Measuring hadrons around leptonic Z bosons in CMS open data using Z drop

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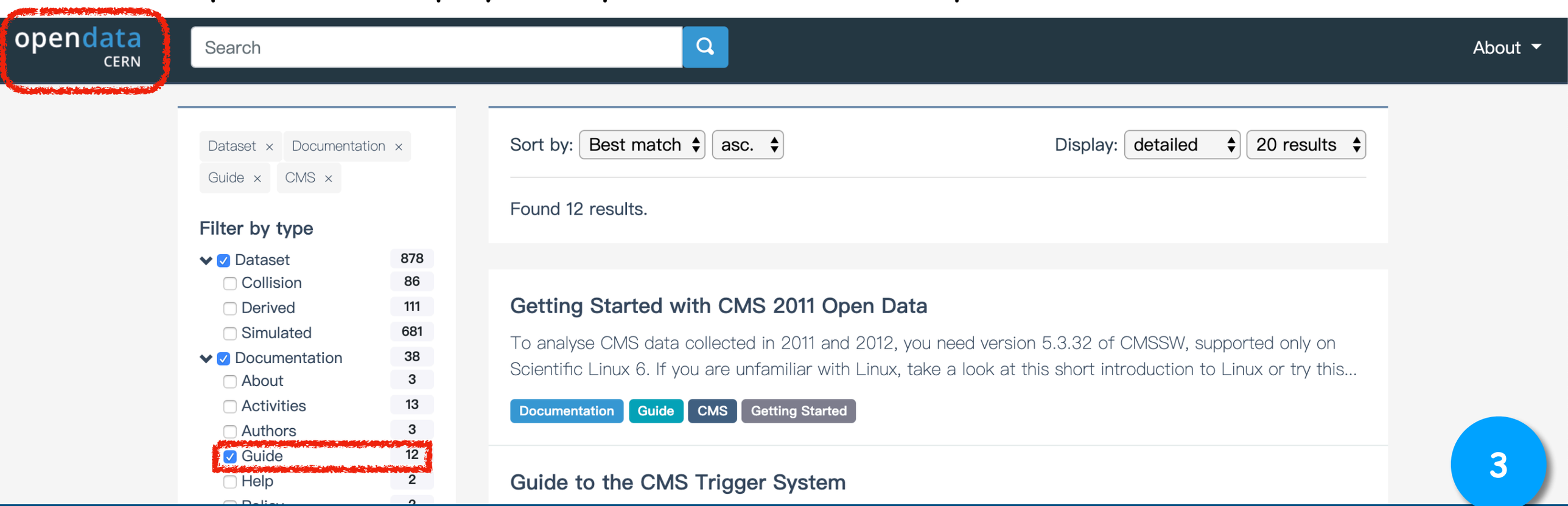
Outline

- CMS Open Data
- Motivation
  - Precision measurement of soft radiation
  - Underlying Events and Pileup
- Z drop
  - An observable sensitive to underlying events and pileup
- Result Plots
  - Dependence on :
    - Z_pT
    - Number of Vertex
    - Radius R of Z cone
  - Pileup “mitigation” : PUPPI/SoftKiller
- Conclusion

CMS Open Data

- CMS open data is available on CERN open data portal.
- REAL DATA is available for everyone.
  - To verify measured observables
  - To test new, special ideas
  - It is a great resource for education.
- Open data can play an important role for complete searches and studies.



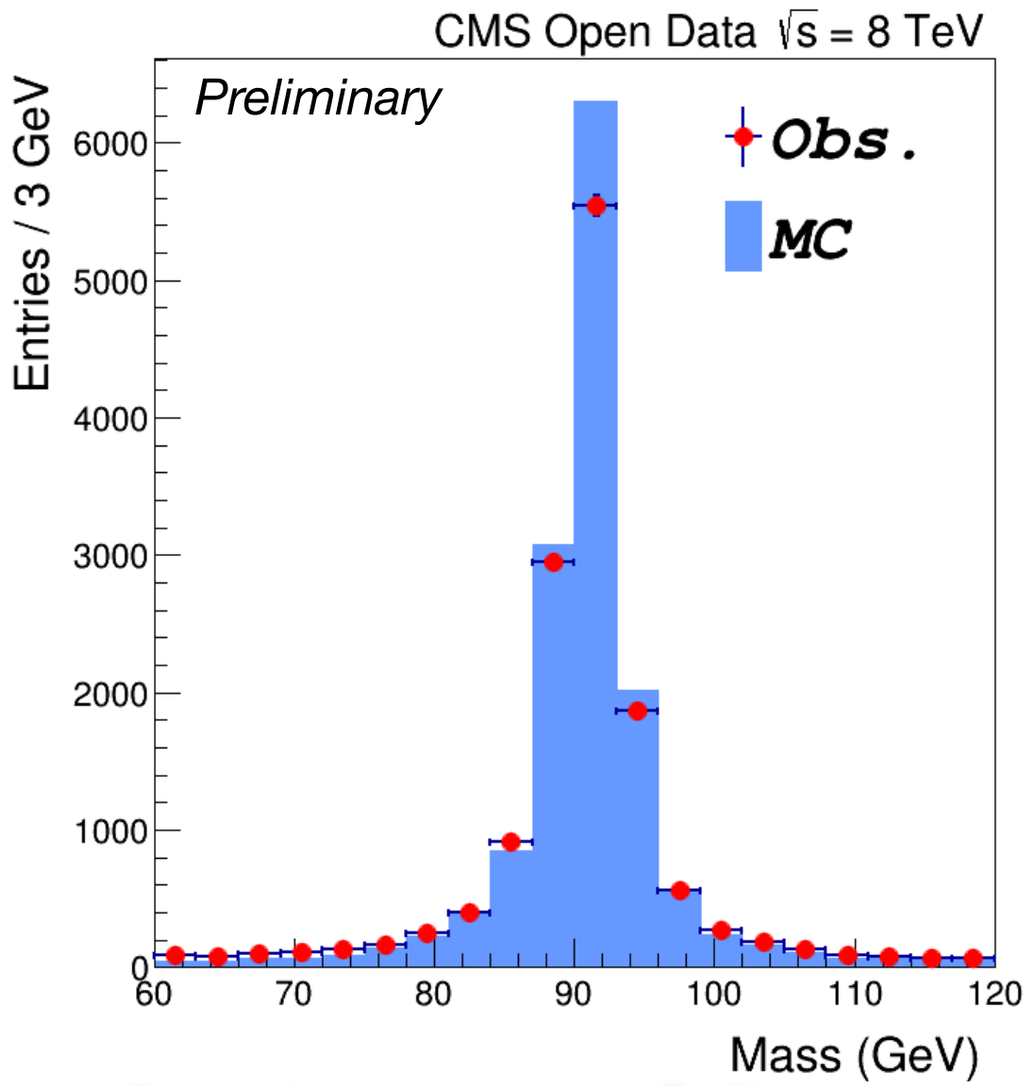
CMS Open Data

- Both data and Monte Carlo sample are available on open data portal.
- <u>Data</u> :

