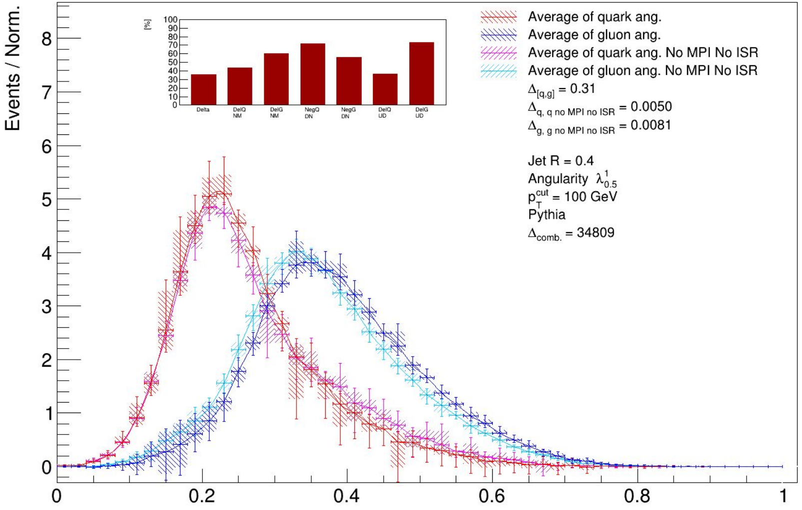
Wild cards (chosen by “eye”): mass



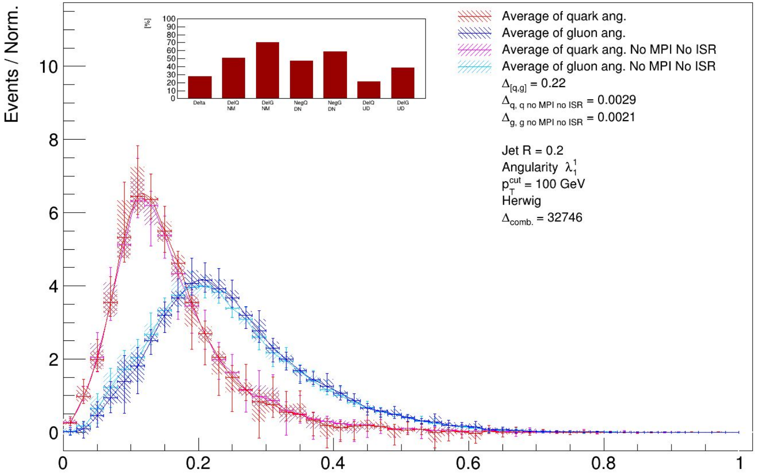


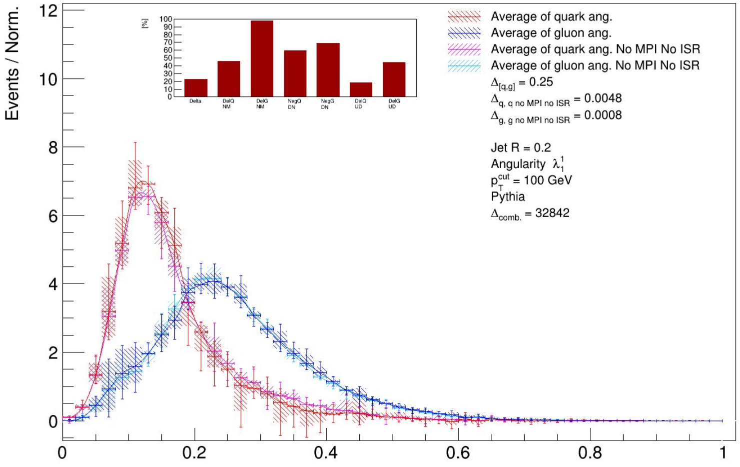
Wild cards (chosen by “eye”): LHA





Wild cards (chosen by “eye”): width





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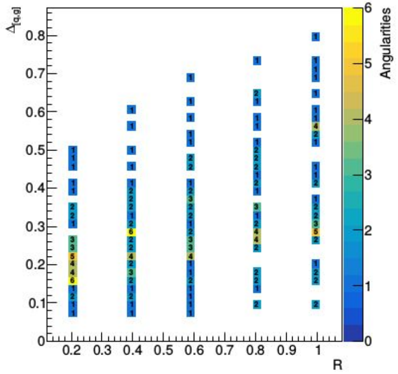


Fig. 19 First column scatter plot of $\Delta_{[q,g]}$ as a function of jet radius.

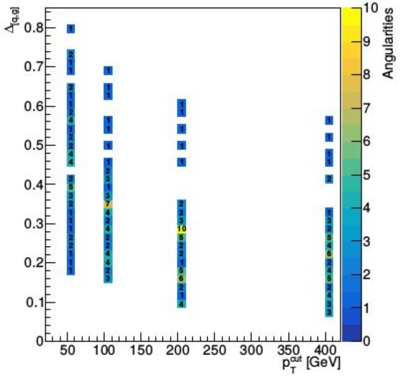


Fig. 21 First column scatter plot of $\Delta_{[q,g]}$ as a function of p_T^{cut}.

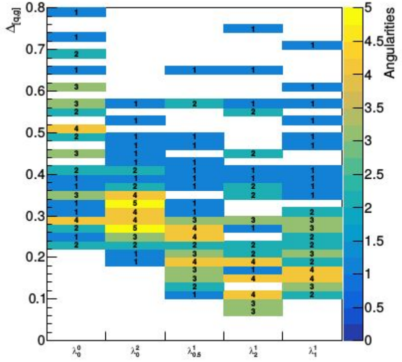


Fig. 20 First column scatter plot of $\Delta_{[q,g]}$ as a function of jet angularity.

Back-up

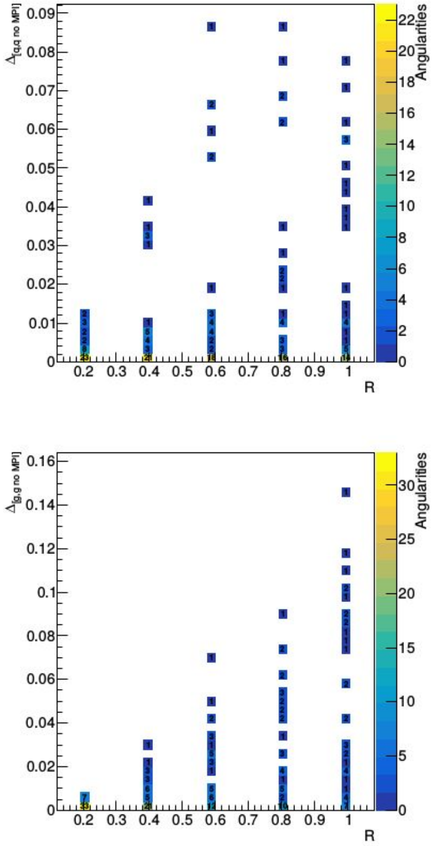


Fig. 22 Second/third column quark $\Delta_{[q,q \text{ noMPI}]}$ (top) and gluon $\Delta_{[g,g \text{ noMPI}]}$ (bottom) as a function of jet radius.

