

Timepix4 spectral measurements to support deep learning for staff dose assessment during interventional procedures

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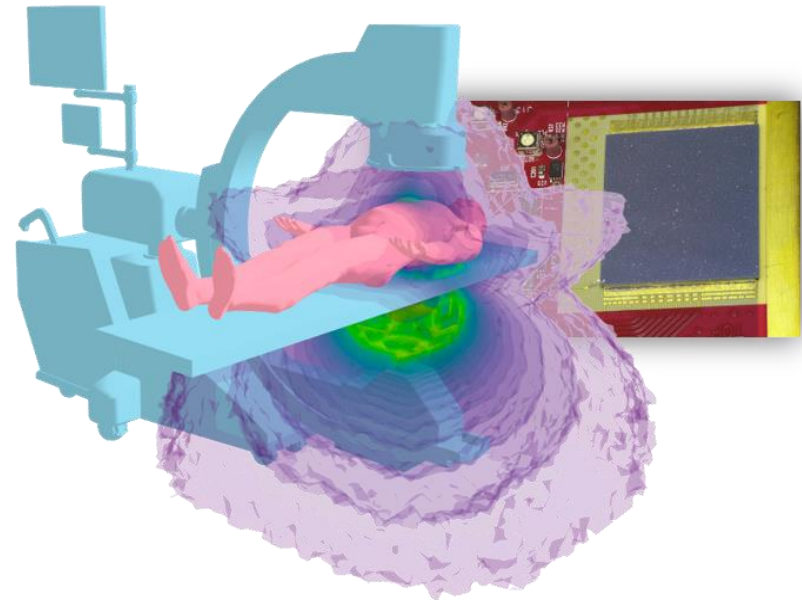
³Physikalisch-Technische Bundesanstalt (PTB)

⁴Technical University Braunschweig

Eurados working Group 12

33rd EURADOS Webinar

15.09.2026



Interventional Radiology

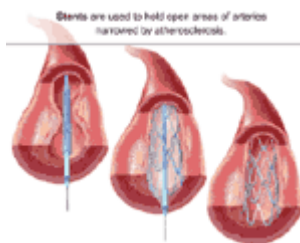
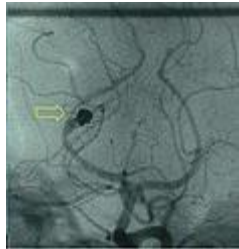
Introduction

Surgeries under x-ray fluoroscopy
(medical personnel stays in the room)

Cardiac catheter laboratory
heart valves

Angiography/-plastic

Imaging
Stents
Aneurysms



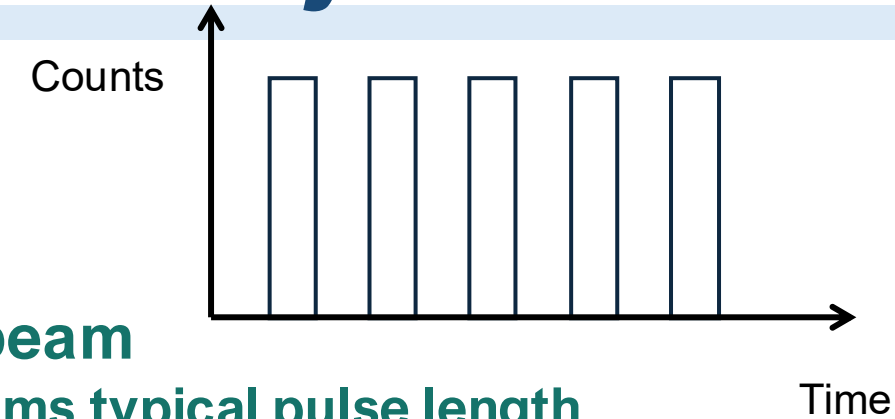
Interventional Radiology: Dosimetry

Introduction



Planar detector

X-ray tube



Pulsed beam

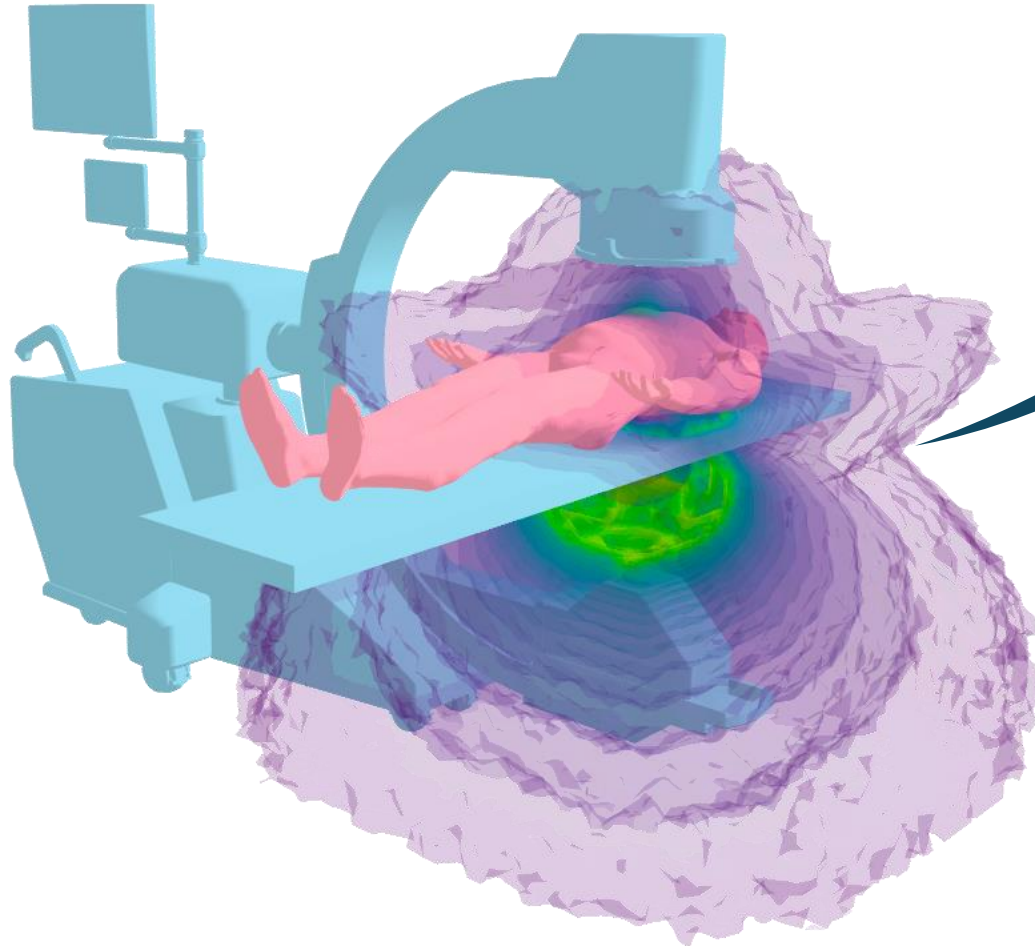
- 1 to 10 ms typical pulse length
- Up to 30 pulses per second

Interventional Radiology and Cardiology Parameters

Parameter	Range
High Voltage	60 to 120 kVp
Intensity	5 to 1000 mA
Inherent filtration	3 to 6 mm Al _{eq}
Additional filtration	0.2 to 0.9 mm Cu
Energy range of scattered spectra	20 keV to 100 keV

Interventional Radiology: Dosimetry

Introduction



[Calculated using RadField3D]

Point measurements are not able to capture the heterogeneous properties of interventional fields



In practice:
Personal dosimeters are
not even given to every staff member

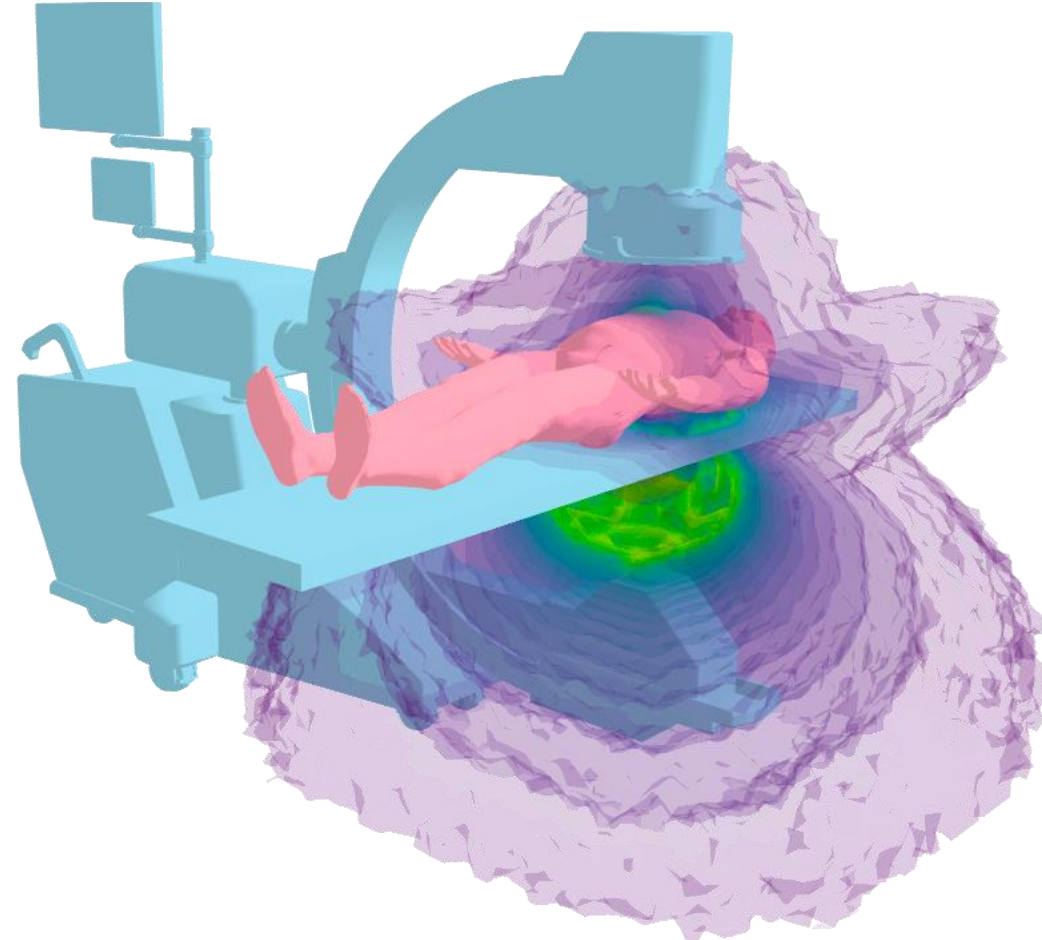
Interventional Radiology: Dosimetry

Introduction

Computational personal dosimetry

Computational personal dosimetry

- Personal dosemeter-less dosimetry
- Aims to simulate the real room using the machine parameters
- Track the personnel in the room visually
- Compute the doses to the personnel live during the intervention



[Calculated using RadField3D]

Computational Personal Dosimetry

Introduction

Computational personal dosimetry

Radiation Transport Simulation

- In general, based on Monte-Carlo Simulation
 - Photon-wise simulation
 - Slow in terms of real-time calculations
- Well suited for generating training datasets to use surrogate models instead



