Vessel light collection studies

F. Nuti

*The University of Melbourne

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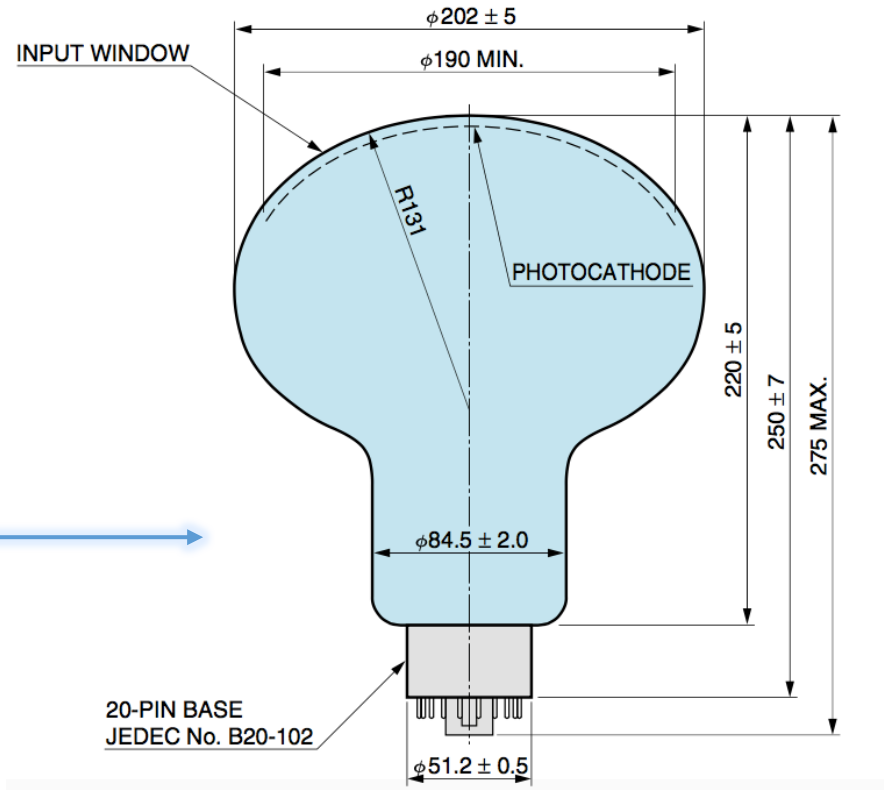
Picture by M. Volpi

THE UNIVERSITY OF MELBOURNE

STAWELL UNDERGROUND PHYSICS LAB

SABRE

PMT MODELING



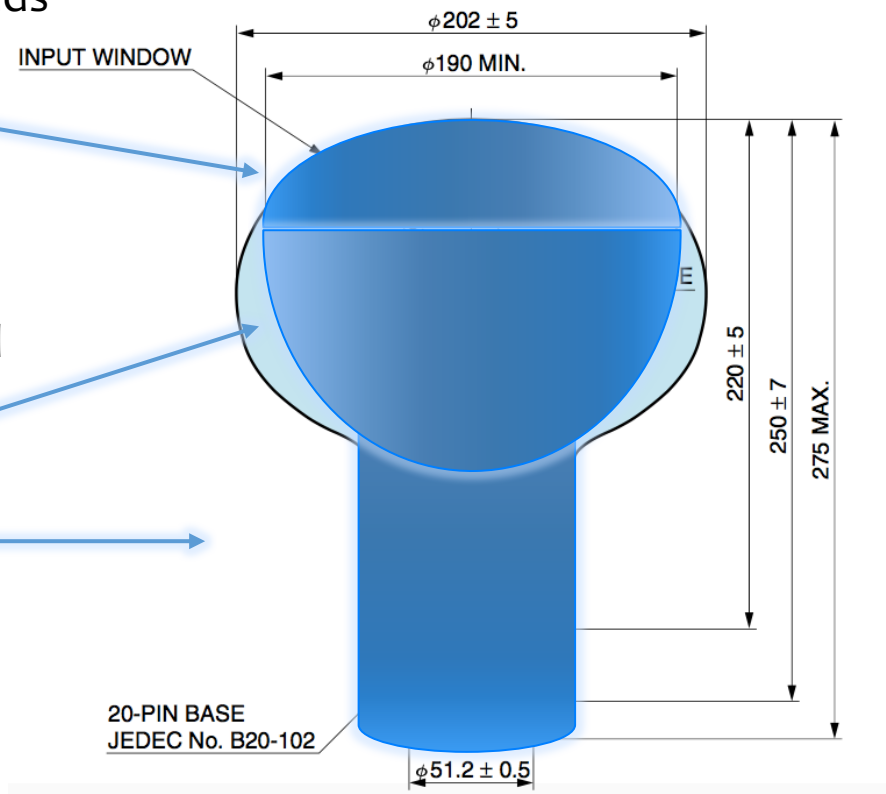
Type No.	Diameter (mm) / (inch)	Minimum effective area (mm)	Surface area		Dynode		Weight (g)
			Min. (cm^2)	Typ. (cm^2)	Structure	Number of stages	
R5912	202 / 8	ϕ190	330	380	Box & Line	10	approx. 1100
R5912-20	202 / 8	ϕ190	330	380	Box & Line	14	approx. 1100
R5912-100	202 / 8	ϕ190	330	380	Box & Line	10	approx. 1100

