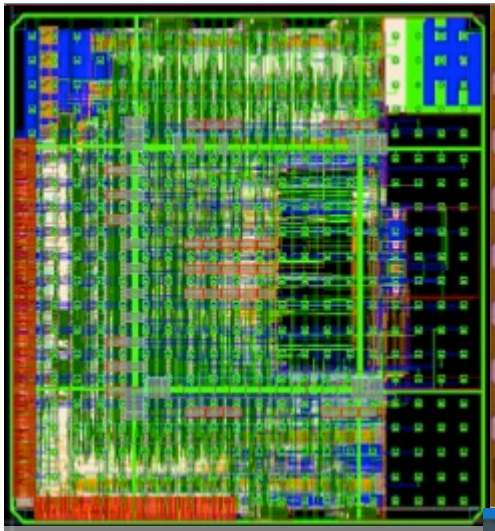
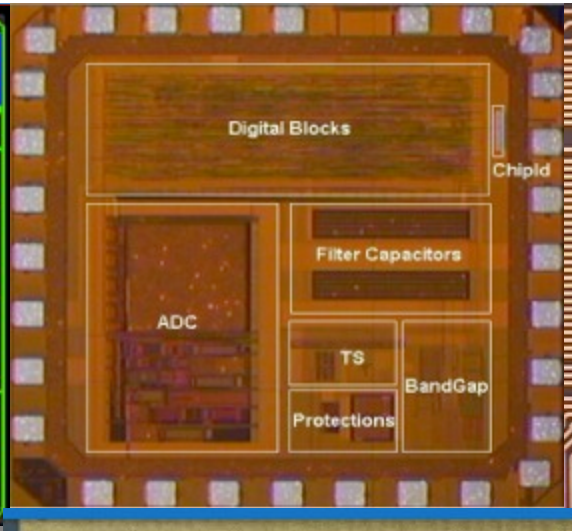
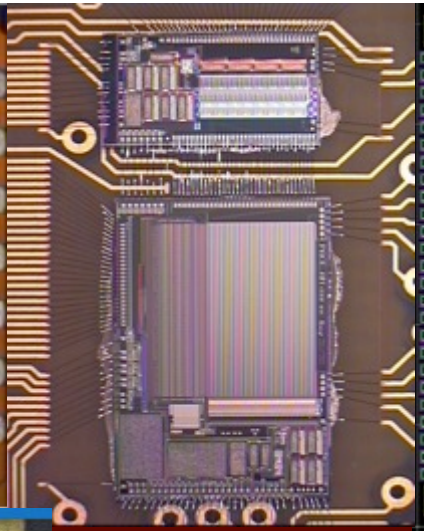
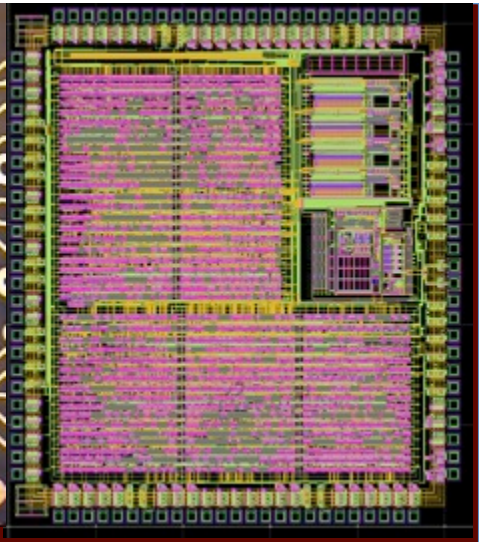
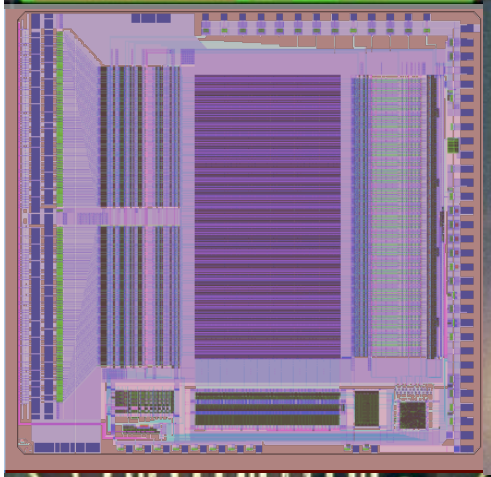
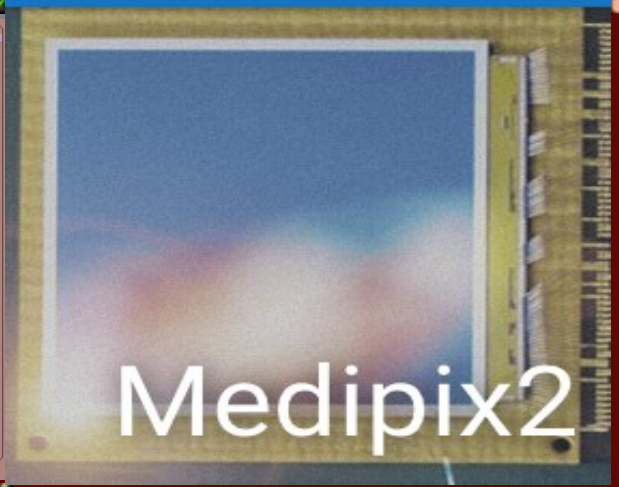








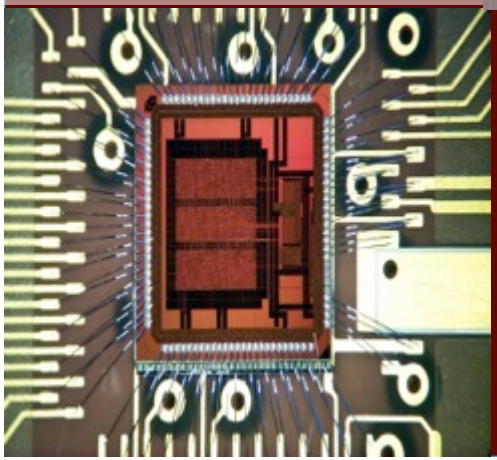




Silicium

Pixel Detectors

CERN en Medipix

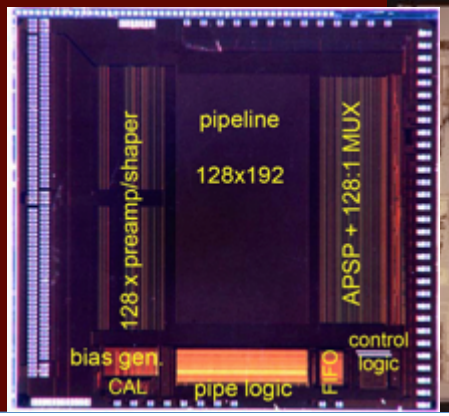


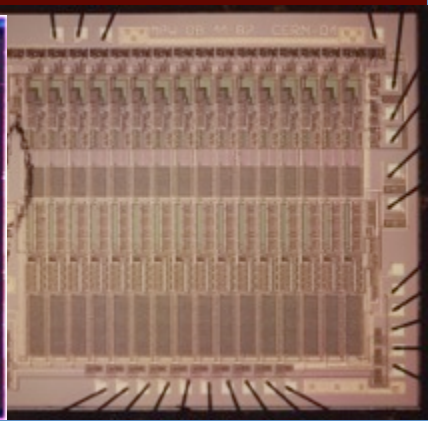
Erik H.M. Heijne

CERN – PH Dept. CH 1211
Geneva 23

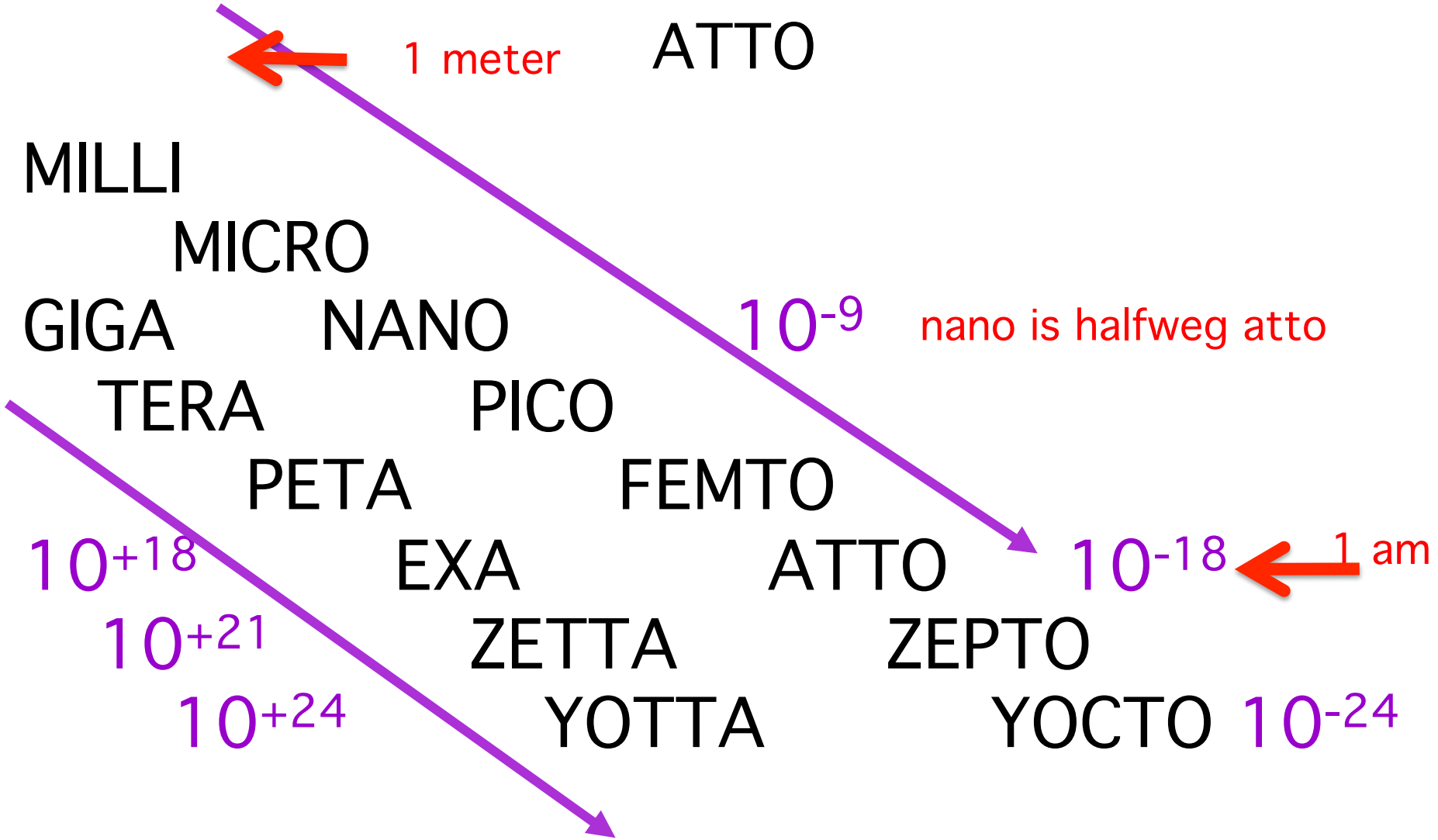
Institute for Experimental and Applied Physics of the Czech Technical University in Prague

Nikhef Amsterdam
Erik.Heijne@cern.ch





Groter en Kleiner
wat is atto?


1 meter
ATTO
MILLI
MICRO
GIGA
NANO
10^{-9}
nano is halfweg atto
TERA
PICO
PETA
FEMTO
10^{+18}
EXA
ATTO
10^{-18}
1 am
10^{+21}
ZETTA
ZEPTO
10^{+24}
YOTTA
YOCTO
10^{-24}

Kun je elementaire deeltjes zien?

het deeltje zelf niet, maar wel het spoor
omdat energie wordt afgegeven in materie

moet wel een handig materiaal kiezen als detector

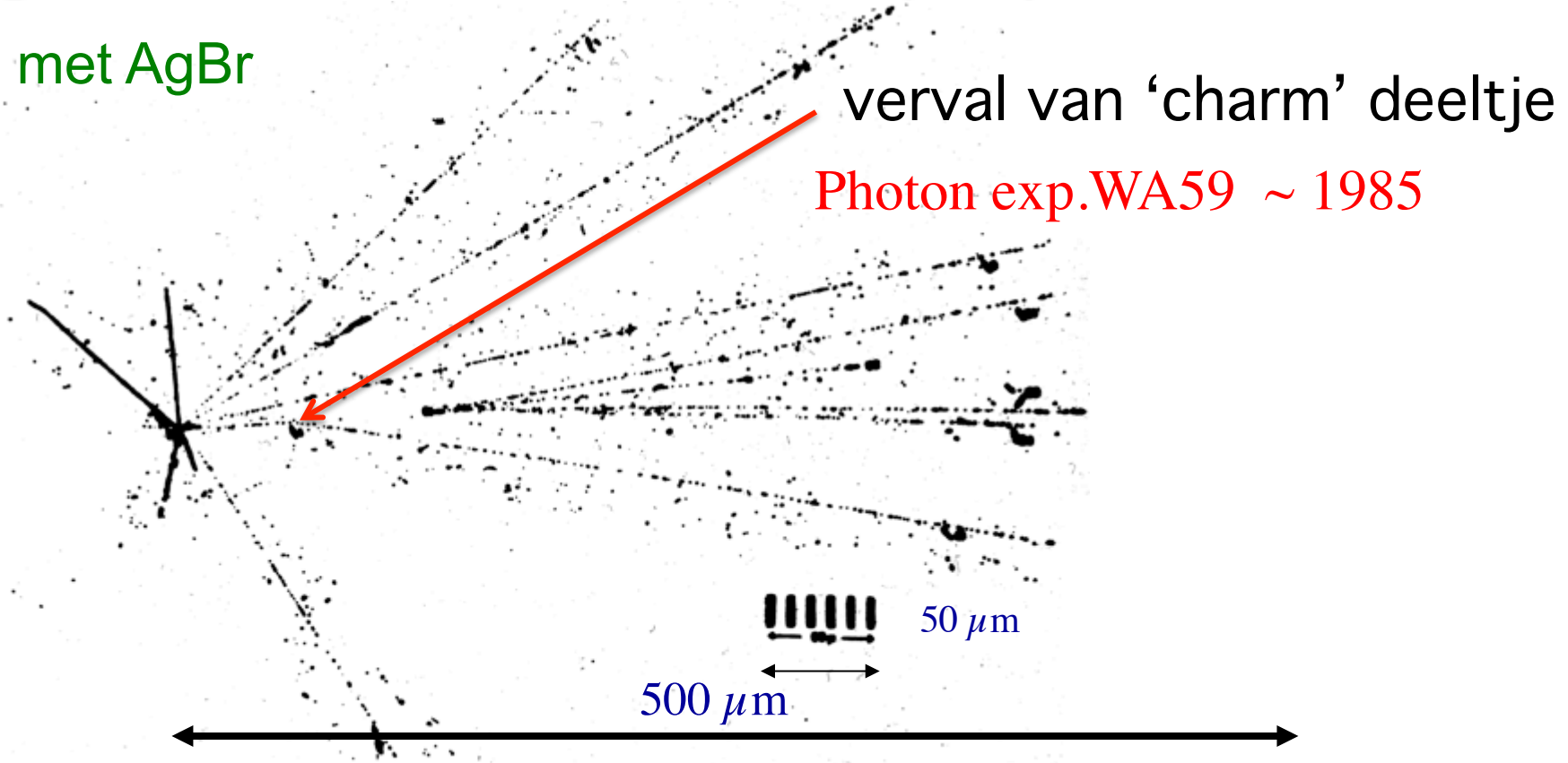
gas: Geiger-Müller, nevelkamer, dradenkamer, ..
vloeistof: bellenvat, argon-ionisatiekamer, ..
vaste stof: film, scintillator, halfgeleider, ..

signaal: zwarting, belletjes, licht, elektrische puls

Lichtgevoelige Emulsie als Detektor (>1945)

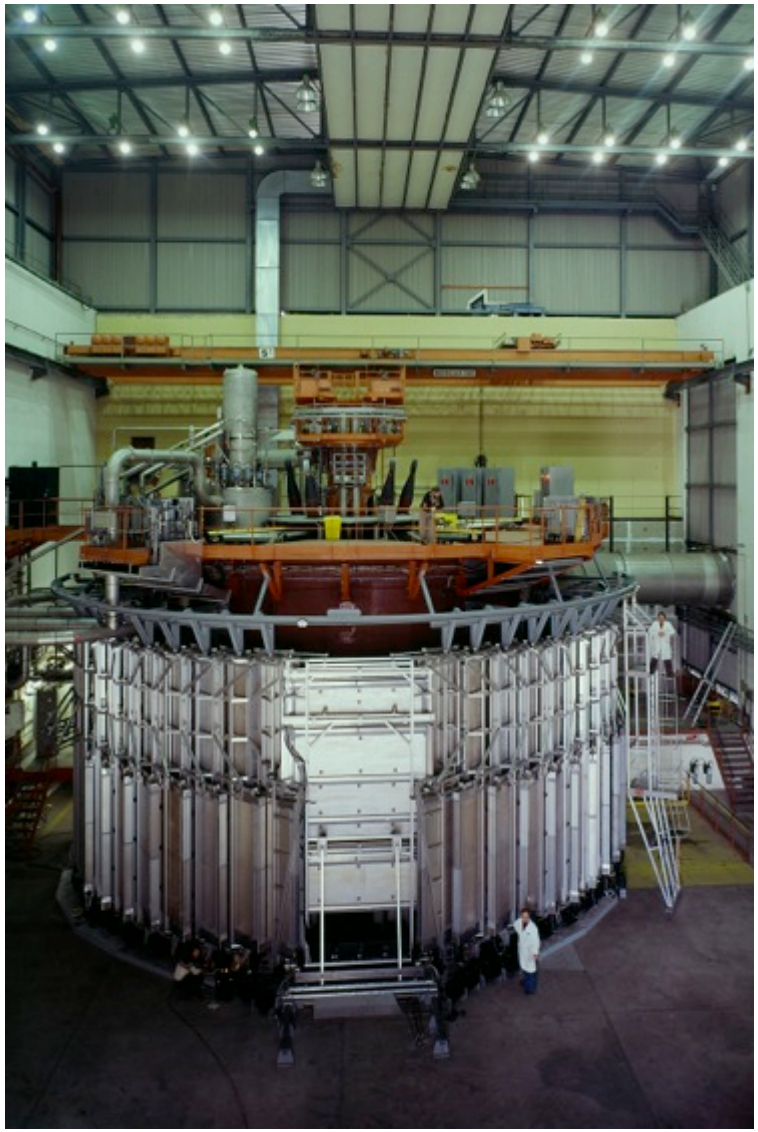
gelatine film 3D, sub-µm precisie

met AgBr

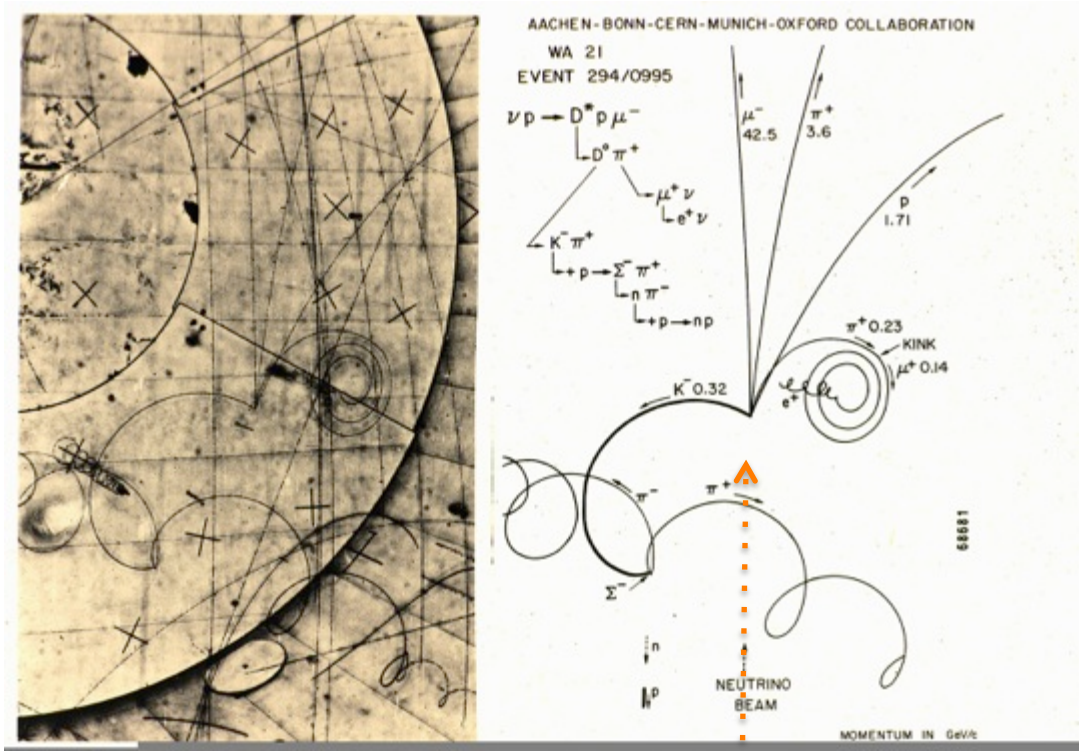


opeenvolgende ionizerende overdrachten van energie (~5keV)
creëren latent beeld van zilverkorrels, zichtbaar na ontwikkelbad
afstand ~50µm met lichtsnelheid $3x10^8$m/s = $3x10^{14}$µm/s dus t=$1.6x10^{-13}$ s

Big European Bubble Chamber BEBC



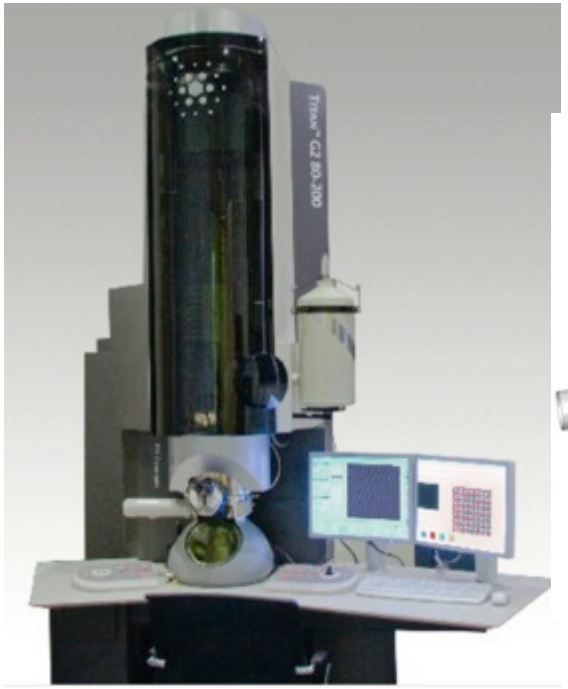
BEBC Bellenvat
Neutrino Interactie



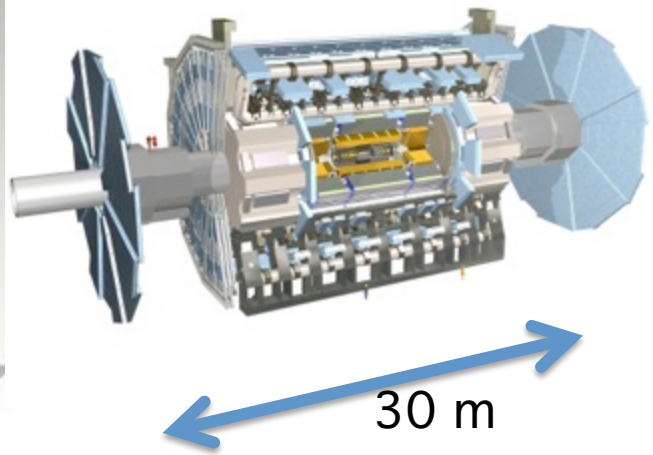
precisie van de banen~ 1mm
hele volume is gevoelig --->
meten van impulsen
belangrijkste apparaat tot ~ 1985

Hoe korter de golflengte, hoe groter de imager

microscoop
zichtbaar licht
fotons ~1eV
afmeting 30 cm
μm objecten



TEM transmissie
electron microscoop
electron bundel ~100 keV
afmeting 3 m
Å objecten



