2 – 6 June 2014 / Amsterdam, The Netherlands

"Instrumentation as enabler of Science"

Systematic study of a SiPMT array readout for fast time-of-flight Detectors

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presented by M. Bonesini

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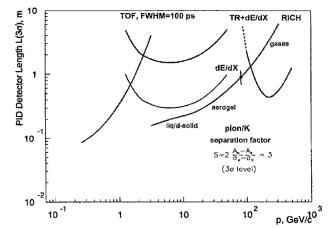
Outline

- □ Introduction
- ☐ Scintillator based TOF detectors
- □ PMTs vs SiPMT arrays
- ☐ Test setup
- □ Results
- □ Conclusions

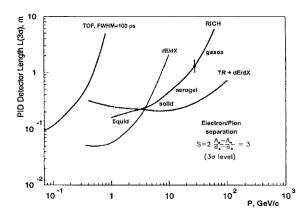
PID methods

- Particle identification (PID) is crucial in most experiments (from π/K identification in B physics to e/π separation at 10^{-2} level for p< 1GeV)
- At low momenta TOF methods are used (p≤ 3-4 GeV/c)

Pion-Kaon separation for different PID methods. The length of the detectors needed for 3σ separation.

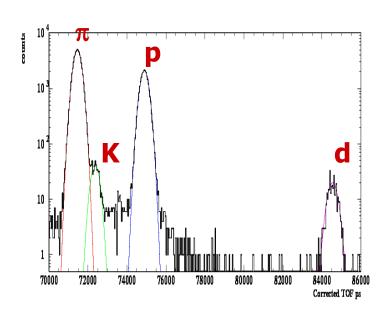


The same as above, but for electronpion separation.



Dolgoshein, NIM A 433 (1999)

Particle ID with TOF



Beam particle separation in HARP beam Tof , for a 3 GeV beam

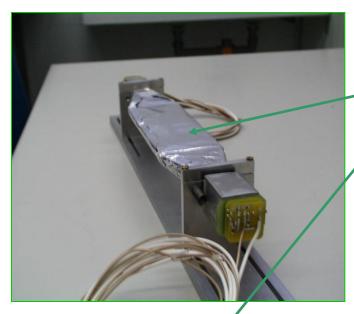
 TOF based on measure of t over a fixed length L

$$m = p\sqrt{\frac{c^2t^2}{L^2} - 1}$$

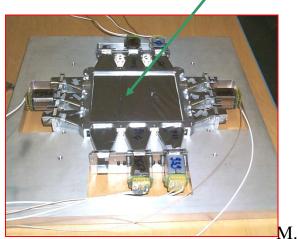
- Mass resolution dominated by σ_{t} (not measure of L, p)
- Separation power in standard deviation

$$n_{\sigma_t, 1-2} = \frac{L(m_1^2 - m_2^2)}{2p^2 c \sigma_t}$$

Examples of TOF detectors



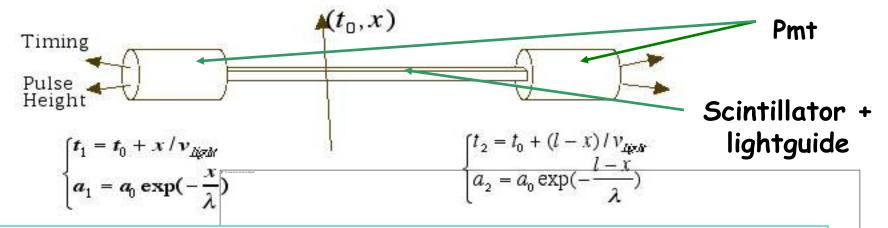
 □ Based on scintillator counters: simple to made, sensitive to B, read at both ends by PMTs, good resolutions -> 50-100 ps (depends mainly on L,N_{pe})



- □ Based on PPC or spark chambers: some care in production, not sensitive to B, very good resolutions -> 30-50 ps
- □ Based on RPC's: cheap (suitable for large areas), not sensitive to B, R&D in development, very good resolutions -> 50 ps

Rate problems

Basics of double-sided scintillator counters



$$\therefore \begin{cases} t_0 = \frac{t_1 + t_2}{2} - l/v_{light} \\ x_0 = \frac{t_1 - t_2}{2} - v_{light} \end{cases} \qquad \delta t_0 = \sqrt{\left(\frac{\delta t_1}{2}\right)^2 + \left(\frac{\delta t_2}{2}\right)^2} \cong \frac{\delta t_1}{\sqrt{2}} \\ \delta x = v_{light} \cdot \sqrt{\left(\frac{\delta t_1}{2}\right)^2 + \left(\frac{\delta t_2}{2}\right)^2} \cong v_{light} \cdot \frac{\delta t_1}{\sqrt{2}}$$
Precise TOF and Hit position

