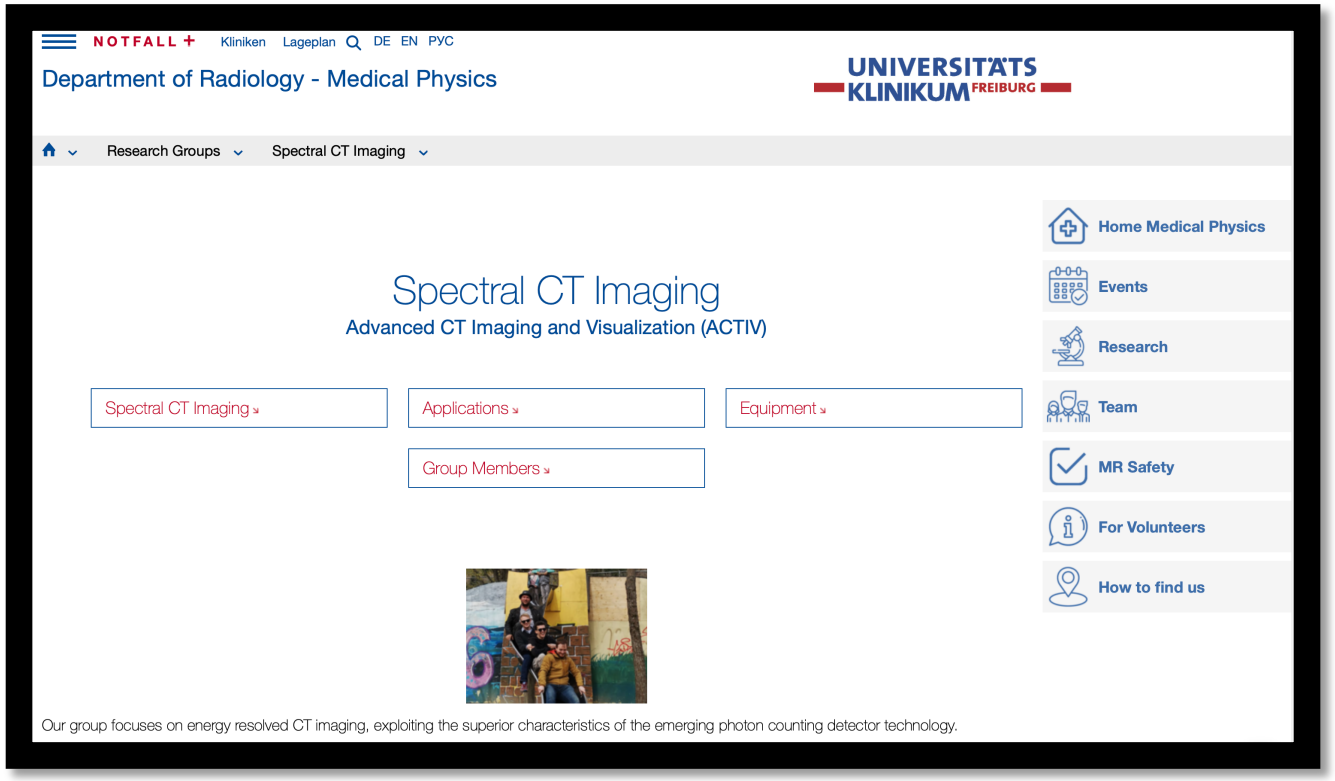
UNIVERSITÄTS KLINIKUM FREIBURG

Simulating the response of Timepix detectors

Thomas Billoud

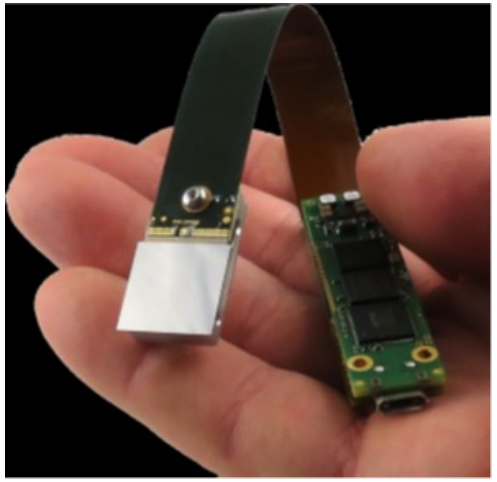
GATE Scientific meeting 2026

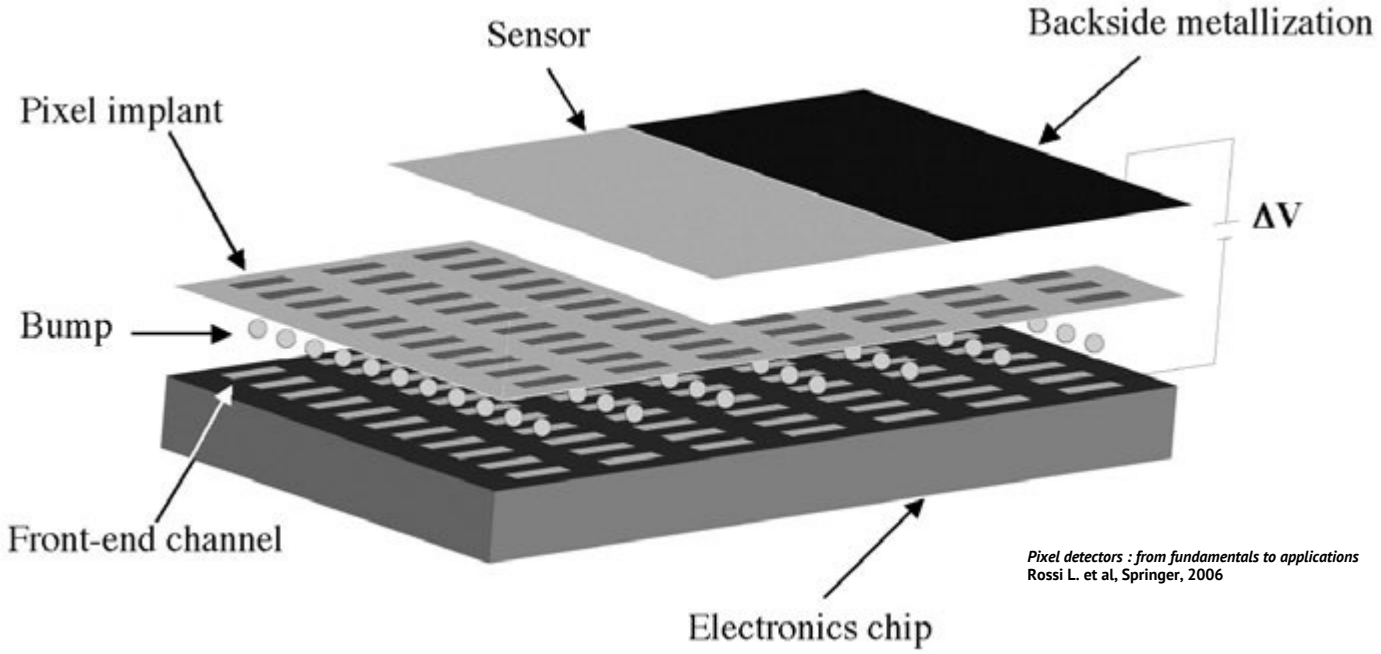
Our team


NOTFALL +
Kliniken
Lageplan
DE EN PYC
Department of Radiology - Medical Physics
UNIVERSITÄTS KLINIKUM FREIBURG
Research Groups
Spectral CT Imaging
Spectral CT Imaging
Advanced CT Imaging and Visualization (ACTIV)
Spectral CT Imaging
Applications
Equipment
Group Members
Home Medical Physics
