Occupancy from incoherent pairs in the HCal endcap at CLIC

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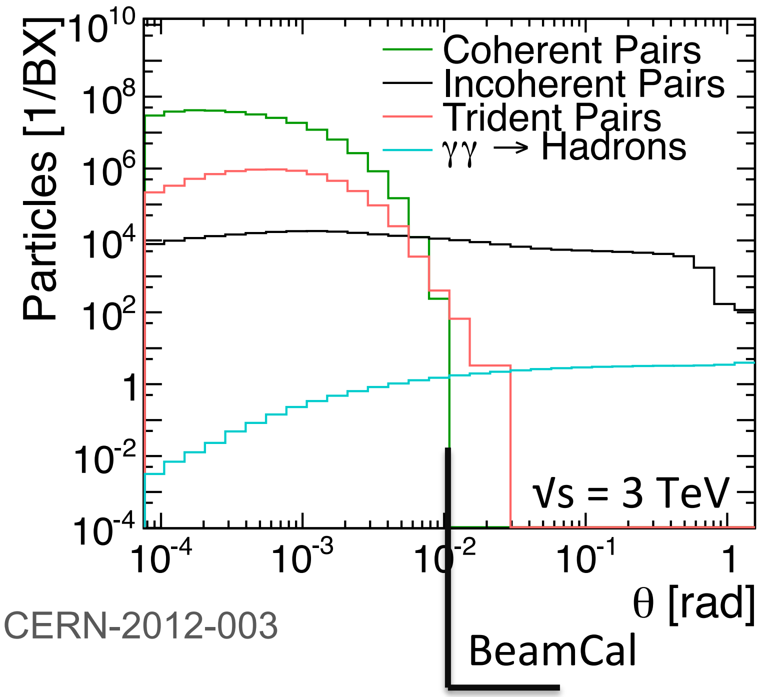
FCAL Collaboration Workshop, 26-27 May 2014

Compact Linear Collider (CLIC)

- CLIC beam structure
  - 312 bunch crossings per bunch train
  - 0.5 ns bunch spacing
  - $3.7 \cdot 10^9$ particles per bunch
- Beam-beam interactions
  - Coherent and trident pairs leave detector through 10 mrad opening angle
  - Incoherent pairs and $\gamma\gamma \rightarrow$ hadrons stay in detector



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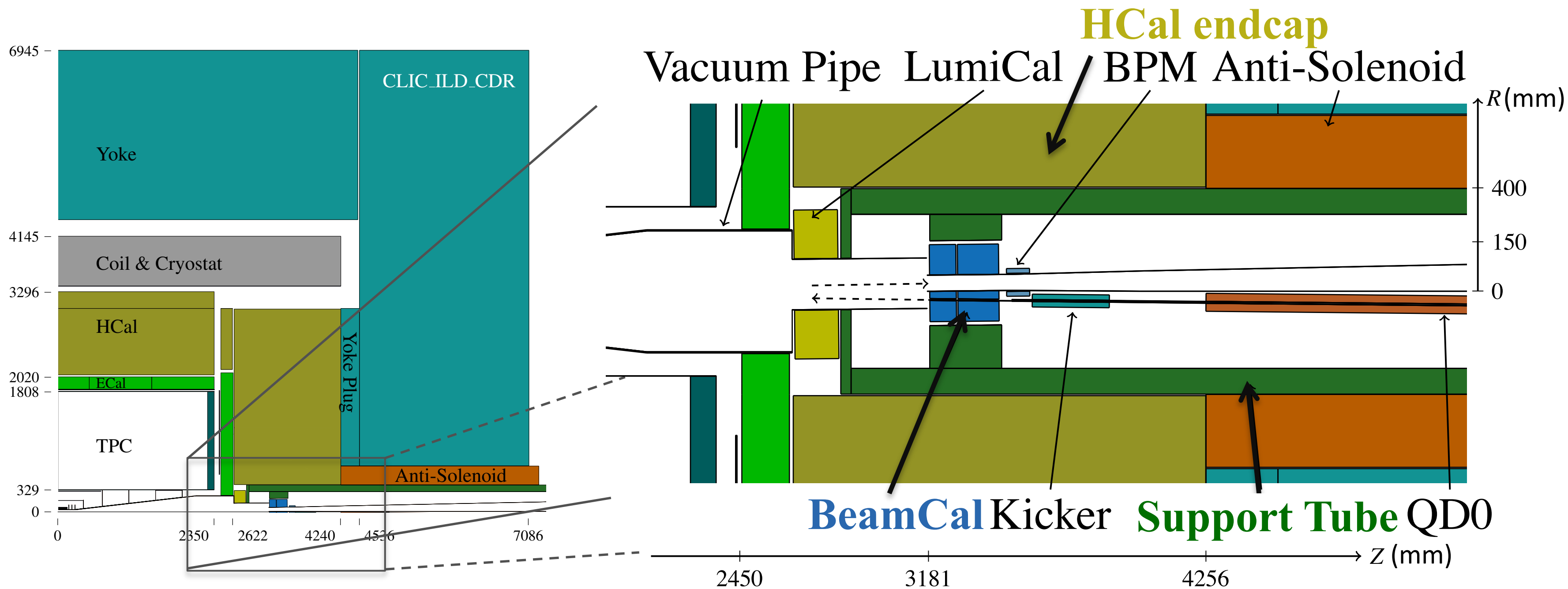
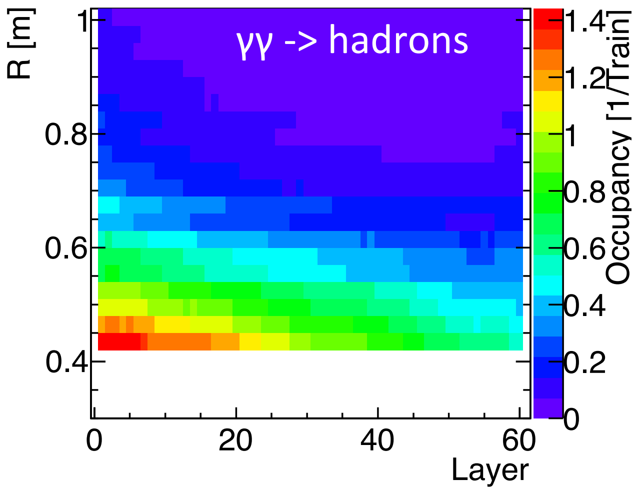
Very forward region

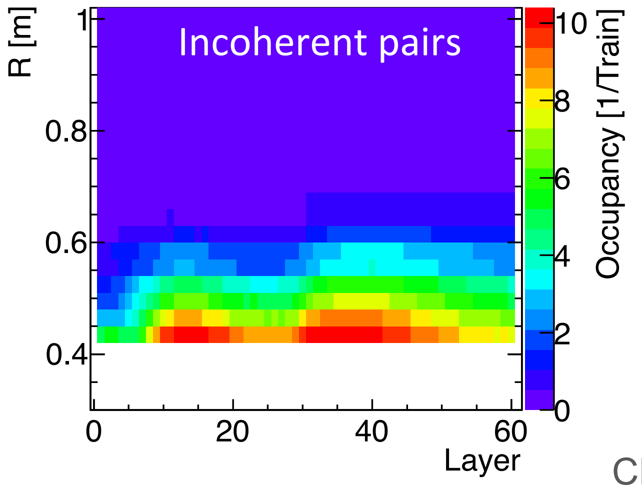
- γγ → hadrons reach the HCal endcap directly
- Incoherent pairs shower in the BeamCal
- Secondary particles pass through the support tube and enter the HCal endcap

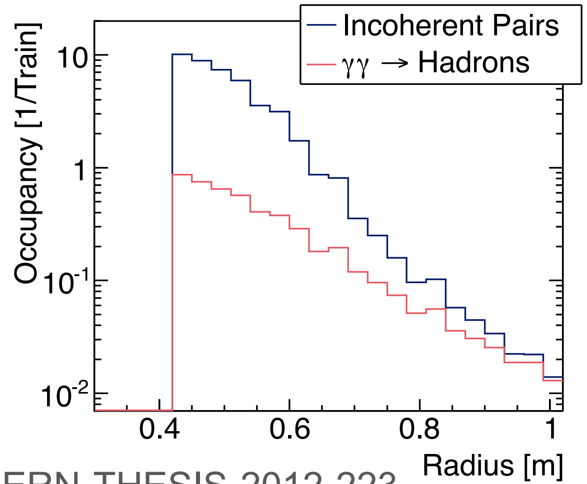


Occupancy in the HCal endcap

- Background induces a too high occupancy in the HCal endcap
  - 30 x 30 mm^2 scintillating tiles
  - Total readout time 300 ns per bunch train, divided in 12 time windows of 25 ns
  - Energy threshold 300 keV (≈0.3 MIP)
  - Occupancy per tile: number of time windows in with an energy deposit above threshold