Tof resolution can be expressed as:

$$\sigma_{t} = \sqrt{\frac{\sigma^{2}_{scint} + \sigma^{2}_{PMT} + \sigma^{2}_{pl}}{N_{pe}} + \sigma^{2}_{elec}}$$

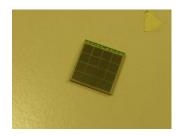
SiPMT arrays vs PMTs

PMTs

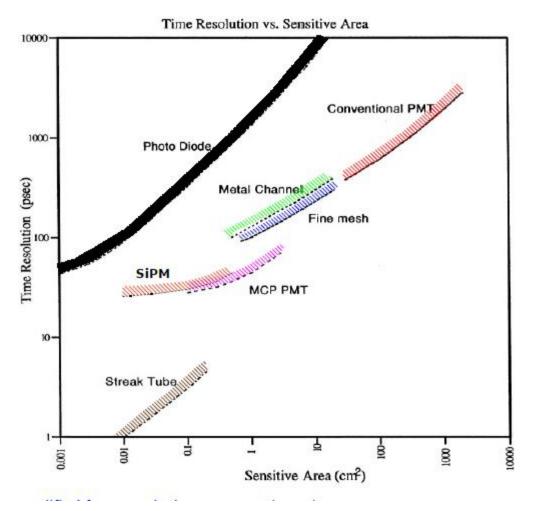
- 1. Large active area > 0.5 1 inches
- Gain G depends on external magnetic fields B (needs shielding, aside fine-mesh PMTs)
- 3. Good TTS: typical values in the range 150-400 ps
- 4. Fast PMTs are quite expensive: 1000-1500 E
- 5. Needs HV: typically 1000-2000 V
- Low noise rate ~1KHZ

SiPMT arrays

- 1. Active area up to 1x1 cm2 typically
- Gain G insensitive to external magnetic fields, but depend on temperature T (needs feedback)
- 3. Good STPR response for single SiPMT \sim 140-300 ps
- 4. Quite cheap
- 5. Needs low voltages: ~30 V for SenSL, Advansid, ~70 V for Hamamatsu
- 6. High noise rate up to MHZ

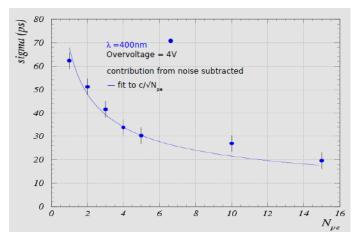


Timing resolution of photo detectors



Resolution improves:

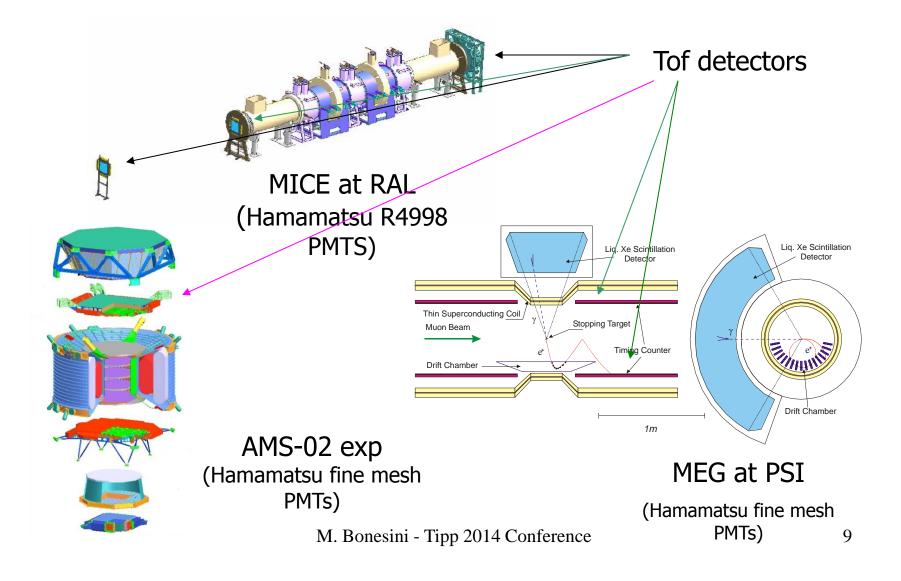
- By decreasing active area
- As σ_t/t ~ 1/√Npe ~1/√QE



