Performance of jet flavor tagging algorithms on B^+-jet reconstruction in LHCb kinematics

June 27th, 2024

Ruide Xu
Undergraduate Student
Department of Physics
University of Michigan

Instructors: Ezra D. Lesser, Christine Aidala

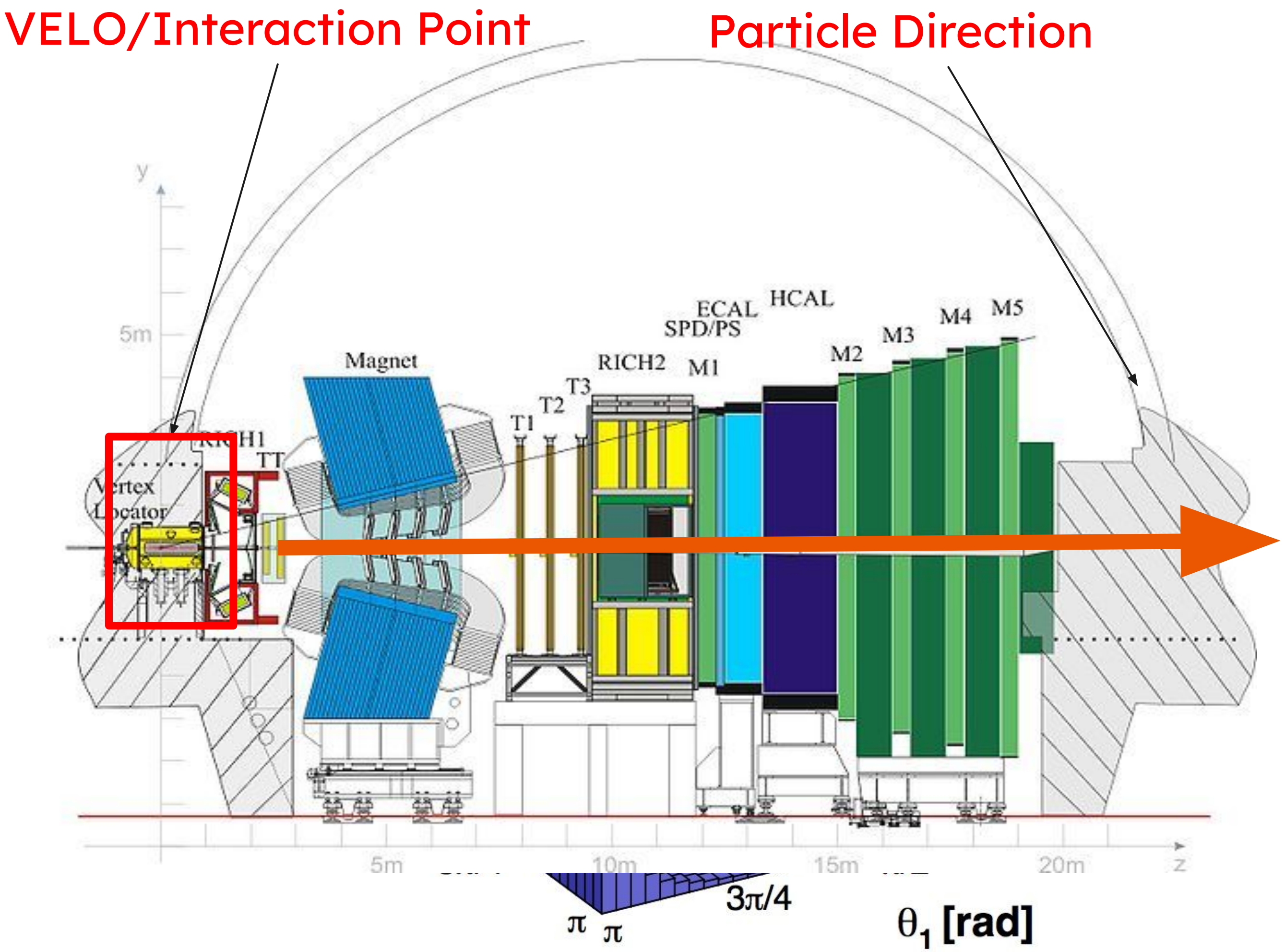
Large Hadron Collider beauty (LHCb)

→ **LHCb detector**

- Single arm forward spectrometer
  - 2 < |η| < 5
- Retractable VELO detector

→ **Goal of the LHCb**

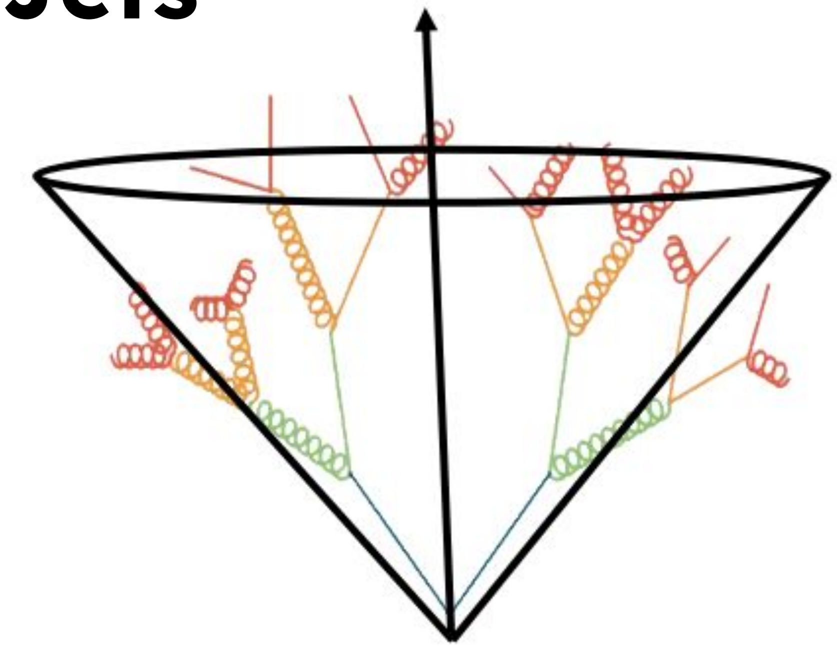
- Measuring the properties of bottom and charm quarks with high precision
- Measure parameters of the CP violation
- Measure rare hadrons

