Science & Innovation

Exemplary illustrations based on Silicon Photomultipliers

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Uni. Insubria & INFN Milano
IPRD10, June 8, 2010, Siena

Knowledge Exchange [KE]:
To do
or
Not to do?

Why KE fits experimental HEP ?

- in general, technology beyond/@ the state-of-the art is required for pursuing the Physics program. *And it is developed in-house…*
- challenges are part of our every day life..
- team work is a built-in attitude..
- …and international collaborations as well
- we do need to fill in the gap between generation of experiments..
- … and to show a return to society beyond the Higgs particle and the

Why KE is not trivial & natural?

- in general, mutual confidence between the Research Community & industries has not to be given for granted..
- recognition for TT/KE activities is not naturally built in the appraisal scheme
- funding/co-funding is not straightforward
- Intellectual Property (IP) protection is not a piece of cake

Remarks

In Europe, everybody talks about KE; many are trying hard, a few are qre effective [UK: revenue driven; Switzerland: volume driven]

Emphasis on the Innovation Model (vs. Licensing Model)

⇒ Knowledge Exchange vs TT

⇒ Pull vs push

⇒ collaborative and contract research!

2008 update: 1895 contracts for 352 MCHF cash return

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TT stats 2005 of Swiss universities (incl. ETHs)
swiTT survey

1041	Research agreements through TTOs
322	Invention disclosures
169	New patent filings (priority filings)
916	Active patent cases (end of 2005)
169	New licenses and options for 154 different technologies
762	Active licenses (end of 2005)
27	new start-ups
210	start-ups created betw. 2000 and 2005

2008 update: 1895 contracts for 352 MCHF cash return

RAPSODI
RAdiation Protection with Silicon Optoelectronic Devices and Instruments

- **Funded by the EC under the Sixth Framework Program** (Co-operative research)
- Start-time Oct 2006; End-time: Jan 2009

- **Main objectives**: Silicon Photo Multipliers development and optimization for three well defined applications: Dosimetry in Mammography, Radon Monitoring, illicit traffic of radioactive material (homeland security)

- **Consortium composition**: 4 Small and Medium Enterprises + 3 R&D performers

SensL (IE)
PTW (DE)
Plch SMM (CZ)
ForimTech (CH)

UNICO (IT) (Leading organization)
AGH (PL)
ITEP (RU)

http://www.rapsodiproject.eu

Silicon Photon Multipliers

genuine *Photon Number Resolving Detectors…*

SiPM = High density (~10^3/mm^2) matrix of diodes with a common output, working in Geiger-Müller regime

advantages over traditional photo-detectors:

- high sensitivity (single photon discrimination)
- high speed (T_{rise}~ 1 ns; T_{fall} ~ 50 ns)
- compactness, robustness, low operating voltage and power consumption, low cost

Producer	Area (mm^2)	Pixel size (μm)	No. cells	$V_{working}$	DCR	GAIN	PDE (%) (peak λ)
SensL	3 x 3	20 x 20	8640	30	~4 MHz	~10^6	10
Hamamatsu	1 x 1	100 x 100	1000	70	~0.4 MHz	~2 x 10^6	65
CPTA	1 x 1	30 x 30	500	24	~3 MHz	~10^6	30
STm	3.5 x 3.5	50 x 50	4900	28+1	~1.2 MHz	2 x 10^5	12
… and FBK-Trento, of course [see Claudio Piemonte's talk]							

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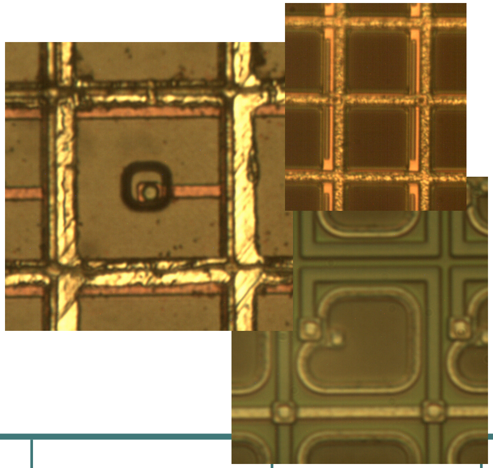

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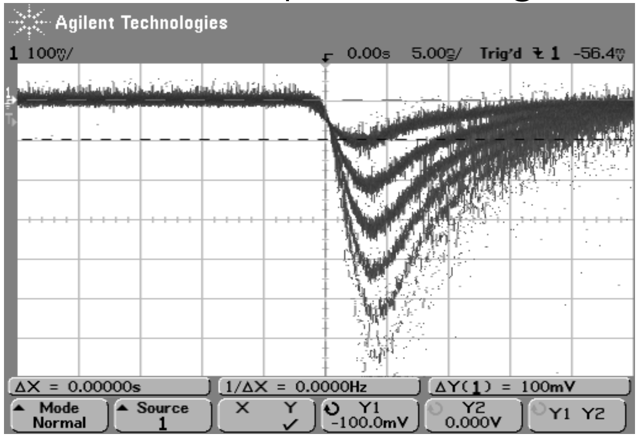

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Flashing a first application: measurement of the indoor Radon concentration [a real counting experiment!]

Radon Risk If You Smoke

Radon Level	If 1,000 people who smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO: Stop smoking and...
20 pCi/L	About 260 people could get lung cancer	250 times the risk of drowning	Fix your home
10 pCi/L	About 150 people could get lung cancer	200 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 120 people could get lung cancer	30 times the risk of dying in a fall	Fix your home
4 pCi/L	About 62 people could get lung cancer	5 times the risk of dying in a car crash	Fix your home
2 pCi/L	About 32 people could get lung cancer	6 times the risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 20 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L	About 3 people could get lung cancer	(Average outdoor radon level)	

⇐ 74 Bq/m^3

Note: If you are a former smoker, your risk may be lower.
pCi/L (pico Curies per Liter)
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

Radon Risk If You've Never Smoked

Radon Level	If 1,000 people who never smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO:
20 pCi/L	About 36 people could get lung cancer	35 times the risk of drowning	Fix your home
10 pCi/L	About 18 people could get lung cancer	20 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 15 people could get lung cancer	4 times the risk of dying in a fall	Fix your home
4 pCi/L	About 7 people could get lung cancer	The risk of dying in a car crash	Fix your home
2 pCi/L	About 4 people could get lung cancer	The risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 2 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
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Note: If you are a former smoker, your risk may be higher.
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EPA figures

