Hall C Reference

SHMS Hodoscope Scintillator Detectors

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Abstract

The design and testing of the scintillator hodoscope paddles in the Super High Momentum Spectrometer.

1 Introduction

The purpose of the scintillator hodoscopes is to provide a clean trigger as well as particle identification by time of flight (TOF). These detectors consist of two pairs of spatially separated scintillator layers/planes: S1X and S1Y, and approximately 2.2 m away another pair of layers; S2X and S2Y. The detector dimensions and granularity were driven by the Monte Carlo simulations of the SHMS acceptance. Results of this simulation showing the size and shape of the acceptance at the position of the S1 and S2 planes are shown in Figure 1 (courtesy of Dr. T. Horn, CUA)

Further design constraints for this detector include:

- High ($\geq$ 99%) detection efficiency, position independent along the scintillator paddle.
- Good time resolution ($\sim$ 100 ps).
- High rate capability ($\sim$ 1 MHz/cm).
- Minimal impact on downstream detectors. This limits the thickness of the scintillator material, especially for the S1 scintillators.

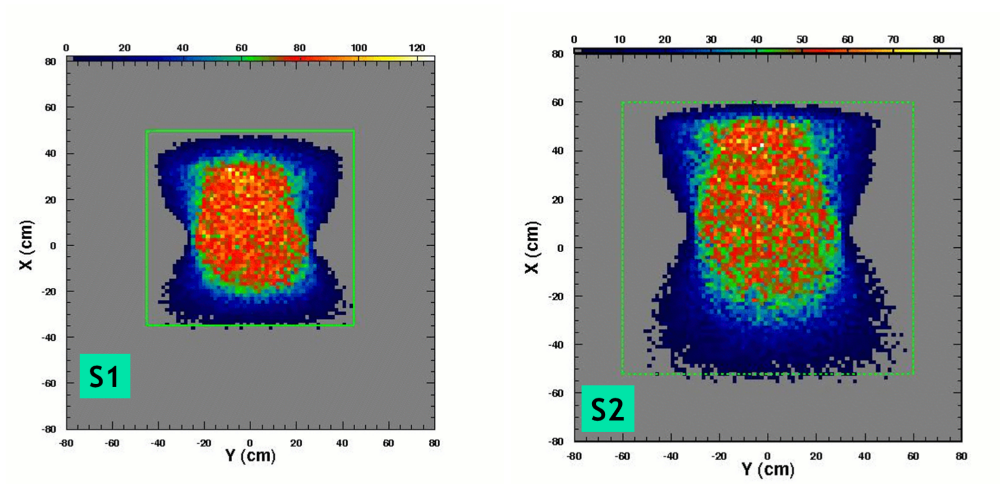


Figure 1: SMS Monte Carlo simulation results. (a) Expected size of the SHMS phase space at the location of the S1 hodoscope planes. (b) Expected size of the SHMS phase space at the location of the S2 hodoscope planes.

- Stability and ease of maintenance. As the detector's presumed lifetime is assumed to be a decade or more a stable, readily available material and readout chain is required.
- Cost effectiveness.

2 Design

To meet the requirements listed above the SHMS Hodoscope was designed as a series of arrays (planes) of plastic scintillators (paddles). The S1X and S1Y planes have 13 paddles each, while the S2X plane has 14 paddles. A 3D view (top right) as well as the standard projections of the SX1 plane is shown in Figure 2. The scintillator material used for all three is **RP-408**, procured from the REXON (*http://www.rexon.com/RP408.htm*) corporation. The main characteristics of this material are summarized below, while the specific dimensions of the paddles are listed in Table 1:

- Polyvinyltoluene (PVT) is the base material.
- Light output is 64% that of Anthracene.

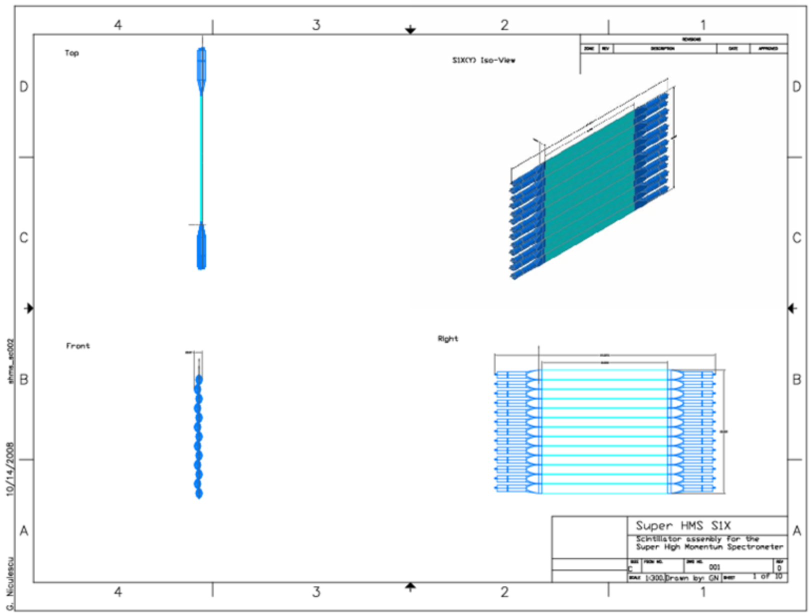


Figure 2: CAD drawing of the S1X SHMS scintillator plane.

- Wavelength of maximum emission is 425 nm.
- Rise Time is 0.9 ns
- Decay Time is 2.1 ns.
- Scintillation Efficiency is 10,000 Photons/ MeV

To eliminate dead spots for all three planes the paddles are staggered by about 7 mm and slightly ($\sim$5 mm) overlapping as shown in Figure 2. The amount by which the paddles are to be staggered was chosen so as to avoid interference between the "fishtails" used to interface the paddle to the PMTs, as seen on the right panel of Figure 2.

Each scintillator is read at both ends by two photomultiplier tubes (PMT's). These tubes were glued to the end of the fishtail using optical glue (BC–600) matching the index of refraction of the lucite fishtail. The paddles were wrapped by the manufacturer (REXON) with millipore paper, aluminum foil, and 2 inch wide electrical tape. The PMT to fishtail joint was originally wrapped with 2

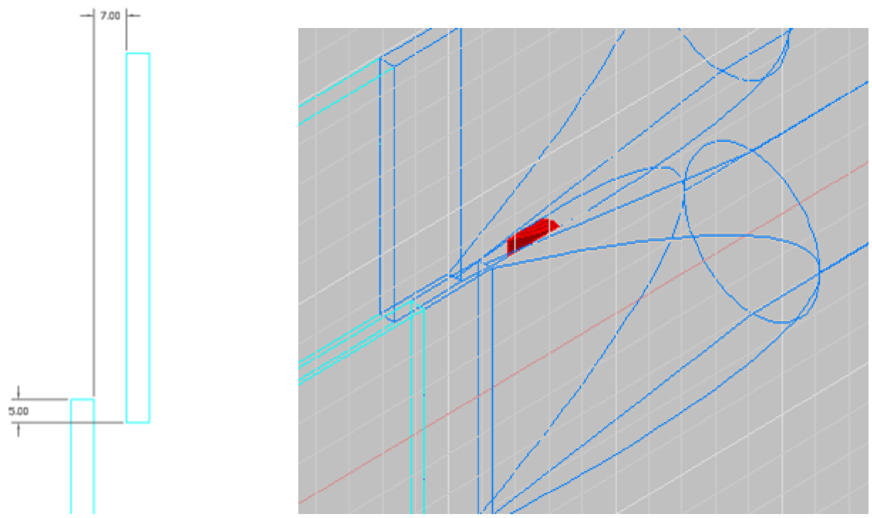


Figure 3: SHMS paddle stagger and fishtail interference. (a) Detail of the SHMS S1X paddles staggering and overlap. (b) Overlap between adjacent fishtails for overlaps smaller than 7 mm.

	Thickness	Width	Length	Number
X1	5 mm	8.0 cm	100 cm	13 units
Y1	5 mm	8.0 cm	100 cm	13 units
X2	5 mm	10.0 cm	110 cm	14 units

Table 1: STP Dimensions of the scintillators for the SHMS TOF system.

inch tape as well (at JMU) and light–leak tested; subsequently this wrapping was reinforced with TEFLON tape and a 3 inch diameter heat–shrink sleeve (at JLab).

As the glued[1] joint between the scintillator paddle is rather fragile (5x80 and 5x100 mm joints) an aluminum "splint" was used to reinforce it. This splint is located inside of the paper/foil/tape wrapping.

