Obtaining high-precision predictions for jet production at the LHC in perturbative QCD

LIP Summer Internship Program2023

Presenter:

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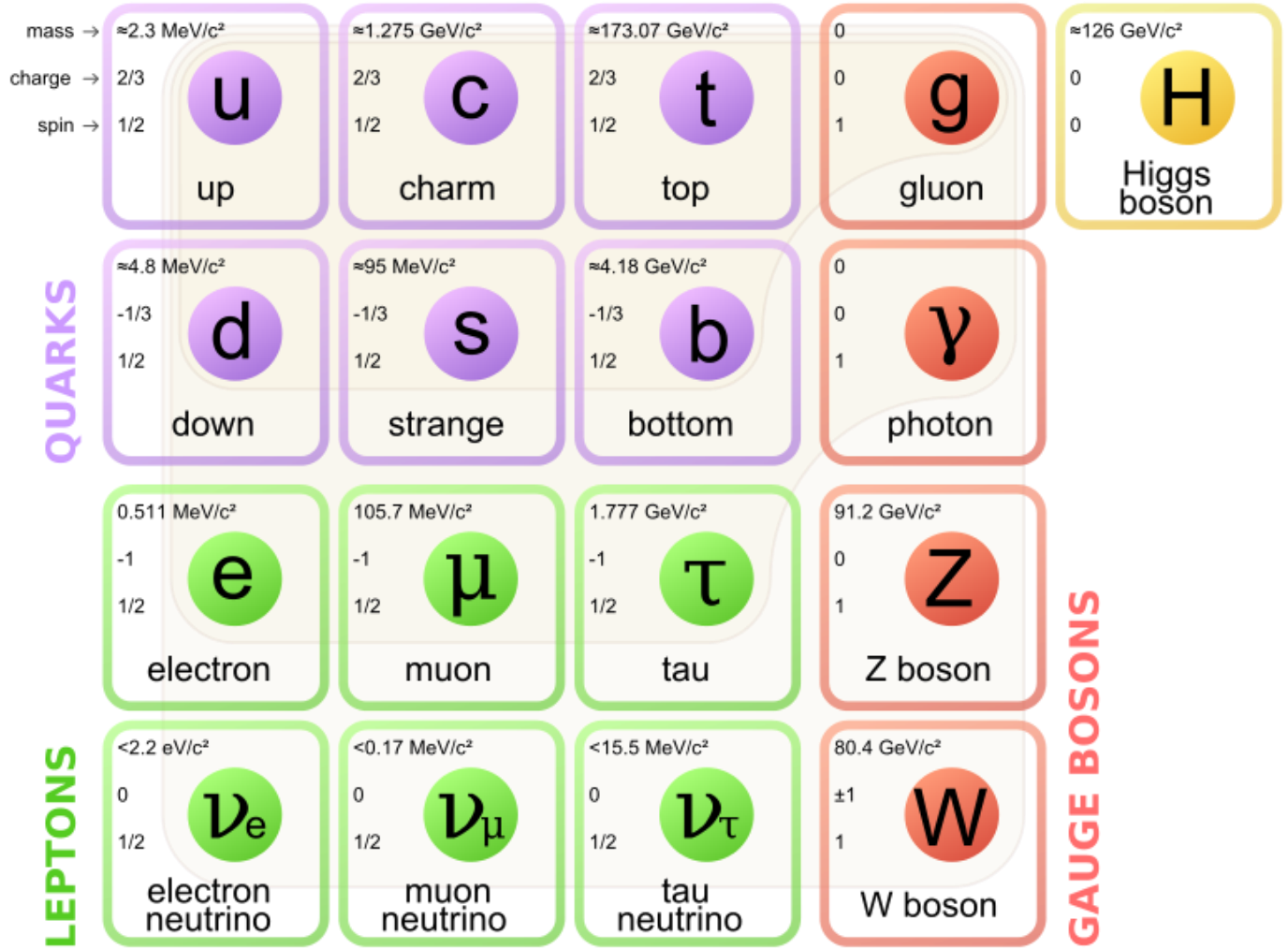
Supervisor:

João Pires

Standard Model



Four Fundamental forces

- Gravitational force

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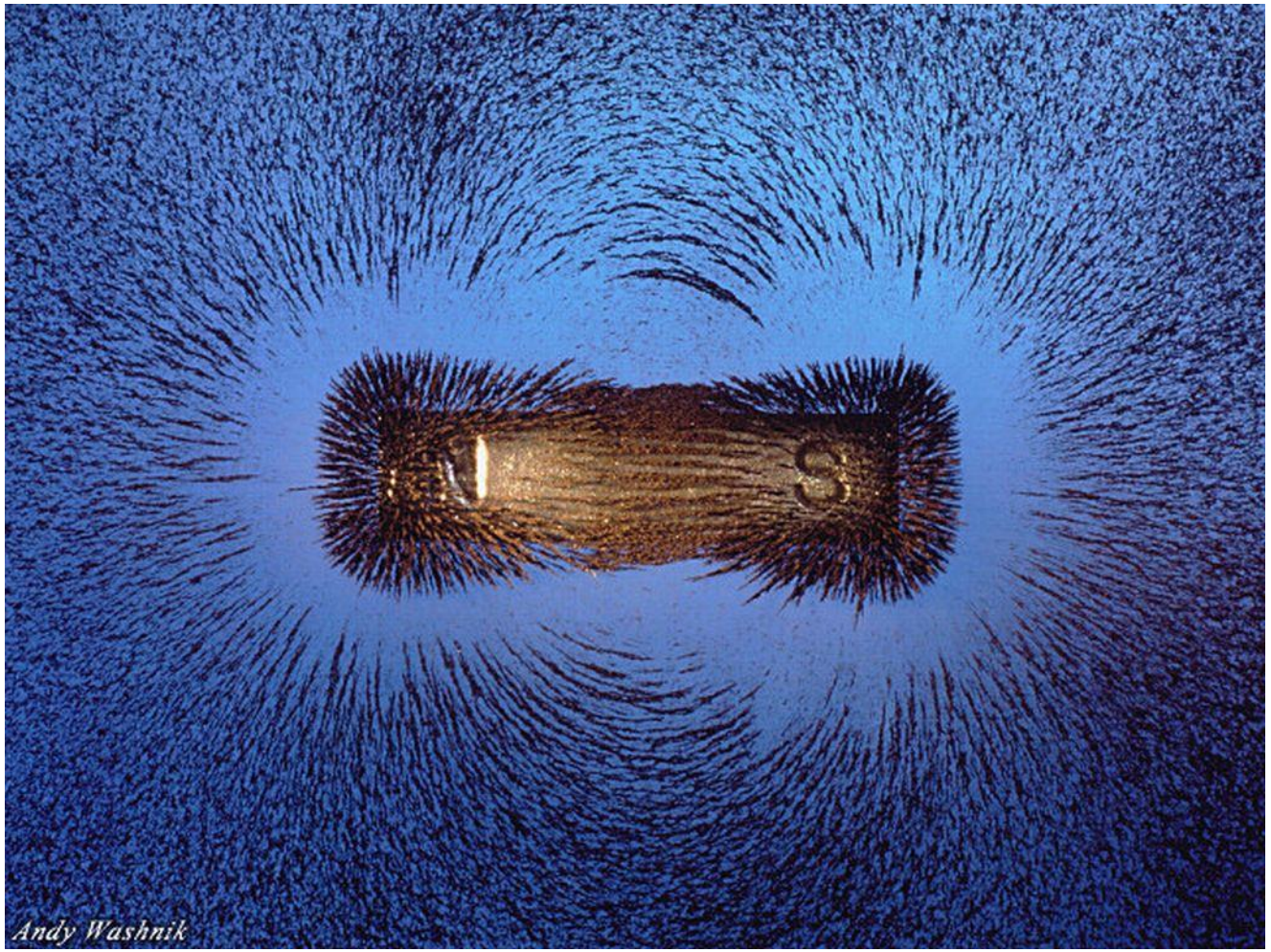
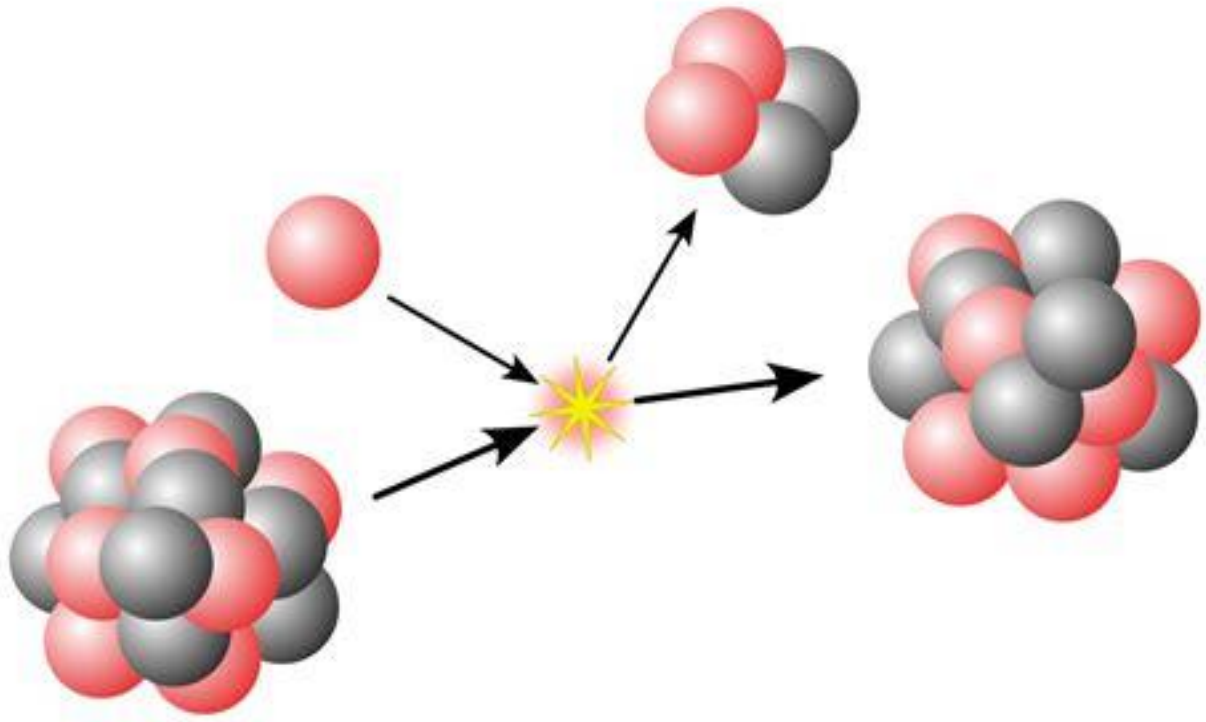
- Gravitational force
- Electromagnetic Force



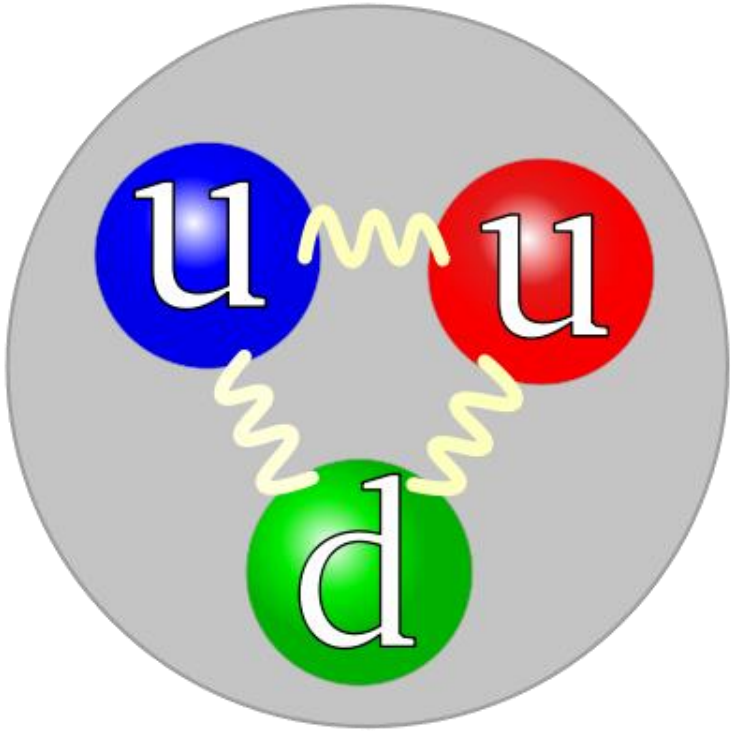
Four Fundamental forces

- Gravitational force
- Electromagnetic Force
- Weak force



Four Fundamental forces

- Gravitational force
- Electromagnetic Force
- Weak force
- Strong Force



Strong Force

- Quantum Chromodynamics (QCD)
- Propagated by gluons
- Applies to particles with colour charge (Quark and Gluons)

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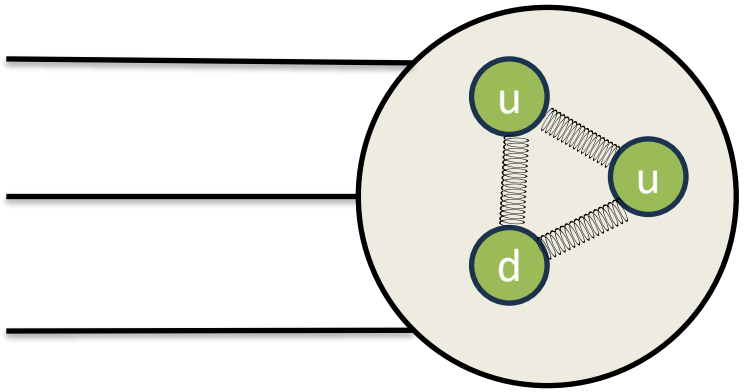
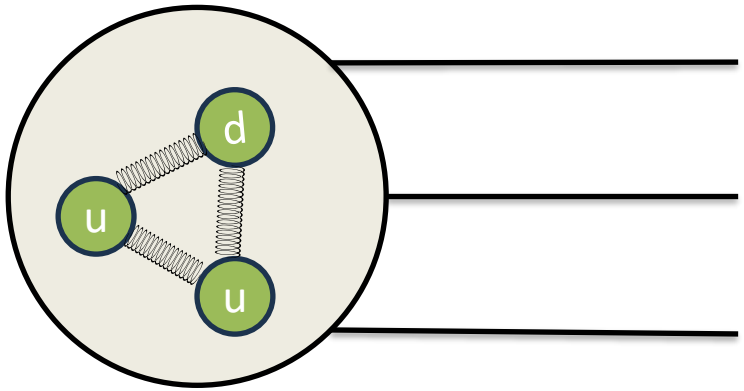
- Quantum Chromodynamics (QCD)
- Propagated by gluons
- Applies to particles with colour charge (Quark and Gluons)

