EVENT-BY-EVENT MONTE CARLO TRACKING OF NEUTRON-NUCLEUS COLLISIONS IN NEUTRON DETECTORS

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Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom

A VERY SIMPLE EXPERIMENT

THERMAL NEUTRONS IN BORON-10

- **ONE ENERGY**
- **ONE MATERIAL**
- **ONE CELL**

TWO INDEPENDENT MONTE CARLO CODES

- **MCNPX**
- **FLUKA**

WHEN EVERYONE'S BUSY MODELLING VERY COMPLEX PROBLEMS

THE EXTREME ...

OR AT LEAST ...

TO SEE THINGS WE WOULDN'T OTHERWISE SEE

T DOSE

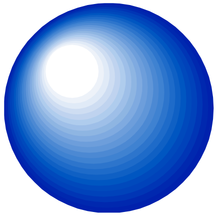
et al 2006
Computing

LARGE H

WHY SHOULD WE SIMULATE

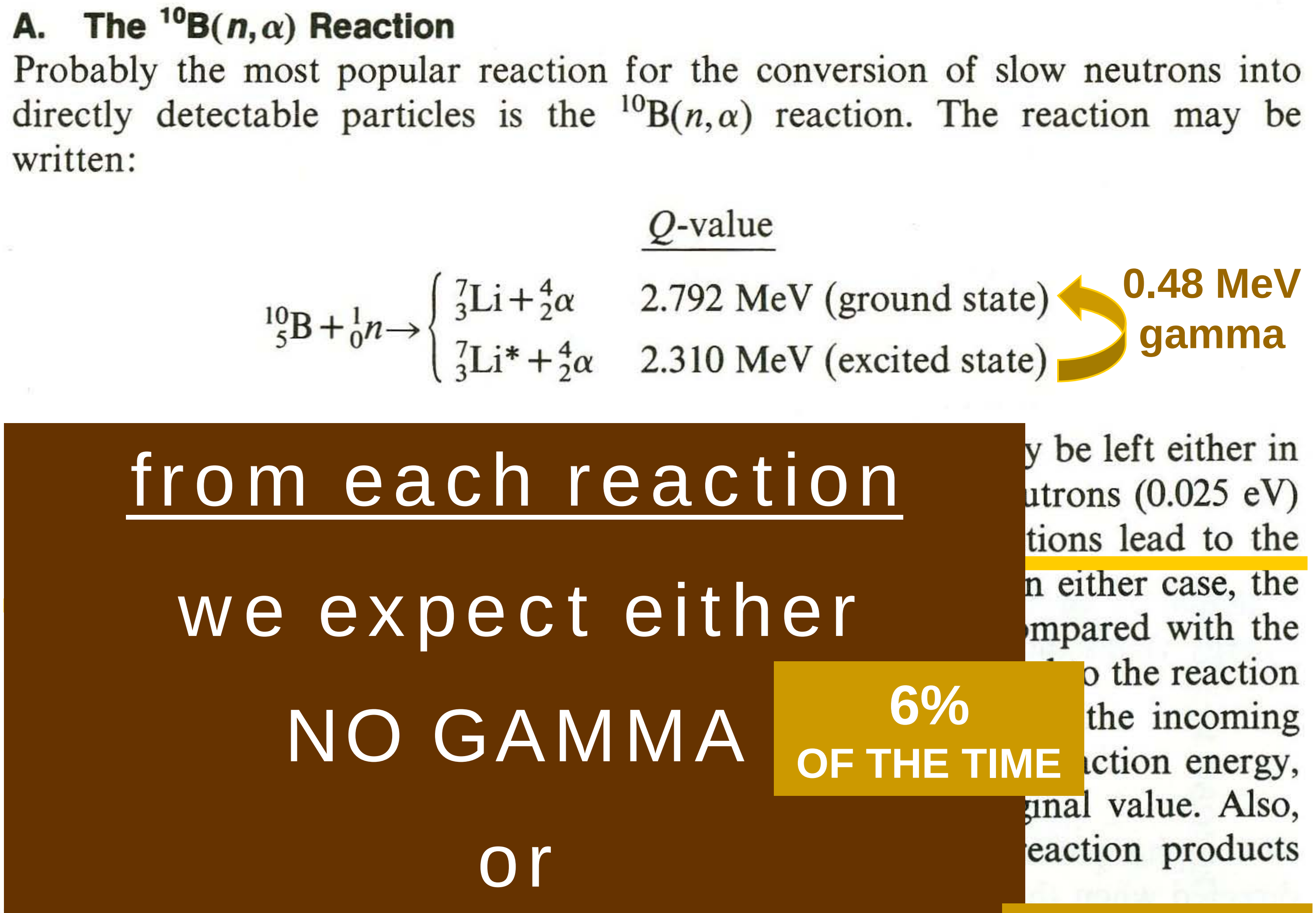
SIMPLE SPHERE

SINGLE NUCLIDE



MONOENERGETIC BEAM

SINGLE PARTICLE TYPE



A. The ^{10}B(n,α) Reaction

Probably the most popular reaction for the conversion of slow neutrons into directly detectable particles is the ^{10}B(n,α) reaction. The reaction may be written:

Q-value

$$ {}^{10}_{5}\mathrm{B} + {}^{1}_{0}n \rightarrow \begin{cases} {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\alpha & 2.792\ \text{MeV (ground state)} \\ {}^{7}_{3}\mathrm{Li}^{*} + {}^{4}_{2}\alpha & 2.310\ \text{MeV (excited state)} \end{cases} $$

0.48 MeV gamma

from each reaction

we expect either

NO GAMMA

6%
OF THE TIME

or

ONE 0.48 MeV GAMMA

94%
OF THE TIME

y be left either in
utrons (0.025 eV)
tions lead to the
n either case, the
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the incoming
action energy,
ginal value. Also,
eaction products

EXCERPT FROM G. KNOLL
RADIATION DETECTION & MEASUREMENT

MCNPX WOULD QUITE HAPPILY GIVE US ONE, TWO, THREE, ...

from each reaction

we expect either

NO GAMMA

6%
OF THE TIME

or

ONE 0.48 MeV GAMMA

94%
OF THE TIME

MCNPX WOULD QUITE HAPPILY GIVE US ONE, TWO, THREE, ...