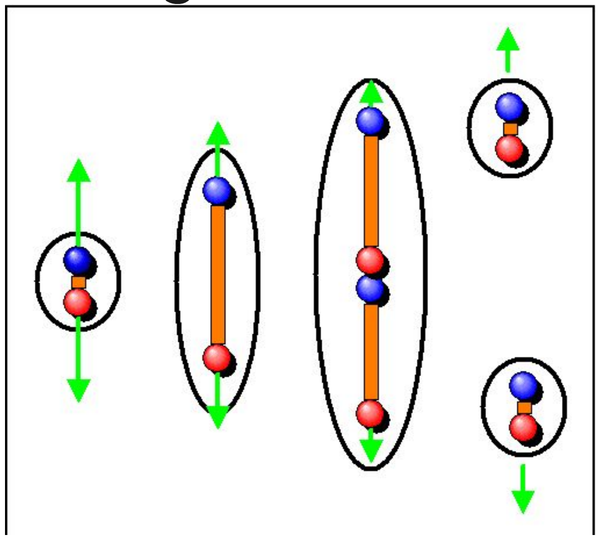


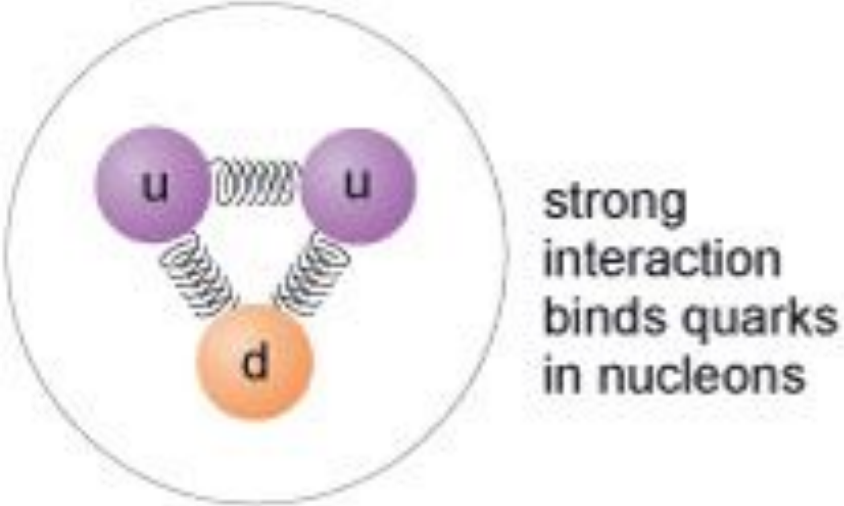
Introduction to Jets

→ **What are jets?**

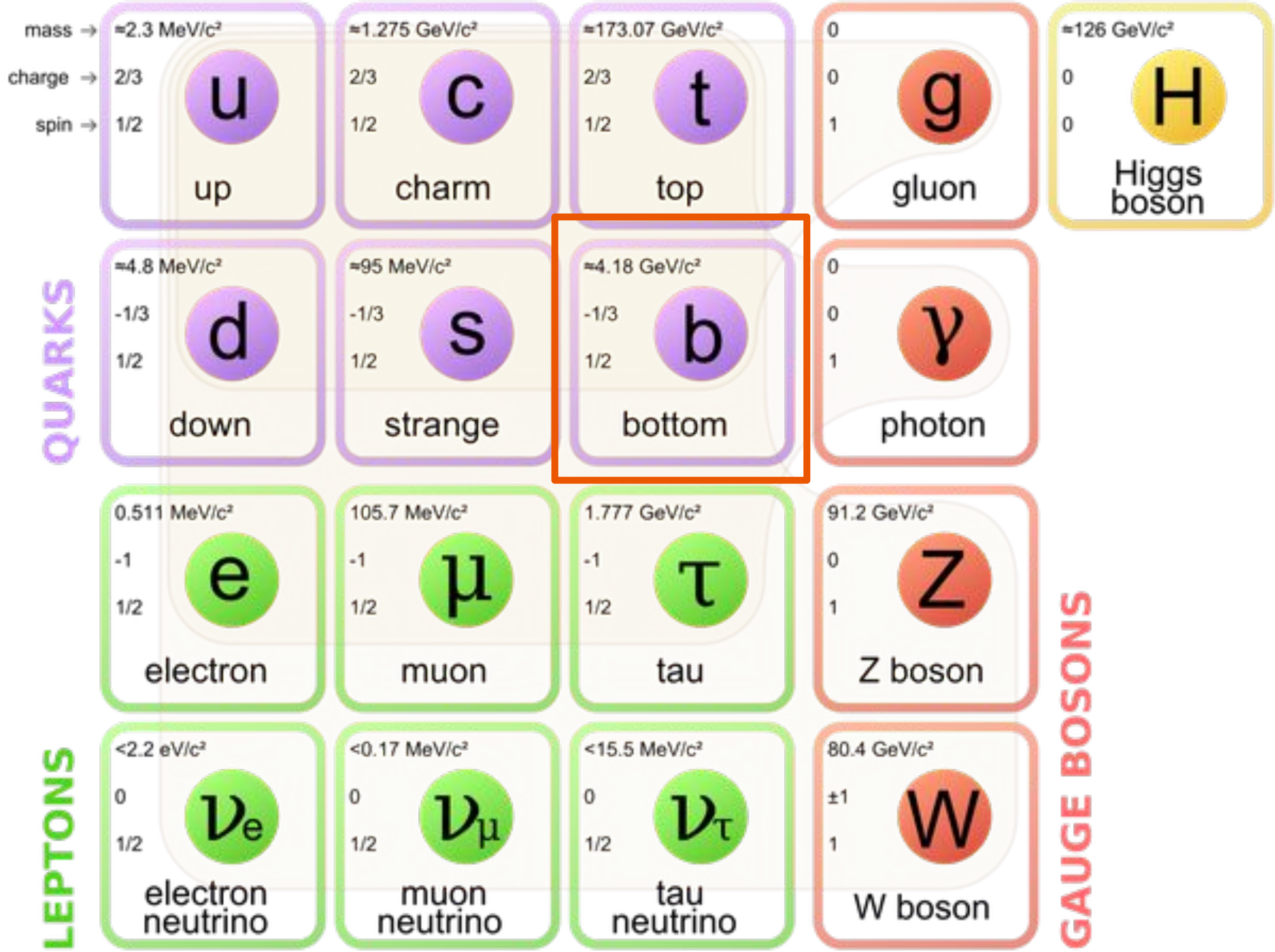
- Narrow cones of hadrons and other particles created by hadronization of quarks and gluons under high energy collision
- Quark Confinement
- **Hadronization**: quarks and gluons turn into hadrons







