Cluster particle production @ SPD experiment

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4th SPD Collaboration Meeting, 27 April 2023

Experience we have in such topic

- Hadron jets reconstruction in CMS experiment at LHC
- Jet energy scale calibration in CMS experiment using “γ+*jet*” process and $W \rightarrow qq$ decay
- Investigation of Jet energy resolution and treatment in CMS experiment
- Implementation of flavor tagging (e.g. b-tagging) for jet reconstruction algorithms in CMS
- Measurement of gluon jets fraction in inclusive pp-collisions using algorithms for quark-gluon discrimination
- Investigation of particles multiplicity of hadron jets in pp-collisions
- Jet energy regression using ML methods in CMS experiment
- Jet triggers development in CMS experiment

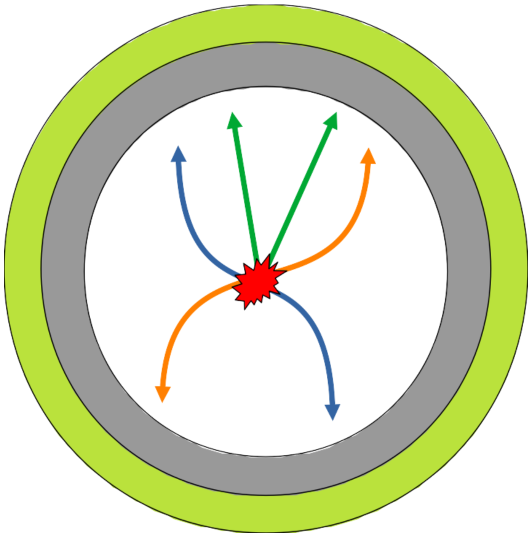
Motivation

- 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:

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

- Initial parton can exchange momentum with beam remnants and other partons
- If the energy/momentum of parton-initiator is *high enough* than the momentum of exchange, the jet can be associated with the parton.
- The goals of this study:
  - Understand the admissibility of such approximation for energies at NICA and SPD experiment
  - Study processes of parton production at energy region between non-pQCD and pQCD
  - Verification of parton fragmentation functions

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

Anti-k_t algorithm

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

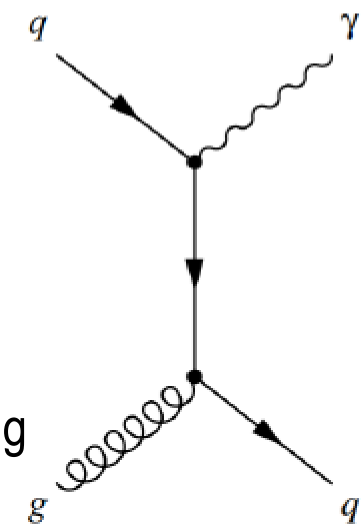
  where $\Delta_{ij}^2 = (y_i - y_j)^2 + (\varphi_i - \varphi_j)^2$
- The functionality of the algorithm can be understood by considering an event with a few hard particles and many soft ones
  - If hard particle 1 has no hard neighbours within a distance 2*R* then we have one perfectly conical jet
  - 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

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 gives similar results

Event generation and jet reconstruction settings



- 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
- Jet should have at least two particles
- We considered events with and without magnetic field impact

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:

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

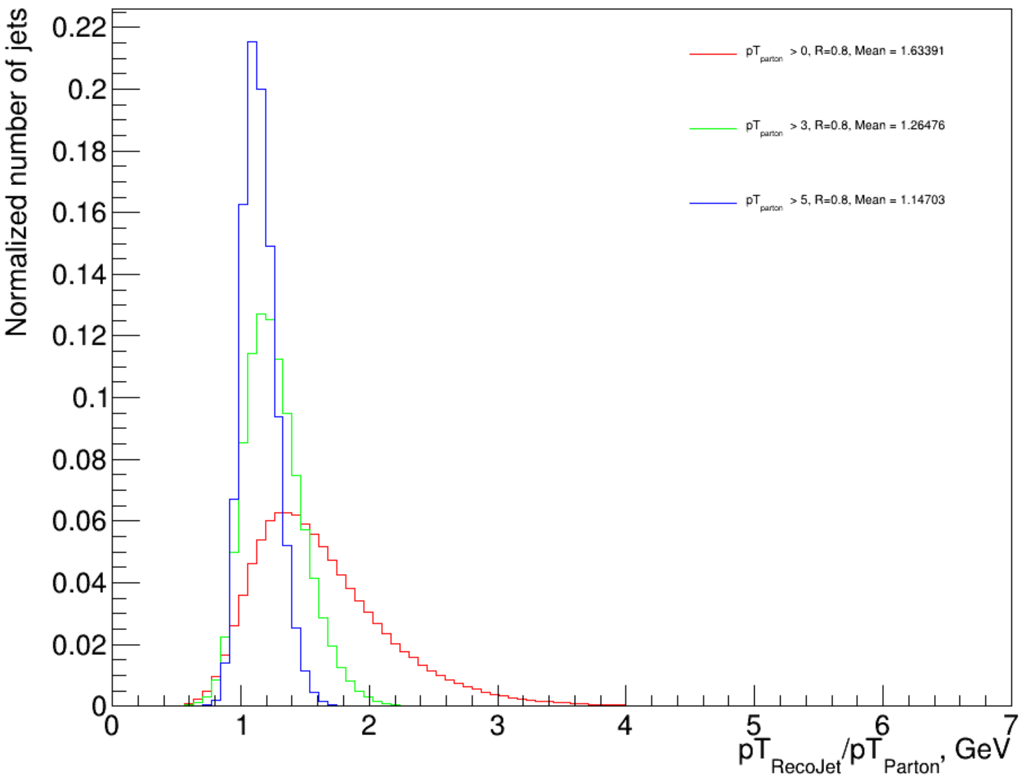
  - And we can calculate change of p_x and p_y:

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

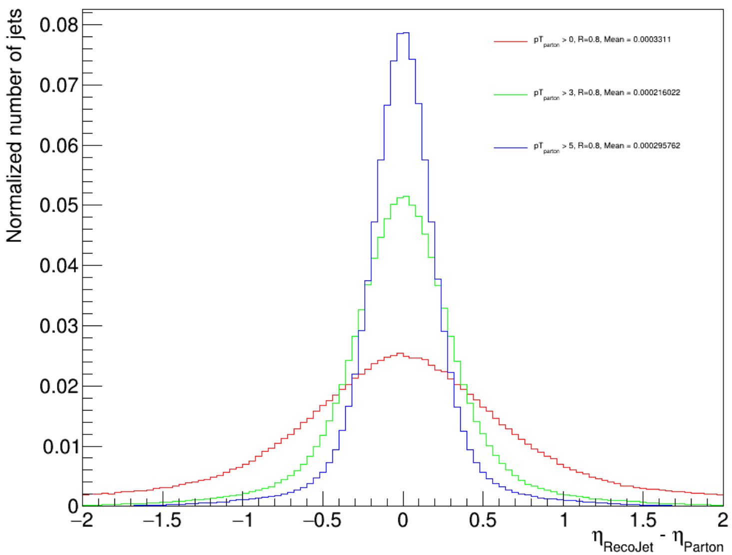
$$dp_y \frac{c^2 q}{E}(-p_x B_z)dt$$

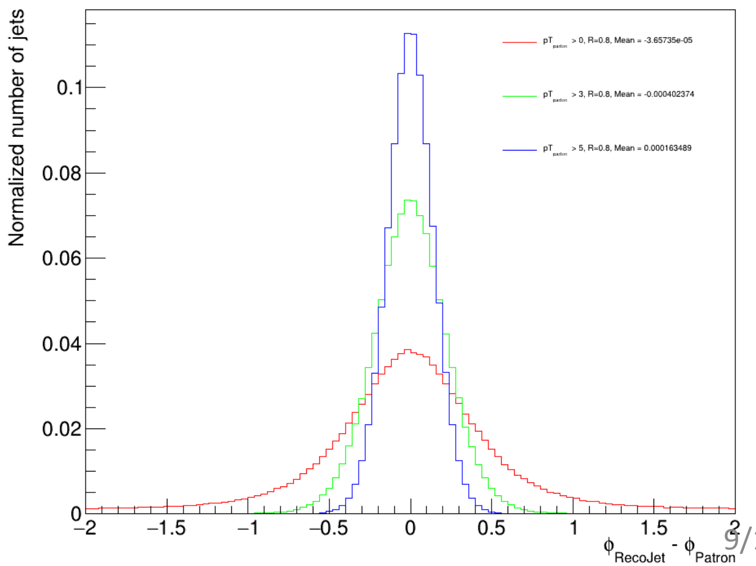
  - We continue this iterations until $v_{xy} < 1080mm$, i.e. particle reach ECal
  - In the end we recalculate momentum of particle assuming that it moves directly from their vertex to place where it reach ECal

Clustered jet vs parton (R=0.8, without magnetic field)

