Subjet observables in Heavy-Ion Collisions

João Cruz & João Silva

Estágios de Verão 2017 Final Workshop

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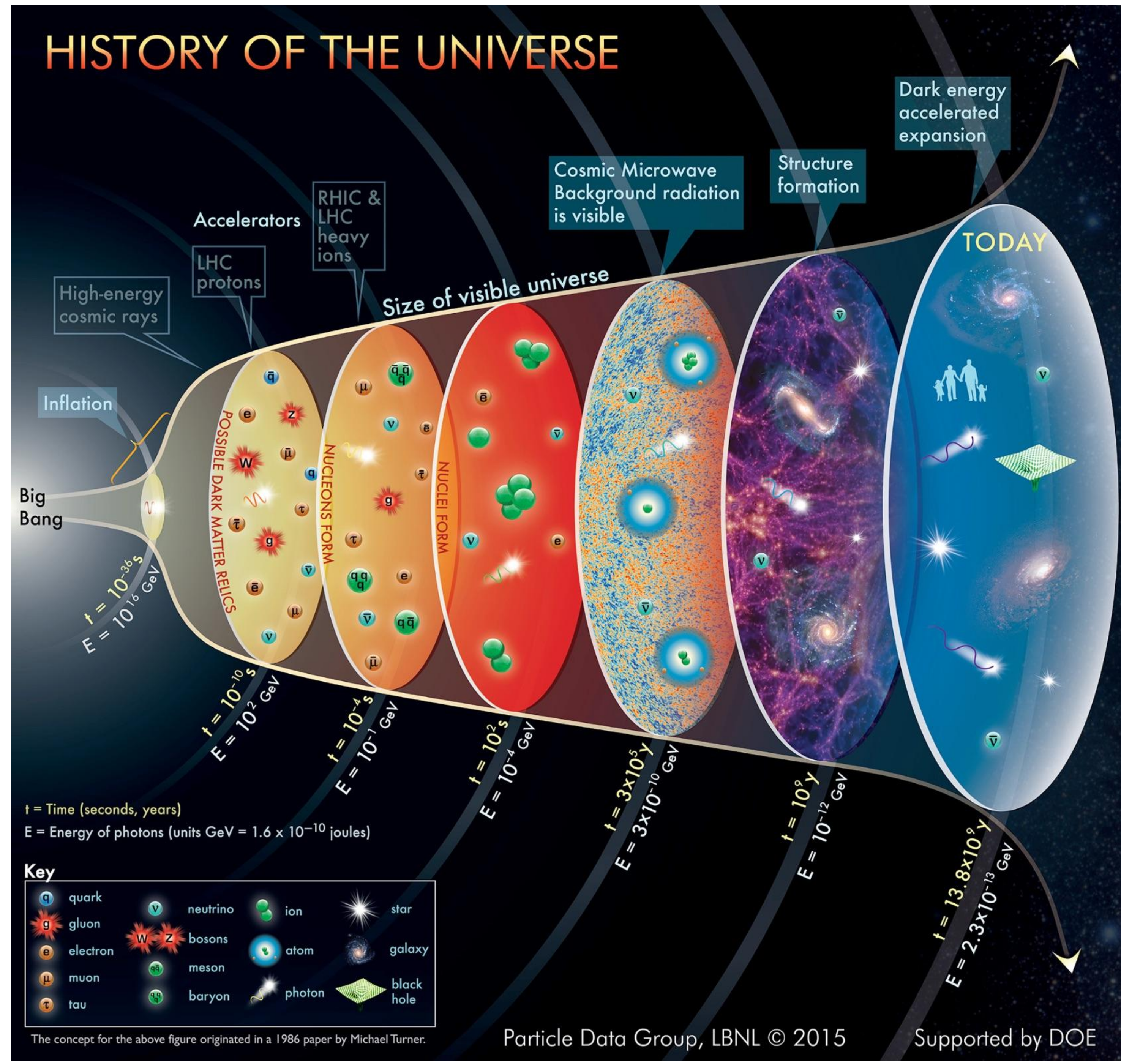
Introduction

- Global aim of this project (and all heavy-ion community!)
  - Study the Quark-Gluon Plasma (QGP) that is created in heavy-ion collisions;
- Why? State of matter where quarks and gluons are not bound into hadrons; also, it is believed that existed at the initial stages of our Universe;



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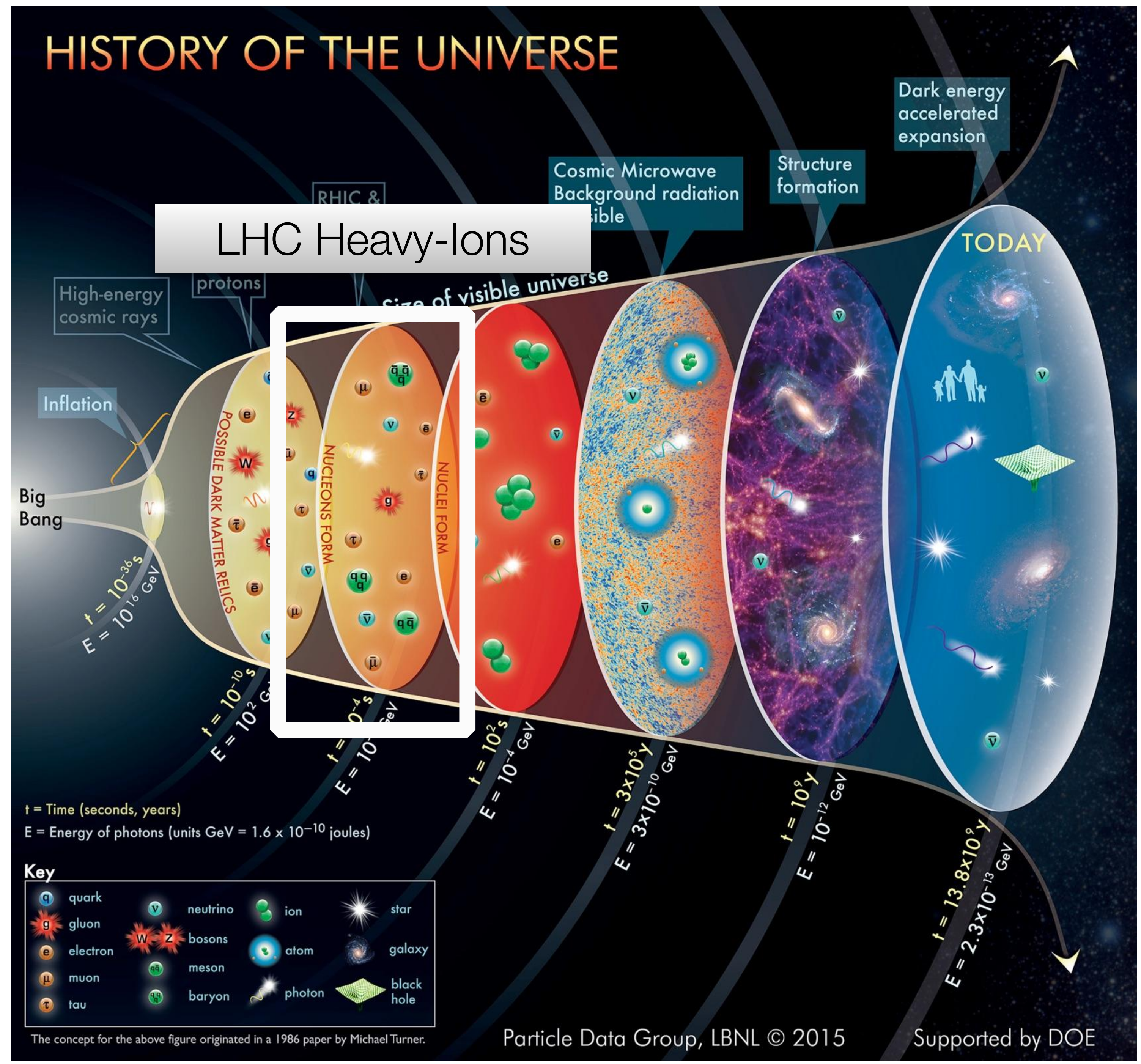

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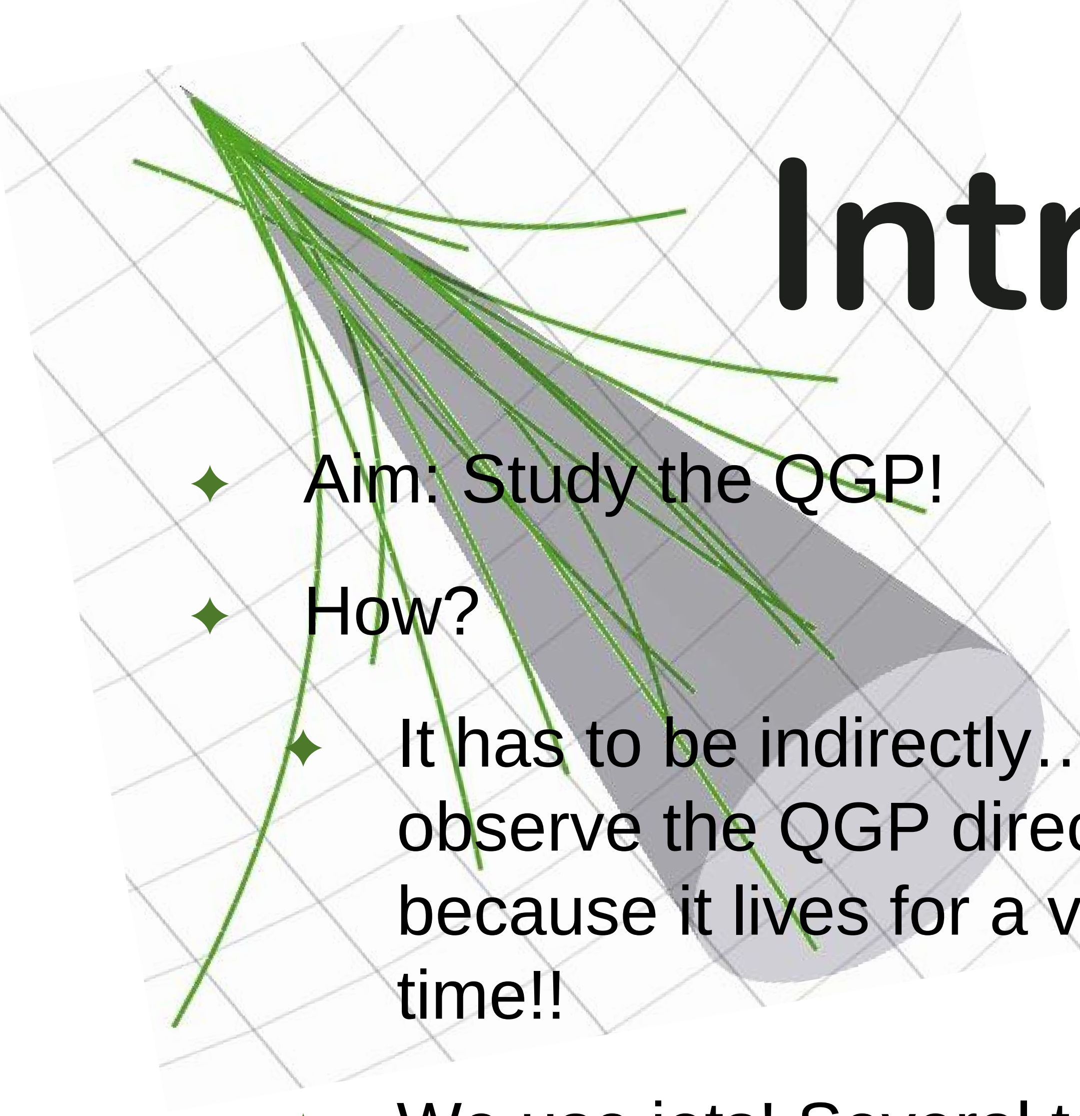
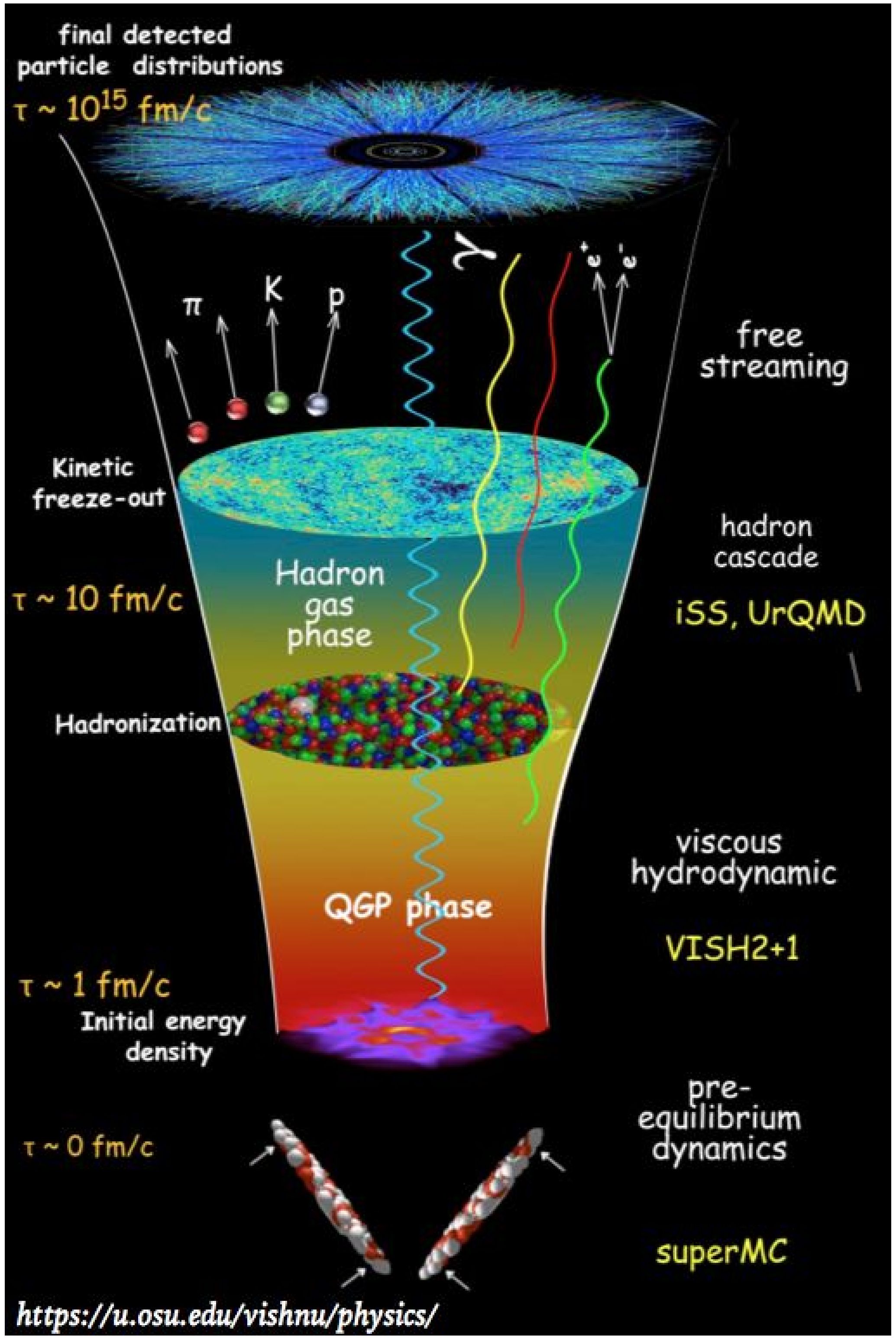
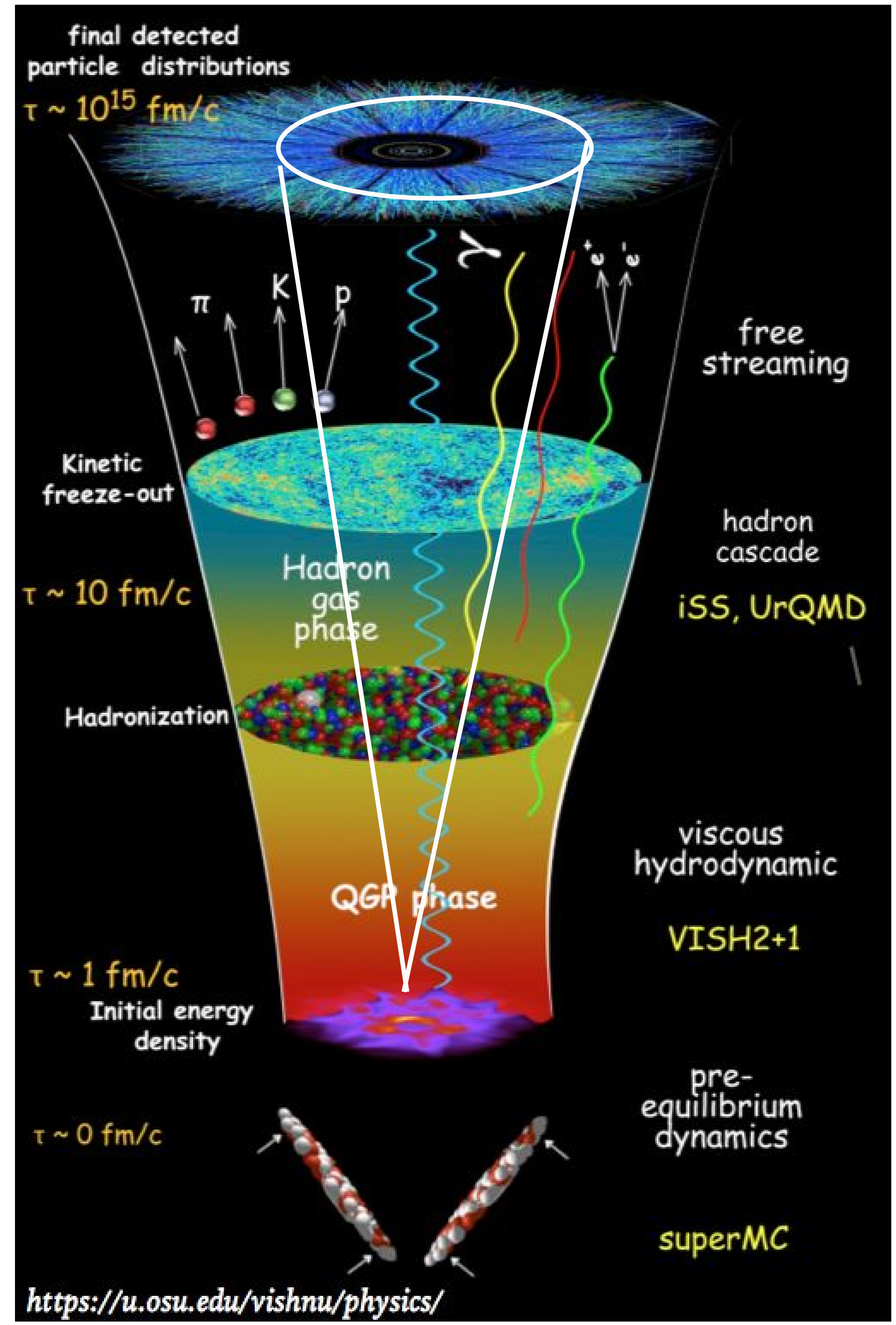


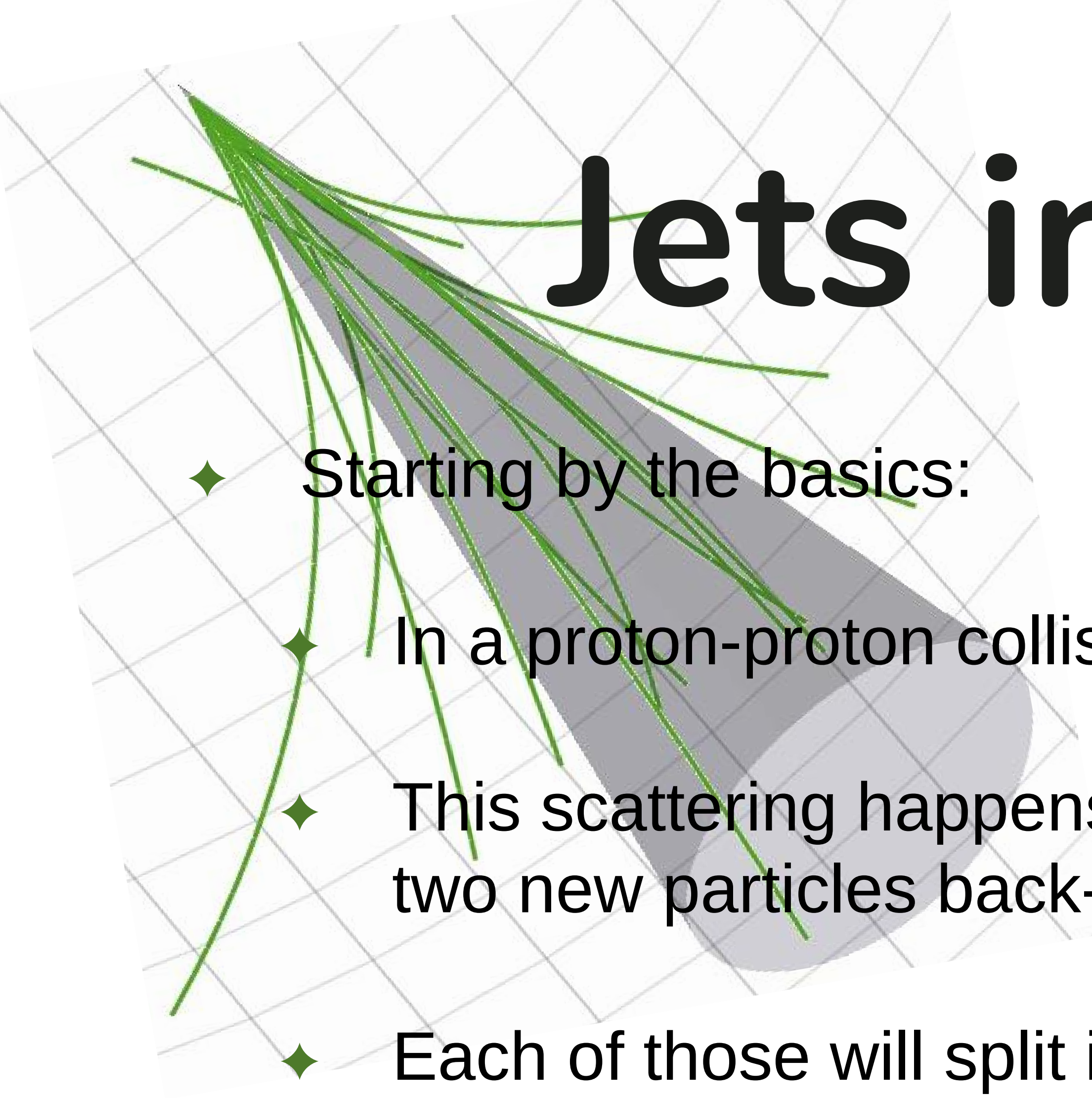
- Aim: Study the QGP!
- How?
  - It has to be indirectly… we cannot observe the QGP directly because it lives for a very short time!!
  - We use jets! Several tools at our disposition: theoretical (perturbative QCD) and phenomenological (Monte Carlo Event Generators).



