Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

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ICDMP Research Team

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

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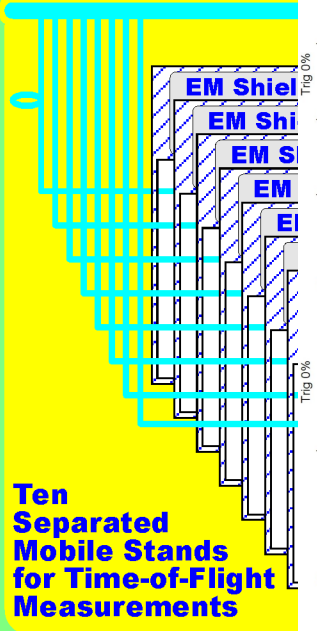
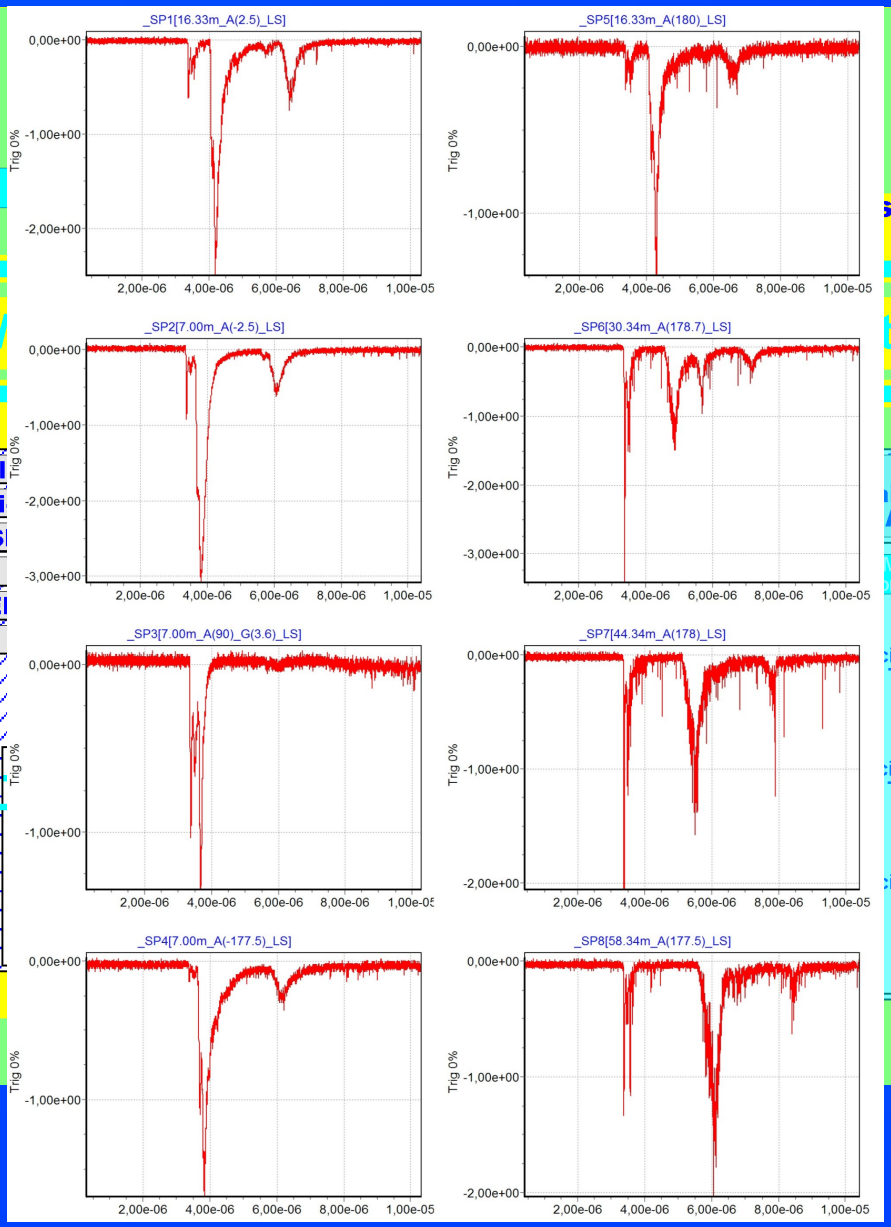
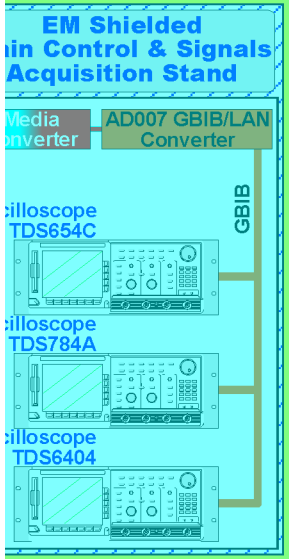


Ten Separated Mobile Stands for Time-of-Flight Measurements





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Advanced Diagnostics Laboratory
ACS Ltd., Warsaw, Poland

Fast Scintillation Probes
FNSP-1 type

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Main Features of FNSP-1 Scintillating Probe:

- It incorporates photomultiplier hybrid assembly H1949-51 type (HAMAMATSU) and BC-408 (BICRON) plastic scintillator;
- Heavy-duty housing ensures high EM shielding effectiveness;
- Overall dimensions: 483 mm (L) x 172 mm (D);
- Weight: up to 11 kg.

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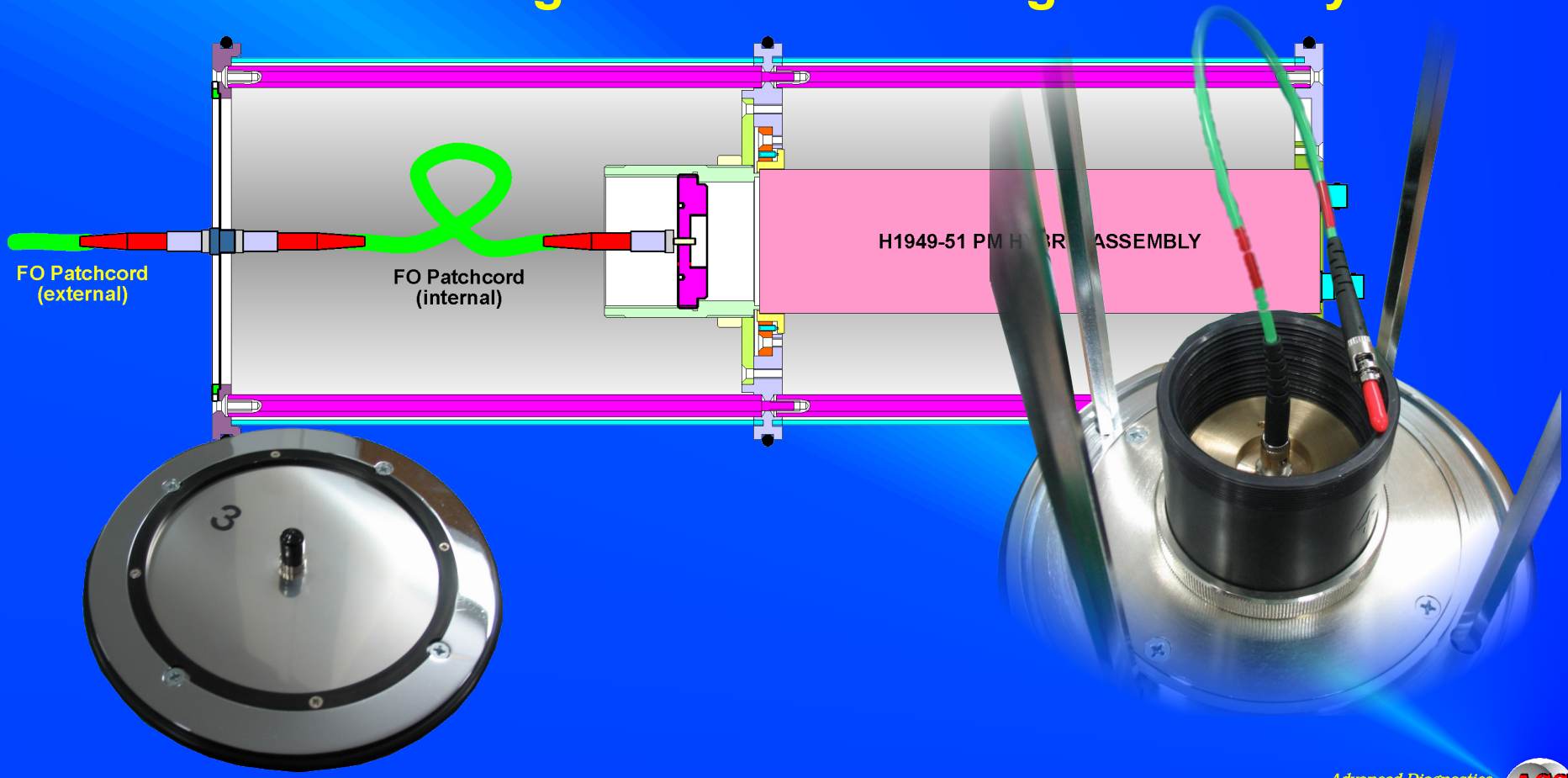
Scintillation Probes FNSP-1 type

Probes' Design

FO Patchcords Arrangement Used During Laboratory Tests



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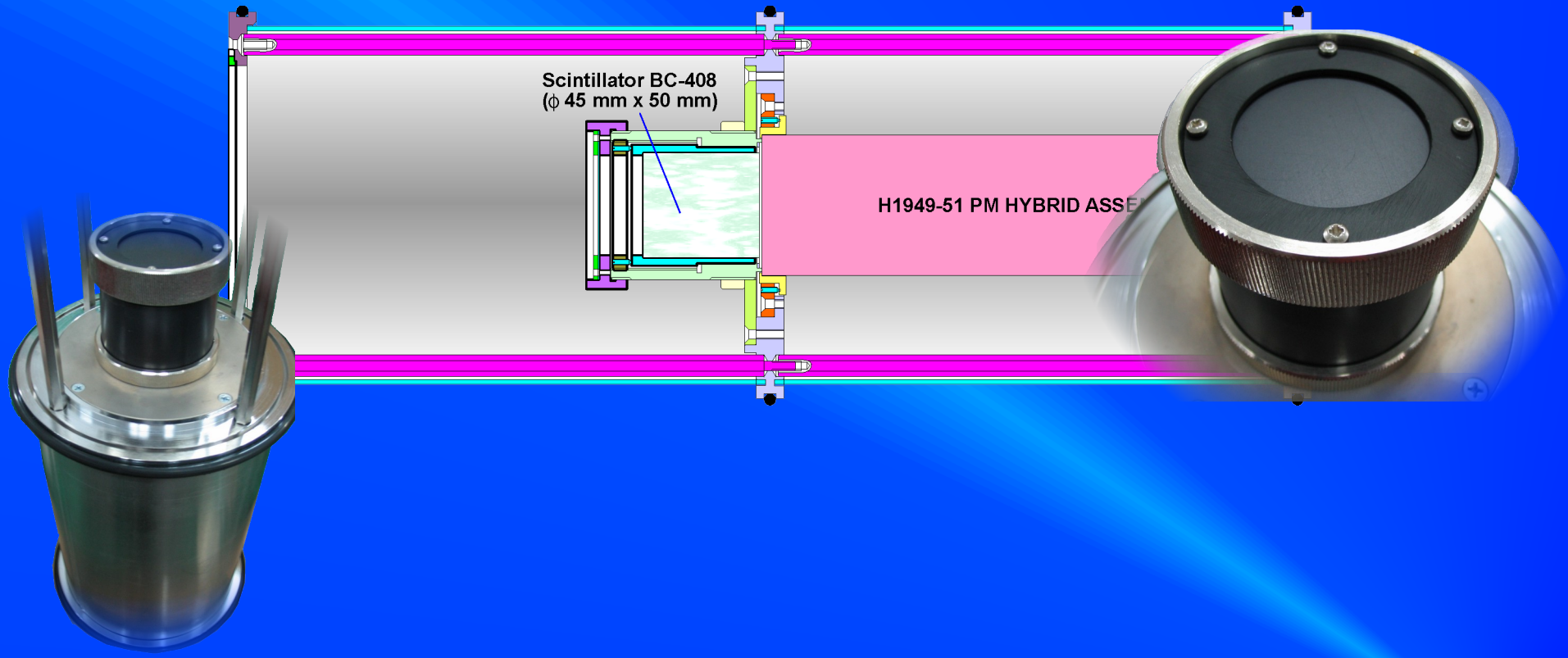
Probes' Design

SPs equipped with small area scintillator



Front cover (0.5 mm Al) may be replaced by very thin foil or non-transparent paper

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

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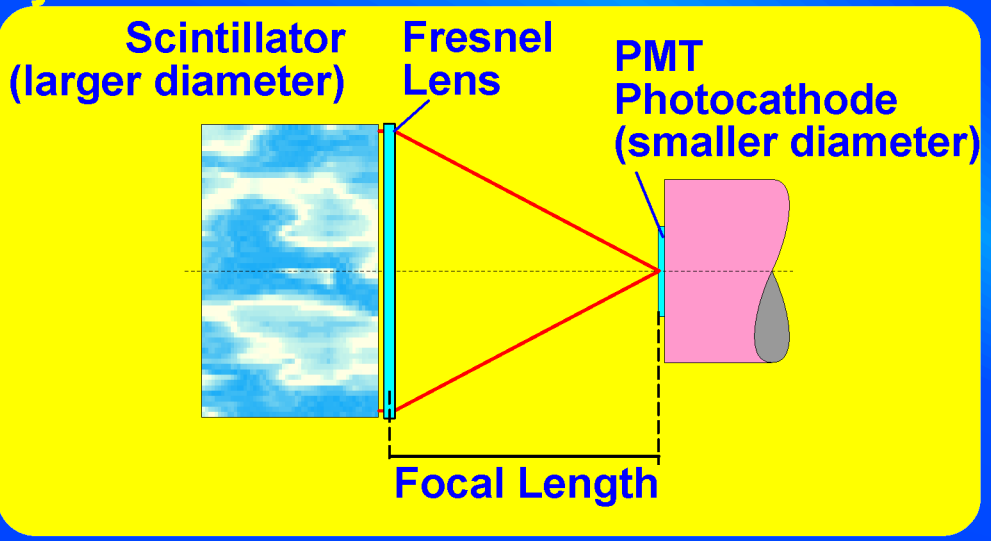
Probes' Design

Large Area Scintillator – PMT's Photocathode Coupling

Nonimaging, Optical - Free of Contact Coupling by means of Fresnel Lens



Scintillator of 120 mm dia. inside housing

Fresnel Lens mounted in front of the scintillator

Relative easy to mount, uncritically against mechanical forces and cheapest solution, with light transmission of about 8%

