LABORATÓRIO DE INSTRUMENTAÇÃO E
FÍSICA EXPERIMENTAL DE PARTICULAS

b-tagging in ATLAS Heavy Ion Collisions

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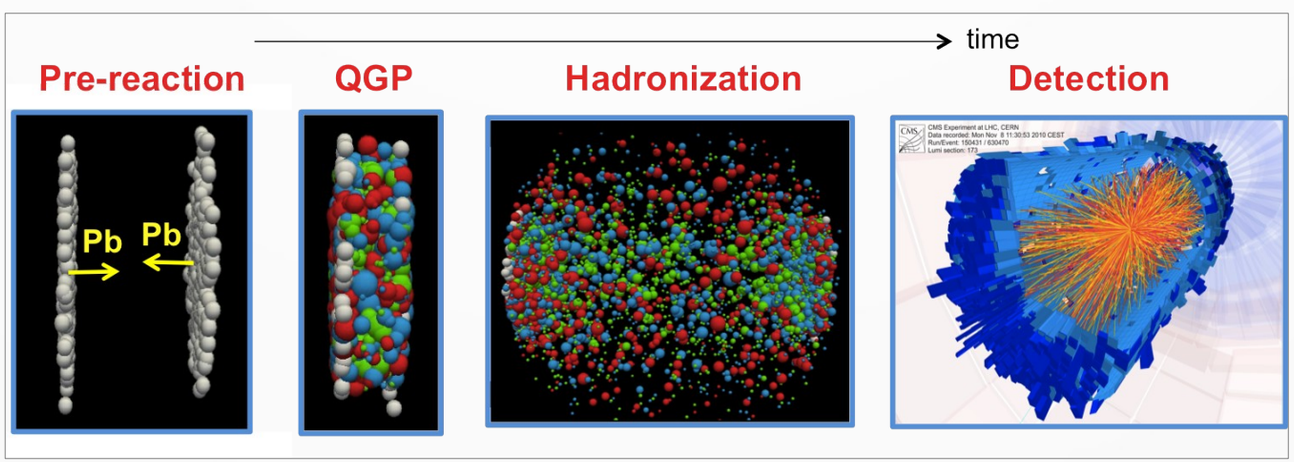
ATLAS EXPERIMENT

Introduction

- Particle jets are produced in high energy physics collisions;
  - Identifying each kind of particle (in particular b quarks) originated the jet is important in several kinds of physics studies;
- Goals:
  - Study the efficiency of the b-tagging algorithm IP3D on ATLAS heavy ion collisions;
  - Study under which conditions (jet pT, centrality, track pT threshold) the efficiency of the algorithm can be increased.

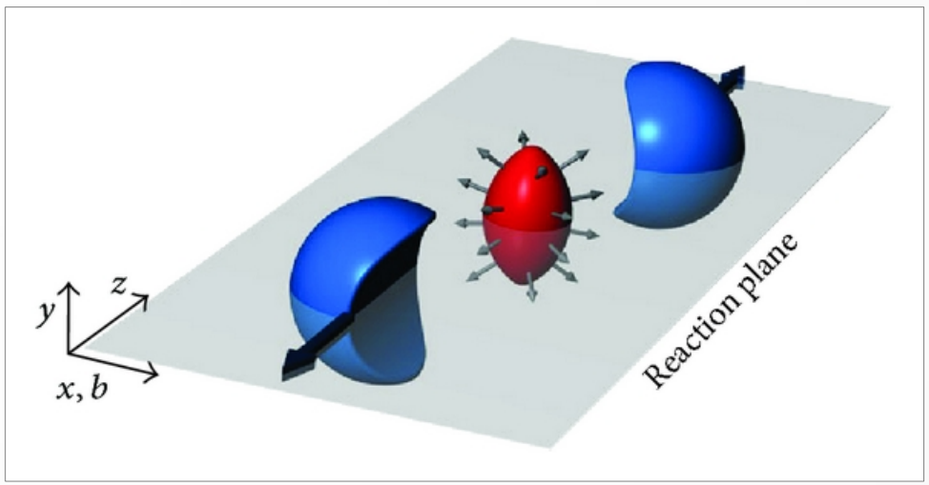
Heavy Ion Collisions

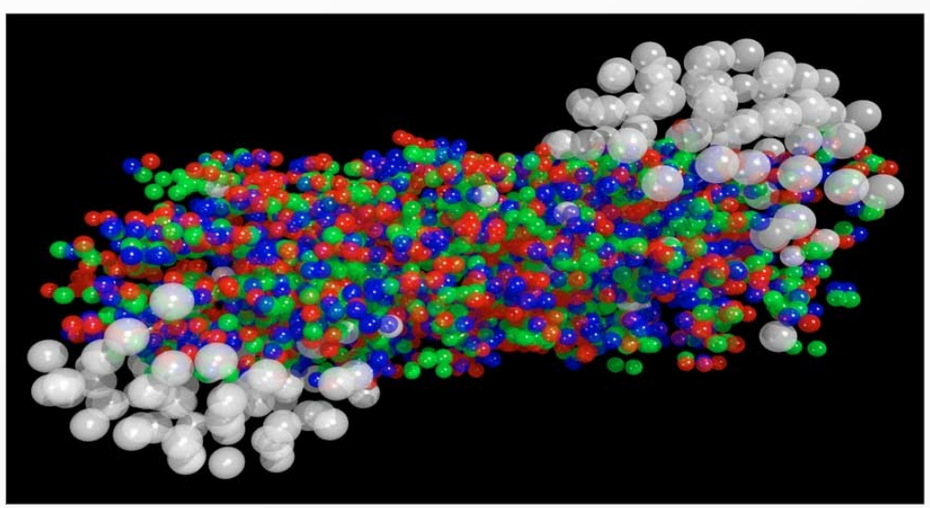
- Collision of lead ions (Pb-Pb);
- Higher number of nucleon collisions with respect to proton events;
- High energy density;
- Formation of a quark-gluon plasma (QGP).



