Beam-induced backgrounds in the CLIC detector models

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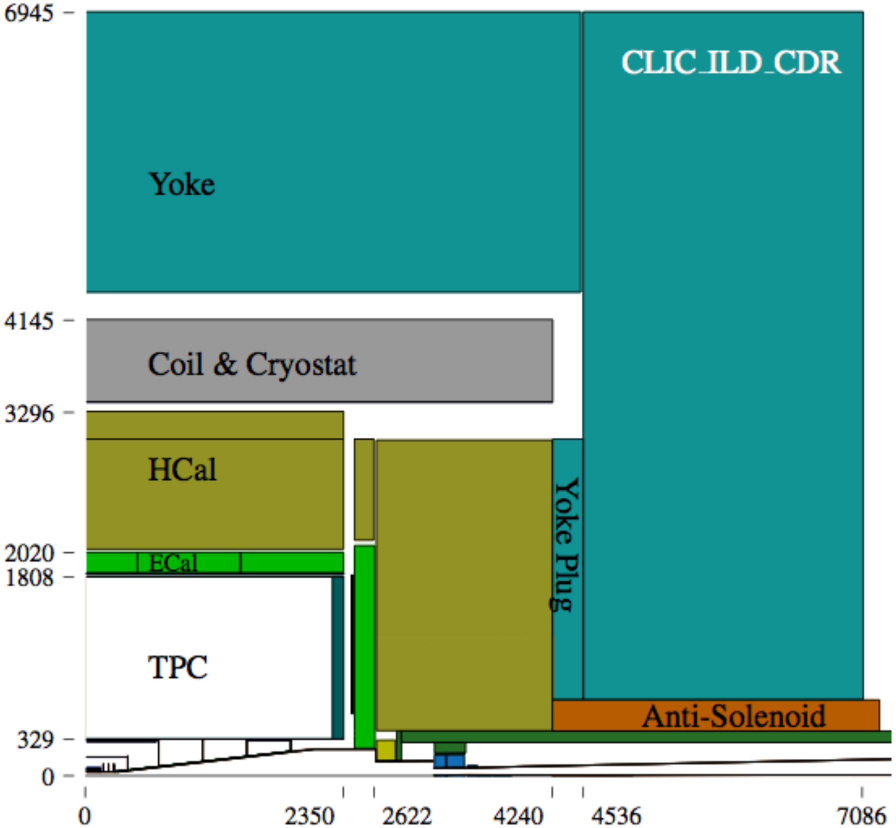
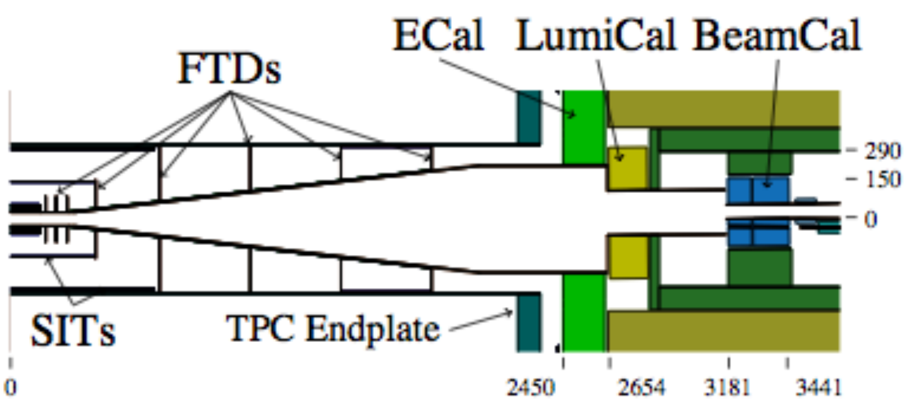
Outline

- CLIC_ILD_CDR and CLIC_SiD_CDR detector models
- Beam-induced backgrounds at 3 TeV CLIC machine:
  - Incoherent e^+e^- pairs
  - $\gamma\gamma \rightarrow$ hadrons
  - Other sources
- Visible energy and background occupancies
- Radiation damage:
  - Non-ionizing energy loss
  - Total ionizing dose
- Summary/conclusions

CLIC_ILD_CDR detector model





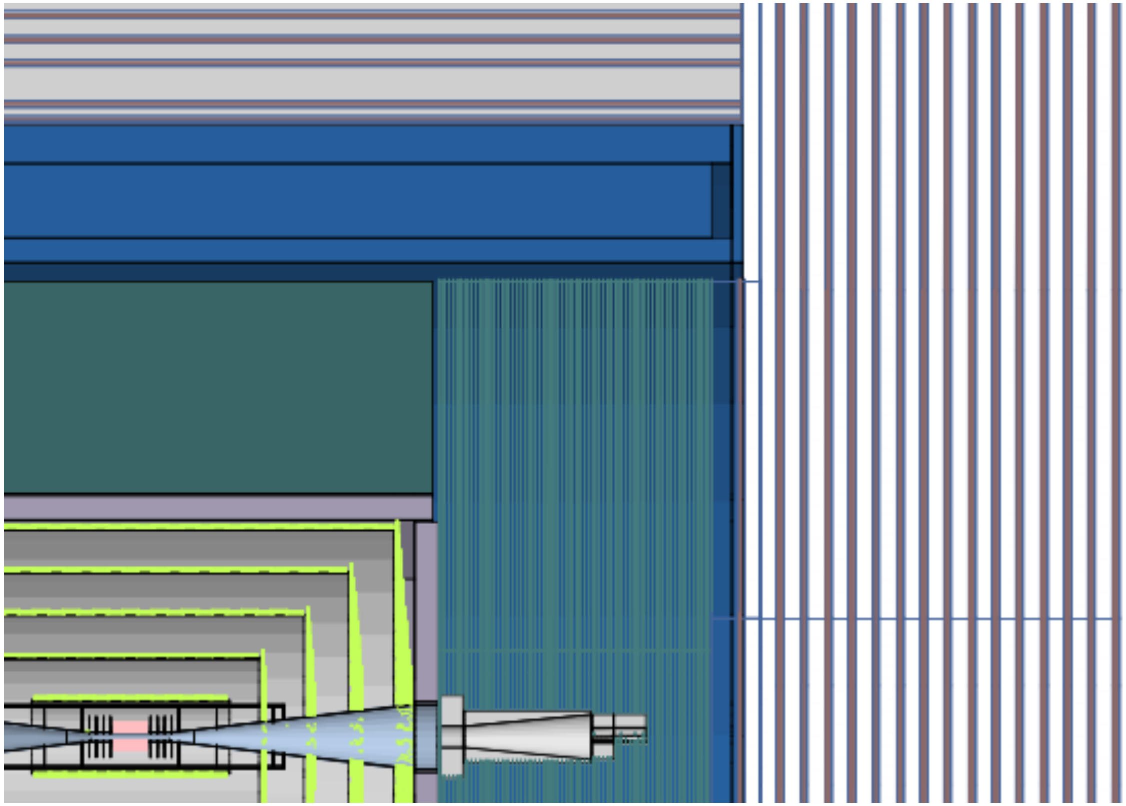
CLIC parameters:

- √s up to 3 TeV
- 312 bx per train, 0.5 ns spaced, 50 Hz train-repetition rate
- 20 mrad crossing angle
- Cross-sections in fwd regions high for many physics and BG processes

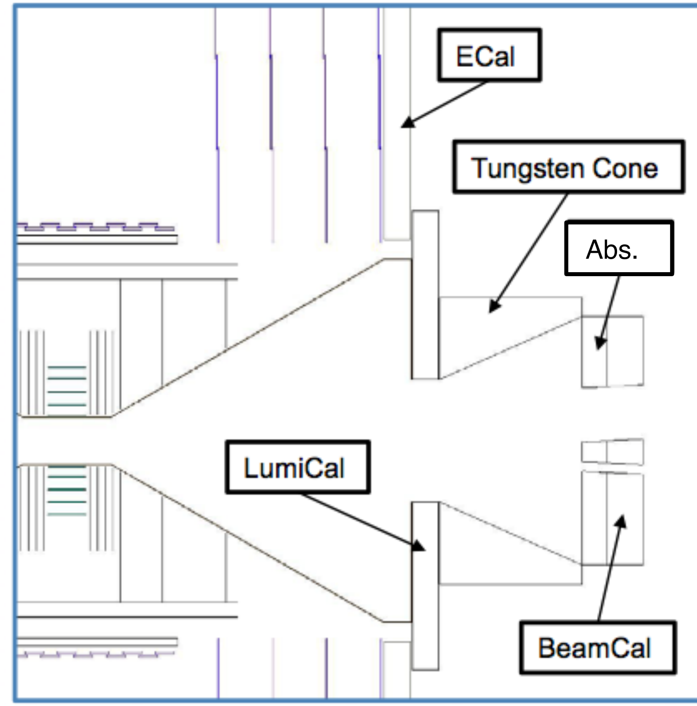
CLIC_ILD_CDR simulation model:

- Based on ILC-ILD
- scaled and optimized for 3 TeV CLIC
- Reduction of backscatters:
  ~pointing conical beam pipe (θ=6.7^o)
- 4 Tesla B-field
- HCal outer radius: 3.3 m (7.5 Λ_i)
- 3 pixel double-layers for barrel vertex detector, 20 x 20 μm^2 pixels, R≥31 mm
- TPC as main tracker + silicon envelope

CLIC_SiD_CDR detector model



Forward region:



- Based on ILC-SiD, scaled and optimized for 3 TeV CLIC parameters
- Similar acceptance and performance as CLIC_ILD_CDR
- Similar reduction of backscatters: pointing conical beam pipe (θ=6.7^{o})
- Larger B-field (5 Tesla), HCal outer radius: 2.7 m (7.5 Λ_i)
- 5 pixel single layers (20 x 20 μm^2) for barrel vertex detector, R≥27 mm
- All-silicon tracker

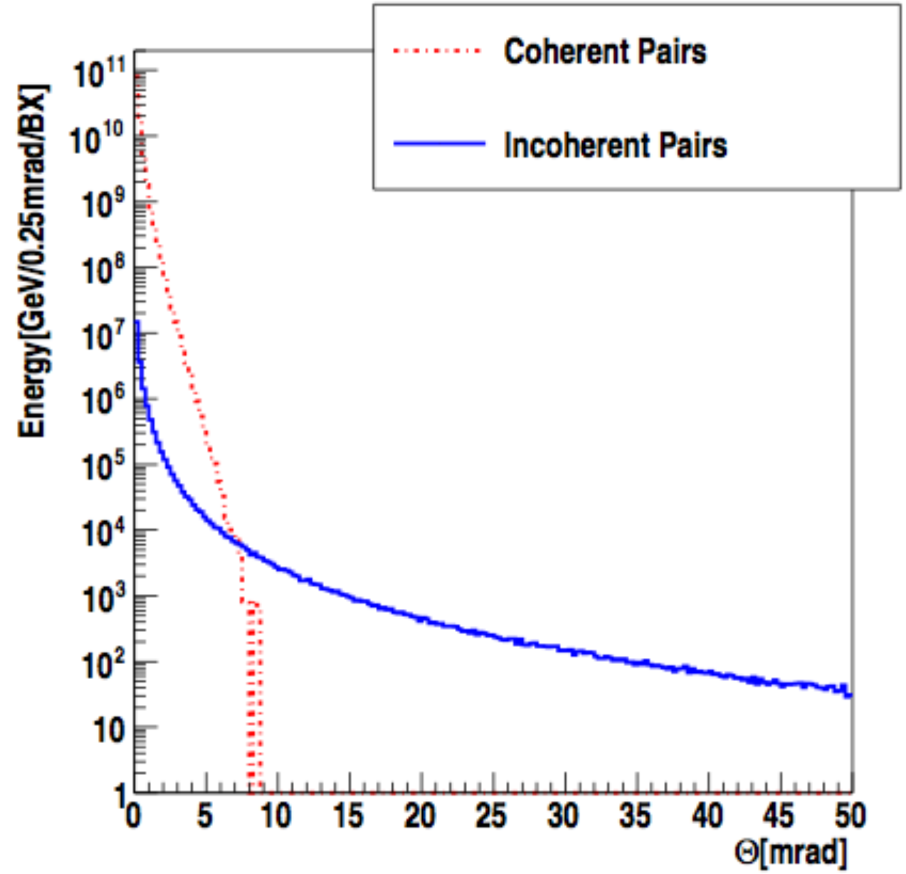
e^+e^- pairs at 3 TeV

•e^+e^- pairs at $\sqrt{s}$=3 TeV
simulated with **GUINEAPIG** (D. Schulte)