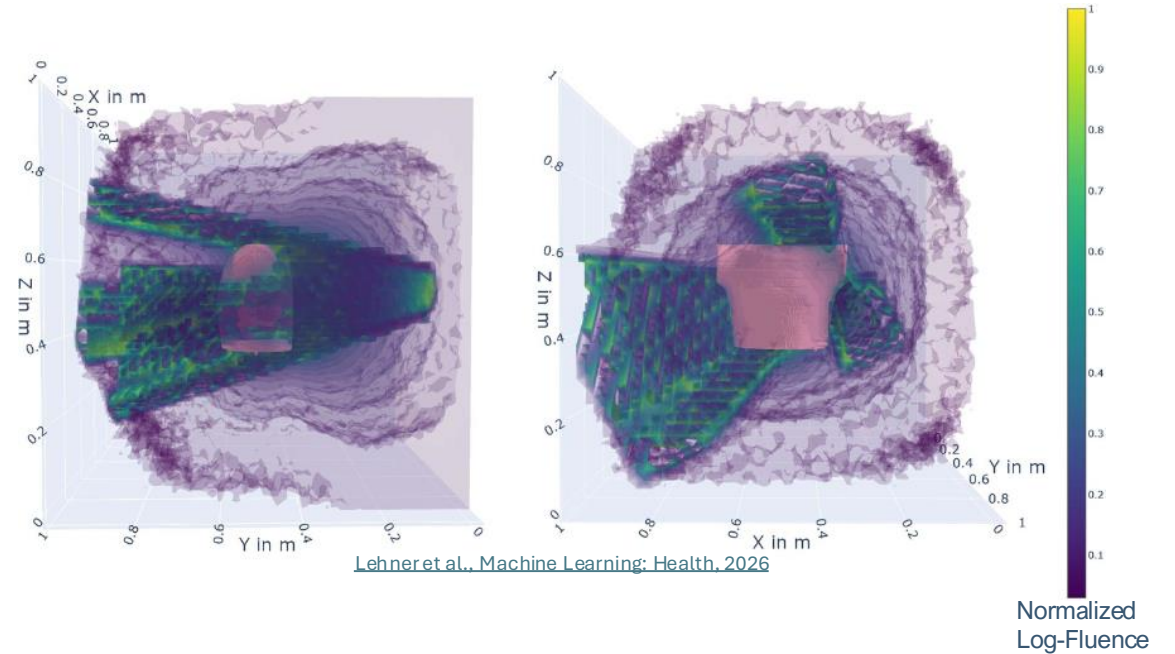
Computational Personal Dosimetry

Introduction

Computational personal dosimetry

Surrogate (Neural) Models

- Explicit function mapping:
 - Input parameters → Simulation result
 - Most important: Dataset
 - Machine parameters and ranges
 - Simulation target
 - Air kerma rate
 - Equivalent doserate
 - Fluence and Spectra
 - Absolute or Relative
- Relative over absolute rates
- Reduce count of orders of magnitude to cover

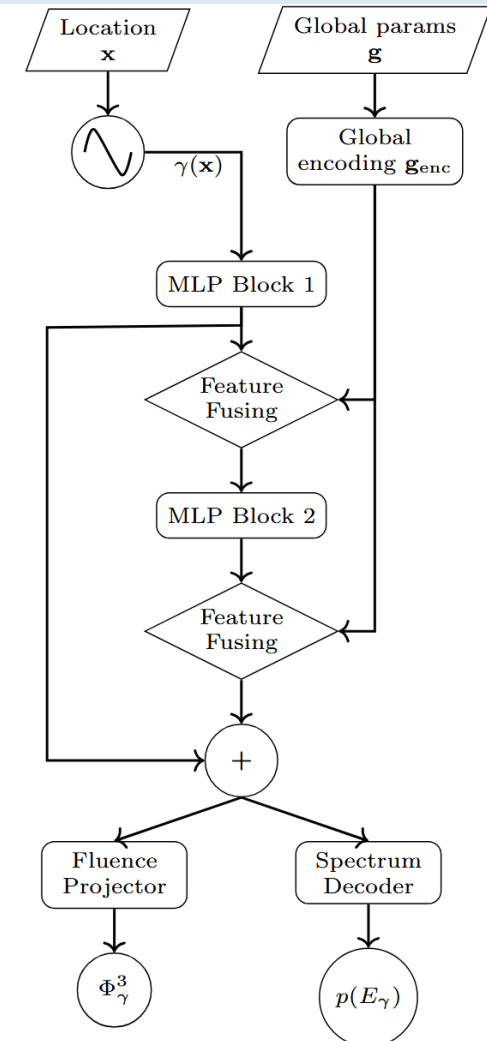


Parametric Beam Radiation Field

- Surrogate neural model
- Estimates relative fluence and spectrum
 - Static geometry
 - Free beam parameters
- Fast execution (via NVIDIA TensorRT)
 - About < 2 ms for single voxels
 - About < 20 ms for whole fields (64^3 voxels)



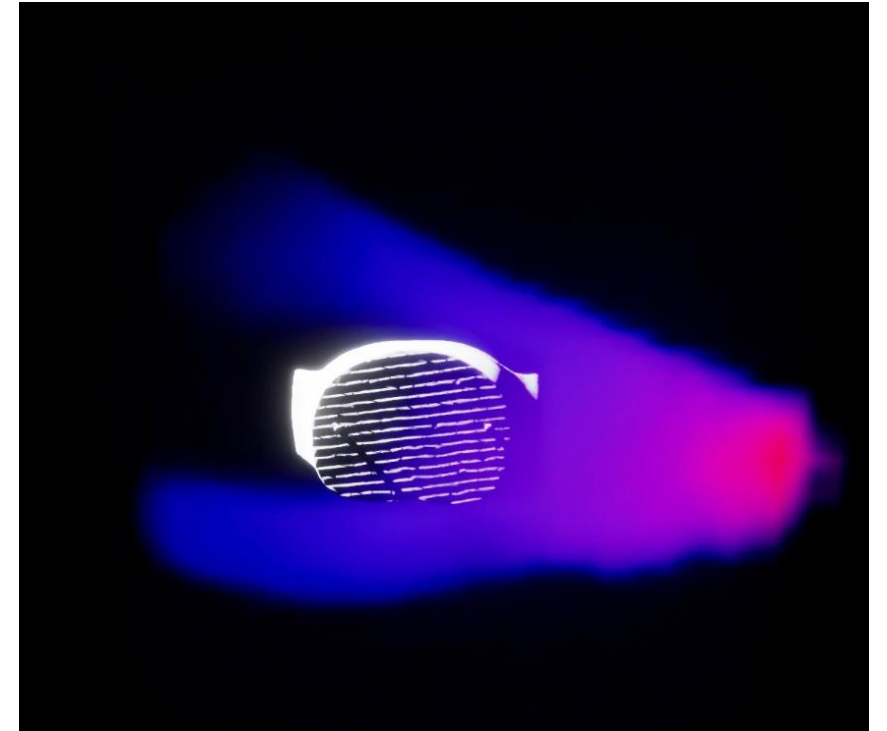
NVIDIA



[Lehner et al., Machine Learning: Health, 2026](#)

Parametric Beam Radiation Field

- Usable with 3D engines for VR/AR training
 - 20 ms per field is 50 fps on x-ray tube changes
 - Rendering itself is much faster
 - Exported to ONNX based binary file format
 - Preserving dataset ranges
 - Callable from any application
- Real world application
 - Inference is quick
 - Fluence is relative ⚠
 - Needs a spatially well-defined base point measurement
 - Base point is the bottleneck



Computational Personal Dosimetry

Introduction

Computational personal dosimetry

Base point measurements

- Large variety of existing detectors
- Different responses to pulsed radiation fields
- High requirements
 - Reliable doserate available in a few seconds
 - Consistent for varying pulse properties
 - Needs to be reliable down to about 20 keV mean photon energy
 - Data availability: Machine readability
 - Small detector volume ($< 8 \text{ cm}^3$)



Computational Personal Dosimetry

Introduction

Computational personal dosimetry

Example: Automess 6150 AD-18/E

- Geiger-Müller counting tube with a volume $< 8 \text{ cm}^3$
- Type tested down to 65 keV
- Can be corrected for a well-known radiation field
 - Local spectra from the neural network
 - Pulse properties from the x-ray tube
- Process
 - Correcting energy dependence using the neural network output
 - Additional measurements in ISO 4037-1 fields of the N series were performed
 - Correcting for the effective dead time given the pulse width and frequency
 - Ranges tested
 - Pulse width: 2 to 10 ms
 - Pulse frequency: 5 and 10 pulses/s
 - Dose rate: 0.16 to 1.88 mSv/h



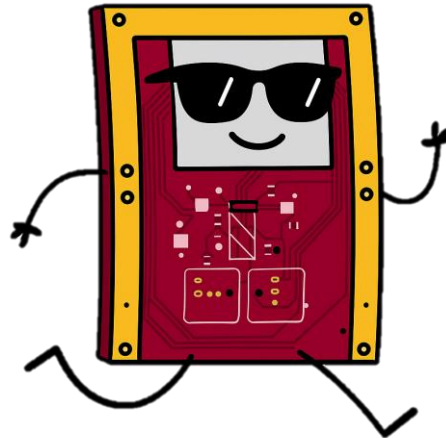
Computational Personal Dosimetry

Introduction

Computational personal dosimetry

Base point measurement devices

- Better use a device that does not suffer any pulse related underestimations
- Ionization chambers
 - Single photon counting detectors → Timepix4



