Hadron Cluster Finding in the SPD/NICA

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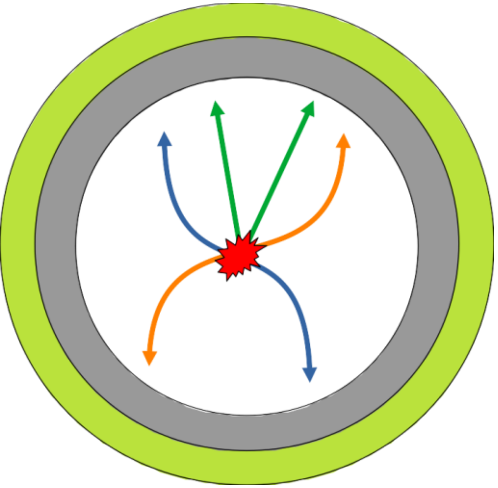
Motivation

- 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-initiator 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

Problem statement



Performance of reconstruction for particles clustered production

- Search for clustered production of particles (efficiency)
- Reconstruction of parton-initiator kinematics depending on reconstructed jet characteristic

Clustering algorithms and parameters

- Cluster/Jet reconstruction algorithm (Iterative Cone, kT, Anti-kT, Cambridge-Aachen, etc.)
- Radius parameter
- Inputs of clustering algorithms as objects of reconstruction and their kinematic thresholds
- Energy/momentum of reconstructed cluster

Machine learning algorithms

- Boosted decision tree with gradient boosting
- Use regression to reconstruct kinematics of parton-initiator

Event generation

- We use Pythia8 generator and FastJet package
- Energy of collisions $\sqrt{s} = 27$ GeV
- *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 $\eta < 5$
- Clustered jets are matched to hard scattered parton (status = 23)
- Jet should have at least two particles

- Considered cases:
  - $qg \rightarrow q\gamma$ process (with and without prompt photon selections)
  - All QCD processes (inclusive case)

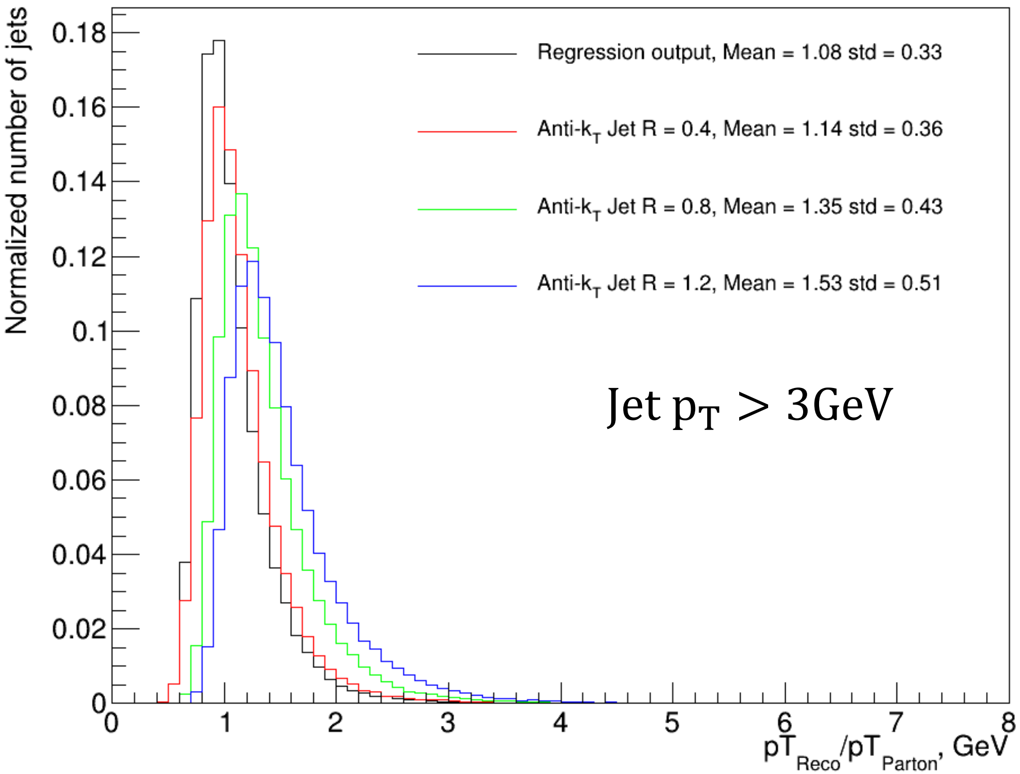
Selection strategies

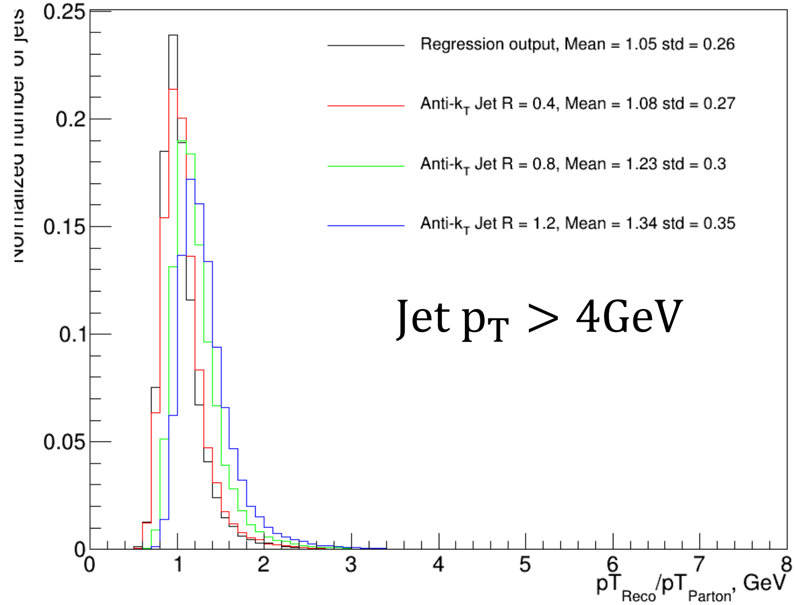
- $qg \rightarrow q\gamma$ process with prompt photon cuts
  - Leading jet p_T cuts: $p_{T,\,jet}$ >3 GeV, >4 GeV, >5 GeV.
  - Leading photon p_T cuts: $p_{T,\,photon}$ >3 GeV, >4 GeV, >5 GeV
  - Photon and jet are back to back: $\Delta\varphi > 2.7$
- $qg \rightarrow q\gamma$ process without prompt photon cuts
  - Leading jet p_T cuts: $p_{T,\,jet}$ >3 GeV, >4 GeV, >5 GeV.
- 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