MCNPX SIMULATION

SOURCE: 0.025 eV NEUTRONS

NUMBER OF HISTORIES: 10 MILLION

MEDIUM: ^{10}B

OUT OF 10 MILLION NEUTRONS STARTED

632,665 COUNTS OF ZERO GAMMA PER NEUTRON

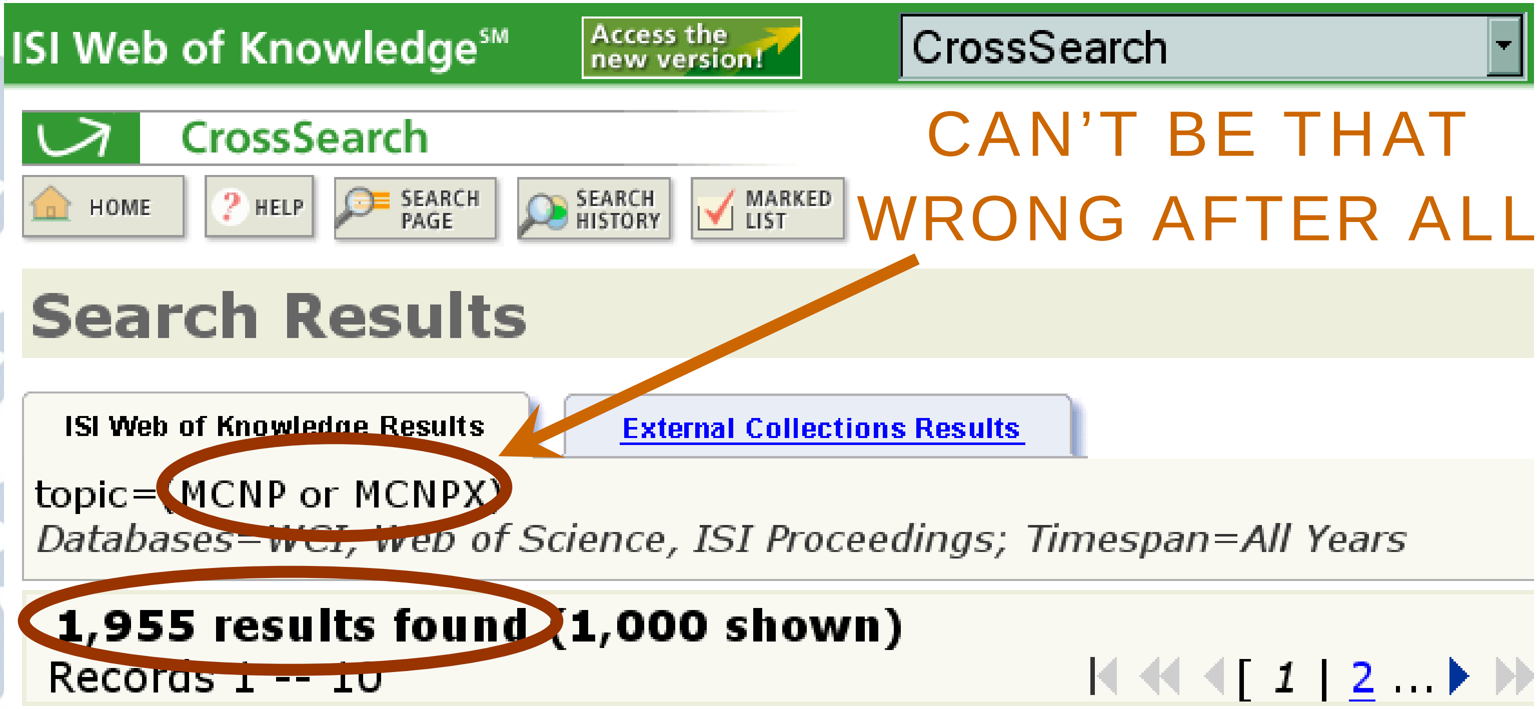
9,362,277 COUNTS OF 1 GAMMA PER NEUTRON

5,053 COUNTS OF 2 GAMMAS PER NEUTRON

5 COUNTS OF 3 GAMMAS PER NEUTRON

VIOLATES THEORETICAL EXPECTATION

YET ...



Search Results

topic=(MCNP or MCNPX)
Databases=WCI, Web of Science, ISI Proceedings; Timespan=All Years

1,955 results found (1,000 shown)
Records 1 -- 10

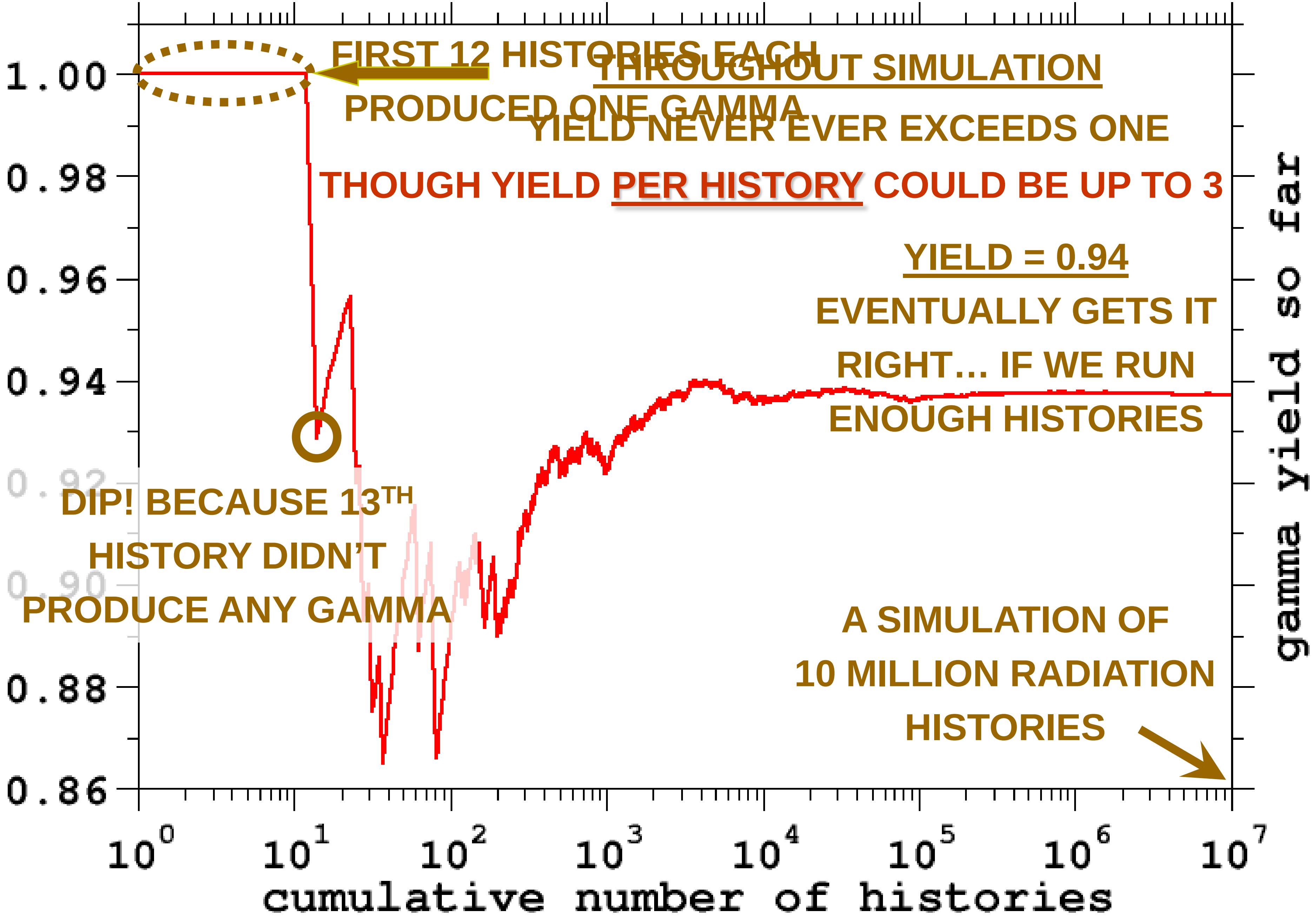
CAN'T BE THAT WRONG AFTER ALL

USED WORLDWIDE

TO SOLVE A WIDE RANGE OF PROBLEMS

OVER THE YEARS

VIOLATES THEORETICAL EXPECTATION



FIRST 12 HISTORIES EACH PRODUCED ONE GAMMA

THROUGHOUT SIMULATION YIELD NEVER EVER EXCEEDS ONE

THOUGH YIELD PER HISTORY COULD BE UP TO 3

YIELD = 0.94 EVENTUALLY GETS IT RIGHT… IF WE RUN ENOUGH HISTORIES

DIP! BECAUSE 13TH HISTORY DIDN'T PRODUCE ANY GAMMA

A SIMULATION OF 10 MILLION RADIATION HISTORIES

THIS HAS ALWAYS BEEN IN
MCNP/MCNPX

NOT A BUG, BUT
A DESIGN FEATURE

NOT NEW, JUST THAT
MOST USERS ARE UNAWARE

DOESN'T MATTER IN MOST CASES
AFFECTS EXCEPTIONS ONLY

VIOLATES THEORETICAL EXPECTATION

MCNP-PoliMi: a Monte-Carlo code for correlation measurements

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Department of Nuclear Engineering, Polytechnic of Milan, Via Ponzio 34/3, Milan 20133, Italy

