57th International Winter Meeting on Nuclear Physics
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Istituto Nazionale di Fisica Nucleare

A versatile plastic neutron spectrometer for nuclear reactions and applications: NArCoS

PAGANO EMANUELE VINCENZO(1)

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(4) Università Kore, Enna, Italy
(5) Dipartimento di Scienze MIFT, Universita' Messina, Italy

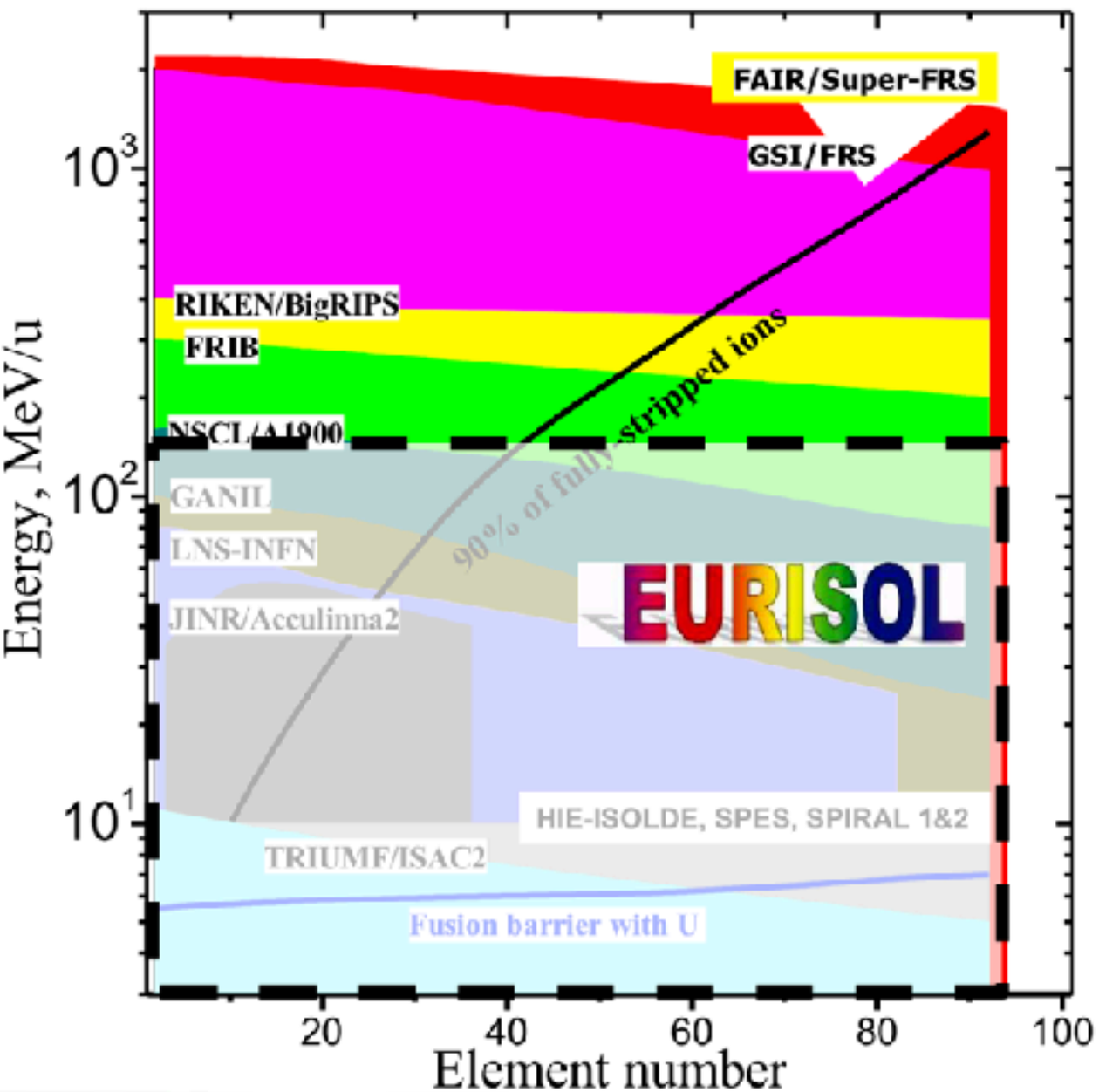
Project's motivations

The advent of the new facility for Radioactive Ion Beams (RIBs)
in particular for the n-rich ones

"The RIBs are an important opportunity"

(C. Horovitz)

From: M. Lewitowicz EURISOL-DF 15-16 Nov 2017, Lisbon



IDEA

To realize a prototype of detector able to detect at the same time charged particles and neutrons whit high energy and angular resolution for reaction studies and applications

