WP28 Silicon Multiplier

Seventh Framework Programme I3 – HadronPhysics3

JRA

Matrix Geiger-Mode Avalanche Micro-Pixel Photo Diodes for Frontier Detector Systems

„Silicon Multiplier“

Spokesperson: Herbert Orth, GSI Darmstadt, Germany

Objectives

Exploiting and further developing the properties of SiPM

Development of integrated electronics: preamplifier, ASIC

Larger scale integration of sensors: Arrays, Matrices

The R&D projects:

- **SiPM-based position sensitive large area photon detectors**
- **SiPM-coupled fiber detectors**
- **Ultra-fast timing with plastic scintillators using SiPMs**

Participants to WP28

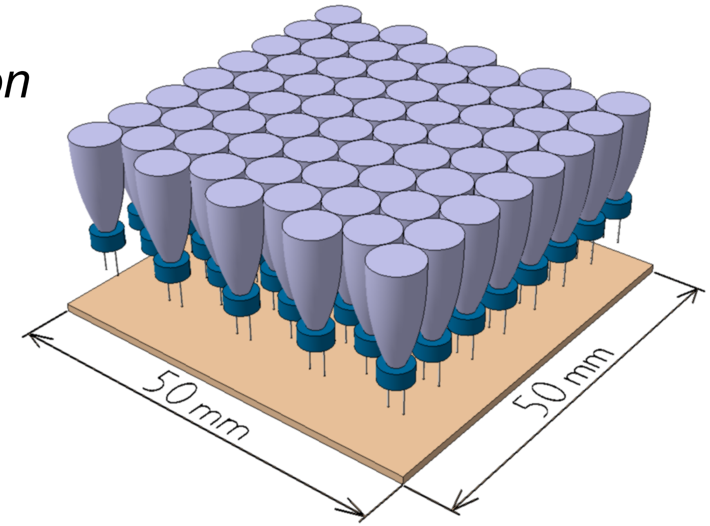
Beneficiary number	Organization legal name *(in italics the Research Units)*	Short name	Activity leaders *(in **bold** the spokesperson)*	Human effort[1] (see note below) *(person-months)*
9	Gesellschaft für Schwerionenforschung mbH	GSI	**H.Orth**	12(24)
1	Istituto Nazionale di Fisica Nucleare	INFN		24(48)
	INFN Laboratori Nazionali di Frascati	*INFN-LNF*	*C.Curceanu*	*12(30)*
	INFN Sezione di Pisa	*INFN-PI*	*A.Del Guerra*	*12(18)*
2	Oesterreichische Akademie der Wissenschaften	OeAW	J.Marton	(12)
4	Charles University in Prague	CUNI	R.Leitner	12(18)
18	Justus Liebig Universität Giessen	PIG-JLU	R.Novotny	(6)
35	Foundation Bruno Kessler	FBK		(3)
	FBK-irst	*FBK*	*C. Piemonte*	*(3)*
41	Jagiellonian University	UJ	J.Smyrski	(12)
45	Institutul National de Cercetare-Dezvoltare pentru Fizica si Inginerie Nucleara – Horia Hulubei	IFIN-HH	M.Bragadireanu	24(60)
51	University of Glasgow	UGlasgow	B.Seitz	(12)

Other involved institutions not receiving EC funds	Activity leaders	Estimated human effort involved in the WP
Institute of Nuclear Physics, Moscow (Russia)	F.Guber	(12)
Joint Institute for Nuclear Research, Dubna (Russia)	A.Olchevski	(24)
Petersburg Nuclear Physics Institute, Gatchina (Russia)	S.Belostotski	(18)
Zecotek Photonics, Zuerich (Switzerland)	Z. Sadygov	(12)
Institute for Scintillation Materials, Kharkov (Russia)	B.Gryniov	(3)
Bhabha Atomic Research Center, Mumbai (India)	S.Kailas	(12)
Inst. of Solid State Physics, RAS, Chernogolovka, Russia	V. Kurlov	(3)
Laboratory for High Energy Physics, Bern, Switzerland	I.Kreslo	(6)

T1: SiPM-based position sensitive large area photon detector

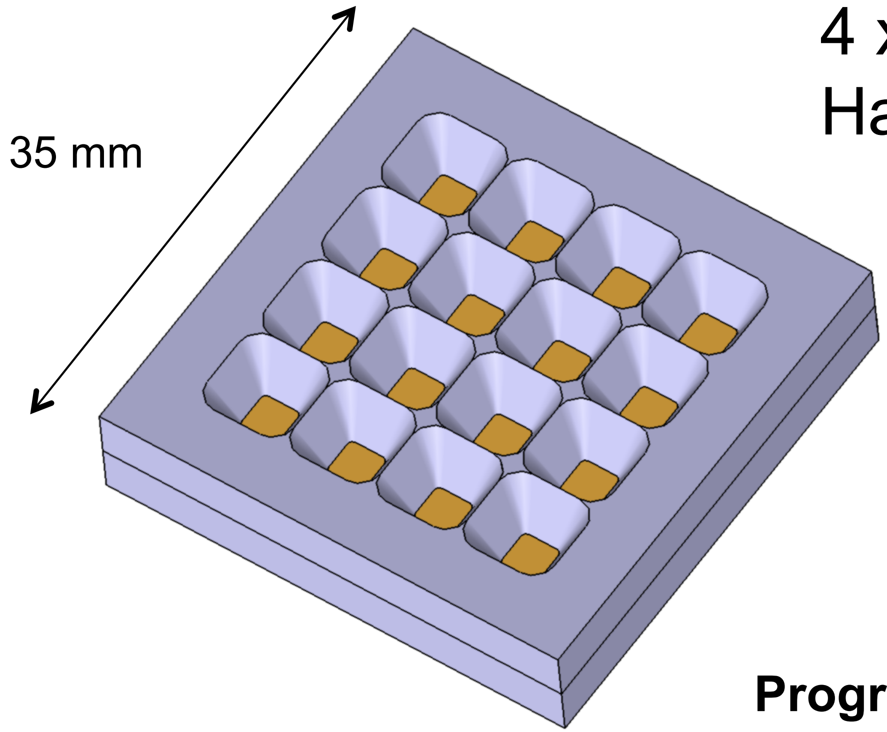
Important parameters of SiMP for very low light level detection:

- *Large PDE and large area coverage*
- *small pixel granularity and large pixel size*
- *Fast single photon response for time resolution*
- *Working in high magnetic field*
- *No aging due to accumulated anode currents*



R&D: Large SiPM sensor matrix for coincident photons (e.g. Cherenkov radiation)

Large area sensor with light catcher 4x4



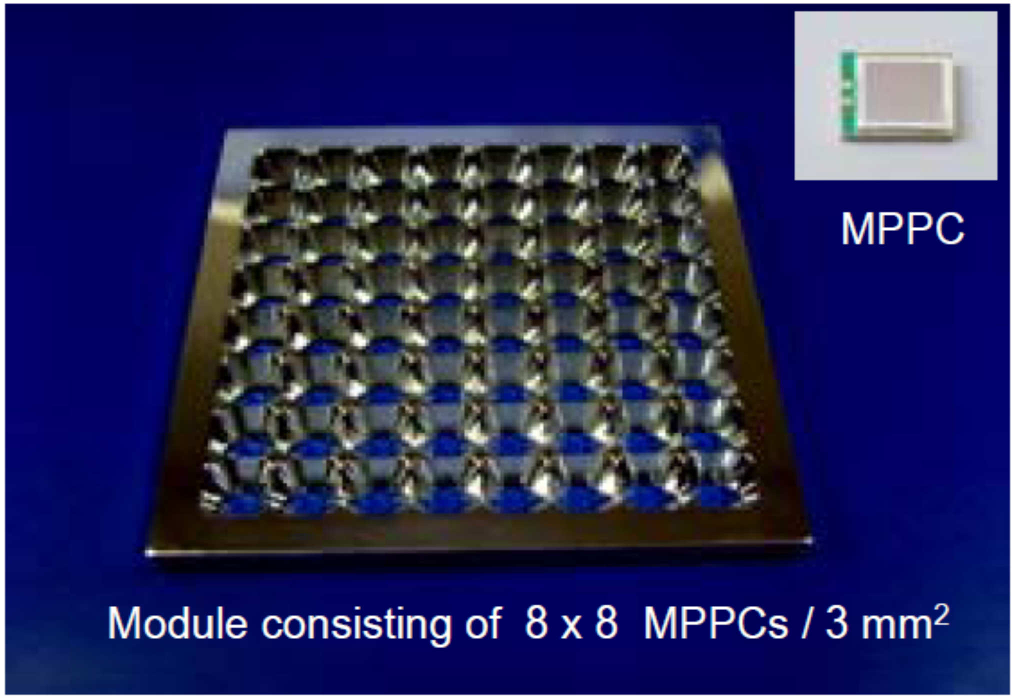
4 x 4 matrix
Hamamatsu 33-050C

Program for HP2

Readout board for 16 channel matrix
- INFN preamplifiers
- INFN power supplies
- Trigger electronic using NINO chip

Large area sensor with light catcher 8x8

Development of the light-catcher matrix
High photon detection efficiency
Good timing at single and few photon level
Cooling
Study with naked sensors (without resin coverage)
Electronics integration
Majority filter implemented



First design for
present version of 3x3 mm MPPCs

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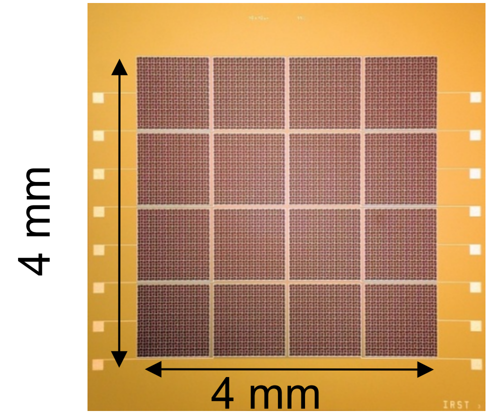
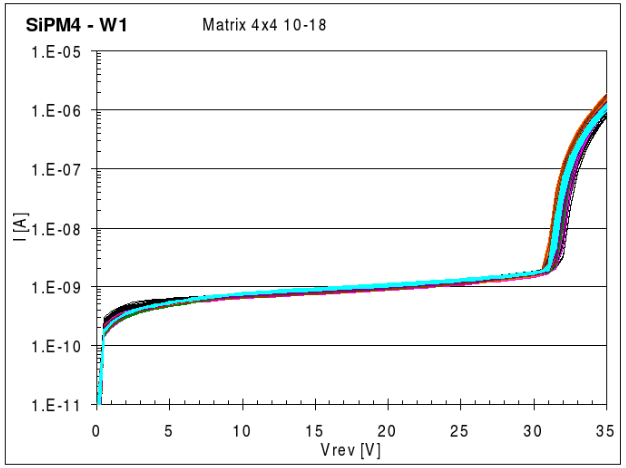
Large area open 8x8 sensor matrix

