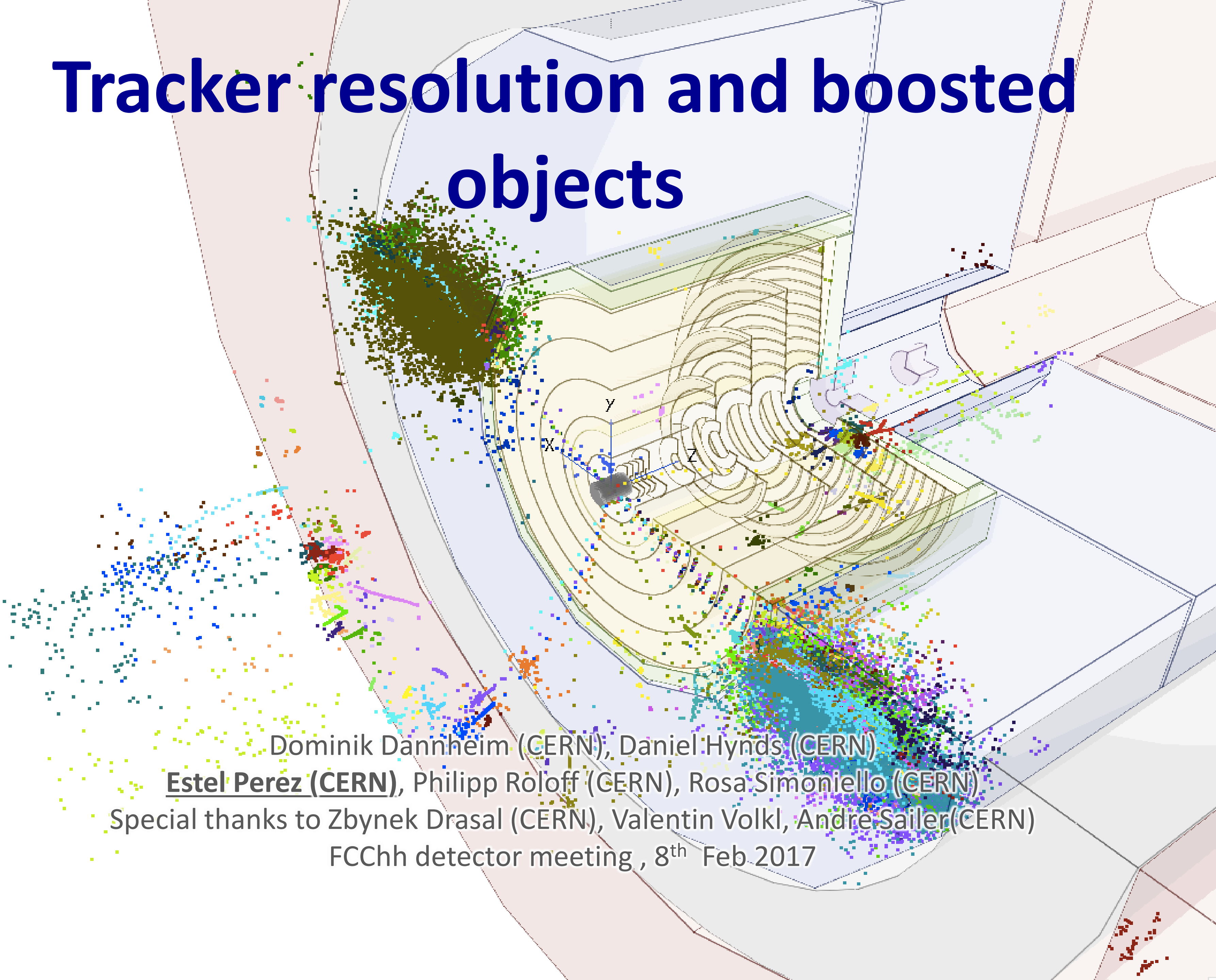
Tracker resolution and boosted objects



Dominik Dannheim (CERN), Daniel Hynds (CERN)
Estel Perez (CERN), Philipp Roloff (CERN), Rosa Simoniello (CERN)
Special thanks to Zbynek Drasal (CERN), Valentin Volkl, Andre Sailer(CERN)

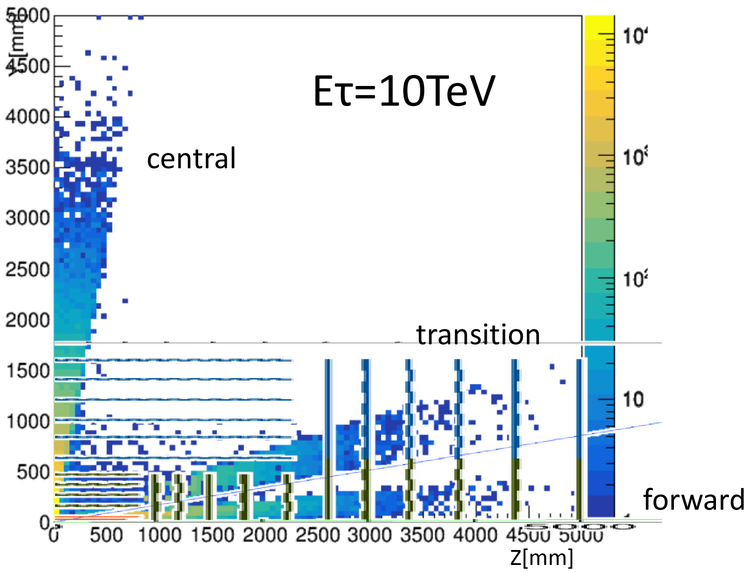
FCChh detector meeting , 8th Feb 2017

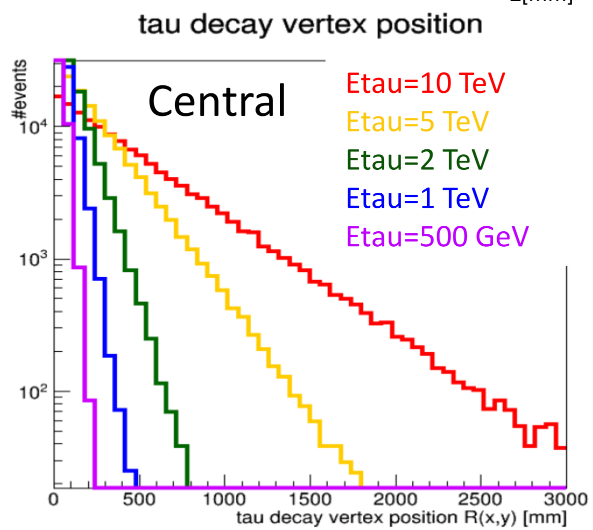
Introduction

- Q: What is the requirement on the detector granularity given by our need to resolve close-by hits from decays of very boosted particles?

- Our Benchmark: high energy taus decaying to 3 prongs (worst case scenario)
  - tkLayout geom + drivers, new CLIC SW **full simulation**
- Notice 2 effects are convoluted:
  - small opening angle between the prongs
  - very displaced decay vertex
- Efficiency of resolving the 3 prongs
  - vs tau flight distance
  - vs tau energy
  - vs detector granularity
- NEW: Similar study using B-jets

Tau samples used





Z'-> tau tau events (no ISR, taus back-to-back) with at least one 3-prong tau

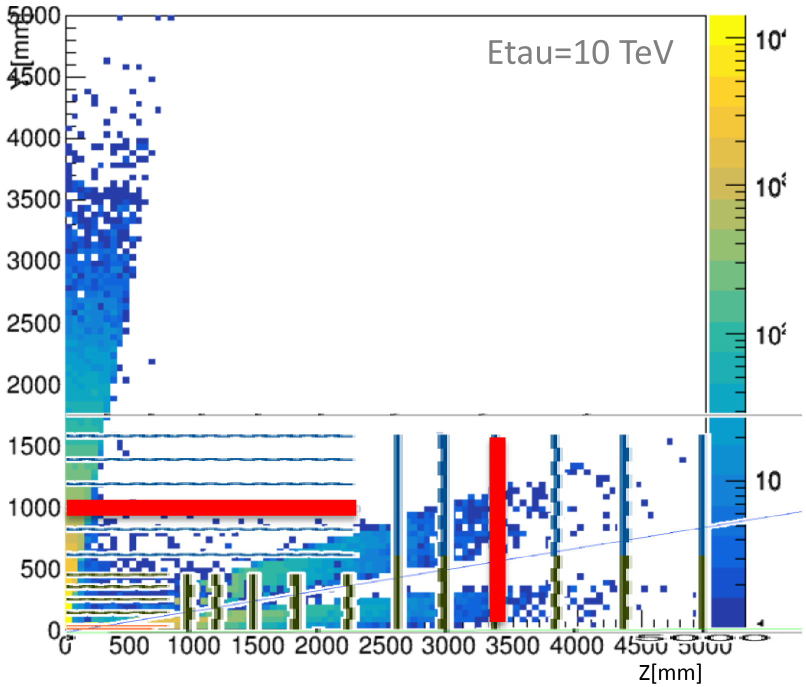
Fraction of central **taus decaying inside the beampipe**
(within **R(x,y)<20mm**)
Etau=10 TeV : 0.045
Etau=5 TeV : 0.088
Etau=2 TeV : 0.201
Etau=1 TeV : 0.357
Etau=0.5 TeV : 0.586
Etau=0.2 TeV : 0.888
Etau=0.1 TeV : 0.987

- While **99% of central 100 GeV taus** decay within the beampipe, only **4% of 10TeV** central taus do.