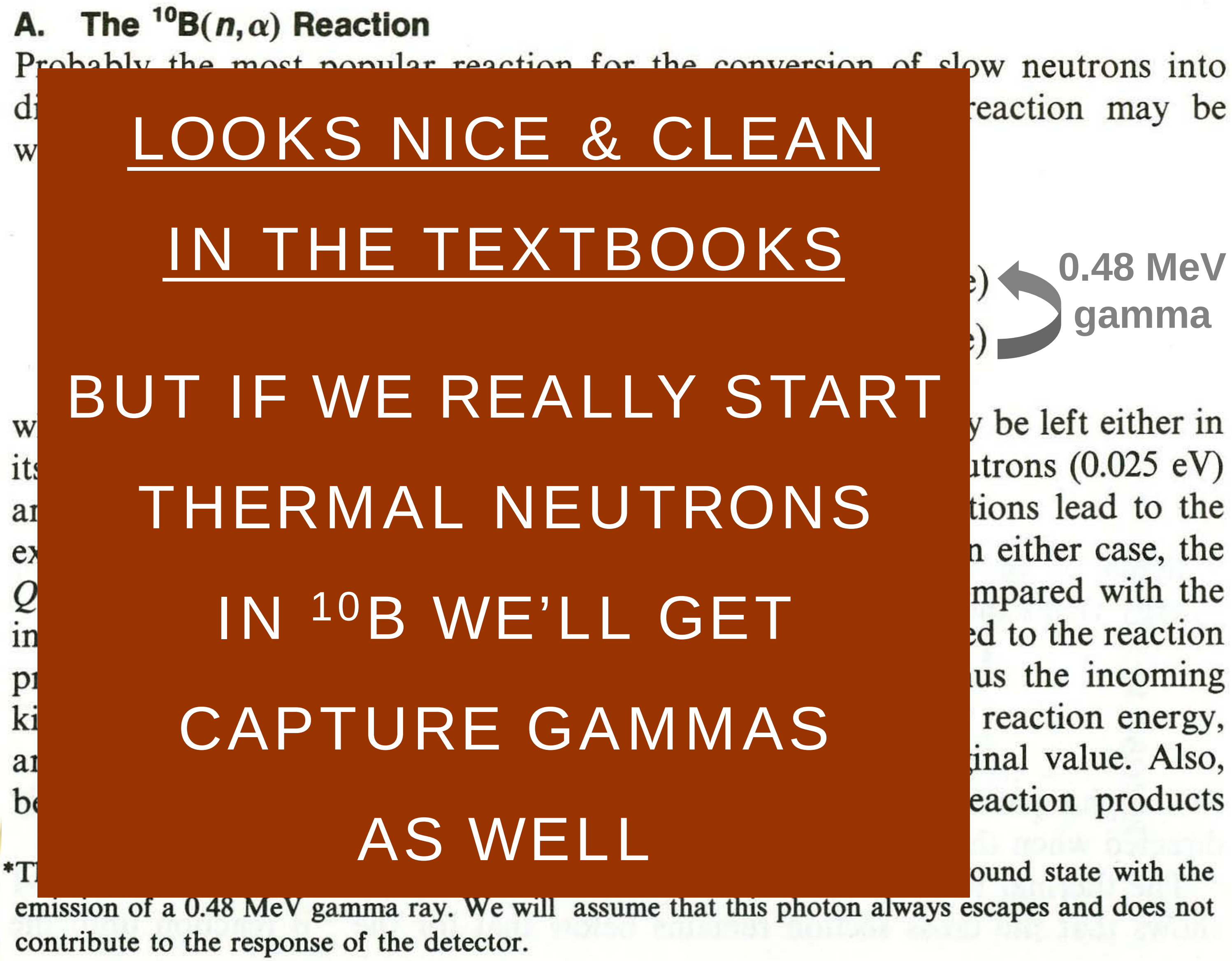
Nuclear Instruments and Methods in Physics Research A 513 (2003)

deviation from physical reality: the emission of secondary gamma rays from neutron collisions. In fact, in MCNP secondary photons are sampled independently from the type of neutron collision. For example, it is possible for a neutron in a collision with uranium to generate fission photons in the course of an elastic scattering. This technique provides correct answers when we consider the average outcome of a large number of histories, and it is well suited for biased calculations, but it fails when considering the single history [2]. This is a severe drawback in the simulation of correlation measurements in which the experimental quantity of interest is the delay between particles emitted by a single event [1,3].

In this paper we describe the MCNP-PoliMi of the standard MCNP cod
A major deviation to th
introduced by inverting th
photon production and neu

The MCNP-PoliMi cod
particle tracking. This me
equal to one to each of the
the source and to each of t
born at a collision. With
particles have weight equ
escape or are absorbed,
process simpler to model.

The modifications to th
transport can be grouped in
first concerns secondary
whereas the second concer



A. The ^{10}B(n,α) Reaction

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*T
ound state with the emission of a 0.48 MeV gamma ray. We will assume that this photon always escapes and does not contribute to the response of the detector.

0.48 MeV
gamma

LOOKS NICE & CLEAN

IN THE TEXTBOOKS

BUT IF WE REALLY START

THERMAL NEUTRONS

IN ^{10}B WE'LL GET

CAPTURE GAMMAS

AS WELL

EXCERPT FROM G. KNOLL
RADIATION DETECTION & MEASUREMENT

THERMAL NEUTRONS IN ^{10}B

WHAT DO WE EXPECT OF THE GAMMA SPECTRUM?

What do we get from a FLUKA[‡] simulation?

