Veto performance studies (Update)

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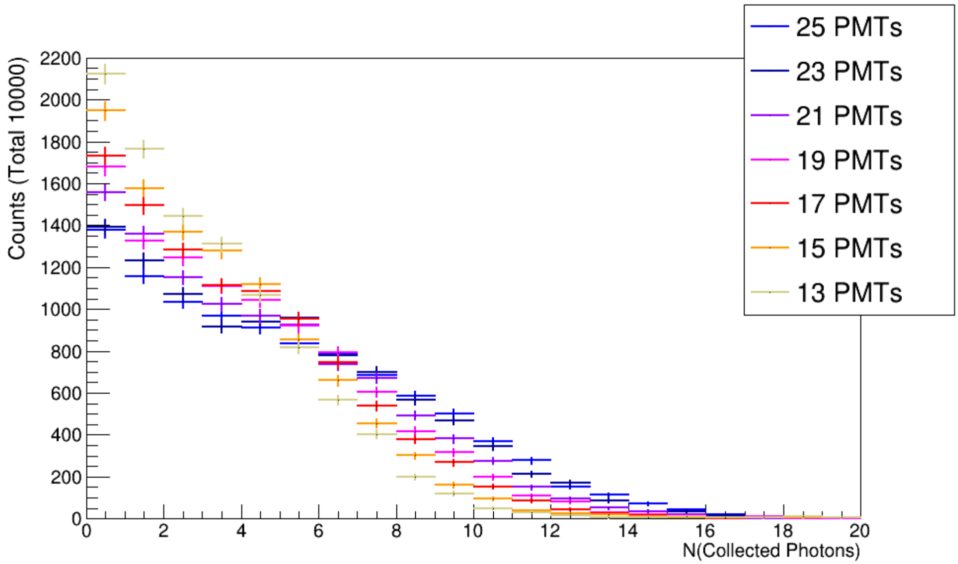
1st of May 2017

Picture by M. Volpi

VETO ENERGY LIMIT

- What's the minimum energy detectable by the vessel PMTs?
- Tests with 0.1 MeV, discussed in the last meeting (see backup), show significant fraction of events with few or no photoelectrons
- The energy sensitivity is also limited by the frequency of dark counts and coincident dark counts



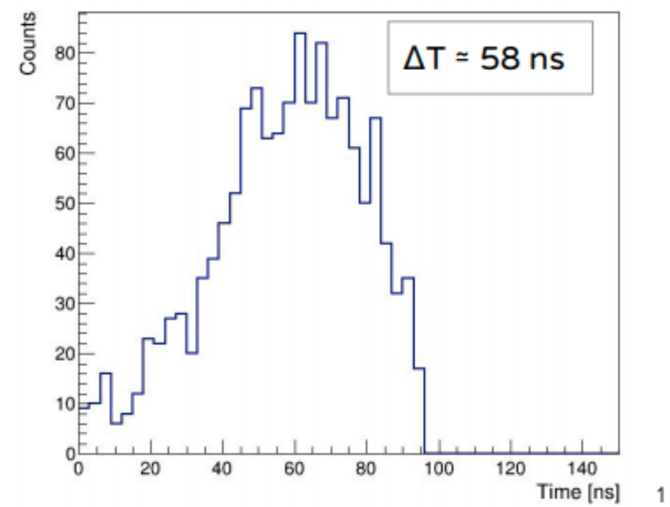
SUPL Vessel (prelim.)

- Scintillator: Linear Alkyl Benzene (LAB)
- ~16 PMTs
- r x h = 1.29 x 1.83.3 (m^2)

RELEVANT INFORMATION

- LAB optical properties
  - Absorption length 10-25 m → absorption probability after ~1.5m (6%-14%)
  - index of refraction ~1.5
  - 12000 optical photons per MeV
  - mean wavelength 365 nm
  - LAB scintillation time 20.0 ns (taken from Pseudocumene, need to find proper value) → time distribution of the observed photons → acquisition time of liquid scintillator signals (τ)
- Delays in signals produce in the crystals and in the scintillator by the main radioactive isotopes (τ')

Detection time window: distribution of interval time between the last and the first photon seen by PMTs for each event.