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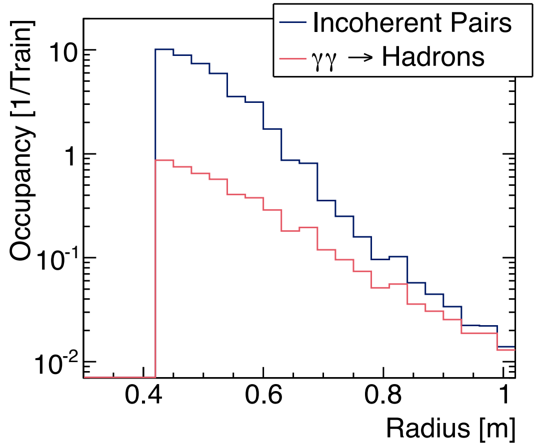
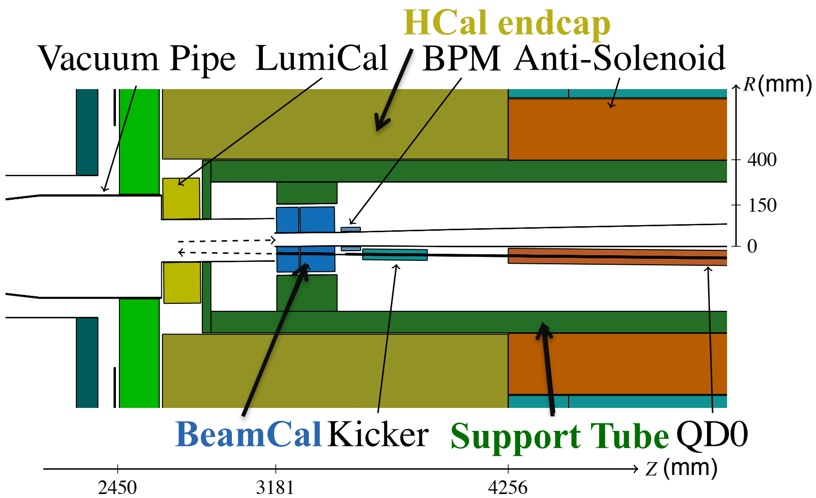
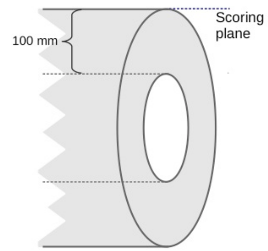
Reduction of the occupancy

- For γγ → hadrons the occupancy cannot be reduced by geometrical changes
- For incoherent pairs the support tube serves as a shielding
- ~80% occupancy due to incoherent pairs should be reduced to below γγ → hadrons contribution of ~8%
- This is done by:
  - Optimization of the support tube
    - Material
    - Thickness
  - Taking into account engineering perspective
  - HCal granularity





Two estimation methods



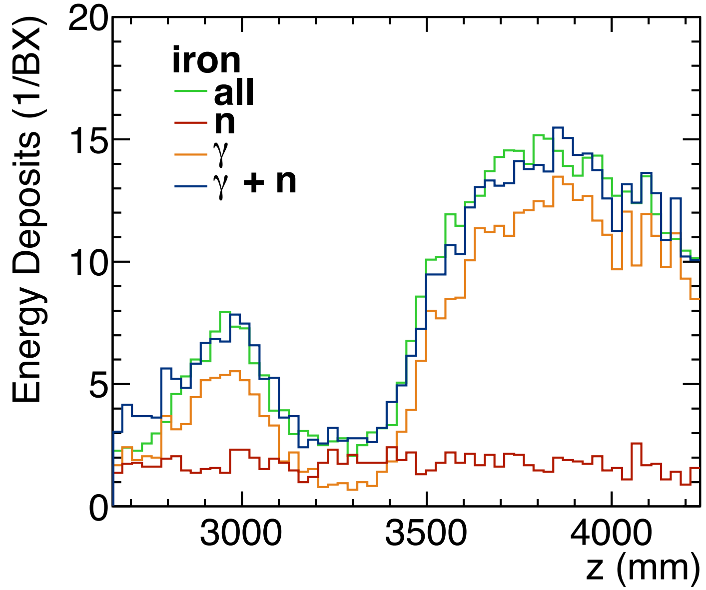
1. Particle counting
   – Count the number of particles passing through the support tube by registration in a scoring plane around it
   – Find the increase or decrease of the occupancy but no quantitative estimation of it
   – Requires a few bunch crossings (BX) of simulation data: fast simulation
2. Full occupancy estimation
   – Quantitative estimation of the occupancy
   – Requires a few bunch trains of 312 BX of simulation data: demands a lot of simulation time

Full detector simulations with MOKKA, GEANT4
Physics list: QGSP_BERT_HP
Detector model: CLIC_ILD_CDR

Secondary particles

- Secondary particles pass through support tube and cause energy deposits in the HCal endcap
- Neutrons (n) and photons (*γ)* together are responsible for the majority of energy deposits
- The support tube should shield these particles
- In the particle counting method only neutrons and photons have to be considered

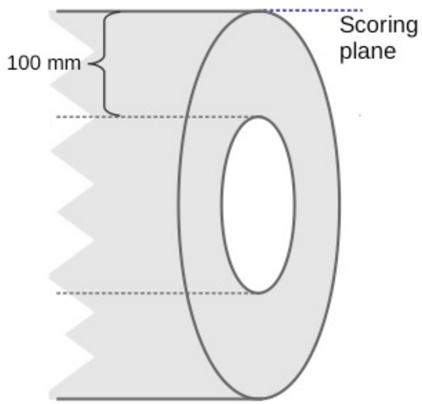
Energy deposits in HCal endcap



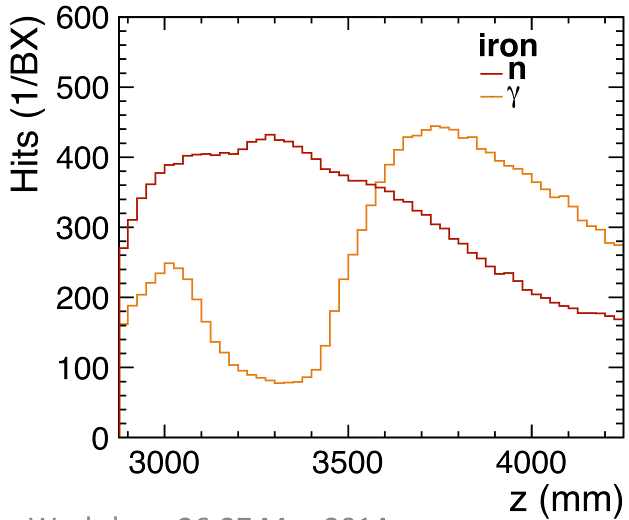
Relative impact of neutrons and photons

- Count the number of neutrons and photons passing through the support tube by registering hits (H) in a scoring plane around it
- Compare the number of hits in the scoring plane to the number of energy deposits in the HCal per particle type
- Photons cause more energy deposits per hit (factor 4.38)
- Define a figure of merit (FOM) that should be minimized:

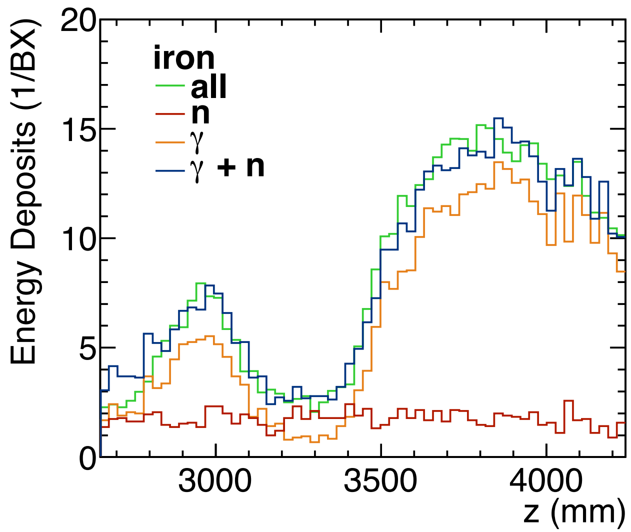
$$FOM = H_n + 4.38 H_\gamma$$



Hits in scoring plane

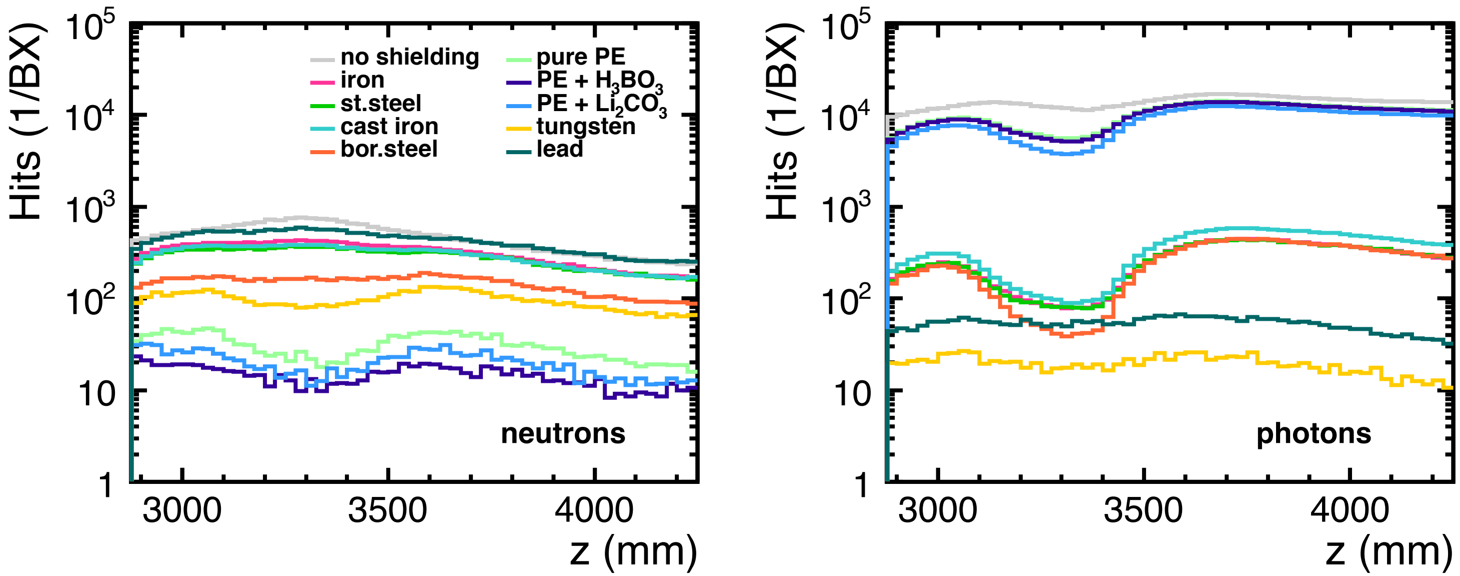


Energy deposits in HCal endcap

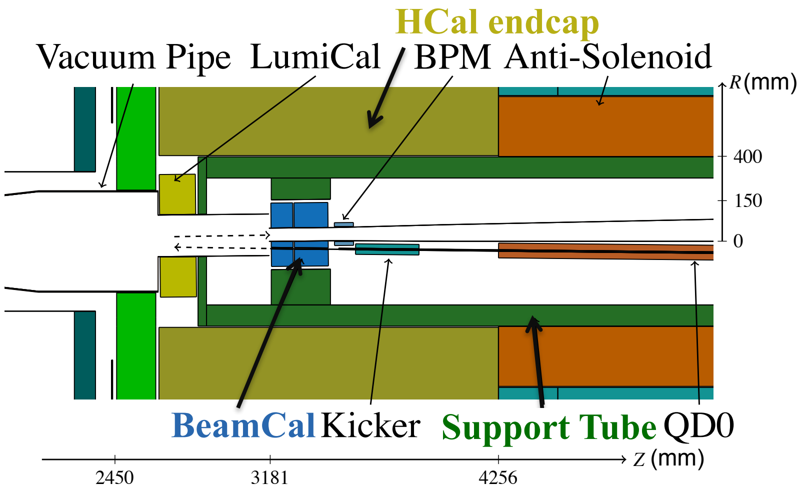


Support tube material

- Simulations with different support tube materials:
  - Polyethylene (PE) → neutron shielding
  - Tungsten (W) → photon shielding
  - Combine materials to shield both neutrons and photons

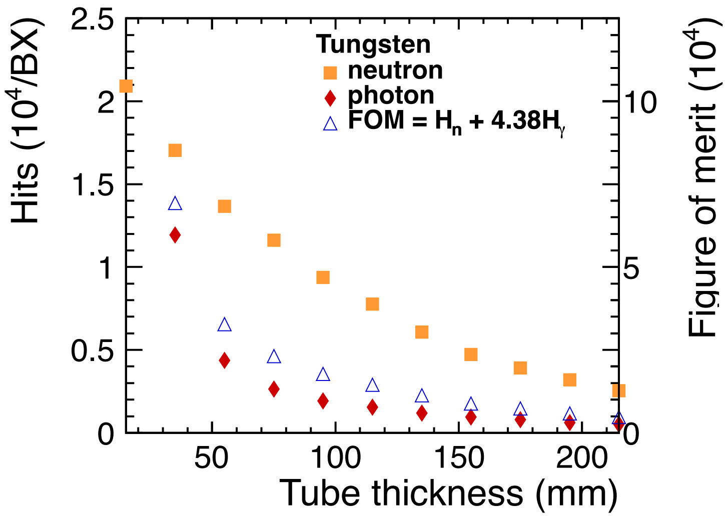


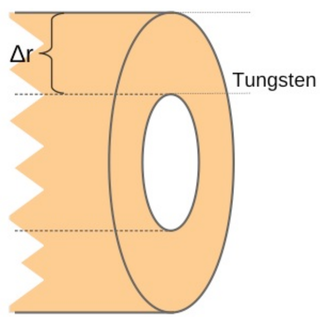
Support tube thickness



- Constraints on thickness:
  - r_{max} = 400 mm (HCal endcap)
  - r_{min} = 185 mm (BeamCal)
  - Max Δr = 215 mm

Tungsten

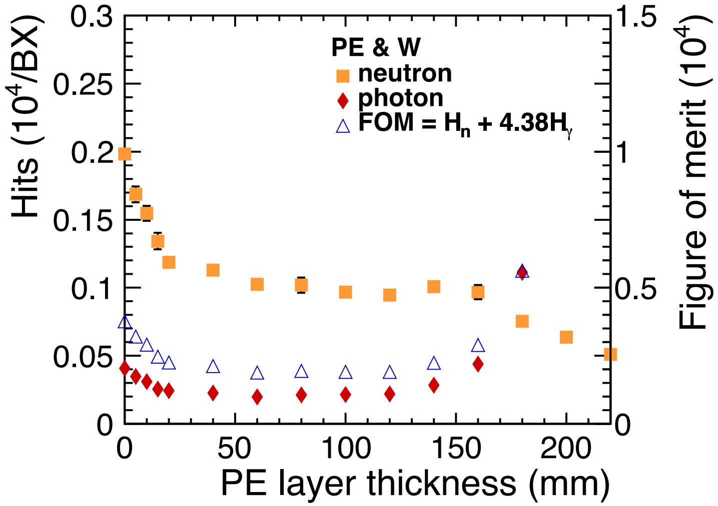


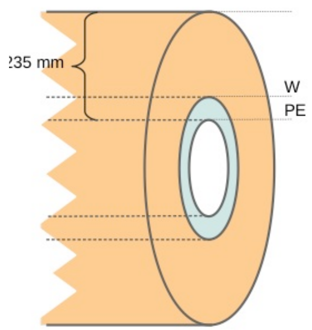


- Thicker tube → less hits in scoring plane
- Tungsten support tube with maximal thickness minimizes the figure of merit

Combination of materials

PE – W



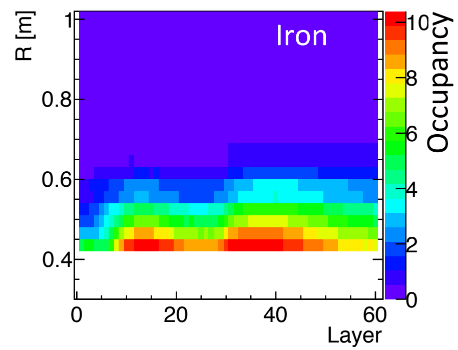


- W + PE = 215 mm
- The figure of merit is minimized for 90 mm PE + 125 mm W

Occupancy for optimised geometries

- Using method 2: full occupancy estimation
- Compare the situation before optimisation to the two optimised tubes:
  - 215 mm W
  - 90 mm PE + 125 mm W

