Additional modeling comparing Hamamatsu and Broadcom SiPM for HEP PWO readout

Consider 15, 20, 25, 30% optical coupling efficiency between PWO and SiPM to estimate non-linearity

Modeling computation (energy linearity)

- Estimate the number of cells firing from incident particle
- Compute integral non-linearity at 15GeV
- Photon collection from crystal to SiPM? Use 100% and 20% (more realistic)

$$N_{fired}(M,V,\lambda) = M.\left\{1 - exp\left[-\frac{PDE(V,\lambda).N_{ph}}{M}\right]\right\}$$

$N_{fired} = number\ of\ activated\ cells$

$M = total\ number\ of\ cells$

$PDE(V,\lambda) =$ photodetection efficiency

$V = bias\ voltage, \lambda = photon\ wavelength$

$N_{ph} = number\ of\ incident\ photons$

	Hamamatsu S14160-3010	Onsemi 60035	Hamamatsu S14160-3015	Broadcom AFBR-S4N44C013	Broadcom AFBR-S4N44P014M
Total number of cells	89984	22292	39984	15060	8334
Incoming Particle energy (eV)	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10
Scintillator light yield (ph/eV)	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05
N photon / incoming particle	2.25E+05	2.25E+05	2.25E+05	2.25E+05	2.25E+05
Crystal surface area (mm2)	400	400	400	400	400
Nflux (ph/mm2)	563	563	563	563	563
Nb of SiPM	16	9	16	16/25	16
SiPM active area (mm2)	9	37	9	13.84	13.47
Nph for one SiPM	5063	20725	5063	7784.1	7575
Include fill factor to Nph	1569	15544	2481	4687	5757
Nb of activated sites/SiPM	907	6635	1588	3001	3633
INL at 15GeV	0.18%	10.69%	1.26%	8.21%	24%
Total activated cells	14506	59713	25402	48021	58131
Resolution (bit)	14	16	15	16	16
INL at 15GeV 20% coupling efficiency	0.04%	2.56%	0.26%	1.85%	6.59%
Total activated cells	2913	13687	5163	10476	14428
Resolution (bit)	12	14	13	14	14

Best compromises

Additional NL estimates vs. optical coupling

	Hamamatsu S14160-3010	Onsemi 60035	Hamamatsu S14160-3015	Broadcom AFBR-S4N44C013	Broadcom AFBR-S4N44P014M
Total number of cells	89984	22292	39984	15060	8334
Nb of SiPM	16	9	16	16/25	16
SiPM active area (mm2)	9	37	9	13.84	13.47
Nph for one SiPM	5063	20725	5063	7784.1	7575
Include fill factor to Nph	1569	15544	2481	4687	5757
Nb of activated sites/SiPM	907	6635	1588	3001	3633
INL at 15GeV 100% coupling efficiency	0.5%	15.8%	2.0%	10.33%	24%
Total activated cells	14506	59713	25402	48021	58131
Resolution (bit)	14	16	15	16	16
INL at 15GeV 15% coupling efficiency	0.08%	2.6%	0.30%	1.65%	4.17%
Total activated cells	2185	10355	3876	7900	10975
Resolution (bit)	12	14	12	13	14
INL at 15GeV 20% coupling efficiency	0.10%	3.45%	0.40%	2.19%	5.51%
Total activated cells	2913	13687	5163	10476	14428
Resolution (bit)	12	14	13	14	14
INL at 15GeV 25% coupling efficiency	0.13%	4.29%	0.50%	2.73%	6.83%
Total activated cells	3640	16960	6447	13023	17785
Resolution (bit)	12	15	13	14	15
INL at 15GeV 30% coupling efficiency	0.15%	5.12%	0.61%	3.26%	8.12%
Total activated cells	4367	20176	7729	15542	21047
Resolution (bit)	13	15	13	14	15