Fraction of event vetoed due to dark counts

rate of dark counts per PMT = 6kHz, liquid scintillator acquisition window = 100ns, Total acquisition time of the event = 1μs

N(PMTs)	1 dark count	2 dark coincidences	3 dark coincidences
13	1.6E-01	1.1E-03	7.4E-06
14	1.7E-01	1.3E-03	9.4E-06
15	1.8E-01	1.5E-03	1.2E-05
16	1.9E-01	1.7E-03	1.5E-05
17	2.0E-01	2.0E-03	1.8E-05
18	2.2E-01	2.2E-03	2.1E-05
19	2.3E-01	2.5E-03	2.5E-05
20	2.4E-01	2.7E-03	3.0E-05
21	2.5E-01	3.0E-03	3.4E-05
22	2.6E-01	3.3E-03	4.0E-05
23	2.8E-01	3.6E-03	4.6E-05
24	2.9E-01	4.0E-03	5.2E-05
25	3.0E-01	4.3E-03	6.0E-05
26	3.1E-01	4.7E-03	6.7E-05
27	3.2E-01	5.1E-03	7.6E-05
28	3.4E-01	5.4E-03	8.5E-05
29	3.5E-01	5.8E-03	9.5E-05
30	3.6E-01	6.3E-03	1.1E-04
31	3.7E-01	6.7E-03	1.2E-04
32	3.8E-01	7.1E-03	1.3E-04

Backup

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

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

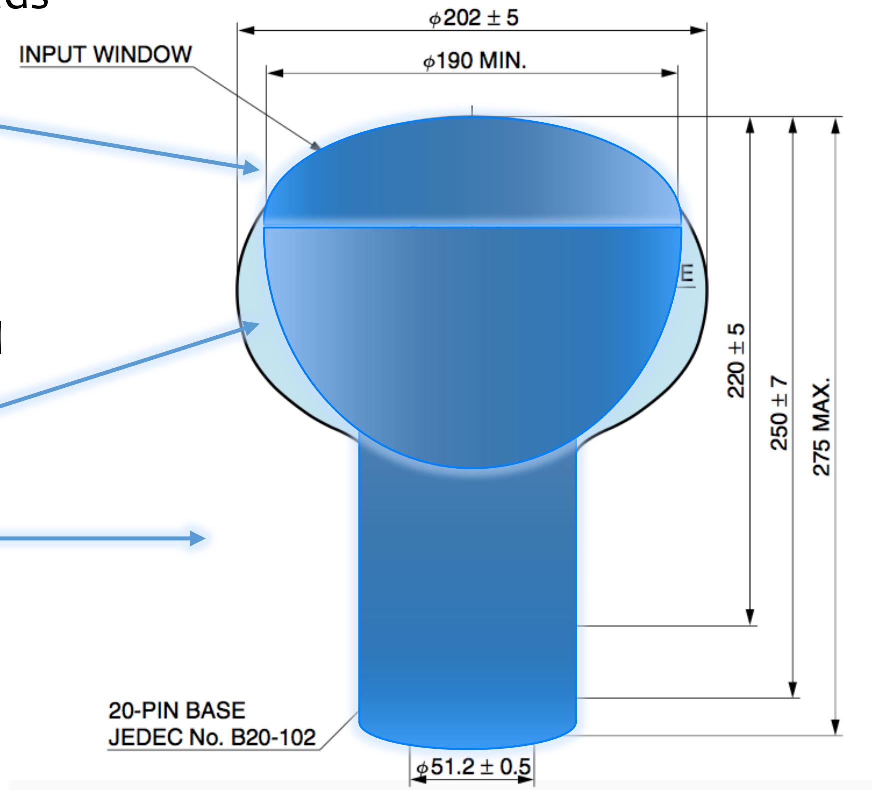
*files were incomplete. About 80% of statistics was available

