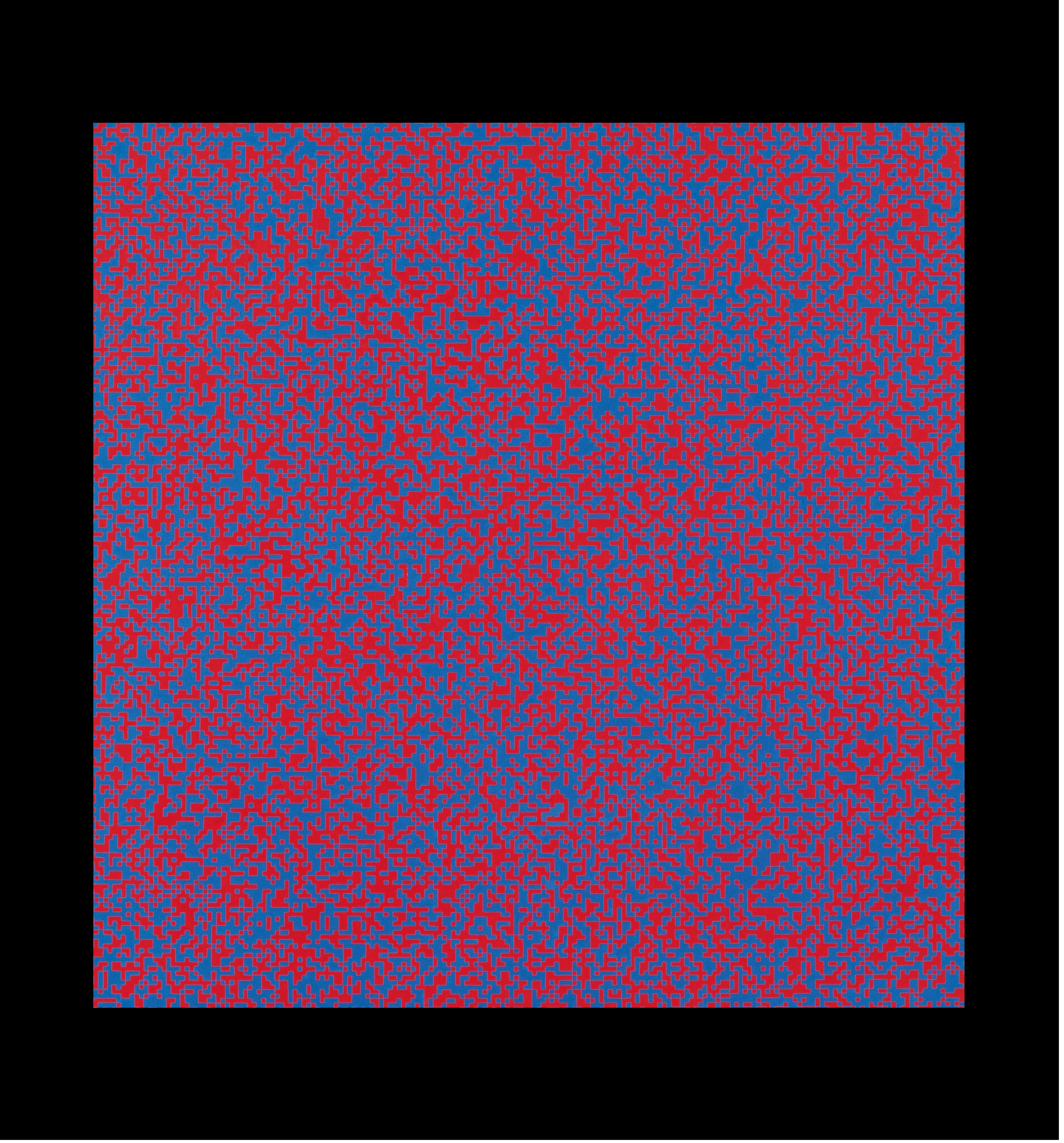


François Morellet
Random Distribution of 40,000 Squares using the Odd and Even Numbers of a Telephone Directory 1960

In-Silico generation of random bit streams

the value of unpredictability

Massimo Caccia

Università dell'Insubria & Random Power s.r.l.

massimo.caccia@randompower.eu

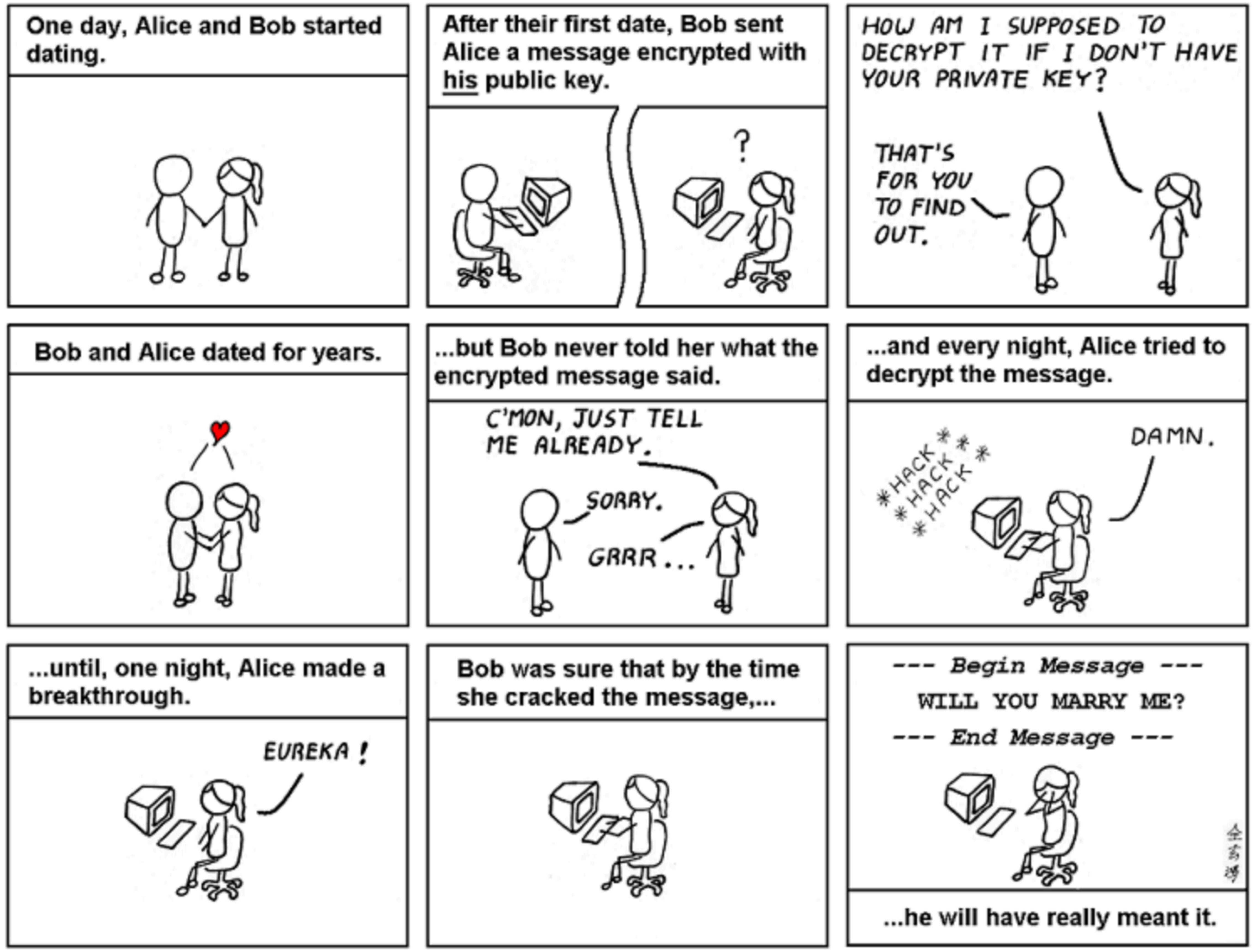
May 24st, 2023

2. introduction:

WHAT FOR?

Unpredictability to preserve the predictability of our clockwork world

- the **RSA** (Rivest–Shamir–Adleman) public key cryptography protocol uses two random prime numbers of length up to 2048 bits to generate the keys



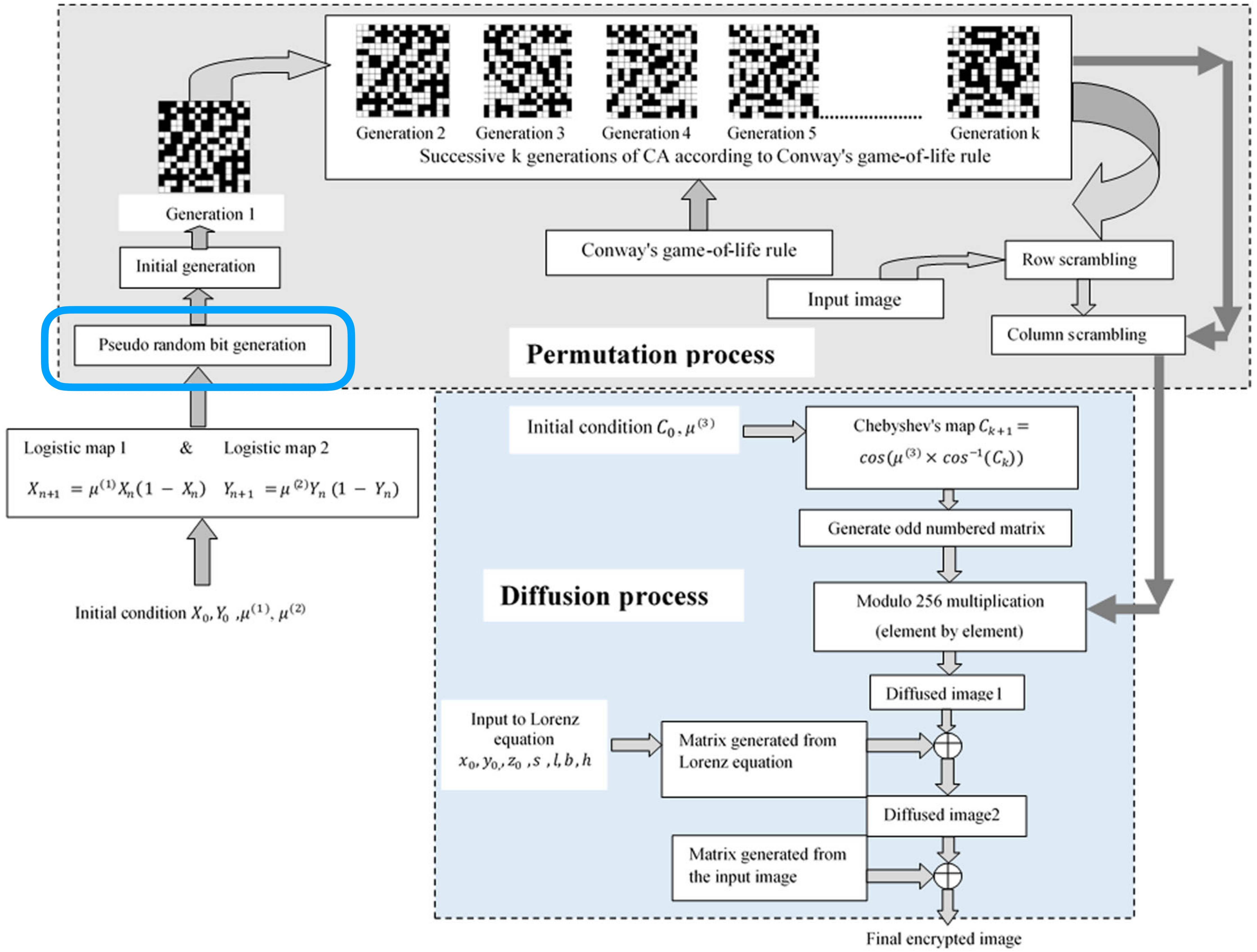
https://xkcd.com; Randall Munroe

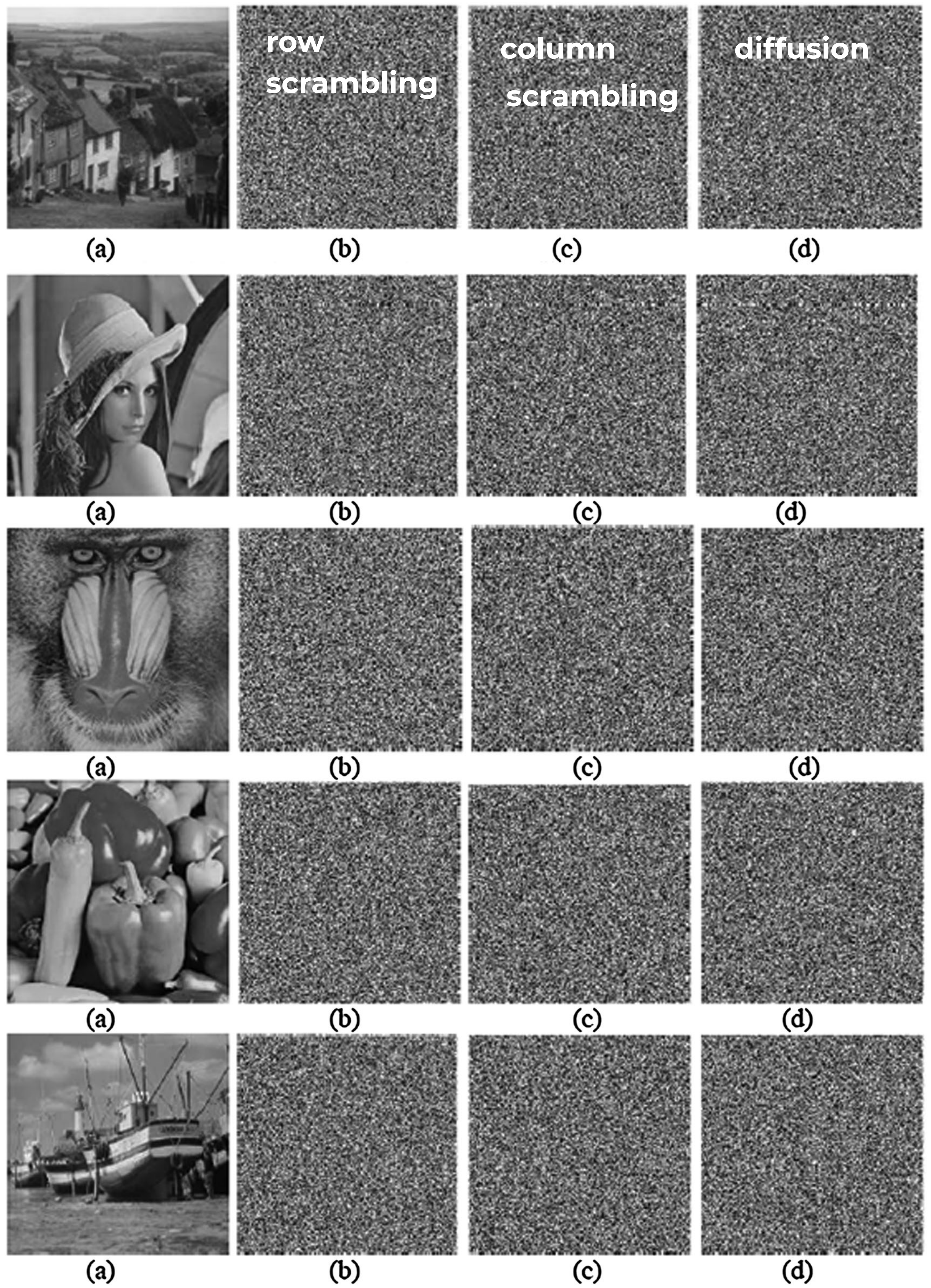
1. introduction:

WHAT FOR?

