Study of multi-neutron emission in the β-decay of ^{11}Li

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for the
IS525 Collaboration

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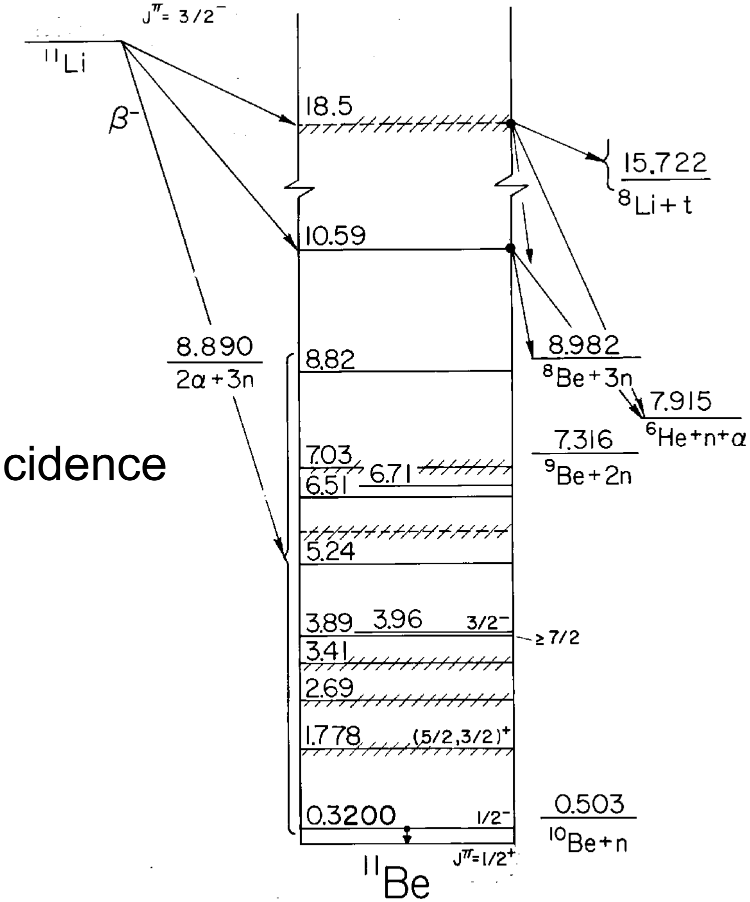
Motivation

^{11}Li β-decay

- Large Q_{β} (20.6 MeV), weakly bound ^{11}Be daughter

→ Many β-delayed emission channels open
(1n, 2n, 3n, α, d, t...)

- P_{2n} = 4.2 %
- No measurement of delayed 2n kinematics



Goals

- Measure for the 1st time the kinematics of 2n in coincidence

→ Sequential or simultaneous emission?

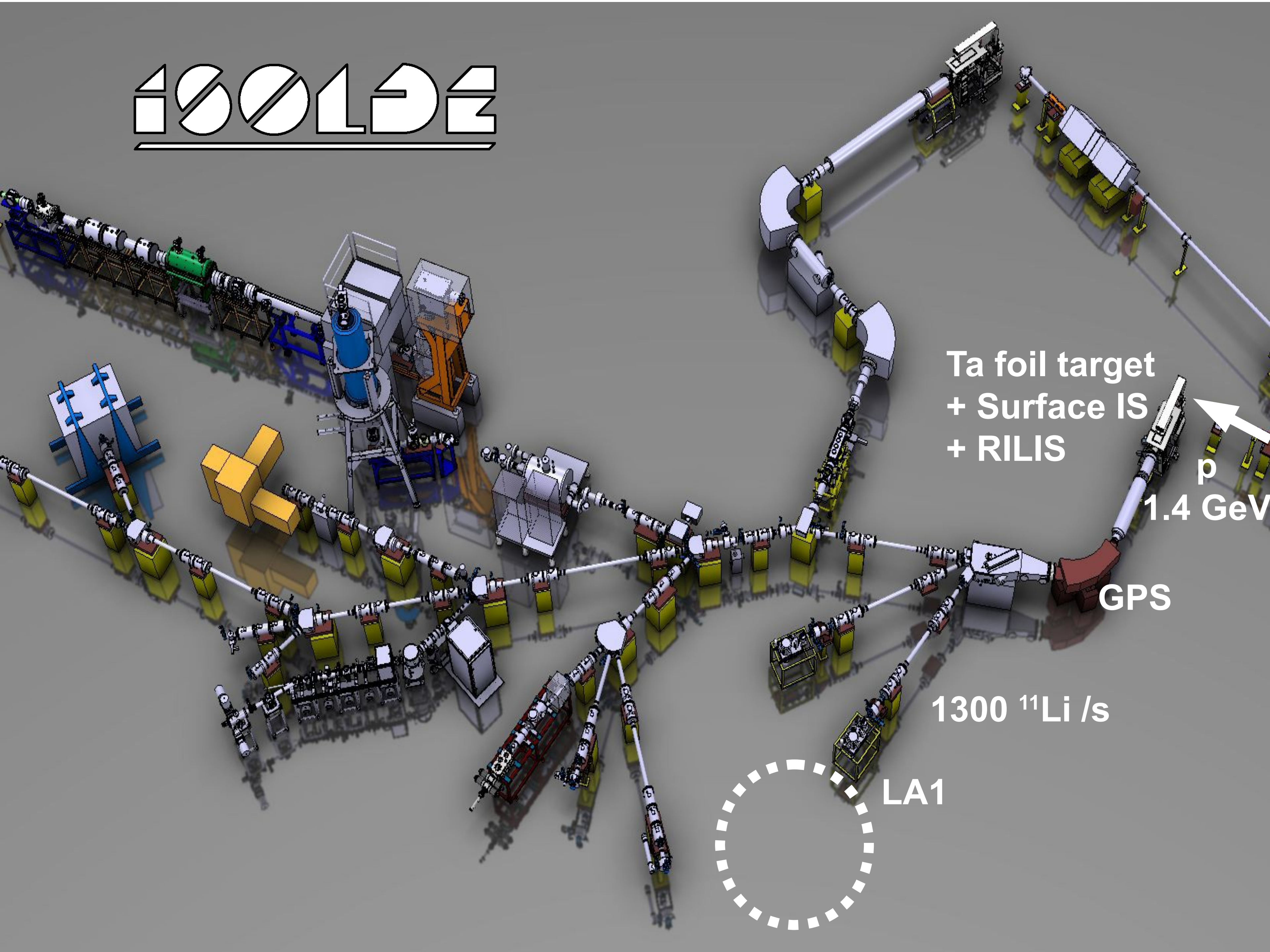
→ Correlations?

- Improve the β-1n picture

Requirements

- Neutron energy → TOF detector
- nn relative angle → Granularity
- Cross-talk rejection filters → Independent modules
- Reduce background to allow β-2n detection → n-γ discrimination

→ Array of liquid-scintillator neutron detectors



ISOLDE
Ta foil target
+ Surface IS
+ RILIS
p
1.4 GeV
GPS
1300 ¹¹Li /s
LA1

Experimental setup

39 liquid scintillator modules
- 20 or 15 cm in diam., 5 cm thick
- MONSTER [1], EDEN [2], CEA
- ≈ 40 % intrinsic efficiency
- n-γ pulse-shape discrimination

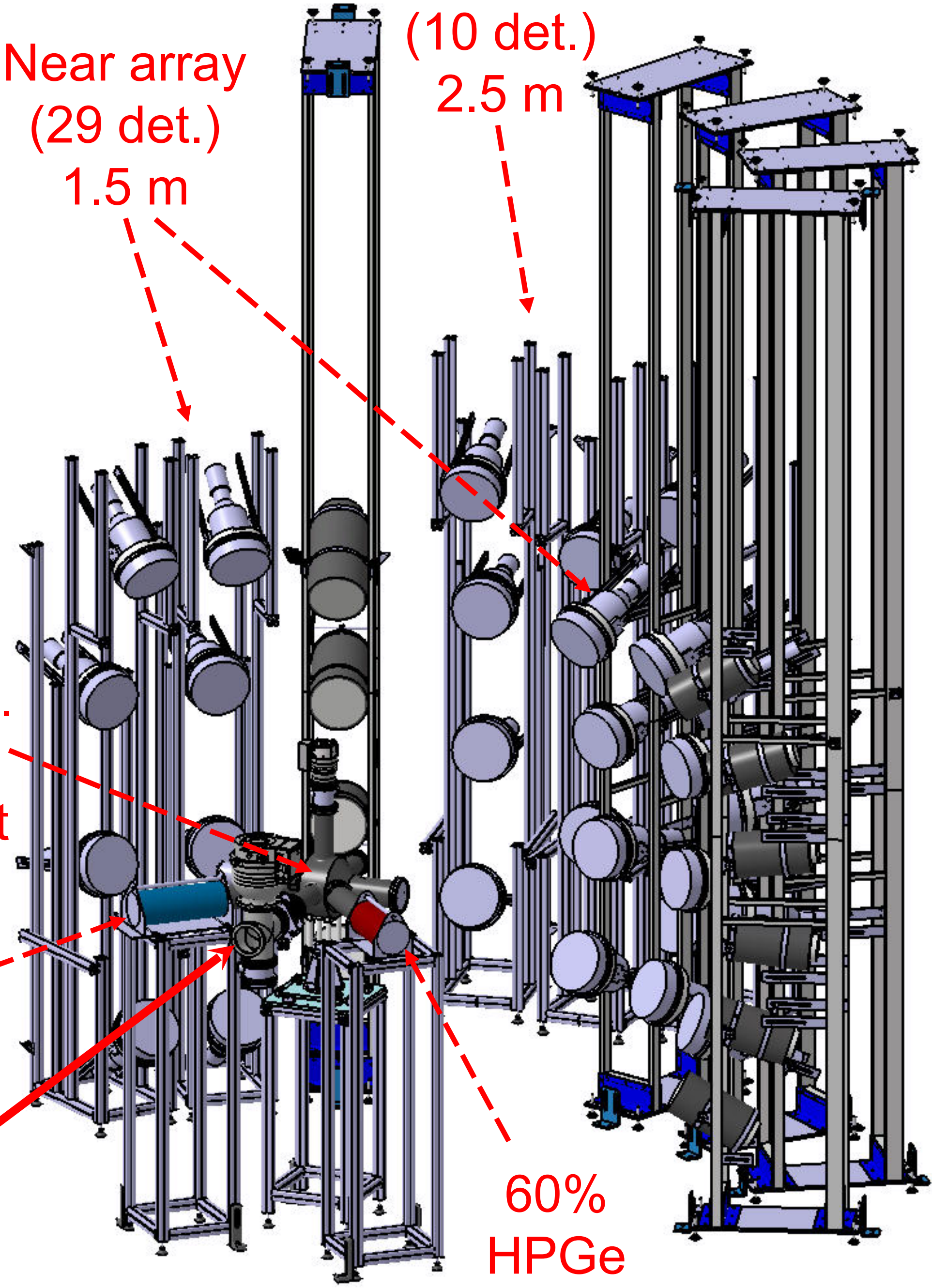
Near array: d = 1.5 m
- Ω = 3.3 % of 4π
- δE = 70 keV at 1 MeV