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

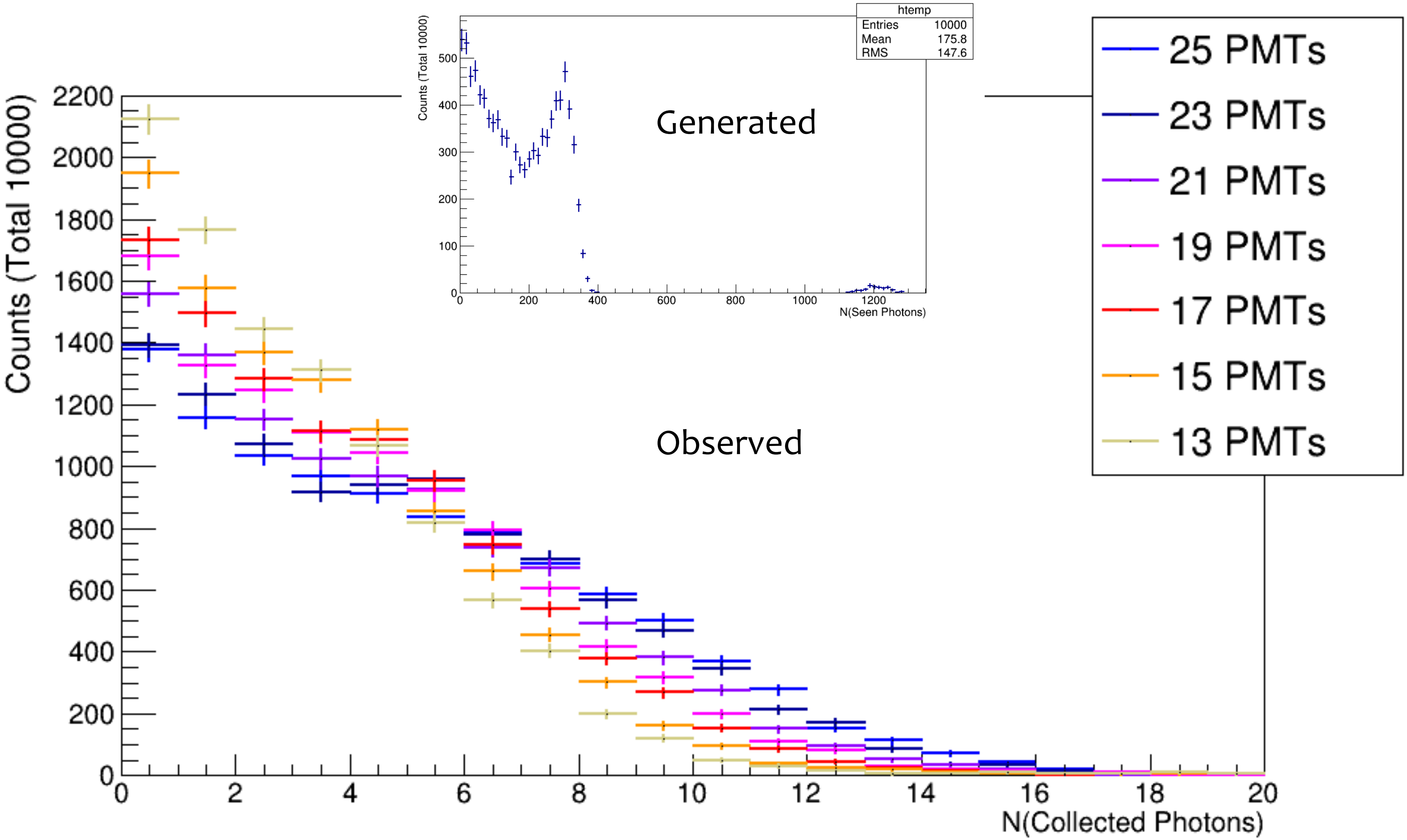
Cylinder
r=4.5cm
h =16.4 cm



Type No.	Diameter	Minimum effective area	Surface area		Dynode		Weight
			Min.	Typ.	Structure	Number of stages	
	(mm) / (inch)	(mm)	(cm^2)	(cm^2)			(g)
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