Efficiency definition (I)

- Resolve all prongs → reconstruct all tracks → have enough hits per track
- Assume: we need at least 3+1(backup) non-shared hits per track
- Assume: outside-in tracking
- → the hits from different prongs must be resolved in the 4^{th}-to-last layer of the tracker

tau decay vertex position

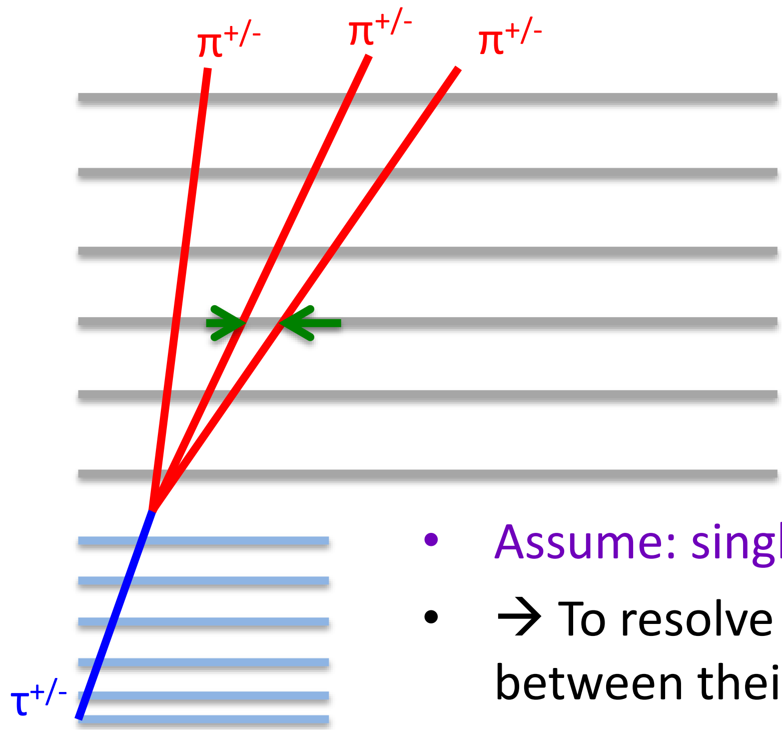


«Acceptance»:
Fraction of **central** taus decaying before the **4th-to-last barrel layer**
Etau=10 TeV : 0.857
Etau=5 TeV : 0.978
Etau=2 TeV : 0.9999
Etau=1 TeV : 1

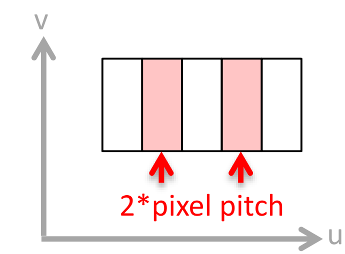
Fraction of **forward** taus decaying before the **4th-to-last barrel layer**
Etau=10 TeV : 0.9992

Start by studying the barrel…

Efficiency definition (II)



Consider the closest pair of hits in the 4th-to-last layer



- Assume: single-hit clusters
- → To resolve the two prongs, the distance between their hits > 2*pixel pitch

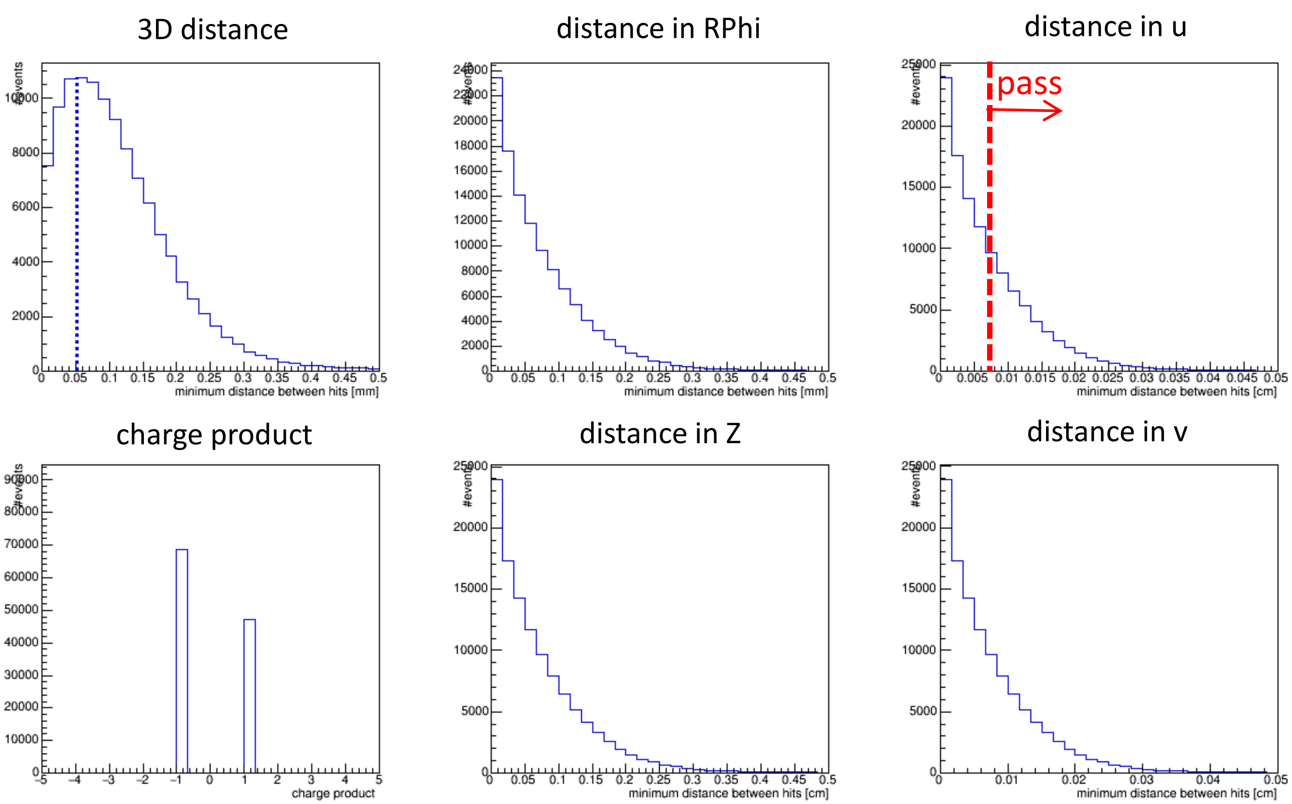
(In either the RPhi(u) or Z(v) direction)

Efficiency = ΔRPhi (ΔZ) distance between closest hits > 2*RPhi (Z) pixel pitch / closest pair of pion hits in the 4th-to-last layer

[effectively factoring out taus that decay after the 4th-to-last layer – out of acceptance]

Efficiency definition (III)

- Assume: 10x100 [μm] single point resolution in the 4th-to-last layer
- Assume: pixel pitch = single point resolution * √12
- → if (ΔRPhi > 2 * 10 μm * √12); pass



(module local coordinates)

Central tau of E=10 TeV decaying before 9th barrel layer (86% acceptance)

