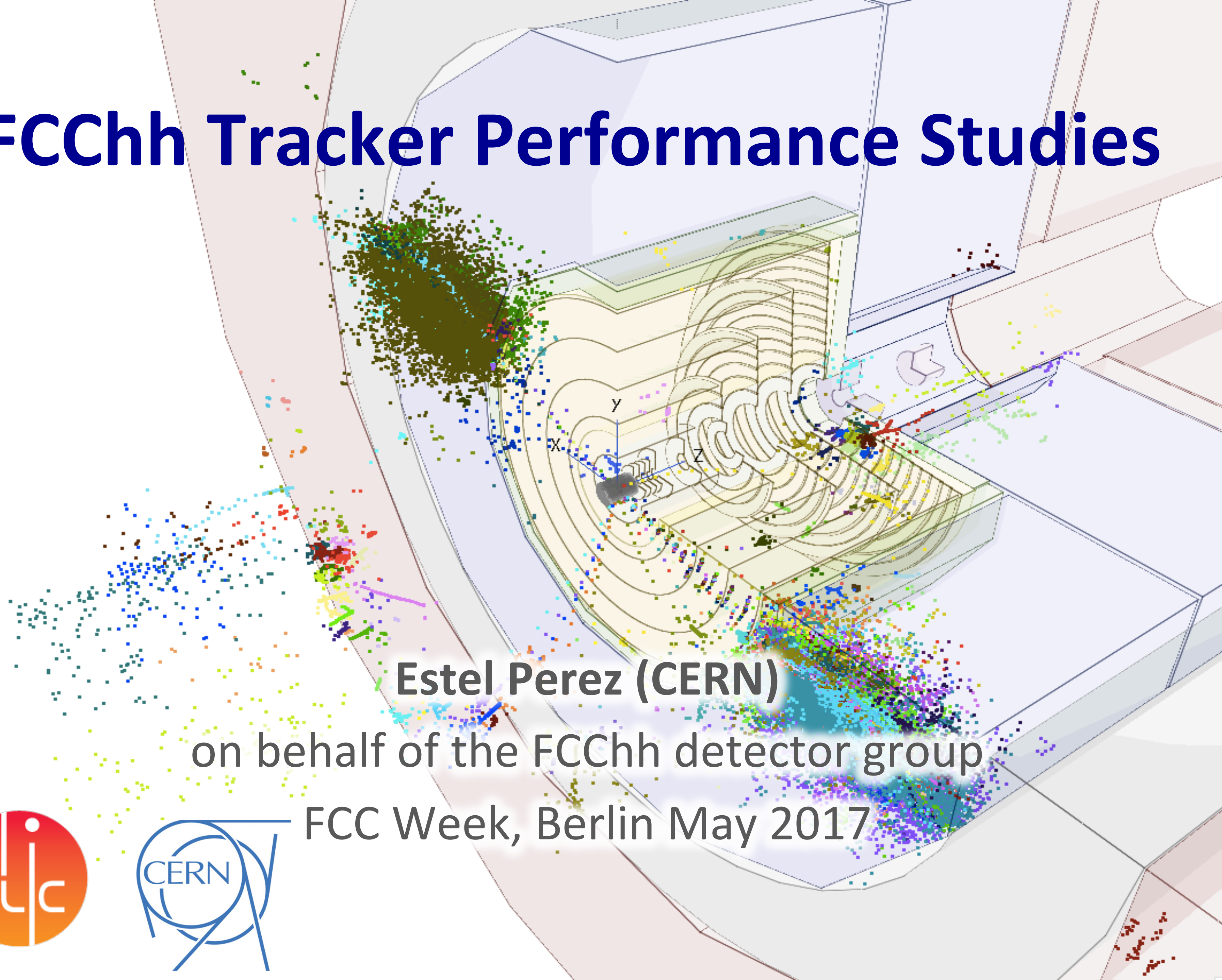
FCChh Tracker Performance Studies



Estel Perez (CERN)

on behalf of the FCChh detector group

FCC Week, Berlin May 2017

Introduction and Outline

- Goal: show performance studies leading to changes in the FCChh detector design

1. Tools and validation
2. Pattern recognition studies
   - dependence on detector layout, material and granularity
3. Reconstruction of boosted objects
   - dependence on granularity
4. Flavor tagging performance
   - dependence on granularity, material, jet energy

Tools

- Different software tools were required for the various performance studies:

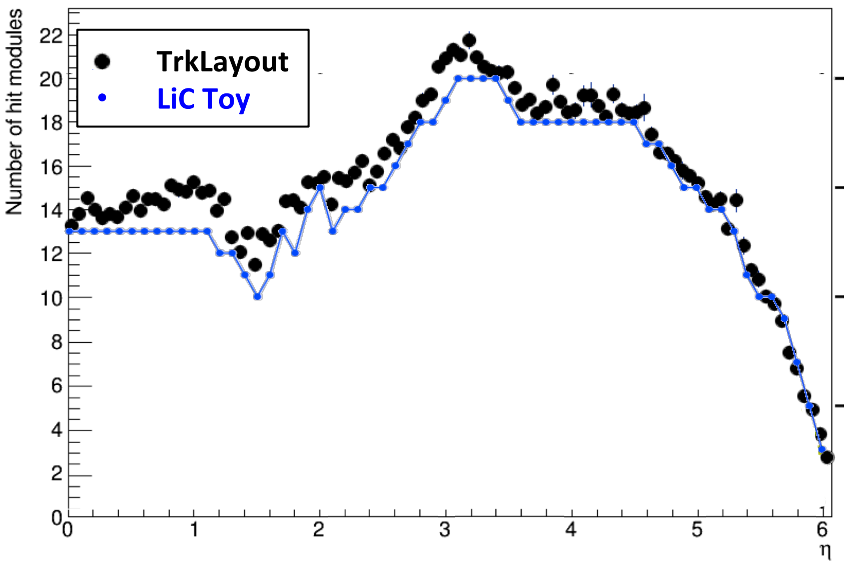
Software previously used by	**tkLayout*** (CMS)	**LicToy** (ILC, CLIC)	**CLIC SW** (CLIC)	**SiD SW** (SiD, CLIC)
Simulation	Fast analytic method to compute covariance matrix	Fast full track reconstruction, outside-in	Full pattern recognition	Full full reconstruction chain
used for studying	**pattern recognition**	**pattern recognition**	**boosted objects**	**flavor tagging**
geometry	v3.00	v3.00	v3.01	v3.02

- Validated the different tools against each other

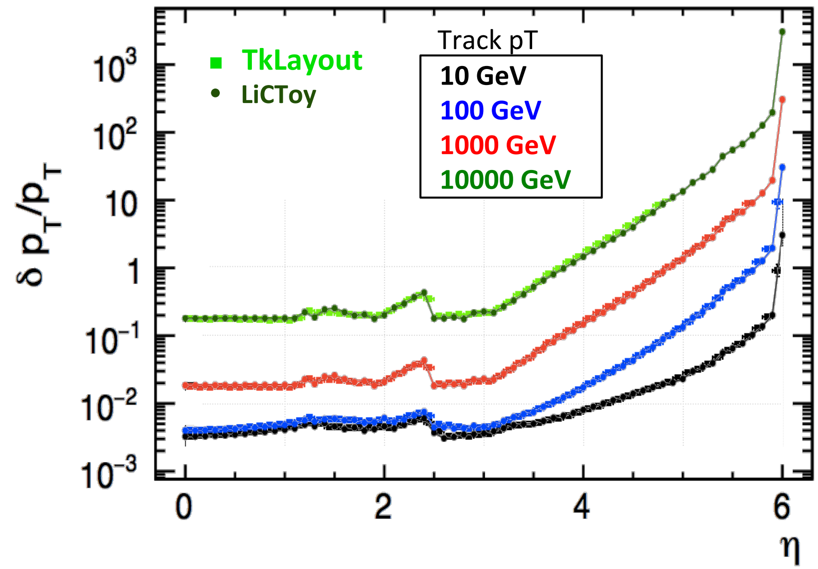
*see Valentin Volkl's talk

Validation of tkLayout against LiCToy

Number of modules with at least one hit



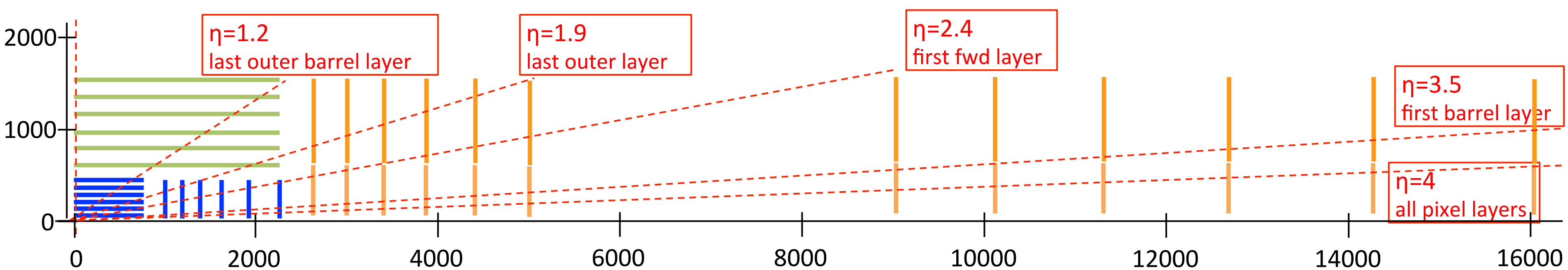
pT resolution



Small differences due to tkLayout allowing several hits per layer

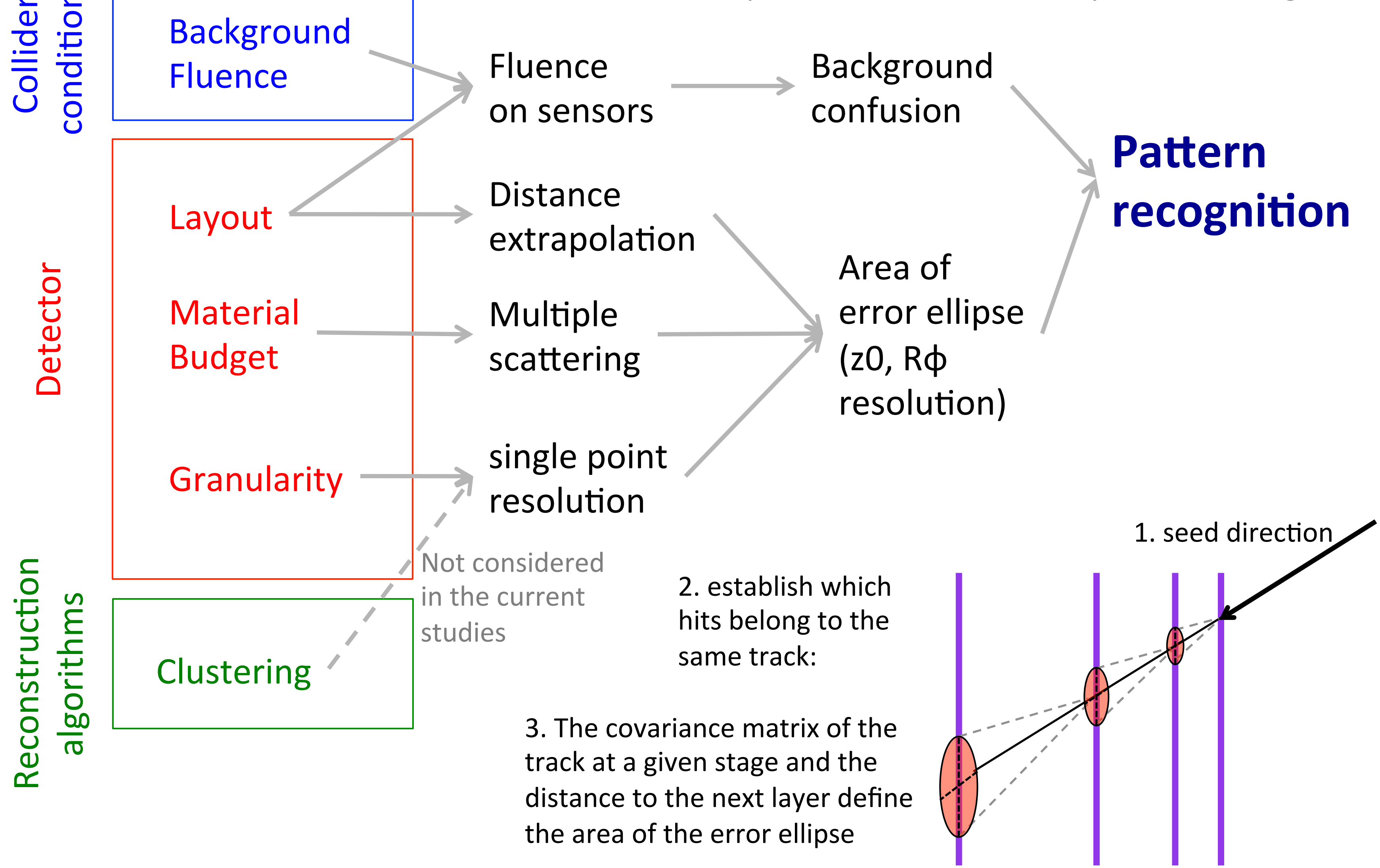
Very good agreement in the pT resolution at all pTs