PMT MODELING

Sensitive paraboloids
rlo=9.5 cm
rhi=0 cm
h/2=2.1 cm
Surface=333 cm^2

Bottom paraboloid
rlo=4.5 cm
rhi=9.5 cm
h/2=3.7 cm

Cylinder
r=4.5cm
h =16.4 cm



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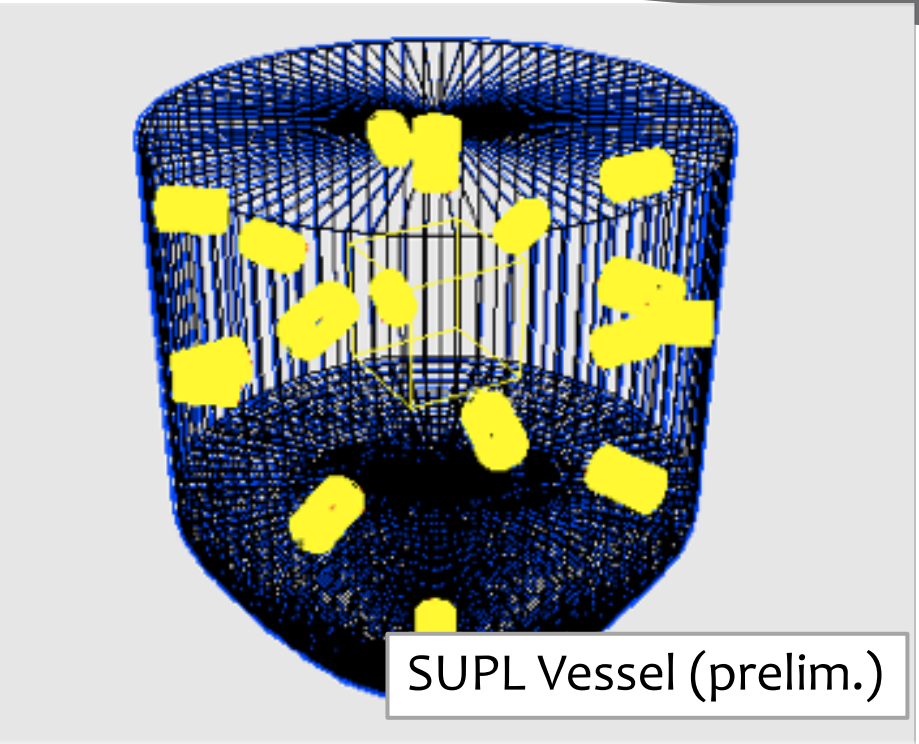
Veto Energy limit

