FONDAZIONE BRUNO KESSLER

SENSORS AND DEVICES

Micro- and Nano- Fabrication & Quantum Technology: Towards Applications

Prof. Richard Hall-Wilton

FBK-SD director

...from Sweden

Aim of the talk

First talk was about looking at the data acquisition system as a whole …
- How this fits into the whole for a particular application ….

In this talk, will looking towards Sensing ….
- i.e. front-end input into the DAQ pipeline …
- Creating the data that can be used

- Will concentrate on Silicon and related technologies …
- … Scalability …

- As last time, will use FBK as an example of how this works in this sector …

Presentations
2 different perspectives

Micro-Nano Facility at the FBK Sensors & Devices Centre

Top-down overview: Outline of FBK SD centre from a helicopter view

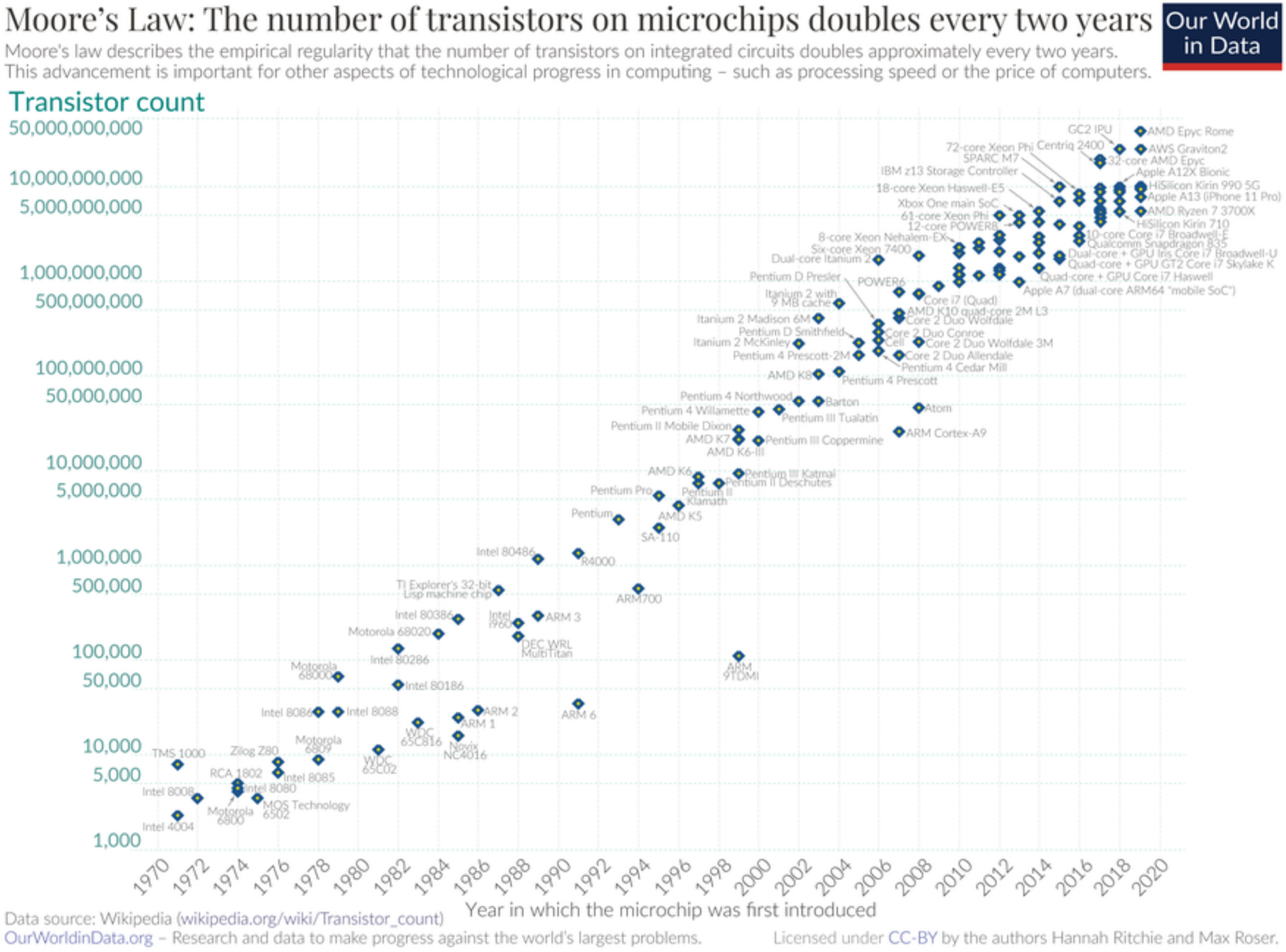
Quantum Technology: The Sensors & Devices Niche

Application focussed on providing sensors & devices to enable quantum science

An invitation to take different perspectives on how
you approach the challenges in your research

Scalability
Moore's Law

- Incredible rate of growth
- Accompanied by ability to scale to huge volumes of production
- AI is going through a comparable scaling now …?
- Quantum just starting…?
- Silicon et al. is a huge area divided into 1 000s of niches …

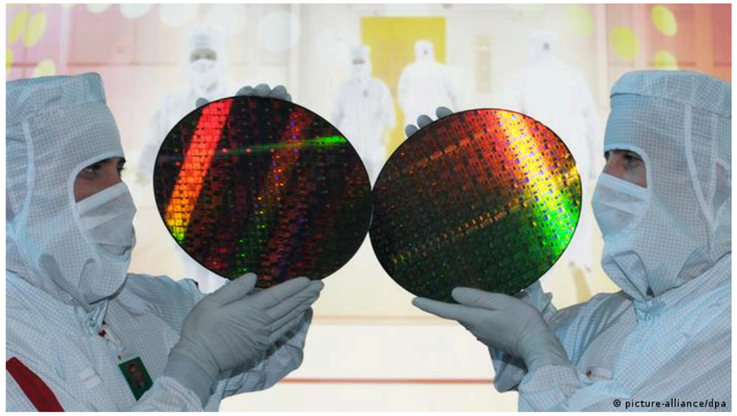


… highly topical themes …

BUSINESS

The EU's microchip dilemma: Too little or too late?

The EU is running low on semiconductors — advanced chips used in smartphones, medical devices and more — exposing its vulnerability to the vicissitudes of the China-US trade war. The bloc plans to change that. Can it?



Chipmaker GlobalFoundries is part of the Cool Silicon cluster in Dresden, Germany

The European Union said in March it planned to more than double microchip manufacturing output in the 27-member bloc to 20% of the global market by 2030. The announcement came after a supply crunch disrupted production earlier this year, in particular for German auto manufacturing, the key industry in Europe's most important economy.

Chip shortages led to a million fewer cars — 5% of total production — being produced in the first quarter of 2021 as compared with the same period a year earlier, according to market analyst IHS Markit.

The bloc's ambitious "Digital Compass" plan is based on an investment of €140 billion ($166 billion) in the digital sector over the next two to three years. Brussels also wants EU firms to step back into the

Date 29.04.2021

Author Jo Harper

Related Subjects European Union (EU)

Keywords microchips, chips semiconductors, bottlenecks, shortage, EU

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An official website of the European Union How do you know?

BLOG POST | By Thierry Breton | 15 September 2021

How a European Chips Act will put Europe back in the tech race

The world is short of semiconductors.

The shortage of semiconductors – also known as chips – has very concrete consequences on the EU economy, jobs and even leisure. Carmakers postpone the production of vehicles. Broadband providers run out of Internet routers. Gamers cannot get their hands on next-gen consoles.

The situation might last for a while. Semiconductors are at the core of our world's digitisation, but global supply is currently struggling to meet the explosion of demand driven by smartphones, Internet of Things and connected cars.

But it is not only about supply and demand.

Semiconductors are at the core of the global technological race

Semiconductors are at the centre of strong geostrategic interests, and at the core of the global technological race.

Superpowers are keen to secure their supply in the most advanced chips as they are well aware that it will condition their capacity to act (militarily, economically, industrially) and drive digital transformation.

Chips are a strategic component of any industrial chain. **The race for the most advanced chips is a race about technological and industrial leadership.**

https://ec.europa.eu/commission/commissioners/2019-2024/breton/blog/how-european-chips-act-will-put-europe-back-tech-race_en

- The silicon crisis has been front page news
- This is an opportunity
- Message: this is solved by having <u>a strong ecosystem backed up by research</u>
- This leads to the capacity to solve it

Since 2 years … now EU chips act, US, …

- Semiconductors, Nanotechnology, small scales and low dimensional materials are very topical
- The ability to look at these scales and these topologies makes this relevant

David Selbert, pexels

Ubiquitous Sensors …

Sensors	Face ID
	LiDAR Scanner
	Barometer
	High dynamic range gyro
	High-g accelerometer
	Proximity sensor
	Dual ambient light sensors

Location	Precision dual-frequency GPS (GPS, GLONASS, Galileo, QZSS, and BeiDou)
	Digital compass
	Wi-Fi
	Cellular
	iBeacon microlocation

Source: apple

- + microphone
- + butttons
- + magsafe
- +++

Ubiquitous Sensors …

- + video
- + true depth camera …

Camera	Pro camera system
	48MP Main: 24 mm, ƒ/1.78 aperture, second-generation sensor-shift optical image stabilization, seven-element lens, 100% Focus Pixels
	12MP Ultra Wide: 13 mm, ƒ/2.2 aperture and 120° field of view, six-element lens, 100% Focus Pixels
	12MP 2x Telephoto (enabled by quad-pixel sensor): 48 mm, ƒ/1.78 aperture, second-generation sensor-shift optical image stabilization, seven-element lens, 100% Focus Pixels
	12MP 3x Telephoto: 77 mm, ƒ/2.8 aperture, optical image stabilization, six-element lens
	3x optical zoom in, 2x optical zoom out; 6x optical zoom range; digital zoom up to 15x
	Sapphire crystal lens cover
	Adaptive True Tone flash
	Photonic Engine
	Deep Fusion
	Smart HDR 4
	Portrait mode with advanced bokeh and Depth Control
	Portrait Lighting with six effects (Natural, Studio, Contour, Stage, Stage Mono, High-Key Mono)
	Night mode
	Night mode portraits enabled by LiDAR Scanner
	Panorama (up to 63MP)
	Photographic Styles
	Macro photography
	Apple ProRAW
	Wide color capture for photos and Live Photos
	Lens correction (Ultra Wide)
	Advanced red-eye correction
	Auto image stabilization
	Burst mode
	Photo geotagging
	Image formats captured: HEIF, JPEG, and DNG

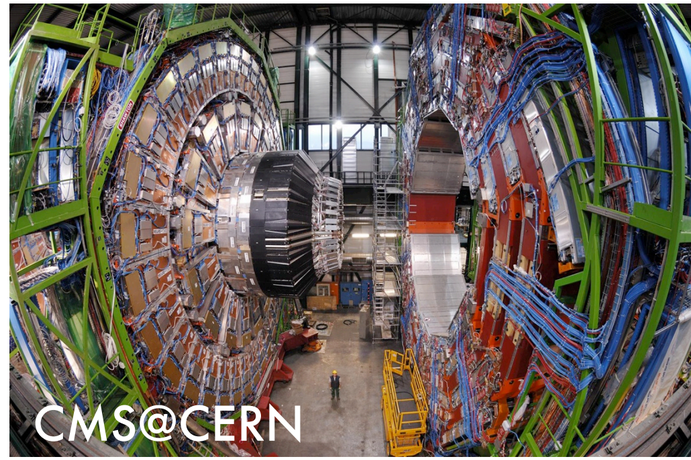
- Note the combination of sensors & software

Source: apple

Sensors are completely ubiquitous in modern life

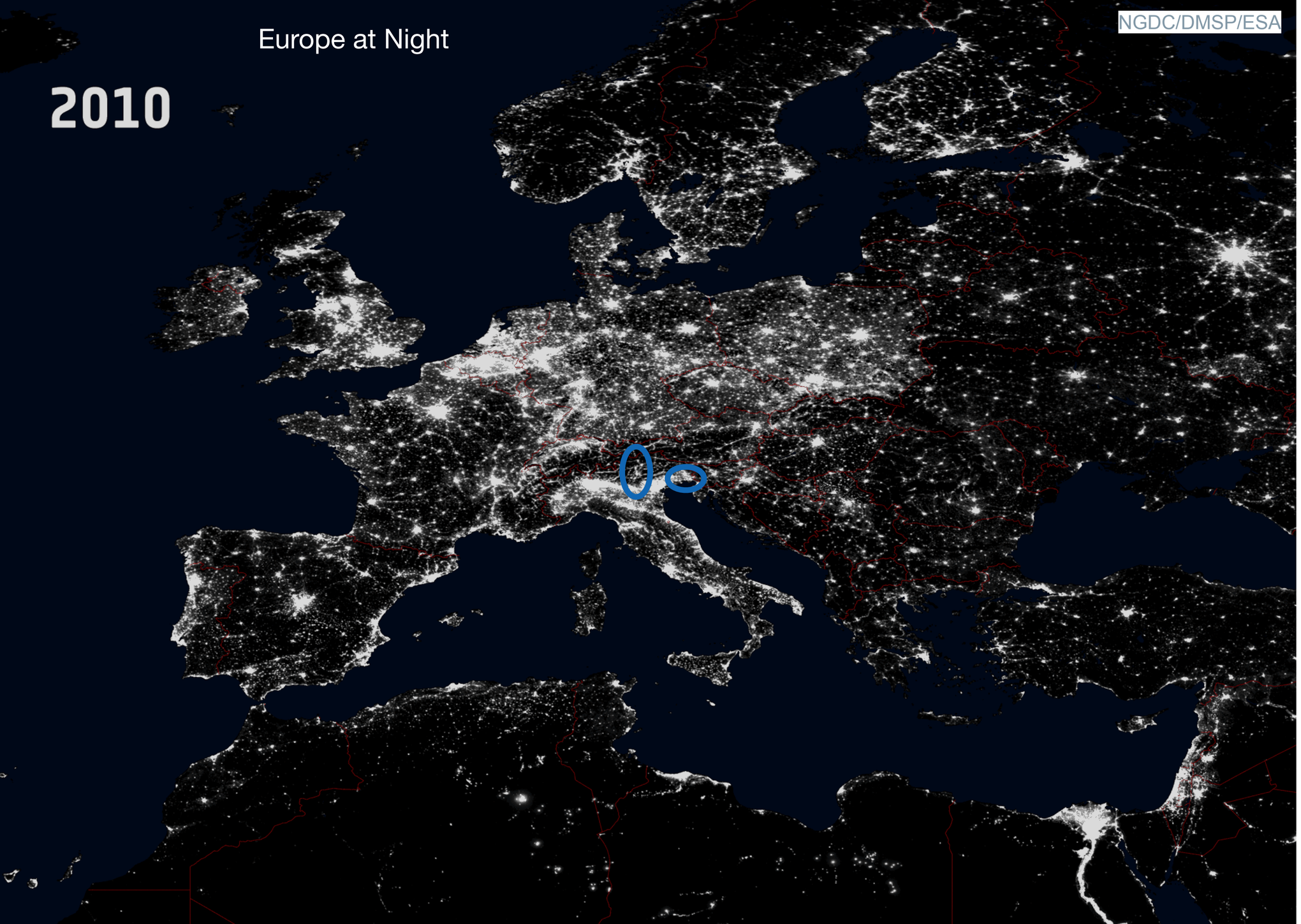
Instrumentation

What camera you use has a big impact on the quality of photos that you get out of it …



Bleeding edge Instrumentation enables novel and future science

FBK Sensors & Devices Centre & Micro- Nano-Facility



- Trento is on one of the main north - south Europe routes
- Region close to Austria and Switzerland

Trade routes and borders are drivers of ideas and creativity

Fondazione Bruno Kessler

About us

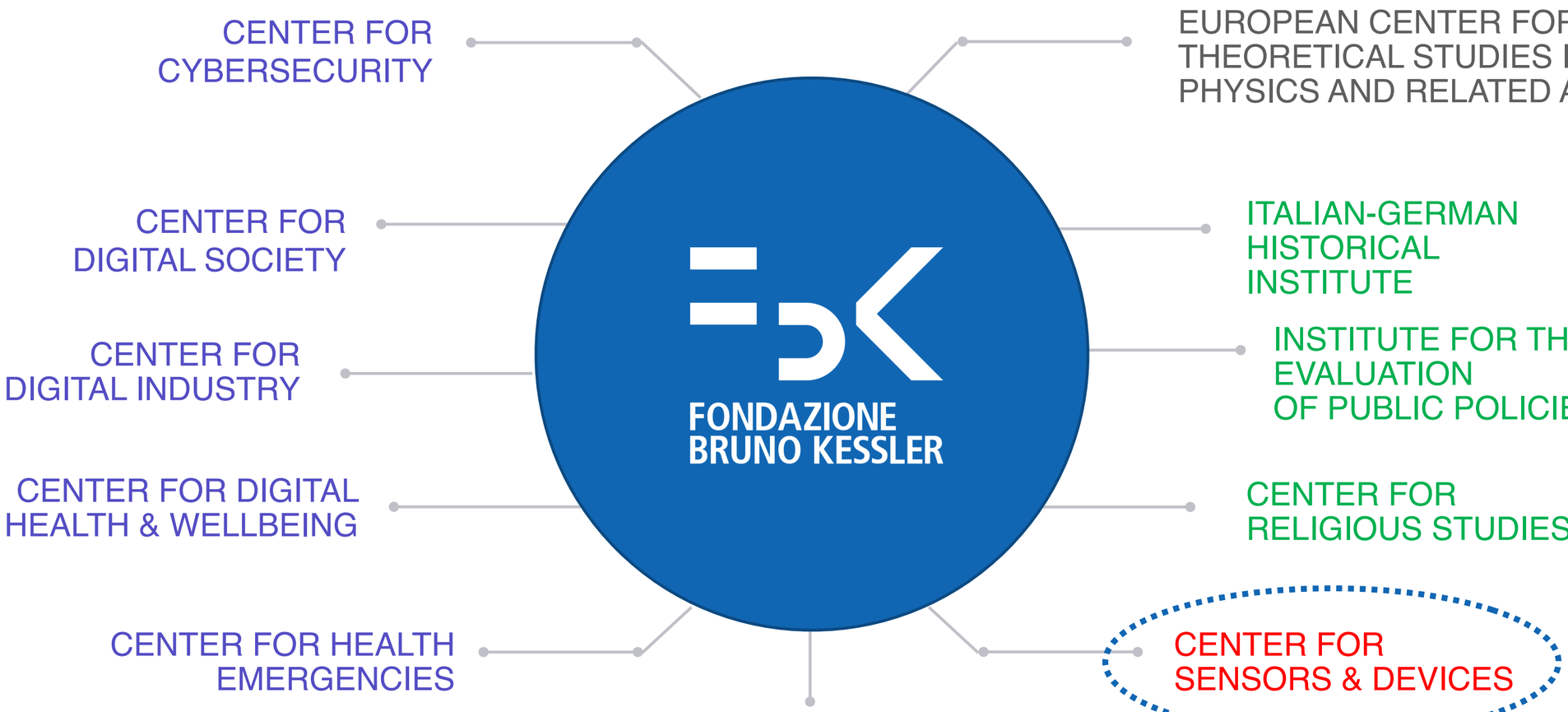
PROFILE

Fondazione Bruno Kessler (FBK) is a research not-for-profit public interest entity result which is 60 years old

MISSION

FBK aims to excellence in science and technology with particular emphasis on interdisciplinary approaches and to the applicative dimension.

