Cluster particle production @SPD experiment. Pythia vs Herwig

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SPD collaboration meeting, 15 May 2025

Motivation

- Partons - products of hadron-hadron hard scattering are not accessible for direct measurement
- We can get an information about these particles from the final state products resulting from harmonization of quark-gluon shower created by the initial parton
- If the energy of parton is high in the final state a *jet* of particles will be formed, which will correspond to initial parton

- The goals of this study:
  - Understand the admissibility of such approximation at low energies
  - Study processes of parton production at energy region between non-pQCD and pQCD

Event generation

- Pythia8/Herwig/Herwig+MadGraph generators and FastJet package were used
- Energy of collisions $\sqrt{s} = 27$ GeV
- Herwig's generation parameters are setup same as Pythia
- Clustered jets were matched to:
  - hard scattered parton (status = 23) – Pythia
  - Highest p_T parton among all particles – Herwig/ Herwig+MadGraph
- To reconstruct parton's p_T decision tree was used
- Considered cases:
  - $qg \rightarrow q\gamma$ process
  - All QCD processes

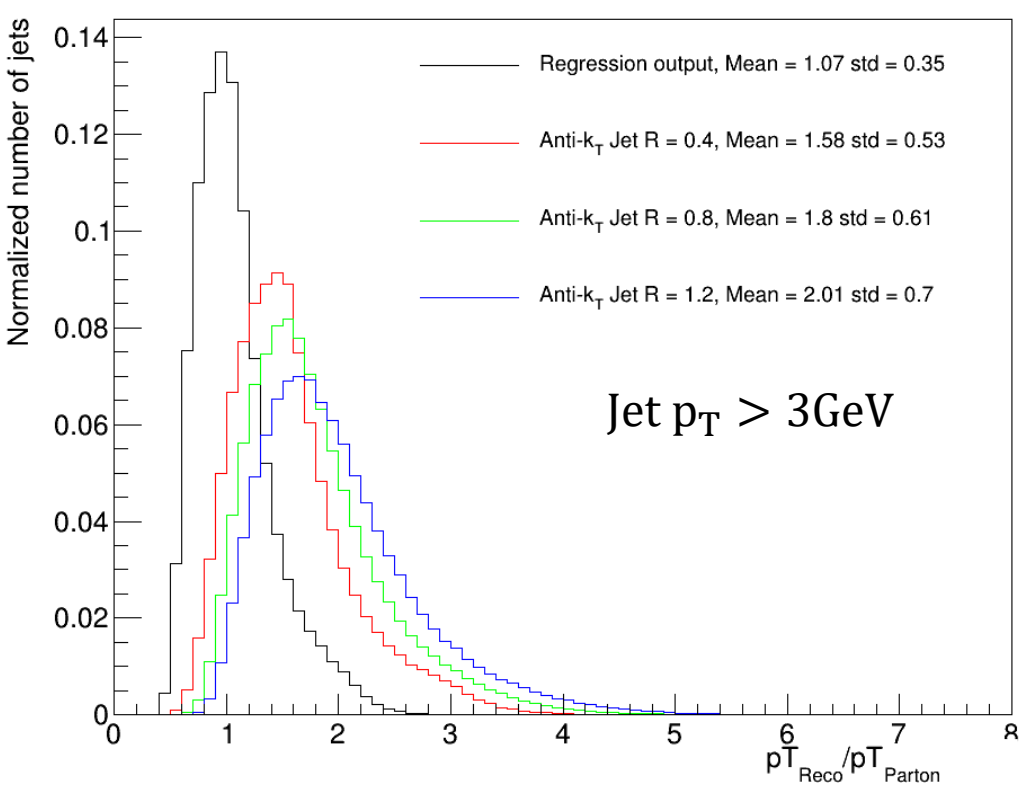
Selection strategies

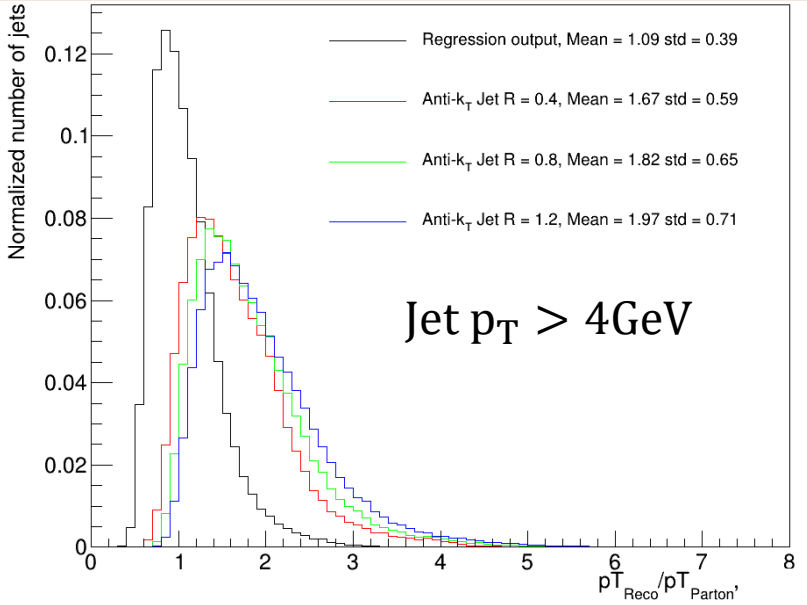
- *anti-kt* algorithm with parameter R = 0.4, 0.8, 1.2 was used for jet clustering
- Jet was clustered from final state particles with $p_T > 0.25$ GeV and $\eta < 5$
- Jet should have at least two particles
- $qg \rightarrow q\gamma$ process
  - Leading jet p_T cuts: $p_{T,\,jet}$ >3 GeV, >4 GeV, >5 GeV.
  - Leading photon is excluded from jet
- QCD processes (Inclusive case)
  - Leading jet p_T cuts: $p_{T,\,jet}$ >3 GeV, >4 GeV, >5 GeV.
  - At least 2 jets in event
  - Secondary jet p_T > 2 GeV

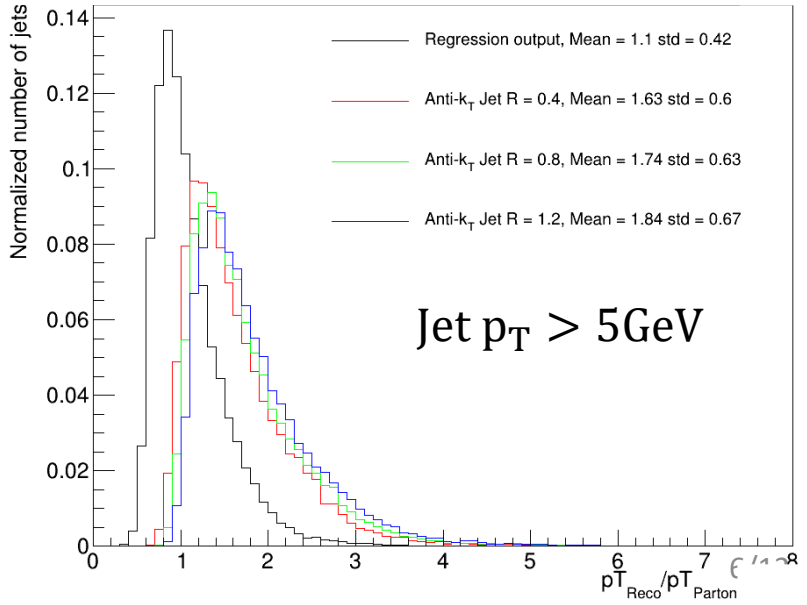
Boosted decision tree training

- $qg \rightarrow q\gamma$ process training parameters
  - p_x, p_y of leading jet
  - leading jet η
  - leading jet particle multiplicity
  - Mean p_T of jet particles
  - p_x, p_y of leading and secondary particles in jet
- Inclusive case training parameters
  - p_x, p_y of secondary jet in addition to already mentioned parameters
- Jets reconstructed with different R are used together for training