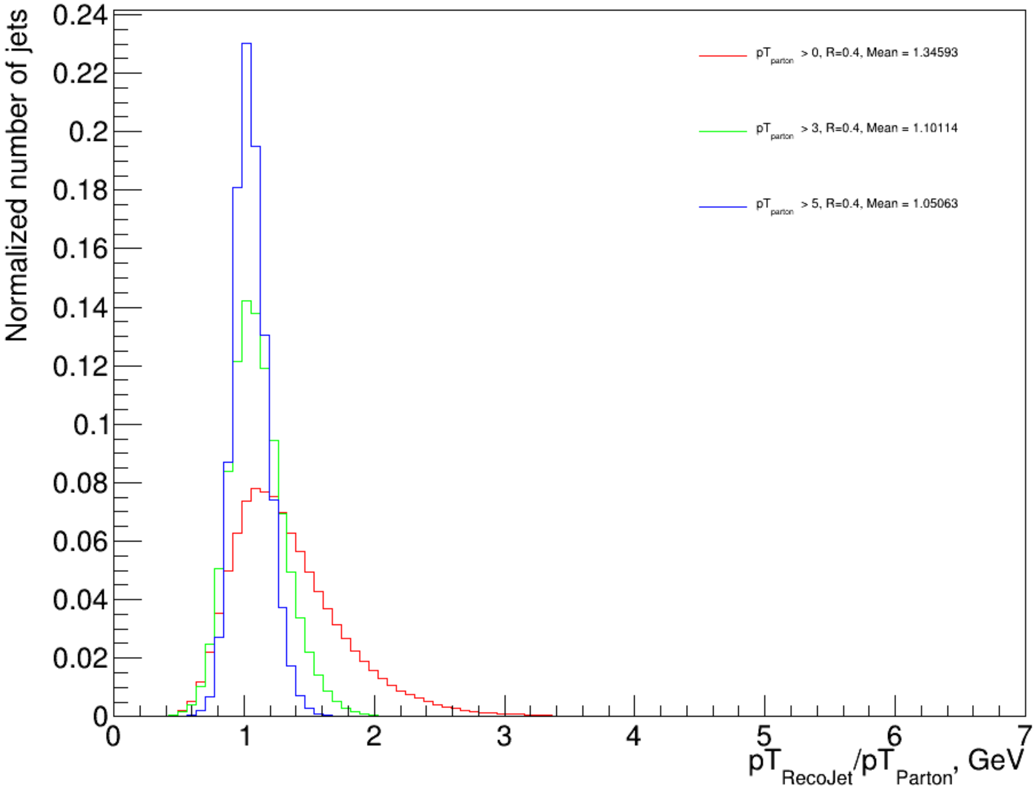


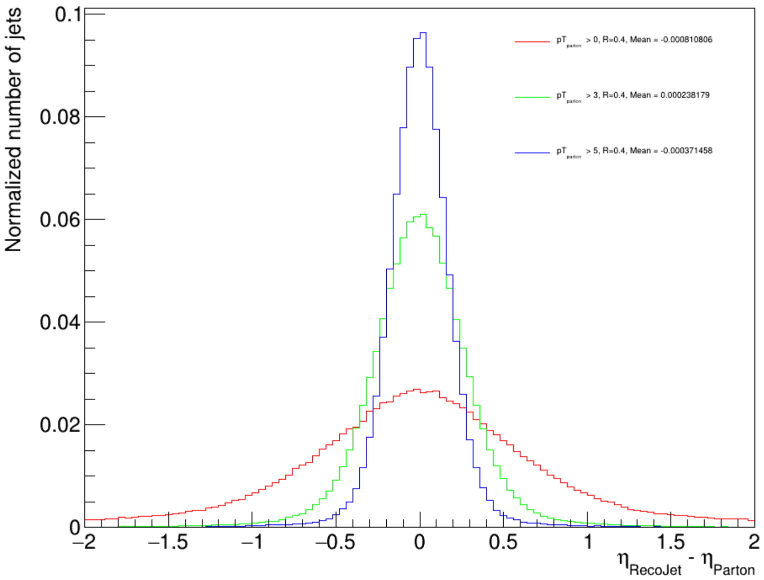
- Jet properties have good agreement with properties of initial parton
- Fraction of jets with charged leading particle ~70%

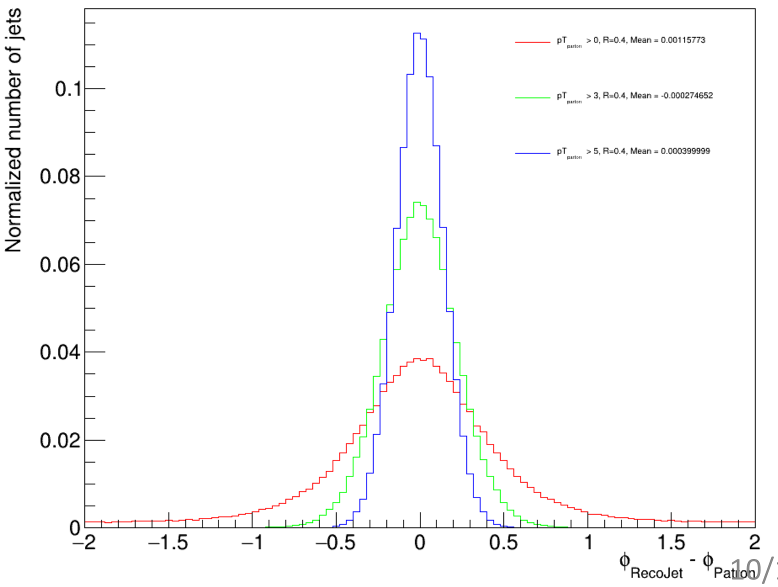




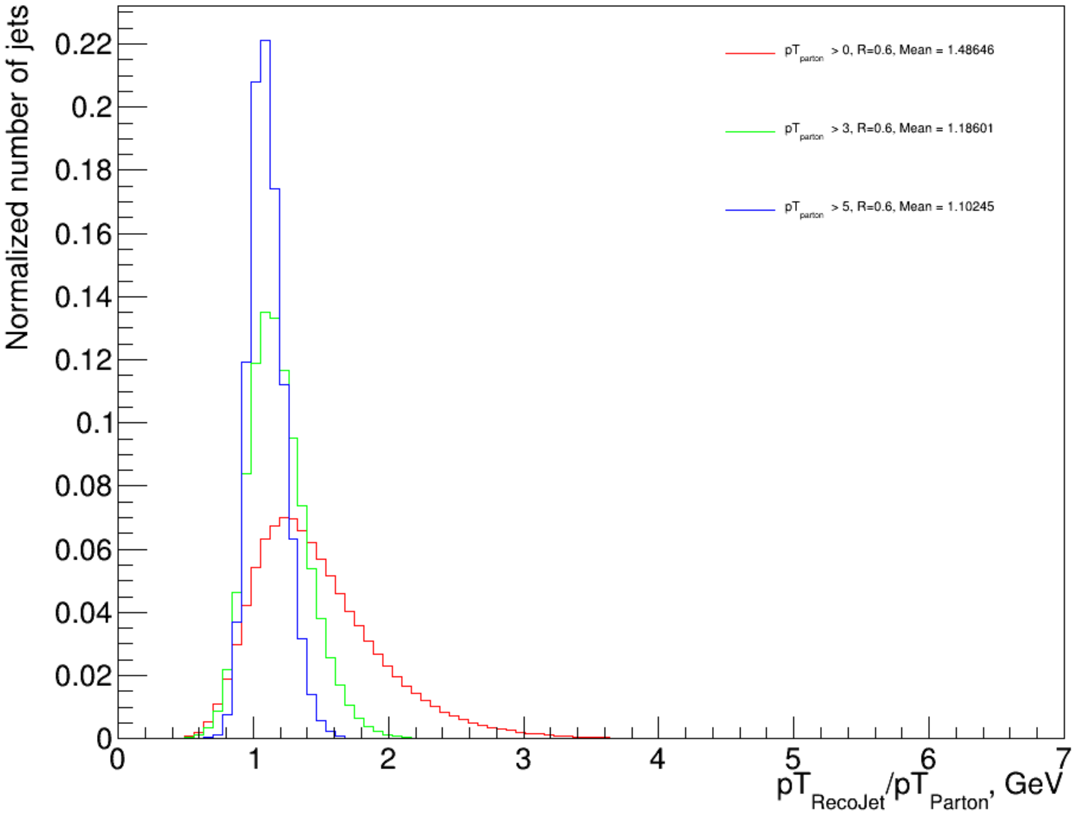
Clustered jet vs parton (R=0.4, without magnetic field)