BEFORE



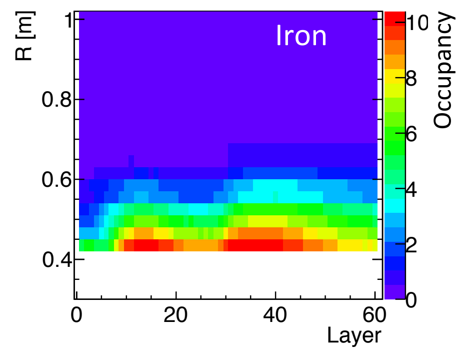
Iron:
~80% occupancy

Occupancy per tile: number of time windows of total 12 with an energy deposit above threshold
30 x 30 mm^2 scintillating tiles
Energy threshold 300 keV (≈0.3 MIP)
Total readout time 300 ns
12 time windows of 25 ns

Result for optimised geometries

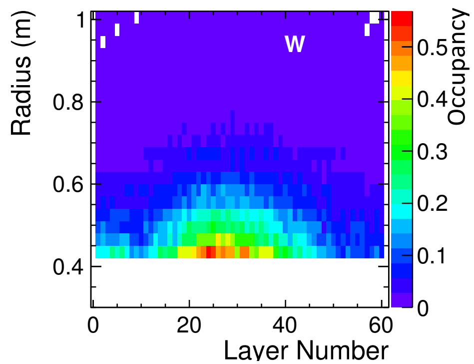
- Using method 2: full occupancy estimation
- Compare the situation before optimisation to the two optimised tubes:
  - 215 mm W
  - 90 mm PE + 125 mm W

BEFORE

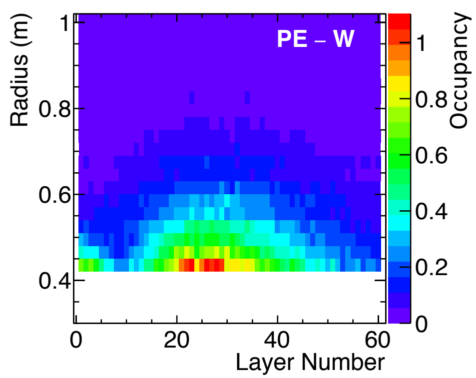


Iron:
~80% occupancy

AFTER OPTIMISATION



Tungsten:
~4% occupancy



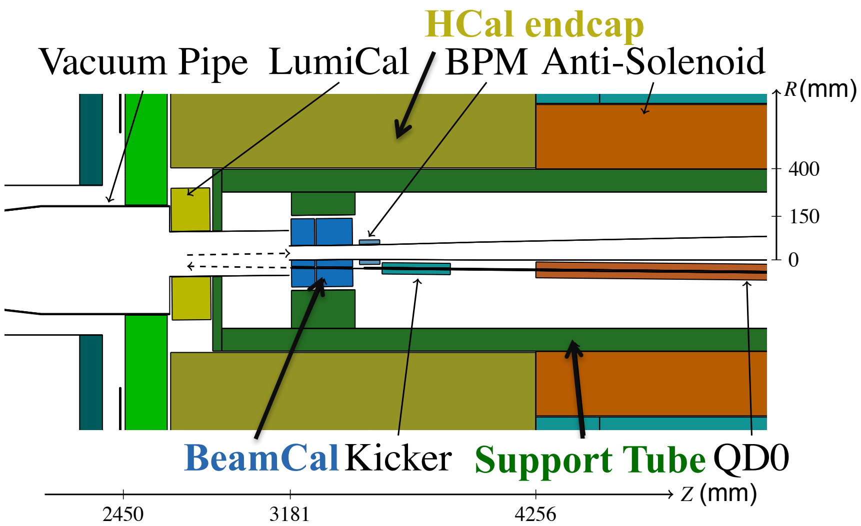
PE – W:
~8% occupancy

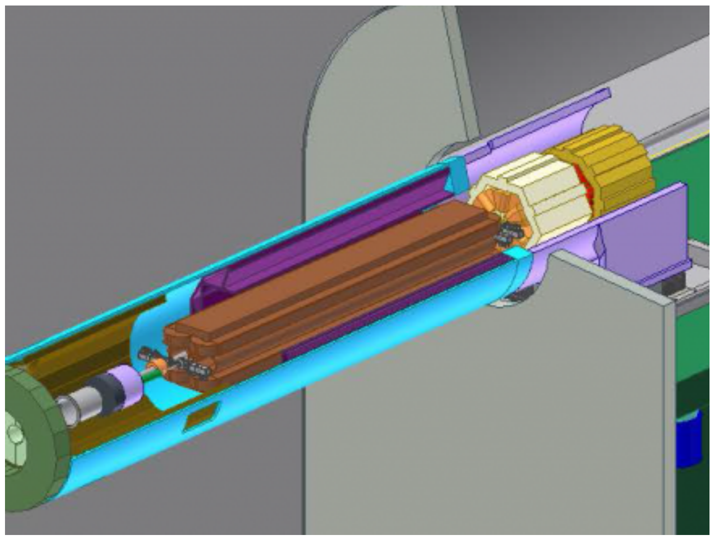
≈ γγ → hadrons

Occupancy per tile: number of time windows of total 12 with an energy deposit above threshold
30 x 30 mm^2 scintillating tiles
Energy threshold 300 keV (≈0.3 MIP)
Total readout time 300 ns
12 time windows of 25 ns

Engineering perspective

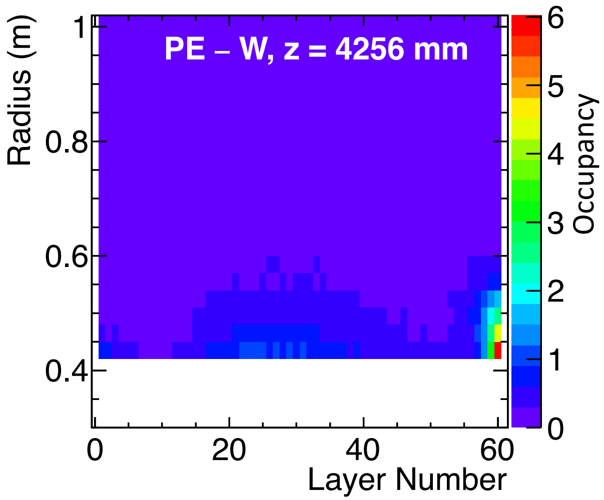
- Supporting a heavy tungsten support tube from the cavern wall is challenging:
  - As little weight as possible: Use the PE – W tube and not W tube
- Need enough room for the QD0 support structure:
  - Shorter thick part of the support tube



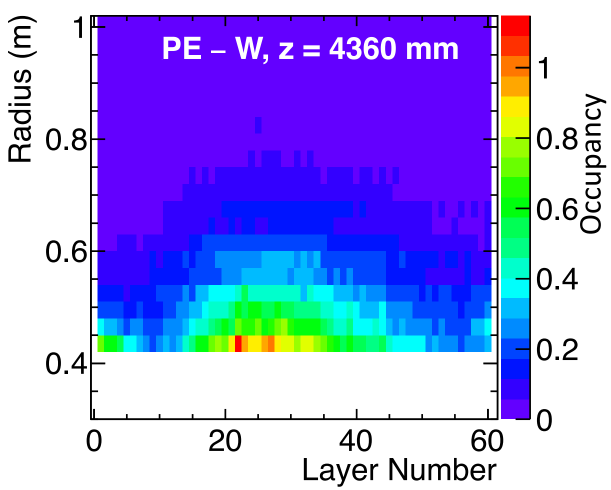


Shorter support tube

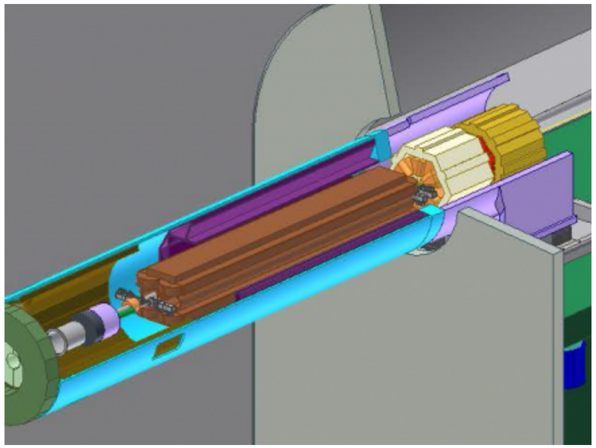
- Initial tube extends to $z = 7500$ mm
- Shorten to only cover the HCal endcap with max $z = 4240$ mm
- A tube until $z = 4256$ mm gives a high occupancy in the last HCal endcap layers
- With a tube until $z = 4360$ mm the same result as for the long tube to $z = 7500$ mm is obtained



