CLD detector performance with beam pipe with reduced diameter at IP - a first look -

Emilia Leogrande (CERN),
on behalf of the CLICdp and FCC Collaborations

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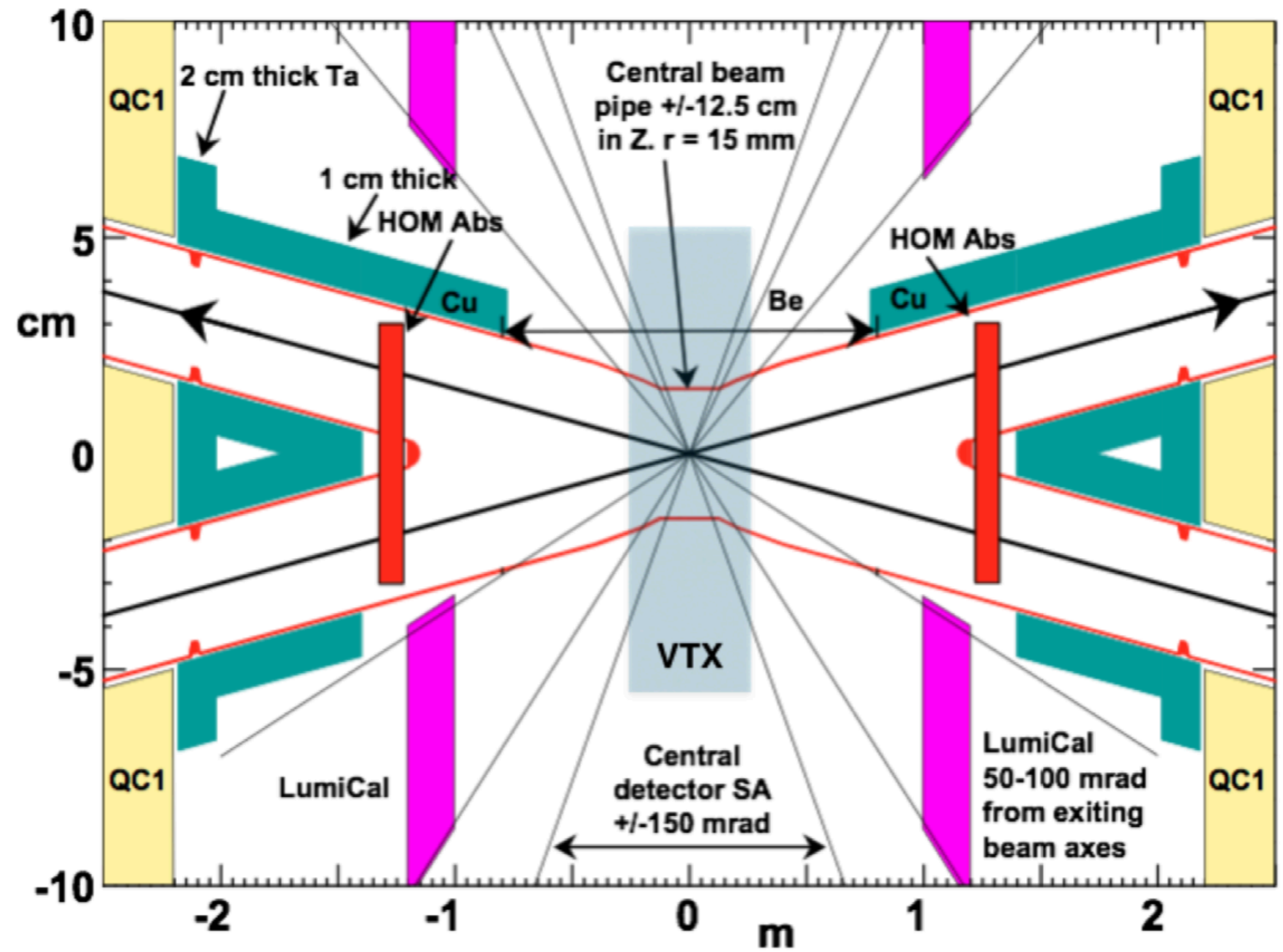
Introduction

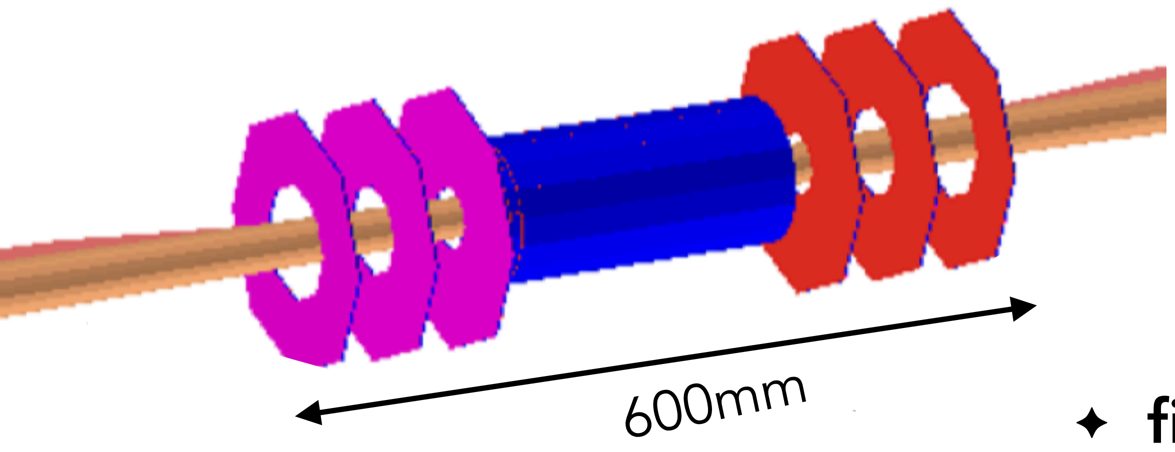
- **CLD** (CLIC-Like Detector) is a detector concept developed for FCC-ee
- Design for the CDR (Dec 2018) **adapted from the CLICdet to the FCC-ee** interaction region specifics (crossing angle, magnets, beam pipe, background conditions)
- Performance satisfying the physics requirements O. Viazlo's talk

Concept	CLICdet	CLD
Vertex inner radius [mm]	31	17
Tracker half length [m]	2.2	
Tracker outer radius [m]	1.5	2.1
ECAL absorber	W	
ECAL X_0	22	
HCAL absorber	Fe	
HCAL λ_I	7.5	5.5
Solenoid field [T]	4	2
Overall height [m]	12.9	12.0
Overall length [m]	11.4	10.6



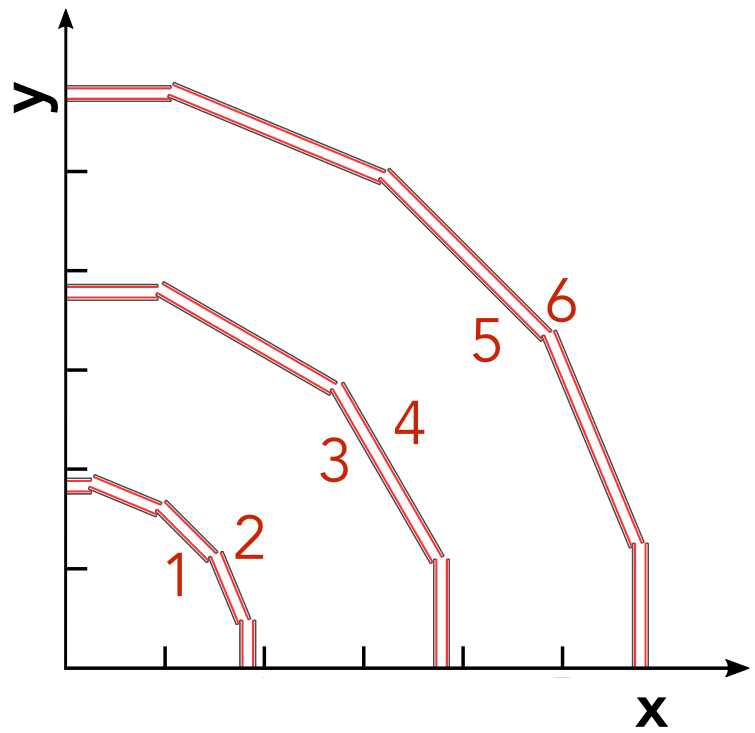
- **Novel design option post-CDR**:
  - **beam pipe** at IP **radius** reduced **from 15 mm to 10 mm**
  - CLD detector design adjusted to the new IR layout

Vertex detector - design update



- 3 double barrel layers + 3 double layer disks per side
  - 0.6%X_0 per double layer
  - pixel size 25 x 25 μm^2
  - sensitive thickness 50 μm per layer

- **first double barrel layer closer to beam pipe**
- third barrel layer unchanged
- second barrel layer equidistant from first and third
- vertex disks unchanged