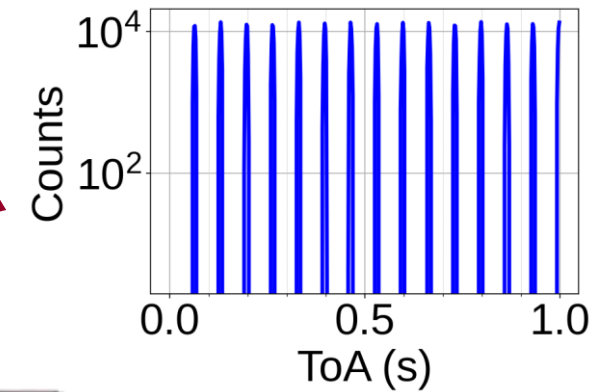
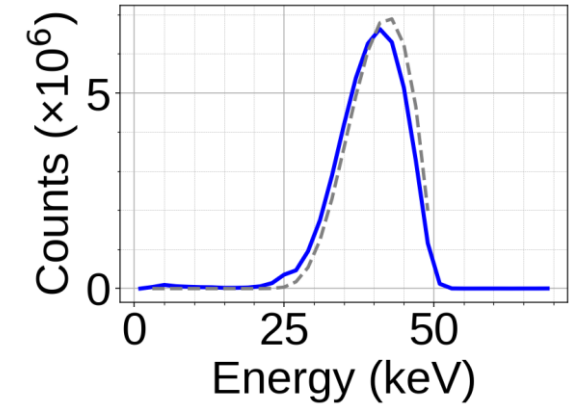
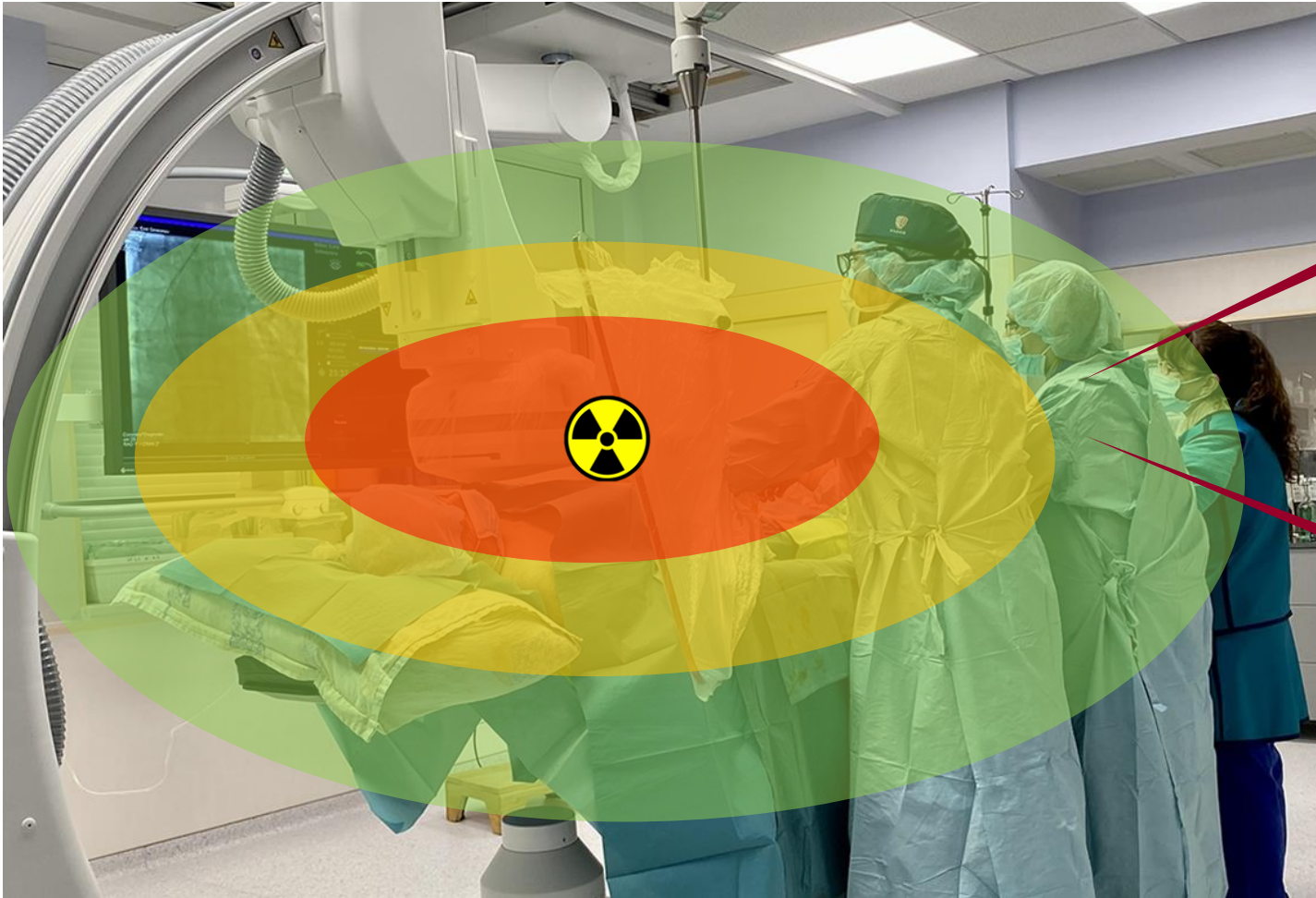
Context

Introduction

Computational personal dosimetry

Timepix4

Courtesy of Marie Nowak, Cours FMH pour les Médecins utilisant la fluoroscopie, 2024



Why is Timepix a good candidate ?

Introduction

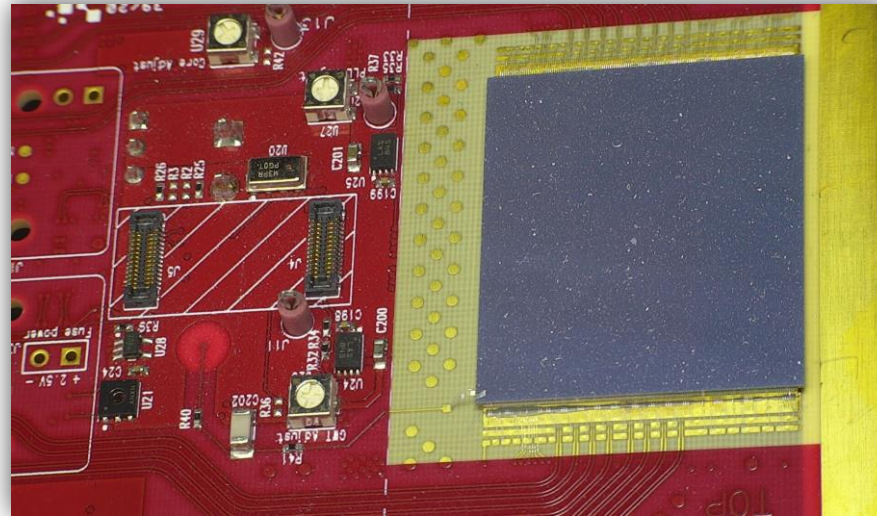
Computational personal dosimetry

Timepix4



1-10ms

VS



195ps !

Practically no dead time
200 ns per pixel

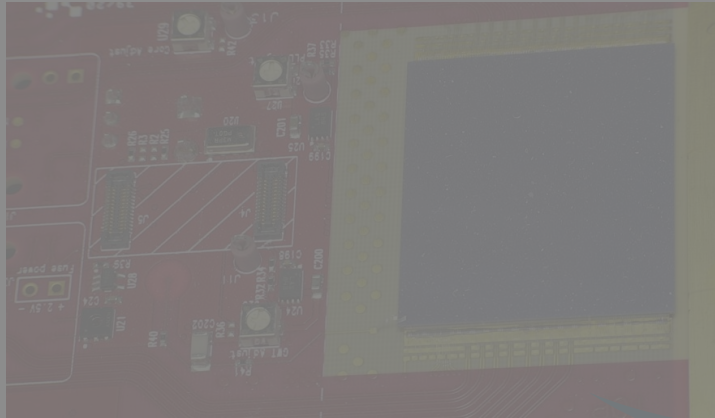
Limited effect of pileup
preamplifier output pulse typically last 1 μ s in such configuration

Pixels acting as self-trigger
Pixels are trigger asynchronously

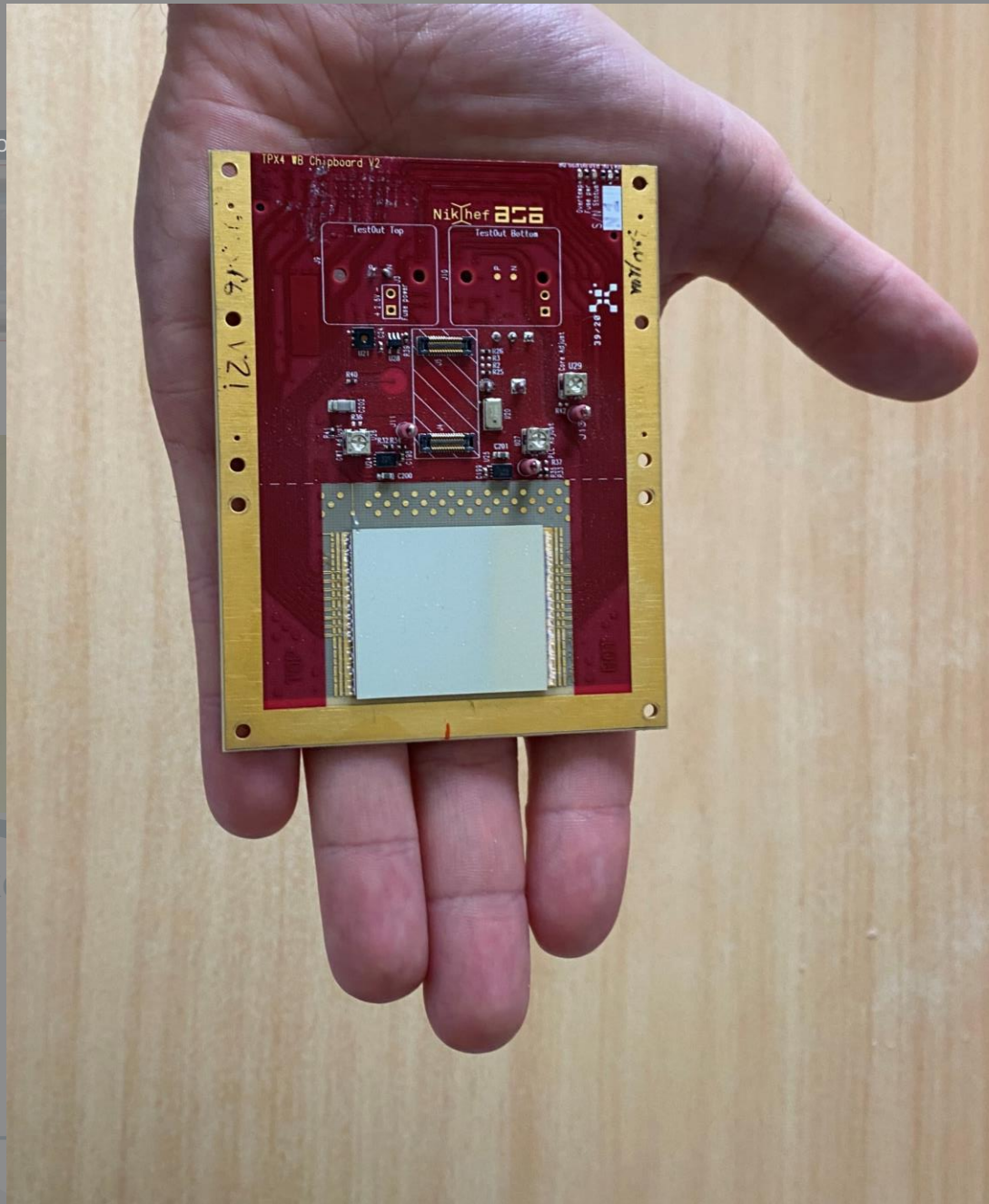
Decent energy resolution
1.5 to 4 keV FWHM over the energy range of interest

Timepix4

Introduction



x 229376 pix



At the pixel level

Recorded information for each incoming hit

Spatial coordinates

Time of Arrival Time over threshold

~ Energy deposited per pixel

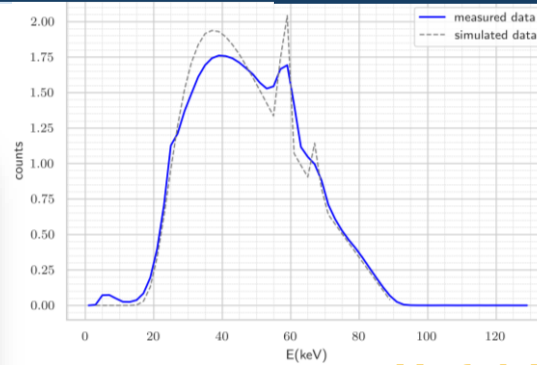
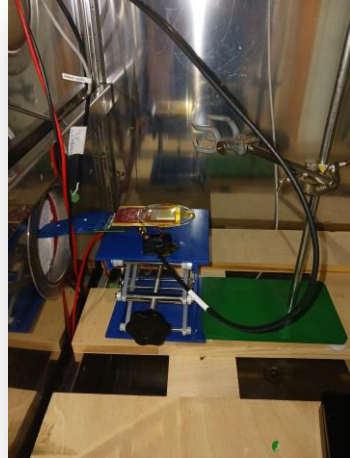
From particle physics to interventional theatres

