Status of NEDA simulations

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for the NEDA collaboration

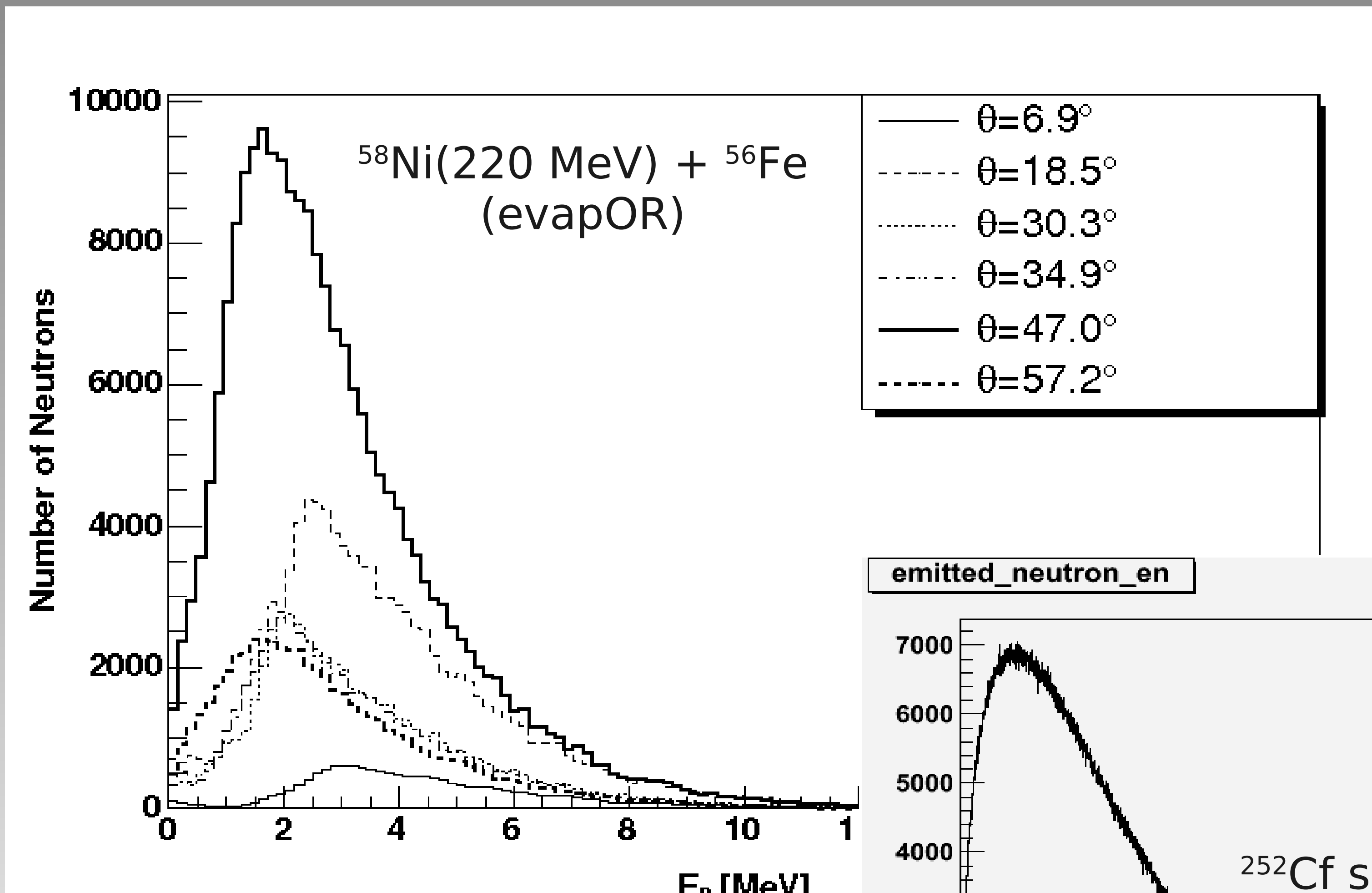
NEDA introduction

- Aim of the project: tu build a new array of neutron detectors, with the primary application as a neutron multiplicity filter in fusion-evaporation studies of neutron deficient nuclei, for AGATA, EXOGAM, etc.
- Basic properties:
  - efficiency,
  - n/γ discrimination,
  - ability to distinguish multiple neutrons from 1 neutron interacting in 2 or more detectors, enabling 2n, 3n, 4n filtering.
- Should be better than existing Neutron Wall: $\varepsilon_{1n} \sim 0.23$, $\varepsilon_{2n} \sim 0.01$, $\varepsilon_{3n} \sim 0.001$, $P_{\gamma \to n} \sim 0.005$ (in approximately symmetric fusion evaporation-reactions)

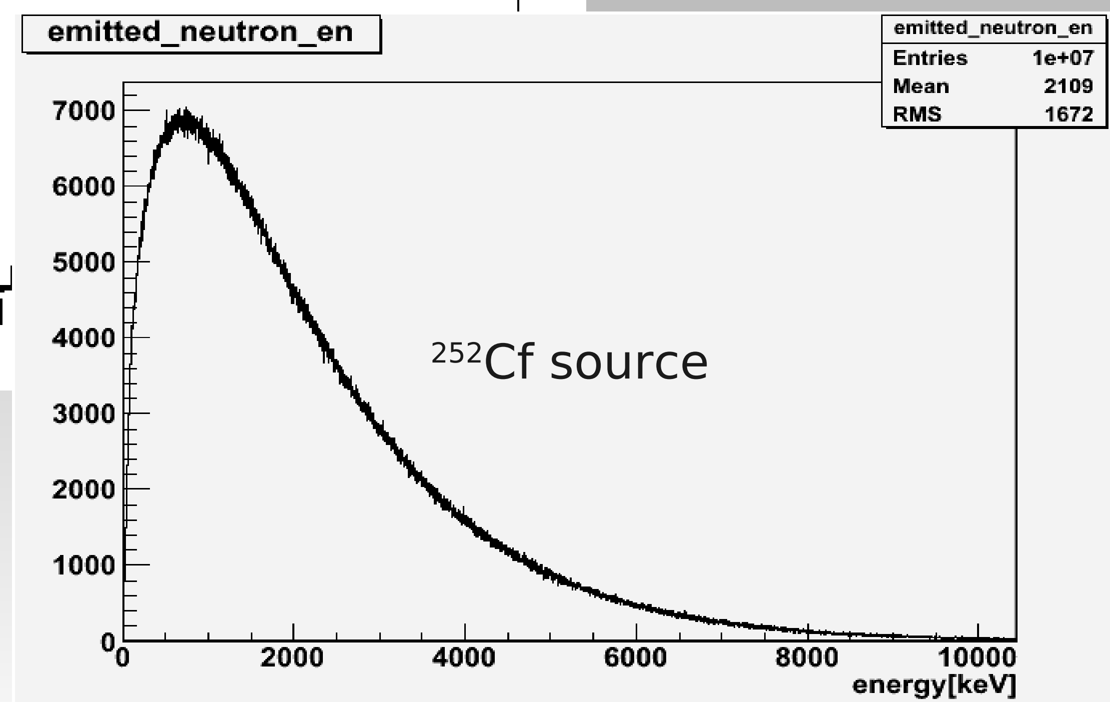
Simulations agenda

- Validation of Geant4 neutron interaction model and light formulas
- Optimizing single detector size:
  - efficiency, cross-talk, time resolution
- Comparing properties of two scintillators: proton based (BC501A) and deuterated (BC537)
- Determining size of the entire array
- Creating various possible geometries of the array
- Determining efficiency and P(1n→2n) without and with gamma background
- Comparing simulations to NEDA prototype tests BC501A and BC537

Neutrons of interest



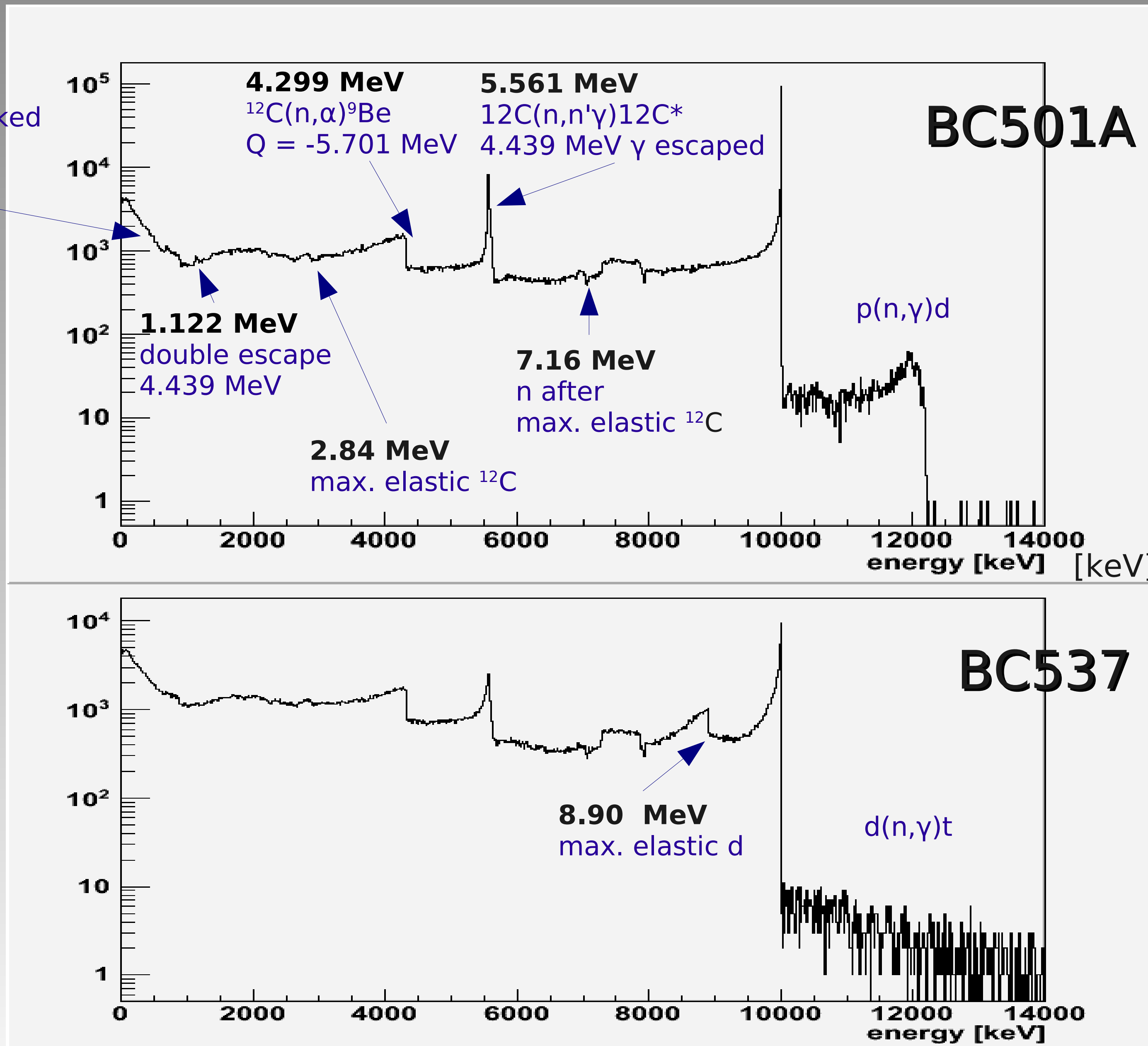
J.Ljungvall et al. NIMA 528, 741 (2004)



Energy deposit in the detector: BC501A, BC537

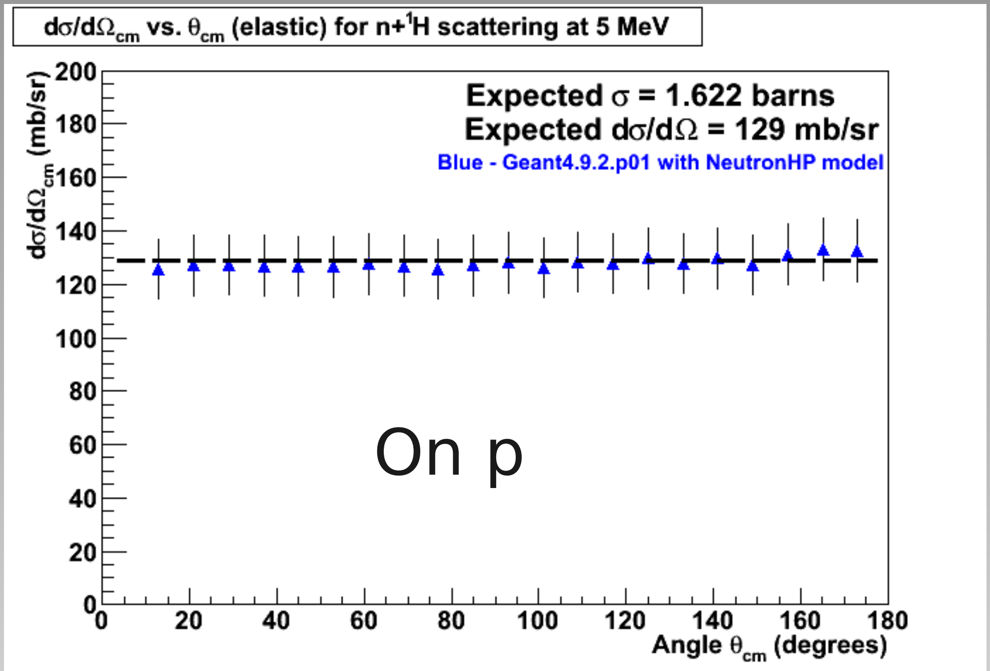
10 MeV neutrons

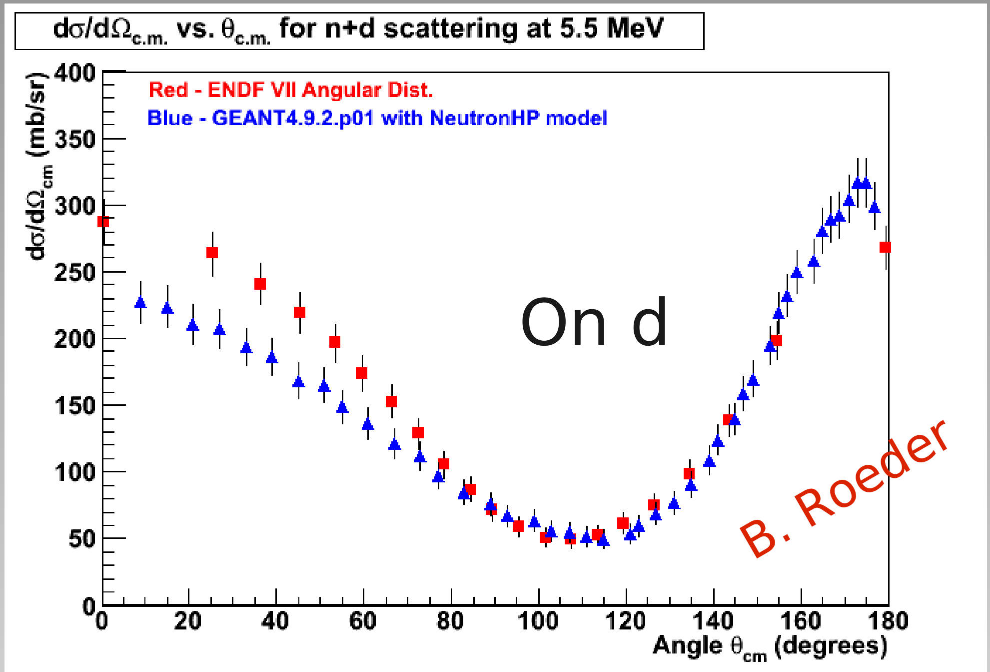
16.5 x 15 cm cylinder (3.2 l)



Deuterated scintillator, what is it all about ?

