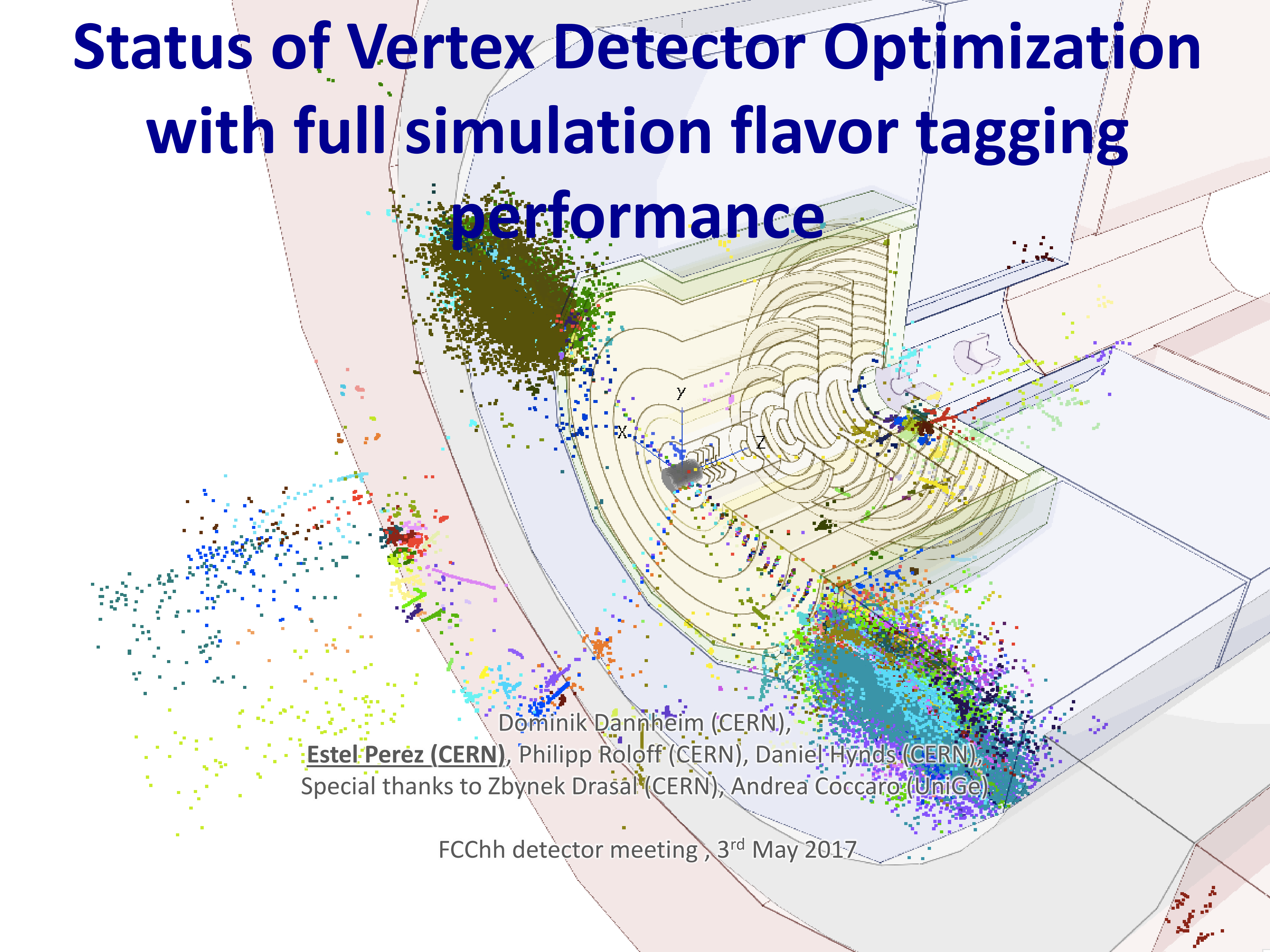
Status of Vertex Detector Optimization with full simulation flavor tagging performance



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Special thanks to Zbynek Drasal (CERN), Andrea Coccaro (UniGe)

FCChh detector meeting , 3rd May 2017

Introduction

Goal: optimize the **Vertex detector** taking into account the **flavor tagging performance**

Tools: evaluate performance using **CLIC_SiD software chain**

Steps:

1. Updating geometry to current baseline → **done**
2. Variations
   - resolution → **preliminary**
   - layout/material → **ongoing**
   - tracking strategies → **ongoing**
3. Scan over jet energies
   - obtain preliminary parameterization

Software chain: Summary

- **Generation**: MG5 central dijets, restricted quark pT. *
- **Hadronization**: Pythia6. Multiple interactions: off, ISR/FSR: on. *
- **Detector Model**: CLIC_SiD with FCC vertex and squeezed FCC tracker (Option3_v02). Barrel only. *
- **Simulation**: FCC material budget (services included in the module)
- **Digitization**: FCC pixel sizes. Smear sim. hit position by Gaussian of $\sigma=p/\sqrt{12}$. *
- **Tracking**: Nhits>=6, chi2<10, d0<10 [mm] (under study) *
- **Particle flow**: Pandora
- **Vertexing**: LCFIPlus. PFOs in 2 kT jets R=0.5. (to be revised)
- **Flavour Tagging**: LCFIPlus (to be revised) *

(*)=some details in the next slides

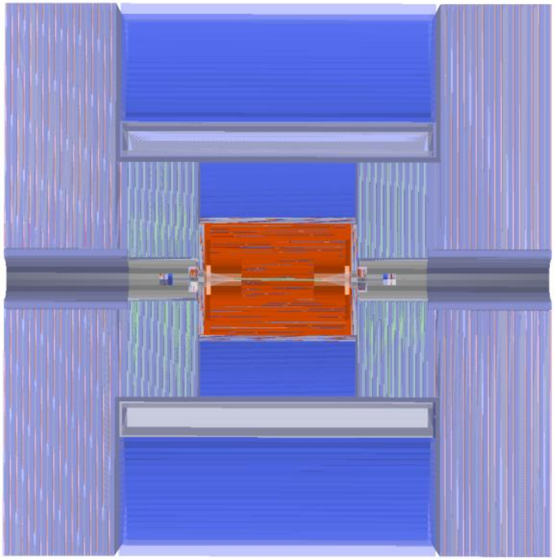
Event Generation

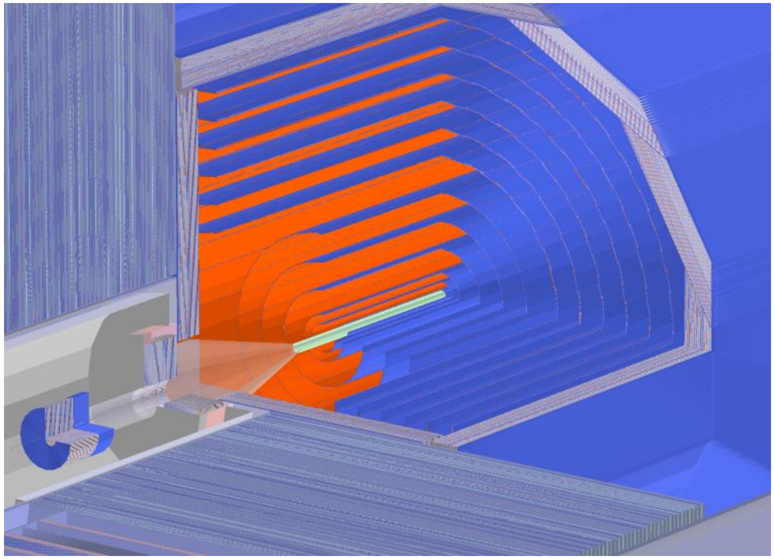
- Event generation in MadGraph5: (By Andrea Coccaro)
  - pp->bb / cc / ll (udsg) at √s=100TeV
  - **restricted quark pT**: Ex: **47.5 < pT(b) < 52.5 GeV**
  - **Central** eta: **|η(b)|<0.05**
  - DR(bb)>0.4
- Samples:
  - Quark pT in GeV: **50, 100, 200, 500, 1000, 2000, 5000, 10000**
  - 20k events per sample
  - 1M events for 50 & 500 GeV samples

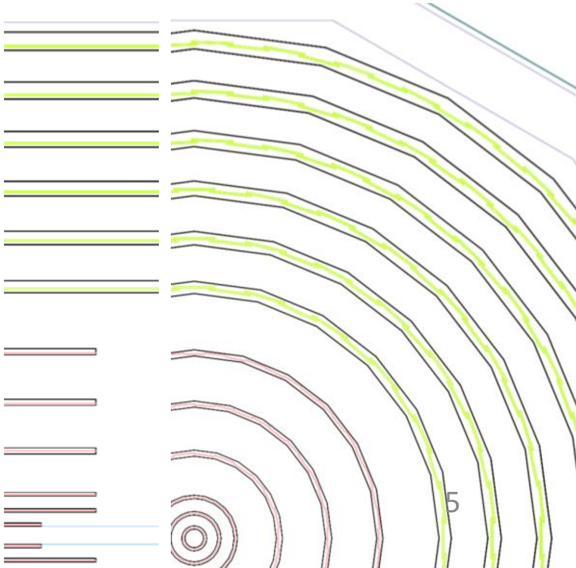
- Hadronization in Pythia6:
  - **Multiple Interaction: OFF**
  - FSR: ON
  - ISR: ON

Detector Model

- CLIC_SiD with **FCC vertex and squeezed FCC** tracker.
  - Version [Option3_v02 from Zbynek]
  - Barrel only. Vertex and tracker endcaps removed (do not fit inside CLIC_SiD).
    - Tracker max z = 1536 mm instead of 2250mm (FCC), to avoid clashes with the CLIC endcap calorimeter
  - Tracker outer layer R reduced from 1541mm (FCC) to 1206mm (CLIC)
  - No explicit cables or supports. Material budget included in the modules material.
- Digitisation:
  - Both vertex and tracker detectors are digitized as long pixels.
  - We used a simplified digitizer, **smearing the simulated hit position with a Gaussian of σ=pitch/√12** , which provides with a direct relationship between pitch and single point resolution (as done for Fast Sim).
  - → Factor out detector technology