Introduction

Computational personal dosimetry

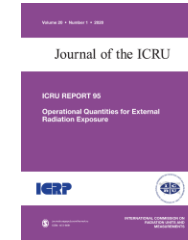
Timepix4

Characterisation

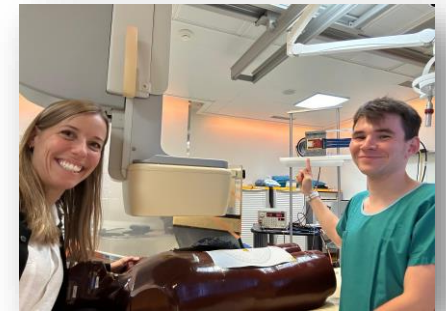
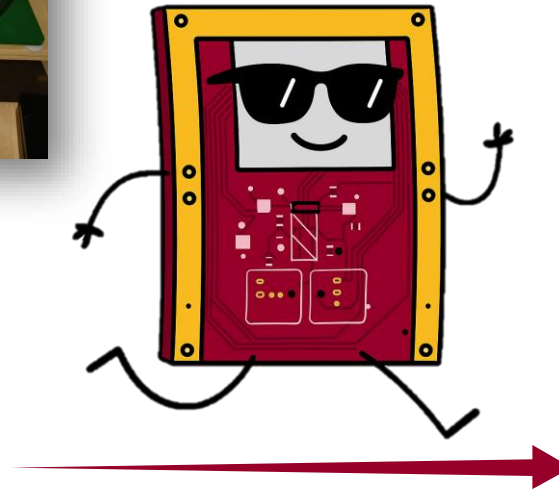
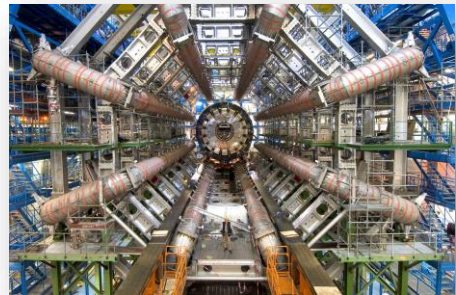


Timepix4

Unfolding



Dosimetry



We are here!

EURADOS

Tristan Genetay & Felix Lehner

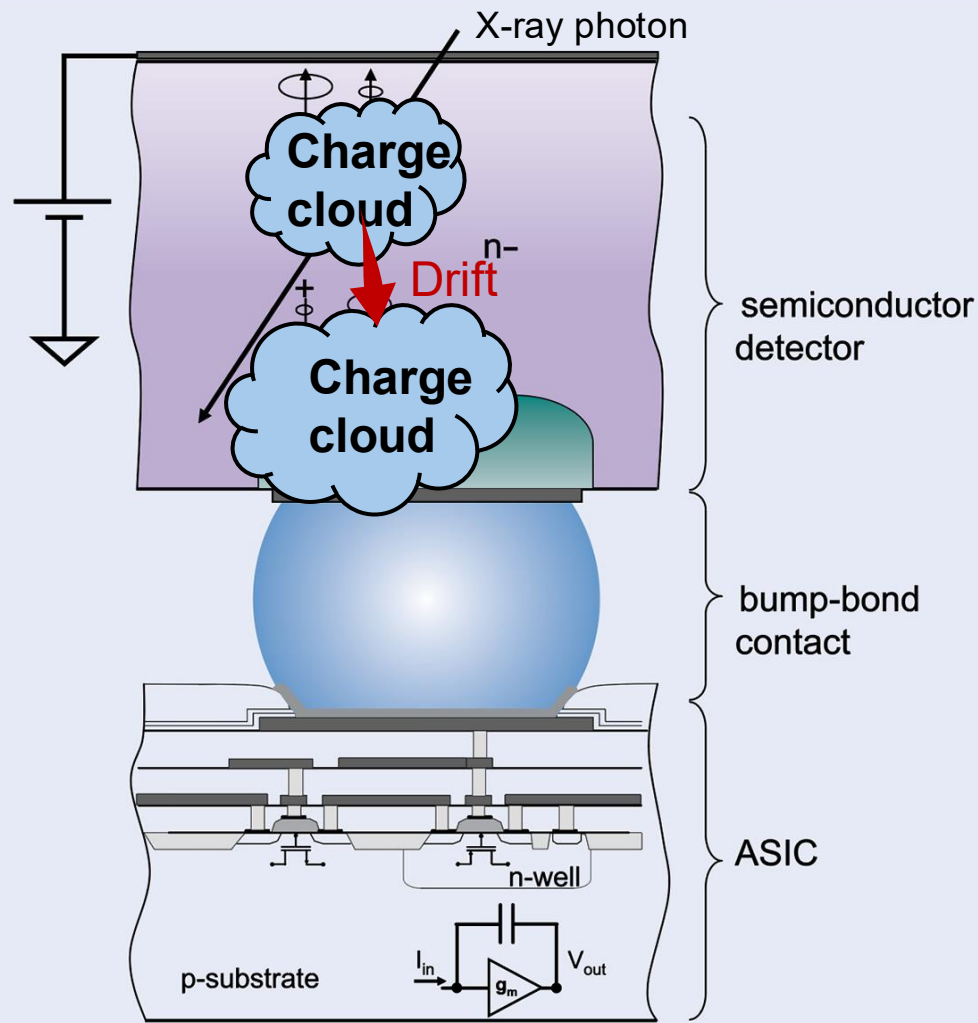
16

Charge sharing

Introduction

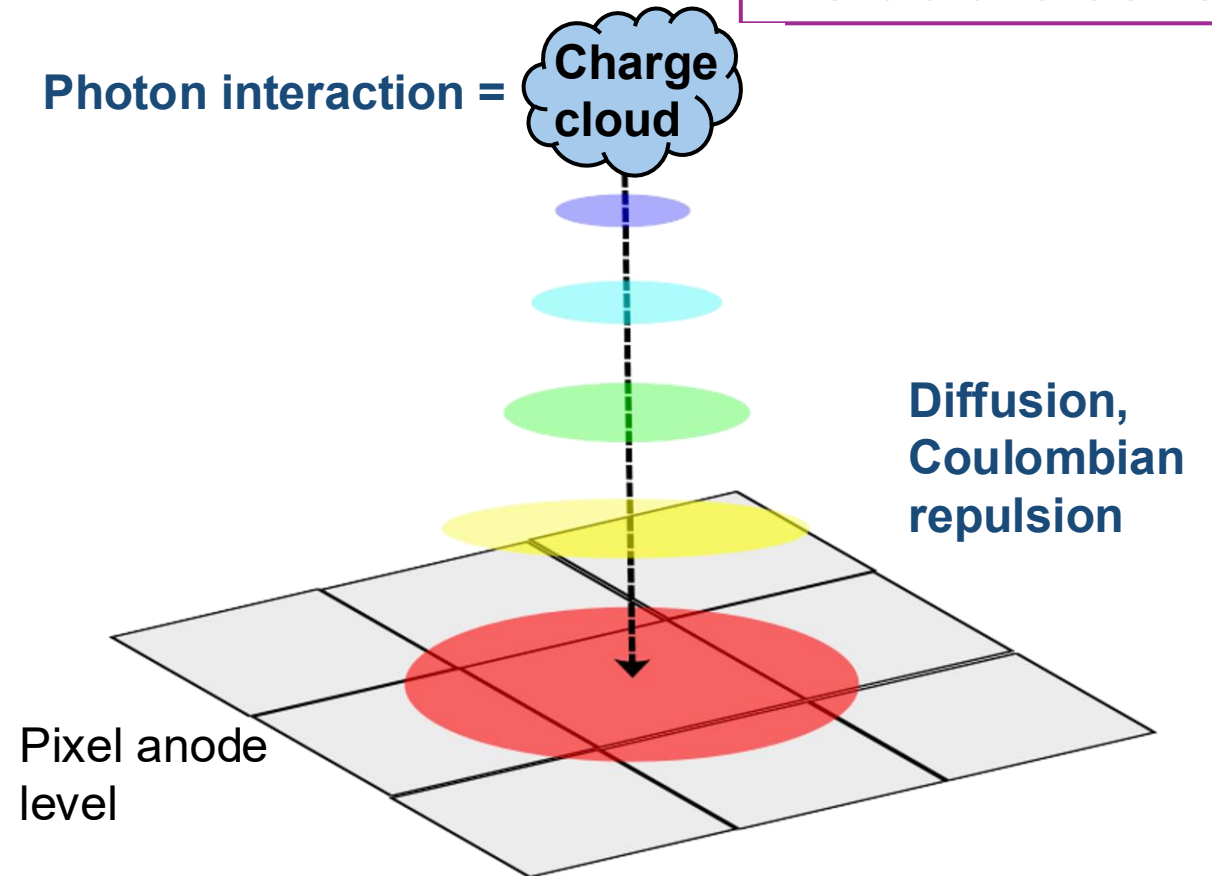
Computational personal dosimetry

Timepix4



Inside the sensor

Photon interaction =



Charge shared between several pixels !