⇒ n-n coincidences

Far array: d = 2.5 m
- δE = 40 keV at 1 MeV
- Ω = 0.4 % of 4π

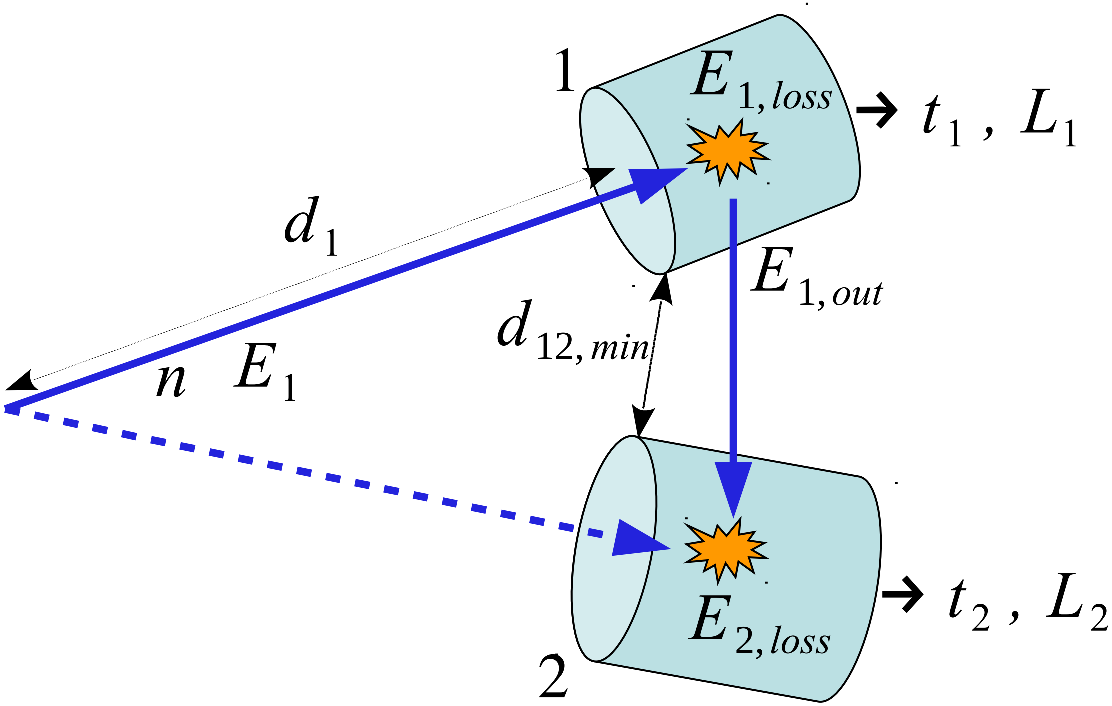
⇒ Improved 1n data

Digital electronics (LPC)



[1] Martinez et al., Nuclear Data Sheets 120, 78
[2] Laurent et al., NIM A 326, 517

Neutron Cross-Talk: 1 neutron → 2 hits



$$t_1 , d_1 \rightarrow v_1 \rightarrow E_1$$

$$E_{1,loss} = f(particle, L_1)$$

$$E_{1,out} = E_1 - E_{1,loss}$$

$$E_{2,loss} = f(particle, L_2)$$

"Strong" cross-talk filter *:

Event = CT if:

$$E_1 > E_{1,loss} = f(e, L_1)$$

$$E_{1,out} > E_{12,min}$$

$$E_{1,out} > E_{2,loss} = f(e, L_2)$$

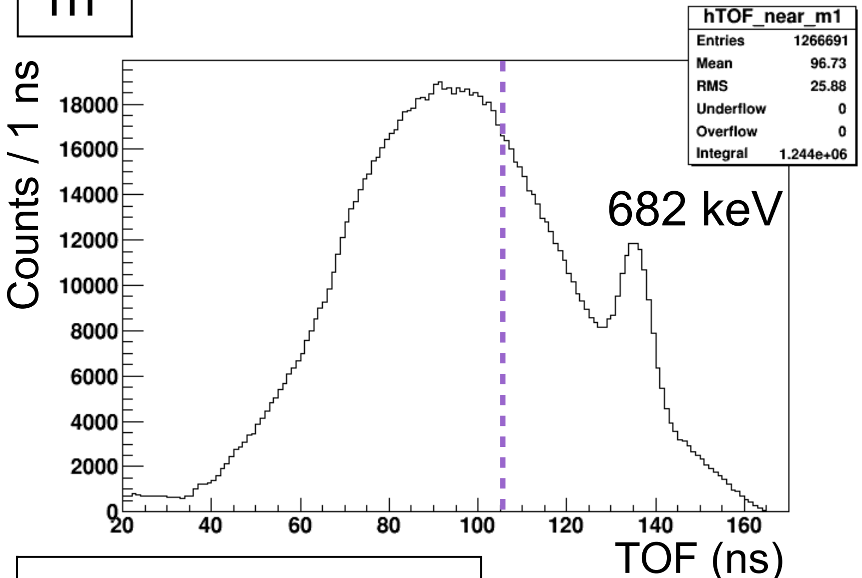
$$E_{12,min} = \frac{M_n}{2}\left(\frac{d_{12,min}}{t_2 - t_1}\right)^2$$

* Marqués et al., NIM A 450, 109

Validation of cross-talk filter: ^{9}Li

^{9}Li: β-1n emitter

1n

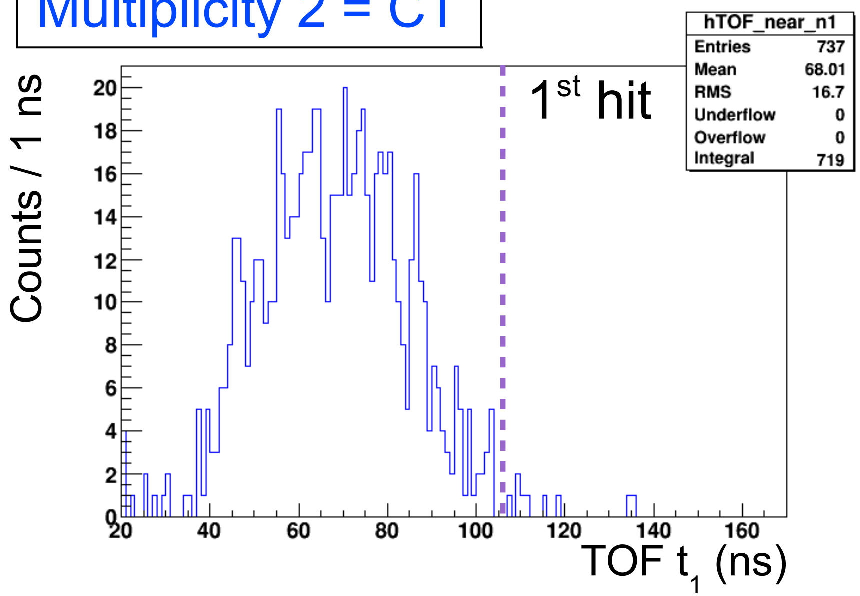


Near array (d = 1.5 m)

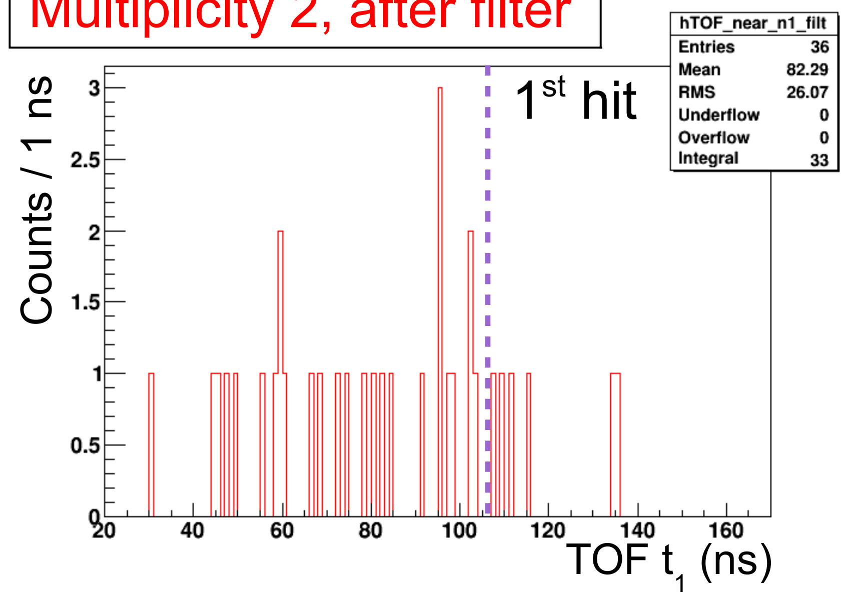
Threshold L > 75 keVee ↔ E_n > 530 keV

CT : E_n > 1060 keV ↔ TOF < 107 ns

Multiplicity 2 = CT

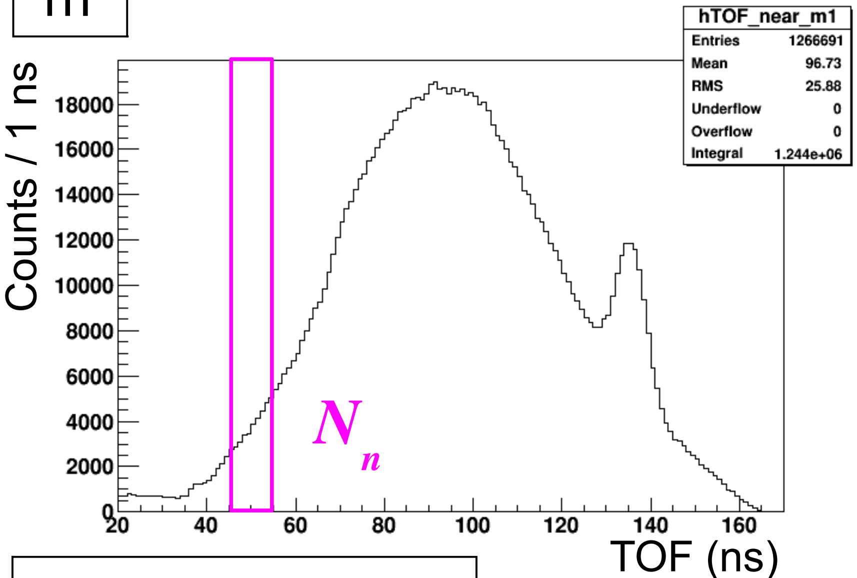


Multiplicity 2, after filter



Validation of cross-talk filter : ^{9}Li

1n



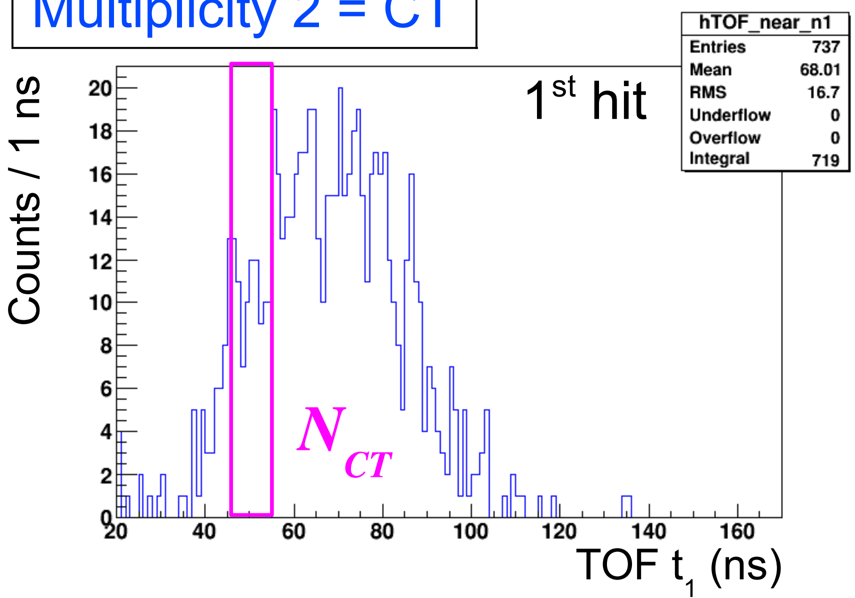
CT probability:

$$P_{CT} = \frac{N_{CT}}{N_n}$$

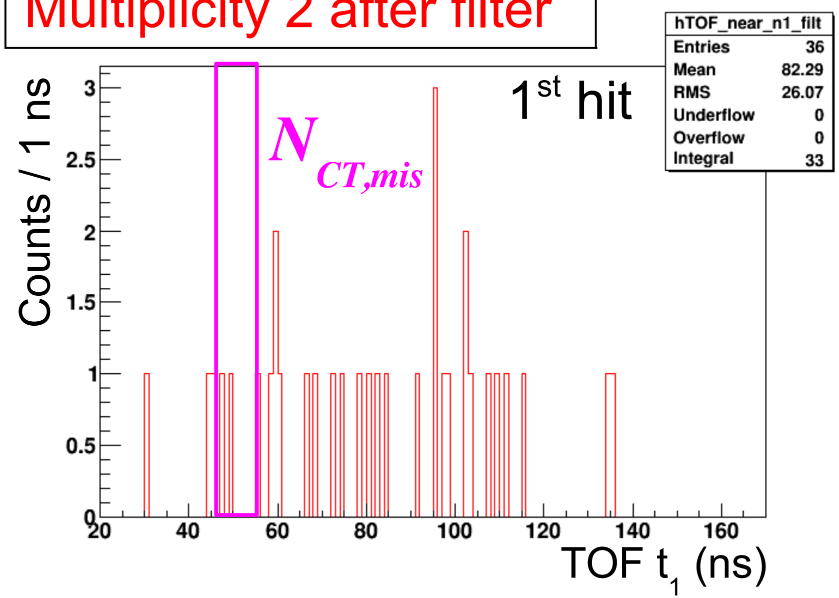
Filter rejection rate:

$$R_{CT} = 1 - \frac{N_{CT,mis}}{N_{CT}}$$

Multiplicity 2 = CT



Multiplicity 2 after filter



Validation of cross-talk filter : ^{9}Li

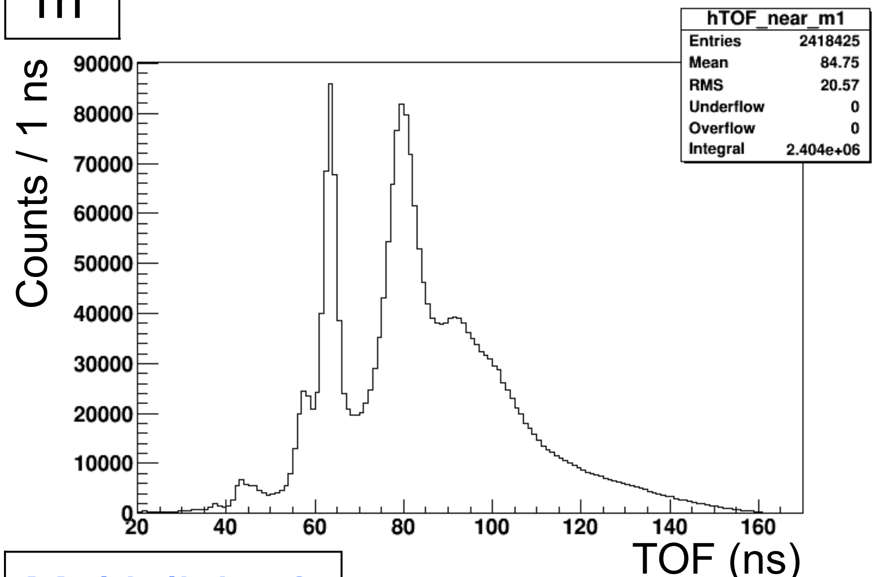
TOF (ns)	E_n (MeV)	P_{CT} (%)	R_{CT} (%)
[35, 52]	[10.1, 4.5]	0.30(3)	97(2)
[52, 61]	[4.5, 3.3]	0.24(2)	96(2)
[61, 68]	[3.3, 2.6]	0.18(2)	99(1)
[68, 75]	[2.6, 2.2]	0.13(1)	97(2)
[75, 83]	[2.2, 1.8]	0.088(9)	97(2)
[83, 107]	[1.8, 1.1]	0.027(3)	92(3)

PRELIMINARY

- P_{CT} increases with E_n (consistent with dedicated CT measurements)
- Filter rejection rate R_{CT} large, ≈ independent of E_n