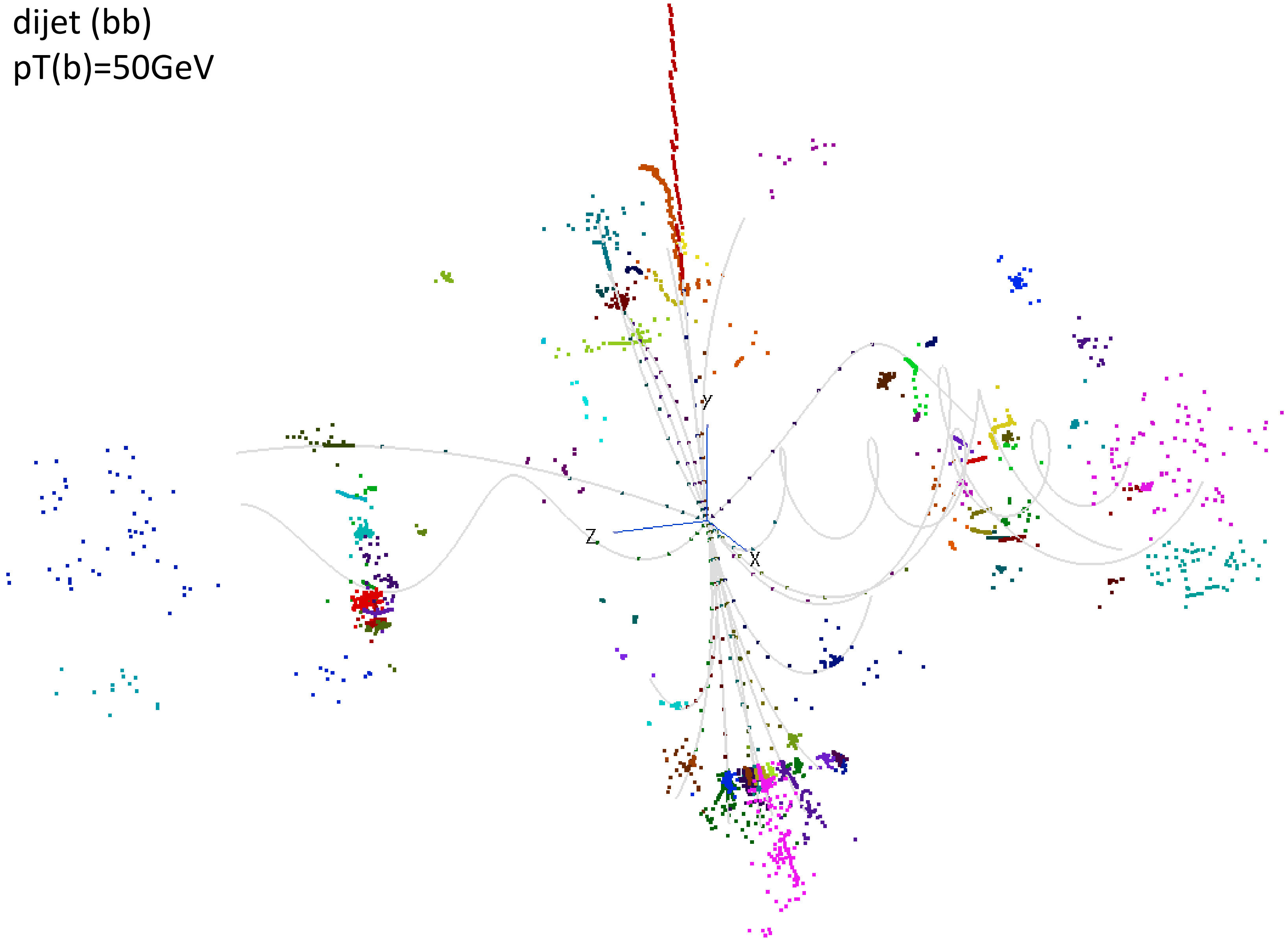






Event display

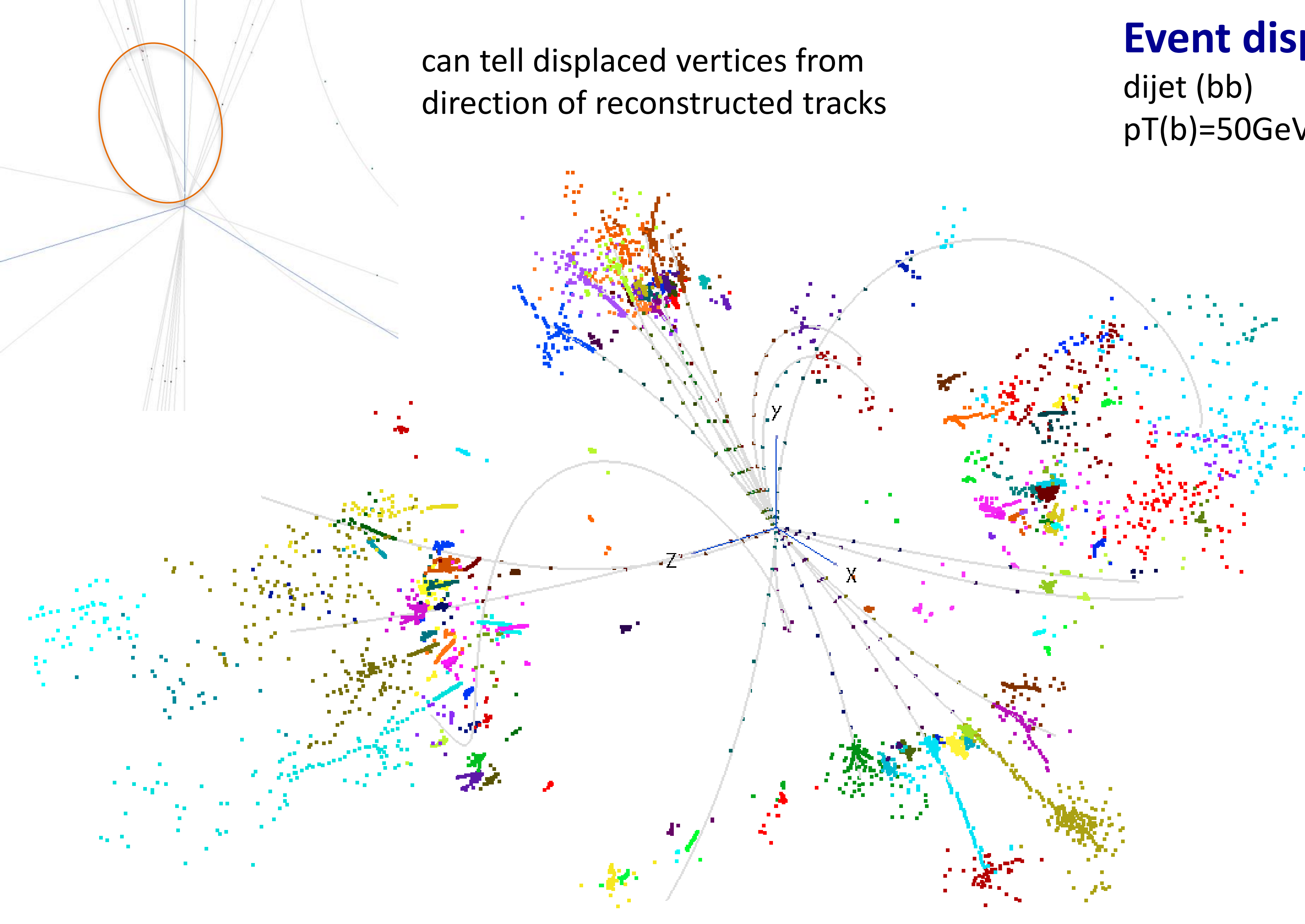
dijet (bb)
pT(b)=50GeV



Event display

dijet (bb)
pT(b)=50GeV

can tell displaced vertices from
direction of reconstructed tracks



Tracking

- Tracking parameters used

MinPT=	0.2 GeV
MinHits=	**6**
MaxD0=	**10.0 mm**
MaxZ0=	10.0 mm
MaxChisq=	10.0

- We have 6+6 layers, but we want to be able to reconstruct tracks only in the vertex or only in the tracker (to target very displaced decays)
- Tracking strategies trained with **displaced** single muon tracks (to account for missing inner hits)

Under review & optimization

Preliminary track resolution comparison

resolution	Full Sim*	Fast Sim**
$\delta pT/pT$	0.75%	0.48 %
$\delta d0[\mu m]$	6.1	5.02
$\delta z0[\mu m]$	13.1	10.59

*Full Sim
E=100GeV prompt muon
$|\eta|<0.175$ (θ=80-100 degrees)

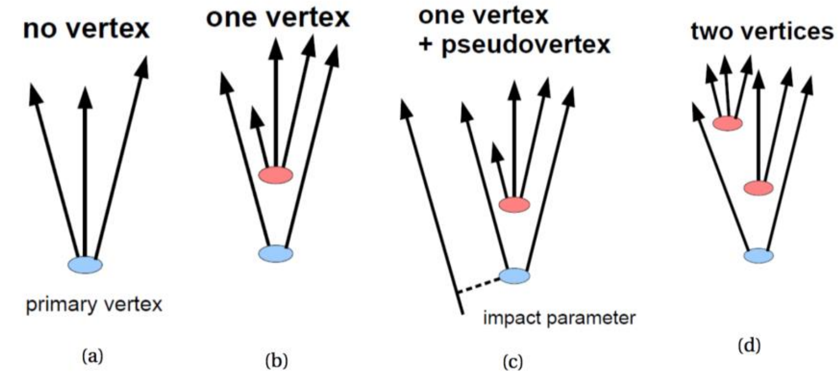
**Fast Sim
pT=100GeV prompt muon
$0.001<|\eta|<1.5$

(remember: we have **squeezed the tracker**, and fast sim averages over a larger eta range)

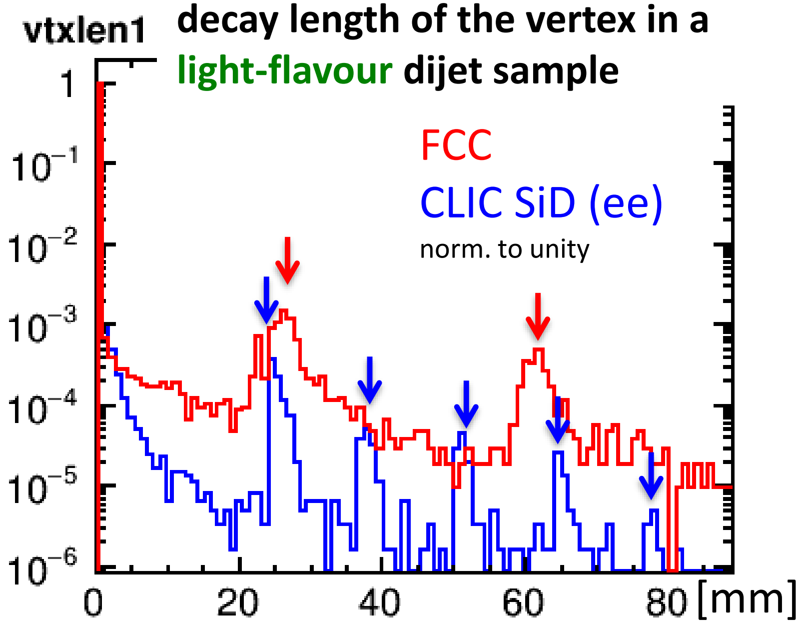
good enough approximation for our purposes

Flavor Tagging

- Jets are classified in 4 categories according to the number of secondary vertices
- BDTs are trained using variables related to: [ref] (see backup)
  - track d0/z0/momentum
  - vertex mass/momentum/angle/decay length

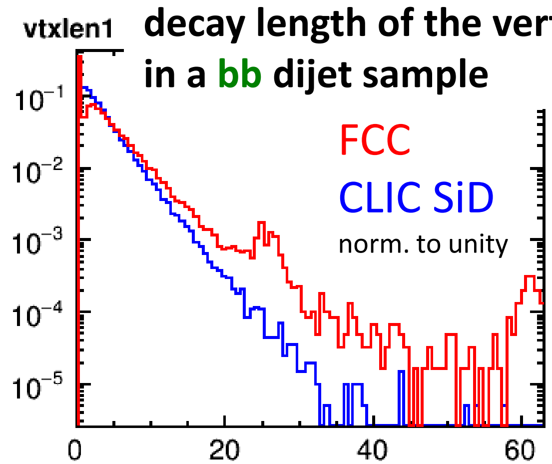


decay length of the vertex in a light-flavour dijet sample



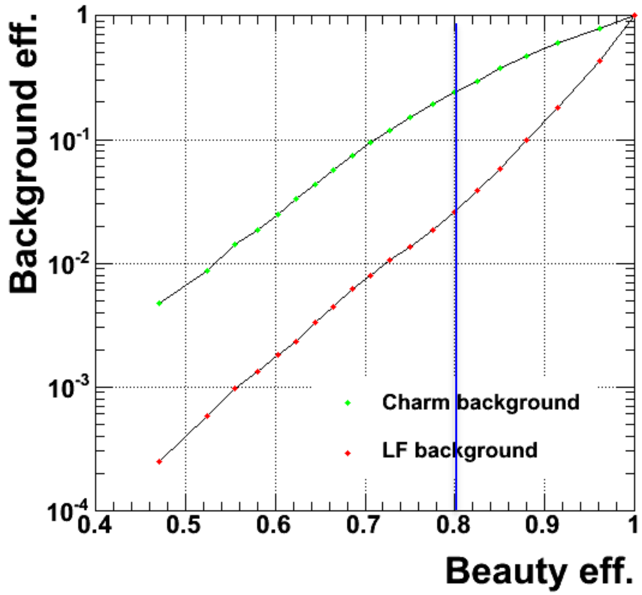
In the light flavor sample, vertices due mainly to **interaction with the material**