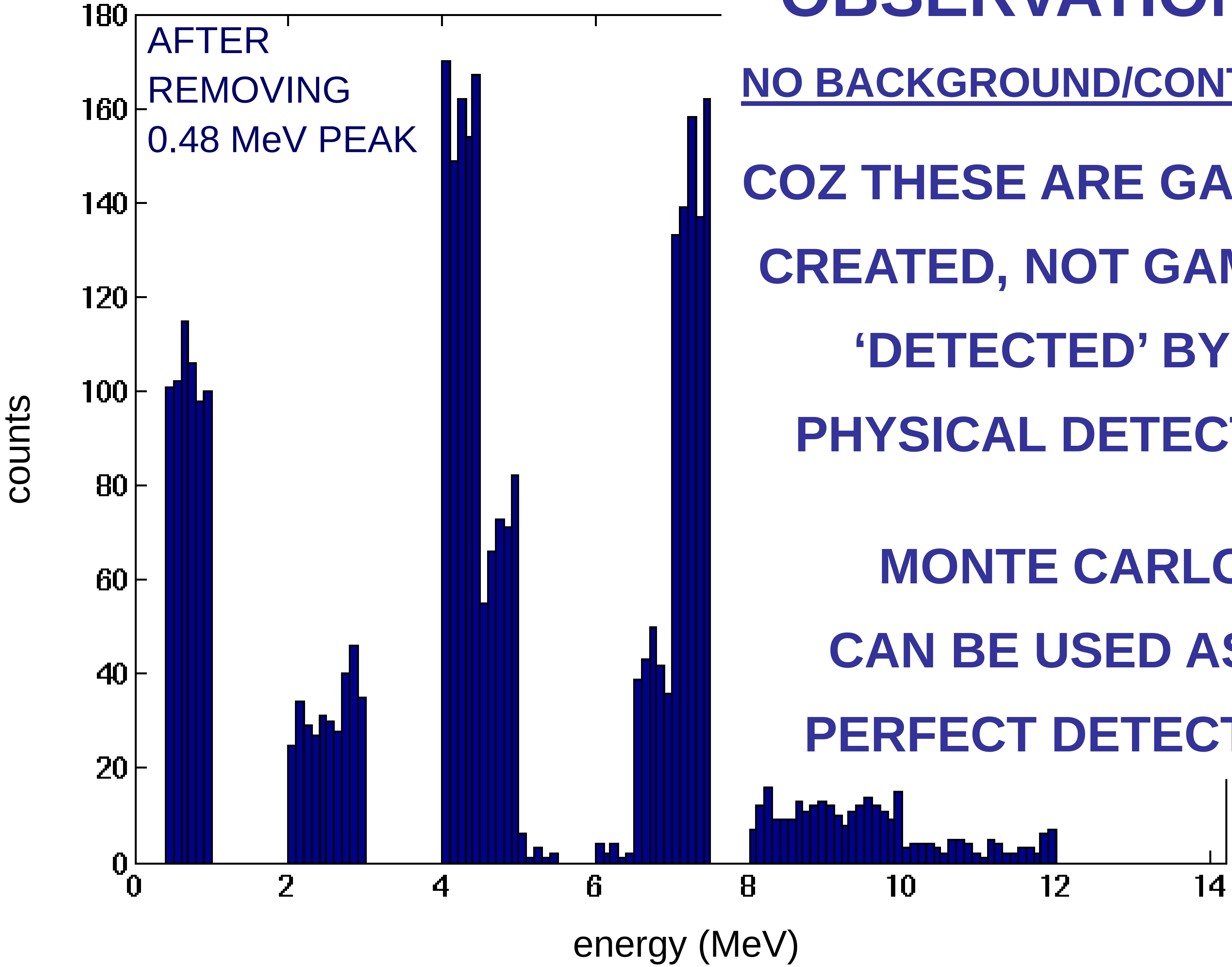
[‡] ***developed by INFN & CERN***

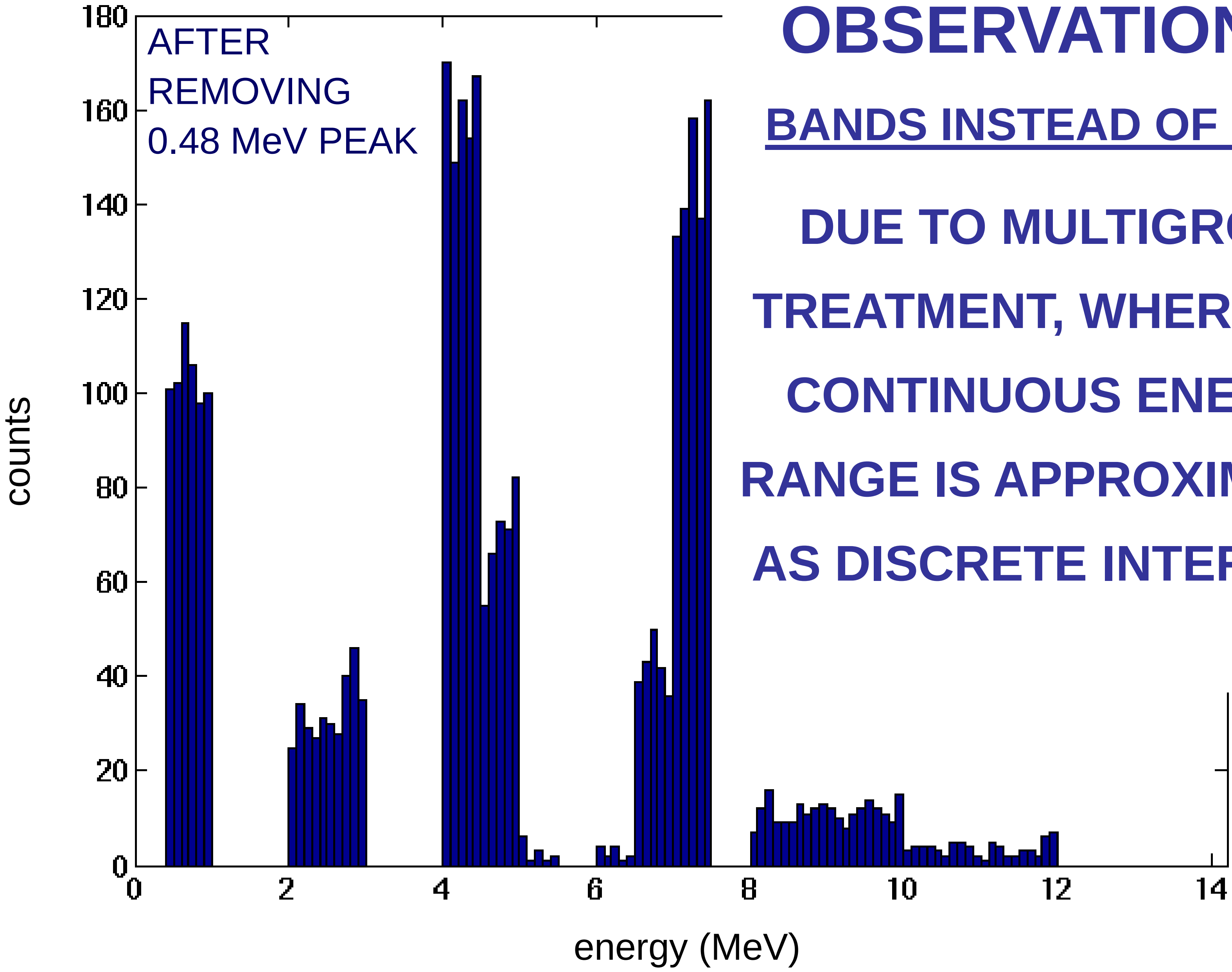
OBSERVATION #1

NO BACKGROUND/CONTINUUM

COZ THESE ARE GAMMAS CREATED, NOT GAMMAS ‘DETECTED’ BY A PHYSICAL DETECTOR

MONTE CARLO CAN BE USED AS A PERFECT DETECTOR


AFTER REMOVING 0.48 MeV PEAK



OBSERVATION #2

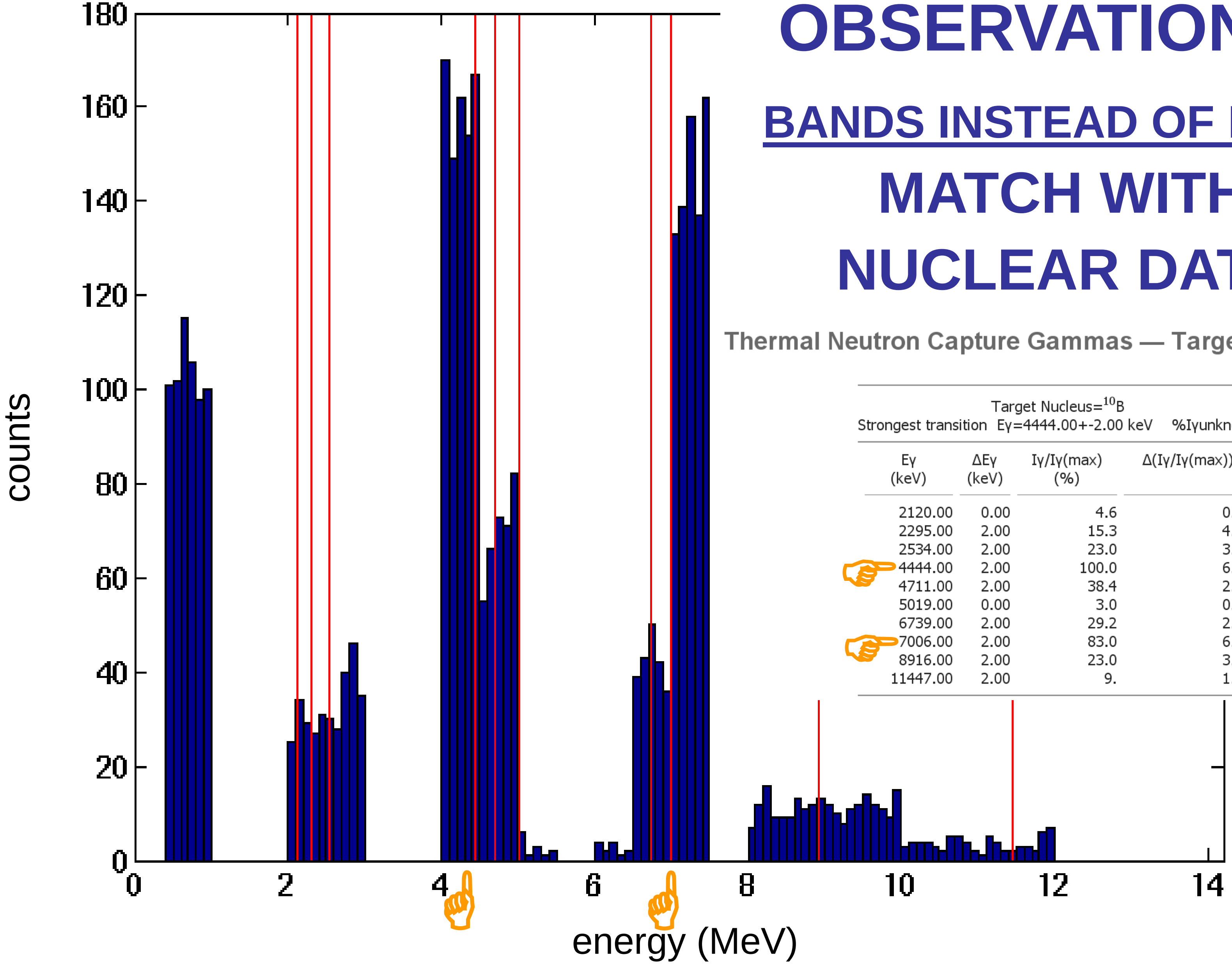
BANDS INSTEAD OF LINES

DUE TO MULTIGROUP TREATMENT, WHERE THE CONTINUOUS ENERGY RANGE IS APPROXIMATED AS DISCRETE INTERVALS

OBSERVATION #2

BANDS INSTEAD OF LINES

MATCH WITH NUCLEAR DATA



Thermal Neutron Capture Gammas — Target Nucleus ^{10}B

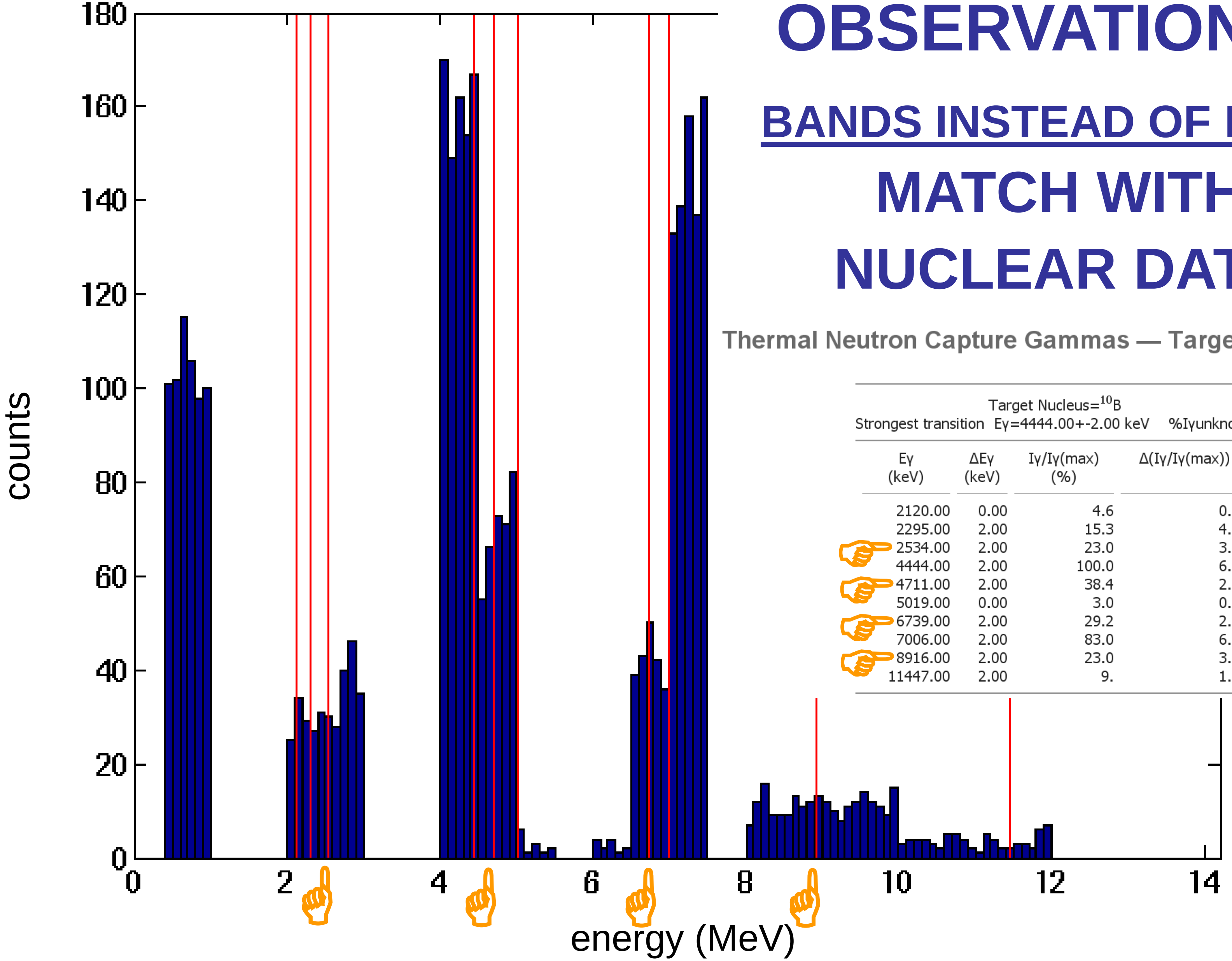
Target Nucleus=^{10}B
Strongest transition Eγ=4444.00+-2.00 keV %Iγunknown

