TIPP '14

International Conference on Technology and Instrumentation in Particle Physics

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"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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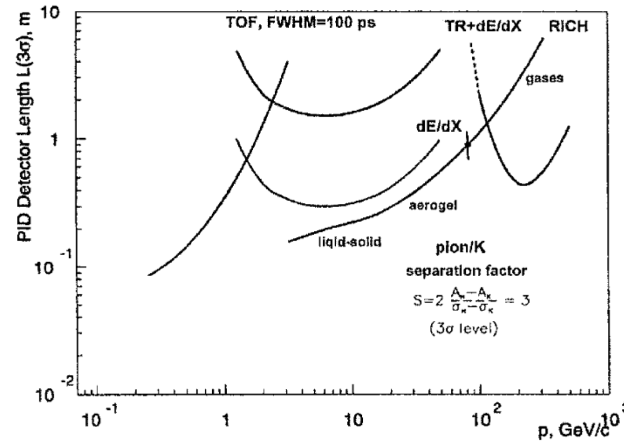
Outline

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

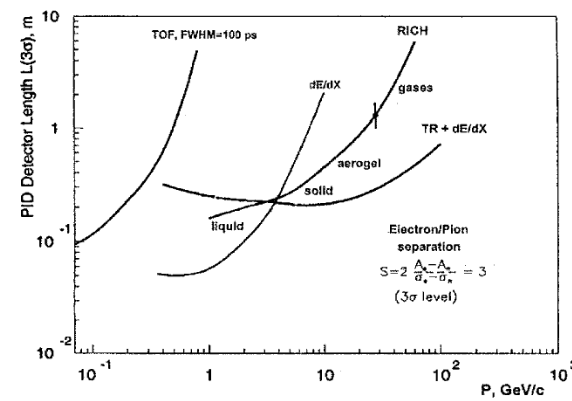
PID methods

- 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$\leq$ 3-4 GeV/c)

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

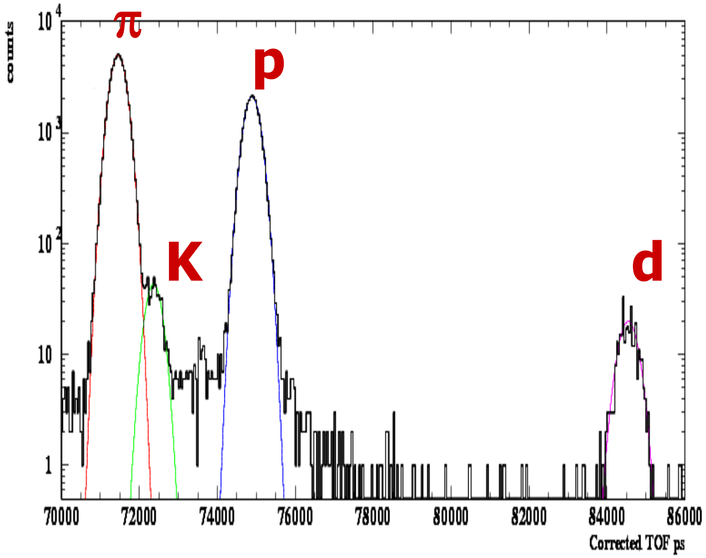


The same as above, but for electron-pion separation.



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

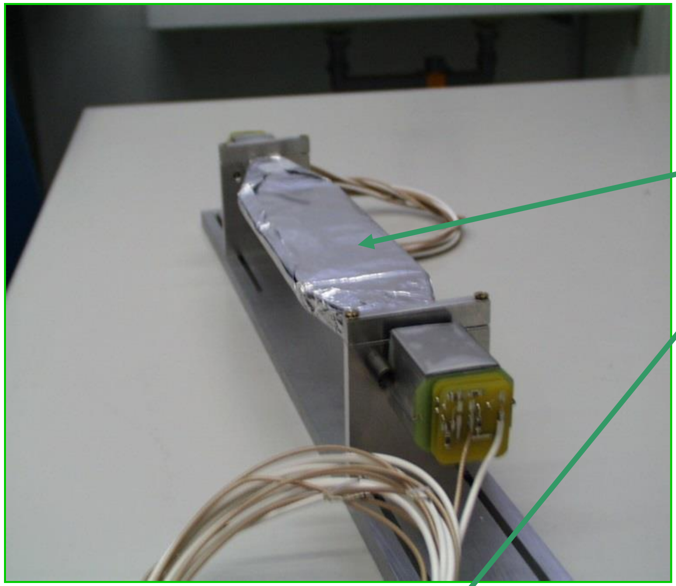
$$m = p\sqrt{\frac{c^2t^2}{L^2} - 1}$$

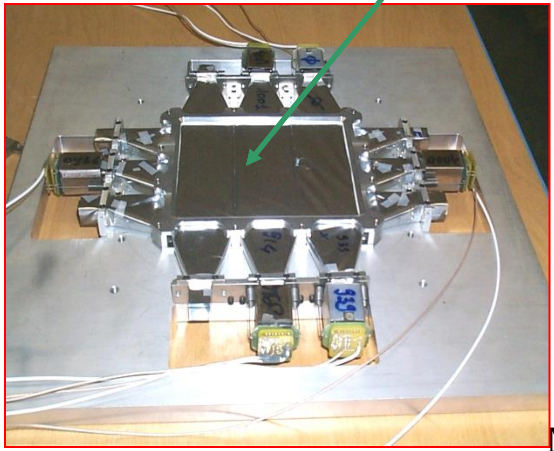
- Mass resolution dominated by σ_t (not measure of L, p)

- Separation power in standard deviation

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

Examples of TOF detectors

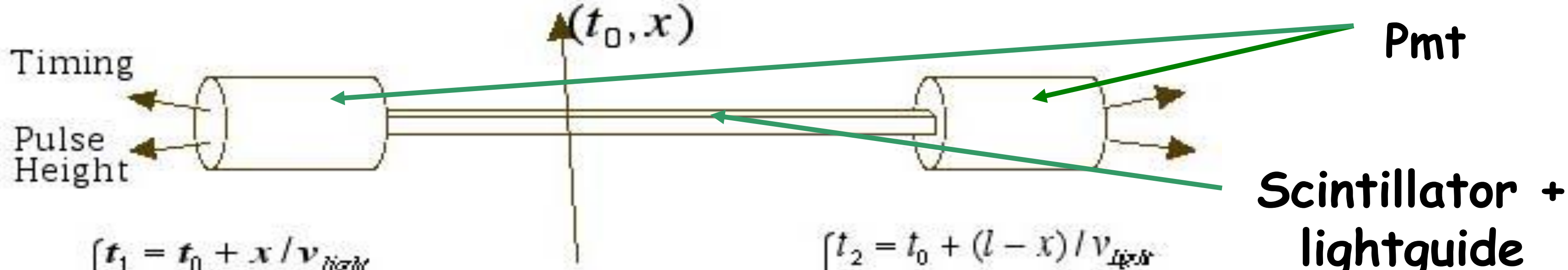




- Based on scintillator counters: simple to made, sensitive to B, read at both ends by PMTs, good resolutions -> 50-100 ps (depends mainly on L,N_{pe})
- Based on PPC or spark chambers: some care in production, not sensitive to B, very good resolutions -> 30-50 ps
- Based on RPC's: cheap (suitable for large areas), not sensitive to B, R&D in development, very good resolutions -> 50 ps

Rate problems

Basics of double-sided scintillator counters



$$\begin{cases} t_1 = t_0 + x / v_{light} \\ a_1 = a_0 \exp(-\frac{x}{\lambda}) \end{cases}$$

$$\begin{cases} t_2 = t_0 + (l - x) / v_{light} \\ a_2 = a_0 \exp(-\frac{l - x}{\lambda}) \end{cases}$$

$$\therefore \begin{cases} t_0 = \frac{t_1 + t_2}{2} - l / v_{light} \\ x_0 = \frac{t_1 - t_2}{2} - v_{light} \end{cases}$$

$$\delta t_0 = \sqrt{\left(\frac{\delta t_1}{2}\right)^2 + \left(\frac{\delta t_2}{2}\right)^2} \cong \frac{\delta t_1}{\sqrt{2}}$$

$$\delta x = v_{light} \cdot \sqrt{\left(\frac{\delta t_1}{2}\right)^2 + \left(\frac{\delta t_2}{2}\right)^2} \cong v_{light} \cdot \frac{\delta t_1}{\sqrt{2}}$$

Precise TOF and Hit position

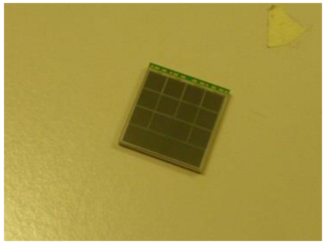
Tof resolution can be expressed as:

$$\sigma_t = \sqrt{\frac{\sigma^2{}_{sc\,int} + \sigma^2{}_{PMT} + \sigma^2{}_{pl}}{N_{pe}} + \sigma^2{}_{elec}}$$

