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Silicon Photomultipliers
Commercial Opportunities

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Science and Technology Division

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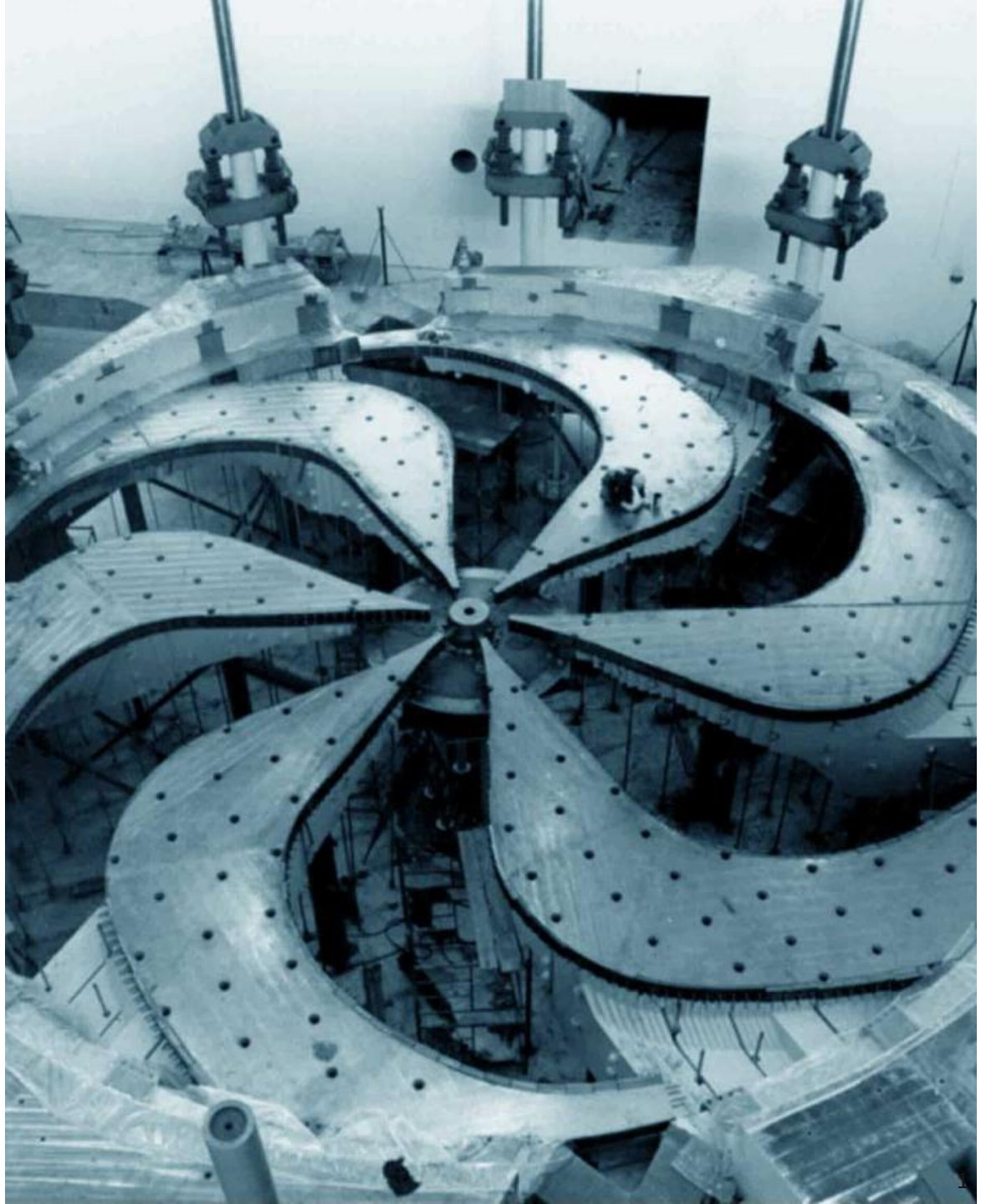

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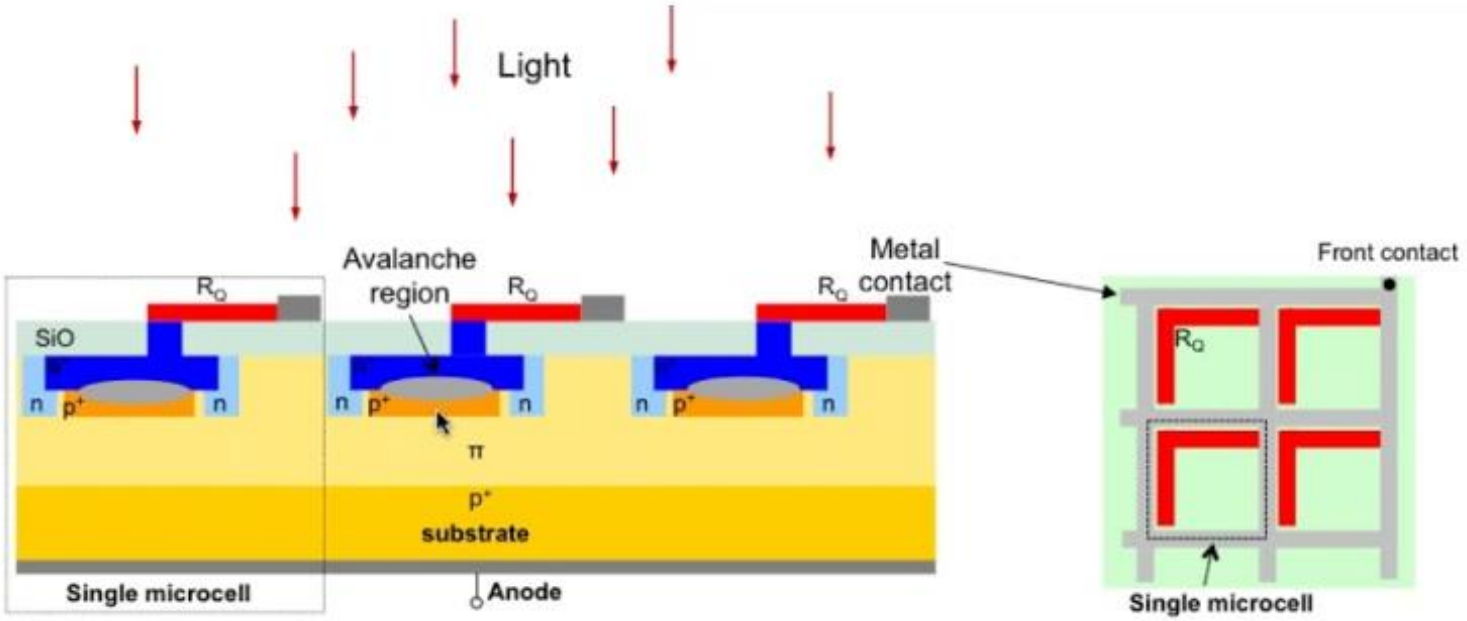
Outline