Introduction

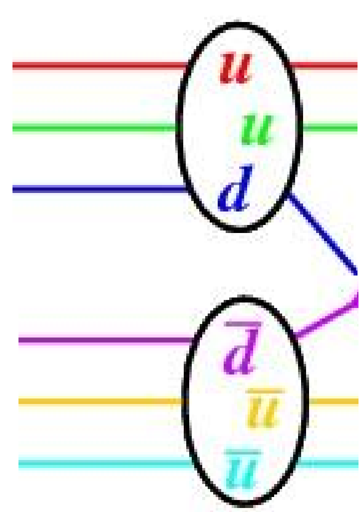
- Aim: Study the QGP!
- How? Jets!
- Problem: observations are based on the result of the jet development inside the expanding QGP;
    - Our BIG challenge: Create new ways of using jets in heavy-ions to assess QGP properties, namely its <u>initial timescales</u>;
- But for that, starting by something simple…
    - Jet development in vacuum!





Jets in "vacuum"

- Starting by the basics:
  - In a proton-proton collision, we have two particles that scatter;
  - This scattering happens at a very large energy scale and produces two new particles back-to-back;
  - Each of those will split into two, and these processes add to form what we define as a jet.



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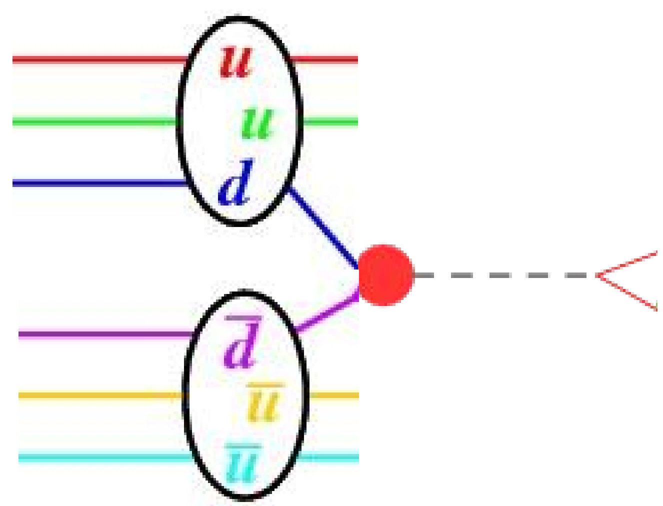

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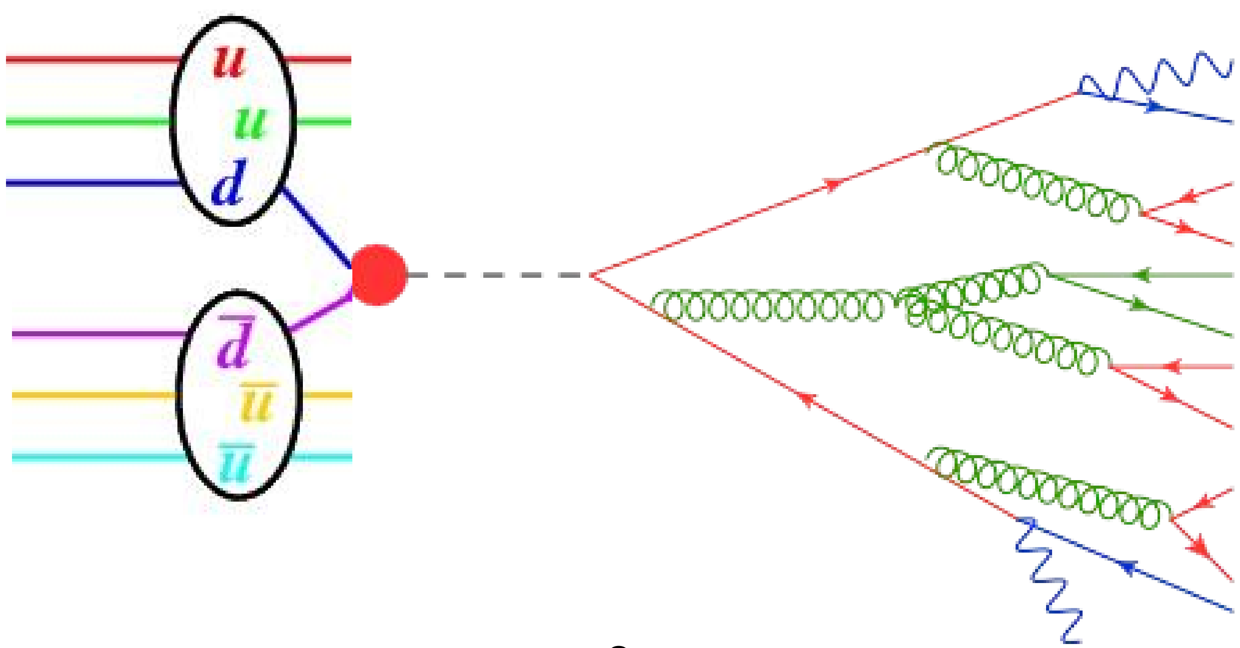

Our Working Setup

- To study what exactly is a jet, we used Pythia8 Monte Carlo event generator tuned for:
  - Hard QCD processes (dijets)
  - $\sqrt{s}_{cm}$ = 5.02 TeV (current PbPb collisions)
  - $|\eta_{jet}| < 2.5$, $p_{T,Hat} \in [50, \infty[$
- And Fastjet package to reconstruct jets with the following settings:
  - Anti-k_T algorithm
  - R = 0.2 … 1.0

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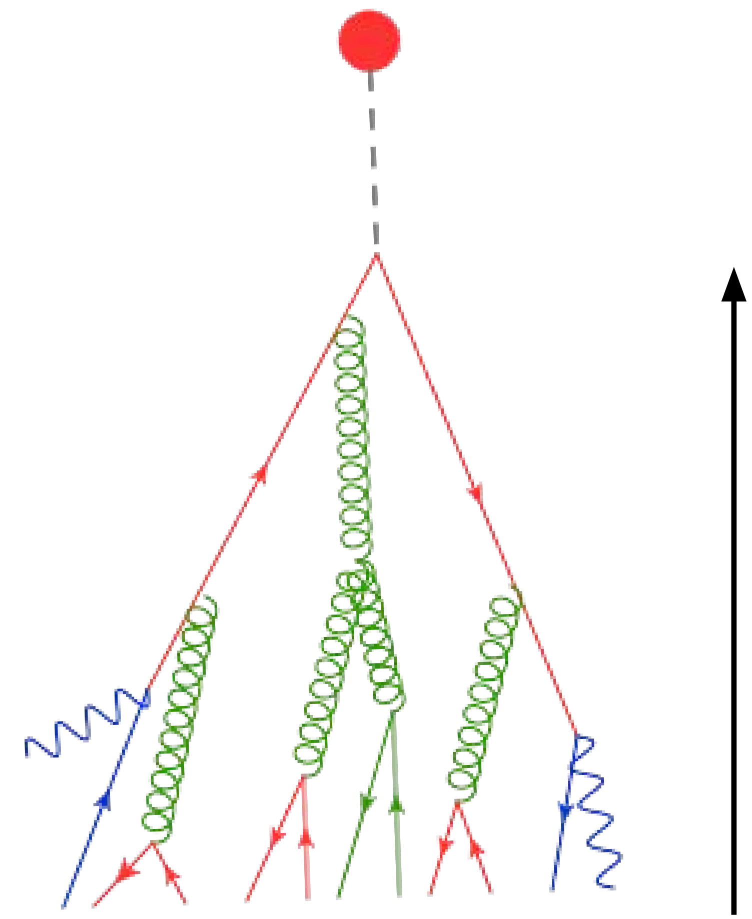
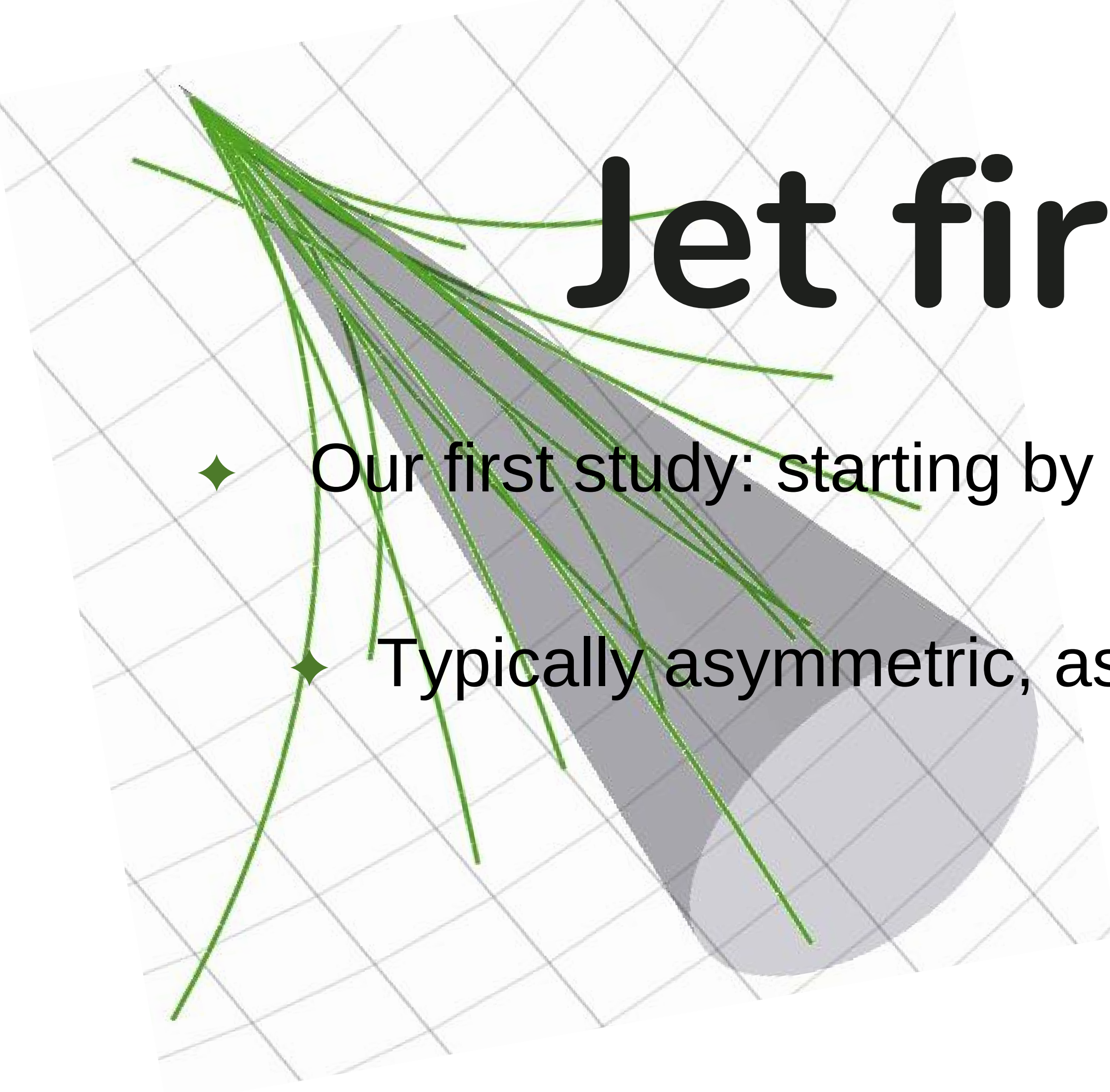
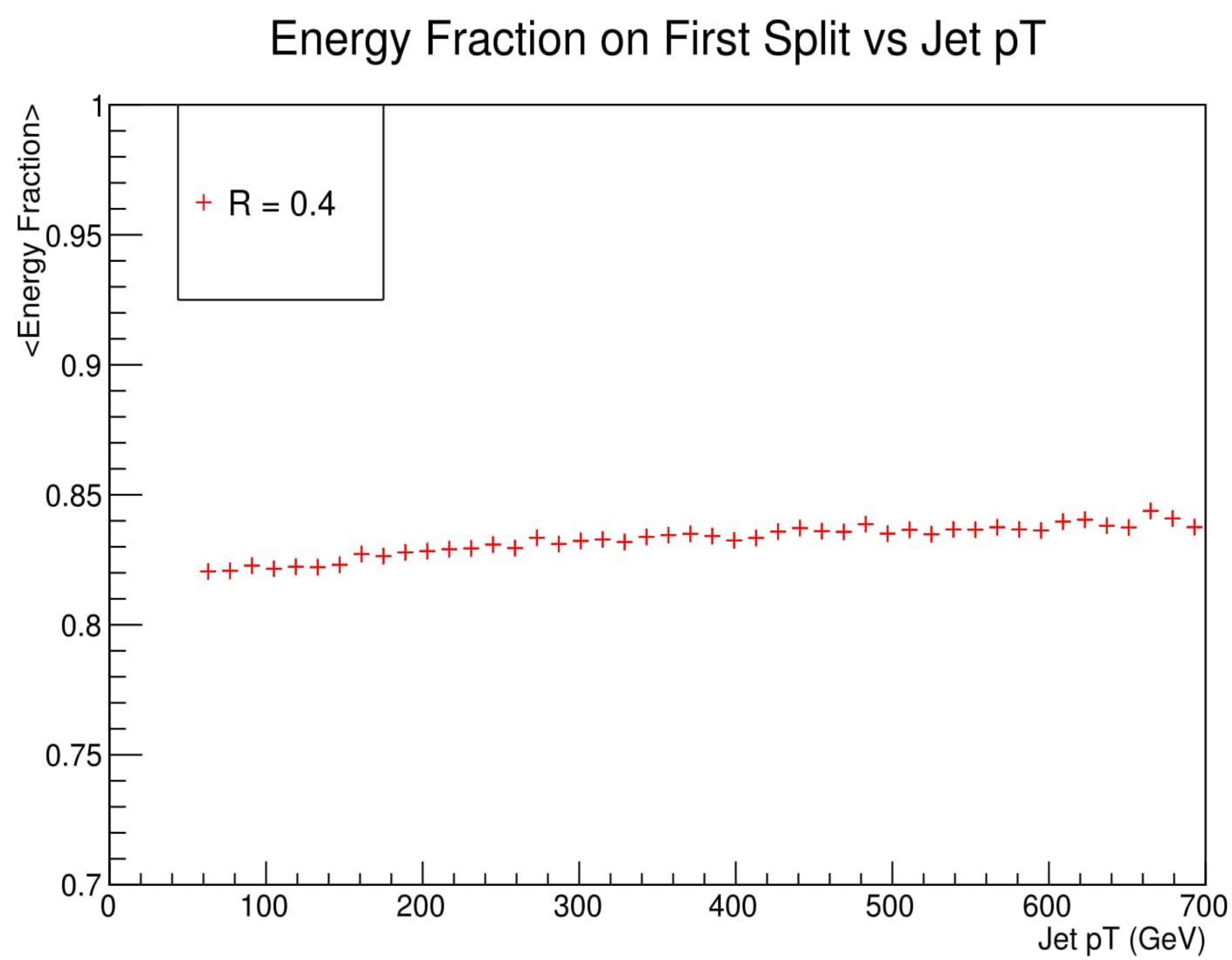


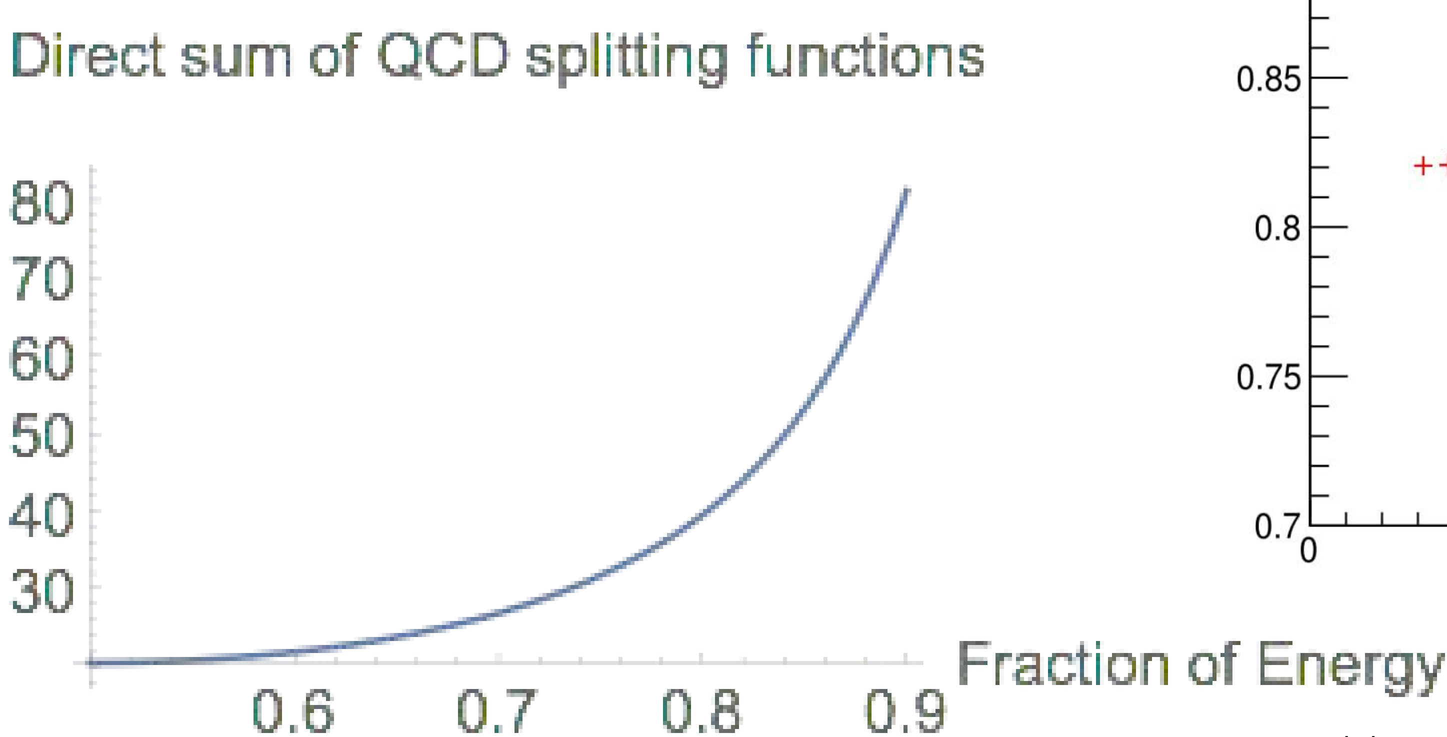
The idea is to go back in the pythia event record to track all the jet history (mainly the number of splittings and its fraction of energy)

