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3rd EIROforum School on Instrumentation

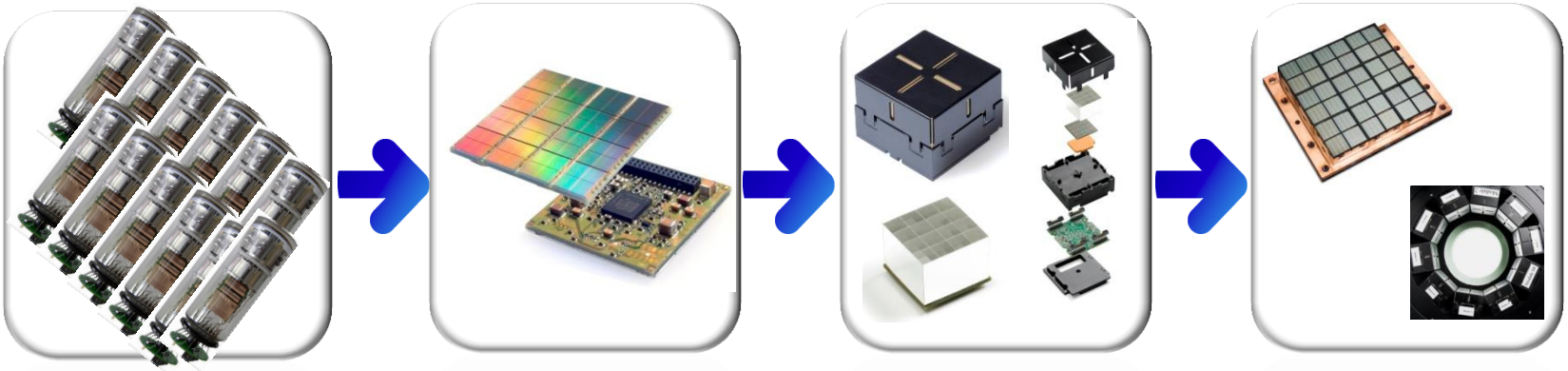
CERN, Geneva, Switzerland

27–31 May 2013

From innovation to product: The challenge of disruptive technologies such as Digital Photon Counting (DPC)

York Haemisch

Philips Digital Photon Counting, Aachen, Germany



OUTLINE

- About PDPC
- Characteristics of disruptive technologies
- Our approach of bringing DPC technology to market and into applications

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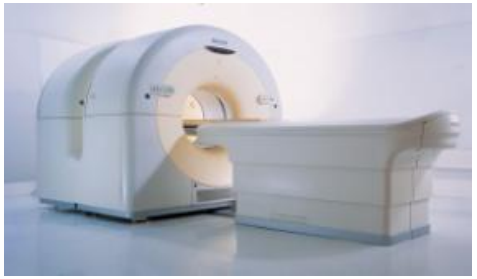
Who is Philips Digital Photon Counting (PDPC)?

Philips Digital Photon Counting is designing and manufacturing **scalable** detectors based on **digital Silicon Photomultiplier (dSiPM) technology** – a new type of advanced solid state light detector, now called **Digital Photon Counter (DPC)**.

Potential Applications

- **Medical Imaging**
- **Life Sciences**
- **High Energy Physics**
- **Material Testing/Detection**
- **Process Control**



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PDPC short history

2004	Research project: “Novel technologies for future PET systems”
2005	**Dr. Thomas Frach** invented the digital SiPM
2006	Research project: “Integrated digital light sensor”; first test chip with promising results **(incubator)**
2007	Disentanglement of Philips Semiconductors – now NXP
2008	Start of the PDPC **venture**
2009	Proof of concept of **single pixel dSiPM**
2009	**Technology launch** at IEEE NSS-MIC sensor V1.0
2010	**PDPC separate unit** of Philips Corporate Technologies
2011	Introduction of **PDPC-TEK** (Technology Evaluation Kit), **sensor version 2.1** and **PET detector module**
2012	**First digital time-of-flight (TOF) PET ring with 260 ps CRT (FWHM) and first Cerenkov detector with 48 ps (σ)**

The mother of invention….

"Necessity is often not the mother of invention. In many cases, it surely has been just the opposite. When humans possess a tool, they excel at finding new uses for it. The tool often exists before the problem to be solved."

Dye, David E: " Technology Matters: Questions to Live With" MIT Press (2007), ISBN 978-0262640671

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Innovation strategies of companies

Continuous Improvement ("Kaizen" = good change)

- Long-term approach to work that systematically seeks to achieve **small, incremental changes** in processes in order to improve efficiency and quality.
- Low risk
- Often geared towards **reducing costs.**
- Relies on improving position in **existing markets**

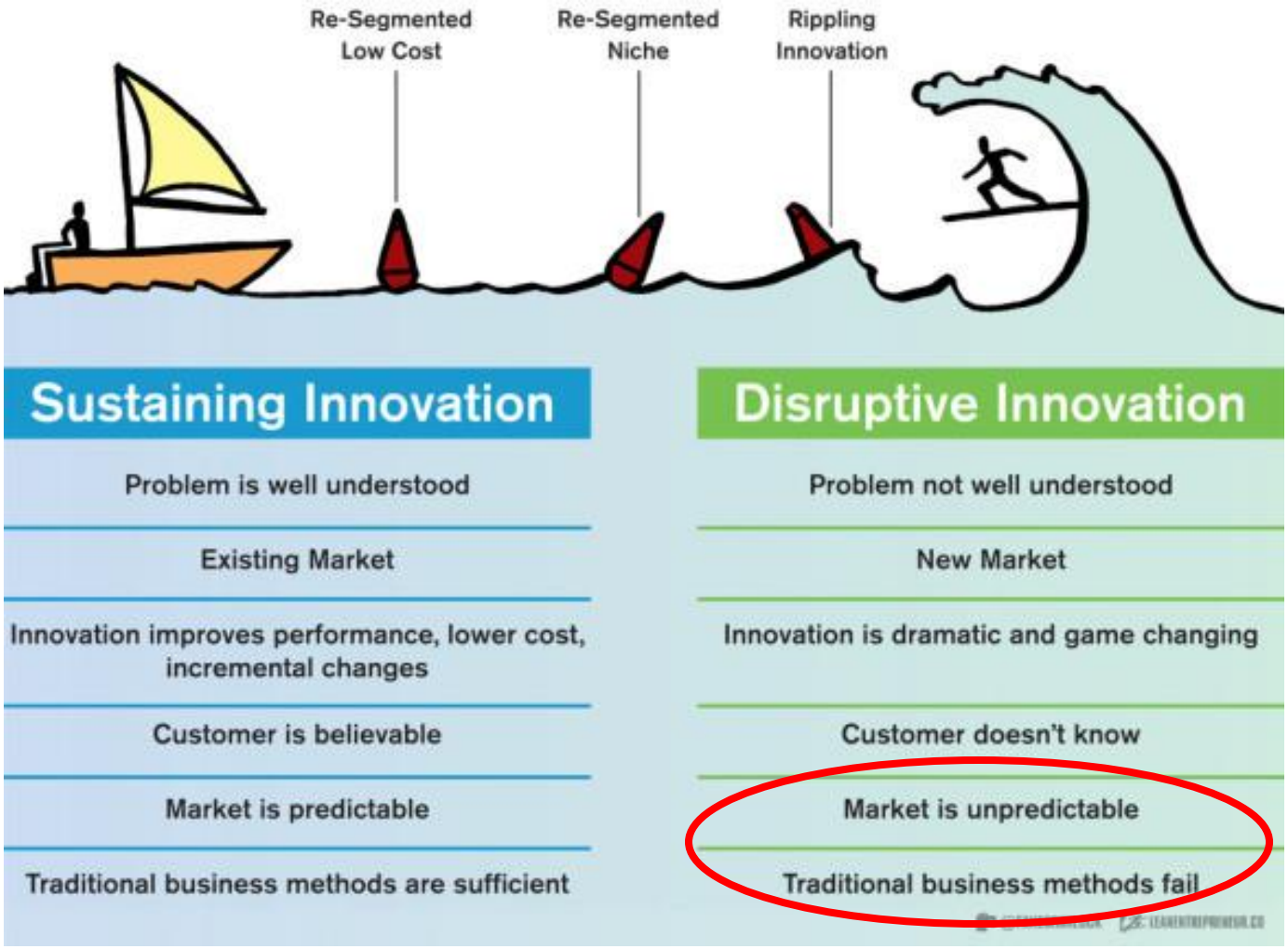
Disruptive Innovation

- Introduction of new technologies, products or services in an effort to **promote change and gain advantage** over the competition.
- **Risky** because it requires employees to embrace a radically different approach to product development or marketing.
- Calls for **investments** rather than cost savings.
- Creates **new market opportunities** where none existed before.