Events
Research
Team
MR Safety
For Volunteers
How to find us
Our group focuses on energy resolved CT imaging, exploiting the superior characteristics of the emerging photon counting detector technology.

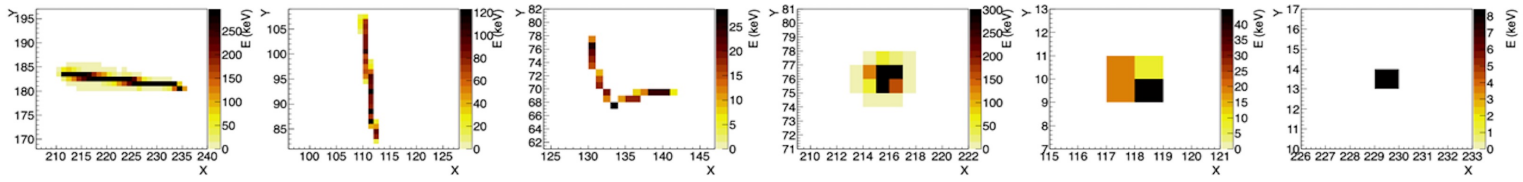
The Timepix detector

- Chip: 256 x 256 pixels, 55 µm pitch
- Sensor: Si, CdTe, CZT, GaAs
- Measures energy / time / counts

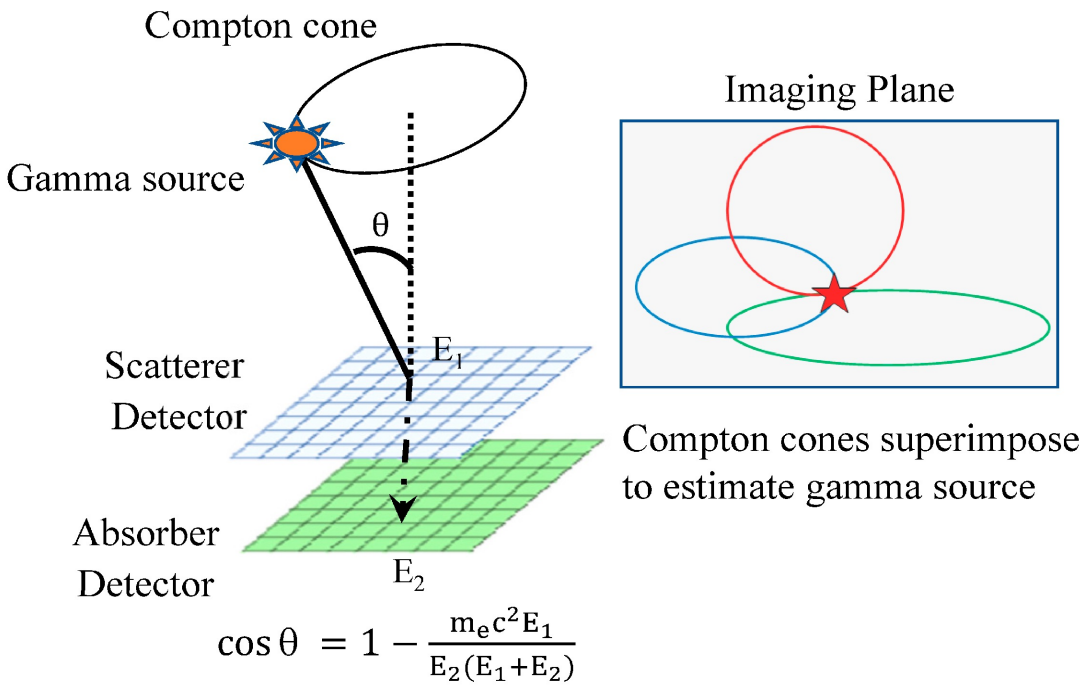


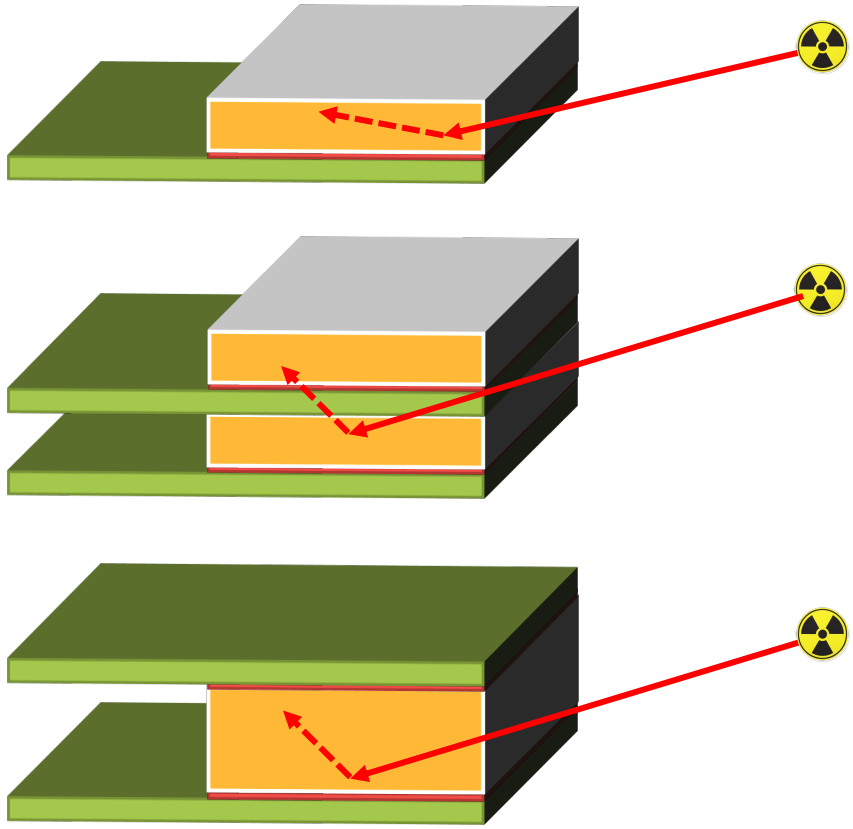


Pixel detectors : from fundamentals to applications
Rossi L. et al, Springer, 2006