Jet first splitting

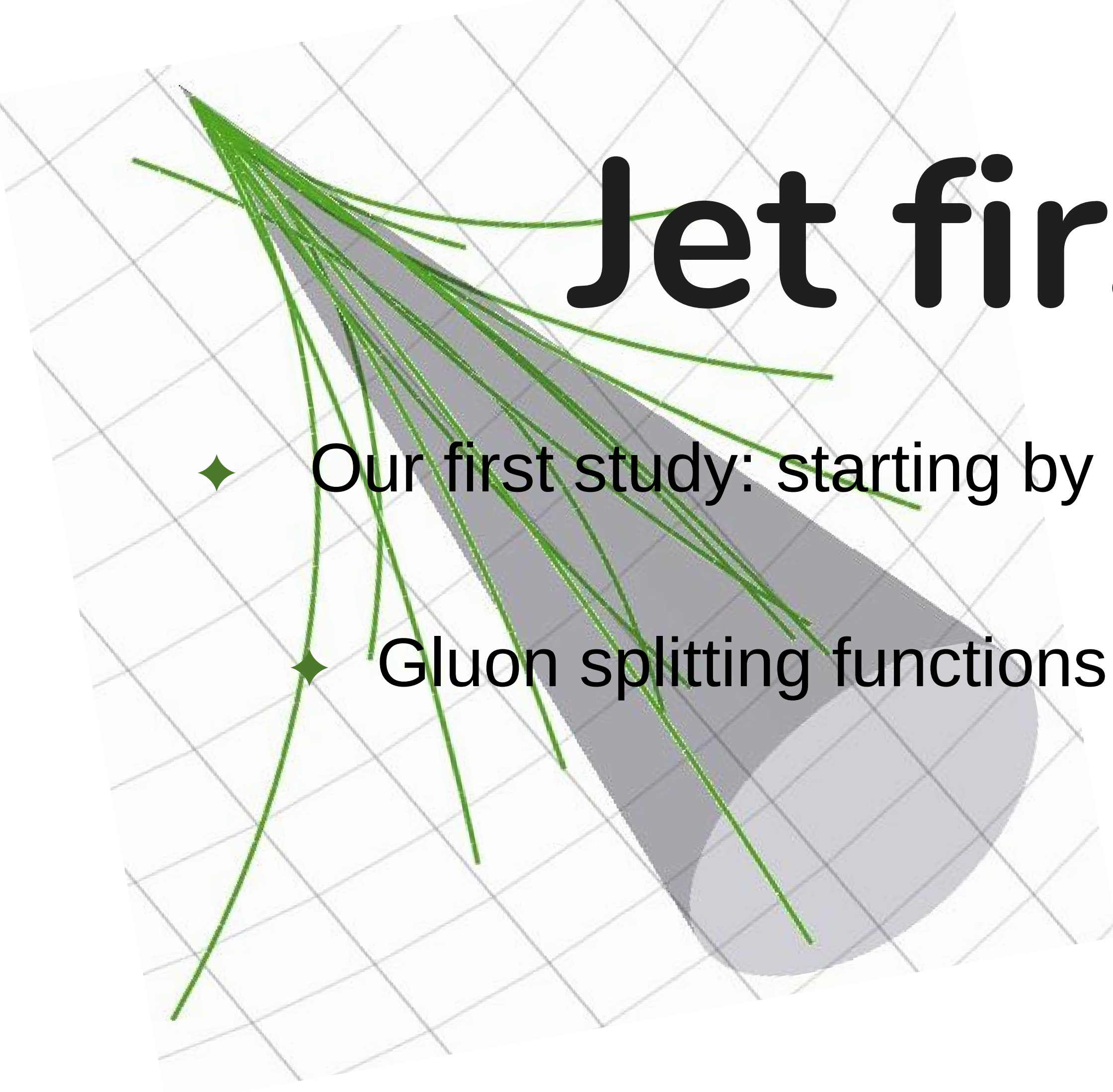
- Our first study: starting by the first splitting…
  - Typically asymmetric, as predicted by pQCD





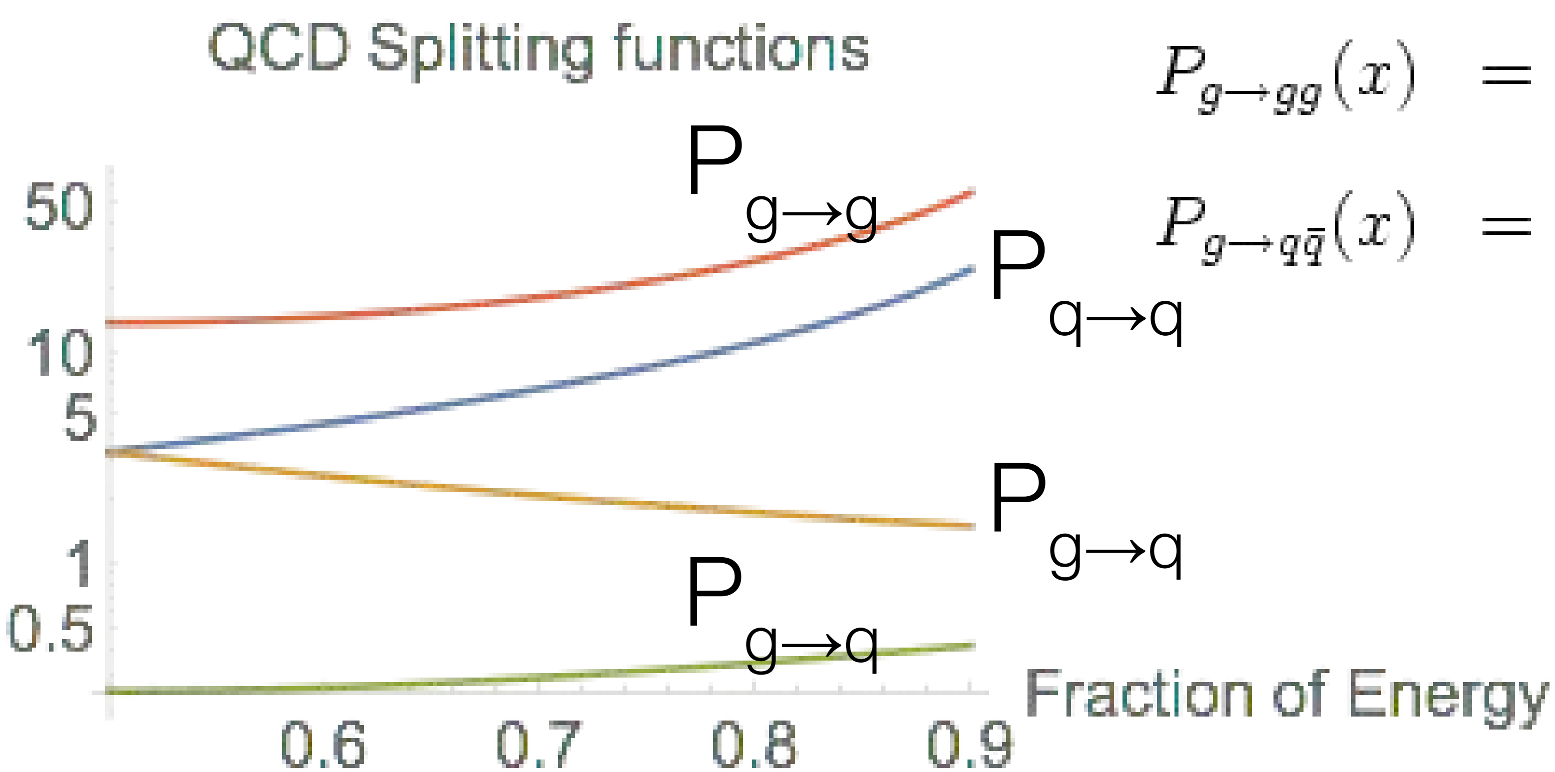


Jet first splitting



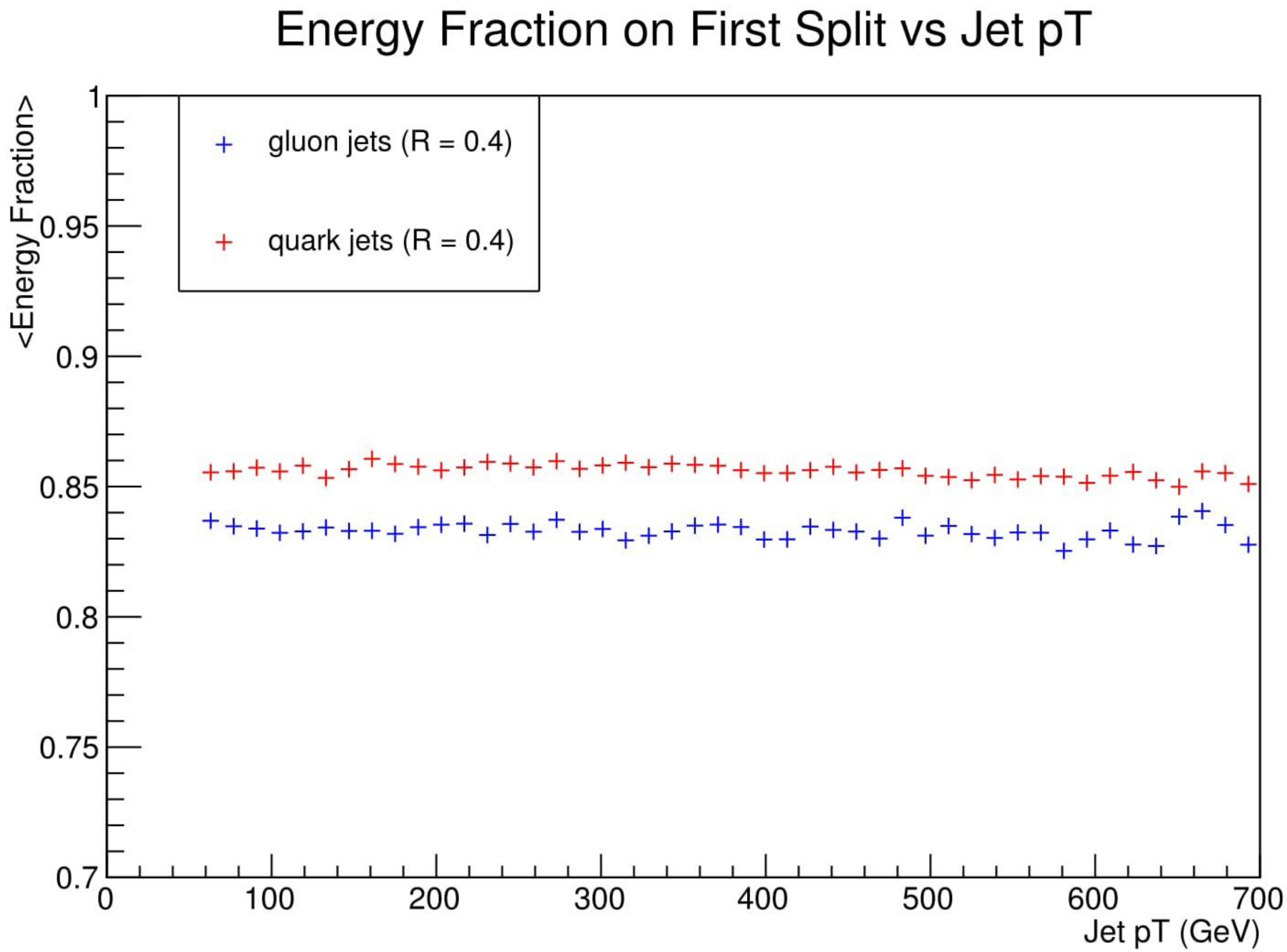
- Our first study: starting by the first splitting…
  - Gluon splitting functions dominate over Quark splitting functions

$$
\begin{aligned}
P_{q\to qg}(x) &= P_{\bar{q}\to\bar{q}g}(x) = C_F\frac{1+x^2}{1-x}\,, \\
P_{q\to gq}(x) &= P_{q\to qg}(1-x) = C_F\frac{1+(1-x)^2}{x}\,, \\
P_{g\to gg}(x) &= 2C_A\left[\frac{x}{1-x}+\frac{1-x}{x}+x(1-x)\right], \\
P_{g\to q\bar{q}}(x) &= T_R\left[x^2+(1-x)^2\right],
\end{aligned}
$$

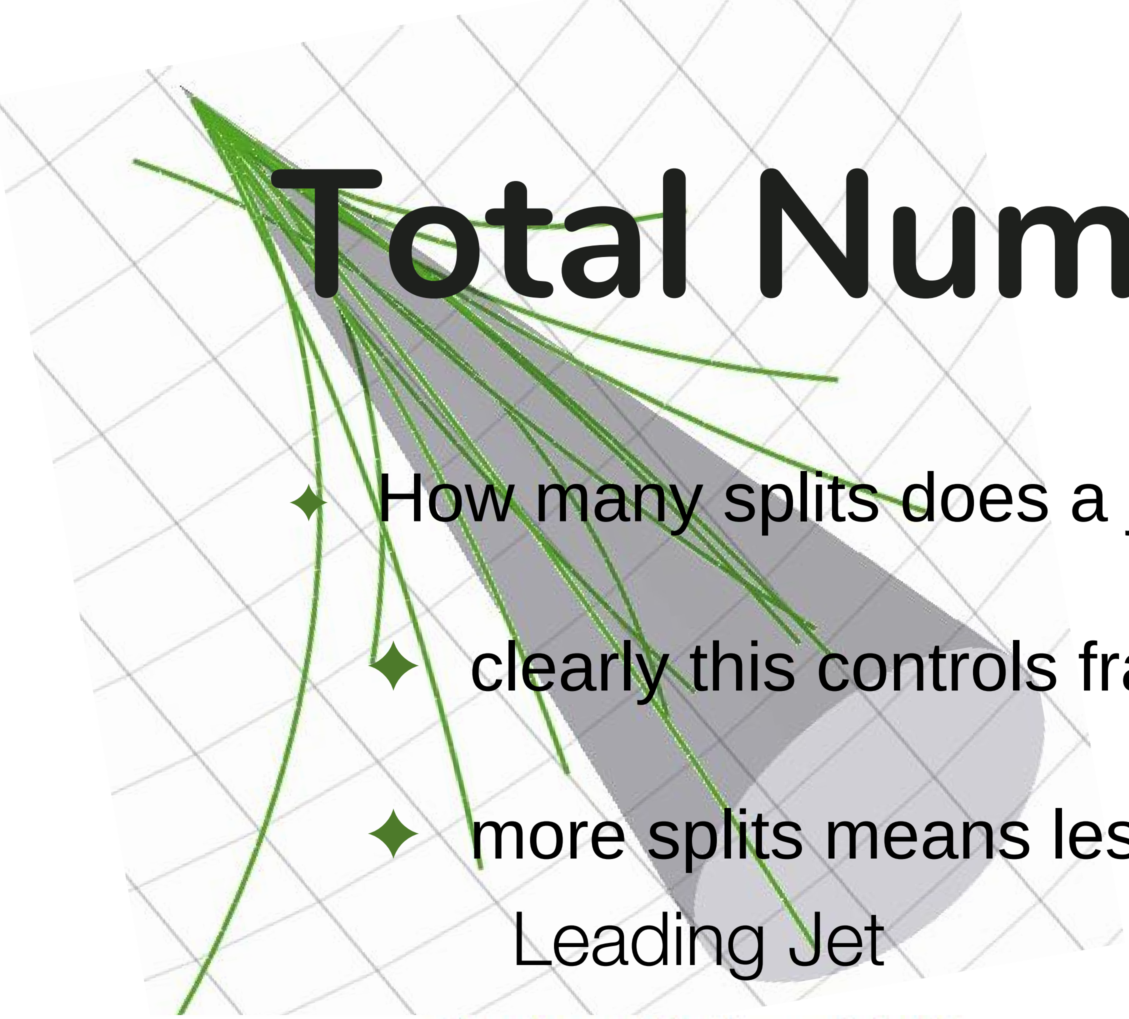


Jet first splitting

- Tagging each event's leading jet original particle, one can accumulate enough statistics to confirm the result of both the quarks and gluons splitting functions.

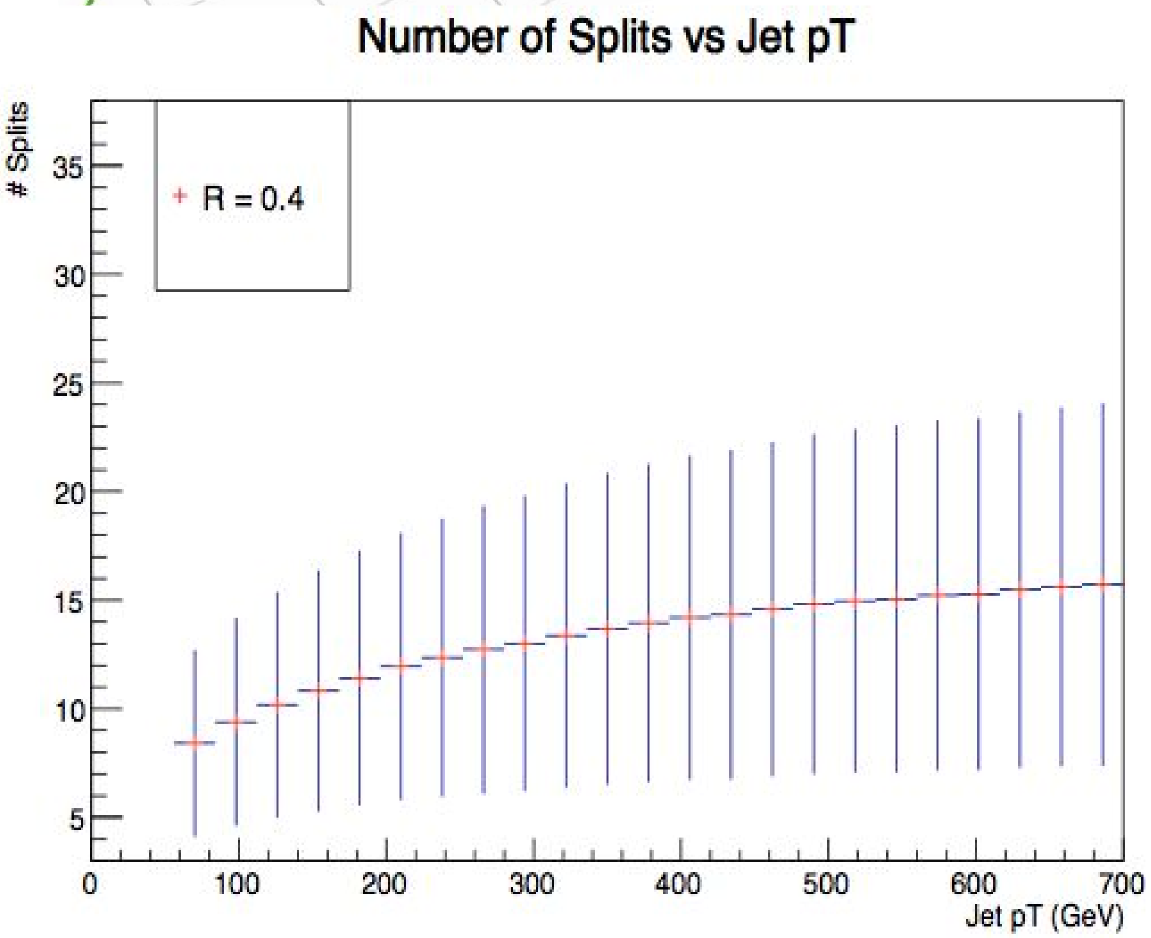


Total Number of splittings

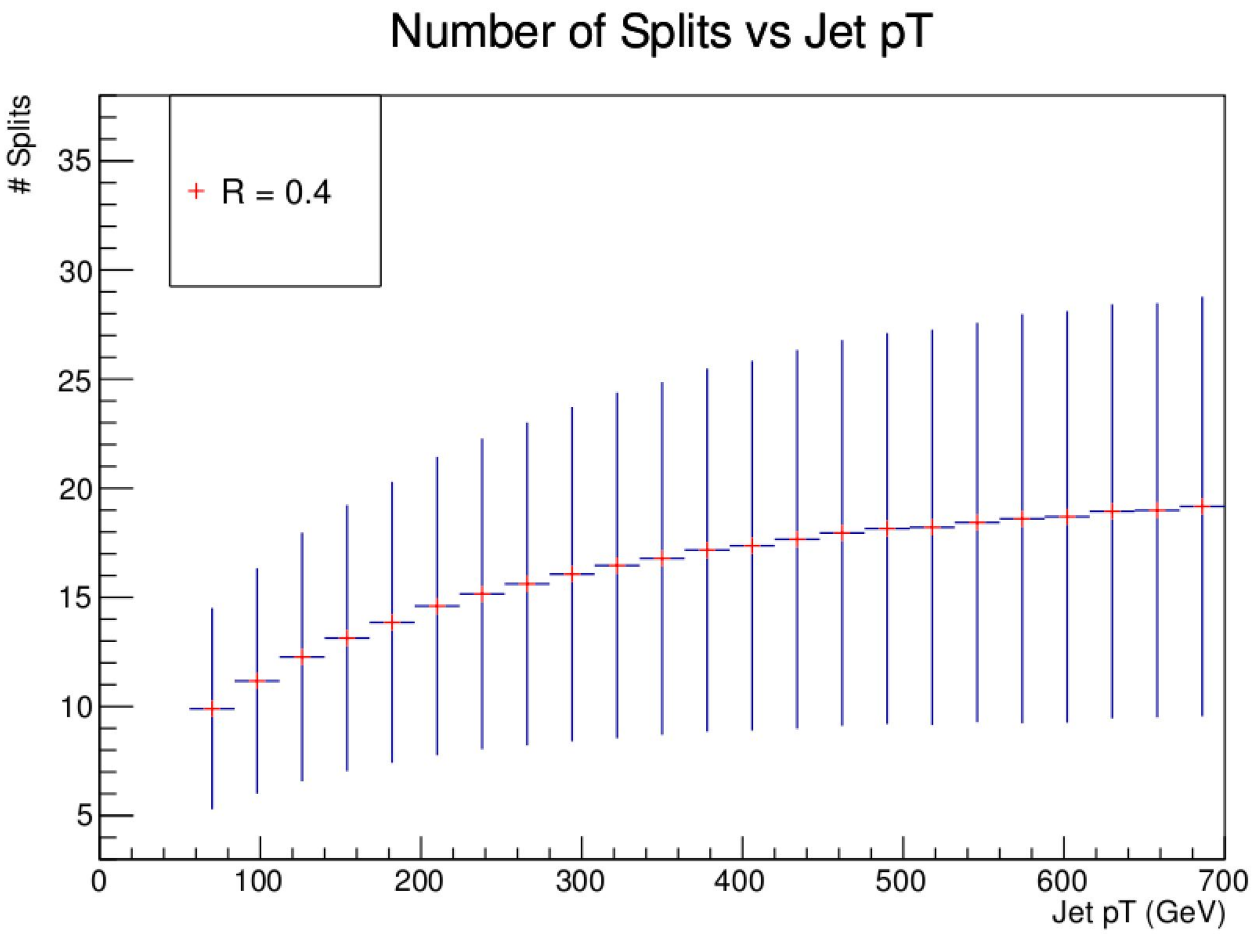


- How many splits does a jet contain, on average?
  - clearly this controls fragmentation of jet
  - more splits means less jet energy inside of the jet radius

