CREATEC

csem centre suisse d'électronique et de microtechnique

Fraunhofer IZM

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UNIVERSITY OF TRENTO - Italy

CERN

IAEA International Atomic Energy Agency

FONDAZIONE BRUNO KESSLER

NATIONAL NUCLEAR LABORATORY

Geant4 ASSOCIATES INTERNATIONAL Experts in Radiation Simulation

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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cnrs IN2P3 Les deux infinis

IEAP

VERTIGO

Vertically Integrated Heterogeneous Micro-System

Cinzia Da Vià, the University of Manchester, UK

Introduction

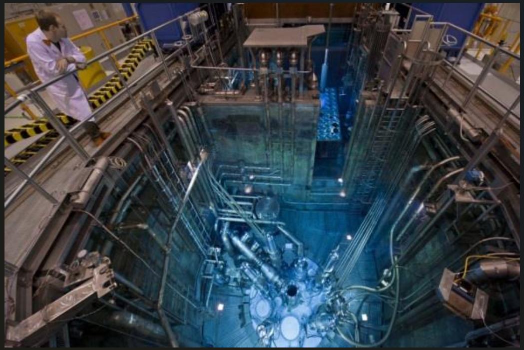
Specific environmental radiation monitoring at

- Accelelators sites
- Nuclear processing
- Nuclear contaminated waste sites.
- Nulear reactors
- Monitoring after accidents or terroristic attacks

can only be performed remotely due to the radiation distribution and intensity uncertainty

Fukushima accident

CERN fixed target
Experimental area



Cherenkov radiation in the reactor pool of the FRM II (Picture: Jürgen Neuhaus, FRM II)

Nuclear waste storage
Sellafield UK

Cinzia Da Via, the University of Manchester, UK

An ideal radiation environmental monitor for harsh environments

- Sensitive to neutrons, hadrons and X- and gamma- rays
- Radiation tolerant
- Portable - lightweight
- Wireless - autonomous
- With both storage and real time visualization capabilities

VERTIGO (Vertically Integrated Heterogeneous Microsystem

Cinzia Da Via, the University of Manchester, UK

VERTIGO’s Objectives

Design, fabrication and test of novel autonomous and movable 3-dimensional heterogeneous integrated microsystem composed by:

- Active multiple-particle, radiation-hard sensors
- Fast high resolution pixellated readout electronics,
- Embedded novel converting materials for neutron, detection
- Overlapped visualization and radiation map
- Wireless high-band communication systems
- Realtime monitoring

- **Target weight: 200g**

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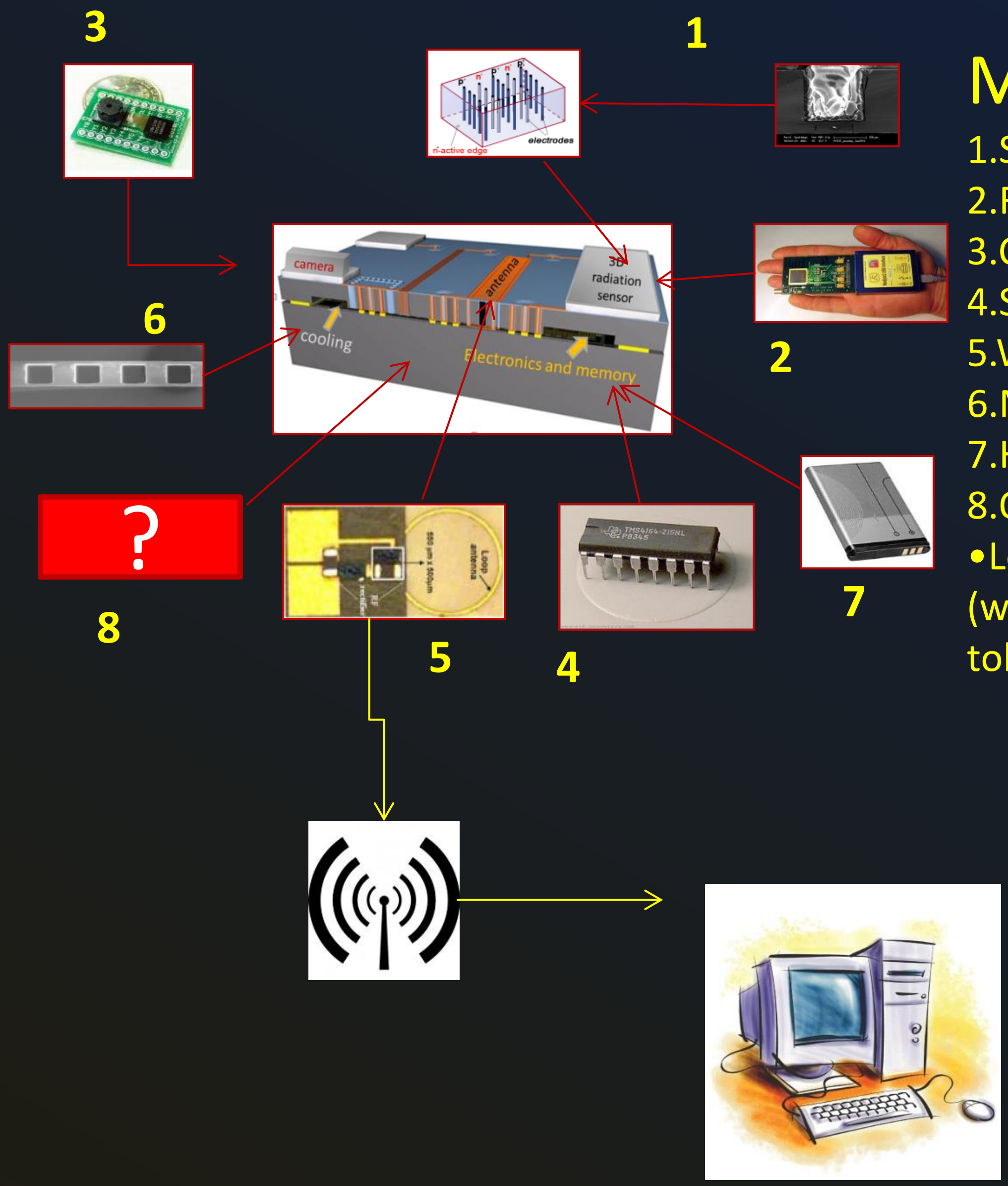
The VERTIGO system



MOBILE UNIT:

1. Silicon 3-dimensional multiple-radiation sensor
2. Fast and pixellated readout electronics chip,
3. Camera
4. Storage memory
5. Wireless transmission circuit
6. Micro-channel cooling.
7. High efficient batteries
8. Other measurements (spectroscopy etc.)