Angular neutron elastic scattering distribitions (in CM)

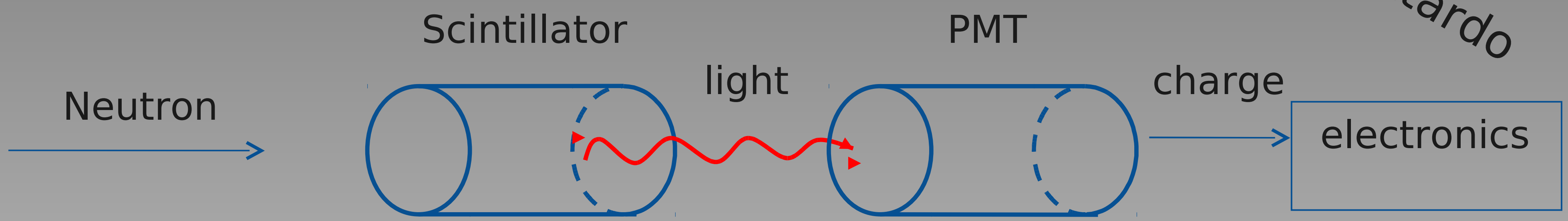




Elastic scattering on **d** should lead to a better correlation of the depositied energy (light ?) with the incoming neutron energy,
as compared to scattering on **p**.
Could be used to improve multiple neutron discrimination.

Light output

A.Gottardo



Neutrons with the same energy do not always produce the same light output, i.e. the same signal.

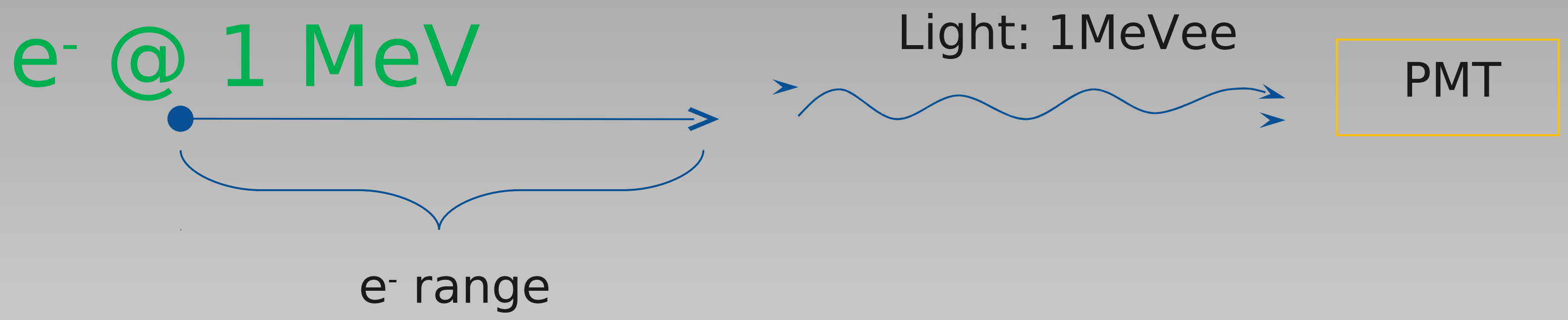
The light-response depends on:

- The **energy** of the particle(s) scattered by collisions with the incoming neutrons
- The **kind** of the particle(s) scattered by collisions with the incoming neutrons
- Other characteristics of the scintillator such as the **optical coupling** to the PMT, the **light transport** and reflection in the scintillator itself…

Light output definition

A.Gottardo

The light-output L is usually given in **MeVee** (keVee)
1 MeVee light is produced when a 1 MeV electron deposits all its energy in the scintillator



Heavier particles such as protons, deuterons, alphas, beryllium, carbon… produce less light than electrons

Phenomenological light output parametrisation

The light-output function for **protons:**
$L_p(E)=A_0+A_1E+A_2E^2+A_3E^3$

E_p (MeV)	0.0–0.4	0.4–1.1	1.1–3.0	3.0–6.4	6.4–8.9	8.9–16.0
A_0	0.0	0.00829	−0.02060	−0.07129	3.85138	−0.76801
A_1	0.06798	0.01275	0.09088	0.18958	−1.36975	0.57306
A_2	0.06034	0.18149	0.11066	0.06138	0.26122	0.0
A_3	0.05527	−0.03206	−0.01055	−0.00326	−0.01138	0.0

Carbon, Boron: L(E) = 0.0097 E
(~ 3 times less than proton)
Deuteron: $L(E) = 2\,L_p(E/2)$

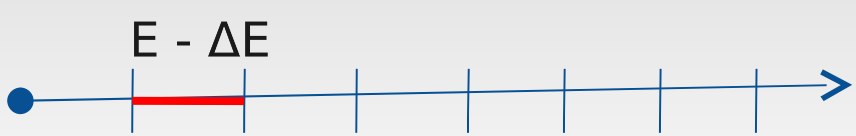
Be: L(E) = 0.013E

Dekempeneer et Liskien
NIM A 256 (1987) 489-498: NE213

Alpha: L(E) =
- $0.0201E^{1.871}$ $E < 6.76$ MeV
- $-0.6278+0.1994\,E$ $E \geq 6.76$ MeV

ΔL = light output of the particle scattered by a neutron in a single *i*th step of its stopping process

$$\Delta L = L(E) - L(E-\Delta E)$$



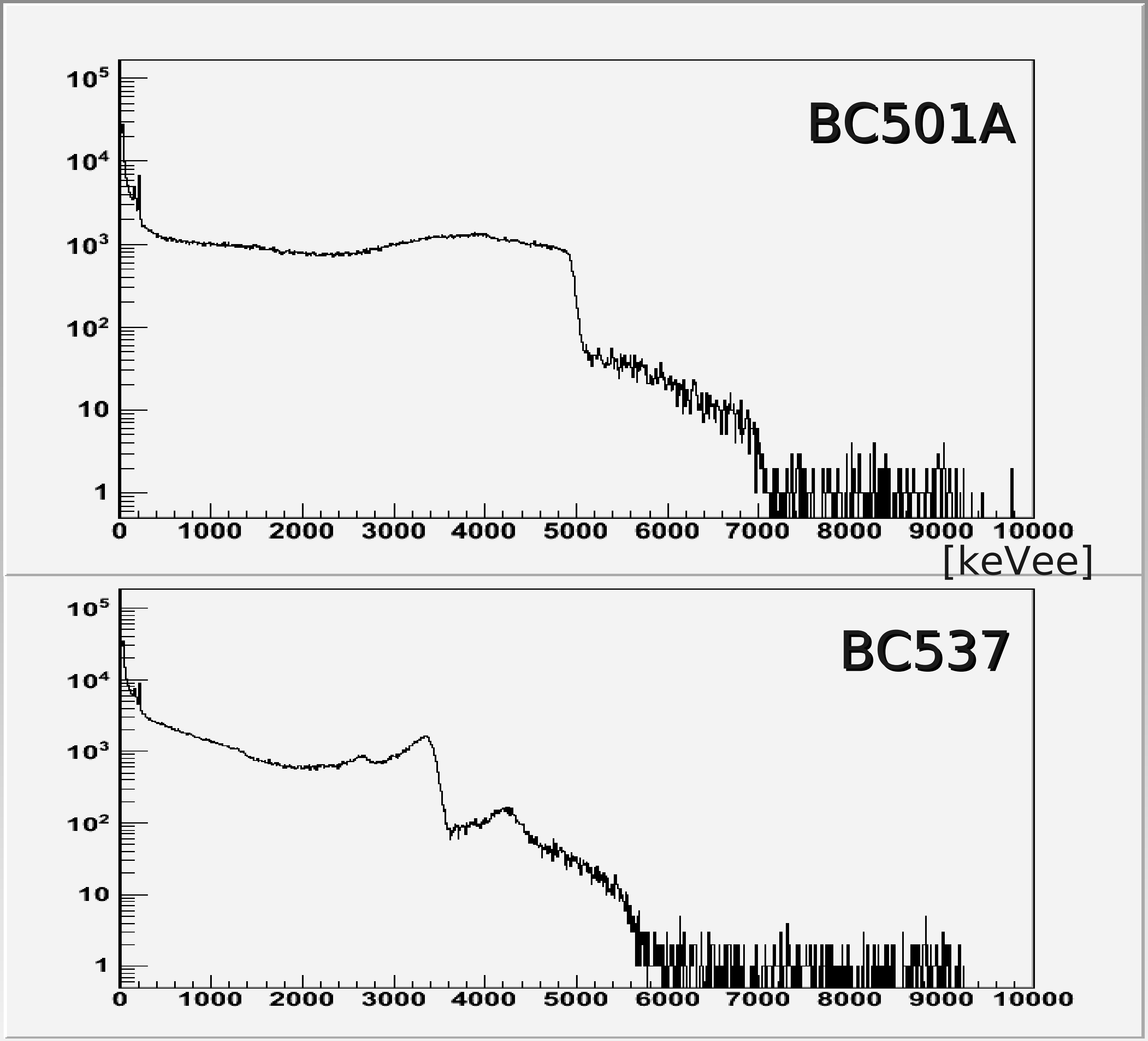
$$L=\sum_i \Delta L_i$$

A.Gottardo

Light produced: BC501A, BC537

10 MeV neutrons

16.5 x 15 cm cylinder



Experimental validation of the simulations

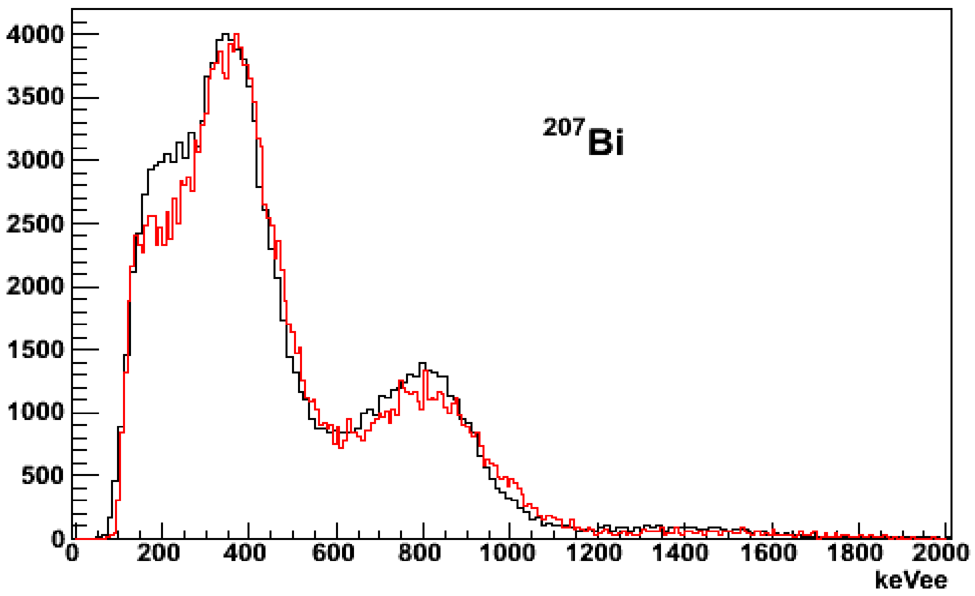
Measurements in Uppsala and Warsaw
two BC501 detectors