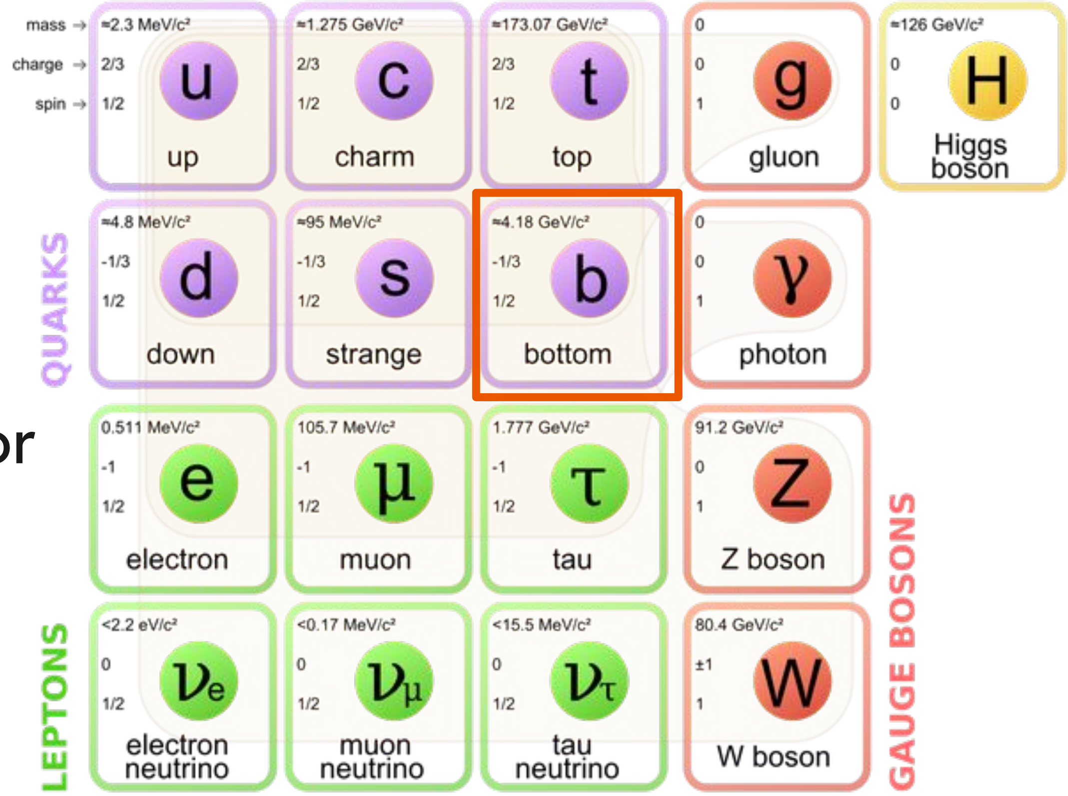
Flavor



mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈126 GeV/c²
0
0
H
Higgs boson
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
80.4 GeV/c²
±1
1
W
W boson
QUARKS
LEPTONS
GAUGE BOSONS

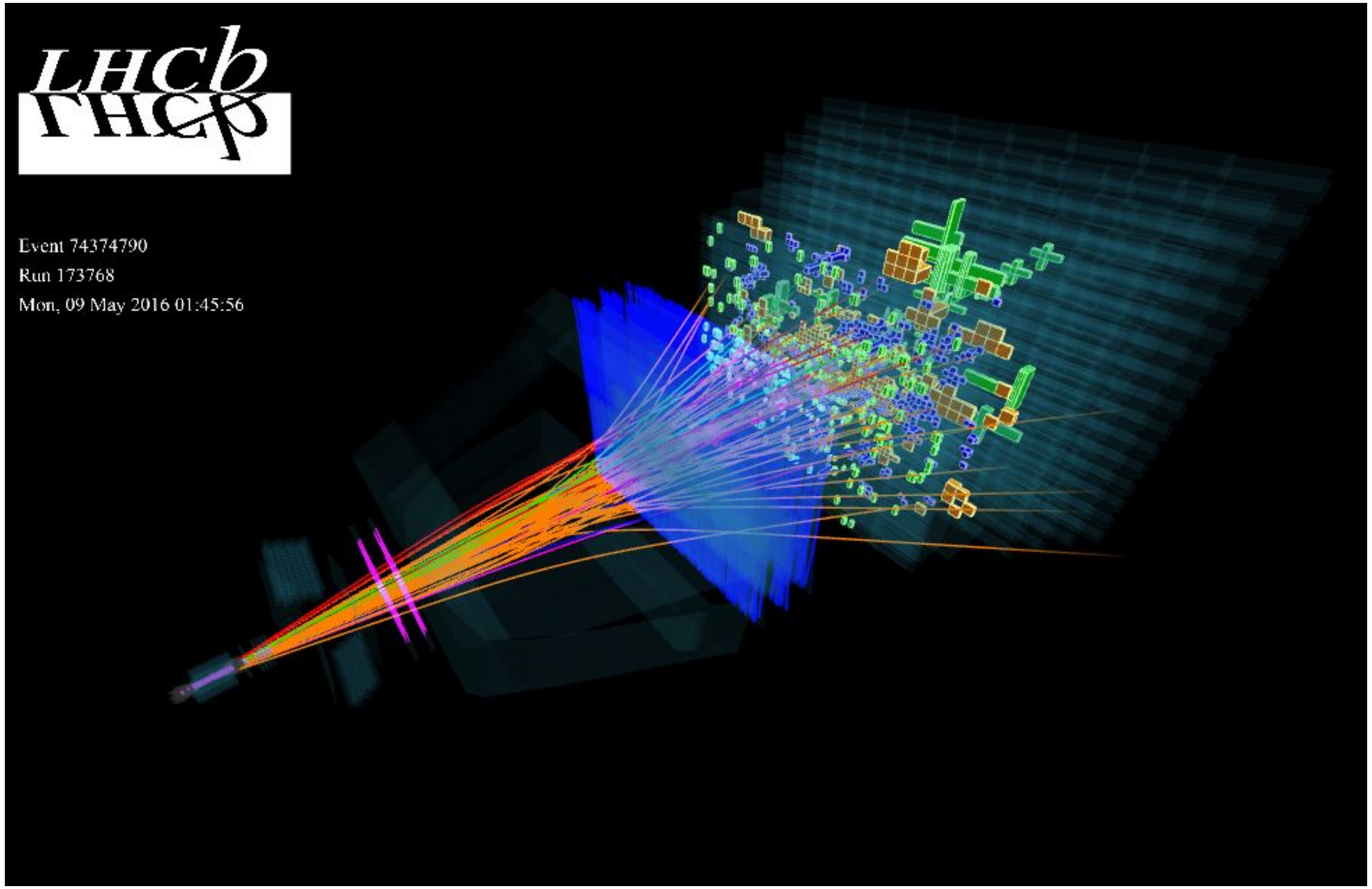
Heavy Flavor Jets

- ➔ Bottom quarks have the second highest mass of all partons
- ➔ Bottom quarks is the heaviest quarks which are stable enough to hadronize.
- ➔ Heavy-flavor jets: Jets initiated by a heavy flavor quark
  - ◆ They offer a unique probe to test QCD calculations where quark mass is substantial
  - ◆ Usually quarks are treated as massless in jet calculations.



