Cluster particle production @ SPD experiment

on behalf of the SPD collaboration

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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

Jets at low energies in other experiments

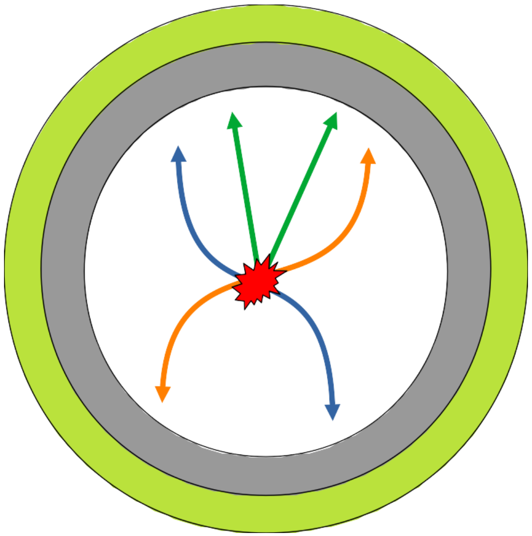
- Jets at low energies was studied in 70s-80s in many experiments: PETRA, SFM 412, Pisa–Stony Brook, AFS etc.

- 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

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

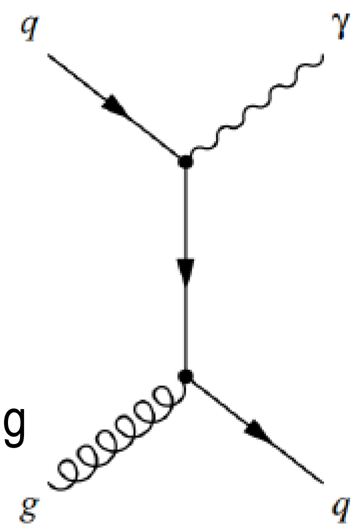
Clustering algorithms and parameters

- 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

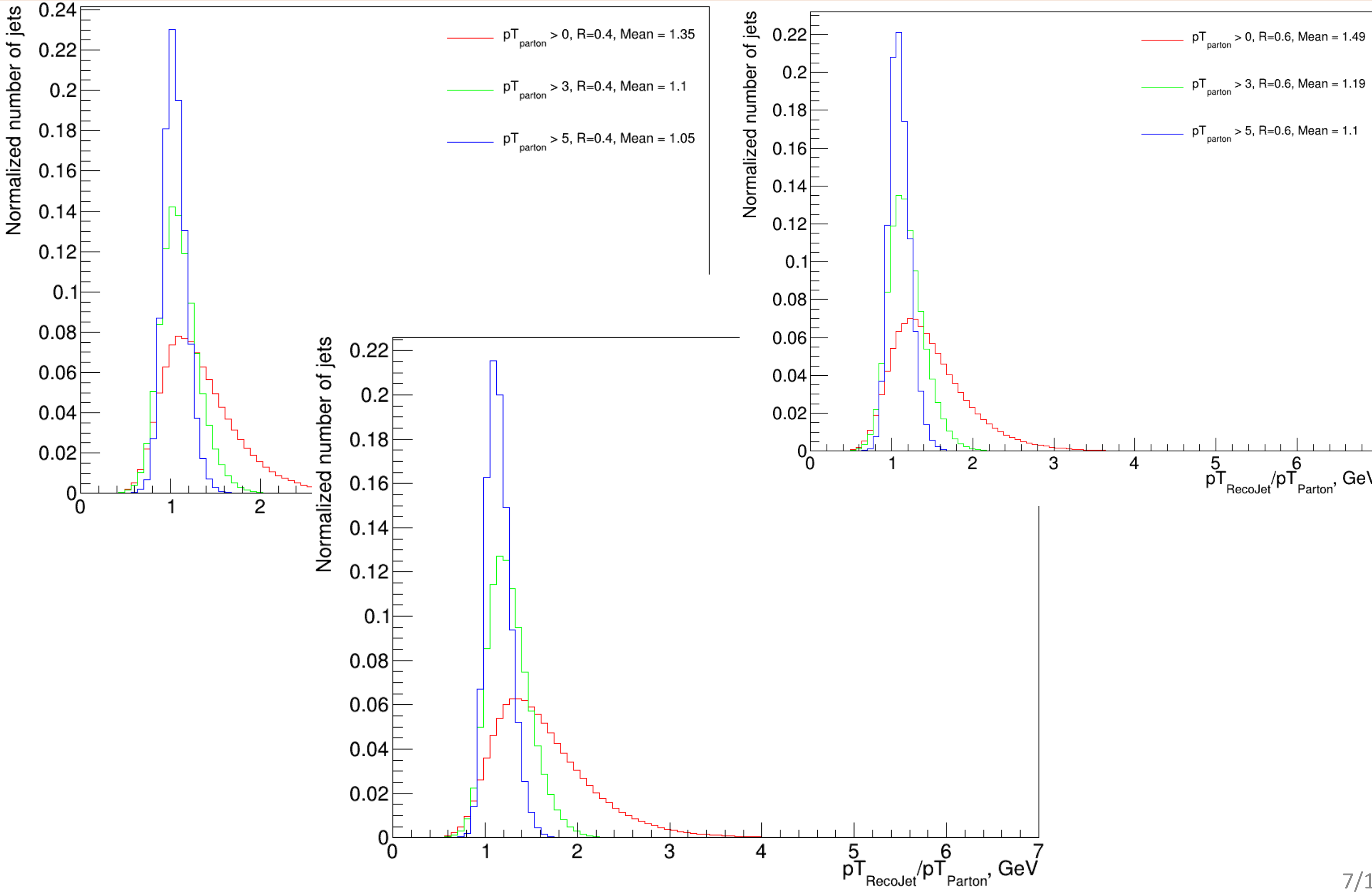
- Clustering algorithms can find many jet-like objects in single event
- But we want to choose only objects, which could be associated with initial parton
- Clustered jets (with gen information):
  - We take leading p_T jet and check, at least one jet constituent originated from hard scattered parton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

