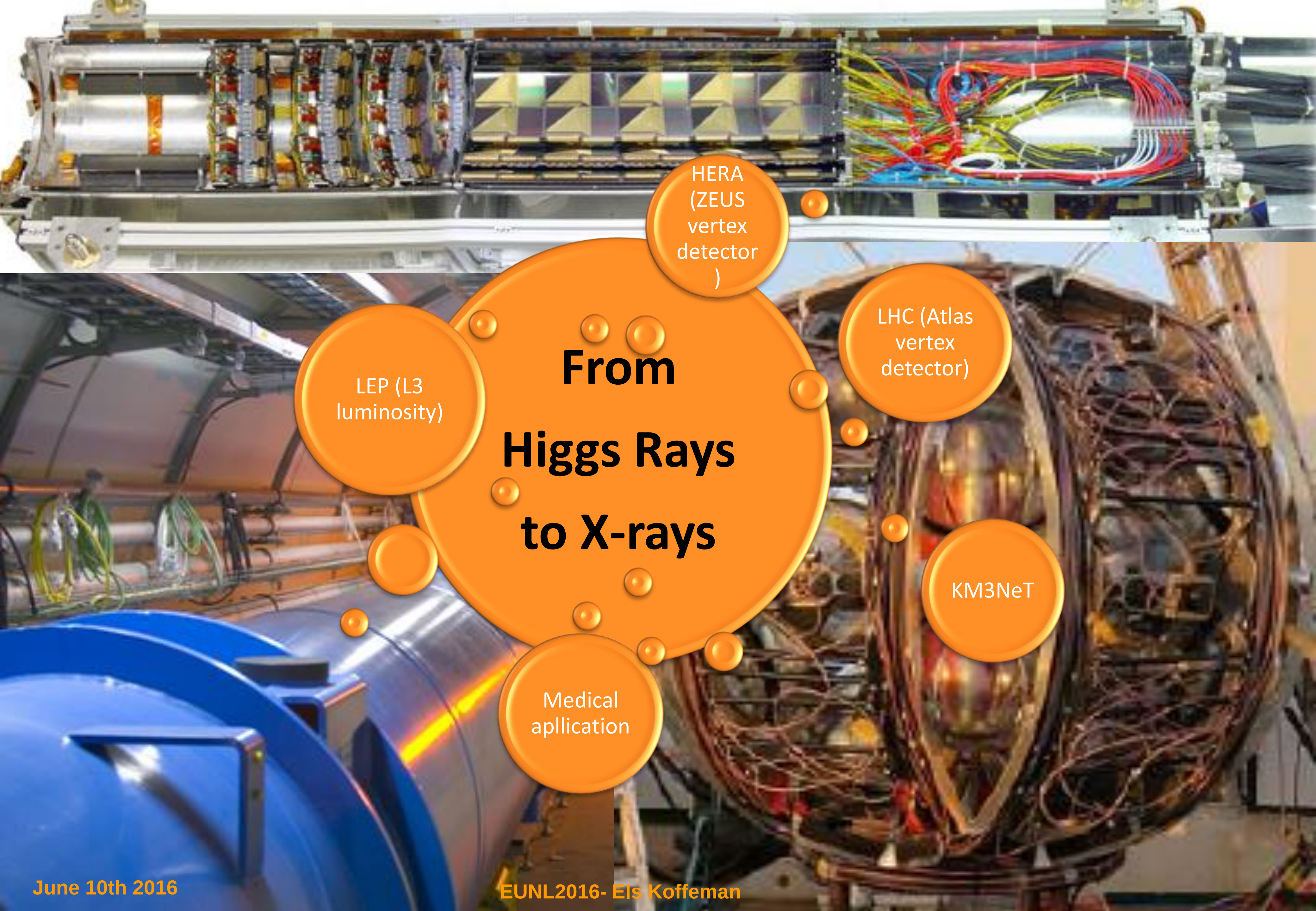
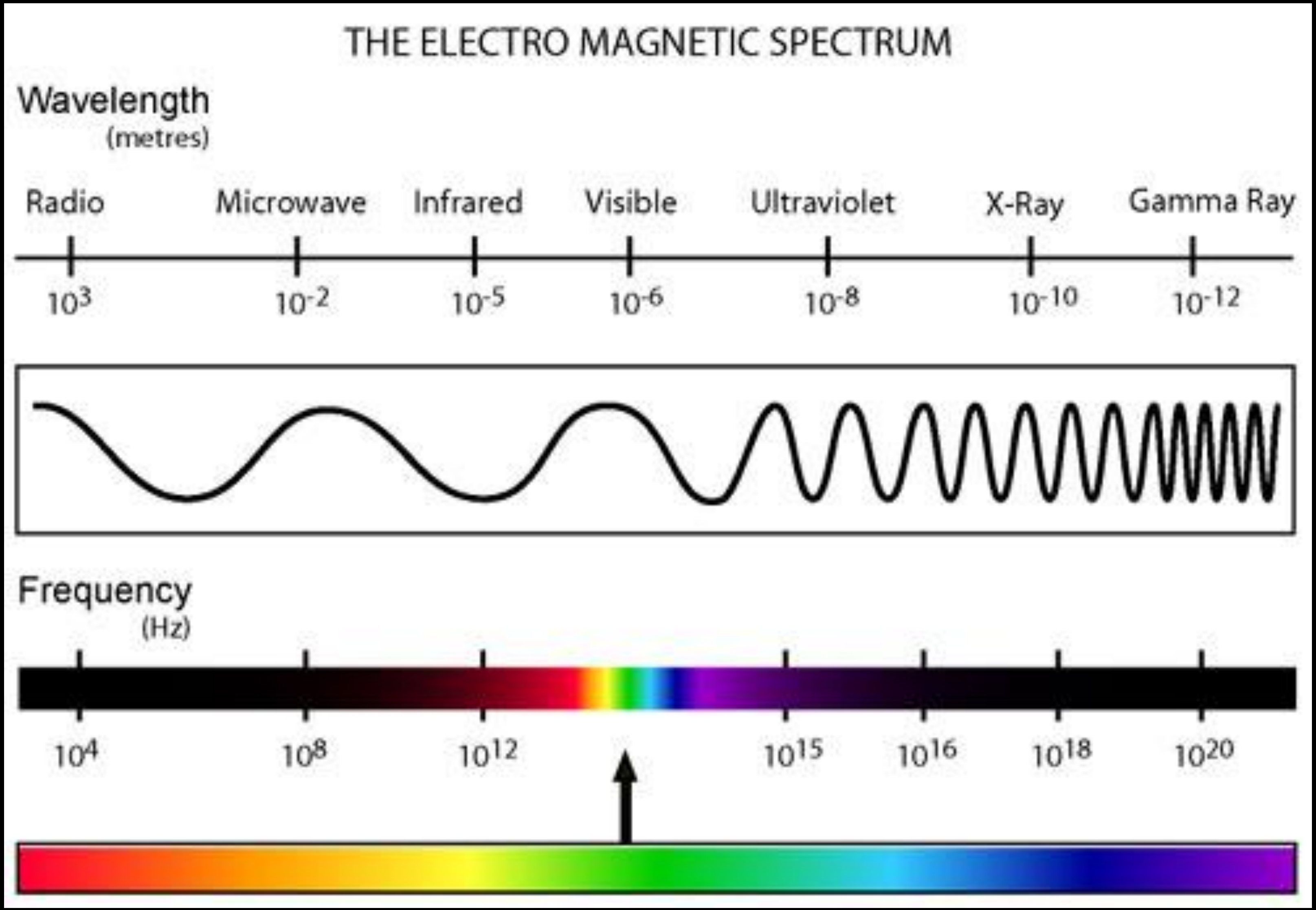
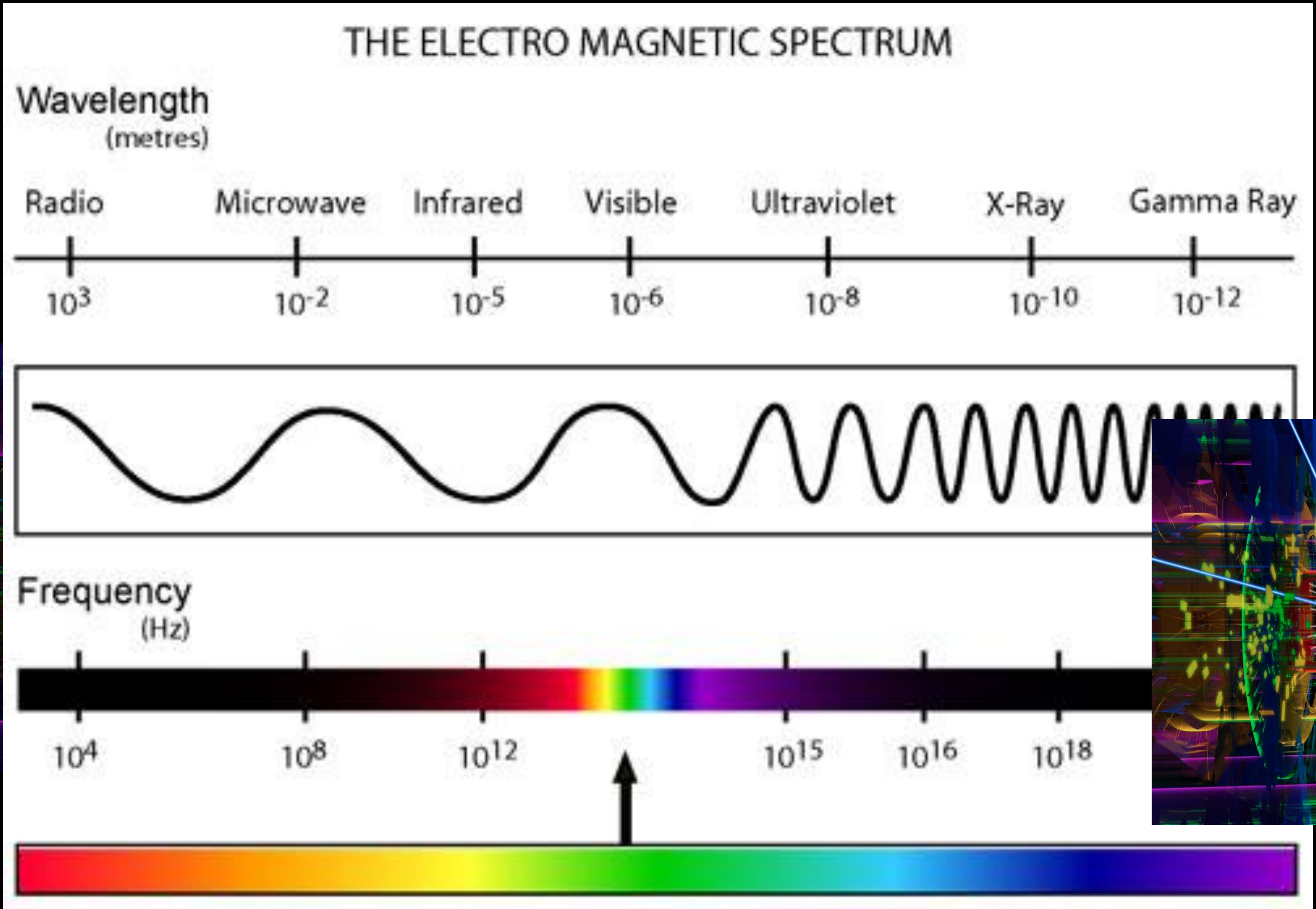
# From Higgs Rays to X-rays