Unpredictability to preserve the predictability of our clockwork world

- **Image encryption** is also relying on random single-bit arrays:

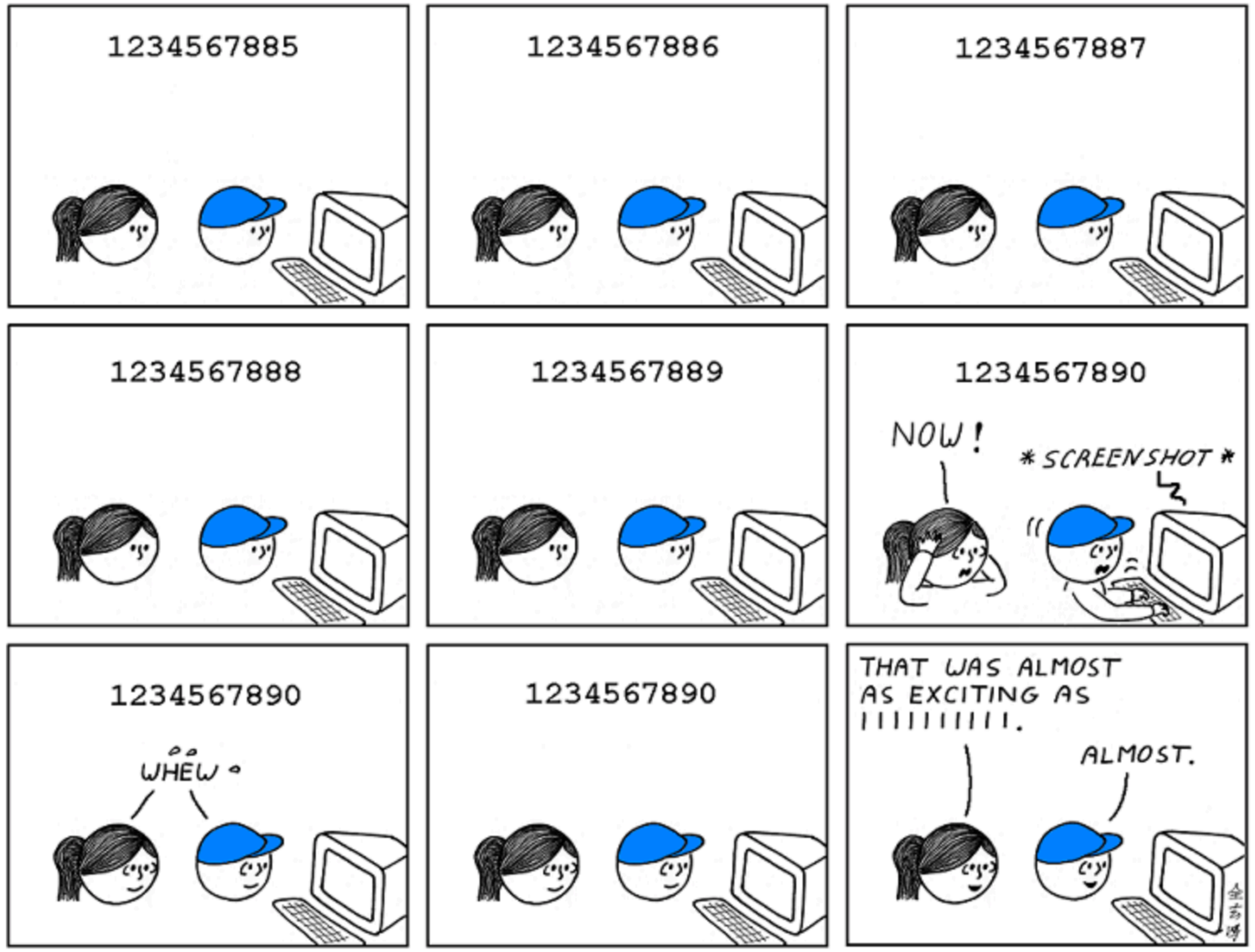




B. Murugan et al., A hybrid image encryption algorithm using chaos and Conway's game-of-life cellular automata, Security Comm. Networks 2016; 9:634–651, DOI: 10.1002/sec.1386

WHAT FOR?

there is definitely a hype about Random bit streams, not only for crypto but also for gaming, virtual reality , Monte Carlo simulations and IoT (notably car security, smart houses, drones to guarantee authentication and secure transmission & control)



https://xkcd.com; Randall Munroe

https://www.cryptomathic.com/news-events/blog/generating-cryptographic-keys-with-random-number-generators-prng

INSIDE QUANTUM TECHNOLOGY

Primary Market:
cybersecurity & simulation

Quantum Random Number Generators: A Ten-year Market Assessment

Report IQT-QRNG-0121
Published January 19, 2021

Main findings: expected market volume of $7.2B by 2026

- most relevant segment: Data Centers [$3.1B]
- significant interest by financial service providers for improved Monte Carlo simulations & data protection [$2.2B]

Georges de la Tour
The dice players (1651 c.a.)

Secondary Market:
gaming & gambling

Main applications:

- Replacement market of

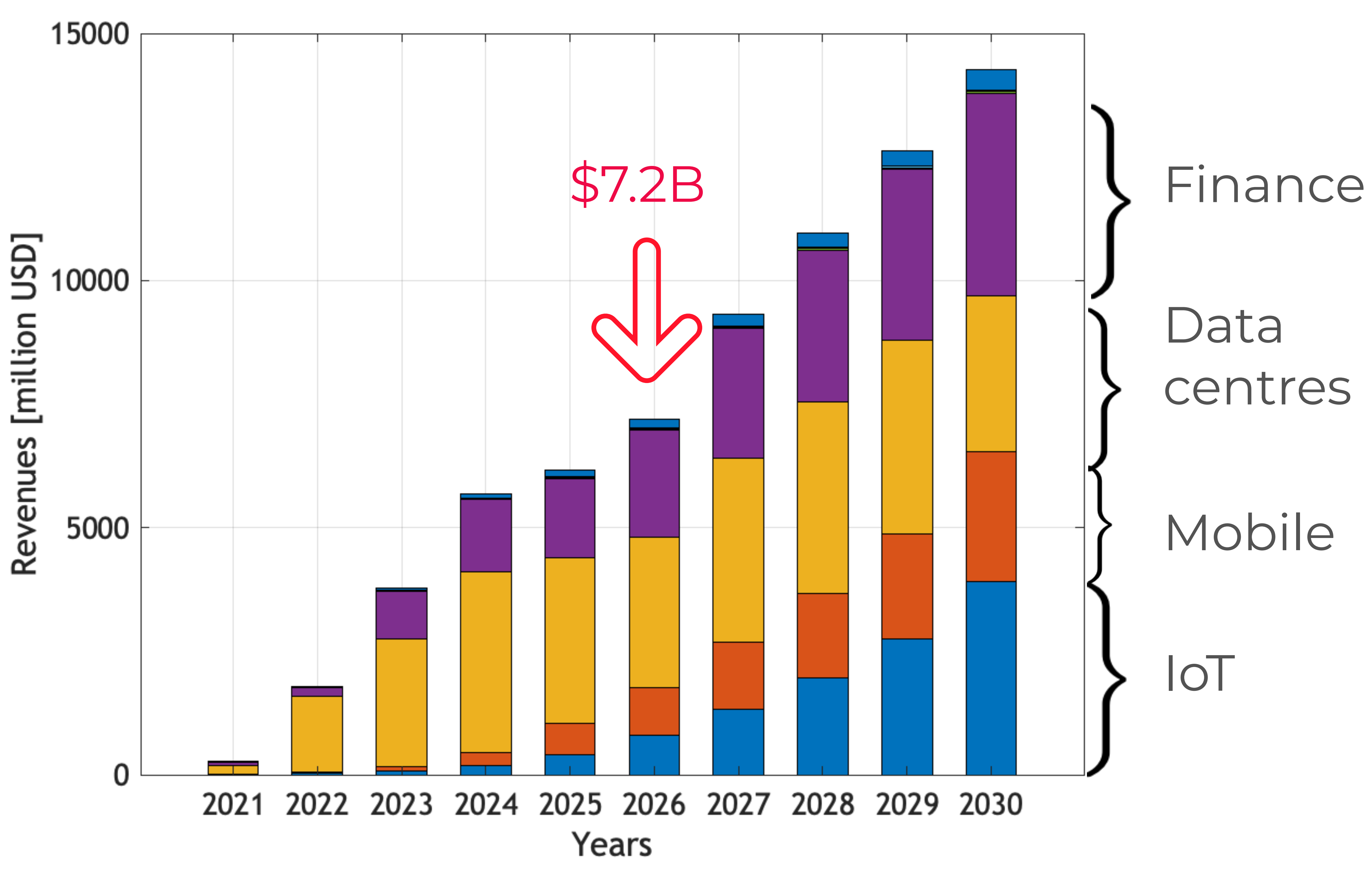
“physical gambling devices”

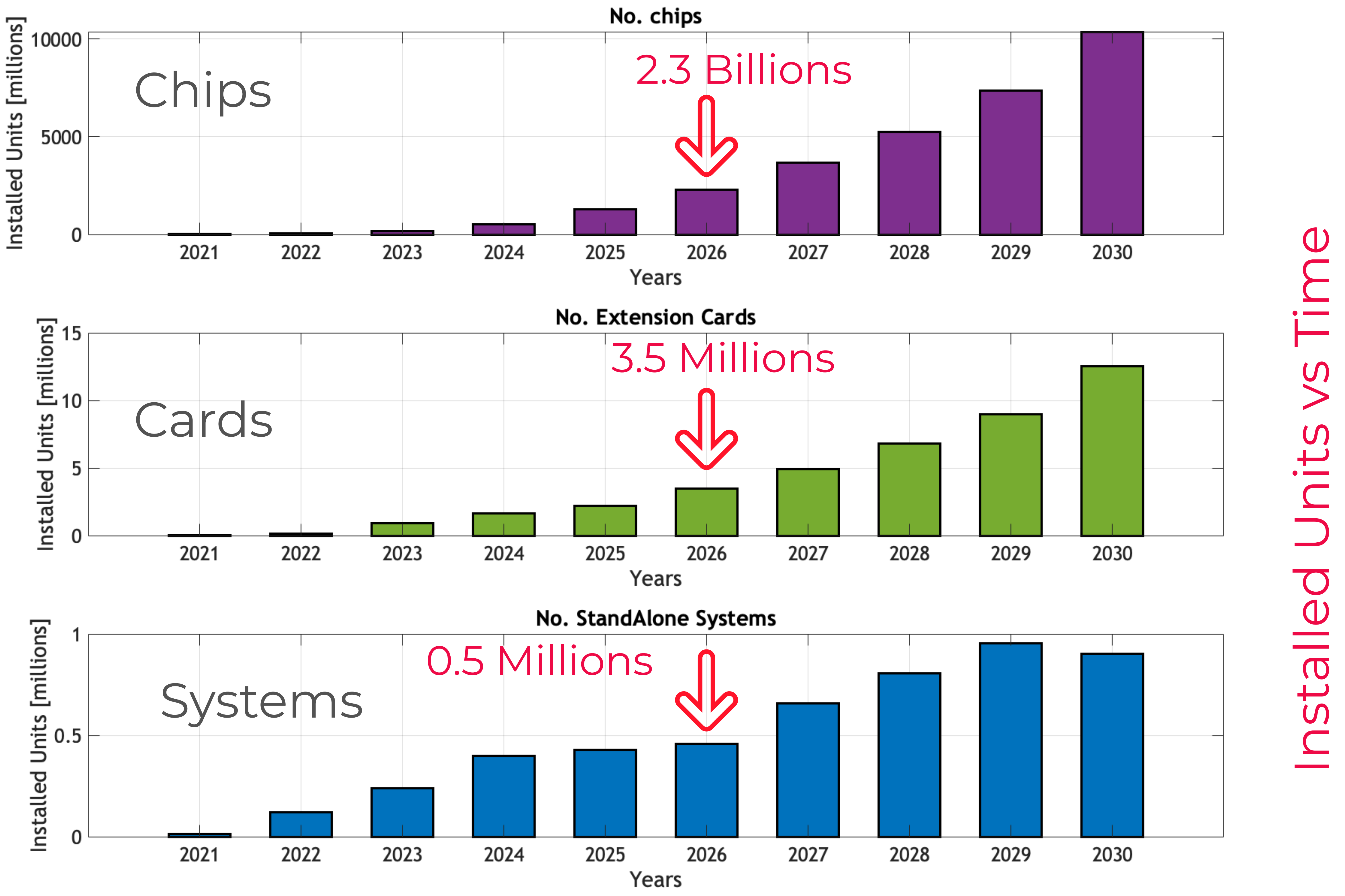
[~ 7 Million cabinets worldwide, 5 years lifespan ⇒ ~1.4M new devices/year]

- Random number streaming to on-line platforms

RANDOM POWER

2. market potential:





Total Market by Product Type

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Chips	1.2	48.5	159.2	455.6	1,038.7	1,771.4	2,688.8	3,672.1	4,877.9	6,544.5
Extension Cards	85.6	210.7	1,014.7	1,560.8	1,768.0	2,388.7	2,915.5	3,414.4	3,841.2	4,577.7
Standalone Devices	180.0	1,530.0	2,594.5	3,658.0	3,356.7	3,035.8	3,712.1	3,874.1	3,904.8	3,134.7
Total ($M)	**266.8**	**1,789.2**	**3,768.4**	**5,674.4**	**6,163.3**	**7,195.9**	**9,316.5**	**10,960.7**	**12,623.9**	**14,256.9**