SiPMT arrays vs PMTs

- **PMTs**

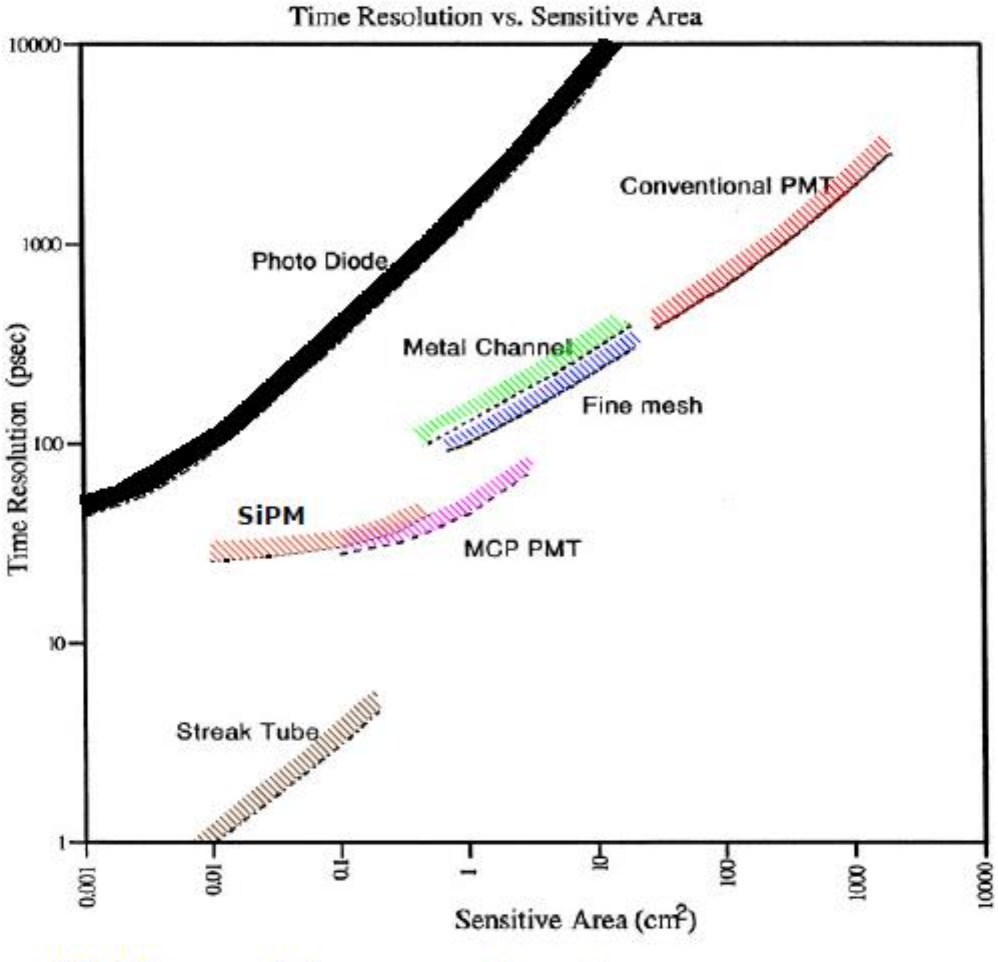
1. Large active area > 0.5 – 1 inches
2. Gain G depends on external magnetic fields B (needs shielding, aside fine-mesh PMTs)
3. Good TTS: typical values in the range 150-400 ps
4. Fast PMTs are quite expensive: 1000-1500 E
5. Needs HV: typically 1000-2000 V
6. Low noise rate ~1KHZ



- **SiPMT arrays**

1. Active area up to 1x1 cm2 typically
2. Gain G insensitive to external magnetic fields, but depend on temperature T (needs feedback)
3. Good STPR response for single SiPMT ~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

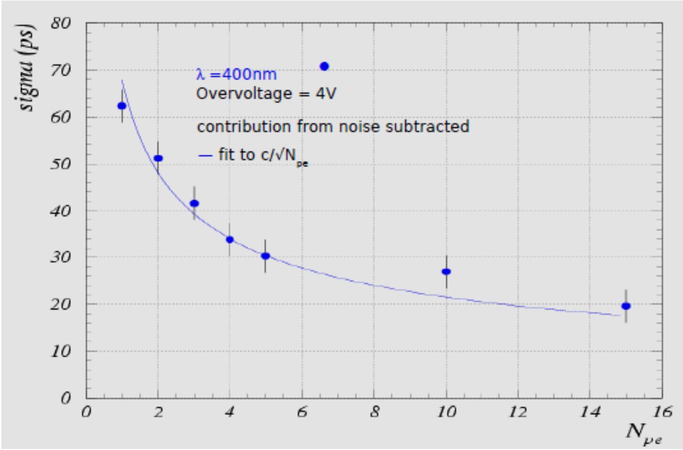
Timing resolution of photo detectors



From K. Arikasa NIM A422 (2000)

Resolution improves:

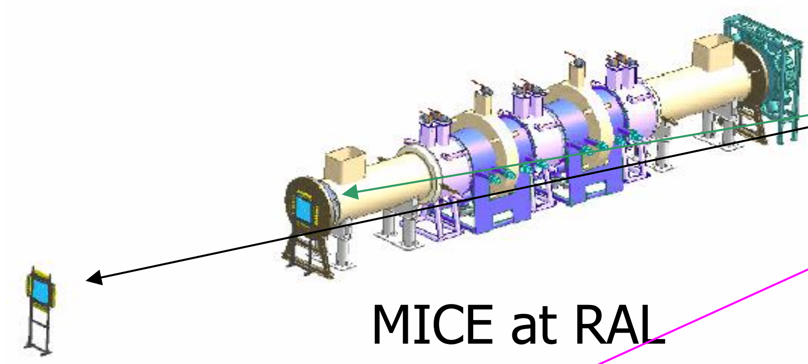
- By decreasing active area
- As $\sigma_t/t \sim 1/\sqrt{Npe} \sim 1/\sqrt{QE}$



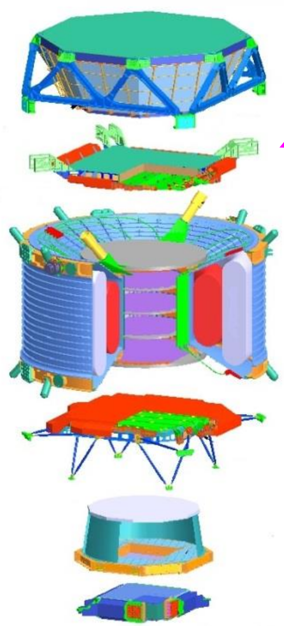
From G. Colazzuol (LIGHT11 2011)

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

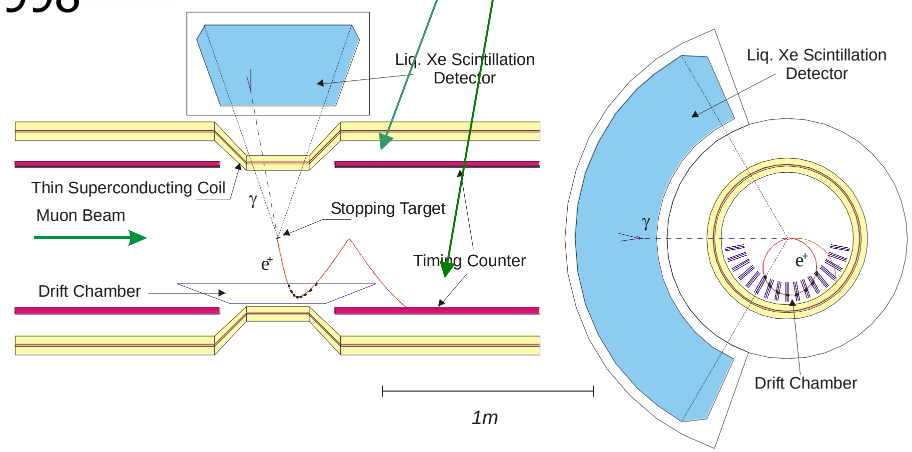
Tof detectors



MICE at RAL
(Hamamatsu R4998 PMTS)