MATRICES VERY UNIFORM BREAKDOWN POINT

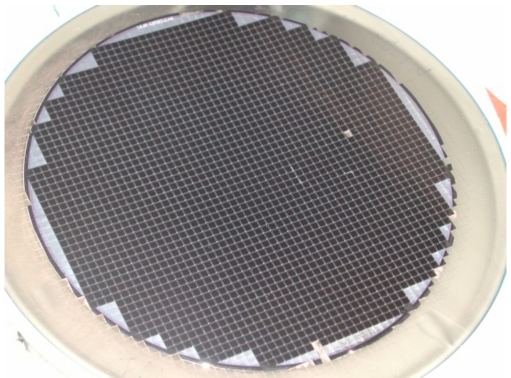
FBK-irst

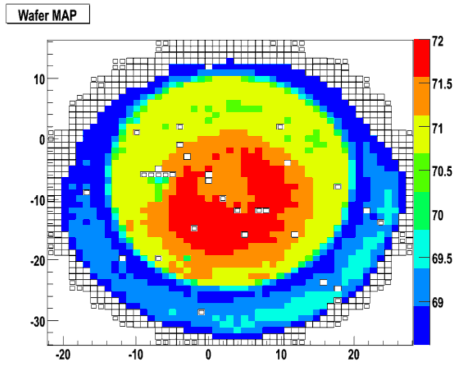


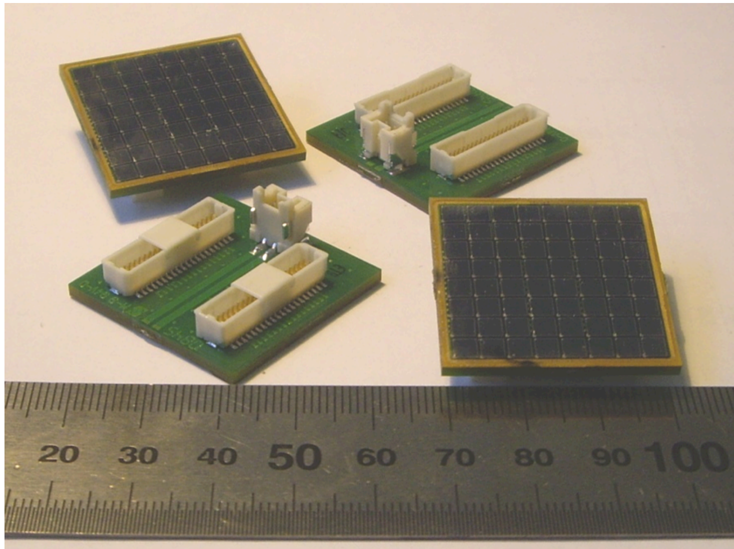


Matrices 16 elements (4x4)
Matrices 64 elements(8 x 8) soon available

Zecotek MAPD







Built at Dubna

Workplan fo Task 1

TASKS/Subtasks	**2012**				**2013**				**2014**			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Cherenkov light detection with Single photon readout												
1.1 Construction of different 64 channel light catchers												
1.2 Selection of the SiPM sensor with dedicated preamplifier					1							
1.3 Read-out electronics with implementation of majority filter							2					
1.4 Tests with pulsed laser source								3				
1.5 Tests with Cherenkov radiator												4
1.6 Study of 64 pixel sensor matrix from Zecotek												5

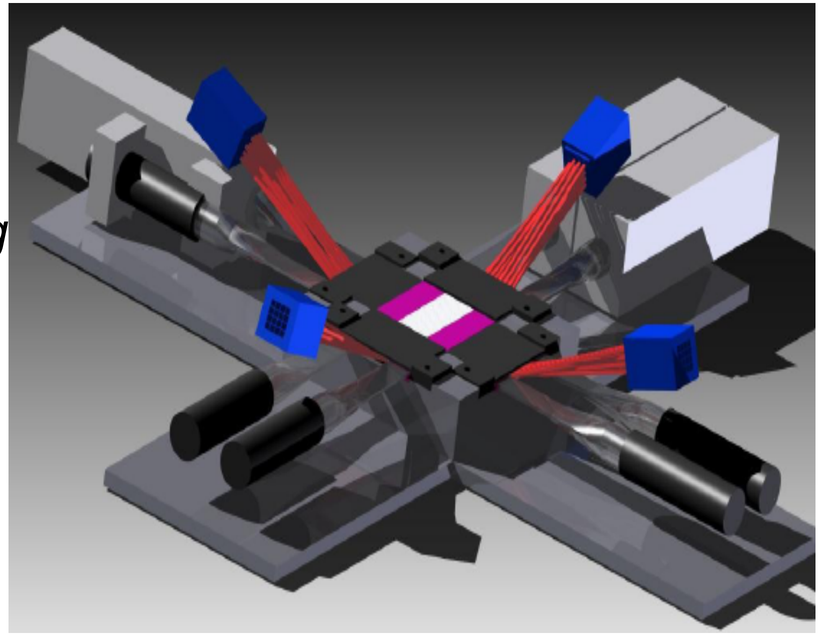
Milestones

1 SiPM and preamplifier selected
2 DAQ with coincident Photon trigger implemented
3 Report of laser test
4 Report of beam tests
5 64 pixel sensor matrix tested

T2a: Read-out of crystalline fibers with SiPM

Important parameters of SiMP coupled to inorganic fibers:

- *Small sensor area high PDE (>30 %)*
- *High granularity for good linearity*
- *Fast single photon response for good timing*
- *Working in high magnetic field*
- *Noise performance uncritical*



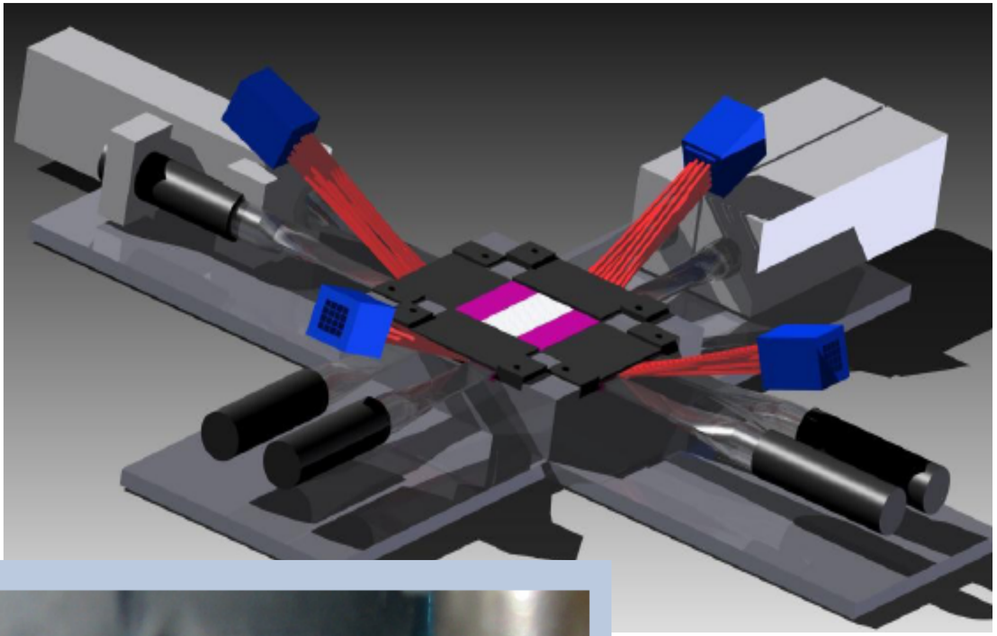
R&D: Planar Beam Monitor

Closely together with WP21 SciFI

YAG:Ce

Detector Applications (WP21)

e⁻ / γ beam monitor
(Bonn)