Nhits and Resolution reflects the layout structure, the **two tools give consistent results**

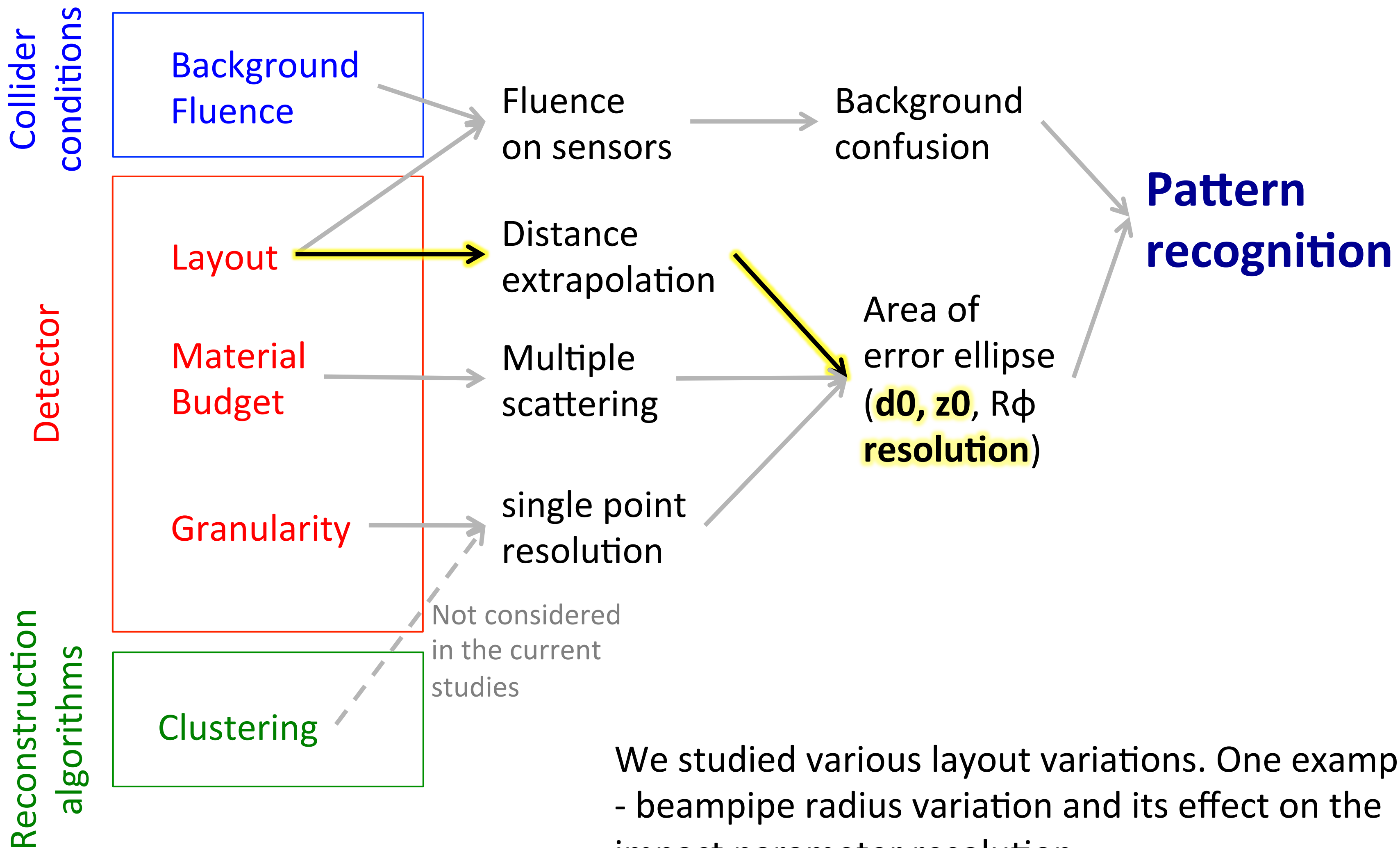


Pattern recognition studies

Technique to study in fast simulation how the detector parameters affect the pattern recognition:



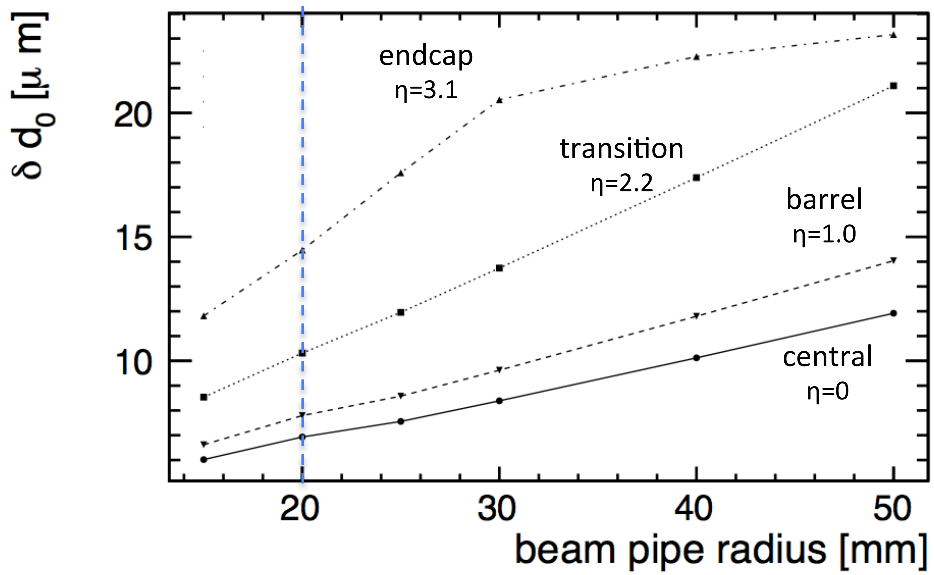
Pattern recognition studies

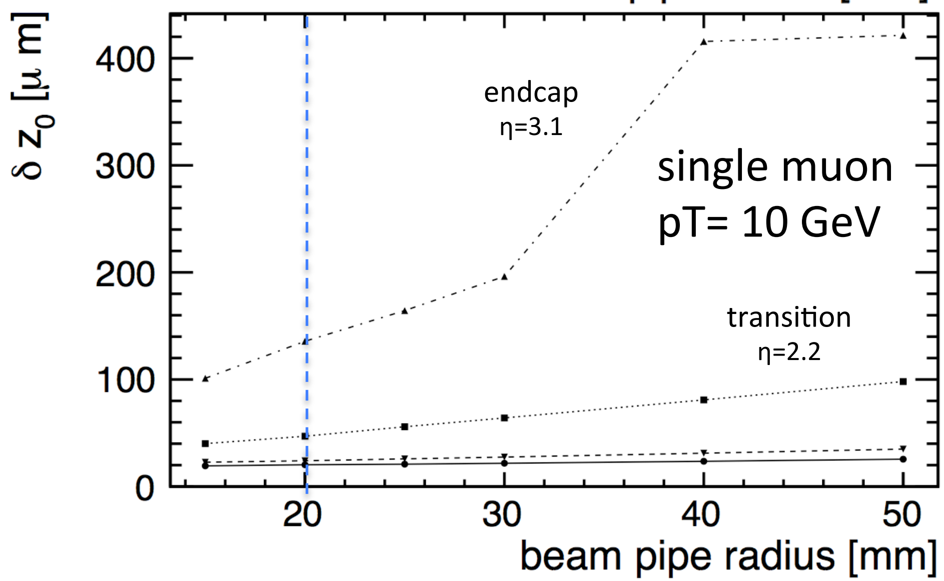


We studied various layout variations. One example:
- beampipe radius variation and its effect on the impact parameter resolution

Dependence of the impact parameter resolution on the beampipe radius

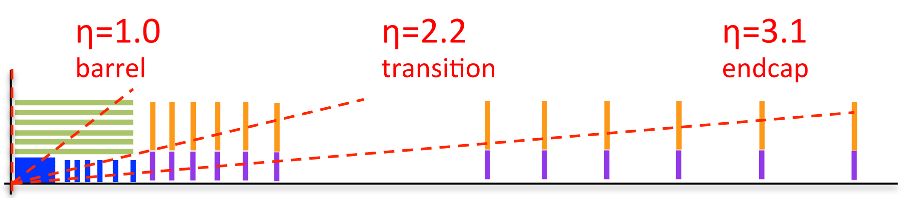
Default radius: 20 mm



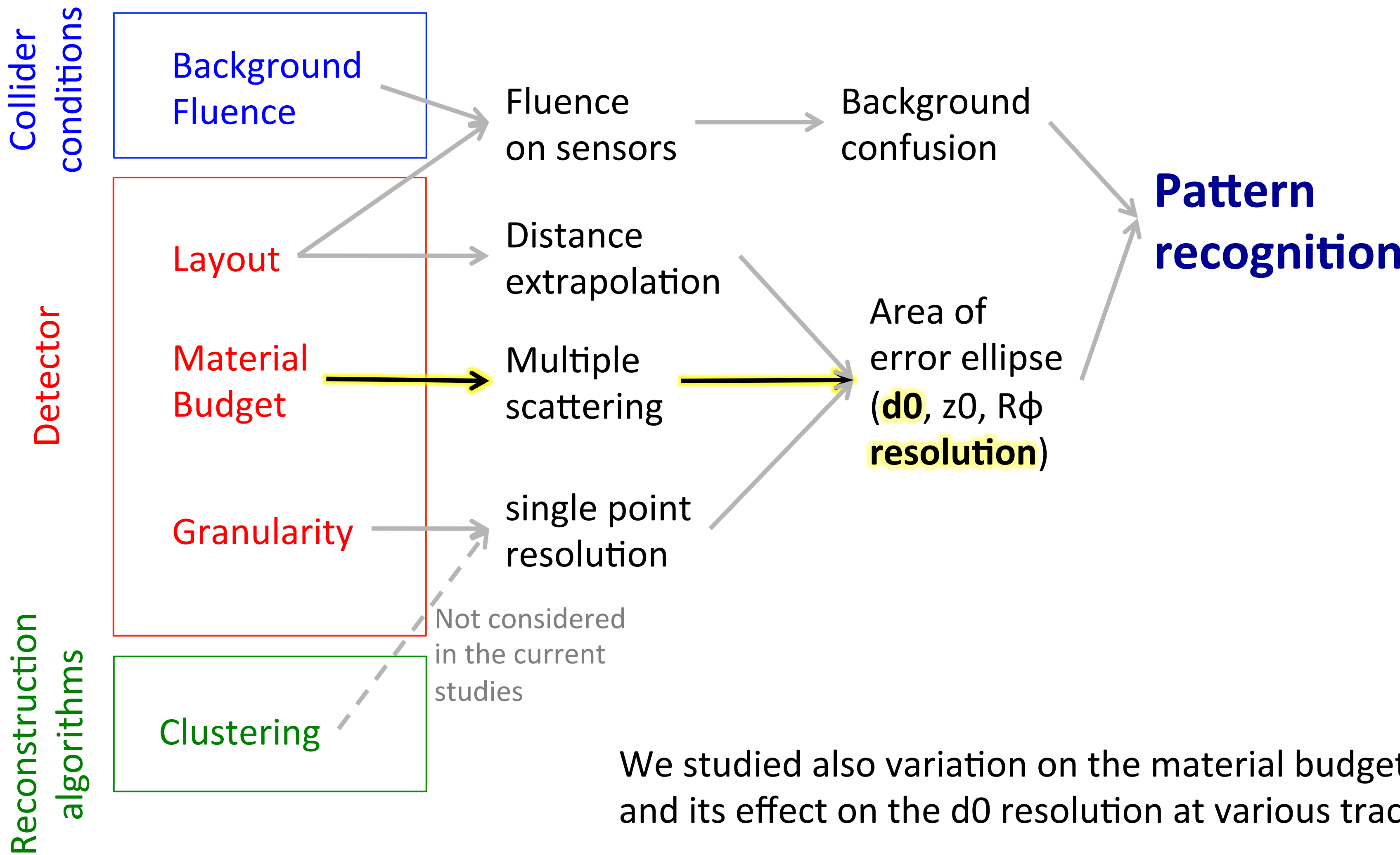


By increasing the beampipe radius, the very forward particles will cross the beampipe more perpendicularly and will be less affected by multiple scattering.

