Medipix: Un ejemplo de transferencia tecnológica desde la física de altas energías hacia otros campos de la ciencia

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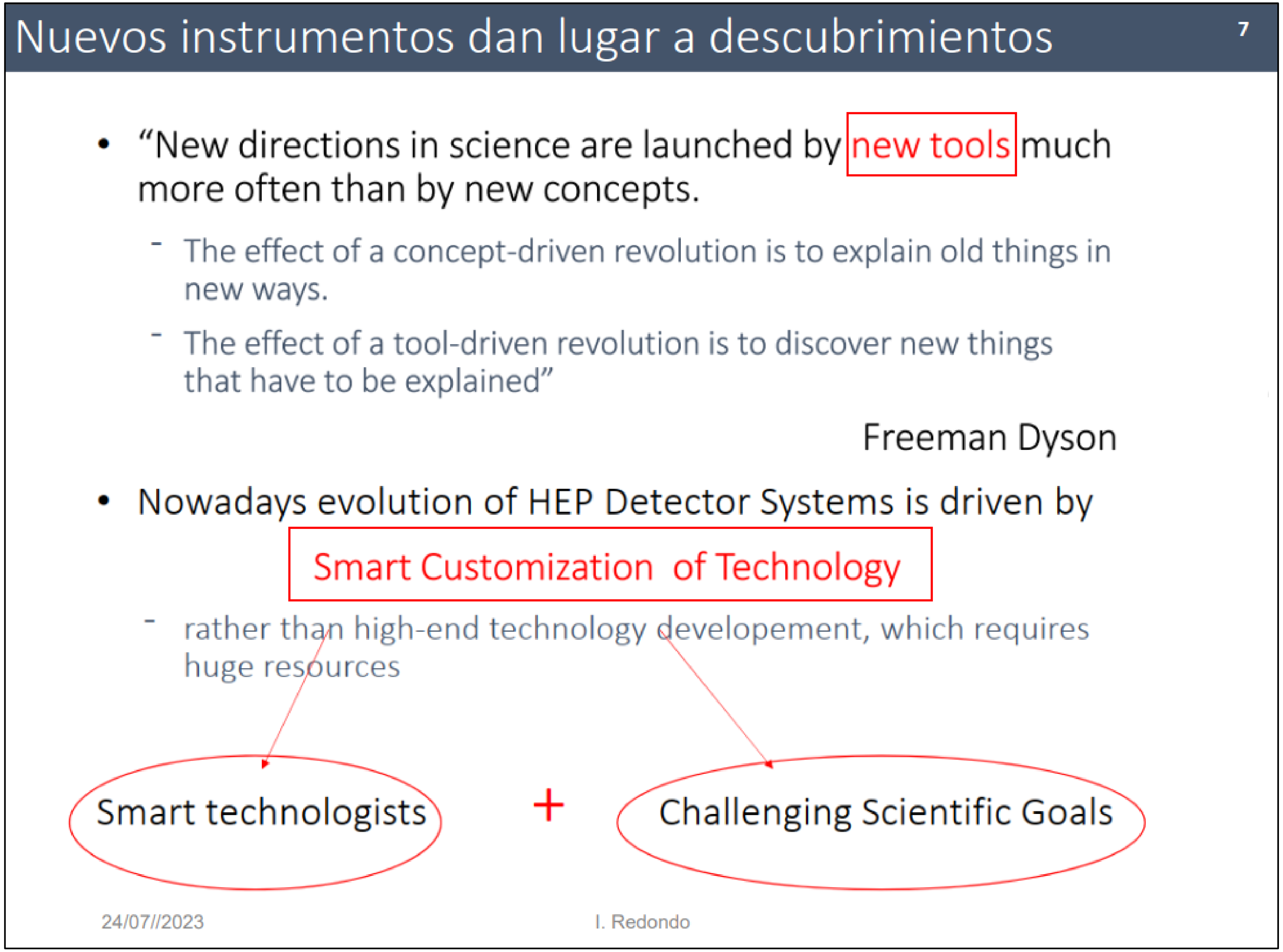
Sección de Microelectrónica, CERN



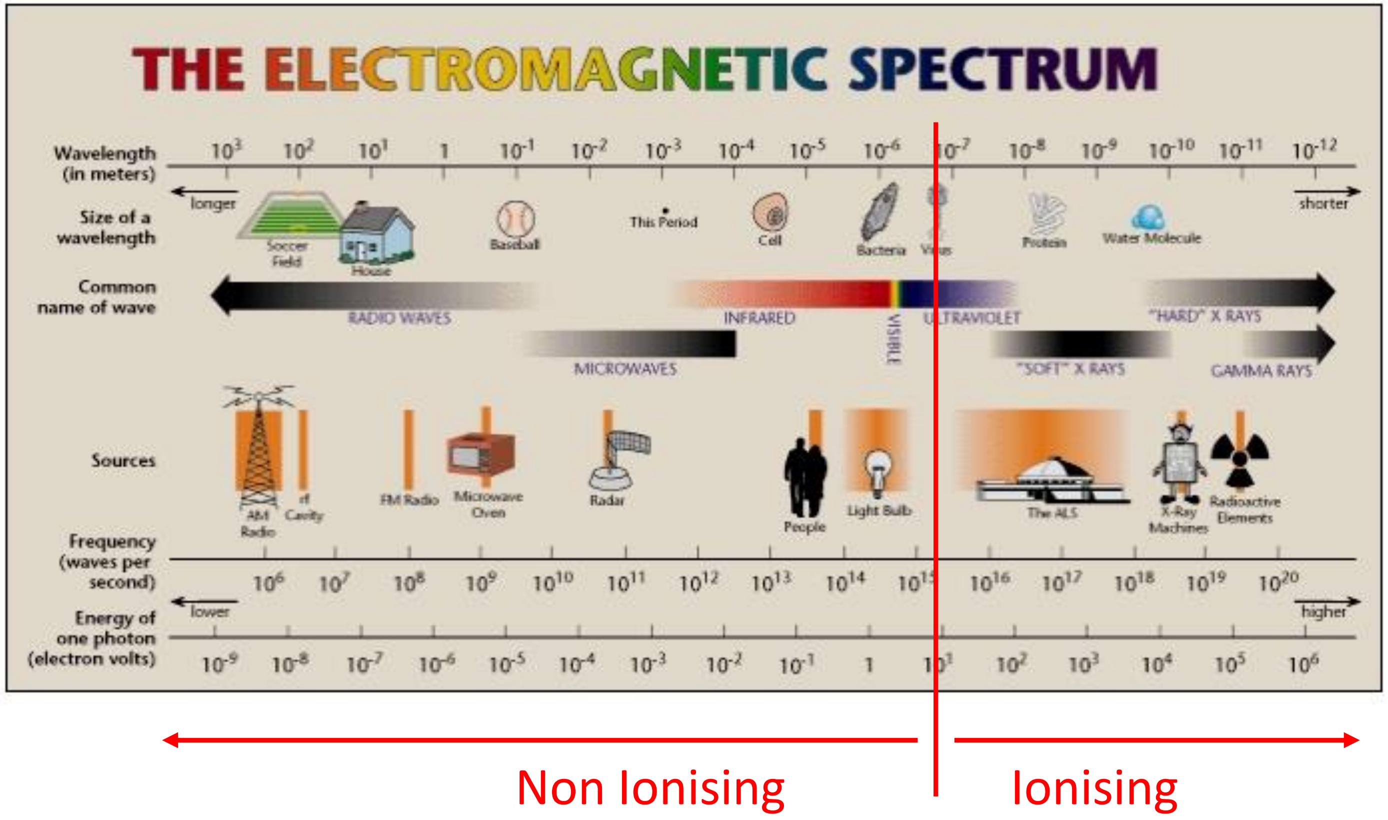
Slide: Ignacio Redondo

Índice

Introducción:
La radiación ionizante

La radiación ionizante

- La radiación es la emisión o propagación de energía en forma de ondas o partículas a través del espacio o de un medio material.
- La radiación ionizante se refiere a un tipo de radiación que posee suficiente energía para eliminar electrones fuertemente ligados de átomos o moléculas, lo que resulta en la creación de iones. La radiación ionizante puede estar en forma de partículas (α, β, muones (μ), neutrones) u ondas electromagnéticas (rayos X, rayos γ).



Sources of Annual Dose to the Population

Average annual human exposure to ionizing radiation in millisieverts (mSv) per year

natural

artificial

Radiation source	World[2]	US[3]	Japan[4]	Remark
Inhalation of air	1.26	2.28	0.40	mainly from radon, depends on indoor accumulation
Ingestion of food & water	0.29	0.28	0.40	(K-40, C-14, etc.)
Terrestrial radiation from ground	0.48	0.21	0.40	depends on soil and building material
Cosmic radiation from space	0.39	0.33	0.30	depends on altitude
sub total (natural)	2.40	3.10	1.50	sizeable population groups receive 10–20 mSv
Medical	0.60	3.00	2.30	worldwide figure excludes radiotherapy; US figure is mostly CT scans and nuclear medicine.
Consumer items	–	0.13		cigarettes, air travel, building materials, etc.
Atmospheric nuclear testing	0.005	–	0.01	peak of 0.11 mSv in 1963 and declining since; higher near sites
Occupational exposure	0.005	0.005	0.01	worldwide average to workers only is 0.7 mSv, mostly due to radon in mines;[2] US is mostly due to medical and aviation workers.[3]
Chernobyl accident	0.002	–	0.01	peak of 0.04 mSv in 1986 and declining since; higher near site
Nuclear fuel cycle	0.0002		0.001	up to 0.02 mSv near sites; excludes occupational exposure
Other	–	0.003		Industrial, security, medical, educational, and research
sub total (artificial)	0.61	3.14	2.33	
Total	3.01	6.24	3.83	**millisieverts per year**

A 70 kg human body contains about 140 grams of potassium, hence about 0.000117 × 140 = 0.0164 grams of ^{40}K; whose decay produces about 3,850 to 4,300 disintegrations per second (becquerel) continuously throughout the life of the person.

Radionuclides of concern: Thorium (^{232}Th), Uranium (^{238}U) and (^{40}K) Potassium and their decay products

mSv is a unit for Equivalent Dose intended to represent the health risk of ionizing radiation.
Equivalent dose (H) = Absorbed dose (D) [joules/kilogram] x Quality factor (Q)
Q=f(radiation type, biological context) (ex. W_α particle=20x W photon.)

In the US and Japan artificial exposure is, on average, greater than the natural exposure, due to greater access to medical imaging

*"Coming out of space and incident on the high atmosphere, there is a thin rain of charged particles known as the primary **cosmic ray** radiation"*

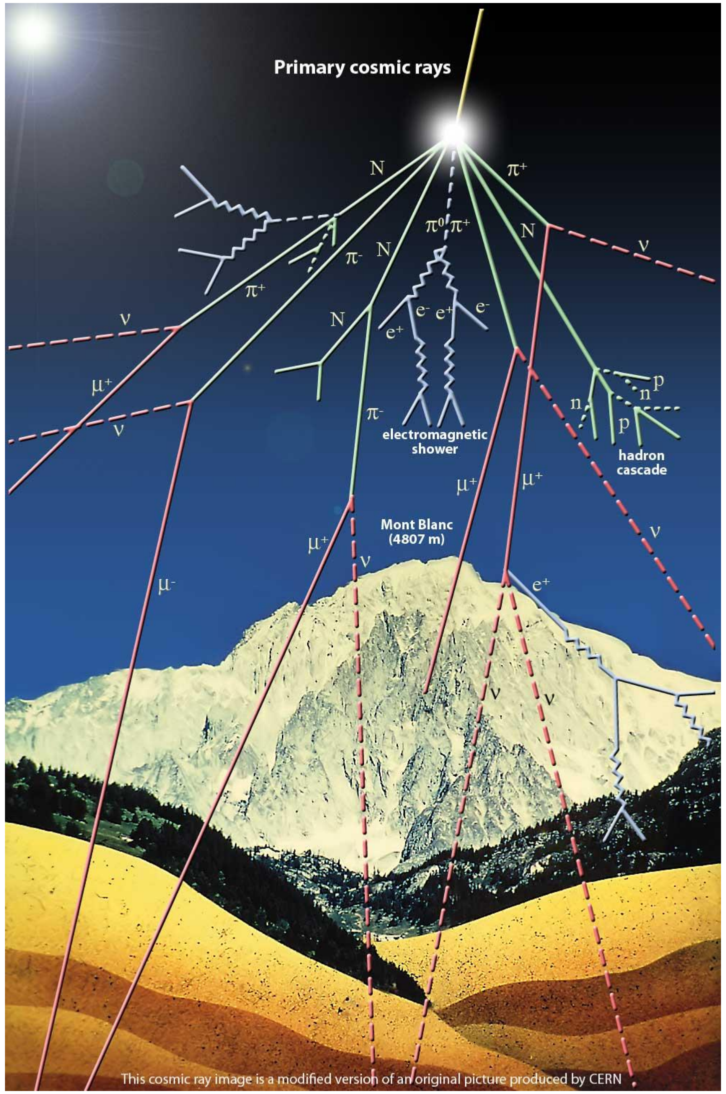
(Cecil Powell, Nobel Prize Lecture, 1950)

cosmic ⇒ with an extraterrestrial origin

rays ⇒ a "misnomer" due to a historical accident as cosmic rays were at first, and wrongly, thought to be mostly electromagnetic radiation

Slide: Pol Bordas

Natural Background Radiation – Galactic Cosmic Rays



Primary cosmic rays hit the upper atmosphere

- ~50% of Cosmic Rays are protons
- ~25% are alpha particles (He nuclei)
- ~13% is C, N, O nuclei
- < 1% are electrons
- < 0.1% are gamma-rays

They collide with molecules in the atmosphere producing secondaries which can reach earth

- X-rays
- Protons
- Neutrons
- Electrons
- Alpha (He nucleus)
- Muons (high energy electron-like)
- Pions

About 150 muons are striking the earth evert square meter every second

Introducción:
La radiación ionizante

- La radiación ionizante está presente en el ambiente sin que necesariamente haya una fuente radioactiva artificial.
- La dosis se calcula a partir de aplicar un factor de calidad que depende del contexto biológico y del tipo de partícula.

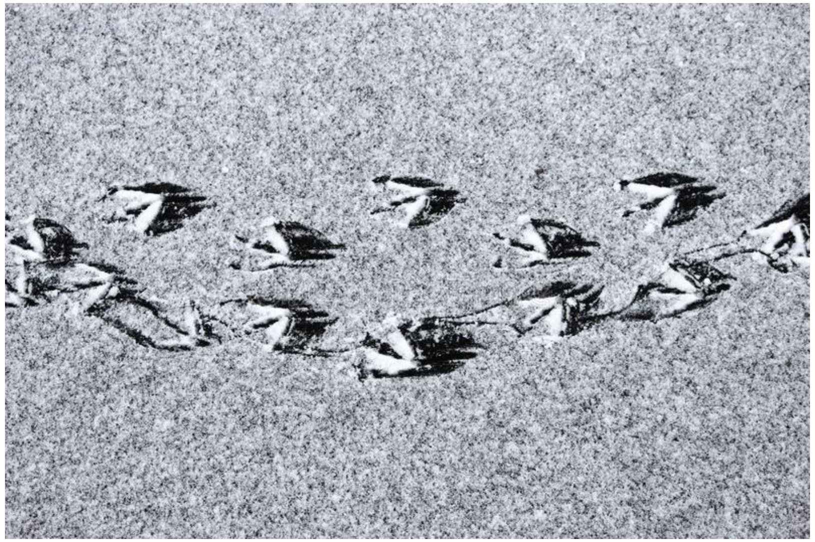
Introducción:
La detección de particulas

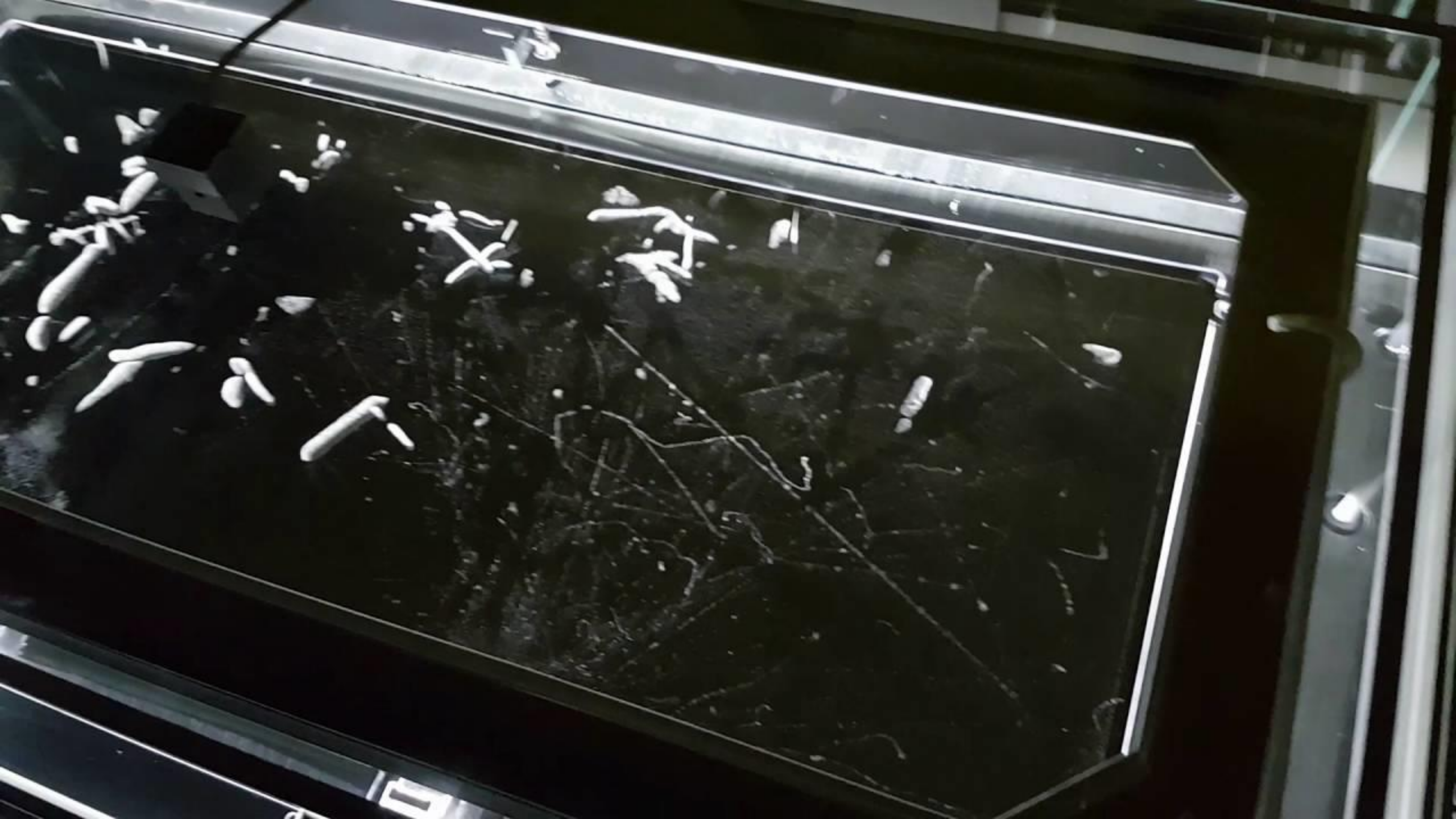
"Detector: instrumento que sirve para descubrir la presencia de algo a través de indicios"

https://www.freepik.com/vectors/detective

Detección de partículas

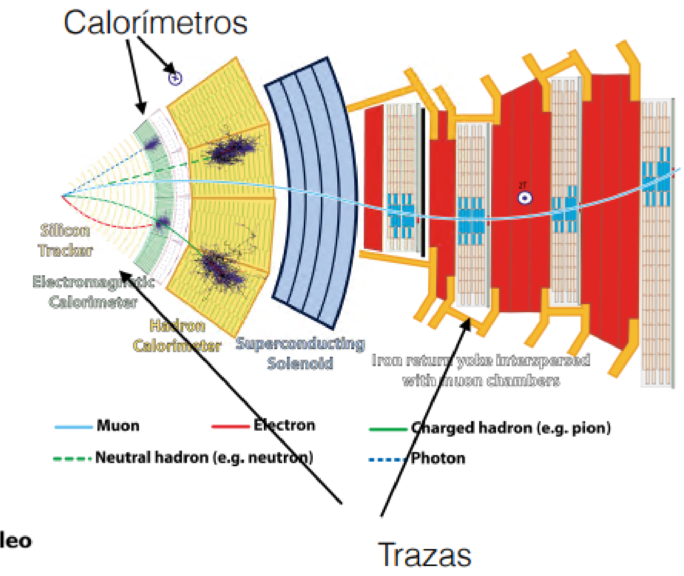
- Podemos reconocer las partículas por sus "huellas"
- Estas huellas indican de qué **tipo** de partícula se trata, su **energía**, la **carga** eléctrica, el punto donde se creó y su **trayectoria**
- Las huellas dependen no solo del tipo de partícula sino también del material del detector





Detectores en LHC

- Dadas estos requisitos, qué tipo de detectores se pueden construir para detectar y medir las propiedades de las partículas?
- Ejemplo CMS: configuración típica en experimentos de colisiones de altas energías
  - Detector de trazas interno
  - Calorímetros (EM,HAD)
  - Detector de trazas de muones



Trazas — **Detectores de Silicio**

Calorimetría — **Detectores de centelleo**

Sistemas de muones — **Detectores de Gas**

SPANISH TEACHING PROGRAM 26 JUL 2022

Cada familia de partículas interacciona de forma diferente con los materiales que encuentra (una huella característica)

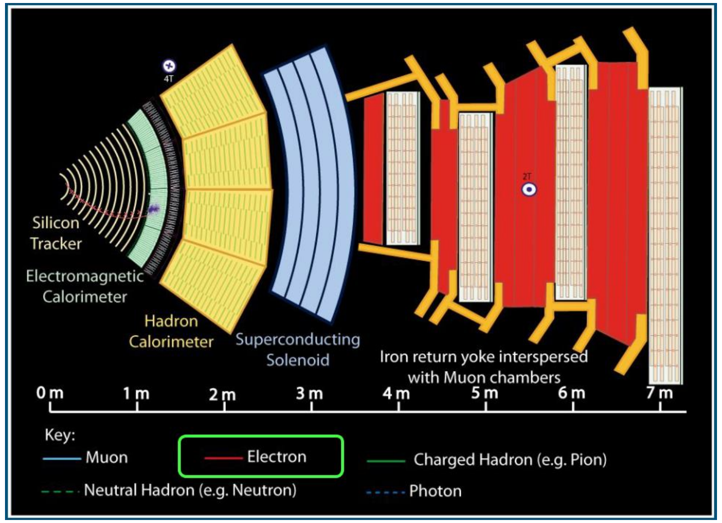
Imagen: Silvia Goy
Detectores: Presentacion Ignacio Redondo (CIEMAT)

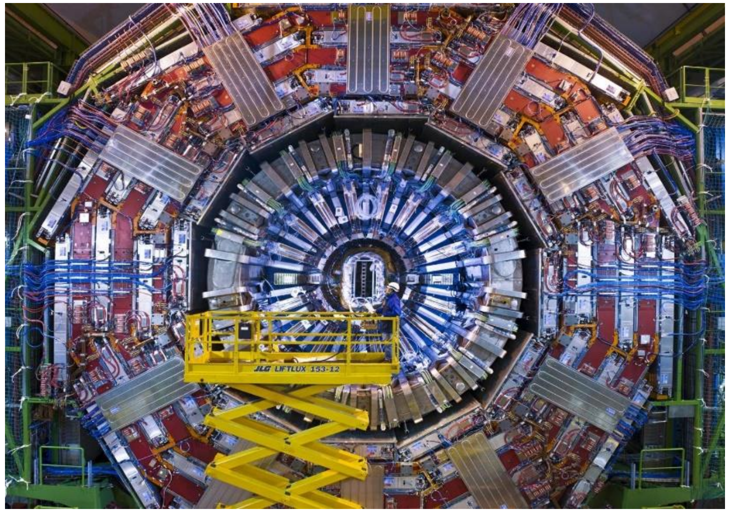
Detectores de trazas

Capas de finos, O(100 um), sensors de silicio. Última gran revolución

Su capacidad para identificar la desintegración de partículas de vida corta permitió hacer toda la física de los mesones B, “viven” O(10^{-12})s.

Detectores de trazas





Especificaciones de los detectores de trazas (tracking detector):

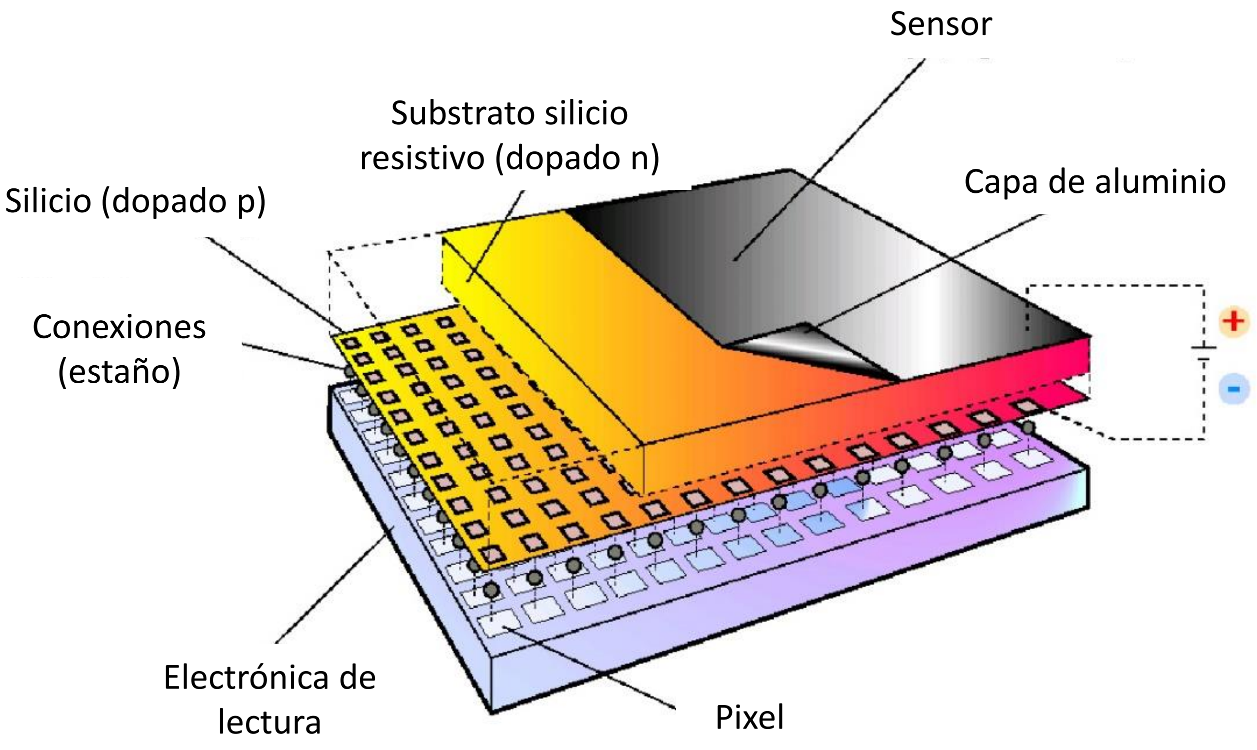
- Procesado individual de la señal depositada en el sensor para cada partícula
- Asignación de las partículas al instante de la colisión (25ns/40MHz)
- Resolución espacial del orden de decenas de micrómetros
- Masa mínima
- Bajo consumo de potencia
- Resistencia a la radiación

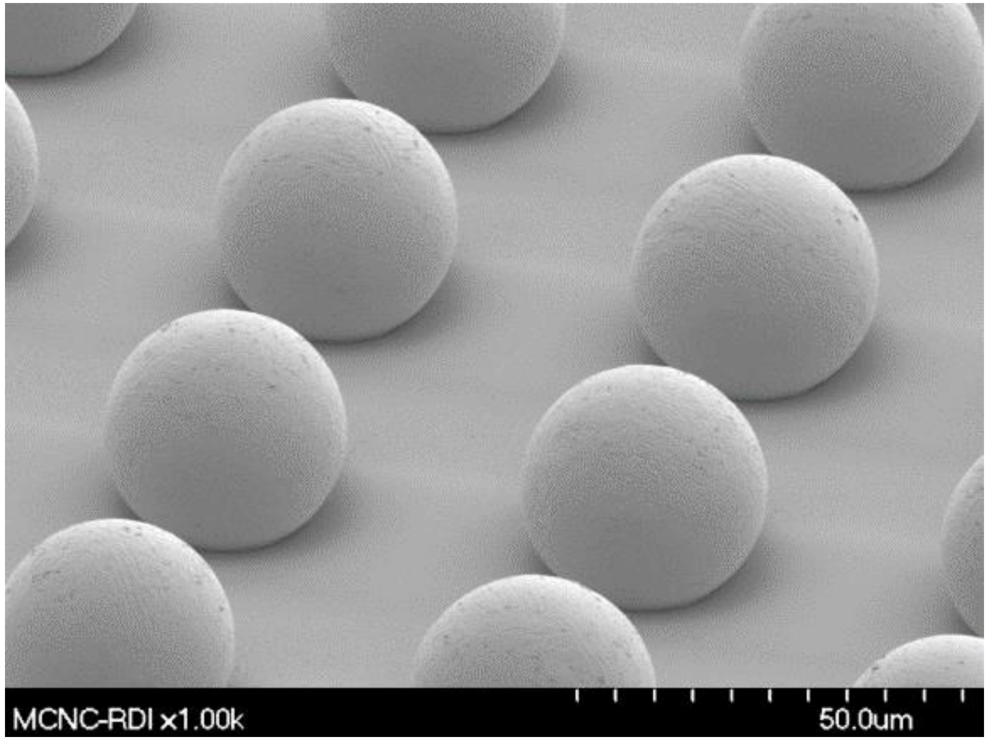
Actualmente solamente la tecnología de pixeles híbridos cumple con estas especificaciones

Introducción:
La detección de particulas

- No podemos ver las partículas, pero podemos descubrir su presencia a través de las huellas que dejan en un material detector.
- Cada partícula tiene una forma "característica" de interactuar al pasar por un material.
- Podemos utilizar esta característica para la identificación de partículas.

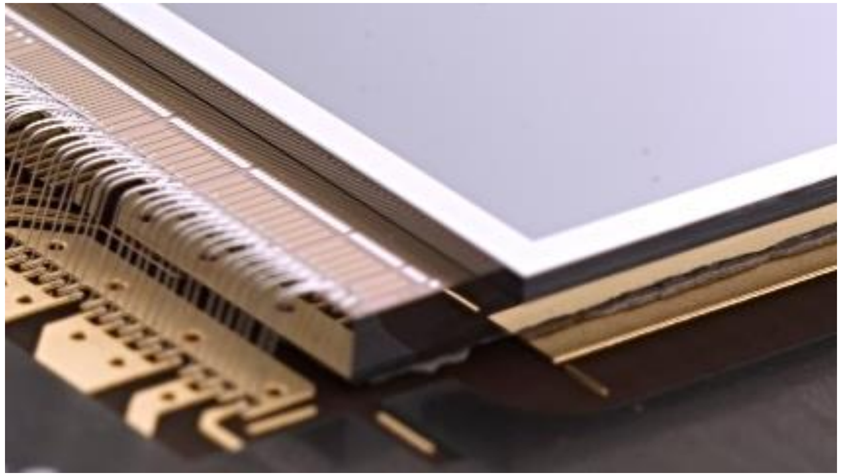
Introducción a los detectores de píxeles híbridos

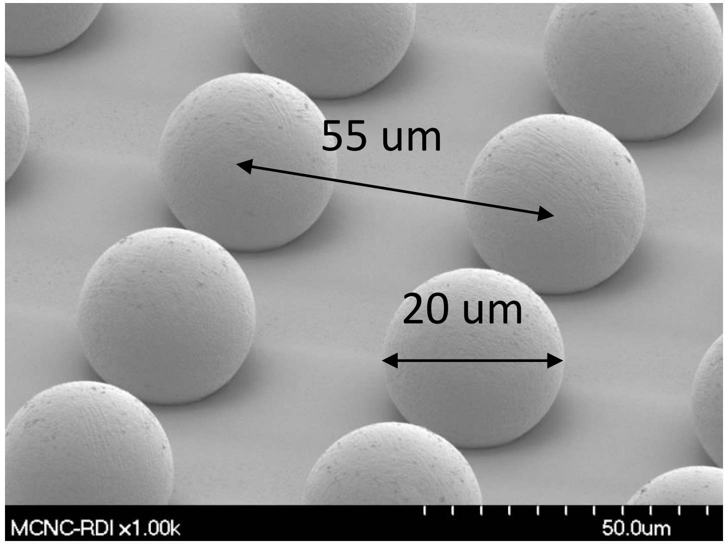


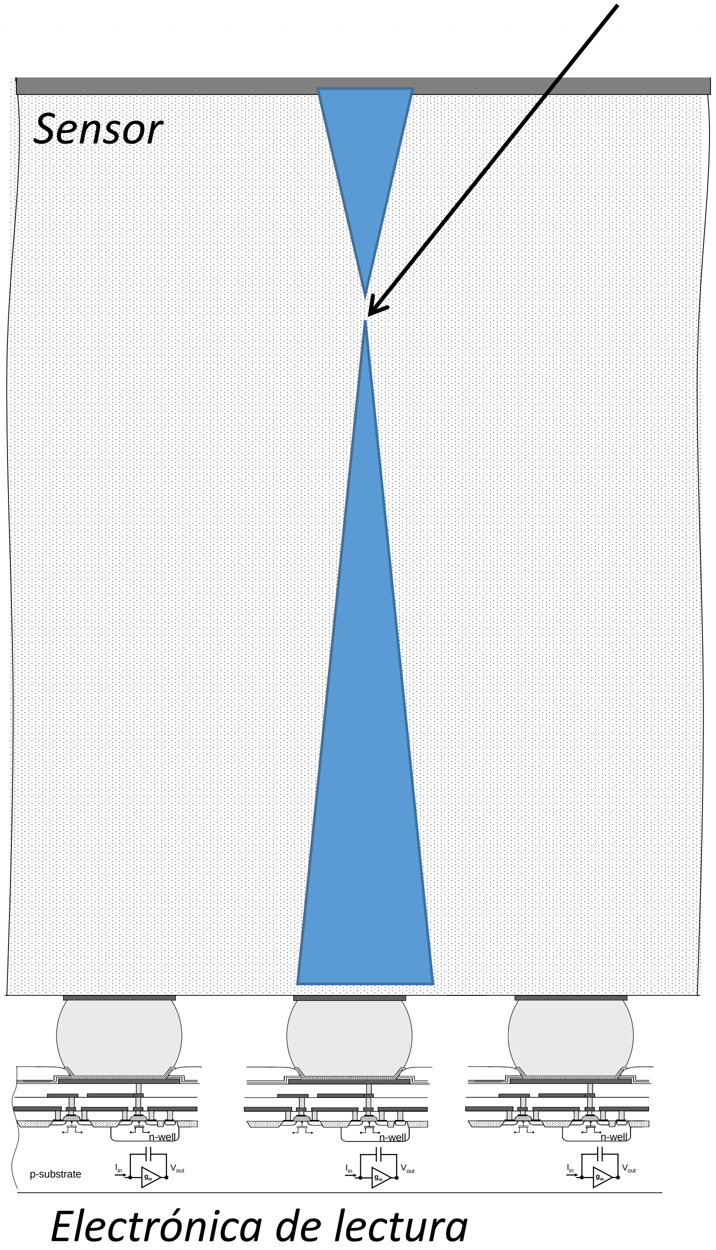


- Un detector de píxeles híbrido es una matriz de elementos microscópicos sensibles a la radiación cada uno de los cuales está conectado a su propia electrónica de lectura
- El sensor y la electrónica están implementados en substratos diferentes y se pueden optimizar por separado

Los detectores híbridos







Information from the incoming beam

- The number of particles deposited during a given exposure time
- The energy deposited by an individual particle
- The time of arrival of the particle

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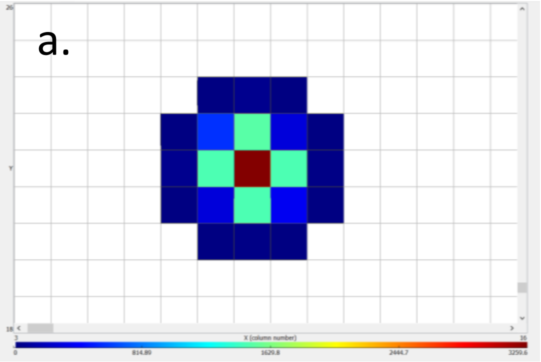
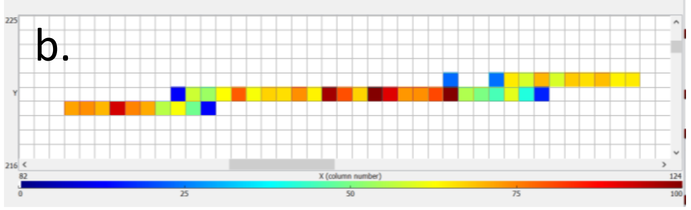
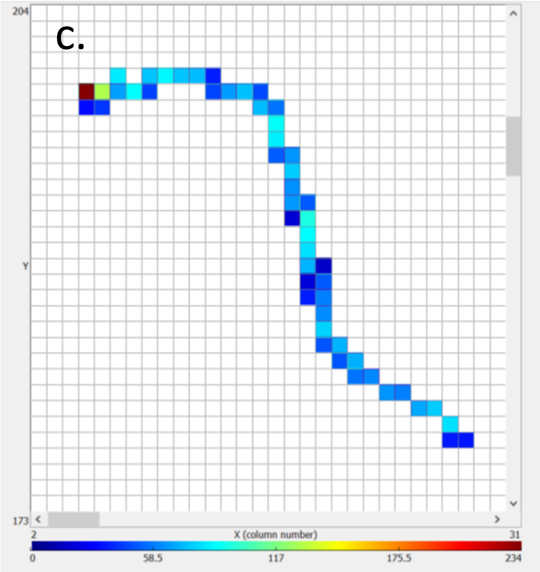


~270μm



~2mm



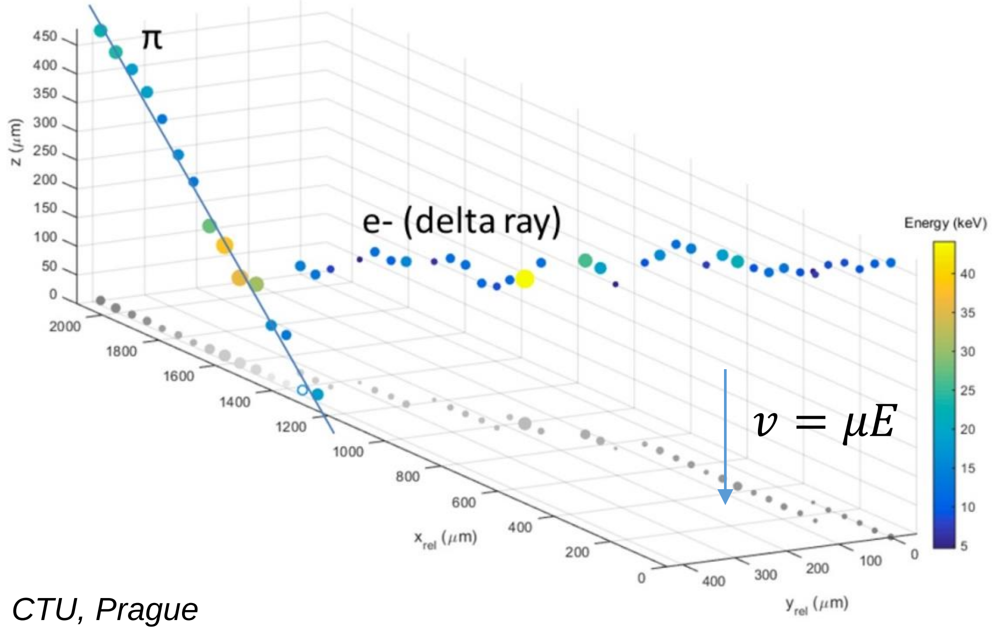
~1.3mm

a. Alpha particle, b. Muon, c. Electron
Timepix data, 55μm pixels

Information from the incoming beam

- The number of particles deposited during a given exposure time
- The energy deposited by an individual particle
- The time of arrival of the particle
- The incoming type of particle, based on the shape of the cluster of pixels responding to a single charge deposition event
- The angle of incidence of the incoming charged particle based on the difference in the induced signal time of the drifting charge in the different pixels

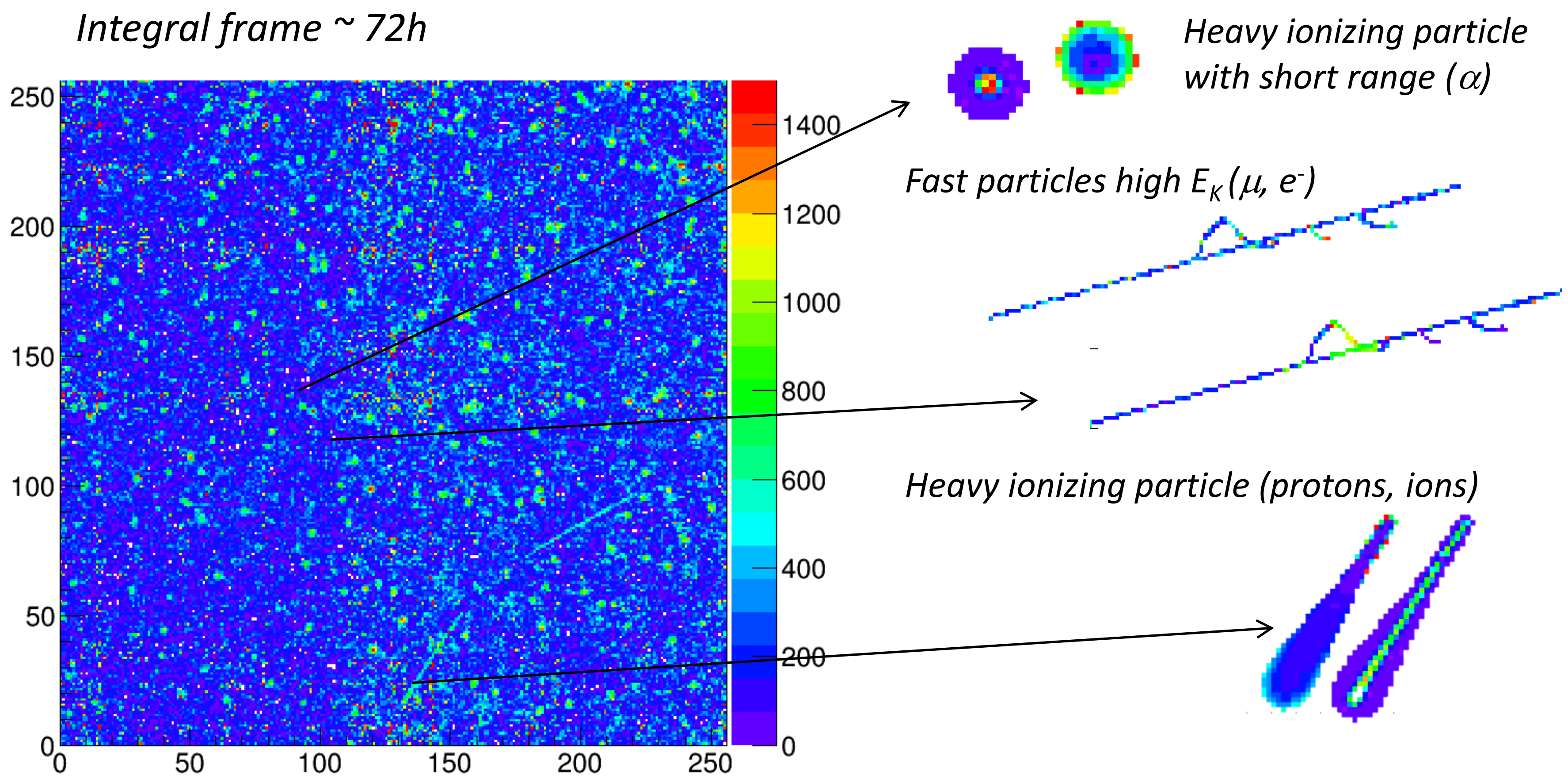
60 deg
p+ in n Si sensor, Timepix3
500μm thick
V_{bias} = 130V
Colour (and diameter) indicate charge
Measured z resolution ~50μm