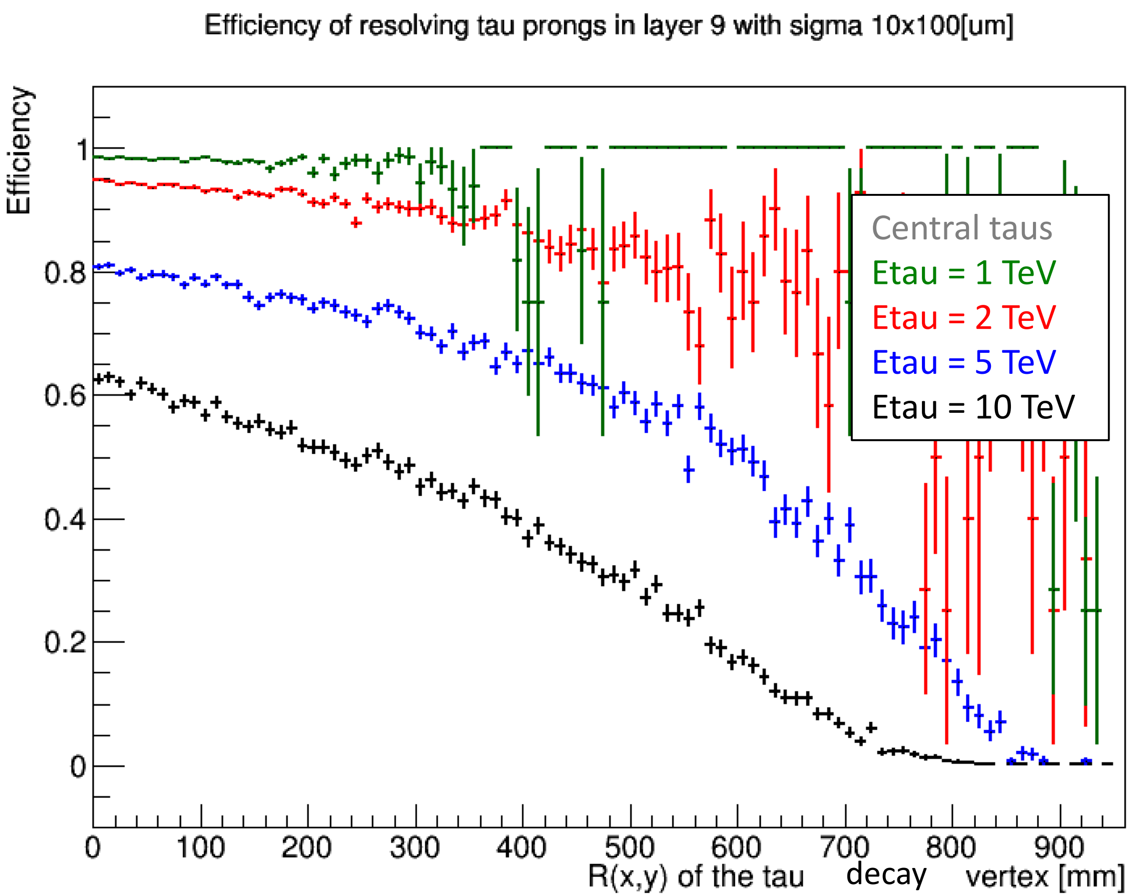
Distance between the closest pion hits in the 9th barrel layer

41% efficiency
(acceptance not included)

Same separation in RPhi and Z, no privileged direction
Efficiency driven by cut in RPhi since pitch is 10 times smaller

Efficiency vs tau decay vertex position

For various tau energies



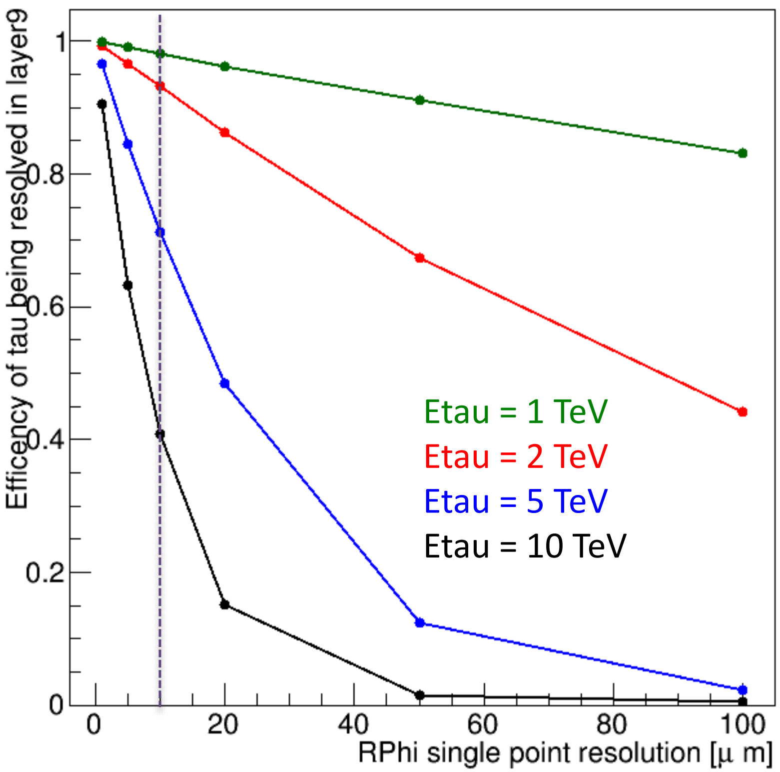
- For 10 TeV taus decaying before the beampipe: ~**60% efficiency** only due to the small **opening angle** between decay products
  - Could be improved by using higher detector **granularity**
- Efficiency drops in R due to tau displaced decay
  - Could one **use** the **tau track** in the vertex detector as an extra handle for identification?
- **No significant inneficiency for taus of E < 1 TeV**

Efficiency vs detector single point resolution

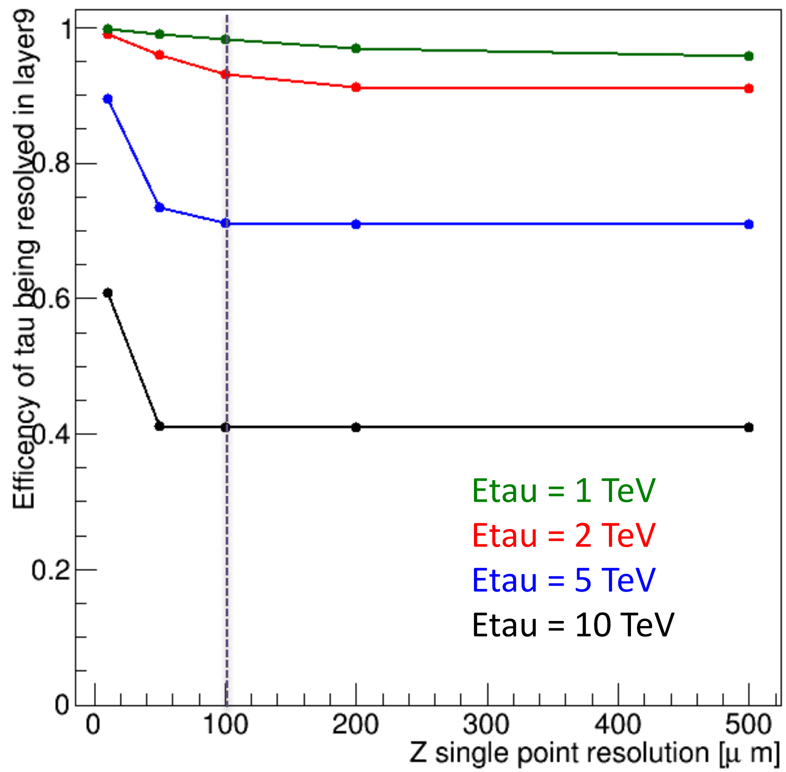
Assuming: pixel pitch = single point resolution * √12

Vertical line shows the default 10x100 [µm]

(Z single point resolution = 100 µ m)



(RPhi single point resolution = 10 µ m)

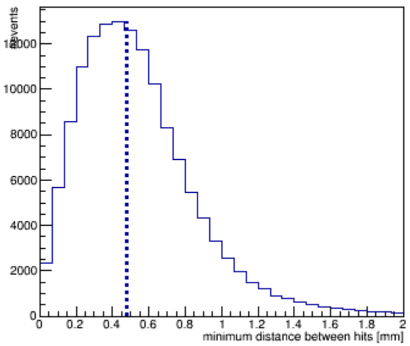


- Rapid change with pixel pitch (single point resolution), specially for highest energy taus
- In the current design, efficiency driven by RPhi. Not much gain by improving Z resolution unless comparable to RPhi.