Big Picture

➔ **Investigate the substructures of b jets**



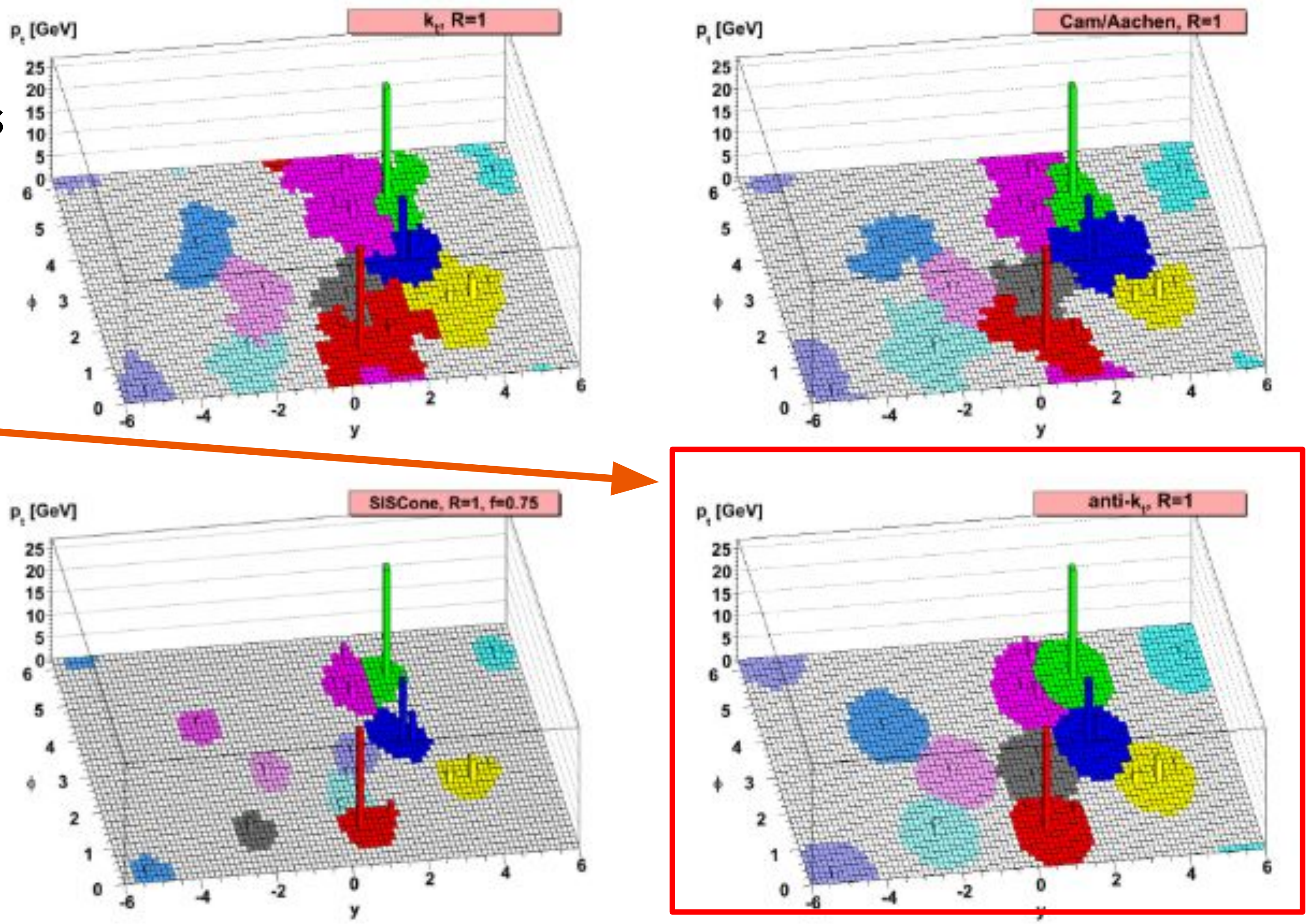
Jet Reconstruction

→ **Anti k_T algorithm**

- Find the hardest particle
- Group surrounding soft particles
- Find the next hardest particle
- Group the soft particles
- Iterate

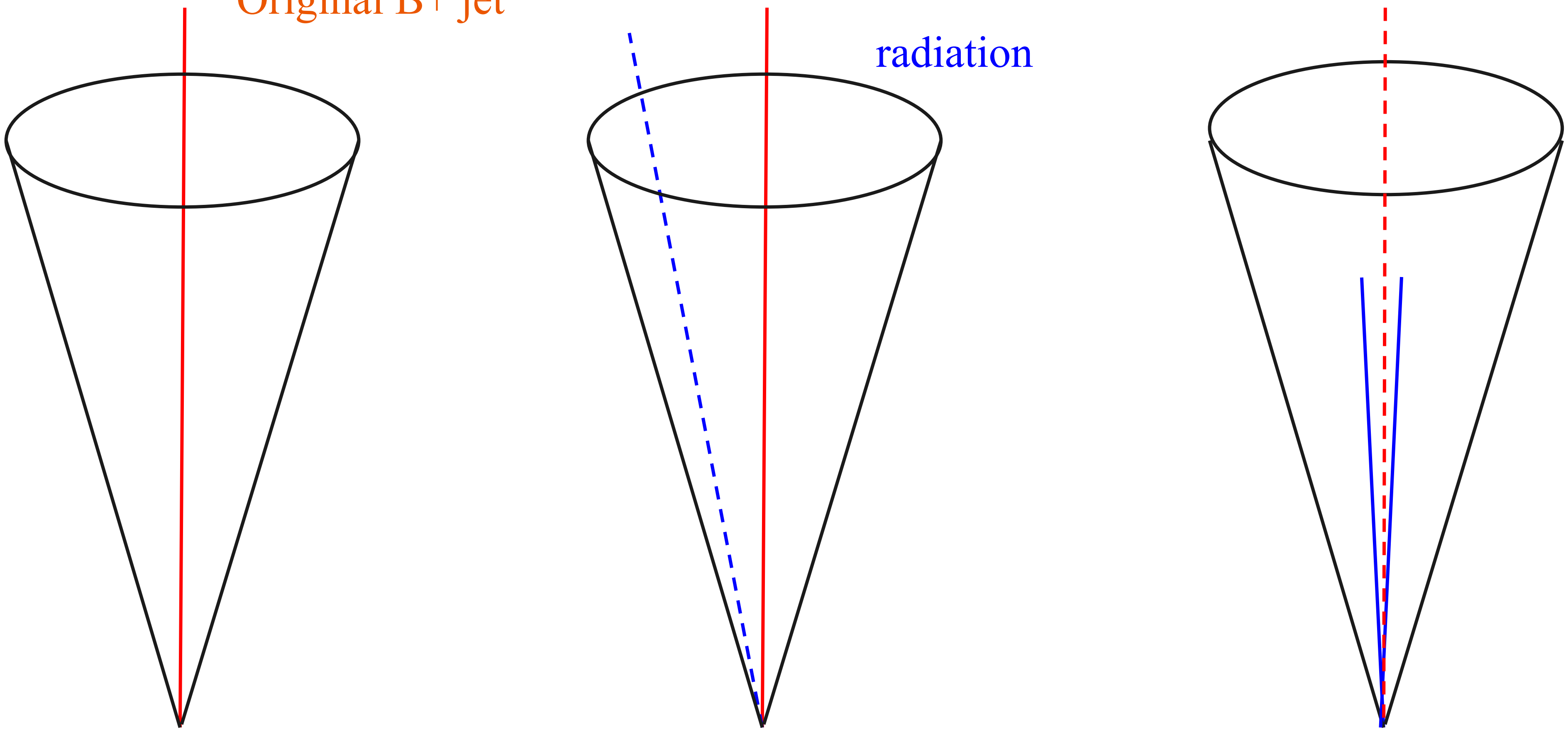
→ **Features**

- Resistant to soft radiation
- (particles with low *p*)
- Gives regular, cone-like shape
- **IRC (Infrared-Collinear) safe**