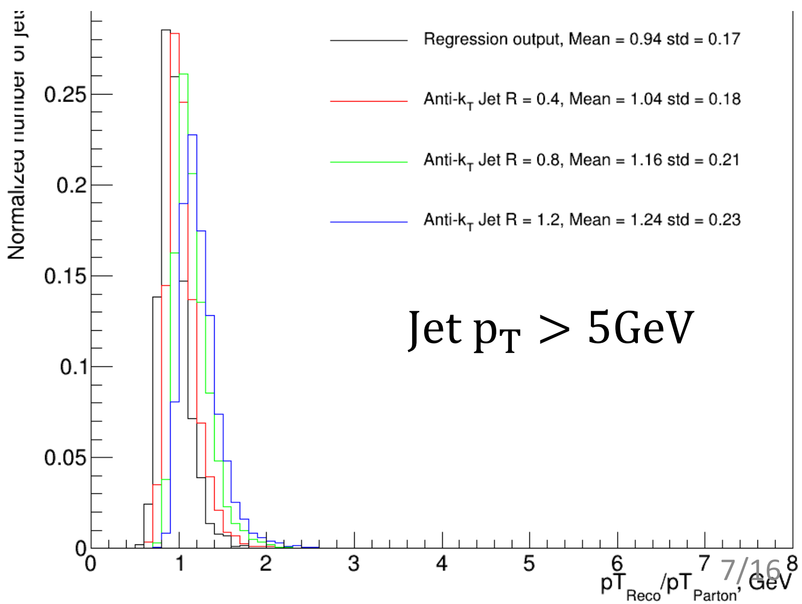
Boosted decision tree training

- $qg \to q\gamma$ 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
- Training and analyzed samples were created independently
- Analyzed sample has two times more events

