Simulation for online beam monitoring with a Compton camera (SiFi-CC Project)

07.07.2023

Linn Mielke, on behalf of the SiFi-CC group

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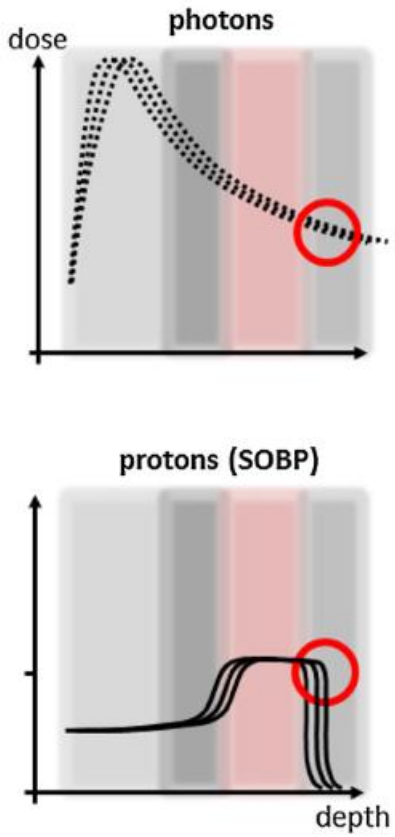
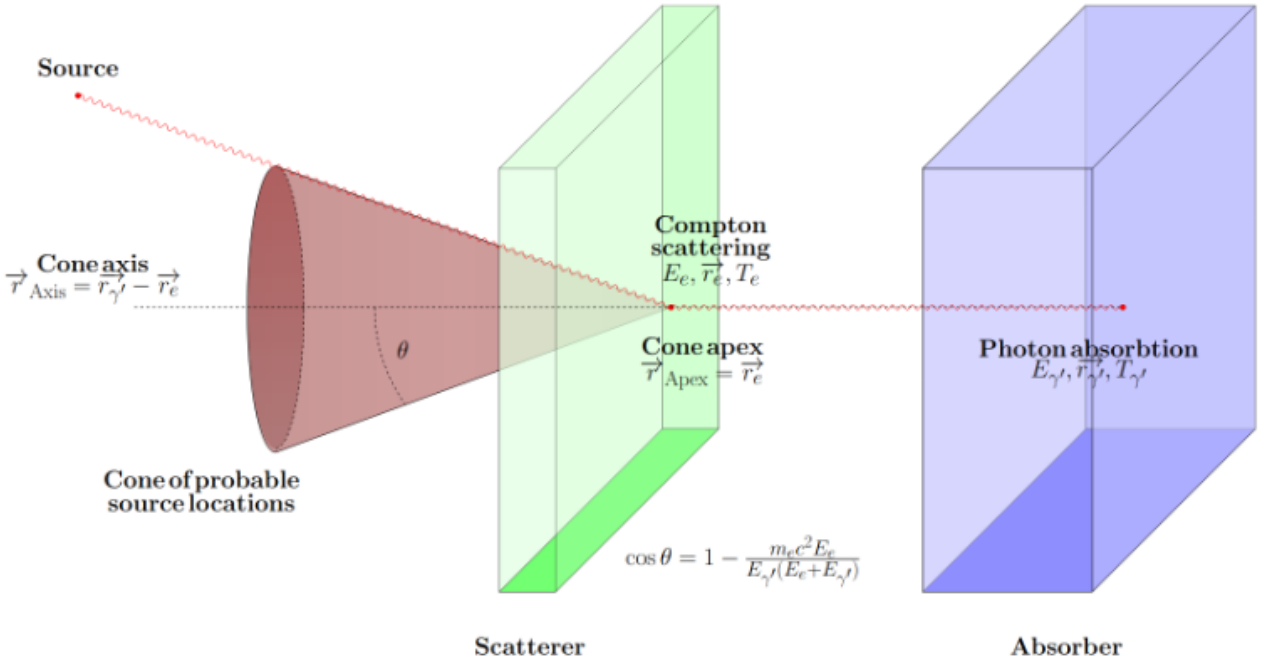
The SiFi-CC Project: A Recap

Silicon Photomultiplier and Scintillating **Fi**bre-based **C**ompton **C**amera





Left: Taken from „***In vivo* proton range verification: a review“ (**Antje-Christin Knopf and Antony Lomax, 2013, *Phys. Med. Biol.* **58** R131)

Right: Taken from https://publications.rwth-aachen.de/record/856966/files/856966.pdf (PhD dissertation by Jonas Kasper, 2022)