Eγ (keV)	ΔEγ (keV)	Iγ/Iγ(max) (%)	Δ(Iγ/Iγ(max))
2120.00	0.00	4.6	0.21
2295.00	2.00	15.3	4.67
2534.00	2.00	23.0	3.26
4444.00	2.00	100.0	6.53
4711.00	2.00	38.4	2.35
5019.00	0.00	3.0	0.14
6739.00	2.00	29.2	2.05
7006.00	2.00	83.0	6.00
8916.00	2.00	23.0	3.26
11447.00	2.00	9.	1.60

OBSERVATION #2

BANDS INSTEAD OF LINES

MATCH WITH NUCLEAR DATA



Thermal Neutron Capture Gammas — Target Nucleus ^{10}B

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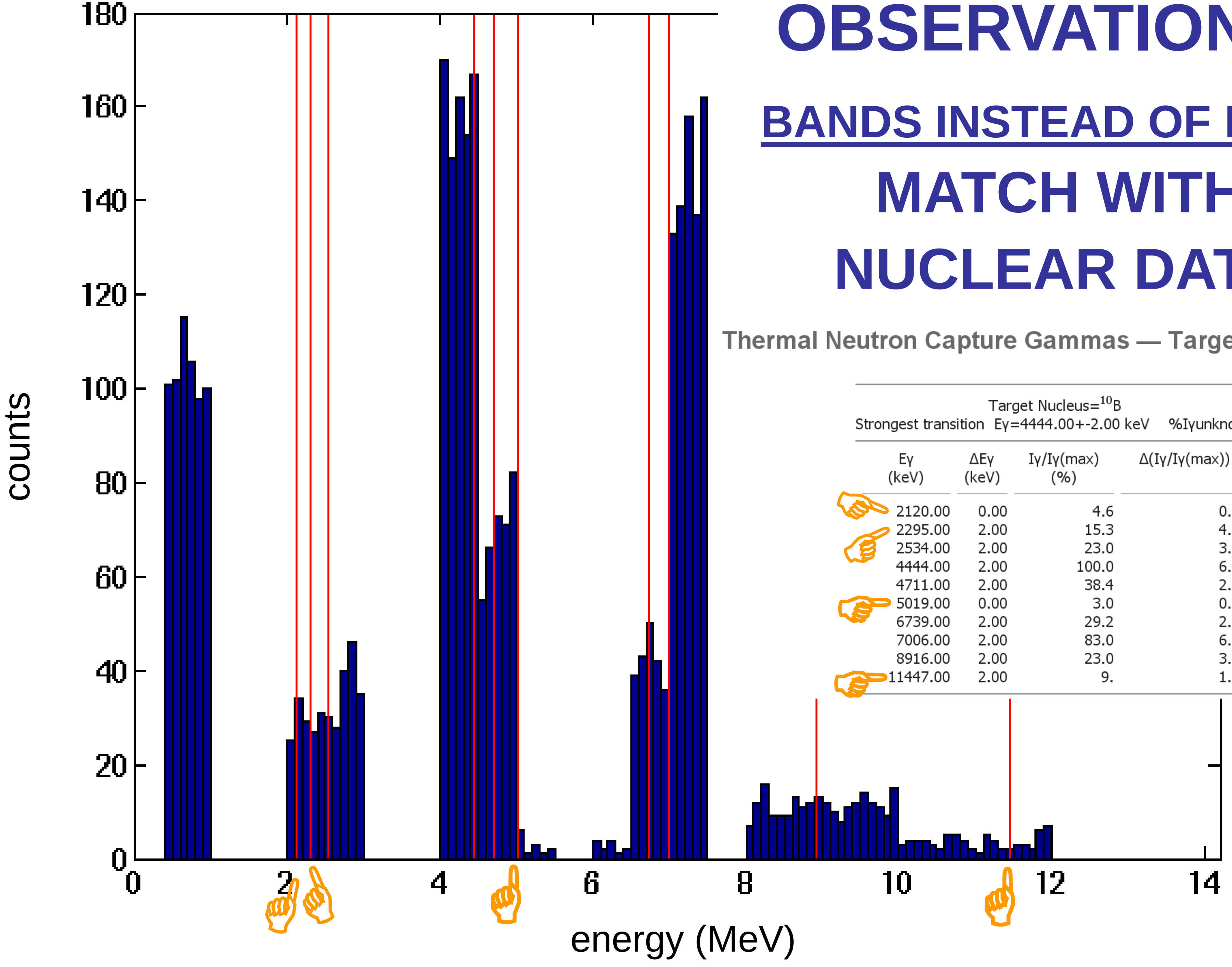
	11447.00	2.00	9.	1.60

OBSERVATION #2

BANDS INSTEAD OF LINES

MATCH WITH NUCLEAR DATA

OK



Thermal Neutron Capture Gammas — Target Nucleus ^{10}B

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Strongest transition Eγ=4444.00+-2.00 keV %Iγunknown