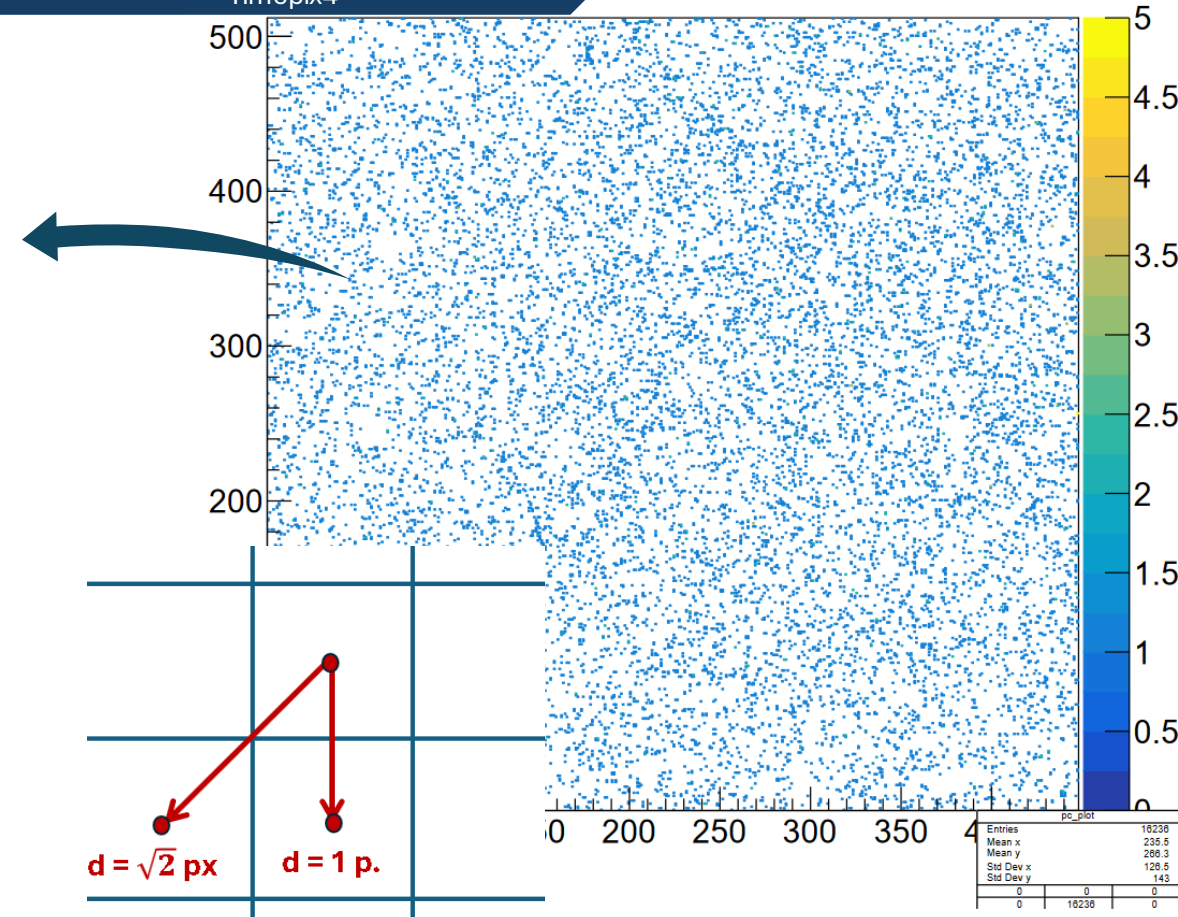
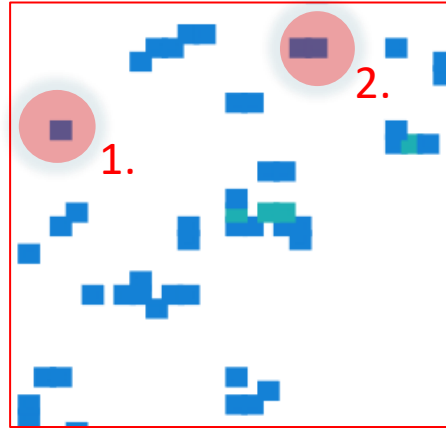
Charge sharing

Introduction

Computational personal dosimetry

Timepix4

Solution : 3D density-based scan (x,y,t) to reconstruct photon energy



→ Optimal parameters :

- Spatial distance = 1.33 pixel

- Temporal window = 200 ns (preamplifier rising + charge drift)

Unfolding

Introduction

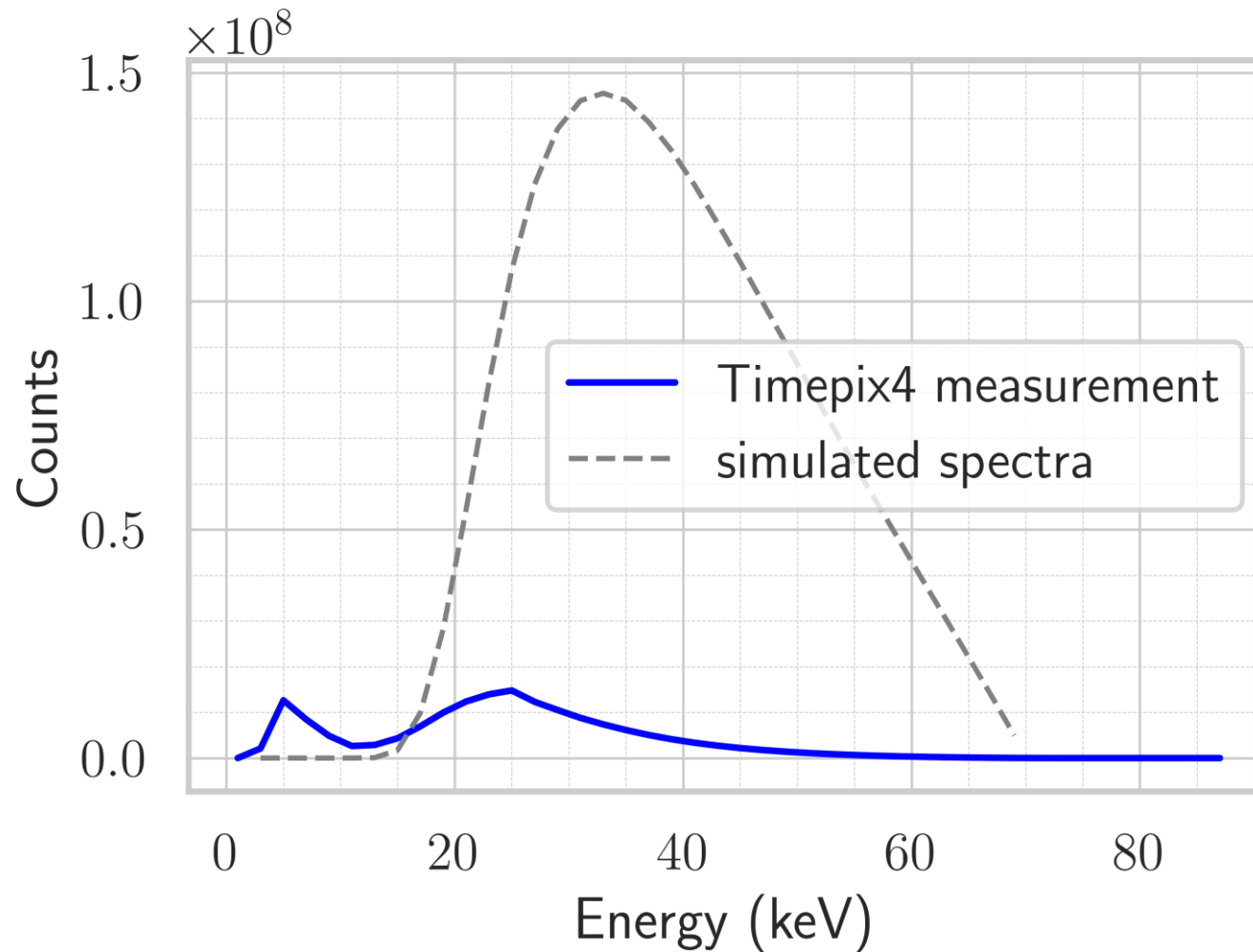
Computational personal dosimetry

Timepix4

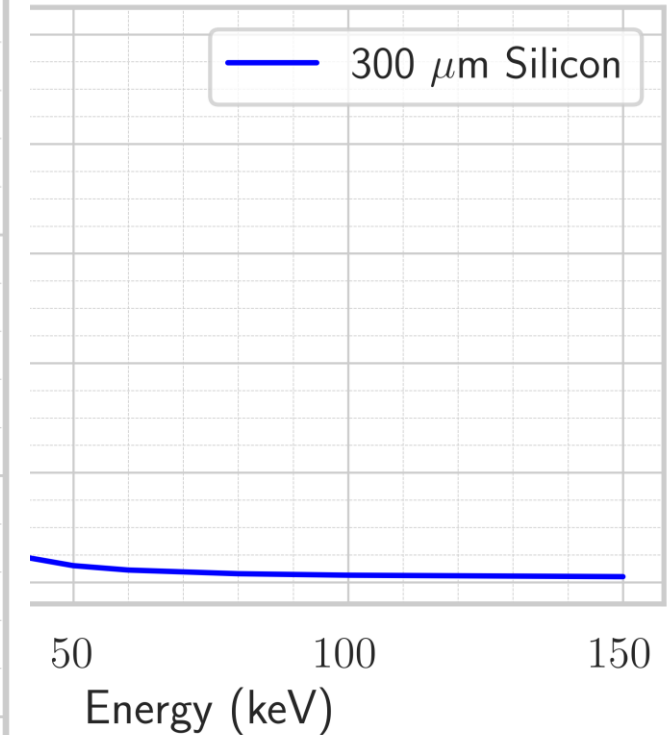


300 μm

- Excellent **stability**
- Excellent **angular response**
- Limited amount of **fluorescence**



efficiency of the sensor



Example with RQR5: unfolding required.

Unfolding

Introduction

Computational personal dosimetry

Timepix4

Detector response matrix



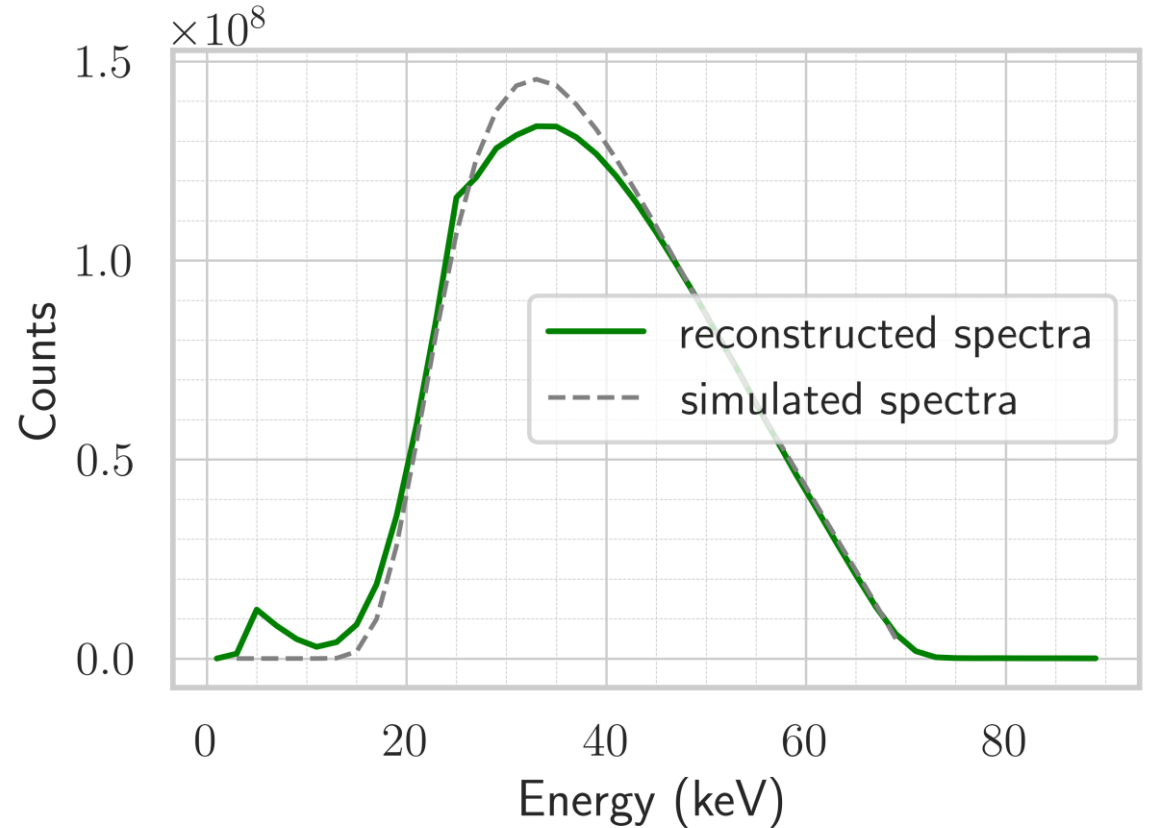
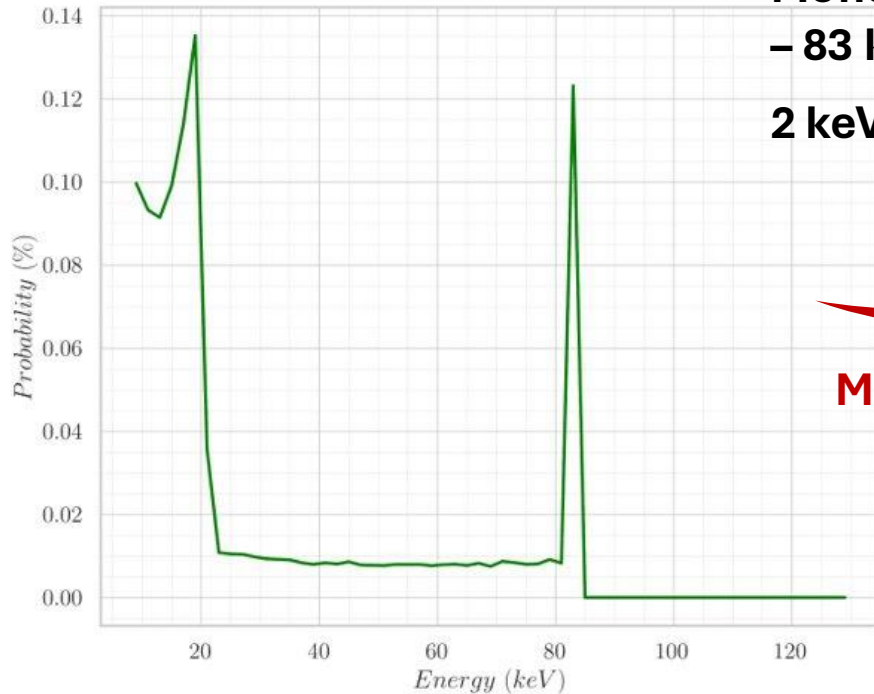
e.g.