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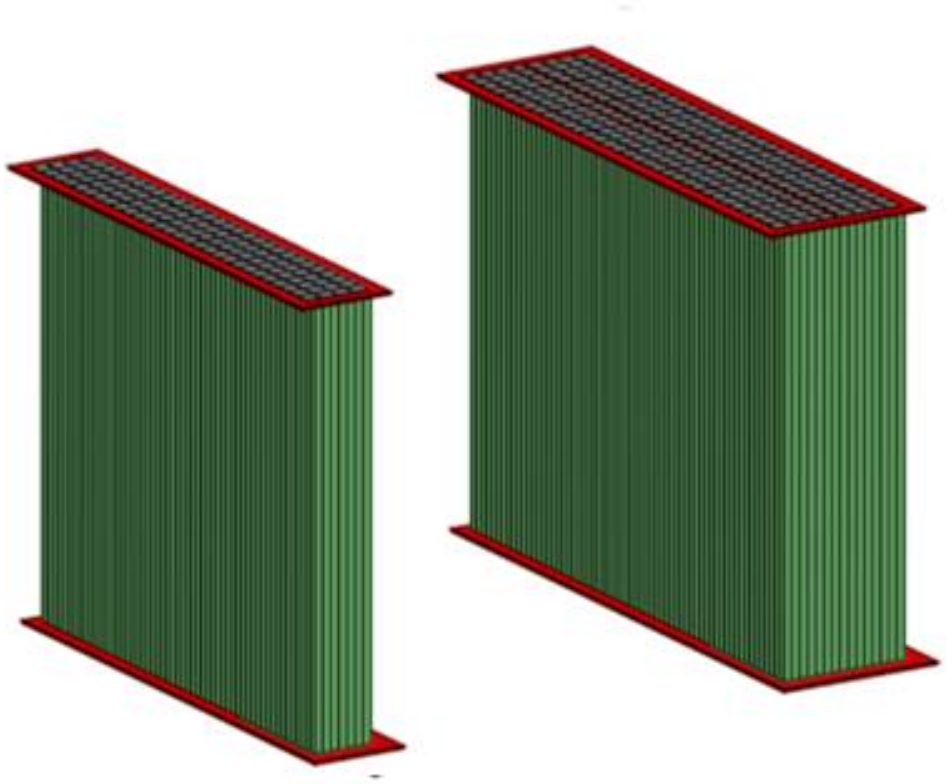

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1. Significance of the Simulation

2. Overview Simulation Framework

3. Base Units and Geometry

4. Implementation of Particle Source

5. Event Mixing

6. Optical Photon Model

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Optimising the SiFi-CC Design

1. Build Prototypes

2. Code Simulation
   - mirrors the design we have in mind
   - input for our further analysis and image reconstruction

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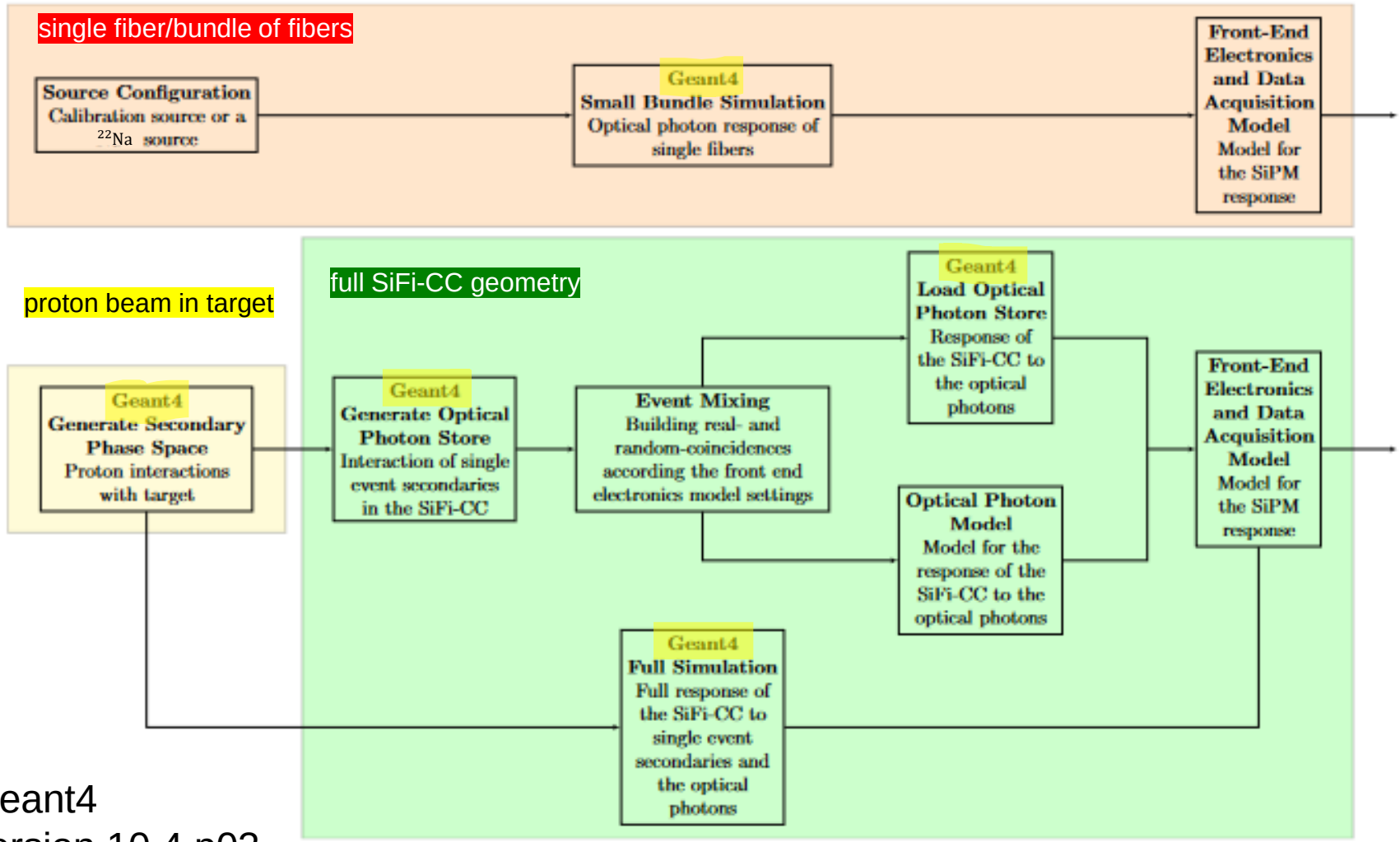
Simulation Framework: Overview



Geant4
version 10.4.p03

Taken from https://publications.rwth-aachen.de/record/856966/files/856966.pdf (PhD dissertation by Jonas Kasper)