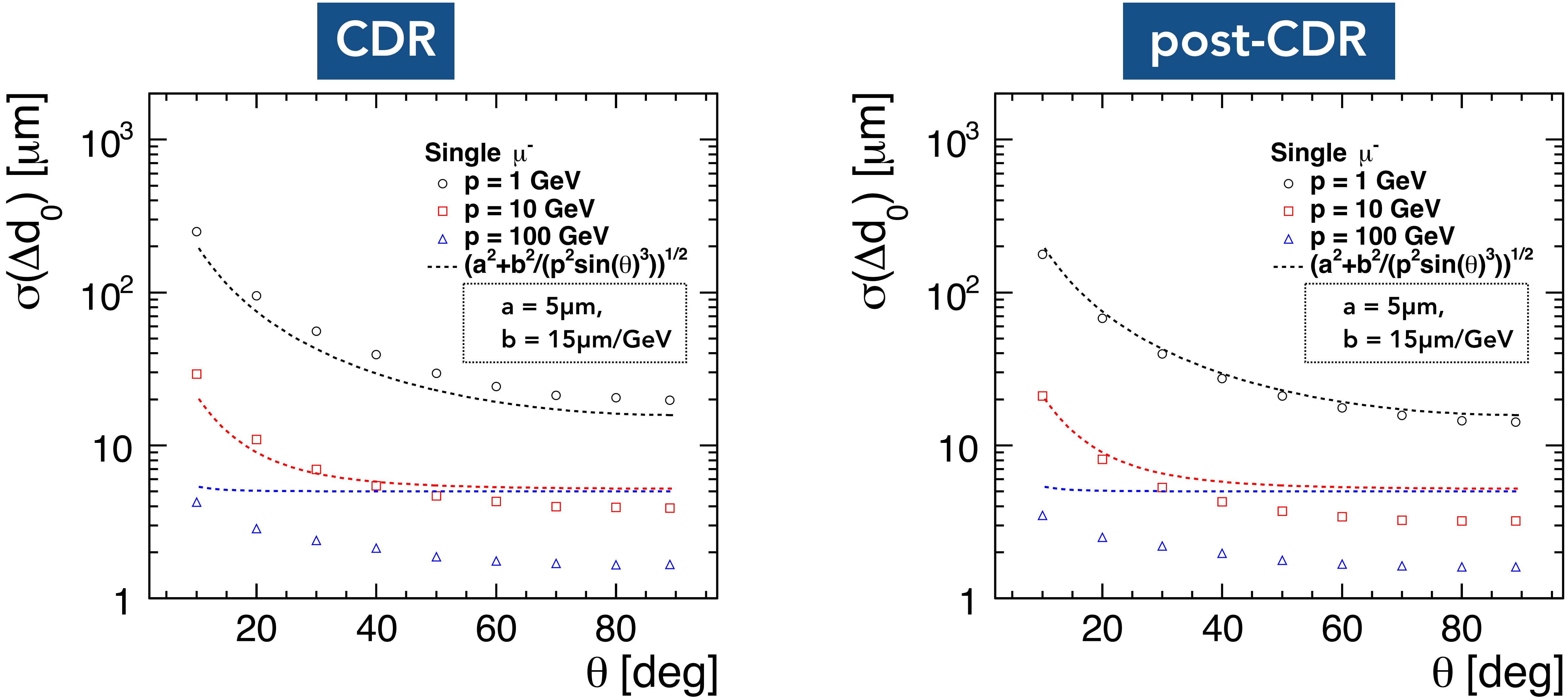


	CDR	post-CDR
beam pipe radius [mm]	15	10
r1 [mm]	17.5	12.5
r2 [mm]	18.5	13.5
r3 [mm]	37	35
r4 [mm]	38	36
r5 [mm]	57	57
r6 [mm]	58	58

Transverse impact parameter resolution

- **σ(Δd₀)** expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Resolution calculated as width of the Gaussian fit to the residual distribution per data point

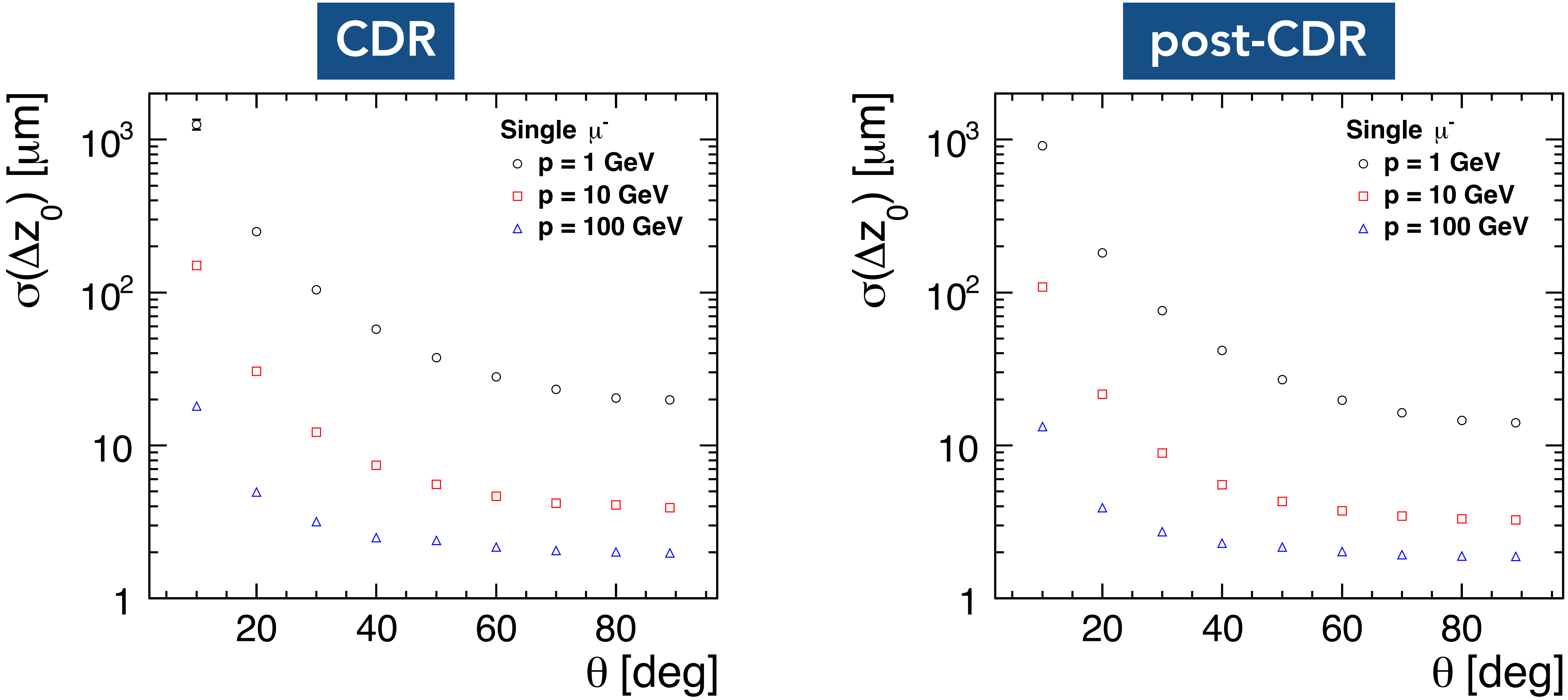
CDR | **post-CDR**



- improvement overall more visible for lower-energy muons
- resolution for muons with momentum of 1 GeV also matches the design goal

Longitudinal impact parameter resolution

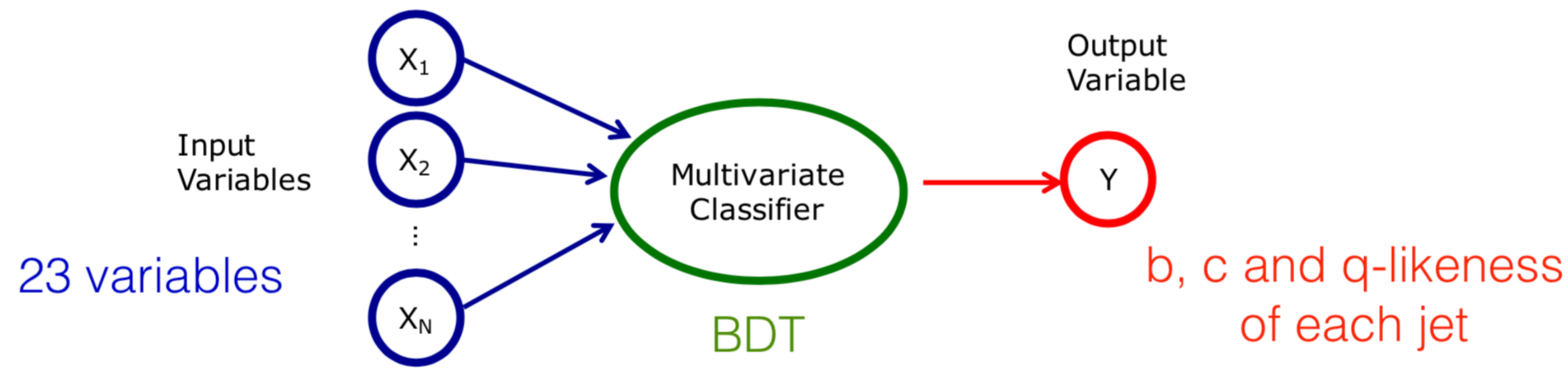
- $\sigma(\Delta z_0)$ expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Resolution calculated as width of the Gaussian fit to the residual distribution per data point



- improvement overall more significant for lower-energy muons

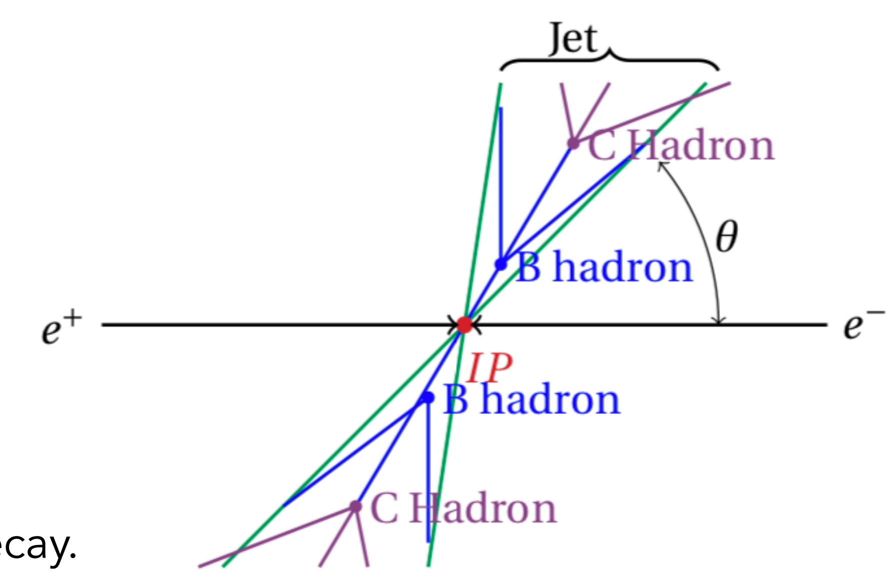
Flavour tagging algorithm

- Full simulation and reconstruction with LCFIPlus implemented in the Marlin framework of iLCSoft
- Algorithm chain:
  - vertex finder
  - jet clustering
  - vertex refiner
  - multivariate analysis



- dataset divided in 4 categories, used to train the BDT

Category	A	B	C	D
Number of vertices	0	1	1	2
Number of pseudovertices*	0-2	0	1	0
	uds	c	b	b