Event generation and jet reconstruction settings (with gen information)

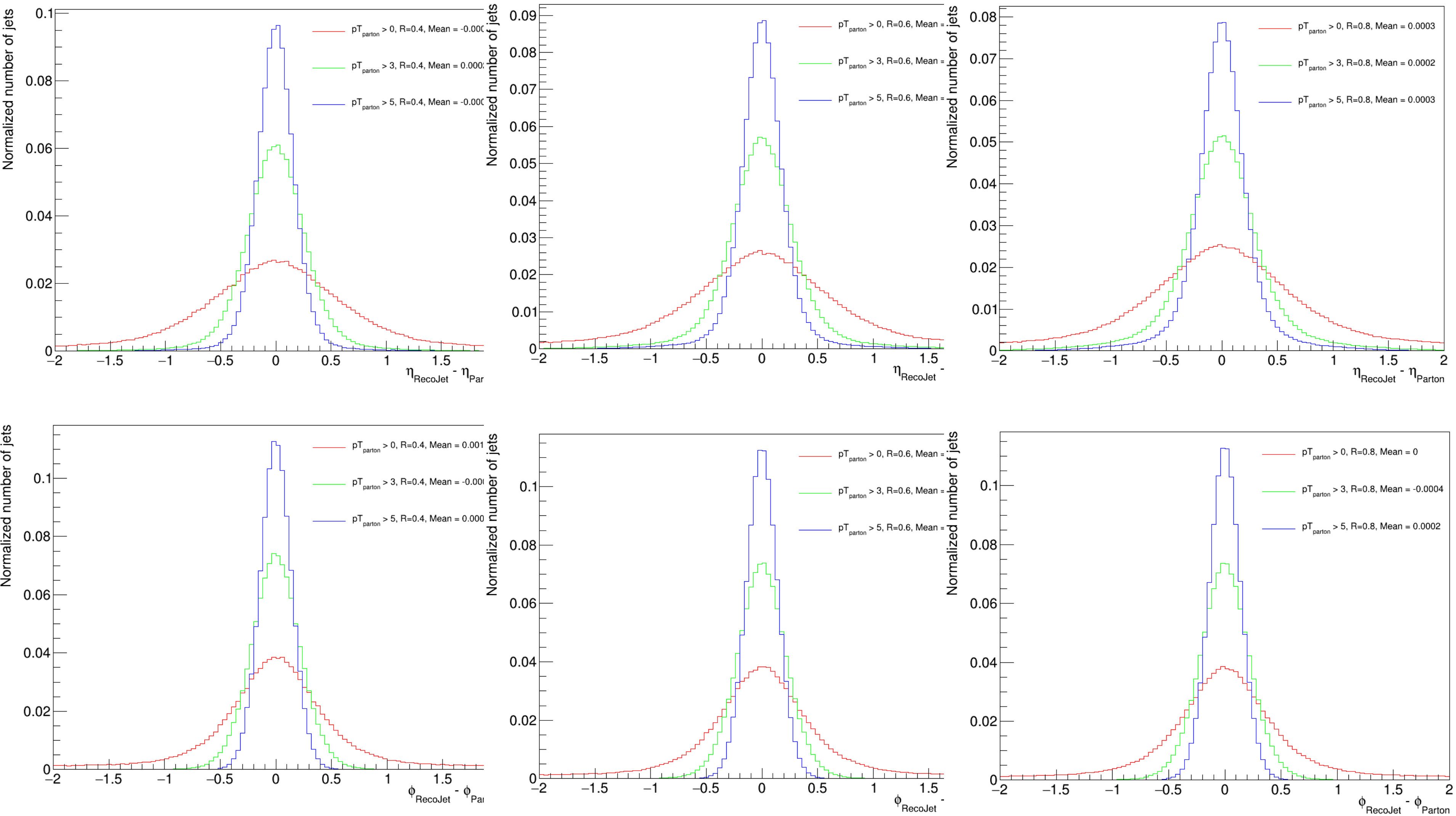


- We use Pythia8 generator and FastJet package
- We generate process: $qg \to q\gamma$
- Energy of collisions $\sqrt{s} = 27$ GeV
- *anti-kt* algorithm with parameter R = 0.4, 0.6, 0.8 was used for jet clustering
- Minimum jet $p_T = 0.5 GeV$
- Jet was clustered from final state particles with $p_T > 0.25$ 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 p_T vs parton p_T