- SiPM
- Some possible SiPM Applications
  - Radiation Detection
  - Flow Cytometry
  - Automotoive Time of Flight LiDAR
- Investigating the commercial opportunities

Silicon Photomultiplier

- Parallel connected arrays of SPADs
- Operated in Geiger mode
- Passive quenching resistor stops avalanche
- “Binary” output from each pixel
- Final output is the summation of all fired pixels



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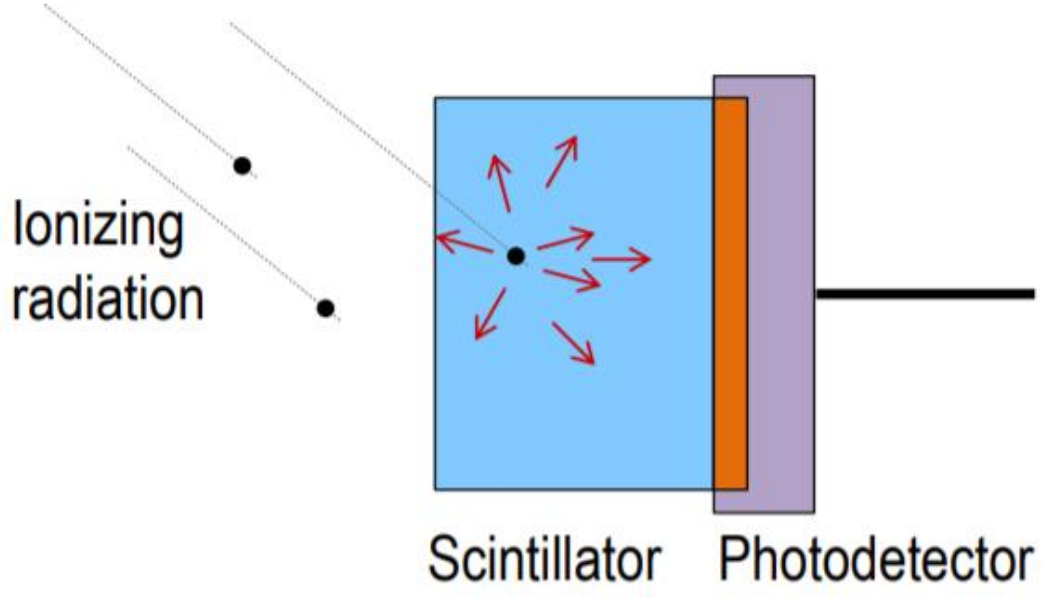
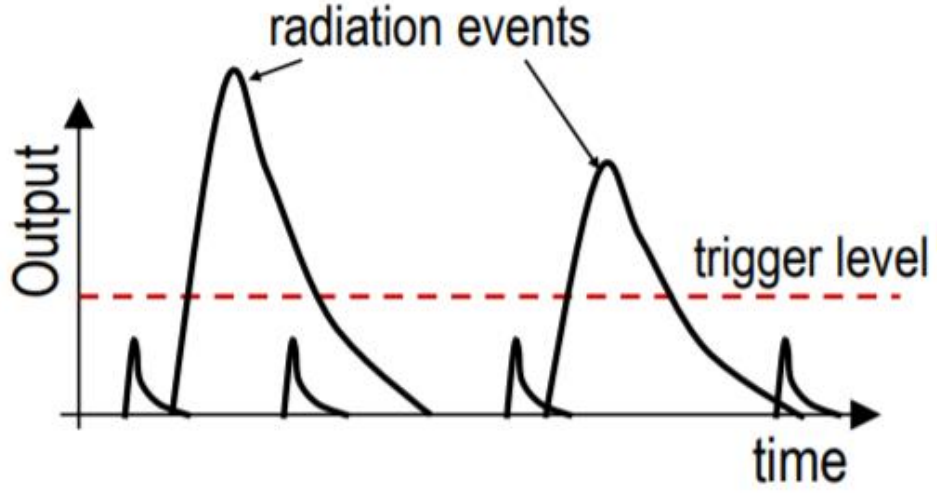
Possible Applications of SiPM

1) Radiation Detection and monitoring





https://www.hamamatsu.com

1) Radiation Detection and monitoring

Characteristics of received light

- Wavelength dependent on the choice of scintillator
- Number of photons per pulse → energy of ionizing radiation and type of scintillator
- Duration of the pulse → size and type of the scintillator (decay time constants range from ns to μs)
- Frequency of pulses → the rate of incoming radiation

Photodetector requirements

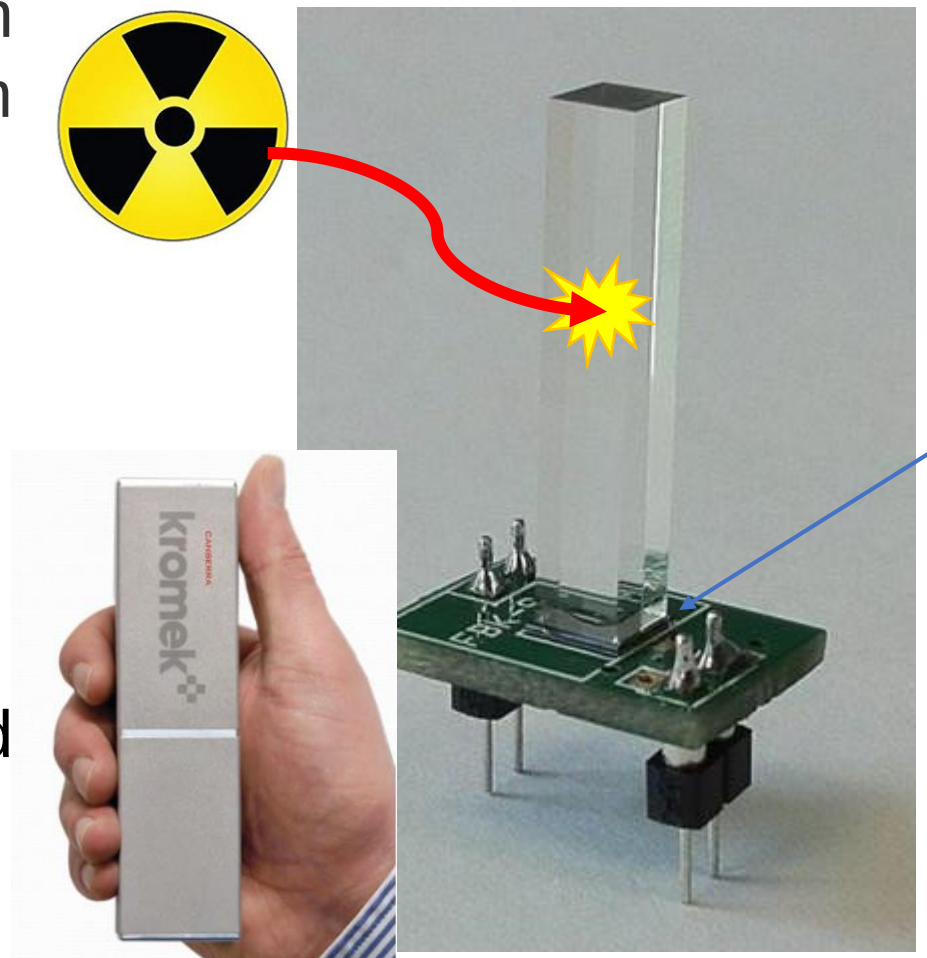
- High photodetection efficiency
- High intrinsic gain
- Large Active Area
- Ability to couple to a scintillator
- Suitable for portable hand-held devices

