

Simulating the response of Timepix detectors

Thomas Billoud



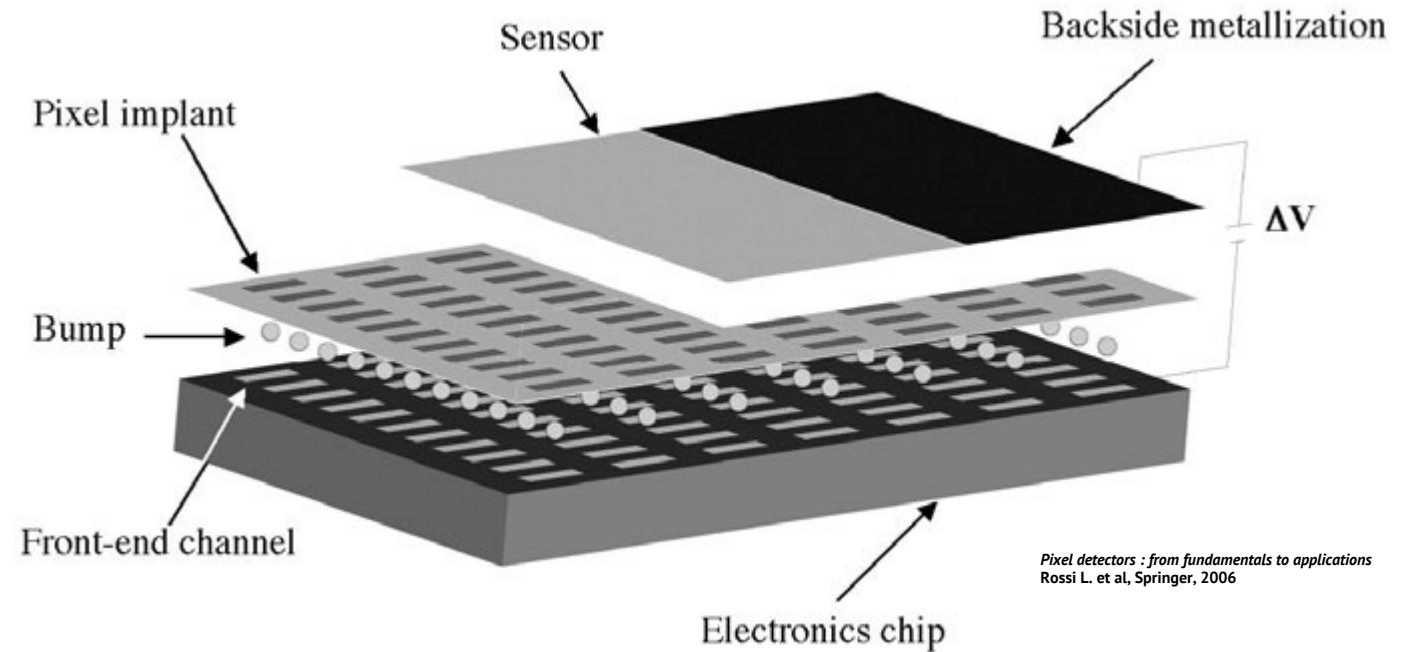
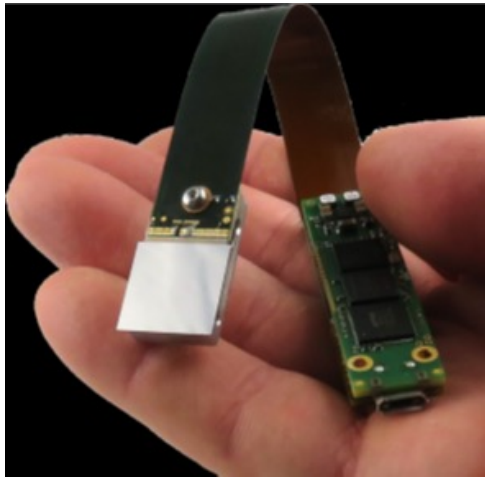
Our team

The screenshot shows the website for the Spectral CT Imaging group. At the top, there is a navigation bar with 'NOTFALL +', 'Kliniken', 'Lageplan', and language options 'DE EN PYC'. Below this is the 'Department of Radiology - Medical Physics' header and the 'UNIVERSITÄTS KLINIKUM FREIBURG' logo. A breadcrumb trail indicates 'Research Groups' > 'Spectral CT Imaging'. The main content area features the title 'Spectral CT Imaging' and subtitle 'Advanced CT Imaging and Visualization (ACTIV)'. There are four menu items: 'Spectral CT Imaging', 'Applications', 'Equipment', and 'Group Members'. A small photo of the team is shown below. On the right, a vertical sidebar contains icons and links for 'Home Medical Physics', 'Events', 'Research', 'Team', 'MR Safety', 'For Volunteers', and 'How to find us'. At the bottom, a short paragraph states: 'Our group focuses on energy resolved CT imaging, exploiting the superior characteristics of the emerging photon counting detector technology.'