FBK
Research Centres



FBK-Sensors & Devices Centre
at a glance

20 mil €
ANNUAL BUDGET

130+
PUBLICATIONS/YEAR

65 Researchers
20 Technicians
20 PhD

100+
EMPLOYEES

65+
ACTIVE FINANCED PROJECTS

20 EU projects

6
RESEARCH UNITS
+ Partnership with CNR

2
MAIN INFRASTRUCTURES
(MicroNanoFacility + Labssah)

40+
COMPANY COLLABORATIONS
Inc. 1 newco

41
ACTIVE PATENTS

Sensors and Devices Centre

sensors

a device that is used to record that something is present or that there are changes in something

devices

an object or machine that has been invented for a particular purpose: an electronic device

Cambridge English dictionary

Bleeding Edge Sensors and Devices based around technological platforms

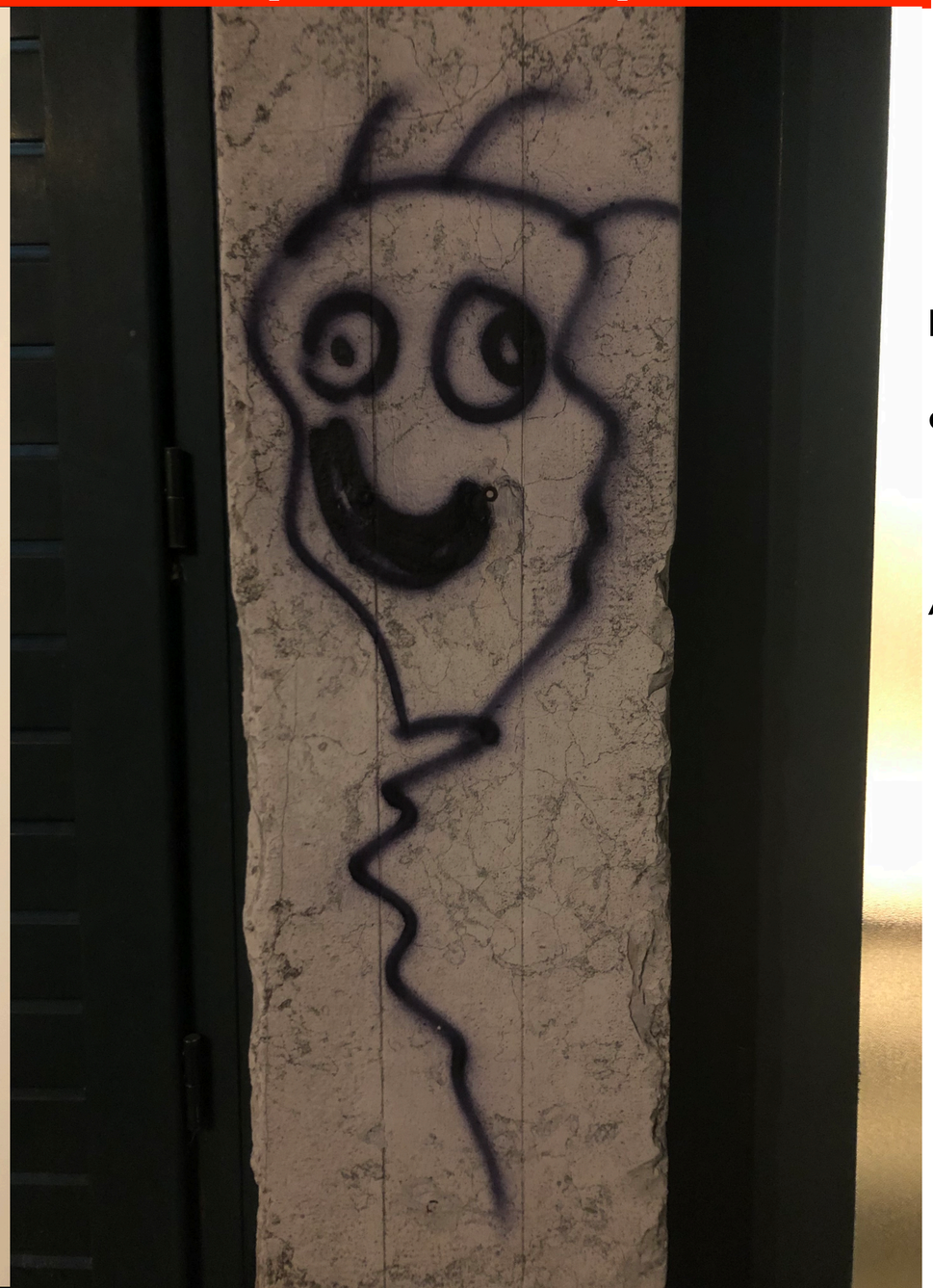
Scalable: silicon et al. fabrication techniques

Contribution across the development chain: ideation to fabricate in-house to bring to market

For science and society

Development Philosophy: *Unique capability*

… capability is only limited by creativity …



In terms of capability, this means:

- processing capabilities of silicon to a very fine scale
- crafting features
- ability to scale

Ability to create:

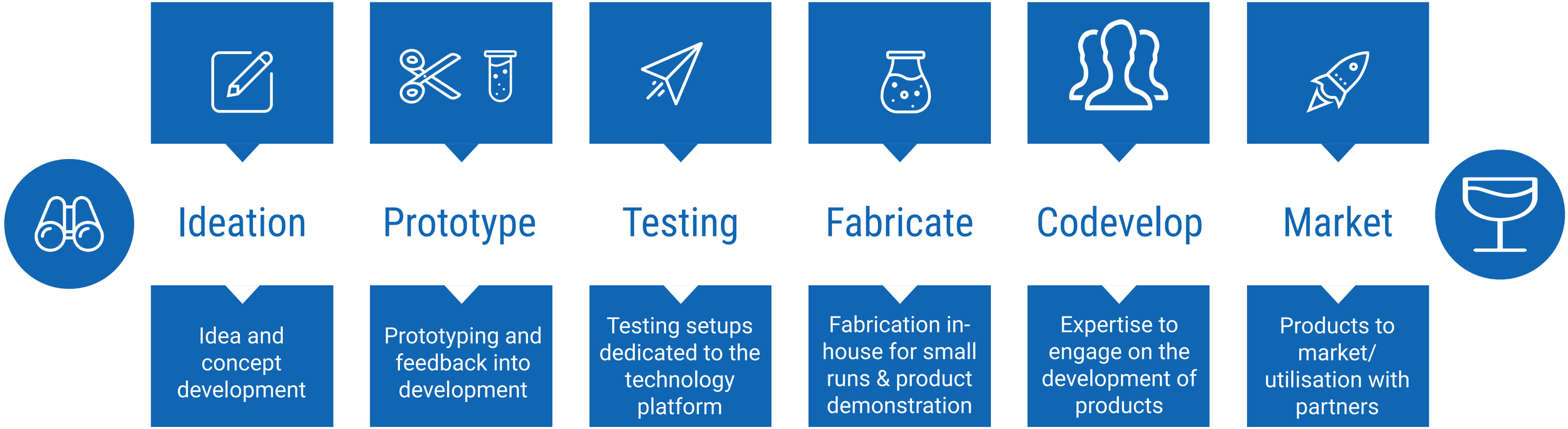
- 1D features of considerable length
- 2D features
- 3D designs and integration

"Sculpting on silicon"

- Collaboration is typically needed with the application experts

SD Centre Modus Operandi
Technological Platforms

The technology platforms have expertise over the whole development chain



Feedback loop: advances in the technology platforms lead to seeds for the idea creation

This represents a unique capability from the centre to collaborate and contribute at any and all stages of the development chain

SD Centre
Scientific Pillars

Quantum Technology

Space Industry & Big Science

Health & Environment

Industry

Training

Dissemination

SD Centre
Technological Pillars

Integrated Optics

Silicon Radiation Detectors: strip, pixel, SDD, LGAD, 3D, …

SiPMs

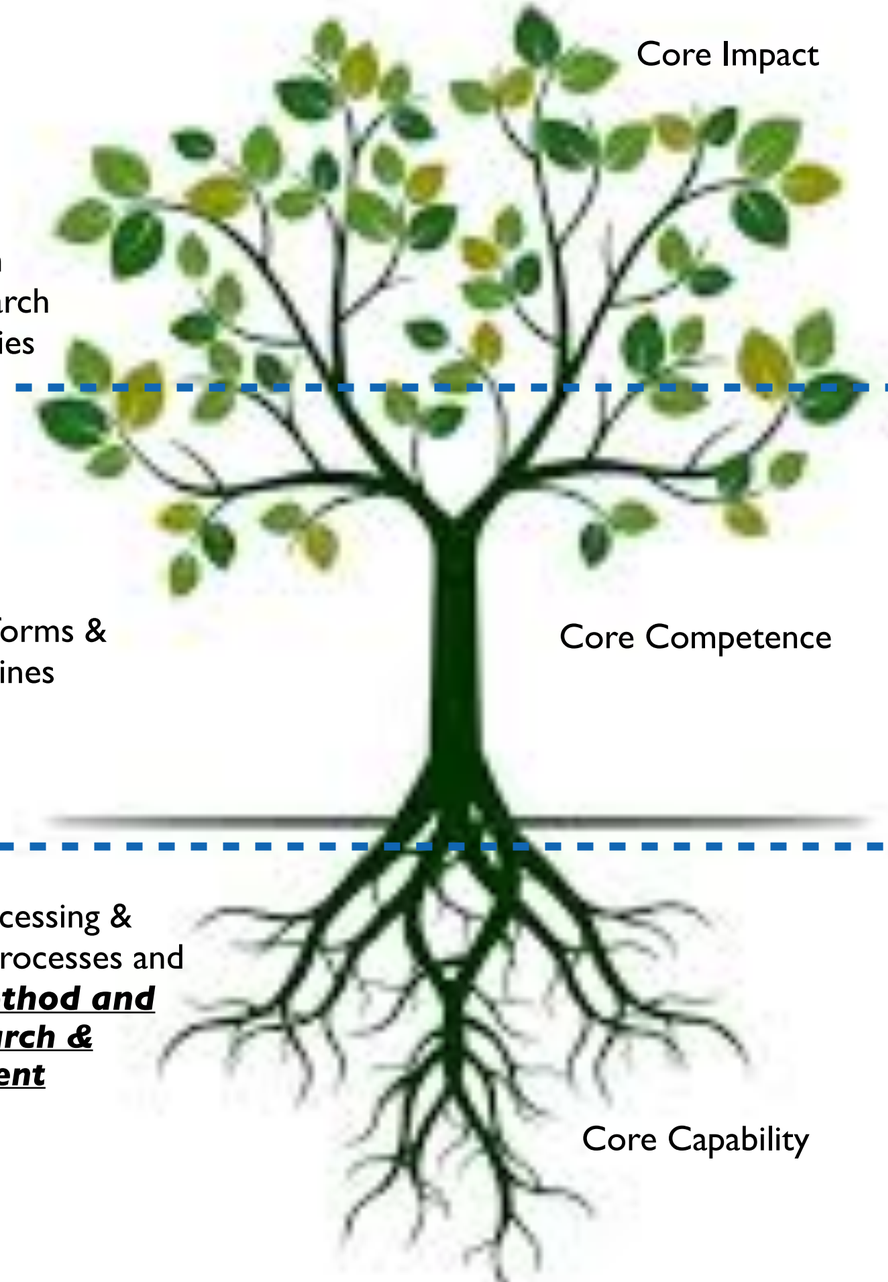
CMOS: SPADs, MAPs, ASICS, …

MEMs and Mechatronics

Surface Interfaces

Superconducting devices: Bolometers, Josephson junctions, Josephson Parametric Amplifies, SQUIDs, …

FBK-SD Centre - How does it fit together?



Core Impact

Impact through Applications: research fields and industries

Quantum Technology

Industry

Environment & Health

Big Science (Space Industry, HEP, …)

Training, dissemination, …

Applications are vast and disparate
Collaborations (University, RI & Industrial) essential to maximise impact across applications
Expertise in-house to engage in these networks and with the best partners

Technological Platforms & Development lines

Core Competence

Integrated optics, diamond and related materials, integrated optical circuits for QT

SiPM, Pixel&Strip Detectors, LGADs, SDDs, 3D

CMOS-SPADs, ASICS, MAPS

MEMs devices, mechatronics, surface & bio interfaces, Josephson junctions, Brain inspired devices

Laboratories, processing & analysis equipment, processes and quality control, ***method and process research & development***

Core Capability

Detector, MEMS, Integration, testing/dicing, analytical labs
Bio- and optical labs
Expertise on equipment and processes
Expertise&research for process and method development
Quality System for continual improvement

Research capacity & expertise of people

SD Centre
Research Units

Micro- and Nano- Fabrication

Cleanrooms and micro fabrication as well as the analytical capability.

Custom Radiation Sensors

Provide the SiPMs and silicon detectors to a wide range of clients.

Integrated & Quantum Optics

Integrated photonic and quantum systems.

Integrated Radiation & Image Sensors

Imaging sensors designed by CMOS processes and related techniques

Micro Systems Technologies

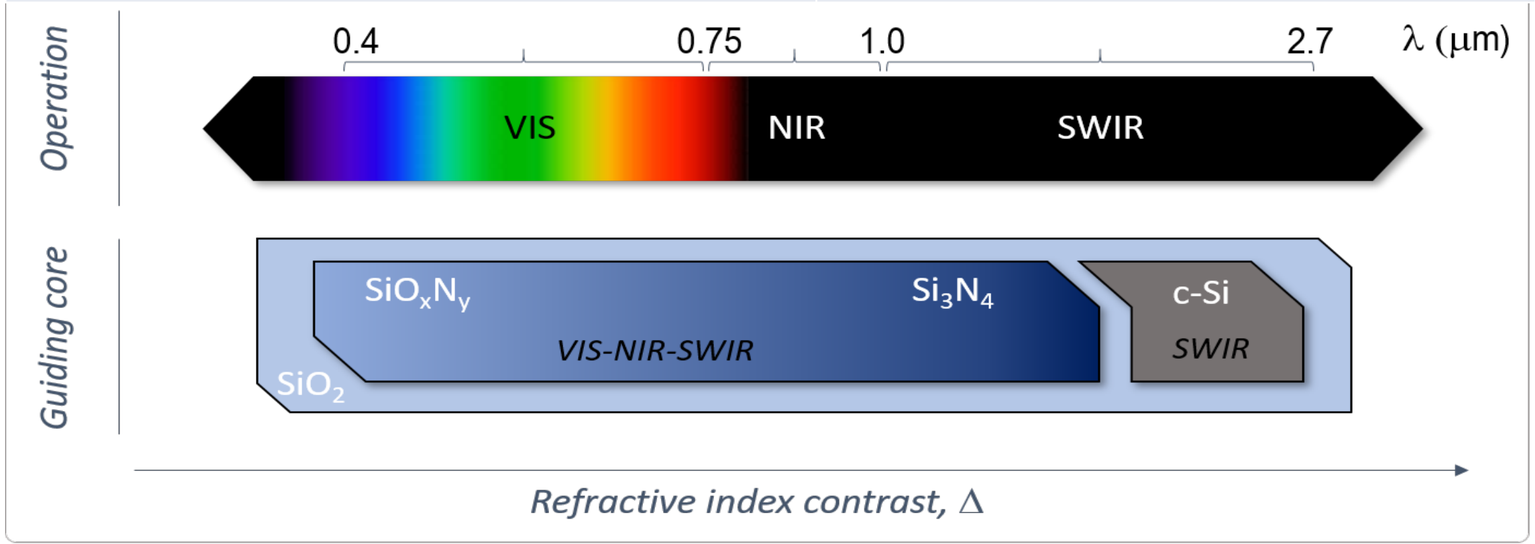
MEMS technology to cover a broad range of application fields, in particular in the mechatronics, health and environment sectors. Responsible for the joint bio-labs.