  DoubleMuParked primary dataset in AOD format from RunB of 2012 in 8 TeV pp collisions from CMS

- <u>MC Sample</u> :

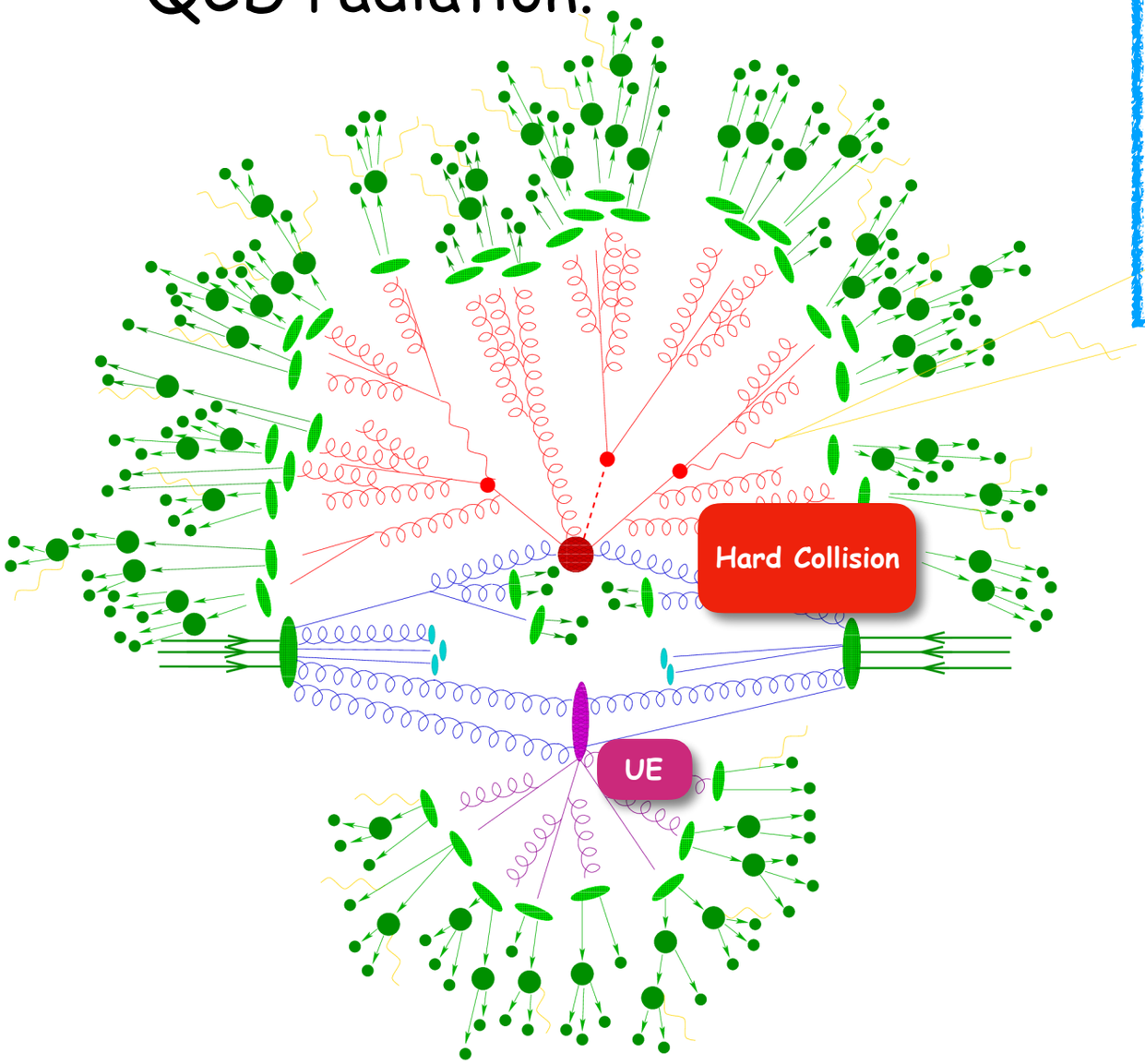
  DY process generated by Madgraph + Pythia in 8 TeV, and selected by dimuon mass larger than 50 GeV



Invariance mass of dimuon selected by larger than 50 GeV

Soft QCD Study

- Underlying events(UE) and pileup(PU) are complicated components of soft QCD radiation.



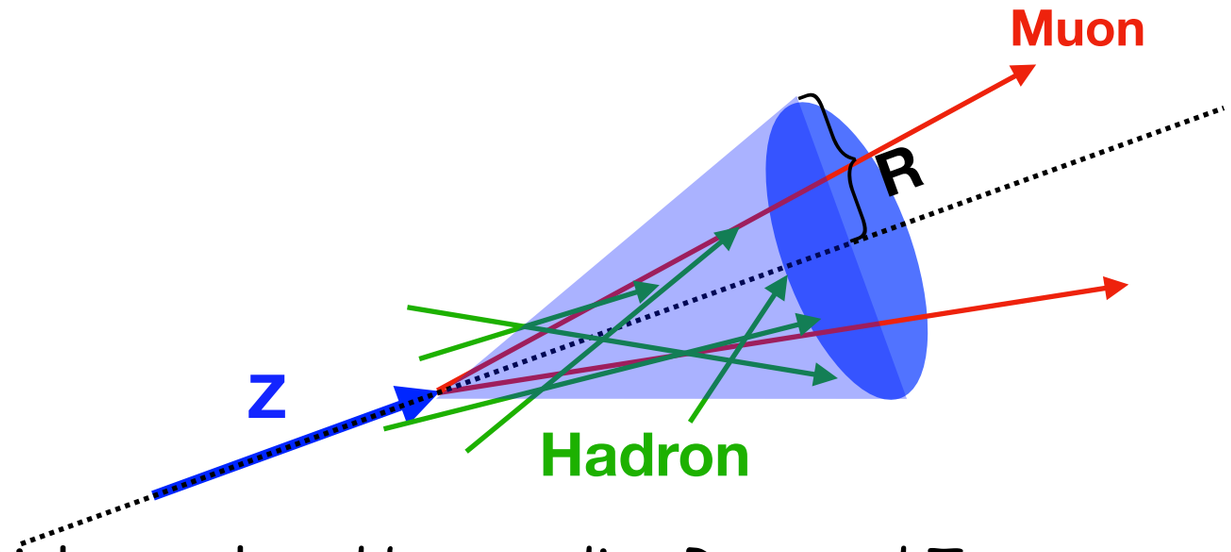
Conventionally, the studies of soft QCD activities are performed in the direction far from jets.

We will define a new observable "Z drop" to study hadrons around leptonic Z.

Z Drop

- Z drop definition :

$$\frac{m_R^2 - m_Z^2}{2p_T}$$



  - m_R^2 : Invariant mass square of particles enclosed by a radius R around Z
  - P_T : Transverse momentum of Z boson
- The difference of mass squared measures the hadrons around the Z.
  - The Z drop is zero if there are no hadrons in the radius R cone.
- We will use CMS open data to measure Z drop. However, Z drop can also be used to isolate Z as in photon isolation or tau isolation.