- Low weight packaging adapted to the final use (weather resistant, vibration resistant, radiation tolerant)

RECEIVING UNIT

- Data acquisition system
- Display and data processing
- Simulation packages

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3D is rad hard and works at low V_{bias}

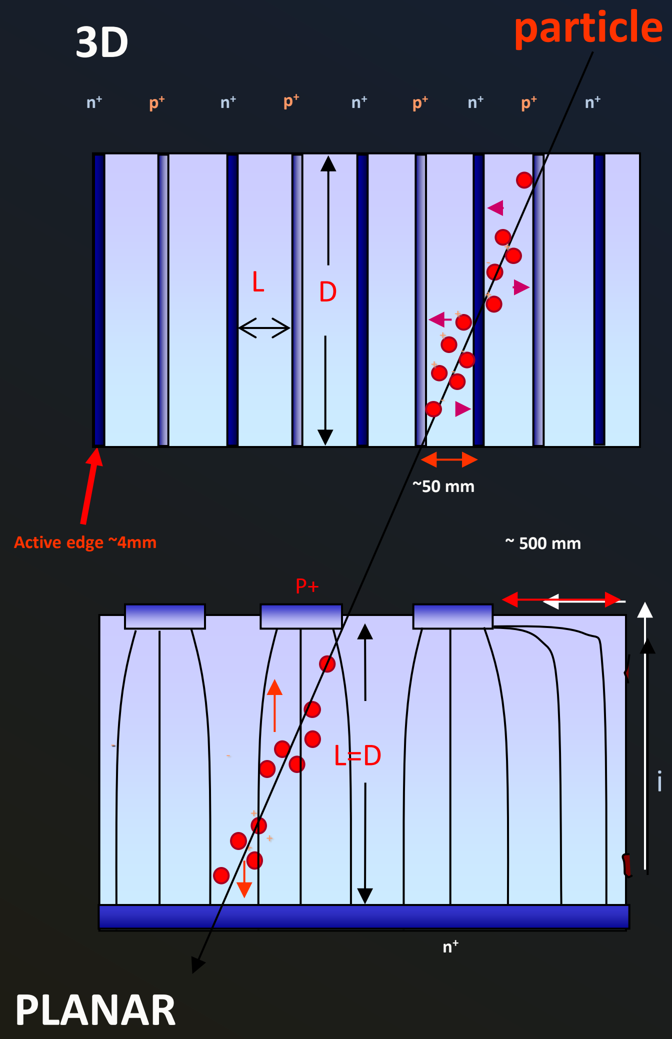
Carrier generation (substrate thickness D)
Carrier drift (L)

Effective carrier drift length

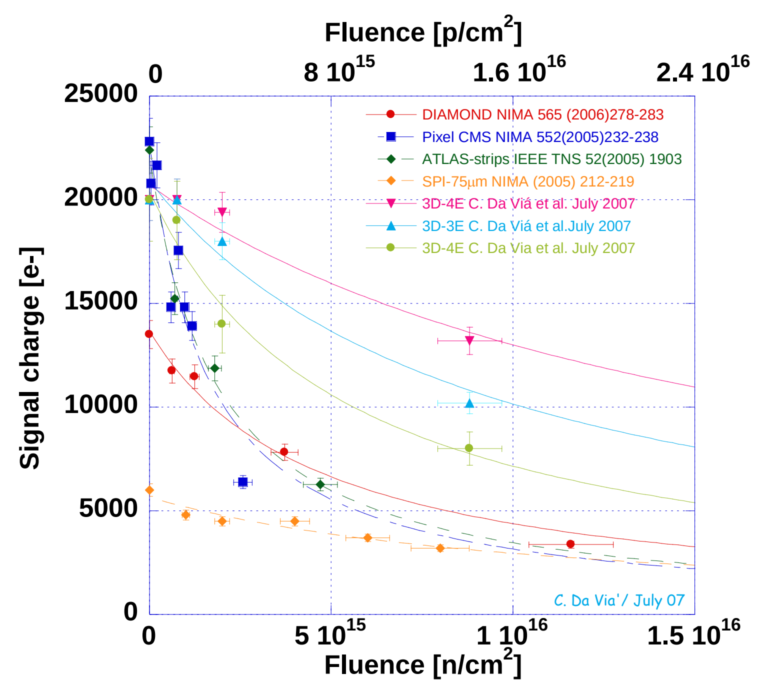
$$\lambda = v_D \cdot \tau$$

Ramo's theorem

$$S = \frac{\lambda}{L}\left[1 - \exp\left(-\frac{x}{\lambda}\right)\right]$$



3D 4E (54um)
3D 3E (71um)
3D 2E (105um)
Diamond
Thick Si
Thin Si



C. Da Via NIM A 603 (2009) 319–324

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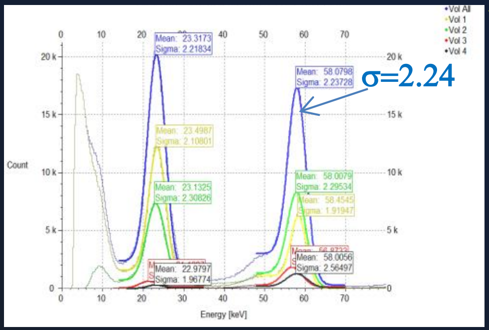
Reduced Charge Sharing in 3D sensors

Better spectroscopic response

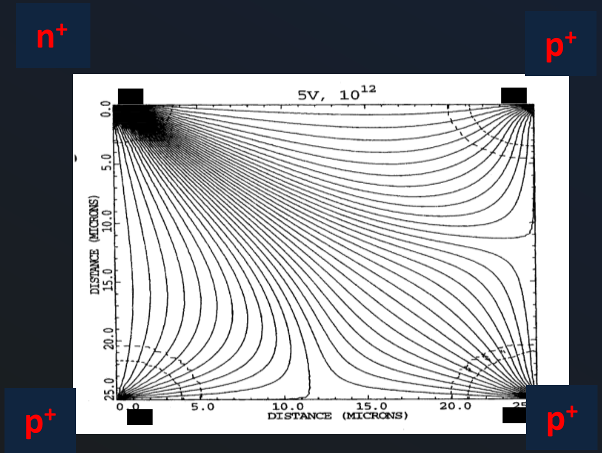
Test performed in Prague
by T. Slavicek

300 µm thick Si sensor with 55 µm pixels
^{241}Am gamma source and In XRF

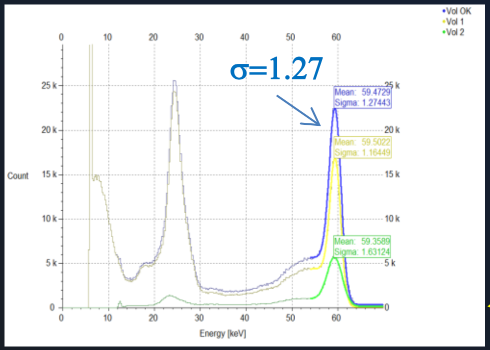


^{241}Am

Type	Energy	Percentage
Alpha (α)	5.485 MeV	84.5 %
Alpha (α)	5.443 MeV	13.0 %
Beta (β)	52 keV	Unknown
Gamma (γ)	59.5 keV	35.9 %
Gamma (γ)	26.3 keV	2.4 %
Gamma (γ)	13.9 keV	42 %