Project Support & Management

Support unit to enhance research output, enable greater strategic focus, better exploitation of opportunities and effective dissemination.

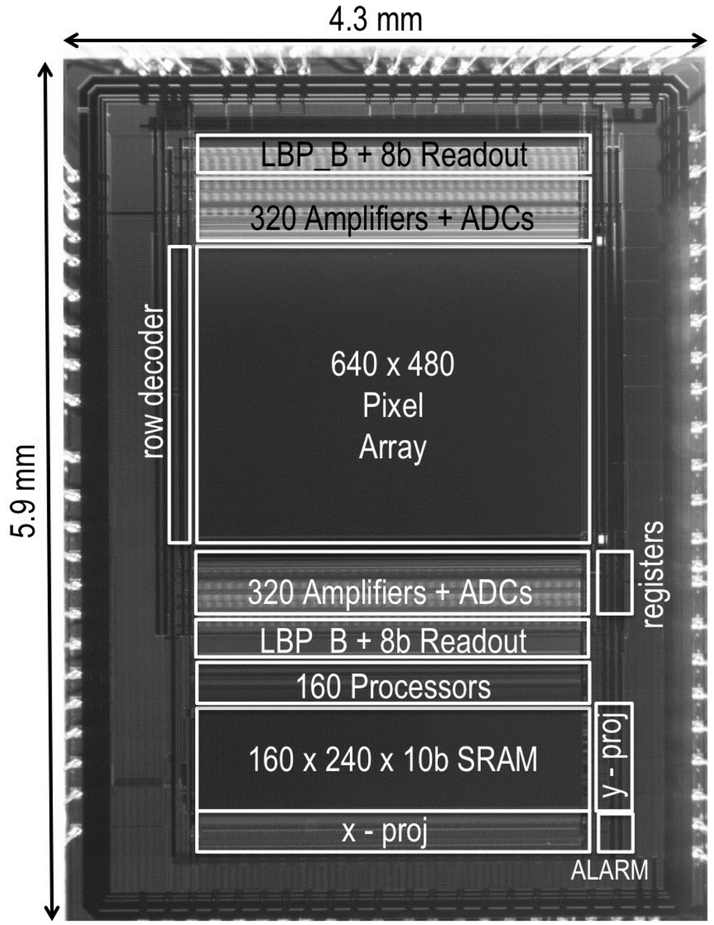
I&QO Custom Products
Photonics and Quantum Technology

Nanomaterials	**Upconversion nanoparticles** TRL 5-6 Nanodiamonds and bulk **diamond with NV centers** TRL 3-4	
Integrated Optics	Integrated **spectral shaper** TRL3 **Evanescent microring biosensors** TRL 3-4 PICs* with **integrated photodetectors** TRL 3 PCB boards, **electrical control circuits** for heater TRL 3-4	SOI based PICs TRL 2 Si3N4 and SiON based PICs TRL 3
Quantum Optics	PiCs for **linear quantum optics** TRL2 PiCs with **integrated single photon counter** TRL2	SOI PICs with **entangled photon generation** TRL 2 Si3N4 and SiON based PICs TRL 3



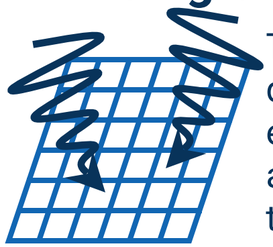
* PIC Photonic integrated circuit

Integrated Readout ASICS and Image Sensors products



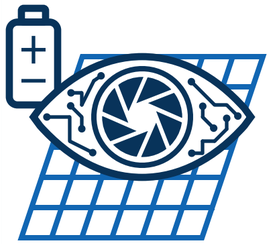
Example of a low-power vision sensor for battery-operated surveillance systems.

Single-photon Imagers



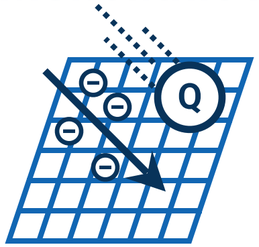
They combine single-photon detectors and high-speed electronics to count photons and measure their arrival time in parallel for each pixel.

Low-Power Vision Sensors



They gather extra information from the scene at chip- or pixel-level to perform complex tasks using a small amount of power.

Monolithic Active Pixel Sensors

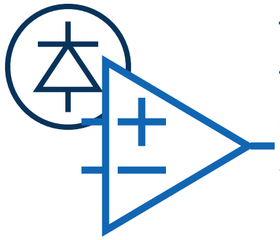


MAPS exploit the interaction of charged particles with matter to measure their energy, position and direction with a low energy budget.

Multispectral, X-ray and THz

They add the wavelength as another variable capable of increasing the information carried by an image, to see things our eye cannot see.

Readout ASICs



They extract the useful signal from custom detectors (SiPM, SDD, strip detectors, 3D SiPM, …), minimizing noise and distortions.

IRIS Technology / Application matrix

IRIS
INTEGRATD READOUT ASICS AND IMAGE SENSORS

	Quantum S&T	Space S&T	Science	Bio-/Medical Food, Health	Security	Industrial / Automotive	Consumer / IoT
Single-Photon imagers	Quantum & ghost QRNG Quantum comm.	[1] **Solid-state LiDAR** Scientific imaging HDR imaging	Time-resolved img Quanta imaging	FLIM, PET, hadron therapy Raman, SPECT, …		LiDAR/d-ToF	3D imaging Depth sensing 2D imaging
Low-Power Vision Sensors		Star-tracking			[3] **Low-power video-surveillance**	High-speed vision	AI-enhanced imaging, HDR
Multispectral, X-ray and THz			Multi-spectral (THz) imaging	X-ray imaging for dental appl.	THz / MIR sensing	[4] **Quality control with THz**	
Monolithic Active Pixel Sensors			Particle tracking for HEP	[2] **Particle tracking for hadron therapy**			
Readout ASICs	Readout ASICs for quantum detectors & photonic circuits	Readout ASICs for SiPM, SDD, InGaAs	Readout ASICs for SiPM, SDD, InGaAs	Air quality monitoring		Self-mixing interferometry	Self-mixing interferometry

TRL LEVEL

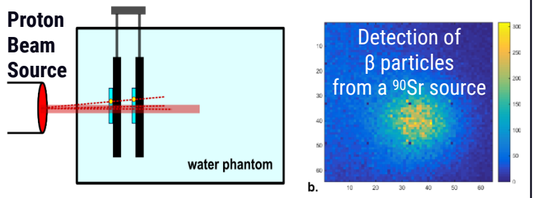
Examples

[1] Solid-State LiDAR

Direct Time-of-Flight depth sensing based on single-photon detectors

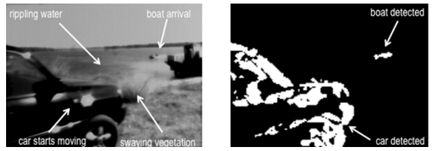
[2] Particle tracking for hadron therapy

Direct detection of charged particles with a low material budget



[3] Low-power video-surveillance

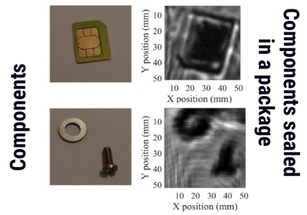
Surveillance of large areas with battery operated devices



Smart motion detection insensitive to standard background variations (sea waves, trees moving)

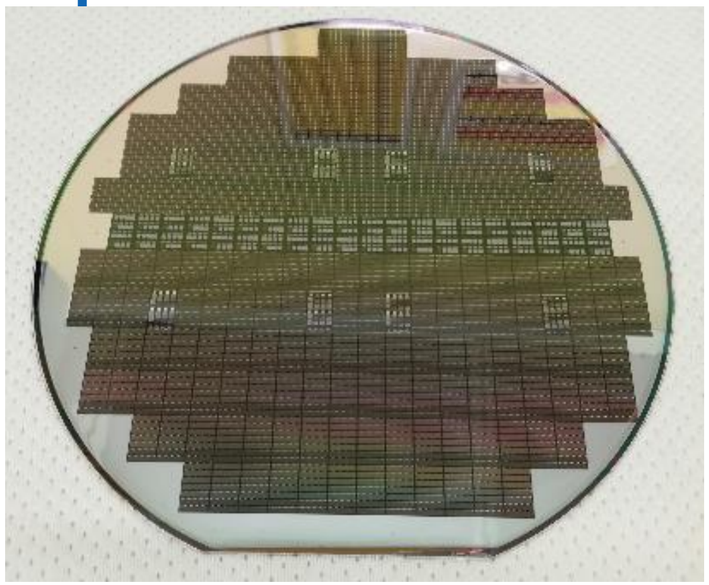
[4] Quality control with THz

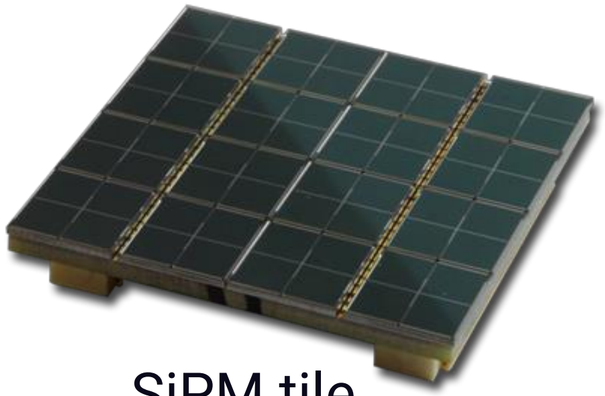
Multi-spectral analysis of packaged components



Custom Radiation Sensors at a glance

CRS CUSTOM RADIATION SENSORS



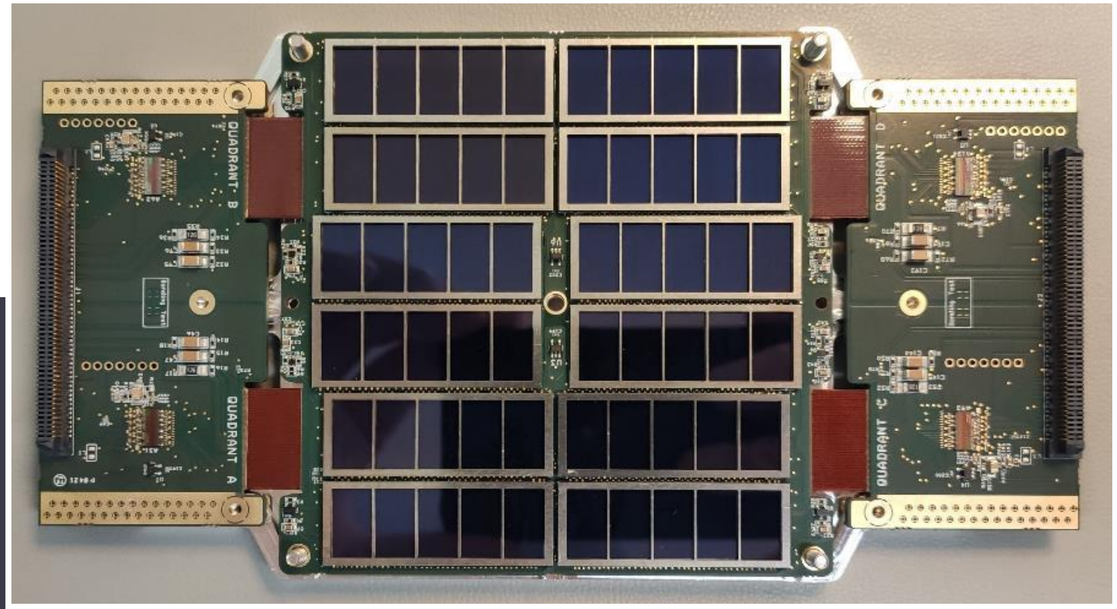


SiPM tile

Applications (amongst others):

Medical Physics

Big Science: High Energy Physics, neutrino physics, …



X/Gamma sensors (SDD produced at FBK) integrated on PCB in FBK with space compliant components (payload of nanostallite constallation)

Space Industry

Mission: Sensors designed and realized to meet vour needs

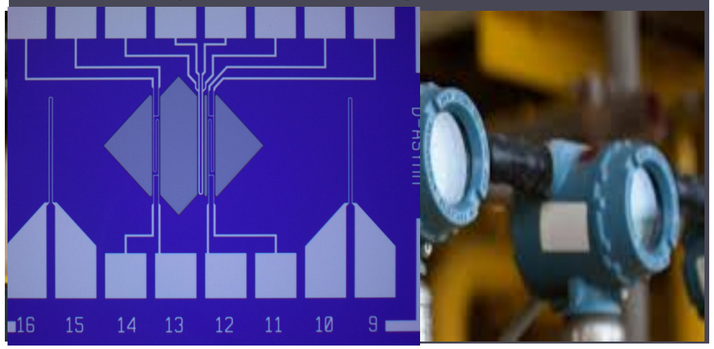
Our mission is highest quality research in the field of radiation sensors to stay at the forefront of the worldwide understanding of the physical processes and the technological developments to provide our partners with leading-edge devices.

MEMS Technology

Flow sensors for Gas Energy metering

Objectives

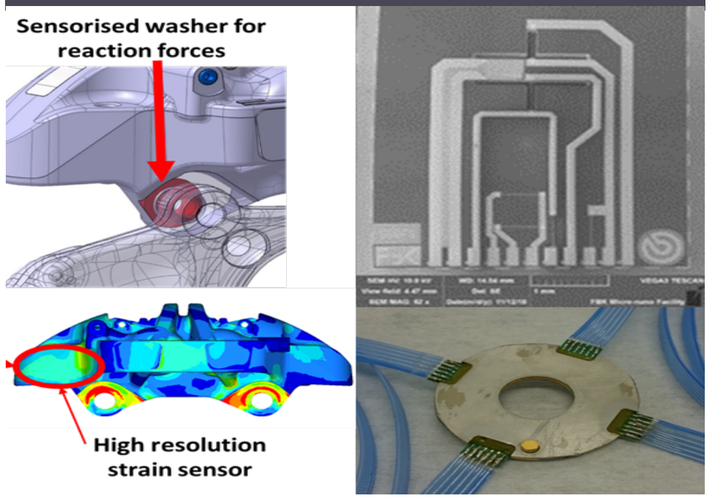
- Measurement of gas quality at the point of delivery, also in the perspective use of hydrocarbons / hydrogen mixtures for residential or industrial use.
- A multisensor MEMS device and an artificial intelligence approach to measure the higher heating value of natural gas



Stress Sensors for the automotive sector

Objective

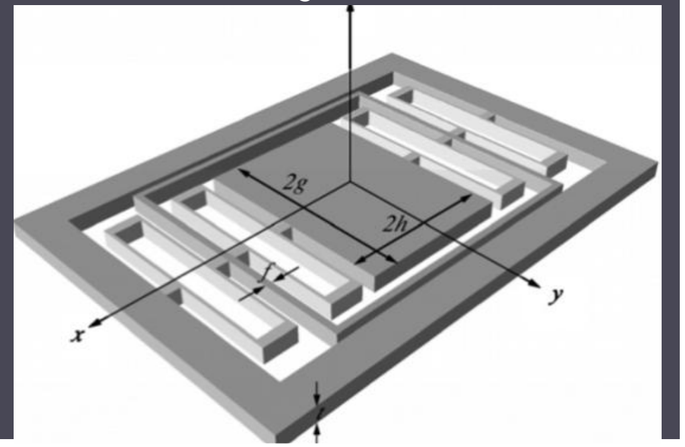
To study MEMS sensors for direct measurement of braking torque.



Nano-g accelerometer for Space satellite (MST/MNF)

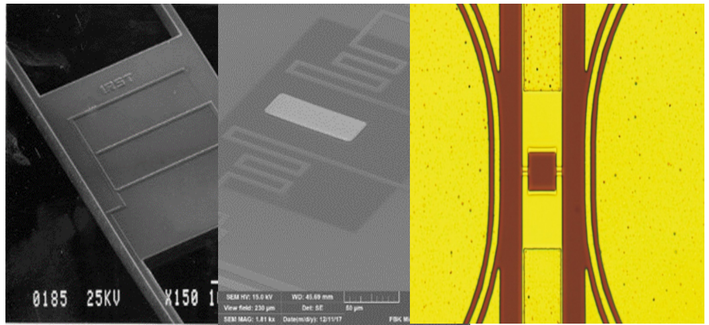
Objectives

- The accelerometer will be based on an inertial sensor on silicon "capacitive comb" with transversal movement, realized through a process of bulk micromachining.