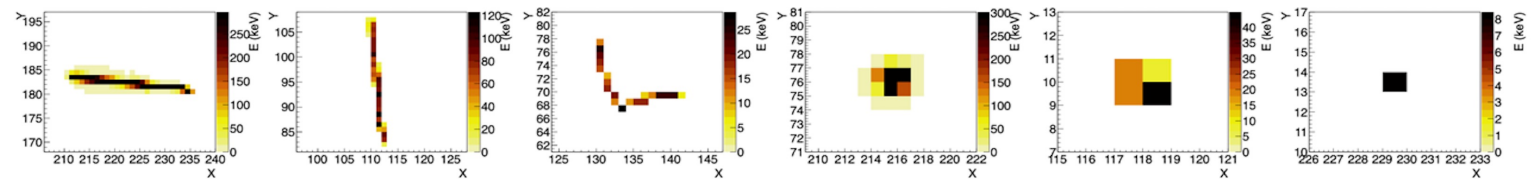


The Timepix detector

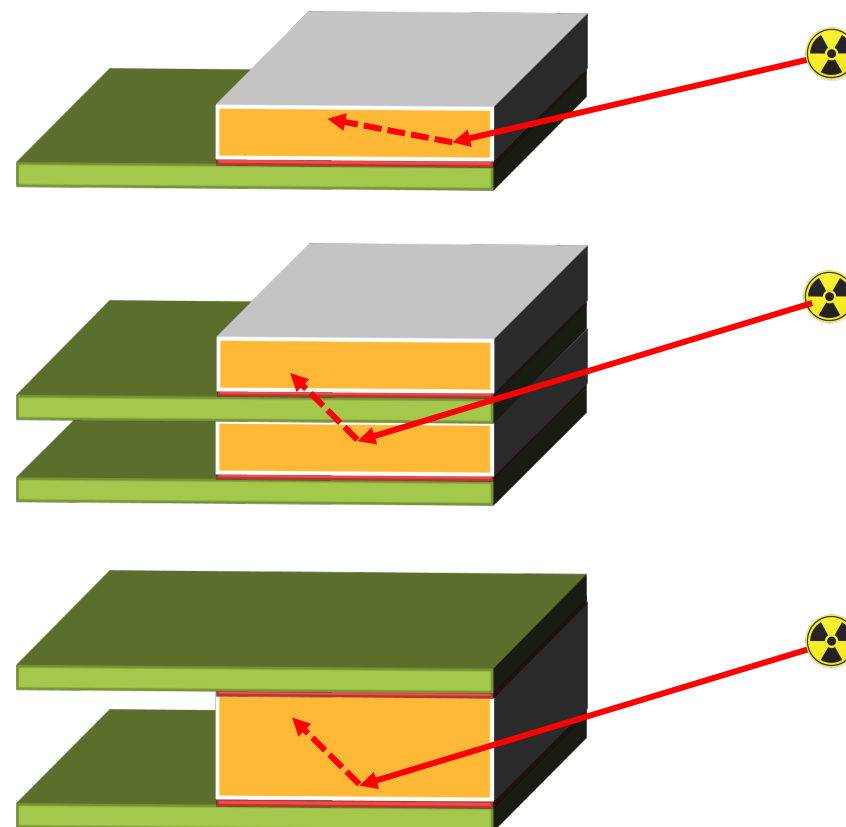
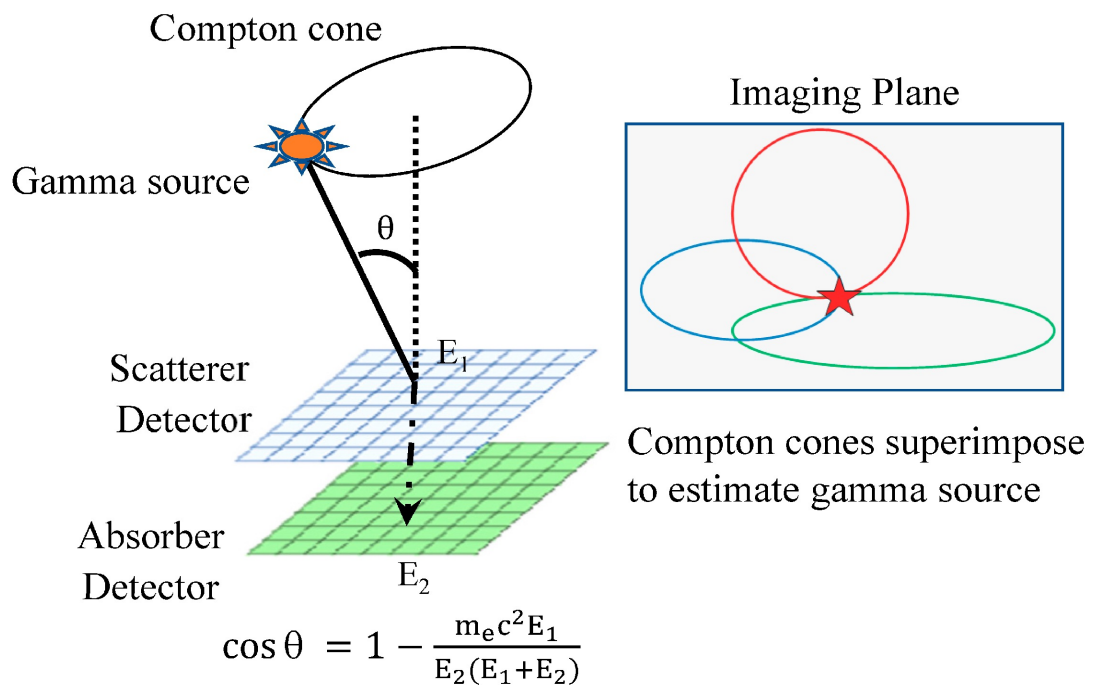
- Chip: 256 x 256 pixels, 55 μm pitch
- Sensor: Si, CdTe, CZT, GaAs
- Measures energy / time / counts