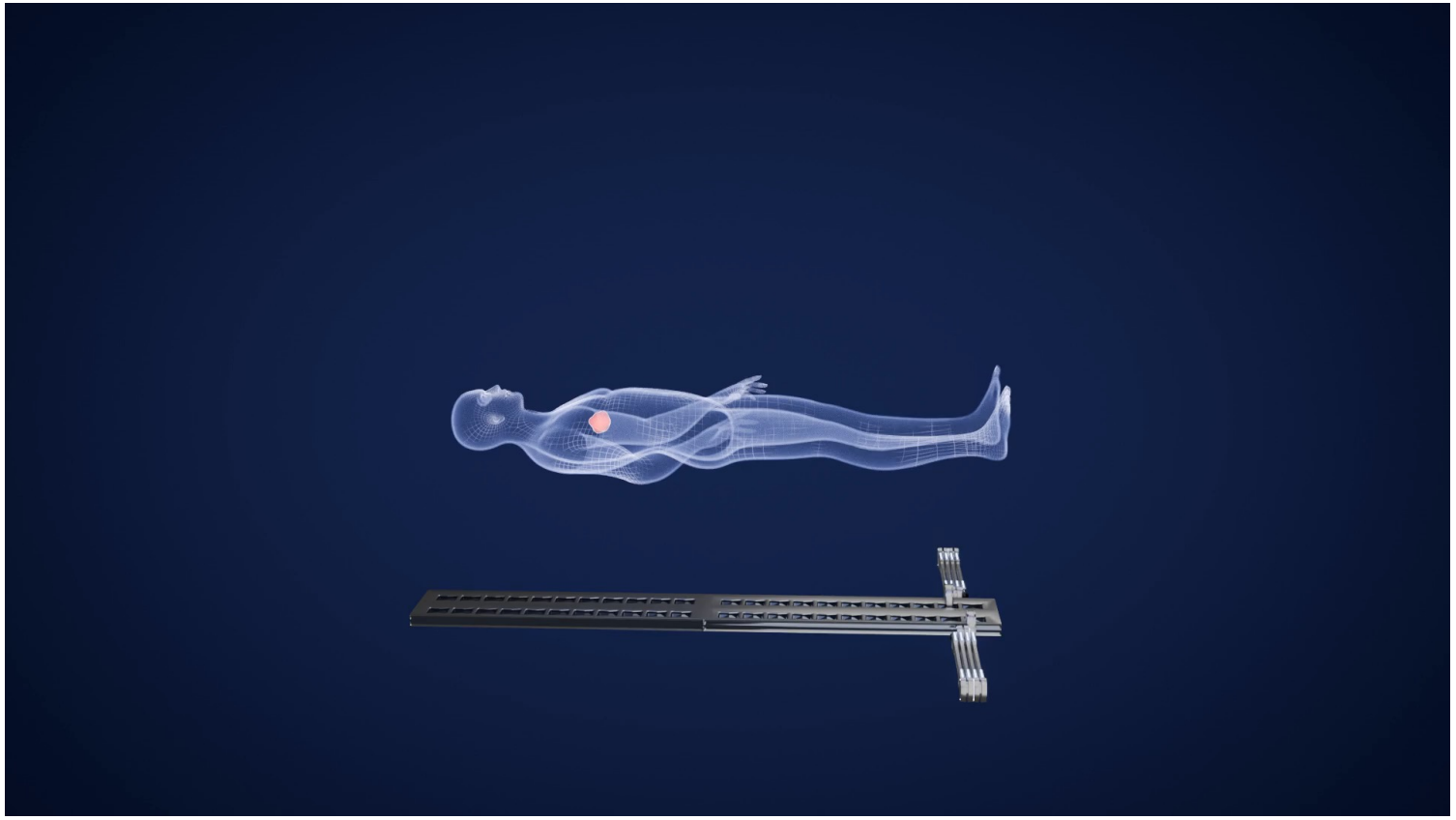
Compton cameras with Timepix





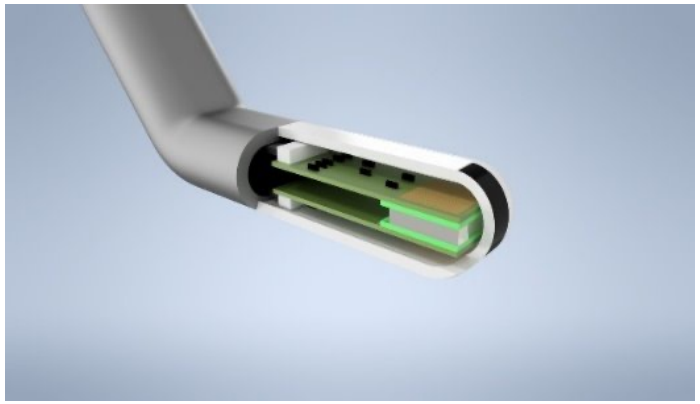
The VORTEX project

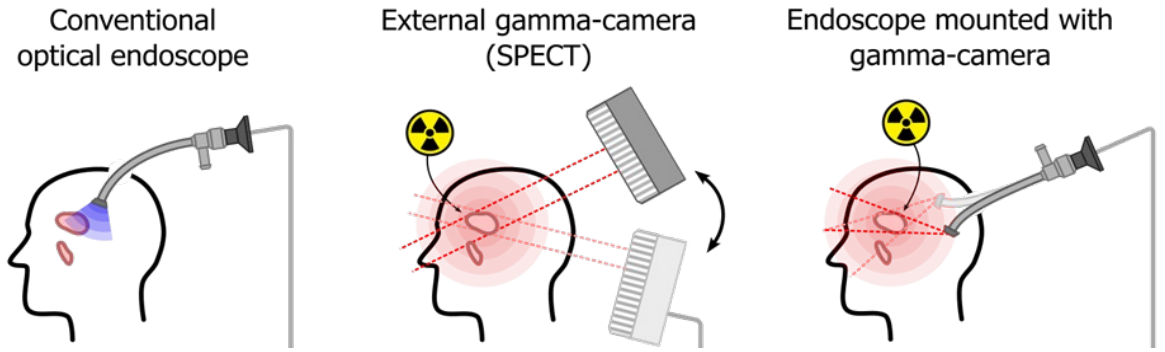
- Multi-modal medical scanner
- Compact, no infrastructure
- Molecular & structural imaging:
  - SPECT
  - PET
  - Spectral CT
- Funded by the Carl Zeiss Foundation

