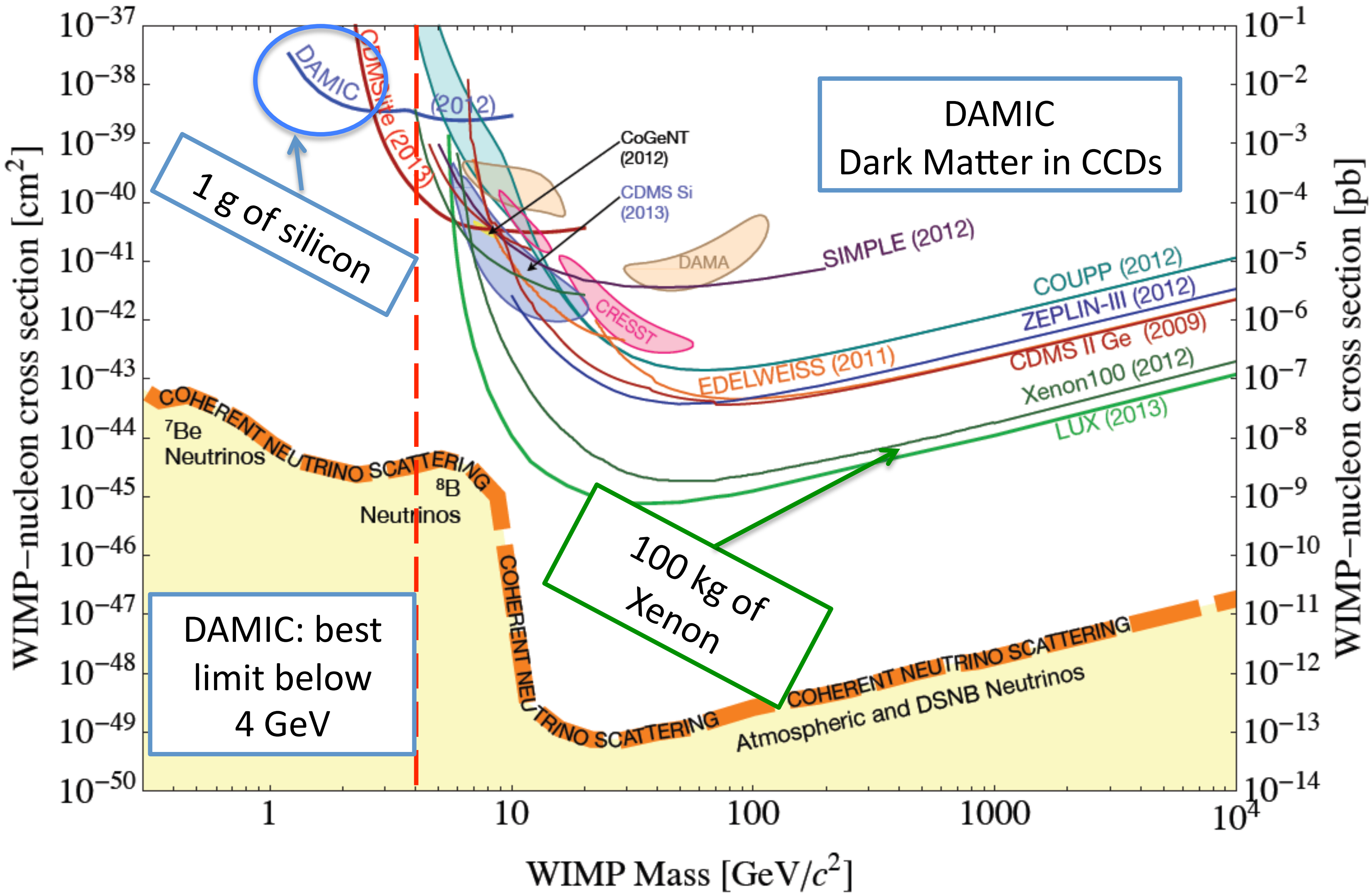
Outline

- History and motivations
- Semiconductors physics
- Silicon radiation detectors
- Perspectives

Perspectives

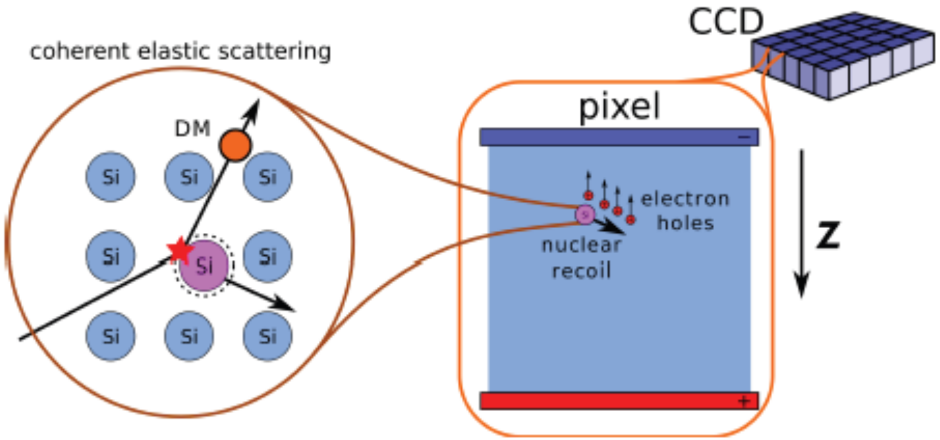
- In the following slides an author's selection among the most recent developments in the silicon radiation detectors

Perspectives in low mass Dark Matter searches



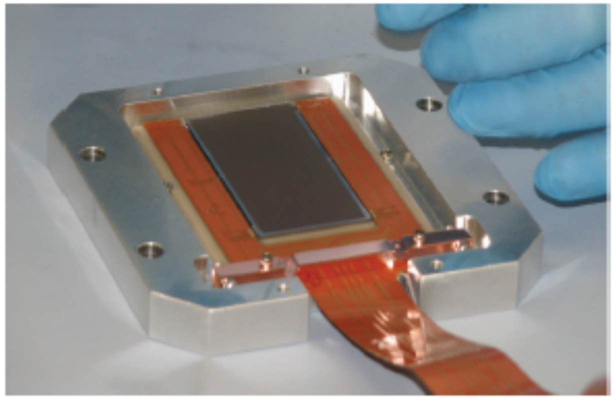
DAMIC: Dark Matter in CCDs

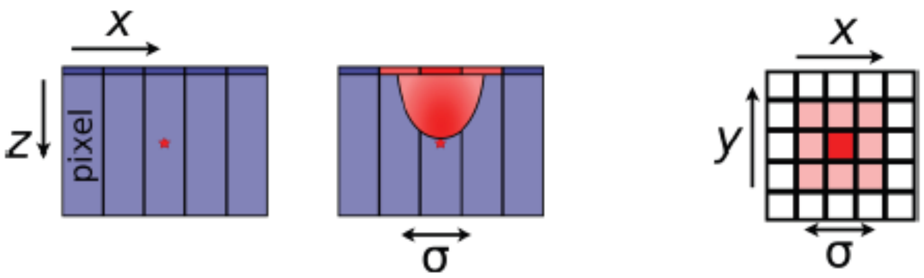
P. Privitera
COSMO2014



- A point-like energy deposit from nuclear recoil induced by the WIMP interaction (10 keV Si ion range 200 A)

- Fully-depleted thick CCDs (originally developed by LBL for DECam) provide target mass of few g





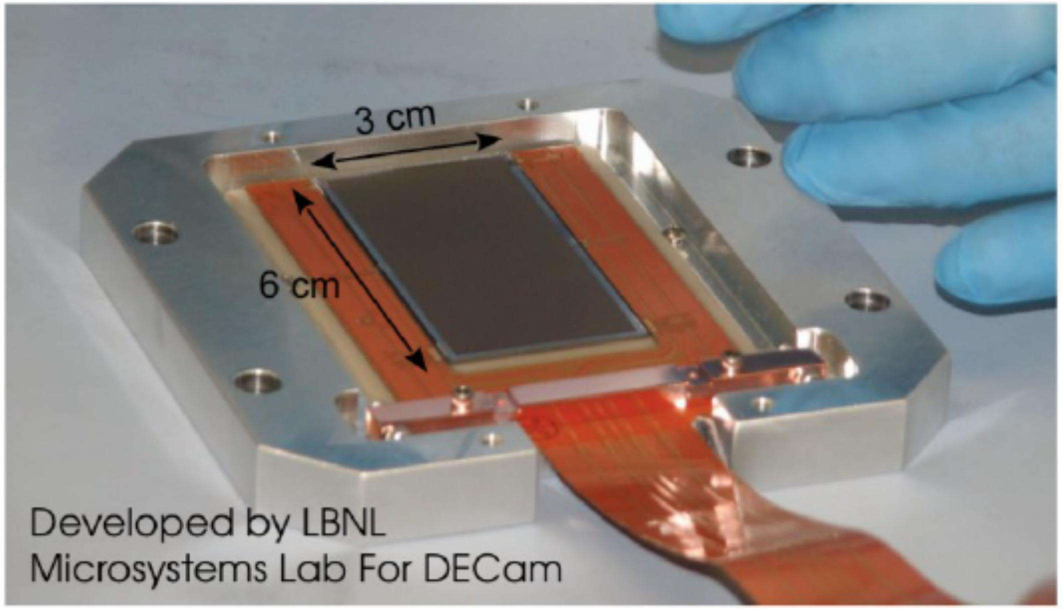
- The charge diffuses towards the CCD pixel gates, producing a "diffusion-limited" cluster