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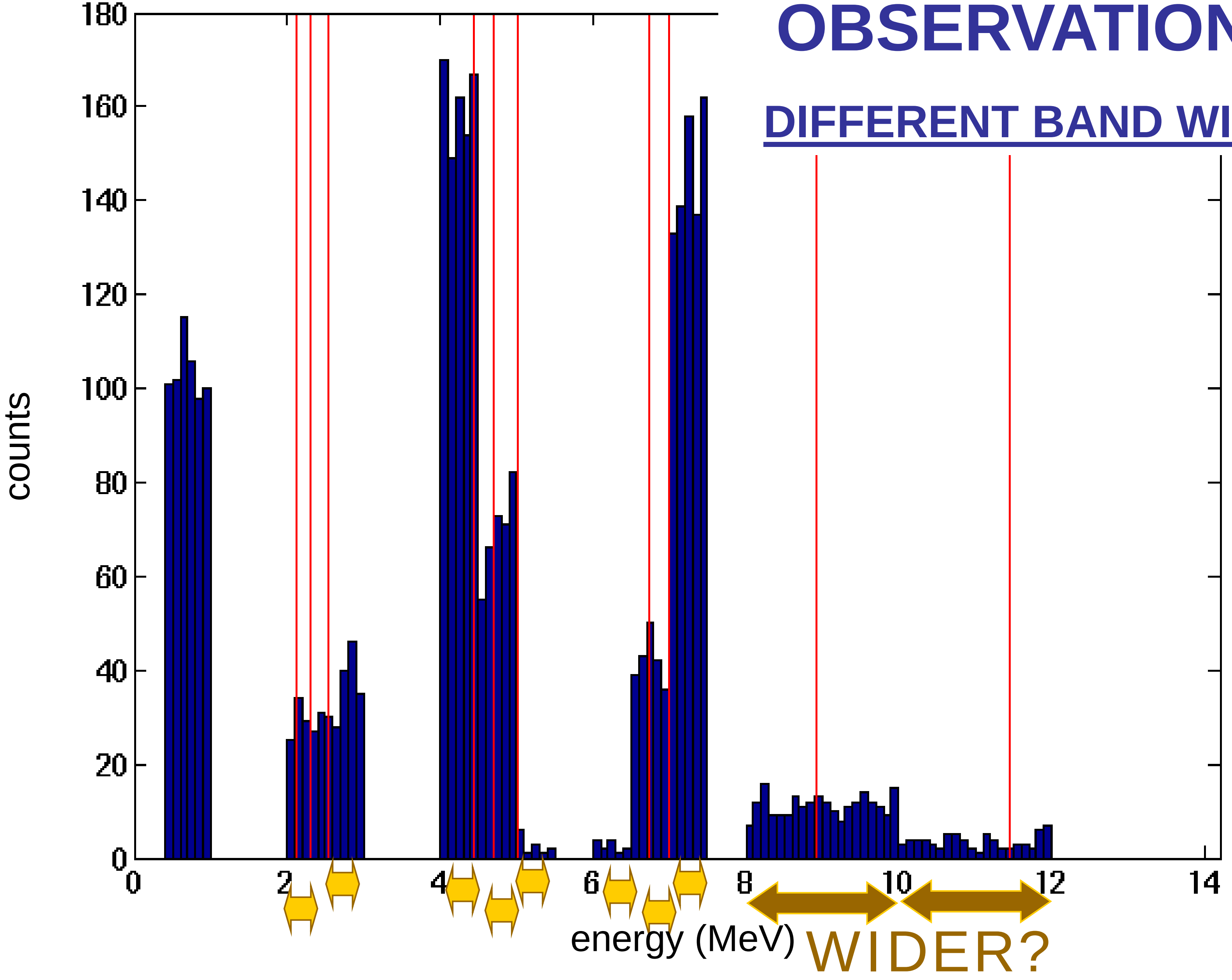
7006.00	2.00	83.0	6.00
8916.00	2.00	23.0	3.26
11447.00	2.00	9.	1.60

OBSERVATION #3

DIFFERENT BAND WIDTHS



OBSERVATION #3

DIFFERENT BAND WIDTHS

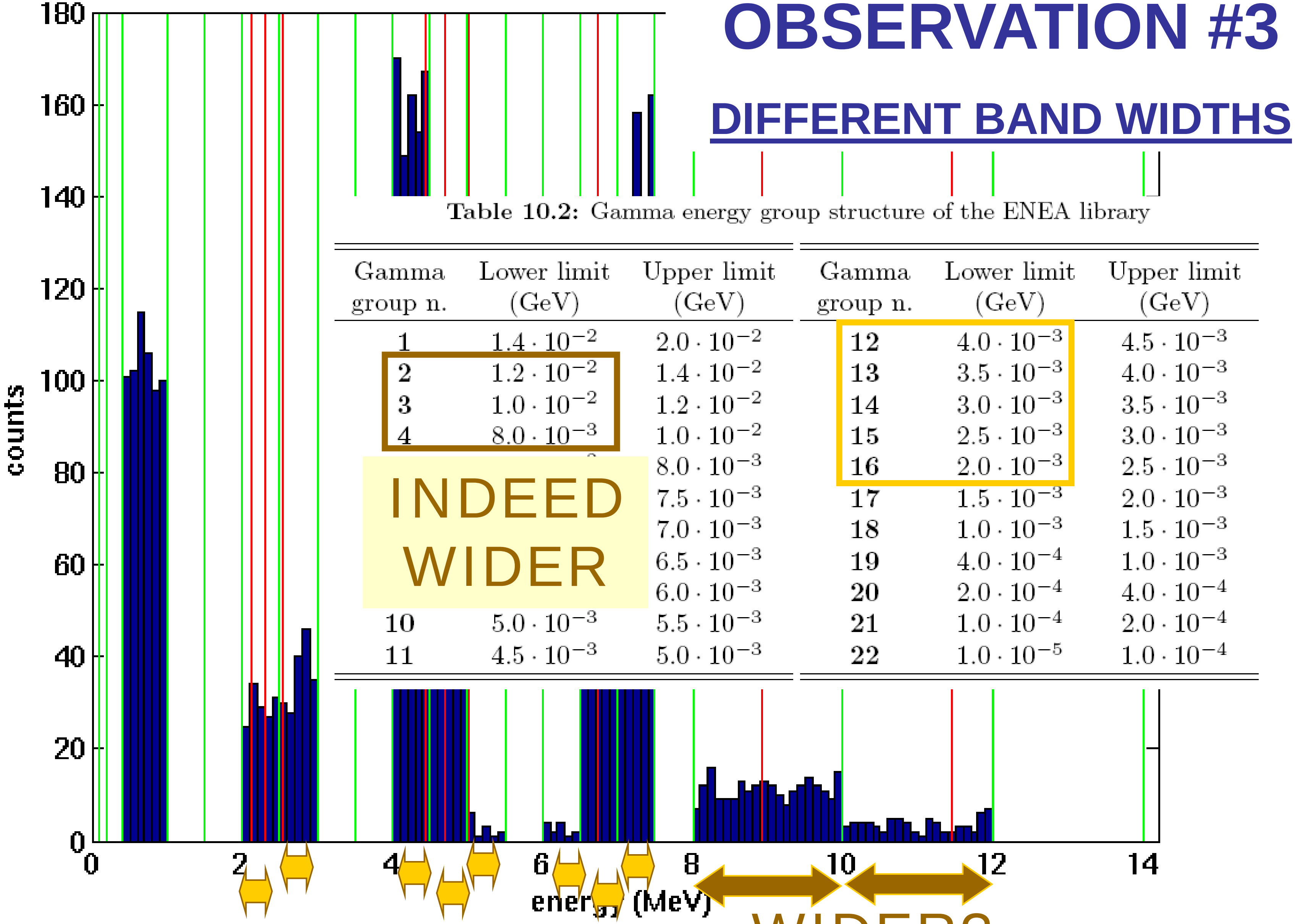


Table 10.2: Gamma energy group structure of the ENEA library

Gamma group n.	Lower limit (GeV)	Upper limit (GeV)	Gamma group n.	Lower limit (GeV)	Upper limit (GeV)
1	$1.4 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$	**12**	$4.0 \cdot 10^{-3}$	$4.5 \cdot 10^{-3}$
2	$1.2 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$	**13**	$3.5 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$
3	$1.0 \cdot 10^{-2}$	$1.2 \cdot 10^{-2}$	**14**	$3.0 \cdot 10^{-3}$	$3.5 \cdot 10^{-3}$
4	$8.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-2}$	**15**	$2.5 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$
[illegible]	[illegible]	$8.0 \cdot 10^{-3}$	**16**	$2.0 \cdot 10^{-3}$	$2.5 \cdot 10^{-3}$
[illegible]	[illegible]	$7.5 \cdot 10^{-3}$	**17**	$1.5 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$
[illegible]	[illegible]	$7.0 \cdot 10^{-3}$	**18**	$1.0 \cdot 10^{-3}$	$1.5 \cdot 10^{-3}$
[illegible]	[illegible]	$6.5 \cdot 10^{-3}$	**19**	$4.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-3}$
[illegible]	[illegible]	$6.0 \cdot 10^{-3}$	**20**	$2.0 \cdot 10^{-4}$	$4.0 \cdot 10^{-4}$
10	$5.0 \cdot 10^{-3}$	$5.5 \cdot 10^{-3}$	**21**	$1.0 \cdot 10^{-4}$	$2.0 \cdot 10^{-4}$
11	$4.5 \cdot 10^{-3}$	$5.0 \cdot 10^{-3}$	**22**	$1.0 \cdot 10^{-5}$	$1.0 \cdot 10^{-4}$