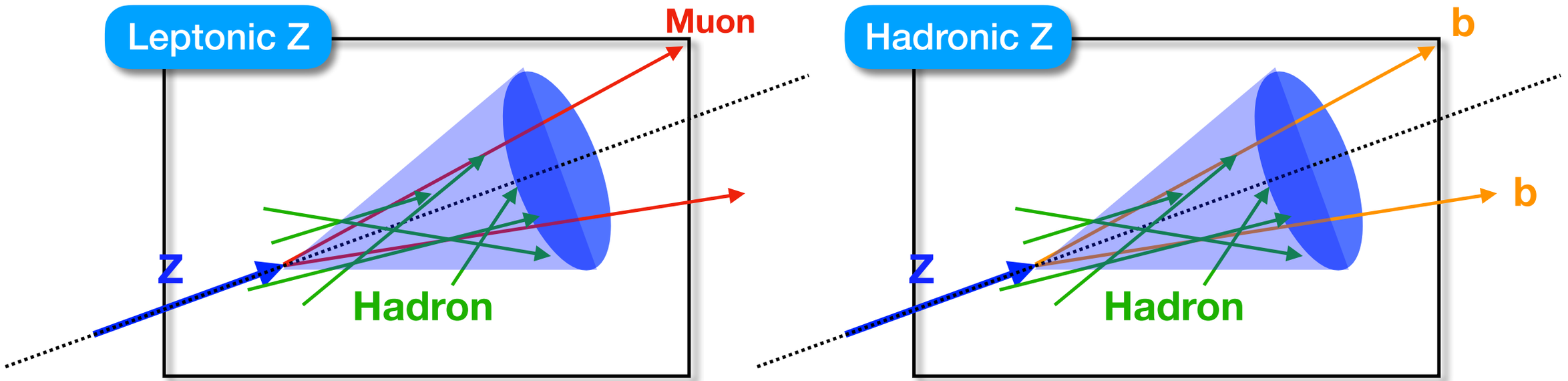
Compared With Other Observables

- Multiplicity : number of particle flow candidates in a cone with radius R
- Multiplicity is strongly affected by hadronization, so it is good to compare Z drop which is infrared and collinear safe, to multiplicity.
- Z drop is defined utilizing the mass, which is a natural choice for a resonance study. The mass alone is not enough in the hadronic case because of the large background.
- Z_pT is not sensitive to pileup.

Z drop is sensitive to pileup therefore we can use it to quantify pileup. It is also affected by hadronization less than multiplicity.

$$\frac{m_R^2 - m_Z^2}{2p_T}$$

Why Leptonic Z ?



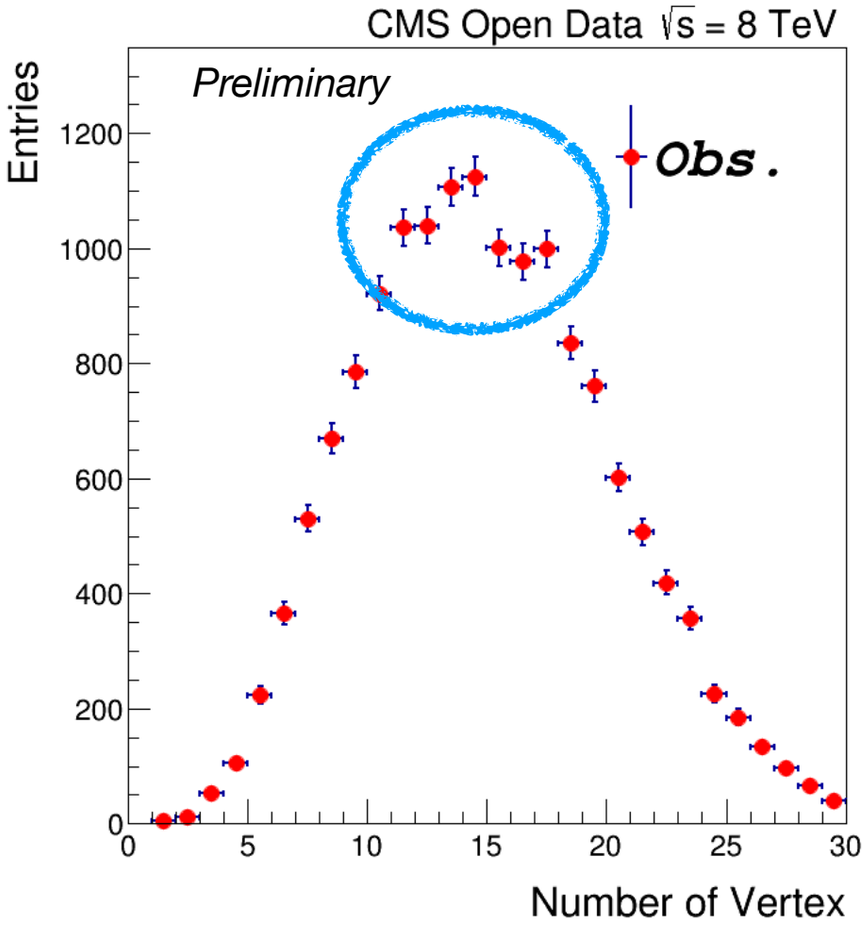
- Extracting the UE and Pileup component.
  - Leptonic Z provides a perfect channel to study all the hadrons not from Z decays.
  - Z drop will be an essential verification when one extends the method from leptonic Z to hadronic Z because it is independent of Z decay

Related to Collinear Drop, see Yang-Ting's talk on Thursday

Analysis

- We will focus on Z drop and multiplicity.
  - Multiplicity gives us a reference for how Z drop works.
  - We impose a lepton cut of pT > 30 GeV and eta < 1.4.
  - We impose Z_pT > 50 GeV and Mass > 50 GeV to select boosted Z's.
- We study the dependence on N_V (Number of vertex) and radius R.
- We also study the effect of performing PUPPI and SoftKiller on Z drop distributions.