Pythia - $qg \rightarrow q\gamma$ process

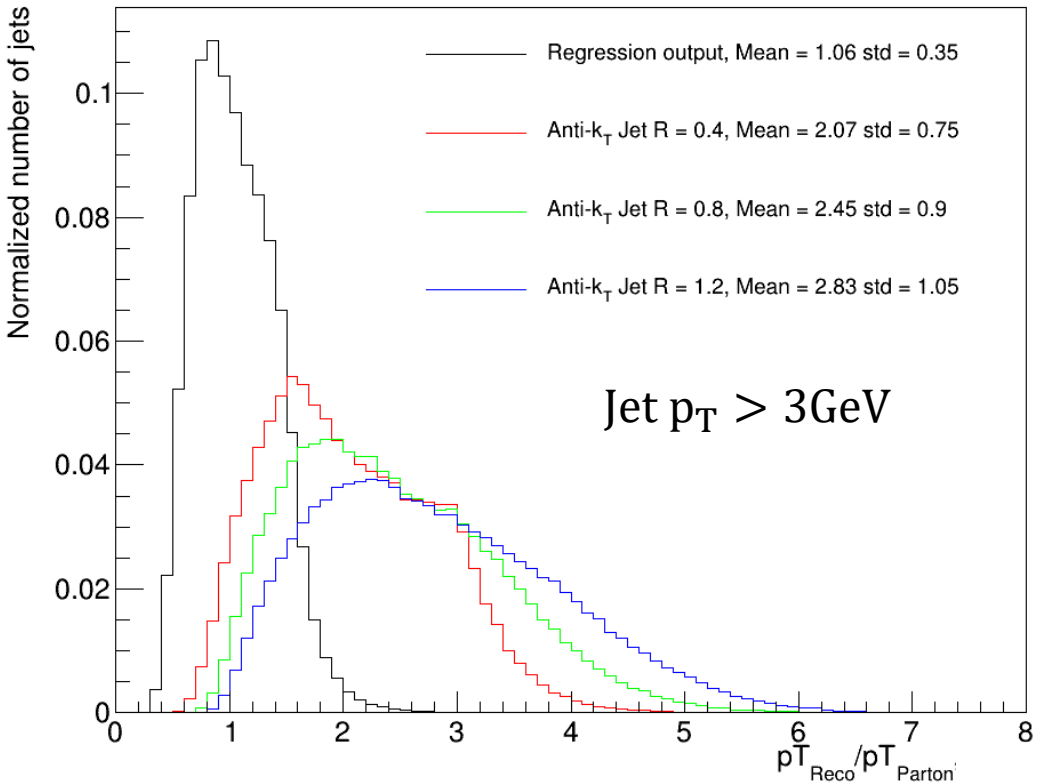


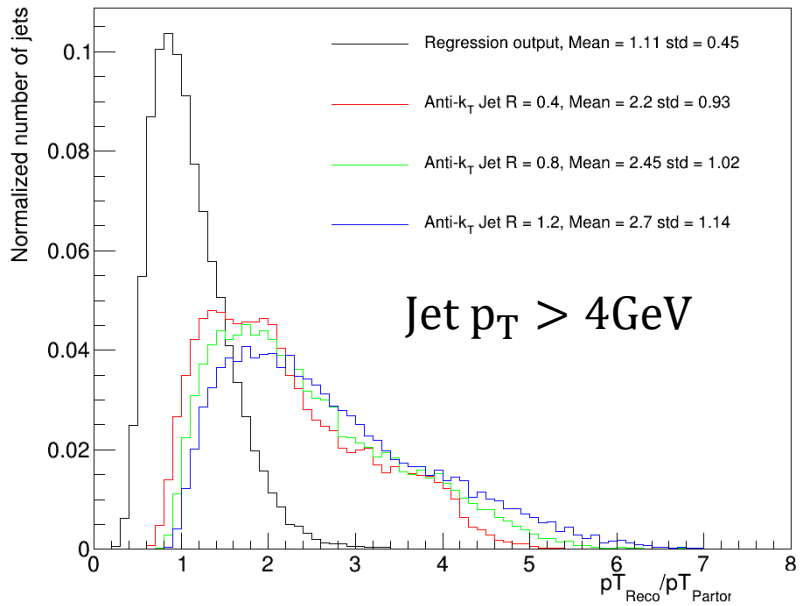


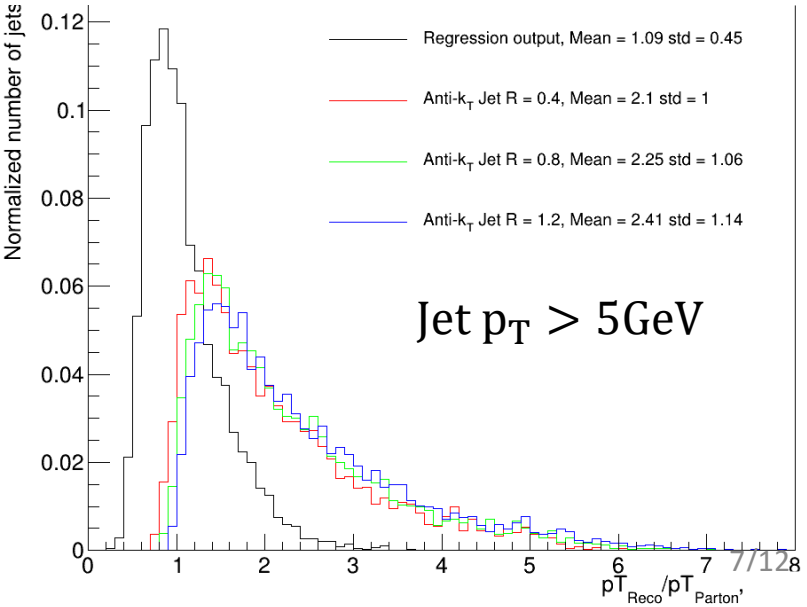


- Regression gives good prediction to parton p_T
- Since cuts on photon doesn't applied, it increases statistics but keep the reconstructed parton p_T same as with cuts