^{11}Li β-2n

1n

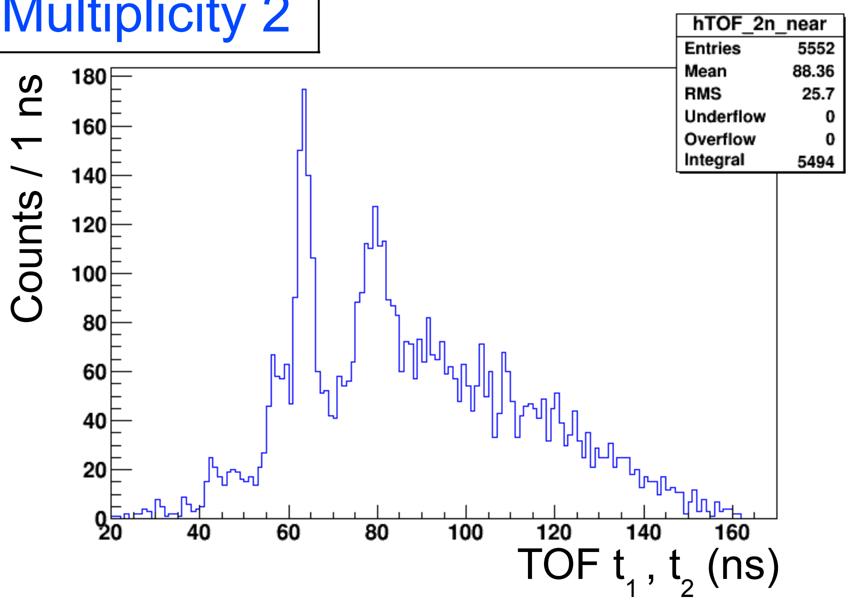


PRELIMINARY

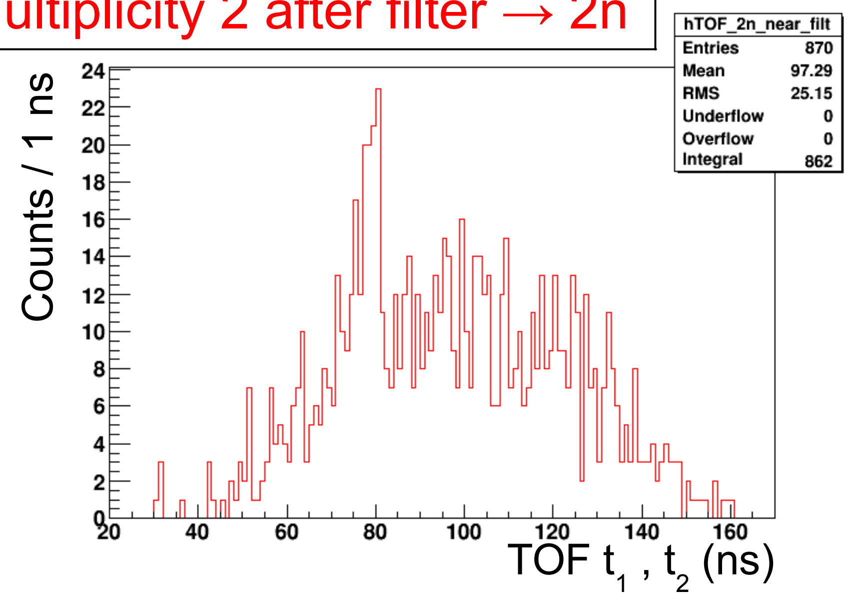
Near array

Threshold L > 75 keVee ↔ E_n > 530 keV

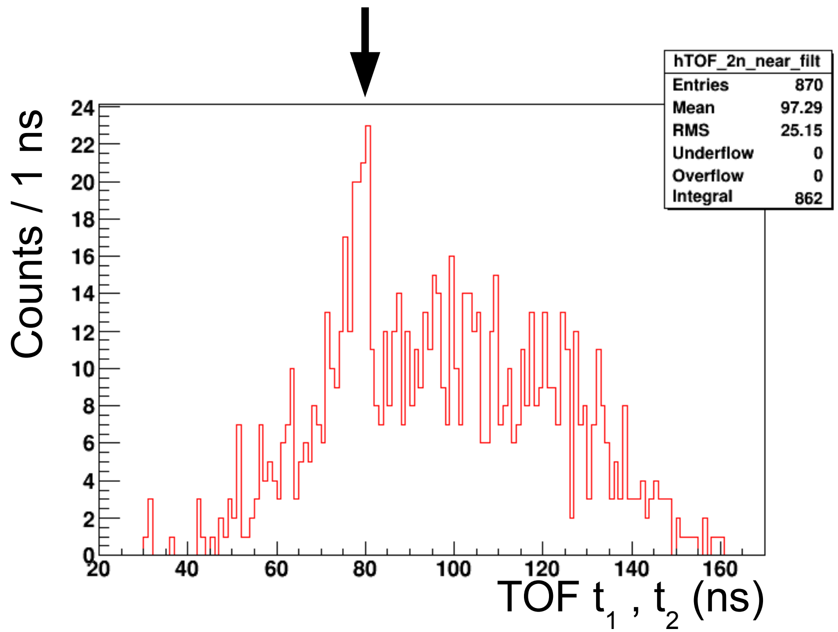
Multiplicity 2



Multiplicity 2 after filter → 2n

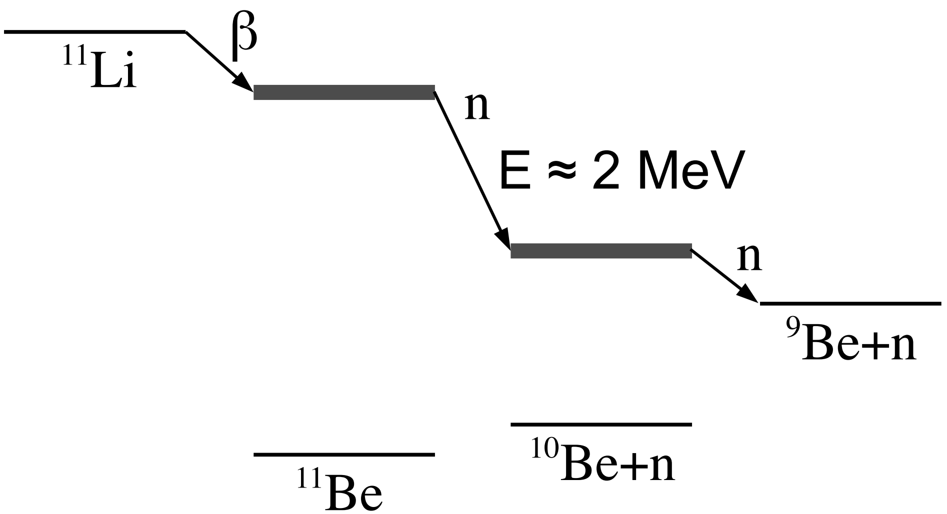


^{11}Li β-2n

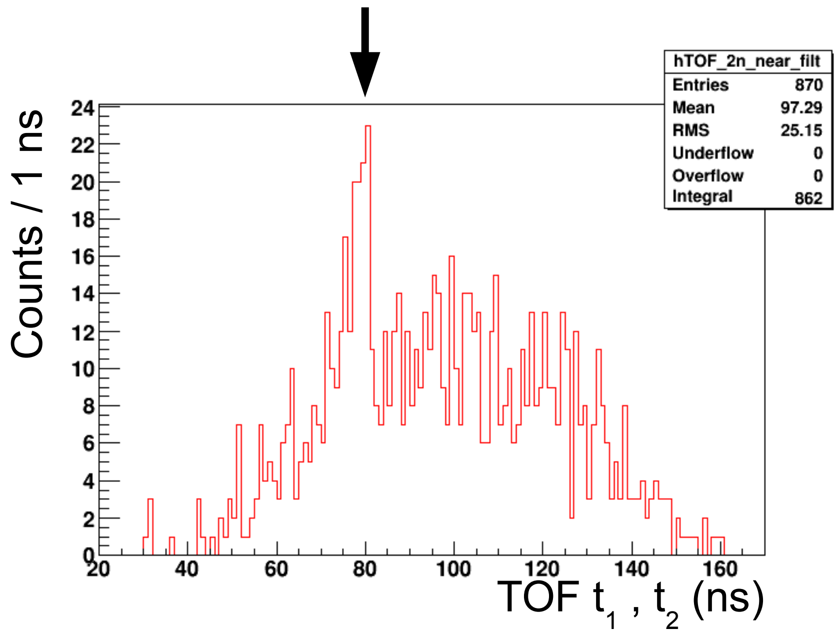


PRELIMINARY

→ n line
→ E ≈ 2 MeV
→ Fastest n
→ Sequential 2n emission?



^{11}Li β-2n



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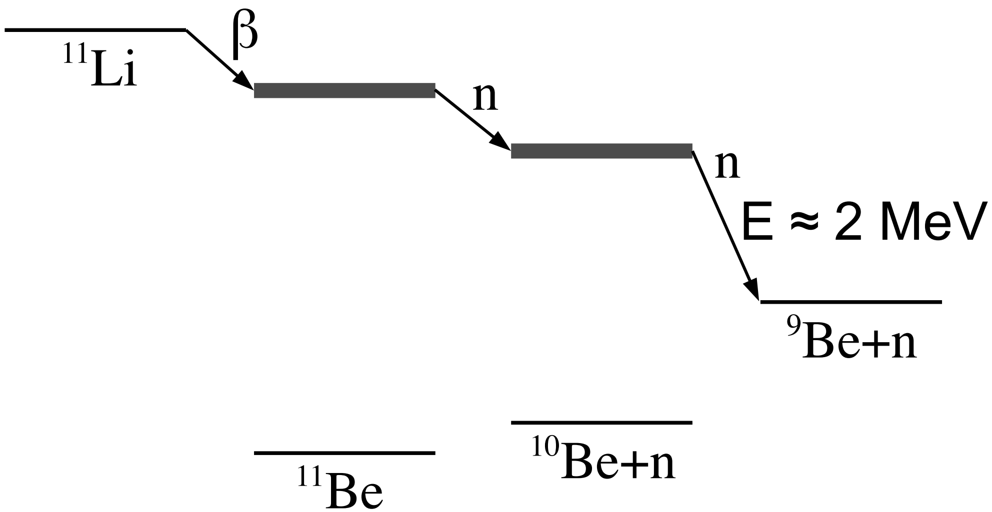
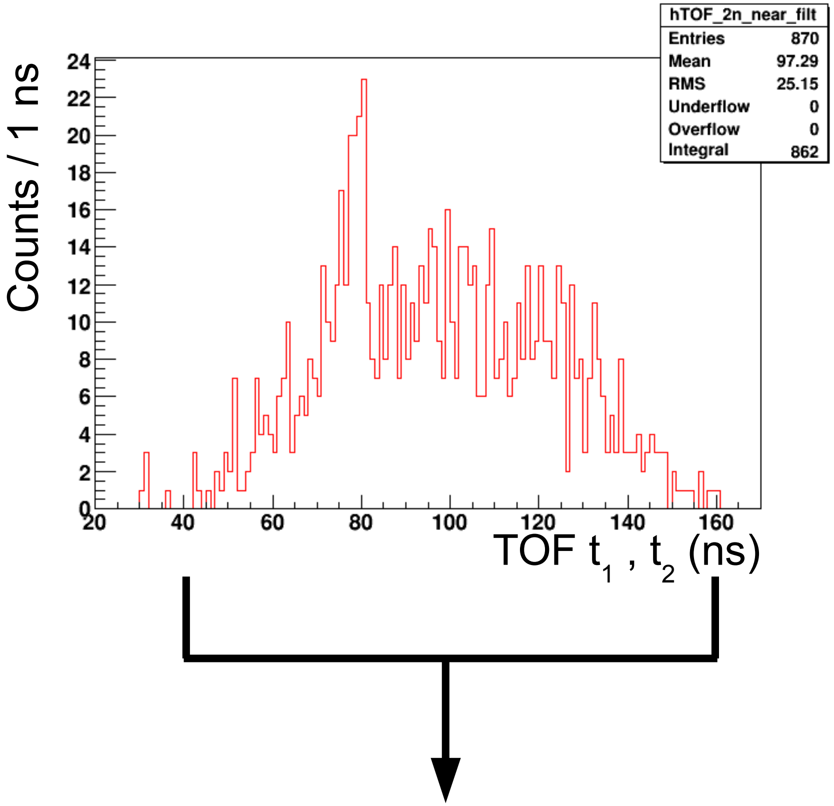


^{11}Li β-2n



PRELIMINARY

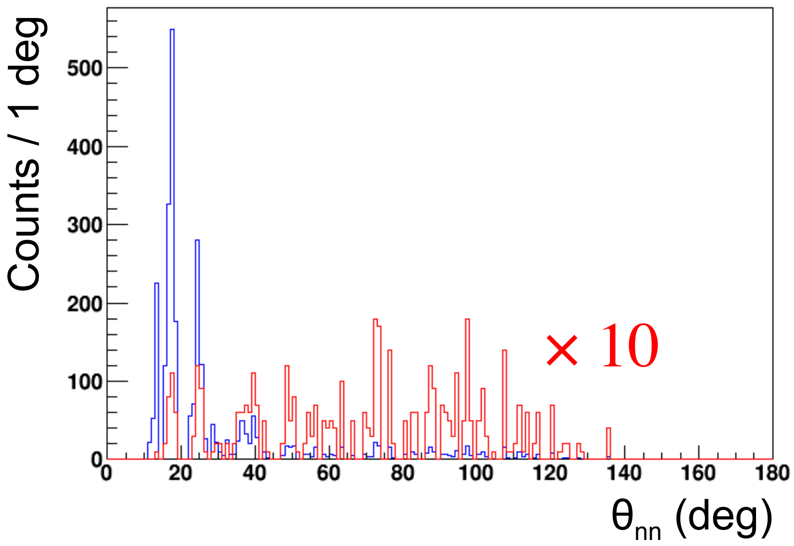
Continuum

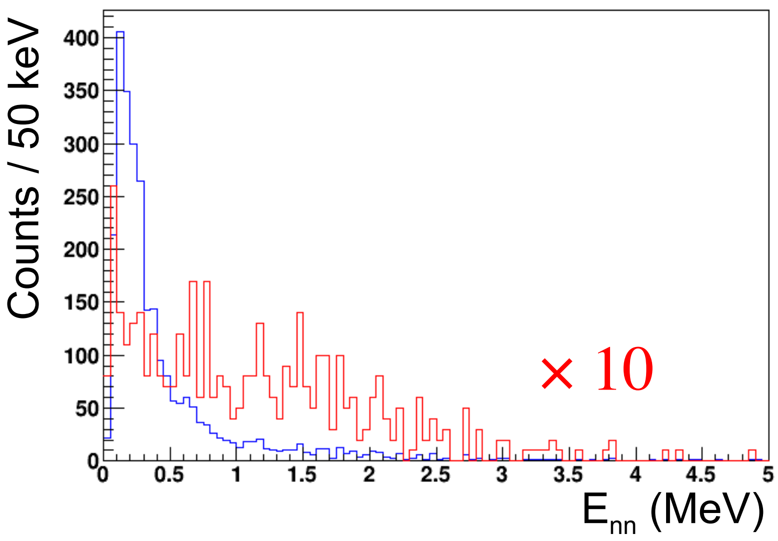
→ unresolved lines?

→ direct 2n emission?

^{11}Li β-2n

Multiplicity 2
Multiplicity 2, after filter





PRELIMINARY

Conclusions

^{11}Li β–delayed neutron emission explored with an array of liquid-scintillator neutron detectors

Goals:

- Kinematics of 2-neutron emission
- Improved picture of β-1n

- CT filter tested on ^{9}Li β-1n → large CT rejection rate
- ^{11}Li β-2n events
  → ≈ 2-MeV n line → sequential 2n emission?
- CT filter expected to reject real 2n events
  → Investigate other filters
  → Increase of 2n statistics?
  → Maintain a high CT rejection rate?

IS525 Collaboration

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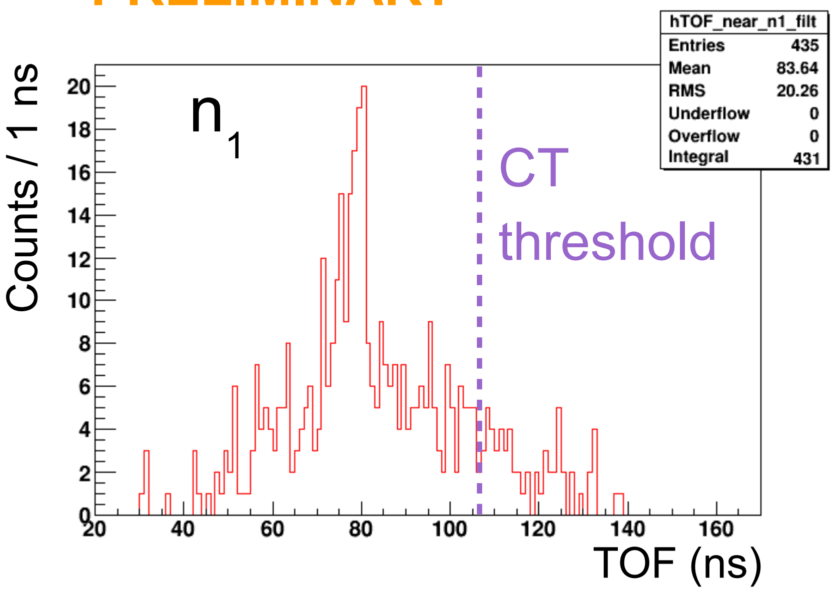
Thank you for your attention