Response of the
300 μm sensor

Mono-E photons
– 83 keV

2 keV energy bins

Matrix inversion



Example with RQR5

RQR serie

Introduction

Computational personal dosimetry

Timepix4

NORME
INTERNATIONALE

CEI
IEC

RQR serie

Physikalisch
Technische
Bundesanstalt
PTB-Bericht

Ulrike Ankerhold

Catalogue of X-ray spectra and their characteristic data
-ISO und DIN radiation qualities, therapy and diagnostic
radiation qualities, unfiltered X-ray spectra-

PTB-Dos-04
Braunschweig, April 2000

ISSN 0941-6074
ISSN 3-89701-513-7

PTB

	U (kV)	Add. Filtration (mm Al)
	50	2.6
	70	2.6
	90	3.6
	120	3.6



Published energy
distributions.

Kerma factors to
estimate Φ at the
reference point.

**Standard guarantee the Kerma
value at the reference point**

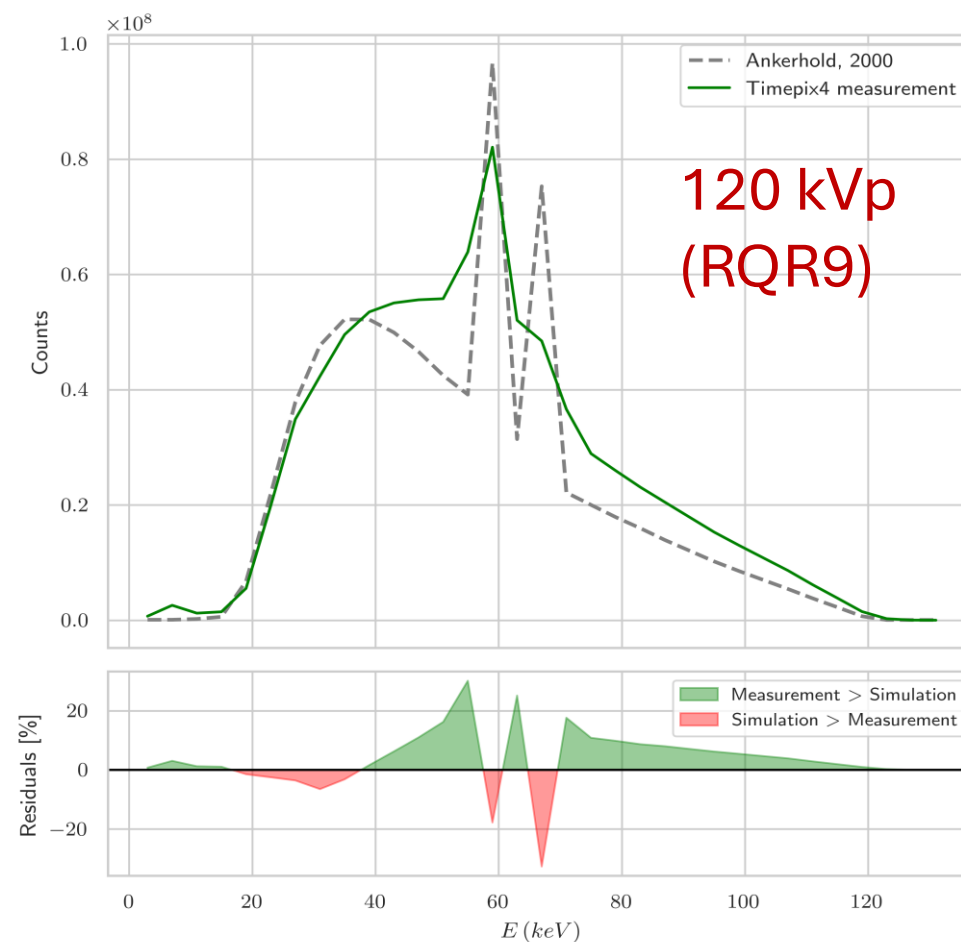
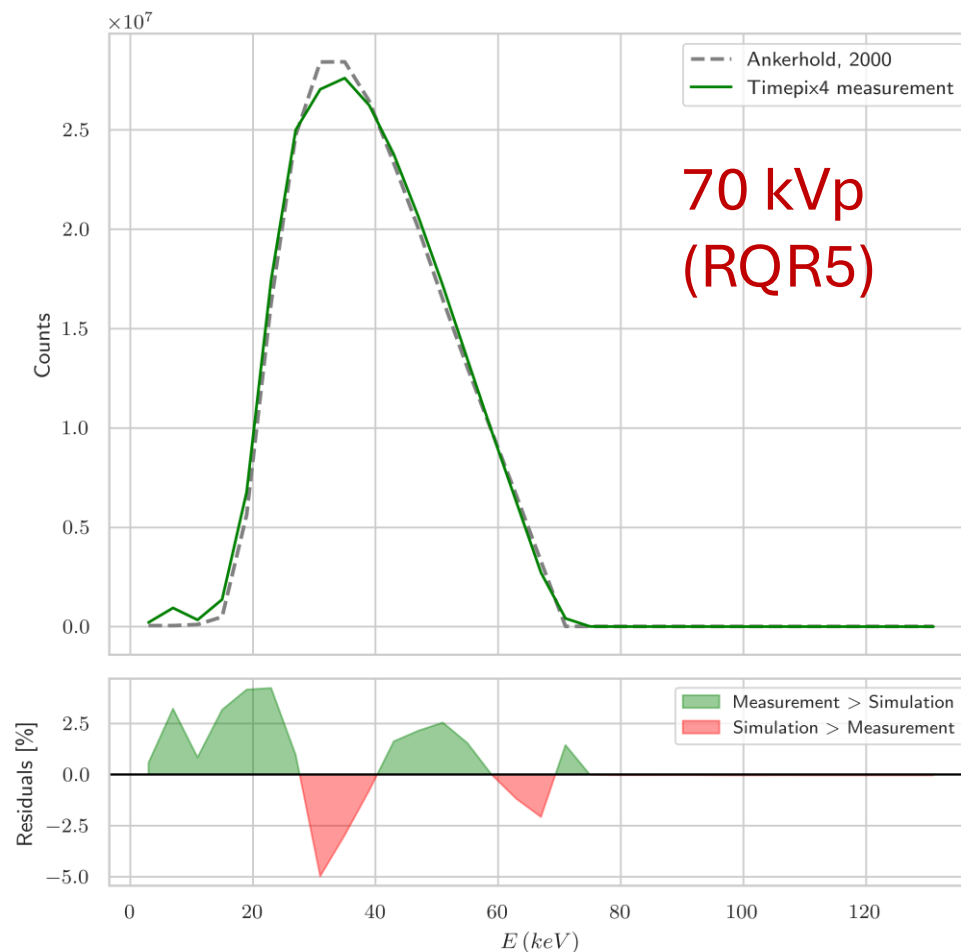
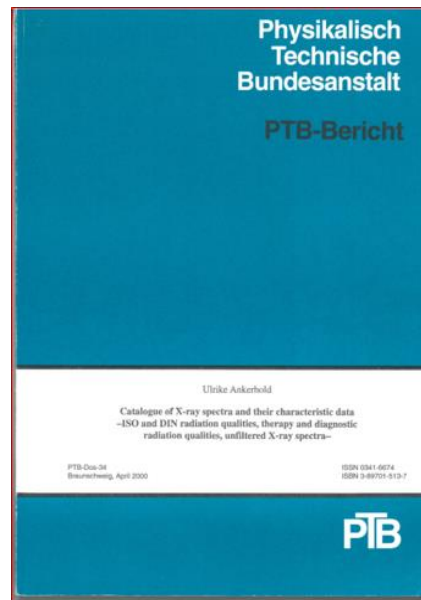
- Not the energy distribution.
- Not the fluence Φ .