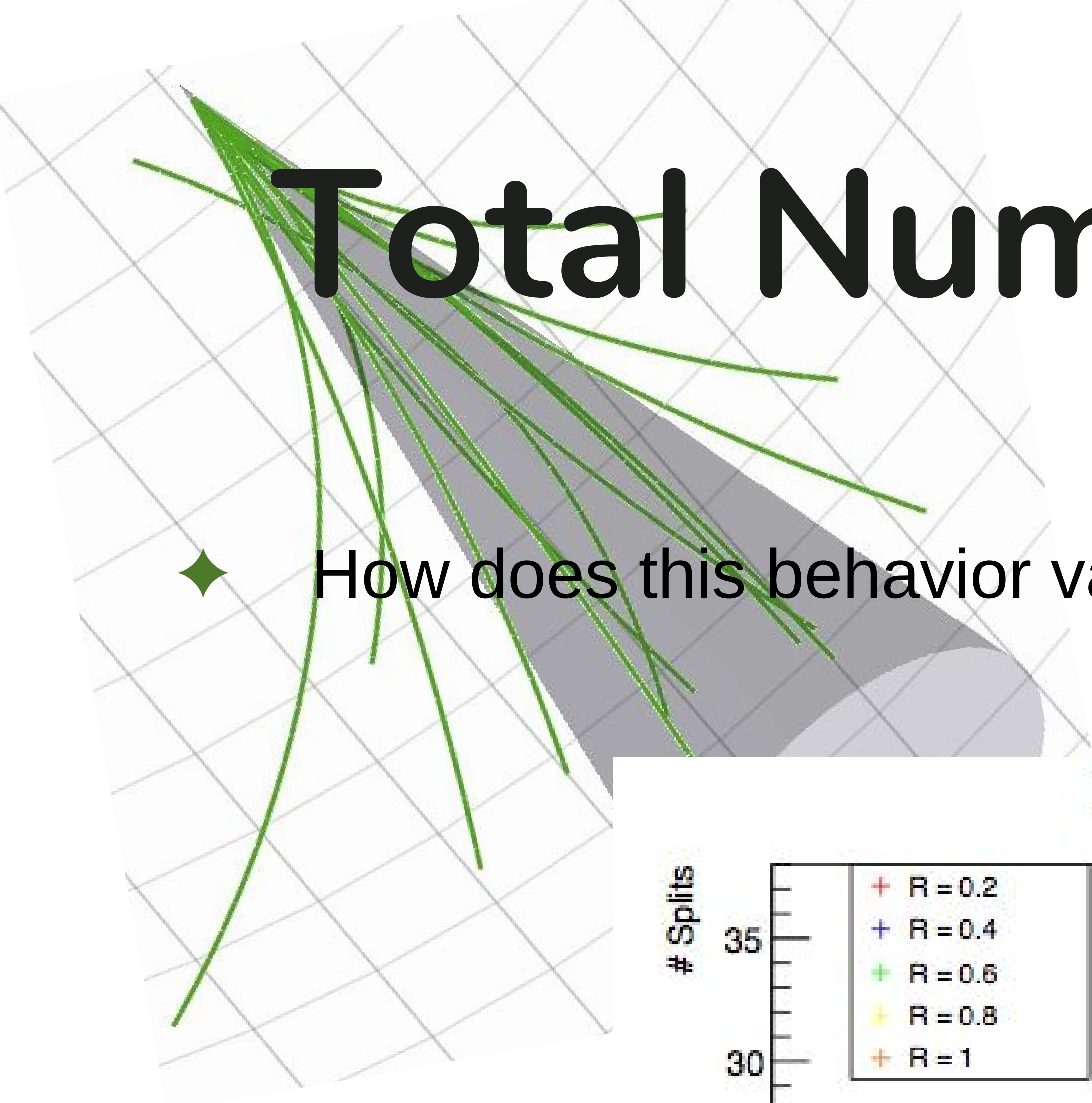
Leading Jet



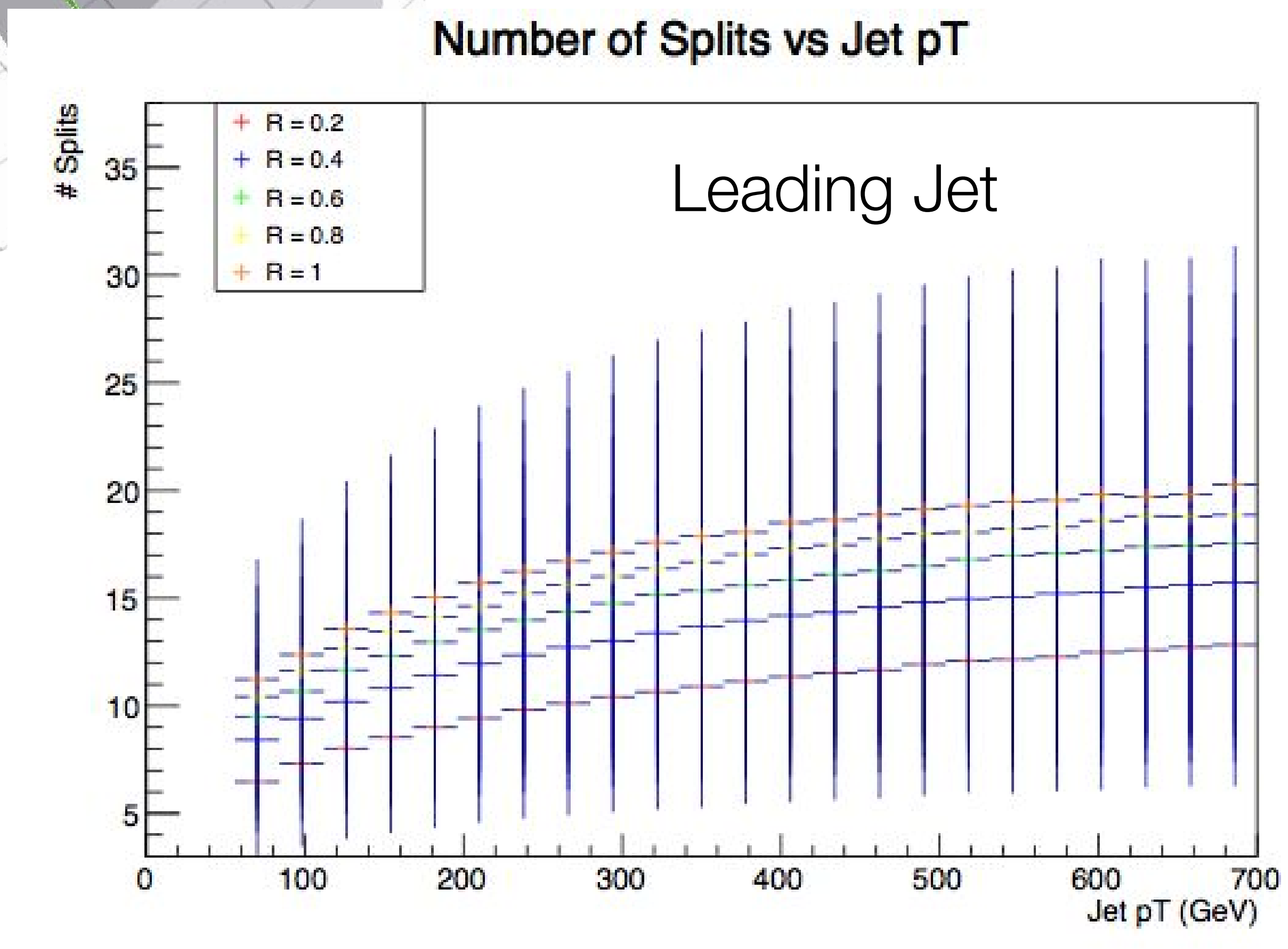
Subleading Jet



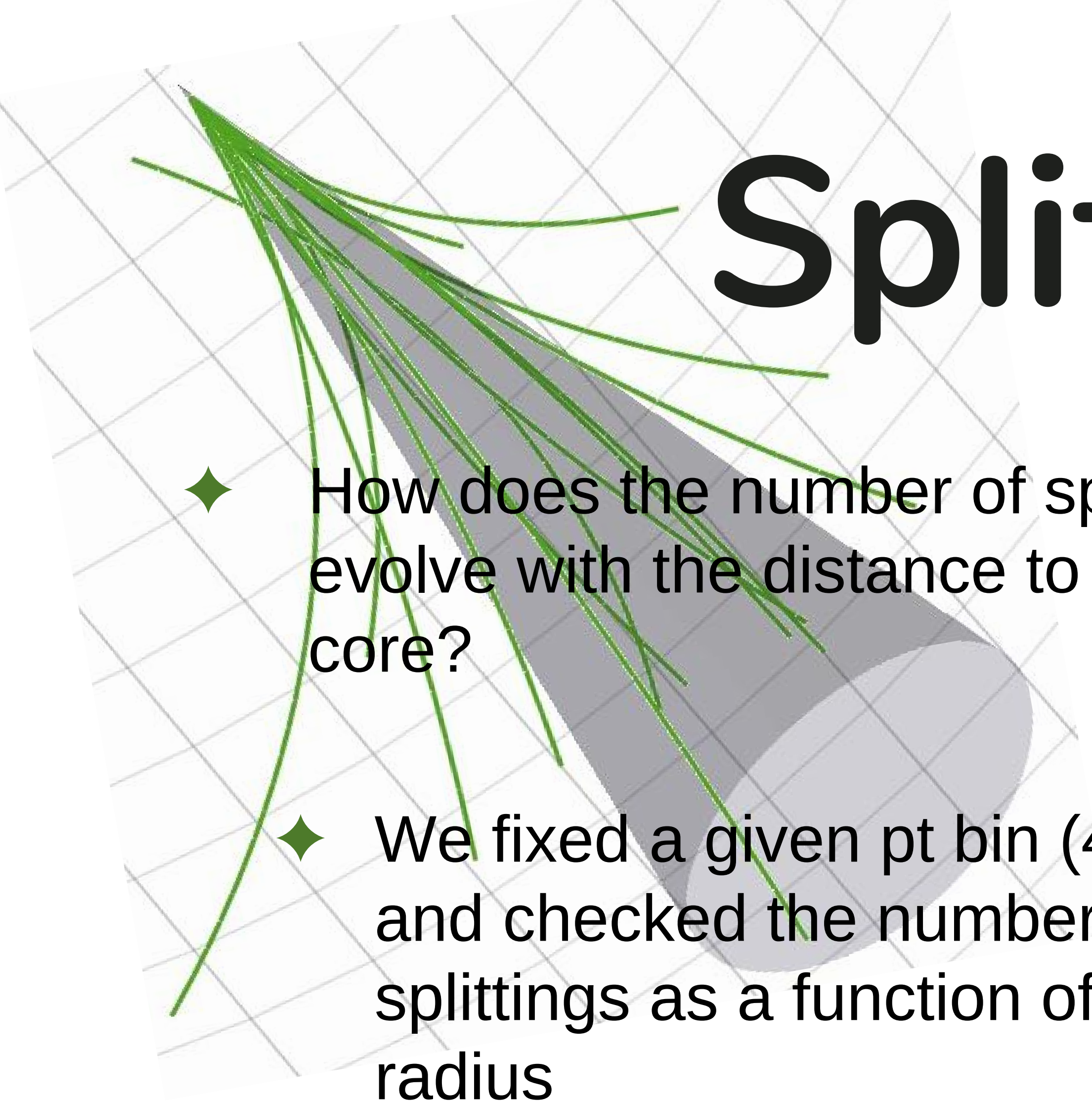
Total Number of splittings



- How does this behavior varies with the jet radius?

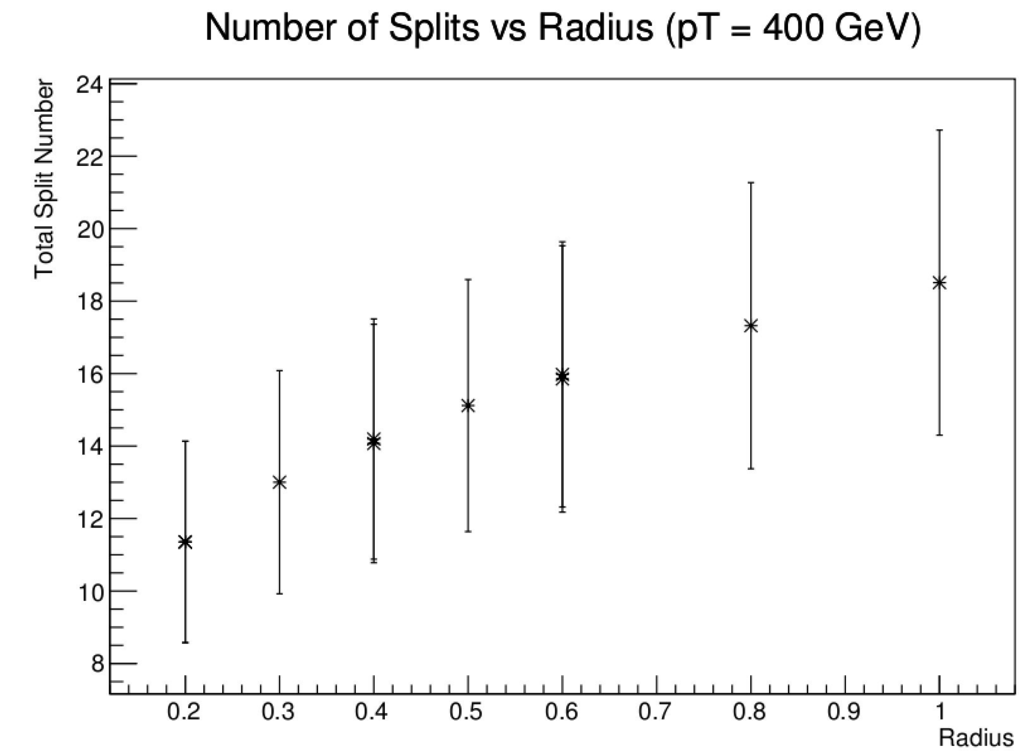


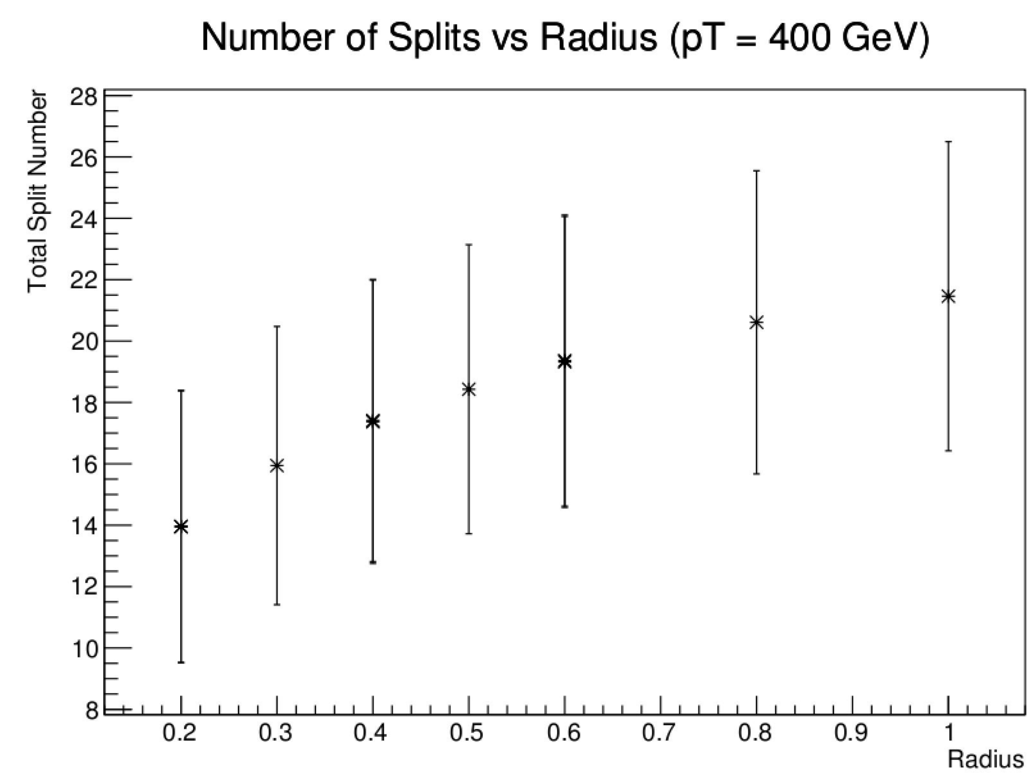
Splits vs Jet R



- How does the number of splittings evolve with the distance to the jet core?
  - We fixed a given pt bin (400 GeV) and checked the number of total splittings as a function of the jet radius
  - QCD energy spectrum goes as follows: k_T is the transverse momentum of the emitted particle with respect to the mother (so, similar info to jet R)

$$\omega \frac{dI}{d\omega dk_\perp^2} \sim \alpha_s \frac{1}{k_T^2} \Rightarrow \omega \frac{dI}{d\omega} \sim \alpha_s \log(k_T)$$