measurement of the indoor Radon concentration: the US map

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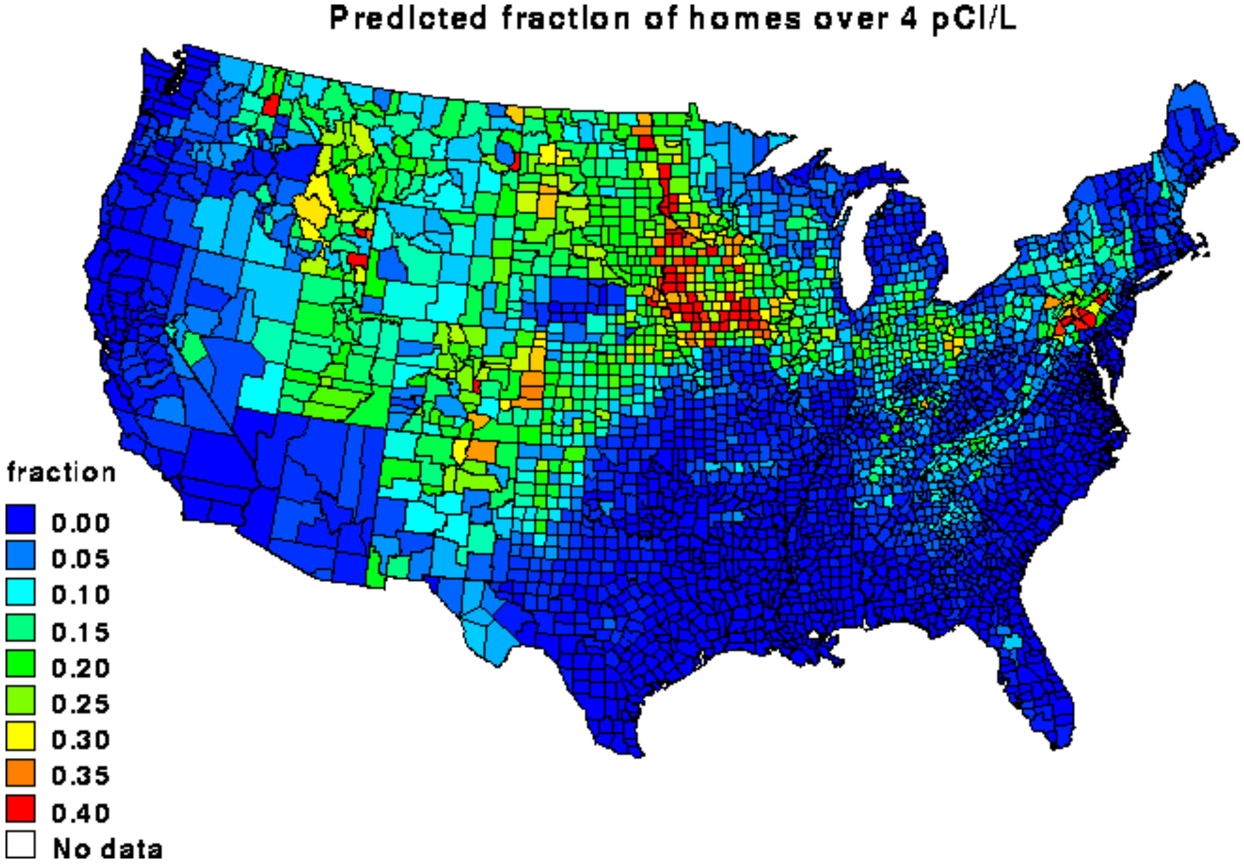
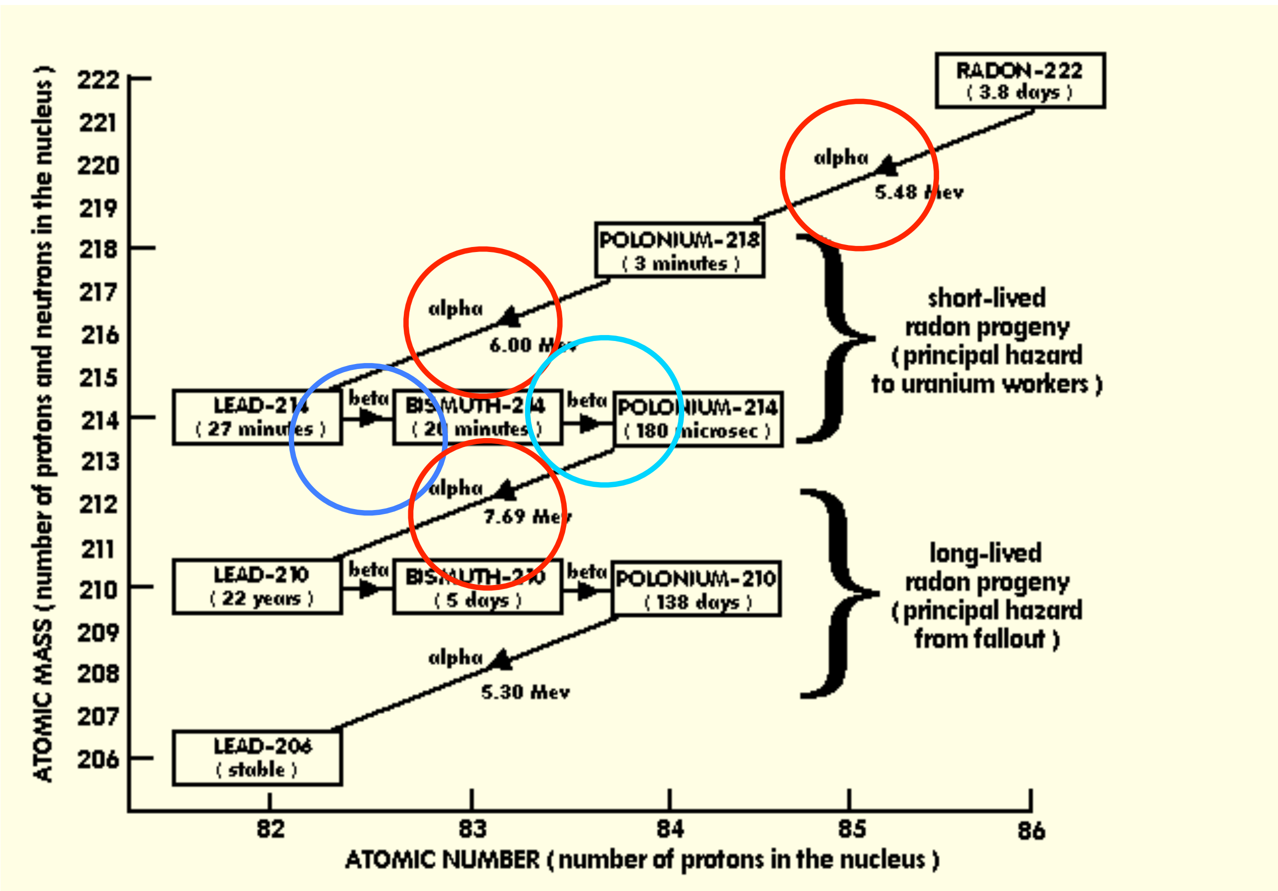


measurement of the indoor Radon concentration: the US map

The RADON decay chain



The radon progeny

measurement of the indoor Radon concentration: classes of instruments

A brief survey of the state-of-the-art:

a. Long term measurements, currently based on alpha track detectors ⇐Good for mapping /surveying
b. High sensitivity instruments for the measurements of Radon concentrations in buildings; in general, these instruments are based on either passive ionization chambers (electrets, more info for instance at http://www.radelec.com/product.html) or active systems, where the Radon progeny is collected on the surface of a semiconductor detector. In general, as a reference figure of merit, sensitivity to a concentration of 100 Bq/m^3 over 1 hour sampling can be retained. ⇐ Reasonably Good for RT monitoring
c. High sensitivity instruments with spectrometric capabilities ⇐ In general for professionals
d. Low cost instruments for the measurements of Radon in soil; the baseline technology can be tracked to the Lucas cell.

Exemplary illustrations of market products

Reference *class c* instruments:

Name	*Producer*	*Quality (Plch)*	*Detection principle*	*Price*
Atmos	Gammadat, Sweden	Very high	Multiwire air chamber	13 000EUR
AlphaGuard	Genitron, Germany	High	Impulse ion. chamber	12000EUR
Radim3A	Plch, CZ	High	Daughters collection	4700 EUR
Sarad 2000	Sarad, Germany	Medium	Daughters collection	9000 EUR
RAD7	Durridge,USA	Medium	Daughters collection	???

Reference *class b* instruments:

Radim5	Plch, CZ	Medium	Daughters collection	2200EUR
InAir Sensor	Sarad	low sensitivity	Daughters collection	1200EUR
Ramon	FSPI, USA	low sensitivity	Daughters collection	200 EUR

Brief about the AlphaGuard and the Sarad Indoor Air Monitor

Sensitivity: 3 counts/hour @ 1 Bq/m^3

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	P30 / P2000 / PQ2000 / PQ2000 PRO	PQ2000 PRO (only)
[illegible] detector	ionization chamber HV = 750 VDC	
Mode of operation	3D alpha spectroscopy and current mode	
Total / active detector volume	0,62 liter / 0,56 liter	
Detector filling mechanism	design optimized for fast passive diffusion (10/60 min cycle)	flow mode (1/10 min cycle)
Instrument calibration error	3% (plus uncertainty of primary standard)	
System linearity error	< 3% within total range	
Transient response function (time delay)	signal > 30% after 10 min / signal > 70% after 20 min / signal > 90% after 30 min	
Sensitivity of detector	1 CPM at 20 Bq/m³ (0,55 pCi/l)	
Background signal due to internal detector contamination (delivery status)	< 1 Bq/m³ (0,03 pCi/l)	
Operating range	-10 ... +50 °C (+14 ... 122°F) / 700 ... 1.100 mbar / 0 ... 99 %rH	

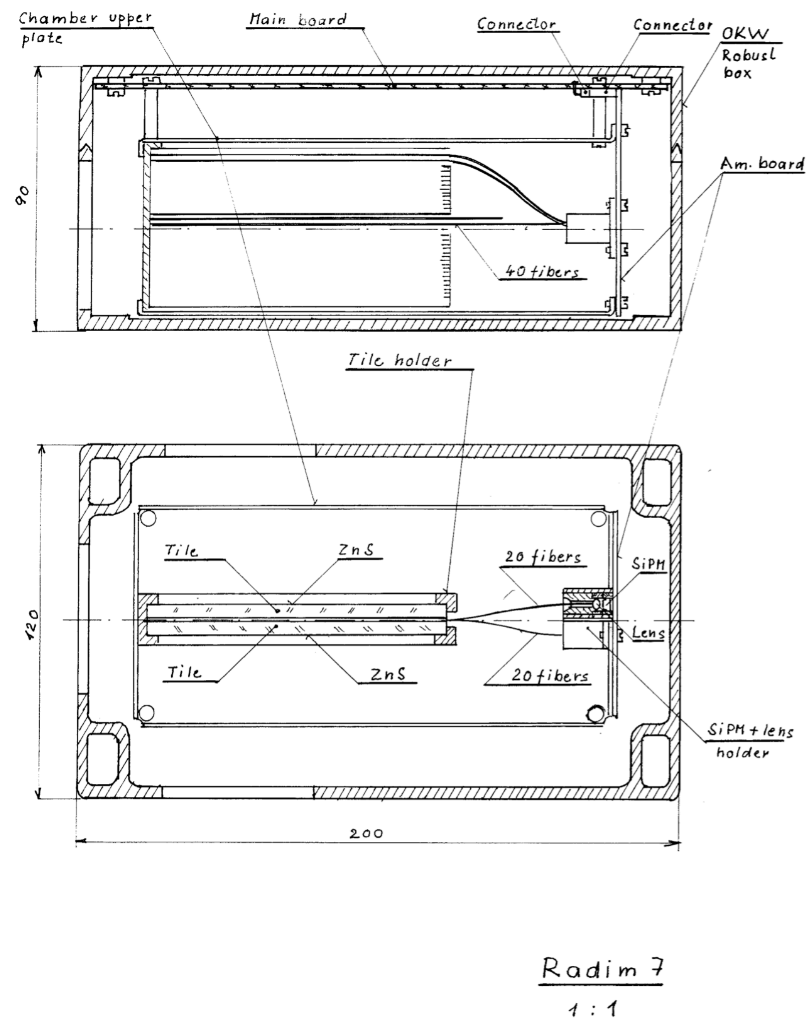
SARAD®

Indoor Air Sensor

Technical Data

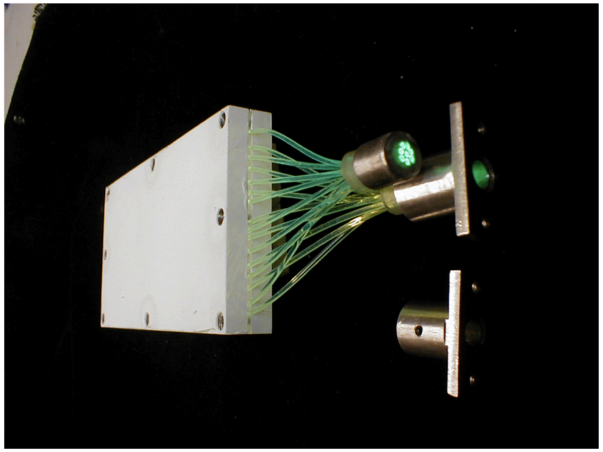
Sensitivity: 0.003 counts/hour @ 1 Bq/m^3