Preferred Mode

run full-setup in one step SLOW

Three separate simulations:
1. Generate Optical Photon Store
Interactions of prompt gammas in the detector & generation of optical photons (stored and killed immediately)

2. Optical Photon Model
Propagation of optical photons & generation of coincidences (event mixing)

3. Front-End Electronics and Data Acquisition Mode/Detector Response
Simulation of detector response (SiPMs, front-end electronics, data acquisition settings)

FAST

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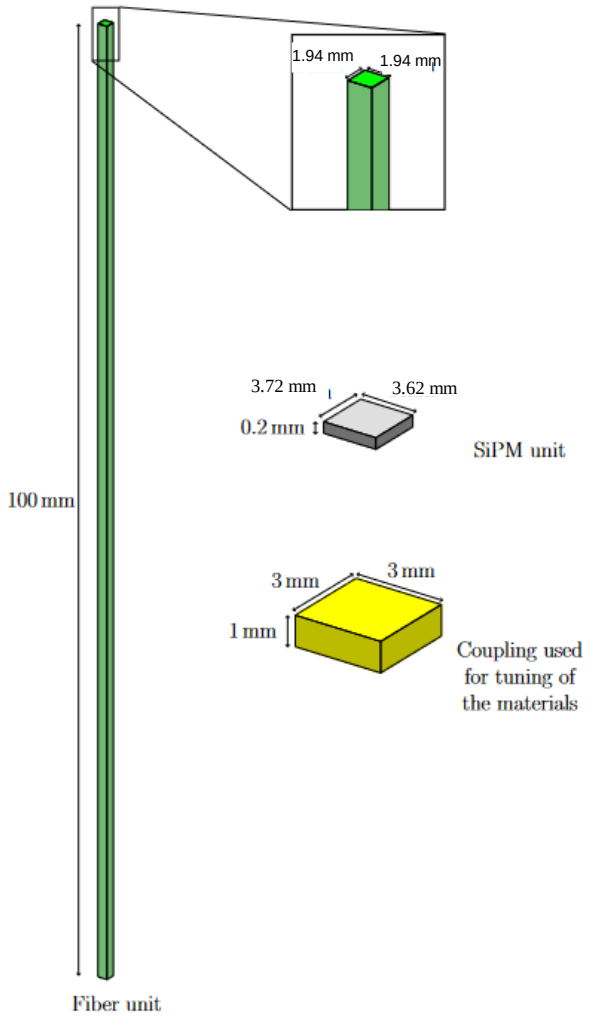
Base Units (Geant4)



-ensure same geometry across applications
-base units with fixed settings
-detector dictates intuitive base units:

- Fibres
- SiPMs,
- couplings between fibres and SiPMs

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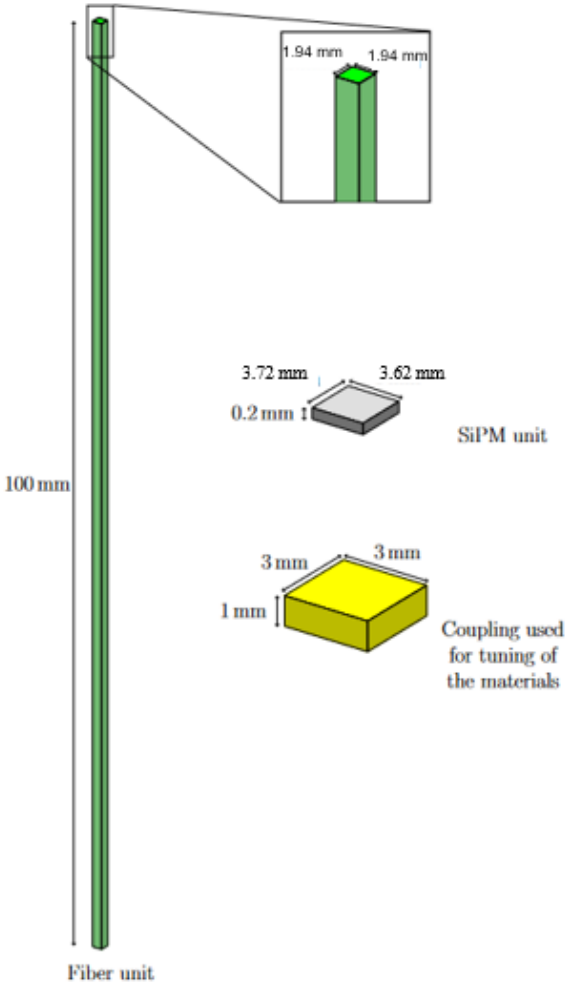
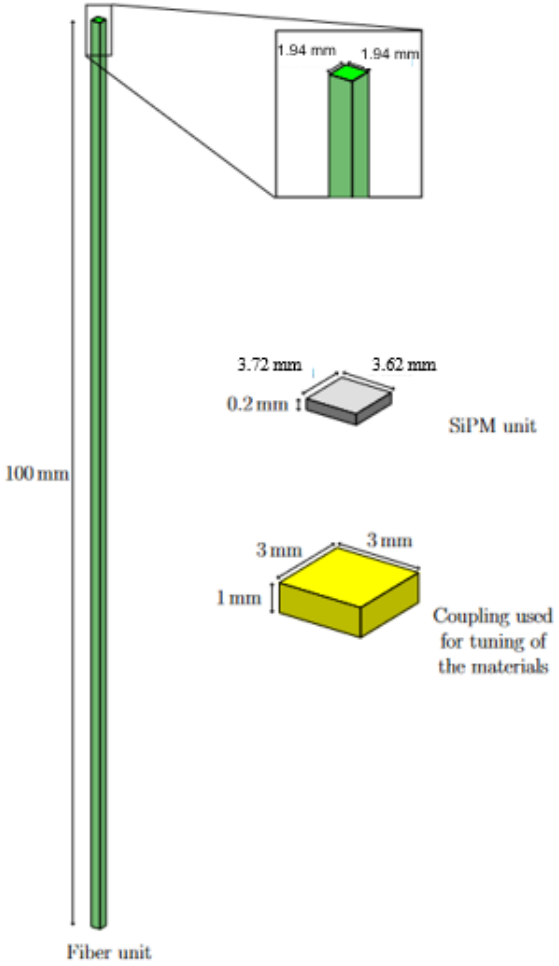
Base Units (Geant4): Fiber Unit