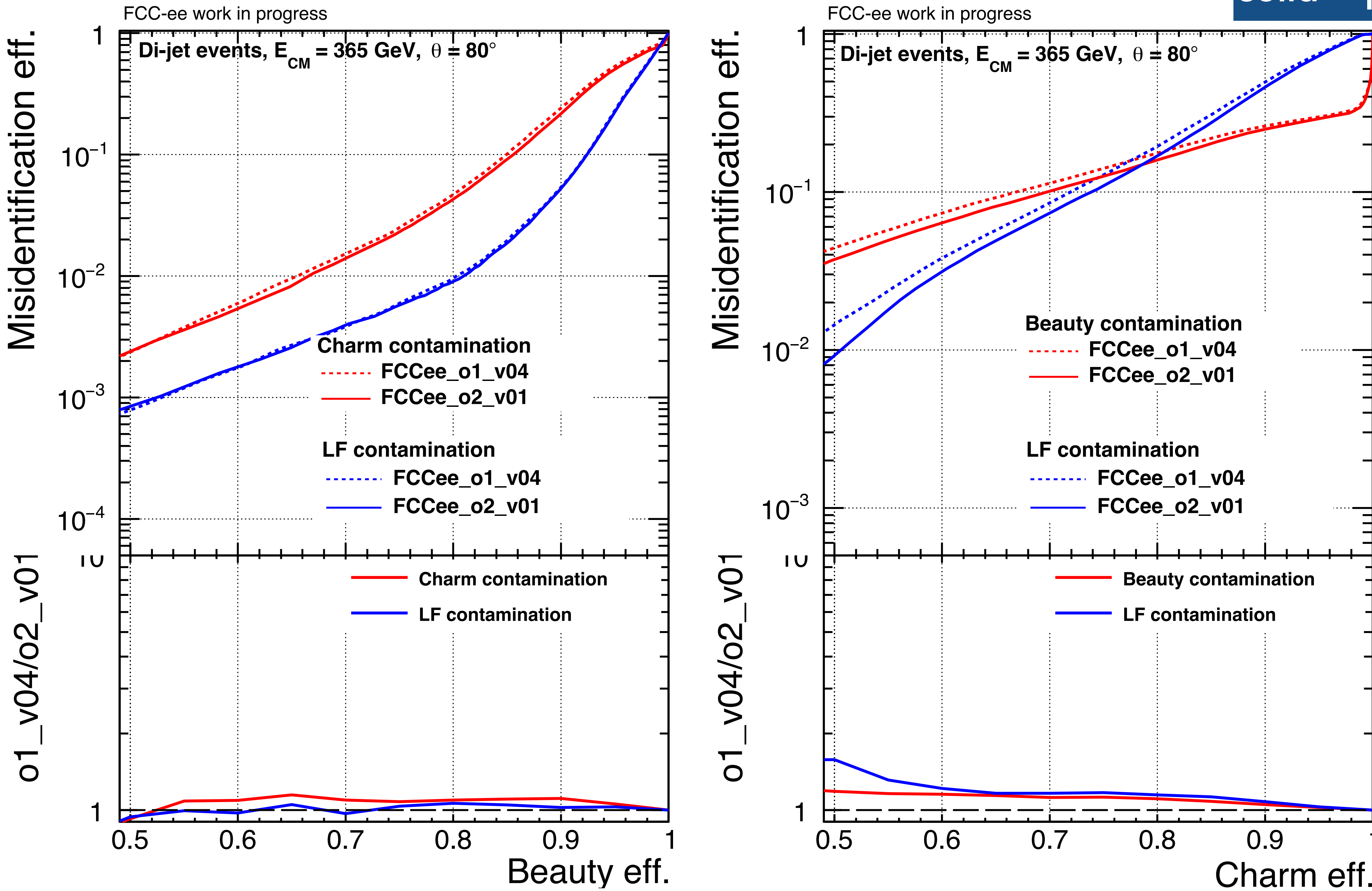
*pseudovertices: b jets containing only one reconstructed secondary vertex with a possible track that could be interpreted as the result of an additional secondary decay. The cascade decays in a b jet are expected to result in decay points that are nearly collinear with the primary vertex. If only one secondary vertex is found, and if there is a track whose trajectory passes near a point collinear to the primary and secondary vertices, then the track is taken as a pseudo-vertex.

Flavour tagging for dijets at 365 GeV

- **Flavour tagging relies on the capability of primary and secondary vertices reconstruction =>**expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with Ecm = 365 GeV and **θ = 80 deg**

dashed = CDR

solid = post-CDR



Flavour tagging for dijets at 365 GeV

- **Flavour tagging relies on the capability of primary and secondary vertices reconstruction**
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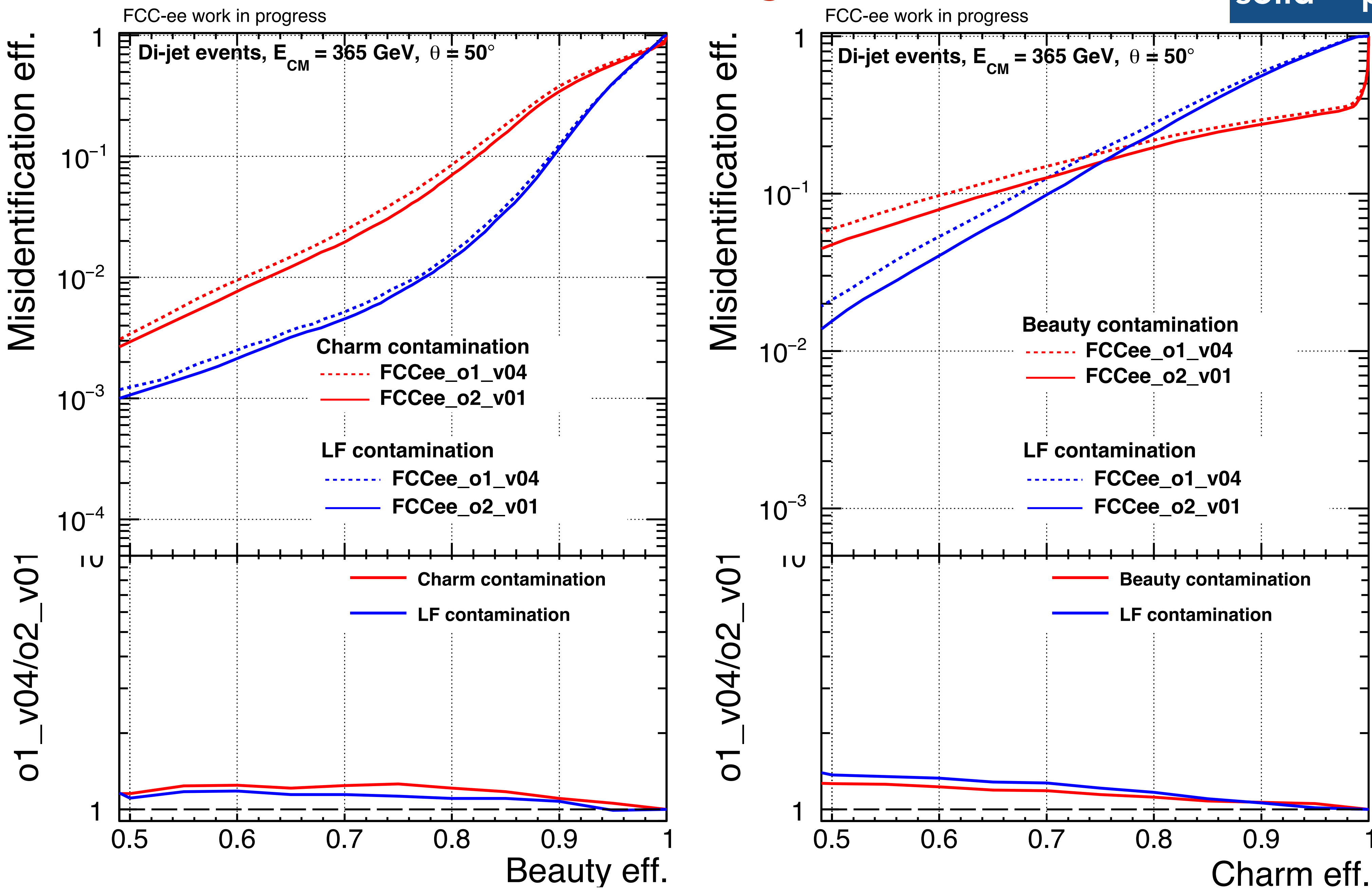
- Results obtained in full detector simulation and reconstruction
- Dijet events with Ecm = 365 GeV and **θ = 50 deg**