Incoming Particle energy (eV)	1.50E+10
Scintillator light yield (ph/eV)	1.50E-05
N photon / incoming particle	2.25E+05
Crystal surface area (mm2)	400
Nflux (ph/mm2)	563

$$N_{fired}(M,V,\lambda) = M.\left\{1 - exp\left[-\frac{PDE(V,\lambda).N_{ph}}{M}\right]\right\}$$

$$INL = \left(\frac{PDE(V,\lambda).N_{ph} - N_{fired}}{PDE(V,\lambda).N_{ph}}\right)$$

$$N_{fired} = number\ of\ activated\ cells$$

$$M = total\ number\ of\ cells$$

$$PDE(V,\lambda) = \text{ photodetection efficiency}$$

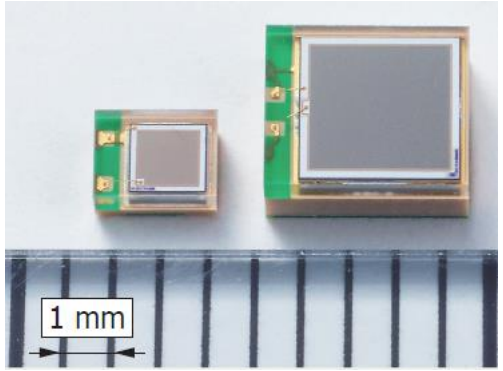
$$V = bias\ voltage, \lambda = photon\ wavelength$$

$$N_{ph} = number\ of\ incident\ photons$$

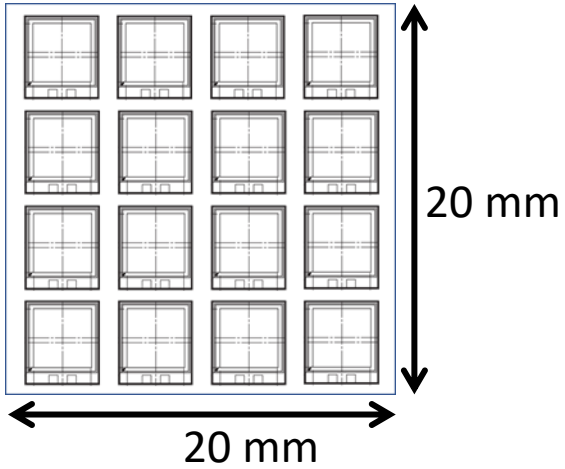
Hamamatsu S14160-3015

- 3 mm x 3 mm active
- PDE 32% (at 420 nm)
- 15 µm microcells
- Anode capacitance 530 pF
- Dark count rate 700 kcps (typ.)
- VOP variation within reel ±0.1V (± 8% gain)

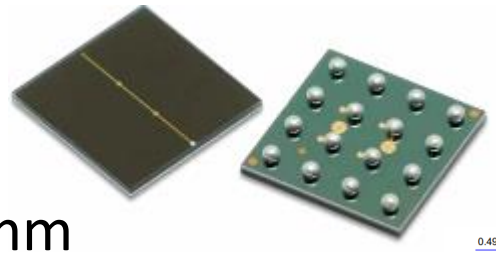
- ➢16 pcs to fill 20 mm x 20 mm
- ➢Active fill: 36% of area
- ➢Rough computation for # activated cells for 15GeV deposited in crystal: 5,160 (20% coupling eff.)
- ➢Expected Integral Non-linearity at 15GeV: 0.40% (20% coupling eff.)
- ➢Measured fast timing (70ns FWHM)



16 x 3015

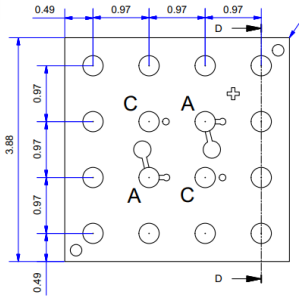


Broadcom AFBR-S4N44C013

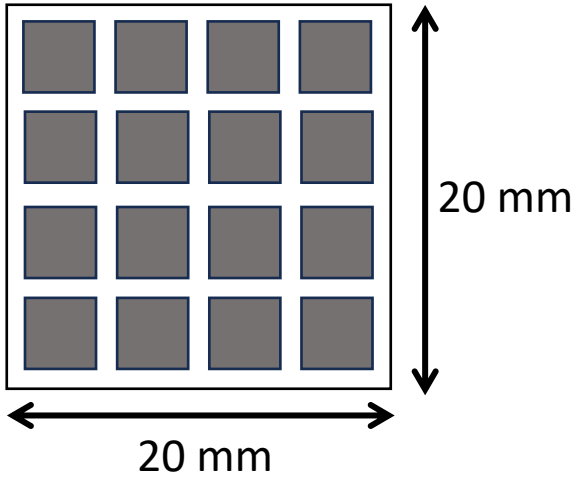


- 3.72 mm x 3.72 mm active
- PDE 43/55% (420 nm) (typ./perf.)
- 30 µm microcells
- Anode capacitance 990/760 pF (typ./perf.) slightly longer pulse
- Dark count rate 1660 kcps (typ.)