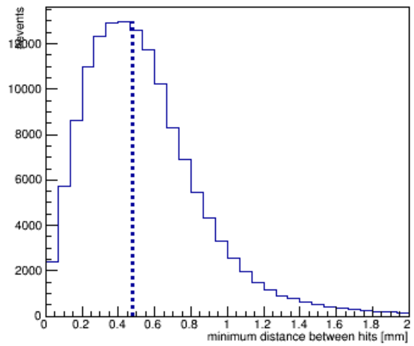
Endcap region

- Assume: 10x100 [µm] single point resolution
- Assume: pixel pitch = single point resolution * √12
- → if ΔRPhi(u) > 2 * 10 µm * √12 or ΔR(v) > 2 * 100 µm * √12 ; pass

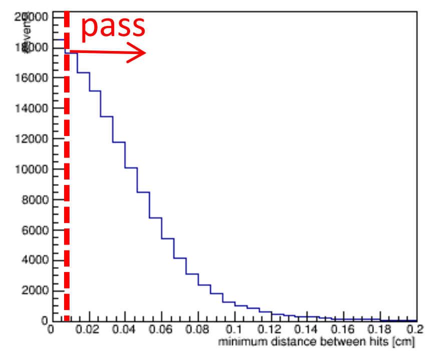
3D distance



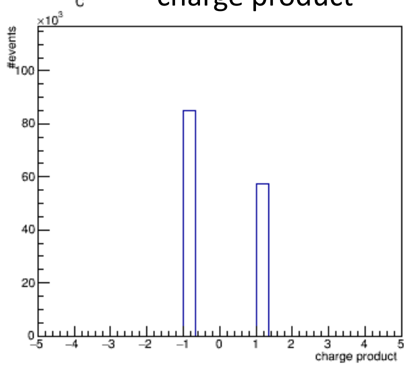
distance in RPhi



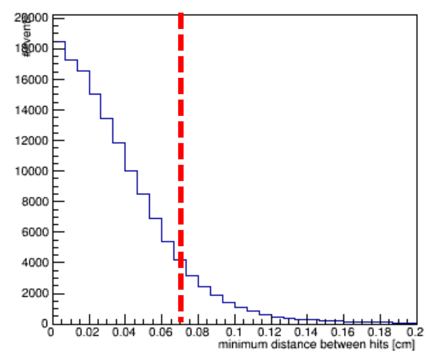
distance in u



charge product



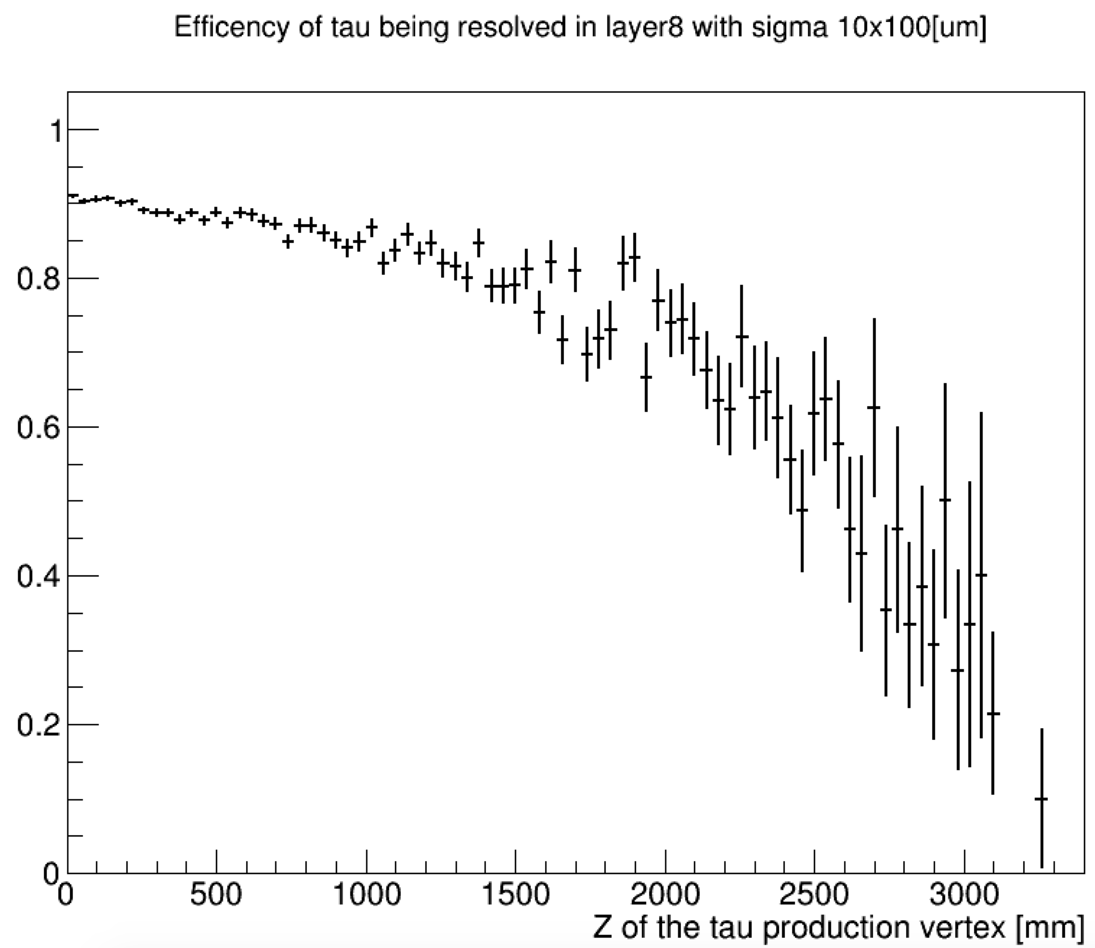
distance in v



(module local coordinates)

- Forward tau of E=10 TeV decaying before 8th endcap disk (99.9% acceptance)
  - 4th-to last layer is more than 3 times further out
- efficiency > 85% (acceptance not included)
- → Endcaps much less problematic due to longer lever arm

