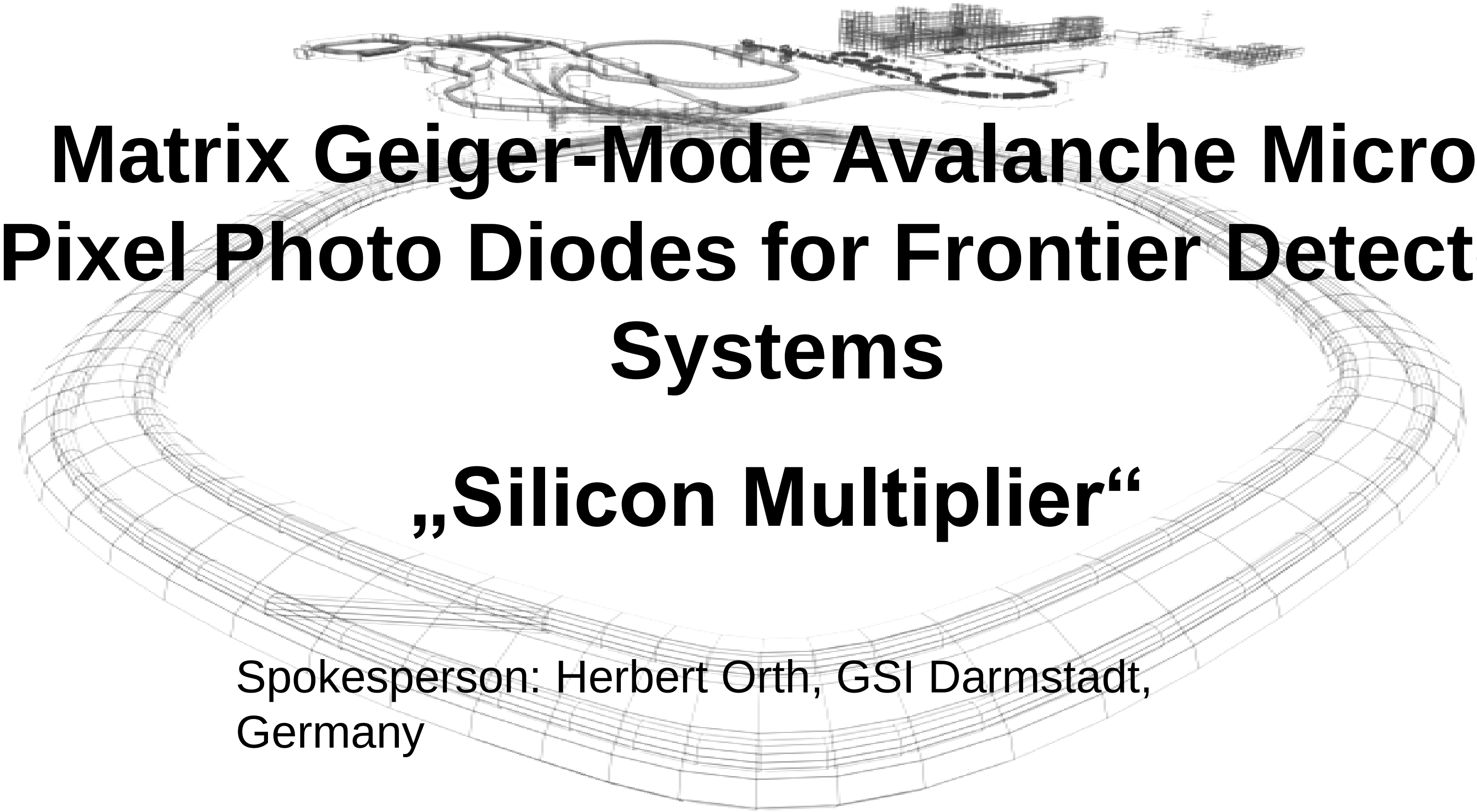
Seventh Framework Programme I3 - HadronPhysics2&3



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

„Silicon Multiplier“

Spokesperson: Herbert Orth, GSI Darmstadt, Germany

What are Silicon Multipliers?

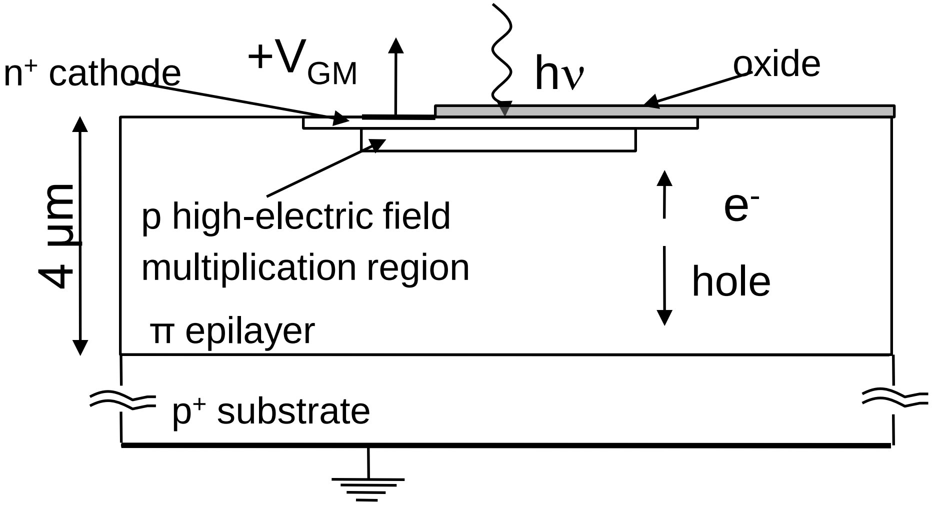
- PMT is a traditional photo sensor of nuclear/hadron physics for more than half a century
  - legacy device / reliable
  - new PMTs still actively being developed

- SiPM is a newly developed matrix of avalanche photo diodes (APD) operated in Geiger-mode
  - characteristics of a photon sensor
  - many advantages over PMT
  - potential to replace PMT in many applications

Frontier Detectors using Silicon Multipliers

Silicon **P**hoto**M**ultiplier = **SiPM**
Working principle

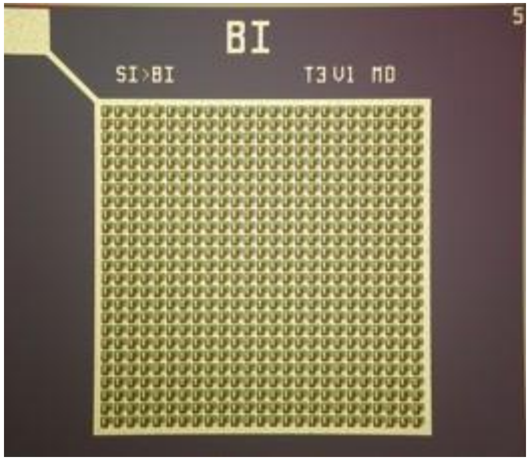
SOLID STATE PHOTODETECTOR➔



- **The photon is absorbed and generates an electron/hole pair**
- **The electron/hole diffuses or drifts to the high-electric field multiplication region**
- **The drifted charge undergoes impact ionization and causes an avalanche breakdown.**
- **Resistor in series to quench the avalanche (limited Geiger mode).**

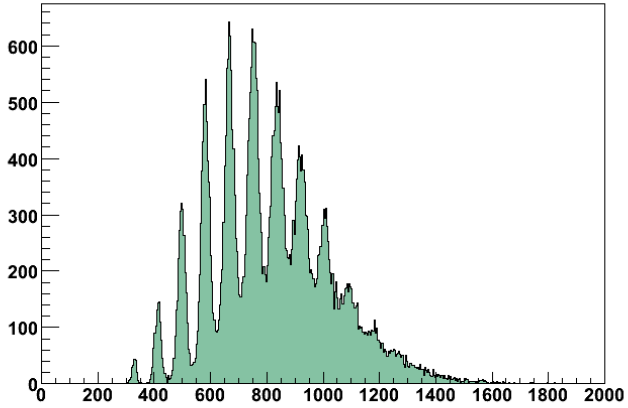
SiPM: **Multicell Avalanche Photodiode** working in limited Geiger mode

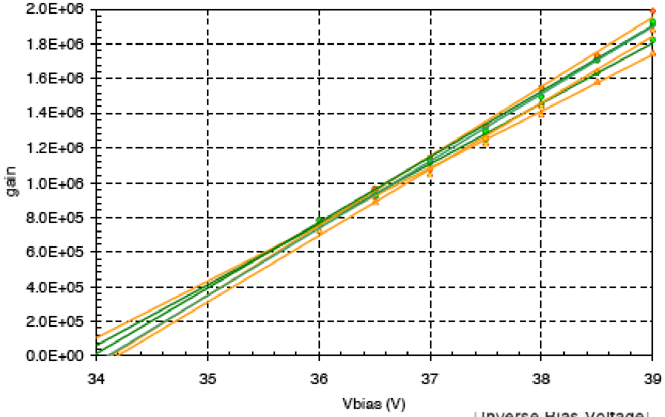
- **2D array of microcells: structures in a common bulk.**
- **$V_{bias} > V_{breakdown}$: high field in mult. region**
- **Microcells work in Geiger mode: the signal is independent of the particle energy**
- **The SiPM output is the sum of the signals produced in all microcells fired.**

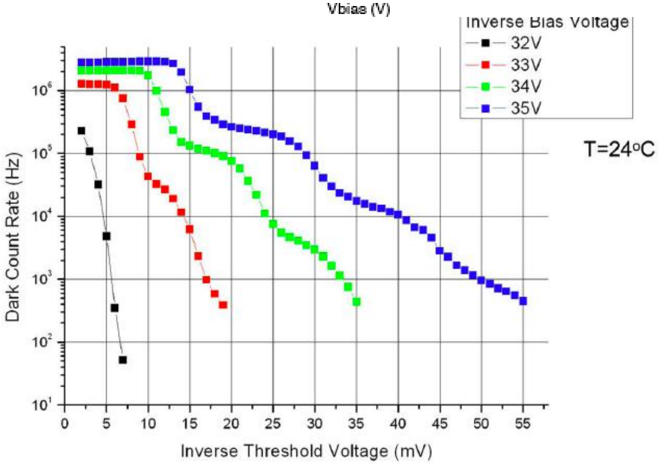


Results: characterization

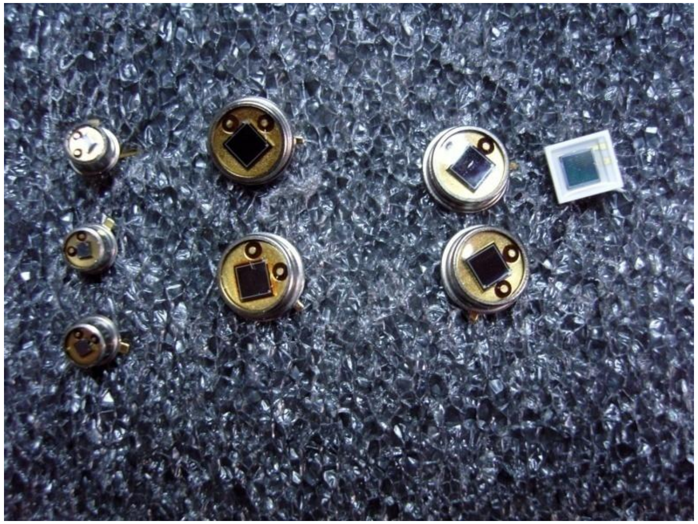
- Breakdown voltage **VB ~ 30V**, very good uniformity.
- **Single photoelectron** spectrum: well resolved peaks.
- **Gain: ~10^6**
  - Linear for a few volts over V_{BD}.
  - Related to the recharge of the diode capacitance C_D from V_{BD} to V_{BIAS} during the avalanche quenching. $G=(V_{BIAS}-V_B) \times C_D/q$
- **Dark rate**:
  - 1-3 MHz at 1-2 photoelectron (p.e.) level, ~kHz at 3-4 p.e (room temperature).
  - Not a concern for calorimetry.







Characteristics



Typical values:

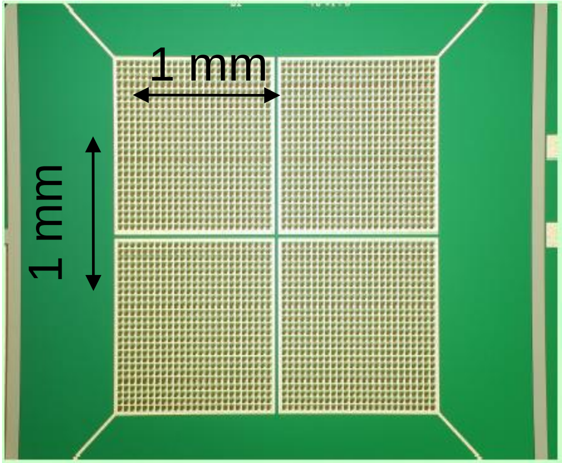
- Gain 10^5-10^6
- Time resolution < 50 ps
- Operating voltage < 100 V
  (at 2-4 V overvoltage $\Delta V = V_{bias} - V_{BD}$)
- Matrix size 1-3 mm^2
- Microcell size 10-100 µm

Dynamic range:

- Determined by the number of microcells and the Photon detection efficiency (PDE).

  Linear while N photons detected <<N of microcells.

  PDE = QE x Pt x GF.
- Increases with overvoltage, but also the noise



Noise:

- $10^5 – 10^6$ per mm^2 sensor at T=25 ° C
- $10^4 – 10^5$ per mm^2 sensor at T= 0 ° C

Optimization depends on the application

Results: intrinsic timing

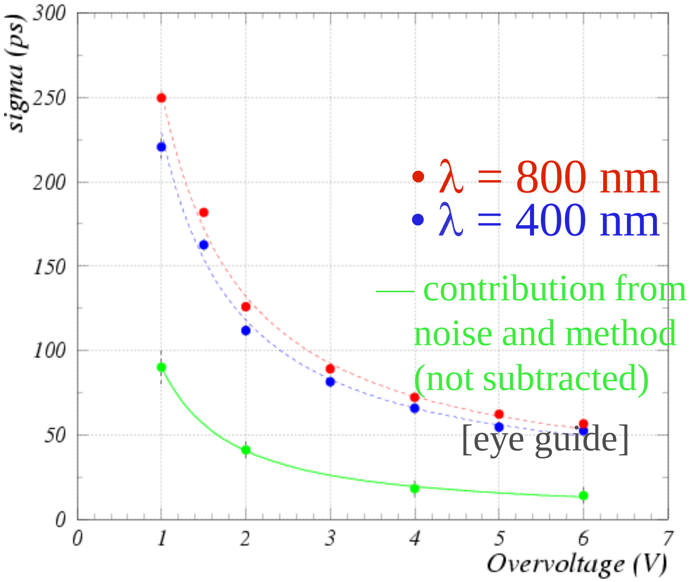
- Intrinsic timing measured at s.p.e level:

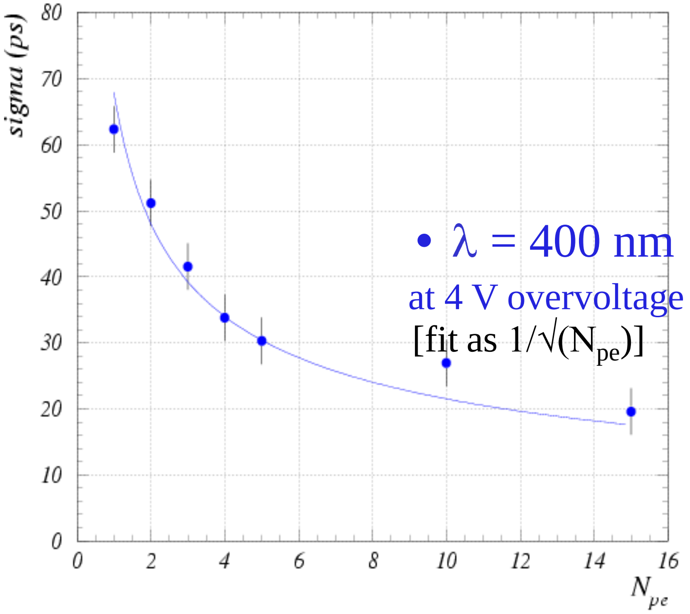
  σ = 60 ps for blue light

- SiPM illuminated with a pulsed laser with 60 fs pulse width and ~12 ns period, with less than 100 fs jitter.
- Two wavelengths measured:

  λ = 400 ±7 nm and λ = 800 ±15 nm.

- Time difference between contiguous pulses is determined.
- The timing decreases with the number of photoelectrons as $1/\sqrt{(N_{pe})}$:
- **20 ps at 15 photoelectrons**





[G. Collazuol et al., VCI 2007, to be published in NIM A.]

Objectives of EU-project

Exploiting and further developing the properties of SiPM in a collaborative effort from designer over producer to physics user

The R&D projects:

- **Low level light detection and single photon read-out with SiPM**
- **Detection of medium to high light levels using SiPM-coupled to fiber material**
- **Ultra-fast timing with plastic scintillators using SiPMs**

The focus in more detail

- Development and test of new SiMPs, integrated in arrays which are compatible with the demands of position sensitive detectors (e.g. single photon detectors, scintillating fibre detectors, gamma ray detectors using state-of-the-art crystals like LSO).
- Optimization of the timing performance in the picosecond time resolution range,
- Development and test of the performance as single photon counters.
- Studies of damage effects from ionizing radiation
- Investigation and characterization of the intrinsic and induced noise behavior.
- Development of associated electronics for the supply/readout as well as data acquisition
- Assembly and installation in detector systems working in magnetic fields: characterization of the overall performances and check of the short and long time stabilities on various test beams

Participating Institutions

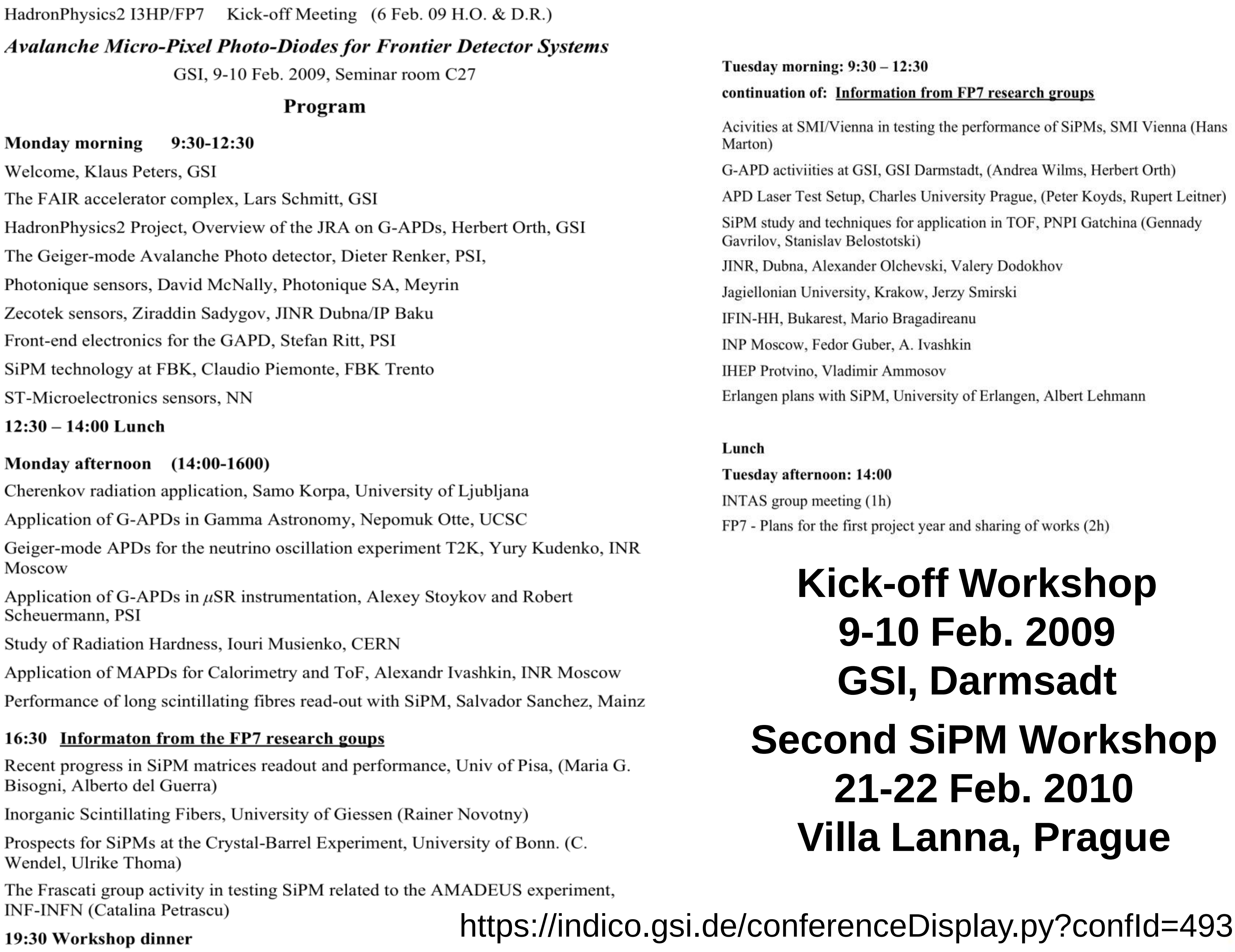
Work package title	Avalanche Micro-Pixel Photo-Diodes for Frontier Detector Systems

Participant number	**Organization legal name**	**Short name**	**Activity leaders** *(in **bold** the spokesperson)*	**Person-months (total)**
9	Gesellschaft für Schwerionenforschung mbH	GSI	**H.Orth**	12
1	Istituto Nazionale di Fisica Nucleare *INFN Laboratori Nazionali di Frascati* *INFN Sezione di Pisa*	INFN *INFN-LNF* *INFN-PI*	 *C.Curceanu,* *A.Del Guerra*	48 *30* *18*
2	Oesterreichische Akademie der Wissenschaften	OeAW	J.Marton	12
4	Charles University in Prague	CUNI	R.Leitner	12
14	Rheinische Friedrich-Wilhelms-Universität Bonn *Universität Bonn*	UBO *UBO*	 *U.Thoma*	12 *12*
15	Friedrich-Alexander- Universität Erlangen-Nuernberg	FAU	A.Lehmann	6
18	Justus Liebig Universität Giessen	JLU	R.Novotny	6
33	Foundation Bruno Kessler *FBK-irst*	FBK *FBK*	 *C. Piemonte*	
37	Jagiellonian University	UJ	J.Smyrski	12
40	Institutul National de Cercetare-Dezvoltare pentru Fizica si Inginerie Nucleara – Horia Hulubei	IFIN-HH	M.Bragadireanu	60

Other involved institutions	**Activity leaders**	**Person-months**
Paul Scherrer Institut,Villigen (Switzerland)	D.Renker	3
Zecotek Photonics, Zuerich (Switzerland)	Z. Sadygov	12
Joint Institute for Nuclear Research,Dubna (Russia)	A.Olchevski	24
Petersburg Nuclear Physics Institute, Gatchina (Russia)	S.Belostotski	18
Institute for Scintillation Materials, Kharkov (Russia)	B.Gryniov	3
Institute of Nuclear Physics,Moscow (Russia)	F.Guber	6
Institute of High Energy Physics,Protvino (Russia)	V.Ammosov	12

Deliverables

Task	Deliverable	Month of Delivery
Single-photon readout with SiPMs	Design and construction of a 64-pixel prototype matrix	36
SiPM-coupled advanced fiber detectors	Feasebility studies for new detectors with SiPM readout using: a)Crystalline fibers b)Scintillating fibers c)Wavelenght shifting fibers	36
Ultra-fast timing for TOF applications	Prototype, radiation hardness and tests in beam	36



HadronPhysics2 I3HP/FP7 Kick-off Meeting (6 Feb. 09 H.O. & D.R.)