•6 x 10^8 coherent particles / bx
- •Spectrum falls very steeply with θ
- •Acceptance BeamCal θ<10 mRad

•3 x 10^5 incoherent particles / bx
- •Larger contribution in detector
- •Backscatters from forward region need particular attention

•Only incoherent pairs fully simulated in Geant-4 (Mokka&SLIC)



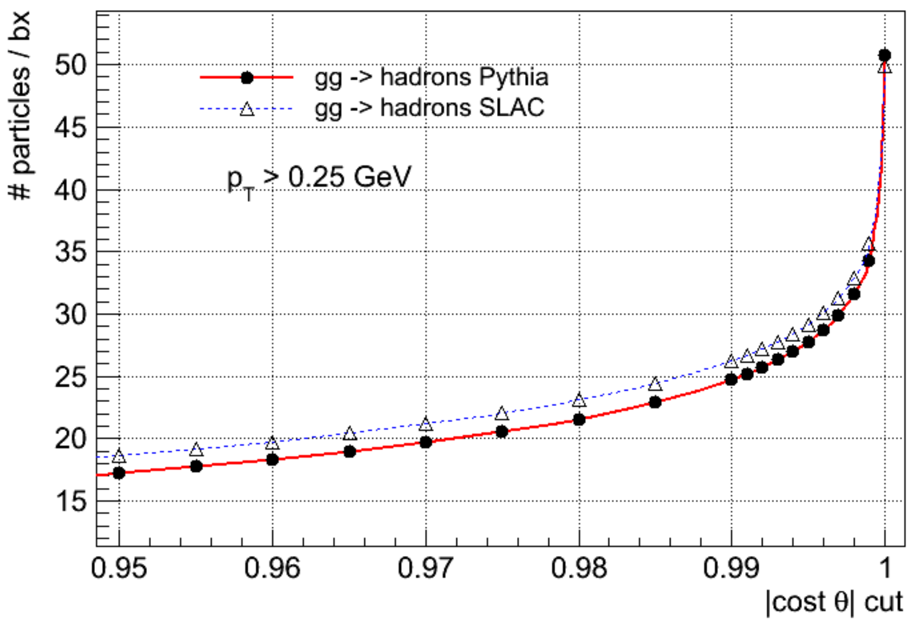
•comprehensive studies by A. Sailer and C. Grefe in 2009/2010:
- •Optimisation of forward region and beam pipe layout
- •In resulting optimized detector geometries: indirect hits reduced to ~10% of direct hits for vertex region
- •See André's presentation at ECFA-CLIC-ILC Joint Meeting (Oct. 2010)

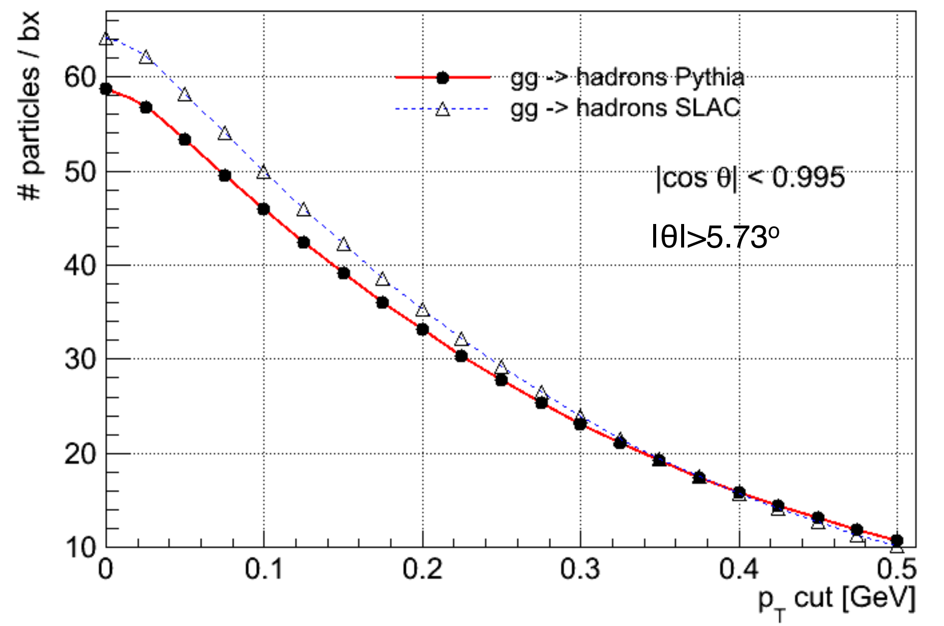
γγ→hadrons at 3 TeV

- Two different MC generators for gg→hadrons simulation:
  - Pythia (D. Schulte): 3.2 events / bx
  - SLAC generator (T. Barklow) + Pythia for hadronization: 4.1 events / bx
- Comprehensive comparison of the two generators performed
- resulting detector effects very similar
- Details in γγ→hadrons WG-6 presentations:

http://indico.cern.ch/categoryDisplay.py?categId=3395

- Pythia sample is default for event overlay in CDR Monte Carlo production, also used for most results presented in the following

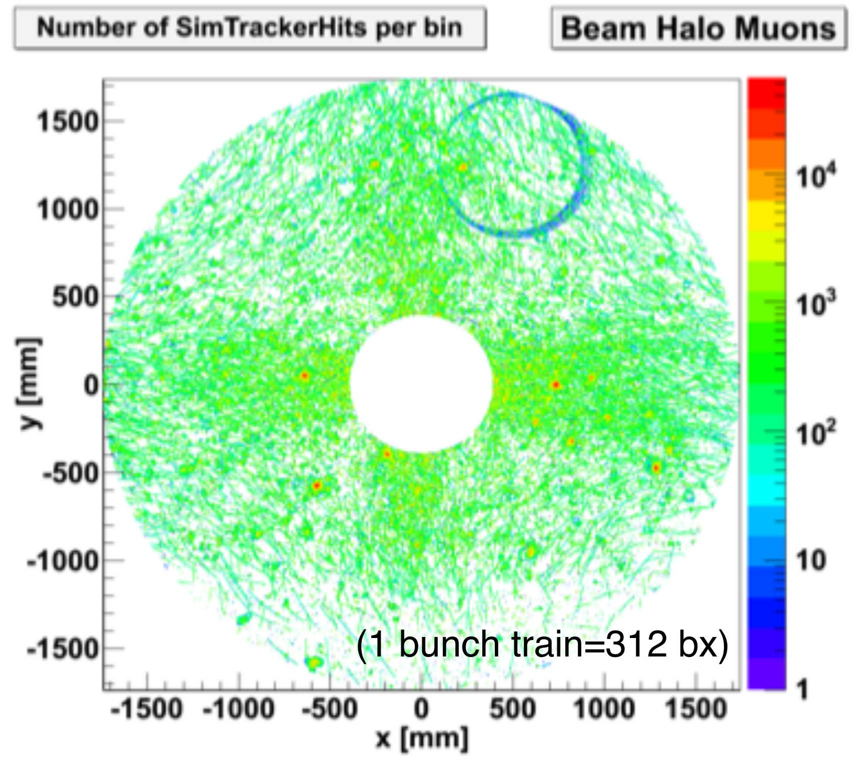




Other sources of machine-induced backgrounds

- **Beam-halo muons**
  - $2x10^4$ μ's per train expected
  - Almost parallel to beam axis
  - rate falls only slowly with radius
  - deflection expensive (magnetized iron), under study
  - Main source of background for outer tracker
  - in particular challenging for TPC in CLIC_ILD and for calorimeters, studies ongoing

Beam-halo muons in CLIC_ILD TPC:



- **Incoherent synchrotron radiation** from BDS
  - No direct hits by design of collimator system
  - However: possibly sizeable rate of low-energy particles bouncing along beam-delivery system
  - to be studied in more detail

- **$\gamma\gamma \rightarrow \mu\mu$**
  - Same production mechanism as incoherent e^+e^- pairs
  - ~same shape as for e^+e^- pairs, but rate is reduced by $1/10^4$

- Will focus on incoherent pairs + $\gamma\gamma \rightarrow$hadrons for rest of this talk

Visible energy from γγ→hadrons - results

- Estimate visible energy per subdetector by applying p_T and θ-acceptance cuts to MC true particles

Pythia 2010 sample (D. Schulte) 3.2 events / bx		
Section	CLIC_ILD_CDR E_{vis}/bx [GeV]	CLIC_SiD_CDR E_{vis}/bx [GeV]
no cuts	1365.2	1365.2
LUMI-CAL	101.5	120.2
CAL-Endcap	35.4	45.3
CAL-Barrel	3.6	4.4
CAL-all	37.8	47.5

- Up to 15 TeV / bunch train in calorimeters
- Larger values for CLIC_SiD_CDR, due to more compact layout