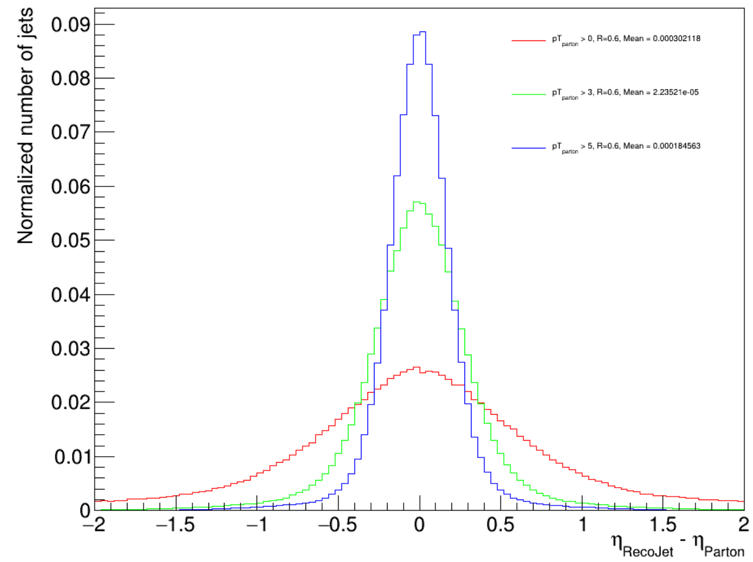


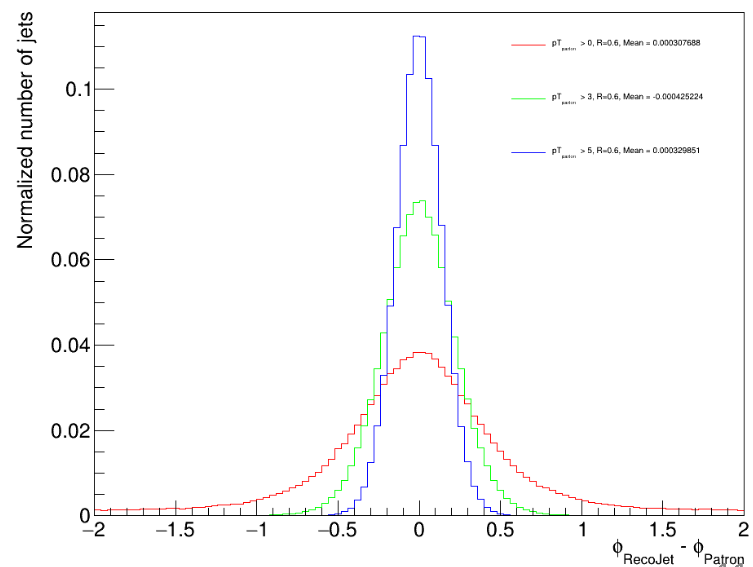




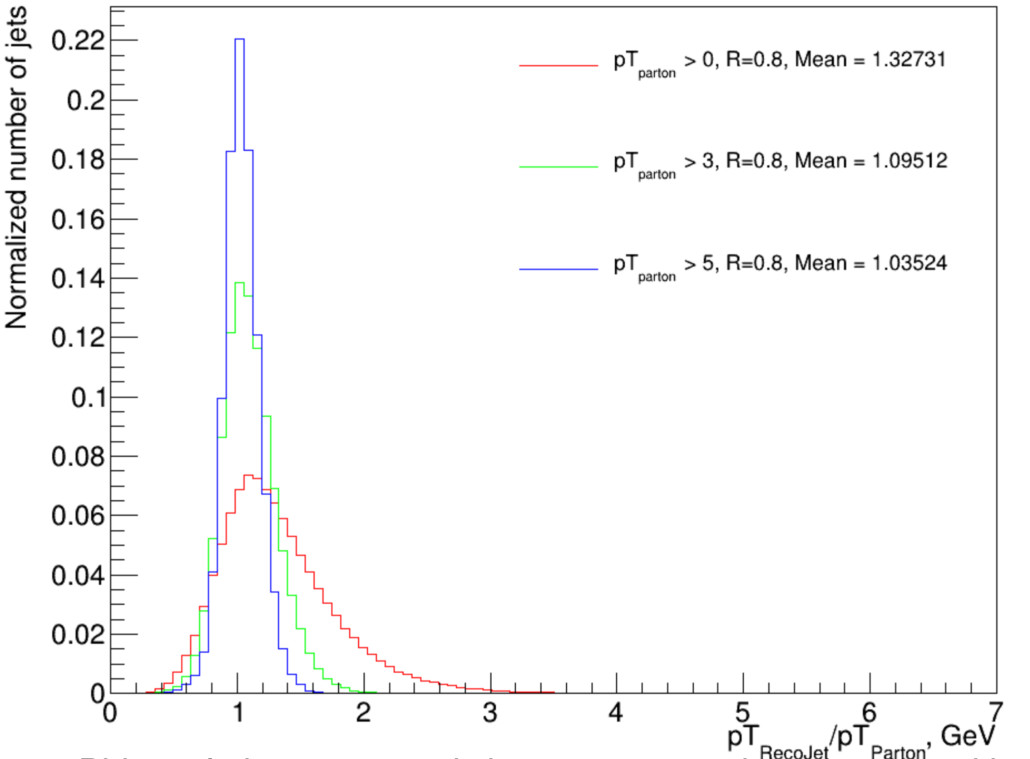
Clustered jet vs parton (R=0.6, without magnetic field)