The RADIM7 - an innovative approach

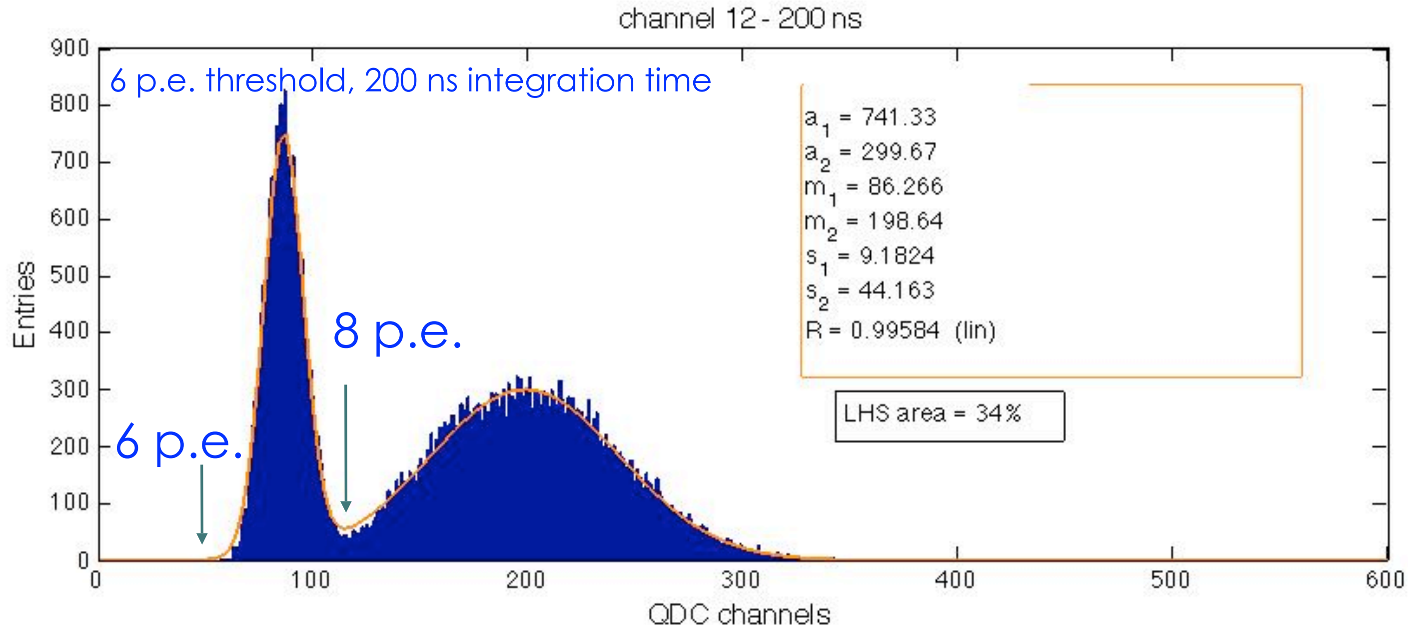


- ❖ Yet based on the detection of the Radon alpha-emitting progeny
- ❖ replace the detector with a high sensitive scintillator + SiPM system ⇒ get to a system with top class performance and middle class price

The detecting system (qualified with 241Am)



⇐ The scintillating unit & fiber light conveying bundles



Exemplary illustration spectrum

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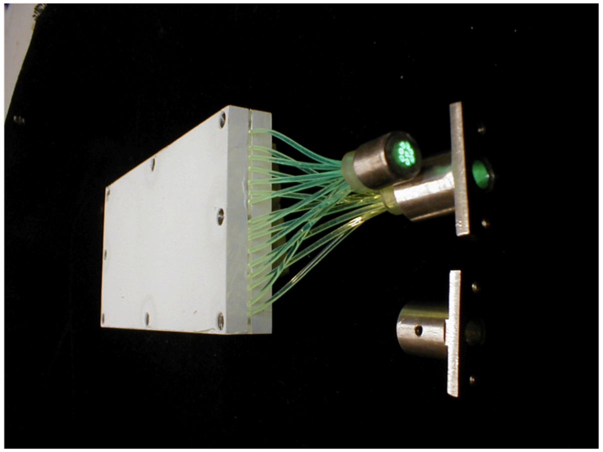


⇐ The scintillating unit & fiber light conveying bundles

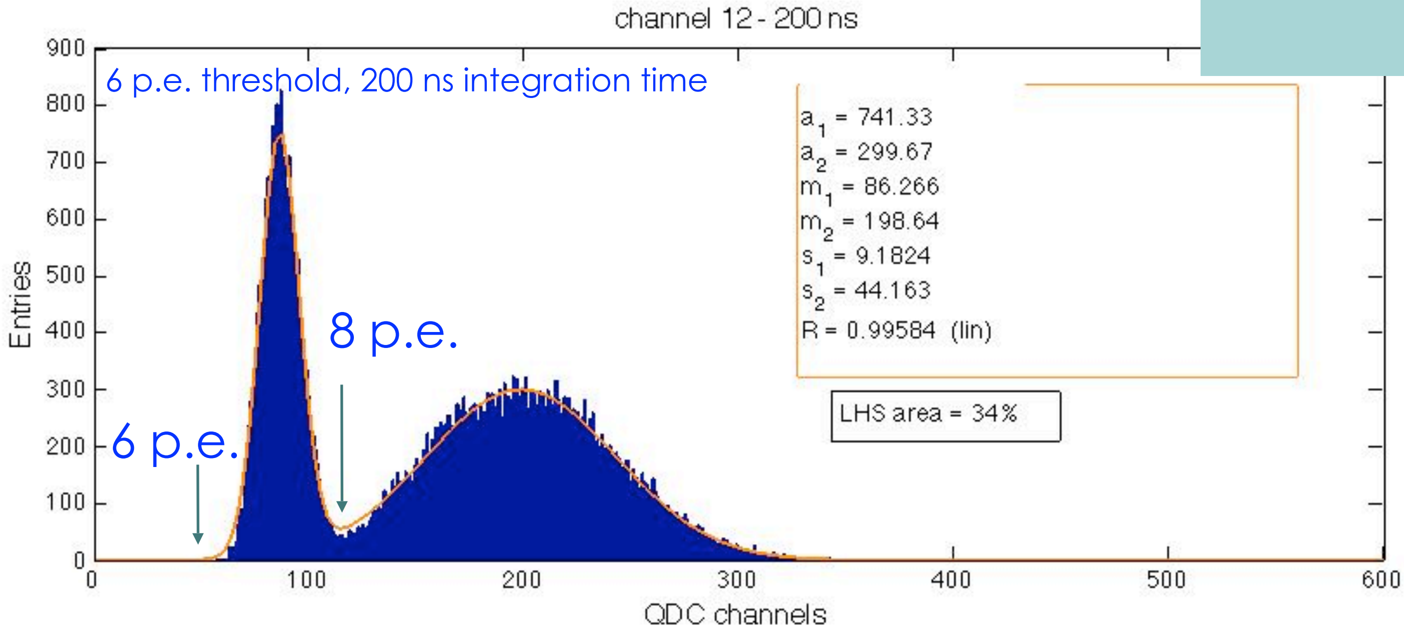
241Am efficiency ⇒

❖source activity (single pinhole) as of the ORTEC System:

(25 ± 5) Hz

❖ source activity as of Jirka's tile:

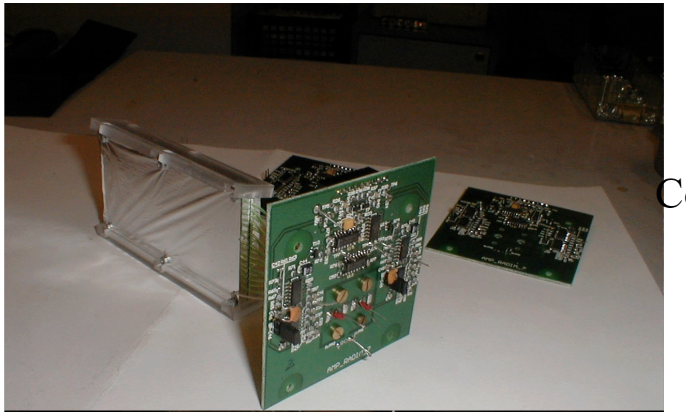
(24 ± 7) Hz

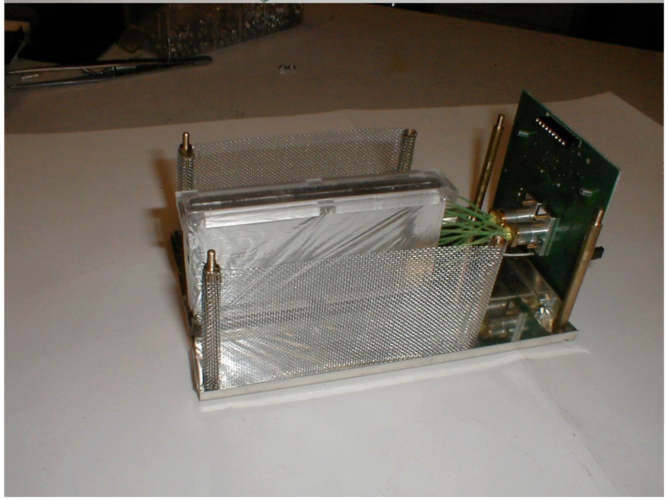


Exemplary illustration spectrum

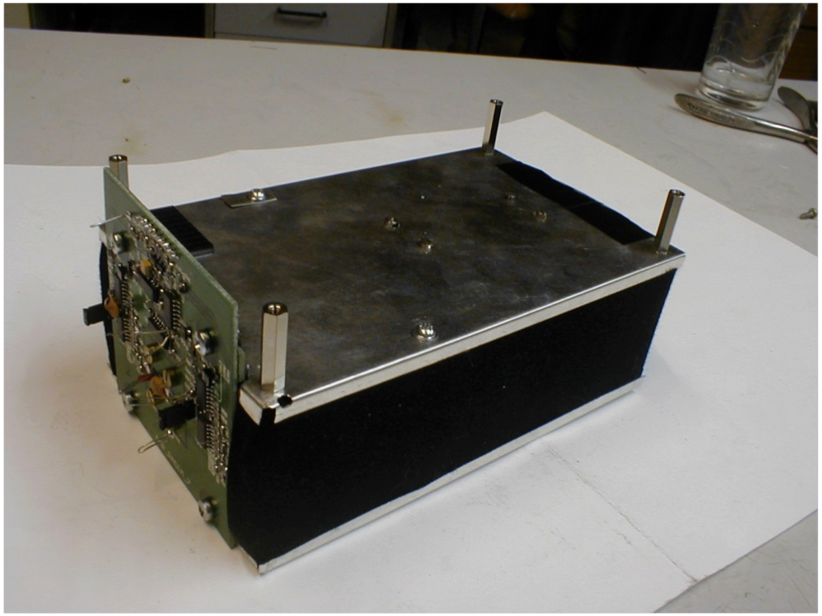
Chamber & electronics

The tile was mounted with the AGH electronics:

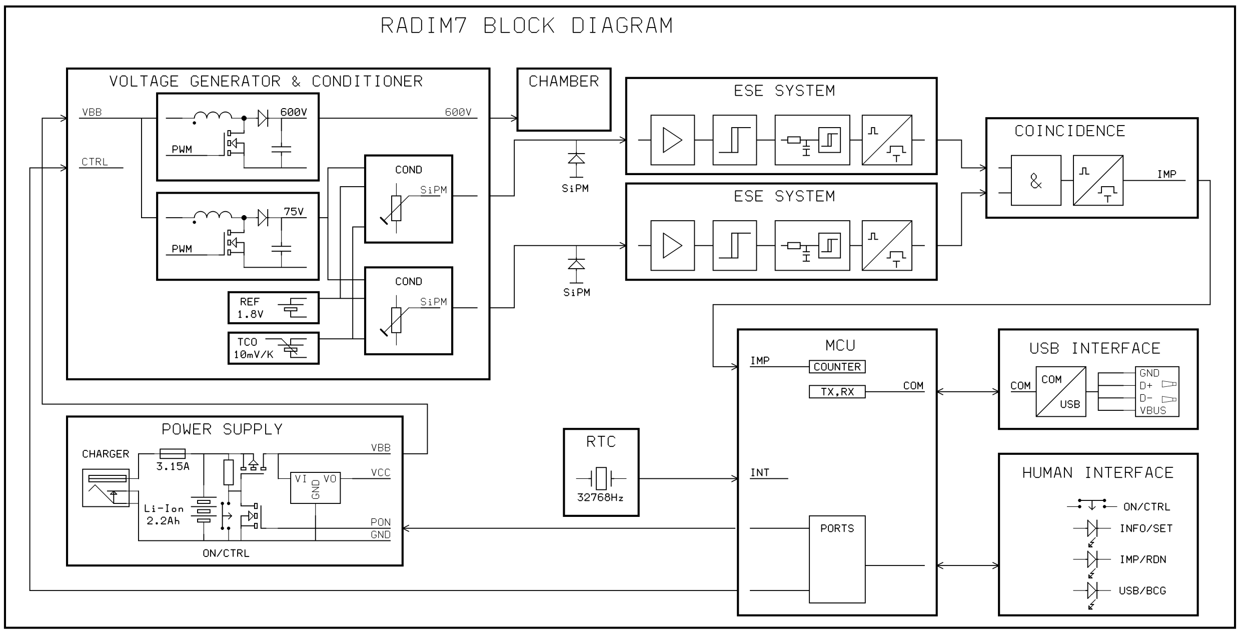




Complete chamber:



At the heart of the problem: kill the DCR and fix the stability!



Main figures from a non-trivial exercise:

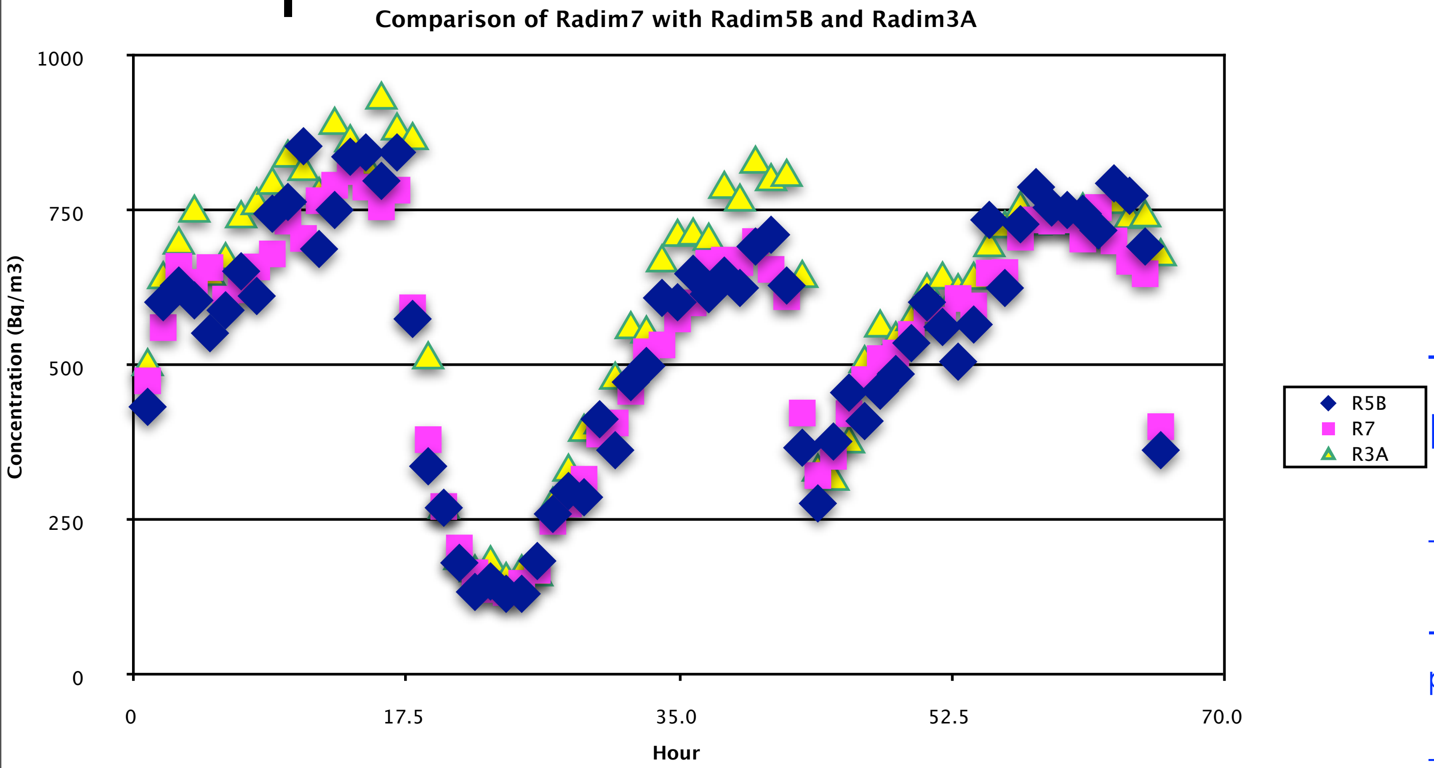
- dark counts reduced from 1 000 000 per second to 1 per hour
- stabilized in the 3-40 C temperature range