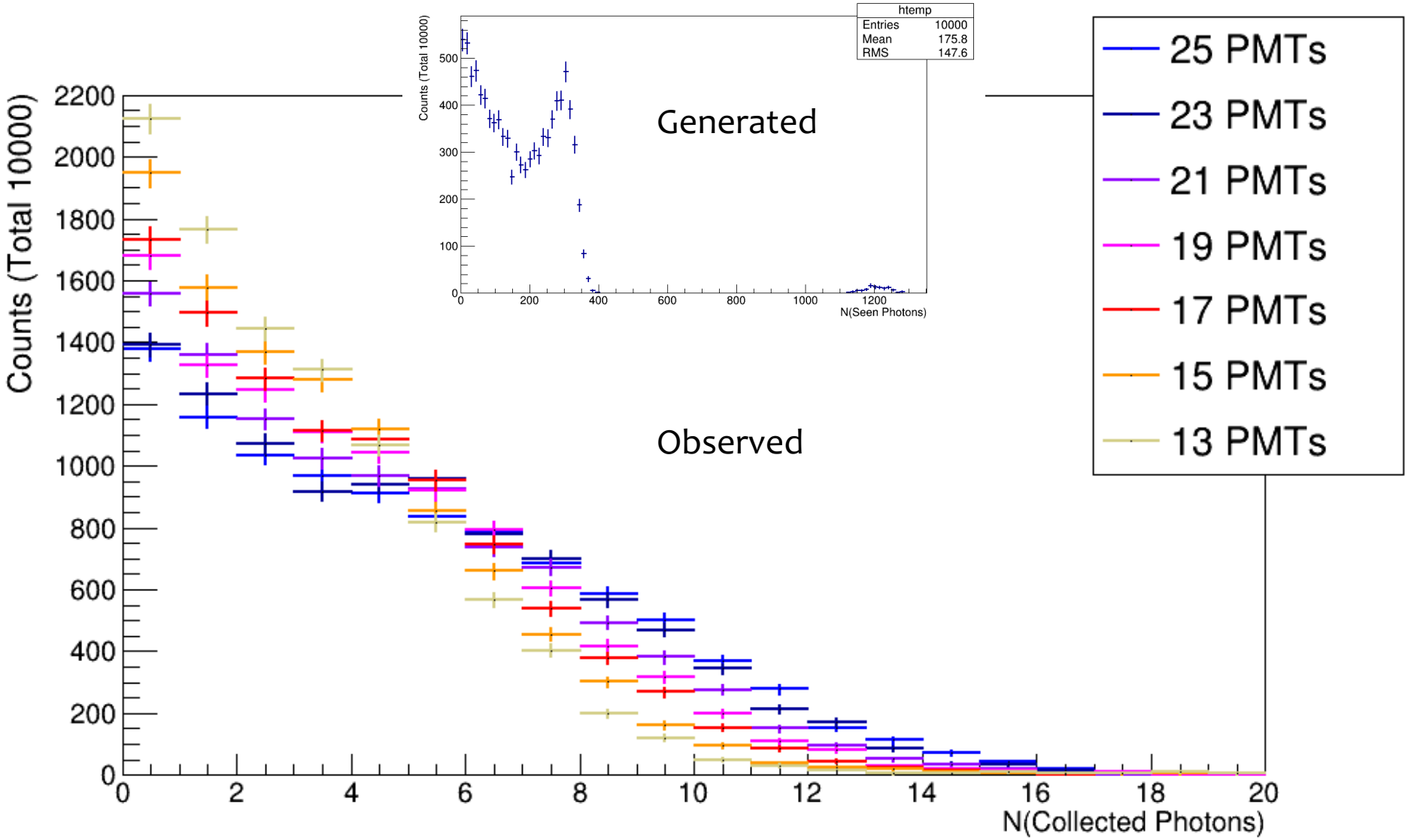
- What's the limit in energy that can be observed with this configuration?