~50% occupancy



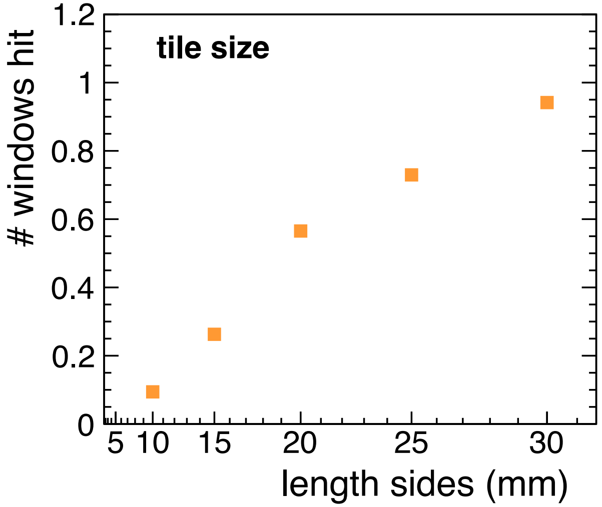
~8% occupancy



HCal endcap granularity

- Standard: square scintillating tiles, 30x30 mm^2
- Reduce tile size
- No saturation behaviour: occupancy reduction is proportional to the reduction of tile area

PE – W



Occupancy: number of time windows with an energy deposit in the inner radius of the HCal endcap, averaged over layers 20 to 30

Summary of the results

- The support tube has to shield photons and neutrons to reduce the occupancy in the HCal endcap. Photons have a larger contribution to the occupancy

- Combinations of materials can shield both photons and neutrons:
  - Tungsten for photons; polyethylene for neutrons

- The occupancy is reduced from ~80% to ~4% with a W support tube
- A short PE – W support tube within engineering constraints reaches an occupancy of ~8%, a level comparable to $\gamma\gamma \rightarrow$ hadrons
- With the tile size this can be decreased further if required

Conclusions

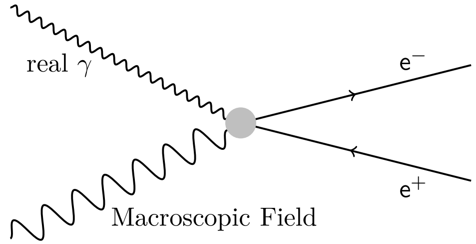
- A safety factor of 5 is used for incoherent pairs in the CLIC Conceptual Design Report
- With this factor, it is expected that changes of the support tube alone cannot reduce the occupancy sufficiently
- An additional reduction of the tile size in the HCal endcap inner radius would be required

- The CLIC study aims to design a new detector model
- The results found here are expected to be applicable to a new model to a great extent
- For a detailed description of the occupancy in the new model a full occupancy estimation will be required

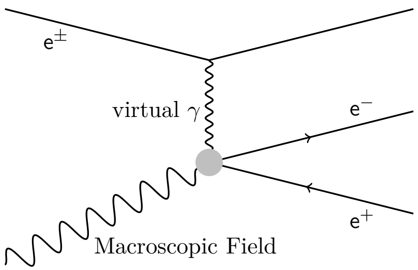
Backup

Coherent, incoherent, and trident pairs

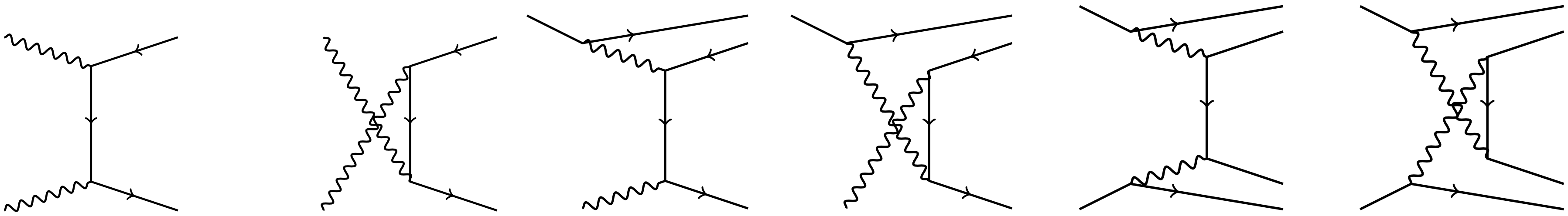
- Coherent pairs



- Trident pairs



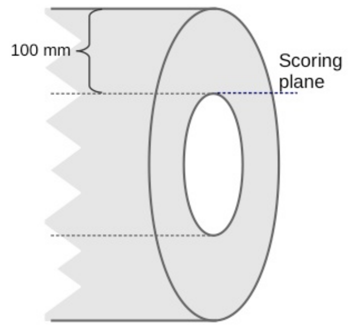
- Incoherent pairs

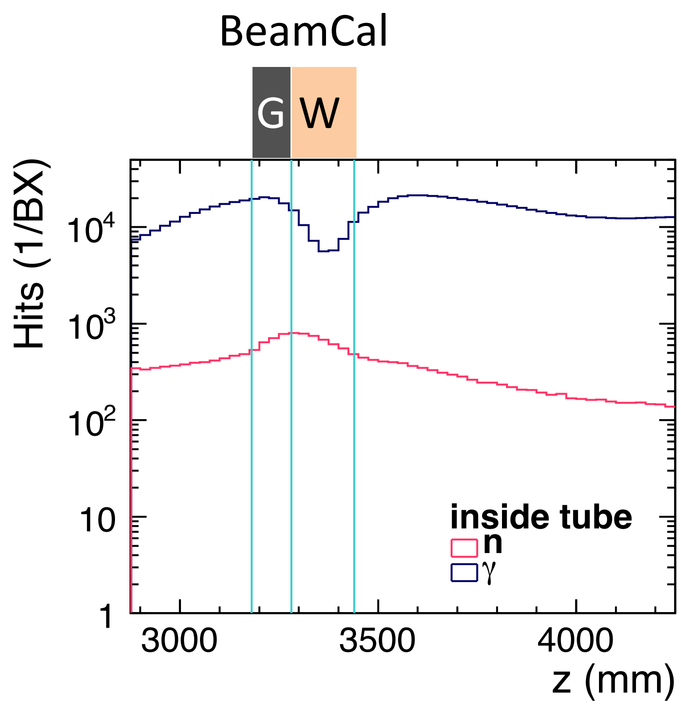


(a) Breit–Wheeler (b) Bethe–Heitler (c) Landau–Lifschitz

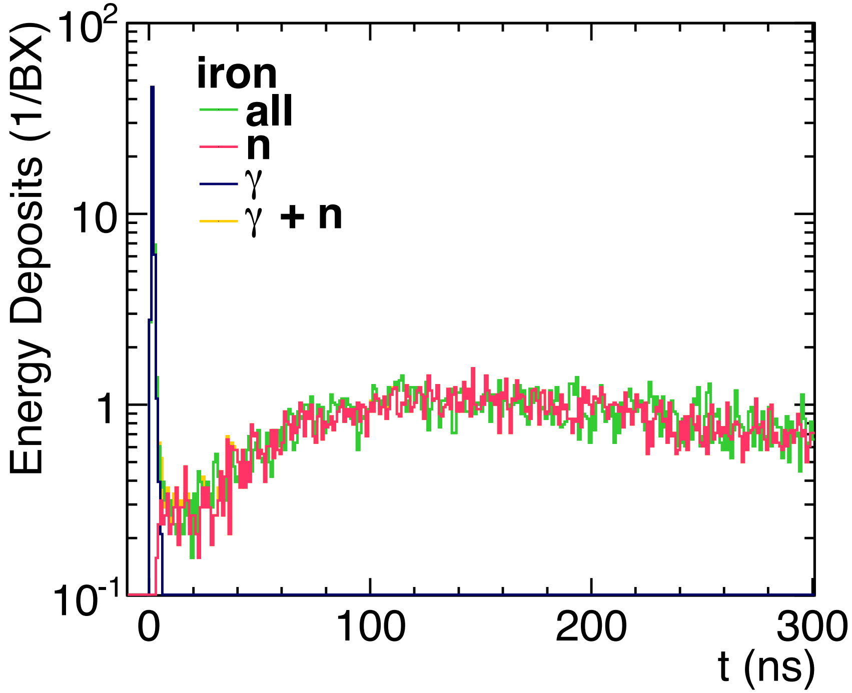
Particles inside the support tube

- Photon hits on a scoring plane inside the support tube (without BeamCal support) show a dip at the location of the BeamCal
- Neutron hits peak at the location of the BeamCal
- → Photons from showers in the BeamCal are shielded by the tungsten absorber