Centrality

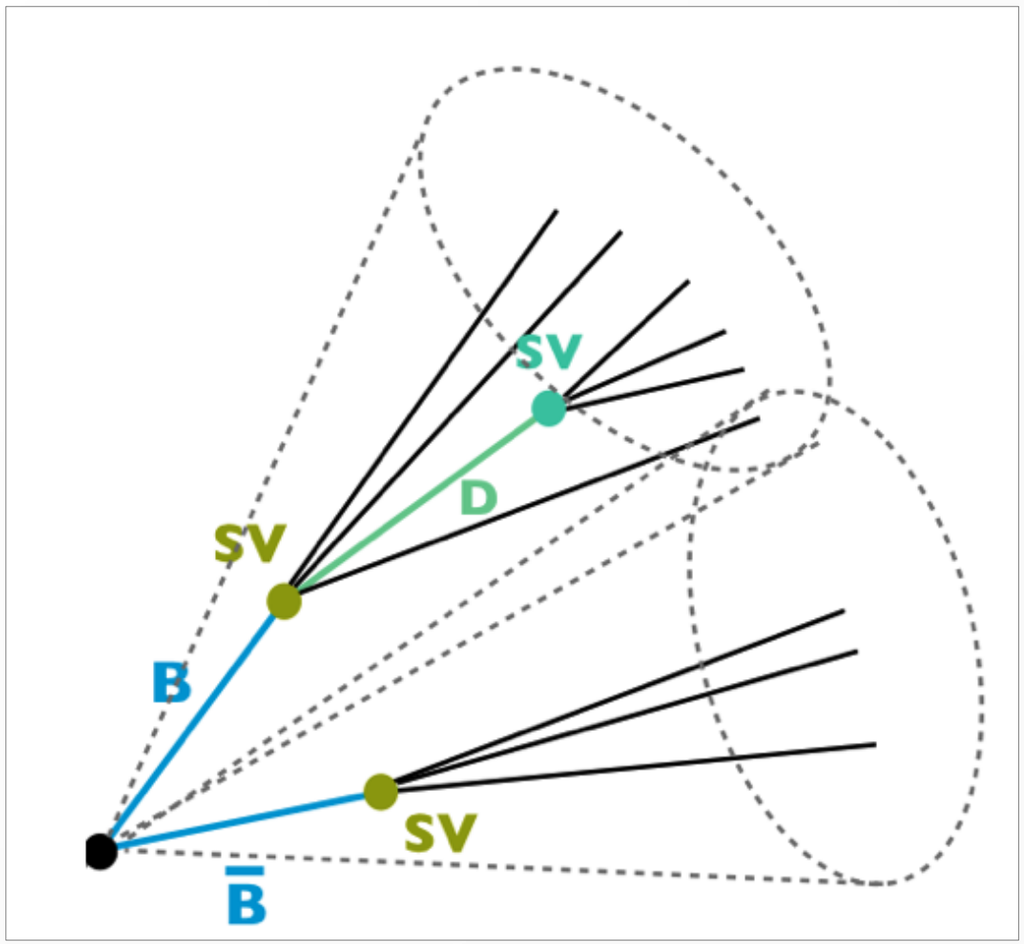
- Measured by the energy deposited in Forward Calorimeter;
  - More energy = more central;
- Peripheral collisions:
  - Smaller number of nucleon collisions (similar to p-p);
  - Higher number of occurrences;
- Central collisions:
  - High number of nucleon collisions;
  - Less frequent;





B Meson

- Relatively long lifetime ($\tau \approx 1.5$ ps);
- Able to cross a longer distance before decay ($c\tau \approx 0.5$ mm);
- Great tool to study the QGP.

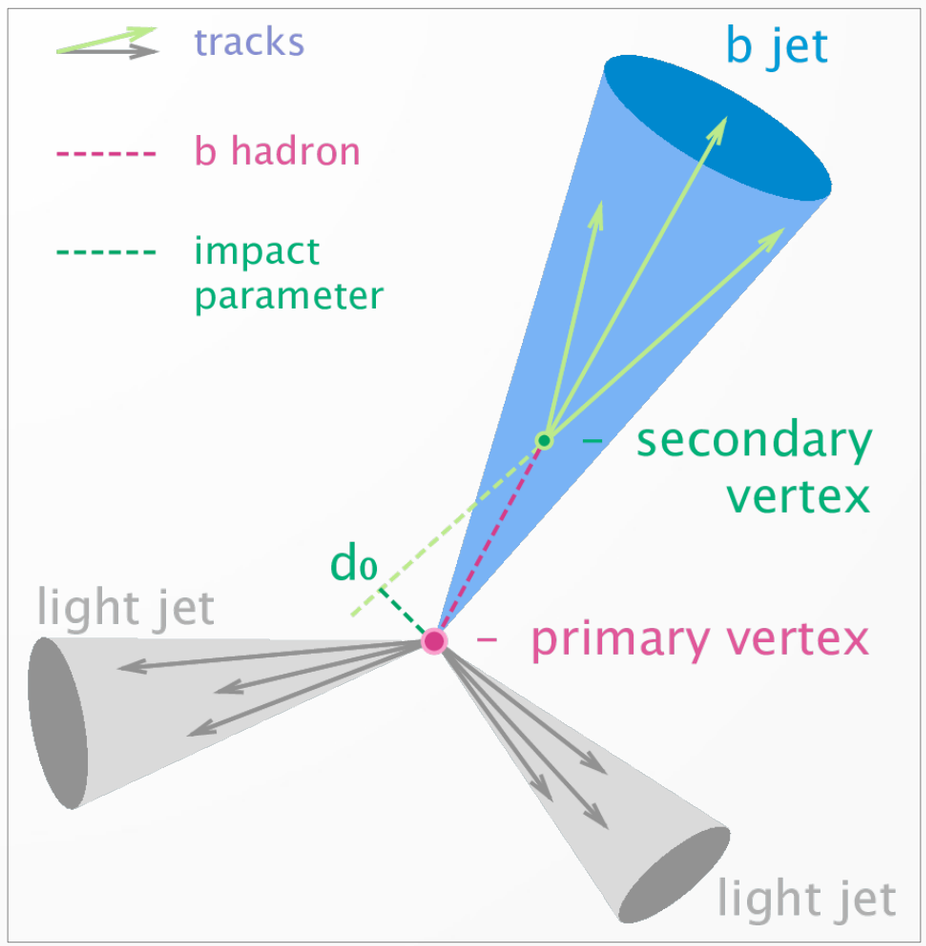


b-tagging

- Method for identifying jets originating on a b quark;
- Several types of algorithms (Lifetime-based, muon-based, etc.);
- Lifetime-based:
  - Impact Parameter-based (JetProb, **IP3D**);
  - Vertex-based (SV, JetFitter);

Impact Parameters

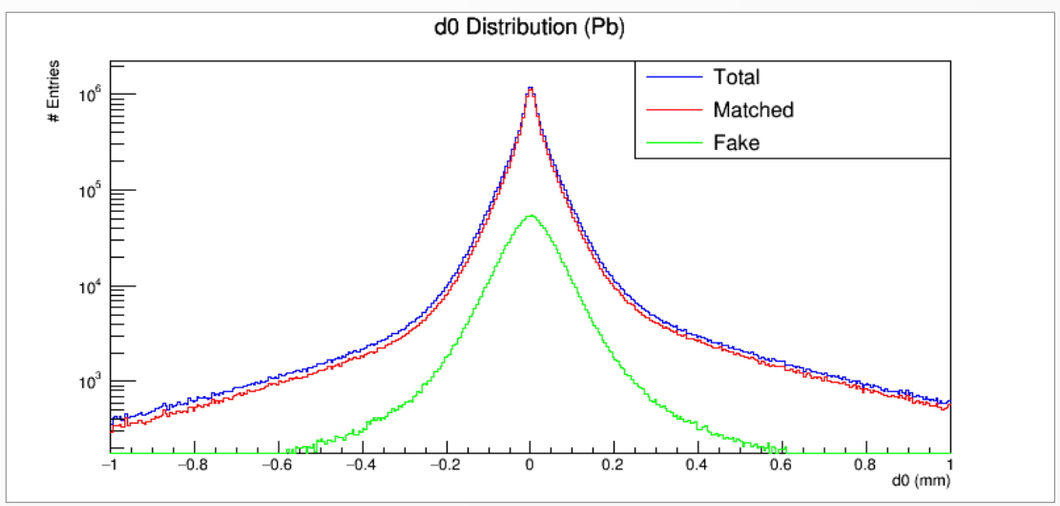
- Transverse impact parameter (d_0): distance of closest approach of the track to the primary vertex (PV);
- Longitudinal impact parameter (z_0): diference between the z coordinates of the PV and the point of closest approach of the track.