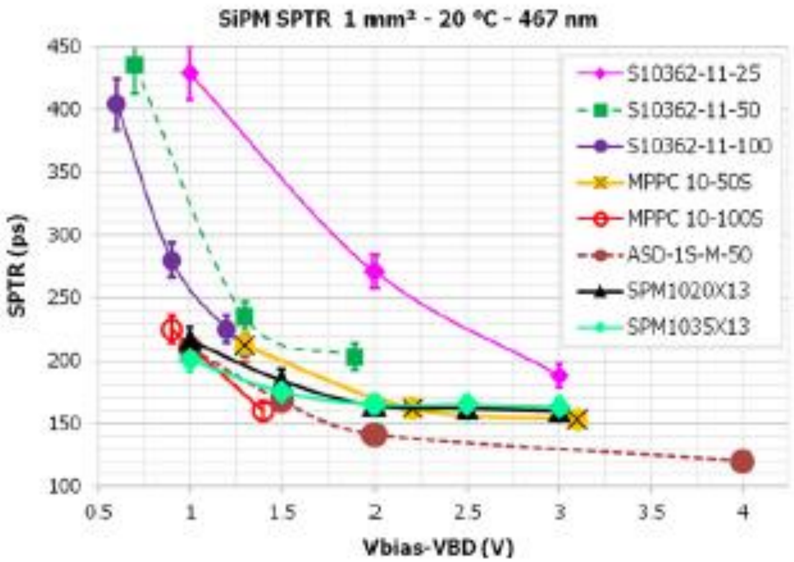
AMS-02 exp
(Hamamatsu fine mesh PMTs)



MEG at PSI

(Hamamatsu fine mesh PMTs)

Studies of SPTR (timing for single photoelectrons)

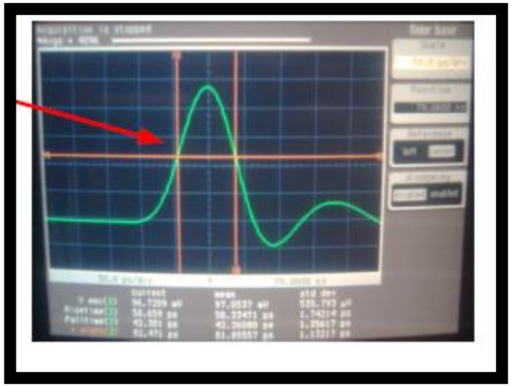


- Timing studies are usually done for single SiPMT (not arrays) with single p.e.
- For scintillation counters needs to study multiphoton response

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

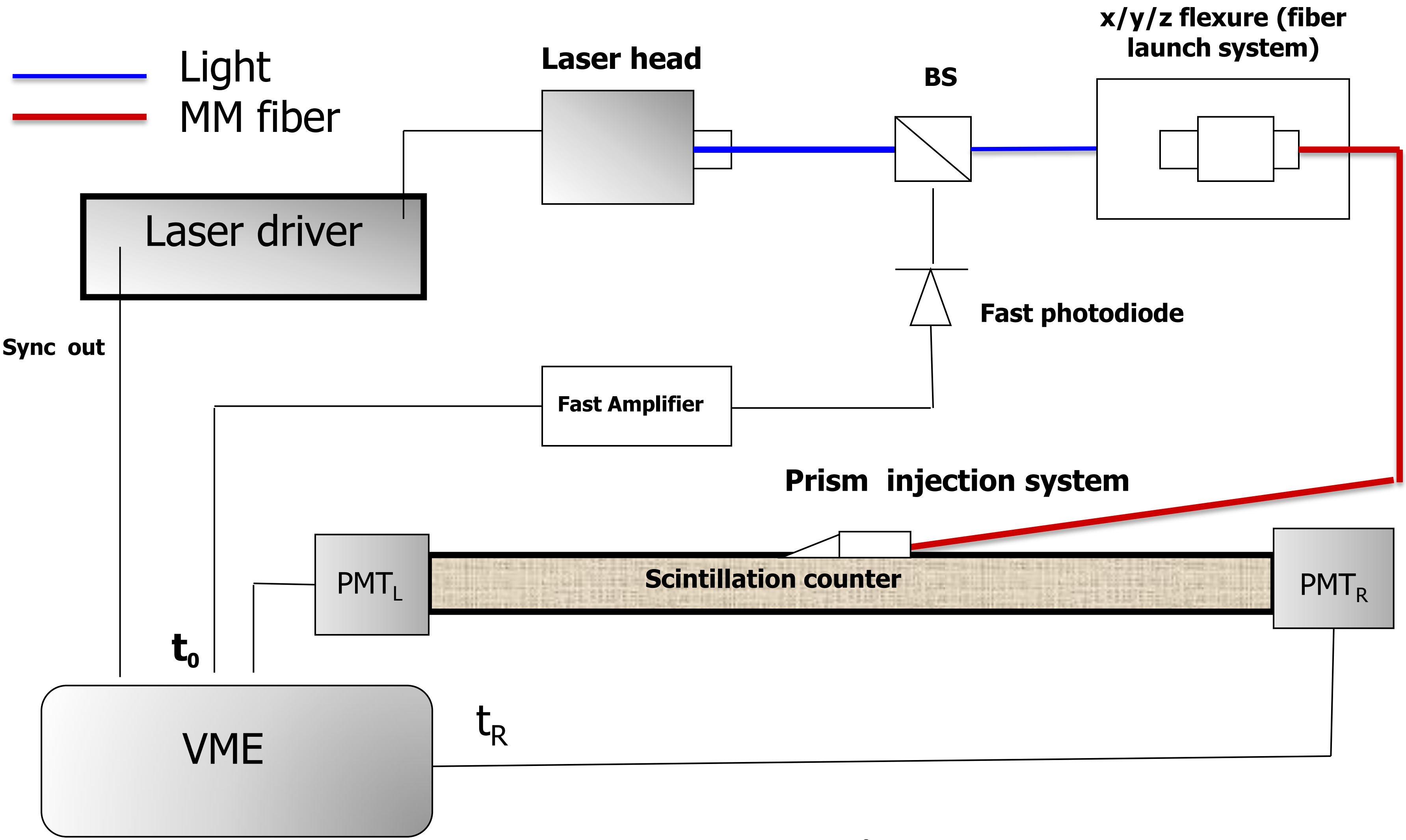
A small remark

- 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 …

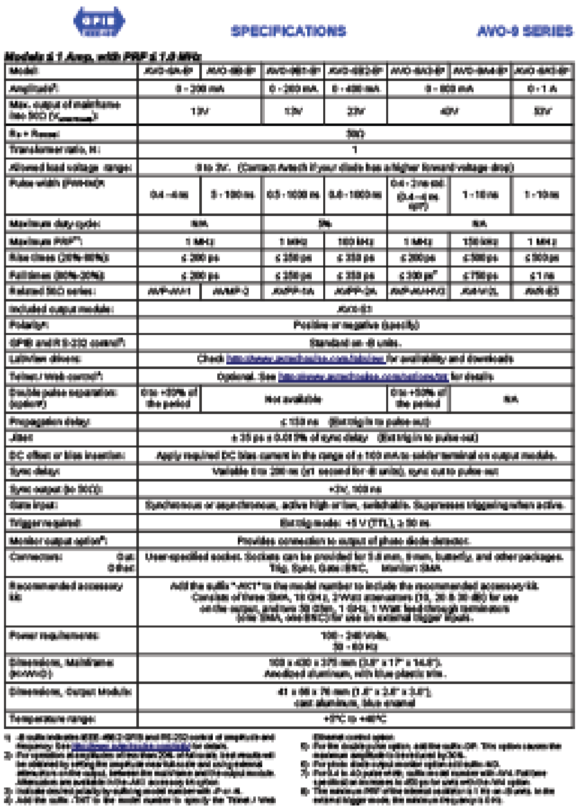


- Needs laser signals that resemble more physical scintillation light

Experimental lab setup

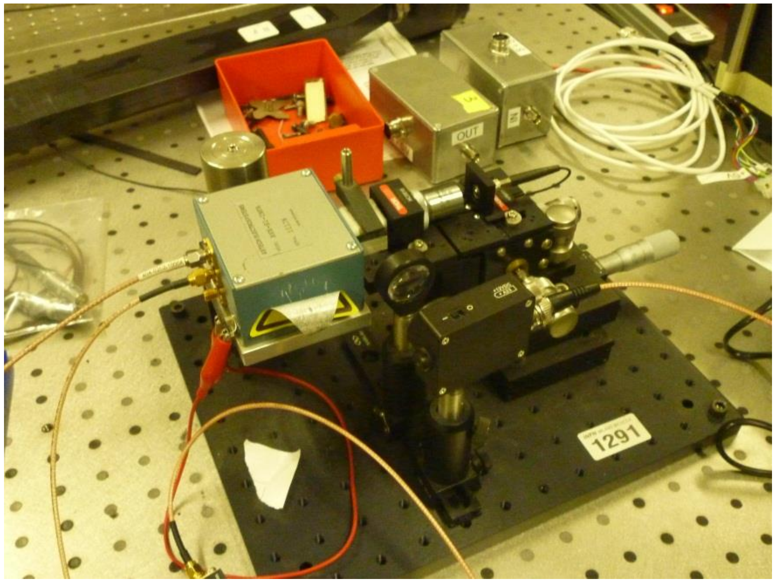


Test setup: home-made laser system



1. **Fast Avtech AVO pulser + Nichia violet laser diode (λ ~408 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)**