Pythia - QCD processes

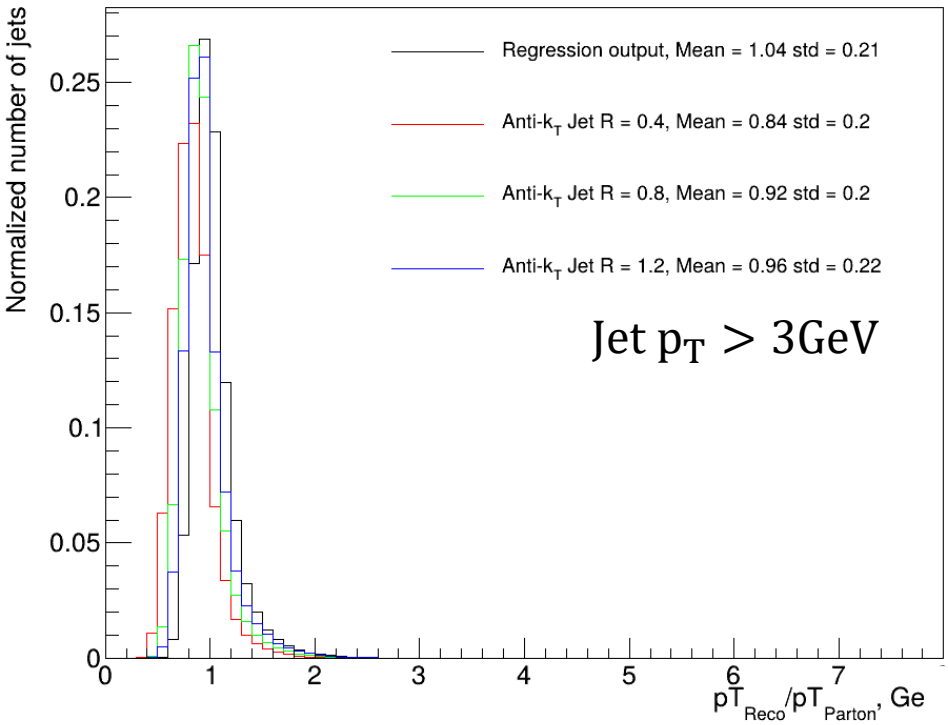


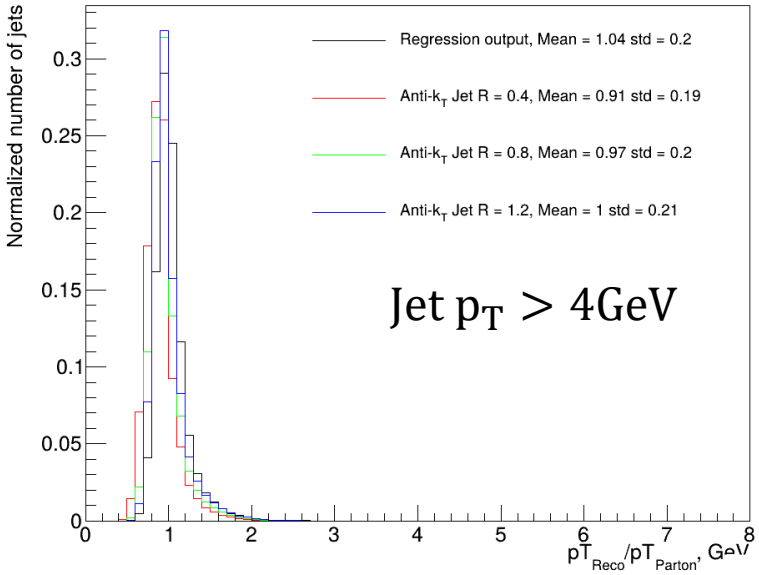


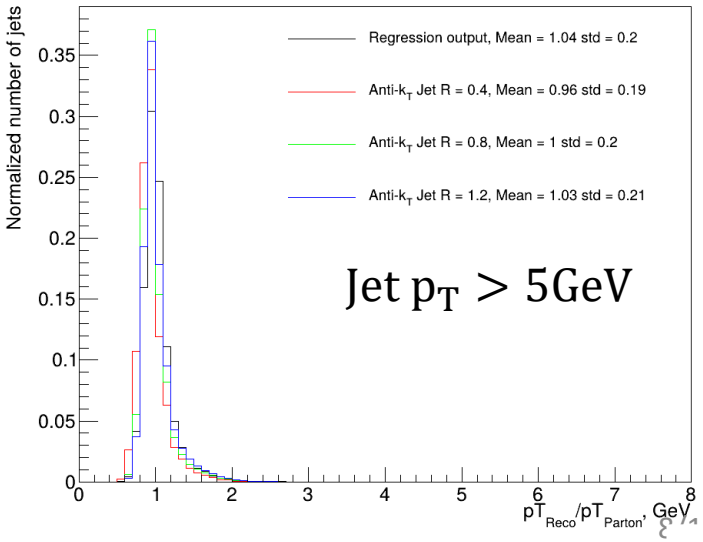


- QCD processes produce jets that cannot be simply associated with initial parton
- Problem is caused by events with high p_T jets and low p_T parton
- Regression gives reasonable results for initial parton p_T

