Cluster particle production @ SPD experiment

on behalf of the SPD collaboration

D. Budkouski[1,2], I. Lapushanskii[3], A. Tumasyan[4], S. Shmatov[1]

[1]JINR (Dubna)
[2] INP BSU (Minsk)
[3] MEPhI(Moscow)
[4] ANSL (Yerevan)

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Motivation

- Partons - products of hadron-hadron hard scattering are not accessible for direct measurement

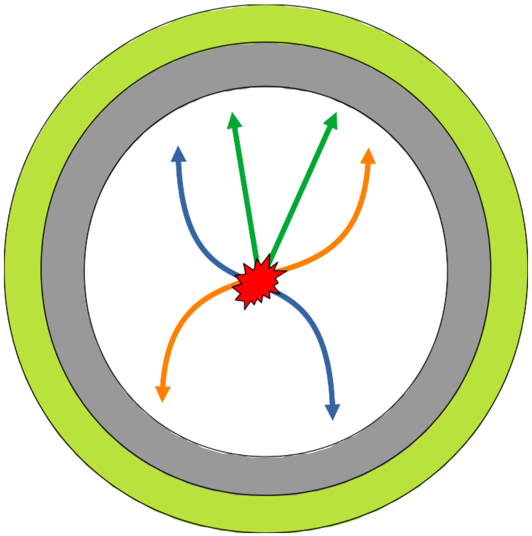
- We can get an information about these particles from the final state products resulting from harmonization of quark-gluon shower created by the initial parton

- When the energy of parton-initiator is *high enough* in the final state a *jet* of particles will be formed, which will correspond to initial parton with high accuracy:

$$\mathbf{p^{Jet}\,(E, Px, Py, Pz) \approx p^{parton}\,(E, Px, Py, Pz)}$$

- 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
- Reconstruction of parton-initiator flavour depending on reconstructed jet characteristic

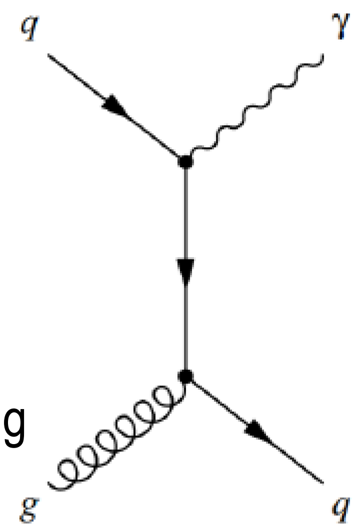
Clustering algorithms and parameters

- 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

Objects definition

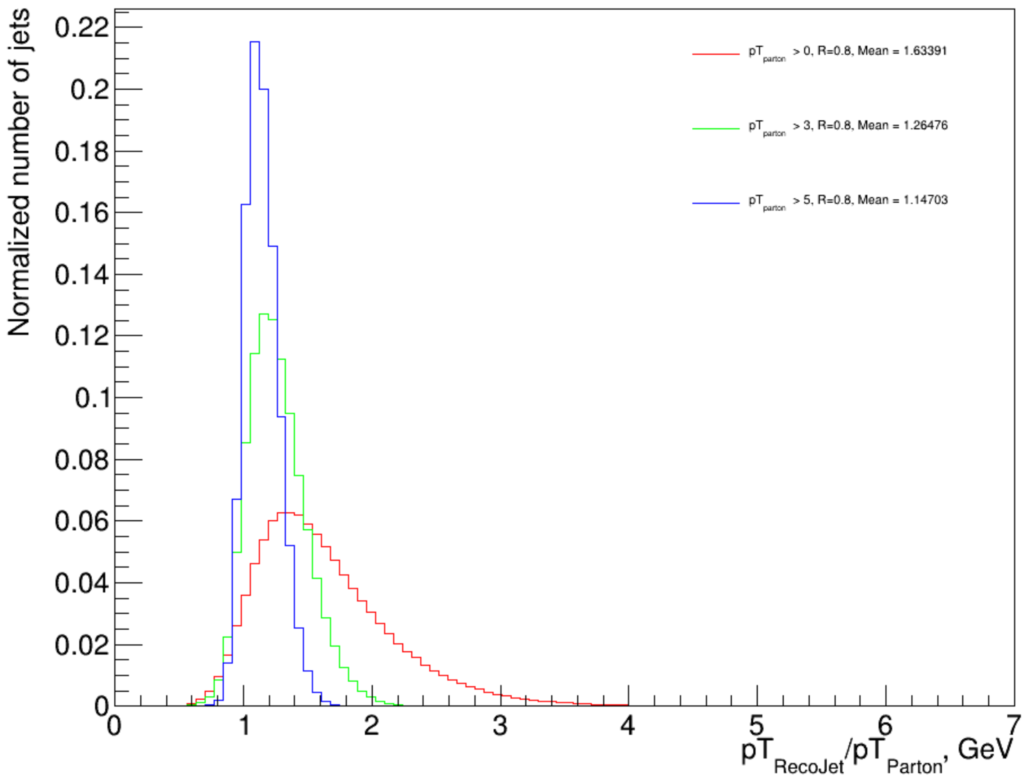
- Clustered jets:
  - Clustering algorithms can find many jet-like objects in single event
  - But we want to choose only objects, which could be associated with initial parton
  - We use two methods based on gen information to find such objects
    - We take all jets, which are found by clustering algorithm and select the closest one by distance (η,φ) to hard scattered parton, but the distance should be less than R
    - We take highest p_T jet and check, at least one jet constituent originated from hard scattered parton
  - Both methods give similar results

Event generation and jet reconstruction settings

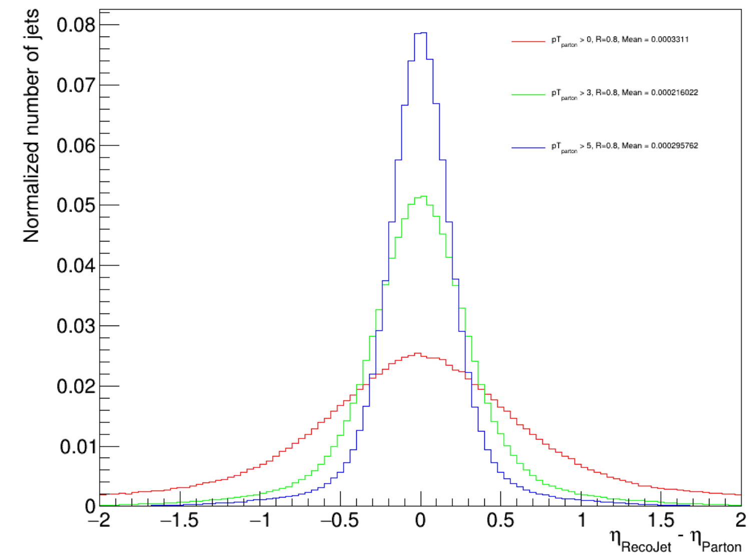


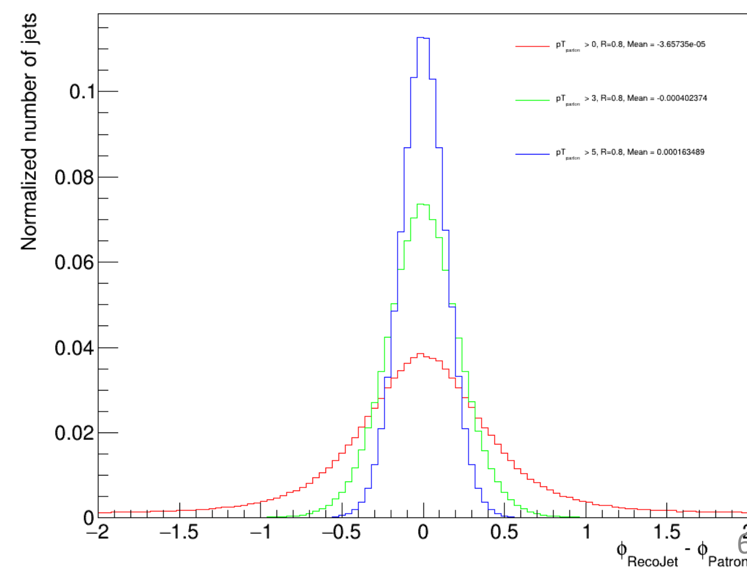
- We use Pythia8 generator and FastJet package
- We generate process: $qg \rightarrow q\gamma$
- Energy of collisions $\sqrt{s} = 27$ GeV
- *anti-kt* algorithm with parameter R = 0.4, 0.6, 0.8 was used for jet clustering
- Minimum jet $p_T = 0.5 GeV$
- Jet was clustered from final state particles with $p_T > 0.25$ GeV and $\eta < 5$
- Clustered jets are matched to hard scattered parton (status = 23)
- Hard scattered parton cuts: $p_{T,\, parton}$ >0 GeV, >3 GeV, >5 GeV (**gen information cut**)
- Jet should have at least two particles

Clustered jet vs parton (R=0.8)