- Candidate: The plastic scintillator EJ276-Green Type (ex EJ299-33) (3x3x3cm^3)
- 1 cluster: 4 consecutively cubes -> 3x3x12 cm^3
- Reading the light signal: Si-PD or Si-PM and digitalization
- Modular, reconfigurable (in mechanic and electronic)
- Discrimination of n/γ from PSD (but also light charged particles)
- Energy measurement from ToF ($\Delta t \leq 1.5$ ns with $L_{ToF} \approx 1 \div 1.5$m)

  TOF measured using the RF of the CS or with an ancillary MCP (low intensity exotic beams)

*Si incrocia l'info ampiezza-PSD e info da fasci di calibrazione (n,CP)

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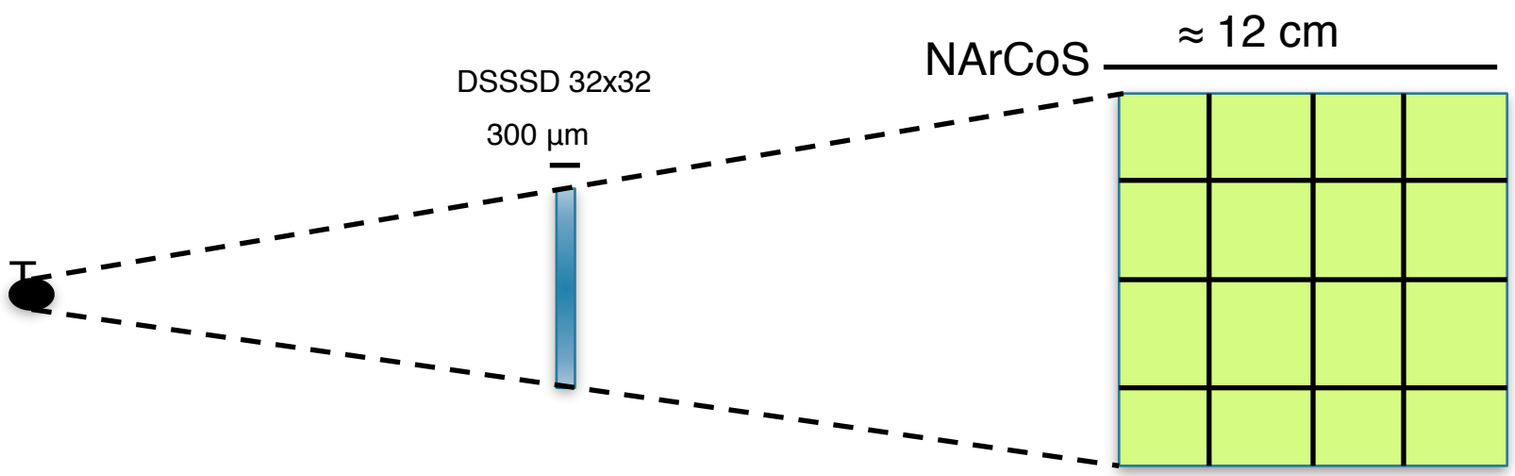

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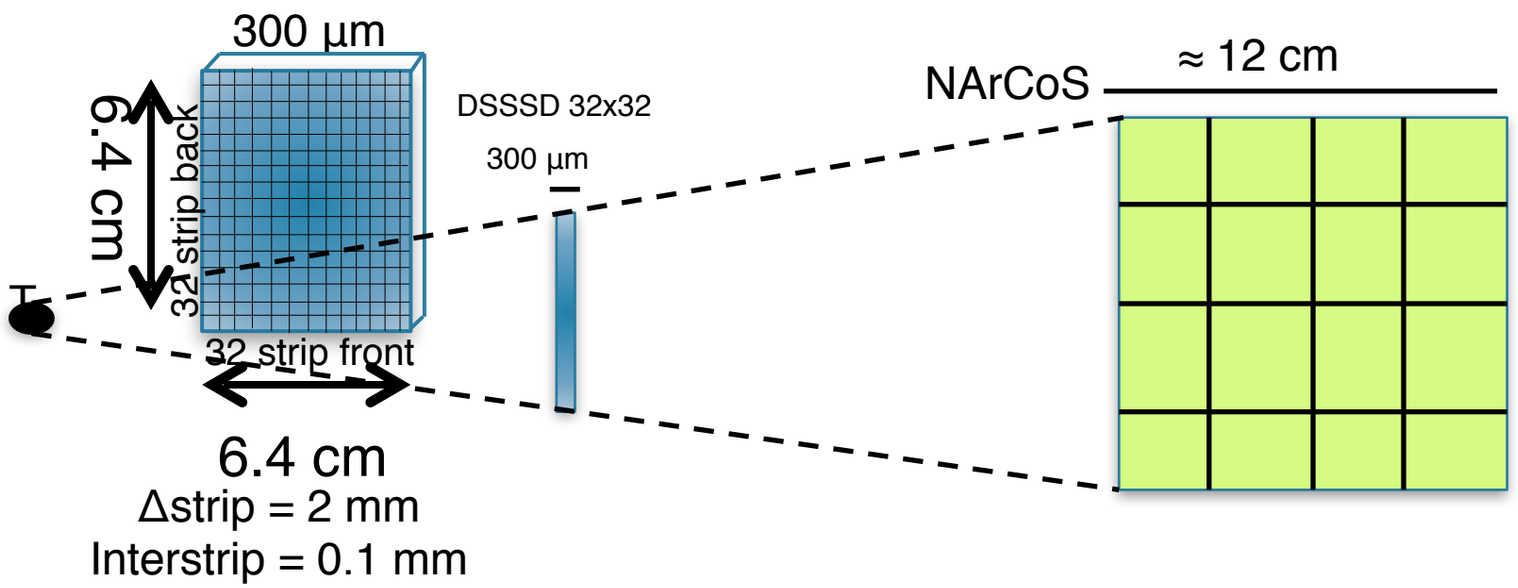