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

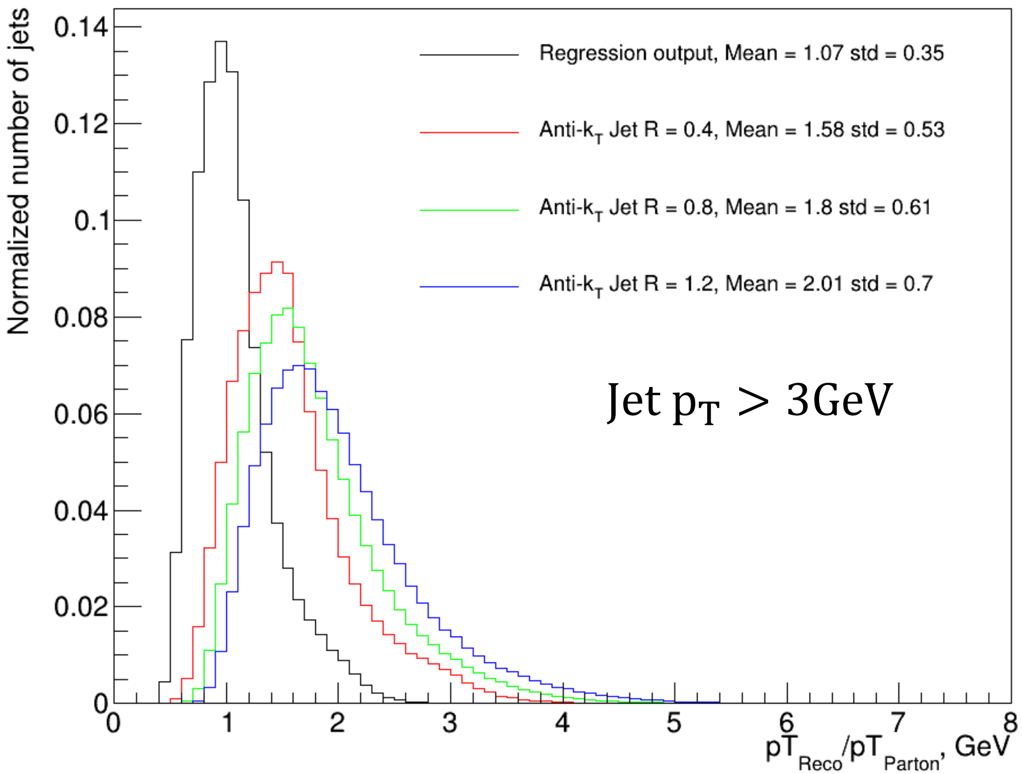


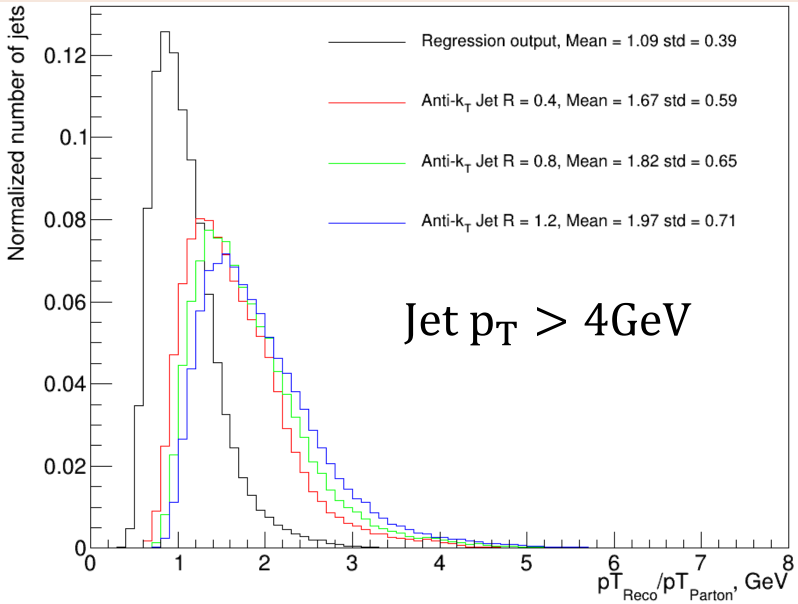


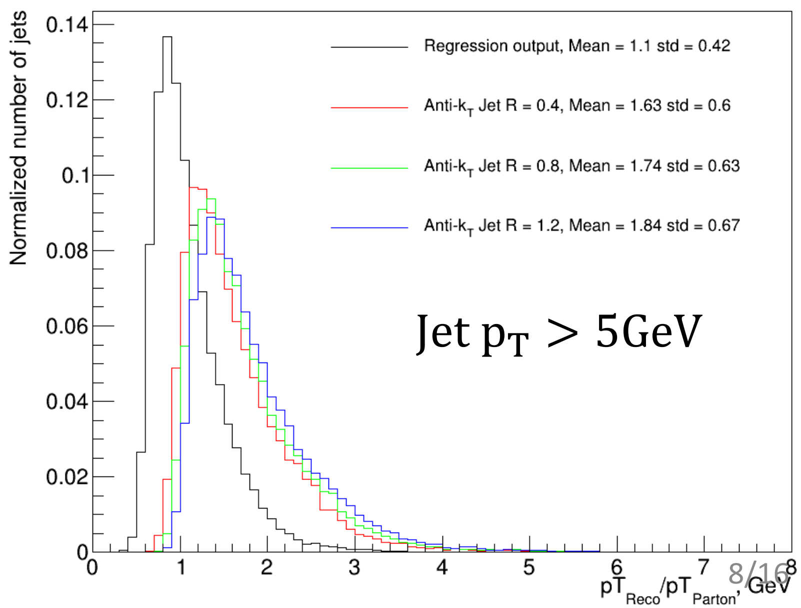


- High p_T jets have good association with initial parton
- Regression improve σ but not significantly