decay length of the vertex in a bb dijet sample



small differences due to **energy spectrum**

FCC Flavor tagging performance

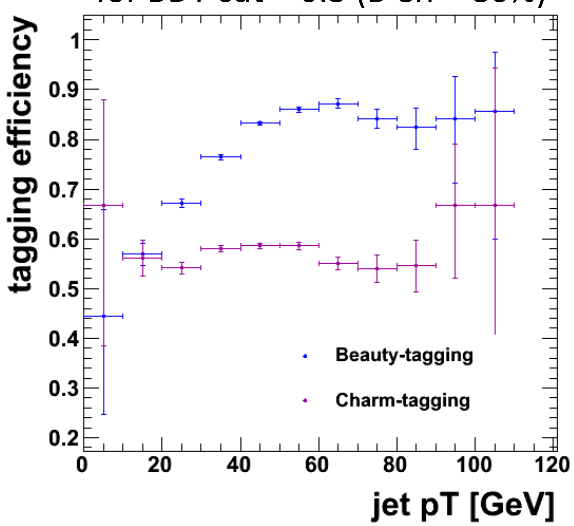


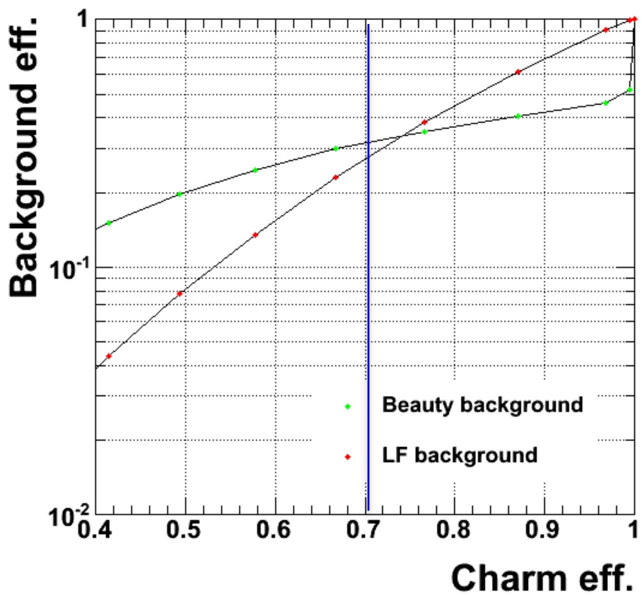
central dijets , pT(quark)=50GeV (before hadronization)

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
C bkg eff.	2.8 x 10^-1

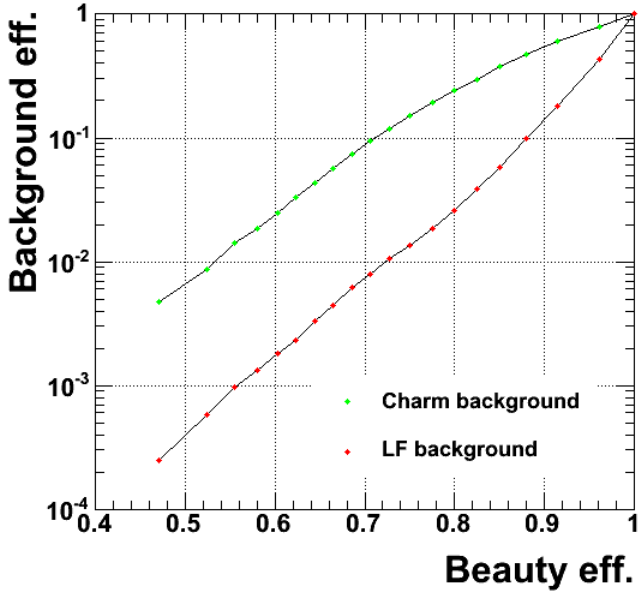
tagging efficiency relatively **flat in jet pT above 40 GeV**

Reasonable performance
(comparisons in next slides)

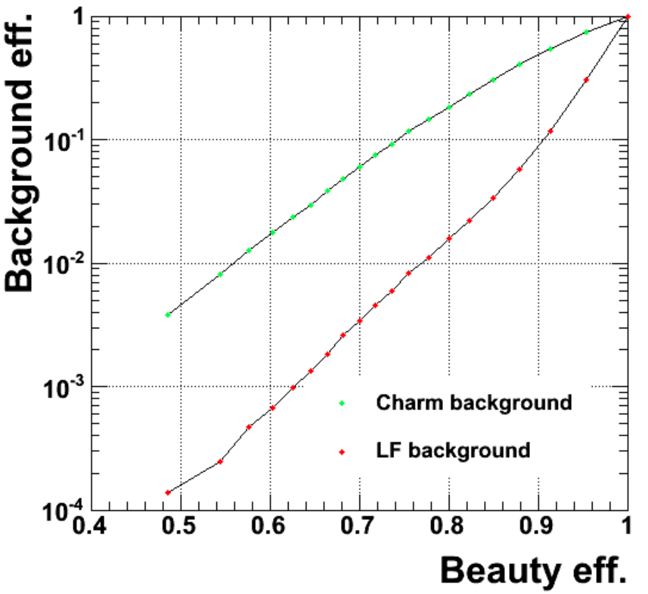
Flavor tagging – pitch variation

central dijets
pT(quark)=50GeV

FCC default



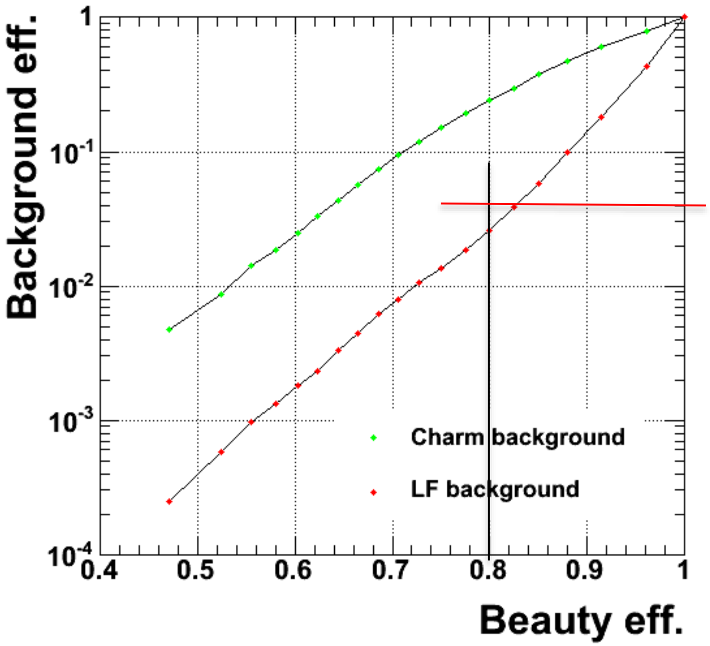
FCC with **20um pitch** in the 3 innermost layers

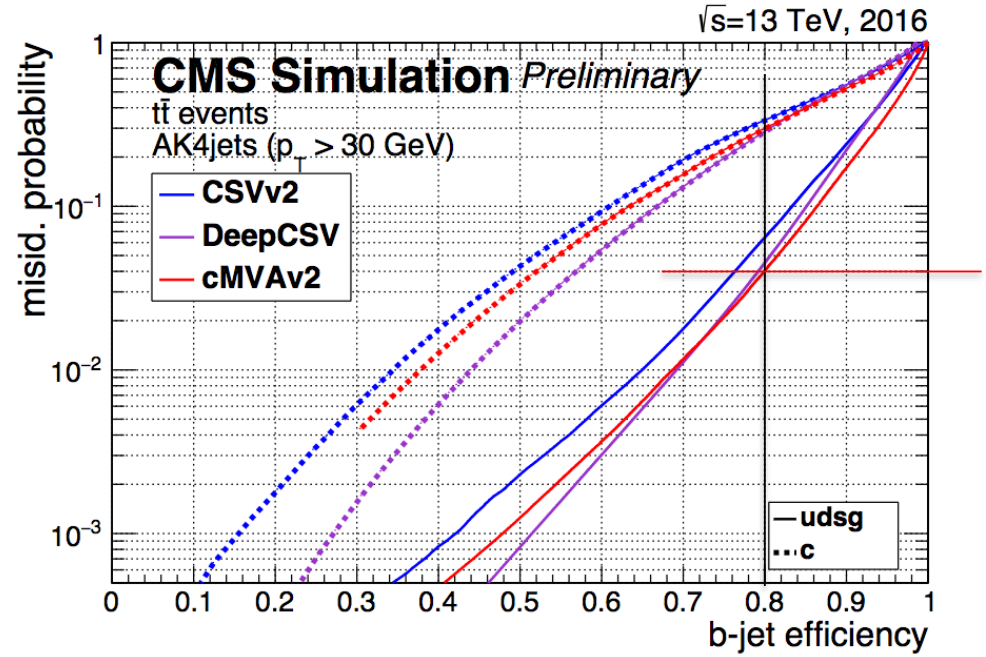


By using **20x20um pitch** instead of 25x50um pitch in the **3 innermost layers** (3umx3um single point resolution, as CLIC_SiD, instead of 7.5x15um),
light flavor rejection improves by 50%

B eff. = 80%	FCC - 20um	FCC	
LF bkg eff.	1.6 x 10^-2	2.6 x 10^-2	→ factor of ~ 1.6
C bkg eff.	1.8 x 10^-1	2.4 x 10^-1	→ factor of ~ 1.3