1) Radiation Detection and monitoring

The design and operation of scintillation detectors are shifting to SiPM detectors from PMT

- lower operation voltage
- magnetic field insensitivity
- mechanical robustness
- smaller size

- Mirion Technologies
  - based on a CsI scintillator crystal coupled to Silicon Photomultiplier detector



https://www.mirion.com

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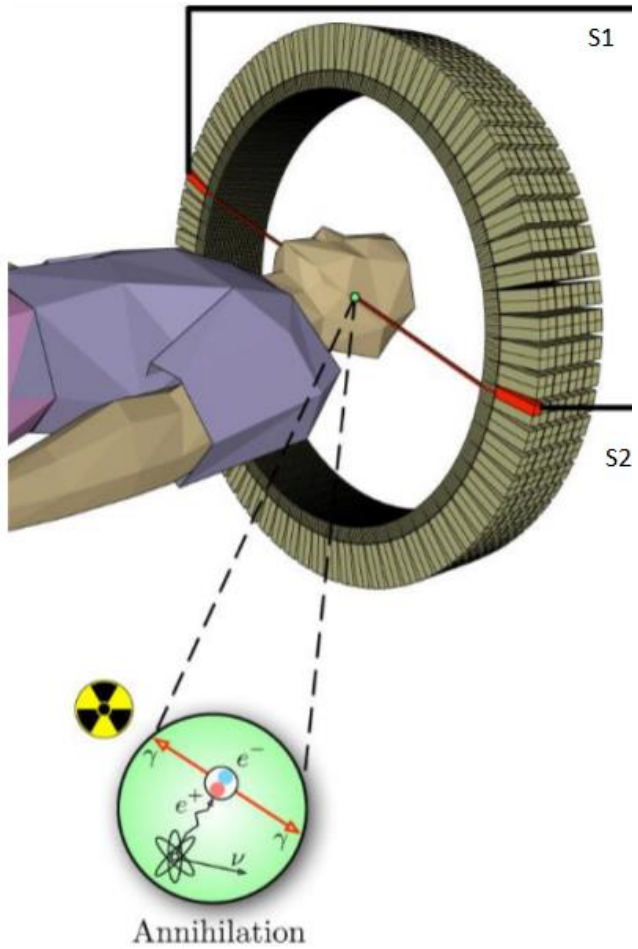
1) Radiation Detection and monitoring

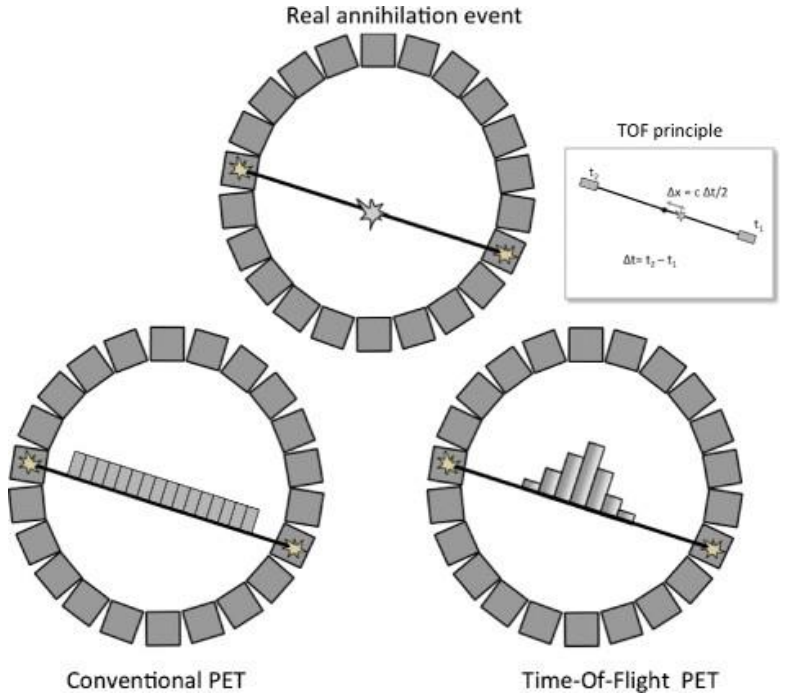
PET = **P**ositron **E**mission **T**omography

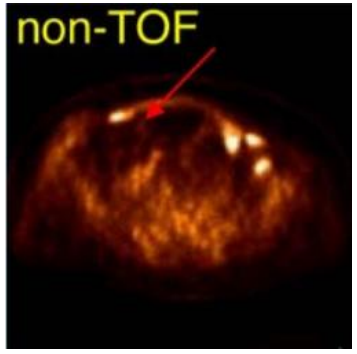
- A medical imaging technique that is used to quantitatively and non-destructively measures the 3-D distribution of radiolabeled biomolecules processes in vivo
- Inject radiotracer → a chemical tracer doped with a radioisotope → undergoes positive beta decay (positron emission)
- Positrons emitted from beta decay annihilate with nearby electrons → generating photons → detected by a scintillator crystal coupled to a photodetector

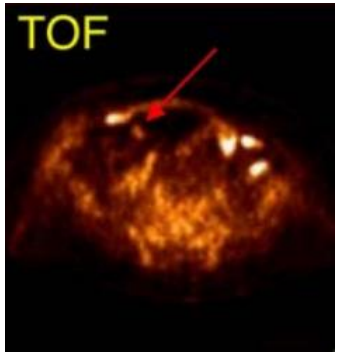


Positron Emission Tomography

- The location of the annihilation event → narrowed to a line of 1 response (LOR) from two coincident detections
- PET systems with high timing resolution → annihilation location can be further constrained to a segment on the LOR → time-of-flight (TOF) PET
  - Faster computer processing times
  - Better image quality





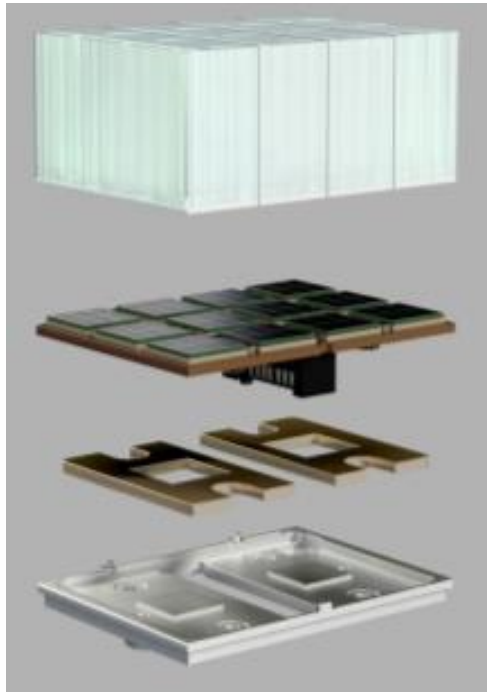


SOURCE: Courtesy of Joel Karp, University of Pennsylvania.