- Colour charge, comes in 6 types, red, green, blue and corresponding anti-colours.
- Colour confinement: Hadronization

LHC

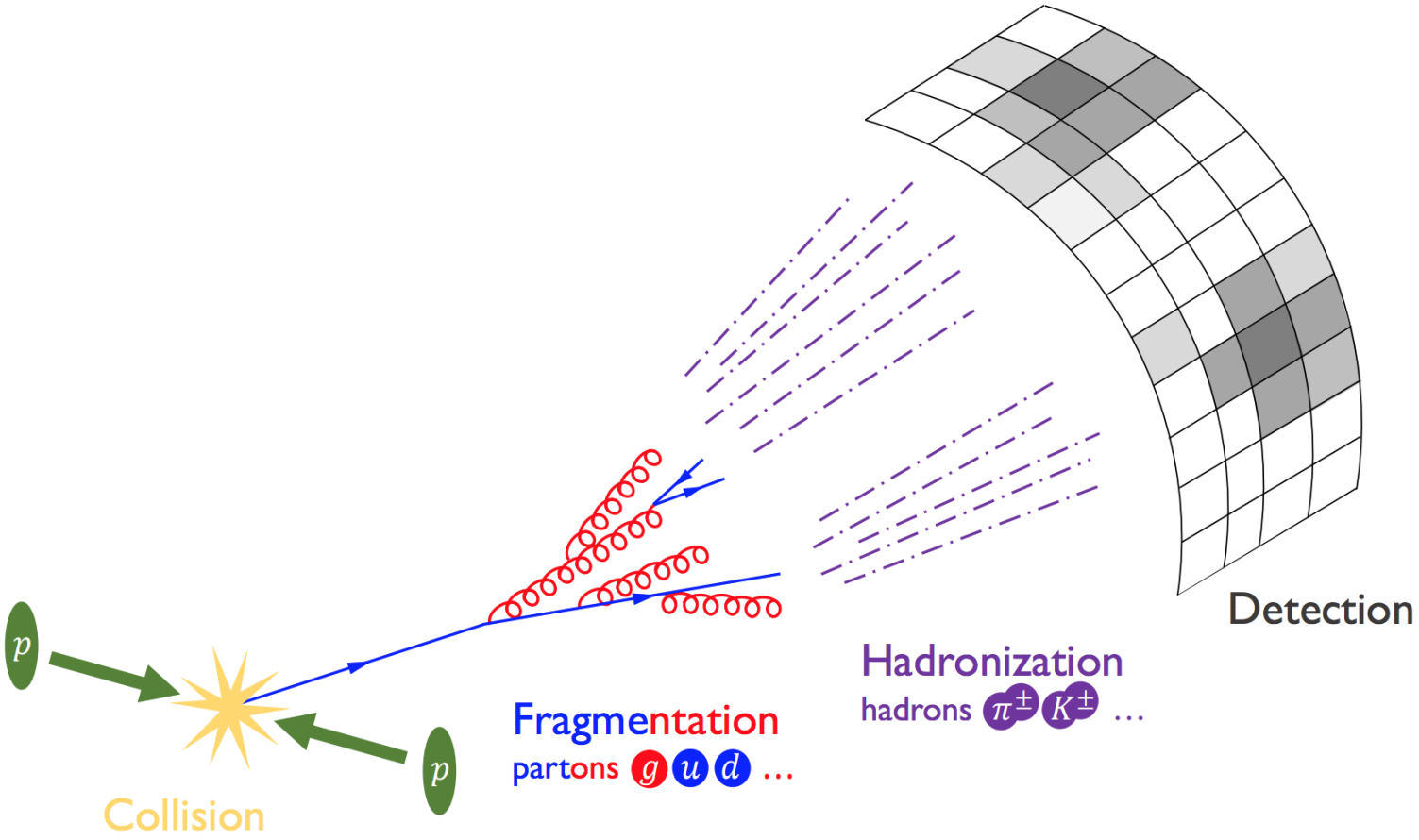


Proton

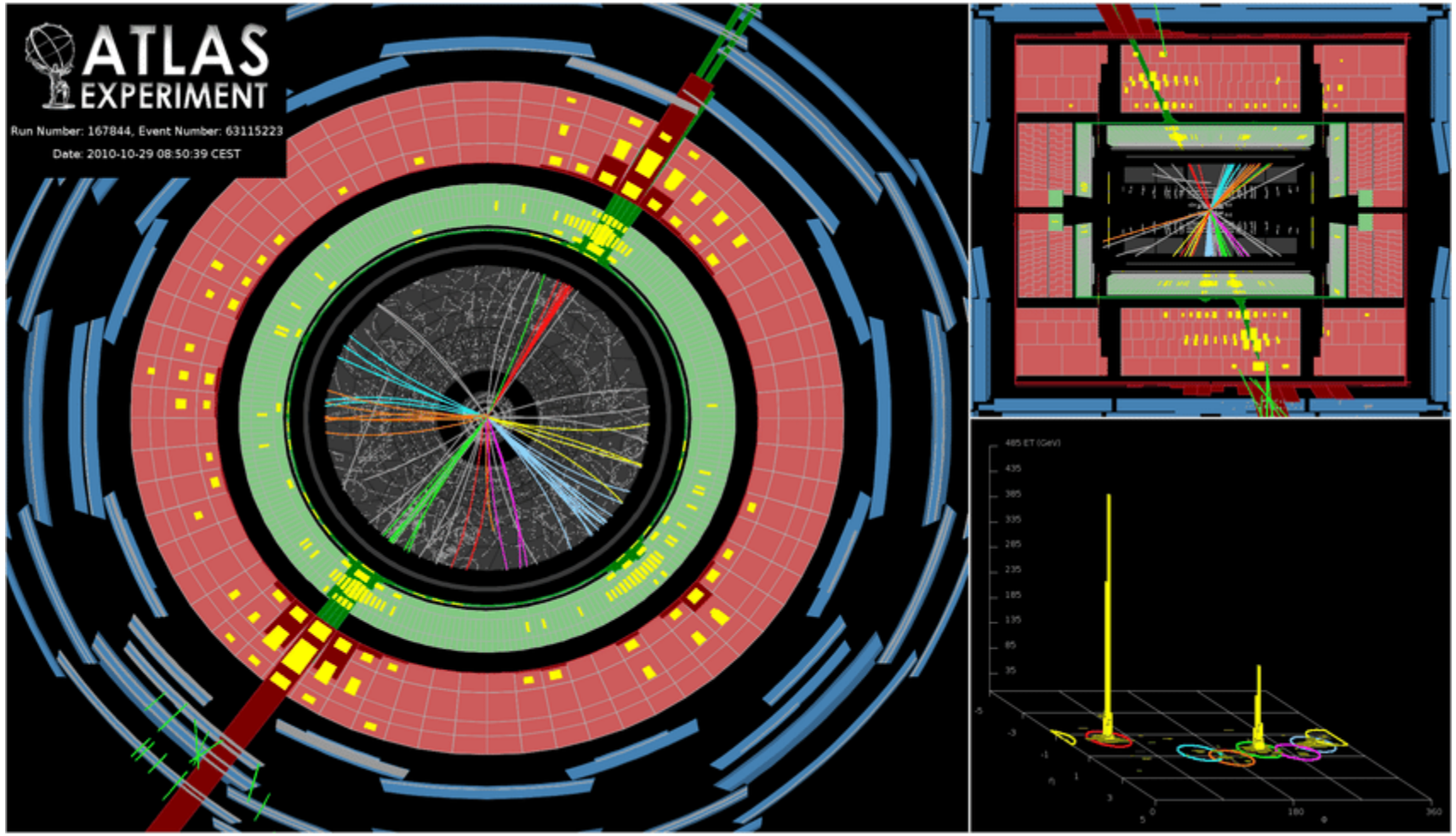


Proton

LHC


Detection
Hadronization
hadrons $\pi^{\pm}$ $K^{\pm}$ …
Fragmentation
partons g u d …
Collision
p
p

LHC


ATLAS
EXPERIMENT
Run Number: 167844, Event Number: 63115223
Date: 2010-10-29 08:50:39 CEST

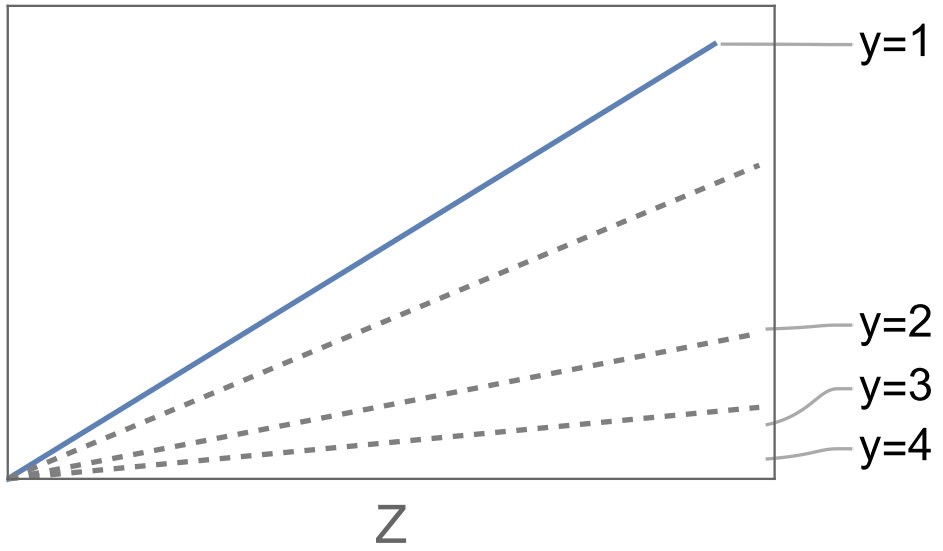
Jet Algorithm

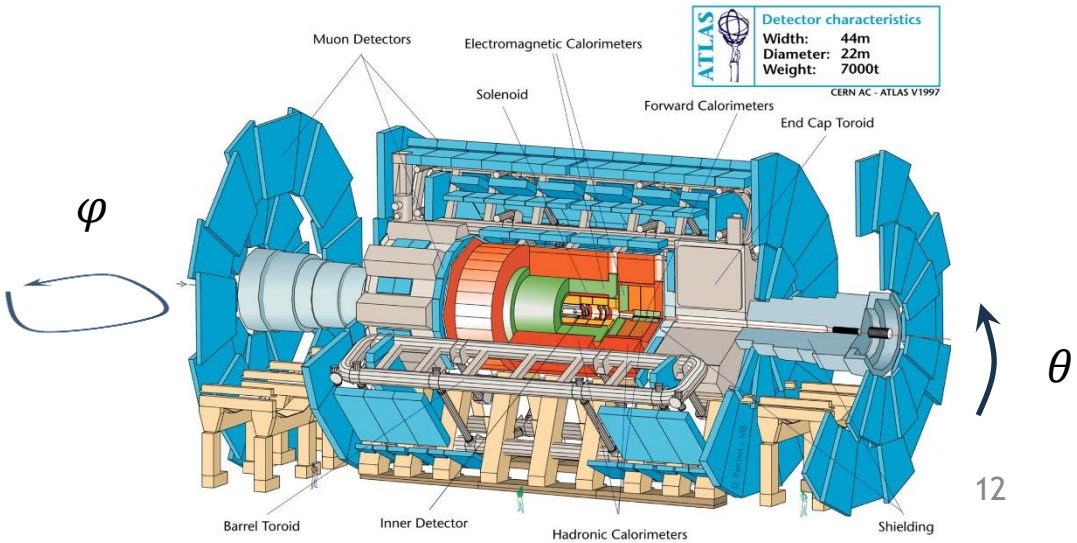
p_t is the transverse momentum of the particle and is defined by $P_t = \sqrt{P_x^2 + P_y^2}$.

y is the rapidity of the particle and is defined by $y = \frac{1}{2}\ln\left(\frac{E+P_z}{E-P_z}\right)$ which serves as the jet angle along the polar angle.

φ is the azimuthal angle and was defined by $\phi = Tan^{-1}(\frac{P_x}{P_y})$.

R is a parameter chosen to fit the algorithm.





Jet Algorithm

$$d_{ij} = \min\left(p_{ti}^{2p}, p_{tj}^{2p}\right)\frac{\Delta R_{ij}^2}{R^2} \qquad \Delta R_{ij}^2 = \left(y_i - y_j\right)^2 + \left(\phi_i - \phi_j\right)^2$$

$$d_{iB} = p_{ti}^{2p}$$

p is the parameter that will distinguish an algorithm from the other with p = 1 being called the inclusive k_t algorithm, p= 0 is the Cambridge/Aachen algorithm and p = -1 the anti-k_t algorithm.

Jet Algorithm

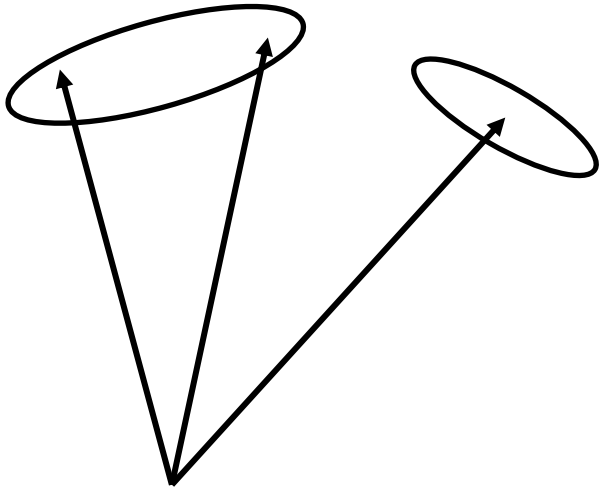
1. Compute $\Delta R_{ij}^2, d_{ij}$ and d_{iB}.
2. Find the minimum of d_{ij} and d_{iB}.
3. If it is d_{ij}, recombine i and j into a single particle and return to step 1.
4. If it is a d_{iB}, declare i to be a jet and remove it from particles and return to step 1.