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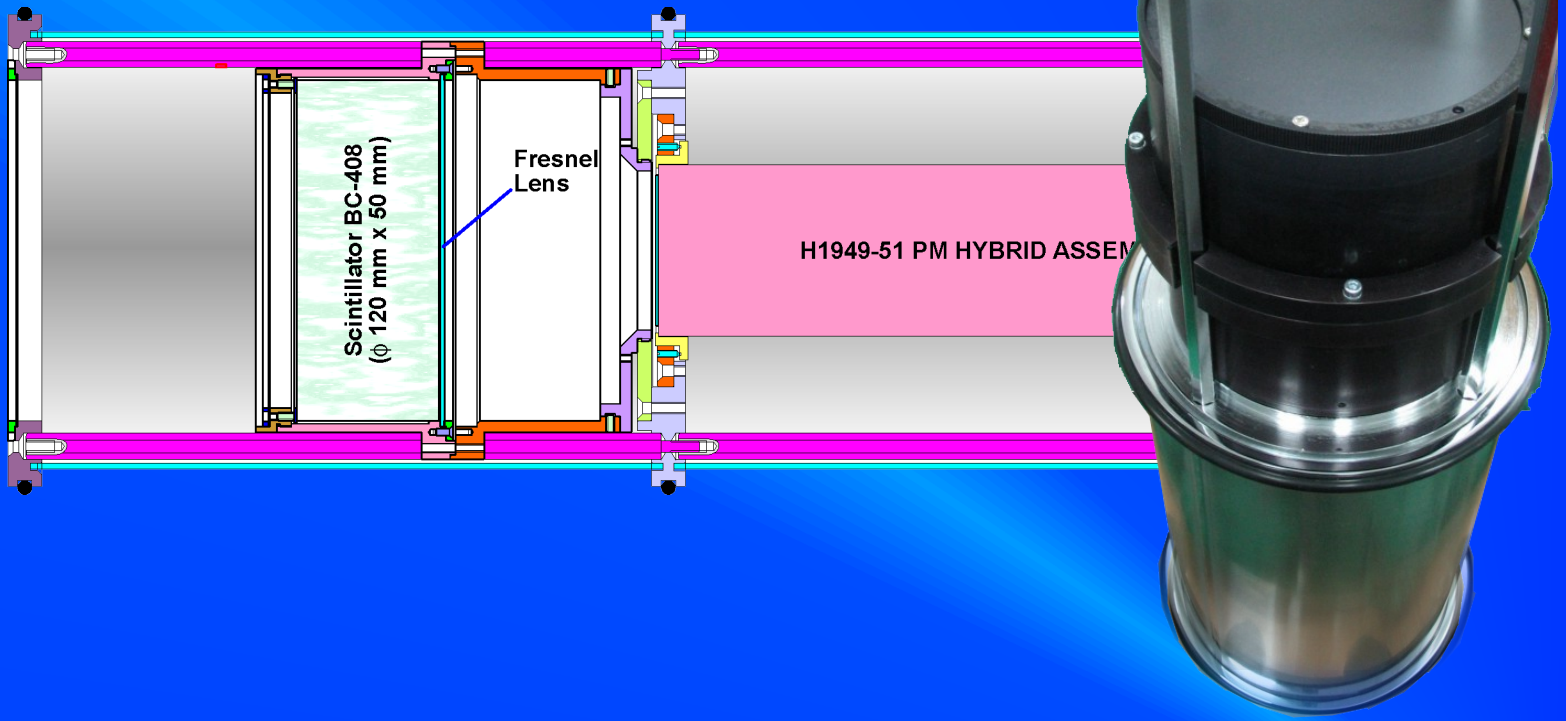
Probes' Design

SPs equipped with large area scintillator



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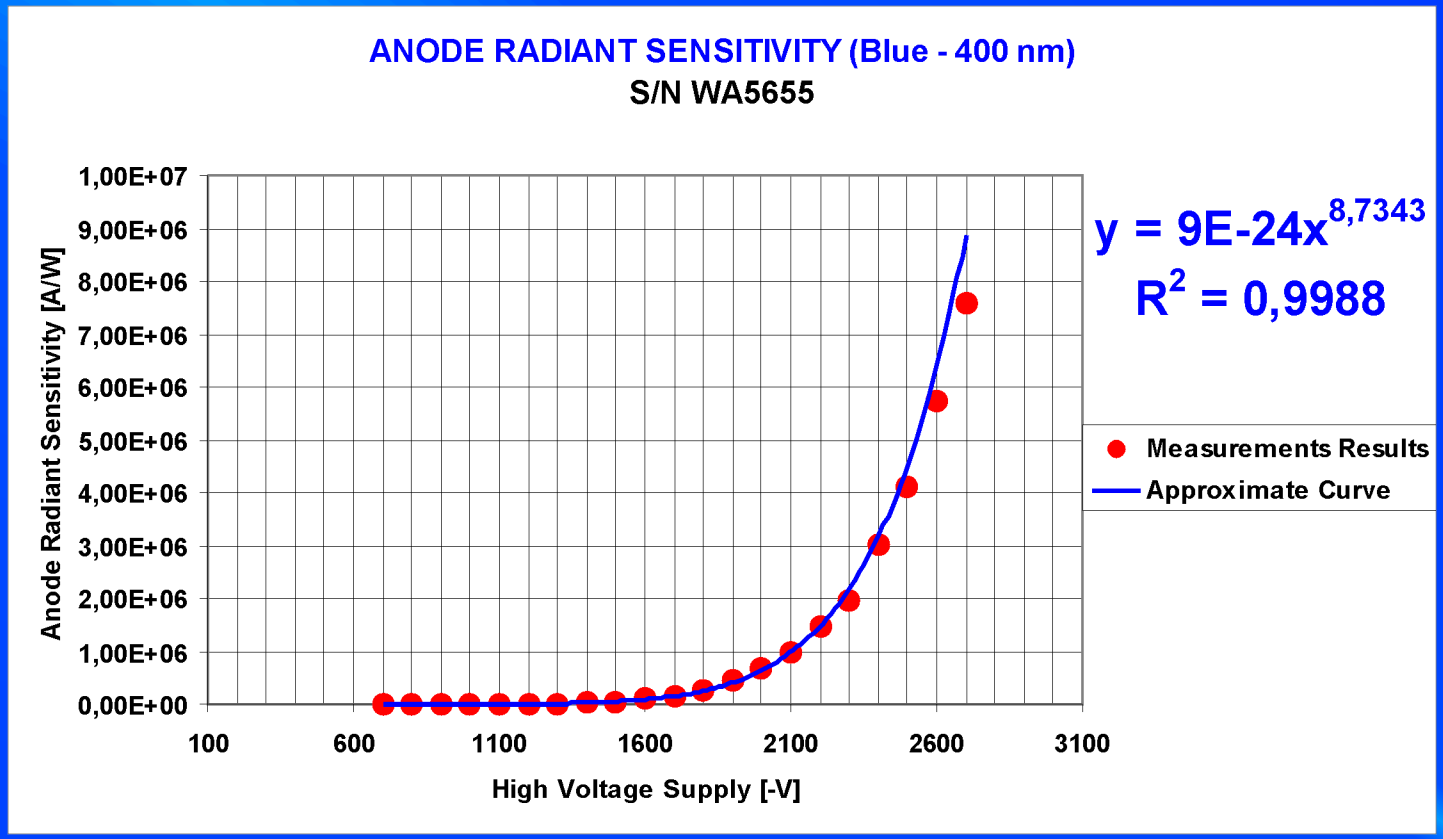
Laboratory Tests

Anode Radiant Sensitivity and Electron Transition Time



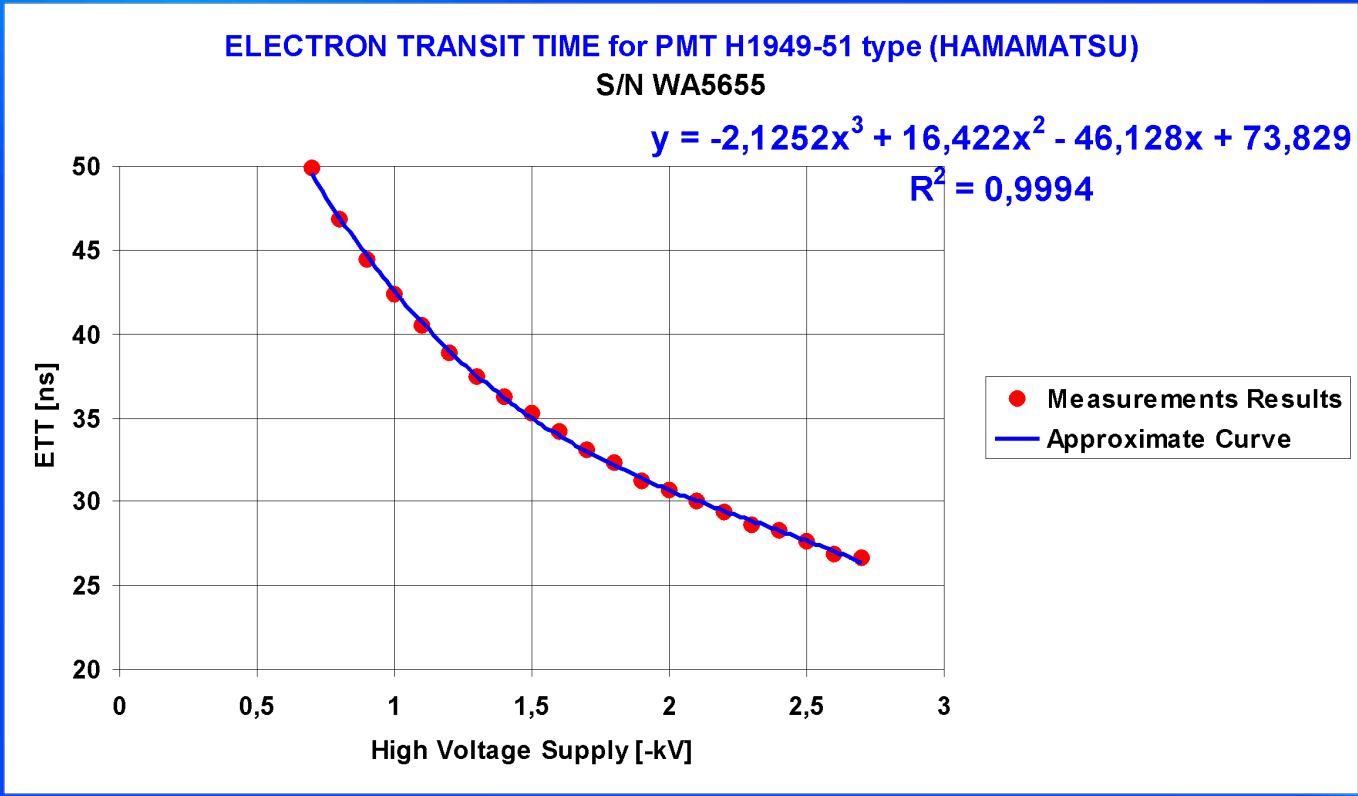
The best approximation - power function (in accordance with PMT theory)

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Scintillation Probes FNSP-1 type

Laboratory Tests

Anode Radiant Sensitivity and Electron Transition Time



The best approximation - polynomial function

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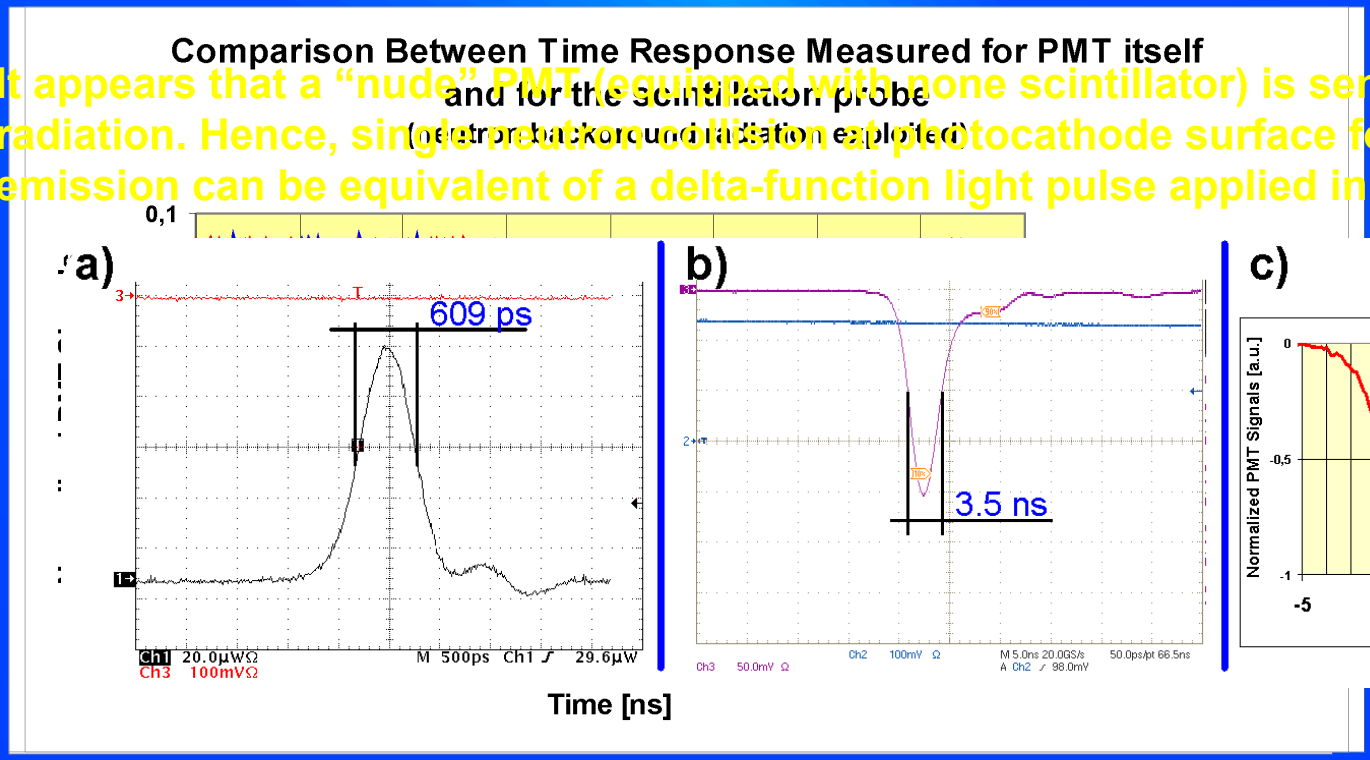
Laboratory Tests – Time Response Measurements

Usage of Neutron Background Radiation

The time response measurements have been based on detection of a neutron background radiation which originates either in nuclear interactions of high-energy cosmic ray particles with the Earth's atmosphere and neutron production in the Earth's crust.