→ Event overlay challenging for simulation and reconstruction

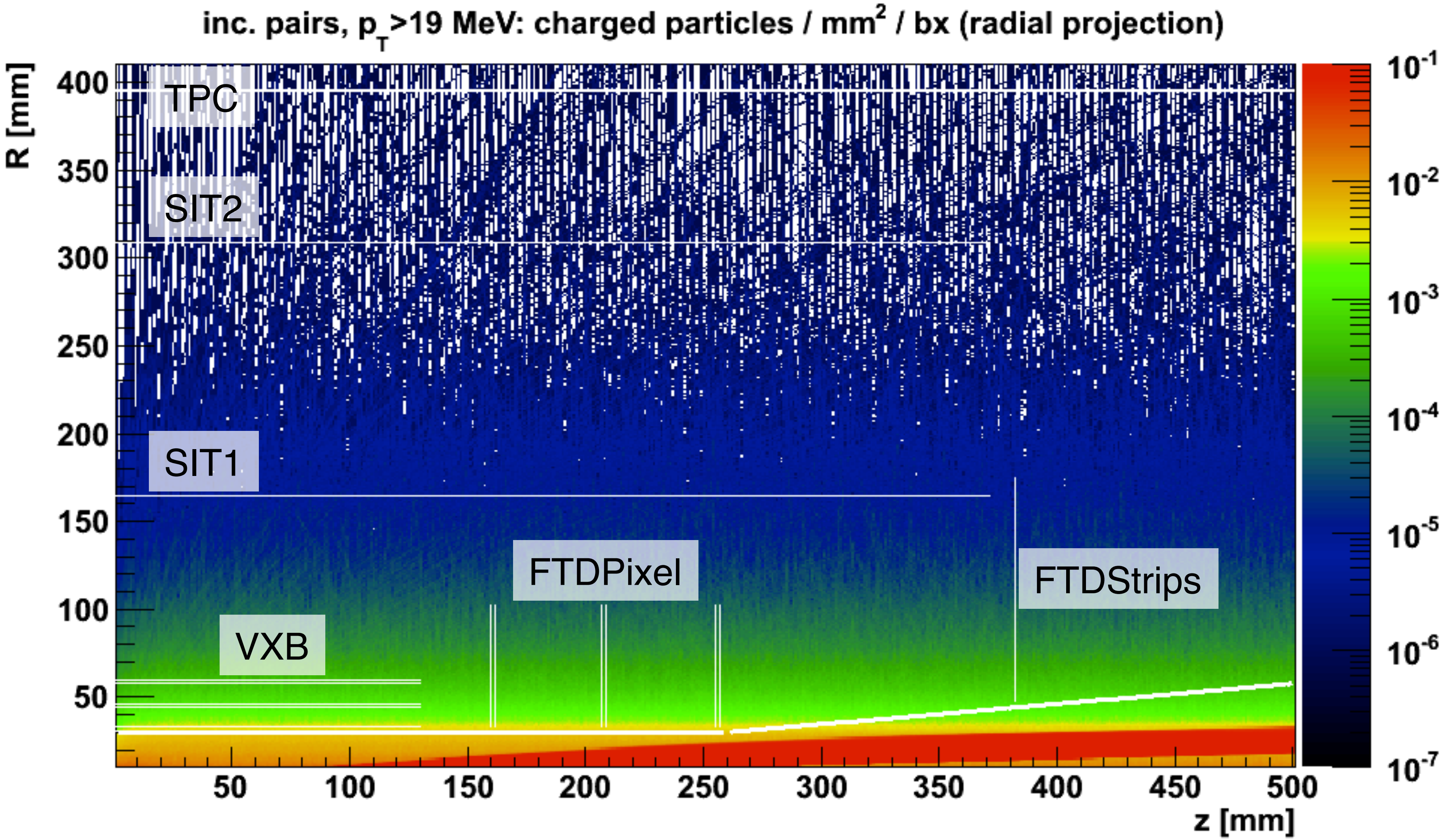
Occupancies

- Two **independent simulations** to estimate occupancies:

  - Standalone fast simulation in C++
    - Tracks final-state particles from Monte Carlo generator
    - Calculates helix in B-field for each particle
    - Follows particles along helix (no interactions take place)
    - Projects particle tracks on horizontal/vertical slices
    - Takes into account multiple hits from curlers
    - Used for all detector regions and both CLIC_ILD_CDR and CLIC_SiD_CDR
    - MC statistics: incoherent pairs: 312 bx, $\gamma\gamma \rightarrow$hadrons: 2100 bx

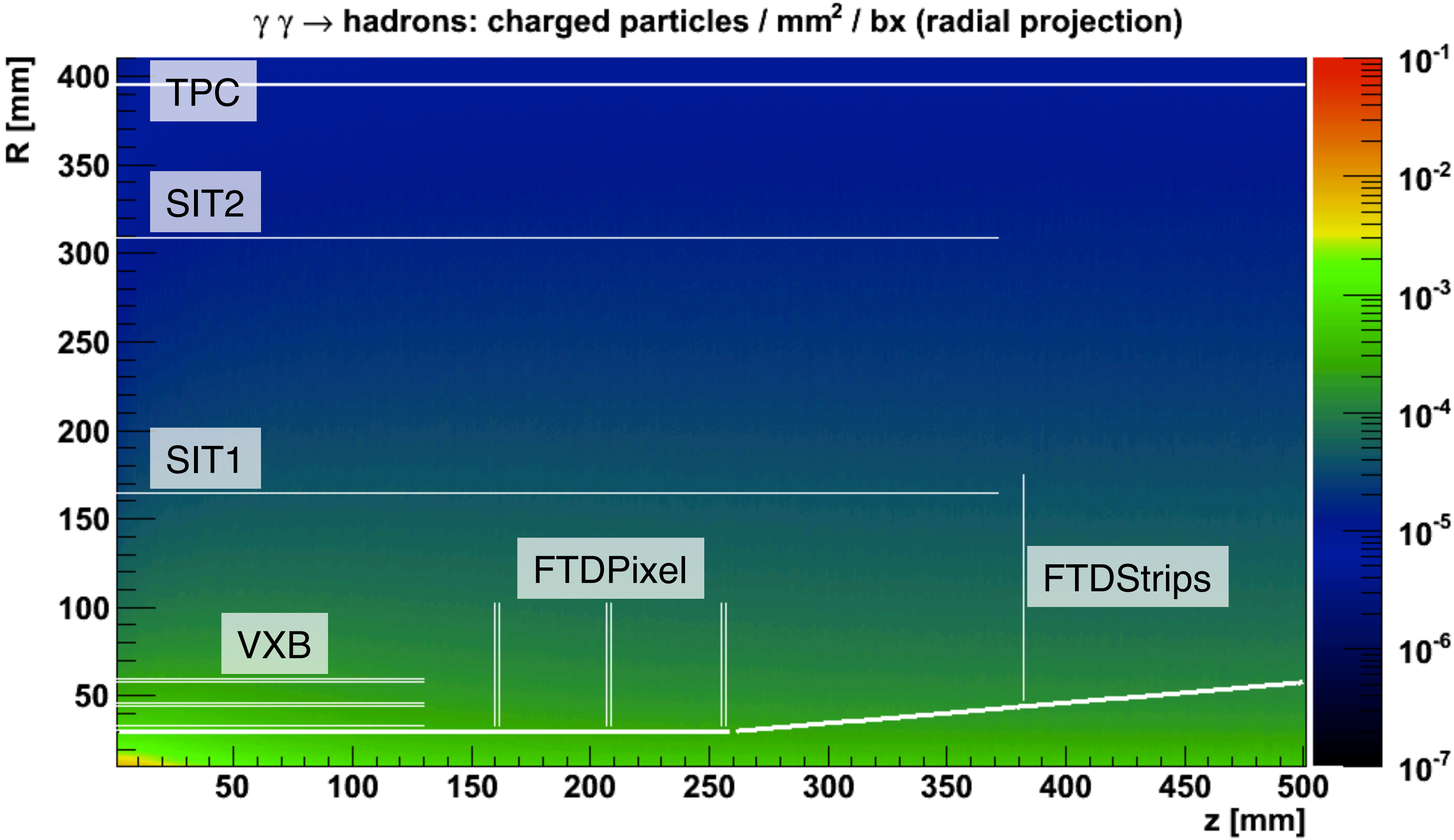
  - Full Geant-4 simulation of detector response:
    - Based on Mokka/SLIC
    - Takes into account interactions and decays
    - Includes backscatters from very forward region
    - Has been used to optimize detector design, see André Sailer's talk at ECFA-CLIC-ILC Joint Meeting (Oct. 2010)
    - Results for limited number of scoring planes in CLIC_ILD_CDR
    - MC statistics: incoherent pairs: 100 bx, $\gamma\gamma \rightarrow$hadrons: 900 bx

Cylindrical occupancies from pairs



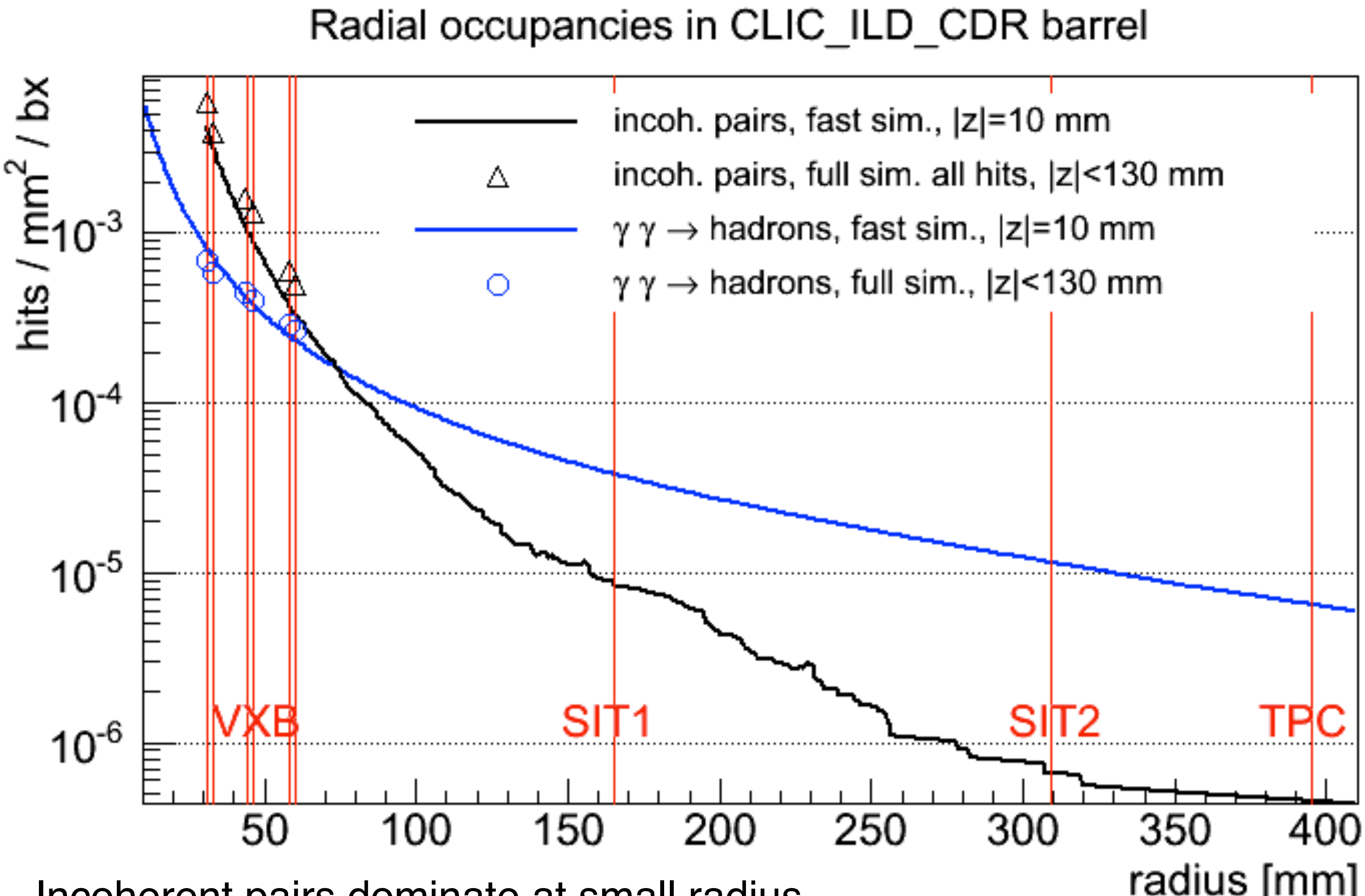
- Results obtained with fast simulation and for radial projection
- Pair background large at small radii, falls steeply with radius