Avalanche Micro-Pixel Photo-Diodes for Frontier Detector Systems

GSI, 9-10 Feb. 2009, Seminar room C27

Program

Monday morning 9:30-12:30

Welcome, Klaus Peters, GSI

The FAIR accelerator complex, Lars Schmitt, GSI

HadronPhysics2 Project, Overview of the JRA on G-APDs, Herbert Orth, GSI

The Geiger-mode Avalanche Photo detector, Dieter Renker, PSI,

Photonique sensors, David McNally, Photonique SA, Meyrin

Zecotek sensors, Ziraddin Sadygov, JINR Dubna/IP Baku

Front-end electronics for the GAPD, Stefan Ritt, PSI

SiPM technology at FBK, Claudio Piemonte, FBK Trento

ST-Microelectronics sensors, NN

12:30 – 14:00 Lunch

Monday afternoon (14:00-1600)

Cherenkov radiation application, Samo Korpa, University of Ljubljana

Application of G-APDs in Gamma Astronomy, Nepomuk Otte, UCSC

Geiger-mode APDs for the neutrino oscillation experiment T2K, Yury Kudenko, INR Moscow

Application of G-APDs in μSR instrumentation, Alexey Stoykov and Robert Scheuermann, PSI

Study of Radiation Hardness, Iouri Musienko, CERN

Application of MAPDs for Calorimetry and ToF, Alexandr Ivashkin, INR Moscow

Performance of long scintillating fibres read-out with SiPM, Salvador Sanchez, Mainz

16:30 <u>Informaton from the FP7 research goups</u>

Recent progress in SiPM matrices readout and performance, Univ of Pisa, (Maria G. Bisogni, Alberto del Guerra)

Inorganic Scintillating Fibers, University of Giessen (Rainer Novotny)

Prospects for SiPMs at the Crystal-Barrel Experiment, University of Bonn. (C. Wendel, Ulrike Thoma)

The Frascati group activity in testing SiPM related to the AMADEUS experiment, INF-INFN (Catalina Petrascu)

19:30 Workshop dinner

Tuesday morning: 9:30 – 12:30

continuation of: <u>Information from FP7 research groups</u>

Acivities at SMI/Vienna in testing the performance of SiPMs, SMI Vienna (Hans Marton)

G-APD activiities at GSI, GSI Darmstadt, (Andrea Wilms, Herbert Orth)

APD Laser Test Setup, Charles University Prague, (Peter Koyds, Rupert Leitner)

SiPM study and techniques for application in TOF, PNPI Gatchina (Gennady Gavrilov, Stanislav Belostotski)

JINR, Dubna, Alexander Olchevski, Valery Dodokhov

Jagiellonian University, Krakow, Jerzy Smirski

IFIN-HH, Bukarest, Mario Bragadireanu

INP Moscow, Fedor Guber, A. Ivashkin

IHEP Protvino, Vladimir Ammosov

Erlangen plans with SiPM, University of Erlangen, Albert Lehmann

Lunch

Tuesday afternoon: 14:00

INTAS group meeting (1h)

FP7 - Plans for the first project year and sharing of works (2h)

Kick-off Workshop
9-10 Feb. 2009
GSI, Darmsadt

Second SiPM Workshop
21-22 Feb. 2010
Villa Lanna, Prague

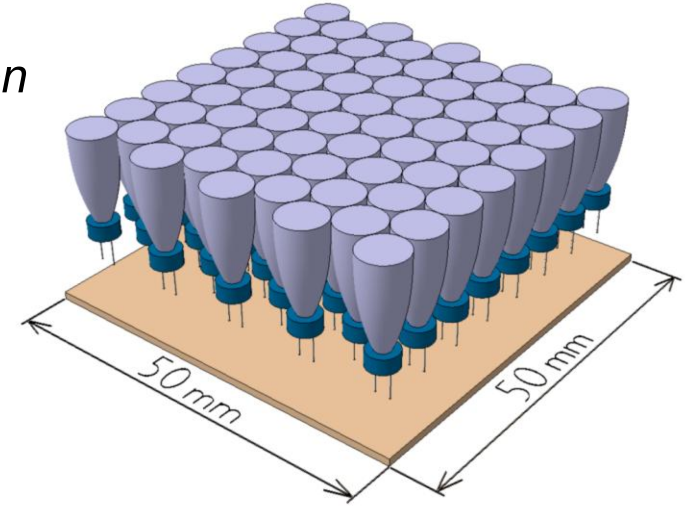
https://indico.gsi.de/conferenceDisplay.py?confId=493
https://indico.gsi.de/conferenceDisplay.py?confId=969

Frontier Detectors using Silicon Multipliers

T1: Low level light detection and single photon read-out with SiPM

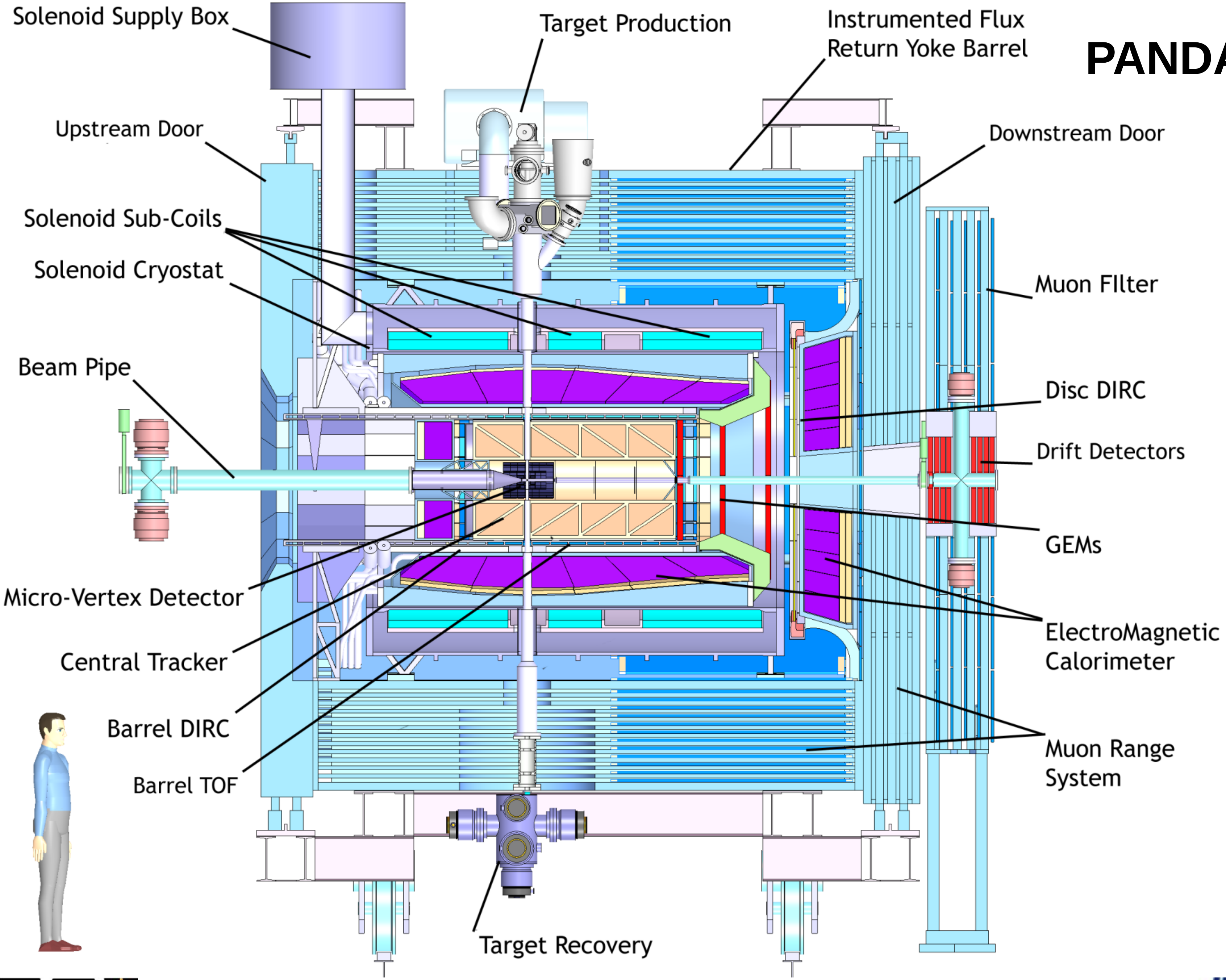
Important parameters of SiMP for very low light level detection:

- *Large PDE (50 %) and large area coverage*
- *small pixel granularity and large pixel size*
- *Fast single photon response for time resolution*
- *Working in high magnetic field*
- *Low sensor noise performance*

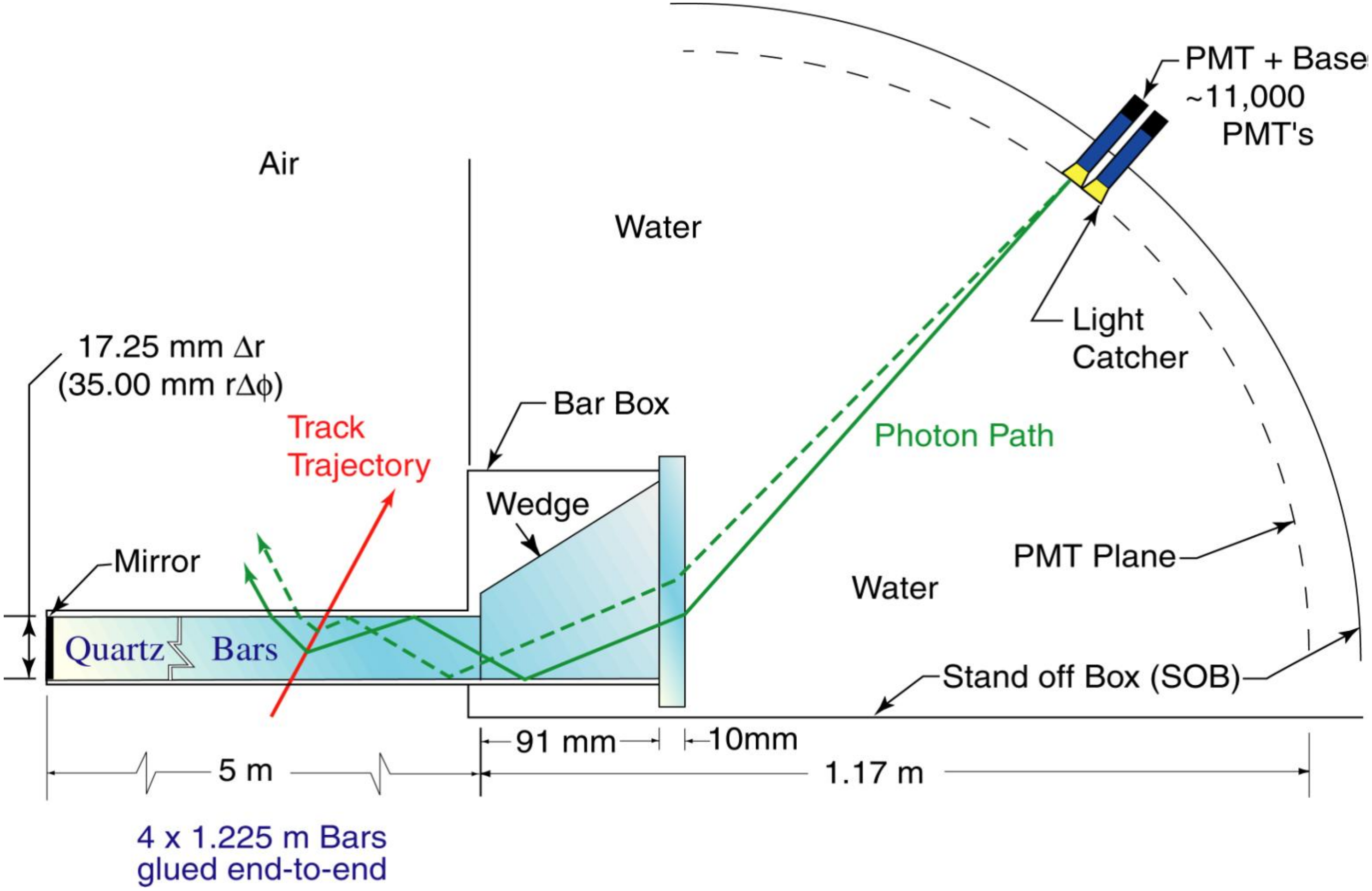


R&D: Large SiPM sensor matrix for coincident photons (e.g. Cherenkov radiation)

PANDA

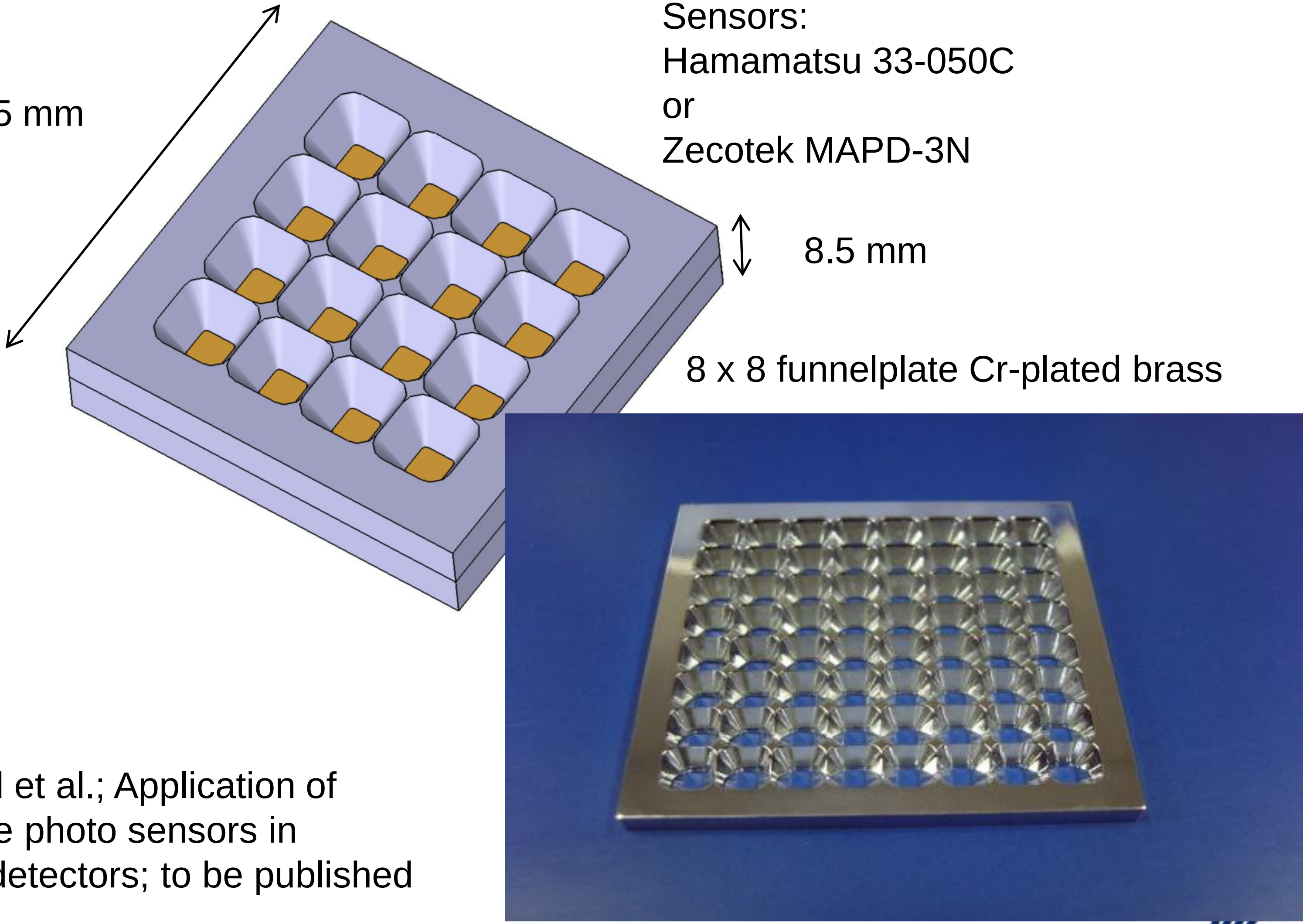

Solenoid Supply Box
Target Production
Instrumented Flux
Return Yoke Barrel
Upstream Door
Downstream Door
Solenoid Sub-Coils
Solenoid Cryostat
Muon FIlter
Beam Pipe
Disc DIRC
Drift Detectors
GEMs
Micro-Vertex Detector
ElectroMagnetic
Calorimeter
Central Tracker
Barrel DIRC
Muon Range
System
Barrel TOF
Target Recovery

DIRC working principle



Large area sensor with light catcher

4 x 4 matrix
Sensors:
Hamamatsu 33-050C
or
Zecotek MAPD-3N

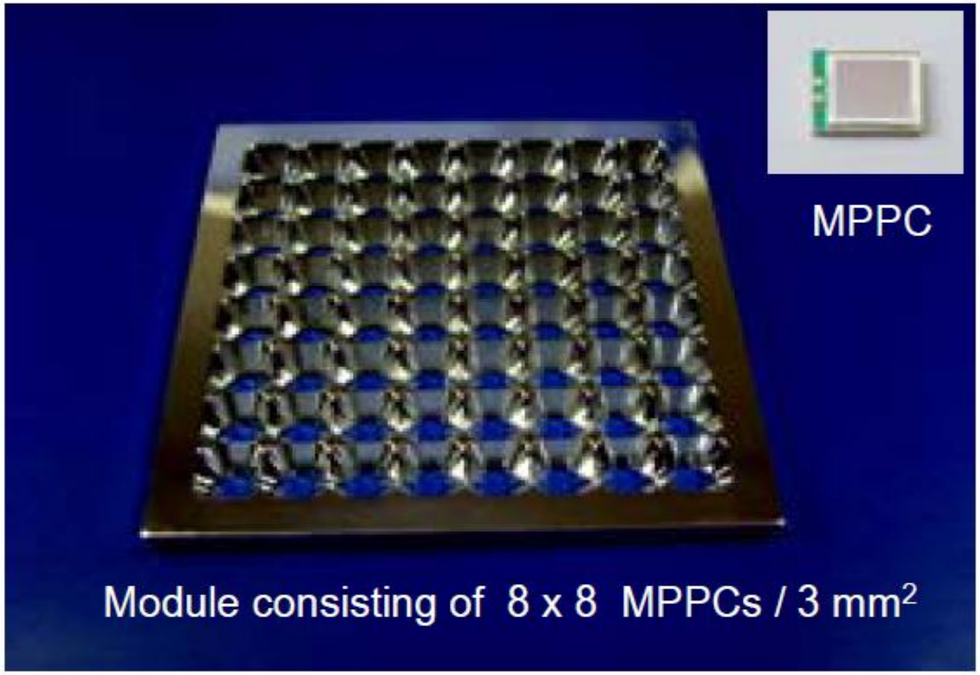


8 x 8 funnelplate Cr-plated brass

G.M. Ahmed et al.; Application of Geiger-mode photo sensors in Cherenkov detectors; to be published

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

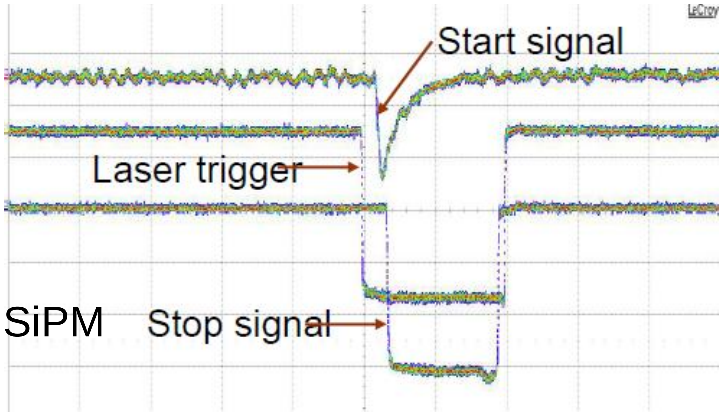


Module consisting of 8 x 8 MPPCs / 3 mm^2

First design for
present version of 3x3 mm MPPCs

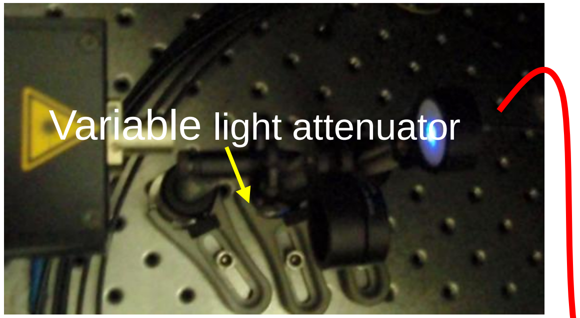
Test equipment at SMI

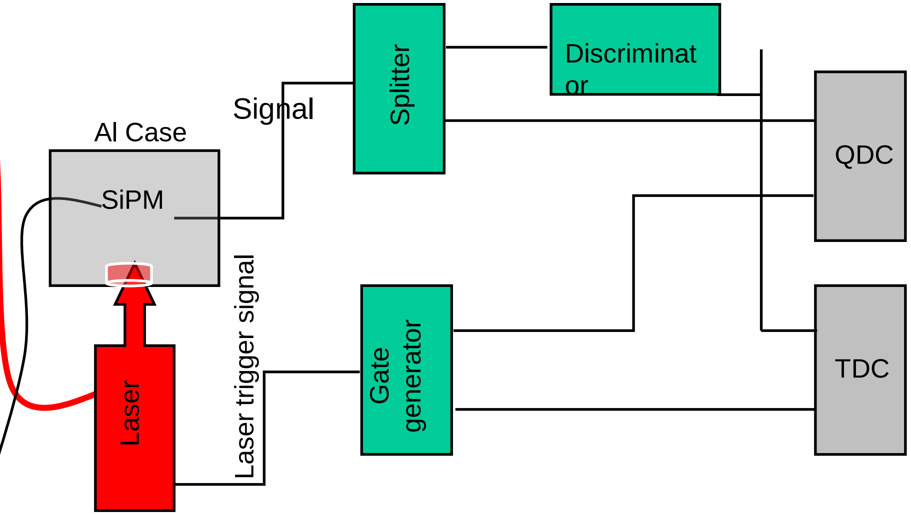
Test bench with insulation vacuum vessel, vacuum pump, Peltier cooling
Bias voltage supply (Keithley), preamp supply voltages
Picosecond laser system @ 408 nm (32ps) for timing tests
Optical bench for laser beam (coupling to optical fiber)
Fast digital oscilloscope
CAMAC/VME DAQ system for TDC, QADC data acquisition

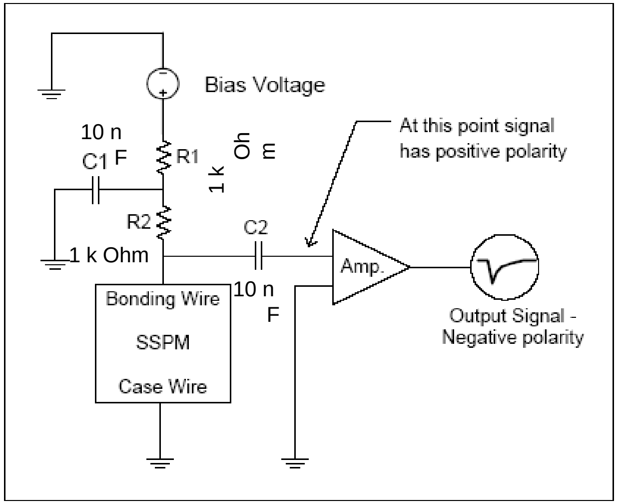


SiPM time resolution measurements

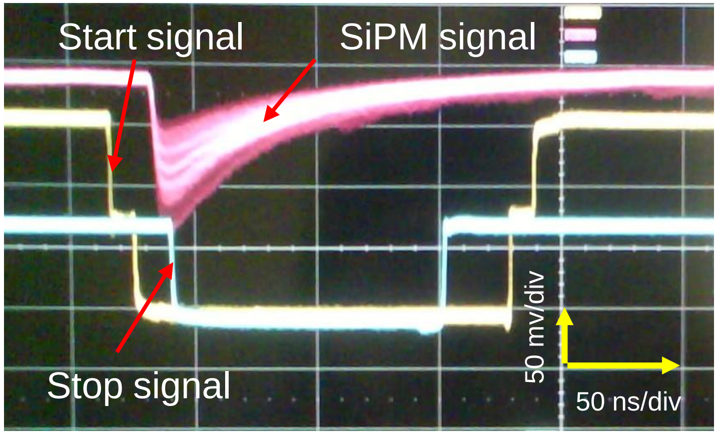
- Time resolution was studied by illuminating SiPM with blue laser light pulse width 32 ps at wave length 408nm.

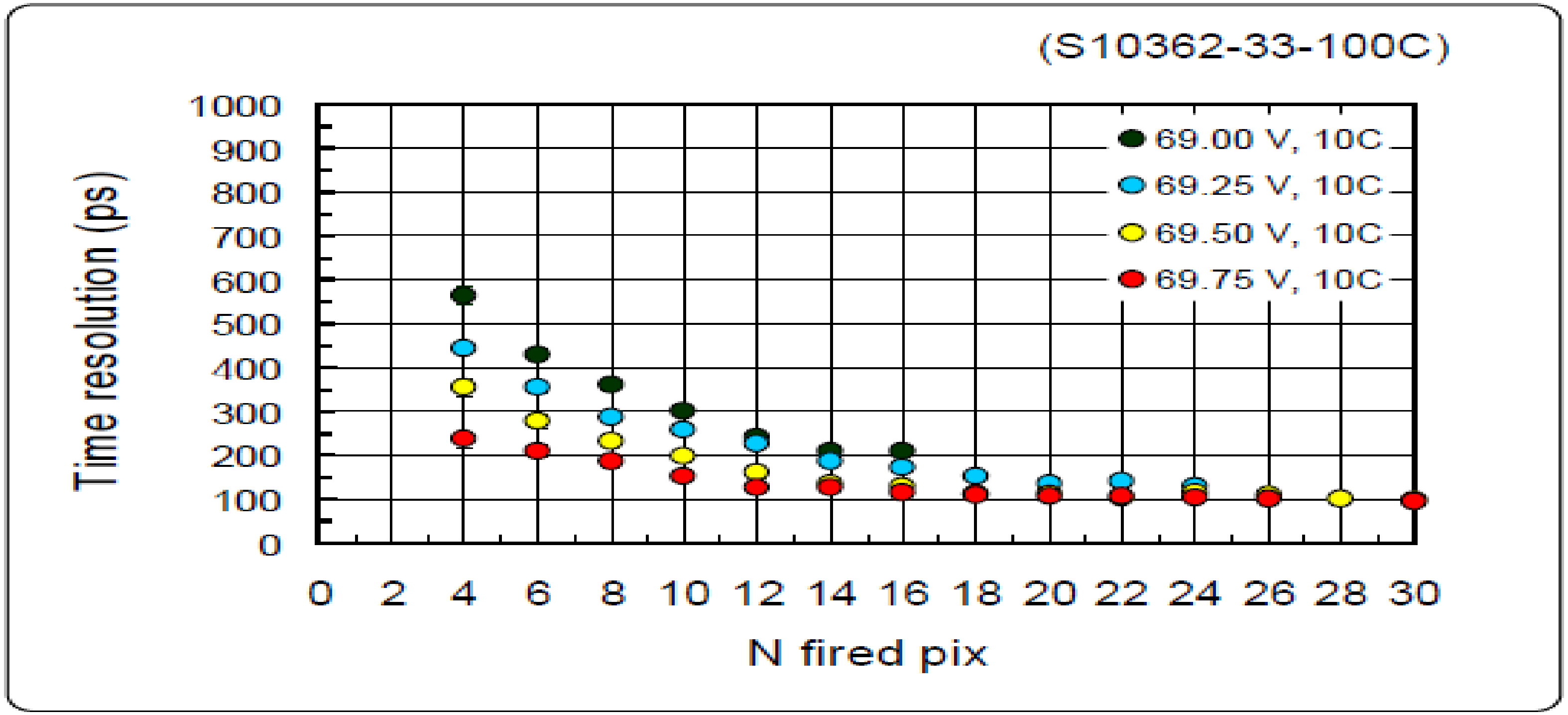






Photonique preamplifier (AMP-0611) (700 ps)





Publications:

G.S.M. Ahmed, P. Bühler, J. Marton and K. Suzuki, “Studies of GM-APD (SiPM) Properties,” Journal of Instrumentation 4, 2009, P09004 .