(σ ≈ Z allowing for fiducial volume definition and surface event rejection) 3

X. Bertou
DM @ LPNHE

CCD as low energy threshold particle detectors

Charge-coupled device



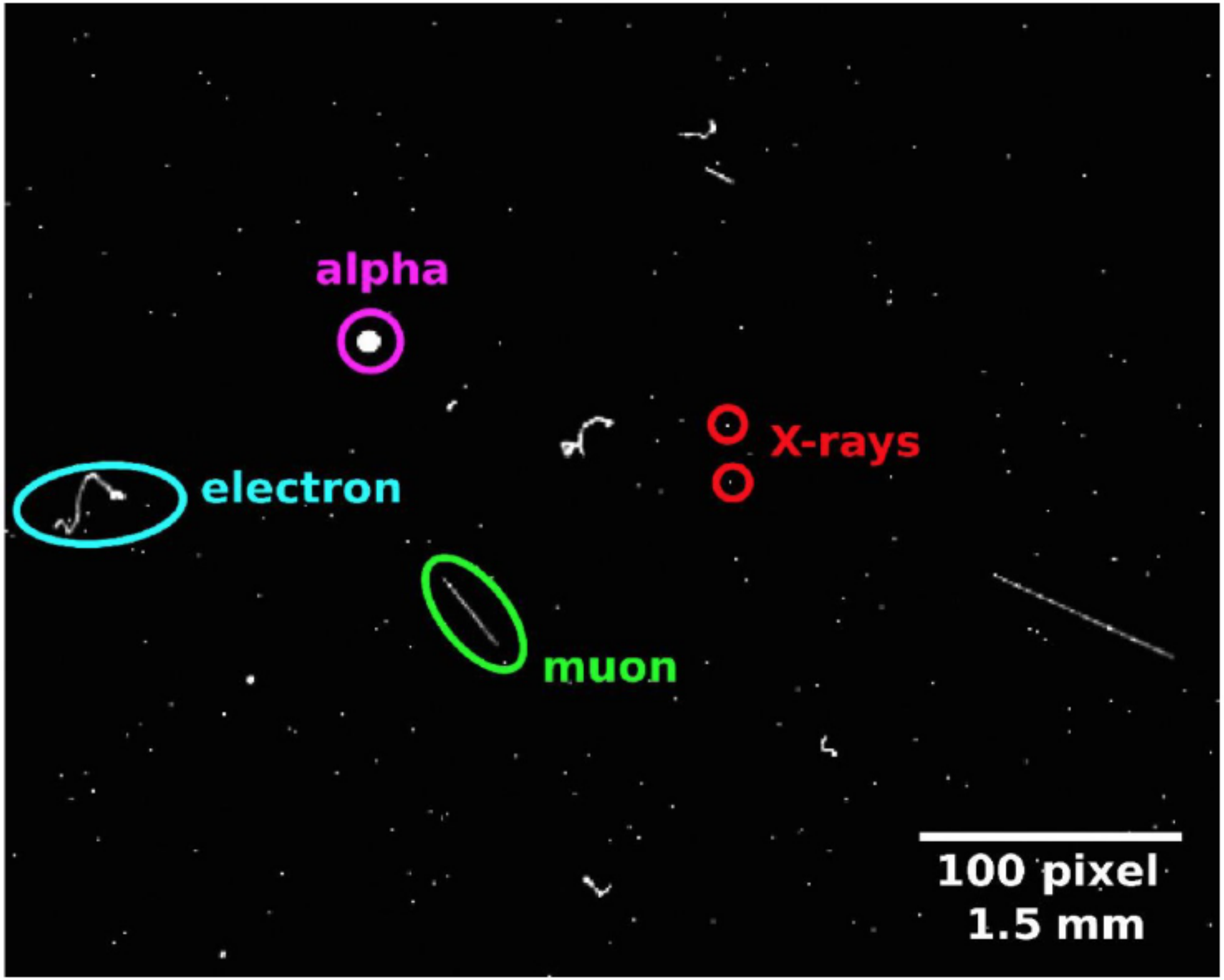
Pixel size: 15 µm x 15 µm
# of pixels: 2000 x 4000
CCD Thickness: 250 µm
CCD Mass: 1 gram
Operation Temp: 150 K