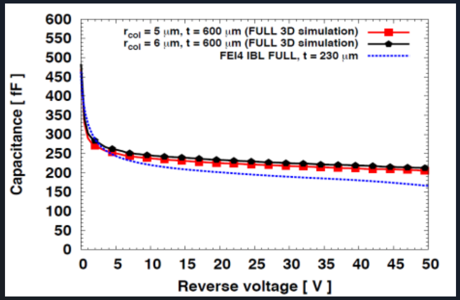
3D Electric field



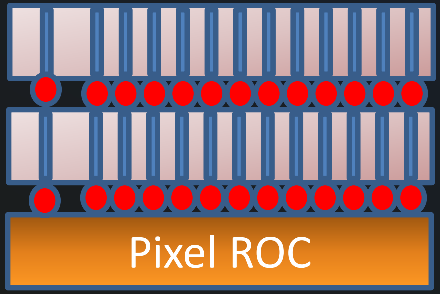
325 µm thick Si 3D sensor with 55 µm pixels
^{241}Am gamma source and In XRF

Reduced charge sharing allows better energy resolution at lower energies

Simulation by M. Povoli Oslo



Stacked geometry allows thicker substrates and better detection efficiency at higher X-ray energies with preserved performance



Da Via C. NIMA 765 (2014) 151–154

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High Efficiency Neutron Detection

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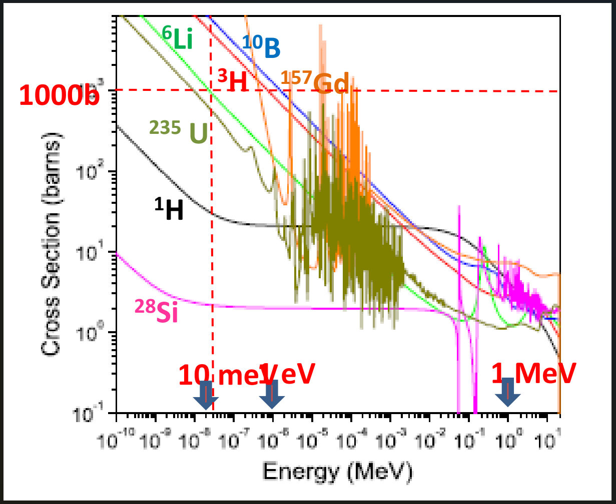
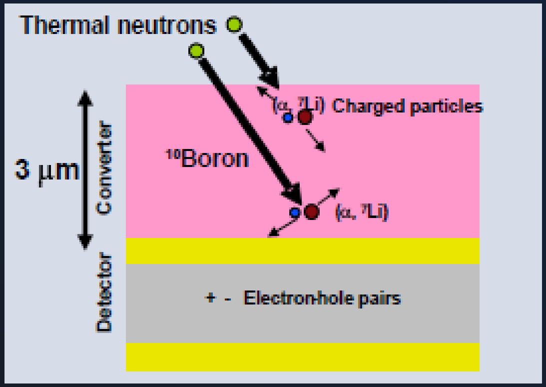
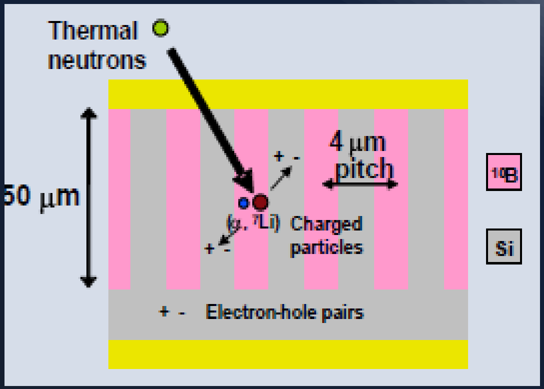
- Silicon is not sensitive to neutrons but is a well known radiation detector
- Need neutron reactive converter materials usually deposited on the surface thin films or different geometries
- With reference to ^{10}B converter:
  - 90% capture in 43 µm
  - Range of reaction products 2-5 µm

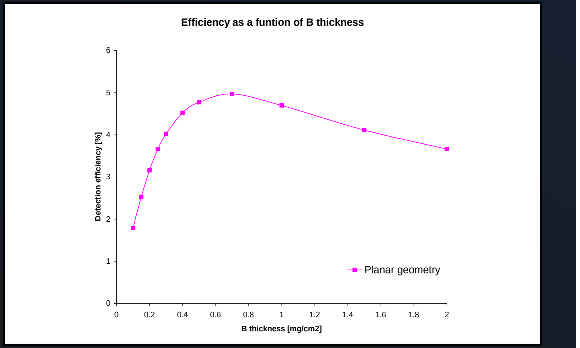


J. Phys.: Condens. Matter **22** (2010) 443201 (32pp)

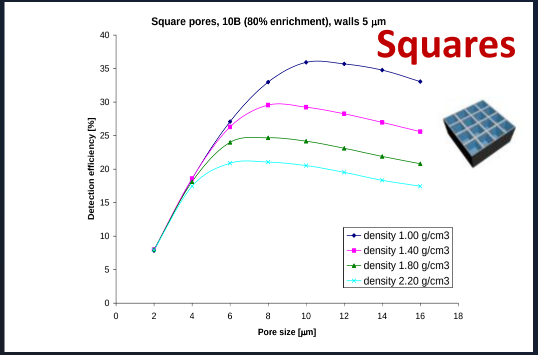
Uher et al. Nuclear Instruments and Methods in Physics Research A 576 (2007) 32–37