Positron Emission Tomography

PMT

- 40 year old technology
- Limited performance
- Average ToF: 550 ps
- Magnetic sensitivity
- Bulky



SiPM

- new solid state photosensor
- Superior performance
- Excellent image quality
- ToF ~250-400 ps
- Magneto resistive → Ideal for PET-MR

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Positron Emission Tomography

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PHILIPS
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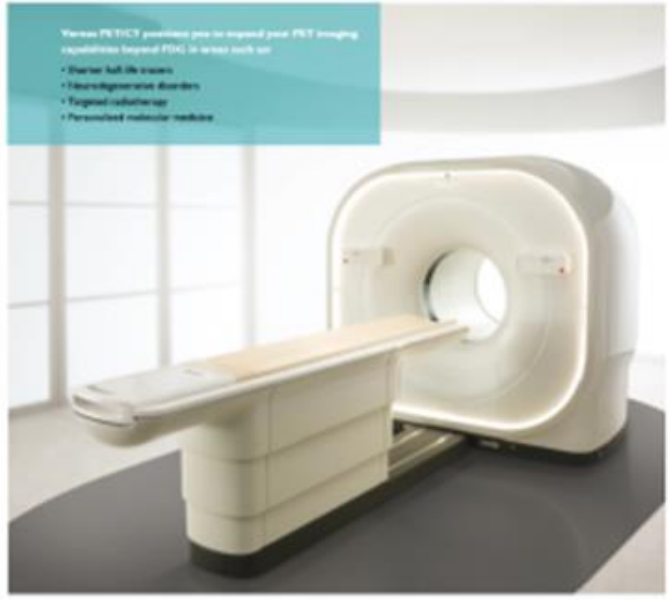

TOF 345ps

Signa PET/MR

TOF 380ps

SIEMENS Healthineers

Biograph Vision

TOF 249ps

on

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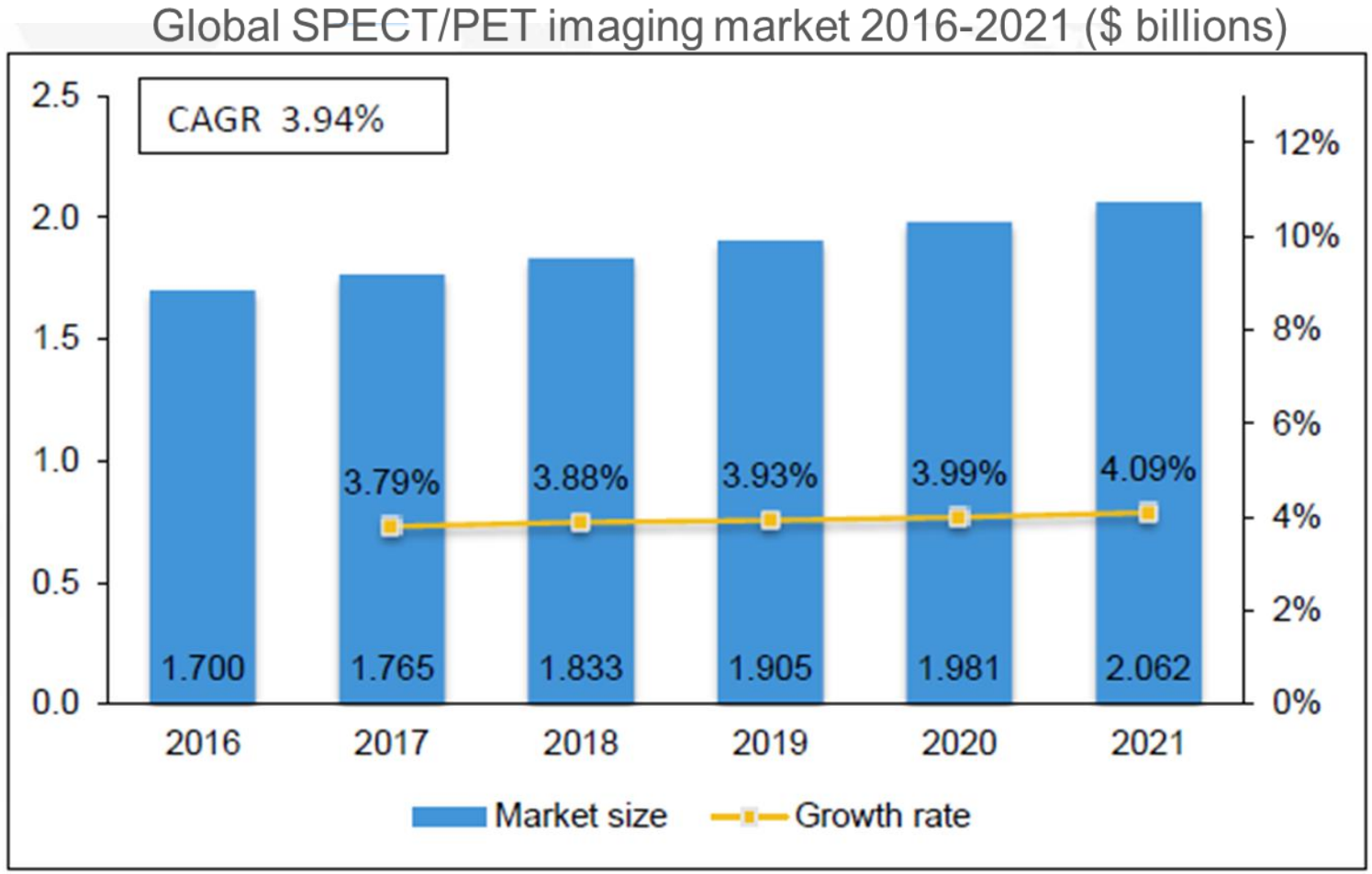
Positron Emission Tomography

- The global market for SPECT/PET imaging will grow at 3.94% during the forecast period.
- It is expected that by 2021, the market will account for a revenue of $2.062 billion.