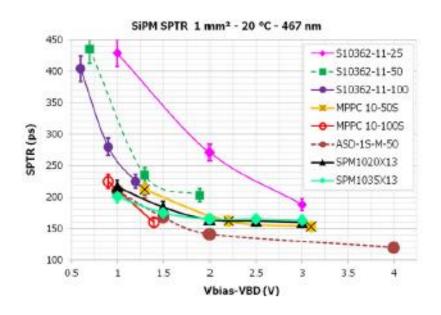
From G. Colazzuol (LIGHT11 2011)

From K. Arikasa NIM A422 (2000)

Conventional fast TOF with PMT readout have found application in many experiments



Studies of SPTR (timing for single photoelectrons)



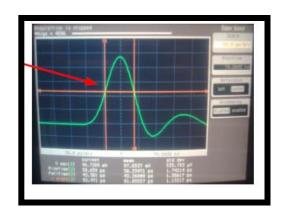
- Timing studies are usually done for single SiPMT (not arrays) with single p.e.
- For scintillation counters needs to study multiphoton response

from V.Puill et al NIM A695 (2012) 354

A small remark

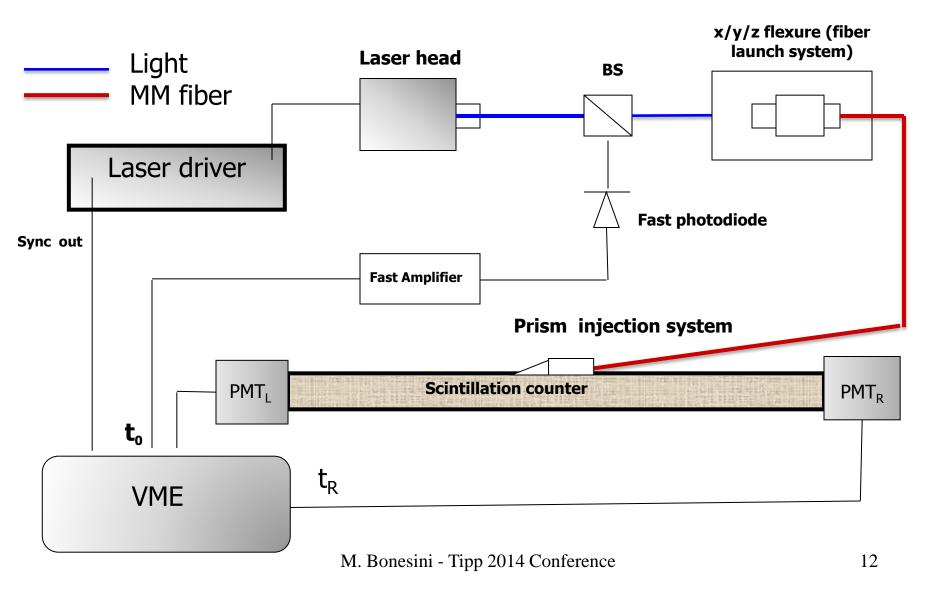
 Timing studies are usually done with fast lasers (eg 30-50 ps FWHM): good for single p.e. studies, but scintillator have typically 200-300 p.e. signals and scintillator risetime are in the 1-2 ns range ...



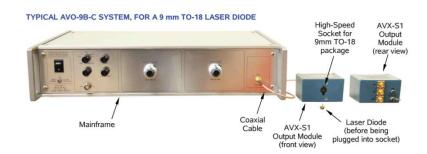


Needs laser signals that resemble more physical scintillation light

Experimental lab setup



Test setup: home-made laser system



- 1. Fast Avtech AVO pulser + Nichia violet laser diode ($\lambda \sim 408 \text{ nm}$)
- 2. Laser pulses width selectable between 120 ps and 3 ns length, with a ~200 ps risetime (simulate scintillator response)
- 3. Laser pulse height selectable to give scintillator response between a fraction of MIP and 10-50 MIPS
- 4. Laser repetition rate selectable between ~100 Hz and 1 MHz
- 5. The laser beam is splitted by a 50% beamsplitter to give a reference t0 on a fast photodiode (Thorlabs DET10A risetime ~1 ns) amplified via a CAEN A1423 wideband inverting fast amplifier (up to 51 dB, ~1.5 GHz bandwidth)