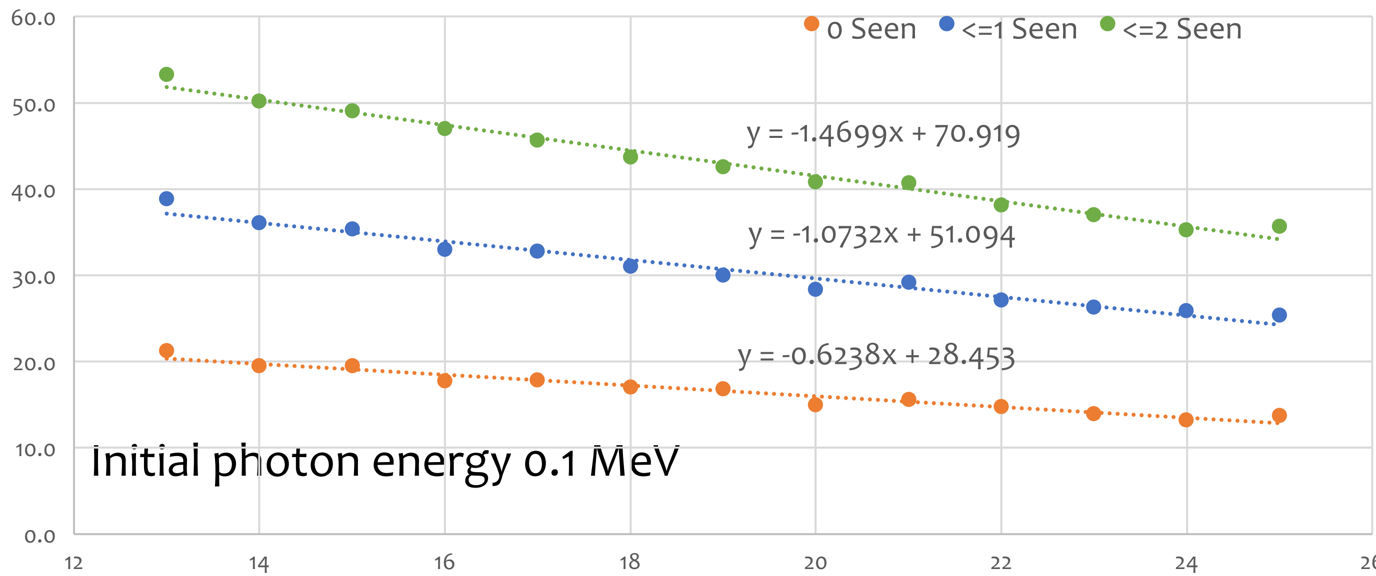
Light yields per # PMTs

Initial photon energy 0.1 MeV

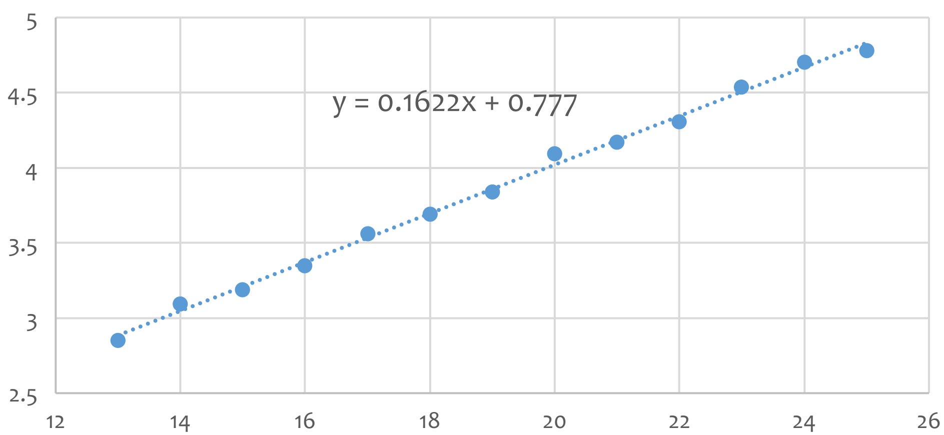


Light yields per # PMTs

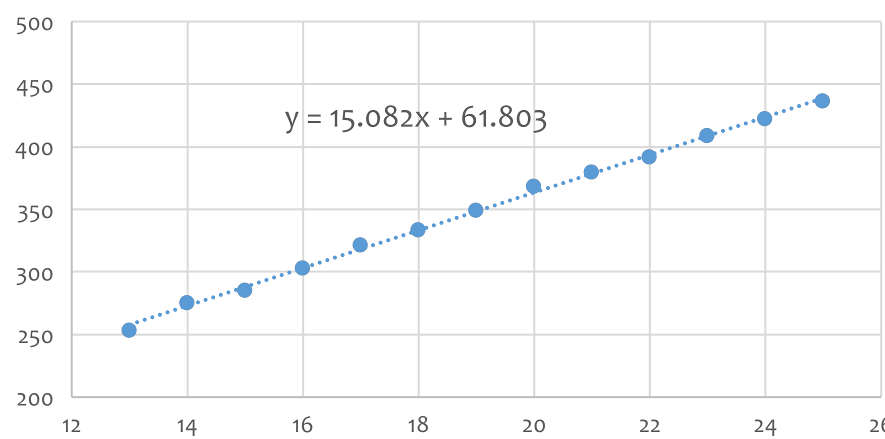
Percentage of events with N(Ph)<=X



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.
Typ. (nA)	Max. (nA)	1500V Typ. (s^{-1})	1800V Max. (s^{-1})	Rise time Typ. (ns)	Electron transit time Typ. (ns)	Transit time spread (FWHM) Typ. (ns)	Min.	Typ.	at ±2 % Deviation Typ. (mA)	at ±5 % Deviation 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, liquid scintillator acquisition window τ=100ns

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

RATE OF 2 COINCIDENT DARK COUNTS $R_2 = N \cdot r \cdot (N-1) r \cdot \cancel{2} \tau = \cancel{2} N(N-1) r^2 \tau$

RATE OF 3 COINCIDENT DARK COUNTS $R_3 = N \cdot r \cdot (N-1) r \cdot (N-2) r \cdot \cancel{3} \tau^2 = \cancel{3} N(N-1)(N-2) r^3 \tau^2$

Coincidence rates