-reality: LYSO:Ce fibre wrapped in aluminium foil
-Geant4: LYSO:Ce fibre wrapped in aluminium foil with 5 µm air layer between foil and fibre
-hits not stored for wrapping

Taken from https://publications.rwth-aachen.de/record/856966/files/856966.pdf (PhD dissertation by Jonas Kasper)

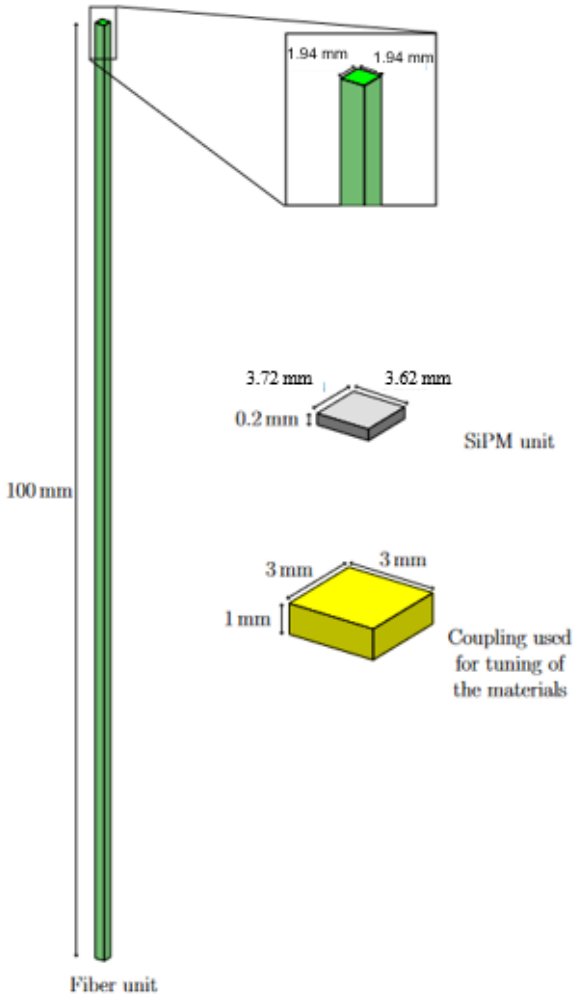
Base Units (Geant4): SiPM unit



-only sensitive parts of physical SiPM (ex.: no housing)
-any optical photon is treated as absorbed by SiPM

Taken from https://publications.rwth-aachen.de/record/856966/files/856966.pdf (PhD dissertation by Jonas Kasper)

Base Units (Geant4): Coupling Unit



-purpose: connection of fibres to SiPMs
-different version in different parts
-built for a detector side, not single fibre/SiPM pair
-4 to 1 coupling for full SiFiCC

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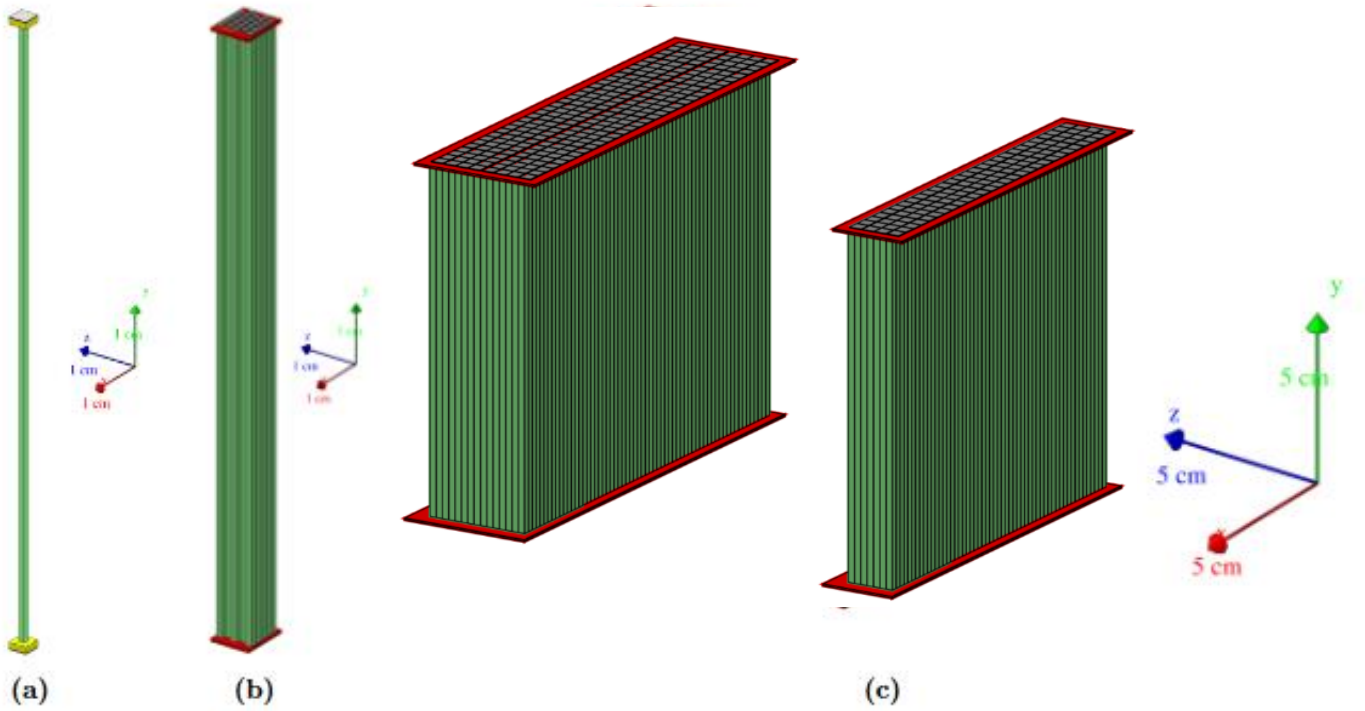
Full Geometry