Measurement B. Bergmann, S. Pospisil, IEAP, CTU, Prague

Demostración

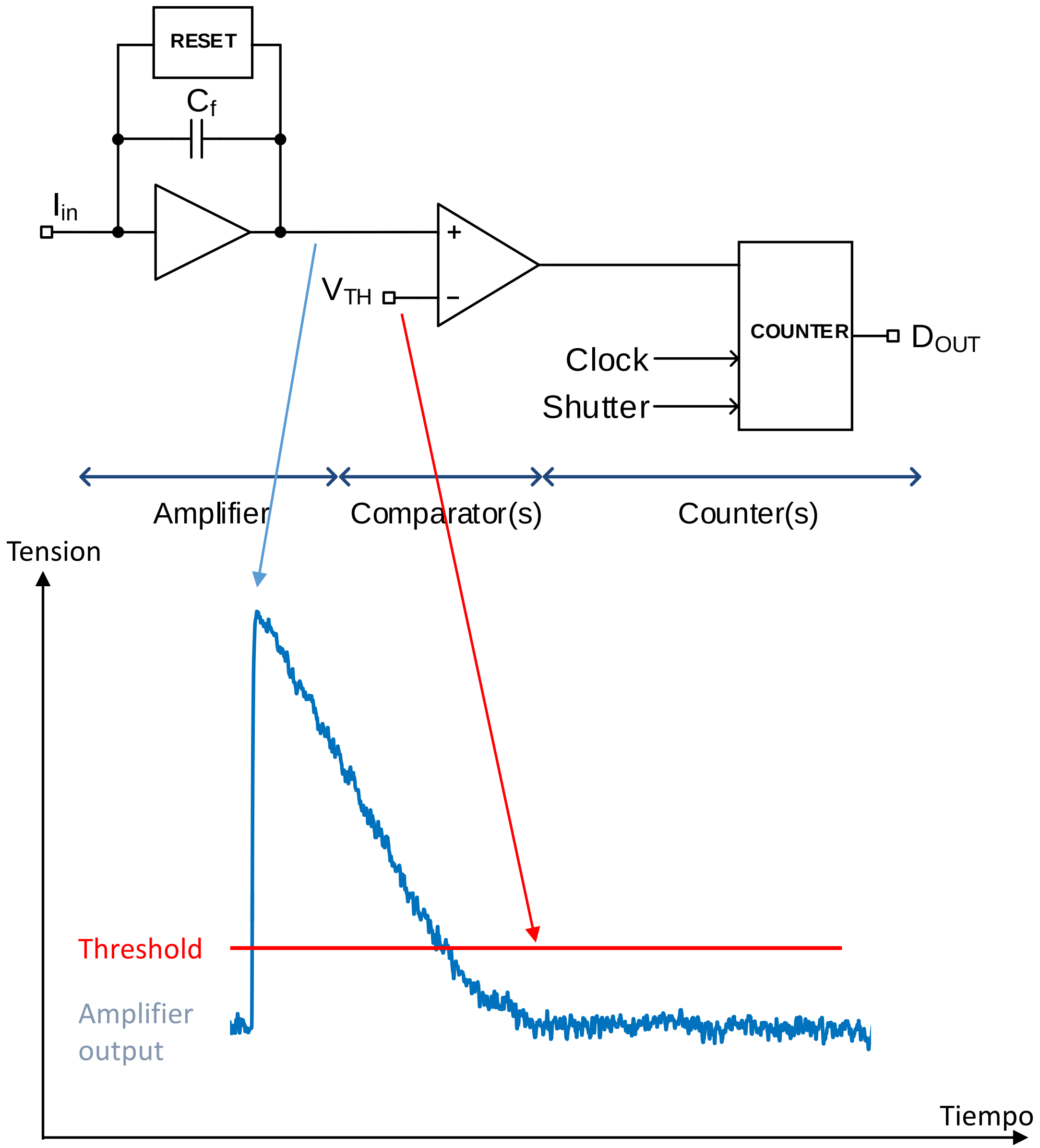
Energy and time measurements with cosmic particles



Timepix chip: matrix of 256x256 pixels

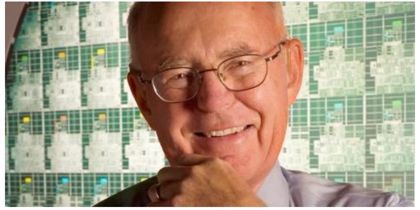
Different particles present a different signature in their interaction with the pixelated semiconductor detector

Los detectores de píxeles híbridos

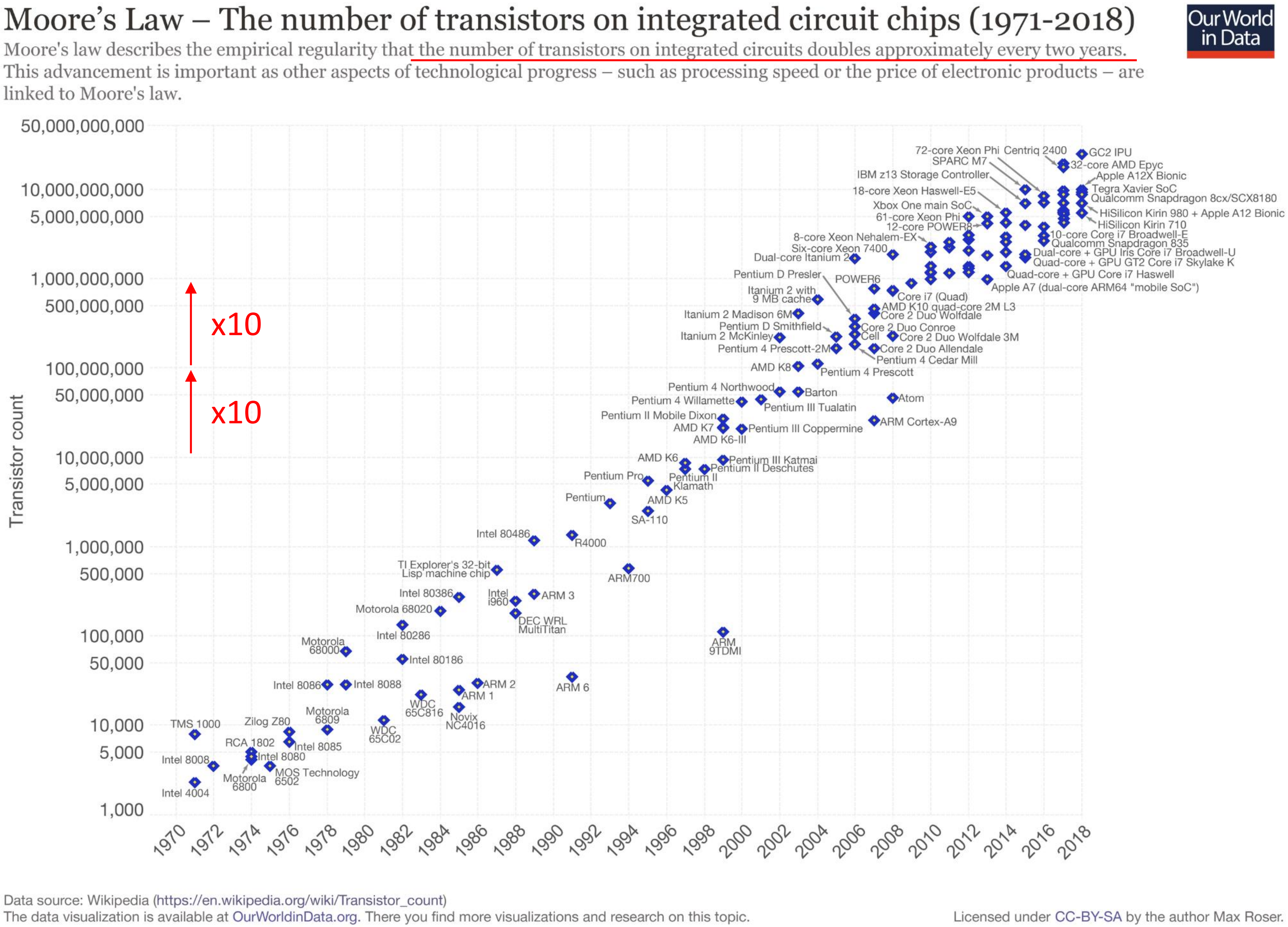


- Sistema "noise hit free" (sin detecciones falsas)
- Medidas posibles:
  - Presencia/ausencia de partícula en intervalo de tiempo
  - Cámara: Numero de cuentas durante el tiempo en el que el obturador esta abierto — *Medipix
  - Energía (Midiendo la amplitud o la duracion) — *Timepix
  - Tiempo de llegada
- Limitación: tiempo muerto ("dead time")

** Simplificación, para mas información, ver transparencias adicionales*



El transistor: la ley de Moore (1965)



El transistor: la ley de Moore

El transistor: la ley de Moore

¿Cuántos kilos de arroz se necesitan para llenar todas las casillas del tablero?

a. ~1

b. ~10

c. ~100

d. Ninguna de los anteriores

El transistor: la ley de Moore

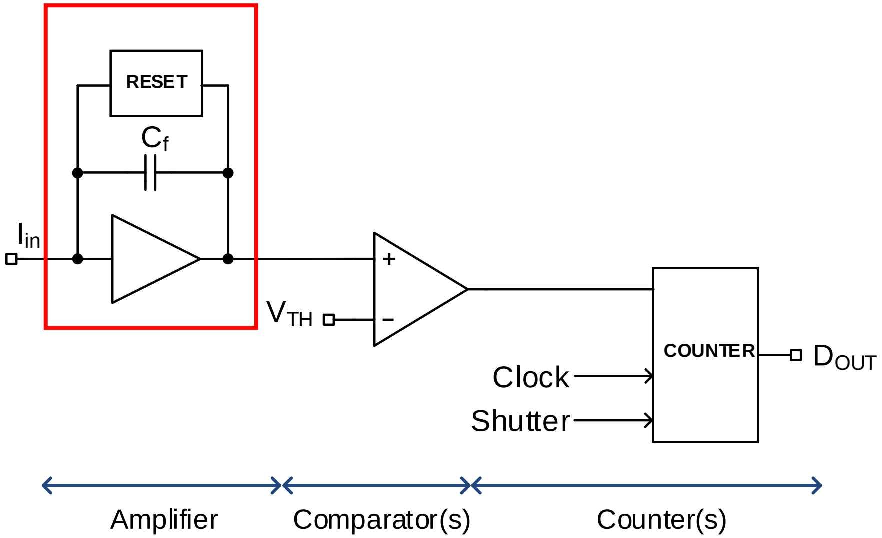
Casella	Grans	Quilos
8	128	0.00256
16	32768	0.65536
24	8388608	167.77216
32	2147483648	42949.67296
40	5.49756E+11	10995116.28
48	1.40737E+14	2814749767
56	3.60288E+16	7.20576E+11
64	9.22337E+18	1.84467E+14

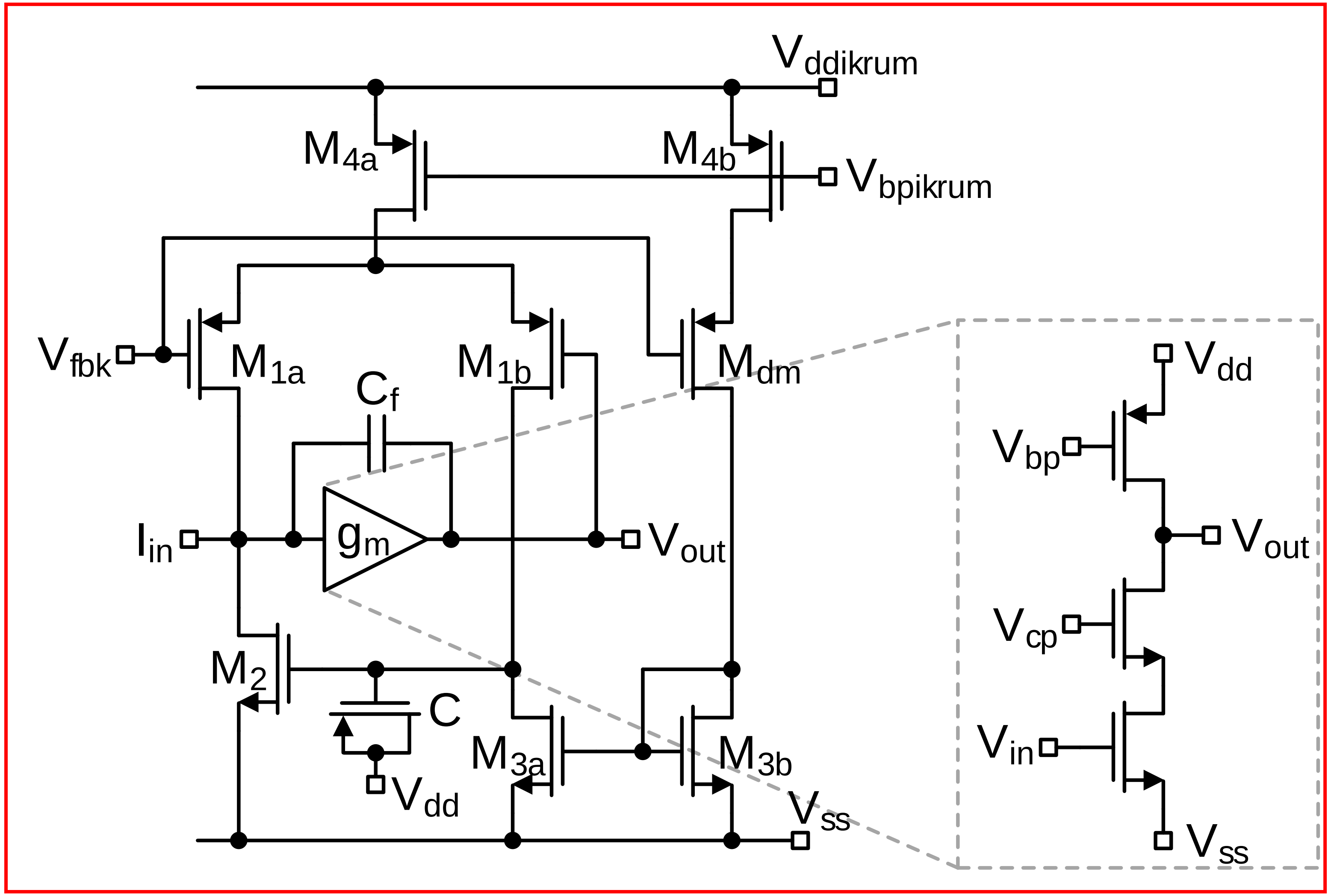
263 veces la producción mundial!!!

1kg 50000 grans
Producción mundial anual 700 10^6 tones

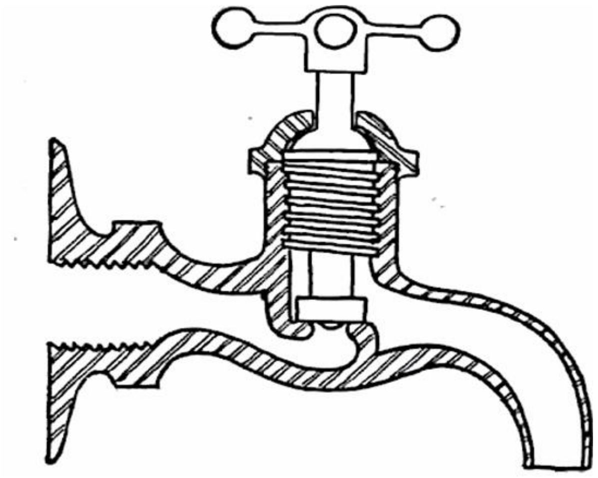
1er transistor: 1959 (Casilla 1)
Ley de Moore 1965 (~1000 transistores/chip) (casilla 11)
Hoy >10 000 10^6 transistores (casilla 33)

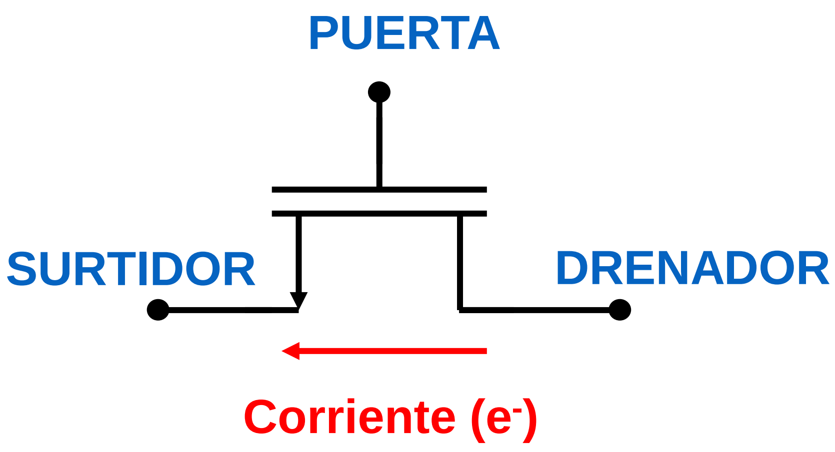
Los bloques se implementan con transistores.

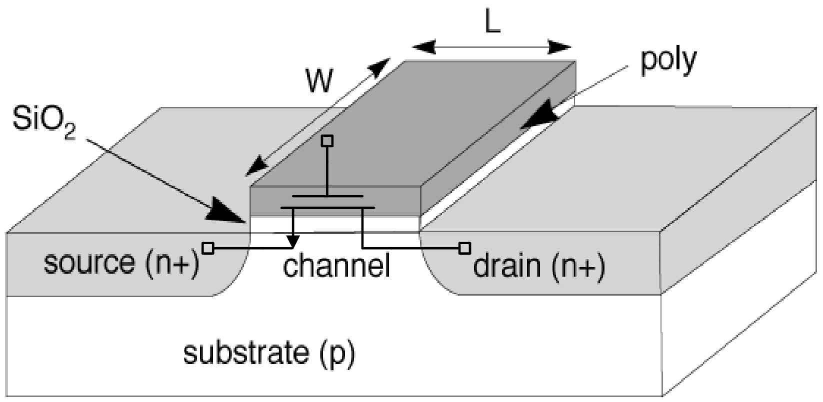




El transistor

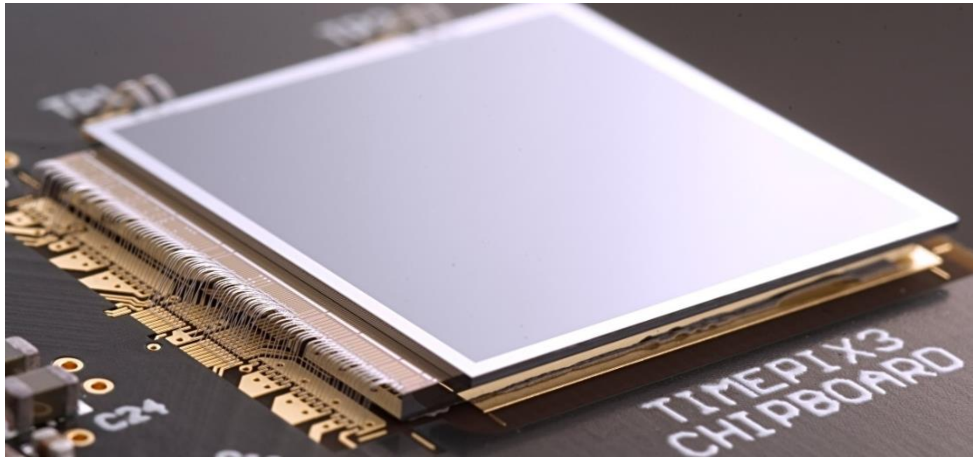


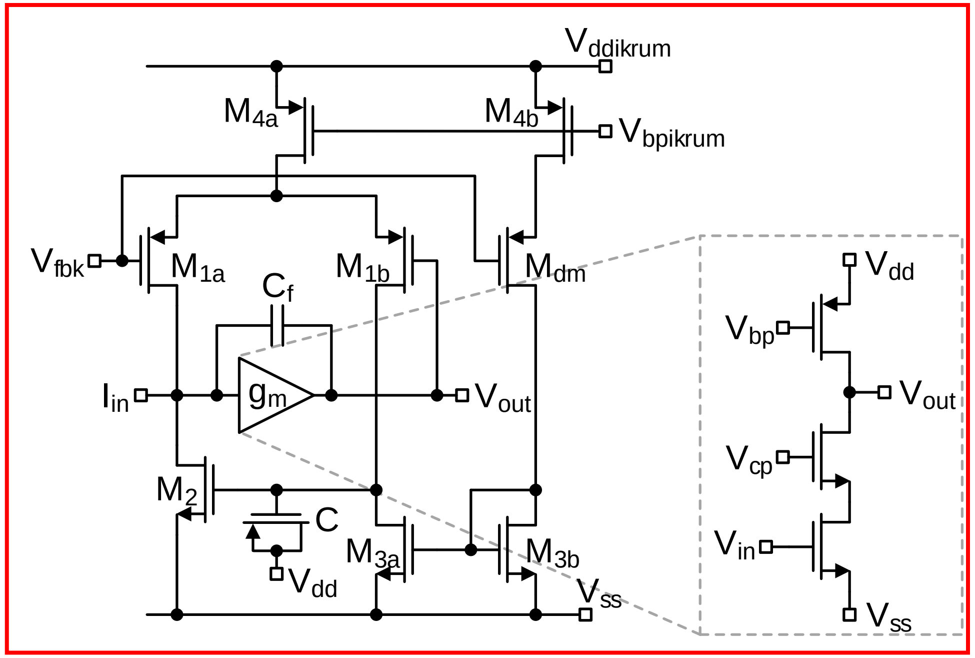




El transistor es un interruptor.

- Puede conmutar rápidamente (cuanto más pequeño, mejor).
- I_{ON}/I_{OFF} debe ser muy grande.
- I_{OFF} debe ser lo más pequeña posible (para evitar el consumo estático).
- I_{ON} debe ser lo más grande posible (para cargar capacidades, es decir, conmutar rápidamente).
- Debe poder encenderse con la señal en la entrada lo más pequeña posible (minimizar potencia).
- Debe tener su componente complementario (si no, el consumo de potencia estática puede ser muy grande).
- Debe tener terminales independientes.
- Debe poder fabricarse en grandes cantidades (>10^9 en un cm^2).
- Debe poder conmutar fiablemente alrededor de 10^{15} veces (10 años de operación).


TIMEPIX3
CHIPBOARD
C24


$V_{ddikrum}$
M_{4a}
M_{4b}
$V_{bpikrum}$
V_{fbk}
M_{1a}
M_{1b}
M_{dm}
C_f
I_{in}
g_m
V_{out}
M_2
C
V_{dd}
M_{3a}
M_{3b}
V_{ss}
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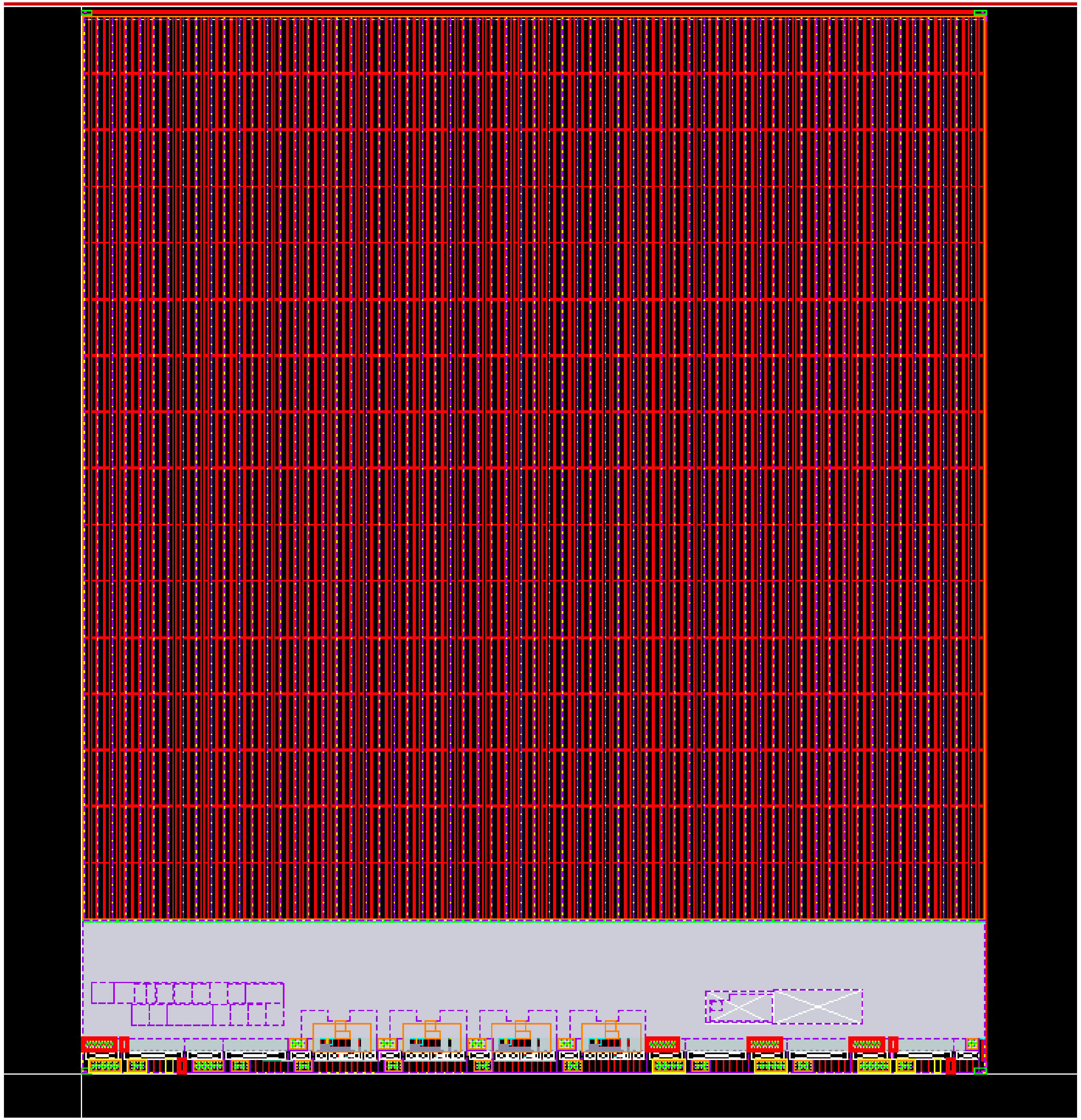
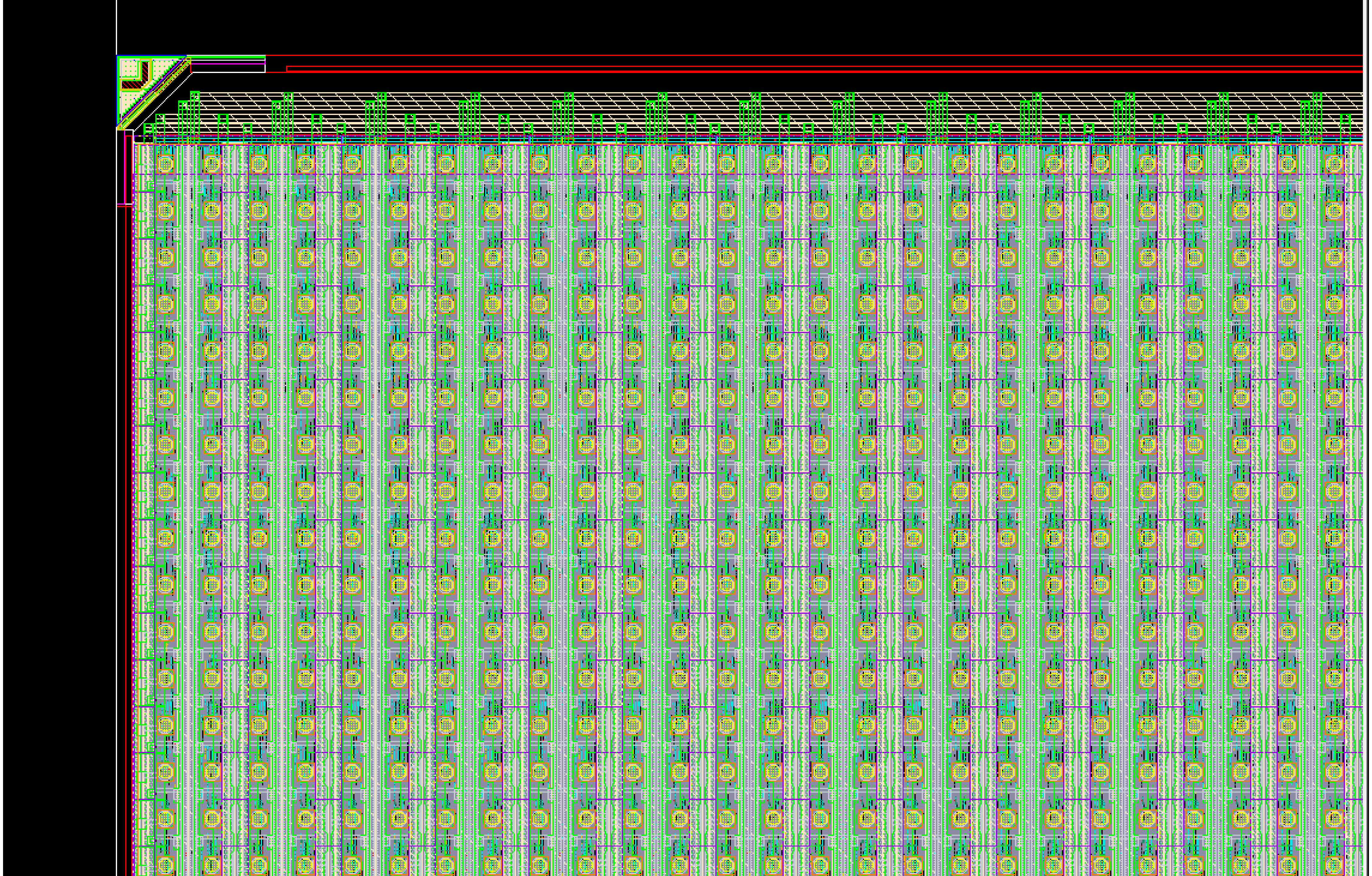
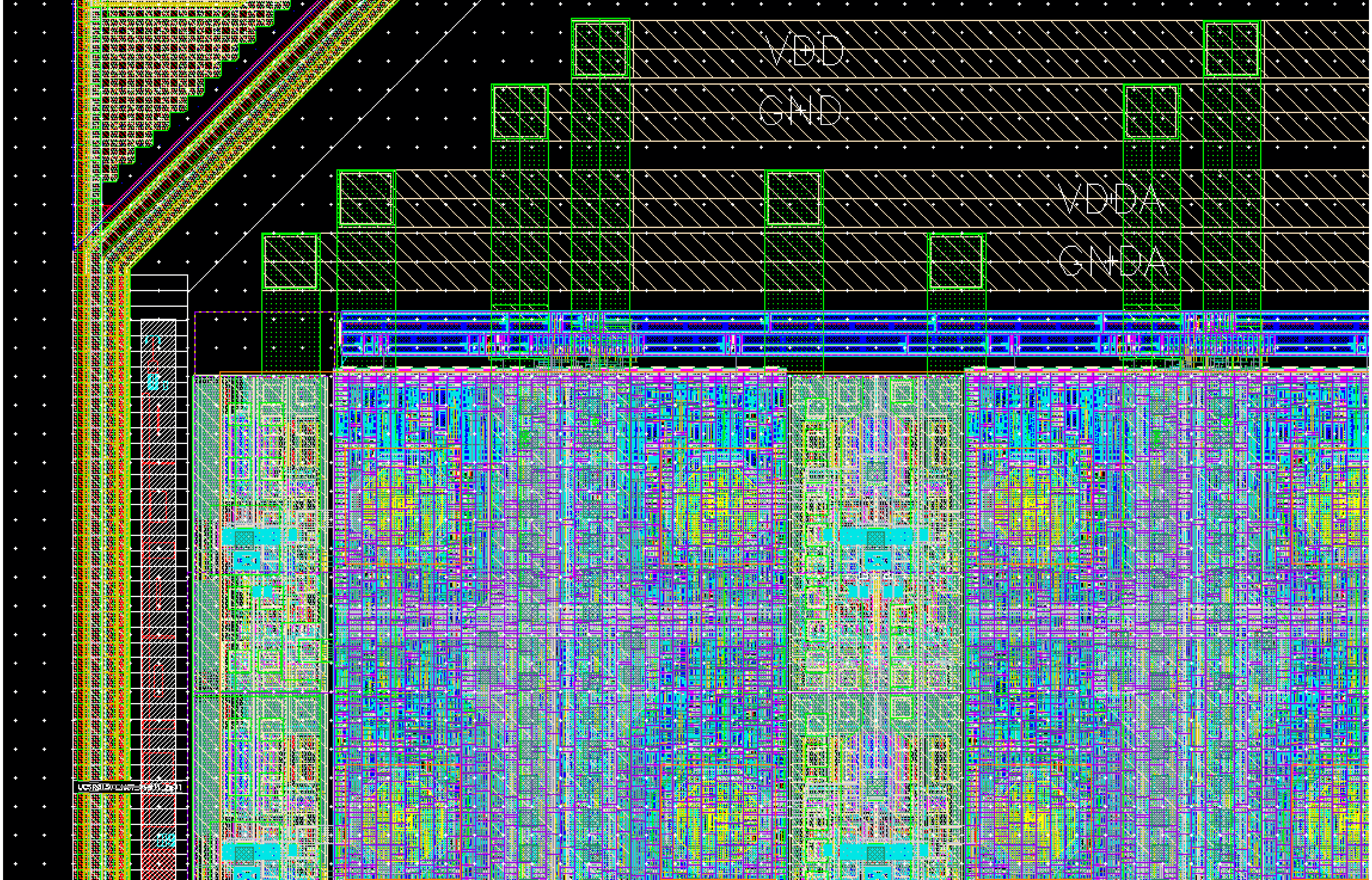
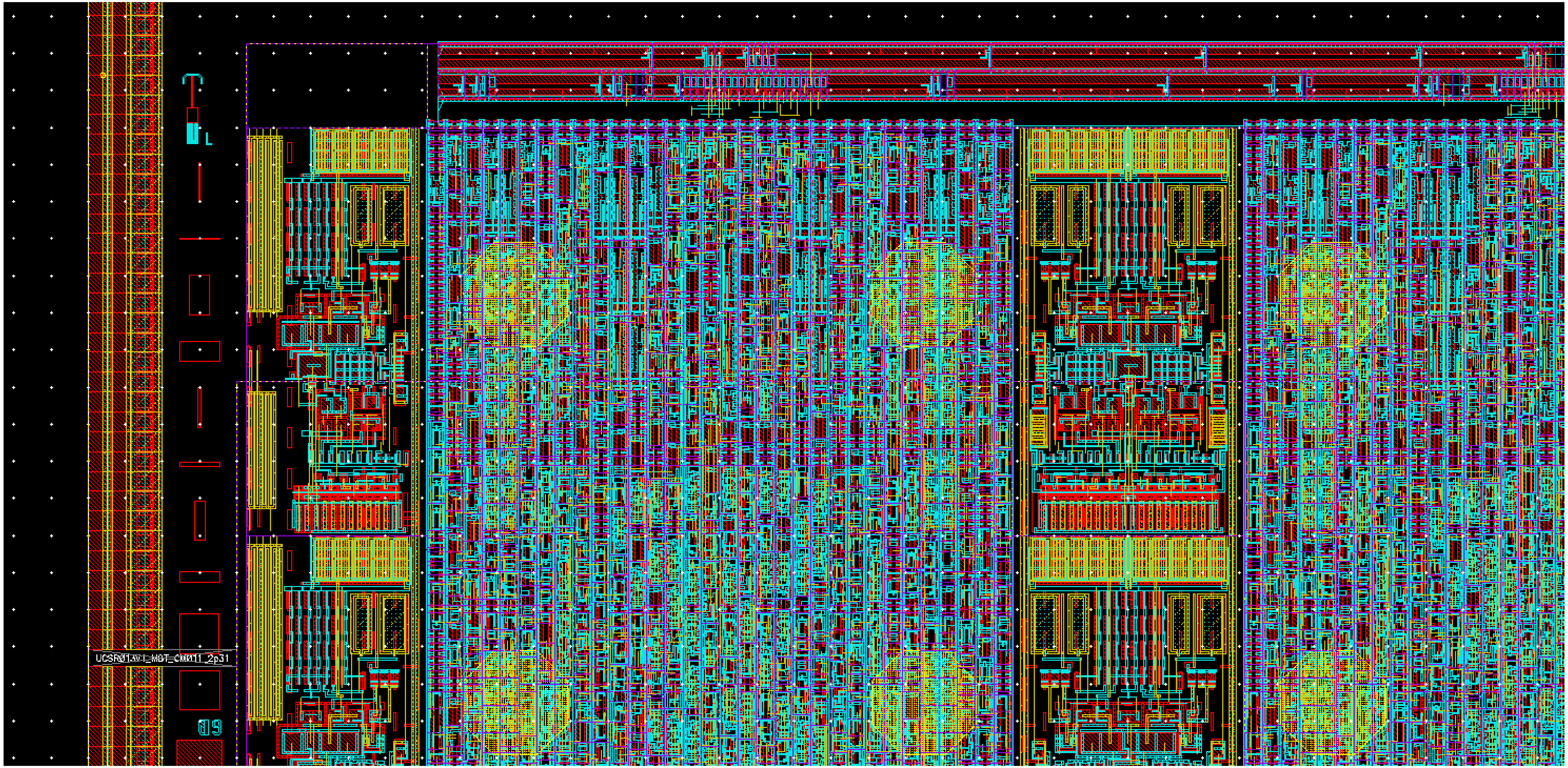
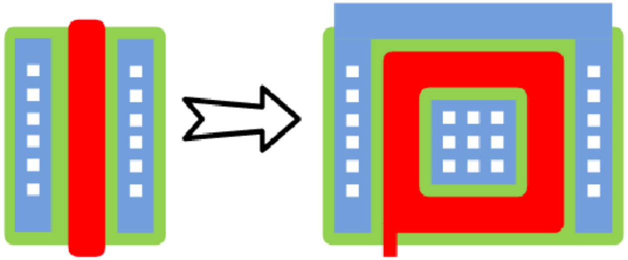
V_{out}
V_{cp}
V_{in}
V_{ss}






VDD
GND
VDDA
GNDA





"En la tecnología CMOS estándar, los transistores se diseñan con una estructura regular. Para protegerlos de los efectos de la radiación, los diseñamos con geometría de 'enclosed layout’.
(“Technology customization” o “Adaptación de la tecnologia”)

Introducción a los detectores de píxeles híbridos

- Un detector de píxeles híbrido consiste en un material sensor segmentado conectado a la electrónica de lectura.
- El sensor convierte la energía depositada por la partícula (total o parcialmente) en señal eléctrica y la electrónica de lectura procesa esa señal.
- Podemos medir muchas de las características del haz incidente (modo cámara, tiempo, energía, tipo de partícula).
- Los chips se fabrican con dispositivos electrónicos elementales que llamamos transistores, cuyas dimensiones son del orden de decenas de nanómetros.

Las colaboraciones Medipix

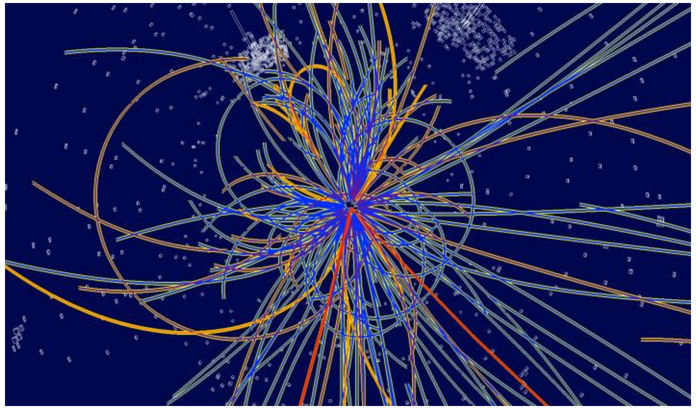
Google My Maps

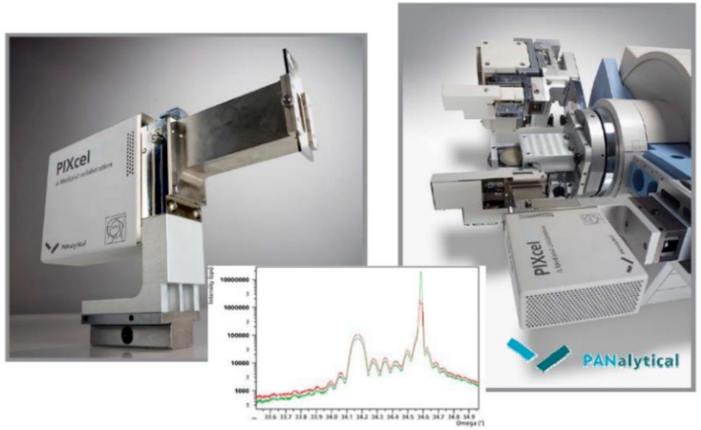

Google My Maps


Google My Maps

Las colaboraciones Medipix

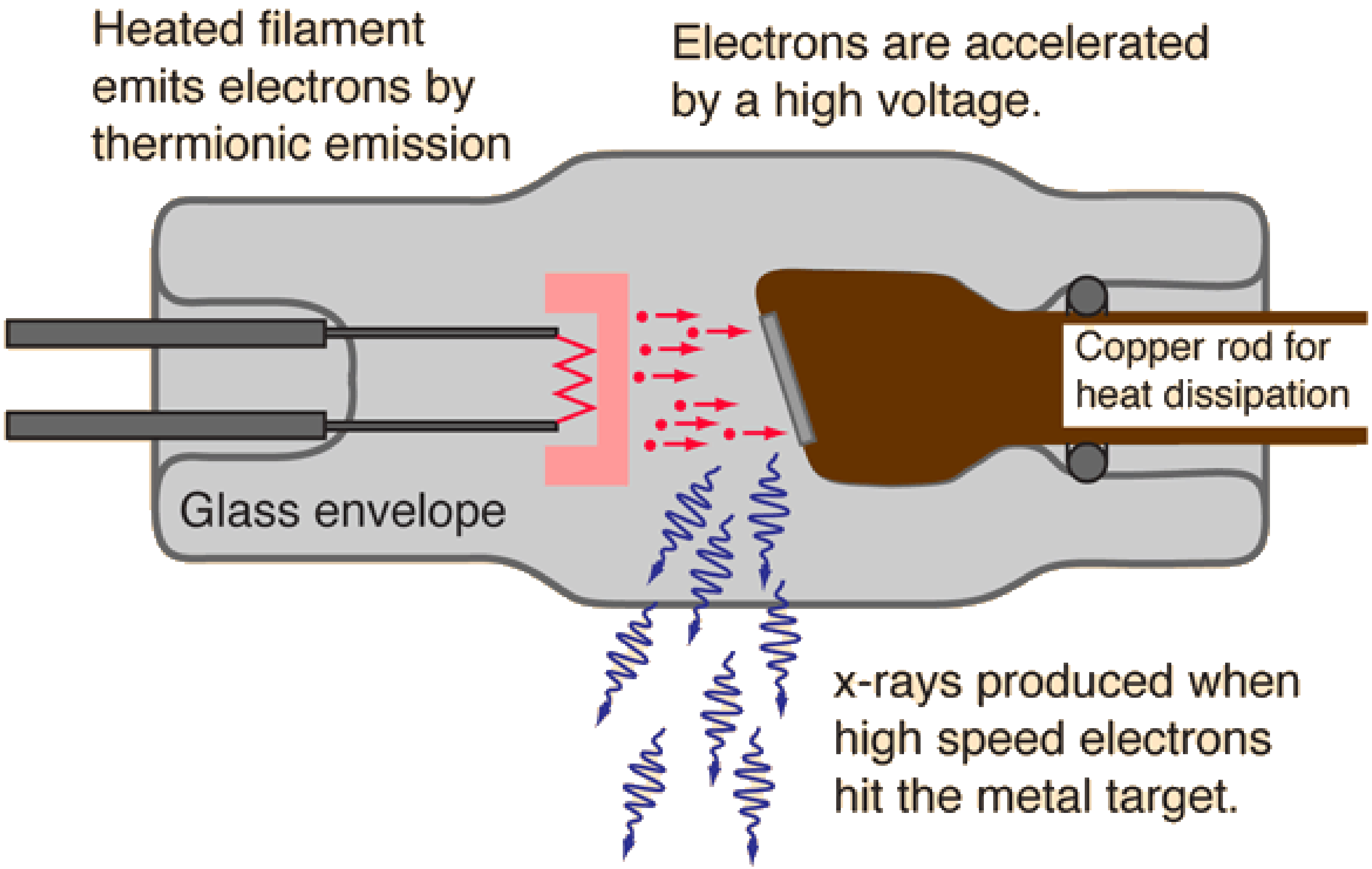
- Se crearon para desarrollar detectores de píxeles híbridos y sus aplicaciones
  - Chips Medipix: procesado rápido de la información en el pixel
  - Chips Timepix: procesado “off-line” (más información por evento, flujo de partículas inferior)
- ¡Science driven!
- Los chips están diseñados en la sección de microelectrónica del CERN
- Los colaboradores desarrollan sistemas de lectura e instalan los sistemas de detectores en sus aplicaciones
- Cuando los sistemas están bien caracterizados se pueden dar licencias de comercialización (e.g. Medipix3: 2 licencias de exclusividad, 5 de no exclusividad)
- Ejemplo de spin-off y spin-back hacia la física de altas energías