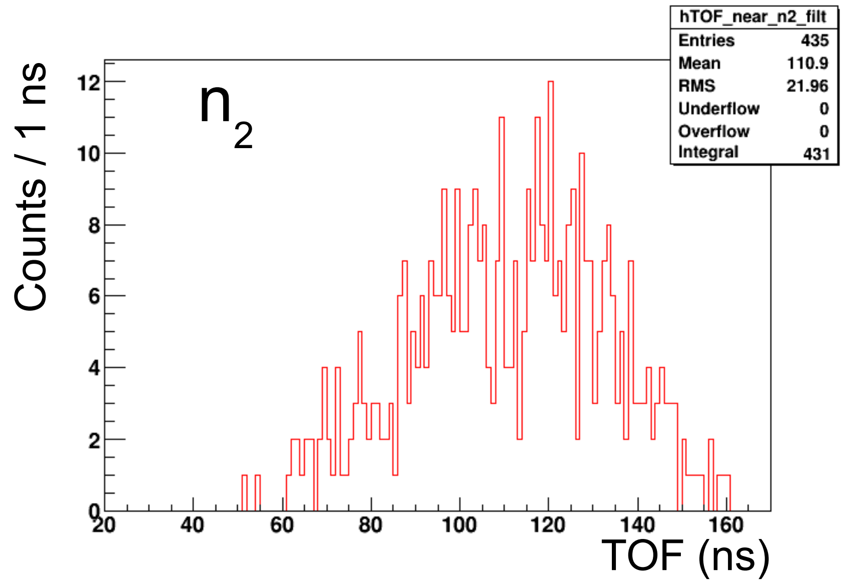
^{11}Li β-2n

$$t_1 < t_2$$

$$E_1 > E_2$$

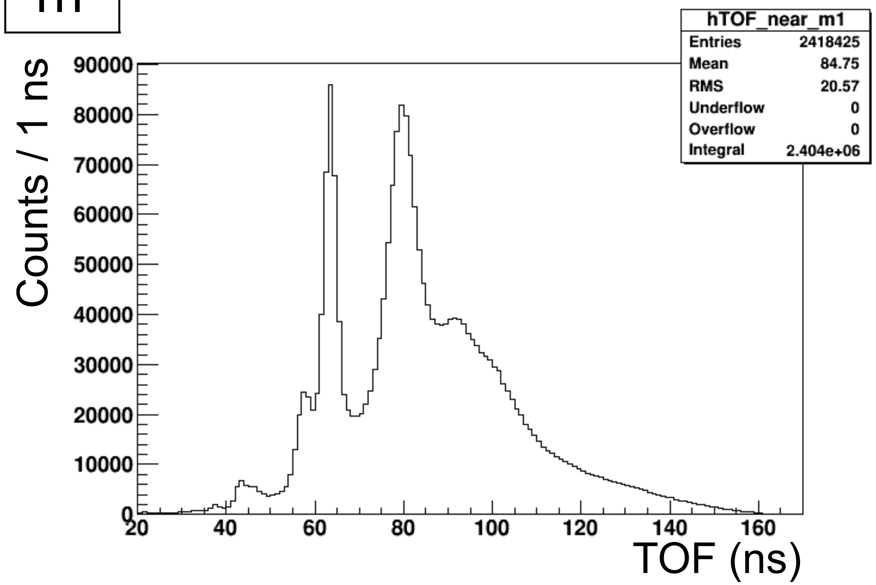
PRELIMINARY

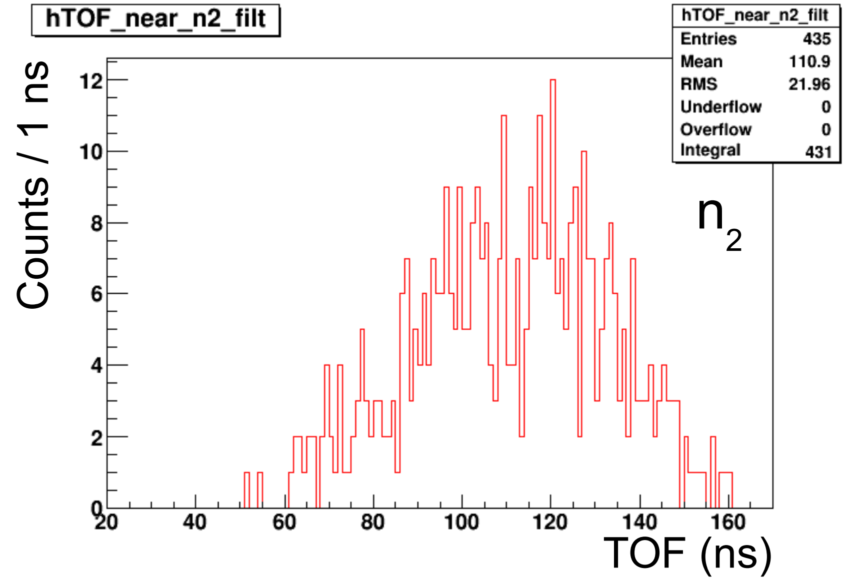




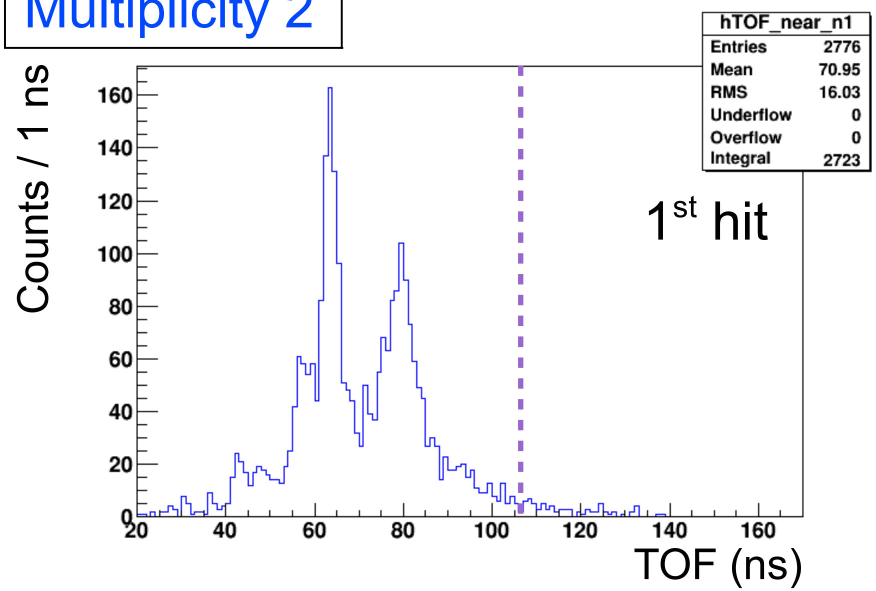
^{11}Li β-2n

1n

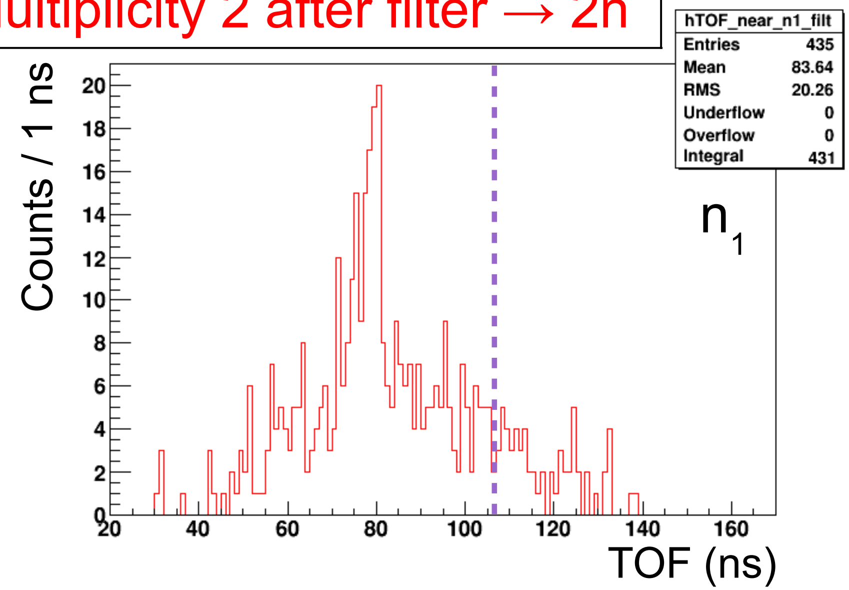




Multiplicity 2

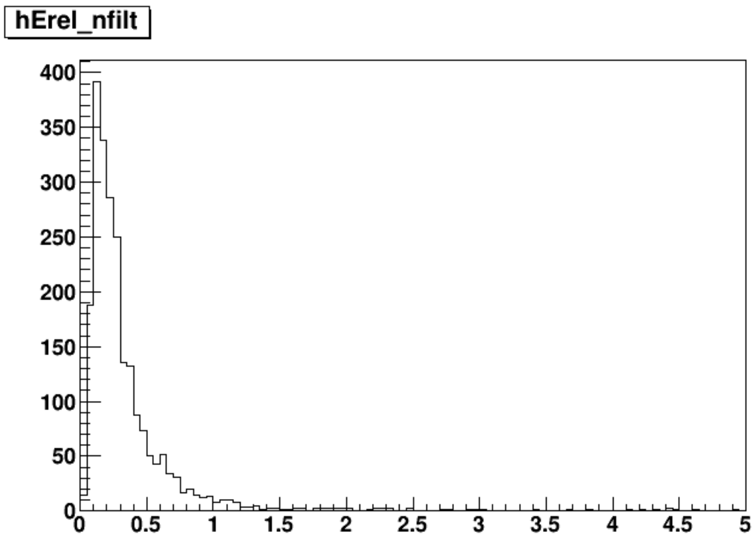


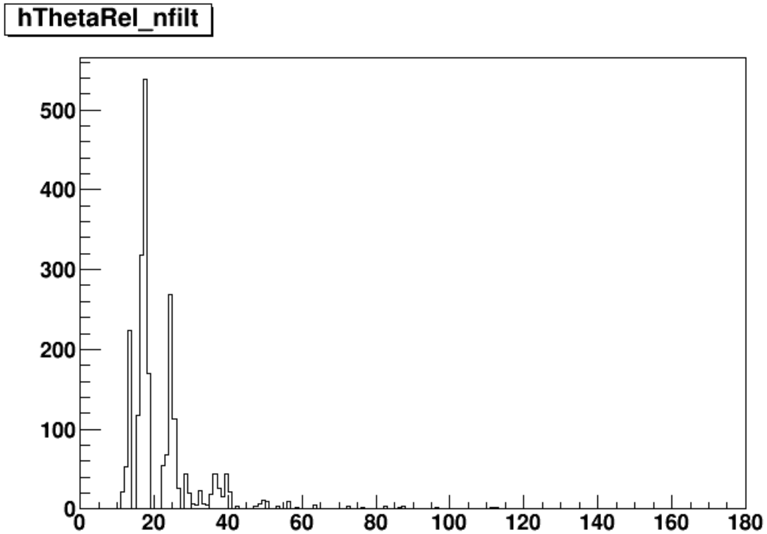
Multiplicity 2 after filter → 2n



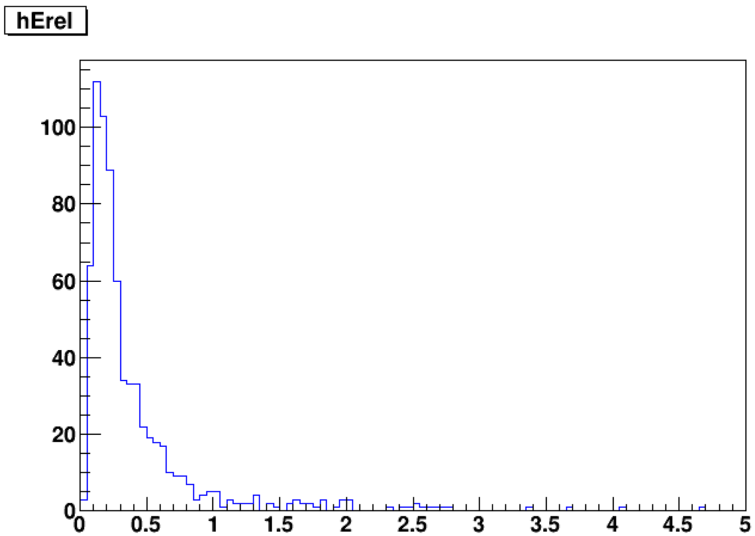
Cross-talk events from ^{11}Li and ^{9}Li β-1n