dashed = CDR
solid = post-CDR



Flavour tagging for dijets at 365 GeV

- **Flavour tagging relies on the capability of primary and secondary vertices reconstruction**
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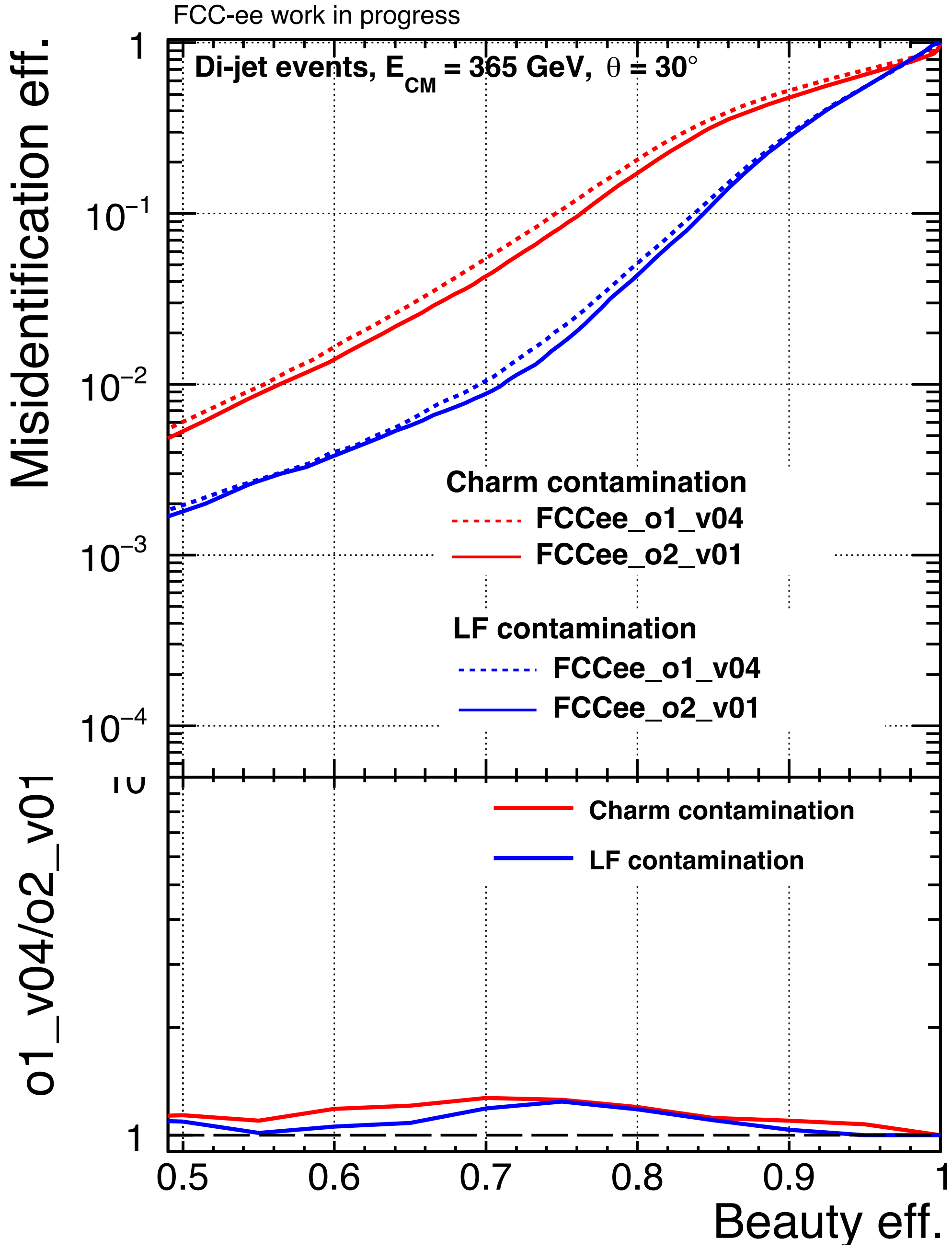
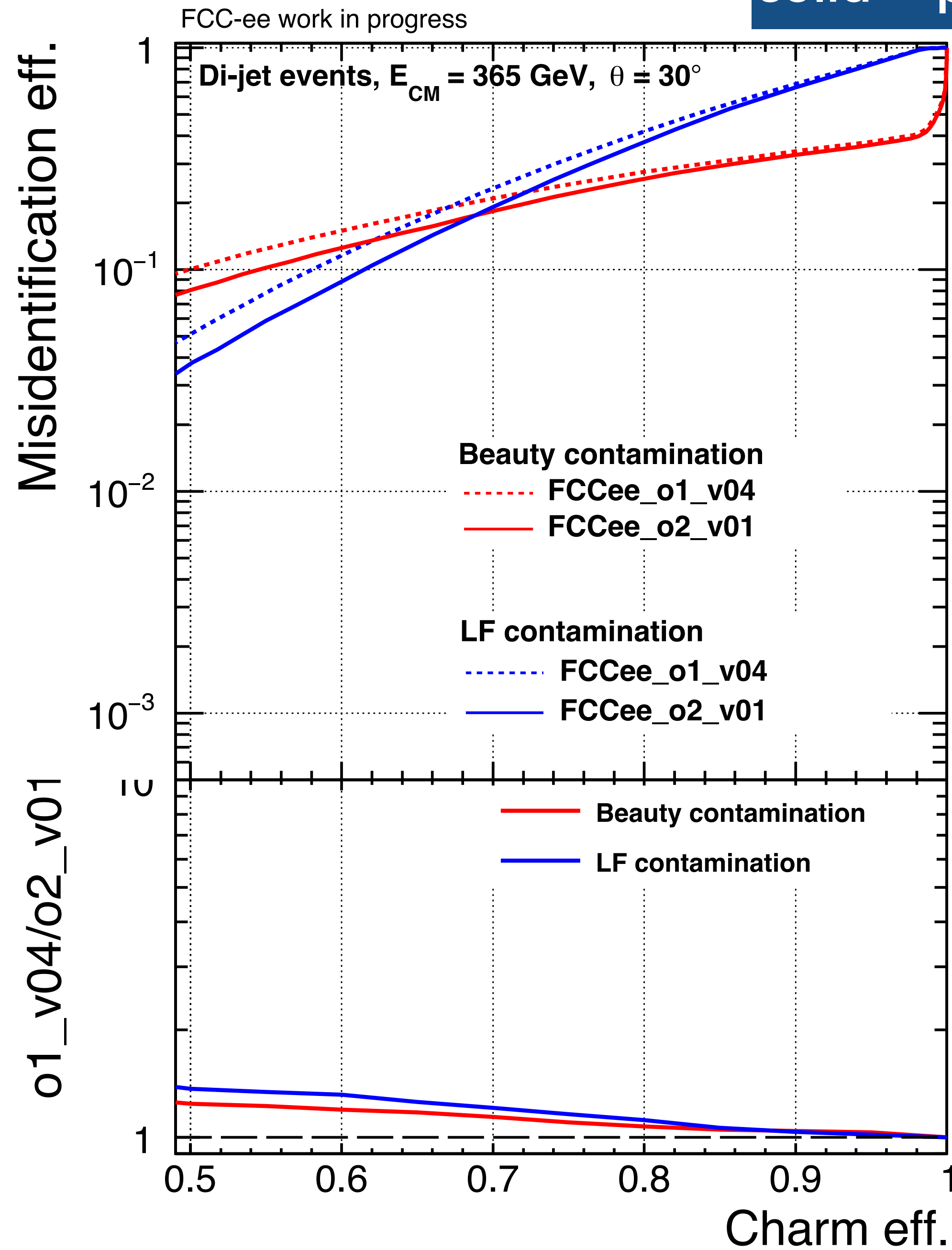
- Results obtained in full detector simulation and reconstruction
- Dijet events with Ecm = 365 GeV and **θ = 30 deg**

dashed = CDR

solid = post-CDR

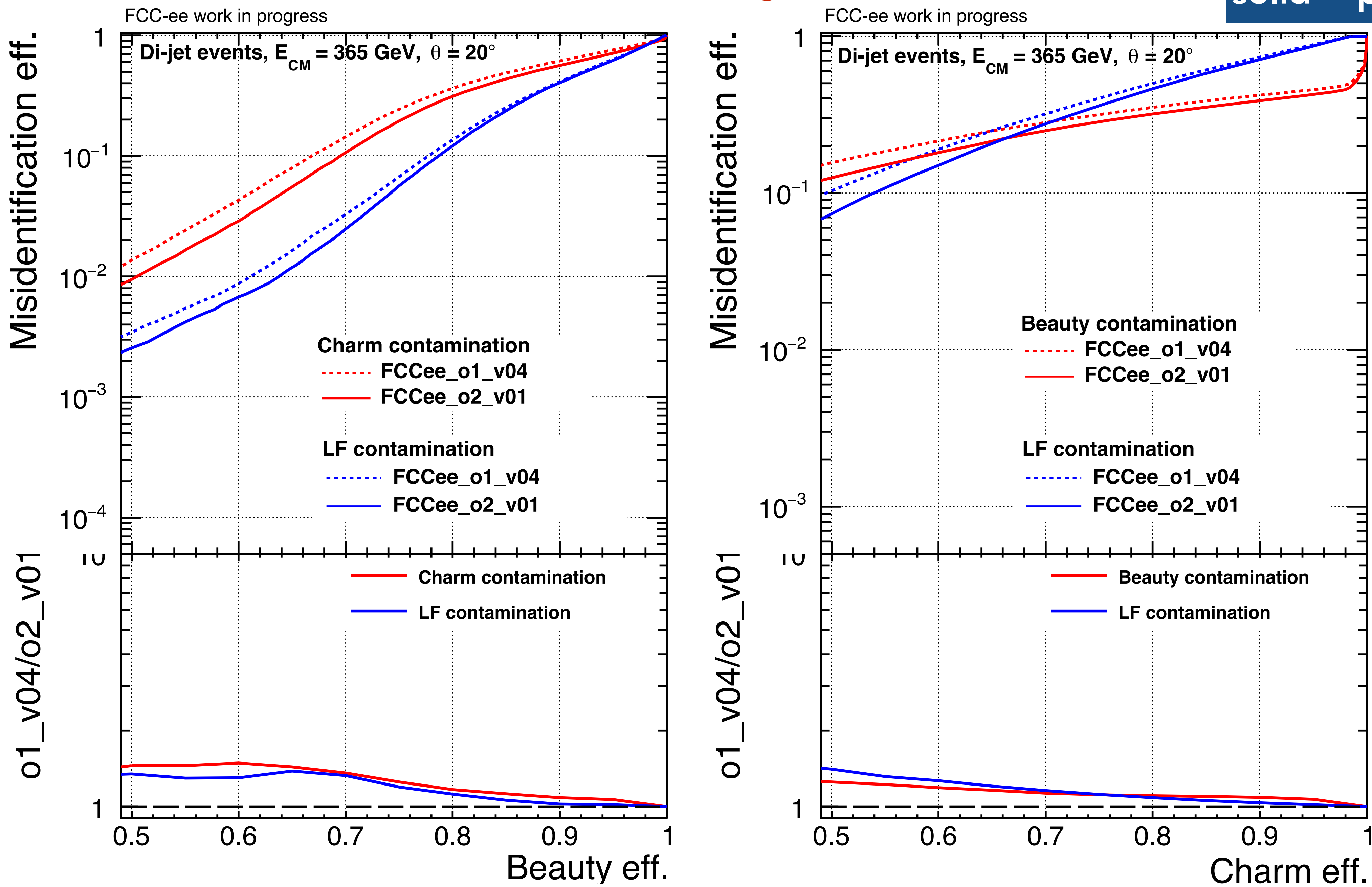




Flavour tagging for dijets at 365 GeV

- **Flavour tagging relies on the capability of primary and secondary vertices reconstruction** **=>**expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with Ecm = 365 GeV and **θ = 20 deg**