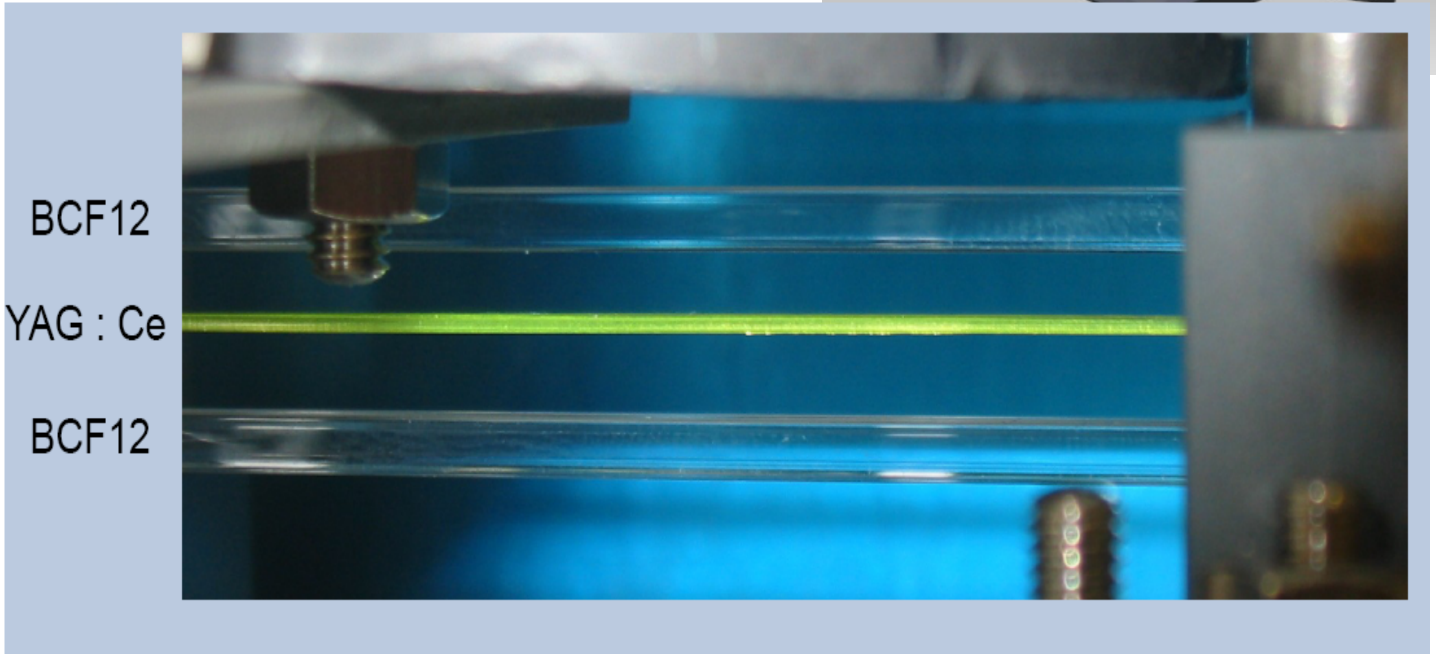


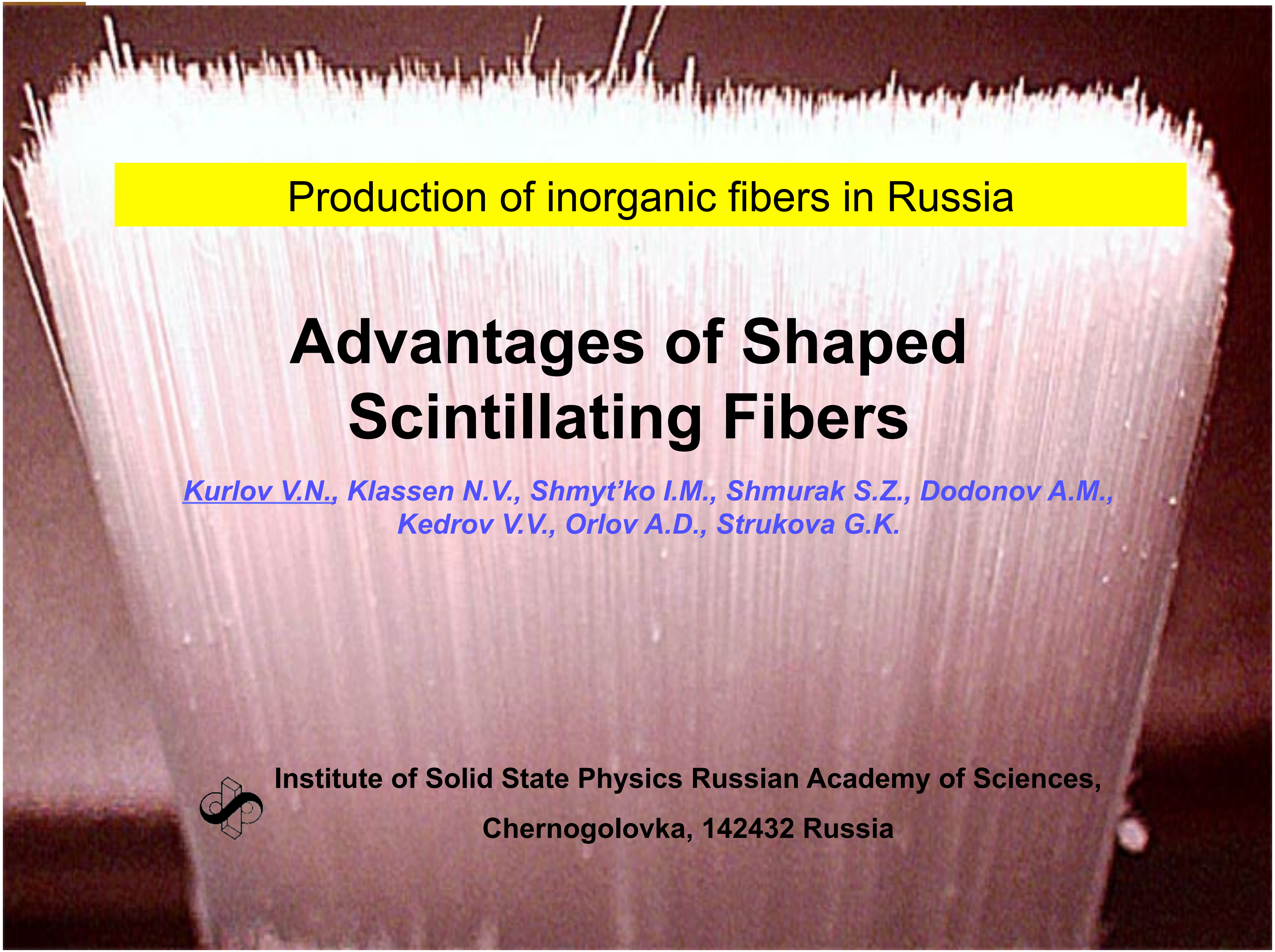
two times two crossed layers:

1st: square organic fibers

2nd: round inorganic fibers

readout via SiPM





Production of inorganic fibers in Russia

Advantages of Shaped Scintillating Fibers

Kurlov V.N., Klassen N.V., Shmyt'ko I.M., Shmurak S.Z., Dodonov A.M., Kedrov V.V., Orlov A.D., Strukova G.K.

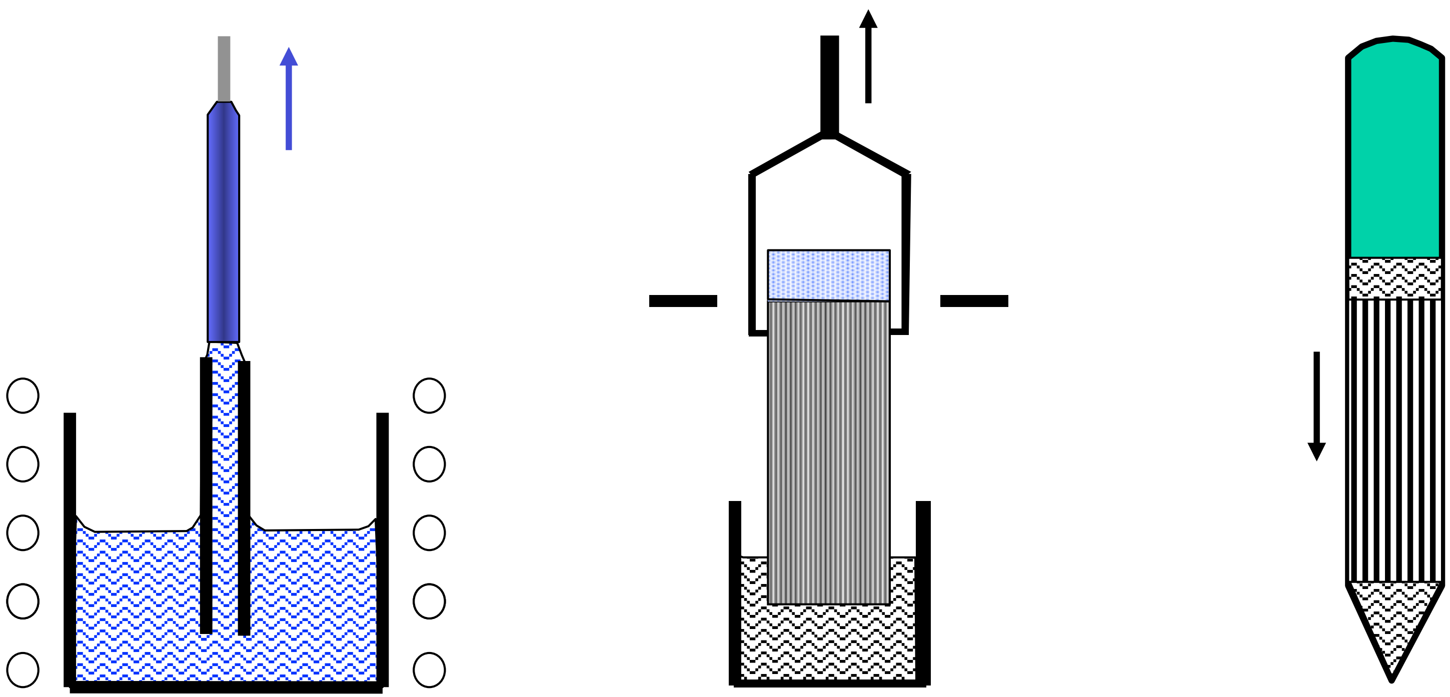
Institute of Solid State Physics Russian Academy of Sciences,

Chernogolovka, 142432 Russia

Growth techniques at ISSP (RAS)