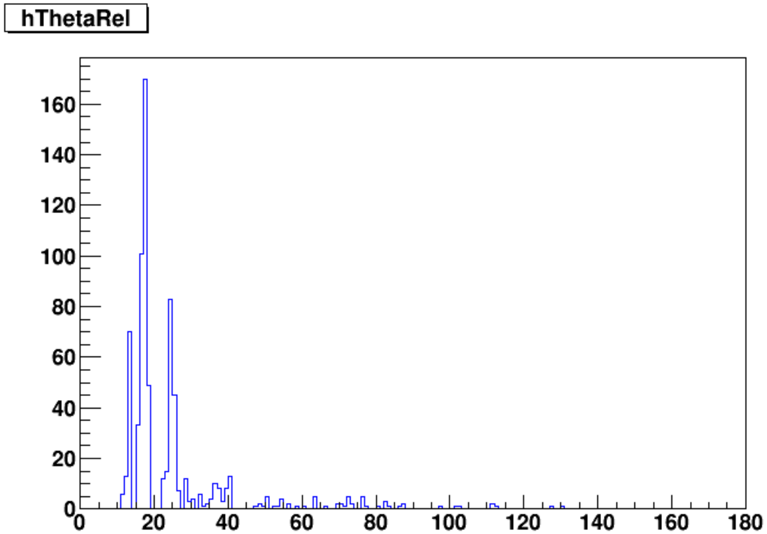
^{11}Li : Mult. 2 rejected events



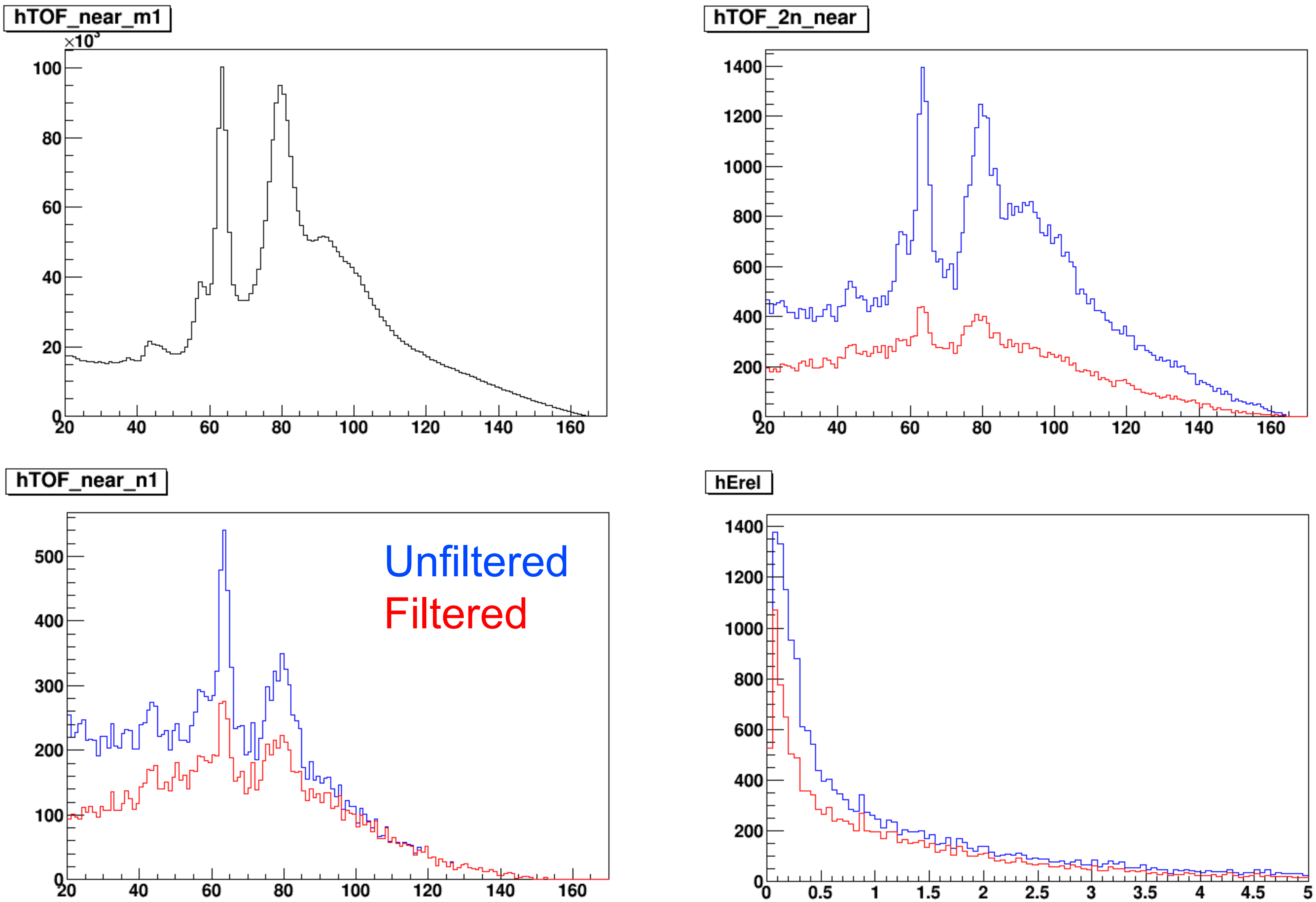


^{9}Li : Mult. 2 events





Without n-γ discrimination: ^{11}Li β-2n?



⇒ Random coincidences involving background (μ, γ)

^{11}Li: Counts

TOF (ns)	E_n (MeV)	N_n	N_{M2}	$N_{CT,id}$	N_{2n}	$N_{CT,est}$	$N_{CT,id,est}$	$N_{CT,mis,est}$
			M2 & CTF			N_n & P_{CT} & R_{CT}		
[35, 52]	[10.1, 4.5]	61096	214	194	20(5)	184(18)	178(17)	6(4)
[52, 61]	[4.5, 3.3]	144128	374	345	29(6)	339(32)	325(32)	14(7)
[61, 68]	[3.3, 2.6]	345745	708	676	32(6)	605(59)	600(59)	6(6)
[68, 75]	[2.6, 2.2]	170555	284	234	50(7)	218(21)	213(21)	6(4)
[75, 83]	[2.2, 1.8]	535078	625	516	109(11)	471(45)	459(44)	12(8)
[83, 107]	[1.8, 1.1]	822616	412	286	126(12)	225(21)	206(20)	19(6)

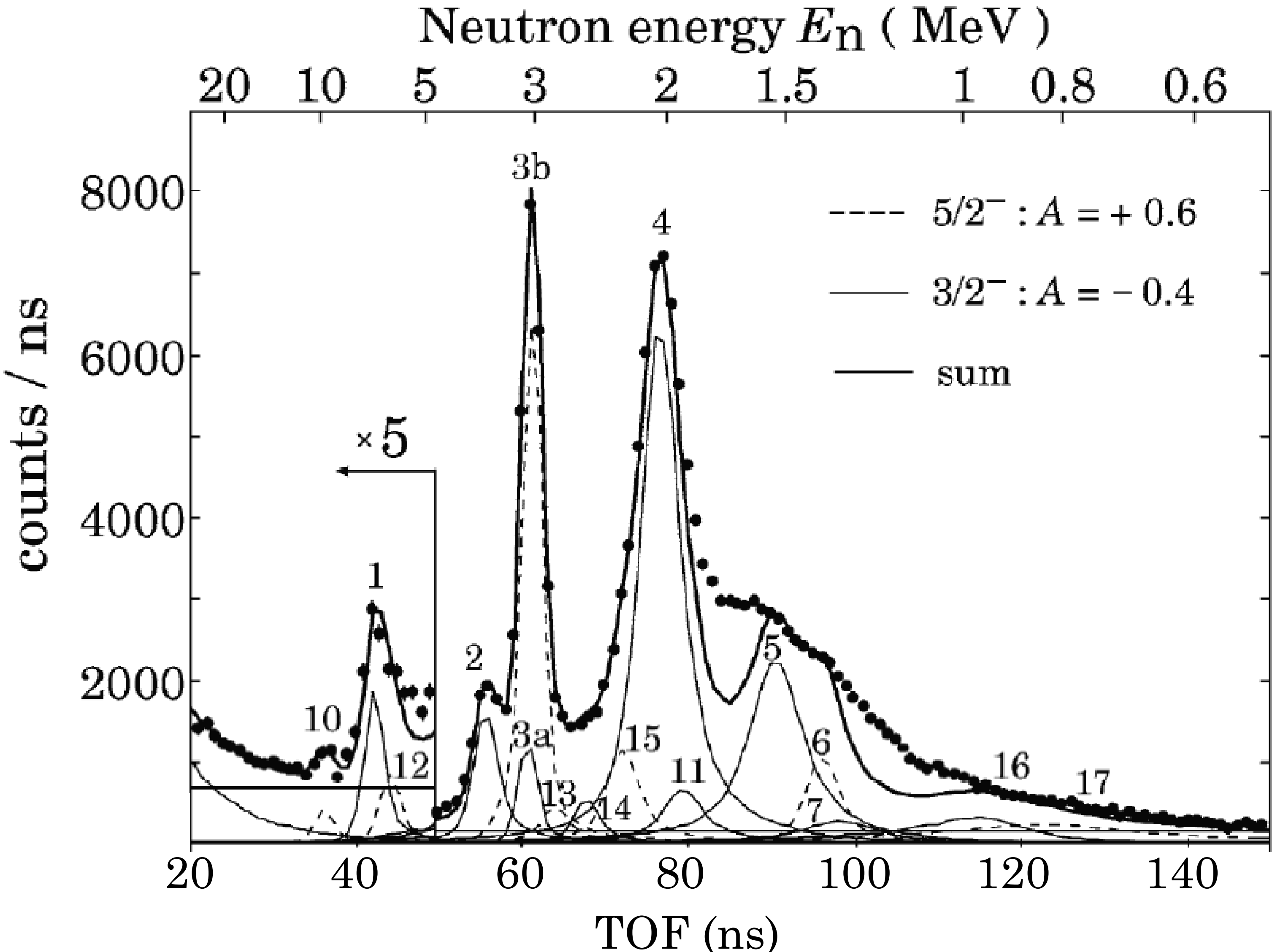
Validation of cross-talk filter : ^{9}Li

TOF (ns)	E_n (MeV)	N_n	N_{CT}	$N_{CT,nid}$	P_{CT} (%)	R_{CT} (%)
[35, 52]	[10.1, 4.5]	38483	116	4	0.30(3)	97(2)
[52, 61]	[4.5, 3.3]	51467	121	5	0.24(2)	96(2)
[61, 68]	[3.3, 2.6]	62796	110	1	0.18(2)	99(1)
[68, 75]	[2.6, 2.2]	92243	118	3	0.13(1)	97(2)
[75, 83]	[2.2, 1.8]	129387	114	3	0.088(9)	97(2)
[83, 107]	[1.8, 1.1]	435126	119	10	0.027(3)	92(3)