INSIDE™ QUANTUM TECHNOLOGY

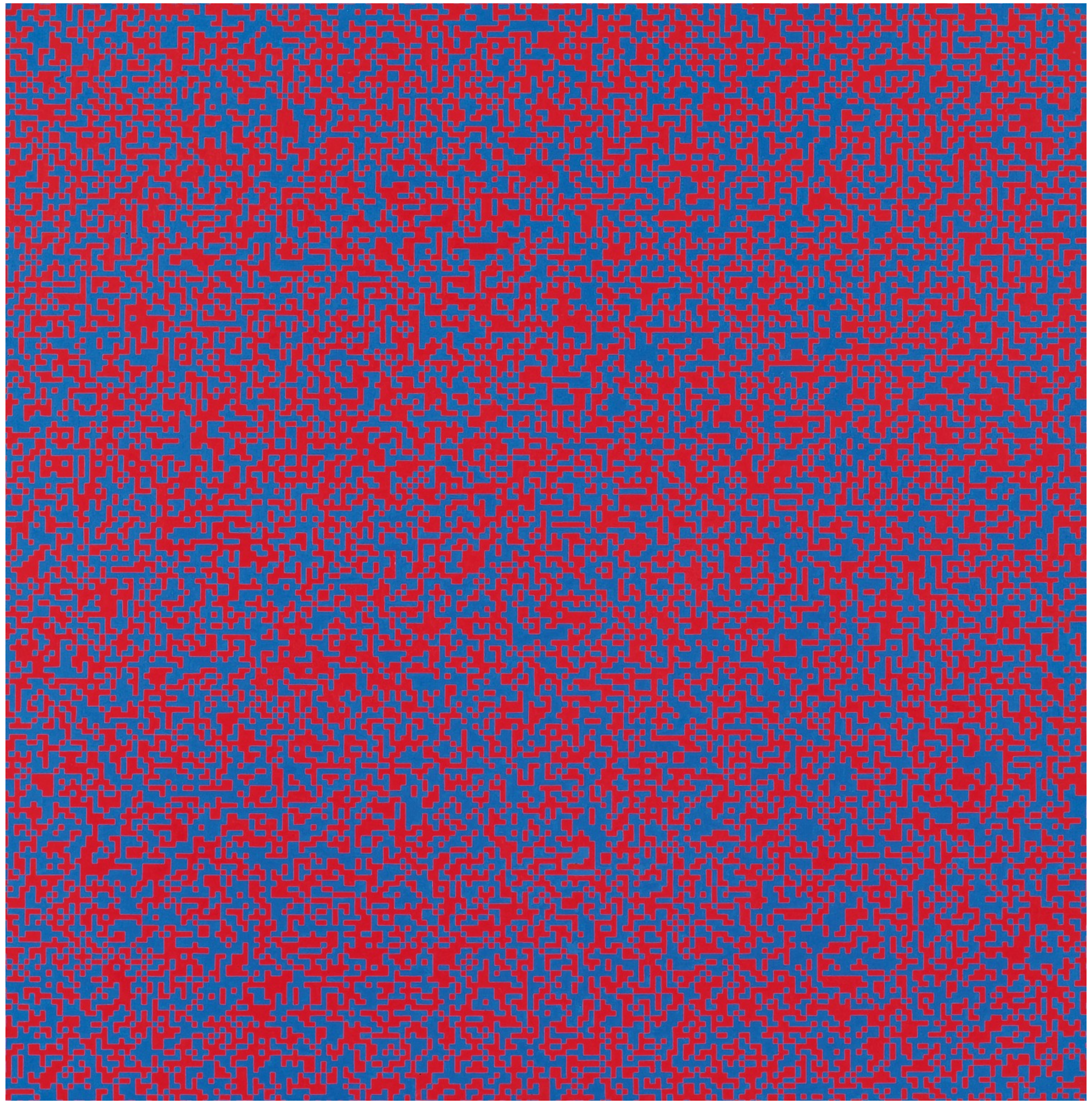
RANDOM POWER

HOW TO GENERATE AN UNPREDICTABLE RANDOM NUMBER?

It is always nice to consider an artist's point of view:

"With *Random Distribution*, the purpose of my system was to cause a reaction between two colours of equal intensity. **I drew horizontal and vertical lines to make 40,000 squares. Then my wife or my sons would read out the numbers from the phone book (except the first repetitive digits), and I would mark each square for an even number while leaving the odd ones blank.** The crossed squares were painted blue and the blank ones red. For the 1963 Paris Biennale I made a 3-D version of it that was shown among the Groupe de Recherche d'Art Visuel installations (and re-created it again on different occasions). I wanted to create a dazzling fight between two colours that shared the same luminosity. This balance of colour intensity was hard to adjust because daylight enhances the blue and artificial light boosts the red. I wanted the visitors to have a disturbing experience when they walked into this room – to almost hurt their eyes with the pulsating, flickering balance of two colours. I like that kind of aggression."

excerpt from https://www.tate.org.uk/context-comment/articles/65-38-21-4-72



François Morellet (1926-2016)
Random Distribution of 40,000 Squares using the Odd and Even Numbers of a Telephone Directory 1960
MOMA, New York

RANDOM POWER

HOW TO GENERATE AN UNPREDICTABLE RANDOM NUMBER?

PRNG
(PseudoRandom Number Generators)

are essentially a piece of software code
⇒ they deterministic and in principle predictable

$$x_n \equiv a x_{n-1} + b \ (mod \ m)$$

an example of linear congruential generator

J. Von Neumann: Anyone who considers arithmetical methods of producing random digits is, of course, in a state of sin.

Von Neumann, John (1951). "Various techniques used in connection with random digits" (PDF). *National Bureau of Standards Applied Mathematics Series*. **12**: 36–38.

TRNG
(True Random Number Generators)

are essentially coin flipping,
namely get bits out observing unpredictable natural phenomena

http://glee.wikia.com/wiki/File:281735_1342370254-coin-flip.gif.gif

HOW TO GENERATE AN UNPREDICTABLE RANDOM NUMBER?

PRNG
(PseudoRandom Number Generators)

Fast, cheap & reasonably easy. However:

- software Random Number Generation is PSEUDO
- code can be bugged
- and it may have a BACKDOOR

Attack Trends
Editor: David Ahmad, drma@mac.com

2006

Two Years of Broken Crypto

Debian's Dress Rehearsal

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POLITICS | EDUCATION | TEXAS

Secret Documents Reveal N.S.A. Campaign Against Encryption

Documents show that the N.S.A. has been waging a war against encryption using a battery of methods that include working with industry to weaken encryption standards, making design changes to cryptographic software, and pushing international encryption standards it knows it can break. Related Article »

2013

Excerpt from 2013 Intelligence Budget Request | Bullrun Briefing Sheet

This excerpt from the N.S.A.'s 2013 budget request outlines the ways in which the agency circumvents the encryption protection of everyday Internet communications. The Sigint Enabling Project involves industry relationships, clandestine changes to commercial software to weaken encryption, and lobbying for encryption standards it can crack.

TRNG
(True Random Number Generators)

Extracting bits from the observation of natural phenomena is not trivial and you may suffer from

- "coin bias" by the embodiment of a great principle
- weakness against environmental parameters
- a significant "attack surface", conditioning the device in use
- low bit rate

HOW DO WE DO IT?

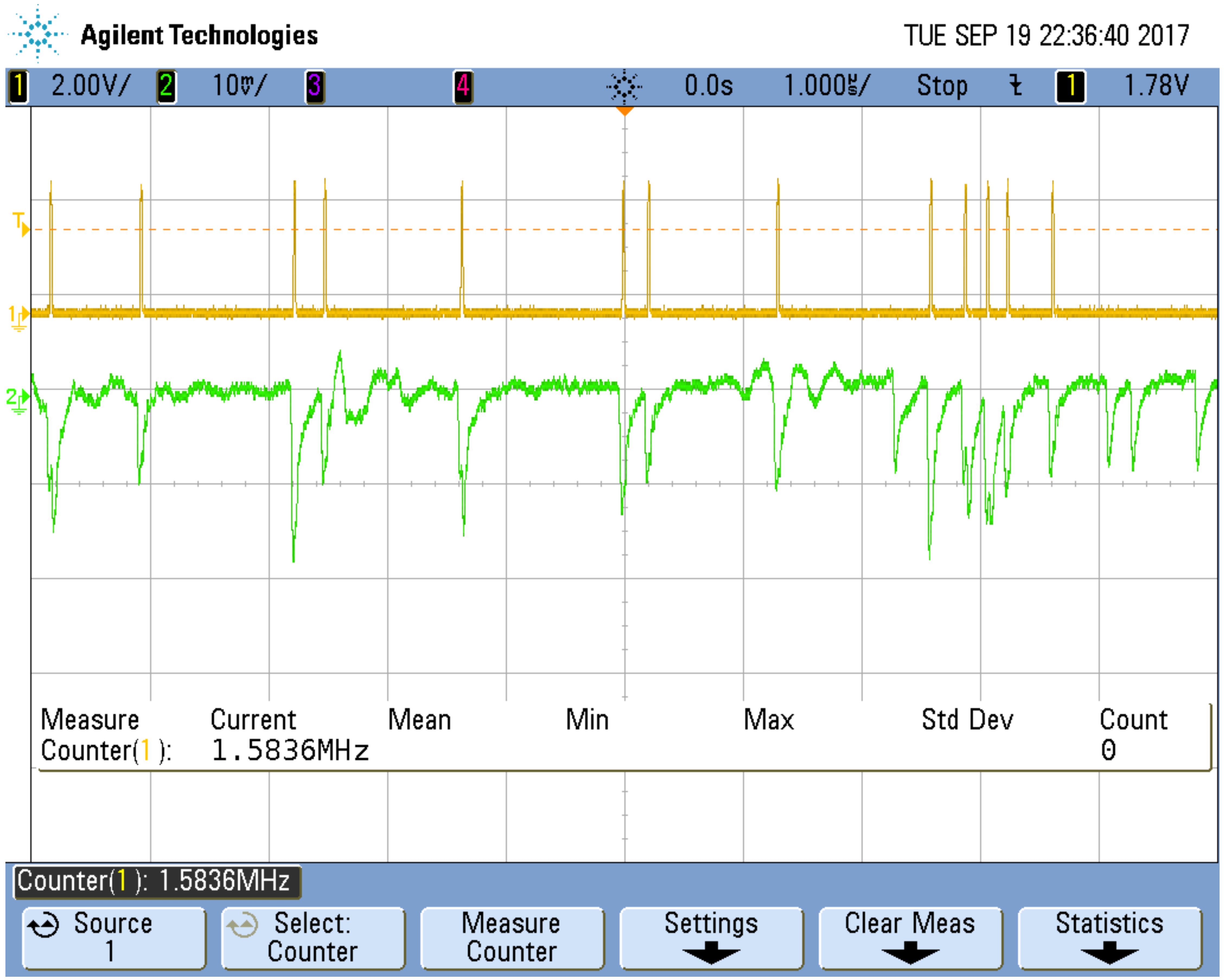
Inspired by Forrest Gump, we say:

RADIOACTIVE IS WHAT RADIOACTIVE DOES

- emission by a radioactive source is due to the quantum laws of Nature
- decays of unstable nuclei are unpredictable

⇒ the sequence of detected decays can be used to generate random bits with different recipes:

- check the parity of the number of pulses in a time window
- pre-define the time window in a way that is equally like to have or not to have a single pulse



Sequence of pulses by the decay of a radioactive source in a nuclear physics detector

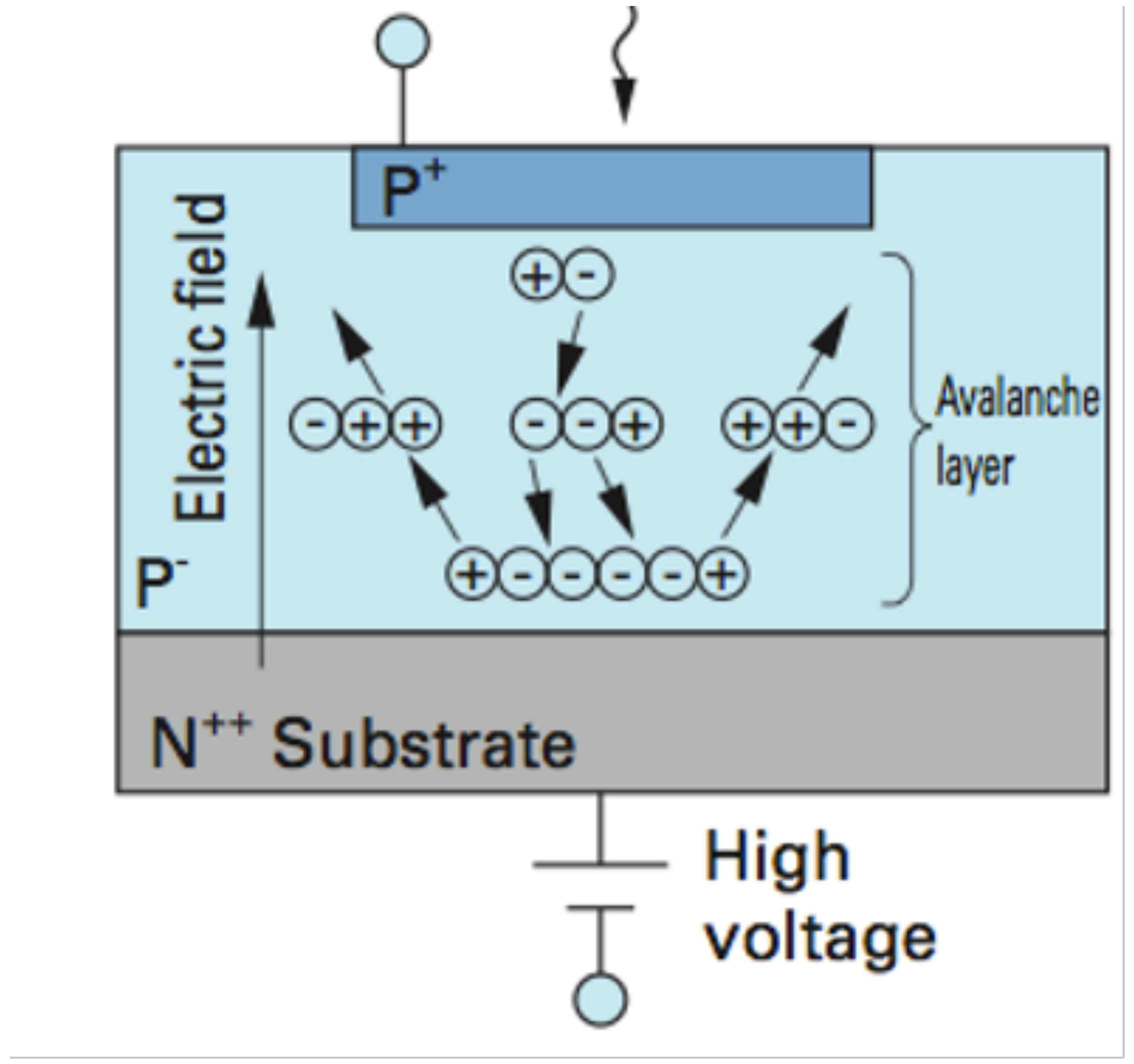
The idea behind RANDOM POWER is to replace a radioactive source with something safer, more handy, cost effective, simple, robust, providing sequences of pulses mimicking radioactive decays.