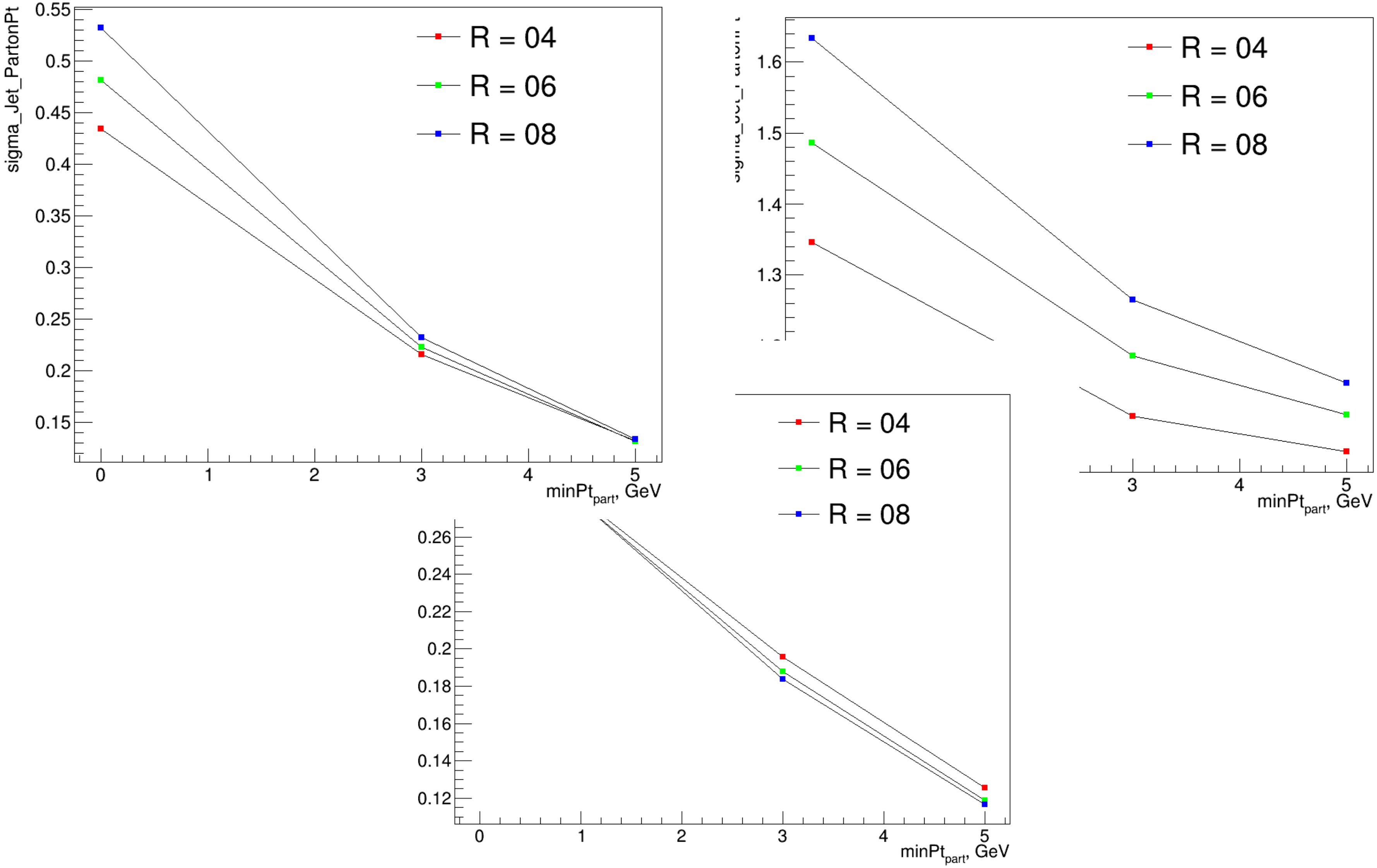


Clustered jet (φ, η) vs parton (φ, η)



- Jet properties have good agreement with properties of initial parton

Mean values and σ



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

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**

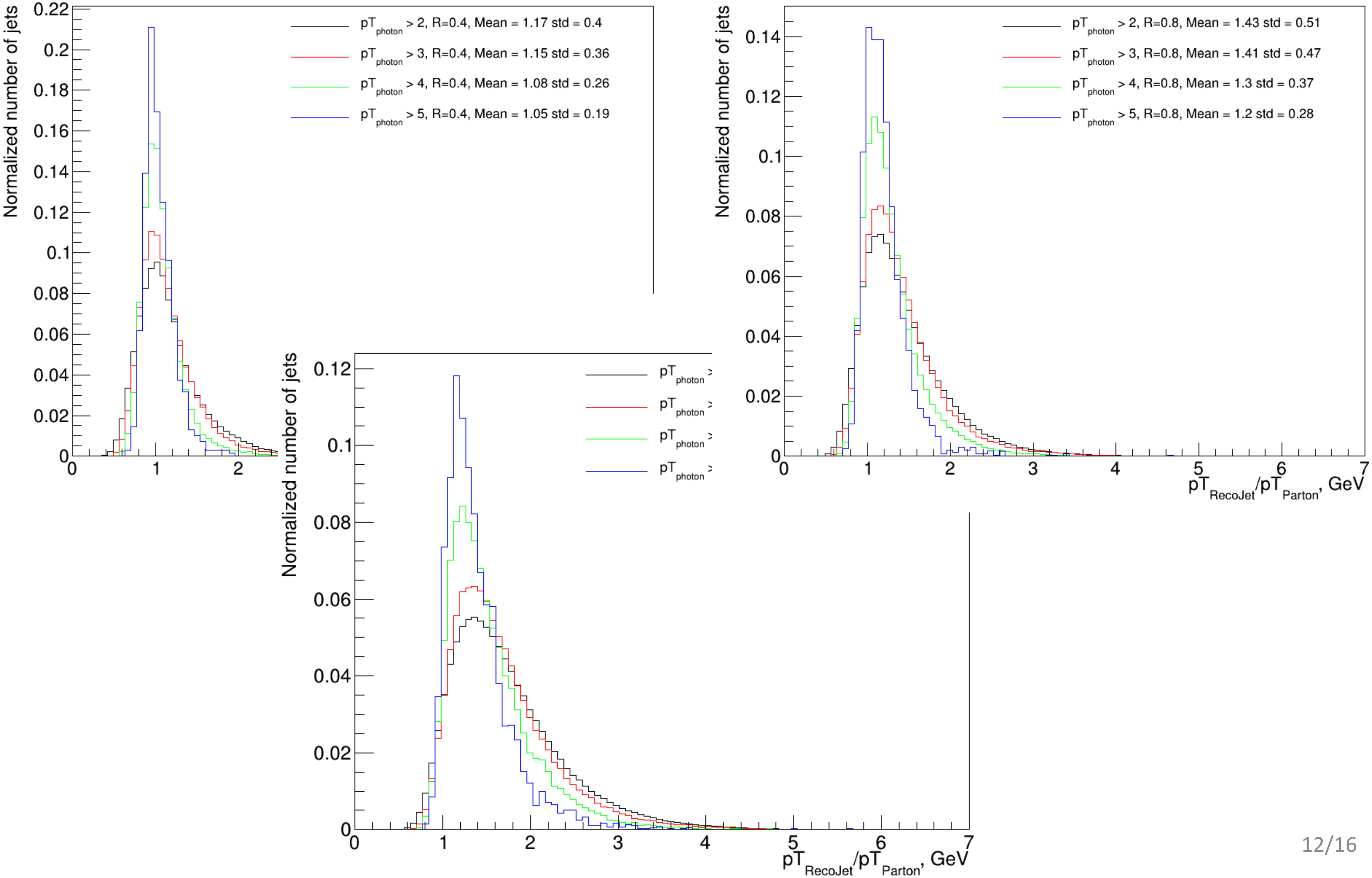
algorithm	mean	σ	σ/mean
Anti-kt, R=0.4	1.5466	0.4573	29.57
Kt, R=0.4	1.5513	0.4606	29.69
CA, R=0.4	1.5478	0.4583	29.61
Anti-kt, R=0.8	1.7480	0.5257	30.07
Kt, R=0.8	1.7478	0.5319	30.43
CA, R=0.8	1.7388	0.5250	30.19