Cylindrical occupancies from γγ→hadrons



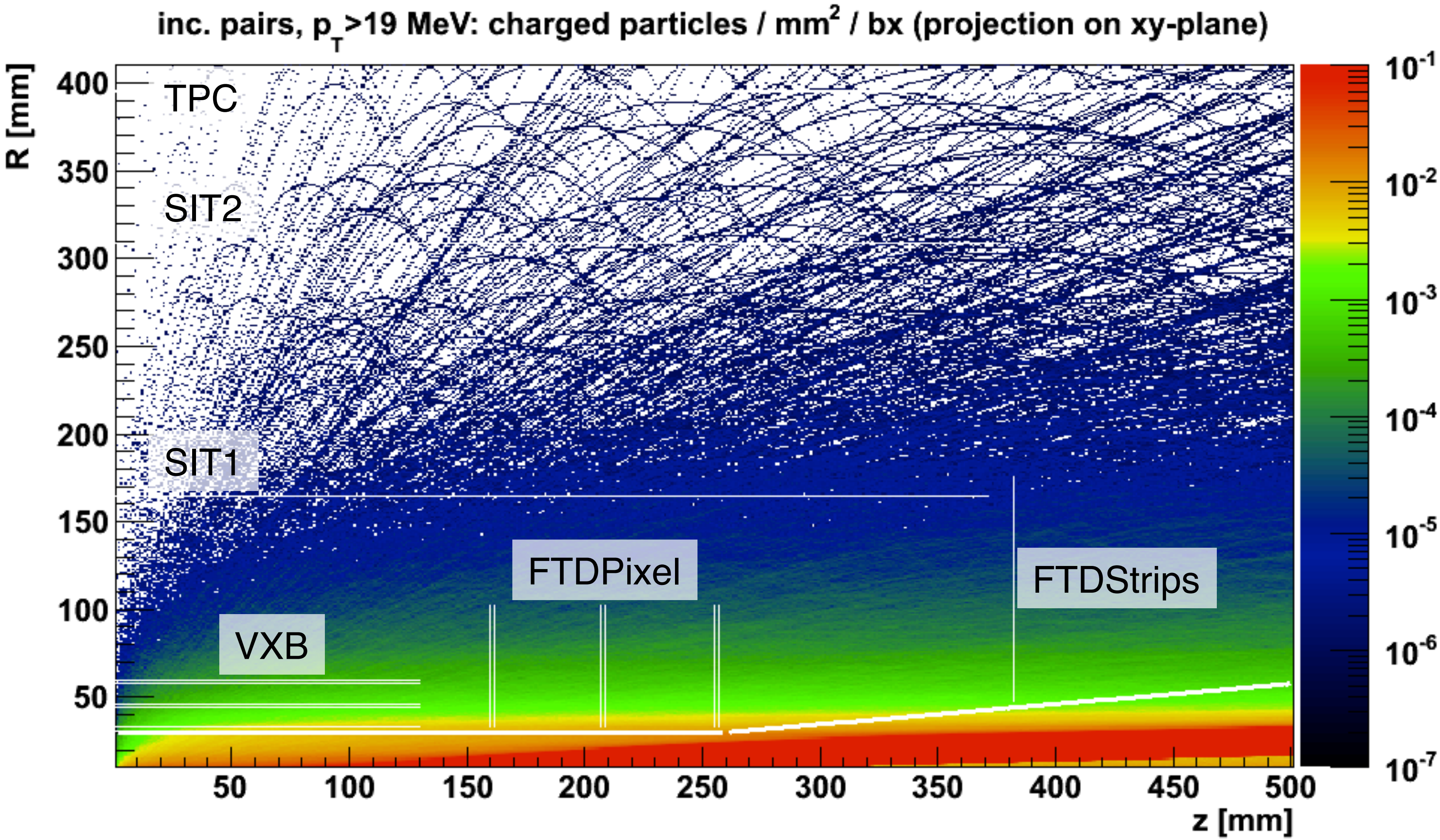
- γγ→hadrons fall less steeply with radius than pairs
- dominates occupancies at large radii

Barrel occupancies in CLIC_ILD_CDR vs. radius



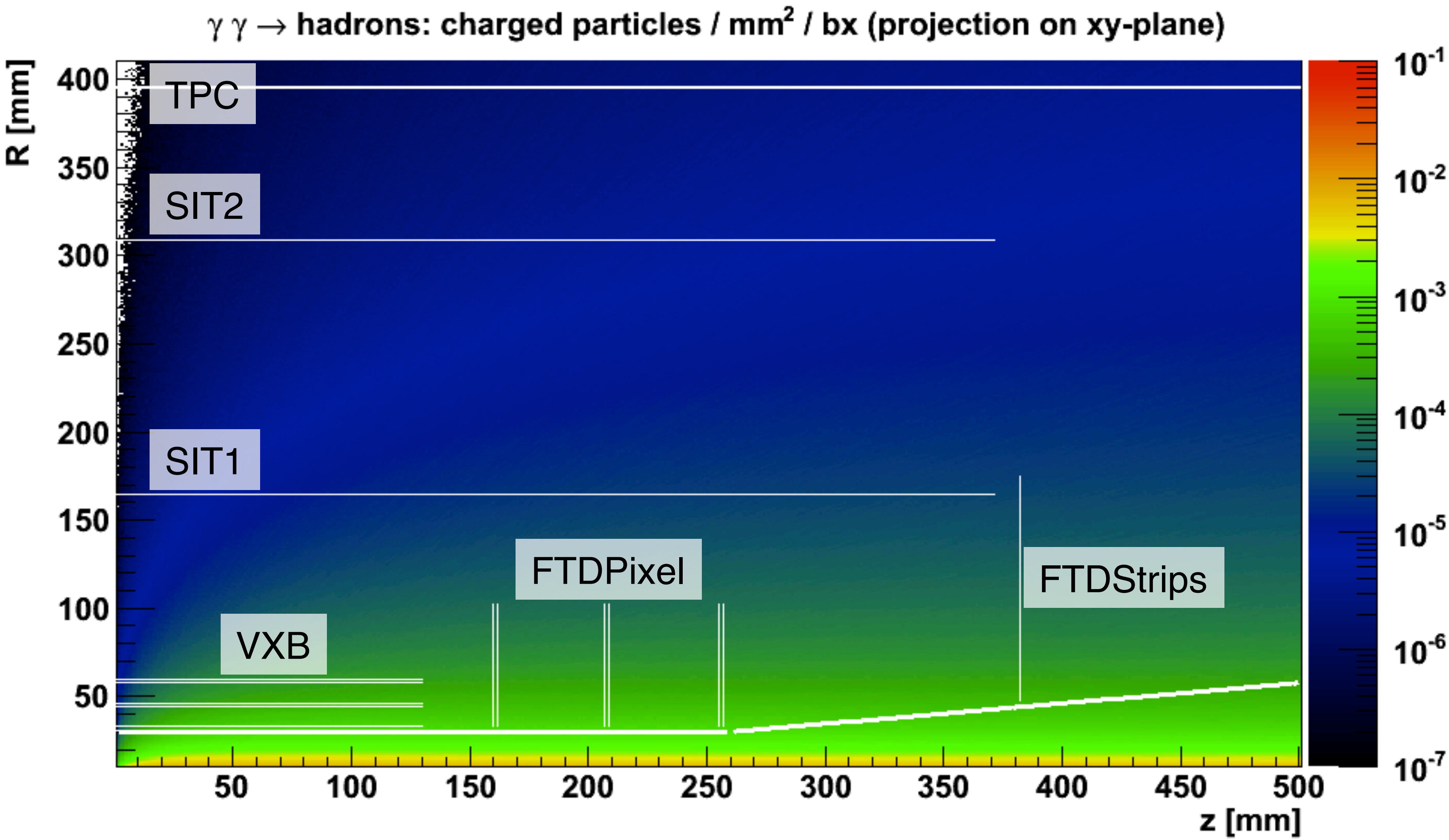
- Incoherent pairs dominate at small radius
- γγ→hadrons dominate at larger radii
- Good agreement between full and fast simulation
- Up to ~1.5 hits / mm^2 / bunch train in innermost vertex layer

Disc occupancies from pairs



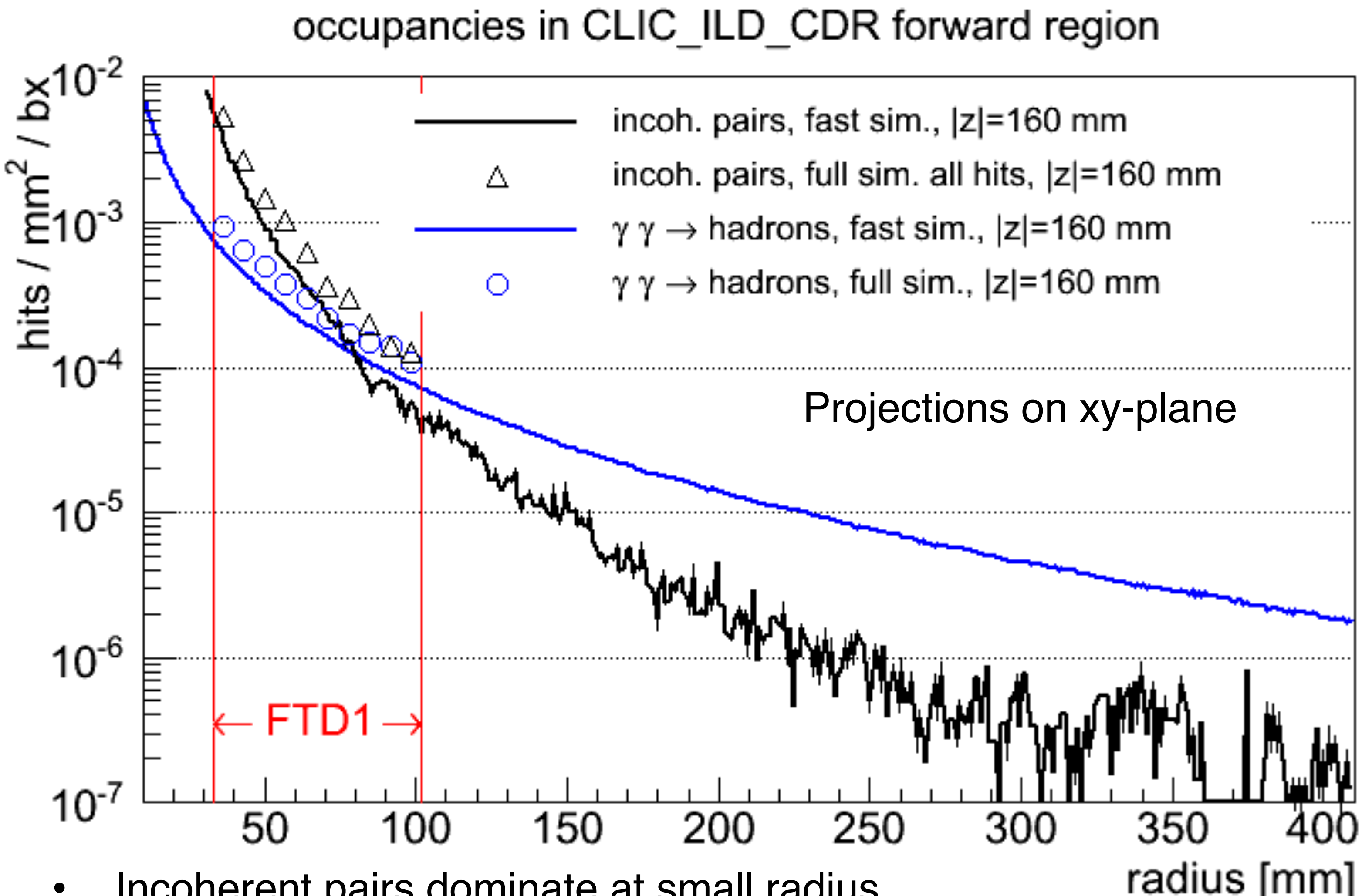
- Results obtained for projection on xy-plane (discs)
- Pair background large at small radii, falls steeply with radius