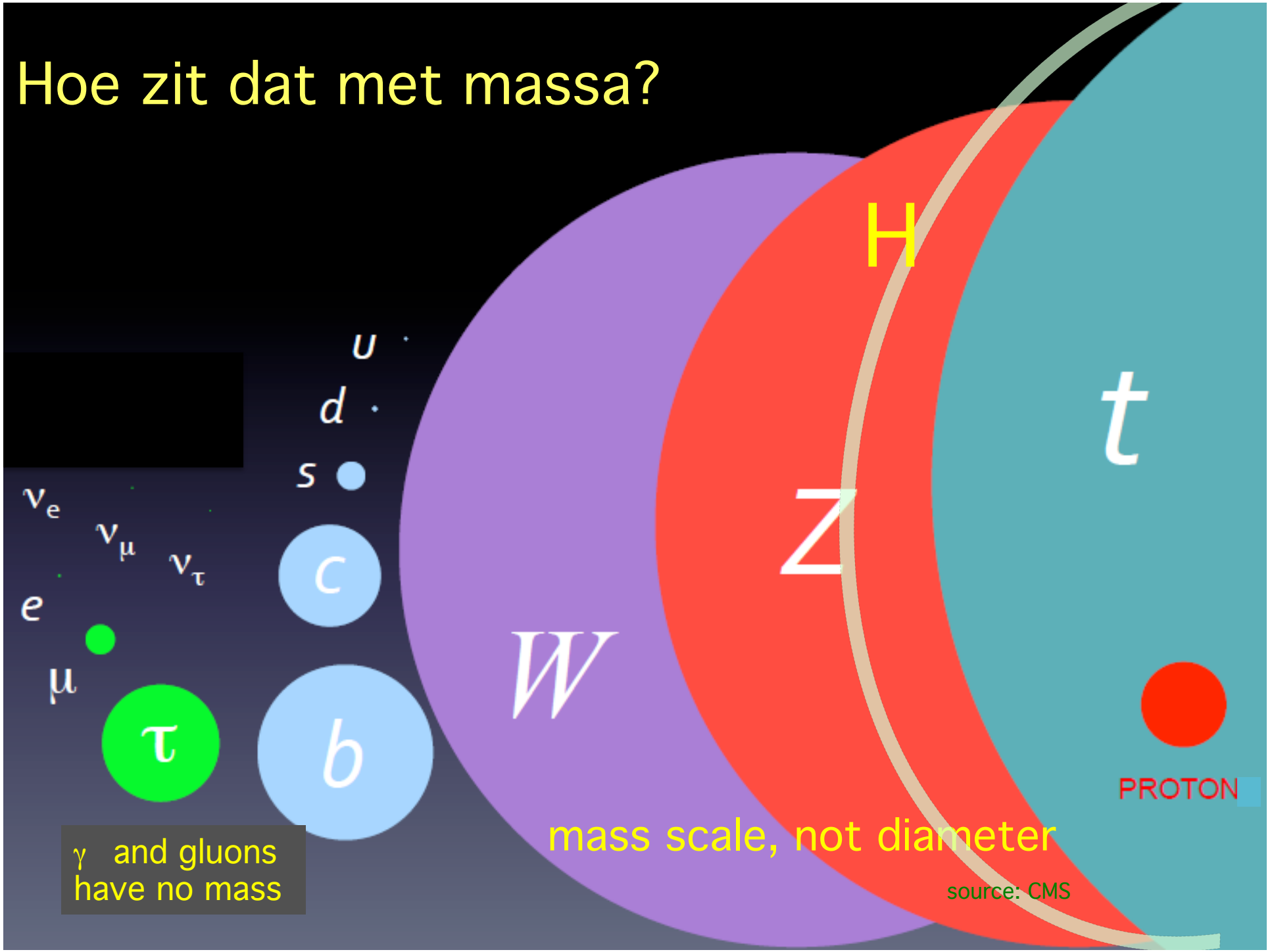
'attoscope' CERN
met protonen 7 TeV

30 m + 30 km ring
atto meter objecten

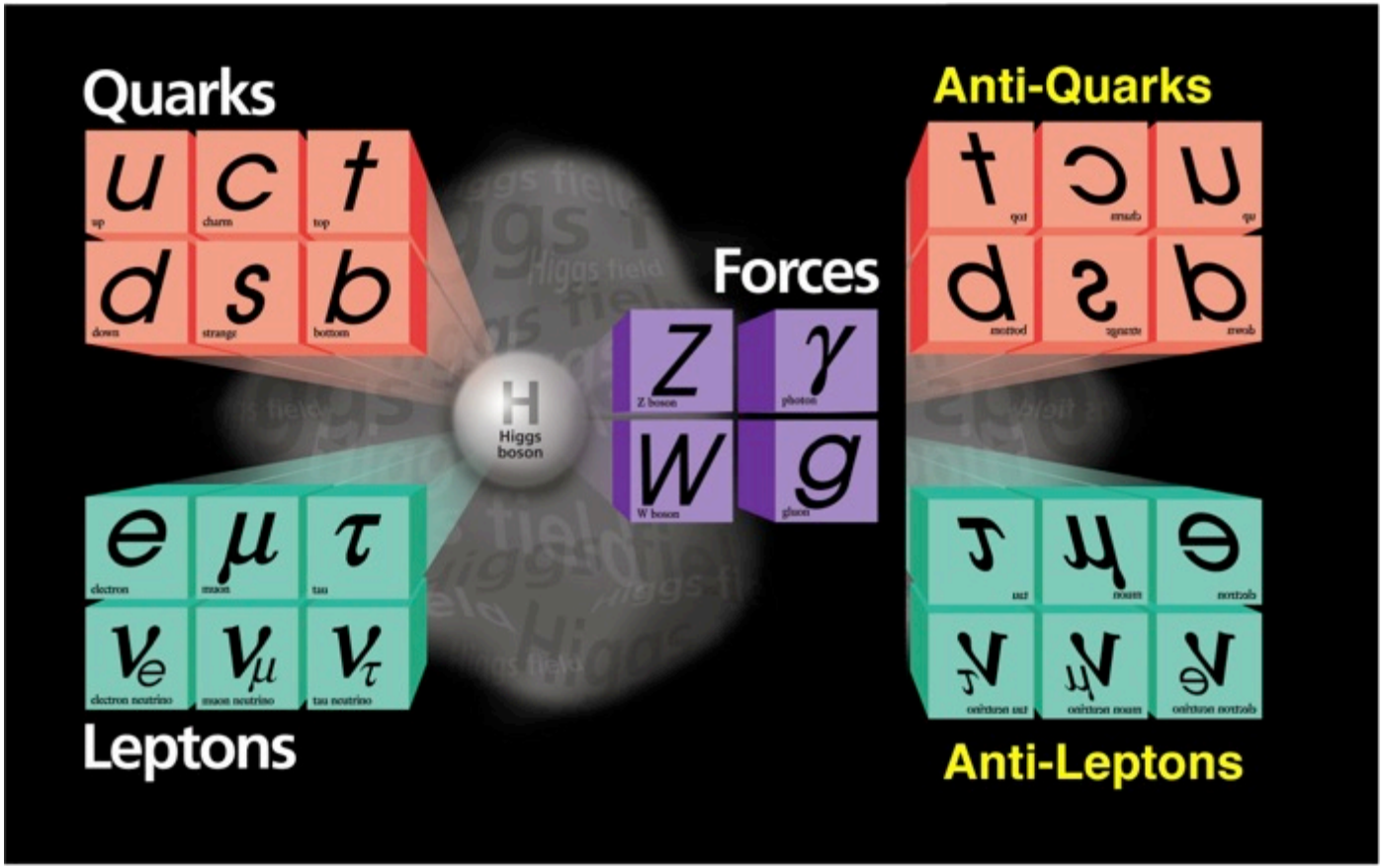
apparaten steeds groter,
deeltjes steeds 'kleiner' en 'zwaarder'

afmeting en massa onafhankelijk

Hoe zit dat met massa?



Periodiek Systeem volgens “Standard Model”
Krachten en Fundamentele Deeltjes

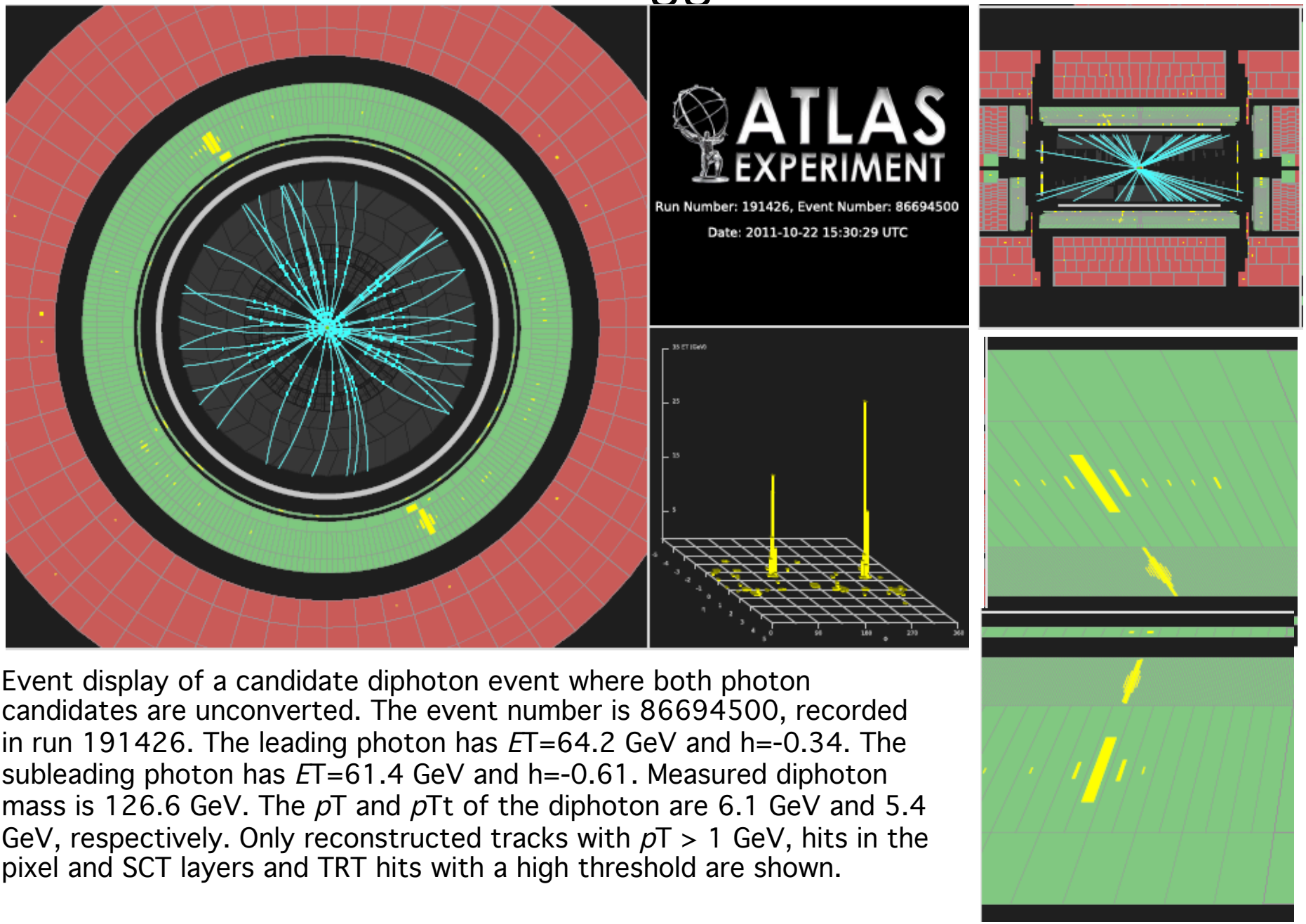


source: Fermilab

Er blijven veel vragen:

- waarom nu juist 3 generaties
- waar zijn de originele anti-deeltjes gebleven
- waar past hierin de zwaartekracht
- .....en nog veel meer

Atlas event Higgs --> twee-fotons



Event display of a candidate diphoton event where both photon candidates are unconverted. The event number is 86694500, recorded in run 191426. The leading photon has *E*T=64.2 GeV and h=-0.34. The subleading photon has *E*T=61.4 GeV and h=-0.61. Measured diphoton mass is 126.6 GeV. The *p*T and *p*Tt of the diphoton are 6.1 GeV and 5.4 GeV, respectively. Only reconstructed tracks with *p*T > 1 GeV, hits in the pixel and SCT layers and TRT hits with a high threshold are shown.

Hoe moet je je de ‘Big Bang’ voorstellen?

het is ondenkbaar, alle energie in het heelal was opgekropt in één punt

dan is opeens het transformeren begonnen
na 10^{-xx} seconde begon massa te ontstaan

sindsdien is alles aan het uitzetten en afkoelen
en wordt nog steeds energie omgezet in massa

bedenk wel dat de materie die wij zien, praktisch leeg is
alleen de lichte elektronen bepalen grootte atomen (~0.1nm)

de kernen (~fm) met massa zijn maar 0.00000000000001 % van het volume

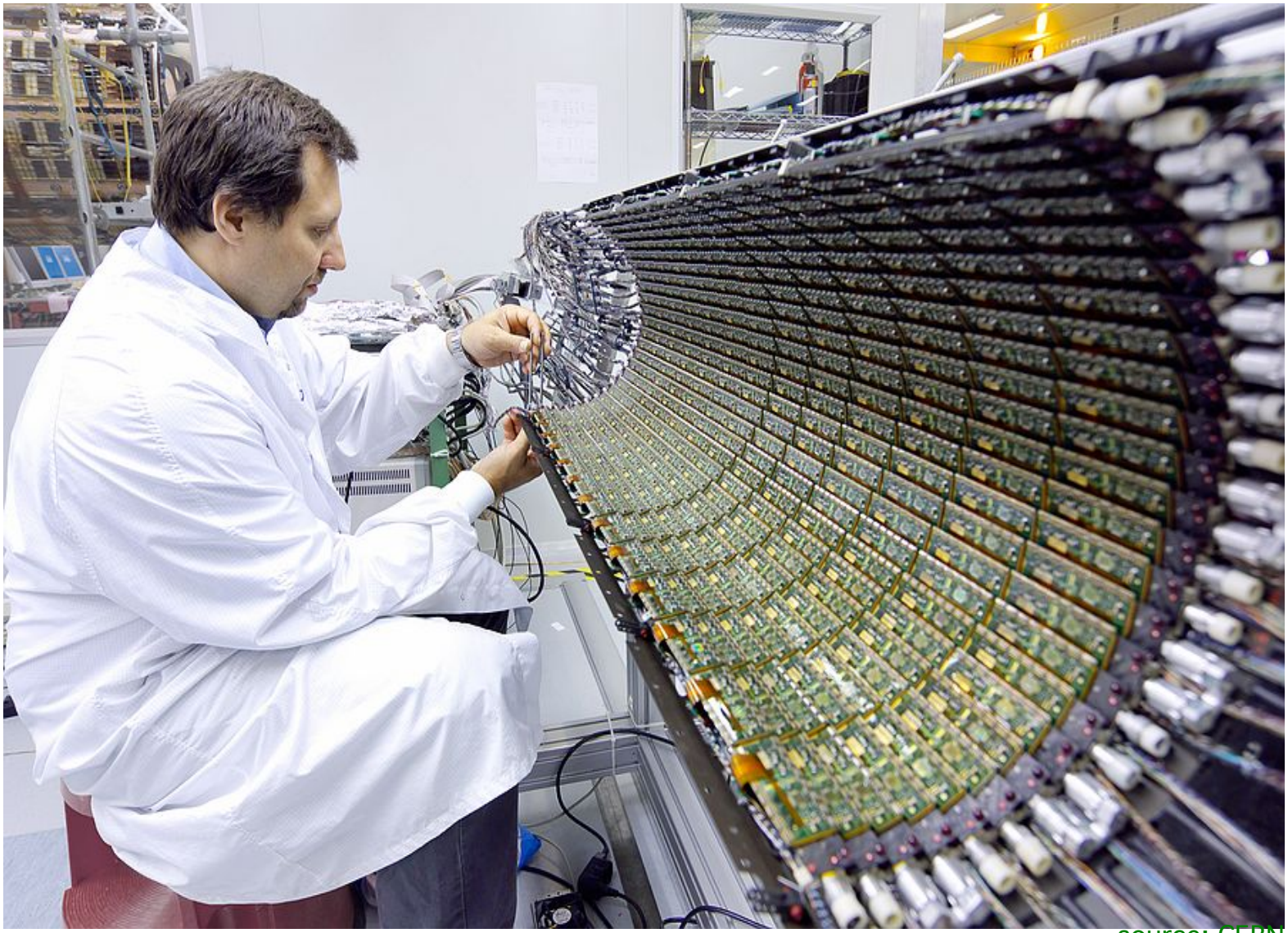
Wat doen we eigenlijk?

1. Versneller:
energie in zo klein mogelijk volume om nieuw deeltje te scheppen

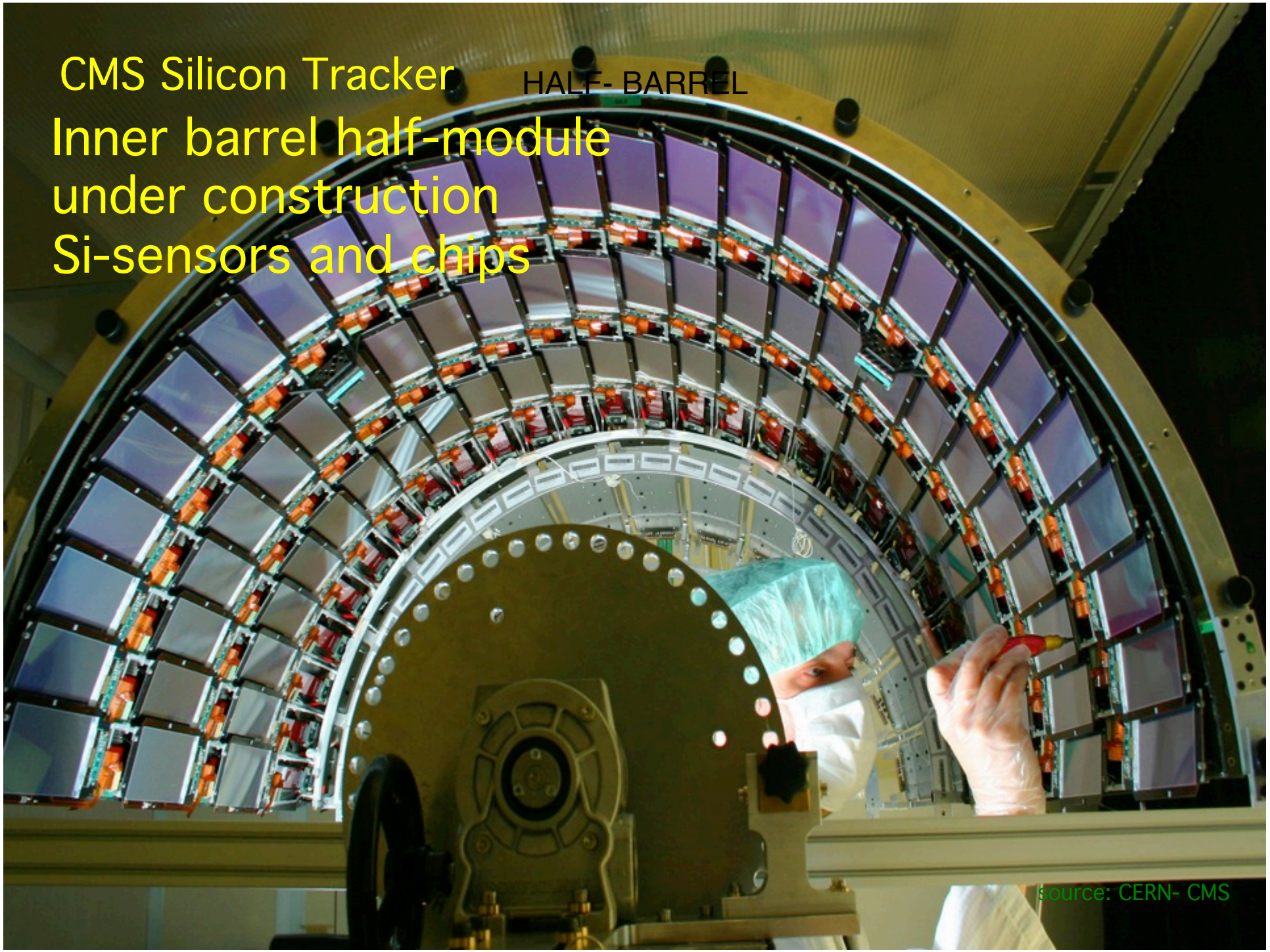
2. Metingen met detektoren om deze deeltjes ook te kunnen bestuderen

direkt om het interaktiepunt
wordt nu meestal silicium gebruikt

ATLAS binnenste Si pixel lagen



source: CERN- ATLAS


CMS Silicon Tracker
HALF- BARREL
Inner barrel half-module
under construction
Si-sensors and chips
source: CERN- CMS


CMS Silicon Tracker
Forward wheel
Si-sensors and chips
Barrel
source: CERN- CMS

Silicium is nu overal in de LHC detektors

Speciale Chips (ASICs) voor alle sub-systems

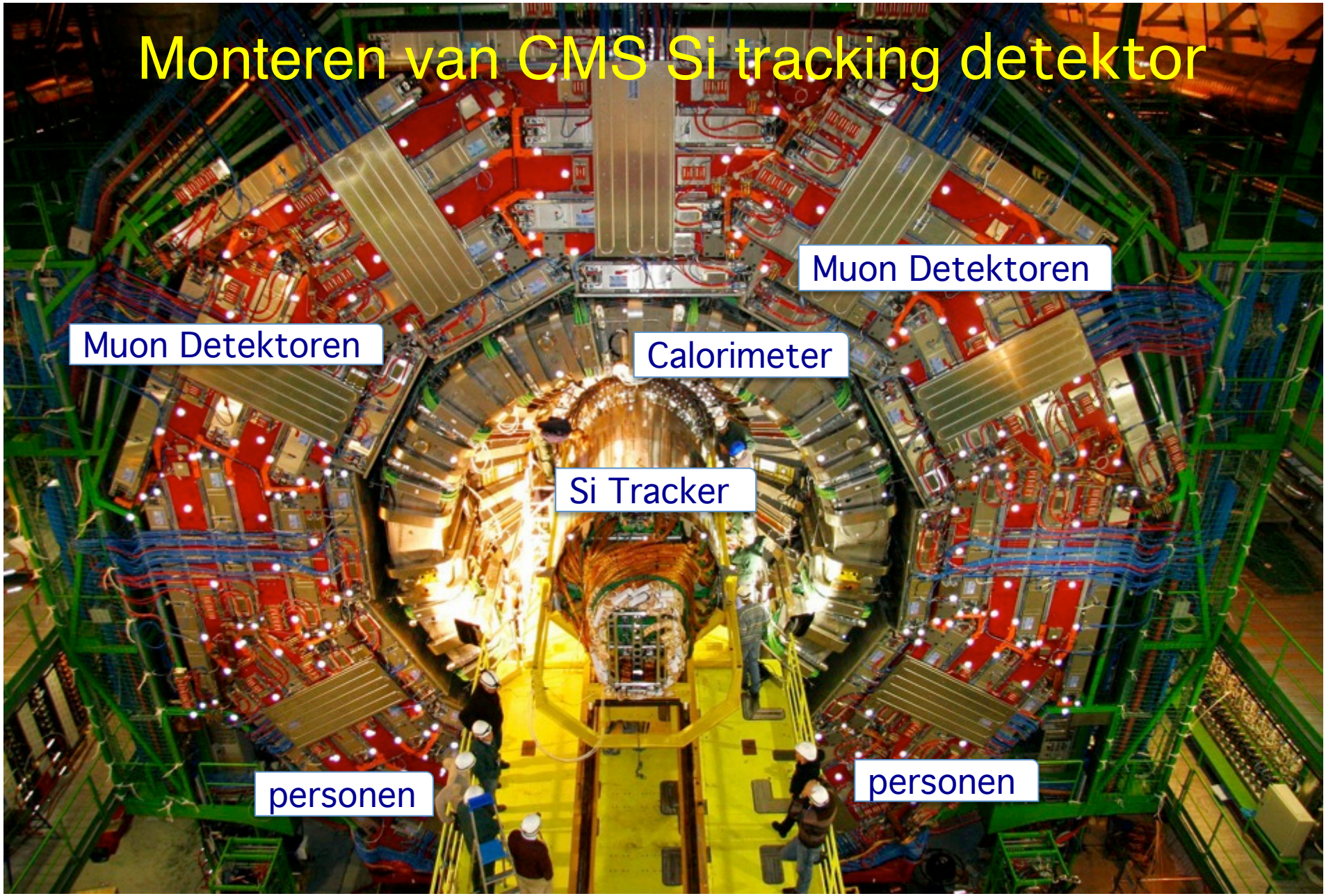
Si sensors in de binnenste schillen:
- Pixels (2D) en Microstrip (1D) in meerdere lagen
- Groot aantal sensor elementen: veel chips