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

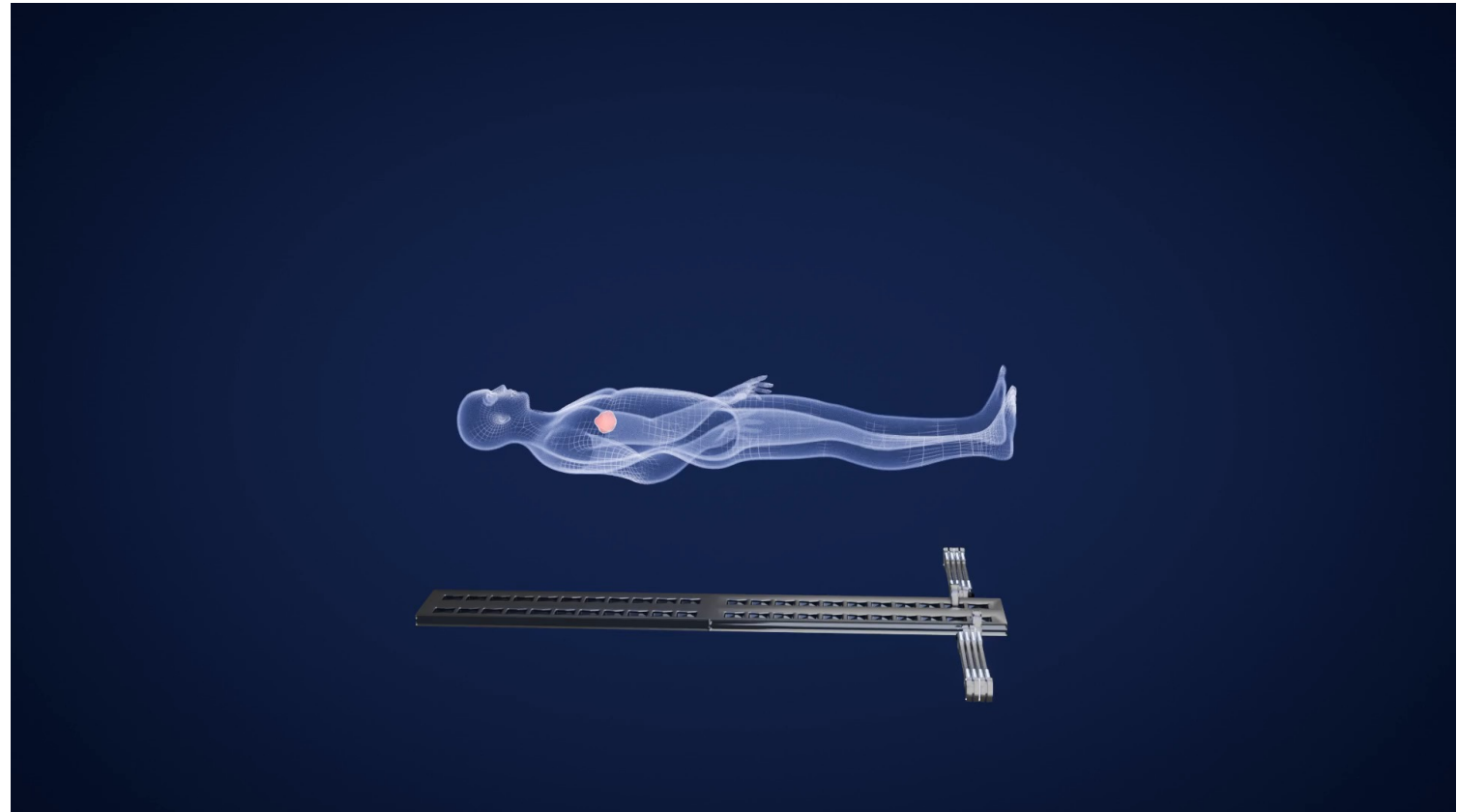


Compton cameras with Timepix



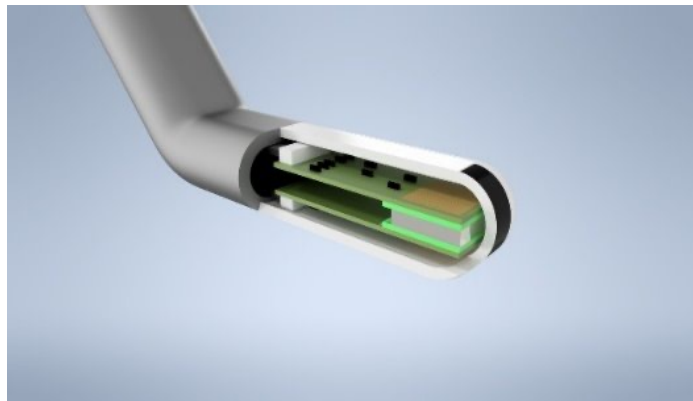
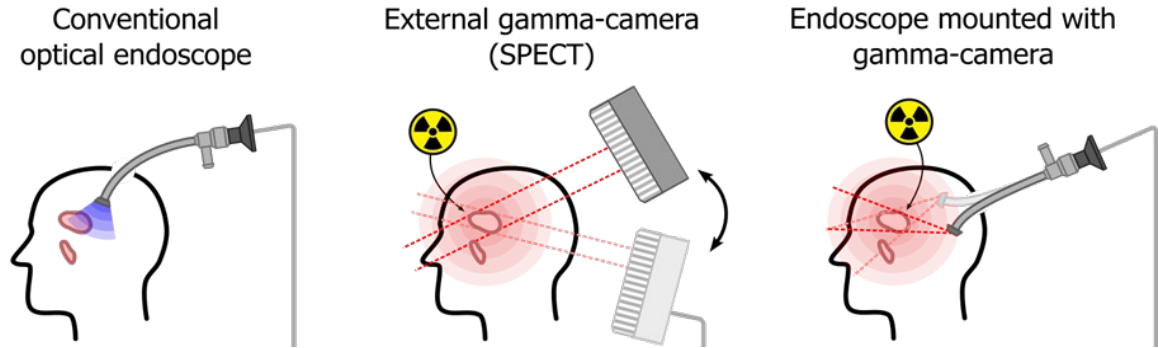
The VORTEX project