Amorphous ^{10}B, enrichment 80%
Efficiency < 5%

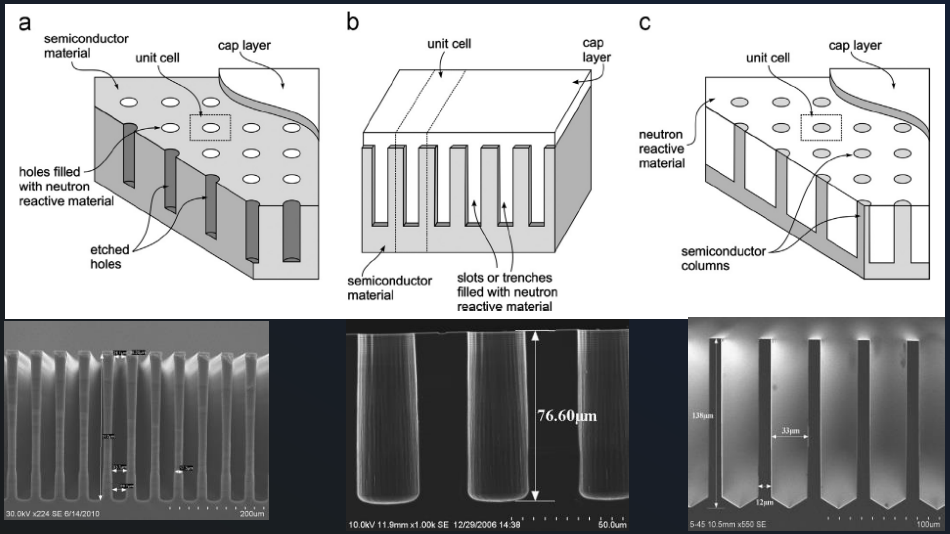


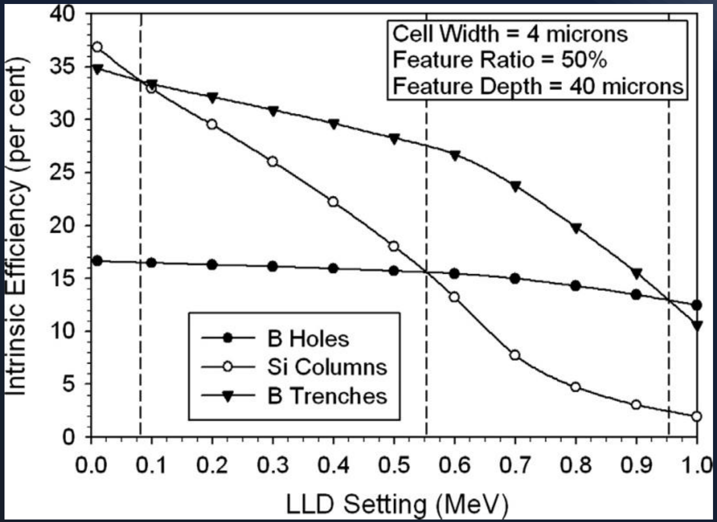
Efficiency up to 36%

Neutron cross sections of some common n-reactive materials

Micro-structured Semiconductor Neutron Detectors (MSND)

D. McGregor et al., J. Crystal Growth 379 (2013) 99





- Extended interaction surface, and higher probability for reaction products to enter the semiconductor
- Different shapes and geometries

Comparison of efficiencies as a function of feature size, as measured by its cell fraction, for hole, trench and column designs with unit cell dimensions of 4 um and feature depths of 40 um. ^{10}B is the back fill material and the LLD was set for 300keV

Maximum efficiencies reported ~50%

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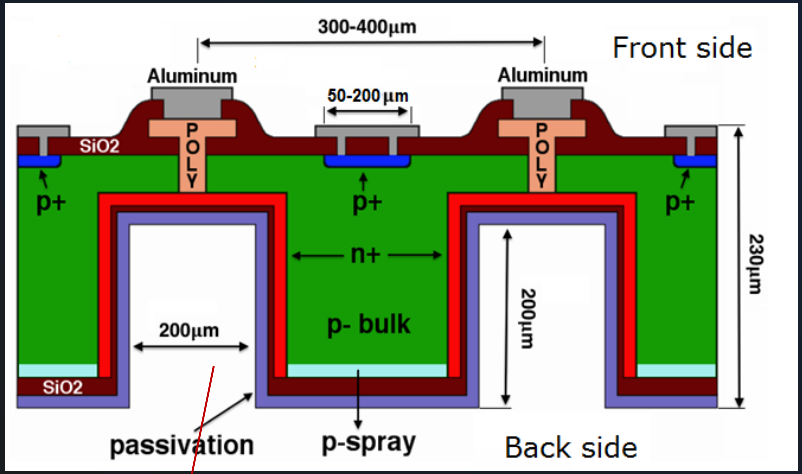
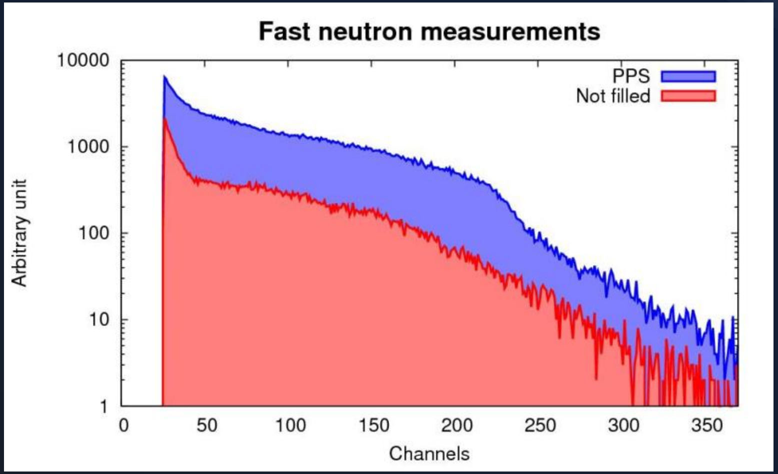
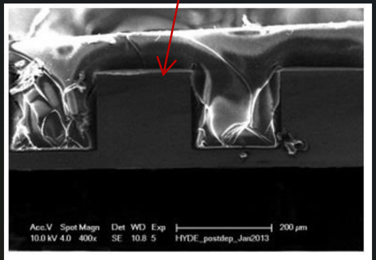
3D with Poly-Syloxane

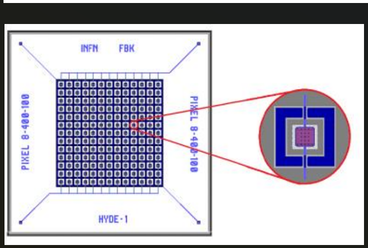
(GF Dalla Betta , A. Quaranta,
The University of Trento, M. Boscardin FBK)

R. Mendicino et al. JINST_029P_0114









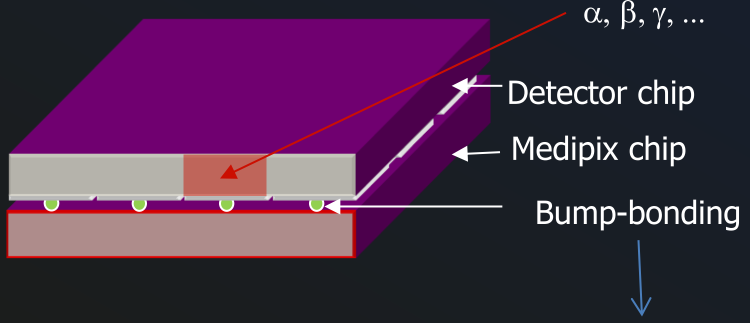
- Hybrid detectors obtained by pouring polysiloxane scintillators into cavities of 3D silicon sensors
- Increase of the active interaction volume for neutrons, giving higher detection efficiencies compared to planar sensors
- Reaction products detected in 3D silicon sensors, coupling to a multiplication photo-detector for the detection of the scintillation light