Teams ontwerpen onze ASICs zelf, niet in industrie

Ondanks ‘kleine’ aantallen, toch essentieel:
- volume, compacte functies, locaal geheugen

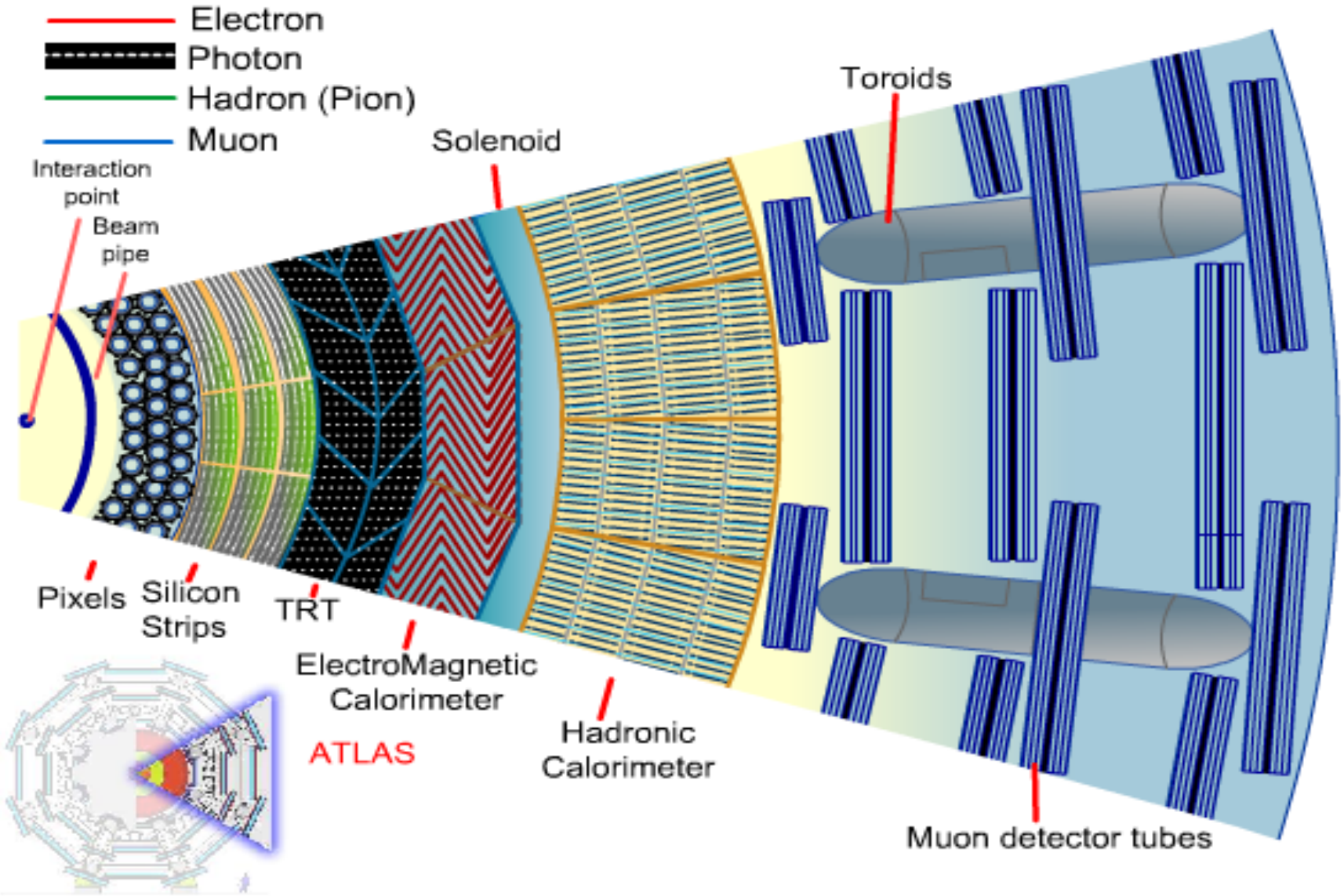
Simulaties moeten zorgen dat chip meteen goed is

Monteren van CMS Si tracking detektor



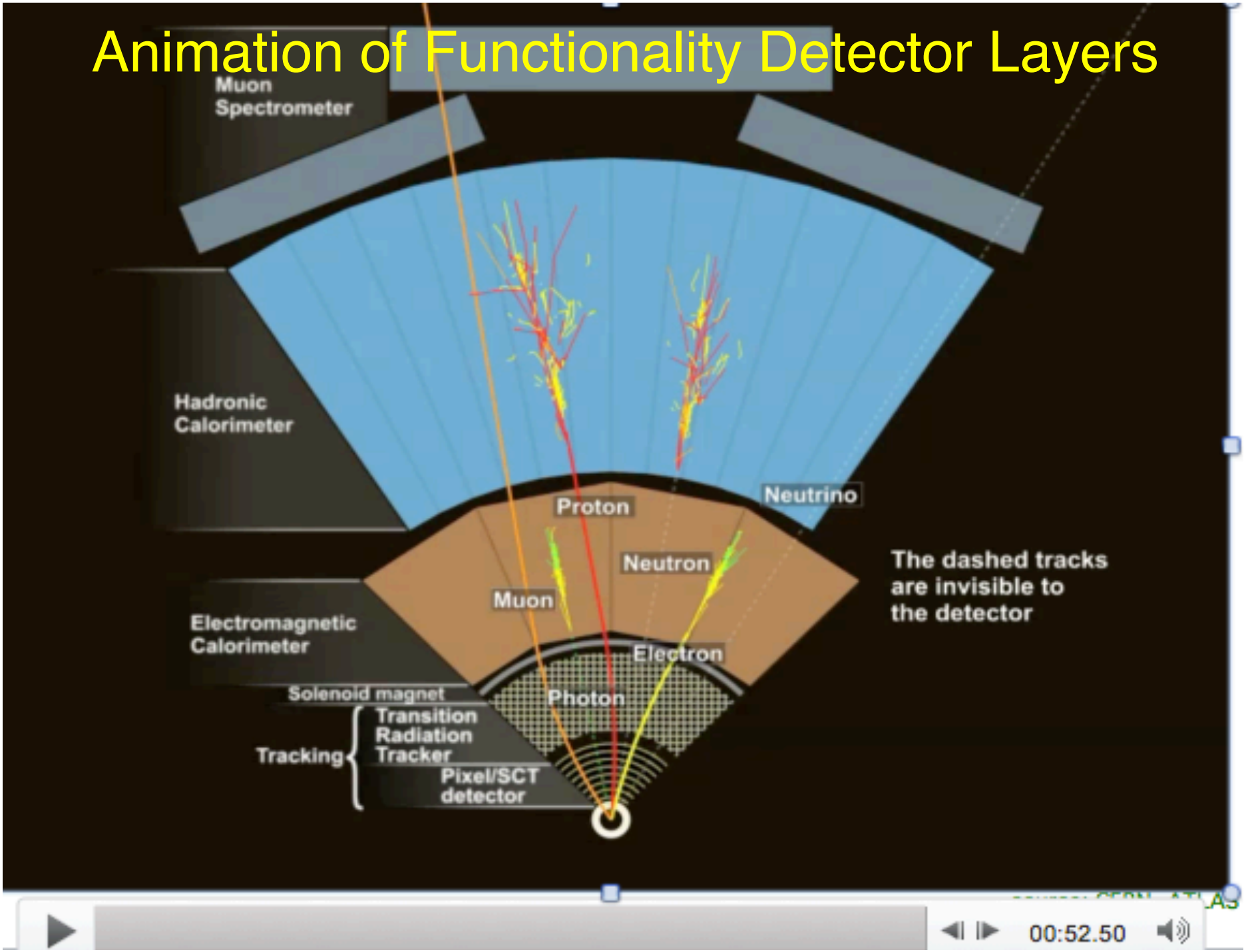
source: CERN- CMS

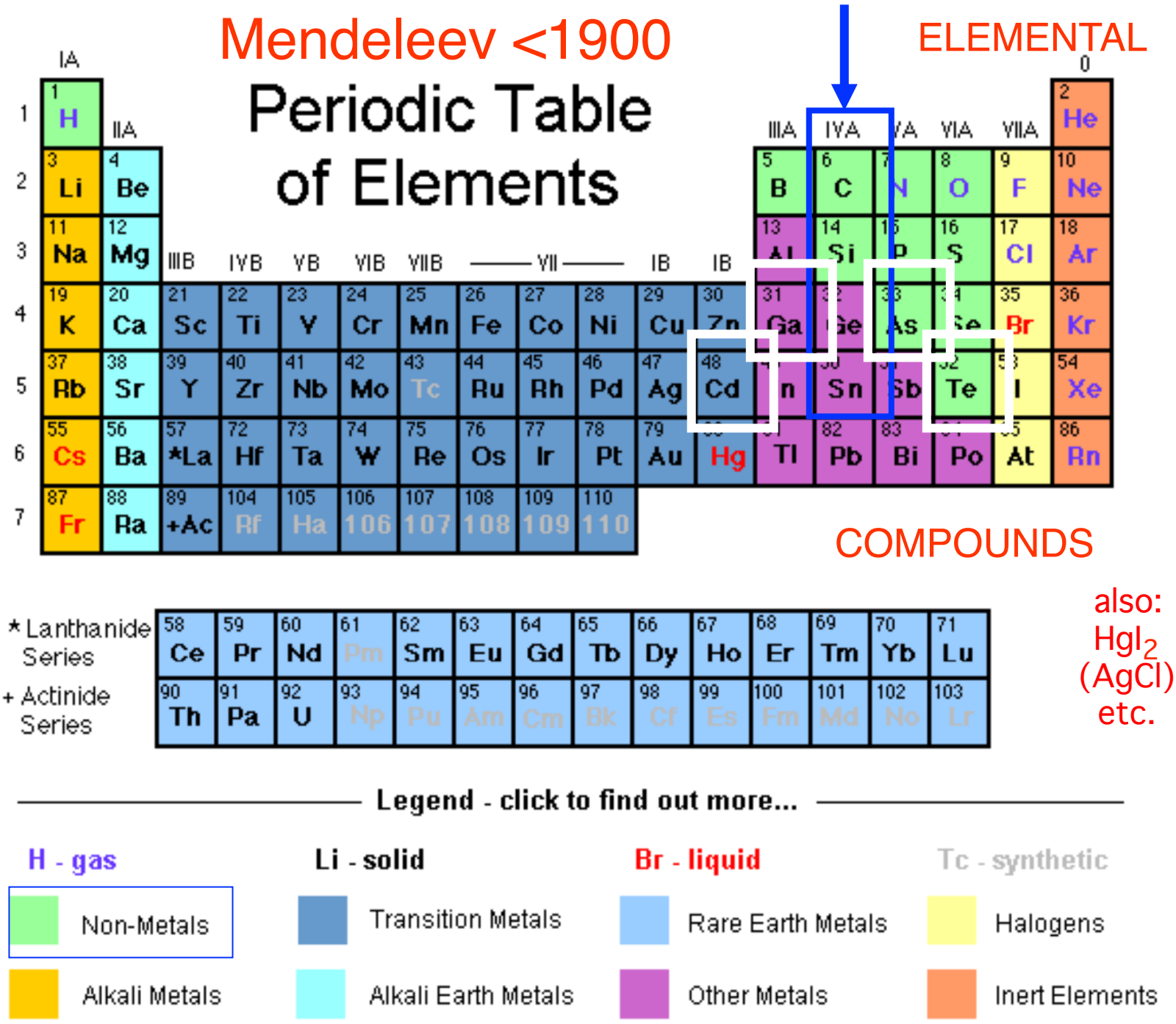
Detector Bestaat uit Schilllen : e.g. ATLAS



Drawing Nikhef

Animation of Functionality Detector Layers




Mendeleev <1900
Periodic Table of Elements
ELEMENTAL
COMPOUNDS
also: HgI_2 (AgCl) etc.
* Lanthanide Series
+ Actinide Series
Legend - click to find out more...
H - gas
Li - solid
Br - liquid
Tc - synthetic
Non-Metals
Transition Metals
Rare Earth Metals
Halogens
Alkali Metals
Alkali Earth Metals
Other Metals
Inert Elements

Isolatoren: alle electronen gebonden

→ keramische materialen, glas, ...

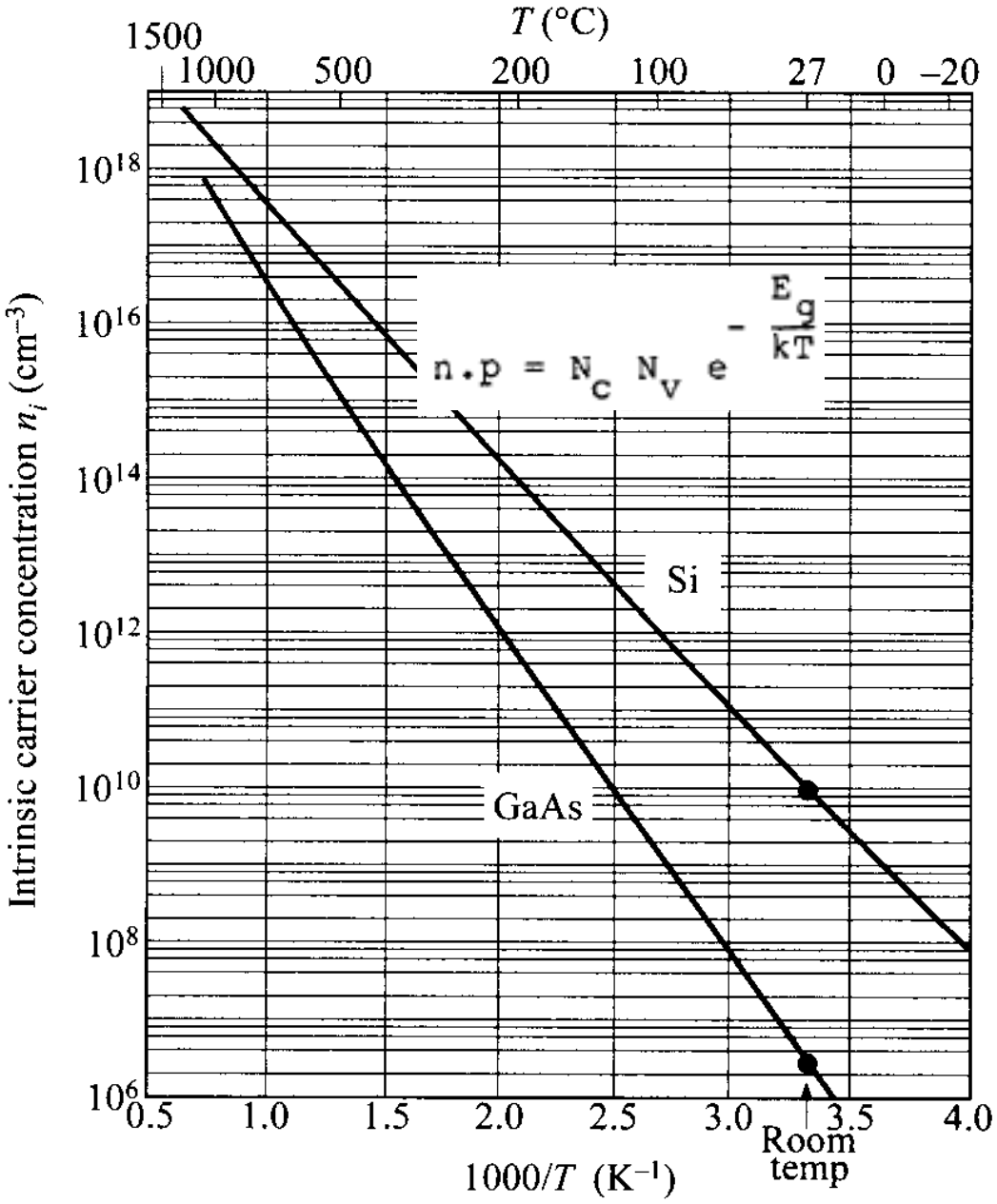
Geleiders: vol vrije electronen

→ metalen: koper, aluminium, ijzer, ...

Halfgeleiders: minder of meer electronen en ‘gaten’

→ silicium, germanium, ...

Variatie concentratie van ladingsdragers n_i



$n_i^2 = n.p$ = konstant

n elektronen
p gaten
hangt af van
bandgap en temperatuur

bij kamertemp

Si $n_i^2 = 2.6 \times 10^{20} cm^{-3}$

6-8 ordes v grootte

met $n = 10^{13} cm^{-3}$

gaten slechts

$p = 10^{7} cm^{-3}$

GaAs $n_i^2 = 1.2 \times 10^{14} cm^{-3}$

volgens Sze
Physics of semiconductor devices
Wiley

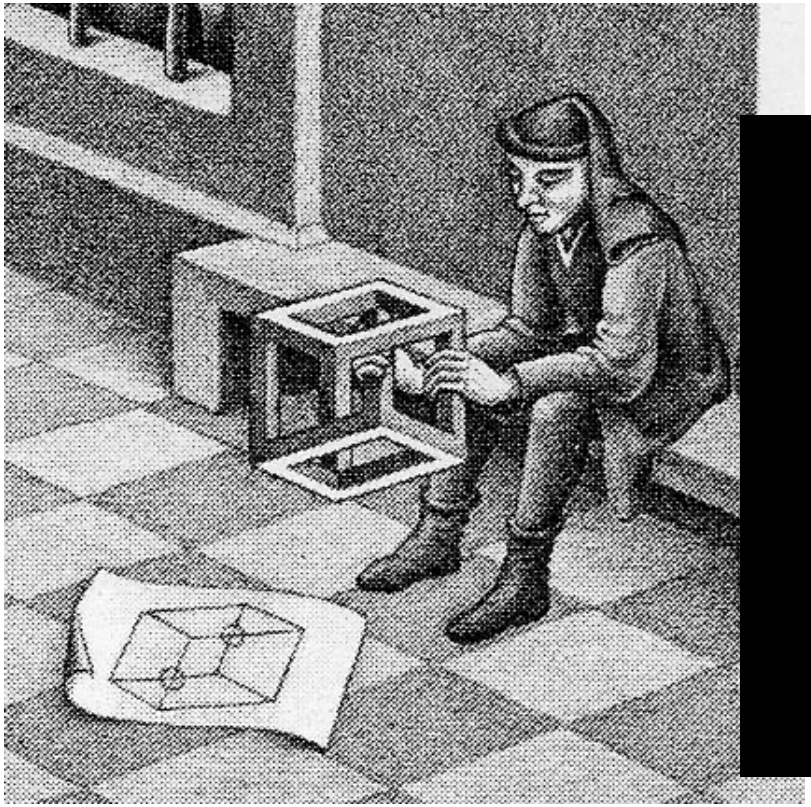
Elektronica: spelen met elektronen

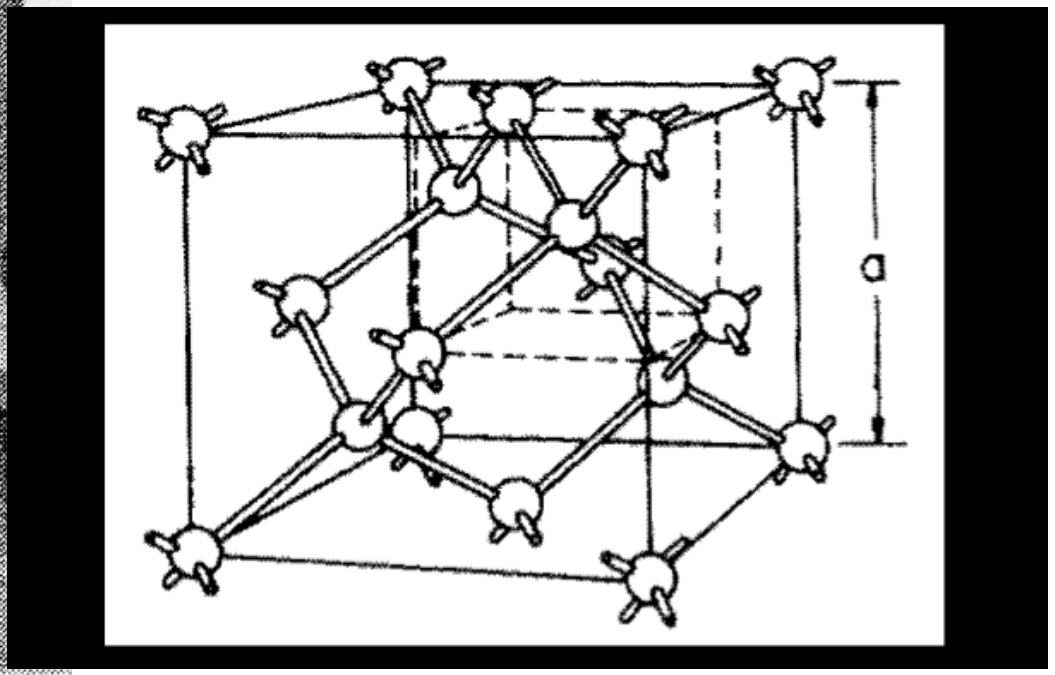
vanaf ~1900 in vaküum buizen

in 1948 halfgeleider transistor

eerst germanium, later silicium...