COLUMN	SPECIFICATIONS			AVO-9 SERIES			
Models & 1 Arep, with PR							
Modelt			AVC-MIT-BY				
Anglisals*:	0 - 200 mA		0 - 200 MA.	0 - 400 mA	0 - 800 mA		0-1A
Max. cutput of maintaine into 500 (Kommun)	1397		13V	23V	401		SW
Ra + Ressei				500			
Transformer ratio, H:	1						
Allowed load voltage range:	0 to 3V. (Contact Artech if your clode has a higher forward-valuage drop))
Pulse width (PWHINI)N	0.4-496	5 - 190 ms	0.5 - 1000 Hs	0.0-1000 ns	0.4 - 276-sol: (0.4 - 4 m (07)	1-10/6	1-10-66
Maximum duty syde:		M.	,		86		
Maximum PRP*:	16	HI	1999	100 MHz	1 MHz 150 kHz		1 MHz
Mise times (20%-90%):	£ 20	0 84	€35094	€ 350 pe	£20094 £50094		€ 900 ges
Fall times (80%-30%)	€ 20	£ 200 pa		€ 250 ps	≤ 300 ps²	£750ps	£176
Related SIGD paries:	WP-WH	MAMP Q	ALPP-IA	AMPP-DA	RIP MANAGE	ASAVICE.	AA 63
Included output module:	Art-61						
Polarigm	Positive or regative (specify)						
OP® andRS-232 coend?	Standard on 49 units.						
Lativien divers	Check <u>http://www.acochoolise.com/abslase</u> for availability and disveloads						
Telest/Web-corted*	Optional. See <u>http://www.acrochosiss.com/selices/acr</u> for details						
Couble pulse separation: (open/y)	the period	the period Not available the period				٨	
Propagation delay:	g till ne - distrigin ta pake aut)						
J461.	± 35 ps ± 0.01 9% of sync delay (Ext régin to pulse out)						
DC offset or biss insertion:	Apply required DC bias current in the range of a 100 mA:to solder terminal on output module.						
Sync delay:	Variable tire 200 ns (yr) second for dt units), sync out to pulse out						
Sync output do 5000:	+3N, 100 ns						
Gara irpat:	Synchronous or asynchronous, active high or low, switchable. Suppresses triggering when active.						
Triggerrequired:	Extrig mode: +5 V (TTL), > 50 ms						
Monker output option*:	Provides connection to output of photo diode detector.						
Carriectura: Que. Qu'es	User-specified socket. Sockets can be provided for 5.6 mm, tream, tream, butterly, and other packages. Tilg, Spec, Gase (Exc., Marrier SAA.						
Recommended accessory like	Add the suffix "ACT" to the model number to include the recommended accessory bit. Consists of three Sten, 18 GHz, 2 West assensatives (18, 26 & 36 dit) for see on the sessor, and the 30 dite, 1 disk, 1 was feel changin semination (500 Stell, 0 weet St.C) for see in cannot all page 16 page.						
Power requirements:	100-240/40 Mg. 30 - 60 Mg						
Cimensions, Mainlianes (00-WHQ)	100 x 400 x 375 mm (J.E' x 1P' x 14.6'). Anadicad aluminum, with blue plants tris.						
Dimensions, Output Module:	41 x 66 x 76 mm (1.8" x 2.8" x 2.8"), cast aluminum, blue engend						
Temperature range:	+9°C ts +80°C						

A sub-industrial RES 482 OF B and RESCO code of implicit a despring the purpose substitutes and response for delete.

to obtained by refling the imperiods near talk a die and analyzed mode affirm the entitle capital before the maintains and the output mode Alternation are published in the ART accessing the price in talk deciral publishing and of agreements. Proc. 4.

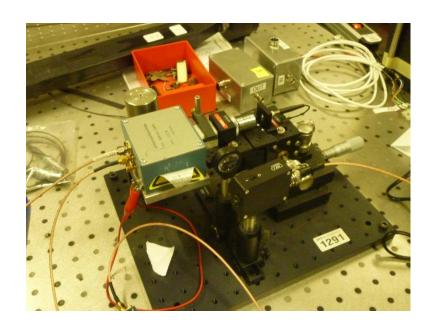
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Some details

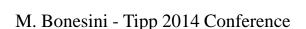


Laser injection system:

- Newport 20X microscope objective
- x/y/z Thorlabs micrometric flexure system

Acquisition system:

- VME based (CAEN V2718 interface)
- VME CAEN TDC V1290A (25 ps res)
- VME CAEN QADC V792
- VME CAEN V895 L.E. discriminator (typ discr values -50 -100 mV)
- home-written acquisition software



Tuning of laser setup

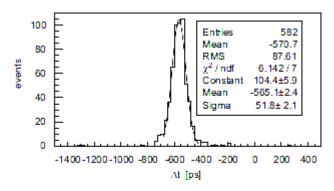


Fig. 12. $(t_L - t_R)/2$ distribution from a BC404 bar specimen and beam impact point at x = 20 cm (counter center).