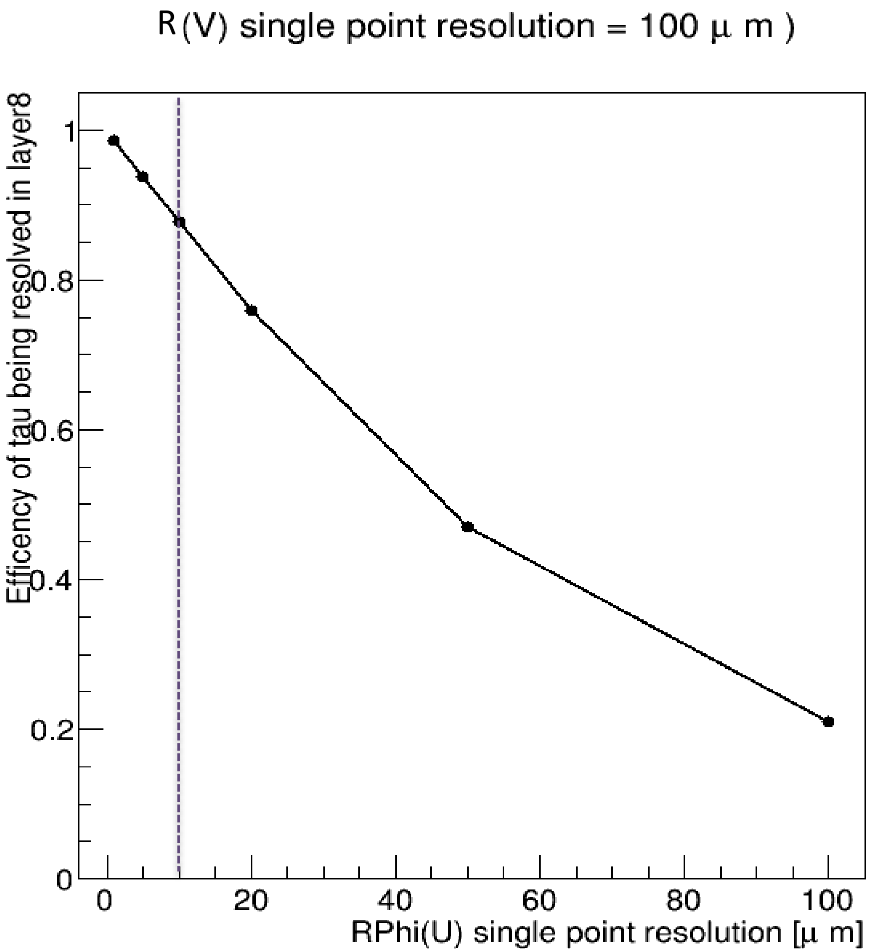
Efficiency vs tau decay vertex position

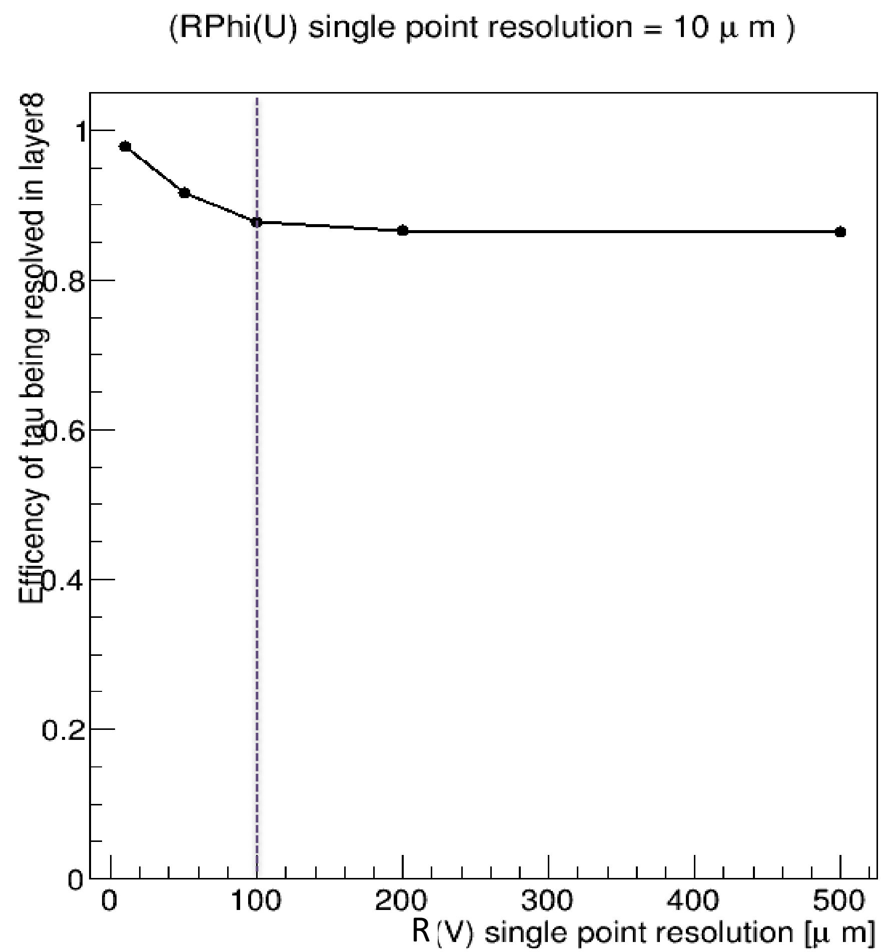


Etau=10TeV

For taus decaying in the beampipe, efficiency close to 90%

Efficiency vs detector single point resolution



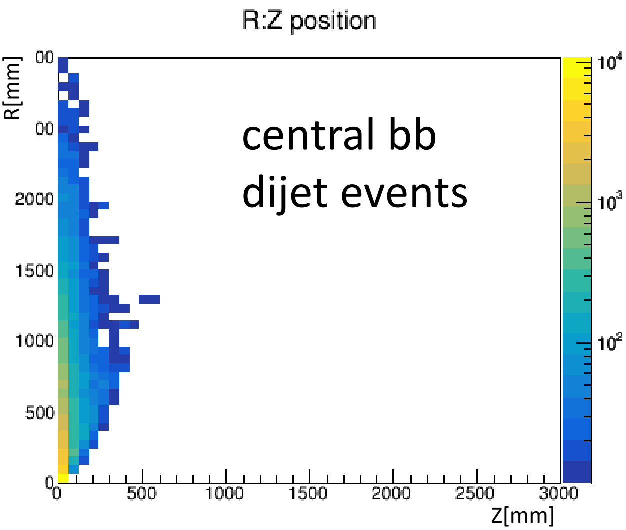


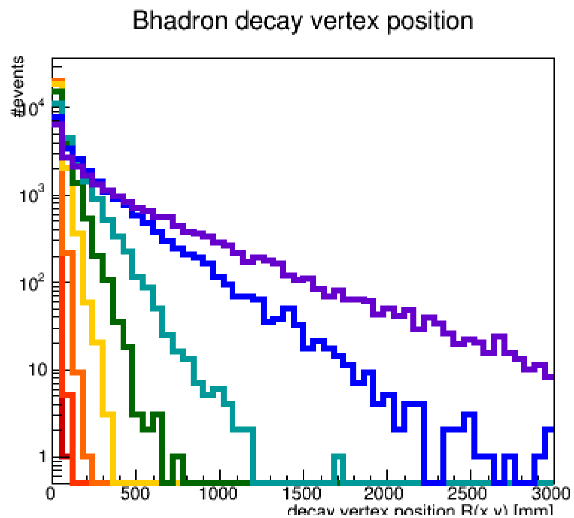
An improve in granularity would not be so helpful for the endcap

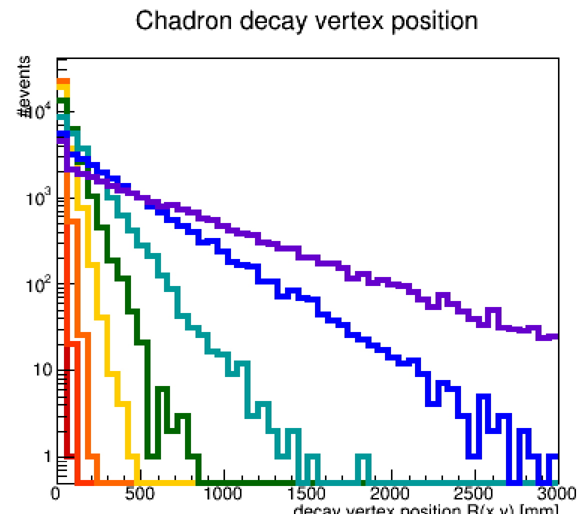
B-jets

pT(Bjet)=10 TeV
pT(Bjet)=5 TeV
pT(Bjet)=2 TeV
pT(Bjet)=1 TeV
pT(Bjet)=500 GeV
pT(Bjet)=200 GeV
pT(Bjet)=100 GeV
pT(Bjet)=50 GeV

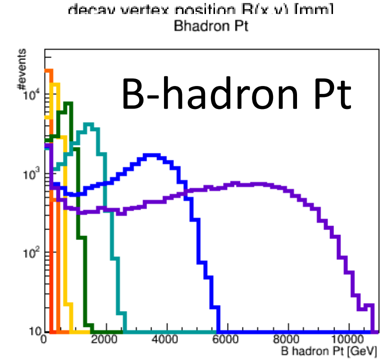
- Similarly, study the long-lived hadrons in a B-jet
- Select B-hadrons as well as their C-hadron daughters
- For different b-jet energies, use bb dijet events in the barrel