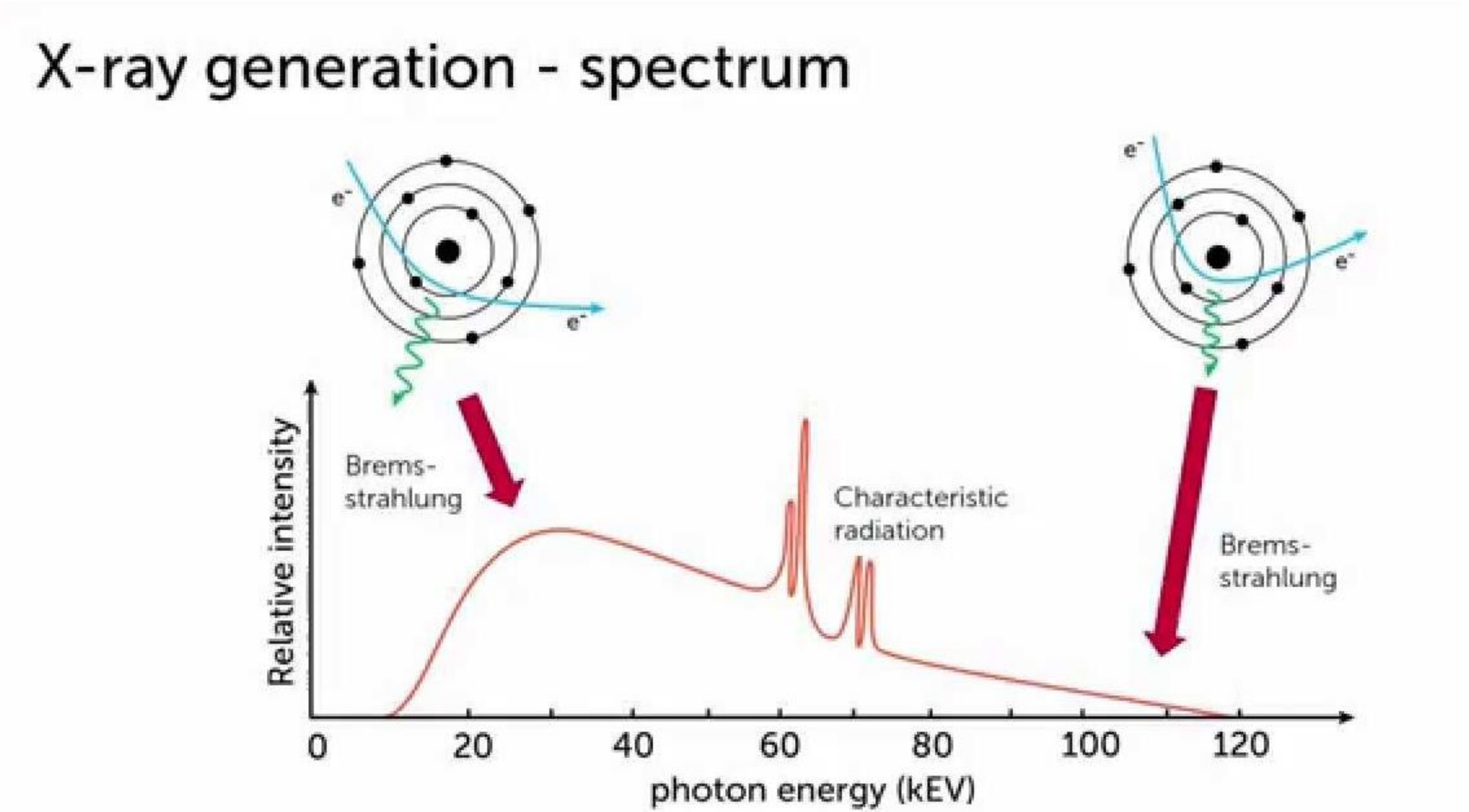




Aplicaciones: Radiografia

Generación de rayos X

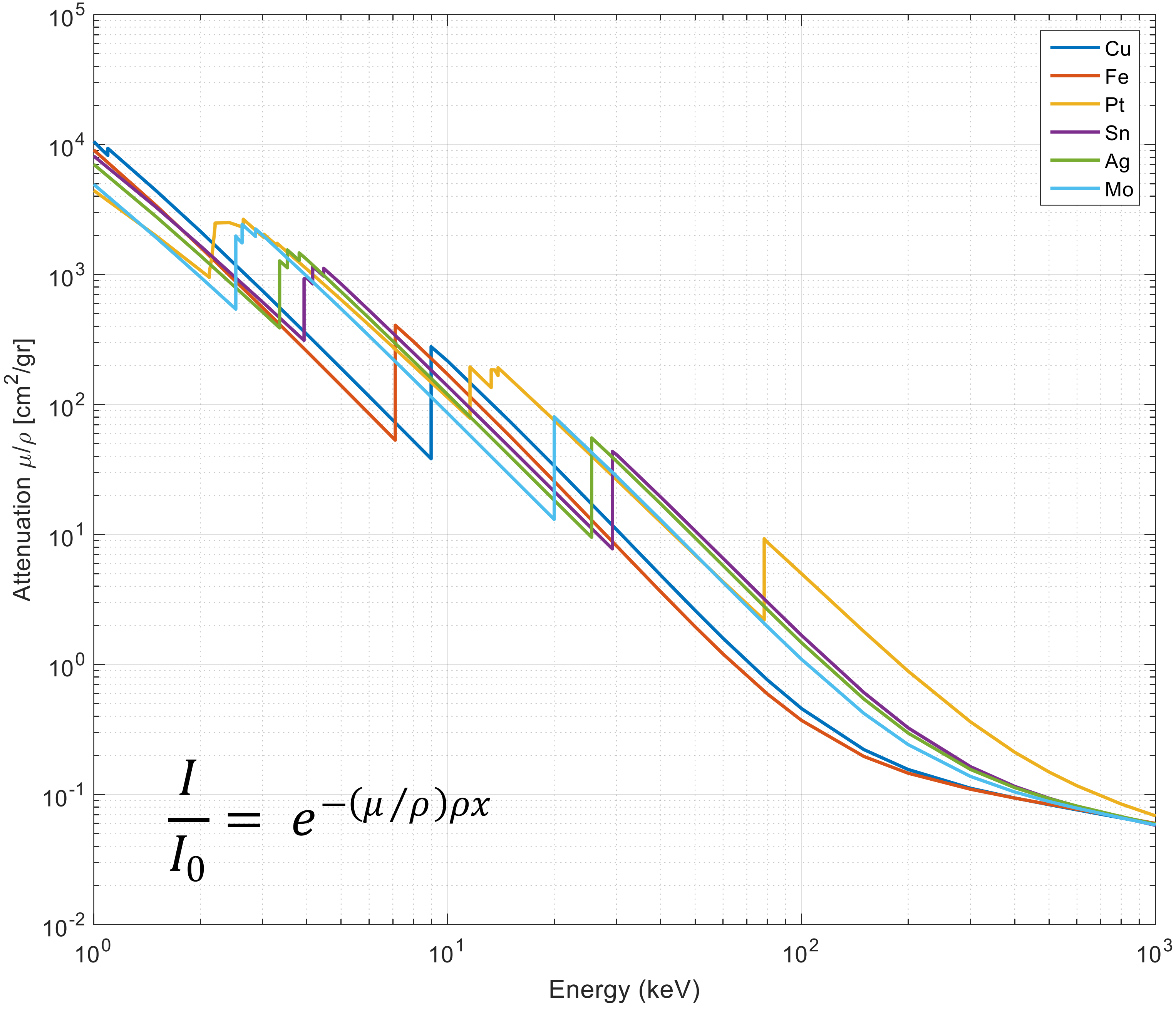




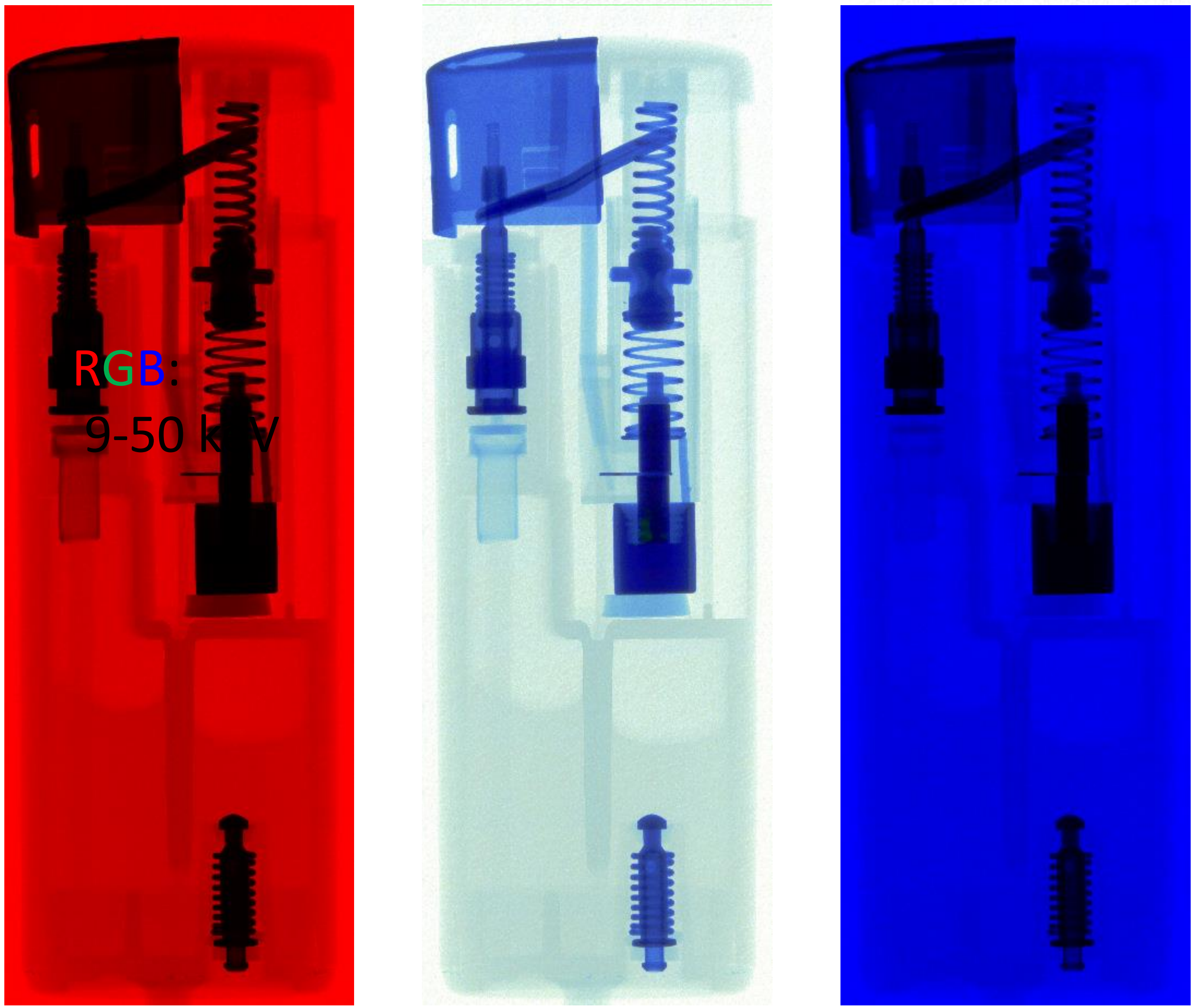
Un electrón de alta energía que impacta el interior de un átomo puede generar fotones de rayos-X por el hecho de que su trayectoria sea desviada por el núcleo atómico sin que altere en su recorrido la estructura electrónica del átomo que ha sido atravesado.

(Presentación ADMIRA Enero 2020, E. Graugés)

"Energia"="Color"

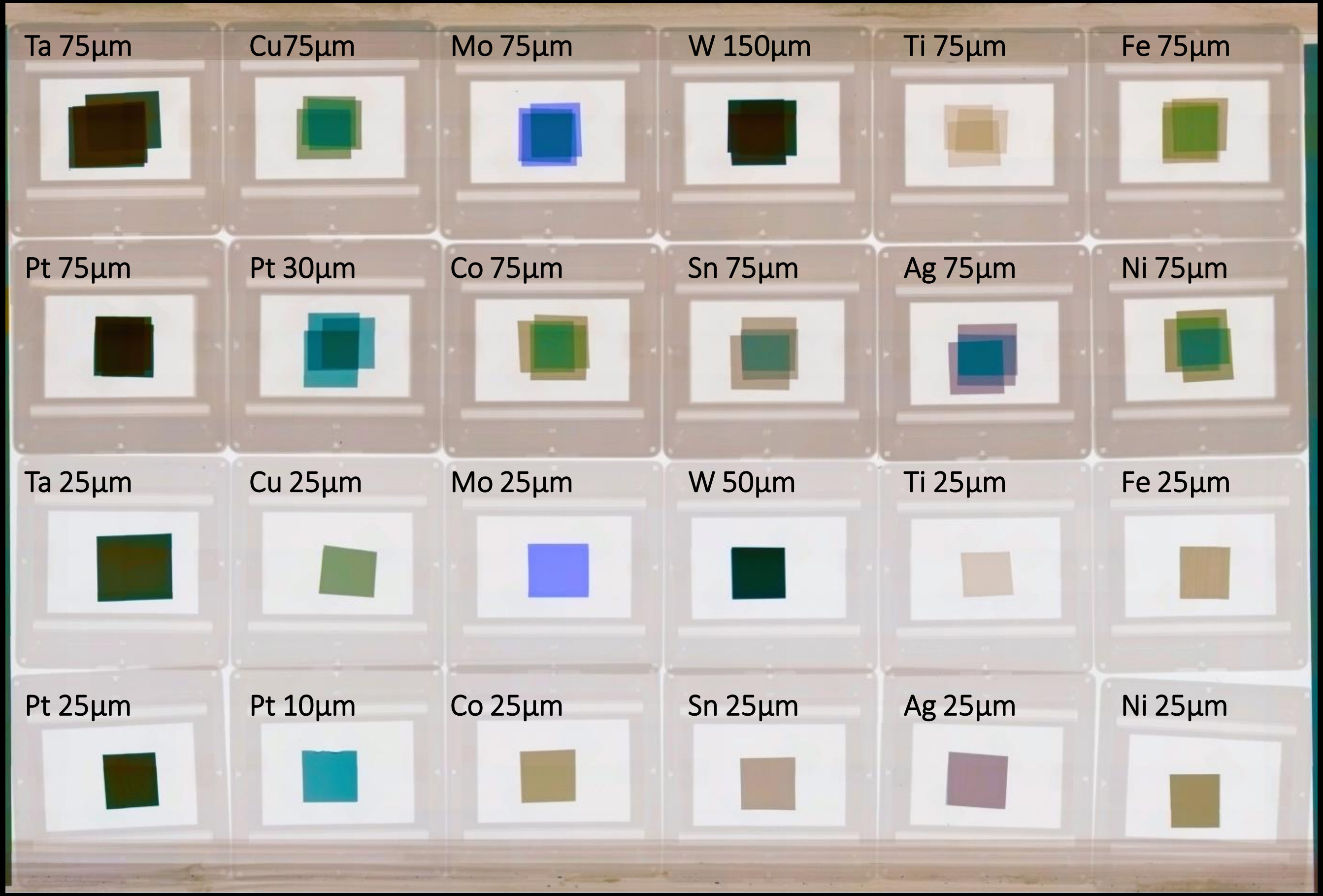


$$\frac{I}{I_0} = e^{-(\mu/\rho)\rho x}$$



Courtesy: S. Procz et al.

The regular vs “colour” X-ray imaging of test samples



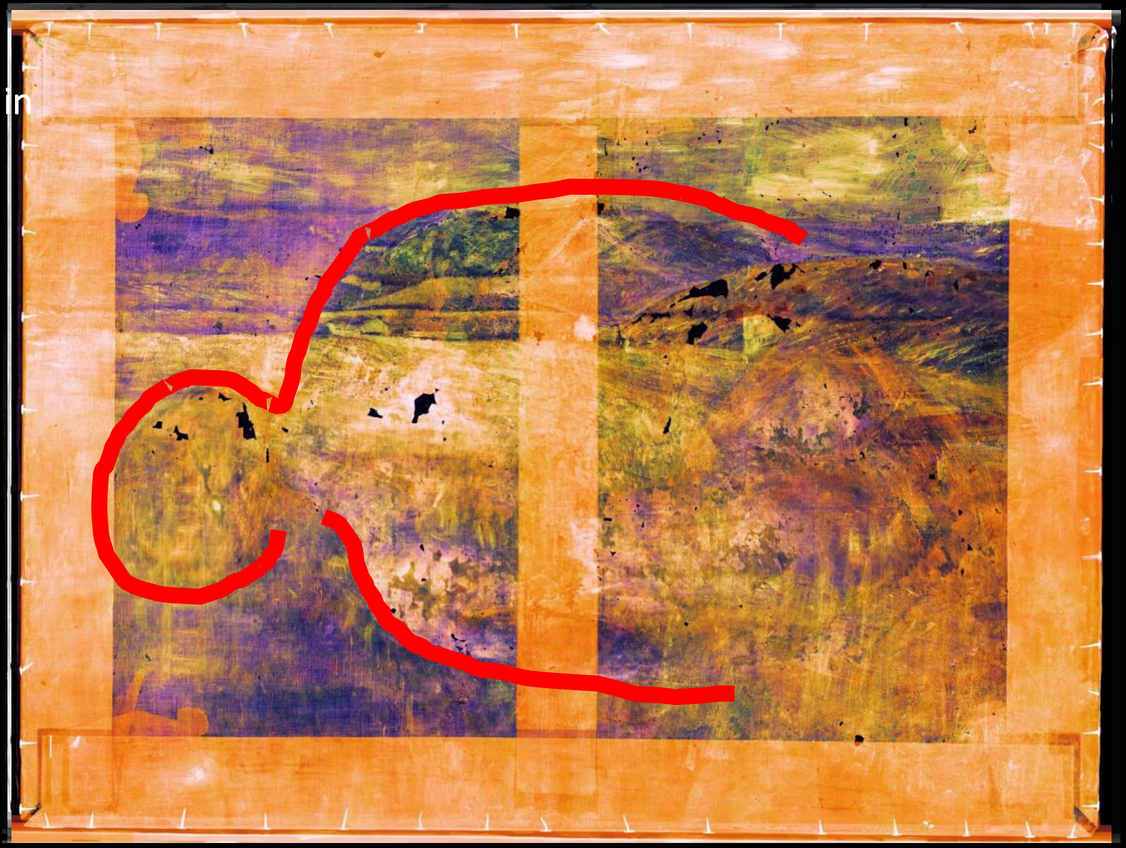
J. Jakubek

BBC Click on Fake Art – InsightART's X-ray colour imaging of art!
https://youtu.be/1xUD0BUzgtQ

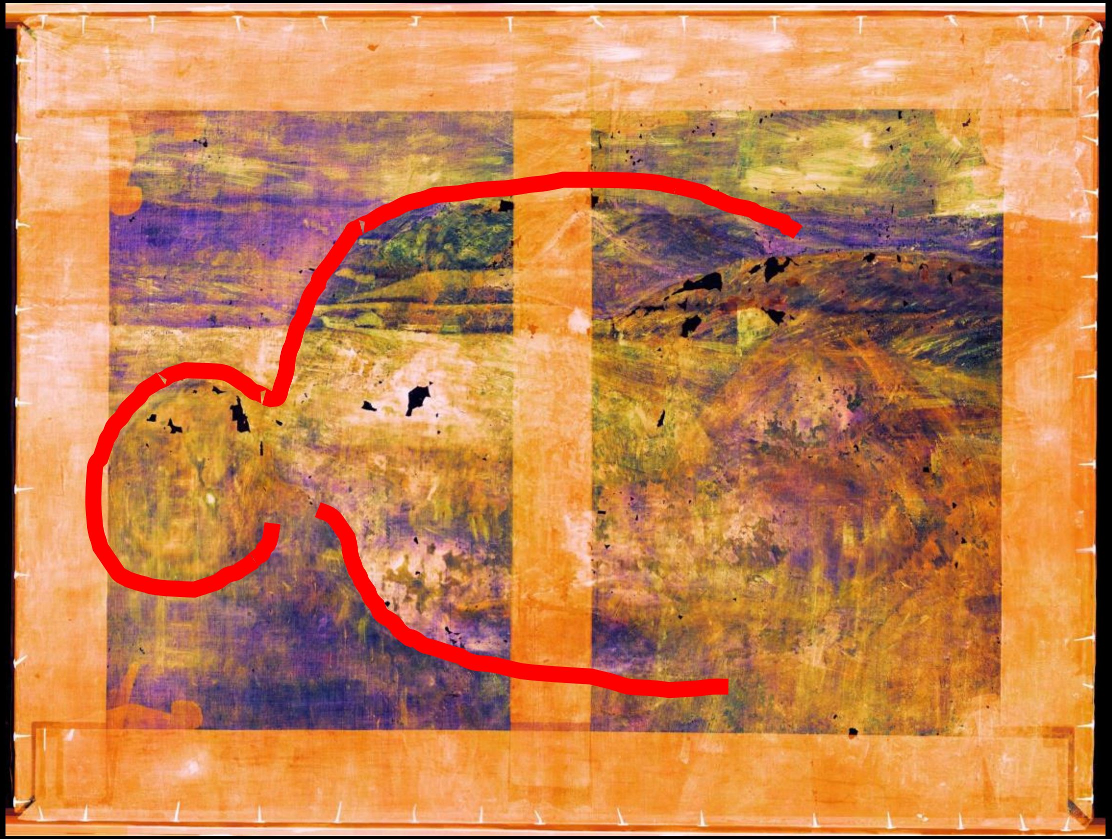
Signed
Vincent van Gogh

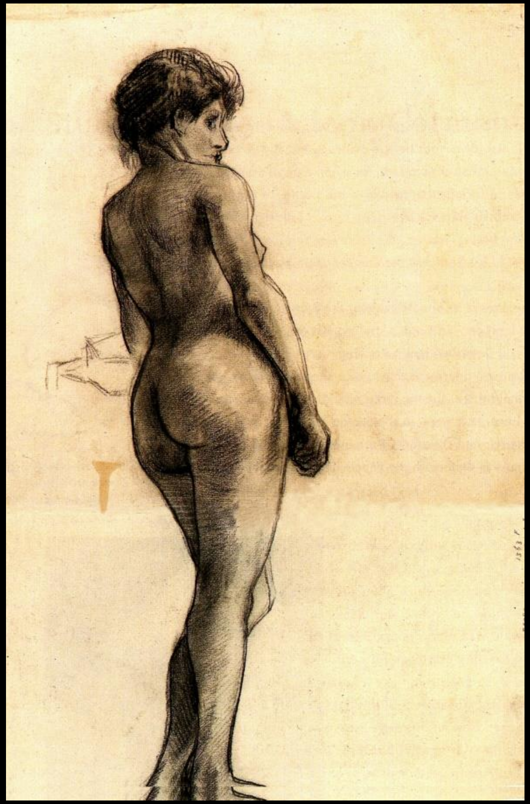
La Crau with Montmajour in the backgroud

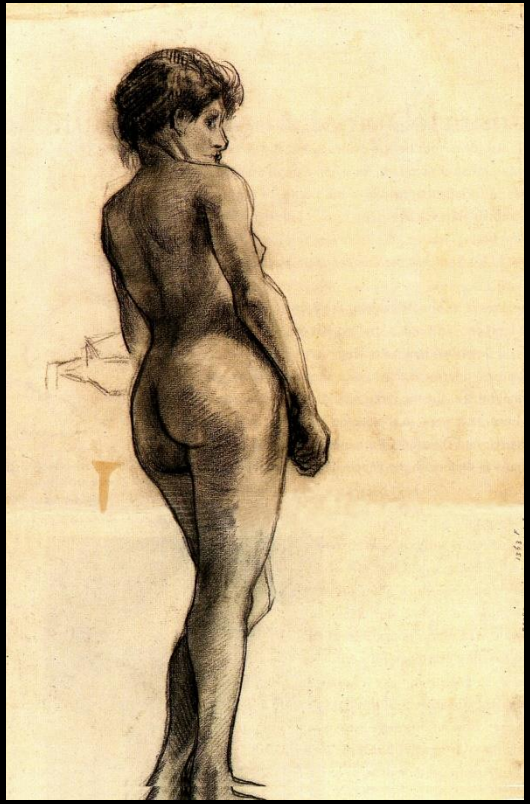
~1888

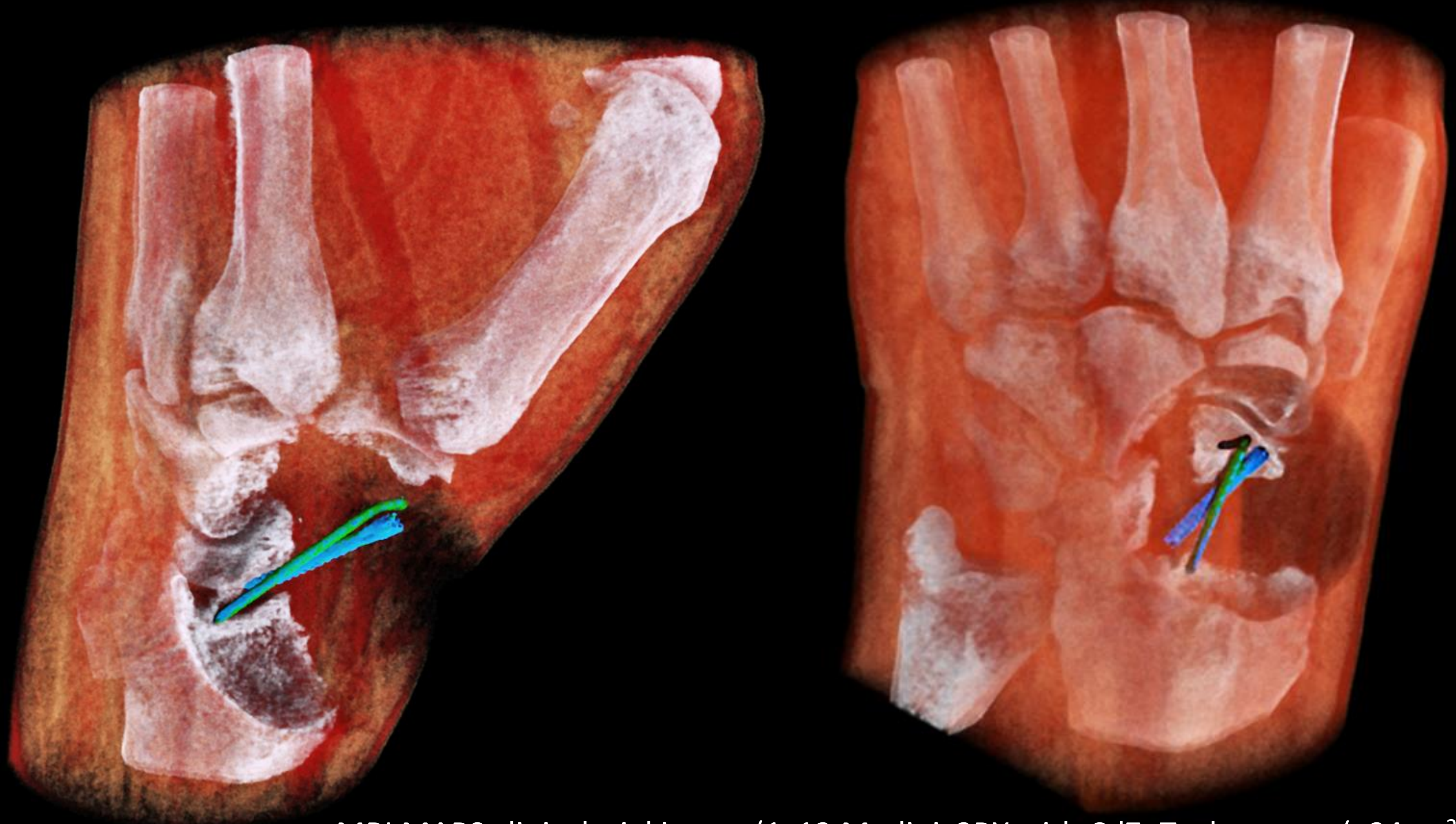


INSIGHTART





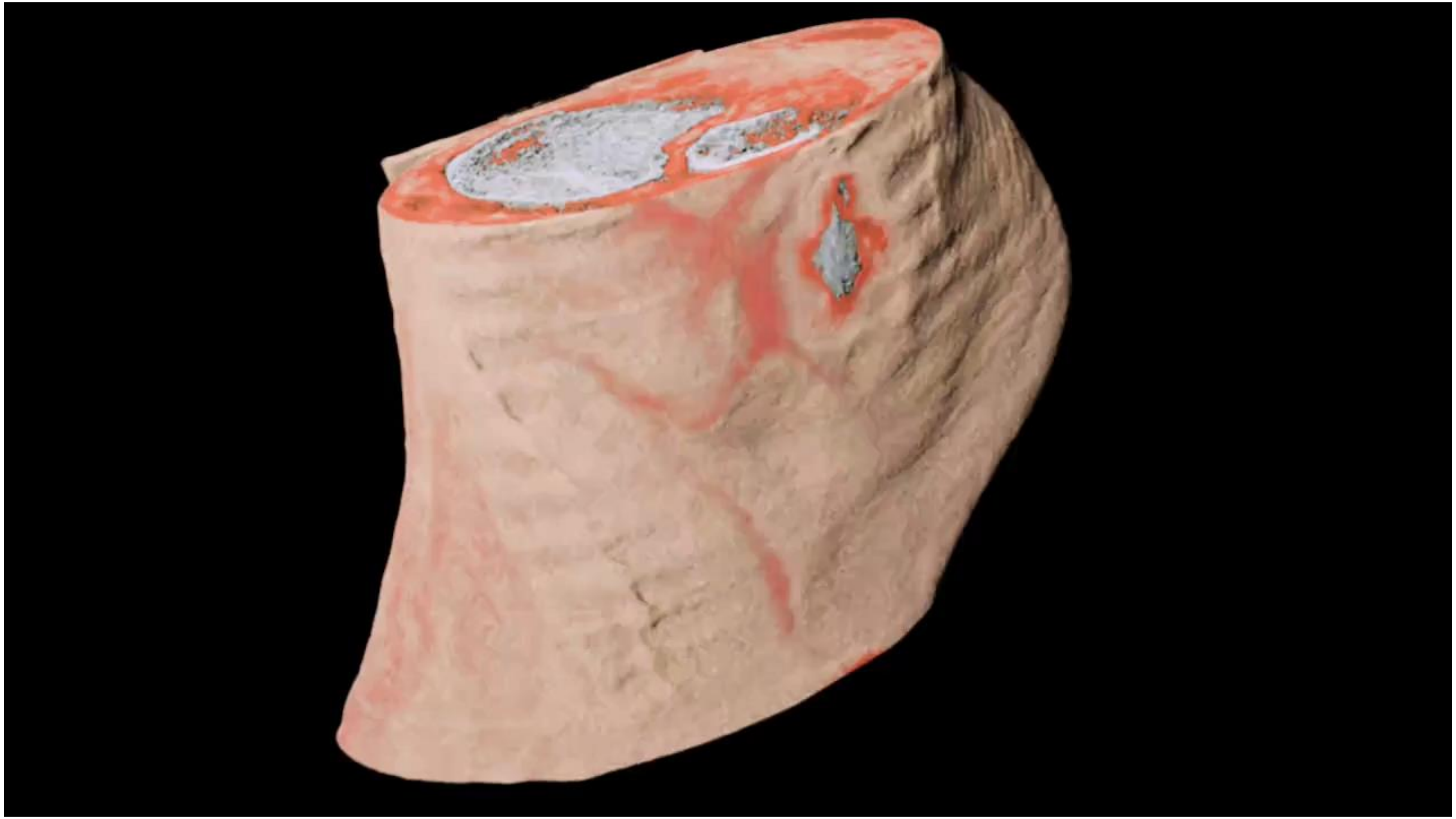



MBI MARS clinical trial image (1x12 Medipix3RX with CdZnTe detectors (~24cm^2))
200K pixels
Wrist with titanium screw and steel wire

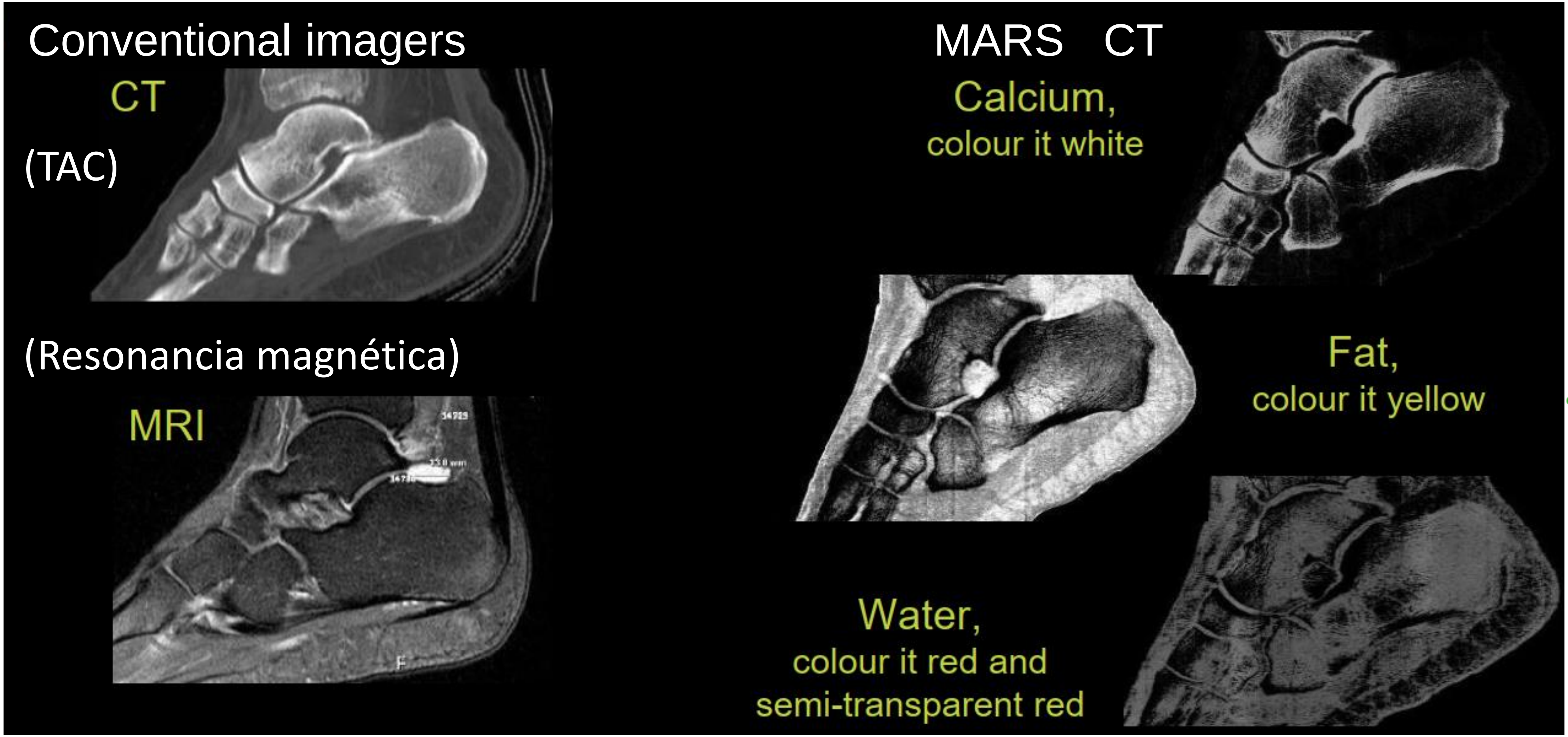
Scanner installed at Centre Hospitalier
Universitaire Vaudois (CHUV),
Lausanne, Switzerland

Courtesy: MARS team

Movie Slice through Phil's ankle



Slice through Phil's ankle



mars

Aplicaciones: Dosimetria en el espacio

Timepix in Space

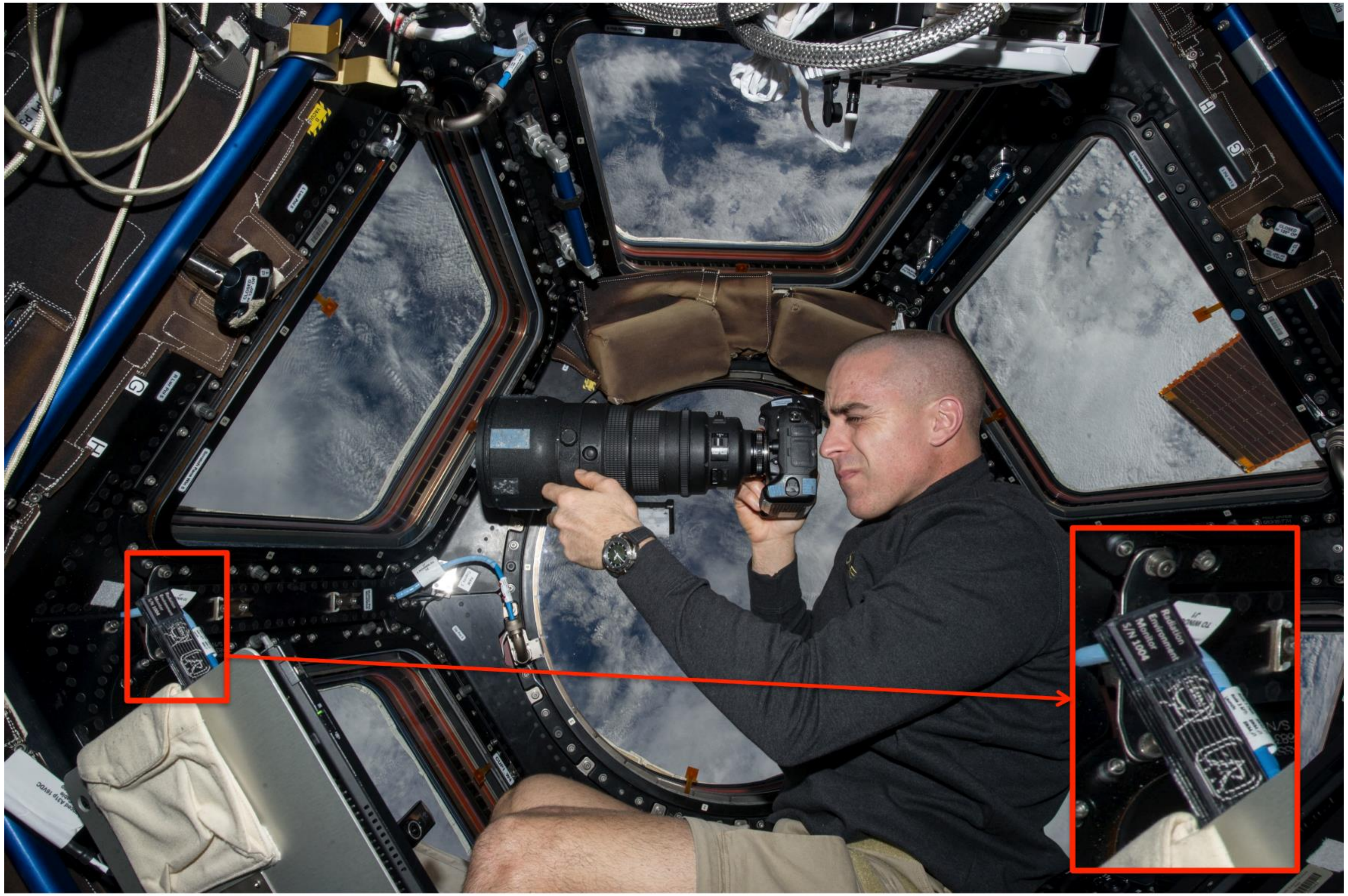
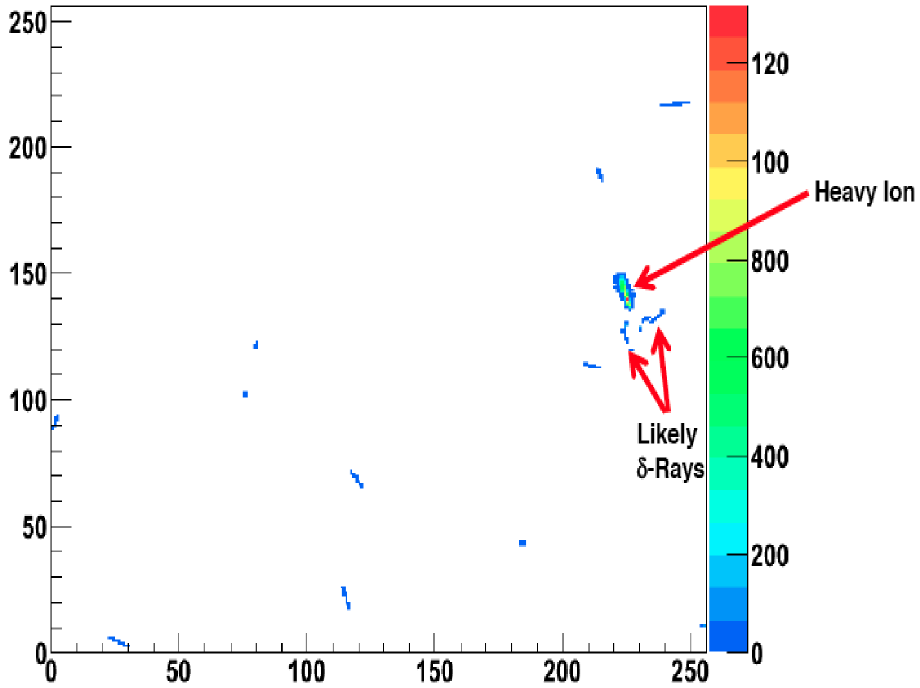
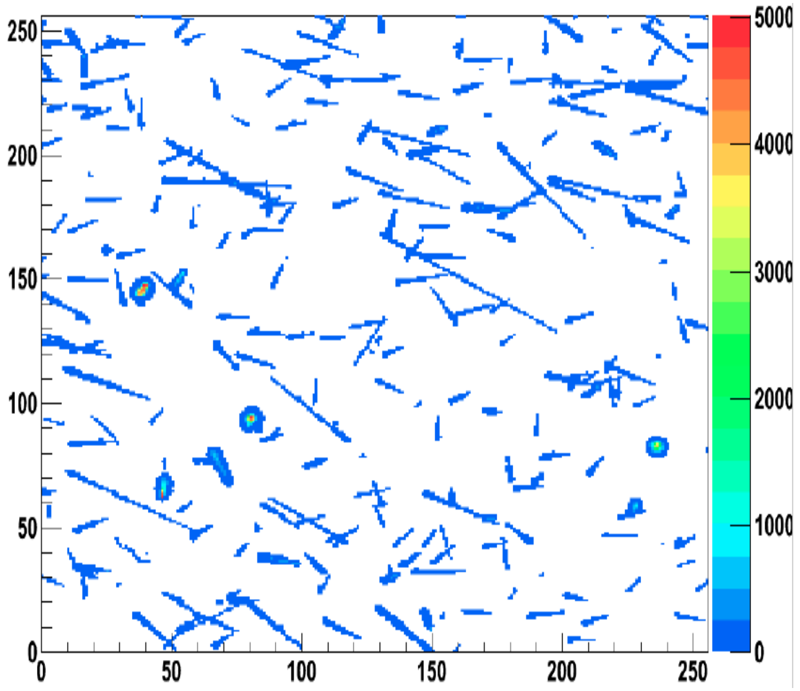


Image of the astronaut Chris Cassidy working near the Timepix USB on the International Space Station (Courtesy of NASA, photo ref. no. iss036e006175)

Timepix - 4s exposures



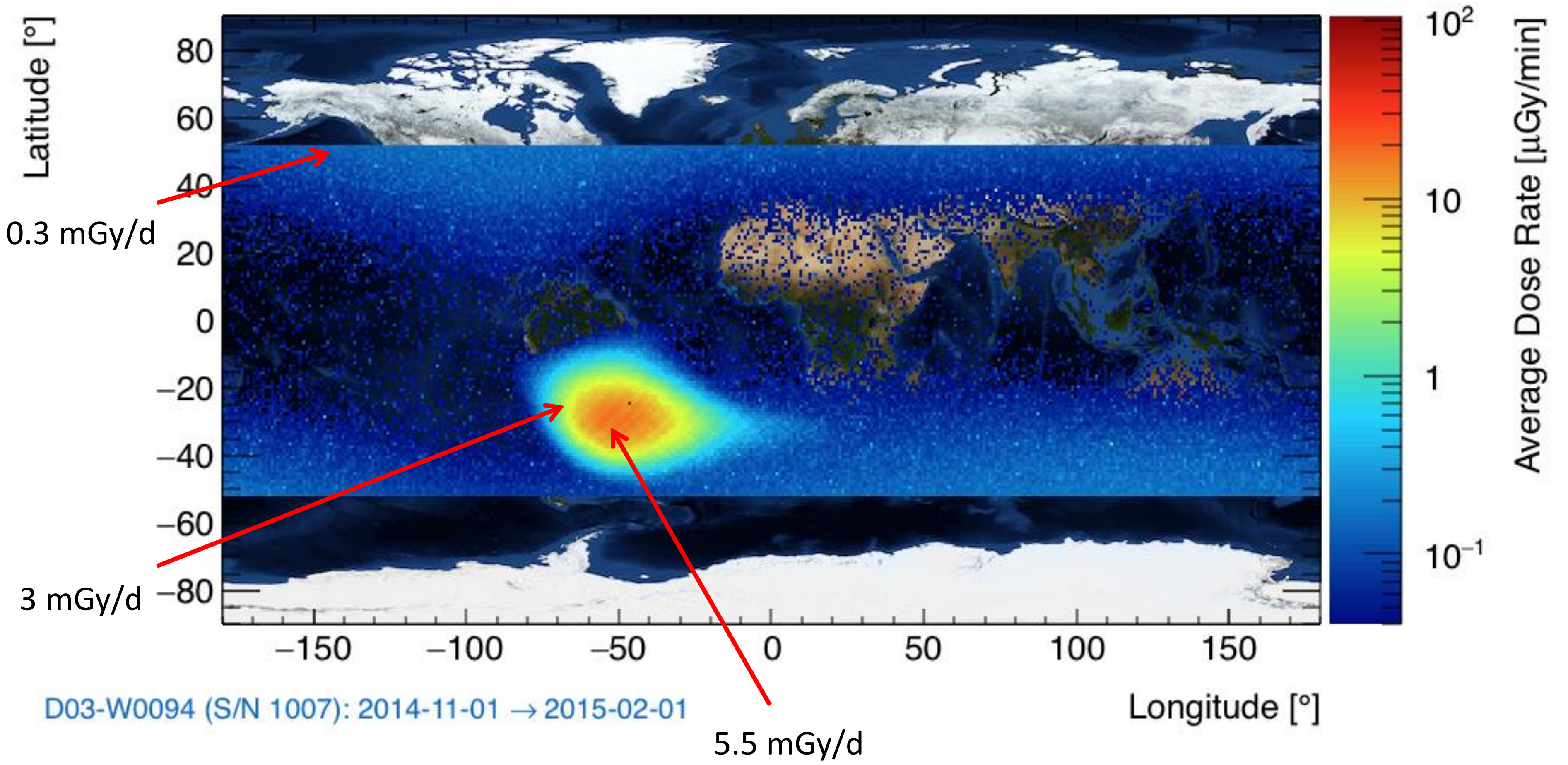
South China Sea



South Atlantic Anomaly

University of Houston, IEAP Prague, NASA

REM Dose Rate Data (μG/min)

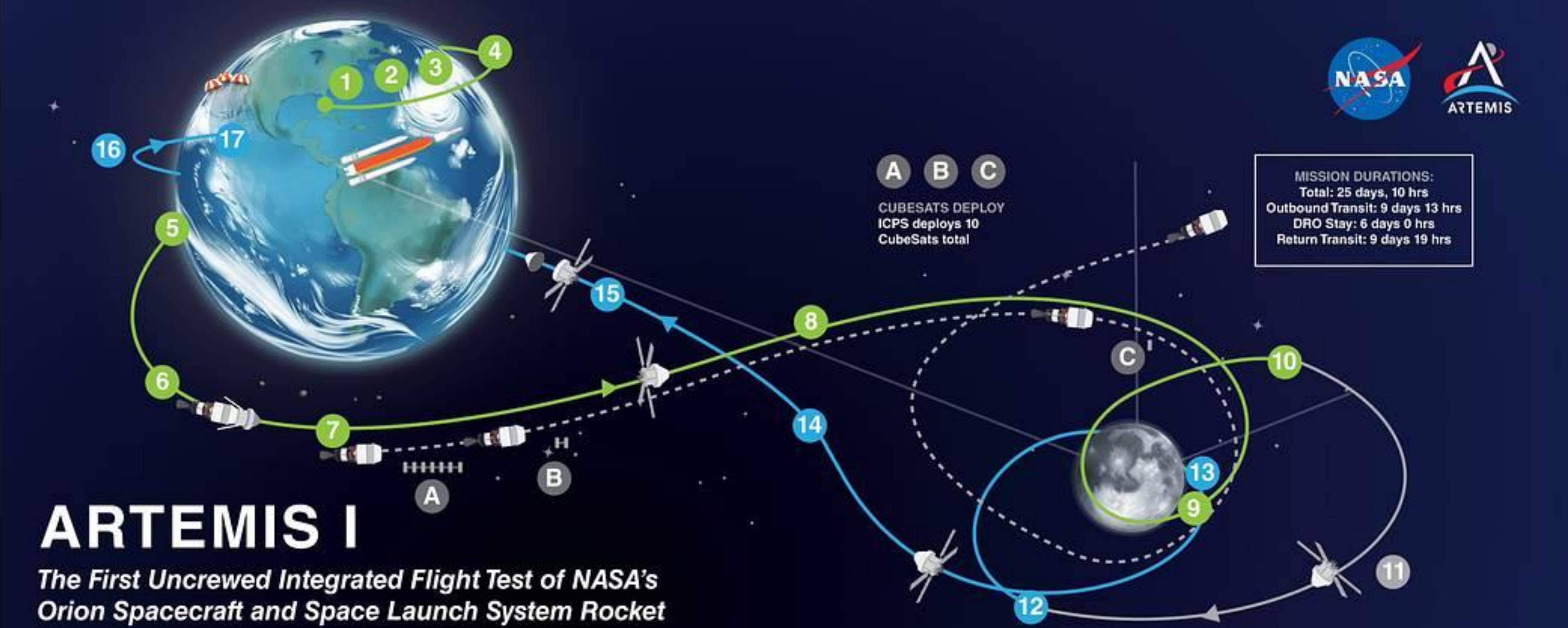


Average exposure on the ground is 3 mGy/year

University of Houston, IEAP Prague, NASA

Timepix on Artemis 1

- Artemis 1 launch Wednesday Nov 16 2022
- Carrying 4 Timepix detectors from the Medipix2 collaboration at CERN on board to measure radiation
- Part of a larger program at NASA using Timepix based instruments for radiation measurement
- 3 devices part of HERA radiation dose monitoring hardware. Successful operation from just after launch to just before splashdown
- 4th device on board Biosentinel cubesat (a biosensor instrument to detect and measure the impact of space radiation on living organisms over long durations) (now at >> 2Mkm from earth)



ARTEMIS I

The First Uncrewed Integrated Flight Test of NASA's Orion Spacecraft and Space Launch System Rocket

1. **LAUNCH (11/16/22)**
   SLS and Orion lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **PERIGEE RAISE MANEUVER**
5. **EARTH ORBIT**
   Systems check with solar panel adjustments.
6. **TRANS LUNAR INJECTION (TLI) BURN**
   Maneuver lasts for approximately 20 minutes.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL**
   ICPS commits Orion to moon at TLI.
8. **OUTBOUND TRAJECTORY CORRECTION BURNS**
   As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).
9. **OUTBOUND POWERED FLYBY**
   105.5 miles from the Moon; targets DRO insertion.
10. **LUNAR ORBIT INSERTION**
    Enter Distant Retrograde Orbit.
11. **DISTANT RETROGRADE ORBIT**
    Perform a half revolution (6 day duration) in the orbit 43,730 miles from the surface of the Moon.
12. **DRO DEPARTURE**
    Leave DRO and start return to Earth.
13. **RETURN POWERED FLYBY**
    RPF burn prep and return coast to Earth initiated. Closest approach in middle of burn, 81 miles.
14. **RETURN TRANSIT**
    Return Trajectory Correction burns as necessary to aim for Earth's atmosphere.
15. **CREW MODULE SEPARATION FROM SERVICE MODULE**
16. **ENTRY INTERFACE**
    Enter Earth's atmosphere.
17. **SPLASHDOWN (12/11/22)**
    Pacific Ocean landing within view of the U.S. Navy recovery ship.