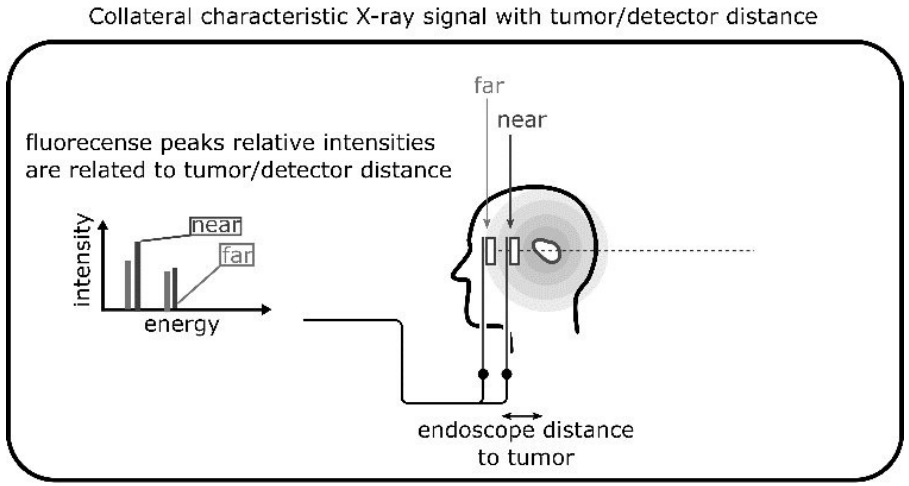


The M3DiCam project

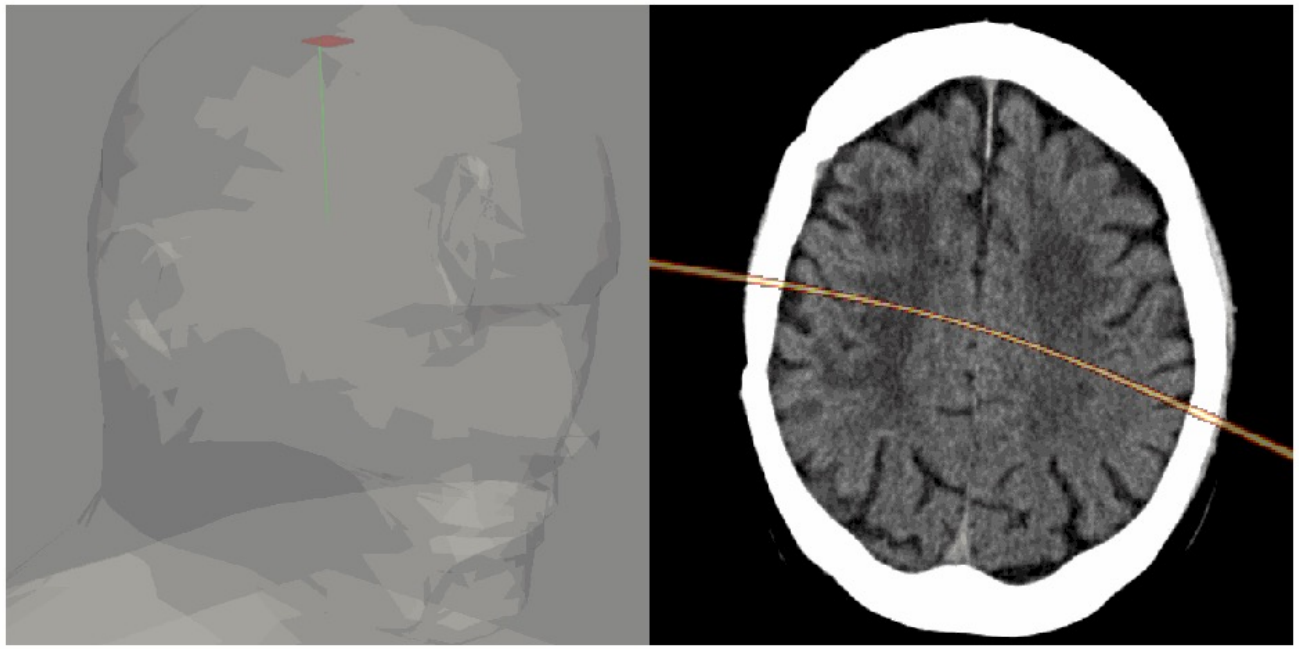
- Intraoperative gamma endoscopy
- Single-layer Compton camera
- Depth resolution via low energy peaks
- Funded by Eurostars