The generator, an array of Single Photon Avalanche Diodes, namely p-n junctions operated beyond the breakdown voltage:

A pioneering development by Prof. S. Cova at Politecnico di Milano

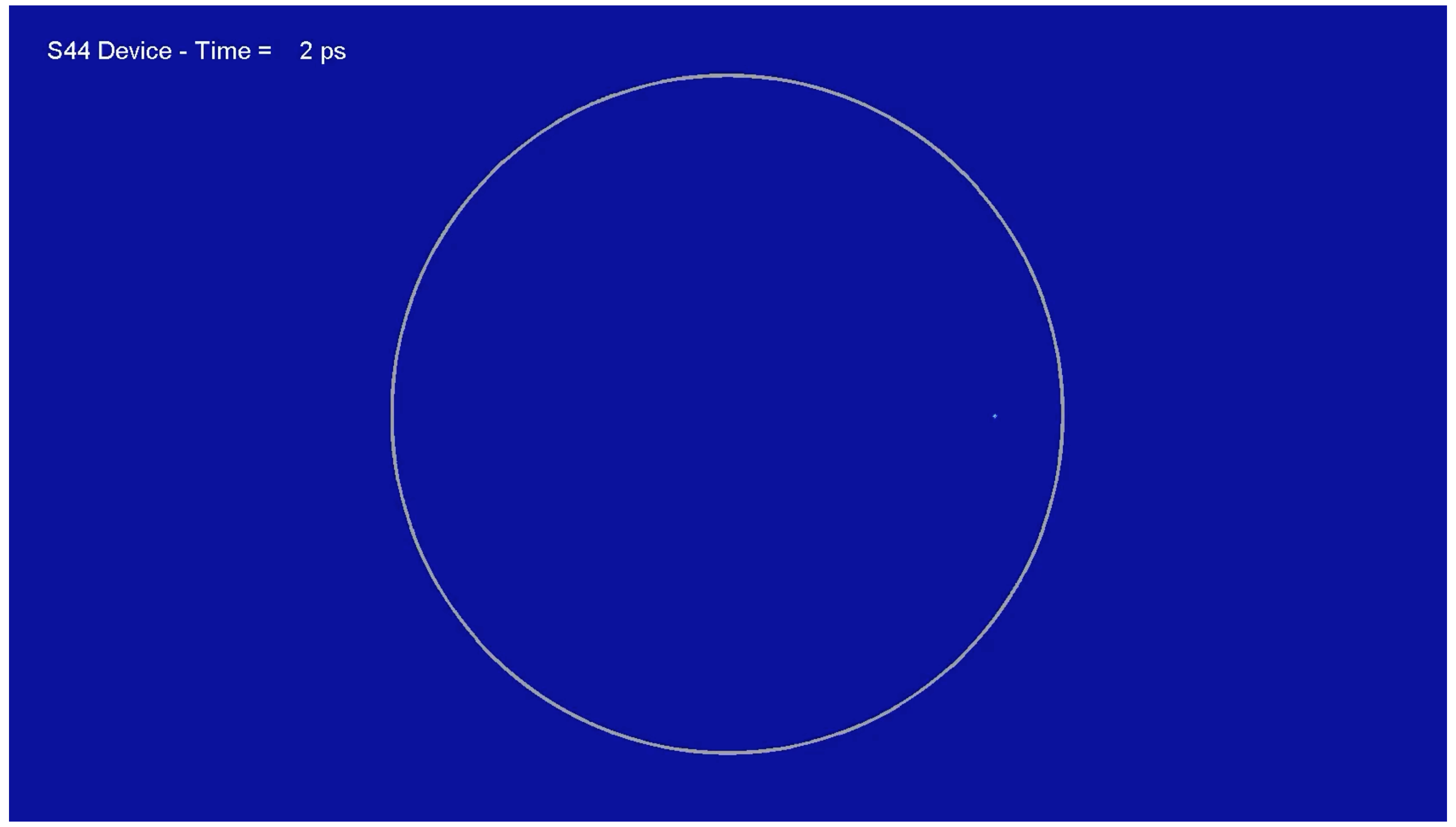
Cova, S., Ghioni, M., Lacaita, A. L., Samori, C., and Zappa, F. "Avalanche photodiodes and quenching circuits for single-photon detection", Applied Optics, 35(12), 1956—1976 (1996)

The essence of a cell



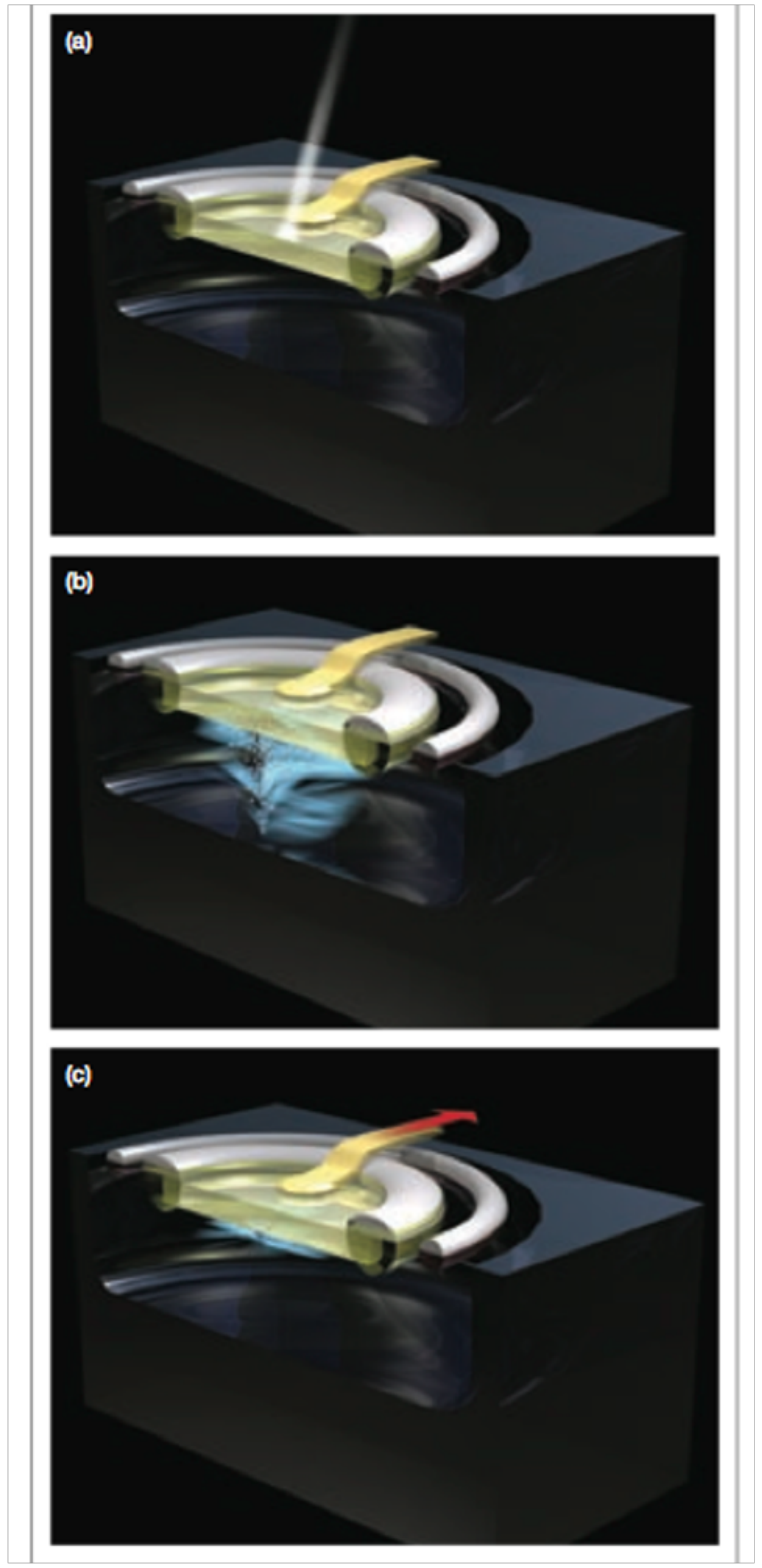
- Very shallow p-n junction ➔ ~ 1 μm
- High electric field ➔ > 3 x 10^5 V/cm
- Mean free path ➔ ≈ 0.01 μm

Simulation of an avalanche development



Courtesy of Ivan Rech, Politecnico di Milano
[50 μm cell size]

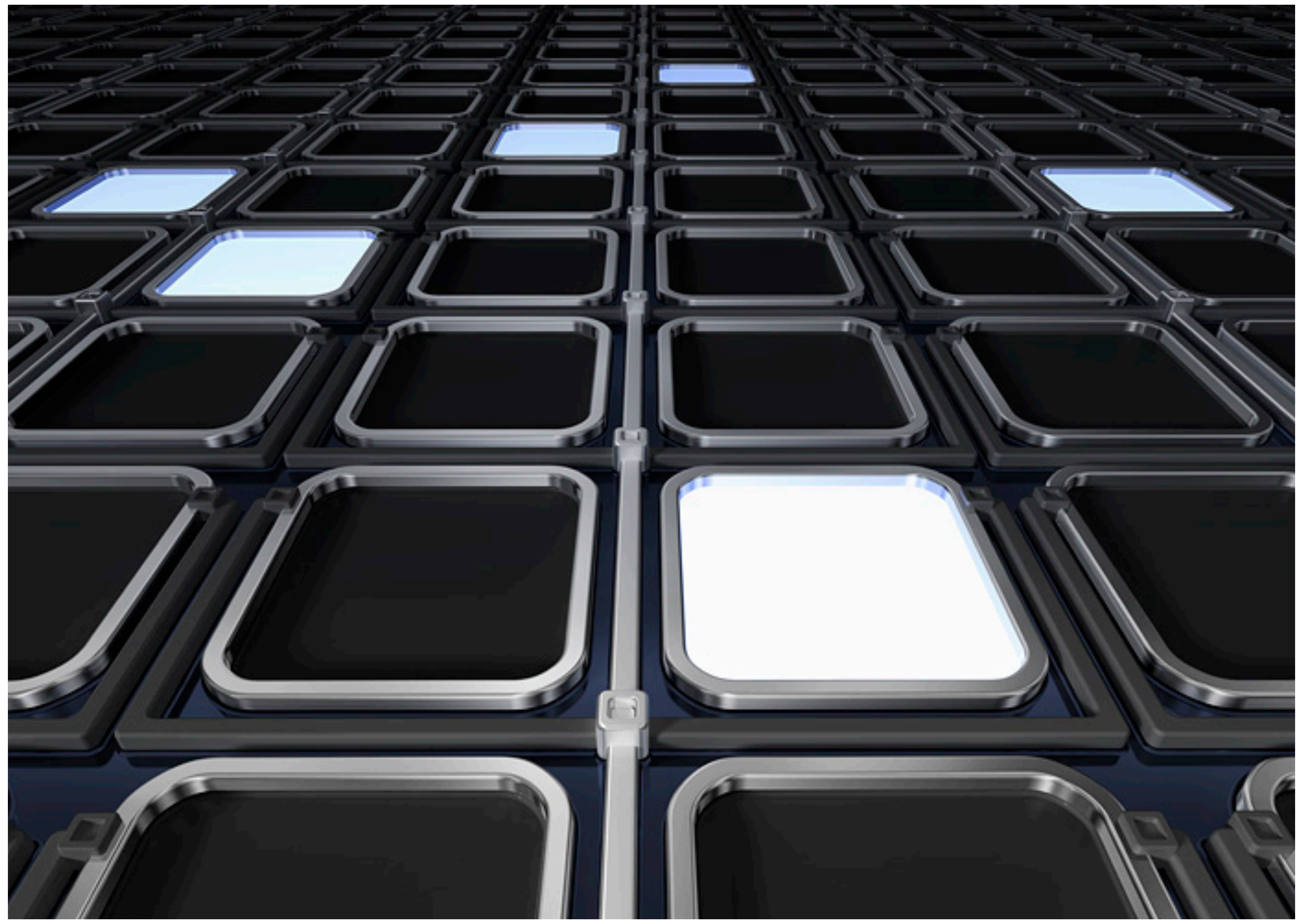
Multiplication by about 1 000 000



E. Charbon & S. Donati, OPN Optics & Photonics News, February 2010

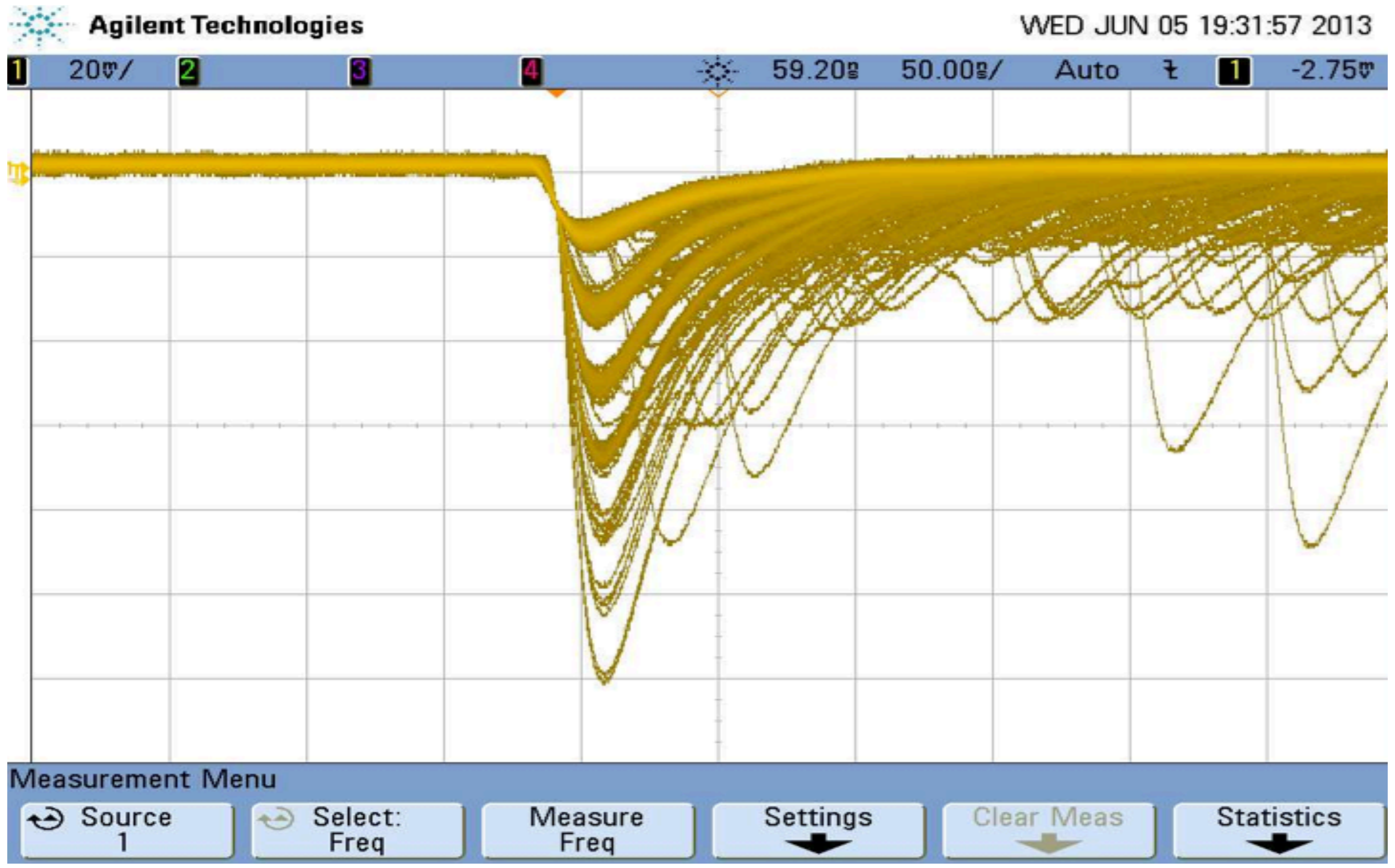
Photon induced charge carrier generation