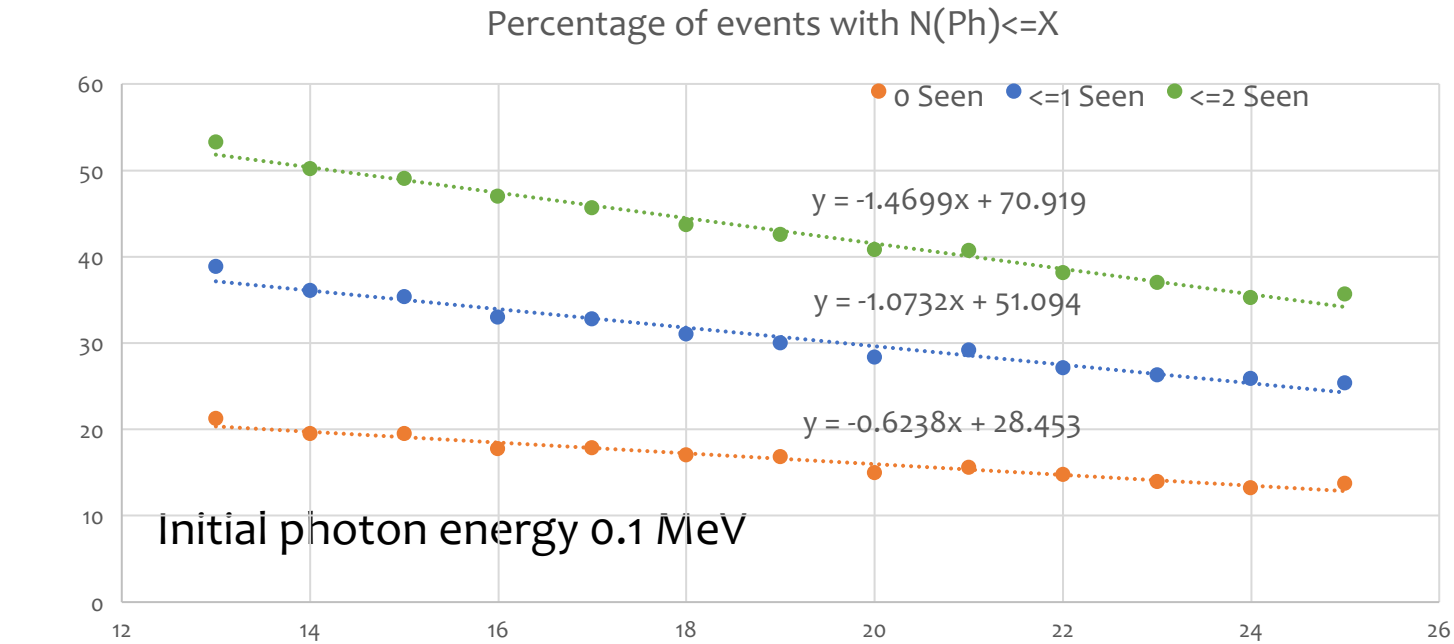
- Linear Alkyl Benzene (LAB)
- ~16 PMTs
- r x h = 1.30 x 1.85 (m^2)