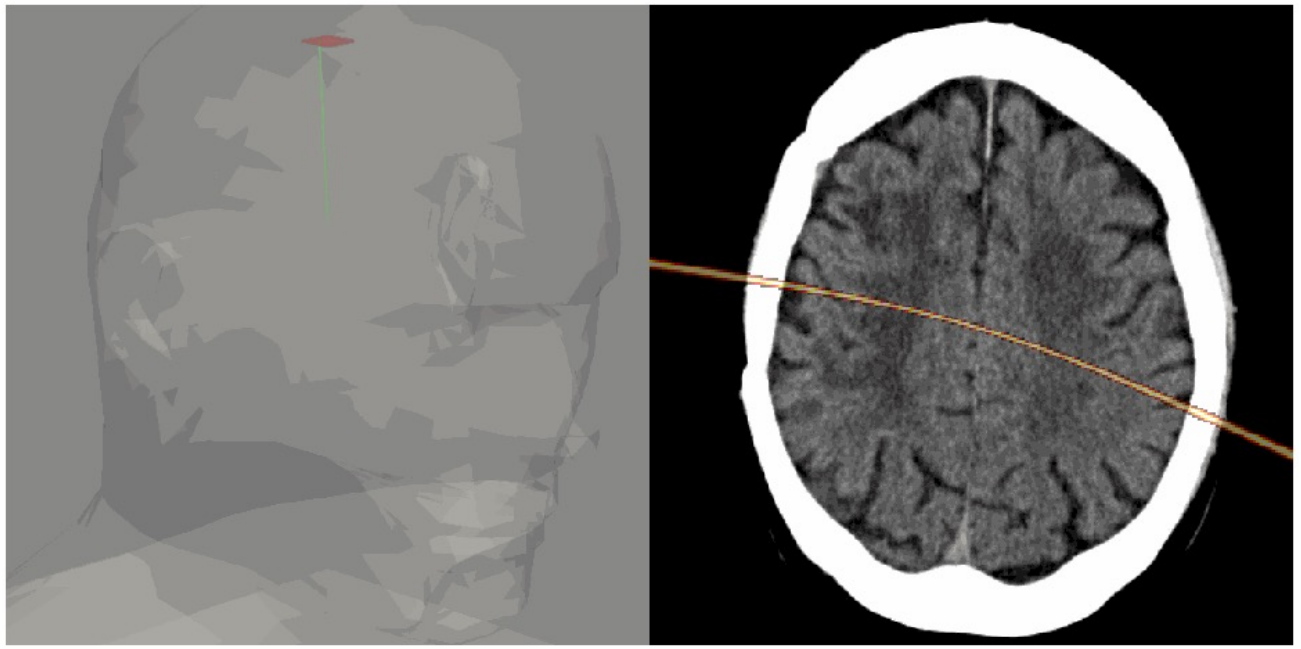




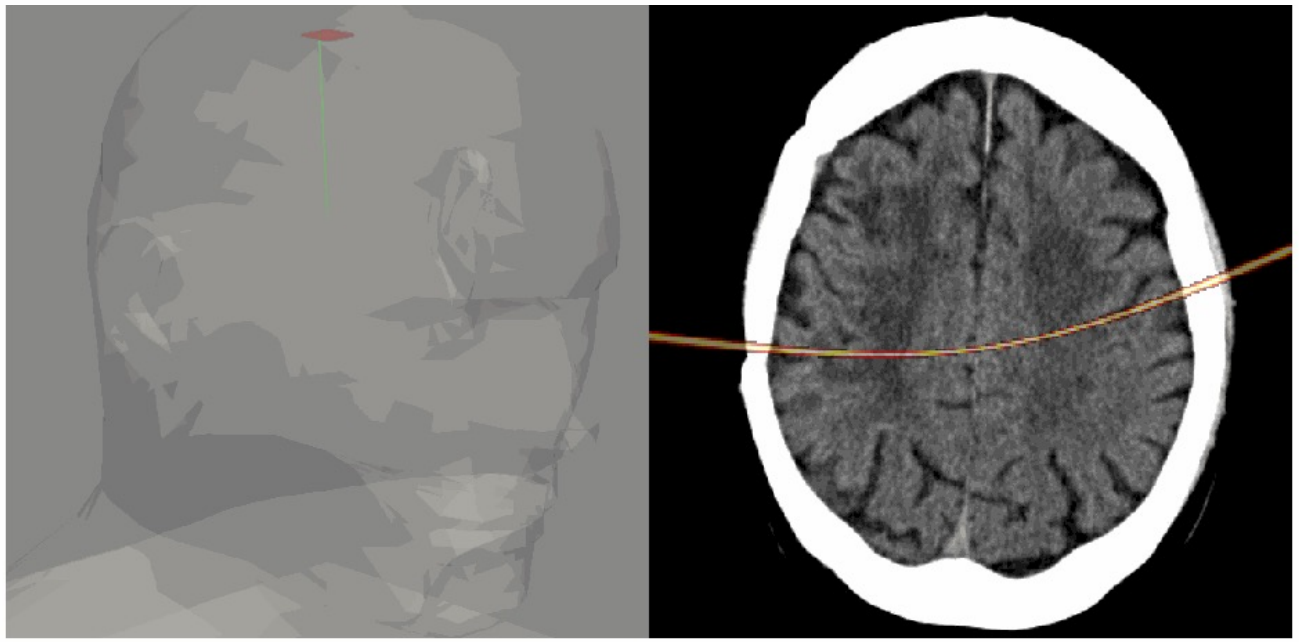
Ideal world



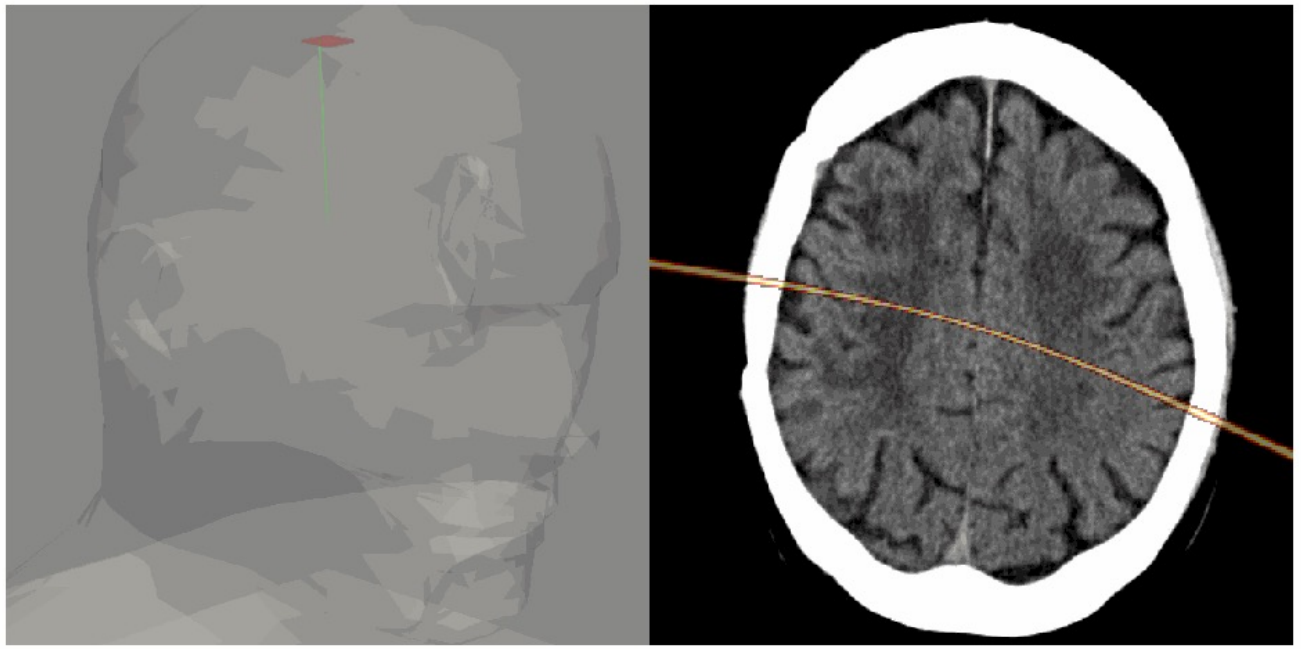