Source: Technavio

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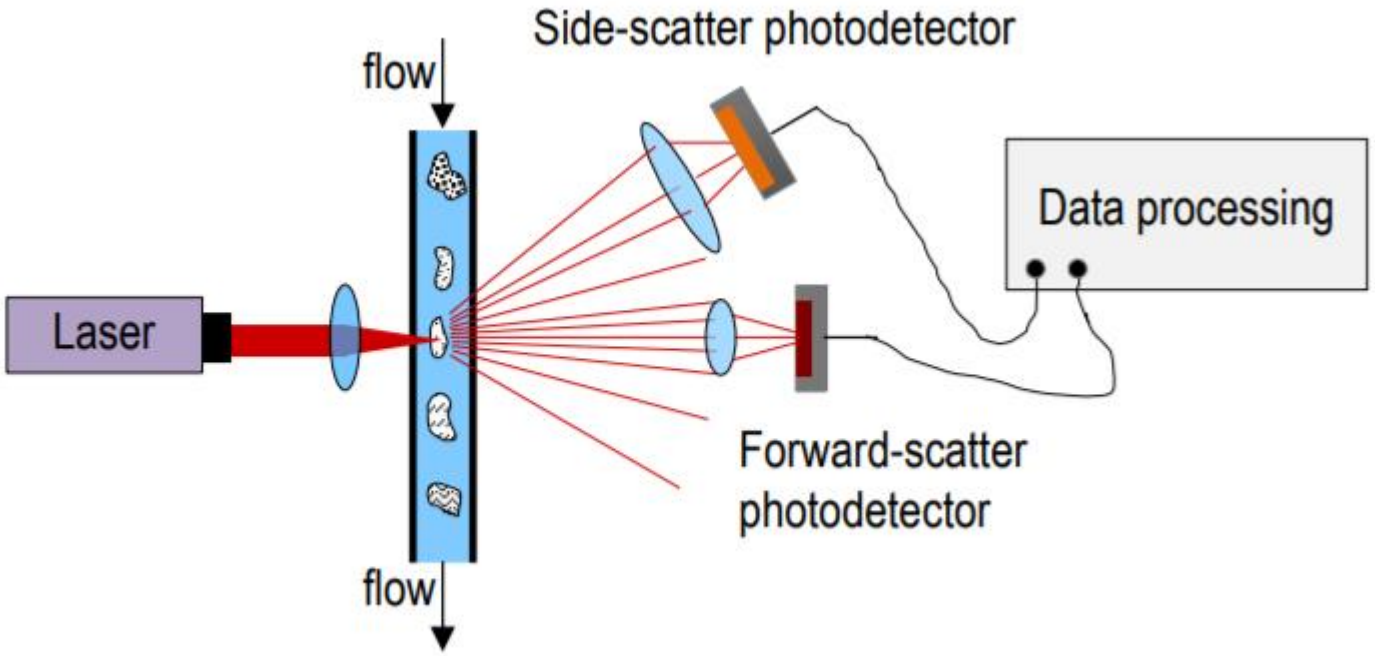
Possible Applications of SiPM

2) Flow Cytometry

Technology used to analyse the physical and chemical characteristics of particles in a fluid as it passes through at least one laser.

- Used to study and sort biological cells
- Used to detect particulates in a stream of fluid
- Scattering Analysis
  - Side-scatter signal/forward scatter signal → depends on cell properties
- Fluorescence Analysis
  - wavelength recognition
  - fluorescence lifetime recognition



https://www.hamamatsu.com

2) Flow Cytometry

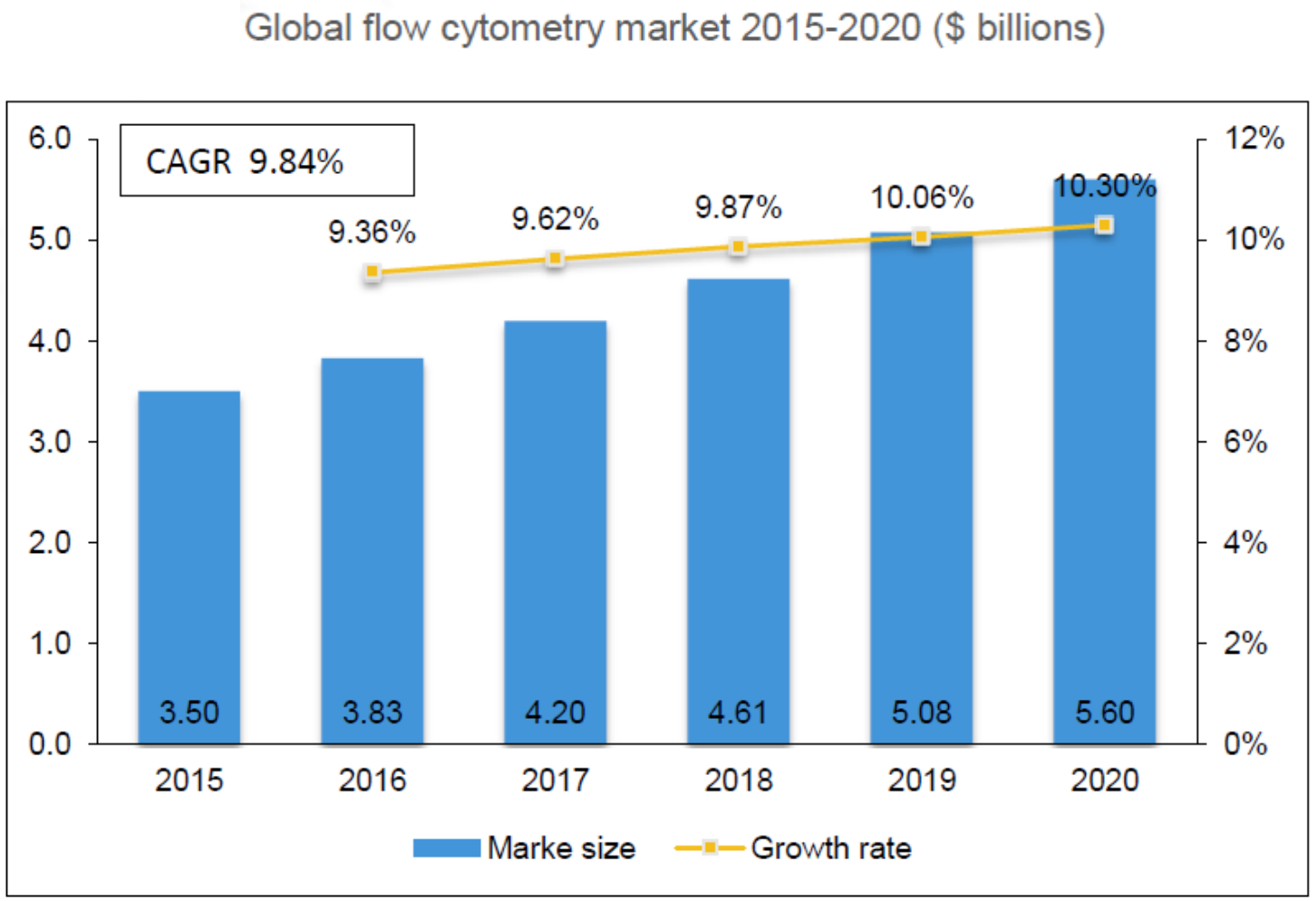
ACEA Biosciences

- The first flow cytometer has integrated SiPM in one of the channels → NovoCyte Quanteon™

https://www.aceabio.com/

2) Flow Cytometry

- The global market for SPECT/PET imaging will grow at 9.84% during the forecast period.
- It is expected that by 2020, the market will account for a revenue of $5.60 billion.