G.S.M. Ahmed, P. Bühler, J. Marton and K. Suzuki, “Study of timing performance of Silicon Photomultiplier and application for a Cherenkov detector”, Proc. Int. Conference on Instrumentation, Nuclear Instruments and Methods in print.

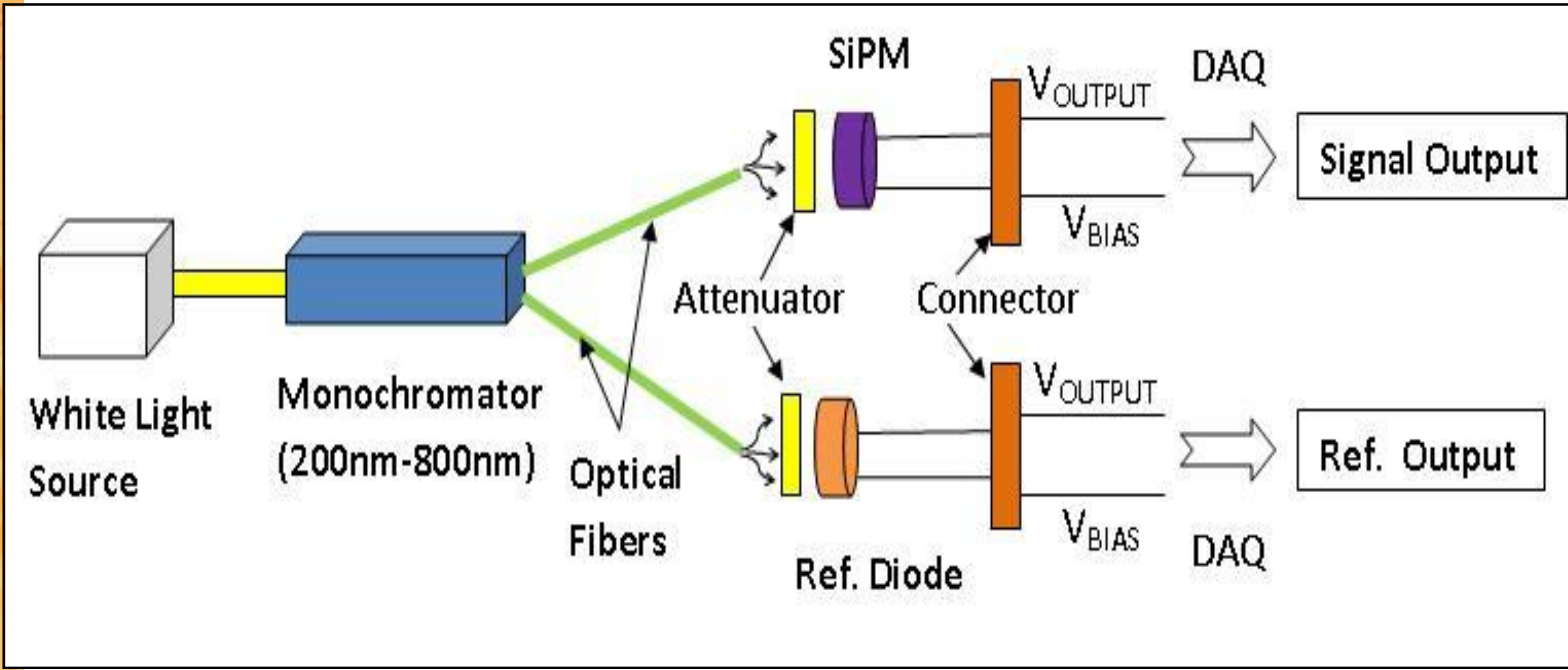
G.S.M. Ahmed, P. Bühler, J. Marton and K. Suzuki, “Characterization and application of Geiger-mode silicon Photosensors in radiation detection,” presentation at 2010 Symposium on Radiation Measurements and Applications, May 24-28, 2010, Univ. Michigan, Ann Arbor, to be published in Nucl. Instr. Meth. A.

G.M. Ahmed, P. Bühler, M. Cargnelli, R. Hohler, J. Marton, H. Orth and K. Suzuki, “Application of Geiger-mode photo sensors in Cherenkov detectors”, Proceedings RICH 2010

Summary of time resolution measurements

- SiPM time resolution improves as a function of the bias voltage and /or the light level at constant temperature.
- SiPM time resolution improves with decreasing operating temperature (>-10 C).
- In this study the best achieved time resolution for MPPC is 33 ± 5 ps, around ~130 p.e. (SiPM limit ?).
- The best achieved time resolution for MAPD-3N is 70 ± 10 ps.
- Time resolution of electronics (Discr., Logics, TDC, DAQ, excluding preamplifier) ~ 20 ps.
- At low light condition, strong dependence on the bias voltage and/or temperature .

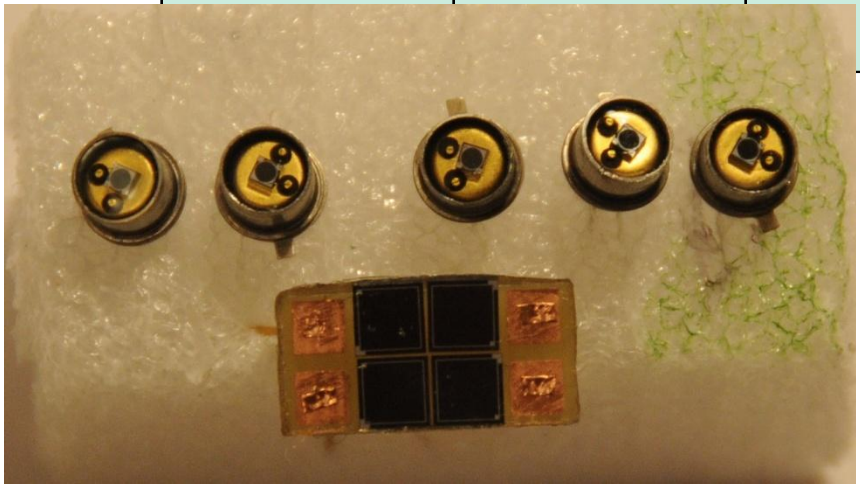
PDE measurements at GSI



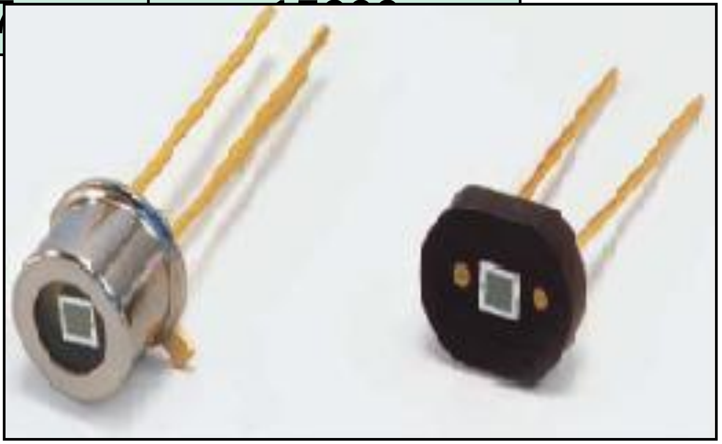
SiPM Sensors

SiPM sensors tested: MPPC from Hamamatsu, MAPD3N from Zecotek

Device	Active Area (mm^2)	Pixel Size (μm)	Pixel Density (1/mm^2)
MPPC-11-25	(1 × 1)	25	1600
MAPD3N	(3 × 3)	7	15000
		7	15000



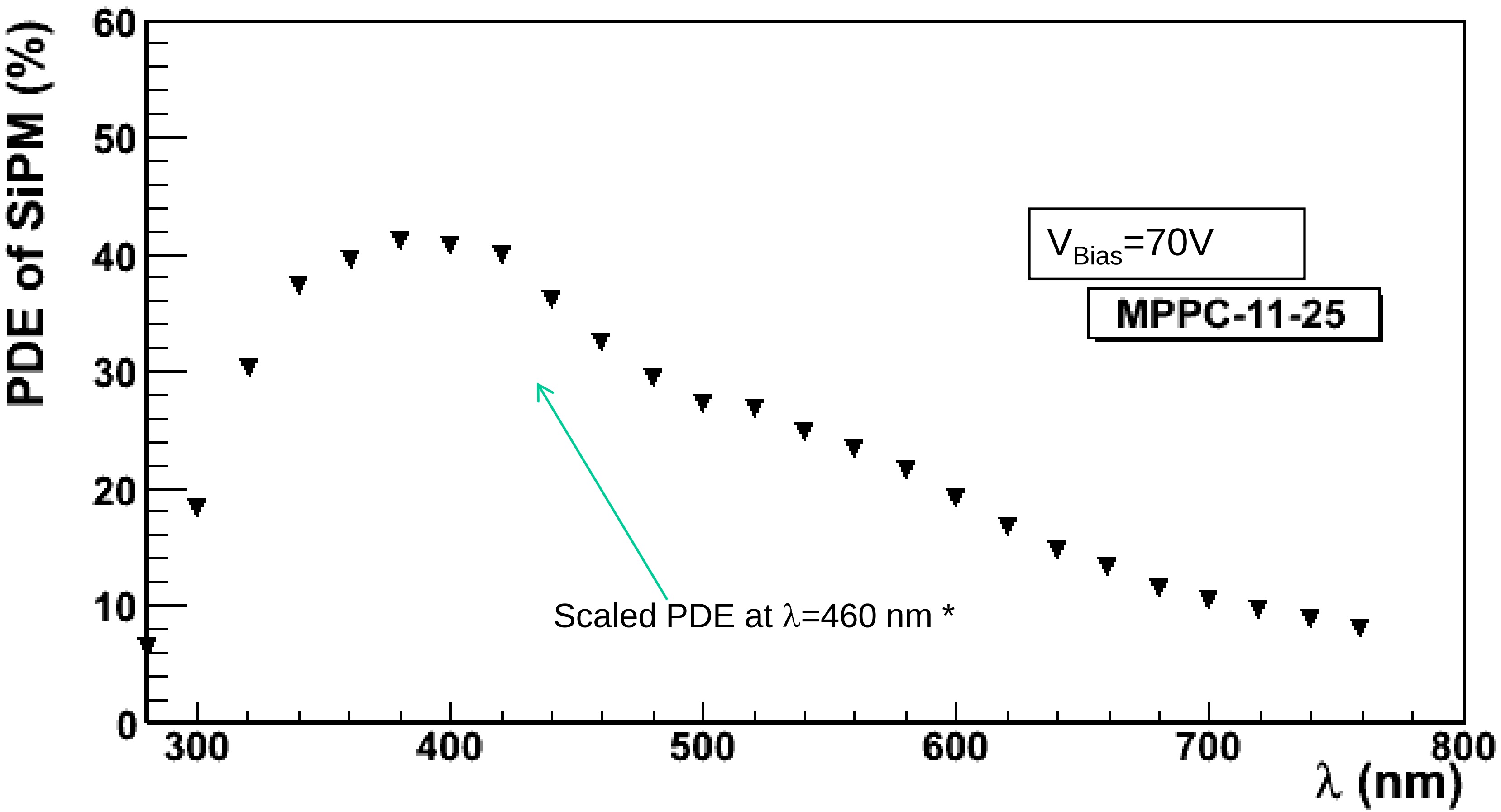
MAPD3N from Zecotek



MPPC from Hamamatsu

Photon Detection Efficiency

Hamamatsu Sensor MPPC-11-25

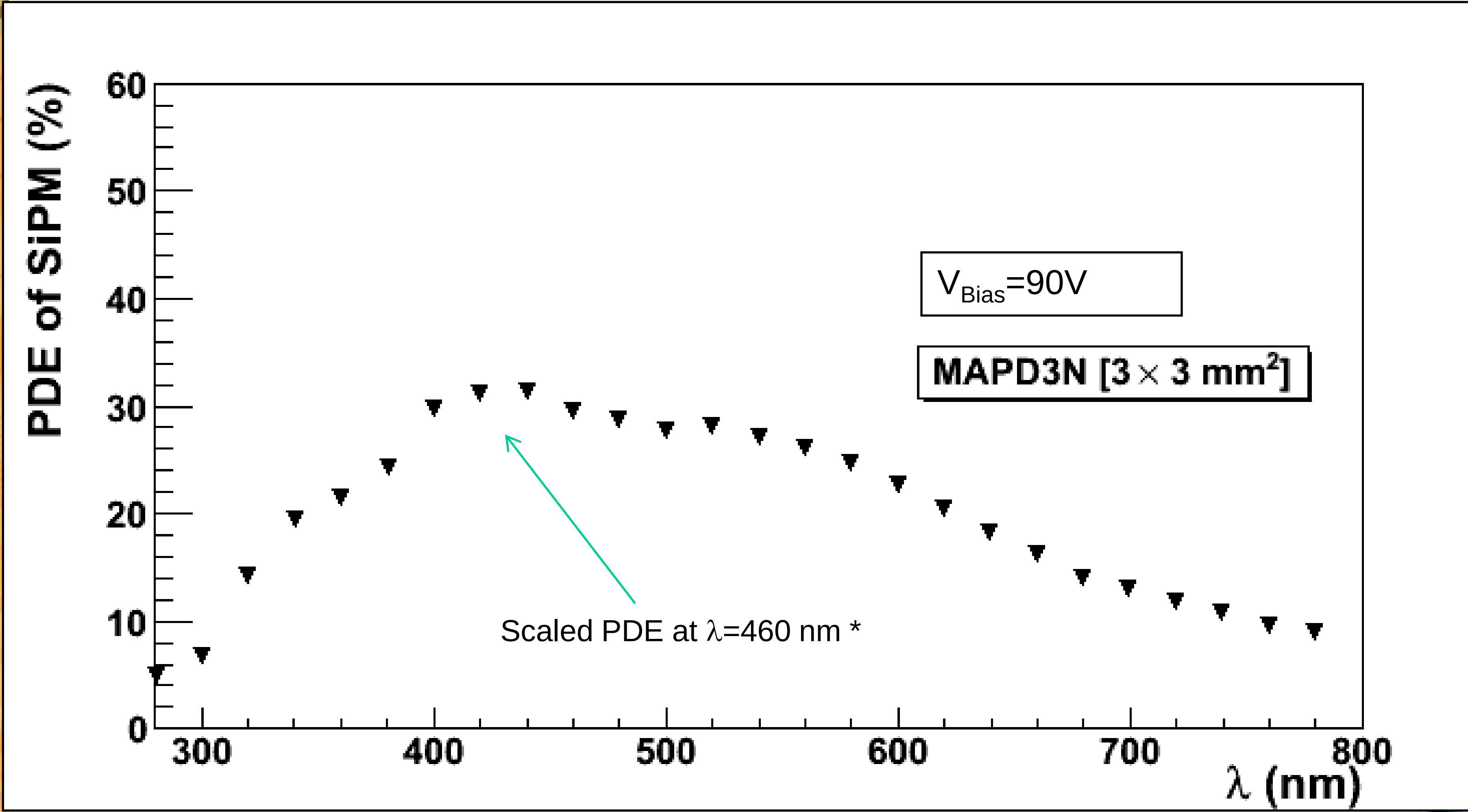


Scaled PDE at λ=460 nm *

* D. Renker, PSI (Private Communication)

Photon Detection Efficiency

Zecotek Sensor MAPD3N [3 × 3 mm^2]



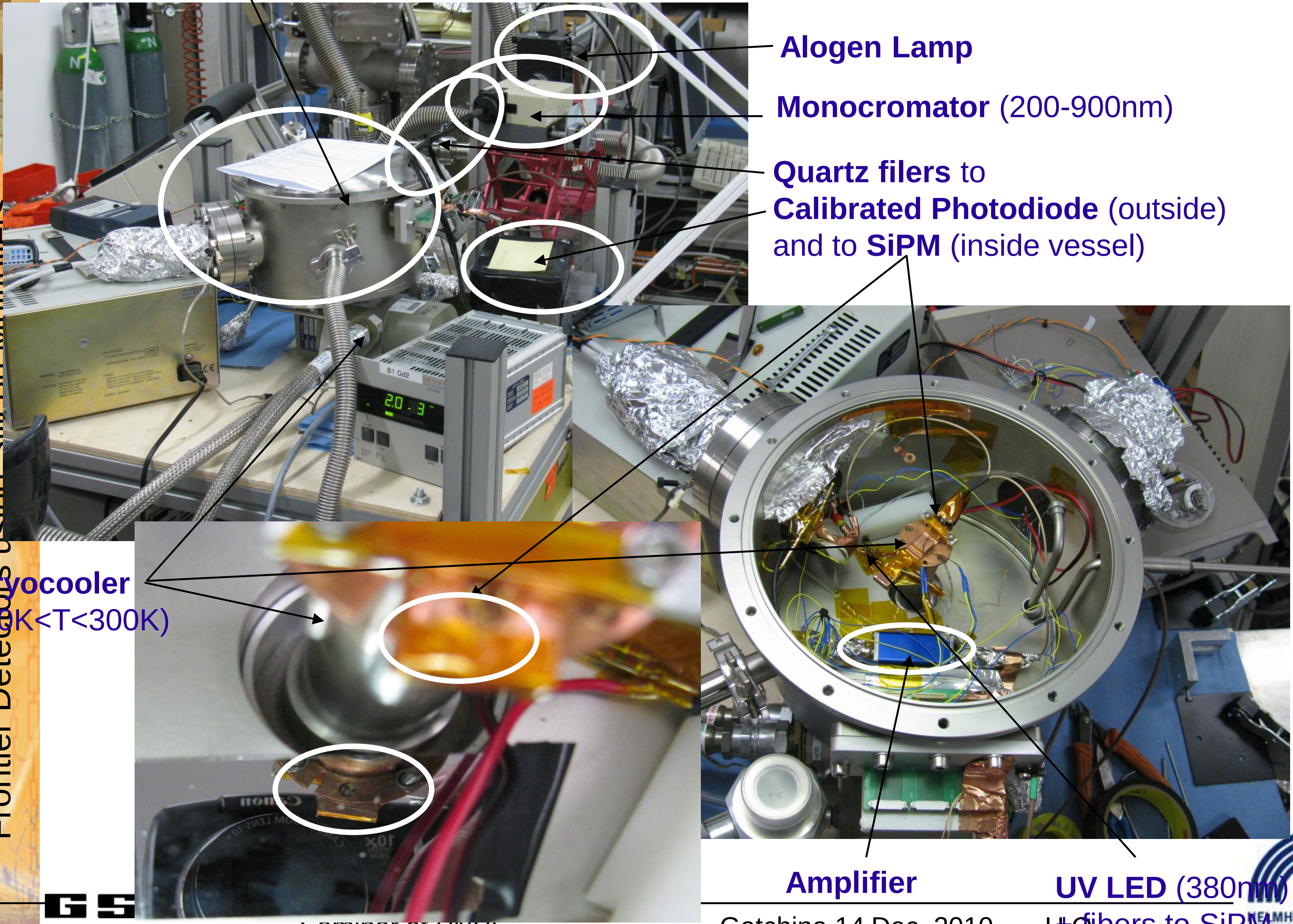
* Yu. Musienko, CERN (Private Communication)

Timing and low temperature behavior of SiPM

G.Bisogni[1], G.Collazuol[1], A.Del Guerra[1,2], C.Piemonte[3]
[1] INFN sezione di Pisa, [2]Dipartimento di fisica Universita` di Pisa, [3]FKB-IRST Trento

INFN PISA

Experimental Setup



Vacuum vessel (P~10^{-3} mbar)

Alogen Lamp

Monocromator (200-900nm)

Quartz filers to **Calibrated Photodiode** (outside) and to **SiPM** (inside vessel)

Cryocooler (50K<T<300K)

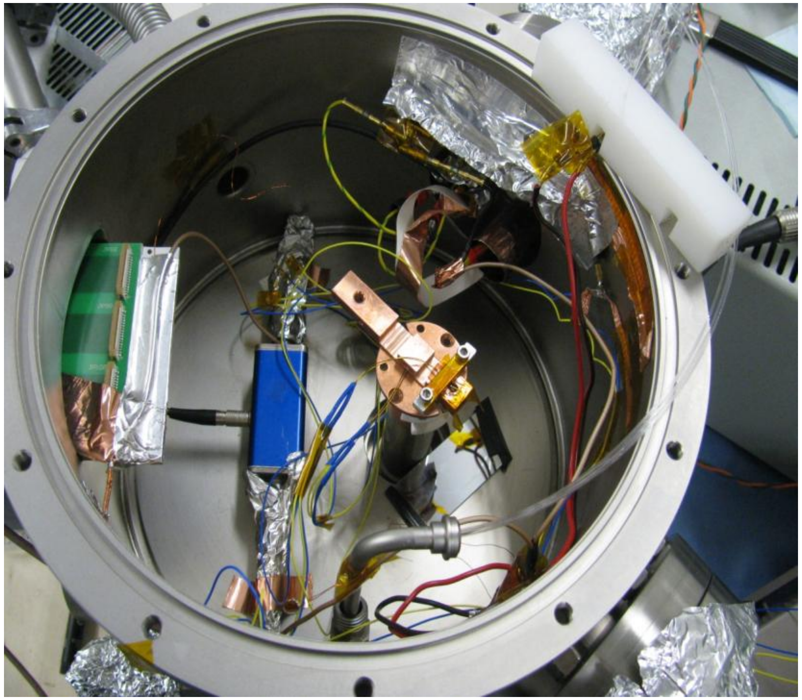
Amplifier

UV LED (380nm) +fibers to SiPM

Experimental setup

Temperature control/measurement

- Cryo-cooler + heating with low R resistor
- thermal contact (critical) with cryo-cooler head: SIPM within a copper rod
- T measurement with 3 pt100 probes
- Measurements on SiPM carried after thermalization (all probes at the same T)
- check junction T with forward characteristic

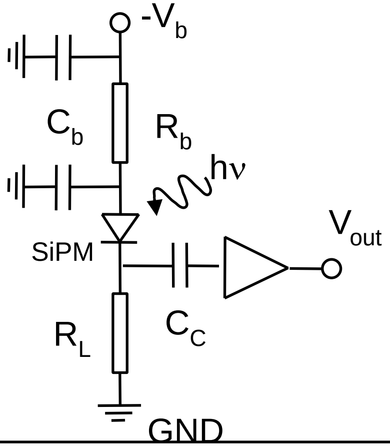


Voltage/Current bias/measurement

- Keytley 2148 for Voltage/Current bias/readout

Pulse measurement

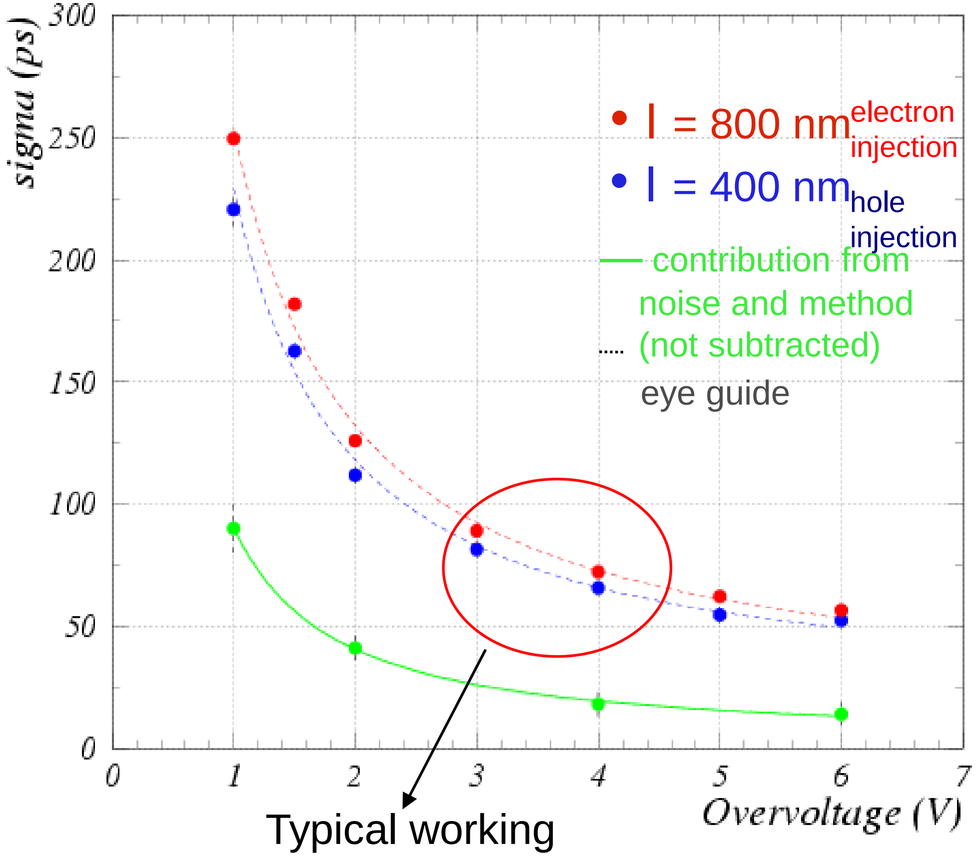
- Care against HF noise → feed-throughts !!!
- Amplifier Photonique/CPTA (gain~30, BW~300MHz)