Moving out the innermost barrel layer by 10mm would degrade the impact parameter resolution by 45% for very forward tracks of pT=10 GeV. → keep radius as small as possible



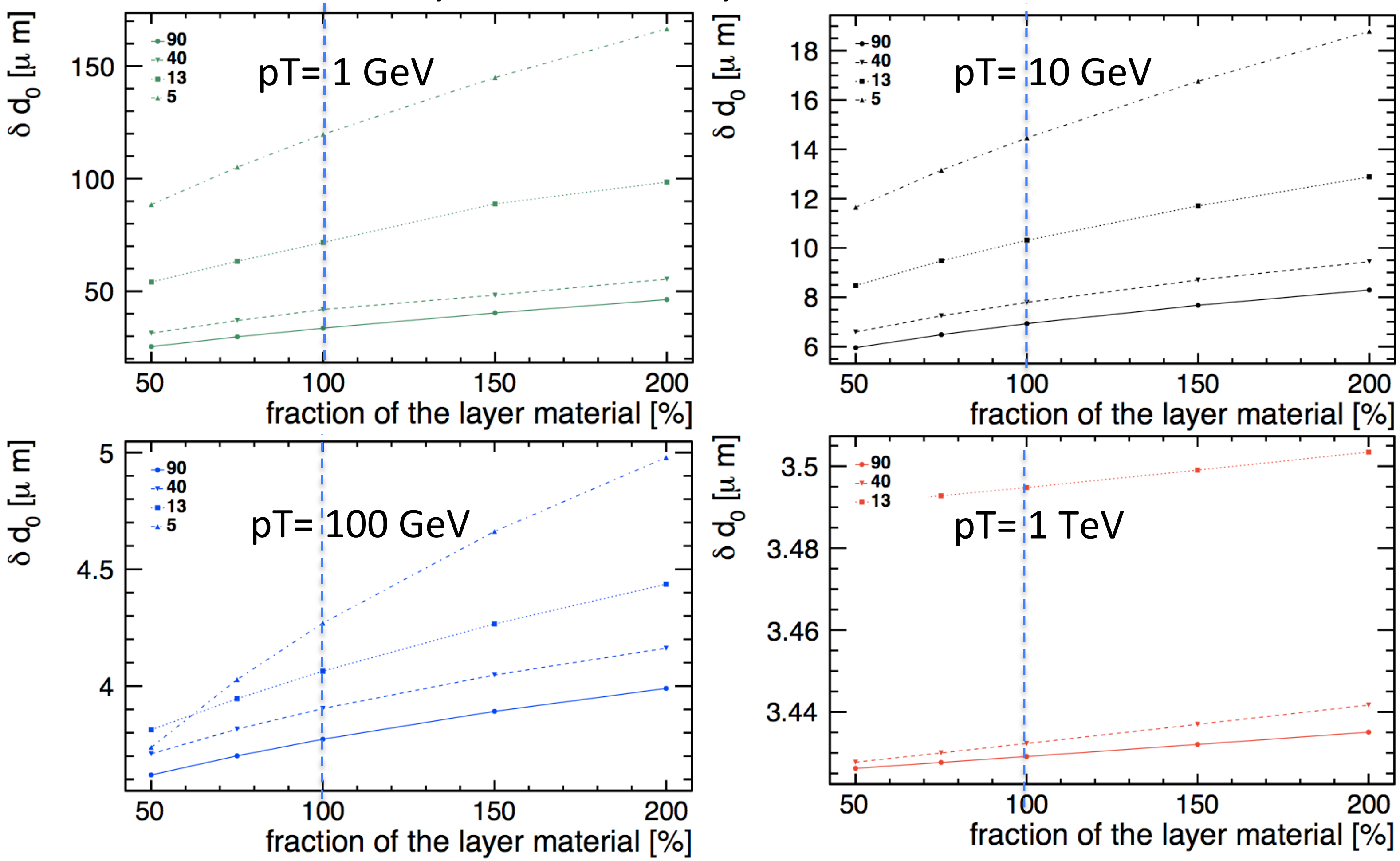
Pattern recognition studies



We studied also variation on the material budget and its effect on the d0 resolution at various track pT

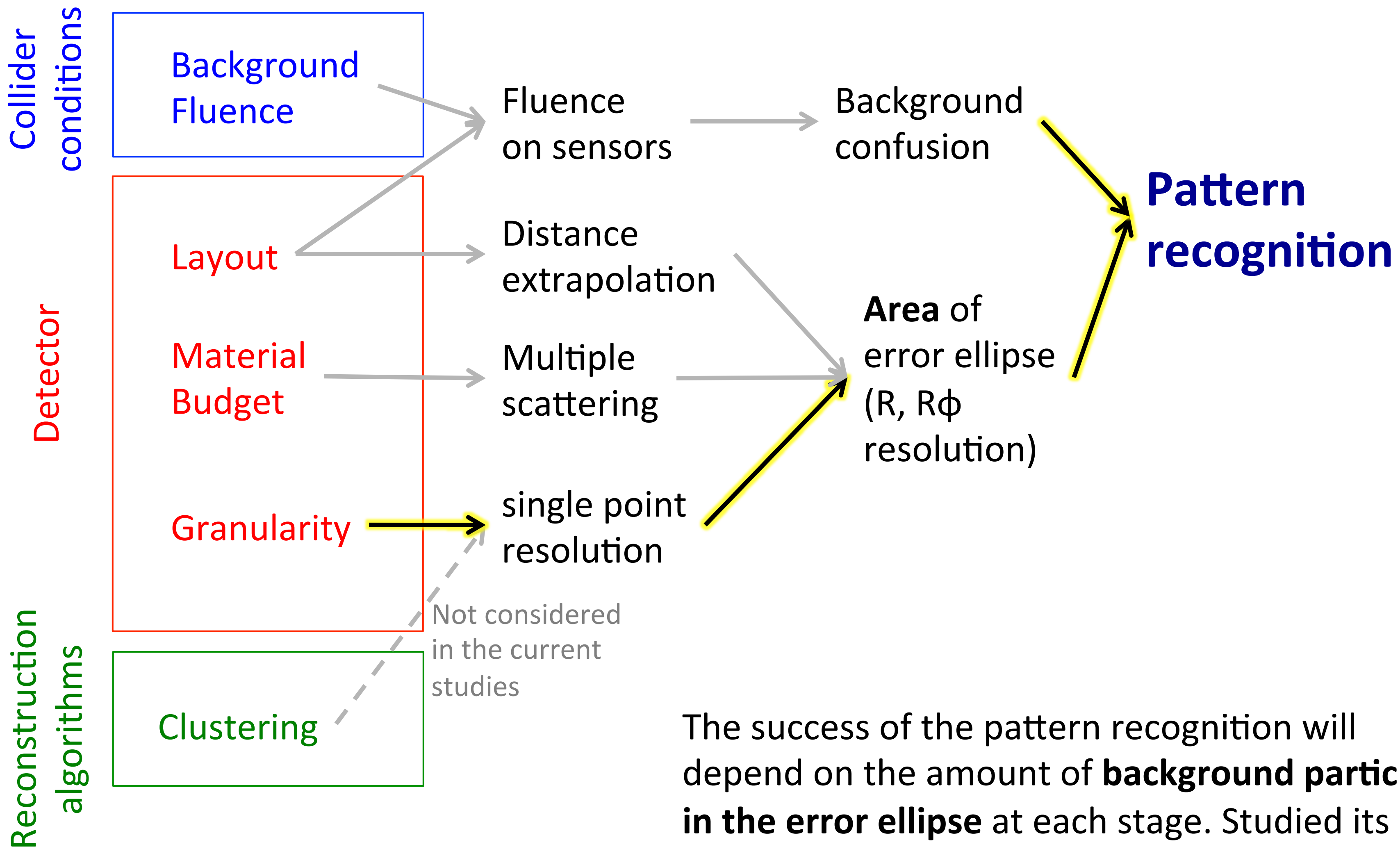
Dependence of the d0 resolution on the layers material budget

Reduce/increase all layers material by: 50%, 75%, . . , 150%, 200%



Reducing the material budget by 50% would improve the d0 resolution by 15%(4%) at pT=10GeV(100GeV)

Pattern recognition studies



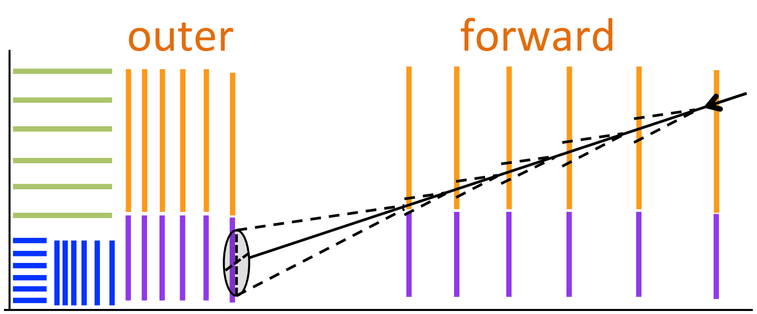
The success of the pattern recognition will depend on the amount of **background particles in the error ellipse** at each stage. Studied its dependence on the sensors granularity.

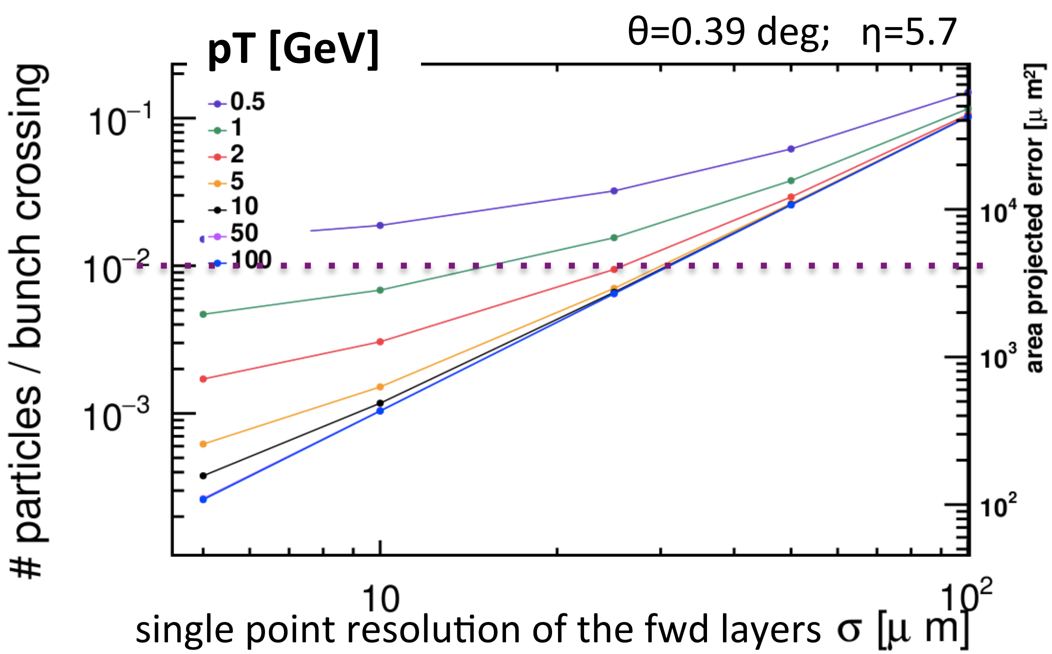
Background in the error ellipse vs granularity

 # bkg particles in error ellipse = Ellipse Area * Pile up * Fluence

Ellipse Area = ¼ $\pi\,\sigma_{R\phi}\,\sigma_z \tan\theta$
Assume # Pile up interactions per bunch crossing **=1100**
Granularity: Assume squared pixels and single point resolution = pitch/√12

Most critical stage**: extrapolation to the outer tracker**. Outside-in: depends on the **granularity of the forward disks**