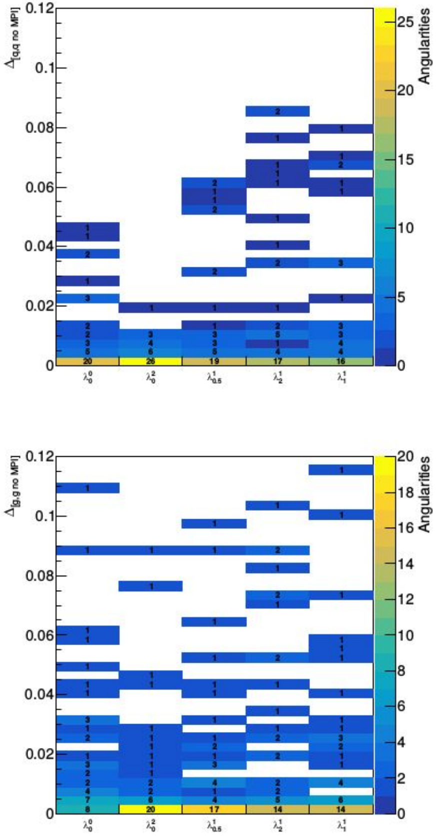


Fig. 23 Second/third column quark $\Delta_{[q,q \text{ noMPI}]}$ (top) and gluon $\Delta_{[g,g \text{ noMPI}]}$ (bottom) as a function of angularities.

Back-up

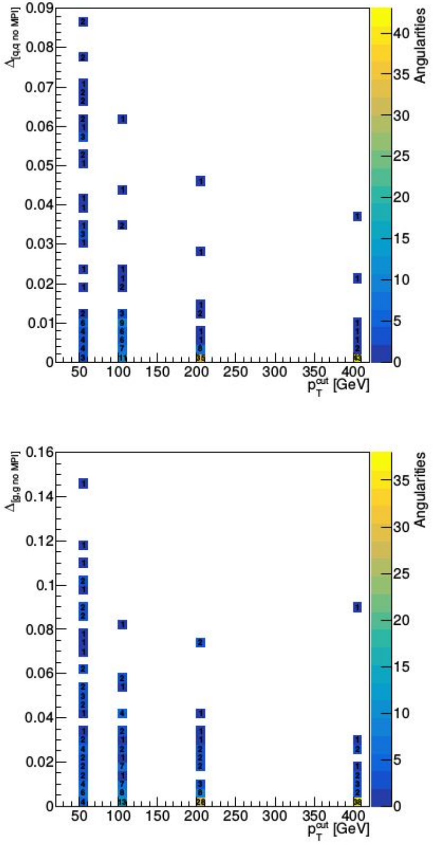


Fig. 24 Second/third column quark $\Delta_{[q,q\ \mathrm{noMPI}]}$ (top) and gluon $\Delta_{[g,g\ \mathrm{noMPI}]}$ (bottom) as a function of p_T^{cut}.

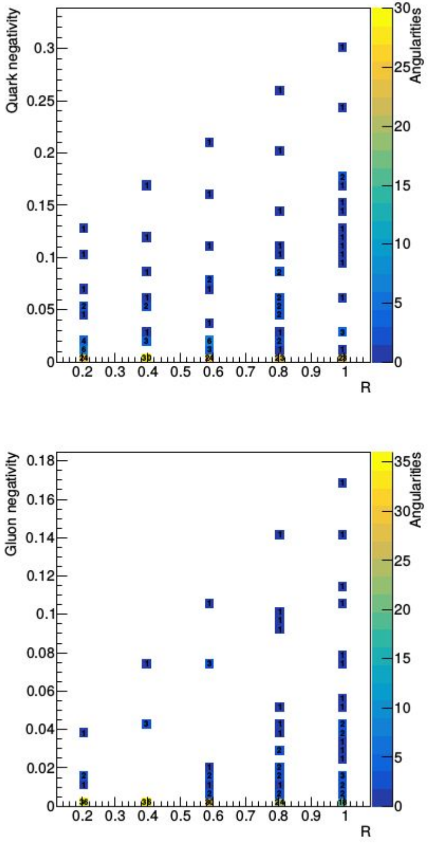


Fig. 25 Fourth/fifth column quark (top) and gluon negativity (bottom) as a function of jet radius.

Back-up

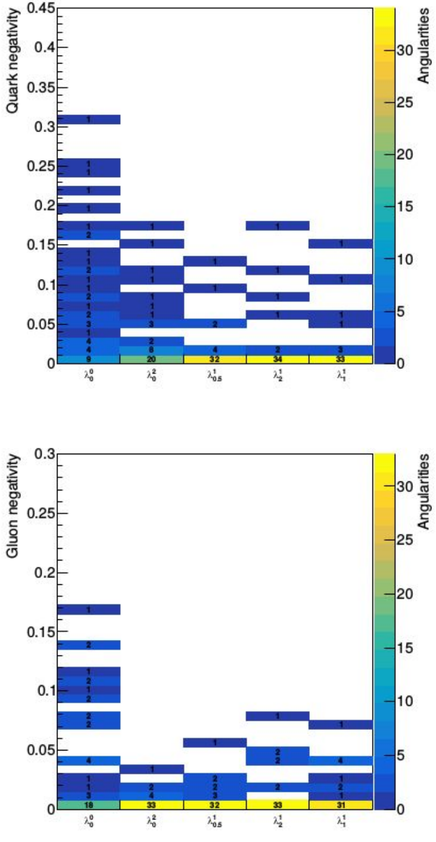


Fig. 26 Fourth/fifth column quark (top) and gluon negativity (bottom) as a function of angularities.

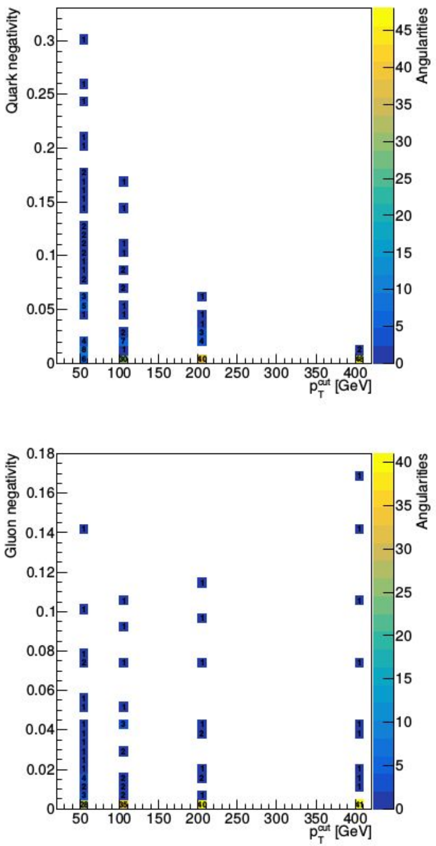


Fig. 27 Fourth/fifth column quark (top) and gluon negativity (bottom) as a function of $p_T^{\rm cut}$.