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

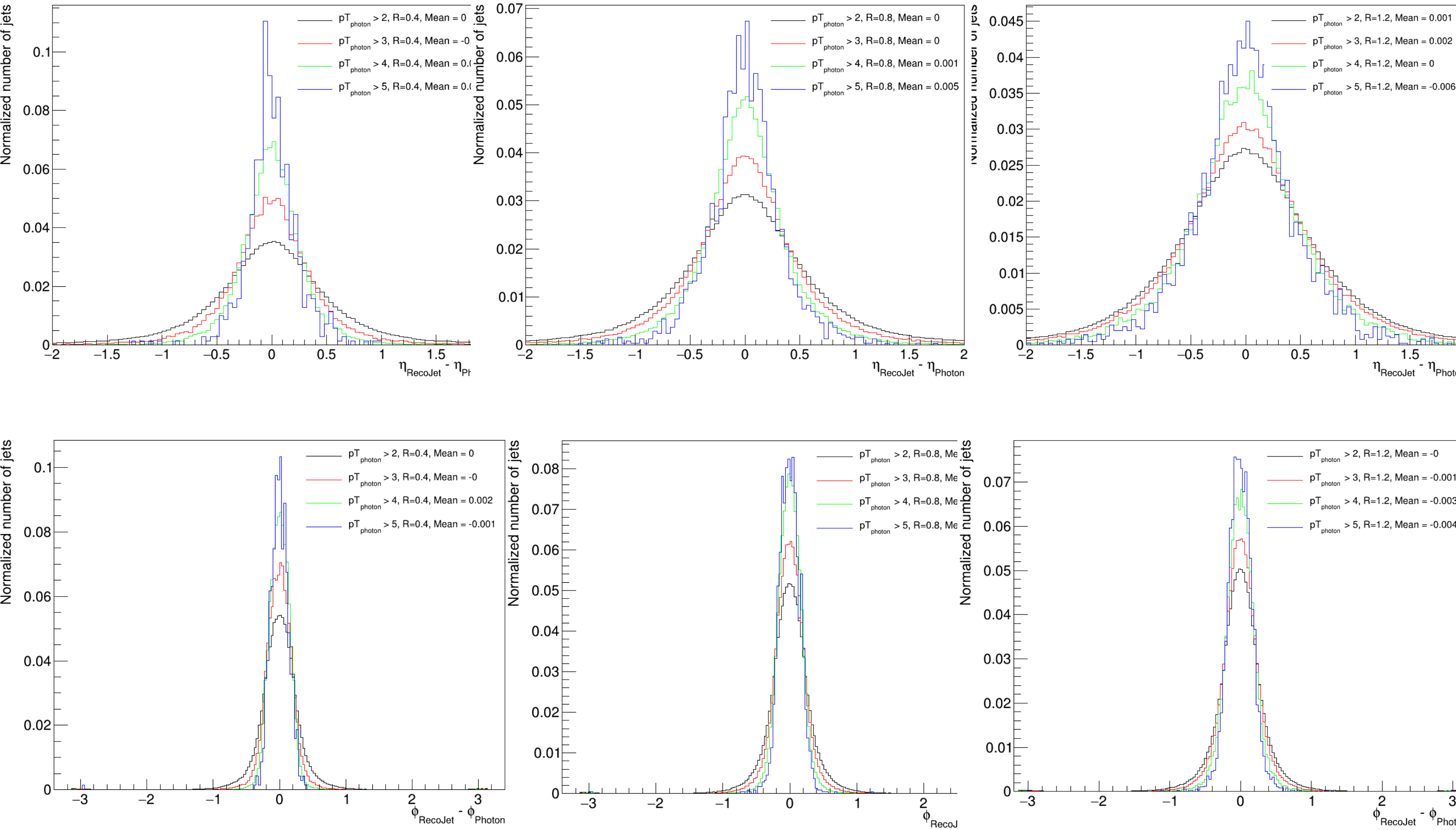
Event selections (only observable parameters)