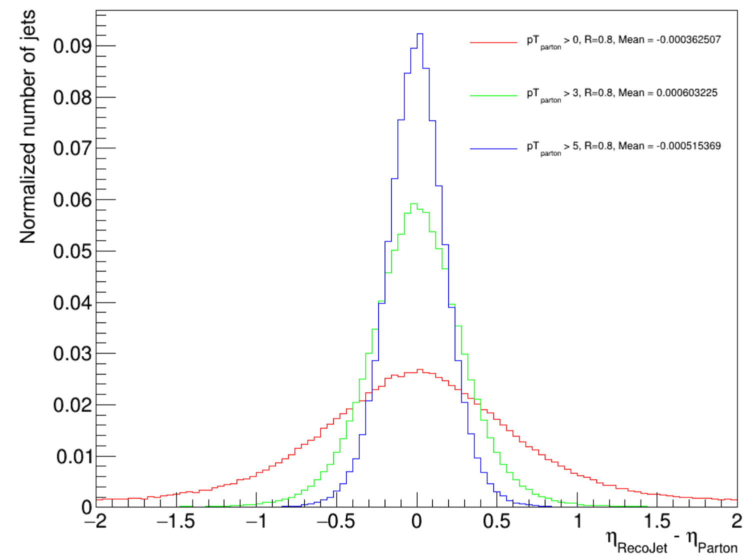


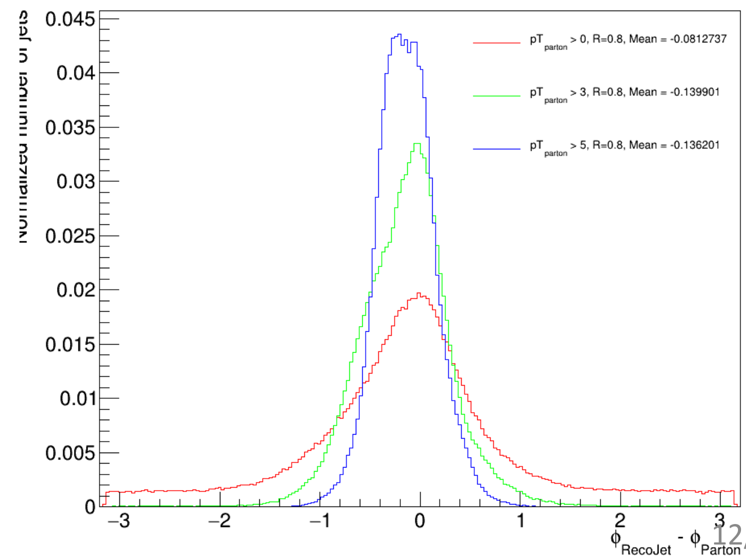




Clustered jet vs parton (R=0.8, with magnetic field)