Bower, Joseph L. & Christensen, Clayton M. (1995) "Disruptive Technologies: Catching the Wave" *Harvard Business Review*, January-February 1995

Christensen, Clayton M. (1997) "The Innovator's Dilemma" *Harvard Business School Press*, ISBN 0-87584-585-1

Innovation strategies of companies (II)



B. Cooper & P. Vlaskovitz (2013) http://pandodaily.com/2013/02/04/three-reasons-not-to-build-a-minimum-viable-product/

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Technology changes in the innovation cycle

Sustaining Technology

- Relies on **incremental improvements** to an already established technology
- **Existing** infrastructure (sales, service)
- Established customer base/relation
- **Low risk** potential
- Incremental improvements, **performance guarantees**
- **Many** proven applications

Large corporations

TECH DISRUPTIVE NOLOGY

- A technology that "unexpectedly" **replaces an existing one**
- **Radical or novel**, but often lacking refinement
- **Crossing a tipping point** in price or performance
- Increase **accessibility** and/or **capabilities**
- Appeals to **limited audience**
- May **not** have yet a **proven application**

Small companies, start-ups

Bower, Joseph L. & Christensen, Clayton M. (1995) "Disruptive Technologies: Catching the Wave" *Harvard Business Review*, January-February 1995
Christensen, Clayton M. (1997) "The Innovator's Dilemma" *Harvard Business School Press*, ISBN 0-87584-585-1

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How to identify TECH DISRUPTIVE NOLOGY

1. Delivers **a capability** at a **previously unavailable** level, which may create disruptive forces;
2. **Combines with other technologies** to create synergies, which may also be disruptive;
3. Evolves from the nexus of seemingly unrelated technologies;
4. **Disrupts** a workforce, society, or the economy when combined with multiple existing technologies;
5. Generates products with **new performance attributes** that may not previously have been valued by existing end users;
6. Requires users to **significantly change their behavior** to take advantage of it;
7. **Changes** the usual product and **technology paradigms** to offer a competitive edge;
8. **Exponentially improves the value** received by the user;

Persistent Forecasting of Disruptive Technologies. THE NATIONAL ACADEMIES PRESS, Washington 2009

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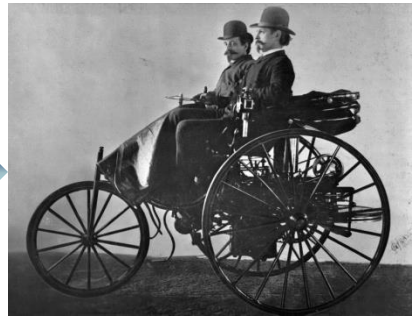
Effects of TECH DISRUPTIVE NOLOGY

Displacing

- **Displaces** incumbent technology in phase transition
- Mostly **same applications**
- Users adopt over a **period of time**

Market Creating

- **Creates a new market or capability** where none had previously existed
- Opens road to **new applications**



Persistent Forecasting of Disruptive Technologies. THE NATIONAL ACADEMIES PRESS, Washington 2009

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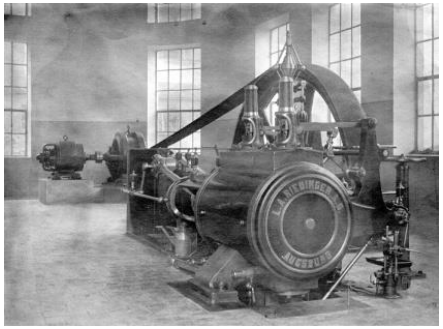
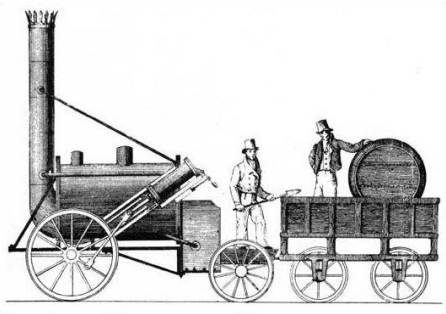
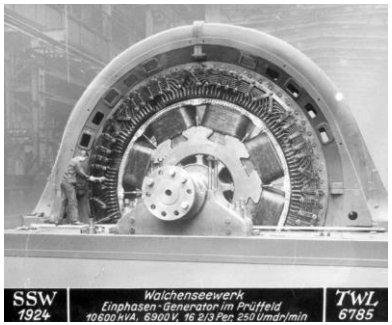
TECH DISRUPTIVE NOLOGY

examples







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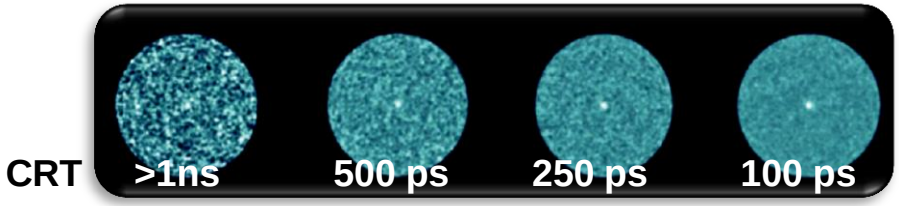
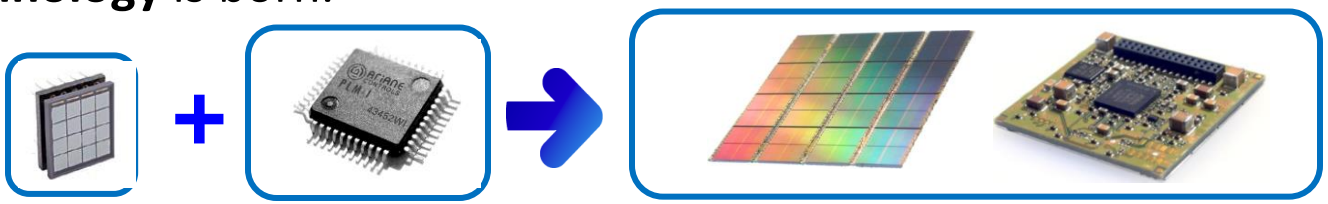
Is the DPC a TECH DISRUPTIVE NOLOGY ?

1. **Discontinuity** when a key factor is plotted against time, e.g. performance, cost, reliability, adoption rate, form factor…

2. **Impact** on other technologies. It is not sufficient for the application to be incidental; it needs to be impactful.

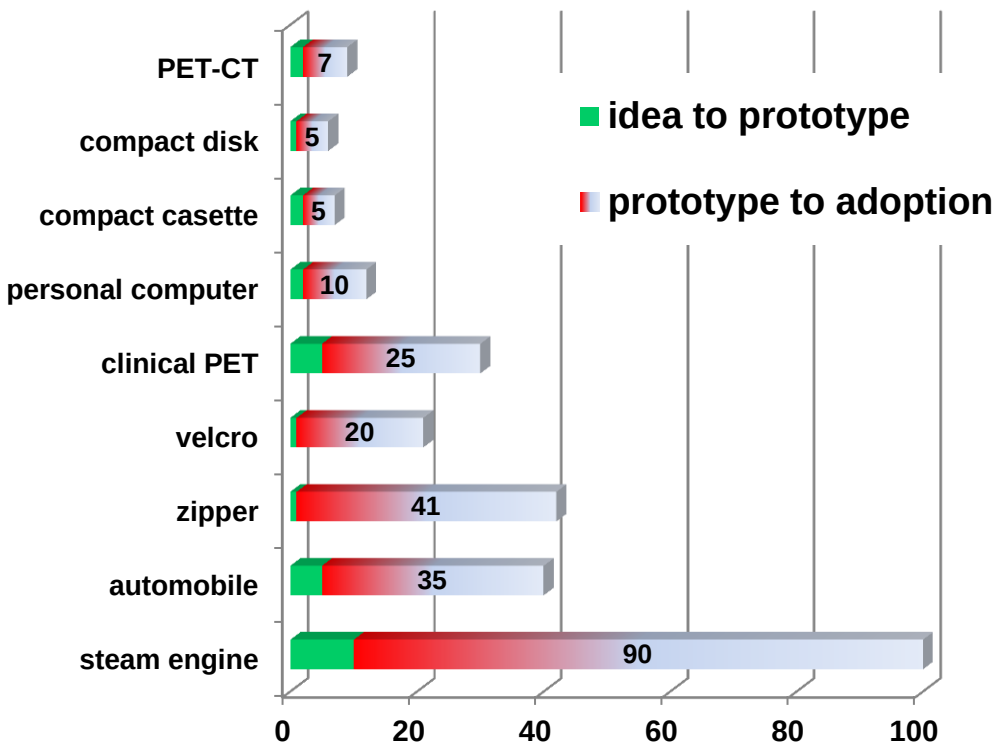


3. **Convergence** of more than a single discipline when a **crossover technology** is born.



Persistent Forecasting of Disruptive Technologies. THE NATIONAL ACADEMIES PRESS, Washington 2009

Disruptive technologies: time from idea to market



year	Vinyl LP	Compact Disc (w/o CD-Single)
1984	71,1 Mio.	3,0 Mio.
1985	74,0 Mio.	6,8 Mio.
1986	68,8 Mio.	13,3 Mio.
1987	66,3 Mio.	22,8 Mio.
1988	57,6 Mio.	39,2 Mio.
1989	**48,3 Mio.**	**56,9 Mio.**
1990	44,7 Mio.	76,2 Mio.
1991	23,4 Mio.	102,2 Mio.
2001		**133,7 Mio.**
2002	0,6 Mio.	129,4 Mio.
2003	0,6 Mio.	106,3 Mio.
2004	0,5 Mio.	105,3 Mio.
2005	0,4 Mio.	106,9 Mio.
2006	0,3 Mio.	108,3 Mio.
2007	0,4 Mio.	107,6 Mio.
2008	0,5 Mio.	105,1 Mio.
2009	0,5 Mio.	103,3 Mio.
2010	0,6 Mio.	98,7 Mio.
2011	0,7 Mio.	97,0 Mio.