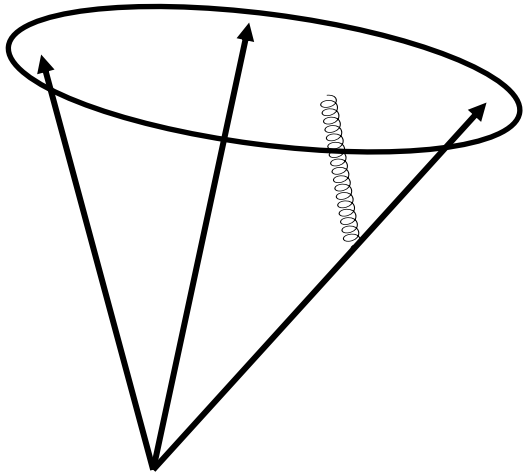
$$d_{ij} = \min\left(p_{ti}^{2p}, p_{tj}^{2p}\right)\frac{\Delta R_{ij}^2}{R^2} \qquad \Delta R_{ij}^2 = \left(y_i - y_j\right)^2 + \left(\phi_i - \phi_j\right)^2$$

$$d_{iB} = p_{ti}^{2p}$$

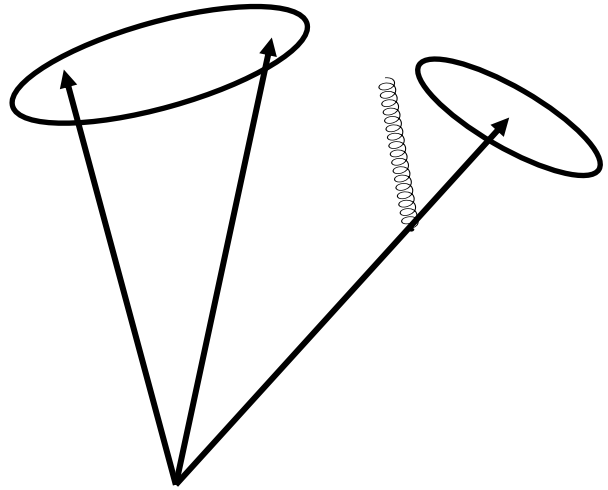
Jet Algorithm-Infrared safety

Infrared (IR) safety is the property that if a soft interacting particle or collinear particle is added to an event, the set of detected jets should remain unchanged





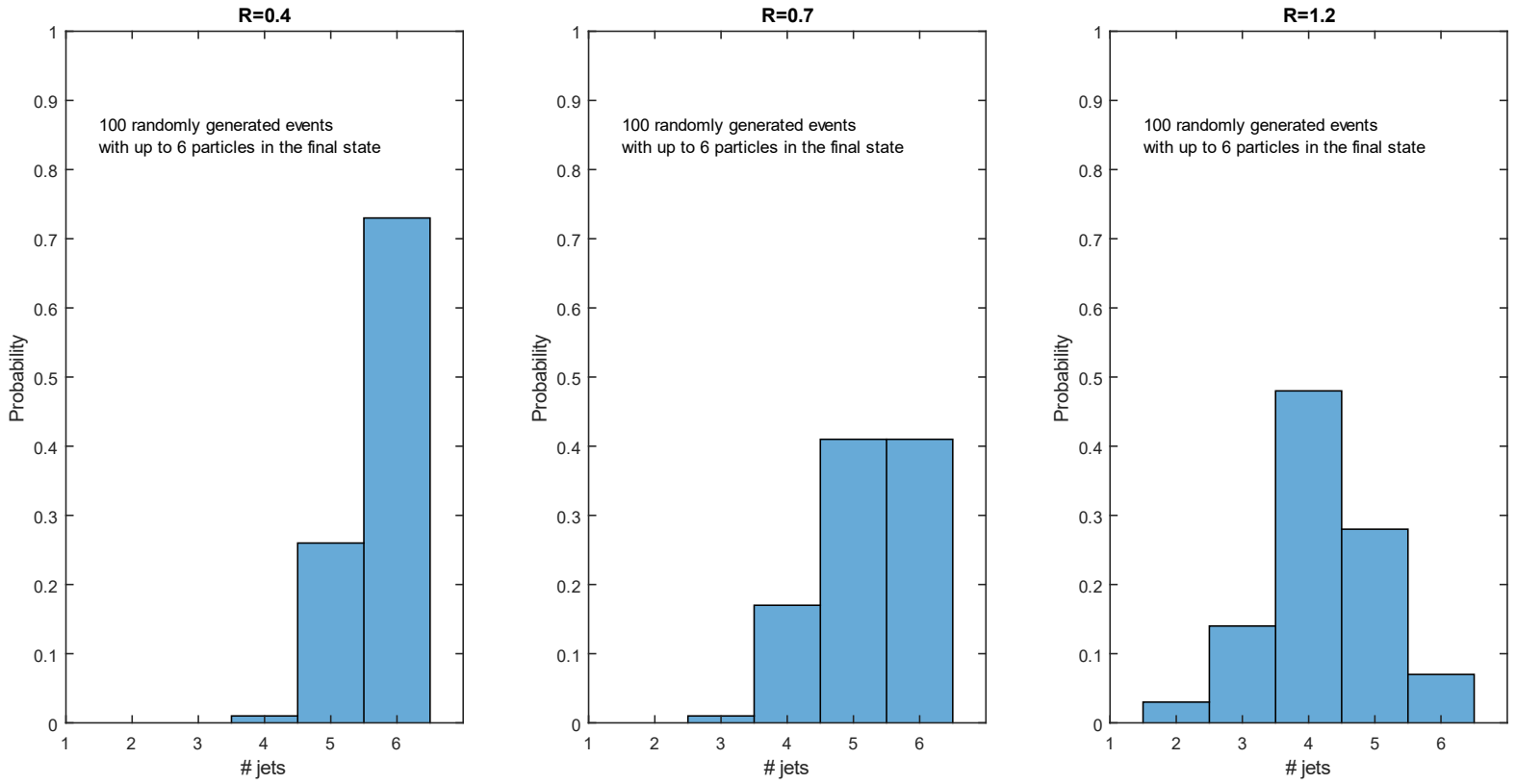
An IR unsafe algorithm would join two jets, which otherwise would not be combined



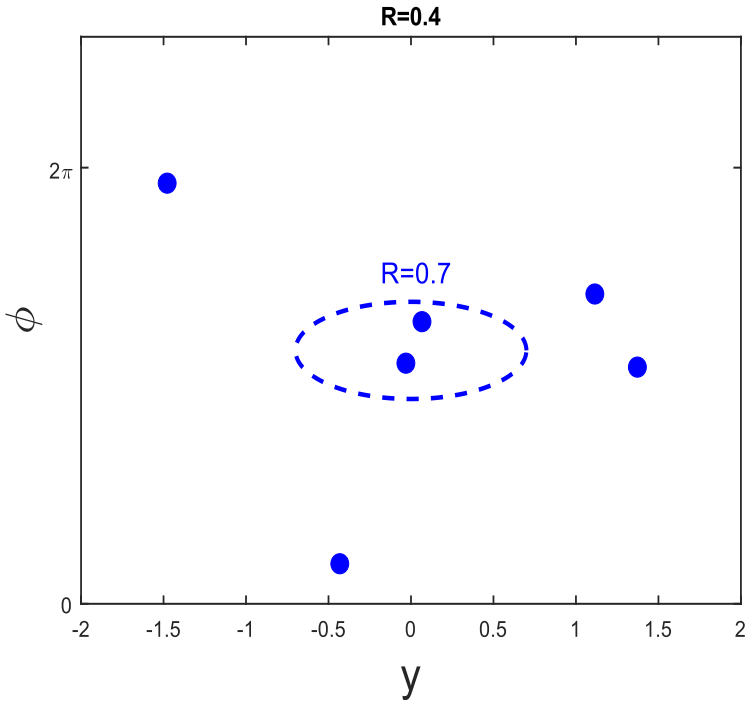
An IR safe algorithm would combine the soft or collinear particle into one jet, thus conserving the number of detected jet

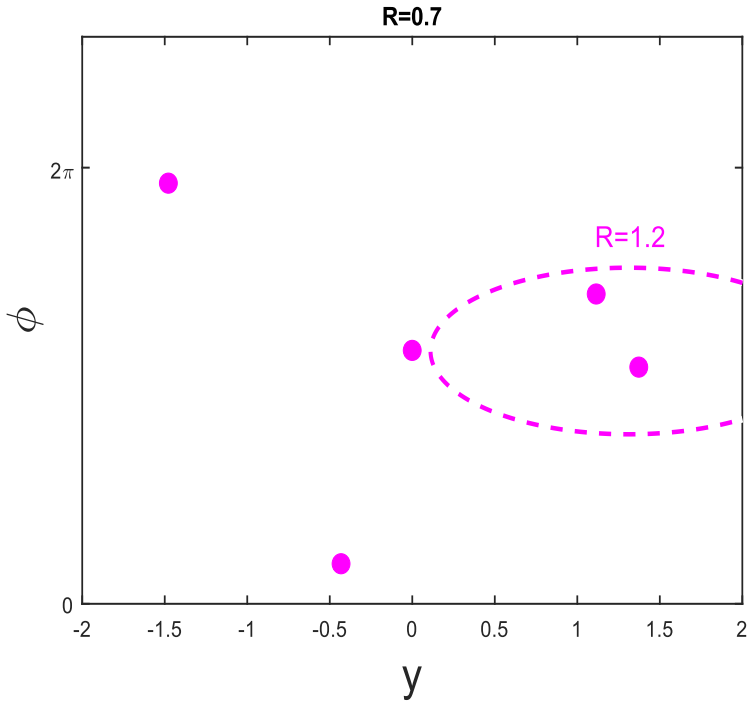
Jet Algorithm-Implementation

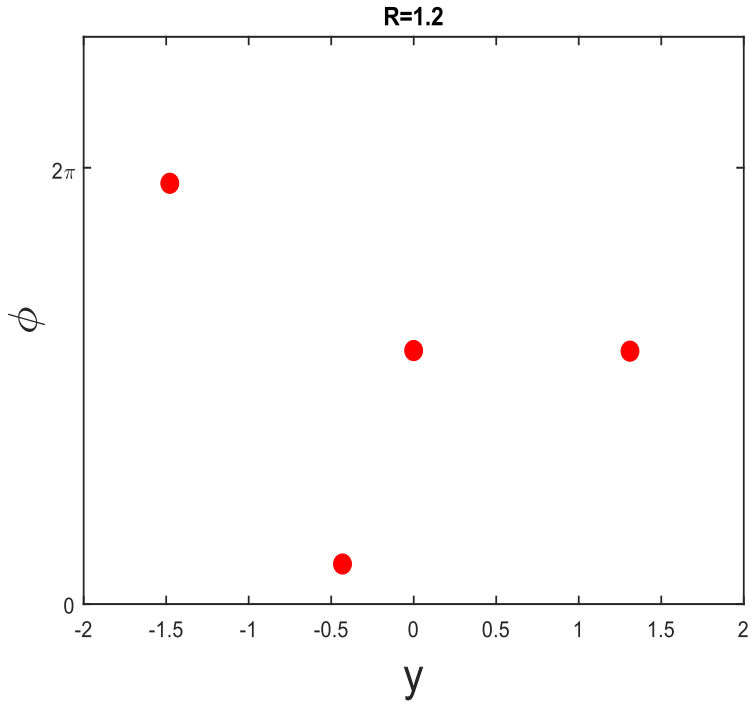
- 100 random events were generated and sorted using an anti-k_t algorithm