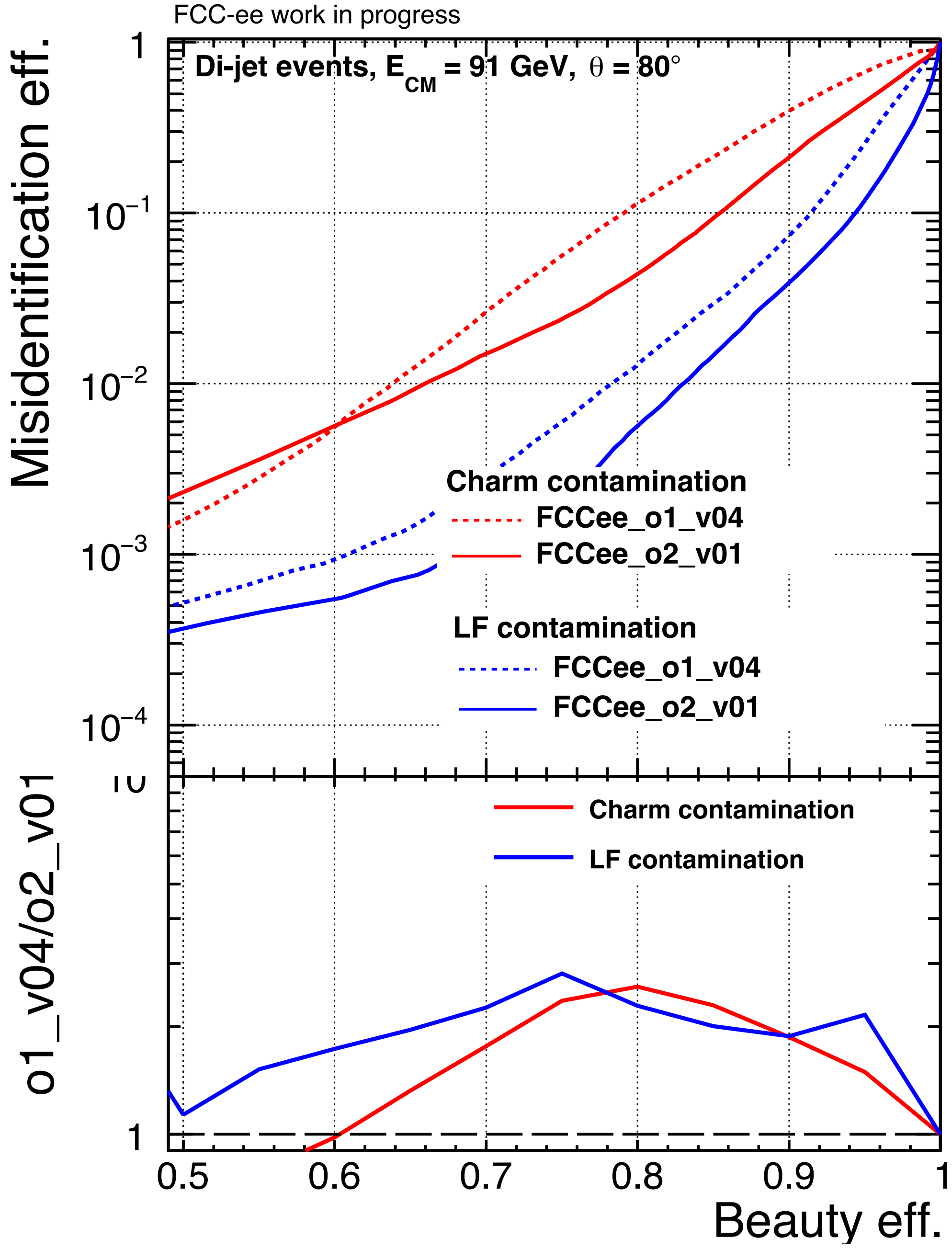
dashed = CDR
solid = post-CDR

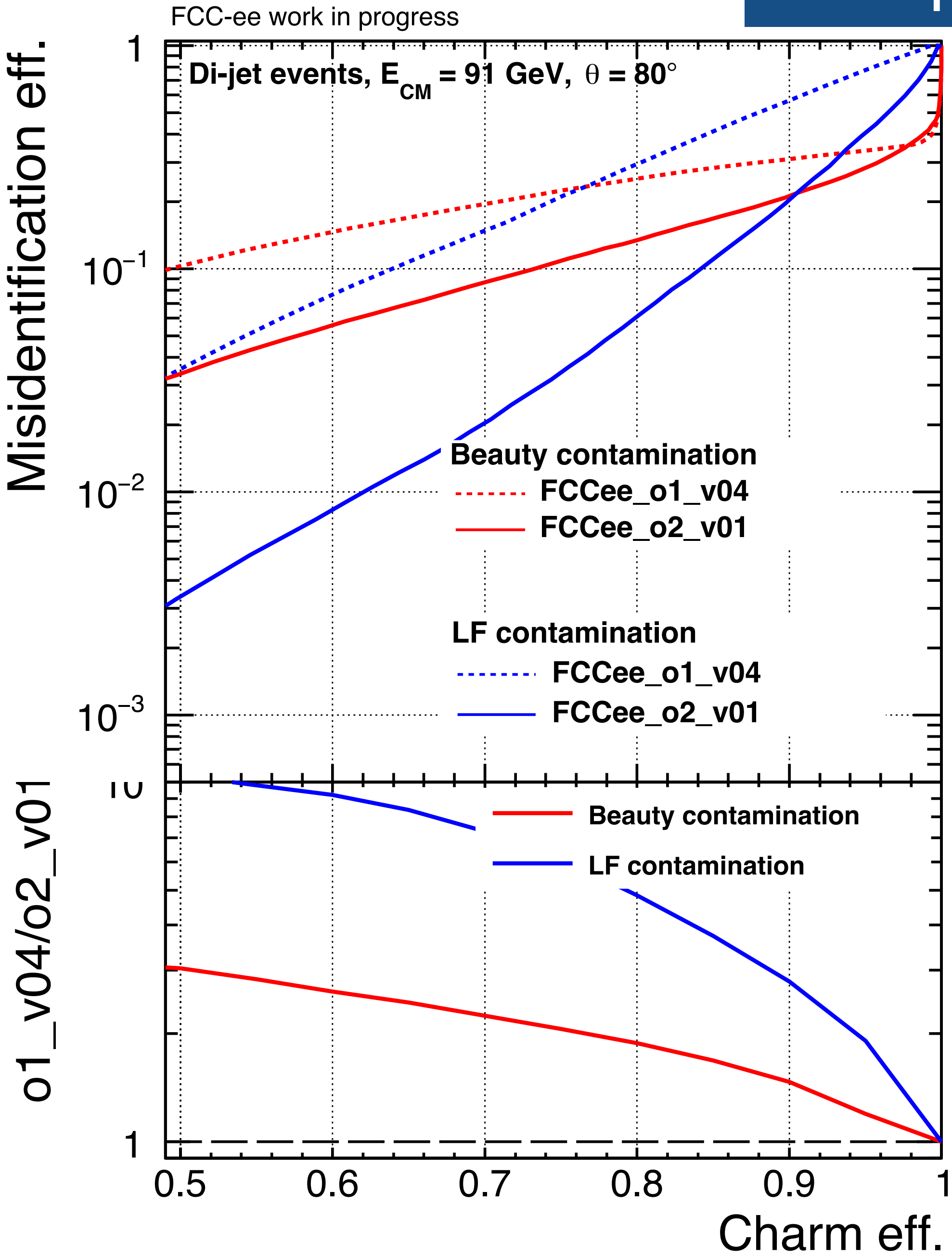


Flavour tagging for dijets at 91 GeV

- **Flavour tagging relies on the capability of primary and secondary vertices reconstruction**
  =>expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with Ecm = 91 GeV and **θ = 80 deg**

dashed = CDR
solid = post-CDR





Flavour tagging for dijets at 91 GeV

- **Flavour tagging relies on the capability of primary and secondary vertices reconstruction**
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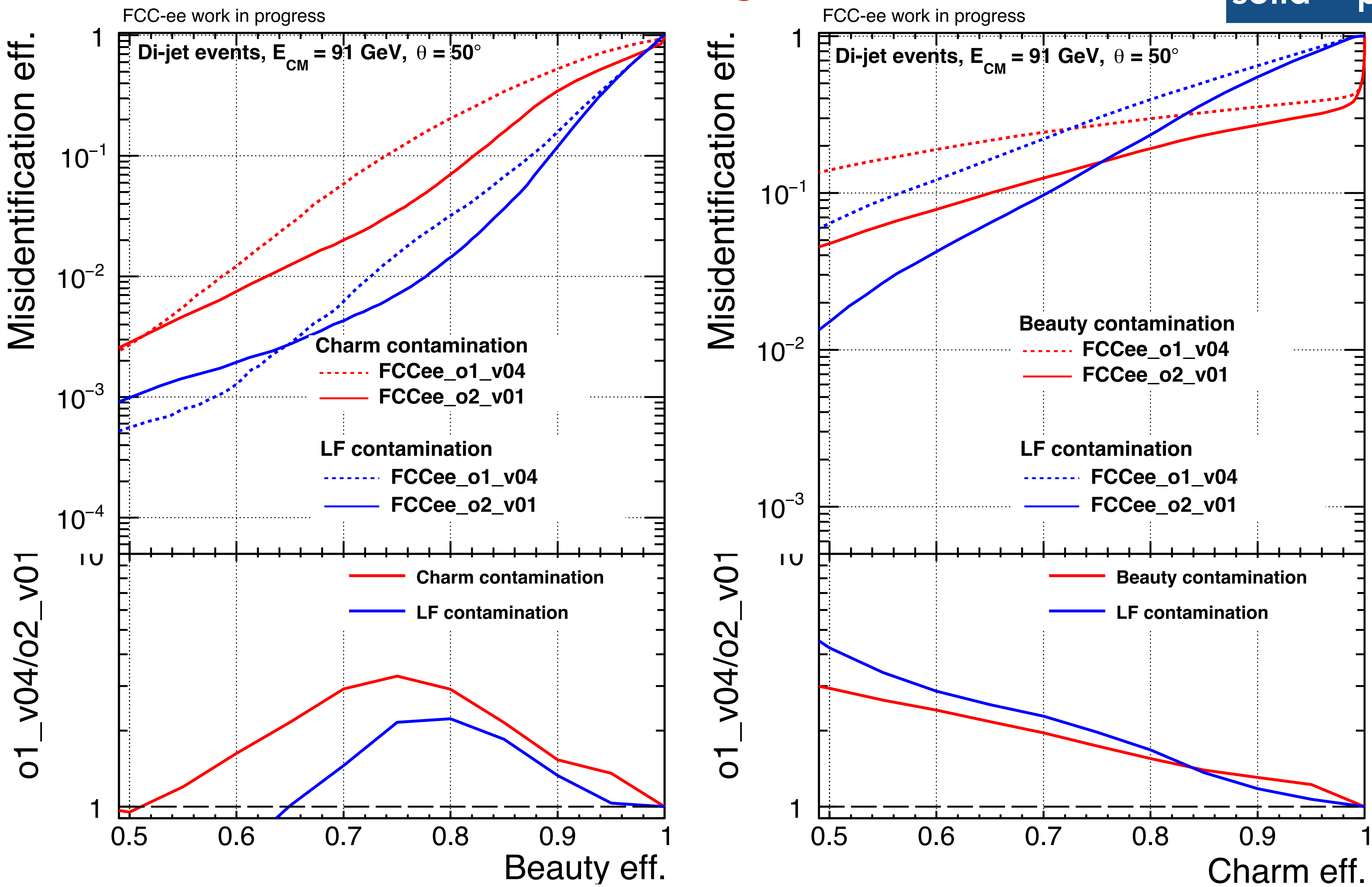
- Results obtained in full detector simulation and reconstruction
- Dijet events with Ecm = 91 GeV and **θ = 50 deg**