It appears that a "nude" PMT (equipped with none scintillator) is sensitive to neutron radiation. Hence, single neutron collision at photocathode surface followed by electrons emission can be equivalent of a delta-function light pulse applied in typical arrangement.



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Performance Tests

Relative calibration of four SPs

Precondition:

- The differences between integrals taken over neutron signals (recorded by means of four SPs) should be not higher than 2%;

Procedure:

- Fine adjustment of HV supply applied to three SPs, fourth SP has been treated as a reference probe;

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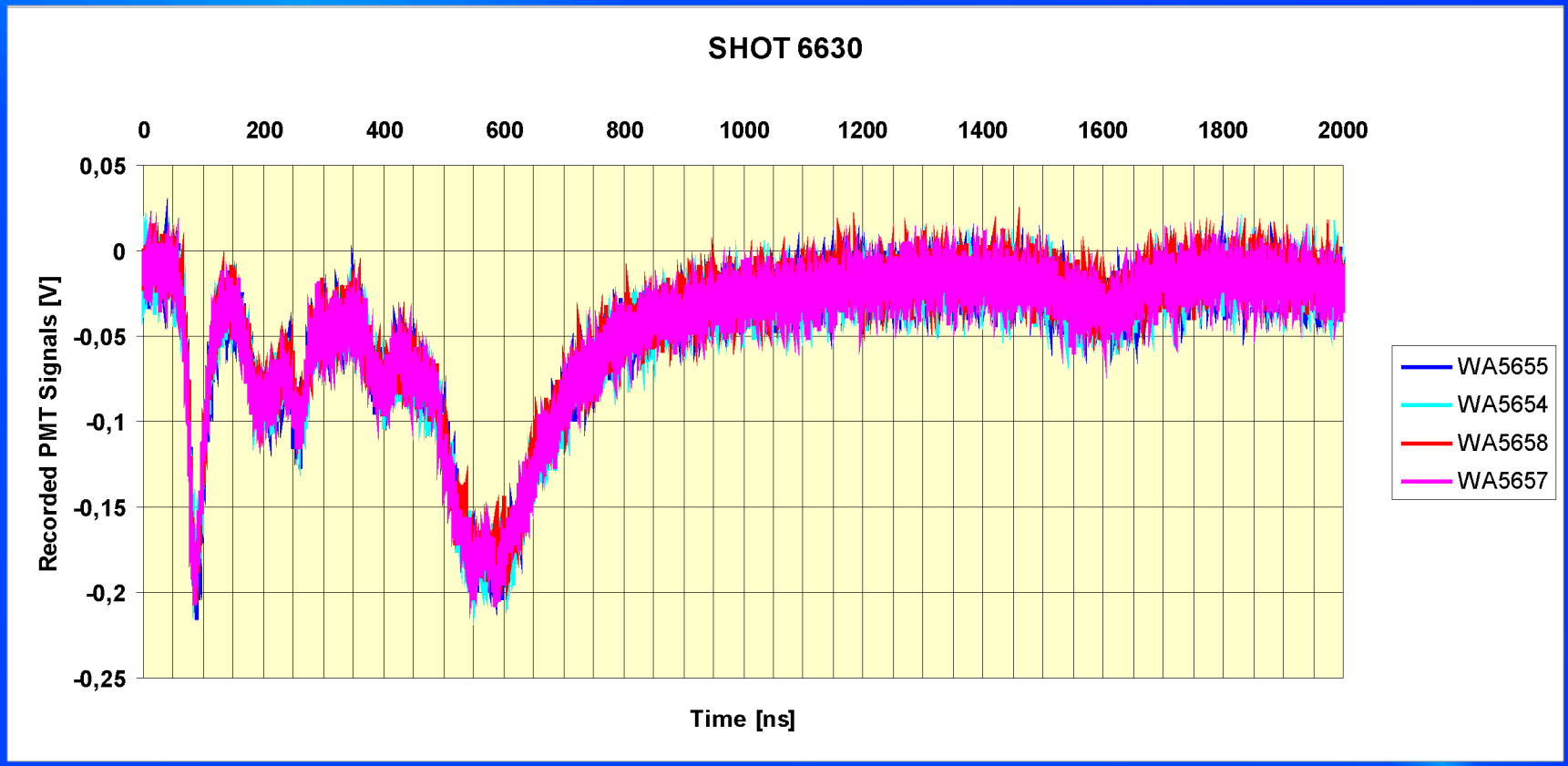
Scintillation Probes FNSP-1 type

Performance Tests

Relative calibration of four SPs



After fine adjustment of HV supply, the requirements for relative calibration have been fulfilled – difference between integrals of neutron signals have been not higher than 2%;

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

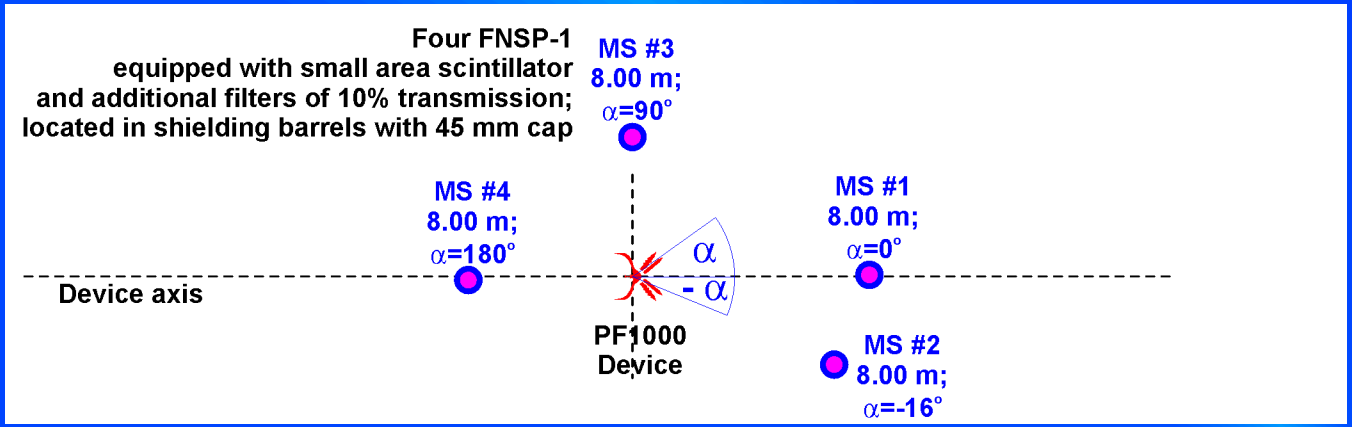
Scintillation Probes FNSP-1 type

Performance Tests

Neutron emission anisotropy measurements

Simplified definition:

- Ratio between number of neutrons emitted in chosen direction of observation and number of neutrons emitted at right angle (in reference to PF device axis);



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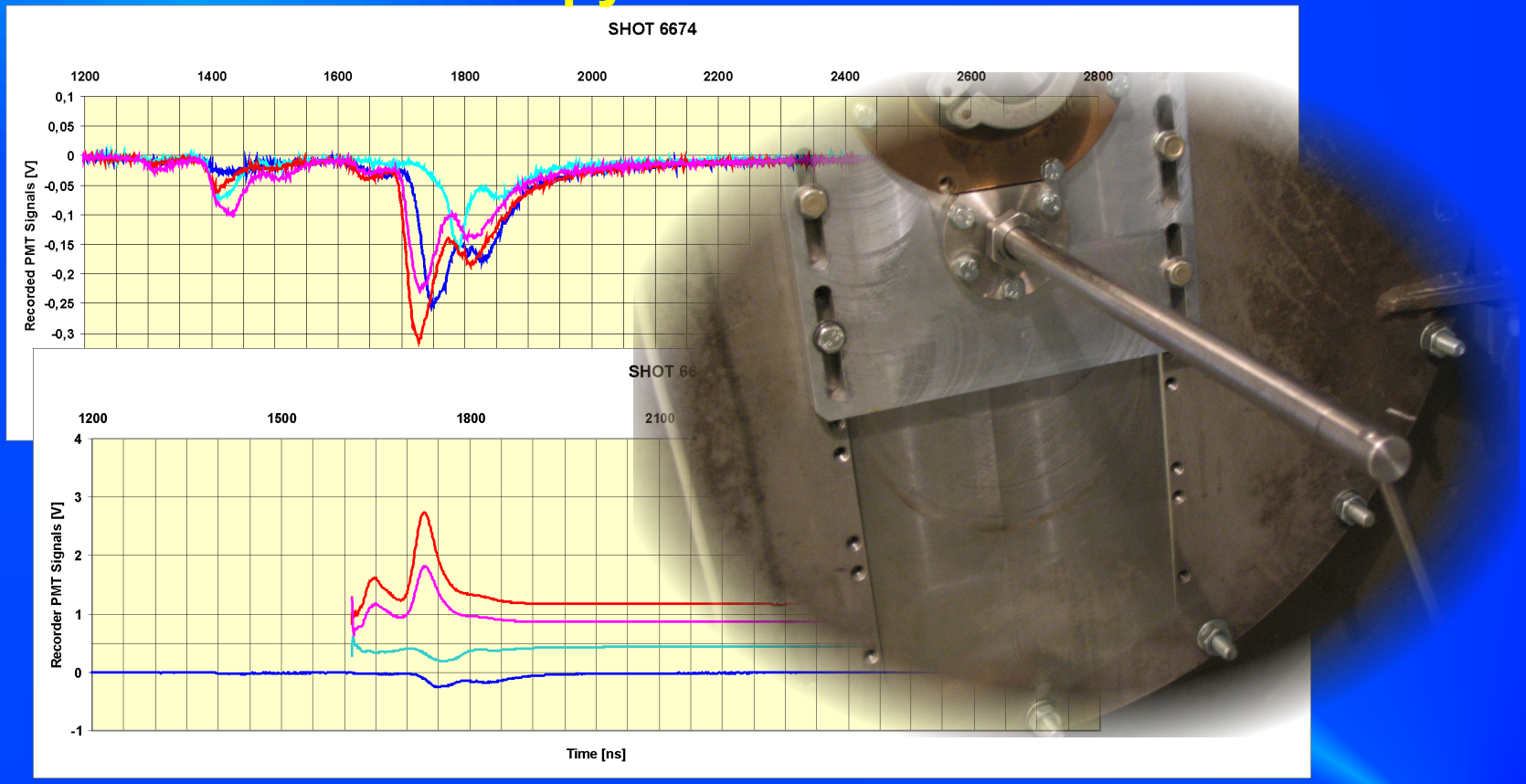
Scintillation Probes FNSP-1 type

Performance Tests

Neutron emission anisotropy measurements



Strange result – from PF theory the number of forwards emitted neutron should be higher than the numbers of neutron recorded along angled axis;

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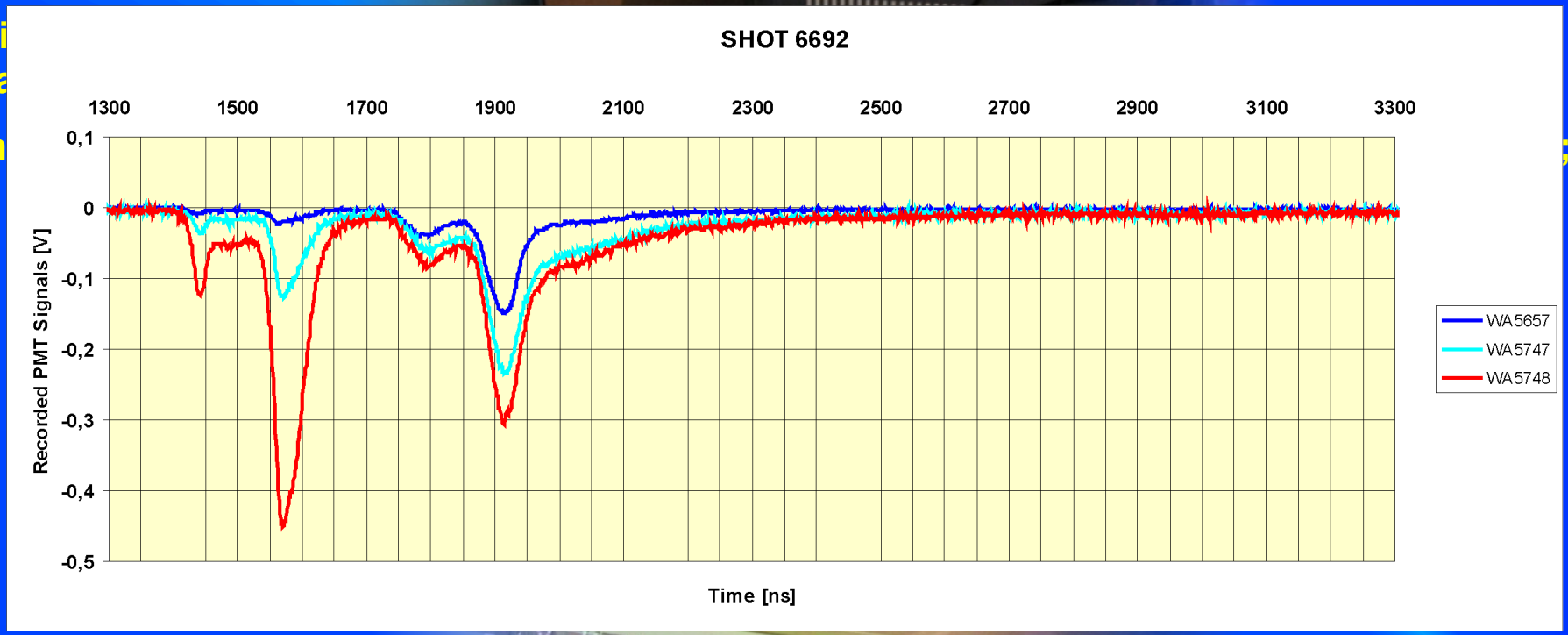
Performance Tests

Investigations of Neutron Radiation Scattering



Distinct attenuation (~24%) of neutron as well as hard X-ray radiation has been observed on waveform taken from SP, which has been covered by glass slab of 30 mm;

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Performance Tests

Investigations of Neutron Radiation Scattering

A lot of materials (differ in composition and thickness) have been tested in presented manner;

Satisfactory agreement (mutual differences lower than 3%) between results taken from experiment and MCNP calculation has been obtained;