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

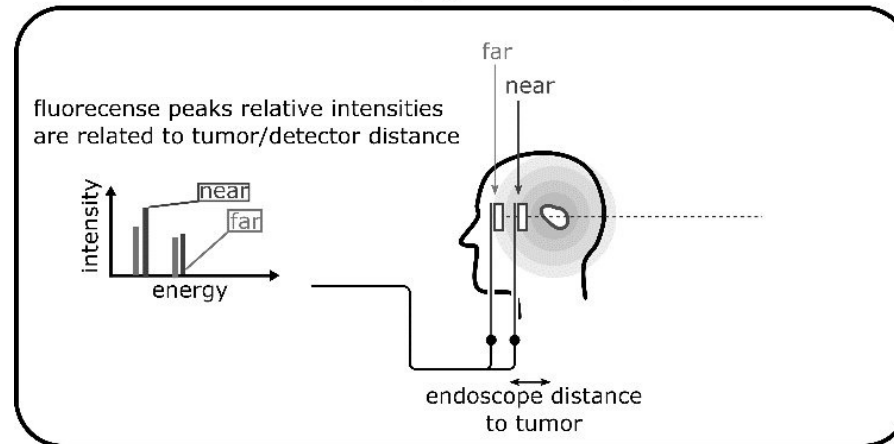


The M3DiCam project

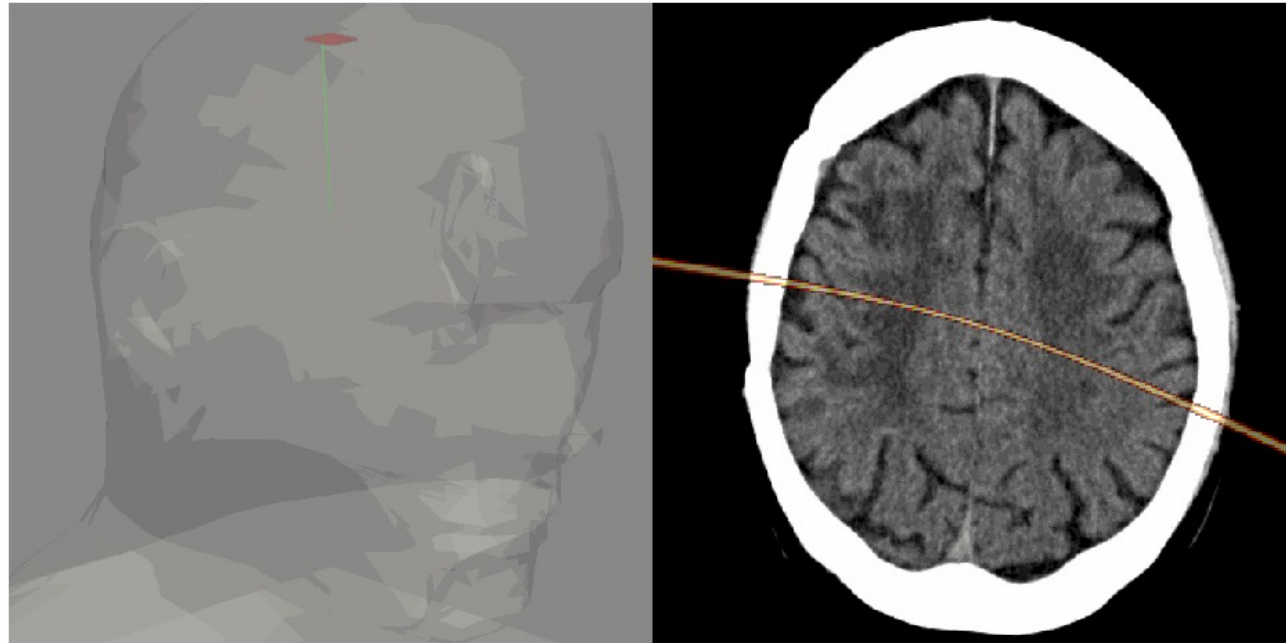
- Intraoperative gamma endoscopy
- Single-layer Compton camera
- Depth resolution via low energy peaks
- Funded by Eurostars