dashed = CDR
solid = post-CDR

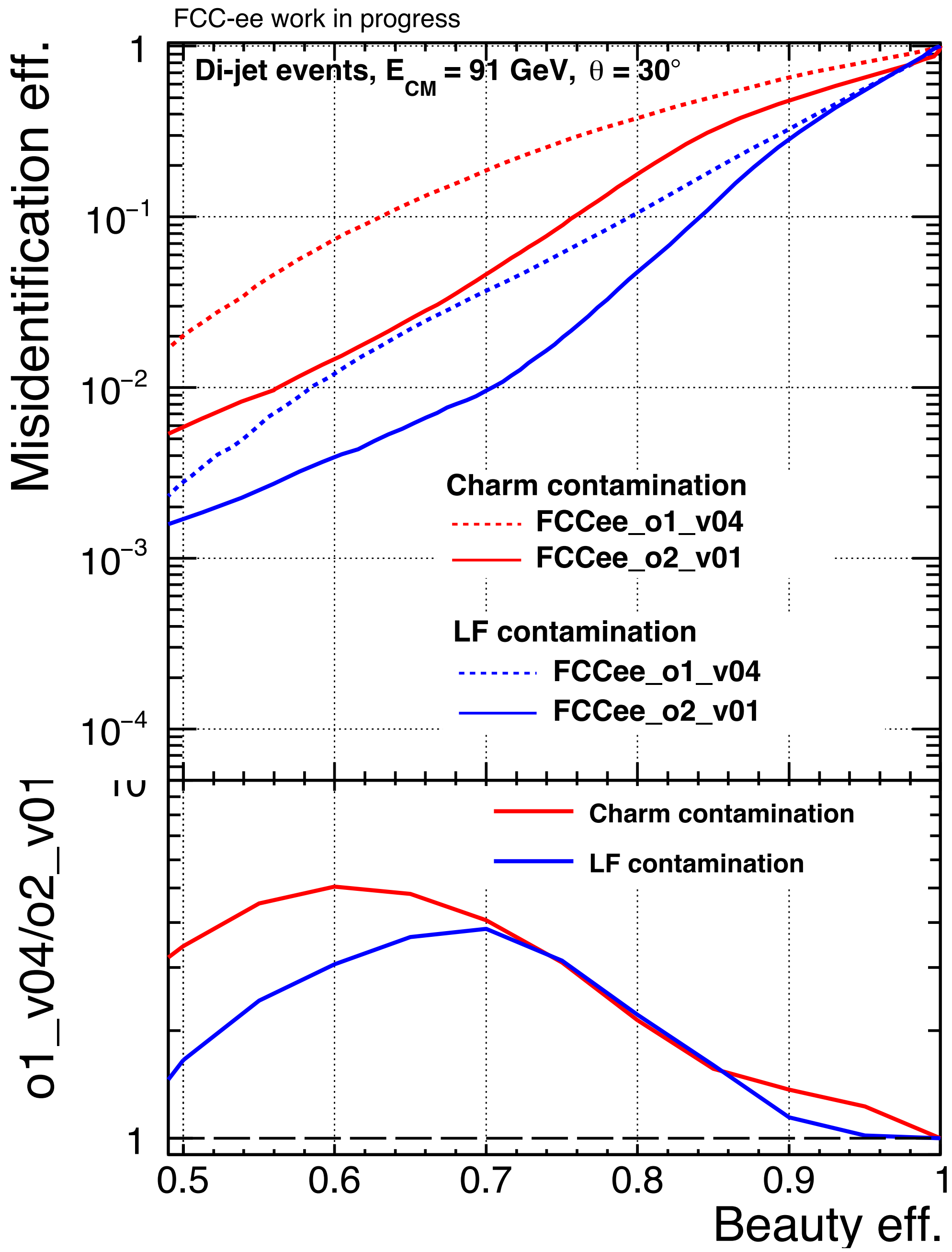


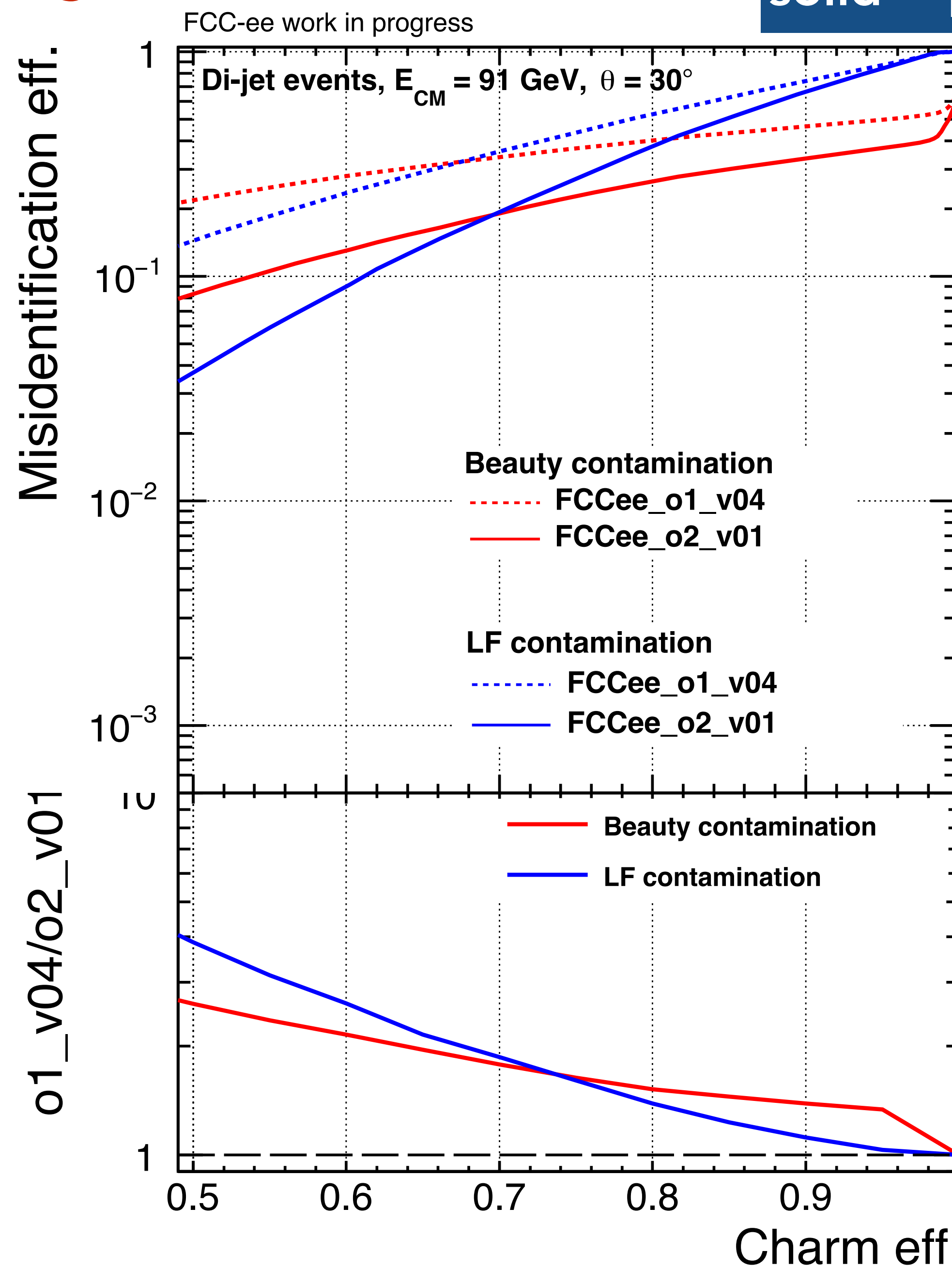
Flavour tagging for dijets at 91 GeV

- **Flavour tagging relies on the capability of primary and secondary vertices reconstruction**
  =>expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with Ecm = 91 GeV and **θ = 30 deg**

dashed = CDR

solid = post-CDR



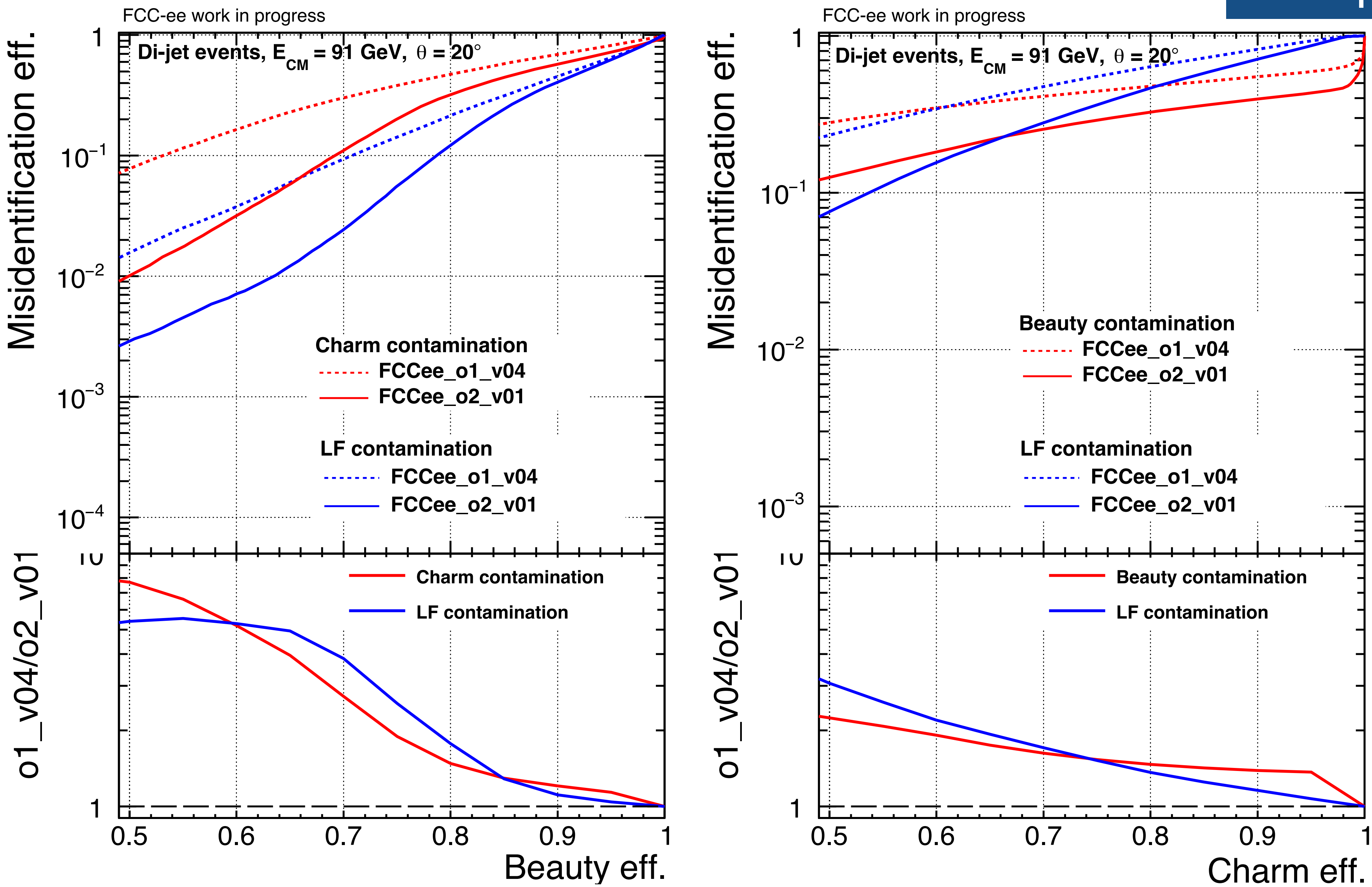


Flavour tagging for dijets at 91 GeV

- **Flavour tagging relies on the capability of primary and secondary vertices reconstruction** **=>**expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with Ecm = 91 GeV and **θ = 20 deg**

dashed = CDR

solid = post-CDR



Preliminary observations

- **Flavour tagging** in dijet events at **365 GeV improves** slightly **with post-CDR model**
- **Flavour tagging** in dijet events at **91 GeV improves** significantly **with post-CDR model**
  - @365 GeV, the polar angle dependence shows that the improvement:
    - is better in the forward direction for the b-tagging
    - is similar in the forward and central direction for the c-tagging
  - @91 GeV, the polar angle dependence shows that the improvement:
    - is better in the forward direction for the b-tagging
    - is better in the central direction for the c-tagging