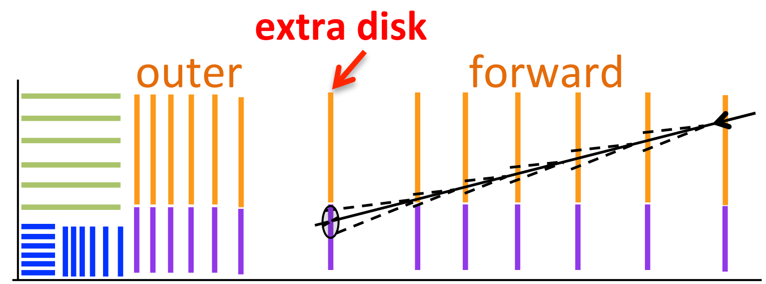


In order to have less than **0.01 background particles** per bunch crossing in the error ellipse area, **would need σ=10x10μm** single point resolution in the forward disks.
Not possible to do **patter recognition** for tracks **below pT=1 GeV** with this layout

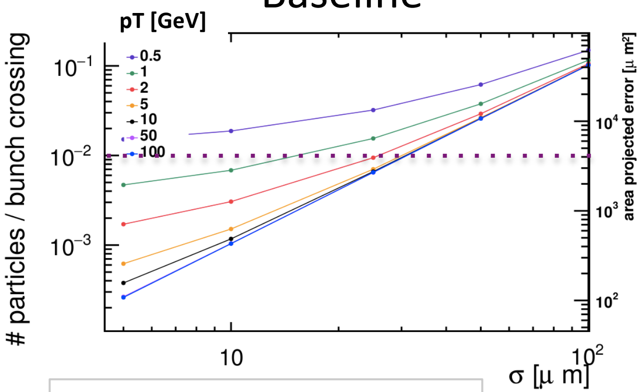
at η=5.7, pT=1 GeV → p=150 GeV

Background in the error ellipse vs layout

One can reduce the error ellipse area by adding an **intermediate disk** and thus reducing the extrapolation distance

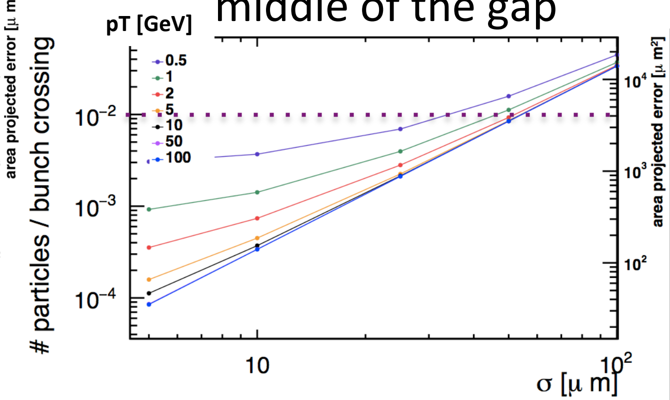


Baseline



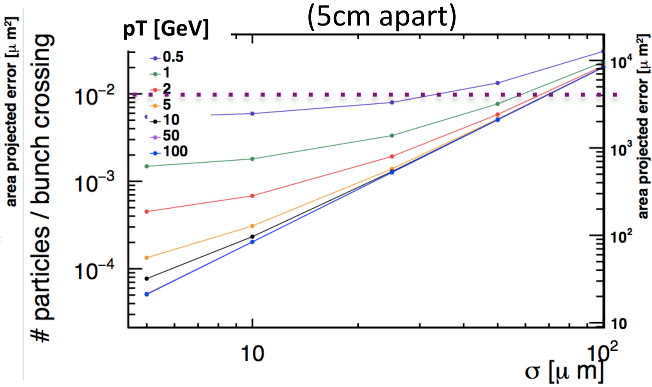
η=5.7 track
Line at # particles in the error ellipse area per BC = **0.01**
Assume #PU/BC = 1100

extra disk in the middle of the gap



→ **factor of 5 less ellipse area**

pair of extra disks in the middle of the gap
(5cm apart)



→ extra material is counter-productive for low pT tracks

By adding one **intermediate layer**, we can use **σ=25x25 μm single point resolution for the forward disks** and reconstruct tracks down to **pT=0.5 GeV**.

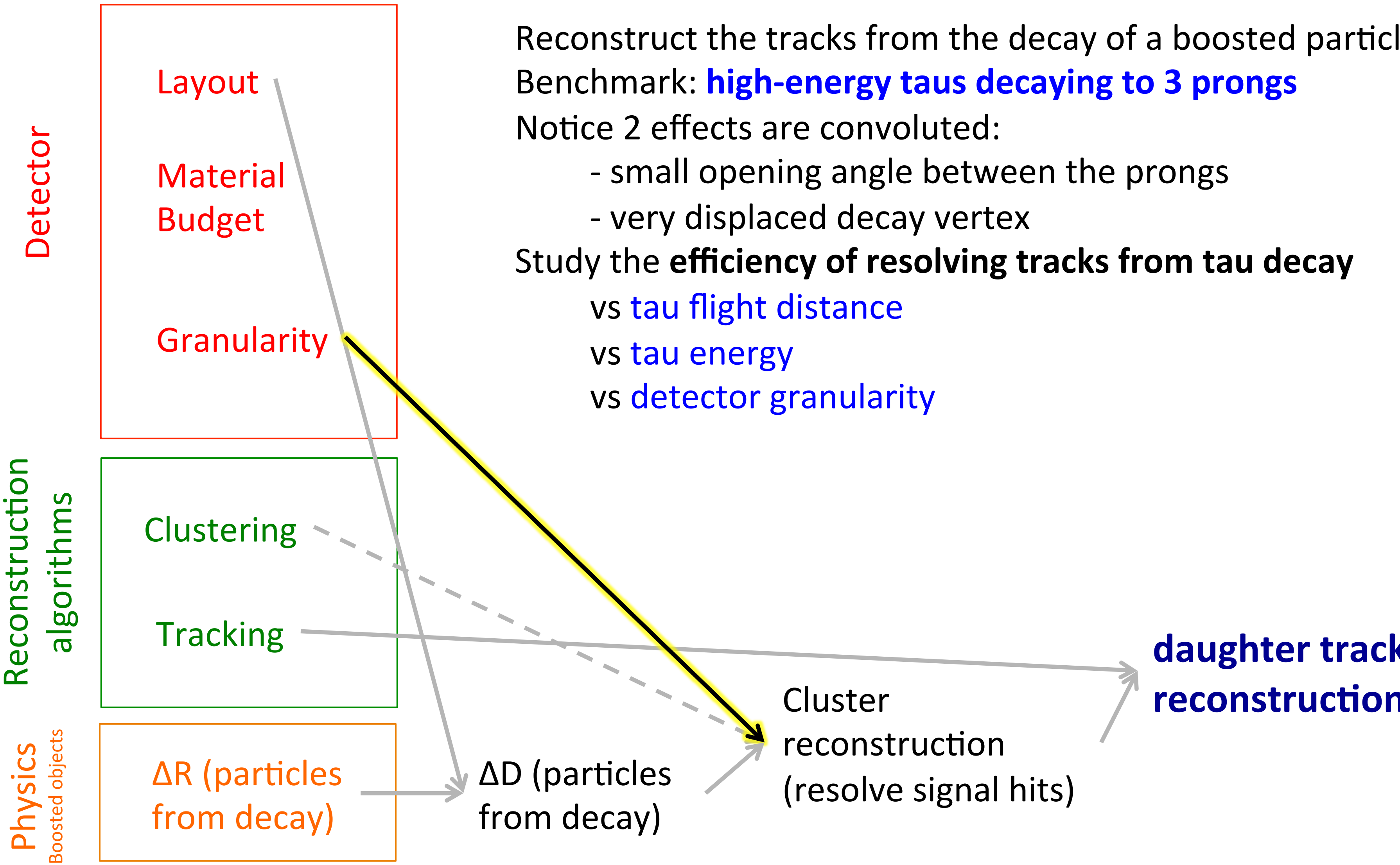
Boosted particle decay

Reconstruct the tracks from the decay of a boosted particle
Benchmark: **high-energy taus decaying to 3 prongs**
Notice 2 effects are convoluted:

- small opening angle between the prongs
- very displaced decay vertex

Study the **efficiency of resolving tracks from tau decay**

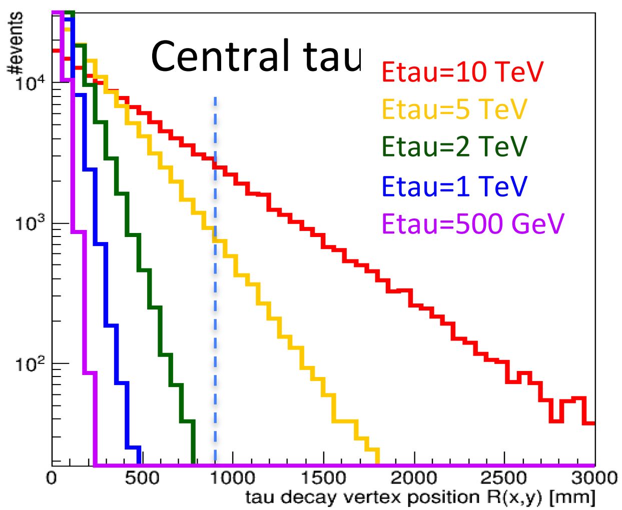
vs tau flight distance
vs tau energy
vs detector granularity



Efficiency definition

- Tracks from taus decaying too far into the detector will be impossible to reconstruct: **assume we need to resolve the hits in at least 4 layers**

tau decay vertex position



«**Acceptance**»:

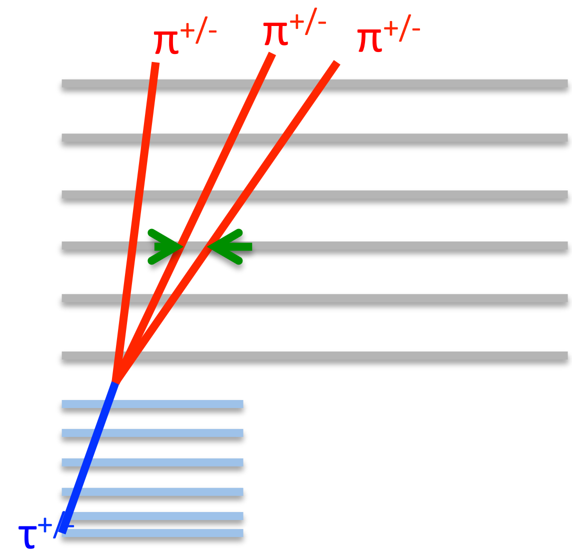
Fraction of **central** taus decaying before the **4th-to-last barrel layer**

Etau=10 TeV : 0.86

Etau=5 TeV : 0.98

Etau=2 TeV : 0.9999

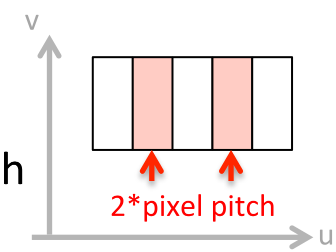
Etau=1 TeV : 1



Assume: single-hit clusters

Resolved hits = distance between two hits > 2*pixel pitch

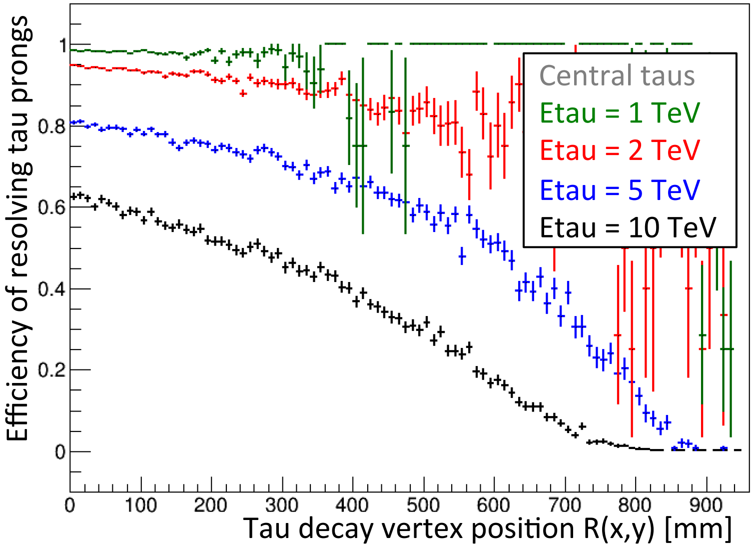
(In either the Rϕ(u) or Z(v) direction)



Efficiency = # resolved hit pairs / closest pair of pion hits in the 4th-to-last layer