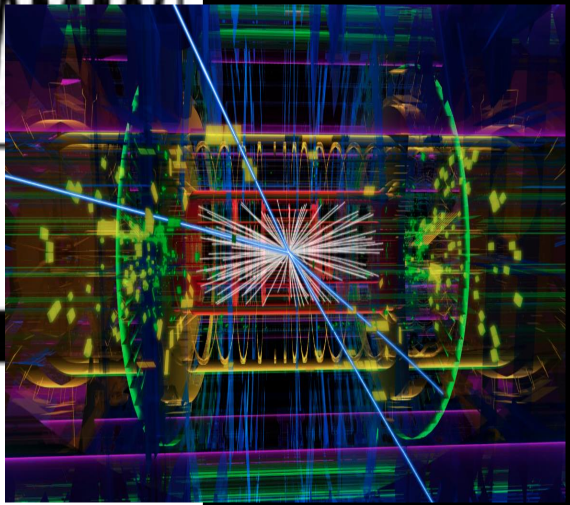



THE ELECTRO MAGNETIC SPECTRUM
Wavelength
(metres)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
$10^3$
$10^{-2}$
$10^{-5}$
$10^{-6}$
$10^{-8}$
$10^{-10}$
$10^{-12}$
Frequency
(Hz)
$10^4$
$10^8$
$10^{12}$
$10^{15}$
$10^{16}$
$10^{18}$
$10^{20}$

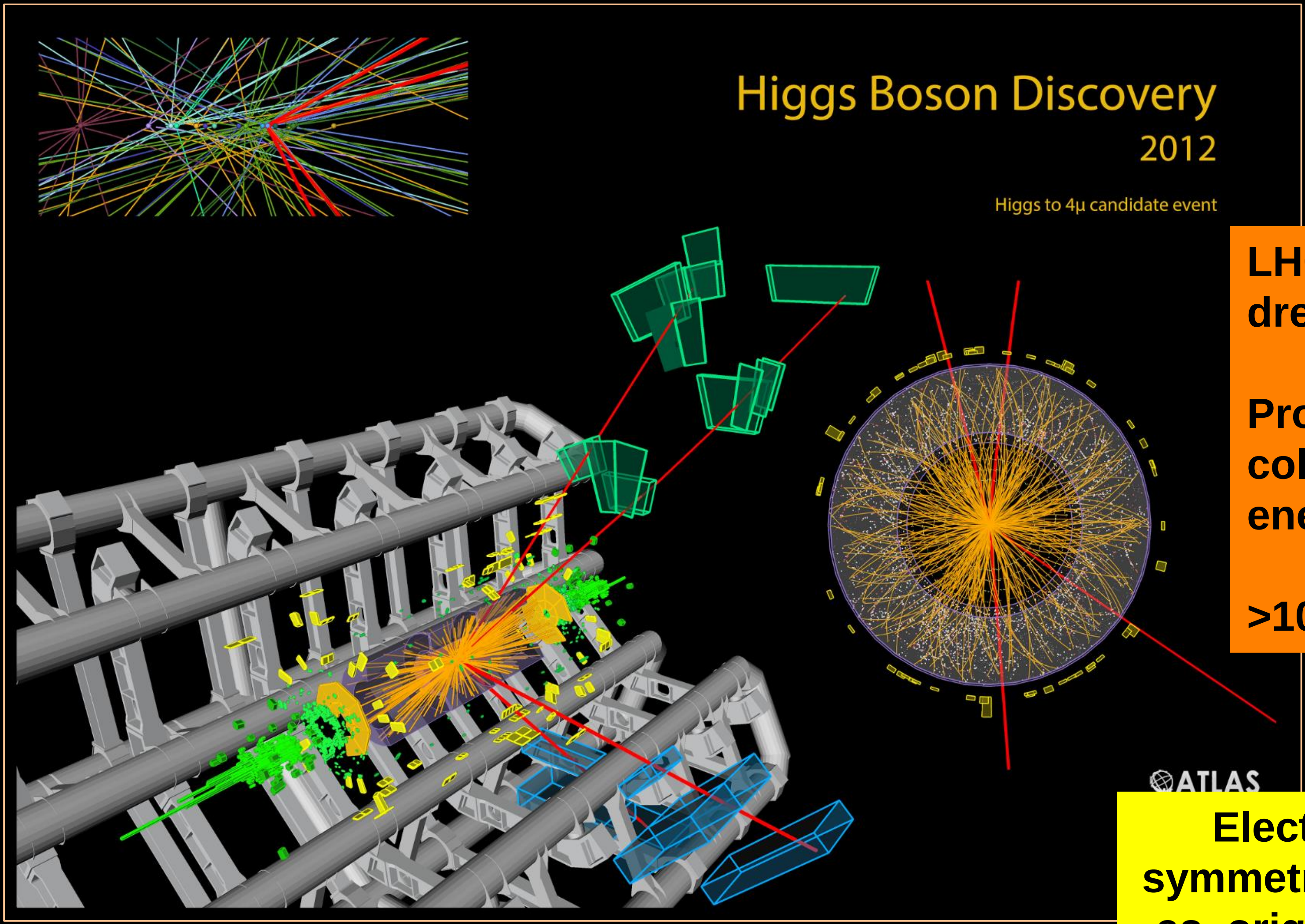



**LHC energy 7 TeV**

**wavelength of $10^{-15}$ m**



# Particle Physics Discovery



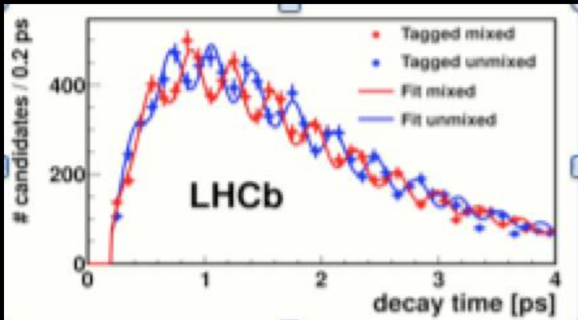

**LHC at CERN is our dream machine:**

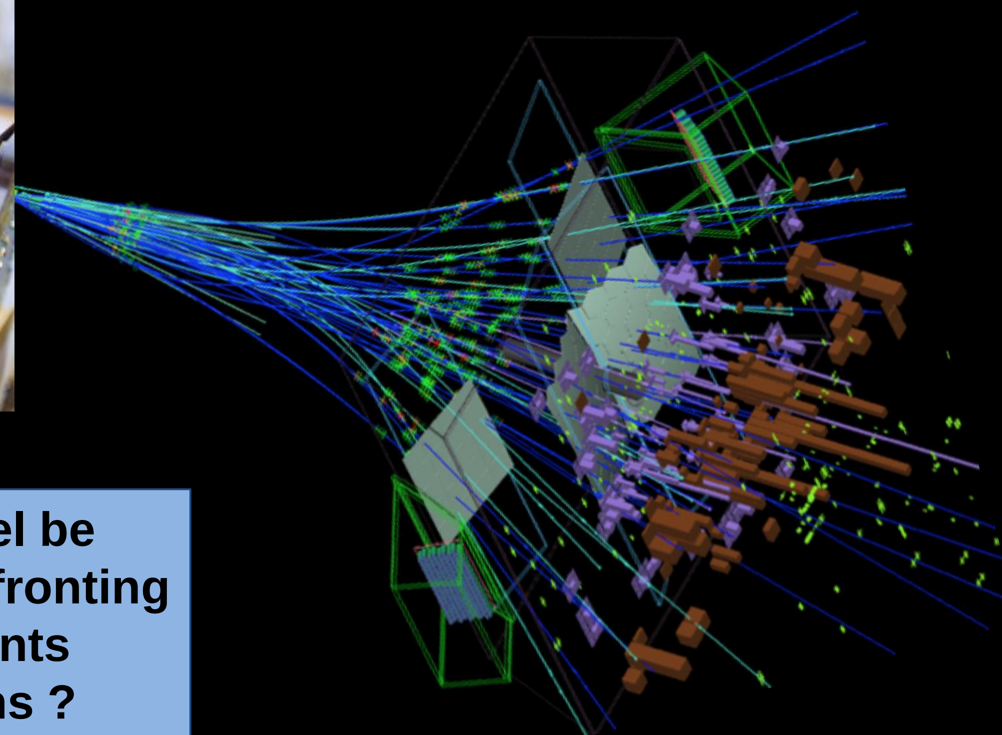
**Proton – Proton collisions at 13/14 TeV energy**