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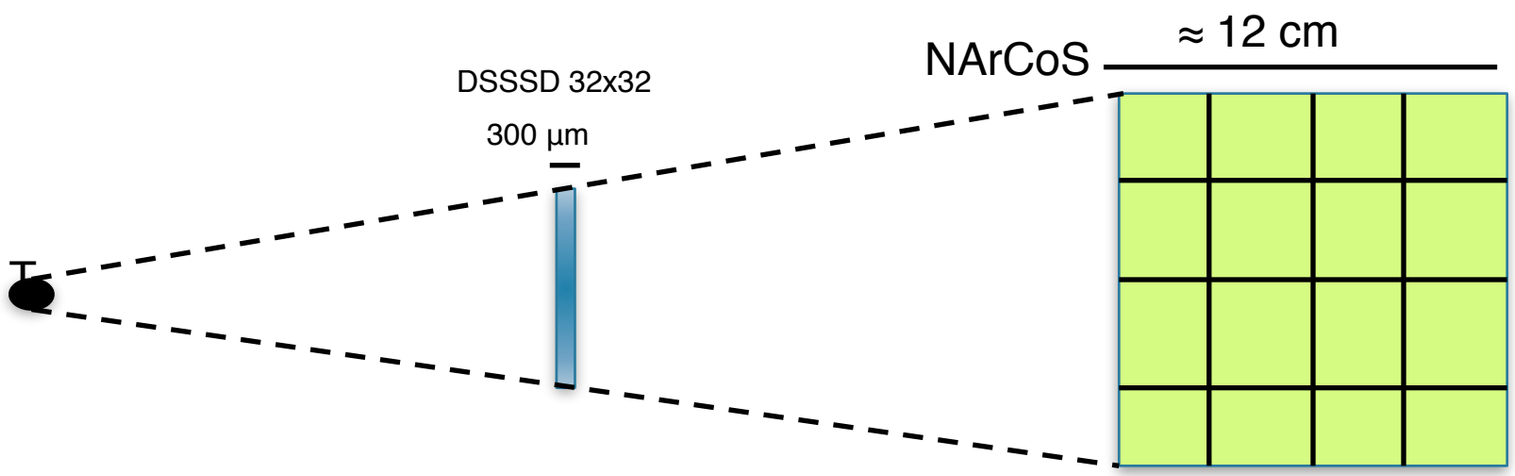

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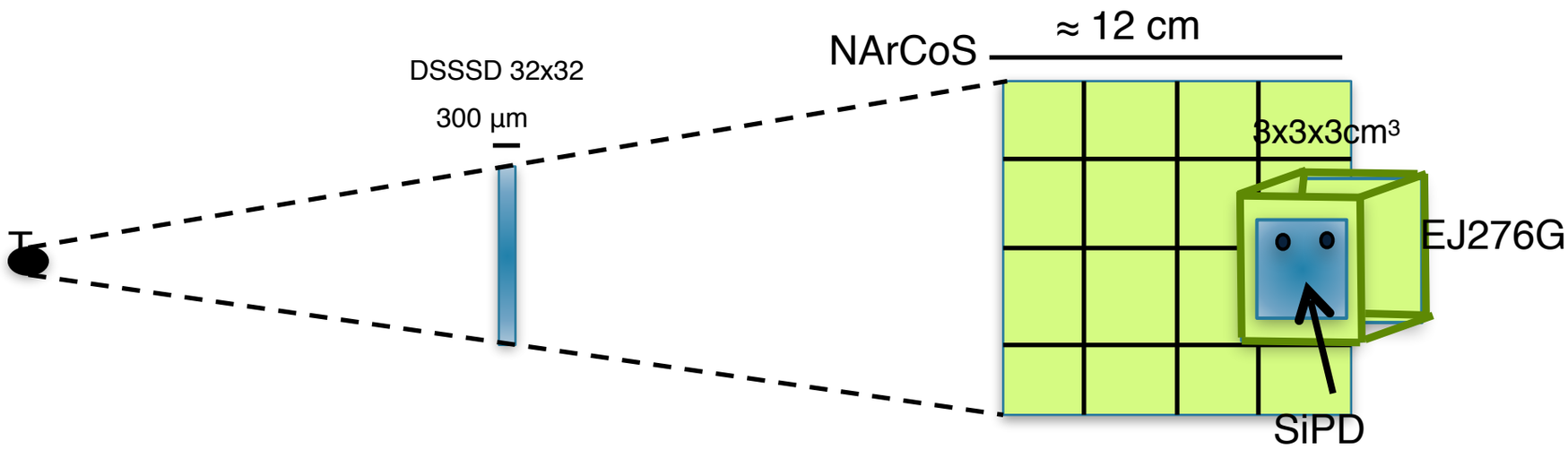