MC Samples

- Samples:
  - p-p simulations (5 TeV);
  - Simulations embedded in real Pb-Pb collision data (minimum bias);
  - 5 samples in each case (JZ1-5);
  - Events weighted to match expected distribution;
- Track minimum pT thresholds:
  - 5 values: 1, 2, 3, 4, 5 GeV;
- Jet types:
  - b-jets;
  - c-jets;
  - Light jets;

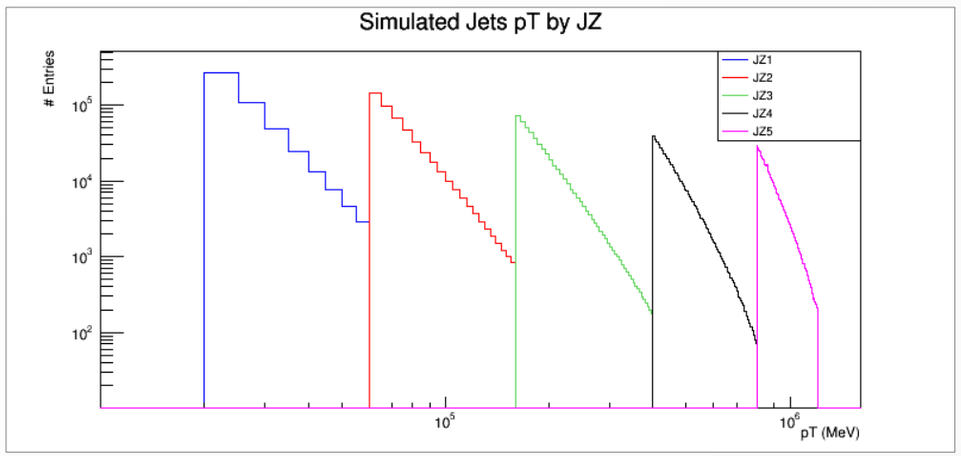
- Matched jets: reconstructed jets with a matching simulated jet;
- Fake jets: reconstructed jets without a matching simulated jet (underlying event).



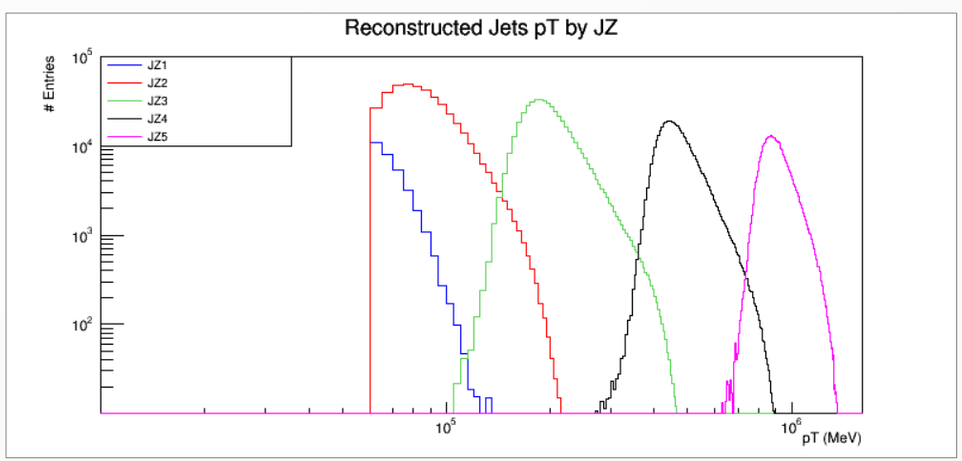
Transverse Momentum (pT)

- Jet pT intervals:
  - JZ1 → 20-60 GeV;
  - JZ2 → 60-160 GeV;
  - JZ3 → 160-400 GeV;
  - JZ4 → 400-800 GeV;
  - JZ5 → 800-1300 GeV.
- Reconstruction of jets with pT under 60 GeV is unreliable;
- Jet selection:
  - Jet pT > 60 GeV;
  - Jet |η| < 2.5;