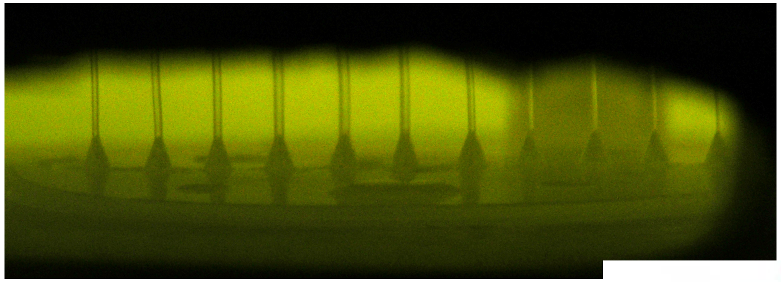
different from FiberCrist

- Stepanov/EFG
- Internal crystallization method
- Modified Bridgman

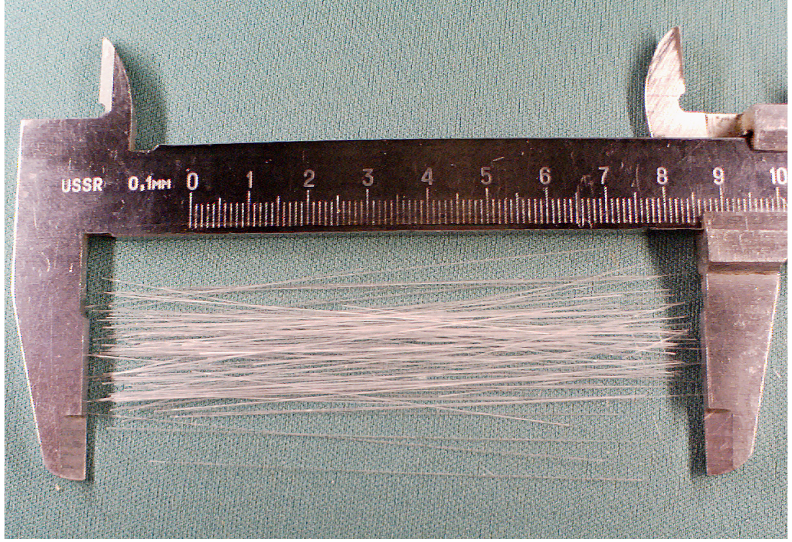


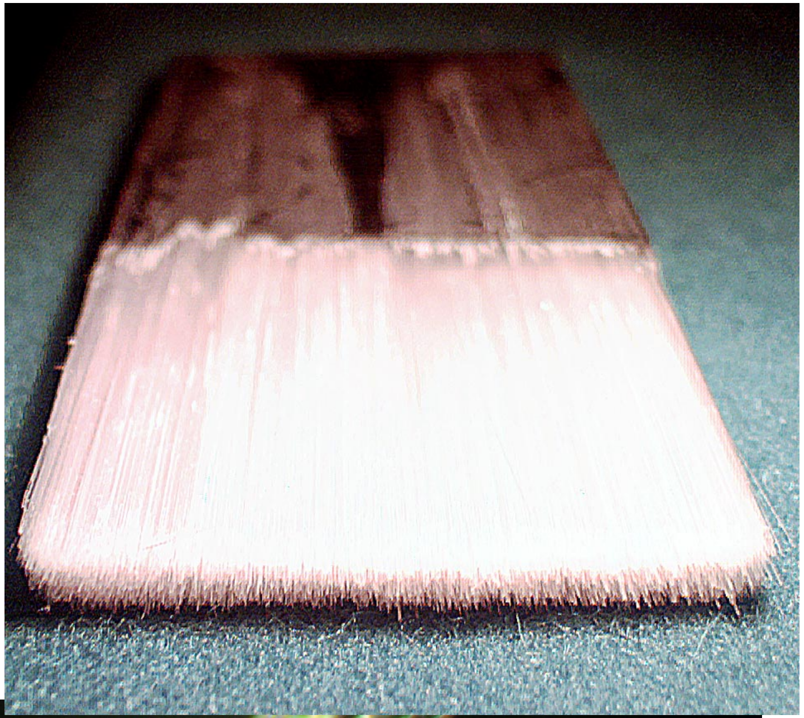
Institute of Solid State Physics RAS

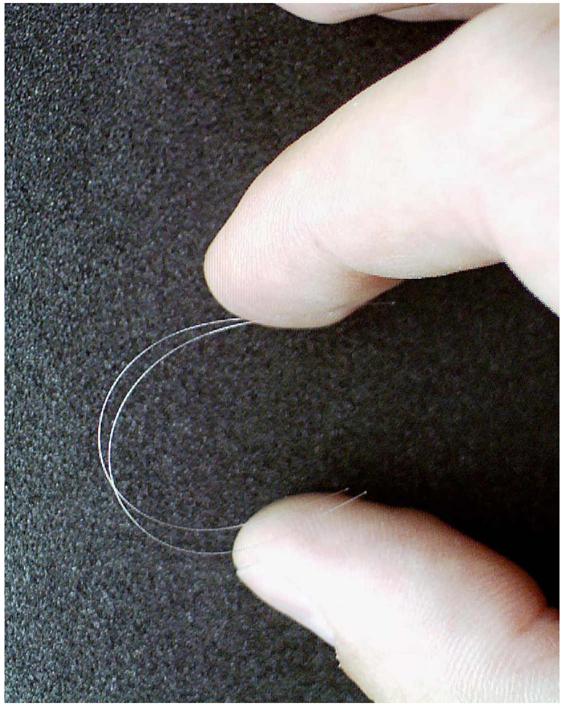
Fiber Pulling Machines at ISSP, Chernogolovka

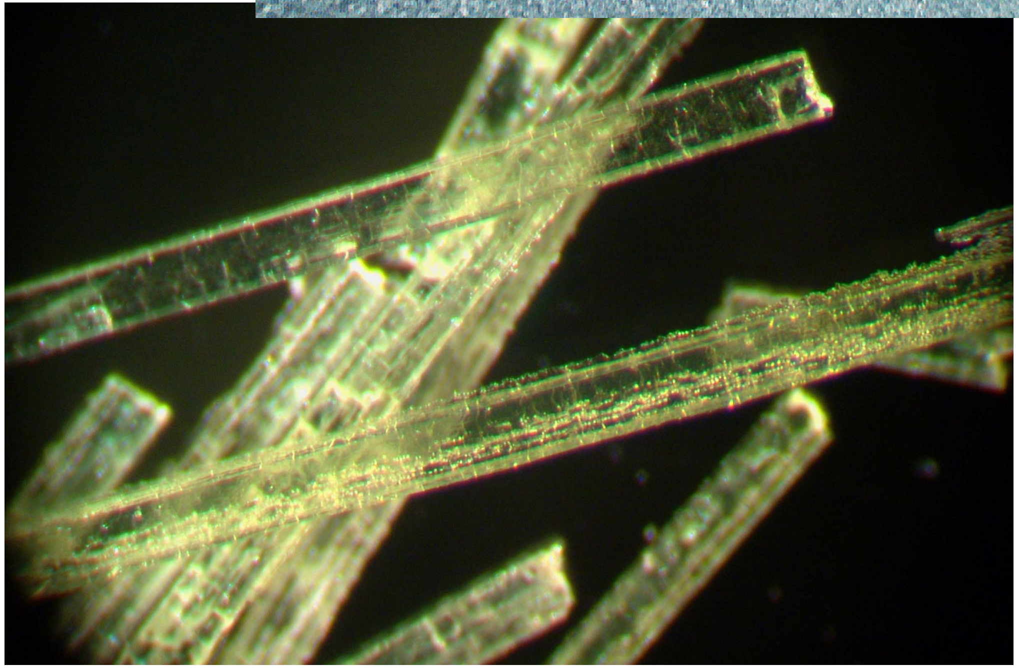


Sapphire

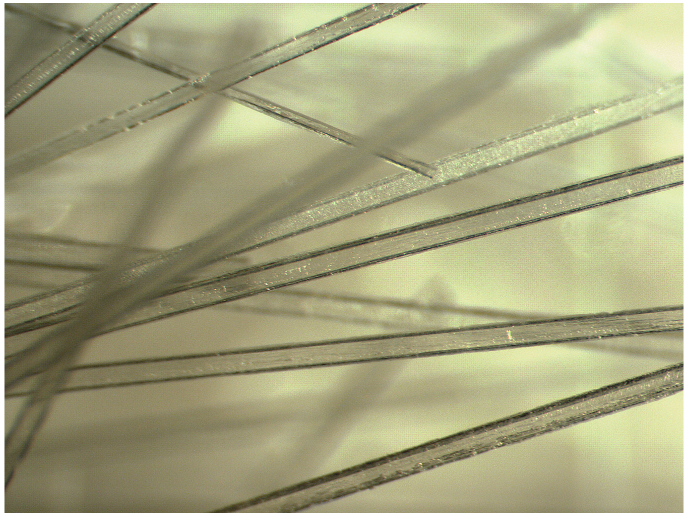

USSR
0,1MM
0 1 2 3 4 5 6 7 8 9 10



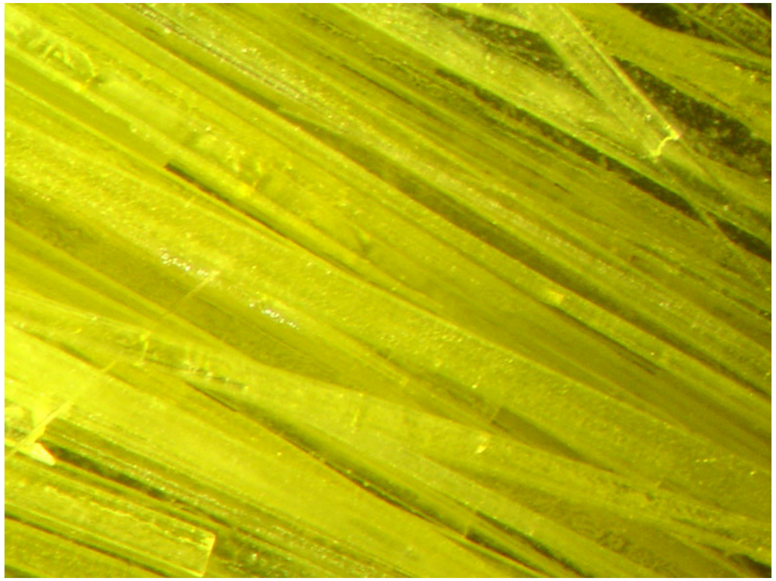




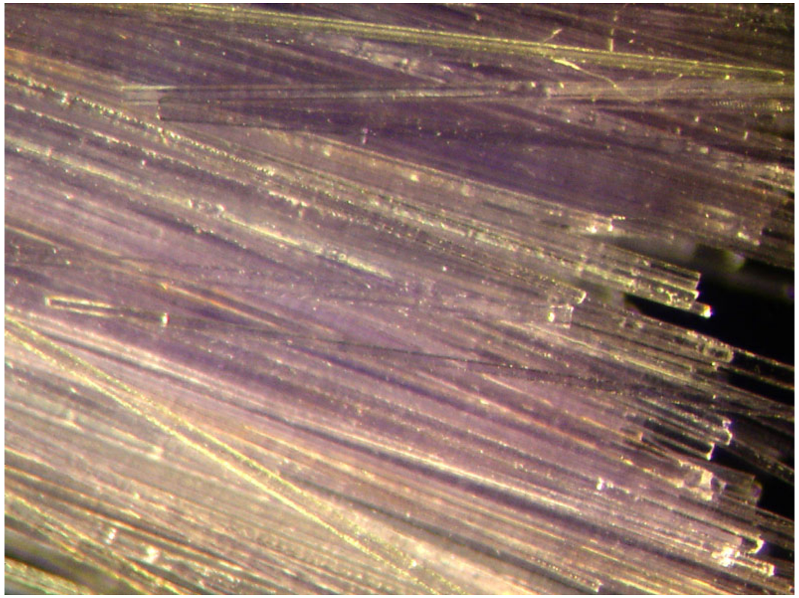
YAG



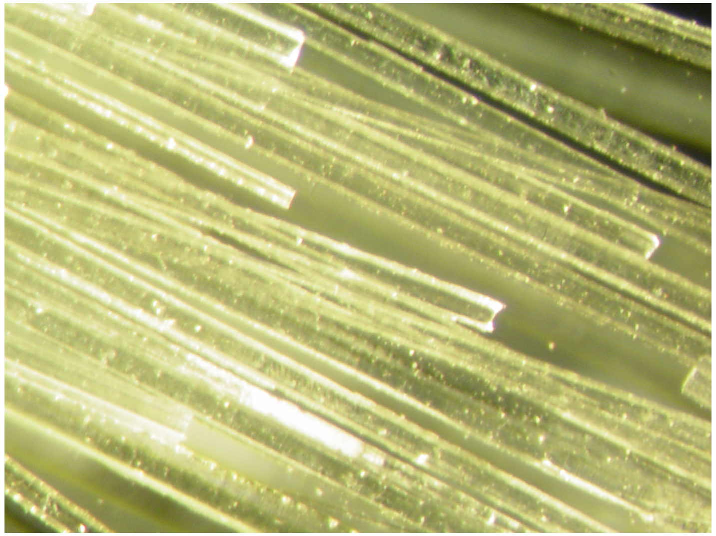
undoped



Ce



EU



Tb

Workplan fo Task 2 (inorganic fibers)