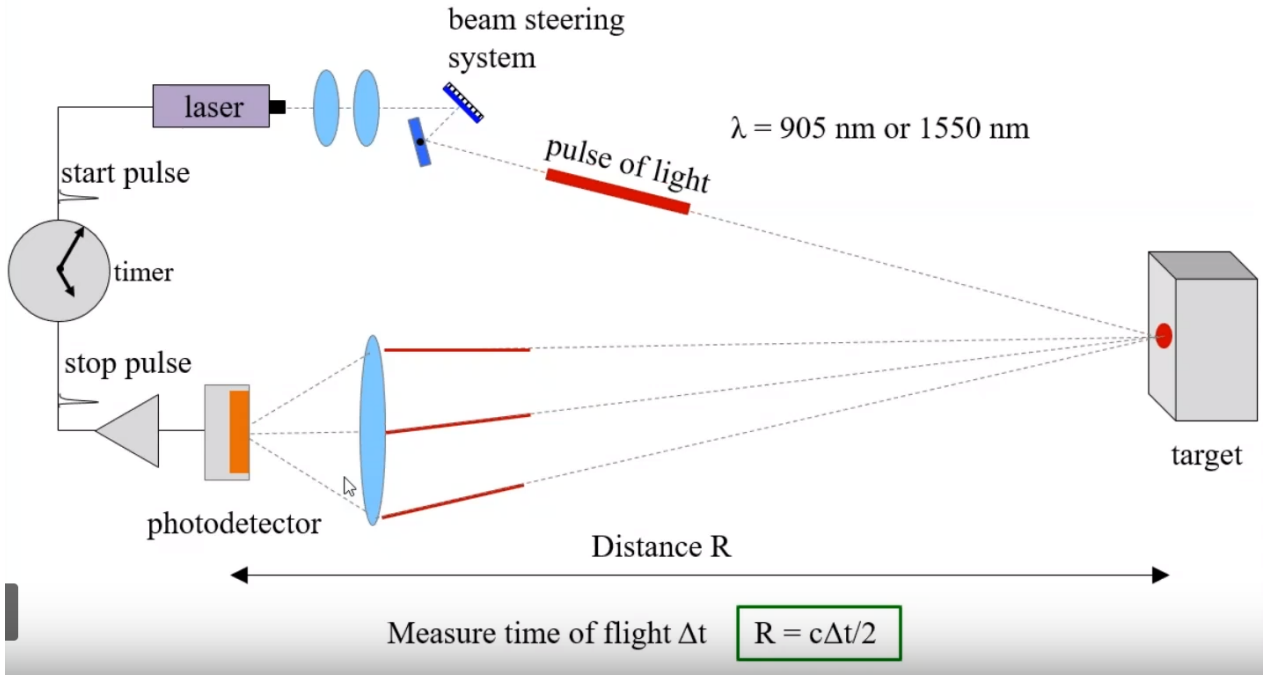
Source: Technavio

Possible Applications of SiPM

3) Automotive time-of-flight LiDAR

LiDAR stands for Light Detection and Ranging

- Great interest in automotive industry for self-driving cars
- Should have a LiDAR system to produce high resolution 3D imaging of the surrounding
- Laser produces a pulse of light → start timer
- The pulse of light is directed to the desired direction and reflected from the target
- Photons collected and projected on to the photodetector
- Stop pulse and stop the timer
- Measure ToF → gives distance to the object
  - Time → ns → lower → better
  - Wavelength → eye safety standards
  - Weak light but high dynamic range due to the target position



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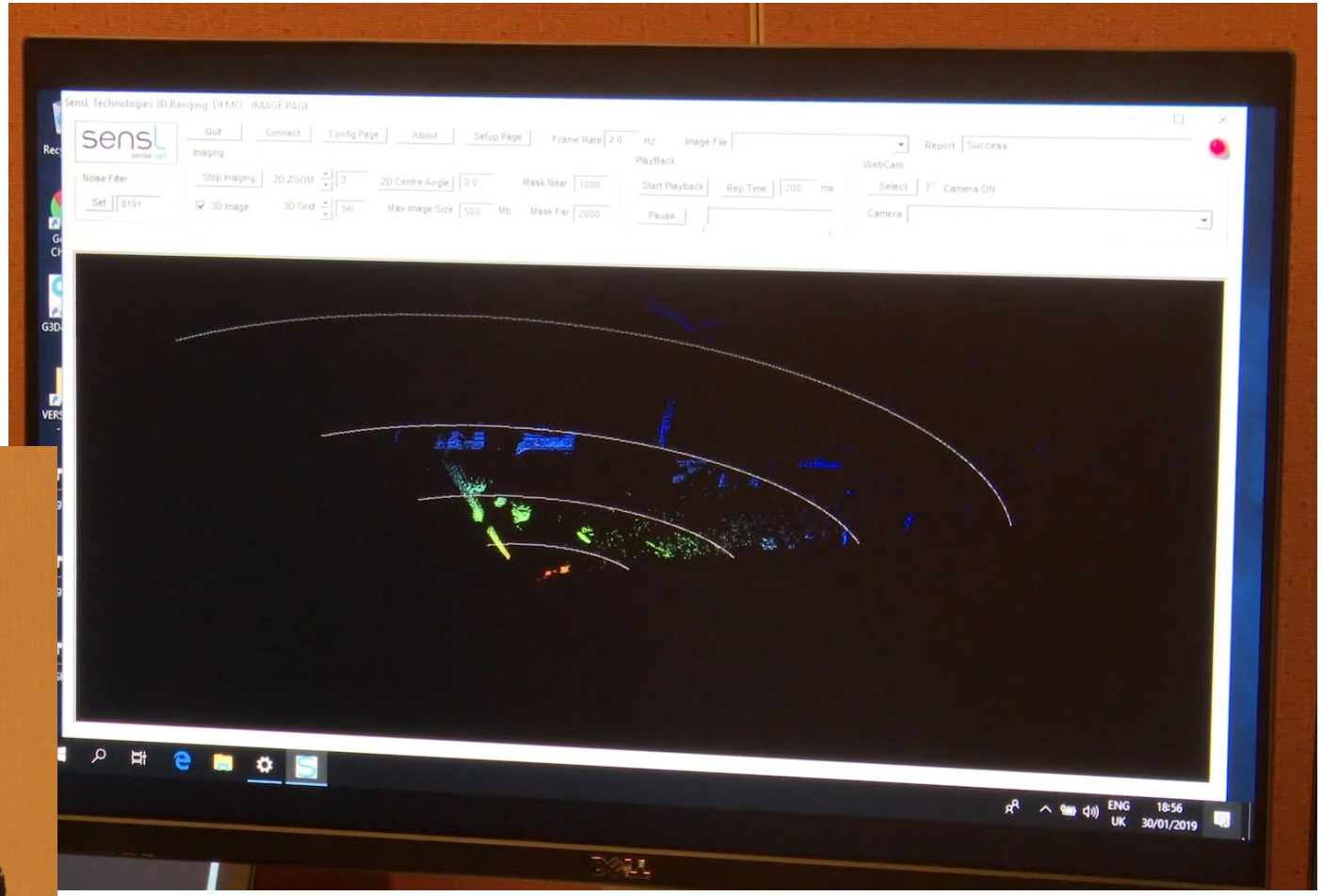
3) Automotive time-of-flight LiDAR