Herwig+MadGraph - $qg \rightarrow q\gamma$ process

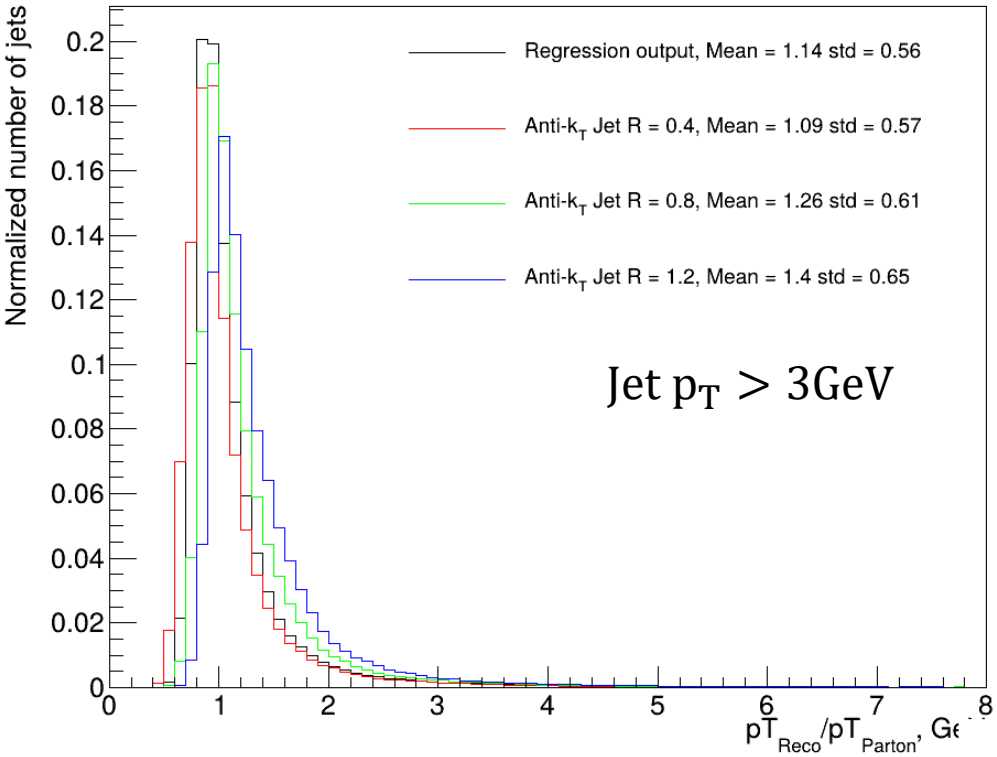


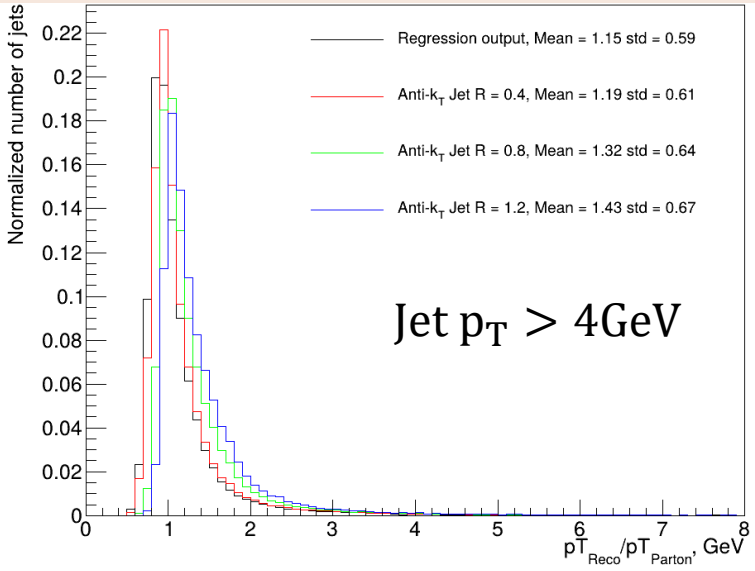


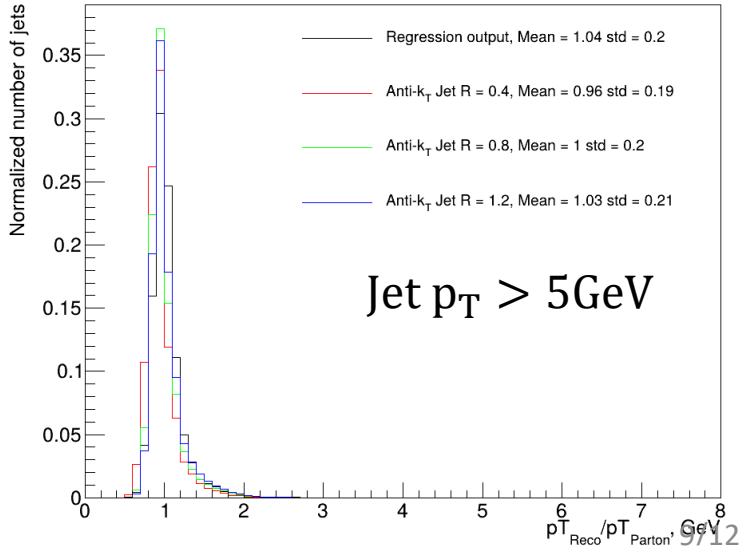


- Jets have good association with the parton even without any special cuts

Herwig+MadGraph - QCD processes

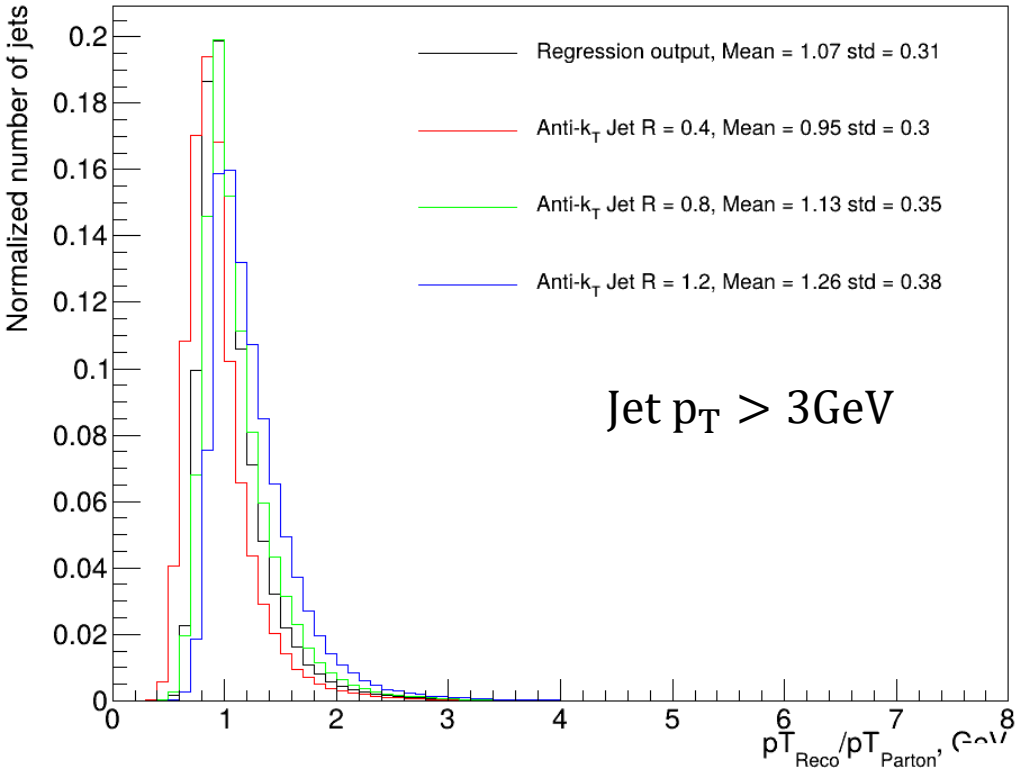


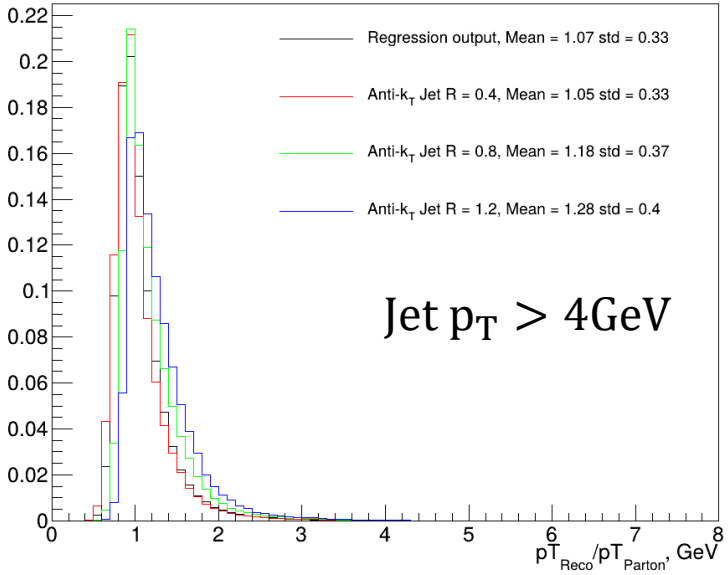


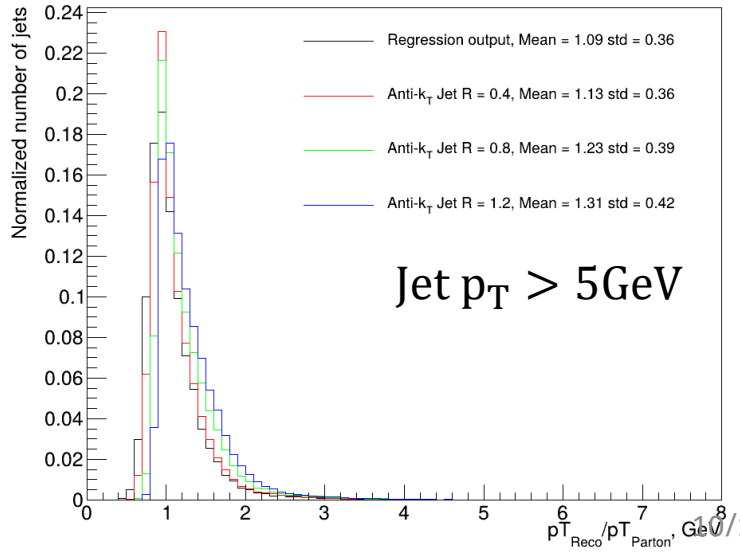


- Surprisingly, jets have good association with partons
- Apparently, it's related to different jet-parton matching