Data contains **2 elements:** time from idea to prototype & time from prototype to adoption

Source: Wkipedia

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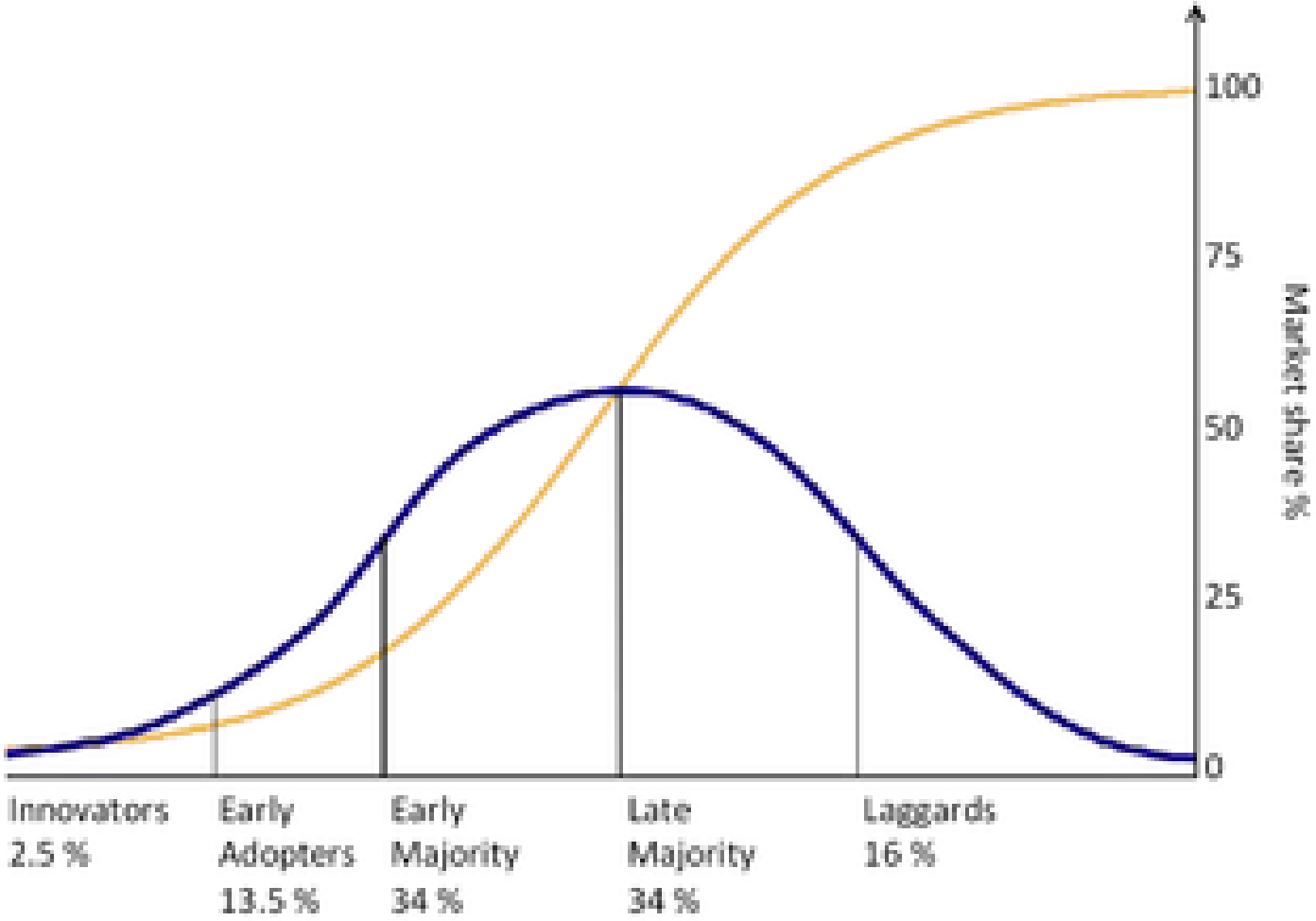
The diffusion of innovation: 5 factors [Rogers]

Factor	Definition
Relative Advantage	How **improved** an innovation is over the previous generation.
Compatibility	The level of **compatibility** that an innovation has to be assimilated into an individual's life.
Complexity or Simplicity	If the innovation is perceived as complicated or difficult to use, an individual is unlikely to adopt it.
Trialability	How **easily an innovation may be experimented**. If a user is able to test an innovation, the individual will be more likely to adopt it.
Observability	The extent that an innovation is **visible to others.** An innovation that is more visible will drive communication among the individual's peers and personal networks and will in turn create more positive or negative reactions.

[1] Rogers, Everett M. (1962). *Diffusion of Innovations*. Glencoe: Free Press. ISBN 0-612-62843-4.

Disruptive Technology Adoption [Rogers]



[1] Rogers, Everett M. (1962). *Diffusion of Innovations*. Glencoe: Free Press. ISBN 0-612-62843-4.

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Technology Adapter Categories [Rogers]

Adapter category	Definition
Innovators	willing to take risks, have great financial liquidity, are very social and have closest contact to scientific sources and interaction with other innovators.
Early Adapters	highest degree of opinion leadership among the other adopter categories. More discrete in adoption choices than innovators.
Early Majority	slower in the adoption process, contact with early adopters, and seldom hold positions of opinion leadership
Late Majority	will adopt an innovation after the average member of the society high degree of skepticism, typically skeptical about an innovation,
Laggards	the last to adopt an innovation, little to no opinion leadership, aversion to change-agents, tend to be focused on "traditions"

[1] Rogers, Everett M. (1962). *Diffusion of Innovations*. Glencoe: Free Press. ISBN 0-612-62843-4.

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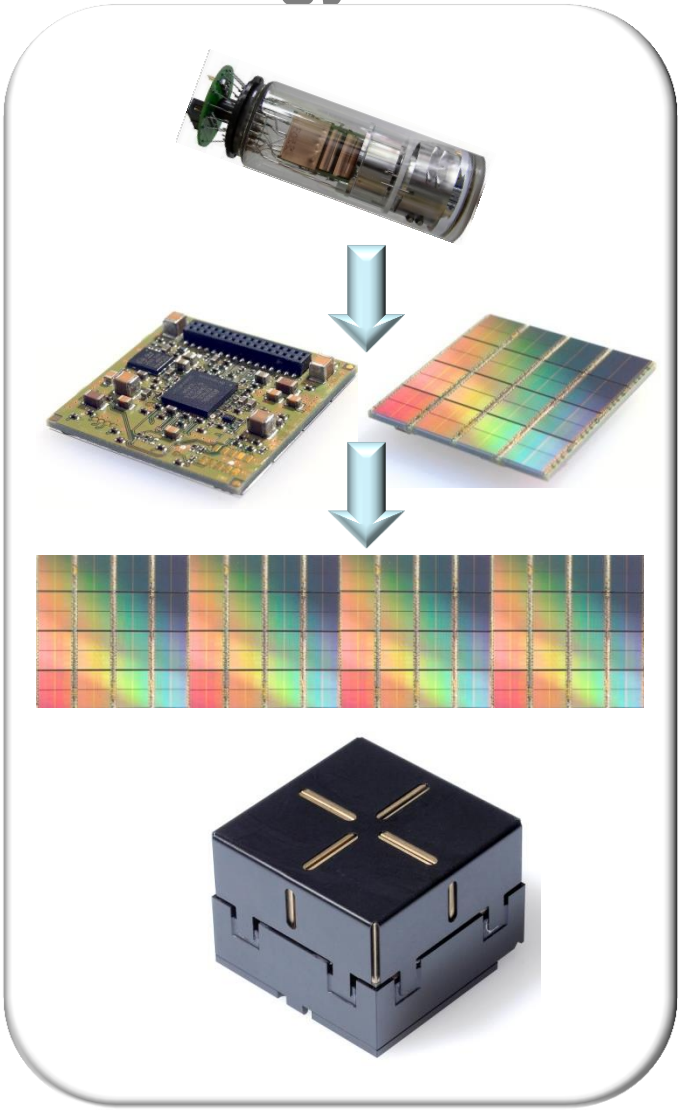
Engineers expect from new technology that it…

- is **SCALABLE**
- allows simpler designs
- consumes less power
- dissipates less heat
- allows higher depth of integration (reduces no. of components)
- is safe, robust, durable & **stable**
- has better
  - performance/cost ratio
  - performance/weight ratio
- is easier/less frequent to service
- **fits into existing infrastructure**



Disruptive Technology: Example TV/displays

- ***size/format:***
  - just standing on support — standing/wall hanging, soon flexible
  - big 3D box — almost 2D, displays everywhere
  - size limited by tubes — flat, no size limitation
- ***image quality:***
  - 60/100/200 Hz flickering — no flickering anymore
  - initially higher resolution — resolution nearly unlimited
  - limited contrast — real life contrast
- ***functionality:***
  - just TV or PC display — internet, TV and PC merge
  - single medial — multi-medial, multi-display etc…
- ***safety:*** - HV — no HV
  - vacuum, risk of implosion — no risk of implosion