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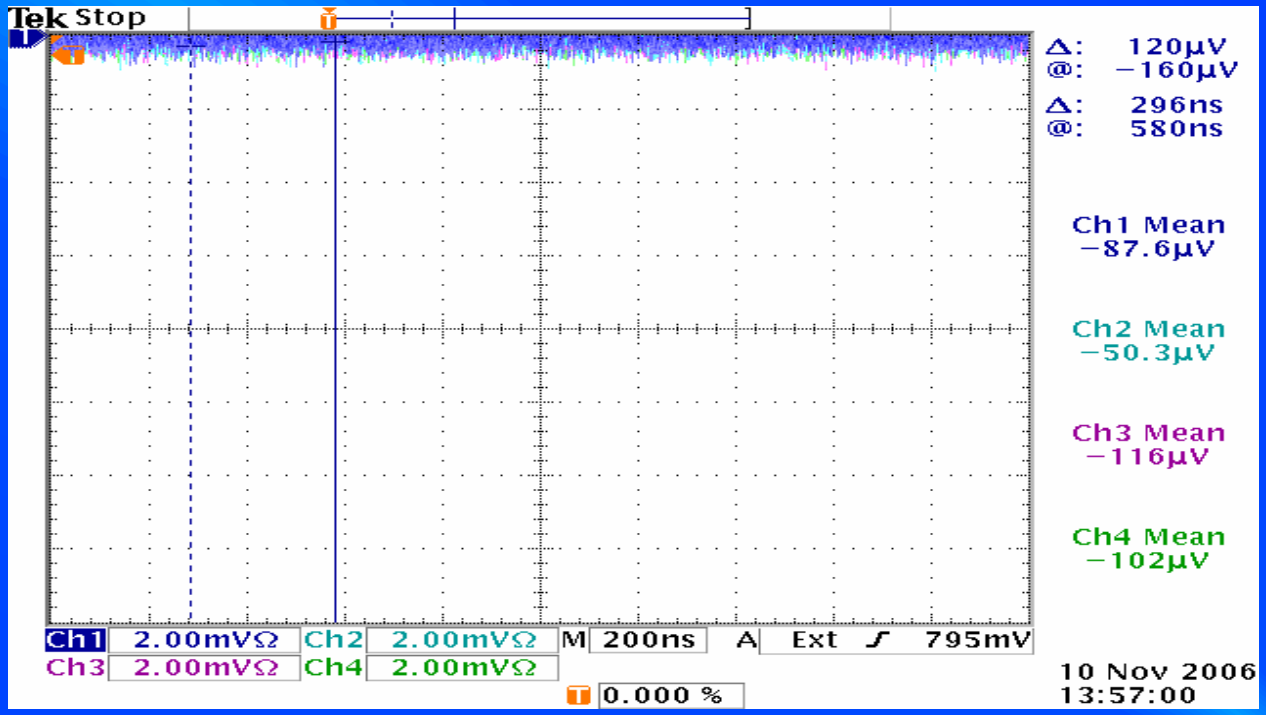
Noises Level Recorded in Mobile Stand

Mobile stand (in fact small Faraday's cage) has been placed 7 m away from experimental chamber of PF1000 device – huge source of EM interference:



Thanks to very effective shielding against EM interference, it has been possible to acquire SPs waveform with vertical sensitivity setting as low as 2 mV per division;

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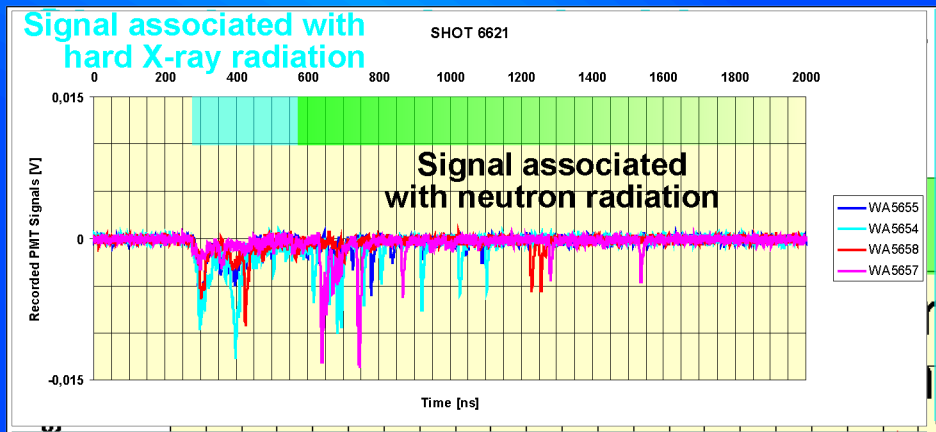
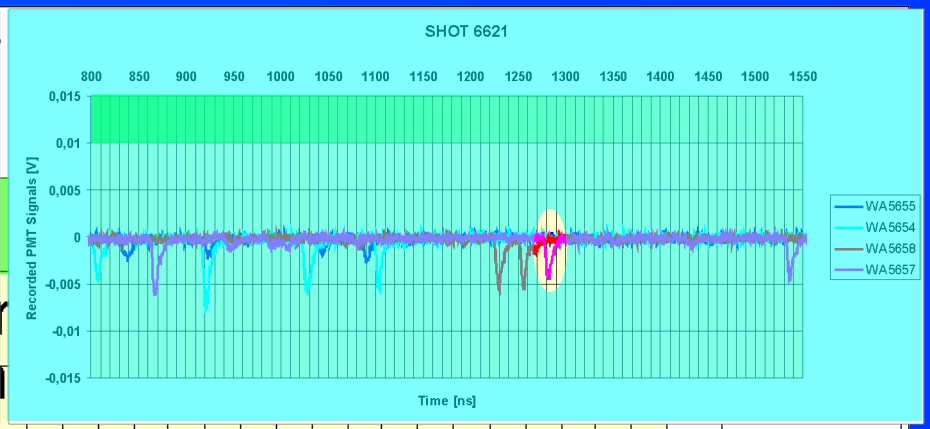
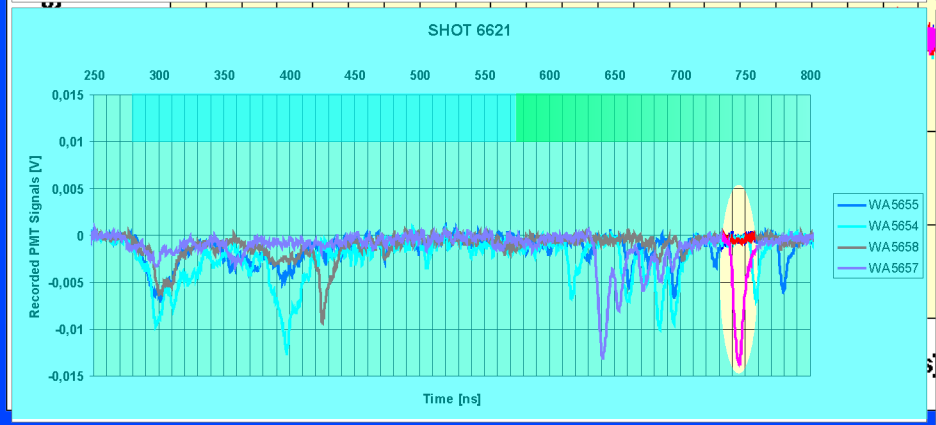
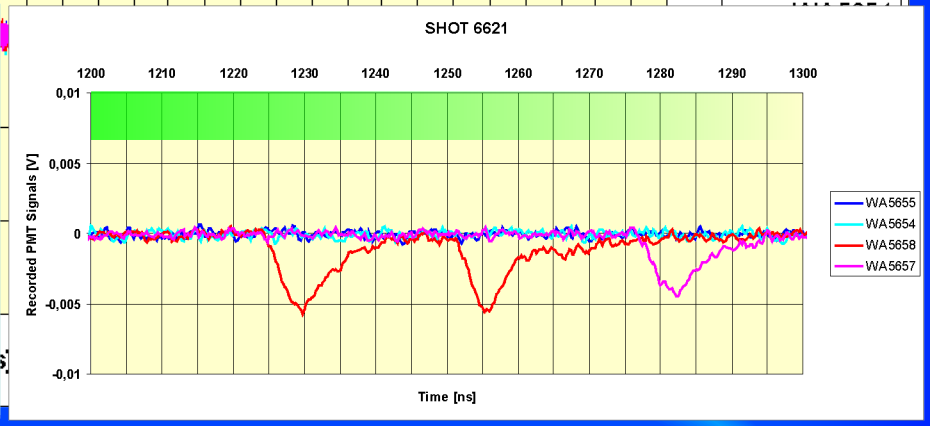
Scintillation Probes FNSP-1 type

In Search of a Single Neutron







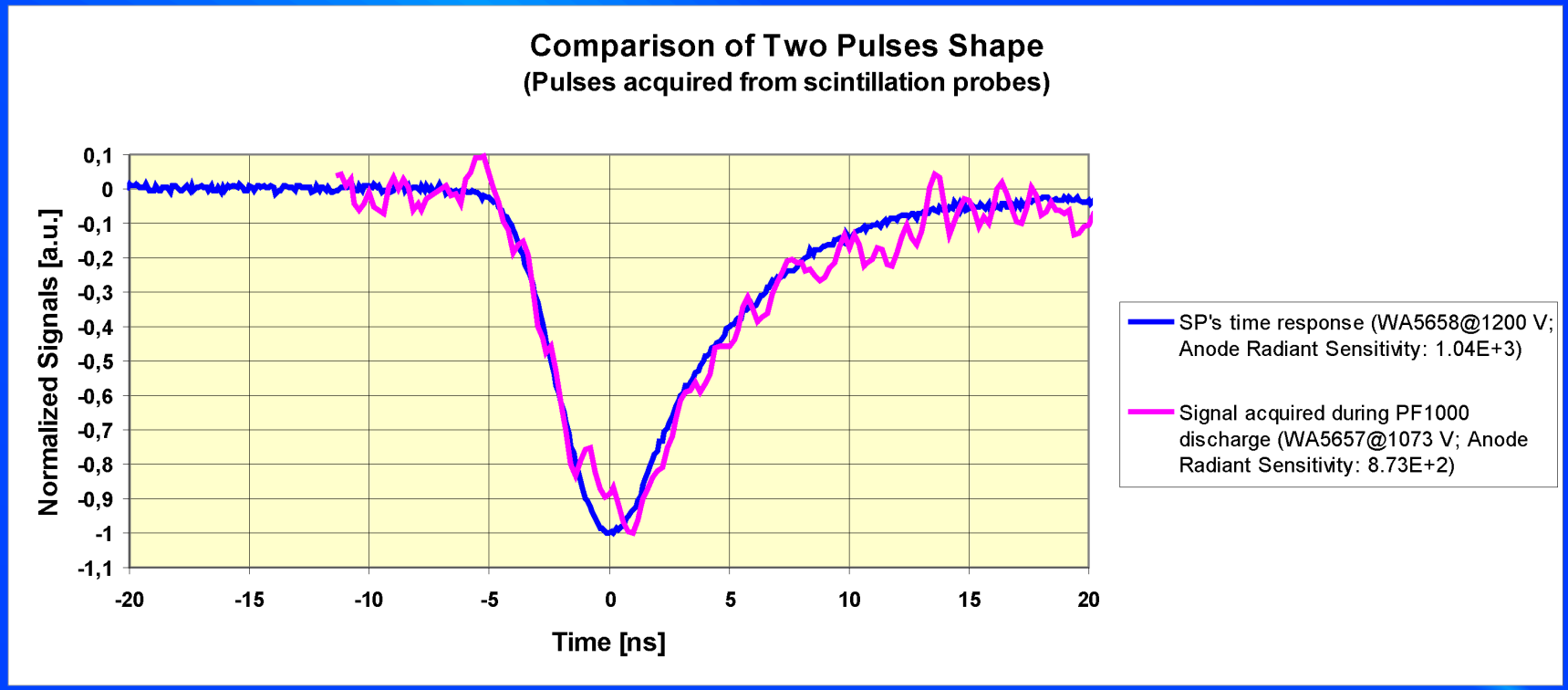


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Scintillation Probes FNSP-1 type

In Search of a Single Neutron – Initial Verification

Important issue: if analyzed signals are really associated with single neutron collision, them shapes should fit the SP's time response shape, which has been obtained during laboratory tests and measurements of which has been based on neutron background radiation recording.



Both shapes are in good agreement;

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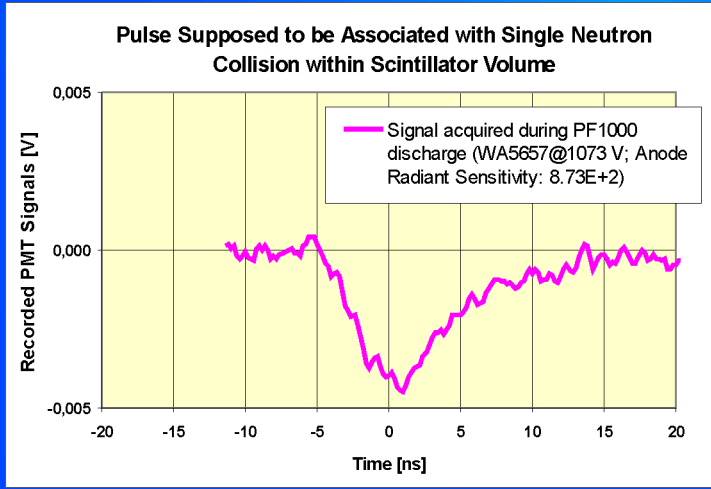
In Search of a Single Neutron



Normalized Integral Value	-8,11088E-09	[1s]
Pulse Peak	-0,00447813	[V]
Integral Over Single Pulse	3,63E-11	[Vs]
Charge deposited at PMT anode	7,26E-13	[As]
Anode Radiant Sensitivity WA5657@ 1073 V	8,73E+02	[A/W]
Energy deposited at photocathode surface	8,32E-16	[J]
Amendment for neutron position within scintillator volume	2,00E-01	[a. u.]
Total energy associated with single neutron scattering (emitted for full solid angle)	4,16E-15	[J]
Total energy associated with single neutron scattering (emitted for full solid angle)	2,60E+04	[eV]
Photons number (emitted at wavelength peak - 425 nm with energy of 2,92 eV)	8,90E+03	
Photons number per every 1 keV energy lost by proton	1,00E+01	[eV]
Total energy lost by proton	8,90E+02	[keV]
Ratio: energy transferred during (n,p) scattering to expected initial neutron energy (2.45 MeV)	36,3	[%]