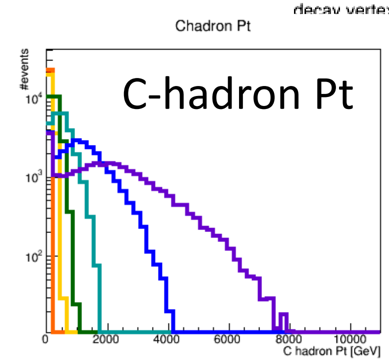




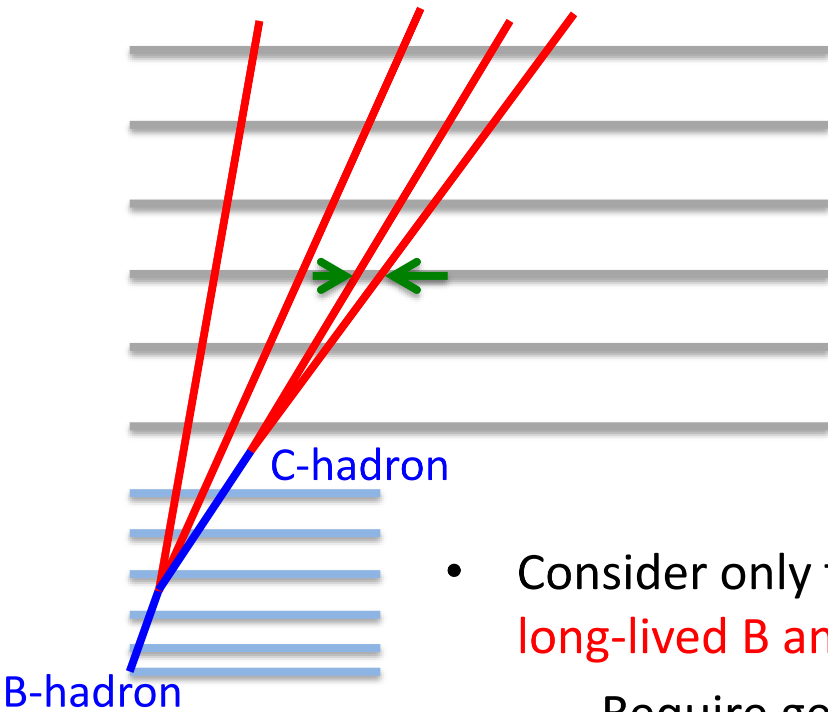


Hadrons not mono-energetic → flight distance distribution deviates from straight line.





Efficiency definition (II)

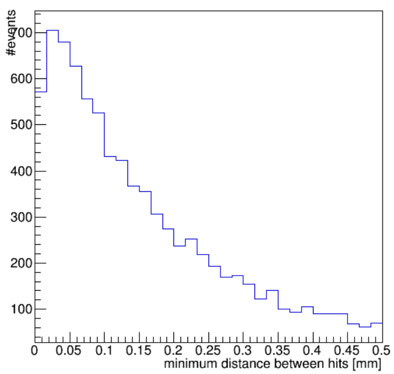


- Consider only the hits produced by the daughters of the long-lived B and C-hadrons
  - Require generator status==1
- Assume: we need to separate the closest pair of daughters
- → Consider the closest pair of hits in the 4th-to-last layer

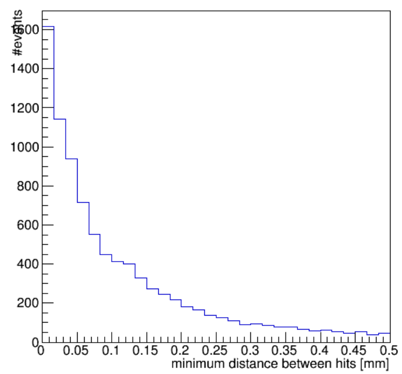
Efficiency definition (III)

- Assume: 10x100 [μm] single point resolution

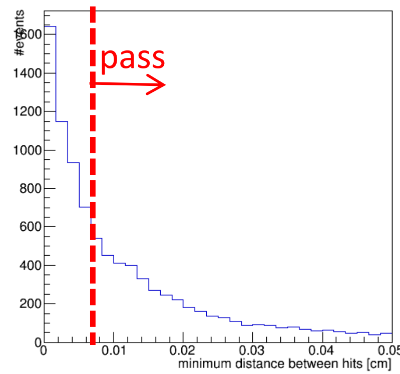
3D distance



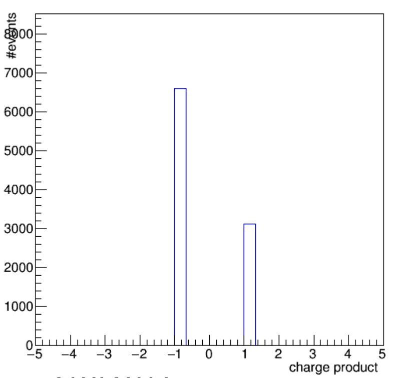
distance in RPhi



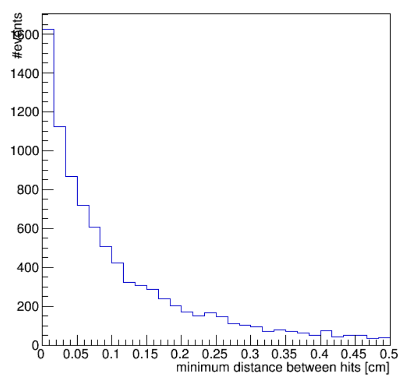
distance in u



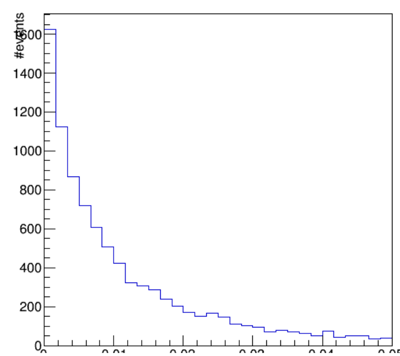
charge product



distance in Z



distance in v



(module local coordinates)

B-jet of pT=10 TeV

Distance between the closest daughters hits in the 9th barrel layer (88% acceptance)

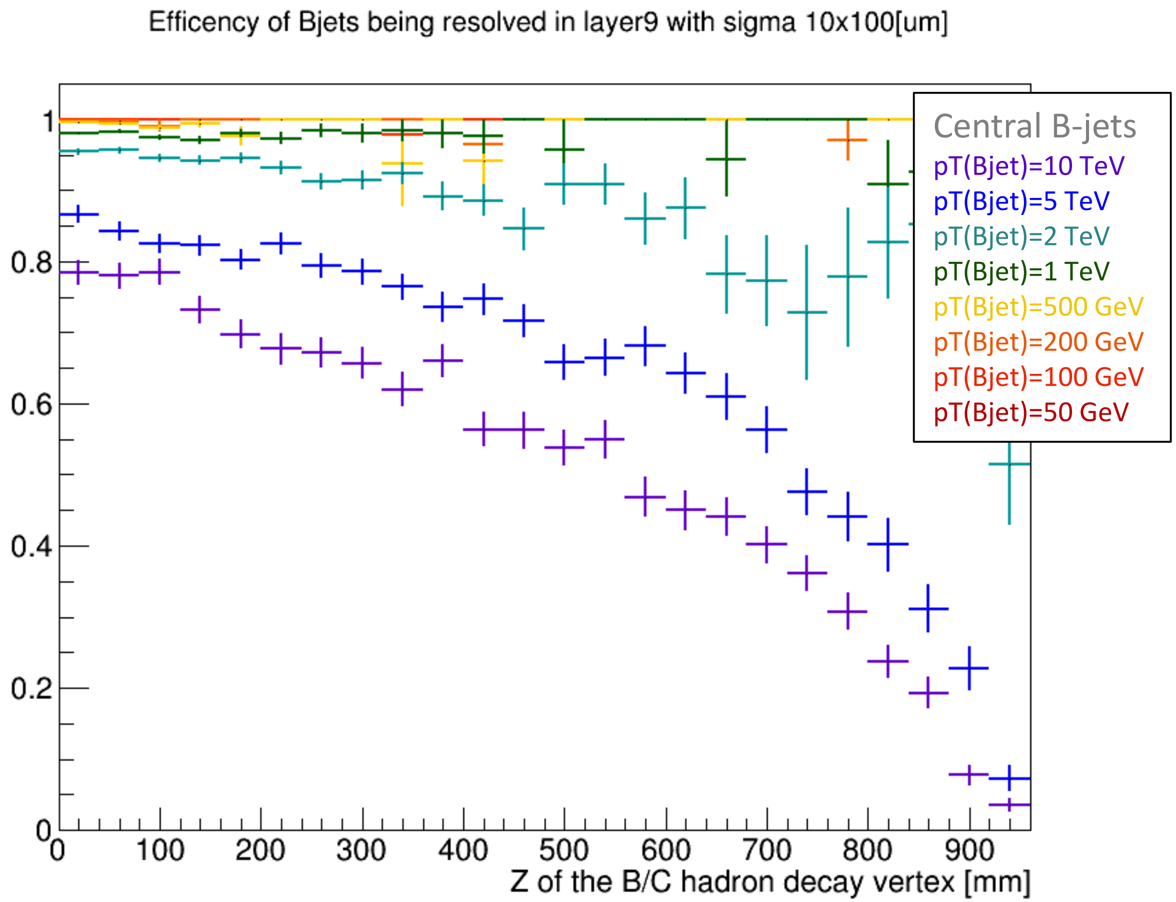
Quite similar to 10 TeV taus :