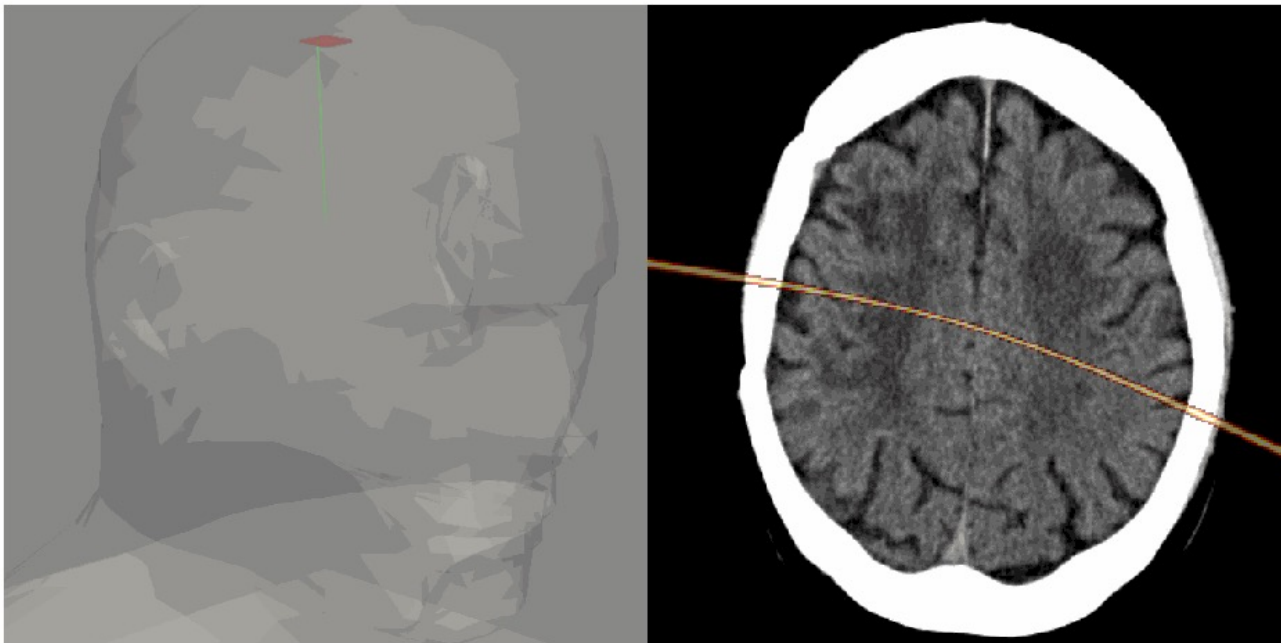
Collateral characteristic X-ray signal with tumor/detector distance