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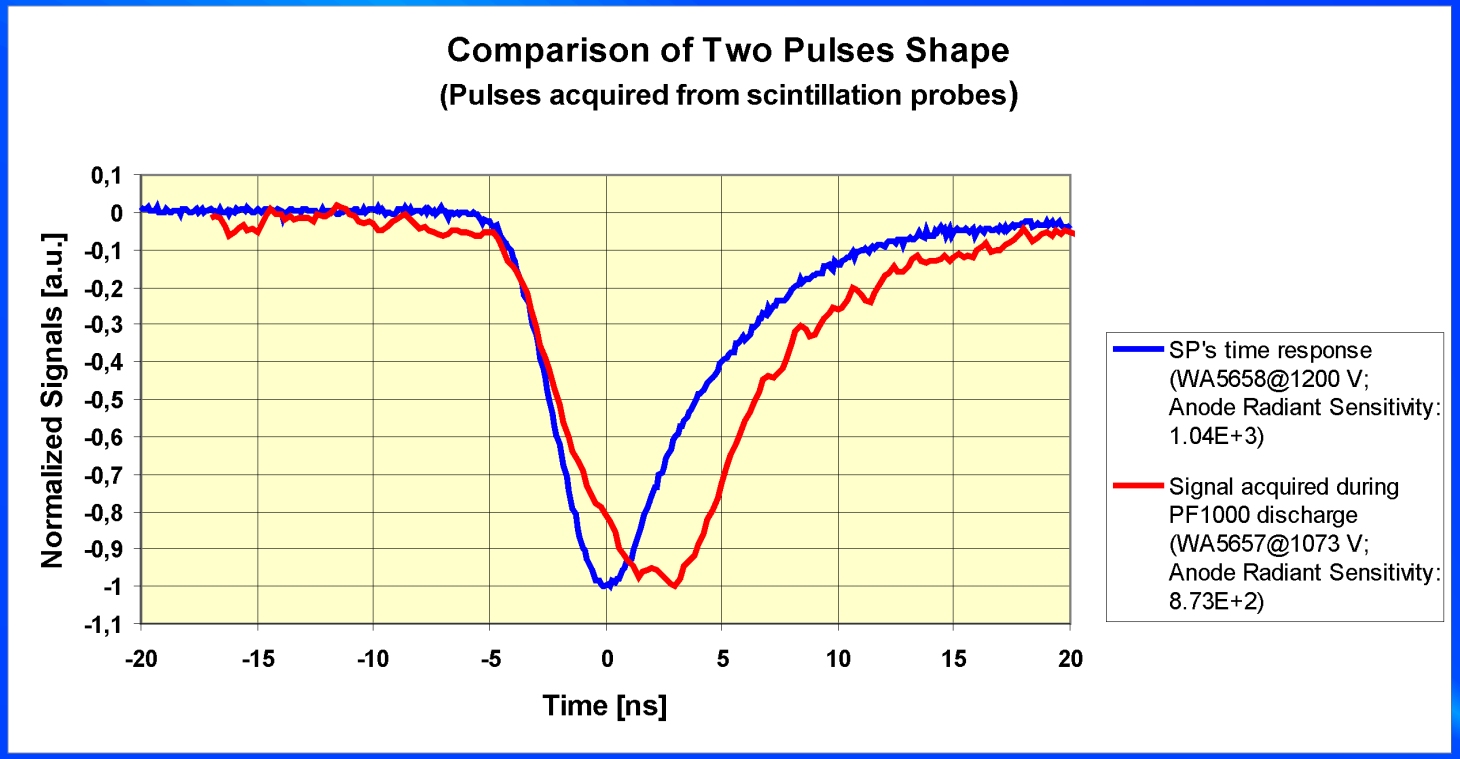
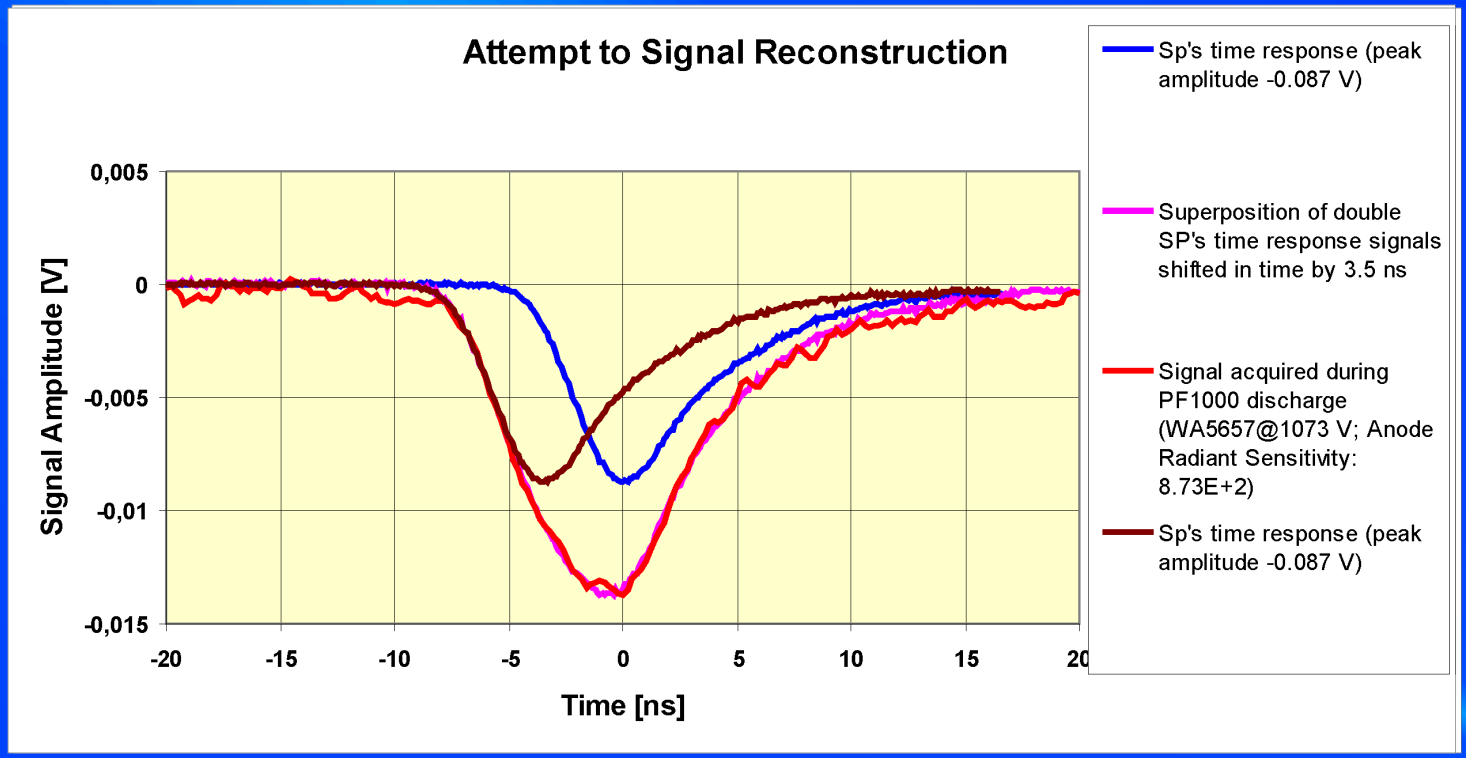


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Scintillation Probes FNSP-1 type

In Search of a Single Neutron

Assumption: recorded signal can result from superposition of two – lower amplitude peaks;



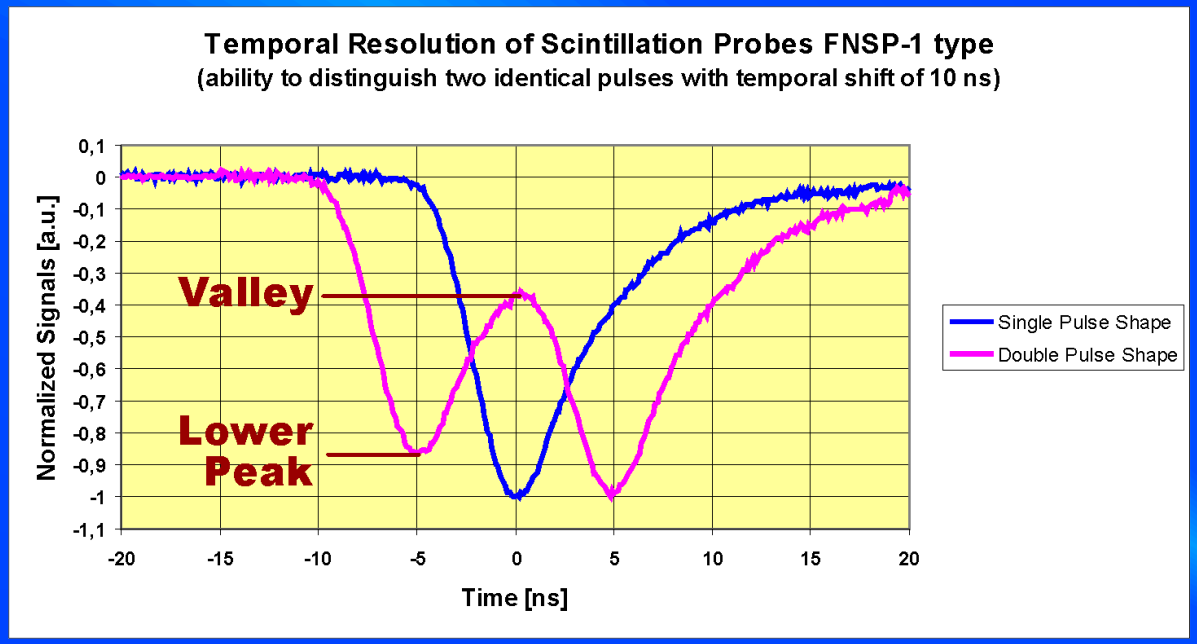
Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Scintillation Probes FNSP-1 type

Limiting Temporal Resolution

Definition:

It is SP's ability to distinguish two, identical delta-function neutron radiation peaks shifted in time. The evaluation consists in the replacement of delta function peaks by the SP's time response and analysis of resulting signal shape;



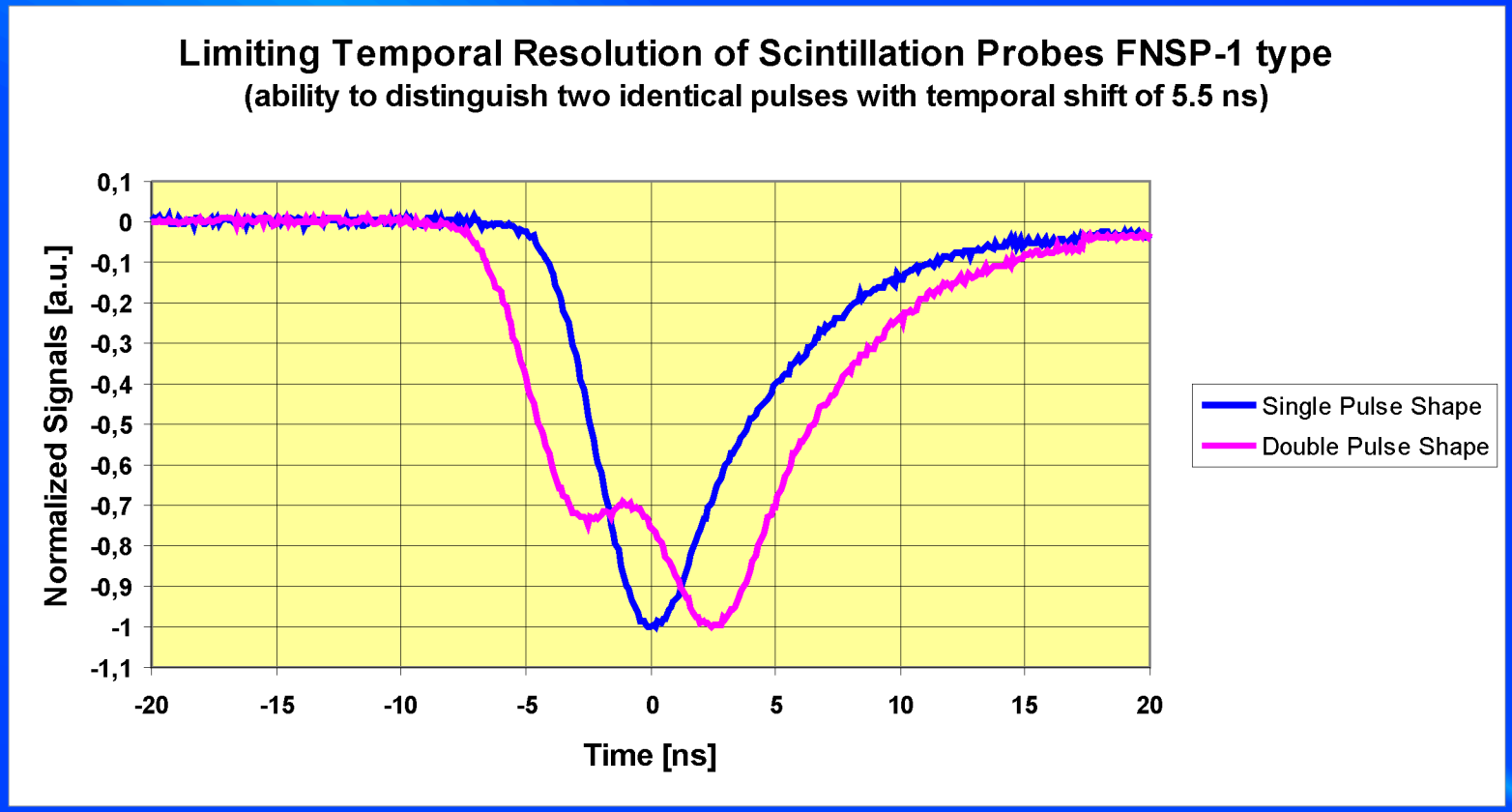
The limiting temporal resolution is equivalent to the time shift for which the difference between lower peak and valley is equal to 5% (for normalized signal).