**>10 years to come**

**Electroweak symmetry breaking as origin of mass**

# Particle Physics Precision Measurements

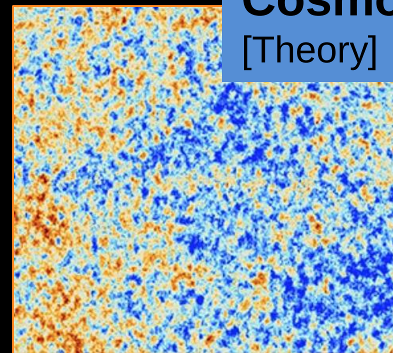


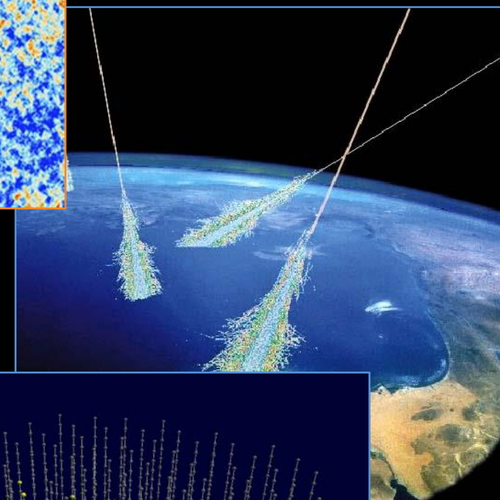
**Or will Standard Model be compromised by confronting precision measurements with theory predictions ?**
[LHCb, Theory]

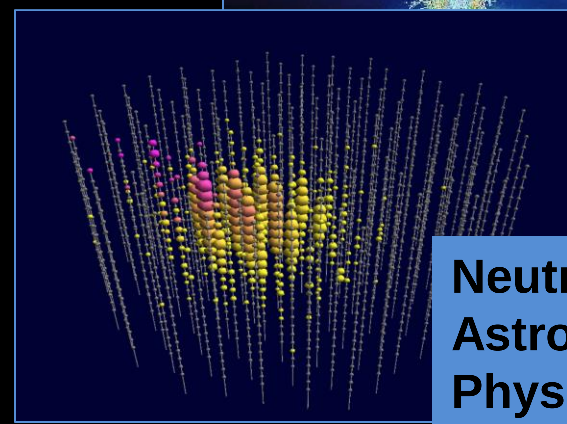
# Emergent fields

**Dark Matter Searches**
[Xenon]

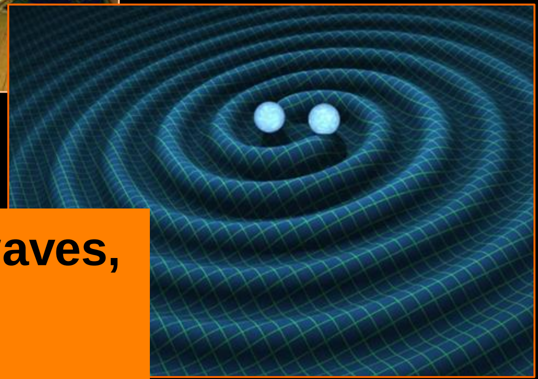


**Cosmology**
[Theory]



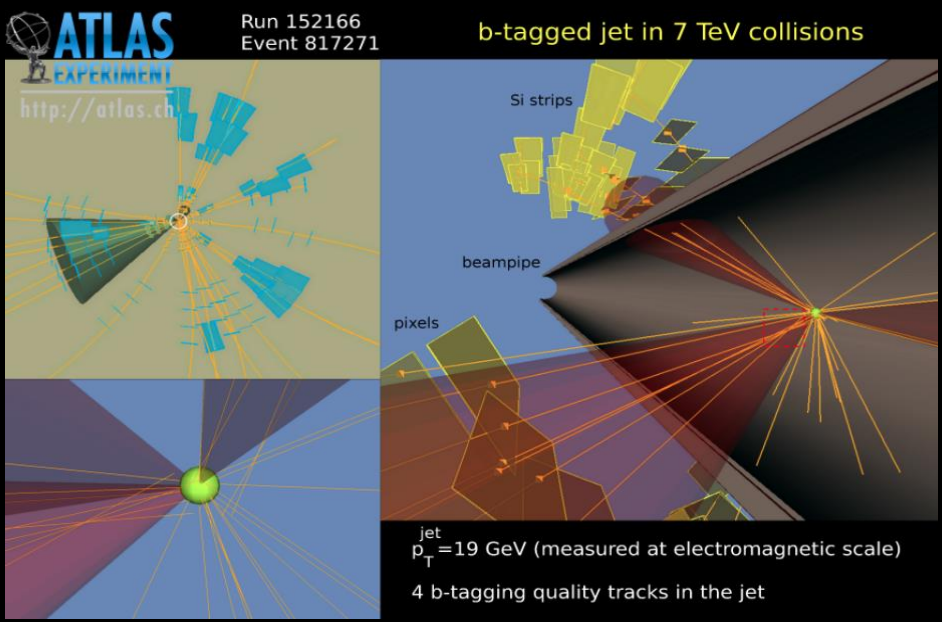


**Neutrino and Astroparticle Physics**
[Auger,KM3NeT]



**Gravitational waves, Asronomy**
[Ligo, VIRGO,…]

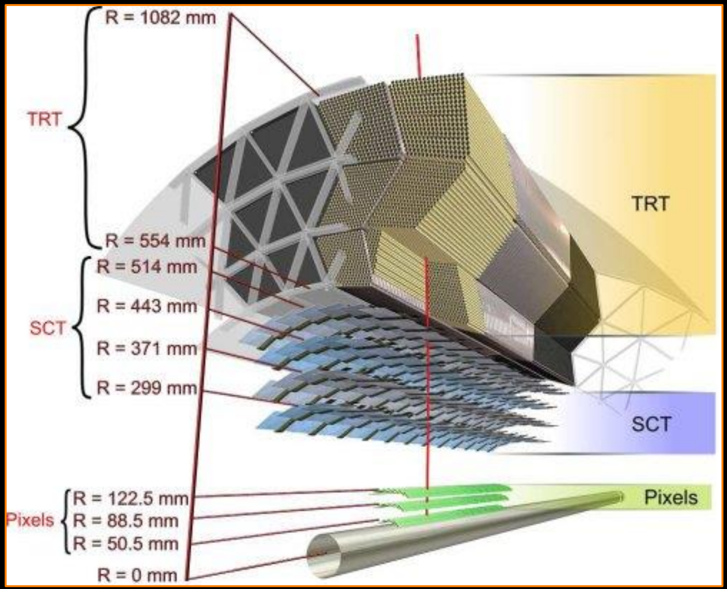
# Develop Particle detector



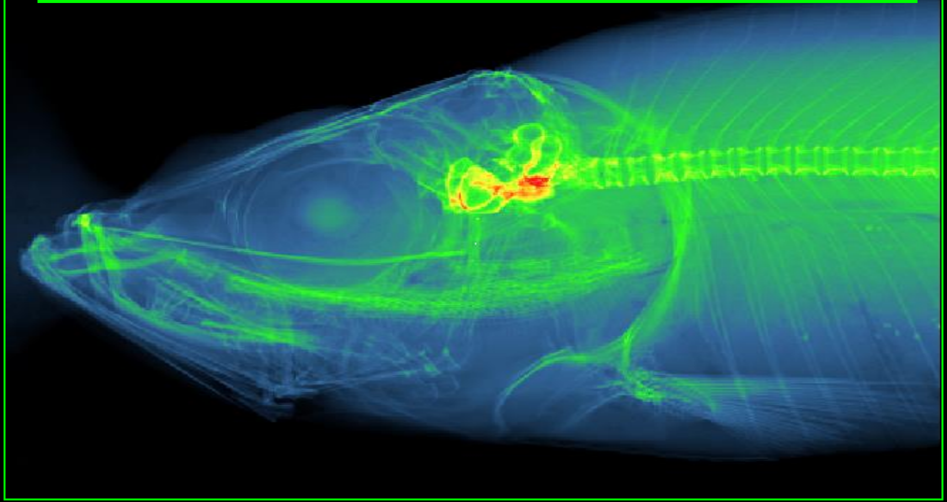

- LHC particle tracking
  1. Collision rate 40 MHz
  2. Record intereaction with slice of silicon
  3. reconstruct data => image event