Not indexed arrays of SPAD, with a single output node, are nowadays known as Silicon Photomultipliers, the state-of-the-art room T detectors with single photon sensitivity and photon-number resolving capability:



- SiPM may be seen as a collection of binary cells, fired when a photon in absorbed

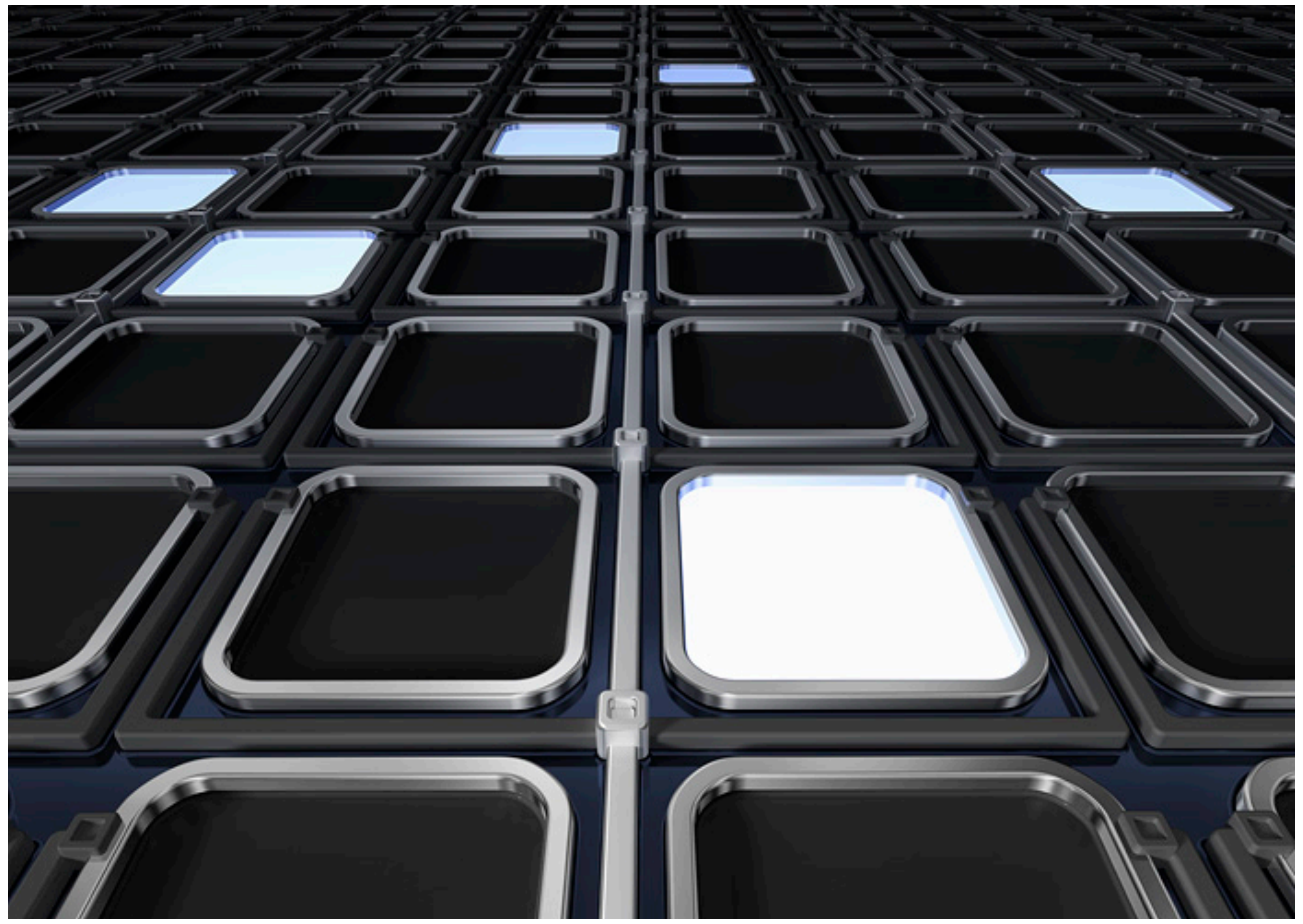
[in principle, a NATIVE DIGITAL DEVICE]



- "counting" cells provides an information about the intensity of the incoming light:

RANDOM POWER

Not indexed arrays of SPAD, with a single output node, are nowadays known as Silicon Photomultipliers, the state-of-the-art room T detectors with single photon sensitivity and photon-number resolving capability:



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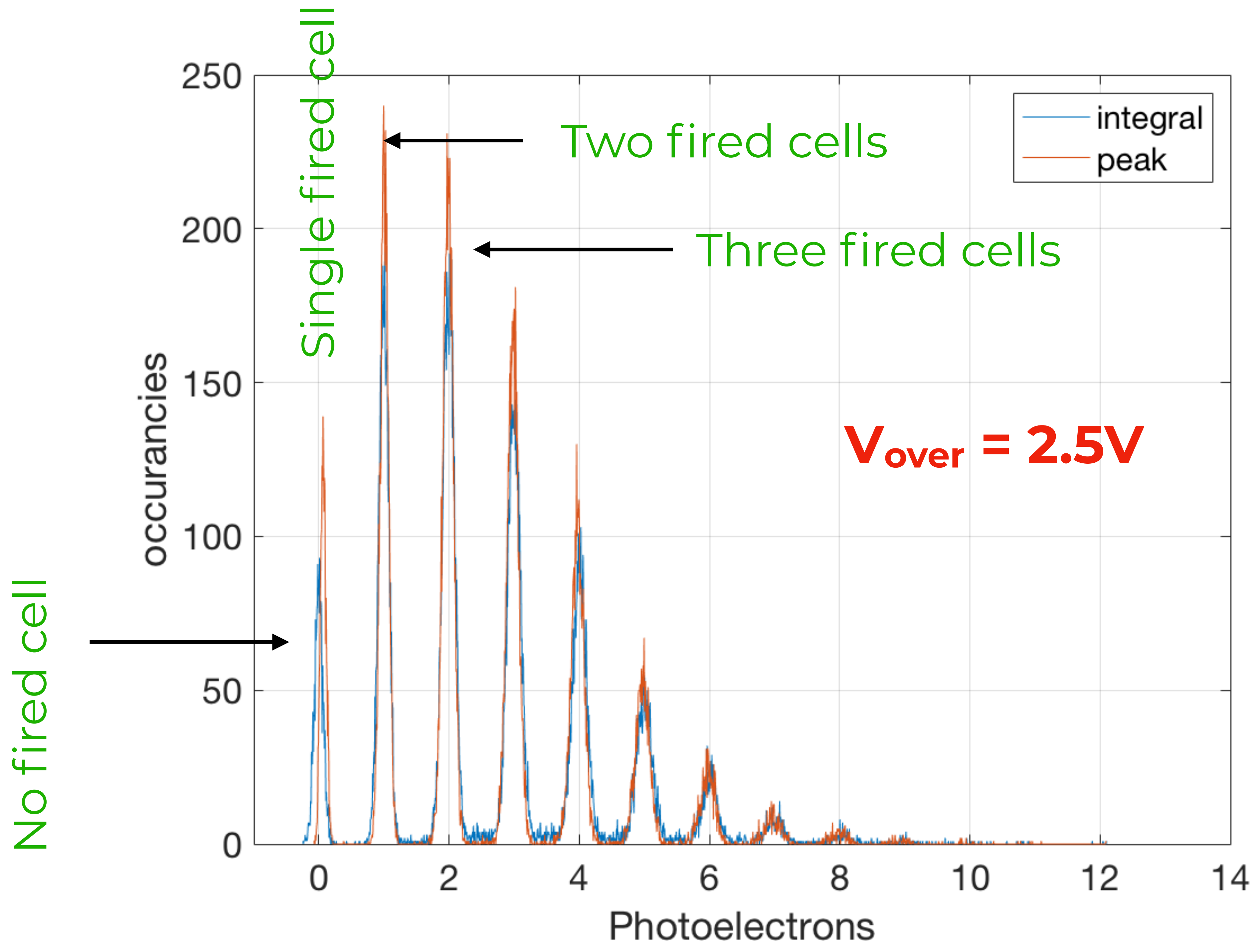


- histogram of the response to a high statistics of low intensity light pulses

The name of the game: charge carriers can be generated "spontaneously", also when no light is illuminating the sensor

A lesson from the past, when this was known since the early days of the Silicon technology development:

1. INTRODUCTION

MOST reverse biased p–n junctions in silicon have their avalanche breakdown caused by microplasma effects. Microplasmas are small regions within the junction,[1] where a local disturbance of the electrical field is believed to reduce the breakdown voltage to a value below the breakdown voltage of the surrounding uniform junction.[2–5] As voltage is increased from low values microplasma breakdown is generally characterized by random "on–off" current fluctuations so long as currents remain below a critical value (40 to 120 μA).[6–8]

from paper 2

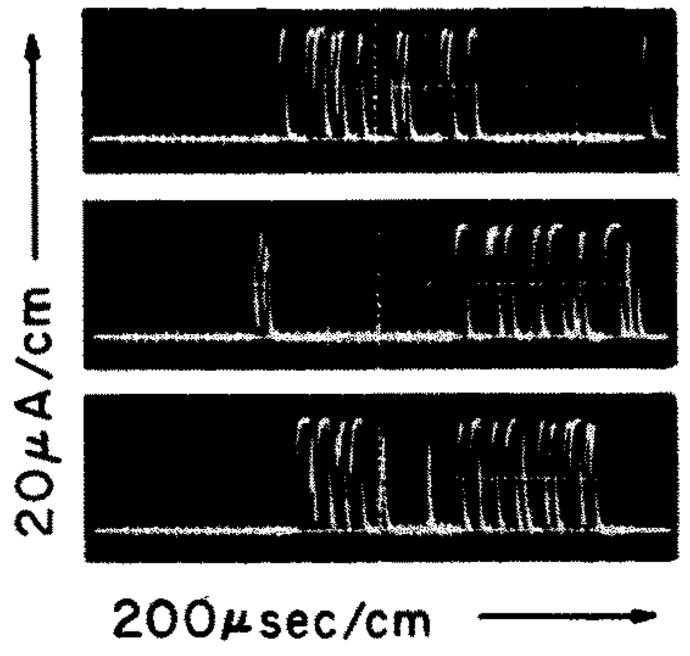


FIG. 5. Avalanche current as a function of time at low temperatures. The group character of the avalanche pulses is obvious.

from paper 3

1

PHYSICAL REVIEW VOLUME 94, NUMBER 4 MAY 15, 1954

Avalanche Breakdown in Silicon

K. G. McKay
Bell Telephone Laboratories, Murray Hill, New Jersey
(Received December 23, 1953)

2

JOURNAL OF APPLIED PHYSICS VOLUME 35, NUMBER 5 MAY 1964

Model for the Electrical Behavior of a Microplasma*

Roland H. Haitz†
Shockley Laboratory, Clevite Corporation Semiconductor Division, Palo Alto, California
(Received 5 November 1963)

The complex current fluctuations observed in connection with microplasma breakdown can be explained by a simple model containing two constants: extrapolated breakdown voltage V_b and series resistance R_s; and two continuous probability functions: turnoff probability per unit time $p_{10}(I)$ as a function of pulse current I and turn-on probability per unit time p_{01}. Experimental methods allowing an accurate measurement of these four quantities are described. The new concept of an extrapolated breakdown voltage V_b is discussed based on two independent measurements: one of secondary multiplication and the other of instantaneous current, both as a function of voltage. Within the experimental accuracy of 20 mV both methods extrapolated to one and the same breakdown voltage. The turnoff probability $p_{10}(I)$ is determined by a new combination of experimental techniques to cover the current range from 5 to 70 μA with a variation of 11 decades for $p_{10}(I)$. The observation of a narrow turnoff interval is explained quantitatively.