Some details



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**

Laser injection system:
- **Newport 20X microscope objective**
- **x/y/z Thorlabs micrometric flexure system**

Tuning of laser setup

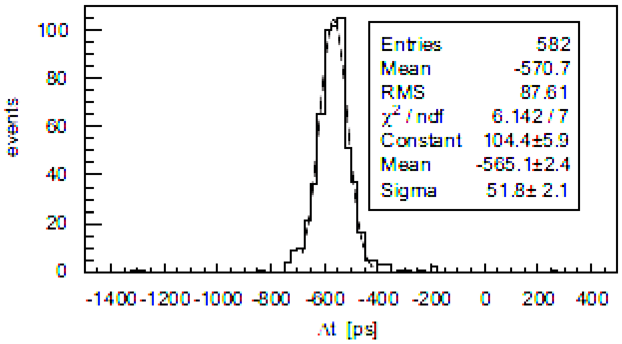


Fig. 12. $(t_L - t_R)/2$ distribution from a BC404 bar specimen and beam impact point at $x = 20$ cm (counter center).

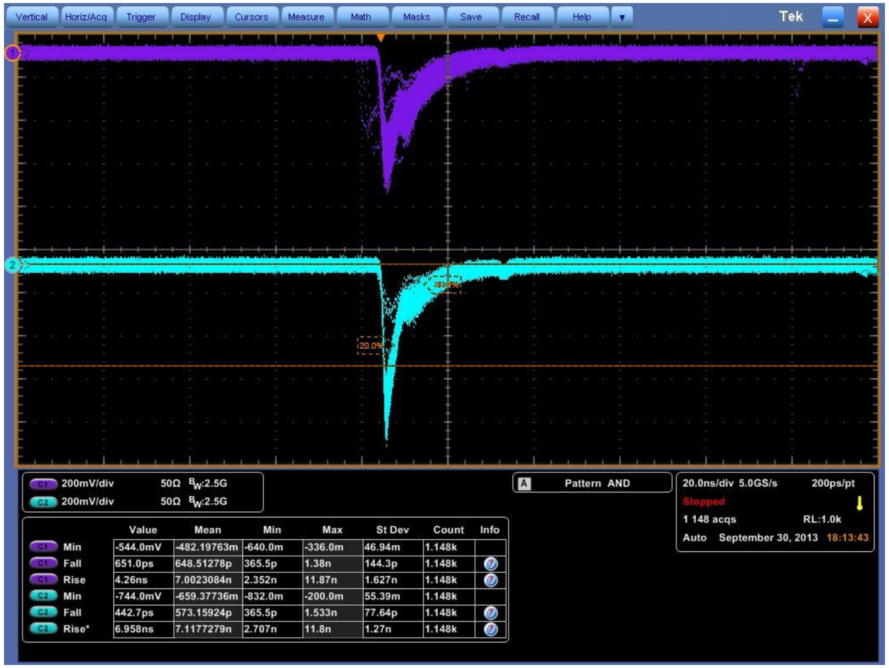
Table 2
Intrinsic resolution of counters made of scintillation bars of 4 or 6 cm width and with lightguides made of different materials and/or of different shape (Winston cone or fishtail).

Counter type	σ_t (ps)
UPS95F 4 cm bar Winston Cone	56 ± 2
UPS95F 4 cm bar REPSOL UVT lightguide	50 ± 8
BC404 6 cm bar REPSOL UVT lightguide	46 ± 5
BC420 6 cm bar REPSOL UVT lightguide	45 ± 1
BC408 6 cm bar PERSPEX UVA lightguide	60 ± 2

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

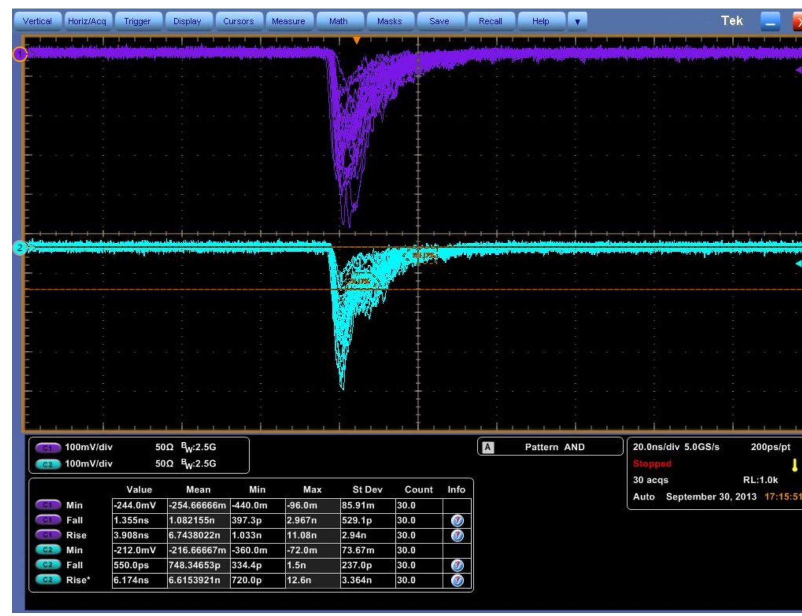
- Tune laser settings to reproduce testbeam results (σ_t)with a single counter equipped with R4998 PMTs and MIP response
- Study single counter response substituting PMTS readout with SiPMT arrays readout
- Advantage as respect to cosmics is the possibility to collect a high statistics in a short time,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