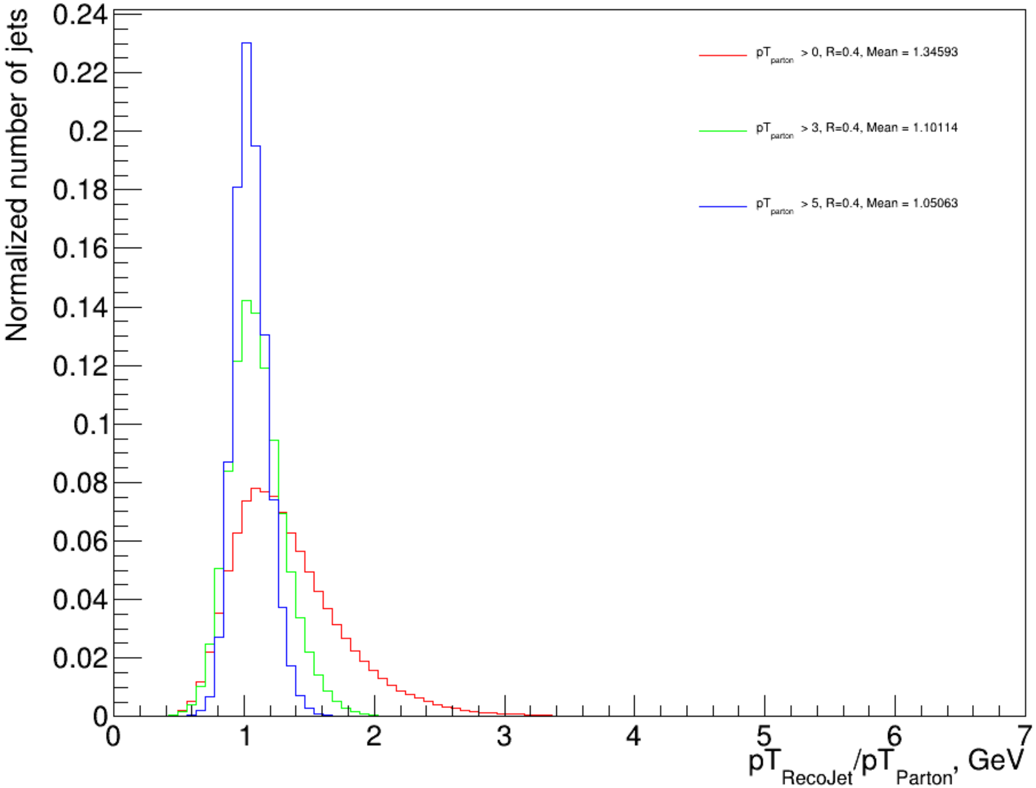


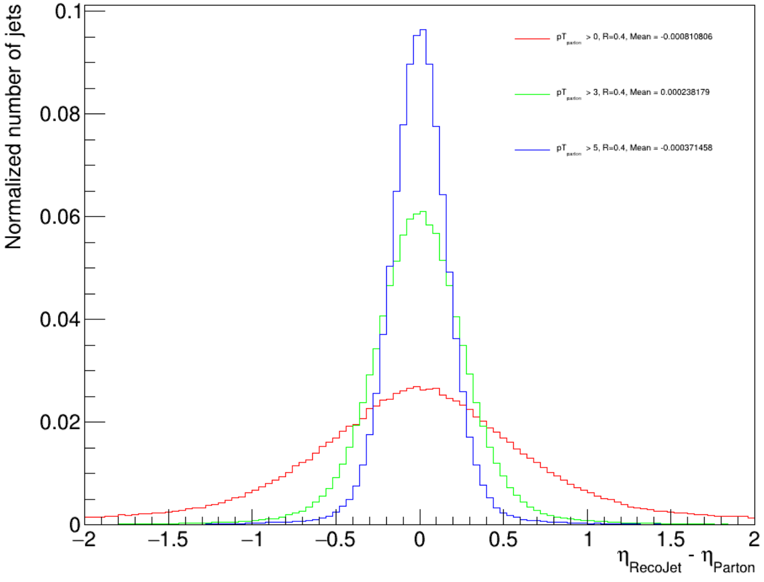
- Jet properties have good agreement with properties of initial parton

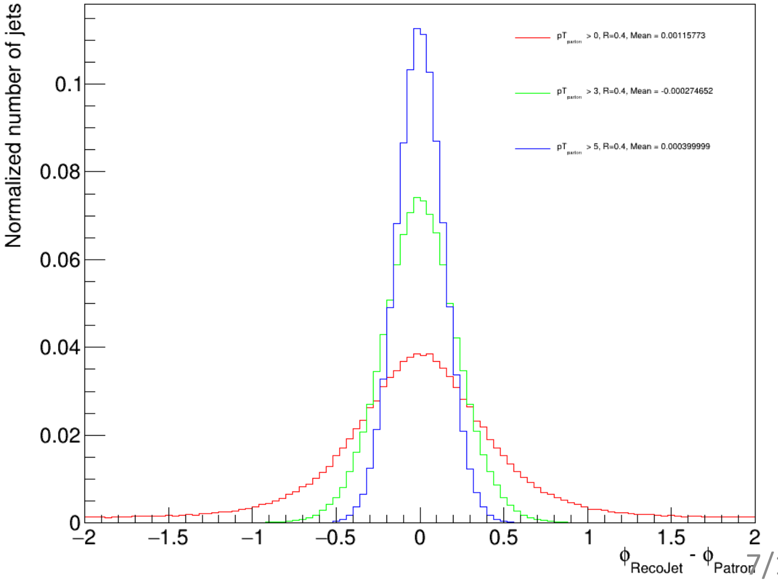




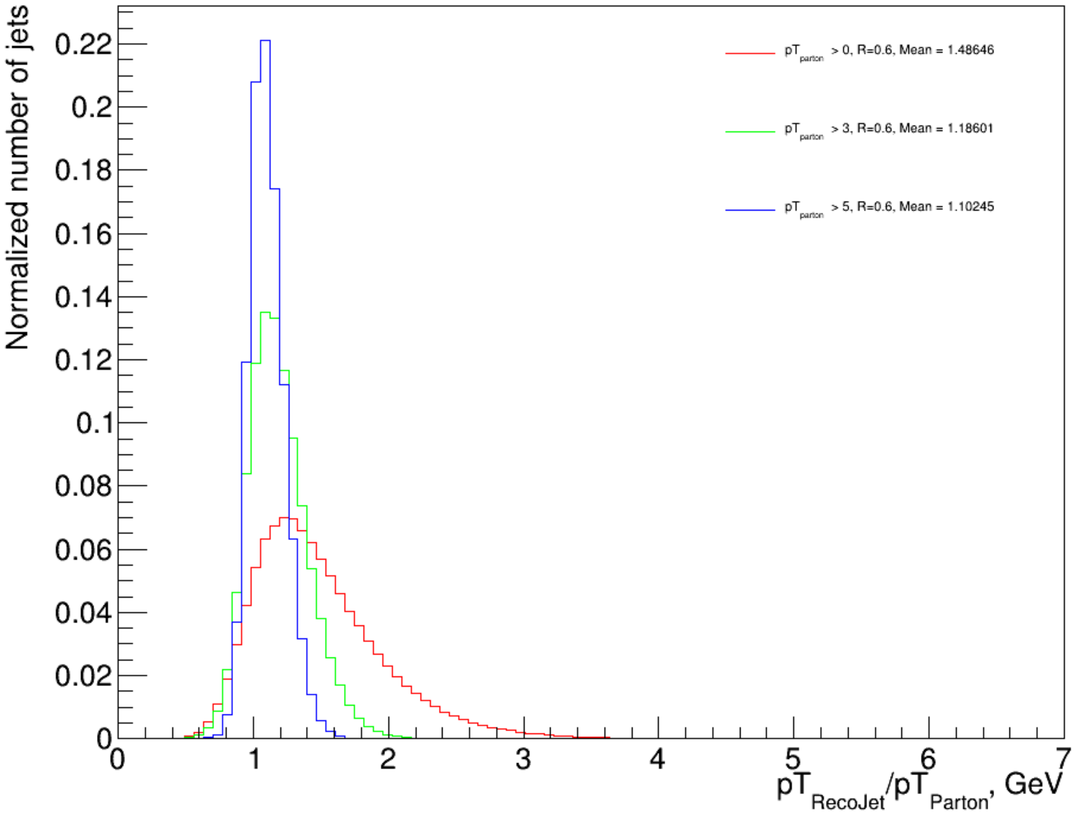
Clustered jet vs parton (R=0.4)