Light yields per # PMTs

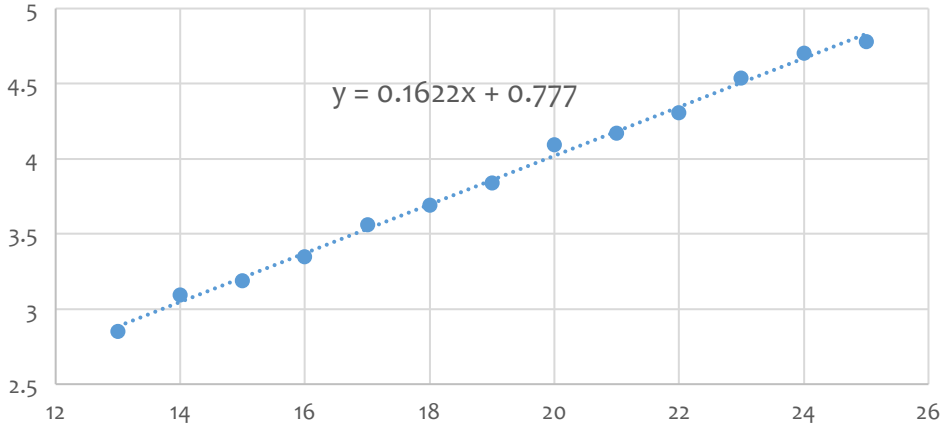
Initial photon energy 0.1 MeV



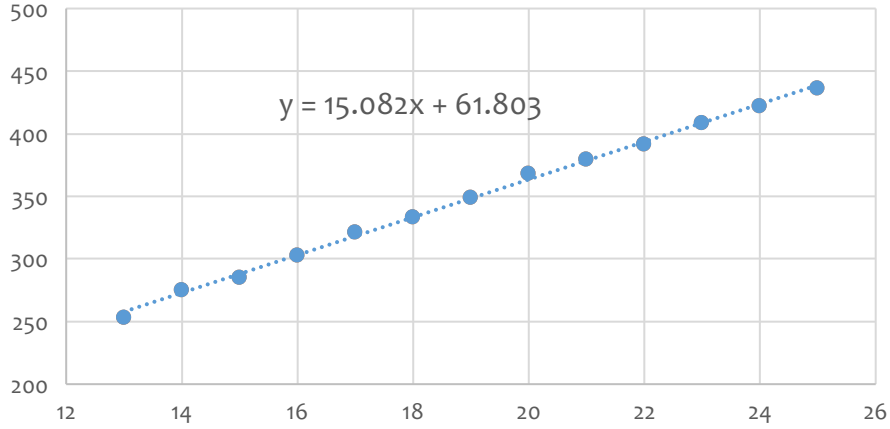
Light yields per # PMTs



Average Seen Ph vs # PMTs (0.1 MeV)



Average Seen Ph vs # PMTs (1.46 MeV)



Veto Energy limit

- Low energy measurements are limited by the PMTs dark noise rate
- Need to set threshold on # photon seen so that coincident dark count rate << 1/acquisition time and background rate in crystals?)
- Hamamatsu R5912-100 specs:

Anode sensitivity (at +25 °C)

Dark current (After 30 min storage in darkness)		Dark count (After 15 hours storage in darkness)		Time response			Single photo-electron (Peak to valley ratio)		Pulse linearity		Type No.
		1500V	1800V	Rise time	Electron transit time	Transit time spread (FWHM)			at ±2 % Deviation	at ±5 % Deviation	
Typ. (nA)	Max. (nA)	Typ. (s^{-1})	Max. (s^{-1})	Typ. (ns)	Typ. (ns)	Typ. (ns)	Min.	Typ.	Typ. (mA)	Typ. (mA)	
100	1000	4000	8000	3.6	54	2.4	1.5	2.8	40	60	R5912
5000	10 000	6000	12 000	4.4	72	3.0	1.5	2.8	30	60	R5912-20
500	1000	6000	10 000	3.6	54	2.4	1.5	2.8	40	60	R5912-100

COINCIDENCE RATES

N=#PMTs, rate of dark counts r=6kHz, acquisition window τ=1μs

RATE OF DARK COUNTS $R_1 = N \cdot r$

RATE OF 2 COINCIDENT DARK COUNTS $R_2 = N \cdot r \cdot (N-1) r \cdot \not{4}\tau = \not{2} N(N-1) r^2 \tau$