Solid State, Digitization & Integration Win

Transistor

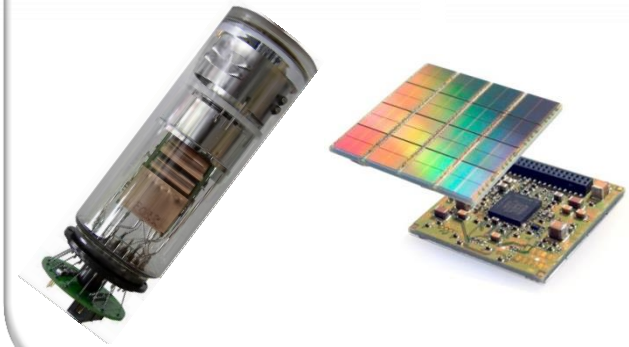
Television

Photography

Telephony

X-Ray imaging

Next: Light Detection



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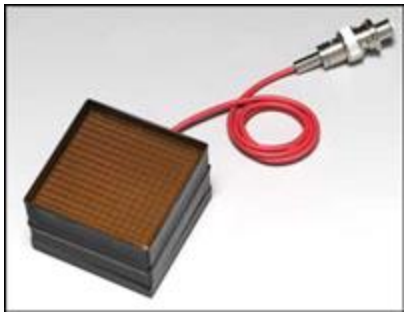
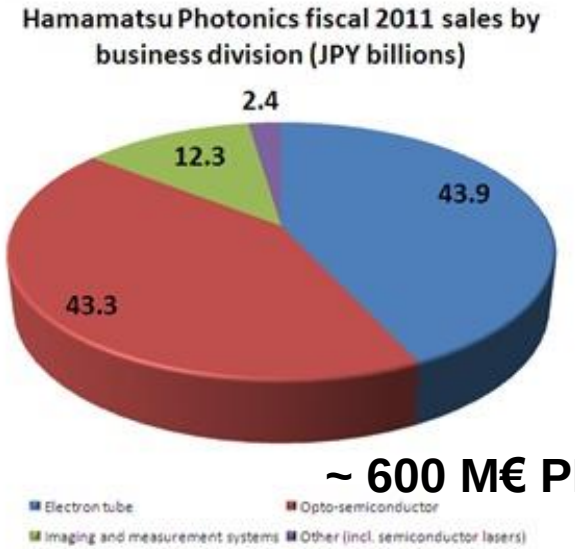
DPC: replacing > 60 yr. old PMT ??

Sizes from ~ 2 mm² to > 0.1 m²



prices from ~ 15 €/cm² to 110 €/cm²
+ HV supply + analog electronics



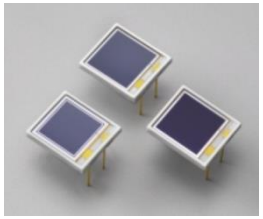
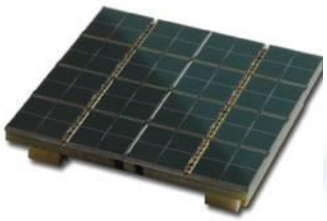
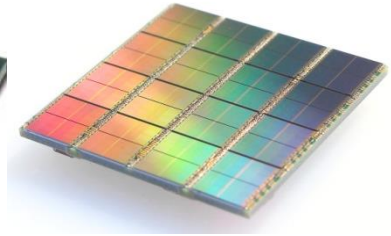
~ 600 M€ PMT/year

Applications*:

- Nuclear medicine (~70%)
  (SPECT and PET scanners)
- Analytics/industrial (~15%)
- Physics research (~15%)

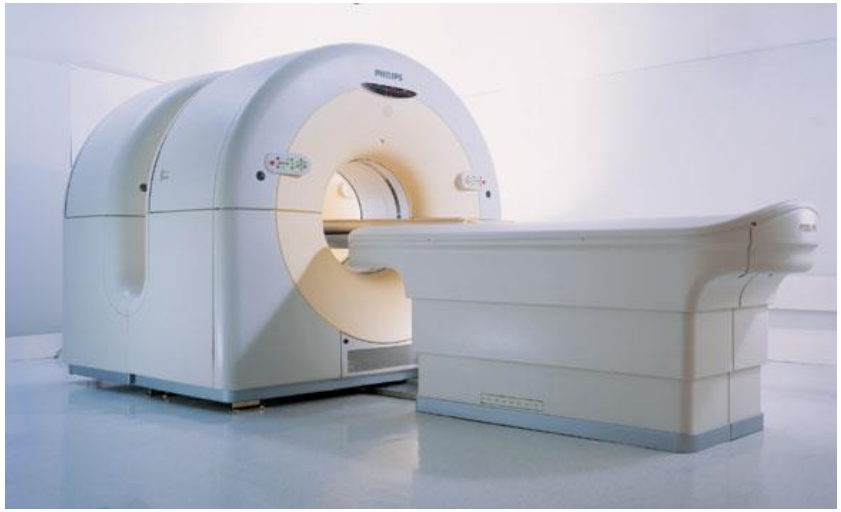
** Data from Photonis, March 2008*

Light Sensors: Will Digital Win also here?

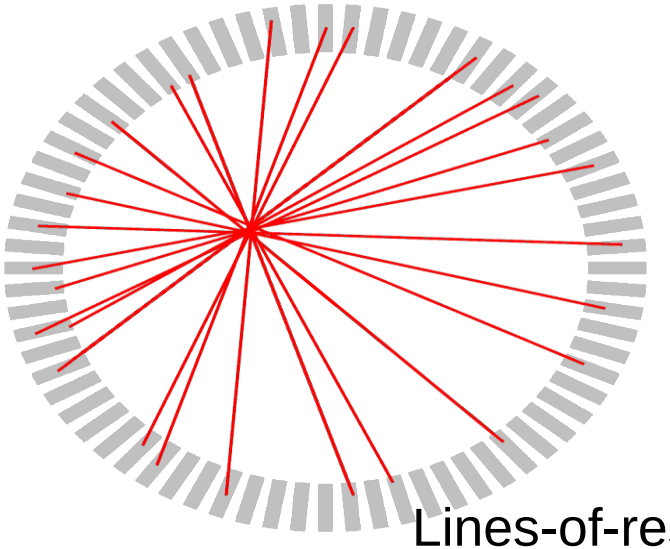





Type	PMT	APD	anal. SiPM	DPC
MR compliance	**No**	**Yes**	**Yes**	**Yes**
ToF capability	limited	No	Yes	Yes
Operational stability	good	good	To be det.	To be det.
Amplification	High (10^6)	Low (10^{2-3})	High (10^6)	meaningless
Compactness	bulky	compact	compact	Very compact
Power/Readout	HV, ASIC, analog	HV, ASIC, analog	LV, ASIC, analog	LV, simple, digital
Scalability	**n/a**	**difficult**	**challenging**	**yes**

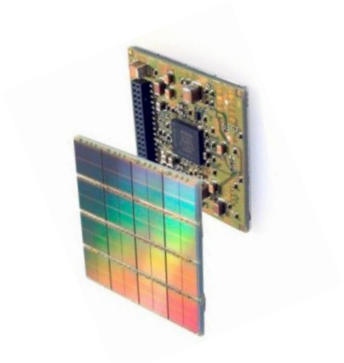
A challenge: information density (example PET)



PMT-PET:
420 channels



Lines-of-response
(LOR)



Solid state PET:
> 35.000 channels

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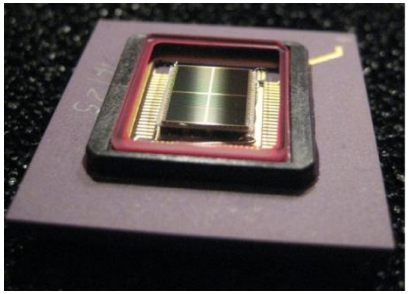
Problem of analog SiPM: Scalability

- in analog systems relation between active detector volume
  and electronics can be up to 1 : 100
- the number of channels in a clinical PET system increases from a few 100's to several 10000's by using solid state technology
- a clinical PET system has ~ 0.01 m^3 detector volume → would need m^3 of electronics

  + power consumption
  + cooling
  + mixed signal processing
- → early integration is mandatory

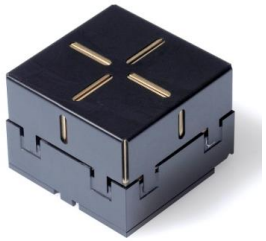
DPC technology is SCALABLE

2 x 2 pixels in ceramic package with Peltier Cooling

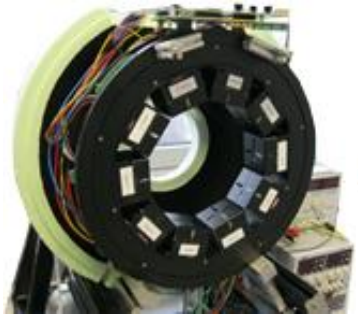


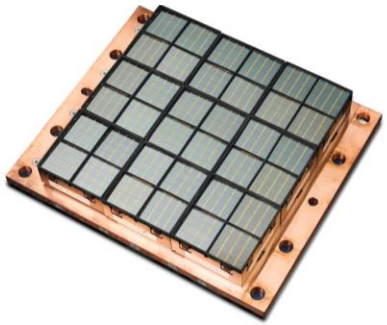
8 x 8 pixels in frames

Coolable Detector Modules (256 pixels)



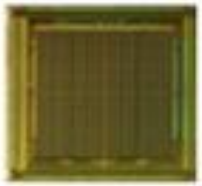
Coolable Detector Rings/Areas (2560 pixels and beyond)





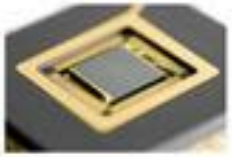
Scalable Technology Maintains Intrinsic Performance