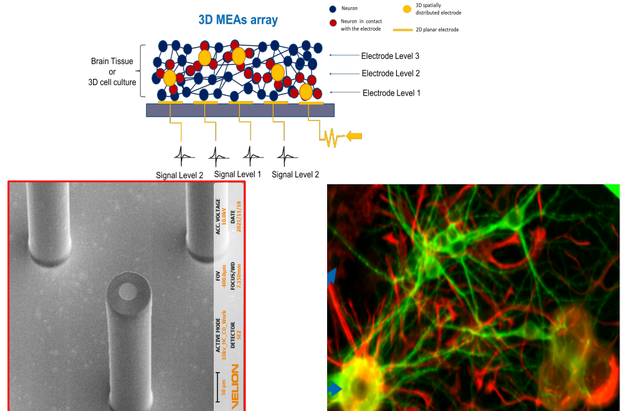


Technologies for Quantum Devices

Superconducting devices such as SQUIDs, Josephson Junctions, Josephson Parametric amplifiers

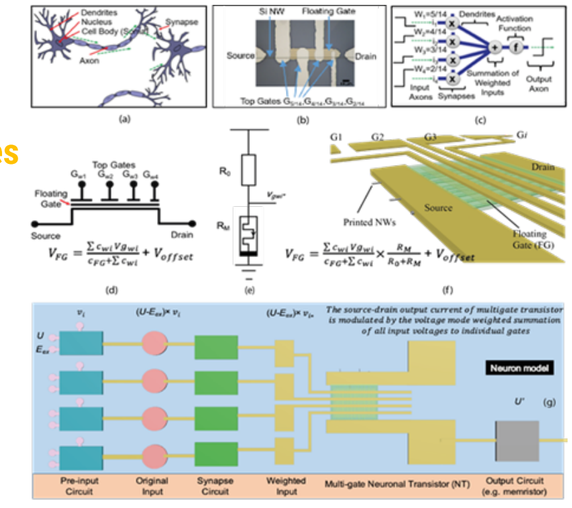


Brain Organoids - On Chip



Brain Inspired Devices

Adaptive Memories for AI



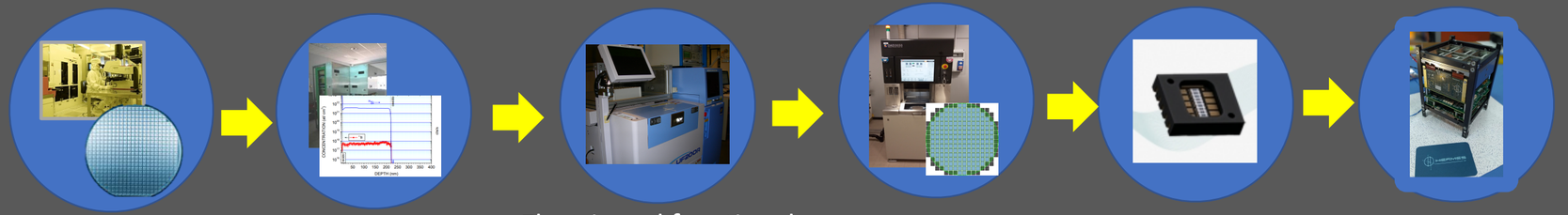
MNF at a glance

FBK Micro-Nano Facility: charting the furrow for the micro-nano technologies of the future

Our mission is to continuously push semiconductor technology, with main attention to silicon micro- and nanoprocessing, beyond consolidated state.
Leading edge sensors are produced at MNF facility thanks to worldwide recognized competences in optical and electronic lithography, etching, PVD and CVD deposition, ion implantation, thermal processes.
Fully controlled process modules allow customization of several technological platforms, like SDD, SiPM, LGAD, opto sensors, gas sensors to different applications, including space and other harsh environment.
Quantum technologies and nanofabrication R&D based on FIB/SEM innovative prototype.

Materials and devices can be characterized in the testing and analytical laboratories.
The packaging and integration laboratories allow to develop full systems at different TRLs

MNF is an open infrastructure, organized to host external users, both from research and industry.
The MNF laboratories are ISO certified.



Sensor micro-nano fabrication | Material characterization | Electric and functional characterization | Dicing | Packaging | System integration

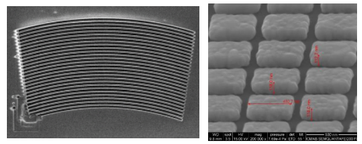
More than 2000 sqm of Semiconductor ISO4-6 cleanrooms, testing, dicing, characterization, packaging and integration laboratories

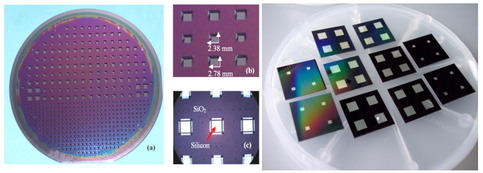
MNF – R&D, technology, infrastructure

Silicon technology platforms for radiation sensors MEMS, photonic and QT sensors :

- Wafer front/back aligned optical lithography
- Highly controlled junctions
- Optical widows
- Passivation layers
- Suspended structures like free standing membranes, bridges, cantilever
- Low stress controlled thin and thick layers by PVD and CVD
- TSV – through silicon vias
- 3D integration

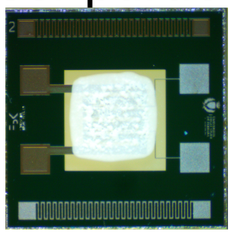
Nano-fabrication and characterization for quantum and plasmonic

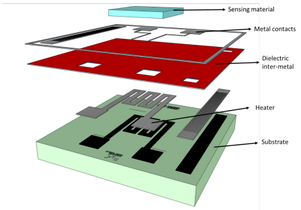




Advanced target materials for the laser driven nuclear fusion physics experiments and laser particles acceleration

Highly selective materials for gas sensing

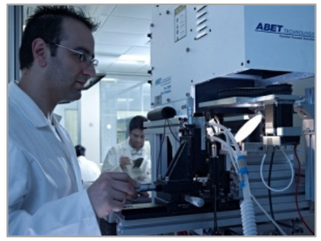


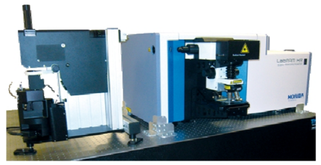


Technology customization for standard conditions and harsh environment applications

Production for industry, CERN and European agencies

Micro and Nano Fabrication Facility
IPCEI1: 1200m² moving to >2000m² semiconductor ISO4-6 cleanrooms





6” Microfabrication Area

Clean Room Detectors

700 m²; Class 10/100 0,8 um CMOS pilot line: Ion Implantation, Oxidation, Diffusion, RIE, Deep RIE (silicon and oxide), Lithography (stepper 0.35 um and mask aligner), metal sputtering, optical profilometry

Clean Room MEMS

500 m² Class 100/1000 diffusion, lithography (mask aligner), wafer bonding, electroplating, Si bulk micromachining, metal evaporation, RIE, mechanical and optical profilometry,

Testing Area

300 m² manual parametric testing, automatic parametric/functional testing, optical testing (spectral responsivity, quantum efficiency), solar cells efficiency characterization, gas and pressure sensors test benches

Integration Area

100 m² clean room Class 1000 Microassembly station; screen printing, bonding (ball & wedge bonder), Shear-Pull Tester, reflow oven, CNC micro-mill, pick and place

Nano- and Micro- Analytical Facility

Nano Ramen, FIB-SEM-EDX-EBSD, D-SIMS, TOF-SIMS, XPS, AFS, XRD/XRF

Analytical facility

D-SIMS Dynamic Secondary Ion Mass Spectrometry

Composition depth profile
very high sensitivity: ppm-ppb
depth resolution: 1nm; lateral resolution: 1mm

ToF-SMS Time of Flight Secondary Ion Mass Spectrometry

Elemental chemical mapping
very high sensitivity: ppm-ppb
lateral resolution: 0.3 mm

XPS X-Ray Photoelectron Spectroscopy

Chemical and elemental surface analysis
sensitivity: 0.5-1%; lateral resolution: 5 mm

FIB-SEM-EDX-EBSD

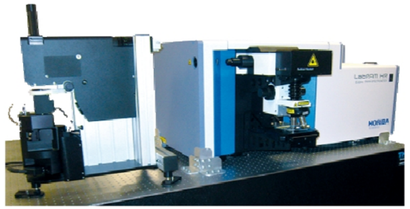
Focused Ion Beam; Electron microscopy; Energy Dispersion X-Ray; Electron Back Scattered Diffraction

AFM Atomic Force Microscopy

Surface microscopy
vertical resolution: 0.5nm; lateral resolution: 5 nm

Nano Raman

Raman Spectroscopy coupled to SPM microscopy



XRD/XRF X-ray Diffraction / X ray Fluorescence

Elemental, crystallographic phase and stress analyses
Spatial resolution: 1cm; Sensitivity: 0.1-1%

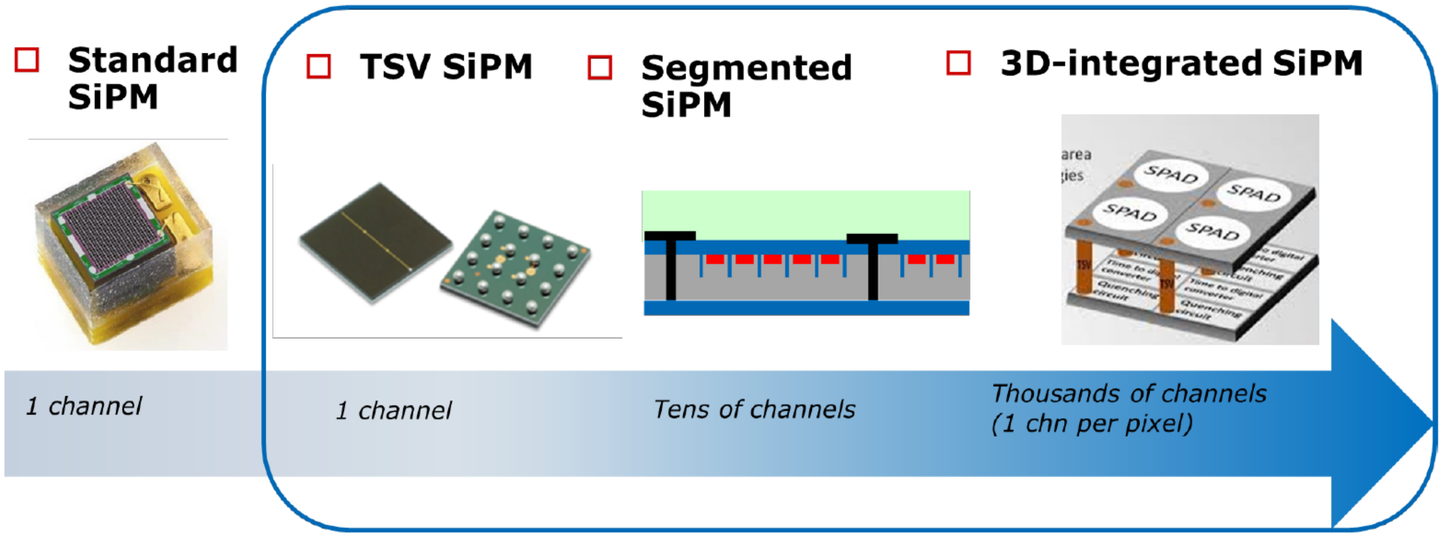
IPCEI ME 1: improve European competivity in microelectronics
Improve production of devices in Europe

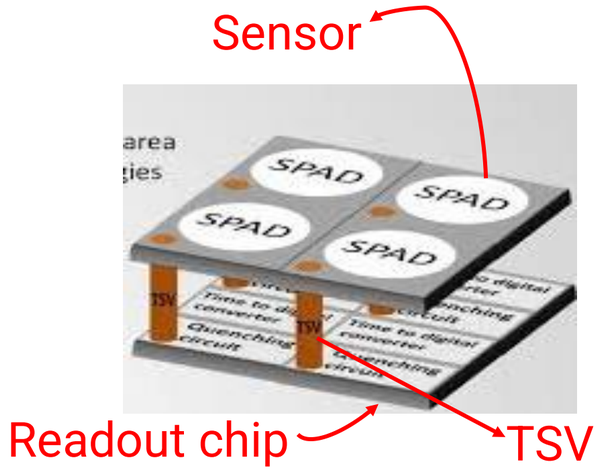
IPCEI: Key strategic instrument with regard to the implementation of the European Union Industrial Strategy
IPCEI ME (Microelectronics) 1: 32 companies and RTOs from FR/DE/IT/AU on 43 sub-projects
Ecosystem: Up to 425 indirect partners involved
5 technology fields: energy efficient chips, power semiconductors, *sensors*, advanced optical equipment and compound materials

IPCEI ME1 for FBK:

- Ongoing 2021-2024
- Equipment, people, research effort to achieve this
- Technical target: towards 3D integration with through silicon vias (sensor + readout chip).

… + new 3D cleanroom …





IPCEI ME/CNT: improve European competitivity in microelectronics
Improve production of devices in Europe

IPCEI ME continuation - *now approved* - expected to be:
- 20 States
- More than 100 members
- Coordination

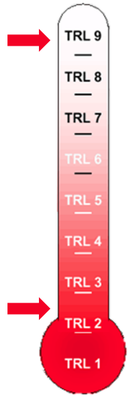
- Future connection with the CHIPS ACT?

- Achieving sustainability by updating equipment, expertise, techniques, research and investing in personnel
- *Sustainability by strengthening the ecosystem*

IPCEI ME/CNT for FBK:
- 3D integration -> heterointegration
- SiC & Ge on Si – with attention to space, QT, environment, automotive sectors

Custom Radiation Sensors

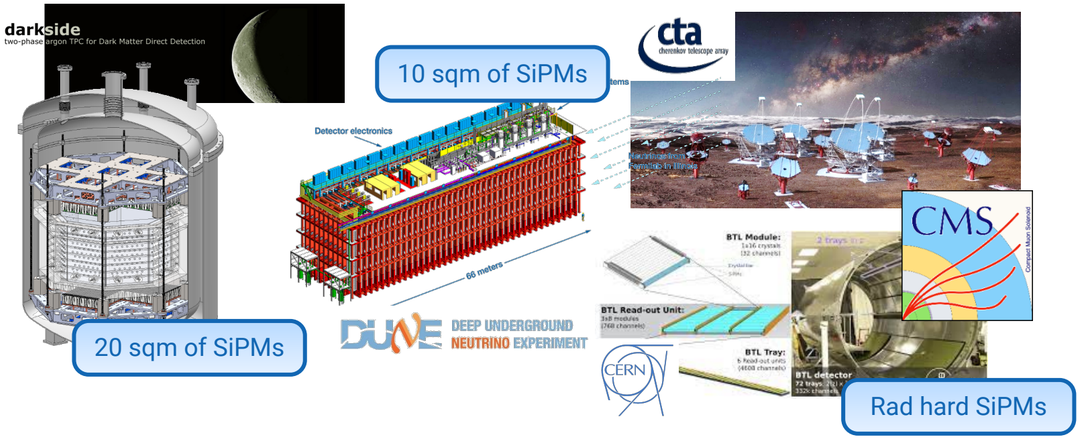
CRS research Unit
Silicon Photomultipliers



FBK-SD is *recognized as one of the world leaders in the development of Silicon Photomultipliers* (SiPMs).

FBK-SD SiPMs are *employed in a wide range of high-tech applications*, from Big Science Experiments to Industry (Medical Imaging, Automotive and Space). All SiPM activities require *high R&D intensity to remain competitive and to serve new applications*.

FBK SiPMs for Big Science Experiments



Relevance: *high-profile experiments*, *large production volumes* of silicon wafers (potentially > 40 sqm), *high TRL* (silicon in package).

Experiments: Darkside-20k (INFN), CMS-BTL (CERN), CTA (INFN + international), DUNE (INFN + US-DoE), nEXO (Stanford)

FBK SiPMs for Industry

Relevance: *Industrialization* of FBK SiPMs (through partnership with Broadcom), *mass-market applications* (automotive LIDAR), *space economy*, strong *scientific network* in medical imaging.

Applications: Health: Medical Imaging (ToF-PET), Automotive LIDAR, Satellite payloads (Atmospheric LIDAR, scientific payloads), + other emerging applications.

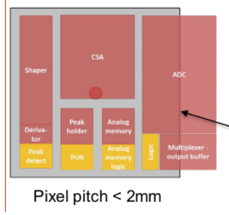
CRS research Unit
Silicon Drift Detectors, planar and 3D sensors

FBK-SD is *recognized as one of the world leaders in the development of Silicon Drift Detectors* (SDD) and silicon planar technology, strip and pixel detectors, and 3D sensors. The detectors are finds applications mainly in high energy physics, and x-ray spectroscopy both for astrophysics and material analysis.

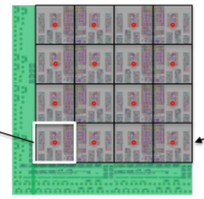
SDDs

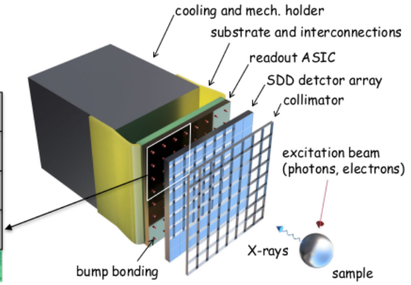
monolithic SDDs arrays to be coupled to the **SCARLET** ASIC for ultra-high rate X-ray spectroscopy (50-100Mcount/s)

ASIC main features:
- >1Mcounts/s/channel count rate
- ΔE<200eV @1Mcps
- full spectroscopy chain on-chip
- bump-bonding with detector



Pixel pitch < 2mm


4x4 2-side buttable structure



Sensors for KAONNIS: the SIDDHARTA-2 experiment

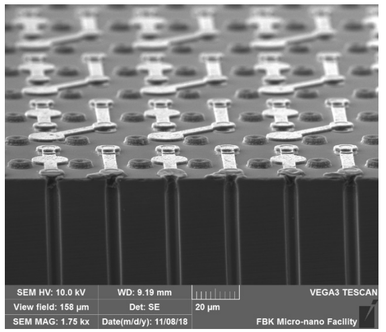
KAONNIS (KAOn Nuclear/Nuclei Interaction Studies) is an integrated initiative dedicated to the experimental studies of the low-energy kaon-nucleon and kaon-nuclei interactions. -> 1mm thick sensors.