Table 2

Intrinsic resolution of counters made of scintillation bars of 4 or 6 cm width and with lightguides made of different materials and/or of different shape (Winston cone or fishtail).

Counter type	σ_{t} (ps)
UFS95F 4 cm bar Winston Cone UFS95F 4 cm bar REPSOL UVT lightguide BC404 6 cm bar REPSOL UVT lightguide BC420 6 cm bar REPSOL UVT lightguide BC408 6 cm bar PERSPEX UVA lightguide	56 ± 2 50 ± 8 46 ± 5 45 ± 1 60 ± 2

From R. Bertoni et al., NIM A615 (2010) 14

- Tune laser settings to reproduce testbeam results (σ_t) with a single counter equipped with R4998 PMTs and MIP response
- Study single counter response substituting PMTS readout with SiPMT arrays readout
- Advantage as respect to cosmics is the possibility to collect a high statistics in a short time, with different exp conditions (amplifier tuning, ...)

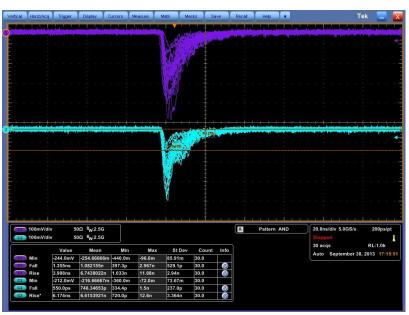


PMT signals with cosmics

BC 404 scintillation counter (60 cm long, 6 cm wide) equipped with Hamamatsu R4998 PMTs (as in the MICE expt at RAL)

PMT signals with laser

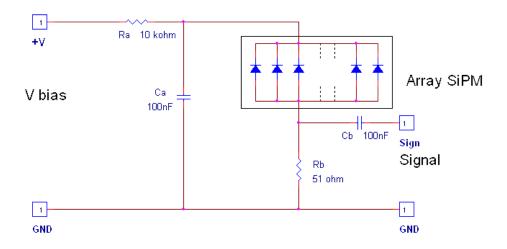




Readout chain for SiPMT arrays



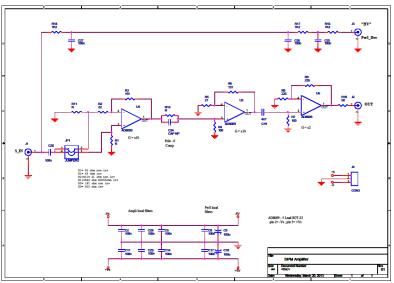
- SiPMT array custom mount
- 16 macrocells signals are summed up in the basette and then amplified



Schematic of one `assette"

Custom amplifier



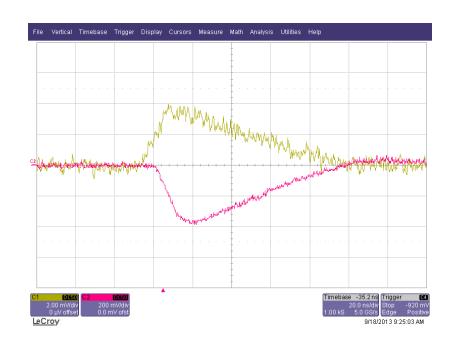


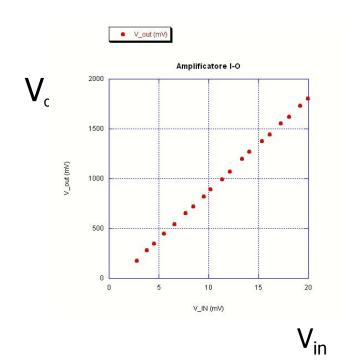
Amplifier:

- Custom made (INFN Pv)
- 1 or 2 channels
- Gain up to 100X (30X with pole zero suppression)
- Input dynamic range: 0-70 mV
- Bandwith: 600 MHz

This may limit timing response, tests will be redone soon with a 50x PLS 774 amplifier (bandwith ~1.50 GHZ)

Amplifier performances





100X amplifier

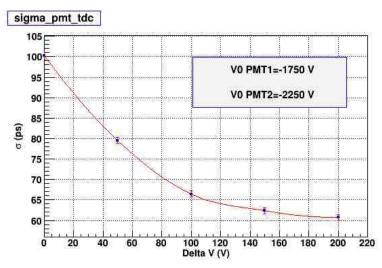
Amplifier linearity

SiPMT arrays under test

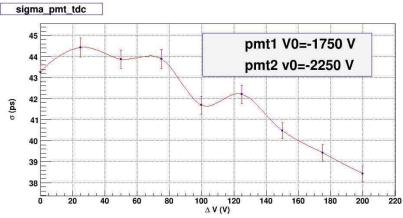
Available SiPMT arrays use 3x3 mm² or 4x4 mm² macro-cells arranged in 4x4 (or more) arrays.