1. X-ray CT
   1. $10^7$ particles mm$^{-2}$ s$^{-1}$
   2. Record interaction with slice of silicon (or high Z material)
   3. Filter date => reconstruct phantom

# Particle Physics Technology



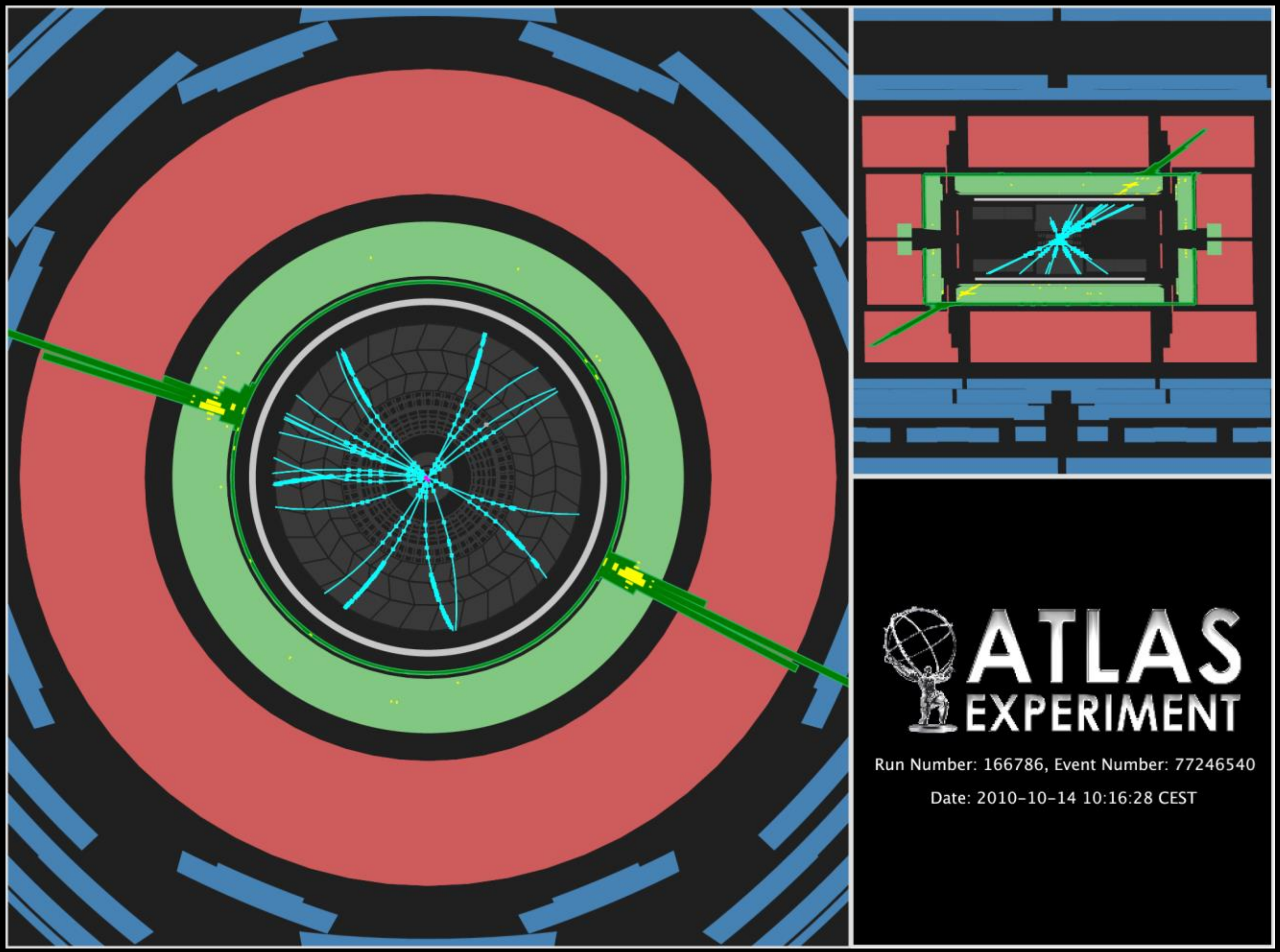

This picture is made with Medipix technology



**Particle Physics Needs & Feeds Technology Development**

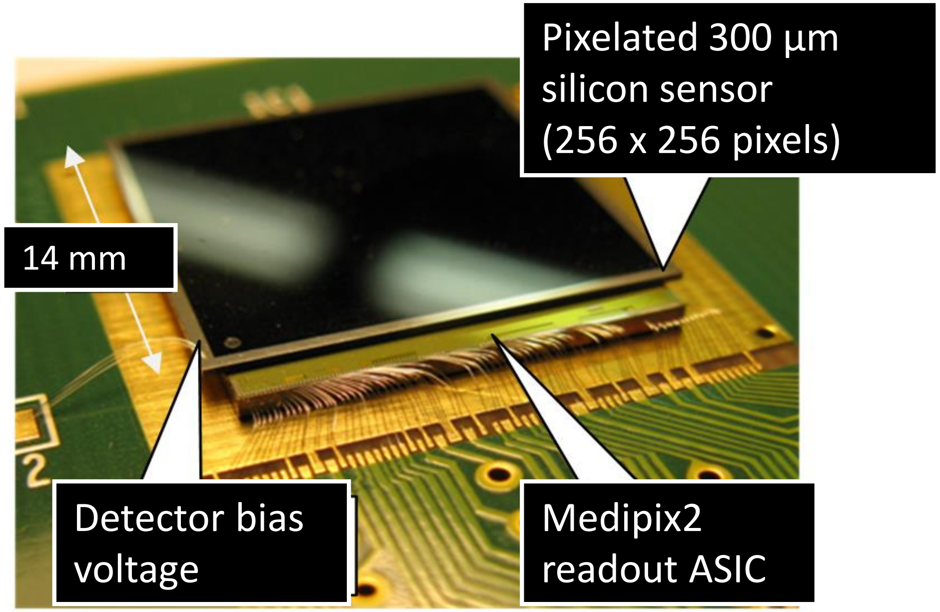
**''small' examples are Photon Counting and Spectral Imaging.**

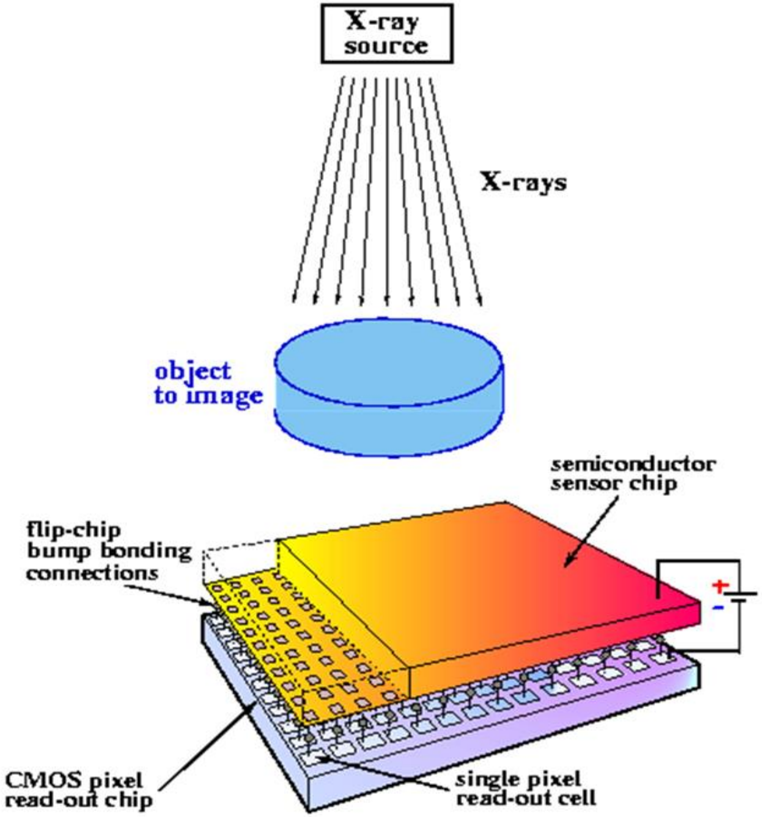
# STAY TUNED


ATLAS
EXPERIMENT
Run Number: 166786, Event Number: 77246540
Date: 2010-10-14 10:16:28 CEST

# Medipix based hybrid detectors
## (HEP spin-off!)

- Photon counting principle (E > 4keV = 1000 e-)
- Large dynamic range
- Pixel size: 55 x 55 $\mu m^2$ (256 x 256 pixels)
- Active area per chip is ~ 14 x 14 $mm^2$
- I/O periphery (wire bonded)



# Medipix Collaborations I

International collaborations of 15-20 institutions

- Aim to use hybrid pixel detectors outside high-energy physics

- Medipix1 in 1997 (1 µm)
  - Proof of principle with small matrix and large pixels