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TASKS/Subtasks	2012				2013				2014			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
2. SiPM-coupled advanced fiber detectors												
2.1 SiPM for LYSO- fiber material selected and tested				6								
2.2 Inorganic fibers from Institute for Solid-State Physics, Russia												
2.3 Design of a 4 layers compact prototype for trigger/tracker				7								
2.4 Development of multi-channel highly stabilized SiPM power supplies												
2.5 Construction and tests of multi-channel integrated read-out electronics												
2.6 Prototype construction									8			
2.7 Test and characterization (in laboratory and on beams) of the prototype												9
2.8 Materials tests and read-out chip design for Shashlik calorimeter												
2.9 Production of the chip with samples tests								10				
2.10 Demonstration of in the calorimeter module												11

Milestones

6 Readiness of SiPM for LYSO fibers
7 Design of compact trigger/tracker
8 Prototype ready
9 Report about tests in beam
10 Read-out chip for fiber bundle ready
11Test of integrated electronics in Shashlik module

T2b: SiPM-coupled advanced scintillating fiber detector

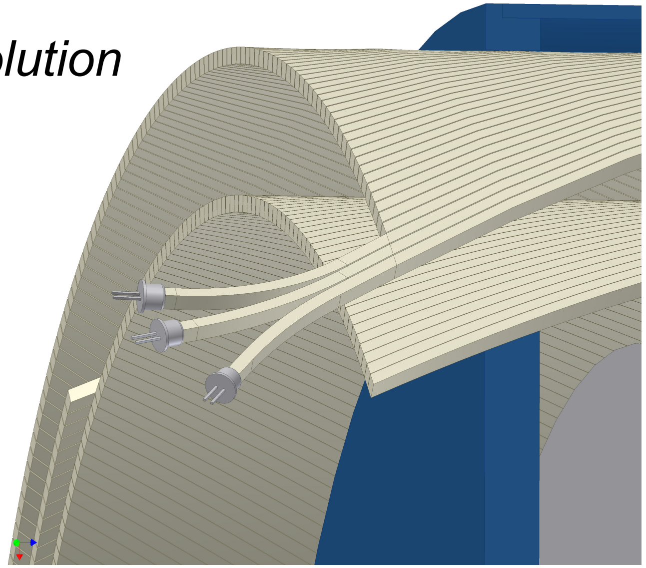
Important parameters of SiMP for low light level detection:

•*Large pixel area for high PDE (> 30 %)*

•*Medium granularity for good linearity and without saturation*

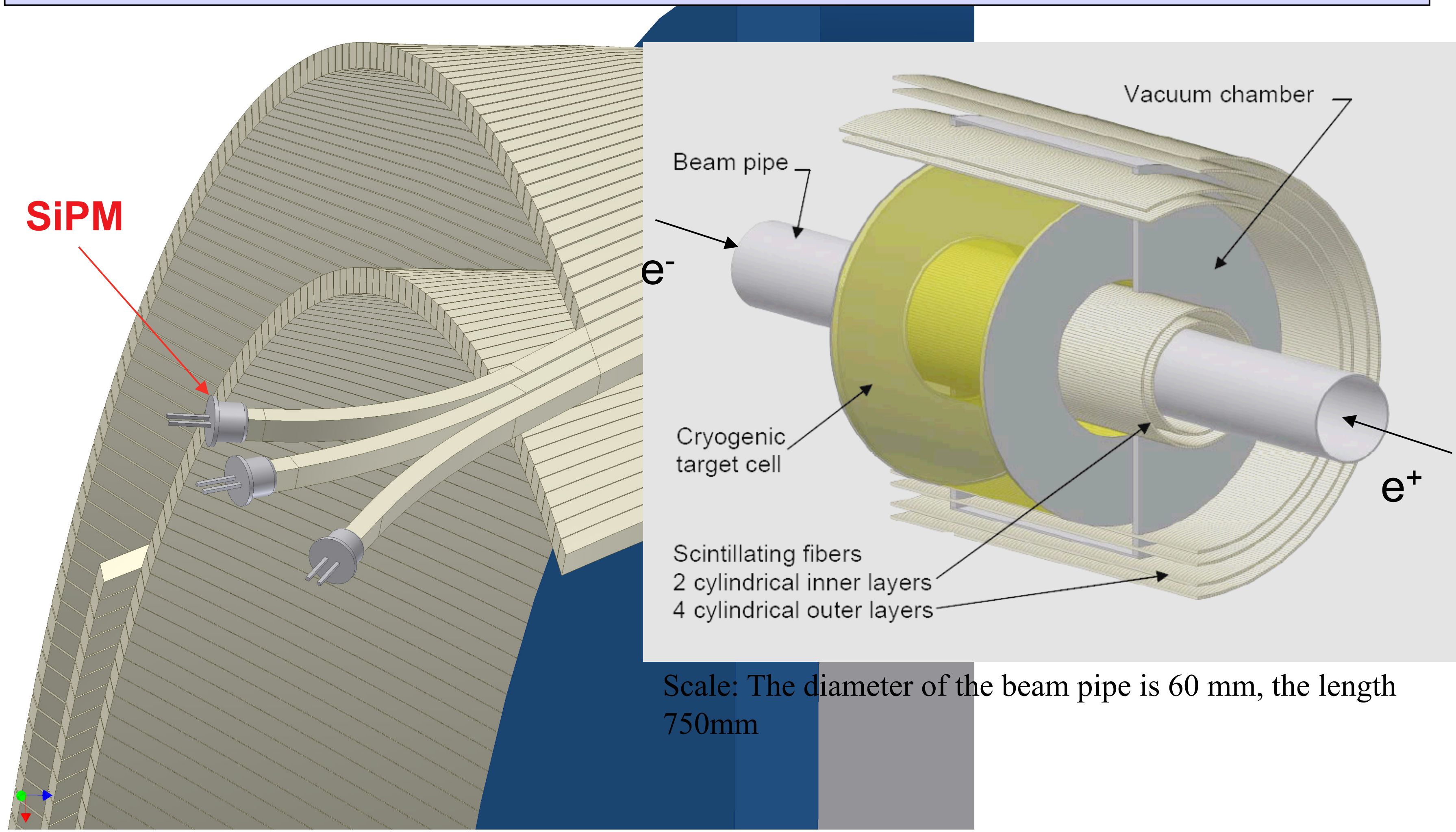
•*Fast single photon response for good time resolution*

•*Working in high magnetic field*



R&D: Prototype for Amadeus central fiber tracker

AMADEUS fiber tracker within KLOE



Scale: The diameter of the beam pipe is 60 mm, the length 750mm

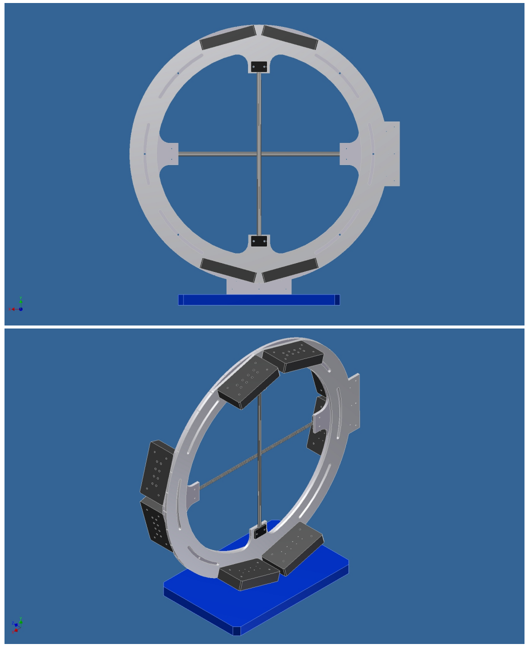
Trigger and tracker systems coupled to SiPM

Prototype of a trigger/tracker system based on 4 layers of 30 scintillating fibers

R&D

- Integrated read-out electronic, with timing resolution of around 100 ps.
- Sensor bias feed-back system with stabilization of the SiPM working point
- Correcting for temperature and gain variations.
- Compact and integrated power supplies with stability in the order of 10 mV.
- Test of the prototype in the presence of strong magnetic fields.

Leading institutions:
LNF-INFN and OeAW. IFIN-HH



Ring system
for a versatile
protototype

Workplan fo Task 2 (organic scintillating fibers)

TASKS/Subtasks	2012				2013				2014			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
2. SiPM-coupled advanced fiber detectors												
2.1 SiPM for LYSO- fiber material selected and tested				6								
2.2 Inorganic fibers from Institute for Solid-State Physics, Russia												
2.3 Design of a 4 layers compact prototype for trigger/tracker				7								
2.4 Development of multi-channel highly stabilized SiPM power supplies												
2.5 Construction and tests of multi-channel integrated read-out electronics												
2.6 Prototype construction									8			
2.7 Test and characterization (in laboratory and on beams) of the prototype												9
2.8 Materials tests and read-out chip design for Shashlik calorimeter												
2.9 Production of the chip with samples tests								10				
2.10 Demonstration of in the calorimeter module												11

Milestones

7 Design of compact trigger/tracker
8 Prototype ready
9 Report about tests in beam
10 Read-out chip for fiber bundle ready
11Test of integrated electronics in Shashlik module

T2c: SiPM for fast calorimetry

Important parameters of SiMP for high light level:

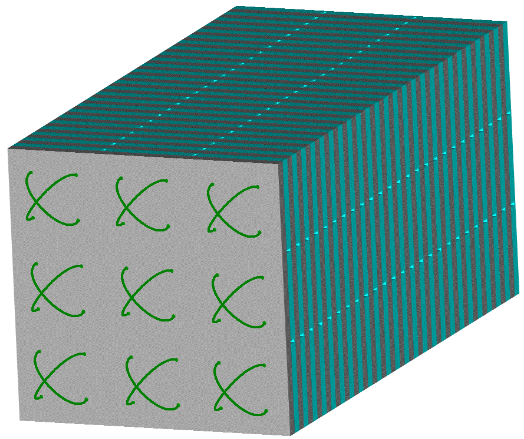
•*Small sensor area with high PDE (30 %)*