- Gen3 LiDAR Demonstrator

LiDAR using SiPM from SensL(acquird by ON Semiconductor)



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3) Automotive time-of-flight LiDAR

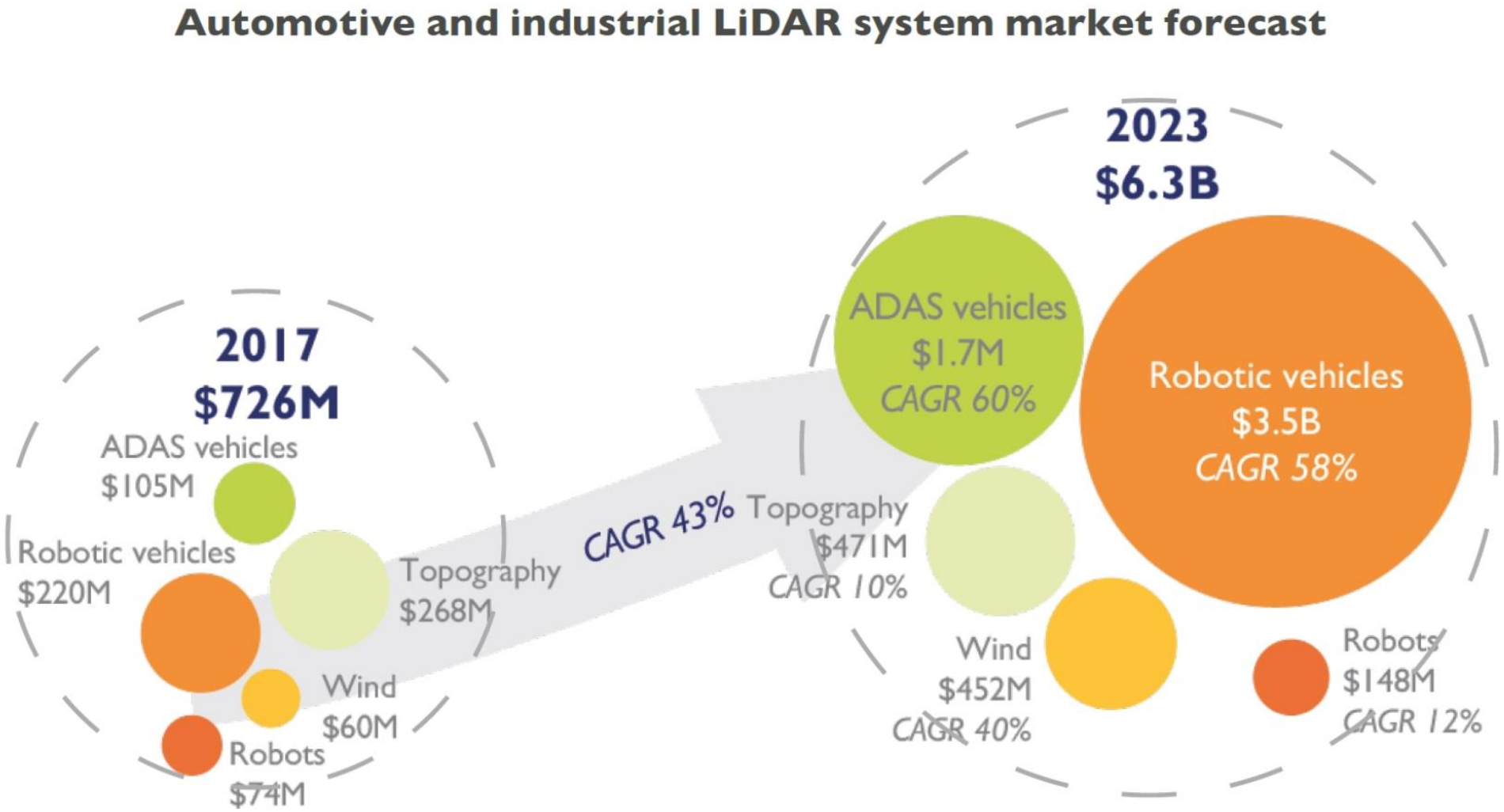

Image: Yole Développement

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I have an innovation idea!

Write down your value proposition

- What it is & does?
- Who it is for?
- What is the need of my customer?
- Why it is special?
- Why is it unique?
- Who are the competitors?
- Why does my customer choose me over the rest of the competitors?

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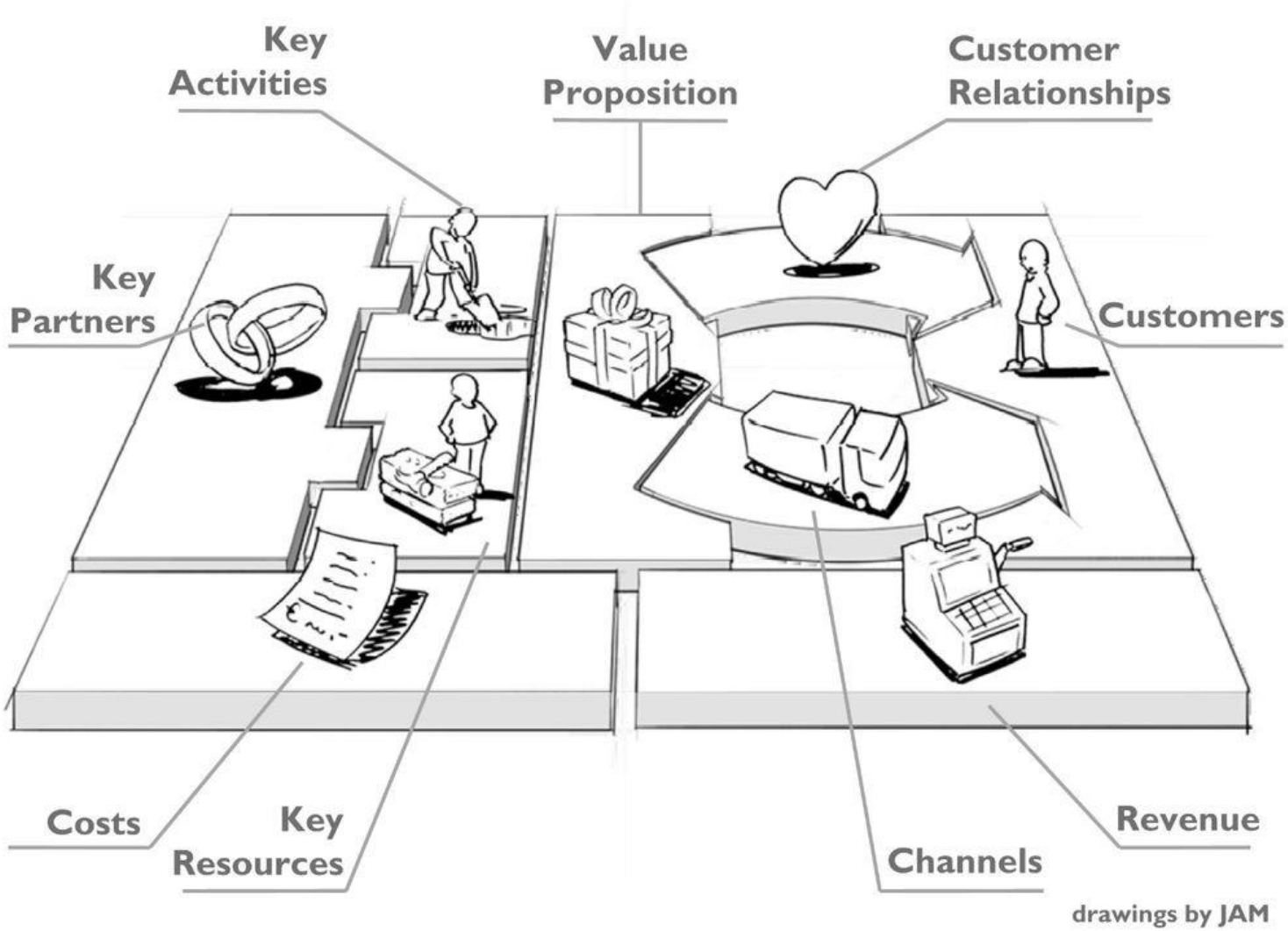
Business Model Canvas