F APPLIED PHYSICS VOLUME 36, NUMBER 10 OCTOBER 1965

Mechanisms Contributing to the Noise Pulse Rate of Avalanche Diodes*

3

Roland H. Haitz†
Shockley Research Laboratory, Semiconductor Division of Clevite Corporation,‡ Palo Alto, California
(Received 16 November 1964)

RANDOM POWER

The name of the game: charge carriers can be generated “spontaneously”, also when no light is illuminating the sensor

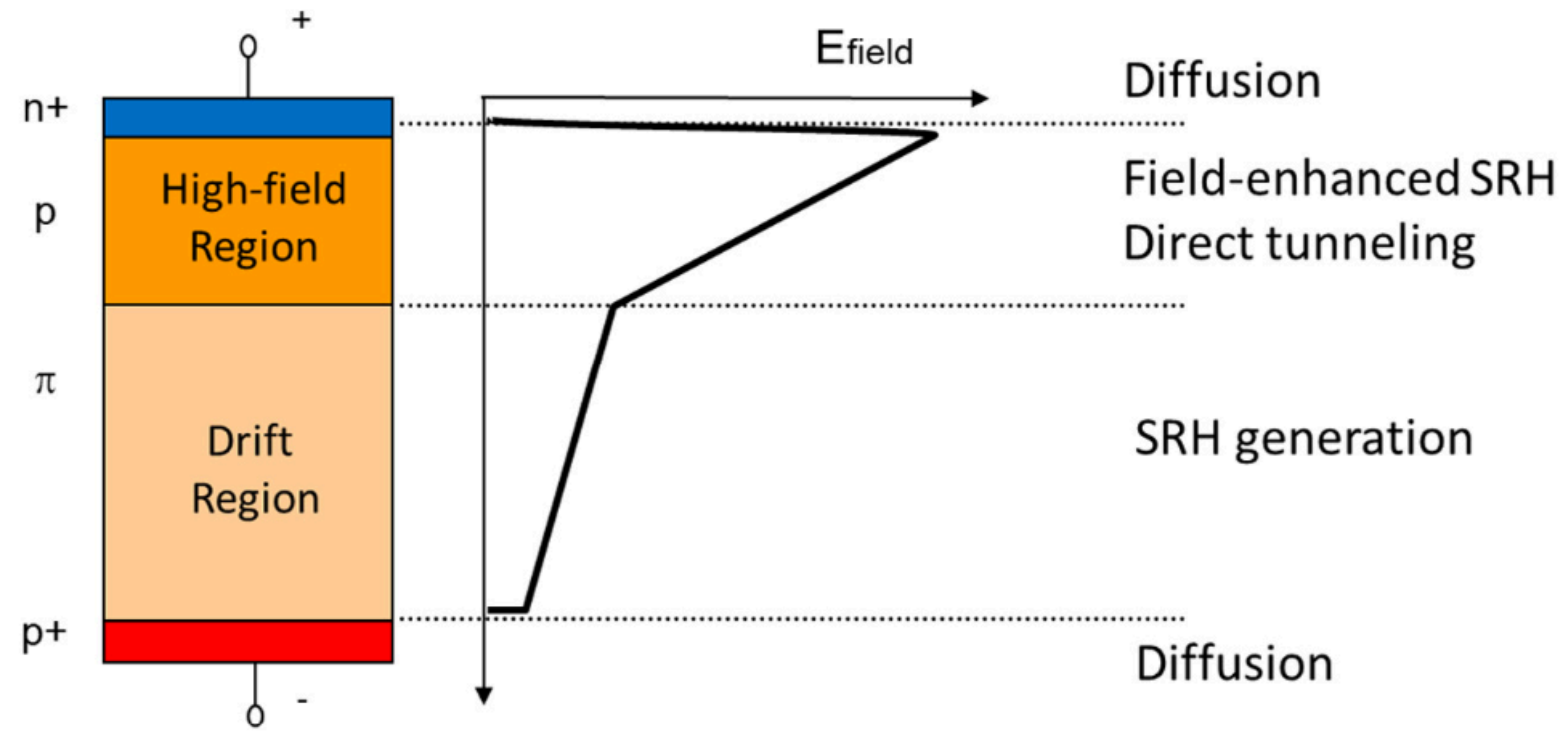


Fig. 8. Representation of the different sources of primary dark events and their location in the SPAD structure.

after A. Gola, C. Piemonte, NIM A926 (2019) 2-15

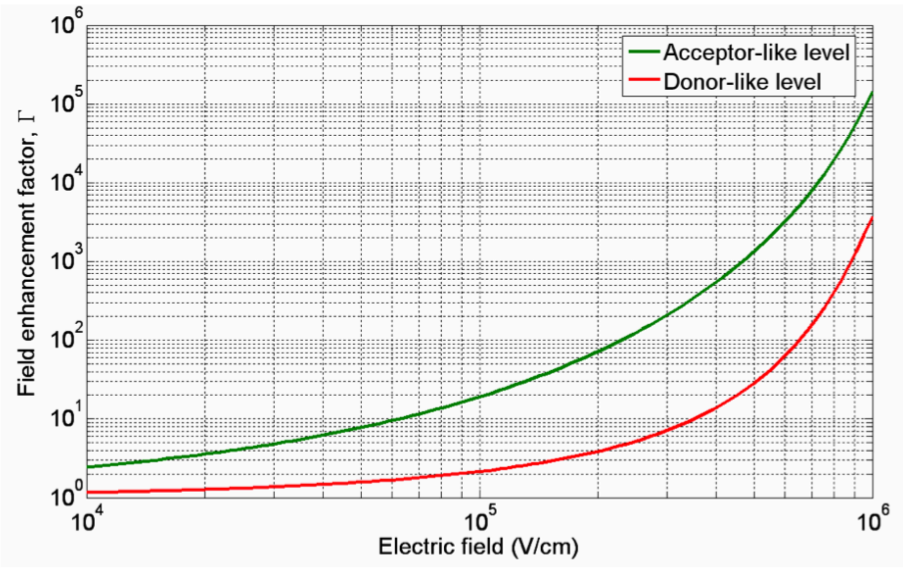
Thermal generation of carriers by states in the bang-gap (Shockley-Read-Hall statistics), where trapping and de-trapping is increased by the high electric field in the junction. The **Generation rate** can be written as:

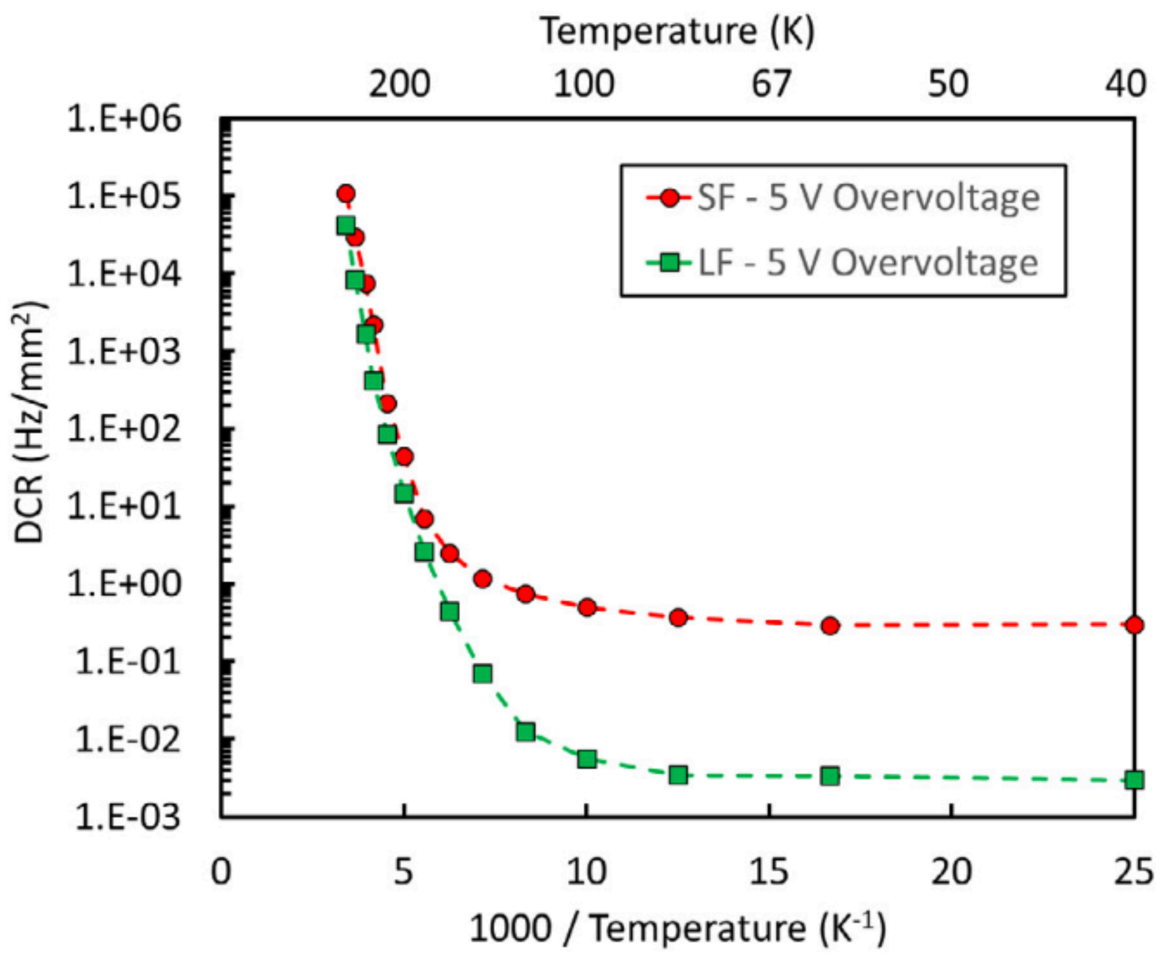
$$G = \frac{n_i}{2 \cdot \cosh\left(\frac{E_0 - E_t}{kT}\right)} N_t \sigma v_{th} = \frac{n_i}{\tau_{g0}}$$

- E_0 = Fermi level
- E_t = trapping level
- n_i = intrinsic carrier concentration
- N_t = trapping concentration
- σ = trapping cross section
- v_{th} = thermal velocity

$$G = \frac{(1+\Gamma)\, n_i}{\tau_{g0}}$$

Γ “boost” by the field





F. Acerbi, et al., IEEE Trans. Electron Devices 64 (2) (2017) 521–526.

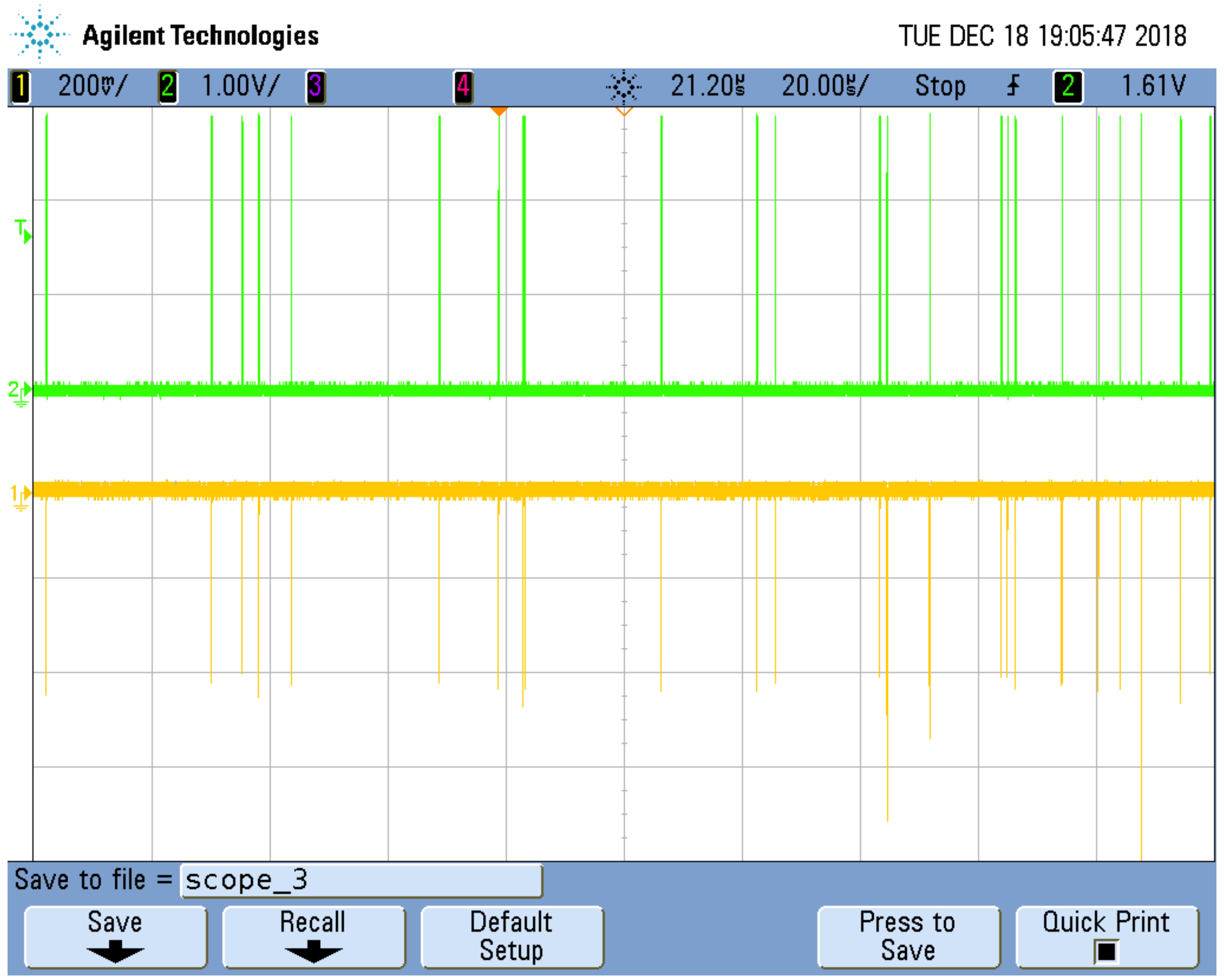
Key issues:

- **in SiPM, the Dark Count Rate is O(1 KHz)/cell, 50 μm pitch (it may be higher for SPAD arrays in CMOS technology)**
- provided the nature of the Dark Pulses, we have a significant dependence on Temperature
- forget-me-not: the Over-voltage is affecting the triggering probability

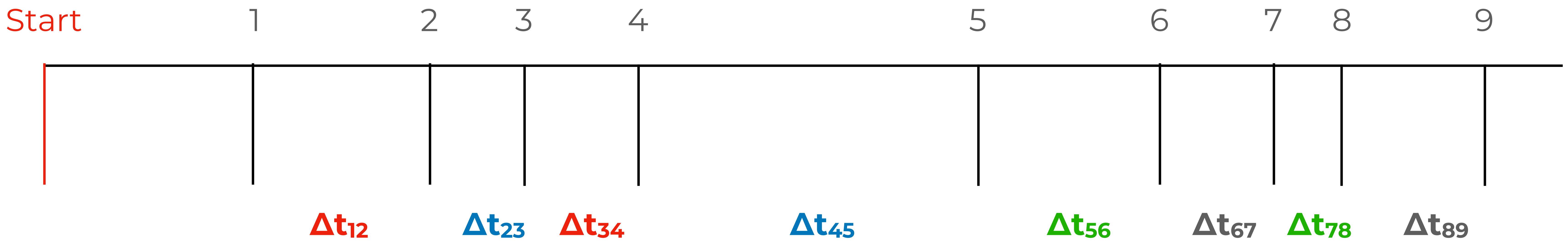
RANDOM POWER

The essence of : turning unpredictable "Dark Pulses" into bits

1. tag & time stamp the occurrences of the random pulses



2. analyse the time series of the pulses:



- bit 1: Δt_{12} vs Δt_{34}
- bit 2: Δt_{23} vs Δt_{45}
- bit 3: Δt_{56} vs Δt_{78}
- bit 4: Δt_{67} vs Δt_{89}

This is the essence of

RANDOM POWER

-Italian Patent granted on Sept.17th, 2020

- 2019 Int'l: PCTIB2019/058340
- application extended to EU, US, China, JP, Korea in April 2021

A genuine **Q(quantum)-True Random Number Generator,** namely **a Quantum Coin Flipper**

providing virtually endless streams of

RANDOM BITS ➜ CRYPTOGRAPHIC KEYS

shielded against any bias by the fundamentals of Quantum Mechanics

ARE WE ALONE IN THE UNIVERSE?