Complying with the cost effectiveness requirement some of these tubes are Photonis XP 2262[2], the rest are ET 9214B tubes[3]. Both the Photonis and the Electronic Tubes PMT's are cylindrical, 2 inch diameter, 12–stage tubes, with their maximum sensitivity in the blue–green range, and typical gains of 3×10^7. The full spec sheets are in Appendices A and B. While the tubes are similar in their characteristics the maximum voltage for the XP2262 tubes is 2400 V, while for the ET 9214B tubes is 1800 V. Typical operating voltages for each tube used in the SHMS Hodoscope are given in Appendix C.

NOTE: Given the vast difference between the nominal operating High Voltage of the XP2262 and the 9214B tubes the user/shift worker should be careful when reseting the HV. The Hall C HV GUI [1] will have the "correct" values to be used. For any **"manual" adjusting** of the HV the Run Coordinator a/o the on–call expert should be consulted first.

3 Testing

Both the Photonis and the ET PMTs were extensively tested in the **P**article and **N**uclear **P**hysics (PNP) Labs at JMU prior to assembly. To reject possible noisy tubes the dark current tube was measured for a number of high voltage settings within the recommended range[4]. No tubes were rejected at this stage. A "superbright" blue LED was pulsed (at ∼500 Hz) using very short (4 ns) pulses and used, via optic fibers, to illuminate the PMTs. Using a CODA–based DAQ system the ADC response of the PMTs were recorded. During subsequent analysis of this data, using C++/ROOT, the PMT gain was obtained. The process was repeated for several high voltages and the resulting "gain versus high voltage" graphs were compared with the spec sheet. A typical gain vs HV graph is shown in Figure 4.

[1]Work done by REXON.

[2]These tube were part of the Hall C inventory at the time the project started so using them was a sound value engineering decision.

[3]Unfortunately as the project progressed through funding the Photonis company went out of business so a second vendor providing a similar PMT had to be identified.

[4]See earlier comment about the different HV ranges for the XP2262 and the 9214-B tubes.

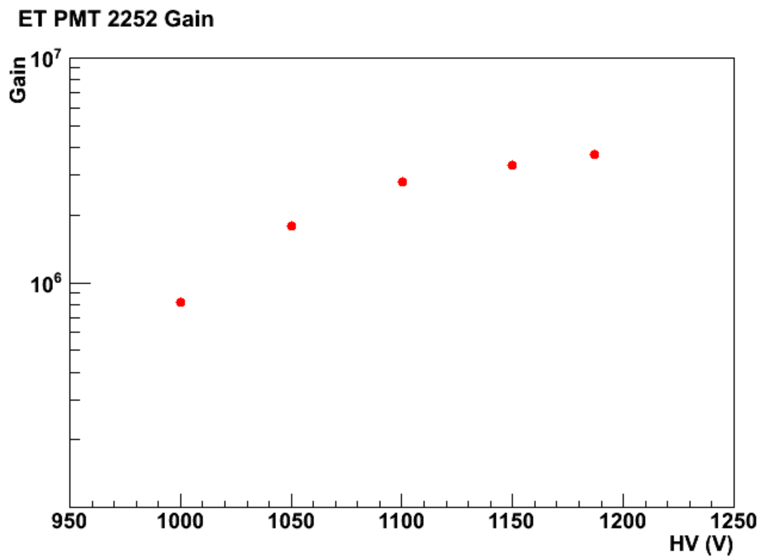


Figure 4: Gain versus high voltage graph for the ET tube with serial number 2252.

All forty SHMS scintillator paddles were assembled (gluing of PMT to the fishtail and wrapping) and tested in the PNP Labs at JMU during the 2010–2012 period. Besides light leak tests the particle detection efficiency along the scintillator paddle was carried out using cosmic rays.

A test stand was specifically designed and built for this purpose. The concept is illustrated in Figure 3. Additional details are shown in Figure 3. The stand's design and testing procedure are summarized below:

- The scintillator paddle to be tested lies flat in the middle of the stand cage.
- Two small, overlapping scintillators (**A** and **B**) sit above the paddle. Each of these is attached to a 2 inch PMT via a fishtail.
- A third scintillator bar **C** sits below the paddle, at the same vertical position as the overlapping scintillators.
- Scintillators **ABC** are supported by a small frame which can slide (effortlessly) with respect to the stand cage.
- The stand is made entirely of 80/20 aluminum.

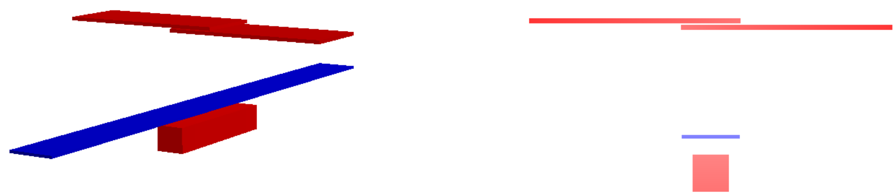


Figure 5: Conceptual drawing of the cosmic ray test stand.

- Given the geometry of the setup cosmic ray particles passing (and getting detected in coincidence) by these three small scintillators must have passed through the hodoscope paddle being tested.
- Comparing the 3–fold (**ABC** scintillators) with the 4–fold (**ABC** scintillators + hodoscope paddle PMT) one can obtain the detection efficiency of the hodoscope paddle. This procedure was carried out simultaneously for both ends (pmtA and pmtB) of the paddle.
- Moving the frame with the 3 small scintillators with respect to the stand cage one can map out the particle detection efficiency along the hodoscope paddle.
- For the extended testing reported here this movement was achieved using a 3–foot long motorized ACME screw.
- The whole testing process: starting/stopping the DAQ, moving the frame, incrementing run number, etc. was automated by the JMU PNP students so at to test a whole paddle with just one command/mouse click.
- Five different positions along the shorter S1X and S1Y paddles were tested. For the longer, S2X paddles efficiency was measured at six different positions.

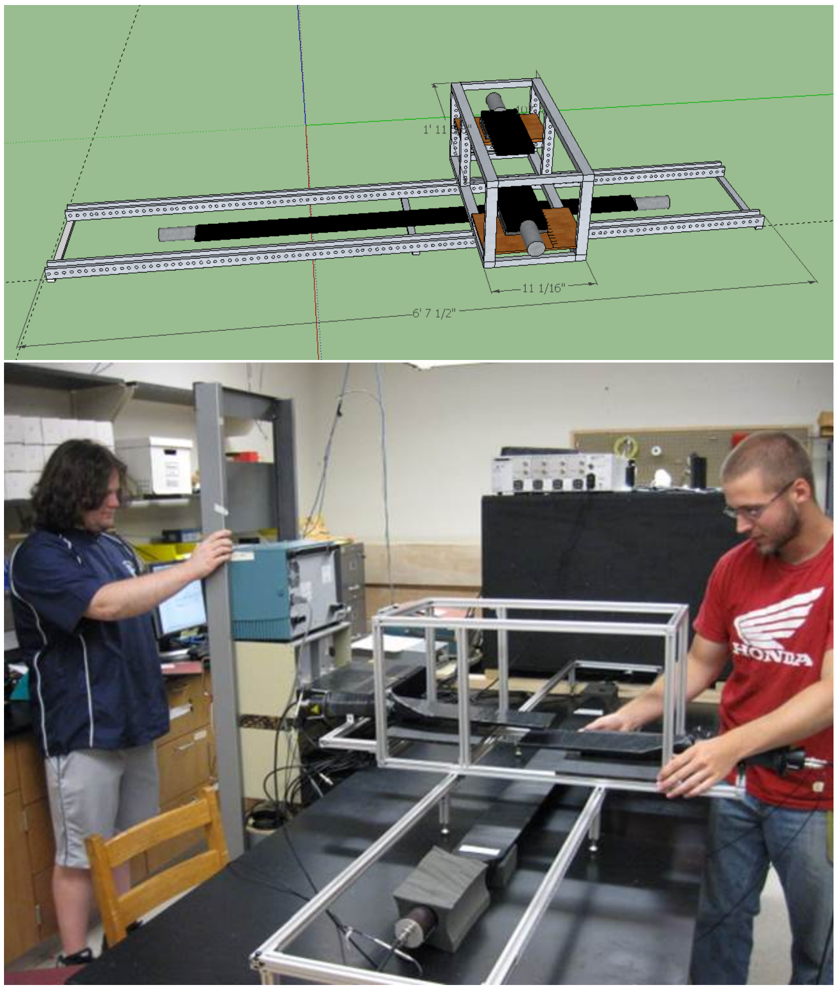


Figure 6: Cosmic ray stand for testing the detection efficiency along the SHMS hodoscope paddles. (a) CAD drawing of the cosmic ray test stand. (b) Building the cosmic ray test stand at JMU. ACME screw and scintillator C yet to be installed at this point.