Back-up

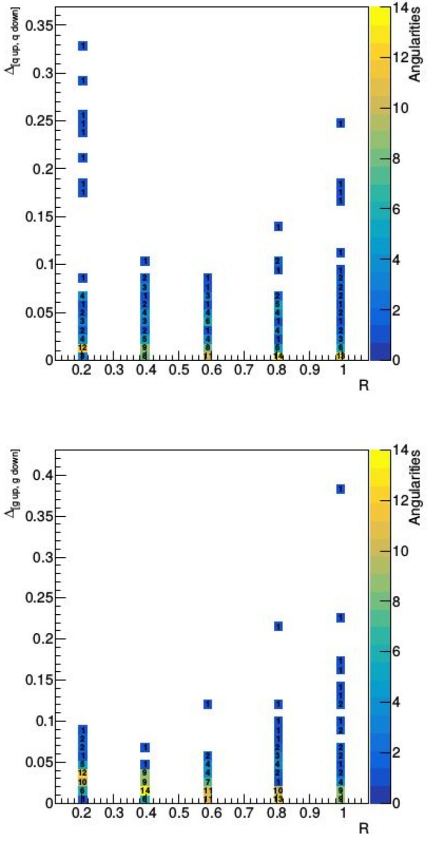


Fig. 28 Sixth/Seventh column quark $\Delta_{[q\ \mathrm{down}, q\ \mathrm{up}]}$ (top) and gluon $\Delta_{[g\ \mathrm{down}, g\ \mathrm{up}]}$ (bottom) as a function of jet radius.

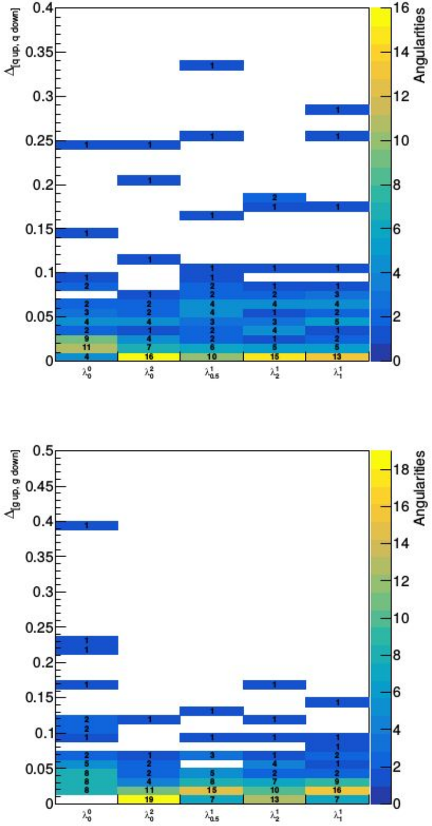


Fig. 29 Sixth/Seventh column quark $\Delta_{[q\ \mathrm{down}, q\ \mathrm{up}]}$ (top) and gluon $\Delta_{[g\ \mathrm{down}, g\ \mathrm{up}]}$ (bottom) as a function of angularities.

Back-up

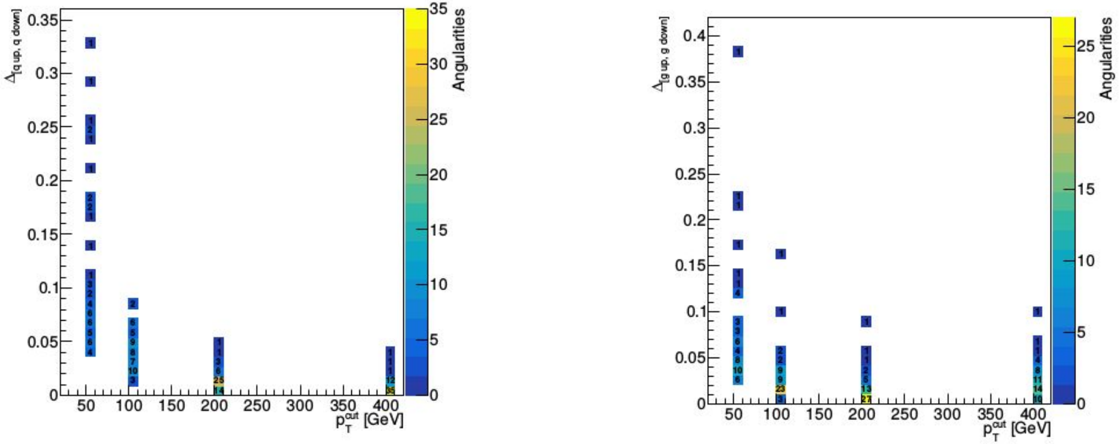
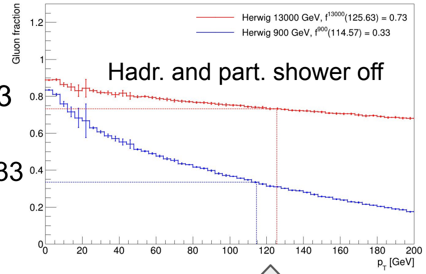


Fig. 30 Sixth/Seventh column quark $\Delta_{[q\ \mathrm{down}, q\ \mathrm{up}]}$ (top) and gluon $\Delta_{[g\ \mathrm{down}, g\ \mathrm{up}]}$ (bottom) as a function of p_T^{cut}.

Back-up



$f^{13000} = 0.73$

$f^{900} = 0.33$

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

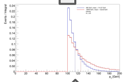
$$\boxed{\lambda = f\,\lambda_g + (1 - f)\,\lambda_q}$$

where

f ... gluon fraction

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

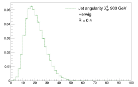
taken from simulation

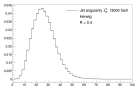


$p_T^{cut} = 100$ GeV

Let's write equations for measurement at energy 900 GeV and 13 000 GeV

(with the same event selection)





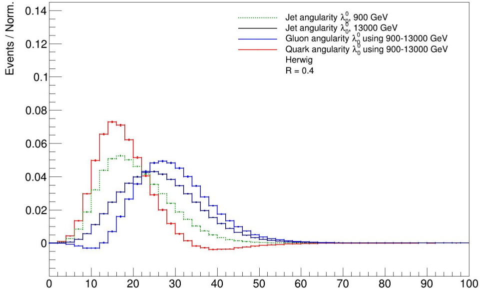
$$\lambda^{900} = f^{900}\,\lambda_g + (1 - f^{900})\lambda_q$$