Eénkristal van halfgeleider - silicium





Silicium

Imagination and Innovation

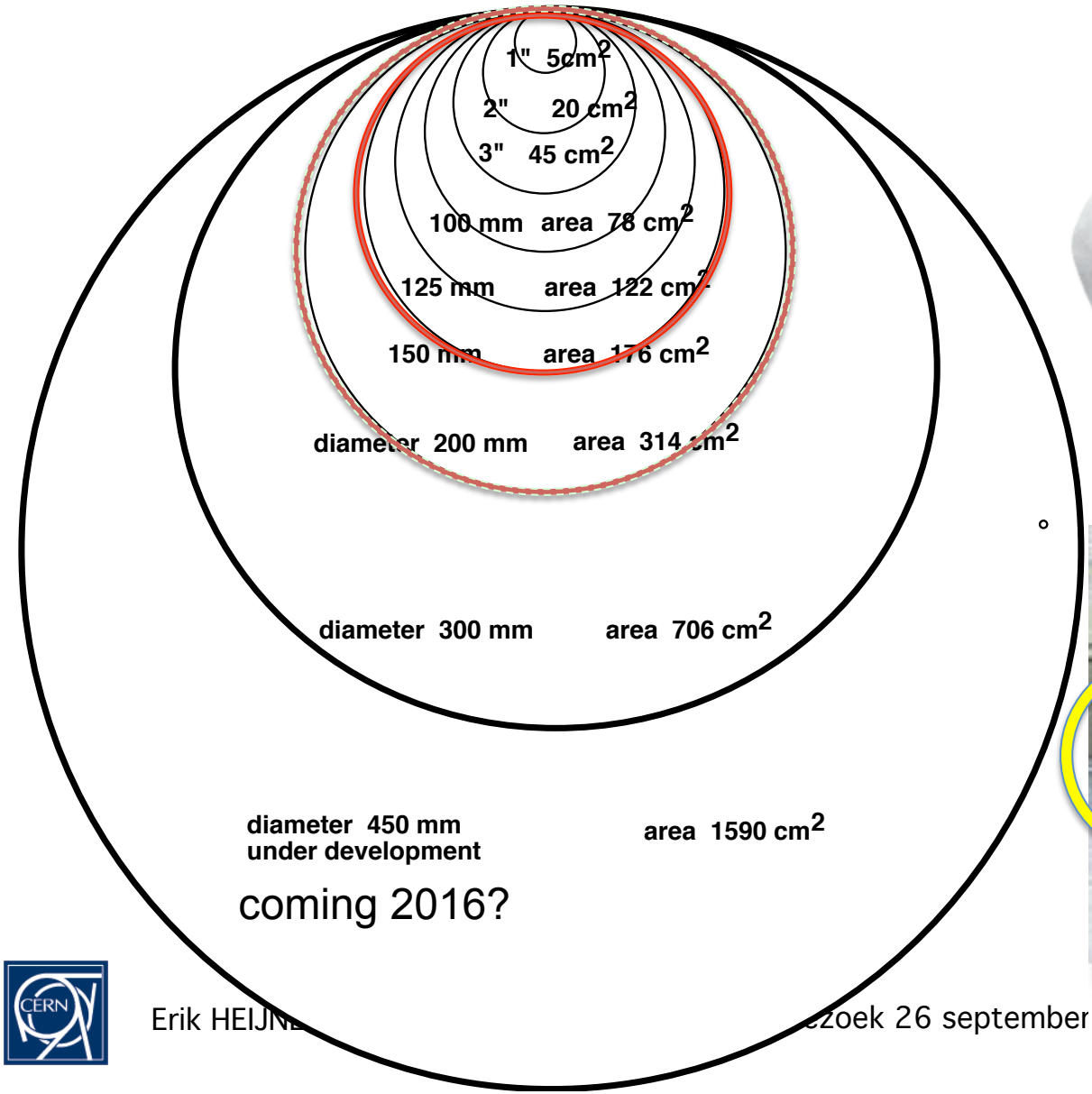
- gevoelig voor zichtbaar licht (CCD, CMOS kamera)
- ook voor allerlei andere straling (>1.12 eV bandgap)
  lage Z, niet efficient voor γ >10keV
- regelbare geleiding over 10 ordes (x10^{10})
- oppervlakte-oxide heeft een hoge impedantie/isolatie

~1955 Bell, 1959 Planair(Hoerni-Fairchild), 1970 LOCOS(Kooi,Philips)

Silicon single crystal growing

1955-2015 **Wafer sizes**

Increase of wafer diameter 3/4” - 450mm



CZ Crystal Pullers
(Mitsubishi Materials Silicon)

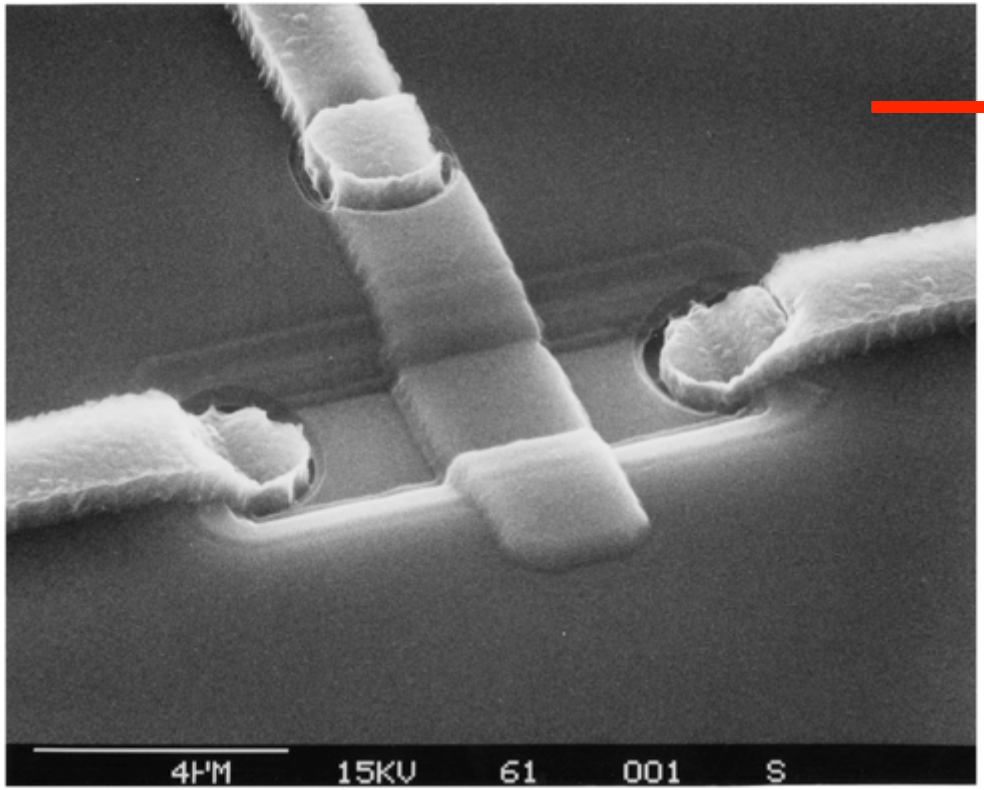
MOS Technologie METAL – OXIDE – SILICON

de fundametele componenten:

* MOS condensator — CCD imager matrix
  'beeldopnemer'
* p – n diode — CMOS imager matrix
* diverse transistors

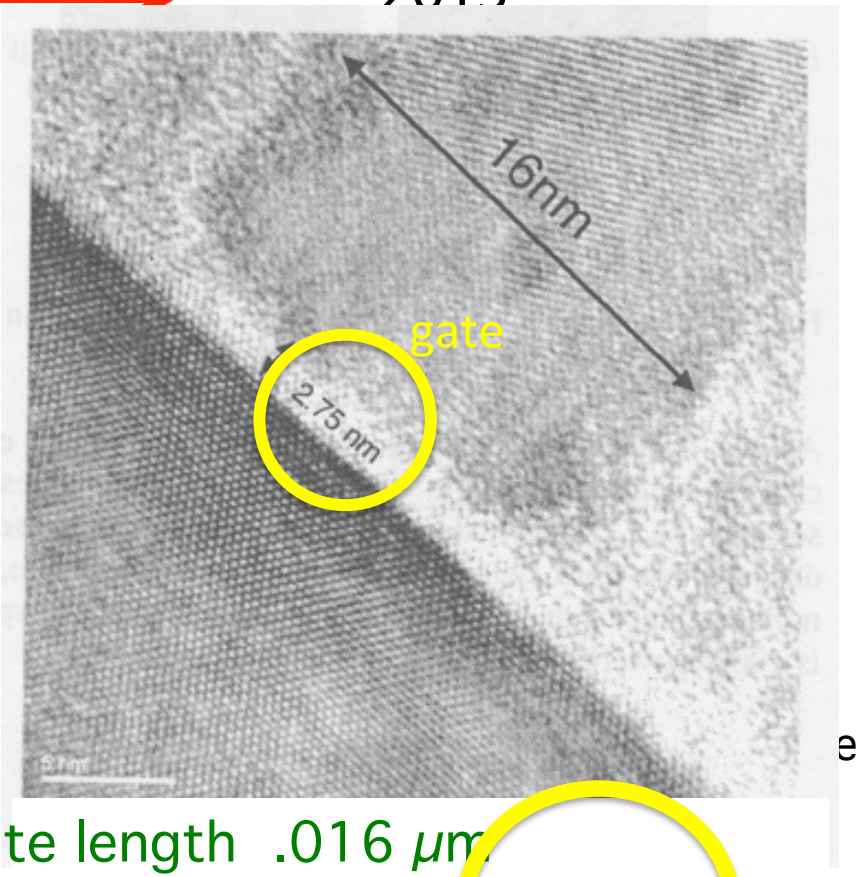
weerstanden met beperkte waardes in dunne metaal-lagen

Integrated electronics is key: silicon MOS transistor



continuous scaling/miniaturization

2015



2 μm TECHNOLOGY

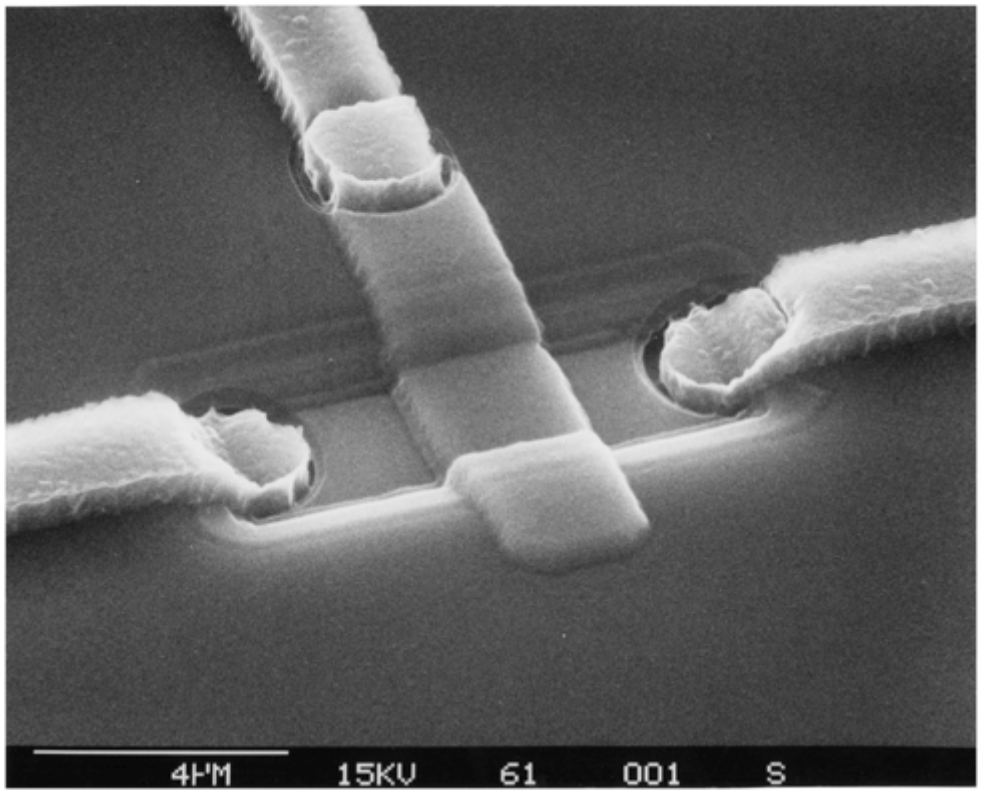
1985

HEP was 2 generations behind industry

gate length .016 μm

SiO_2 gate thickness 2.75 nm

SILICON MOS TRANSISTOR

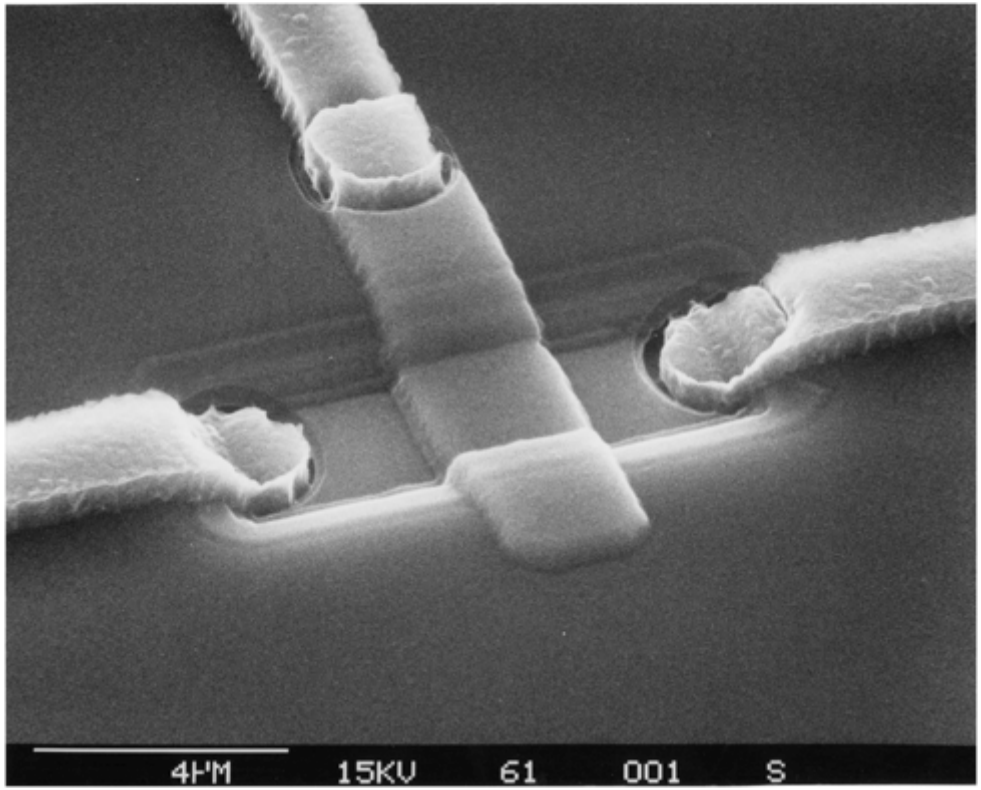


CORRECT SCALE

SiO_2 gate 2.75 nm

2 μm TECHNOLOGY 1982 0.016 μm 2007

Integrated electronics is key: silicon MOS transistor



continuous scaling/miniaturization

2015

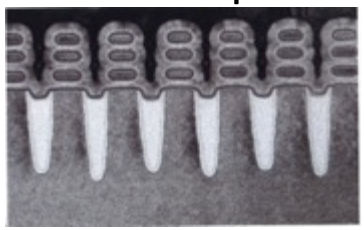
same scale

gate length .016 μm

SiO_2 gate thickness 2.75 nm

thin gate usually radhard

2017 development at IBM



gate-all-around source IBM

not same scale

2 μm TECHNOLOGY

1985

HEP was 2 generations behind industry

0.005 μm

2017

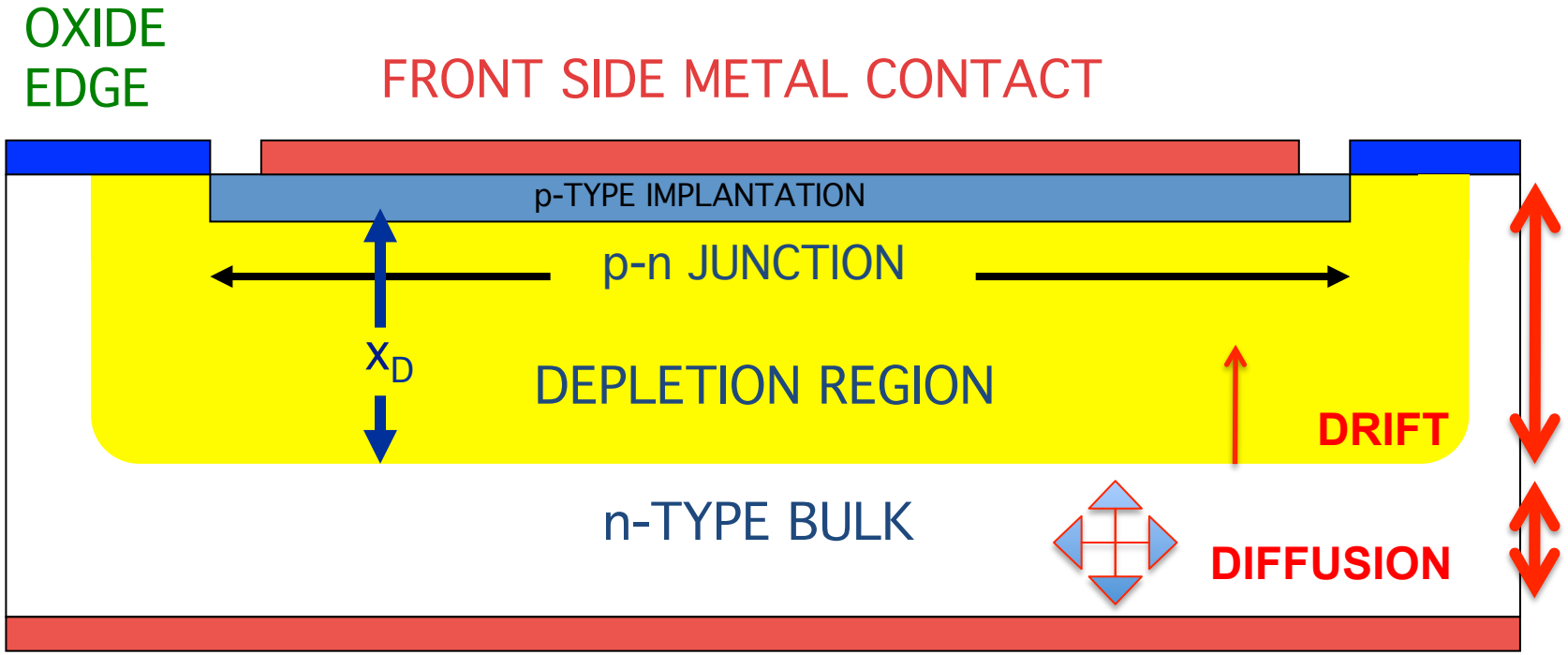
now HEP is 8 generations behind

gelijkrichtende diode is
eenvoudigste component in Si

kan licht en ioniserende deeltjes waarnemen

signaal van elektronen en gaten

SCHEMATIC of DIODE



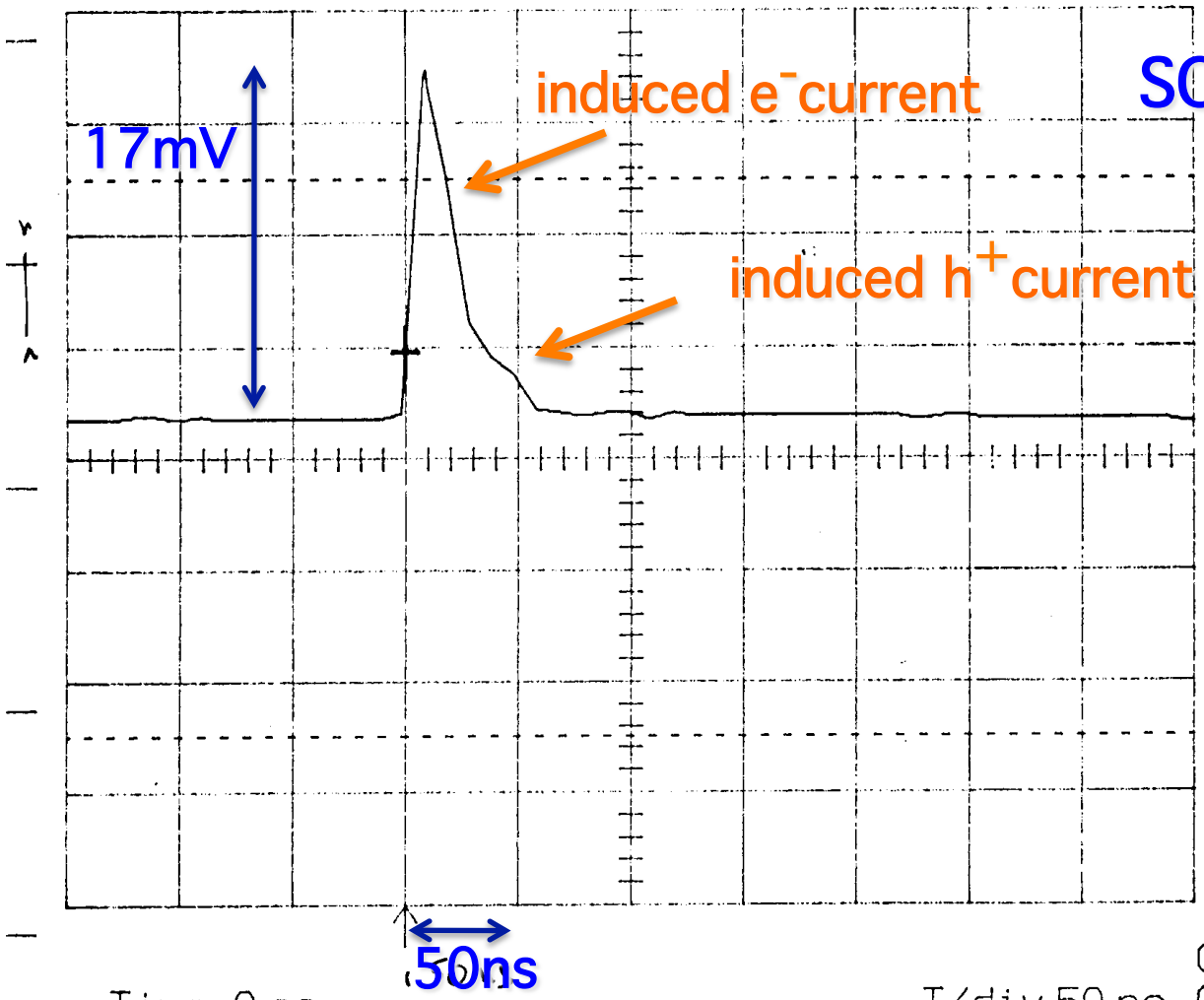
$$x_D = \sqrt{\frac{2\ \varepsilon}{q\ n}(V_0 + V_B)} = \sqrt{2\varepsilon\mu_e\rho\ (V_0 + V_B)}$$

x_D CAN BE LARGE, BECAUSE HIGH RESISTIVITY of BULK Si

Si SIGNAL SPEED

SIGNAL CURRENT from Pb ION in 200μm Si DETECTOR

SCOPE on 50 Ω ONLY



FAST RISE TIME

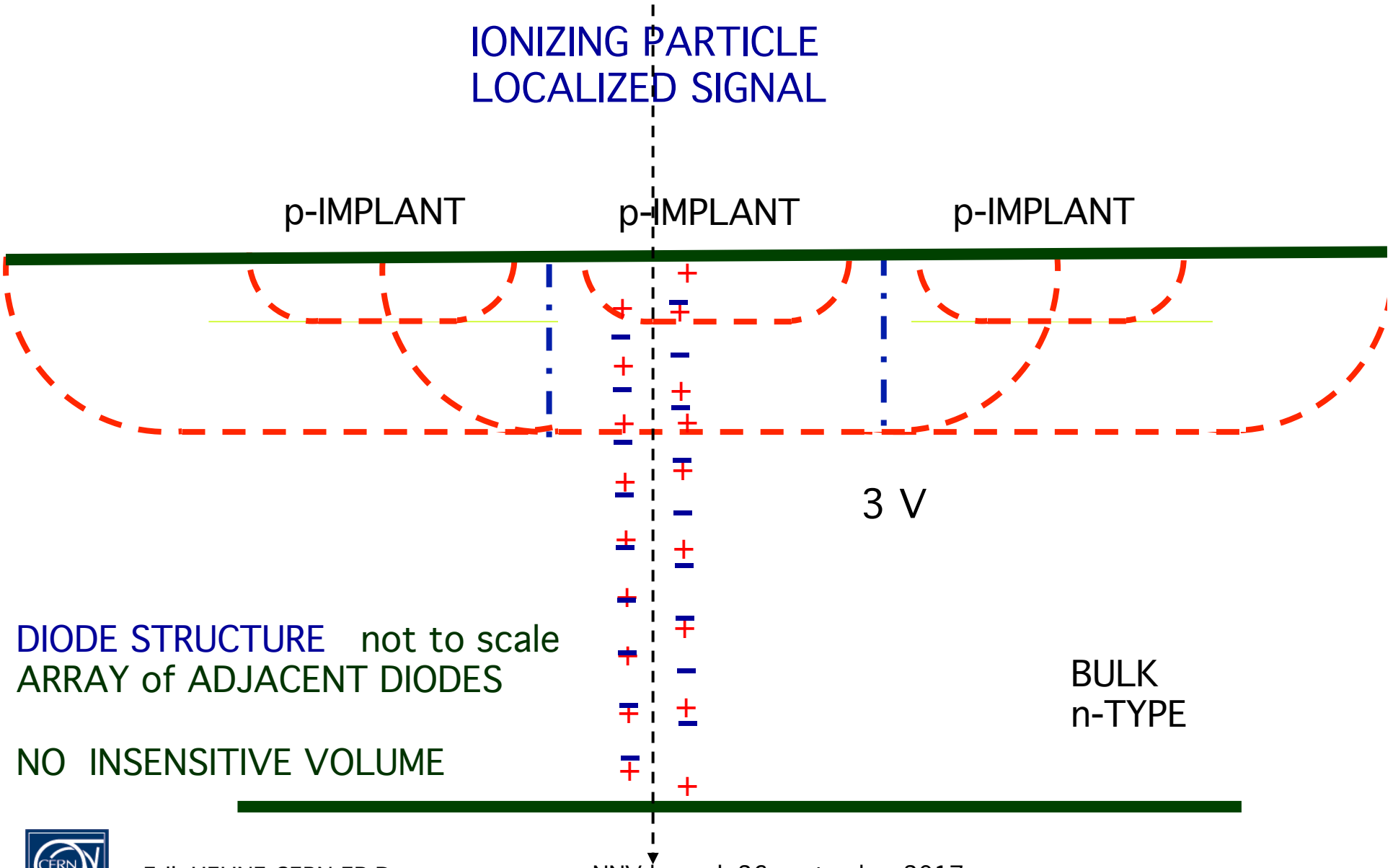
limited by RC time

50 Ω x100pF=5x10^{-9}s

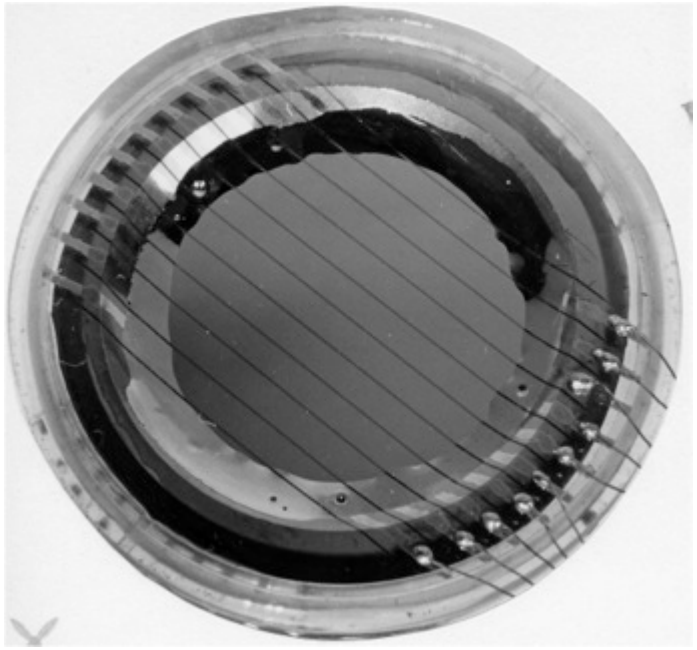
diode-oppervlak kan worden gesegmenteerd