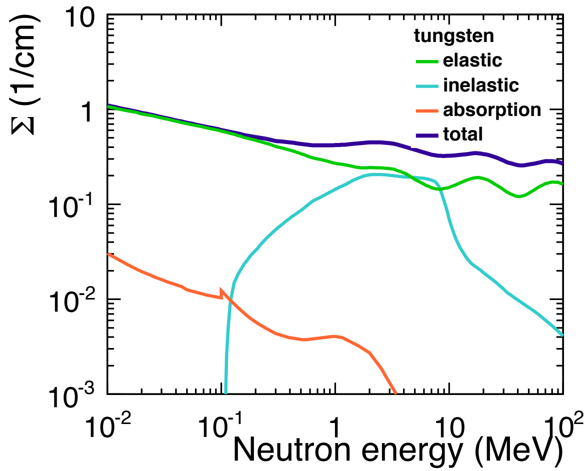


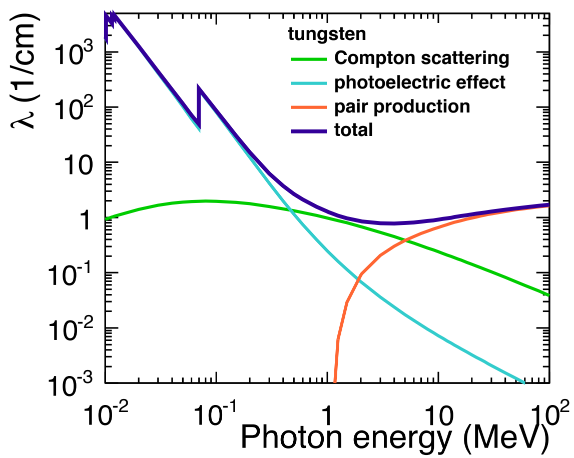
Time of energy deposits



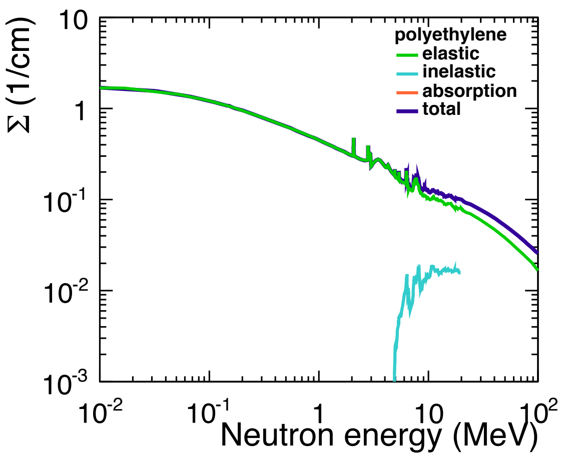
Cross sections

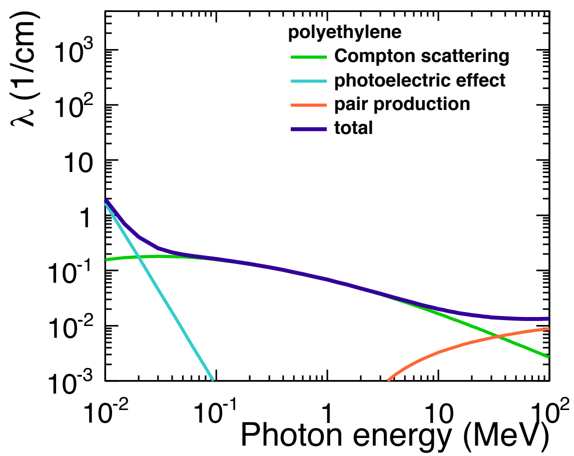
Tungsten



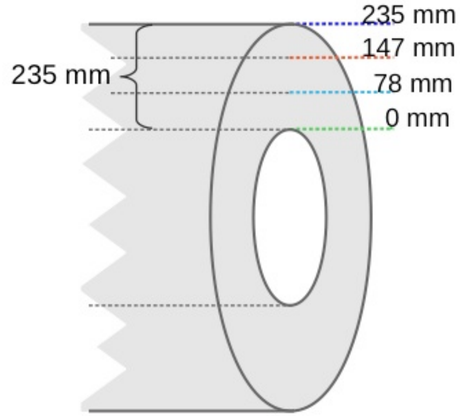


Polyethylene

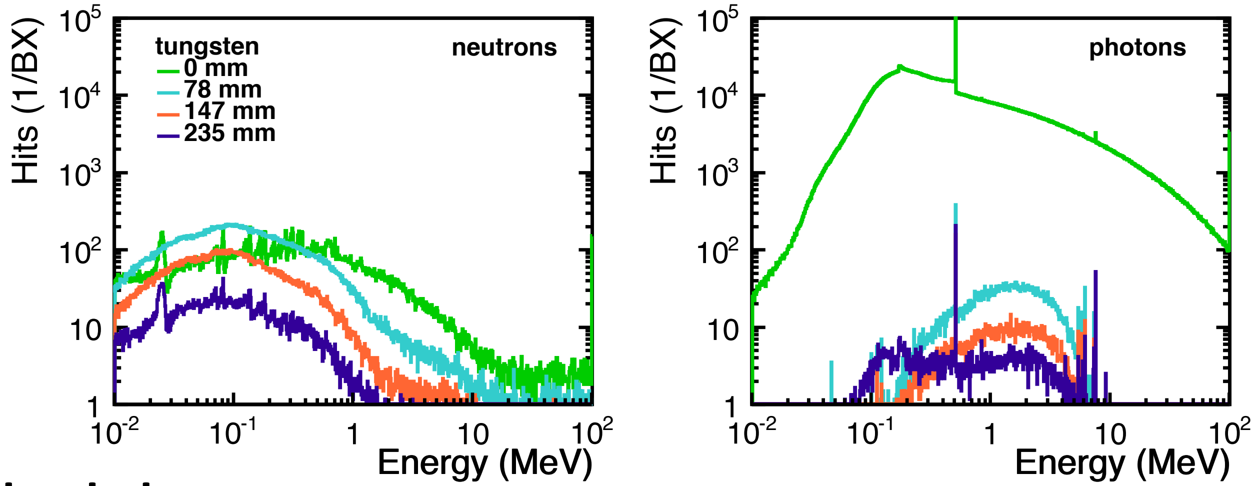




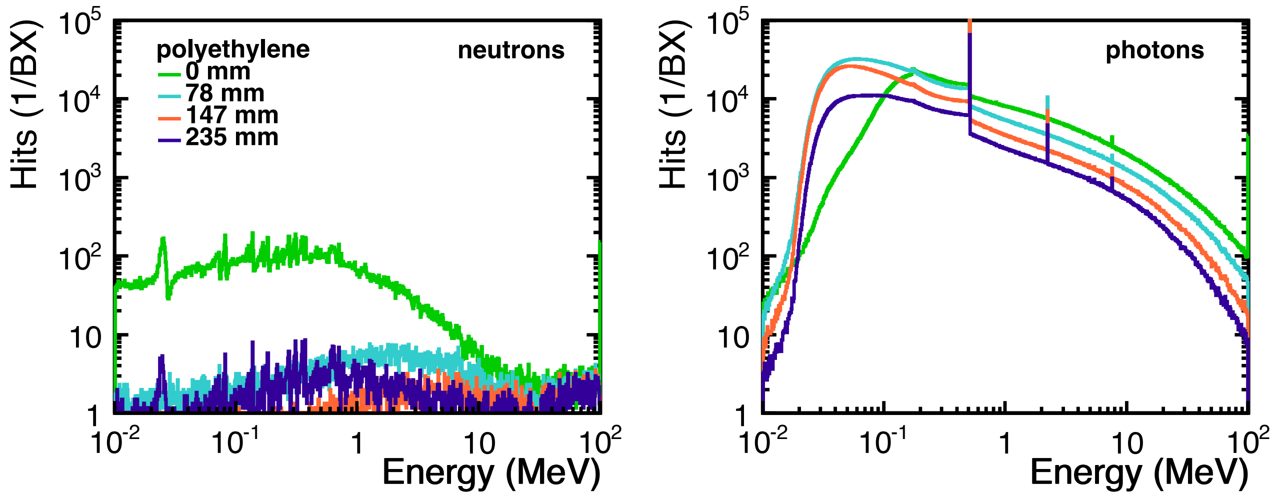
Energy spectra



Tungsten