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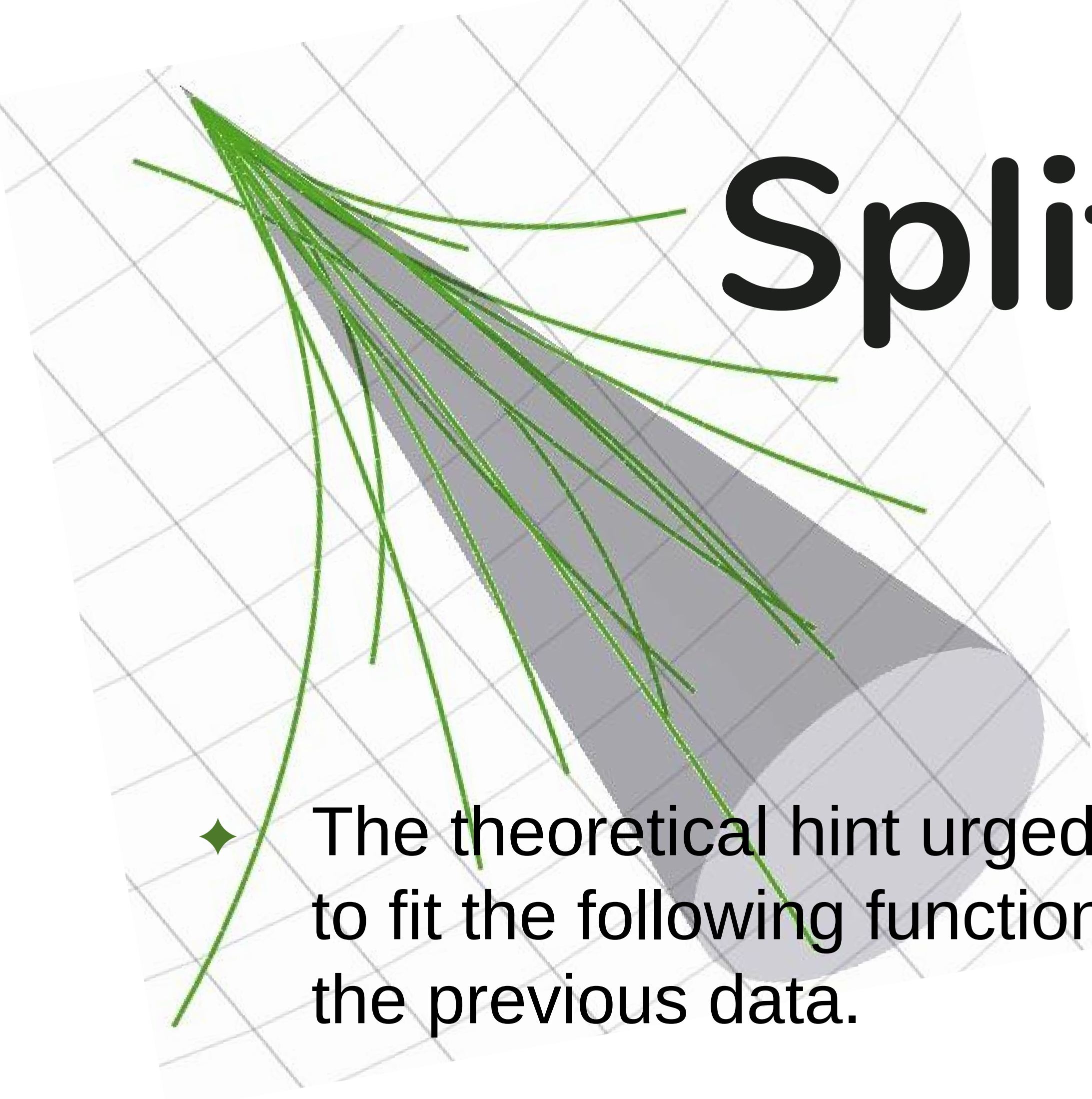
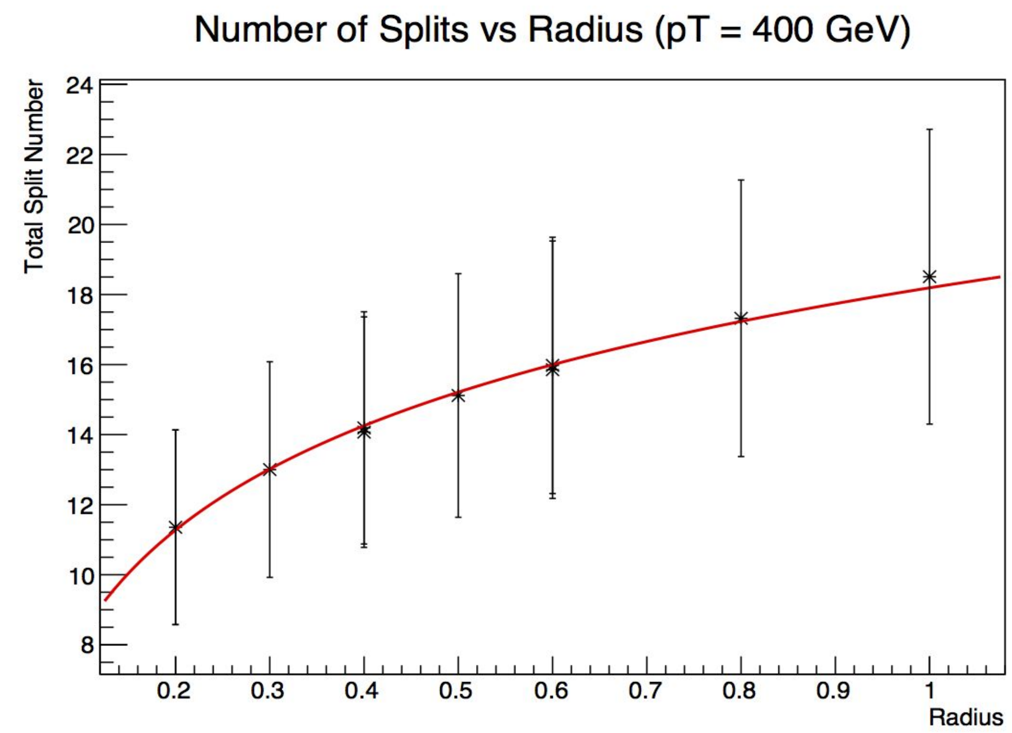
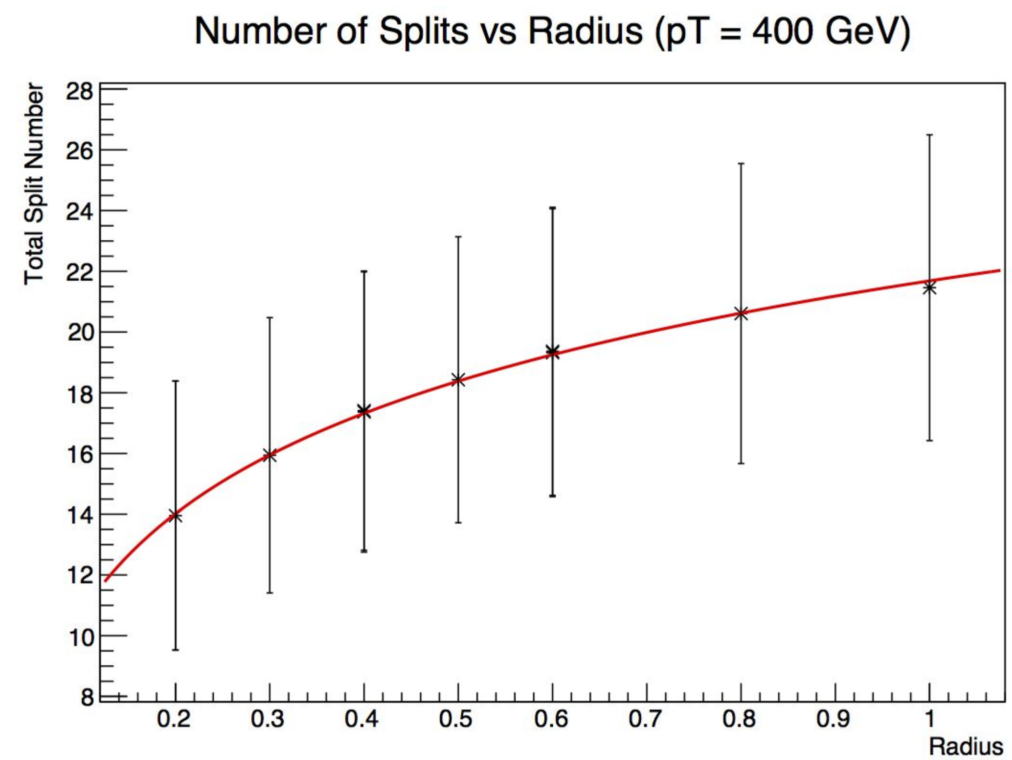


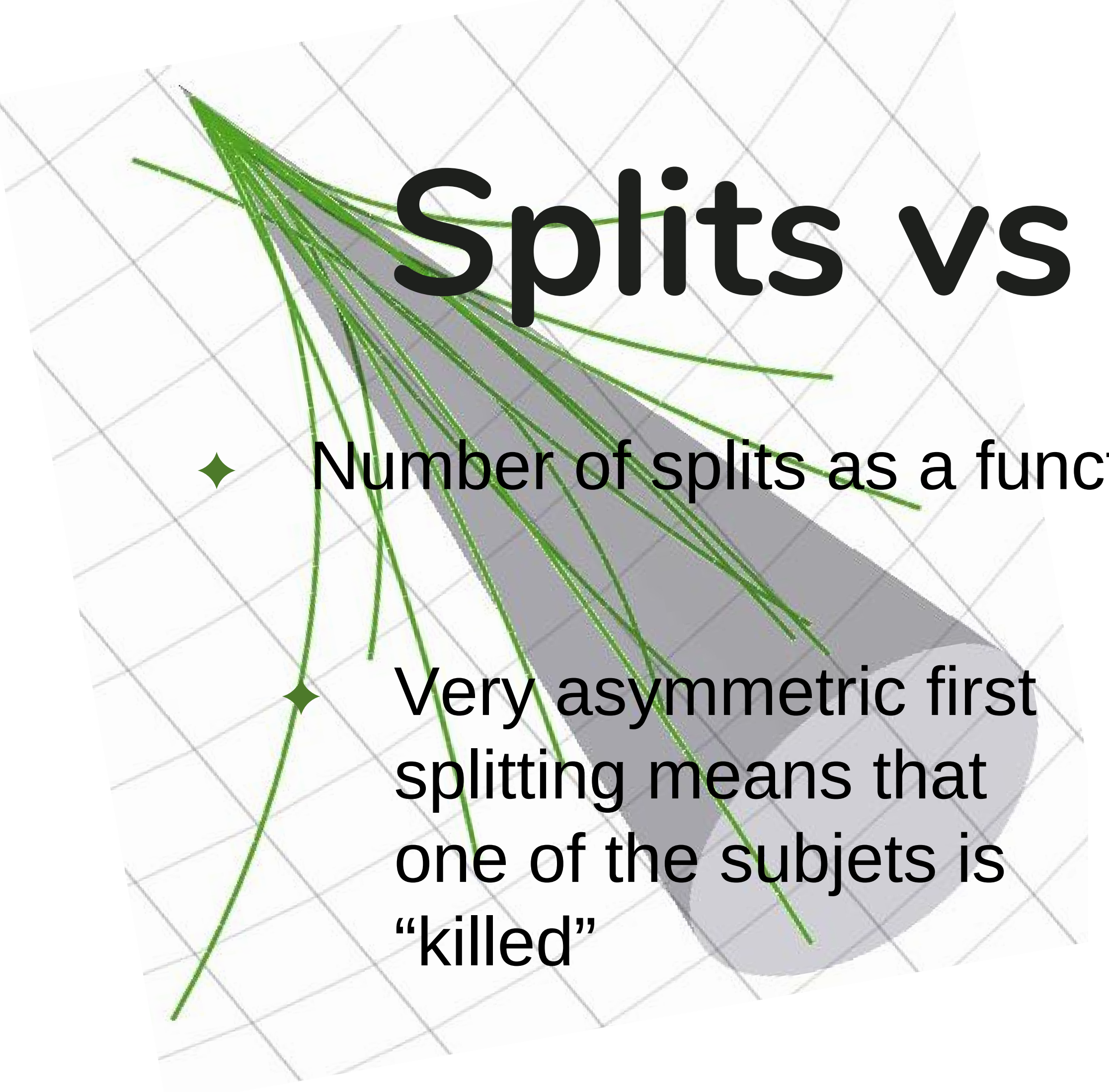
- The theoretical hint urged us to fit the following function to the previous data.

$$f(x) = a + b\log(x)$$

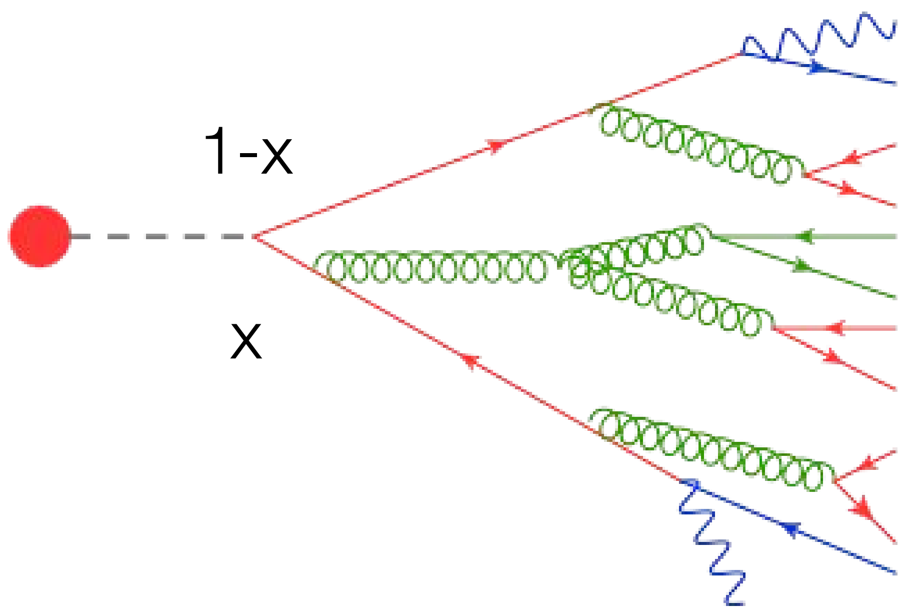


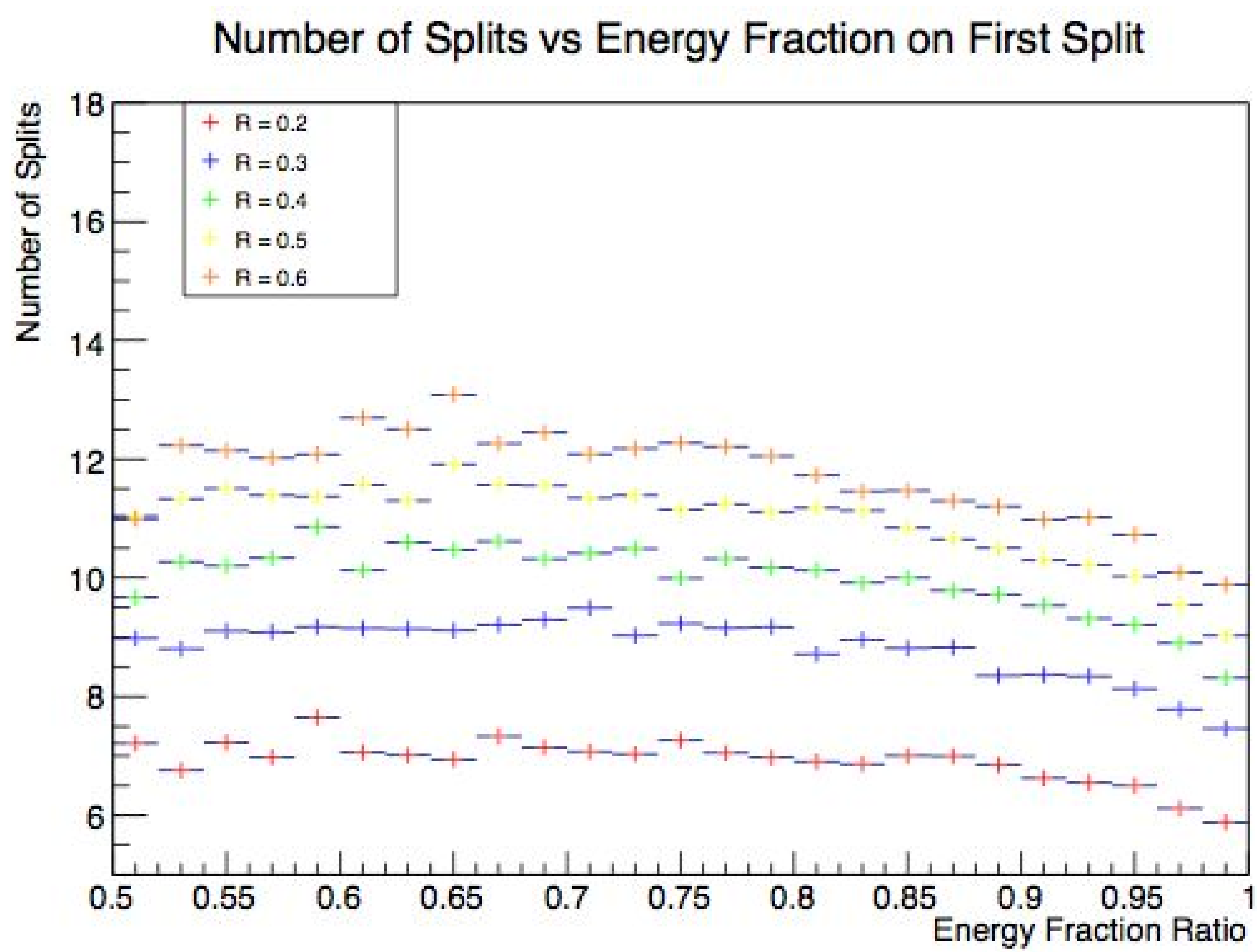


Splits vs Energy fraction



- Number of splits as a function of the energy fraction of the first splitting.
  - Very asymmetric first splitting means that one of the subjets is "killed"





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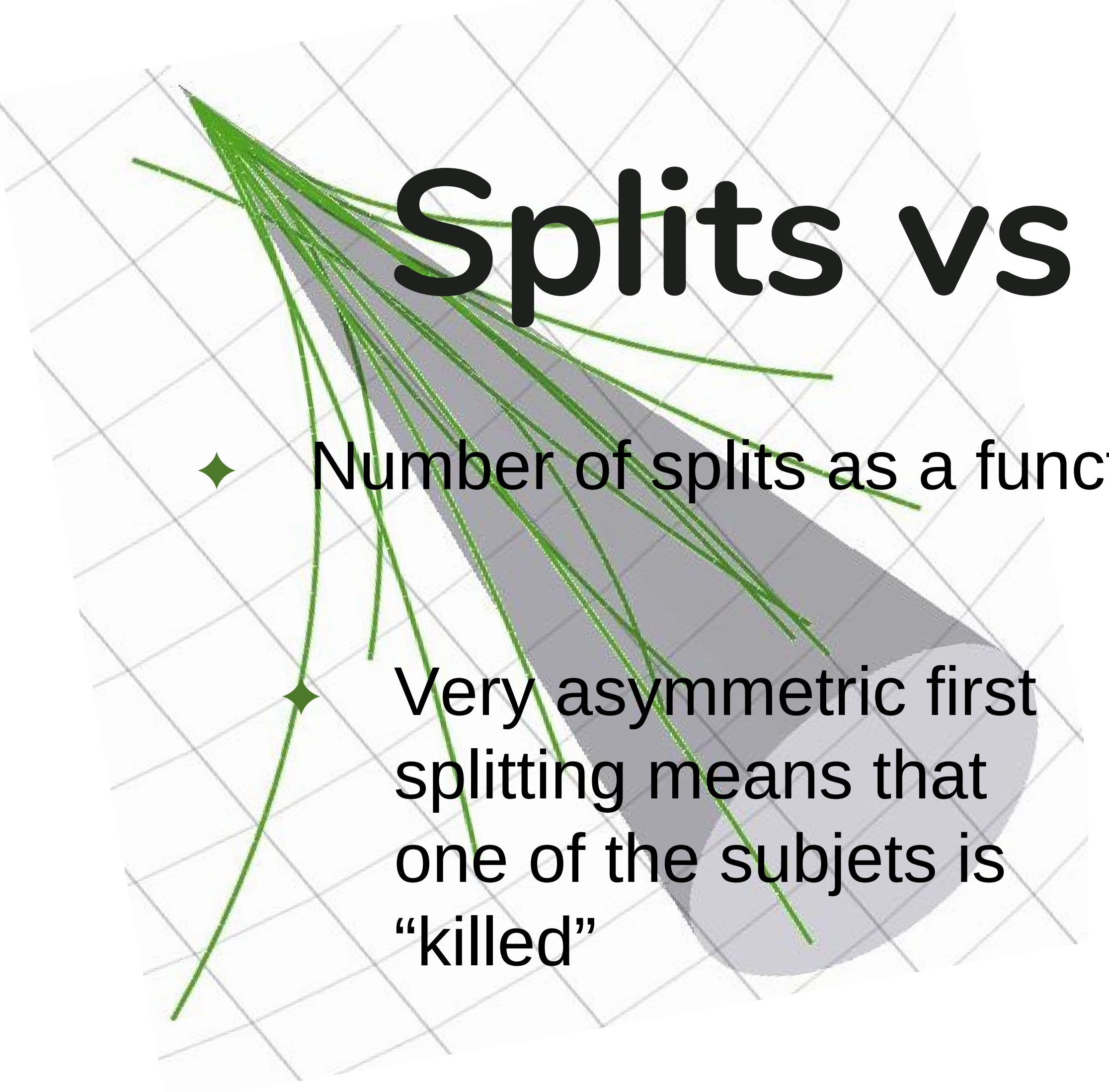