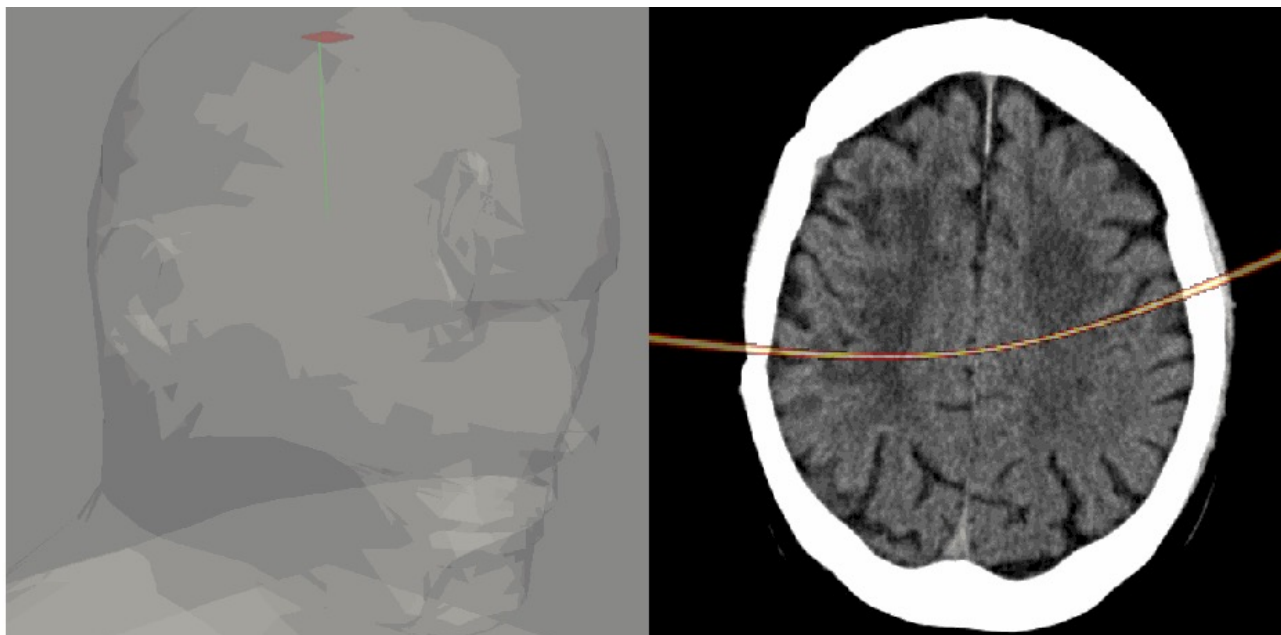
Ideal world



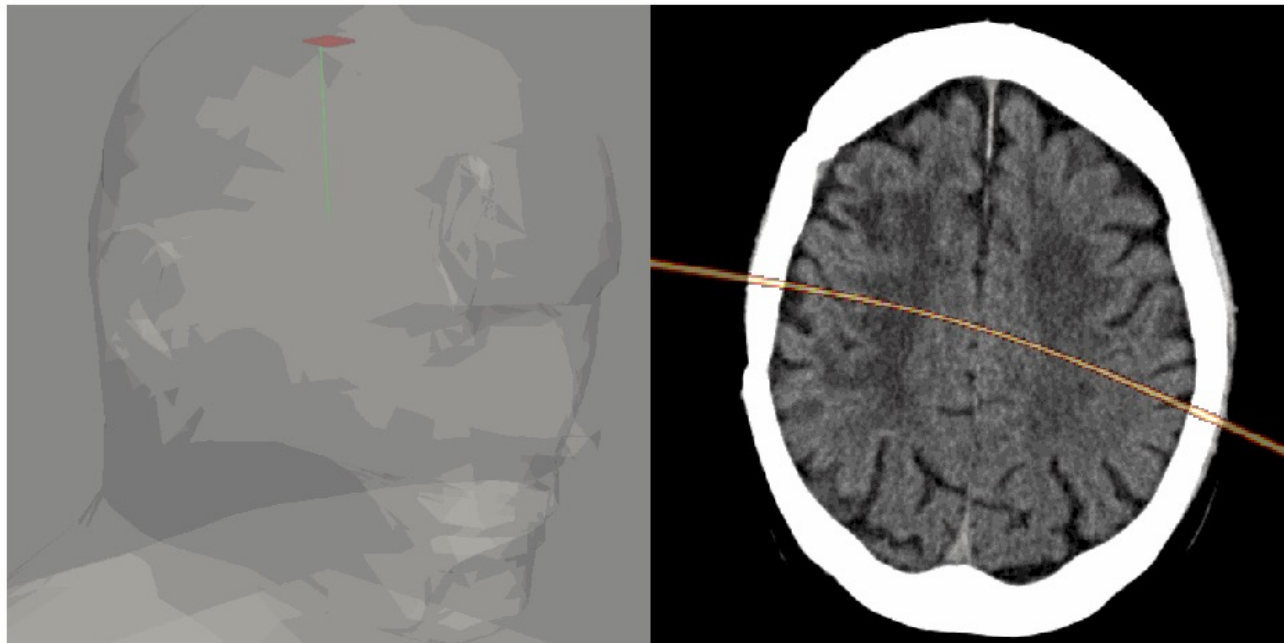
Ideal world



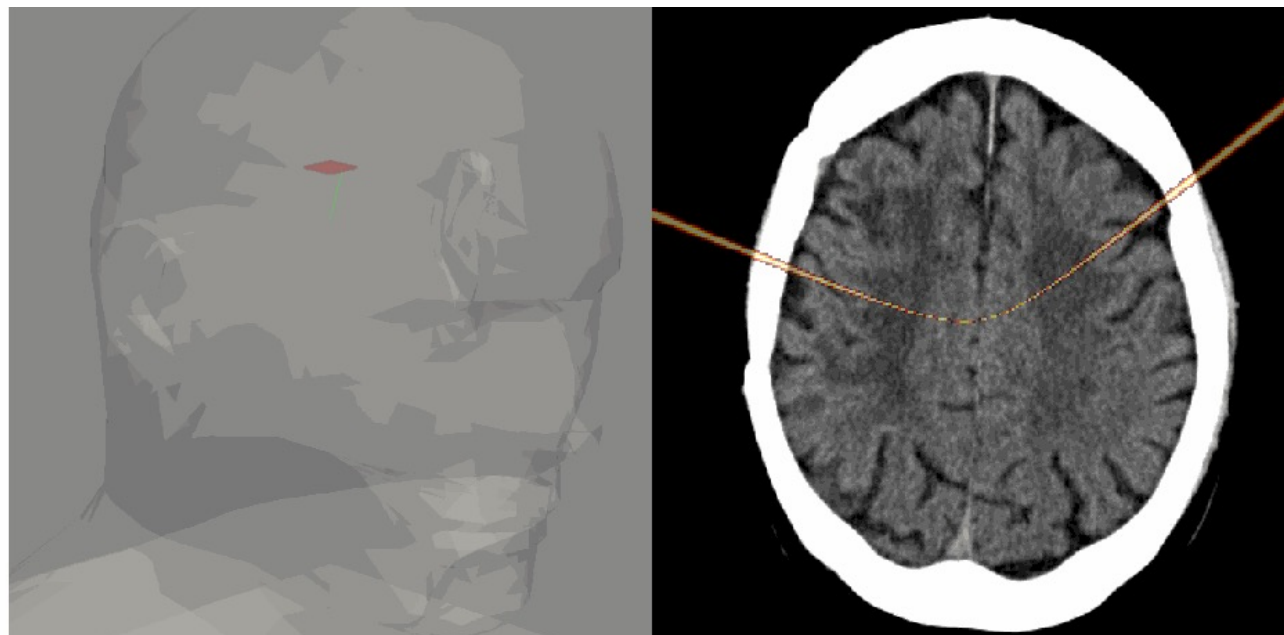
Real world



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

The screenshot shows the Allpix Squared website. At the top, there is a navigation bar with links for News, Publications, Documentation, FAQ, API, Forum, and Community, along with a search bar. The main content area features the 'ap² Allpix Squared' logo and the title 'Semicondutor Detector Monte Carlo Simulation Framework'. Below the title is a terminal window displaying the following text:

```
Allpix Squared version v3.0.1
built on 2023-09-18, 10:18:25 UTC
using Boost.Random 1.74.0
ROOT 6.28/05
Geant4 11.1.1
running on 8x Intel(R) Core(TM) i7-8665U CPU @ 1.98GHz

Copyright (c) 2016-2023 CERN and the Allpix Squared authors.

This software is distributed under the terms of the MIT License.
In applying this license, CERN does not waive the privileges and immunities
granted to it by virtue of its status as an Intergovernmental Organization
or submit itself to any jurisdiction.

allpix -- example.conf

[13:55:45.625] (STATUS) Welcome to Allpix2 v3.0.1
[13:55:45.625] (STATUS) Initialized PRNG with system entropy seed 1538138003174999799
[13:55:45.625] (STATUS) Initialized core PRNG with configured seed 0
[13:55:45.826] (STATUS) Loaded 7 modules
[13:55:45.826] (STATUS) Multithreading enabled, processing events in parallel on 7 worker threads
[13:55:45.826] (STATUS) Allocating a total of 1792 event slots for buffered modules
[13:55:48.536] (STATUS) Initialized 27 module instantiations
[13:55:48.540] (STATUS) Starting event loop
[13:55:52.043] (STATUS) Buffered 1146, finished 2518 of 10000 events
```