$qg \to q\gamma$ process without prompt photon cuts

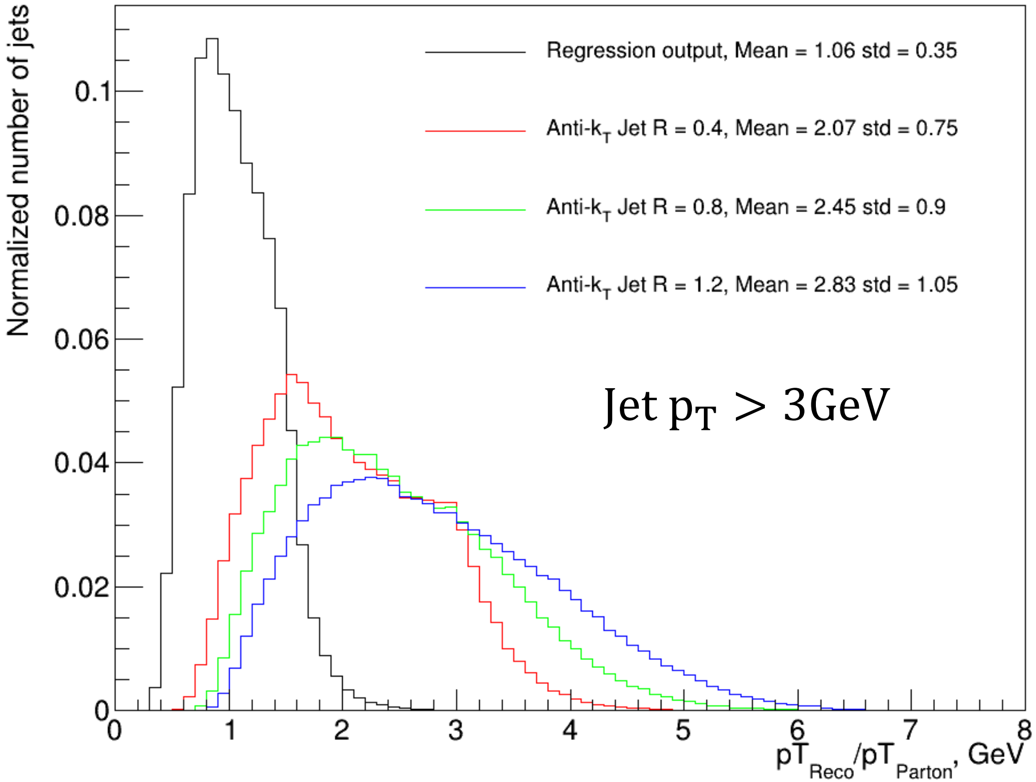


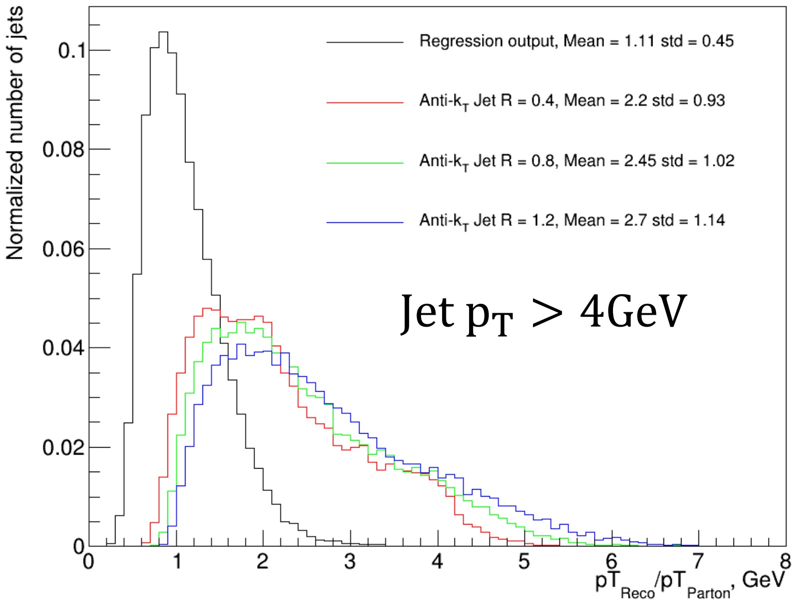


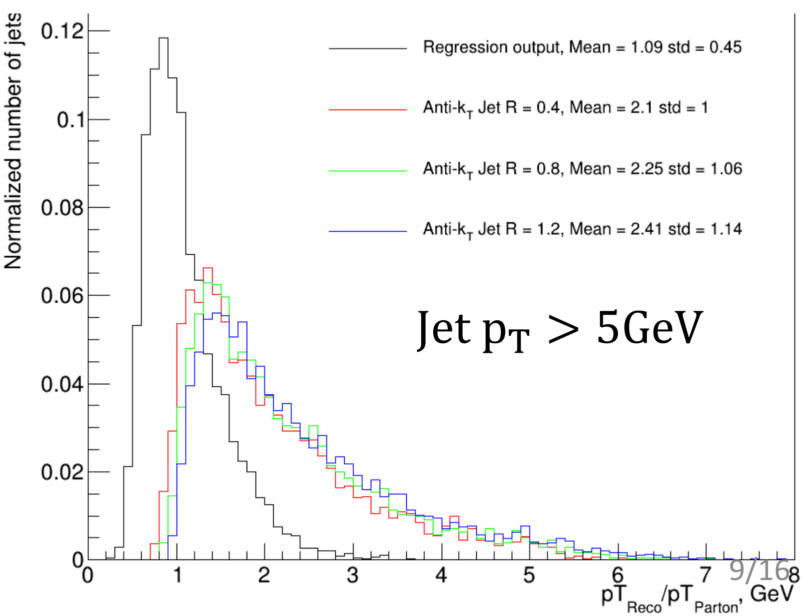


- Jet association with initial parton got worse
- Regression solve this problem and represent result that is close to shown on previous slide
- Since cuts on photon reduce number of events in 10 times we can use regression without cuts to increase statistics

All QCD processes

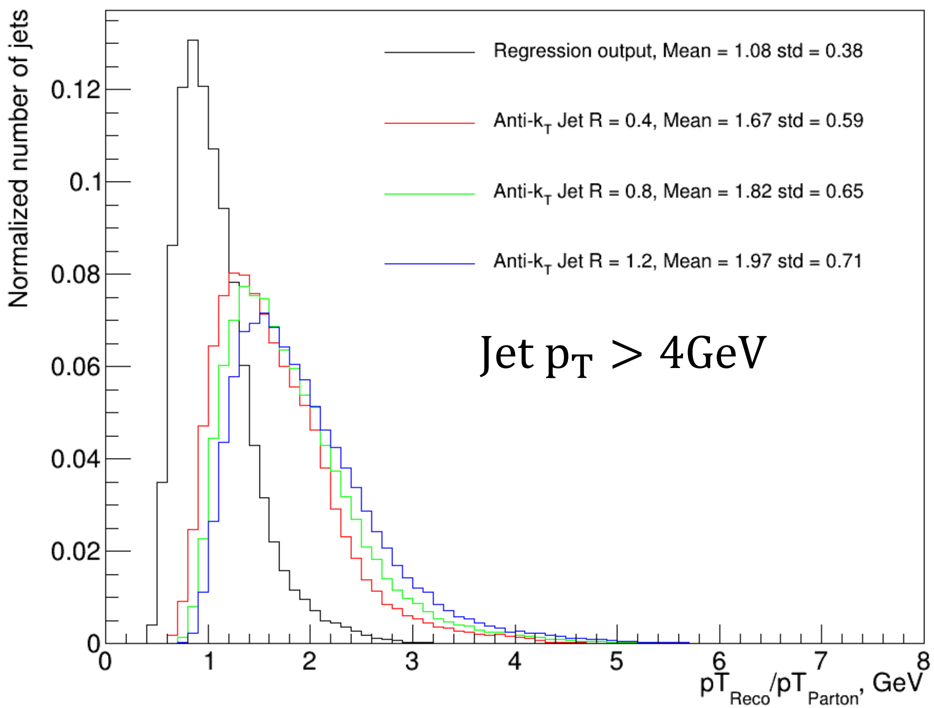




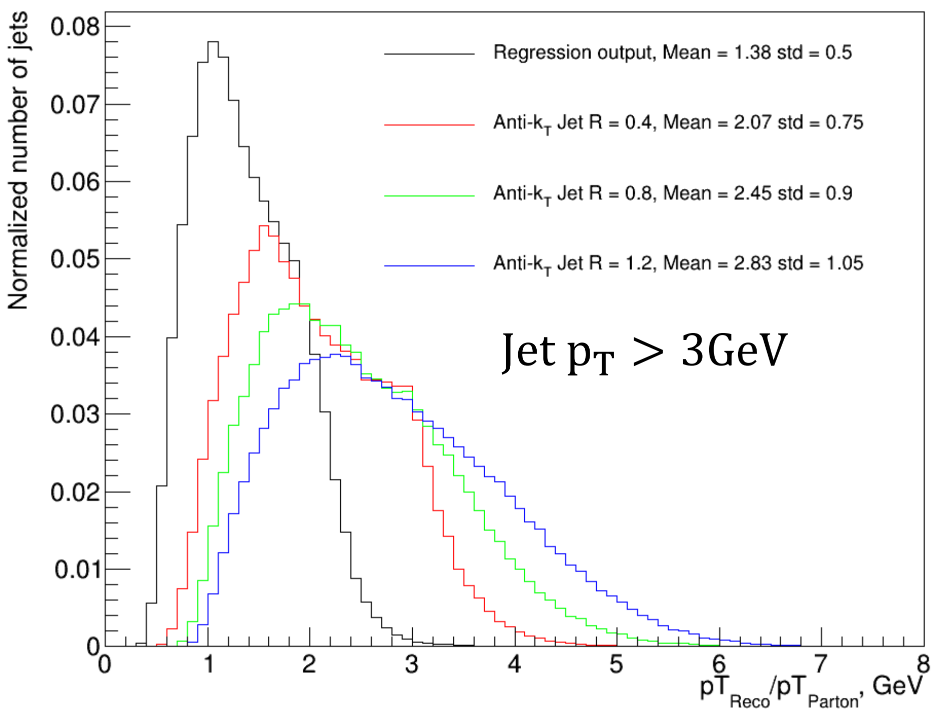


- QCD processes produce jets that cannot be simply associated with initial parton
- Problem is caused by events with high p_T jets and low p_T parton
- Regression gives reasonable results for initial parton p_T

Different training and analyzed samples



$qg \rightarrow q\gamma$ process training with leading jet $p_T > 3$GeV



$qg \rightarrow q\gamma$ process training applied for all QCD processes

- Training from the same channel with one cut on jet pt could be applied for samples with different pt cuts
- Applying training from one channel to sample from different channel needs to be studied

Conclusion and plans

- Kinematical properties of hard scattered partons and clustered jets was compared on generator level

- Cuts on leading photon p_T and back to back condition between jet and photon together with cut on leading jet p_T select jets which could be associated with initial parton