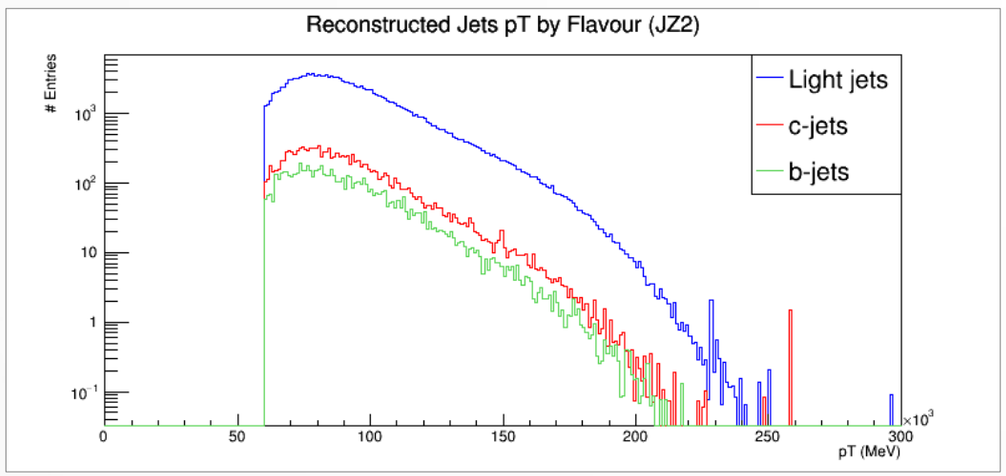
Simulated

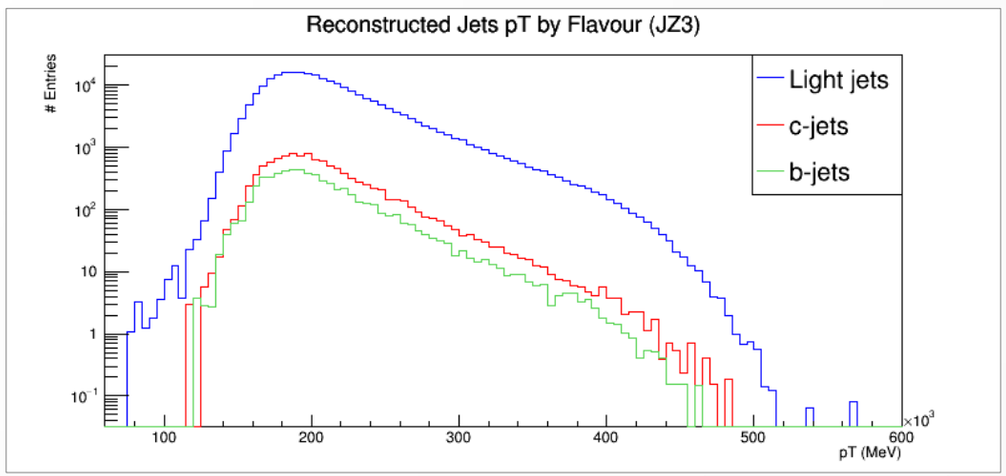


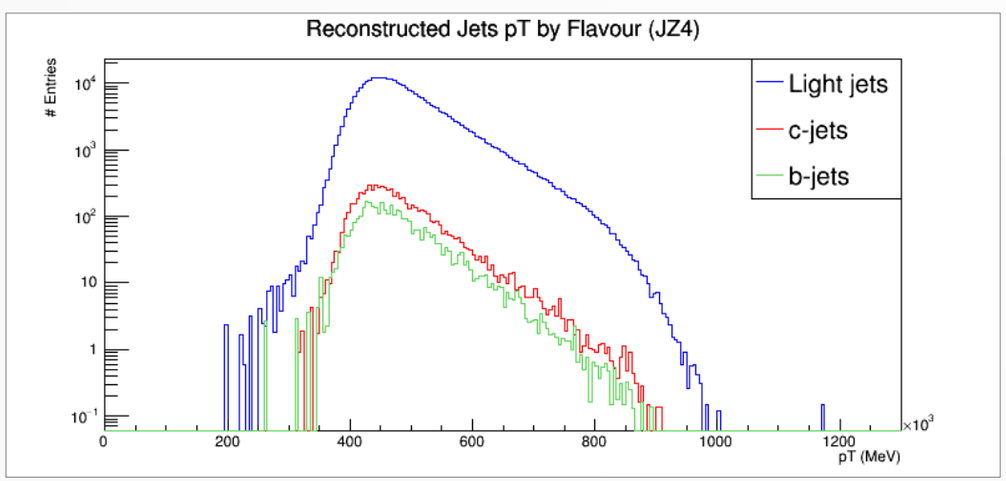
Reconstructed

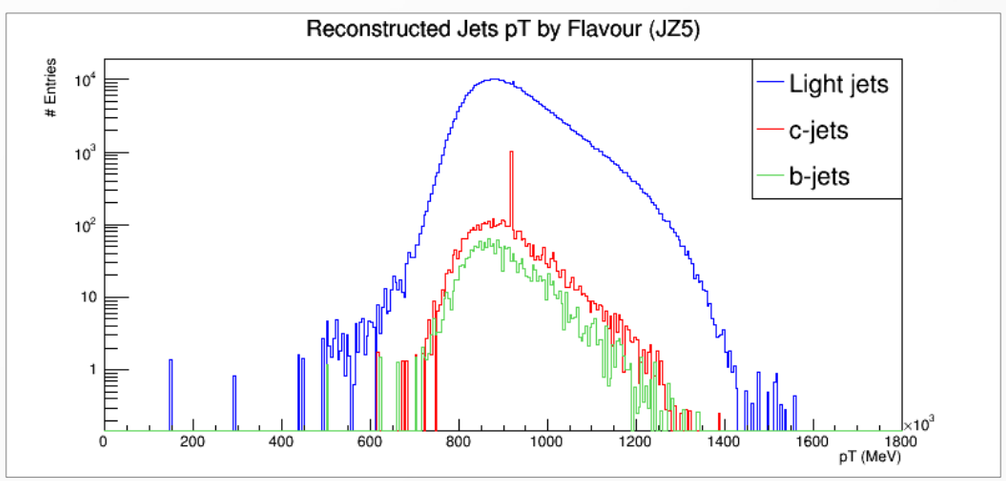


Transverse Momentum (pT)