allerlei patronen mogelijk:
microstrips
pixels

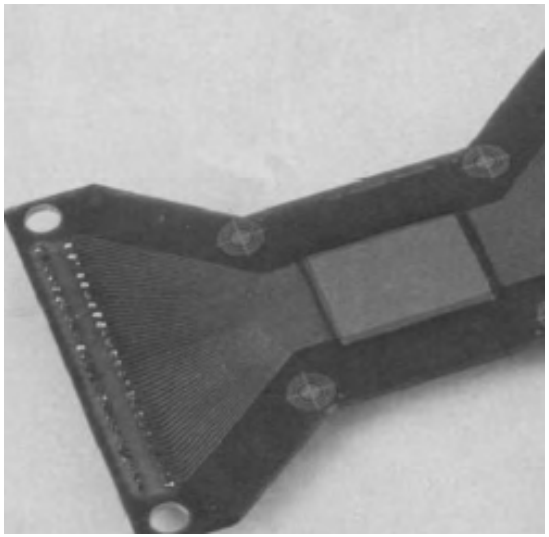
SILICON DIODE DETECTORS



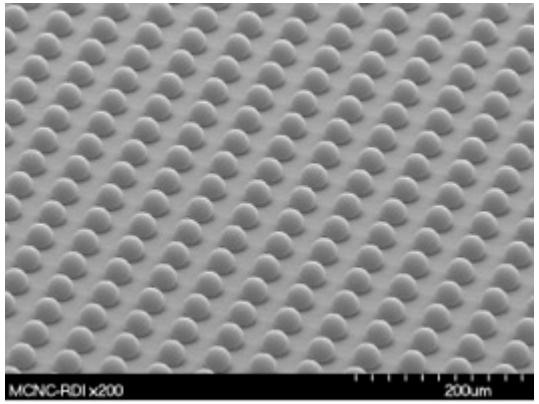
DIODE SEGMENTATION



~1965
PHILIPS
100 x 1370umx1370um

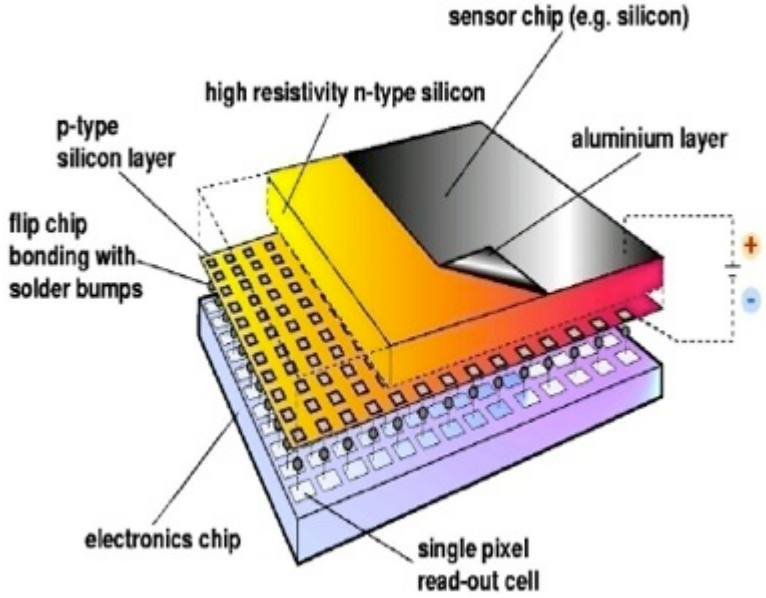


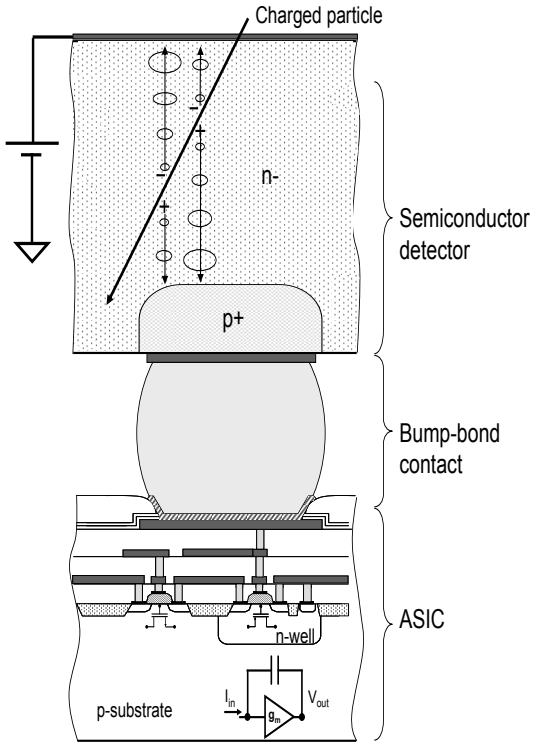
1980
CERN / ENERTEC
100 x 4000umx200um



~2000
CERN / MEDIPIX
65000 x 55umx55um

Hybrid Silicon Pixel Detectors

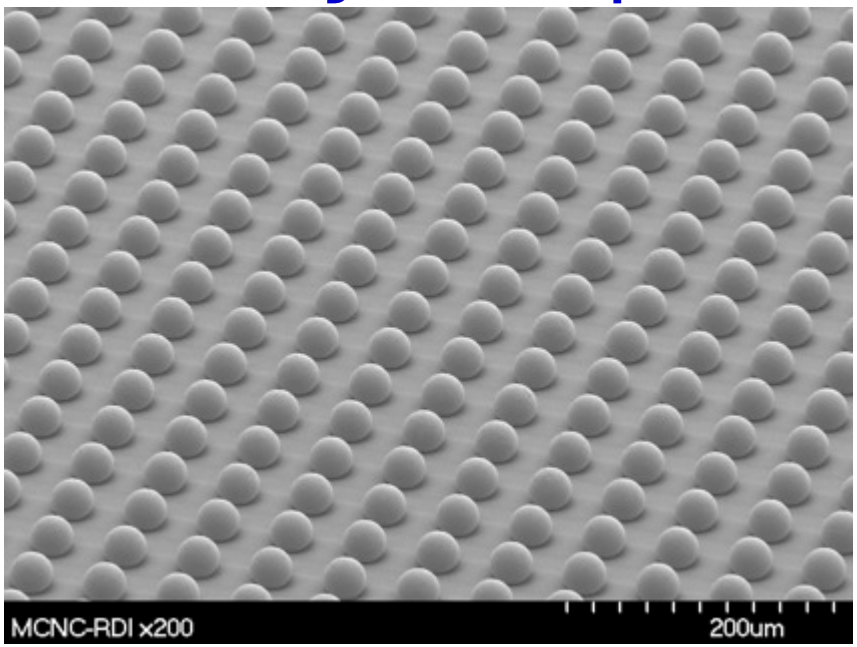




Standard CMOS can be used allowing on-pixel signal processing

Sensor material can be changed (Si, GaAs, CdTe..)

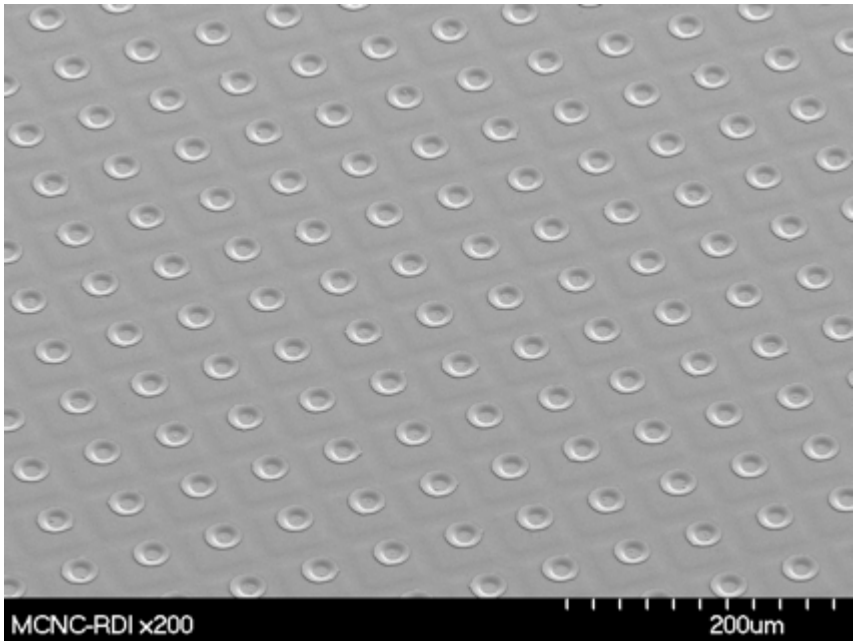
Hybride pixel detektor Medipix2



SEM fotos gemaakt door
MCNC-RDI, DURHAM NC - USA

PITCH 55 µm

MEDIPIX2 CERN 2001
CAMPBELL & LLOPART
256 kolommen x 256 rijen
pixel 55µm x 55 µm



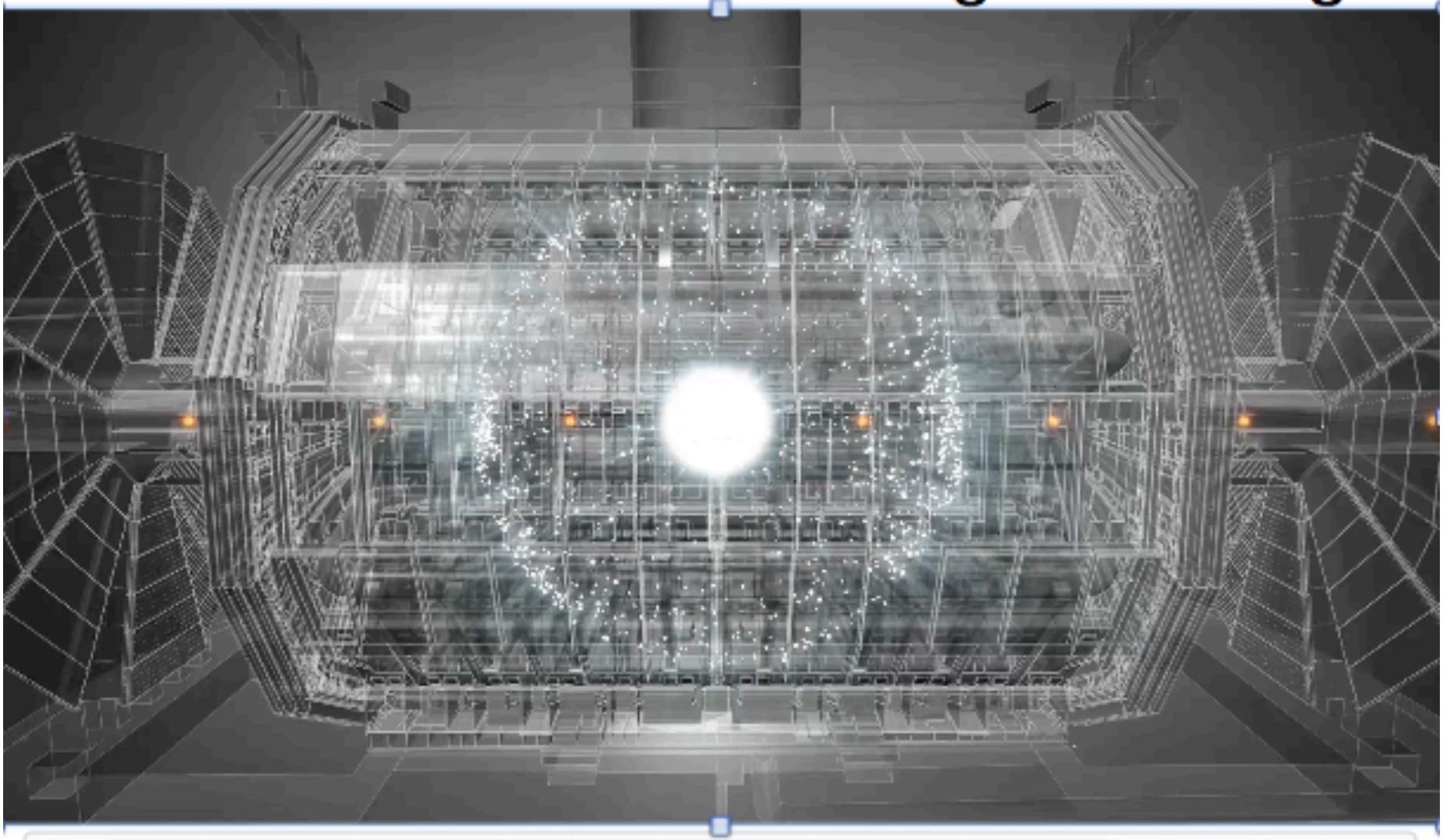
Een halfgeleider-volume/diode als detektor

Een ioniserend deeltje verliest energie, die maakt elektronen ‘e’/ gaten ‘h’ los
zodat er een signaal kan worden geïnduceerd op elektrodes aan de buitenkant van de diode

Dankzij een aangelegd elektrisch veld
vliegen vrijgemaakte ladingen met hoge snelheid

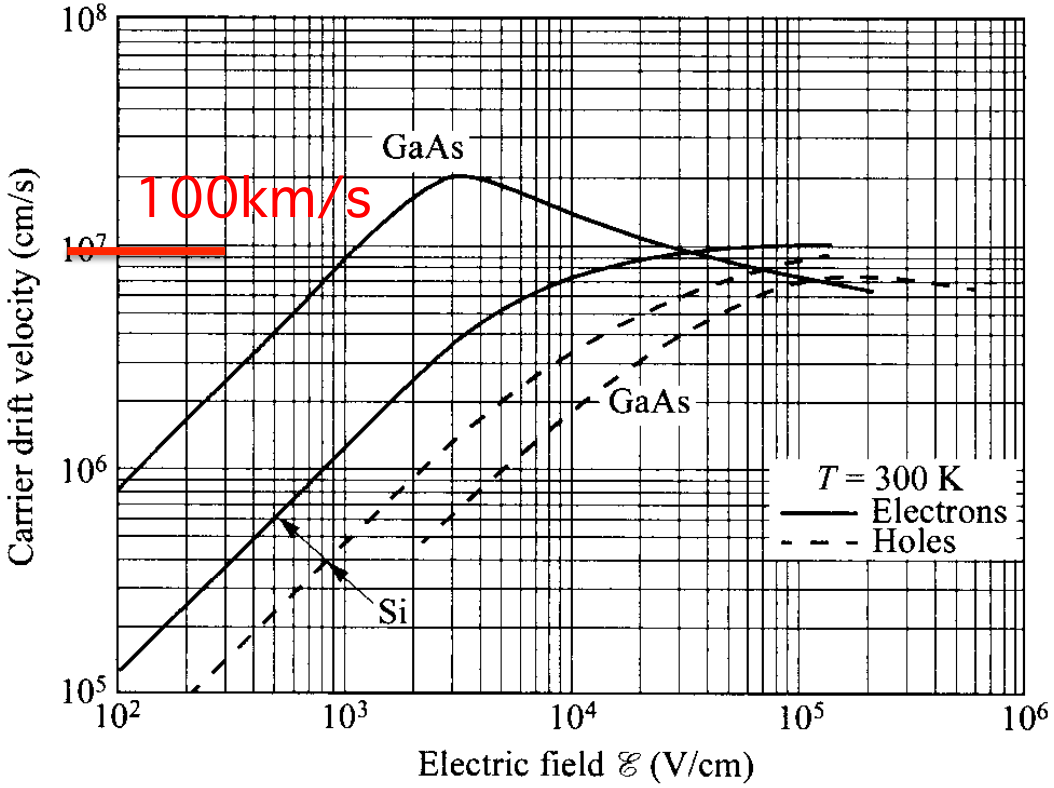
zie volgende snelheids grafiek voor e en h

Animatie van Bunch Crossings en Timing

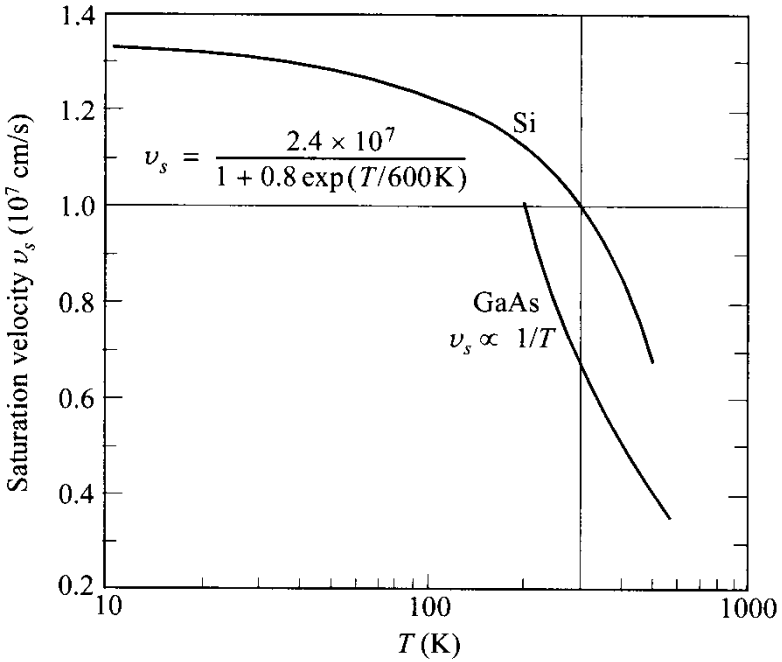


CARRIER TRANSPORT in Si and GaAs

CARRIER DRIFT VELOCITY vs FIELD



SATURATION vs TEMP



MOBILITY is a function of doping, temp, field..

SEMICONDUCTOR DETECTORS ARE INHERENTLY FAST : 5 - 20 ns

360 000 km/h

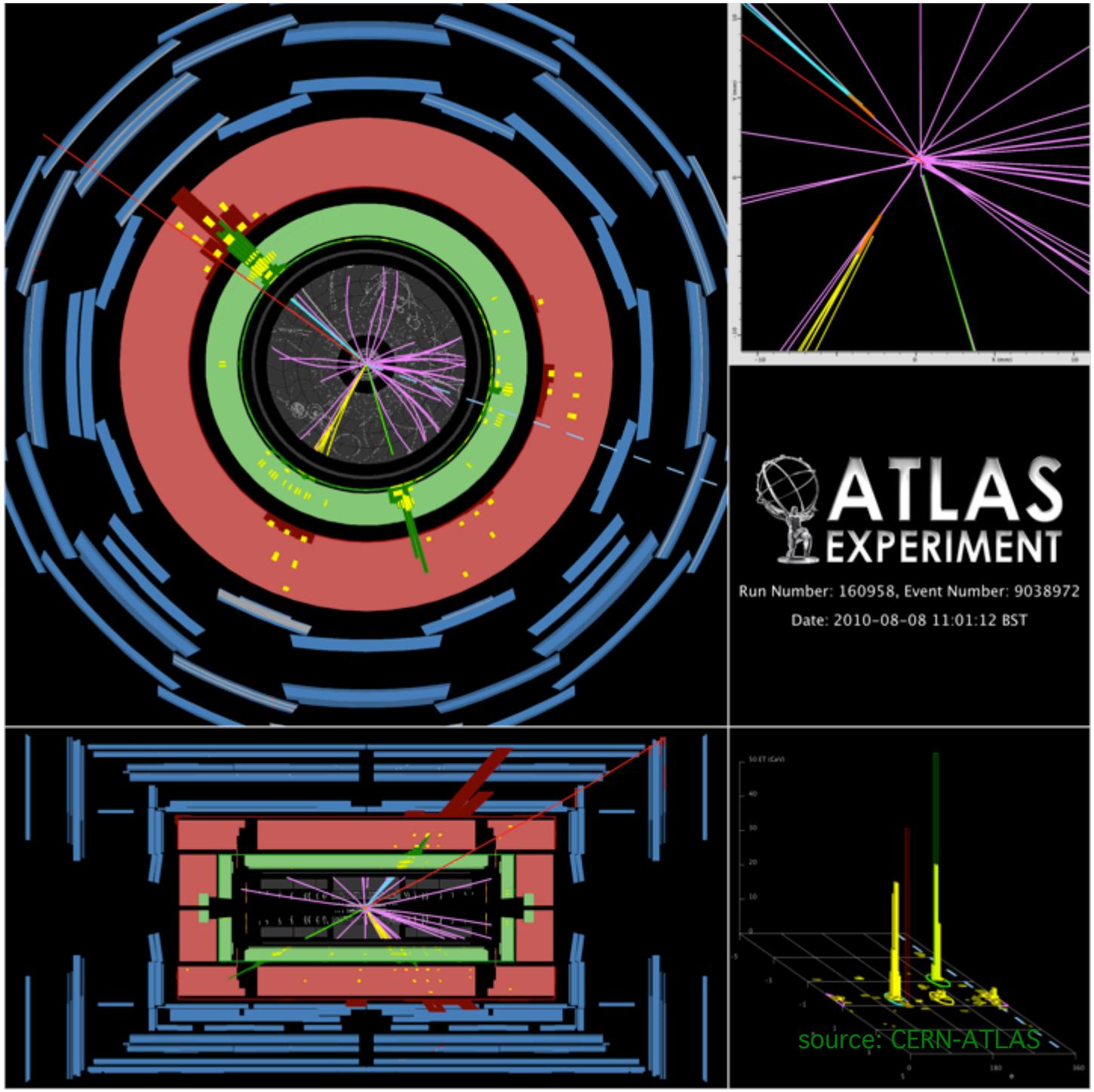
Imaging Now
All Electronic
with 3-D
Reconstruction

Many Tracks
and 2 “Jets”