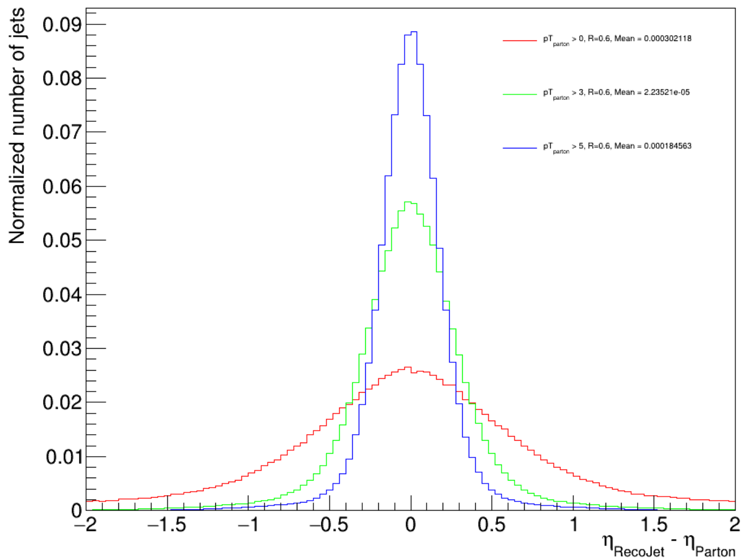


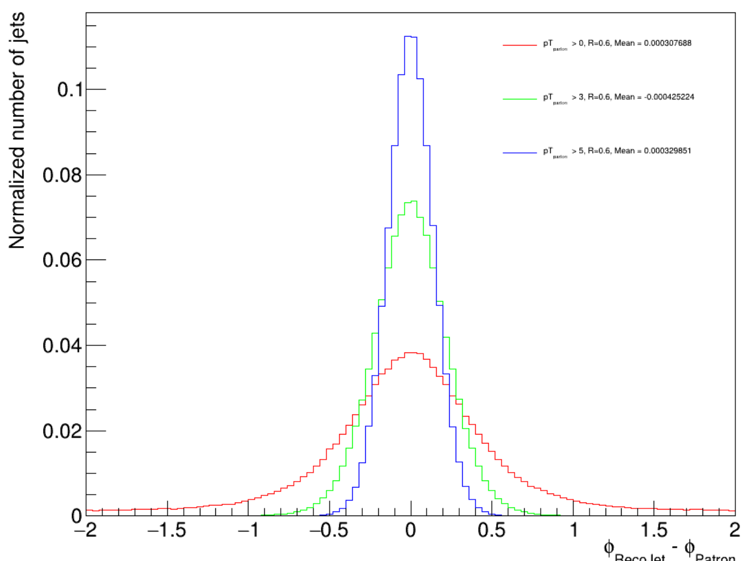




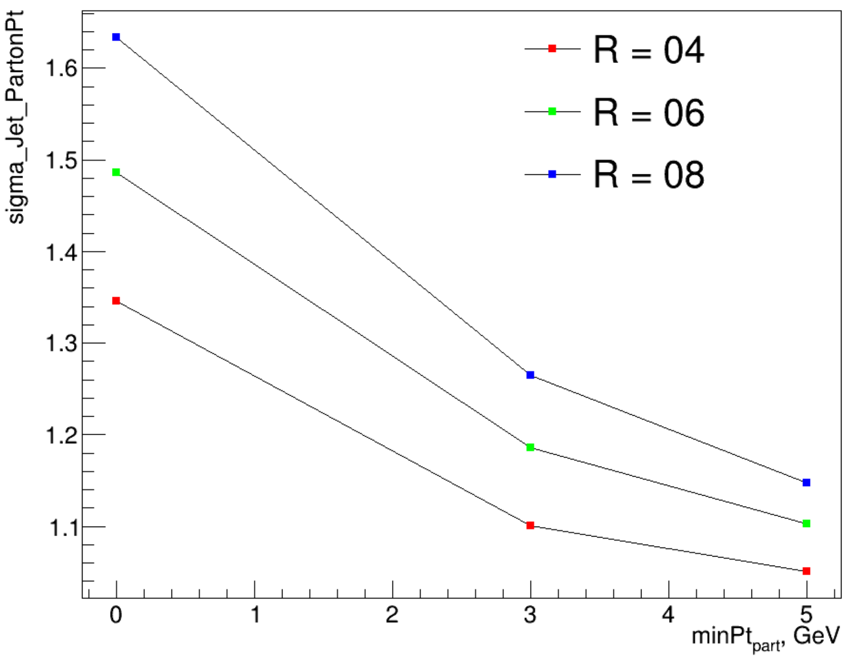
Clustered jet vs parton (R=0.6)

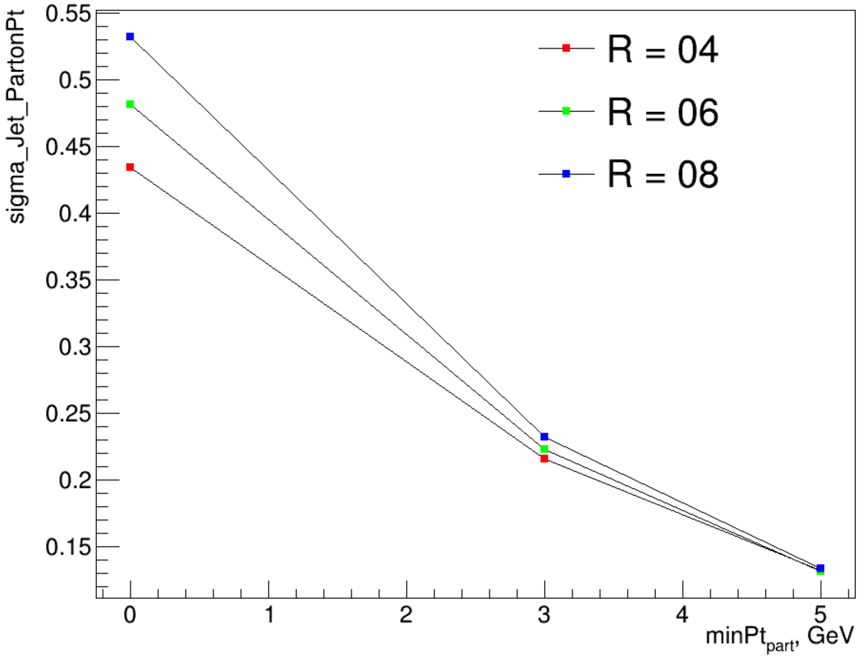






Mean values and σ

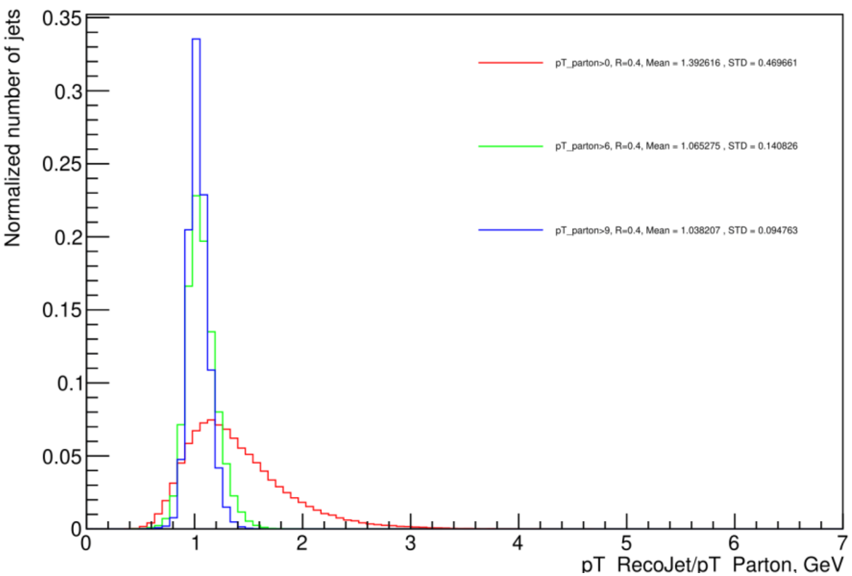




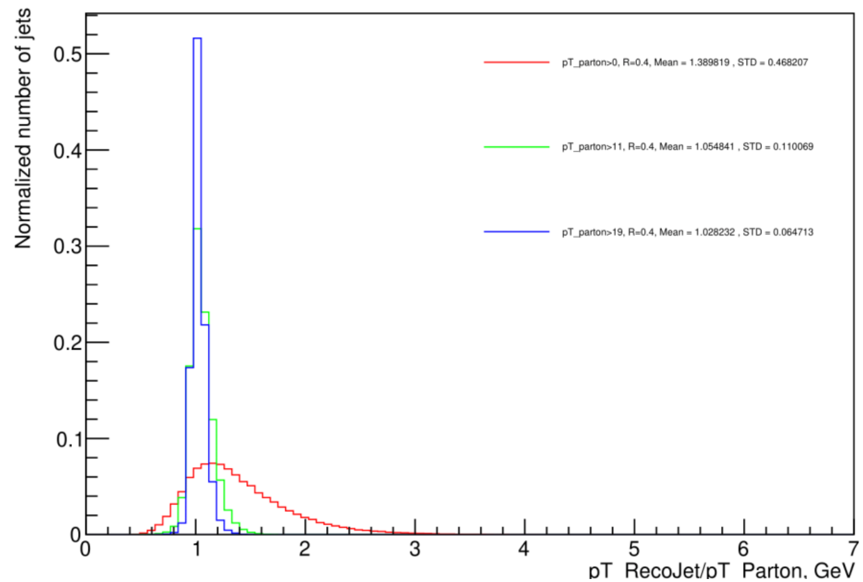
- High p_T partons produce jets, which could be better associated with them

Clustered jet vs parton (R=0.4)