Planer and 3d

HEP applications

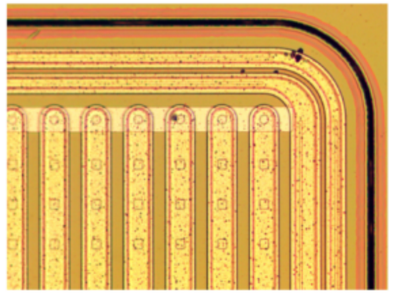
Production of pixel and 3d detectors for ATLAS ITk

Expecting productions for CMS ITk



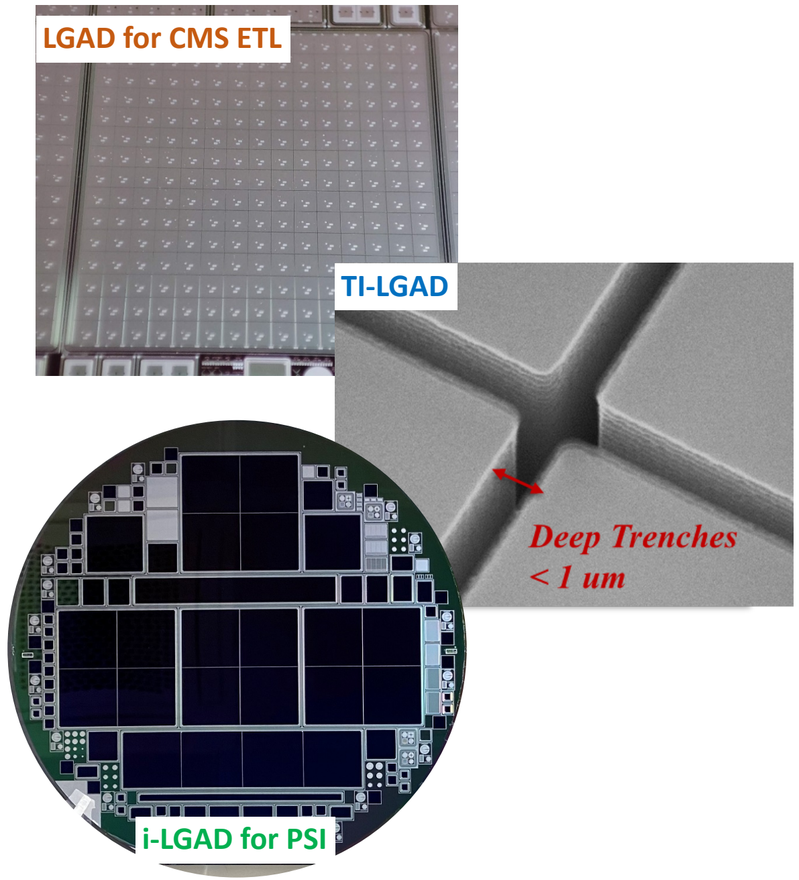
Spectroscopy

Production of pixel detectors with thin entrance window for PSI : soft x-ray (~200eV) spectroscopy



CRS research Unit
Low Gain Avalanche Diodes (LGADs)

FBK-SD was one of the first developer of Low Gain Avalanche Diodes. These detectors are exploited for Timing applications in high energy physics and for soft X-Ray spectroscopy.



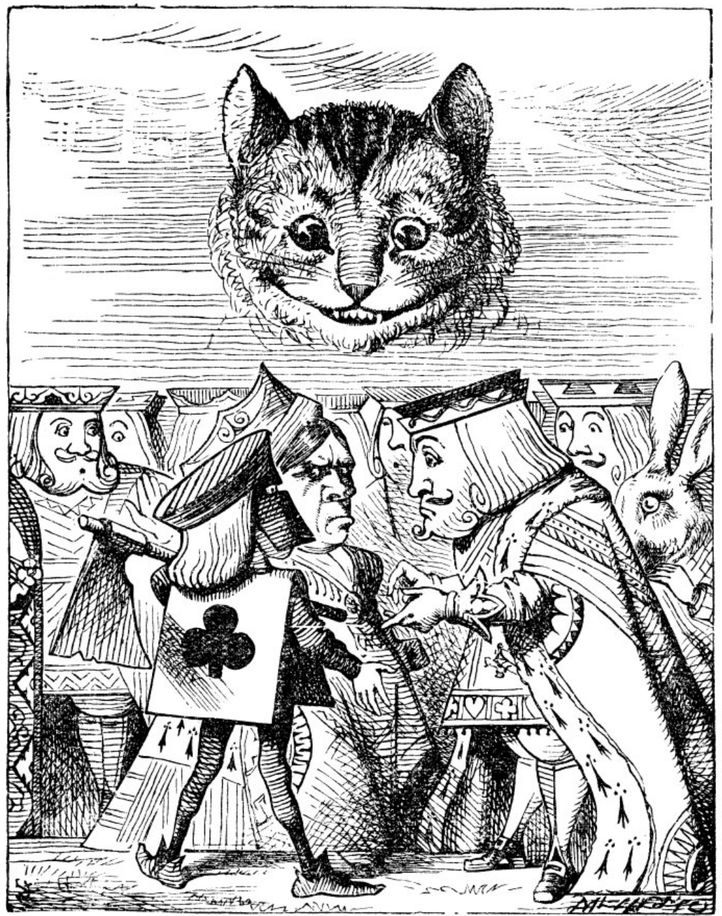
LGADs for Fast Timing: 35 ps time resolution with MIPs after fluence of 2.5e15 neq/cm^2. Demonstration full-size sensors (15x15 pixels, 2x2 cm2) for CMS and ATLAS HL-LHC upgrade.

Fine pixelated LGADs: Development and first production of Trench-Isolated LGADs (TI-LGAD) with pixels down to 50 μm

LGADs for soft x-rays development and production of the first batch of inverted-LGADs with thin entrance window for soft x-ray detection (in collaboration with PSI). Demonstration of photon-counting capability at E< 1keV

Other Projects: Moveit (INFN), HADES (GSI).

Quantum Technology

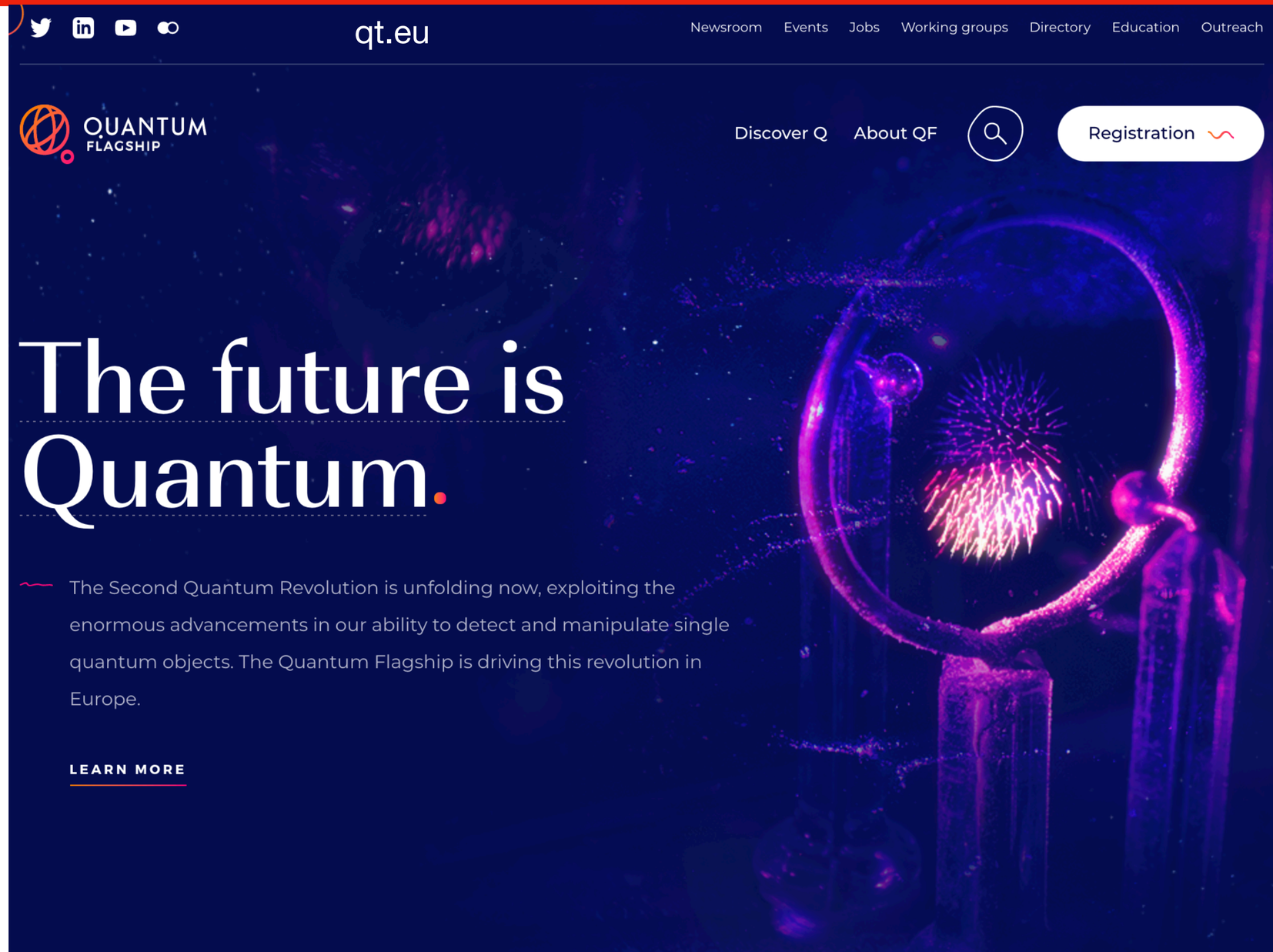


Illustrations: John Tenniel

Alice in Wonderland

Quantum Science & Technology

- Quantum Science and Technology is a big trend at the moment
- Huge investment from US, China, Europe, …
- Most countries have a strategic programme in QST



Why Should You Care?

- TRL1-4 is not the primary concern for society, *however* …
- 2nd quantum revolution will change everything (but not clear when)
- Being informed and aware is the first step in preparation …

2 quick examples:

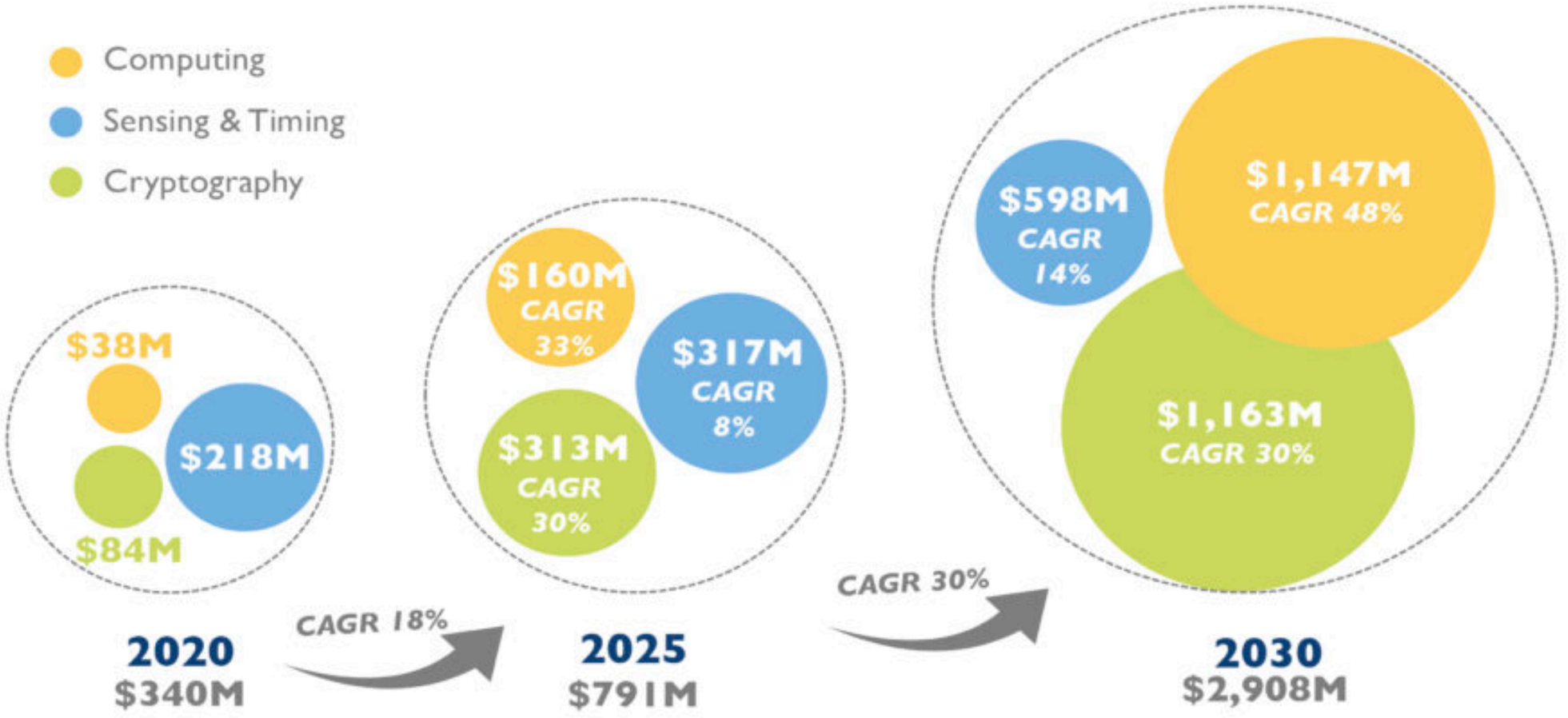
- Quantum Computing will break current digital security (not clear when)
- Being ready and migrating protocols essential
- Quantum Communication field is therefore relevant and important

Archimedes:"Give me a lever long enough and a fulcrum on which to place it, and I shall move the world."

- Quantum Sensing can transform sensitivity
- Quantum Imaging can transform imaging capabilities

2020-2030 market forecast for quantum technologies

(Source: Quantum Technologies 2021 report, Yole Développement, 2021)



What is Quantum Technology?