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Scintillation Probes FNSP-1 type

Limiting Temporal Resolution

It has been checked that the limiting temporal resolution of the SPs FNSP-1 type is equal to 5.5 ns

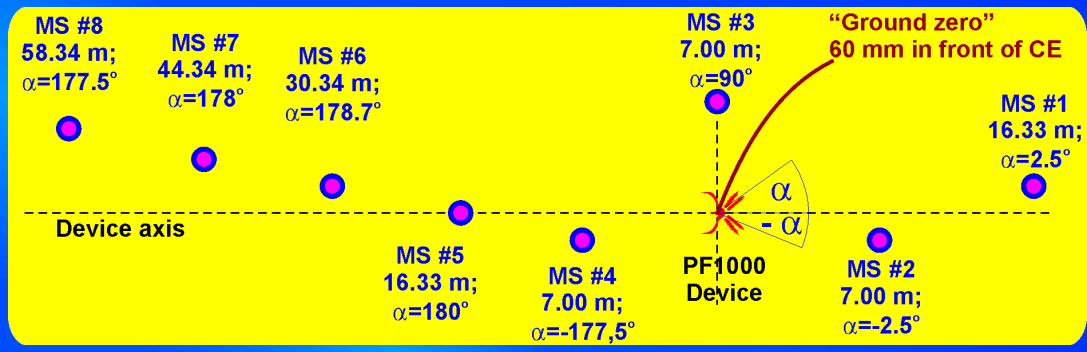


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Neutron Time-of-Flight Diagnostic System

Total, Temporal Error Evaluation

Potential Error Source				Quantum		Neutron	
				Value [ns]	Square	Value [ns]	Square
Radiation Source Spread				0,200	0,040	2,771	7,680
	[m]	+/-	0,060				
Distance Measurement Error				0,067	0,004	0,924	0,853
	[m]	+/-	0,020				
Collision Point/Light Transit Time Spread in Scintillator				0,000	0,000	1,071	1,148
	[m]	+/-	0,025				
Light Transit Time Spread in Optical Coupling				0,000	0,000	0,000	0,000
	[m]	+/-	0,000				
Temporal Resolution of the Scintillation Probe FNSP-1 type				5,500	30,250	5,500	30,250
	[ns]	+/-	5,500				
Electron Transit Time Measurement Error (including Electron Transit Time Spread)				2,000	4,000	2,000	4,000
	[ns]	+/-	2,400				
Trigger Point Jitter (including Sampling Error)				2,000	4,000	2,000	4,000
	[ns]	+/-	2,000				
Total [ns] (Root-Mean-Square Error)				+/-	6	+/-	7
Neutron Energy Measurement Error [keV] (for Auxiliary Stands located at distance of 8 m from source)						+/-	95,53



Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

New Probes' Brief Foredesigns

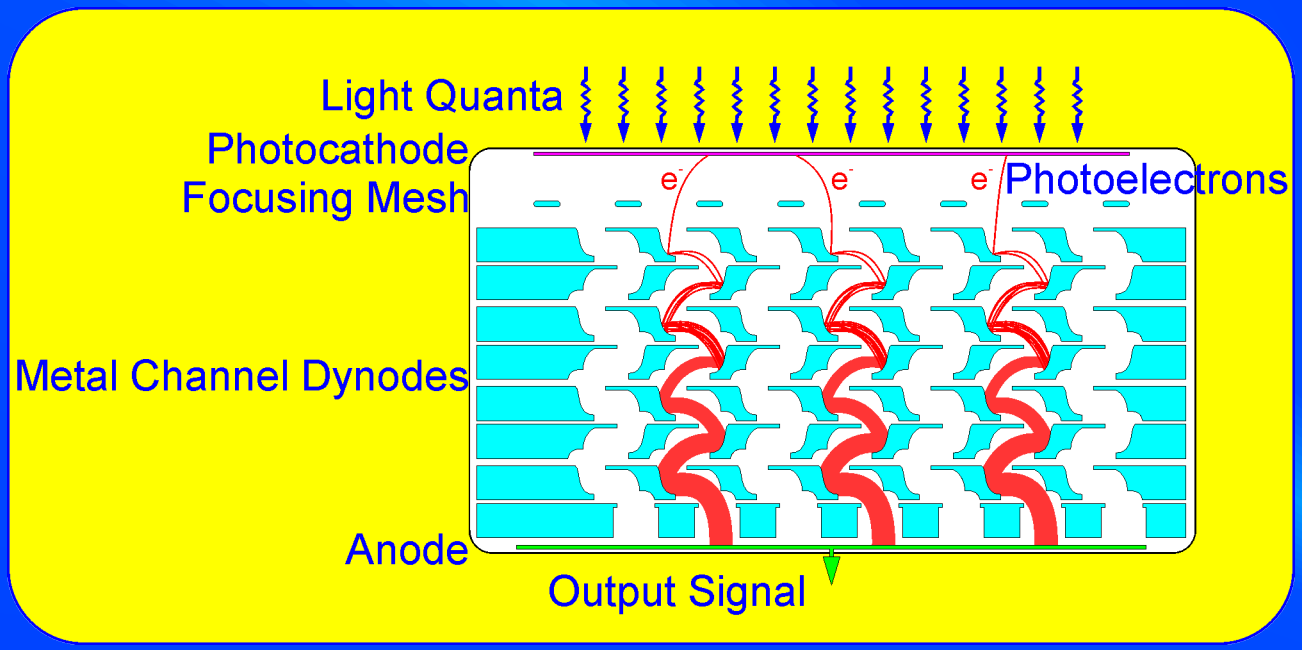
- The new scintillation probes (SPs) are expected to be applied for hard X-ray and neutron radiation recording, emitted during high-speed (or ultra-high-speed) phenomena development (small PF devices, Z-pinch, laser-matter interaction, etc.);
- SPs' limiting temporal resolution has to be kept in the single nanosecond range, however, sub-nanosecond range is preferable;
- The very fast response plastic scintillators with maximum diameter of 50 mm should be applied – these SPs are not dedicated to be located far away from radiation source;
- Employed PMTs' gain should be in the range of 10^3 - 10^5;
- Low, total power consumption of internally applied electronics – all the SPs' versions should be battery operated;
- Heavy duty SPs' housings provide efficient shielding against electromagnetic interference;
- Flexible SPs' design should allow to fit to different experimental requirements.

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Photomultiplier Selection

Metal Package PMT (also called Metal Channel Dynode PMT)

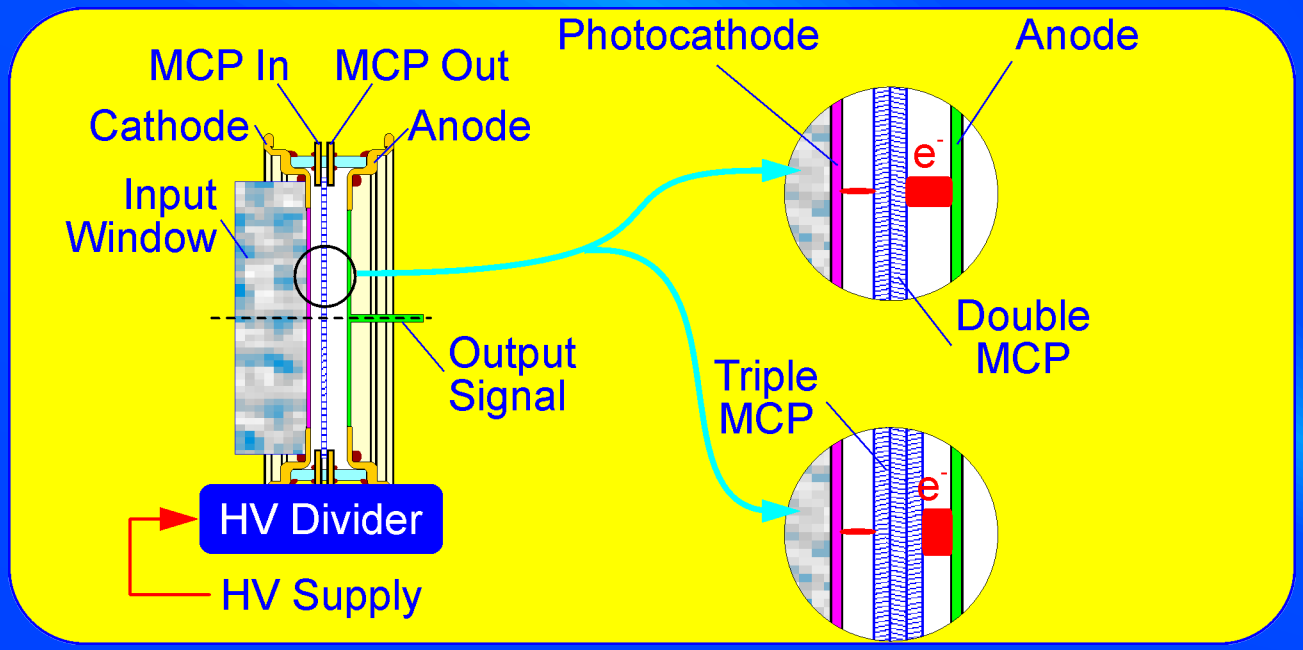


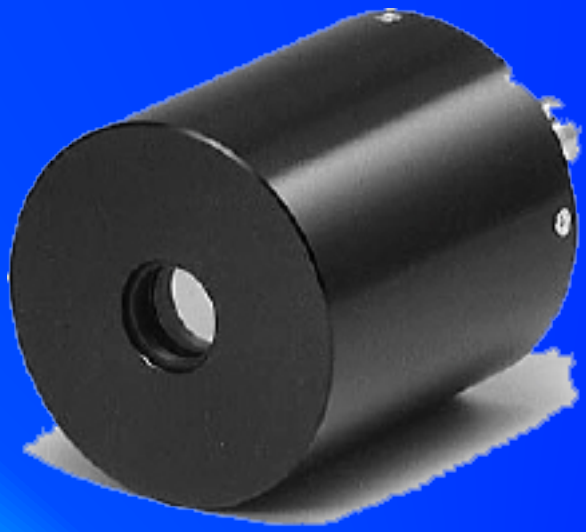
Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Photomultiplier Selection

Microchannel Plate Photomultiplier Tube (MCP-PMT)





Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

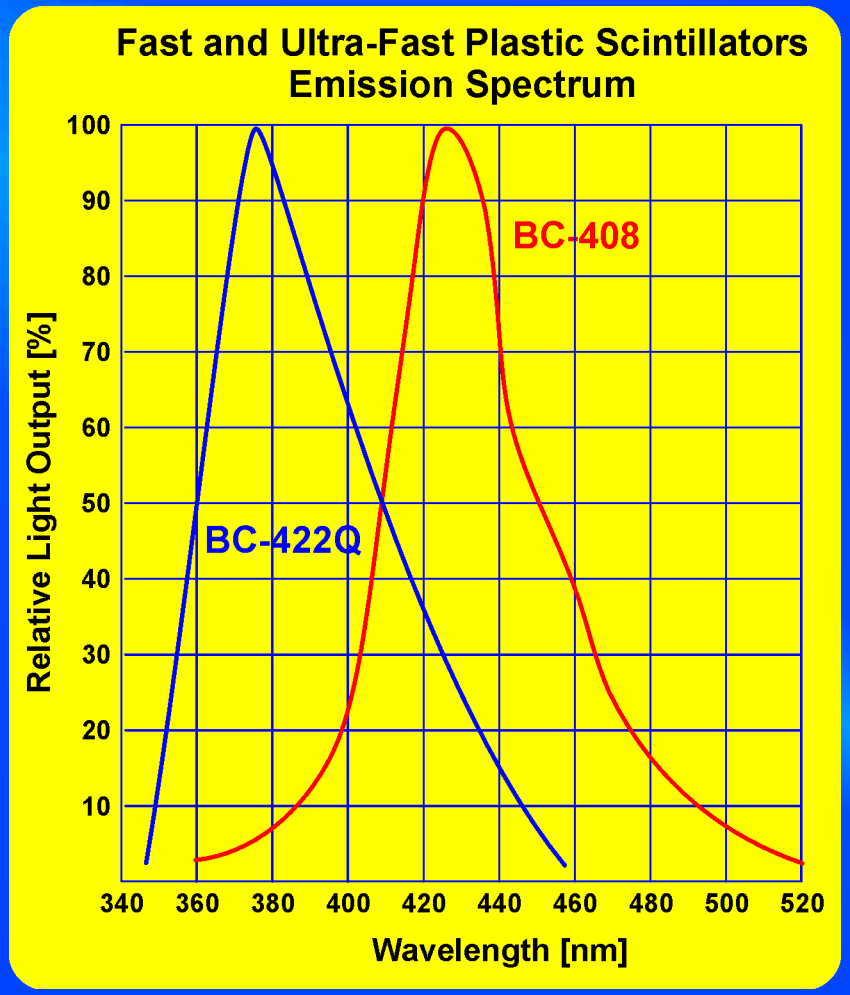
Photomultiplier Comparison

Abridged Specification of PMT Hybrid Assemblies			H1949-51 Assembly	H6780 Assembly	MCP-PMT Assembly
Photomultiplier Type			R1828-01	R7400U	R3809U-52
Spectral Response Range		[nm]	300 to 650	300 to 650	160 to 650
Dynode Structure/Number			Linear/12	Metal Channel/8	Chevron/6 μm
Cathode Useful Diameter		[mm]	51 (Nom.)/46 (Min.)	8	11
Cathode Sensitivity	Blue Index	[a.u.]	10.5	8	6
	Radiant	[mA/W]	85	62	50
Anode Sensitivity	Gain	[a.u.]	2E07(@2.5 kV)	6.9E05(@0.8 kV)	2E05(@3 kV)
	Radiant	[A/W]	1.7E06(@2.5 kV)	4.3E04(@0.8 kV)	1E04(@3 kV)
Rise Time		[ns]	1.3	0.78	0.15
Transit Time		[ns]	28(@2.5 kV)	5.4(@0.8 kV)	0.4(@3 kV)
TTS		[ns]	0,55	-	0.025
Pulse Linearity (2% Dev.)		[mA]	100	-	100
Pulse Linearity (5% Dev.)		[mA]	200	-	-
PMT Case Material			Magnetic Shield	BA Aluminum	BA Aluminum
HV Input Terminal			SHVf	N/A	SHVf
Signal Output Terminal			BNCf 50	RG174 cable	SMAf

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

BC-422Q Scintillator (*BICRON, USA*)