Disc occupancies from γγ→hadrons



- γγ→hadrons fall less steeply with radius than pairs
- dominates occupancies at large radii

Forward occupancies in CLIC_ILD_CDR vs. radius

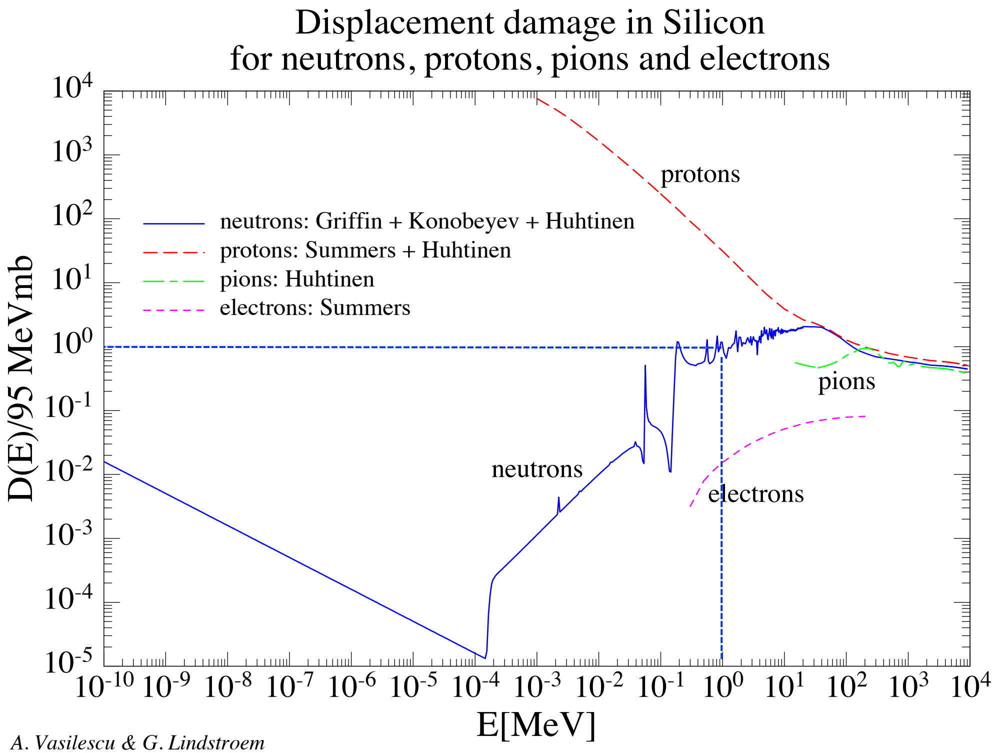


- Incoherent pairs dominate at small radius
- γγ→hadrons dominate at larger radii
- More hits in full simulation: backscatters become important in fwd region
- Up to ~2 hits / mm^2 / bunch train in lower part of first vertex disc

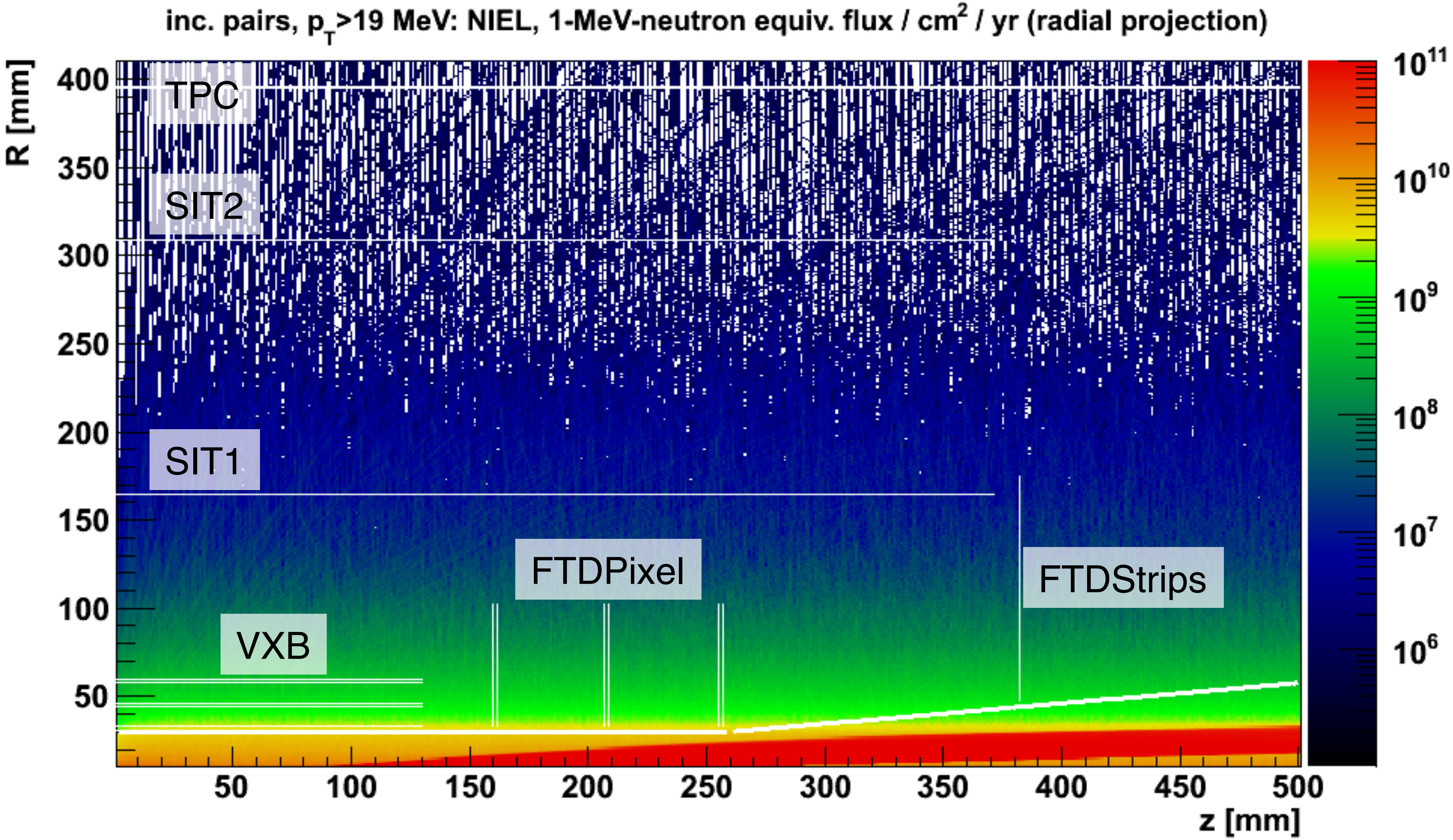
Non-ionizing energy loss

Estimate radiation damage (in silicon) from non-ionizing energy loss (NIEL):

- Simulation based on setups used for estimating occupancies
- Scale hits with displacement-damage factor → 1-MeV-neutron equivalent fluence
- Use energy-dependent tabulated scaling factors for Silicon from: http://sesam.desy.de/members/gunnar/Si-dfuncs.html
- To obtain expected fluence per year, assume:
  1 year =100 days effective runtime = 100*24*60*60 seconds; 50*312 bx per second