- Emerging field relying on quantum effects
- Particularly relevant when you approach quanta - i.e. units of information or particles
- Not new … but there is a growing appreciation of its potential uses

- Why now? Trend of scale: dimensions of structures (10s of atoms) mean that quantum effects are relevant/dominant …

- Like most new technologies - the current hype will be unfulfilled in the short term and exceeded in the long term
- Probably the most significant impacts are yet to be realised …

- Many particle sensors are detecting quanta

How to make the biggest impact? Stick to core competances:

Quantum Sensors
Devices that can be built using features on silicon

Use collaboration to find the applications in quantum technology

Role

Twofold role:

- Provide technologies to industrial and academic partners
- Participate in excellent research

4 main areas/platforms :

- Single photon detectors
- Integrated photonics
- Superconducting devices
- Colour centres in diamond and related materials

Quantum Technology is Horizontal / Cross Unit Activity

I&QO INTEGRATED AND QUANTUM OPTICS

- Integrated optical circuit platform
- Integrated quantum photonics
- Dielectric materials
- Diamond
- LiNbO3

IRIS INTEGRATED RADIATION AND IMAGE SENSORS

- CMOS-SPADs
- Quantum RNG
- Quantum and ghost imaging
- ASICs
- A/D design & readout

CRS CUSTOM RADIATION SENSORS

- Hybrid SPAD array
- SiPMs
- Fund. Physics. Applications

MST MICROSYSTEMS TECHNOLOGY

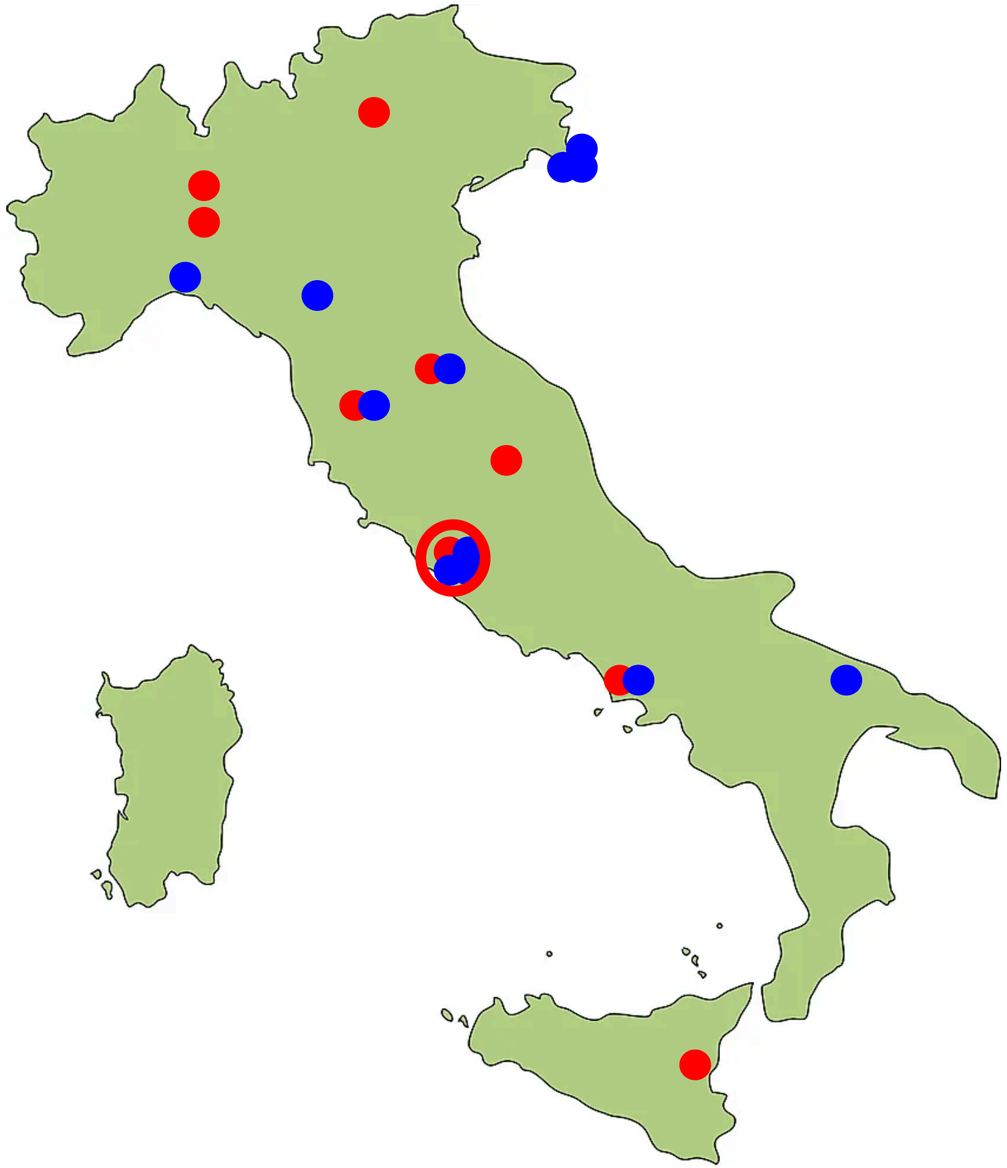
- Josephson Parametric Amplifiers
- Superconducting QuBits
- Superconducting Devices

MNF MICRO NANO FACILITY

- Defects in Diamond, Silicon, SiC, … Single Photon Sources
- Core Processing and Production Capability
- Single ion implantation

Maximal impact from generating synergy from cross-unit activity

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
QST



20 Institutions

Researchers
322

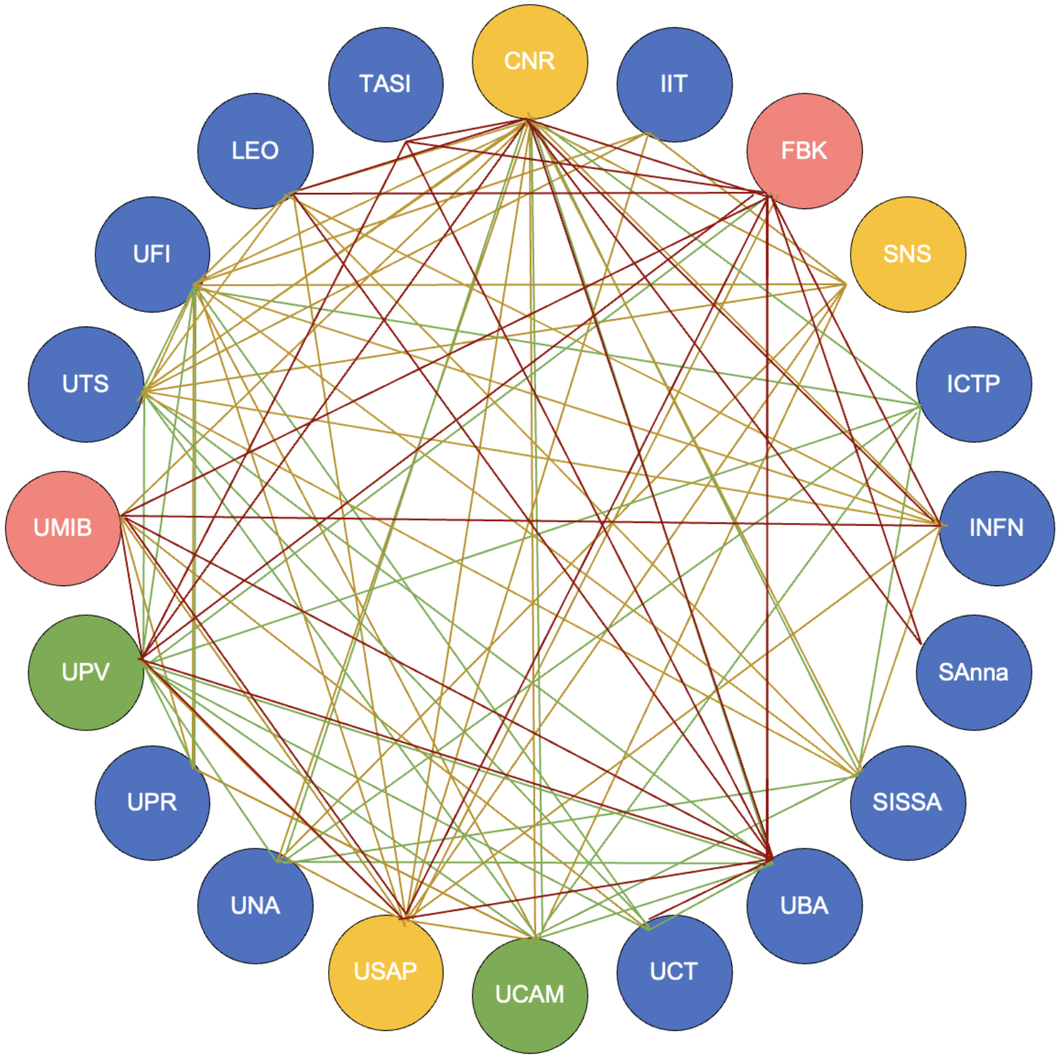
MUR funding
116 MEuro

New RTD
104

Italian National Quantum Science and Technology Institute

Collaborations created by NQSTI activities

NQSTI
National Quantum Science and Technology Institute




International programs
New companies
Outreach and education
SME
Small Medium Enterprises
NQSTI
QST
Quantum research
Industries

SD Centre in Italian National Quantum Science and Technology Institute
PNRR nQSTI (2022-25)

Significant role in PNRR nQSTI

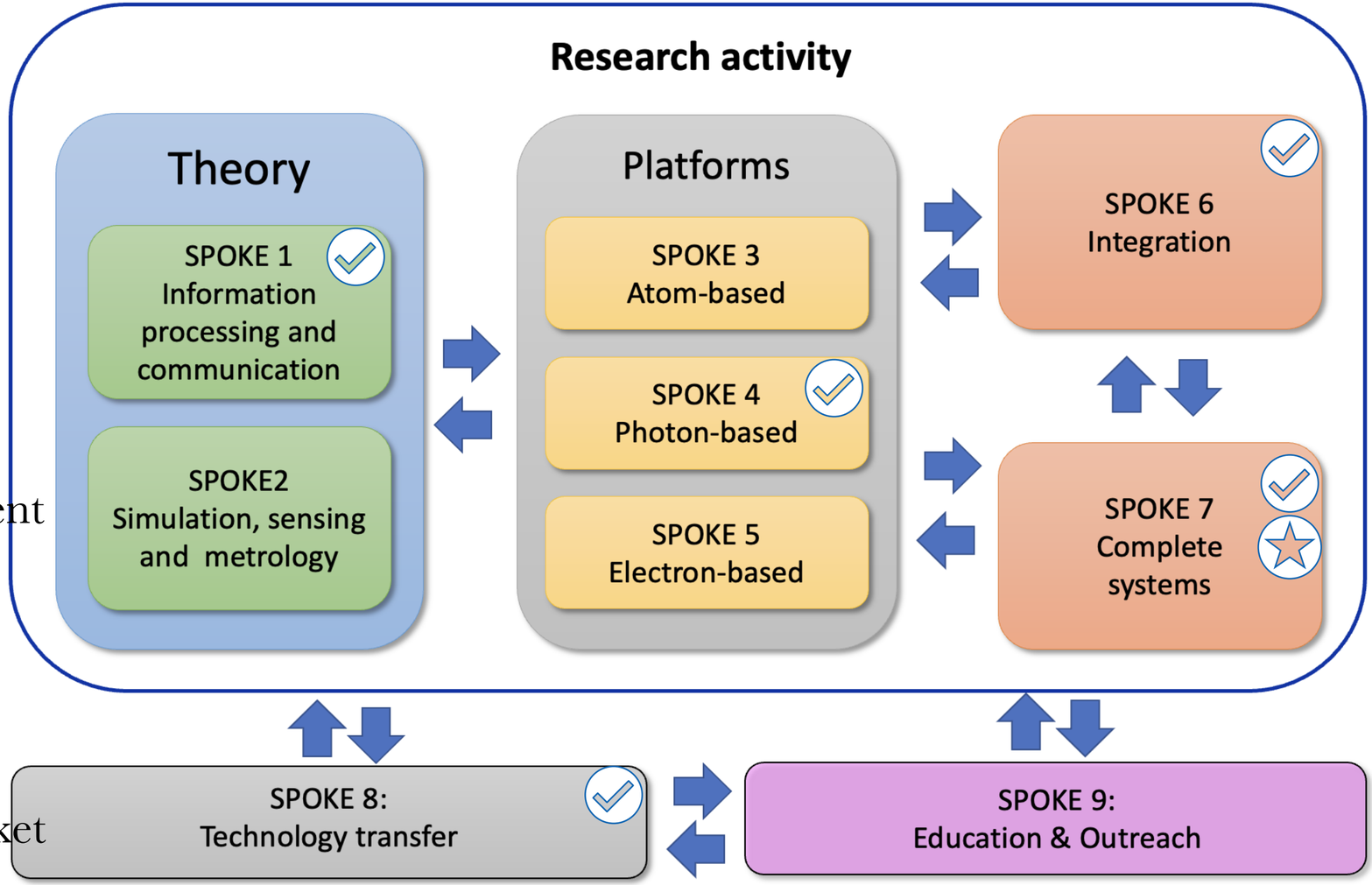
- Leading spoke 7 on complete systems
- Involved in spoke 4, 6 & 8
- ECT* in spoke 1

Complete systems aligned with:

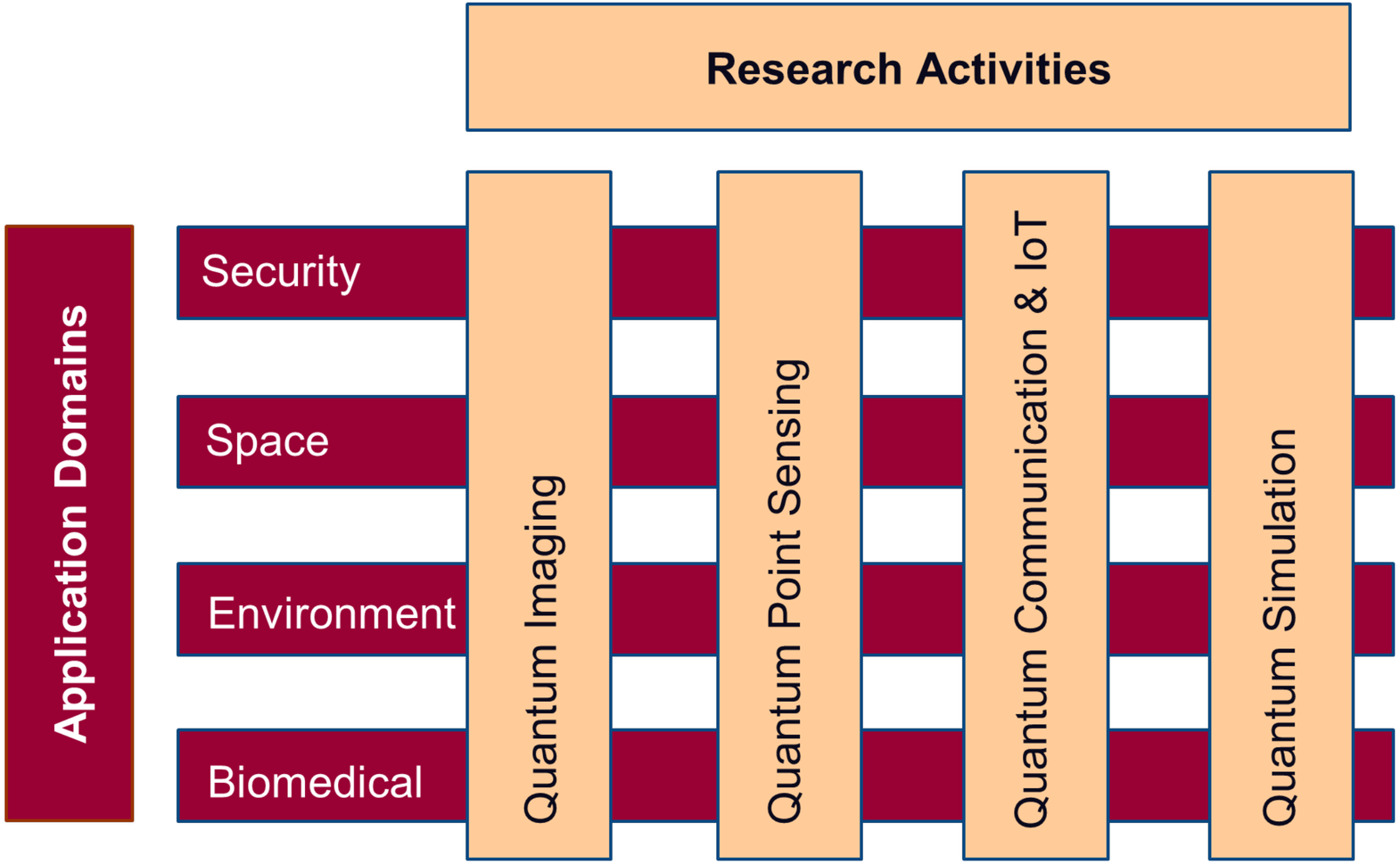
- FBK unique research and fabrication capabilities
- Exceptional record on industrial engagement
- Philosophy of systems of technological platforms
- Strong collaboration networks

Opportunity:

- Sensors and devices utilised + path to market
- Establish technology platforms in QST
- Central in a strong ecosystem

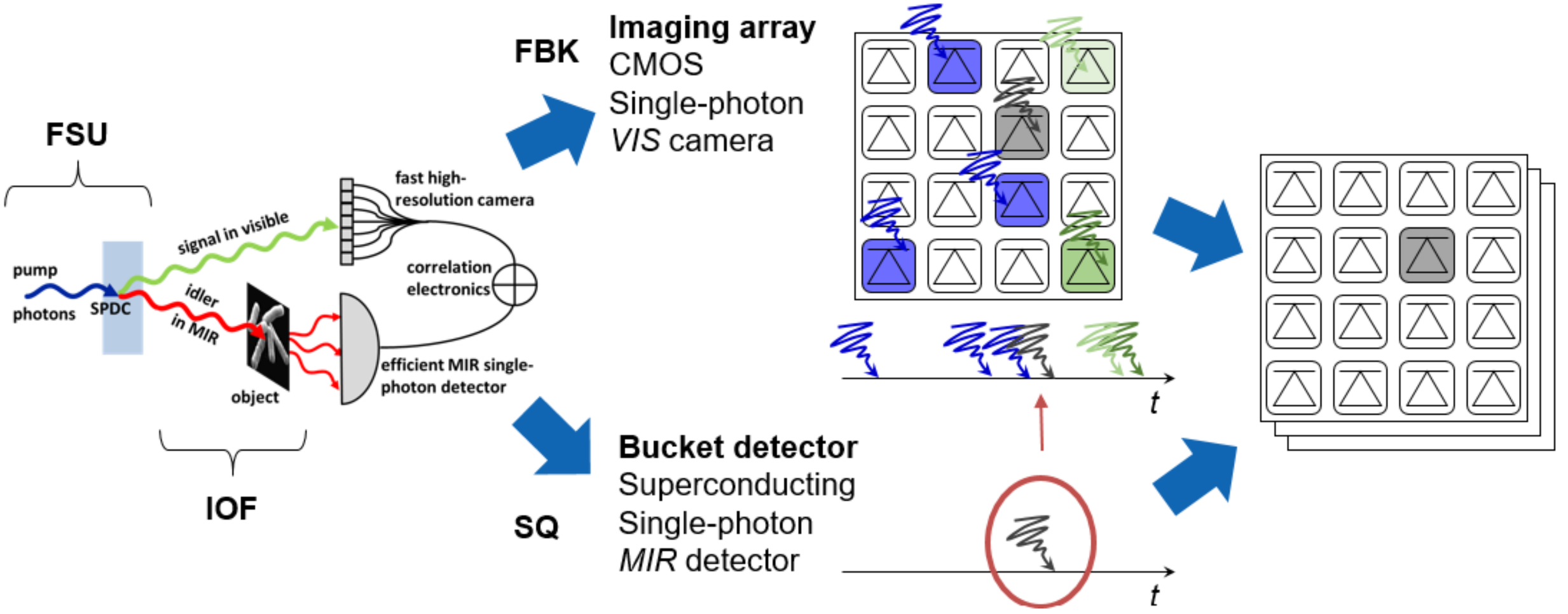


nQSTI Spoke 7: Complete Systems
Research Activities and Application Domains



Quantum imaging with SPADs
EU FET FastGhost – Ghost Imaging

fastGHOST



SC -Josephson junctions - DARTWARS

Precision metrology

Josephson voltage standard

SQUID's are used as very **sensitive magnetometers** and are widely used in science and engineering, e.g. magnetoencephalography