The readout electronics (T. Slavicek, S. Pospisil, Prague Technical University)

Medipix (count)/Timepix (Time over threshold) readout architectures

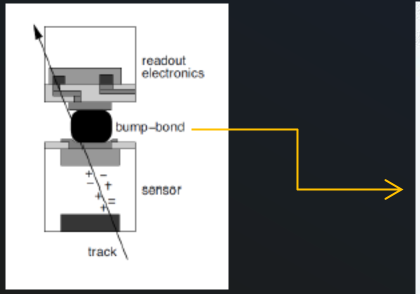
- Pixels: 256 x 256
- Pixel size: 55 x 55 μm^2
- Area: 1.5 x 1.5 cm^2

3D (CNN)+Medipix

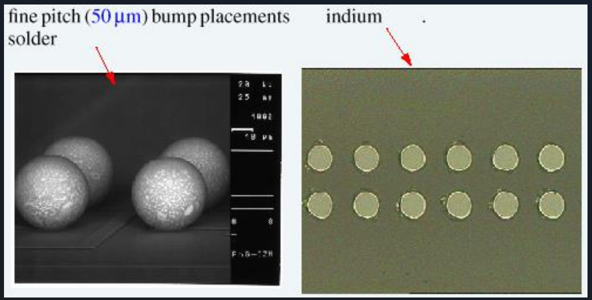


Each pixel:

- amplifier
- double discriminator
- and counter



Bump-bonding hybridization



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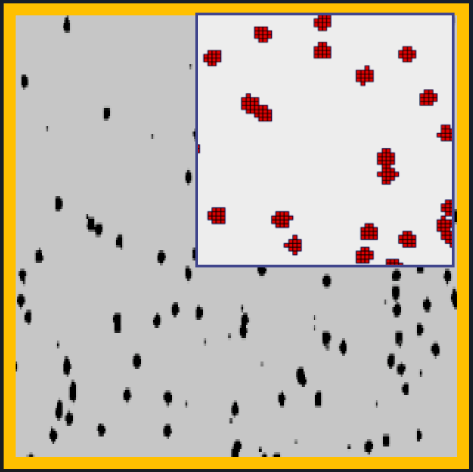
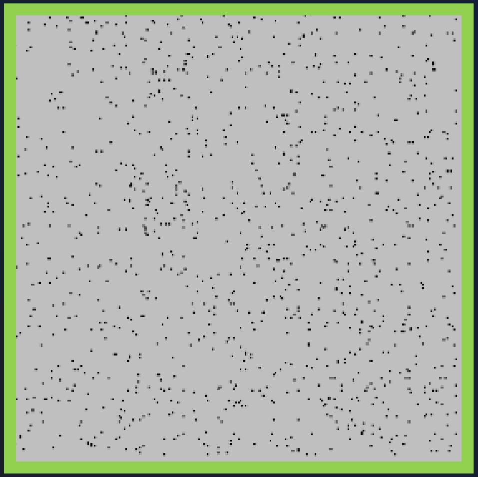
Timepix detector operation

Equivalent results with planar and 3D sensors with less charge sharing for the latter

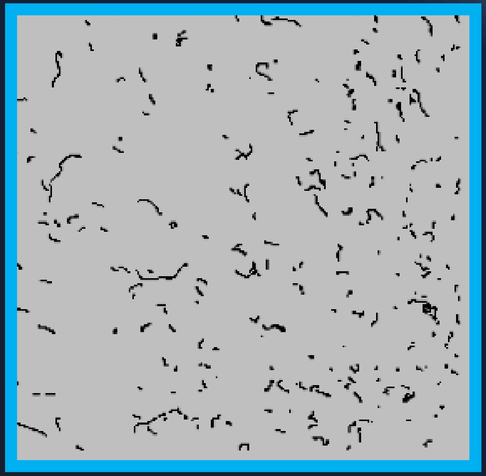
α



5 KeV X-rays



2MeV electrons



- ◆ ^{241}Am alpha source gives clusters of ~5x5 pixels measured with the MEDIPIX-USB device and a 300 µm thick silicon sensor. The clusters are shown in detail in the inlet. The cluster sizes depend on particle energy and threshold setting.
- ◆ Signature of X-rays from a ^{55}Fe X-ray source. Photons yield single pixel hits or hits on 2 adjacent pixels due to charge sharing.
- ◆ A ^{90}Sr beta source produces curved tracks in the silicon detector.
- ◆ A pixel counter is used just to say “YES” if individual quantum of radiation generates in the pixel a charge above the pre-selected threshold

Slide from: Stanislav Pospíšil, VERTEX 2013, 16-20 Sept 2013, Hotel Schlossberg, Lake Starnberg, Germany

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Particle identification by track pattern recognition

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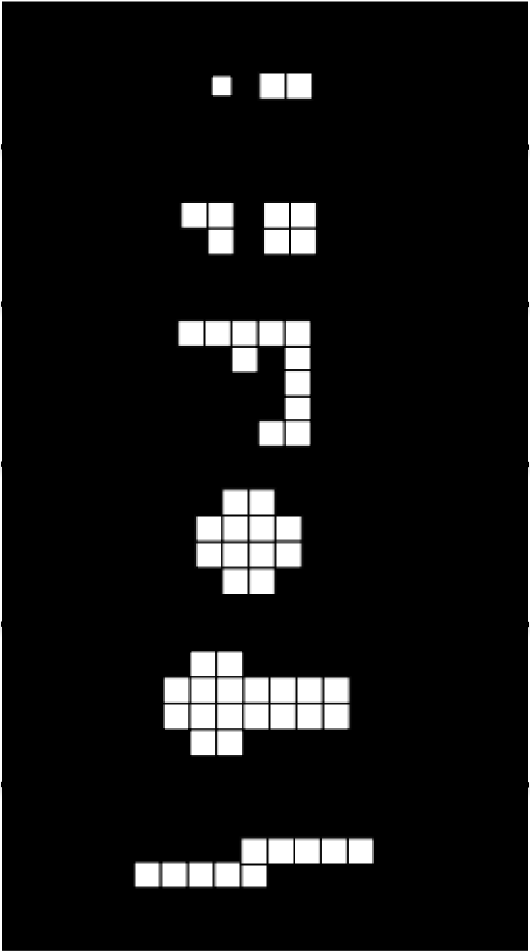