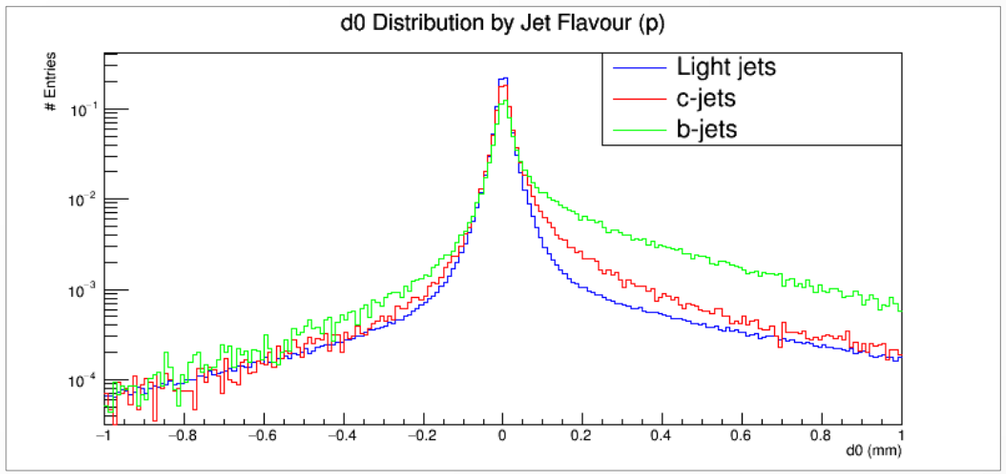


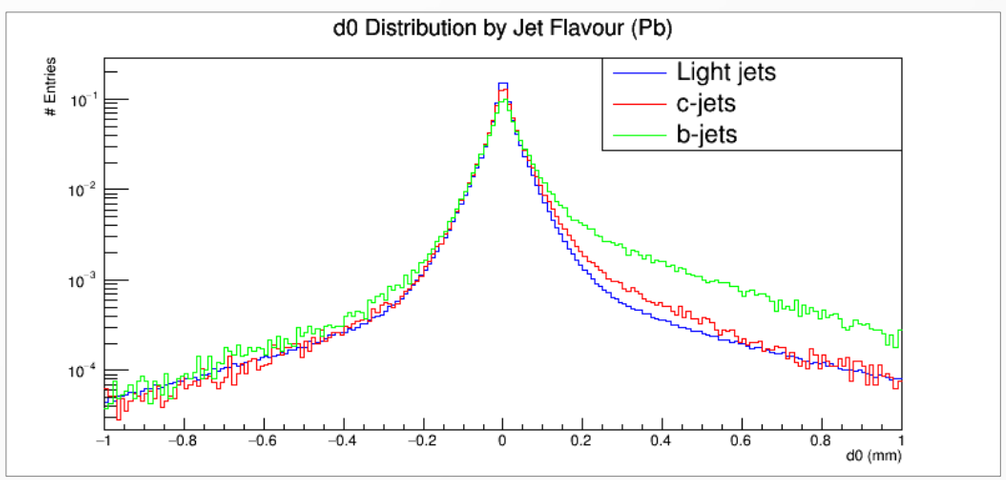




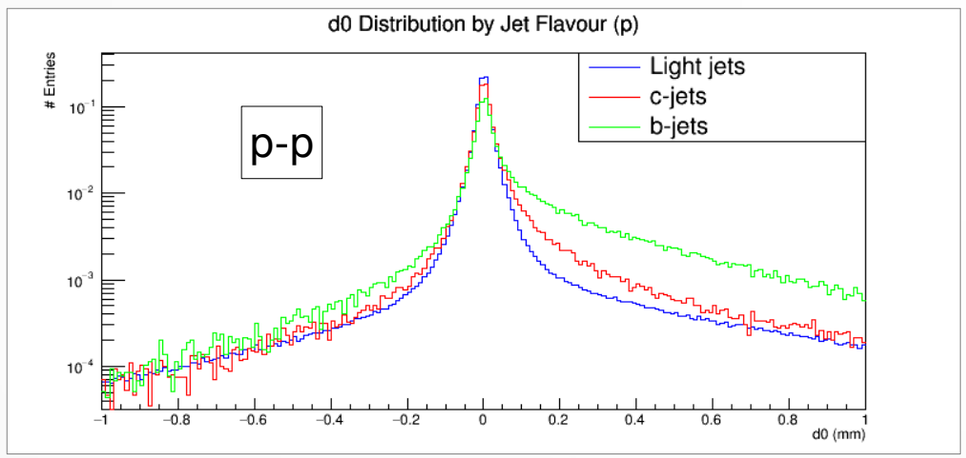
Impact Parameters

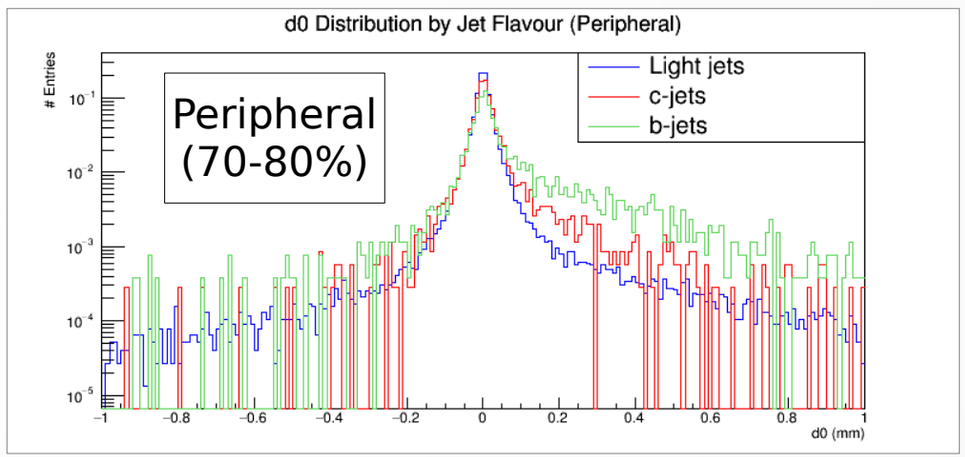
- Signature impact parameters distribution for b-jets;
- The asymmetry in the distribution is less visible in Pb-Pb collisions;
- The distribution is affected by the centrality of the collision

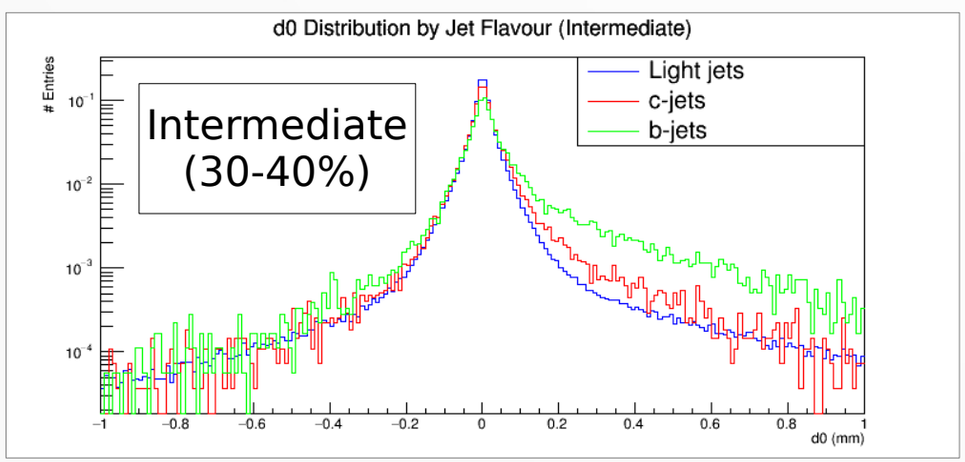


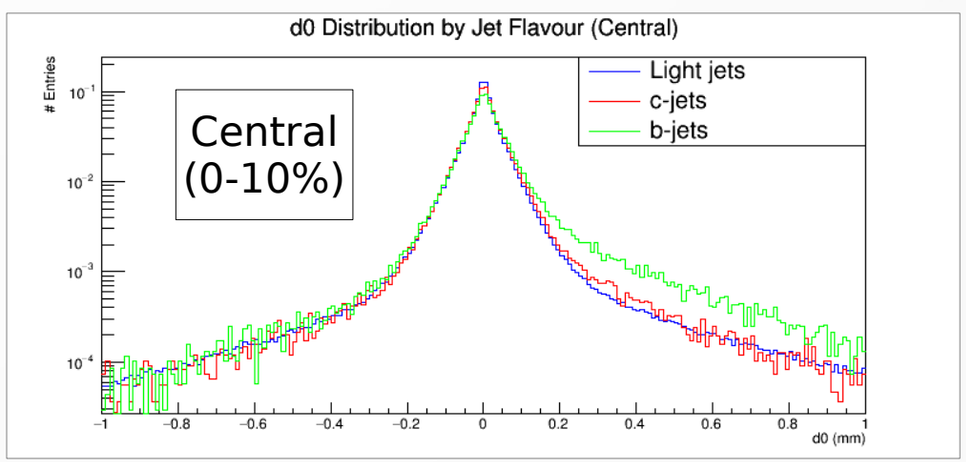


Impact Parameters vs Centrality









b-tagging efficiency

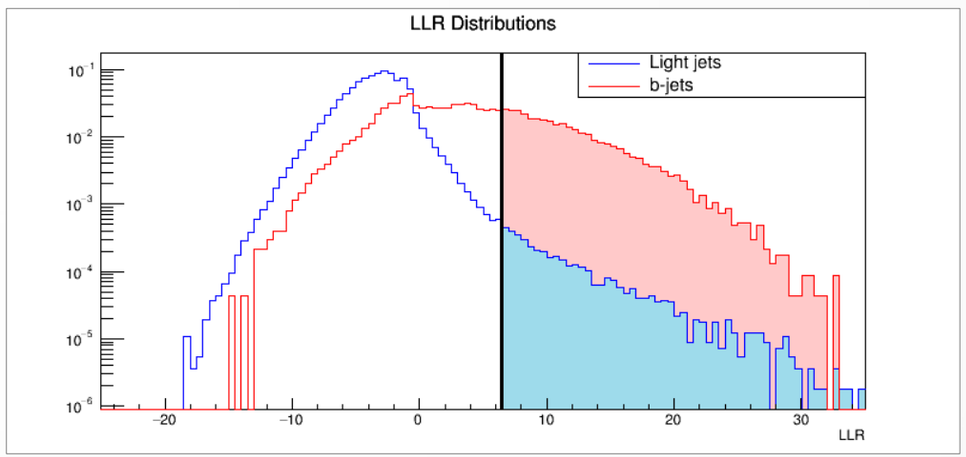
- Log Likelihood Ratio (LLR):
  - Comparison between the probabilities of a jet being a b-jet or light;
- b-tagging efficiency:

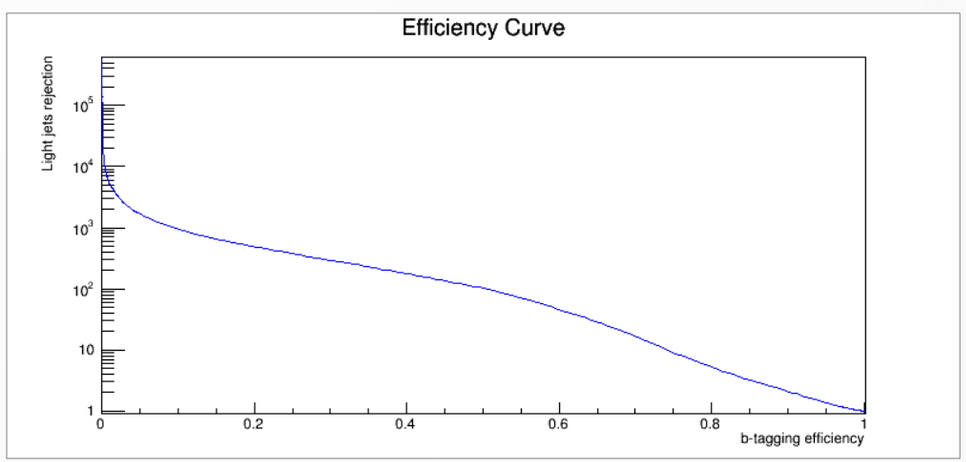
$$\text{efficiency} = \frac{\int_{bin}^{\infty} [\text{b-jets}]}{\int_{-\infty}^{\infty} [\text{b-jets}]}$$

- Light jets rejection:

$$\text{rejection} = \frac{\int_{-\infty}^{\infty} [\text{light-jets}]}{\int_{bin}^{\infty} [\text{light jets}]}$$

- 1 bin = 1 point in the Receiver Operating Characteristics (ROC) curve.