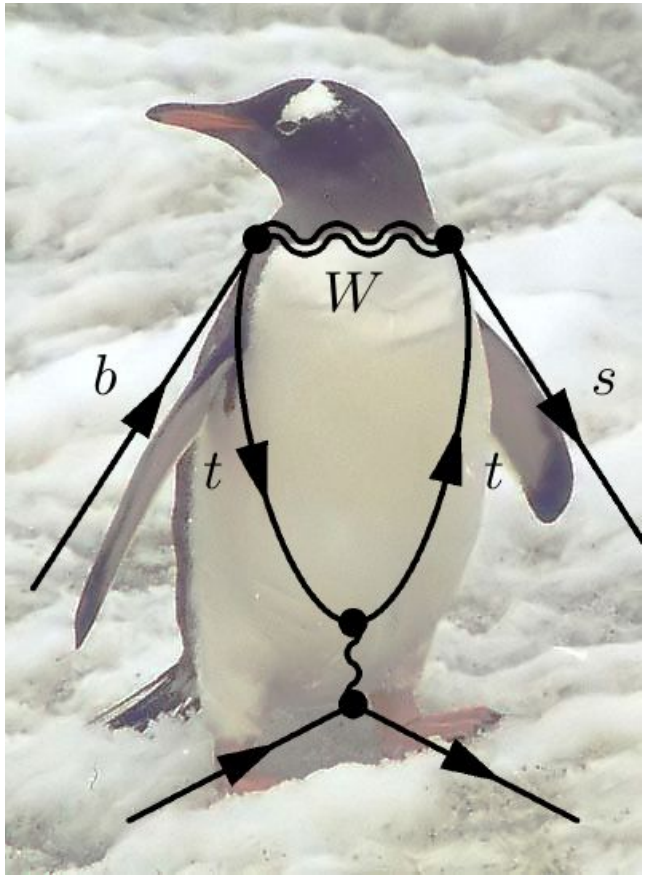
IRC Safety

➔ IRC safety = **Infrared-Collinear safety**



Problem with Heavy Flavor Tagging

- **Problem:**
  - Conventional flavor tagging algorithm using anti-k_T algorithm is only **IRC safe up to Next-to-Leading Order (NLO) calculation in QCD**
- **Solution:** new JetFlav package
  - JetFlav is a new jet flavor tagging software package with lately developed IRC safe algorithms for beyond NLO calculations in QCD
  - **Goal**: Maintain anti-k_T kinematics



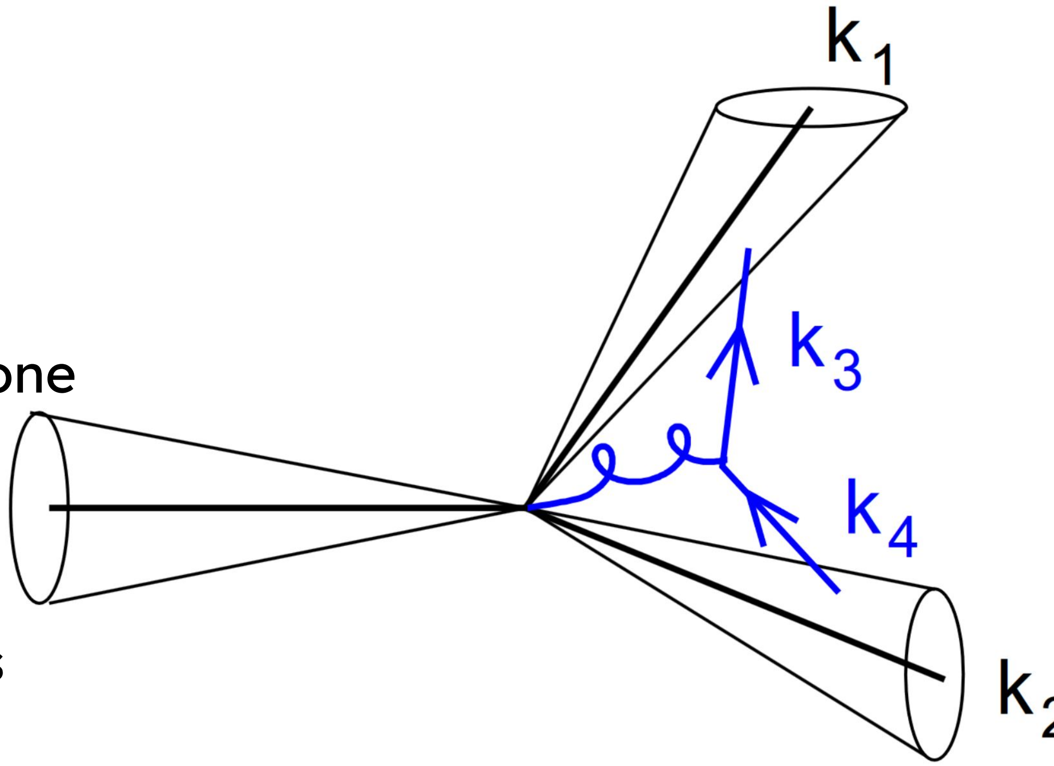
UNIVERSITY OF MICHIGAN LHCb

Goals

- ➔ Implement JetFlav package into DaVinci
  - ◆ DaVinci is the analysis software developed for LHCb
- ➔ Test Performance of JetFlav algorithms on B^+-jet reconstruction in LHCb kinematics
  - ◆ Efficiencies of JetFlav algorithms compared to anti-k_T at generator level
  - ◆ Purities of JetFlav algorithms compared to anti-k_T at reconstruction level

Experimental Limitations

- ➔ We only check want jets initiated by a bottom quark
- ➔ But sometimes, we will get contaminations:
  - ◆ Gluon splitting into quark-antiquark pair
  - ◆ Explicit heavy flavor reconstruction is only done through a single decay channel
    - $B^+ \rightarrow J/\psi\, K^+$ channel trigger line
- ➔ We want to check purity and efficiency of JetFlav as compared to standard AKT



At truth level, should be two flavor neutral jets

At reco level, we see two b flavored jets.