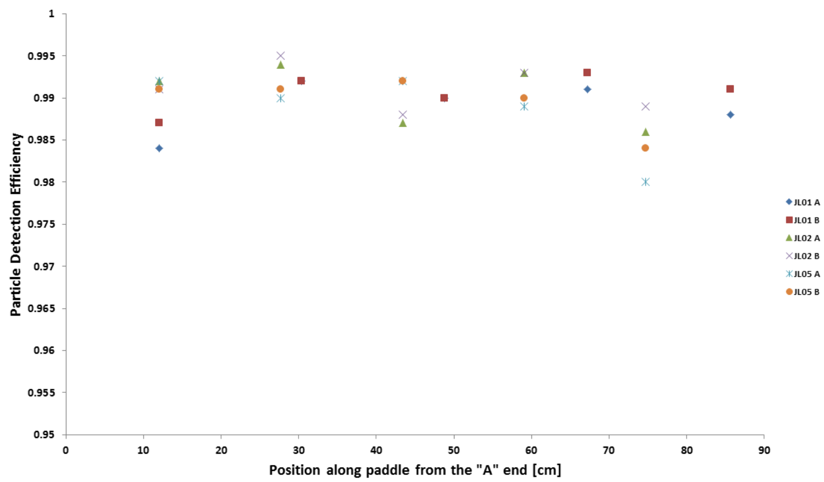


Figure 7: Detection efficiency as function of position along the SHMS hodoscope scintillator paddle.

- These tests were carried out during the Summer of 2012, after a box of 9 assembled paddles was already shipped to the College of William and Mary to help W&M engineers with the layout and dimensioning of the detector frame, which they built. The efficiency for these paddles was not directly measured, though there is no reason to believe that they would be any different than the other 31 paddles that were measured.

- For each position enough cosmic data was acquired to keep the binomial detection uncertainty below 1%.

Figure 7 shows the particle detection efficiency for a few typical SHMS paddles tested. The full list with the test results is tabulated in Appendix D.

Appendices

A Photonis XP–2262 PMT Specifications

Photomultiplier XP2262

12-stage
51mm (2"), Round tube

Application

✓ Energy physics

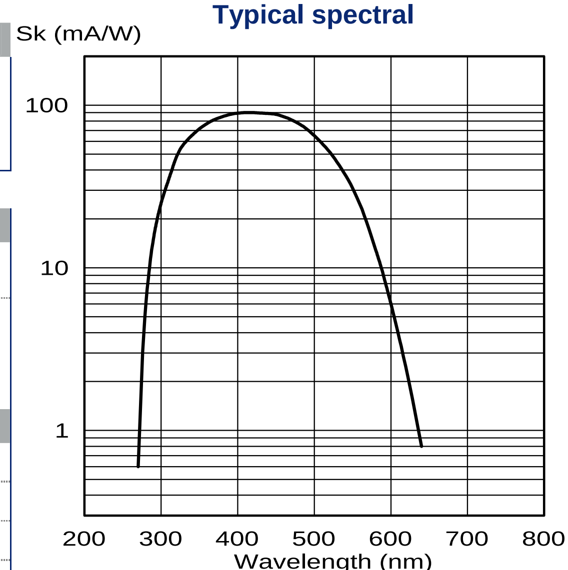
Feature

✓ Fast

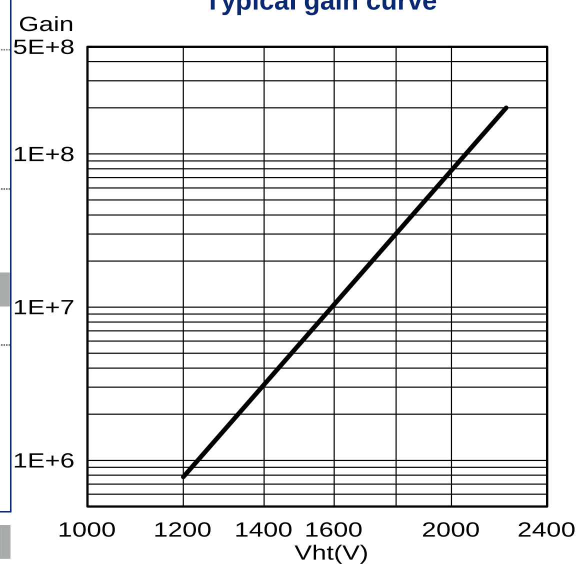
Description	
Window material	Lime glass
Photocathode	Bi-alkali
Refr. Index at 420nm	1.54
Multiplier structure	Linear focused

Photocathode characteristics	Min	Typ	Max	Unit
Spectral range:		290-650		nm
Maximum sensitivity at		420		nm
Sensitivity:				
Luminous		70		µA/lm
Blue *	9	11.2		µA/lmf
Radiant, at 420nm		90		mA/W
Characteristics with voltage divider A	**Min**	**Typ**	**Max**	**Unit**
Gain slope (vs supp. Volt., log/log)		9		
For a gain of		$3x10^7$		V
Supply voltage *	1500	1800	2400	V
Anode dark current *		10		nA
Background noise *		1000	6000	cps
Single electron spectrum resolution		70		%
Peak to valley ratio		3		
Mean anode sensitivity deviation:				
Long term (16h)		1		%
After change of count rate		1		%
Vs temperature between 0 and +40℃ at 420nm		-0.2		%/K
Gain halved for a magnetic field of:				
Perpendicular to axis "n"		0.2		mT
Parallel to axis "n"		0.1		mT
For a supply voltage of : 1900V	**Min**	**Typ**	**Max**	**Unit**
Linearity (2%) of anode current up to:		100		mA
Anode pulse:				
Rise time		2.3		ns
Duration at half height		3.7		ns
Transit Time		31		Ns
Transit time Difference between center of PK and 18 mm from it		0.7		ns

Typical spectral



Typical gain curve



Recommended Voltage Divider

Type A for maximum gain

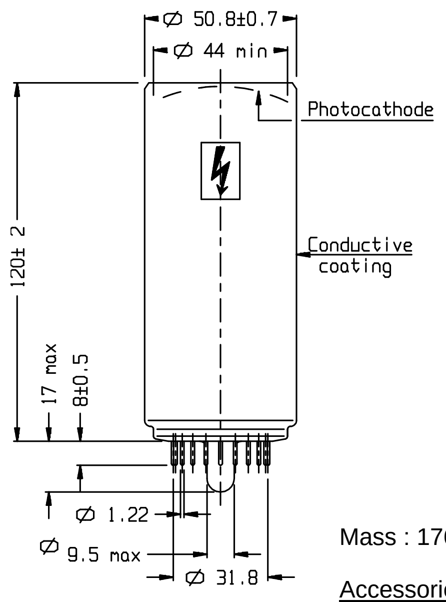
K		D1		D2		D3		D4		D5		D6		D7		D8		D9		D10		D11		D12		A	
	4		1.1		0.9		1		1		1		1		1		1		1		1		1		1		(total : 16)

*** characteristic measured and mentioned on the test ticket of each tube**

Photomultiplier XP2262

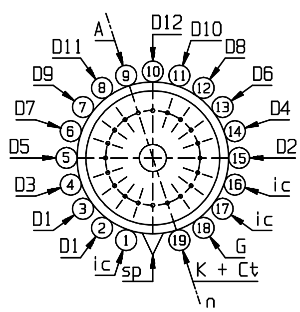
Outline (dimensions in mm)