- Readout noise ~ 2.5 electrons RMS
- Detector Threshold < 50 eV_{ee}

Diffusion → 3D reconstruction
→ surface event rejection

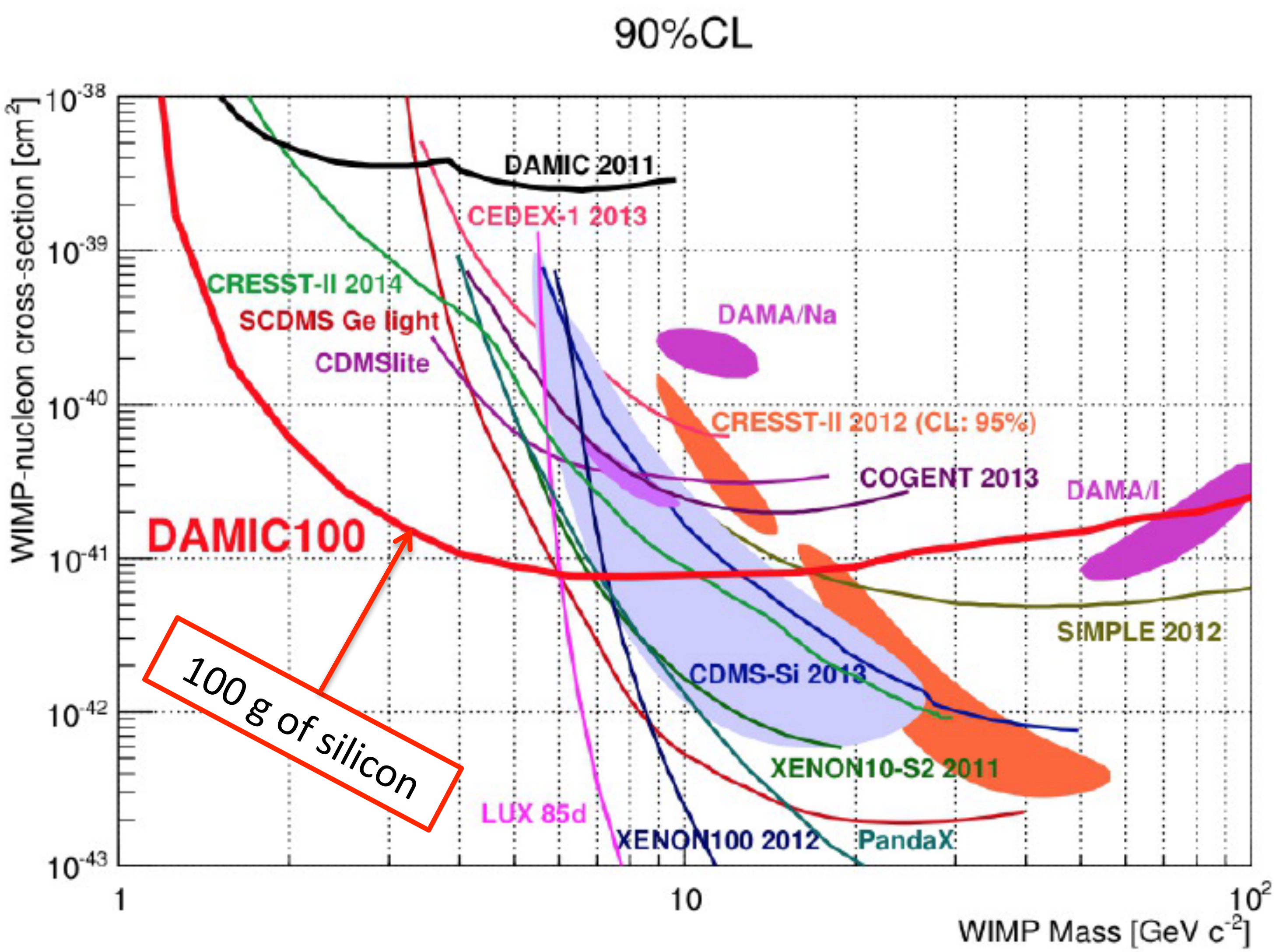
Typical (surface) CCD image

X. Bertou
DM @ LPNHE

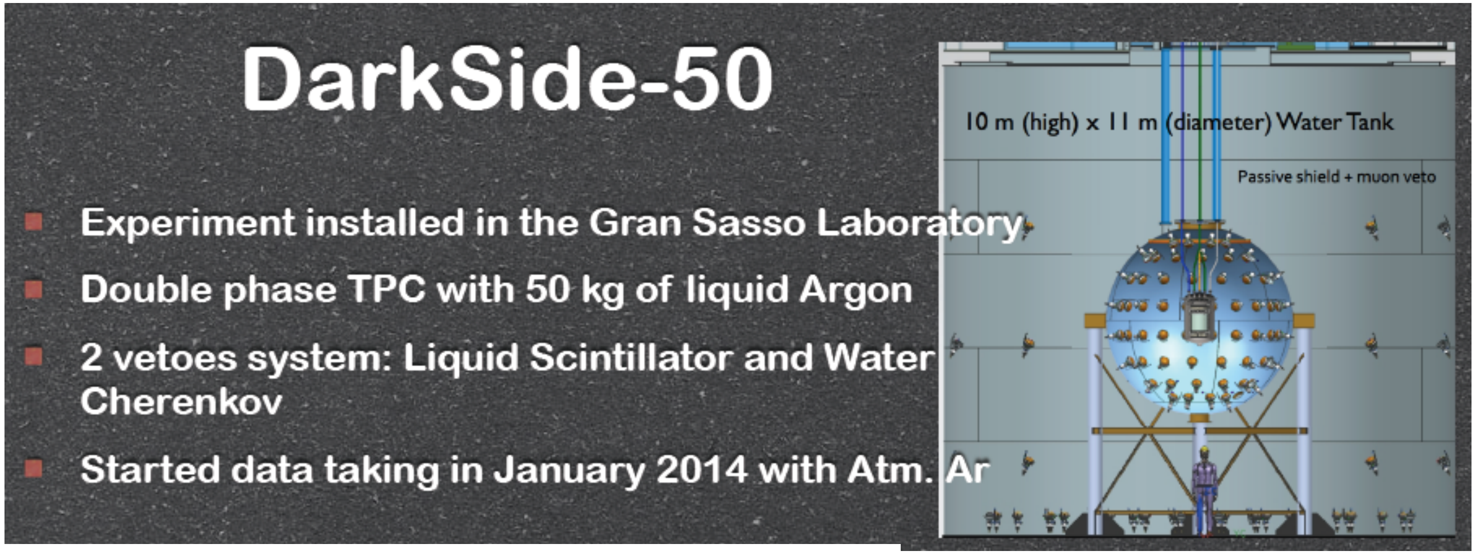


DAMIC-100 expectations

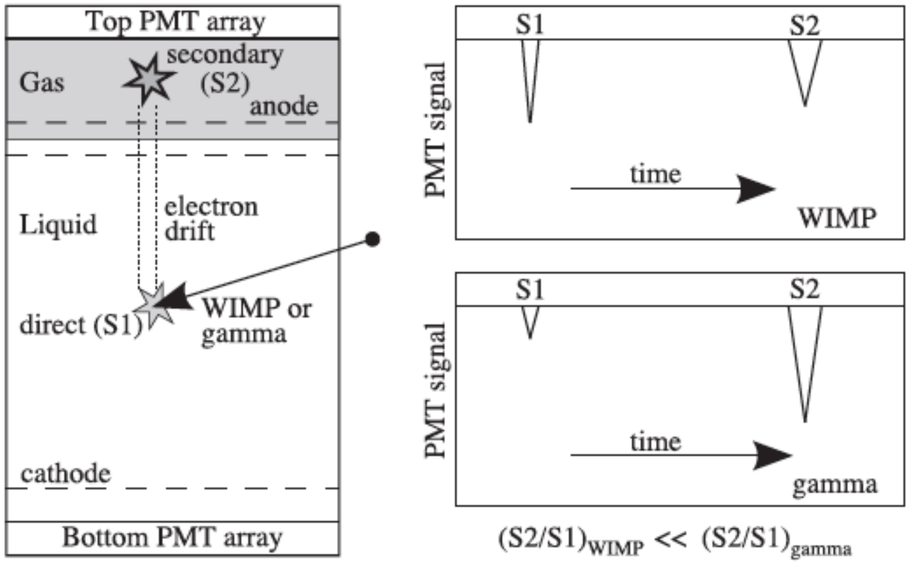
X. Bertou
DM @ LPNHE



Perspectives in in large mass Dark Matter searches



C. Giganti
DM @ LPNHE

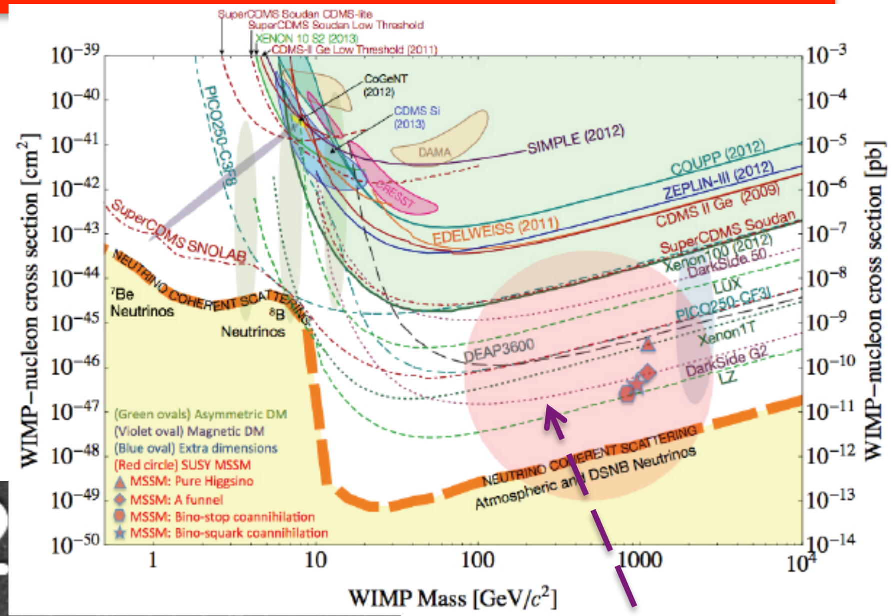


The configuration of a dual phase detector is shown on the left with the locations of where the primary and secondary light are generated. On the right is a schematic view of the signals of both an electron and nuclear interaction illustrating the discrimination power of this method.

Darkside G2

- 5 ton TPC to be installed inside the same veto systems currently used by DS-50
- Some R&D are on-going to instrument the TPC with SiPM

C. Giganti
DM @ LPNHE



DS-G2

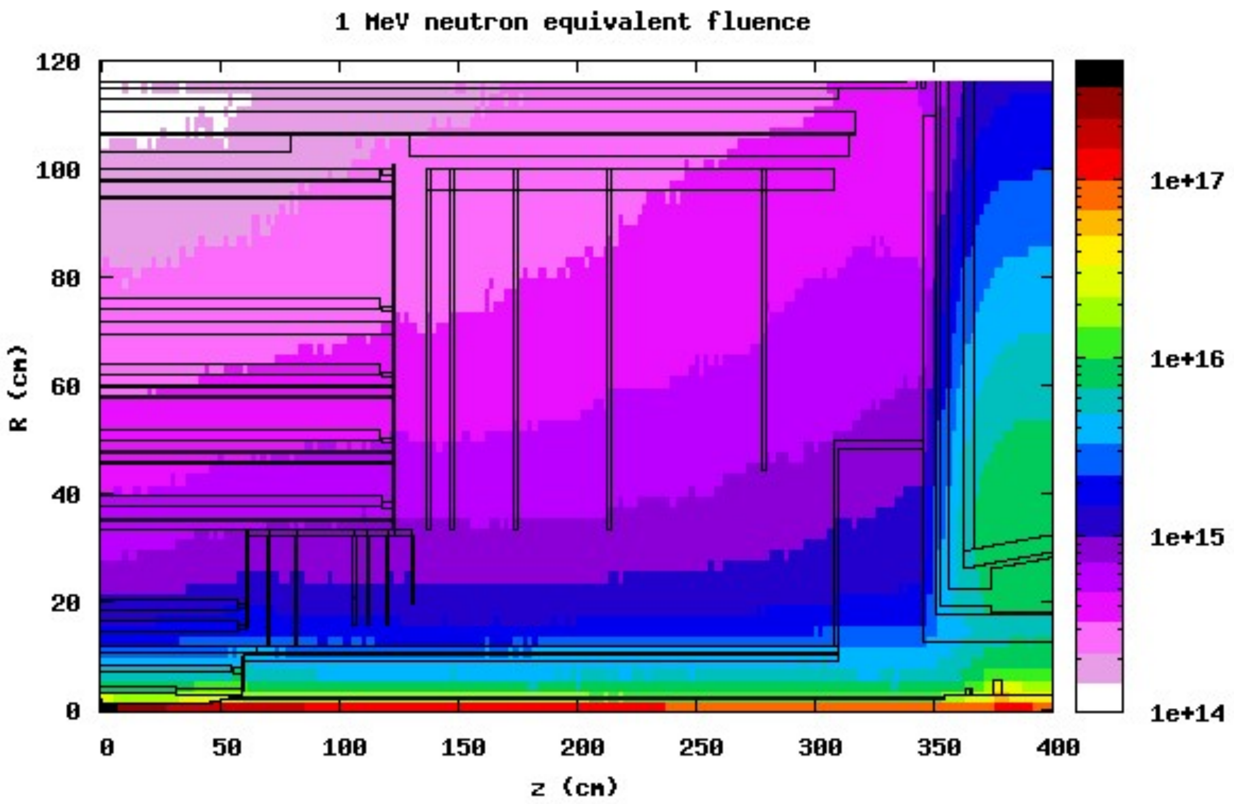
SiPM for DS-G2

- Advantages of SiPM for DS-G2
  - Higher QE → reduce threshold for WIMP search
  - Smaller than PMTs → increase the FV
  - Better PSD thanks to the higher Single Photo-Electron resolution
  - Smaller backgrounds than PMTs that might mimic NR in the TPC