Jet Algorithm-Implementation

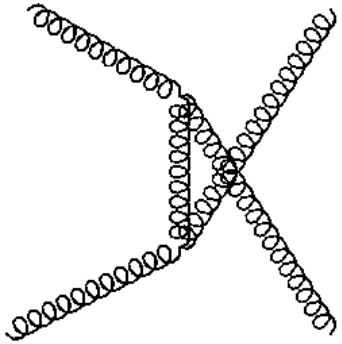




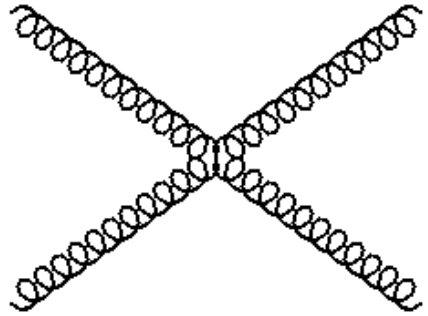


Diagrams that contribute to dijet production at Leading Order

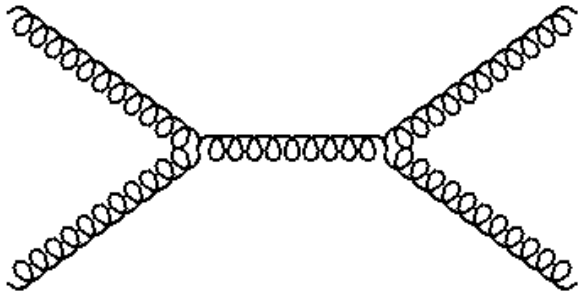
Gluon+Gluon -> Gluon+Gluon



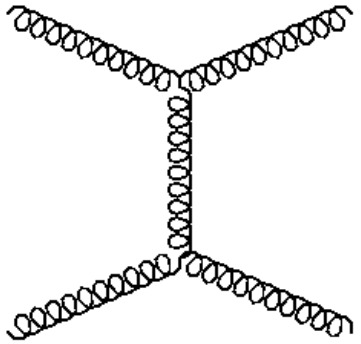
u-channel



Quartic gluon vertice



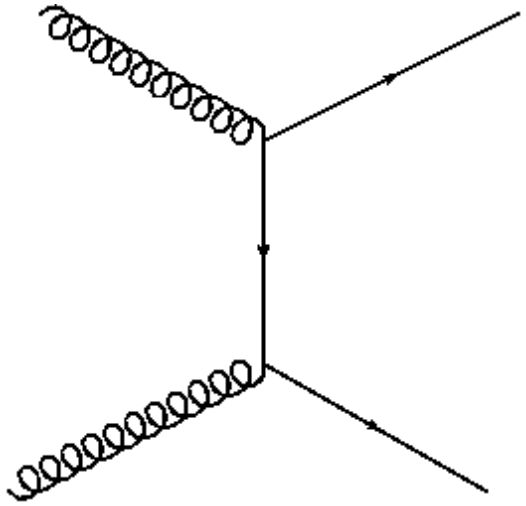
s-channel



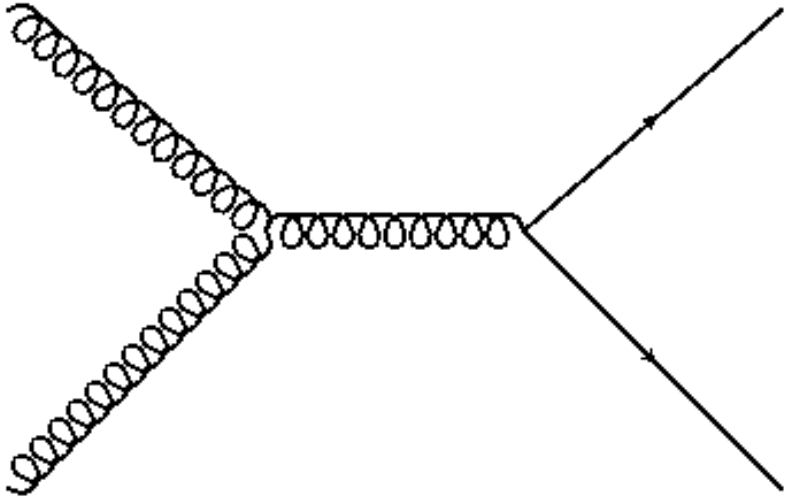
t-channel

Diagrams that contribute to dijet production at leading order

Gluon+Gluon -> Quark+Anti-Quark



t-channel

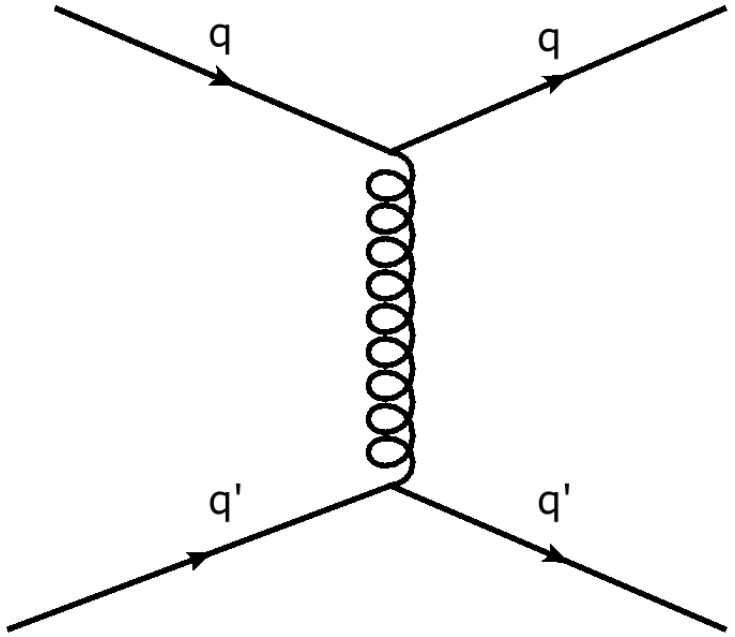


s-channel

Diagrams that contribute to dijet production at leading order

Quark+Quark -> Quark+Quark

With different flavours.

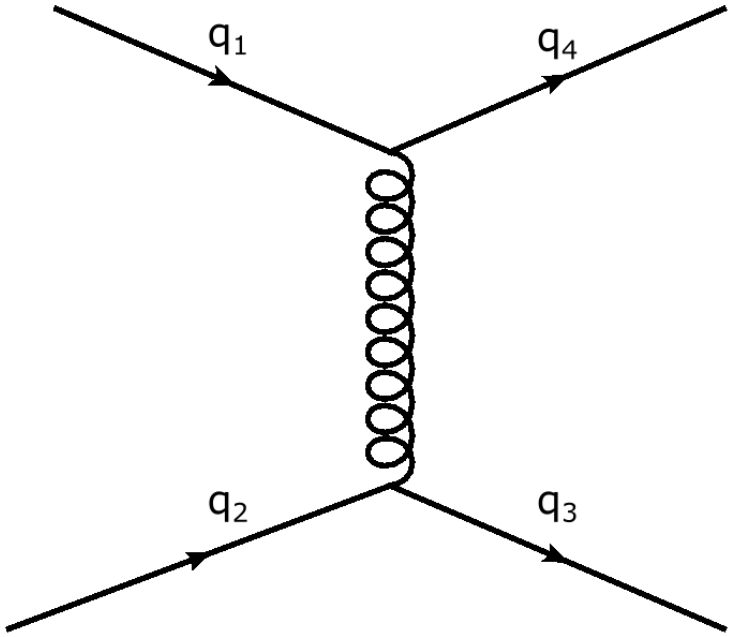


t-channel

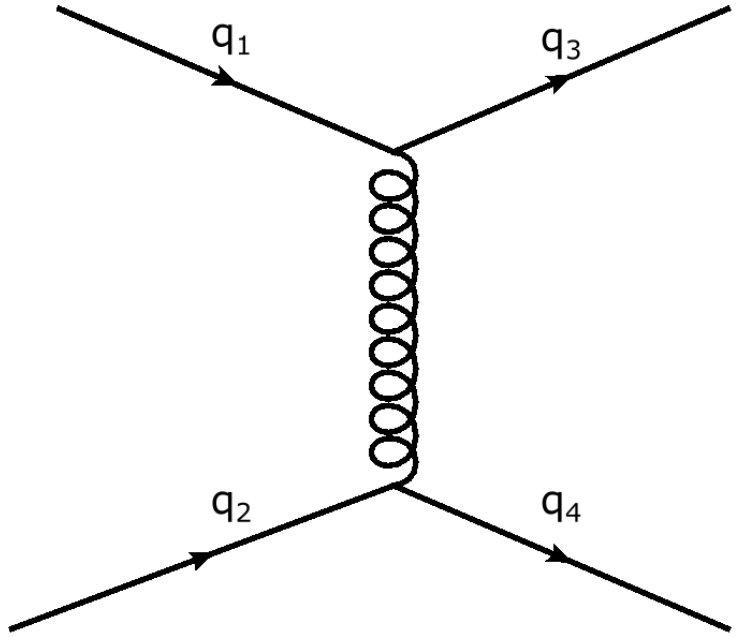
Diagrams that contribute to dijet production at leading order

Quark+Quark -> Quark+Quark

With the same flavours.



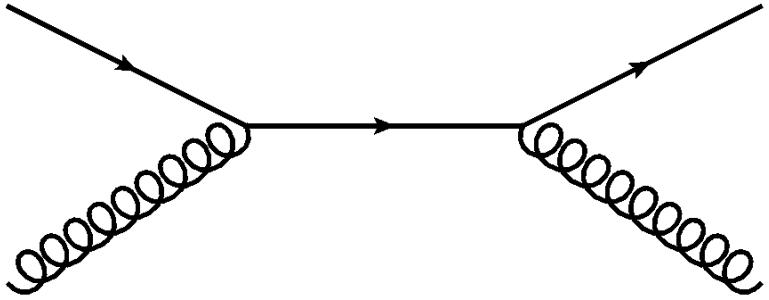
t-channel



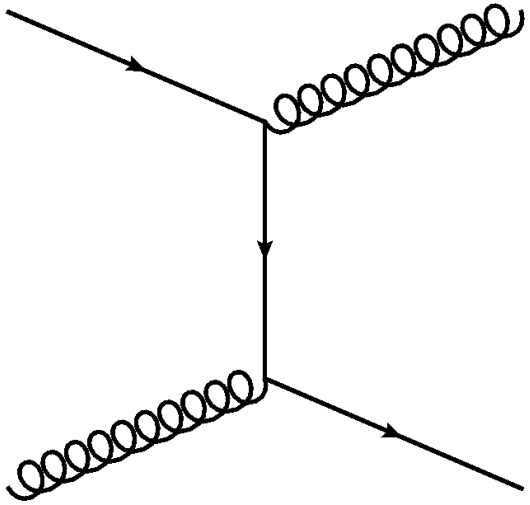
u-channel

Diagrams that contribute to dijet production at leading order

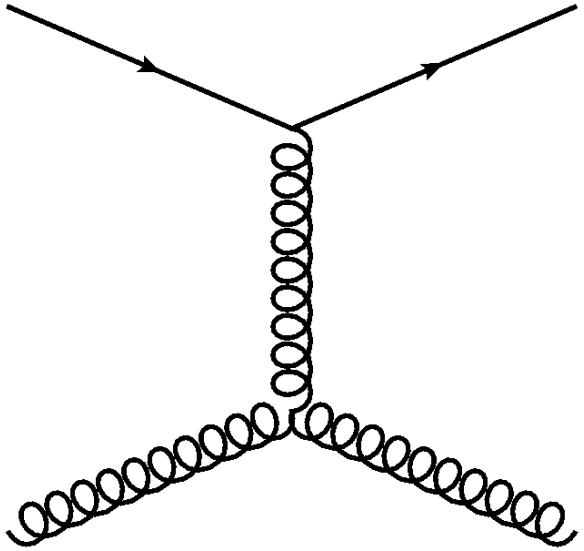
Quark+Gluon -> Quark+Gluon



s-channel



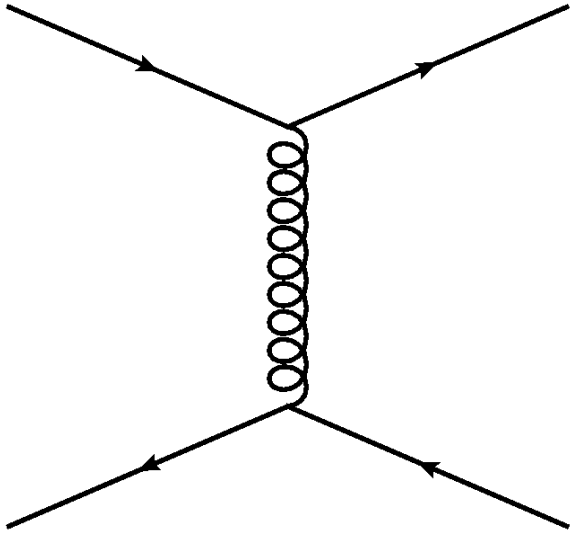
t-channel



t-channel

Diagrams that contribute to dijet production at leading order

Quark+Anti-Quark -> Quark+Anti-Quark
With the same flavour



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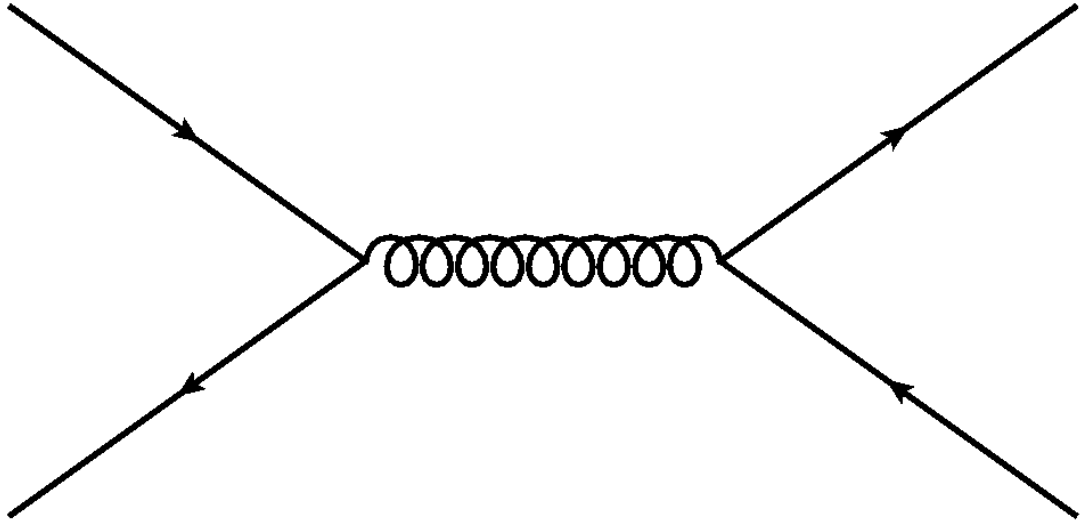
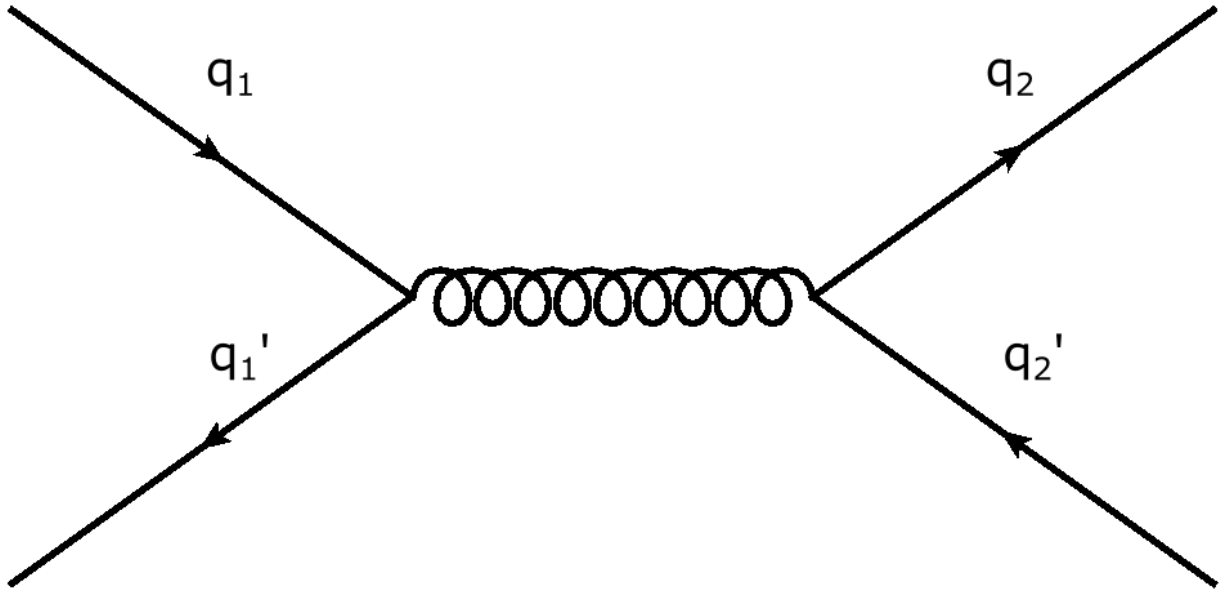