XP2262

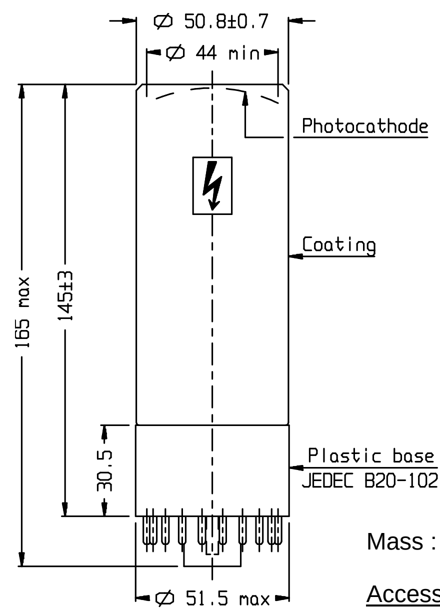


Mass : 176g

Accessories :
Socket : FE2019

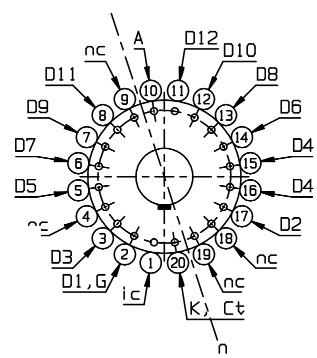


XP2262B



Mass : 216g

Accessories :
Socket : FE1120
Mu-metal shield : MS172
Voltage divider : VD122K



K: cathode
sp: short pin

Dn: dynode
ic: internal connection

A: anode
nc: not connected

nc: not connected
Ct: coating

Limiting values	Min	Max	Unit
Anode Luminous sensitivity		$2x10^8$	
Supply voltage		2500	V
Continuous anode current		0.2	mA
Voltage between :			
D1 and photocathode :	300	800	V
Consecutive dynode :		400	V
Anode and D12:	80	600	V
Ambient temperature :			
Short operation (<30 mn) :	-30	+80	℃
Continuous operation & storage :	-30	+50	℃

Variants

XP2262

Finishing
B with plastic base JEDEC B20-102
F with flying leads ∅ 0.5
FB with flying leads and plastic base

Also, other variants can be made. Please, contact us to discuss any specific product requirements.

B ET 9214-B PMT Specificiations

52 mm (2 ″) photomultiplier 9214B series data sheet

ET Enterprises electron tubes

1 description

The 9214B is a 52mm (2″) diameter, end window photomultiplier with blue-green sensitive bialkali photocathode and 12 high gain, high stability, SbCs dynodes of linear focused design . The 9214WB and 9214QB are variants for applications requiring uv sensitivity.

2 applications

- photon counting of bio-and chemi-luminescent samples
- SO_x NO_x pollution monitoring
- high energy physics studies
- LIDAR

3 features

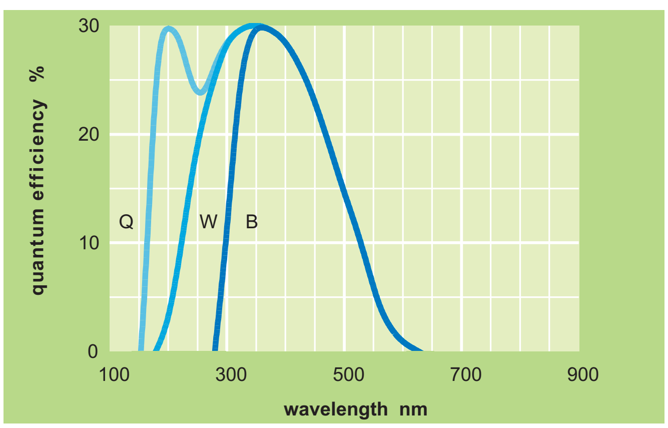
- high gain
- low operating voltage
- good SER
- low rate effect

4 window characteristics

	9214B borosilicate	9214WB uv glass	9214QB* fused silica
spectral range**(nm)	290 - 630	185 - 630	160 - 630
refractive index (n_d)	1.49	1.48	1.46
K (ppm)	300	8500	<10
Th (ppb)	250	30	<10
U (ppb)	100	30	<10

* note that the sidewall of the envelope contains graded seals of high K content
** wavelength range over which quantum efficiency exceeds 1 % of peak

5 typical spectral response curves

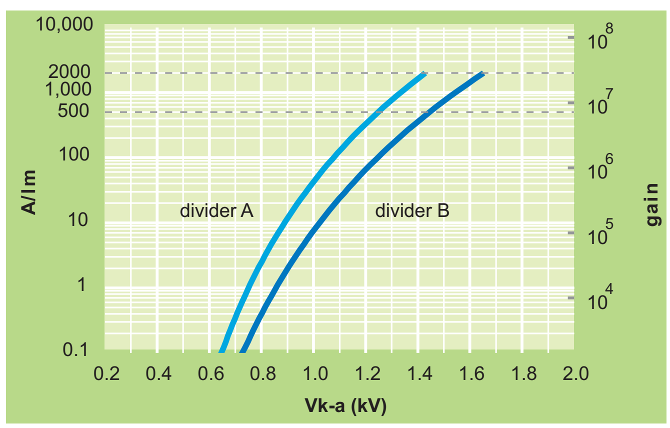


6 characteristics

	unit	min	typ	max
photocathode: bialkali				
active diameter	mm		46	
quantum efficiency at peak	%		30	
luminous sensitivity	µA/lm		70	
with CB filter		8	11.5	
with CR filter			2	
dynodes: 12LFSbCs				
anode sensitivity in divider A:				
nominal anode sensitivity	A/lm		500	
max. rated anode sensitivity	A/lm		2000	
overall V for nominal A/lm	V		1250	1800
overall V for max. rated A/lm	V		1450	
gain at nominal A/lm	$x\ 10^6$		7	
dark current at 20 ºC:				
dc at nominal A/lm	nA		1	10
dc at max. rated A/lm	nA		4	
dark count	s^{-1}		300	
pulsed linearity (-5% deviation):				
divider A	mA		30	
divider B	mA		100	
pulse height resolution:				
single electron peak to valley	ratio		2	
rate effect (I_a for $\Delta g/g$=1%):	µA		20	
magnetic field sensitivity:				
the field for which the output decreases by 50 %				
most sensitive direction	$T\ x\ 10^{-4}$		1	
temperature coefficient:	% $°C^{-1}$		± 0.5	
timing:				
single electron rise time	ns		2	
single electron fwhm	ns		3	
single electron jitter (fwhm)	ns		2.2	
multi electron rise time	ns		3	
multi electron fwhm	ns		4.5	
transit time	ns		45	
weight:	g		160	
maximum ratings:				
anode current	µA			100
cathode current	nA			100
gain	$x\ 10^6$			30
sensitivity	A/lm			2000
temperature	°C	-30		60
V (k-a)(1)	V			2300
V (k-d1)	V			500
V (d-d)(2)	V			450
ambient pressure (absolute)	kPa			202

(1) subject to not exceeding max. rated sensitivity (2) subject to not exceeding max rated V(k-a)

7 typical voltage gain characteristics



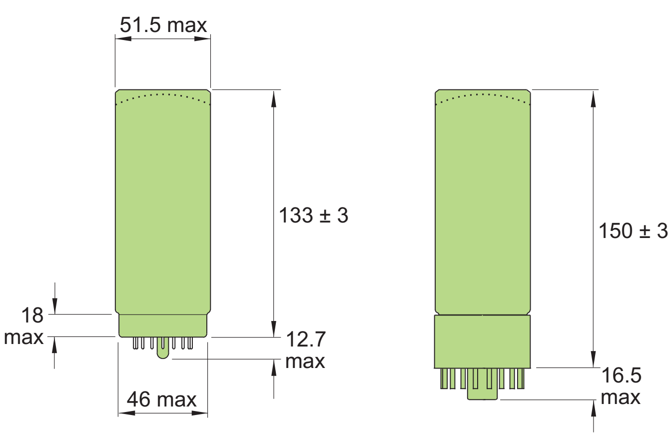
8 voltage divider distribution

	k	d_1	d_2	d_9	d_{10}	d_{11}	d_{12}	a	
A	300V	R	....	R	R	R	2R	R	Standard
B	300V	R	....	R	1.25R	1.5R	2R	3R	High Pulsed linearity

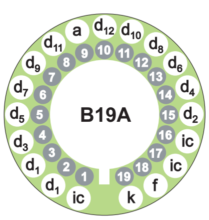
note: focus connected to d_1
Characteristics contained in this data sheet refer to divider A unless stated otherwise.

9 external dimensions mm

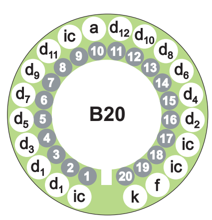
The drawings below show the 9214B in hardpin format and the 9214KB with the B20 cap fitted.



10 base configuration (viewed from below)



B19A hardpin base
(for 9214B)
'ic' indicates an internal connection



B20 cap
(for 9214KB)
'ic' indicates an internal connection

Our range of B19A sockets is available to suit the hardpin base. Our range of B20 sockets is available to suit the B20 cap. Both socket ranges include versions with or without a mounting flange, and versions with contacts for mounting directly onto printed circuit boards.