PSD: pulse shape discrimination

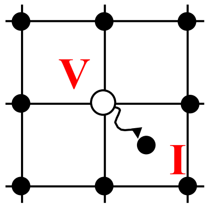
Perspectives in high luminosity colliders

- HL-HLC: a x10 in instantaneous luminosity integrated over 10 years will produce a 10x in integrated fluence for ATLAS & CMS trackers



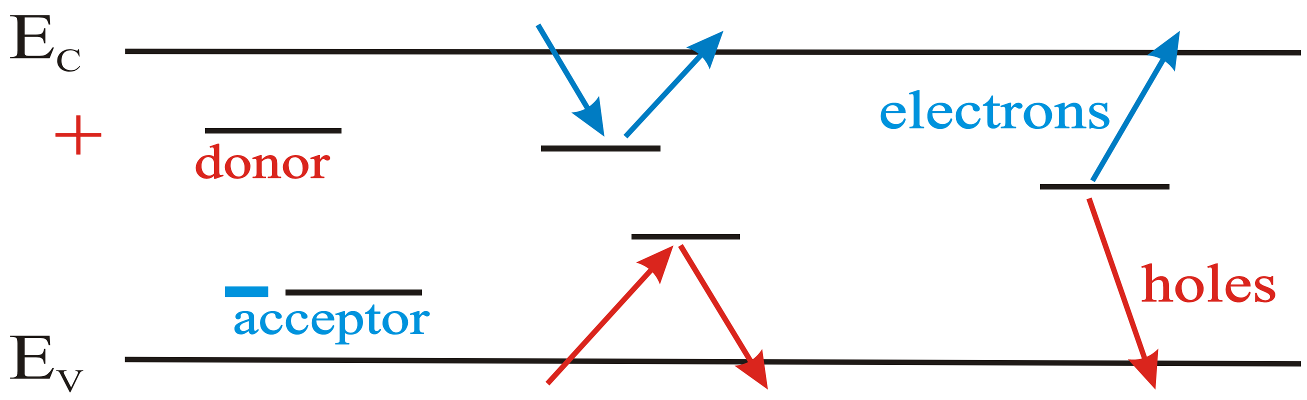
Radiation damage

particle → *Si* → $E_K > 25$ eV



Vacancy + Interstitial → *point defects* ***(V-O, C-O, ..)***

→ $E_K > 5$ keV *point defects and clusters of defects*

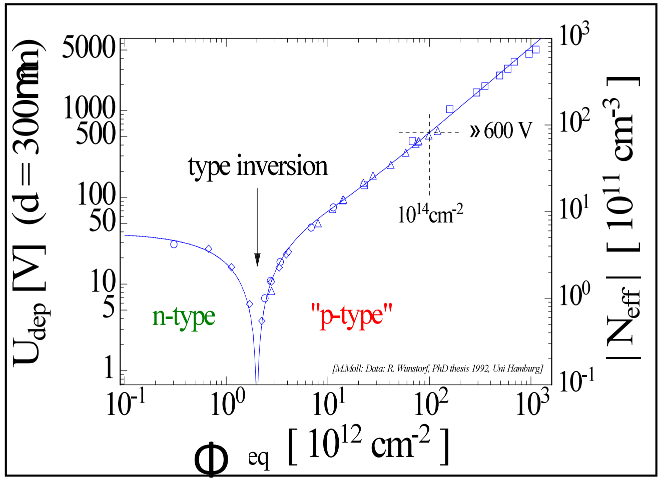


charged defects
⇒ N_{eff} , V_{dep}
e.g. donors in upper and acceptors in lower half of band gap

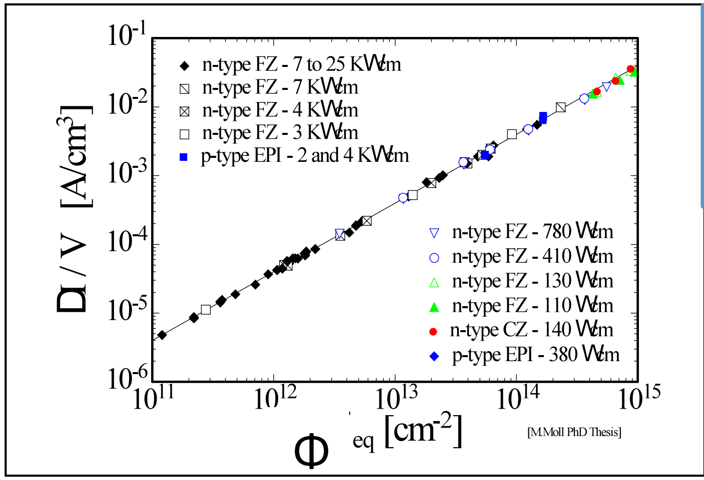
Trapping (e and h)
⇒ CCE
shallow defects do not contribute at room temperature due to fast detrapping

generation
⇒ leakage current
Levels close to midgap most effective

Radiation damage: macroscopic effects

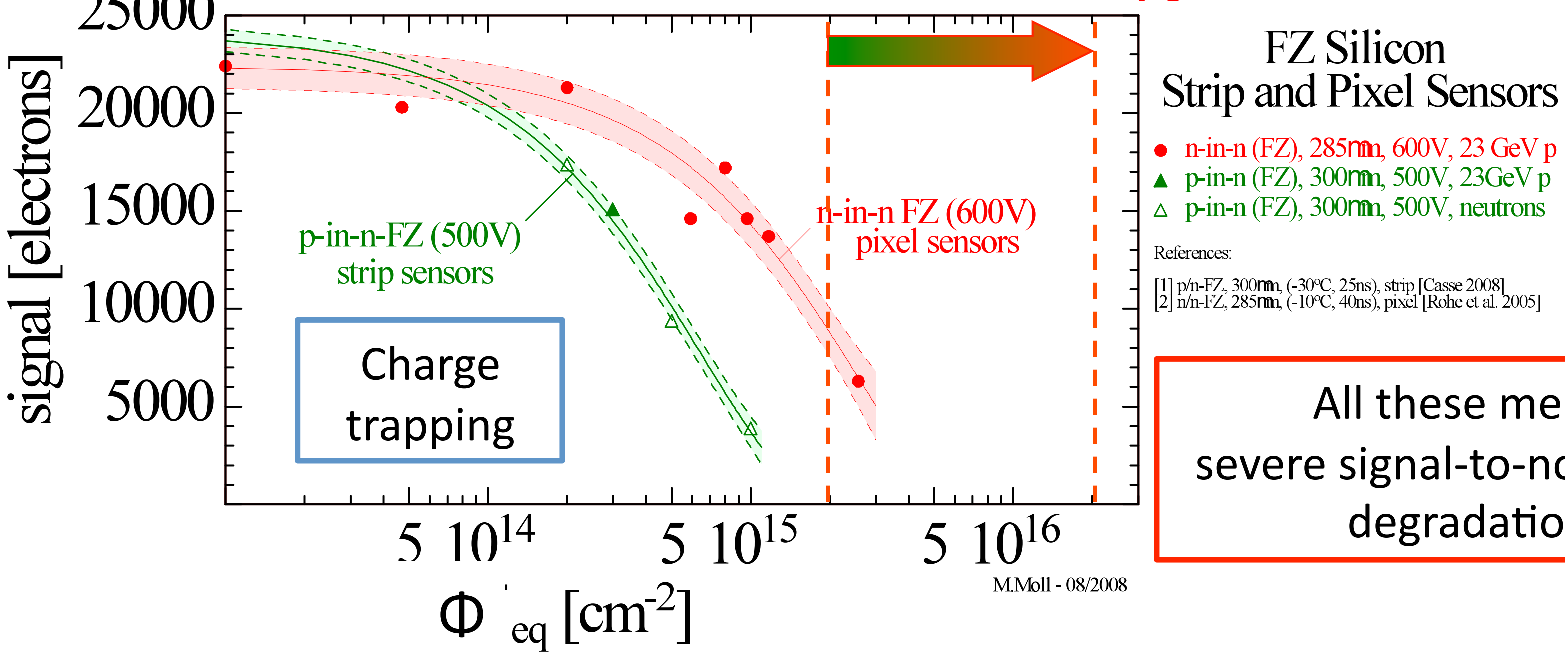


Depletion voltage increase



Leakage current increase

From LHC to HL-LHC upgrade



Charge trapping

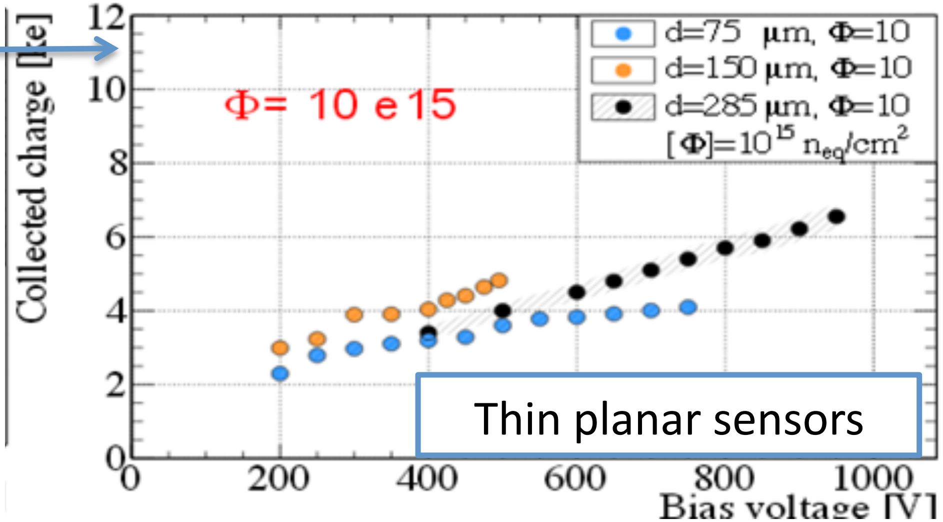
All these mean:
severe signal-to-noise-ratio degradation