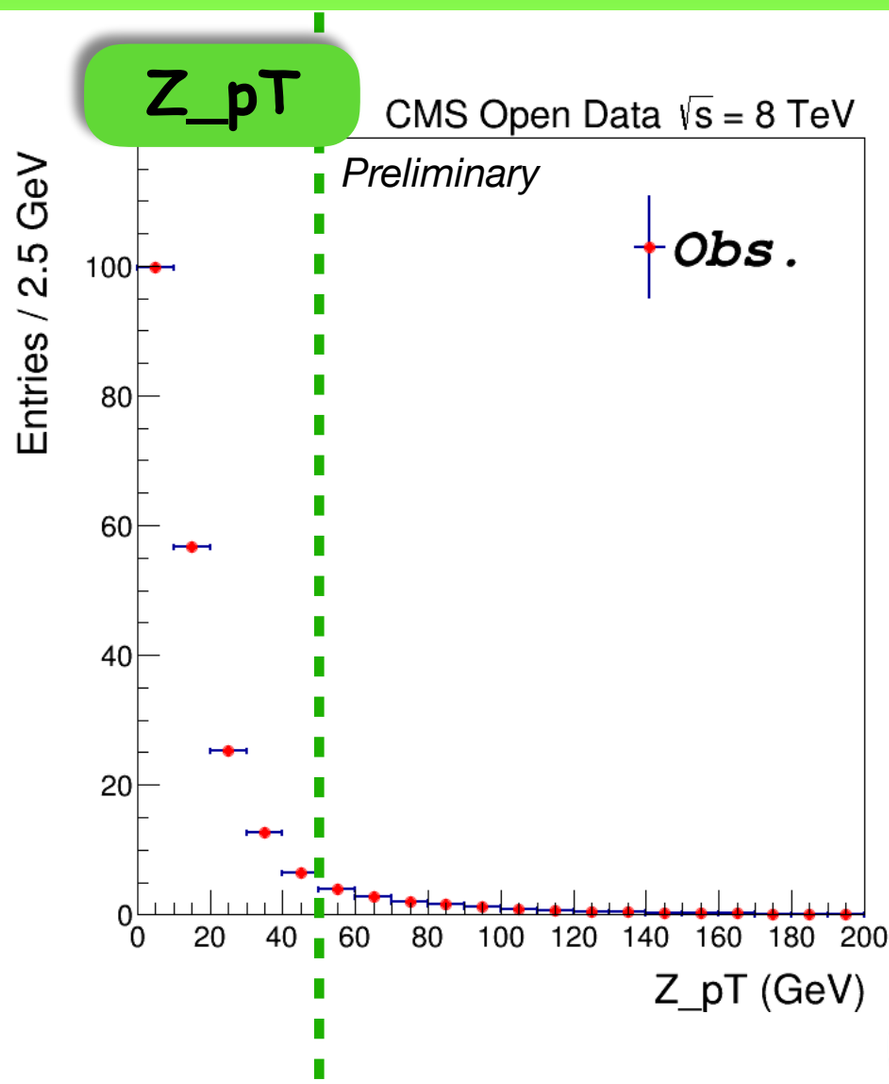
First Glance of PU and Z Candidate



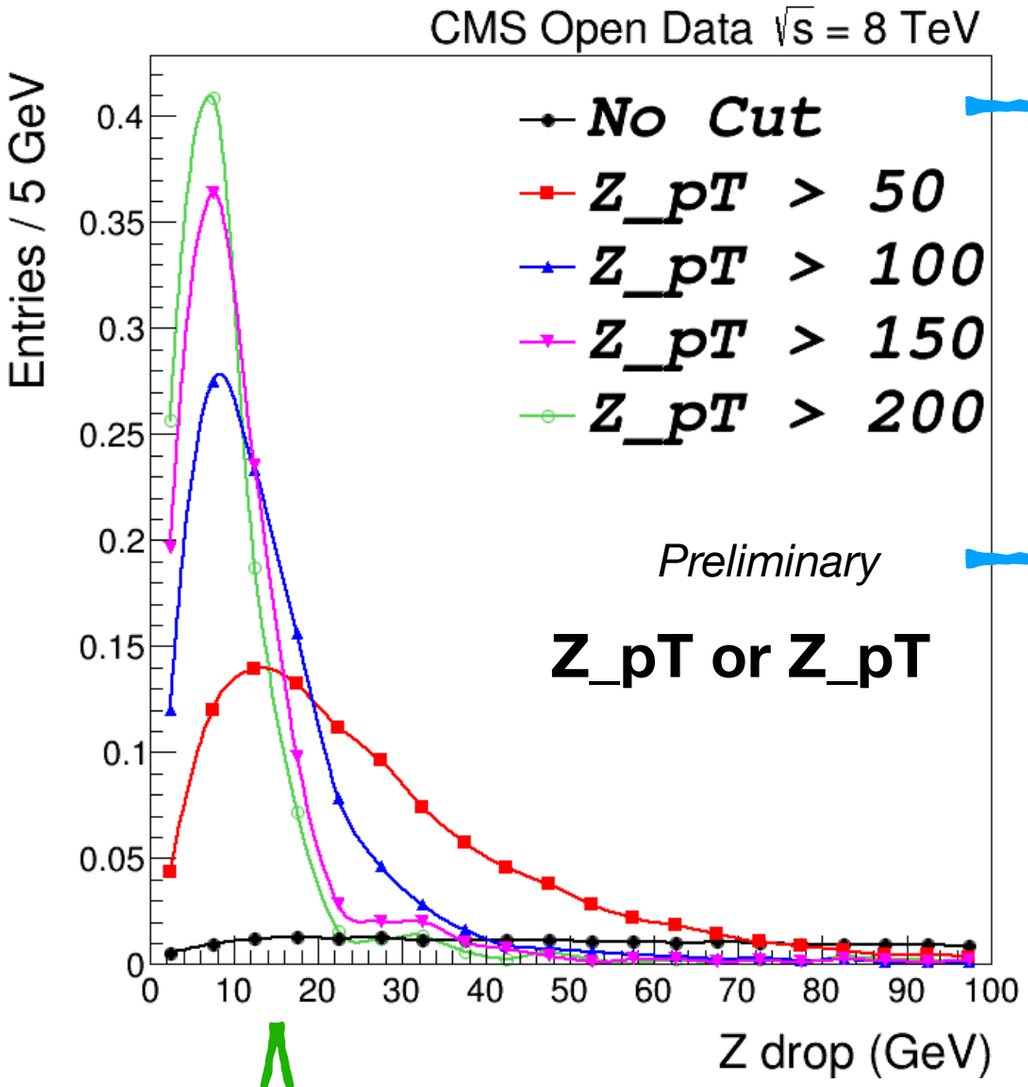
Number of Primary Vertex

- We have most of entries in the range 10 to 20 and have low entries when vertex less than 5 or more than 25.

- Most of the Z produced have low pT. However, we will look at more boosted Z's with pT > 50 GeV.

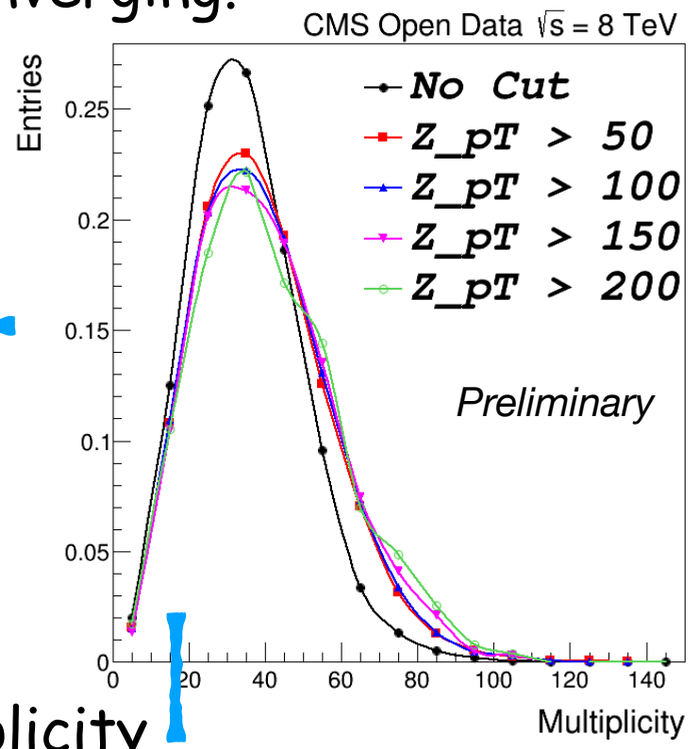


Boost by Z_pT cut



- After boosted, we can see that the tail of Z drop is cut off, and the peak is more significant and converging.