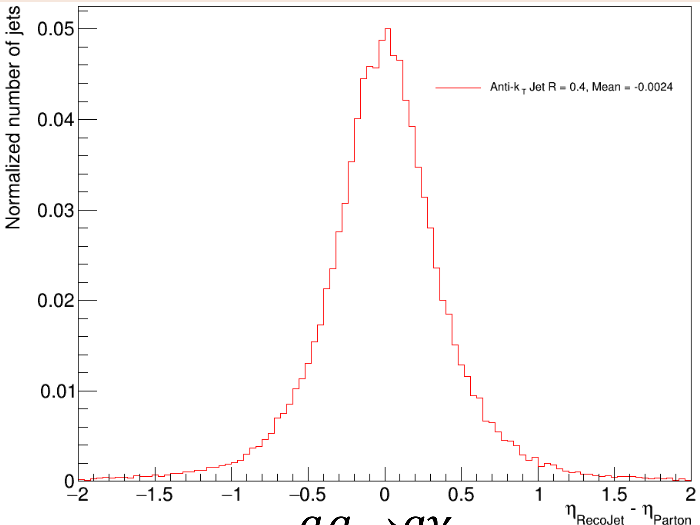
- It seems to be impossible to select jets in inclusive case which could be associated with initial parton

- Using regression could be a solution to reconstruct kinematics of initial parton in inclusive case

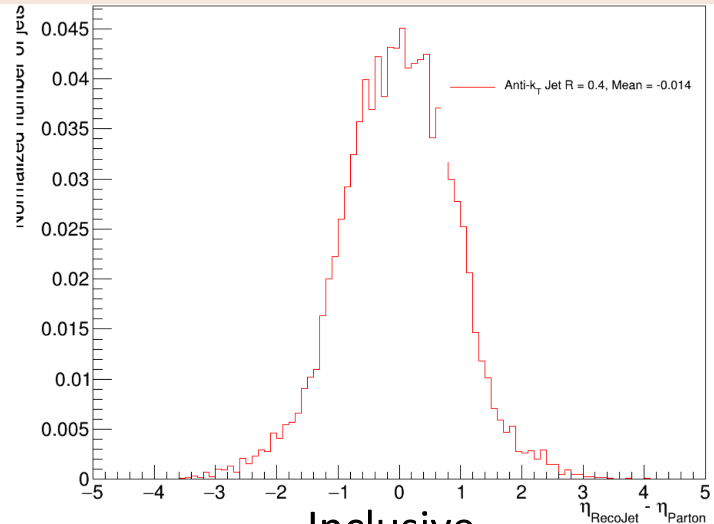
- Plans:
  - Compare different algorithms of regression
  - Find out additional parameters to improve training
  - Try to realize unified training for different channels
  - Repeat this study with full simulation of detector

Back up

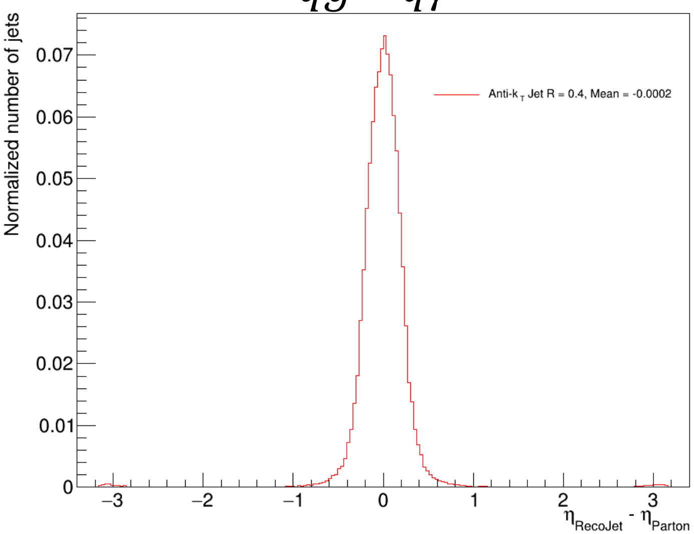
Clustered jet (φ, η) vs parton (φ, η)