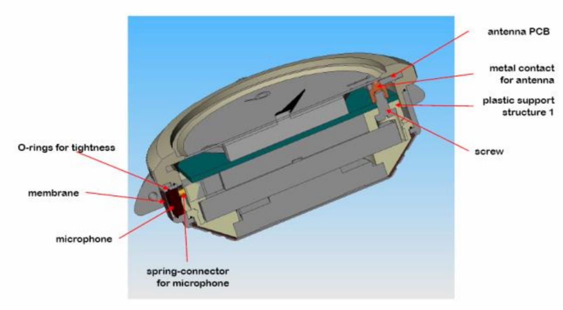
1) Dot	Photons and electrons (10keV)
2) Small blob	Photons and electrons
3) Curly track	Electrons (MeV range)
4) Heavy blob	Heavy ionizing particles with low range (alpha particles,…)
5) Heavy track	Heavy ionizing particles (protons,…)
6) Straight track	Energetic light charged particles (MIP, Muons,…)

Slide from: Stanislav Pospíšil, VERTEX 2013, 16-20 Sept 2013, Hotel Schlossberg, Lake Starnberg, Germany

Wireless communication for Vertigo

csem centre suisse d'électronique et de microtechnique

jean-dominique.decotignie@csem.ch

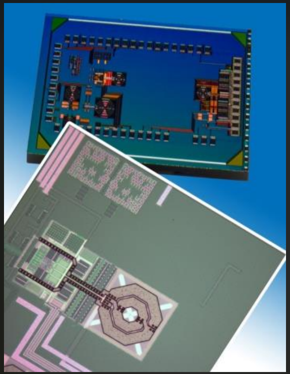


Key challenges:

- Lowest energy consumption to reduce weight
- High bandwidth
- In-door localization (if needed)
- Size
- Radiation tolerance

The idea is not to redevelop a new solution but reuse and combine

- Bluetooth low energy for normal communications
- WiFi for camera streams (turned-on only when needed)
- In-door localization (TBD)



90nm RF chip (2010)

65nm RF circuits (2010)

low-energy radio in 90nm (2.4 GHz)
low-energy radio in 65nm (2.4 GHz)

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The micro-cooling system

A. Cioncolini, Manchester University
P. Petagna, CERN

Power dissipation for a system like Vertigo could well exceed 10W
(Medipix dissipates 1W/cm^2 alone)

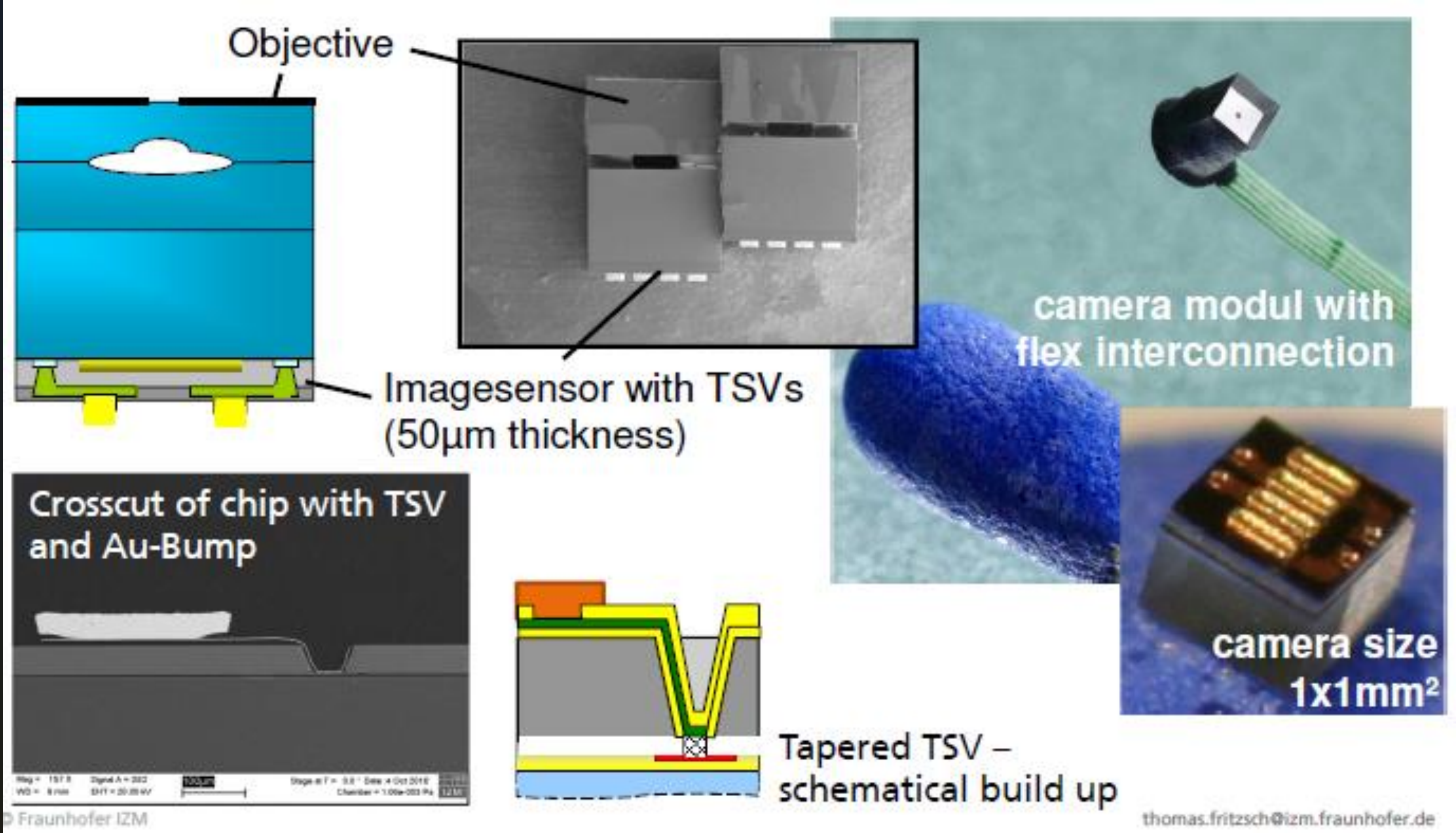
1) **Liquid cooling** (up to 50-100 W)

○Forced liquid flow with micropump;
○Air heat sink;
○Cooling micro-channels in laminar flow;
○Heat transfer enhancement:
    ○Channels surface morphology (3D printing);
    ○Secondary flows promotion (bending);
    ○Nanoparticles seeding.