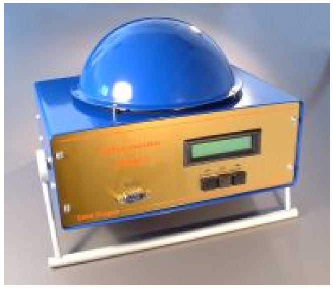
Technical Characteristics of the RADIM7

Measured quantity:	Air radon concentration
Functioning principle:	The radon diffuses into the detection chamber of the instrument, which is covered with a layer of felt. The felt absorbs the radon decay products formed in the external air. The radon activity is determined by measuring the α-activity of the decay products of radon, RaA and RaC', collected on the surface of the scintillation detector by a high-intensity electric field.
Instrument response:	(1.1 imp/h)/(Bq/m^3)
Minimum concentration:	concentration determined with a statistical error equal to ±20%: 25 Bq/m^3 for 1-hour measurement
Maximum concentration:	about 50 kBq/m^3
Time of 1 measurement:	sampling time 1 hour
Effect of humidity:	a change in the relative humidity from 50% to 90% causes a change in the sensitivity less than 5%
Electronics:	low power, data protection against low voltage of the battery, autotest
Consumption:	during measurement 4 mA, standby consumption approx.3 μA
Memory:	the results of 7 years of measurement can be stored, i.e. 65000 individual measurements
Power source:	Li-Ion , 2.2 Ah
Operating time:	minimum of 23 days
Operation and control:	control by button and 3 LED
Data reading:	the data are read by PC connected to standard USB port
Measuring regimes:	Meas regime - measurement of the radon concentration Test regime - test using the internal generator BCKG regime - measurement of the number of impulses with the high voltage turned off
Dimensions and Weight:	200 x 150 x 90 mm, approx. 0.5 kg
Climatic condition:	from 3 to 40 °C, from 5 to 90 % of relative humidity .

Mission Accomplished!

A comparison with other instruments of the RADIM family



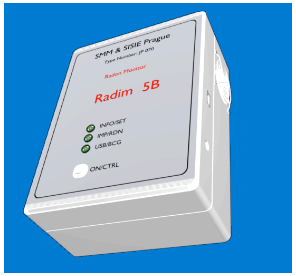


The Sputnik-like RADIM3A:

- 0.8 counts/h/Bq/m^3

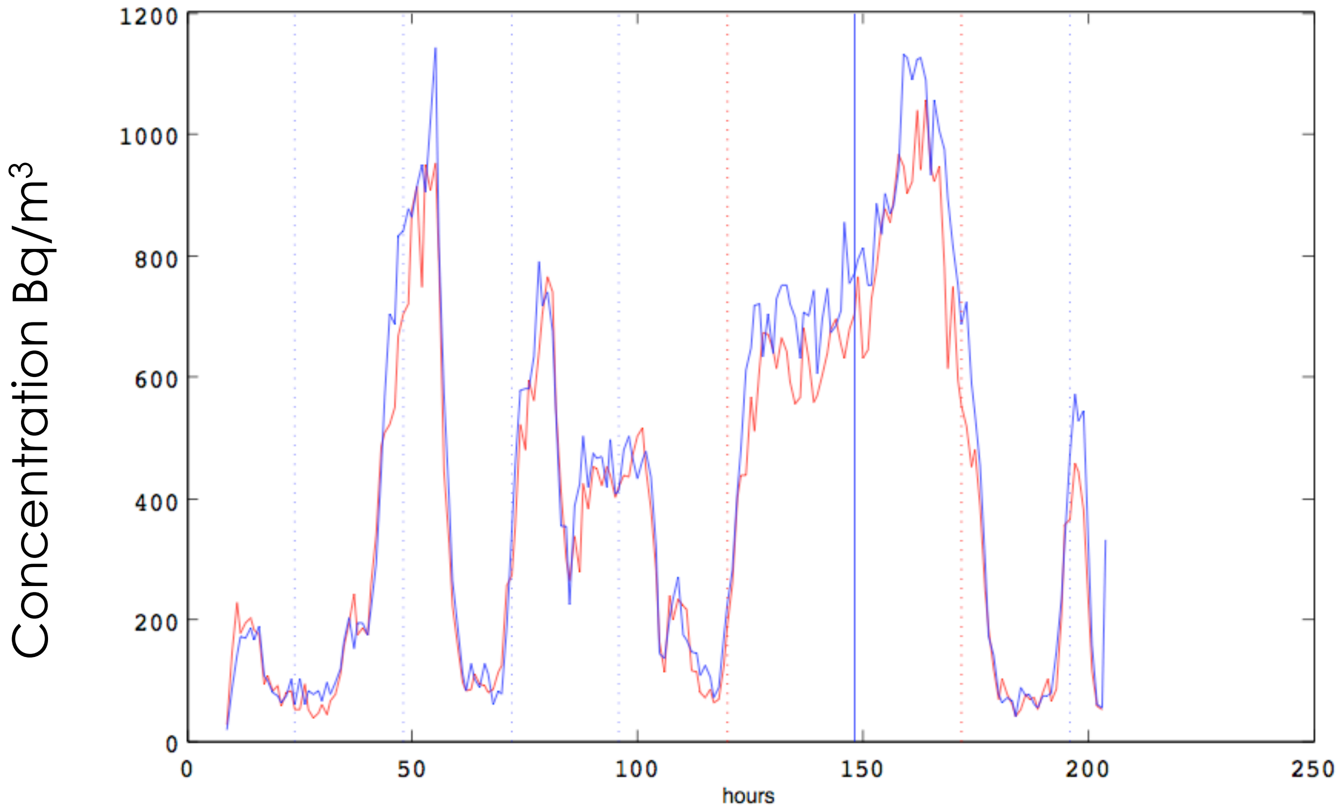
- logs also environmental parameter

- 10' time window



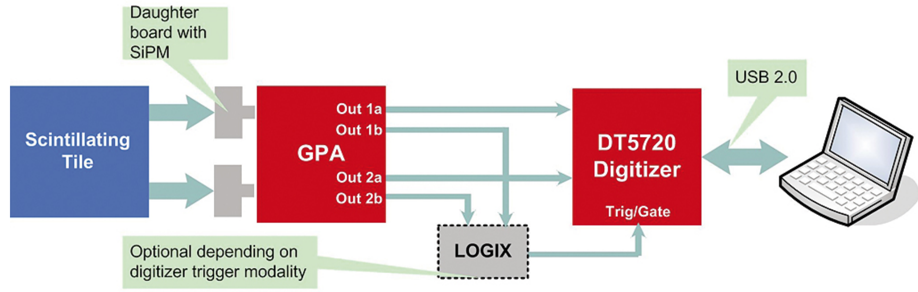
The RADIM5b:
- 0.3 counts/h/Bq/m3
- small volume Þ hourly sampling
- no environmental parameter recorded

Preliminary results from an ongoing collaboration with a Bank group

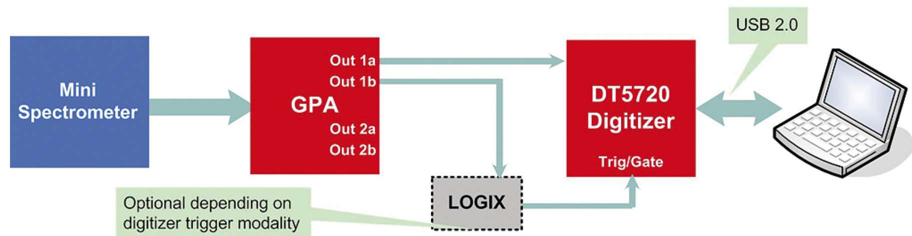


… and the best is hopefully yet to come!

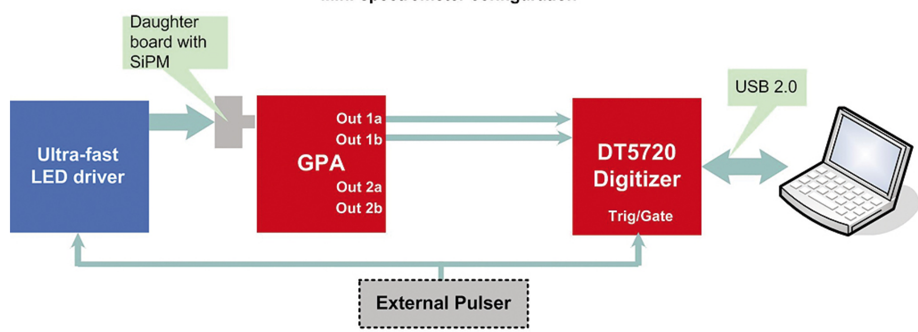
Flashing a second application: a start-up kit, developed with CAEN-Viareggio



Tile configuration



Mini-spectrometer configuration



LED pulsing, controlled by an external pulser

The General Purpose Amplifier

[data and figures refer to the prototype]

❖2 channel mother & daughter architecture

❖ every channel features a 2 stage amplification by wideband (4 GHz) amplifiers, with a tunable gain up to ~ 100

❖ active feedback control on V_{bias} for Gain stabilization (0.1 °C)