•*Large pixel number for good linearity and avoiding saturation*

•*Fast response for good time resolution*

•*Working in high magnetic field*

•*Sensor noise uncritical*



R&D: SiPM for Shashlik modul in COMPASS
Hybrid chip design for

Electromagnetic-Calorimetry with wavelength shifting fibers

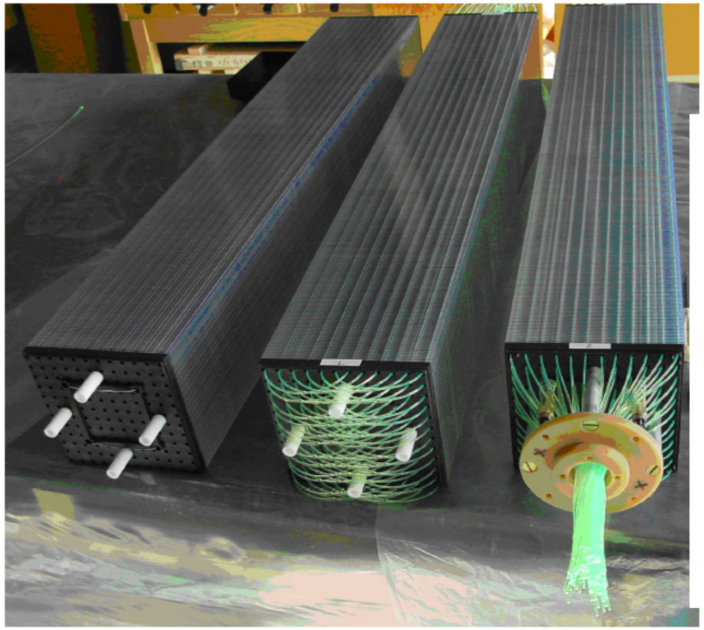
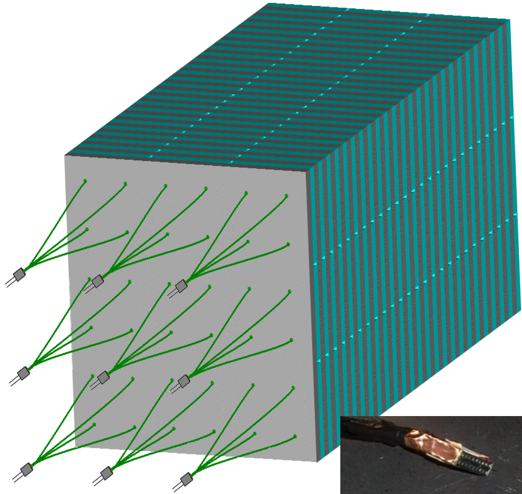
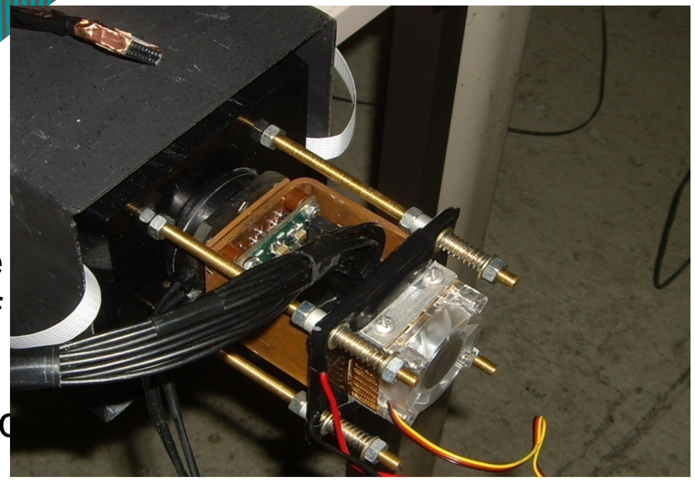


Fig. 1. The Shashlyk modules at different stages of assembly



MAPD3N sensors
+Winston cones



High dynamic range ~ 10^5 ph.e.

After the construction and demonstration of the optical head in a Shashlik calorimeter module (HP2), work will be concentrated on the integrated design and construction of 3x3 MAPD matrix with light concentrators, temperature stabilization and preamplifiers. The idea is to have a hybrid chip (~15x15 mm) made of non-resistive but heat-conductive material with one Peltier element on the back, 3x3 MAPD with Winston cones at the face and possibly also preamplifiers.

Institutions: JINR, CUNY, Zecotek Photonics.

Workplan fo Task 2 (wavelength shifting fibers)

TASKS/Subtasks	2012 Q1	2012 Q2	2012 Q3	2012 Q4	2013 Q1	2013 Q2	2013 Q3	2013 Q4	2014 Q1	2014 Q2	2014 Q3	2014 Q4
2. SiPM-coupled advanced fiber detectors												
2.1 SiPM for LYSO- fiber material selected and tested	■	■	■	6								
2.2 Inorganic fibers from Institute for Solid-State Physics, Russia	■	■	■	■	■	■	■	■	■	■	■	■
2.3 Design of a 4 layers compact prototype for trigger/tracker	■	■	■	7								
2.4 Development of multi-channel highly stabilized SiPM power supplies	■	■	■	■	■	■						
2.5 Construction and tests of multi-channel integrated read-out electronics			■	■	■	■						
2.6 Prototype construction					■	■	■	■	8			
2.7 Test and characterization (in laboratory and on beams) of the prototype									■	■	■	9
2.8 Materials tests and read-out chip design for Shashlik calorimeter	■	■	■	■								
2.9 Production of the chip with samples tests				■	■	■	■	10				
2.10 Demonstration of in the calorimeter module								■	■	■	■	11

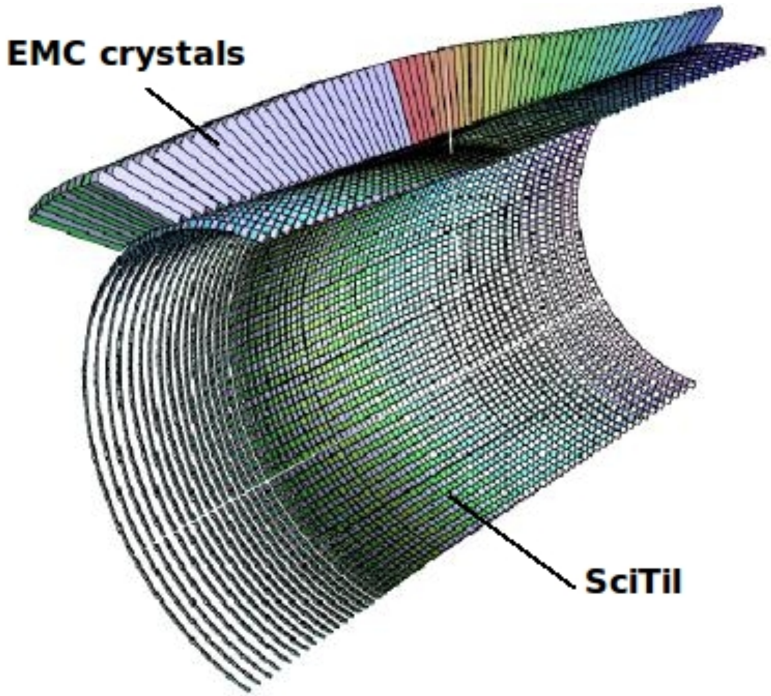
Milestones

1 SiPM and preamplifier selected
2 DAQ for photon trigger implemented
3 Report of laser test
4 Report of beam tests
5 64 pixel sensor matrix tested
6 Readiness of SiPM for LYSO fibers
7 Design of compact trigger/tracker
8 Prototype ready
9 Report about tests in beam
10 Read-out chip for fiber bundle ready
11Test of integrated electronics in Shashlik module

T3:Ultra-fast timing with plastic scintillators for Timing applications using SiPMs

Important parameters of SiMP:

- *Large area for high PDE (>30 %)*
- *High granularity for good linearity*
- *Working in high magnetic field*
- *Temperature stabilization*
- *Fast single photon response for extrem*
- *time resolution*



R&D: Scintillating fiber hodoscope for PANDA

SiPM-coupled scintillator panel for TOF wall

PANDA Detector

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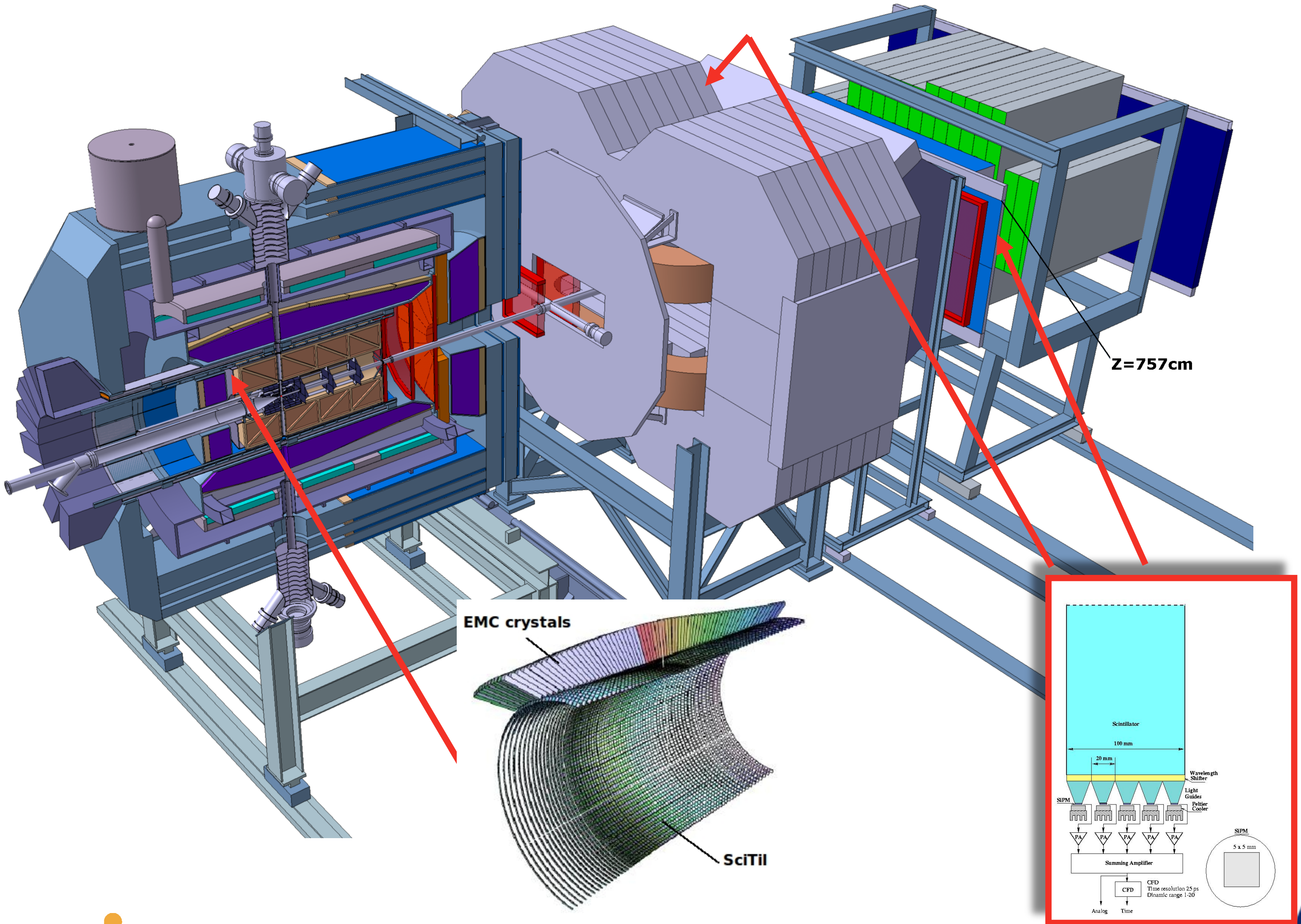
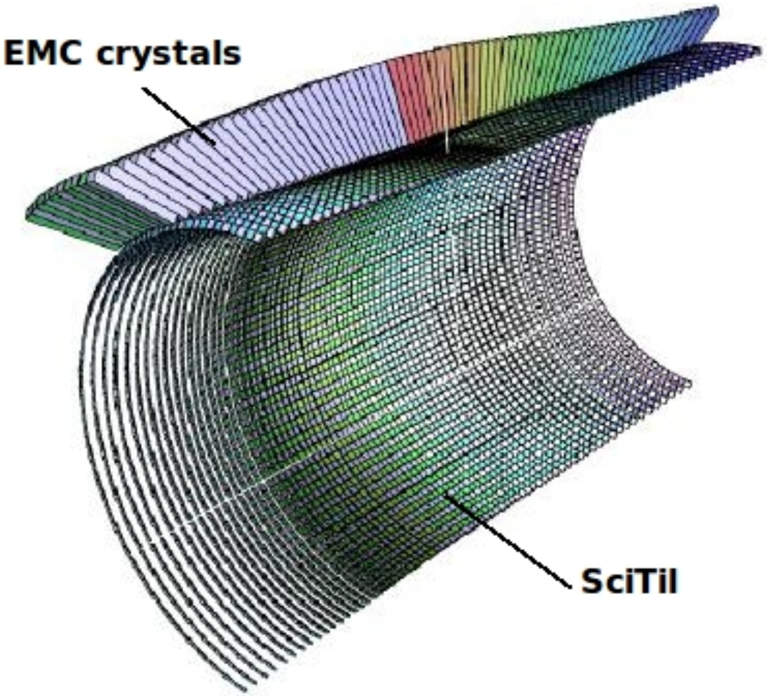