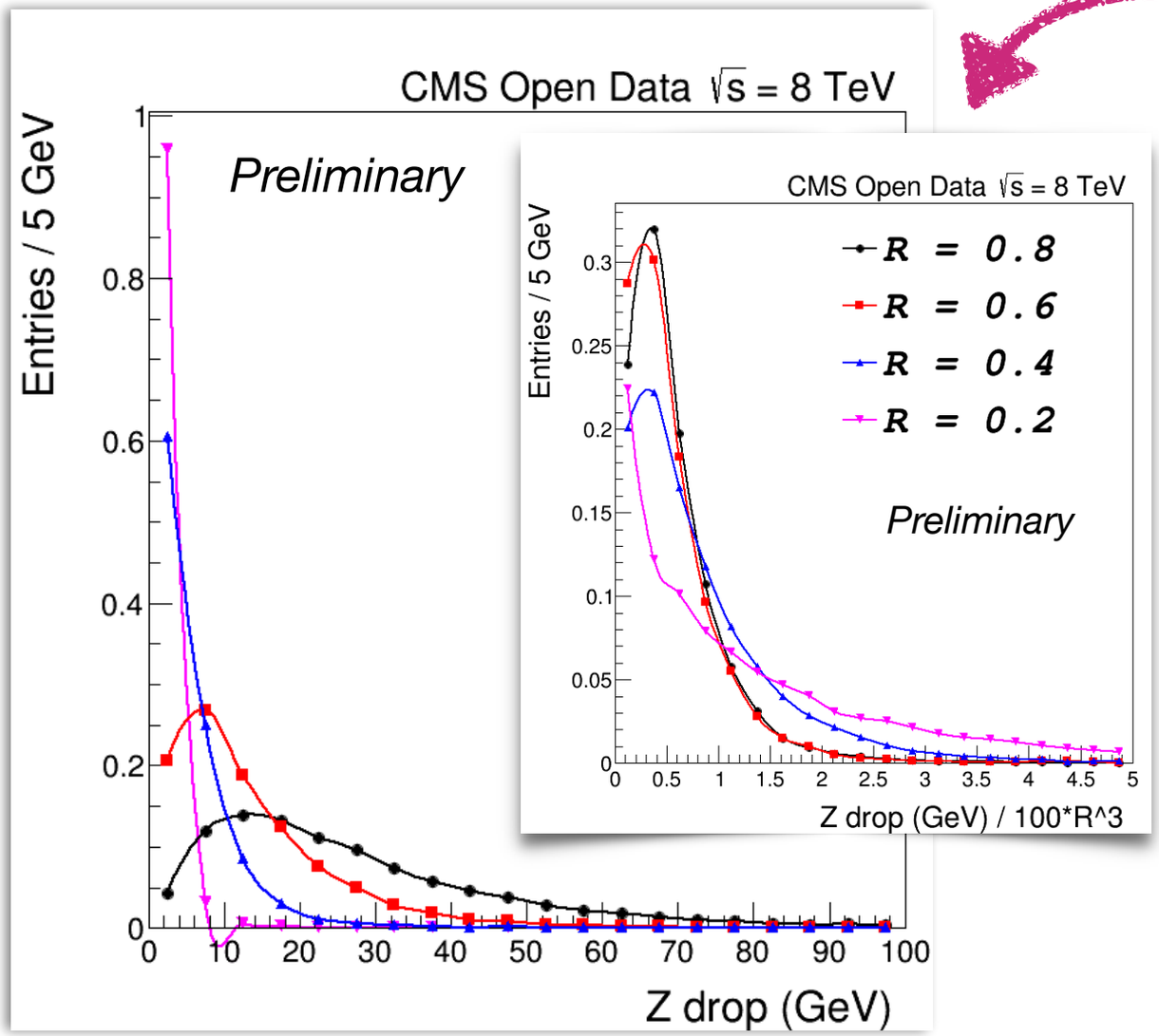
Z_pT cut at 0, 50, 100, 150, 200 GeV.



- The shape of multiplicity distribution has no obvious difference.

Boosting Z makes sure that the decay products are in the region we concern. We use Z_pT > 50 GeV in the following analysis.

Dependence on R (Z drop)