11 ordering information

The 9214B meets the specification given in this data sheet. You may order **variants** by adding a suffix to the type number. You may also order **options** by adding a suffix to the type number. You may order product with **specification options** by discussing your requirements with us. If your selection option is for one-off order, then the product will be referred to as 9214A. For a repeat order, Electron Tubes will give the product a two digit suffix after the letter B, for example B21. This identifies your specific requirement.

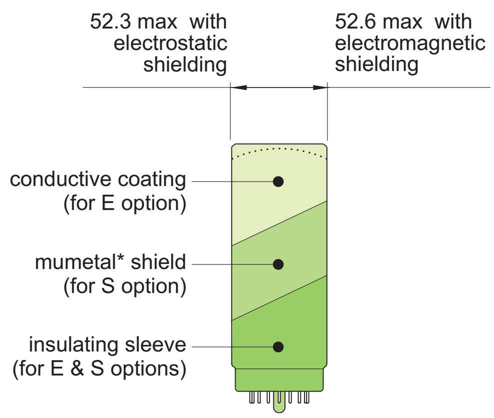
9214 ■ ■ ■ ■

window variants
W uv glass
Q fused silica

base options
K capped

options
E electrostatic shielding see drawing below
S electromagnetic shielding see drawing below
M supplied with spectral response calibration

specification options
B as given in data sheet
A single order to selected specification
Bnn repeat order to selected specification



12 voltage dividers

The standard voltage dividers available for these pmts are tabulated below:

	k	d_1	d_2	d_8	d_9	d_{10}	d_{11}	d_{12} a
C638A	3R	R	....	R	R	R	R	R
C638C	300V	R	....	R	R	R	R	R
C638B	3R	R	....	R	1.25R	1.5R	2R	3R
C638D	300V	R	....	R	1.25R	1.5R	2R	3R

R = 330 kΩ

*mumetal is a regiestered trademark of Magnetic Shield Corporation

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e-mail: sales@electrontubes.com
web site: www.electrontubes.com

C Nominal High Voltages for the SHMS Scintillator Hodoscope PMTs.

Hut Name	Nominal HV	Max HV	Tube Type
S1X-001R	1200	1500	ET 9214B
S1X-002R	1200	1500	ET 9214B
S1X-003R	1200	1500	ET 9214B
S1X-004R	1200	1500	ET 9214B
S1X-005R	1500	2000	XP 2262
S1X-006R	1200	1500	ET 9214B
S1X-007R	1200	1500	ET 9214B
S1X-008R	1200	1500	ET 9214B
S1X-009R	1200	1500	ET 9214B
S1X-010R	1200	1500	ET 9214B
S1X-011R	1200	1500	ET 9214B
S1X-012R	1200	1500	ET 9214B
S1X-013R	1500	2000	XP 2262
S1X-001L	1200	1500	ET 9214B
S1X-002L	1200	1500	ET 9214B
S1X-003L	1200	1500	ET 9214B
S1X-004L	1200	1500	ET 9214B
S1X-005L	1500	2000	XP 2262
S1X-006L	1200	1500	ET 9214B
S1X-007L	1200	1500	ET 9214B
S1X-008L	1200	1500	ET 9214B
S1X-009L	1200	1500	ET 9214B
S1X-010L	1200	1500	ET 9214B
S1X-011L	1200	1500	ET 9214B
S1X-012L	1200	1500	ET 9214B
S1X-013L	1500	2000	XP 2262

Table 2: List of paddles and nominal high voltages for the PMTs for S1X hodoscope plane.

Hut Name	Nominal HV	Max HV	Tube Type
S1Y-001T	1500	2000	XP 2262
S1Y-002T	1500	2000	XP 2262
S1Y-003T	1500	2000	XP 2262
S1Y-004T	1500	2000	XP 2262
S1Y-005T	1500	2000	XP 2262
S1Y-006T	1500	2000	XP 2262
S1Y-007T	1500	2000	XP 2262
S1Y-008T	1500	2000	XP 2262
S1Y-009T	1500	2000	XP 2262
S1Y-010T	1200	1500	ET 9214B
S1Y-011T	1500	2000	XP 2262
S1Y-012T	1200	1500	ET 9214B
S1Y-013T	1500	2000	XP 2262
S1Y-001B	1500	2000	XP 2262
S1Y-002B	1500	2000	XP 2262
S1Y-003B	1500	2000	XP 2262
S1Y-004B	1500	2000	XP 2262
S1Y-005B	1500	2000	XP 2262
S1Y-006B	1500	2000	XP 2262
S1Y-007B	1500	2000	XP 2262
S1Y-008B	1500	2000	XP 2262
S1Y-009B	1500	2000	XP 2262
S1Y-010B	1200	1500	ET 9214B
S1Y-011B	1500	2000	XP 2262
S1Y-012B	1200	1500	ET 9214B
S1Y-013B	1500	2000	XP 2262

Table 3: List of paddles and nominal high voltages for the PMTs for S1Y hodoscope plane.

Hut Name	Nominal HV	Max HV	Tube Type
S2X-001R	1500	2000	XP 2262
S2X-002R	1500	2000	XP 2262
S2X-003R	1200	1500	ET 9214B
S2X-004R	1500	2000	XP 2262
S2X-005R	1200	1500	ET 9214B
S2X-006R	1500	2000	XP 2262
S2X-007R	1500	2000	XP 2262
S2X-008R	1500	2000	XP 2262
S2X-009R	1500	2000	XP 2262
S2X-010R	1500	2000	XP 2262
S2X-011R	1500	2000	XP 2262
S2X-012R	1500	2000	XP 2262
S2X-013R	1500	2000	XP 2262
S2X-014R	1500	2000	XP 2262
S2X-001L	1500	2000	XP 2262
S2X-002L	1500	2000	XP 2262
S2X-003L	1200	1500	ET 9214B
S2X-004L	1500	2000	XP 2262
S2X-005L	1200	1500	ET 9214B
S2X-006L	1500	2000	XP 2262
S2X-007L	1500	2000	XP 2262
S2X-008L	1500	2000	XP 2262
S2X-009L	1500	2000	XP 2262
S2X-010L	1500	2000	XP 2262
S2X-011L	1500	2000	XP 2262
S2X-012L	1500	2000	XP 2262
S2X-013L	1500	2000	XP 2262
S2X-014L	1500	2000	XP 2262

Table 4: List of paddles and nominal high voltages for the PMTs for S2X hodoscope plane.

D Particle Detection Efficiency.

Here we provide a summary table of the SHMS Hodoscope Scintillators particle detection efficiency as a function of position. For all efficiencies quoted the (binomial) statistical uncertainty is below 1%.

Scintillator ID	PMTa SN	PMTb SN	PMTa HV [V]	PMTb HV [V]	Position [cm]	ε_A	ε_B
JL01L (Phillips)	35277	40269	1800	1800	12	0.984	0.987
JL01L (Phillips)	35277	40269	1800	1800	30.4	0.992	0.992
JL01L (Phillips)	35277	40269	1800	1800	48.8	0.990	0.990
JL01L (Phillips)	35277	40269	1800	1800	67.2	0.991	0.993
JL01L (Phillips)	35277	40269	1800	1800	85.6	0.988	0.991
JL02S (Phillips)	34847	35290	1800	1800	12	0.992	0.991
JL02S (Phillips)	34847	35290	1800	1800	27.7	0.994	0.995
JL02S (Phillips)	34847	35290	1800	1800	43.4	0.987	0.988
JL02S (Phillips)	34847	35290	1800	1800	59.1	0.993	0.993
JL02S (Phillips)	34847	35290	1800	1800	74.7	0.986	0.989
JL03S (ET)	2546	2512	1184	1620	12	0.984	0.982
JL03S (ET)	2546	2512	1184	1620	27.7	0.989	0.988
JL03S (ET)	2546	2512	1184	1620	43.4	0.986	0.985
JL03S (ET)	2546	2512	1184	1620	59.1	0.977	0.978
JL03S (ET)	2546	2512	1184	1620	74.7	0.967	0.969
JL04S (ET)	2537	2535	1263	1416	12	0.989	0.988
JL04S (ET)	2537	2535	1263	1416	27.7	0.989	0.987
JL04S (ET)	2537	2535	1263	1416	43.4	0.990	0.990
JL04S (ET)	2537	2535	1263	1416	59.1	0.986	0.987
JL04S (ET)	2537	2535	1263	1416	74.7	0.988	0.990
JL05S (ET)	2547	2548	1155	1180	12	0.992	0.991
JL05S (ET)	2547	2548	1155	1180	27.7	0.990	0.991
JL05S (ET)	2547	2548	1155	1180	43.4	0.992	0.992
JL05S (ET)	2547	2548	1155	1180	59.1	0.989	0.990
JL05S (ET)	2547	2548	1155	1180	74.7	0.980	0.984
JL06S(ET)	2545	2550	1310	1155	12	0.987	0.987
JL06S(ET)	2545	2550	1310	1155	27.7	0.991	0.989
JL06S(ET)	2545	2550	1310	1155	43.4	0.988	0.988
JL06S(ET)	2545	2550	1310	1155	59.1	0.982	0.984