	IDQ	RANDOM POWER
History	**Established in 2001**	Starting-up
Technology floor	**QTRNG platform + services**	Minimum Viable Product
Complexity	**HIGH**	**LOW**
Efficiency	**LOW**	**HIGH**
Robustness	**LOW**	**HIGH**
Miniaturisation	**BIG chip**	**SMALL chip viable**
Cost of the single generator board	**1000+ EUR**	**500 EUR**

ID Quantique - https://www.idquantique.com

+ a handful of other players:

Quintessence Labs, Quantum Numbers Corp, KETS, QUSIDE, Qrypt, PicoQuant, MPD

Major advantage of the Random Power technology, fully CMOS compliant, offering the possibility to integrate the device into a custom chip with advanced features

KEY ISSUES OF RANDOM POWER

- **endogenous in-silico seeding of the pulses** **[simplicity]**
- **self-amplification of the seeds in excess of a factor 1 000 000, making pulse tagging robust**
- **bit extraction through a non parametric local analysis of the time series of pulses** } **[robustness]**
- no influence of temperature on the randomness of the occurrences
- **no need of post-processing to correct left-over bias** } **[efficiency]**
- maximum bit/occurrence rate = 40% [2 random bits every 5 pulses]
- **current rate at the 100Kbps rate for every mm² of Silicon sensor**
- **potential to embed the system into an ASIC [Application Specific Integrated Circuit]** **[miniaturisation]**

WHERE ARE WE NOW

The MINIMUM VIABLE PRODUCT [MVP], the progenitor of a class of Quantum Random Bit Generators:

Qualified according to the NIST standards
(National Institute of Standard & Technology)

Developed thanks to the **seed capital [100 000 €]** granted by

https://attract-eu.com

ATTRACT

which selected Random Power as one of 170 “breakthrough projects” out of 1211 submissions

WHERE ARE WE NOW

8 cm

3.5 cm

Upon request, bits can be routed on pins

FTDI chip for data routing on the USB

FPGA embedding a proprietary TDC and implementing the bit extraction + real-time sanity checks (MONOBIT&RUNS) + conditioning function (SHA-256)

Amplification & discrimination

Single generator (either 1x1 mm2 or 3x3 mm2 - Bit rate for the smaller area device: O(100 kbps) - operated with overvoltage stabilisation against Temperature variations

6. state-of-the-art:

finalAnalysisReport_PART2.txt

```
------------------------------------------------------------------------------
RESULTS FOR THE UNIFORMITY OF P-VALUES AND THE PROPORTION OF PASSING SEQUENCES
------------------------------------------------------------------------------
   generator is </Users/luca/Documents/Random_Power/ProgramAndTechnical/ATTRACT_Eu_Board_Fw8/
TestFW8_4BitNoReshape_1GB_Part2.bin>
------------------------------------------------------------------------------
 C1  C2  C3  C4  C5  C6  C7  C8  C9 C10  P-VALUE  PROPORTION  STATISTICAL TEST
------------------------------------------------------------------------------
100 110  95  93  90  90 114 101  98 109  0.682823    986/1000    Frequency
 97 102  94 103 107  97 105 106 102  87  0.941144    993/1000    BlockFrequency
 95  95 101 100 113 106  93 100  89 108  0.842937    989/1000    CumulativeSums
 94 112 117  90  93  91  89  96 123  95  0.125927    987/1000    CumulativeSums
100  93  91 112  93 112  99 110 101  89  0.647530    992/1000    Runs
105  91  96  80 121  99  85 100 107 116  0.092597    989/1000    LongestRun
100 104  89 110  97  88 126  84  99 103  0.148653    992/1000    Rank
 95 109 103 113  85  94  90 100 106 105  0.630872    995/1000    FFT
104  98  91  89 104  90 110 104 115  95  0.632955    987/1000    NonOverlappingTemplate
111  93 112  88  96  95 100 101 106  98  0.798139    981/1000    NonOverlappingTemplate
111 100  93  94 101 109  93  87 117  95  0.514124    986/1000    NonOverlappingTemplate
 86  94 119 101 107  98  93 103  98 101  0.626709    998/1000    NonOverlappingTemplate
 93 112  93 103  91  89  94  99 115 111  0.498313    989/1000    NonOverlappingTemplate
 84 106 101 109  86 119 111  96  94  94  0.249284    988/1000    NonOverlappingTemplate
114  92  98  96 105 105 101 100  83 106  0.682823    992/1000    NonOverlappingTemplate
117  87  98 101 100 106  91  94 105 101  0.697257    991/1000    NonOverlappingTemplate
 90  93  97 107  99  89 100 116 108 101  0.689019    994/1000    NonOverlappingTemplate
 99 108  98  99 116 104  98  85  96  97  0.743915    991/1000    NonOverlappingTemplate
 88  93 103 101 112  94 111  99 100  99  0.829047    988/1000    NonOverlappingTemplate
 96  97 103 103 106 108 114  97  93  83  0.651693    987/1000    NonOverlappingTemplate
108  95  97 109  84  94 101 101  91 120  0.388990    988/1000    NonOverlappingTemplate
```