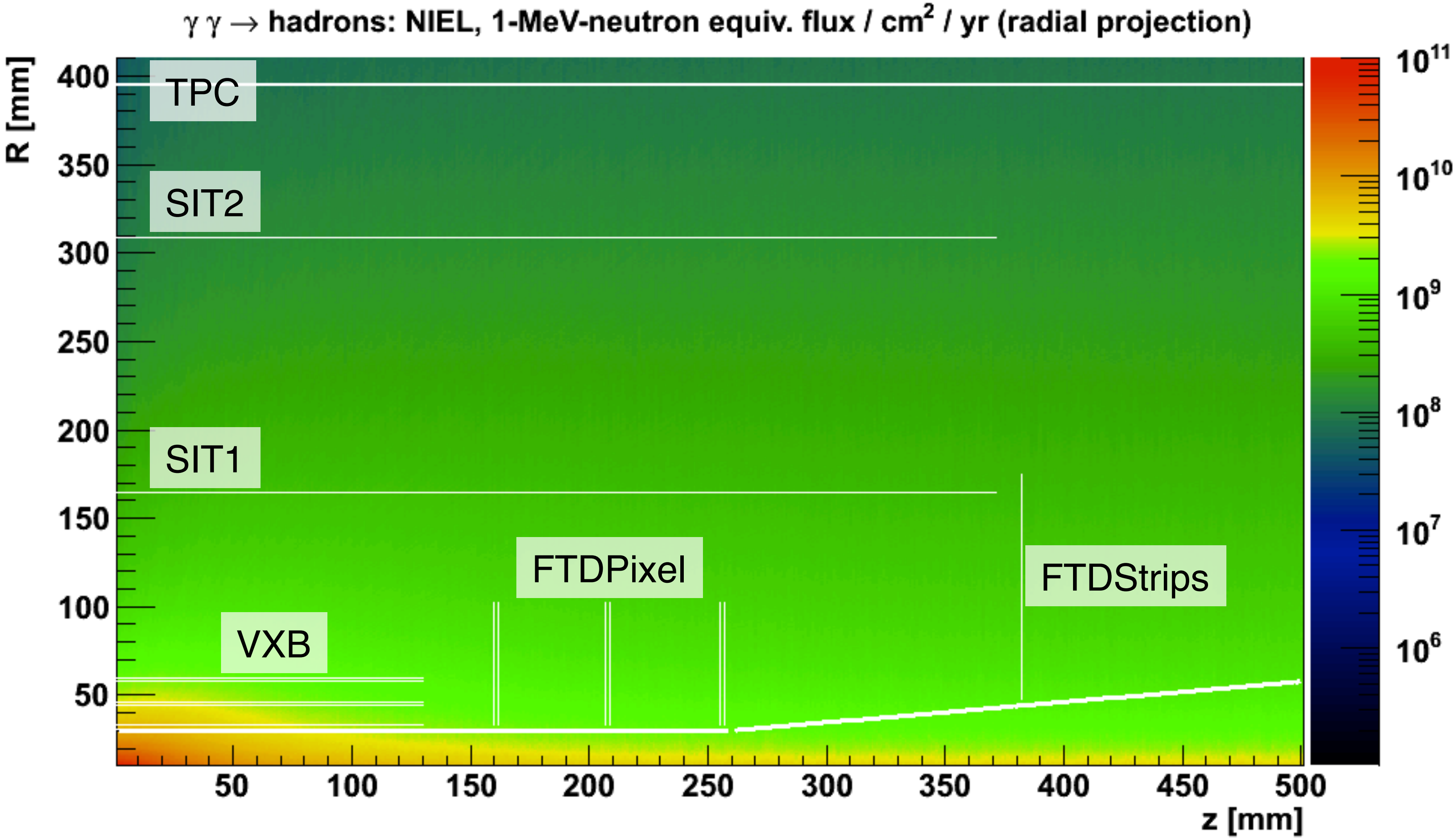


NIEL (cylindrical projection) from pairs



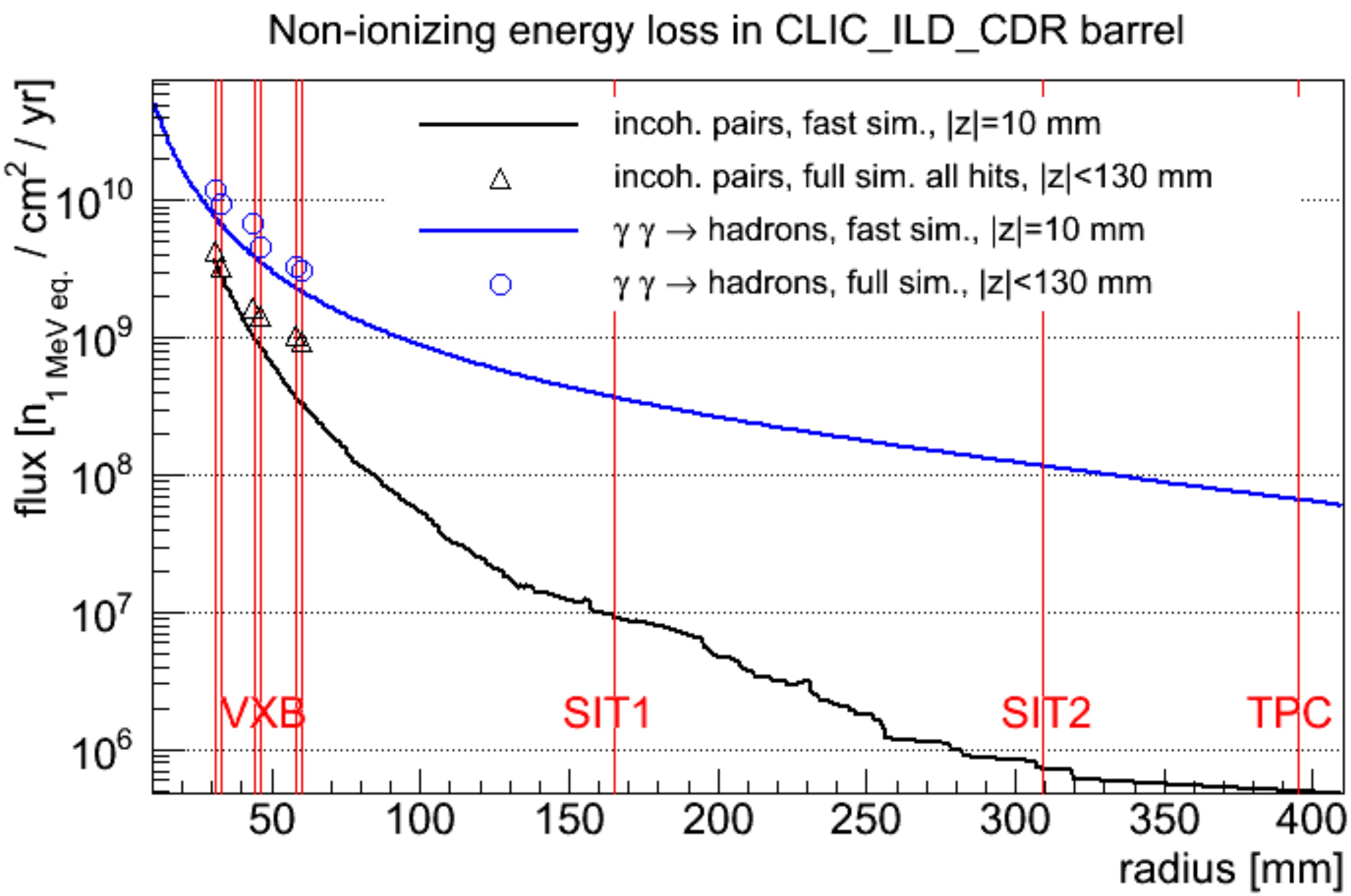
- Similar observations as for occupancies: pair-background falls steeply with radius

NIEL (cylindrical projection) from γγ→hadrons



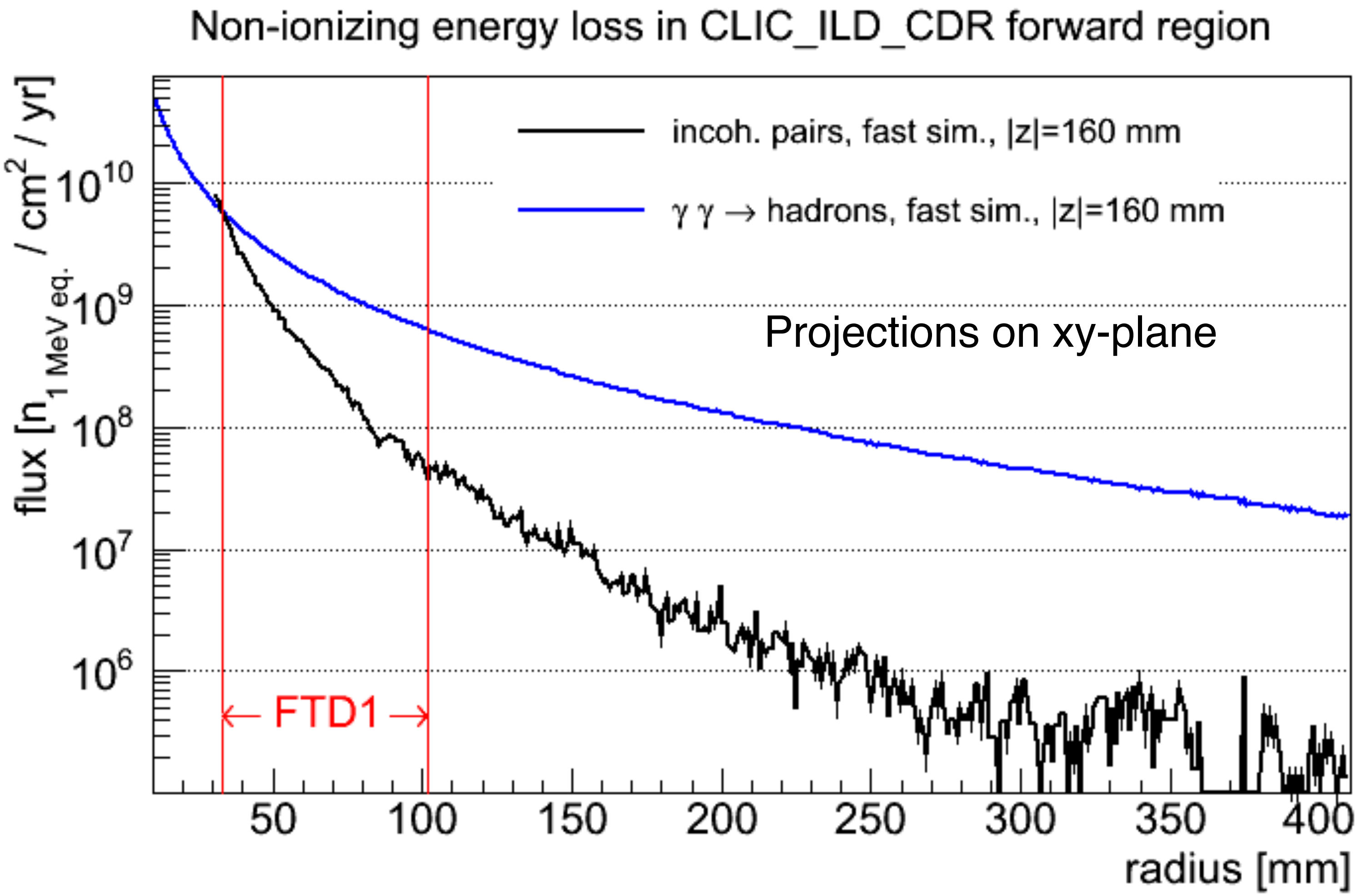
- NIEL for γγ→hadrons falls less steeply with radius and also dominates already at smaller radii, due to larger damage factors

NIEL in CLIC_ILD_CDR barrel vs. radius



- γγ→hadrons dominate at all radii, due to larger damage factors
- Good agreement between full and fast simulation for γγ→hadrons
- More damage in full simulation for incoh. pairs due to backscattered neutrons
- Maximum flux in innermost vertex layers: ~10^{10} 1-MeV-n-equiv. / year, i.e. 4 orders of magnitude below LHC levels

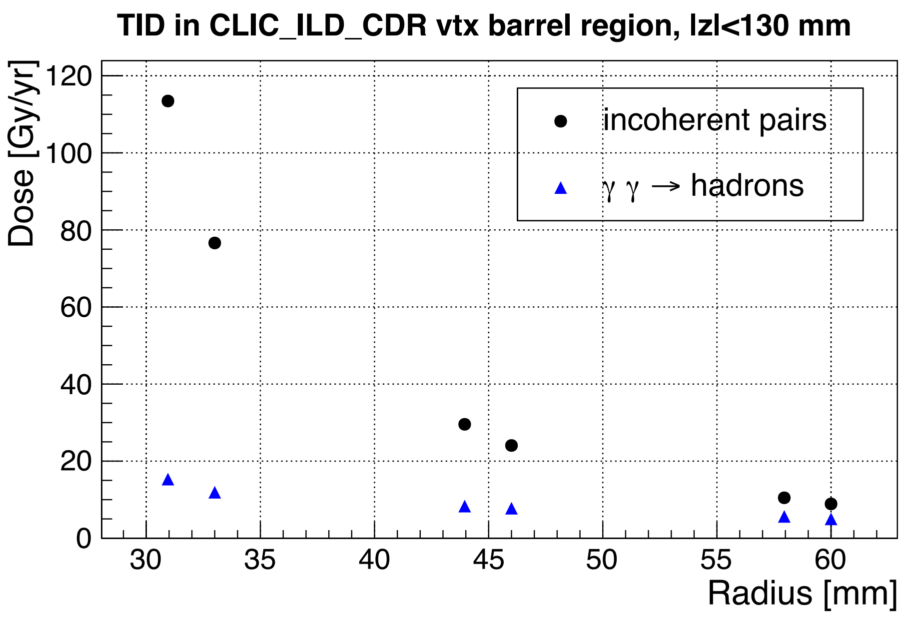
NIEL in CLIC_ILD_CDR forward region vs. radius

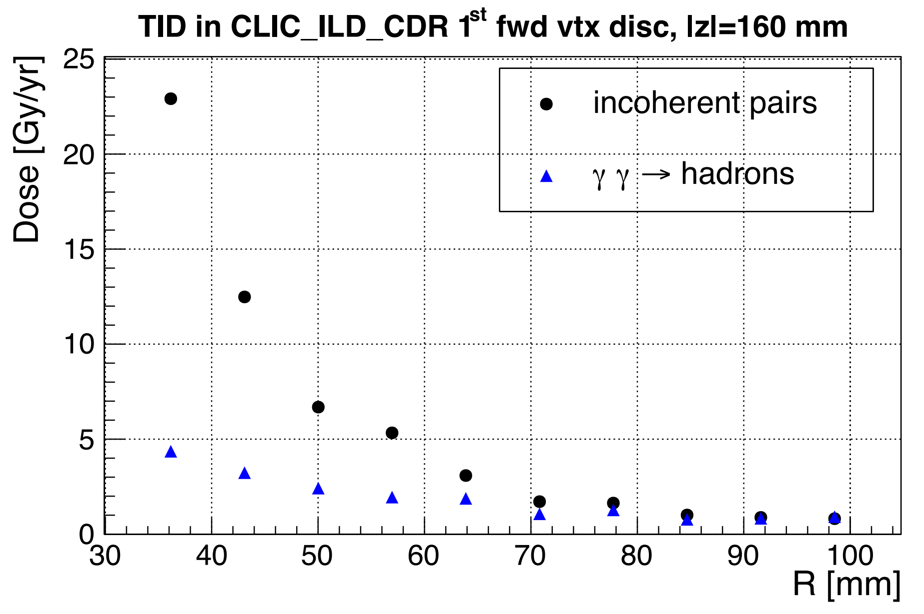


- γγ→hadrons dominate NIEL, due to larger damage factors
- Maximum flux in lower part of 1st forward disc: $\sim 10^{10}$ 1-MeV-n-equiv. / year