Superconducting digital computing

Digital processors with clock frequencies up to 20 GHz have been developed

Superconducting quantum computing

Flux and charge qubit's and transmons

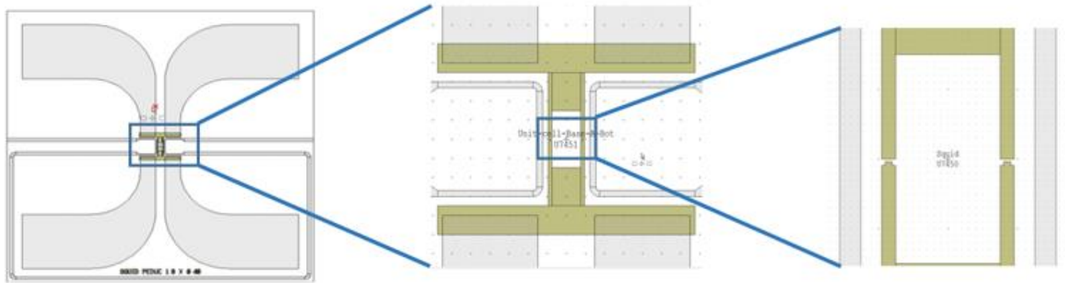
SQUID-based Parametric Amplifiers for ultrasensitive detection at the quantum & subquantum limit

microwave/qubit photon detectors

cavity-based axion detectors

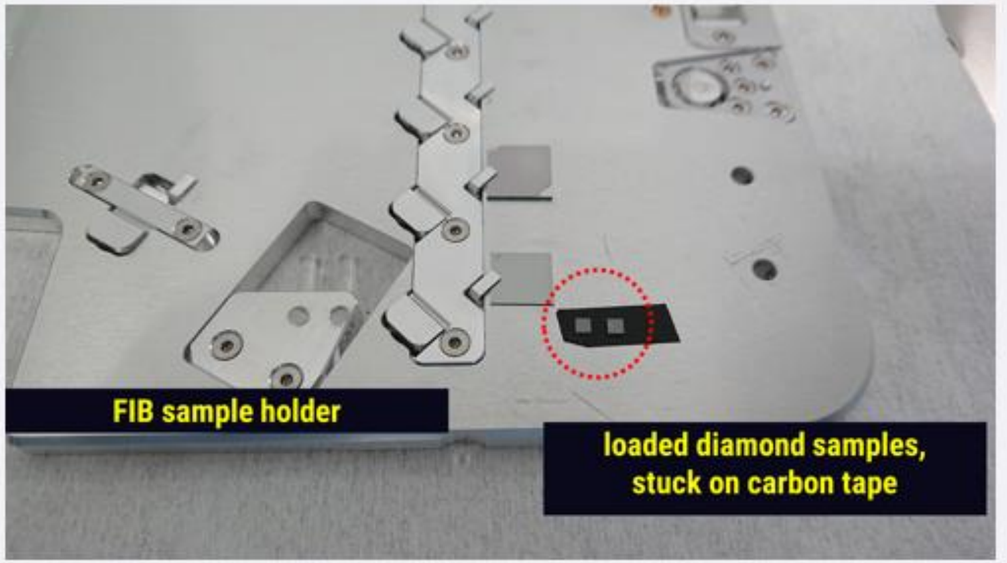
SQUID multiplexing for large scale arrays of TES (Transition Edge Sensors) or Magnetic Calorimeters for CMB and X-ray astronomy.

Etc.



First FBK Production of Single Photon Emitters (Ge-V) in diamond

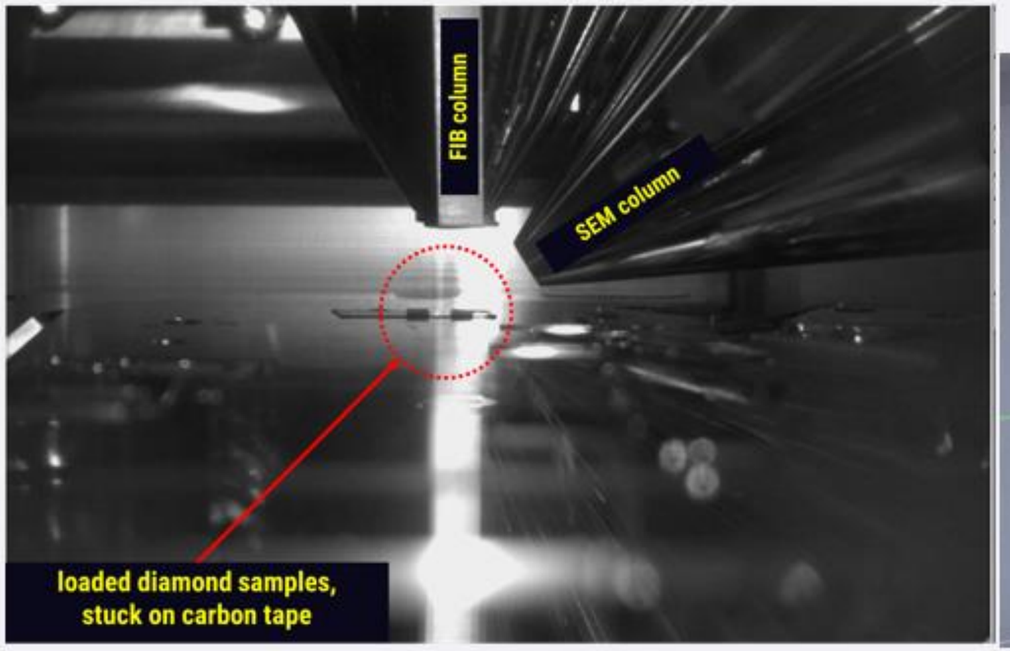
Q@TN Project: GeVion-Q, Sept. 2022

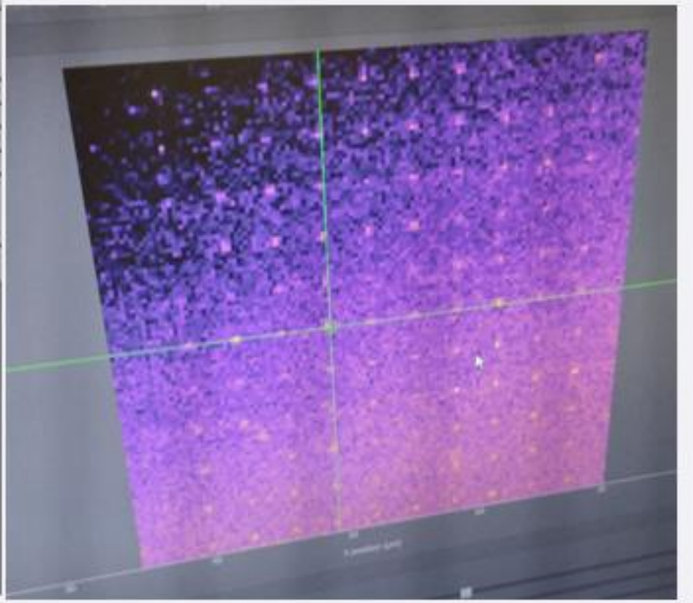


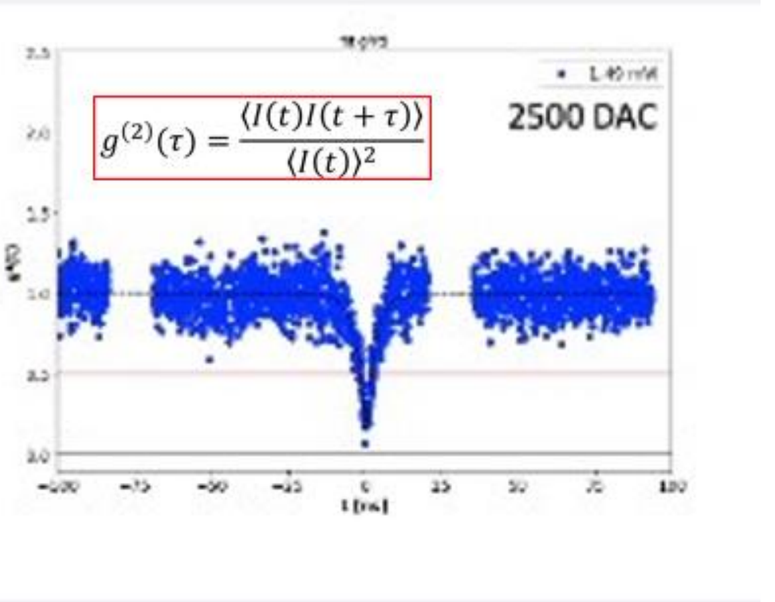
FIRST EVIDENCE of FORMATION of SINGLE Ge-V EMITTER

- Ge^{++} 35 kV => **70 keV impl. energy**
- **beam current: ~2.3 pA** (diameter: ~**10 nm)**
- Annealing: **1000°C/ 2h @ 1E-6 mbar**

- **100 i+ fluence => found single and double photon emitters**
- **ZPL λ = (601.5 ± 0.2) nm**
- **Lifetime τ = (3.6 ± 1.1) ns**
- **Formation Yield: ~0.9 %** (emitters per implanted ions)







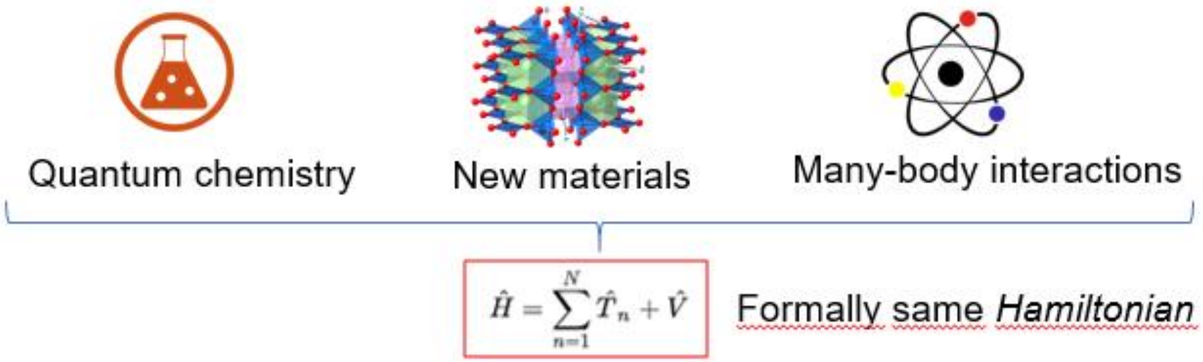
EPIQUS – QT simulation platform

EPIQUS aims to demonstrate a cheap, easy-to-use, performant Quantum Simulator (QS) which will simulate quantum mechanical problems in a compact device operating at ambient temperatures.

What are **Quantum Simulators**?

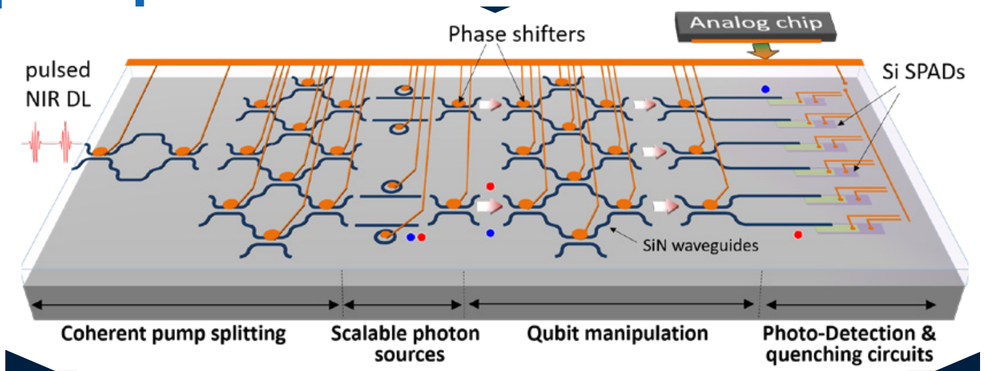
The simulation of quantum mechanical systems using conventional computers, requires resources, which grow exponentially with the system size.

Quantum Simulators are devices that operate according to the laws of quantum mechanics and possess the capability to simulate a broad range of quantum phenomena that relegate beyond the classical computer capabilities [Quantum Manifesto].