Results: Energy distribution

Introduction

Computational personal dosimetry

Timepix4



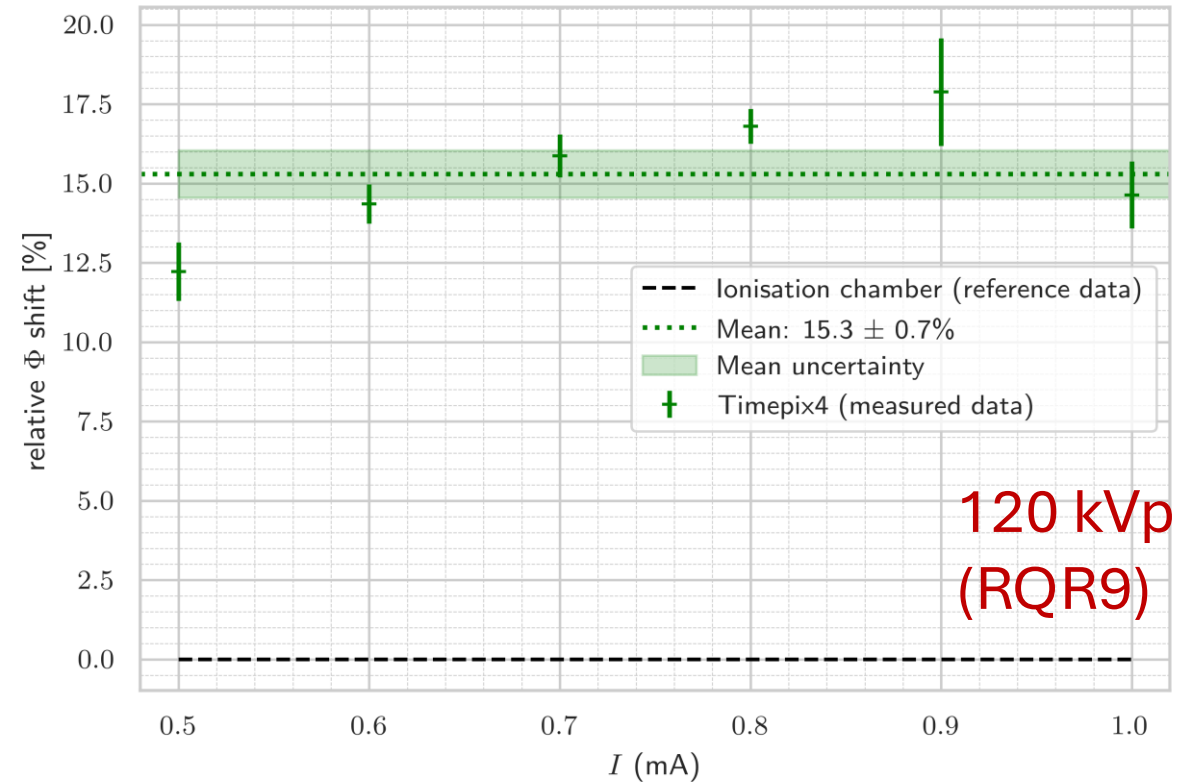
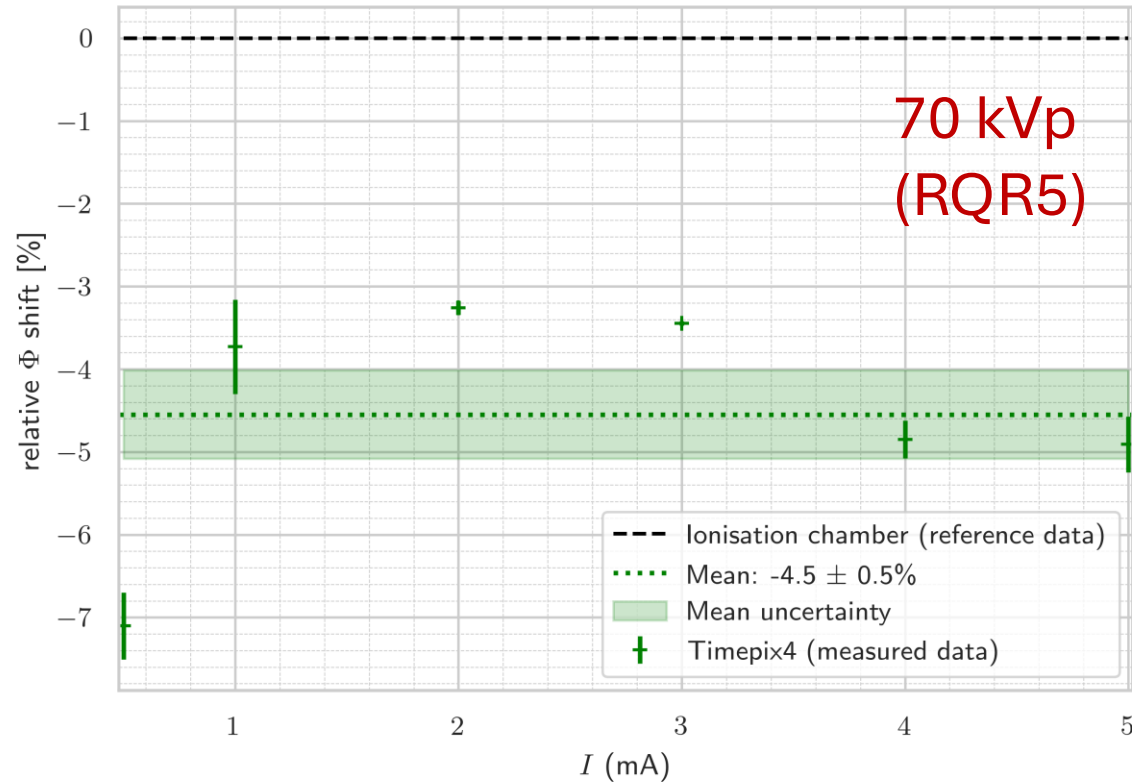
Timepix4 energy spectra vs reference spectra from Ankerhold (2000).

Results: Total photon fluence Φ

Introduction

Computational personal dosimetry

Timepix4



Total particle fluence shift (vs ionisation chamber) as a function of beam intensity.

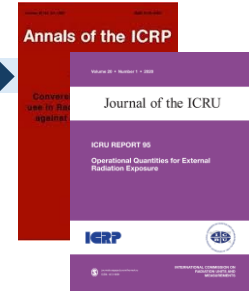
Fluence-based photon dosimetry

Introduction

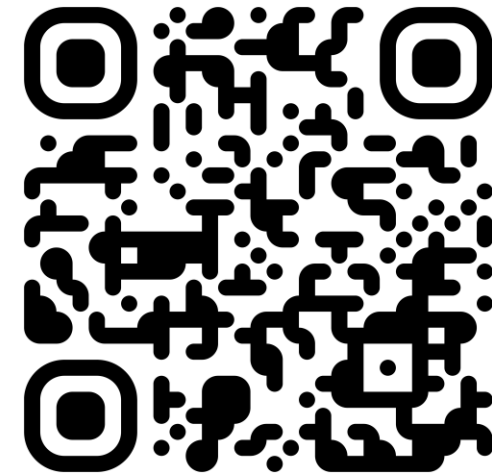
Computational personal dosimetry

Timepix4

$h^*(10); h^*$
[pSv.cm⁻²]

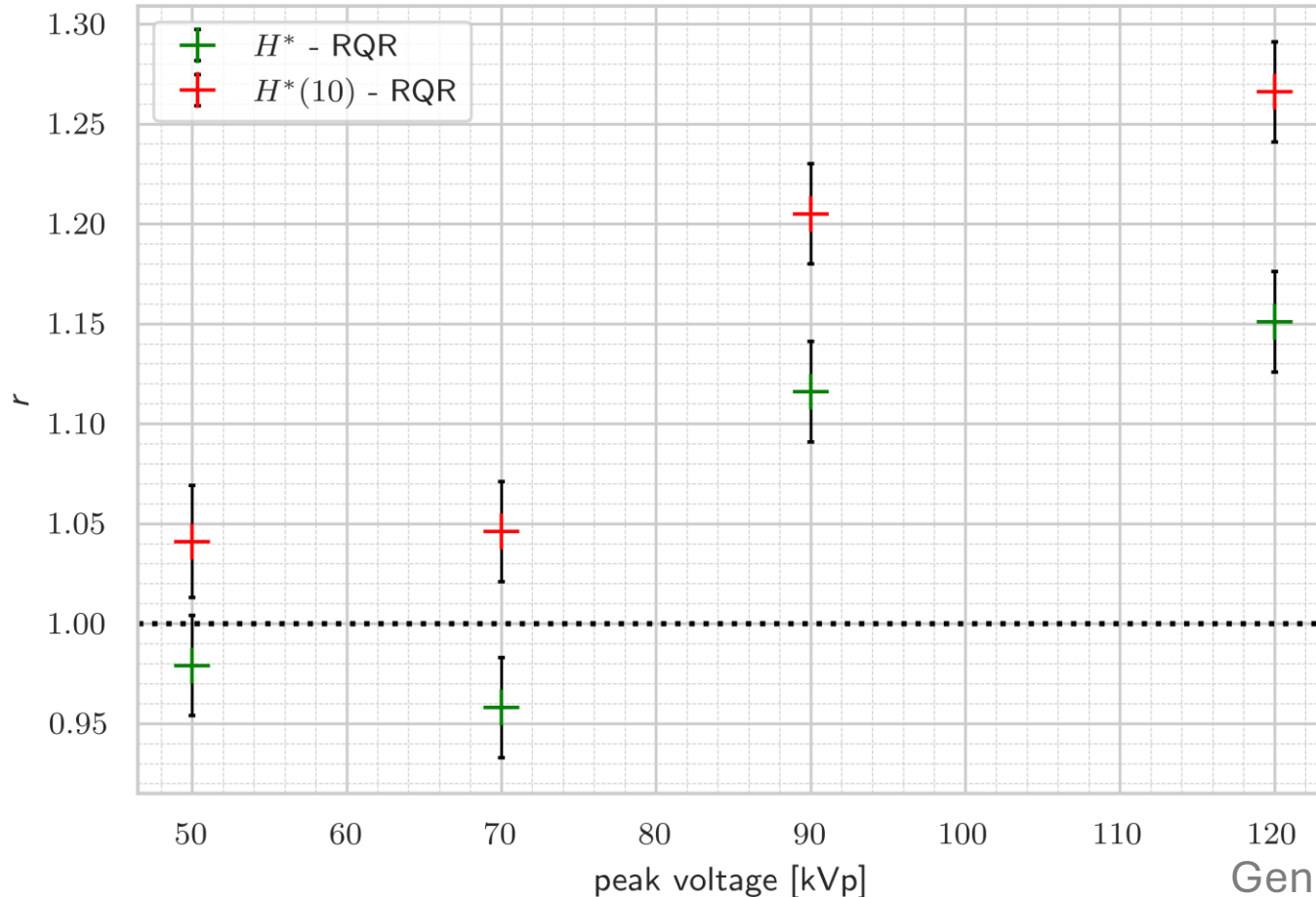


Using published conversion coefficients



Further information here

Genetay et al., <https://doi.org/10.1038/s41598-026-49696-5>



Cover many situations during interventional procedures (in the scattered field).