Comparison to CMS run 2

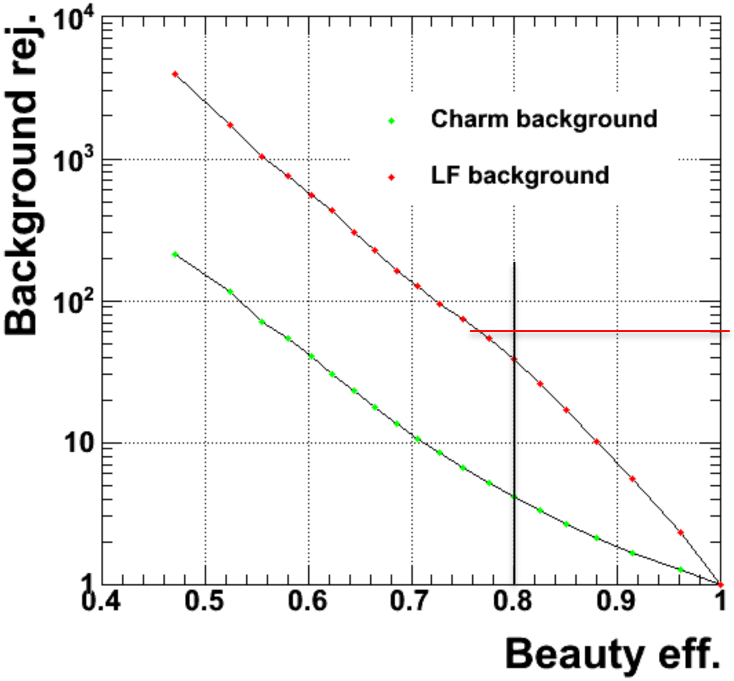


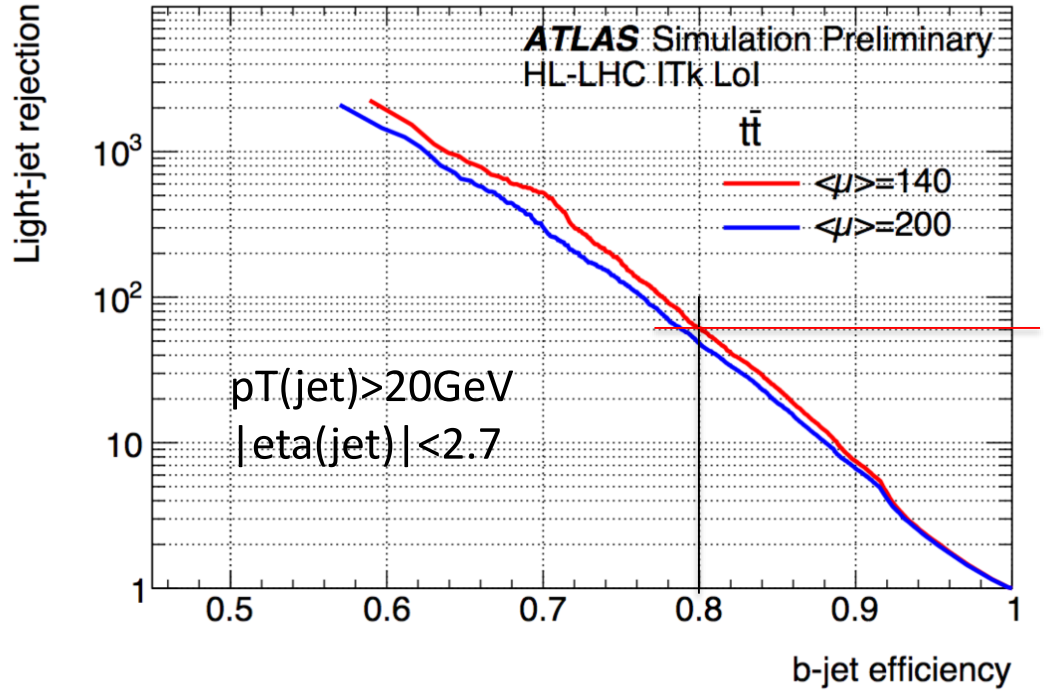


https://twiki.cern.ch/twiki/bin/view/CMSPublic/BTV13TeVDPDeepCSV

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

Comparison to HL-LHC





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)

Conclusions

- Validated setup to optimize the **Vertex detector** taking into account the **flavor tagging performance ,** using **CLIC_SiD software chain**
- Tracking performance validated against Fast Simulation
- Reasonable flavor tagging performance, compared to LHC experiments & CLIC
- In place to perform variations on the detector geometry and layout
  - Example: If single point resolution for the 3 innermost layers improved to 3x3um, LF jet rejection would improve by 50%

Next steps

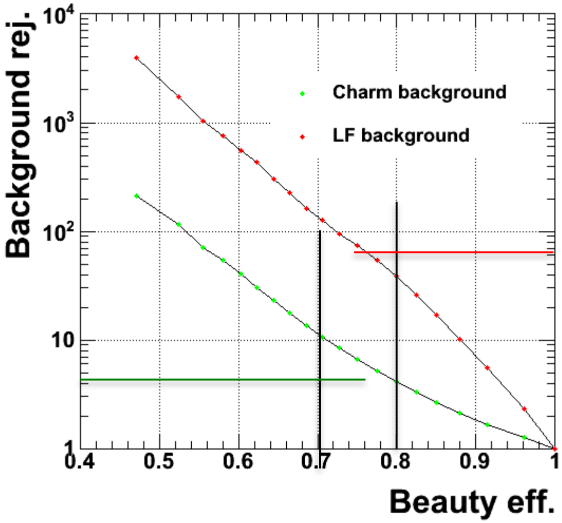
Main upcoming points:

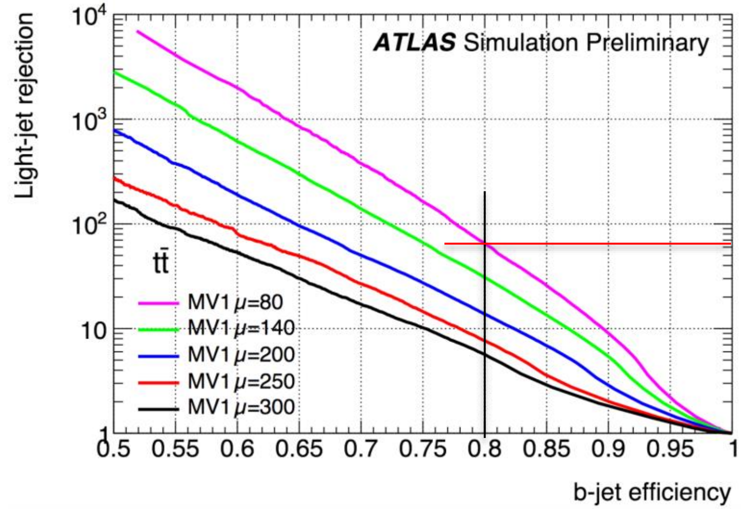
- Optimize tracking strategies for high pT b-jets
- Perform variations in the layout (add 4^{th} inner layer)
- Study flavor tagging performance for high pT jets

BACKUP

comparisons

Comparison to HL-LHC

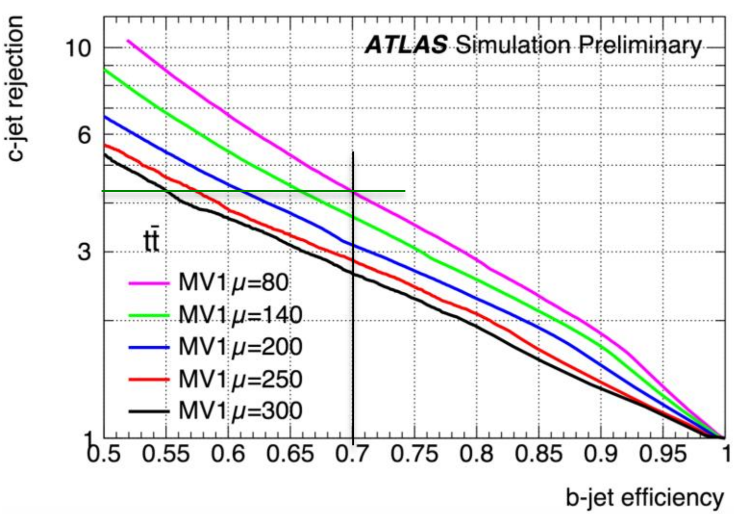




pT(jet)>20GeV
|eta(jet)|<2.5

b-tagging: Run 1 config:
pT(track)>1GeV

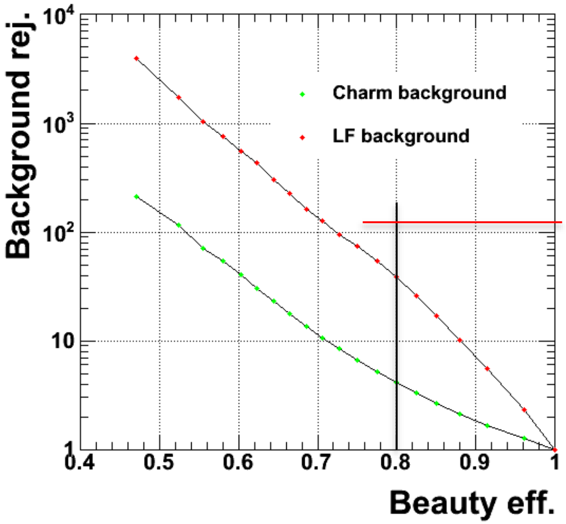
Light-jet rejection (the inverse of the fraction of true light-jets that are falsely tagged as b-jets) as a function of b-tagging efficiency (the fraction of true b-jets that are tagged as b-jets) for the MV1 [0] tagger using jets with transverse momentum p_T>20 GeV and pseudorapidity |η|<2.5 for a MC@NLO+HERWIG tanti-t sample generated for several different μ (mean number of interactions per crossing) scenarios. To factor out the impact of pileup jets on the performance, jets are required to be matched to a parton, with p_T > 15 GeV, from either the top quark or W boson decay within an (η,φ) cone of 0.3. The selected primary vertex was also required to be matched to the truth hard scatter vertex. The b-tagging algorithms only used tracks with p_T > 1 GeV using the the Run 1 optimised configuration and have not yet been optimised for the HL-LHC conditions.



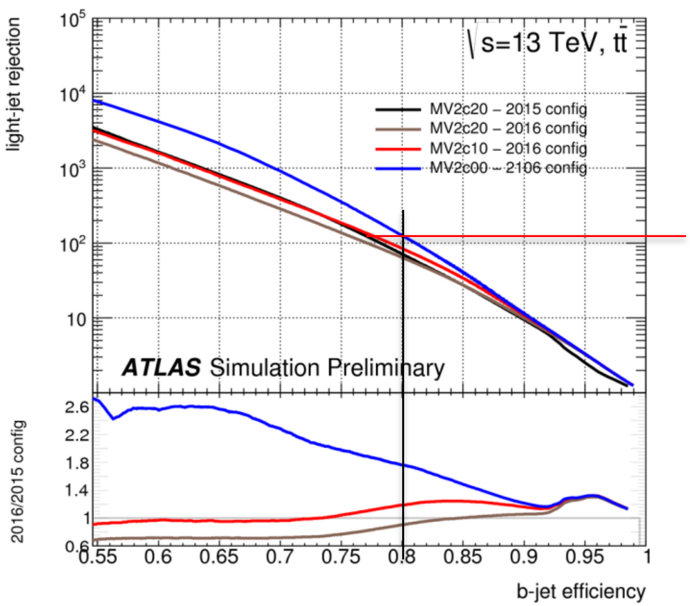
Similar performance as ATLAS HL-LHC
FCC factor of 2 “better” at c-rejection, factor of 1.5 “worse” at l-rejection (for pile up mu=80)

http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/UPGRADE/PLOT-UPGRADE-2014-003/

Comparison to ATLAS run2



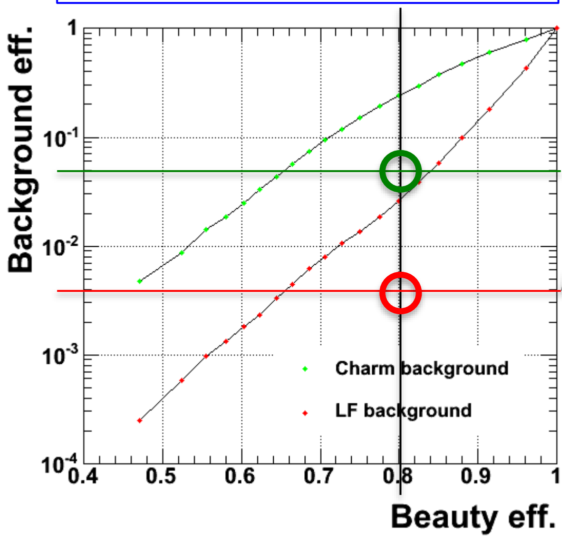
Similar performance as ATLAS run 2
FCC factor of ~3 “worse” at l-rejection



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2016-012/

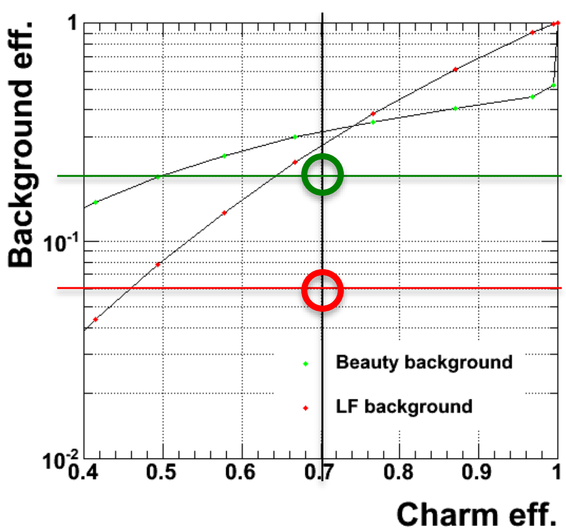
Flavor tagging performance

FCC **default** (min 6 hits)



for central dijet samples with pT(quark)=50GeV
(before hadronization)
Compared to CLIC SiD (e+e-) with √s= 90 GeV