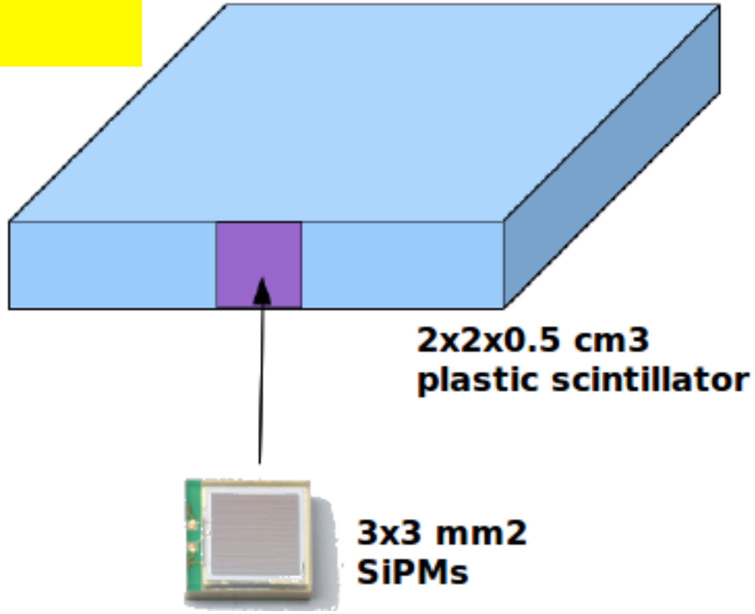
Scintillating Tile Hodoscope

Timing detector for PANDA

Properties:

1 % radiation length
Fast timing (100 ps)
Preshower detector for converted photons
Charged/neutral discrimination





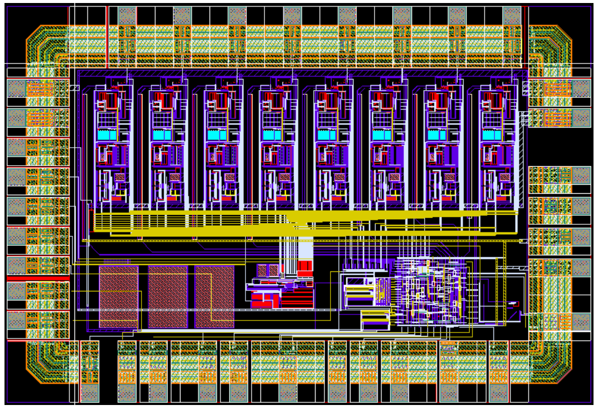
\+ ASIC

R&D
Simulations
Selection of scintillator and mached SiPM
Optimization of SiPM position
Time resolution
Light collection efficiency
Tests in Beam

GSI, BARC, Glasgow, INR

B-ASIC: 8-channel FE ASIC for SiPM

INFN and Politecnico Bari



Current mode approach

High BW (250MHz) and low Z_{in}~17Ω

High dynamic range: max 70pC

Low noise: ~0.3 SiPM cell

Non linearity < 1%

Programmable Gain, 3 ranges: 1V/pC, 0.5V/pC , 0.33 V/pC

Vref adjust → allow Vbias and Temperature control

Fast signal discrimination (programmable threshold)

Self-trigger: OR of the 8 fast signals

Time resolution on fast OR output ~ 650ps (worst, not RMS)

Development of front-end ASIC for Tiles based on the BASIC design (with reversed polarity)

Possible Developments for the future

1) **B-ASIC** chip 8 → 32 channels (+ channel mask)

2) fast ADC implementation on chip

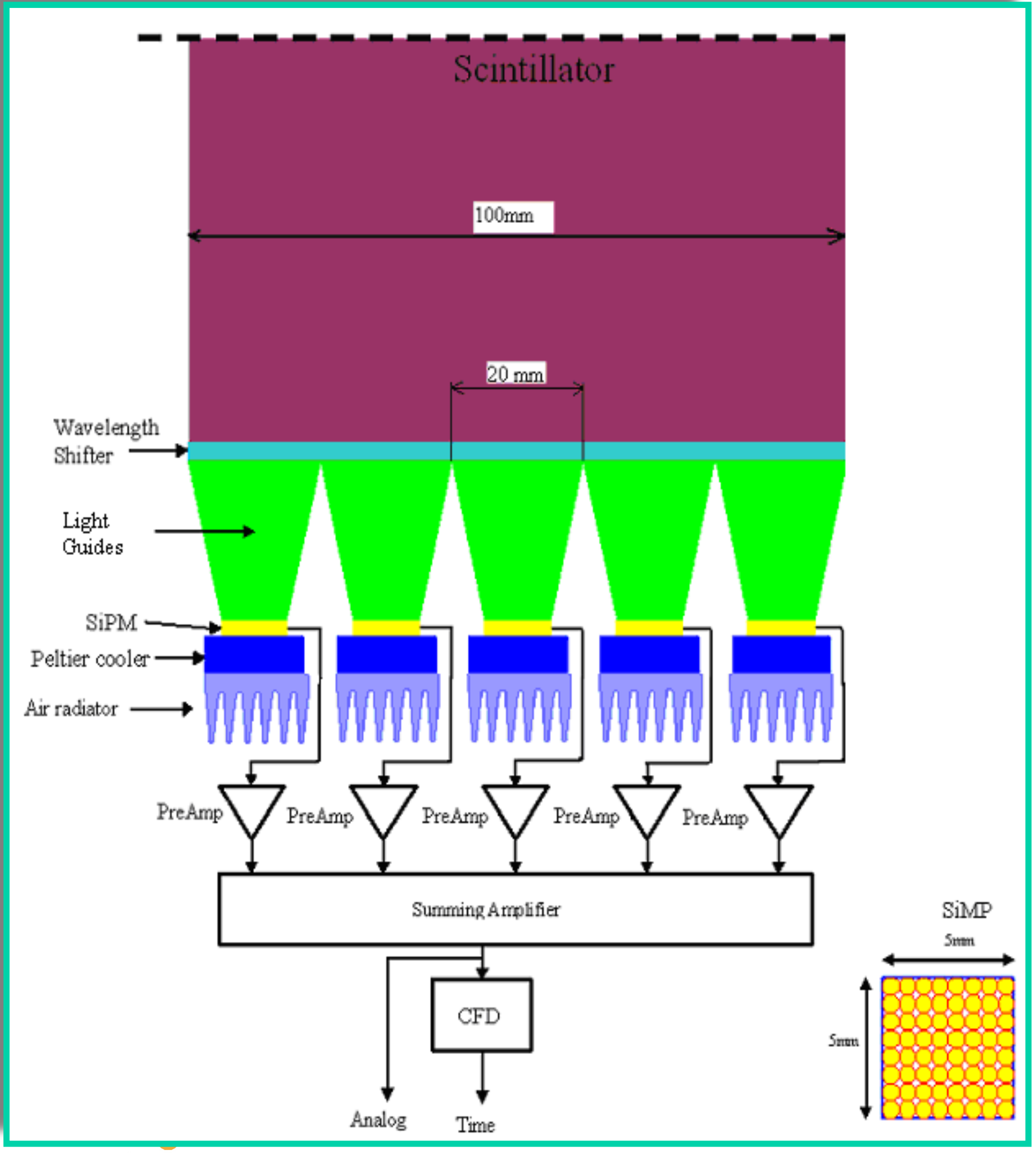
3) control scheme for temperature dependence of SiPM signal

4) additional timing information

5) migration of ASIC design to more up to date CMOS or SiGe technologies → larger transconductance / lower power consump.

Leadings institution: INFN Pisa, FBK-irst, GSI, SMI, Glasgow

Prototype of scintillator slab coupled to SiPM



Work at PNPI (HP2)

Selection of sensor type

Optimization of the *time resolution* and *photon detection efficiency*

Design of suitable *read-out electronic and cooling system*;

Study of the *radiation hardness and aging;*

Study of temperature dependence of the *dark counts*;

Tests using PNPI 1 GeV proton beam.