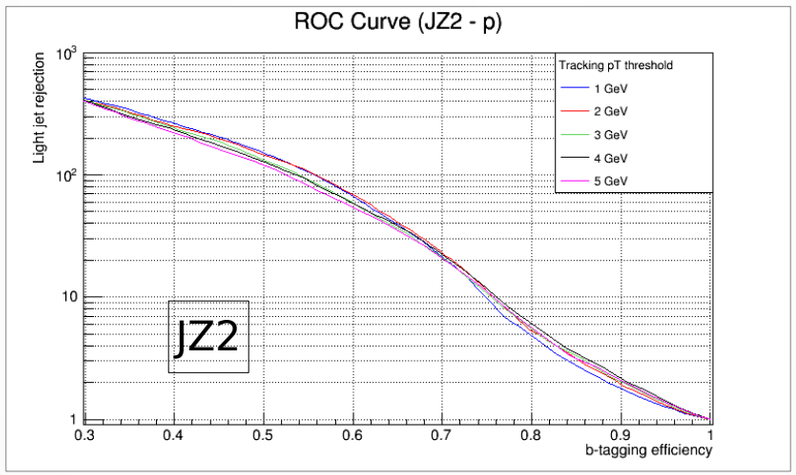


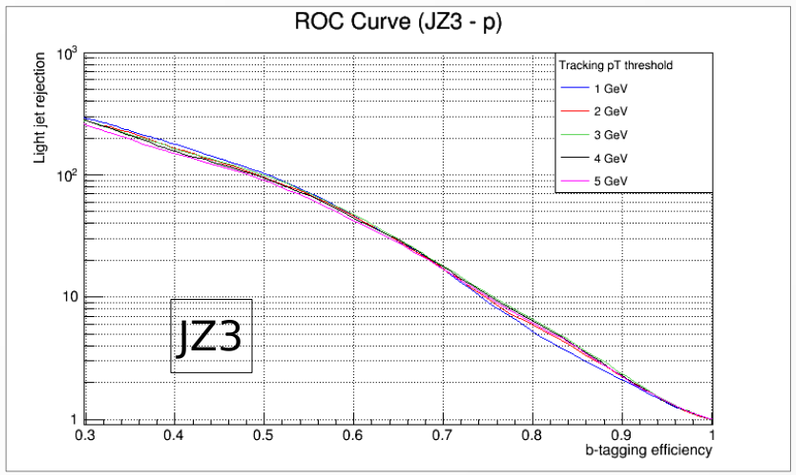


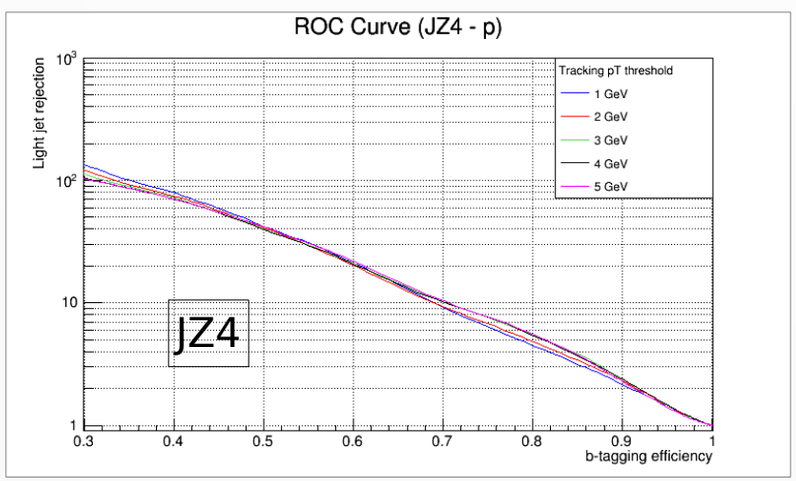
b-tagging efficiency

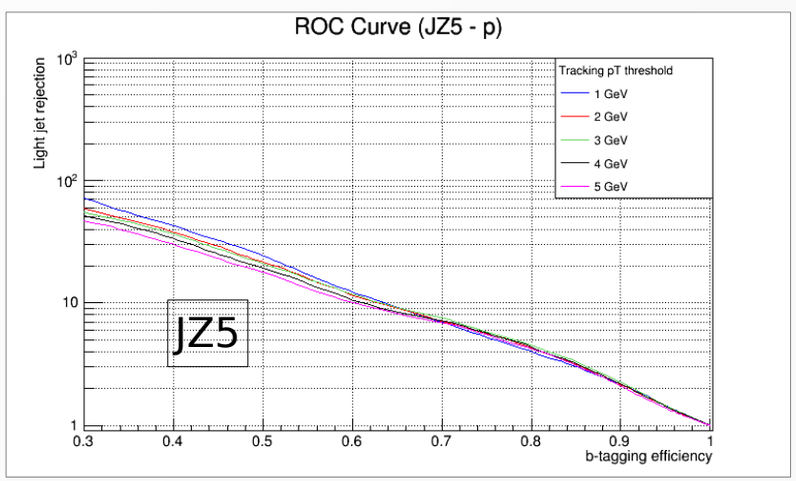
Jet pT interval (p-p)

- Light jet rejection:
  - Higher for JZ2 interval;
  - No significant difference between tracking pT thresholds.