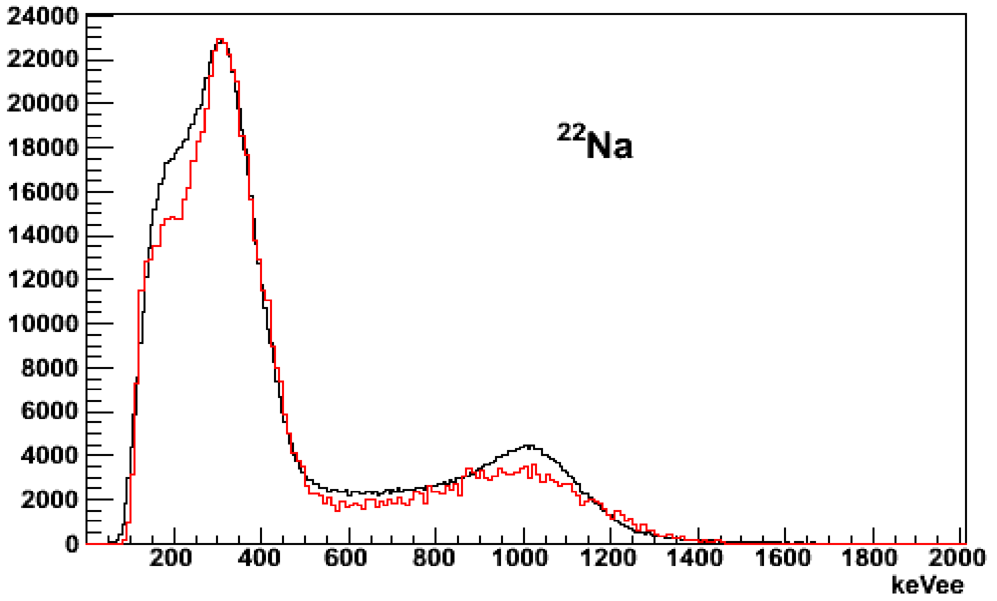
3.9 l

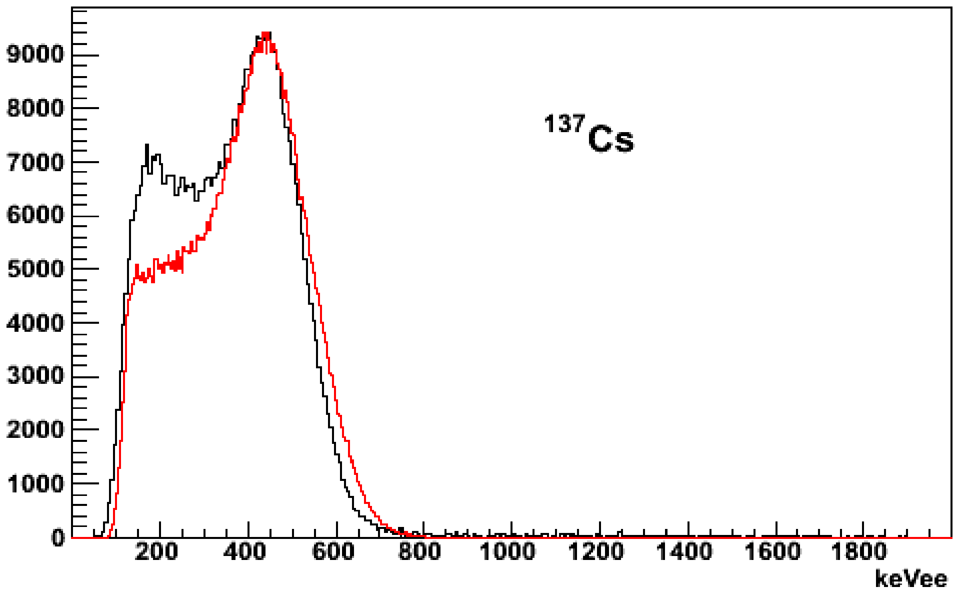
15.3 x 13.5 cm
(2.5 l)

G.Jaworski, J.Nyberg, A.Pippidis, P.-A.Söderström

Experimental validation – γ rays







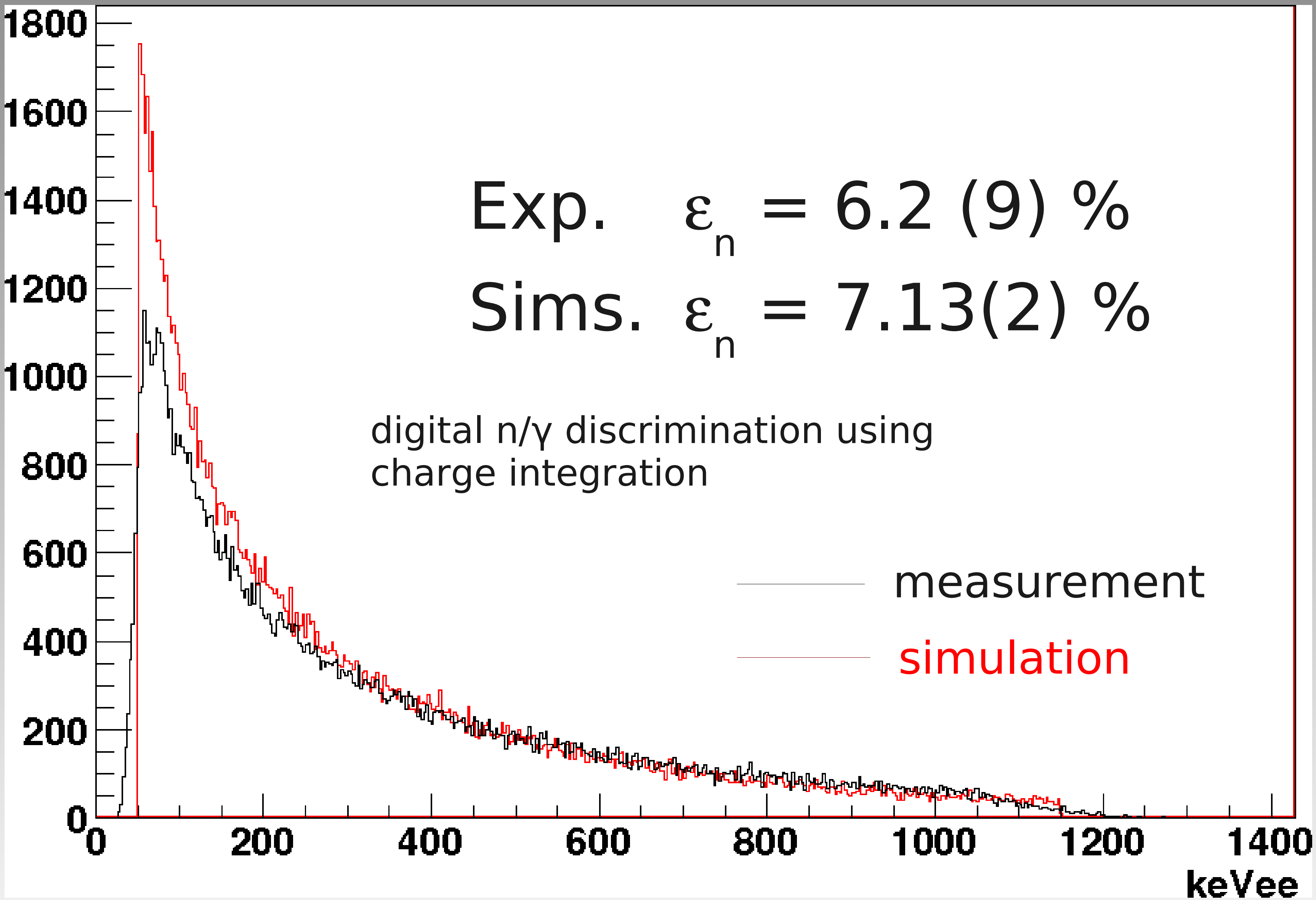
measurement

simulation

G.Jaworski

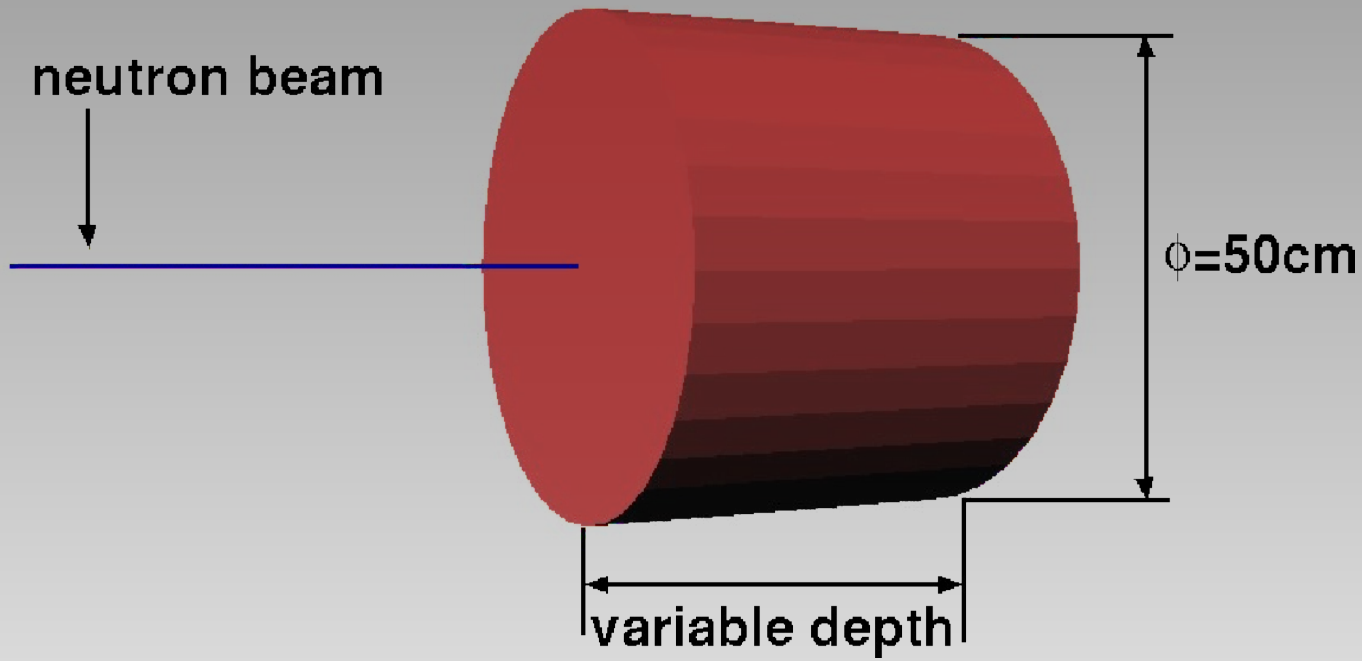
Experimental validation – ^{252}Cf neutrons