Preliminary observations

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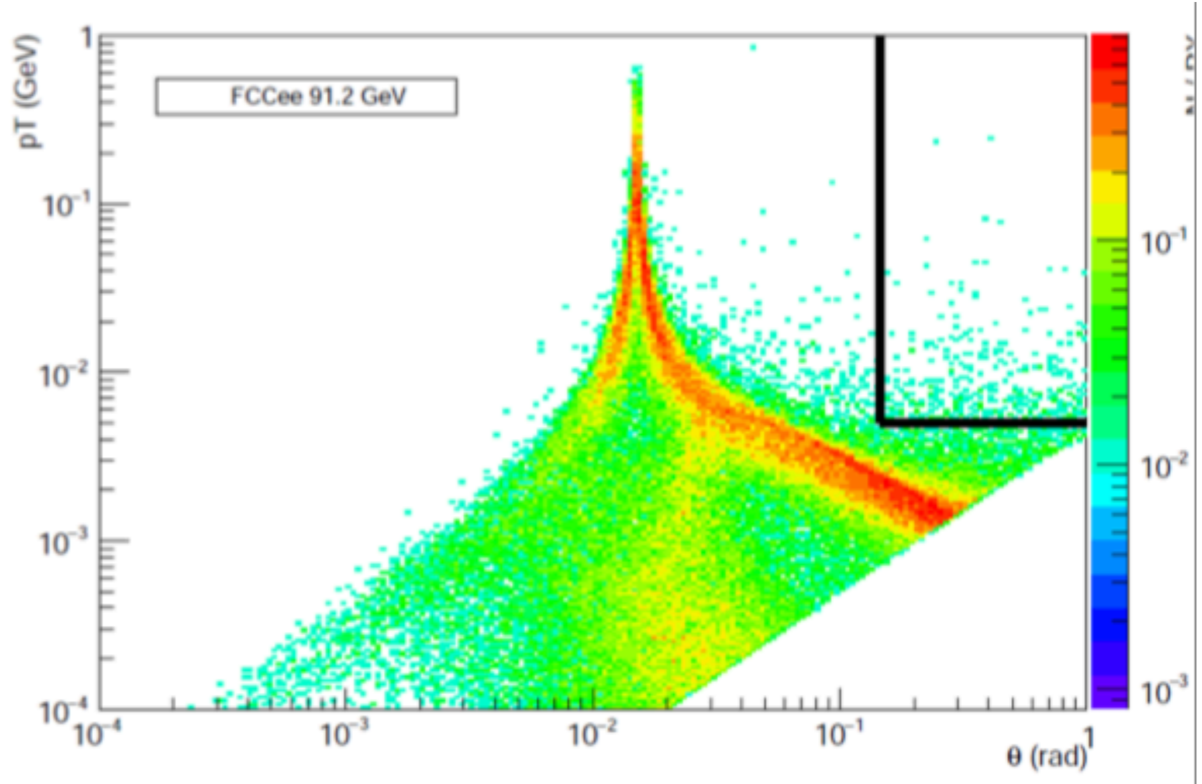
  - @91 GeV, the polar angle dependence shows that the improvement:
    - is better in the forward direction for the b-tagging
    - is better in the central direction for the c-tagging

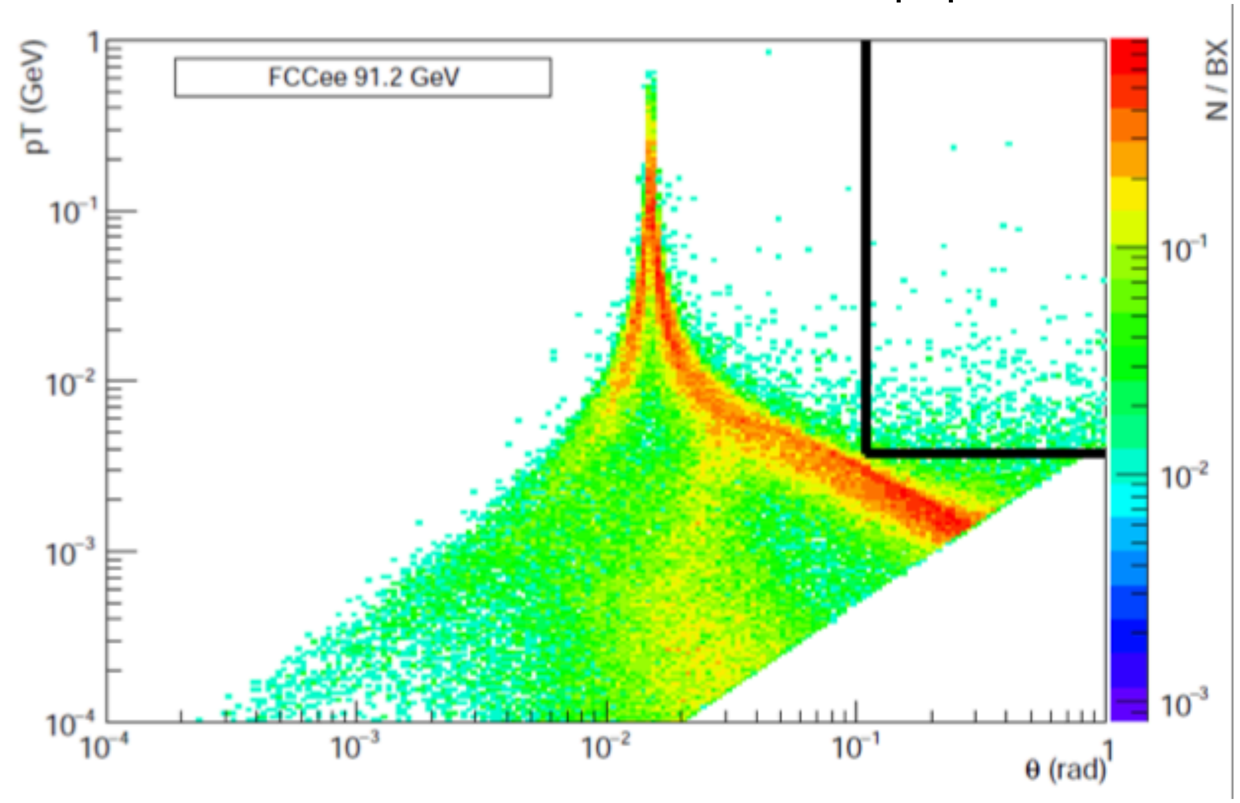
Food for thoughts

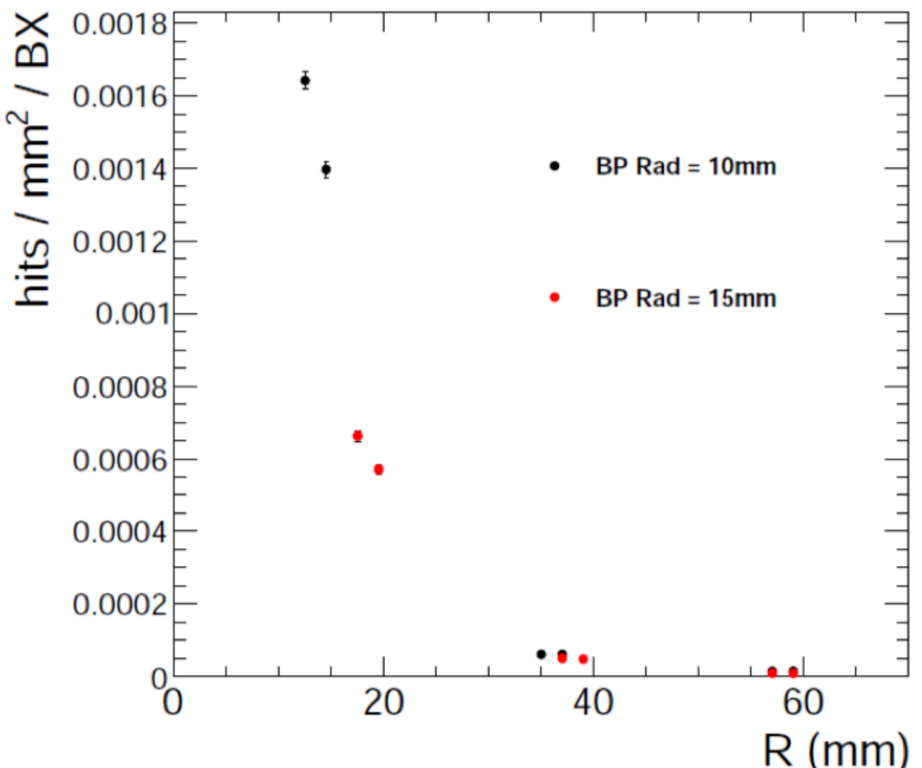
- b tagging
  - improvement stronger at 91GeV than at 365GeV <= fraction of b hadrons that decay after the innermost layer is smaller at 91GeV than at 365GeV
    - @91GeV && 90deg: ~10%, @365GeV && 90deg: ~50%
  - improvement stronger in the forward than in the central region at both energies <= fraction of b hadrons that decay after the innermost layer is smaller at 20deg than at 80deg
- tagging depends on many other variables: vertex mass, vertex resolution, impact parameter significance, … <u>This is only the start of the investigation</u>

Incoherent pairs background

- distribution of produced particles from incoherent pairs @91 GeV
  - old model
  - new model (smaller beampipe)