B eff. = 80%	FCC	CLIC SiD	
LF bkg eff.	26 x 10^-3	4 x 10^-3	→ factor of ~ 6
C bkg eff.	24 x 10^-2	5 x 10^-2	→ factor of ~ 5



C eff. = 70%	FCC	CLIC SiD
B bkg eff.	3.2x 10^-1	2 x 10^-1
C bkg eff.	28 x 10^-2	6 x 10^-2

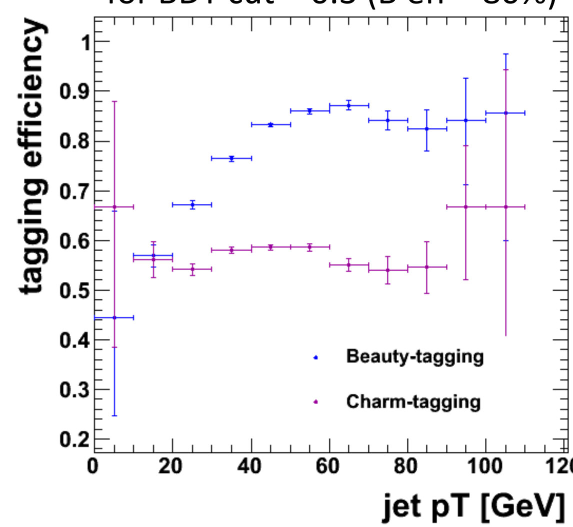
→ factor of ~ 1.5

→ factor of ~ 4.5

Differences expected, due to:
- single point resolution
- material budget
- layout

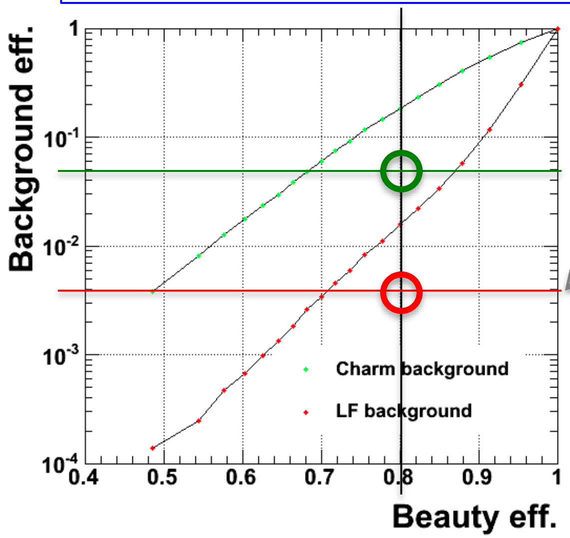
strong dependence in jet pT

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



Flavor tagging performance

FCC with **20um pitch** in the 3 innermost layers (min 7 hits)



for central dijet samples with pT(quark)=50GeV (before hadronization)

Compared to CLIC SiD (e+e-) with √s= 90 GeV

B eff. = 80%	FCC - 20um	CLIC SiD	
LF bkg eff.	16 x 10^-3	4 x 10^-3	→ factor of ~ 4
C bkg eff.	18 x 10^-2	5 x 10^-2	→ factor of ~ 3.5

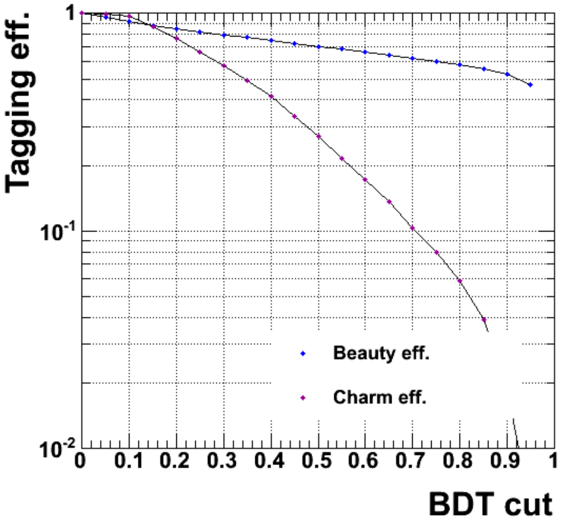
By using 3umx3um single point resolution (as CLIC SiD) in the 3 innermost layers, rejection improves by 50%

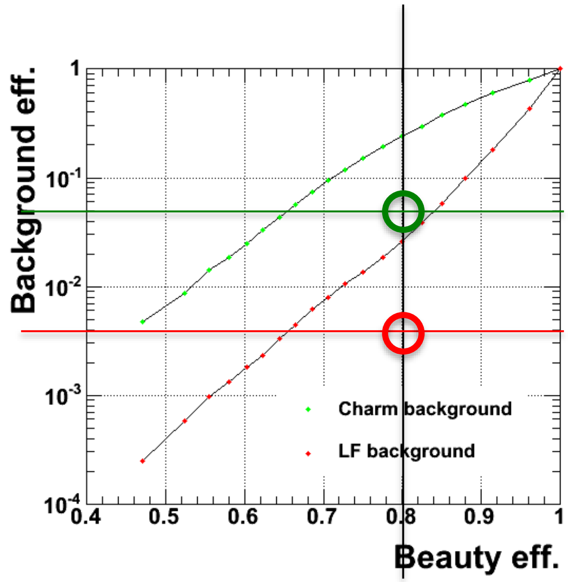
Next step: check impact of reducing material budget

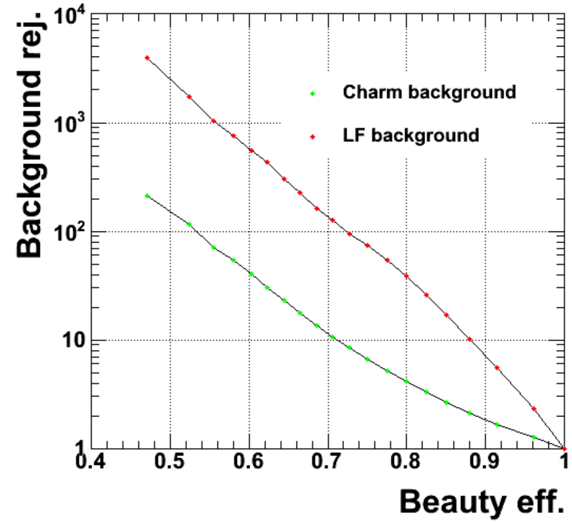
FCC default (min 6 hits)

50GeV

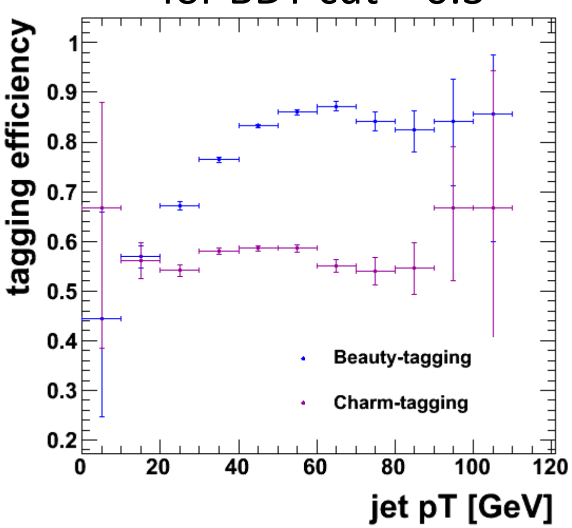
inverted values in Y axis,
for comparison with LHC

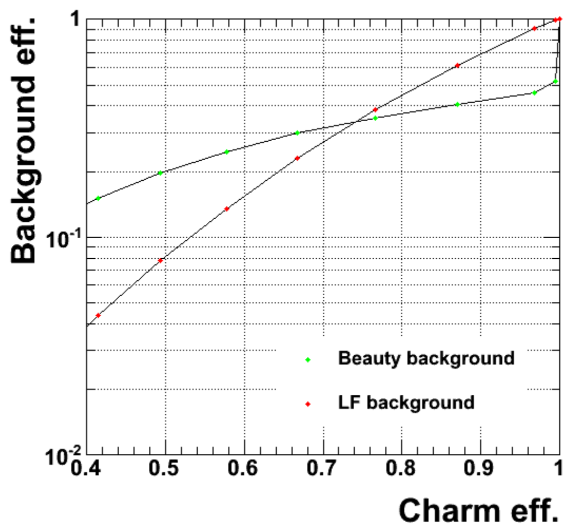


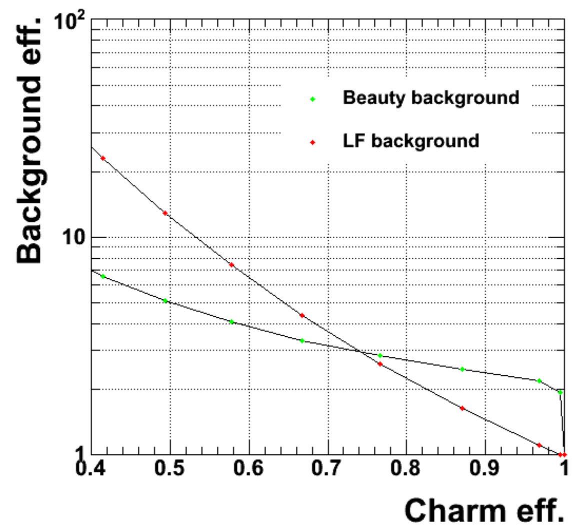




for BDT cut = 0.3



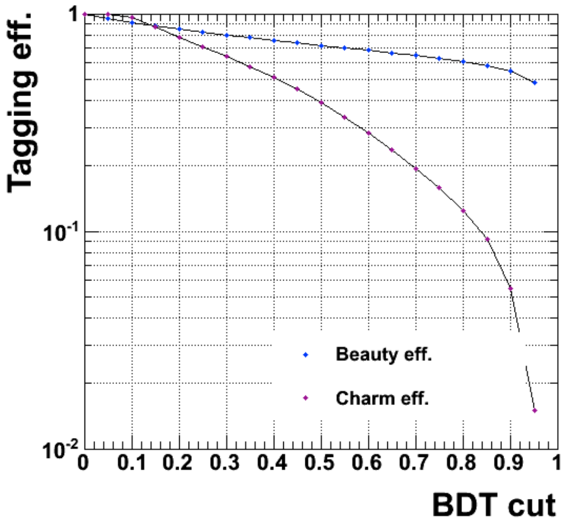


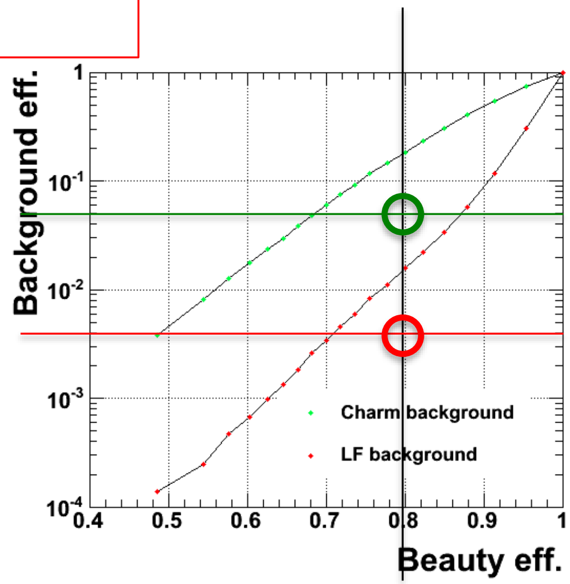


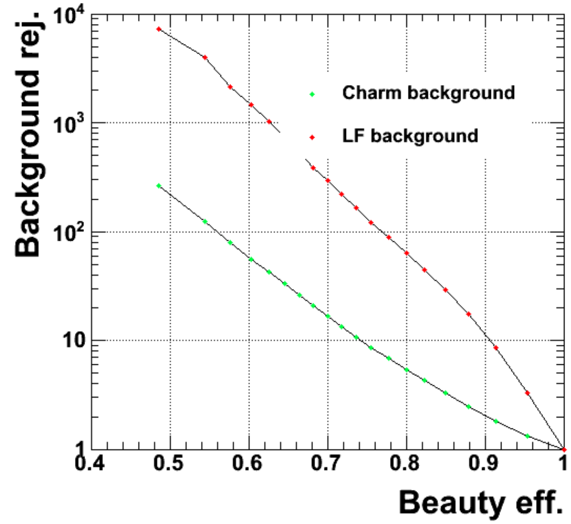
FCC with **20um pitch** in the 3 innermost layers (min 7 hits)