Efficiency vs single point resolution

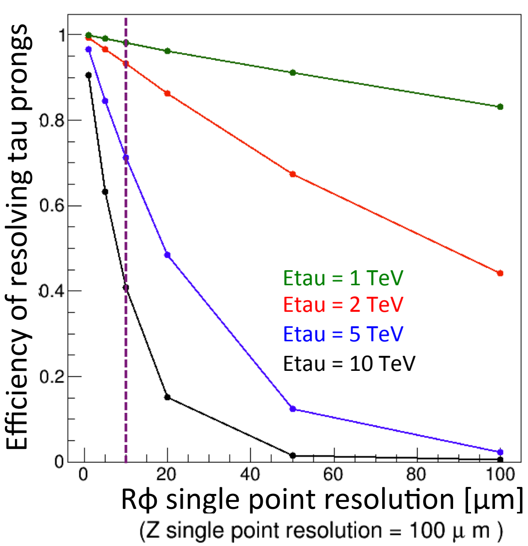
Efficiency vs decay vertex position

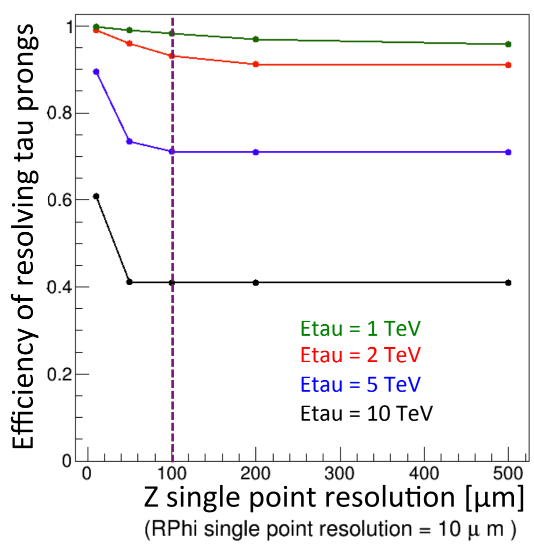


Efficiency vs tau **decay vertex position**:

- 10 TeV "prompt" taus (decaying inside the beampipe) have ~**60% efficiency** only due to the small **opening angle** between their decay products
  - Could be improved by using higher detector **granularity**
- Efficiency drops in R due to tau displaced decay

No significant inefficiency for taus of E < 1 TeV





Efficiency vs **single point resolution:**

- Strong dependence on single point resolution, specially for high energy taus
- In the current design, efficiency driven by Rϕ. Not much gain by improving Z resolution unless comparable to Rϕ.

Efficiency vs single point resolution

- Benchmark: **B-hadrons**
- Acceptance: Fraction of **central** B hadrons decaying before the **4th-to-last barrel layer**

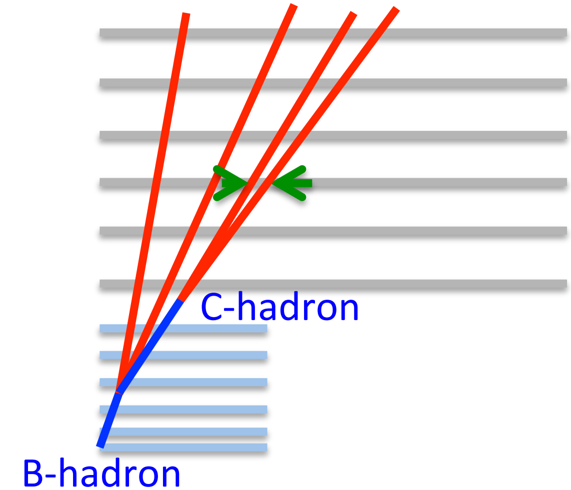
«**Acceptance**»:

$E_{b\text{-}quark}$=10 TeV : 0.88

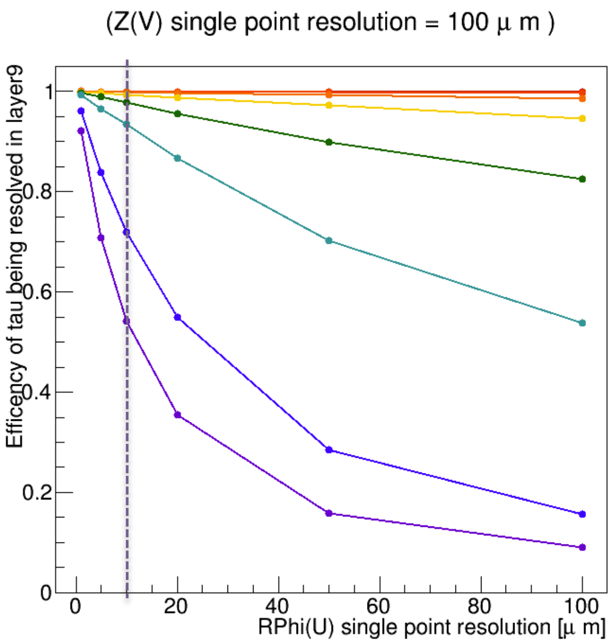
$E_{b\text{-}quark}$=5 TeV : 0.97

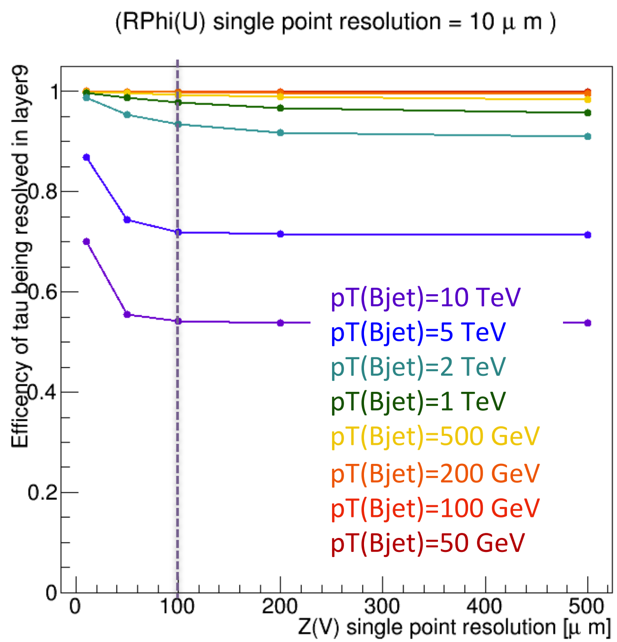
$E_{b\text{-}quark}$=2 TeV : 0.999

$E_{b\text{-}quark}$=1 TeV : 1



Vertical line shows the default 10x100 [µm] single point resolution

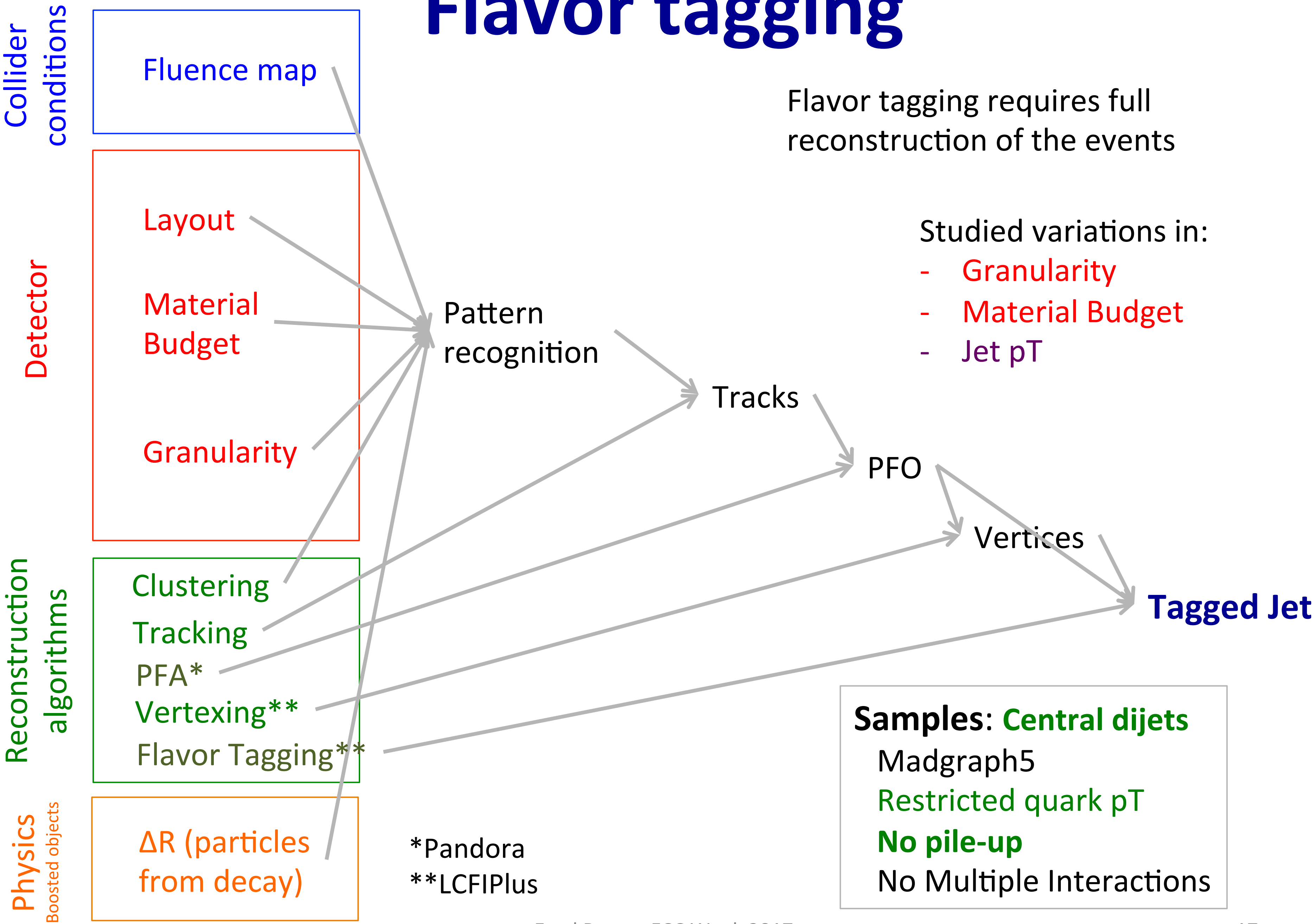




Improving the single point resolution in Rϕ by a factor of 2 would improve the **efficiency from 55%→70% for 10 TeV b-jets**

Flavor tagging

Flavor tagging requires full reconstruction of the events



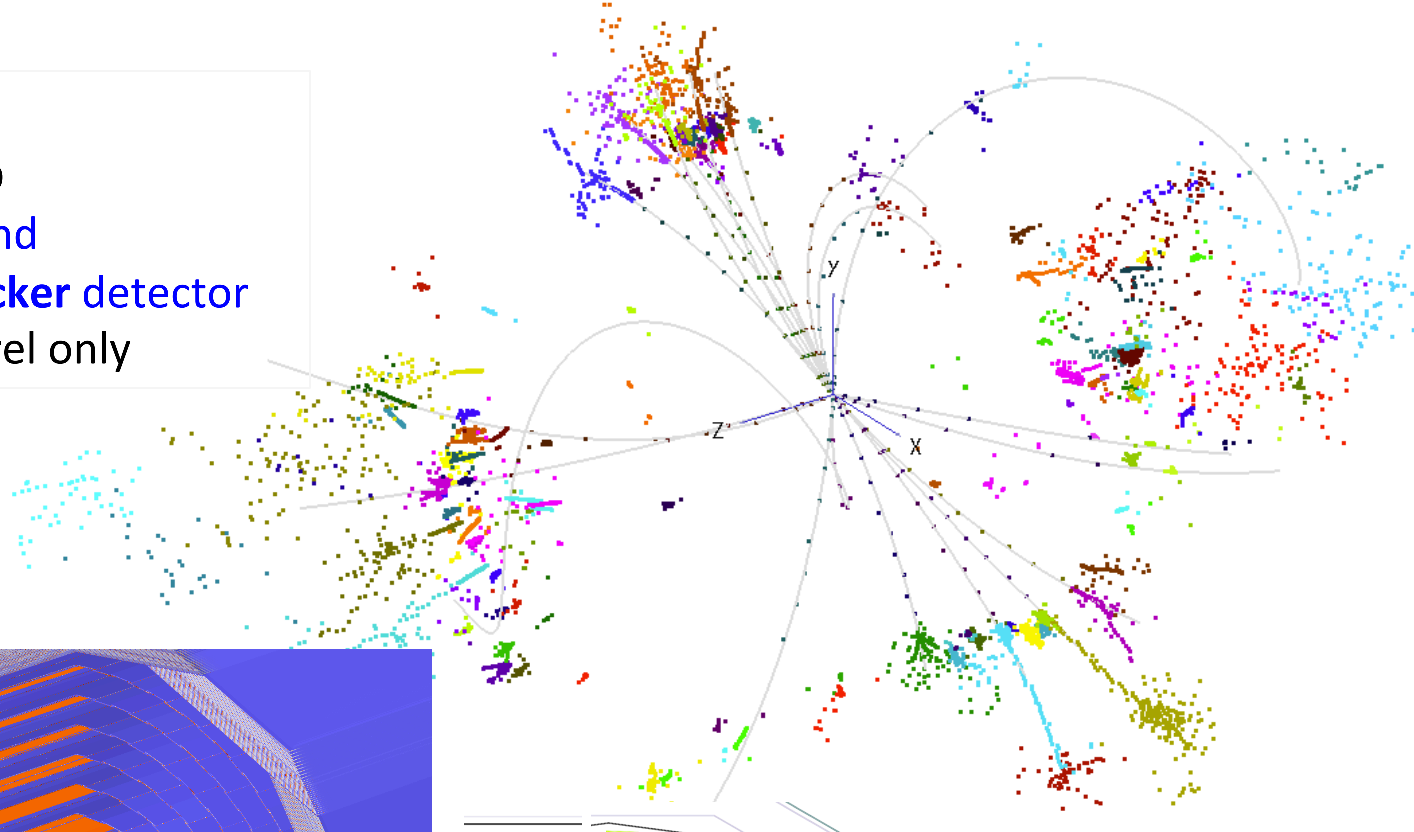
Studied variations in:
- Granularity
- Material Budget
- Jet pT