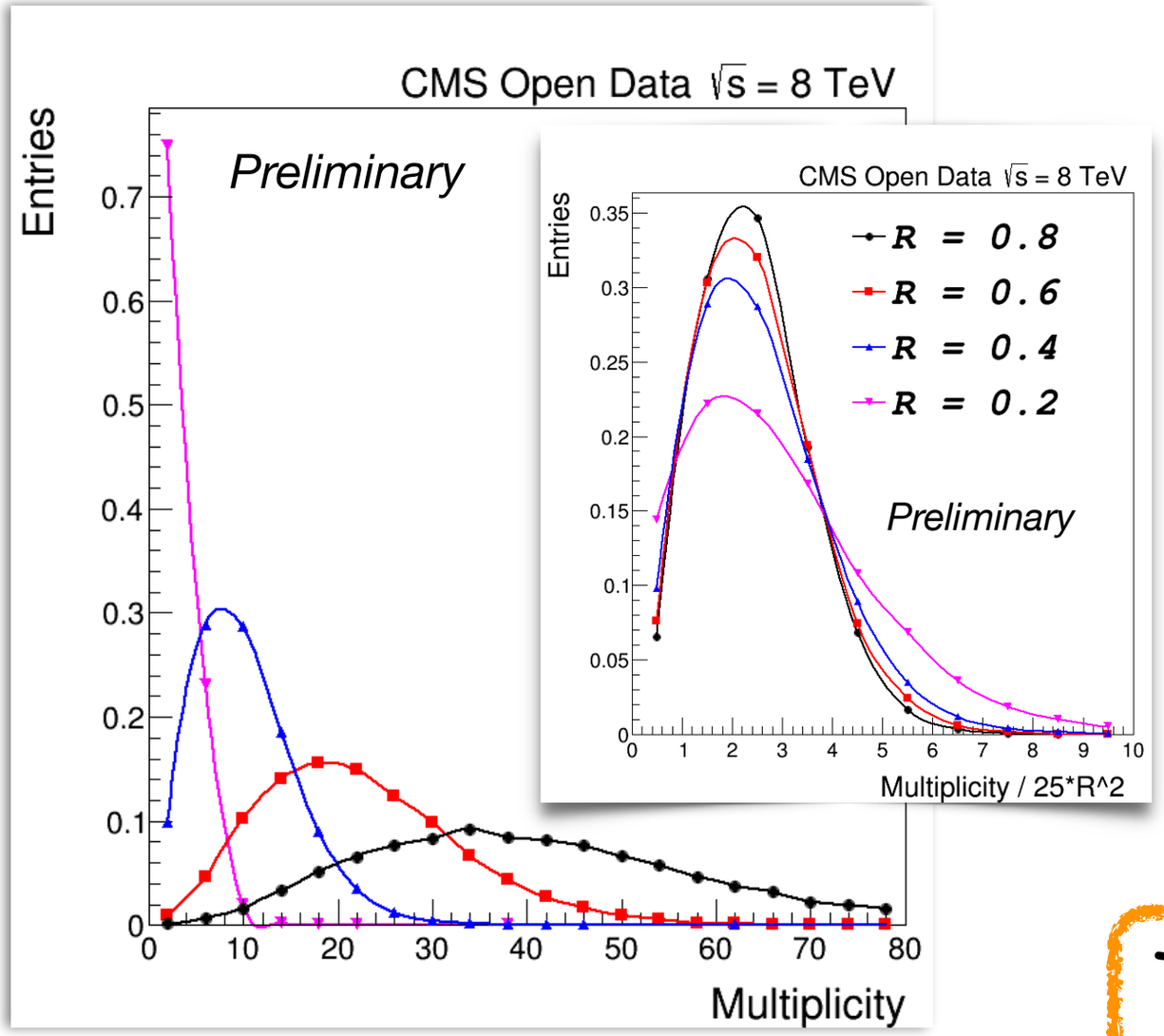


- Pileup is conventionally expected to be uniform, however Z drop does not obey exact R scaling !

- We look at Z cone with radius R = 0.2, 0.4, 0.6, 0.8
- All the Z drop distributions are normalized.
  - The distribution moves toward the right when R increases.

- To quantify it, we scale Z drop with space to see the density. For large radii (0.8 and 0.6), the rescaled distributions are on top of each other, which is not the case for small radii (0.4 and 0.2)

Dependence on R (Multiplicity)

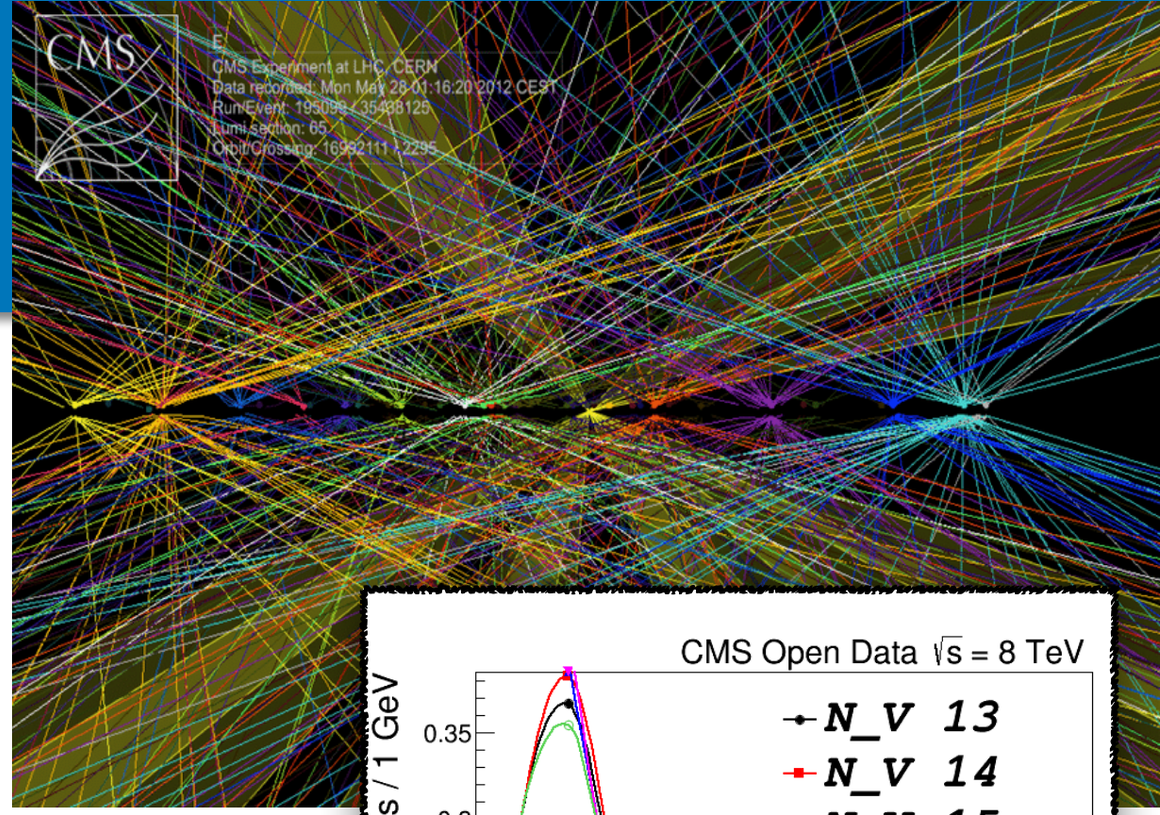


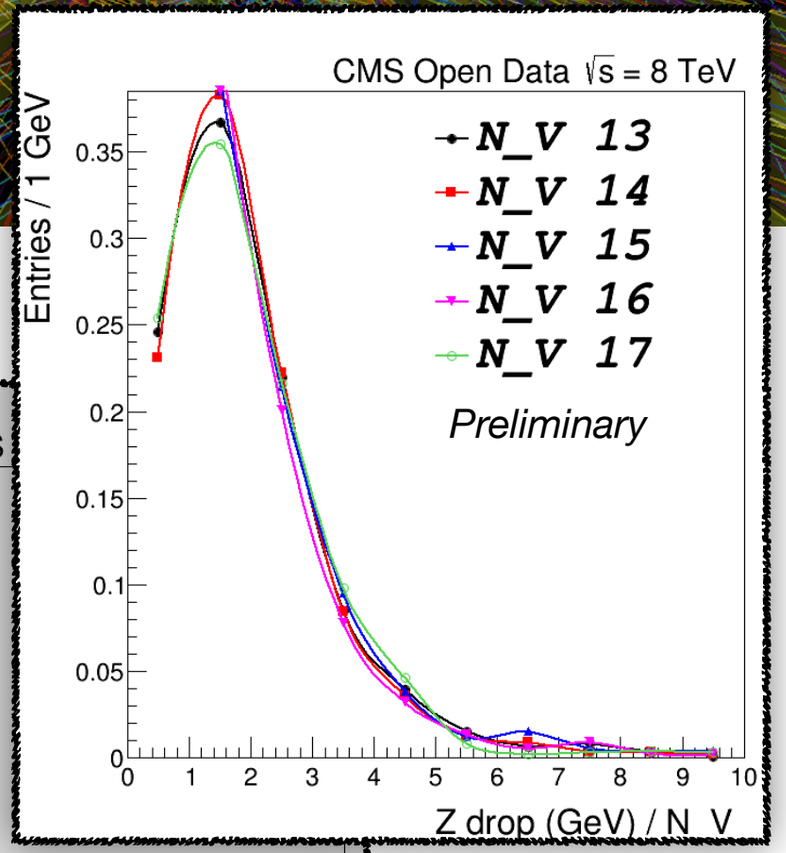
- It shows similar result with Z drop.
- The shape move right when the radius R rise as well pileup increase before scaling.
- Multiplicity doesn't obey exact R scaling, especially for small radii.