Achievements

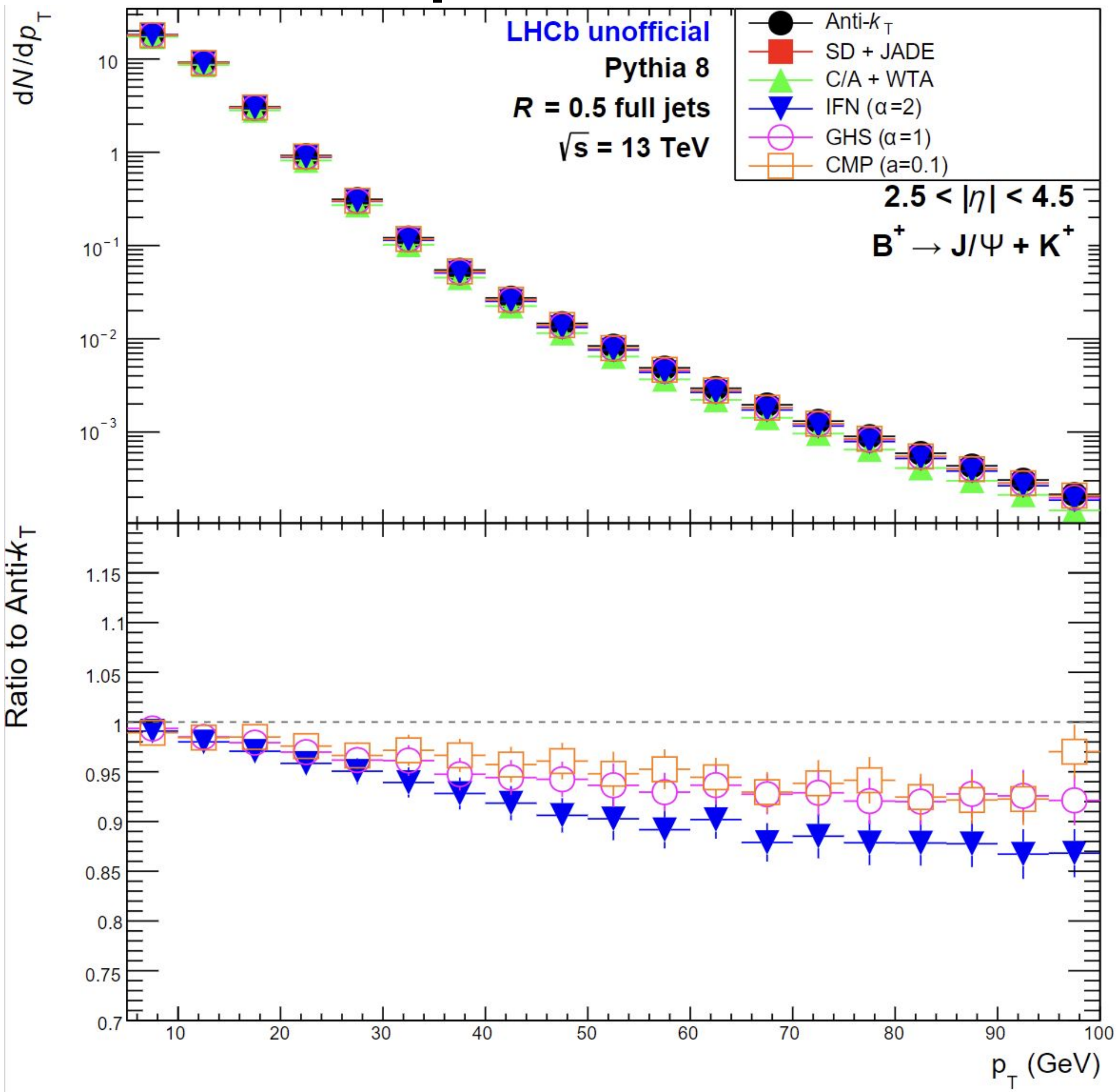
- ➔ Learned to change some parameters in DaVinci and to run DaVinci using an option file
- ➔ Dug through the source code of DaVinci to investigate the possibility of implementing JetFlav algorithms other than anti-k_T
  - ◆ FastJet, which DaVinci uses as jet reconstruction interface, comes with several jet reco algorithms. One can specify the algorithm using options file.
- ➔ Investigated the custom plugin functionality of FastJet
- ➔ Determined that it is temporarily infeasible to implement JetFlav package into DaVinci
- ➔ **Learned to use Pythia 8 to produce Monte Carlo Data**
- ➔ **Evaluated performance of JetFlav at generator level**

p_T spectrum

- [Anti-k_T]()
- [Interleaved Flavor Neutralisation (IFN)]()
- [Modified Flavor Clustering (CMP)]()
- [Flavor Dressing (GHS),]()
- [Winner-Take-All Tagging (WTA)]()