- We use Pythia8 generator and FastJet package
- We generate process: $qg \to q\gamma$
- Energy of collisions $\sqrt{s} = 27$ GeV
- *anti-kt* algorithm with parameter R = 0.4, 0.8, 1.2 was used for jet clustering
- 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)
- Leading photon p_T cuts: $p_{T,\,photon}$ >2 GeV, >3 GeV, >4 GeV, >5 GeV
- Leading jet p_T cuts: $p_{T,\,jet}$ >2 GeV, >3 GeV, >4 GeV, >5 GeV.
- Photon and jet are back to back: $\Delta\varphi > 2.7$
- Jet should have at least two particles

Clustered jet p_T vs parton p_T

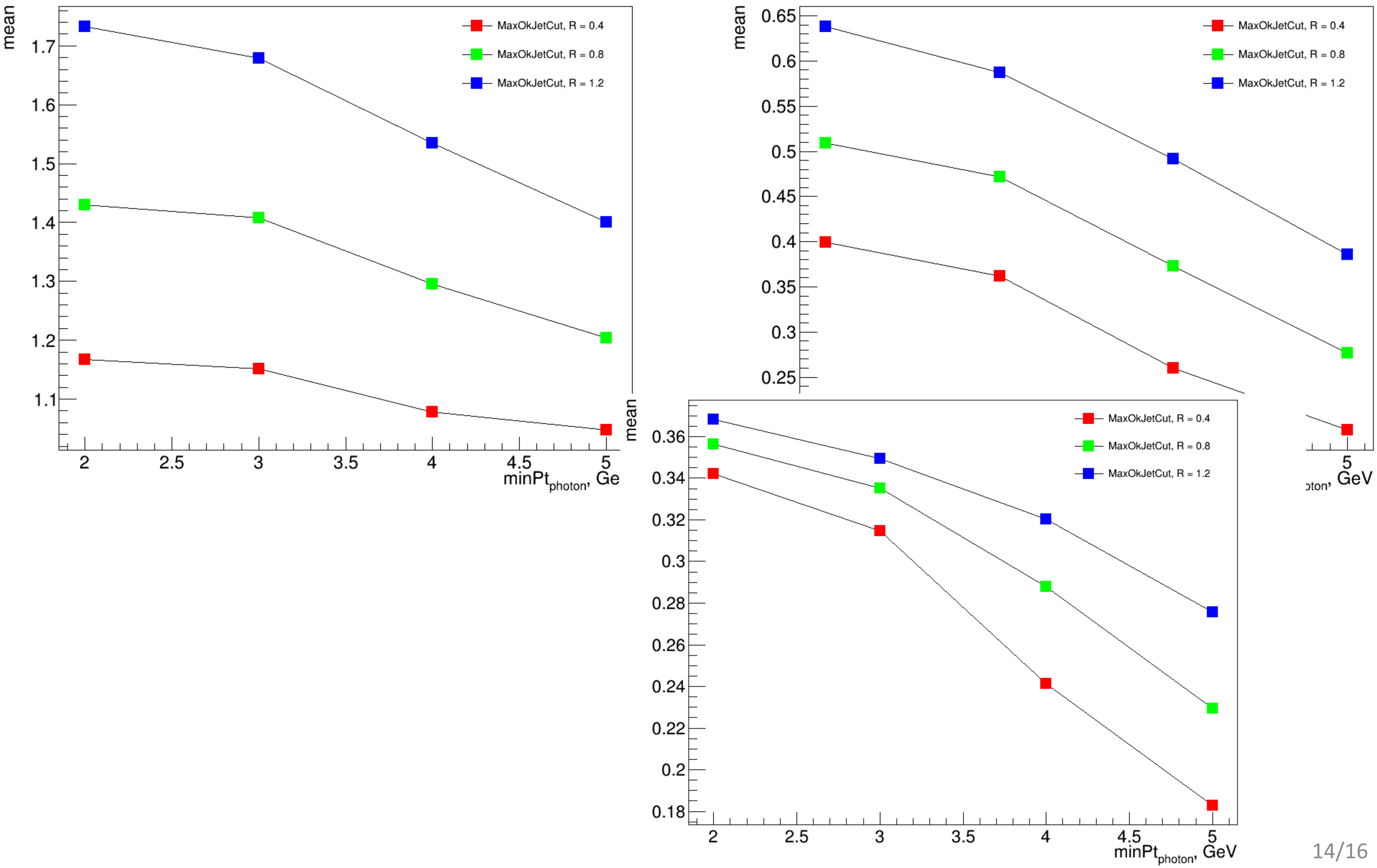


Clustered jet (φ, σ) vs parton (φ, σ)