Ideal world



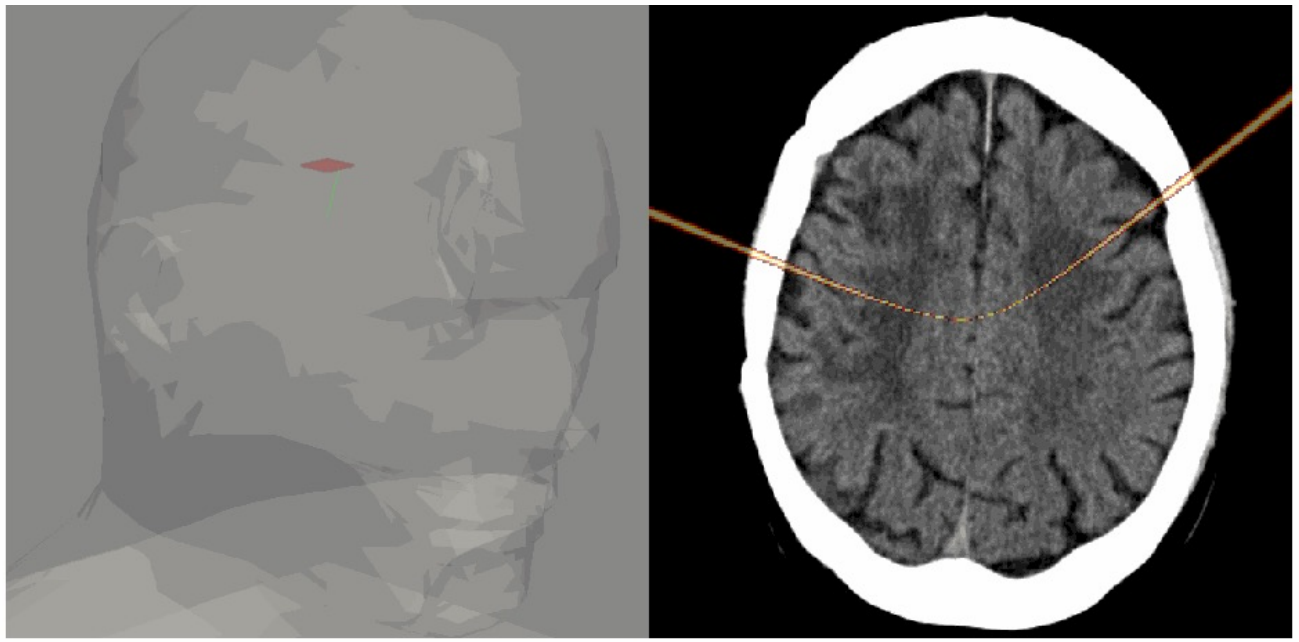
Real world



Ideal world

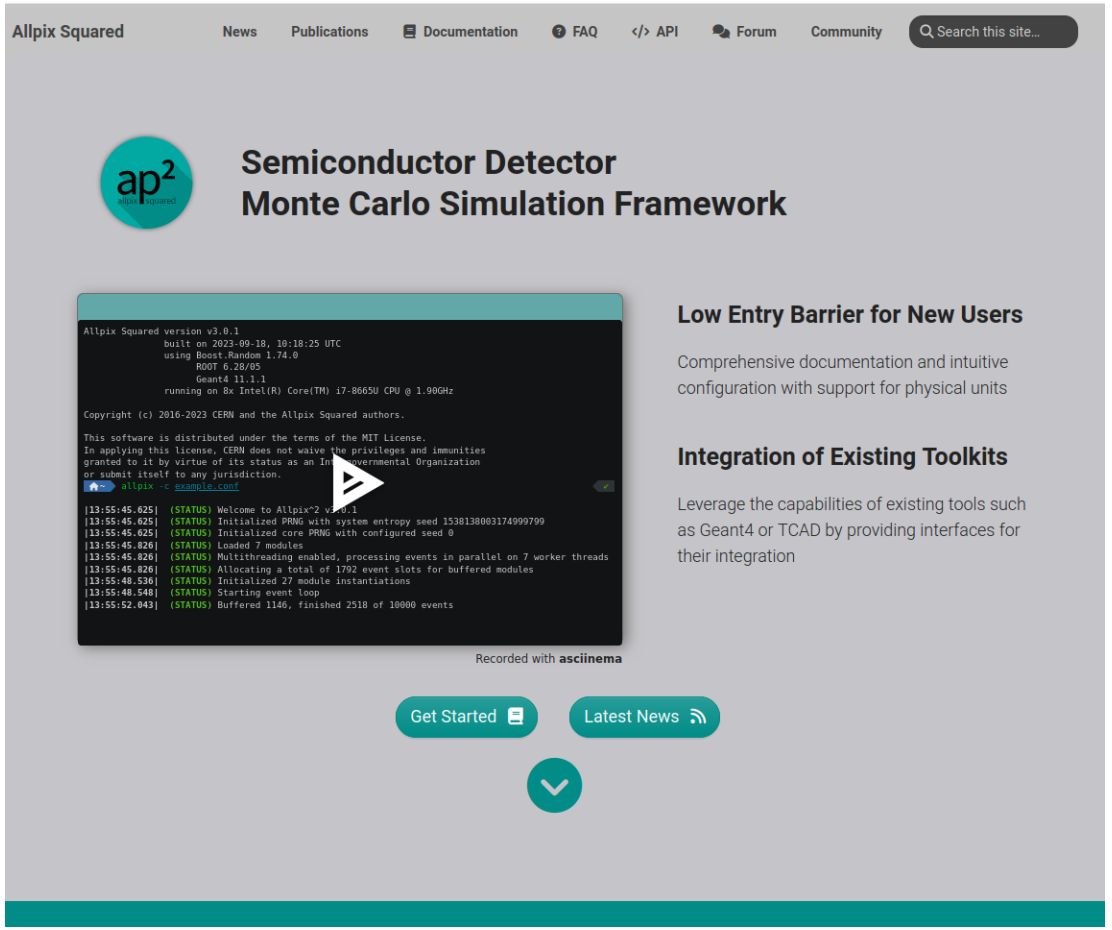


Real world,
made better !