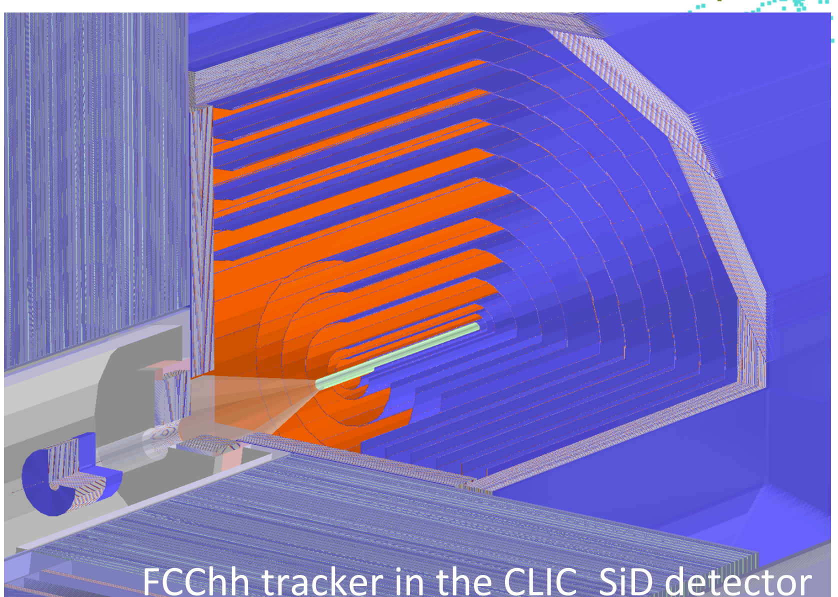
Samples: **Central dijets**
Madgraph5
Restricted quark pT
No pile-up
No Multiple Interactions

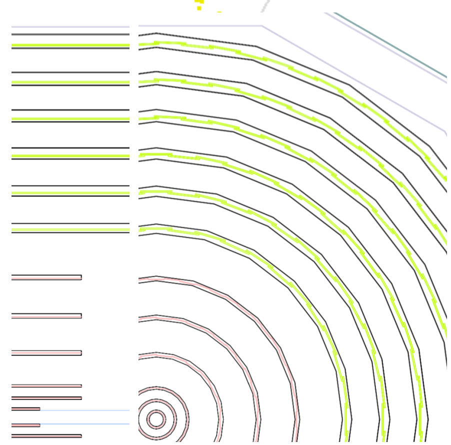
*Pandora
**LCFIPlus

Detector model

Detector Model:
based on CLIC_SiD
with **FCC vertex** and
squeezed FCC tracker detector
Implemented barrel only

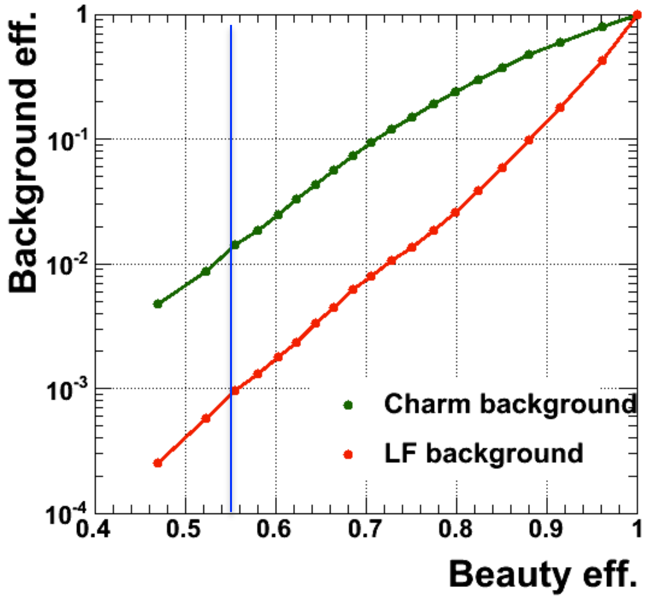



FCChh tracker in the CLIC_SiD detector



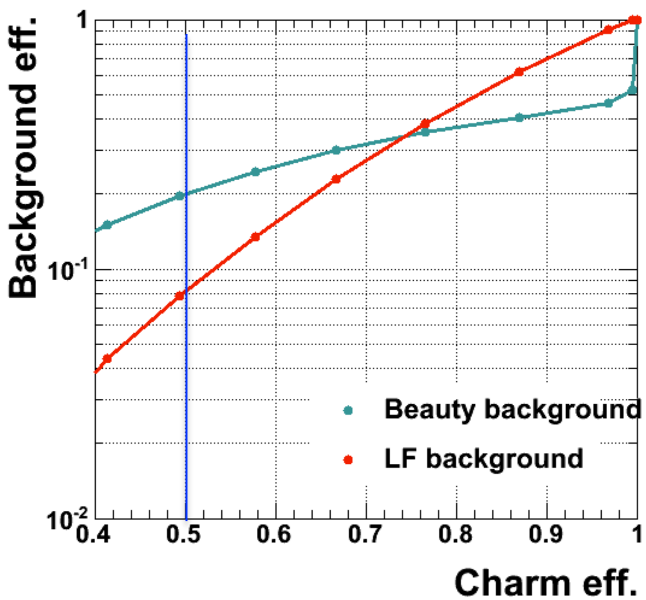
dijet (bb)
pT(b)=50GeV

FCC Flavor tagging performance



central dijets , **pT(quark)=50GeV**

For 55% B-tagging efficiency, the background efficiency is about 1% for C-jets and 0.1% for light flavor jets



For 50% C-tagging efficiency, the background efficiency is of the order of 10%.

Reasonable performance compared to that achieved in CLIC and LHC *

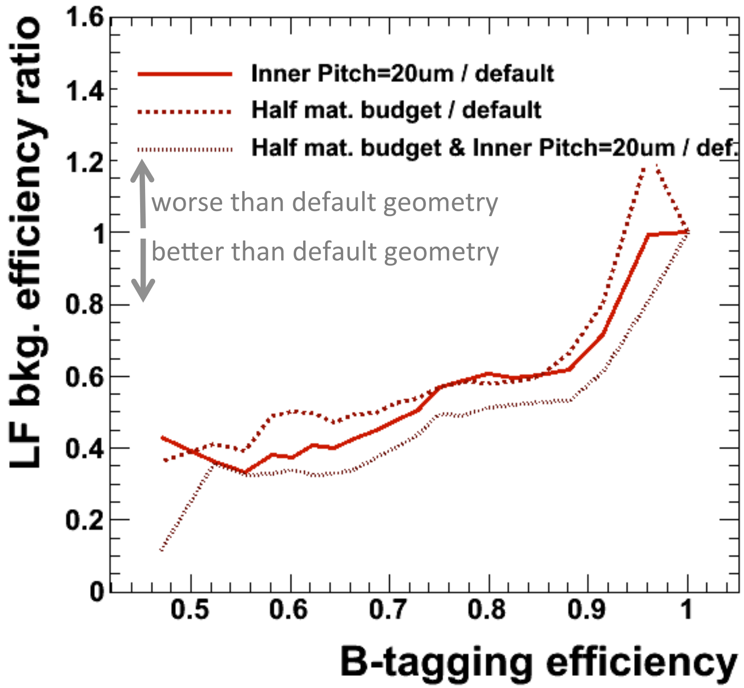
(* = see backup)

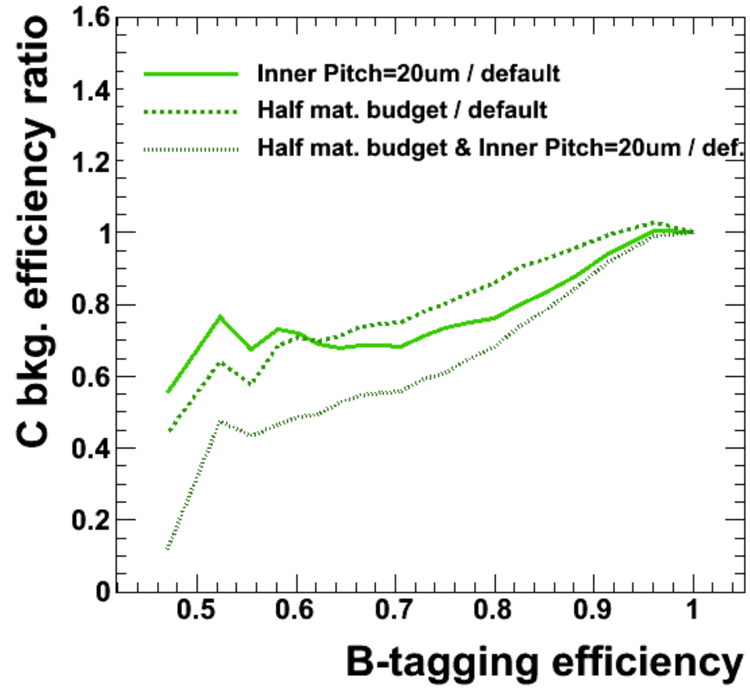
Flavor tagging – variations

Variations:

- Granularity: Use **20x20µm pitch** (instead of 25x50µm pitch) in the **3 innermost layers**
- Material Budget: using **half of the material budget** in all layers
- Granularity and Material Budget combined

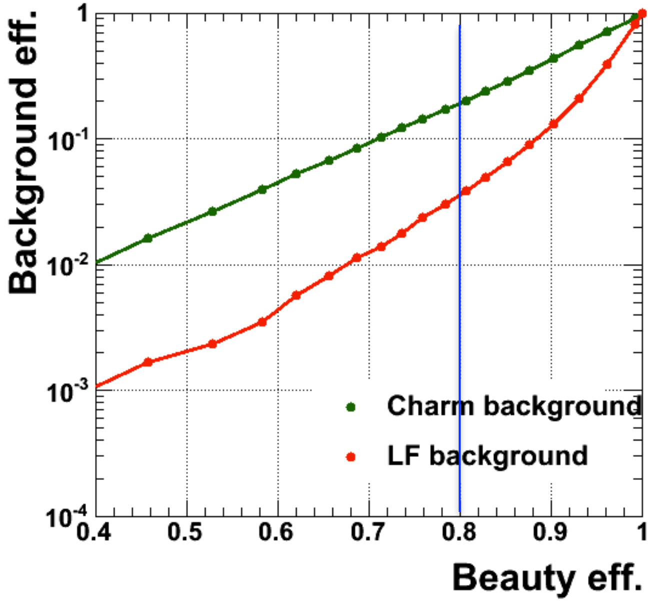
performance for central dijets of pT(quark)=50GeV





Both variations give a 30-60% improvement in the background rejection.
Combining both, gives only a moderate improvement on top of that.