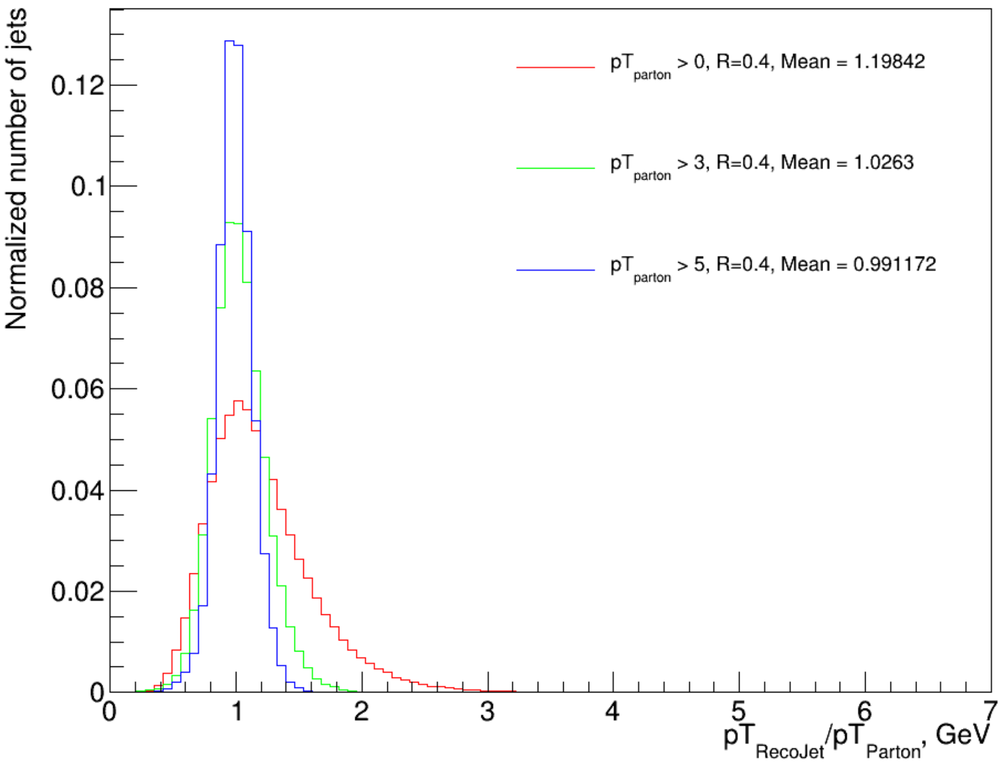


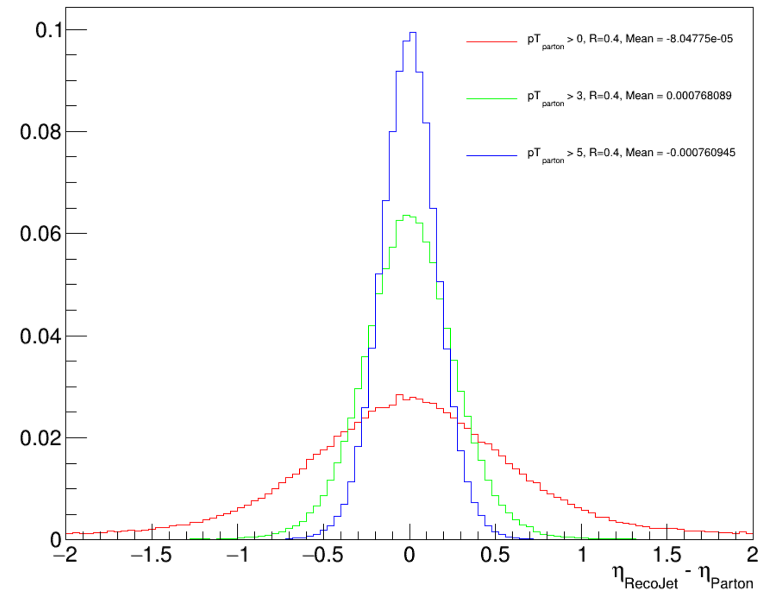


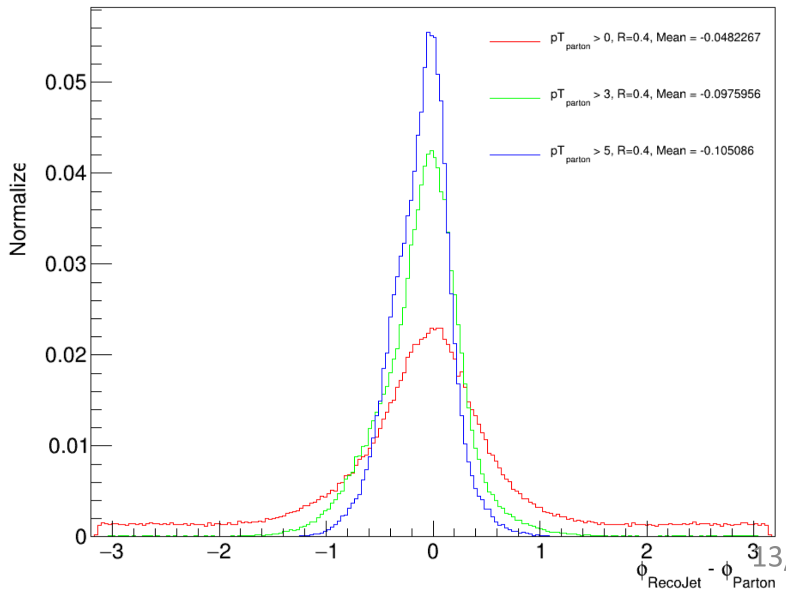


- Phi resolution asymmetric because events have more positive charged particles
- Number of jets with magnetic field ~3 time less that without magnetic field for same statistics
- Fraction of jets with charged leading particle strongly depends on $p_{T,\,parton}$
  - $p_{T,\,parton} > 0$ GeV ~ 30%
 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

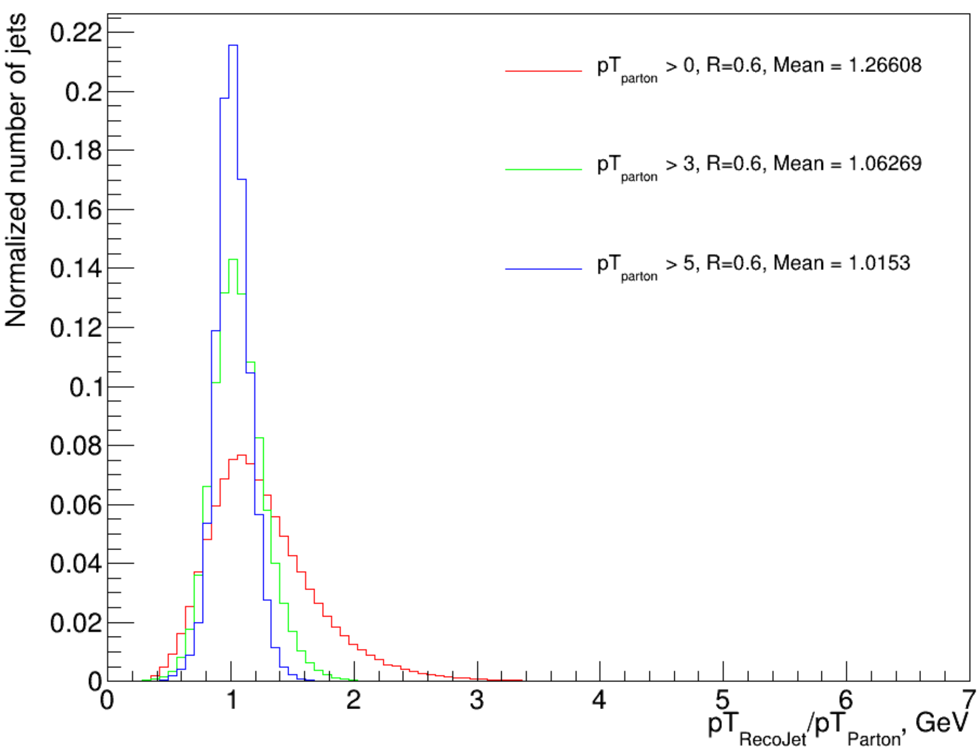
Clustered jet vs parton (R=0.4, with magnetic field)