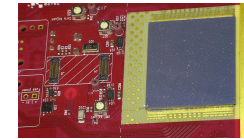
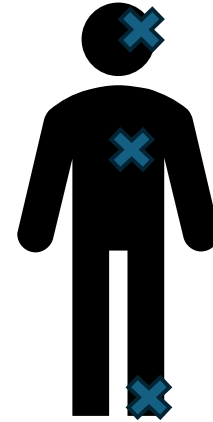
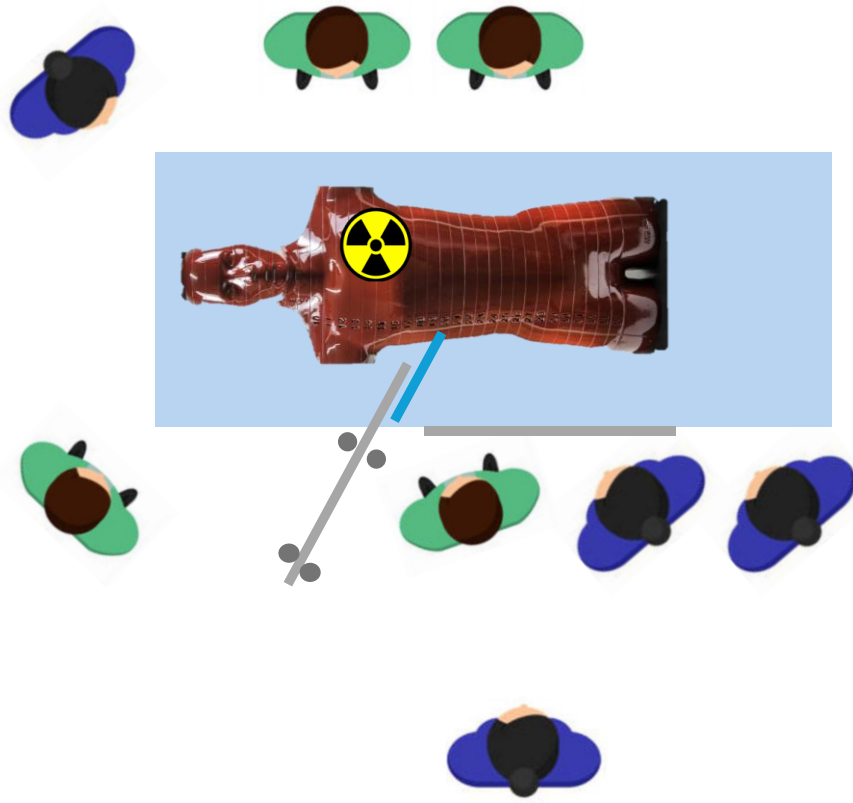
Measurements in interventional cardiology

Introduction

Computational personal dosimetry

Timepix4

Scenario and clinical settings based on **observations** and **discussion** with the local team.
(potential positions)



Three heights per location



Most common angulations investigated (based on our local team recommendations).

Some results

This is an interventional cardiologist.

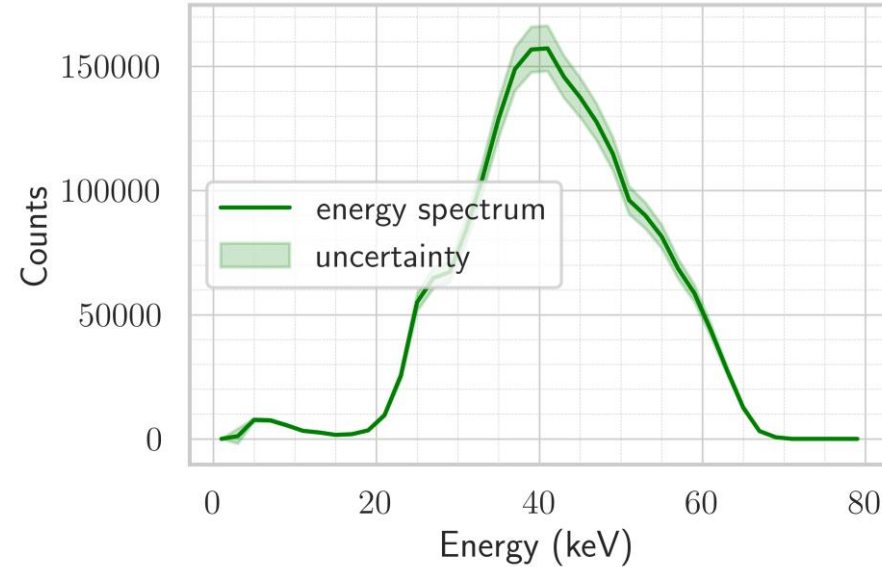
Introduction

Computational personal dosimetry

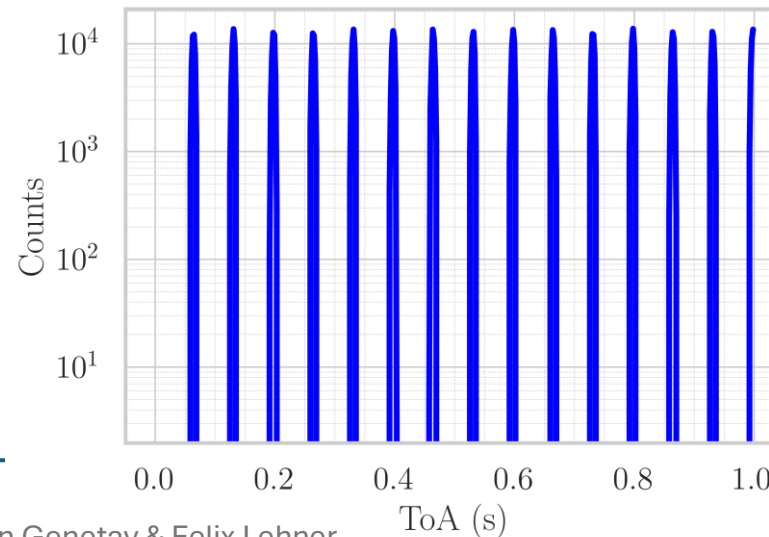
Timepix4



Associated temporal spectrum



Database of energy-dependent fluence spectra



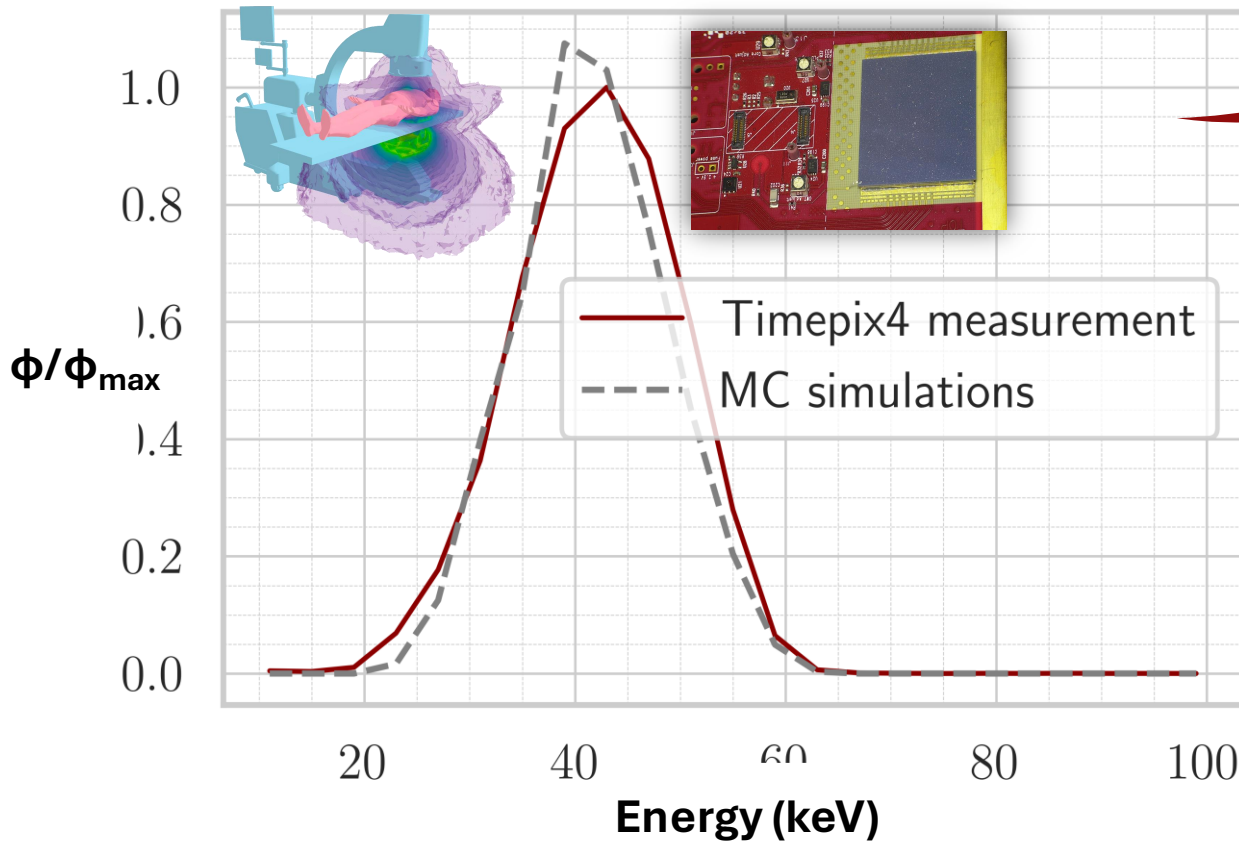
Theoretical pulse duration: **5 ms**

Measured pulse duration: **5 0.03 ms**

15% shift, similar trends observed with different settings / fluoroscopy devices.

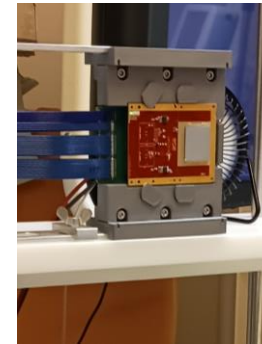
Validation of Monte Carlo simulations

An example:



Intersection over Union (IoU) over the dataset

Mean overlapping = 78 % [65 – 91] %



→ Consistently lower agreement at the eye-lens level: angular response of the chip affected by the holder?

→ Normalisation of measured and simulated fluence using **DAP** was **not conclusive**.

→ **Timepix4** would be instead used to provide a measurement of ϕ , **not affected by time** distribution, and **independent** of the **operational quantities** system.

Production of a dataset



Interventional Cardiology



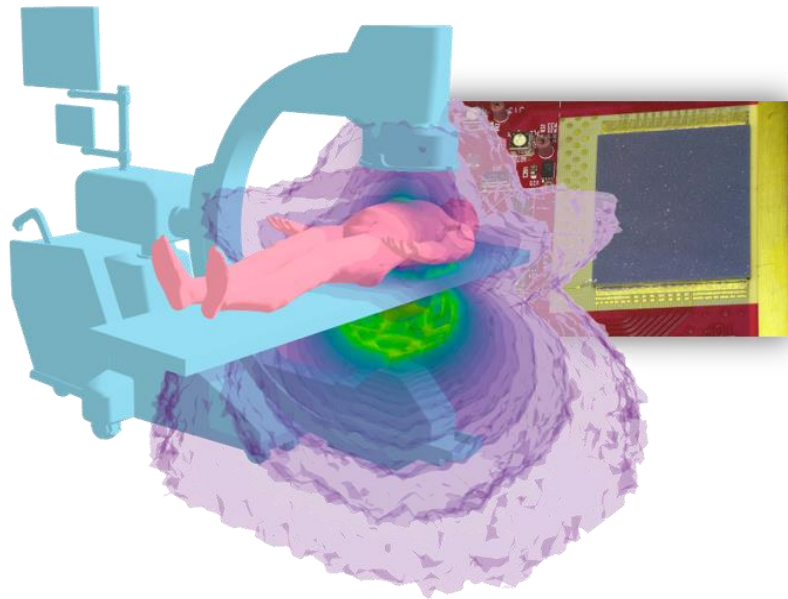
Urology

About a 1000 of spectra with relevant to various situations of exposure (e.g. protective equipment, angulations, ...)

Dataset publicly available within 6 months !

- Detailed methodology
- Device parameters (e.g. filtration)
- Measurements locations relative to the isocentre.

Thank you for your attention!



Work related to the Timepix4 ASIC was funded by the CERN Knowledge Transfer Fund for Medical Applications and conducted within the framework of the Medipix4 Collaboration.