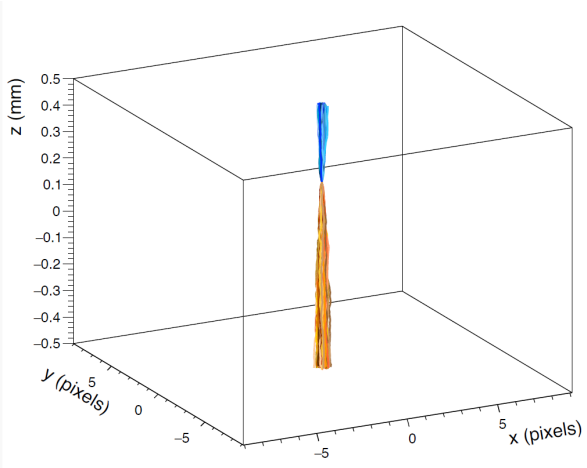
Simulating Timepix with Allpix

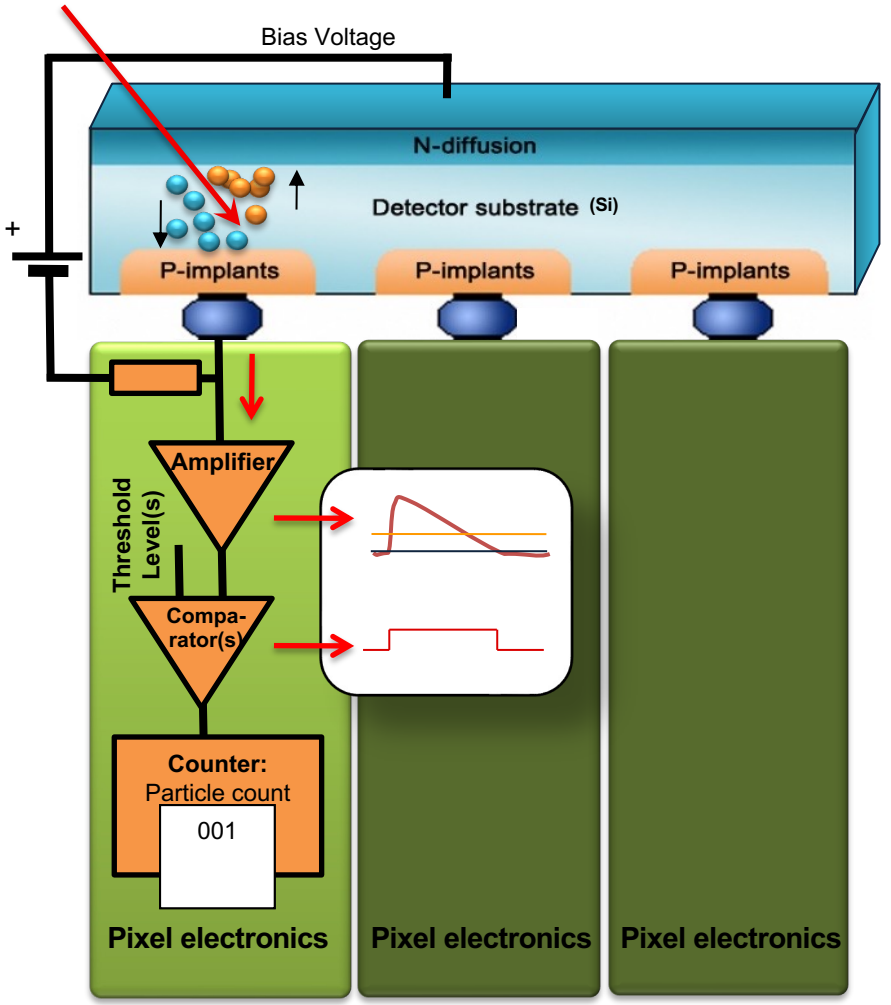
- Free software, hosted by CERN
- Active collaboration
- C++/Geant4 based
- Modular framework
- Speed depends on precision level
- Can read Geant4/Gate hits as input
- Output: ROOT or text files



Pulse simulation with Allpix

- A photon interaction generates charge carriers
- Carriers propagate towards the sensor's electrodes
- Allpix simulates:
  - Drift
  - Diffusion
  - Trapping
  - Pulse induction
  - Digitization





Urban M, Nentvich O, Marek L, Hudec R, Sieger L. Timepix3: Temperature Influence on Radiation Energy Measurement with Si Sensor. *Sensors*. 2023; 23(4):2201. https://doi.org/10.3390/s23042201

Gate10 / Allpix interface

```python
def gate_simu(sensor_material="G4_CADMIUM_TELLURIDE"):  10 usages  tbilloud +1
    sim, sim.output_dir = Simulation(), Path("output")
    sim.random_engine, sim.random_seed = "MersenneTwister", 1
    sim.visu = False
    sim.verbose_level = 'DEBUG'  # DEBUG for data preview, INFO for algo timing only

    # ===========================
    # ==   GEOMETRY            ==
    # ===========================
    npix, pitch, thick = 256, 55 * um, 1 * mm
    sim.world.size = [15 * mm, 15 * mm, 30 * mm]
    sim.world.material = "G4_AIR"
    sensor = sim.add_volume( volume: "Box",  name: "sensor")
    sensor.material = sensor_material  # 'G4_Si', 'G4_CADMIUM_TELLURIDE'
    sensor.size = [npix * pitch, npix * pitch, thick]
    sensor.translation = [0 * mm, 0 * mm, 10 * mm]
    setup_pixels(sim, npix, sensor, pitch, thick)

    ## ===========================
    ## ==  PHYSICS              ==
    ## ===========================
    # sim.physics_manager.physics_list_name = 'G4EmLivermorePhysics' # for Doppler effect
    # set_fluorescence(sim) # for fluorescence (important for CdTe/GaAs sensors)

    ## ============================
    ## == ACTORS                 ==
    ## ============================
    hits = sim.add_actor( actor_type: 'DigitizerHitsCollectionActor',  name: 'Hits')
    hits.attached_to = sensor.name
    hits.authorize_repeated_volumes = True
    hits.attributes = opengate_core.GateDigiAttributeManager.GetInstance().GetAvailableDigiAttributeNames()
    hits.output_filename = 'gateHits.root'

    ## ============================
    ## == SOURCE                 ==
    ## ============================
    source = sim.add_source( source_type: "GenericSource",  name: "source")
    source.particle = "gamma"
    source.energy.mono = 140 * keV
    source.position.translation = [0 * mm, 0 * mm, 0 * mm]
    source.activity = 100e3 * Bq
```

Gate simulation

```python
# ########## ALLPIX ##############
hits_allp = gHits2allpix2pixelHits(sim,
                                   npix=npix,
                                   config='precise',
                                   log_level='FATAL',
                                   skip_hitless_events=False,
                                   bias_V=bias,
                                   mobility_electron_cm2_Vs=mobility_e,
                                   mobility_hole_cm2_Vs=500,
                                   threshold_smearing=30,
                                   electronics_noise=110,
                                   charge_per_step=100,
                                   )
```