- Medipix2 (0.25 µm) (imaging) started in 1999
  - Photon counting
  - Commercialised by PANalytical in field of X-ray diffraction
  - Multiple spin-off companies -> Amsterdam Scientific Instruments from Nikhef
- Timepix (0.25 µm) (tracking) 2005
  - Initiated by Nikhef
  - 10 ns timing resolution to read out time projection chambers

# Medipix Collaborations II

- Medipix3 (0.13 µm) (Imaging) (2006)
  - Charge summing circuitry to combat charge sharing between pixels
  - Spectroscopic mode to use energy information of X-rays
- Timepix3 (0.13 µm) (Tracking) ()
  - Data driven read-out to reduce data volume in sparse data applications
  - 1.6 ns timing resolution based on Gossipo chips from Nikhef

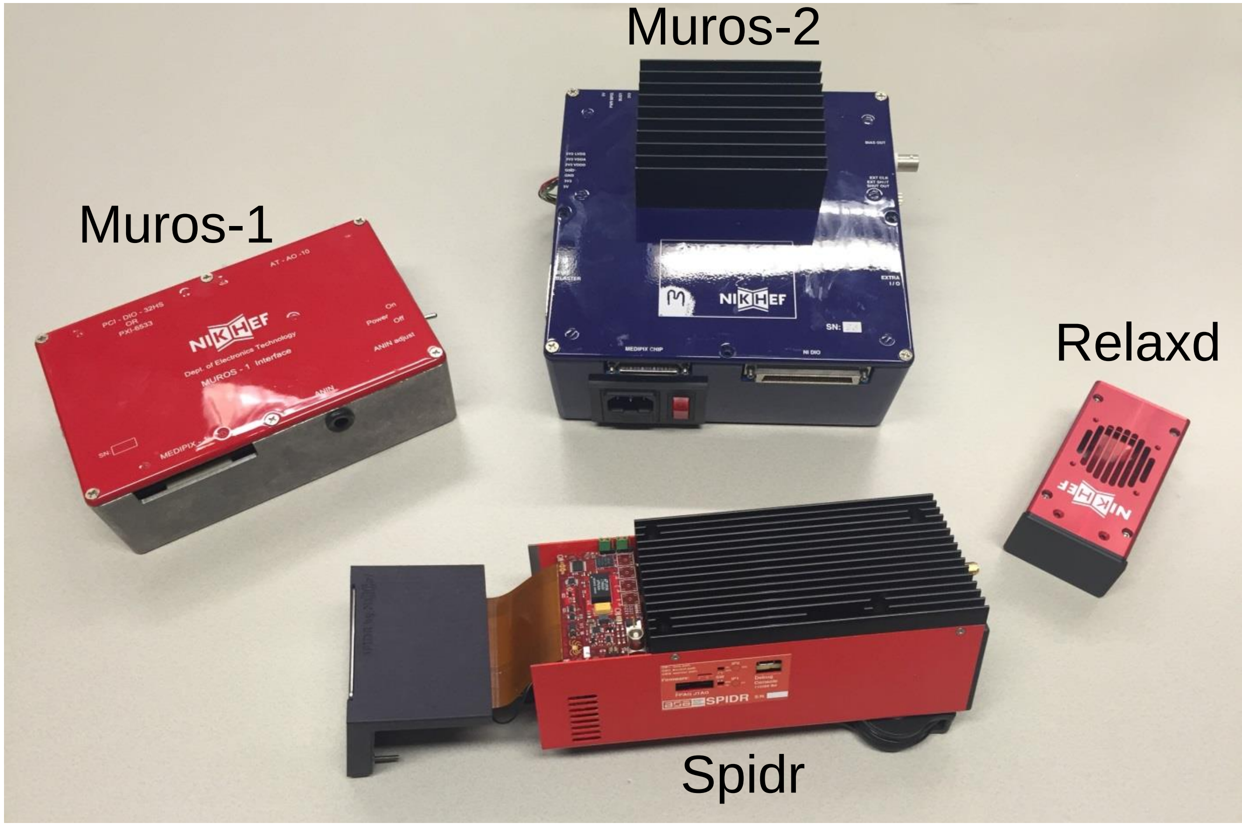
- Medipix4 and Timepix4 (65 nm) (2016)
  - Specifications under discussion
  - Medipix4 chip: 4-side buttable for tiling large areas
  - Timepix4 chip: few hundred picosecond time resolution
  - Nikhef sole design partner of CERN

# Medipix read-out systems

MUROS-1 (Medipix1)
MUROS-2 (Medipix2/Timepix)
- SCSI
- 20 fs

RELAXD (Medipix2/Timepix)
- Collaboration PANalytical
- 1 GbE
- 100 fps
- Tilable

SPIDR (Medipix3/Timepix3)
- 10 GbE
- 1000 fps (Medipix3)
- 80 Mhits/s (Timepix3)



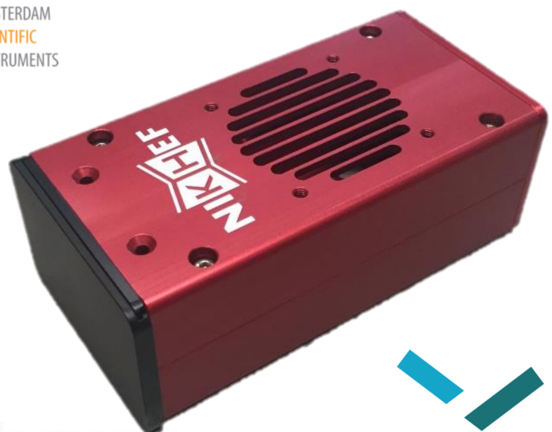
# RELAXD: high Resolution Large area X-ray detector