- SENSL ArraySL-4-30035-CER arrays with 3x3 mm 2 macrocells, $V_{op} \sim 29.5 \text{ V}$
- Hamamatsu S11828-3344, S12642 arrays with 3x3 mm² macrocells, V_{op}~72.5 V
- Advansid ASD-SiPM3S-4x4T (RGB) arrays with 3x3 mm² macrocells, V_{bkw} ~28.5 V
- Advansid ASD-SiPM4S-4x4T (RGB) arrays with 4x4 mm² macrocells, $V_{bkw} \sim 29.2 \text{ V}$
- We plan to extend study to new NUV types, better matched to scintillator light emission

Results with conventional PMTs (as benchmark)



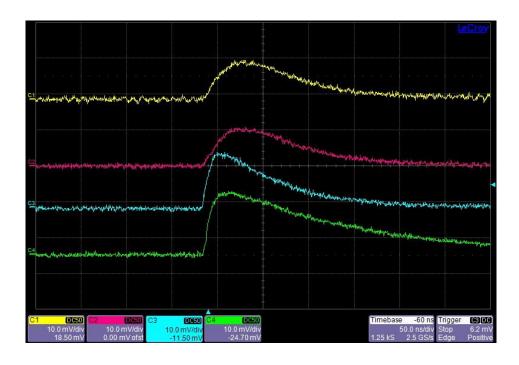
Very low laser light intensity (1 MIP or less)

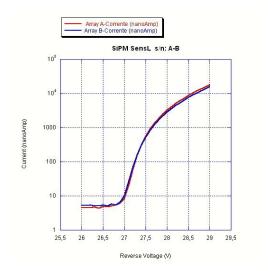


Standard laser light intensity (2-3 MIP)

$$V_{op} = V_0 + \Delta V$$

SenSL ArraySL-4-30035-CER arrays



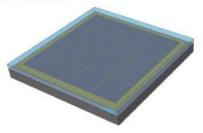


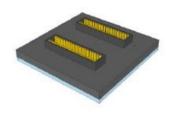
SiPMT I-V characterization (our measure)

- Risetime of SenSL arrays much bigger than one of Hamamatsu or FBK/IRST
- Comparable results also with new blue-extended type
- We decided to concentrate our efforts on Advansid (FBK/IRST) and Hamamatsu ones

Results with Avansid SiPMT arrays

ASD-SiPM3S-P-4X4A





4×4 SiPM Array

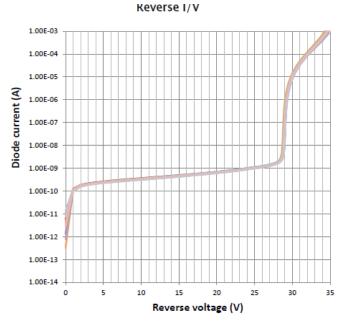
3 mm pixel pitch

2.95x2.95 mm² SiPMs 50 µm gap between SiPMs

Material: FR4 + transparent epoxy layer

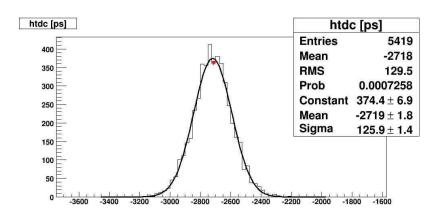
AVX 5602-040 series plug connectors

Receptacles included (AVX 5602-040 series)

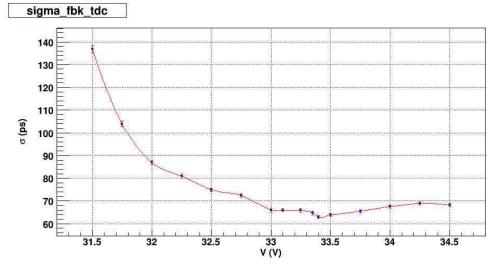


SiPMT I-V characteristics (manufacture specs)

Results with Advansid SiPMT arrays



Typical difference ΔTDC (converted in ps) : $\sigma_t = \sigma_{\Delta TDC}/2$

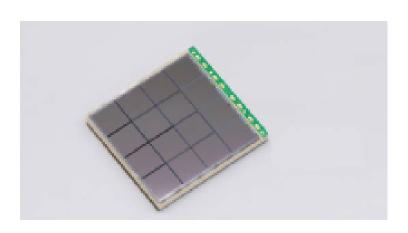


Standard light intensity

 σ_t ~60 ps at best, but RGB array !!