Total ionizing dose in vertex detector

- Estimate radiation damage from total ionizing dose (TID):
  - Use only the setup from full Geant-4 simulation
  - Sum up energy release in silicon, as given by Geant-4
  - Results obtained for vtx layers in CLIC_ILD_CDR



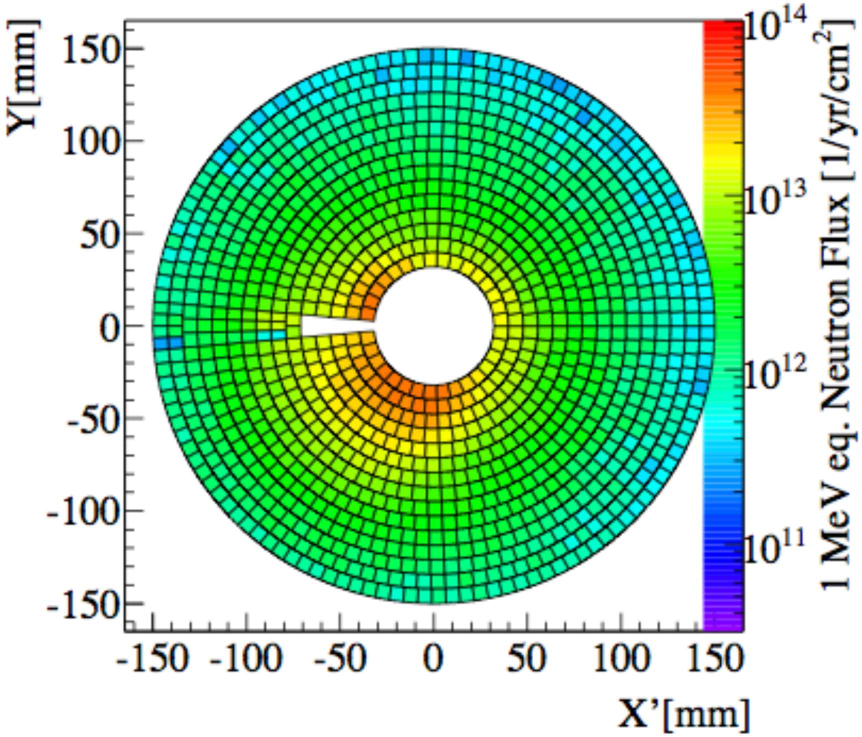


- Up to ~100 Gy / yr in innermost barrel vertex layers
- Up to ~20 Gy / yr on inner side of 1st forward vertex pixel disc
- For comparison: ATLAS innermost pixel layer ~160 kGy / yr

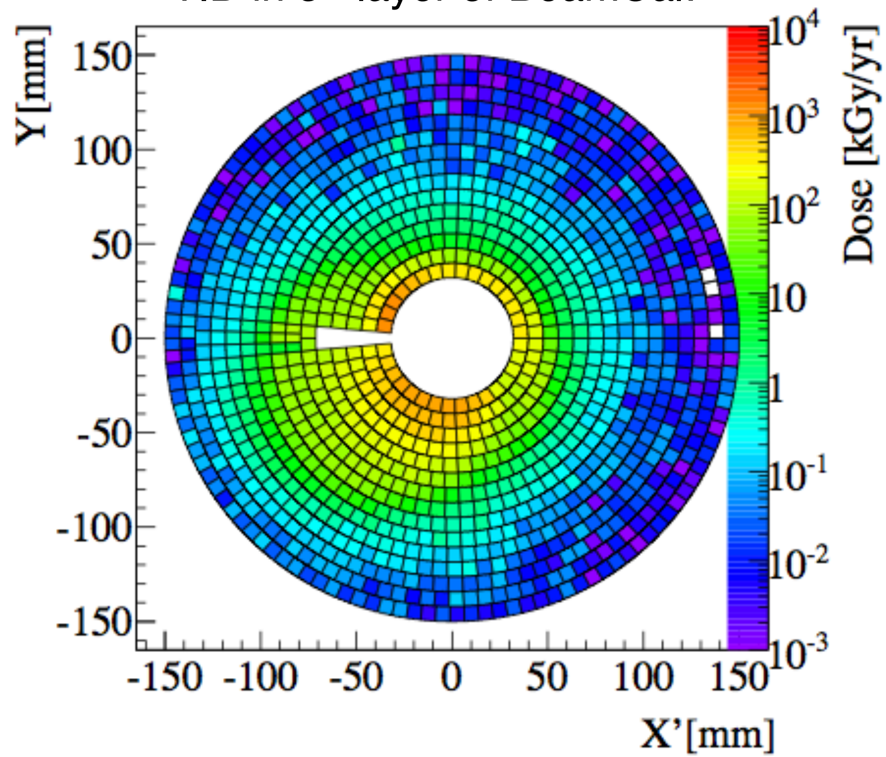
NIEL and TID in BeamCal

- Full Geant-4 simulation of incoherent pairs for BeamCal in CLIC_ILD_CDR
- Obtained estimates for NIEL and TID per year
- cf. also A. Sailer's presentation at FCAL collab. workshop in Oct. 2010

NIEL in 5th layer of BeamCal:



TID in 5th layer of BeamCal:



- Up to ~10^{13} 1-MeV-n-equ. / cm^2 / yr
- Up to 1 MGy / yr

Summary/Conclusions

- Large amount of energy and high rates expected from backgrounds:
  - E_{vis}~12-15 TeV / bunch train in barrel and EC calorimeters
  - Occupancies up to ~2 hits / mm^2 / bunch train in 1st vertex layers

- Major challenge for detector readout and reconstruction software

- Work is ongoing to optimize overlay and reconstruction algorithms, see Jan Strube's talk in yesterday's Physics session

- First estimate of expected radiation damages from selected sources:
  - NIEL: ≤10^{10} 1-MeV-n-equ. / yr in 1st vertex layers,
    up to ~10^{13} 1-MeV-n-equ. / yr in BeamCal
  - TID: up to 100 Gy / yr in 1st vertex layers,
    up to 1 MGy / yr in BeamCal

Backup slides

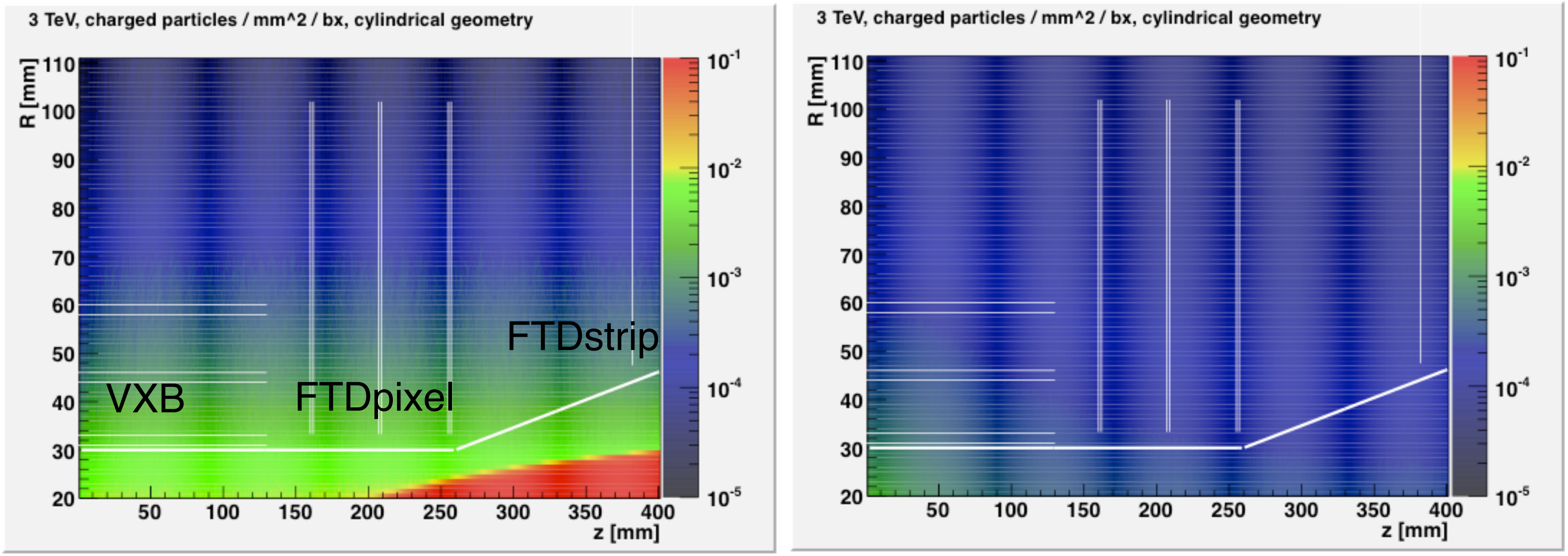
Visible energy from $\gamma\gamma \rightarrow$hadrons

- Simple estimation of energy releases in calorimeters:
  - Define θ-acceptance for sub-detectors
  - Require minimum p_T for charged particles according to B-field
  - No minimum p_T for neutrons/photons
  - assume no decay/interaction before the calorimeters

Section	θ_{min}[deg]	θ_{max}[deg]	Pt_{min}[GeV]
CLIC_ILD_CDR, B = 4 T:			
LUMI-CAL	2.03	6.24	0.060
HCAL-Endcap	7.60	51.32	0.339
ECAL-Endcap	12.17	42.70	0.339
HCAL-Barrel	43.47	90.00	1.335
ECAL-Barrel	40.39	90.00	1.199
CLIC_SiD_CDR, B = 5 T:			
LUMI-CAL	1.89	7.26	0.048
HCAL-Endcap	8.67	55.89	0.388
ECAL-Endcap	6.91	37.88	0.163
HCAL-Barrel	39.77	90.00	1.101
ECAL-Barrel	36.57	90.00	0.981

Barrel Occupancies in CLIC_ILD_CDR vertex region

Incoherent pairs (p_T>19 MeV): γγ → hadrons:

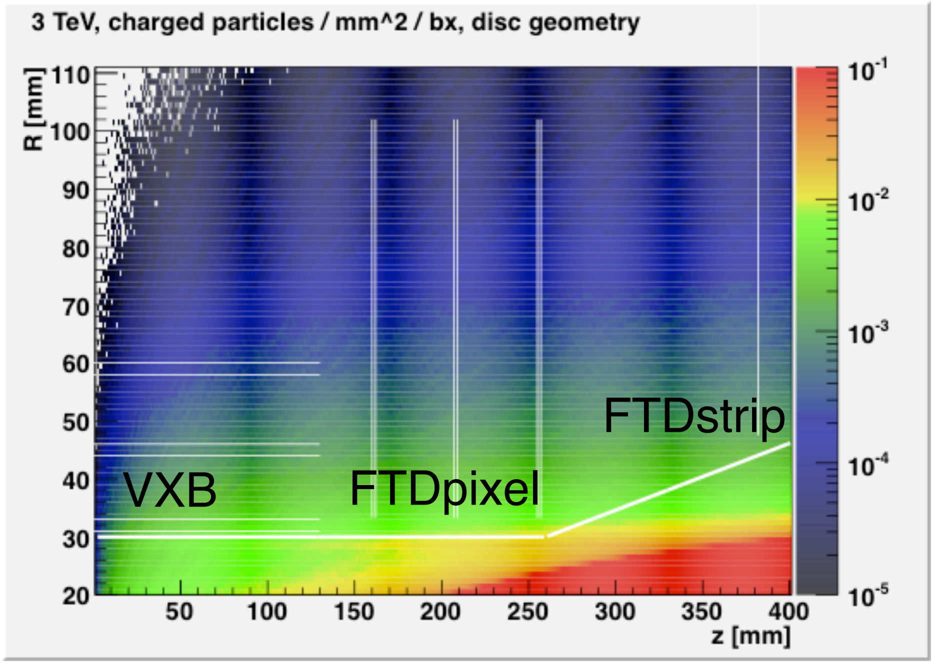


- Pair background dominates at small radii, falls steeply with radius
- γγ→hadrons fall less steeply with radius

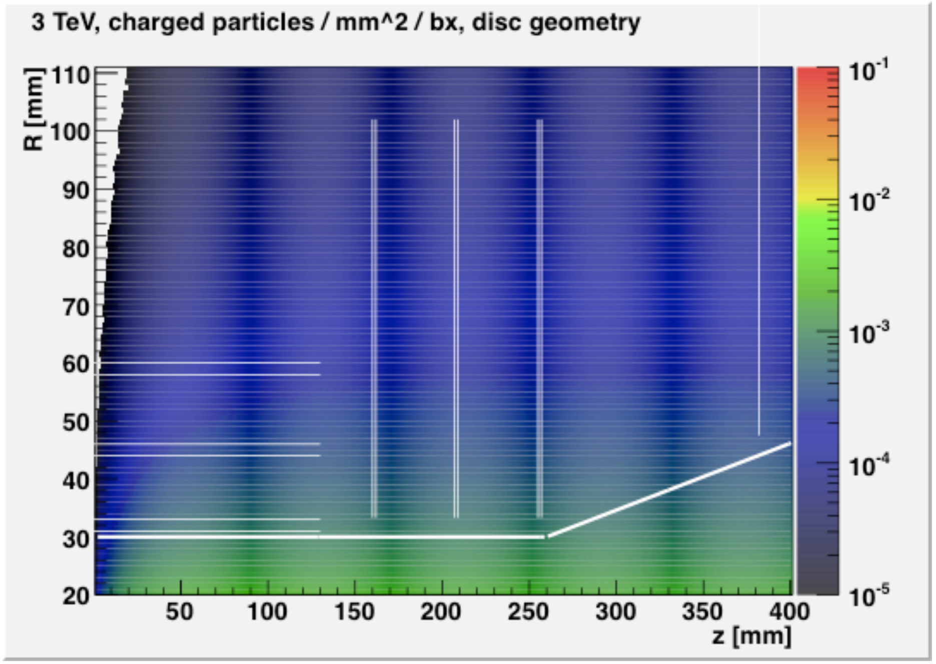
- Pair background shows only small dependence on z in this region
- γγ→hadrons falls steeper with z

Forward Occupancies in CLIC_ILD_CDR vertex region

Incoherent pairs (p_T>19 MeV):

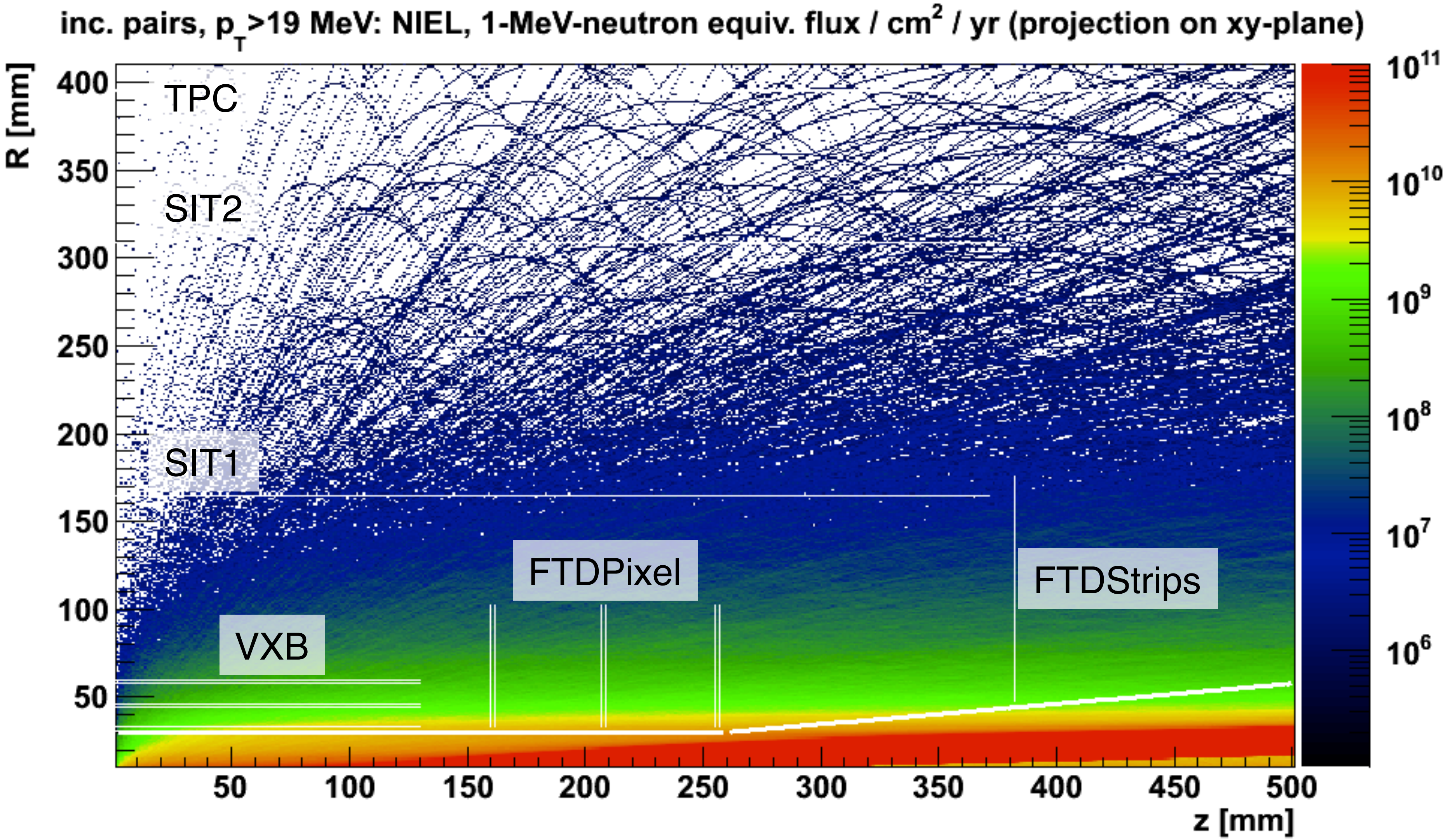


γγ → hadrons:



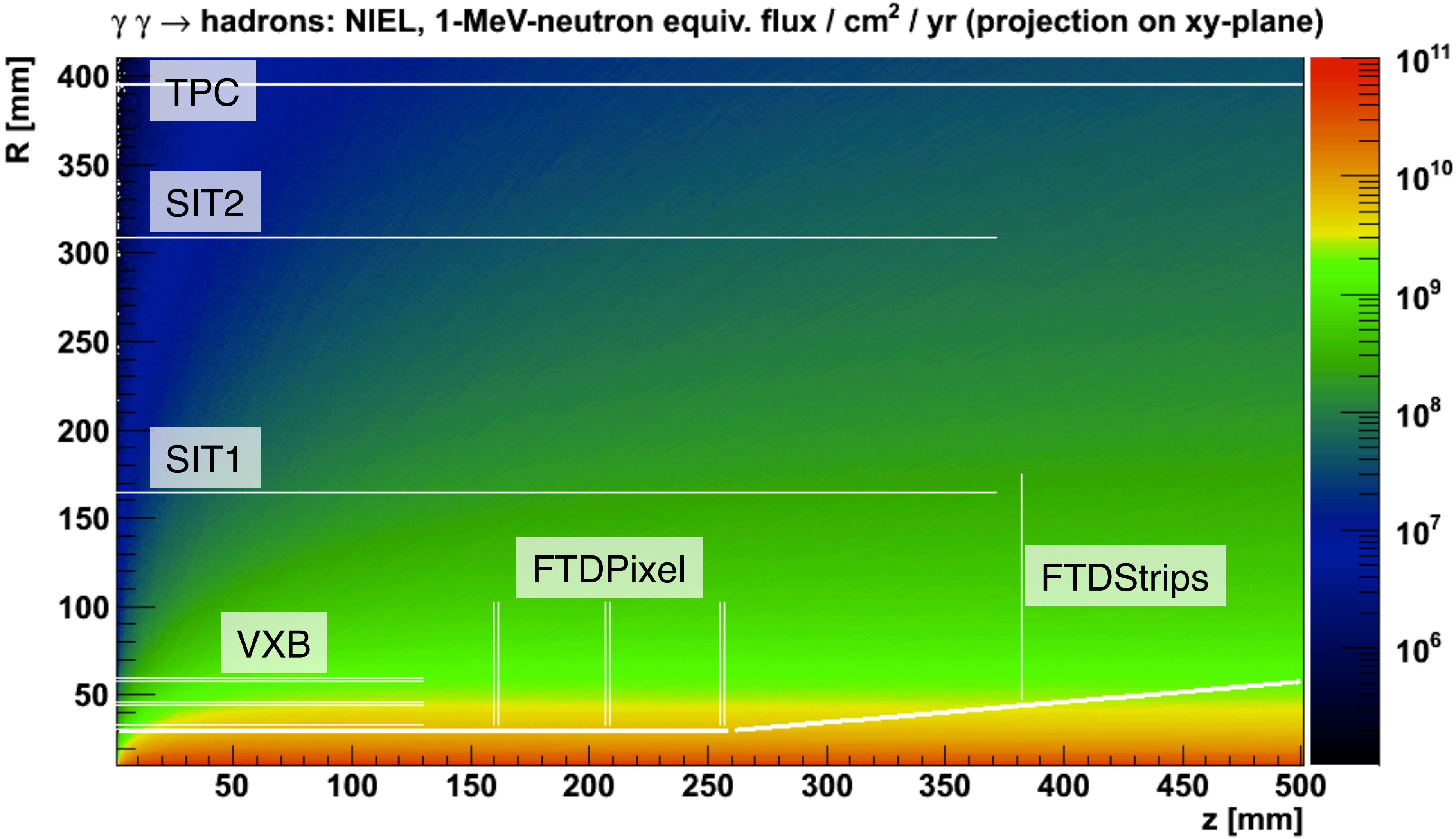
- Pair background strongly peaked in forward direction
- Pair background dominates in vertex region, falls steeply with radius

NIEL (disc projection) from pairs



- Similar observations as for occupancies: pair-background falls steeply with radius

NIEL (disc projection) from γγ→hadrons



- NIEL for γγ→hadrons falls less steeply with radius and also dominates already at smaller radii, due to larger damage factors