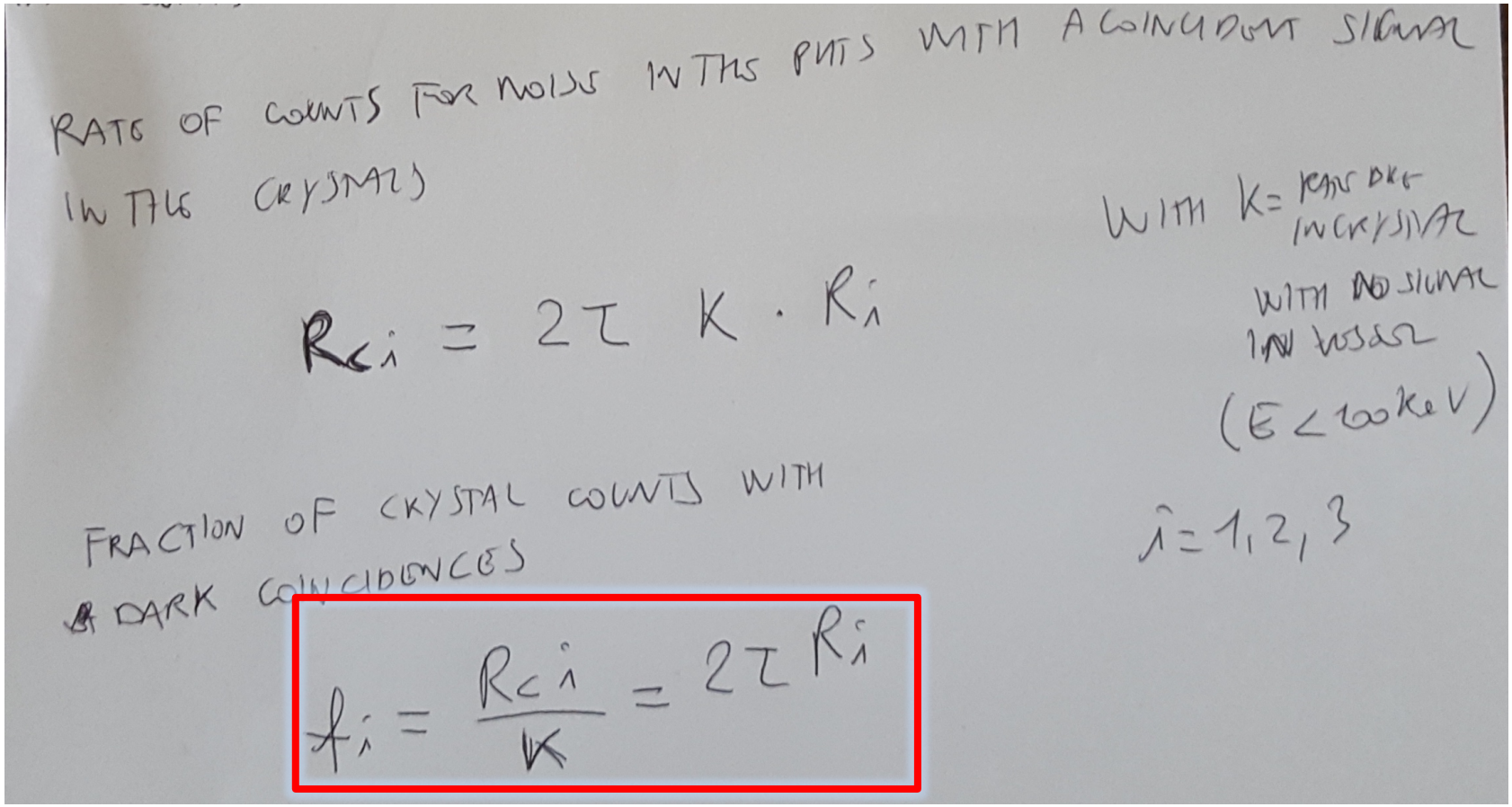
RATE OF 3 COINCIDENT DARK COUNTS $R_3 = N \cdot r \cdot (N-1) r \cdot (N-2) r \cdot \not{3} \tau^2 = \not{6} N(N-1)(N-2) r^3 \tau^2$

COINCIDENCE RATES

N pmts	Dark rate (Hz)	2 coincidences (Hz)	3 coincidences (Hz)
13	7.8E+04	5.6E+03	3.7E+02
14	8.4E+04	6.6E+03	4.7E+02
15	9.0E+04	7.6E+03	5.9E+02
16	9.6E+04	8.6E+03	7.3E+02
17	1.0E+05	9.8E+03	8.8E+02
18	1.1E+05	1.1E+04	1.1E+03
19	1.1E+05	1.2E+04	1.3E+03
20	1.2E+05	1.4E+04	1.5E+03
21	1.3E+05	1.5E+04	1.7E+03
22	1.3E+05	1.7E+04	2.0E+03
23	1.4E+05	1.8E+04	2.3E+03
24	1.4E+05	2.0E+04	2.6E+03
25	1.5E+05	2.2E+04	3.0E+03
26	1.6E+05	2.3E+04	3.4E+03
27	1.6E+05	2.5E+04	3.8E+03
28	1.7E+05	2.7E+04	4.2E+03
29	1.7E+05	2.9E+04	4.7E+03
30	1.8E+05	3.1E+04	5.3E+03
31	1.9E+05	3.3E+04	5.8E+03
32	1.9E+05	3.6E+04	6.4E+03