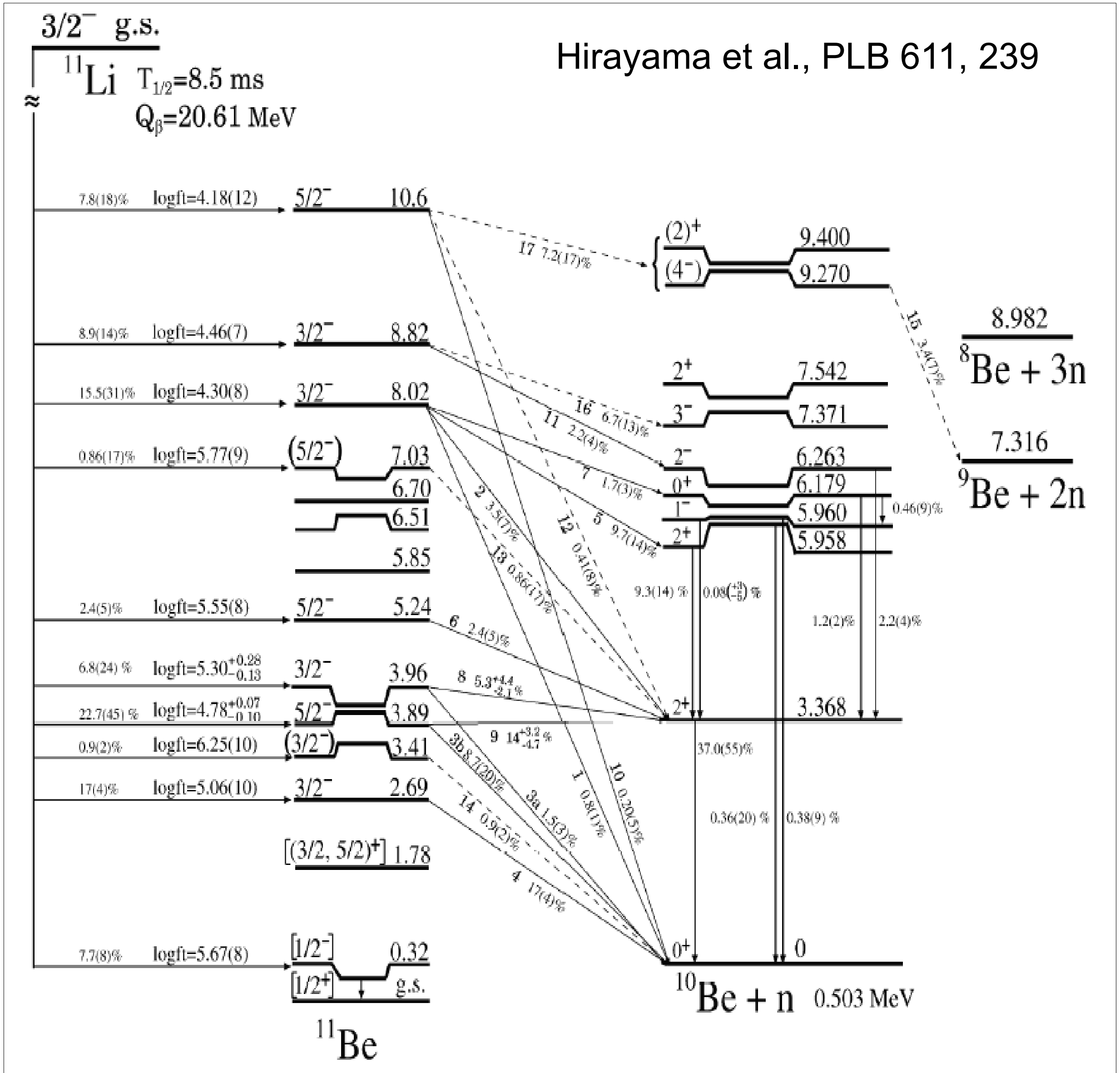
- P_{CT} increases with E_n (consistent with dedicated CT measurements)
- Filter rejection rate R_{CT} large, independent of E_n

Previous β-1n study

Hirayama et al., PLB 611 (2005) 239



Previous β-1n study



Neutron lines

Hirayama #	11Be E*	10Be E*	In %	En	beta	TOF 1.5 m	TOF 2.5 m
9	3,89	3,368	14	0,016	0,006	847,2	1412,0
8	3,96	3,368	5,3	0,080	0,013	383,2	638,6
17	10,6	9,4	(7,2)	0,633	0,037	136,3	227,2
17	10,6	9,27	(7,2)	0,751	0,040	125,1	208,6
16	8,82	7,371	6,7	0,859	0,043	117,0	195,0
7	8,02	6,179	1,7	1,215	0,051	98,4	164,0
6	5,24	3,368	2,4	1,244	0,051	97,3	162,1
5	8,02	5,958	9,7	1,416	0,055	91,2	151,9
11	8,82	6,263	2,2	1,866	0,063	79,4	132,4
4	2,69	0	17	1,987	0,065	77,0	128,3
14	3,41	0	0,9	2,642	0,075	66,8	111,4
13	7,03	3,368	0,86	2,871	0,078	64,1	106,8
3b	3,89	0	8,7	3,078	0,081	61,9	103,2
3a	3,96	0	1,5	3,142	0,082	61,3	102,2
2	8,02	3,368	3,5	3,771	0,089	56,0	93,3
12	10,6	3,368	0,41	6,116	0,114	44,0	73,4
1	8,02	0	0,8	6,833	0,120	41,7	69,5
10	10,6	0	0,2	9,178	0,139	36,0	60,1
	10Be E*	9Be E*					
A	7,371	0		0,503	0,033	152,9	254,8
15	9,27	0	3,4	2,212	0,068	73,0	121,7
15'	9,400	0		2,329	0,070	71,1	118,6

Possible discrete lines from beta-2n:

17+15

16+A

Digital Electronics and DAQ

FASTER project, LPC Caen, D. Etasse et al. (faster.in2p3.fr)

- **CFD + QDC**: 500 MHz, 12 bits, 2.3 V, 100 MHz BW

→ β plastic scintillator, neutron modules, ET2 (impact + 1ms)