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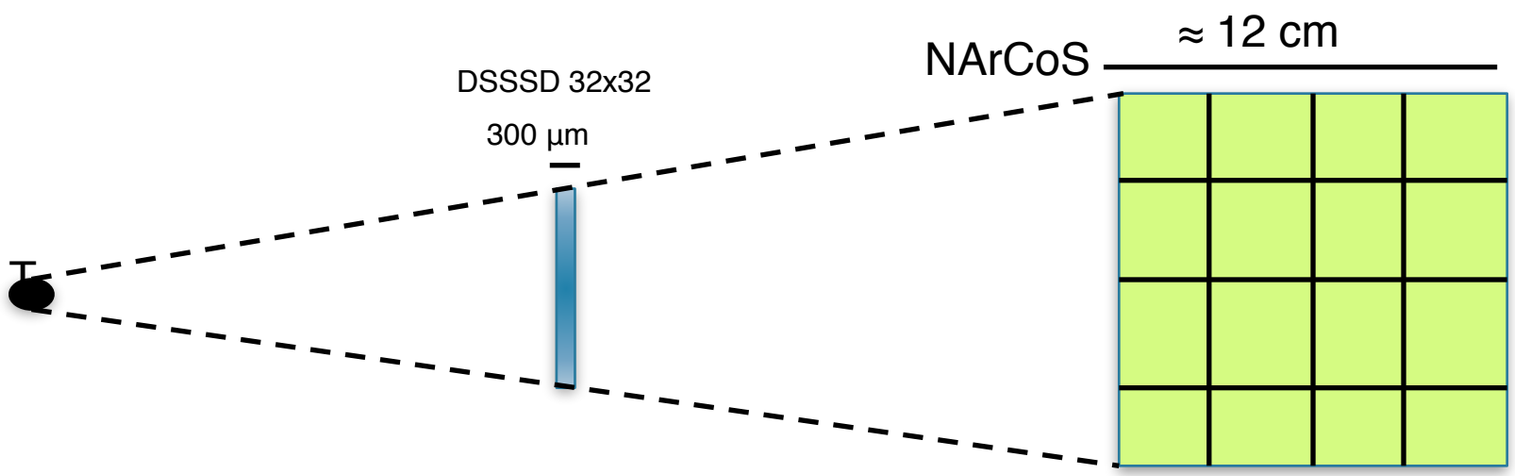

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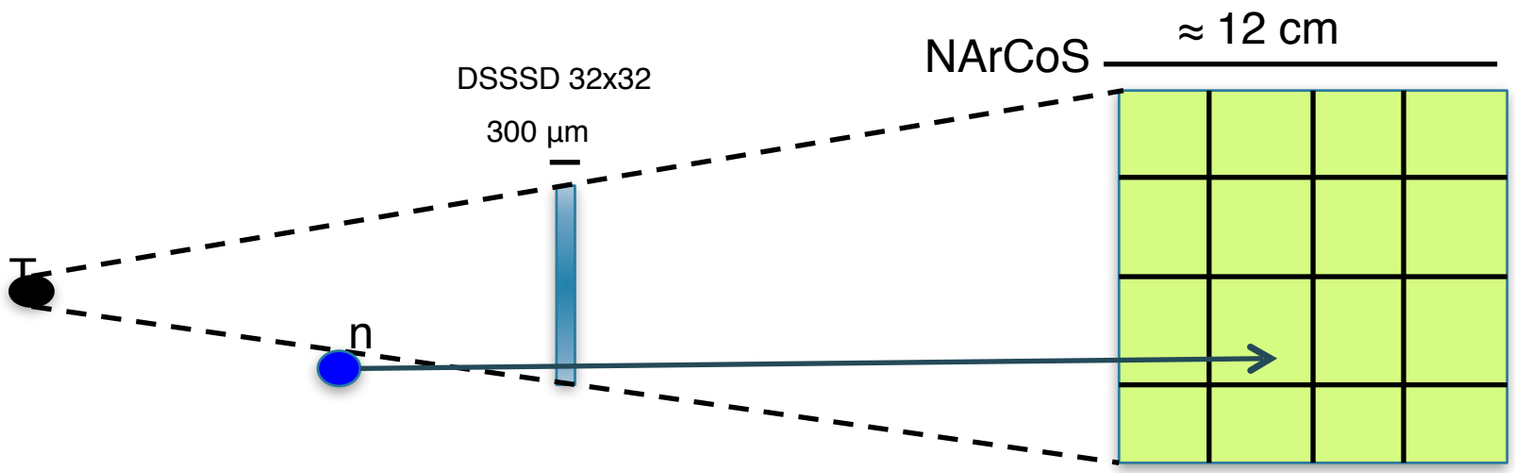