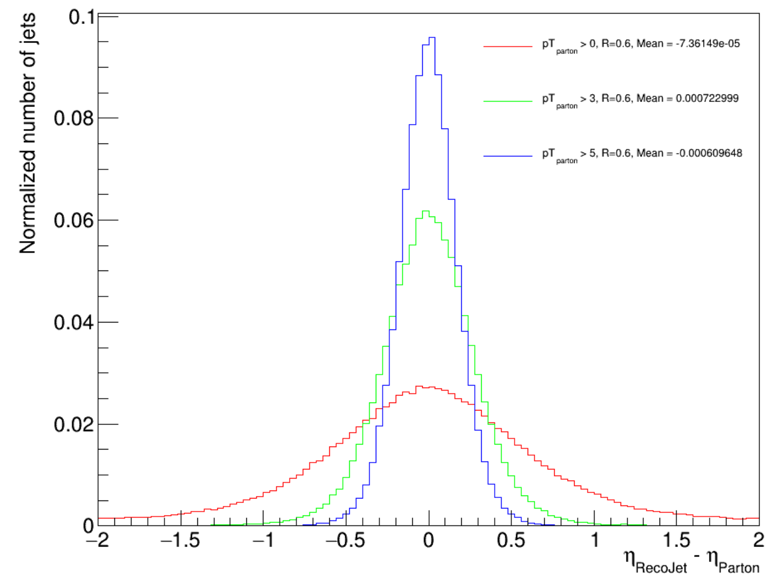


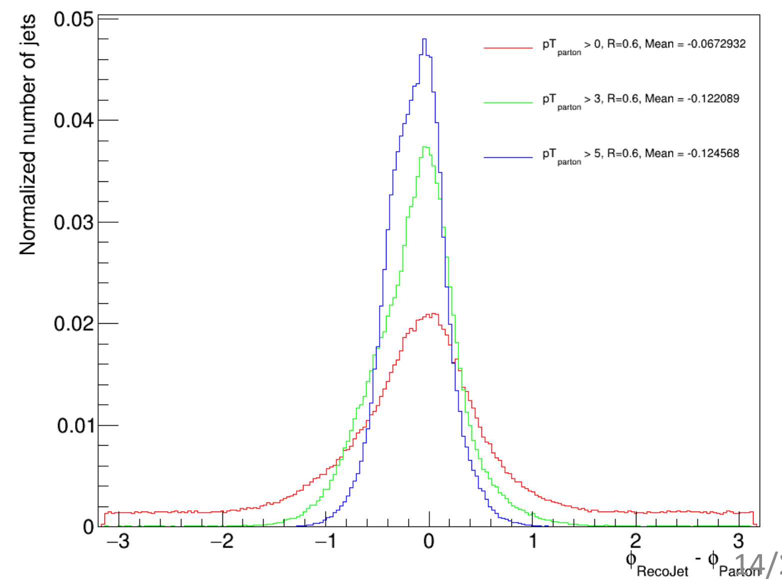




Clustered jet vs parton (R=0.6, with magnetic field)