Taken from https://publications.rwth-aachen.de/record/856966/files/856966.pdf (PhD dissertation by Jonas Kasper)



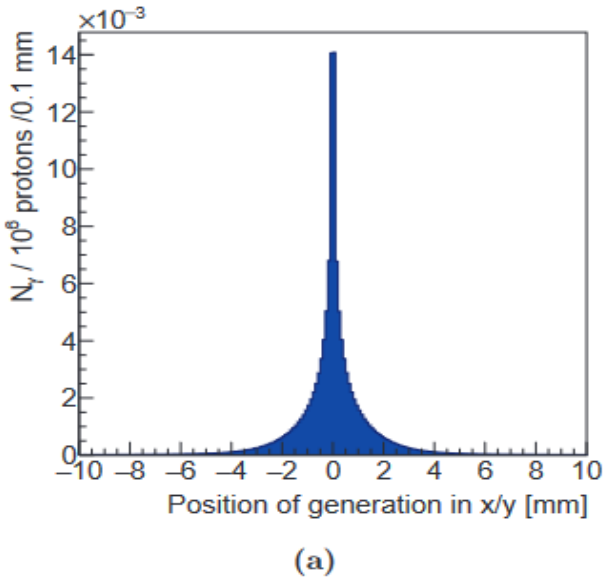
(a) Fibre
(b) Fibre bundle
(c) Complete SiFi-CC
Layer: stack of fibre units + SiPMs + Couplings
Module: stack of layers

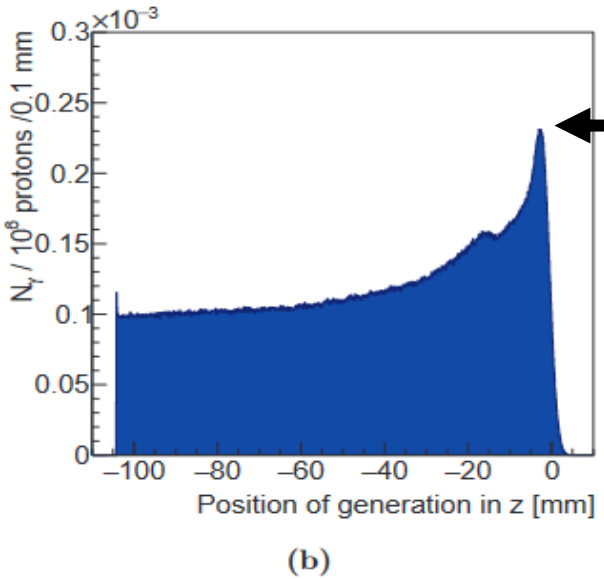
Particle Source

Geant4
Generate Secondary
Phase Space
Proton interactions
with target

-realistic particle source for clinical proton therapy:
- proton beam
- gaussian distributed (μ=130 MeV; σ=0.2 MeV)
- cylindrical PMMA target (10 cm radius)

-secondaries are immediately stopped (for now)
-different positions of the Bragg peak: adjust length of cylinder





Gamma peak (position is related to the position of the Bragg peak)

Taken from https://publications.rwth-aachen.de/record/856966/files/856966.pdf (PhD dissertation by Jonas Kasper)