s-channel

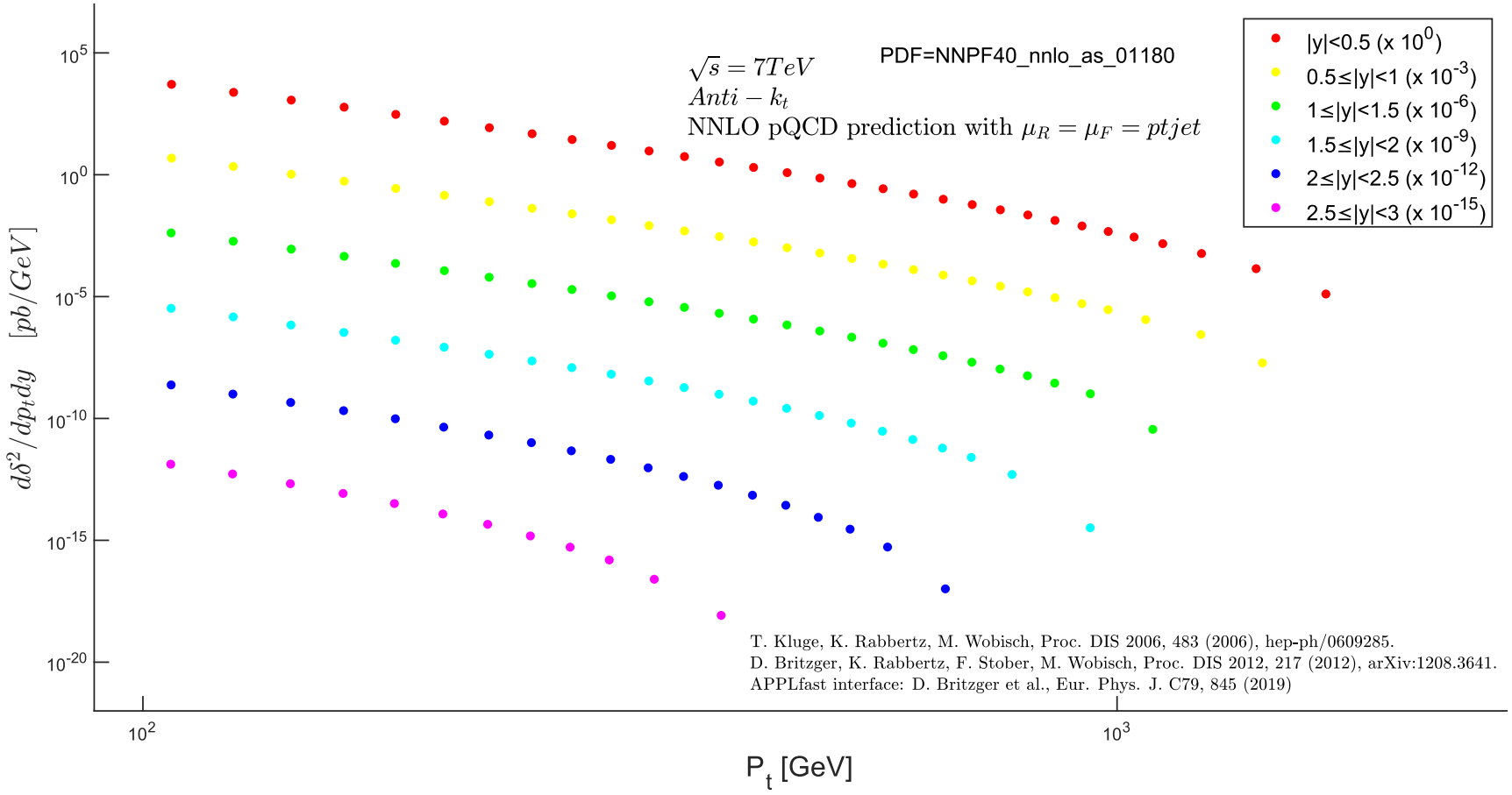
Diagrams that contribute to dijet production at leading order

Quark+Anti-Quark -> Quark+Anti-Quark
With different flavours



s-channel

Results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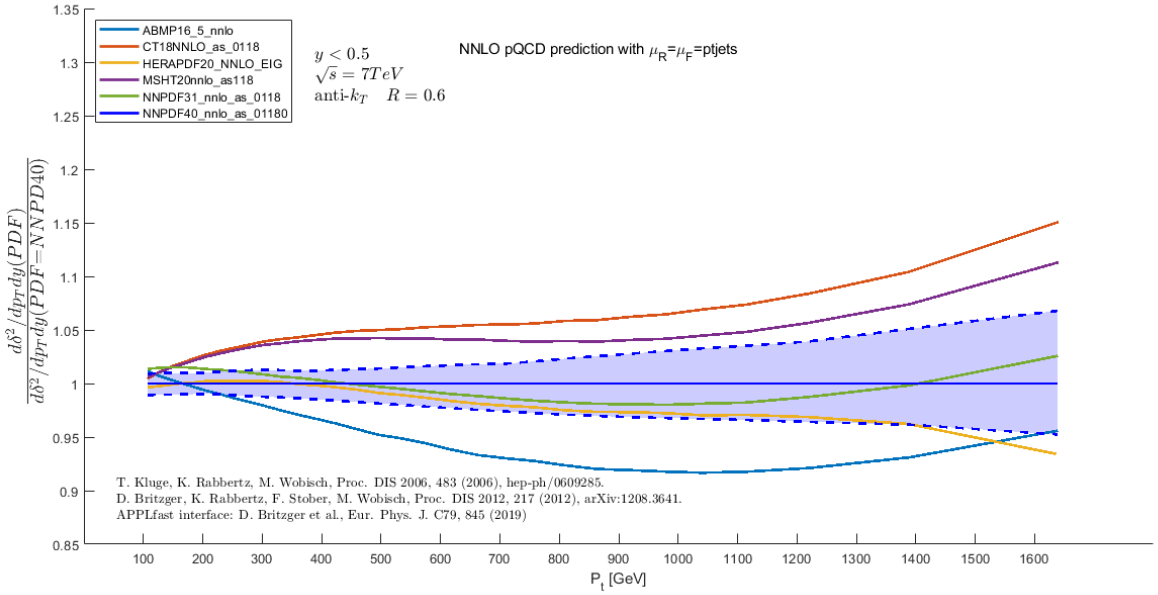
$Anti - k_t$
NNLO pQCD prediction with $\mu_R = \mu_F = ptjet$
PDF=NNPF40_nnlo_as_01180
|y|<0.5 (x 10^0)
0.5≤|y|<1 (x 10^-3)
1≤|y|<1.5 (x 10^-6)
1.5≤|y|<2 (x 10^-9)
2≤|y|<2.5 (x 10^-12)
2.5≤|y|<3 (x 10^-15)
$d\delta^2/dp_t dy \quad [pb/GeV]$
10^5
10^0
10^{-5}
10^{-10}
10^{-15}
10^{-20}
10^2
10^3
P_t [GeV]
T. Kluge, K. Rabbertz, M. Wobisch, Proc. DIS 2006, 483 (2006), hep-ph/0609285.
D. Britzger, K. Rabbertz, F. Stober, M. Wobisch, Proc. DIS 2012, 217 (2012), arXiv:1208.3641.
APPLfast interface: D. Britzger et al., Eur. Phys. J. C79, 845 (2019)

Results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HERAPDF20_NNLO_EIG
MSHT20nnlo_as118
NNPDF31_nnlo_as_0118
NNPDF40_nnlo_as_01180
$y < 0.5$
$\sqrt{s} = 7TeV$
anti-k_T $R = 0.6$
NNLO pQCD prediction with μ_R=μ_F=ptjets
$\frac{d\delta^2/dp_T dy(PDF)}{d\delta^2/dp_T dy(PDF=NNPD40)}$
T. Kluge, K. Rabbertz, M. Wobisch, Proc. DIS 2006, 483 (2006), hep-ph/0609285.
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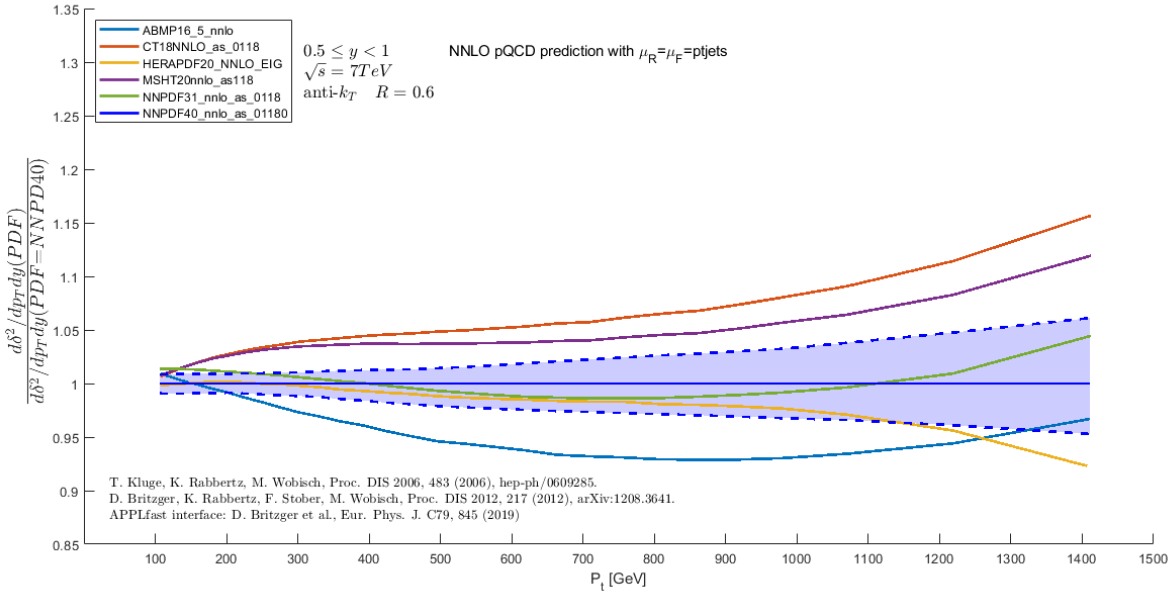
P$_t$ [GeV]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CT18NNLO_as_0118
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MSHT20nnlo_as118
NNPDF31_nnlo_as_0118
NNPDF40_nnlo_as_01180
$0.5 \leq y < 1$
$\sqrt{s} = 7TeV$
anti-k_T $R = 0.6$
NNLO pQCD prediction with μ_R=μ_F=ptjets
$\frac{d\delta^2/dp_T dy(PDF)}{d\delta^2/dp_T dy(PDF=NNPD40)}$
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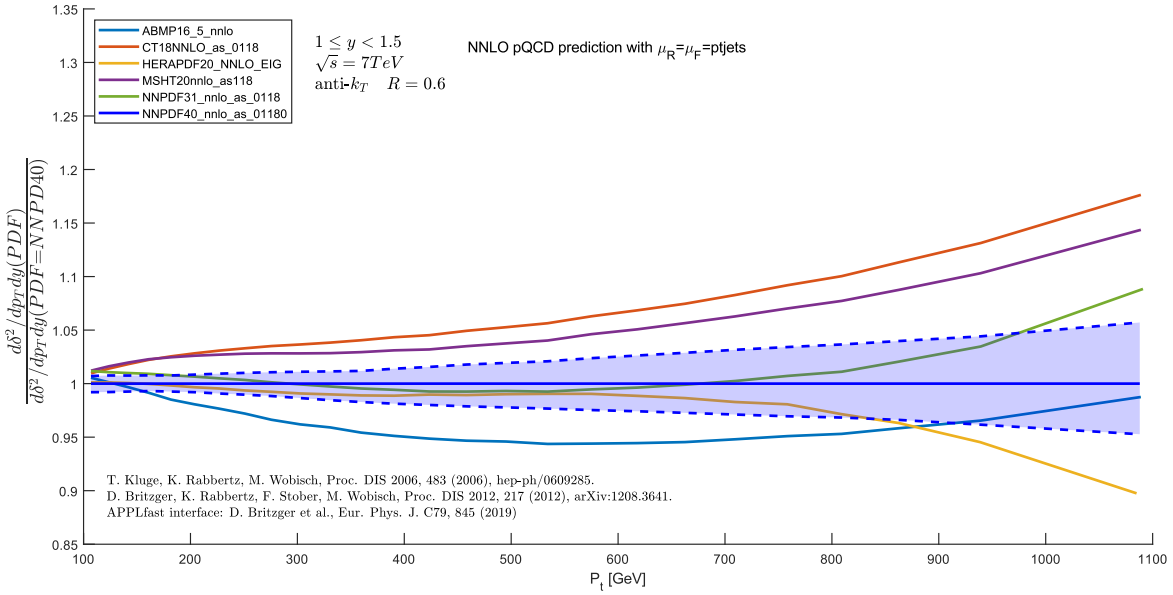
P$_t$ [GeV]