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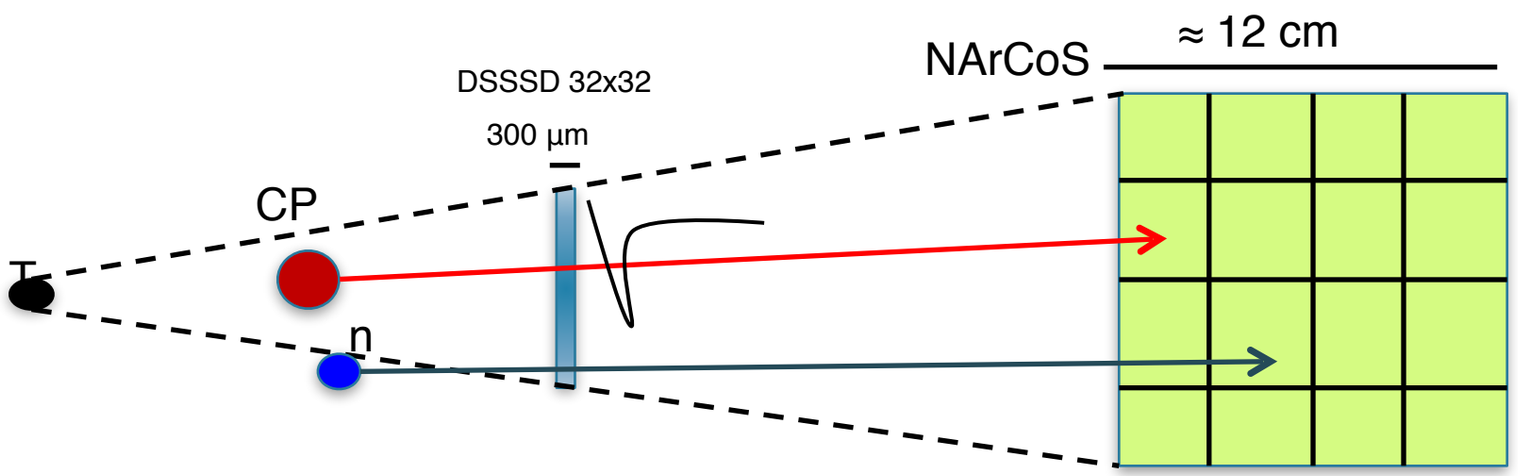

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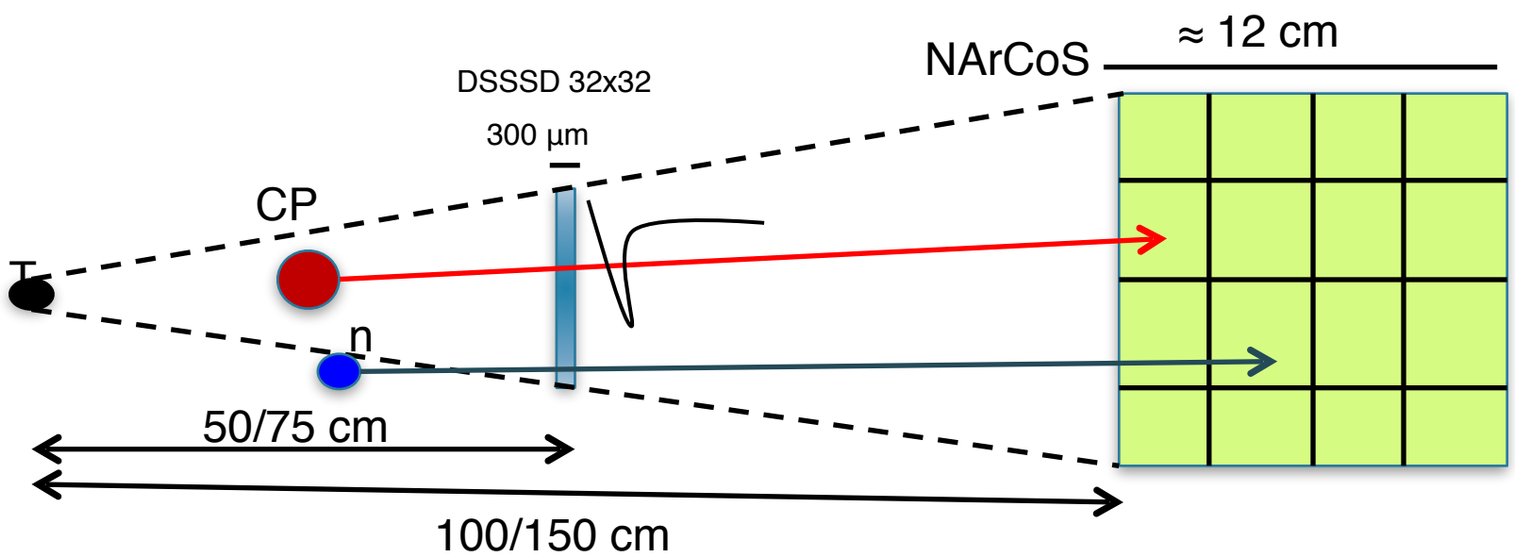