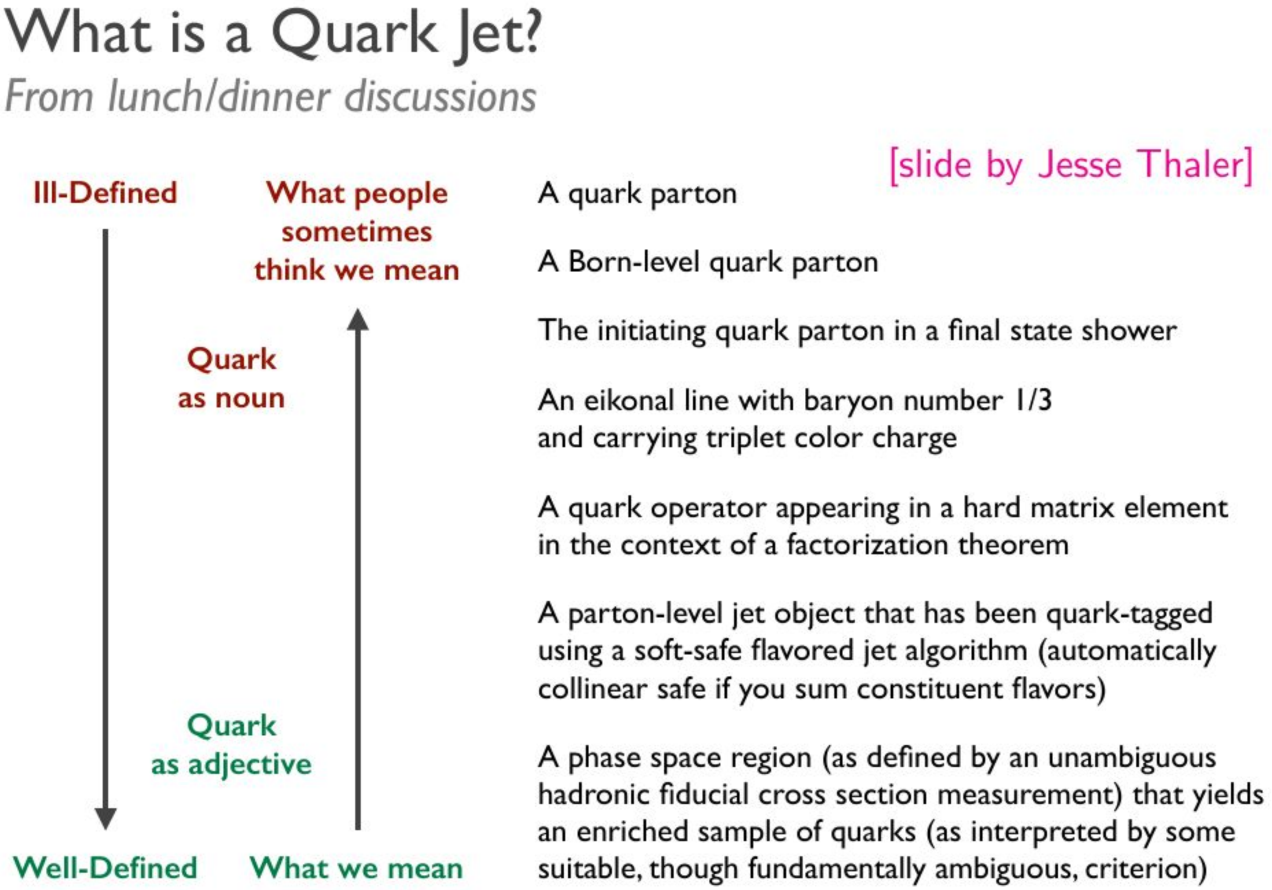
$$\lambda^{13000} = f^{13000}\,\lambda_g + (1 - f^{13000})\lambda_q$$

Assuming λ_g and λ_q are energy independent.

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

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





What is a Quark Jet?

From lunch/dinner discussions

[slide by Jesse Thaler]

Ill-Defined

What people sometimes think we mean

Quark as noun

Quark as adjective

Well-Defined

What we mean

A quark parton

A Born-level quark parton

The initiating quark parton in a final state shower

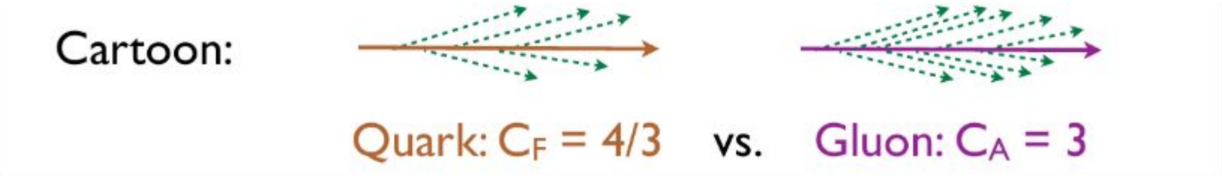
An eikonal line with baryon number 1/3 and carrying triplet color charge

A quark operator appearing in a hard matrix element in the context of a factorization theorem

A parton-level jet object that has been quark-tagged using a soft-safe flavored jet algorithm (automatically collinear safe if you sum constituent flavors)

A phase space region (as defined by an unambiguous hadronic fiducial cross section measurement) that yields an enriched sample of quarks (as interpreted by some suitable, though fundamentally ambiguous, criterion)

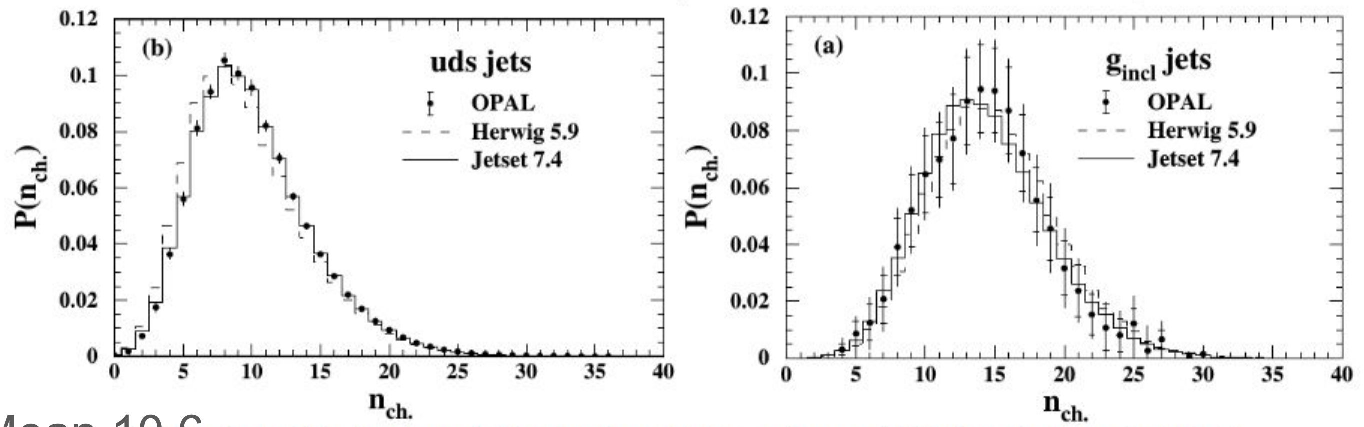
Back-up



Cartoon:

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

Gluon will radiate more, gluon will radiate wider $\frac{\langle N_g \rangle}{\langle N_q \rangle} = \frac{C_A}{C_F}$ = 3/(4/3)=9/4 = 2.25



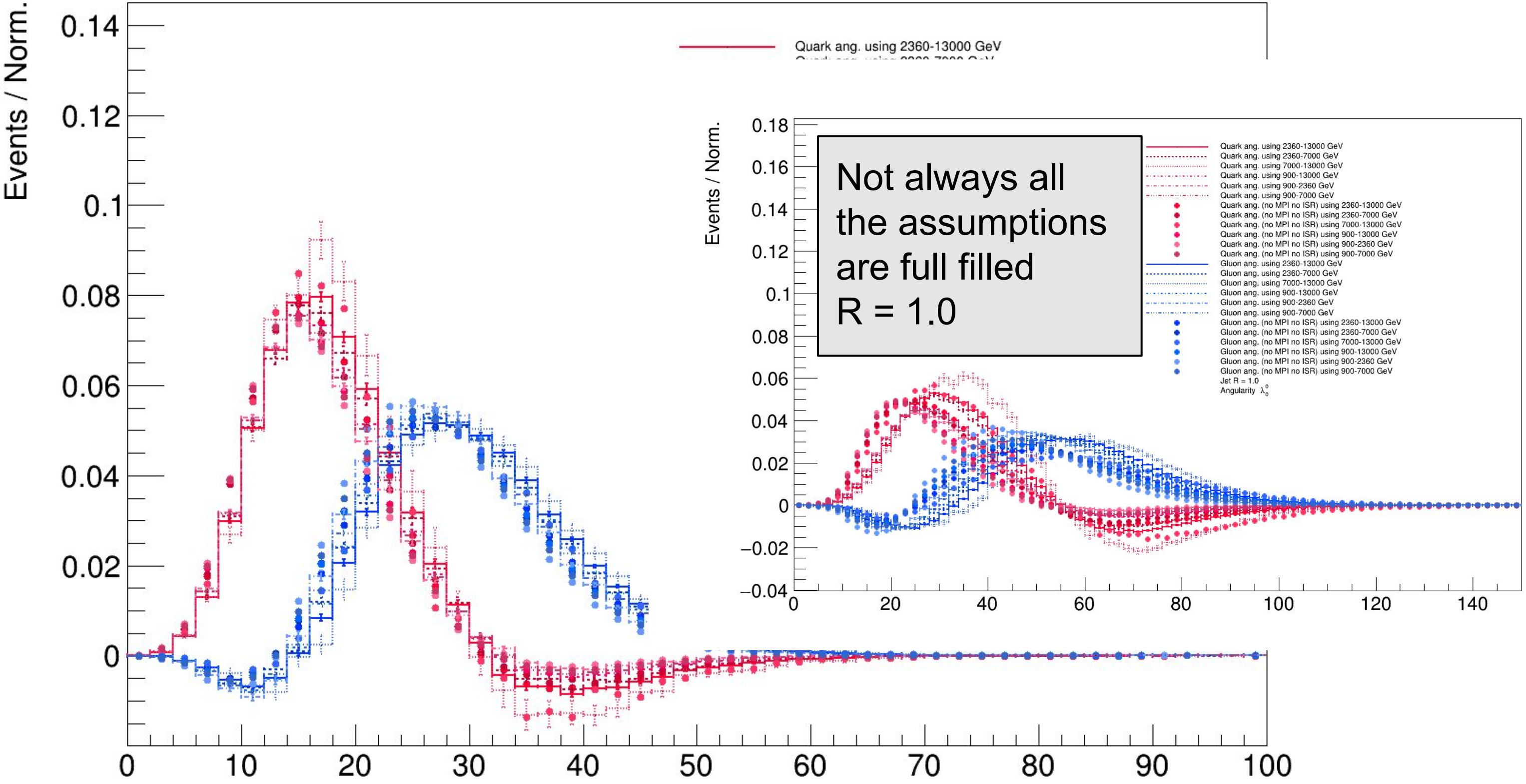
13.82
Sig 4.37
14
41.8 GeV

Mean 10.6
Sig 4.297
8.5
45.6 GeV

“Multiplicity distributions of gluon and quark jets and tests of QCD analytic predictions” [hep-ex/9708029]

Back-up

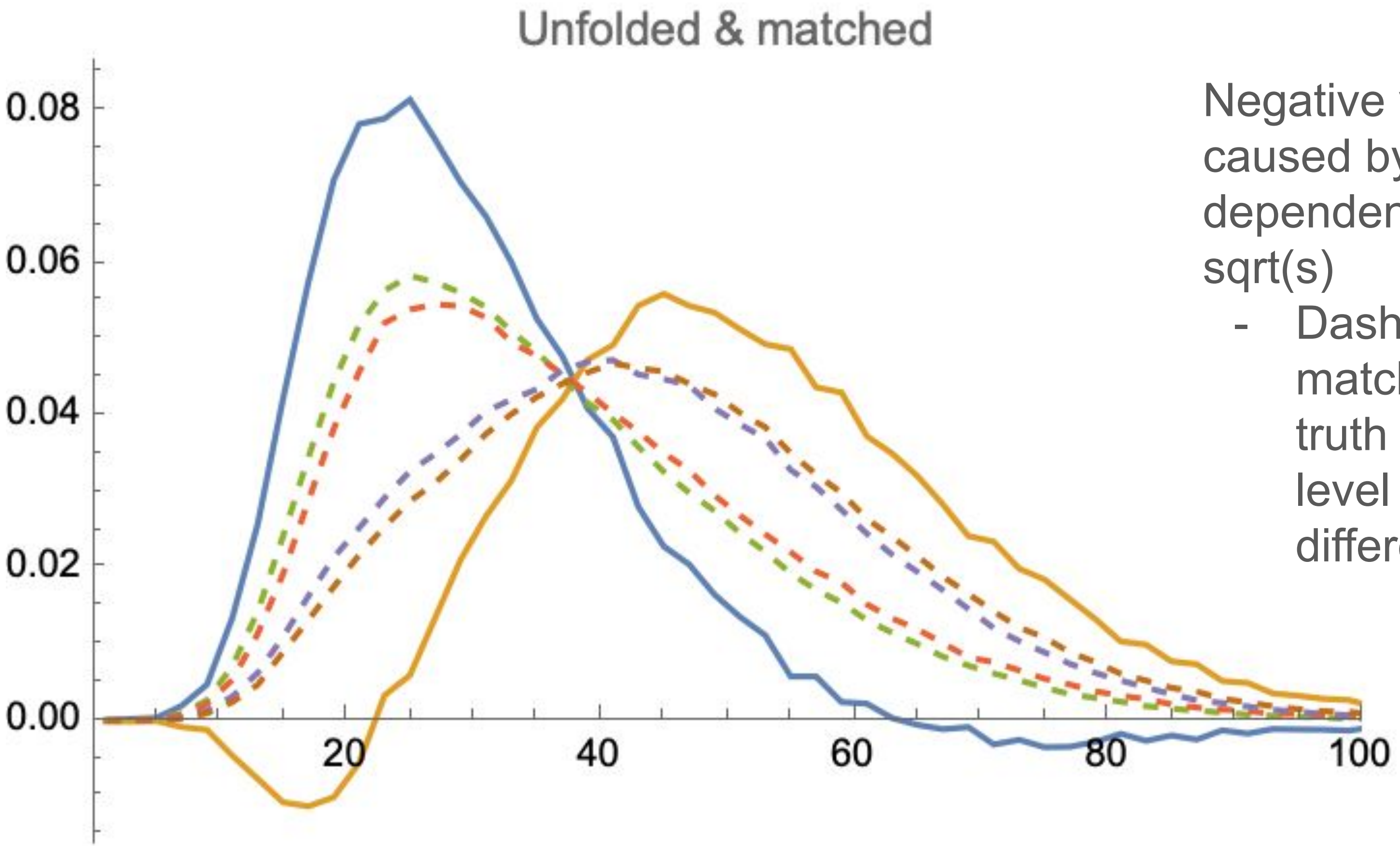
Let’s use more 6 energy combinations:
900-2360, 900-7000, 900-13000, 2360-7000, 2360-13000, 7000-13000 GeV