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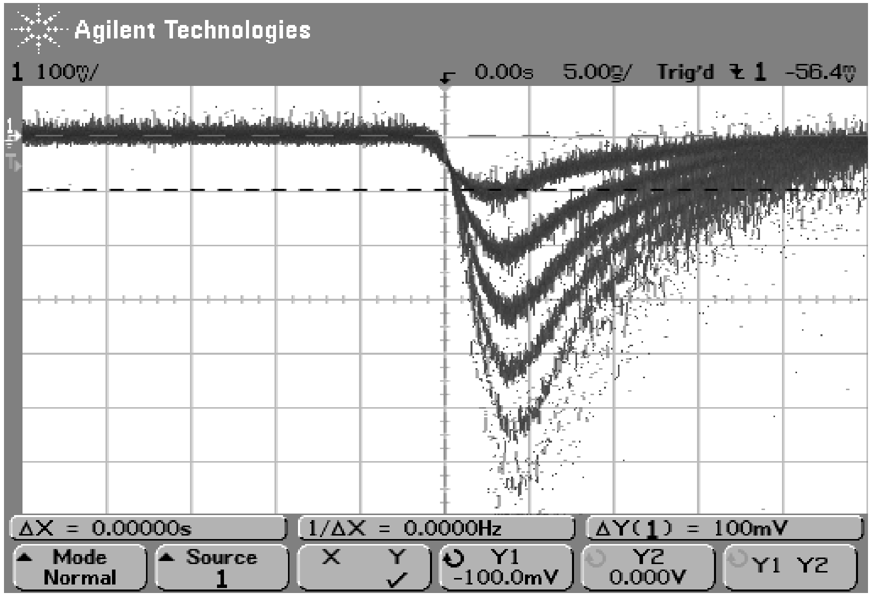

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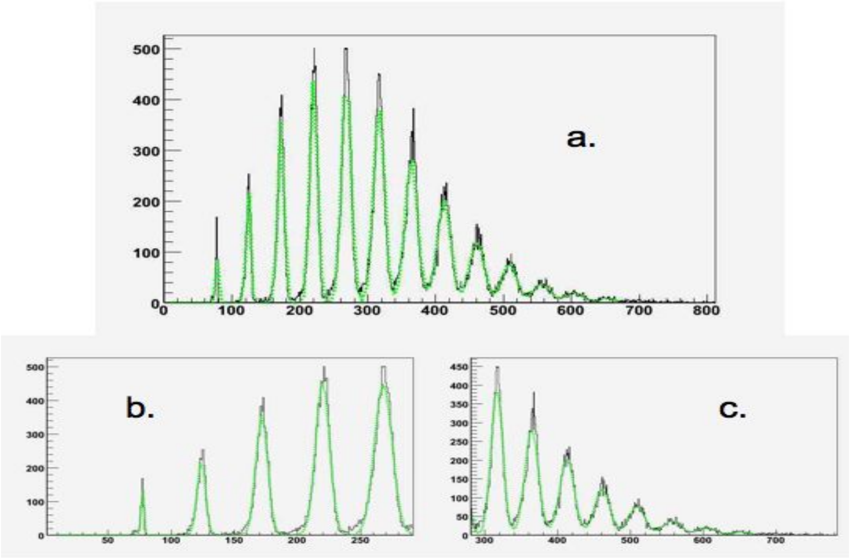

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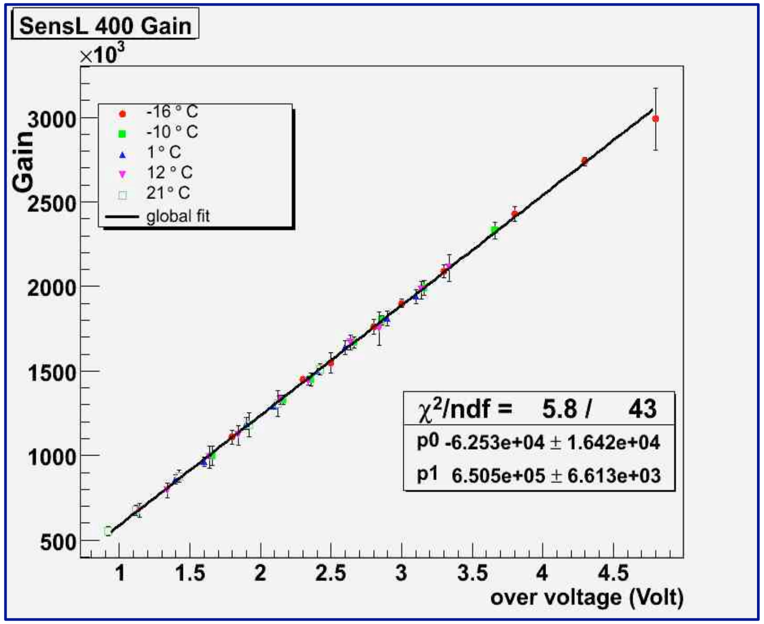


A 3 plot qualification:

Recording the signal: QDC vs Digitization

The V792N QDC

- 16 channels
- VME 6U format
- 12 bits
- 0 → 400 pC range
- granularity: 100 fC/ count

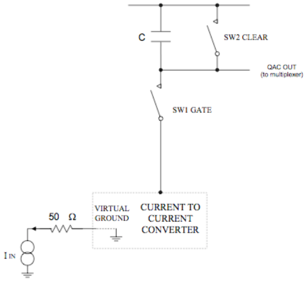
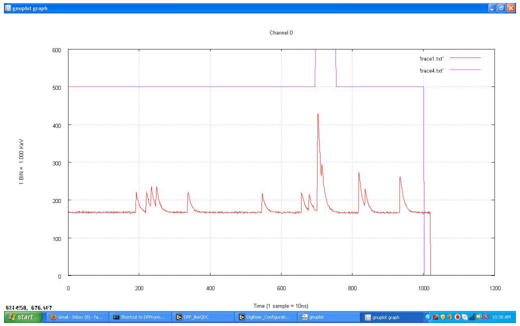


Fig. 2.1: Simplified block diagram of the QAC section

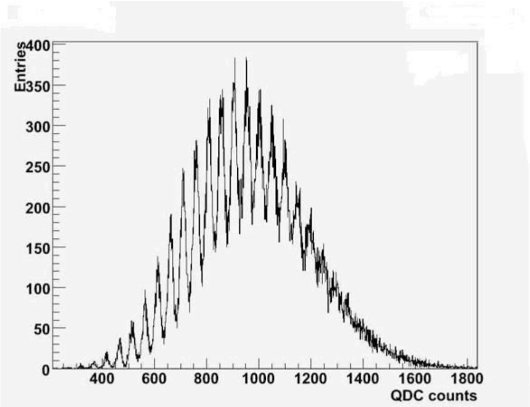
The 720 desktop Digitizer

- 2 channels
- stand-alone
- 250 Ms/s, 12 bits (up to 5 Gs/s)
- -1 → +1V range



Featuring the Digital Pulse processor

The FAST LED, an essential tool for sensor testing

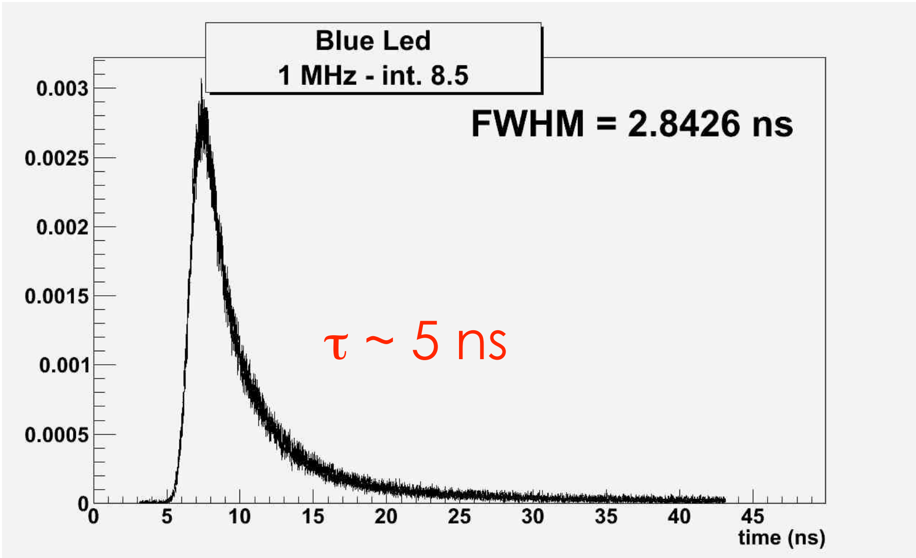


… and for your advertisement multi-photon peak spectrum (something like the LHC Media Event)

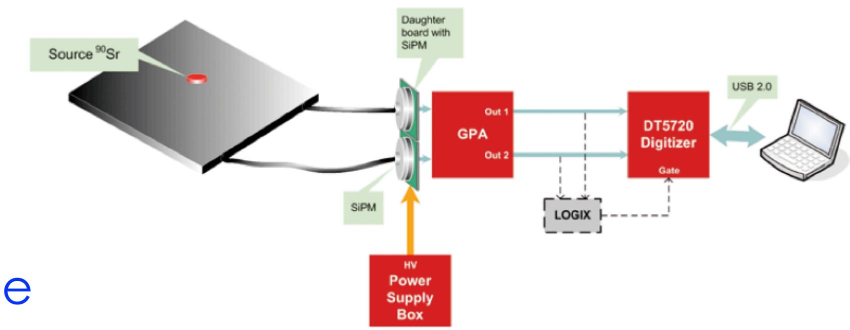
Reference LED:

- λ_{peak} = 470 ± 20 nm
- peak current 120 mA
- luminous intensity = 9500 mcd @20mA
- 30° half-view angle