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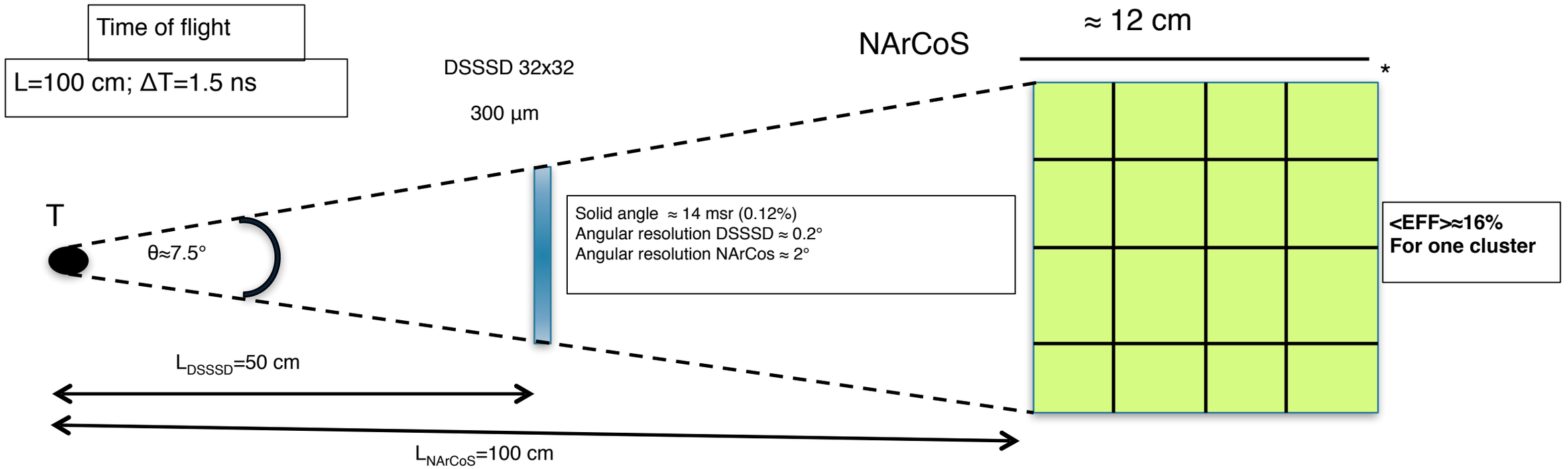

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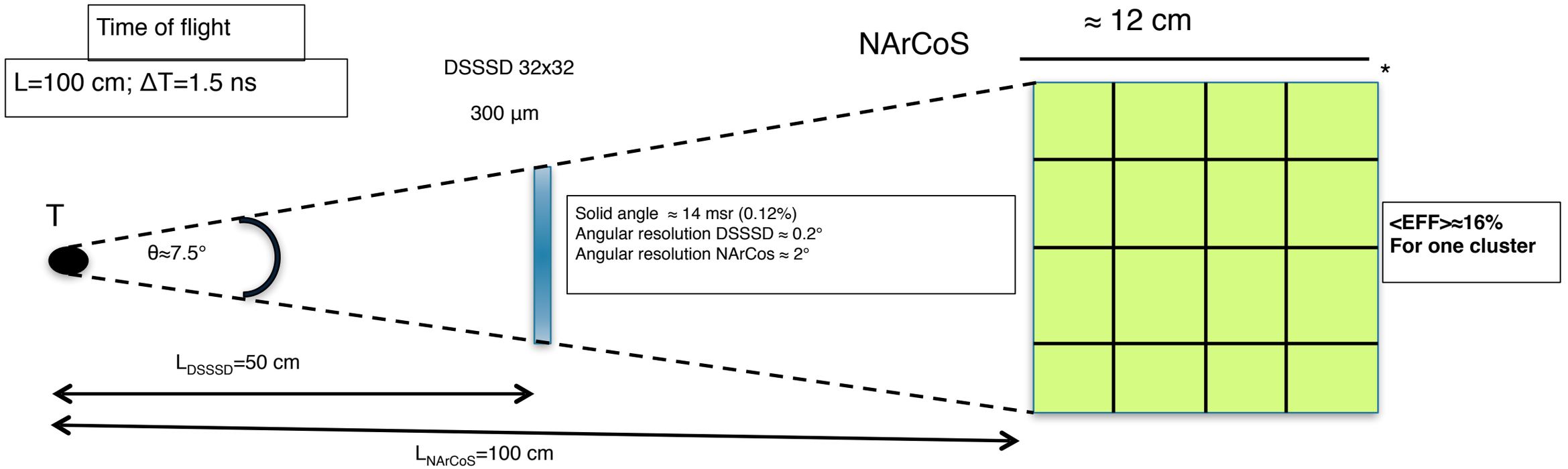