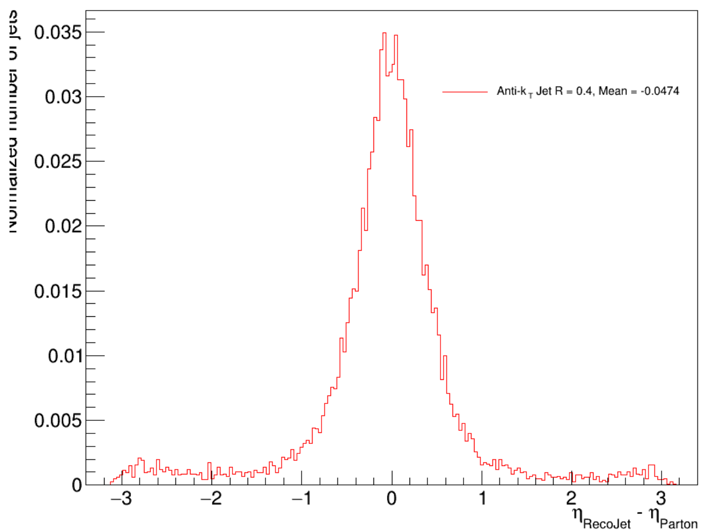


$qg \rightarrow q\gamma$



Inclusive





- Jets and partons moves in the same direction

Jets at low energies in other experiments

- Jets at low energies was 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

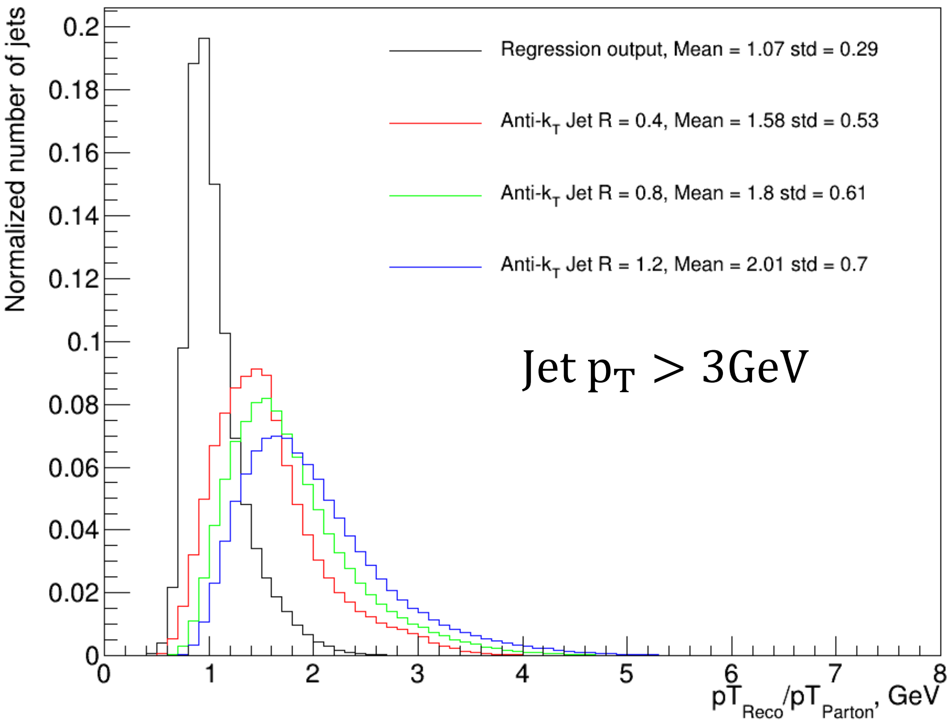
Optimization of parameters

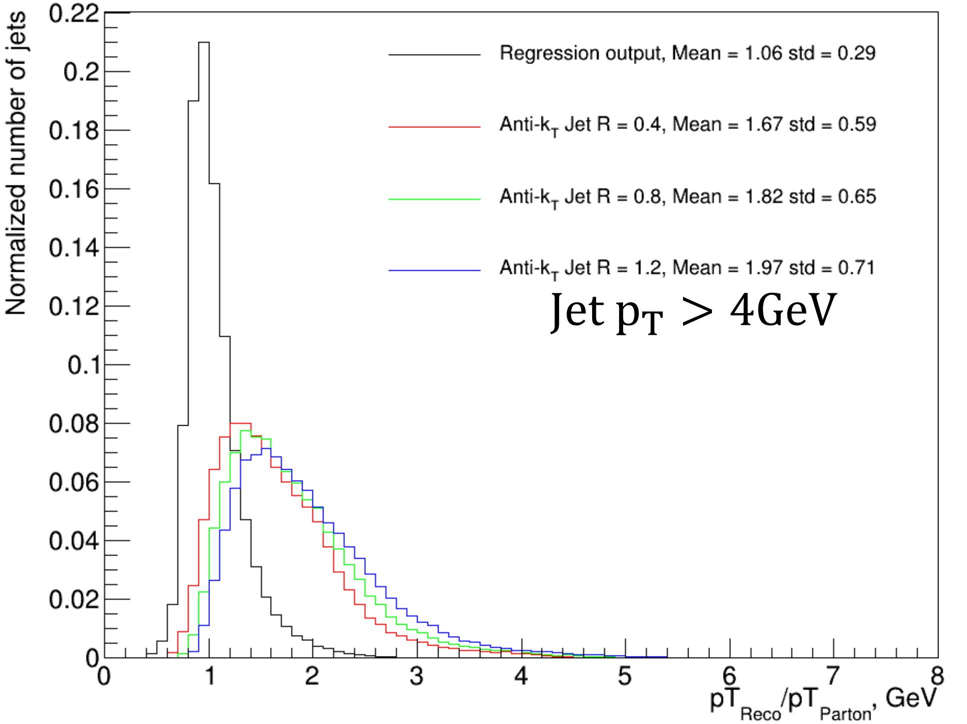
- We studied different cuts on observed parameters and compare clustering algorithms:
  - η regions: 0/0.5/1/1.5/2/3
  - Minimal jet p_T: 2, 2.5, 3, 3.5, 4, 4.5, 5
  - Minimal particle p_T: 0.25, 0.5, 0.75, 1
  - Anti-kt/Kt/CA algorithms with R = 0.4, 0.8, 1.2, 1.5
- **Different clustering algorithms find similar jets**

algorithm	mean	σ	σ/mean
Anti-kt, R=0.4	1.5466	0.4573	29.57
Kt, R=0.4	1.5513	0.4606	29.69
CA, R=0.4	1.5478	0.4583	29.61
Anti-kt, R=0.8	1.7480	0.5257	30.07
Kt, R=0.8	1.7478	0.5319	30.43
CA, R=0.8	1.7388	0.5250	30.19

- The table was prepared for η from 0 to 3, $p_{T,jet} > 2$ GeV and $p_{T,particle} > 0.25$ GeV

$qg \rightarrow q\gamma$ process without prompt photon cuts (photon in training)





- High p_T jets have good association with initial parton

Objects definition

- Clustering algorithms can find many jet-like objects in single event
- But we want to choose only objects, which could be associated with initial parton
- Clustered jets (with gen information)
  - We take leading p_T jet and check, at least one jet constituent originated from hard scattered parton
- Clustered jets (only observable parameters)
  - We take leading p_T jet, but skip the jet with leading photon among jet constituents

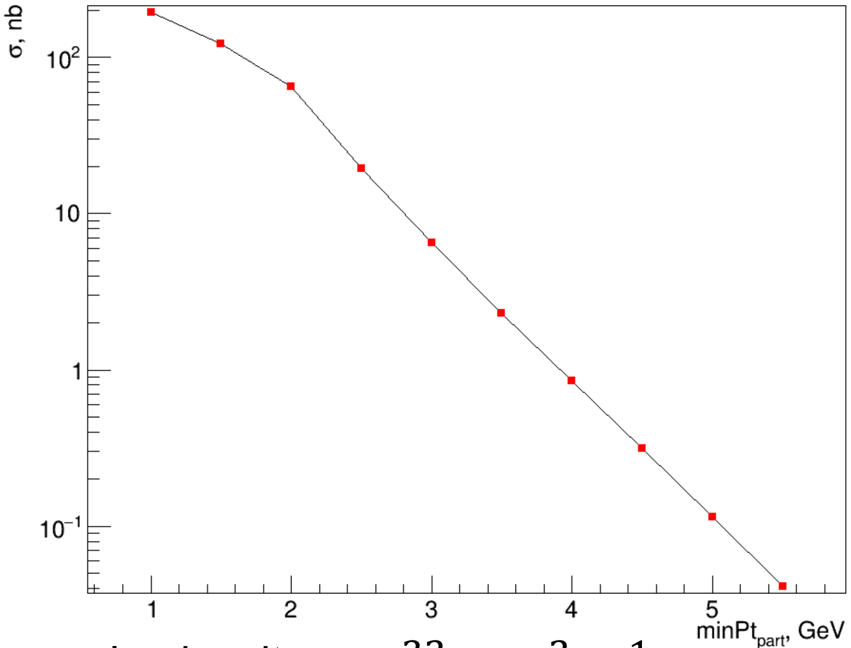
Anti-k_t algorithm

- 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 2*R* 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