3D printed prototype
Manchester

Micro-pump:
Weight: few grams;
Power consumption: less than 1 W;
Size: 10x10x20 mm3;
Cost: tens of €

Example of integrated camera



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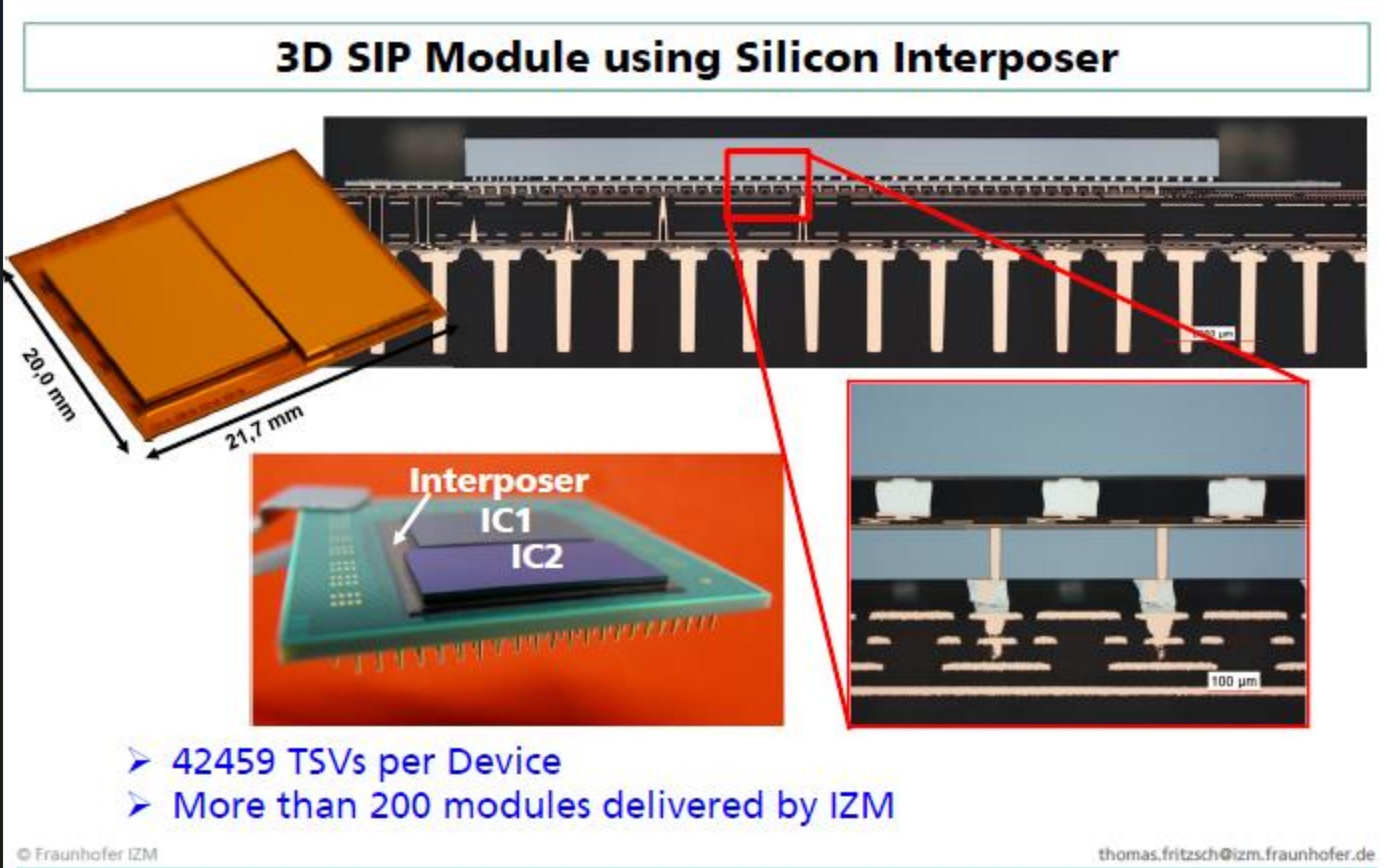
Integration and Packaging

T. Fritzsch

Example of a System in a Chip developed at IZM, Berlin



3D SIP Module using Silicon Interposer

- 42459 TSVs per Device
- More than 200 modules delivered by IZM

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thomas.fritzsch@izm.fraunhofer.de

Movable systems

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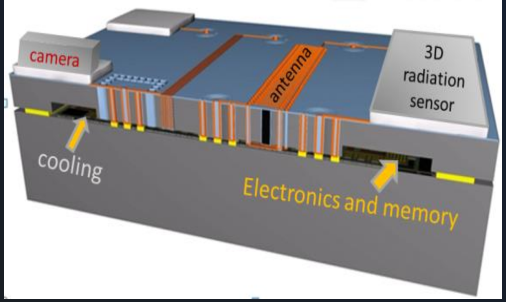
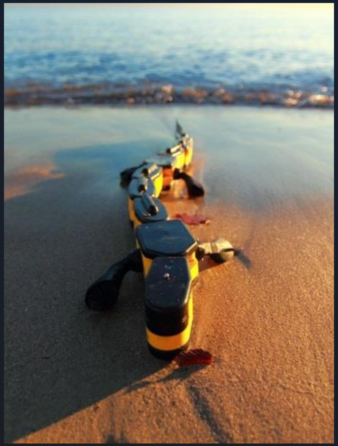
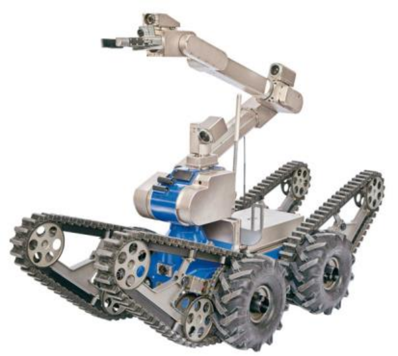




Salamandra
Robotika

Kostas Karakasiliotis,
Biorobotics
Laboratory, EPFL.