DEMONSTRATOR:
single pixel



CRT ~ 270 ps*

CHIP:
2 x 2 = 4 pixels



CRT ~ 270 ps*

ARRAYS (TILES):
8 x 8 = 64 pixels

CRT ~ 270 ps*

MODULES:
256 pixels

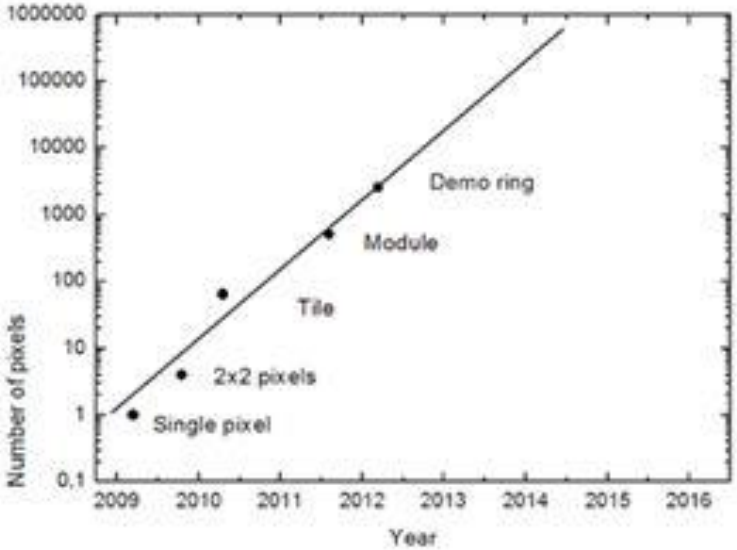
CRT ~ 270 ps*

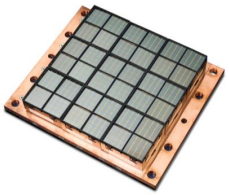
DEMO RING:
2560 pixels

CRT ~ 270 ps*

Many first time rights

PDPC-Moore's law





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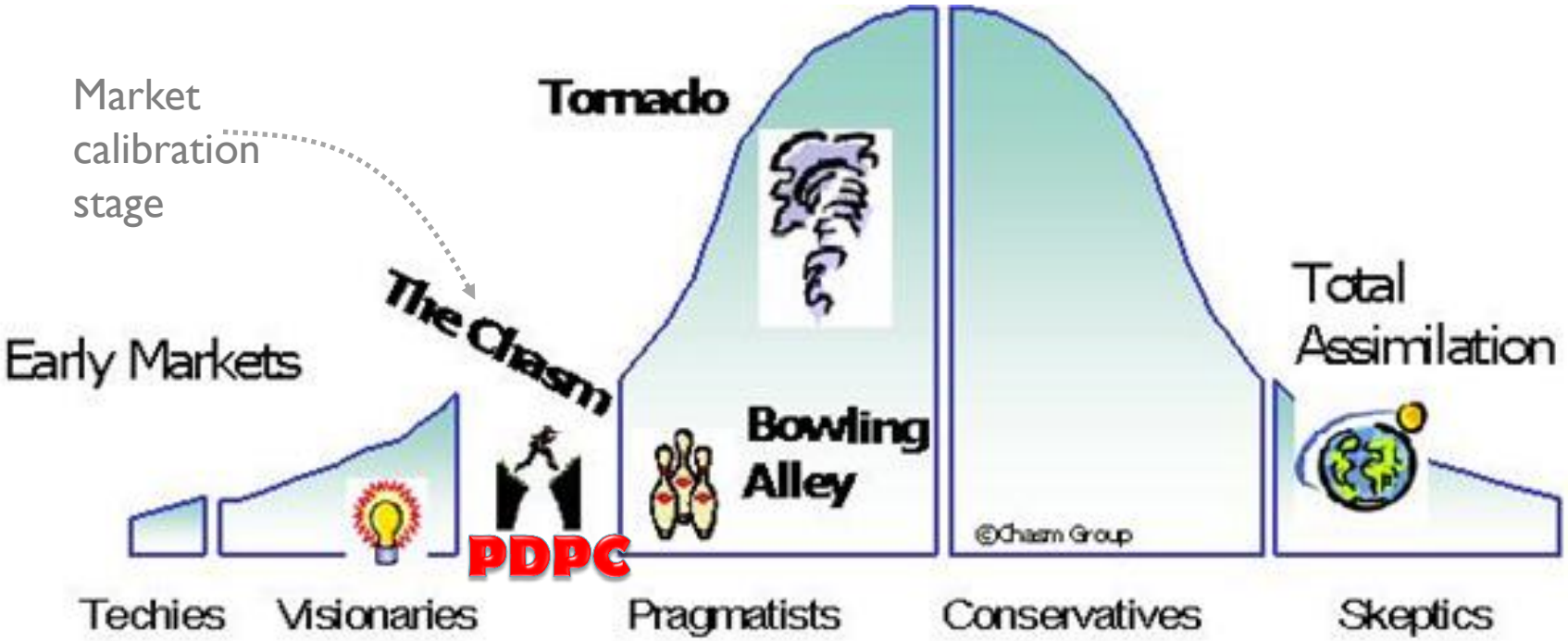
Disruptive Technology Adoption – Crossing the Chasm [Moore]



- Disruptive innovation – early adopters are universities, luminary research sites
- Market growth can only be expected AFTER crossing the Chasm

Moore, Geoffrey A.: "Crossing the Chasm: Marketing and Selling high-tech products to mainstream customers"
Harper Business Essentials (1991) ISBN 0-06-051712-3

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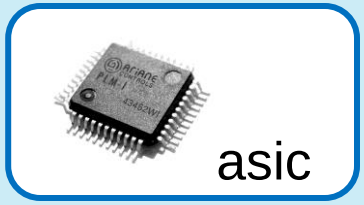
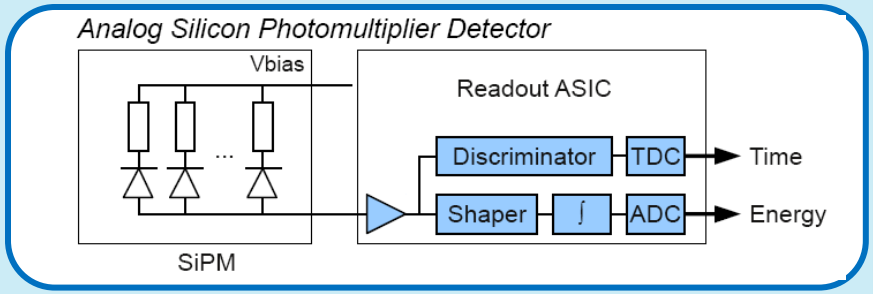
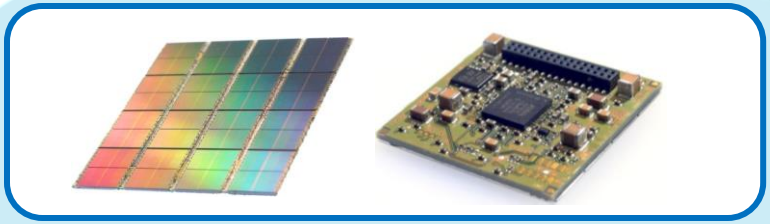
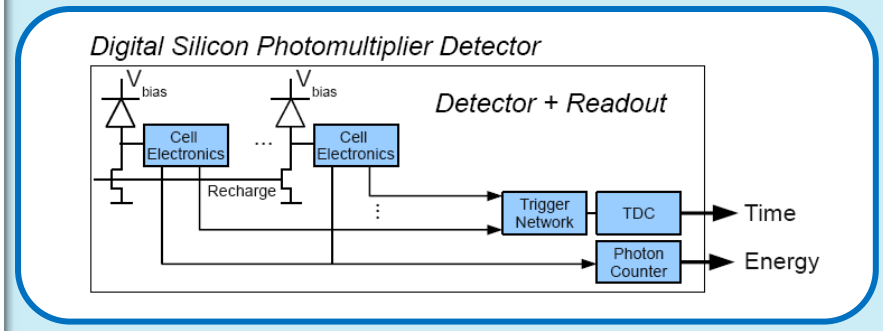
The CMOS based DPC needs VOLUME





- discrete, no integration
- analog, dedicated ASIC needed
- difficult to scale
- no CMOS **(12 masks)**
- simple process – lower volume
- could be used for single apps only
- custom designs easier