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

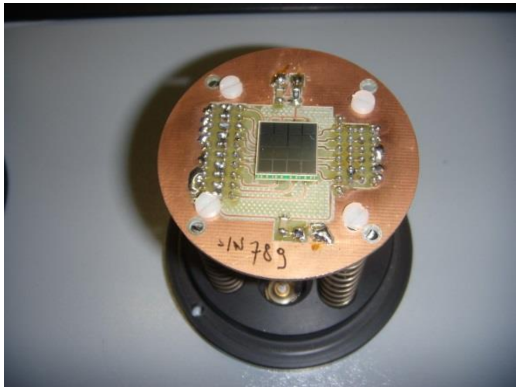


PMT signals with cosmics

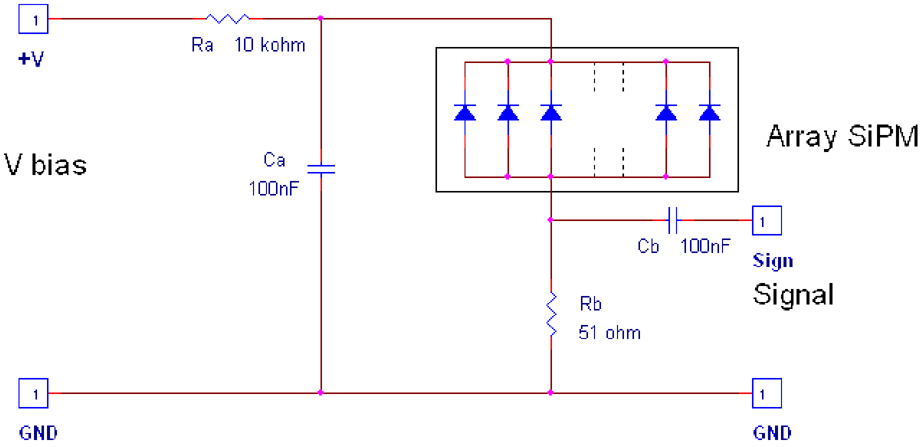
PMT signals with laser



Readout chain for SiPMT arrays

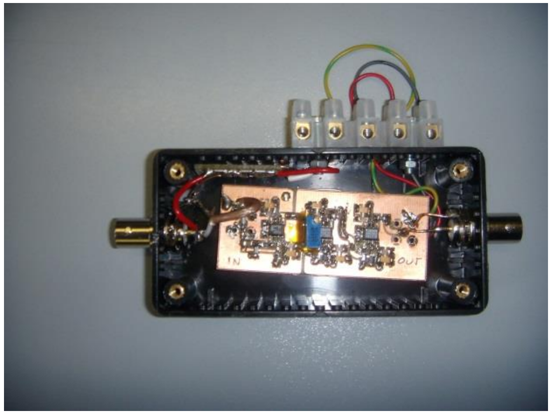


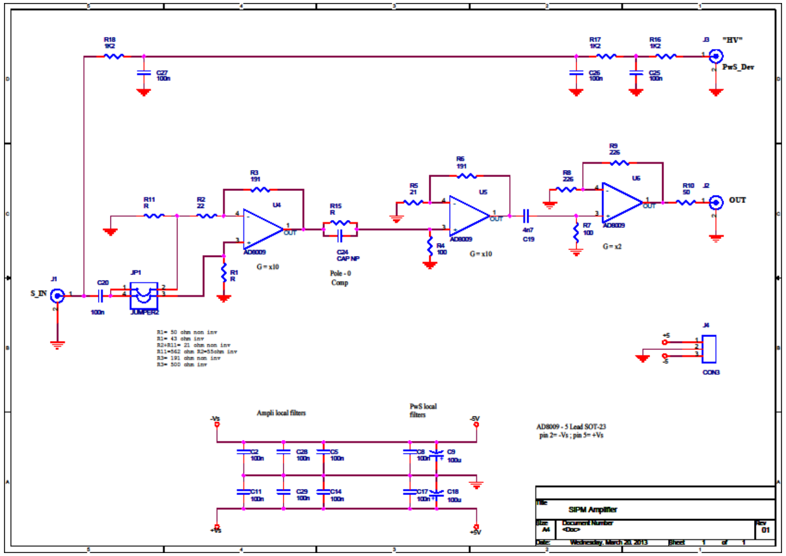
- SiPMT array custom mount
- 16 macrocells signals are summed up in the basette and then amplified



Schematic of one ``basette”

Custom amplifier



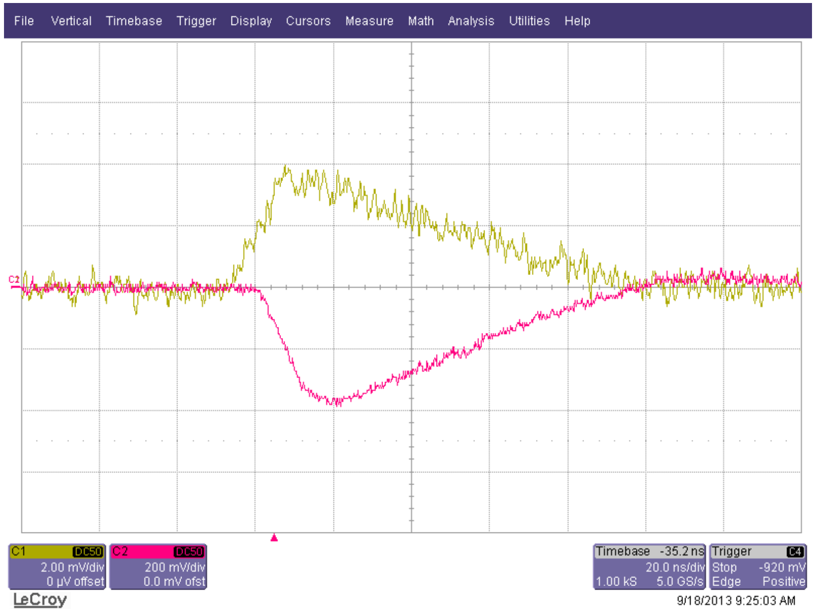


Amplifier:

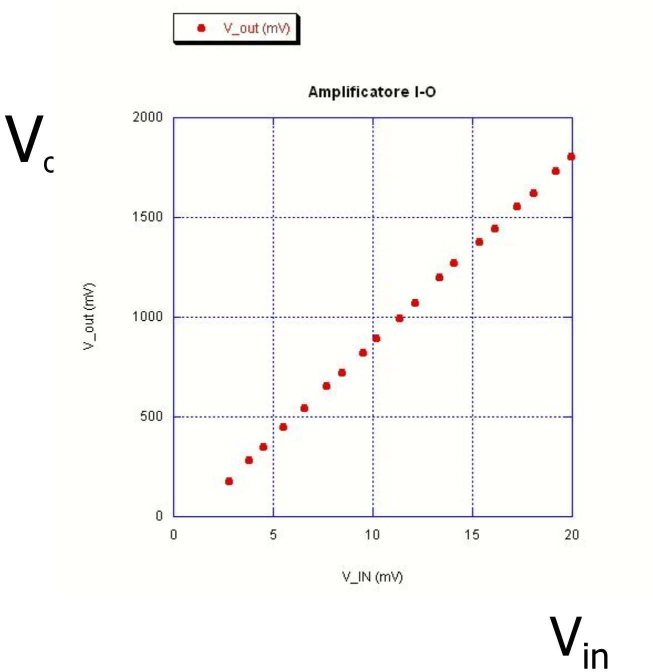
- Custom made (INFN Pv)
- 1 or 2 channels
- Gain up to 100X (30X with pole zero suppression)
- Input dynamic range: 0-70 mV
- Bandwith : 600 MHz

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

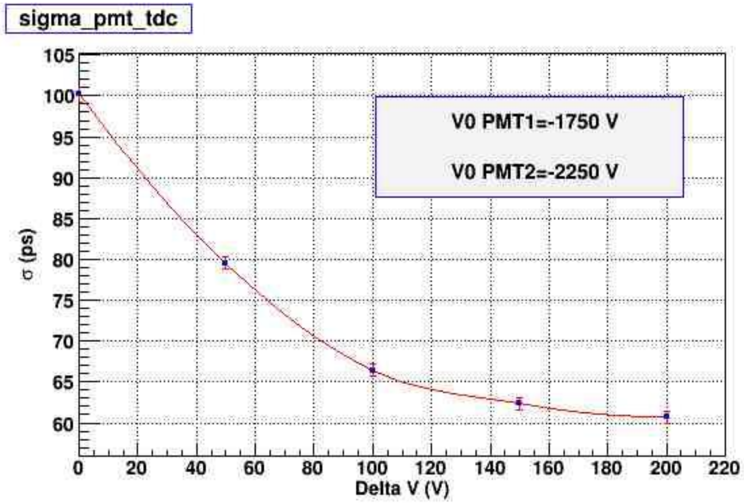
SiPMT arrays under test

Available SiPMT arrays use 3x3 mm^2 or 4x4 mm^2 macro-cells arranged in 4x4 (or more) arrays.

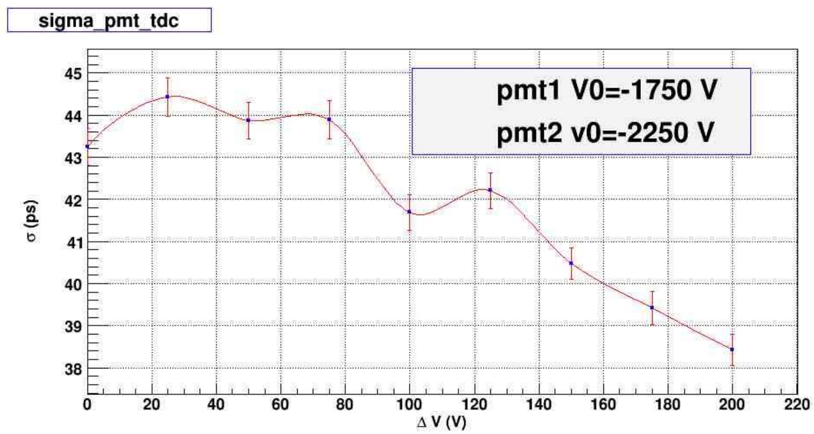
- SENSL ArraySL-4-30035-CER arrays with 3x3 mm^2 macrocells, V_{op} ~29.5 V
- Hamamatsu S11828-3344 , S12642 arrays with 3x3 mm^2 macrocells, V_{op}~72.5 V
- Advansid ASD-SiPM3S-4x4T (RGB) arrays with 3x3 mm^2 macrocells, V_{bkw} ~28.5 V
- Advansid ASD-SiPM4S-4x4T (RGB) arrays with 4x4 mm^2 macrocells, V_{bkw} ~29.2 V

- We plan to extend study to new NUV types, better matched to scintillator light emission

Results with conventional PMTs (as benchmark)