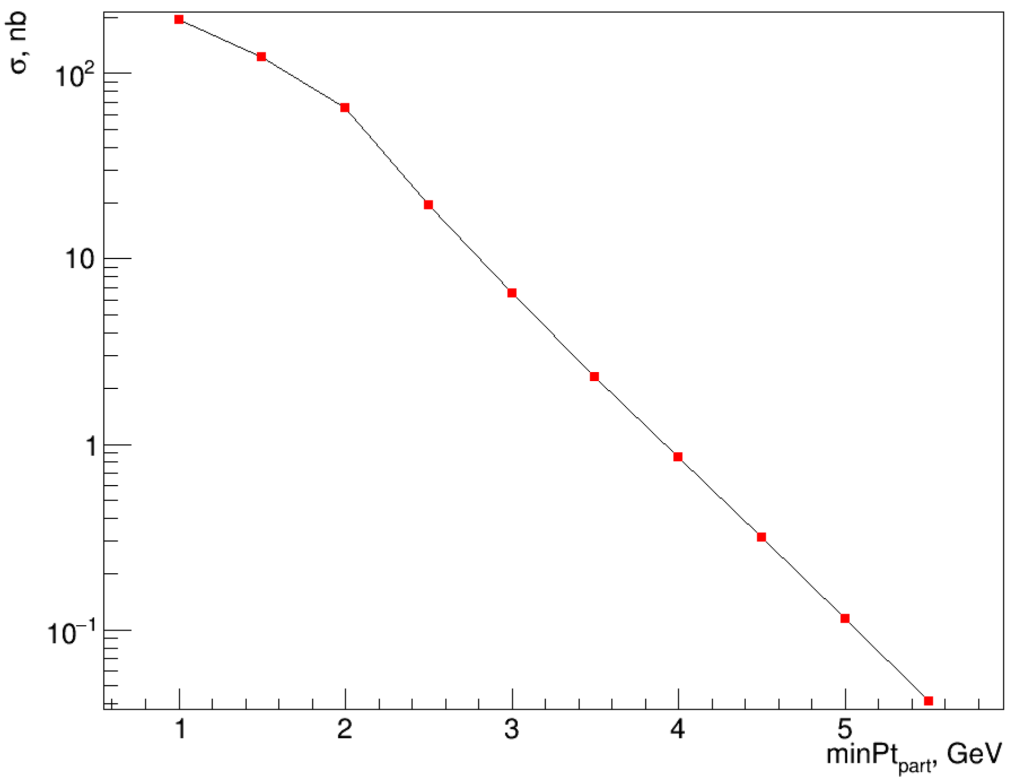


- Jet properties have good agreement with properties of initial parton

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
- Different clustering algorithms find similar jets, but we have to study time of their work
- 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
- Increasing radius parameter of clustering algorithm worsen parton-jet association
- 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:

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

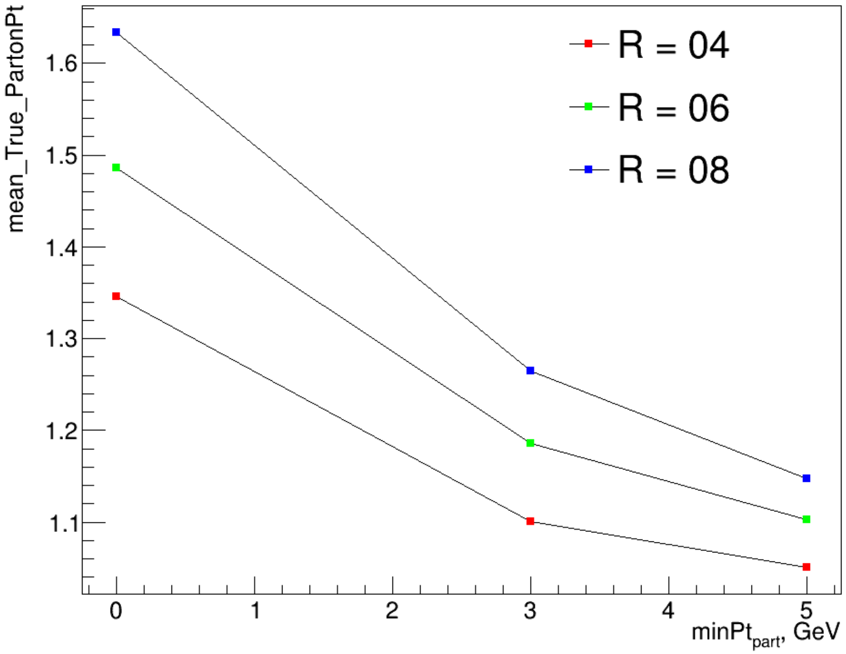
  - And we can calculate change of p_x and p_y:

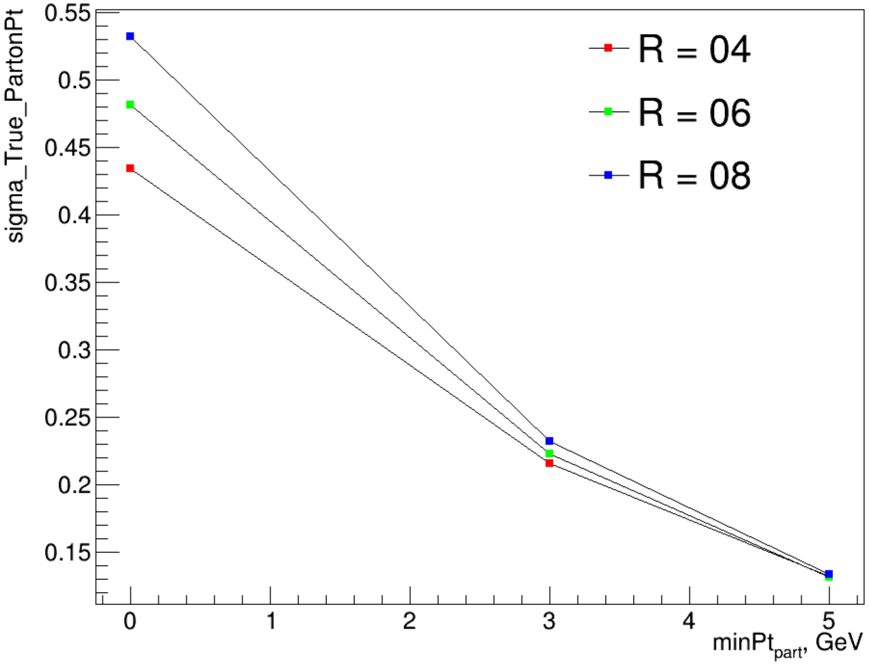
$$dp_x = \frac{c^2 q}{E}\left(p_y B_z\right)dt$$