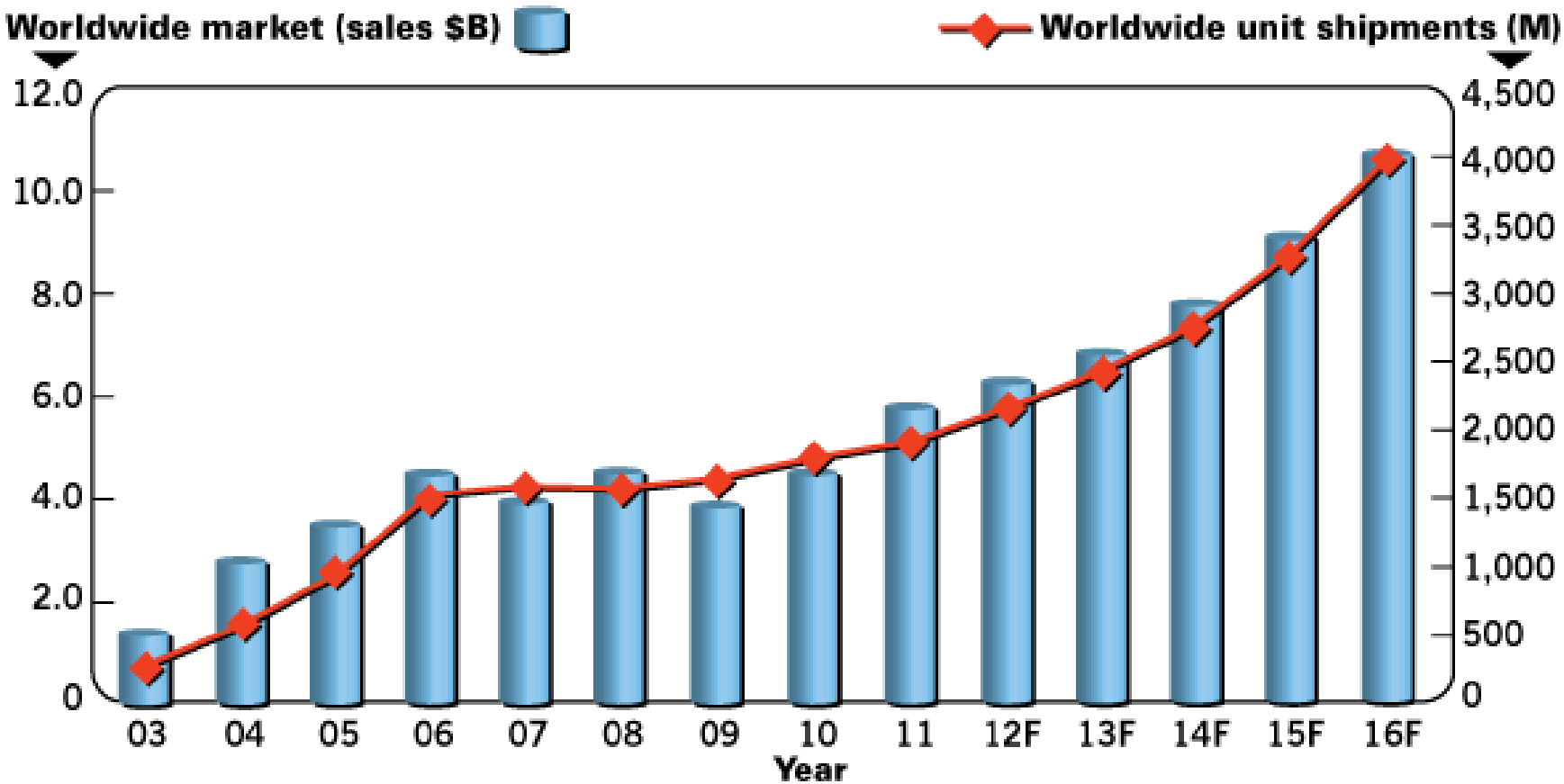




- fully integrated
- fully digital, no ASIC needed
- fully scalable
- CMOS based **(38 masks)**
- **complex process – high volume**
- **needs large markets**

Example: CMOS sensors globally

(source: Image Sensors World blogspot)



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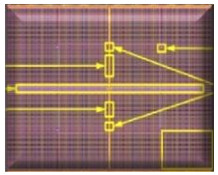
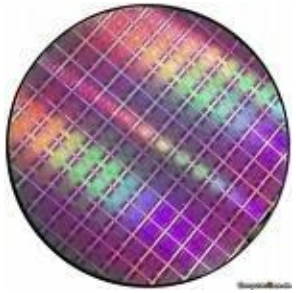
dSiPM Arrays: Production Process

- Sensor design (PDPC)

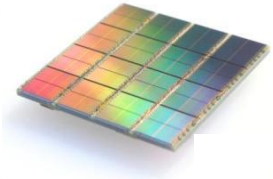


- Silicon processing (180 nm fab, 38 masks, > 500 steps)



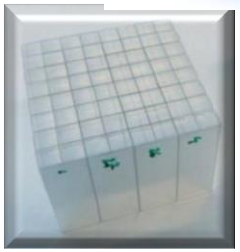
- Die testing (PDPC)

- Tile manufacturing (packaging experts)



- Tile testing (PDPC)

- Scintillator attachment (packaging experts)

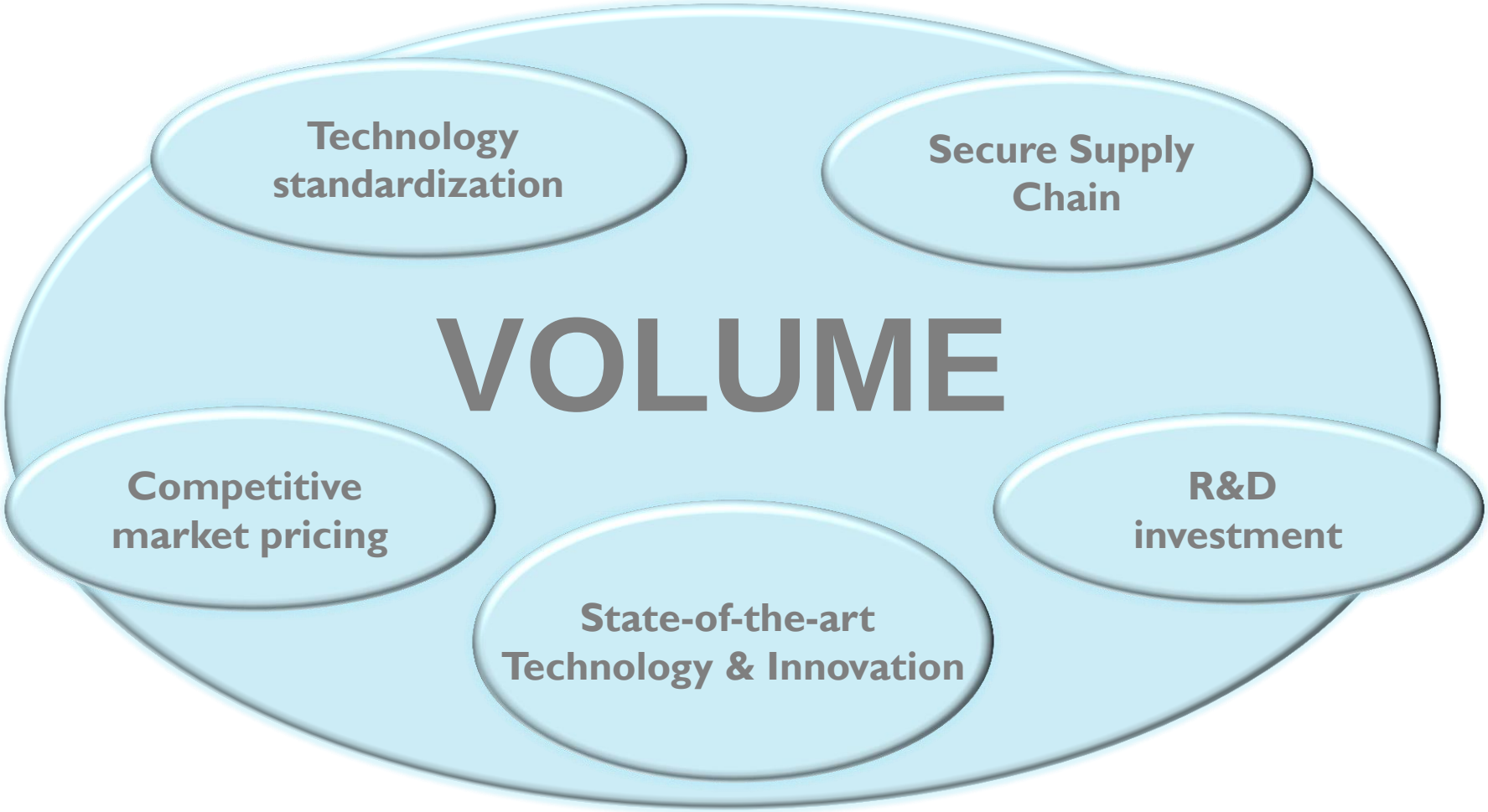


- Module assembly (packaging experts)

- Final module testing (PDPC), overall system design

PHILIPS

The key success factor in Semiconductor process industry is VOLUME

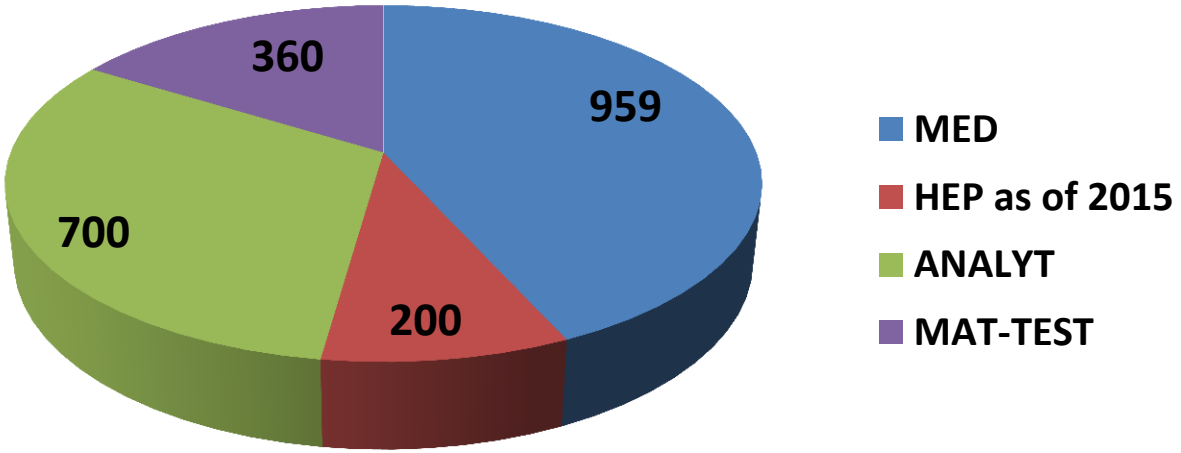


PDPC technology: market potential 2014 - 2020

	Product ready	Investments in product development needed		
M€	Medical Imaging MED	High Energy Physics HEP	Analytical Instr. ANALYT	Material Testing MAT-TEST
Annual TAM	137	35	100	45
TAM 2014-20	959	200	700	360