50GeV

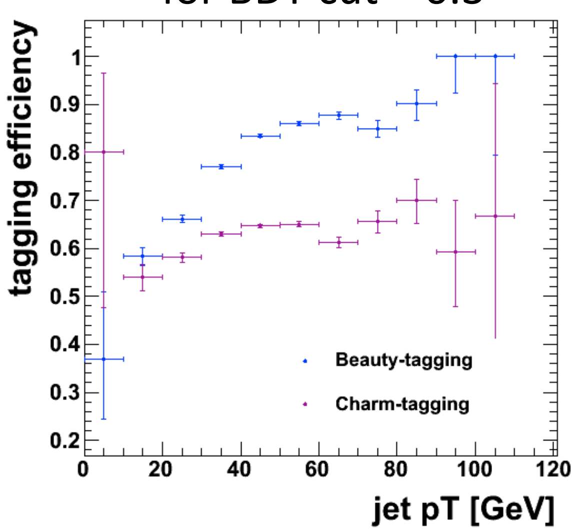
inverted values in Y axis, for comparison with LHC

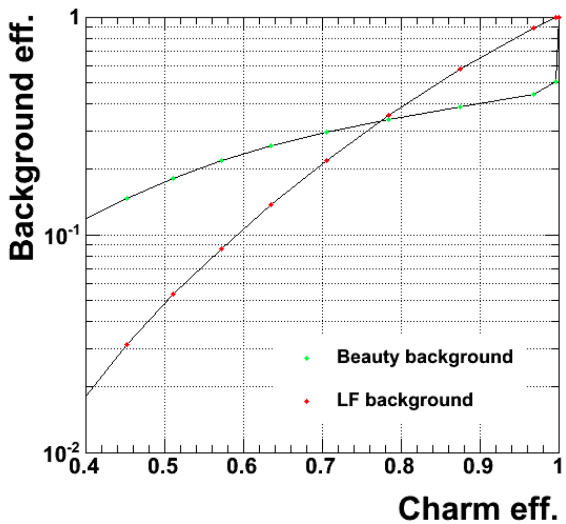


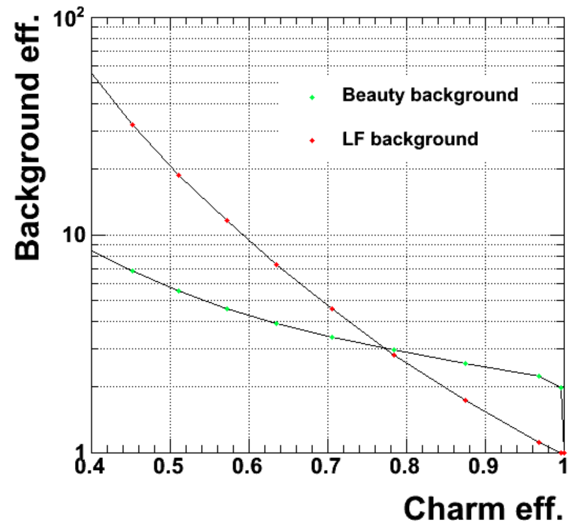




for BDT cut = 0.3





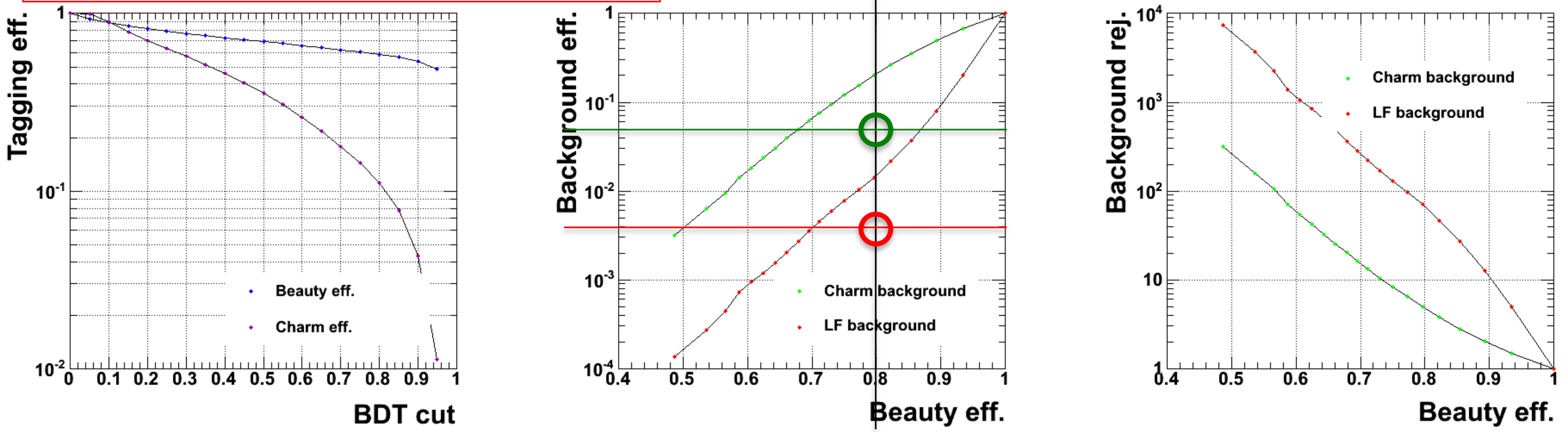


better single point resolution, significantly improves performance

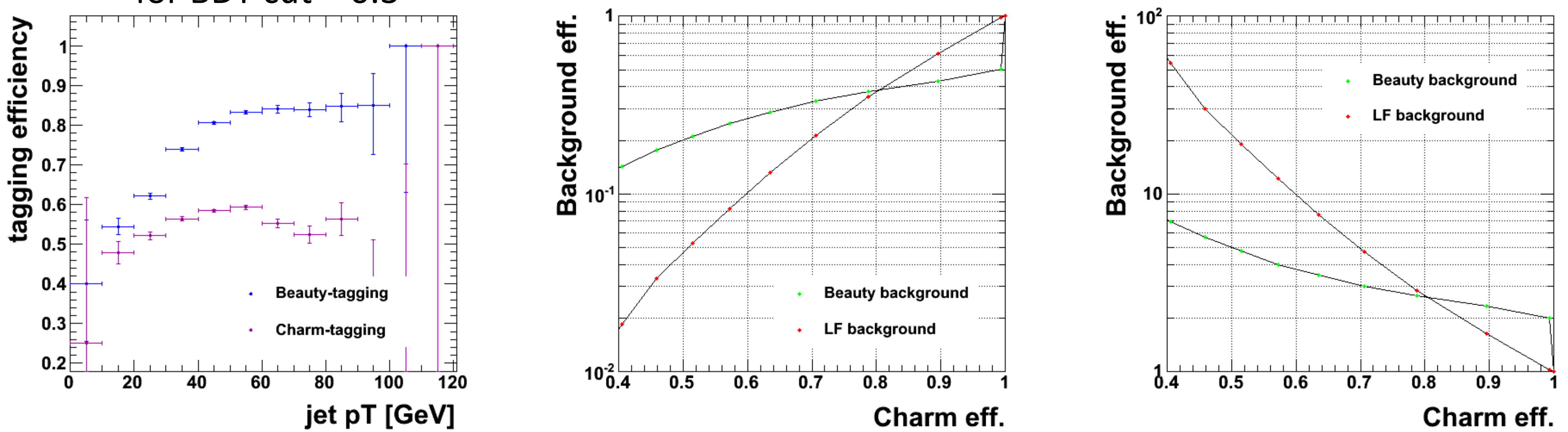
FCC with **HALF of the material budget**
(min 6 hits)

50GeV

inverted values in Y axis,
for comparison with LHC



for BDT cut = 0.3



better single point resolution, significantly improves performance

flavour tagging variables

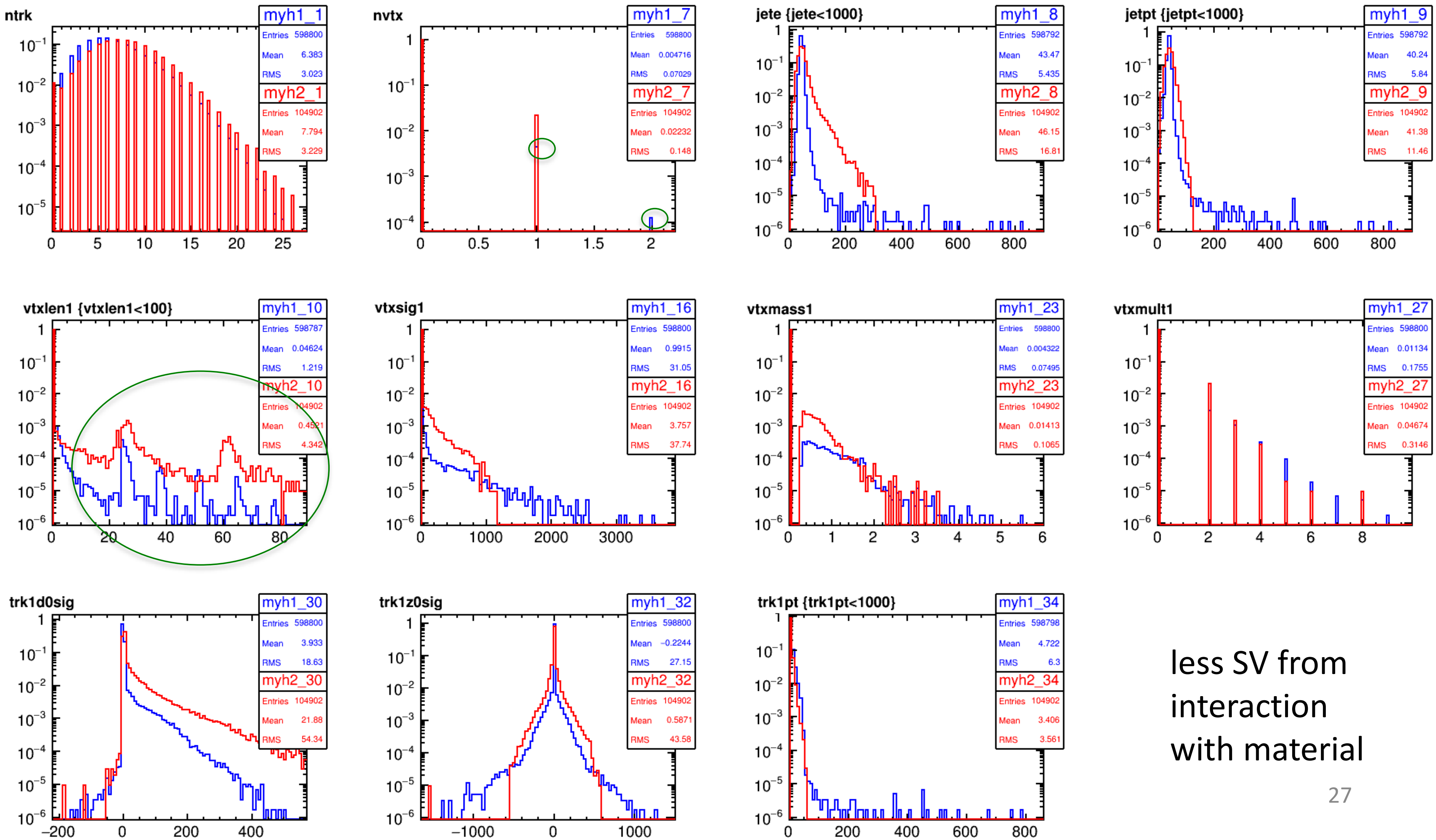
Flavour tagging

Top discriminating variables for the different categories [full definition] ("_jete" = normalized to the jet energy)