Not always all the assumptions are full filled
R = 1.0

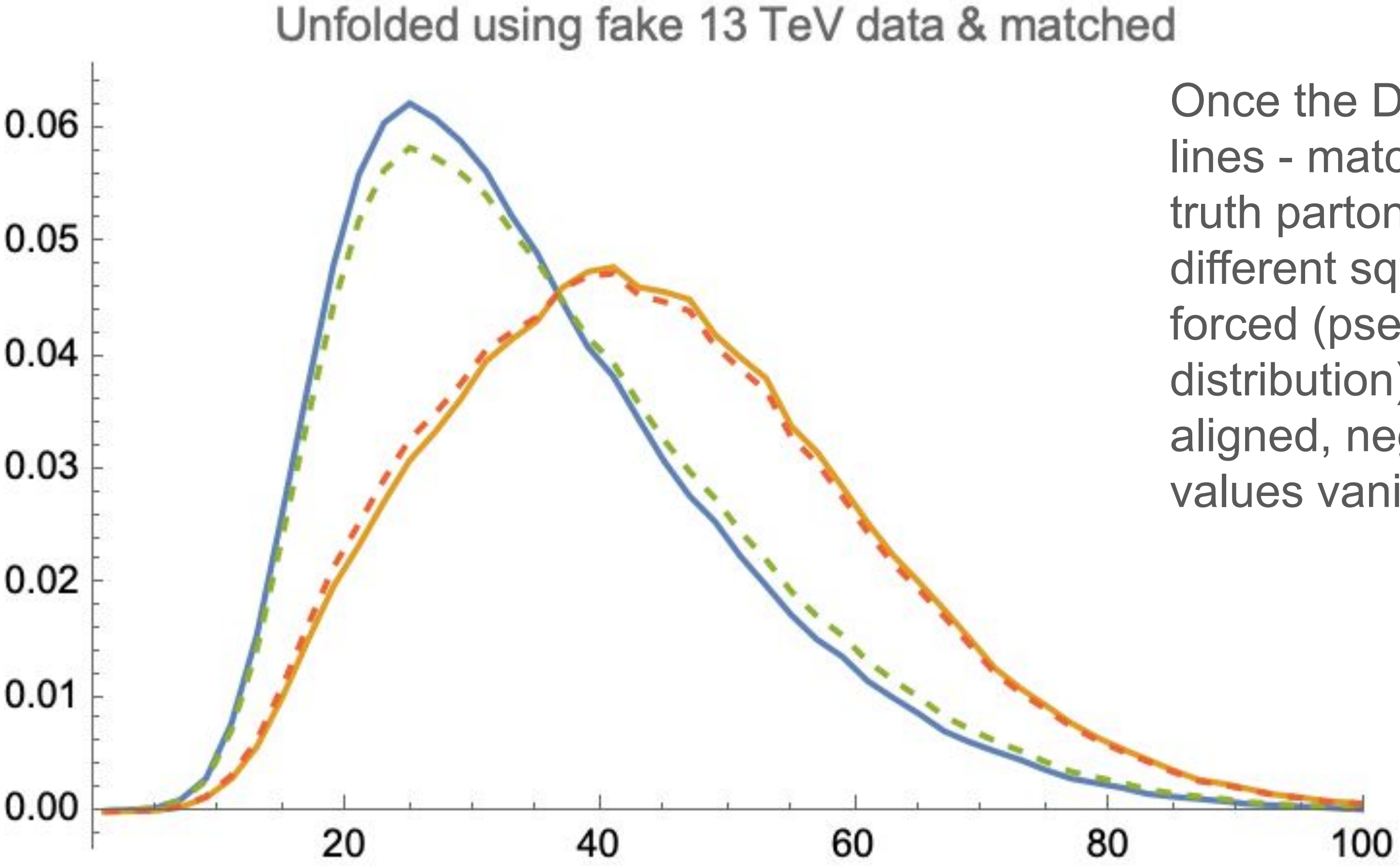
Dotted lines test the robustness to Multi Parton Interactions MPI and Initial State Radiation ISR