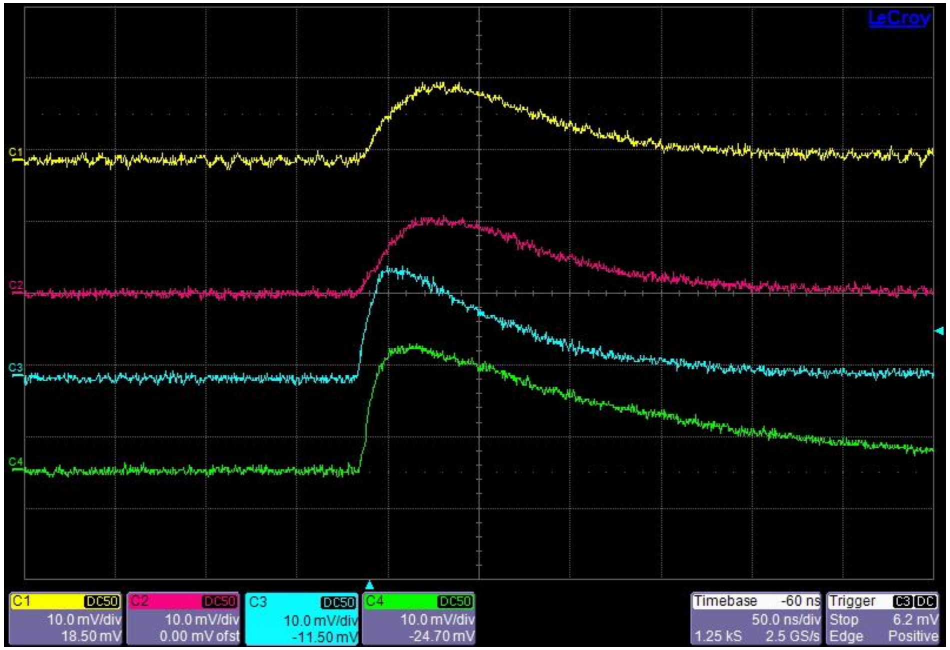
Very low laser light intensity (1 MIP or less)

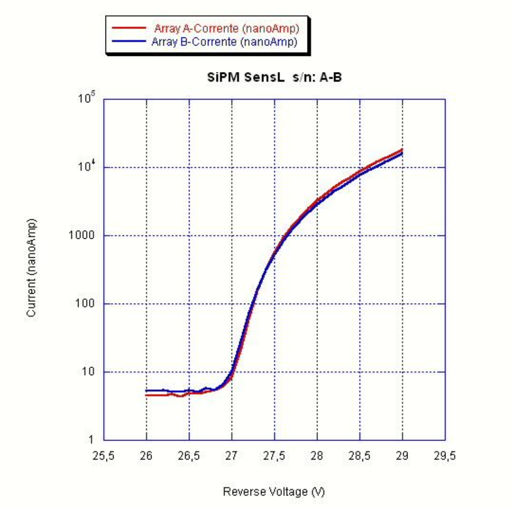


Standard laser light intensity (2-3 MIP)

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

SenSL ArraySL-4-30035-CER arrays



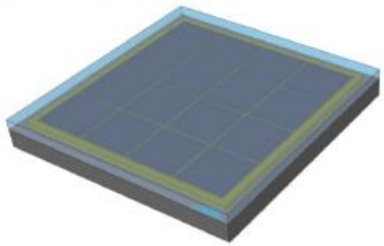


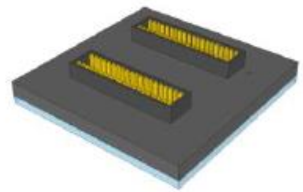
SiPMT I-V characterization (our measure)

- 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

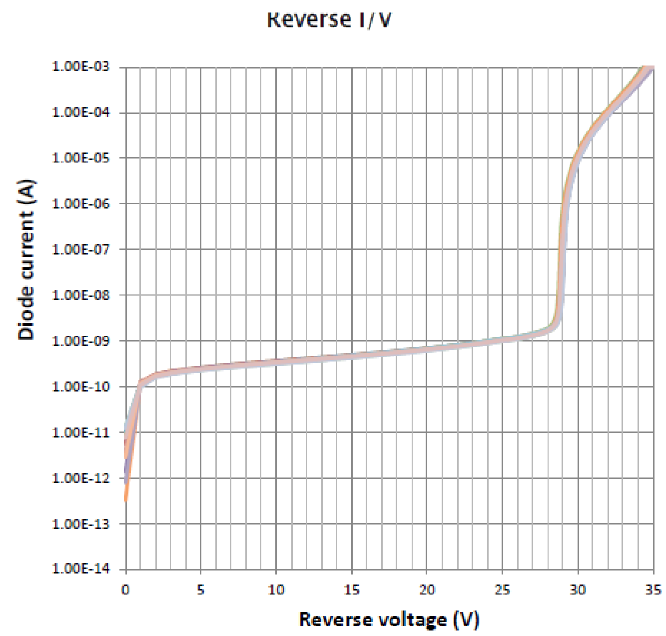
3 mm pixel pitch

2.95x2.95 mm^2 SiPMs
50 μm gap between SiPMs

Material: FR4 +
transparent epoxy layer

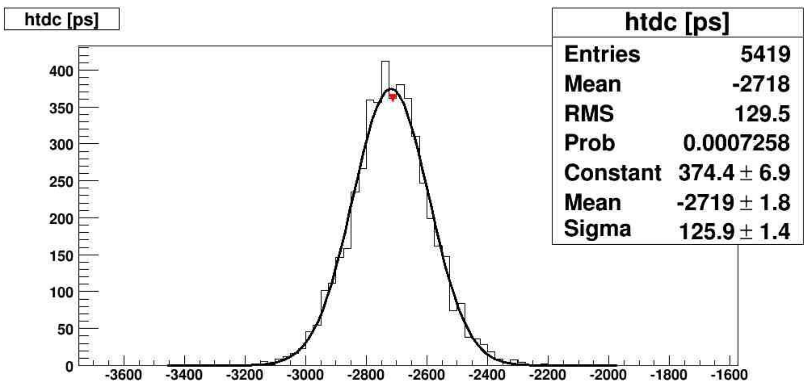
AVX 5602-040 series
plug connectors

Receptacles included
(AVX 5602-040 series)

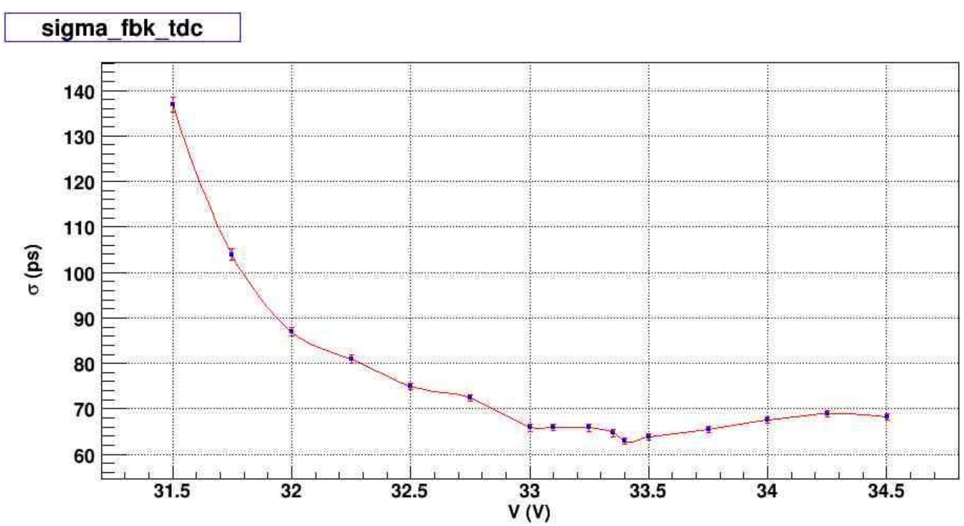


SiPMT I-V characteristics
(manufacture specs)

Results with Advansid SiPMT arrays



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

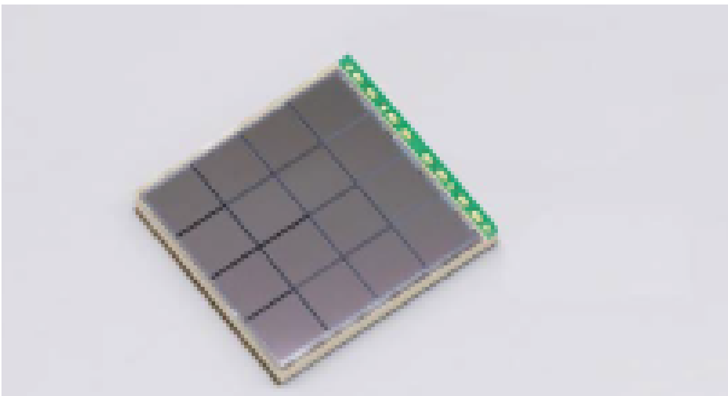


Vop

Standard light intensity

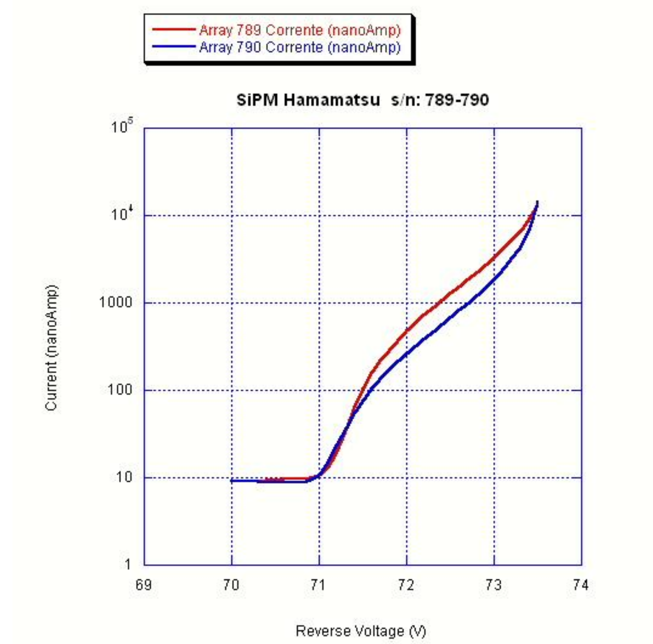
σ_t~60 ps at best, but RGB array !!