G.Jaworski



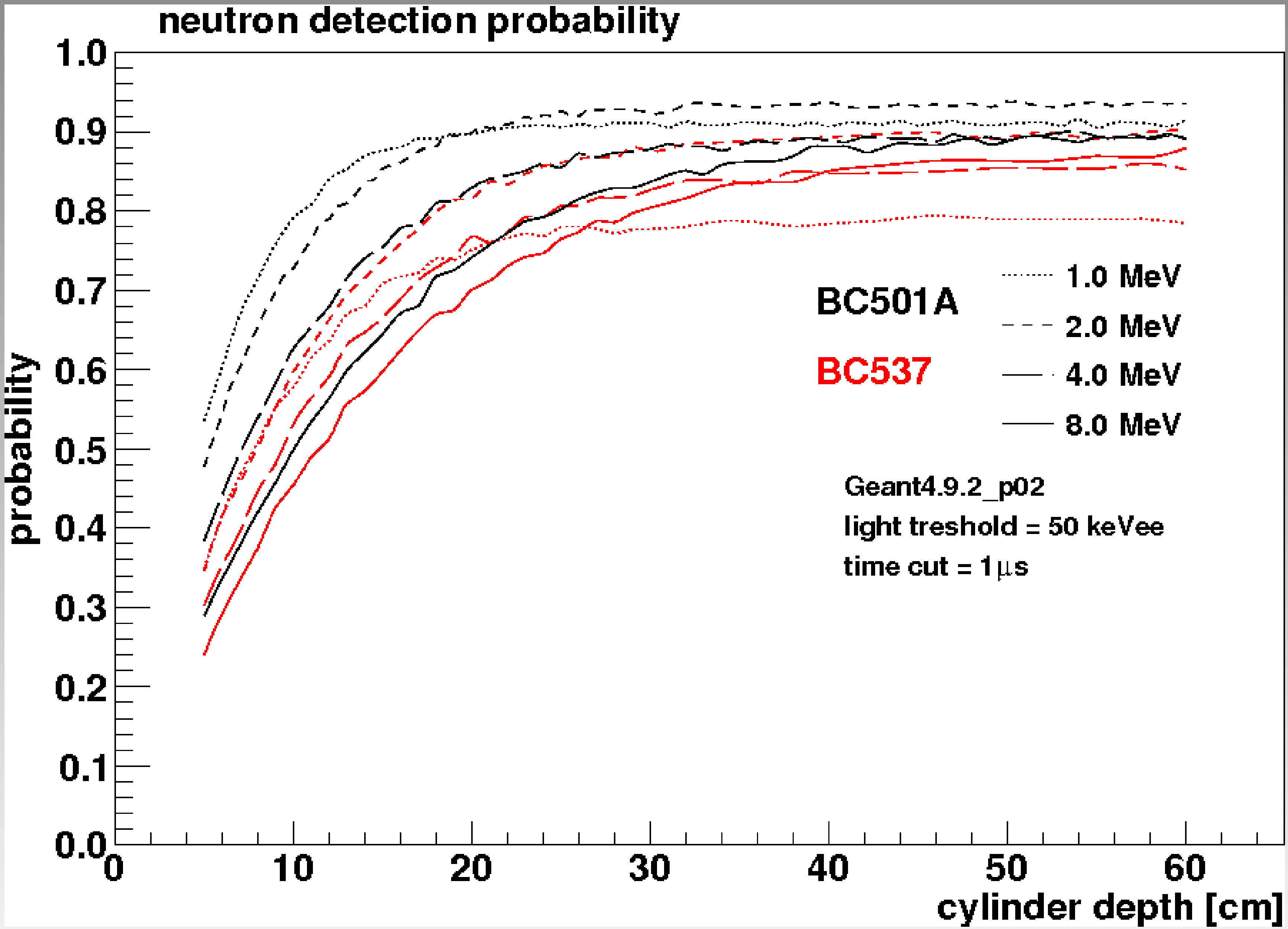
Size of a single detector

Study of efficiency as a function of detector size

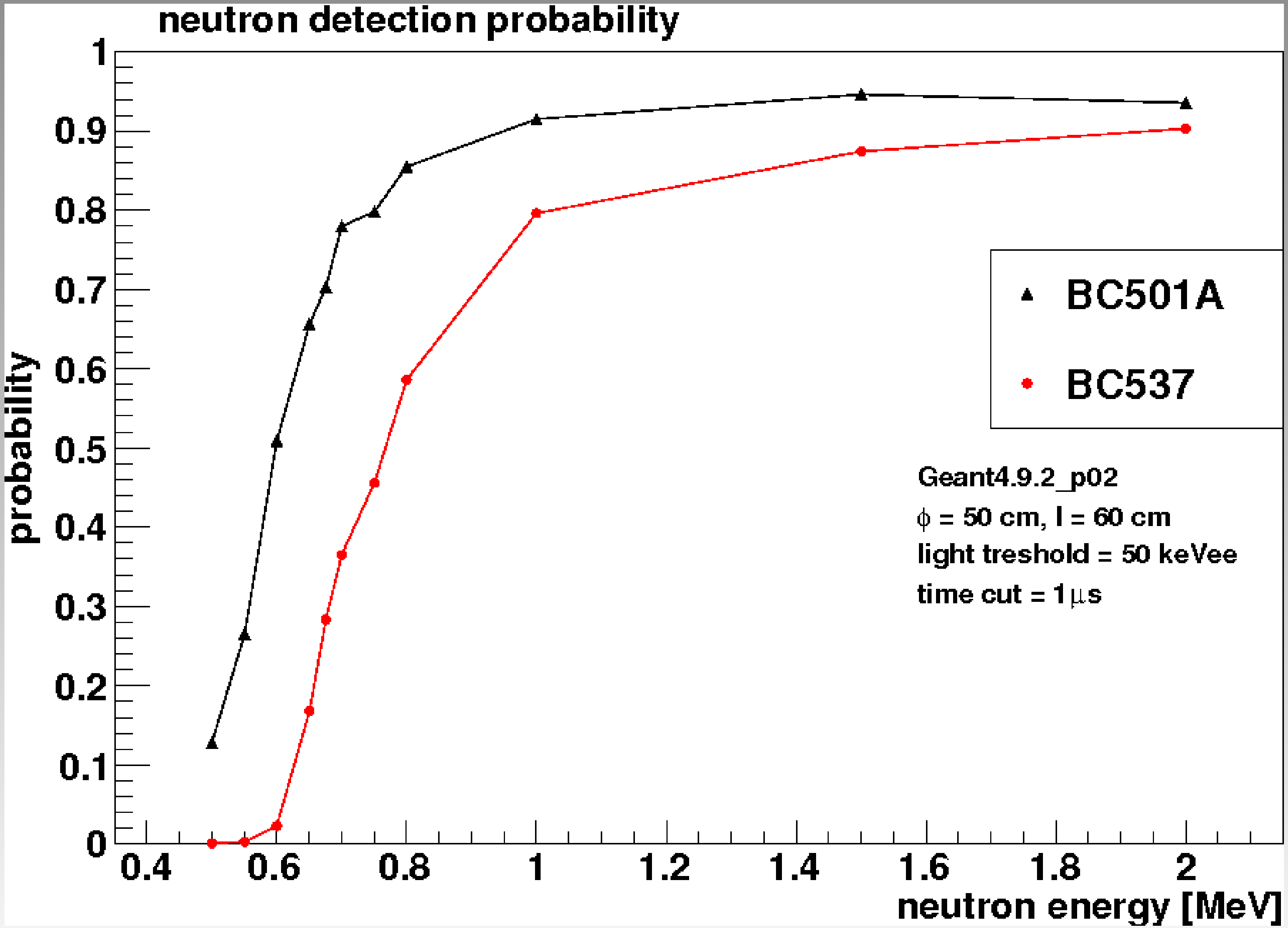


G.Jaworski

Size of a single detector



Efficiency of a single detector



Time resolution

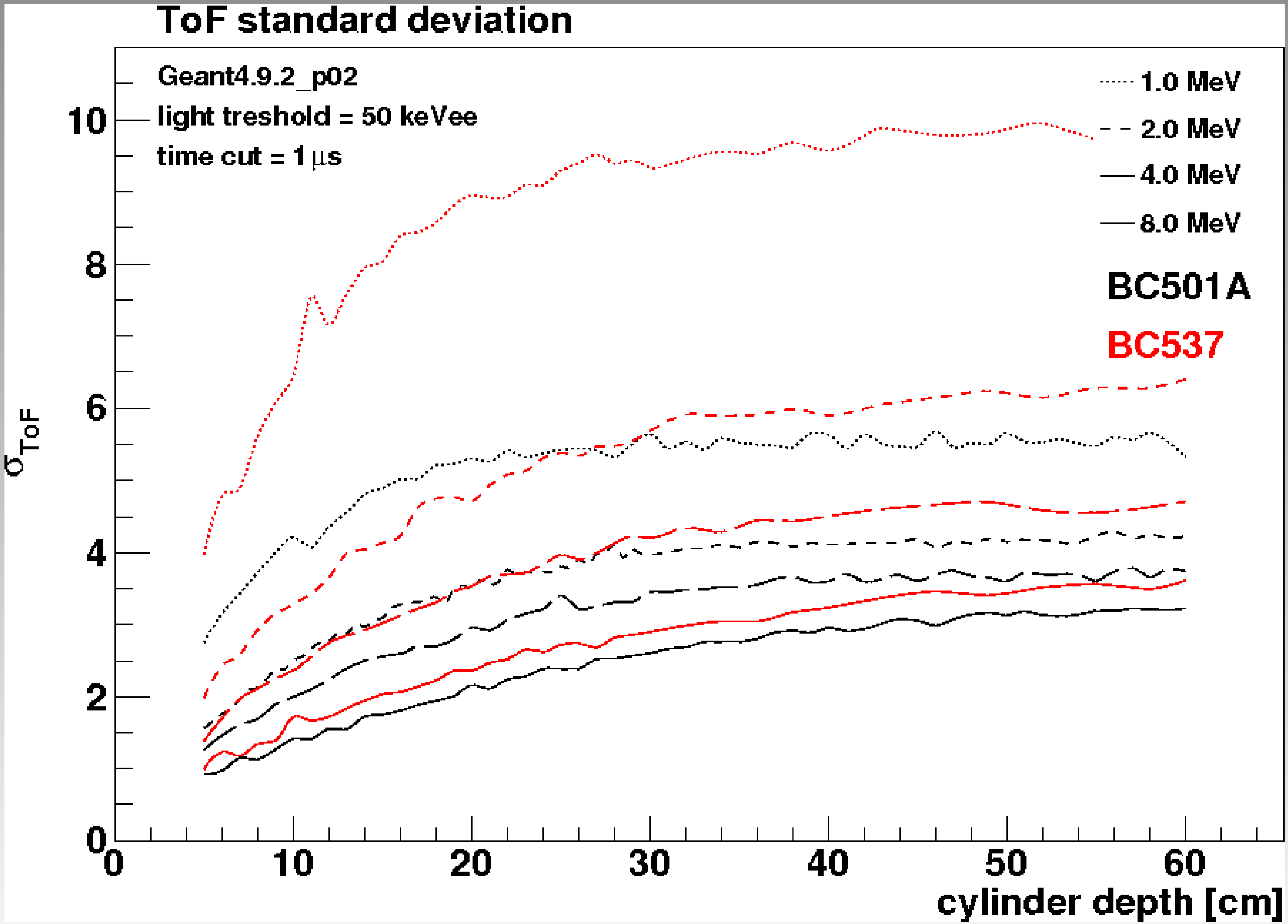
Two components:

- Intrinsic time resolution of the detector
  - cannot be evaluated in this simulation
  Systematically studied as function of detector length in
  K. Banerjee et al., NIM A 608(2009)440-446

  5 inch cylinders, length 1.5 to 7 inch,   2 to 10 MeV neutrons:
  => approximately constant 1.5 ns FWHM

- Varations of interaction time due to the variations of significant interaction depth

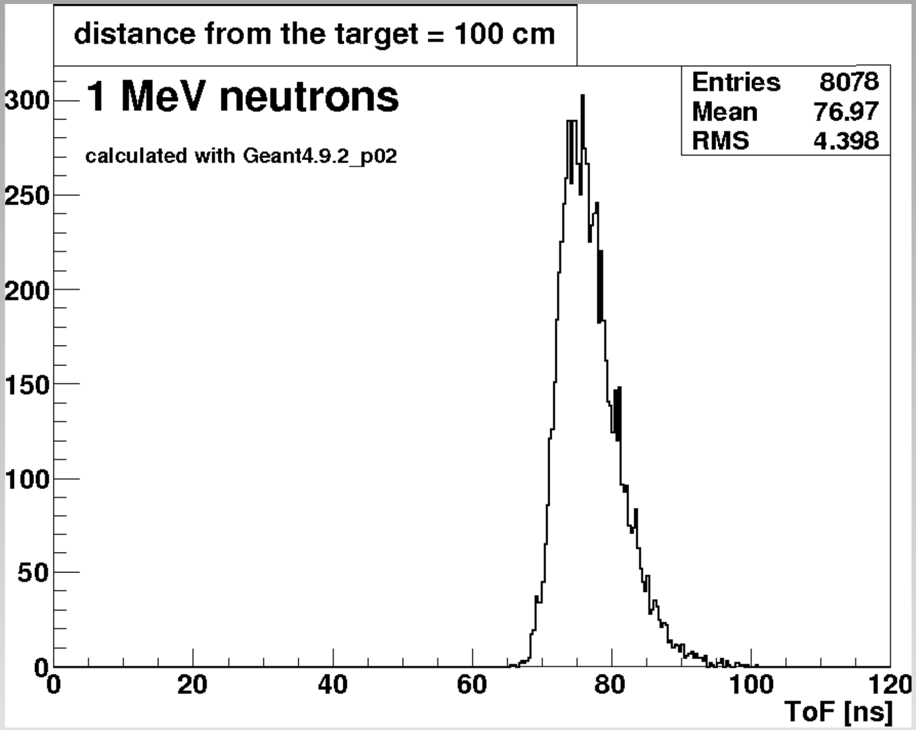
Time resolution – TOF variation



Size of the array

Limited by:

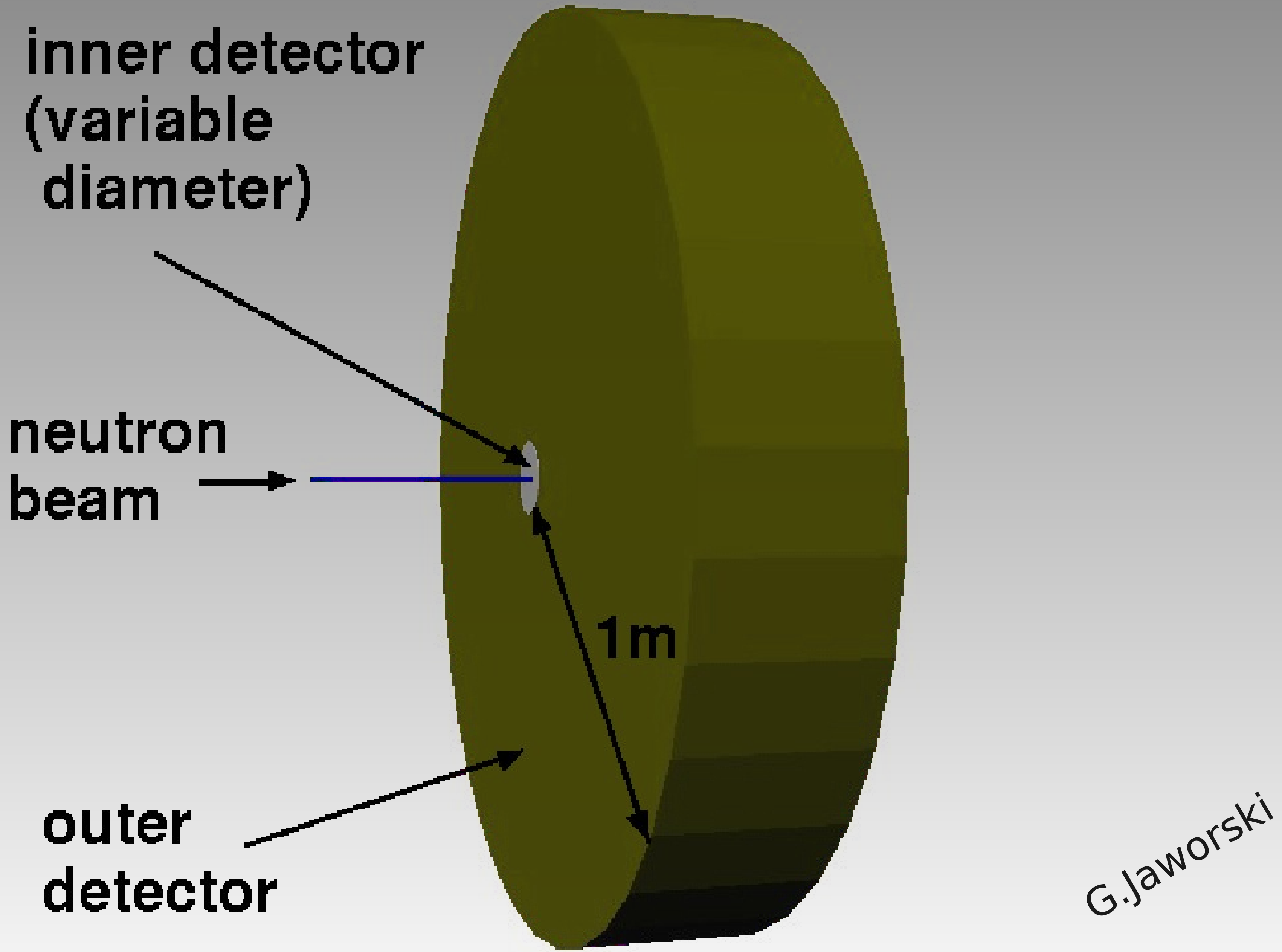
- space constraints: beam line height 1.75 m
- timing