Allpix^2 simulation

```python
clstr_allp = pixelHits2pixelClusters(hits_allp, npix=npix, window_ns=100)
evt_allp = pixelClusters2CCevents(clstr_allp, thick=thick, speed=spd, twindow=100)
```

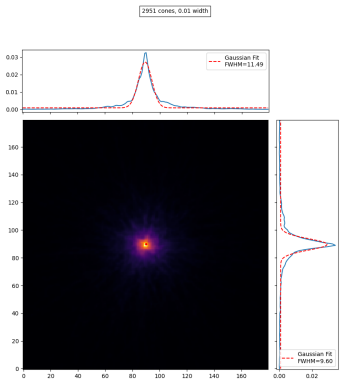
Clustering + Coincidence algorithms

```python
# ###### RECONSTRUCTION  ##########
reco_params = {'vpitch': 0.2, 'vsize': [32, 32, 16],
               'cone_width': 0.01,
               'energies_MeV': [source.energy.mono], 'tol_MeV': 0.01,
               'sensor_position': sensor.translation,
               'sensor_rotation': sensor.rotation,
               'sensor_size': sensor.size,
               'cone_thickness': 'parallel'  # 'parallel', 'angular'
               }
volume = reconstruct(events, method='coresi', **reco_params)
```

Reconstruction

```python
sp = source.position.translation
valid_psource(evt_allp, method='numpy', src_pos=sp, **reco_params)
```

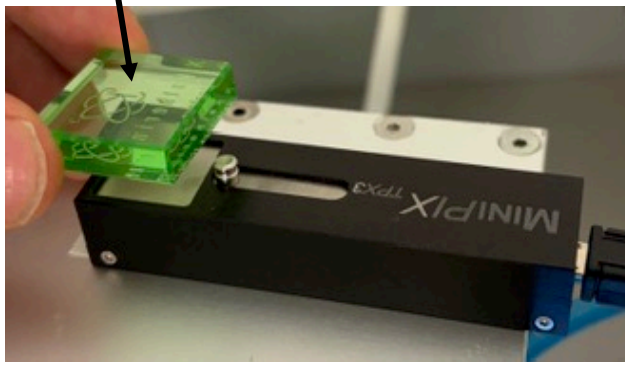
Validation

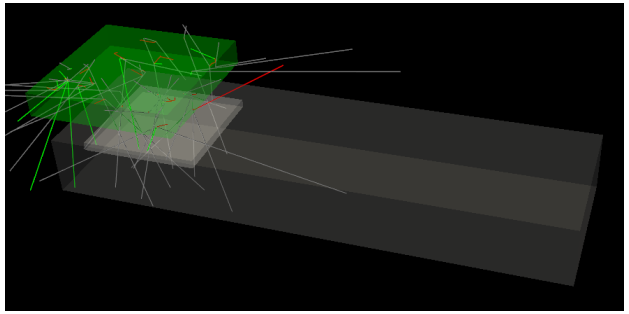


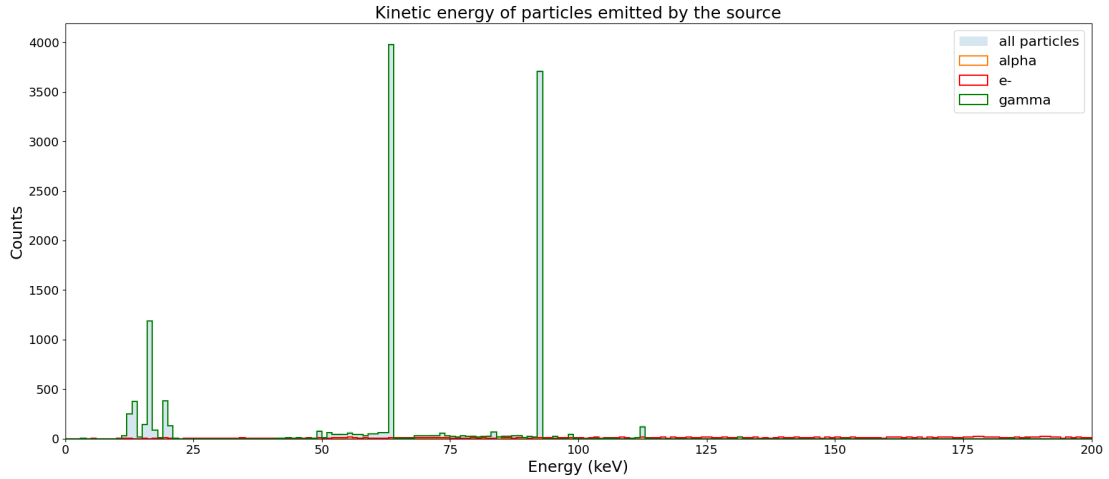
https://github.com/tbilloud/gate-pixel

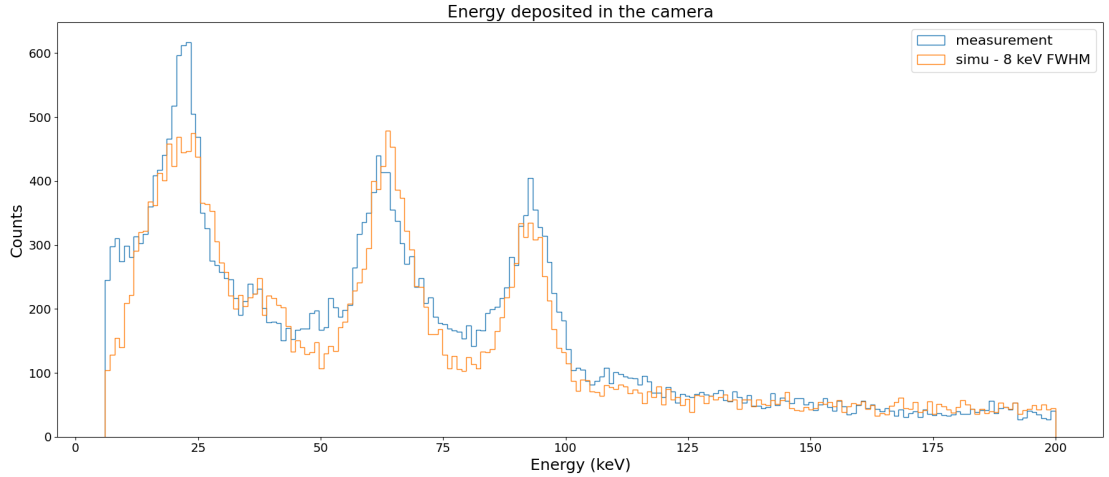
Validation: WIP

Uranium glass









THANK YOU ;)