Telerob
Telemax



Robobusiness May 2014
CERN Future Strategy
Keith.Kershaw@cern.ch

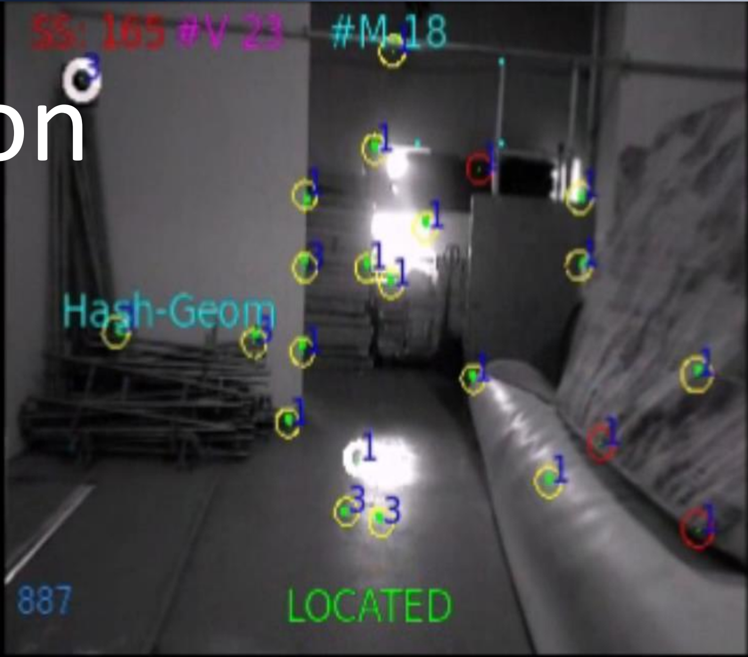
PROJECT RISER

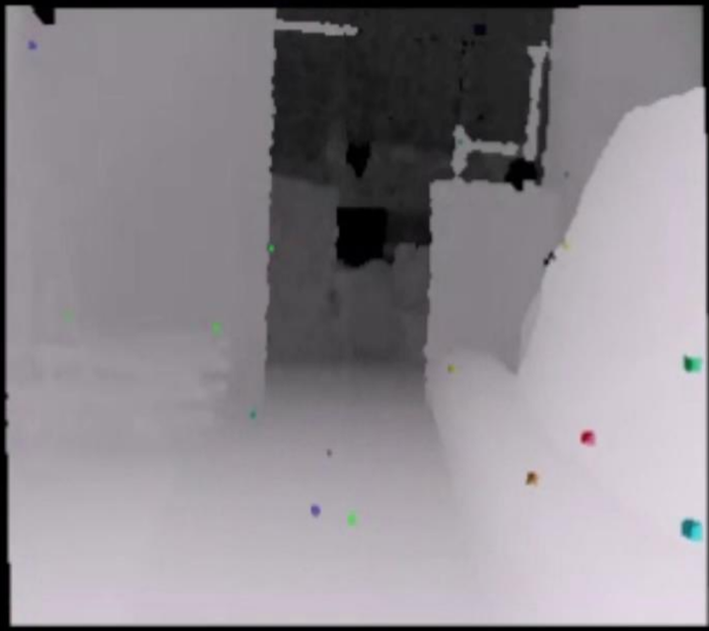
Remote Intelligence Survey Equipment for Radiation

BLUEBEAR

CREATEC

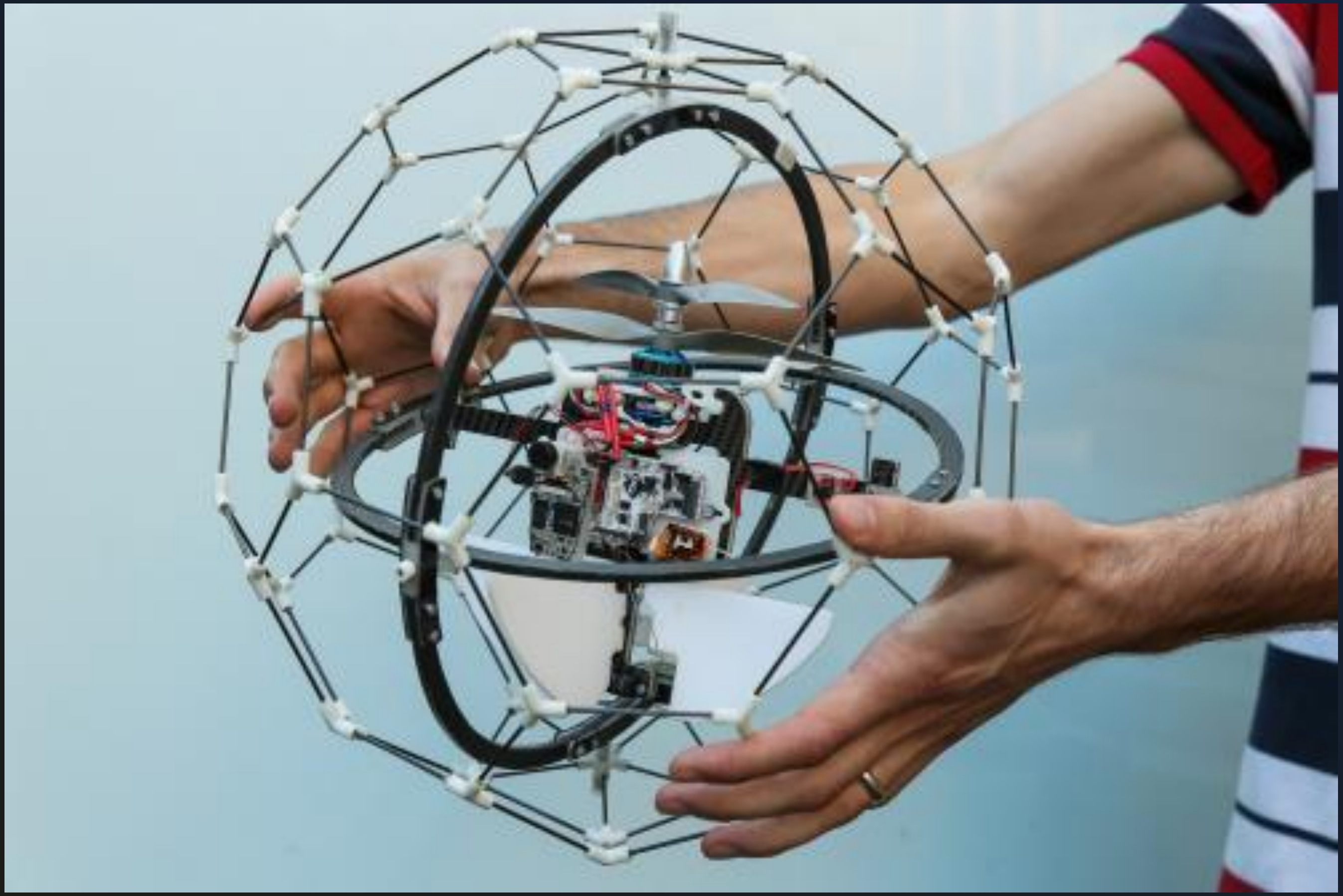
Visual Navigation





GimBall is equipped with a passively rotating protective cage, which keeps it stable even during collisions. It can therefore fly in very cluttered environments without fearing contacts.

Briod Adrien EPFL



Salamandra robotica II

@ Innorobo 2013

Swimming to walking transition

Biorobotics Laboratory EPFL

Plans

We plan the design, fabrication and test of novel autonomous and movable 3-dimensional heterogeneous integrated microsystem composed by:

- Active multiple-particle, radiation-hard sensors
- Fast high resolution pixellated readout electronics,
- Embedded novel converting materials for neutron, detection
- Overlapped visualization and radiation map
- Wireless high-band communication systems
- Realtime monitoring

For radiation monitoring in harsh environments.

- ➢ Most of the components and integration methodology exist.
- ➢ We target a weight of 200g but intermediate prototypes are possible today
- ➢ We are working on the submission of an EU H2020 grant in 2015