INDEED WIDER

WIDER?

Hi Mary,

there are two neutron cut-offs in FLUKA. 1.960E-02GeV is the cut-off for high-energy neutrons, below which the special multigroup treatment starts. With the present version it cannot be changed: it could be changed only when using a different library for low-energy neutrons (one with a different maximum energy). This cut-off is changed with PART-THR, but only when allowed by the low-energy neutron library

The second cut-off, which is changed with LOW-BIAS, is the real cut-off. It is not expressed in energy, but as a neutron group number. Look carefully in the output:

The first cut-off is reported as follows:

```
Cut-off kinetic energy for NEUTRON  transport:  1.960E-02 GeV
```

And the second cut-off as follows: (here the group cut-off has been set as 73 for regions 1 and 2 - which means no cut-off at all - and group 65 in regions 3 and 4)

```
Region      Particle   importances        RR factor   Cut off  N.A. abs.
 number  Fluka part.   EM part.  Low en. n.             group     group

     1     1.0000     1.0000     1.0000                  73        72
     2     1.0000     1.0000     1.0000                  73        72
     3     1.0000     1.0000     1.0000                  65        72
     4     1.0000     1.0000     1.0000                  65        72
```

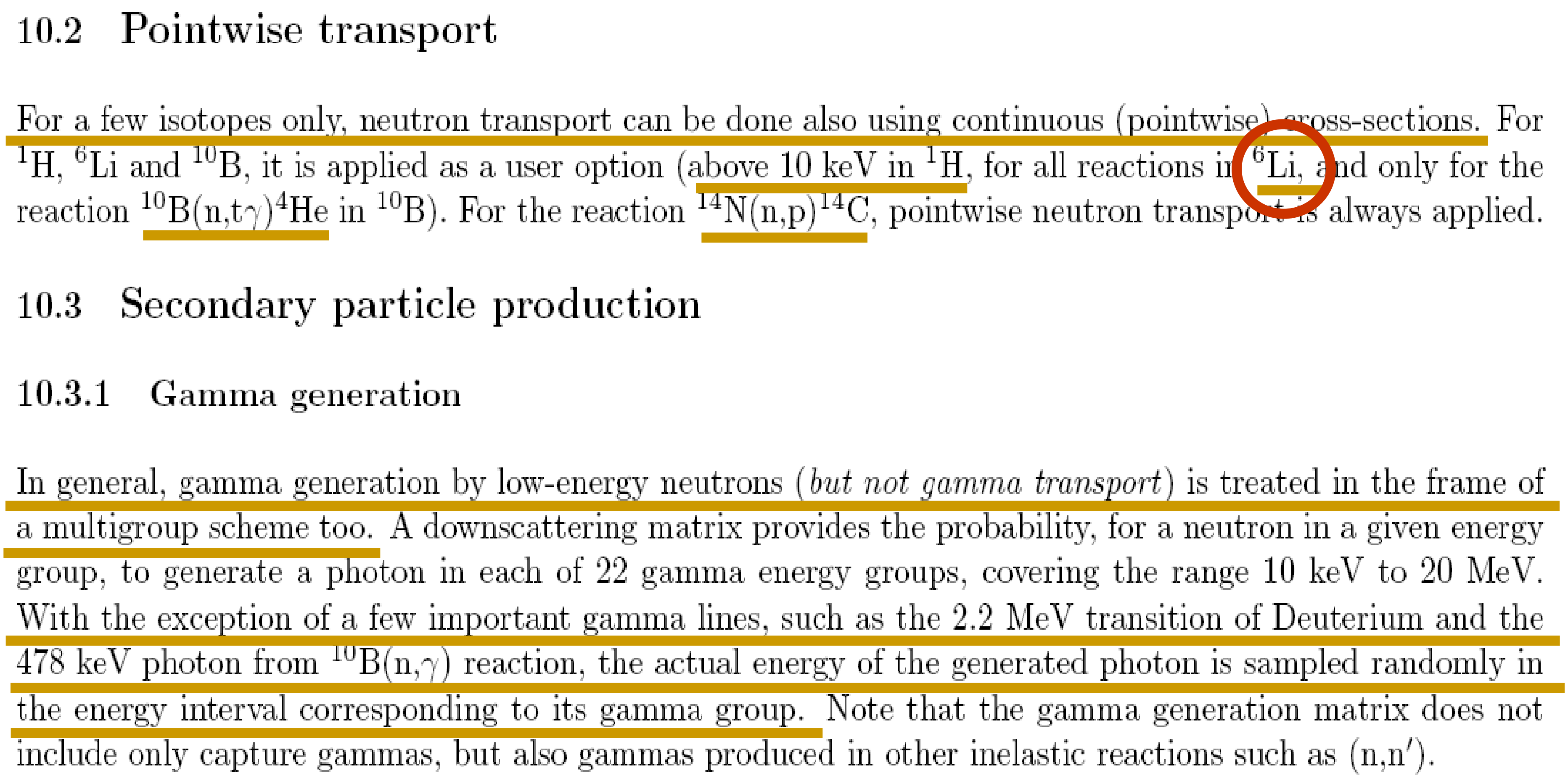
Here the group cut-off has been set as 73 for regions 1 and 2 - which means no cut-off at all - and group 65 in regions 3 and 4, which means 7.3375E-09 GeV (see energy group structure in the Manual).

Alberto

FLUKA

MULTIGROUP vs POINTWISE TREATMENTS

(APPROXIMATION) (CONTINUOUS)



10.2 Pointwise transport

For a few isotopes only, neutron transport can be done also using continuous (pointwise) cross-sections. For ^{1}H, ^{6}Li and ^{10}B, it is applied as a user option (above 10 keV in ^{1}H, for all reactions in ^{6}Li, and only for the reaction ^{10}B(n,tγ)^{4}He in ^{10}B). For the reaction ^{14}N(n,p)^{14}C, pointwise neutron transport is always applied.