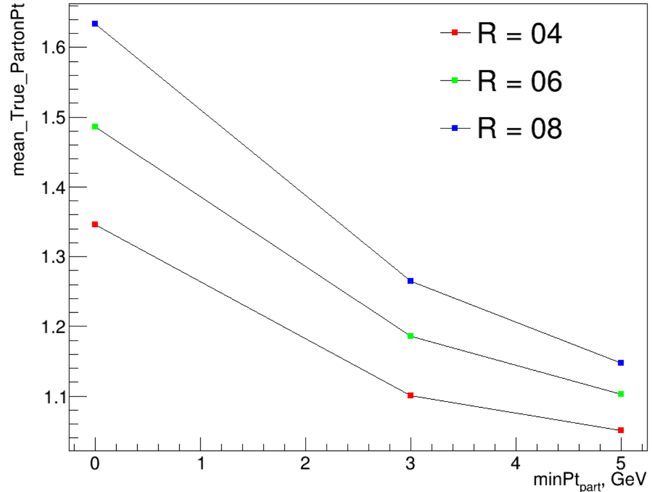


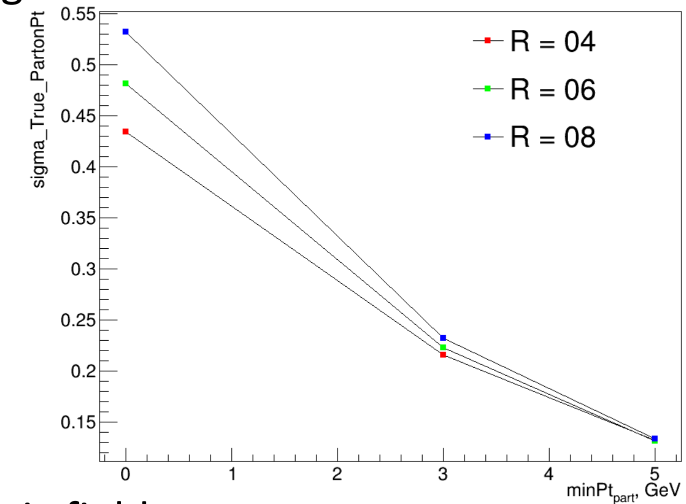




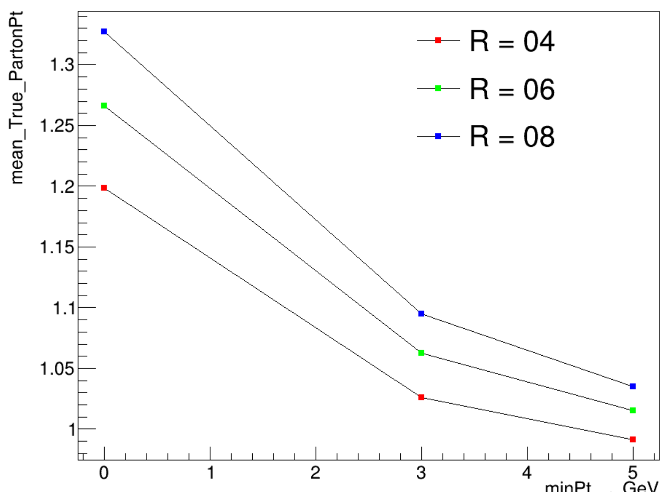
Mean values and sigma

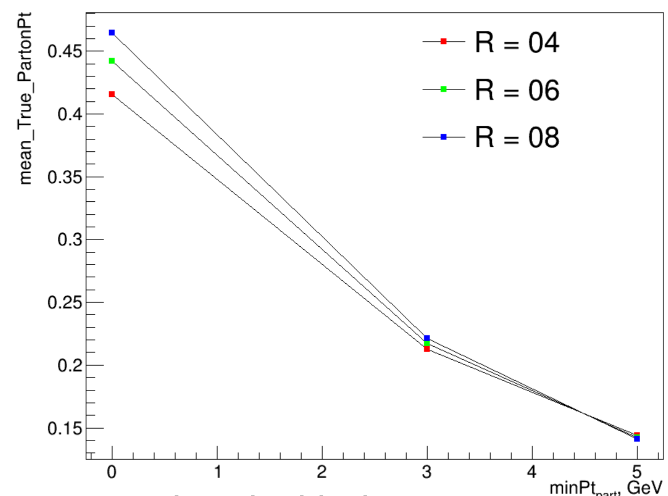
Without magnetic field





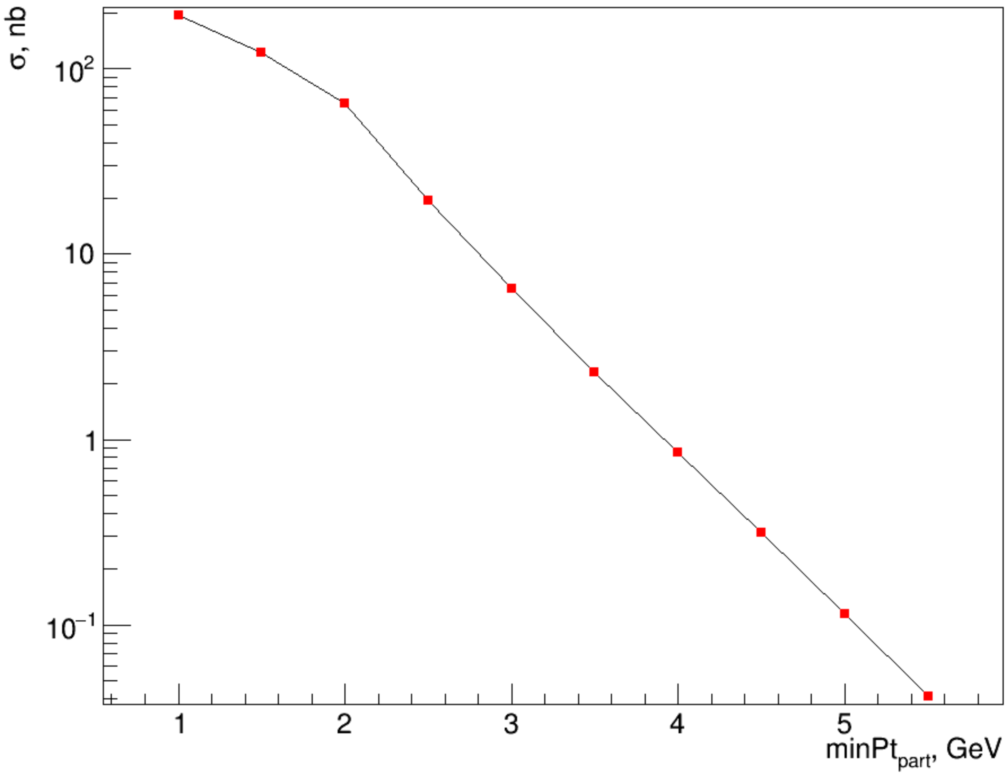
With magnetic field





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

Process $qg \rightarrow q\gamma$ cross section



- 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

- Today's situation:
  - Kinematical properties of hard scattered partons and clustered jets was compared on generator level
  - Estimation of magnetic field impact on jet reconstruction was made
  - After taking into account magnetic field effects number of jets decreases in ~3 times and number of jets with leading charged particle also decreases
  - It seems that clustered jets could be associated with initial parton even with magnetic field impact
  - With increasing of parton p_T we get better association between clustered jets and initial parton
  - We expect enough statistics to make these analysis

- Plans:
  - Choose the best clustering algorithm, i.e. *anti-*k_t, k_t, *Cambridge/Aache* and *Iterative Cone* algorithm

  - Find cuts, which select jets associated with initial parton
    - Minimum particle p_T
    - Minimum jet p_T and η
    - Size of jet cone
    - Specific channel cuts (e.g. opposite photon)