40 million / sec

Secondary
Vertex:
a short-lifetime
particle is a
messenger for
something new

see blow-up

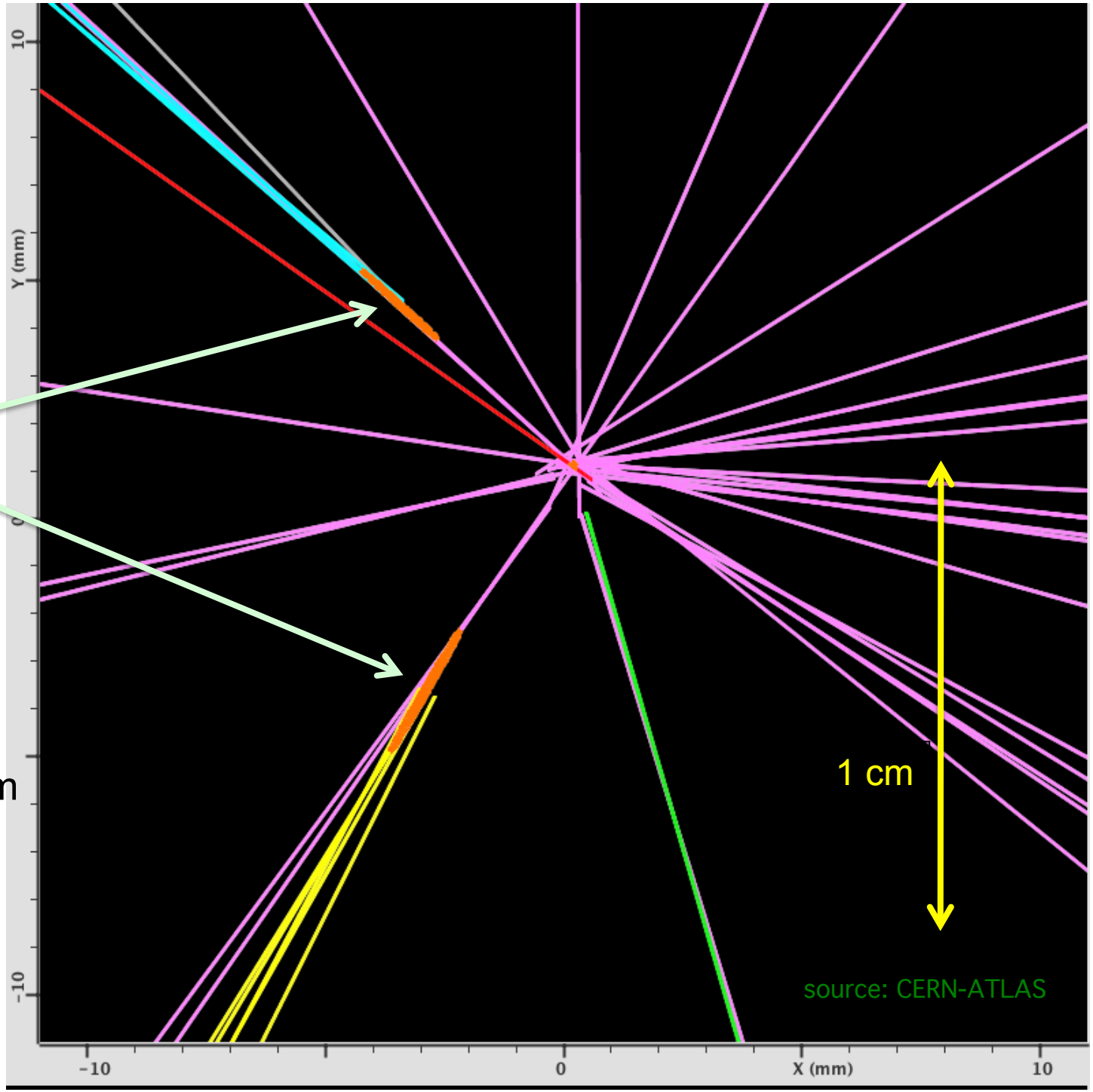


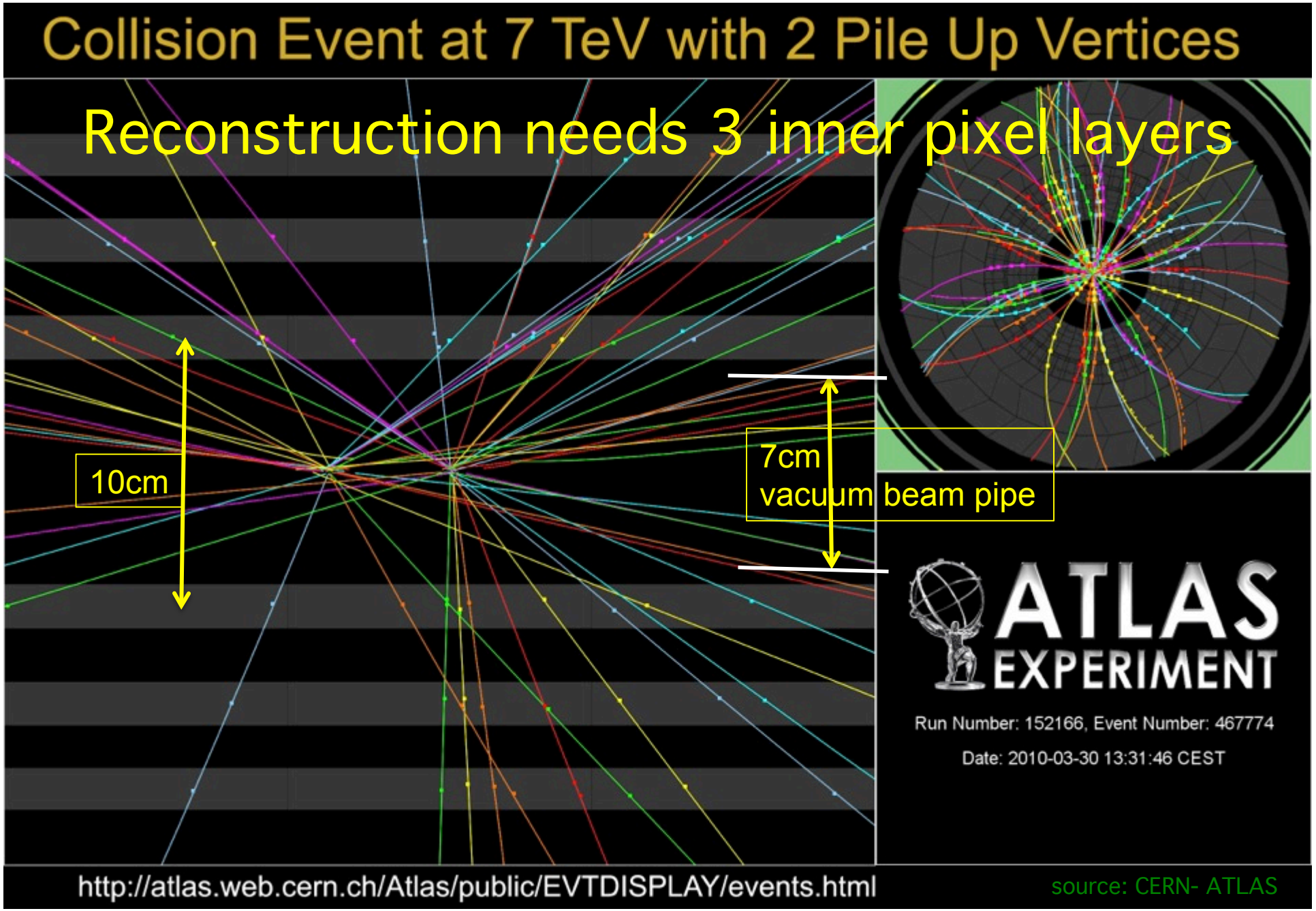
ATLAS

Details around
Primary Vertex

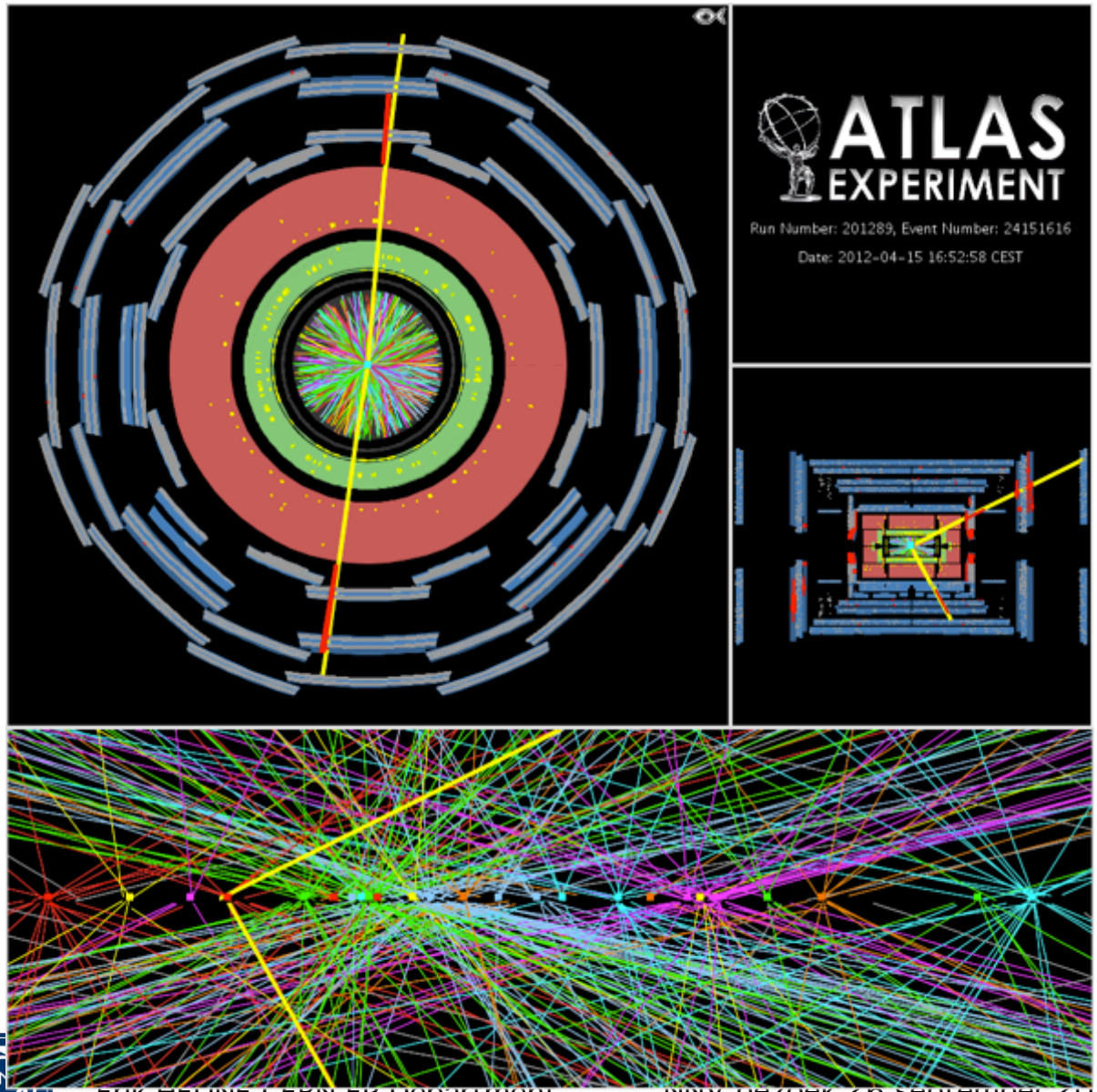
Two Secondary
Vertices

Note scale
1cm
all this is INSIDE
beam pipe ∅ 7cm

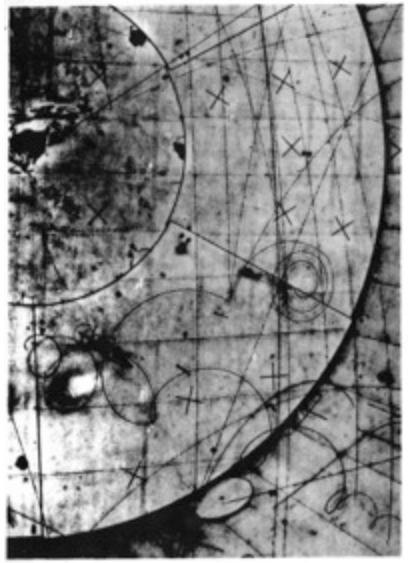


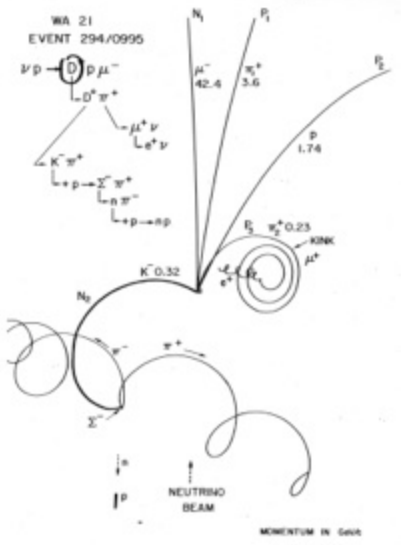

Collision Event at 7 TeV with 2 Pile Up Vertices
Reconstruction needs 3 inner pixel layers
10cm
7cm
vacuum beam pipe
ATLAS
EXPERIMENT
Run Number: 152166, Event Number: 467774
Date: 2010-03-30 13:31:46 CEST
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html
source: CERN- ATLAS

Multiple interactions in one LHC crossing



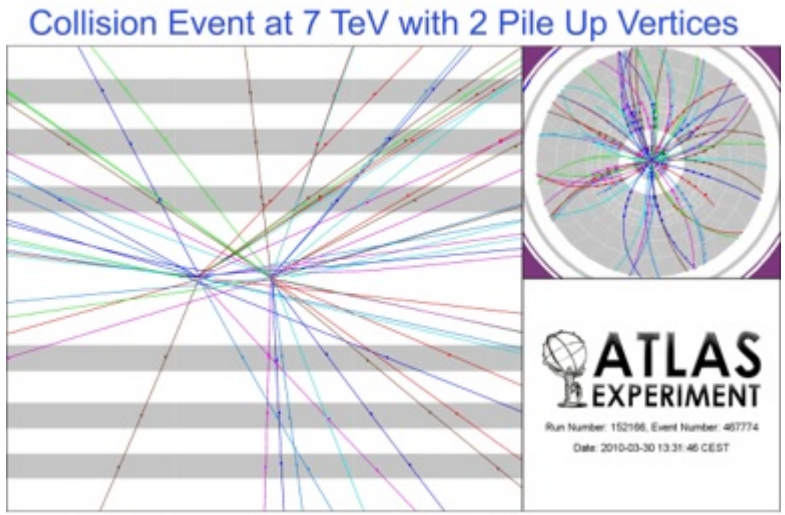
Study of elementary particles:
from Bubble Chambers to fully Electronic Imagers



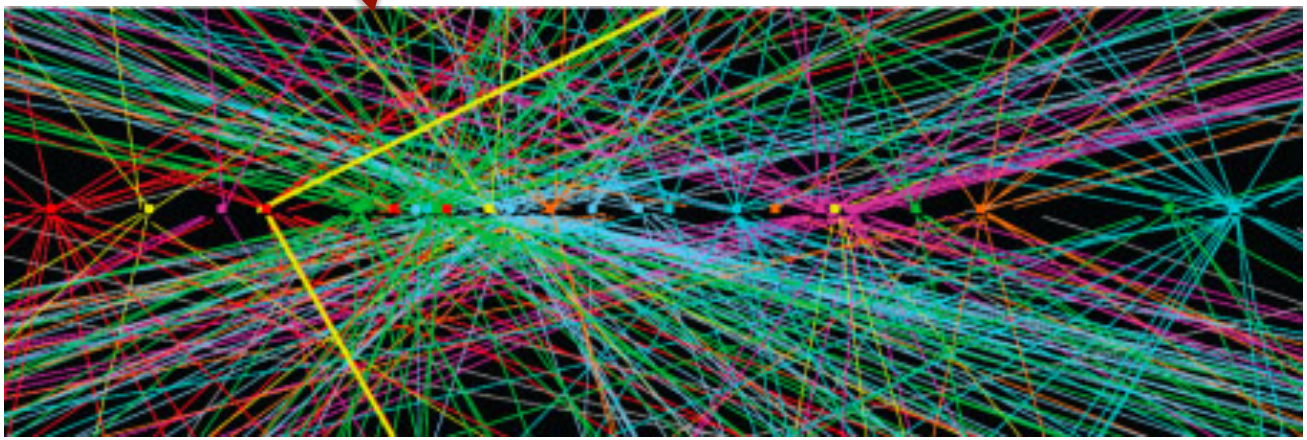


BEBC 1981
photo every ~1s

ATLAS experiment 2012



http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

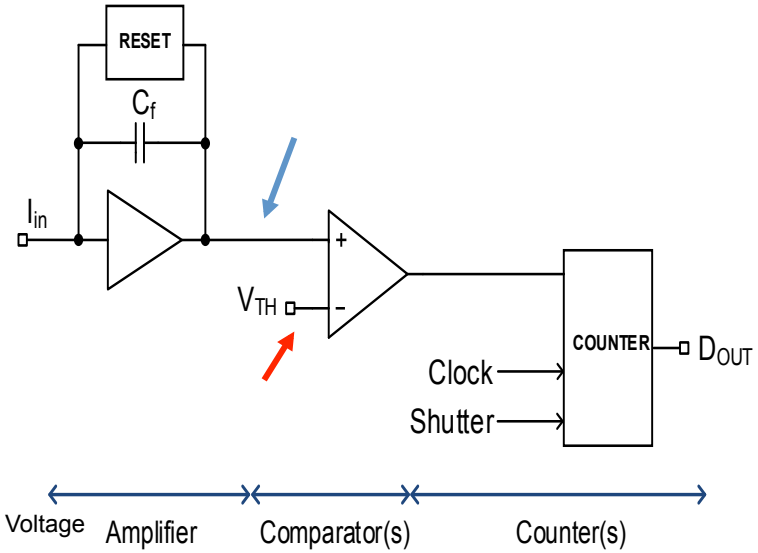


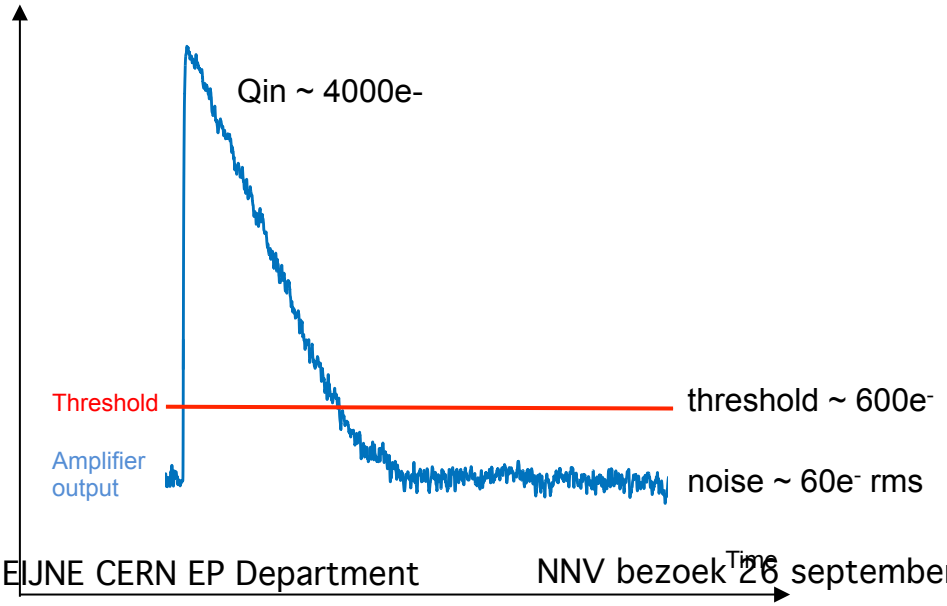
40 million
records per s

Liquid H → silicon for vertexing (but image information is lost)

Timepix miniaturised readout

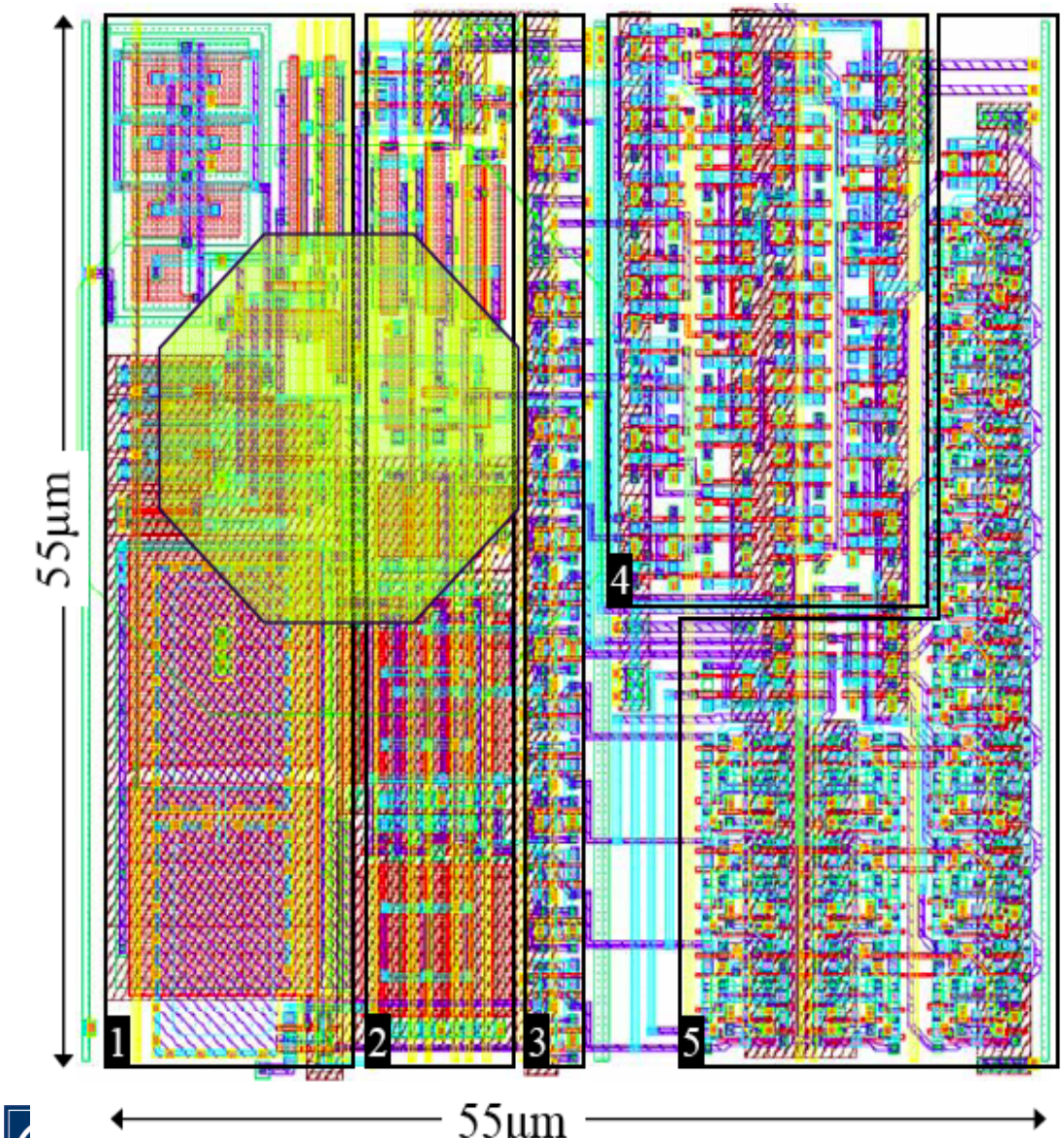
Hybrid Pixel Detector - Basic Detection Pinciple





→ Noise hit free imaging

TIMEPIX CELL LAYOUT



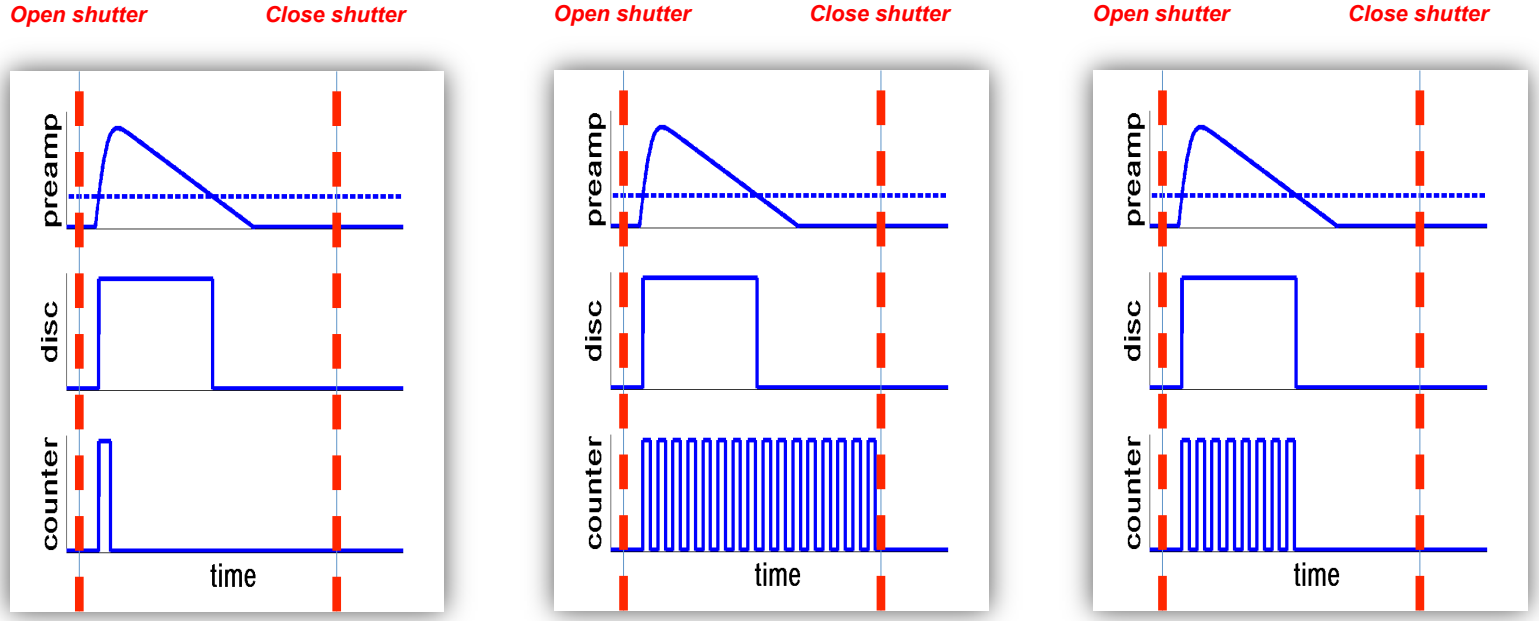
DESIGNER
Xavier LLOPART
CERN
PhD Thesis p. 107