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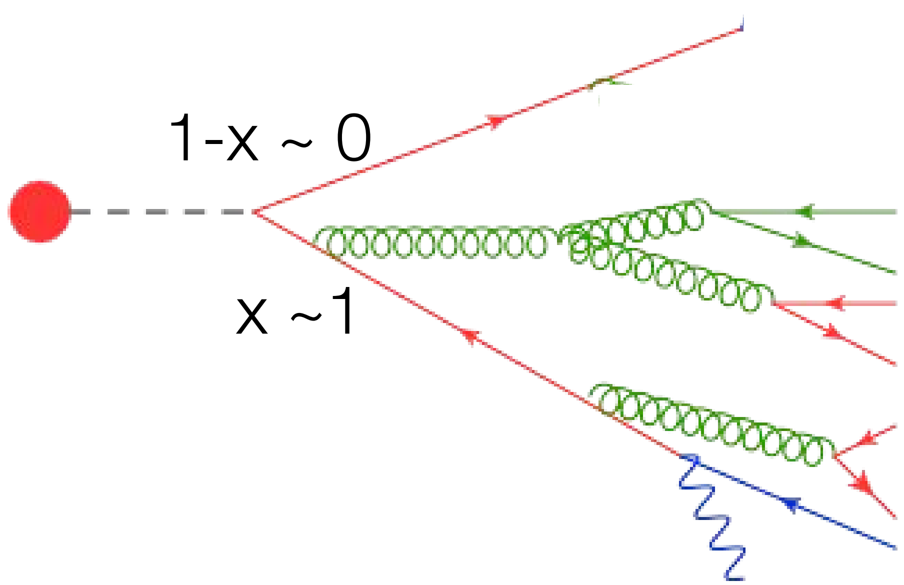
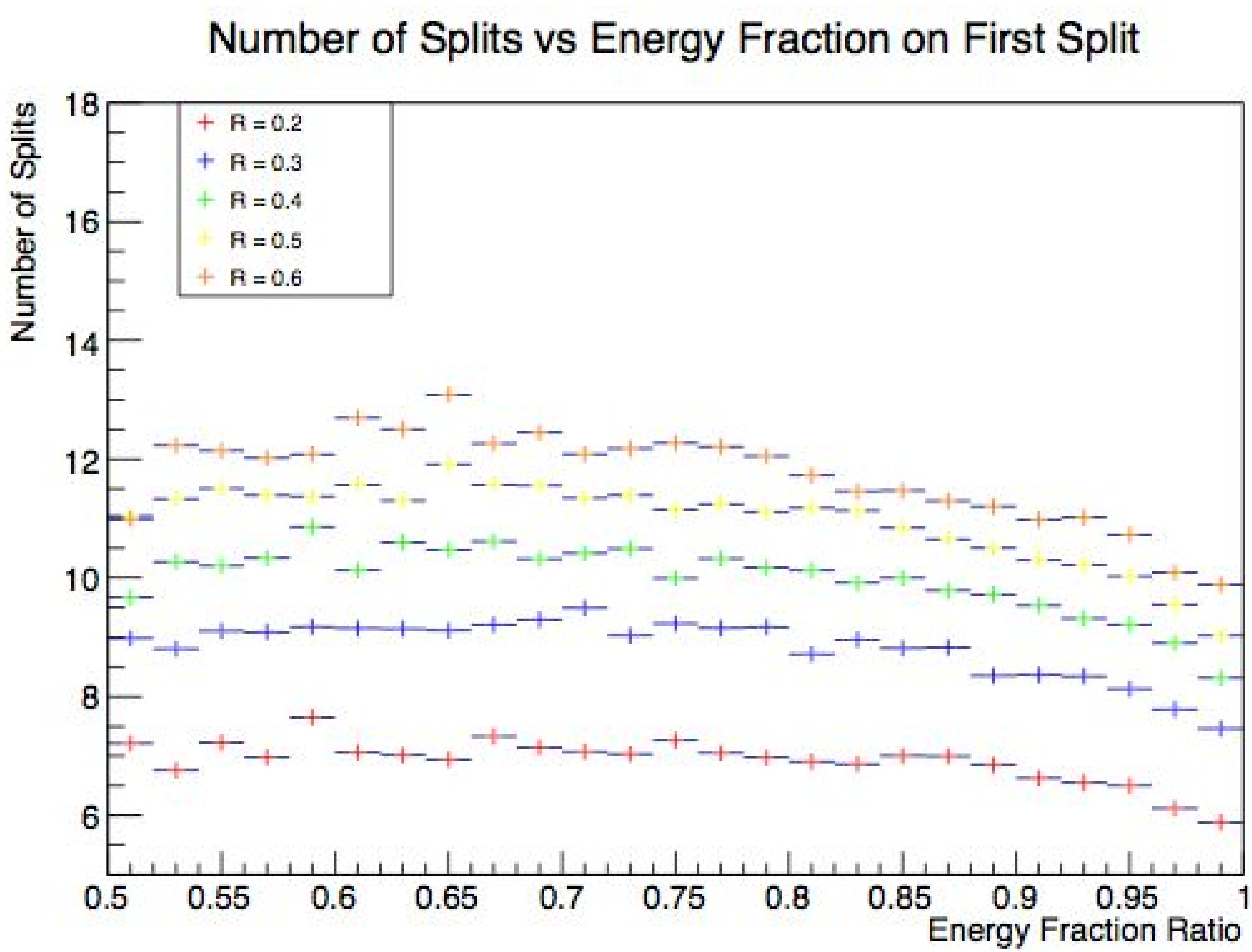
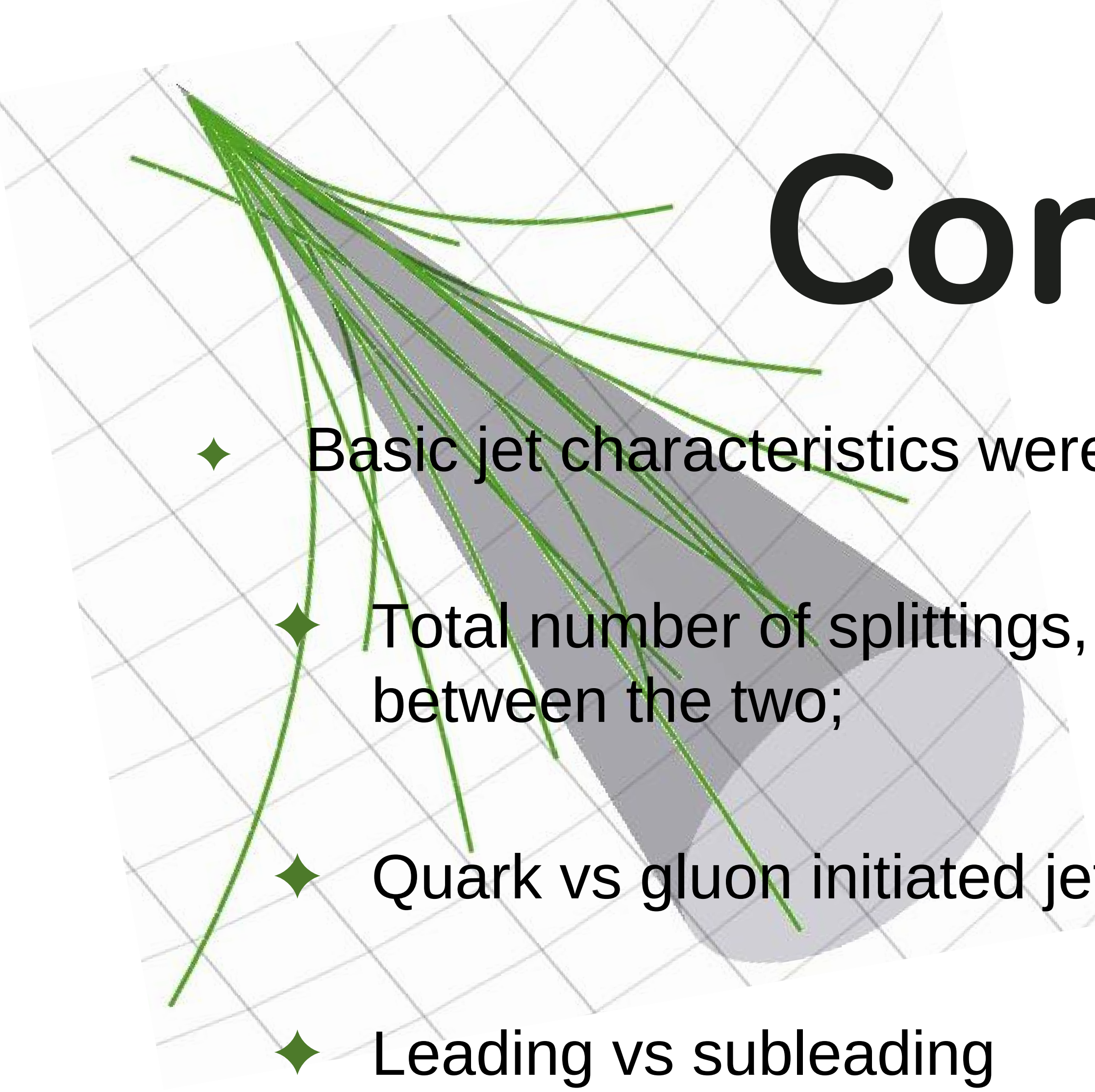
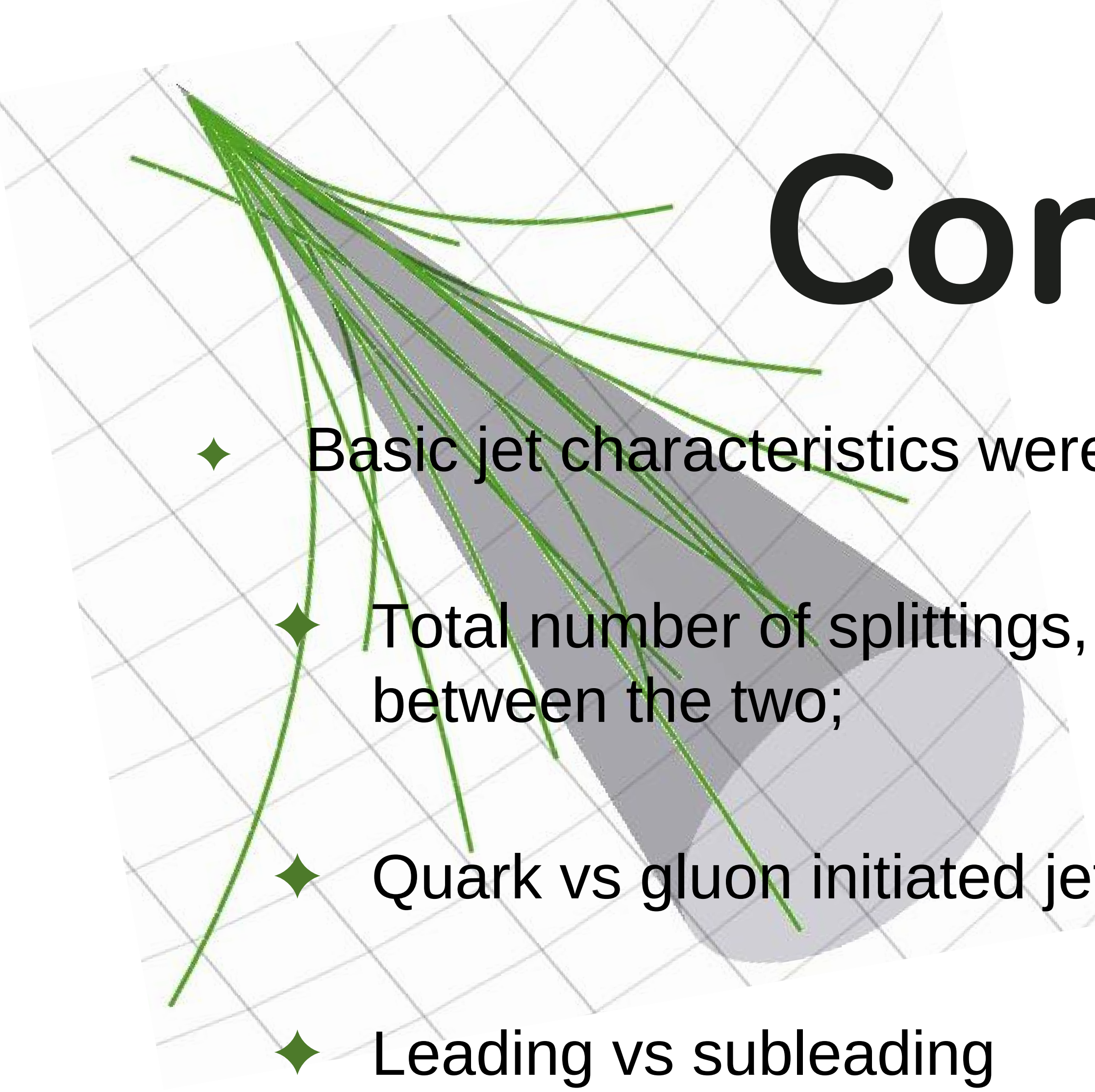






Conclusions

- Basic jet characteristics were investigated to relate to jet evolution
  - Total number of splittings, energy fraction of the first splitting, correlation between the two;
  - Quark vs gluon initiated jets
  - Leading vs subleading



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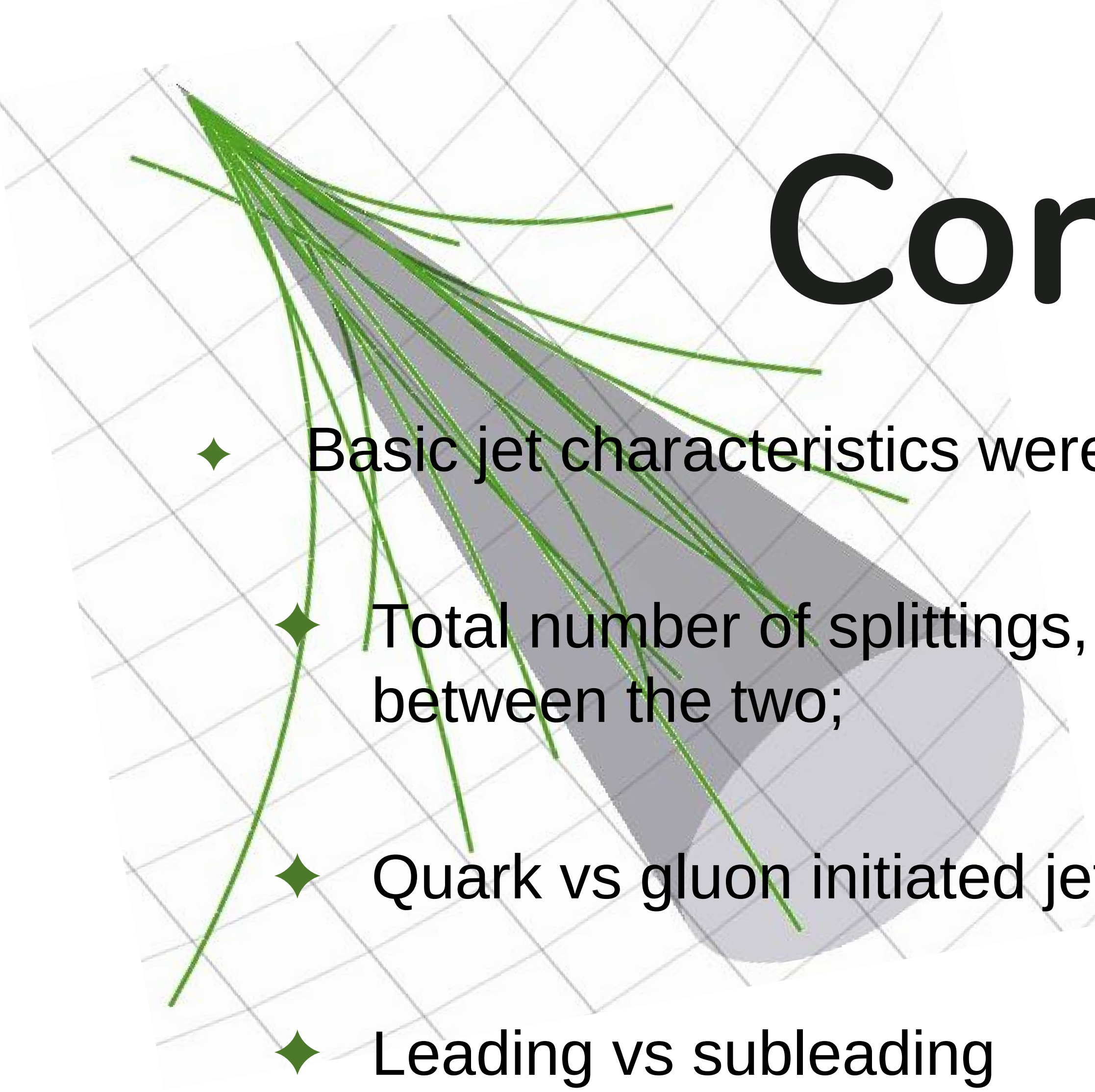
  - We didn’t know 95% of this topic!



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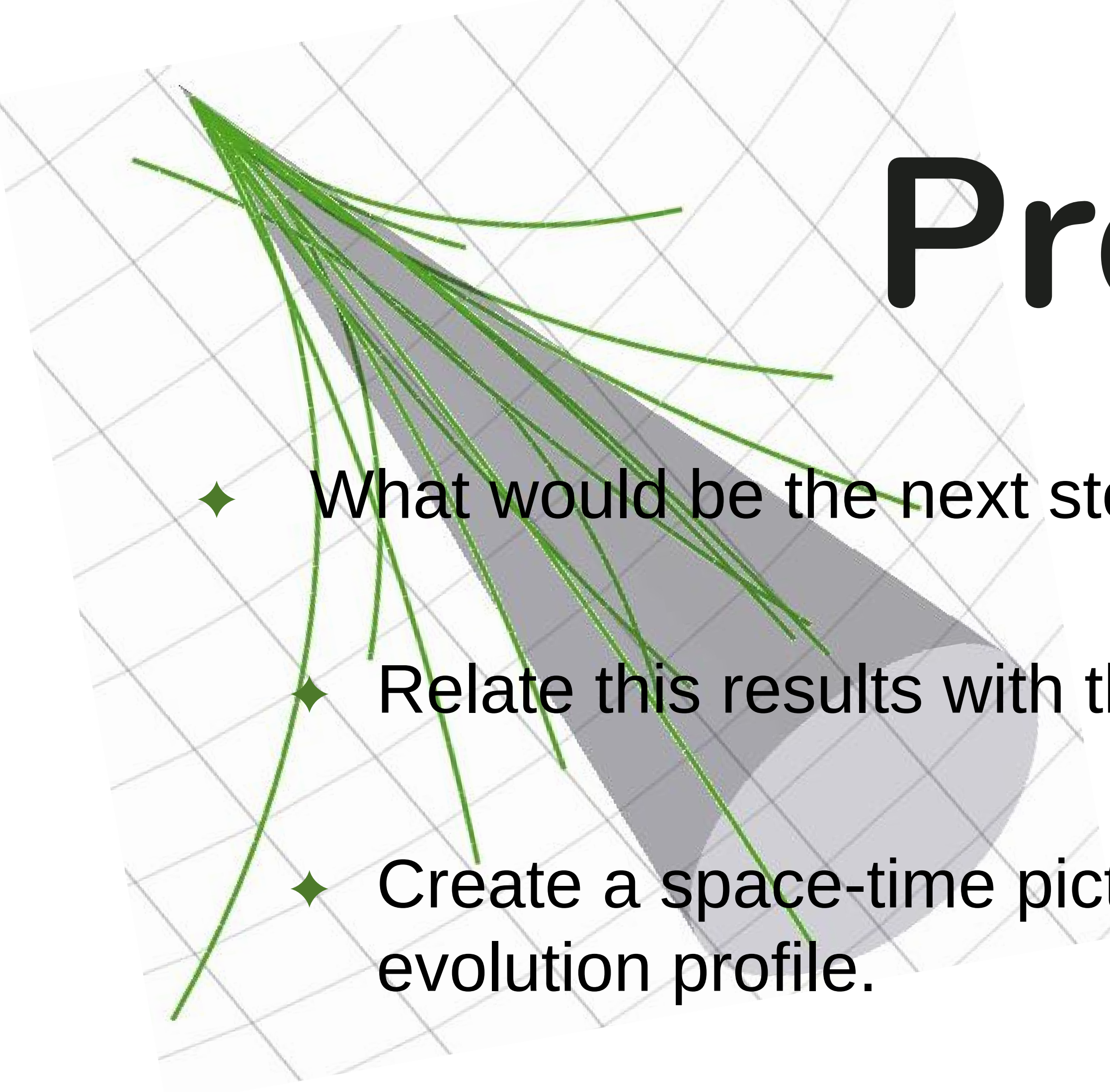
  - Now we don’t know only 90% :-)



Prospects

- What would be the next steps:
  - Relate this results with the in-medium jet development;
  - Create a space-time picture of a jet to better assess QGP density evolution profile.

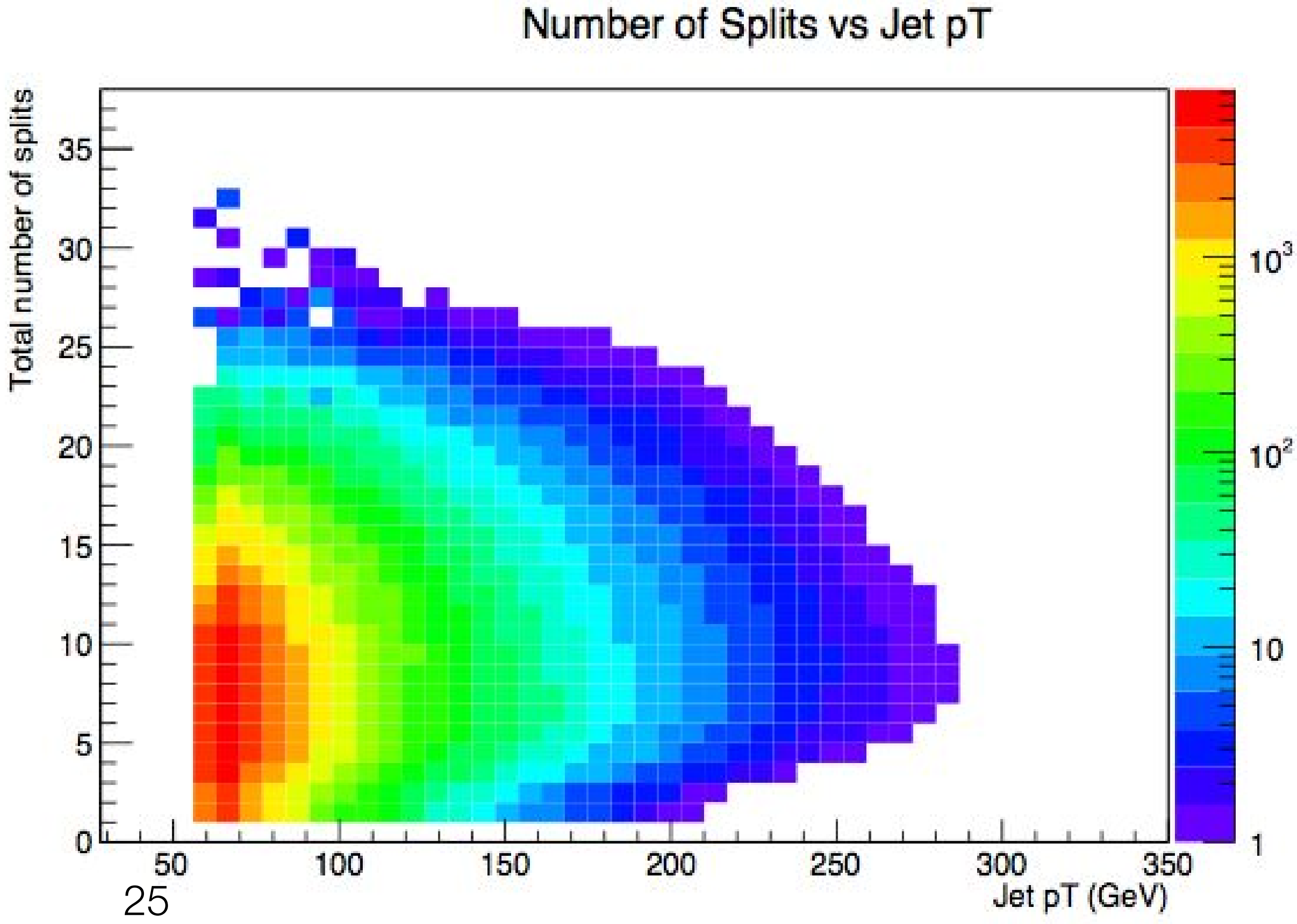
Backup

João Cruz and João Silva

Total Number of Splittings

- How many splits does a jet contain, on average? How does it change with the jet transverse momentum?