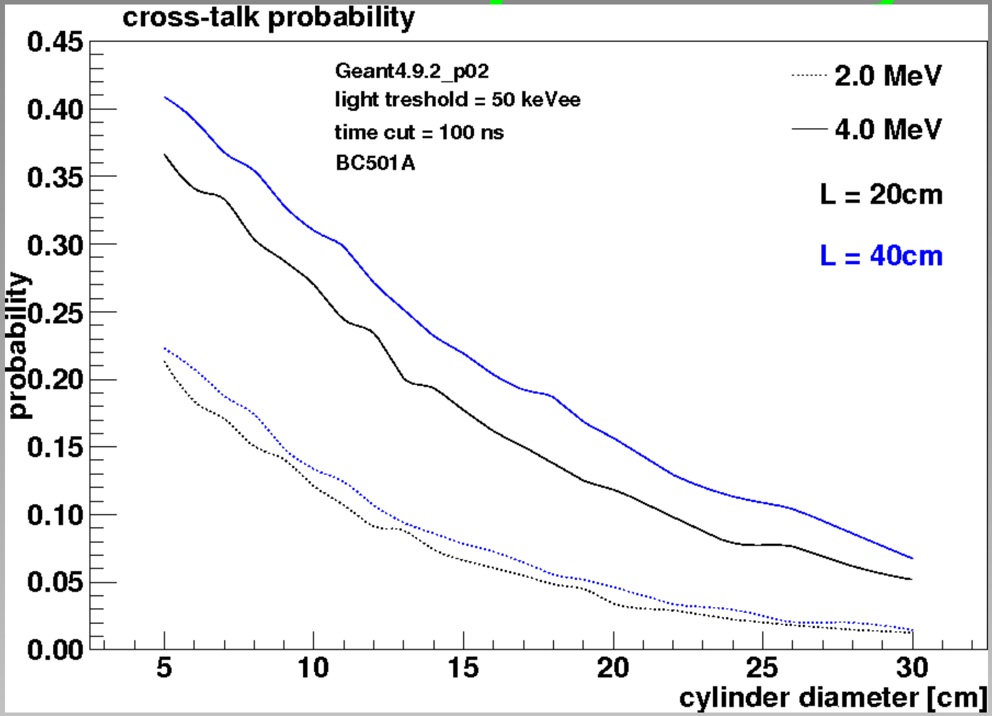
G.Jaworski

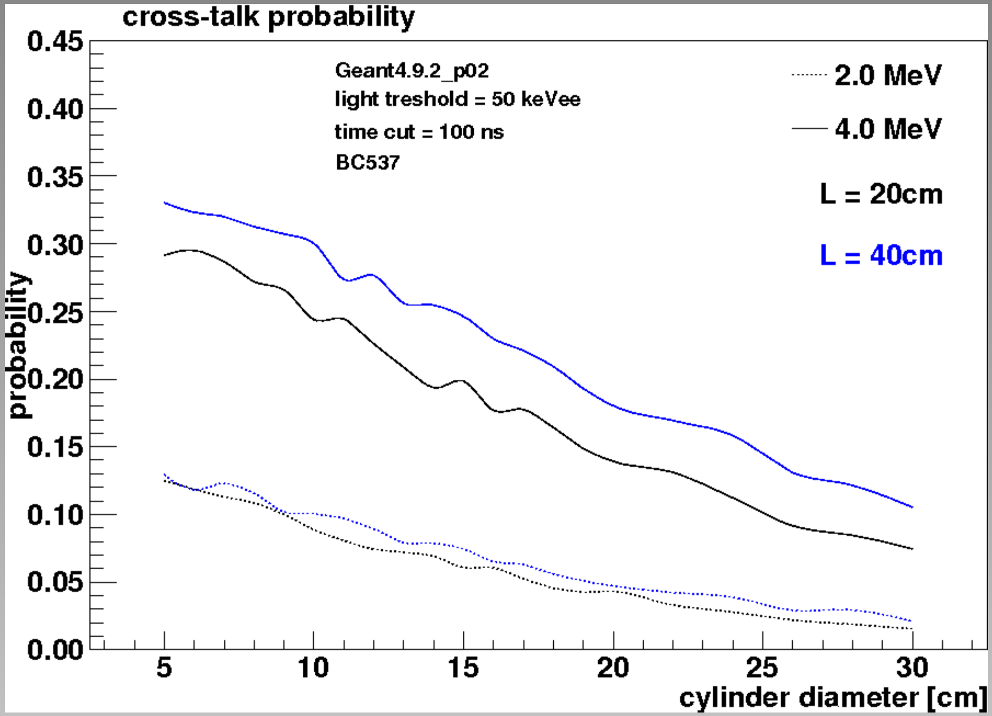
Conclusion: size of the array limited by TOF
=> ~ 1m radius

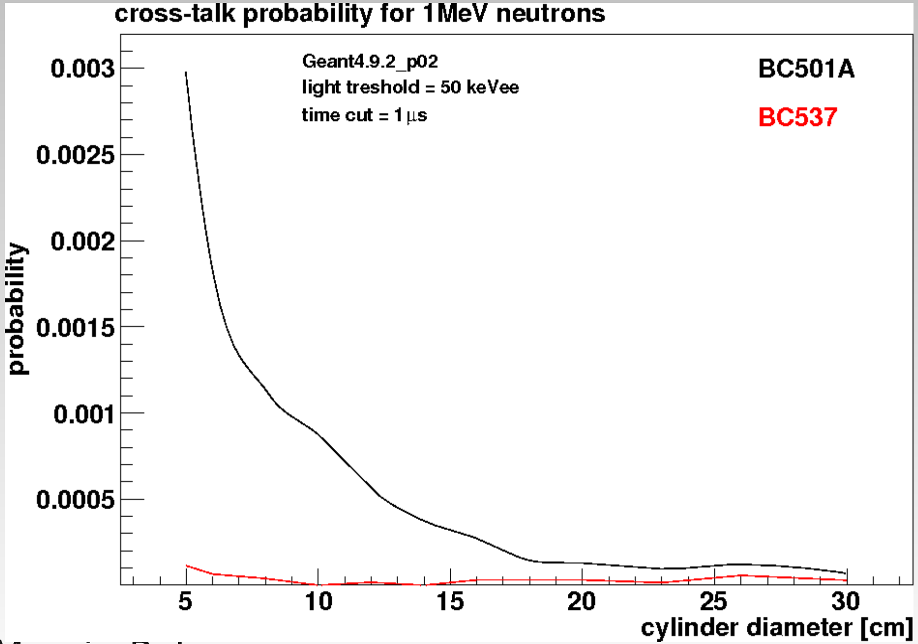
Cross talk

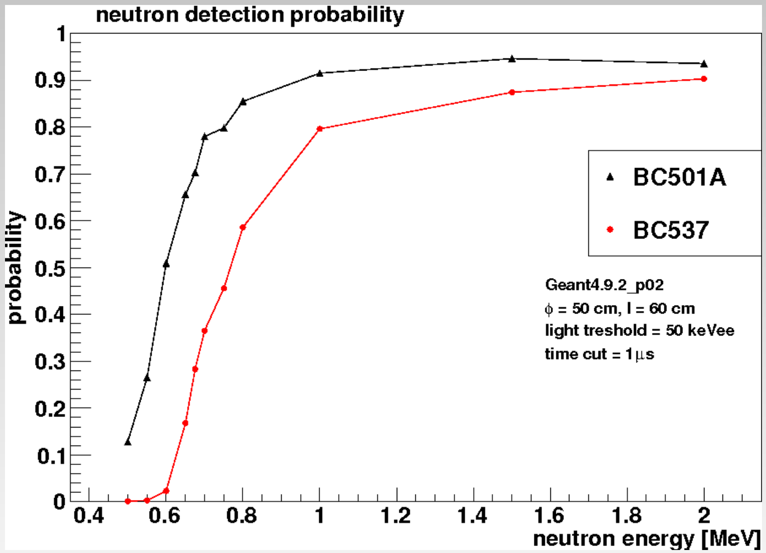

inner detector
(variable
diameter)
neutron
beam
1m
outer
detector
G.Jaworski

Cross-talk probability

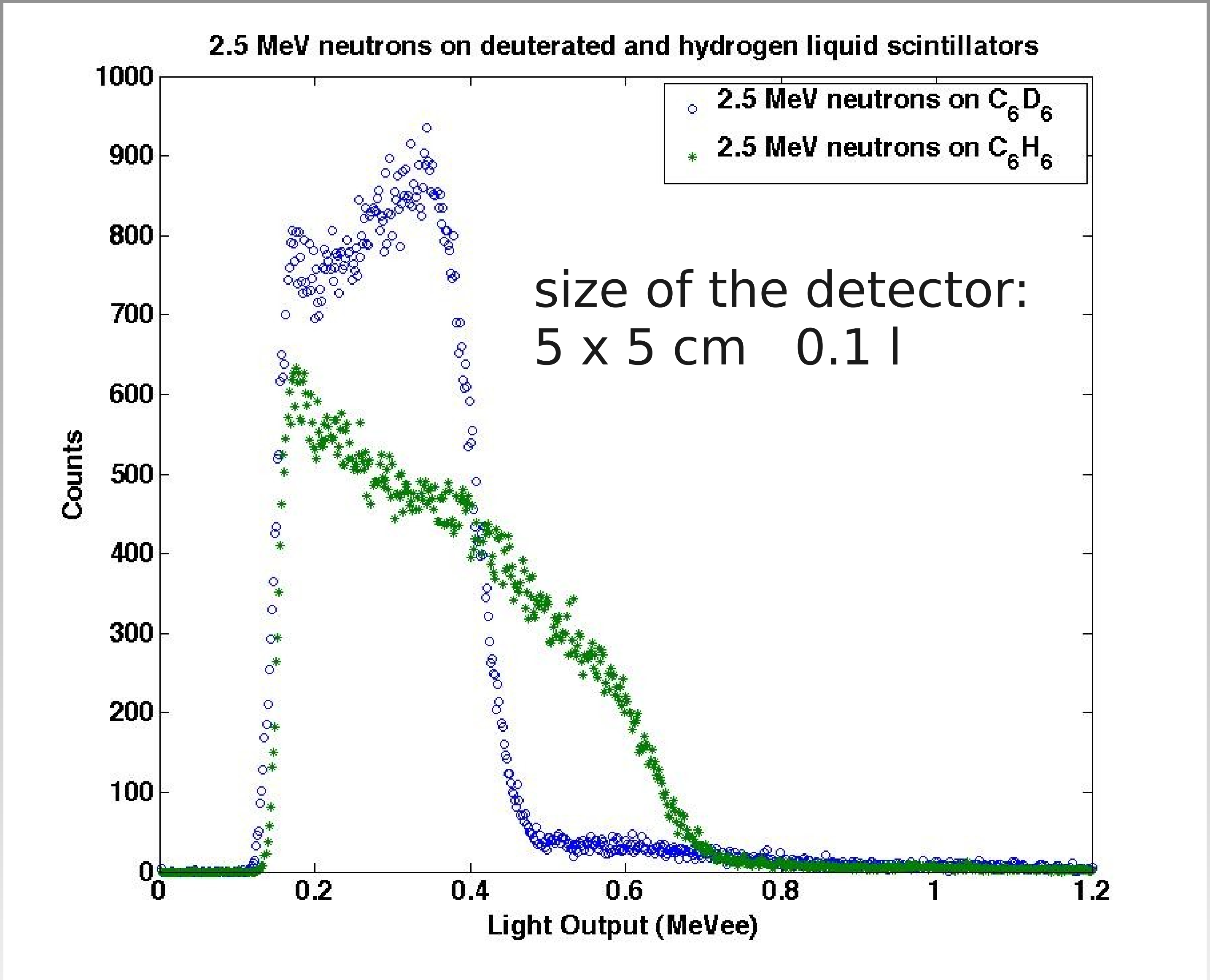








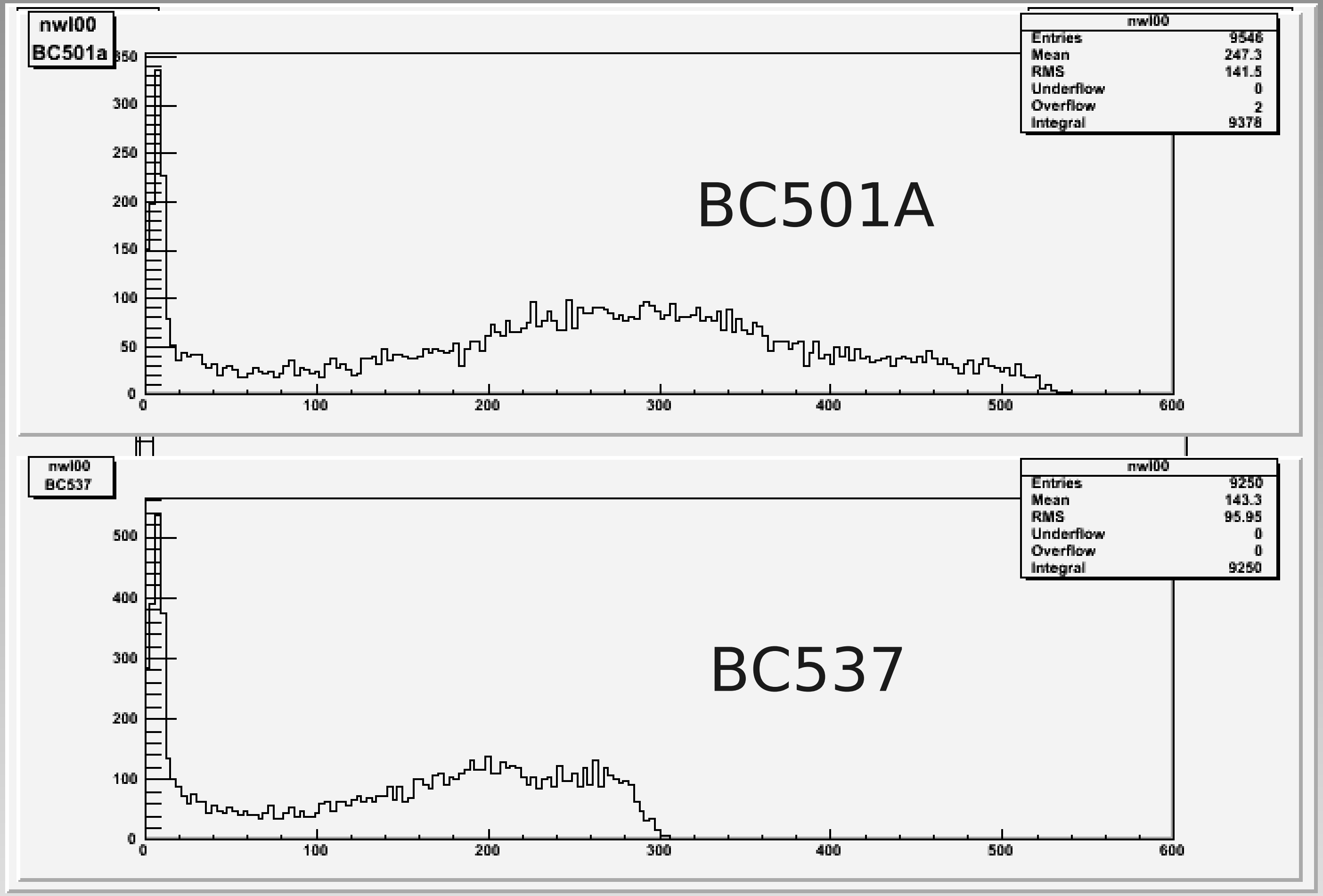
Deuterated scintillator: C_6H_6 vs. C_6D_6 experiment