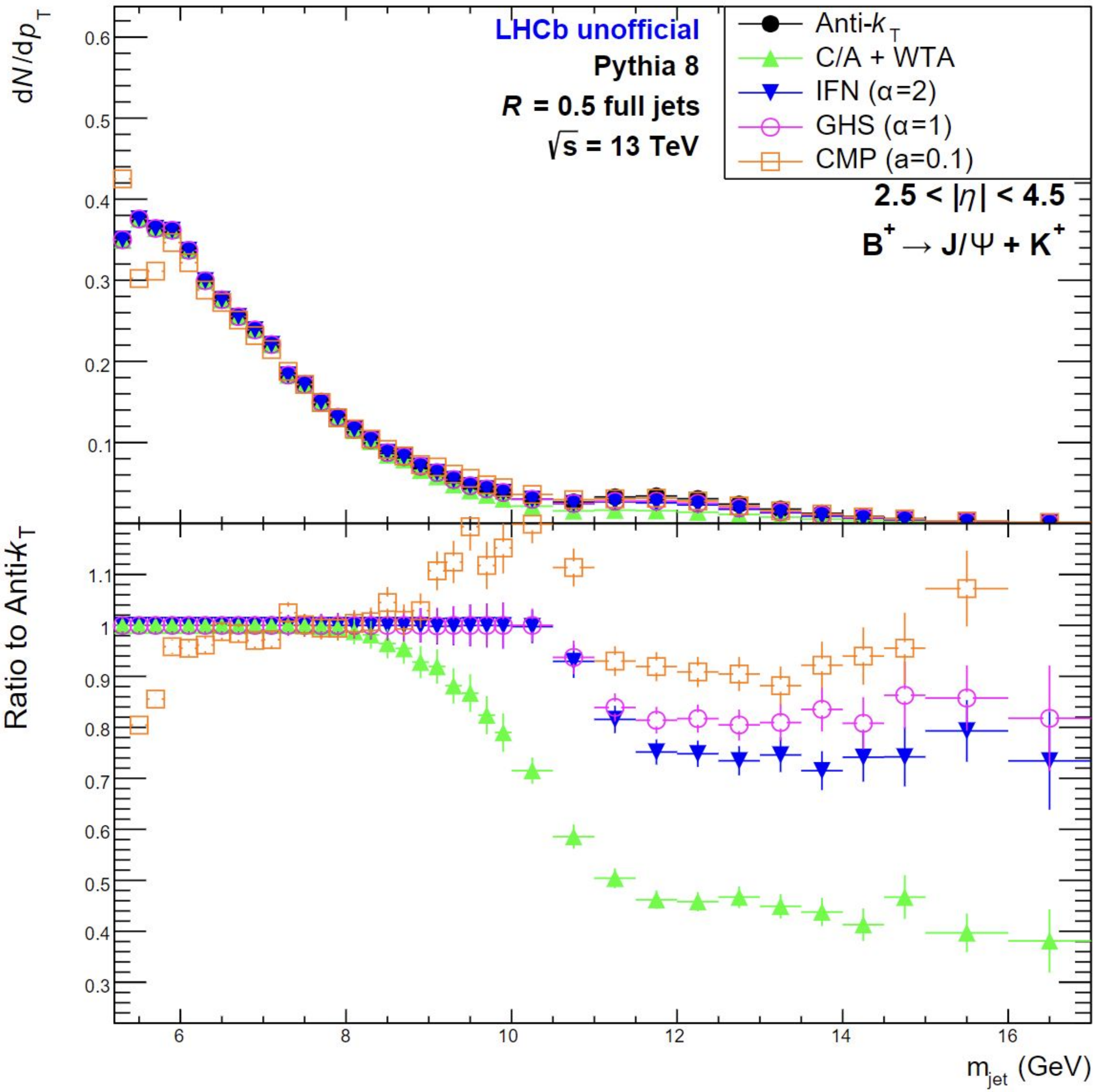
➔ Efficiency correction: **Very small**

◆ 5 - 10%



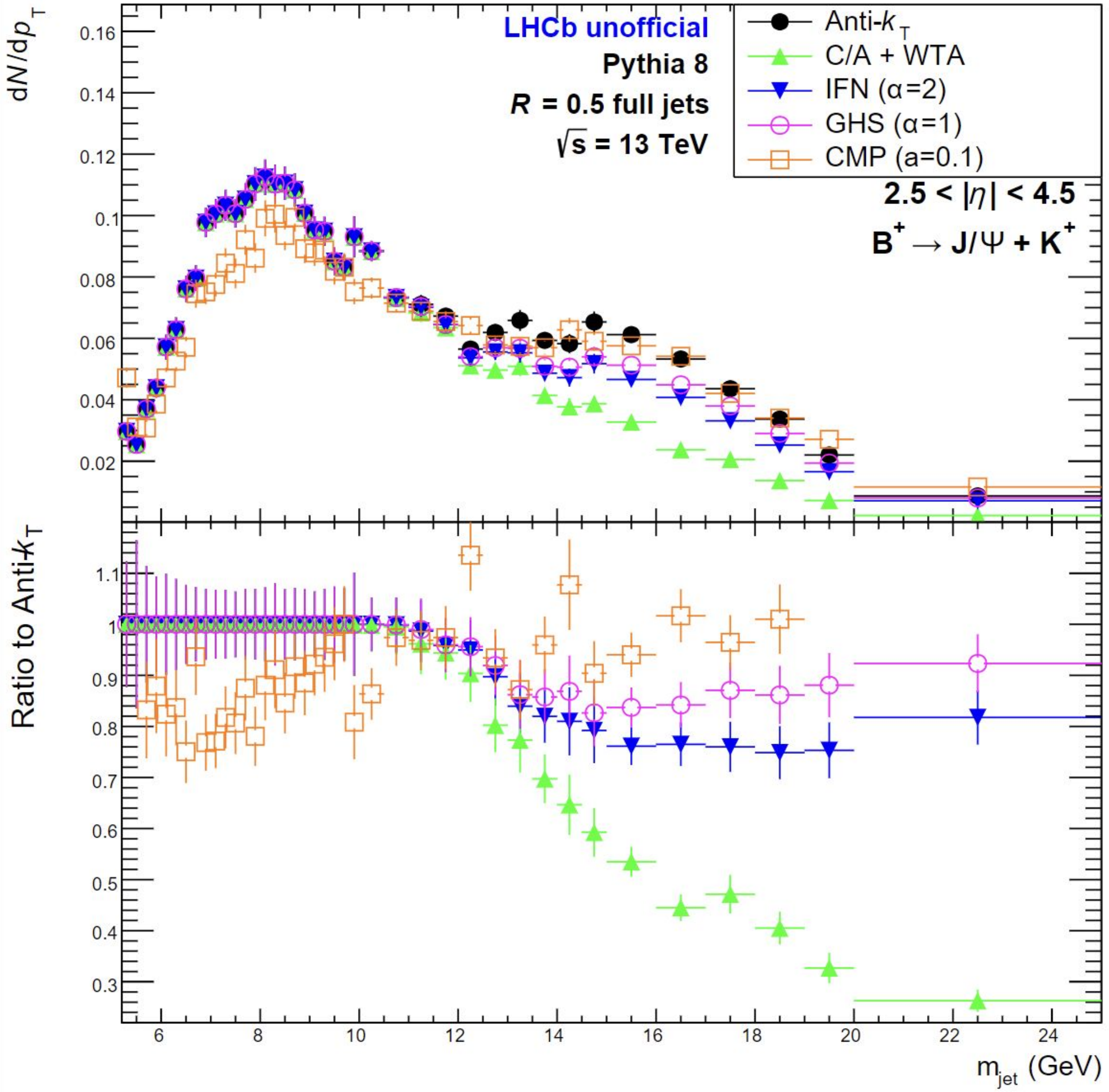
m_{jet} spectrum for p_T = 10-20 GeV

- ➔ shape: two mass peaks
- ➔ huge shape dependence of efficiency at tail
- ➔ 30% efficiency loss, much greater than overall 5 percent efficiency loss in the previous slide



m_{jet} spectrum for p_T = 40-60 GeV

➔ Cranked up p_T
- More pronounced mass peak at the tail
- The shape dependence of efficiency at tail