1 Gbit/s ethernet data transmission by Nikhef

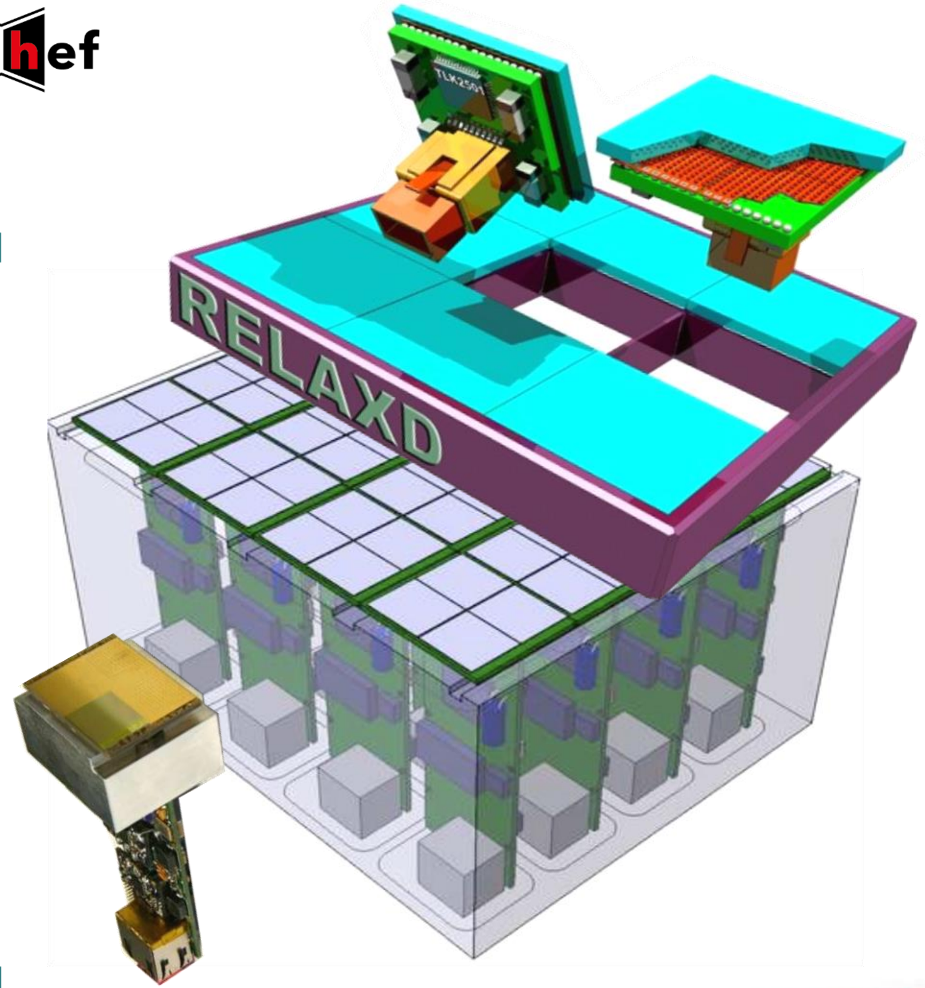
Product development by PANalytical

Read-out used commercially by PANalytical and Amsterdam Scientific Instruments

asi AMSTERDAM SCIENTIFIC INSTRUMENTS



PANalytical

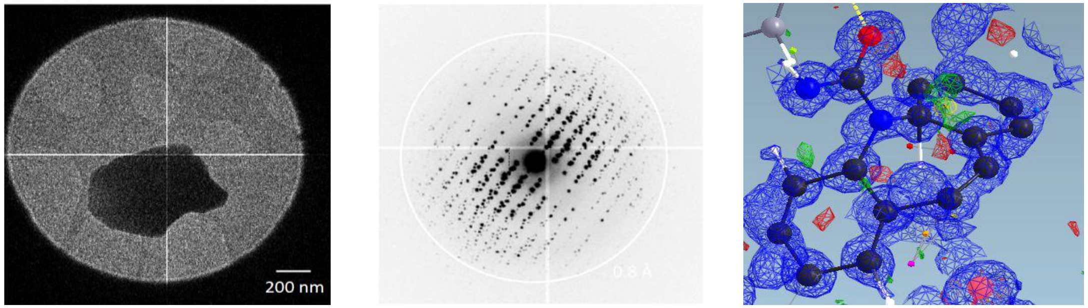


# Spin-off company

AMSTERDAM SCIENTIFIC INSTRUMENTS

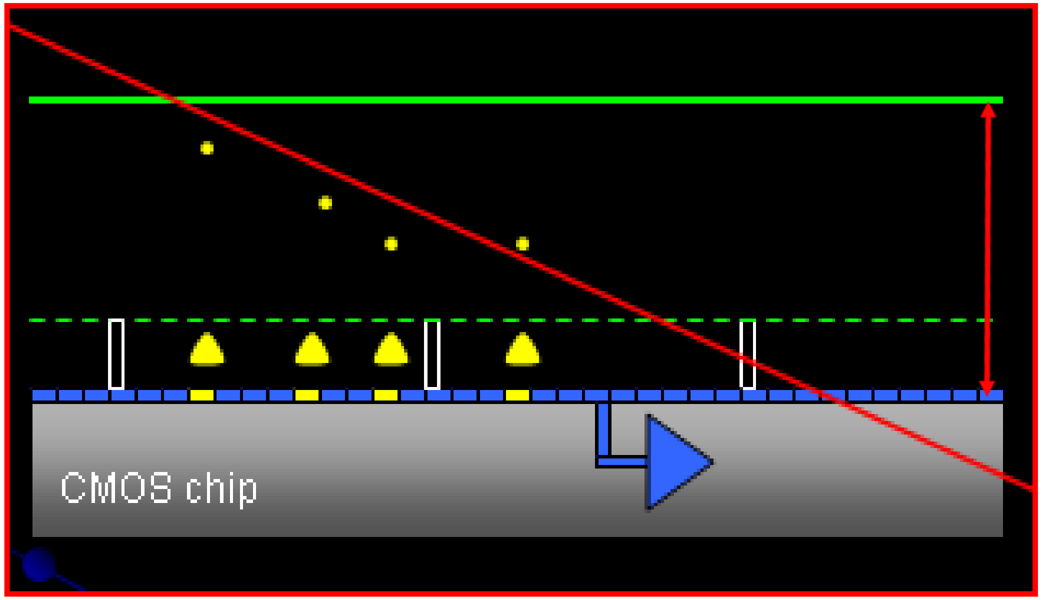
- STW valorisation grant-1 (25k) in 2009
- STW valorisation grant-2 (200k) in 2010
- Founded in 2011
- Selling Relaxd based Timepix systems
- Grown to 8 FTE
- Continuous collaboration and knowledge transfer from Nikhef
- Many applications: mass spectrometry, electron microscopy, neutron detection, X-ray imaging

**Photo** **X-ray CT** **Neutron CT** **Combined CT**

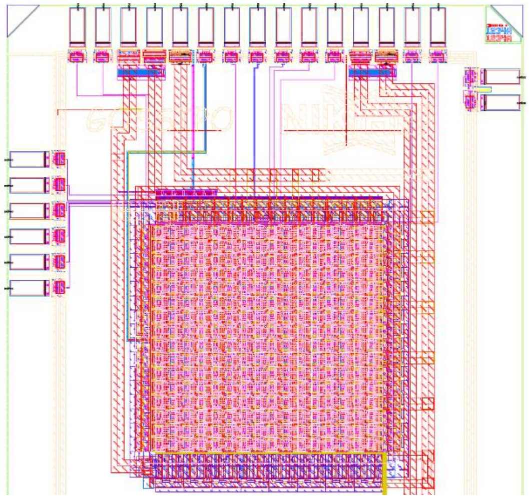



**Electron Crystallography**

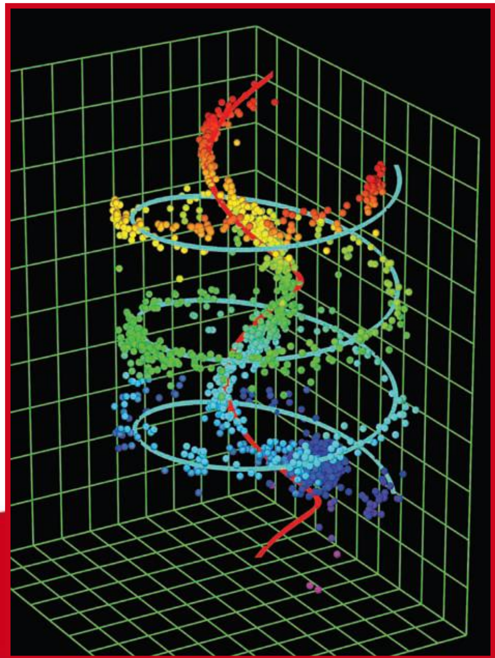
# Timepix chips




Gossipo2



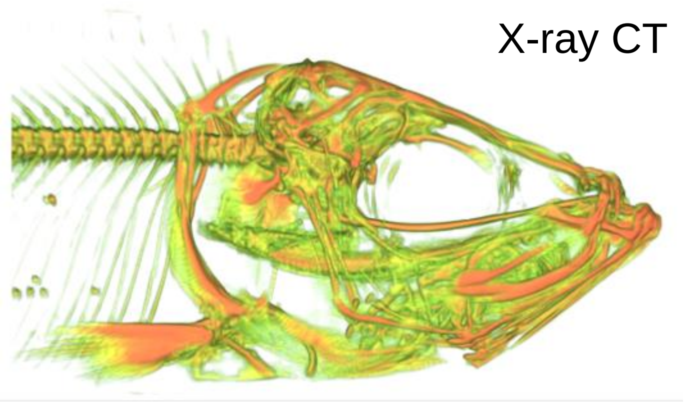
1 x 2 mm

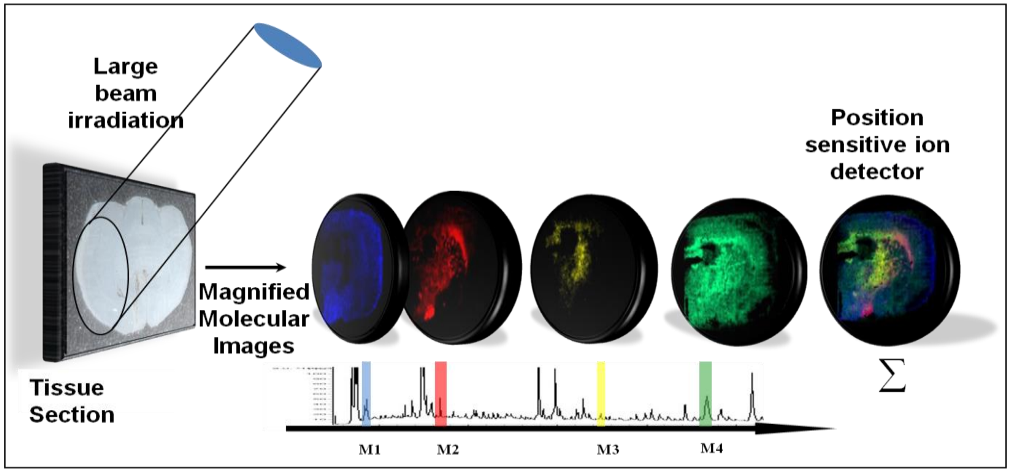


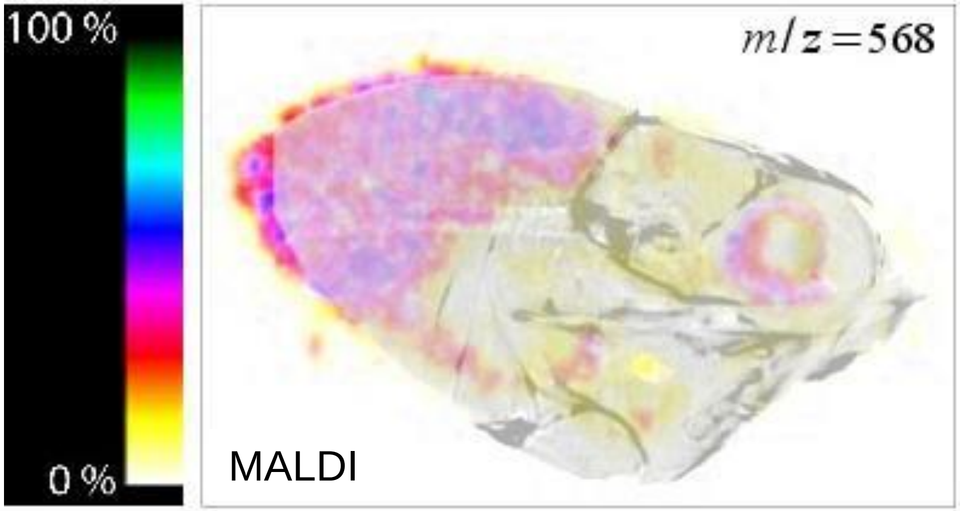
- Idea to use in Time Projection Chambers from Nikhef
- Need for time of arrival measurement – Timepix1 – 10 ns
- Improvements in series of Gossipo chips by Nikhef
- Timepix used in many applications!