N(PMTs)	Dark rate (Hz)	2 coincidences (Hz)	3 coincidences (Hz)
13	7.8E+04	5.6E+02	3.7E+00
14	8.4E+04	6.6E+02	4.7E+00
15	9.0E+04	7.6E+02	5.9E+00
16	9.6E+04	8.6E+02	7.3E+00
17	1.0E+05	9.8E+02	8.8E+00
18	1.1E+05	1.1E+03	1.1E+01
19	1.1E+05	1.2E+03	1.3E+01
20	1.2E+05	1.4E+03	1.5E+01
21	1.3E+05	1.5E+03	1.7E+01
22	1.3E+05	1.7E+03	2.0E+01
23	1.4E+05	1.8E+03	2.3E+01
24	1.4E+05	2.0E+03	2.6E+01
25	1.5E+05	2.2E+03	3.0E+01
26	1.6E+05	2.3E+03	3.4E+01
27	1.6E+05	2.5E+03	3.8E+01
28	1.7E+05	2.7E+03	4.2E+01
29	1.7E+05	2.9E+03	4.7E+01
30	1.8E+05	3.1E+03	5.3E+01
31	1.9E+05	3.3E+03	5.8E+01
32	1.9E+05	3.6E+03	6.4E+01

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

RATE OF COUNTS FOR NOISE IN THE PMTS WITH A COINCIDENT SIGNAL IN THE CRYSTAL

$$R_{ci} = 2\tau K \cdot R_i$$

WITH K = RATE BKG IN CRYSTAL WITH NO SIGNAL IN VESSEL ($E < 100\,keV$)

$i = 1, 2, 3$

FRACTION OF CRYSTAL COUNTS WITH A DARK COINCIDENCES

$$\boxed{f_i = \frac{R_{ci}}{K} = 2\tau R_i}$$