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

  - 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

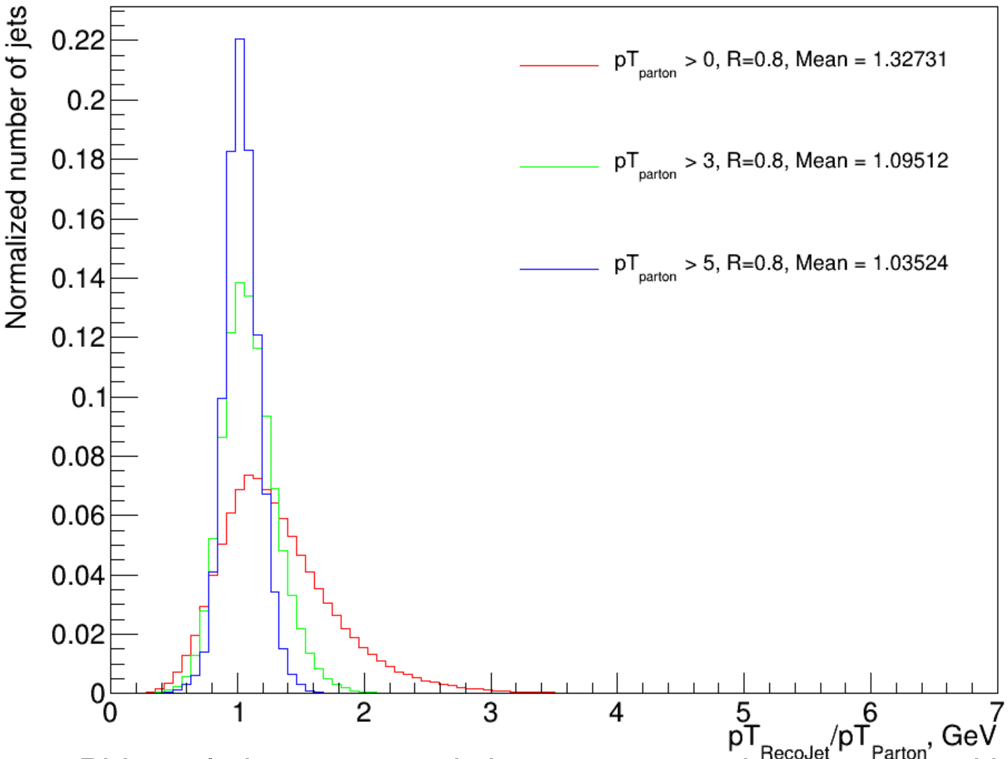
Mean values and sigma

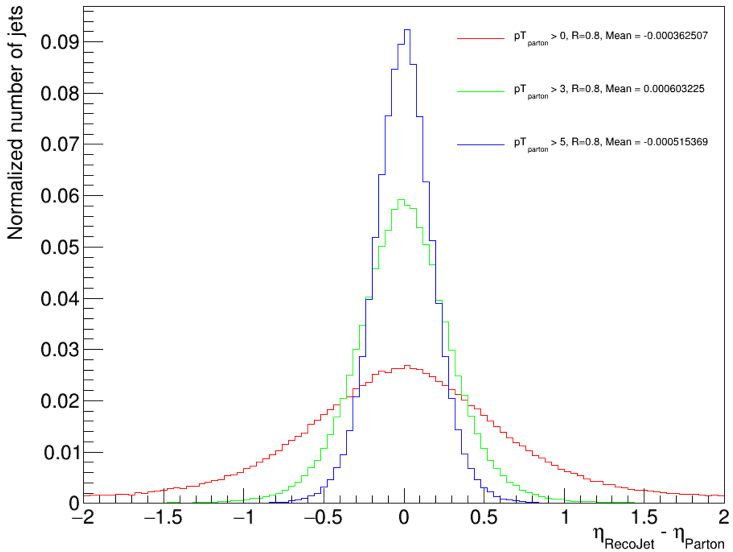


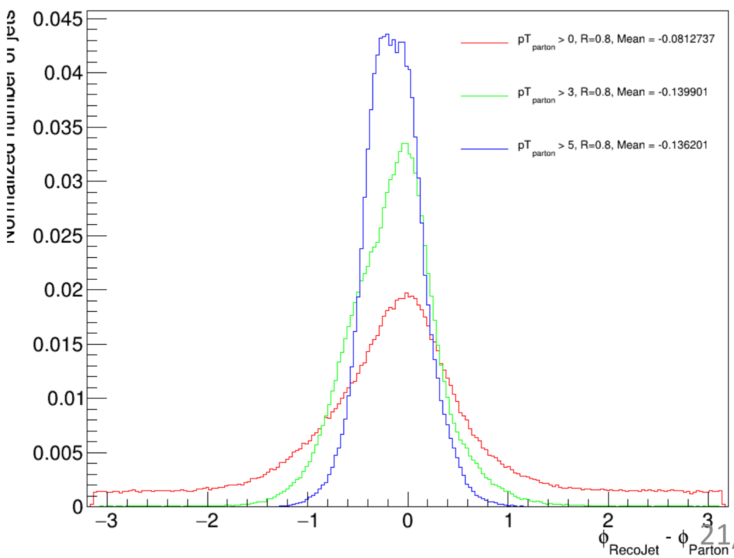


- High p_T partons produce jets, which could be better associated with them

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

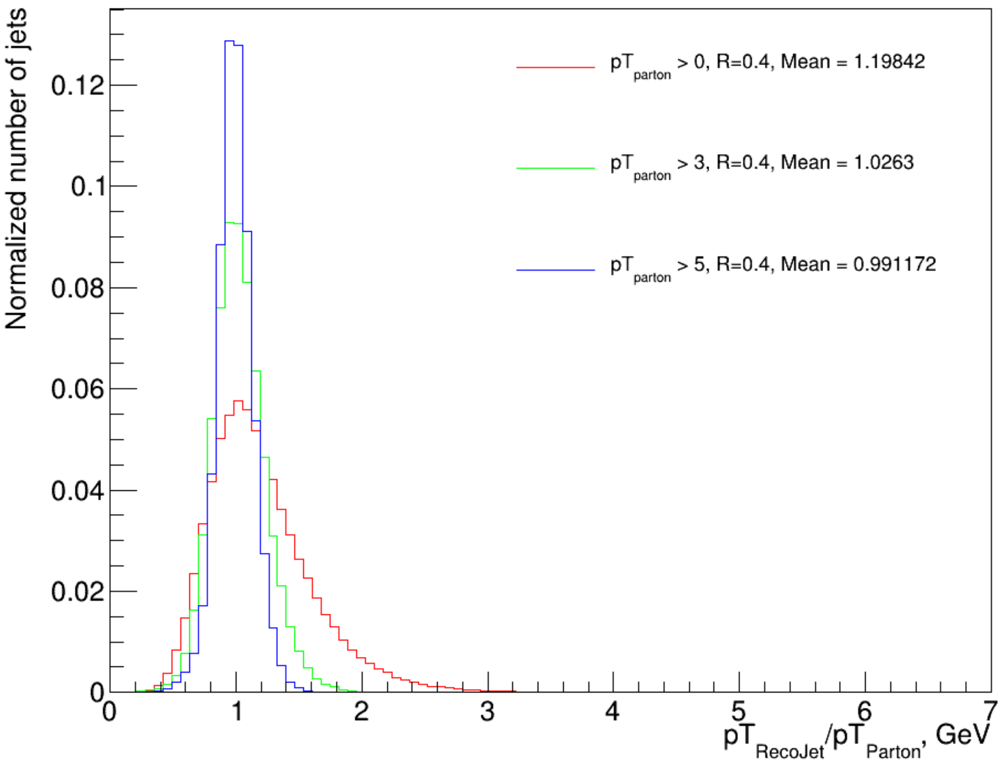


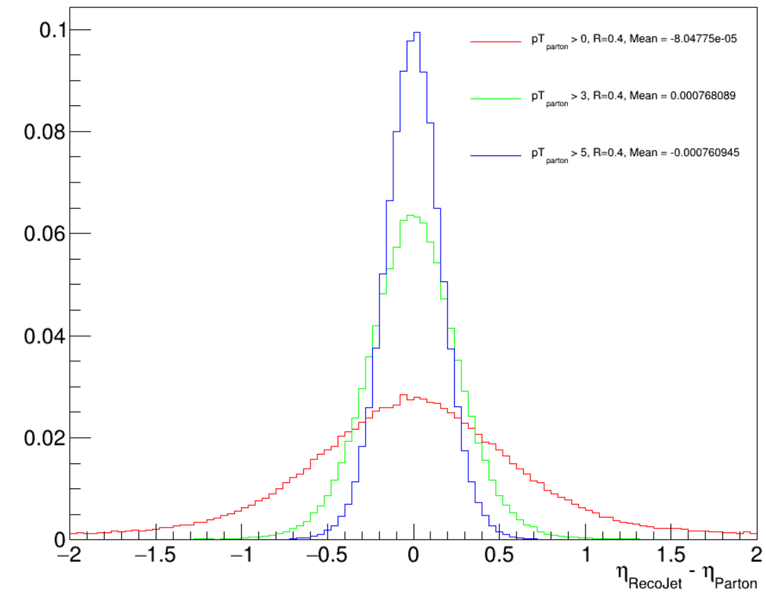