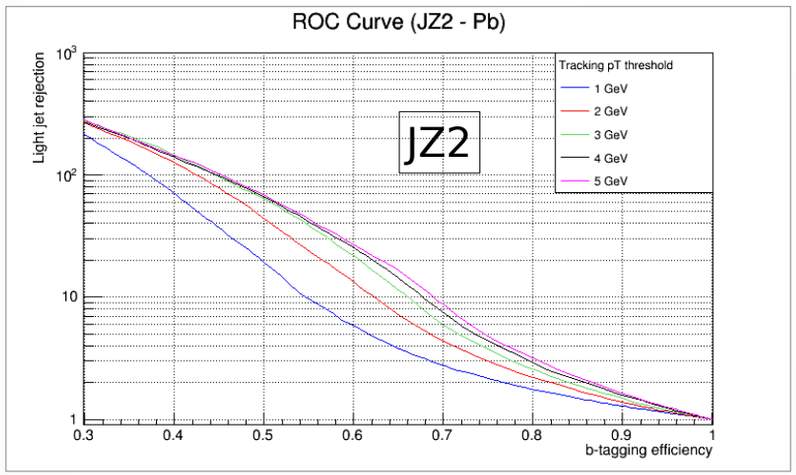


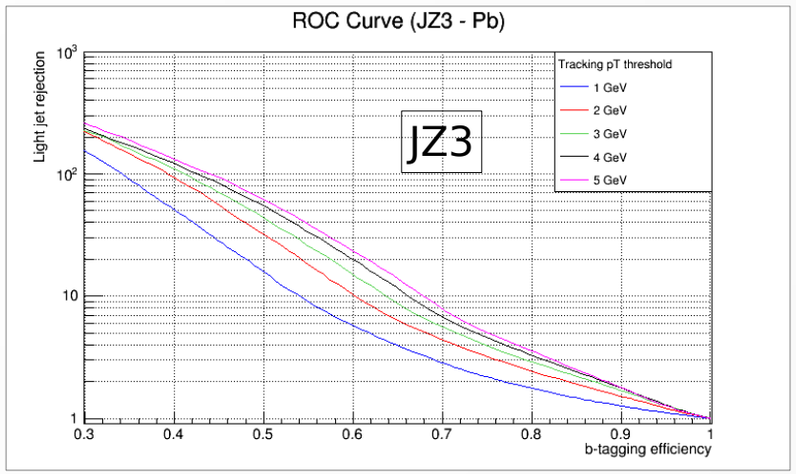


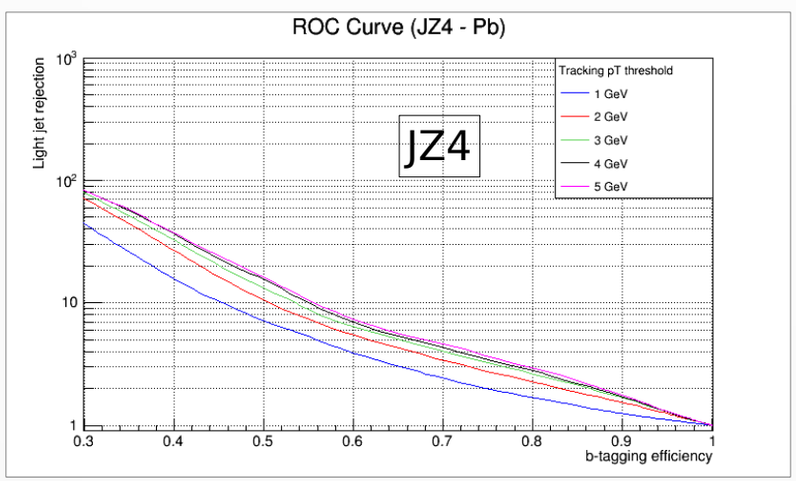
b-tagging efficiency

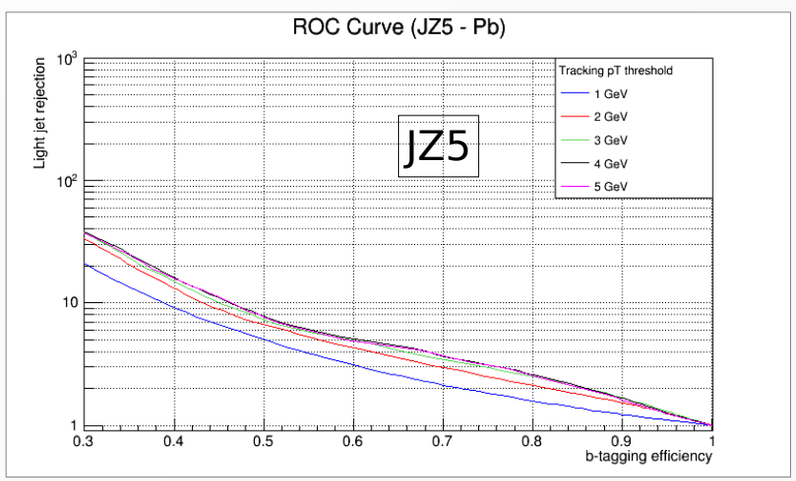
Jet pT interval (Pb-Pb)

- Light jet rejection:
  - Higher for JZ2 interval;
  - Significant improvement from 1 GeV to 3 GeV threshold.