- occupancy in the barrel layers
  - old model x 50BX < $4x10^{-4}$
  - new model x 50BX < $8x10^{-4}$

=> still acceptable

Summary

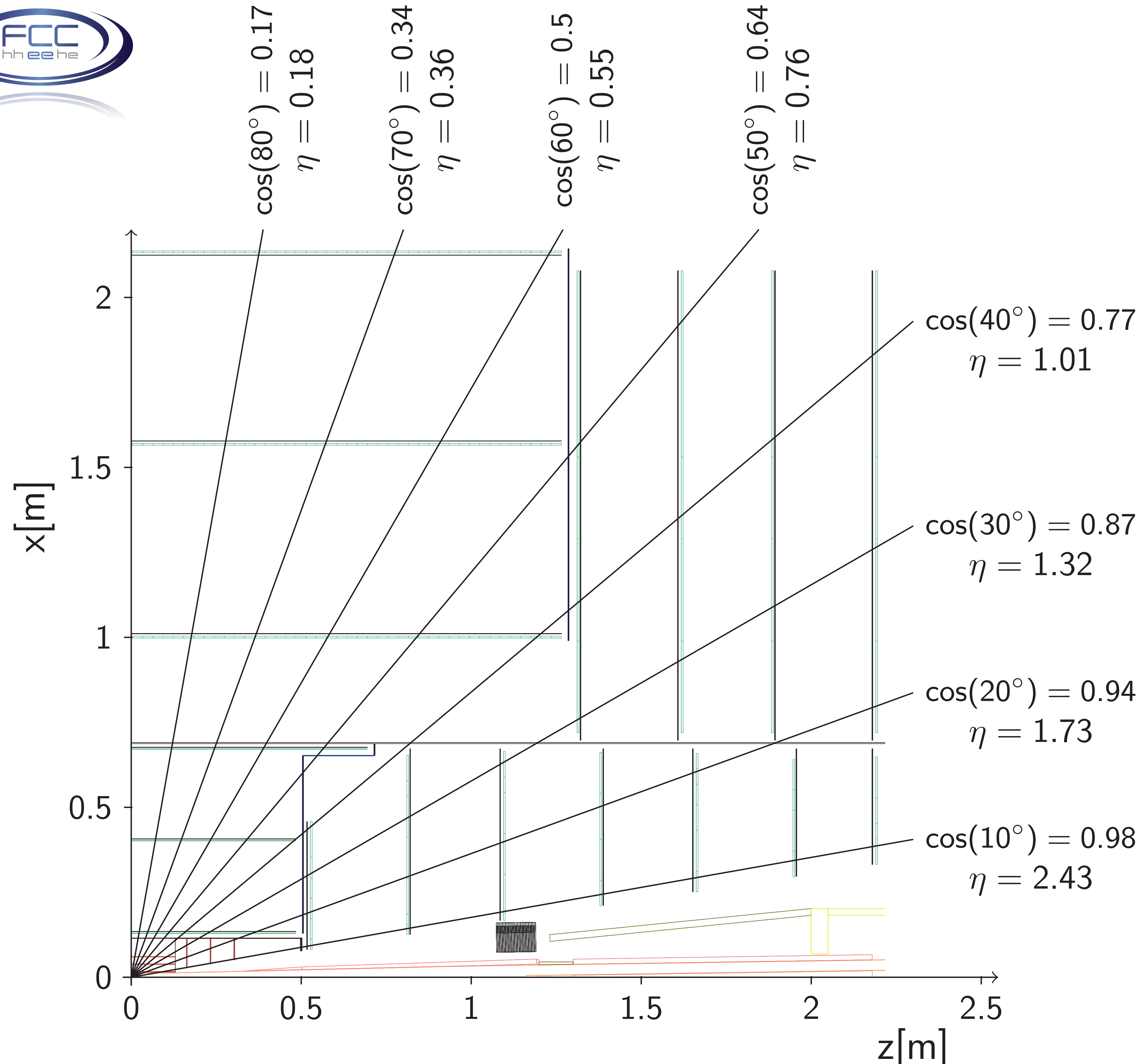
- A new design for the **CLD** detector (**post-CDR**) has been realized for a new FCC-ee interaction region with a reduced beam pipe radius (15 mm —> 10 mm) at the IP
  - **vertex barrel closer to interaction point**

- A very first look at the performance of the post-CDR CLD detector compared with the CDR model
  - The **impact parameter resolutions improve**, especially for low momentum tracks
  - The transverse momentum resolution is unaffected (not shown in the talk)
  - The **flavour tagging capabilities improve**
    - slightly for 365 GeV, strongly for 91 GeV
    - with a dependence on polar angle observed

- Next step: analysis the flavour tagging results case by case
  - vertexing performance, jet clustering and classification
  - thorough investigation of the input variables to the BDT <u>necessary</u>
  - + *part of the problem is the long time for full simulation; place where fast sim tool would be extremely helpful*

- Next^2 step: study effect of the background in the detector performance
  - from preliminary study: incoherent pairs do not seem to represent an issue

Extra



cos(80°) = 0.17
η = 0.18
cos(70°) = 0.34
η = 0.36
cos(60°) = 0.5
η = 0.55
cos(50°) = 0.64
η = 0.76
cos(40°) = 0.77
η = 1.01
cos(30°) = 0.87
η = 1.32
cos(20°) = 0.94
η = 1.73
cos(10°) = 0.98
η = 2.43
x[m]
z[m]
0
0.5
1
1.5
2
2.5

LFCIPlus vertex finder algorithm

- **Vertex Fitter for Primary Vertex**
  - if beam spot is constrained, beam spot centre as initial 3D point
  - 3D fit performed for the vertex position by adding χ^2 contribution from each track; tracks with highest χ^2 and above a threshold are removed
  - *output*: minimized χ^2, vertex uncertainty and probability, tracks associated to PV
- **Vertex Fitter for Secondary Vertices**
  - tracks not associated to the PV are paired and used as seeds for the SVs
  - 3D fit performed for the vertex position by adding χ^2 contribution from each track pair; tracks with highest χ^2 and above a threshold are removed + additional selection criteria (e.g. V^0 discarded)
  - additional tracks are added to the SV and accepted if χ^2 contribution below threshold
  - at this point: tracks may have been used for more than one vertex
  - to remove overlap: vertices are scanned in order of probability (high to low) and number of tracks (3 to 2); tracks associated to vertices are removed from further SVs
  - *output*: minimized χ^2, vertices uncertainty and probability, tracks associated to SVs

Tracks association

- **Classification of tracks for vertex finder performance**
  - *Primary*: tracks originated from the primary vertex
  - *Bottom*: tracks whose most immediate parent with a non-zero lifetime contains a b quark
  - *Charm:* tracks whose most immediate parent with a non-zero lifetime contains a c quark
  - *Others:* all other tracks (τ decays, strange hadrons, photon conversions, …)

Name	Description	Normalization factor	Used by category
trk1d0sig	d0 significance of track with highest d0 significance	1	A, B, C, D
trk2d0sig	d0 significance of track with second highest d0 significance	1	A, B, C, D
trk1z0sig	z0 significance of track with highest d0 significance	1	A, B, C, D
trk2z0sig	z0 significance of track with second highest d0 significance	1	A, B, C, D
trk1pt	transverse momentum of track with highest d0 significance	$1/E_{\text{jet}}$	A, B, C, D
trk2pt	transverse momentum of track with second highest d0 significance	$1/E_{\text{jet}}$	A, B, C, D
jprobr	joint probability in the r-phi plane using all tracks	1	A, B, C, D
jprobr5sigma	joint probability in the r-phi plane using all tracks having impact parameter significance exceeding 5 sigma	1	A, B, C, D
jprobz	joint probability in the z projection using all tracks	1	A, B, C, D
jprobz5sigma	joint probability in the z projection using all tracks having impact parameter significance exceeding 5 sigma	1	A, B, C, D
d0bprob	product of b-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions	1	A, B, C, D
d0cprob	product of c-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions	1	A, B, C, D
d0qprob	product of q-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions	1	A, B, C, D
z0bprob	product of b-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions	1	A, B, C, D
z0cprob	product of c-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions	1	A, B, C, D
z0qprob	product of q-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions	1	A, B, C, D
nmuon	number of identified muons	1	A, B, C, D
nelectron	number of identified electrons	1	A, B, C, D
trkmass	mass of all tracks exceeding 5 sigma significance in d0/z0 values	1	A, B, C, D

Name	Description	Normalization factor	Used by category
1vtxprob	vertex probability with all tracks associated in vertices combined	1	B, C, D
vtxlen1	decay length of the first vertex in the jet (zero if no vertex is found)	$1/E_{\text{jet}}$	B, C, D
vtxlen2	decay length of the second vertex in the jet (zero if number of vertex is less than two)	$1/E_{\text{jet}}$	D
vtxlen12	distance between the first and second vertex (zero if number of vertex is less than two)	$1/E_{\text{jet}}$	D
vtxsig1	decay length significance of the first vertex in the jet (zero if no vertex is found)	$1/E_{\text{jet}}$	B, C, D
vtxsig2	decay length significance of the second vertex in the jet (zero if number of vertex is less than two)	$1/E_{\text{jet}}$	D
vtxsig12	vtxlen12 divided by its error as computed from the sum of the covariance matrix of the first and second vertices, projected along the line connecting the two vertices	$1/E_{\text{jet}}$	D
vtxdirang1	the angle between the momentum (computed as a vector sum of track momenta) and the displacement of the first vertex	E_{jet}	B, C, D
vtxdirang2	the angle between the momentum (computed as a vector sum of track momenta) and the displacement of the second vertex	E_{jet}	D
vtxmult1	number of tracks included in the first vertex (zero if no vertex is found)	1	B, C, D
vtxmult2	number of tracks included in the second vertex (zero if number of vertex is less than two)	1	D
vtxmult	number of tracks which are used to form secondary vertices (summed for all vertices)	1	D
vtxmom1	magnitude of the vector sum of the momenta of all tracks combined into the first vertex	$1/E_{\text{jet}}$	B, C, D
vtxmom2	magnitude of the vector sum of the momenta of all tracks combined into the second vertex	$1/E_{\text{jet}}$	D
vtxmass1	mass of the first vertex computed from the sum of track four-momenta	1	B, C, D
vtxmass2	mass of the second vertex computed from the sum of track four-momenta	1	D
vtxmass	vertex mass as computed from the sum of four momenta of all tracks forming secondary vertices	1	B, C, D
vtxmasspc	mass of the vertex with minimum pt correction allowed by the error matrices of the primary and secondary vertices	1	B, C, D
vtxprob	vertex probability; for multiple vertices, the probability P is computed as 1-P = (1-P1)(1-P2)...(1-PN)	1	B, C, D