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JL06S(ET)	2545	2550	1310	1155	74.7	0.978	0.981
JL08L(ET)	2511	2538	1727	1246	12	0.992	0.992
JL08L(ET)	2511	2538	1727	1246	30.4	0.990	0.990
JL08L(ET)	2511	2538	1727	1246	48.8	0.992	0.992
JL08L(ET)	2511	2538	1727	1246	67.2	0.994	0.995
JL08L(ET)	2511	2538	1727	1246	85.6	0.988	0.991
JL09S(ET)	2549	2541	1105	1298	12	0.988	0.986
JL09S(ET)	2549	2541	1105	1298	27.7	0.992	0.990
JL09S(ET)	2549	2541	1105	1298	43.4	0.991	0.989
JL09S(ET)	2549	2541	1105	1298	59.1	0.995	0.994
JL09S(ET)	2549	2541	1105	1298	74.7	0.987	0.988
JL10S(ET)	2551	2552	1230	1185	12	0.990	0.989
JL10S(ET)	2551	2552	1230	1185	27.7	0.985	0.985
JL10S(ET)	2551	2552	1230	1185	43.4	0.985	0.984
JL10S(ET)	2551	2552	1230	1185	59.1	0.981	0.981
JL10S(ET)	2551	2552	1230	1185	74.7	0.977	0.978
JL11S(ET)	2505	2543	1457	1184	12	0.991	0.991
JL11S(ET)	2505	2543	1457	1184	27.7	0.992	0.991
JL11S(ET)	2505	2543	1457	1184	43.4	0.990	0.990
JL11S(ET)	2505	2543	1457	1184	59.1	0.994	0.994
JL11S(ET)	2505	2543	1457	1184	74.7	0.991	0.993
JL12S(ET)	2502	2443	1133	1175	12	0.993	0.993
JL12S(ET)	2502	2443	1133	1175	27.7	0.994	0.994
JL12S(ET)	2502	2443	1133	1175	43.4	0.993	0.994
JL12S(ET)	2502	2443	1133	1175	59.1	0.987	0.987
JL12S(ET)	2502	2443	1133	1175	74.7	0.989	0.989
JL13S(ET)	2453	2455	1387	1275	12	0.981	0.982
JL13S(ET)	2453	2455	1387	1275	27.7	0.981	0.980
JL13S(ET)	2453	2455	1387	1275	43.4	0.981	0.981
JL13S(ET)	2453	2455	1387	1275	59.1	0.979	0.979
JL13S(ET)	2453	2455	1387	1275	74.7	0.983	0.983
JL14S(ET)	2526	2539	1481	1486	12	0.988	0.986
JL14S(ET)	2526	2539	1481	1486	27.7	0.992	0.991
JL14S(ET)	2526	2539	1481	1486	43.4	0.989	0.989
JL14S(ET)	2526	2539	1481	1486	59.1	0.989	0.989
JL14S(ET)	2526	2539	1481	1486	74.7	0.990	0.992

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JL15S(ET)	2533	2509	1420	1407	12	0.992	0.992
JL15S(ET)	2533	2509	1420	1407	27.7	0.993	0.992
JL15S(ET)	2533	2509	1420	1407	43.4	0.991	0.992
JL15S(ET)	2533	2509	1420	1407	59.1	0.990	0.990
JL15S(ET)	2533	2509	1420	1407	74.7	0.992	0.992
JL16S(ET)	2530	2514	1539	1708	12	0.986	0.986
JL16S(ET)	2530	2514	1539	1708	27.7	0.985	0.984
JL16S(ET)	2530	2514	1539	1708	43.4	0.984	0.985
JL16S(ET)	2530	2514	1539	1708	59.1	0.984	0.984
JL16S(ET)	2530	2514	1539	1708	74.7	0.978	0.979
JL17S(ET)	2544	2498	1278	1054	12	0.981	0.982
JL17S(ET)	2544	2498	1278	1054	27.7	0.989	0.989
JL17S(ET)	2544	2498	1278	1054	43.4	0.983	0.984
JL17S(ET)	2544	2498	1278	1054	59.1	0.973	0.977
JL17S(ET)	2544	2498	1278	1054	74.7	0.960	0.968
JL18S(Phillips)	35381	34857	1798	1807	12	0.987	0.987
JL18S(Phillips)	35381	34857	1798	1807	27.7	0.986	0.986
JL18S(Phillips)	35381	34857	1798	1807	43.4	0.992	0.991
JL18S(Phillips)	35381	34857	1798	1807	59.1	0.991	0.991
JL18S(Phillips)	35381	34857	1798	1807	74.7	0.991	0.992
JL19S(Phillips)	40241	34902	1631	1838	12	0.987	0.986
JL19S(Phillips)	40241	34902	1631	1838	27.7	0.988	0.989
JL19S(Phillips)	40241	34902	1631	1838	43.4	0.988	0.989
JL19S(Phillips)	40241	34902	1631	1838	59.1	0.993	0.993
JL19S(Phillips)	40241	34902	1631	1838	74.7	0.985	0.986
JL20S(Phillips)	35286	40249	1765	1681	12	0.993	0.965
JL20S(Phillips)	35286	40249	1765	1681	27.7	0.986	0.977
JL20S(Phillips)	35286	40249	1765	1681	43.4	0.989	0.984
JL20S(Phillips)	35286	40249	1765	1681	59.1	0.986	0.986
JL20S(Phillips)	35286	40249	1765	1681	74.7	0.987	0.987
JL21L (Phillips)	34871	35280	1787	1726	12	0.995	0.994
JL21L (Phillips)	34871	35280	1787	1726	30.4	0.989	0.990
JL21L (Phillips)	34871	35280	1787	1726	48.8	0.988	0.988
JL21L (Phillips)	34871	35280	1787	1726	67.2	0.990	0.990
JL21L (Phillips)	34871	35280	1787	1726	85.6	0.980	0.991
JL22L (Phillips)	35360	40242	1957	1715	12	0.987	0.966

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JL22L (Phillips)	35360	40242	1957	1715	30.4	0.994	0.989
JL22L (Phillips)	35360	40242	1957	1715	48.8	0.993	0.994
JL22L (Phillips)	35360	40242	1957	1715	67.2	0.991	0.993
JL22L (Phillips)	35360	40242	1957	1715	85.6	0.983	0.989
JL23L (ET)	2529	2499	1562	1047	12	0.991	0.991
JL23L (ET)	2529	2499	1562	1047	30.4	0.990	0.991
JL23L (ET)	2529	2499	1562	1047	48.8	0.989	0.988
JL23L (ET)	2529	2499	1562	1047	67.2	0.987	0.988
JL23L (ET)	2529	2499	1562	1047	85.6	0.993	0.994
JL24L (Phillips)	35288	35359	1754	1870	12	0.992	0.992
JL24L (Phillips)	35288	35359	1754	1870	30.4	0.991	0.990
JL24L (Phillips)	35288	35359	1754	1870	48.8	0.992	0.993
JL24L (Phillips)	35288	35359	1754	1870	67.2	0.988	0.993
JL24L (Phillips)	35288	35359	1754	1870	85.6	0.987	0.992
JL25L (Phillips)	35285	35095	1681	1837	12	0.992	0.991
JL25L (Phillips)	35285	35095	1681	1837	30.4	0.990	0.990
JL25L (Phillips)	35285	35095	1681	1837	48.8	0.988	0.990
JL25L (Phillips)	35285	35095	1681	1837	67.2	0.986	0.990
JL25L (Phillips)	35285	35095	1681	1837	85.6	0.980	0.988
JL26L (Phillips)	40245	40246	1663	1700	12	0.996	0.995
JL26L (Phillips)	40245	40246	1663	1700	30.4	0.991	0.991
JL26L (Phillips)	40245	40246	1663	1700	48.8	0.991	0.995
JL26L (Phillips)	40245	40246	1663	1700	67.2	0.986	0.994
JL26L (Phillips)	40245	40246	1663	1700	85.6	0.984	0.992
JL27L (phillips)	35365	35309	1920	1920	12	0.909	0.994
JL27L (phillips)	35365	35309	1920	1920	30.4	0.967	0.992
JL27L (phillips)	35365	35309	1920	1920	48.8	0.988	0.993
JL27L (phillips)	35365	35309	1920	1920	67.2	0.988	0.990
JL27L (phillips)	35365	35309	1920	1920	85.6	0.985	0.991
JL28L (Phillips)	35312	35332	1750	1838	12	0.989	0.989
JL28L (Phillips)	35312	35332	1750	1838	30.4	0.993	0.993
JL28L (Phillips)	35312	35332	1750	1838	48.8	0.993	0.993
JL28L (Phillips)	35312	35332	1750	1838	67.2	0.989	0.993
JL28L (Phillips)	35312	35332	1750	1838	85.6	0.961	0.989
JL29L (Phillips)	34878	35289	1715	1795	12	0.991	0.990
JL29L (Phillips)	34878	35289	1715	1795	30.4	0.990	0.992