- vtxsig12_jete: distance between the 1st and 2nd vertices
- vtxmom_jete: vertex momentum (sum of its tracks momentum)
- vtxdirang12_jete: angle between the displacement and the momentum vectors between the two vertices
- vtxmassall: vertex mass all tracks forming secondary vertices
- vtxlen1_jete : Decay length of the first vertex in the jet
- vtxmom1_jete: vector sum of the momenta of all tracks in the first vertex
- vtxmasspc: Mass of the vertex with minimum *pT* correction allowed by the error matrices of the primary and secondary vertices.
- d0qprob: Product of light-flavour-quark probabilities of *d*0 values for all tracks
- z0qprob: Product of light-flavour-quark probabilities of *z*0 values for all tracks
- trkmass: Mass of all tracks exceeding 5 sigma significance in *d*0/*z*0 values

Opt3v02 vs CDR

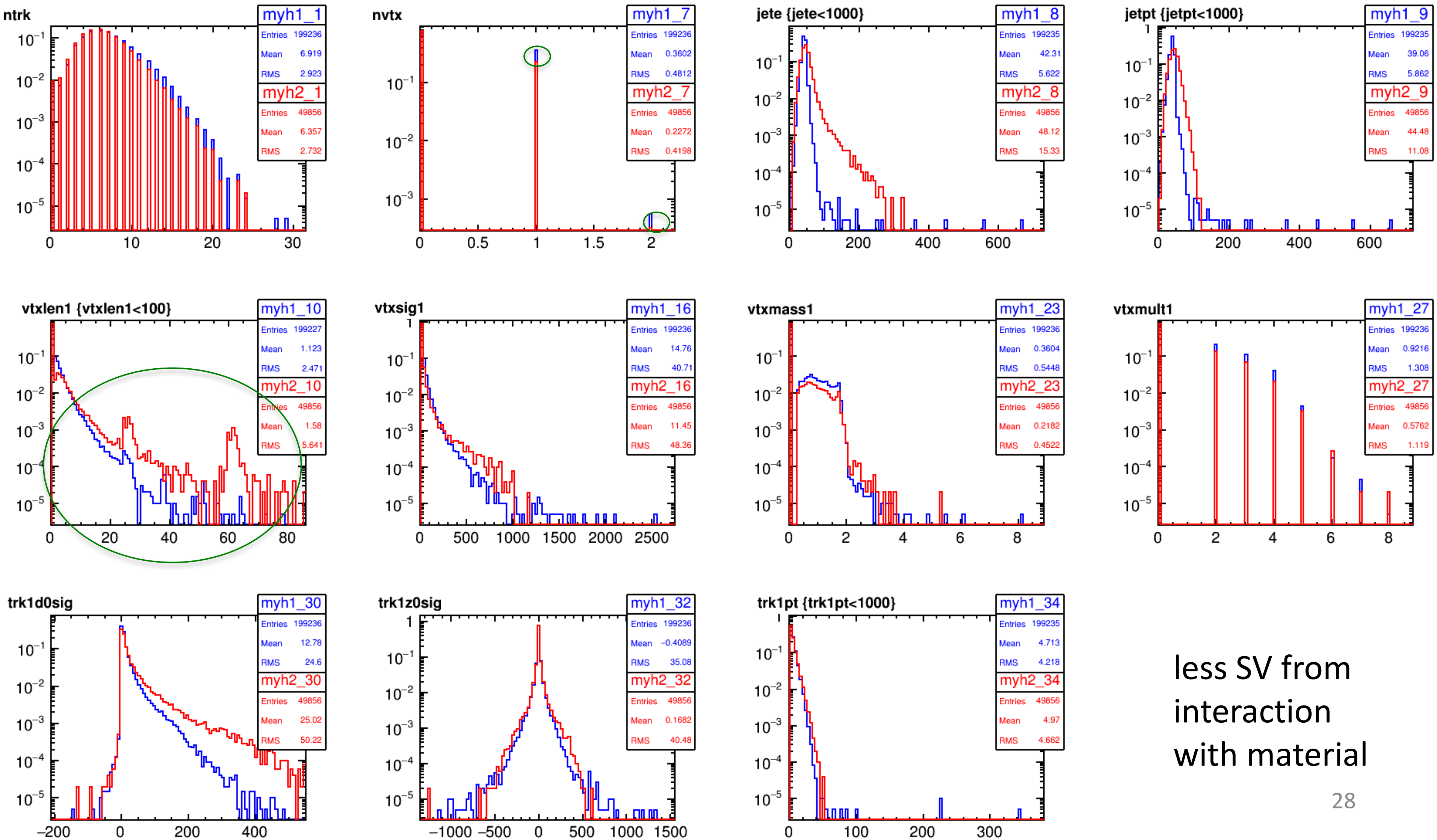
ll dijet sample



less SV from interaction with material

Opt3v02 vs CDR

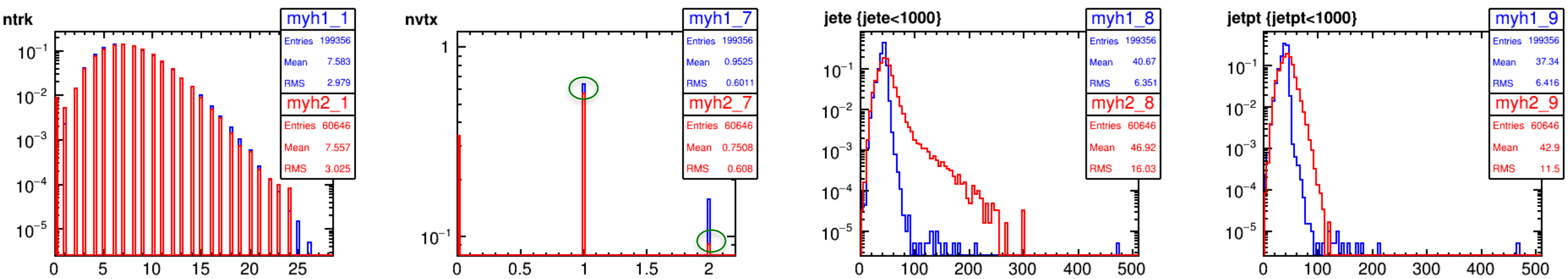
cc dijet sample

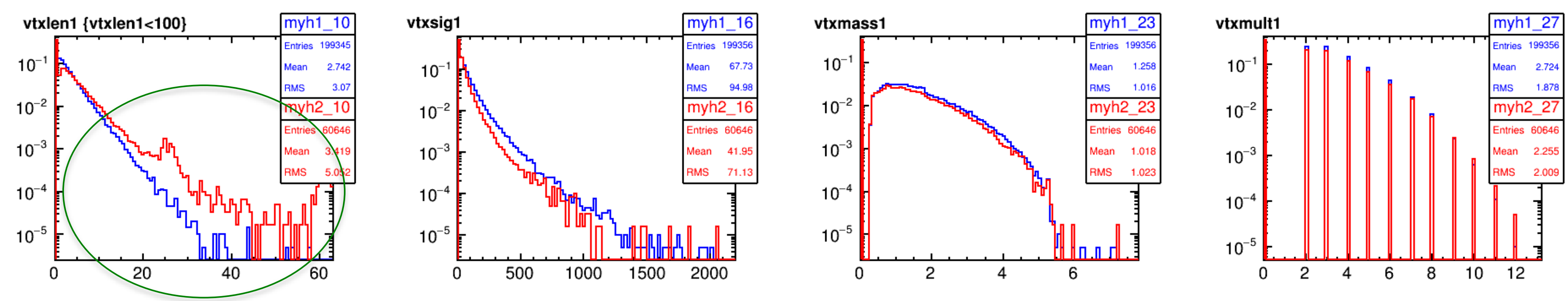


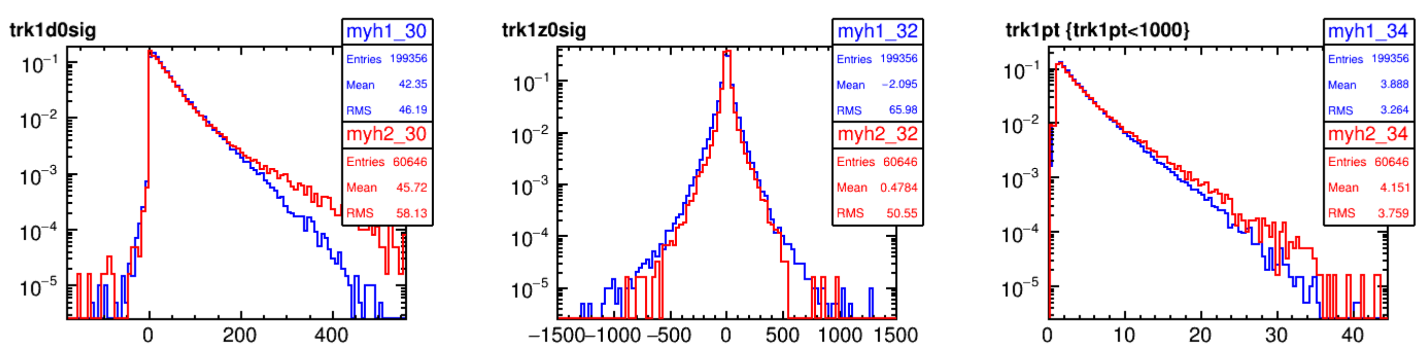
less SV from interaction with material

Opt3v02 vs CDR

cc dijet sample







less SV from interaction with material

more details of SW chain

Simulation

- LCSim
  - use FCC thickness and material budget, which include services&supports
    - Tracker: X/X_0= 3% [200um active Si]
    - Outer vertex: X/X_0= 1.5% [100um active Si]
    - Inner vertex: X/X_0= 1% [100um active Si]

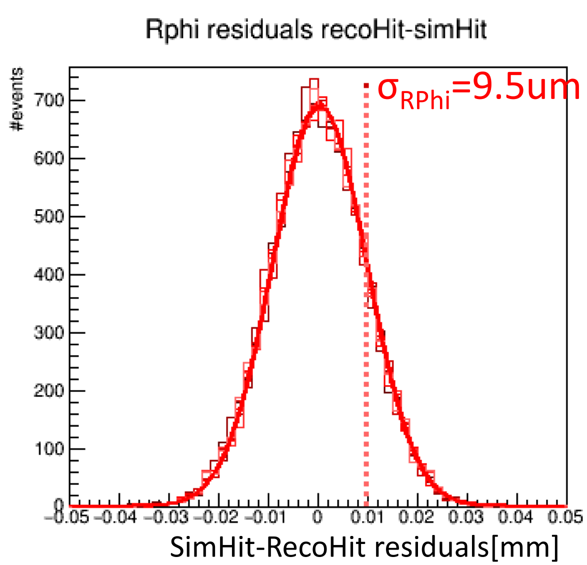
Digitisation

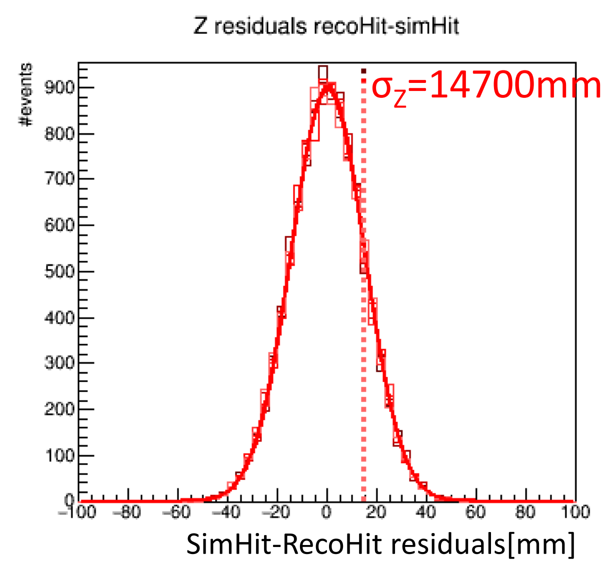
- Both vertex and tracker detectors are digitized as long pixels.
- We used a simplified digitizer, **smearing the simulated hit position with a Gaussian of σ=pitch/√12** , which provides with a direct relationship between pitch and single point resolution (as done for Fast Sim).
  - This factors out the detector technology