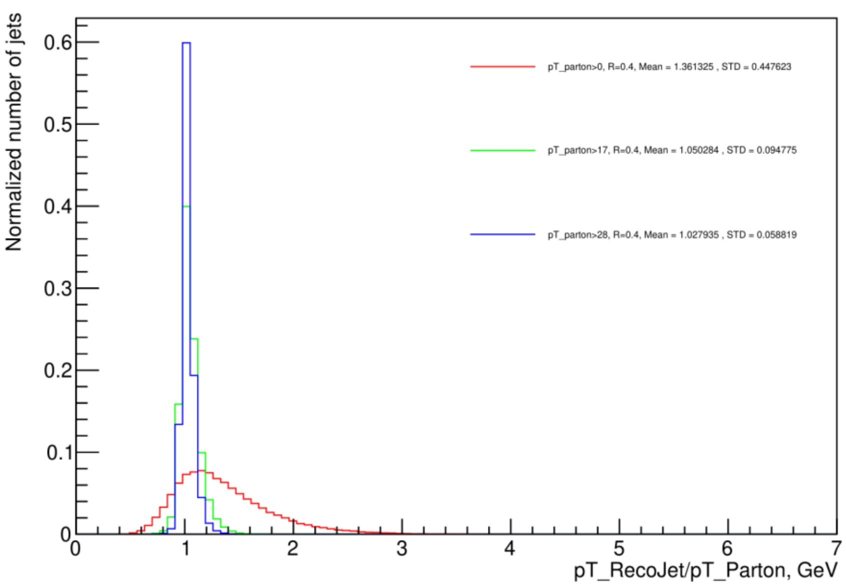
$\sqrt{s}$ = 50 GeV



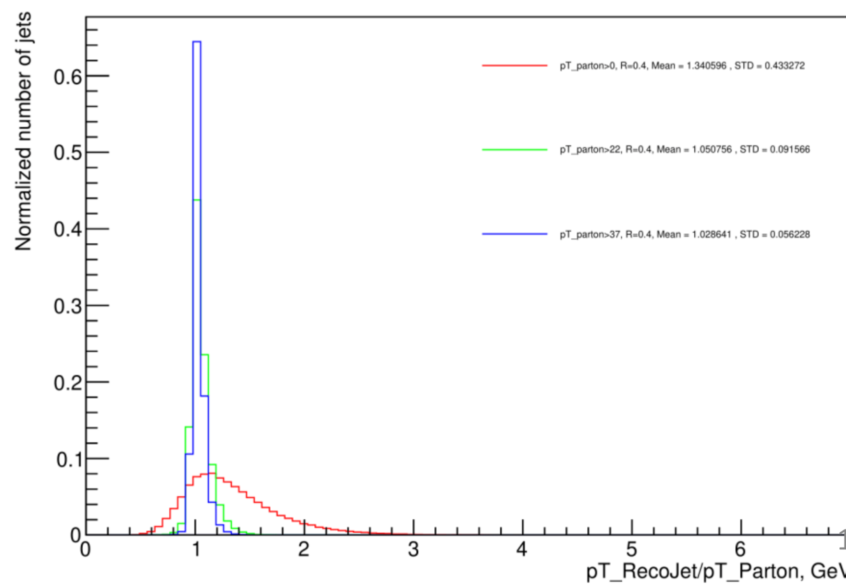
$\sqrt{s}$ = 100 GeV



$\sqrt{s}$ = 150 GeV

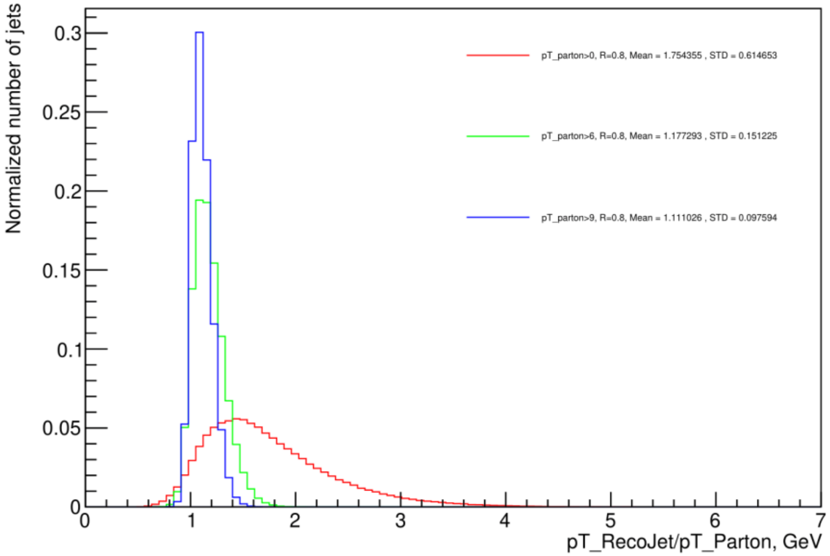


$\sqrt{s}$ = 200 GeV

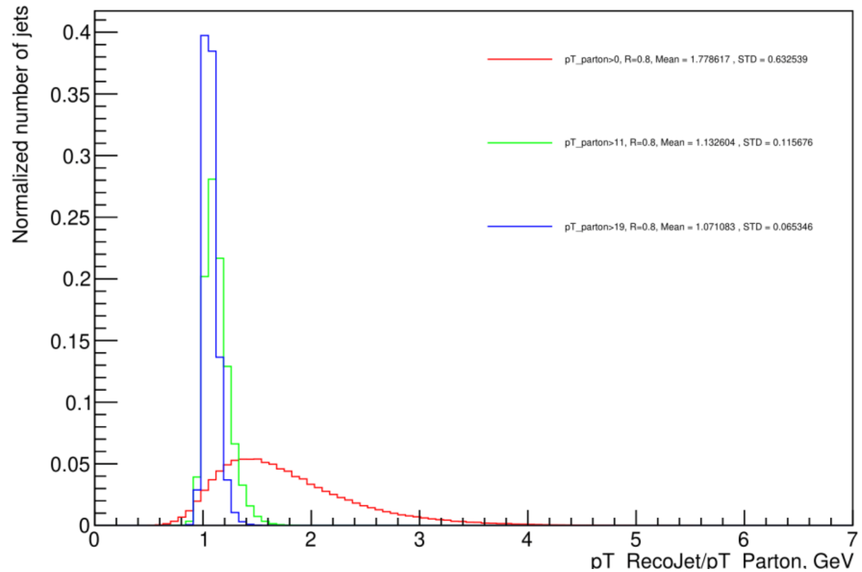


Clustered jet vs parton (R=0.8)