Timepix-based flight hardware

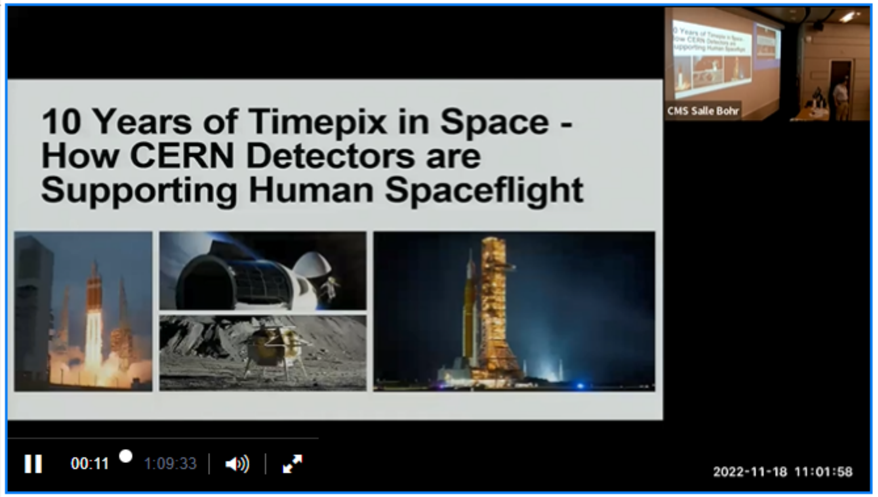
Name	Date Flown	Mission	Location	Objective	Vehicle	Number TPX
REM	2012	ISS	LEO	Demo	ISS	5
BIRD	2014	Orion EFT-1	LEO/MEO	Demo/Science	Orion	2
REM2	2018	ISS	LEO	Ops	ISS	7
MPT	2017	ISS	LEO	Science	ISS	2
Biosentinel	2020	ISS	LEO	Science	ISS	1
ISS-HERA	2018	ISS	LEO	Demo	ISS	3
AHOSS	2020	ISS	LEO	Demo/Ops	ISS	3
LETS(1)	2023	Astrobotic 1	Lunar Surface	Science	Peregrine	1
LETS(2)	2024/5	Berensheet 2*	Lunar Surface	Science	Berensheet 2	1
HERA	2022	Artemis 1	Lunar Orbit	Ops	Orion	3
Biosentinel	2022	Artemis 1	Solar Orbit	Science	Cubesat	1
HERA	2023	Polaris Dawn	MEO	Science	Crew Dragon	1
HERA	2024	Artemis 2	Lunar Orbit	Ops	Orion	6
HERA	2025	Artemis 3	Lunar Orbit	Ops	Orion	6
ARES	2025	Artemis 3	Lunar Surface	Ops	Starship	>=1
LEIA	~~2024	CLPS Lander	Lunar Surface	Science	TBS Lander	1
ARES	2026	Artemis	Lunar Orbit	Ops	Lunar Gateway	2

***Evaluating mission possibility**
7 missions flown, 4 missions next six months, 6 missions manifested, > 23 Timepix in Space to date

S. George (NASA) 10 Years of Timepix in Space – How CERN Detectors are supporting Human Spaceflight https://indico.cern.ch/event/1218130/

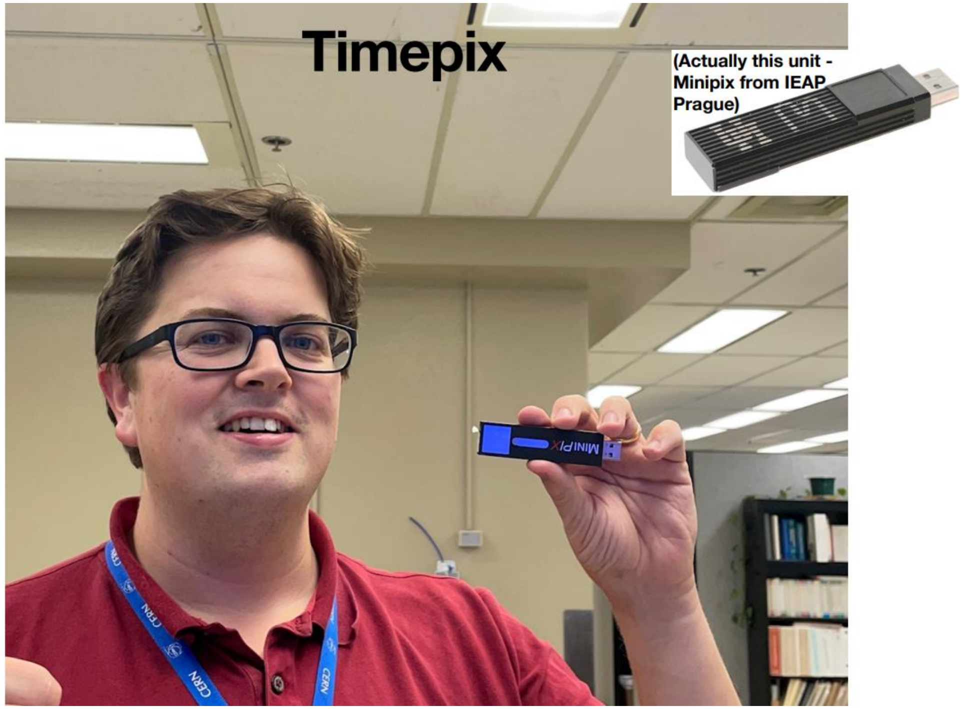
Information | Discussion (0) | Files

Talk

Title	**10 Years of Timepix in Space – How CERN Detectors are supporting Human Spaceflight**
Video	 ℹ If you experience any problem watching the video, click the download button below Download Embed
Author(s)	George, Stuart (speaker) ; George, Stuart P. (speaker) (NASA)
Corporate author(s)	CERN. Geneva
Imprint	2022-11-18. - 1:09:33.
Series	(Detector Seminar)
Lecture note	on 2022-11-18T11:00:00
Subject category	Detector Seminar
Abstract	Starting with a tech demo flight in 2012 CERN designed Timepix hybrid pixel detectors are now ubiquitous in NASA human space flight as charged particle detectors. This seminar reviews the space radiation environment and its relevance to human health, what sort of capabilities are needed from radiation instrumentation in space and how hybrid pixel detectors meet and exceed those goals. We discuss key results from the 10 year history of Timepix on the International Space Station through to the current network of 11 instruments spread throughout the ISS as well as the flight of a Timepix based instrument on the Orion ETF-1 mission. We review how Timepix based instruments are being used to support near future spaceflight efforts including the Artemis 1 lunar mission, the Biosentinel deep space radiation biology experiment, the Peregrine lunar lander and the private SpaceX Polaris Dawn mission all of which are scheduled to fly in the next six months. Finally we discuss the medium and longer term future for Timepix detectors as part of NASA space flight efforts, including continued support of the Artemis manned lunar missions, deployments on the Lunar Gateway and NASA Human Landing system (SpaceX starship) as well as current efforts to develop next generation Timepix sensors for space weather early warning, planetary science and space biology applications.

http://cds.cern.ch/record/2841505?ln=en

Old Shuttle engineering hardware from the "SRAG Museum"



Aplicaciones: Camara Compton

Single Layer Compton Camera with MiniPIX TPX3

Compton camera principle

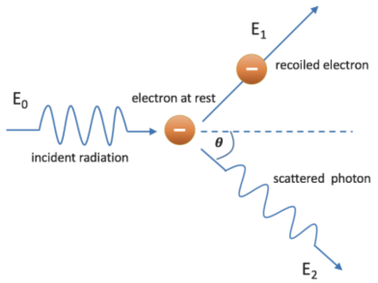
- Typical two detectors
- primary gamma is scattered in first detector (position and energy recorded), scattered gamma continues to second detector (absorbed, position and energy recorded)
- from energies - > scattering angle calculated
- from position and energies -> possible position of the source on the surface of a cone
- Multiple cones intersection - > source position

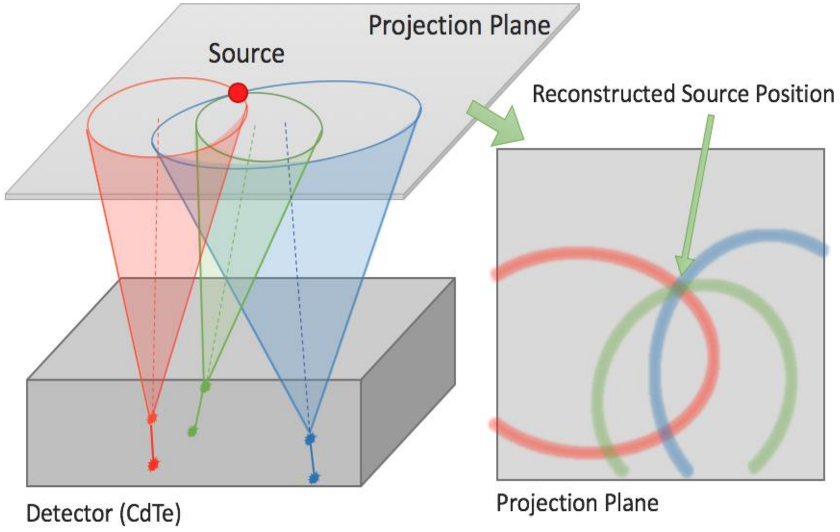
- Single Timepix3 layer camera
  - Instead of 2 detectors, only single TPX3
  - Using time of charge collection to determine relative depth

Courtesy of D. Turecek, Advacam s.r.o

$$\cos\theta = 1 - m_e c^2 \frac{E_1}{E_0(E_0 - E_1)}$$

$$E_0 = E_1 + E_2$$

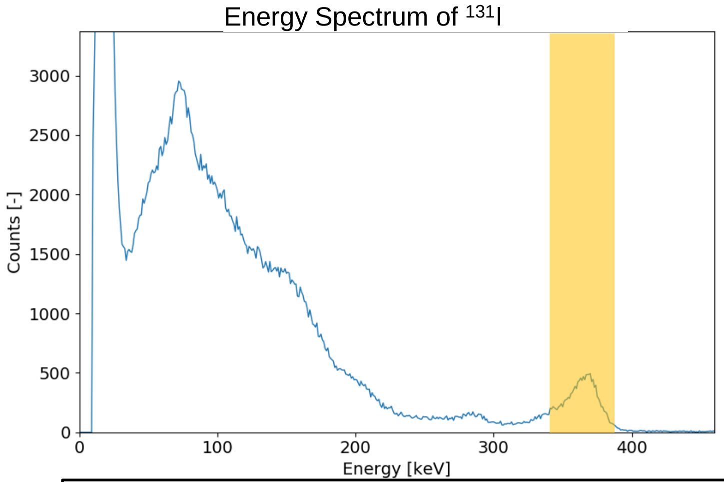




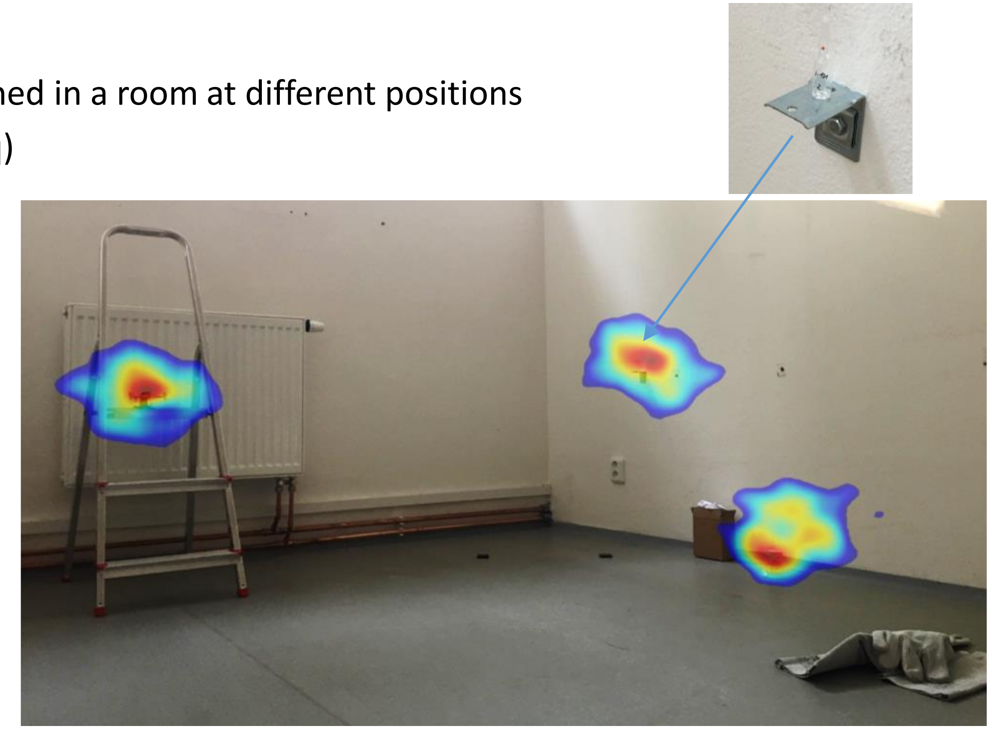
Single Layer Compton Camera with MiniPIX TPX3

^{131}Iodine gamma source

- 3 different Iodine solution in small bottles positioned in a room at different positions
- Distance from detector 3.5 m (activity 10’s of MBq)
- Mapped on photograph of the room
- Sources located correctly within minutes
- Image took hours to collect



Courtesy of D. Turecek, Advacam s.r.o

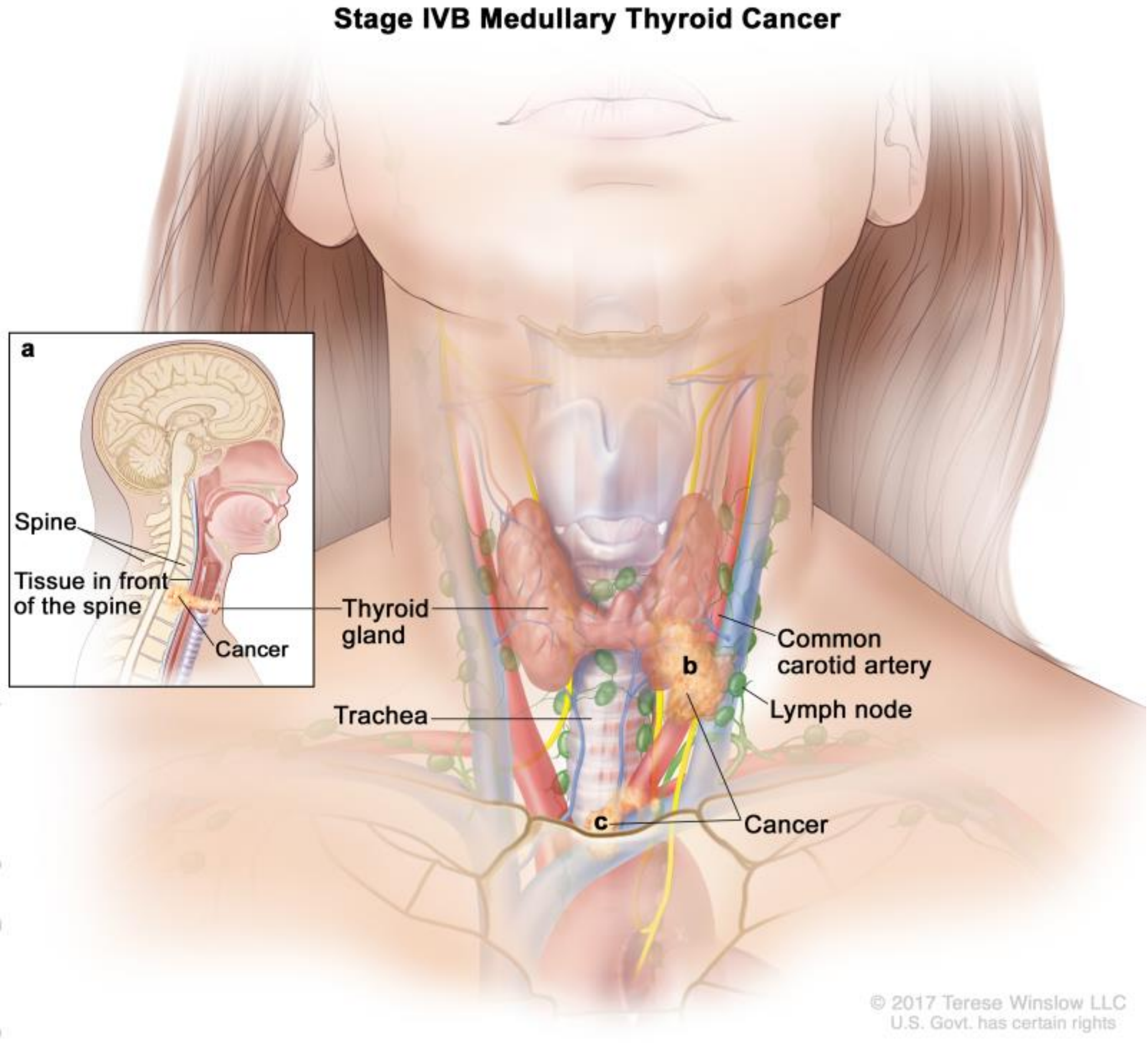


Reconstruction of position of three ^{131}I gamma sources (364 keV)

Gamma camera application: Thyroid diagnostics

Thyroid cancer diagnostics and treatment monitoring:

- The second most frequent cancer for women (after breast cancer)
- Current imaging methods offer resolution of about 12 mm in 2D
- Our technology allows
    - 5 times better resolution and 3D (2.5 mm)
    - 4 times lower dose



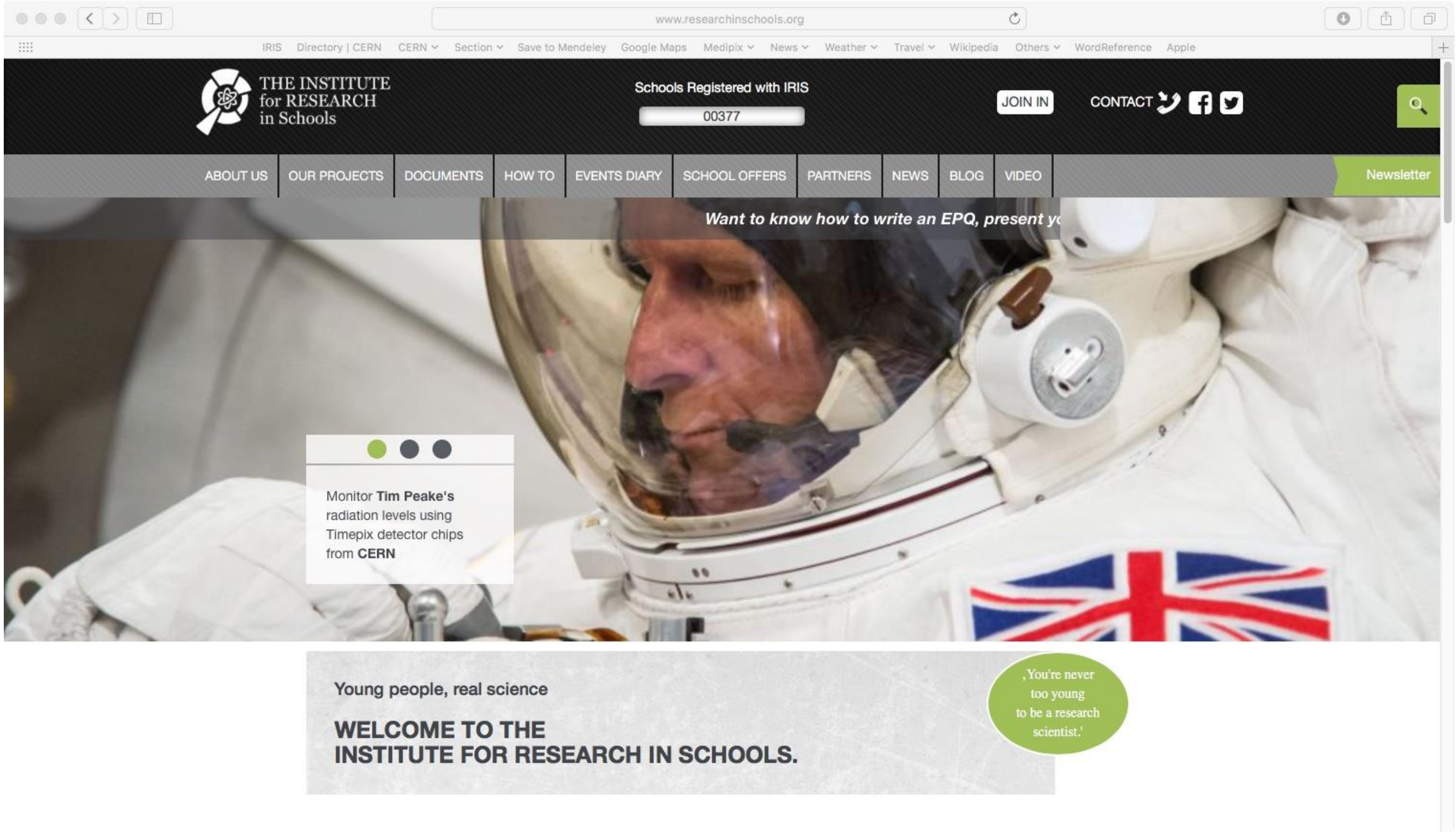
Courtesy of D. Turecek, Advacam s.r.o

Aplicaciones: Educación

CERN@school

Simon Langton School, Canterbury, England

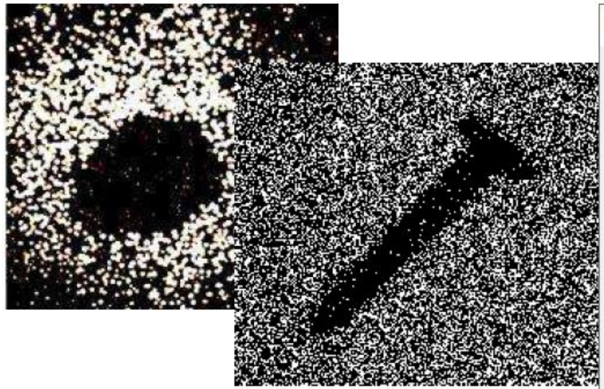
Institute for Research in Schools

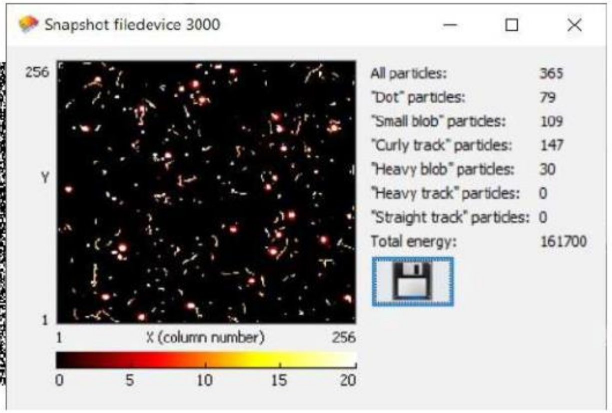


http://www.researchinschools.org/

SESTRA

School **E**ducation **S**et with **T**imepix for **R**adiation **A**nalysis





Kit Components

- Particle Camera MiniPIX EDU with Timepix detector
- Software (acquisition, online visualisation, etc.)
- SZZ Alfa (241Am, α and γ source, 9.5 kBq)
- DZZ Gamma (241Am, γ source, 300 kBq, *optional*)
- Potassium Salt (β and γ source)
- Thoriated Tungsten Electrode (α, β and γ source)
- Uranium Glass (α, β and γ source)
- Mounting Rails
- Source Holder
- Camera Holder
- Aluminium, Stainless, Copper, Brass and Lead Plates
- Radiography Adapter Head and Samples with Hidden Patterns
- Vacuum Cleaner Grate Adapter
- Transport Case
- USB Cable

IEAP CTU in Prague
Husova 240/5, 110 00,
Prague, Czech Republic
http://www.utef.cvut.cz/ieap

https://medipix.web.cern.ch/

Advacam s.r.o.
U Pergmanky 12, 170 00,
Prague, Czech Republic
https://advacam.com/

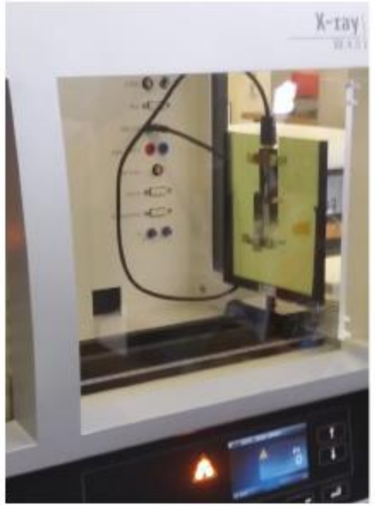
TIMEPIX en la escuela Sagrada Familia de Gavà

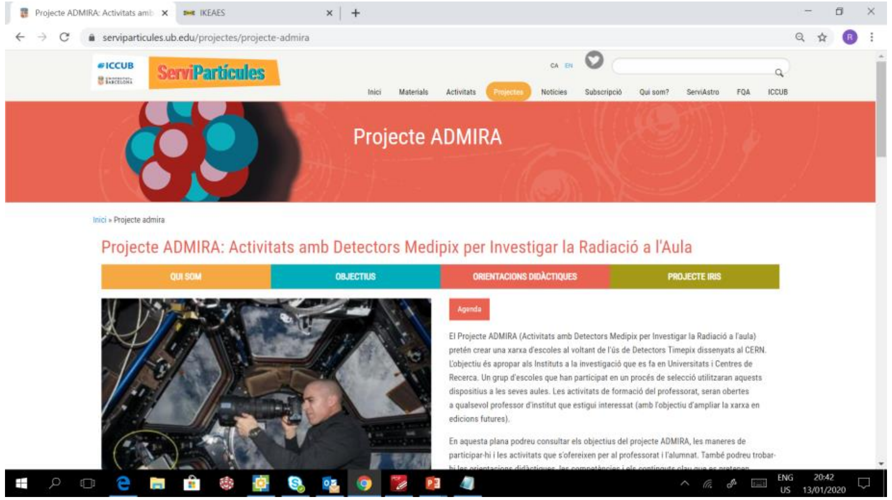
- Conferencia Mayo 2017
- Curso académico 2017-2018
  - Práctica inicial
  - 4 Trabajos de investigación (Supervisión: D. Parcerisas)
    - Investigación teórica común de los 4 trabajos: Detector TIMEPIX, software PIXETPRO
    - Búsqueda de fuentes radioactivas

ADMIRA

Activitats amb Detectors Medipix per Investigar la Radiació a l'Aula

- **ADMIRA: Activitats amb Detectors Medipix per Investigar la Radiació a l'Aula**
- Objetivo (Acercar centros de investigación, universidades y escuelas de secundaria alrededor de la física de partículas)
  - Crear una **red de escuelas que comparten** dispositivos Timepix (cortesía de la sección de microelectrónica del CERN)
  - Los profesores comparten dispositivos, experiencias
  - Ofrecemos formación para profesores y estudiantes impartida por expertos
  - Estudiantes de secundaria participan en proyectos científicos reales
    - Trabajar en problemas en los que la solución no se encuentra en la última página
  - Impacto en muchas disciplinas (física, matemáticas, química, tecnología)



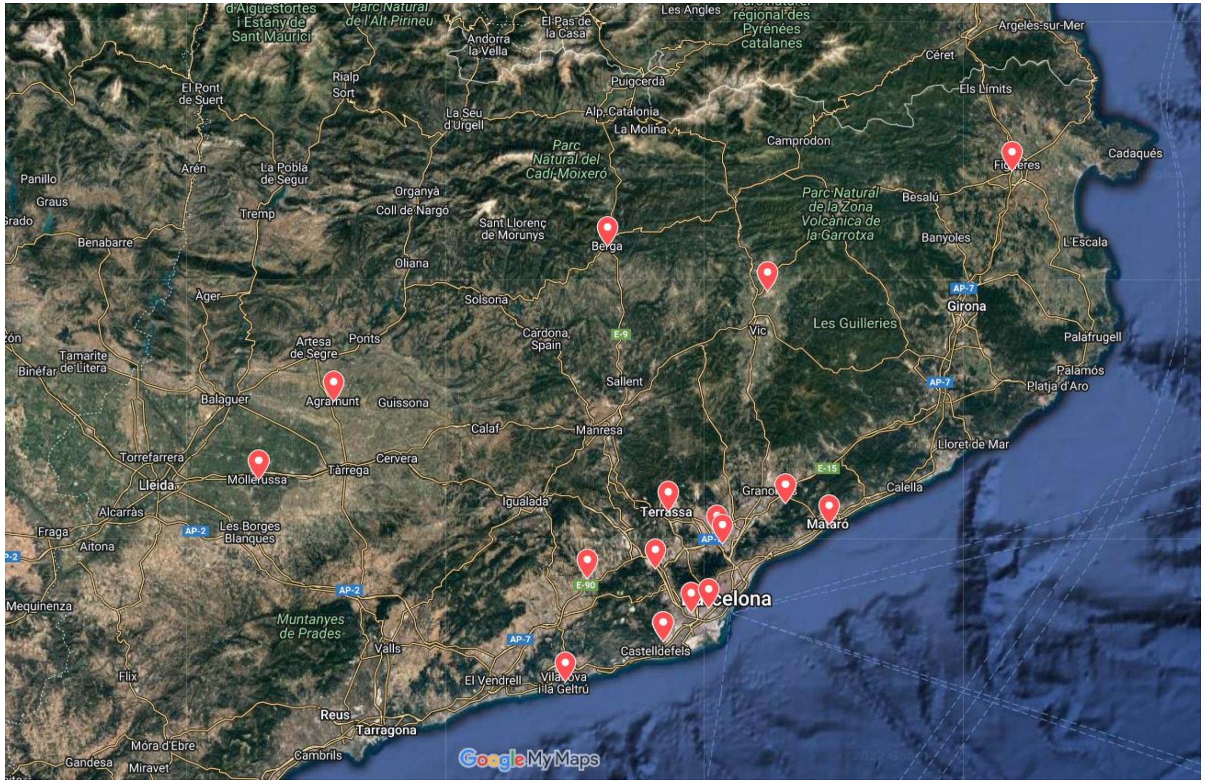


ADMIRA

Activitats amb Detectors Medipix per Investigar la Radiació a l'Aula

TEAM:

- Experimental Physics Department, CERN: R. Ballabriga, M. Campbell
- Institut de Ciències del Cosmos, University of Barcelona: A. Argudó, E. Pallarès, E. Graugés
- Institut de Desenvolupament Professional, University of Barcelona: L. Casas
- Schools: D. Parcerisas, D. Corrons, I. Huguet



The support from University of Barcelona is key (website, logistics for distributing the kit, access to conference rooms, certificates for teachers attending trainings)

Trabajo de investigación

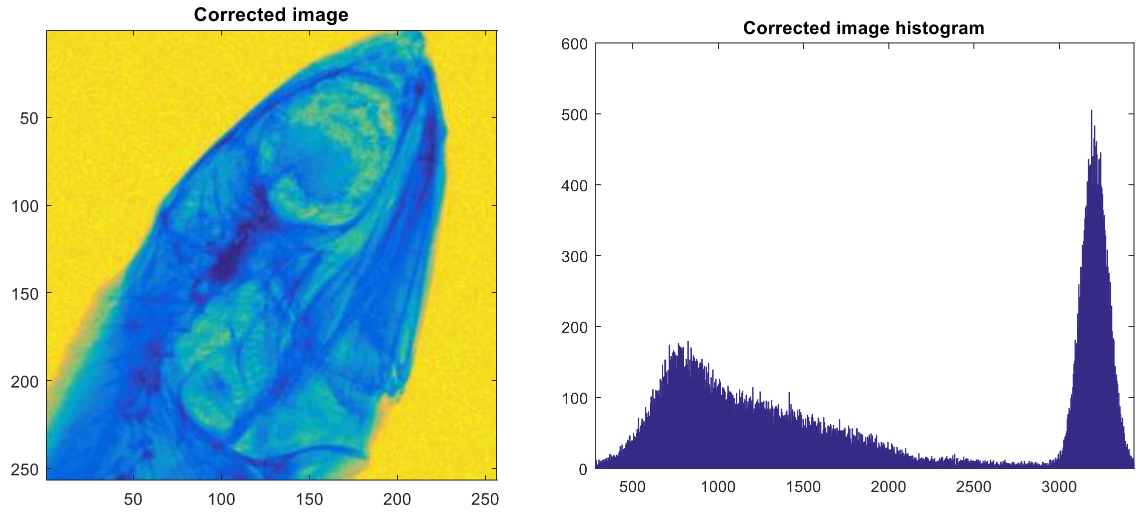
<u>Trabajo de investigación</u>
Asignatura de 18 meses en bachillerato
Requiere investigación experimental
Timepix es una herramienta que permite diversidad de estudios

https://serviparticules.ub.edu/materials/llibres-i-manuals

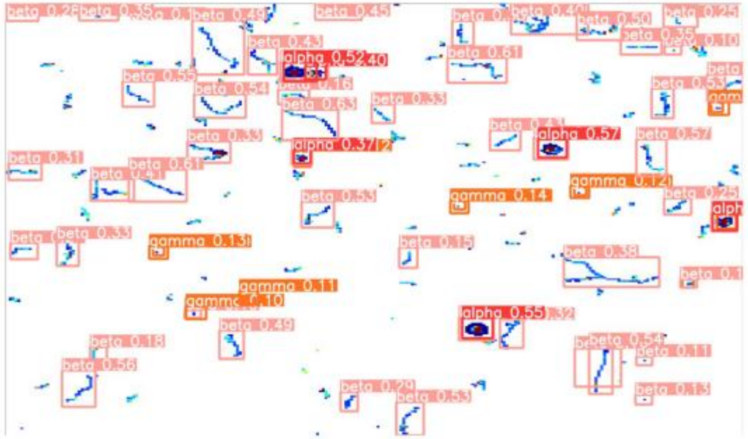
Trabajo de investigación

- Dosimetría y radiación de fondo
- Rayos cósmicos
- Salud
- Detectores de partículas
- Computación e inteligencia artificial

Esther Salvador, Sagrada Familia, Gavà

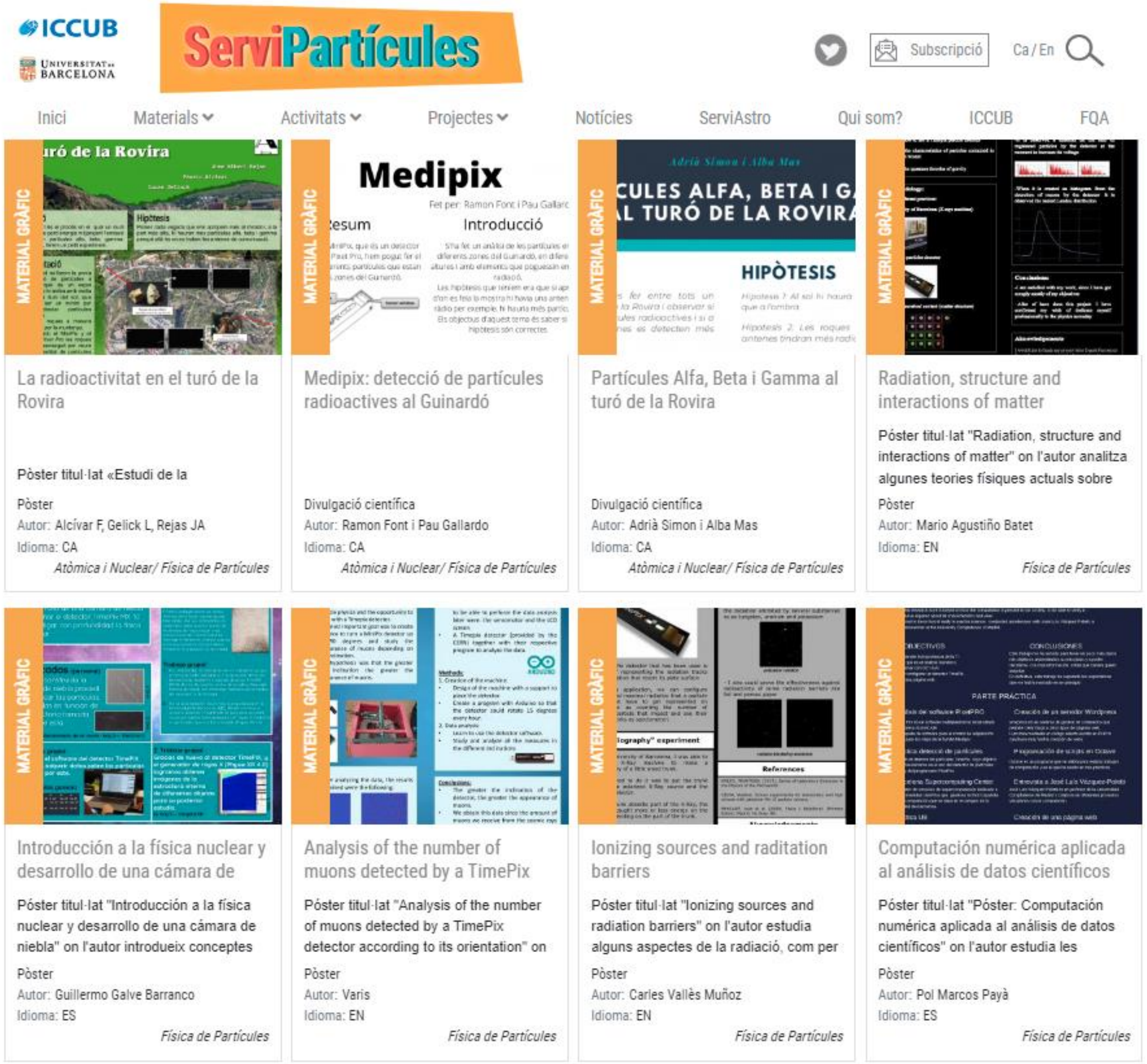


Bruguers Miranzo, Julia Gonzalez, Santo Angel Gavà



Ruben Castaño, Sagrada Familia, Gavà

Trabajo de investigación



https://serviparticules.ub.edu/projectes/projecte-admira/posters

Prácticas

La radioactivitat que ens envolta

Presentació de les pràctiques de radioactivitat a l'aula.

Introducció

En aquest kit de pràctiques de radioactivitat a l'aula es facilita el material necessari perquè el professor pugui realitzar a l'aula un seguit d'experiències en física de radiacions.

L'enfoc d'aquestes experiències es treballar i observar efectes de radiacions beta i alfa sense la necessitat de recórrer a fonts radioactives perilloses per a les persones. La radioactivitat és un fenomen natural que ens envolta, i que moltes vegades els alumnes associen exclusivament a contextos amb dosis de radioactivitat molt elevada i perjudicial per als humans. Amb això, les dues pràctiques presentades en aquests material tenen dos objectiu fonamentals:

1- Treballar i estudiar els fenòmens de radioactivitat, mitjançant la mesura real i l'anàlisi posterior de les dades experimentals recollides.
2- Conscienciar a l'alumnat que els fenòmens de radioactivitat són habituals i estem envoltats d'ells en el nostre dia a dia, lluny d'associar el perjudici de la radioactivitat a exclusivament fonts perilloses per a les persones.

Les pràctiques i el contingut que en elles es treballen estan enfocats idealment per a ser treballat a nivell de batxillerat. Tot i això, són possibles simplificacions en els continguts a tractar i els càlculs a realitzar per part dels alumnes, de forma que pugui ser implementada en cursos d'ESO (més informació a la guia del professor, on es presenta una descripció detallada de les pràctiques, conjuntament amb un solucionari amb mesures reals obtingudes en realitzar les experiències).

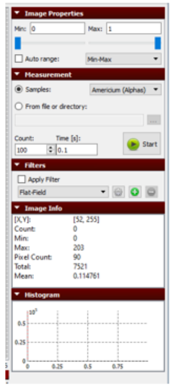
Per realitzar aquestes experiències és altament recomanable tenir accés al sensor TIMEPIX, ja que tant el procés de mesura com de representació de dades resulta molt àgil i eficient. Tot i això, alternatives amb altres aparells de mesura de radiacions poden ser adaptats.

Tot el material descrit s'inclou en un pdf conjunt, el professor interessat pot fer posteriorment ús de les parts que li interessi independentment.

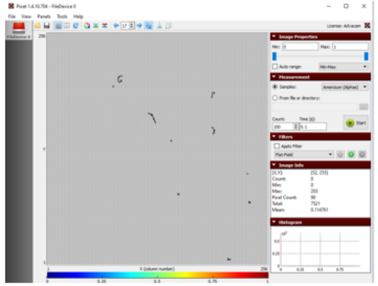
4. Sense utilitzar la mostra radioactiva, obriu la finestra del detector i premeu el botó Start per iniciar la captura de dades.

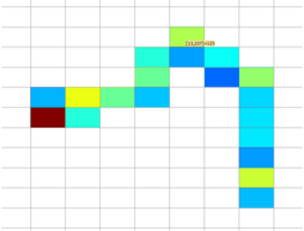
5. Una vegada acabada l'obtenció de les dades, tanqueu la finestra (el protector del xip).

Quan el procés d'obtenció de dades finalitzi, tanqueu el protector del xip.



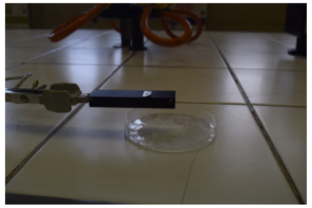
6. Compteu el nombre de Worms (cucs), que són trajectòries llargues i corbades produïdes per la radiació beta d'alta energia. Per assegurar-vos que les partícules beta són d'alta energia, amplia la imatge de cadascuna d'elles, i comprova que la seva energia dipositada és superior als 700 keV.