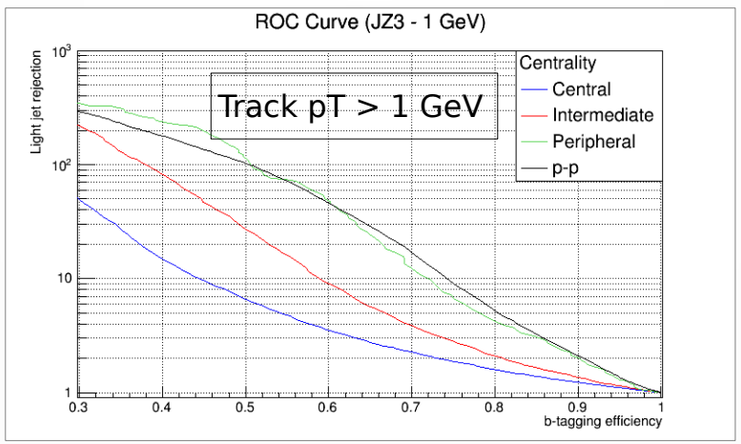


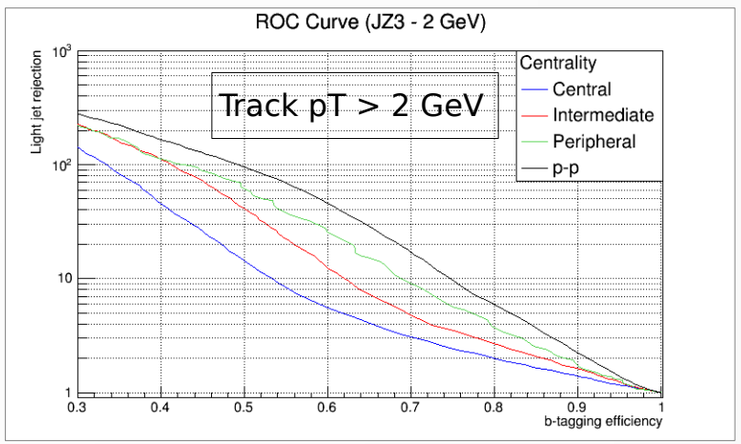


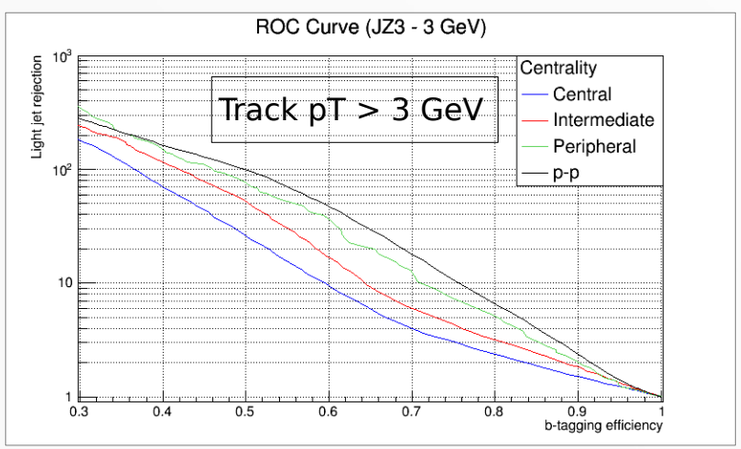
b-tagging efficiency

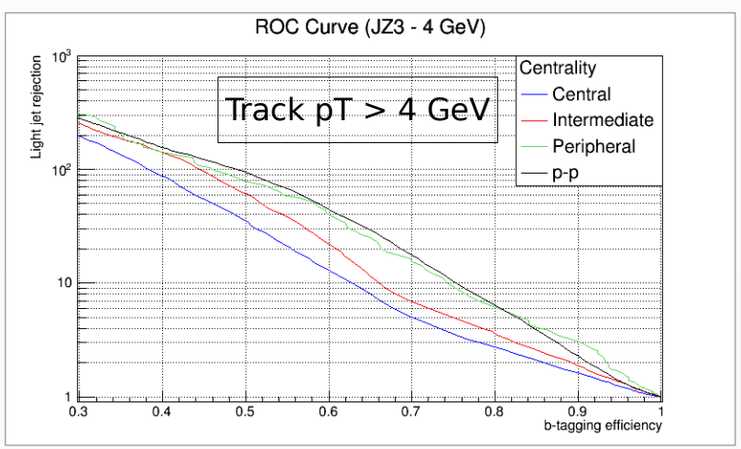
Centrality

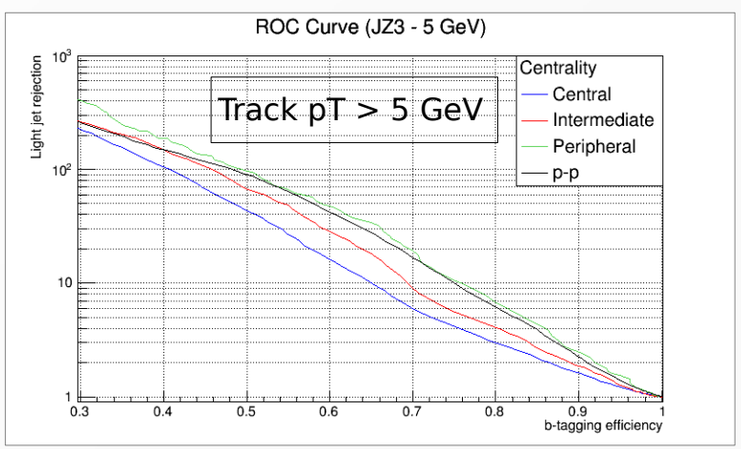
- Better light jet rejection for peripheral collisions (similar to p-p);
- Poorer light jet rejection for central collisions.











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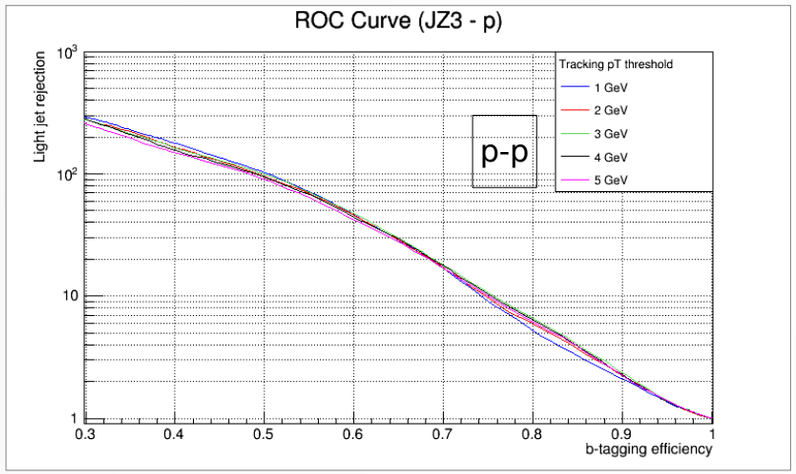

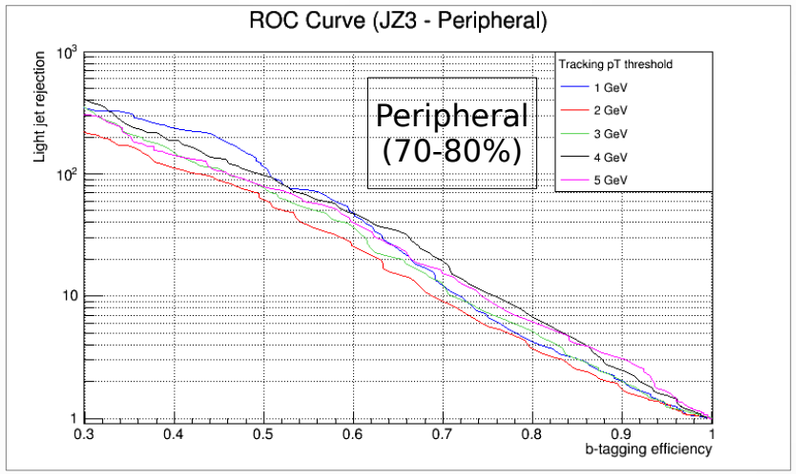

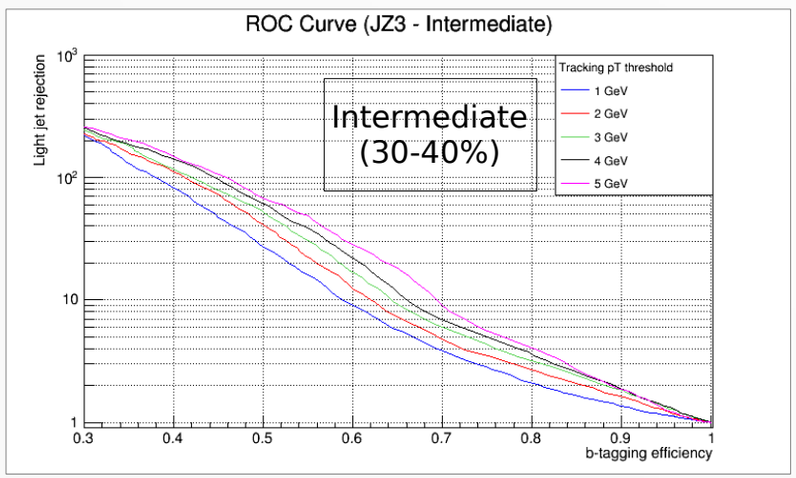

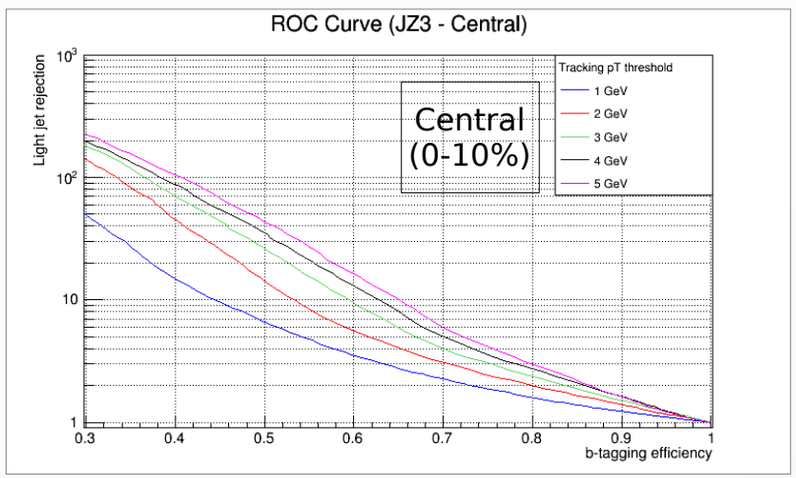

Track pT threshold

- Peripheral collisions:
  - No significant change with respect to track pT threshold;
- Central collisions:
  - Significant increase in light jet rejection between 1 GeV and 3 GeV track pT threshold.

Conclusion

- Higher efficiency for lower leading jet pT;
- Lower efficiency for central collisions;
- Better rejection when the track pT threshold is higher:
  - Greater improvement between 1 and 3 GeV;
  - More significant for central colisions.