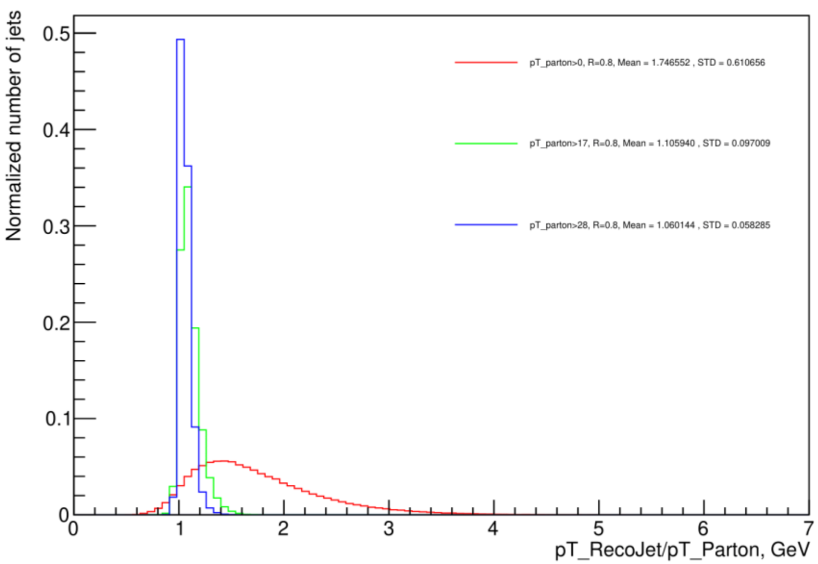
$\sqrt{s}$ = 50 GeV



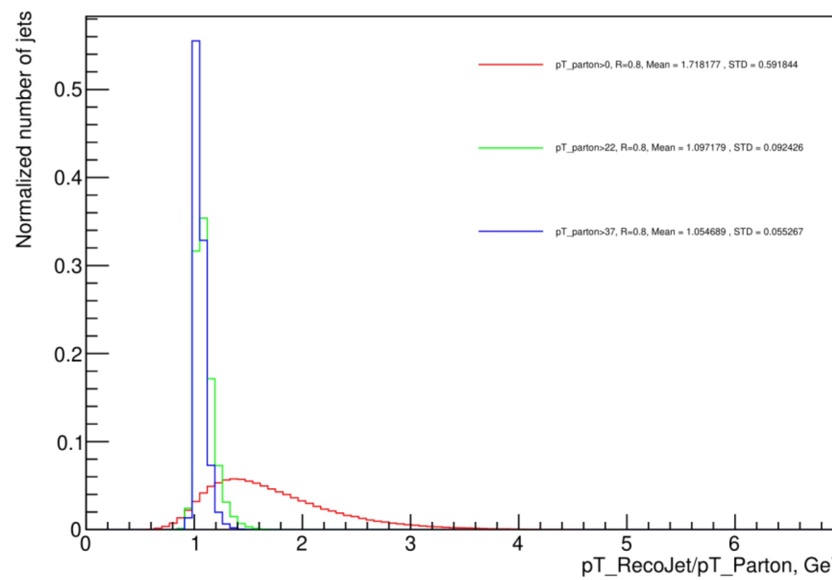
$\sqrt{s}$ = 100 GeV



$\sqrt{s}$ = 150 GeV



$\sqrt{s}$ = 200 GeV



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**

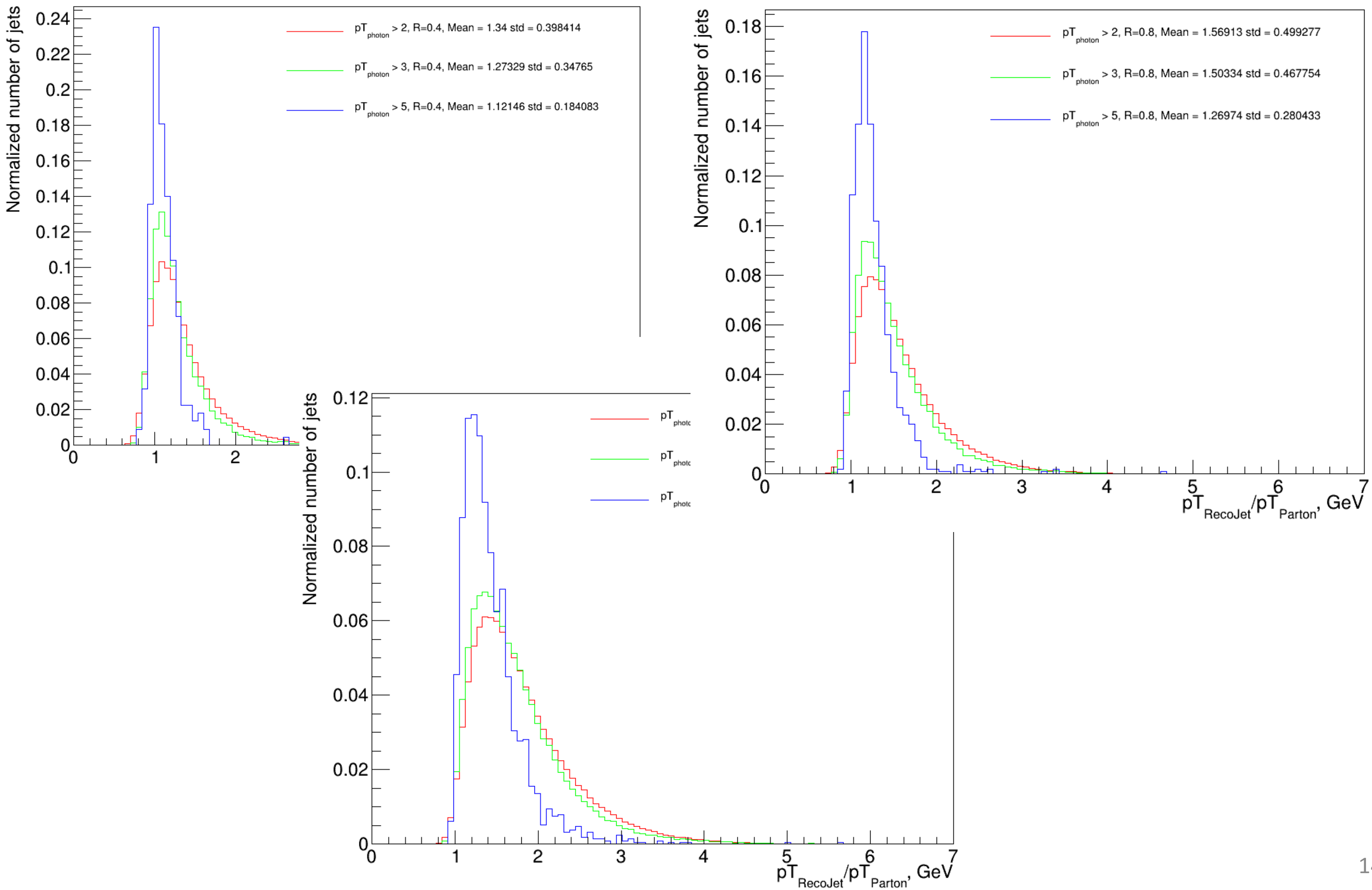
algorithm	mean	σ	σ/mean
Anti-kt, R=0.4	1.5466	0.4573	29.57
Kt, R=0.4	1.5513	0.4606	29.69
CA, R=0.4	1.5478	0.4583	29.61
Anti-kt, R=0.8	1.7480	0.5257	30.07
Kt, R=0.8	1.7478	0.5319	30.43
CA, R=0.8	1.7388	0.5250	30.19

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

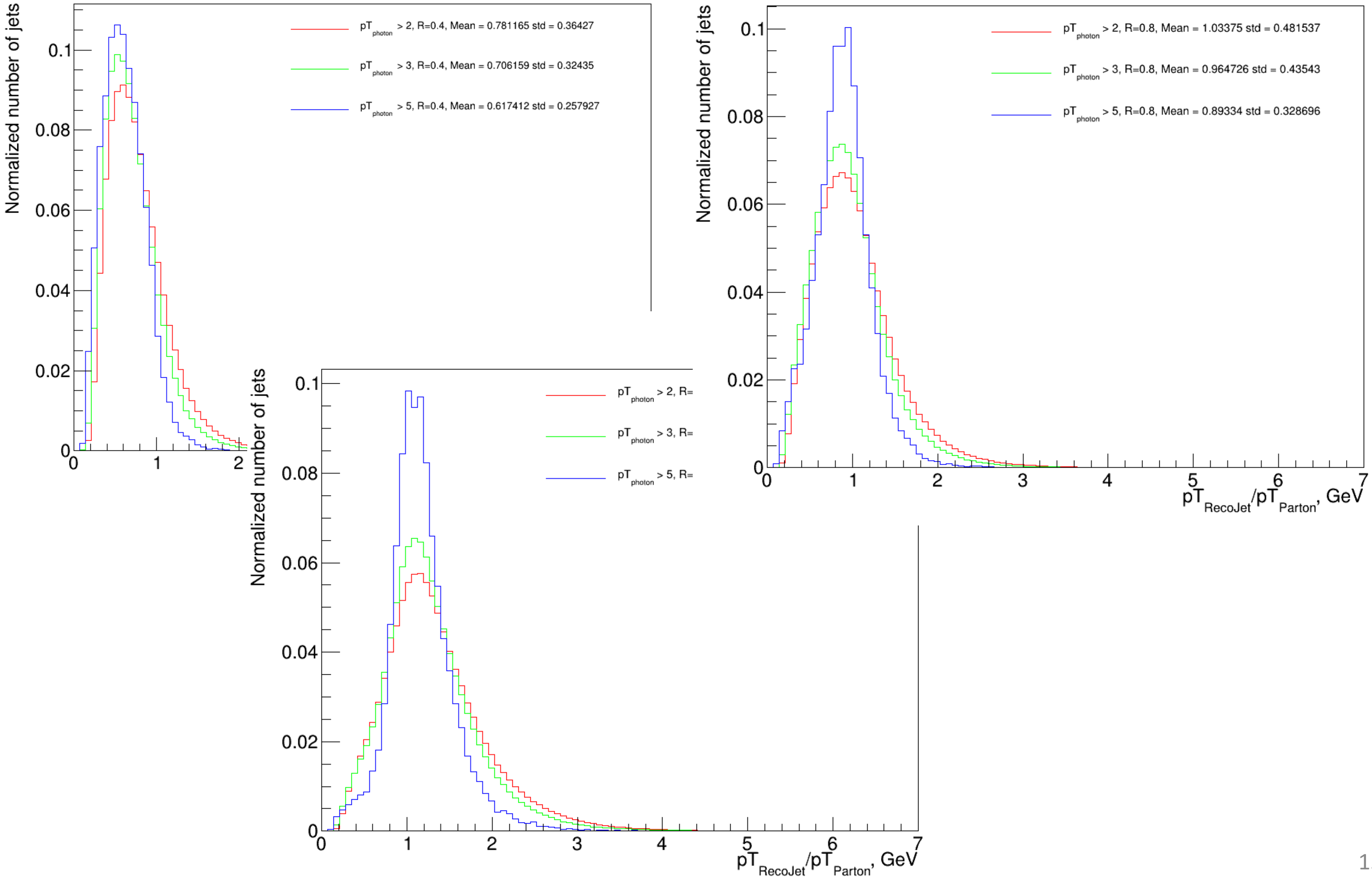
Event selections (without gen information)