→ Time and charges

- **Spec amp + ADC**: 125 MHz, 14 bits, 1-10 V, 25 MHz BW

→ Ge detectors: Energy and time

Baseline restoration

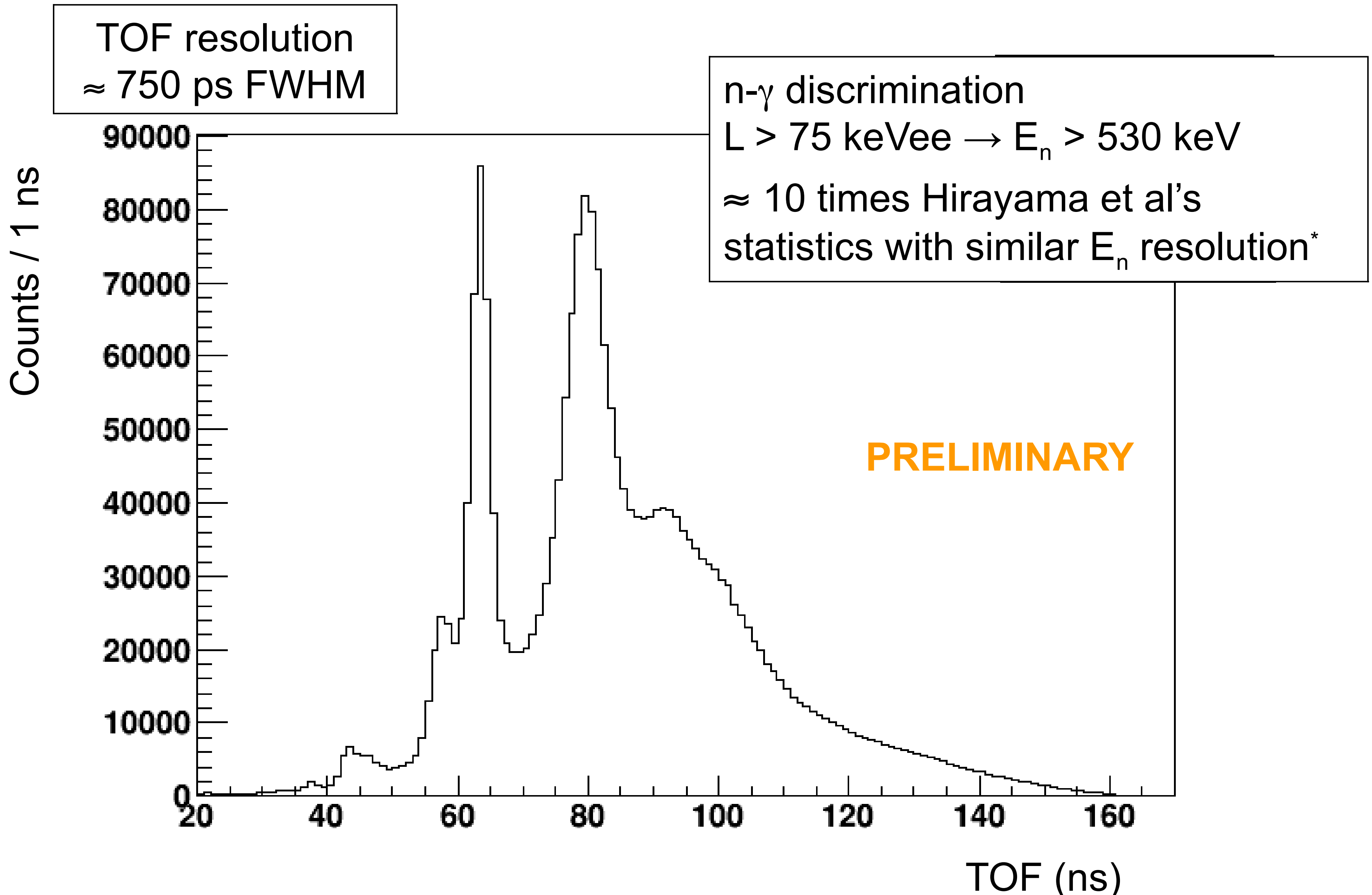
No common dead-time

Time stamping

Triggerless

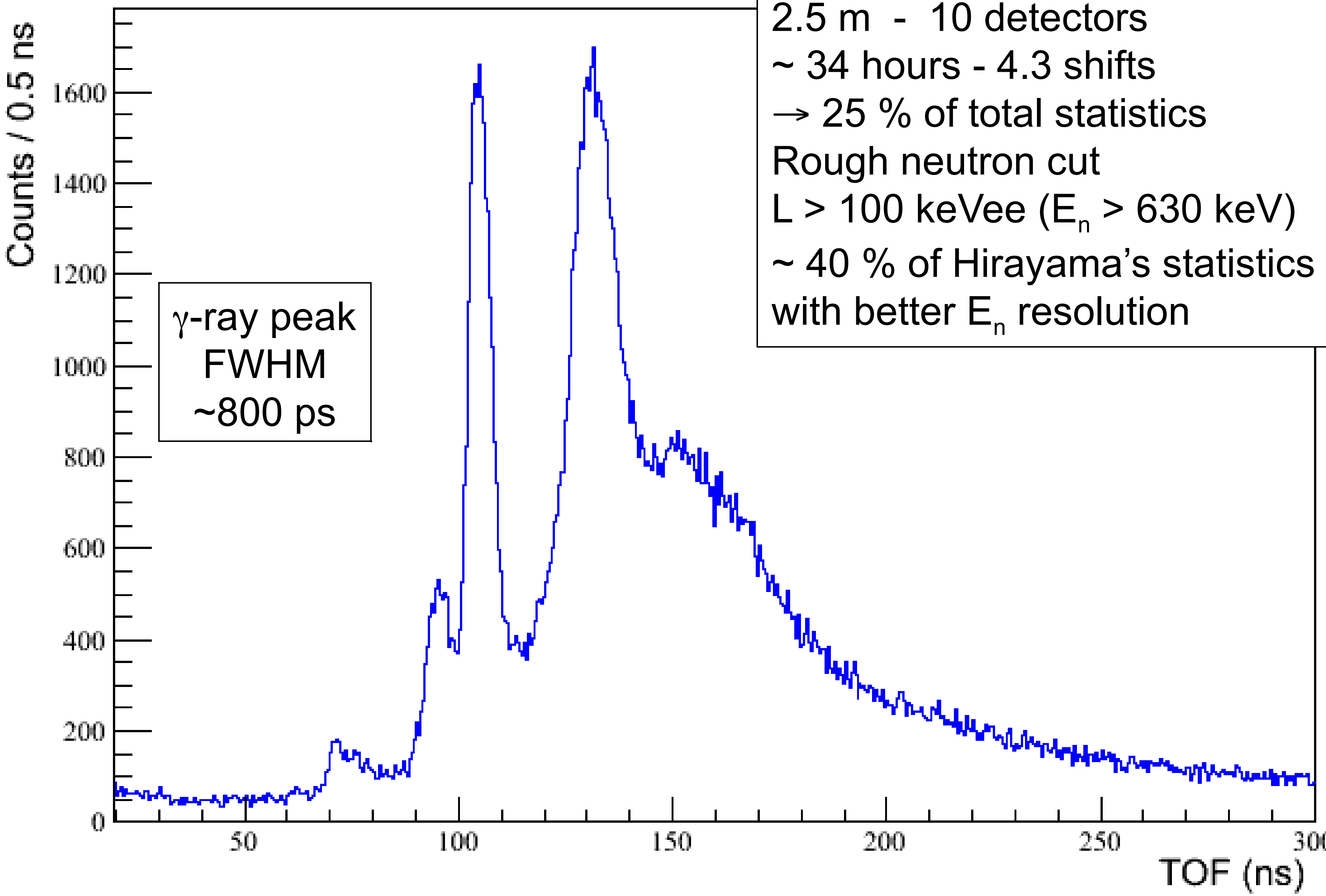
50 channel capability
(MicroTCA standard)

^{11}Li β-1n: Near array



* Hirayama et al., PLB 611 (2005) 239

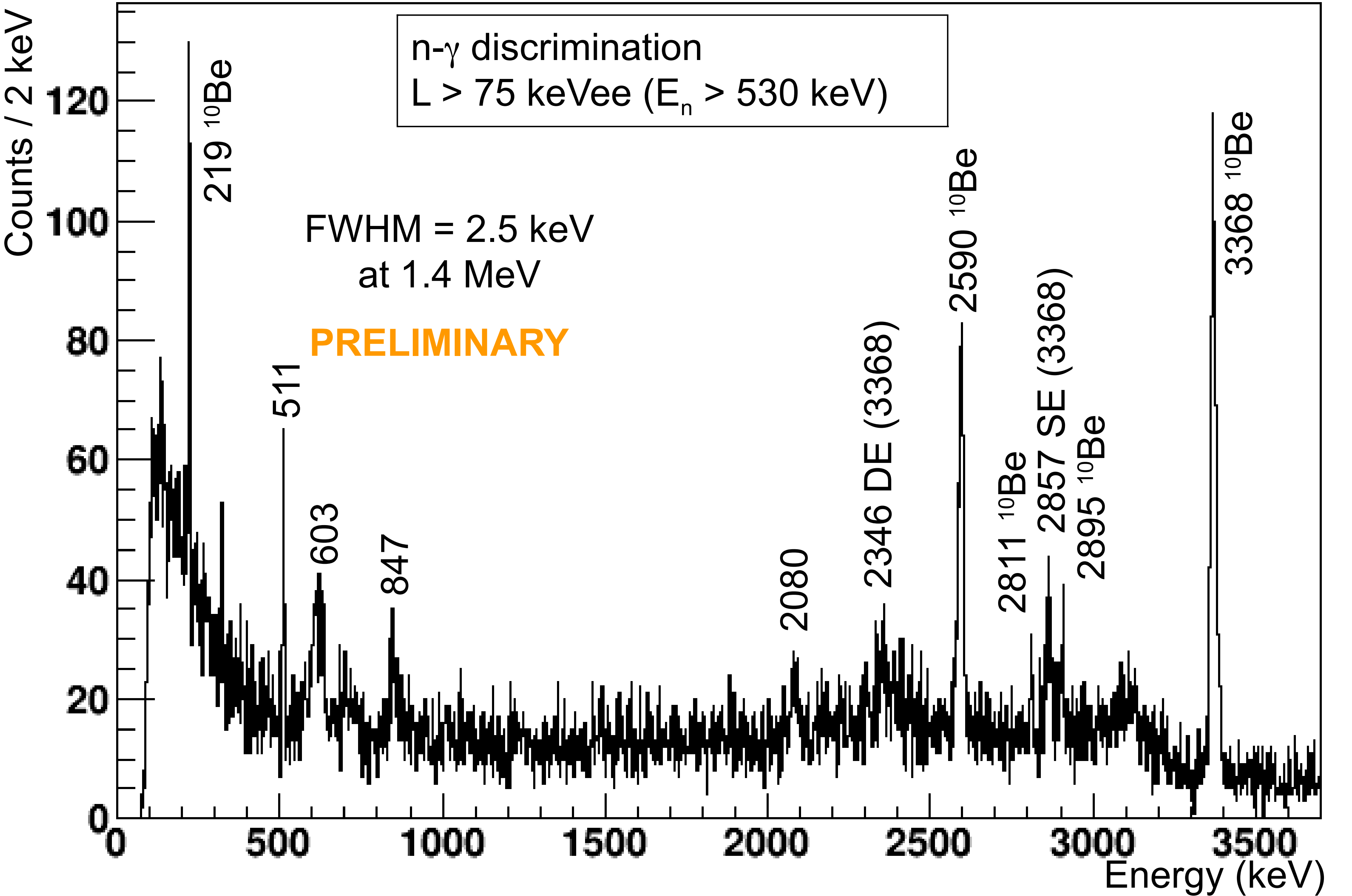
^{11}Li β-1n: Far array



2.5 m - 10 detectors
~ 34 hours - 4.3 shifts
→ 25 % of total statistics
Rough neutron cut
L > 100 keVee (E_n > 630 keV)
~ 40 % of Hirayama's statistics
with better E_n resolution

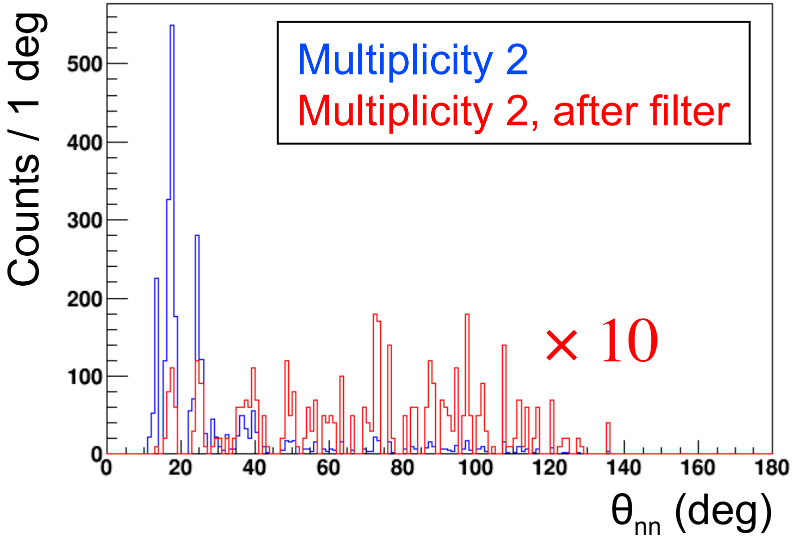
^{11}Li β-n-γ: Near array and 60% Ge detector

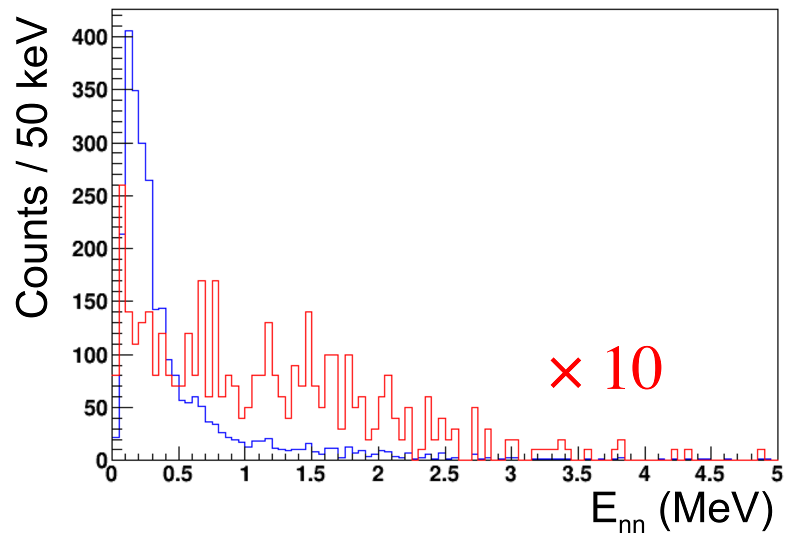
$$^{11}\mathrm{Li} \rightarrow {}^{11}\mathrm{Be}^{*} + e + \bar{\nu} \rightarrow {}^{10}\mathrm{Be}^{*} + n + e + \bar{\nu} \rightarrow {}^{10}\mathrm{Be} + \gamma + n + e + \bar{\nu}$$



^{11}Li β-2n

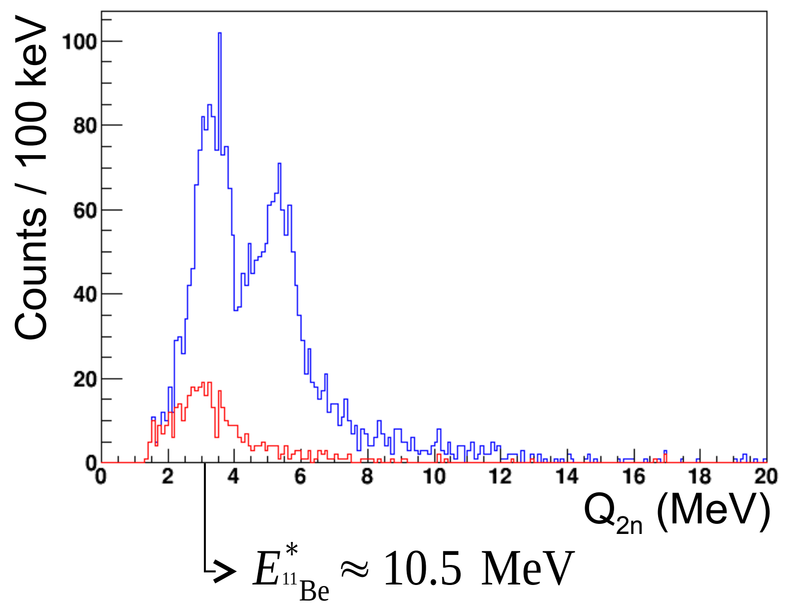
PRELIMINARY





$$Q_{2n} = E_1 + E_2 + \frac{m_n}{m_{9\,\mathrm{Be}}}\left(E_1 + E_2 + 2\sqrt{E_1 E_2}\cos\theta_{nn}\right)$$

$$E^*_{^{11}\mathrm{Be}} = Q_{2n} + S_{2n}$$



^{11}Li β-2n

PRELIMINARY