Single Photon Timing spectrum

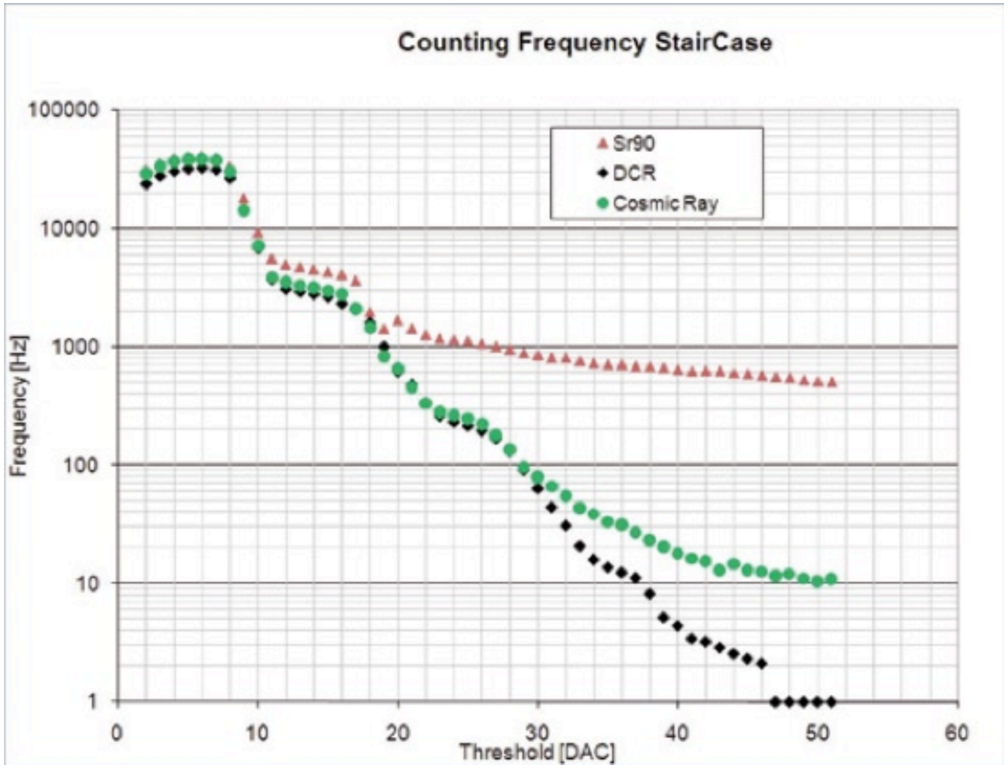


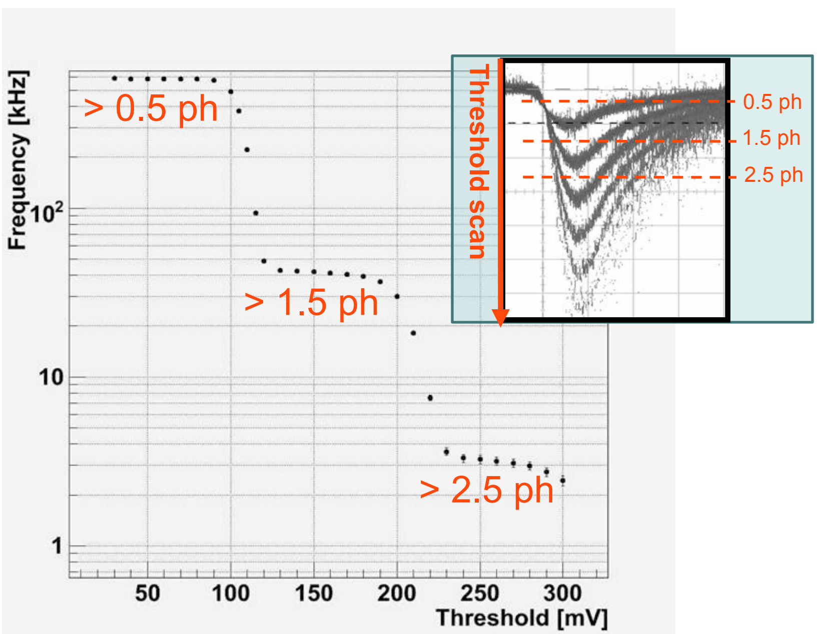
The Cosmic (ray) Tile



- 100 x 100 x 10 mm^3 plastic scintillator tile
- wls fiber => 2 channels in coincidence

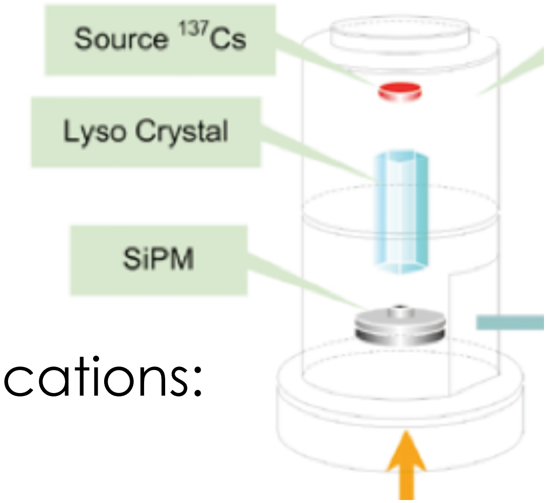
Count rate in coincidence ⇒





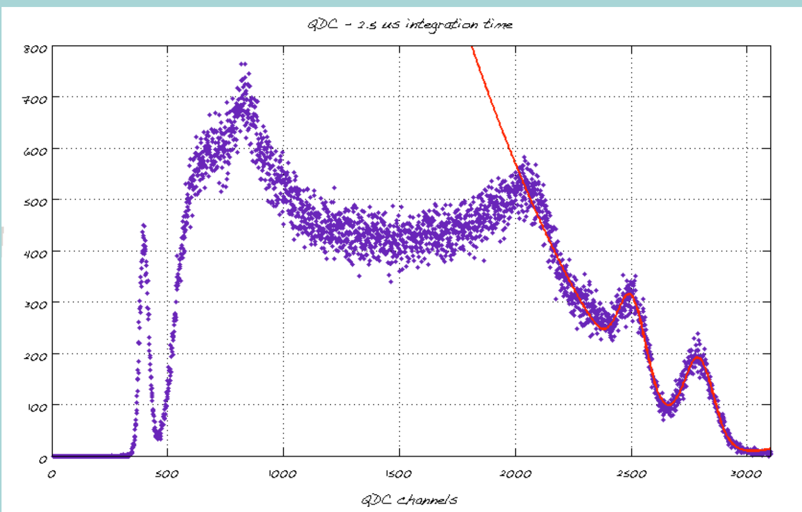
⇐ Single channel Dark Count Rate

The Gamma Ray Spectrometer



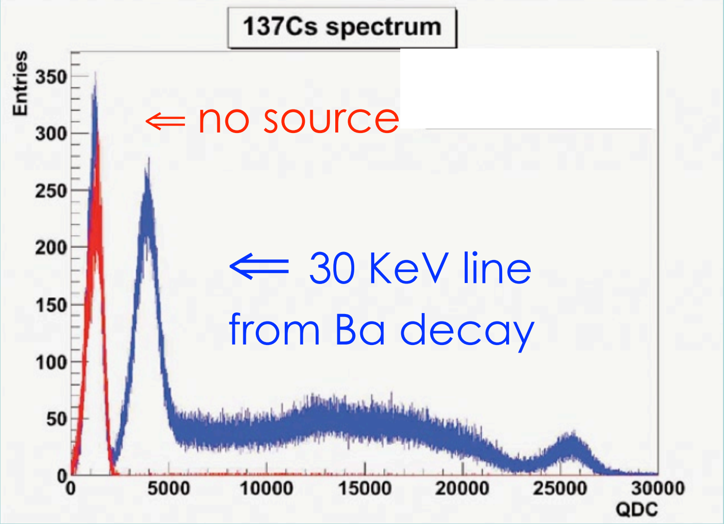
Two basic configurations, oriented to EduApplications:

- 6 x 6 mm^2 SiPM
- 1 CsI crystal, 6 x 6 x 30 mm^3



	^{137}Cs [662KeV]	^{60}Co [1.17MeV]	^{60}Co [1.33MeV]
FWHM [%]	10	6.6	5.8

- 3 x 3 mm^2 SiPM
- 3 crystals 3 x 3 x 15 mm^3 [LYSO, BGO, CsI]



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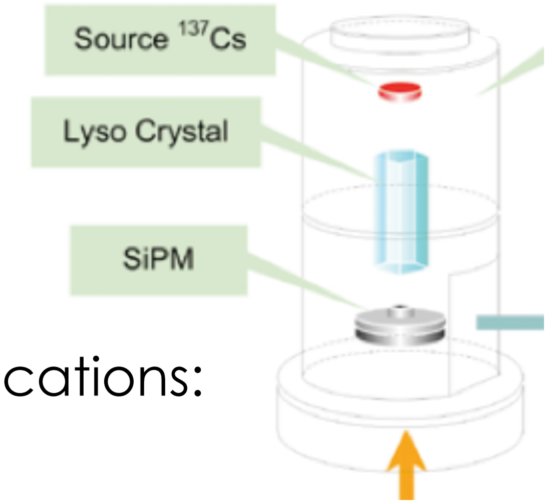