Back-up



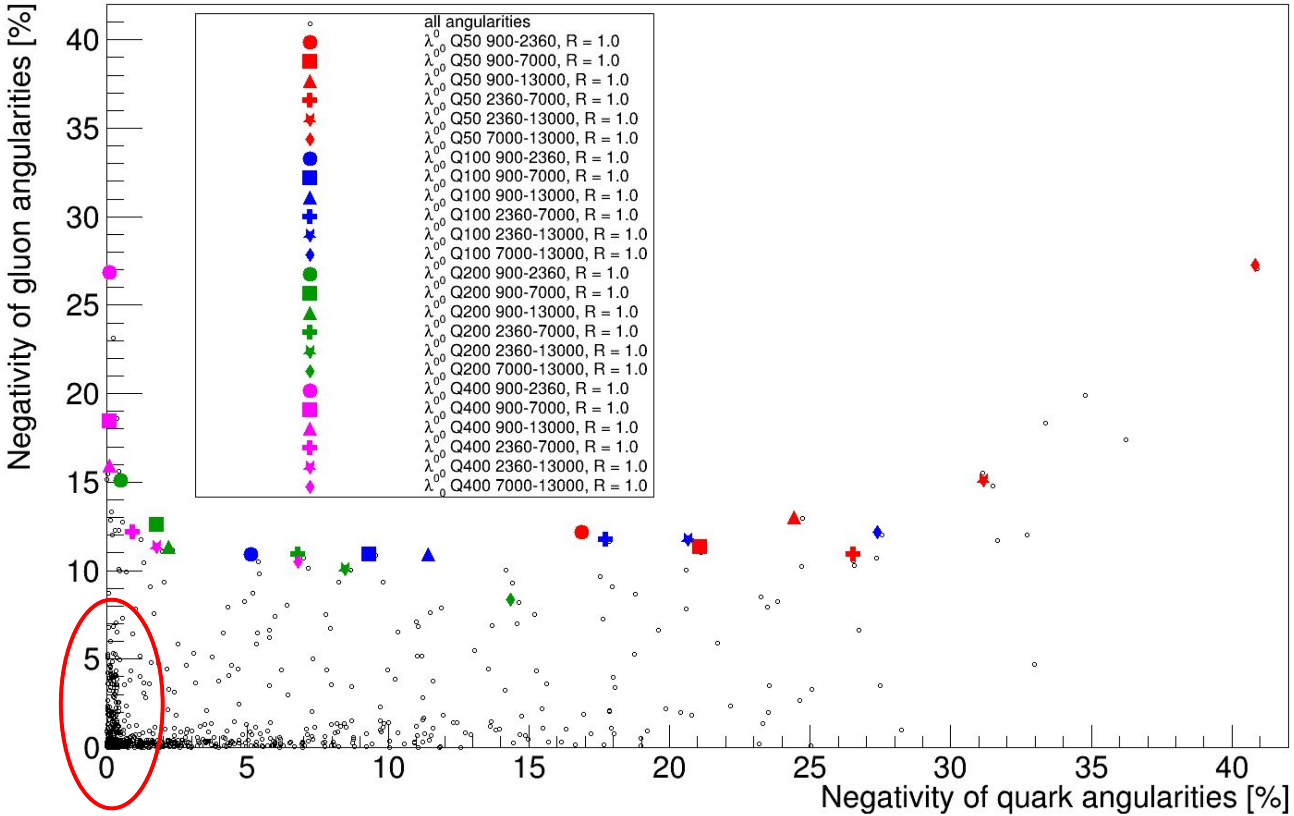
Negative values caused by dependency on sqrt(s)

- Dashed lines matched to truth parton level at different sqrt(s)

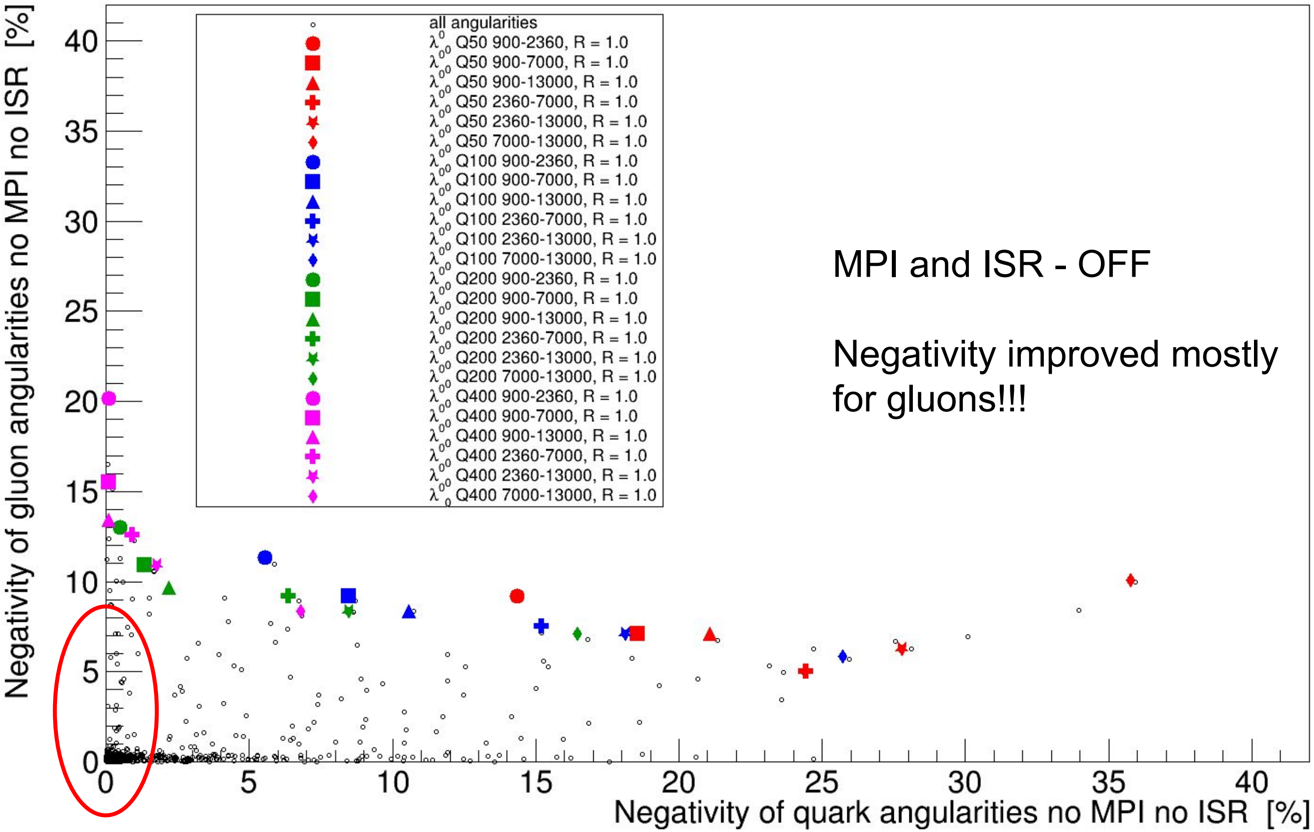


Once the Dashed lines - matched to truth parton level at different sqrt(s) are forced (pseudo-distribution) to be aligned, negative values vanish

Back-up


Negativity of gluon angularities [%]
Negativity of quark angularities [%]
0
5
10
15
20
25
30
35
40
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