7. Dividiu el nombre de partícules detectades pel temps transcorregut (600 s). Obtindreu l'activitat de fons.

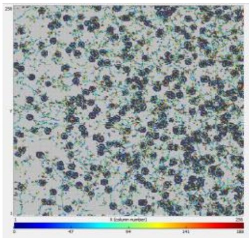
8. Subjecteu el detector verticalment a un suport amb anella de manera que estigui a un centímetre per sobre del banc, tal i com es mostra a la imatge de sota. Col·loqueu un vidre de rellotge o un tap d'ampolla sota la finestra del detector.

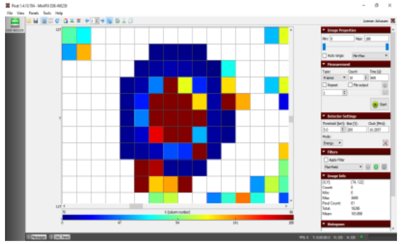


9. Peseu 2 grams de clorur de potassi, i dipositeu-lo al vidre de rellotge.

10. Obriu de nou la finestra del detector i premeu el botó Start per iniciar la captura de dades.

11. Una vegada acabada l'obtenció de les dades, tanqueu la finestra (el protector del xip).



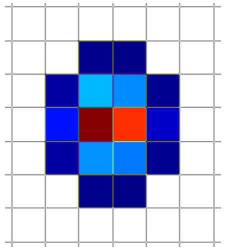


D. Corrons, H. Pino

Prácticas

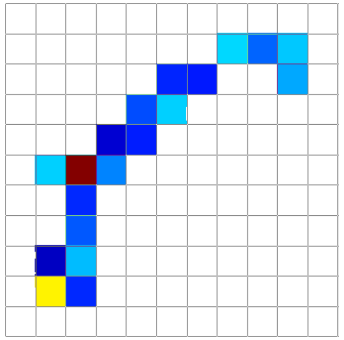
- Práctica de laboratorio

Resultados



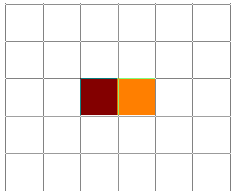
Alfa

Ek [keV]	10809	3912	7487	6164	5497
Ek [J]	1,73E-12	6,27E-13	1,20E-12	9,87E-13	8,81E-13
v [m/s] (relat.)	22788343,53	13728410,69	18978555,51	17224865	16268425,19
v [m/s] (class.)	22837837,18	13739206,06	19007111,86	17246204,4	16286399,46
v/c (relat.)	0,07596114511	0,04576136897	0,0632618517	0,05741621667	0,05422808397
v/c (classica)	0,07612612395	0,04579735353	0,06335703953	0,05748734801	0,05428799819
desviació (%)	0,2167177617	0,07857344563	0,1502403333	0,1237338907	0,1103636552



Beta

Ek [keV]	1953	1878	2504	1282	736
Ek [J]	3,13E-13	3,01E-13	4,01E-13	2,05E-13	1,18E-13
v [m/s] (relat.)	293461408,6	293039615,1	295648441,5	287530123	273603963,7
v [m/s] (class.)	828777947,9	812708607	938435066,1	671476901,6	508775245,3
v/c (relat.)	0,9782046954	0,976798717	0,9854948051	0,9584337434	0,9120132124
v/c (classica)	2,76259316	2,70902869	3,128116887	2,238256339	1,695917484
long. ona (m)	2,48E-12	2,48E-12	2,46E-12	2,53E-12	2,66E-12



Gamma

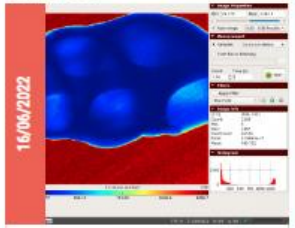
Ek [keV]	82	72	31	18	68
Ek [J]	1,31E-14	1,15E-14	4,97E-15	2,88E-15	1,09E-14
f (Hz)	1,98E+19	1,74E+19	7,50E+18	4,36E+18	1,65E+19
long. ona (m)	1,51E-11	1,72E-11	4,00E-11	6,89E-11	1,82E-11
p (kg·m/s)	4,38E-23	3,84E-23	1,66E-23	9,61E-24	3,63E-23

D. Parcerisas

Formación del profesorado

Aquells professors que s'hagin inscrit al Projecte ADMIRA rebran una formació, reconeguda per l'ICE de la Universitat de Barcelona. Part d'aquesta formació serà oberta a altres professors no participants en el projecte, mentre que algunes de les sessions seran exclusives per al professorat inscrit al programa.

CURSOS



Seminari Advacam en l'ús del Minipix en el món educatiu

El proper dijous dia 16 de juny tindrà lloc el seminari d'iniciació al detector MiniPix de l'empresa Advacam

A càrrec de: Carlos Granja, Advacam Prague
Lloc: Zoom
Hora: 16:00-18:00

Xerrades a escoles
Atòmica i Nuclear/ Física de Partícules

Jornada de formació al professorat del projecte ADMIRA

El proper dijous 21 d'abril reprenem les jornades de formació de

A càrrec de: Varis
Lloc: Facultat de Física de la Universitat de Barcelona
Hora: 16:00-20:00

Cursos
Física de Partícules

1 - Tutorials ADMIRA (1/4): Instal·lació PIXet Pro

Tutorials ADMIRA (1/4): Instal·lació de PIXet Pro

Autor: Daniel Parcerisas - Centre Educatiu Sagrada Família, Gavà

Cursos
Professorat infantil, primària, secundària i FP
Física de Partícules

3 - Tutorials ADMIRA (3/4): Configuració del detector

Tutorials ADMIRA (3/4): Configuració del detector MiniPIX en el programa PIXet Pro

Autor: Daniel Parcerisas - Centre Educatiu Sagrada Família, Gavà

Cursos
Professorat infantil, primària, secundària i FP
Física de Partícules

4 - Tutorials ADMIRA (4/4): Presa de mesures amb el

Tutorials ADMIRA (4/4): Presa de mesures amb el detector MiniPIX i el programa PIXet Pro

Autor: Daniel Parcerisas - Centre Educatiu Sagrada Família, Gavà

Cursos
Professorat infantil, primària, secundària i FP
Física de Partícules

La matèria fosca

Conferència tracta sobre què és la matèria fosca a càrrec de l'astrònom Xavi Luri

A càrrec de: Xavier Luri, ICCUB [IEEC-UB]
Hora: 09:30

Cursos
Professorat infantil, primària, secundària i FP
Física de Partícules
Xavier Luri, ICCUB [IEEC-UB]

Antimatèria

Aquesta xerrada es du a terme en el context del projecte ADMIRA (Activitats amb Detectors Medipix per Investig

A càrrec de: Lluís Garrido, ICCUB

Cursos
Física de Partícules

Detectors de partícules semiconductors

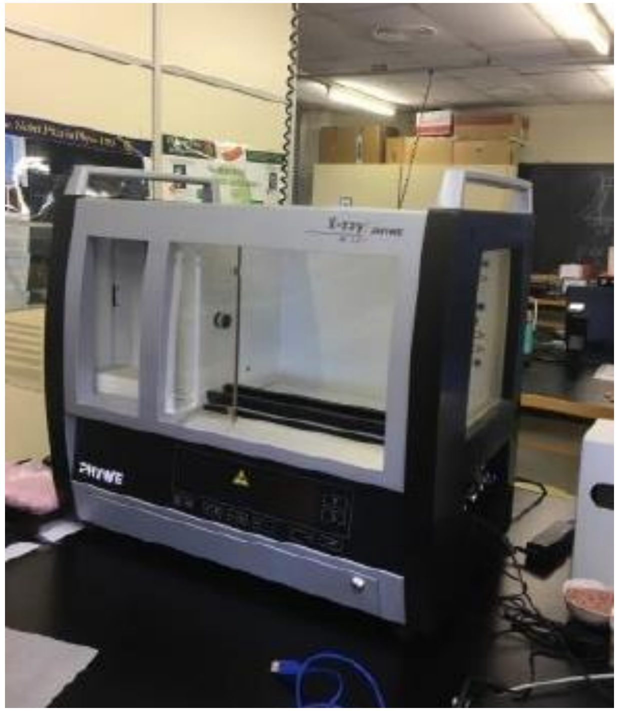
La xerrada, dividida en dues parts d'una hora cadascuna, començarà fent una introducció al CERN, als detectors de

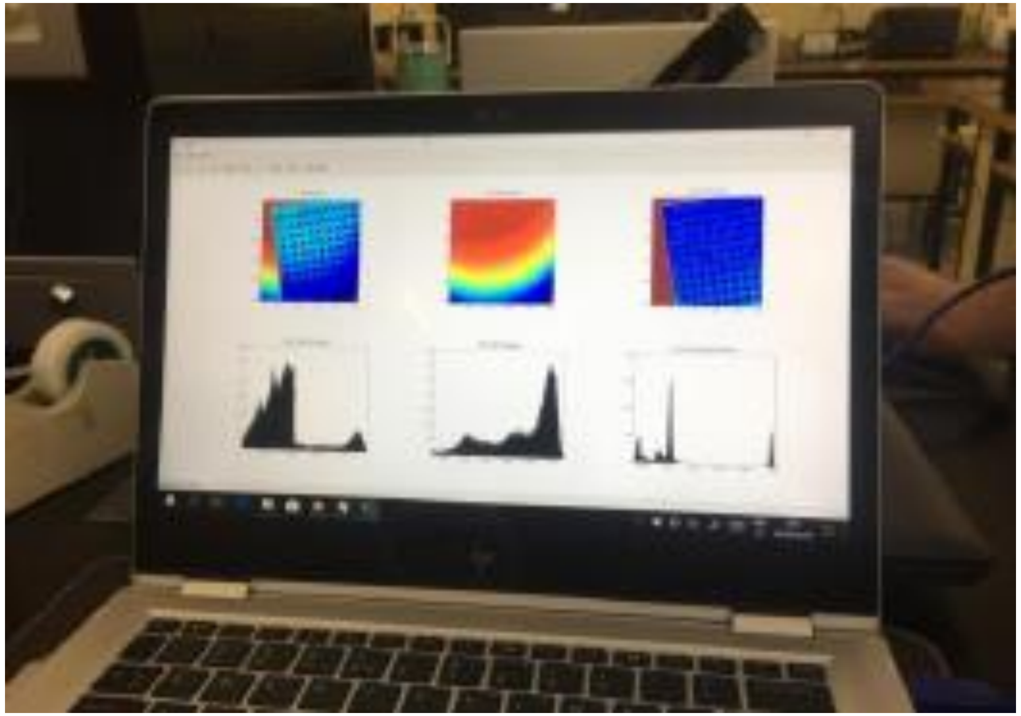
A càrrec de: Rafel Ballabriga, CERN

Cursos
Física de Partícules

https://serviparticules.ub.edu/projectes/projecte-admira/formacio-per-professors

Visita centros a laboratorios de la UB

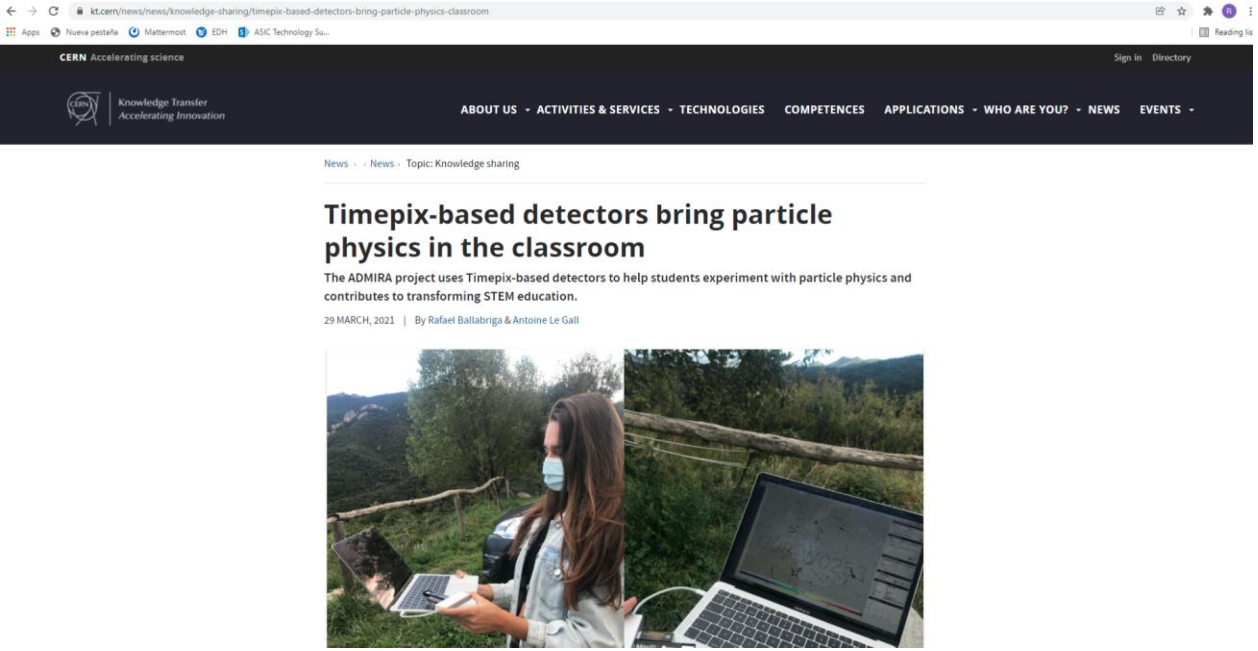




UNIVERSITAT DE BARCELONA

Visita escuela Santo Angel Gavà al CERN

Artículos web CERN



kt.cern/news/news/knowledge-sharing/timepix-based-detectors-bring-particle-physics-classroom

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Knowledge Transfer — Accelerating Innovation

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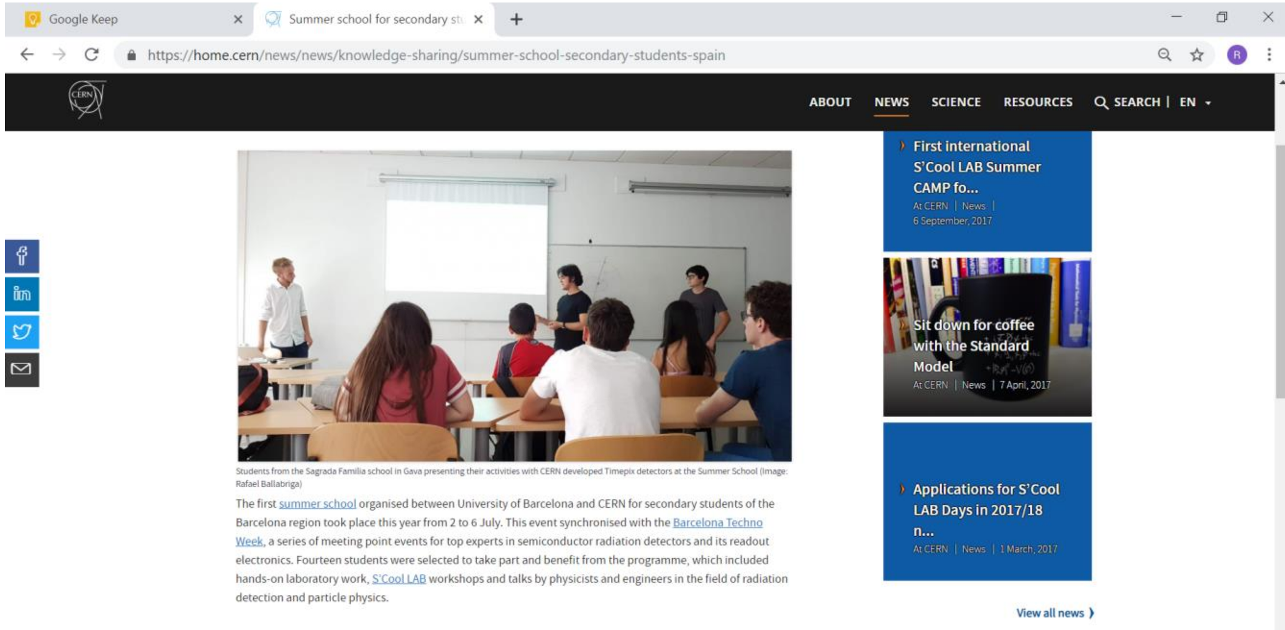
News › News › Topic: Knowledge sharing

Timepix-based detectors bring particle physics in the classroom

The ADMIRA project uses Timepix-based detectors to help students experiment with particle physics and contributes to transforming STEM education.

29 MARCH, 2021 | By Rafael Ballabriga & Antoine Le Gall



https://home.cern/news/news/knowledge-sharing/summer-school-secondary-students-spain

ABOUT · NEWS · SCIENCE · RESOURCES · SEARCH | EN

Students from the Sagrada Familia school in Gava presenting their activities with CERN developed Timepix detectors at the Summer School (Image: Rafael Ballabriga)

The first summer school organised between University of Barcelona and CERN for secondary students of the Barcelona region took place this year from 2 to 6 July. This event synchronised with the Barcelona Techno Week, a series of meeting point events for top experts in semiconductor radiation detectors and its readout electronics. Fourteen students were selected to take part and benefit from the programme, which included hands-on laboratory work, S'Cool LAB workshops and talks by physicists and engineers in the field of radiation detection and particle physics.

First international S'Cool LAB Summer CAMP fo... — At CERN | News | 6 September, 2017

Sit down for coffee with the Standard Model — At CERN | News | 7 April, 2017

Applications for S'Cool LAB Days in 2017/18 n... — At CERN | News | 1 March, 2017

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Artículo científico

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PAPER

Phys. Educ. 57 (2022) 025018 (14pp)

iopscience.org/ped

ADMIRA project: teaching particle physics at high school with Timepix detectors

D Parcerisas[1,*], R Ballabriga[2,*], E Amorós[5], A Argudo[3], M Campbell[2], L Casas[4], P Christodoulou[2], R Colomé[5], D Corrons[6], V Curcó[7], M Enajas[8], C Granja[9], E Grauges[3], A Gou[10], E Lleó[11], X Llopart[2], E Pallares[3], H Pino[12], S Serra[13] and G Valero[14]

[1] Sagrada Familia School, Gavà, Barcelona, Spain
[2] Experimental Physics Department, CERN, Meyrin, Switzerland
[3] Institut de Ciències del Cosmos, University of Barcelona, Barcelona, Spain
[4] Institut de Desenvolupament Professional, University of Barcelona, Barcelona, Spain
[5] Vilafant High School, Vilafant, Girona, Spain
[6] La Salle School, Manlleu, Barcelona, Spain
[7] La Roca del Vallès High School, La Roca del Vallés, Barcelona, Spain
[8] Intermunicipal School of Penedés, Sant Sadurní d'Anoia, Barcelona, Spain
[9] Advacam, Prague, Czech Republic
[10] Quatre Cantons High School, Barcelona, Spain
[11] F. X. Lluch i Rafecas High School, Barcelona, Spain
[12] Learn It With Us, Barcelona, Spain
[13] Terrassa High School, Barcelona, Spain
[14] Joan Brossa High School, Barcelona, Spain

E-mail: d.parcerisas@safagava.edu and rafael.ballabriga@cern.ch

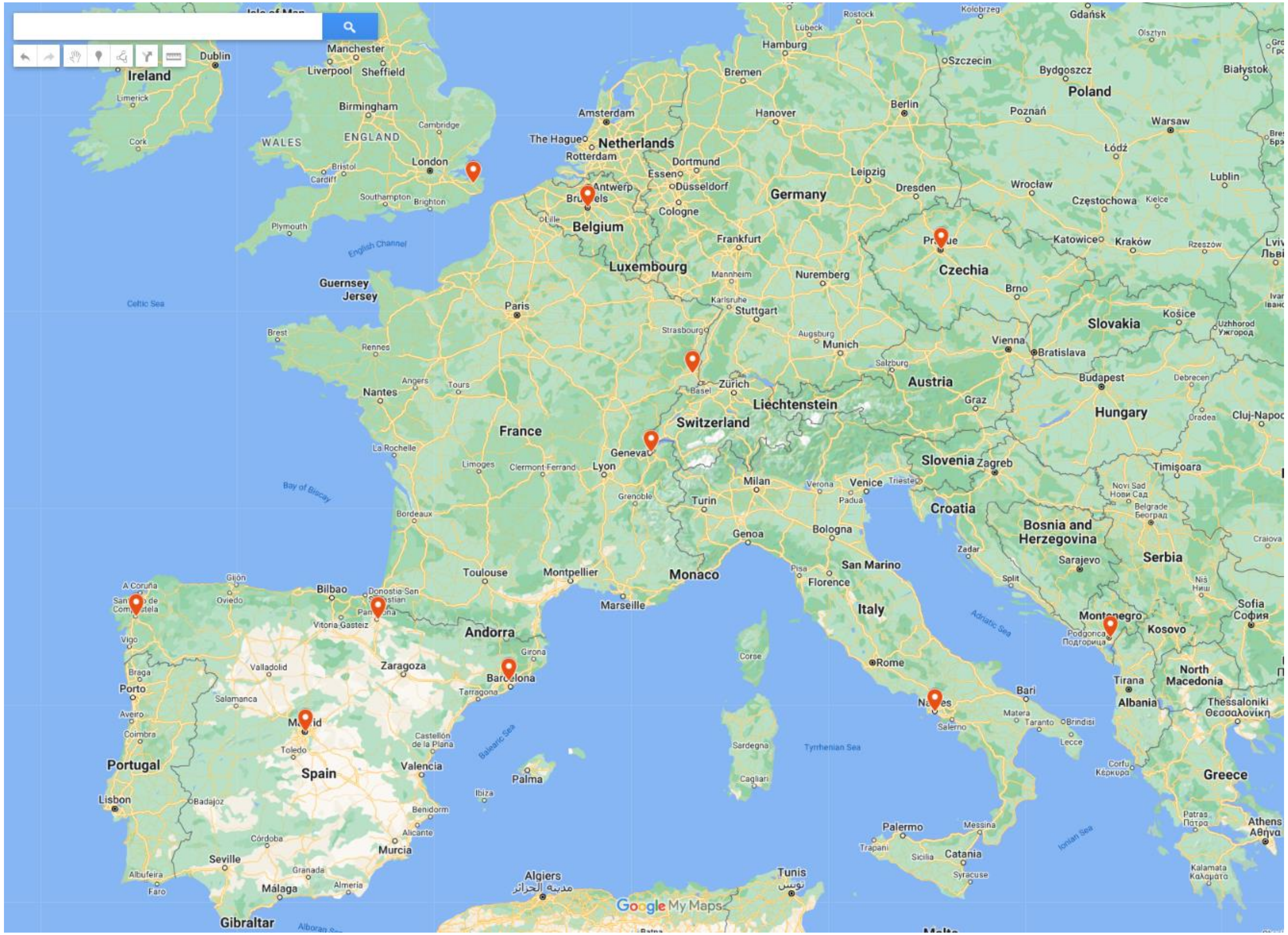
CrossMark

Abstract

This paper presents the case for how students can be helped to increase their scientific vocation by experimental work and the introduction of particle physics into pre-university studies. These two ideas are the two main lines of work of the ADMIRA initiative, which has been created by individuals belonging to different and complementary educational and research institutions. The initiative consists of a network of schools that share Minipix

https://iopscience.iop.org/article/10.1088/1361-6552/ac4143

Minipix-Edu kits that have been distributed for educational purposes: The Timepix Teachers Network



Minipix-Edu kits that have been distributed for educational purposes: The Timepix Teachers Network

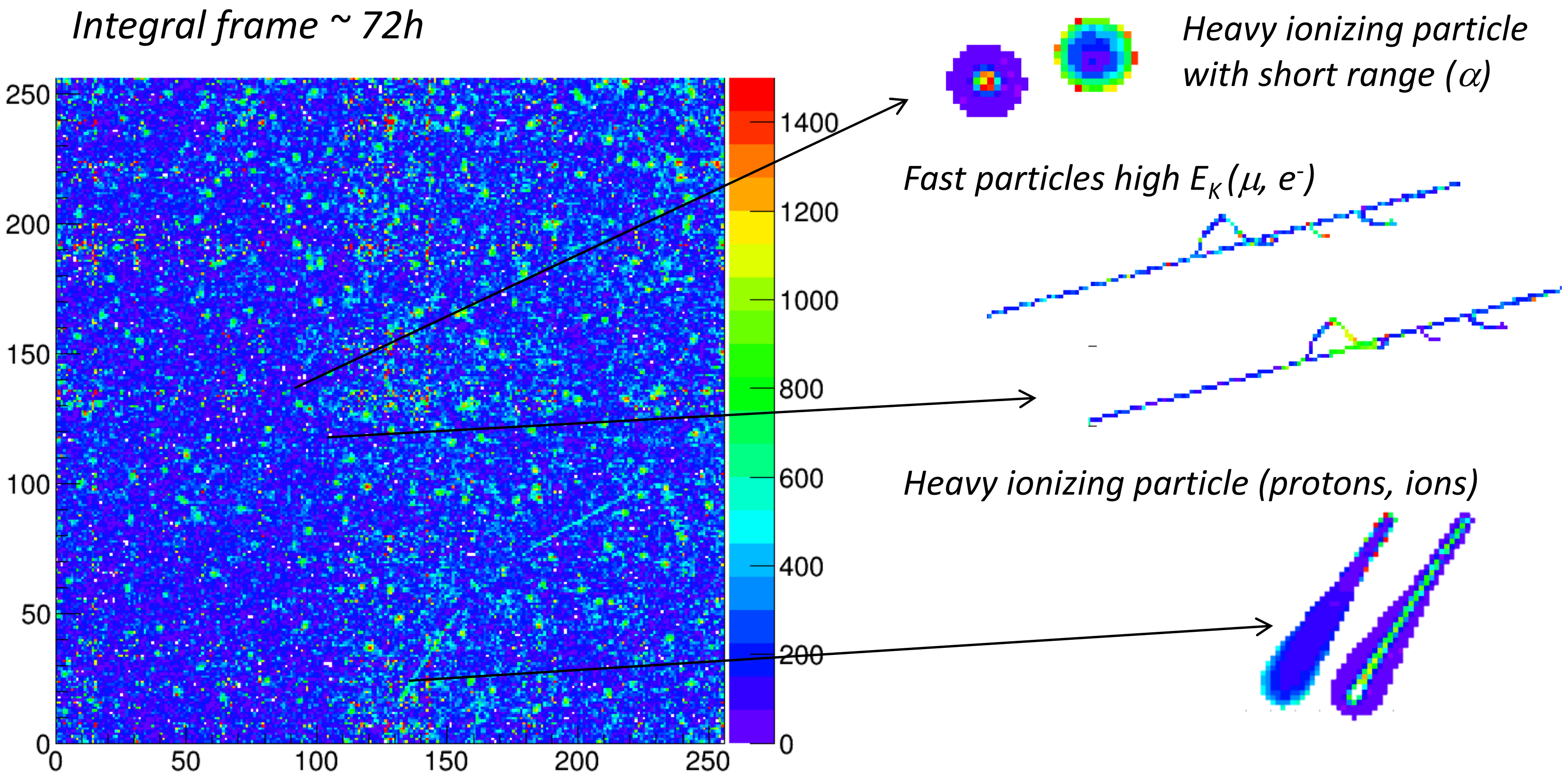
Proxecto MEDRA

IGFAE

Instituto Galego de Física de Altas Enerxías

Conclusión

Los Detectores Timepix permiten visualizar la radiación



Timepix chip: matrix of 256x256 pixels
Different particles present a different signature in their interaction with the pixelated semiconductor detector

El Ciclo del Conocimiento

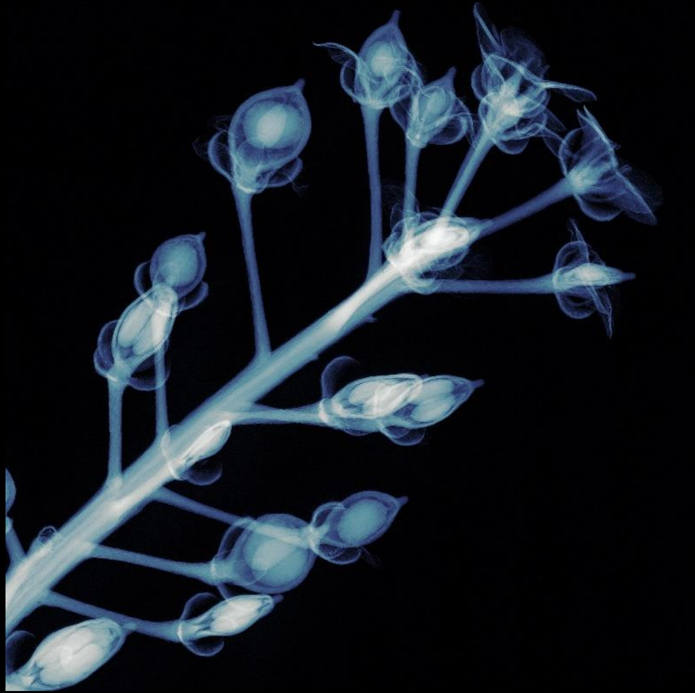
Metodología Clásica

El Ciclo del Conocimiento

ADMIRA

Timepix Teachers Network

Muchas gracias



Bonus

Introducción a la radiación

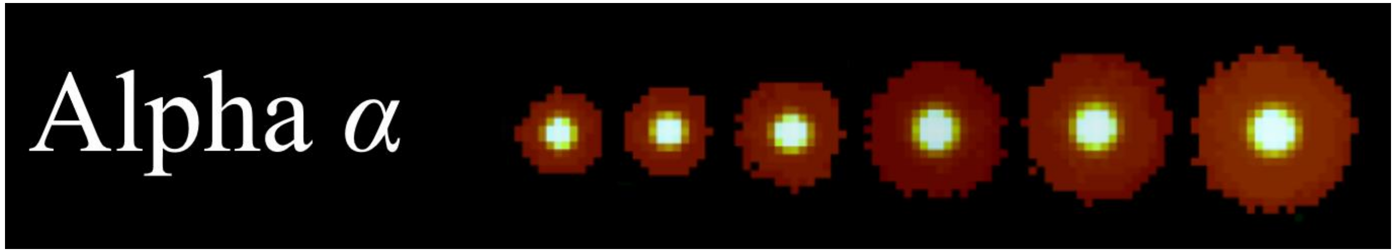
Definiciones

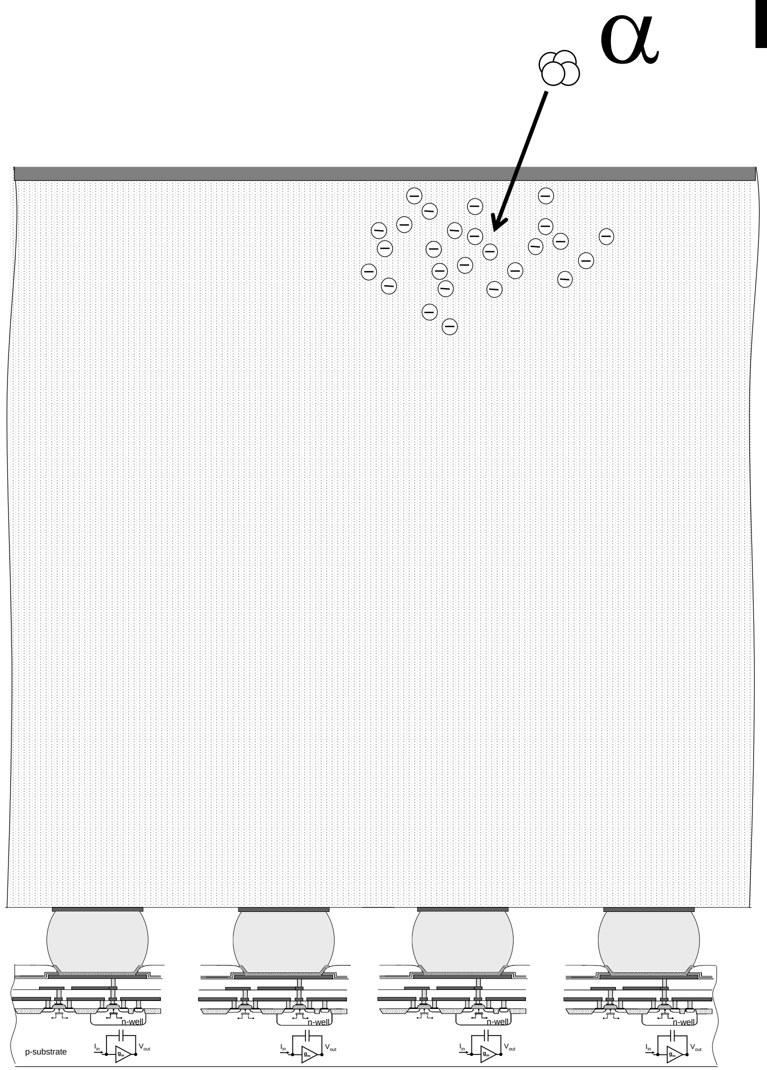
Radiación es la emisión de energía en el espacio en forma de ondas electromagnéticas o en forma de partículas altamente energéticas (electrones, protones, iones, etc.).

La **radioactividad** es un fenómeno físico por el cual ciertas sustancias con núcleos atómicos inestables, se transforman espontáneamente perdiendo energía en forma de rayos de partículas, para adquirir unos núcleos atómicos más estables i de menor masa.

Radiación con carga eléctrica	Radiación sin carga
Partículas α, Iones pesados	Neutrones
Electrones (β^-), Positrones (β^+), Muones (μ^+, μ^-), Taus (τ^+, τ^-)	Fotones (Rajos X, rajos γ)

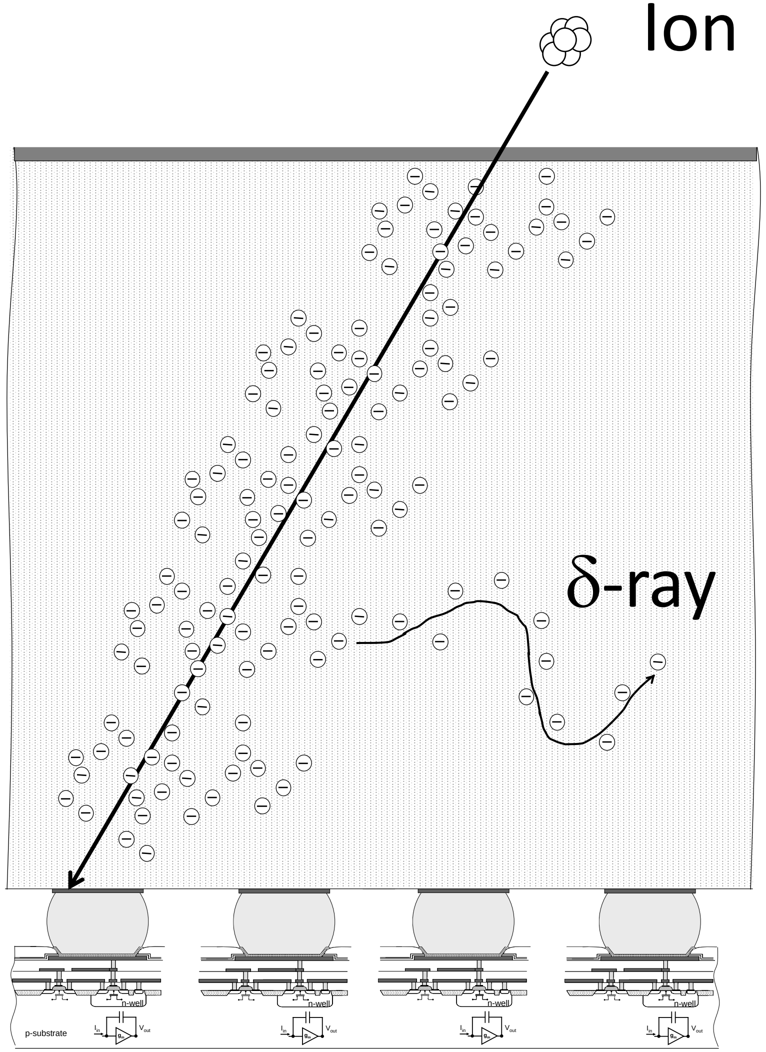
Partículas α





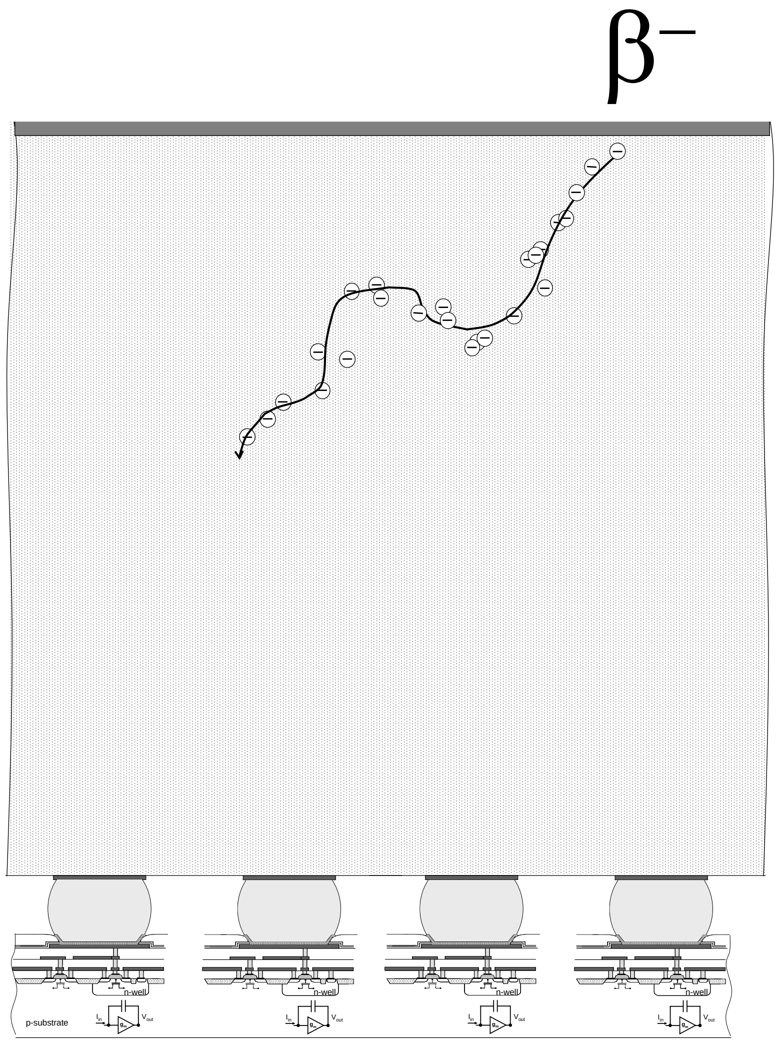
- He nuclei: 2 protons and 2 neutrons
- Interact strongly with matter due to their charge (coulombic forces) and to their mass
- At their typical speeds they can only travel a few centimeters in air. They can be stopped by a sheet of paper
- In their interactions with electrons in the absorbing material, α particles can generate δ rays

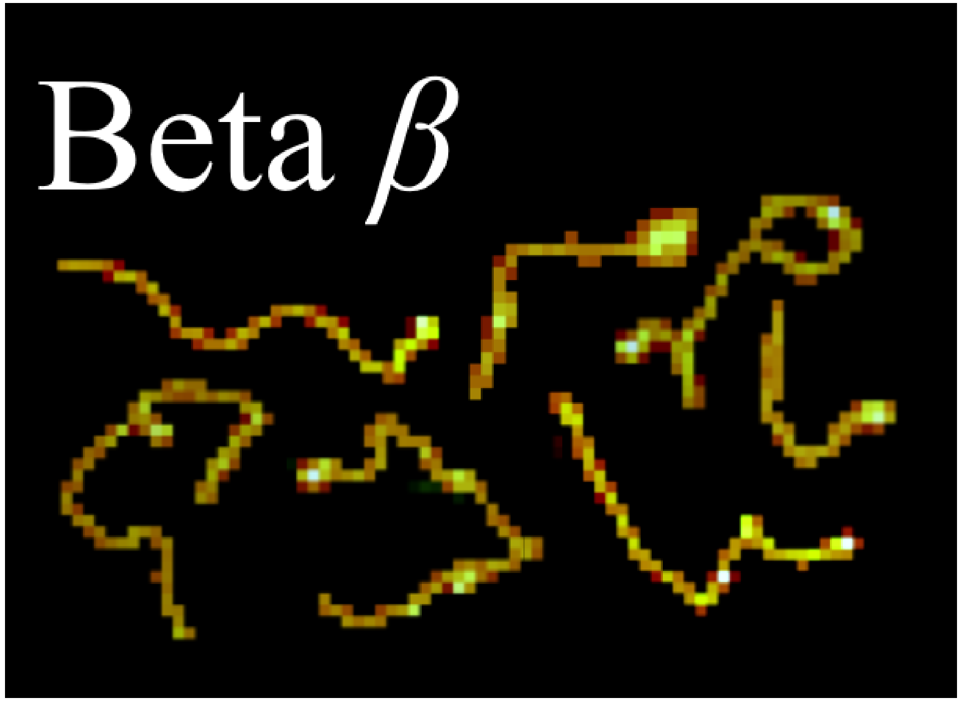
Iones pesados



- A heavy ion is an ionized atom (heavier than He)
- Interact strongly with matter due to their charge (coulombic forces) and to their mass
- In their interactions with electrons in the absorbing material, they can generate δ rays

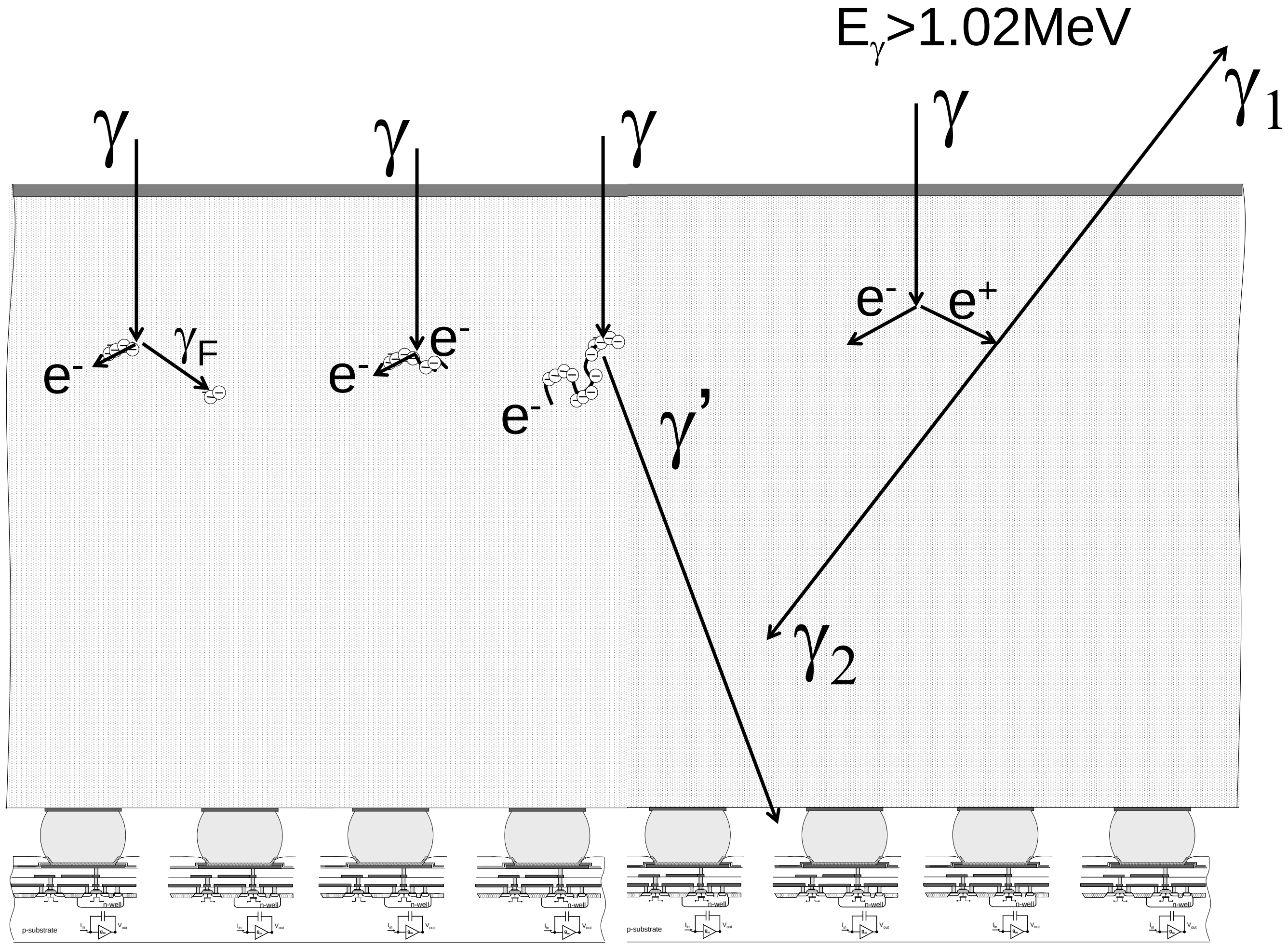
Radiación β





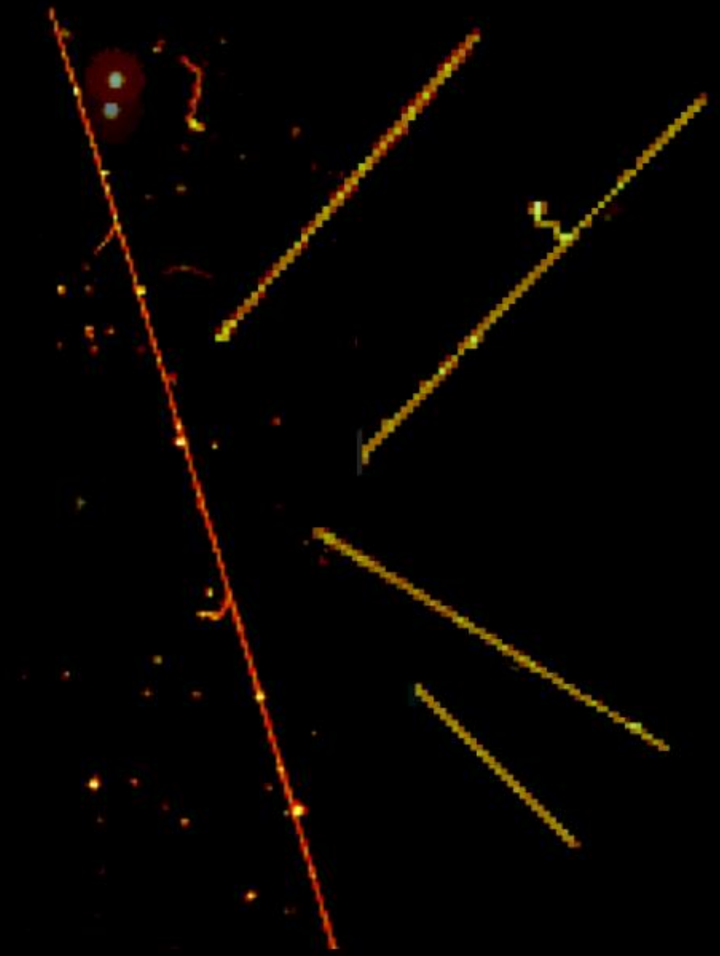
- Beta radiation consists of electrons (β^-) (or positrons (β^+)).
- Electrons follow random trajectories inside the absorbing material because they have the same mass as the electrons with which they interact