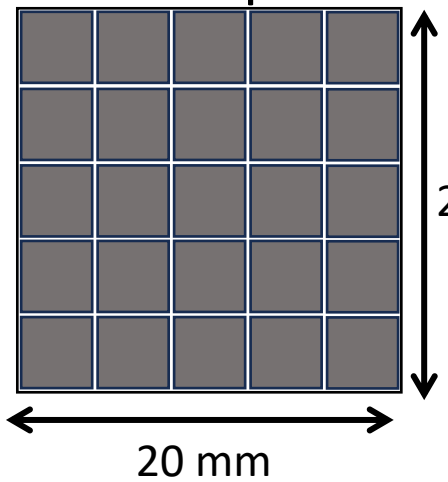
- ➢16/25 pcs to fill 20 mm x 20 mm
- ➢Active fill: 55/86% of area
- ➢Rough computation for # activated cells for 15GeV deposited in crystal: 10,476 (20% coupling eff.)
- ➢Expected Integral Non-linearity at 15GeV: 2.2% (20% coupling eff.)



3.88mm



16 x S4N44C013



5x5 matrix for area coverage is possible
86% active coverage (better than PMT)

Expected resolution with different SiPMs

- Use measured resolution from experiment as reference
- Compute relative signal level from change in PDE and active area
- Compute resolution change (1rst order scales with square root of signal)

	Hamamatsu 14160-3010	Hamamatsu 14160-3015	Hamamatsu 14160-6015	Hamamatsu 14160-6010	Broadcom AFBR-S4N44C013	Broadcom AFBR-S4N44C013	Broadcom AFBR-S4N44P014M	PMT Hamamatsu R4125 (19mm dia, 15mm cthode)
configuration	4x4	4x4	2x2	2x2	4x4	5x5	4x4	1
PDE (% 420nm)	17	30	30	17	43	43	63	27
active fill (%)	36	36	36	36	55	86	54	71
relative signal level (100%)	57	100	100	57	219	342	314	177
expected resolution at 4.54 GeV (%)	**2.86**	**2.15**	**2.15**	**2.86**	**1.45**	**1.16**	**1.21**	**1.62**
expected resolution at 5.8 GeV (%)	**2.27**	**1.71**	**1.71**	**2.27**	**1.16**	**0.92**	**0.96**	**1.28**