New pixels for the HL-LHC Phase

The new pixel detector needs many improvements:

A. Blue, Vertex 2014

Increased radiation hardness

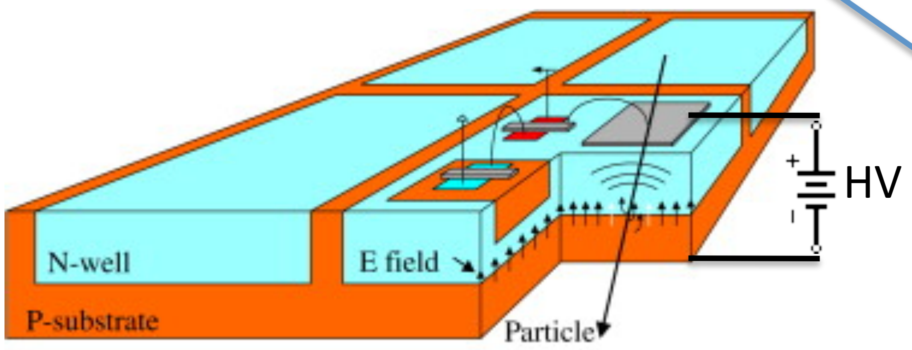


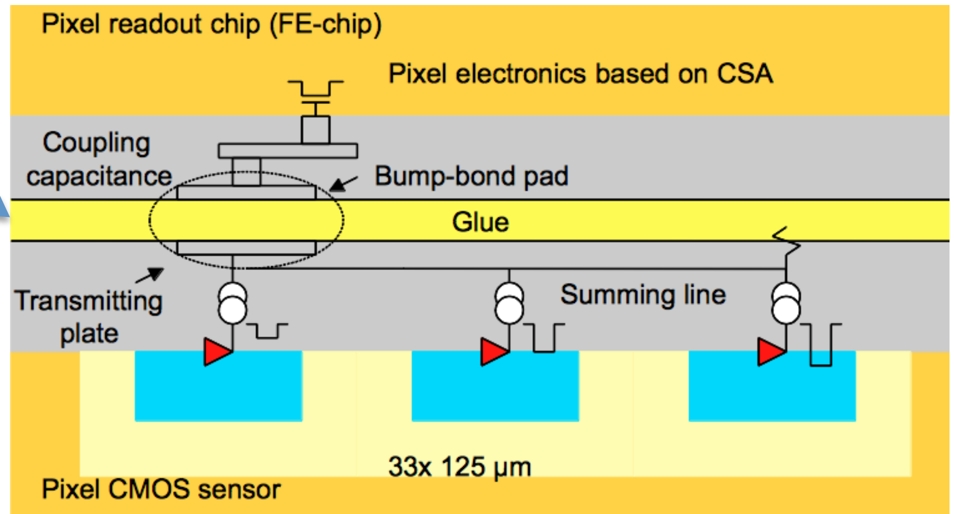
Smaller pixels

Efficiency improvements in sensor design

Low(-er) cost (interconnect) technology

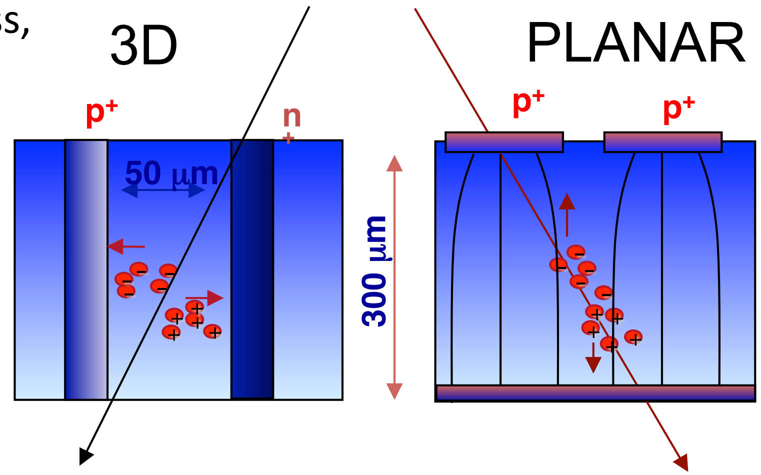
HV CMOS

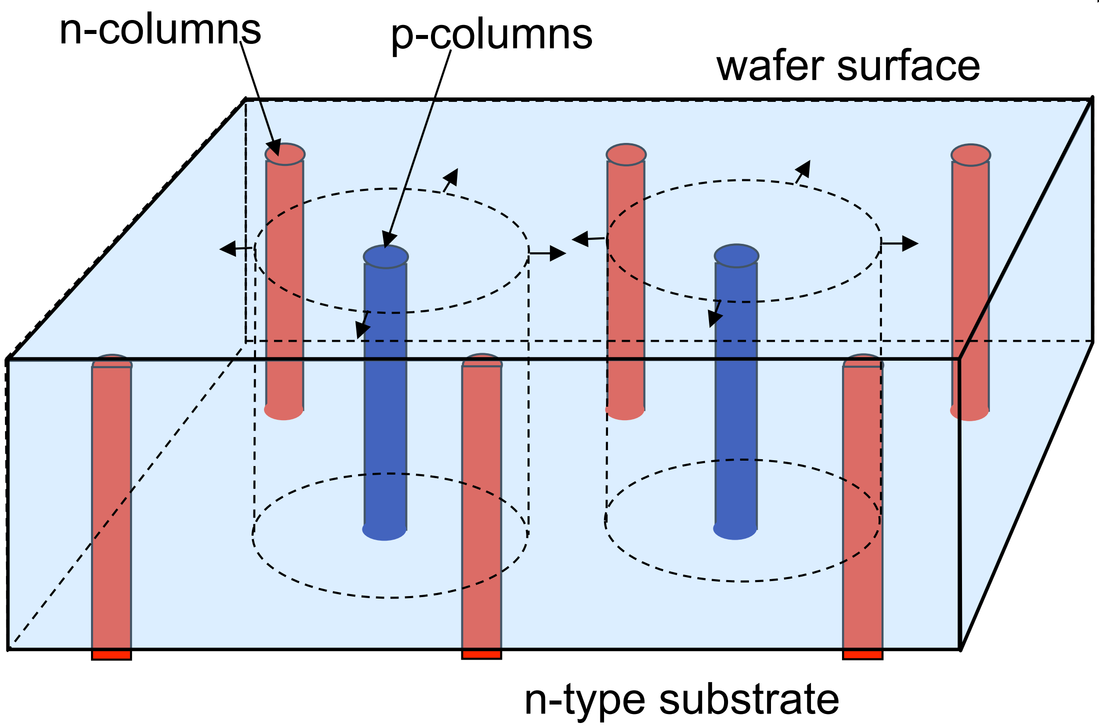




3D sensor technology

- "3D" electrodes: - narrow columns along detector thickness,
  - diameter: 10mm, distance: 50 - 100mm
- Lateral depletion: - lower depletion voltage needed
  - thicker detectors possible
  - fast signal
  - radiation hard: smaller collection path!