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JL29L (Phillips)	34878	35289	1715	1795	48.8	0.992	0.992
JL29L (Phillips)	34878	35289	1715	1795	67.2	0.990	0.992
JL29L (Phillips)	34878	35289	1715	1795	85.6	0.989	0.993
JL30L (Phillips)	34896	40243	1766	1631	12	0.989	0.642
JL30L (Phillips)	34896	40243	1766	1631	30.4	0.992	0.728
JL30L (Phillips)	34896	40243	1766	1631	48.8	0.992	0.887
JL30L (Phillips)	34896	40243	1766	1631	67.2	0.987	0.972
JL30L (Phillips)	34896	40243	1766	1631	85.6	0.977	0.990
JL31L (Phillips)	34880	35291	1812	1790	12	0.982	0.992
JL31L (Phillips)	34880	35291	1812	1790	30.4	0.988	0.990
JL31L (Phillips)	34880	35291	1812	1790	48.8	0.988	0.990
JL31L (Phillips)	34880	35291	1812	1790	67.2	0.987	0.990
JL31L (Phillips)	34880	35291	1812	1790	85.6	0.985	0.989
JL32L (Phillips)	35219	35283	1815	1835	12	0.935	0.991
JL32L (Phillips)	35219	35283	1815	1835	30.4	0.980	0.993
JL32L (Phillips)	35219	35283	1815	1835	48.8	0.990	0.994
JL32L (Phillips)	35219	35283	1815	1835	67.2	0.983	0.992
JL32L (Phillips)	35219	35283	1815	1835	85.6	0.948	0.991

Table 5: Detection efficiency along the SHMS scintillator paddles. All positions in the table are with respect to the "PMTa" end. Tests were carried out during the Summer of 2012, after a box of 9 assembled paddles was shipped to the College of William and Mary, thus scintillators JL07, and JL33-JL40 are missing from this table.

E Particle Detection Efficiency.

Here we provide a summary table of the SHMS Hodoscope Scintillators particle detection efficiency as a function of position. For all efficiencies quoted the (binomial) statistical uncertainty is below 1%.

Scintillator ID	PMTa SN	PMTb SN	PMTa HV [V]	PMTb HV [V]	Position [cm]	ε_A	ε_B
JL01L (Phillips)	35277	40269	1800	1800	12	0.984	0.987

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JL01L (Phillips)	35277	40269	1800	1800	30.4	0.992	0.992
JL01L (Phillips)	35277	40269	1800	1800	48.8	0.990	0.990
JL01L (Phillips)	35277	40269	1800	1800	67.2	0.991	0.993
JL01L (Phillips)	35277	40269	1800	1800	85.6	0.988	0.991
JL02S (Phillips)	34847	35290	1800	1800	12	0.992	0.991
JL02S (Phillips)	34847	35290	1800	1800	27.7	0.994	0.995
JL02S (Phillips)	34847	35290	1800	1800	43.4	0.987	0.988
JL02S (Phillips)	34847	35290	1800	1800	59.1	0.993	0.993
JL02S (Phillips)	34847	35290	1800	1800	74.7	0.986	0.989
JL03S (ET)	2546	2512	1184	1620	12	0.984	0.982
JL03S (ET)	2546	2512	1184	1620	27.7	0.989	0.988
JL03S (ET)	2546	2512	1184	1620	43.4	0.986	0.985
JL03S (ET)	2546	2512	1184	1620	59.1	0.977	0.978
JL03S (ET)	2546	2512	1184	1620	74.7	0.967	0.969
JL04S (ET)	2537	2535	1263	1416	12	0.989	0.988
JL04S (ET)	2537	2535	1263	1416	27.7	0.989	0.987
JL04S (ET)	2537	2535	1263	1416	43.4	0.990	0.990
JL04S (ET)	2537	2535	1263	1416	59.1	0.986	0.987
JL04S (ET)	2537	2535	1263	1416	74.7	0.988	0.990
JL05S (ET)	2547	2548	1155	1180	12	0.992	0.991
JL05S (ET)	2547	2548	1155	1180	27.7	0.990	0.991
JL05S (ET)	2547	2548	1155	1180	43.4	0.992	0.992
JL05S (ET)	2547	2548	1155	1180	59.1	0.989	0.990
JL05S (ET)	2547	2548	1155	1180	74.7	0.980	0.984
JL06S(ET)	2545	2550	1310	1155	12	0.987	0.987
JL06S(ET)	2545	2550	1310	1155	27.7	0.991	0.989
JL06S(ET)	2545	2550	1310	1155	43.4	0.988	0.988
JL06S(ET)	2545	2550	1310	1155	59.1	0.982	0.984
JL06S(ET)	2545	2550	1310	1155	74.7	0.978	0.981
JL08L(ET)	2511	2538	1727	1246	12	0.992	0.992
JL08L(ET)	2511	2538	1727	1246	30.4	0.990	0.990
JL08L(ET)	2511	2538	1727	1246	48.8	0.992	0.992
JL08L(ET)	2511	2538	1727	1246	67.2	0.994	0.995
JL08L(ET)	2511	2538	1727	1246	85.6	0.988	0.991
JL09S(ET)	2549	2541	1105	1298	12	0.988	0.986
JL09S(ET)	2549	2541	1105	1298	27.7	0.992	0.990

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JL09S(ET)	2549	2541	1105	1298	43.4	0.991	0.989
JL09S(ET)	2549	2541	1105	1298	59.1	0.995	0.994
JL09S(ET)	2549	2541	1105	1298	74.7	0.987	0.988
JL10S(ET)	2551	2552	1230	1185	12	0.990	0.989
JL10S(ET)	2551	2552	1230	1185	27.7	0.985	0.985
JL10S(ET)	2551	2552	1230	1185	43.4	0.985	0.984
JL10S(ET)	2551	2552	1230	1185	59.1	0.981	0.981
JL10S(ET)	2551	2552	1230	1185	74.7	0.977	0.978
JL11S(ET)	2505	2543	1457	1184	12	0.991	0.991
JL11S(ET)	2505	2543	1457	1184	27.7	0.992	0.991
JL11S(ET)	2505	2543	1457	1184	43.4	0.990	0.990
JL11S(ET)	2505	2543	1457	1184	59.1	0.994	0.994
JL11S(ET)	2505	2543	1457	1184	74.7	0.991	0.993
JL12S(ET)	2502	2443	1133	1175	12	0.993	0.993
JL12S(ET)	2502	2443	1133	1175	27.7	0.994	0.994
JL12S(ET)	2502	2443	1133	1175	43.4	0.993	0.994
JL12S(ET)	2502	2443	1133	1175	59.1	0.987	0.987
JL12S(ET)	2502	2443	1133	1175	74.7	0.989	0.989
JL13S(ET)	2453	2455	1387	1275	12	0.981	0.982
JL13S(ET)	2453	2455	1387	1275	27.7	0.981	0.980
JL13S(ET)	2453	2455	1387	1275	43.4	0.981	0.981
JL13S(ET)	2453	2455	1387	1275	59.1	0.979	0.979
JL13S(ET)	2453	2455	1387	1275	74.7	0.983	0.983
JL14S(ET)	2526	2539	1481	1486	12	0.988	0.986
JL14S(ET)	2526	2539	1481	1486	27.7	0.992	0.991
JL14S(ET)	2526	2539	1481	1486	43.4	0.989	0.989
JL14S(ET)	2526	2539	1481	1486	59.1	0.989	0.989
JL14S(ET)	2526	2539	1481	1486	74.7	0.990	0.992
JL15S(ET)	2533	2509	1420	1407	12	0.992	0.992
JL15S(ET)	2533	2509	1420	1407	27.7	0.993	0.992
JL15S(ET)	2533	2509	1420	1407	43.4	0.991	0.992
JL15S(ET)	2533	2509	1420	1407	59.1	0.990	0.990
JL15S(ET)	2533	2509	1420	1407	74.7	0.992	0.992
JL16S(ET)	2530	2514	1539	1708	12	0.986	0.986
JL16S(ET)	2530	2514	1539	1708	27.7	0.985	0.984
JL16S(ET)	2530	2514	1539	1708	43.4	0.984	0.985