Herwig - QCD processes

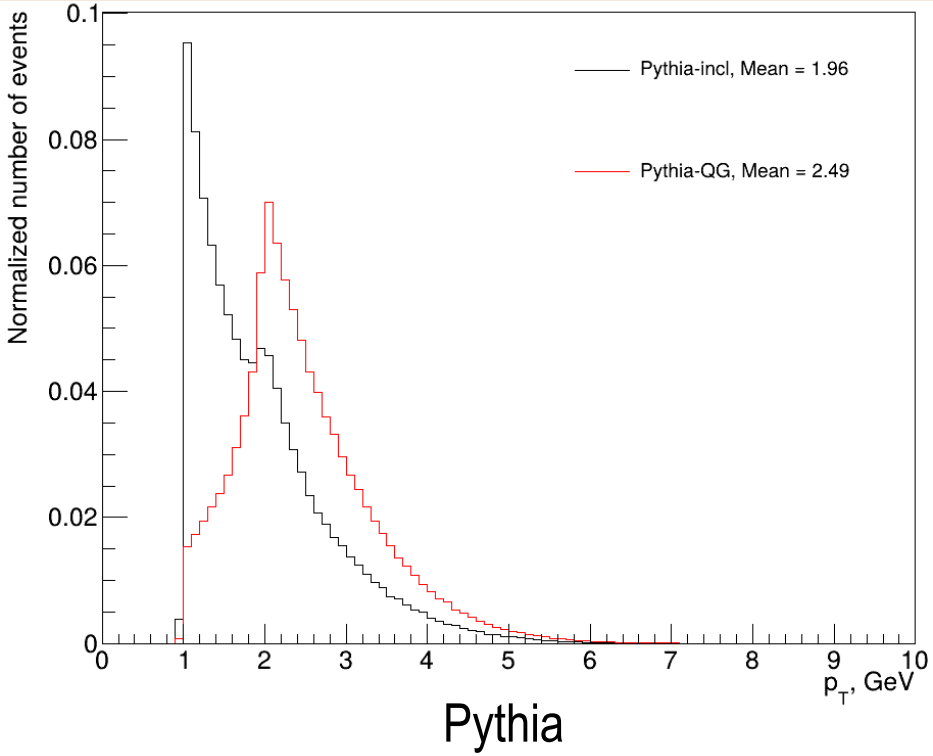




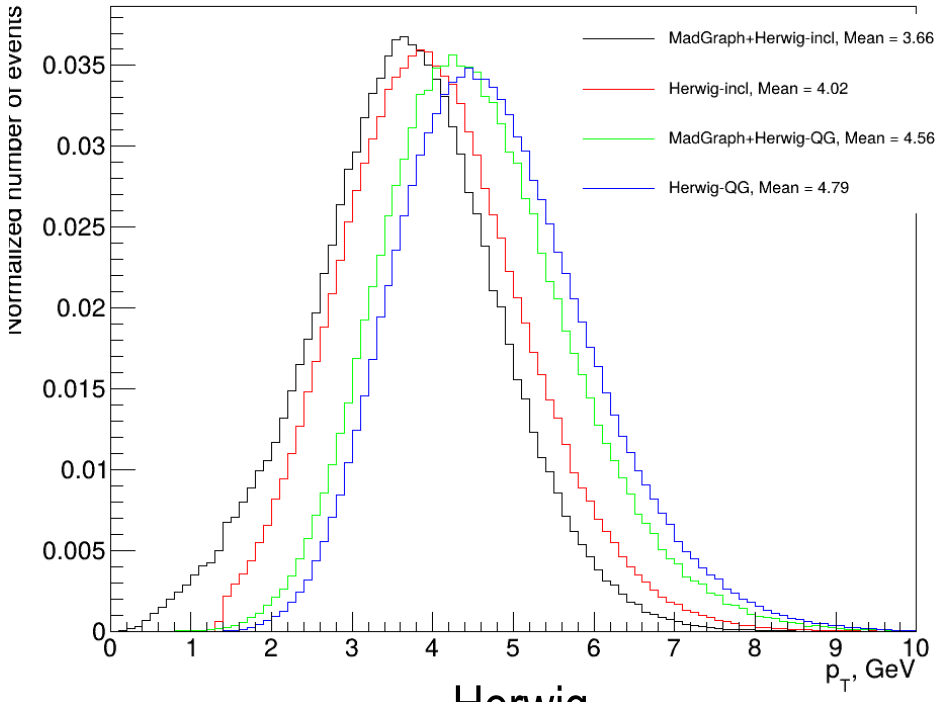


- Same situation with herwig without madgraph

Transverse momentum of Herwig/Pythia partons



Pythia



Herwig

- Pythia produces hard-scattered partons with “more reasonoble” momentum
- Partons used in Herwig has higher momentum, which is closer to momentum of jets

Conclusion and plans

- Kinematical properties of partons and clustered jets were compared on generator level for Pythia and Herwig
- Using regression can be a solution to reconstruct kinematics of initial parton for inclusive case in Pythia
- Since Herwig+MadGraph produces “weird” hard-scattered partons it was decided to use the highest p_T parton in event as initiator parton
- It gives better agreement between jet p_T and parton p_T in comparison to pythia
- Plans:
  - Investigate differences between Pythia and Herwig
  - Repeat this study with full simulation of detector

Back up

Jets at low energies in other experiments

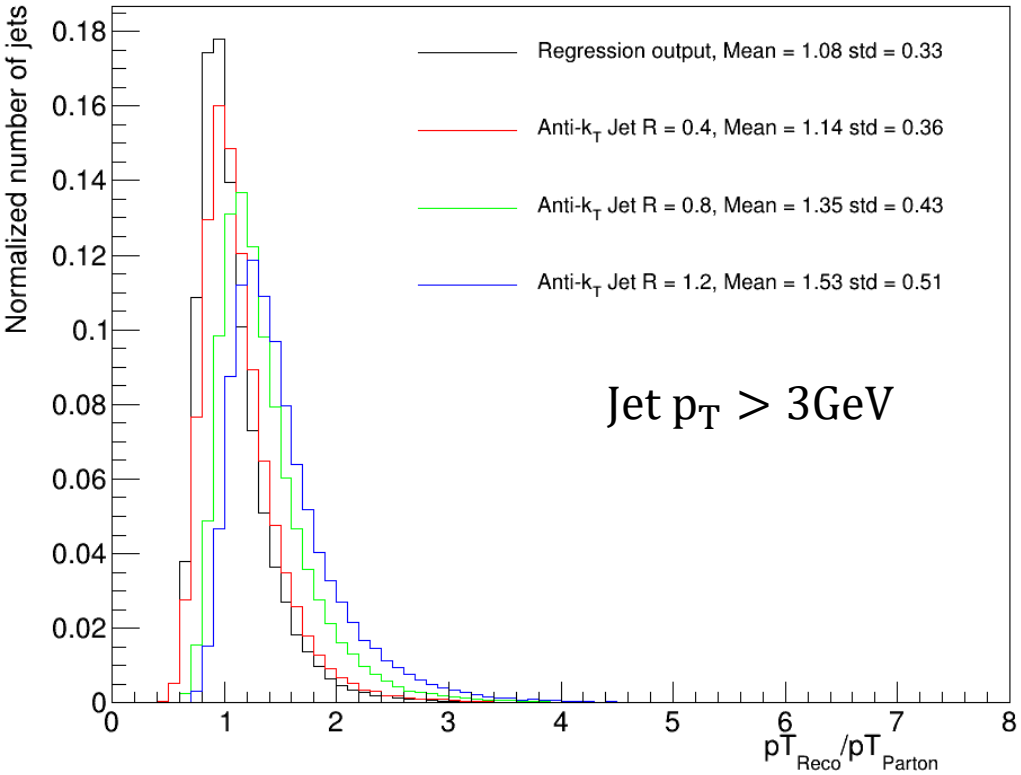
- Jets at low energies were studied in 70s-80s in many experiments: PETRA, SFM 412, Pisa–Stony Brook, AFS etc.