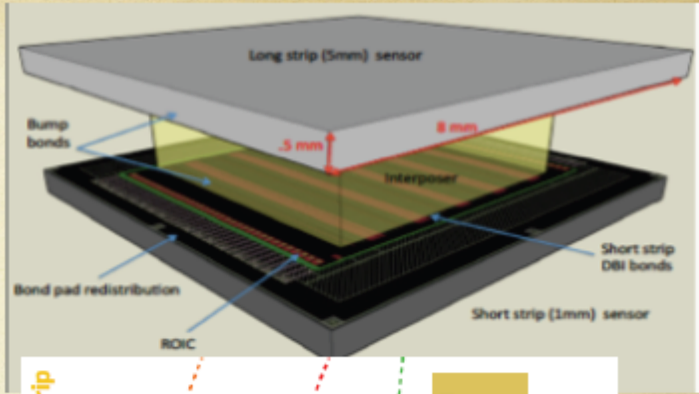


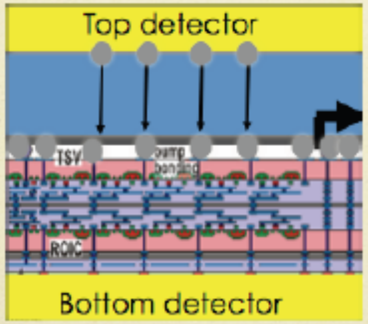


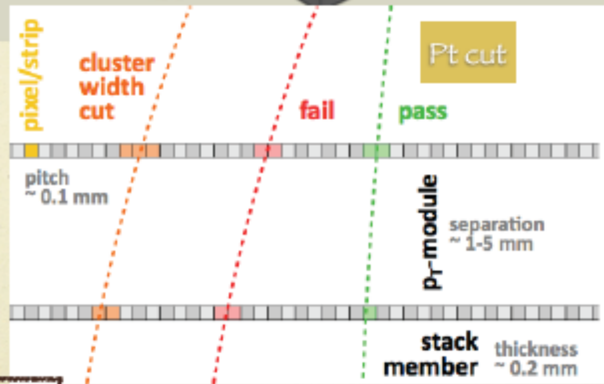
Installed in ATLAS IBL
(Inner b-layer)

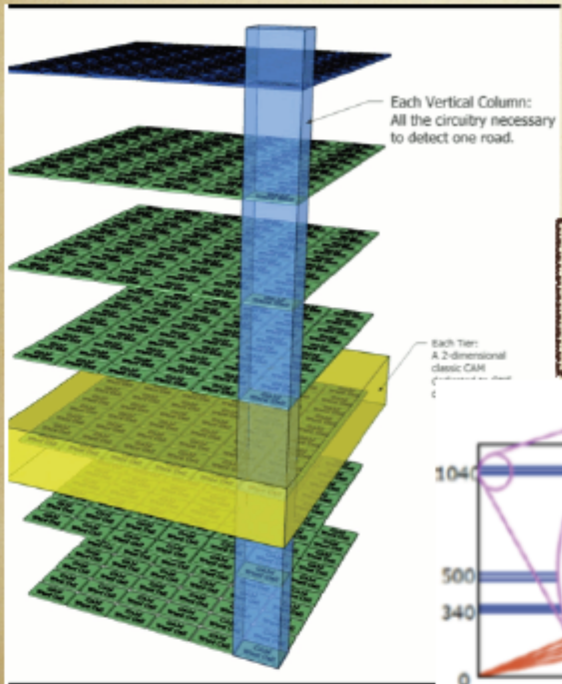
Smart detectors

- Granularity is not enough for high rates
- LHC @ 10^{34} cm-2s-1: 200 events overlapping
- Build track segments or measure pt at sensor levels and use track in LVL1-2 Trigger
- Use 3D chip technology