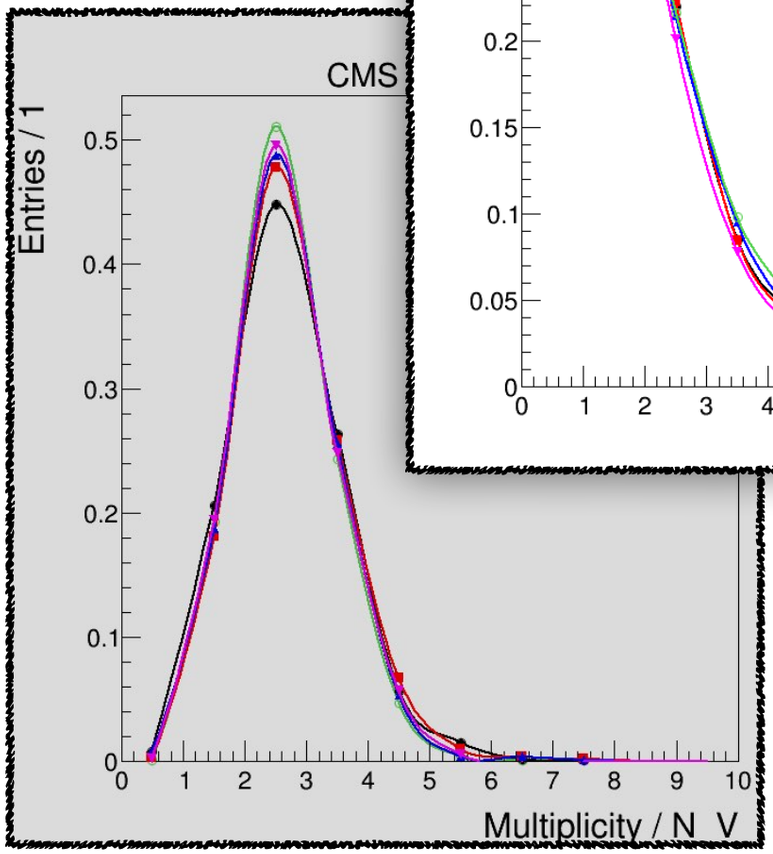
There is no perfect R square uniform in multiplicity.

N of Vertex

- What we will check here is pileup from each vertex are independent!!

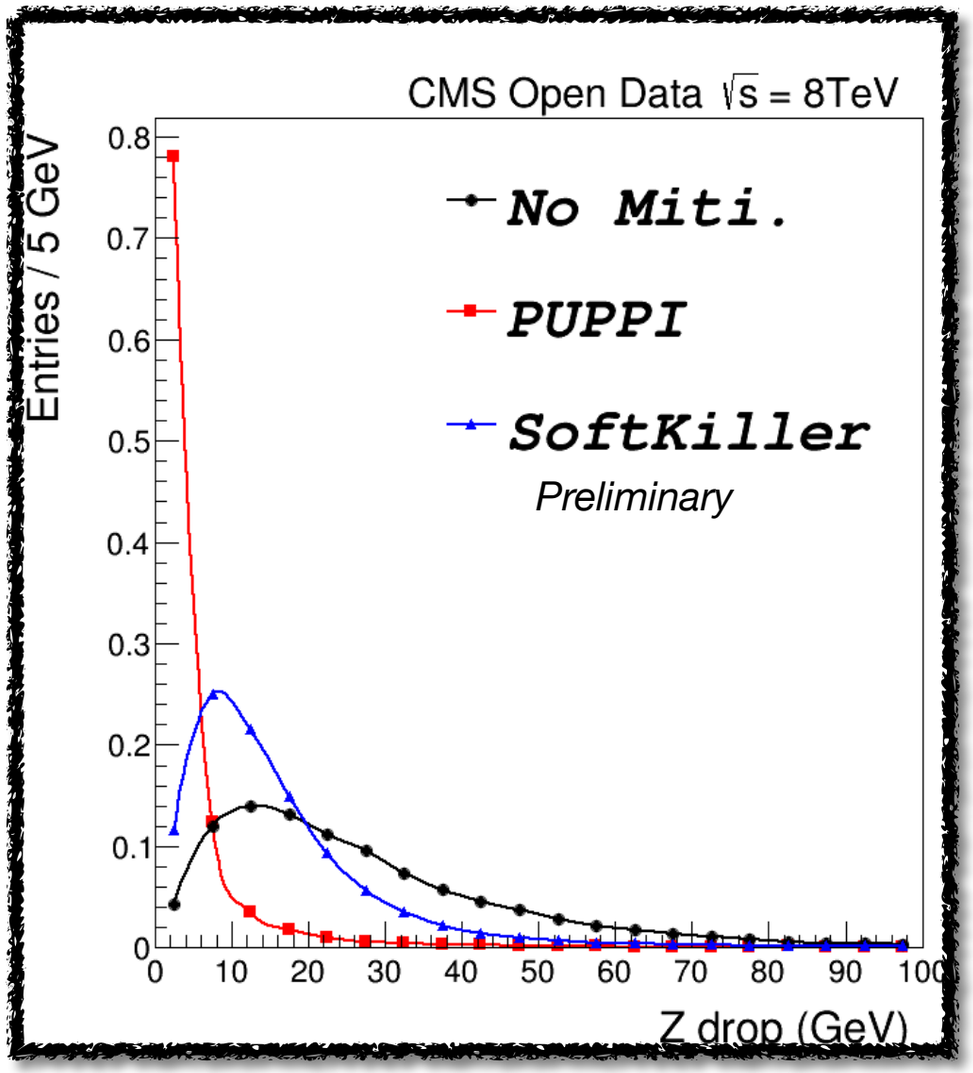






- We rescale Z drop and multiplicity by the number of vertex.
- We choose N_V = 13, ..., 17 because they have the most entries.
- The rescaled distributions overlap with each other as a per-pileup distribution.