M.I.Ojaruega PhD. thesis, Univ. of Michigan 2009

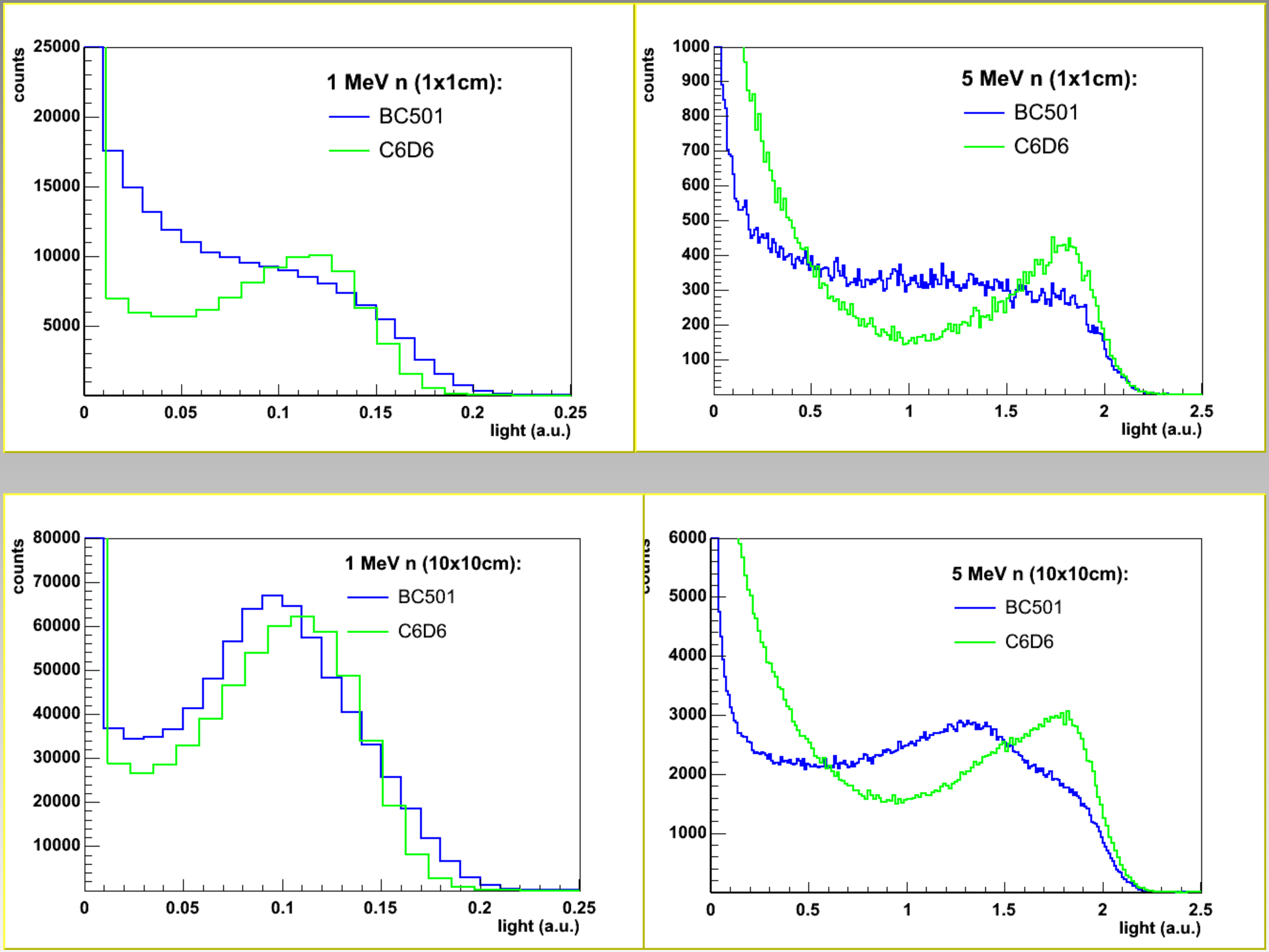
BC501A vs BC537

16.5 x 15
cm cylinder
3.2 l



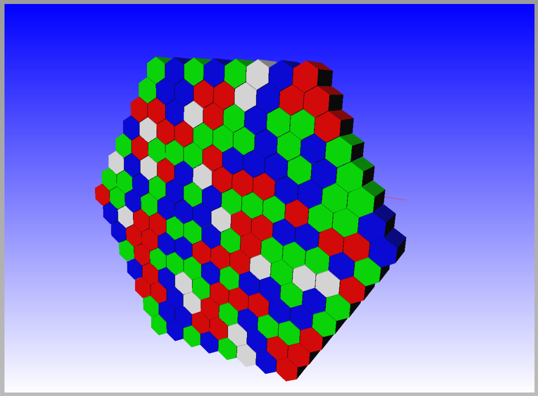
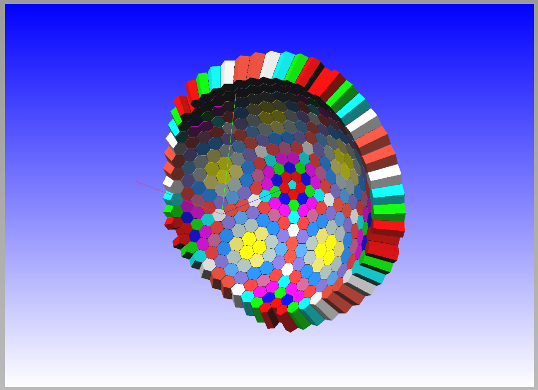
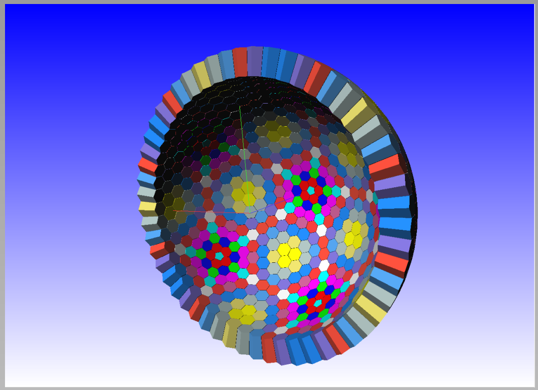
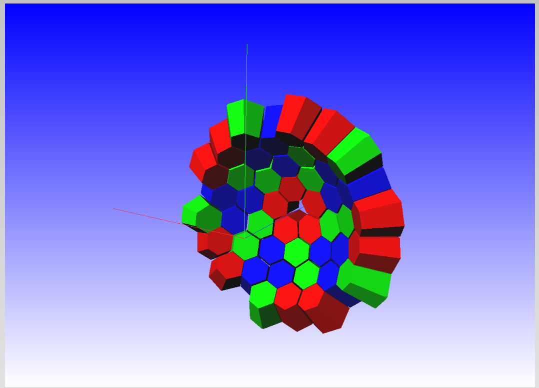
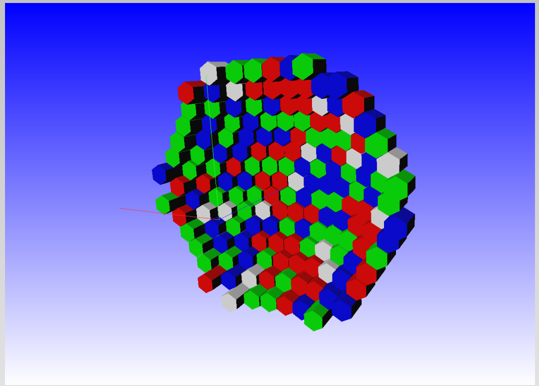
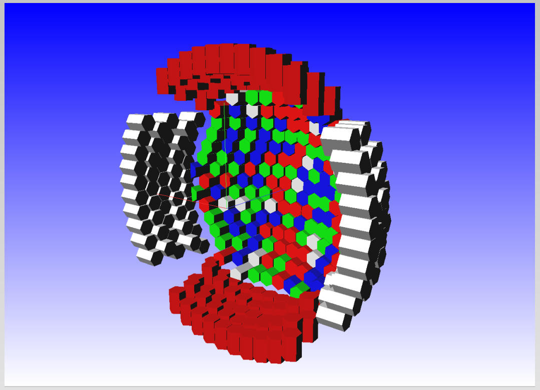
BC501A vs BC537

independent simulation by J.L.Tain



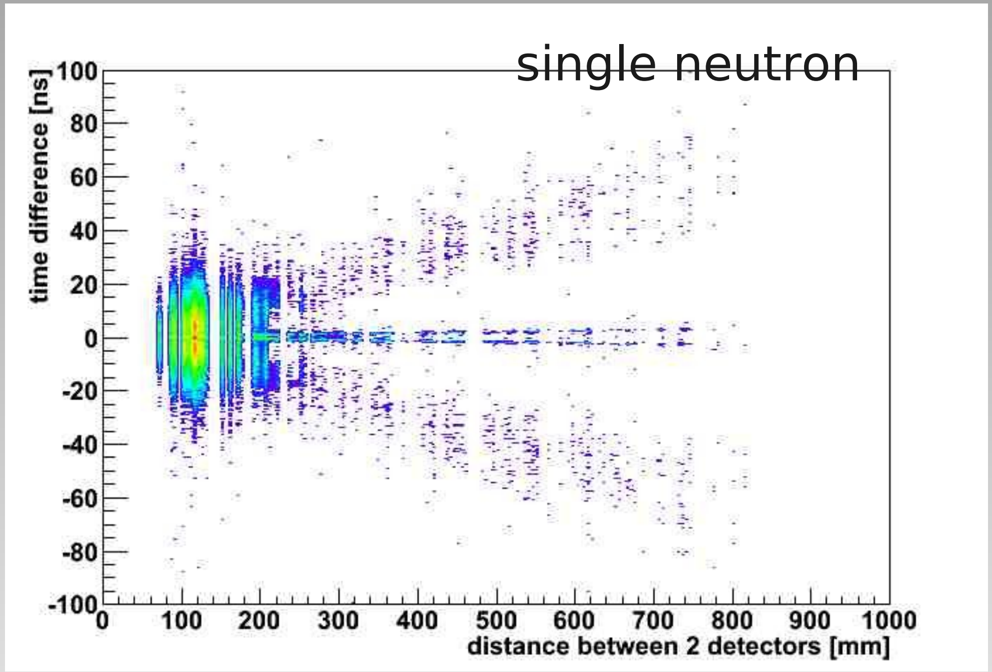
Geometries

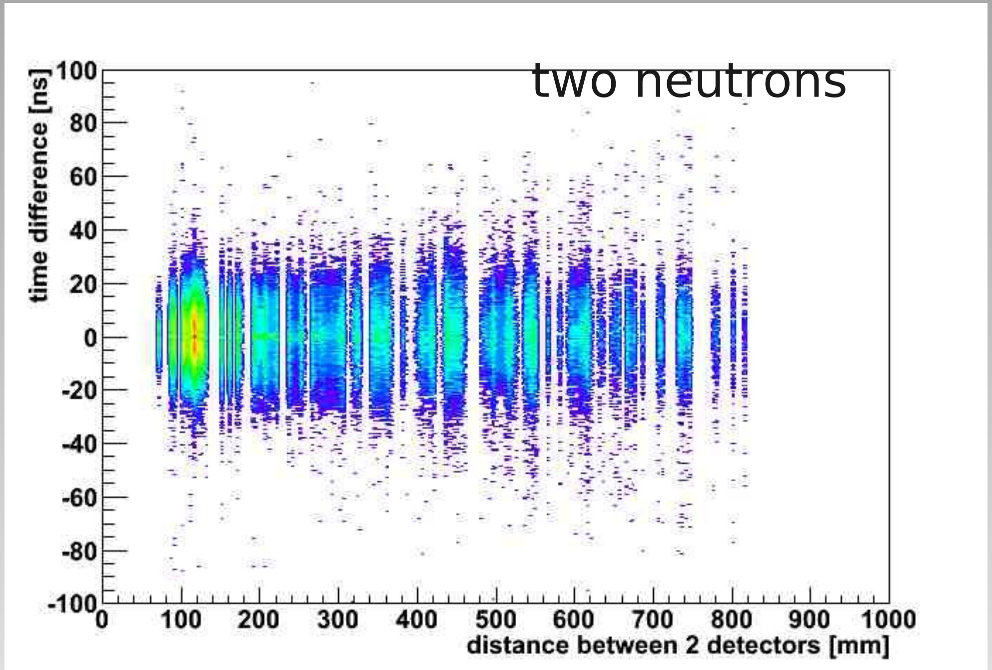
T.Huyuk

2n discrimination

Simultaneous interaction in distant detectors can not be due to one scattered neutron