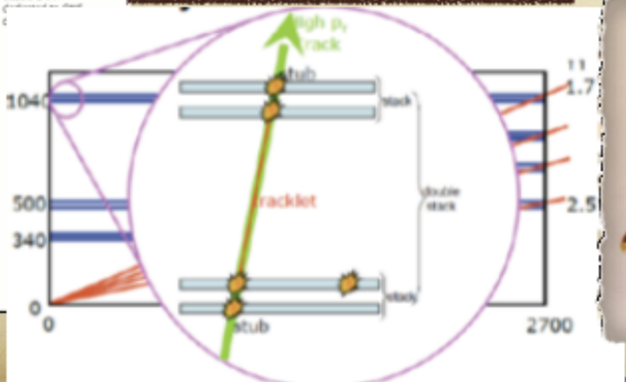


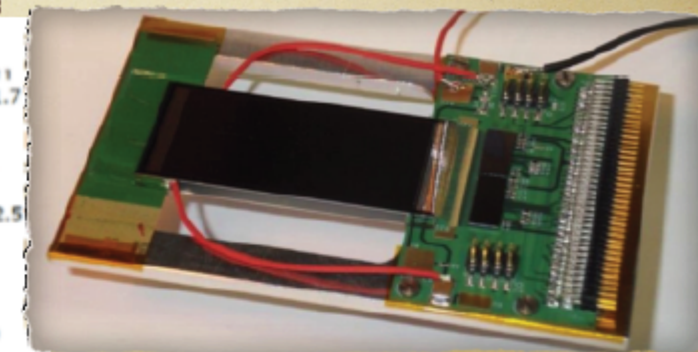






Content addressable memory in each layer



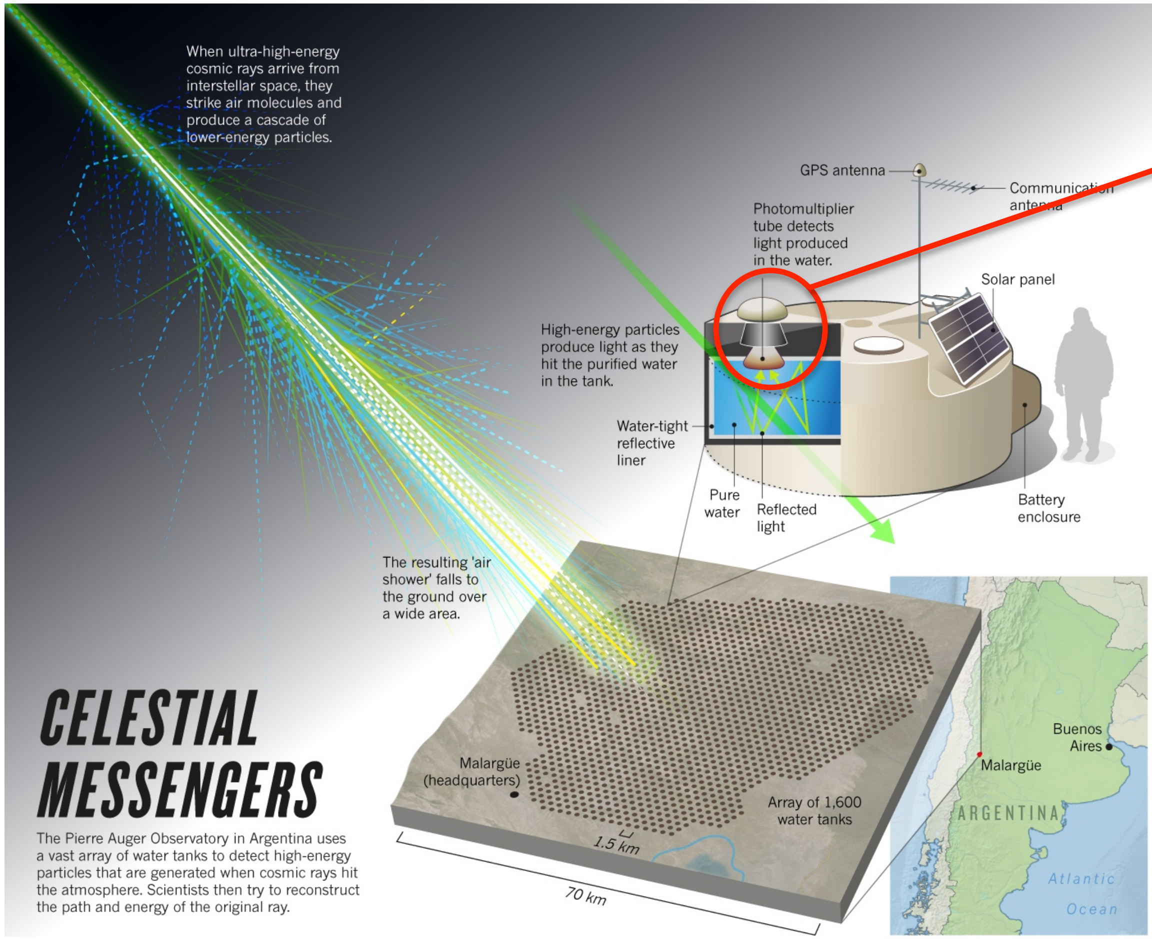


G. Sguazzoni: VTX2014 E. Ramberg, VCI 2013

VERTEX 2014, 19/9/2014 36 F.Forti, Summary and outlook

Perspectives in high-energy γ-ray astronomy with Cherenkov

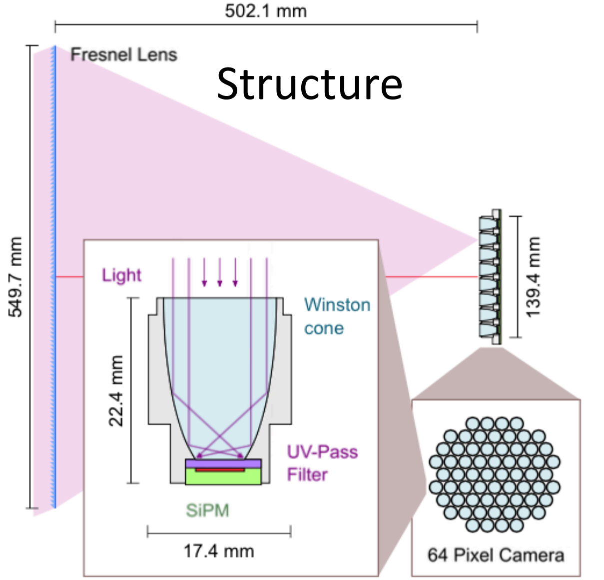
Nature, 01/10/2014



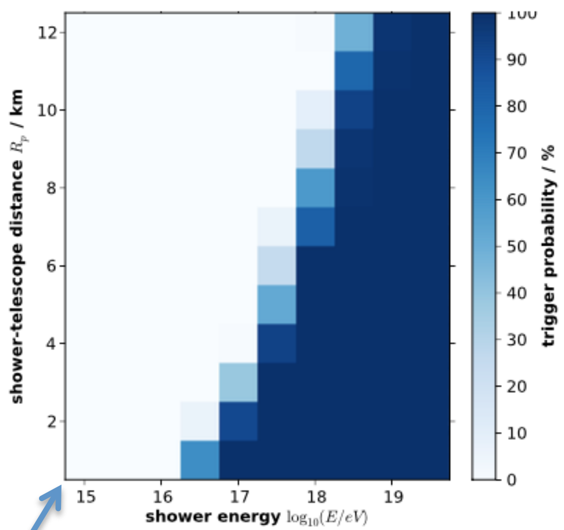
Replace PMTs with SiPMs

SiPM for Atmospheric Cherenkov telescopes

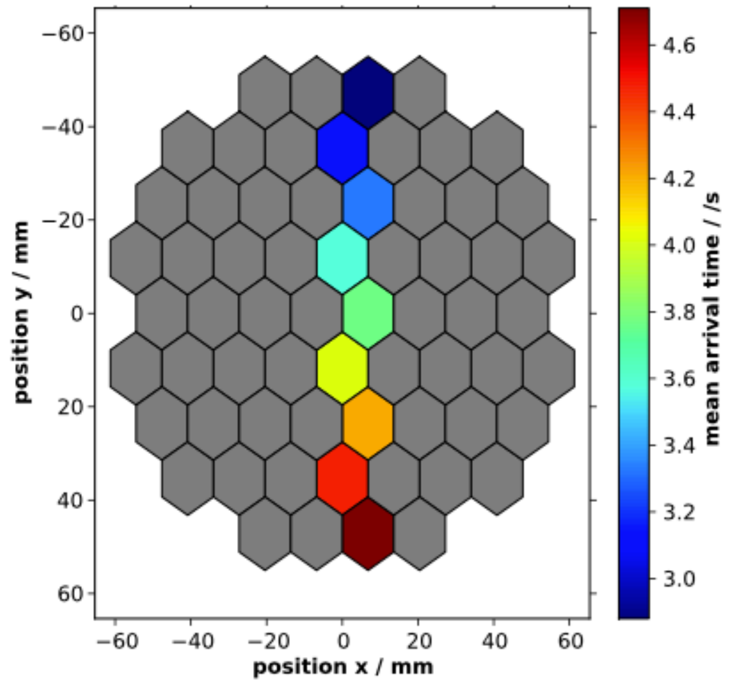
http://wwwo.physik.rwth-aachen.de/institute/institut-iiia/forschung/auger/famous/



Comparable to Auger



Simulated. Full efficiency for vertical 10^{18} eV showers up to 6 km distance



Simulation of a vertical $E = 10^{18}$ eV shower, 4 km distance

→ increase duty cycle of up to 40 %

Thanks to SiPM!

Wrap-up

Silicon detectors pros

- Large signal
- Low noise
- Fast response
- Low voltage
- Can be operated in magnetic field
- Micrometric spatial resolution
- Huge thrust in the industry
- (Cheap)
- Rigid

Charged particle detectors: comparison

Table 33.1: Typical resolutions and deadtimes of common charged particle detectors. Revised November 2011.

Detector Type	Intrinsinc Spatial Resolution (rms)	Time Resolution	Dead Time
Resistive plate chamber	$\lesssim 10$ mm	1–2 ns	—
Streamer chamber	300 μm[a]	2 μs	100 ms
Liquid argon drift [7]	$\sim$175–450 μm	$\sim$ 200 ns	$\sim$ 2 μs
Scintillation tracker	$\sim$100 μm	100 ps/n[b]	10 ns
Bubble chamber	10–150 μm	1 ms	50 ms[c]
Proportional chamber	50–100 μm[d]	2 ns	20-200 ns
Drift chamber	50–100 μm	2 ns[e]	20-100 ns
Micro-pattern gas detectors	30–40 μm	$<$ 10 ns	10-100 ns
Silicon strip	pitch/(3 to 7)[f]	few ns[g]	$\lesssim 50$ ns[g]
Silicon pixel	$\lesssim 10$ μm	few ns[g]	$\lesssim 50$ ns[g]
Emulsion	1 μm	—	—

precise

fast

Photodetectors: comparison

Table 33.2: Representative characteristics of some photodetectors commonly used in particle physics. The time resolution of the devices listed here vary in the 10–2000 ps range.

Type	λ (nm)	$\epsilon_Q\ \epsilon_C$	Gain	Risetime (ns)	Area (mm^2)	1-p.e noise (Hz)	HV (V)	Price (USD)	B ?
PMT*	115–1700	0.15–0.25	10^3–10^7	0.7–10	10^2–10^5	10–10^4	500–3000	100–5000	✗
MCP*	100–650	0.01–0.10	10^3–10^7	0.15–0.3	10^2–10^4	0.1–200	500–3500	10–6000	≈
HPD*	115–850	0.1–0.3	10^3–10^4	7	10^2–10^5	10–10^3	$\sim 2 \times 10^4$	∼600	✗
GPM*	115–500	0.15–0.3	10^3–10^6	$O(0.1)$	$O(10)$	10–10^3	300–2000	$O(10)$	☺
APD	300–1700	∼0.7	10–10^8	$O(1)$	10–10^3	1–10^3	400–1400	$O(100)$	☺
PPD	320–900	0.15–0.3	10^5–10^6	∼ 1	1–10	$O(10^6)$	30–60	$O(100)$	☺
VLPC	500–600	∼0.9	$\sim 5 \times 10^4$	∼ 10	1	$O(10^4)$	∼7	∼1	☺

*These devices often come in multi-anode configurations. In such cases, area, noise, and price are to be considered on a "per readout-channel" basis.

PMT = PhotoMultiliers Tubes, MCP = MicroChannel Plate, HPD = Hybrid Photon Detectors, GPM = Gaseous PhotoMultiliers, APD = Avalanche Photo Diodes, PPD= Pixelized Photo Diodes, VLPC = Visible Light Photo Counters

Solid State Detectors

Silicon detectors: larger and larger areas

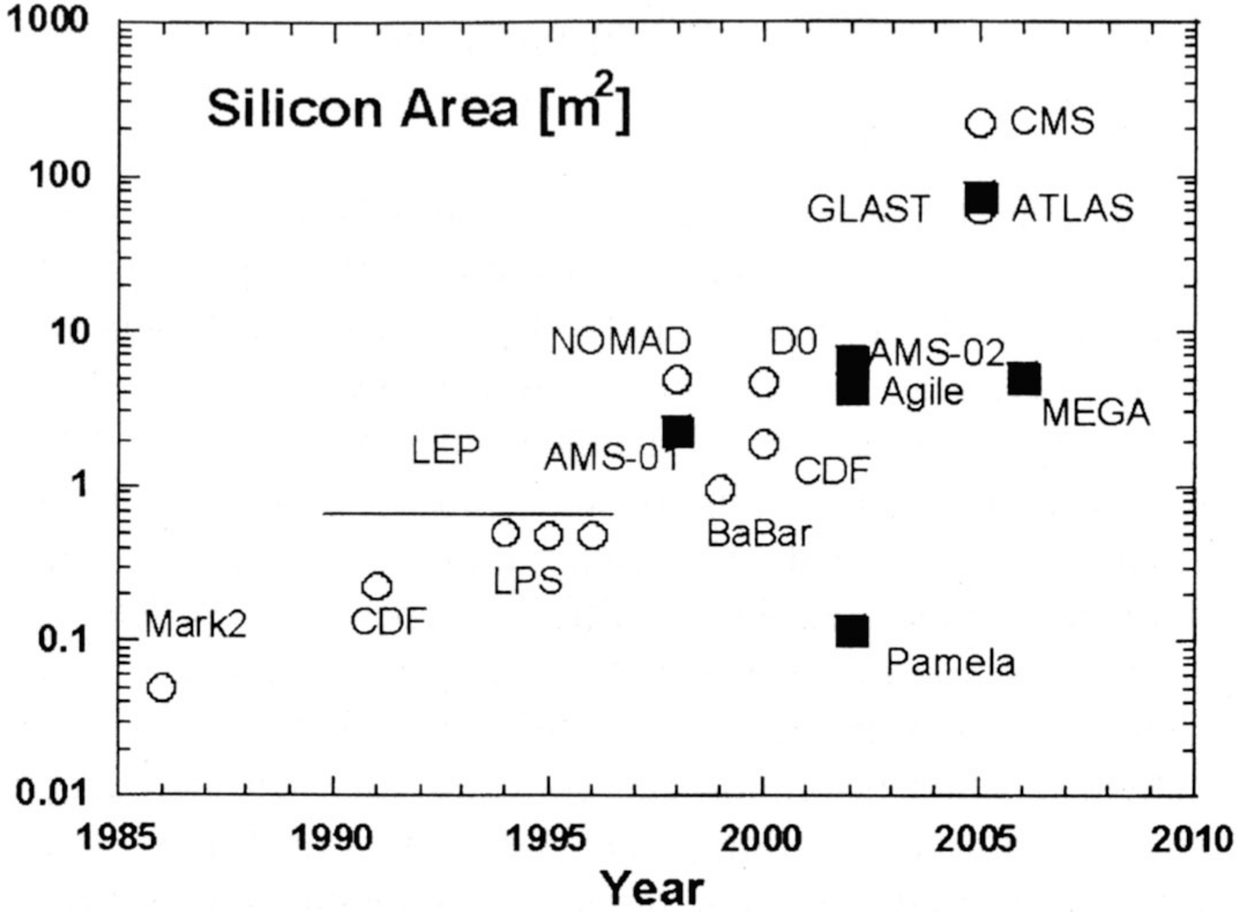


Fig. 4. The rise of the silicon detector: area of silicon detectors in experiments as a function of time. The full squares denote space-based instruments. The exponential growth of the area with time is an expression of Moore's law.