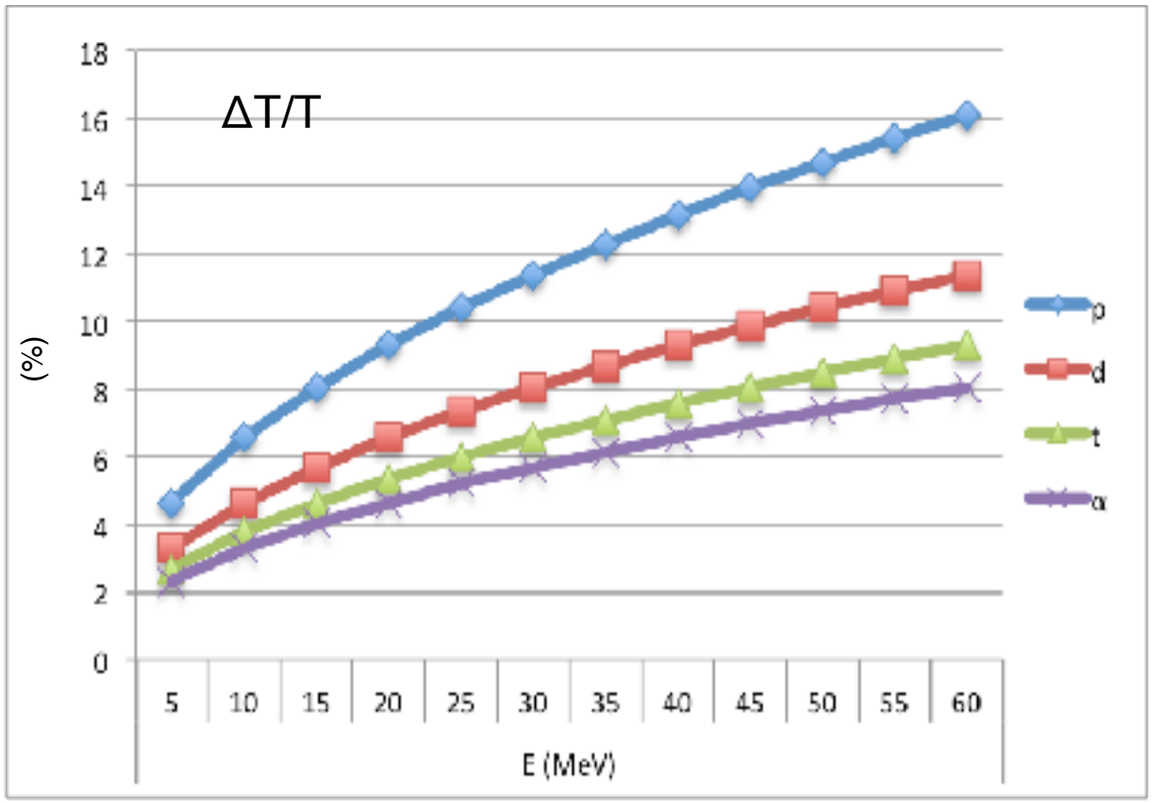

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