1. PREAMPLIFIER CSA
2. THRESHOLD, 4-BIT TUNING
3. 8-BIT CONF REGISTER
4. REF_CLK & SYNCHR LOGIC
5. 14-BIT COUNTER

Timepix Pixel Operation Modes

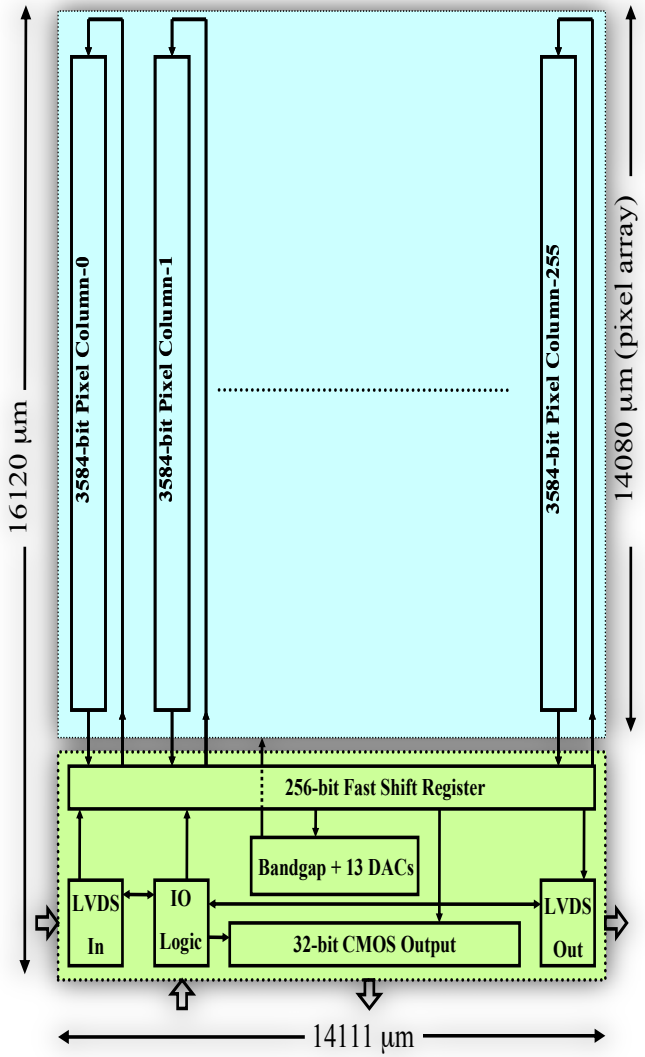
Particle counting

- Arrival Time*
- Time over threshold



* Implemented at the request of the EUDet Collaboration

Timepix chip architecture



3-side Buttable floorplan

In acquisition mode chip an external clock is used as a time reference (up to 100 MHz)

256x256 55μm square pixels
Analog Power → 440mW
Digital Power (Ref_Clk=50MHz) → 220mW

> 36M Transistors

System on chip design:

- On-chip digital global biasing:
  - 14 DACs + Bandgap
- Simple control logic
- Serial readout (@100MHz) → 9.17 ms
- Parallel readout (@100MHz) → 287 μs
- Daisy-chain (serial only) for simple multiple chip readout

Timepix Specificaties

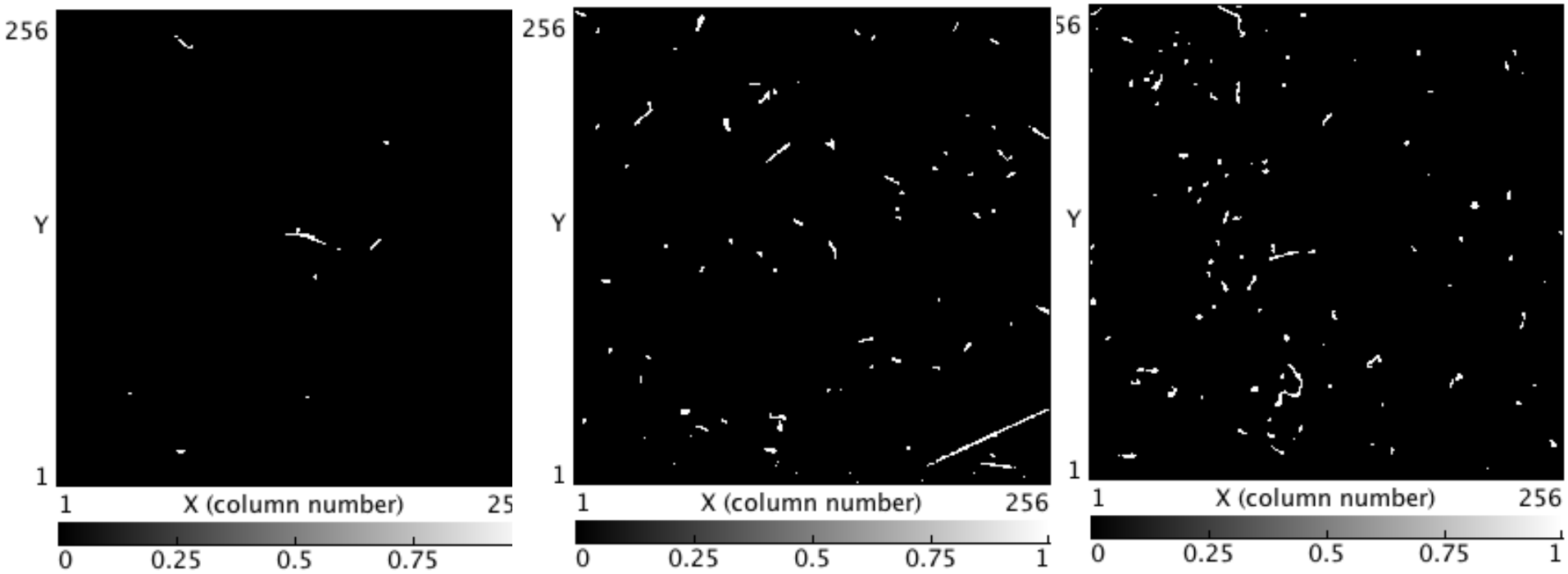
CMOS node	250nm
Pixel Array	256 x 256
Pixel pitch	55µm
Charge collection	e^-, h^+
Pixel functionality	PC (Particle Counting), TOT (Energy) or TOA (Arrival time)
Preamp Gain	~16.5mV/ke^-
ENC	~100e^-
FE Linearity	Up to 50ke^-
TOT linearity (resolution)	Up to 200ke^- (<5%)
TOA resolution	Up to 10ns (@ 100 MHz)
Time-walk	<50ns
Minimum detectable charge	~700e^- → 2.5 KeV (Si Sensor)
Counter Depth/ Overflow	14-bits(11810)/Yes
Max Analog power (2.2V)	6.5µW/pix 190mA/chip
Static Digital Power (2.2V)	~500mW@100MHz/chip
Readout (@ 100 MHz)	Serial readout → 9.17 ms 32-bit Parallel readout → 287 µs

Single Quanta zijn overal om ons heen

60s Exposure at ground level

60s Exposure in plane at 24 000 feet

6s Exposure with old wristwatch (radium)



Dose levels steeds nog op veilig niveau

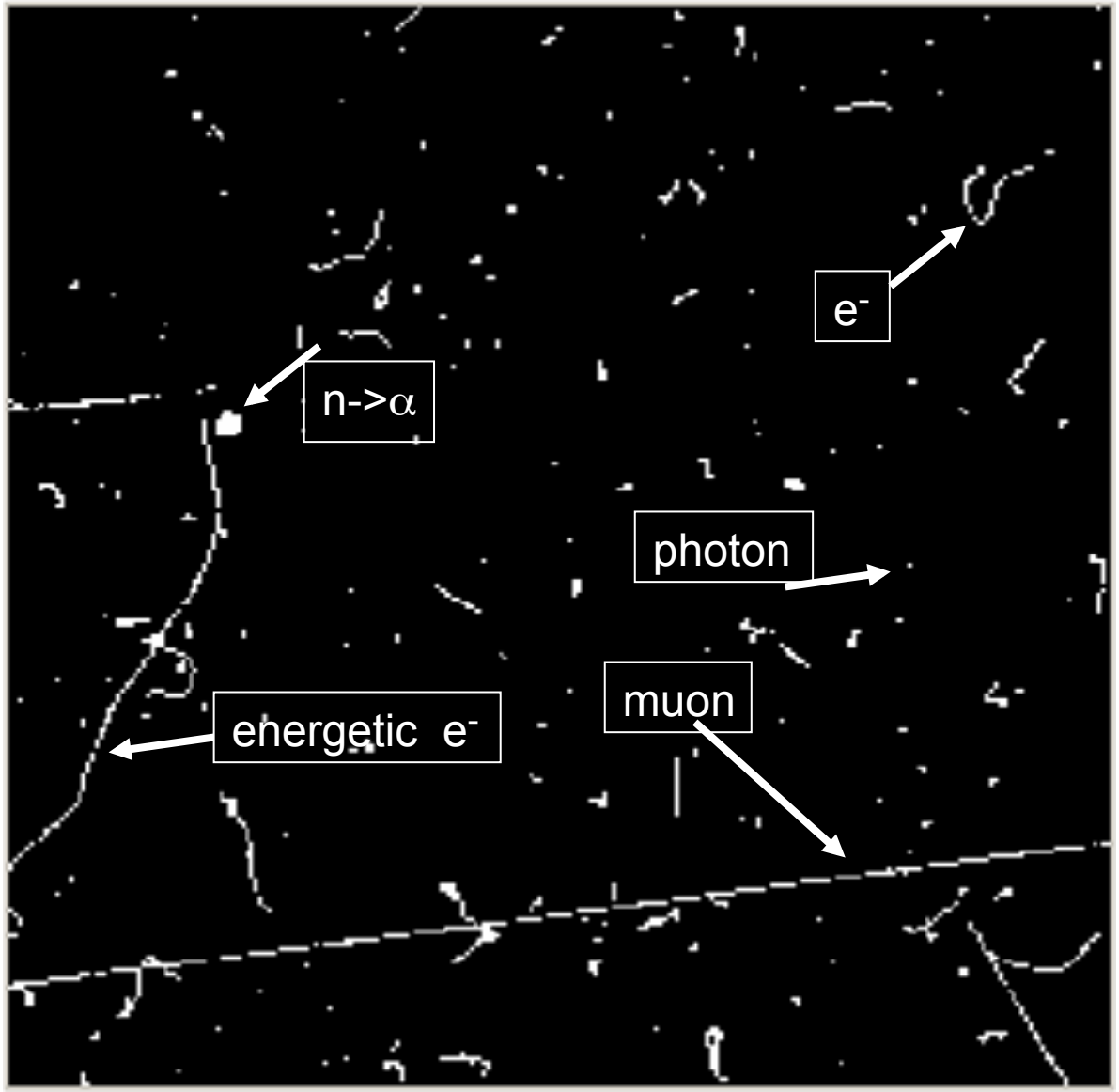
COSMIC PARTICLES in MXR Si PIXEL

256 x 256 PIXELS
300 µm THICK

CAN BE
RADIATION
DOSE METER

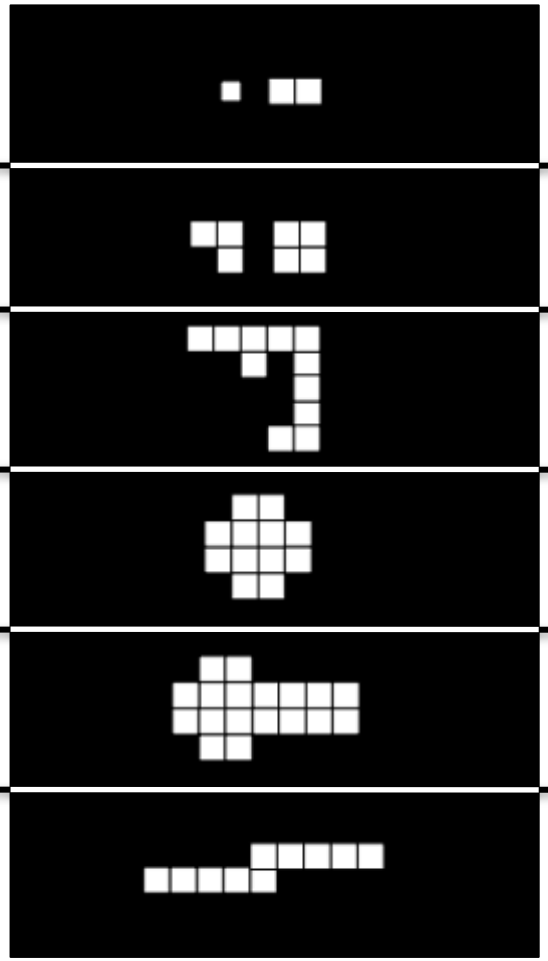
IDENTIFY SPECIFIC QUANTA
- ELECTRONS
- PHOTONS
- MIPs
- NEUTRONS -> ALPHAs

ADJUSTABLE EXPOSURE
ms - minutes GIVES
LARGE DYNAMIC RANGE

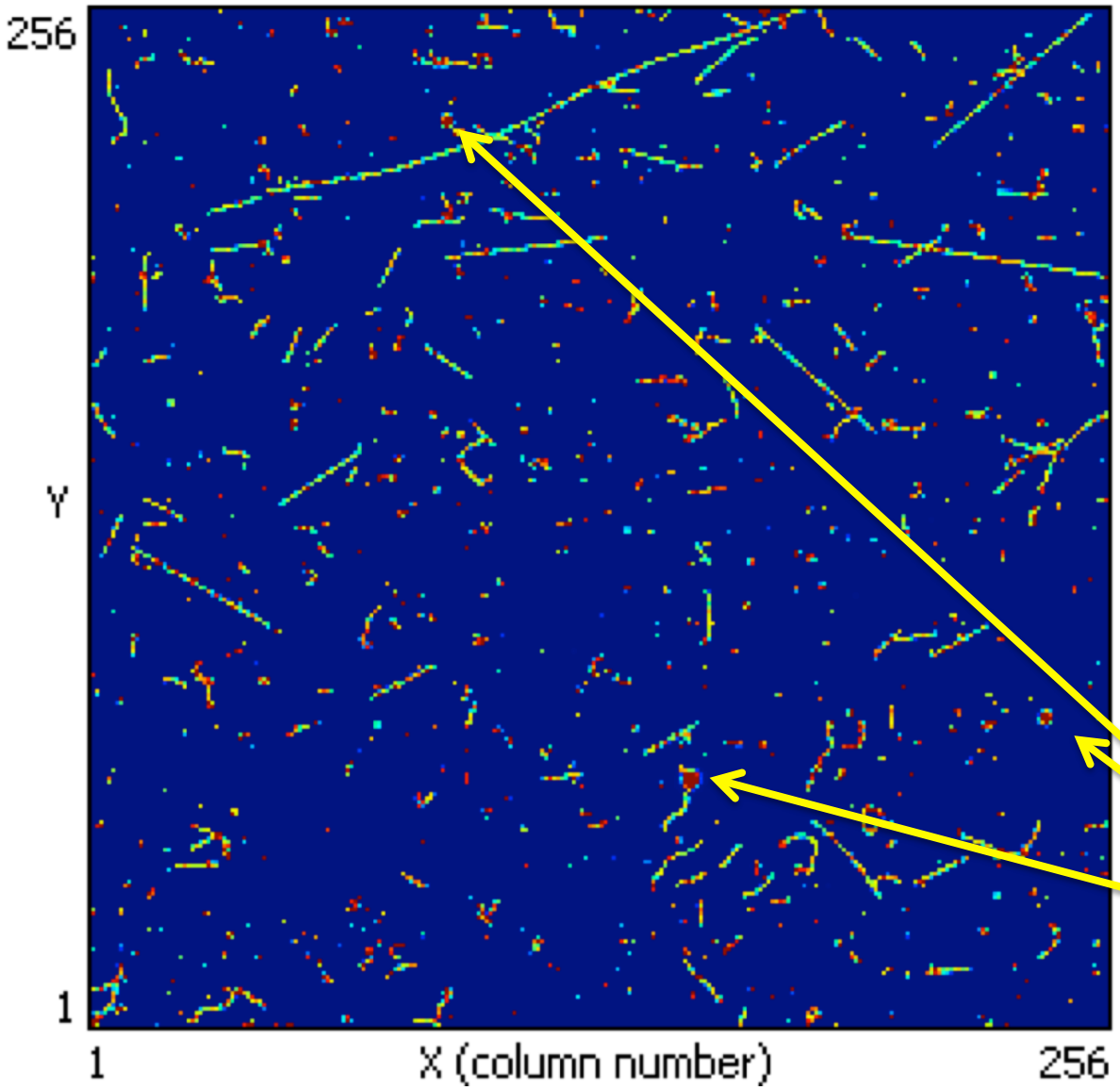


Frame CTU Prague

Characteristic cluster patterns in Medipix



1) Dot	Photons and electrons (10keV)
2) Small blob	Photons and electrons (~100keV
3) Curly track	Electrons (MeV range)
4) Heavy blob	Heavy ionizing particles with short range (alpha particles,…)
5) Heavy track	Heavy ionizing particles (protons,nuclei, Fe, …)
6) Straight track	Energetic light charged particles (MIP, Muons,…)



kwt-011May12-j-D9W15-tot-3n-4764s

Natural background at home with Medipix-T

0.51 mSv el.mag.component
0.63 mSv alpha.component

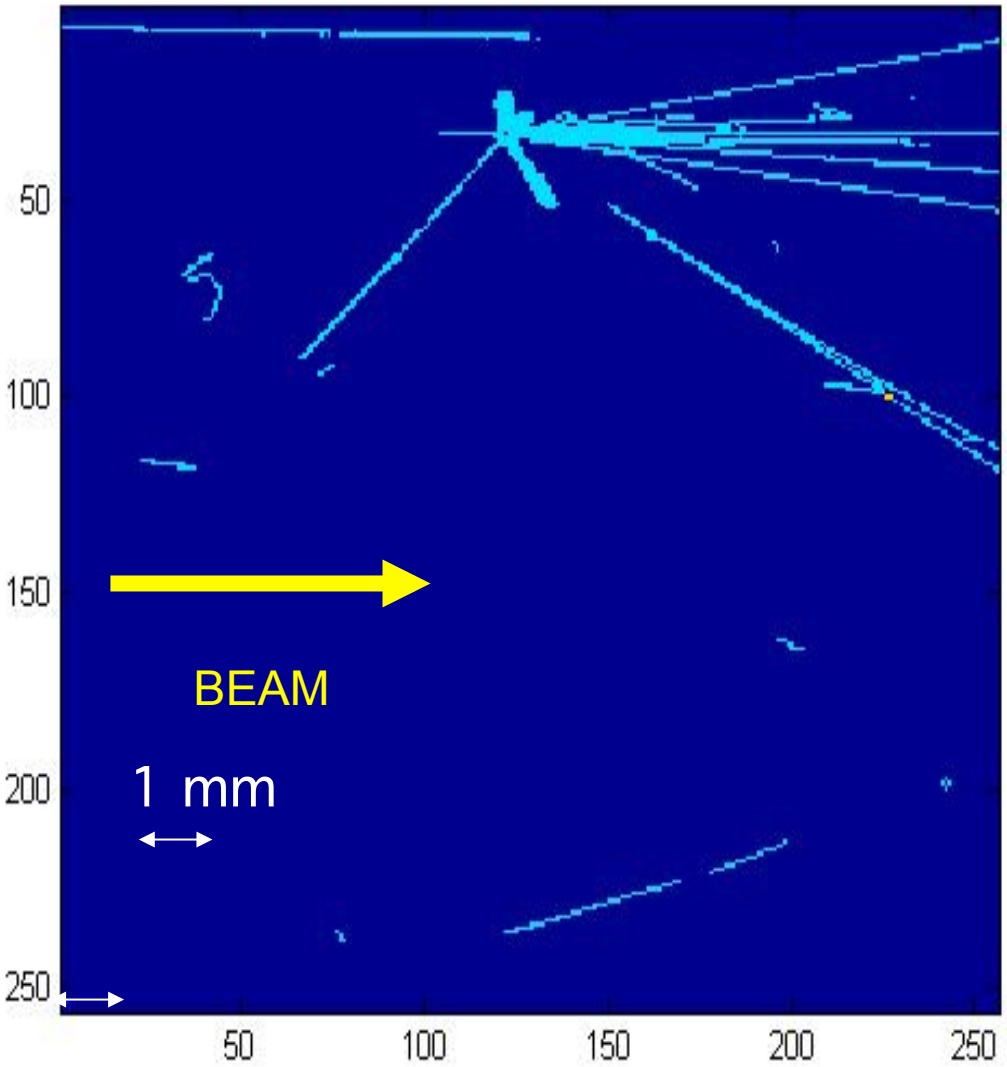
4764s exposure
(extrapolated per year)

dose per hour
e.m. 0.06 uSv/h
alpha 0.07 uSv/h

The 3 alpha impacts contribute >half of the dose

E.H.M. Heijne et al. NIMA699(2013) 198

120 GeV PIONS in Si IMAGER : MEDIPIX



INTERACTION in
Medipix DETECTOR
Si 'BUBBLE CHAMBER'

DECAY of K_0 ?