- We use Pythia8 generator and FastJet package
- We generate process: $qg \rightarrow q\gamma$
- Energy of collisions $\sqrt{s} = 27$ GeV
- *anti-kt* algorithm with parameter R = 0.4, 0.8, 1.2 was used for jet clustering
- Minimum jet $p_T = 0.5 GeV$
- 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)
- Hard highest p_T **photon cuts**: $p_{T,\,photon}$ >2 GeV, >3 GeV, >5 GeV
- Photon and jet are back to back: $\Delta\varphi > 2.7$
- Jet should have at least two particles
- **Three approaches** for considered jets

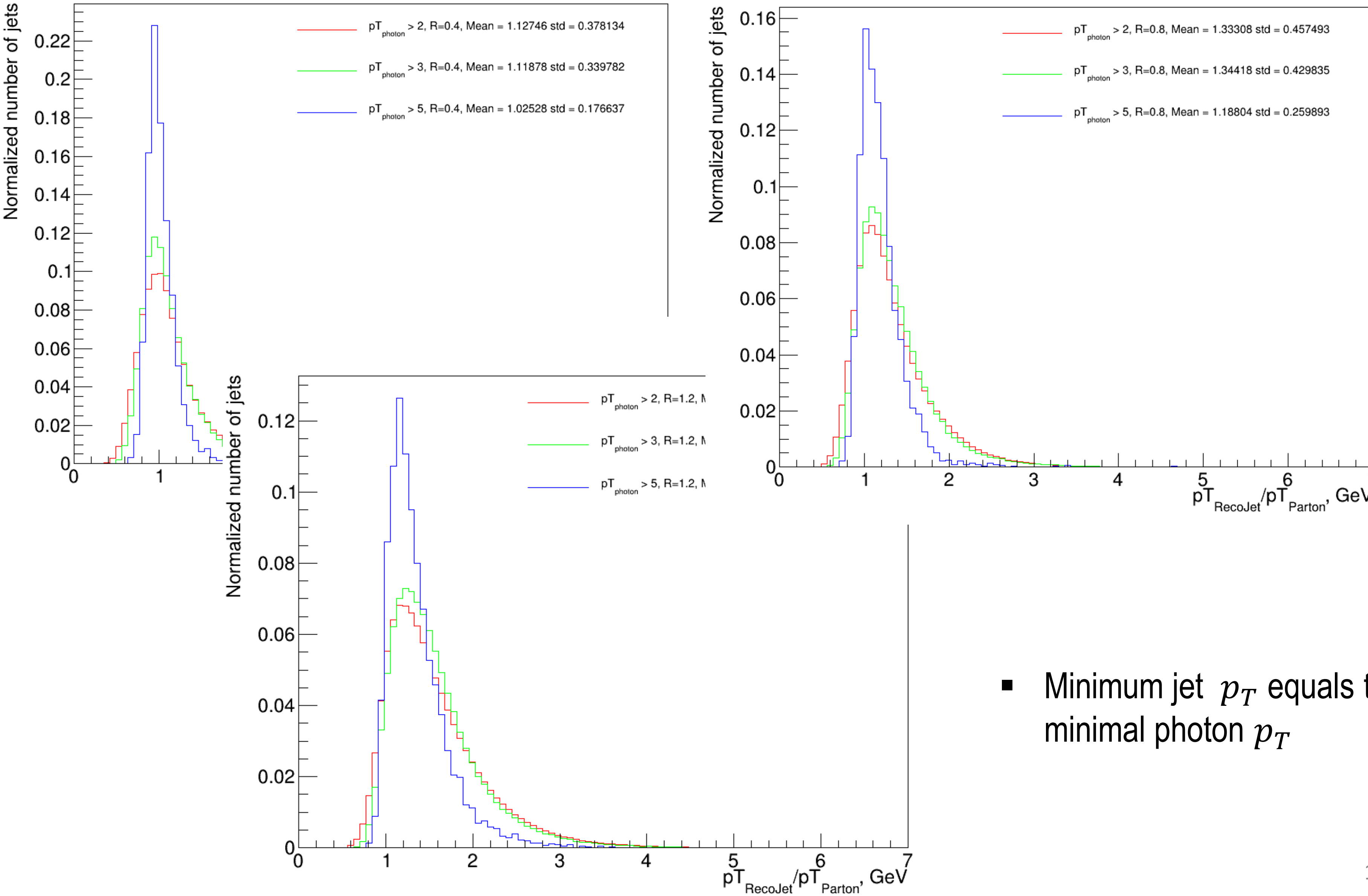
Clustered jet vs parton (leading jet before condition on photon)



Clustered jet vs parton (leading "correct" jet)

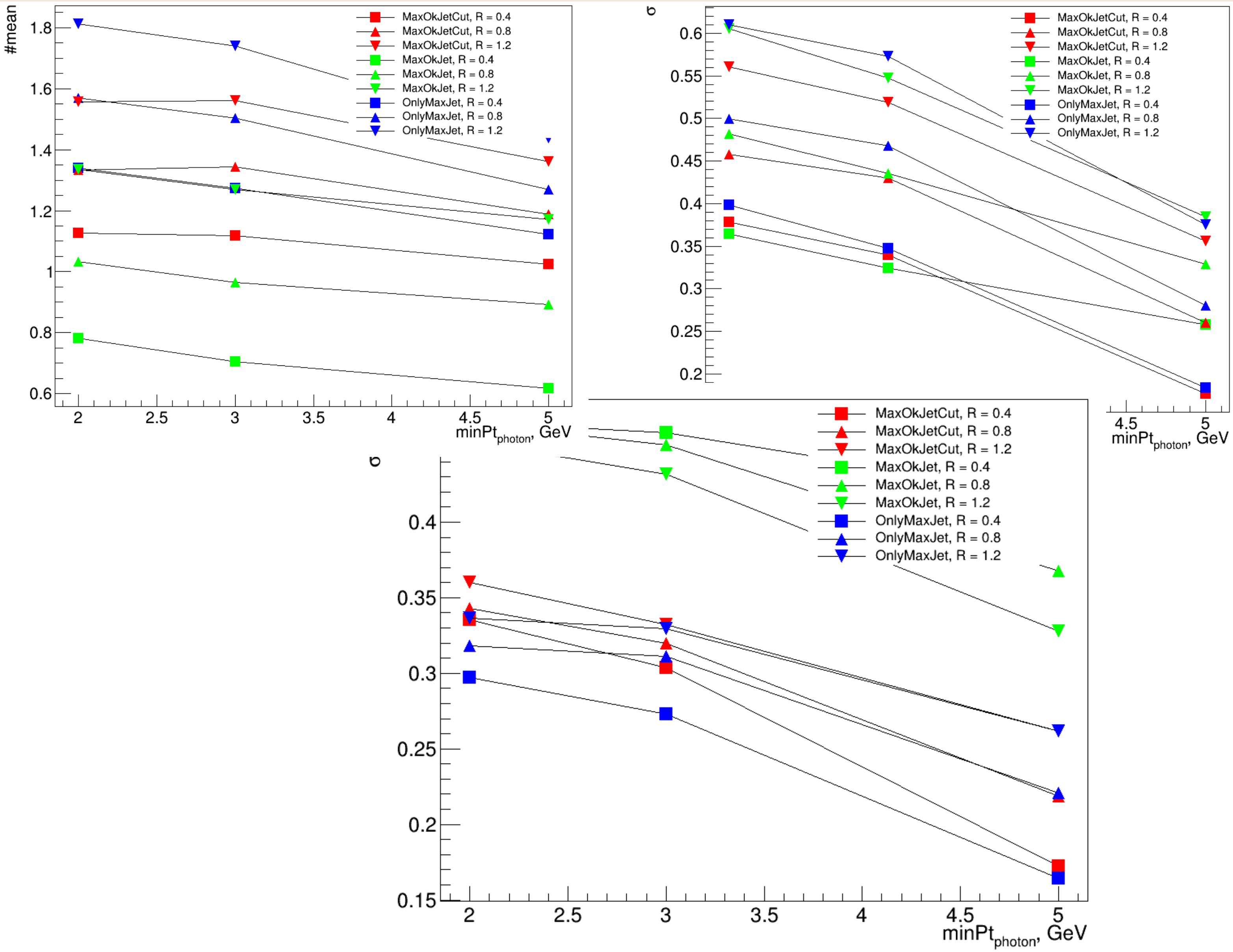


Clustered jet vs parton (leading “correct” jet with cut on jet p_T)