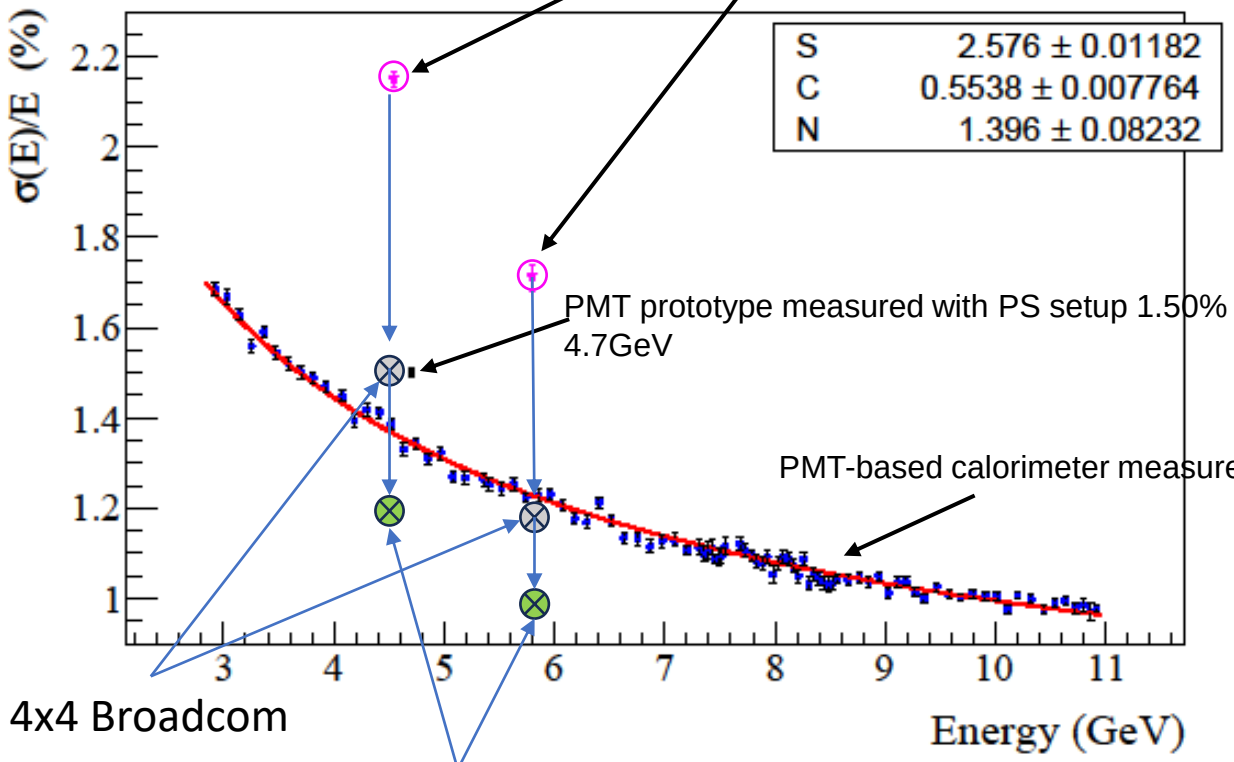
Measured at JLab w. 3x3 Crytur prototype 2.0

predicted

Predicted PMT resolution: 1.59% at 4.7GeV
Measurement: 1.5%
3x3 PMT based detector measured at JLAB

Energy resolution: comparison with PMT

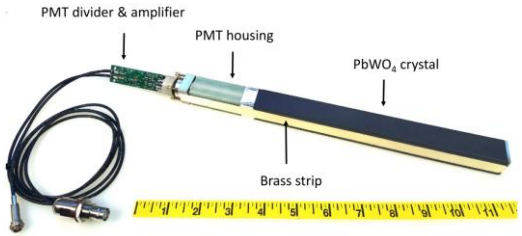
Energy (GeV)	Resolution (%)	Res_error
4.542	2.14872	0.01644
5.797	1.71093	0.02872



Using Broadcom AFBR-S4N44C013 w. higher PDE and active area

4x4 array res. 4.54 GeV 2.15% -> 1.45%; 5.8 GeV 1.71% -> 1.16%

5x5 array res. 4.54 GeV 2.15% -> 1.16%; 5.8 GeV 1.71% -> 0.92%



Hamamatsu 4125

Better than PMT: better PDE, better coverage

Summary table

	Hamamatsu 14160-3010	Hamamatsu 14160-3015	Hamamatsu 14160-6015	Hamamatsu 14160-6010	Broadcom AFBR-S4N44C013	Broadcom AFBR-S4N44C013	Broadcom AFBR-S4N44P014M	PMT Hamamatsu R4125 (19mm dia, 15mm cthode)
Cell pitch (µm)	10	15	15	10	30	30	40	15000
Capacitance (pF)	530	530	2500	2500	990/760	990/760	580	
PDE at 420nm (%)	17	30	30	30	43/55	43/55	63	27
configuration	4x4	4x4	2x2	2x2	4x4	5x5	4x4	1
PDE (% 420nm)	17	30	30	17	43	43	63	27
active fill (%)	36	36	36	36	55	86	54	71
relative signal level (100%)	57	100	100	57	219	342	314	177
expected resolution at 4.54 GeV (%)	**2.86**	**2.15**	**2.15**	**2.86**	**1.45**	**1.16**	**1.21**	**1.62**
expected resolution at 5.8 GeV (%)	**2.27**	**1.71**	**1.71**	**2.27**	**1.16**	**0.92**	**0.96**	**1.28**

PMT: 1.59% at 4.7GeV
Measurement: 1.5%

Significant resolution improvement, slight pulse timing and NL tradeoff

Response linearity check, peak position vs beam energy