For HP3

Removing light guides for better time resolution

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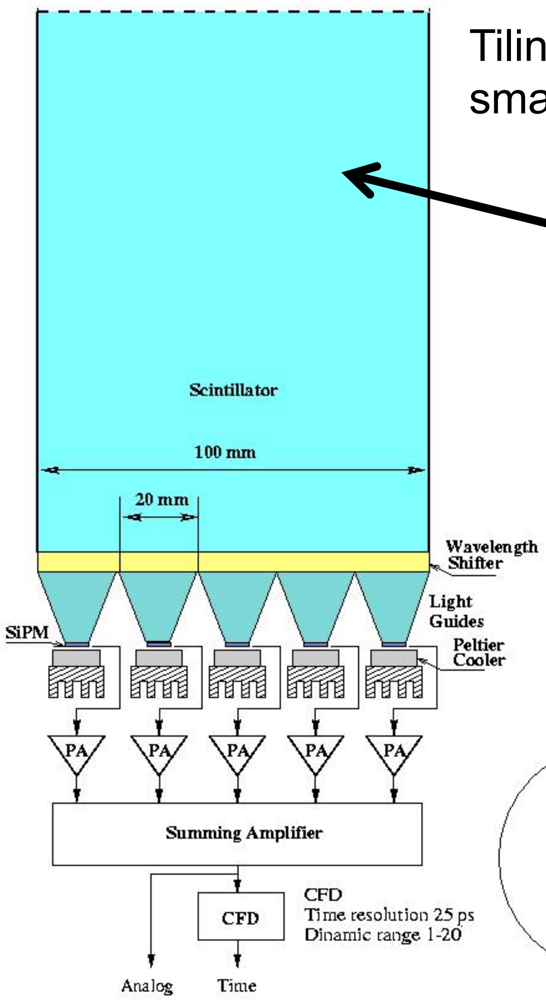
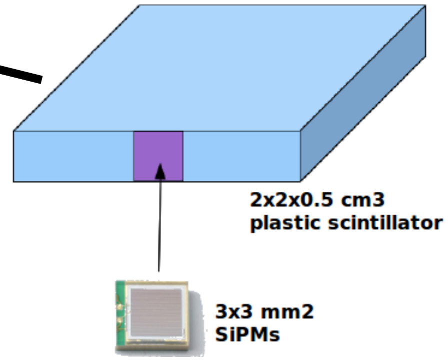
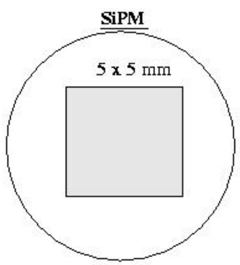
Tiled large Scintillator Panel



Tiling the panel surface with a single layer of small scintillating plates





Aim:
Improving time resolution through measurement of position and local light amplitude

R&D
Simulations
Development of correction algorithm
Test in beam near secondary target

Leading institution: PNPI, UJ, GSI, INR

Workplan fo Task 3

3. Ultra-fast timing with plastic scintillators for TOF applications												
3.1 Monte-Carlo Simulations of tiles for SciTil												
3.2 Selection of SiPM												
3.3 Construction and test of a tile prototype					12							
3.4 Design and construction of dedicated ASIC									13			
3.5 SciTil hodoscope tests in particle beam												14
3.6 Scintillator panel for TOF wall ready									15			
3.7 Study of TOF with tiled scintillator panel												
3.8 Beam tests												16

Milestones

12 Tile prototype
13 ASIC ready
14 SciTil test in beam
15 TOF wall panel ready
16 Test with particle beam at PNPI

Deliverables

Deliverable No.[1]	*Deliverable name*	*WP No.*	*Nature*[2]	*Dissemination level*[3]	*Delivery date*[4]
WP28.1	New SiPM matrix sensor with light concentrator	28	D	PU	36
WP28.2	Characterization of the Zecotek MAPD 8x8 sensor matrix.	28	R	PE	36
WP28.3	Characterization of SiPM for LYSO fibers	28	R	PU	12
WP28.4	Prototype of SciTil hodoscope	28	P	PU	18
WP28.5	ASIC for compact SciTil readout	28	P	PP	24
WP28.6	Hybrid Chip for SiPM readout in Shashlik calorimeter	28	D	P	36
WP28.7	SiPM TOF-wall panel with <<100 ps time resolution	28	D	PU	36

EC requested costs

Contr. No	Contractor Acronym	Personnel (EUR)	Durables (EUR)	Consumables (EUR)	Travel and workshops (EUR)	Total direct costs (EUR)	Indirect costs (EUR)	Requested EC contribution (EUR)
	WP28: Silicon Multiplier							
	REQUESTED EC CONTRIBUTION PER BUDGETARY ITEM AND PER BENEFICIARY							
1	INFN	70,000	0	16,000	12,000	98,000	58,800	156,800
	INFN-LNF	*35,000*	*0*	*8,000*	*8,000*	*51,000*	*30,600*	*81,600*
	INFN-PI	*35,000*	*0*	*8,000*	*4,000*	*47,000*	*28,200*	*75,200*
2	OeAW	0	0	48,000	4,000	52,000	0	52,000
4	CUNI	15,000	0	14,000	4,000	33,000	6,600	39,600
9	GSI	46,000	0	45,000	15,000	106,000	9,200	115,200
18	PIG-JLU	0	0	5,000	3,000	8,000	4,800	12,800
41	UJ	0	0	12,000	3,000	15,000	9,000	24,000
45	IFIN-HH	25,000	0	2,000	3,000	30,000	6,000	36,000
51	UGlasgow	0	0	10,000	4,000	14,000	7,800	21,800
	TOTAL	**156,000**	**0**	**152.000**	**48,000**	**356,000**	**102,200**	**458,200**

Complementary Costs

WP28: Silicon Multiplier COMPLEMENTING RESOURCES PER BUDGETARY ITEM AND PER BENEFICIARY								
Contr. No	**Contractor Acronym**	**Personnel (EUR)**	**Durables (EUR)**	**Consumables (EUR)**	**Travel and workshops (EUR)**	**Total direct costs (EUR)**	**Indirect costs (EUR)**	**Total complementing resources (EUR)**
1	INFN	80,000	15,000	36,000	9,000	140,000	84,000	224,000
	INFN-LNF	*50,000*	*15,000*	*20,000*	*5,000*	*90,000*	*54,000*	*144,000*
	INFN-PI	*30,000*	*0*	*16,000*	*4,000*	*50,000*	*30,000*	*80,000*
2	OeAW	50,000	0	3,000	2,000	55,000	43,930	98,930
4	CUNI	30,000	0	1,000	1.000	32,000	19,200	51,200
9	GSI	46,000	20,000	5,000	2,000	73,000	9,200	82,200
18	PIG-JLU	0	0	3,000	1,000	4,000	2,400	6,400
41	UJ	20,000	0	1,000	1,000	22,000	13,200	35,200
45	IFIN-HH	40.000	5,000	3,000	2,000	50,000	10,000	60,000
51	UGlasgow	20,000	7,000	2,000	4,000	33,000	19,800	52,800
	TOTAL	**286,000**	**47,000**	**54,000**	**22,000**	**409,000**	**201,700**	**610,700**

Summary of costs and comparison with HP2

WP28: Silicon Multiplier

INDICATIVE TOTAL COSTS AND INDICATIVE REQUESTED EC CONTRIBUTION PER BUDGETARY ITEM

	Personnel (EUR)	Durables (EUR)	Consumables (EUR)	Travel and workshops (EUR)	Total direct costs (EUR)	Indirect costs (EUR)	Total costs (EUR)
REQUESTED EC CONTRIBUTION	156,000	0	152.000	48,000	356,000	102,200	458,200
COMPLEMENTING RESOURCES	286,000	47,000	54,000	22,000	409,000	201,700	610,700
TOTAL BUDGET	**442,000**	**47,000**	**206,000**	**70,000**	**765,000**	**303,900**	**1068,900**
HP2 Requested EC	**110,000**	**0**	**190,000**	**40,000**	**348,000**	**92,000**	**440,000**

Summary

This JRA will continue to investigate the unique capabilities of Silicon Multipliers.

A new focus will be signal processing, well adapted to the SiPM sensor.

Development of integrated electronics is mendatory.

Direct contact to producers must be maintained.

New developments, e.g. the digital SiPM , are closely observed.

Deliverables will be:

Feasability studies and prototypes of new detector concepts for immediate use in Hadron Physics

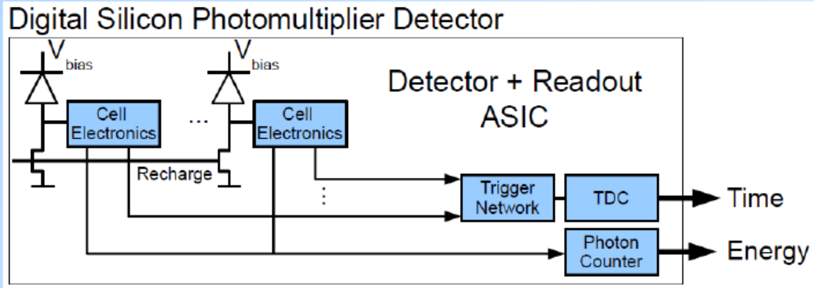
Add ons

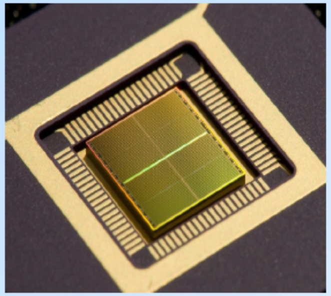
New developments

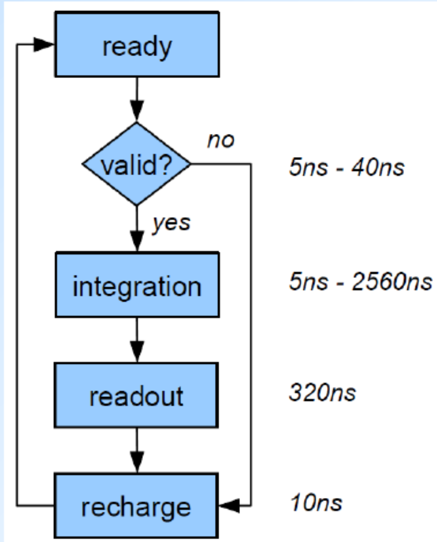
dSiPM-Digital SiPM (Philips)

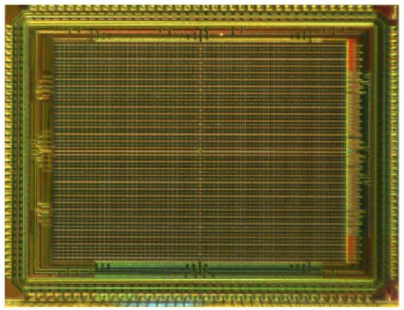
Signal from each pixel is is digitized and the information is processed on chip:

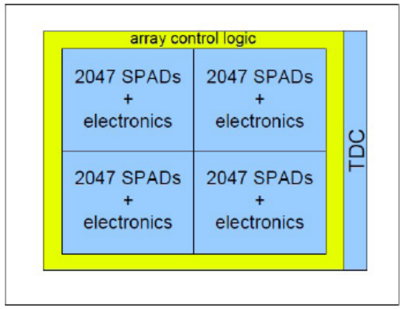
- time of first fired pixel is measured
- number of fired pixels is counted
- active control is used to recharge fired cells
- 4 x 2047 micro cells
- 50% fill factor including electronics
- integrated TDC with 8ps resolution











T. Frach (Philips) @ IEEE2009