Hartmut F.-W. Sadrozinski
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 48, NO. 4, AUGUST 2001

Silicon detectors: far future

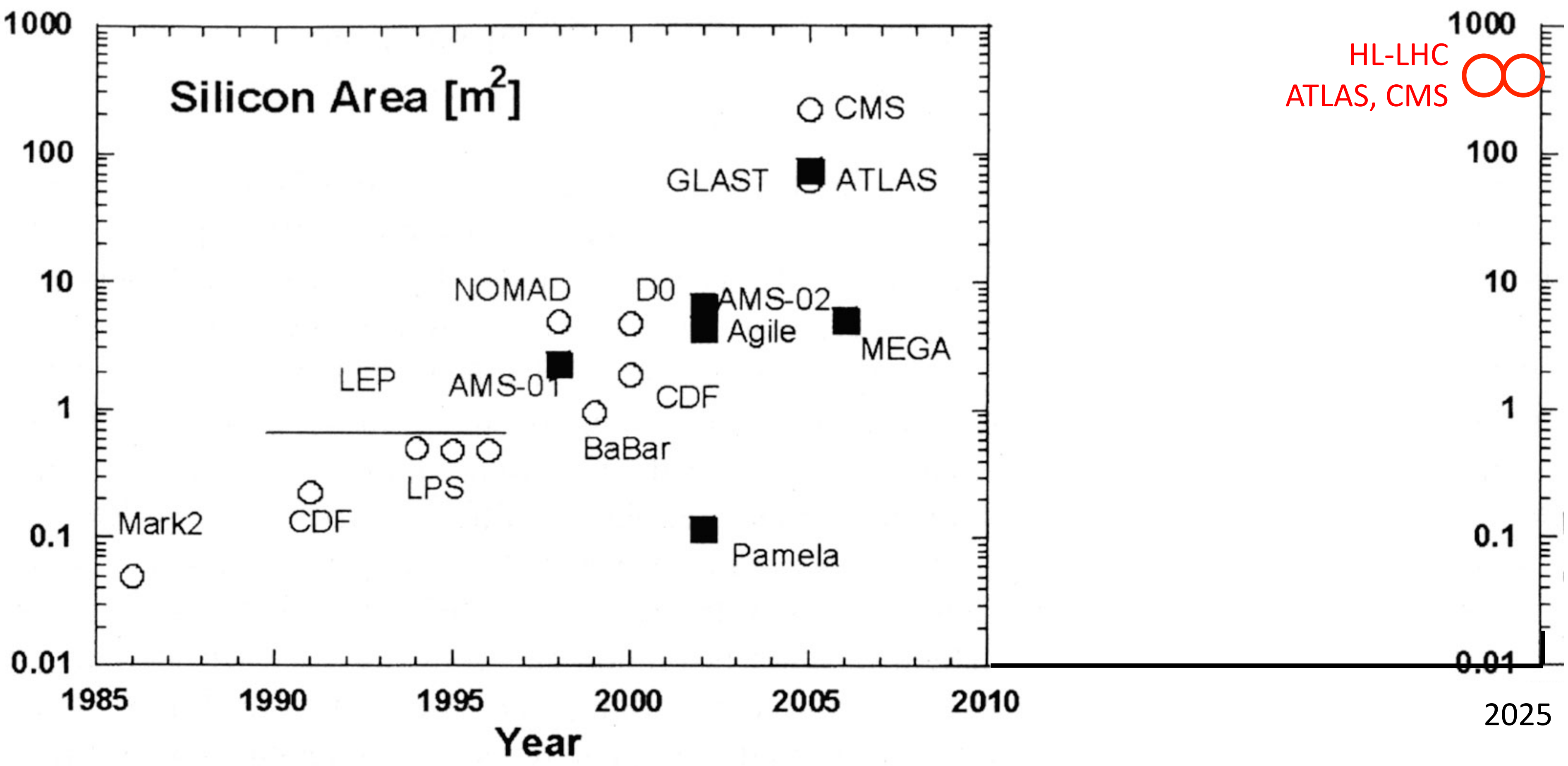
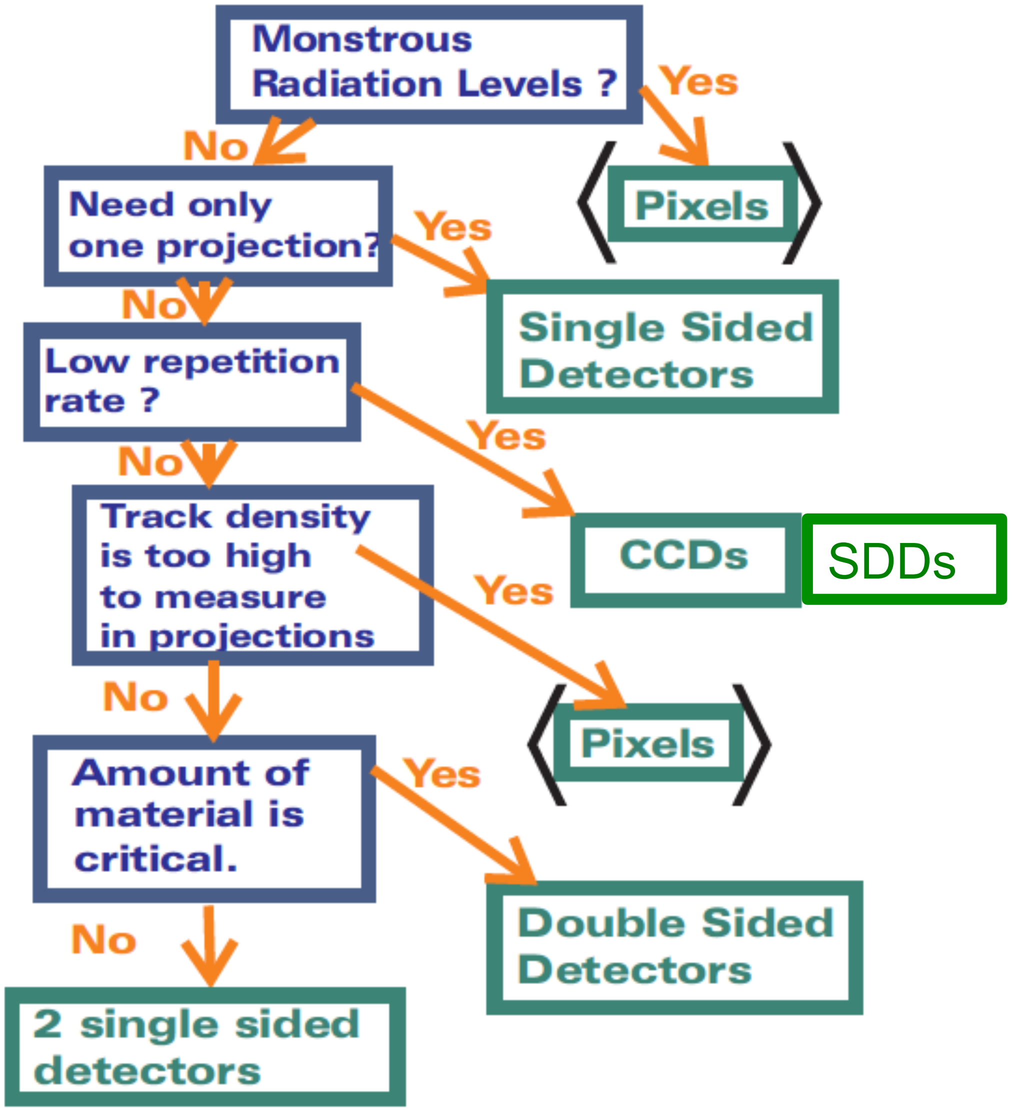


Fig. 4. The rise of the silicon detector: area of silicon detectors in experiments as a function of time. The full squares denote space-based instruments. The exponential growth of the area with time is an expression of Moore's law.

Which detector should I use?

Extreme simplification




THANK YOU FOR YOUR ATTENTION