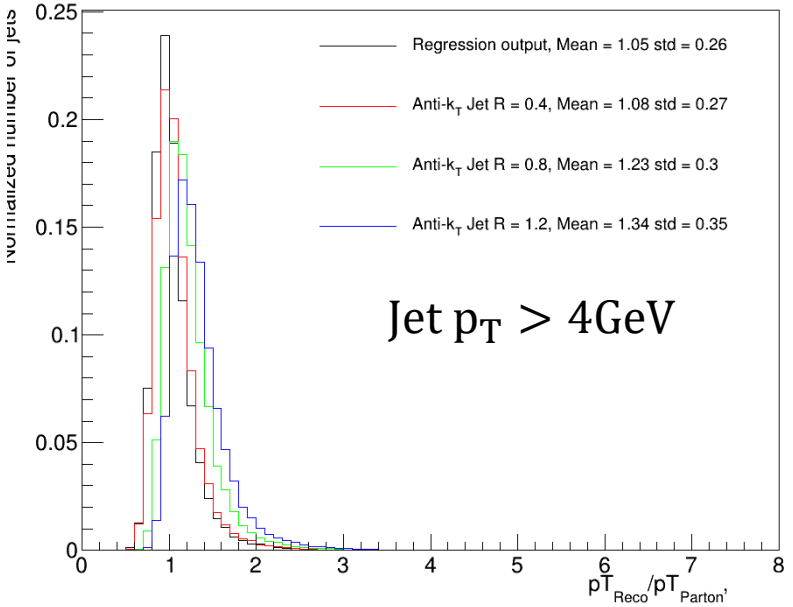
- Since there was not good enough clustering algorithms, single high p_T hadrons and clusters of particles were considered as jets

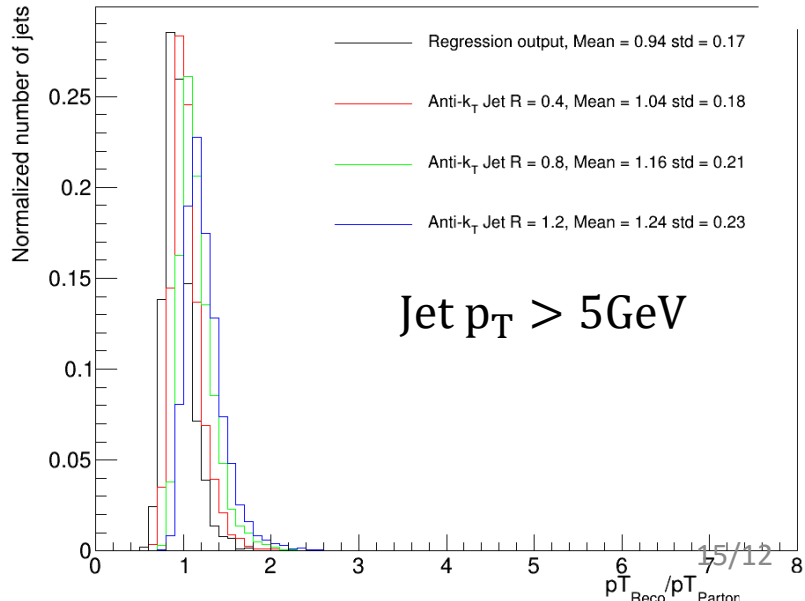
- Main idea of those experiments was in confirmation of events with jets and measurement cross sections

https://inspirehep.net/literature/179516
https://inspirehep.net/literature/153610
https://inspirehep.net/literature/100764
https://inspirehep.net/literature/188734

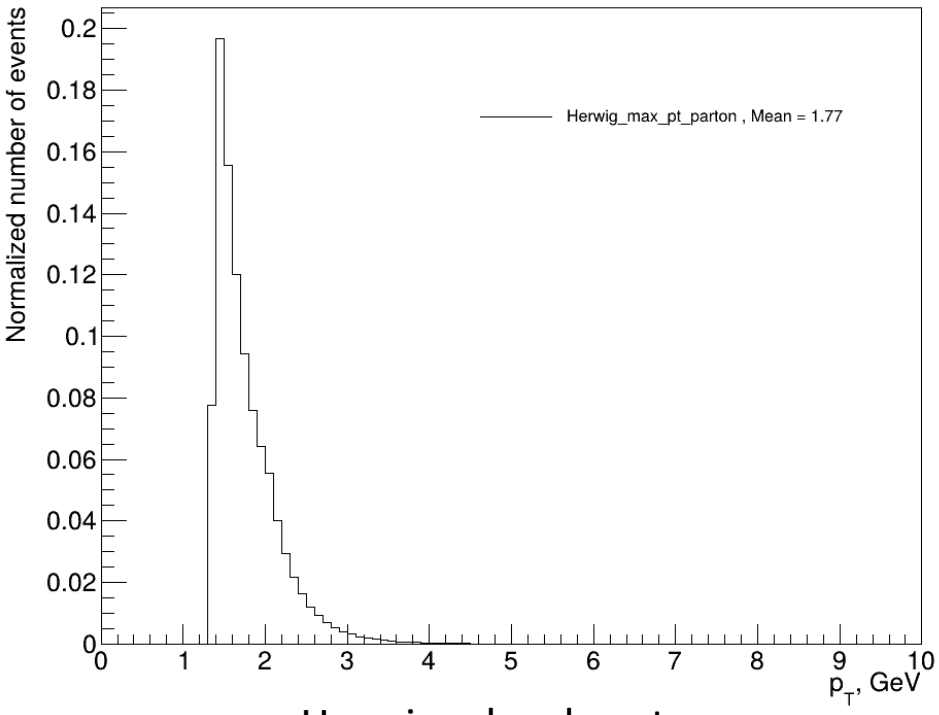
$qg \rightarrow q\gamma$ process with prompt photon cuts



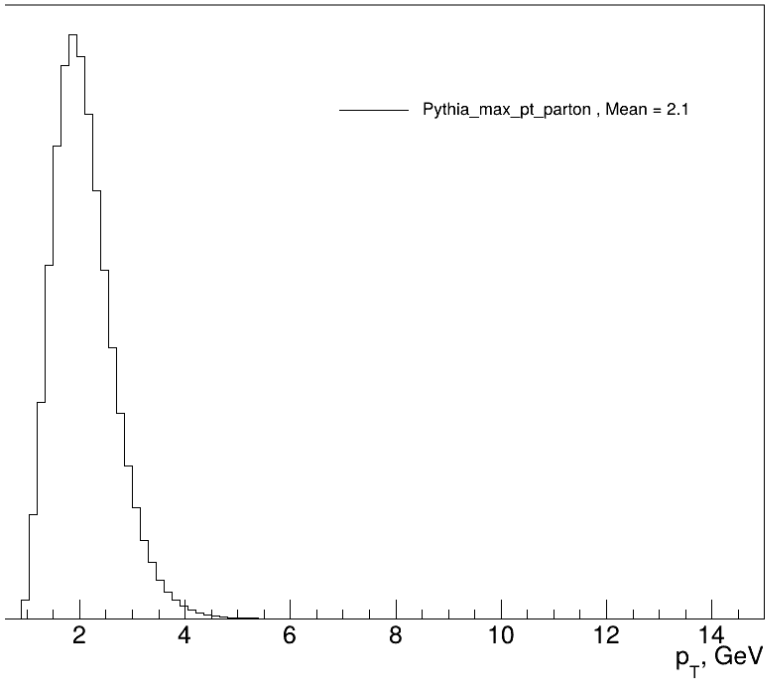




- High p_T jets have good association with initial parton
- Regression improve σ but not significantly