54% efficiency (acceptance not included)

(efficiency higher since actual B/C-hadron energy is lower)

Efficiency vs decay vertex position

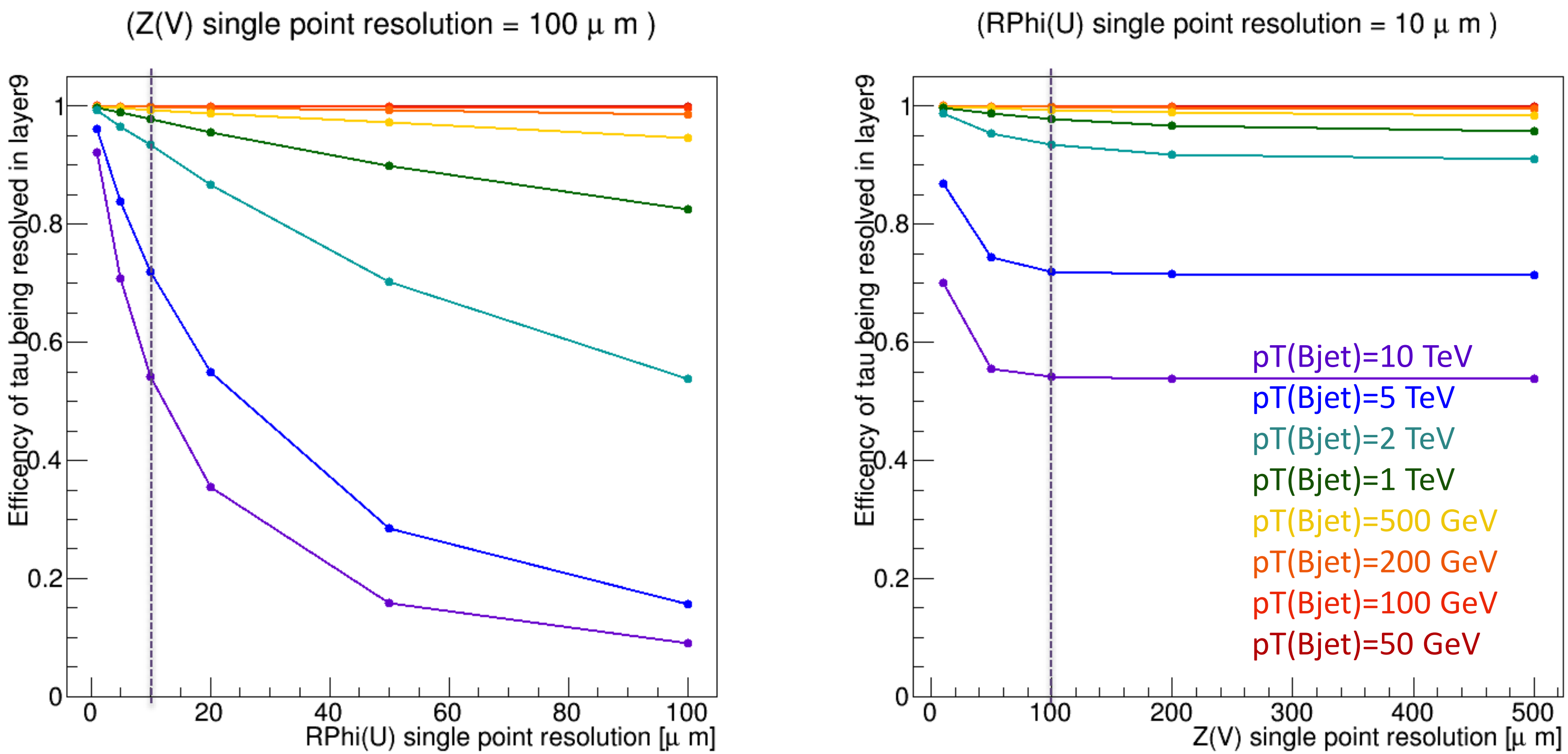
For various B-jet energies



- For 10 TeV B-jets, with B or C-hadrons decaying before the beampipe: ~**80% efficiency** only due to the small opening angle between decay products
- No significant inneficiency for B-jets of Pt < 1 TeV

Efficiency vs detector single point resolution

Vertical line shows the default 10x100 [μm]



- Improving resolution in RPhi by a factor of 2 would mean efficiency 55%→70% for 10 TeV b-jets

Conclusions

- The **current granularity is suitable for E=1TeV 3-prong taus and for Pt=1 TeV b-jets**
- The efficiency of reconstructing all the charged daughters of a central:
  - 3-prong tau (E tau = 10 GeV) is about 40%
  - B-hadron (from a Pt=10 TeV b-jet) is about 55%
- If we want to increase this efficiency, we could improve the RPhi granularity of the strips in the barrel
- This problem is less important in the endcaps (efficiency > 85%) since we have a larger lever arm

Backup

B jets acceptance

- B hadrons

E(Bjet)=50 GeV ,B Fraction up to R=20 [mm]: 0.996848
E(Bjet)=100 GeV ,B Fraction up to R=20 [mm]: 0.959081
E(Bjet)=200 GeV ,B Fraction up to R=20 [mm]: 0.829957
E(Bjet)=500 GeV ,B Fraction up to R=20 [mm]: 0.583421
E(Bjet)=1000 GeV ,B Fraction up to R=20 [mm]: 0.398114
E(Bjet)=2000 GeV ,B Fraction up to R=20 [mm]: 0.275022
E(Bjet)=5000 GeV ,B Fraction up to R=20 [mm]: 0.192235
E(Bjet)=10000 GeV ,B Fraction up to R=20 [mm]: 0.161509

E(Bjet)=1000 GeV ,B Fraction up to R=925 [mm]: 1
E(Bjet)=2000 GeV ,B Fraction up to R=925 [mm]: 0.999217
E(Bjet)=5000 GeV ,B Fraction up to R=925 [mm]: 0.965865
E(Bjet)=10000 GeV ,B Fraction up to R=925 [mm]: 0.875244