SiPM samples

- FBK SiPM runII – 1mm^2 (Vbr~33V, fill factor~20%)

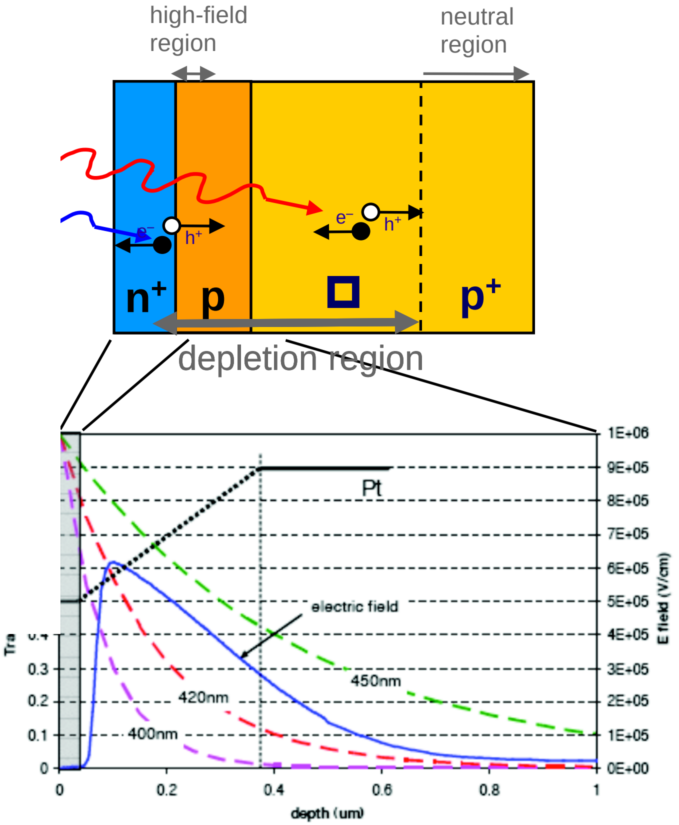
IRST – single photon timing res. (SPTR)



Typical working region

G.Collazuol et al NIMA 581 (2007) 461

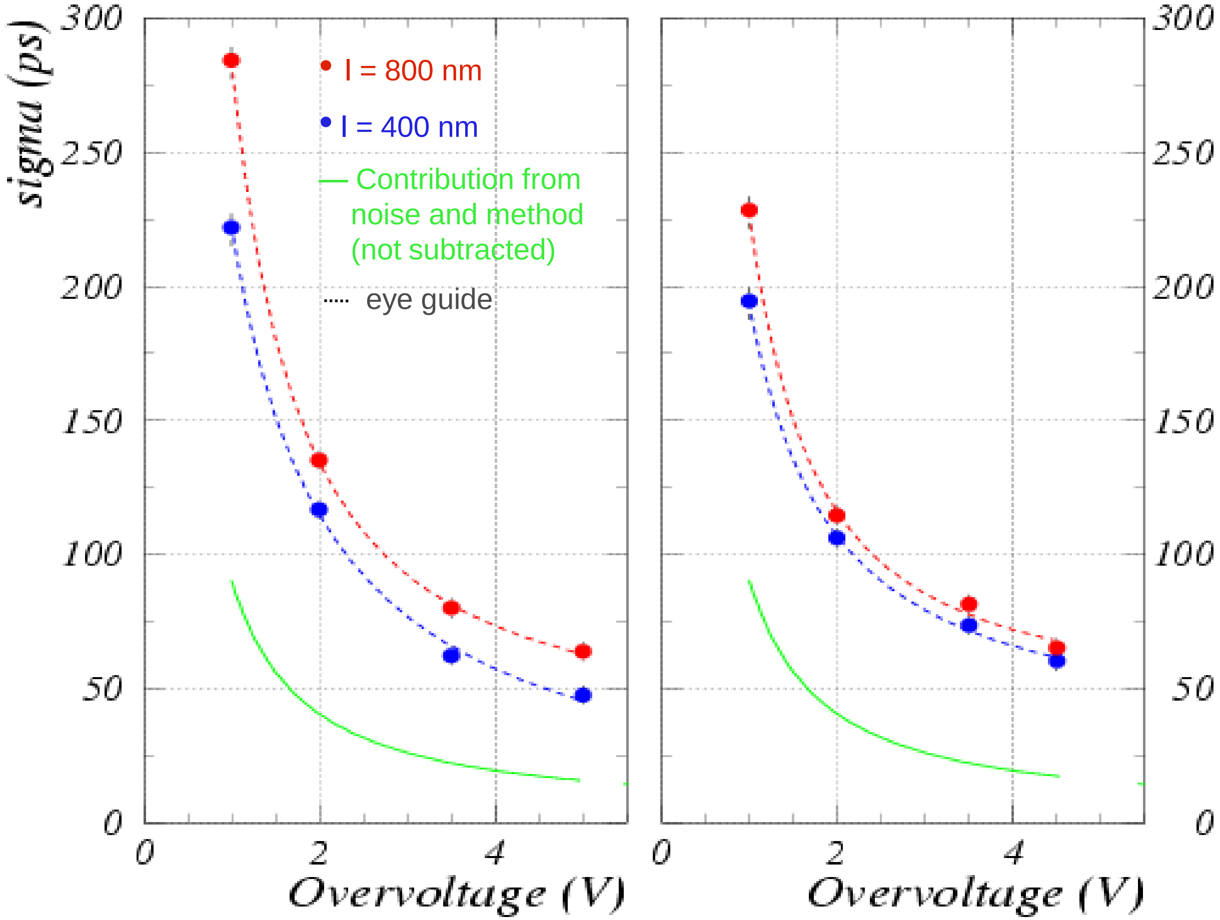
Better resolution for short wavelengths: carriers generated next to the high E field region

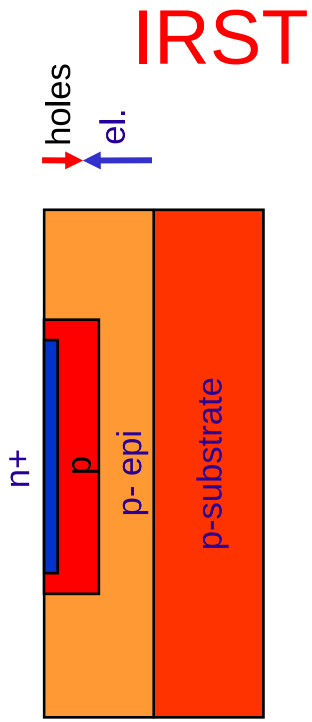


IRST devices (different types)

SiPM type without optical trench

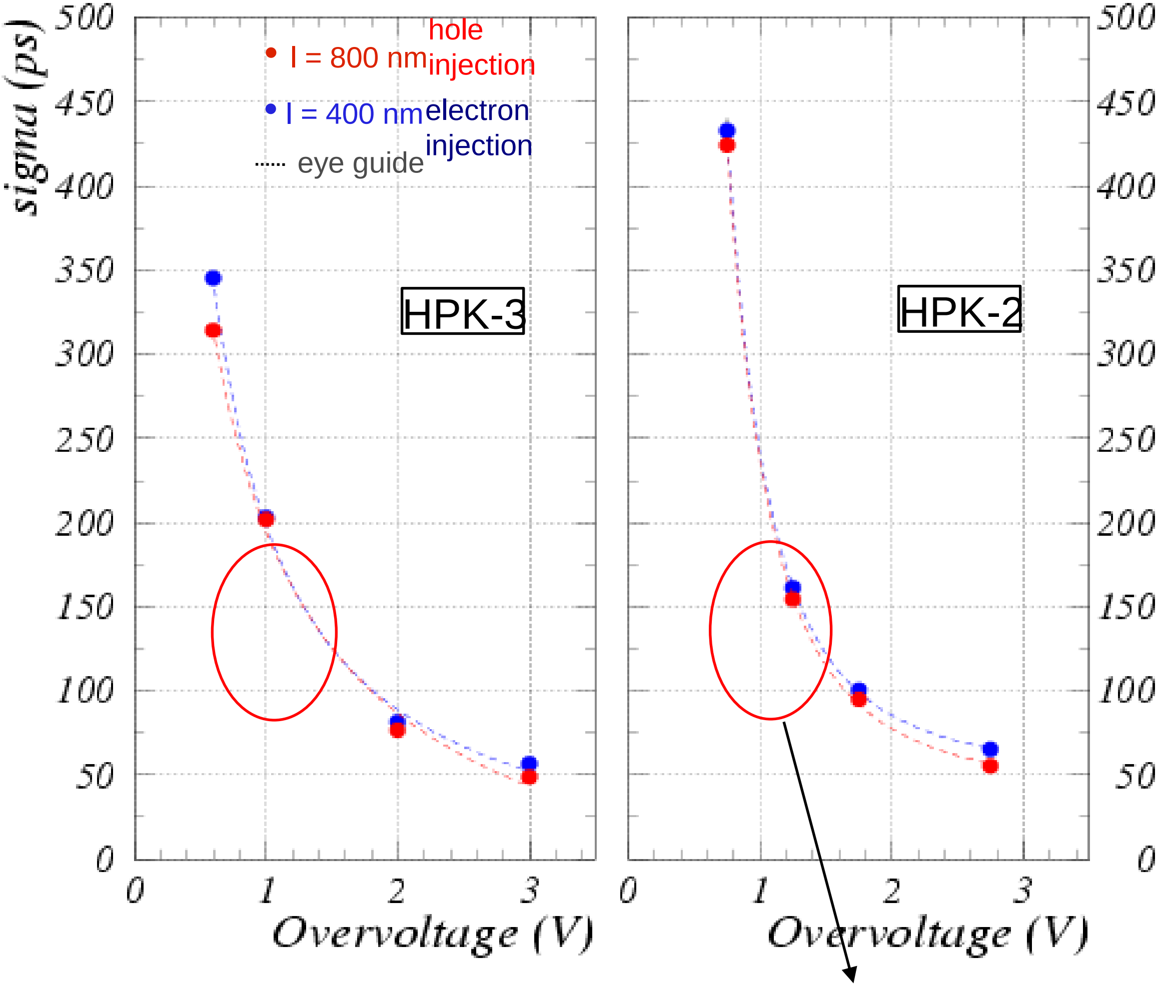
SiPM type with optical trench





Results in fair agreement for devices with the same structure

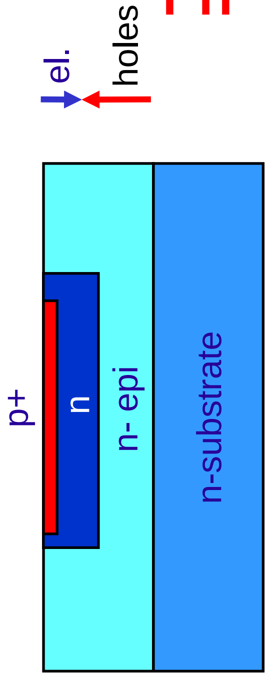
Hamamatsu – single photon timing res.



1600 cells (25x25µm²)

400 cells (50x50µm²)

HPK



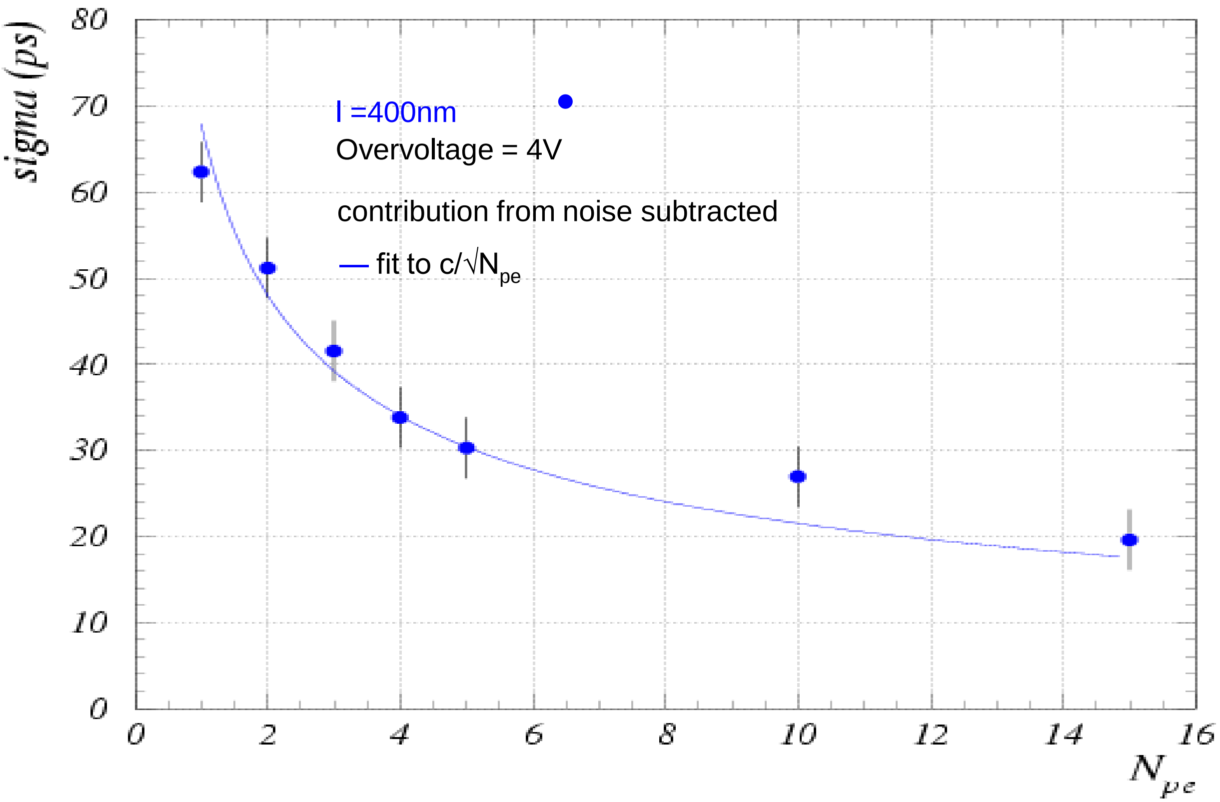
G.Collazuol et al (unpublished)

Suggested Operating range

Timing studies

Dependence of SiPM timing on the
number of simultaneous photons

Poisson statistics: $s_t \propto 1/\sqrt{N_{pe}}$



N of simultaneous photo-electrons

Conclusions

SiPM behave very well at low T, even better than at room T

In the range 100K<T<200K SiPM perform optimally;
→ excellent alternatives to PMTs in cryogenic applications (eg Noble liquids)

- Breakdown V decreases non linearly with T

→ stability of devices wrt T is even better at low T

- Dark rate reduced by orders of magnitude

→ different (tunneling) mechanism(s) below ~200K

- After-pulsing increases swiftly below 100K
- Cross-talk and Gain (detector capacity) are independent of T (at fixed Over-V.)
- PDE higher than at T room at low T for short λ

I just carried on **additional measurements at low T** with short laser pulses for:

- accurately measuring of after-pulsing characteristic time constant(s) vs T
- cross-checking PDE (pulsed vs current method)
- measuring timing resolution vs Temperature (expected to improve at low T)
- checking Gain resolution at low T

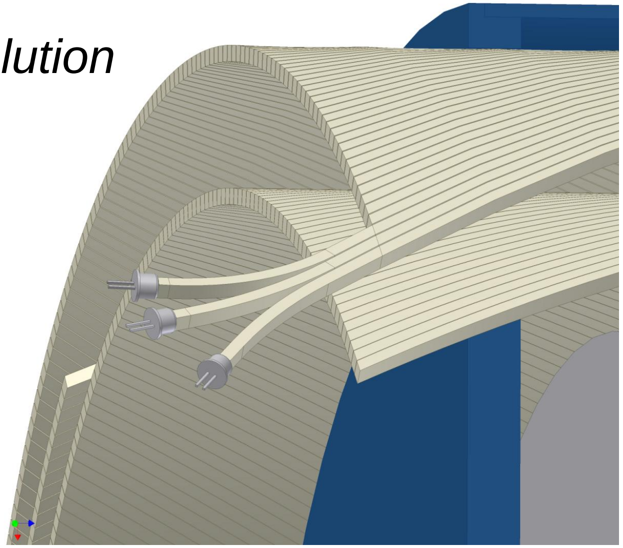
Simulations and modeling going on to understand better After-Pulsing and PDE features at low T

We measured also the **excellent SiPM intrinsic timing resolution (<100ps for 1p.e.)**
Recent additional measurements to be analyzed (time to avalanche, different devices, ...)
Simulations and modeling work going on to understand timing data in more detail

T2.1: SiPM-coupled advanced scintillating fiber detector

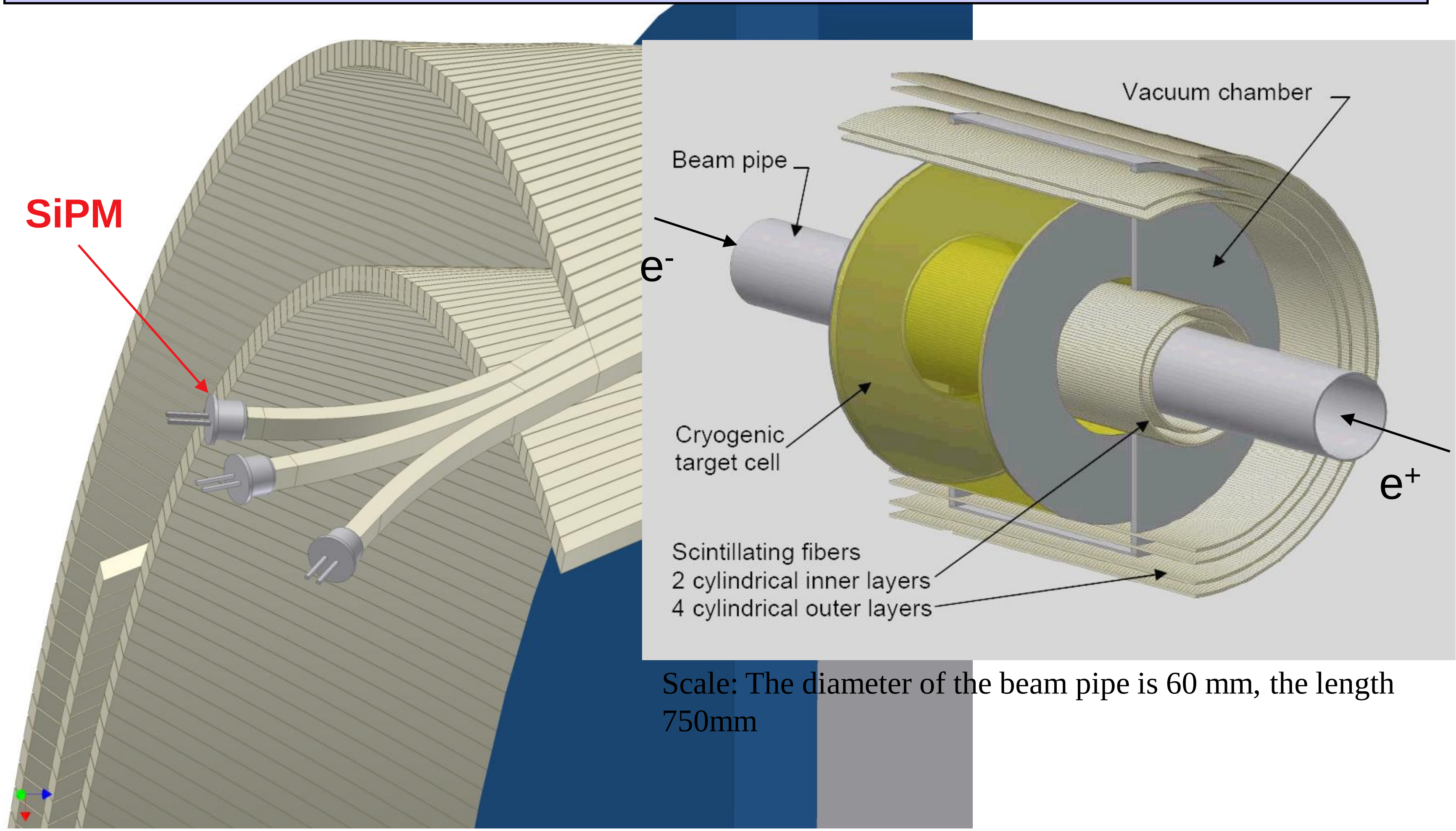
Important parameters of SiMP for low light level detection:

- *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



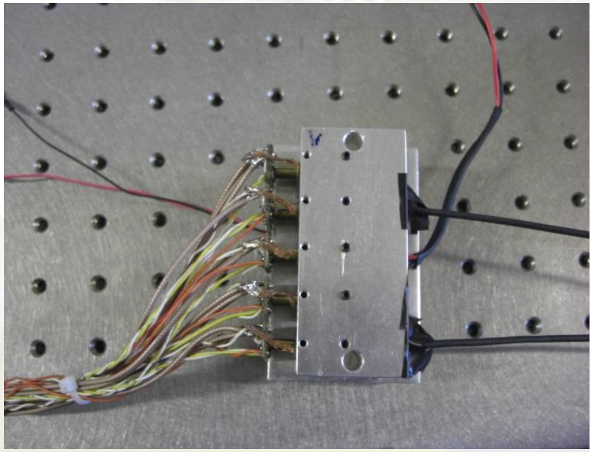
Scale: The diameter of the beam pipe is 60 mm, the length 750mm

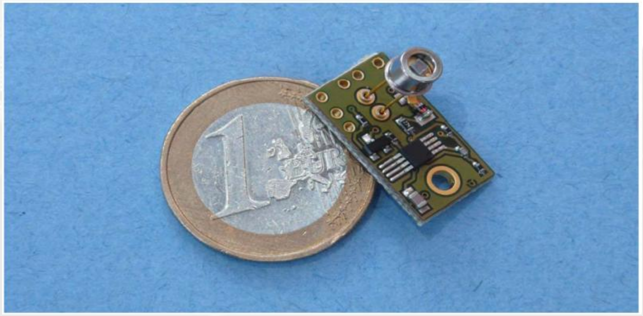
Trigger and tracker systems coupled to SiPM

Work at LNF

Characterizing SiPM : HAMAMATSU S10362-11-050U

Experimental details



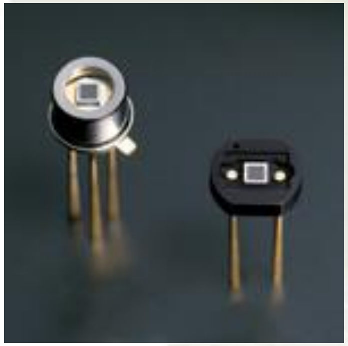


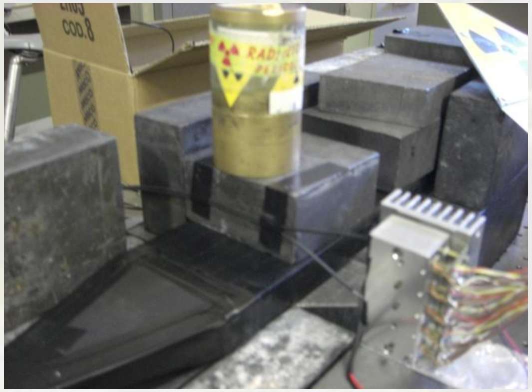
Pre-Amplifiers (X 100)

5 Channles HV power supply (stability better than 10 mV)

Scintillating fibers Bicron BCF-10 (blue)

SiPM (HAMAMATSU U50) (400 pixels)
Operating voltage ~70V



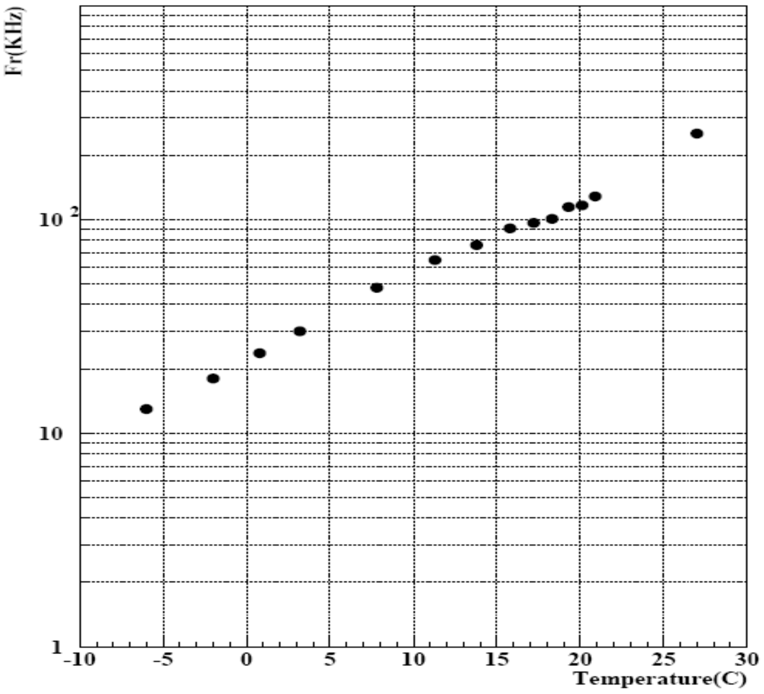


- Sr90 beta source (37 MBq)

Characterizing MPPC: Dark Count

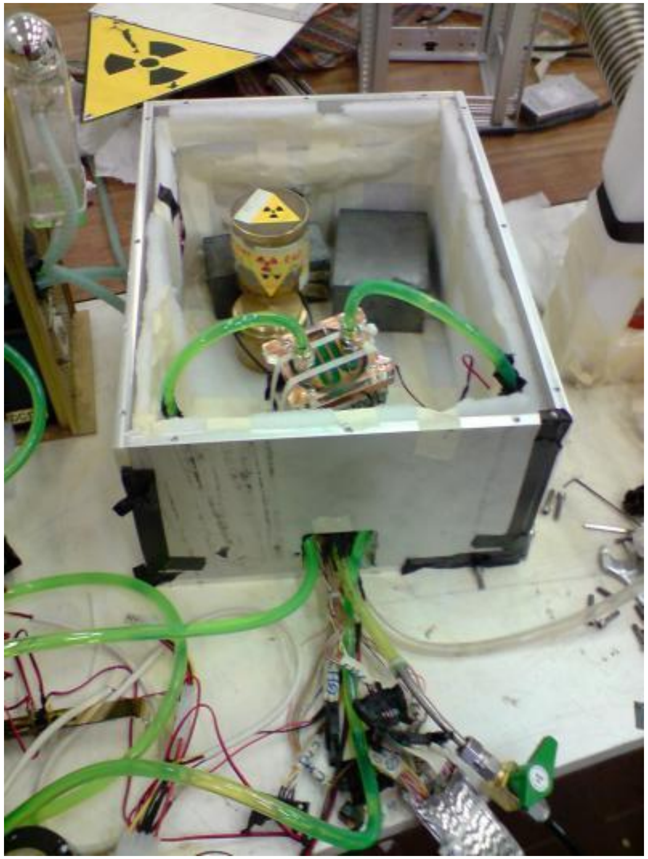
Detectors were cooled down in order to study their behaviour with temperature variations.