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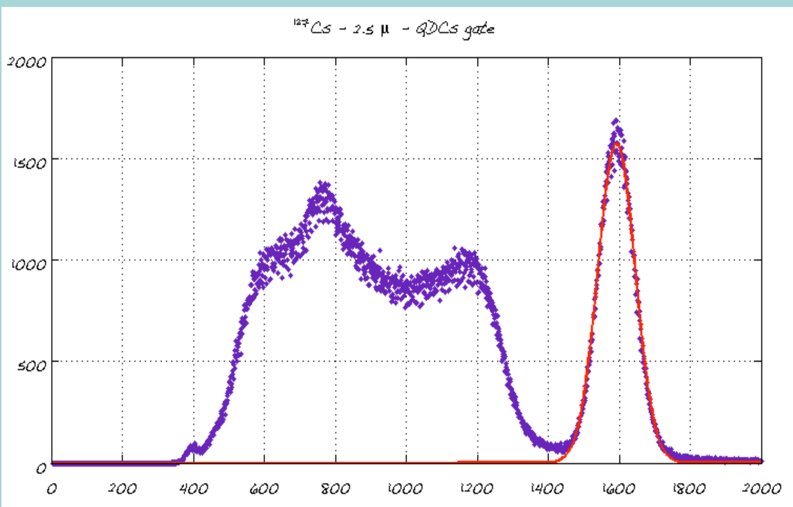

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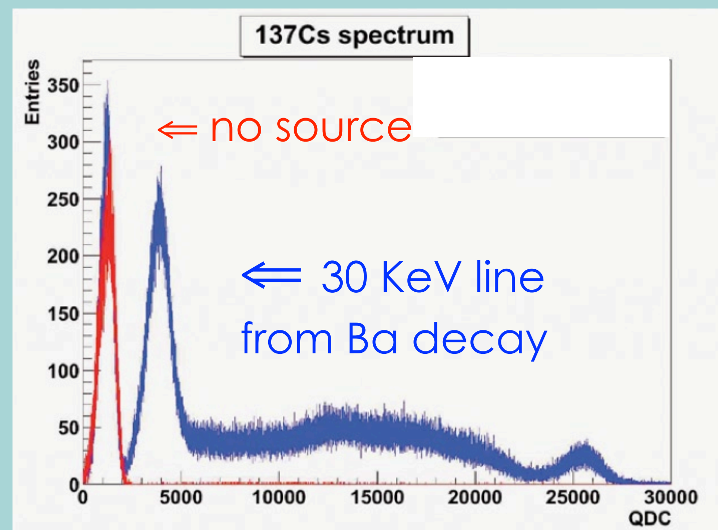
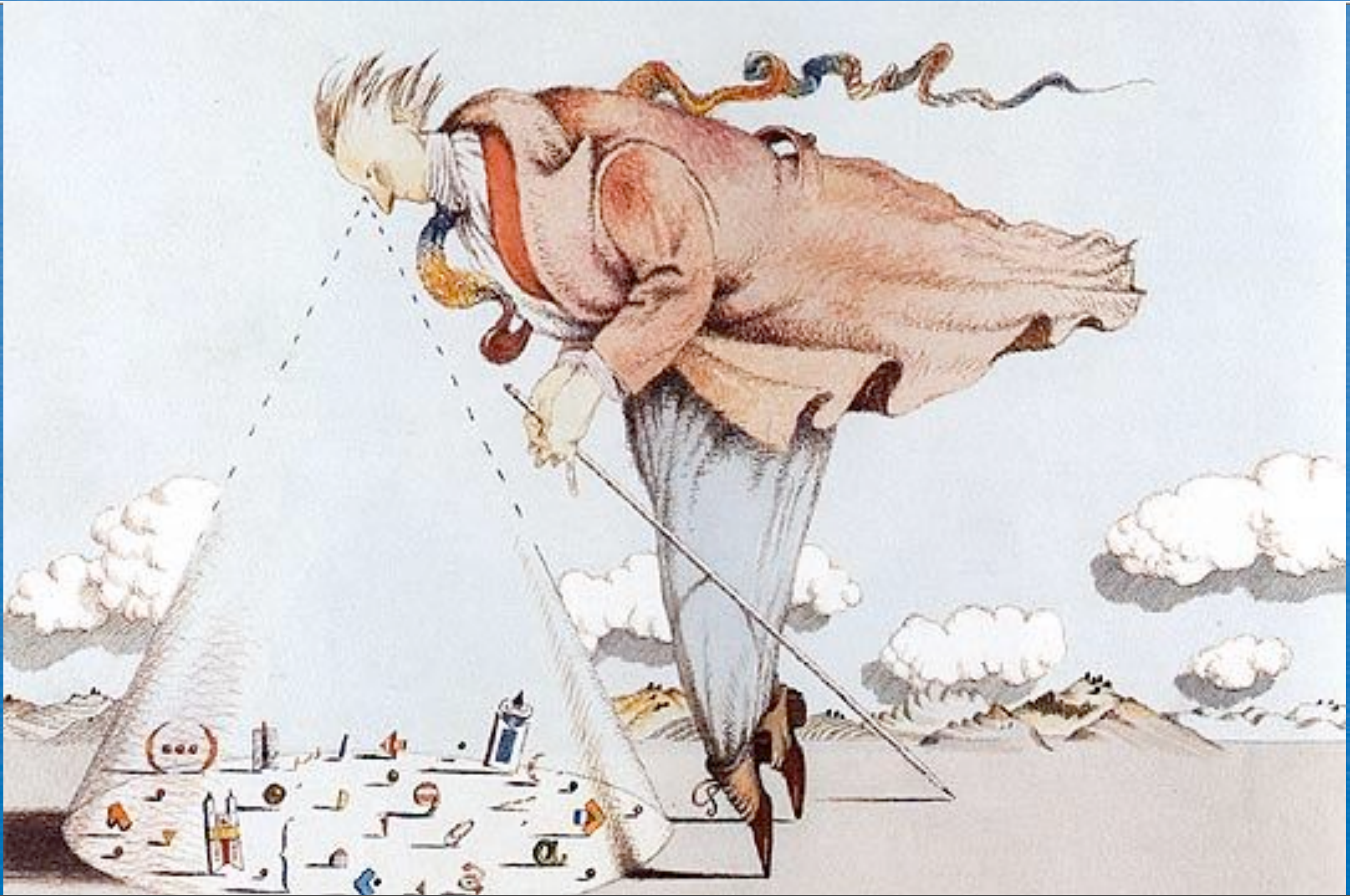


Go to the next level:

SiPM as a technology platform for collaborative research

promoted by the Technology Transfer Network, grouping a sub-set of CERN member states



A bit about the SiPM activities
Info gathering distributed on Feb.23rd, 2010
In view of organizing a matching event

a. contact details

b. main drive for the ongoing activities (likely to be an HEP R&D or experiment)

c. main expertise (e.g. ASIC design, sw development, TOF measurements, else)

d. state of the art (feasibility study, proof of principle, prototype, demonstrator, engineered product(!), else)

e. level of IP protection (honestly speaking: not such a big issue here! I'm truly convinced know-how matters most than a patent for such a project)

f. binding agreements/possible show-stoppers (e.g. ASIC development with an educational license, contracts in force with companies/other research institutions)

g. available public documents

h. pre-existing/running contacts with industries

i. companies in the wish-list.

A non-exhaustive list of feedbacks

Contact Person	Main drive	Key aspects
P. Iacobucci (Napoli) (see G. Saracino's talk)	MU-RAY, volcano radiography with cosmic muons	"large" system management: • active hybrids (+CAEN) • opto-coupling • thermal management
		Avalanche multiplication in semiconductor devices (A. Irace)
P.S. Marocchesi (Siena) (see the poster by M.G. Bagliesi)	SPIDER, SiPM in space (charge identification of cosmic nuclei)	SiPM based Cherenkov detector (proto)
		128 ch SiPM ASIC + readout board (+IDE-AS) (HDR-transimpedence)
C. Marzocca (Bari)	DA-SIPM, TOF-PET systems	8 ⇒ 32 ASIC [current buffer, twin output (HDR + fast trigger)]
MG. Bisogni (Pisa) (see G.M. Collazuol's talk)	DA-SiPM, TOF-PET systems	System aspects optimized for SiPM matrix (DAQ)
		Sensor array on a wafer (+FBK)
V. Bonvicini (Trieste)	FACTOR, calorimetry	Large system aspects

M.Ca	RAPSODI - FP6	• RADON (JPSMM) • dosimetry (PTW) (patent) • Homeland security (FORIMTECH) • start-up kit (CAEN)
W. Kucewicz (AGH-Krakow)	RAPSODI - FP6	2 ch. ASIC for homeland security application
H.G. Moser (MPI MUNICH)	Sensor development	• backside illumination (patent) • bulk resistor APD (patent)
Chiara Casella (ETH-Zurich)	Axial PET	• *New concept* • *system aspect*
Christophe de la Taille	Calorimetry at ILC	The SPIROC ASIC (36 ch, HDR; CSA + memory cells + TAC)
Erika Garutti & Felix Sefkow(DESY)	• Calorimetry @ ILC • Time resolution	No feedback yet
Pierre Jarron & Paul Lecoq	• TOF for ALICE • Crystal Clear	The NINO ASIC for TOF-PET (patent on a time based RO system)
A. Ranieri (Bari) (see A. Gabrielli's talk)	INFN specific project	A SiPM based system for prostate imaging

Who can be interested in what we are doing?

-sensor producers (e.g., HAMAMATSU, SENSL, IRST-FBK, STm)

-producers of electronics/services for OEM or dedicated general purpose modules (e.g. CAEN, Bridgeport, ORTEC...)

-companies developing Not Destructive Test systems, quite often based on X ray detection...

-companies in powder crystallography

-homeland security

-gamma spectrometry companies

-obviously medical imaging (Big and small (ClearPEM))

- disciplines other than HEP: CherenkovTelescopeArray, geologists, biologists (PCH and FCS)
- crystal companies
- in general, whoever is concerned with LIDAR and ranging

Conclusions

Do not be afraid
to look out there...