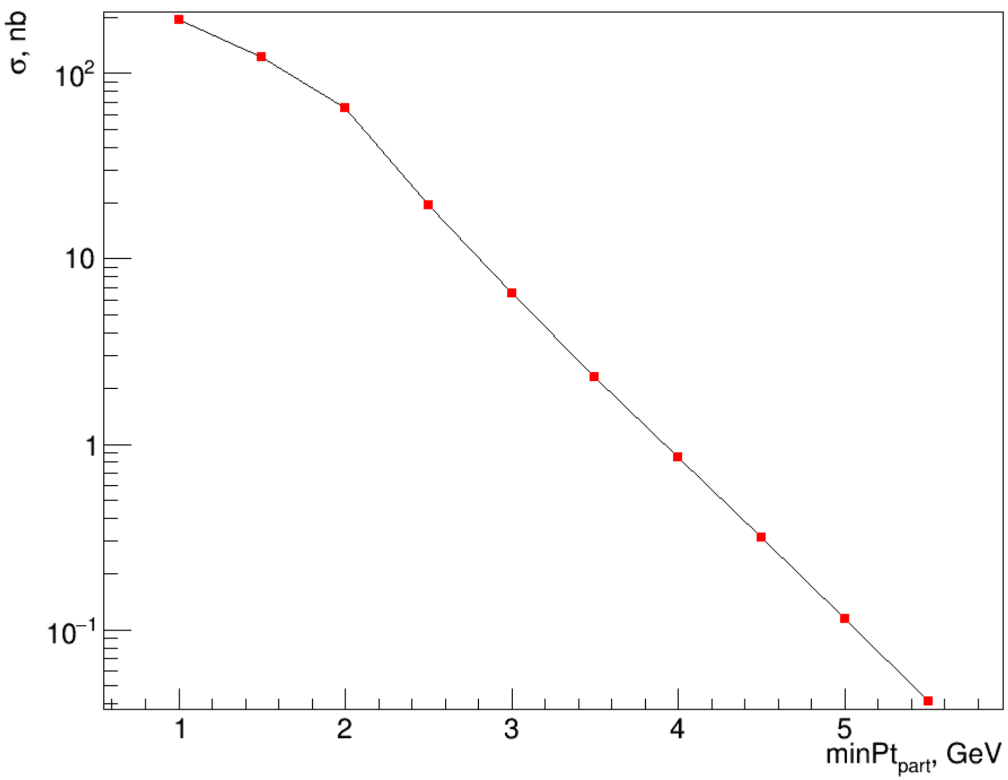


- Minimum jet p_T equals to minimal photon p_T

Mean values and σ



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

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

Conclusion and plans

- Kinematical properties of hard scattered partons and clustered jets was compared on generator level
- If we use cuts on $p_{T,parton}$ then there are objects which could be associated with initial parton
- We have shown that increasing $\sqrt{s}$ lead to better association between jets and parton
- Different clustering algorithms find similar jets, but we have to study time of their work
- We studied cuts on the photon:
  - Increasing radius parameter of clustering algorithm worsen parton-jet association
  - It is necessary to use cut on $p_{T,jet}$ together with cut on photon
- We expect enough statistics to make these analysis
- Plans:
  - Analyzing of inclusive jet production
  - Check additional approaches to find clusters of particles
  - Repeat this study with full simulation of detector

Back up

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

Magnetic field effects

- Magnetic field change trajectories of charged particles and affect on jet reconstruction:
  - Jets becomes wider along phi angle
  - Some low p_T particles spin and go to endcaps

- How can we imitate magnetic field impact:
  - We assume that magnetic field is uniform and equal to 1T in whole detector
  - We take particle coordinates and calculate their change after some small dt as:

$$dv_x = c(p_x/p)dt$$

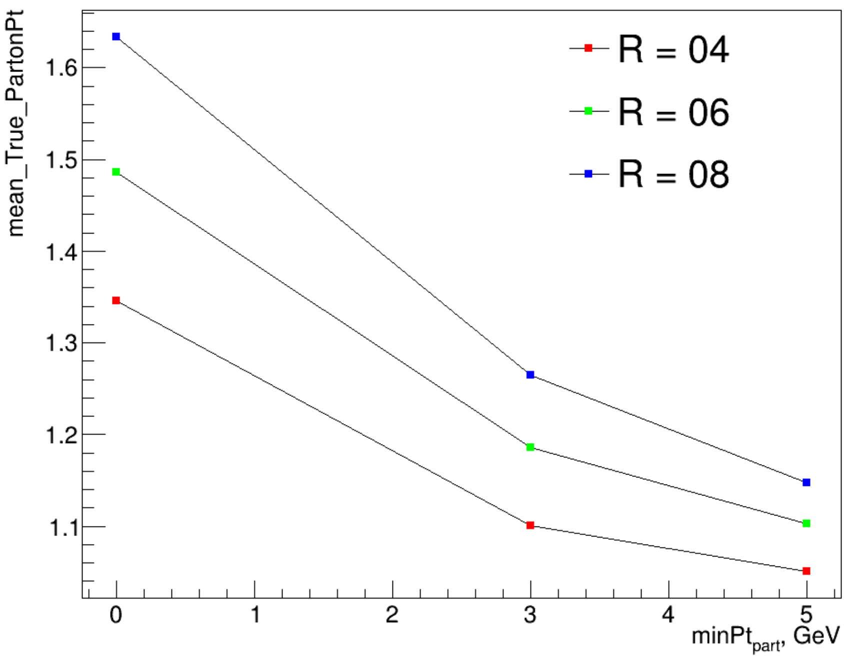
  - And we can calculate change of p_x and p_y:

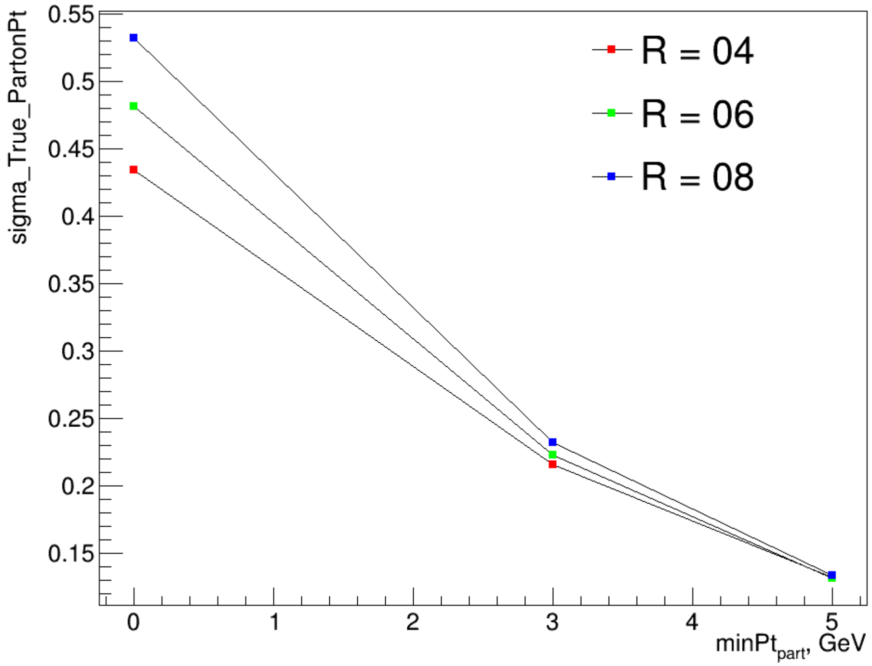
$$dp_x = \frac{c^2 q}{E}\left(p_y B_z\right)dt$$

$$dp_y \frac{c^2 q}{E}(-p_x B_z)dt$$

  - We continue this iterations until $v_{xy} < 1080mm$, i.e. particle reach ECal
  - In the end we recalculate momentum of particle assuming that it moves directly from their vertex to place where it reach ECal