Thank you
Merci

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- Describe the competition in the market place for the product/Service. Please address the following points:
  - Which current market stakeholders may feel threatened by your product/Service?
  - Why will your product/Service “beat” the competition?

•*Question #9: Barriers to competition*: Describe any barriers to others competing with your product or service. Examples might be:

- Patent or copyright protection.
- Time to engineer a new product.
- Market presence as first to market.

•*Question #10: Business Plan Status:* Describe the current status of your business plan. In your response please address the following points:

- Who wrote the business plan?
- What advisors were consulted or what additional research was conducted?
- What key sources are included to document and support your plan?

•*Question #11: Management Capacity:* Describe the business skills (leadership, directorships, finance, marketing, operations, HR, etc.) of your Team. Please address the following points:

- Highlight the key credentials of the management team.
- What key skill sets remain to be recruited?
- Does management regularly consult with market-based advisors or experts? How?

•*Question: #12: Financial:* Describe the financial position of your venture. Your answer should address the following points and be supported by attached statements.

- How will your revenue model enhance market acceptance in the target market?
- How are you going to price your service/product?
- Include reference to your cash flow statement.
- Include reference to one- and two-year pro-formas, plus three- to five- year summaries.
- How much money has been spent?

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GLOBAL MOLECULAR IMAGING DEVICE MARKET COMPETITIVE ANALYSIS, 2013
($ MILLIONS/%)

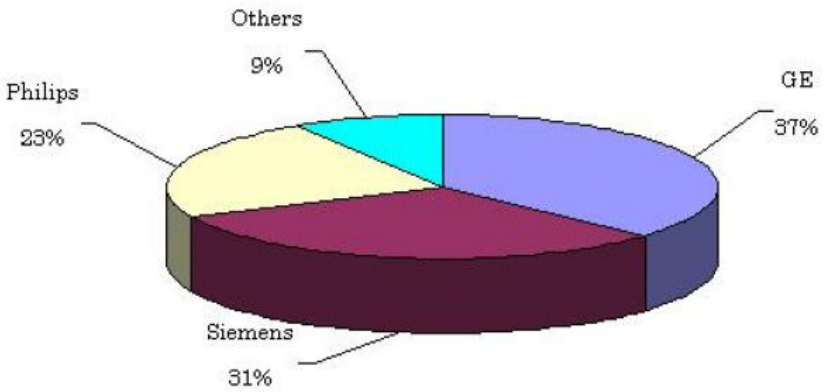
Manufacture	Revenues	
	$ Millions	Percent
GE Healthcare	814.0	37
Siemens Healthcare	682.0	31
Philips Healthcare	506.0	23
Others*	198.0	9
Total	2,200.0	100

*The Others category includes: CardiArc, Gamma Medica–Ideas, GVI Medical Devices, Neurologica, Nuclear Cardiology Systems, Orbotech, Photon 2, Positron Corporation and Spectrum Dynamics

Source: BCC Research

FIGURE 7

GLOBAL MOLECULAR IMAGING DEVICE MARKET COMPETITIVE ANALYSIS, 2013
(%)



Source: BCC Research

4D-PET/MRI

4D–PET/MRI imaging is a detector concept (not yet in production) for hybrid modalities to develop faster scintillating crystals and silicon based segment photon sensors, which could allow for more precise measurements. The 4D-PET project, funded by Instituto Nationale di Fiscia Nucleare (INFN) is a PET block detector concept using 3D response and 4D images to create a detection module using fast scintillation crystals, which are coupled on both sides to arrays of Silicon Photomultipliers (SiPM), which collect scintillation light. Signals are compared from both sides of the crystal and the interaction time is measured using TOF techniques and processes, which reduce errors. Monte Carlo experiments (using repeated, random simulations) indicate good results in performance, energy, spatial and time resolutions.

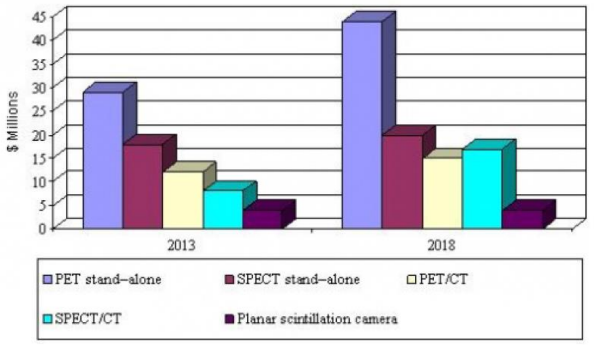
MARKET FOR MOLECULAR IMAGING DEVICES BY COMPANY IN THE AMERICAS, 2013
($ MILLIONS/%)

Company	$ Millions	Percent
Siemens Healthcare	223.0	29
Philips Healthcare	208.0	27
GE Healthcare	208.0	27
Dilon Diagnostics	38.0	5
Digirad	31.0	4
Others*	62.0	8
Total	770.0	100

*Includes Hitachi Medical Systems, CardiArc, Gamma Medica Ideas, GVI Medical Devices, NeuroLogica, Nuclear Cardiology Systems, Orbotech, Photon 2 and Spectrum Dynamics.

Source: BCC Research

CANADIAN REVENUE BY MOLECULAR IMAGING DEVICE TYPE, 2013 AND 2018
($ MILLIONS)



Source: BCC Research

With the current challenges of chronic age-related conditions such as cardiovascular disease, cancer and neurological diseases, the demand for imaging equipment, especially PET/CT and SPECT/CT scanners, is rising.

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