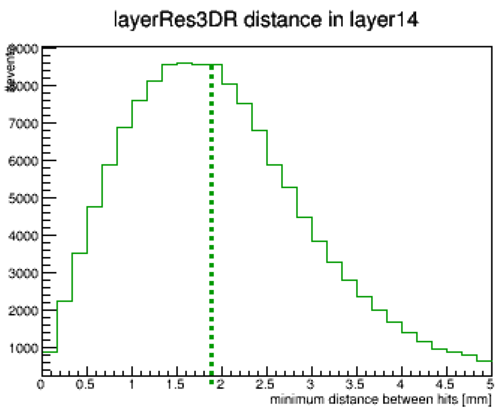
B jets acceptance

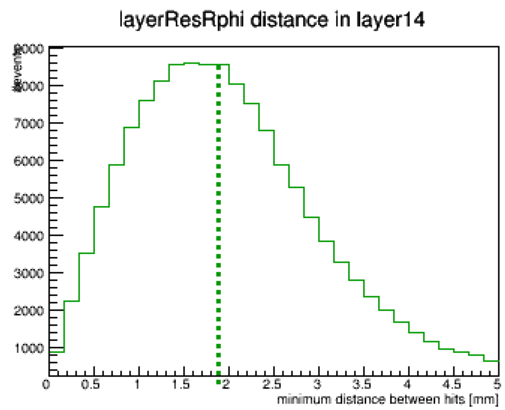
- C hadrons

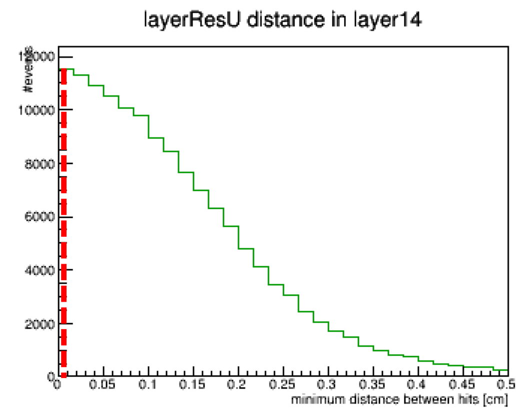
E(Bjet)=50 GeV ,C Fraction up to R=20 [mm]: 0.991606
E(Bjet)=100 GeV ,C Fraction up to R=20 [mm]: 0.92315
E(Bjet)=200 GeV ,C Fraction up to R=20 [mm]: 0.719064
E(Bjet)=500 GeV ,C Fraction up to R=20 [mm]: 0.407441
E(Bjet)=1000 GeV ,C Fraction up to R=20 [mm]: 0.233609
E(Bjet)=2000 GeV ,C Fraction up to R=20 [mm]: 0.147122
E(Bjet)=5000 GeV ,C Fraction up to R=20 [mm]: 0.113189
E(Bjet)=10000 GeV ,C Fraction up to R=20 [mm]: 0.102258

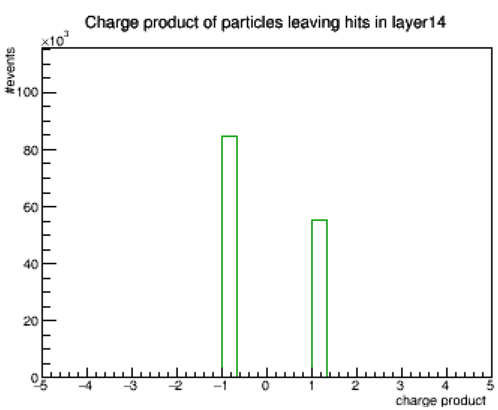
E(Bjet)=1000 GeV ,C Fraction up to R=925 [mm]: 1
E(Bjet)=2000 GeV ,C Fraction up to R=925 [mm]: 0.997447
E(Bjet)=5000 GeV ,C Fraction up to R=925 [mm]: 0.934408
E(Bjet)=10000 GeV ,C Fraction up to R=925 [mm]: 0.793054

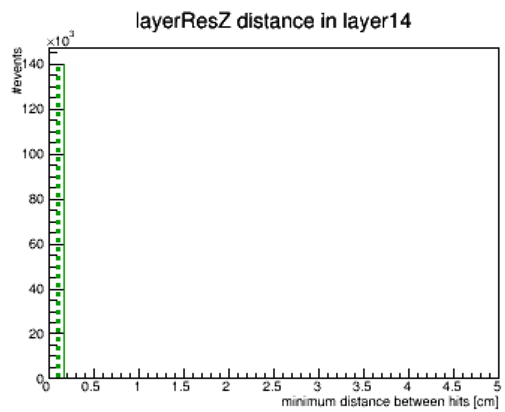
Forward region

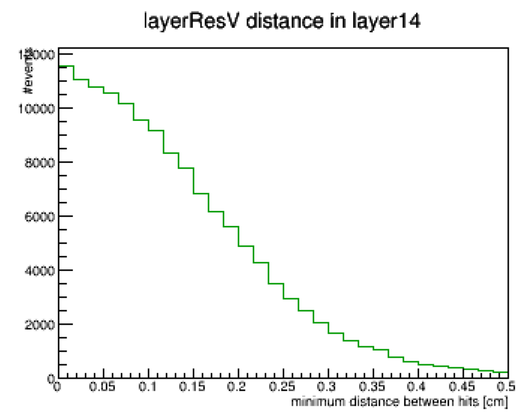


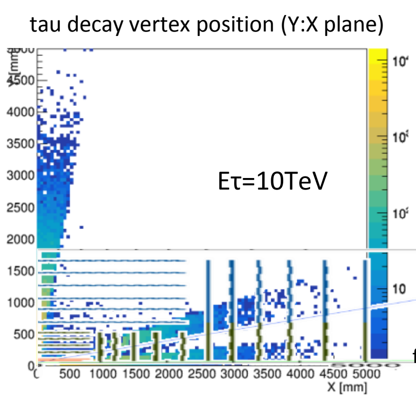




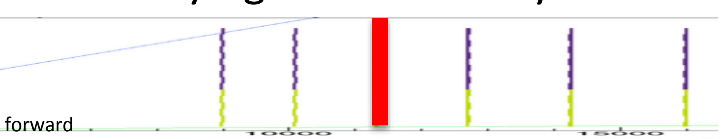




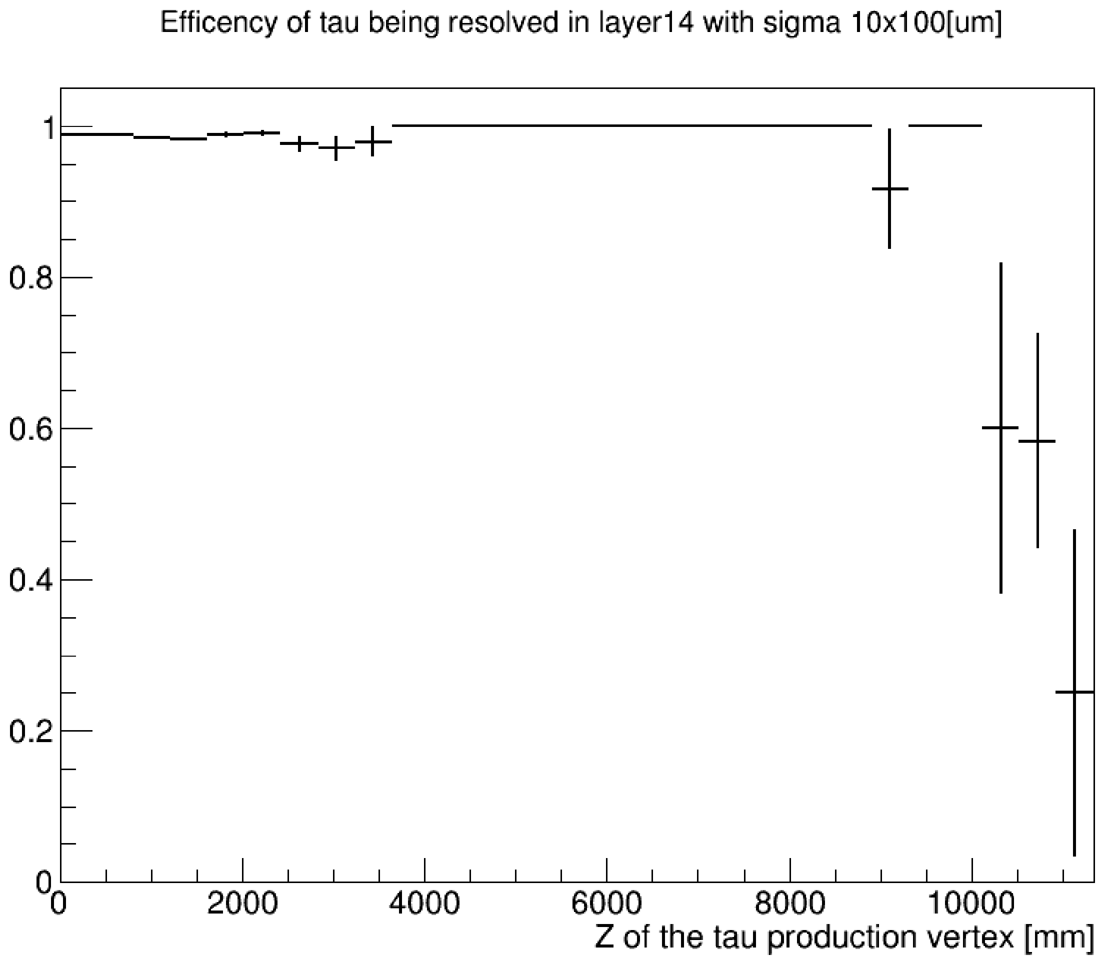




fraction of E=10TeV taus decaying before this layer = 1



Efficiency vs tau decay vertex position



Efficiency vs detector single point resolution