Results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NNPDF40_nnlo_as_01180
$1 \leq y < 1.5$
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NNLO pQCD prediction with μ_R=μ_F=ptjets
$d\delta^2/dp_T dy(PDF)$ / $d\delta^2/dp_T dy(PDF{=}NNPD40)$
T. Kluge, K. Rabbertz, M. Wobisch, Proc. DIS 2006, 483 (2006), hep-ph/0609285.
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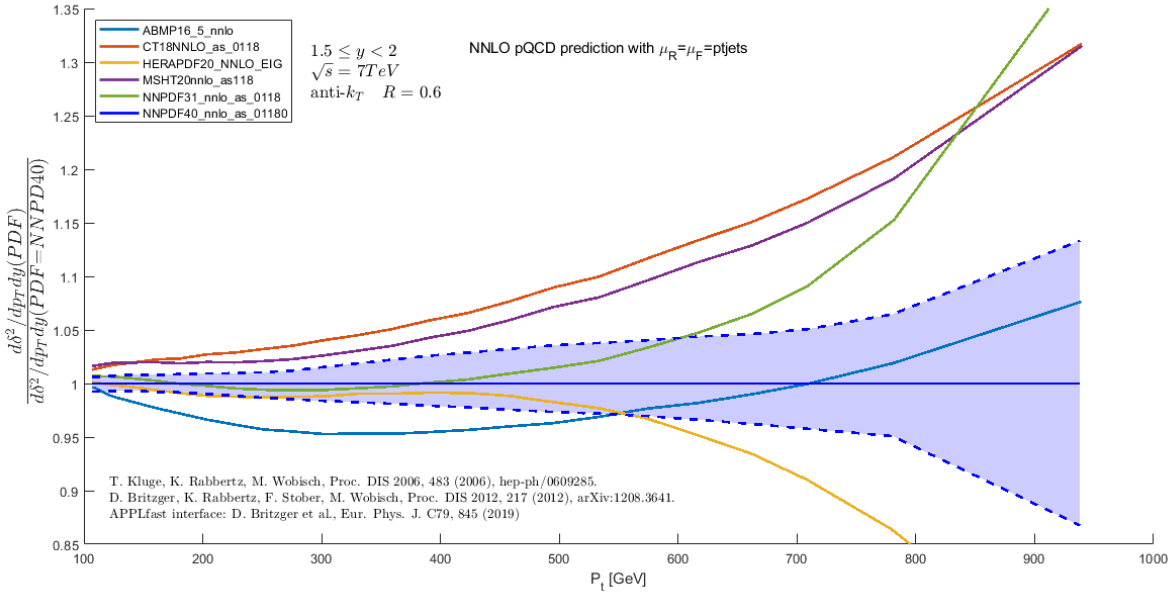
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MSHT20nnlo_as118
NNPDF31_nnlo_as_0118
NNPDF40_nnlo_as_01180
$1.5 \leq y < 2$
$\sqrt{s} = 7TeV$
anti-k_T $R = 0.6$
NNLO pQCD prediction with μ_R=μ_F=ptjets
$d\delta^2/dp_T dy(PDF)$ / $d\delta^2/dp_T dy(PDF{=}NNPD40)$
T. Kluge, K. Rabbertz, M. Wobisch, Proc. DIS 2006, 483 (2006), hep-ph/0609285.
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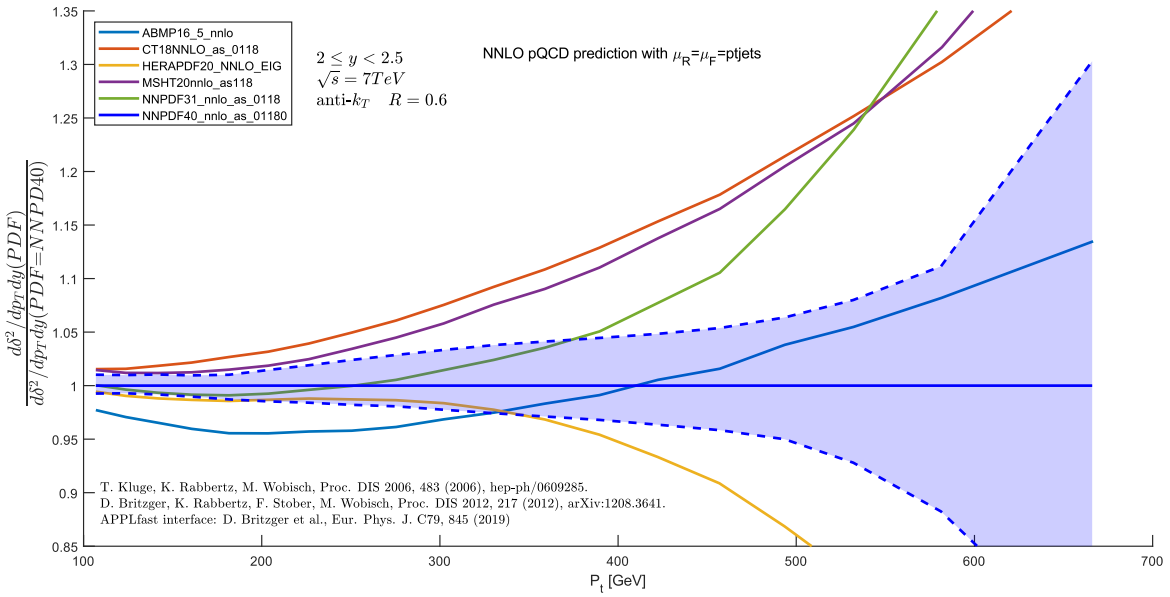
P$_t$ [GeV]

Results


ABMP16_5_nnlo
CT18NNLO_as_0118
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NNPDF31_nnlo_as_0118
NNPDF40_nnlo_as_01180
$2 \leq y < 2.5$
$\sqrt{s} = 7TeV$
anti-k_T $R = 0.6$
NNLO pQCD prediction with μ_R=μ_F=ptjets
$\frac{d\delta^2/dp_T dy(PDF)}{d\delta^2/dp_T dy(PDF=NNPD40)}$
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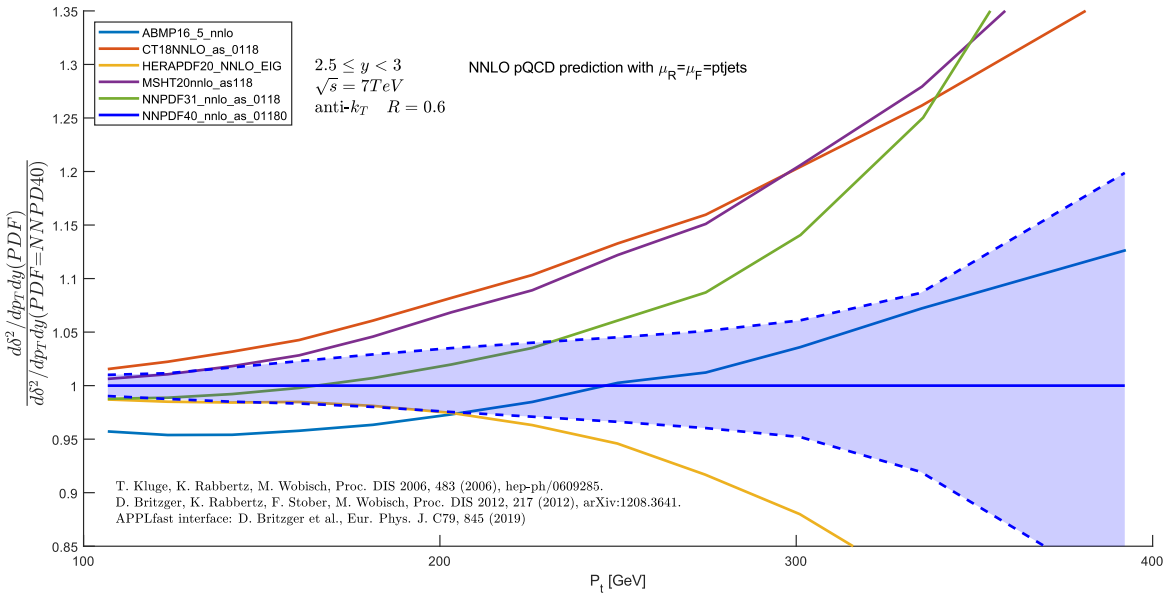
ABMP16_5_nnlo
CT18NNLO_as_0118
HERAPDF20_NNLO_EIG
MSHT20nnlo_as118
NNPDF31_nnlo_as_0118
NNPDF40_nnlo_as_01180
$2.5 \leq y < 3$
$\sqrt{s} = 7TeV$
anti-k_T $R = 0.6$
NNLO pQCD prediction with μ_R=μ_F=ptjets
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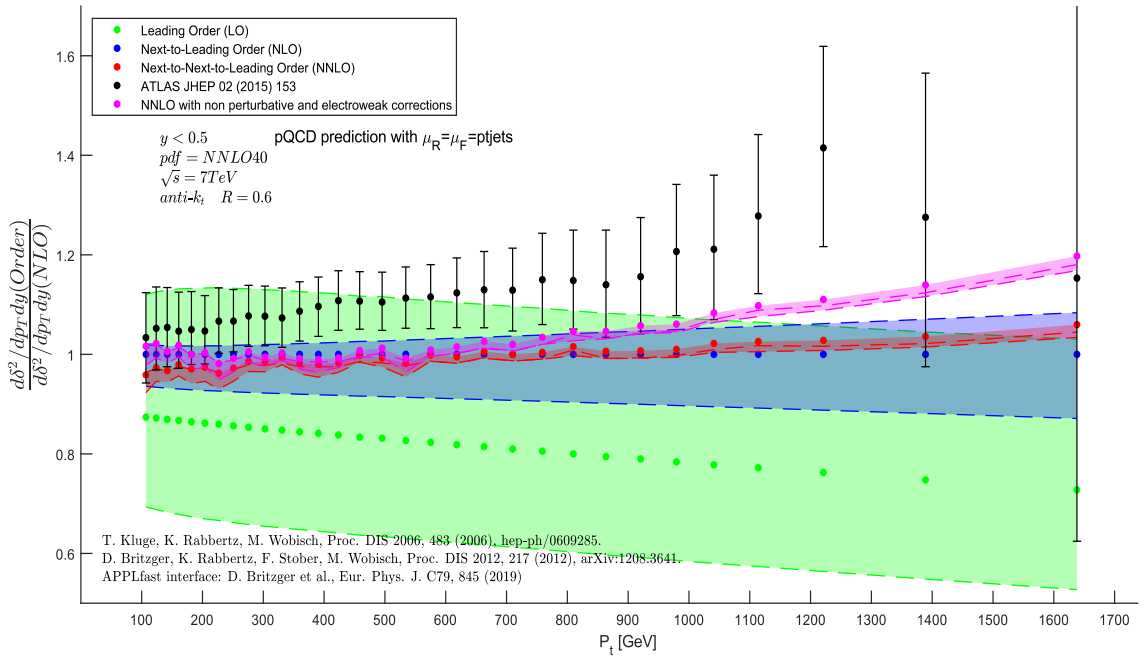
APPLfast interface: D. Britzger et al., Eur. Phys. J. C79, 845 (2019)
P$_t$ [GeV]