- Large dispersion on the total number of splittings.



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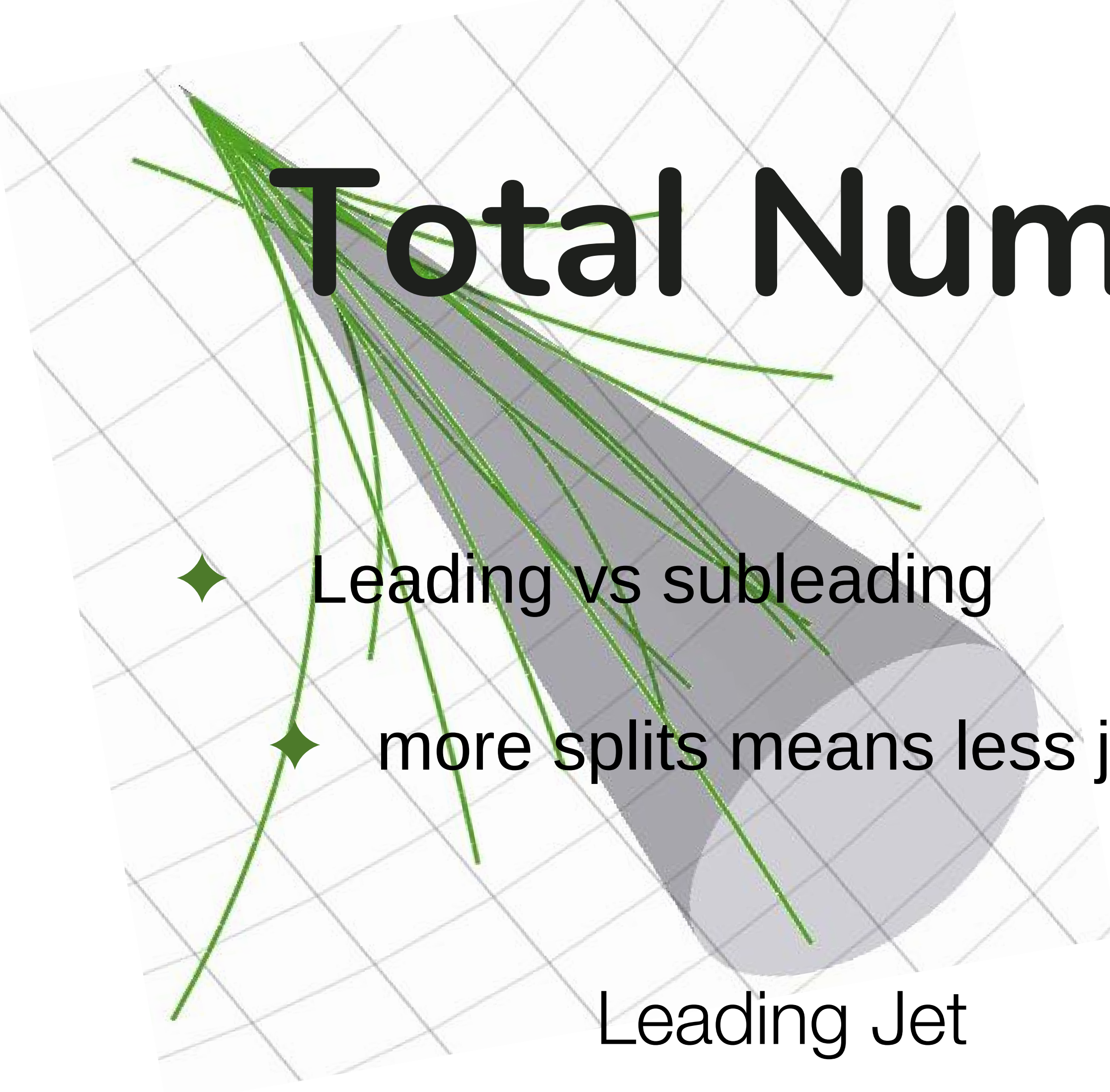
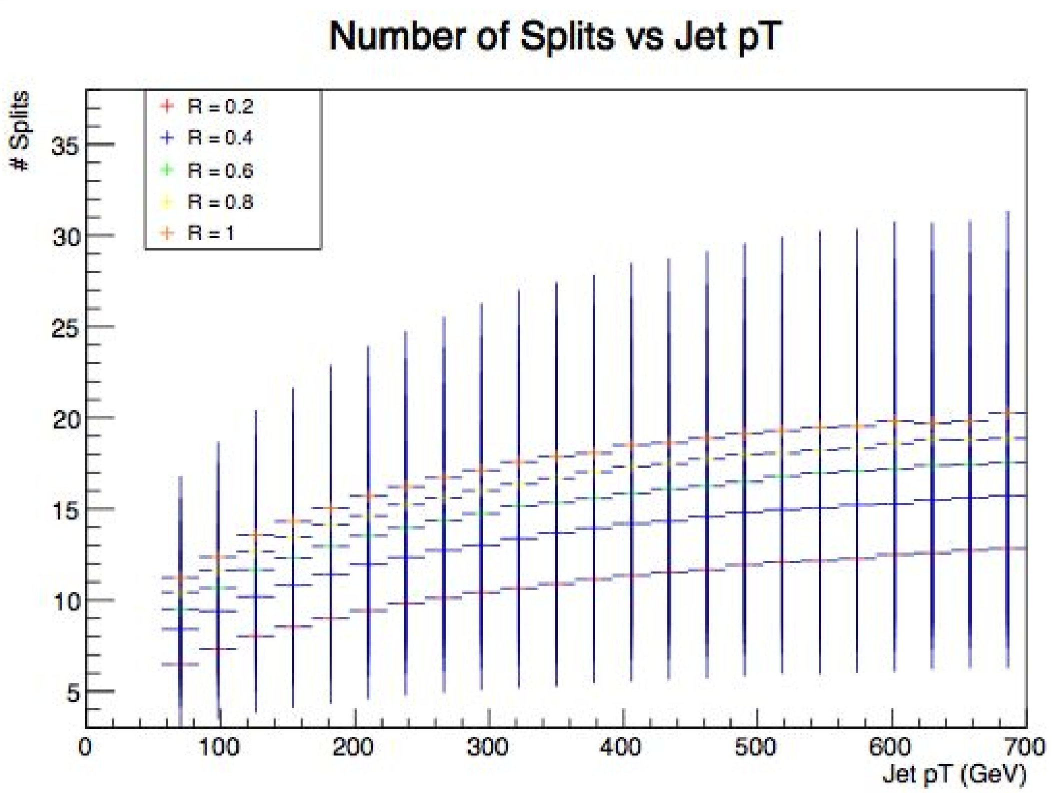
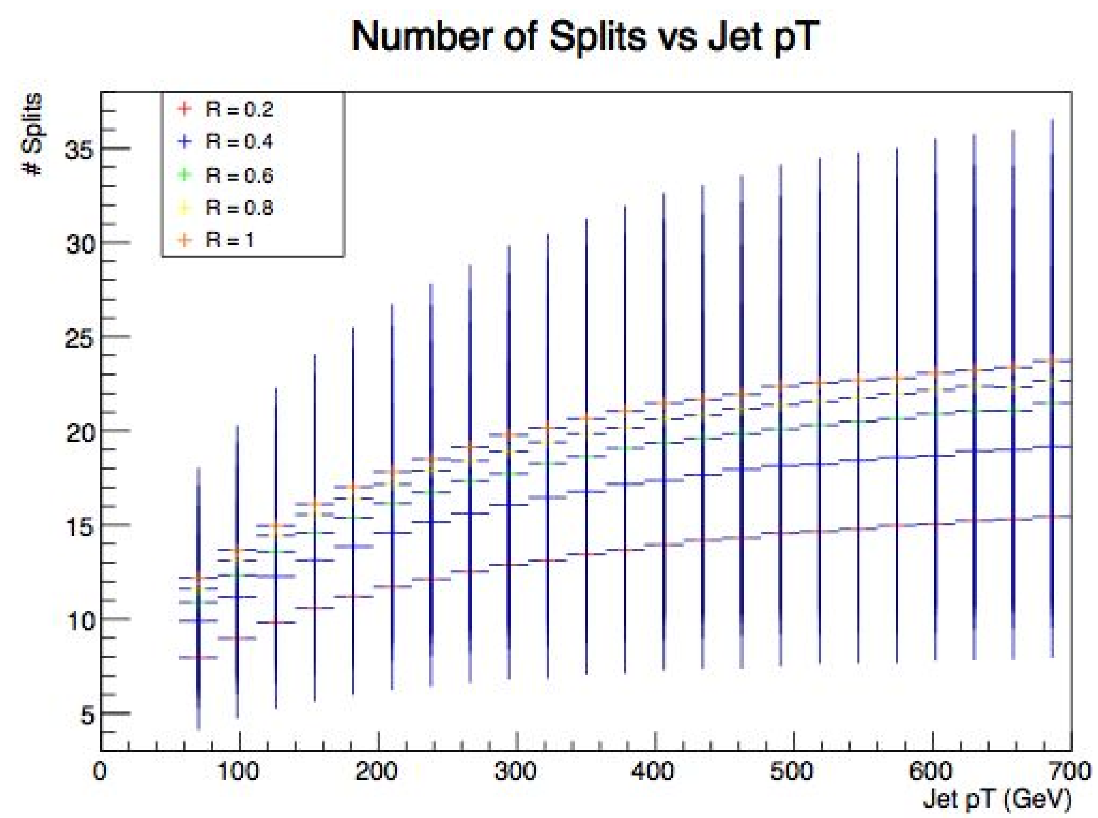


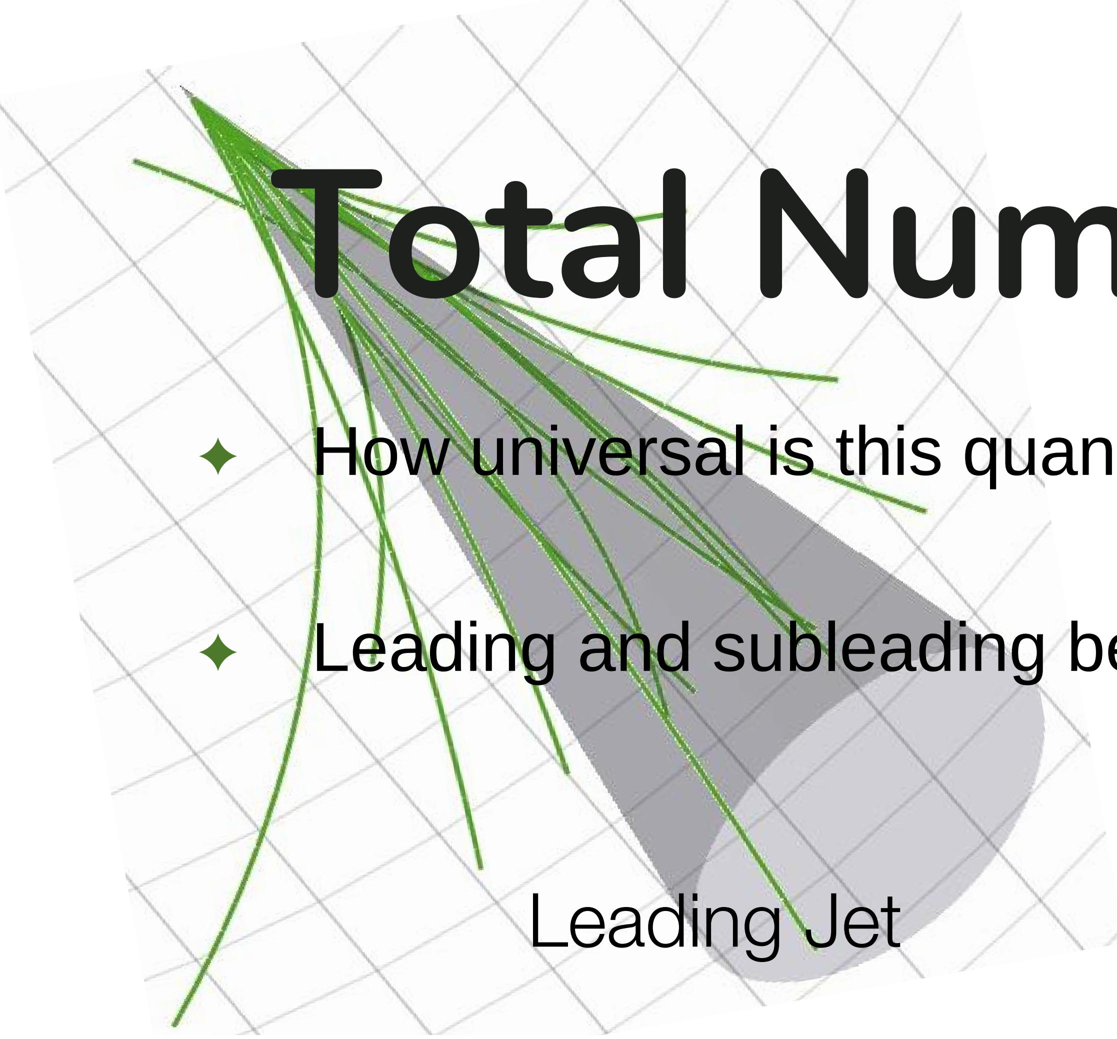
- Leading vs subleading
    - more splits means less jet energy inside of the jet radius

Leading Jet



Subleading Jet

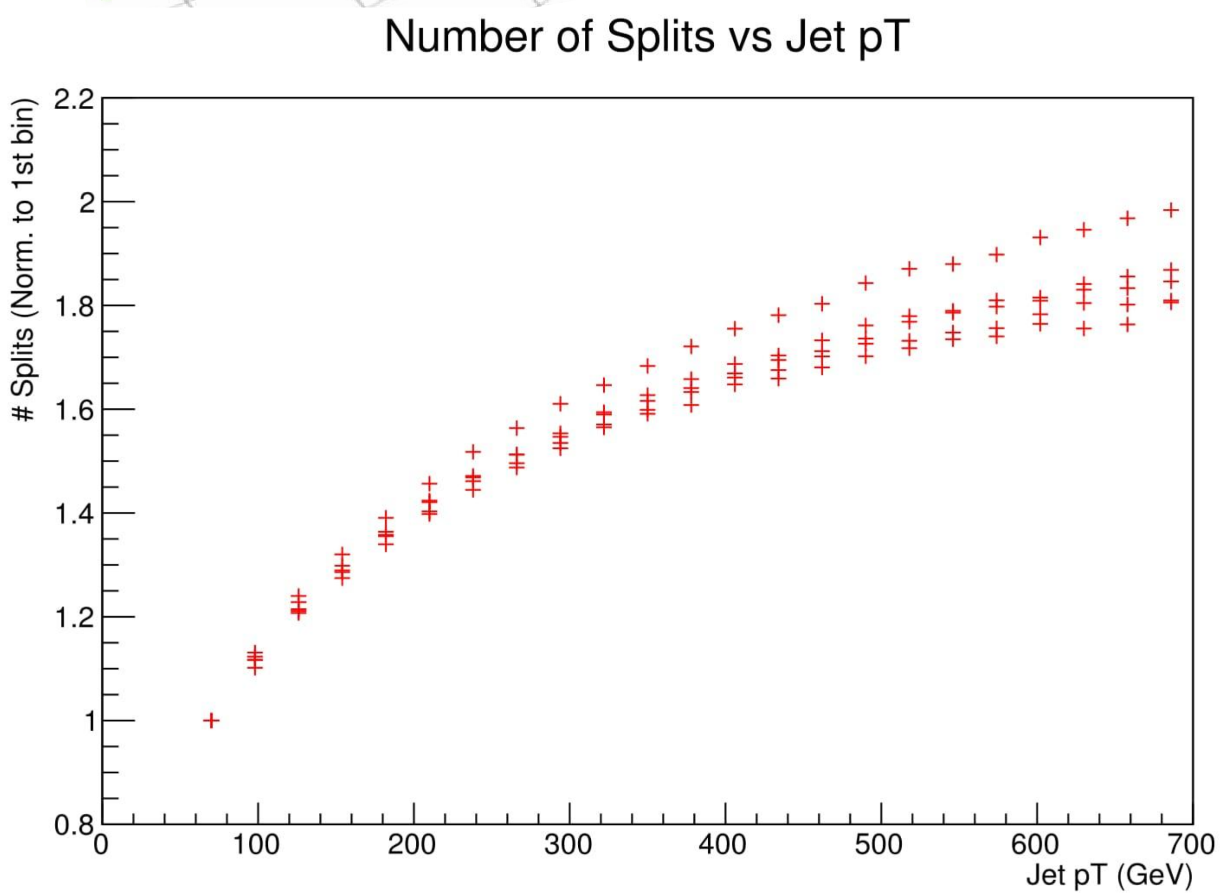




Total Number of splittings

- How universal is this quantity's evolution with respect to the jet pT?
- Leading and subleading behave very differently.