Work in progress for considered geometries

Geometries

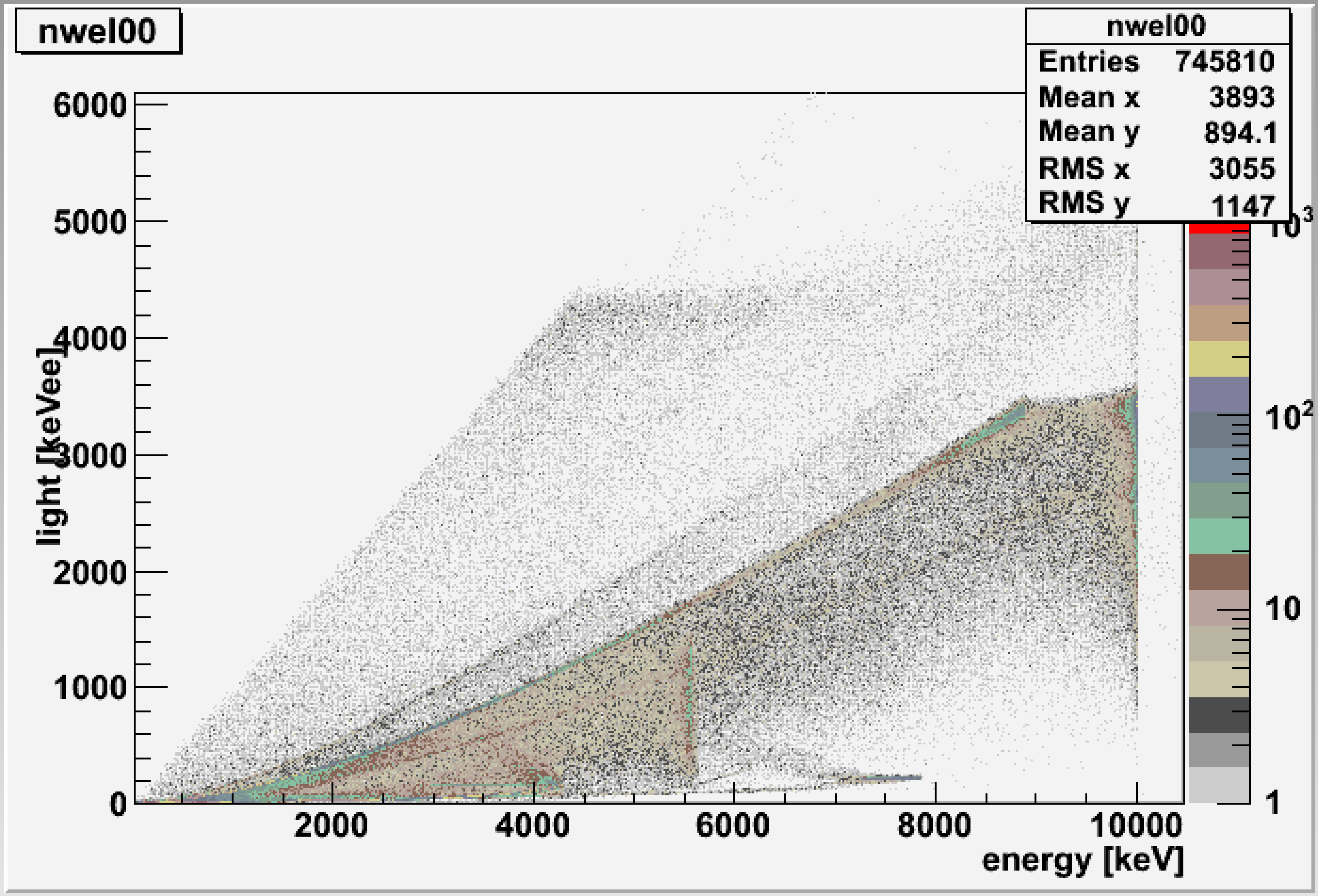
	Distance /radius	Granularity	Total Volume (L)	Cell Volume (L)	Solid Angle (π)	Material	Efficiency (1n)	Efficiency (2n)	P(1n->2n)
Flat	1 m	169	507	3	0.6	BC501A	9.90 %		
						BC537	6.89 %		
Zigzag	1 m	169	507	3	0.6	BC501A	7.33 %		
						BC537	5.82 %		
Stairs 1π	1 m	163	489	3	1	BC501A	15.54 %	1.9 %	$1.1*10^{-5}$
						BC537	12.05 %		
Stairs 2π	1 m	355	1065	3	~2	BC501A	31 %		
						BC537	24 %		
Spherical N180	0.5 m	45	202.5	4.5	1	BC501A	15.57 %		
						BC537	12.66 %		
Sperhical 1π	1 m	326	652	2	1	BC501A	19.25 %		
						BC537	15.27 %		
Sperhical 2π	1 m	606	1212	2	2	BC501A	37 %		
						BC537	29.35 %		
NWall	0.51 m	50	150	~3	1	BC501A	15 %	0.087 %	$2.2*10^{-5}$
						BC537	N/A		

Summary and conclusions

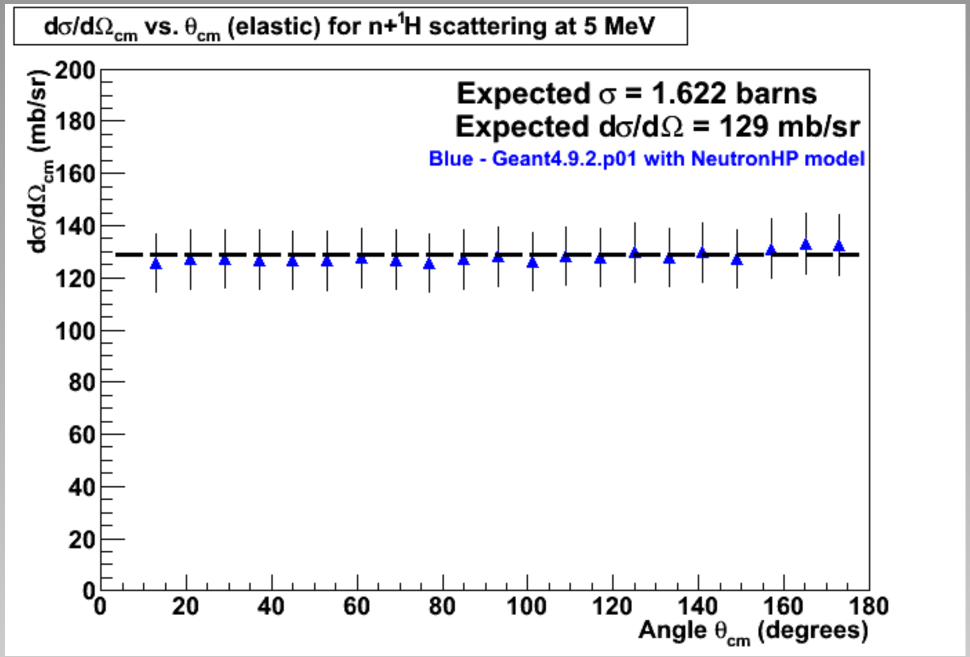
- Neutron interaction model of Geant4
  (ver. 4.9.2.pl02 and higher)
  found reliable for neutrons E_n<10 MeV
- Single detector size evaluated:
  "diameter" limited by the size of PMTs available: 5 inch
  depth: 20-30 cm
- Array diameter <= 1m
- Simulations show no advantages of using deuterated scintillator
- Work in progress on evaluating different geometries,
  in particular on the ability to discriminate multiple neutrons

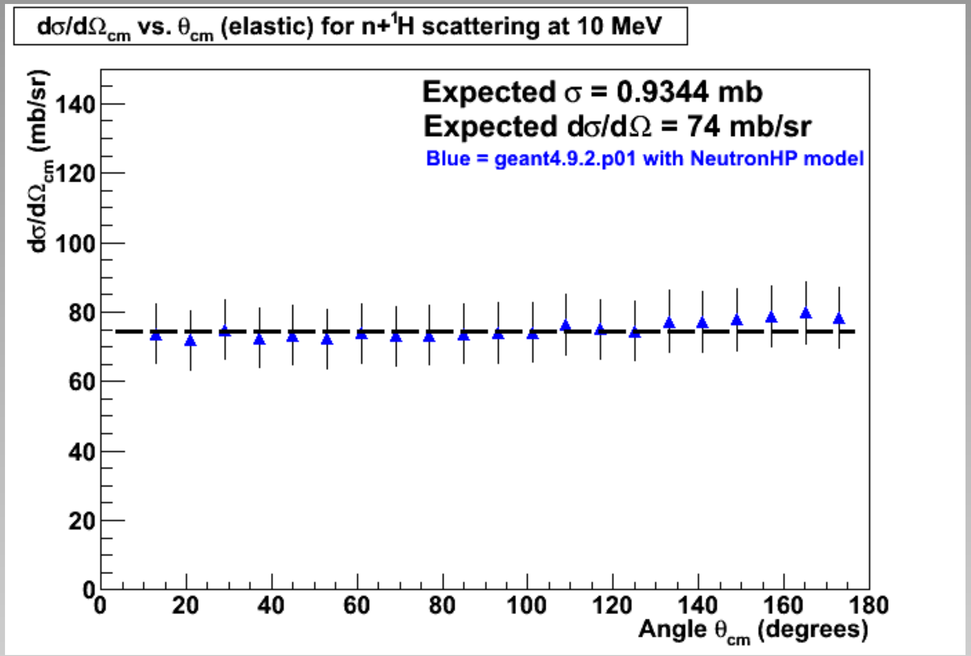
Two BC501A and two BC537 detectors purchased by the collaboration, tests start next week.

Light vs energy BC537



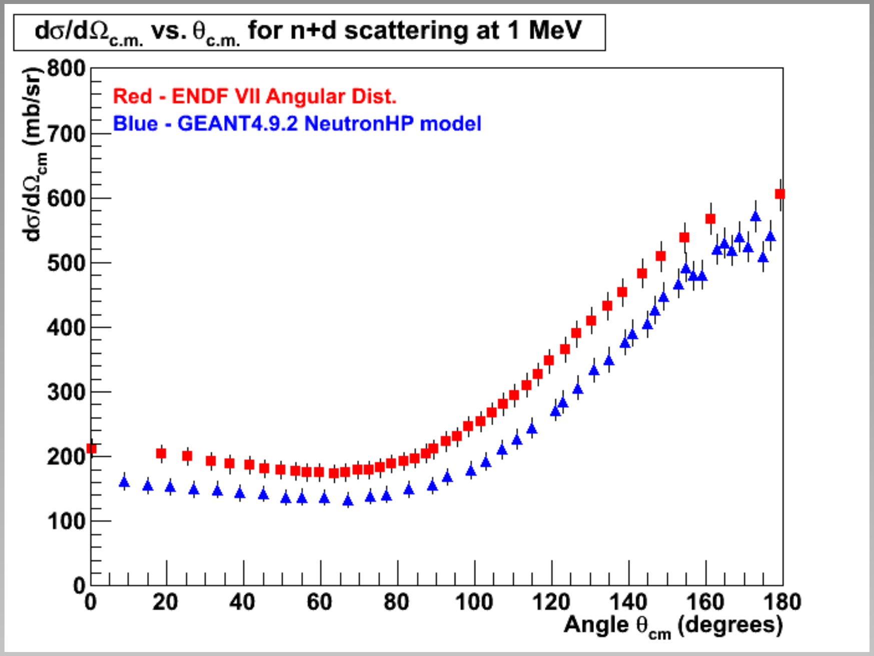
Angular distributions – elastic scattering on p