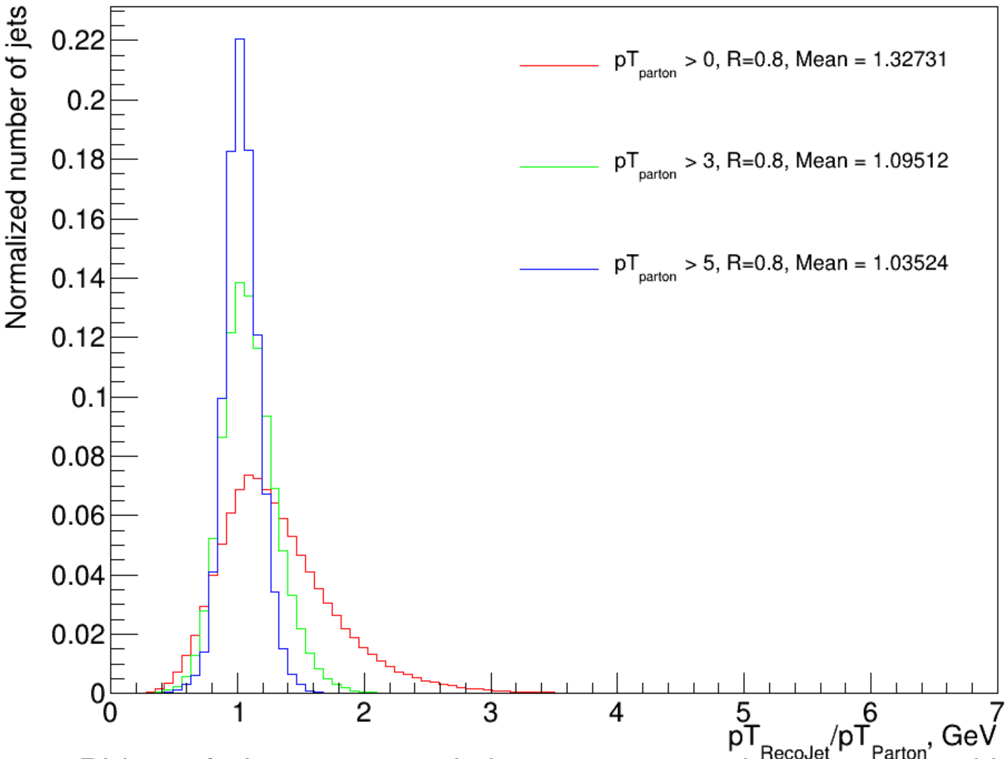
Mean values and sigma

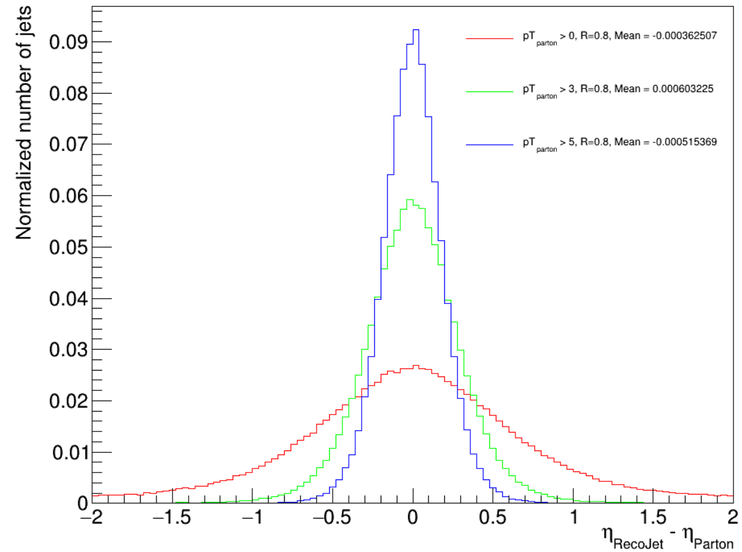


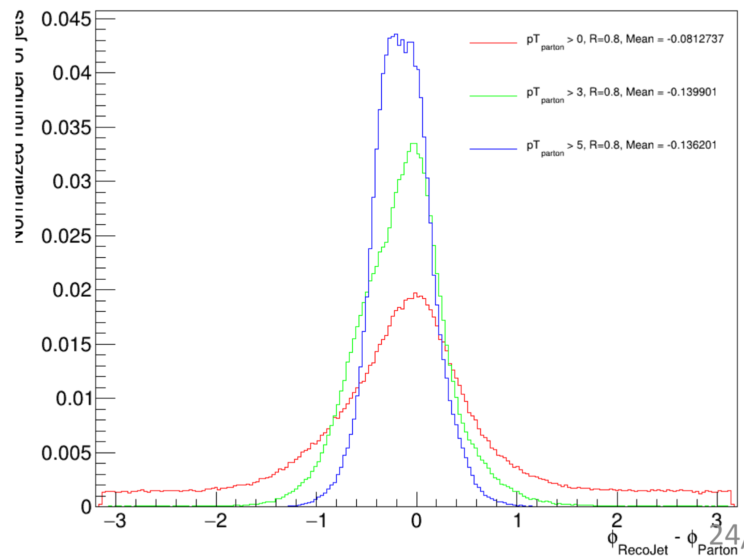


- High p_T partons produce jets, which could be better associated with them

Clustered jet vs parton (R=0.8, with magnetic field)

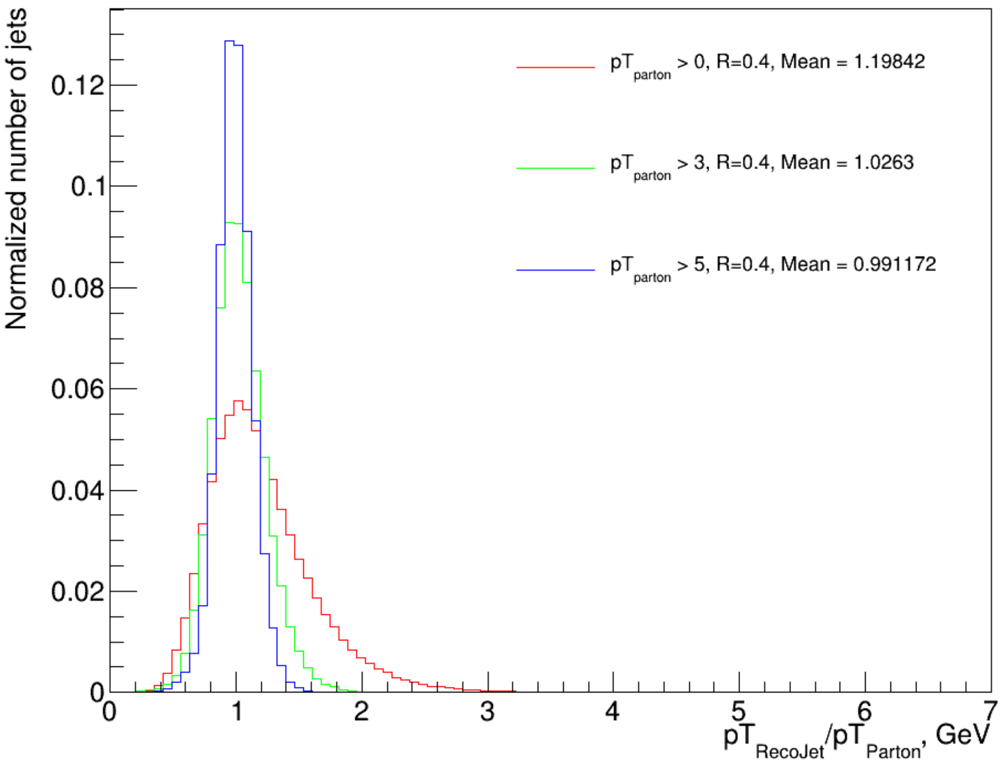


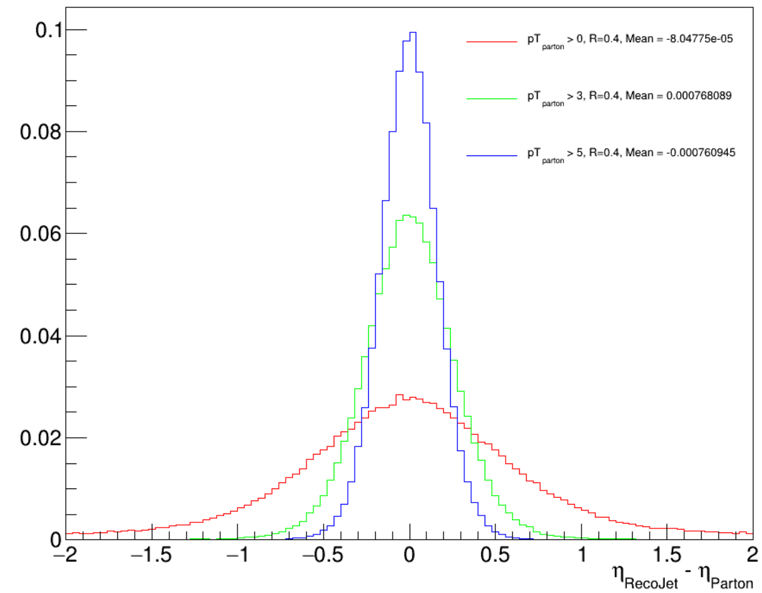


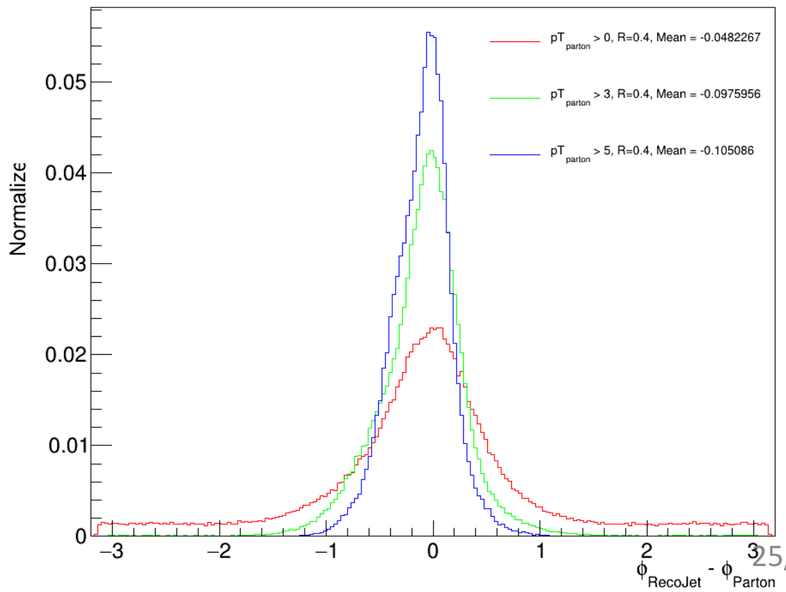


- Phi resolution asymmetric because events have more positive charged particles
- Number of jets with magnetic field ~3 time less that without magnetic field for same statistics
- Fraction of jets with charged leading particle strongly depends on $p_{T,\, parton}$
  - $p_{T,\, parton} > 0$ GeV ~ 30%
  - $p_{T,\, parton} > 5$ GeV ~ 60%

Clustered jet vs parton (R=0.4, with magnetic field)







Clustered jet vs parton (R=0.6, with magnetic field)