Results


Leading Order (LO)
Next-to-Leading Order (NLO)
Next-to-Next-to-Leading Order (NNLO)
ATLAS JHEP 02 (2015) 153
NNLO with non perturbative and electroweak corrections
$y < 0.5$
pQCD prediction with μ_R=μ_F=ptjets
$pdf = NNLO40$
$\sqrt{s} = 7TeV$
$anti\text{-}k_t \quad R = 0.6$
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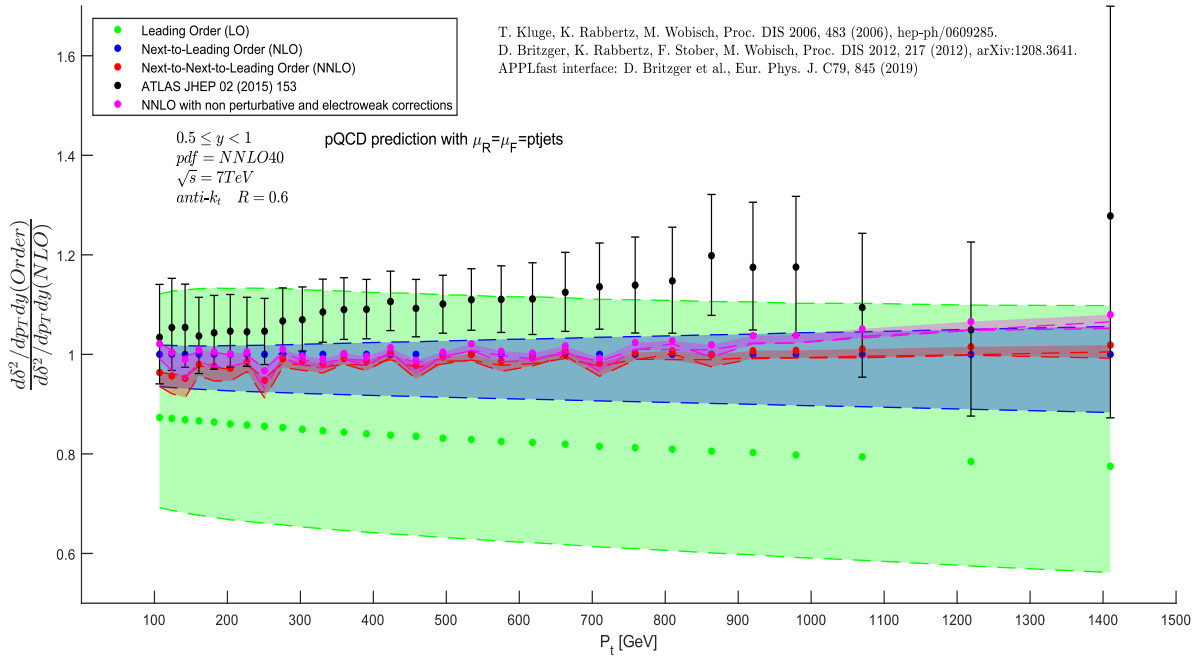
Leading Order (LO)
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ATLAS JHEP 02 (2015) 153
NNLO with non perturbative and electroweak corrections
$0.5 \leq y < 1$
pQCD prediction with μ_R=μ_F=ptjets
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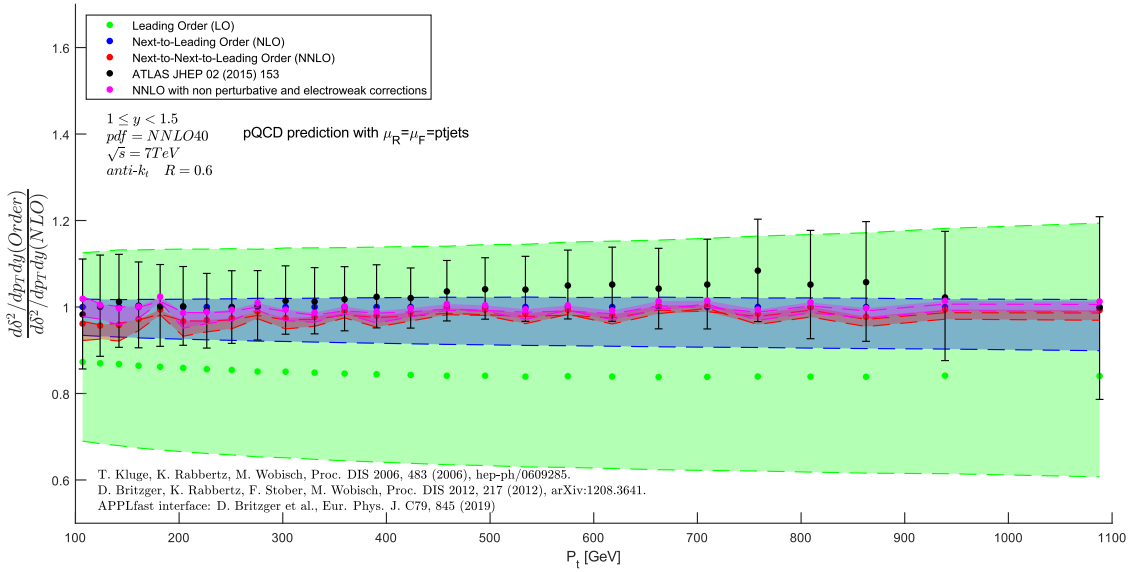
Leading Order (LO)
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ATLAS JHEP 02 (2015) 153
NNLO with non perturbative and electroweak corrections
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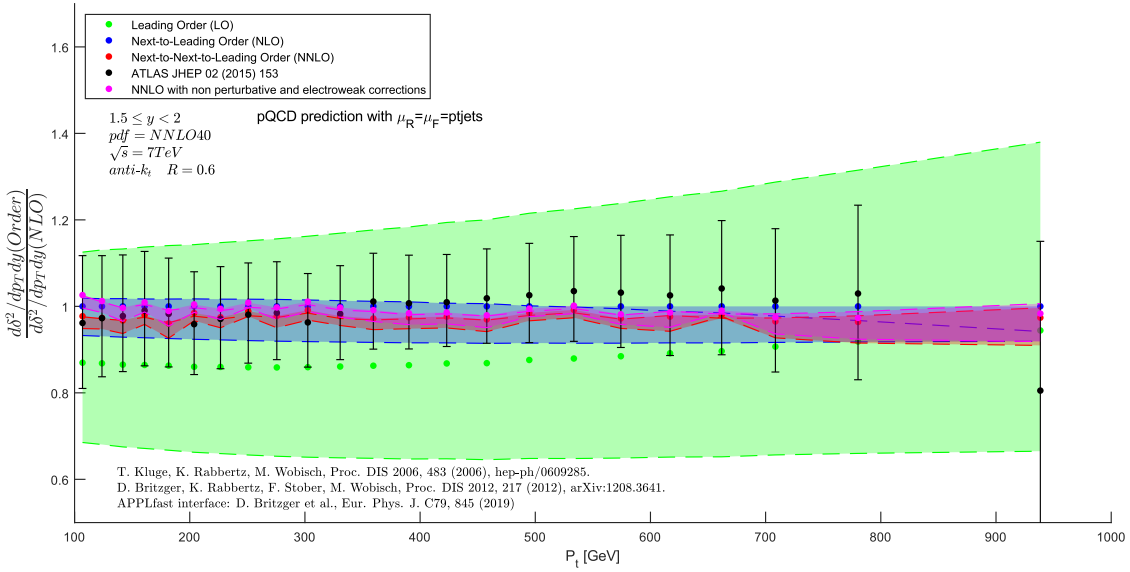
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ATLAS JHEP 02 (2015) 153
NNLO with non perturbative and electroweak corrections
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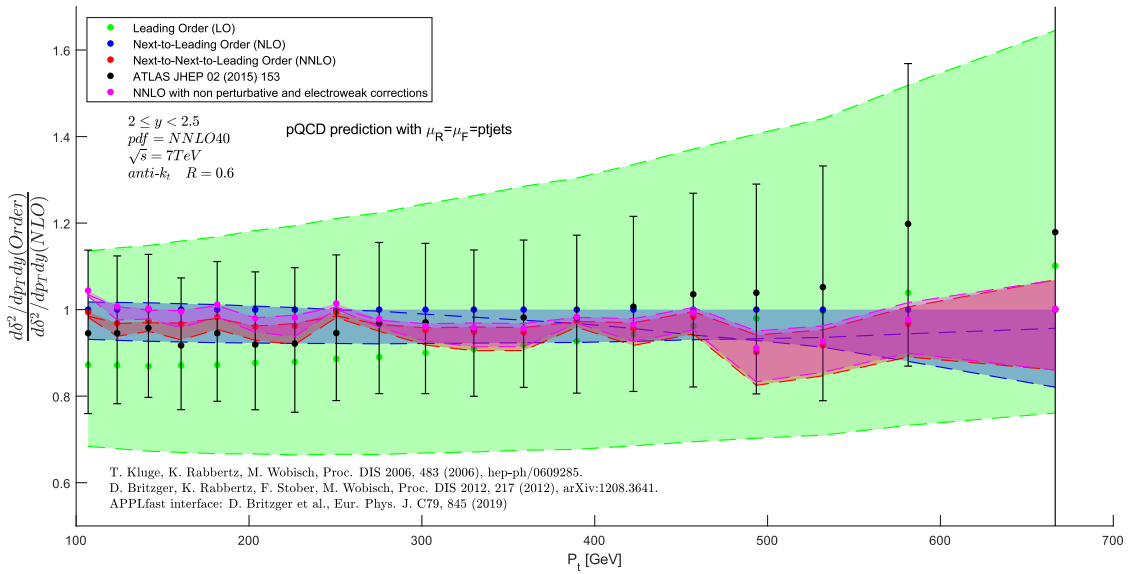
Leading Order (LO)
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NNLO with non perturbative and electroweak corrections
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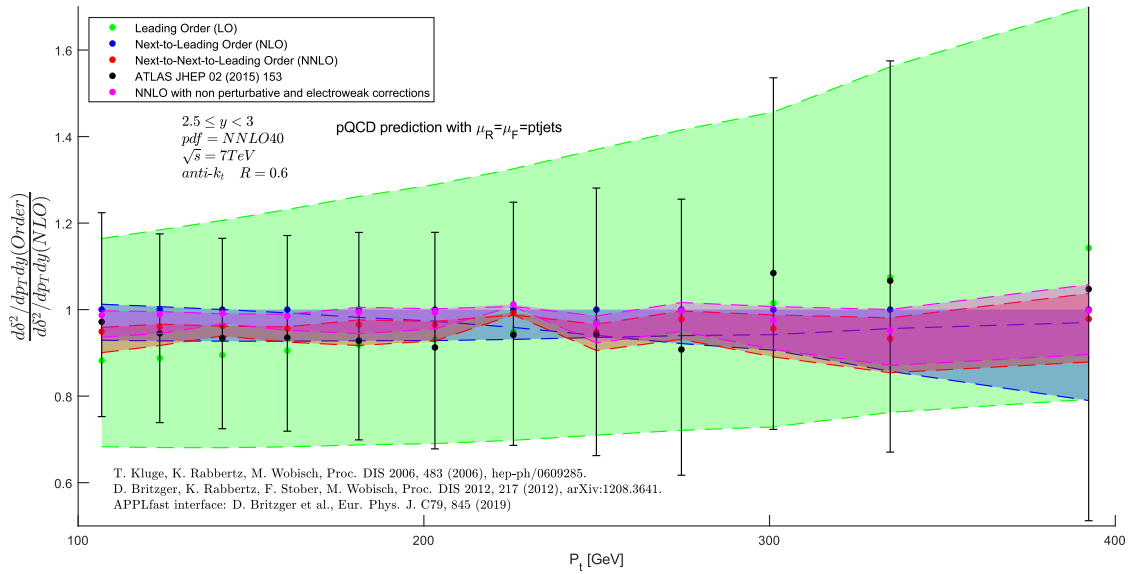
Leading Order (LO)
Next-to-Leading Order (NLO)
Next-to-Next-to-Leading Order (NNLO)
ATLAS JHEP 02 (2015) 153
NNLO with non perturbative and electroweak corrections
$2.5 \leq y < 3$
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pQCD prediction with μ_R=μ_F=ptjets
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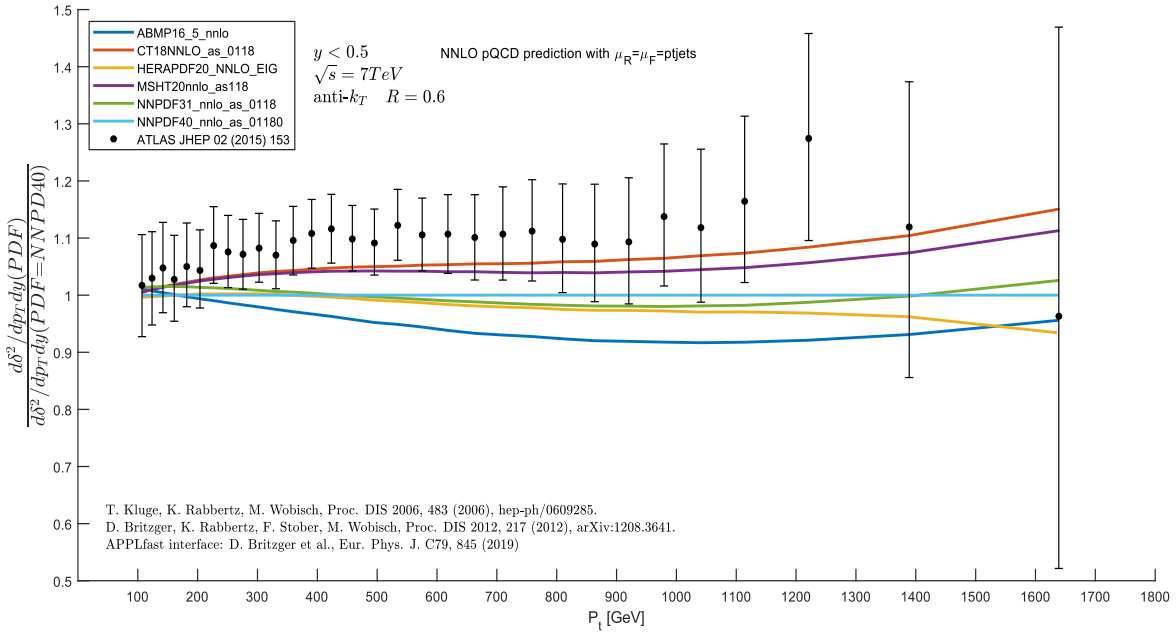
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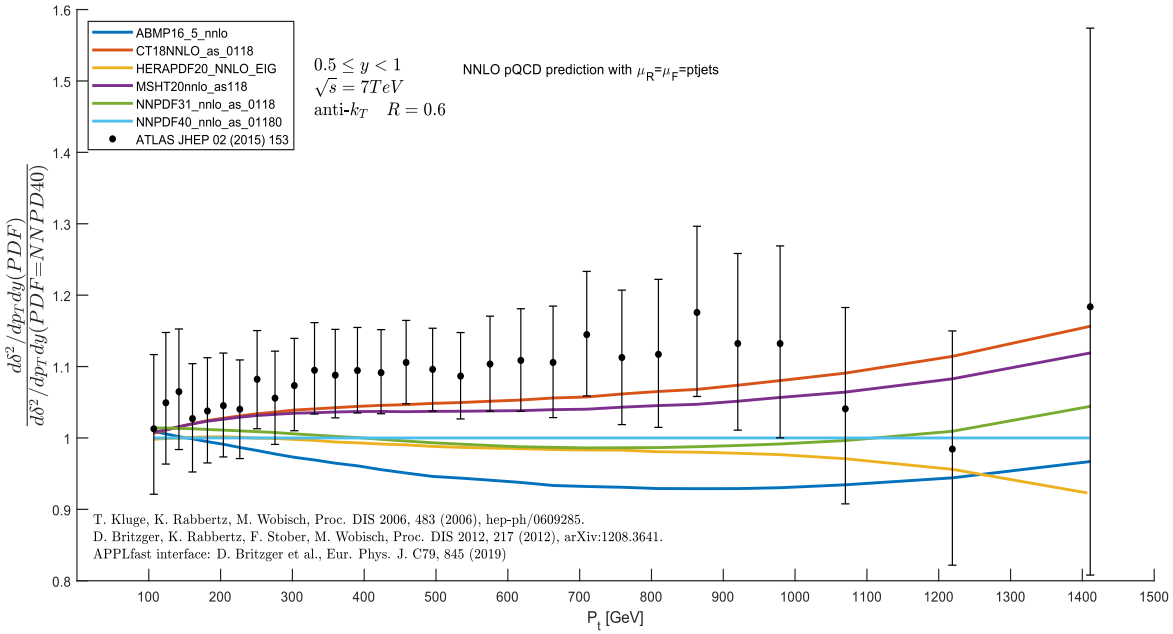
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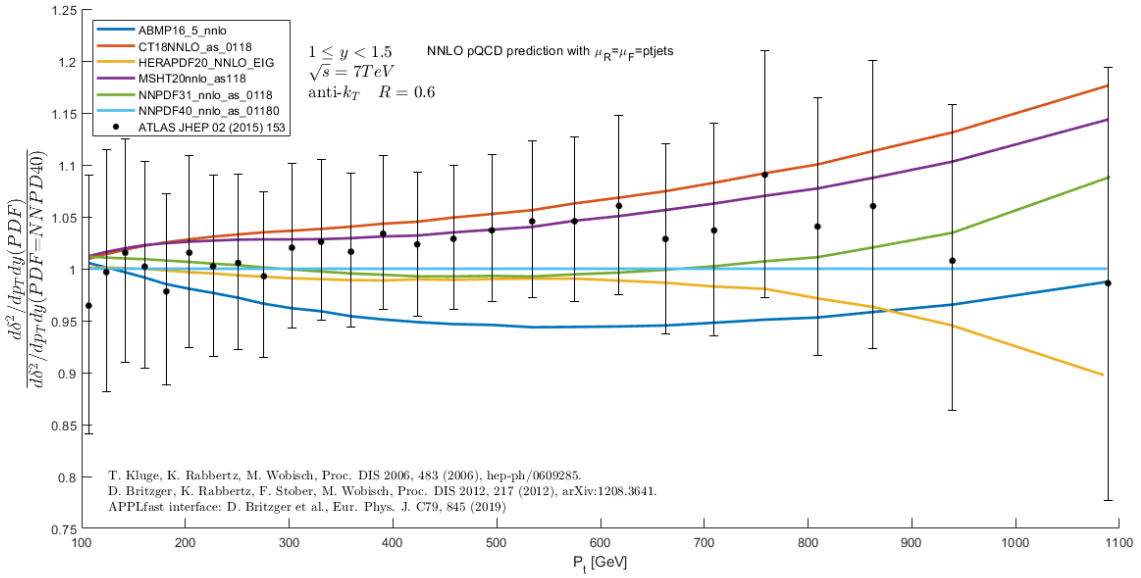
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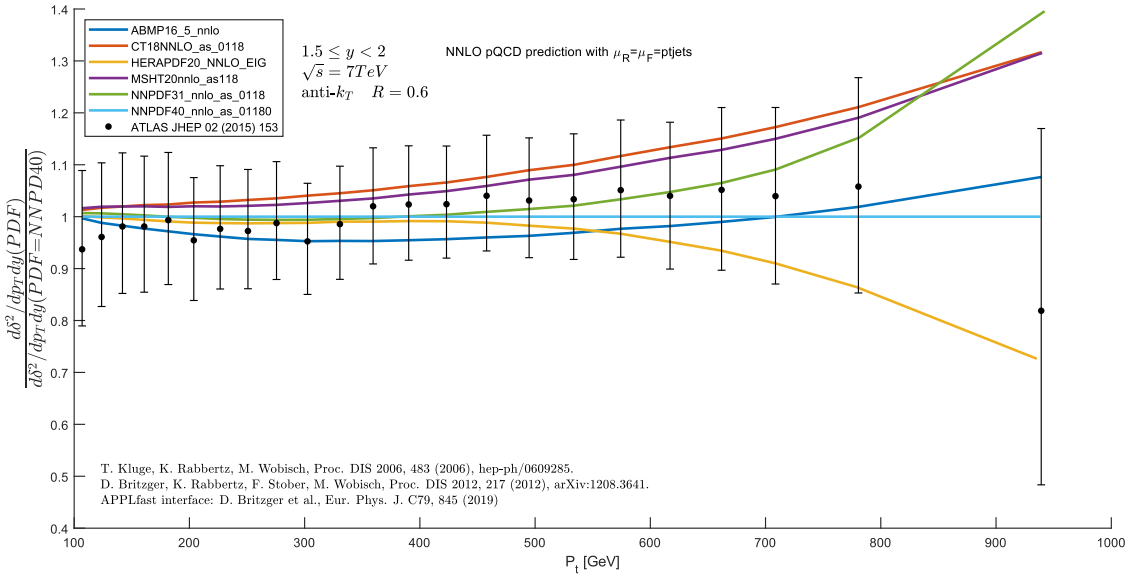
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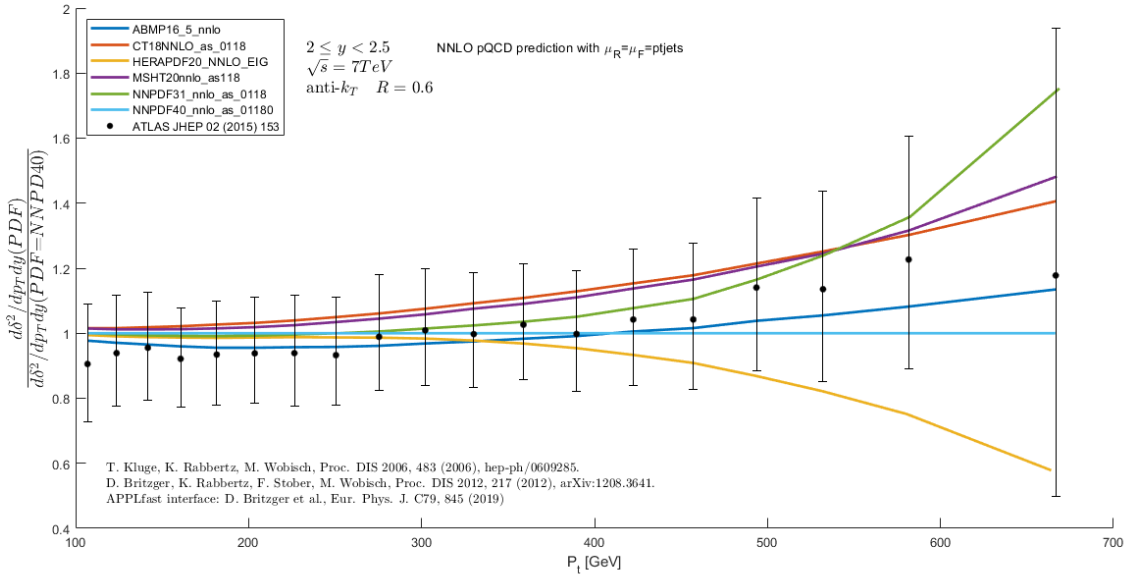
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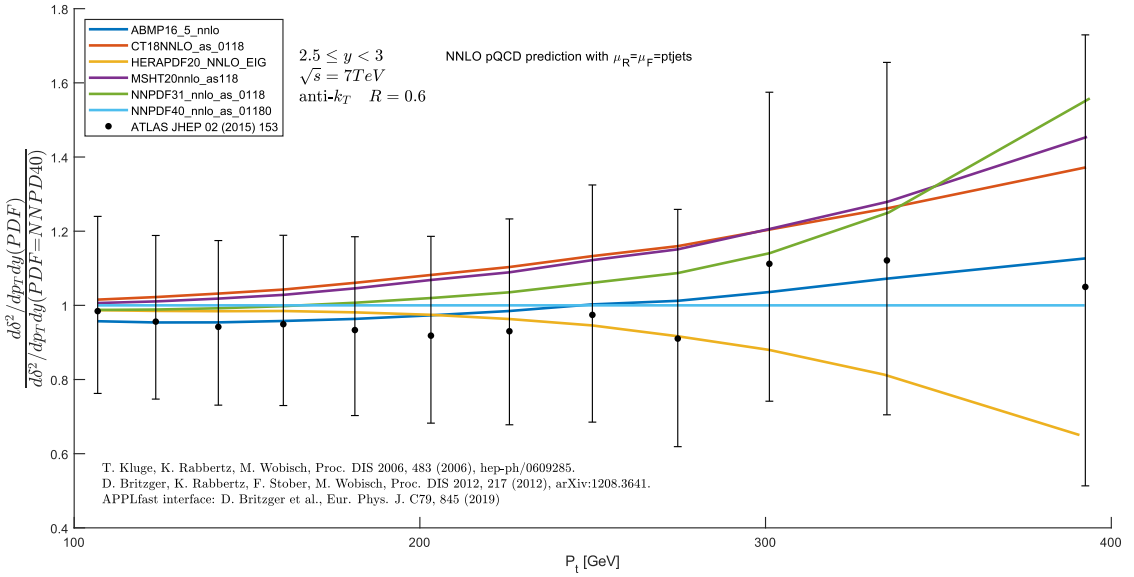
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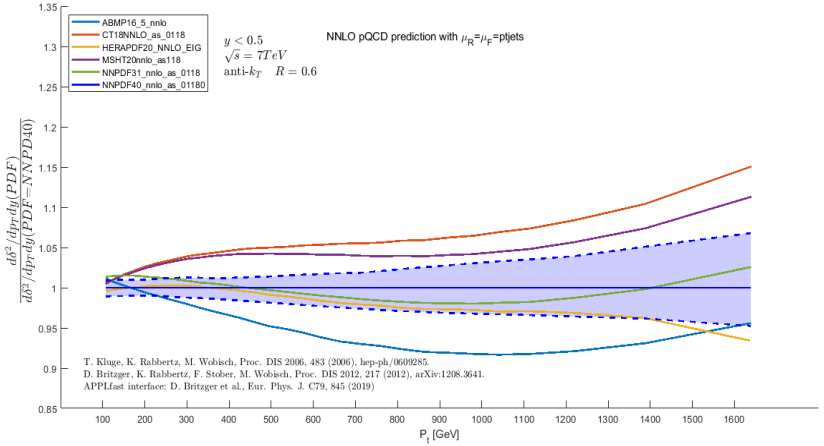