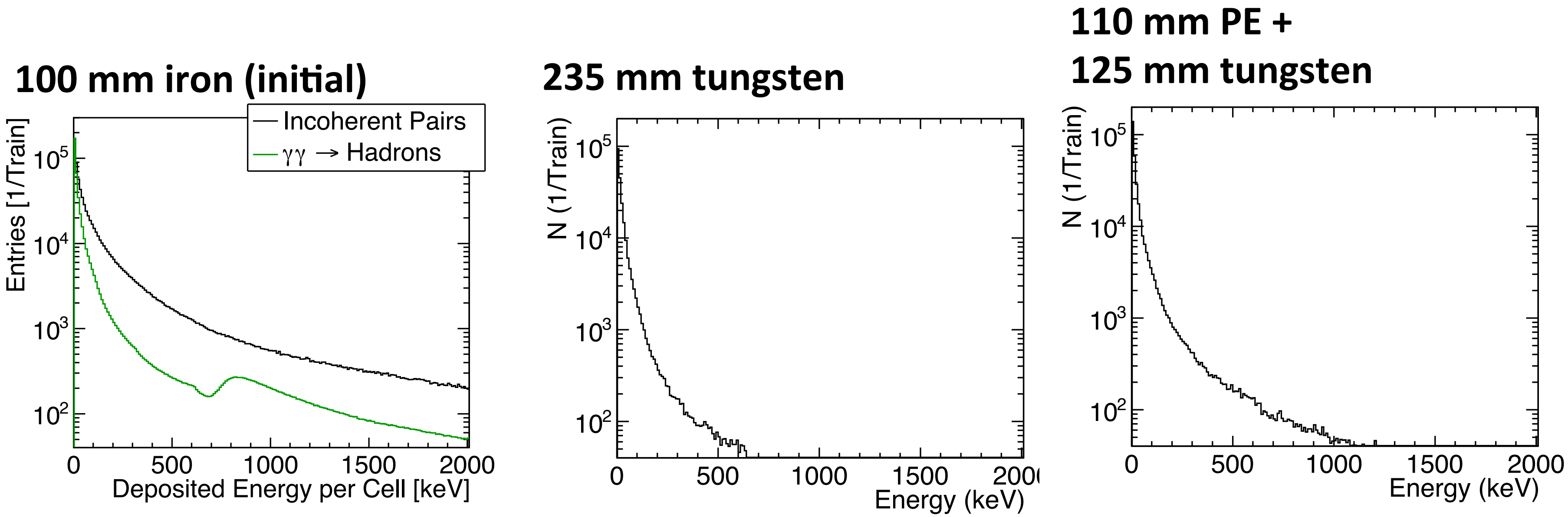


Polyethylene



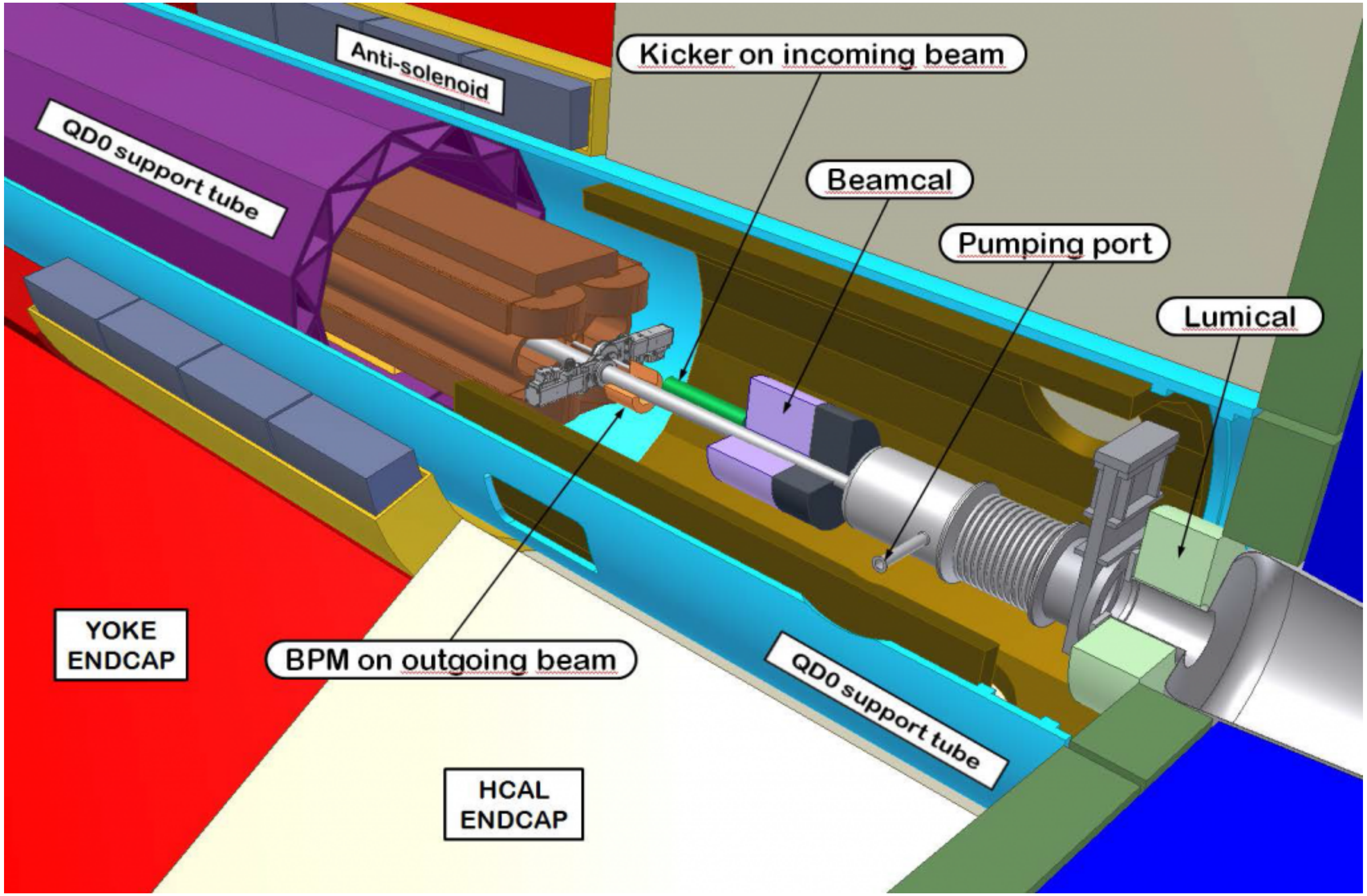
NIST Photon Cross Section Database

Spectrum of energy deposits



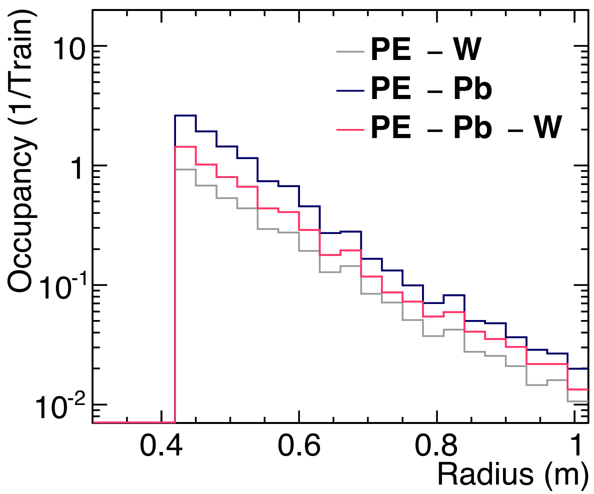
- The spectrum of energy depositions in the HCal endcap drops of more quickly for the W and PE+W tube, compared to the initial iron support tube.
- The energy threshold is 300 keV (0.3 MIP)