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Event Mixing

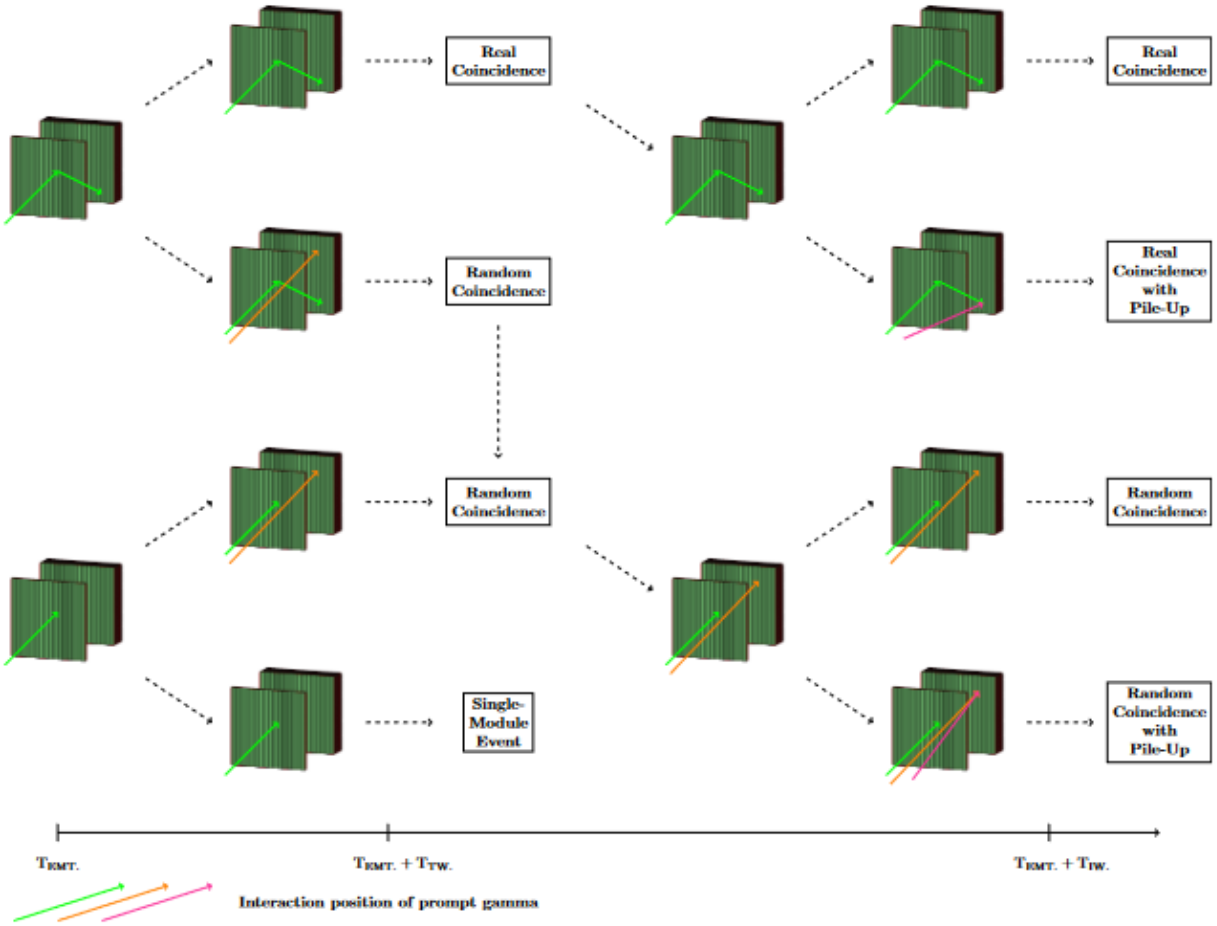
Event Mixing
Building real- and random-coincidences according the front end electronics model settings

Before:
- one primary proton
- events unrelated
- interactions mostly confined to single module

After:
create coincidences between modules
- coincidence: at least one SiPM triggered in each module within trigger window TTW
- real coincidence: caused by a single prompt gamma
- random coincidence: caused by several prompt gammas (indistinguishable from real)
- record over set integration window TIW -> pile-up in integrated fibres possible

Event Mixing

Event Mixing
Building real- and random-coincidences according the front end electronics model settings



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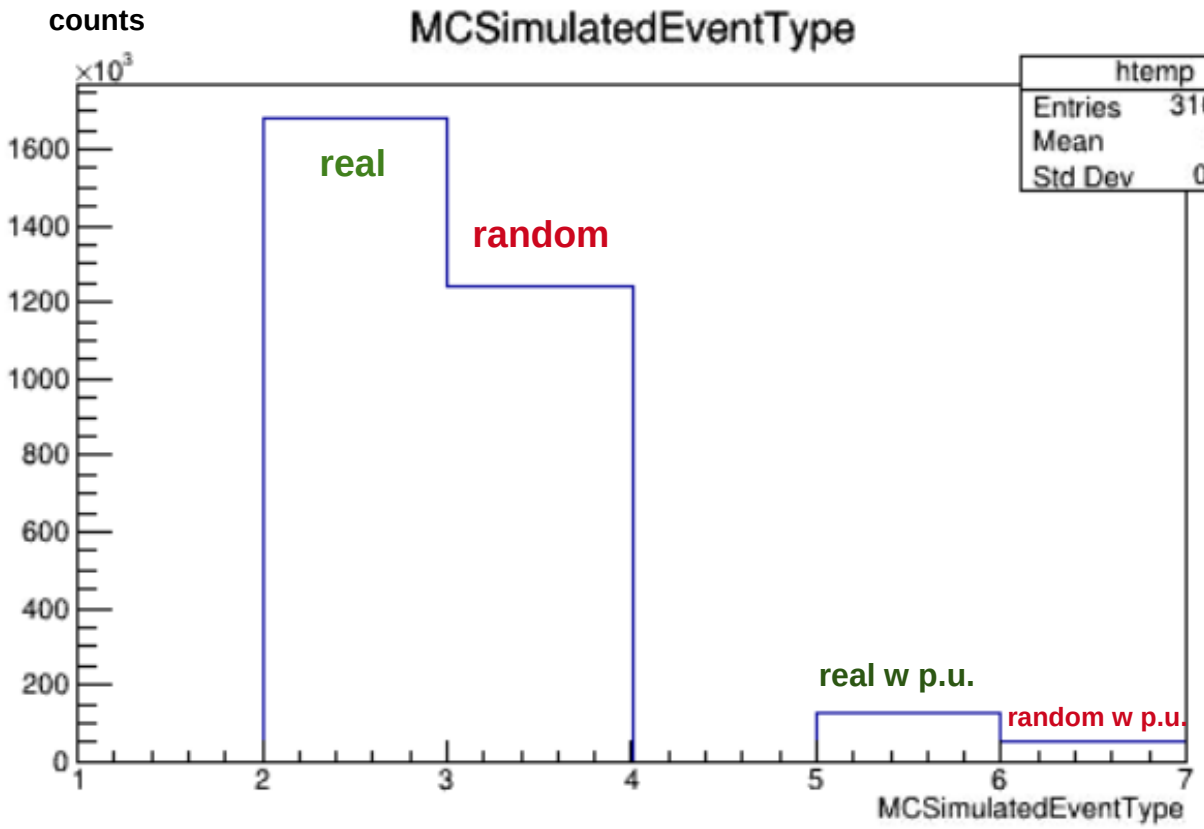
Outcome