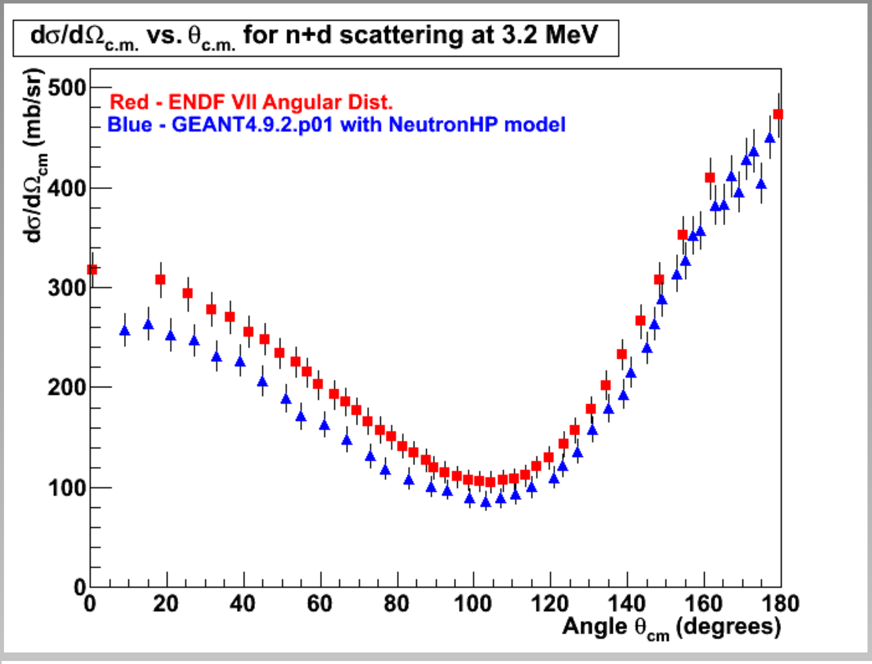


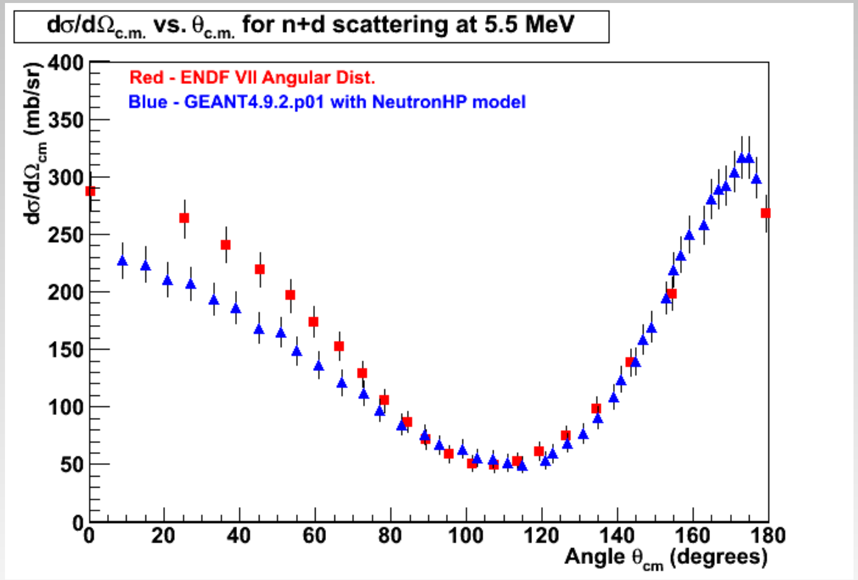


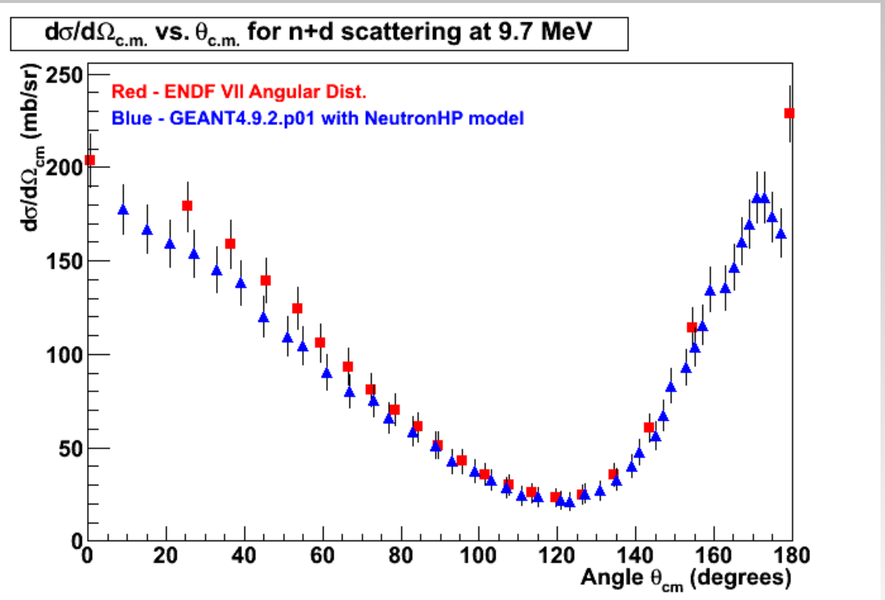
by Brian Roeder

Angular distributions – elastic scattering on d



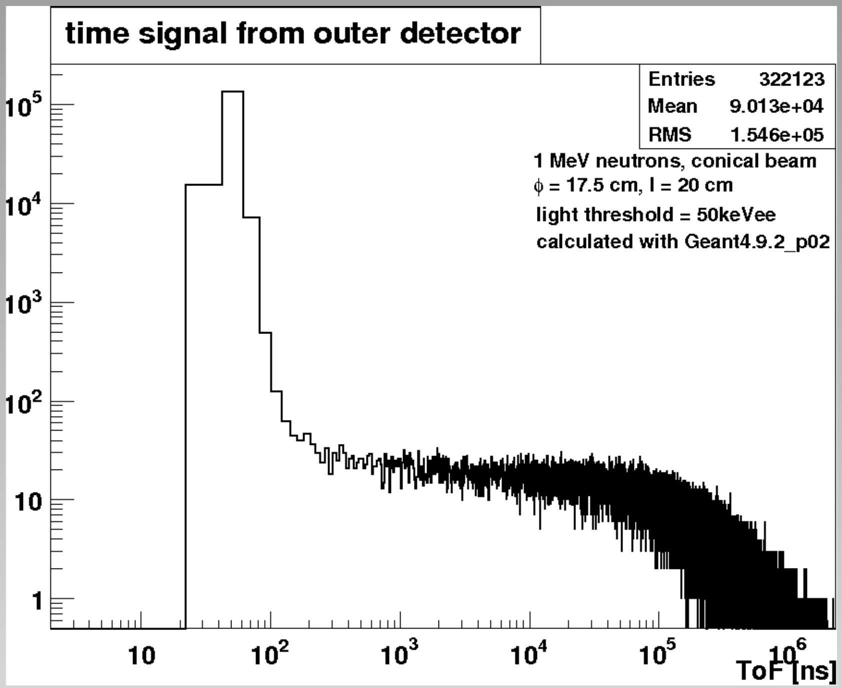


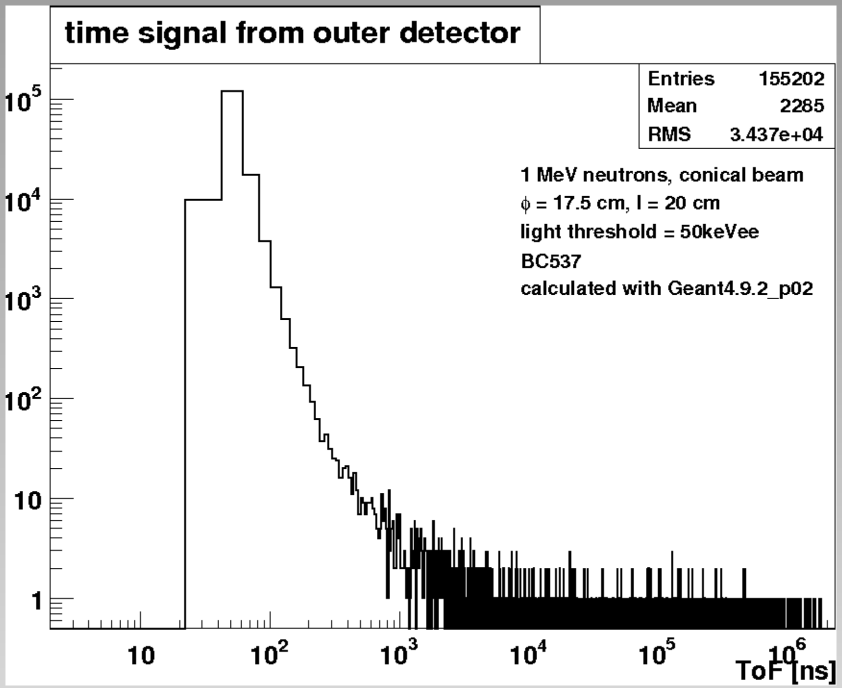




by Brian Roeder

Times of the interactions – late light flash

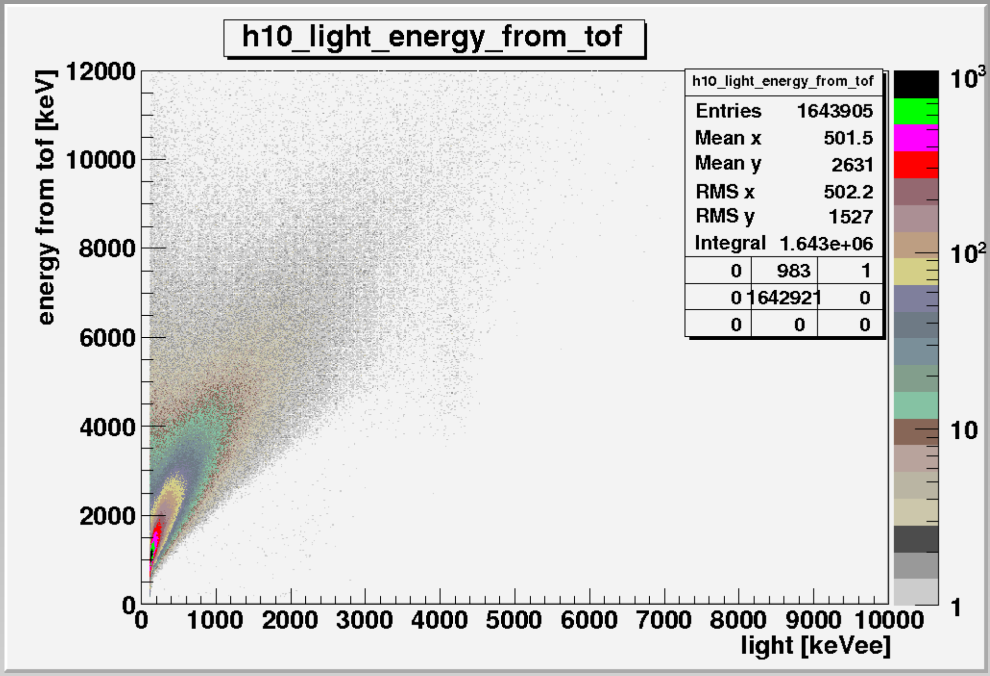




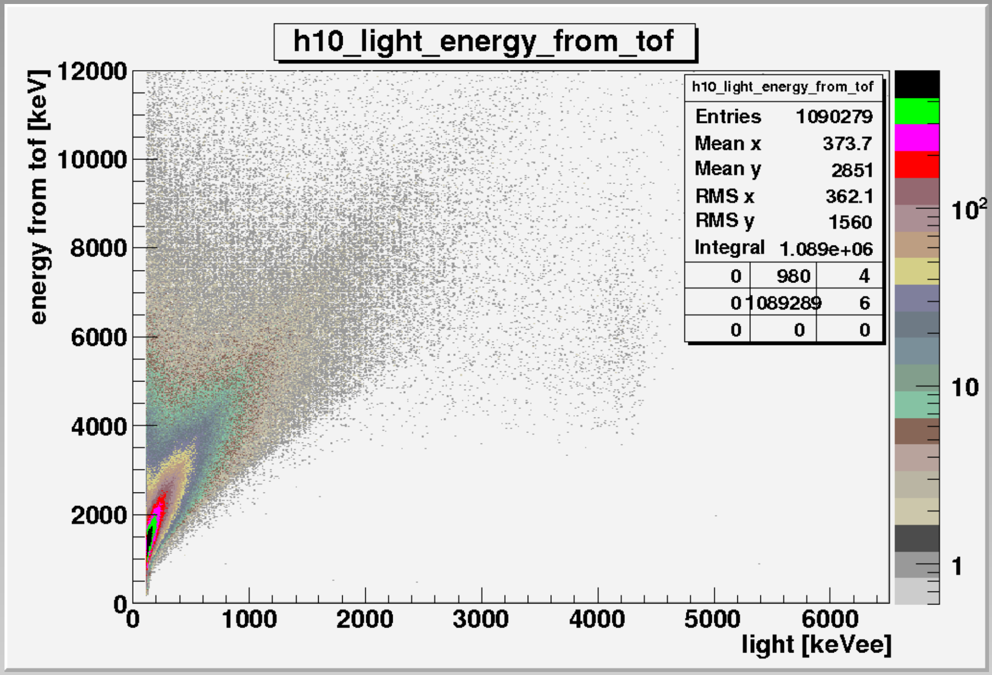
Time gates adopted in the simulations of GJ and TH:
light threshold must be exceeded within 100 ns
light collection gate 0-400 ns

Light vs. energy (from TOF) correlation ?

BC501



BC537



Neutron interactions in the scintillator

Geant4.9.2.p03

- elastic scattering on p, d and ^{12}C
- $^{12}C(n,n'\gamma)^{12}C$, $E_\gamma = 4.439$ MeV
- endothermic $^{12}C(n,a)^{9}Be$ Q=-5.701
- exothermic neutron capture on p, d, ^{12}C followed by gamma emission
- similar reactions on rare isotopes contained in the scintillators: ^{13}C and d (in case BC501A), ^{13}C and p (BC537)

Energy of p, d, 9Be, 12C, electrons and gammas converted to light. Light transportation and collection not included in the simulation.

Warning: . “The Physics processes and models available in the Geant4 Low Energy Electromagnetic package have been entirely re-designed from Geant4 version 9.3”

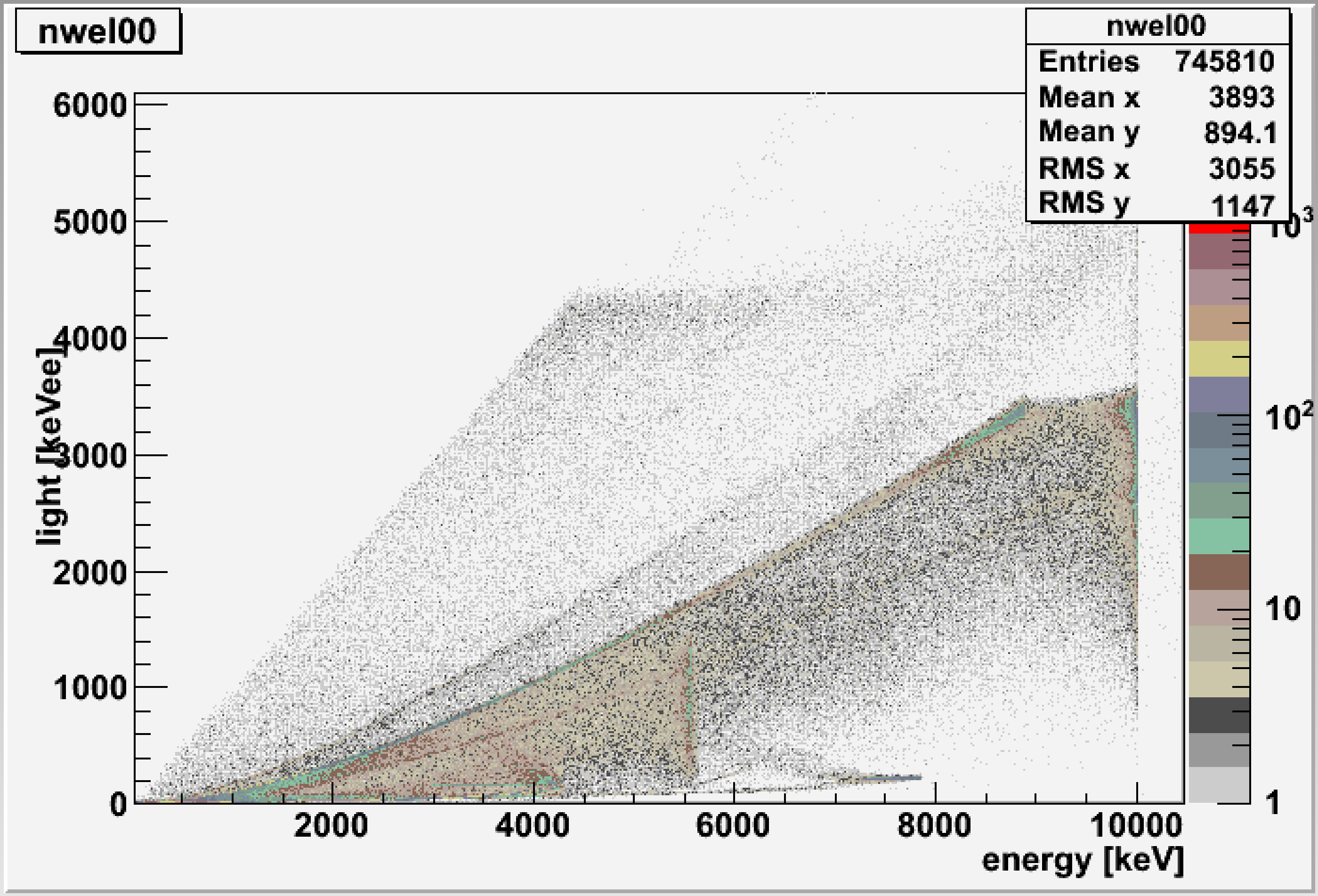
Definitions of the parameters

1n: $$eff_{1n} = \frac{N^{1n}_{d \geqslant 1}}{N^{1n}_{emitted}}$$

2n: $$eff_{2n} = \frac{N^{2n}_{d \geqslant 2}}{N^{2n}_{emitted}} \qquad P_{1n\,2n} = \frac{N^{1n}_{d \geqslant 2}}{N^{1n}_{d \geqslant 1}}$$

d – number of neutrons detected (with all additional conditions)

Light vs energy BC537



Energy deposit in the detector: BC501A, BC537

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16.5 x 15 cm cylinder