Vop

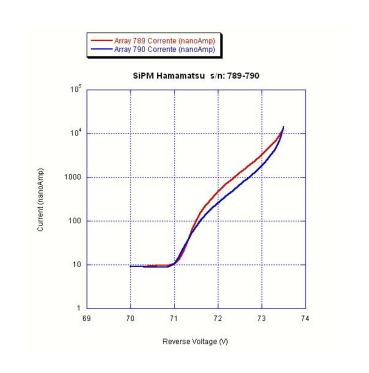
Results with Hamamatsu S11828-3344 Arrays



Monolithic MPPC array in SMD package S11828-3344M

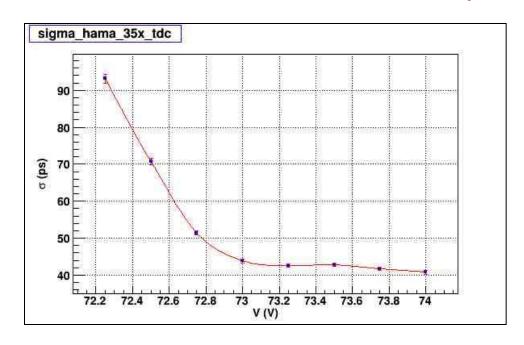
Features.

- Monolithic array: 16 ch (4 × 4 array)
- Nonmagnetic package
- Effective active area: 3 x 3 mm/dn
- Pixel pitch: 50 µm
- Allows multiple devices to be arranged in a buttable format



SiPMT I-V characterisation (our characterisation)

Results with Hamamatsu 511828 Arrays

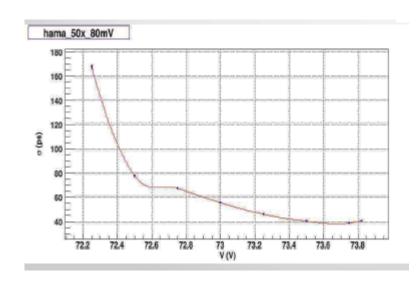


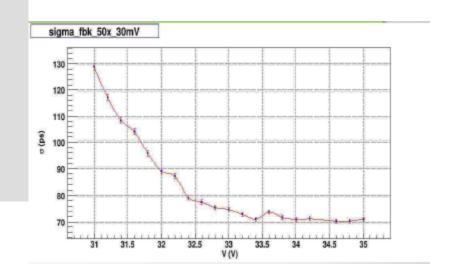
Standard light intensity

We foresee soon tests with Hamamatsu S12642 arrays, TSV package, where better results may be expected

Tests with a fast PLS 774 amplifier

- High bandwidth: 1.8 GHz, 50X amplification
- External pole-zero circuit + inversion
- No clear improvements seen as respect to our custom amplifier

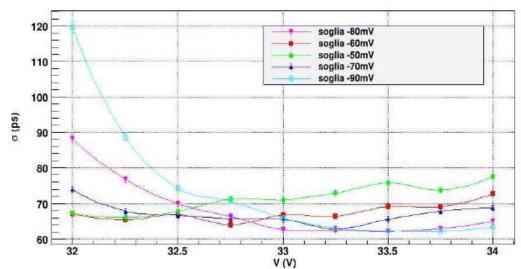




Advansid SiPM3S-4x4A with -30 mV threshold

Hamamatsu S1182-334 with -80 mV threshold

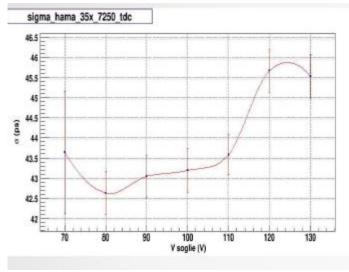
Changing the L.E. discriminator threshold