Events lost

- If dark counts are coincident with a signal in the crystal, the event may be rejected cause above threshold
- The fraction of event rejected is calculated



Events lost

τ=1μs

N pmts	1 dark count	2 dark coincidences	3 dark coincidences
13	1.6E-01	1.1E-02	7.4E-04
14	1.7E-01	1.3E-02	9.4E-04
15	1.8E-01	1.5E-02	1.2E-03
16	1.9E-01	1.7E-02	1.5E-03
17	2.0E-01	2.0E-02	1.8E-03
18	2.2E-01	2.2E-02	2.1E-03
19	2.3E-01	2.5E-02	2.5E-03
20	2.4E-01	2.7E-02	3.0E-03
21	2.5E-01	3.0E-02	3.4E-03
22	2.6E-01	3.3E-02	4.0E-03
23	2.8E-01	3.6E-02	4.6E-03
24	2.9E-01	4.0E-02	5.2E-03
25	3.0E-01	4.3E-02	6.0E-03
26	3.1E-01	4.7E-02	6.7E-03
27	3.2E-01	5.1E-02	7.6E-03
28	3.4E-01	5.4E-02	8.5E-03
29	3.5E-01	5.8E-02	9.5E-03
30	3.6E-01	6.3E-02	1.1E-02
31	3.7E-01	6.7E-02	1.2E-02
32	3.8E-01	7.1E-02	1.3E-02

Conclusion

- 1.5%, 1.1%, 0.6% low energy events (0.1 MeV) are lost when a PMT dies and requiring N(Ph)>2, N(Ph)>1, N(Ph)>0 respectively
- Average number of photon seen varies of 0.16 per PMT for low energy events (about 4% for 18 PMTs)
- Rate of event lost due to dark count estimated. Need to know acquisition time more precisely

Backup

Light yields per # PMTs

Initial photon energy 0.1 MeV

N(PMTs)	Average	0 Seen	<=1 Seen	<=2 Seen
13	2.9	21.2	38.8	53.3
14	3.1	19.5	36.1	50.2
15	3.2	19.5	35.3	49.0
16	3.4	17.7	33.0	47.0
17	3.6	17.8	32.8	45.6
18	3.7	17.1	31.0	43.7
19	3.8	16.8	30.0	42.5
20	4.1	14.9	28.4	40.8
21	4.2	15.6	29.2	40.7
22	4.3	14.8	27.1	38.1
23	4.5	13.9	26.3	37.0
24	4.7	13.3	25.9	35.3
25	4.8	13.8	25.3	35.7

Initial photon energy 1.46 MeV

N(PMTs)	Average
13	253.6
14	275.2
15*	285.2
16*	302.9
17	321.7
18	333.8
19*	348.9
20*	368.4
21*	379.6
22*	391.5
23*	409.2
24*	422.4
25*	436.4

*files were incomplete. About 80% of statistics was available

Events lost

$\tau = 0.1\mu s$

N pmts	1 dark count	2 dark coincidences	3 dark coincidences
13	1.0E-02	5.0E-05	2.2E-07
14	1.1E-02	5.8E-05	2.8E-07
15	1.2E-02	6.7E-05	3.5E-07
16	1.3E-02	7.7E-05	4.3E-07
17	1.4E-02	8.7E-05	5.2E-07
18	1.4E-02	9.8E-05	6.3E-07
19	1.5E-02	1.1E-04	7.4E-07
20	1.6E-02	1.2E-04	8.8E-07
21	1.7E-02	1.3E-04	1.0E-06
22	1.8E-02	1.5E-04	1.2E-06
23	1.8E-02	1.6E-04	1.4E-06
24	1.9E-02	1.8E-04	1.6E-06
25	2.0E-02	1.9E-04	1.8E-06
26	2.1E-02	2.1E-04	2.0E-06
27	2.2E-02	2.2E-04	2.2E-06
28	2.2E-02	2.4E-04	2.5E-06
29	2.3E-02	2.6E-04	2.8E-06
30	2.4E-02	2.8E-04	3.1E-06
31	2.5E-02	3.0E-04	3.5E-06
32	2.6E-02	3.2E-04	3.8E-06