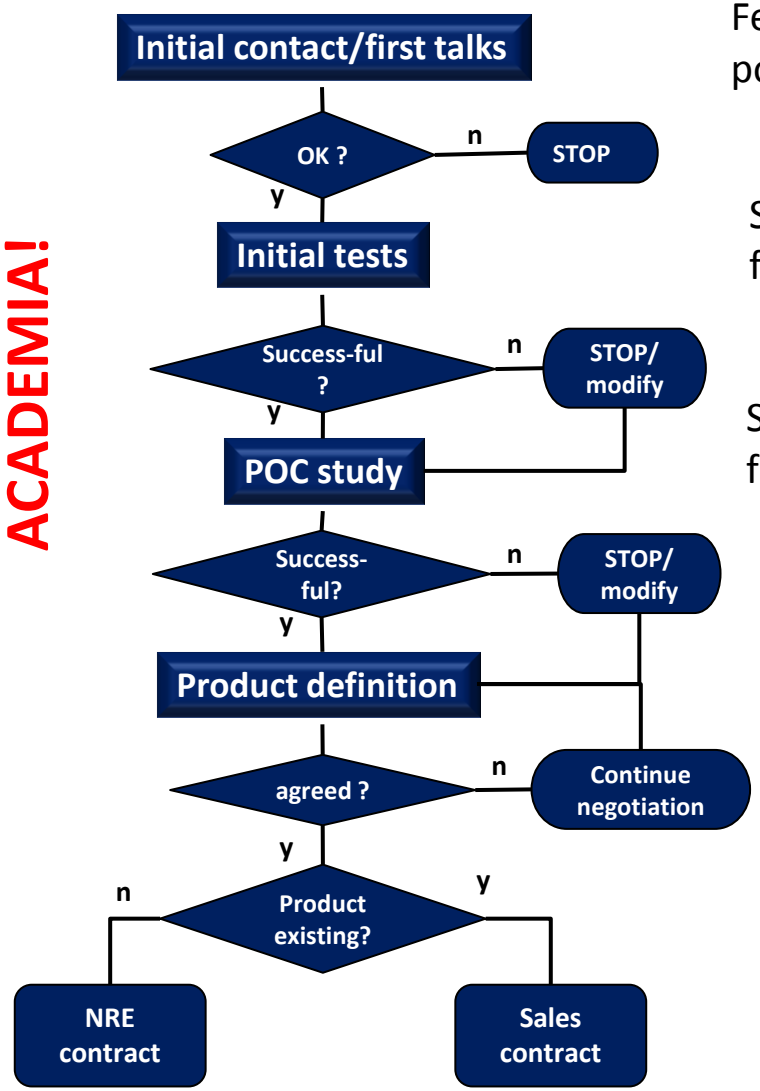
(TAM: Total Available Market detectors only, conservative assumptions w/o market growth, HEP very conservative)

total TAM 2014-20 [M€]



PDPC: Technology adaption model

ACADEMIA!



Steps	Action/content	Required items
Initial contact/first talks	Feasibility, market size, potential conflicts	NDA
Initial tests	Sell/rent TEK, check fundamental physics	
POC study	Sell TEK, perform functional test, prototype	
Product definition	Receive product specifications from customer	Project plan Product specification document
Product existing? (y)	Offer to customer	Financial & technical quote
Sales contract	Settle NRE and/or sales contract	Legal support

PDPC TEK

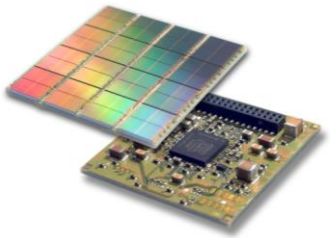
We are here!

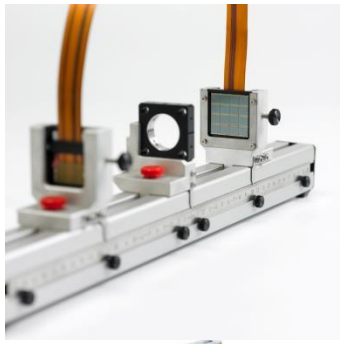
(25 TEK's out, 3 POC)

PDPC TEK

PDPC technology to business approach

Integration



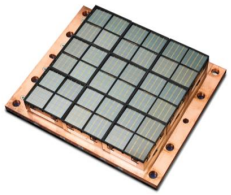


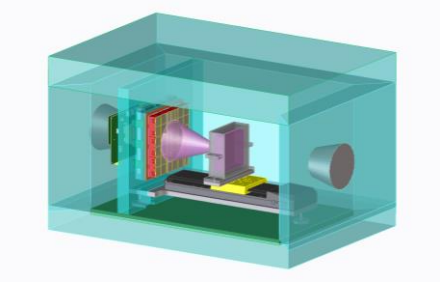
TEK 1 - POP (tile TEK)

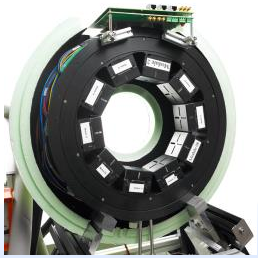
POP - proof of principle

TEK 2 - POC (module TEK)

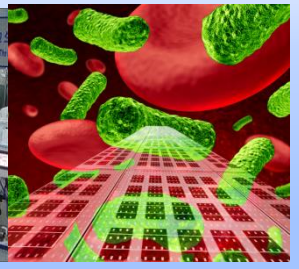
POC - proof of concept







Rapid prototyping



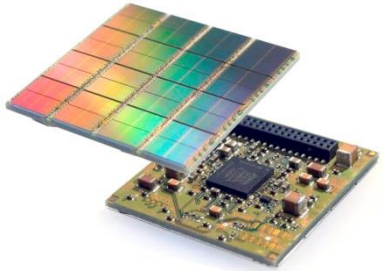
Application Business

PDPC Technology Evaluation Kit (TEK)