Leading Jet



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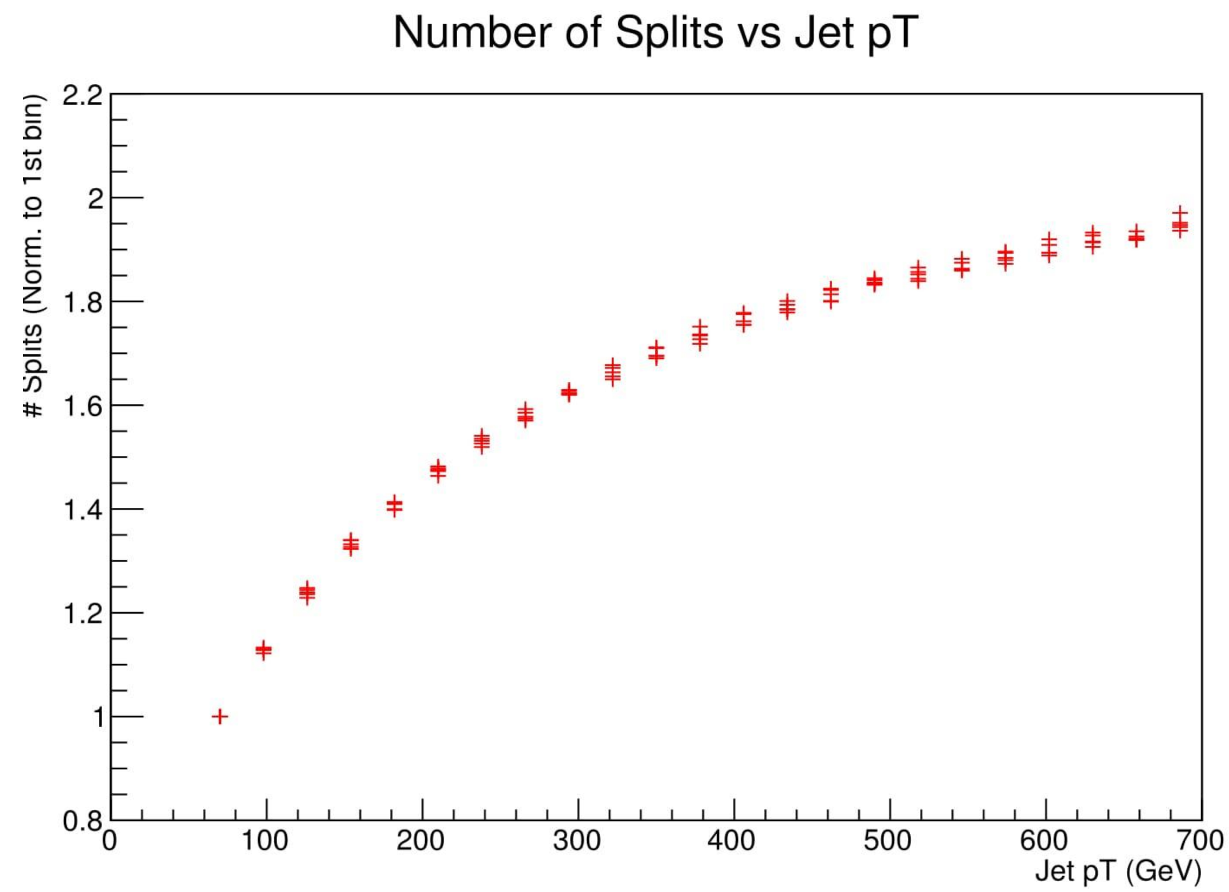
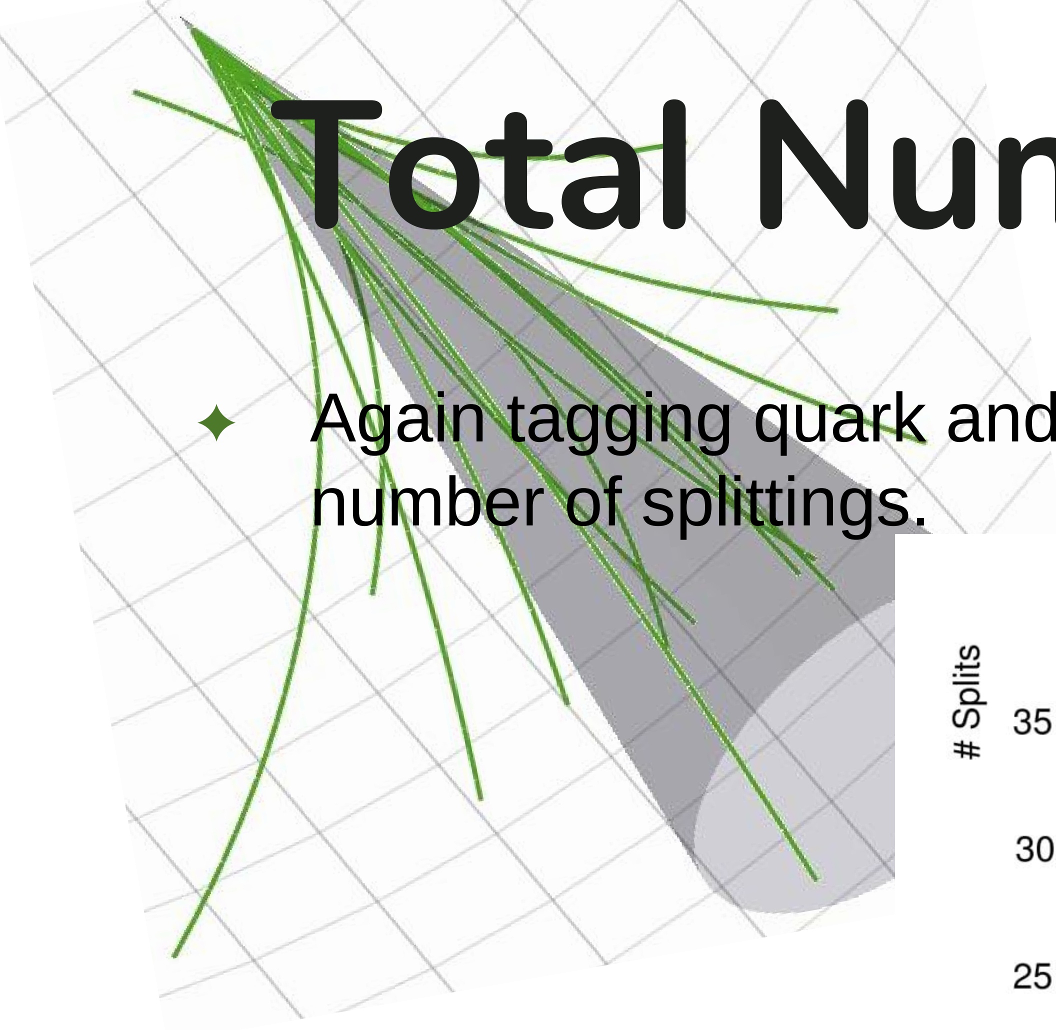
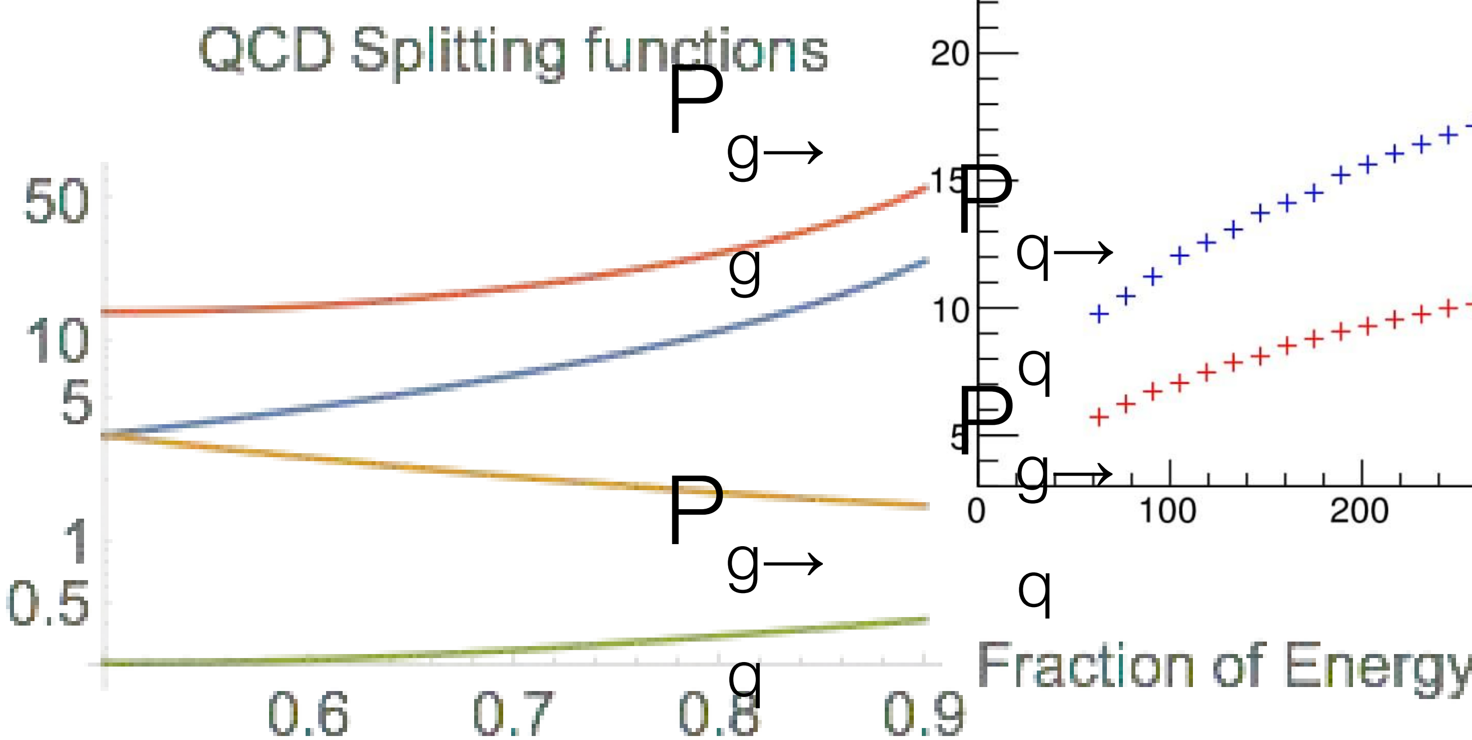
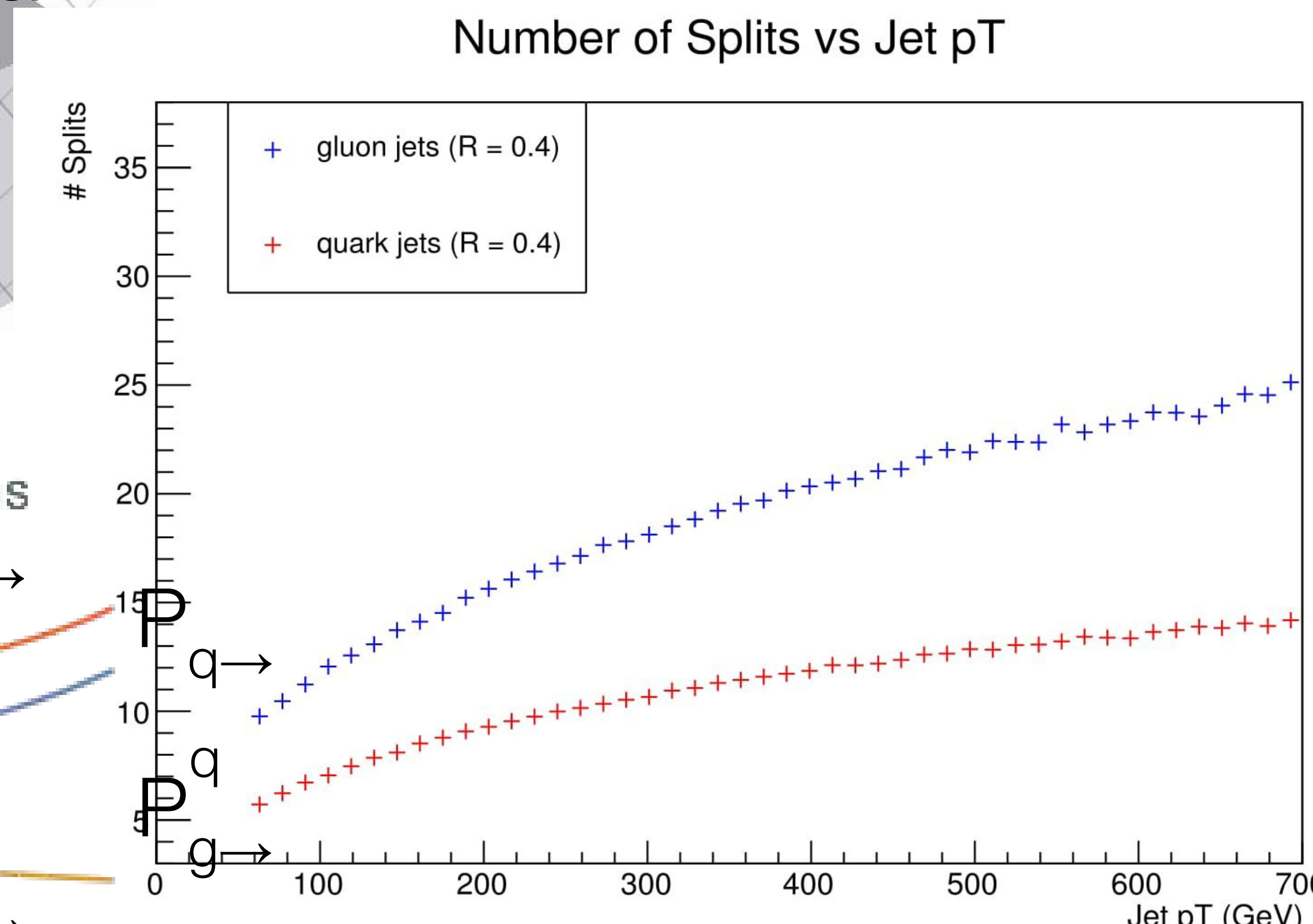


Total Number of splittings

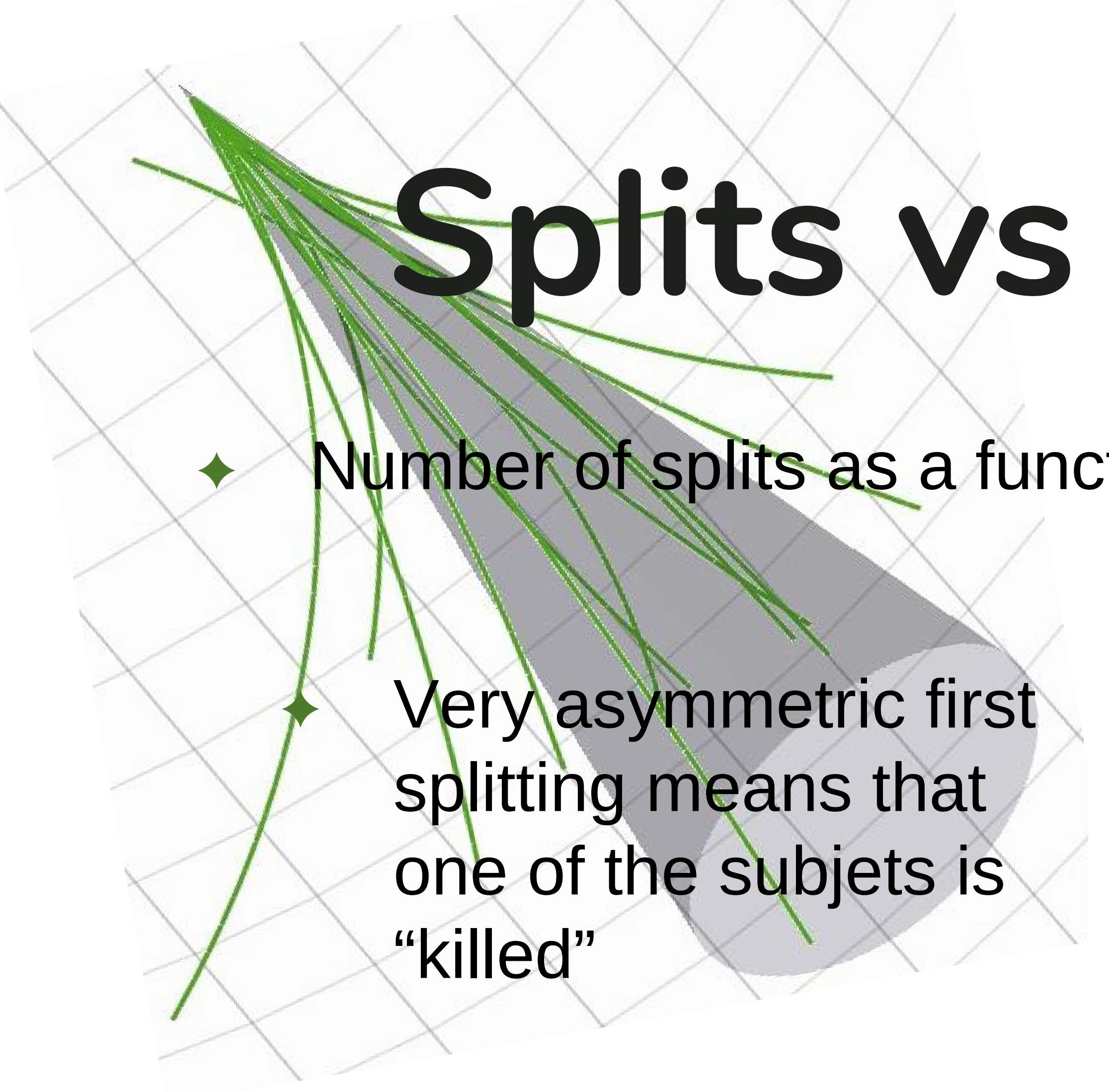
- Again tagging quark and gluon initiated jets, gluon jets show a higher number of splittings.



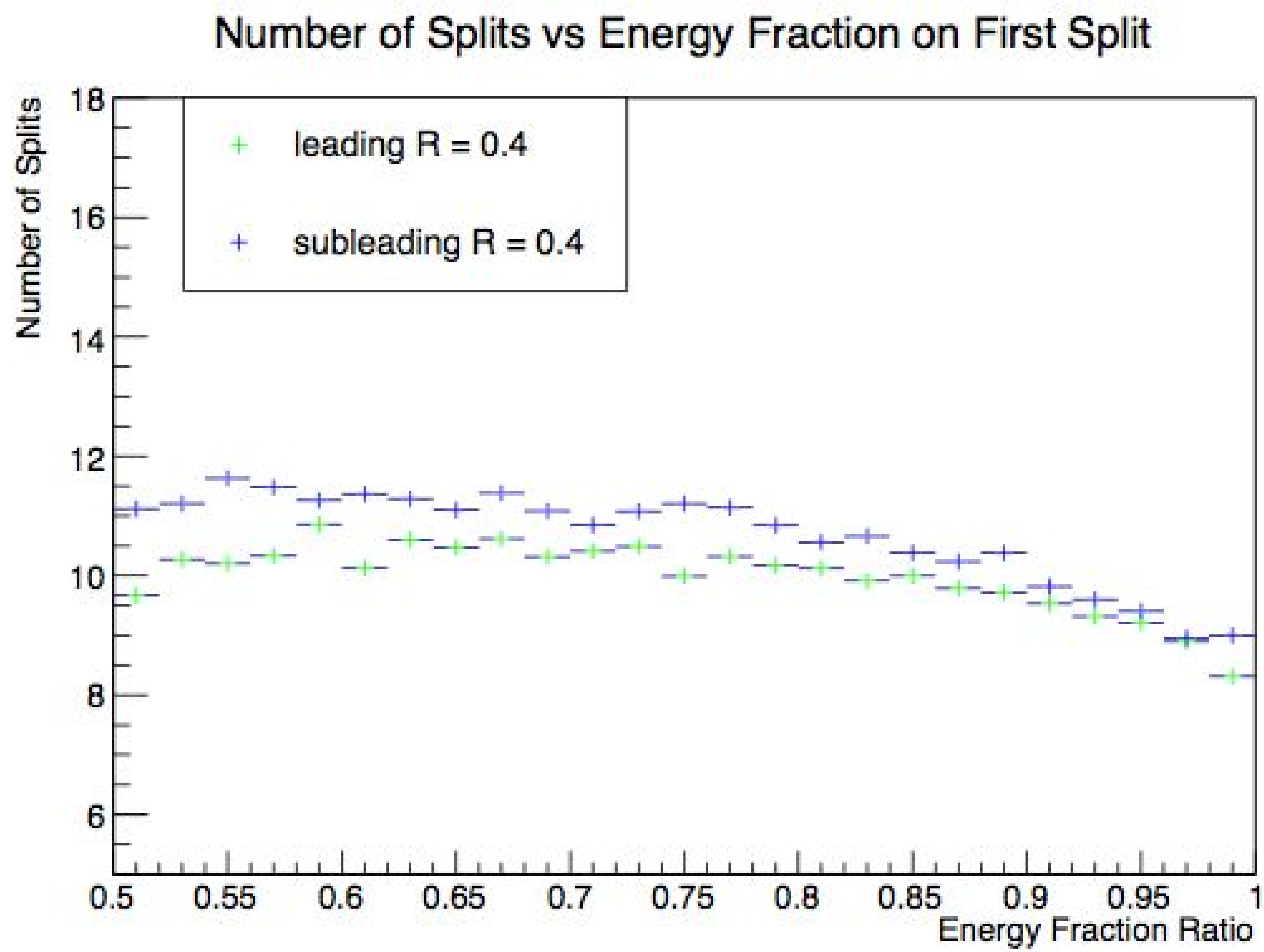




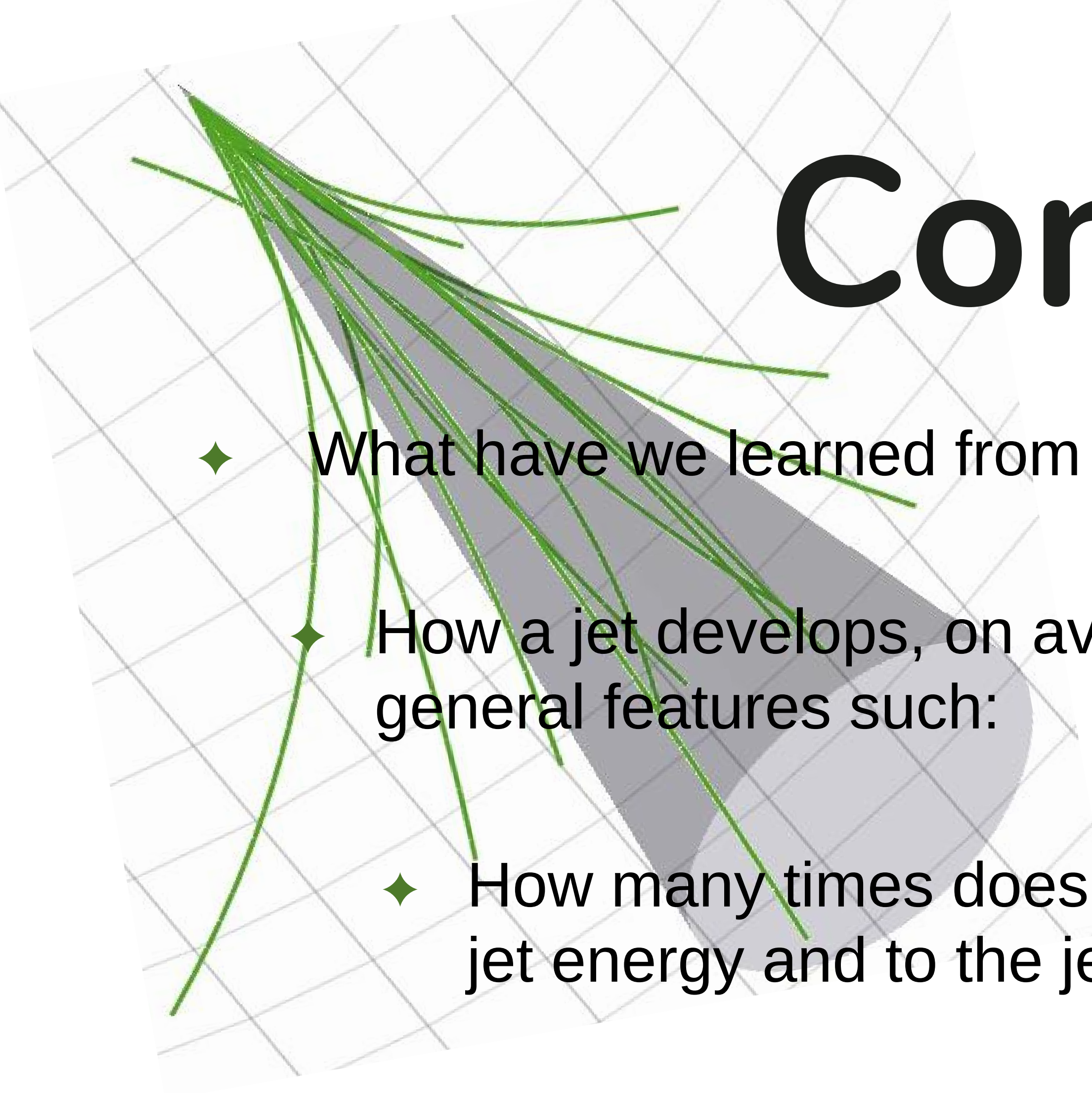
Splits vs Energy fraction



- Number of splits as a function of the energy fraction of the first splitting.
  - Very asymmetric first splitting means that one of the subjets is “killed”
  - Same trend is found for both leading and subheading



Conclusions



- What have we learned from this work?
    - How a jet develops, on average, in vacuum, taking into account very general features such:
        - How many times does it splits; How this quantity can be related to the jet energy and to the jet fragmentation pattern (leading or subleading)
        - How the first splitting controls the jet development;
        - How we can recover the number of splitting when increasing the jet radius (direct link also to the jet energy - next question would be how is the energy recovered with the jet radius)
        - How quark and gluon initiated jets can be different