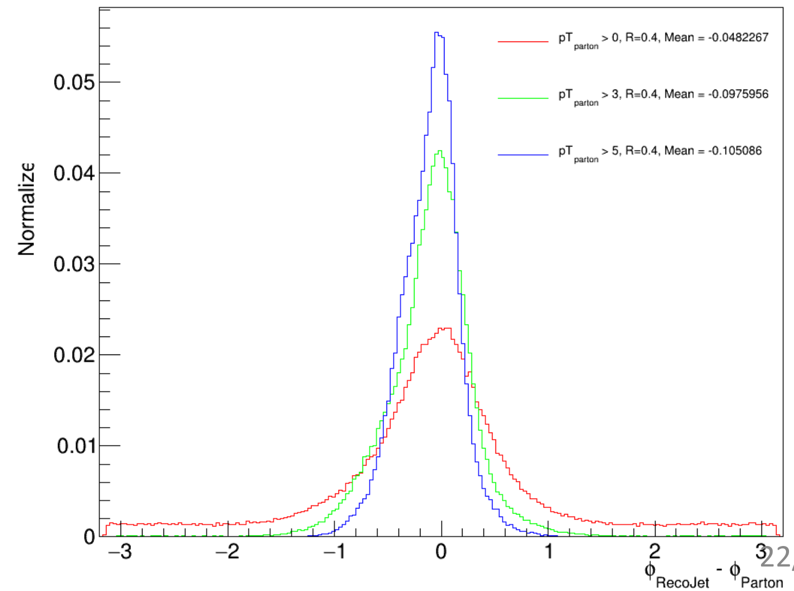


- Phi resolution asymmetric because events have more positive charged particles
- Number of jets with magnetic field ~3 time less that without magnetic field for same statistics
- Fraction of jets with charged leading particle strongly depends on $p_{T,\,parton}$
  - $p_{T,\,parton} > 0$ GeV ~ 30%
 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

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







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