25 kits installed so far

PHILIPS

PDPC technology & product development

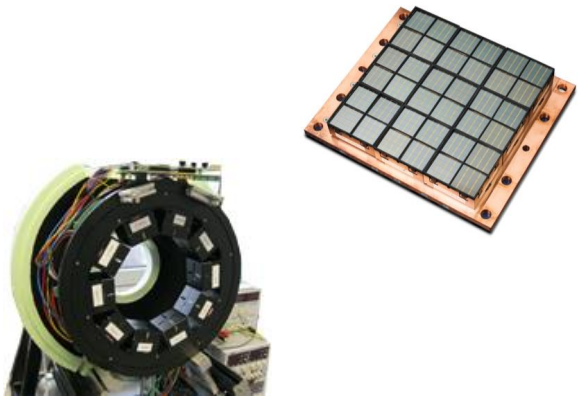


dSiPM sensors
and firmware

Customized detector
module designs

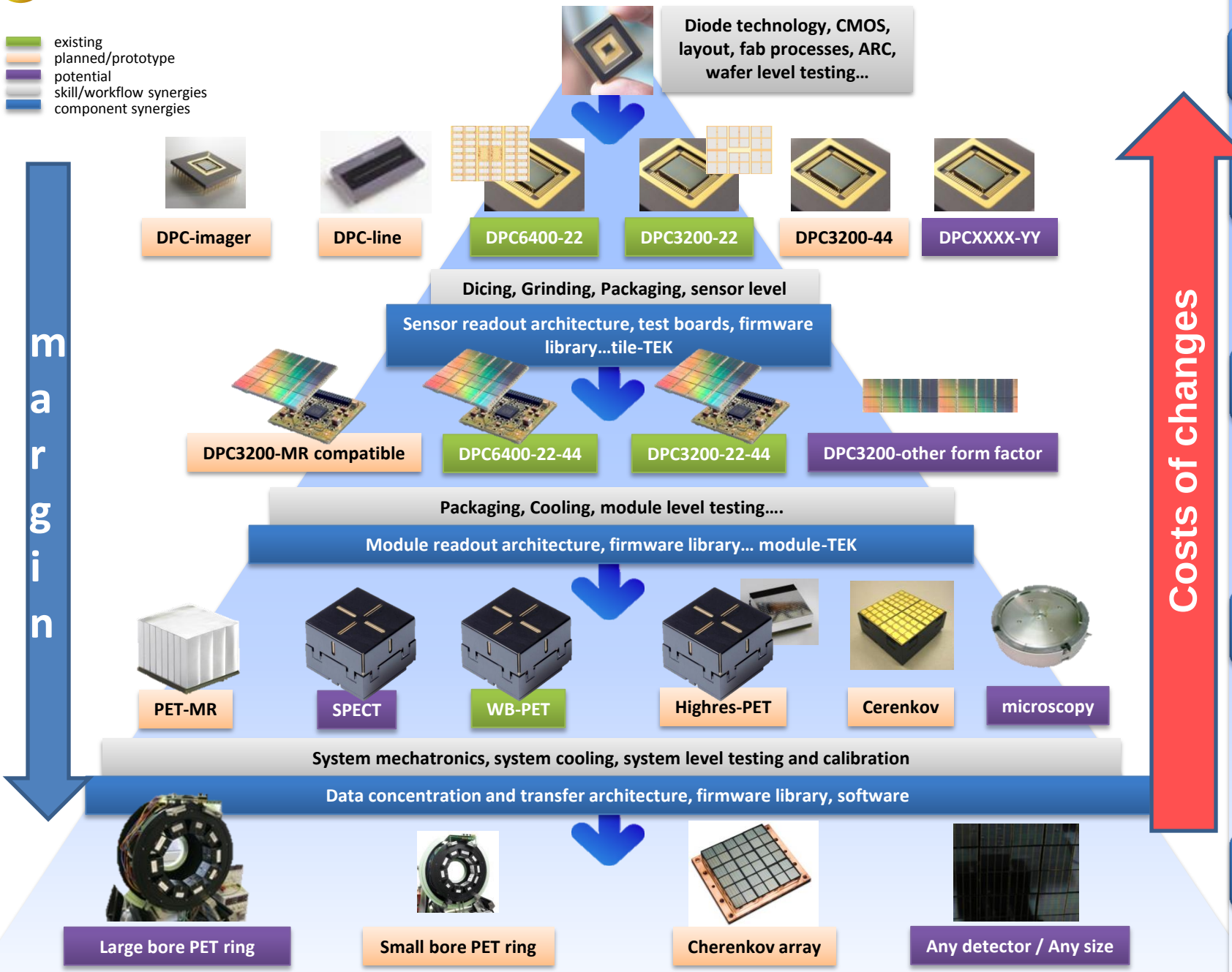
Electronic Infrastructure

Technology Evaluation Kit (TEK) launched
October 2011



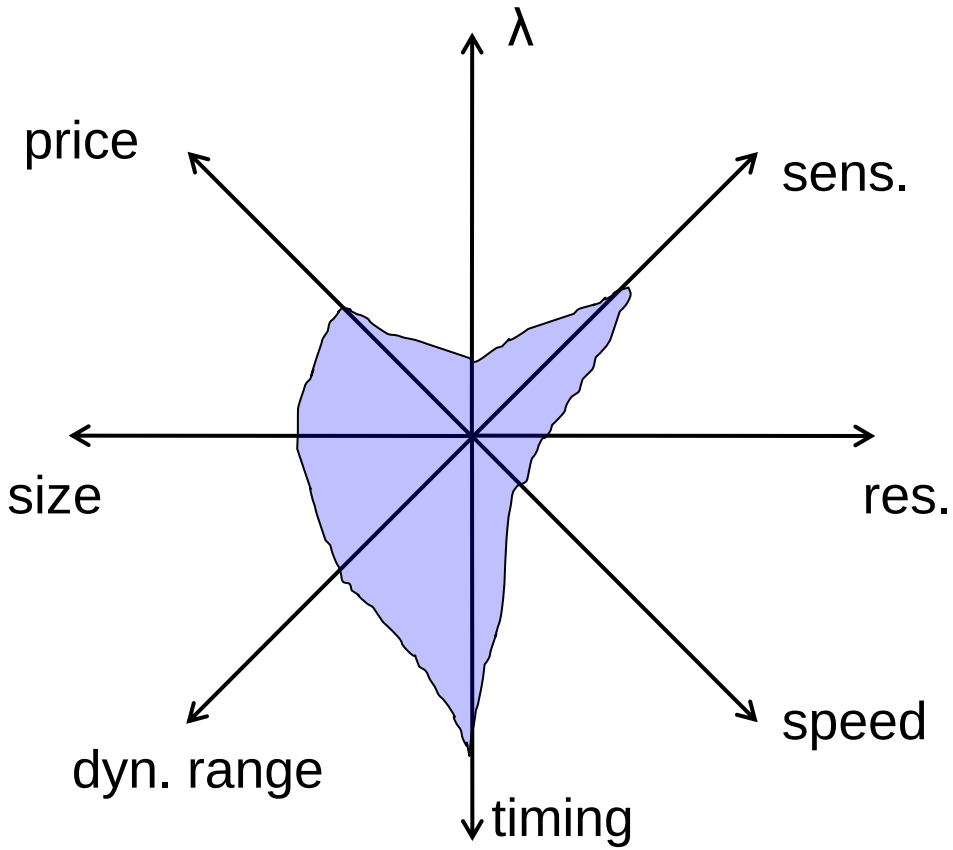
Prototype Systems - POC

The Philips tree of scalable DPC technology



The future: what direction to go?

DPC: current parameters are optimized for TOF-PET

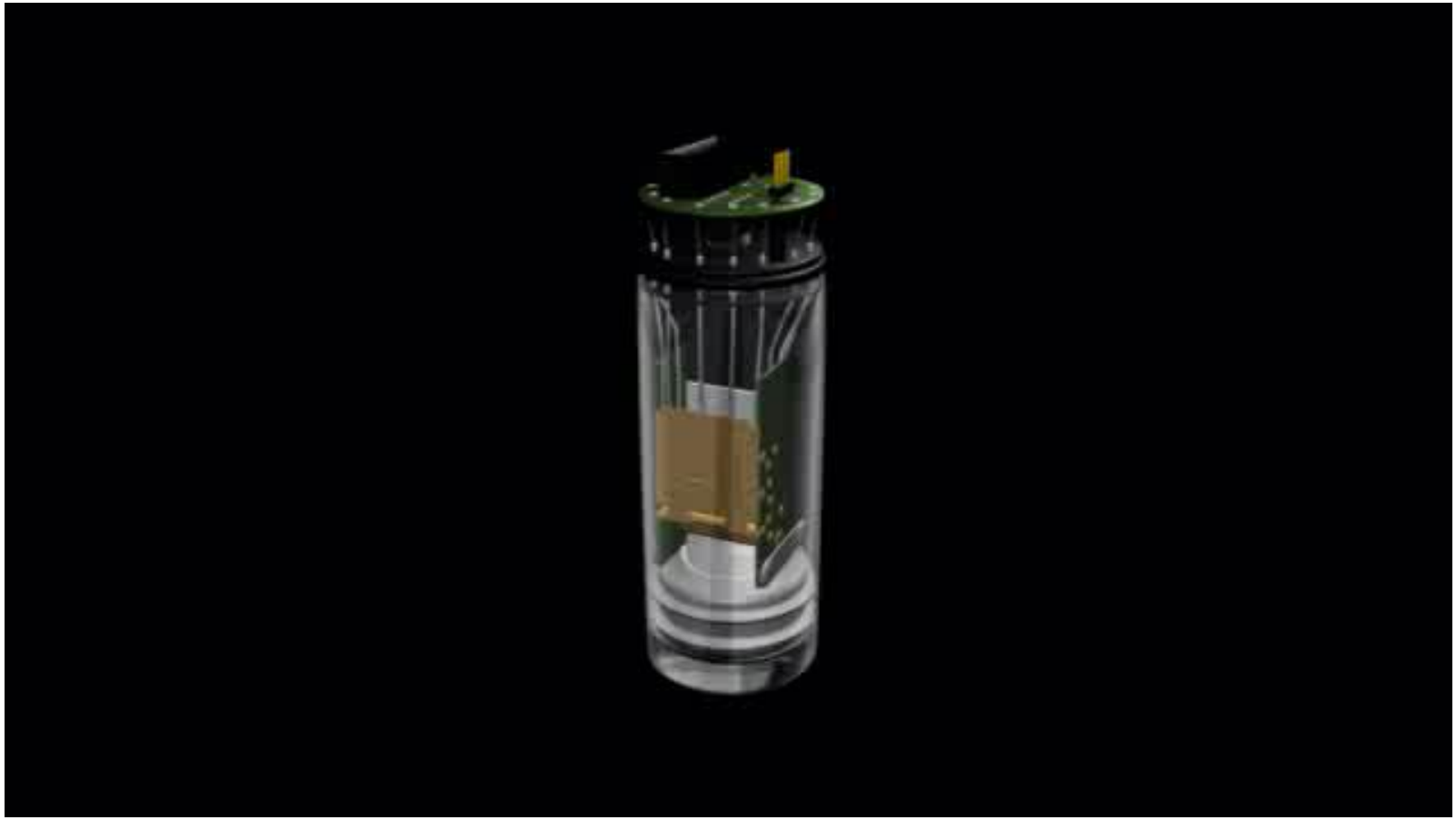


Summary

- **DPC is a disruptive technology that will induce changes in applications.**
- **DPC development was triggered by ToF-PET and shows clear advantages, as well as for PET-MR.**
- **DPC has shown superior performance and ease of use vs. analog SiPM technology (> 20 abstracts are submitted to IEEE2013).**
- **DPC demonstrated scalability of technology in maintaining intrinsic performance over larger systems:**
  - ***PDPC PET test ring***
  - ***FARICH detector prototype***
- **As a CMOS based technology DPC needs volume to succeed, therefore a systems architecture concept is developed.**
- **New application areas for DPC are explored by adapted designs.**

And perhaps this might happen…

Video showing glass PMT burning into flames and PDPC sensor evolving



Thank you very much for your attention!

Thanks also to:

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