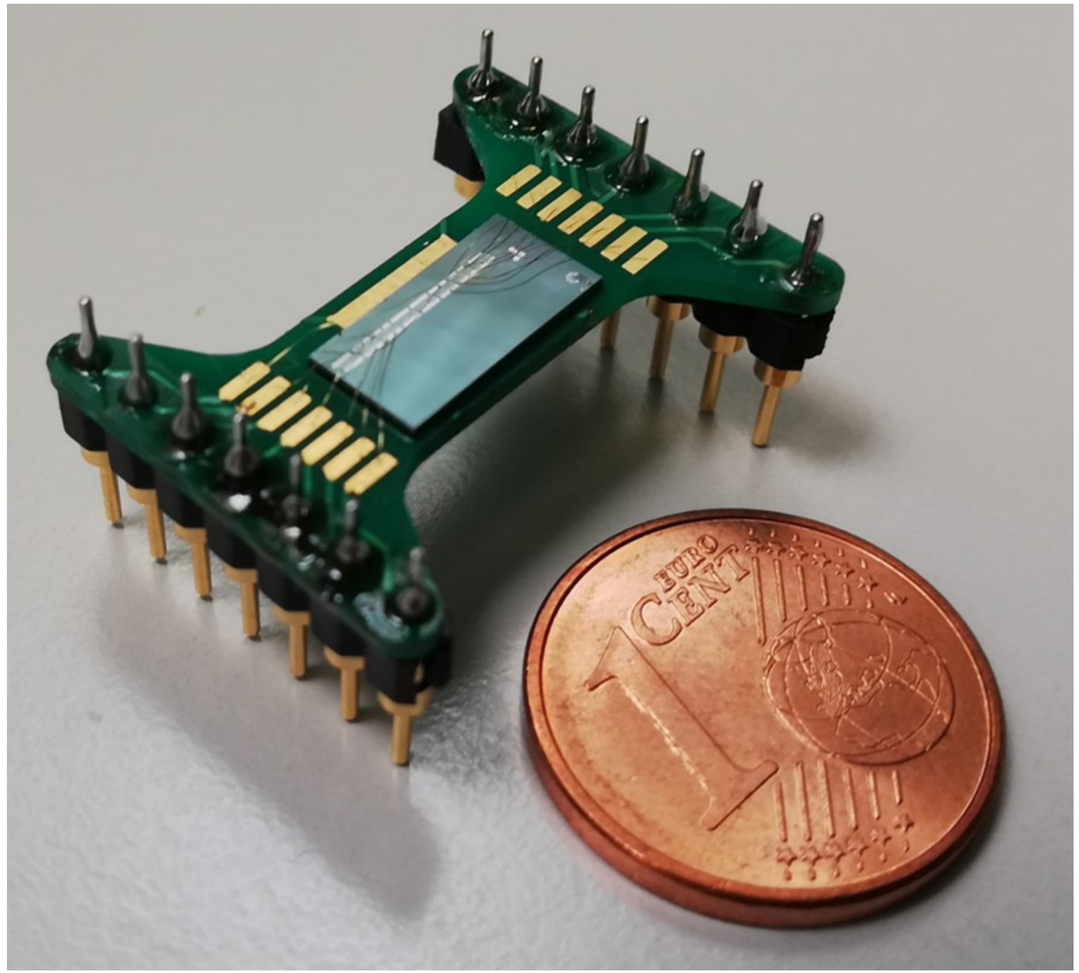


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 899368

Quantum Simulations on a Chip



Quantum Simulations on a fully functional QS module



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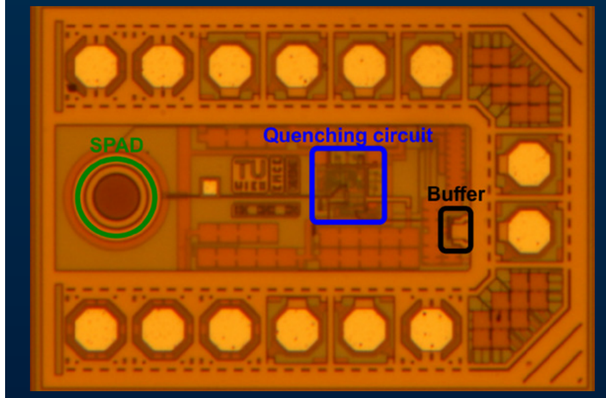
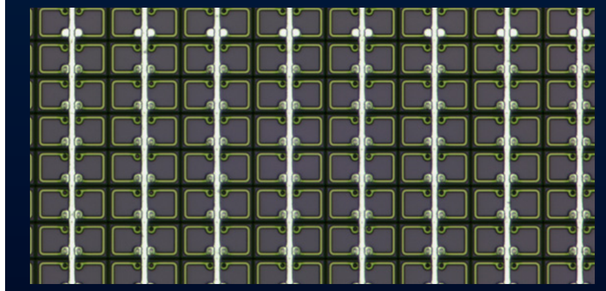
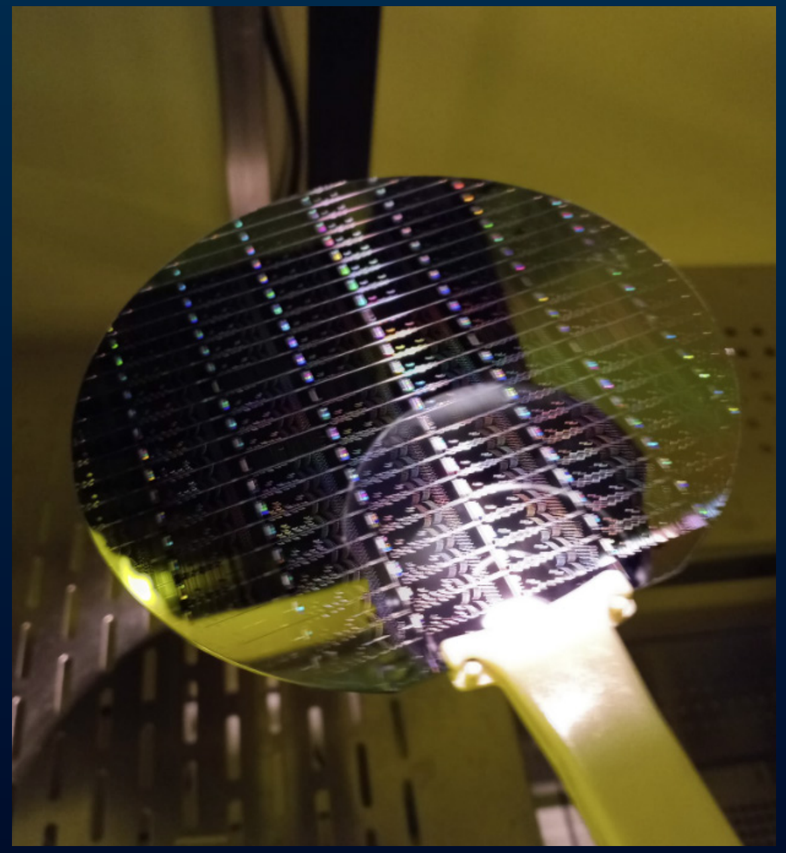
Quantum Simulations on a Chip



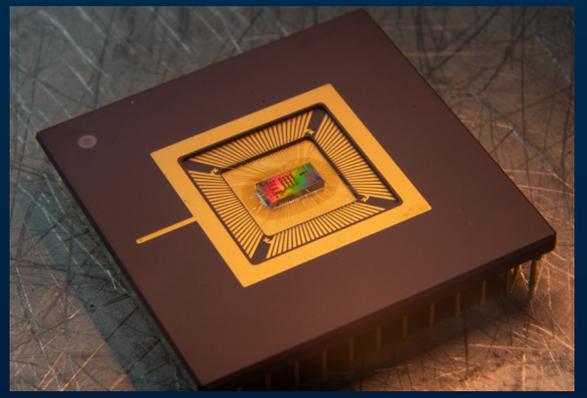
Analog control and readout



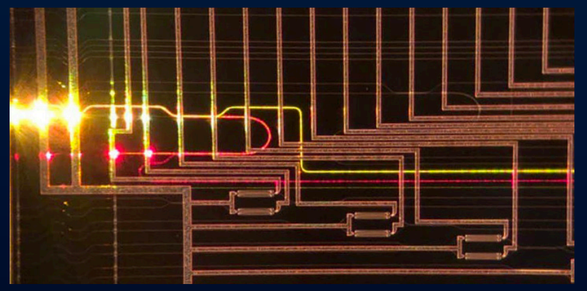
SPAD arrays



Quantum Photonic chip wafer



Interfaced Quantum PC



Quantum simulation on chip

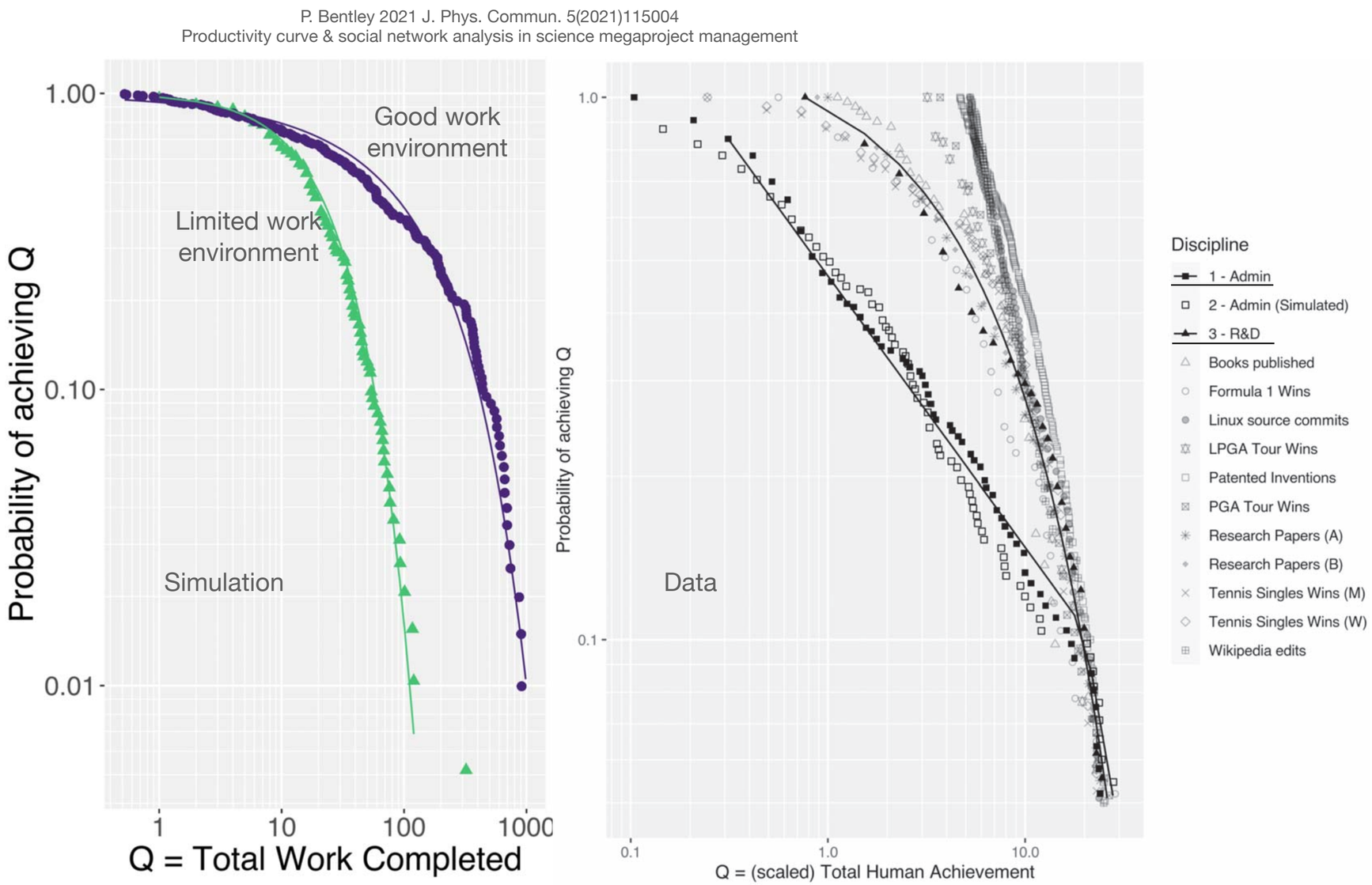
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 899368

Last Reflections …

- Competition to develop talent and expertise is nothing new …

- This School is in this spirit - about enhancing contact between experts in a very exciting field
- Enjoy it! Be Creative!
- Use the environment and location to tickle your creativity and innovation

Research is all about people ...



- Who they are ...
- ... and the conditions they work in ...

- Research is about experts
- Centre is a mixture of scientists, engineers, technicians, admin: all experts, all *"rare"*
- Best leadership style is a mixture of coaching and democratic
- Clear Vision and Mission, communicated often

- Typically projects deliver incremental progress
- i.e. deliver what they promise
- Transformative progress comes often through *obliquity*
- i.e. outside the projects direct objectives
- Important to build curiousity into the work and project culture
- *"Academic freedom"or the "google 20%"*

Interdisciplinary Collaboration

Important to get the teamwork right …

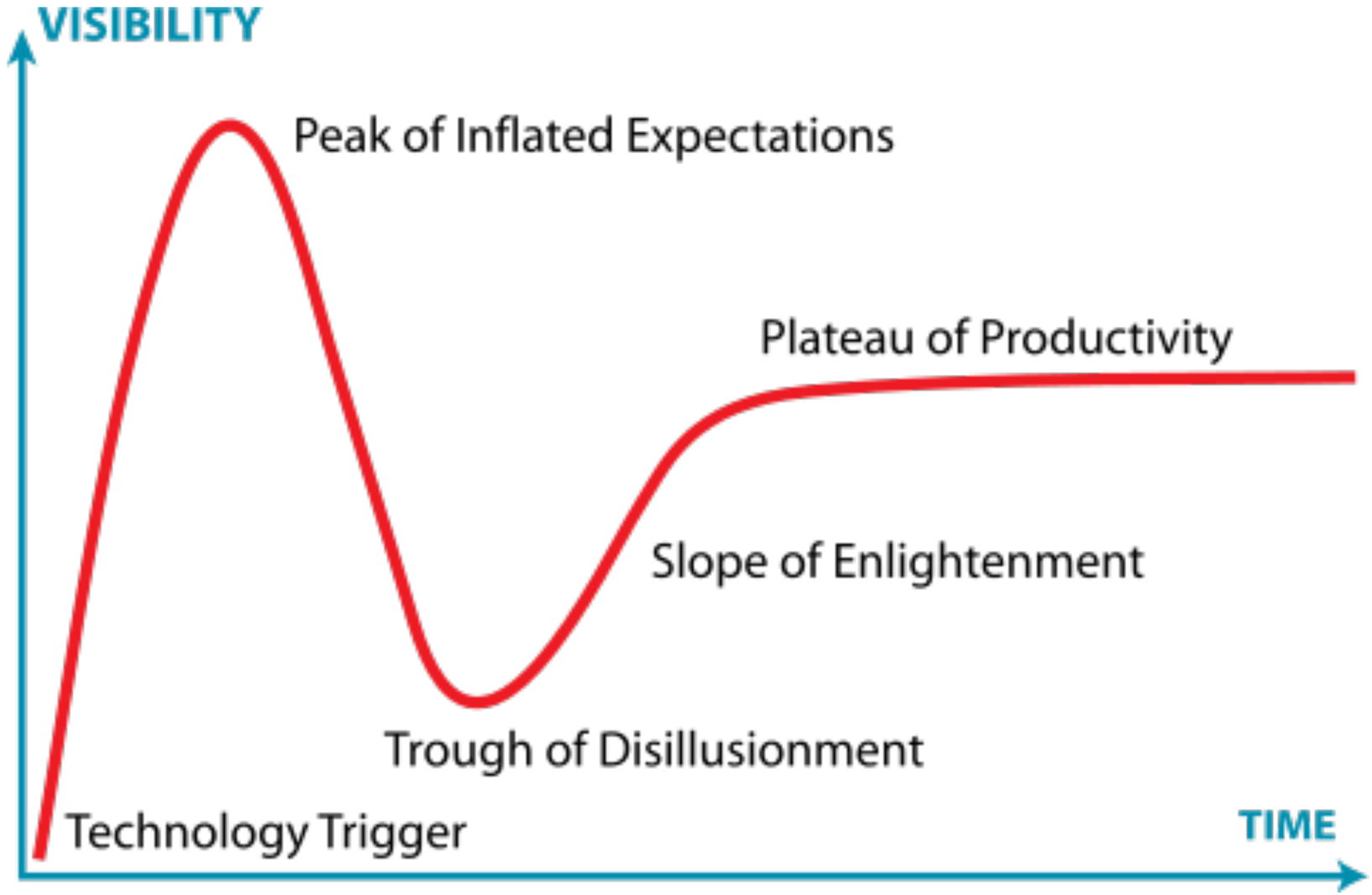
- Everyone should play to their strengths
- Interdisciplinary aspects vital to success

Specialisation
- Specialisation: be excellent at what you do
- Collaborate with experts for everything else

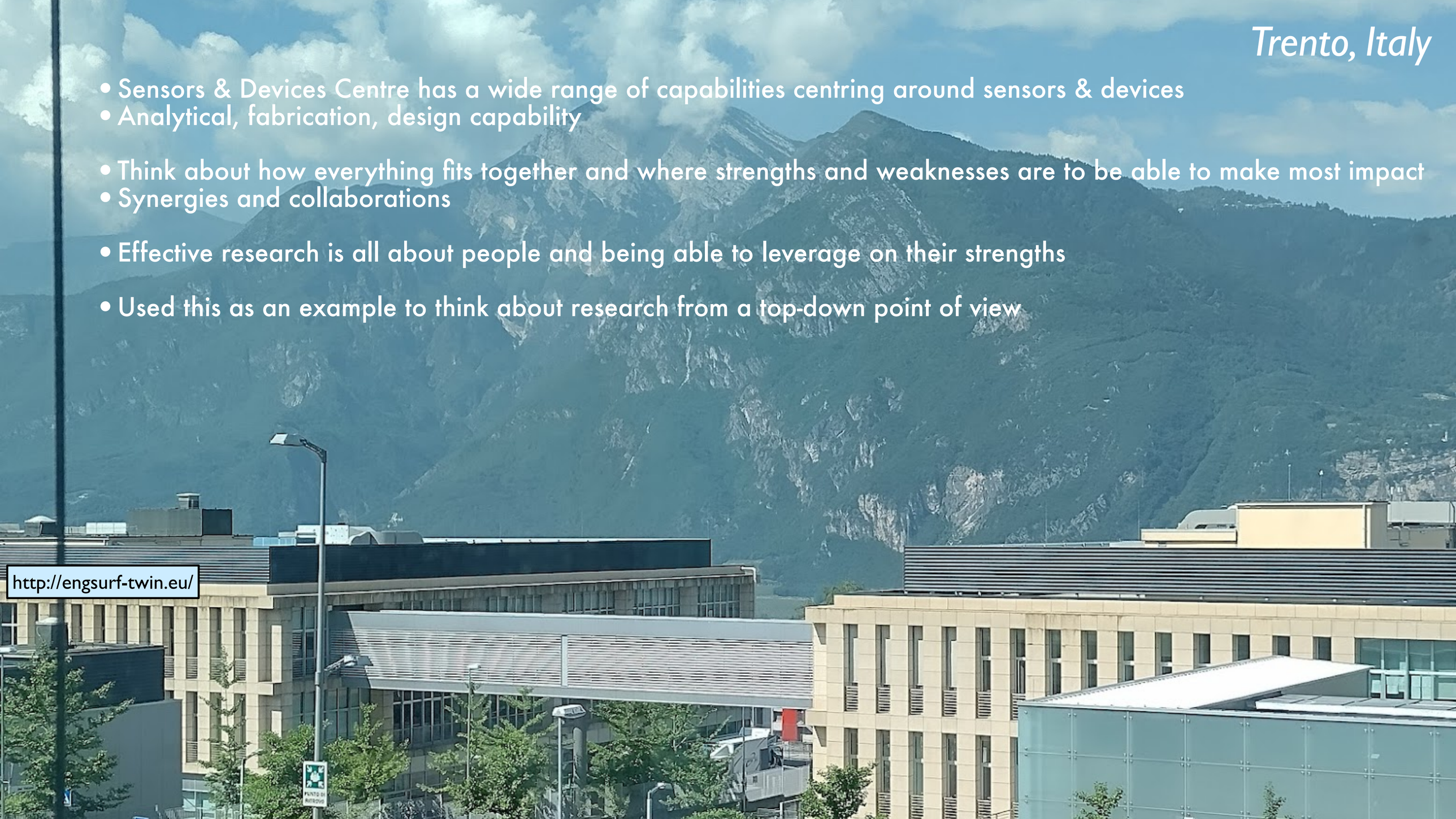
<u>Collaboration is the greatest strength of the European research environment</u>

- Publish and disseminate also the technological techniques

Development?
Beware the Hype Cycle and “Bandwagon-ing”




How research works …
You work in many collaborations ….
Established, stable, successful interdisciplinary environment
increases the probability of productive interactions



Trento, Italy

- Sensors & Devices Centre has a wide range of capabilities centring around sensors & devices
- Analytical, fabrication, design capability

- Think about how everything fits together and where strengths and weaknesses are to be able to make most impact
- Synergies and collaborations

- Effective research is all about people and being able to leverage on their strengths

- Used this as an example to think about research from a top-down point of view

http://engsurf-twin.eu/

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Thanks!

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