Engineering model of CLIC_ILD_CDR

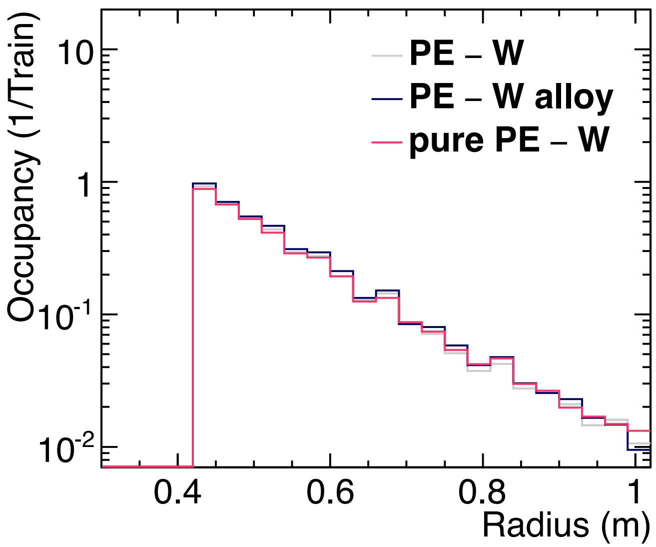


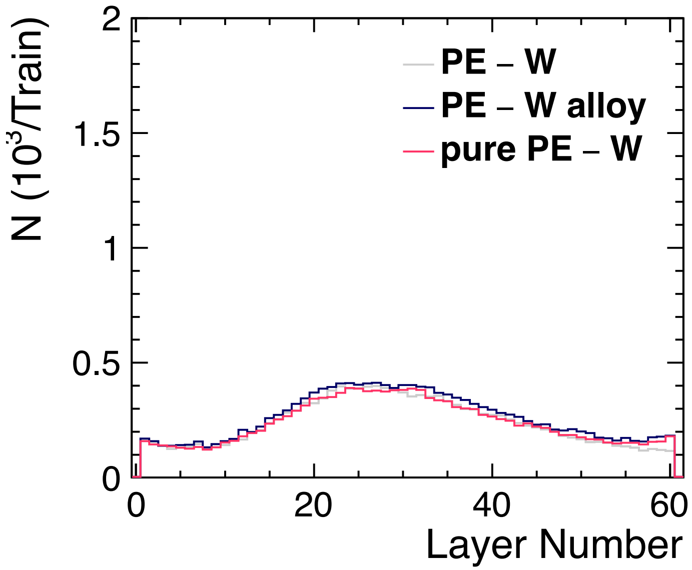
Tungsten → lead

- Part of the tungsten in the support tube is replaced by lead:
  - 110 mm polyethylene + 125 mm Pb
  - 110 mm polyethylene + 65 mm Pb + 60 mm W
- In both cases a higher occupancy level.



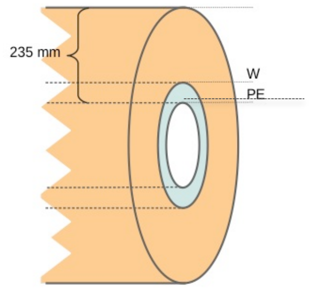
PE + H_3BO_3 → Pure PE, pure W → W alloy



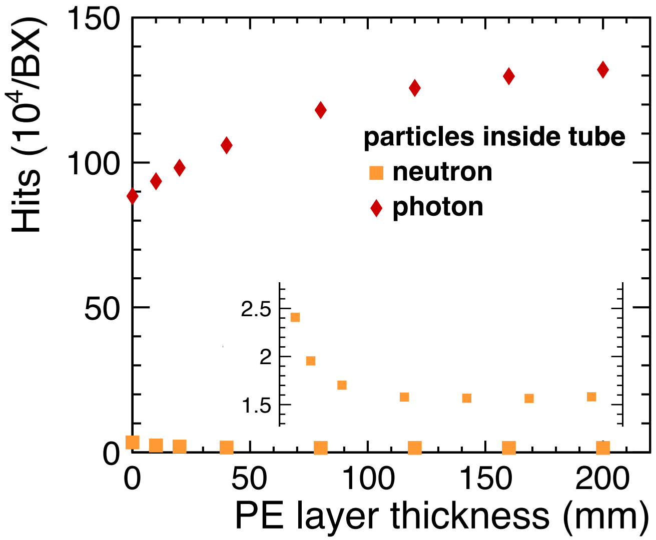


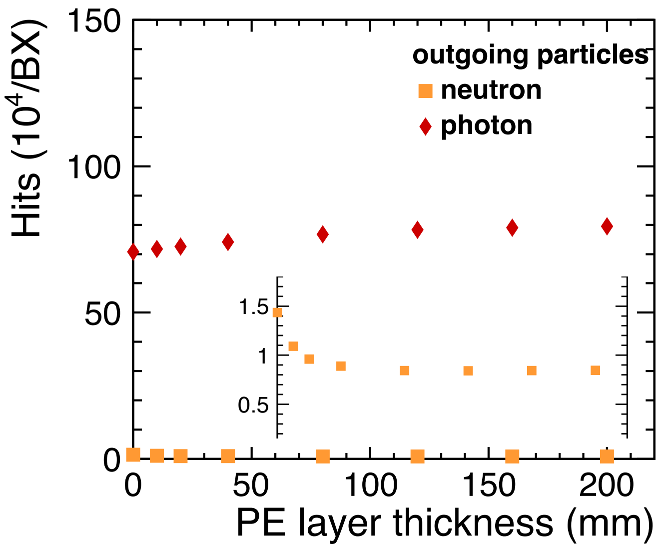
Limitation of the FOM

- The number of hits in the scoring plane before the support tube depends on the material choice.



- This is possibly due to reflections in the tube.
- Looking at only outgoing particles shows the dependency not for photons, but still for neutrons.
- A description of the occupancy in terms of hits in the scoring plane becomes complex

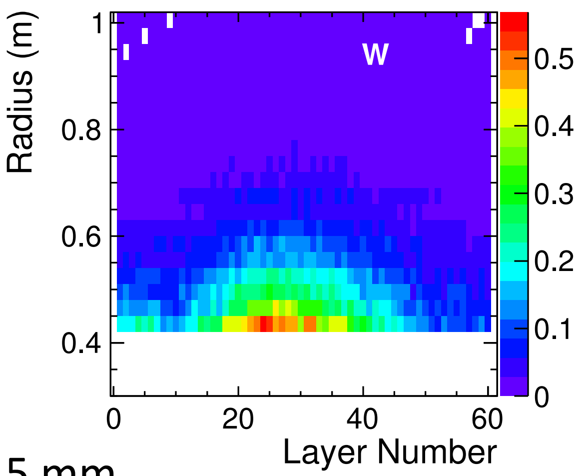




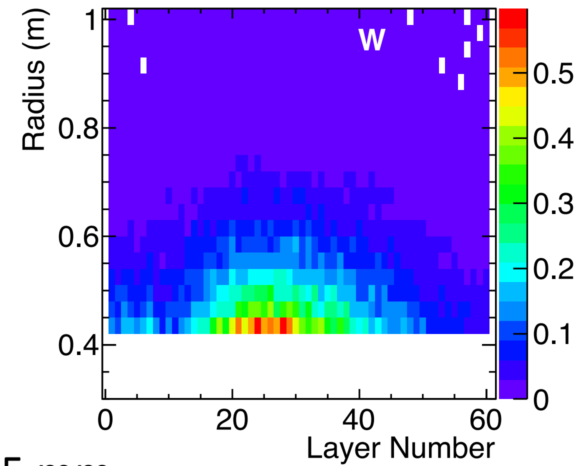
215 mm vs 135 mm thickness

W

215 mm

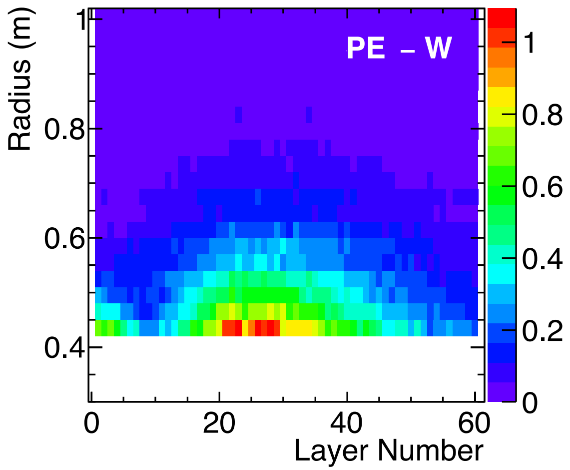


235 mm



PE – W

215 mm



235 mm