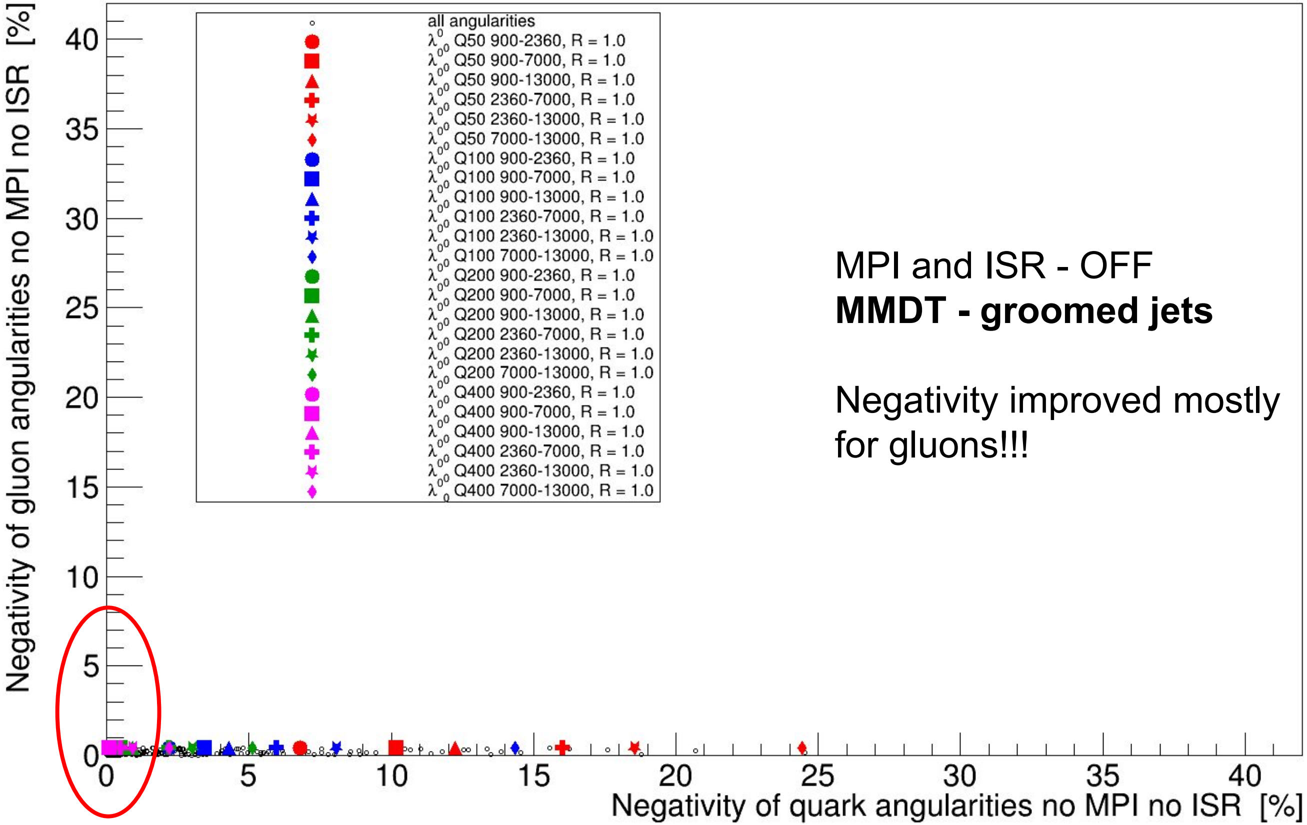
Back-up



MPI and ISR - OFF

Negativity improved mostly for gluons!!!

Back-up

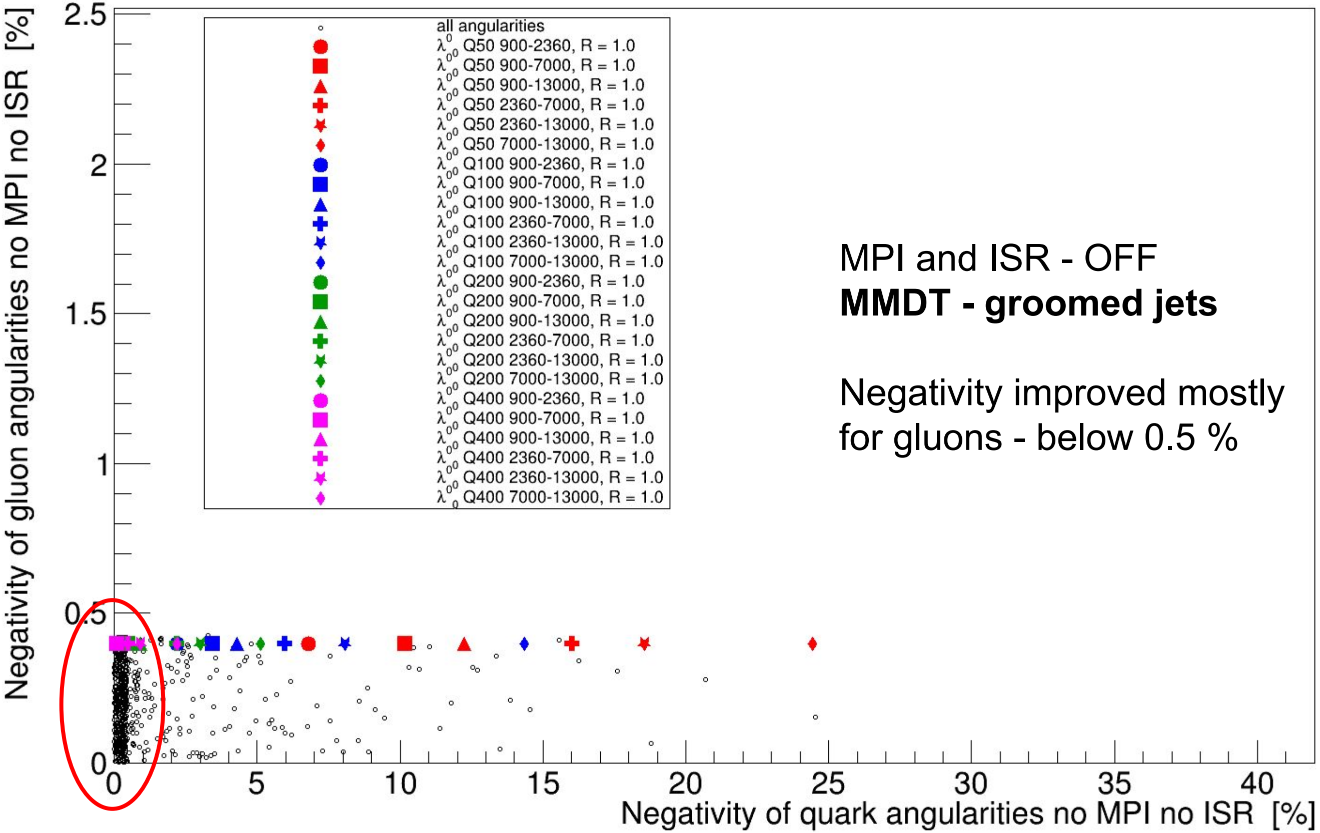


MPI and ISR - OFF

MMDT - groomed jets

Negativity improved mostly for gluons!!!

ZOOMED



MPI and ISR - OFF
MMDT - groomed jets

Negativity improved mostly for gluons - below 0.5 %