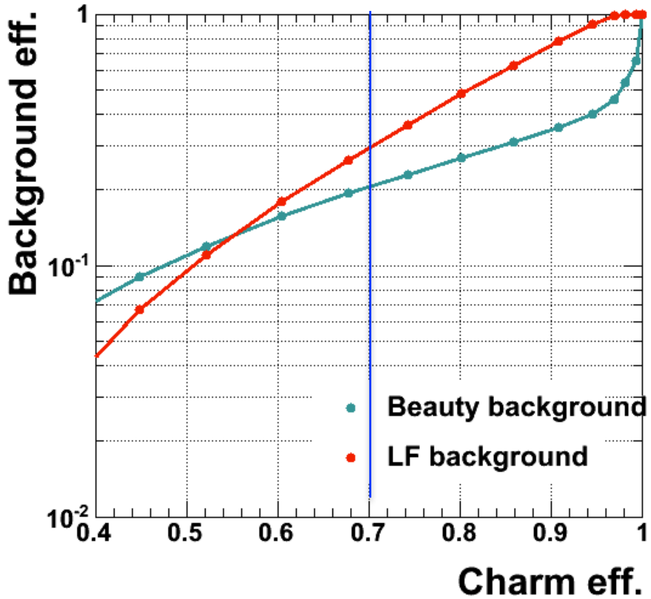
FCC Flavor tagging performance



central dijets , **pT(quark)=500 GeV**

Somewhat worse B-tagging performance for higher pT jets

For **40%** B-tagging efficiency, the background efficiency is about 1% for C-jets and 0.1% for light flavor jets



C-tagging performance similar to 50 GeV jets

Plan to study performance at even higher pTs

Conclusions & Outlook

- Performance **tools** (using fast and full simulation) are in place and **validated**
- **Studies serve as an input for the vertex and tracker optimization**
  - Need intermediate disks between outer and forward tracker, to facilitate pattern recognition
  - Boosted particle decays reconstruction strongly depends on the sensor granularity
  - Flavor tagging studies motivate an additional vertex detector layer at low radius

Next steps:

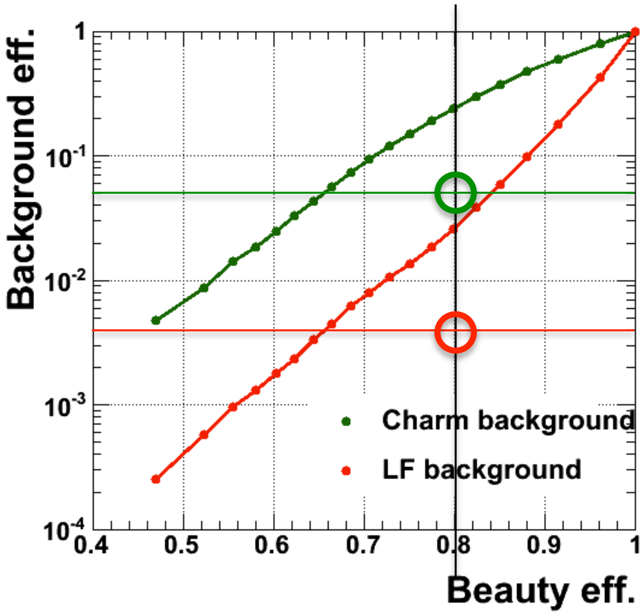
- Perform further flavor tagging studies, including performance evaluation of the **latest detector layout**.

BACKUP

central dijets ,
pT(quark)=50GeV

50GeV – Comparison with CLIC

ee->jj , No ISR, narrower pT spectrum, x50 more stats
better single point resolution, very low material budget



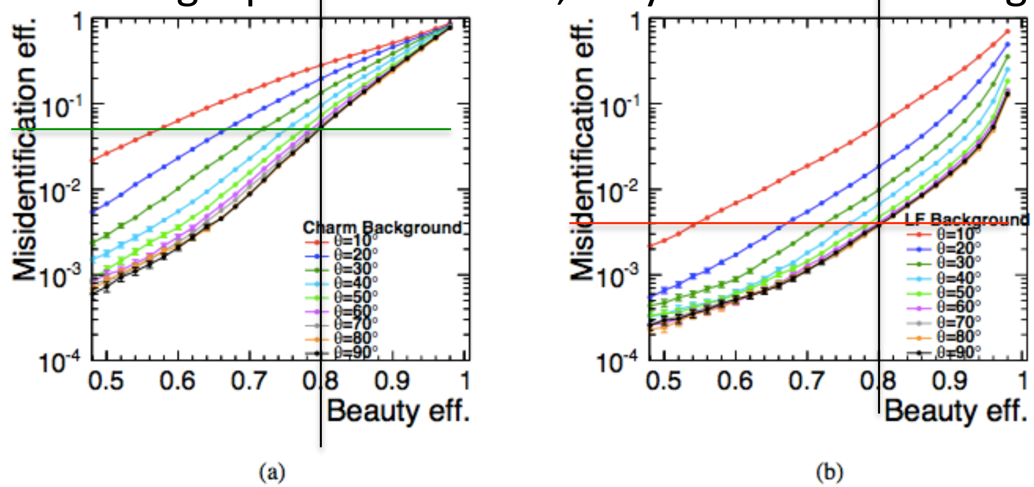
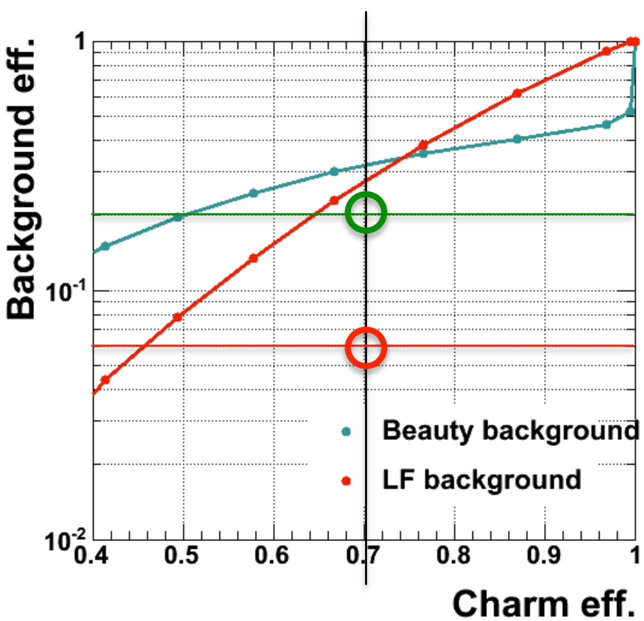
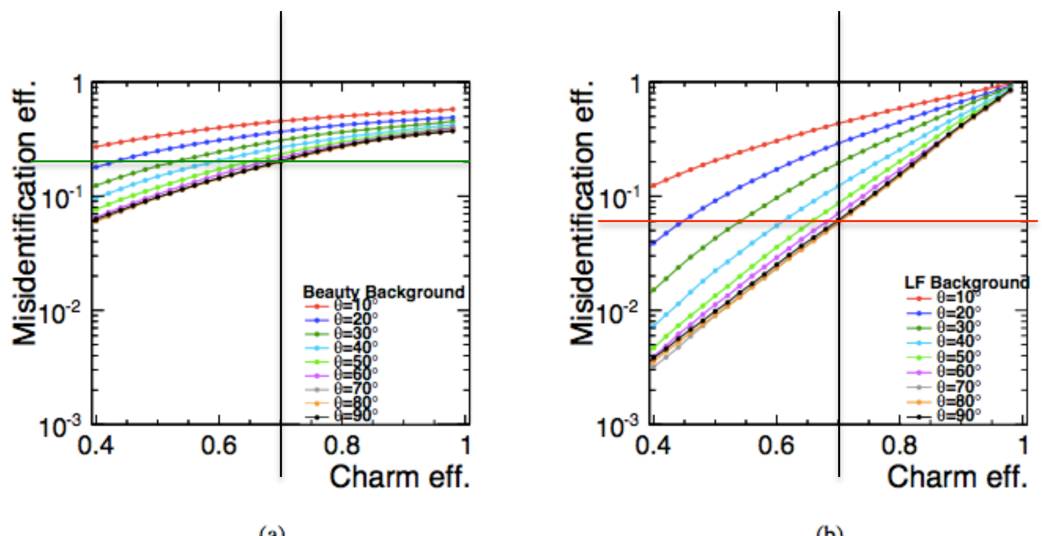


Figure 53: b-tag efficiency for jets in dijet events at $\sqrt{s}$ =91 GeV with different polar angles using the *double_spirals* geometry.



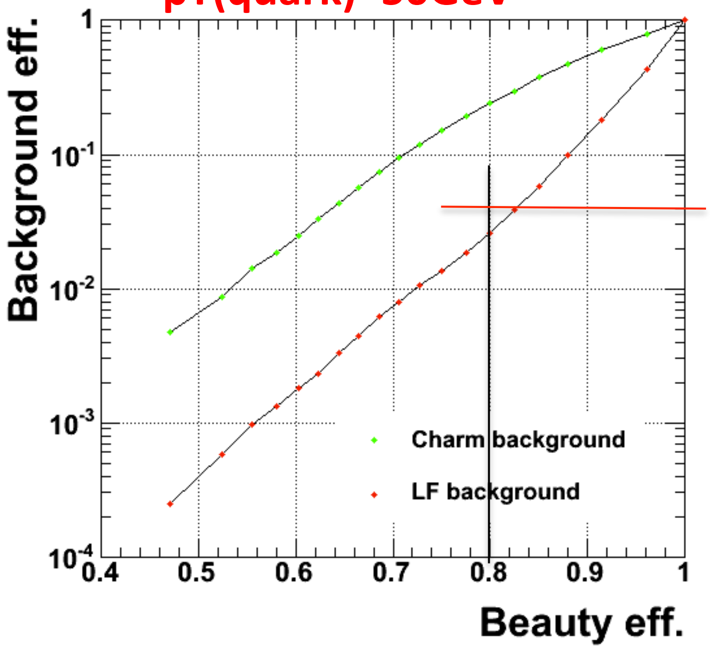


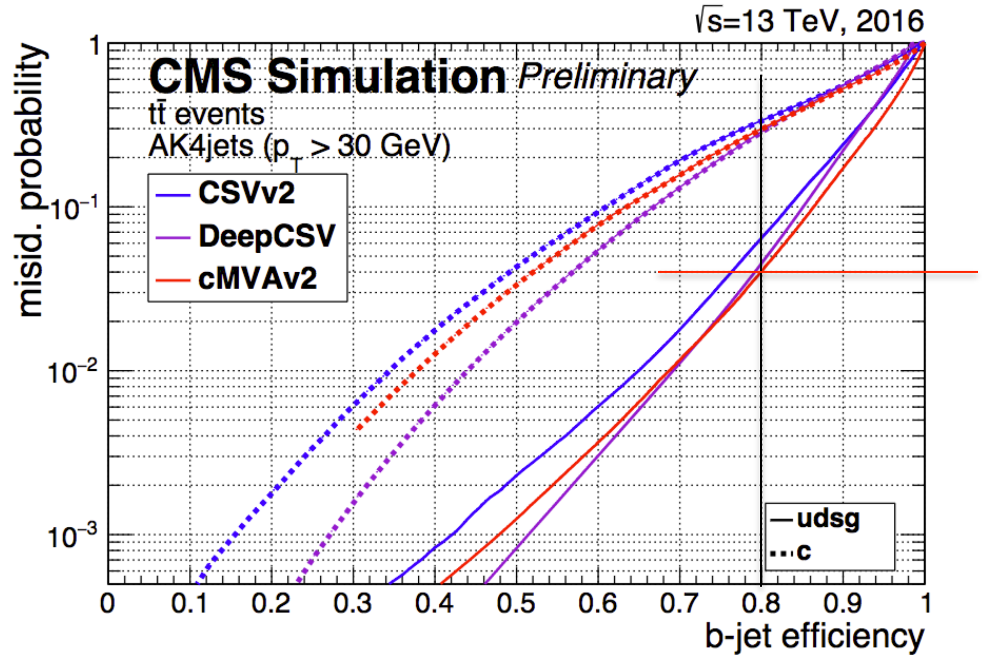
https://cds.cern.ch/record/1606436?ln=en