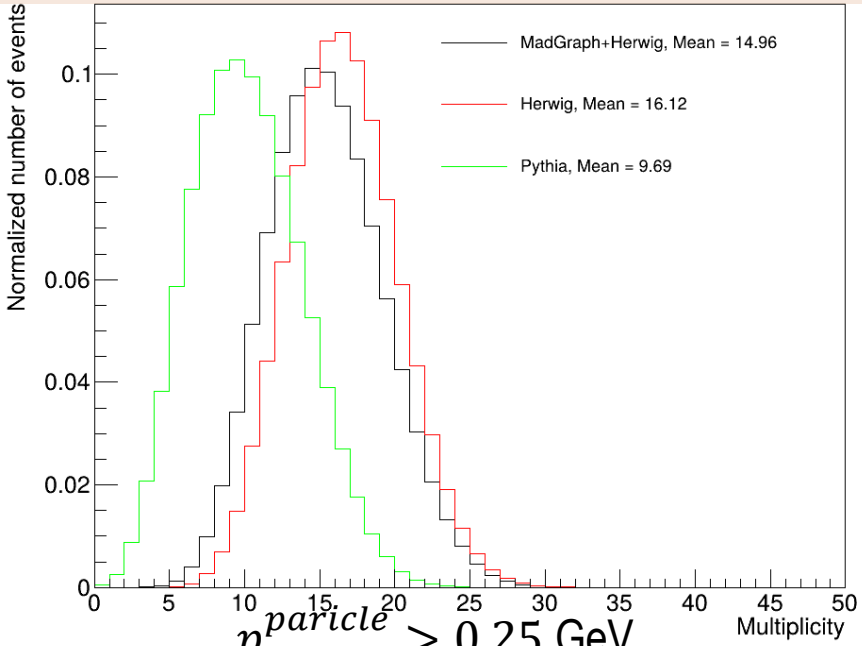


Herwig – hard parton

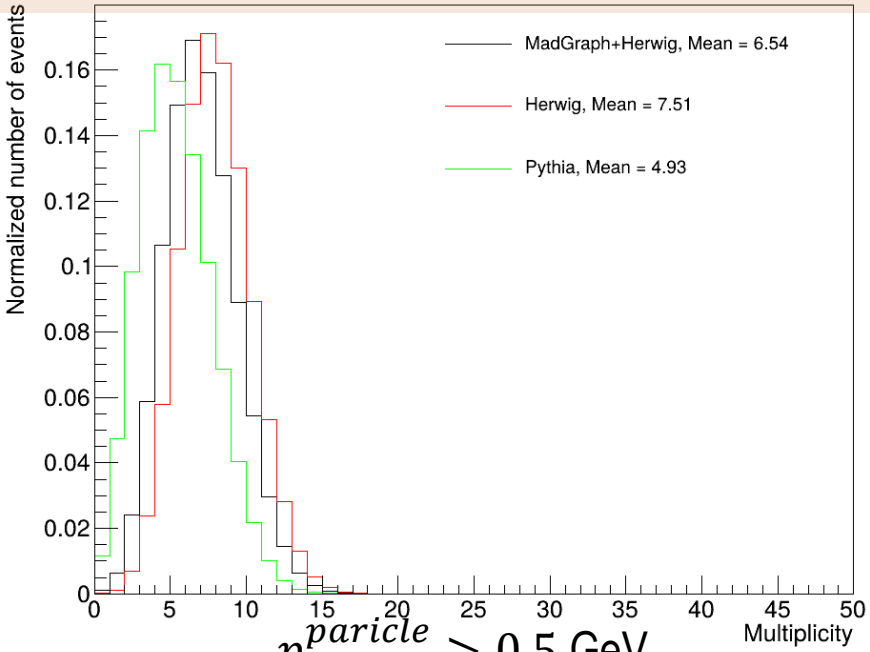


Pythia – max pt parton

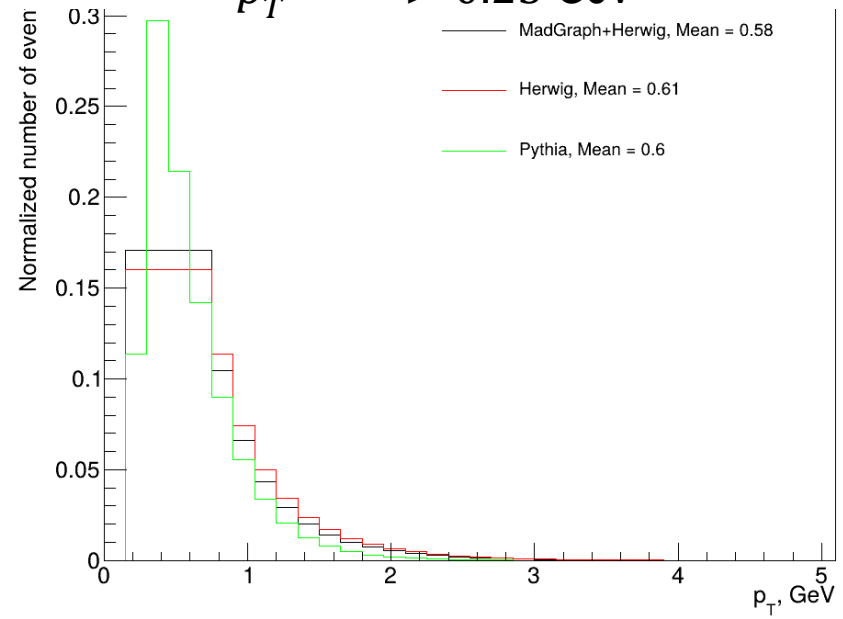
Particle multiplicity and pt in event

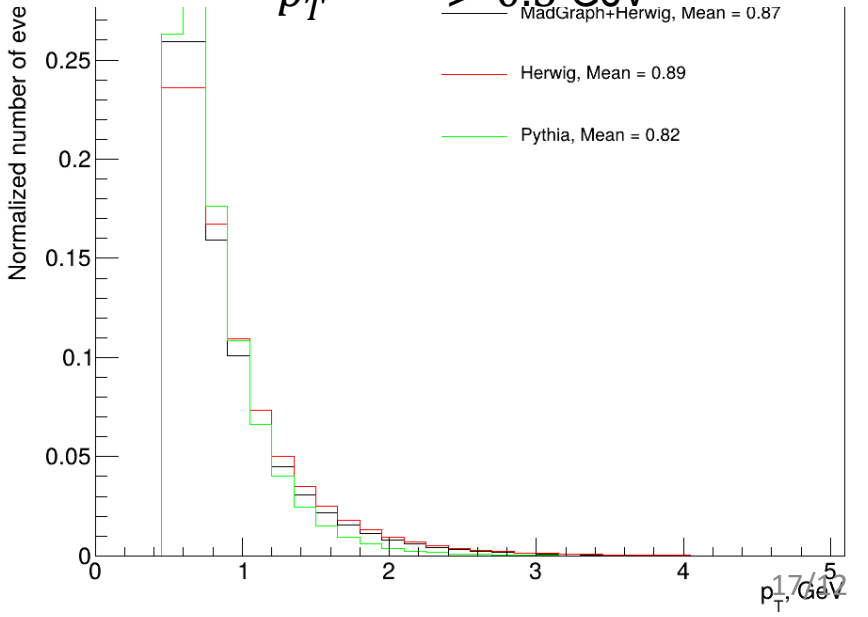


$p_T^{paricle} > 0.25$ GeV

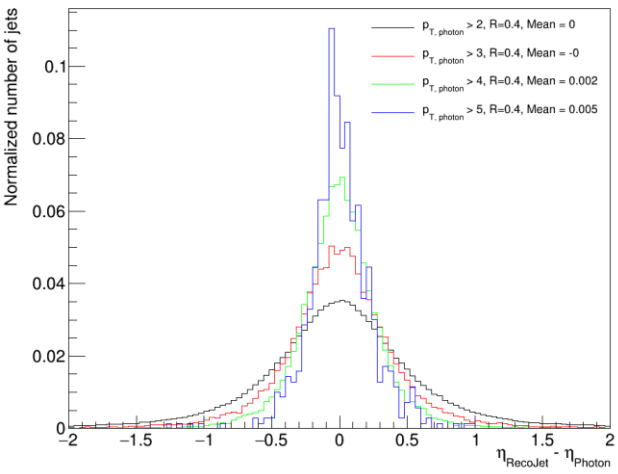


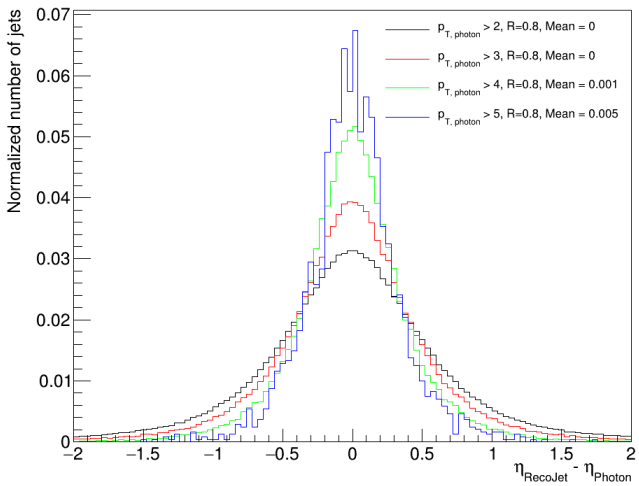
$p_T^{paricle} > 0.5$ GeV

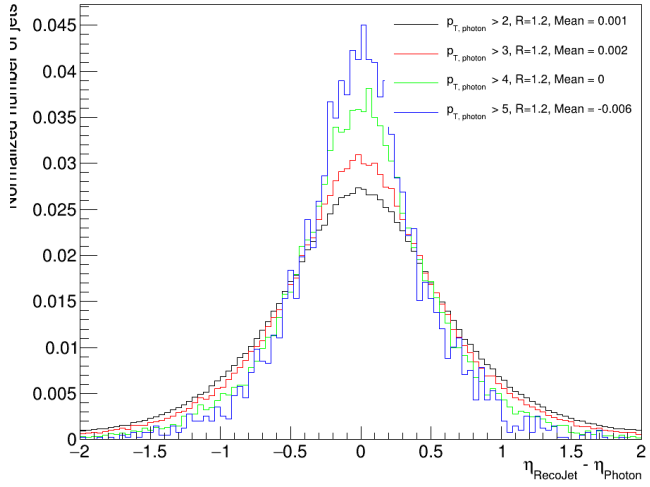


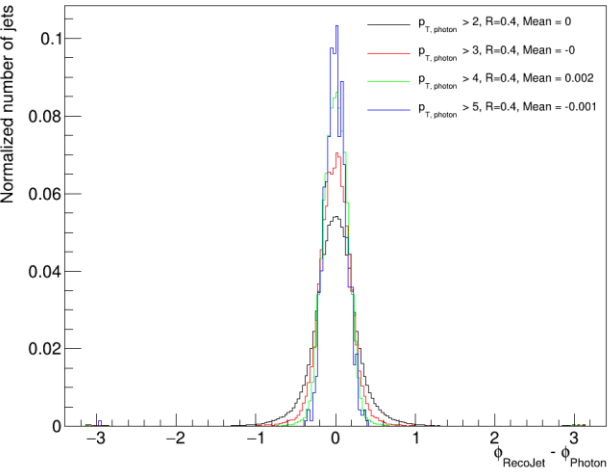


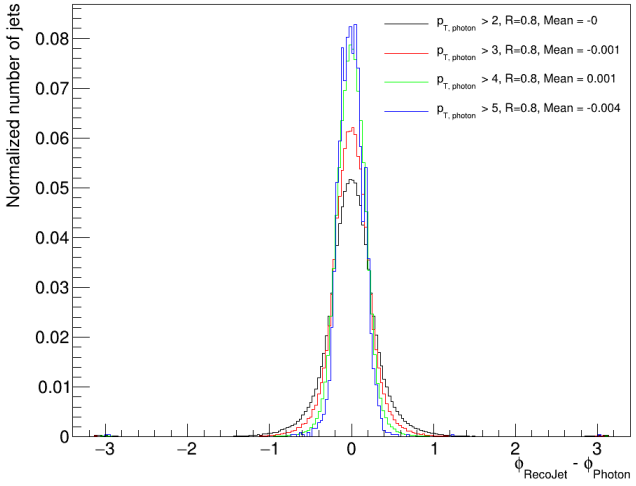
Clustered jet (φ, η) vs parton (φ, η)

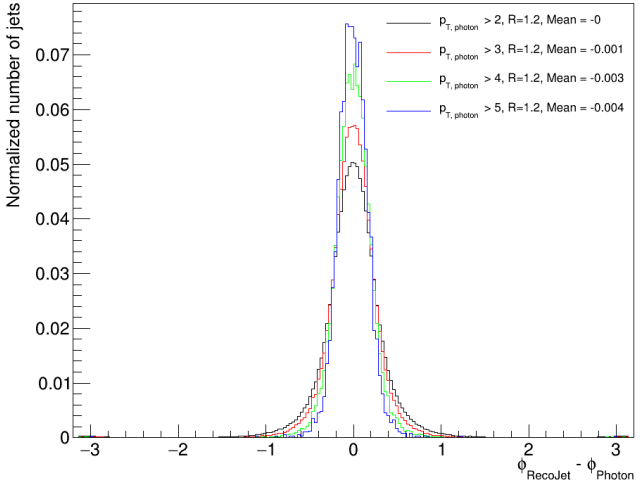












- Jets and partons moves in the same direction

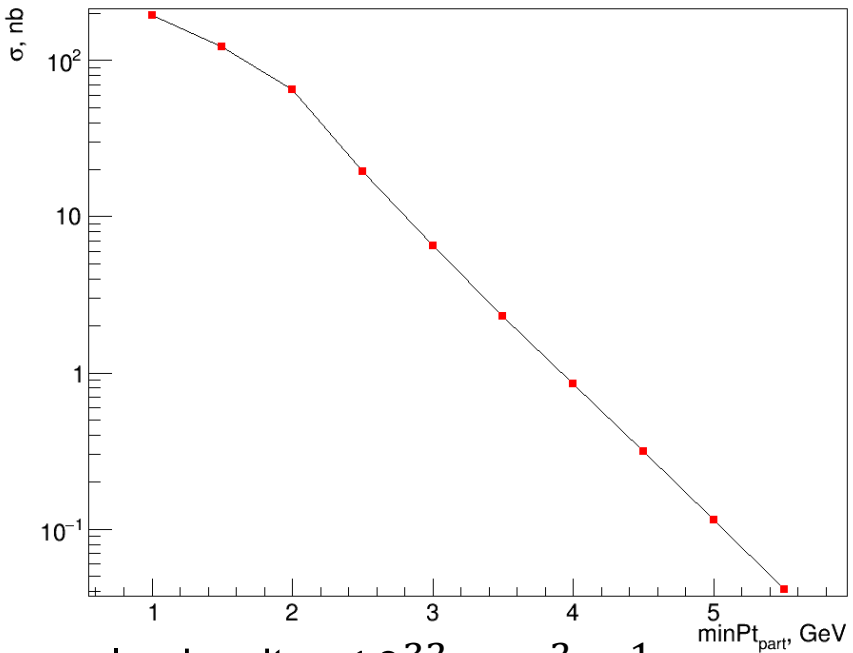
Anti-k_t algorithm

- Jets are clustered with *anti-k_t* algorithm
- Distance between objects in *anti-k_t* algorithm defined as $d_{ij} = \min\left(\frac{1}{k_{ti}^2}, \frac{1}{k_{tj}^2}\right)\frac{\Delta_{ij}^2}{R^2}$,

  where $\Delta_{ij}^2 = (y_i - y_j)^2 + (\varphi_i - \varphi_j)^2$
- The functionality of the algorithm can be understood by considering an event with a few hard particles and many soft ones
  - If hard particle 1 has no hard neighbours within a distance $2R$ then we have one perfectly conical jet
  - If another hard particle 2 is present such that $R < \Delta_{12} < 2R$ then we have two jets with some overlapping parts
  - If distance between particles 1 and 2 $\Delta_{12} < R$ then both formed one jet

https://arxiv.org/abs/0802.1189

Process $qg \to q\gamma$ cross section ($\sqrt{s} = 27$ GeV)



- Expected instantaneous luminosity - $10^{32} cm^{-2} s^{-1}$
- For 100 days of work integral luminosity ~ $10^{5} nb^{-1}$
- We have enough statistics even for high p_T partons
- For partons with $p_T > 3GeV$ we expect ~ 10^{6} events

Technical Design Report of the Spin Physics Detector. Version 1.00 (February 12, 2023)