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JL16S(ET)	2530	2514	1539	1708	59.1	0.984	0.984
JL16S(ET)	2530	2514	1539	1708	74.7	0.978	0.979
JL17S(ET)	2544	2498	1278	1054	12	0.981	0.982
JL17S(ET)	2544	2498	1278	1054	27.7	0.989	0.989
JL17S(ET)	2544	2498	1278	1054	43.4	0.983	0.984
JL17S(ET)	2544	2498	1278	1054	59.1	0.973	0.977
JL17S(ET)	2544	2498	1278	1054	74.7	0.960	0.968
JL18S(Phillips)	35381	34857	1798	1807	12	0.987	0.987
JL18S(Phillips)	35381	34857	1798	1807	27.7	0.986	0.986
JL18S(Phillips)	35381	34857	1798	1807	43.4	0.992	0.991
JL18S(Phillips)	35381	34857	1798	1807	59.1	0.991	0.991
JL18S(Phillips)	35381	34857	1798	1807	74.7	0.991	0.992
JL19S(Phillips)	40241	34902	1631	1838	12	0.987	0.986
JL19S(Phillips)	40241	34902	1631	1838	27.7	0.988	0.989
JL19S(Phillips)	40241	34902	1631	1838	43.4	0.988	0.989
JL19S(Phillips)	40241	34902	1631	1838	59.1	0.993	0.993
JL19S(Phillips)	40241	34902	1631	1838	74.7	0.985	0.986
JL20S(Phillips)	35286	40249	1765	1681	12	0.993	0.965
JL20S(Phillips)	35286	40249	1765	1681	27.7	0.986	0.977
JL20S(Phillips)	35286	40249	1765	1681	43.4	0.989	0.984
JL20S(Phillips)	35286	40249	1765	1681	59.1	0.986	0.986
JL20S(Phillips)	35286	40249	1765	1681	74.7	0.987	0.987
JL21L (Phillips)	34871	35280	1787	1726	12	0.995	0.994
JL21L (Phillips)	34871	35280	1787	1726	30.4	0.989	0.990
JL21L (Phillips)	34871	35280	1787	1726	48.8	0.988	0.988
JL21L (Phillips)	34871	35280	1787	1726	67.2	0.990	0.990
JL21L (Phillips)	34871	35280	1787	1726	85.6	0.980	0.991
JL22L (Phillips)	35360	40242	1957	1715	12	0.987	0.966
JL22L (Phillips)	35360	40242	1957	1715	30.4	0.994	0.989
JL22L (Phillips)	35360	40242	1957	1715	48.8	0.993	0.994
JL22L (Phillips)	35360	40242	1957	1715	67.2	0.991	0.993
JL22L (Phillips)	35360	40242	1957	1715	85.6	0.983	0.989
JL23L (ET)	2529	2499	1562	1047	12	0.991	0.991
JL23L (ET)	2529	2499	1562	1047	30.4	0.990	0.991
JL23L (ET)	2529	2499	1562	1047	48.8	0.989	0.988
JL23L (ET)	2529	2499	1562	1047	67.2	0.987	0.988

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JL23L (ET)	2529	2499	1562	1047	85.6	0.993	0.994
JL24L (Phillips)	35288	35359	1754	1870	12	0.992	0.992
JL24L (Phillips)	35288	35359	1754	1870	30.4	0.991	0.990
JL24L (Phillips)	35288	35359	1754	1870	48.8	0.992	0.993
JL24L (Phillips)	35288	35359	1754	1870	67.2	0.988	0.993
JL24L (Phillips)	35288	35359	1754	1870	85.6	0.987	0.992
JL25L (Phillips)	35285	35095	1681	1837	12	0.992	0.991
JL25L (Phillips)	35285	35095	1681	1837	30.4	0.990	0.990
JL25L (Phillips)	35285	35095	1681	1837	48.8	0.988	0.990
JL25L (Phillips)	35285	35095	1681	1837	67.2	0.986	0.990
JL25L (Phillips)	35285	35095	1681	1837	85.6	0.980	0.988
JL26L (Phillips)	40245	40246	1663	1700	12	0.996	0.995
JL26L (Phillips)	40245	40246	1663	1700	30.4	0.991	0.991
JL26L (Phillips)	40245	40246	1663	1700	48.8	0.991	0.995
JL26L (Phillips)	40245	40246	1663	1700	67.2	0.986	0.994
JL26L (Phillips)	40245	40246	1663	1700	85.6	0.984	0.992
JL27L (phillips)	35365	35309	1920	1920	12	0.909	0.994
JL27L (phillips)	35365	35309	1920	1920	30.4	0.967	0.992
JL27L (phillips)	35365	35309	1920	1920	48.8	0.988	0.993
JL27L (phillips)	35365	35309	1920	1920	67.2	0.988	0.990
JL27L (phillips)	35365	35309	1920	1920	85.6	0.985	0.991
JL28L (Phillips)	35312	35332	1750	1838	12	0.989	0.989
JL28L (Phillips)	35312	35332	1750	1838	30.4	0.993	0.993
JL28L (Phillips)	35312	35332	1750	1838	48.8	0.993	0.993
JL28L (Phillips)	35312	35332	1750	1838	67.2	0.989	0.993
JL28L (Phillips)	35312	35332	1750	1838	85.6	0.961	0.989
JL29L (Phillips)	34878	35289	1715	1795	12	0.991	0.990
JL29L (Phillips)	34878	35289	1715	1795	30.4	0.990	0.992
JL29L (Phillips)	34878	35289	1715	1795	48.8	0.992	0.992
JL29L (Phillips)	34878	35289	1715	1795	67.2	0.990	0.992
JL29L (Phillips)	34878	35289	1715	1795	85.6	0.989	0.993
JL30L (Phillips)	34896	40243	1766	1631	12	0.989	0.642
JL30L (Phillips)	34896	40243	1766	1631	30.4	0.992	0.728
JL30L (Phillips)	34896	40243	1766	1631	48.8	0.992	0.887
JL30L (Phillips)	34896	40243	1766	1631	67.2	0.987	0.972
JL30L (Phillips)	34896	40243	1766	1631	85.6	0.977	0.990

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JL31L (Phillips)	34880	35291	1812	1790	12	0.982	0.992
JL31L (Phillips)	34880	35291	1812	1790	30.4	0.988	0.990
JL31L (Phillips)	34880	35291	1812	1790	48.8	0.988	0.990
JL31L (Phillips)	34880	35291	1812	1790	67.2	0.987	0.990
JL31L (Phillips)	34880	35291	1812	1790	85.6	0.985	0.989
JL32L (Phillips)	35219	35283	1815	1835	12	0.935	0.991
JL32L (Phillips)	35219	35283	1815	1835	30.4	0.980	0.993
JL32L (Phillips)	35219	35283	1815	1835	48.8	0.990	0.994
JL32L (Phillips)	35219	35283	1815	1835	67.2	0.983	0.992
JL32L (Phillips)	35219	35283	1815	1835	85.6	0.948	0.991

Table 6: Detection efficiency along the SHMS scintillator paddles. All positions in the table are with respect to the "PMTa" end. Tests were carried out during the Summer of 2012, after a box of 9 assembled paddles was shipped to the College of William and Mary, thus scintillators JL07, and JL33-JL40 are missing from this table.

References

[1] S. A. Wood. Operation of the caen high voltage system. http://hallcweb.jlab.org/document/howtos/PDF/CAEN_HV_operation.pdf. Hall C User Howto.