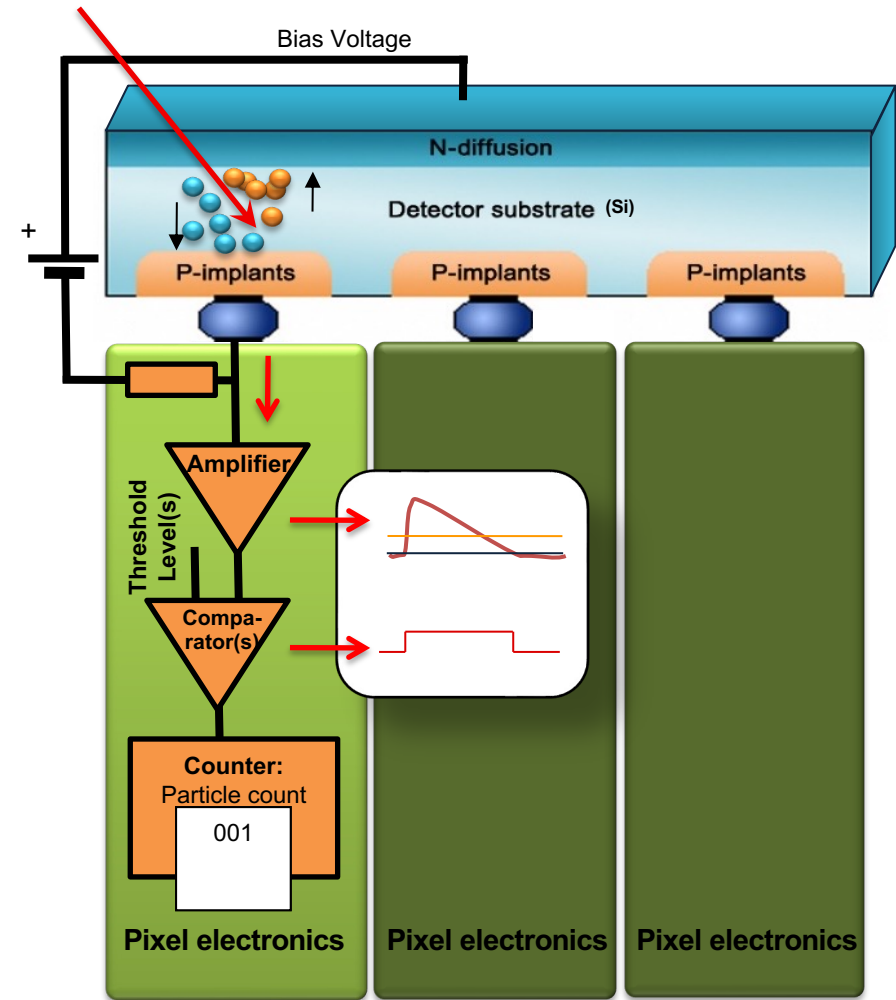
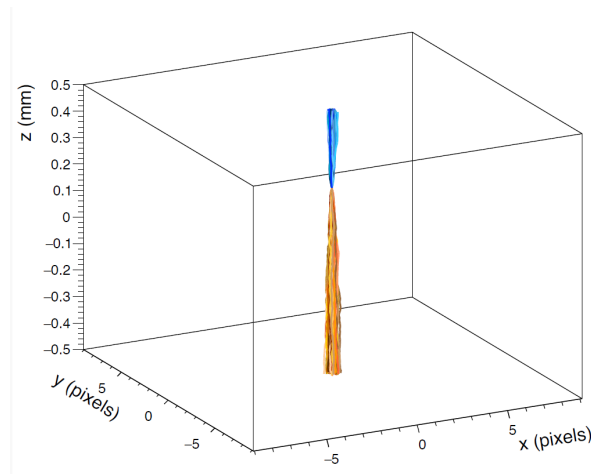
Below the terminal window, there are two buttons: 'Get Started' and 'Latest News'. A play button icon is overlaid on the terminal window. The text 'Recorded with asciinema' is visible below the terminal window.

On the right side of the page, there are two sections:

- Low Entry Barrier for New Users**: Comprehensive documentation and intuitive configuration with support for physical units
- Integration of Existing Toolkits**: Leverage the capabilities of existing tools such as Geant4 or TCAD by providing interfaces for their integration

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

```
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

```
# ##### 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,
)
```

Allpix² simulation

```
clstr_allp = pixelHits2pixelClusters(hits_allp, npix=npix, window_ns=100)
evt_allp = pixelClusters2CEvents(clstr_allp, thick=thick, speed=spd, twindow=100)
```

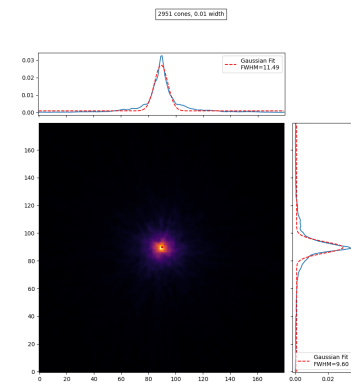
Clustering + Coincidence algorithms