A scan of the 1 p.e peak rate is reported

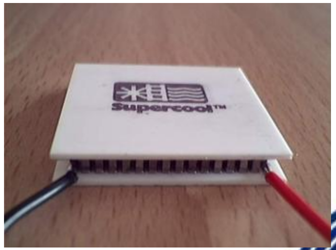


Dark count 1 p.e signal is reduced by a factor 20!

Cooling system



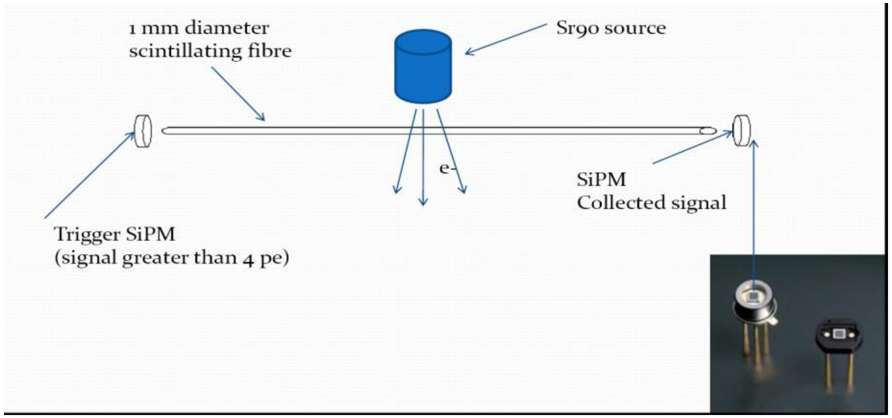
Peltier cell

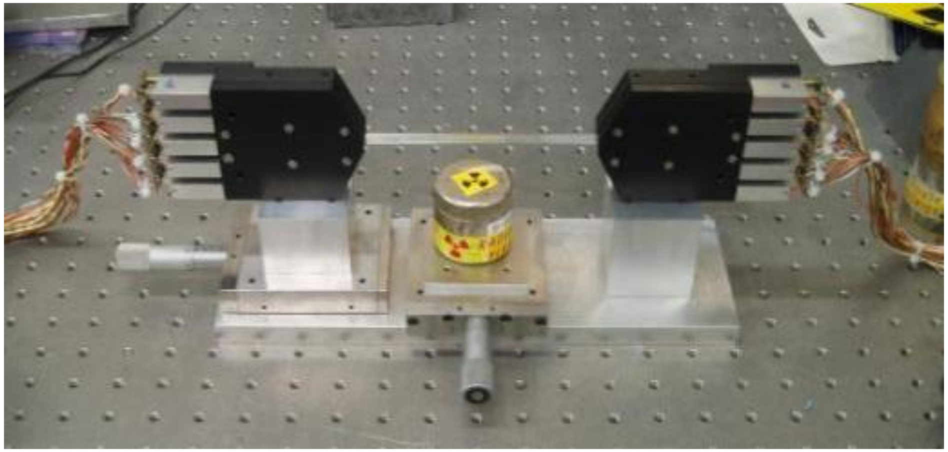


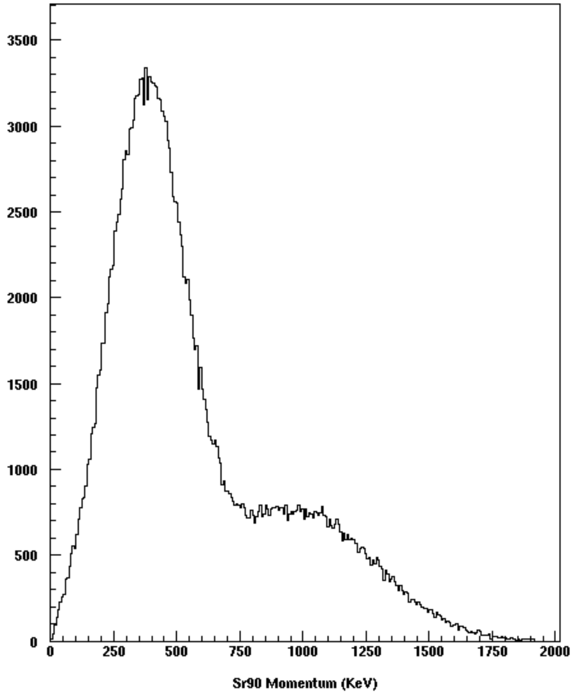
Characterizing SiPM:
reading scintillating fibers

-Saint Gobain BCF- 10 single cladding:

- -Emission peak 432 nm
- -Decay time 2,7 ns
- -1/e 2.2 m
- -4000 ph./MeV



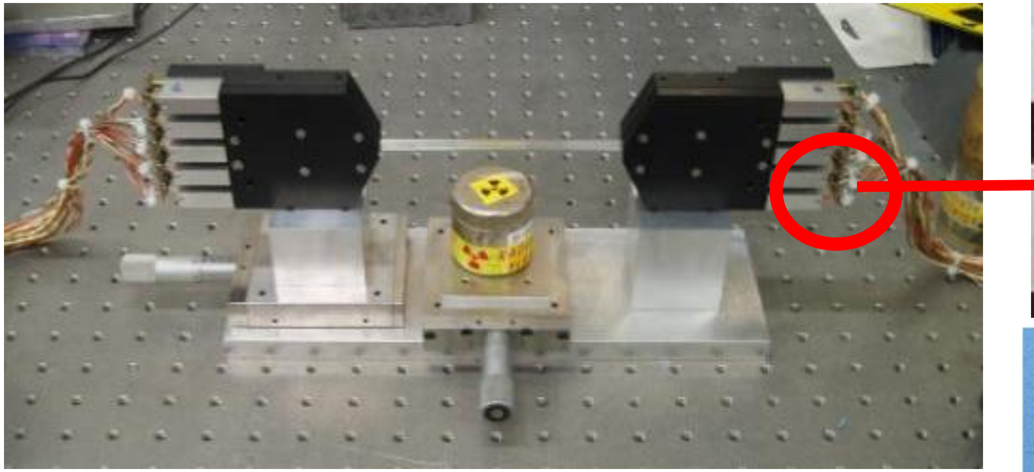


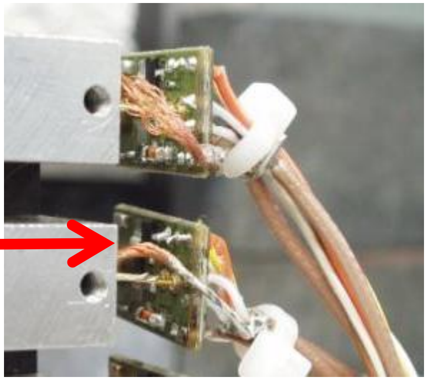


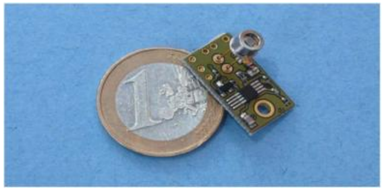
A scintillating fiber is activated by a beta Sr90 source

Both ends are coupled to detectors; one is used as trigger. When setting the threshold for the SiPM used as trigger, most part of dark count is eliminated.

SiPM+Fibers: ELECTRONICS





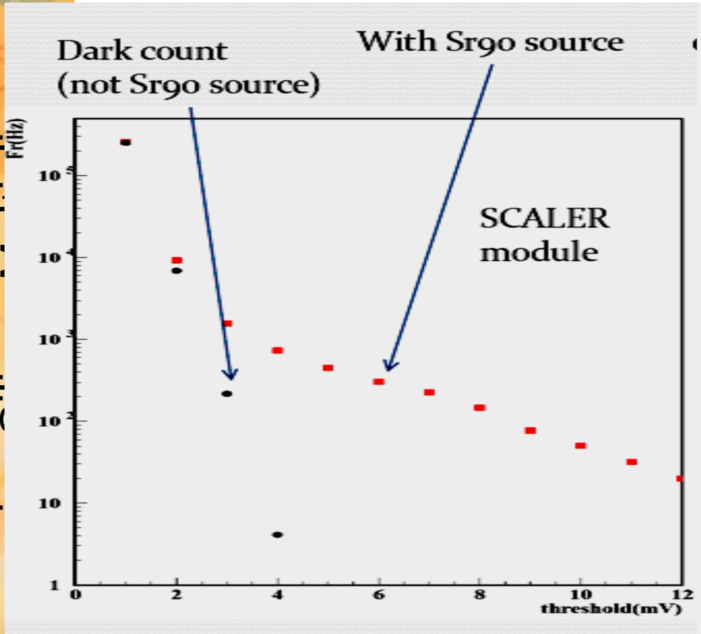


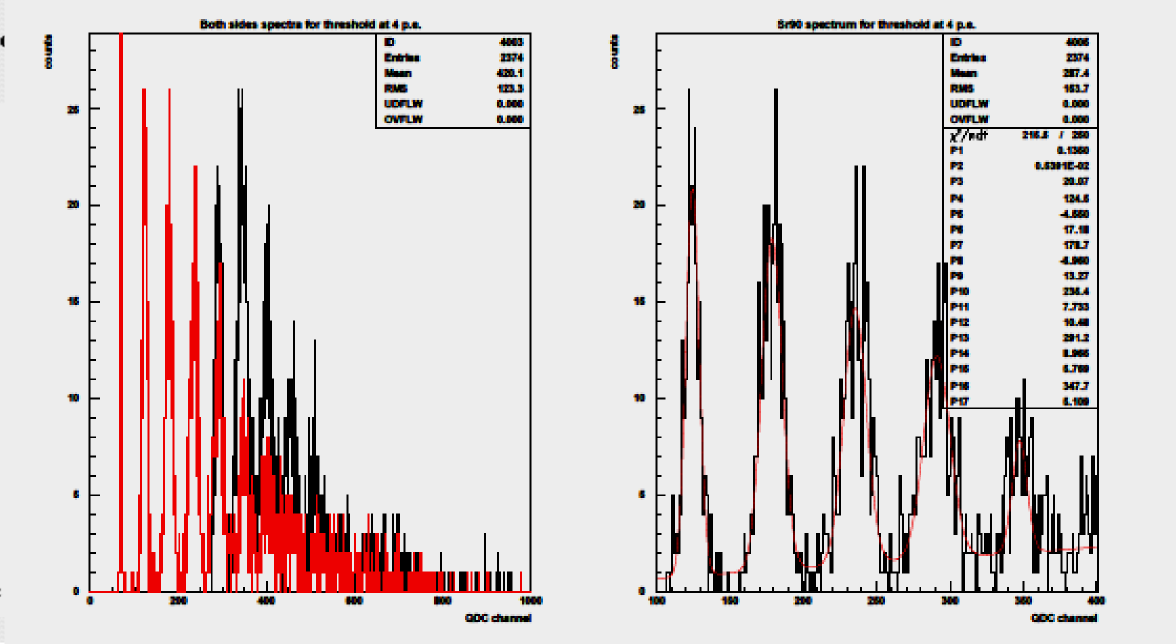
Electronics: New NIM modules providing:

- Variable V_{bias} for 5 channels with a **stability fo**
- **nominal voltages below 10 mV**
- 2 output / channel:
  - -Amplified (x25-x50-x100) signal
  - -Discriminated signal (variable threshold)

•Designed by G. Corradi, D. Tagnani, C. Paglia, INFN

SiPM+Scintillating Fibers



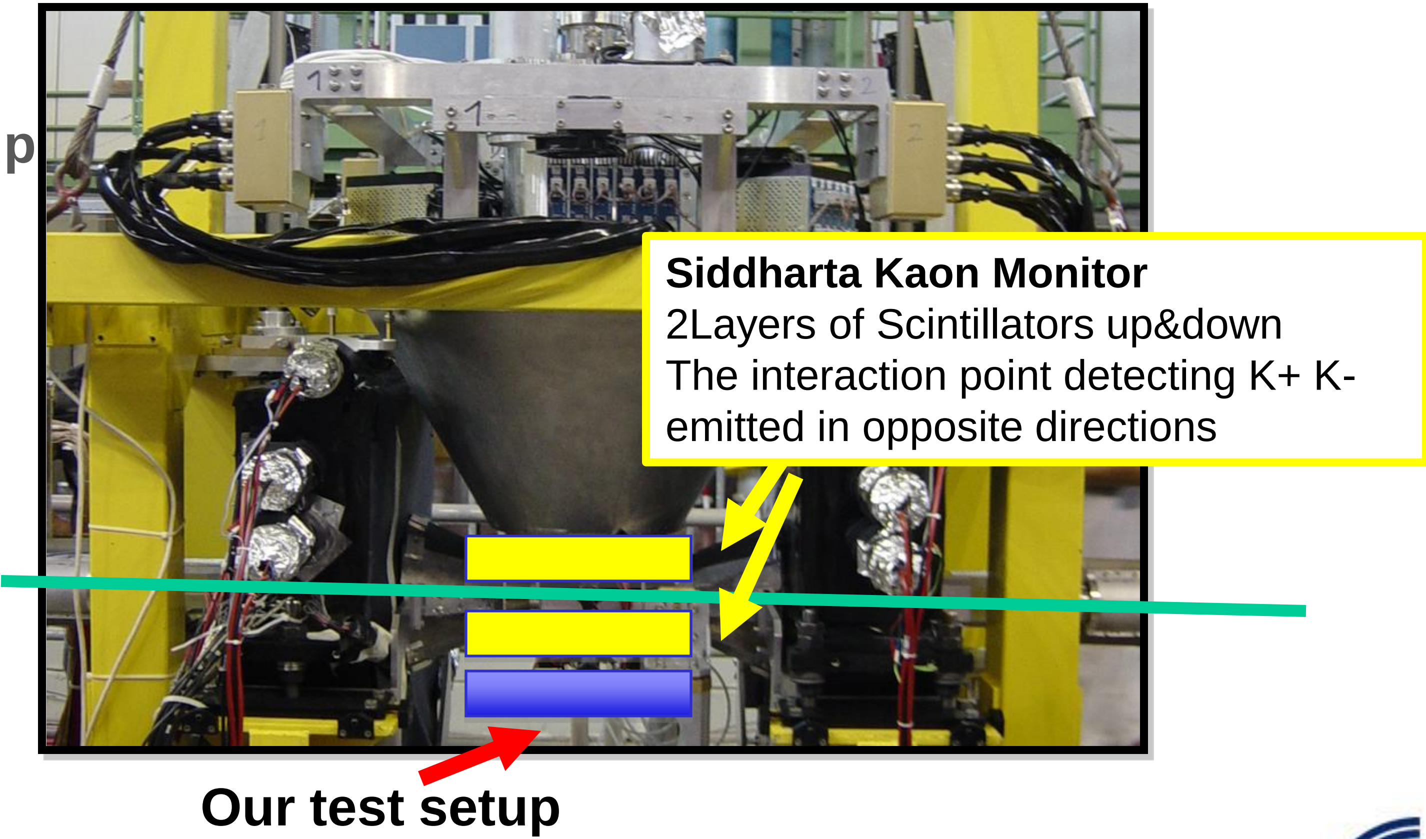


* Studying rates with and without the beta source, it turned out that starting from the 4th p.e. peak, dark count contribution is negligible

* No cooling is needed in this case!!!!

* With 4 p.e. threshold, main peaks of Sr90 are of 4 and 5 photoelectrons.

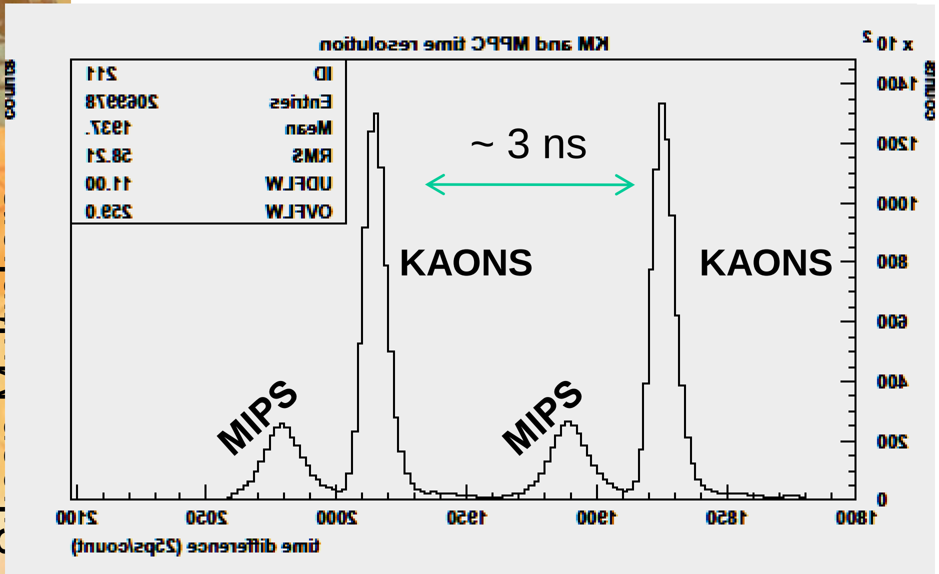
Tests installation at DAΦNE

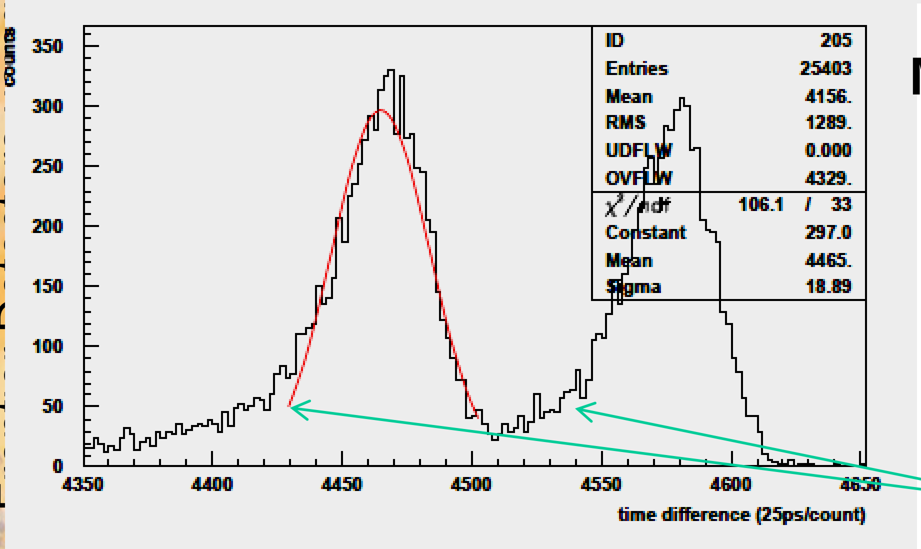


Siddharta Kaon Monitor
2Layers of Scintillators up&down
The interaction point detecting K+ K- emitted in opposite directions

Our test setup

Results with Kaon Monitor





Kaon Monitor TDC (upper/lower coincidence)

- TDC working in Common Start (RF/2)
- Single peak resolution~ 100 ps
- MIP/K separation ~ 1 ns

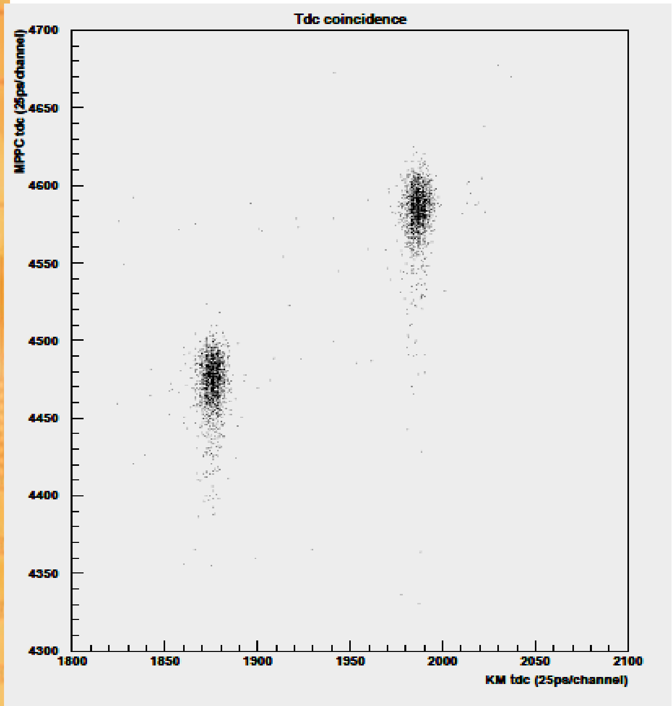
MPPC tdc spectra

- TDC working in Common Stop (RF/4)