- **Layer 1-3** (red) & **EC 1st ring** (dark red): 25um x 50um pitch → assumed ~ **7.5um x 15.0um** resolution
- **Layer 4-6 & other EC rings** (black): 100/3um x 100um pitch → assumed ~ **9.5 x 30um** resolution

SimHit-RecoHit residuals
in the tracker layers

Min-Max R-Phi resolution (μm): 9.5-9.5
Min-Max Z(R) resolution (μm): 14780.0-14780.0





Vertexing

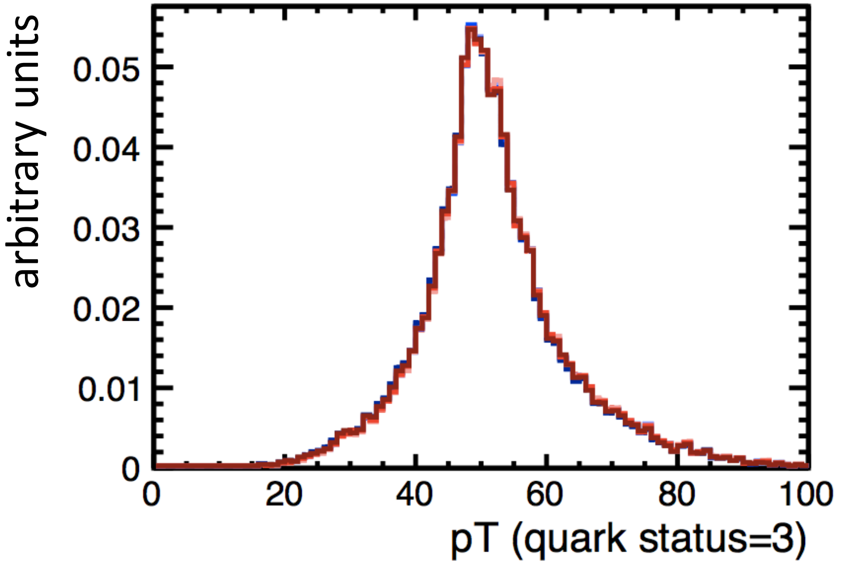
- LCFIPlus. Default
  - Consider only PFOs in 2 kT jets of R=0.5.
    - Avoid including particles in the “beam jets” (fwd particles close to the beam)
    - (Vertexing will rerun its own jet algorithm)

```
<!-- parameters for secondary vertex finder -->
<parameter name="BuildUpVertex.TrackMaxD0" type="double" value="10." /> <!--used-->
<parameter name="BuildUpVertex.TrackMaxZ0" type="double" value="20." />
<parameter name="BuildUpVertex.TrackMinPt" type="double" value="0.1" />
<parameter name="BuildUpVertex.TrackMaxD0Err" type="double" value="0.1" />
<parameter name="BuildUpVertex.TrackMaxZ0Err" type="double" value="0.1" />
<!--parameter name="BuildUpVertex.TrackMinTpcHits" type="int" value="4" /-->
<!-- not active parameter name="BuildUpVertex.TrackMinFtdHits" type="int" value="3" /-->
<!-- not active parameter name="BuildUpVertex.TrackMinVxdHits" type="int" value="3" /-->
<parameter name="BuildUpVertex.TrackMinVxdFtdHits" type="int" value="0" />
<!-- does not seem to affect parameter name="BuildUpVertex.PrimaryChi2Threshold" type="doubl
<parameter name="BuildUpVertex.SecondaryChi2Threshold" type="double" value="9." />
<parameter name="BuildUpVertex.MassThreshold" type="double" value="10." />
<parameter name="BuildUpVertex.MinDistFromIP" type="double" value="0.3" />
<!-- seems to have no effect parameter name="BuildUpVertex.MaxChi2ForDistOrder" type="double
<parameter name="BuildUpVertex.AssocIPTracks" type="int" value="1" />
<parameter name="BuildUpVertex.AssocIPTracksMinDist" type="double" value="0." />
<parameter name="BuildUpVertex.AssocIPTracksChi2RatioSecToPri" type="double" value="2.0" />
<parameter name="BuildUpVertex.UseV0Selection" type="int" value="1" />
```

To do: review how these cuts are actually applied
(ongoing)

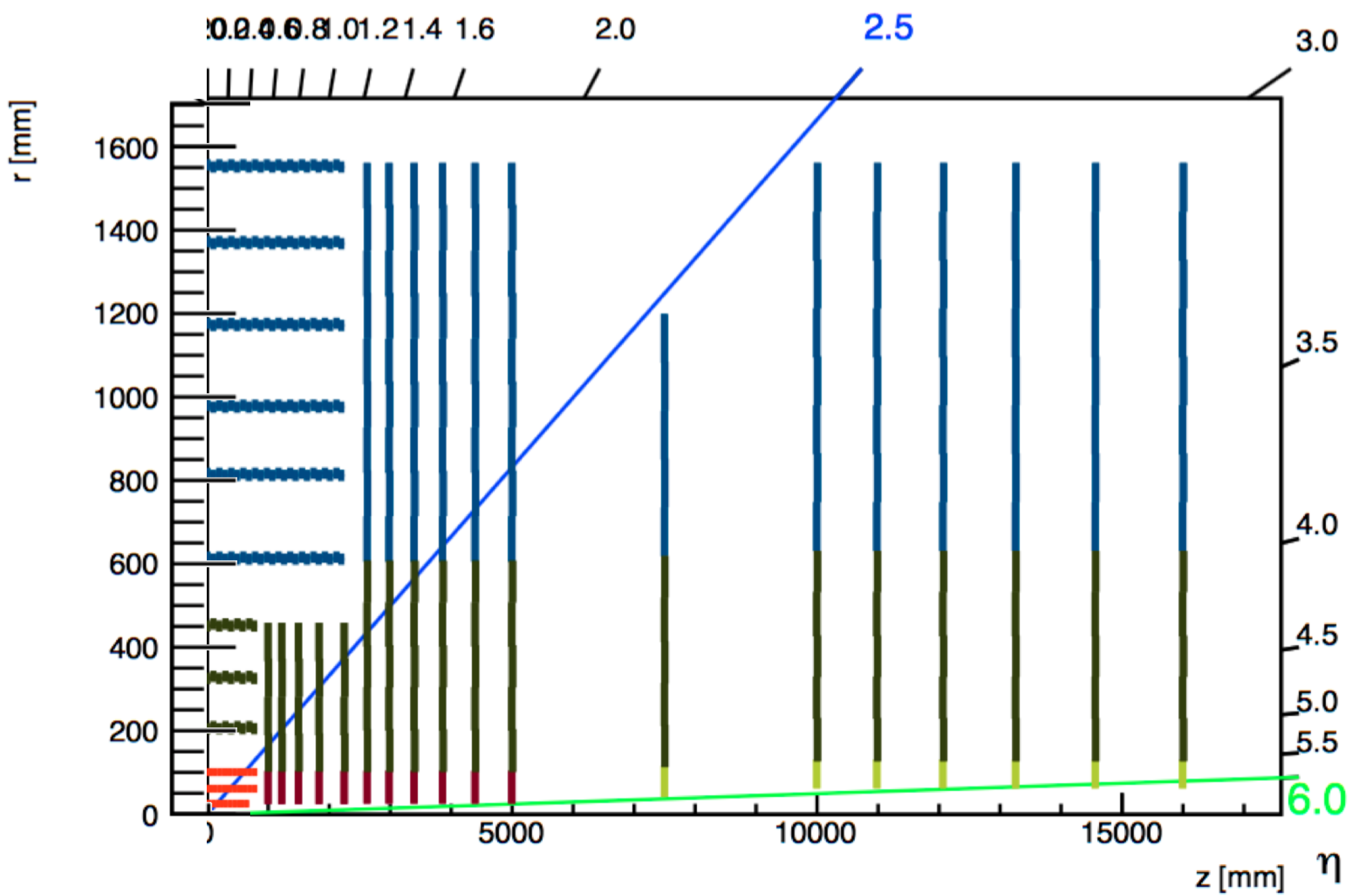
Hadronization

- Pythia6:
  - MSTP(81)=20 Multiple Interaction: OFF
  - MSTP(61)=1 FSR: ON
  - MSTP(71)=1 ISR: ON
- b quark pT spectrum

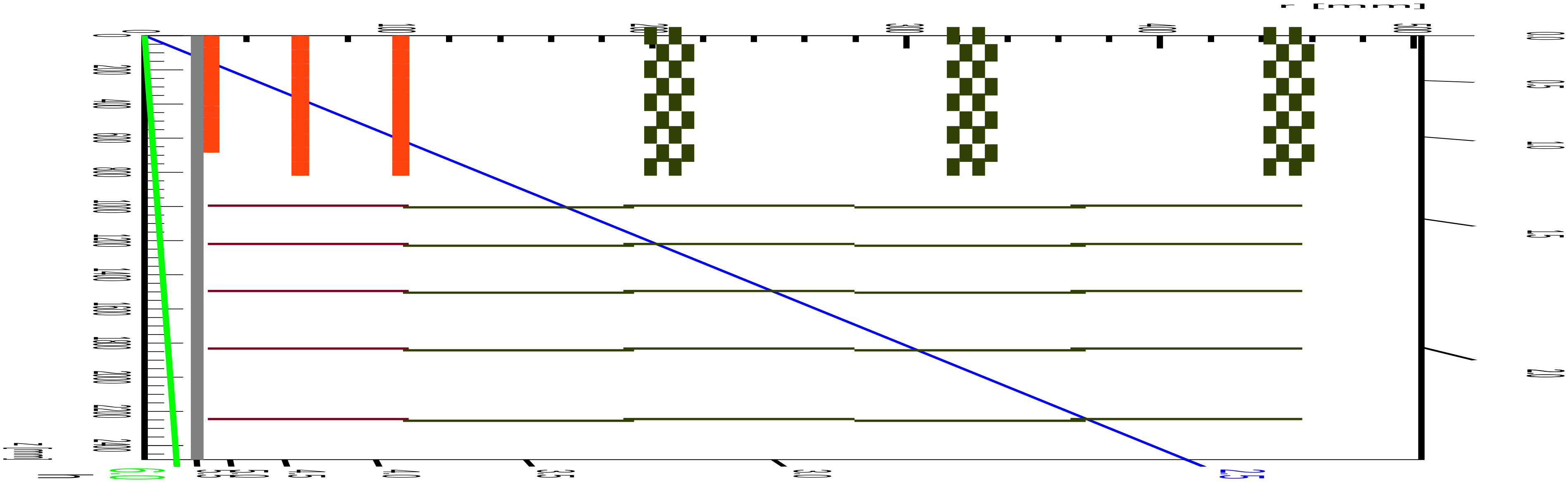


Current baseline geometry

- http://fcc-tklayout.web.cern.ch/fcc-tklayout/FCChh_Option3.v02/index.html



Current baseline geometry – Vertex Detector



(version v03 will have 4 innermost layers and tilted modules)