```
# ##### 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

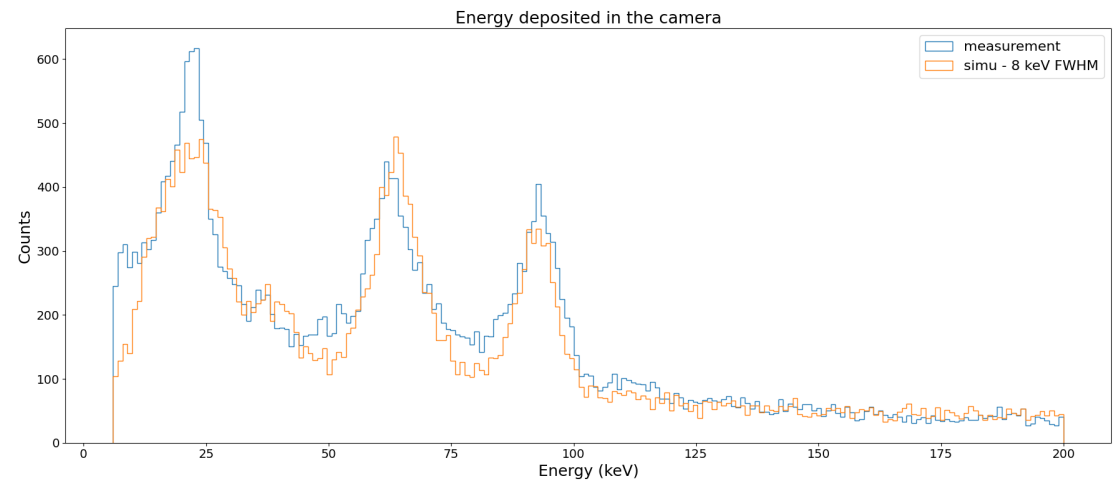
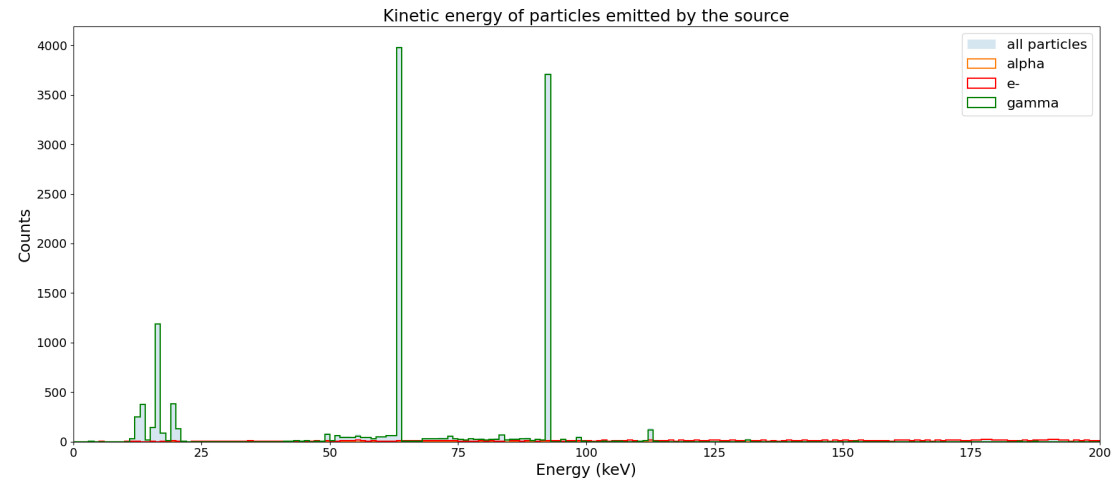
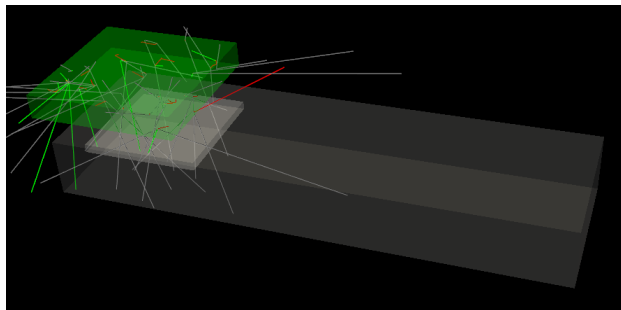
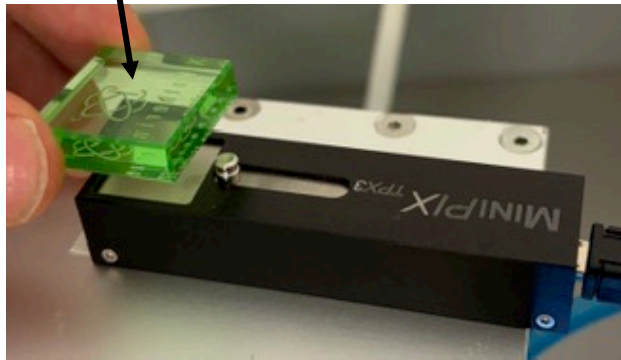
```
sp = source.position.translation
valid_psources(evt_allp, method='numpy', src_pos=sp, **reco_params)
```

Validation



Validation: WIP

Uranium glass



THANK YOU ;)