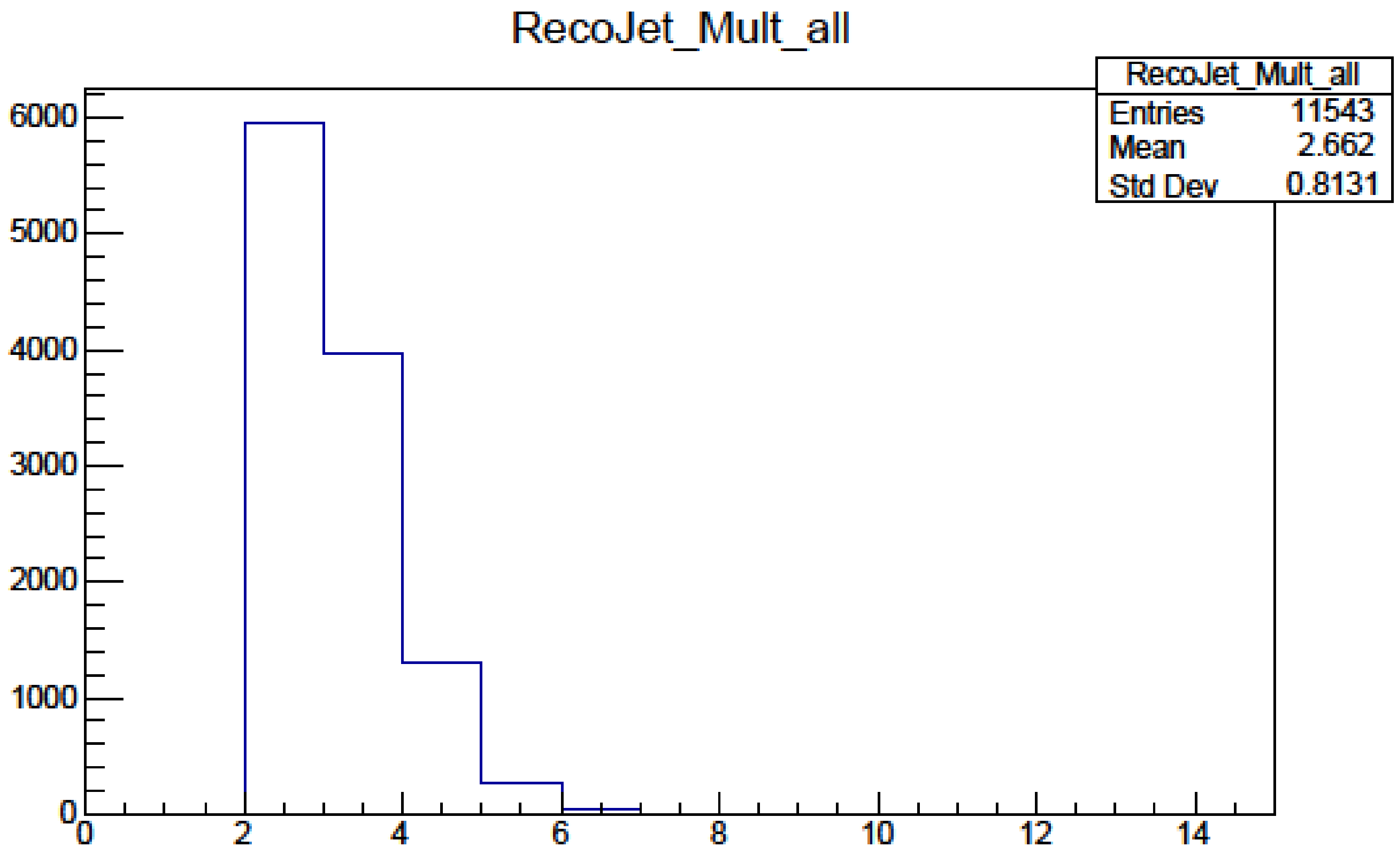
Process $qg \rightarrow q\gamma$ cross section ($\sqrt{s} = 27$ GeV)