Results with Hamamatsu S11828-3344 Arrays



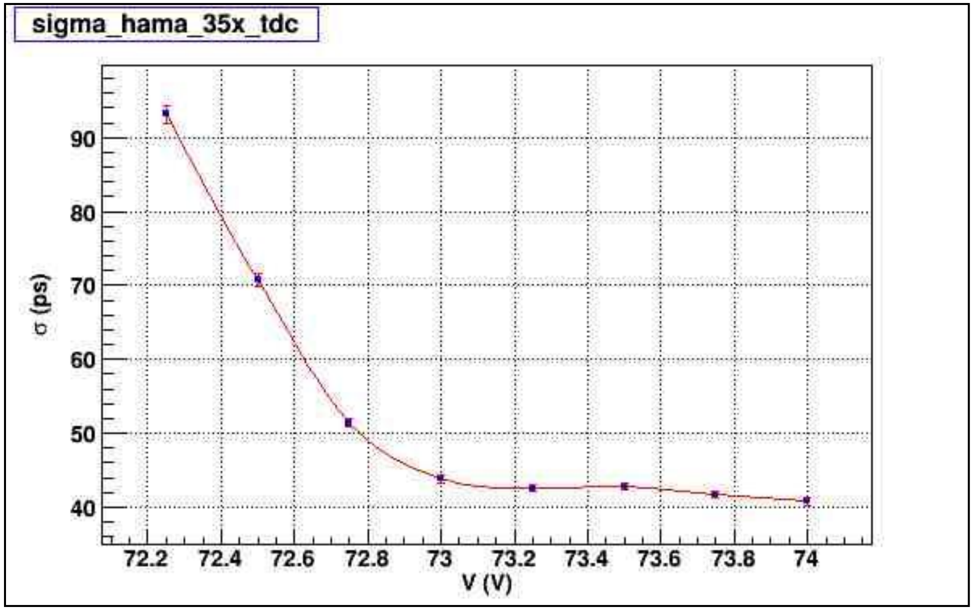
Monolithic MPPC array in SMD package
S11828-3344M

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



SiPMT I-V characterisation
(our characterisation)

Results with Hamamatsu S11828 Arrays

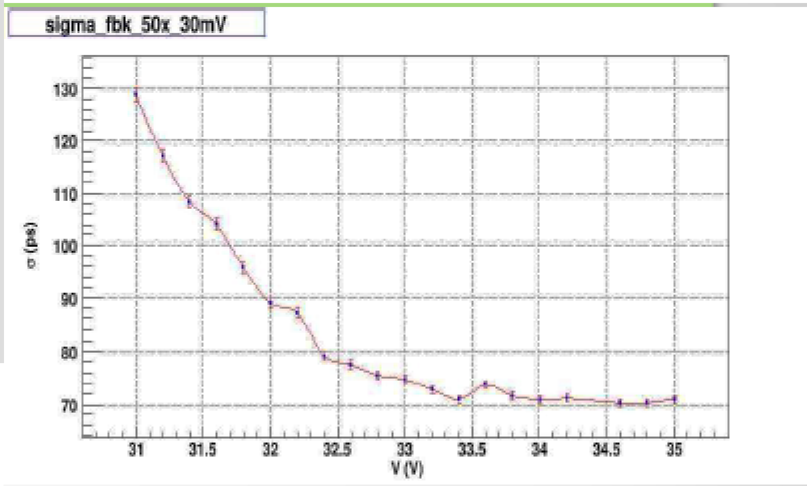


Standard light intensity

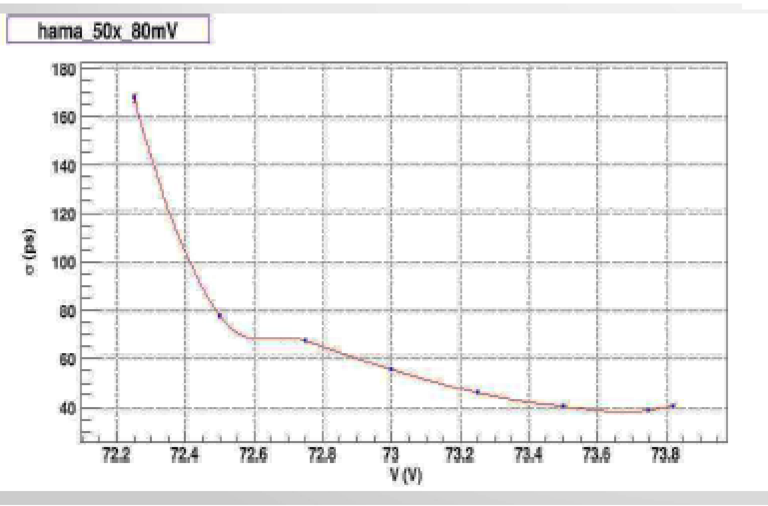
We foresee soon tests with Hamamatsu S12642 arrays, TSV package , where better results may be expected

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

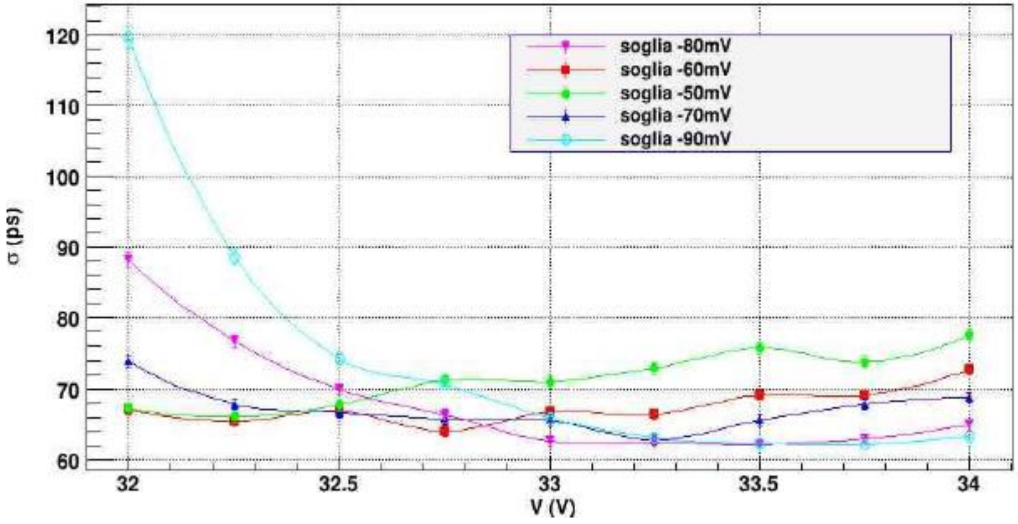


Advansid SiPM3S-4x4A with -30 mV threshold



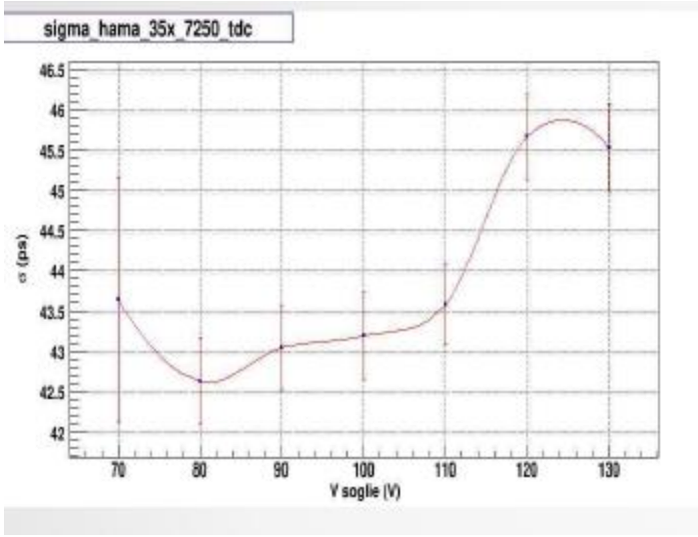
Hamamatsu S1182-334 with -80 mV threshold