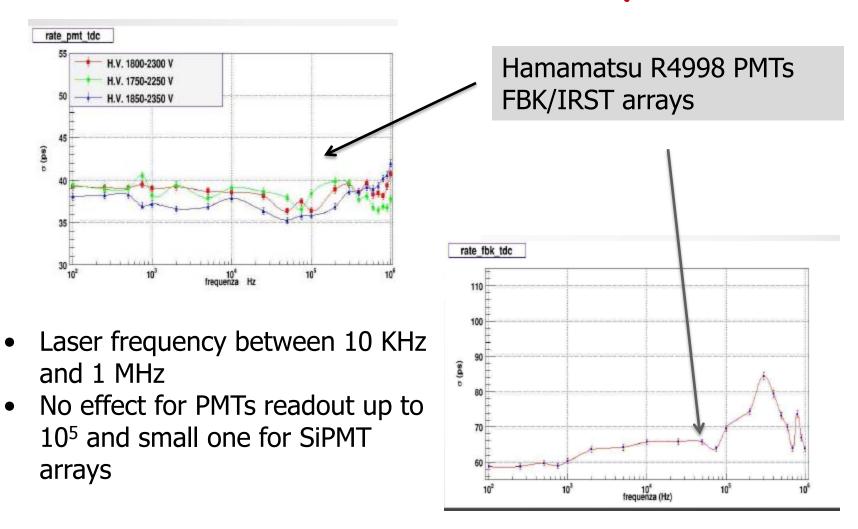
FBK/IRST SiPM3S-4x4A

Hamamatsu S1182-3344 at V_{op} =-72.5 V

Choice of -80 mV seems fine for both

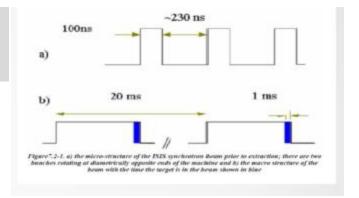


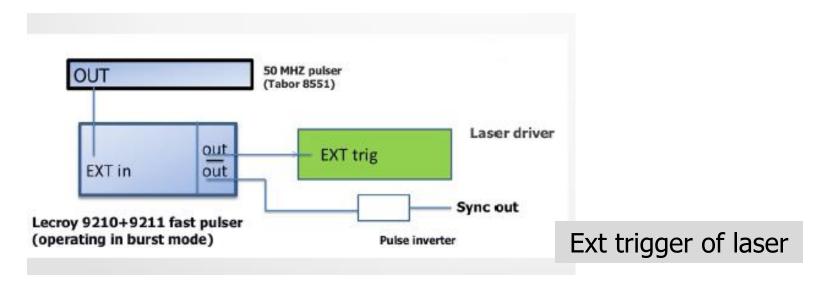
Rate effects study



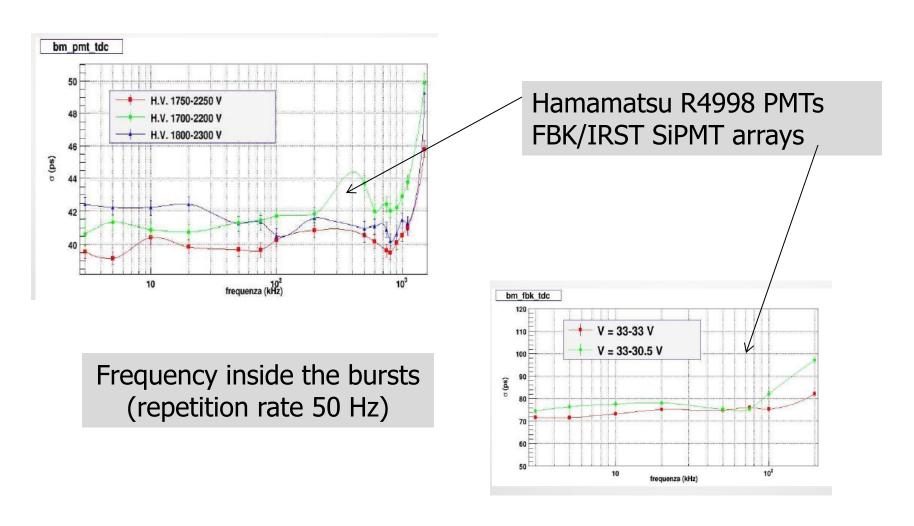
Rate effects study (II):

Simulate burst structure of an accelerator (eg ISIS at RAL): 50 Hz repetition cycle.





Rate effects study (III):



Conclusions

- SiPMT arrays may be a good repacement for fast PMTs in scintillator time-of-flight system
- Preliminary conclusions show a "comparable" timing resolution with fast PMTs
- we have taken data at LNF BTF (not fully analyzed yet) that show comparable results of PMTs vs SiPMT arrays for low particle rates
- further studies with the new-technology TSV Hamamatsu arrays under way
- Acknowledgements: many thanks Mr. F. Chignoli, G. Stringhini, L. Maver and O. Barnaba for skilful help and work in the setup installation and laboratory measurements and Dr. Bombonati of Hamamatsu Italia