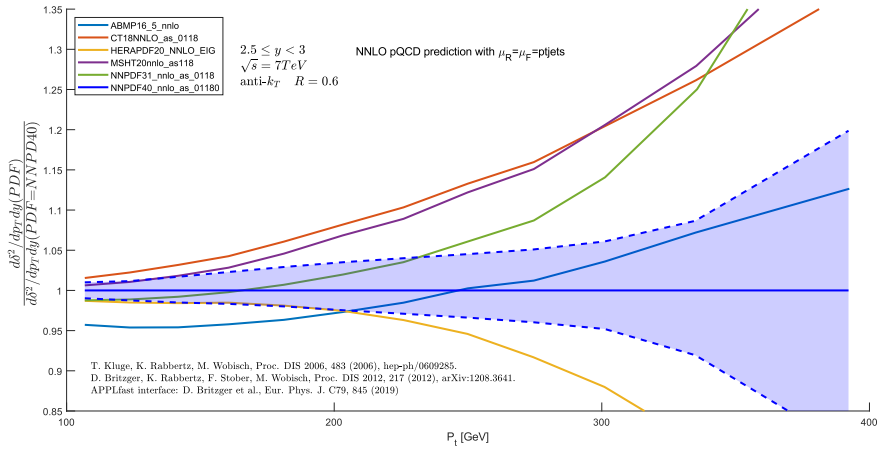

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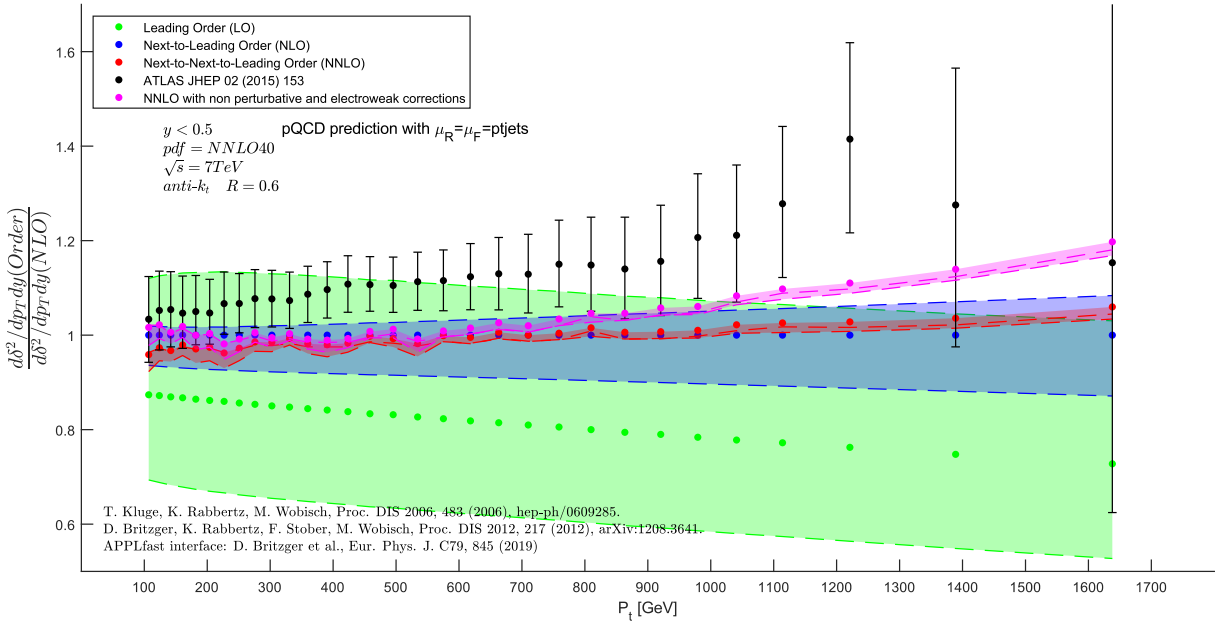

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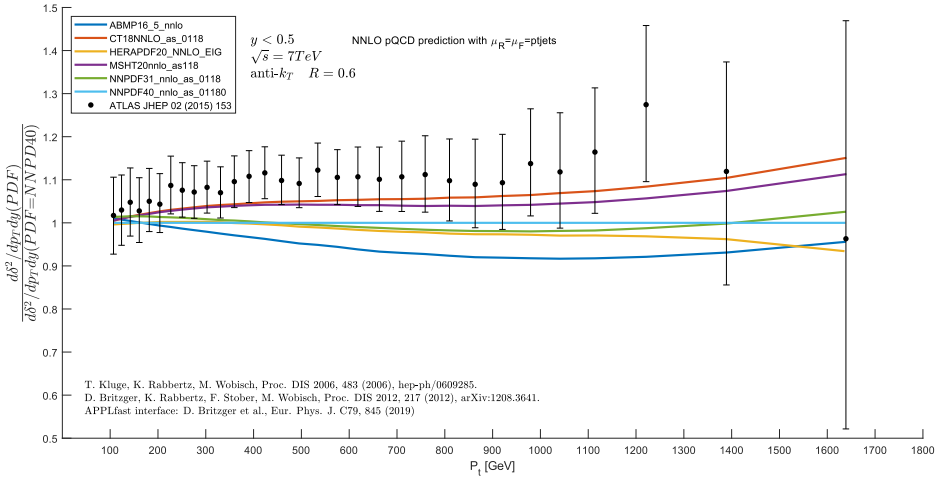

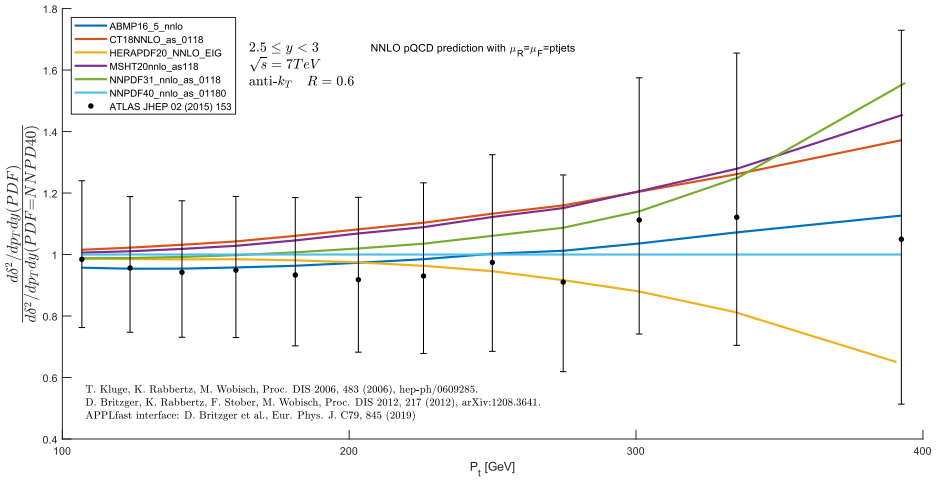

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- So, we conclude that the analysis made in this project shows no evidence for new physics for the observables studied at the LHC

Thank you