Out of all coincidences for a dataset with 20 billion protons…



Type	Percentage
Real	54.2%
Random	39.9%
Real w pile-up	4.2%
Random w pile-up	1.7%

Optical Photon Model

Optical Photon Model
Model for the response of the SiFi-CC to the optical photons

- tracking of OP in Geant4 is slow and crosstalk not modelled
- alternative custom MC model to fix
- same output format as the processing of OP with Geant4

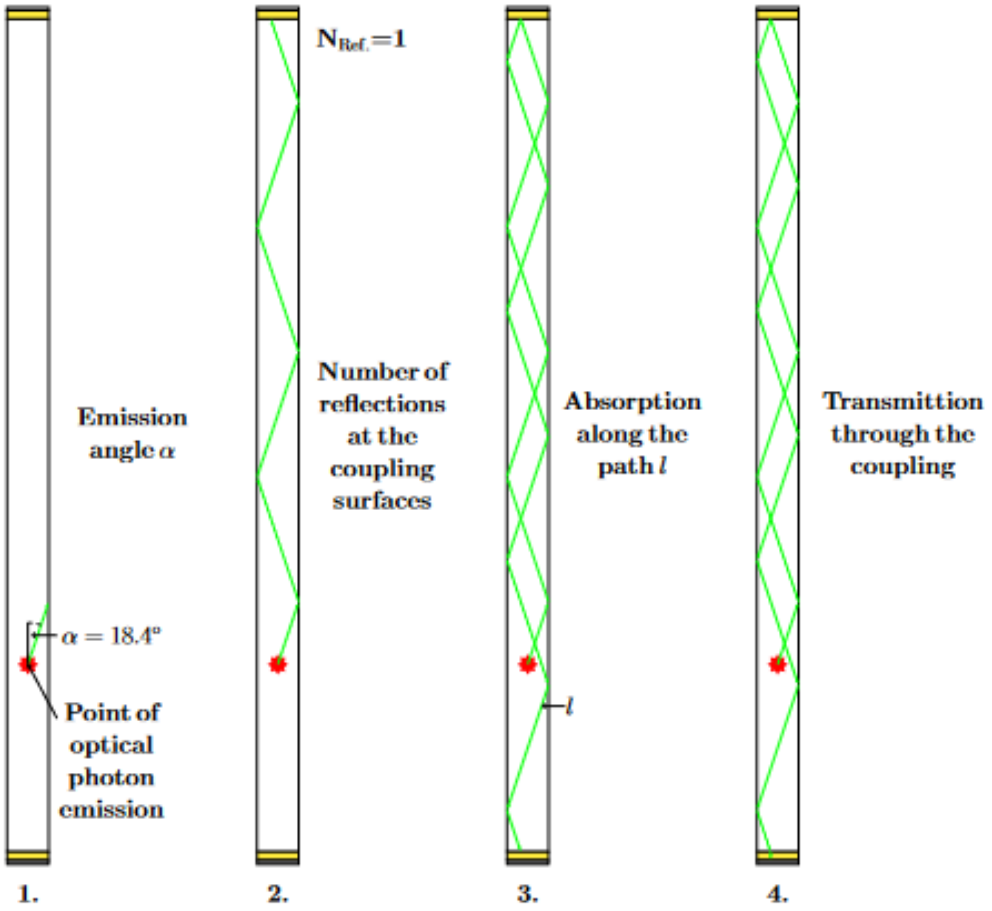
Generate Optical Photon Store Mode (OP)
scin./Cher. (and charge/velocity), number of OP produced, Geant4 step, velocity

- every photon individually tracked according to certain rules

Optical Photon Model

Optical Photon Model
Model for the response of the SiFi-CC to the optical photons

- 2D fibre, OP emission point in the middle
- in fibre, OP are always reflected (Snell's law)
- at coupling, OP can be reflected or go into coupling
- OP can be absorbed on path
- OP in the coupling are absorbed or reach SiPM