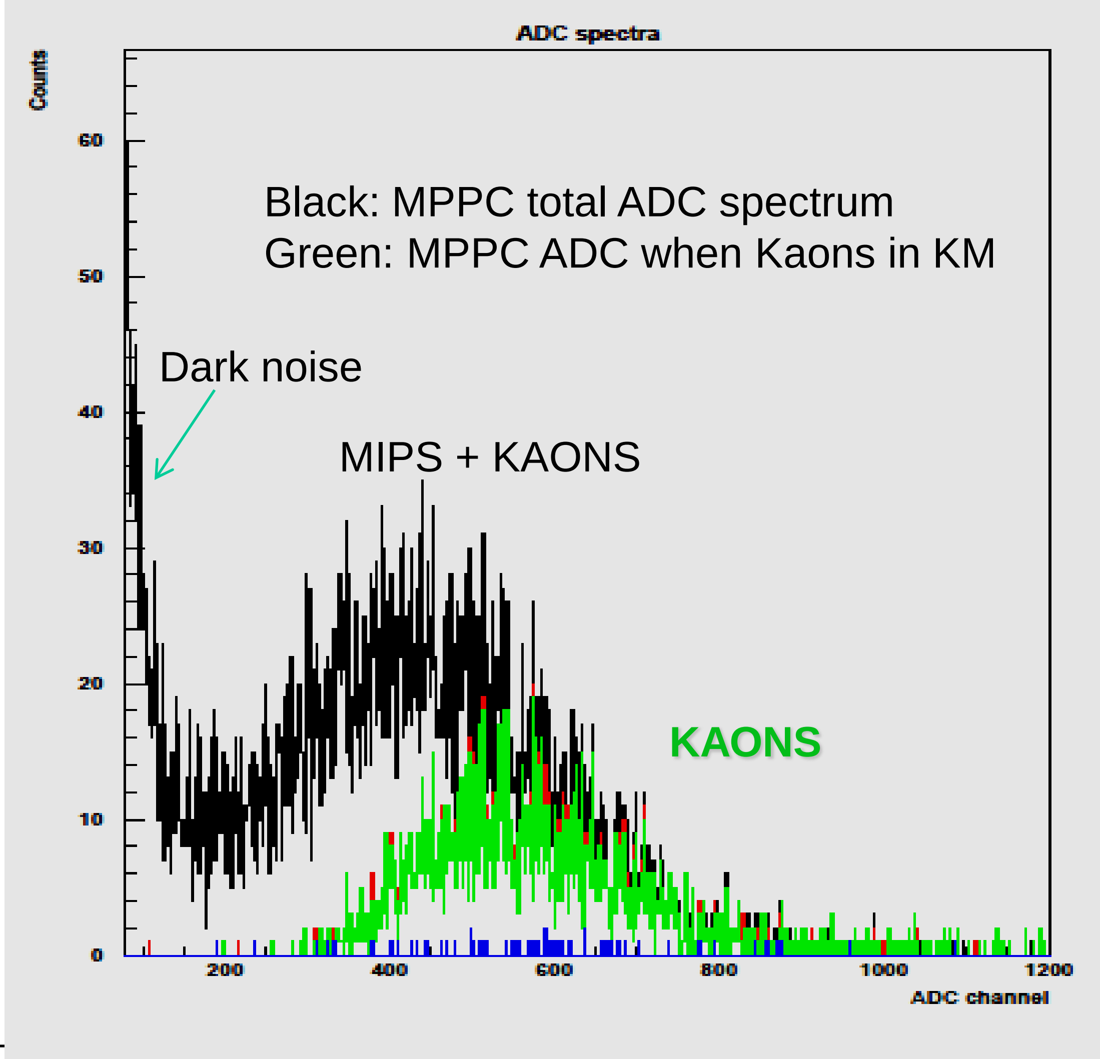
Achieved best single peak resolution around 500 ps

Missing MIPS

Results with Kaon Monitor



Time correlation between MPPCand KM



Black: MPPC total ADC spectrum
Green: MPPC ADC when Kaons in KM

Dark noise

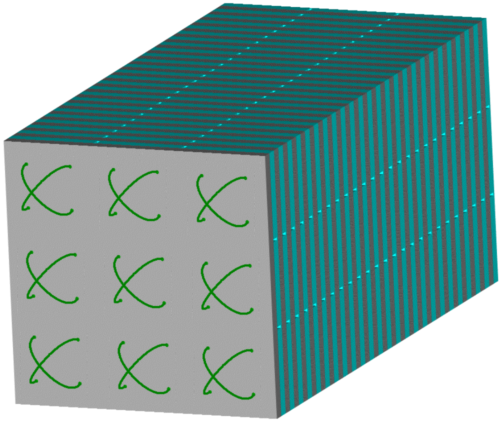
MIPS + KAONS

KAONS

T2.2: SiPM for fast calorimetry

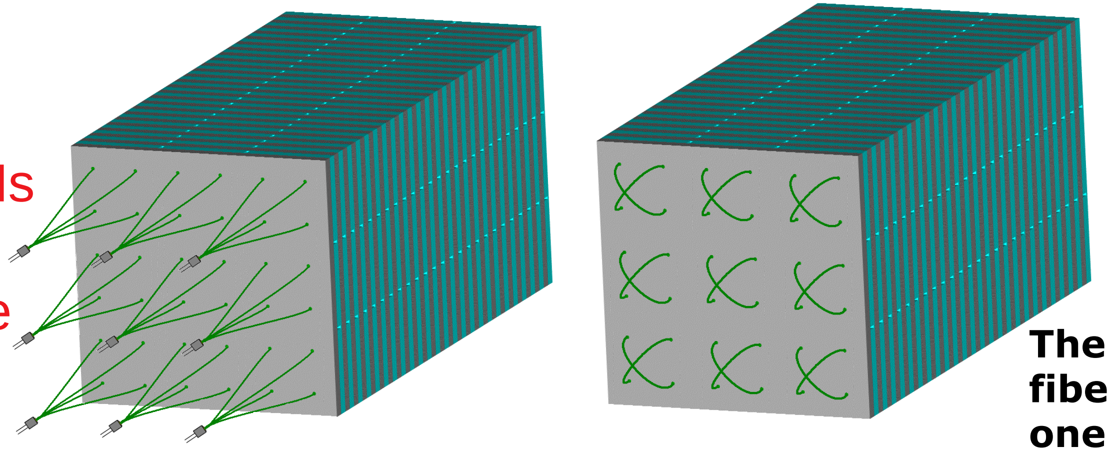
Important parameters of SiMP for high light level:

- *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

Construction of prototype “Shashlik” module with SiPM



9 SiPMs per module

Parameters of the prototype “Shashlik” module for COMPASS.

Transverse size	100 x 100 mm^2
Number of the layers	20 (25)
Polystyrene scintillator thickness	4.0 mm
Lead absorber thickness	4.0 mm
Number of holes per layer	6 x 6
Holes spacing	16.6 mm
Holes diameter in Scintillator/Lead	1.2/1.3 mm
WLS fibers per module	18 x 0.6 m ≈ 11m
Diameter of WLS fiber	1.0 mm, (1.2 mm)
Diameter of fiber bundle	3 mm, (3.5 mm)
Effective radiation length X0	11.5 mm
Effective Moli`re radius RM	20 mm
Active length	160mm /14,5.X0 (200mm/18 XO)
Number of SiMP per module	9

The outputs of 4 fibers are joined into one channel hence we have the grid with 33 x 33 mm cell. Each cell is optically isolated from others. Such calorimeter structure provides good resolution for a few gamma-events in particular the possibility to identify effectively the photons from π^0 decay.

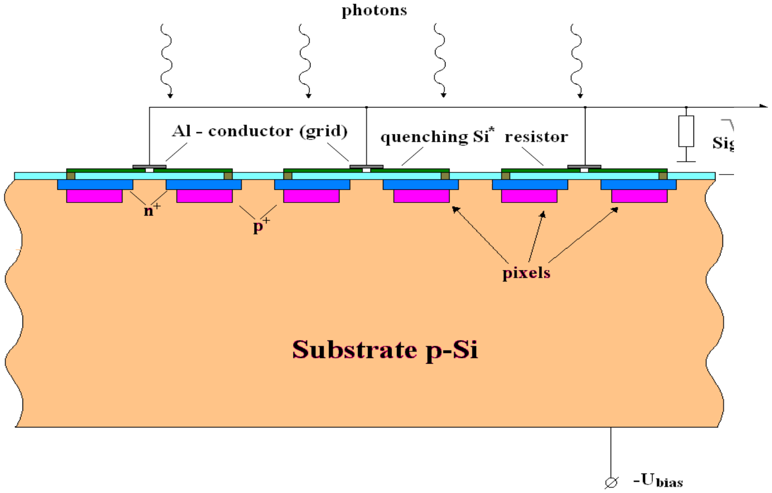
Novel deep micro-well MAPD with super high pixel density and their applications

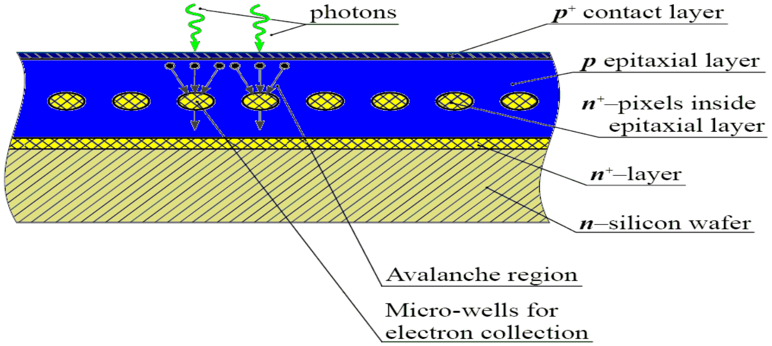
Anfimov Nikolay

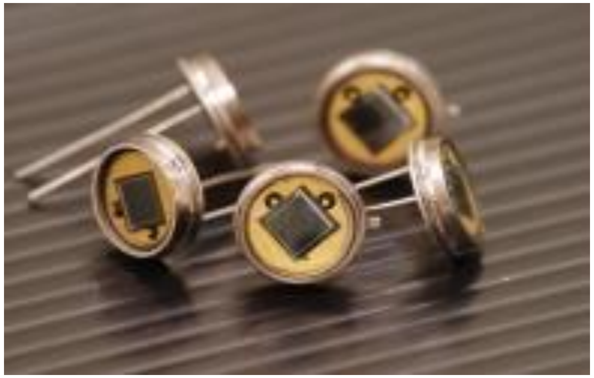
anphimov@gmail.com, +7(49621)6-24-83

DLNP, Joint Institute for Nuclear Research,
141980, Joliot-Curie 6, Dubna, Russia.

Two basic constructions of MAPDs





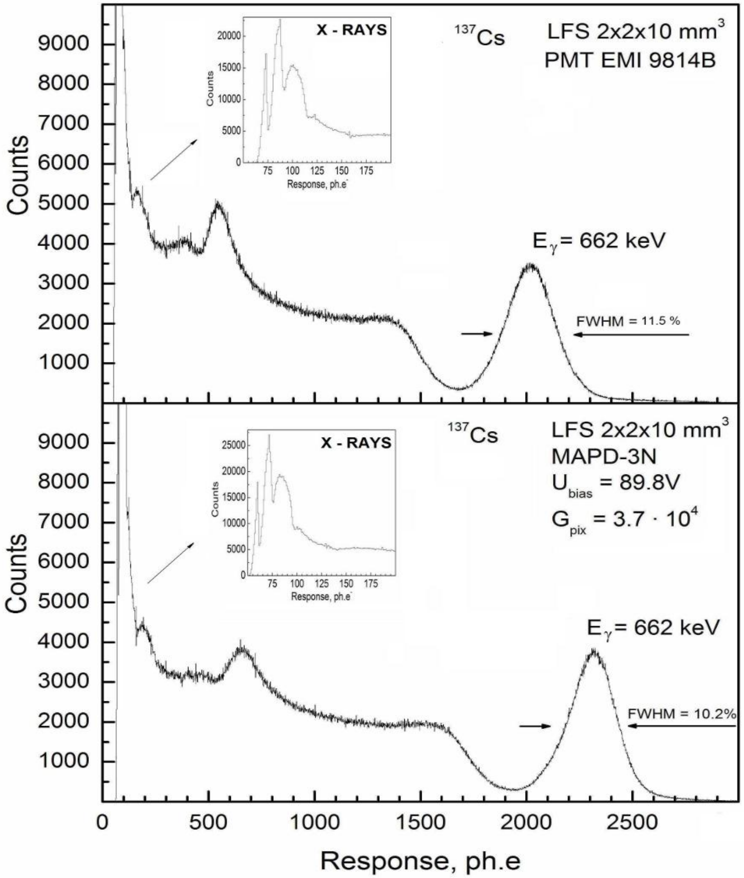


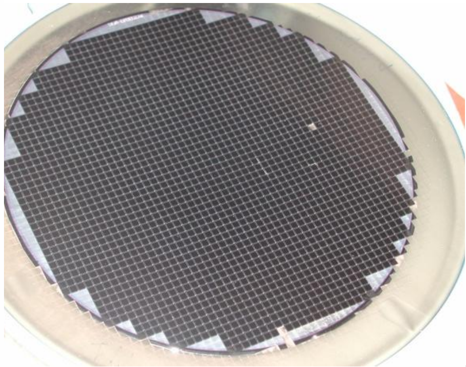
Main Features of DMW-MAPD:

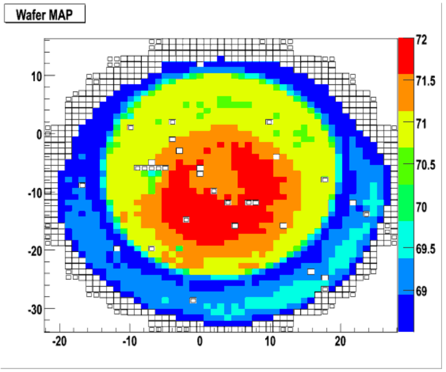
- High Dynamic Range (pixel densities of up to 40000 mm^{-2})
- Photon Detection Efficiency up to 30 %
- Gain up to 10^{5}
- Better radiation hardness
- Insensitivity to magnetic field.
- Compact and rigid
- Low voltage supply (<100 V)

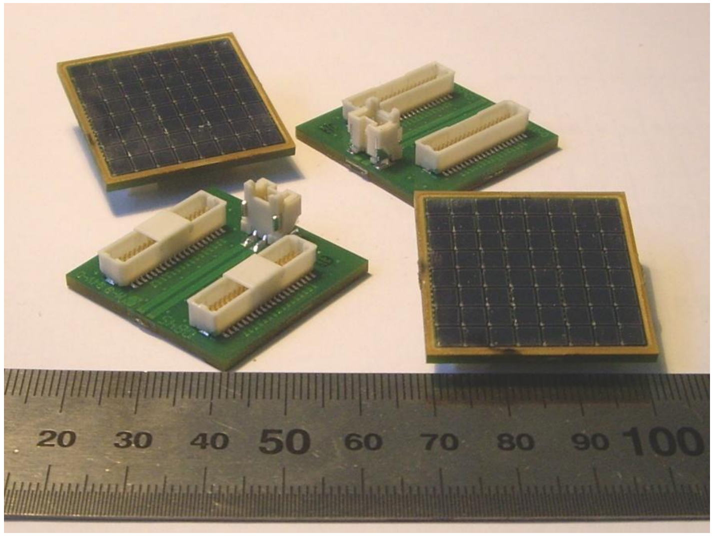
- Drawbacks:
- Temperature dependence
- High dark rate (> 0.5 MHz/mm^{2})
- Large Recovery time.

Sensor Matrices from Zecotek/Dubna









EM - Calorimetry

Insensitivity to magnetic field;

High dynamic range ~ 10^5 ph.e.

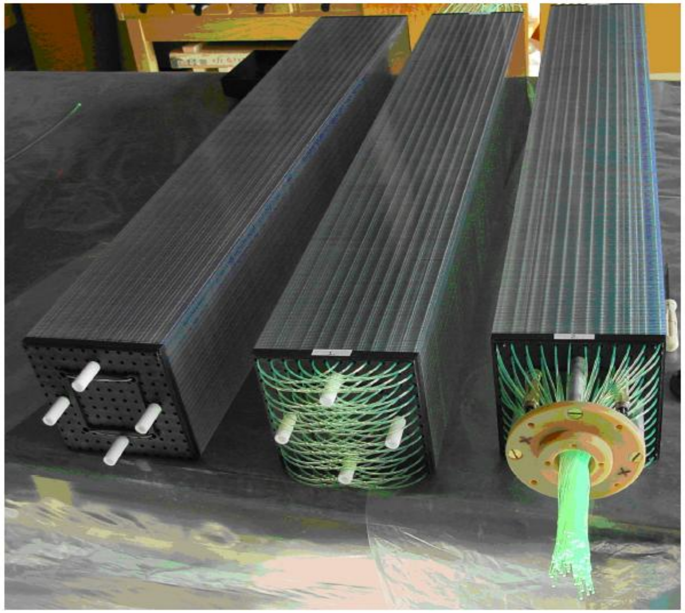
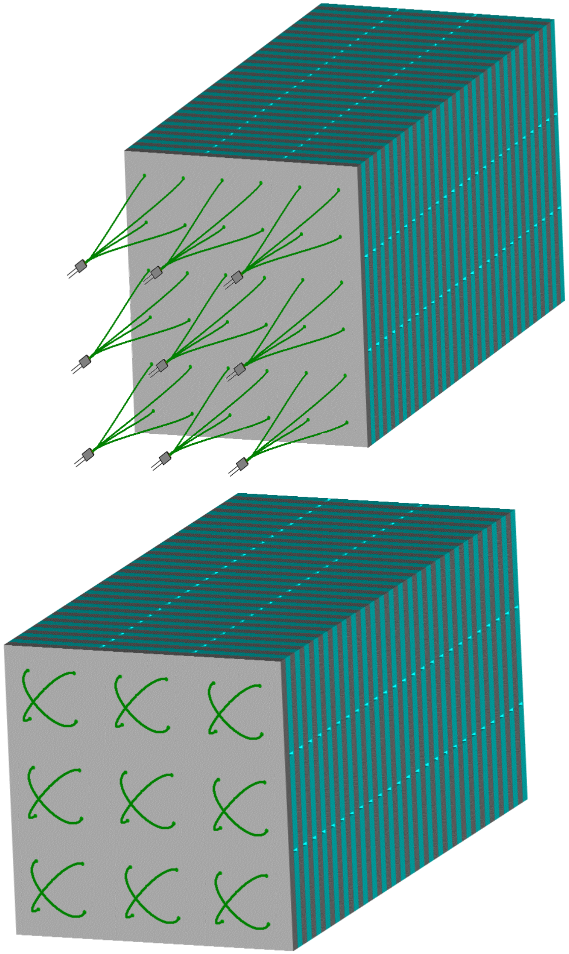
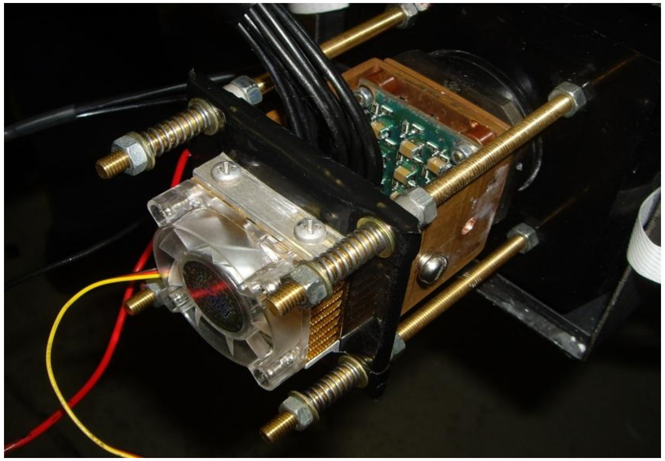


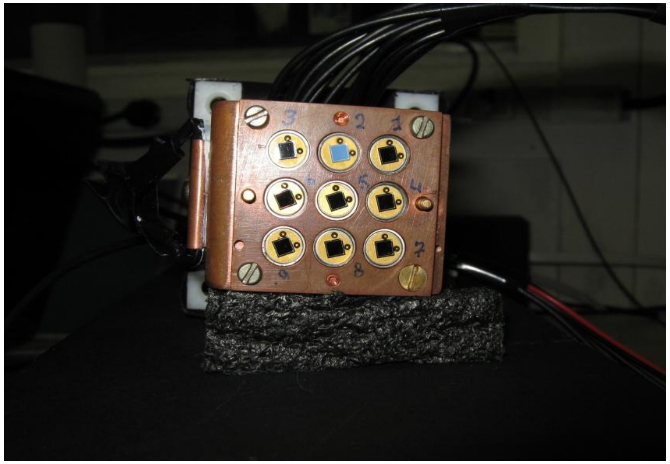
Fig. 1. The Shashlyk modules at different stages of assembly

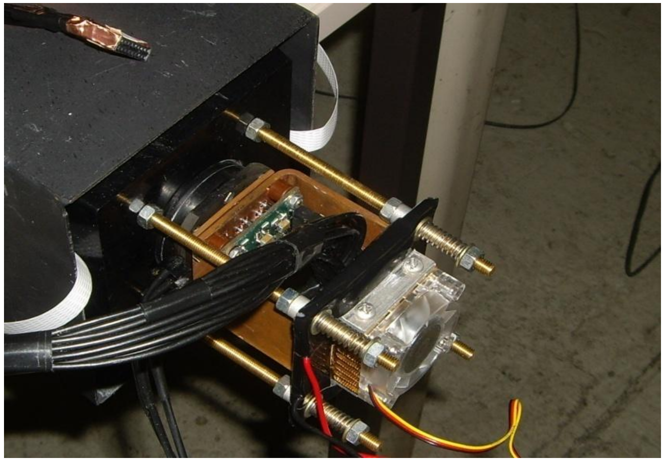


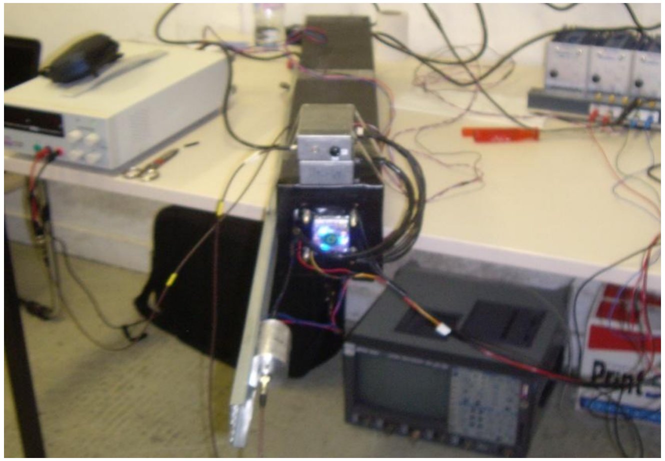
EM - Calorimetry

- General view of the optical head with 9-MAPD mounted on a shashlik module



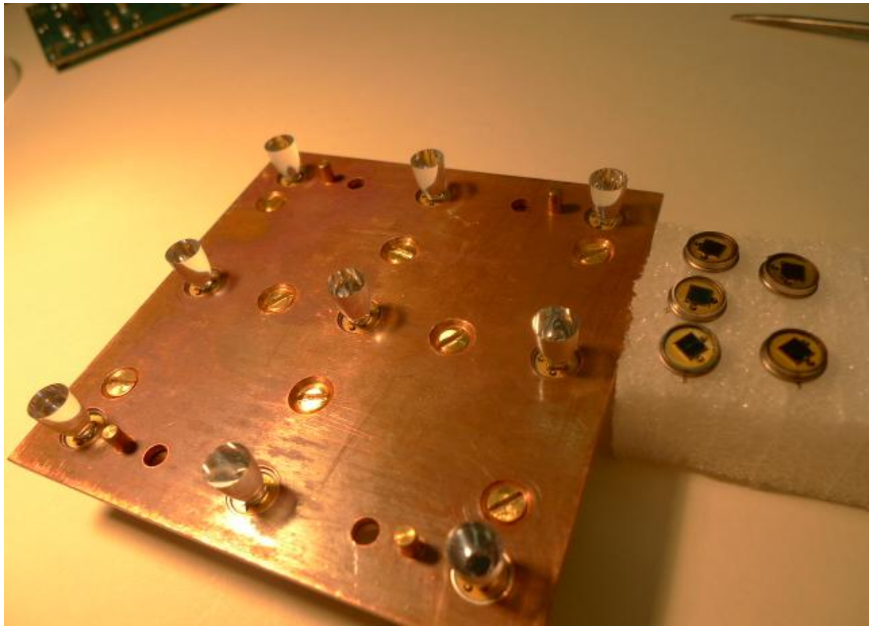






EM - Calorimetry

- Winston's cones allow to collect more light from fibers



Increase of MAPD sensitive area

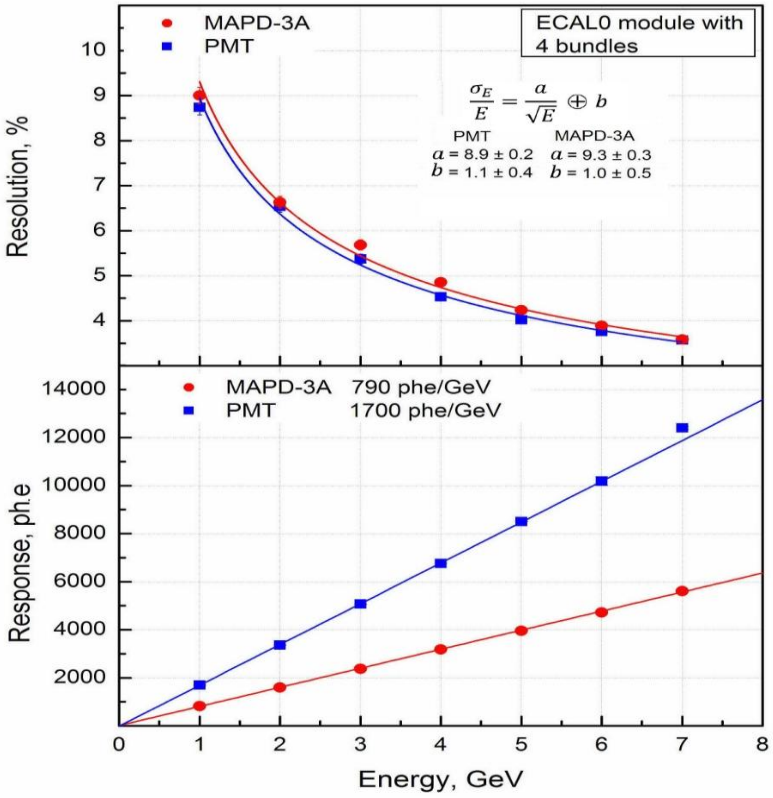
EM - Calorimetry

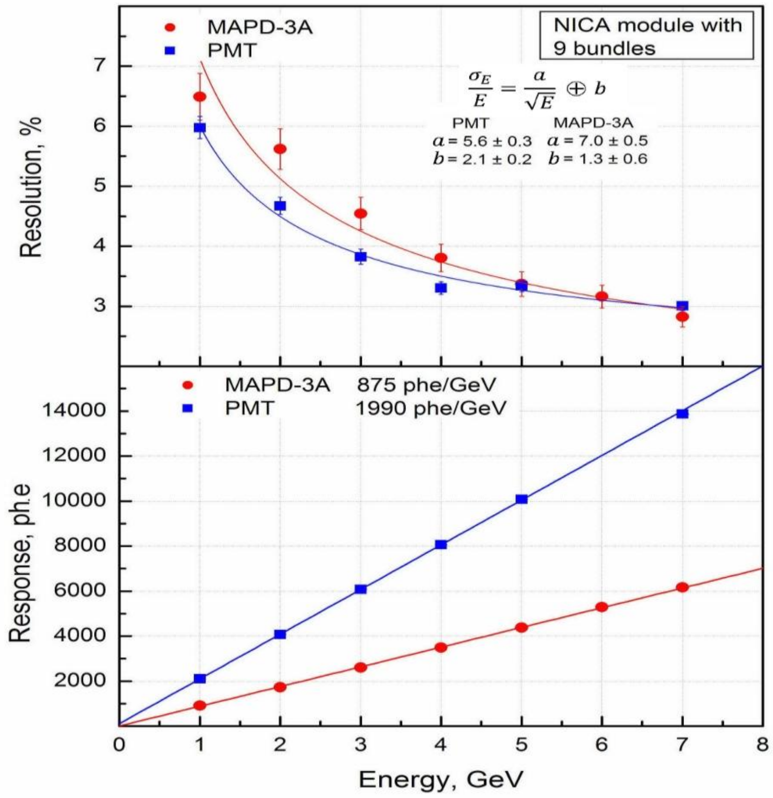
- Parameters of the tested modules:

ECAL0 – 4 bundles	NICA – 9 bundles
Scintillator – 4 mm	Scintillator - 1.5 mm
Lead - 2 mm	Lead - 0.275 mm
Distance between scintillators – 2.36 mm	Distance between scintillators – 0.35 mm
Number of pair – 66 pcs.	Number of pair – 300 pcs.
Size of plates - 121.0×121.0 mm^2	Size of plates - 109.7×109.7 mm^2
Radiation length – 16.4 mm	Radiation length, X_0 – 34.9 mm
Total length – 420 mm (25 X_0)	Total length – 555 mm (15.9 X_0)
Moliere radius – 35 mm	Moliere radius – 59. 8 mm
Number of fibers – 64 pcs	Number of fibers – 144 pcs
Number of bundles – 4 pcs	Number of bundles – 9 pcs
Diameter of fibers – 1.2 mm	Diameter of fibers – 1 mm
Bundle diameter – 6.5 mm	Bundle diameter – 6 mm

EM - Calorimetry

- Energy resolutions for two different modules
- MAPD readout in comparision with PMT readout





Electromagnetic-Calorimetry with wavelength shifting fibers

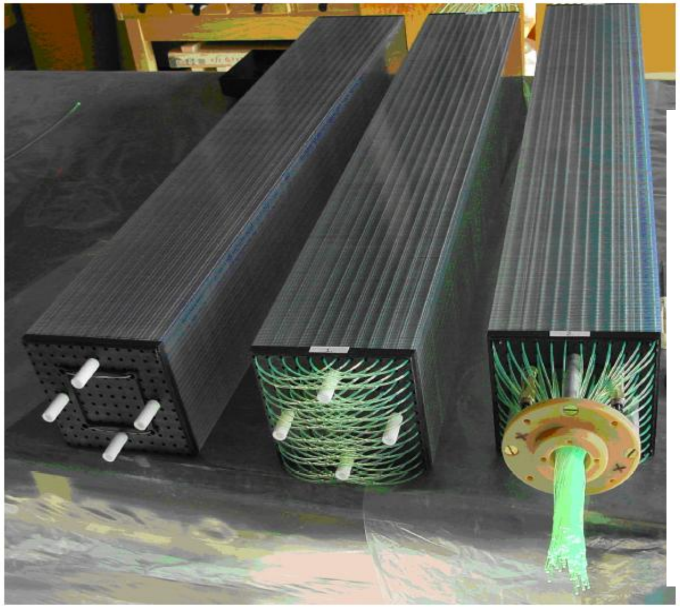
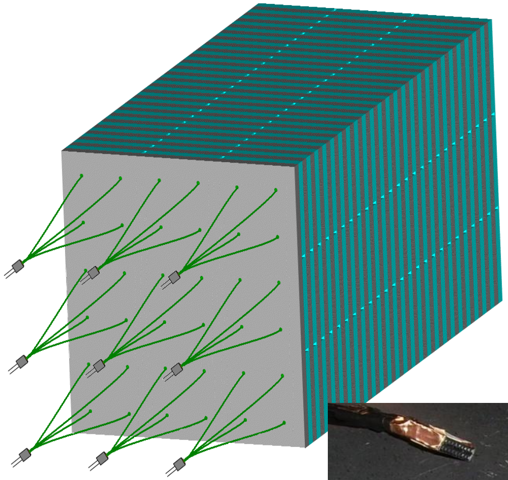
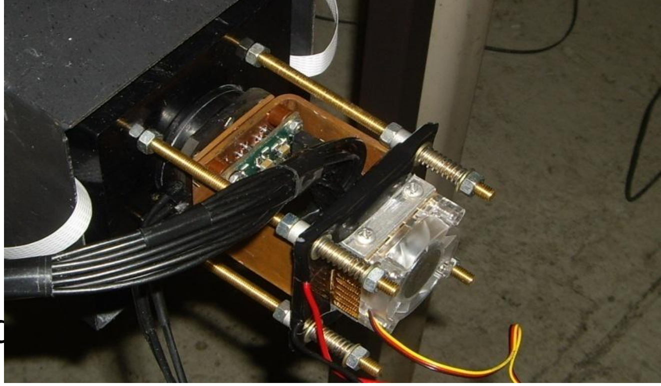


Fig. 1. The Shashlyk modules at different stages of assembly



MAPD3N sensors+Winston cones



High dynamic range ~ 10^5 ph.e.

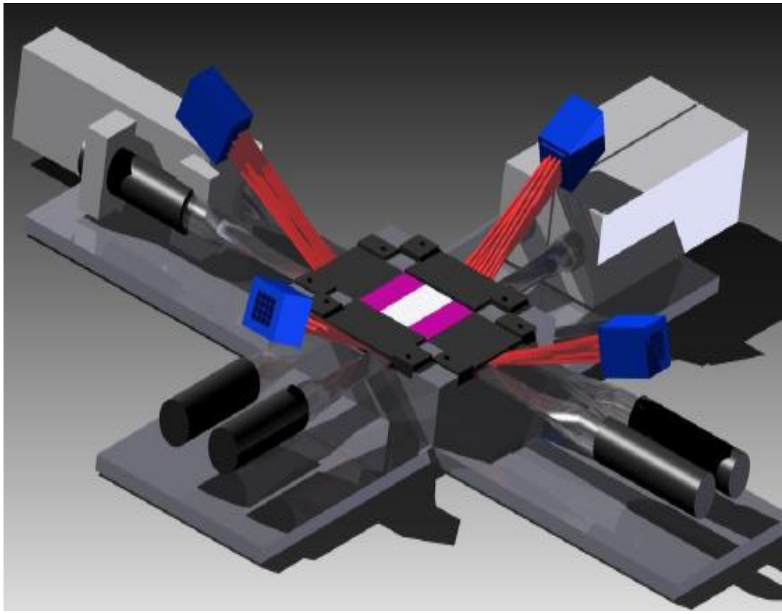
After the construction and demonstration of the optical head in a Shashlik calorimeter module (HP2), work will be concentrated on the integrated design and construction of 3x3 MAPD matrix with light concentrators, temperature stabilization and preamplifiers. The idea is to have a hybrid chip (~15x15 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.

T2.3: Read-out of crystalline fibers with SiPM

Important parameters of SiMP coupled to inorganic fibers:

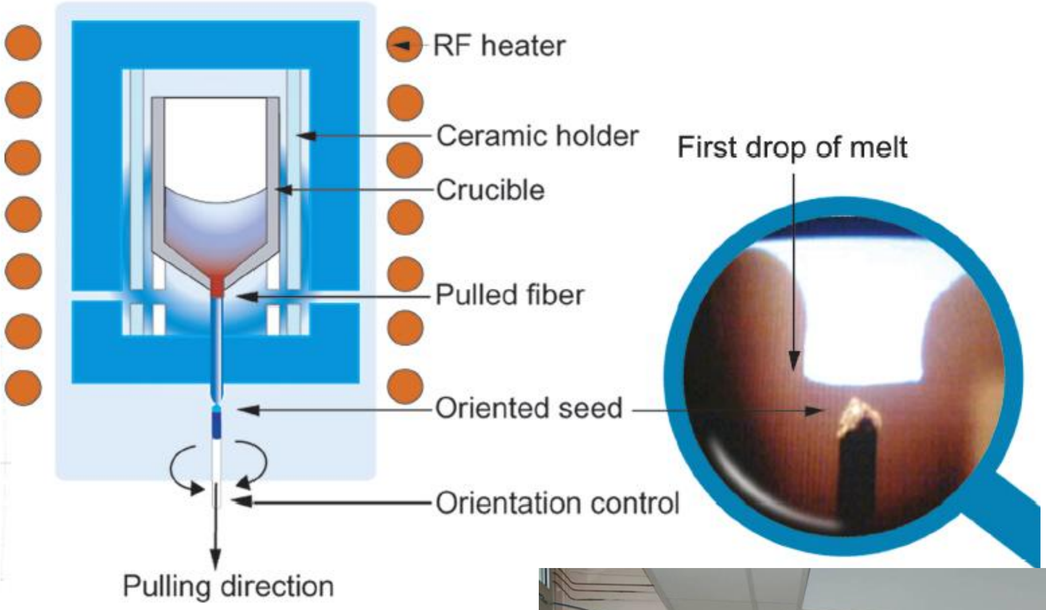
- *Small sensor area high PDE (>30 %)*
- *High granularity for good linearity*
- *Fast single photon response for good timing*
- *Working in high magnetic field*
- *Noise performance uncritical*



R&D: Planar Beam Monitor

Closely together with WP21 SciFI

• technology: micro-pulling-down technique (μPD)

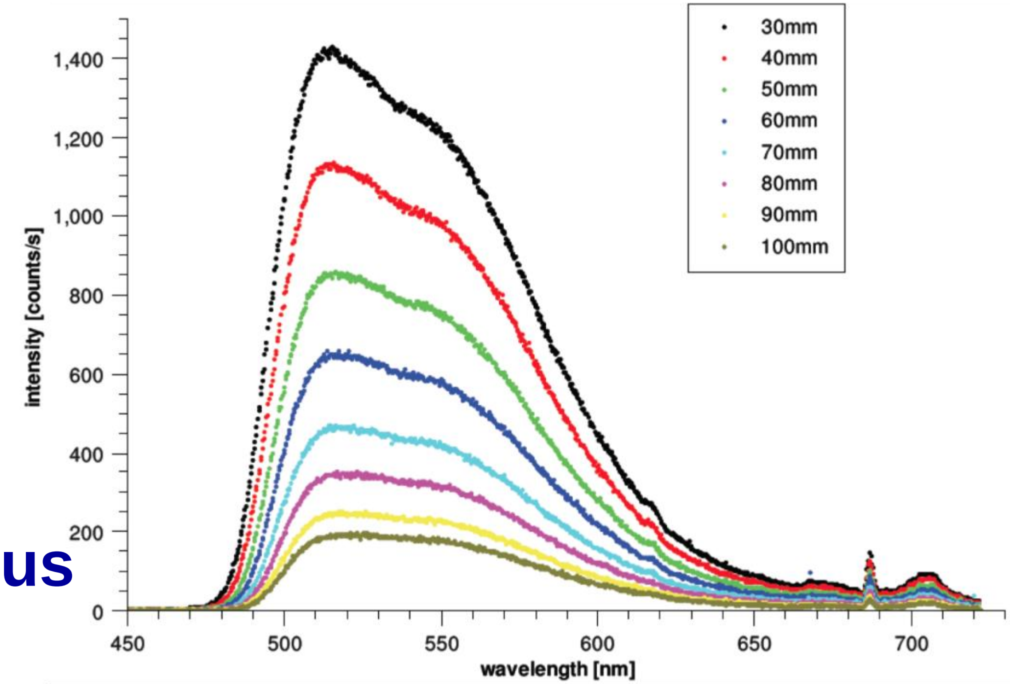


installation @ Fiber*Cryst*

material	density g/cm^3	Z_{eff}	emission wavelength nm	index of refraction	decay time ns	light Yield ph/MeV
LuAG :Ce	**6.7**	**63**	**530**	**1.84**	**50-100**	**15.000**

$Lu_3Al_5O_{12}:Ce^{3+}$

tested fibers: 0.45mm - 2.0mm

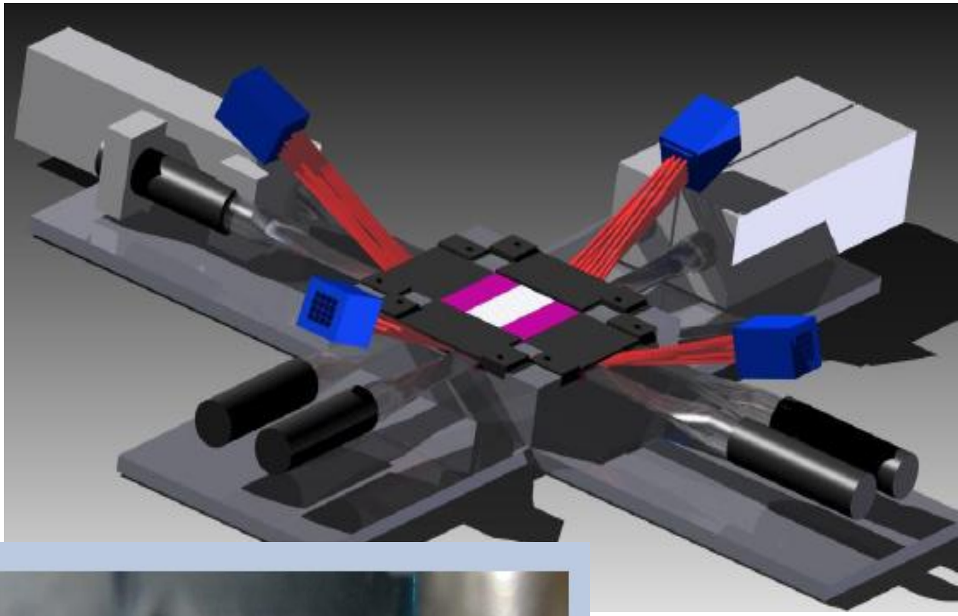


emission spectra at various positions: slight changes

YAG:Ce

Detector Applications (WP21)

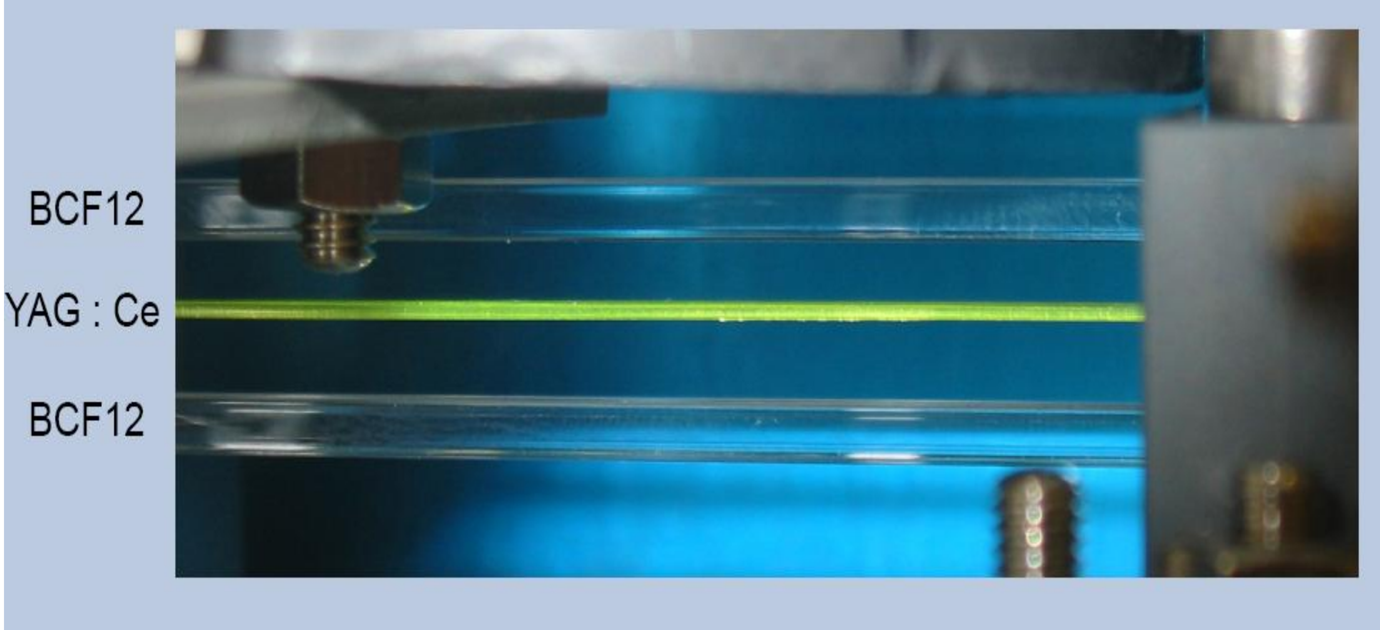
e⁻ / γ beam monitor
(Bonn)



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.

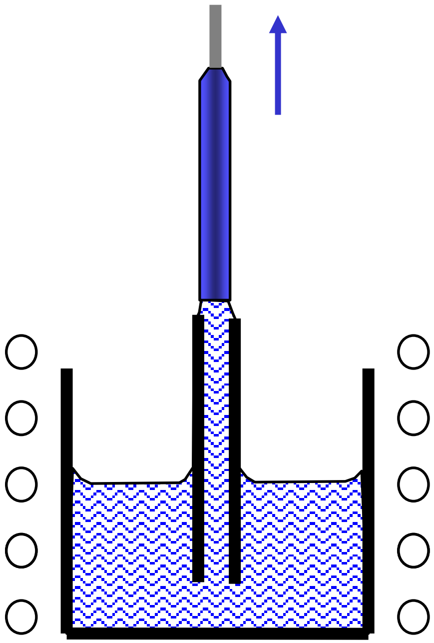
Institute of Solid State Physics Russian Academy of Sciences,

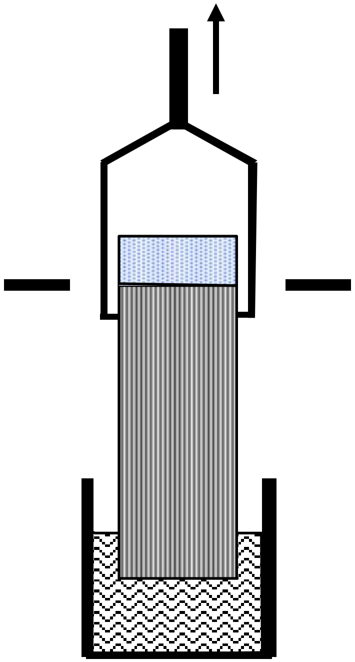
Chernogolovka, 142432 Russia

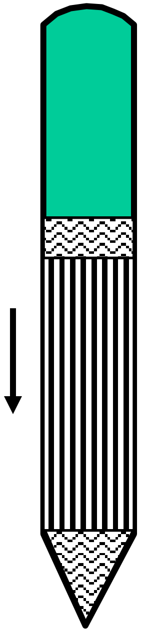
Growth techniques at ISSP (RAS)

different from FiberCrist

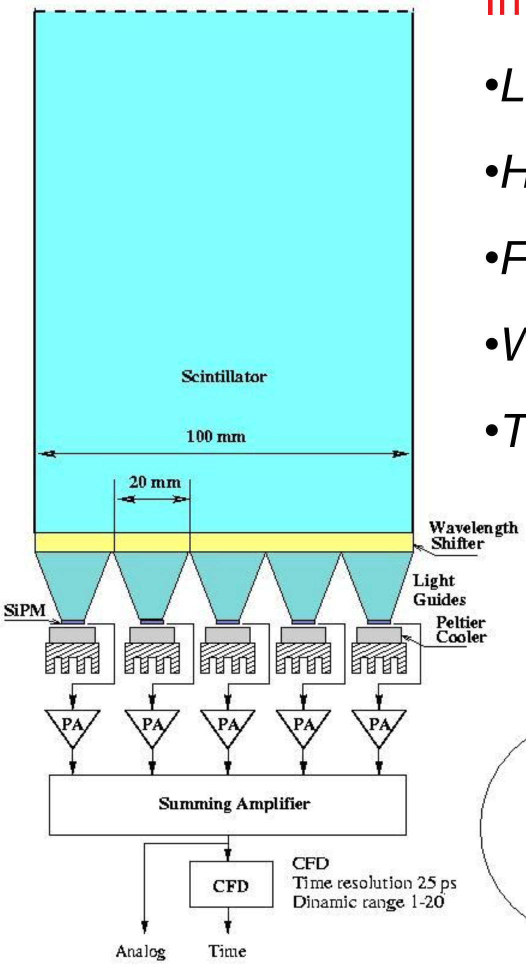
- Stepanov/EFG
- Internal crystallization method
- Modified Bridgman





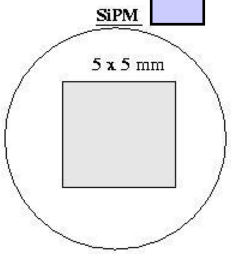


T3:Ultra-fast timing with plastic scintillators for TOF applications using SiPMs



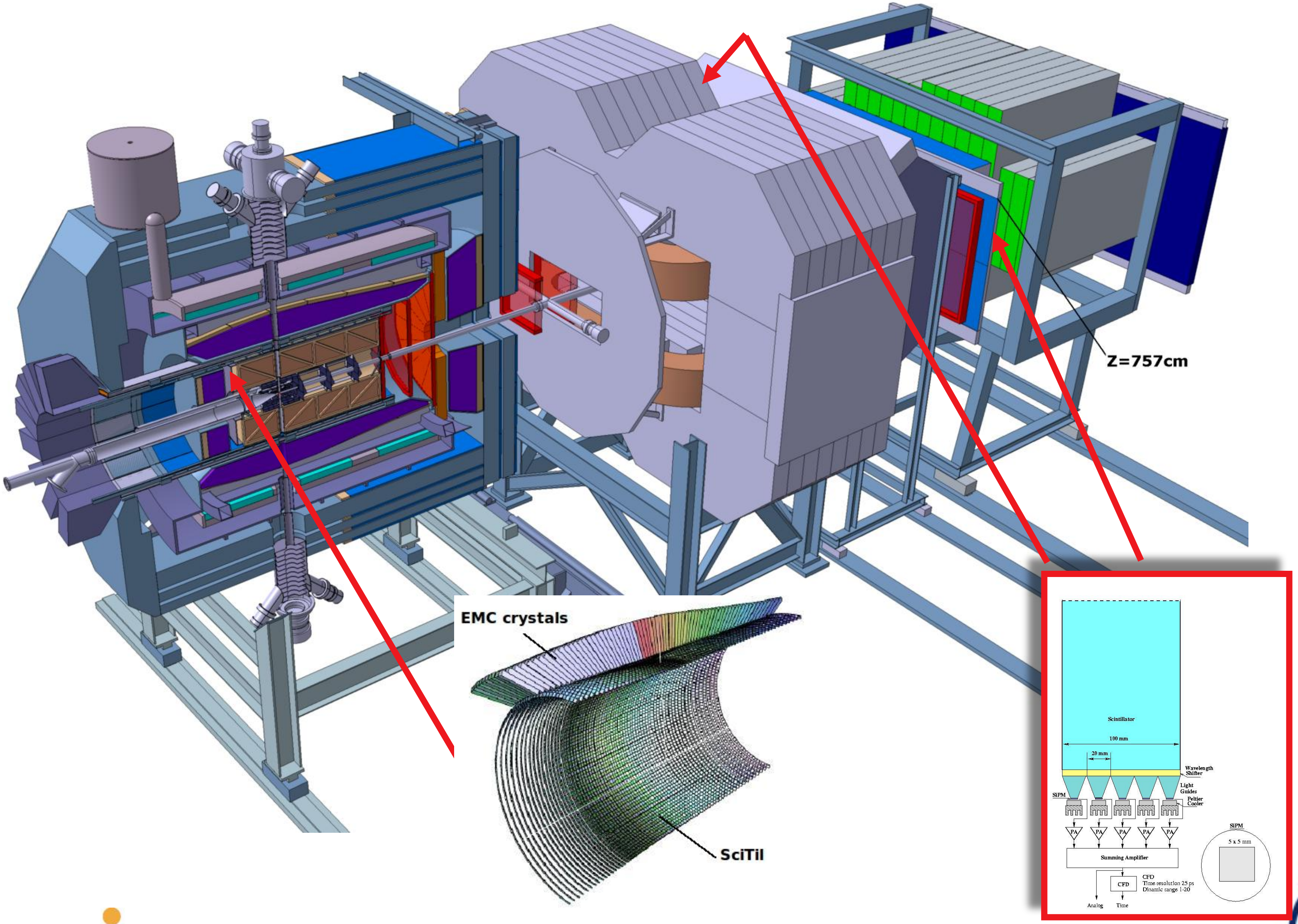
Important parameters of SiMP:

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

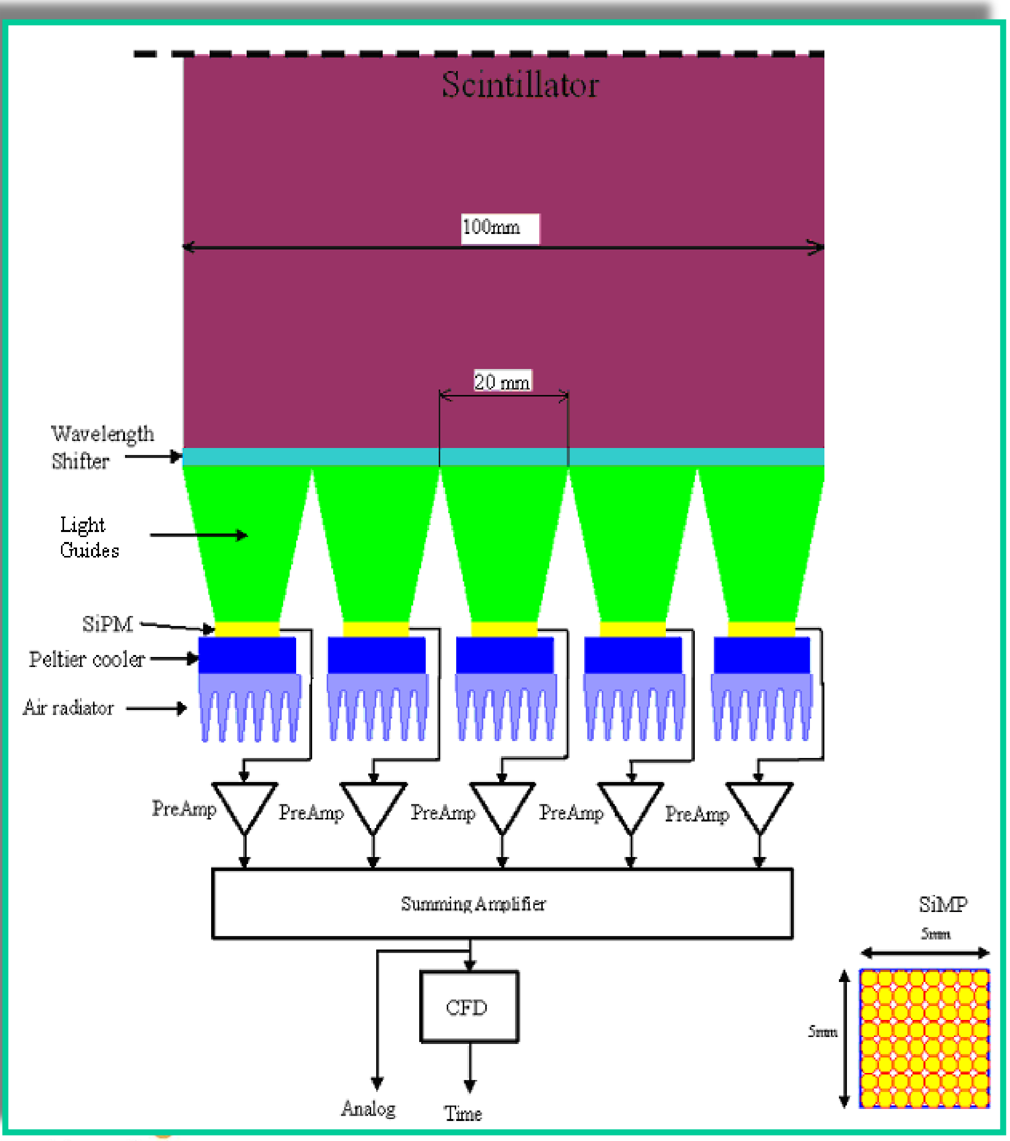


R&D: prototype of SiPM-coupled scintillator slab for TOF wall

PANDA Detector



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;*

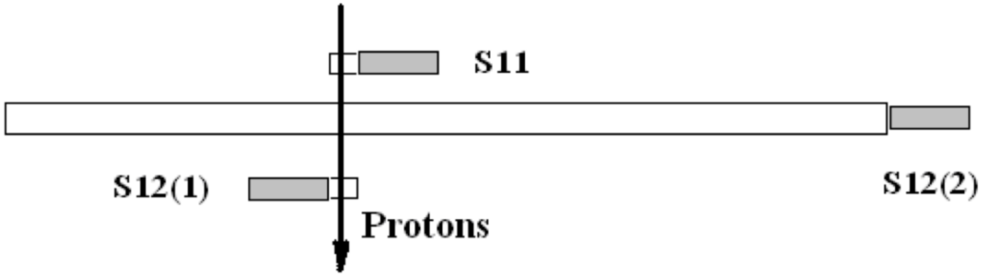
Study of temperature dependence of the *dark counts*;

Tests using PNPI 1 GeV proton beam.

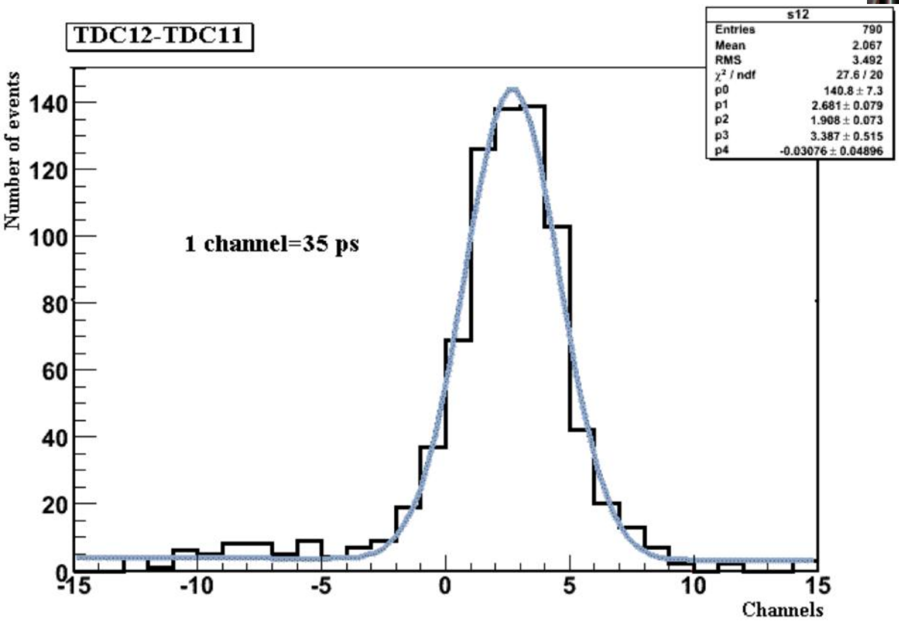
For HP3

Removing light guides for better time resolution

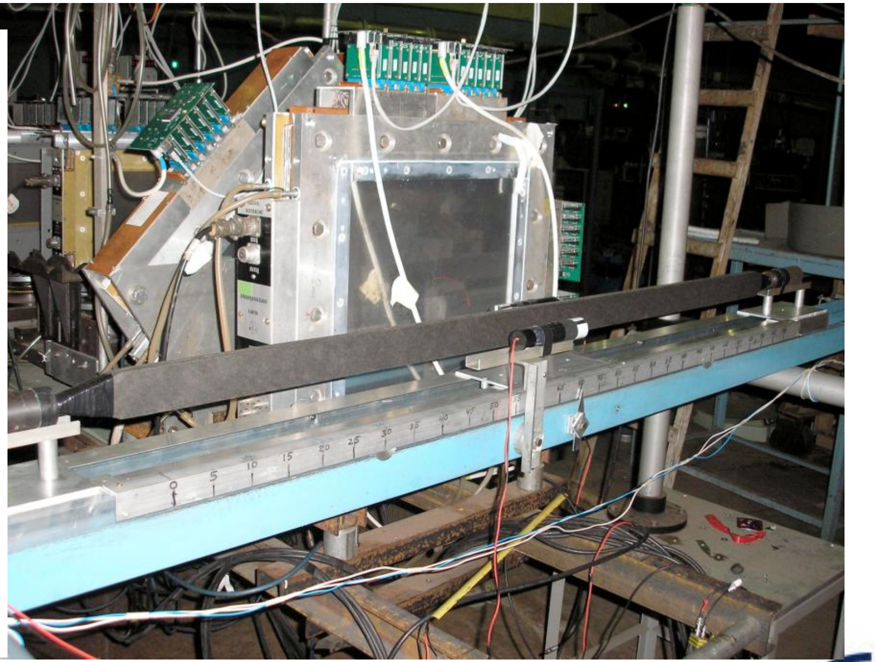
TOF measurements at PNPI in beam



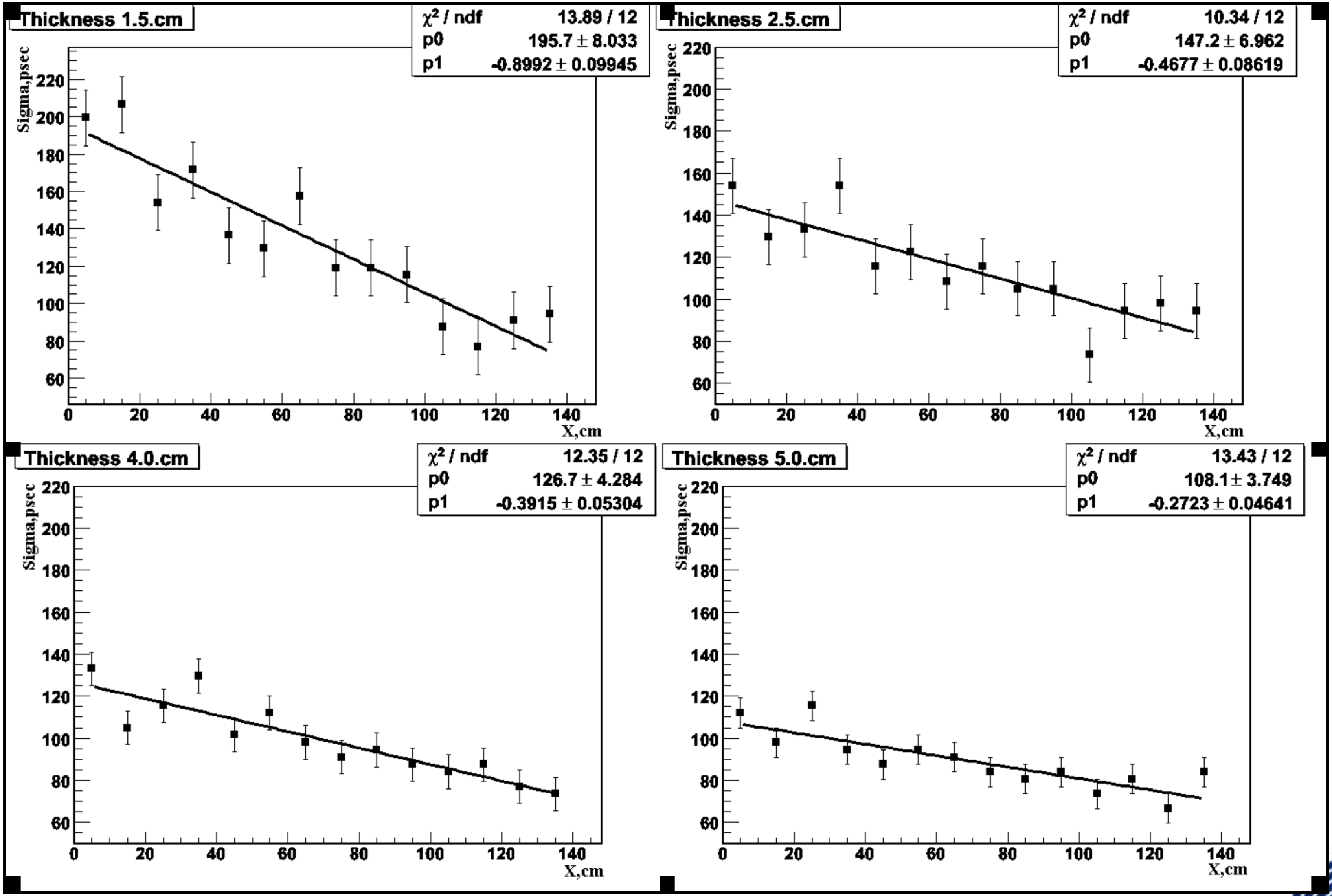
Set-up



Time resolution



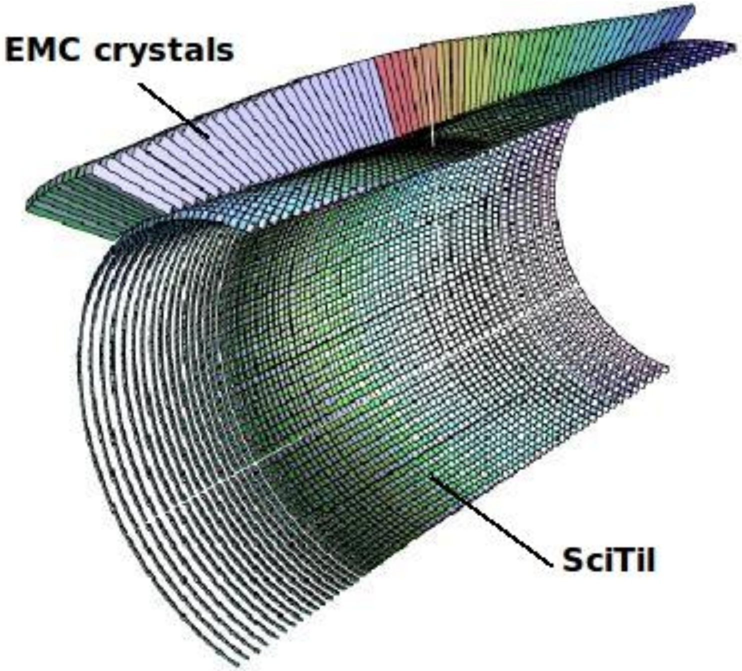
Results of TOF measurements with unilateral readout of large Scintllator pannels using PMTs



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*



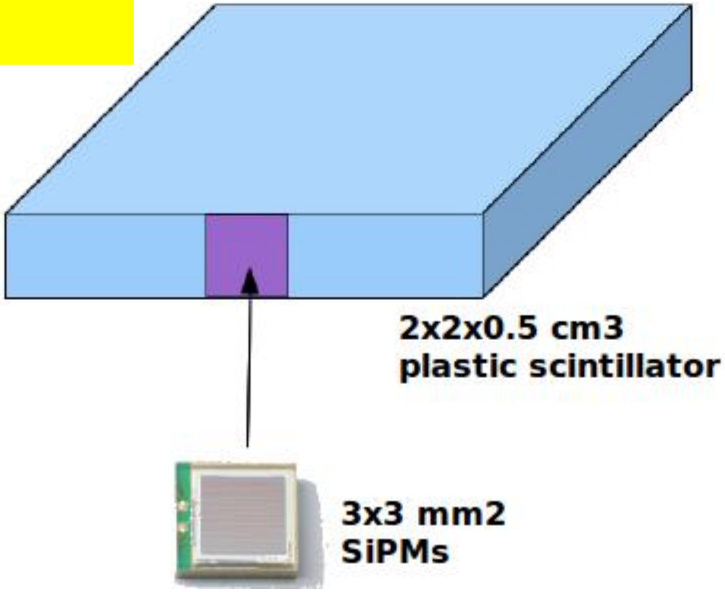
R&D: Scintillating fiber hodoscope for PANDA

SiPM-coupled scintillator panel for TOF wall

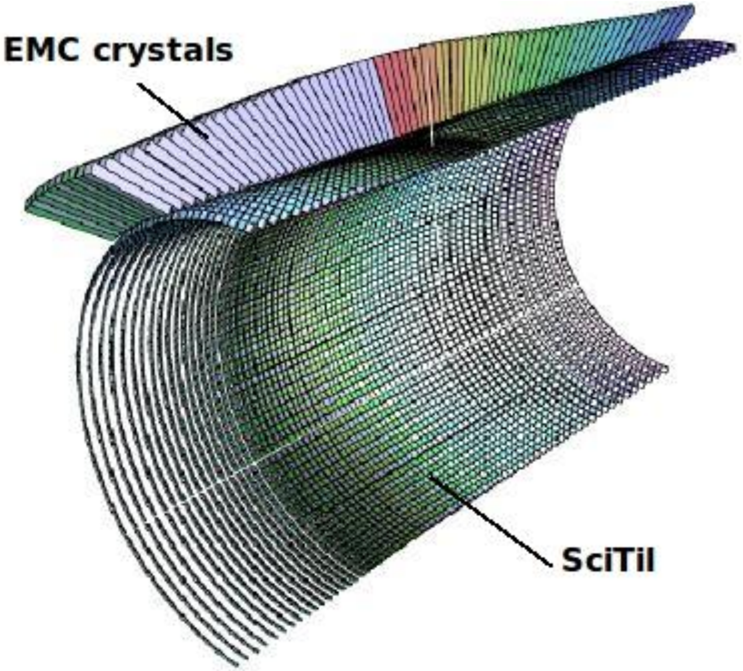
Scintillating Tile Hodoscope

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

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

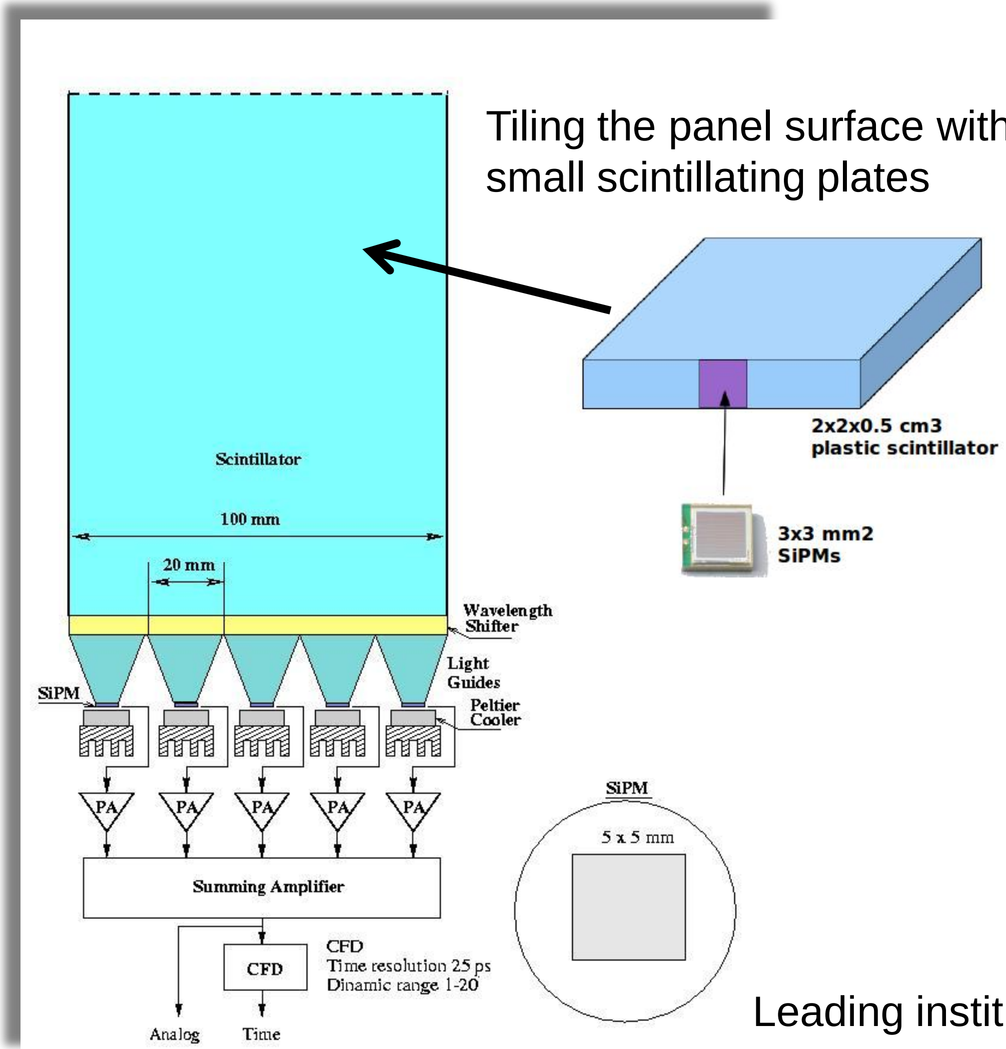
4) additional timing information

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

Tiled large Scintillator Panel

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

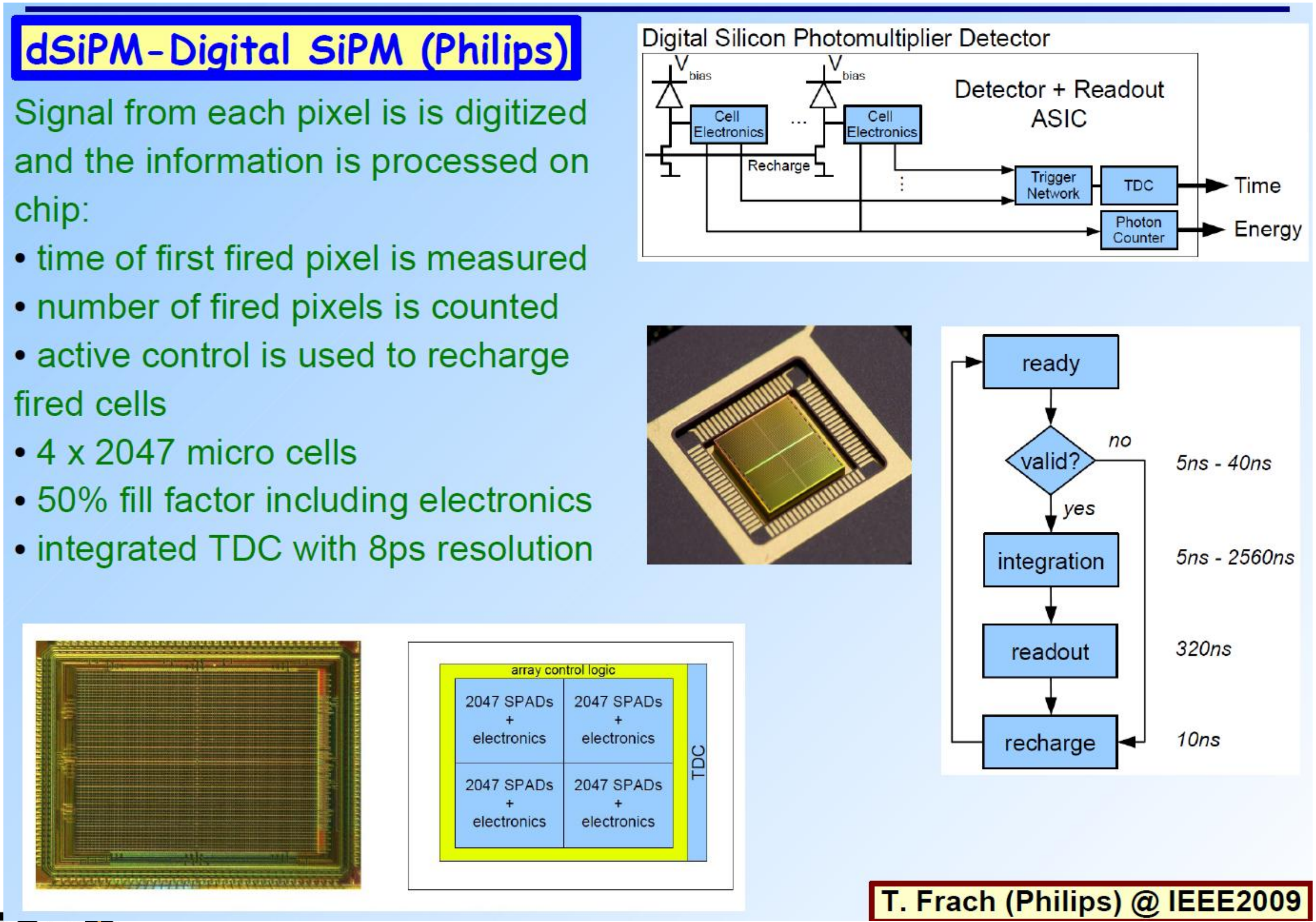


Aim:
Improving time resolution through measurement of position and local light amplitude

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

Leading institution: PNPI, UJ, GSI, INR

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

Digital Silicon Photomultiplier Detector

T. Frach (Philips) @ IEEE2009

Summary

This EU-Project investigates the unique capabilities of Silicon Multipliers guided by different case studies:

Detection of very low light levels	**Cherenkov Radiation**
Detection of low to medium light levels	**Fiber Readout**
Detection of high light levels	**Calorimetry**
Ultra fast time resolution	**TOF**

- The proposed tasks of have been performed and the milestones achieved.
- The results give us better insight to the SiPM sensor both the benefits and the deficiencies.
- We expect to learn much more during the second half of the project.
- The development of prototype detectors using SiPMs progresses.

The project will be continued within HadronPhysics3