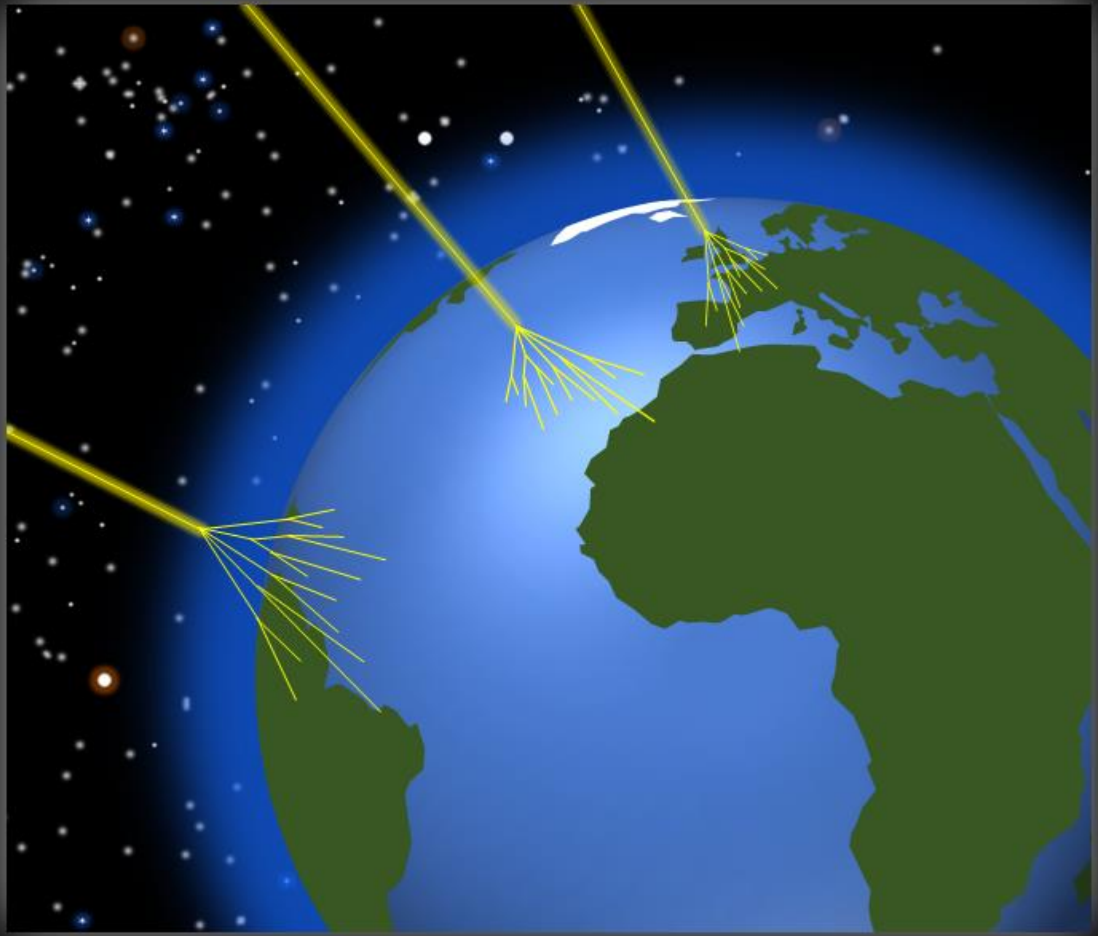
Rayos X y radiación γ



- Gamma radiation consists of high energy photons
- Photoelectric effect, Compton scattering, pair production

Muon μ





Admira

Trabajo de investigación

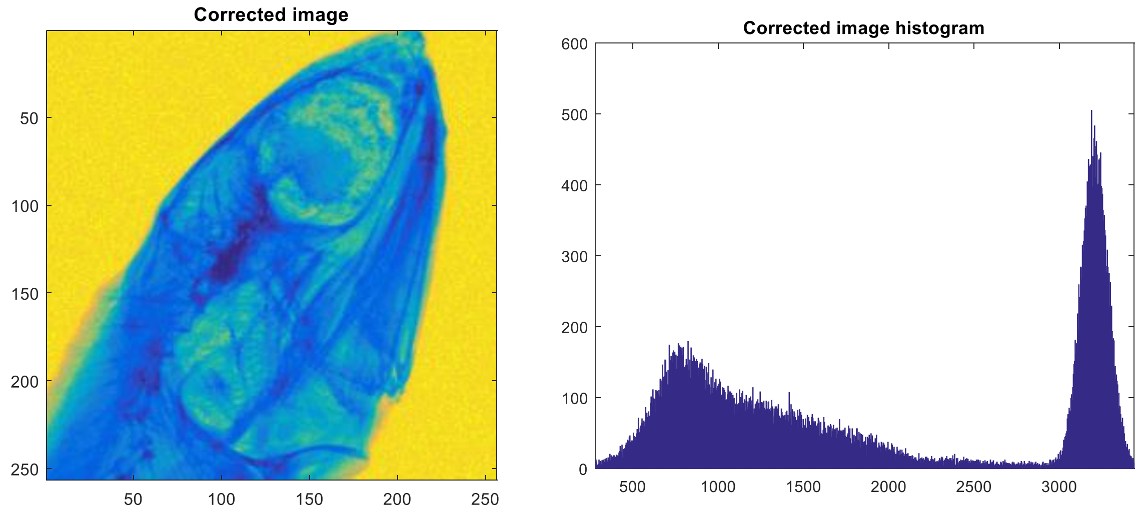
<u>Trabajo de investigación</u>
Asignatura de 18 meses en bachillerato
Requiere investigación experimental
Timepix es una herramienta que permite diversidad de estudios

https://serviparticules.ub.edu/materials/llibres-i-manuals

Trabajo de investigación

- Dosimetría y radiación de fondo
- Rayos cósmicos
- Salud
- Detectores de partículas
- Computación e inteligencia artificial

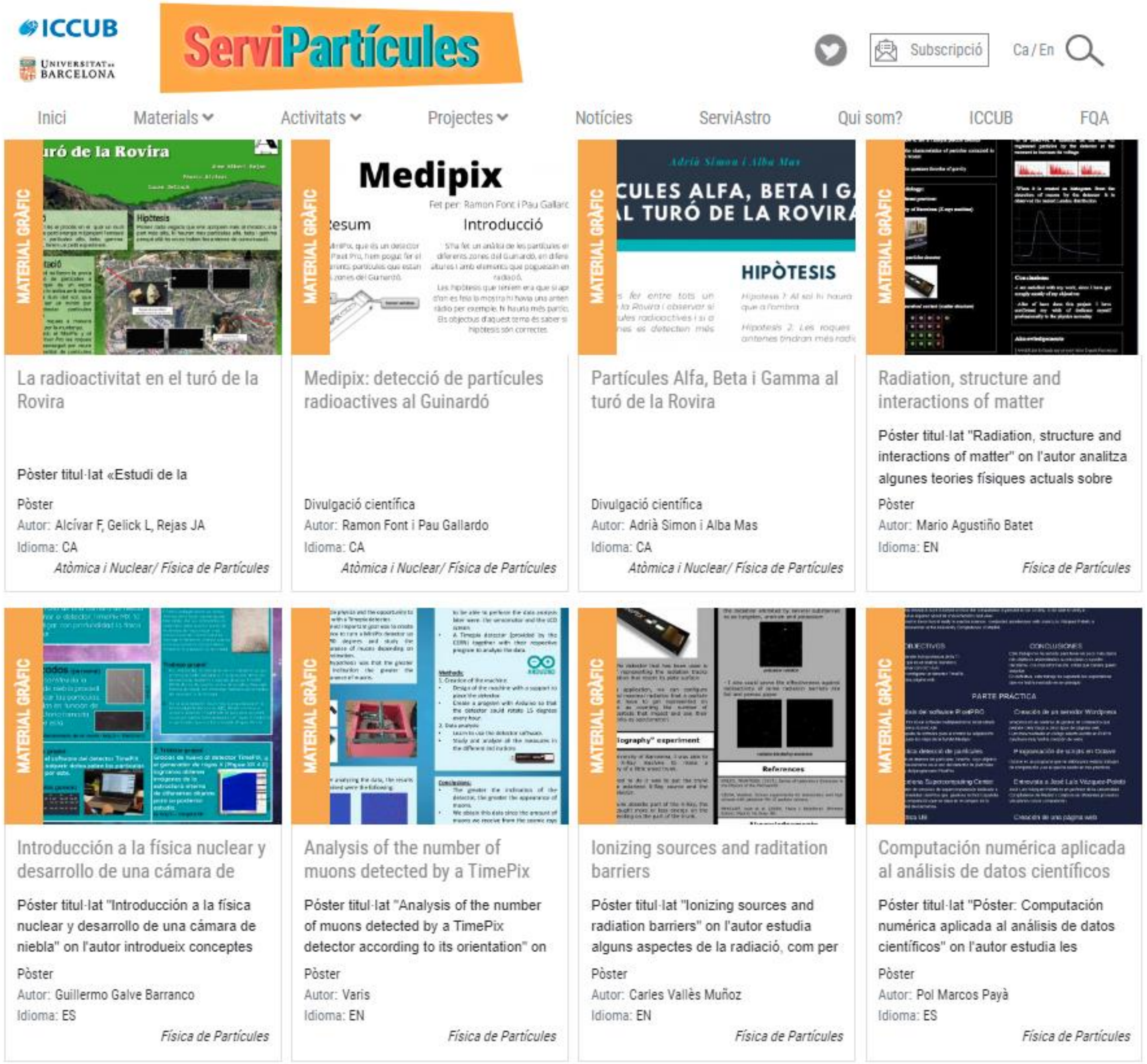
Esther Salvador, Sagrada Familia, Gavà



Bruguers Miranzo, Julia Gonzalez, Santo Angel Gavà

Ruben Castaño, Sagrada Familia, Gavà

Trabajo de investigación



https://serviparticules.ub.edu/projectes/projecte-admira/posters

Prácticas

La radioactivitat que ens envolta

Presentació de les pràctiques de radioactivitat a l'aula.

Introducció

En aquest kit de pràctiques de radioactivitat a l'aula es facilita el material necessari perquè el professor pugui realitzar a l'aula un seguit d'experiències en física de radiacions.

L'enfoc d'aquestes experiències es treballar i observar efectes de radiacions beta i alfa sense la necessitat de recórrer a fonts radioactives perilloses per a les persones. La radioactivitat és un fenomen natural que ens envolta, i que moltes vegades els alumnes associen exclusivament a contextos amb dosis de radioactivitat molt elevada i perjudicial per als humans. Amb això, les dues pràctiques presentades en aquests material tenen dos objectiu fonamentals:

1- Treballar i estudiar els fenòmens de radioactivitat, mitjançant la mesura real i l'anàlisi posterior de les dades experimentals recollides.
2- Conscienciar a l'alumnat que els fenòmens de radioactivitat són habituals i estem envoltats d'ells en el nostre dia a dia, lluny d'associar el perjudici de la radioactivitat a exclusivament fonts perilloses per a les persones.

Les pràctiques i el contingut que en elles es treballen estan enfocats idealment per a ser treballat a nivell de batxillerat. Tot i això, són possibles simplificacions en els continguts a tractar i els càlculs a realitzar per part dels alumnes, de forma que pugui ser implementada en cursos d'ESO (més informació a la guia del professor, on es presenta una descripció detallada de les pràctiques, conjuntament amb un solucionari amb mesures reals obtingudes en realitzar les experiències).

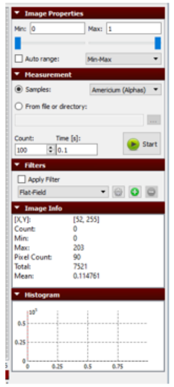
Per realitzar aquestes experiències és altament recomanable tenir accés al sensor TIMEPIX, ja que tant el procés de mesura com de representació de dades resulta molt àgil i eficient. Tot i això, alternatives amb altres aparells de mesura de radiacions poden ser adaptats.

Tot el material descrit s'inclou en un pdf conjunt, el professor interessat pot fer posteriorment ús de les parts que li interessi independentment.

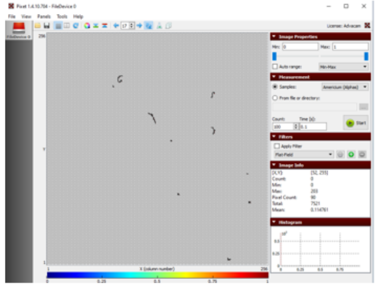
4. Sense utilitzar la mostra radioactiva, obriu la finestra del detector i premeu el botó Start per iniciar la captura de dades.

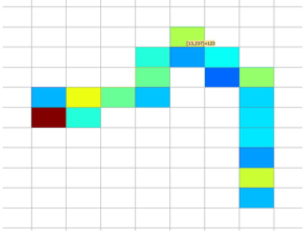
5. Una vegada acabada l'obtenció de les dades, tanqueu la finestra (el protector del xip).

Quan el procés d'obtenció de dades finalitzi, tanqueu el protector del xip.



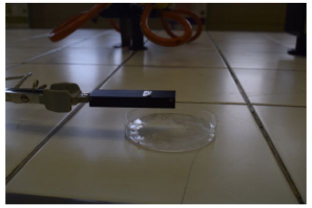
6. Compteu el nombre de Worms (cucs), que són trajectòries llargues i corbades produïdes per la radiació beta d'alta energia. Per assegurar-vos que les partícules beta són d'alta energia, amplia la imatge de cadascuna d'elles, i comprova que la seva energia dipositada és superior als 700 keV.





7. Dividiu el nombre de partícules detectades pel temps transcorregut (600 s). Obtindreu l'activitat de fons.

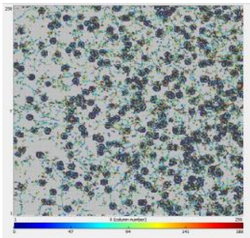
8. Subjecteu el detector verticalment a un suport amb anella de manera que estigui a un centímetre per sobre del banc, tal i com es mostra a la imatge de sota. Col·loqueu un vidre de rellotge o un tap d'ampolla sota la finestra del detector.

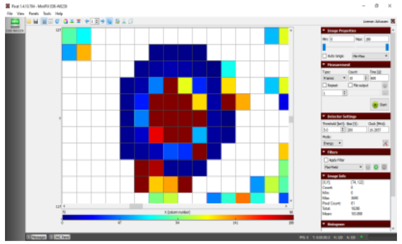


9. Peseu 2 grams de clorur de potassi, i dipositeu-lo al vidre de rellotge.

10. Obriu de nou la finestra del detector i premeu el botó Start per iniciar la captura de dades.

11. Una vegada acabada l'obtenció de les dades, tanqueu la finestra (el protector del xip).



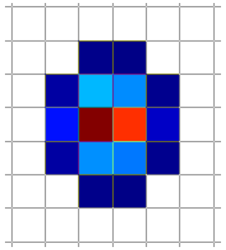


D. Corrons, H. Pino

Prácticas

- Práctica de laboratorio

Resultados



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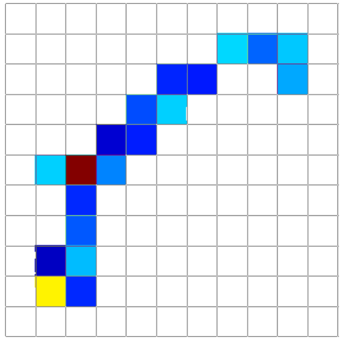
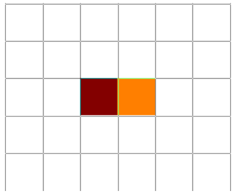
v [m/s] (class.)	22837837,18	13739206,06	19007111,86	17246204,4	16286399,46
v/c (relat.)	0,07596114511	0,04576136897	0,0632618517	0,05741621667	0,05422808397
v/c (classica)	0,07612612395	0,04579735353	0,06335703953	0,05748734801	0,05428799819
desviació (%)	0,2167177617	0,07857344563	0,1502403333	0,1237338907	0,1103636552



Beta

Ek [keV]	1953	1878	2504	1282	736
Ek [J]	3,13E-13	3,01E-13	4,01E-13	2,05E-13	1,18E-13
v [m/s] (relat.)	293461408,6	293039615,1	295648441,5	287530123	273603963,7
v [m/s] (class.)	828777947,9	812708607	938435066,1	671476901,6	508775245,3
v/c (relat.)	0,9782046954	0,976798717	0,9854948051	0,9584337434	0,9120132124
v/c (classica)	2,76259316	2,70902869	3,128116887	2,238256339	1,695917484
long. ona (m)	2,48E-12	2,48E-12	2,46E-12	2,53E-12	2,66E-12

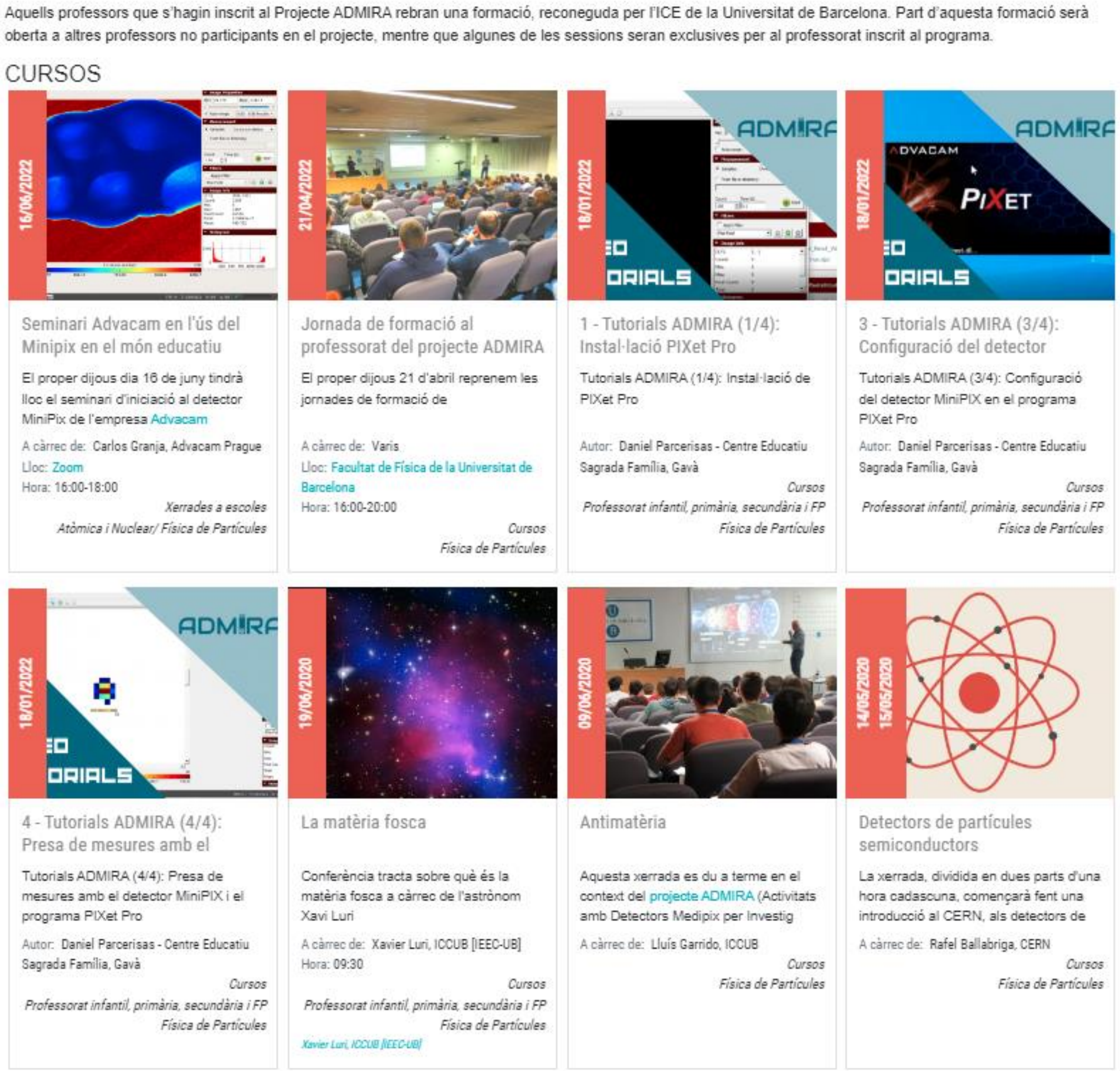


Gamma

Ek [keV]	82	72	31	18	68
Ek [J]	1,31E-14	1,15E-14	4,97E-15	2,88E-15	1,09E-14
f (Hz)	1,98E+19	1,74E+19	7,50E+18	4,36E+18	1,65E+19
long. ona (m)	1,51E-11	1,72E-11	4,00E-11	6,89E-11	1,82E-11
p (kg·m/s)	4,38E-23	3,84E-23	1,66E-23	9,61E-24	3,63E-23

D. Parcerisas

Formación del profesorado



Aquells professors que s'hagin inscrit al Projecte ADMIRA rebran una formació, reconeguda per l'ICE de la Universitat de Barcelona. Part d'aquesta formació serà oberta a altres professors no participants en el projecte, mentre que algunes de les sessions seran exclusives per al professorat inscrit al programa.

CURSOS

16/06/2022

Seminari Advacam en l'ús del Minipix en el món educatiu

El proper dijous dia 16 de juny tindrà lloc el seminari d'iniciació al detector MiniPix de l'empresa Advacam

A càrrec de: Carlos Granja, Advacam Prague
Lloc: Zoom
Hora: 16:00-18:00

Xerrades a escoles
Atòmica i Nuclear/ Física de Partícules

21/04/2022

Jornada de formació al professorat del projecte ADMIRA

El proper dijous 21 d'abril reprenem les jornades de formació de

A càrrec de: Varis
Lloc: Facultat de Física de la Universitat de Barcelona
Hora: 16:00-20:00

Cursos
Física de Partícules

18/01/2022

1 - Tutorials ADMIRA (1/4): Instal·lació PIXet Pro

Tutorials ADMIRA (1/4): Instal·lació de PIXet Pro

Autor: Daniel Parcerisas - Centre Educatiu Sagrada Família, Gavà

Cursos
Professorat infantil, primària, secundària i FP
Física de Partícules

18/01/2022

3 - Tutorials ADMIRA (3/4): Configuració del detector

Tutorials ADMIRA (3/4): Configuració del detector MiniPIX en el programa PIXet Pro

Autor: Daniel Parcerisas - Centre Educatiu Sagrada Família, Gavà

Cursos
Professorat infantil, primària, secundària i FP
Física de Partícules

18/01/2022

4 - Tutorials ADMIRA (4/4): Presa de mesures amb el

Tutorials ADMIRA (4/4): Presa de mesures amb el detector MiniPIX i el programa PIXet Pro

Autor: Daniel Parcerisas - Centre Educatiu Sagrada Família, Gavà

Cursos
Professorat infantil, primària, secundària i FP
Física de Partícules

19/06/2020

La matèria fosca

Conferència tracta sobre què és la matèria fosca a càrrec de l'astrònom Xavi Luri

A càrrec de: Xavier Luri, ICCUB [IEEC-UB]
Hora: 09:30

Cursos
Professorat infantil, primària, secundària i FP
Física de Partícules
Xavier Luri, ICCUB [IEEC-UB]

09/06/2020

Antimatèria

Aquesta xerrada es du a terme en el context del projecte ADMIRA (Activitats amb Detectors Medipix per Investig

A càrrec de: Lluís Garrido, ICCUB

Cursos
Física de Partícules

14/05/2020
15/05/2020

Detectors de partícules semiconductors

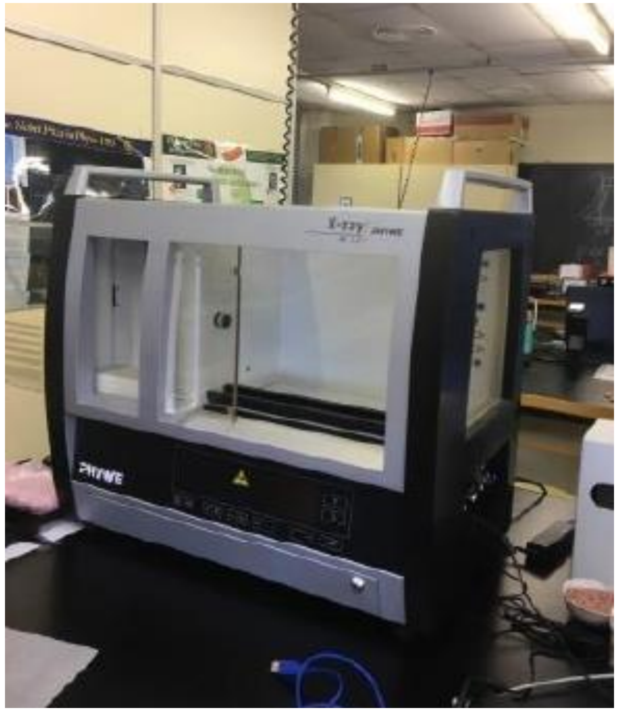
La xerrada, dividida en dues parts d'una hora cadascuna, començarà fent una introducció al CERN, als detectors de

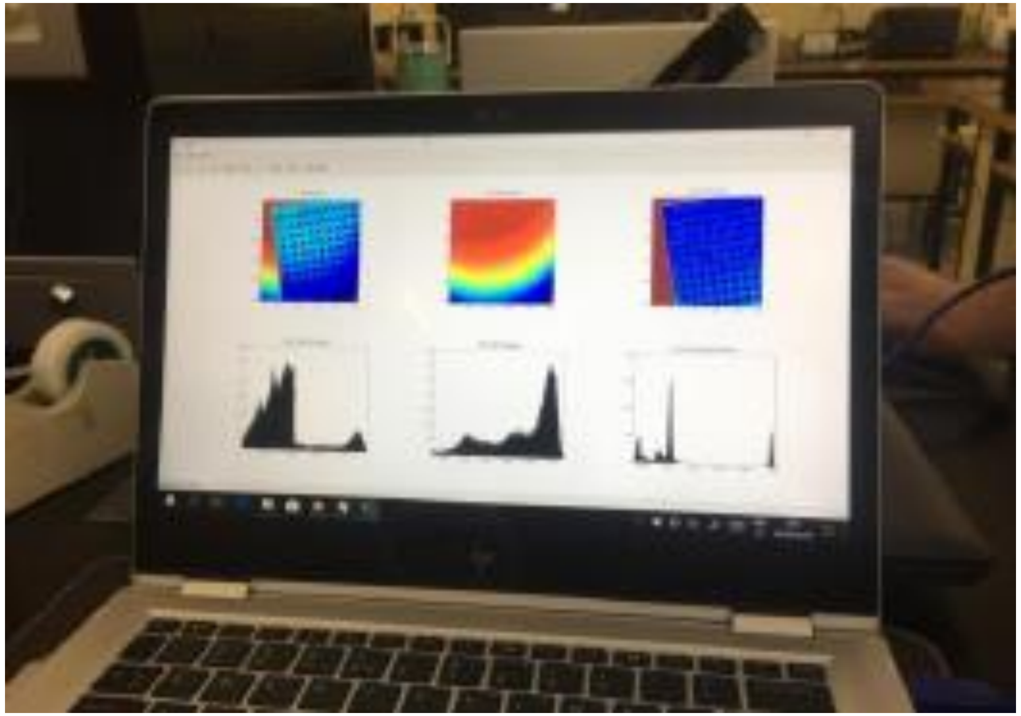
A càrrec de: Rafel Ballabriga, CERN

Cursos
Física de Partícules

https://serviparticules.ub.edu/projectes/projecte-admira/formacio-per-professors

Visita centros a laboratorios de la UB

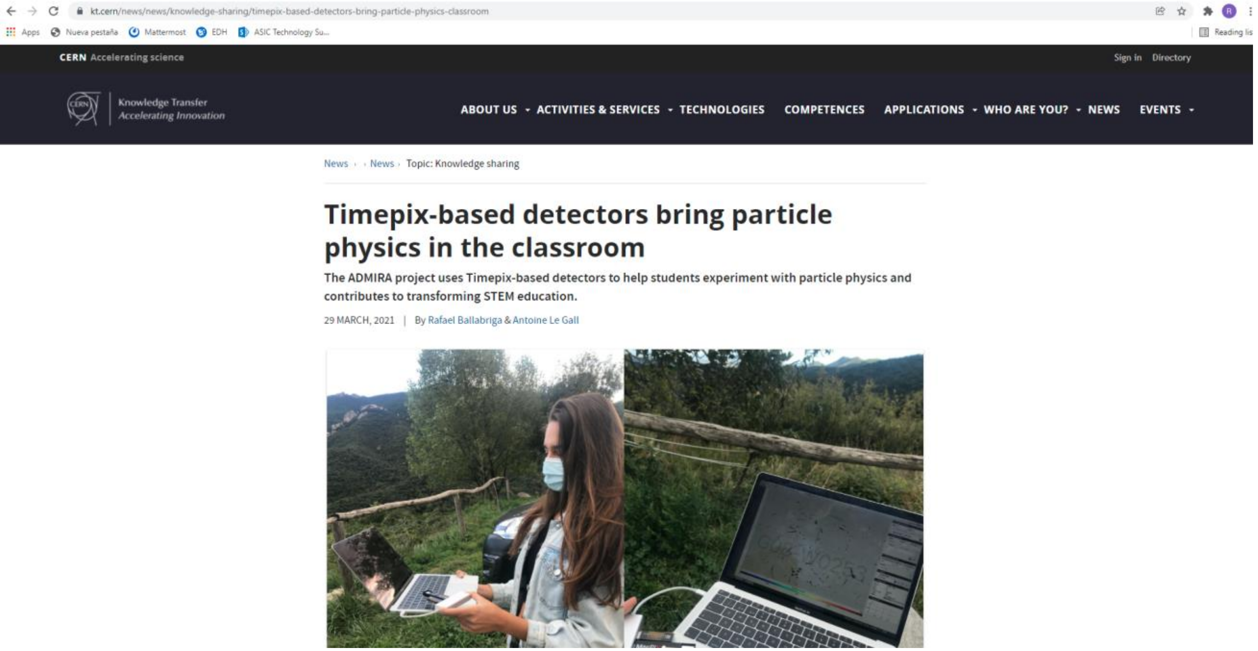


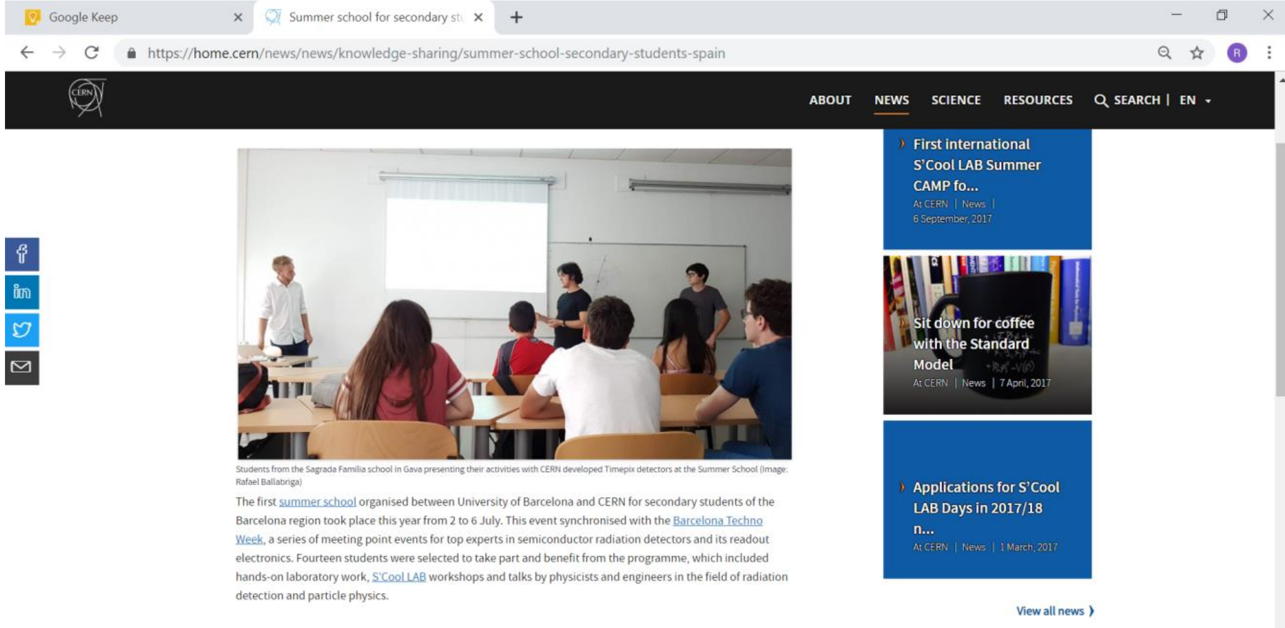


UNIVERSITAT DE BARCELONA

Visita escuela Santo Angel Gavà al CERN

Artículos web CERN





Artículo científico

OPEN ACCESS PAPER

Phys. Educ. 57 (2022) 025018 (14pp) iopscience.org/ped

ADMIRA project: teaching particle physics at high school with Timepix detectors

D Parcerisas[1,*], R Ballabriga[2,*], E Amorós[5], A Argudo[3], M Campbell[2], L Casas[4], P Christodoulou[2], R Colomé[5], D Corrons[6], V Curcó[7], M Enajas[8], C Granja[9], E Grauges[3], A Gou[10], E Lleó[11], X Llopart[2], E Pallares[3], H Pino[12], S Serra[13] and G Valero[14]

[1] Sagrada Familia School, Gavà, Barcelona, Spain
[2] Experimental Physics Department, CERN, Meyrin, Switzerland
[3] Institut de Ciències del Cosmos, University of Barcelona, Barcelona, Spain
[4] Institut de Desenvolupament Professional, University of Barcelona, Barcelona, Spain
[5] Vilafant High School, Vilafant, Girona, Spain
[6] La Salle School, Manlleu, Barcelona, Spain
[7] La Roca del Vallès High School, La Roca del Vallés, Barcelona, Spain
[8] Intermunicipal School of Penedés, Sant Sadurní d'Anoia, Barcelona, Spain
[9] Advacam, Prague, Czech Republic
[10] Quatre Cantons High School, Barcelona, Spain
[11] F. X. Lluch i Rafecas High School, Barcelona, Spain
[12] Learn It With Us, Barcelona, Spain
[13] Terrassa High School, Barcelona, Spain
[14] Joan Brossa High School, Barcelona, Spain

E-mail: d.parcerisas@safagava.edu and rafael.ballabriga@cern.ch

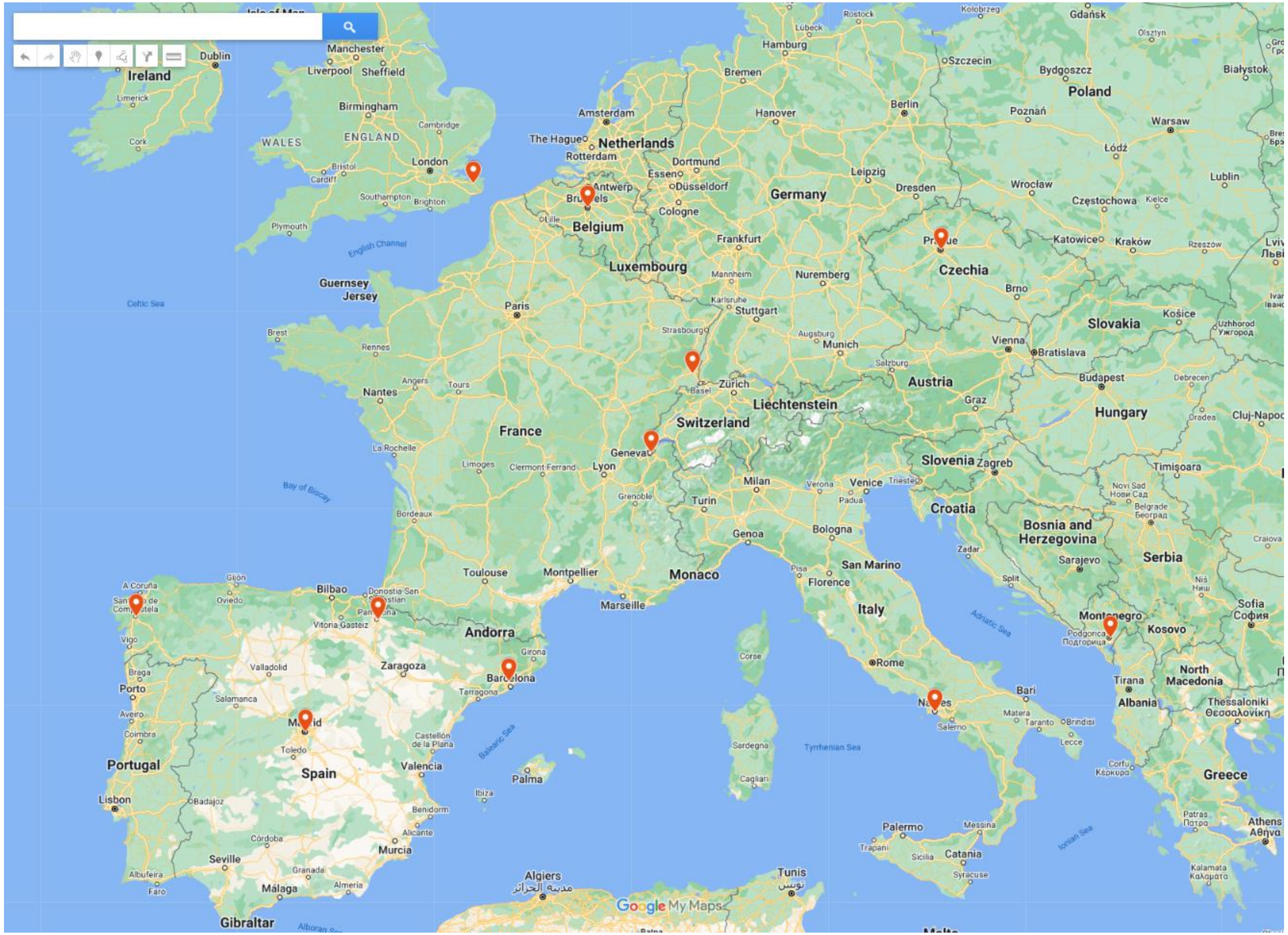
CrossMark

Abstract
This paper presents the case for how students can be helped to increase their scientific vocation by experimental work and the introduction of particle physics into pre-university studies. These two ideas are the two main lines of work of the ADMIRA initiative, which has been created by individuals belonging to different and complementary educational and research institutions. The initiative consists of a network of schools that share Minipix

https://iopscience.iop.org/article/10.1088/1361-6552/ac4143

What is next?

Minipix-Edu kits that have been distributed for educational purposes: The Timepix Teachers Network

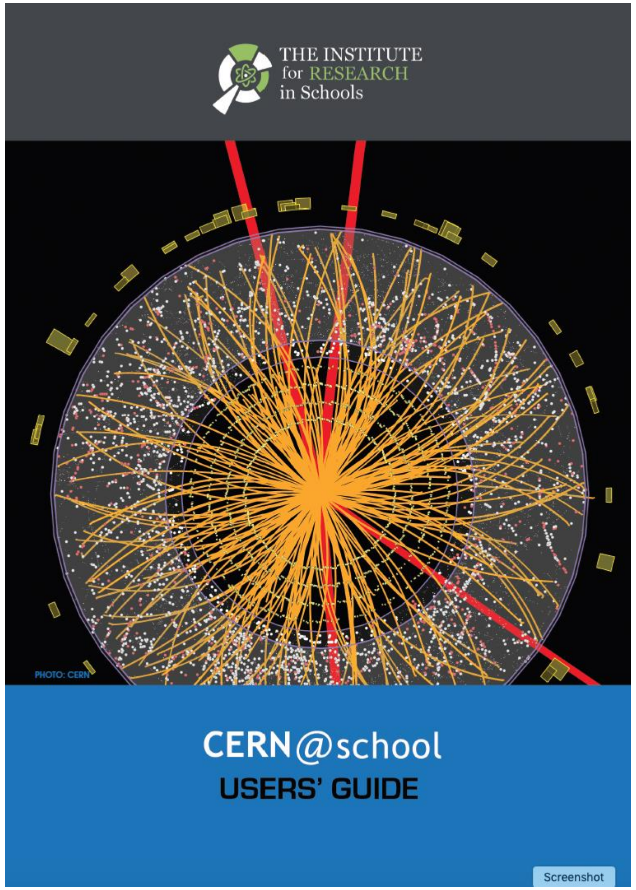


University of Barcelona has agreed to host a Timepix Teachers Network conference for students and teachers in June-July 2023

Let's keep in contact and looking forward to see you there in person!

Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA
ICCUB
EXCELENCIA MARÍA DE MAEZTU 2020-2023

Impact in UK schools (CERN@school project)



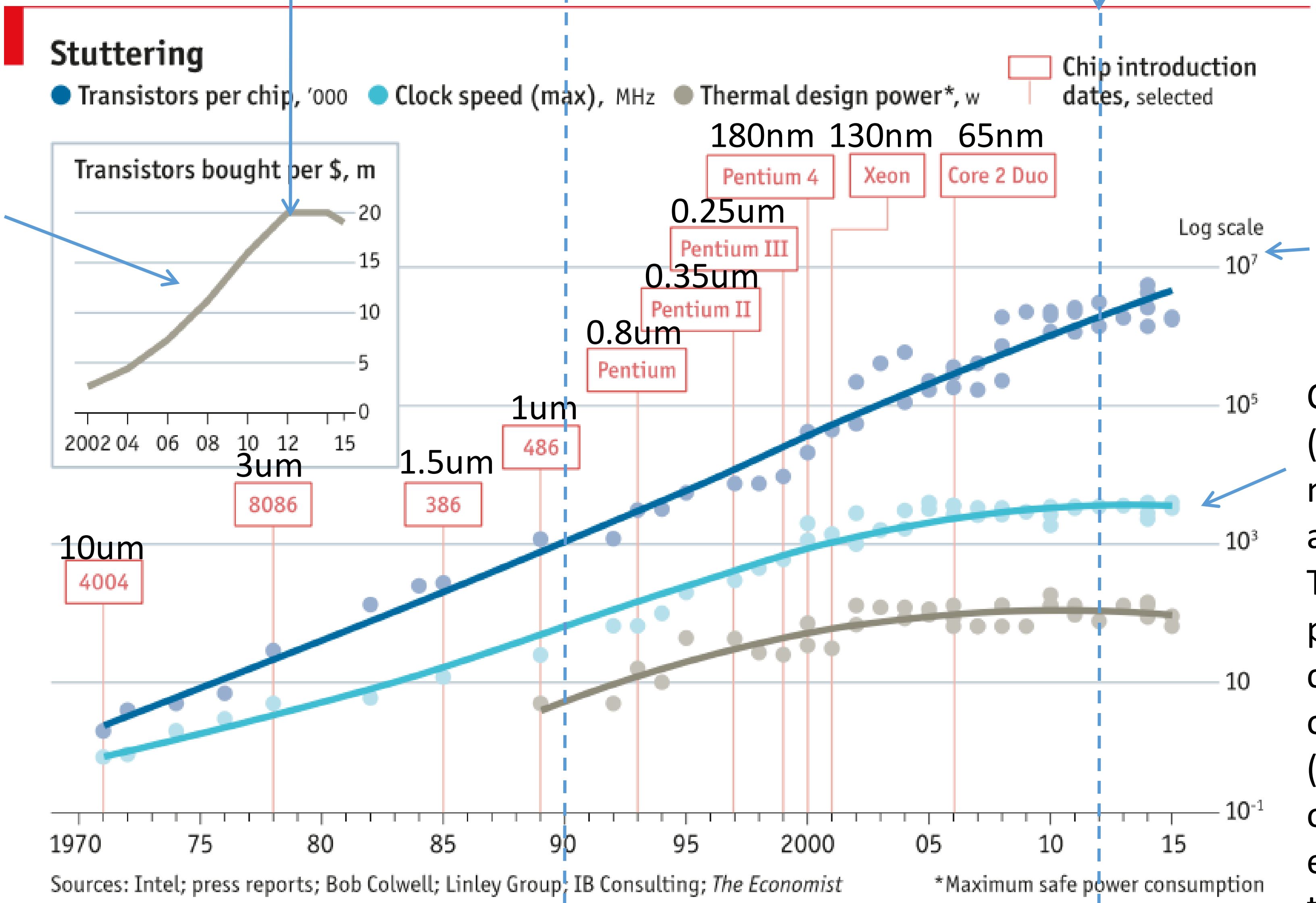
Location of CERN@school kits 2018-2019

~7000 students used the detector between 2016 and 2019

~2015-2016 the transistor cost starts rising

Intel introduces the FinFet (2012, 22nm CMOS) ~40% Faster, ½ power

Moore's law has been pushed to lower the costs of transistors (and in the last decade it is more about cost tan performance)



$10.000\ 10^6$ transistors already achieved

Clock speed plateau (Benefits of miniaturization falling away)

Today most of the performance gains come from integration of multiple cores (several processors in one chip) (4, 8, 16) enabled by cheaper transistors

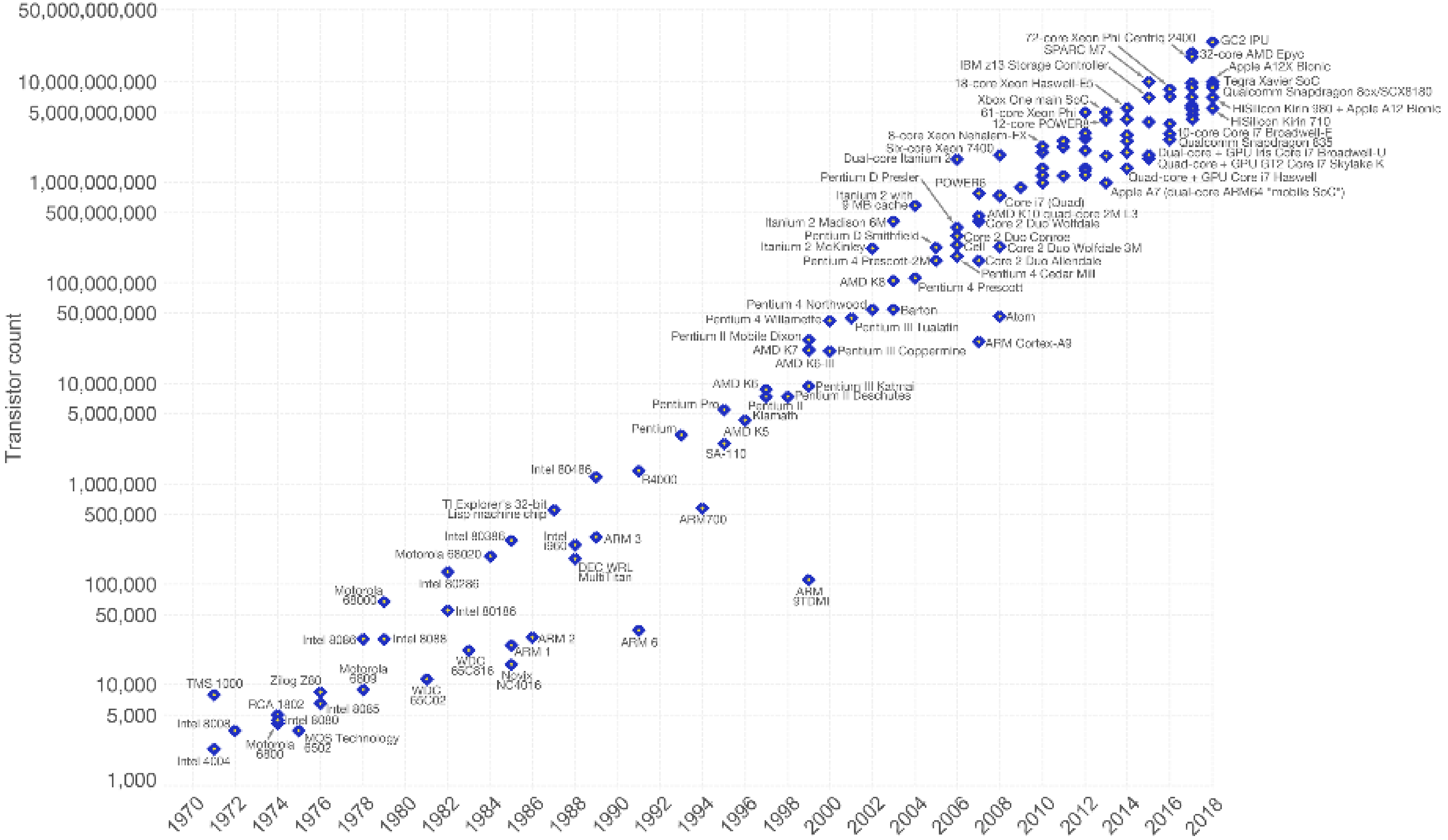
First 5nm chips expected in 2020

Technology named after shrinking features

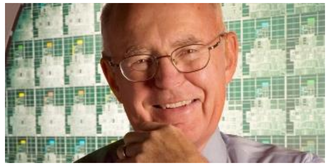
Moore's Law – The number of transistors on integrated circuit chips (1971-2018)

Our World in Data

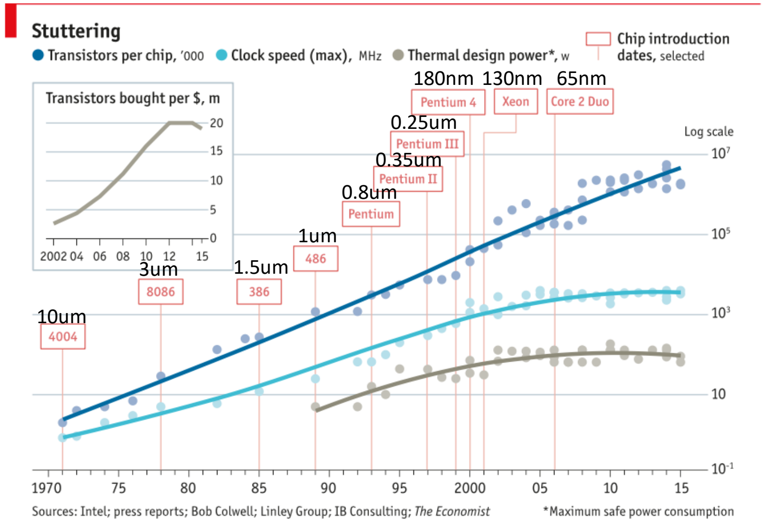
Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.

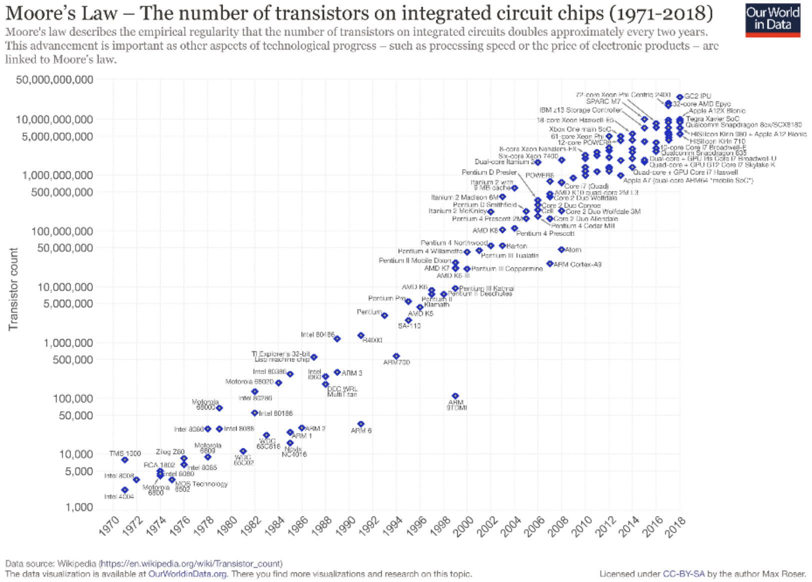


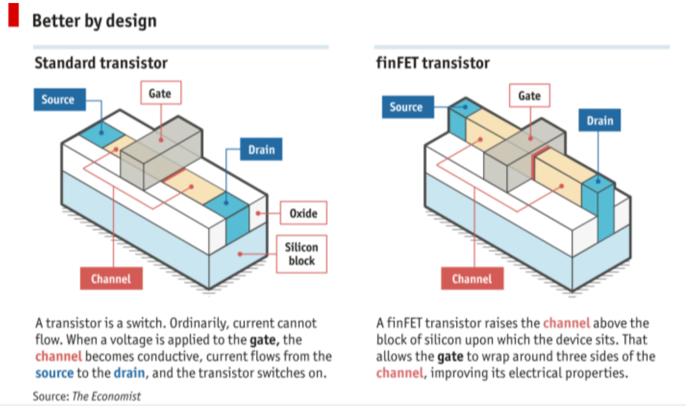
Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

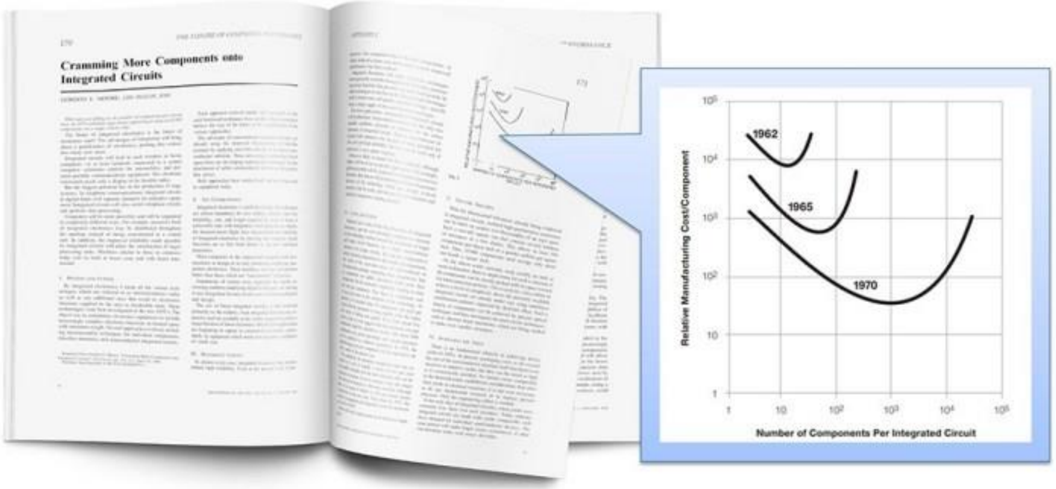


Moore’s law









G.E.Moore, Cramming More components onto Integrated Circuits, Electronics, vol.38, no. 8, 1965.

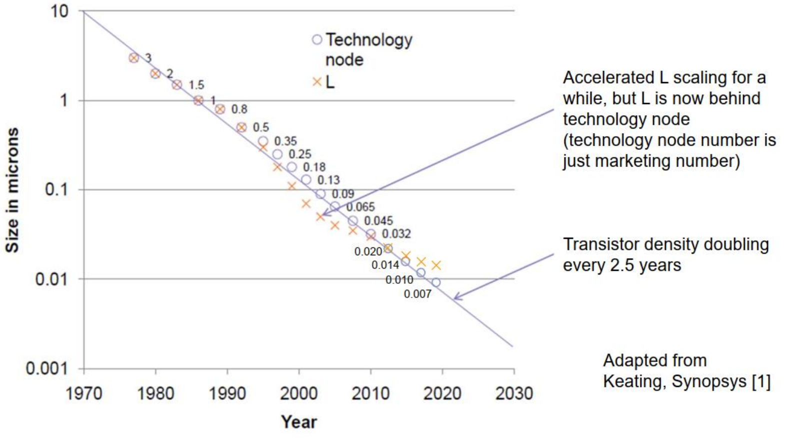
Moore predicted a trajectory of progress in which the transistor count of integrated circuits would roughly double every two years while the cost per transistor would decrease.

1st transistor 1959

Number of Foundries with a Cutting Edge Logic Fab

180 nm	130 nm	90 nm	65 nm	45 nm/40 nm	32 nm/28 nm	22 nm/20 nm	16 nm/14 nm	10 nm	7 nm	5 nm
SilTerra										
X-FAB										
Dongbu HiTek										
ADI	ADI									
Atmel	Atmel									
Rohm	Rohm									
Sanyo	Sanyo									
Mitsubishi	Mitsubishi									
ON	ON									
Hitachi	Hitachi									
Cypress	Cypress	Cypress								
Sony	Sony	Sony								
Infineon	Infineon	Infineon								
Sharp	Sharp	Sharp								
Freescale	Freescale	Freescale								
Renesas (NEC)	Renesas	Renesas	Renesas	Renesas						
SMIC	SMIC	SMIC	SMIC	SMIC						
Toshiba	Toshiba	Toshiba	Toshiba	Toshiba						
Fujitsu	Fujitsu	Fujitsu	Fujitsu	Fujitsu						
TI	TI	TI	TI	TI						
Panasonic	Panasonic	Panasonic	Panasonic	Panasonic	Panasonic					
STMicroelectronics	STM	STM	STM	STM	STM					
UMC	UMC	UMC	UMC	UMC	UMC					
IBM	IBM	IBM	IBM	IBM	IBM	IBM				
AMD	AMD	AMD	GlobalFoundries	GF	GF	GF	GF			
Samsung	Samsung	Samsung	Samsung	Samsung	Samsung	Samsung	Samsung	Samsung	Samsung	
TSMC	TSMC	TSMC	TSMC	TSMC	TSMC	TSMC	TSMC	TSMC	TSMC	
Intel	Intel	Intel	Intel	Intel	Intel	Intel	Intel	Intel	Intel	Future

CMOS Scaling Still Alive But Slowing…



- Leading foundries (TSMC, SEC) scrambled to match Intel 22nm finFET at 16/14nm
- Planar 20nm short-lived
- Foundries now in 7nm early production ahead of Intel
- 5nm engagement with foundries already underway

2017

Moore's law

Moore's law 1.0:

Scaling up. More components in a chip

Reliably adding more components and packaging them. In 1989 one was speaking about the 4Mb DRAM node or in 1992 the 16Mb DRAM node.

Moore's law 2.0:

Scaling down the transistor (decreasing cost).

After 1990 the technology nodes are named after the shrinking features.

Today 10 billion transistors in a chip.

Today, benefits of miniaturization are progressively falling away.

Started in 2000s, with sub 100nm channels that show leakage currents, lower reliability (requiring new materials).

2015-2016 could be the year when the cost of transistors started to rise (stopped falling)

Moore's law is morphing again (**Moore's law 3.0**) More than Moore

Innovation will continue in the semiconductor industry but will not lower the transistor costs.

Progress will be defined by new forms of integration:

- Lower the system cost by uniting non logic functions that have been separated from our silicon chips. (example: image sensor onto a digital signal processor with TSVs, MEMs, Microfluidics).
- Sensors and actuators should take advantage of mass production approaches common to silicon manufacturing.
- Moore 3.0 does not offer a predictable road to success.
- We could see an explosion of creative applications.

Research:

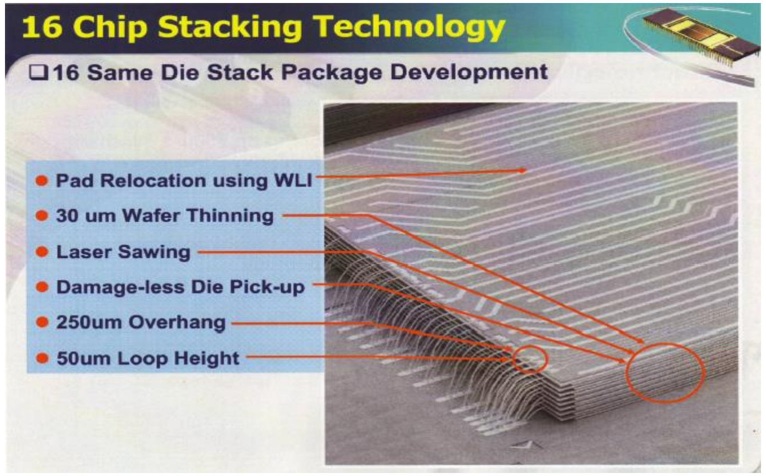
Transistor Redesign (Finfets)

New materials (e.g. graphene)

New ASIC architectures/ redefine the computer (e.g. emulate biological brains)

Customized designs (rather than general purpose)

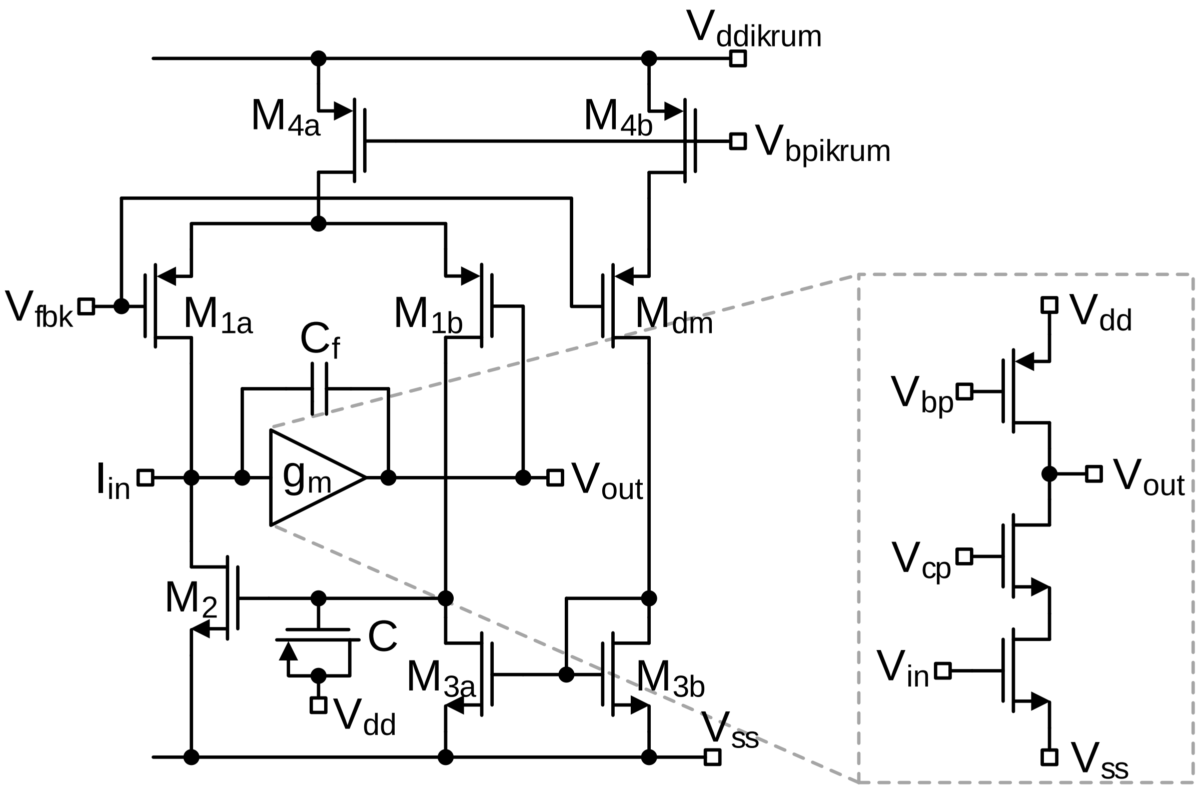
Clever programming (in the past less incentive to programming improvements due to doubling computer power every two years)

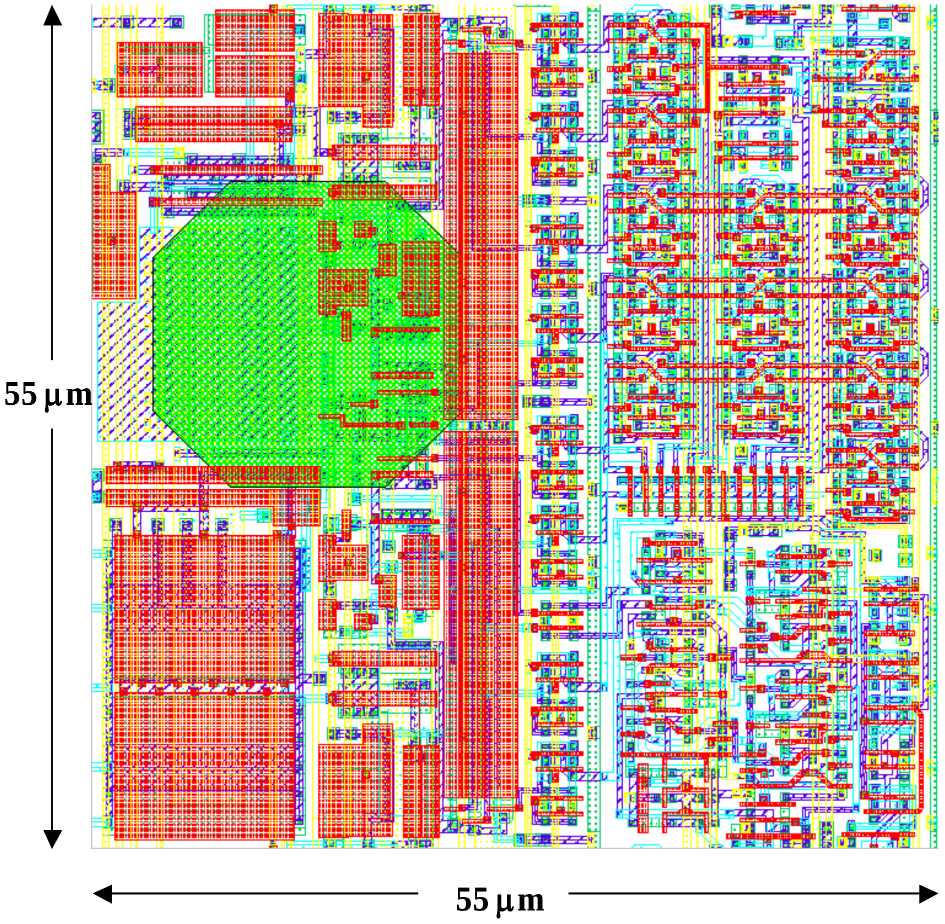


BACKUP

Fabrication steps

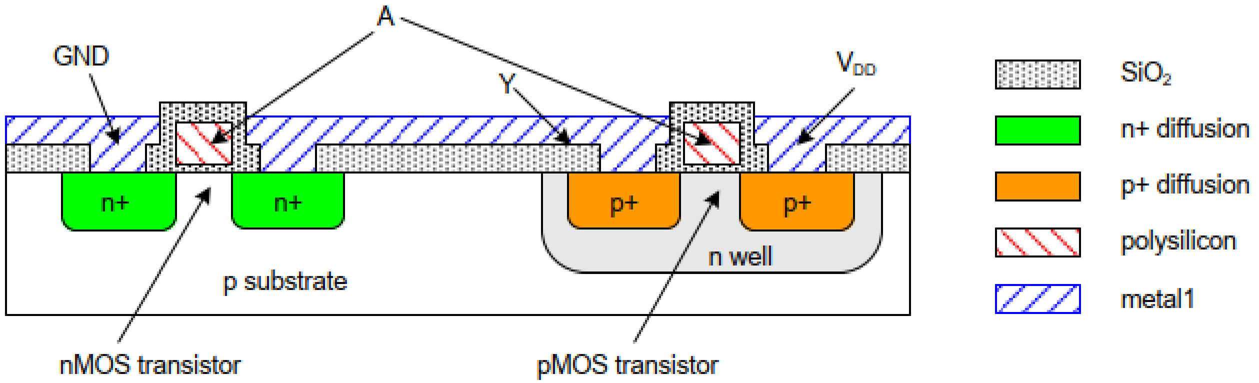
Del esquema al layout





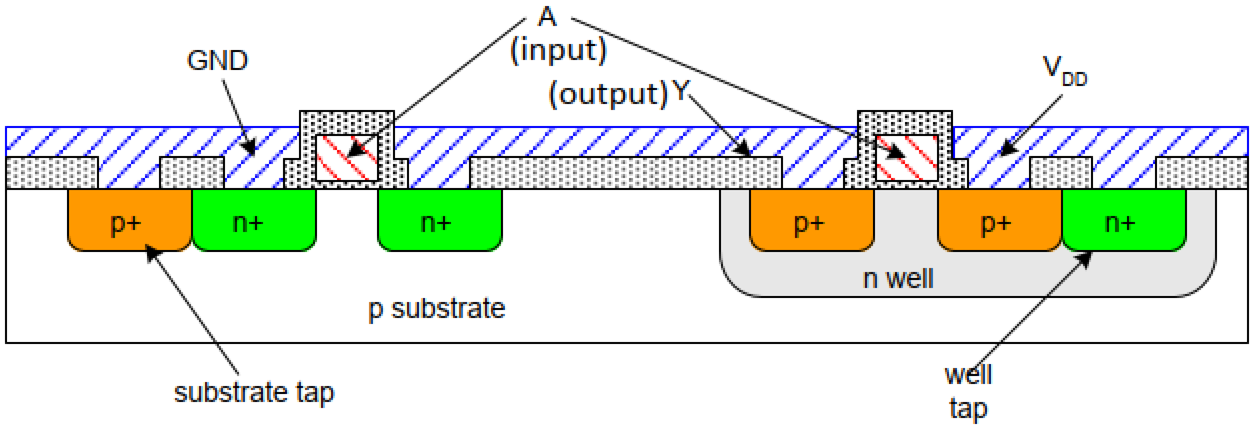
Inverter Cross-section

- Typically use p-type substrate for NMOS transistors.
- Requires n-well for body of PMOS transistors.
- Substrate and n-well voltage needs to be controlled.



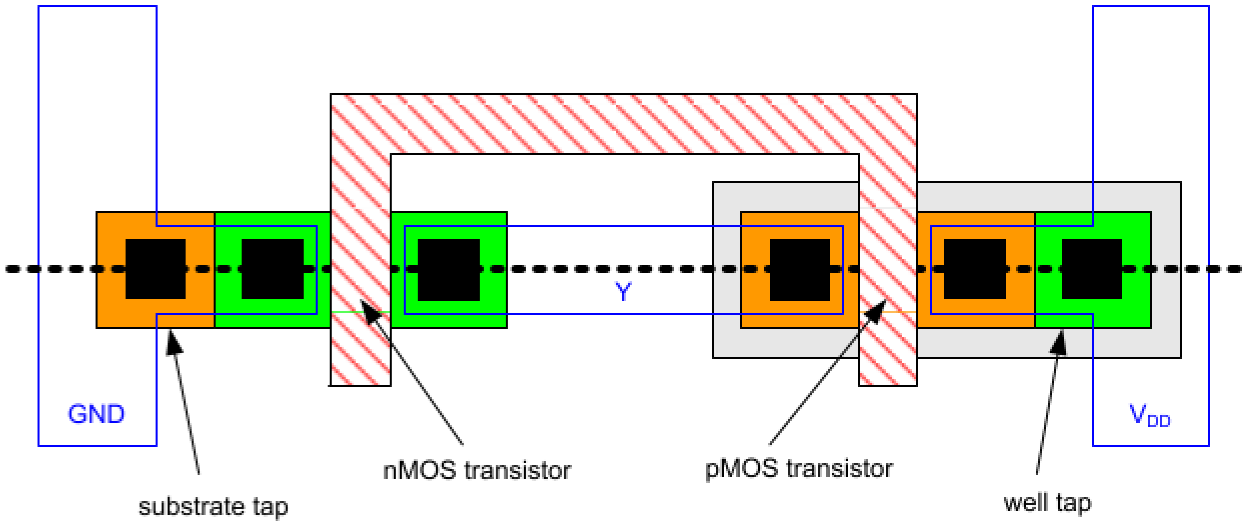
Well and Substrate Taps

- Substrate must be tied to GND and n-well to V_{DD}.
- Metal to lightly-doped semiconductor forms poor connection called Shottky Diode.
- Use heavily doped well and substrate contacts / taps.



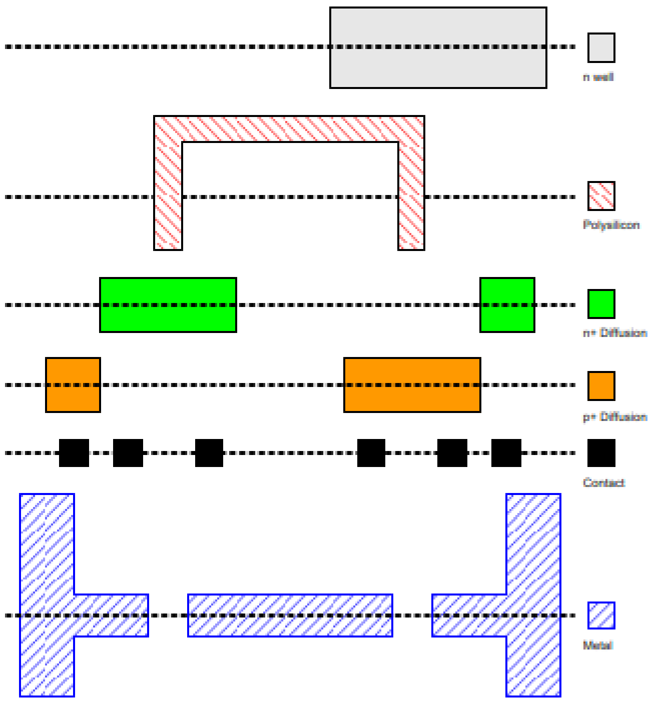
Inverter Mask Set

- Transistors and wires are defined by *masks.*
- Cross-section taken along dashed line.



Detailed Mask Views

- Six masks (simplified):
  - n-well
  - Polysilicon
  - n+ diffusion
  - p+ diffusion
  - Contact
  - Metal



Fabrication

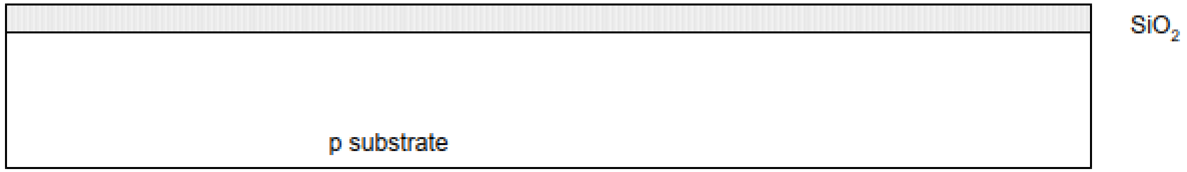
- Chips are built in huge factories called fabs.
- Contain clean rooms as large as football fields.

Fabrication Steps

- Start with blank wafer.
- Build inverter from the bottom up.
- First step will be to form the n-well.
  - Cover wafer with protective layer of SiO_2 (oxide).
  - Remove layer where n-well should be built.
  - Implant or diffuse n dopants into exposed wafer.
  - Strip off SiO_2.

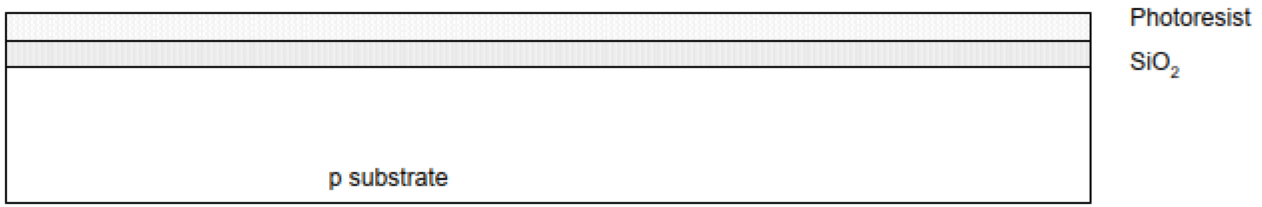
Oxidation

- Grow SiO_2 on top of Si wafer.
  - 900 – 1200 C with H_2O or O_2 in oxidation furnace.



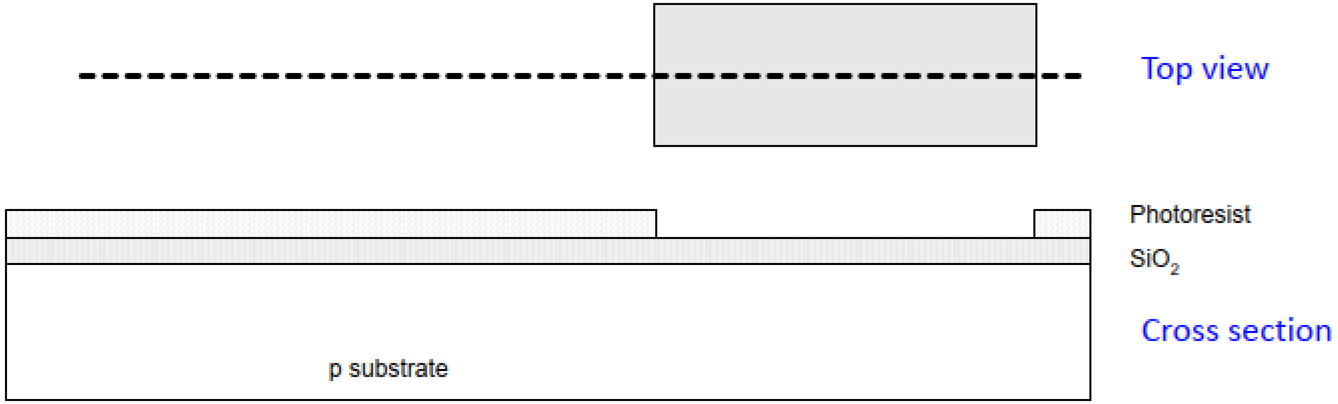
Photoresist

- Spin on photoresist.
  - Photoresist is a light-sensitive organic polymer.
  - Softens where exposed to light.



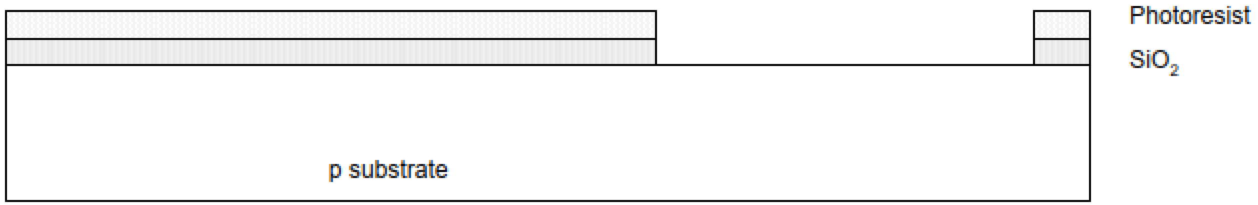
Lithography

- Expose photoresist through n-well mask.
- Strip off exposed photoresist.



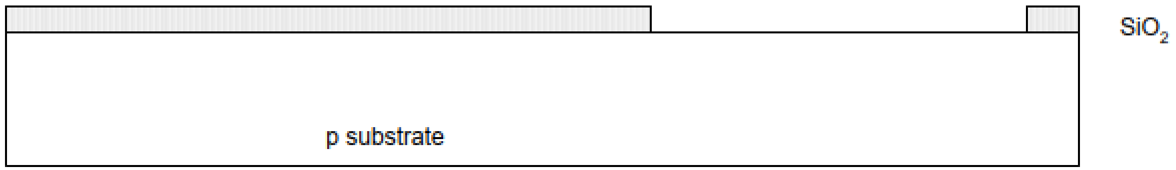
Etch

- Etch oxide with hydrofluoric acid (HF).
  - Seeps through skin and eats bone; nasty stuff!!!
- Only attacks oxide where resist has been exposed.



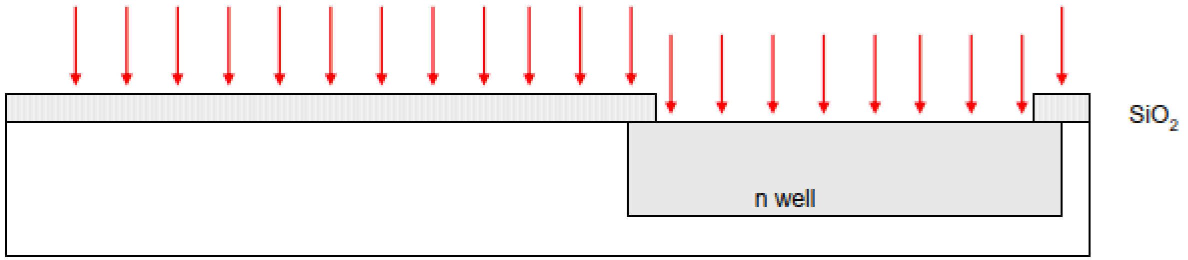
Strip Photoresist

- Strip off remaining photoresist.
  - Use mixture of acids called piranha etch.
- Necessary so resist doesn't melt in next step.



N-well

- N-well is formed with diffusion or ion implantation.
- Diffusion.
  - Place wafer in furnace with arsenic gas.
  - Heat until As atoms diffuse into exposed Si.
- Ion Implantation.
  - Blast wafer with beam of As ions.
  - Ions blocked by SiO_2, only enter exposed Si.

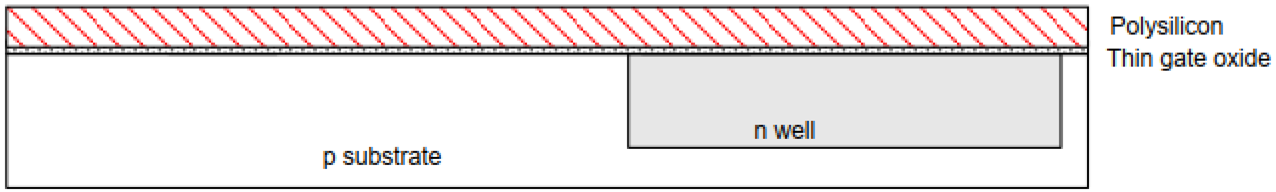


Strip Oxide

- Strip off the remaining oxide using HF.
- Back to bare wafer with n-well.
- Subsequent steps involve similar series of steps.

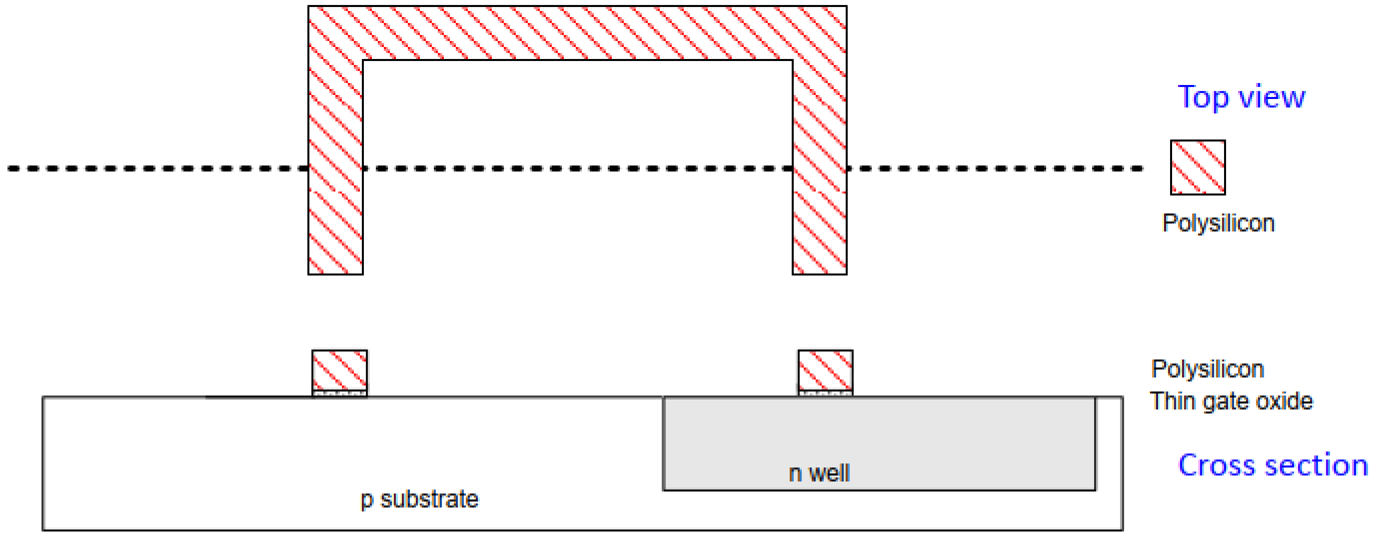
Polysilicon

- Deposit very thin layer of gate oxide.
  - < 20 Å (6-7 atomic layers).
- Chemical Vapor Deposition (CVD) of silicon layer.
  - Place wafer in furnace with Silane gas (SiH_4).
  - Forms many small crystals called polysilicon.
  - Heavily doped to be good conductor.



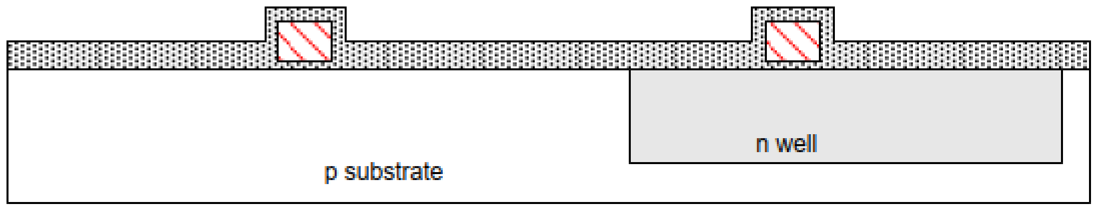
Polysilicon Patterning

- Use same lithography process to pattern polysilicon.



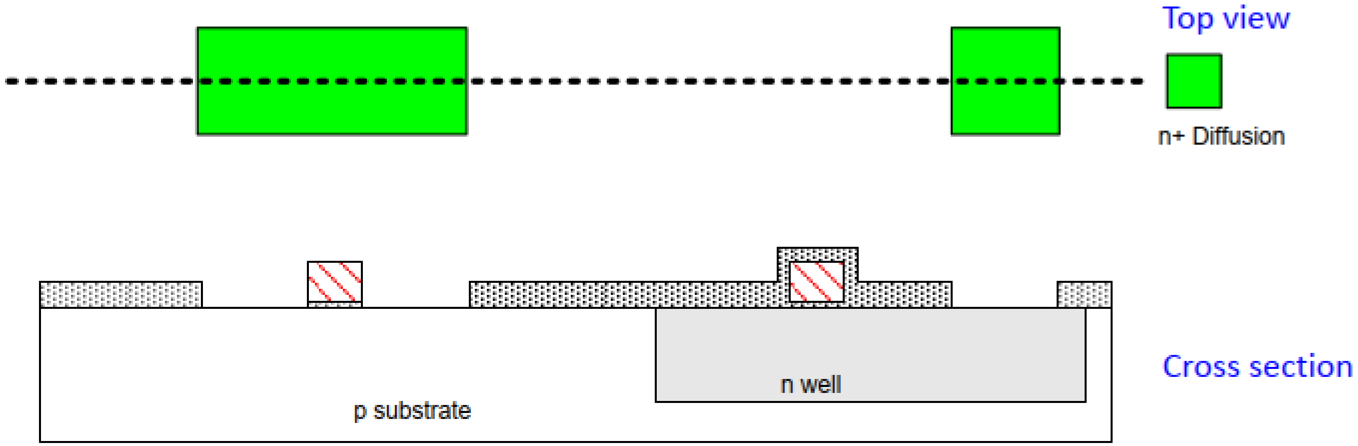
Self-Aligned Process

- Use oxide and masking to expose where n+ dopants should be diffused or implanted.
- N-diffusion forms NMOS source, drain, and n-well contact.



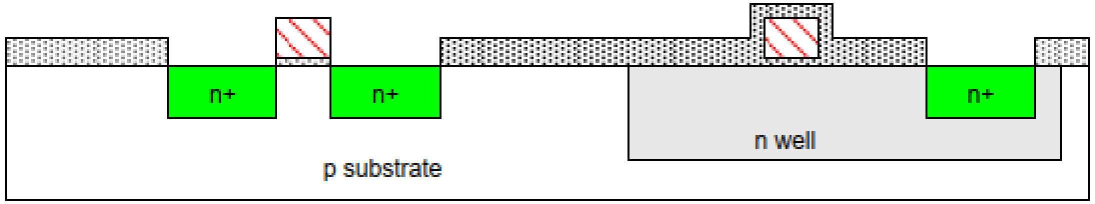
N-diffusion

- Pattern oxide and form n+ regions.
- *Self-aligned process* where gate blocks diffusion.
- Polysilicon is better than metal for self-aligned gates because it doesn't melt during later processing.



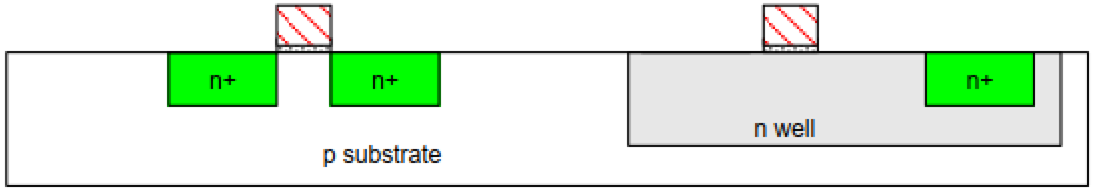
N-diffusion (2)

- Historically dopants were diffused.
- Usually ion implantation today.
- But regions are still called diffusion.



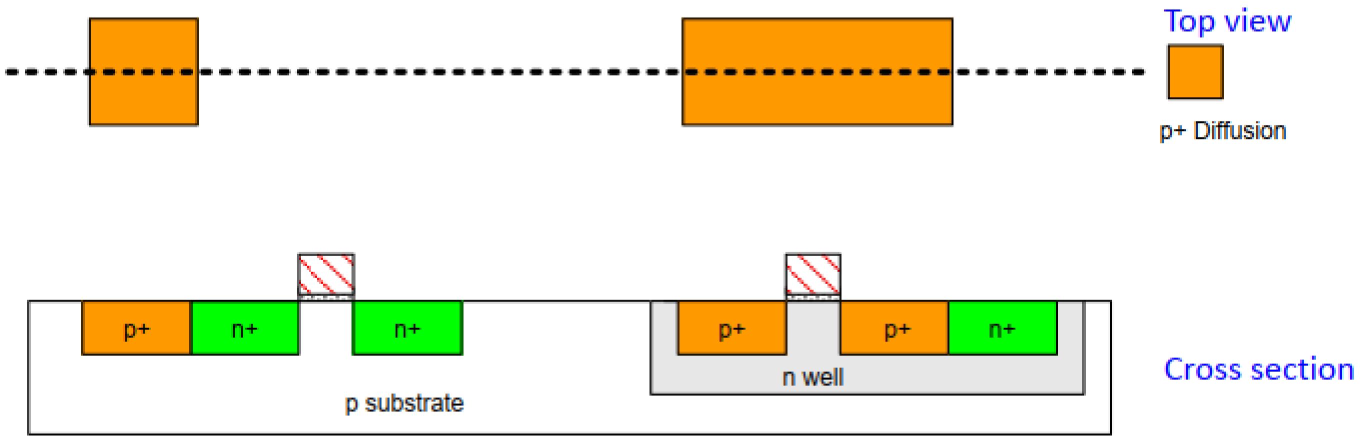
N-diffusion (3)

- Strip off oxide to complete patterning step.