# Combining Imaging Techniques: X-ray CT with Mass Spectrometry

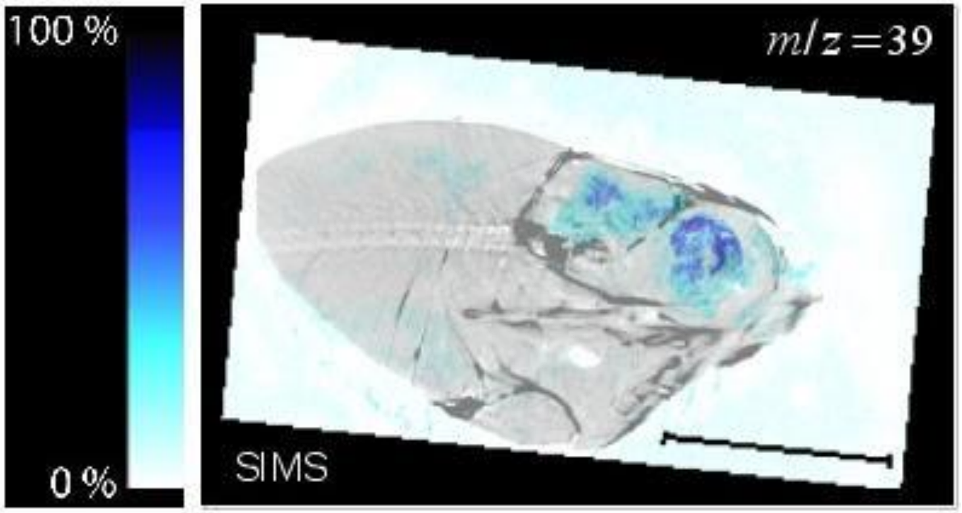
X-ray CT






DNA, proteins, sugars




Elements and molecules

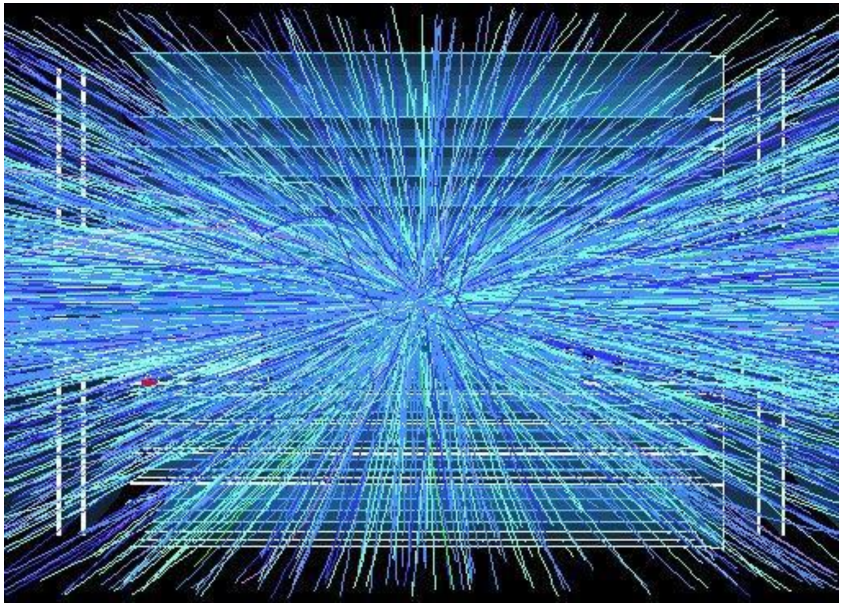


Courtesy of Enrico Schioppa & Anne Bruinen

# HEP to Medipix and back

**The idea to measure time crucial to disentangle future events!**

- Timepix chip 10 ns
- Gossipo series 1.6 ns
- Timepix3 1.6 ns
- Velopix spin-off from Timepix3 chip
  - Re-use of 130 nm IP blocks
  - Time of Arrival measurement to separate bunch crossings
  - Sparse / data driven readout
- Timepix4 aiming for 200 ps



Courtesy of ATLAS collaboration

**Successor in future LHCb, ATLAS, CMS experiments?!**
**and opening the way for many more other applications!**

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# Medipix at PANalytical

Eugene Reuvekamp
Roelof de Vries

# Agenda

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- Who we are
- History PANalytical – CERN/NIKHEF/Medipix collaboration
- Some applications
- Detector requirements
- Lessons learned

# History/facts

- The US, Norelco, part of Philips started the production of X-ray diffractometers in 1948.
- In the 1970's, the development and production of X-rays systems is moved to Almelo, the Netherlands. The production of X-ray tubes is in Eindhoven, the Netherlands.
- Instruments are sold worldwide.
- In 2002, Philips Analytical was acquired by Spectris (British) and the company changed its name to PANalytical.
- Currently: ~ 1000 Employees wordwide

# X-ray diffractometers

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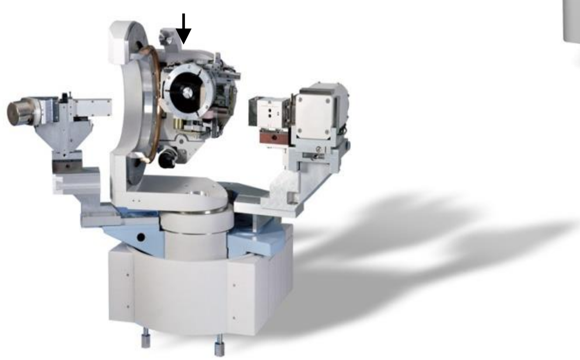
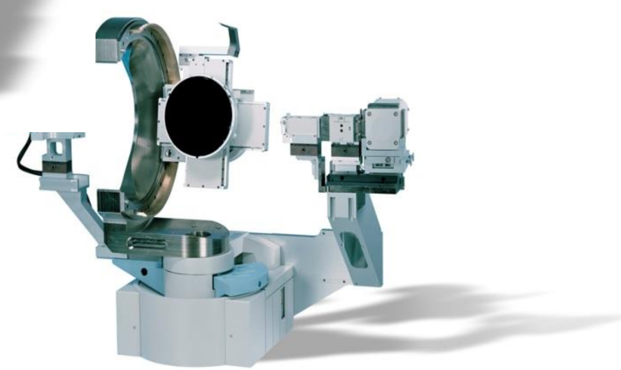
X'Pert PRO

Empyrean

CubiX PRO

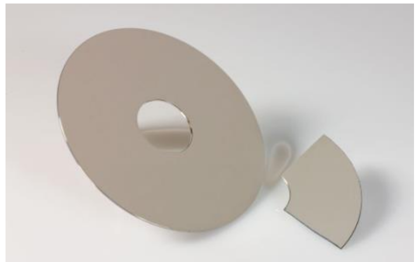


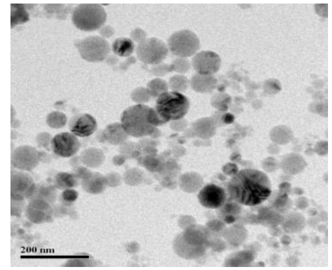
Materials Research Diffractometer (MRD)



MRD XL

# The multi-purpose solution



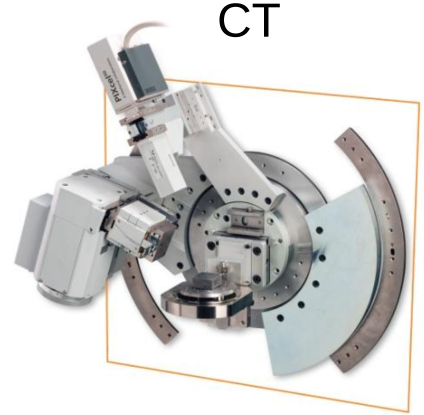


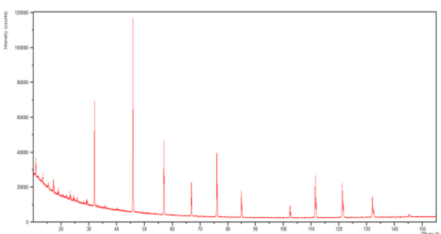

Powder XRD

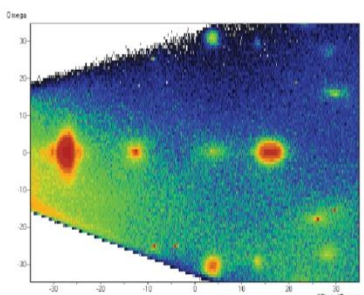
Thin-film XRD

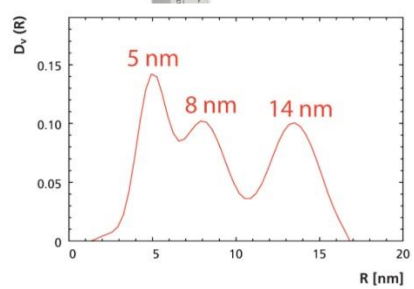
SAXS / WAXS

CT








# History PANalytical/CERN/NIKHEF/MEDIPIX

- First contacts early 2000
- Technology transfer agreement signed in 2001
- First Medipix 2 chip available in 2002
- Final chip ready in 2005
- Product introduced in 2007
- PANalytical joins the Medipix collaboration in 2009
- First Medipix 3 based detectors available in 2010
- Final version of the chip available end 2012
- Product launched in 2014