Changing the L.E. discriminator threshold



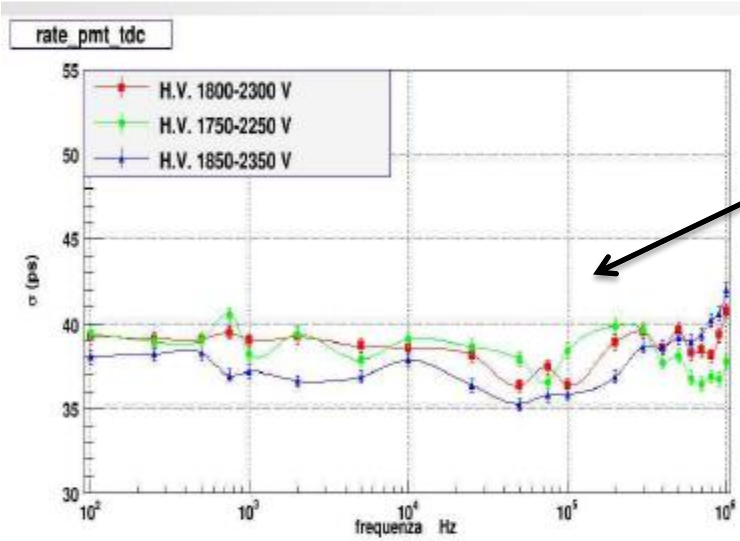
FBK/IRST SiPM3S-4x4A

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

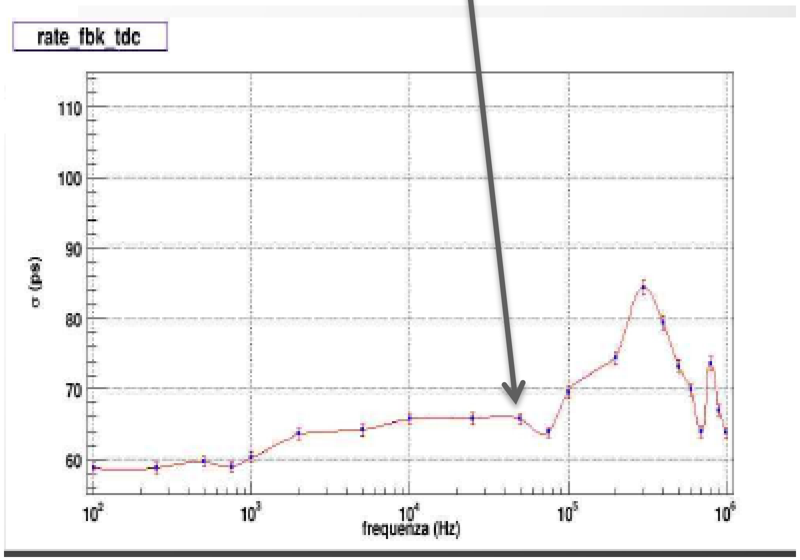


Choice of -80 mV seems fine for both

Rate effects study



Hamamatsu R4998 PMTs
FBK/IRST arrays



- Laser frequency between 10 KHz and 1 MHz
- No effect for PMTs readout up to 10^5 and small one for SiPMT arrays

Rate effects study (II):

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

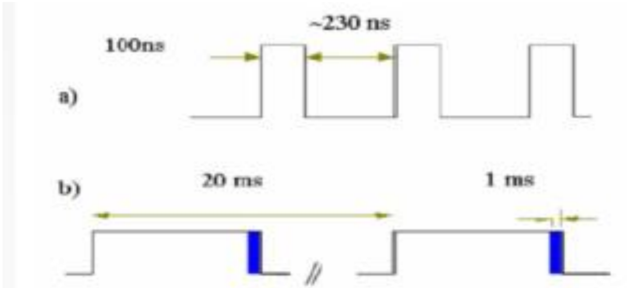
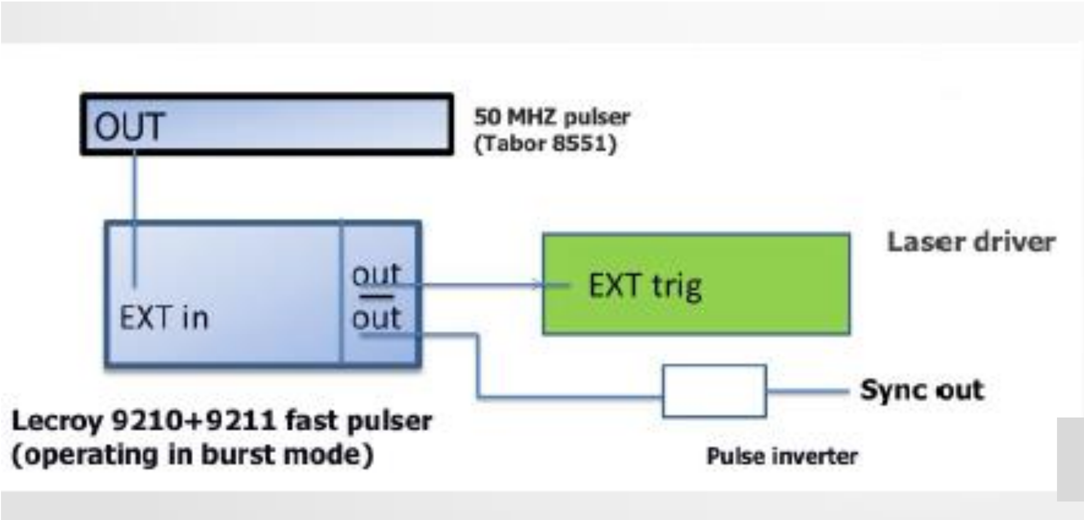
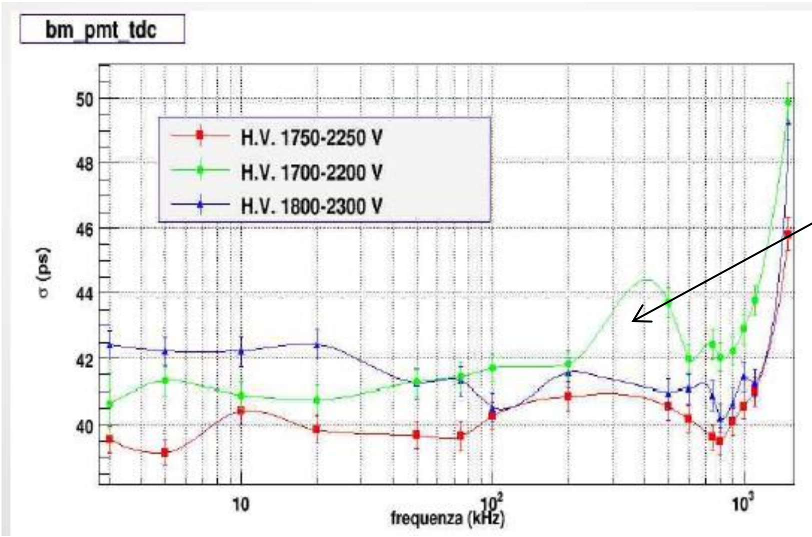


Figure7.2-1. a) the micro-structure of the ISIS synchrotron beam prior to extraction; there are two bunches rotating at diametrically opposite ends of the machine and b) the macro structure of the beam with the time the target is in the beam shown in blue



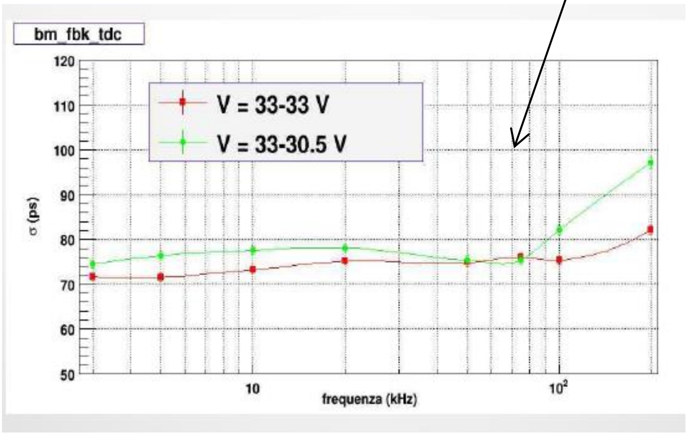
Ext trigger of laser

Rate effects study (III):



Hamamatsu R4998 PMTs
FBK/IRST SiPMT arrays

Frequency inside the bursts
(repetition rate 50 Hz)



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