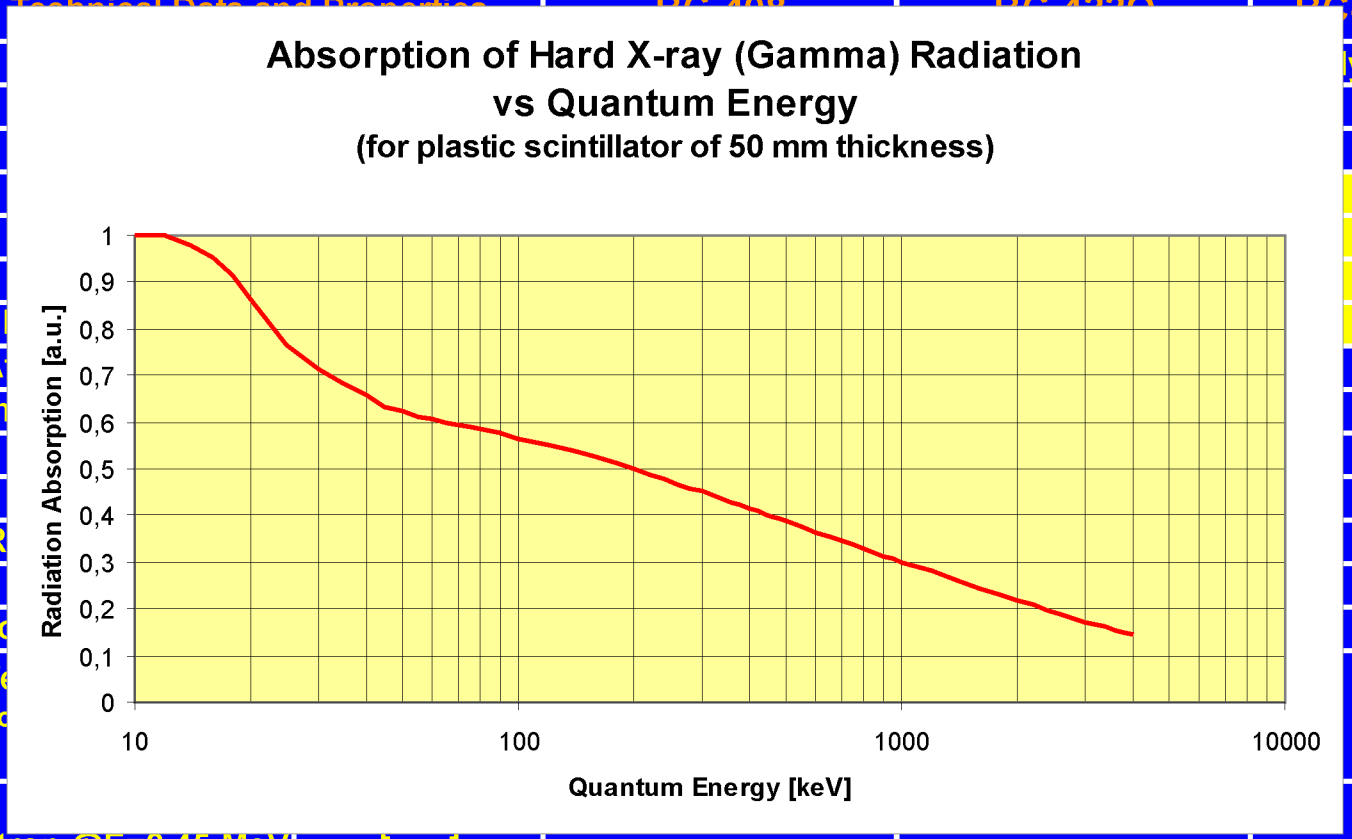


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

BC-422Q Scintillator (*BICRON, USA*)

Scintillators' Technical Data and Properties	BC-408	BC-422Q	BC-422Q(0.5B)
			yvinyltoluene
			1.032
			1.58
			19
			0.11
			0.7
Pul			0.36
Light A			<8
Wavelength			370
			5.23
			4.74
R			1.104
			3.37
Range of Pro			<0.1
Scintillation effe of Created Pho			10
for Neutron @E=2.45 MeV			47.6

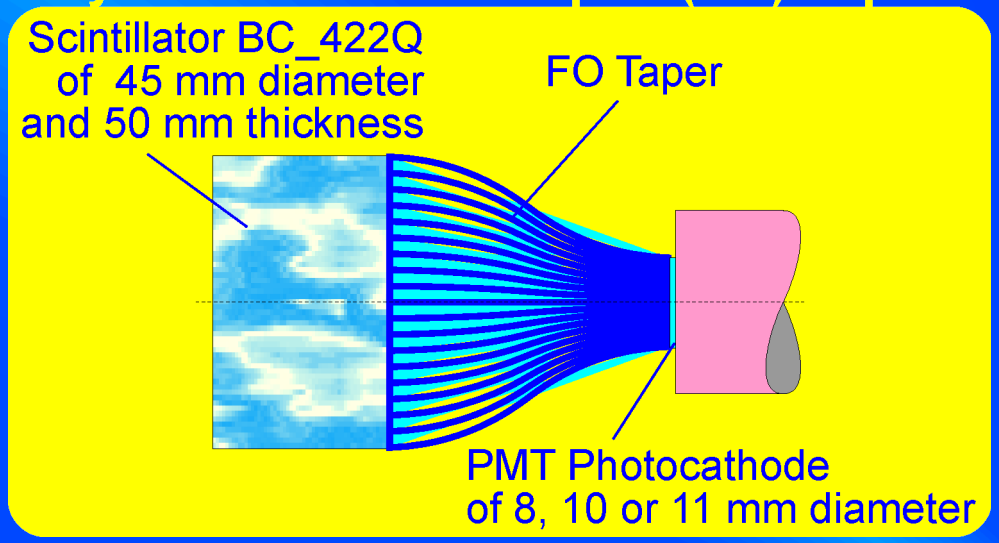


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Scintillator - PMT Photocathode Coupling Manner

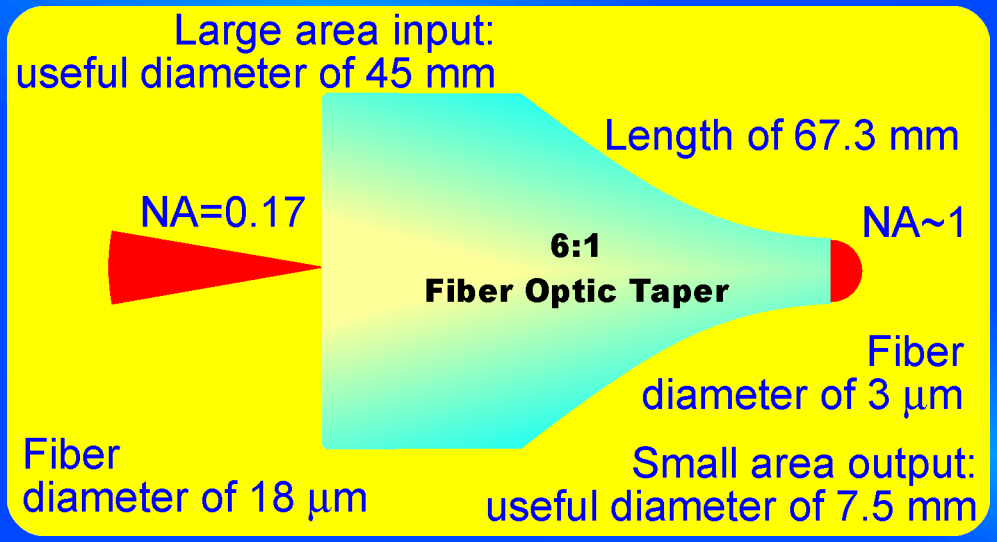
Direct Coupling by means of Fiber Optic (FO) Taper

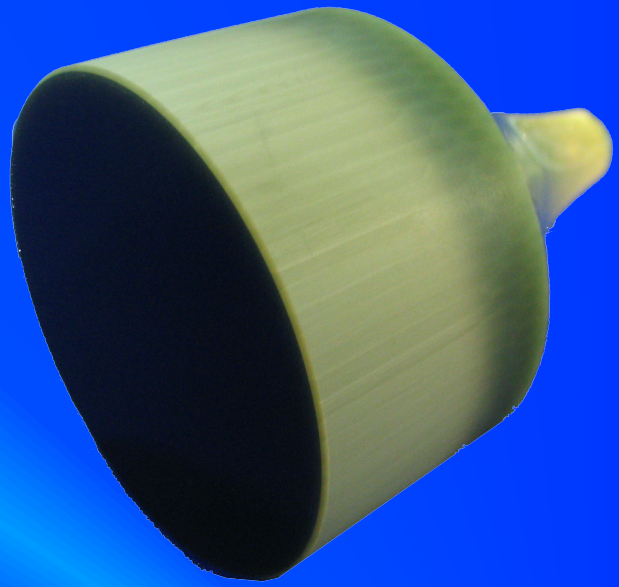


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

6:1 Fiber Optic Taper (*INCOM,USA*)



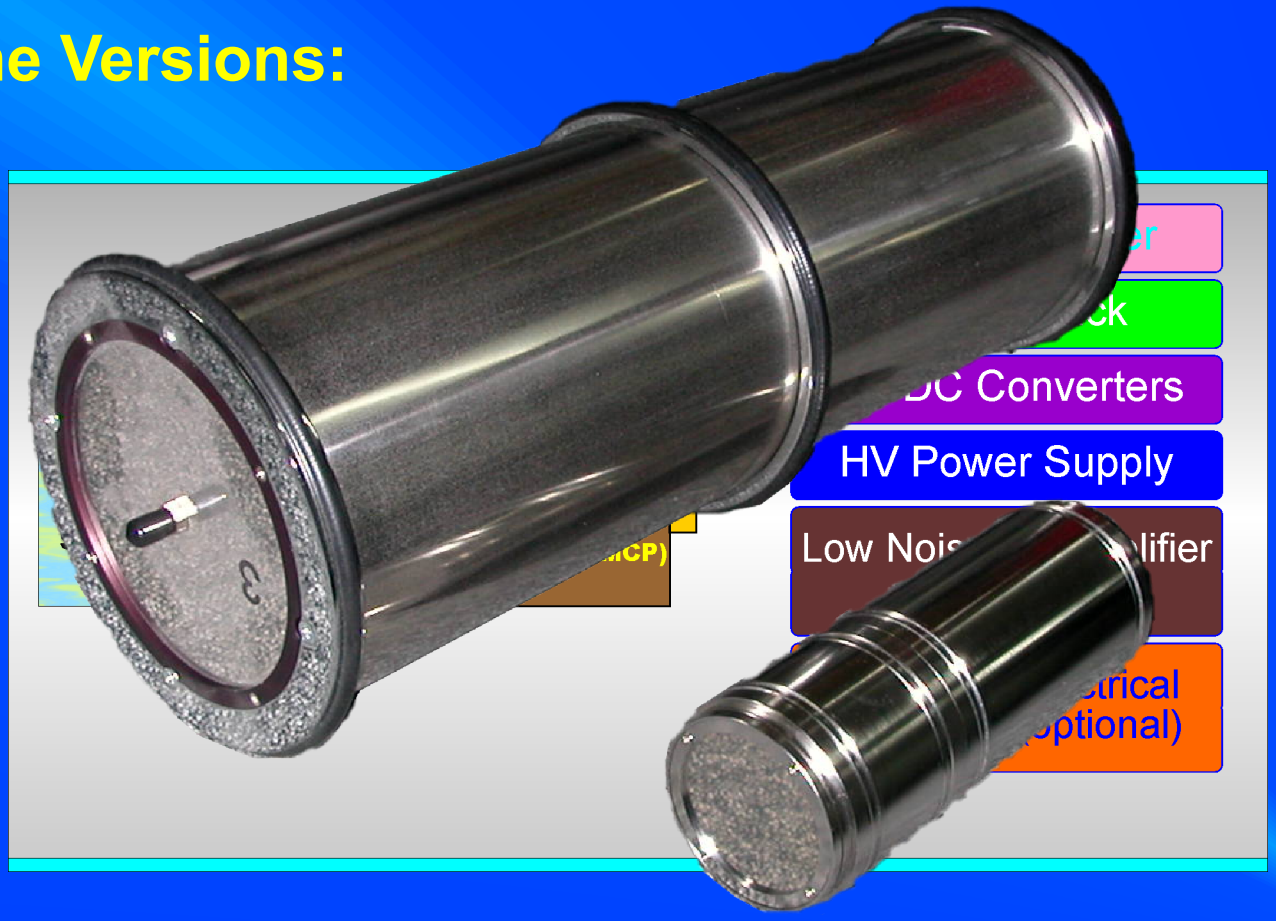


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Design Options

Standalone Versions:



Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

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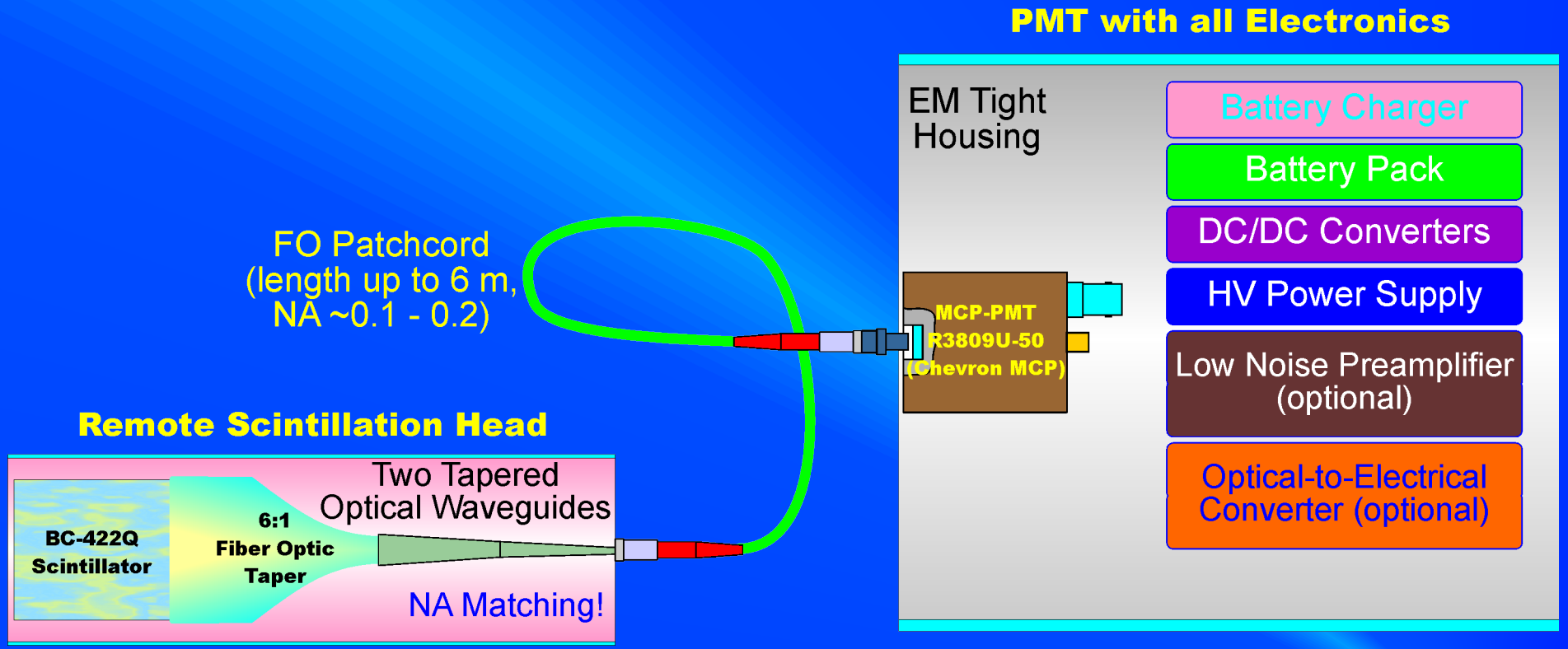
Design Options

Flexible versions:

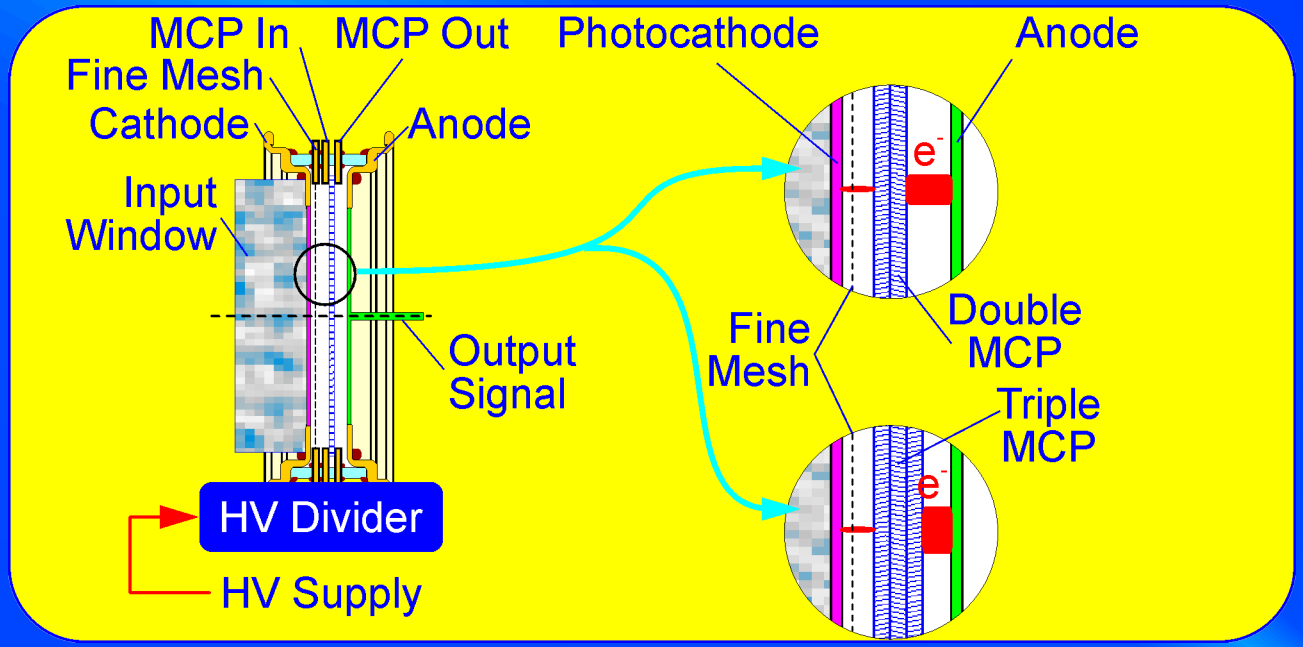


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Design Options

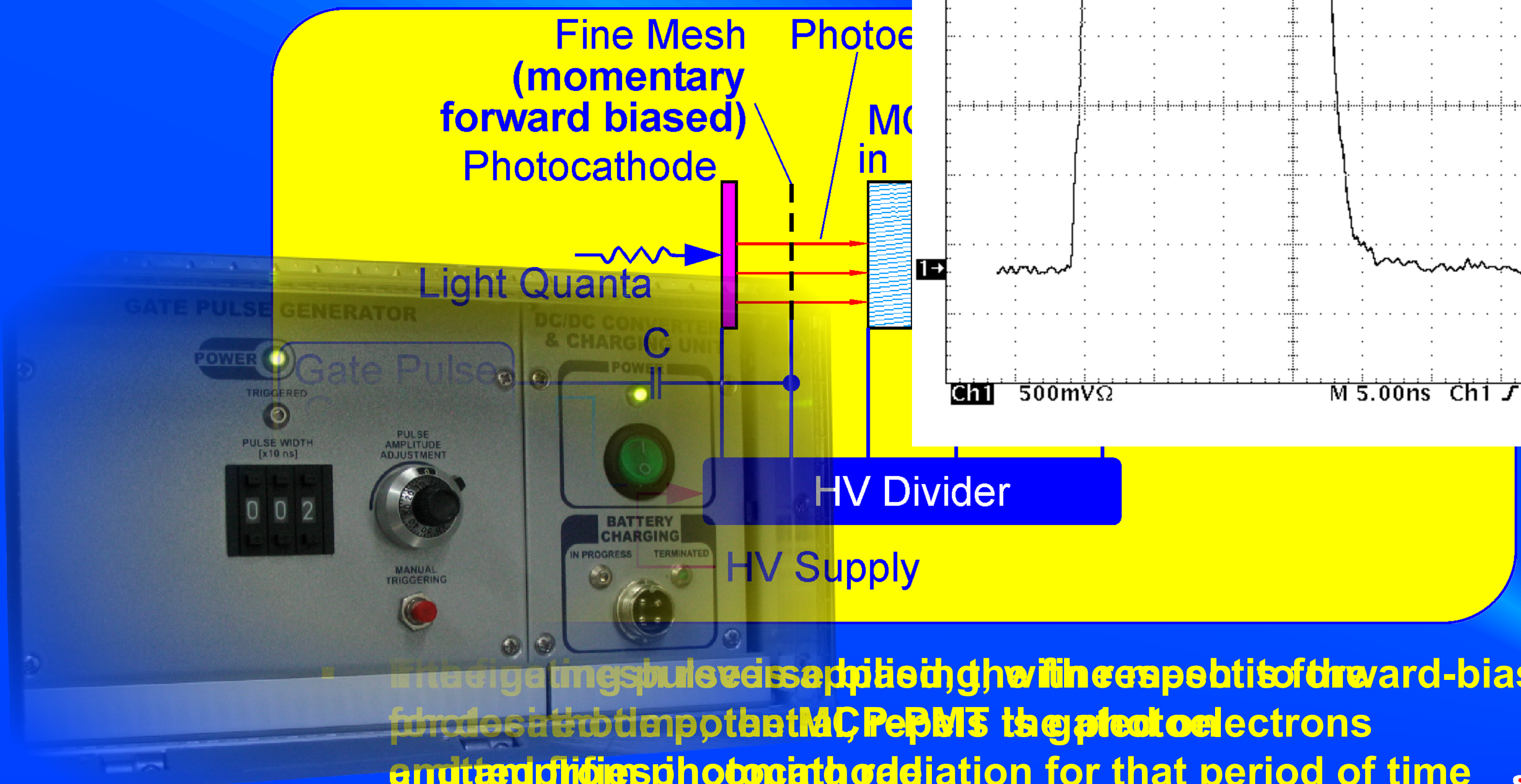
Gated MCP-PMT Applied Instead of Standard MCP-PMT

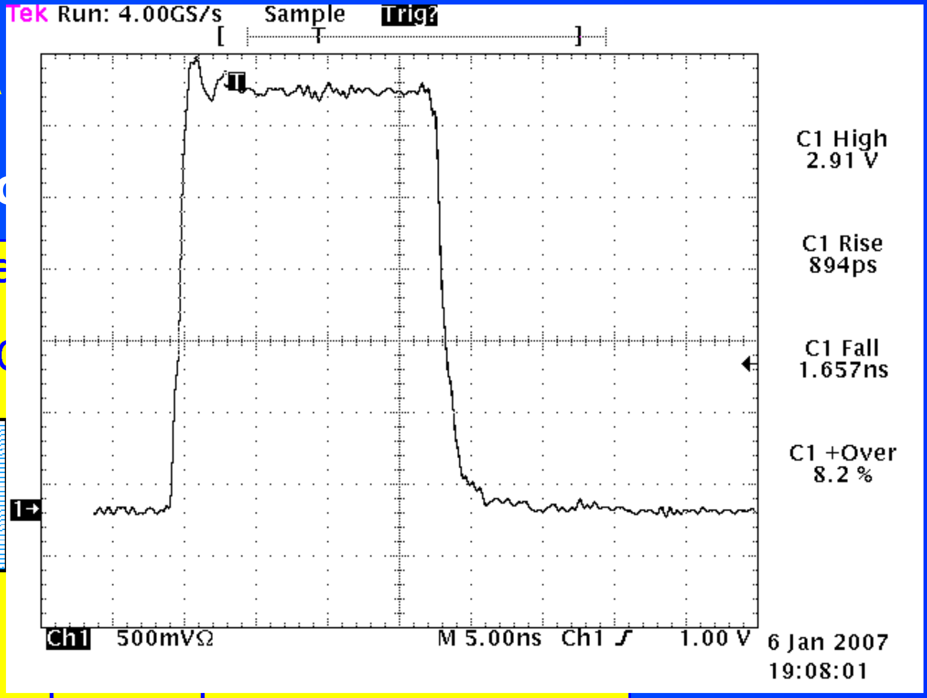


Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Design Options





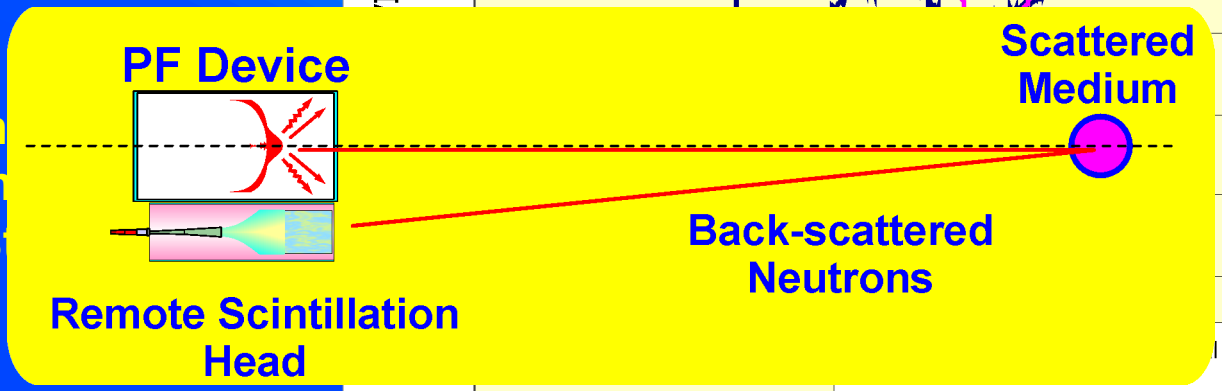
Advanced Diagnostics Laboratory
ACS LABORATORY
ACS Ltd., Warsaw, Poland

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Gated MCP-PMT: Advantages and Possible Applications

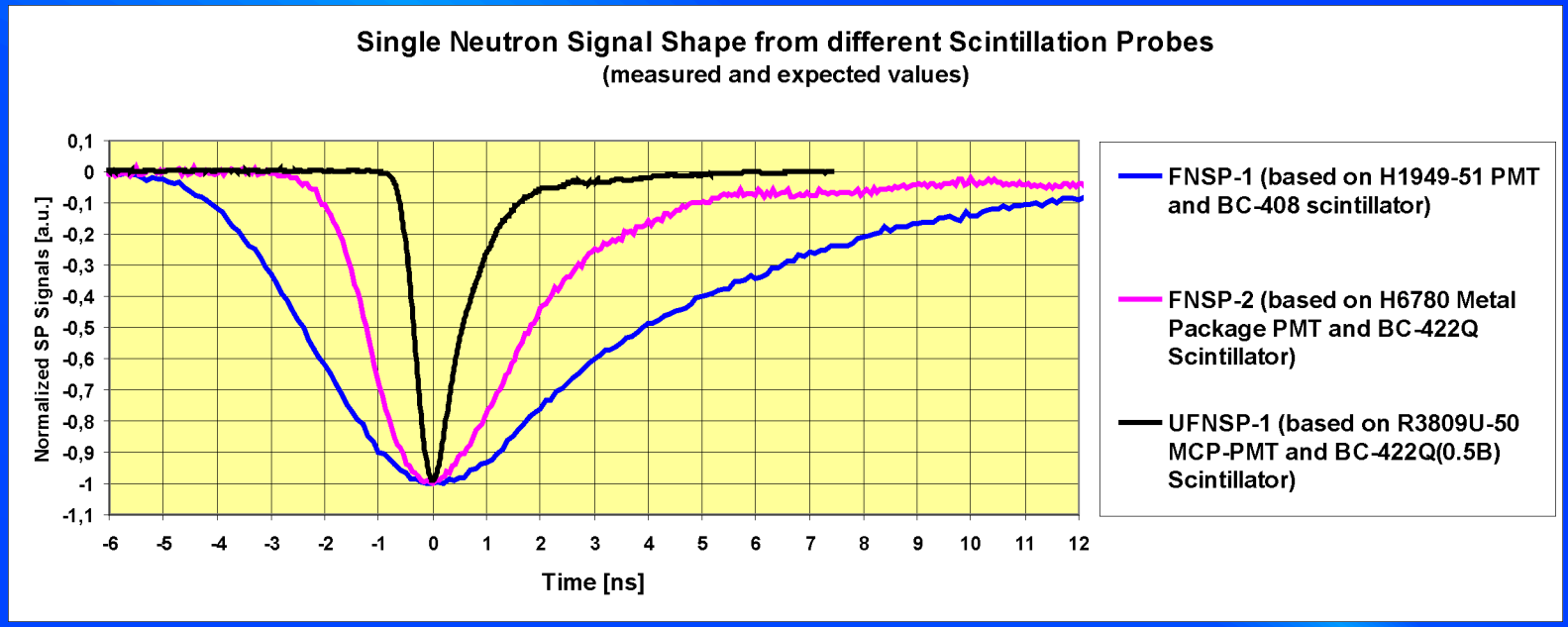
- The PMT's overloading caused by a very bright, hard X-ray flashes accompanying neutron generation is no longer a problem;
- The remote scintillation he
  vicinity of pulsed neutron
  neutron recording;
- Due to high
  chopper, ar
  and well-es
- It seems, that an absolutel
  direct measurements of ne
  sources (magnetically con



Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Very Fast and Ultra-Fast Scintillation Probes

Expectations Concerning Time Response



Summary and Final Remarks

Scintillation Probes for Pulsed X-ray and Neutron Radiation Recording

Summary and Final Remarks

- The fast scintillation probes (SPs) FNSP-1 type have been developed and put into experimental practice;
- SPs' design allows to apply scintillators with different diameter and thickness;
- During the laboratory tests a number of working parameters have been determined (for each probe individually):
    - Time response;
    - Electron transit time and radiant sensitivity dependence on HV supply;
    - Conditions for linear operation;
- The SPs' limiting temporal resolution value has been evaluated on 5.5 ns;
- During the performance test, the very precise – relative calibration of employed SPs has been done. Thanks to that, it became feasible to conduct measurements of neutron emission anisotropy and to investigate the neutron radiation scattering by different materials;
- The usefulness of scintillation probes FNSP-1 type – embedded in the neutron time-of-flight diagnostic system was proven during experimental campaigns carried out on the plasma-focus PF1000 device;

- The some details concerning the new – very fast and ultra-fast scintillation probes have been presented;
- These probes are expected to be launched by the end of March 2008 and could be applied for hard X-ray/neutron radiation recording during investigations of extremely high-speed phenomena.

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