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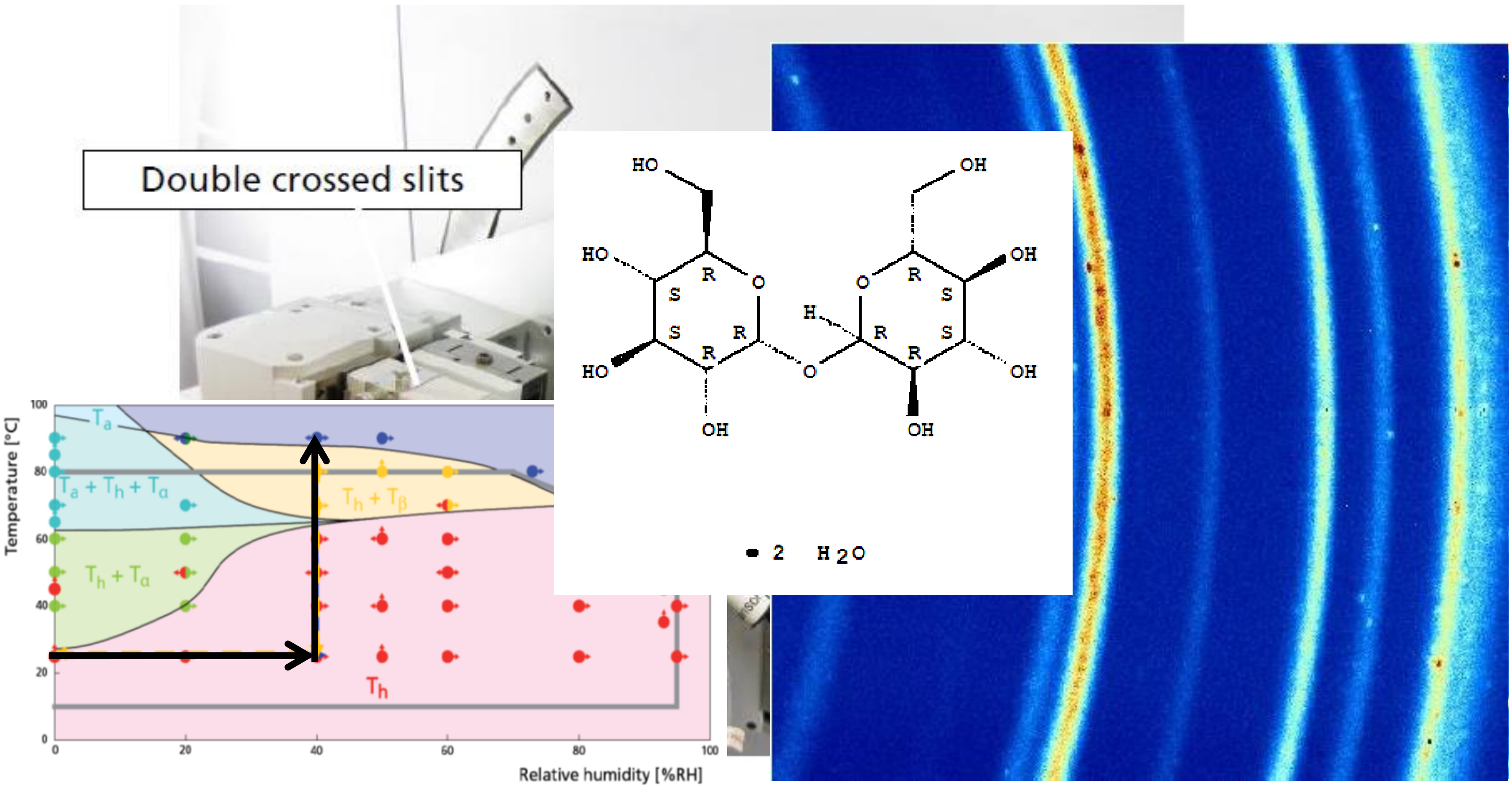
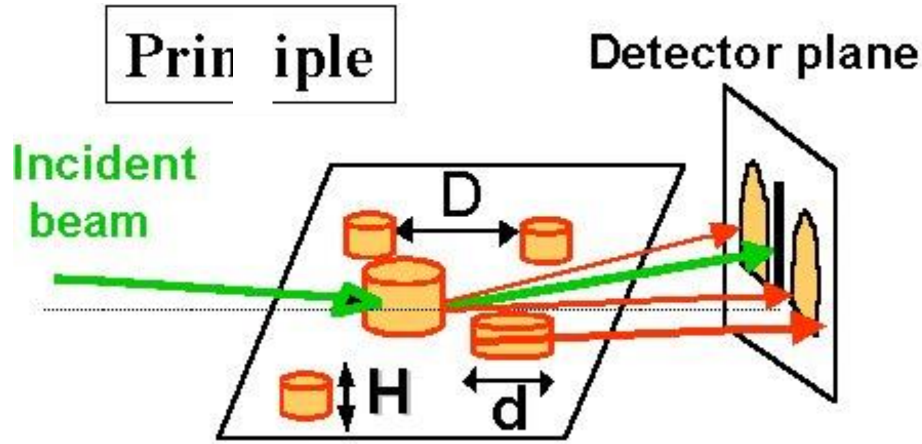
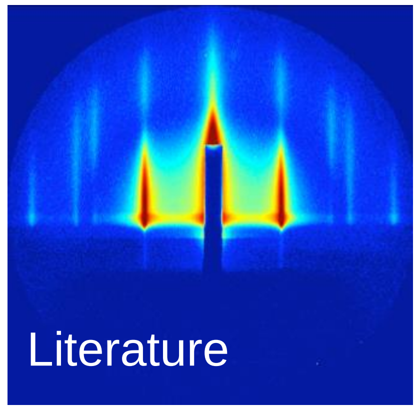
# Application example: XRD powder trehalose dihydrate



# NEW: High-Resolution GI-SAXS with PIXcel$^{3D}$

- GI-SAXS is used to study nanostructures in thin films.
- Examples:
  - porous layers
  - quantum dots
  - self-assembled structures
- Key properties:
  - Particle size/shape
  - Average distance/periodicity



# Application example: GI-SAXS mesoporous $SiO_2$

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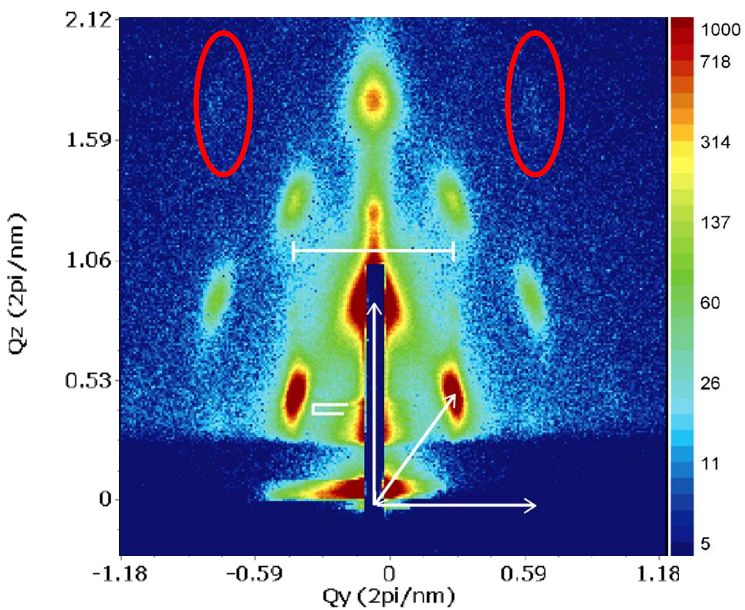


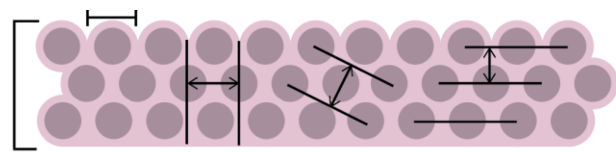

| | | pixels | size (nm) |
|---|---|---|---|
| [ | film thickness | 4 | 170 |
| ⊢⊣ | surface modulation | 74 | 9.1 |
| ⟷ | pore repeat | 74 | 9.1 |
| ↕ | pore repeat | 95 | 7.1 |
| ⤢ | pore repeat | 64 | 11 |

Measurement time : 15h

Alternative: synchrotron
- Pro: Fast data collection (seconds)
- Con: Not always available
  Usually not next door

# Detector requirements

- Imagers/strip
  - Large area
  - High count rate
  - High energy resolution (~few hundred eV)
  - Low noise
  - Energy range 1-100 keV
  - Low maintenance/cost of ownership
  - Radiation hard

- Point detectors
  - High Energy Resolution ( physical limit)
  - High count rate
  - Large area
  - Energy range 0.1-80 keV
  - Radiation hard

# Lessons learned

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- Business wise very successful (in the end)
  - Success of the project depends on the willingness of the academic partner(s) to get familiar with industrial application
  - Project timeline can be very unpredictable
- Industrial involvement will lead to new insights and improved designs
- Challenging is the continuity on timescales 10-20 yrs.
  - Follow-up project definitions
  - Keeping mutual interests
  - Always a trade-off between scientific goal(s) and good working devices

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