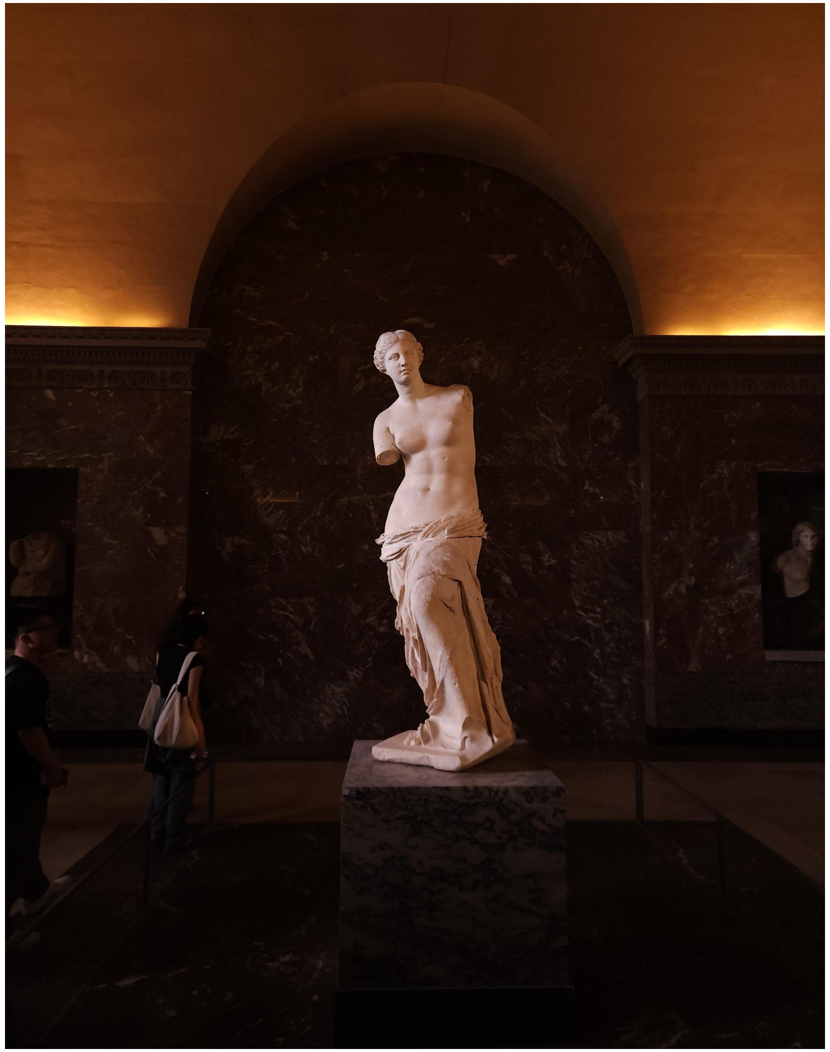


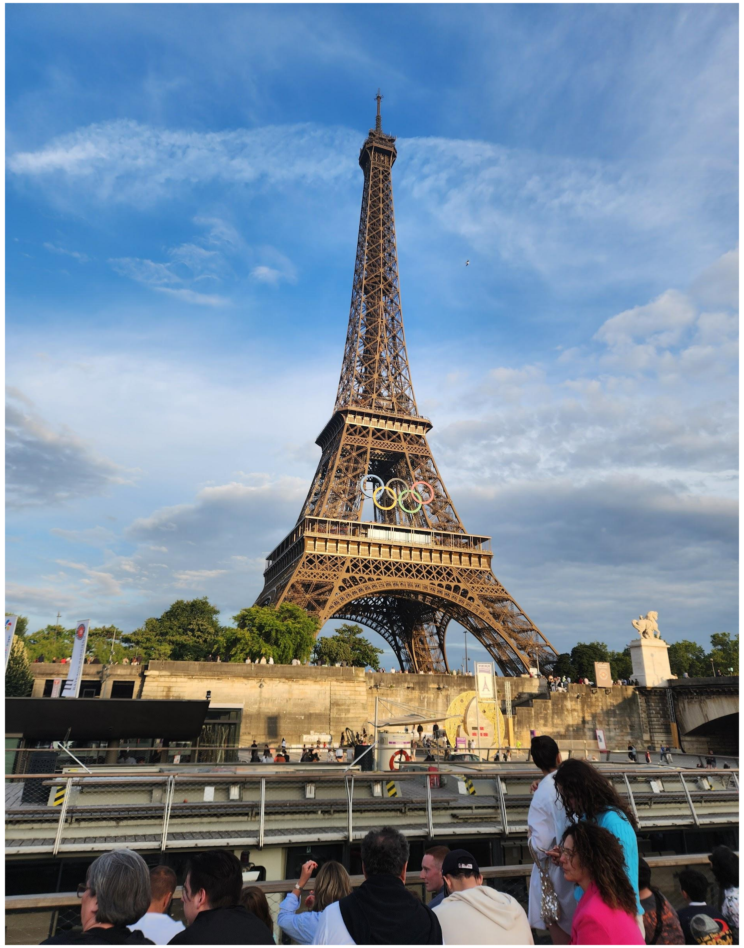
Summary

- ➔ The performance analysis will facilitate our understanding of JetFlav algorithms
- ➔ It will also help us understand the effects of experimental restrictions (i.e. cannot reconstruct the HF hadrons in every event) and how to make useful measurements to test QCD at higher precision in collaborations with theorists
- ➔ **Future Prospects**
  - ◆ Look for observables more resilient to flavor tagging efficiency
  - ◆ Extend to reco level purity in a future DaVinci upgrade
    - Test detector effects on JetFlav efficiency

Cultural Experience

Paris





Cultural Experience

Rome

Cultural Experience

Rome

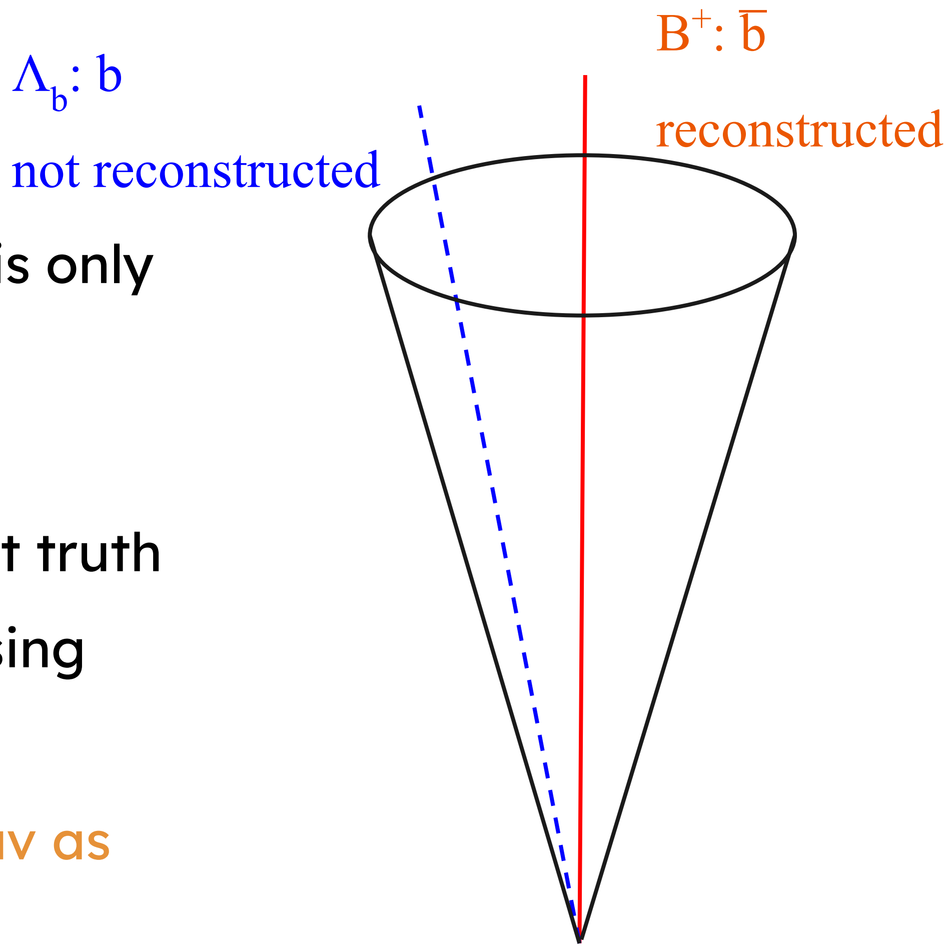
Cultural Experience

Annecy

Thank you!!

Experimental Limitations

- ➔ JetFlav assumes that all hadrons are truthfully reconstructed
- ➔ But, in fact, explicit heavy flavor reconstruction is only done through a single decay channel
  - ◆ $B^+ \rightarrow J/\psi K^+$ channel trigger line
- ➔ In other words, there may be less flavored jets at truth level compared to reco level because of the missing flavored hadrons
- ➔ We want to check purity and efficiency of JetFlav as compared to standard AKT



At truth level, should be flavor neutral

At reco level, we see a $\bar{b}$ flavored jet

Some Obstacles

- ➔ JetFlav requires nightly builds of DaVinci compatible with latest FastJet
  - ◆ Nightly builds are unstable and currently under development

- ➔ Alternative: Try to reconstruct outside of DaVinci where all particle info is needed
  - ◆ But DaVinci does not like dumping all event information
  - ◆ Using DaVinci to output all original b hadrons at reco level jets for analysis may be difficult

mass 10-20 spectrum

$$m = \sqrt{E^2 - p^2}$$