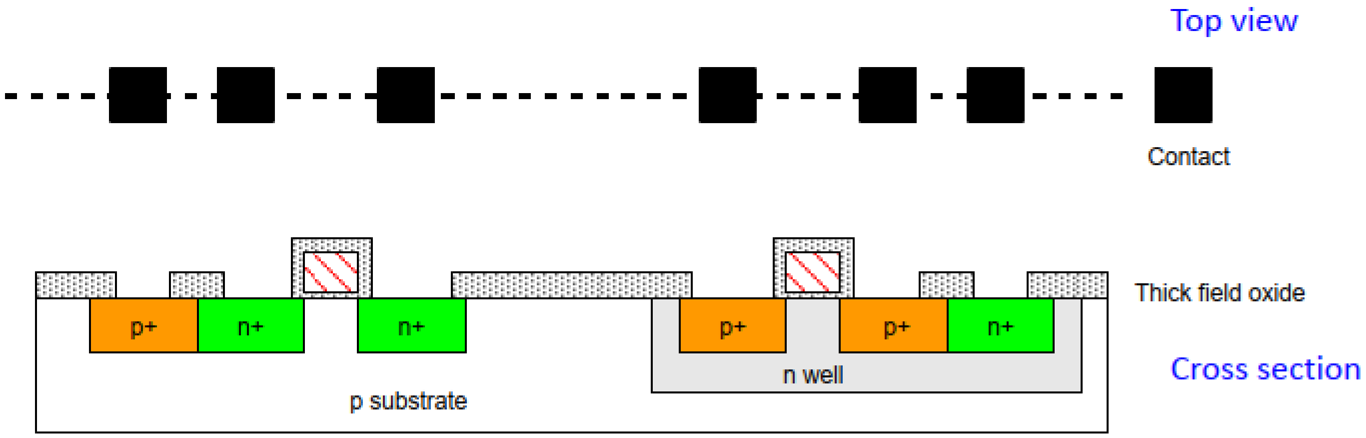
P-diffusion

- Similar set of steps form p+ diffusion regions for PMOS source and drain and substrate contact.



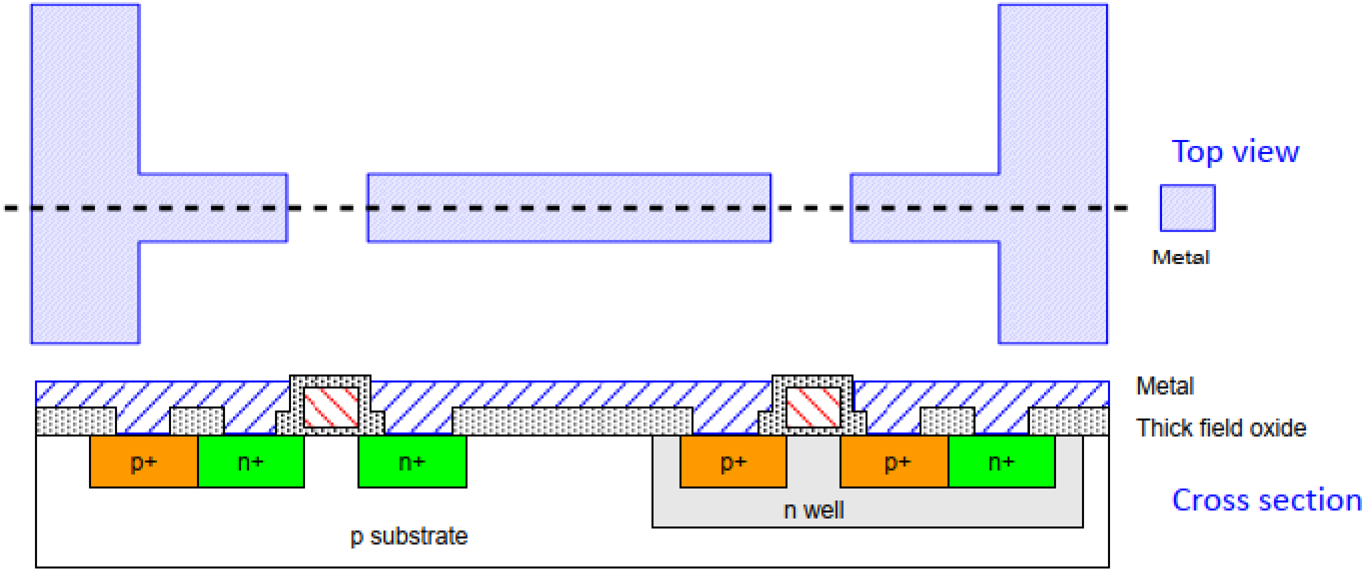
Contacts

- Now we need to wire together the devices.
- Cover chip with thick field oxide.
- Etch oxide where contact cuts are needed.



Metallization

- Sputter on aluminum over whole wafer.
- Pattern to remove excess metal, leaving wires.

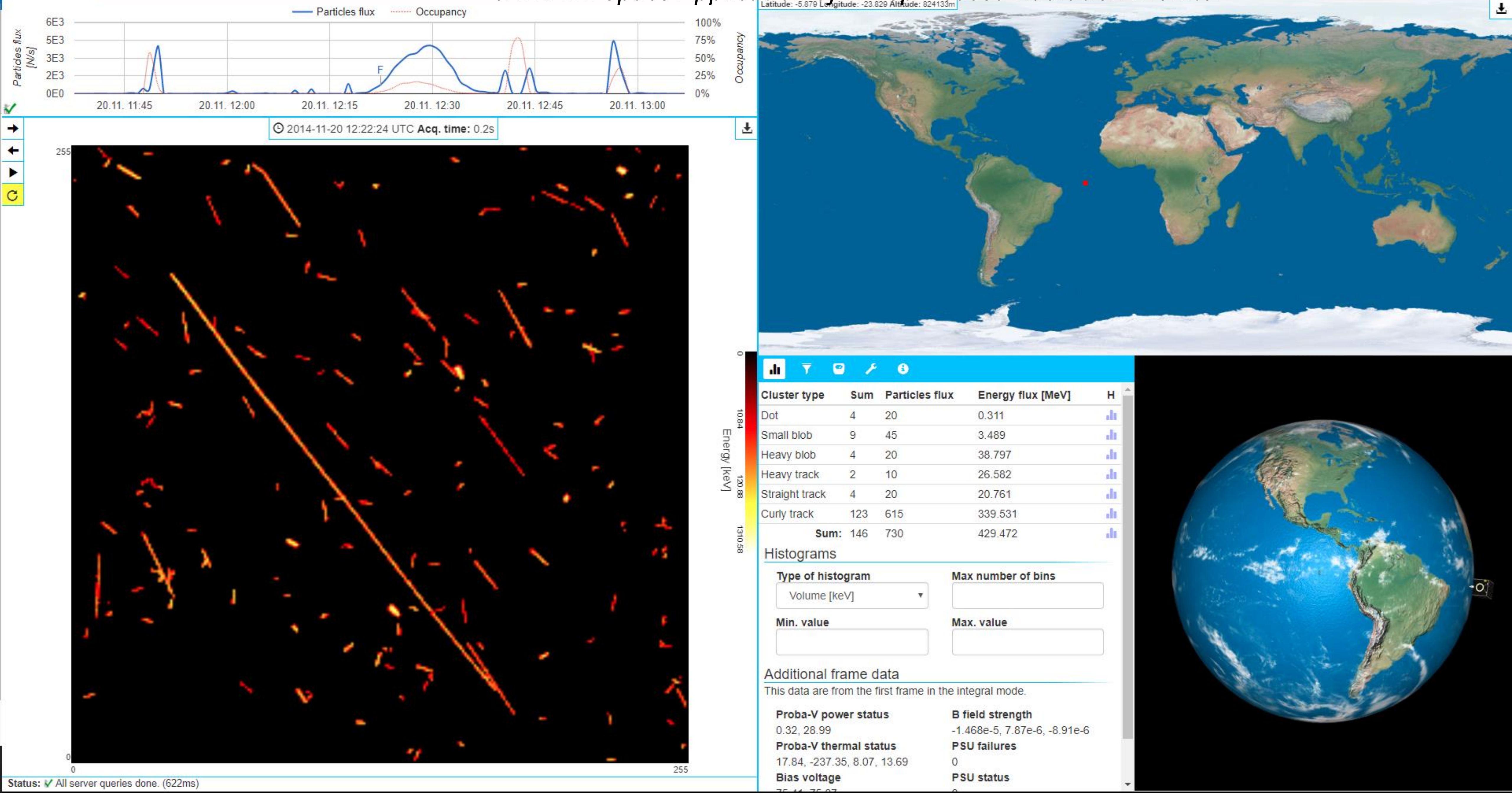


Wafer fabrication process

https://www.youtube.com/watch?v=2qLI-NYdLy8

Proba-V satellite (820km)

SATRAM: Space Application of Timepix based Radiation Monitor



Particle Tracking through time: Cloud chambers

- Also known as the Wilson Chamber (used 1920-1950)
- A cloud chamber consists of a sealed volume containing a supersaturated vapor of water or alcohol.
- Can be achieved by cooling alcohol vapour below its dew point
- Ionising radiation leaves a trace of condensation centres – like an aircraft vapour trail

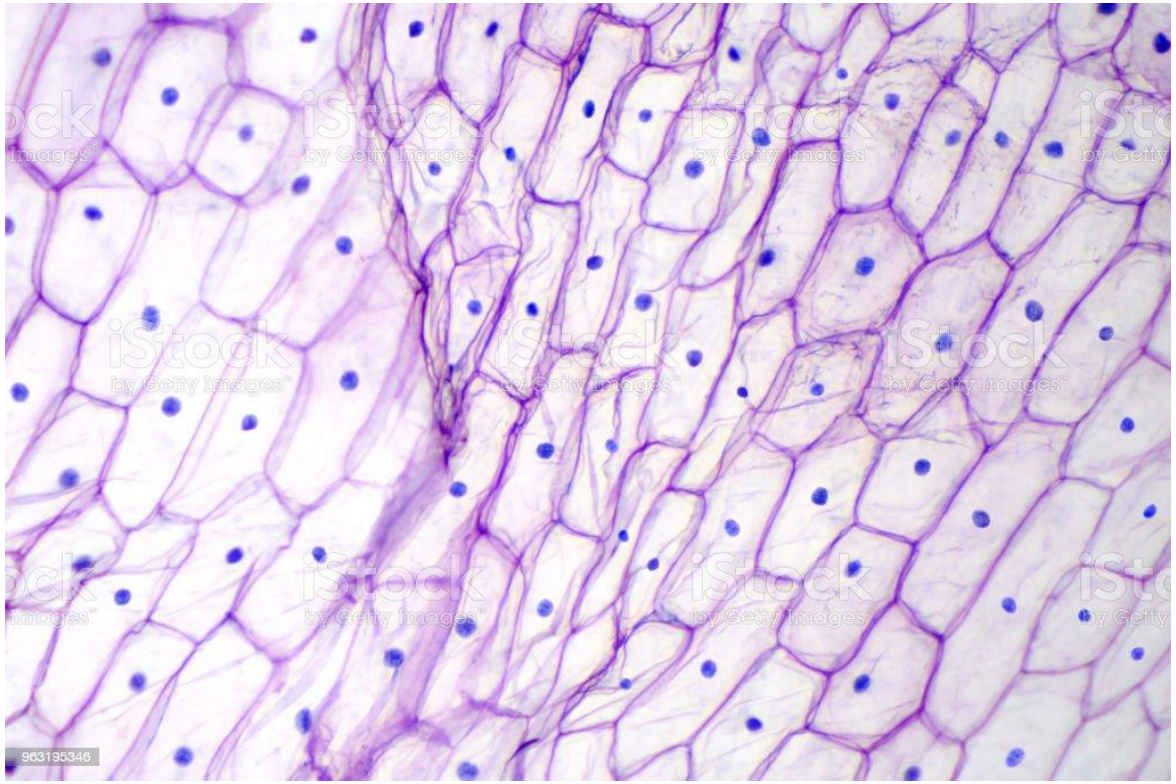
Advantages:

- Gives real time images
- Can yield 3D track information
- You can make one yourself ☺

Disadvantages

- A bit delicate and cumbersome to maintain
- Impossible to trigger


KERN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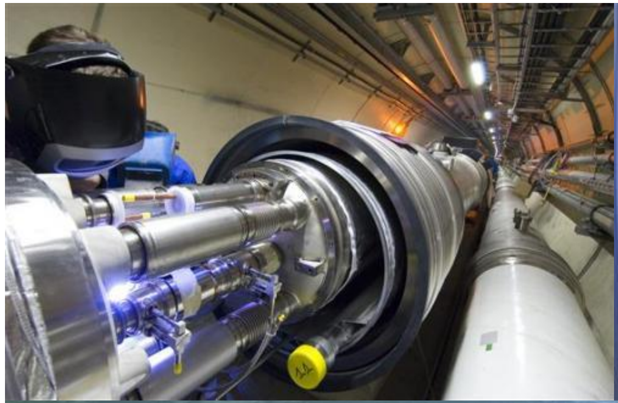
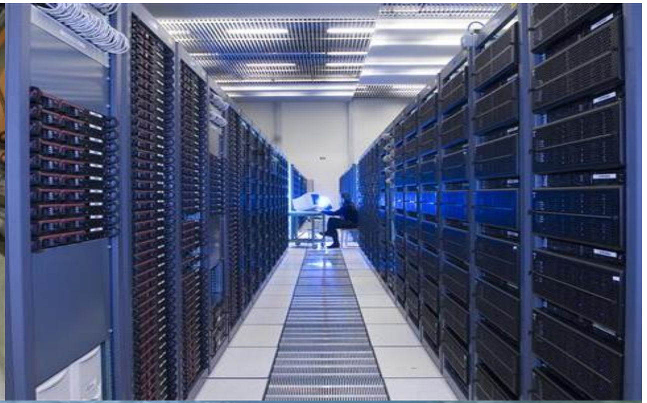
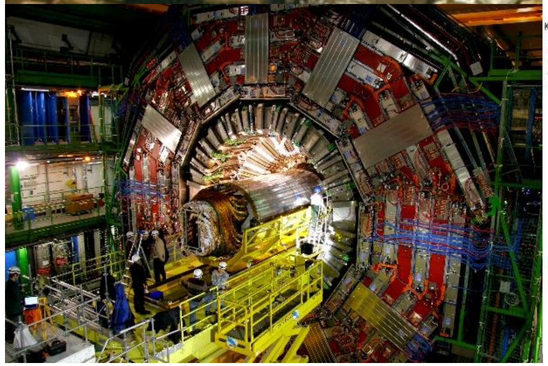
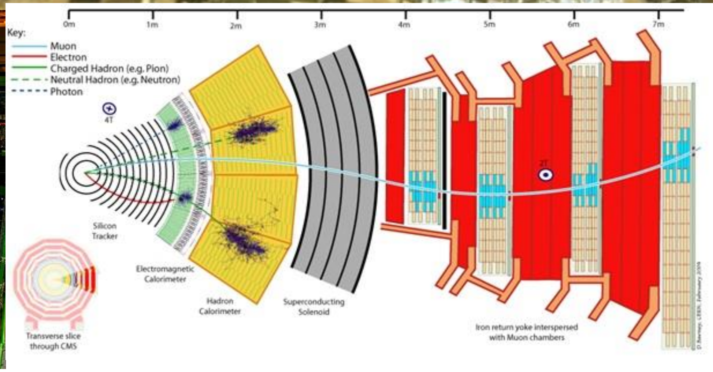
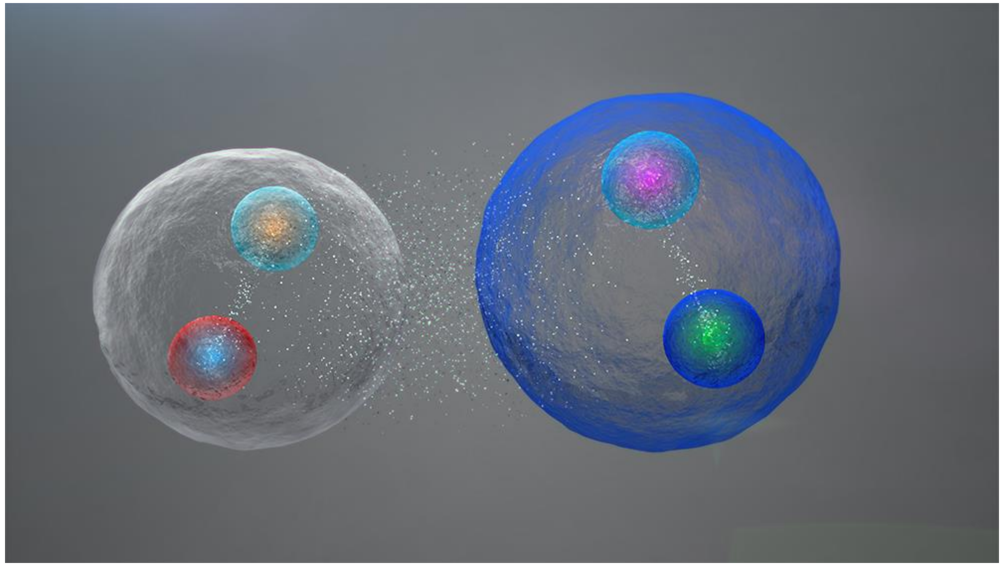






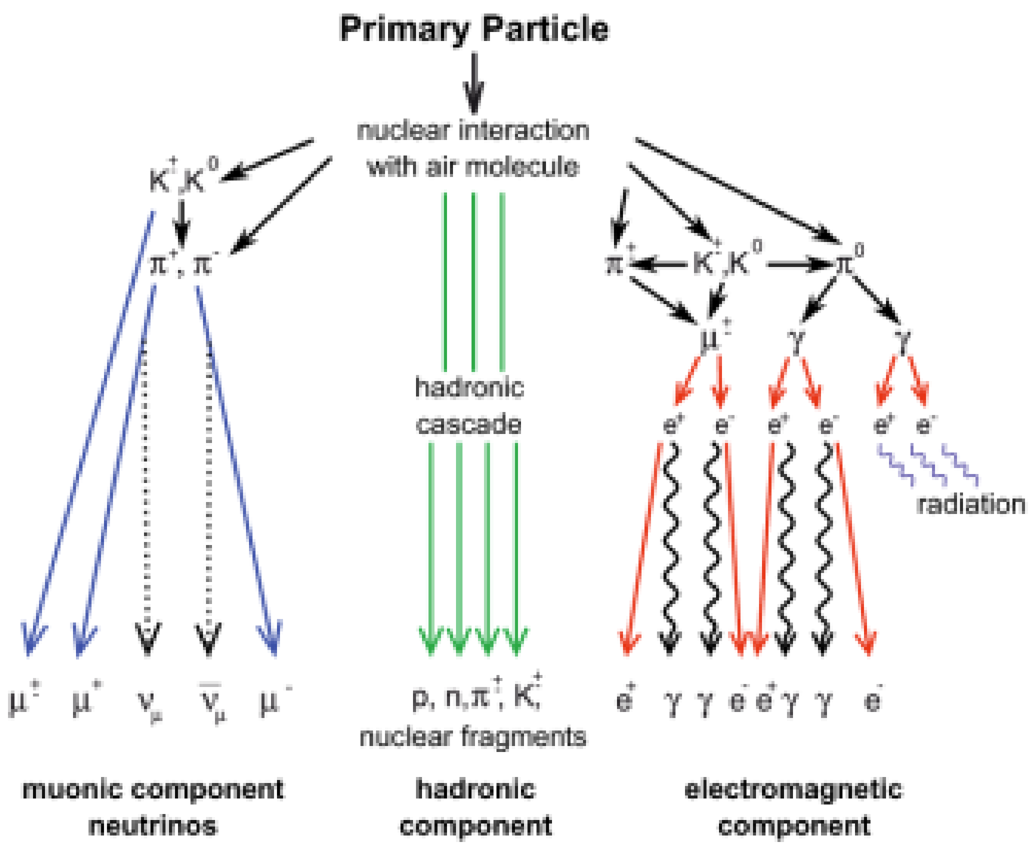




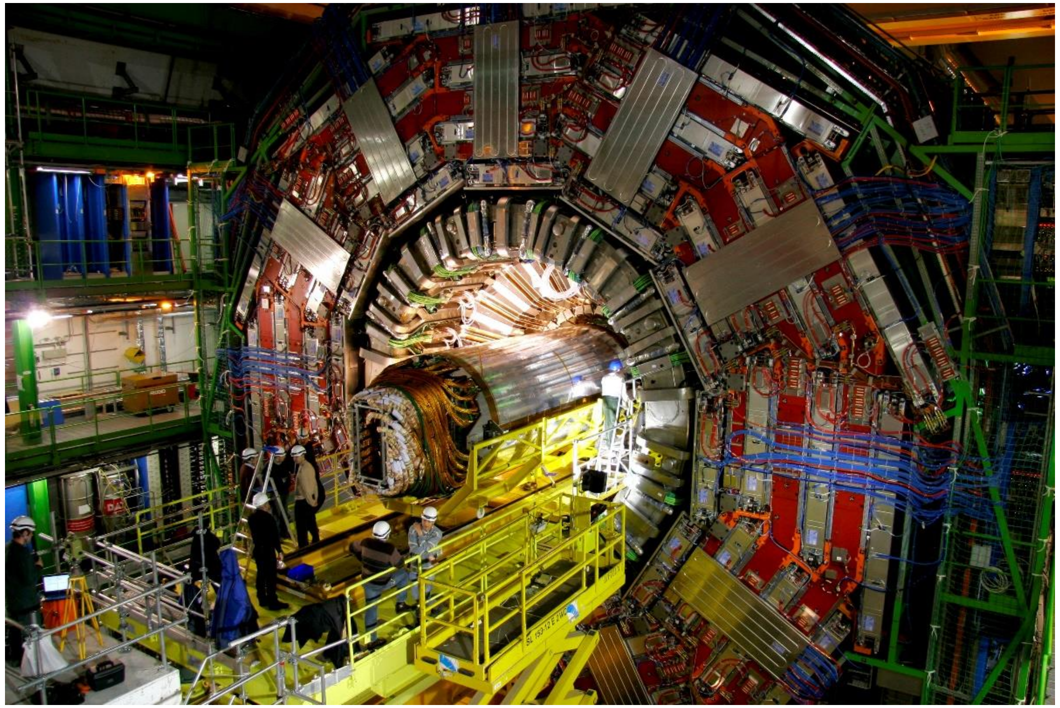
Para estudiar la estructura de la materia a la escala del attometro (10^{-18}m), utilizamos aceleradores de partículas, detectores e infraestructura para el análisis de datos.

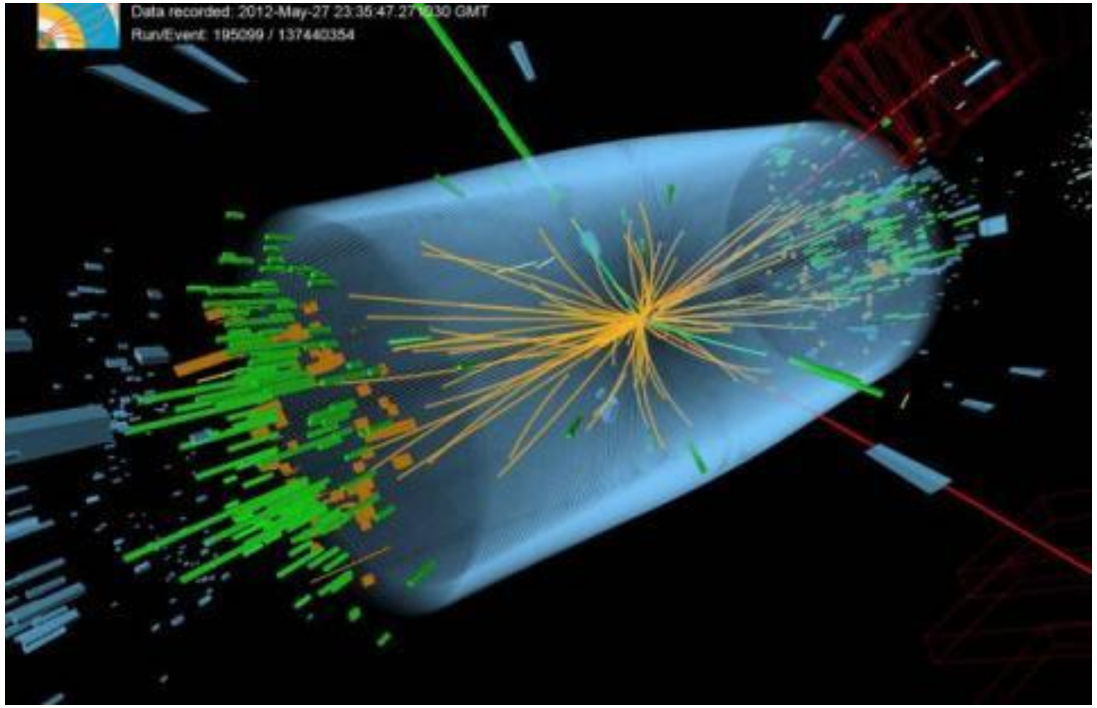
Aceleradores + Detectores + Análisis de datos = **Attoscopio (10^{-18}m)**

Secondary Cosmic Rays: Extensive Air Showers



- **shower particles**: electrons, photons, kaons, pions, muons, neutrinos
- particles can travel **faster than the speed of light** in air (but still slower than the speed of light in vacuum)
- about 150 muons are striking every square meter of the Earth every second
- **Not all shower particles reach the ground** – some are stopped in the atmosphere (low-energy particles and/or transformed to radiation at relatively lower frequencies





Los detectores del CERN son como **cámaras de fotos gigantes** con centenares de millones de canales, capaces de registrar 40 millones de fotos por segundo.

Timepix deployments in Outer Space: Heritage + ongoing developments

Human flight/Dosimetry: LEO/on board ISS/2012, Radiation effects/Space Weather: spacecraft/satellite payloads/Proba-V/2013

Orbit	Launch	
		Spacecraft payloads: Micro-satellites
LEO, 820 km	May 2013	❑ SATRAM-Timepix on board **ESA Proba-V satellite** QinetiQ ESA (in LEO orbit since May 2013), successful commissioning, continuous data taking
LEO, 600 km	July 2014	❑ LUCID-5xTimepix array payload on board **TechDemoSat-1 SSTL-UK satellite** Langton Ultimate Cosmic-ray Intensity Detector, successful commissioning, continuous data taking
LEO, 600 km	1Q-2019	❑ Particle telescope/2x stack Timepix for **RISESAT satellite** Tohoku U./Japan (ongoing, FM delivery 3Q 2018, launch 4Q 2018/1Q2019)
		Spacecraft payloads: nanosatellites/cubesats
LEO, 500 km	June 2017	❑ Focal plane X-ray detector 1xTimepix/X-ray telescope 1D optics on board **Cubesat VZLUSAT-1**, successful commissioning continuous data taking
CIS-lunar/deep space	2020	❑ Timepix radiation monitor payload on board **BioSentinel cubesat** for **NASA-ORION flight EM1**, NASA Ames
		Spacecraft payloads: large satellites
GEO 36000 km	>2020	❑ Miniaturized Radiation Monitor MIRAM, for **ESA/ARTES telecommunication satellites at GEO orbit**
		Sub-orbital sounding rockets
LEO, 200 km	April 2018	❑ Focal plane X-ray detector 2xTimepix/X-ray telescope 2D optics REX payload Penn State U. for **NASA WRX-R sounding sub-orbital rocket**, launched 4th April 2018, successful operation, data collected, payload retrieved
		Pressurized/manned space modules
LEO, 420 km	Aug 2012	❑ Miniaturized Quantum imaging on-line space radiation dosimeters/Radiation Environment Monitors REM 5xTPX on board **ISS-NASA**, successful commissioning, continuous data taking, NASA JSC
MEO, 6000 km	Dec 2014	❑ 2x Battery Operated Radiation Detectors BIRD-Timepix fully autonomous operation, **NASA Orion Exploration Flight Test EFT-1**, successful commissioning, continuous data taking , NASA JSC
LEO, 420 km	May 2017	❑ Energetic Particle Telescope EPT-Timepix 2x stack on board **ISS-NASA**, successful commissioning continuous data taking, NASA JSC
CIS-lunar/deep space	2020	❑ Hybrid Electronic Radiation Assessor HERA-Timepix for **NASA-ORION flights EM1** and **EM2**, NASA JSC

Complete List of NASA Timepix Based Flight Hardware

Name	Date Flown	Mission	Location	Objective	Vehicle	Number TPX
REM	2012	ISS	LEO	Demo	ISS	5
BIRD	2014	Orion EFT-1	LEO/MEO	Demo/Science	Orion	2
REM2	2018	ISS	LEO	Ops	ISS	7
MPT	2017	ISS	LEO	Science	ISS	2
Biosentinel	2020	ISS	LEO	Science	ISS	1
ISS-HERA	2018	ISS	LEO	Demo	ISS	3
AHOSS	2020	ISS	LEO	Demo/Ops	ISS	3
LETS(1)	2023	Astrobotic 1	Lunar Surface	Science	Peregrine	1
LETS(2)	2024/5	Berensheet 2*	Lunar Surface	Science	Berensheet 2	1
HERA	2022	Artemis 1	Lunar Orbit	Ops	Orion	3
Biosentinel	2022	Artemis 1	Solar Orbit	Science	Cubesat	1
HERA	2023	Polaris Dawn	MEO	Science	Crew Dragon	1
HERA	2024	Artemis 2	Lunar Orbit	Ops	Orion	6
HERA	2025	Artemis 3	Lunar Orbit	Ops	Orion	6
ARES	2025	Artemis 3	Lunar Surface	Ops	Starship	>=1
LEIA	~~2024	CLPS Lander	Lunar Surface	Science	TBS Lander	1
ARES	2026	Artemis	Lunar Orbit	Ops	Lunar Gateway	2

***Evaluating mission possibility**

7 missions flown, 4 missions next six months, 6 missions manifested, > 23 Timepix in Space to date

<u>**Highly successful technology transfer from CERN, powering NASA missions for the last 10 years, and likely for the next 10**</u>

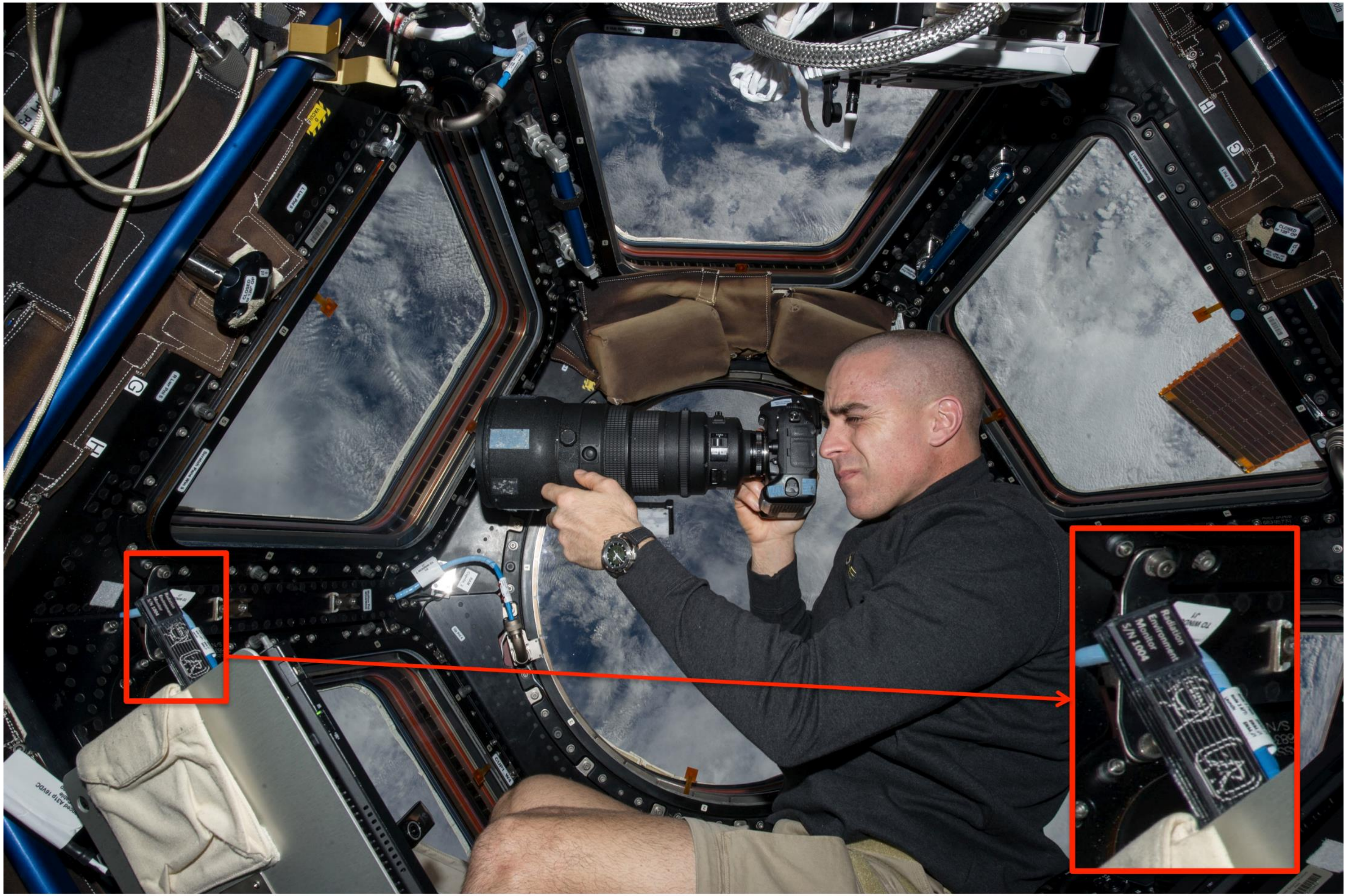
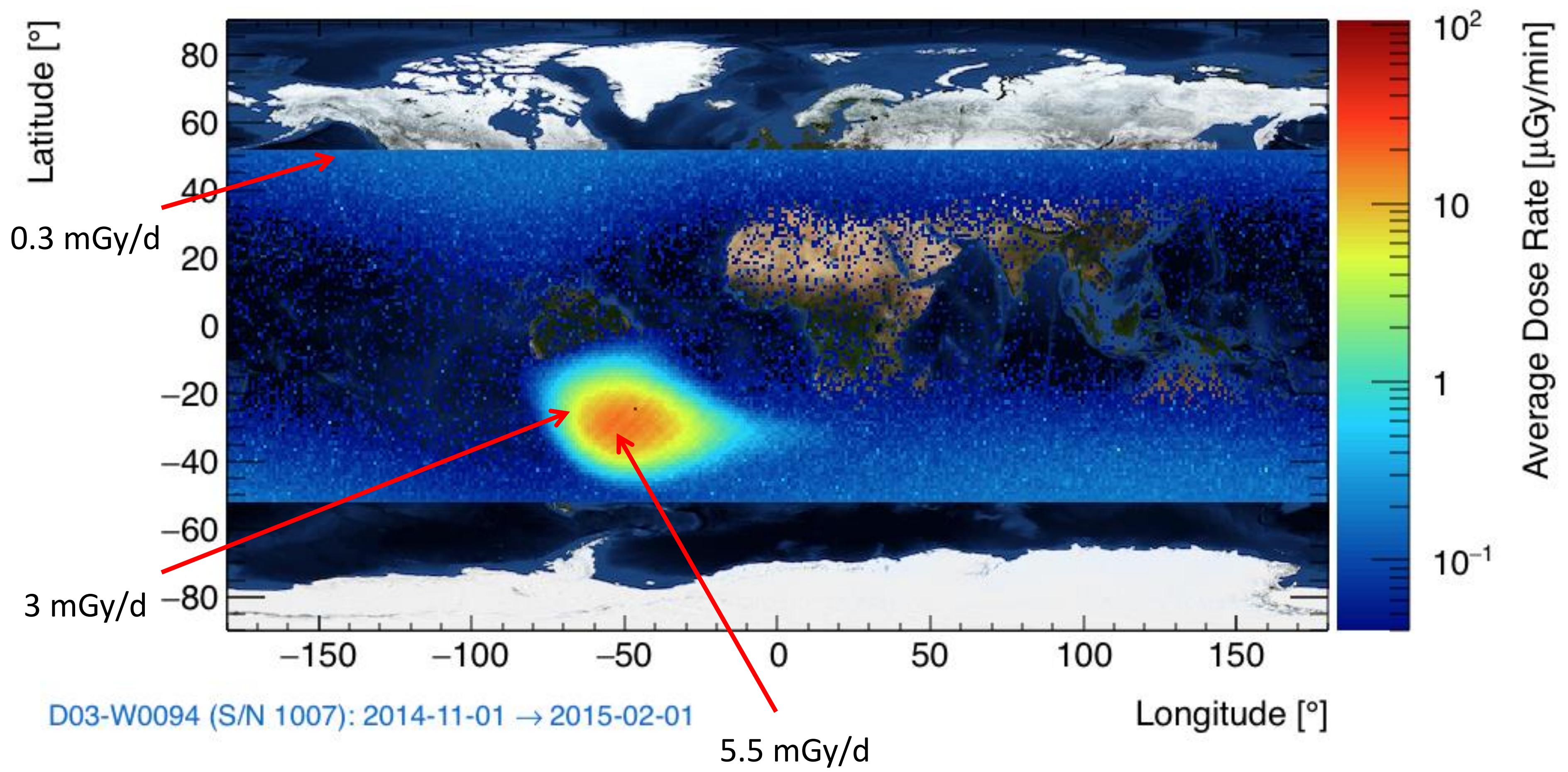


Image of the astronaut Chris Cassidy working near the Timepix USB on the International Space Station (Courtesy of NASA, photo ref. no. iss036e006175)

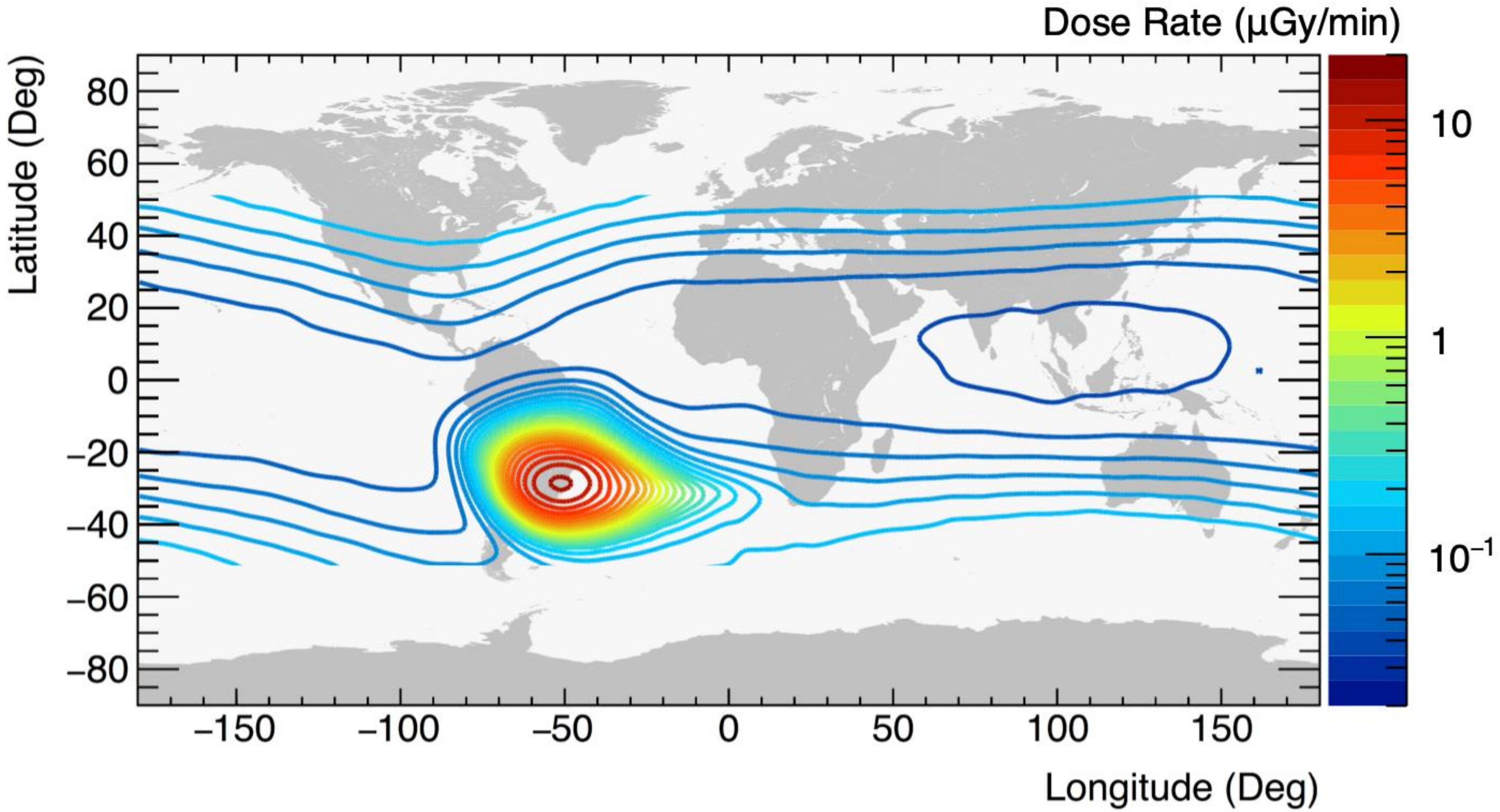
REM Dose Rate Data (μG/min)



Average exposure on the ground is 3 mGy/year

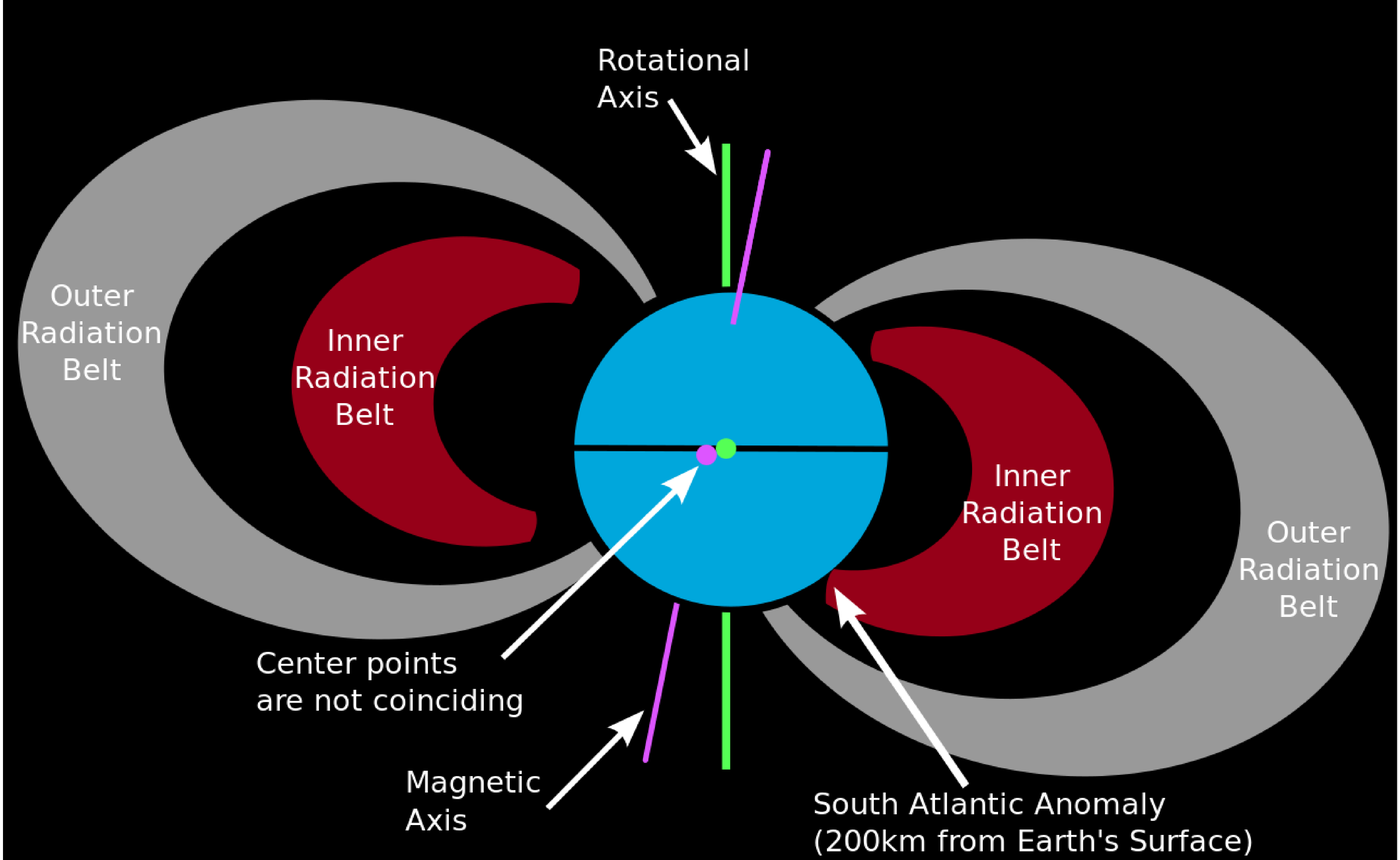
University of Houston, IEAP Prague, NASA

REM Dose Rate Data (μG/min)



Timepix dose rates measured in 2014 on ISS

University of Houston, IEAP Prague, NASA



Rotational
Axis
Outer
Radiation
Belt
Inner
Radiation
Belt
Inner
Radiation
Belt
Outer
Radiation
Belt
Center points
are not coinciding
Magnetic
Axis
South Atlantic Anomaly
(200km from Earth's Surface)