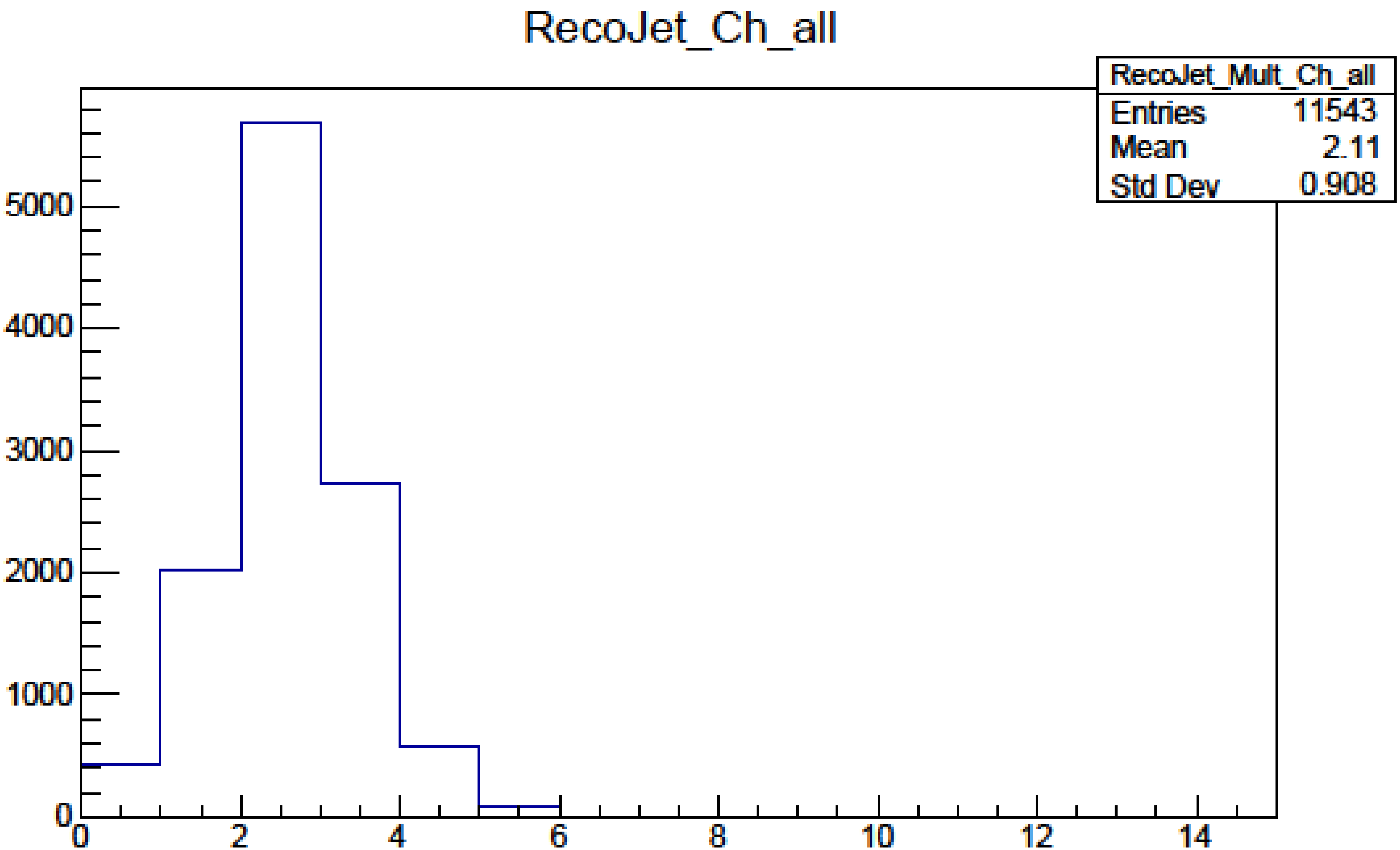
- Expected instantaneous luminosity - $10^{32} cm^{-2} s^{-1}$
- For 100 days of work integral luminosity ~ $10^5 nb^{-1}$
- We have enough statistics even for high p_T partons
- For partons with $p_T > 3 GeV$ we expect ~ 10^6 events

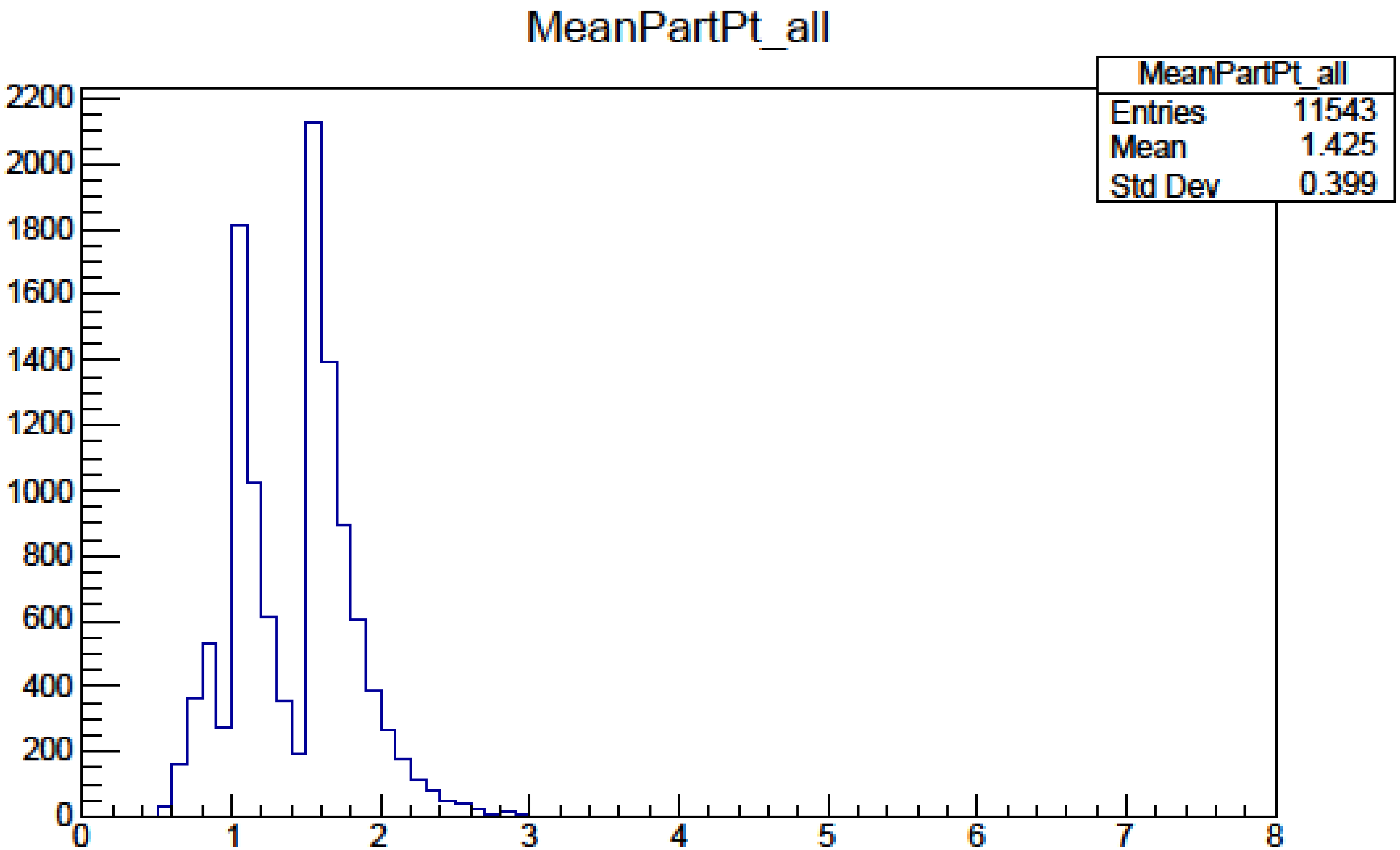
Technical Design Report of the Spin Physics Detector. Version 1.00 (February 12, 2023)

Full Multiplicity



Charged Multiplicity

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MeanPartPt_all
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Mean 1.425
Std Dev 0.399
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
1
2
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