Comparison to CMS run 2

central dijets ,

pT(quark)=50GeV





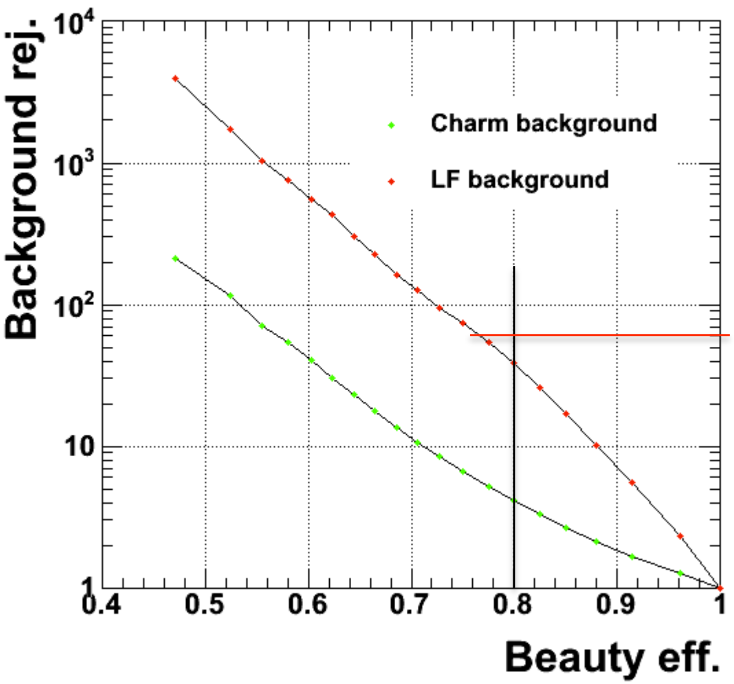
https://twiki.cern.ch/twiki/bin/view/CMSPublic/BTV13TeVDPDeepCSV

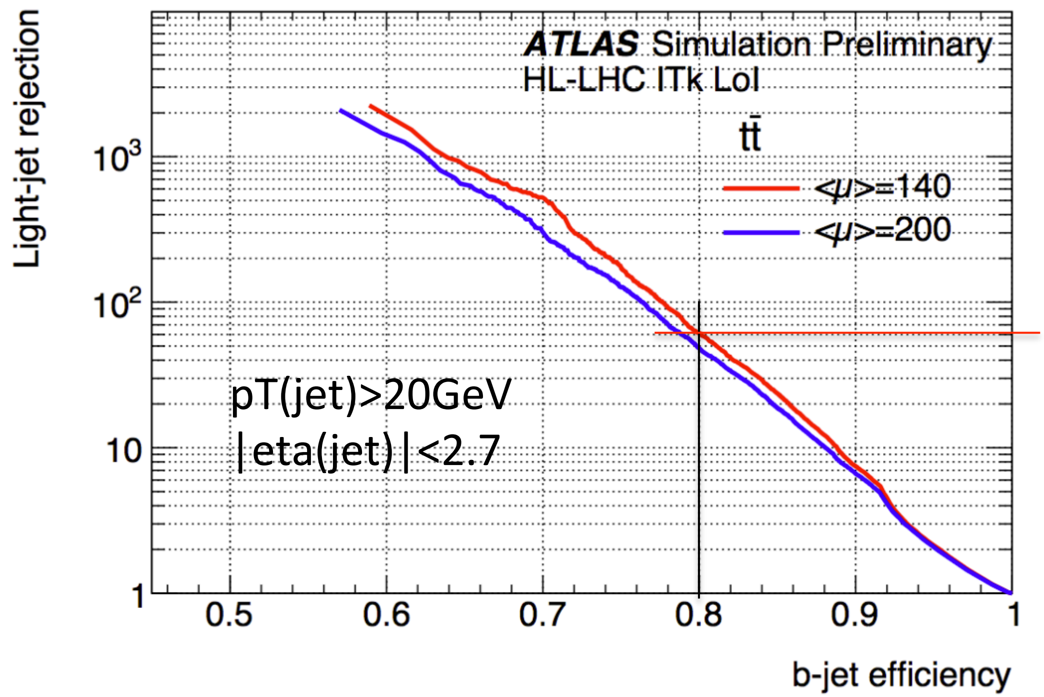
Similar performance as CMS run 2.
FCC factor of ~1.5 better at LF-rejection

Comparison to HL-LHC

central dijets ,

pT(quark)=50GeV

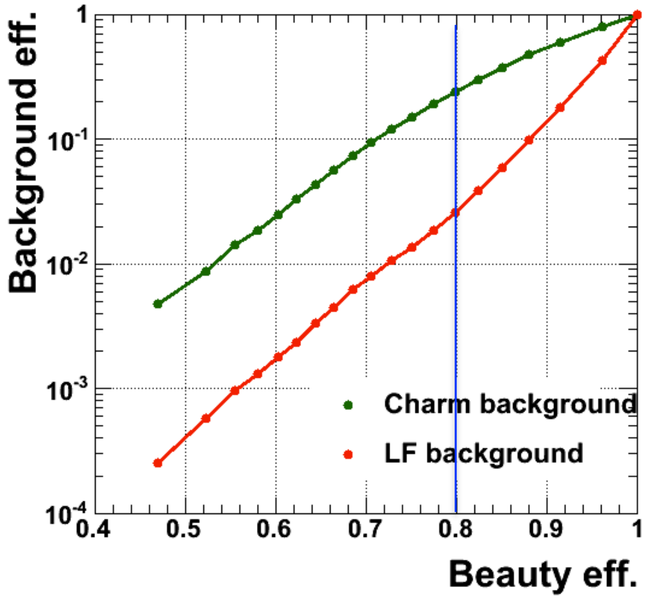




https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2016-026/

Similar performance as ATLAS HL-LHC
FCC factor of 1.5 worse at LF-rejection (for pile up mu=140)

FCC Flavor tagging performance

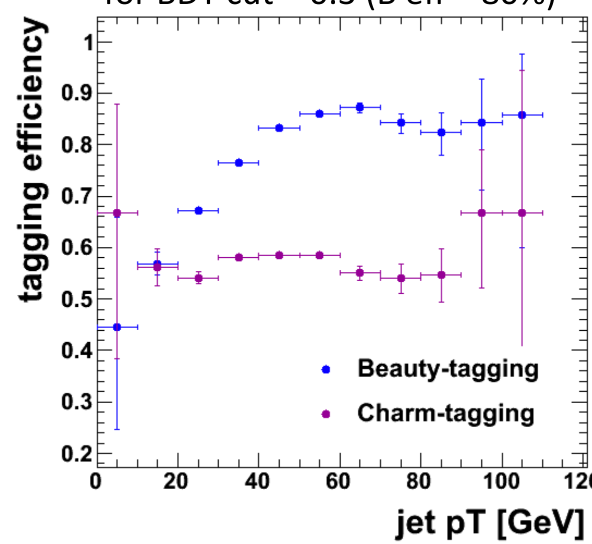


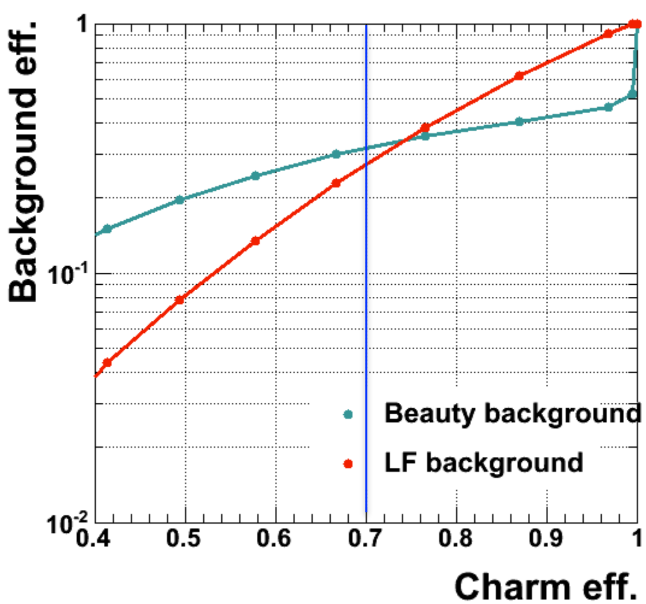
central dijets , **pT(quark)=50GeV**

FCC B-tagging

B eff. = 80%	FCC
LF bkg eff.	2.6 x 10^-2
C bkg eff.	2.4 x 10^-1

for BDT cut = 0.3 (B eff = 80%)





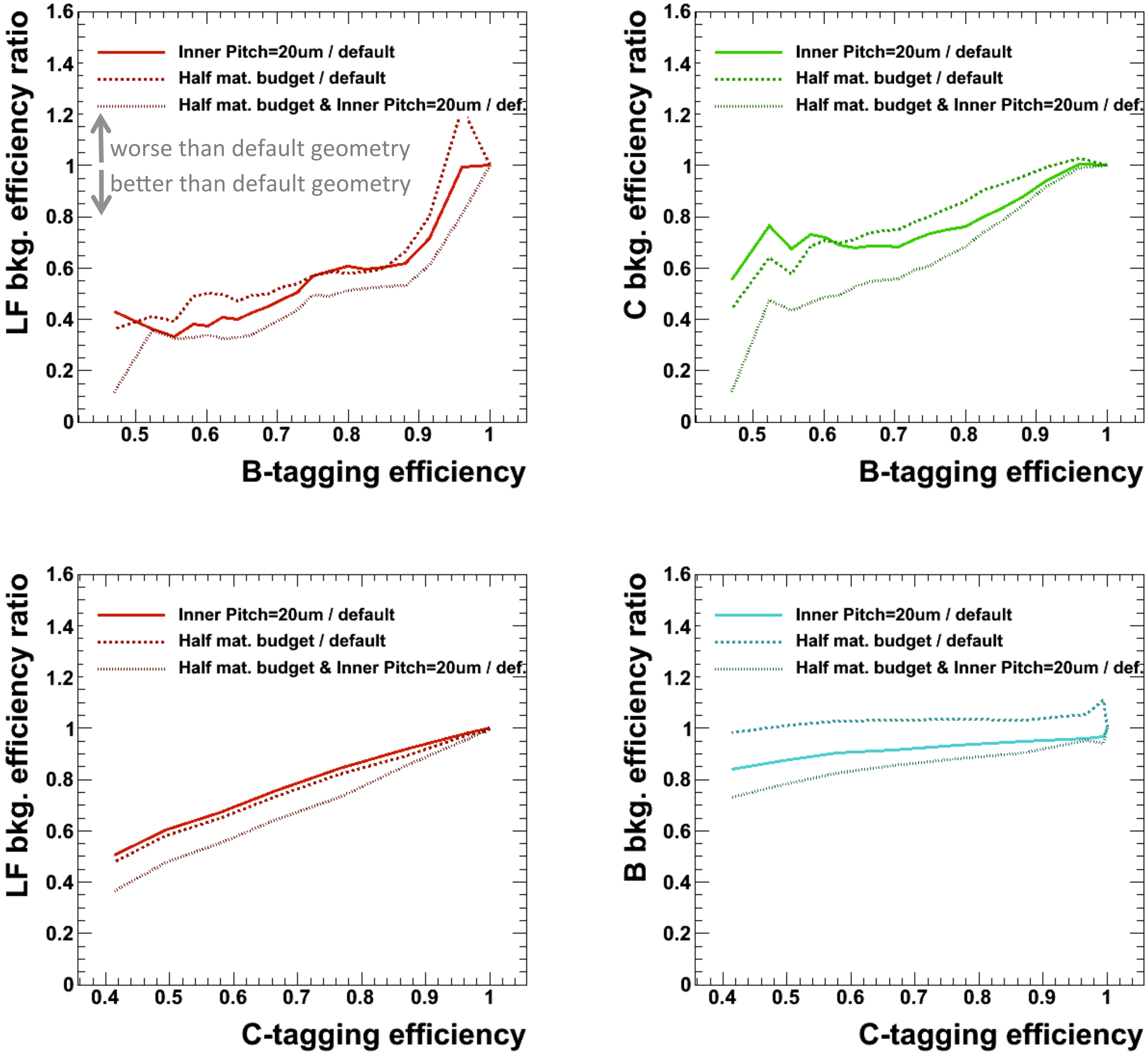
FCC C-tagging

C eff. = 70%	FCC
B bkg eff.	3.2x 10^-1
LF bkg eff.	2.8 x 10^-1

Reasonable performance compared to CLIC and LHC *
Tagging efficiency relatively **flat in jet pT above 40 GeV**

(* = see backup)

Flavor tagging – variations



Variations

- Granularity
- Material Budget
- Granularity+Mat.Budget

Using **20x20µm pitch** (instead of 25x50µm pitch) in the **3 innermost layers,** or using **half of the material budget** in all layers*, improves the light flavor rejection by 40%.

The two modifications combined do not add up in terms of improvement in LF rejection, but they do for C background rejection

performance for central dijets of pT(quark)=50GeV