Pileup Mitigation



Pileup mitigation algorithm in CMSSW :

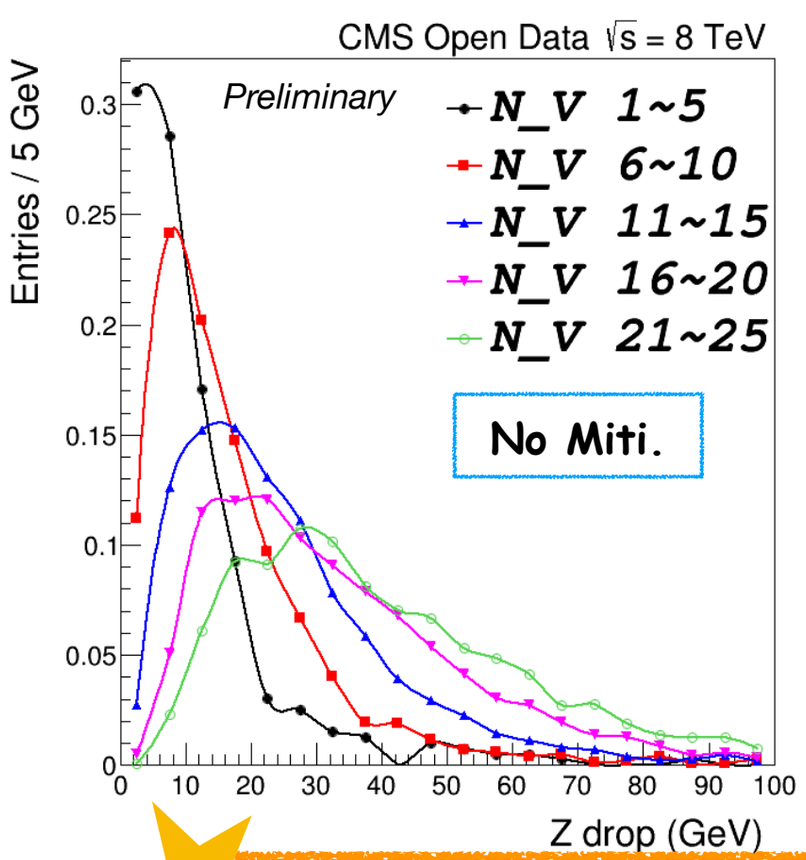
PUPPI/SoftKiller

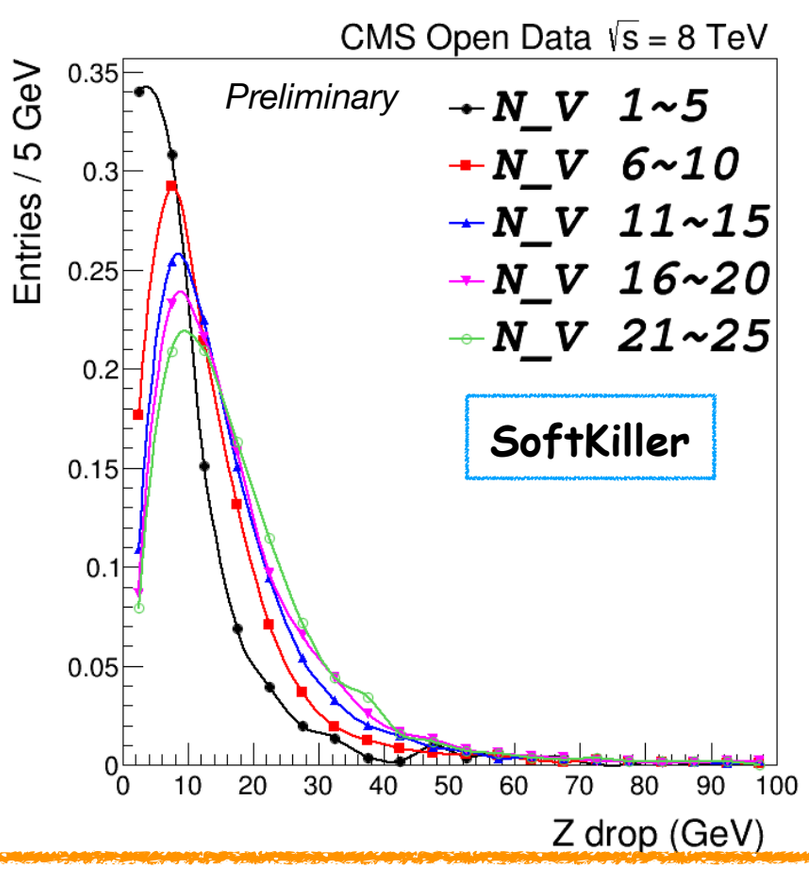
What PUPPI and SoftKiller do are very different !

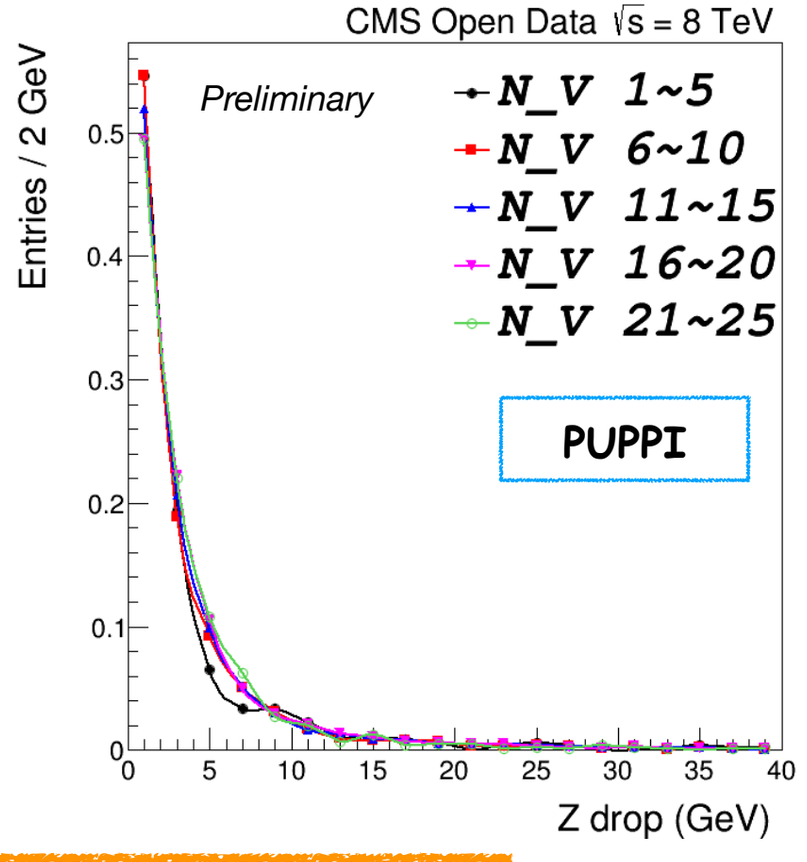
➡Let's look into the performance of these two pileup mitigation methods in more details.

Pileup Mitigation

- We cut a range of number of vertex selection on the data with PUPPI and SoftKiller.
- If the mitigation algorithm works perfectly, the distribution of Z drop in each selection should be the same as well as there is no pileup.







SoftKiller does remove pileup but not perfectly. On the other hand, PUPPI seems to remove more and most of the pileup.

Summary

- We use CMS open data to do an independent study.
- An observable, Z drop is defined to probe underlying event and pileup contributions.
  - Z drop is sensitive with pileup.
  - Z drop is affected by hadronization less than multiplicity.
  - Z drop does not obey exact R scaling, but does in N_V scaling.
- PUPPI removes almost all pileup, but SoftKiller does not.
- Z drop method will be extended to hadronic Z boson.
- Z drop can be used as a new probe of the quark-gluon plasma produced in heavy ion collisions.