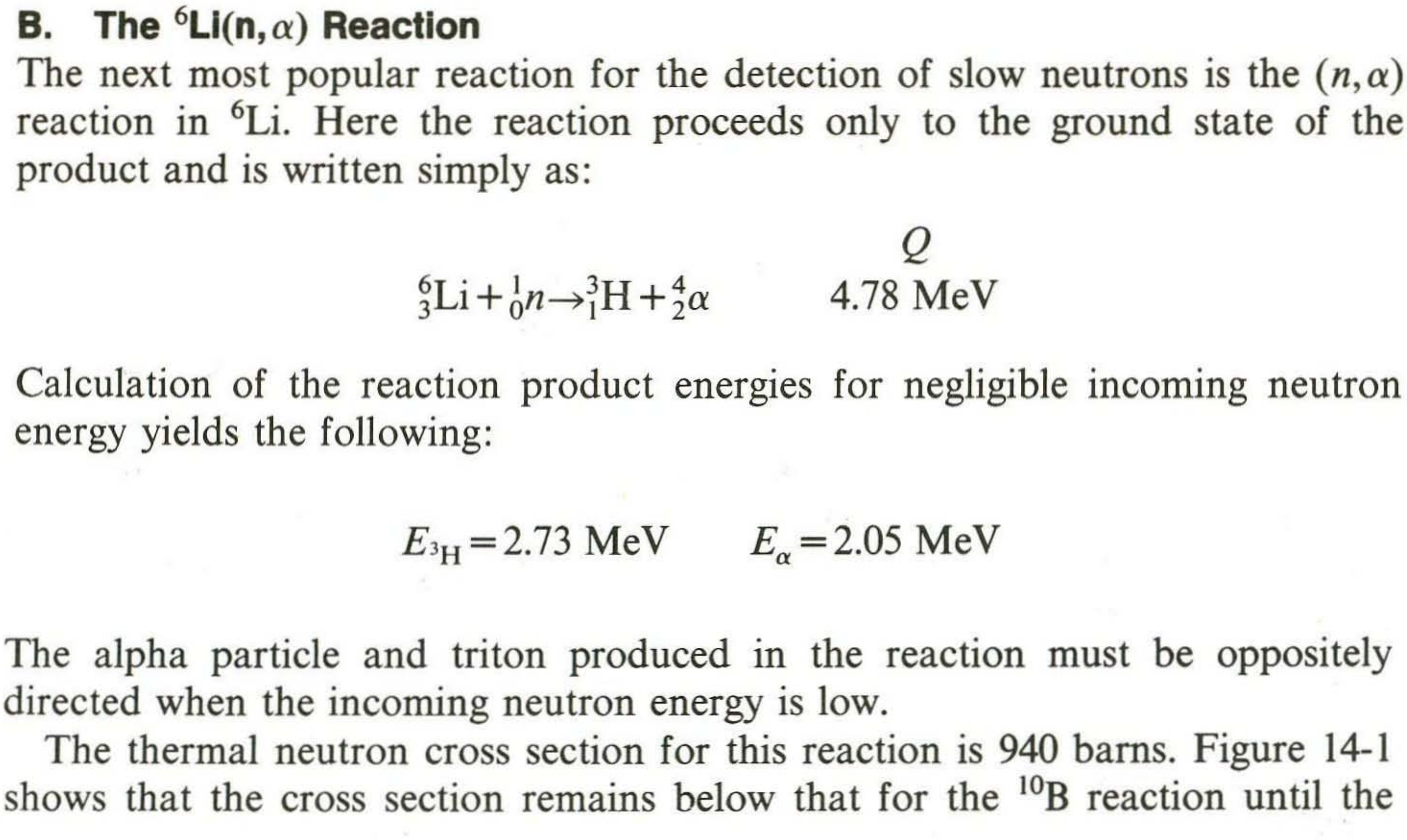
10.3 Secondary particle production

10.3.1 Gamma generation

In general, gamma generation by low-energy neutrons (*but not gamma transport*) is treated in the frame of a multigroup scheme too. A downscattering matrix provides the probability, for a neutron in a given energy group, to generate a photon in each of 22 gamma energy groups, covering the range 10 keV to 20 MeV. With the exception of a few important gamma lines, such as the 2.2 MeV transition of Deuterium and the 478 keV photon from ^{10}B(n,γ) reaction, the actual energy of the generated photon is sampled randomly in the energy interval corresponding to its gamma group. Note that the gamma generation matrix does not include only capture gammas, but also gammas produced in other inelastic reactions such as (n,n′).

EXCERPT FROM FLUKA MANUAL

NOT COVERED IN THIS TALK
BUT DETAILED IN *SUMMARY* (ANS TRANS)



B. The ^{6}Li(n, α) Reaction

The next most popular reaction for the detection of slow neutrons is the (n, α) reaction in ^{6}Li. Here the reaction proceeds only to the ground state of the product and is written simply as:

$$^{6}_{3}\mathrm{Li} + ^{1}_{0}n \rightarrow ^{3}_{1}\mathrm{H} + ^{4}_{2}\alpha \qquad \overset{Q}{4.78\ \mathrm{MeV}}$$

Calculation of the reaction product energies for negligible incoming neutron energy yields the following:

$$E_{^{3}\mathrm{H}} = 2.73\ \mathrm{MeV} \qquad E_{\alpha} = 2.05\ \mathrm{MeV}$$

The alpha particle and triton produced in the reaction must be oppositely directed when the incoming neutron energy is low.

The thermal neutron cross section for this reaction is 940 barns. Figure 14-1 shows that the cross section remains below that for the ^{10}B reaction until the

EXCERPT FROM G. KNOLL
RADIATION DETECTION & MEASUREMENT

BEHIND THE SCENES

How we use FLUKA as a perfect detector

Cut-out from $FLUPRO/usermvax/mgdraw.f

```
ENTRY USDRAW ( ICODE, MREG, XSCO, YSCO, ZSCO )
     IF ( .NOT. LFCOPE ) THEN
        LFCOPE = .TRUE.
        IF ( KOMPUT .EQ. 2 ) THEN
           FILNAM = '/'//CFDRAW(1:8)//' DUMP A'
        ELSE
           FILNAM = CFDRAW
        END IF
        OPEN ( UNIT = IODRAW
    &          'UNFORMATTED' )
     END IF
     IF ( JTRACK .EQ. 8 .AND. Np.GT.0) THEN
       IF ( Np .EQ. 1 .AND. Kpart(1) . EQ. 8) THEN
       ELSE
          DO I = 1, Np
              WRITE (IODRAW) NCASE
    &                   SNGL (Tki(I))
          END DO
       END IF
     END IF
     RETURN
*=== End of subrutine Mgdr
```

IF NEUTRON, AND

IF THERE ARE SECONDARIES

FILTER OUT ELASTIC

SCATTER TO AVOID FILESIZE

EXPLOSION

LOOP THRU EACH SECONDARY

HISTORY #, TOTAL SECONDARIES

ENERGY OF PARENT

PARTICLE ID OF SECONDARY

ENERGY OF SECONDARY

	INFN + CERN	LOS ALAMOS
	FLUKA	MCNPX
ANALOG TRANSPORT	☺	
CROSS SECTION		☺

EVENT-BY-EVENT INVESTIGATIONS

Chin & Spyrou. Monte lo simulation of (n, γ)
activations: a comparis n
Int Con rends in Activat kyo,
2007.

NEUTRONS

MCNPX
FLUKA

Chin & S stories a o
simula Biomedical A
Energy eams. Guildford, 2007.

PROTONS
DEUTERONS

GEANT4
MCNPX
FLUKA

Chin & Spyrou. Monte C rlo investigation of p
annihilation in sitron emissi
Nucl. In thods Phys. Res., 481.

POSITRONS

EGSnrc
PENELOPE

CHOICE OF CODE

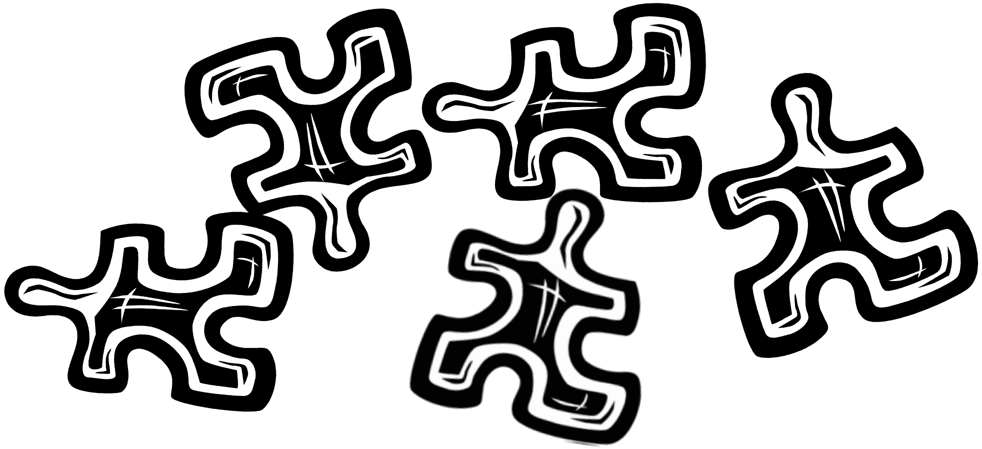
WRONG EMPHASIS ON CONVENIENCE

“GEOMETRY CODING IS THE EASIEST WITH GATE, SO WE USE GATE.”

“OUR GROUP HAS ALWAYS USED MCNP, SO WE USE MCNP FOR EVERYTHING.”

OUR POINT

Different codes combine to give the full picture



We need to understand each code

Scratching the surface is not enough

OUR POINT

We need different codes (with independent history and different philoshophy) so that Monte Carlo results may be used to validate each other