↔ 500 μm

July 2006 Parallel Medipix P-05-0583

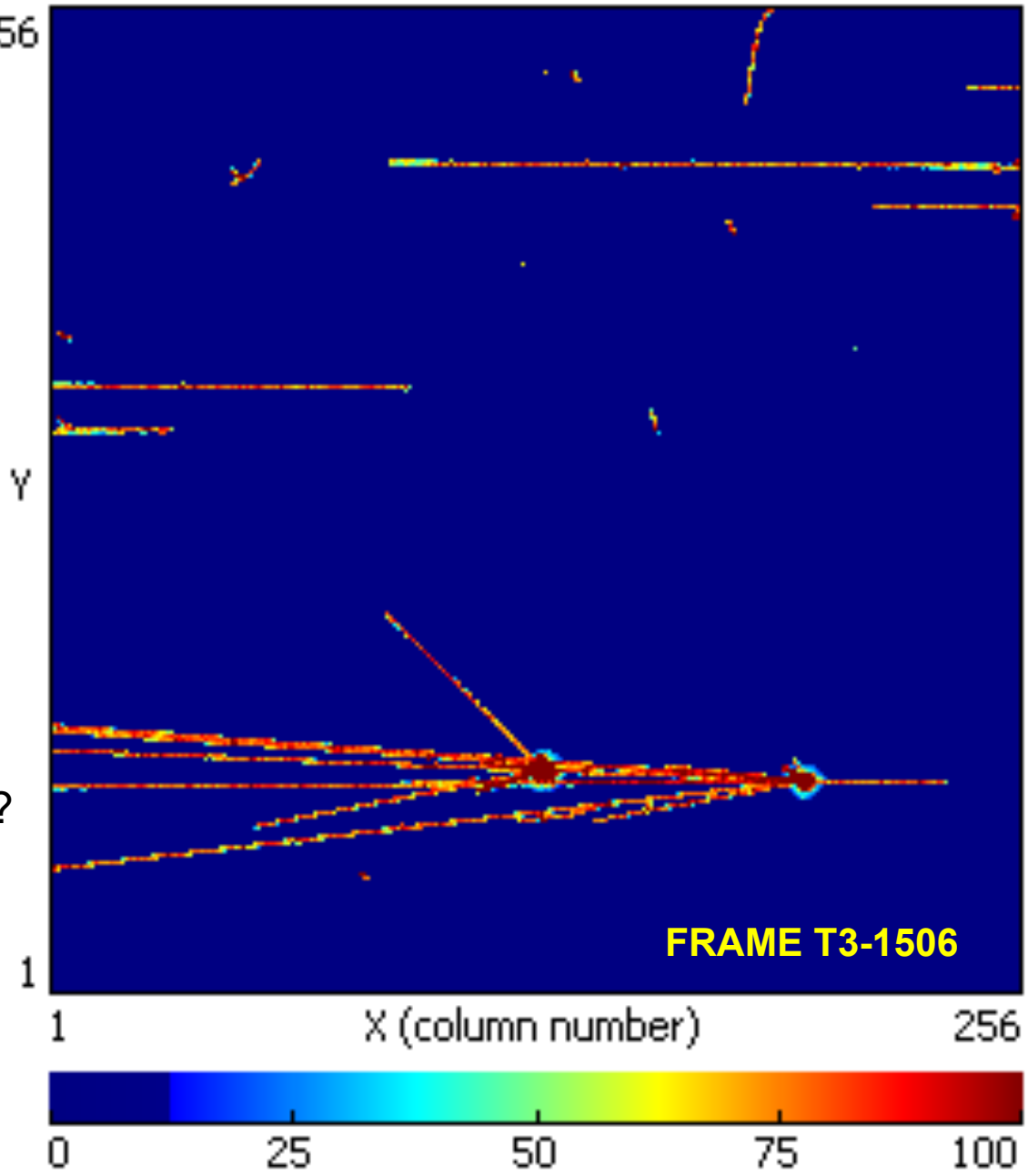
TIMEPIX CHIP as SILICON 'EMULSION' or 'BUBBLE CHAMBER'

H6 PION BEAM 2007

INCIDENT from RIGHT

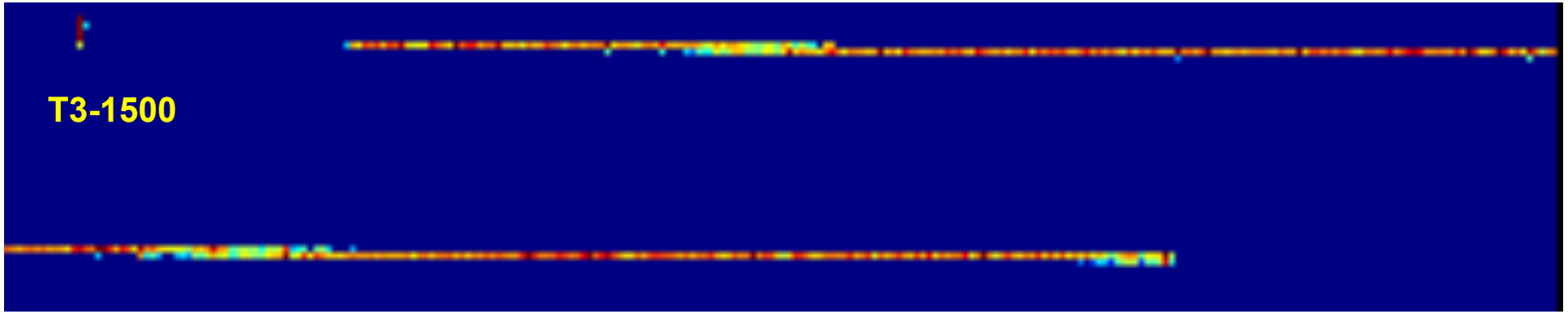
BEAM ←

WHICH DIRECTION of TRAILS ?

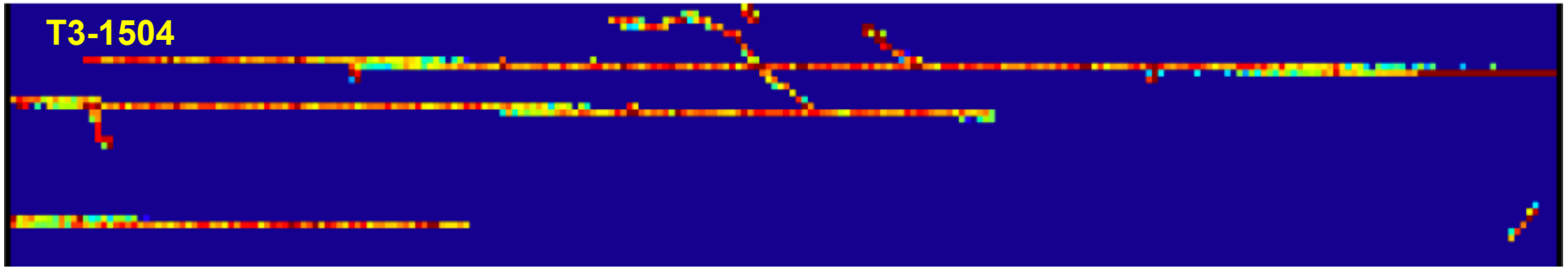


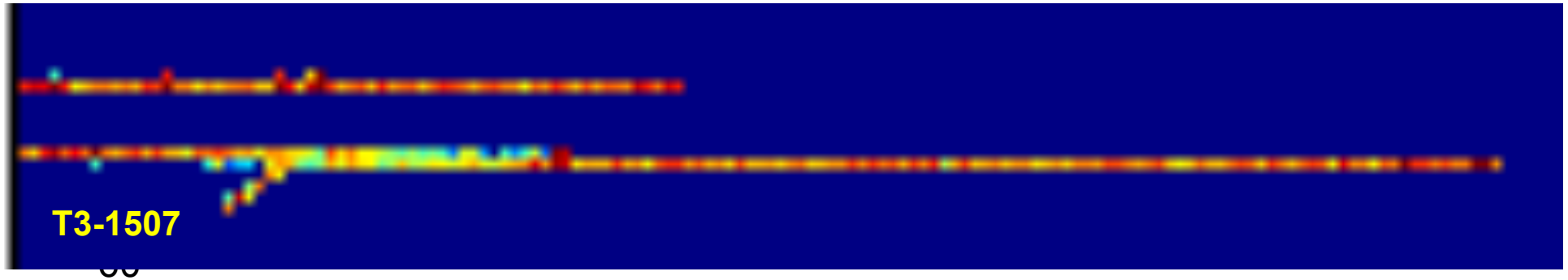
with John Idarraga / Montréal now

Erik HEIJNE CERN EP Departmer

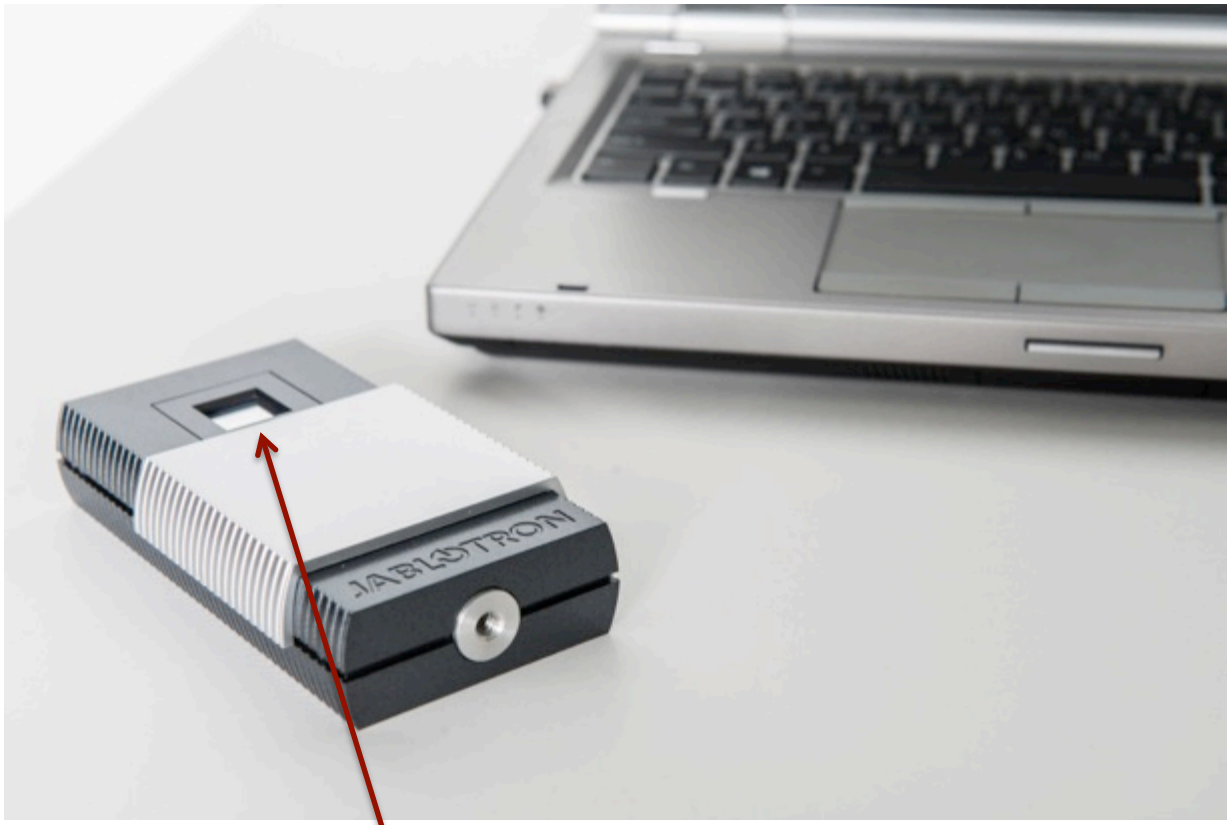


TYPICAL TRAILS ...





Radiation imager for schools with educational kit



CERN Timepix inside

http://ardent.web.cern.ch/ardent/ardent.php

ARDENT

Advanced Radiation Dosimetry European Network Training

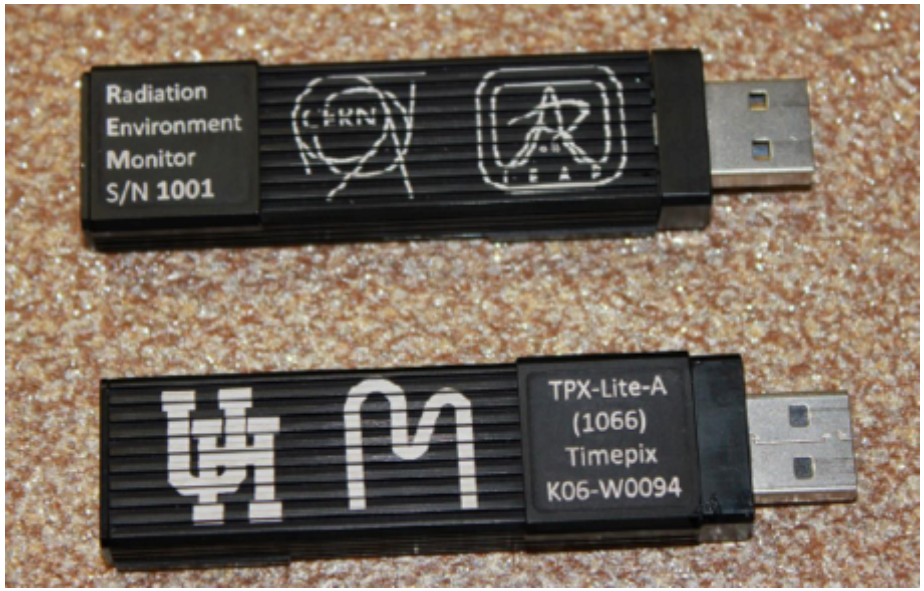
MARIE CURIE ACTIONS

PEOPLE

JABLOTRON

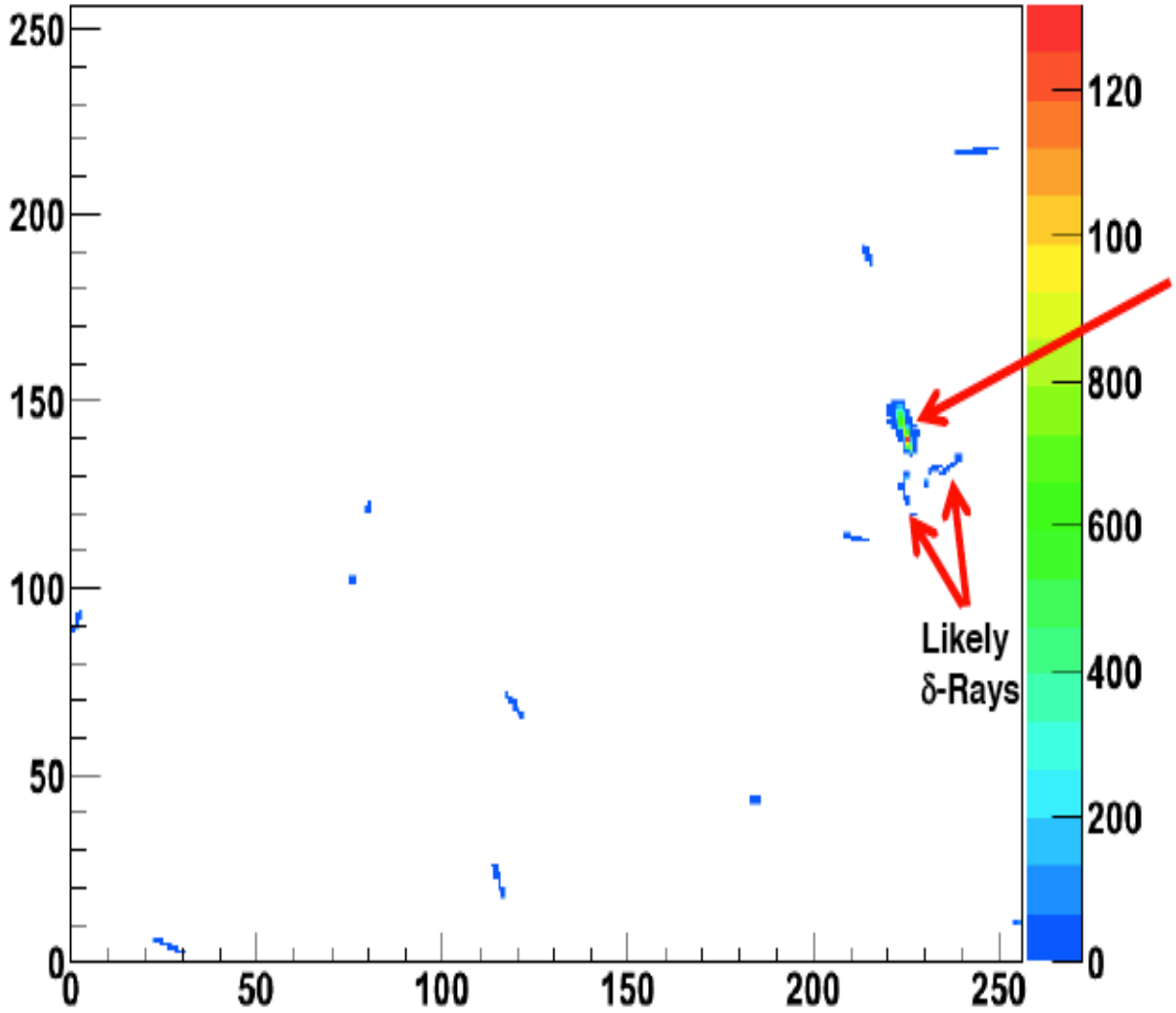
CREATING ALARM!

Pixel chips for dosimetry in Int Space Station ISS



AMS largest experiment....
Pixel chip maybe smallest

Dosimetry at the Int Space Station ISS



4s Timepix exposure taken in ISS passingover South China Sea

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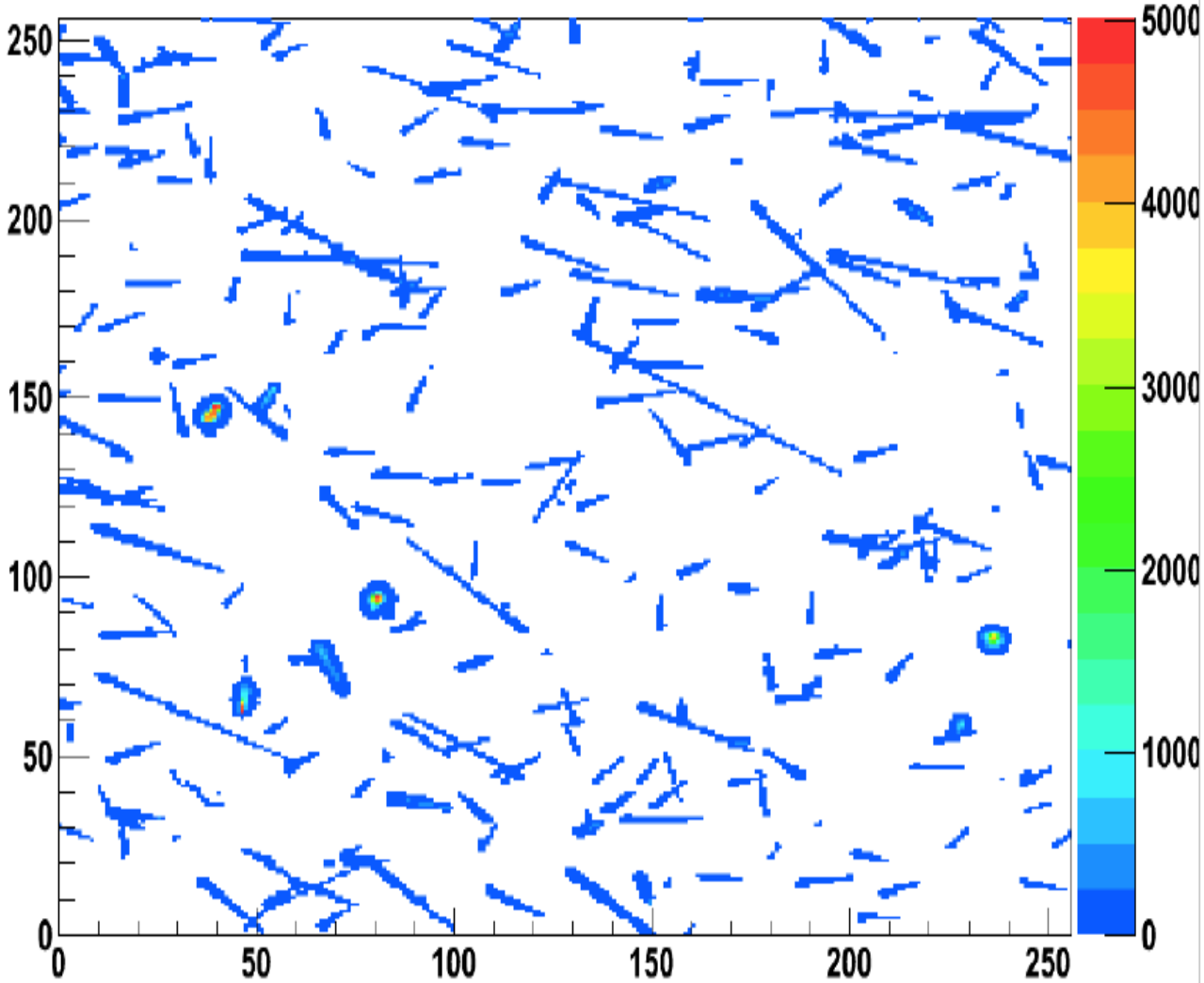
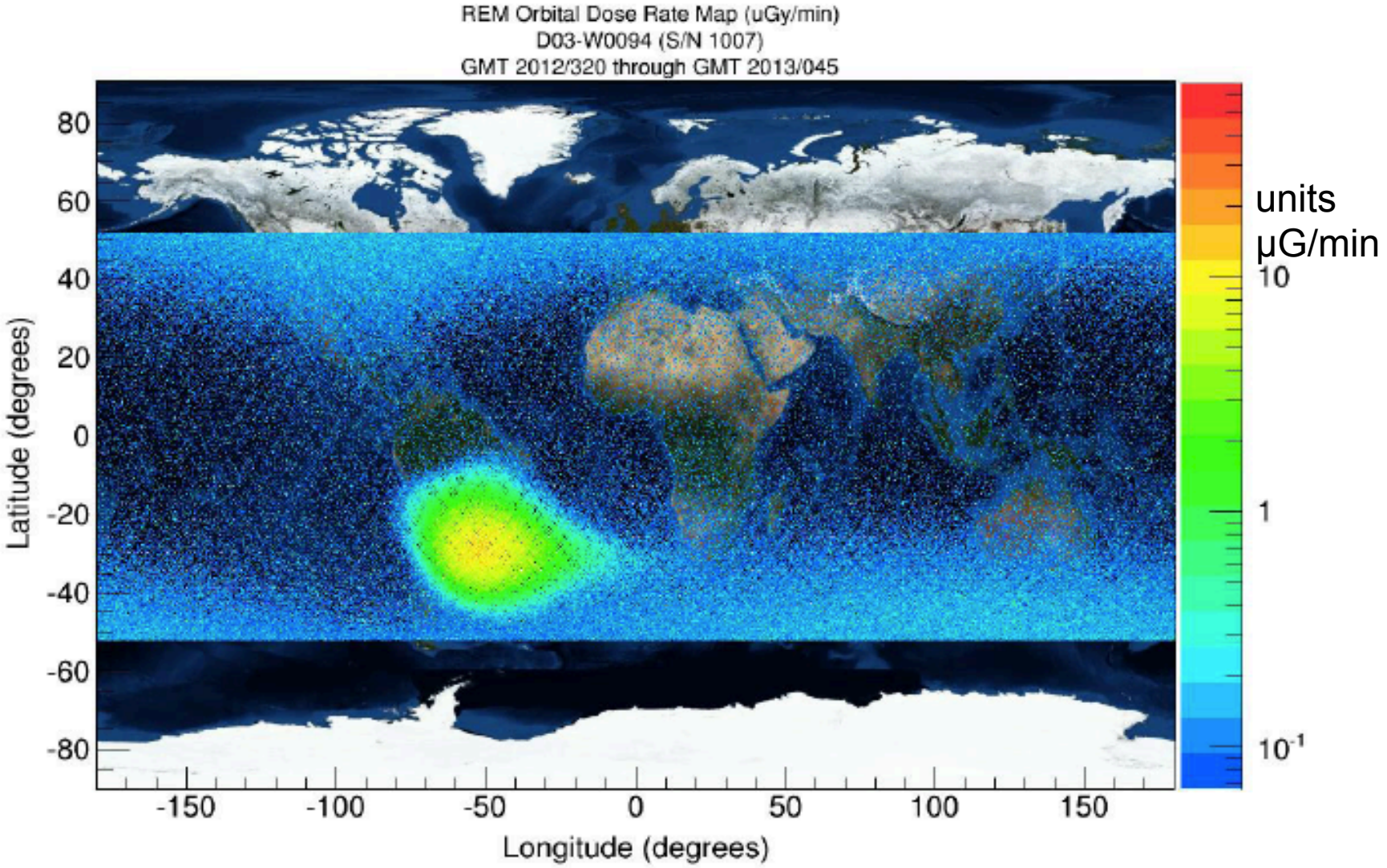
Dosimetry at the Int Space Station ISS



4s Timepix exposure taken in ISS passing through SAA South America Anomaly

Dosimetry at the Int Space Station ISS



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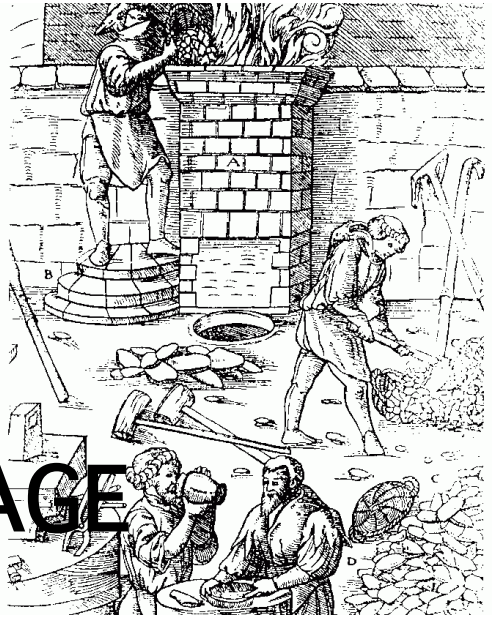
NASA

I E A P

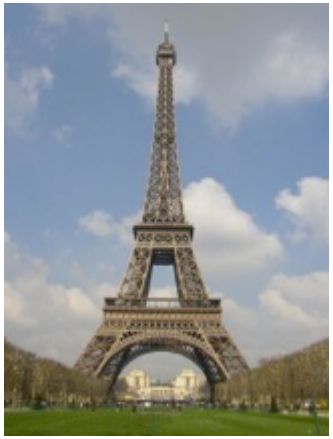
CERN

STONE AGE

BRONZE AGE



IRON AGE



SILICON AGE

Besluit