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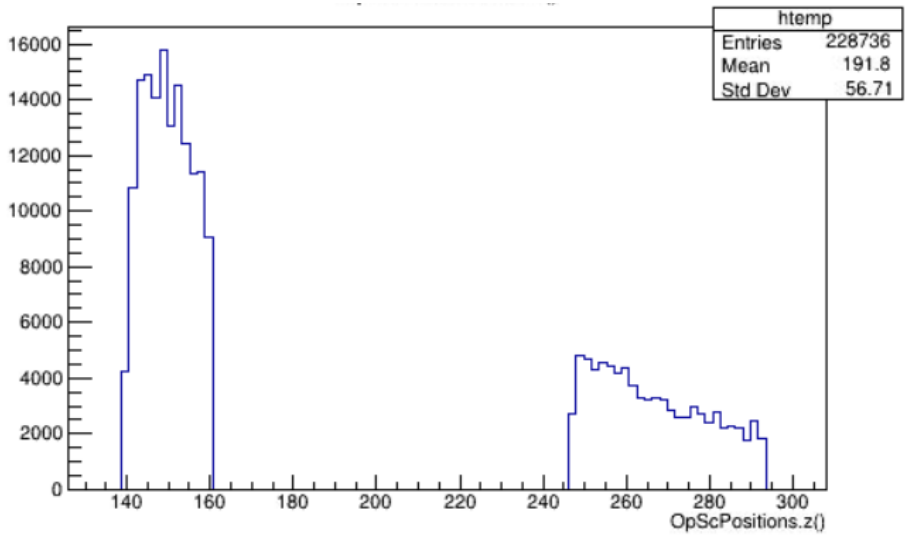
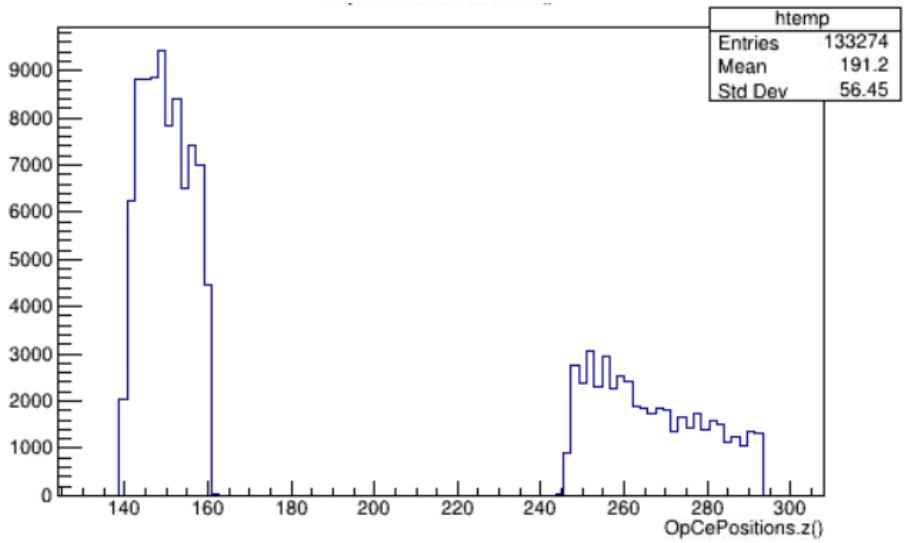
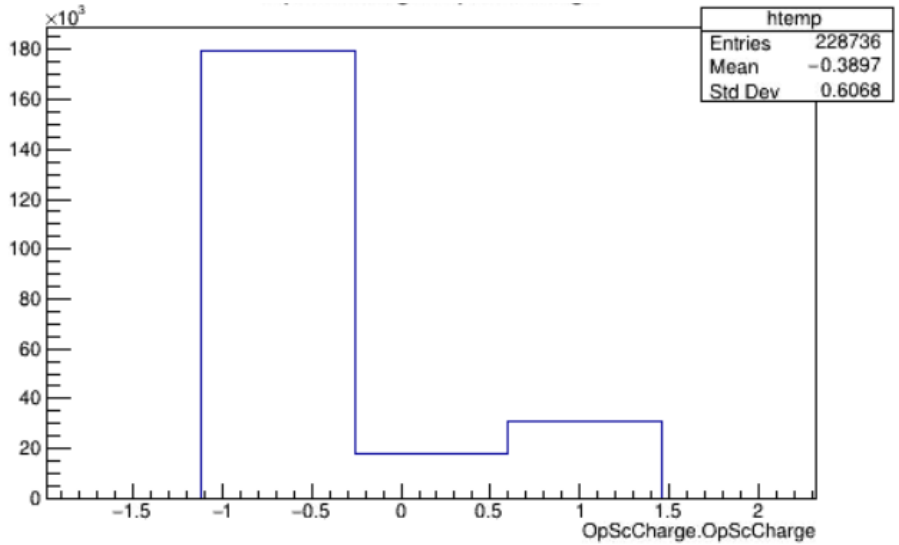
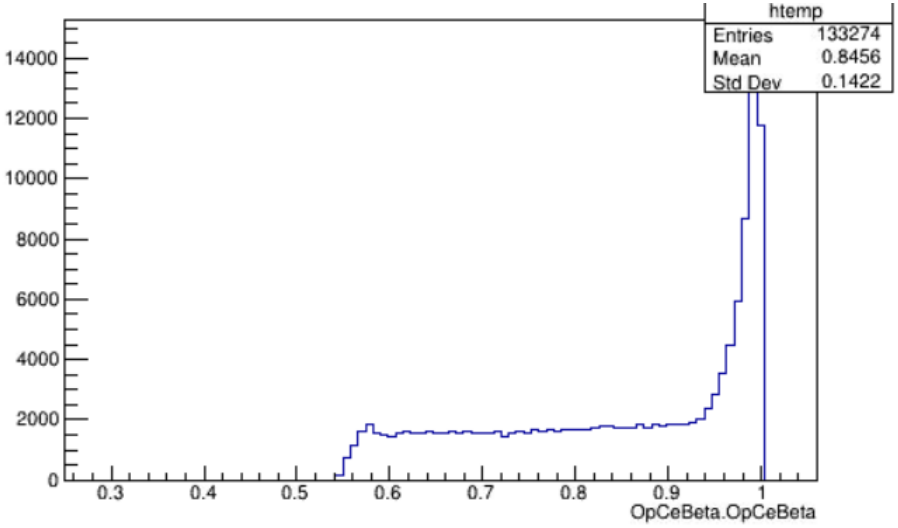
Some outcomes for Optical Photons









Summary

The simulation is…

- customisable
- still subject to changes
- interdependent
- split to execute more easily
- based on physical design with few exceptions

Notable custom code includes…

- Optical Photon Model
- Event Mixing

Acknowledgements

SiFi-CC website: bragg.if.uj.edu.pl/sificc

Thank you for your attention!

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