series of tests on non-overlapping templates

```
  80  98 115 100  98 115 107  91  83 113  0.106877    993/1000    OverlappingTemplate
  86 116 121 101  91  87  96 101  87 114  0.084037    990/1000    Universal
  97  90 107 116 110  95 103  93  92  97  0.668321    987/1000    ApproximateEntropy
  70  62  54  60  55  66  60  63  77  65  0.668486    626/632     RandomExcursions
  62  69  58  70  58  61  56  71  63  64  0.909311    626/632     RandomExcursions
  60  53  59  62  76  72  60  59  66  65  0.681642    620/632     RandomExcursions
  70  64  83  45  62  69  70  65  51  53  0.040275    622/632     RandomExcursions
  66  69  69  73  73  73  38  49  52  70  0.009611    627/632     RandomExcursions
  65  52  67  82  68  54  51  63  72  58  0.136536    627/632     RandomExcursions
  61  55  60  72  66  71  67  56  55  69  0.711017    626/632     RandomExcursions
  47  61  62  58  71  63  71  61  68  70  0.553450    625/632     RandomExcursions
  60  57  66  62  58  61  67  67  73  61  0.941564    624/632     RandomExcursionsVariant
  60  70  43  60  64  58  58  88  64  67  0.030676    622/632     RandomExcursionsVariant
  66  58  51  65  51  61  72  72  71  65  0.447593    624/632     RandomExcursionsVariant
  63  67  59  46  67  60  68  70  73  59  0.483876    623/632     RandomExcursionsVariant
  61  67  58  69  63  74  48  60  66  66  0.615645    624/632     RandomExcursionsVariant
  75  62  63  58  63  55  66  54  71  65  0.717488    624/632     RandomExcursionsVariant
  68  63  66  54  57  65  63  67  56  73  0.827336    620/632     RandomExcursionsVariant
  75  54  64  57  65  64  56  62  64  71  0.733547    623/632     RandomExcursionsVariant
  76  68  70  56  55  50  66  52  64  75  0.176734    624/632     RandomExcursionsVariant
  89  63  57  59  59  55  58  68  63  61  0.134074    624/632     RandomExcursionsVariant
  67  68  61  57  60  69  66  63  63  58  0.979797    624/632     RandomExcursionsVariant
  65  64  62  71  58  68  67  53  60  64  0.917568    626/632     RandomExcursionsVariant
  71  58  56  62  75  62  67  64  53  64  0.701268    626/632     RandomExcursionsVariant
  64  71  49  62  61  69  69  59  59  69  0.694743    626/632     RandomExcursionsVariant
  61  65  54  59  63  63  64  76  62  65  0.879806    626/632     RandomExcursionsVariant
  58  55  57  67  65  66  54  66  76  68  0.642077    629/632     RandomExcursionsVariant
  46  64  65  61  64  61  81  59  75  56  0.150772    624/632     RandomExcursionsVariant
  50  56  65  67  74  67  51  63  73  66  0.353061    629/632     RandomExcursionsVariant
 106 107  87 107  94 109 100  83  92 115  0.352107    989/1000    Serial
 105 100  94  98  96  95  96 101  95 120  0.790621    991/1000    Serial
 105  97  89 101  96 106  92 112 105  97  0.875539    991/1000    LinearComplexity


 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 The minimum pass rate for each statistical test with the exception of the
 random excursion (variant) test is approximately = 980 for a
 sample size = 1000 binary sequences.

 The minimum pass rate for the random excursion (variant) test
 is approximately = 618 for a sample size = 632 binary sequences.

 For further guidelines construct a probability table using the MAPLE program
 provided in the addendum section of the documentation.
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

- **A proto-randomness farm based on 10 boards have been collecting about 1.5 Tb, qualified through the NIST and TESTU01 suites.**

Results show that the stream looks extremely "white", essentially with no failures on the raw data beside what can be statistically expected.

- **Two tests have been implemented in firmware to guarantee real-time sanity checks:**

✳ **MONOBIT**: essentially testing the asymmetries between 0's and 1's in a bit string:

1 1 1 1 1 0 1 0 0 1 1 1 0 0 0 1

✳ **RUNS**: testing the statistics of the number of sequences of identical bits in a string

1 1 1 1 1 0 1 0 0 1 1 1 0 0 0 1

5 bits 1 bit 2 bits 3 bits 3 bits 1 bit

WHAT'S NEXT?

$\approx 10^5$ € [2021-2022]	$\approx n \times 10^5$ € [2022-2023]	$\approx 2\text{-}3 \times 10^6$ € [2022-2025]

Time & Money

- **GO TO THE MARKET and EXPLOIT THE MVP**

N&G CONSULTING

LiFT — GIVING IDEAS THE HIGHEST VALUE

- Enhance IP protection
- build int'l collaborations
- grant seeking

- GO MACRO & SECURE:

- development of "agnostics" applications

e.g. LINUX entropy pool refill

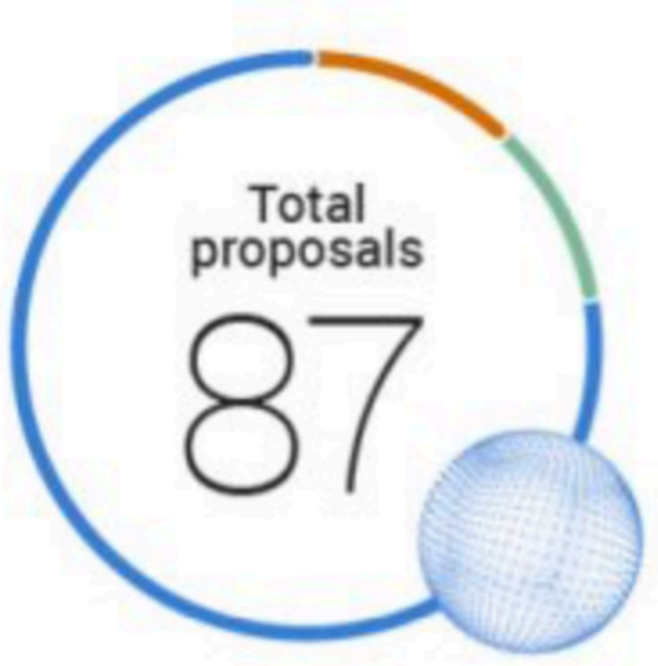
- GO MICRO & SECURE:

- High End applications [e.g. Differential privacy is one of our priorities, even if FULL HOMOMORPHIC ENCRYPTION is still the holy grail]

Phase II:

- submission Sept. 20th, 2021
- notification of approval Jan. 31st, 2022
- Duration: May 2022 to August 2024
- funding: 2 MEUR
- selection & competitiveness:

1211 submissions in Phase 1 ➜ 170 approved ➜ 87 submissions for phase II (68 R&D proposals) ➜ 18 R&D approved



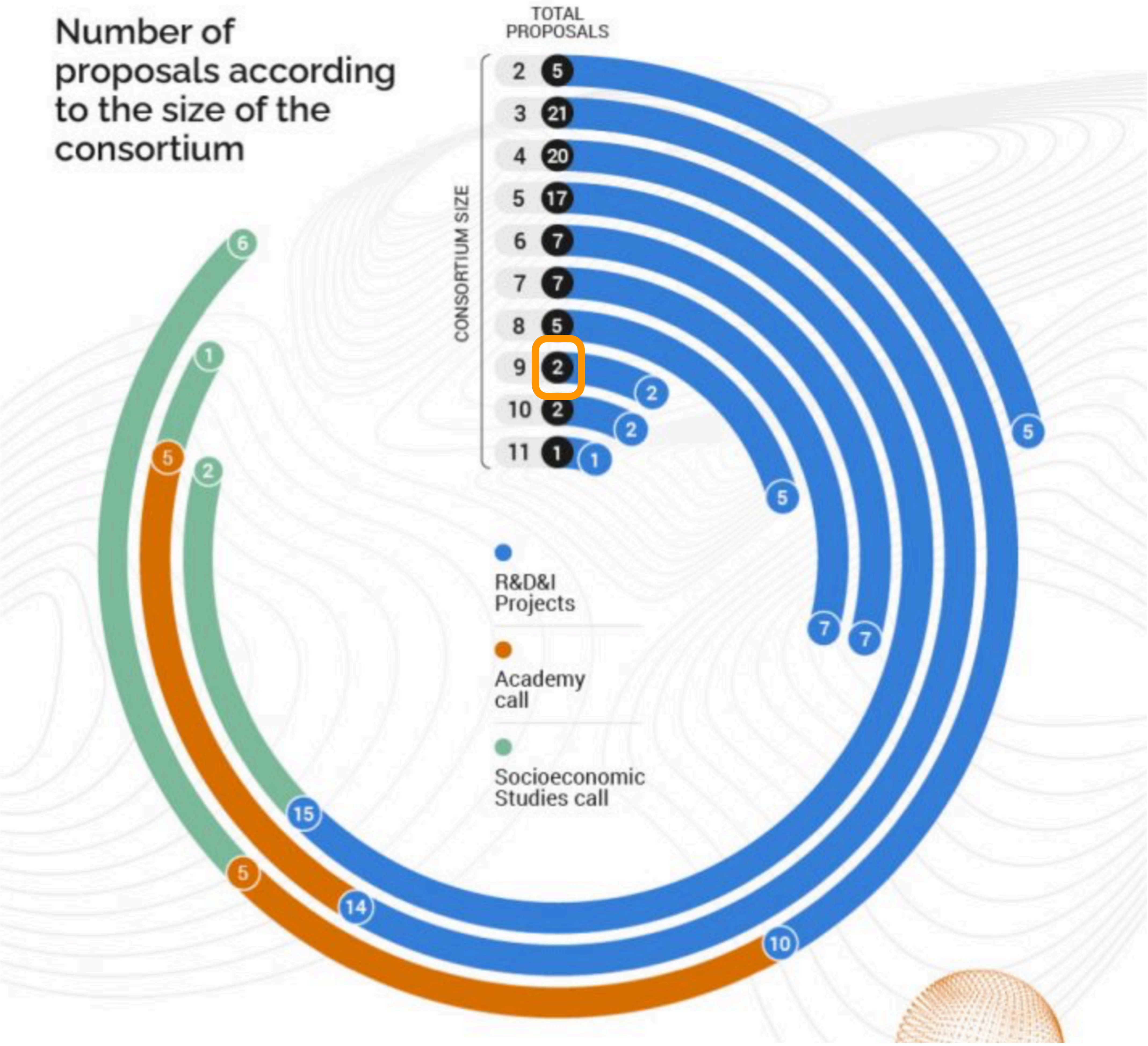
Proposals received	TOTAL FUNDING	SUBMITTED PROPOSALS
R&D&I Projects Thematic call	€25M	68
Academy call	€2M	10
Socioeconomic Studies call	€1M	9

combined success rate: 18/1211 = 1.5%, so we did well!

7. roadmap:

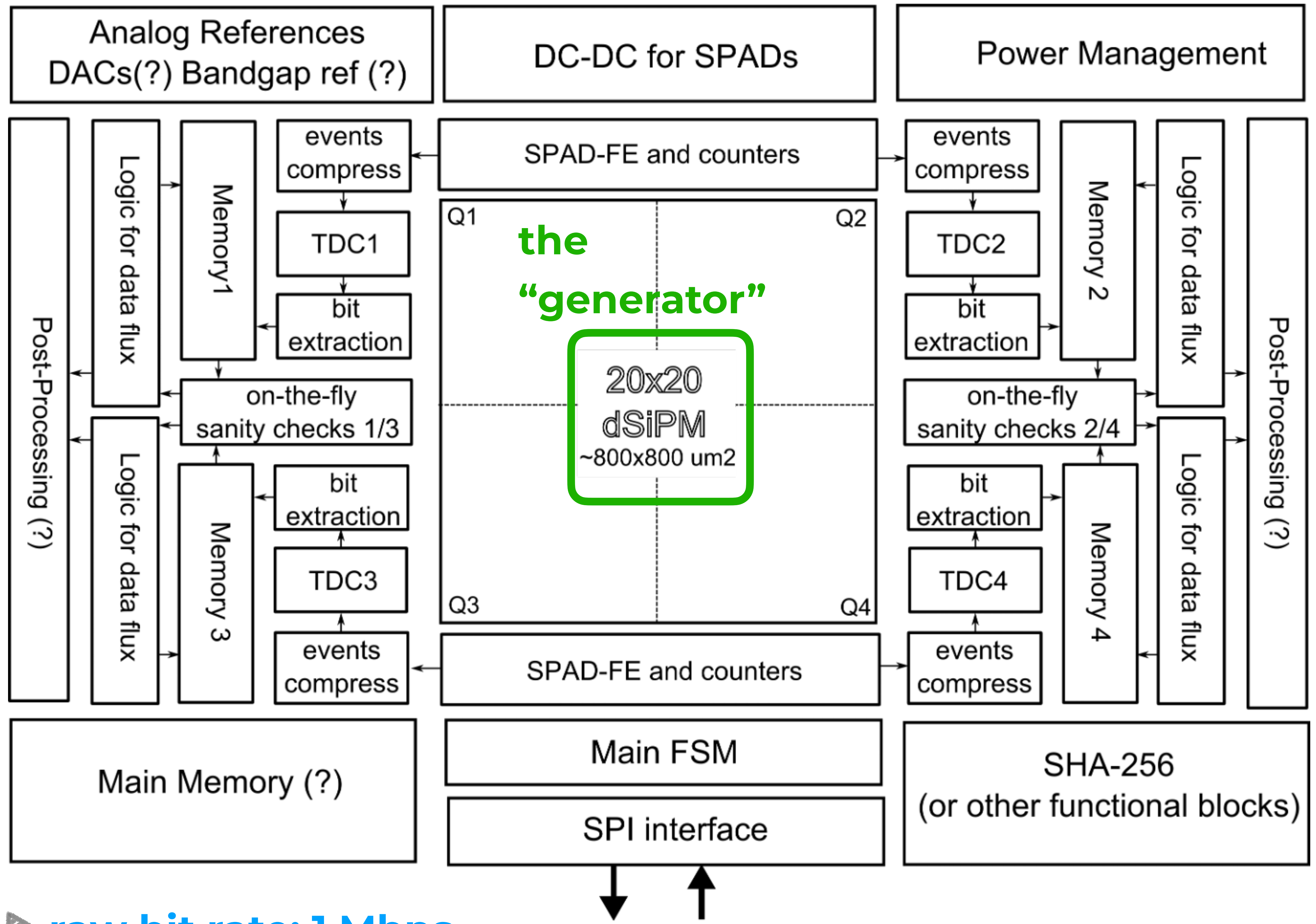
Our consortium:

leading party



Our main goals:

- **design a FIPS-compliant ASIC embedding a SPAD array in standard CMOS technology:**



- **raw bit rate: 1 Mbps**
- **FIPS mode (NIST DRBG): 4096 Bytes in 1050 μs (31.2 Mbps) with prediction resistance**
- **bits delivered in an encrypted stream**
- **expected to be back from the foundry in Dec. 2023**

- **design a scalable multi-generator system based on an array of SiPM and a LIROC front end ASIC by LIROC**

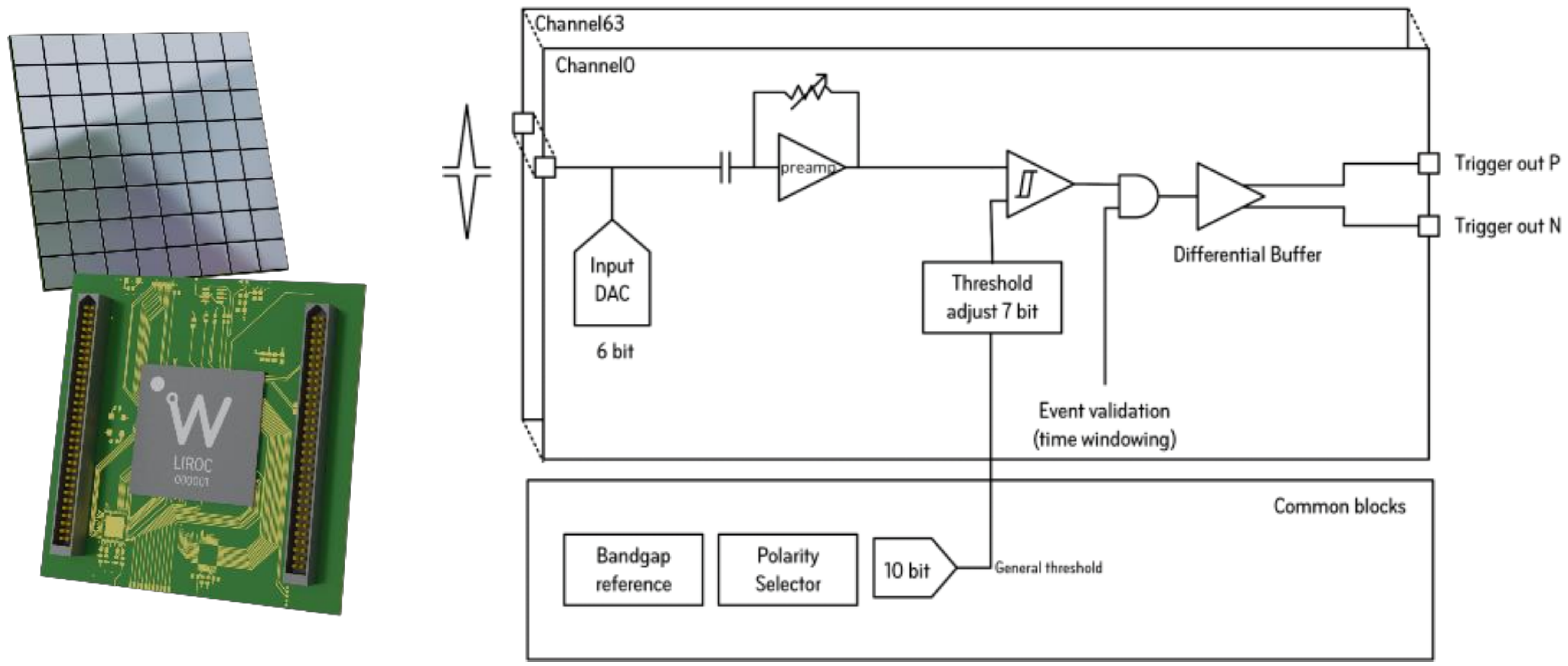


Table 2 - LIROC main features and performances

Detector Read-Out	SiPM, SiPM array
Number of Channels	64
Signal Polarity	Positive or Negative (selectable ASIC-wise)
Sensitivity	Trigger on 1/3 of photo-electron
Timing Resolution	Better than 20 ps FWHM on single photo-electron Better than 5ns double-peak separation on single photo-electron
Dynamic Range	Over 100MHz photon counting rate
Packaging & Dimension	BGA 20x20 mm2 Flip-Chip low inductance packaging technology

- **raw bit rate: 50 Mbps/board**
- **FIPS mode (NIST DRBG): 32x the raw bit stream**
- **DRBG isolated in the Trusted Execution Environment of a KRIA KR26 System-On-chip**

- **Hw for the 64 generator board expected in June 2023**

State-of-the-art (May2023 update):

design a FIPS-compliant ASIC embedding a SPAD array in standard CMOS technology (TJ 180 nm node):

✳ **Entropy Producer:**

- SPAD test structures under test
- on-cell functions and signal compression scheme defined
- DC-DC converter for biasing designed
- protocol for rate stabilisation vs T defined
- NIST Real-time tests implemented
- two different TDC designs implemented

✳ **Entropy Consumer:**

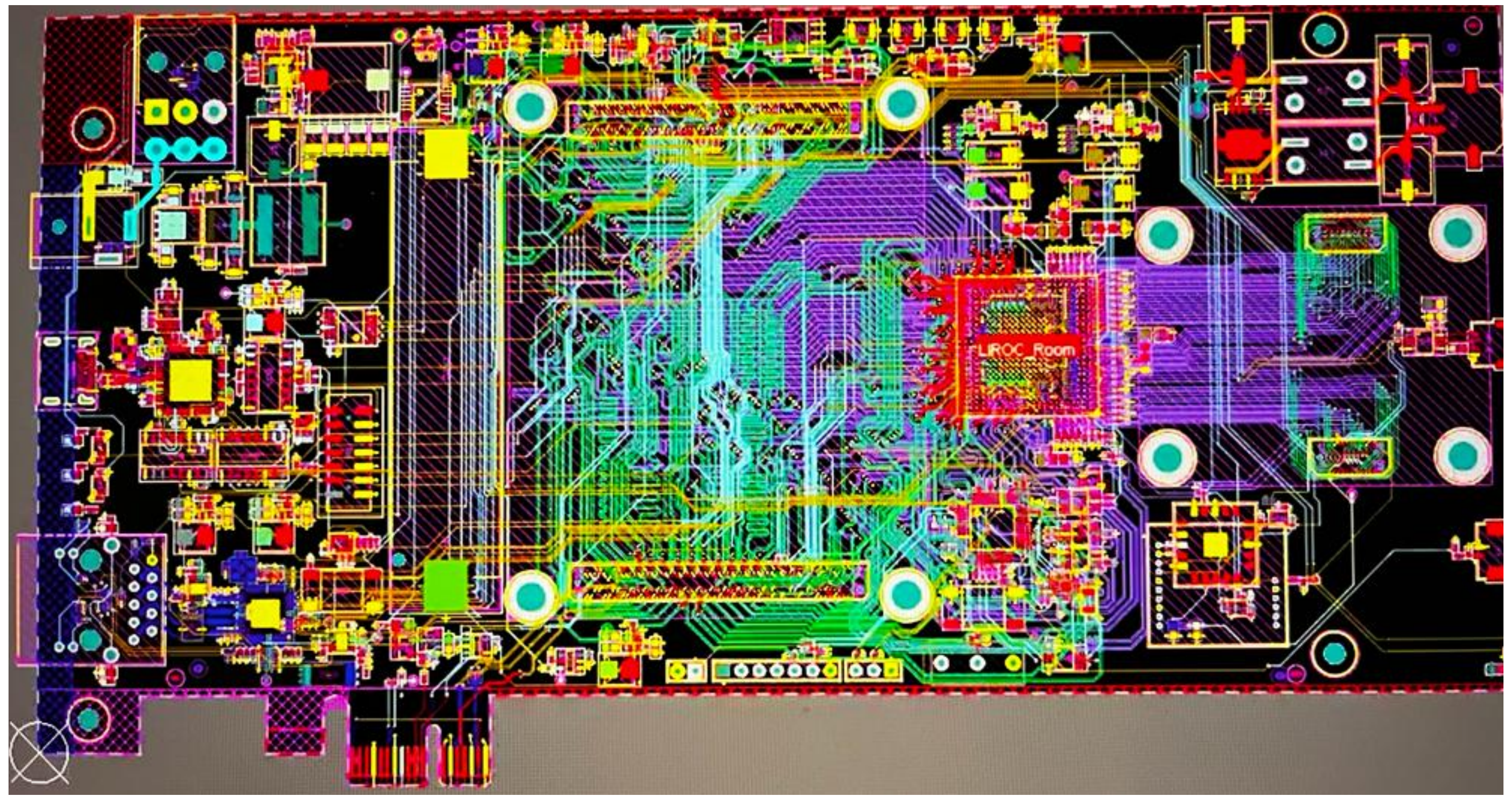
- NIST DRBG implemented (based on AES256)
- Known-Good-Answer tests implemented
- Encryption of the bit stream implemented
- single user authentication implemented

✳ **Integration & verification on the way**

✳ **Packaging under study**

✳ **planned tape-out: Early September 2023**

design a scalable multi-generator system based on an array of SiPM and a LIROC front end ASIC by LIROC



✳ design completed, production ongoing

✳ box with anti-tamper micro-switch and ventilation designed and being produced

RANDOM POWER

www.randompower.eu

Established in June 2021

This project has received funding from the ATTRACT project funded by the EC under Grant Agreement 777222

Join us, we will be happy to walk with you!

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