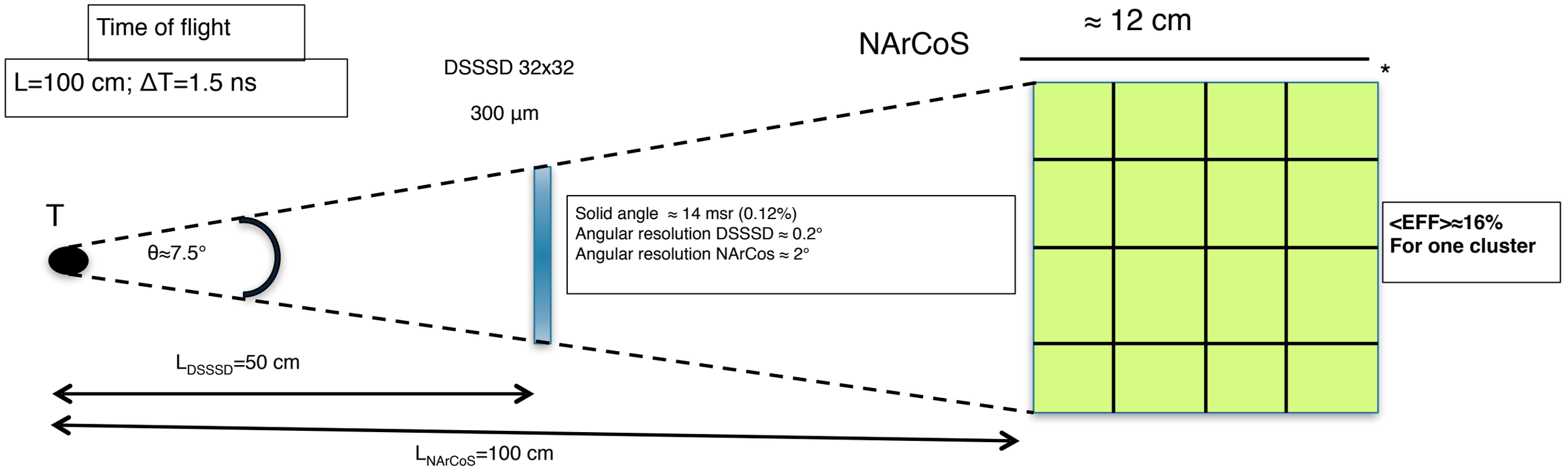

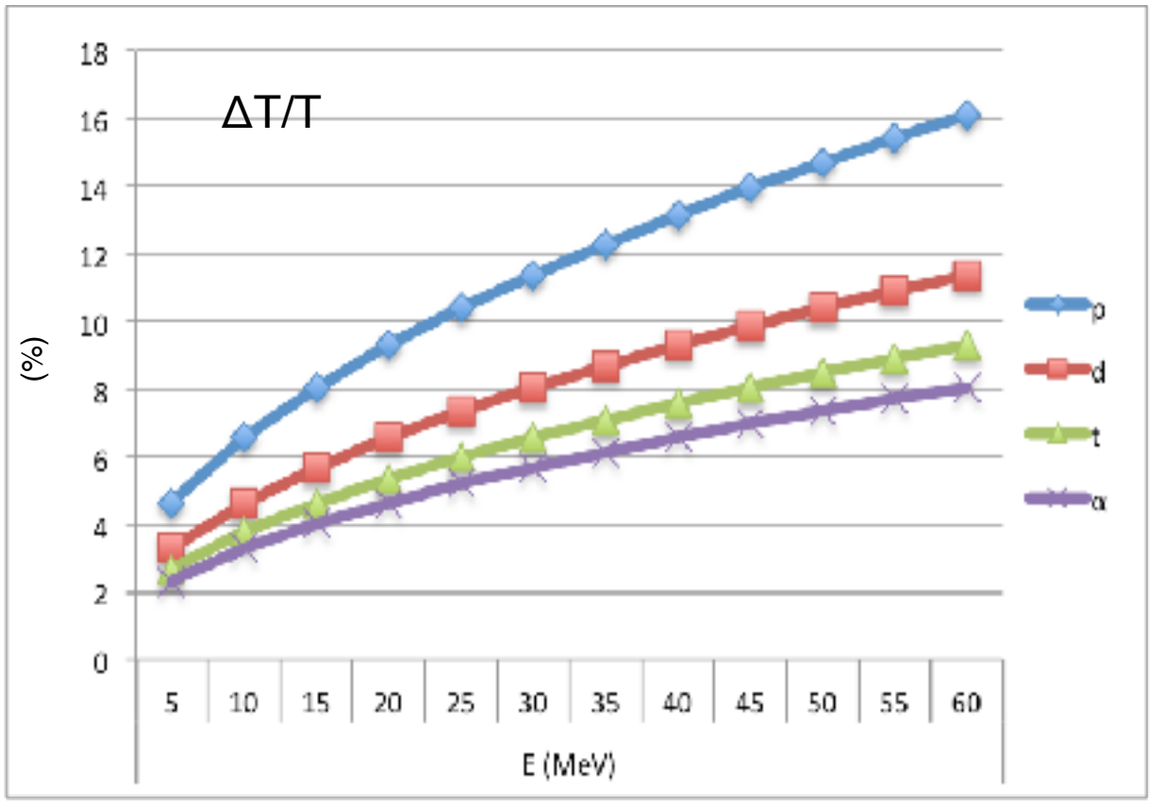

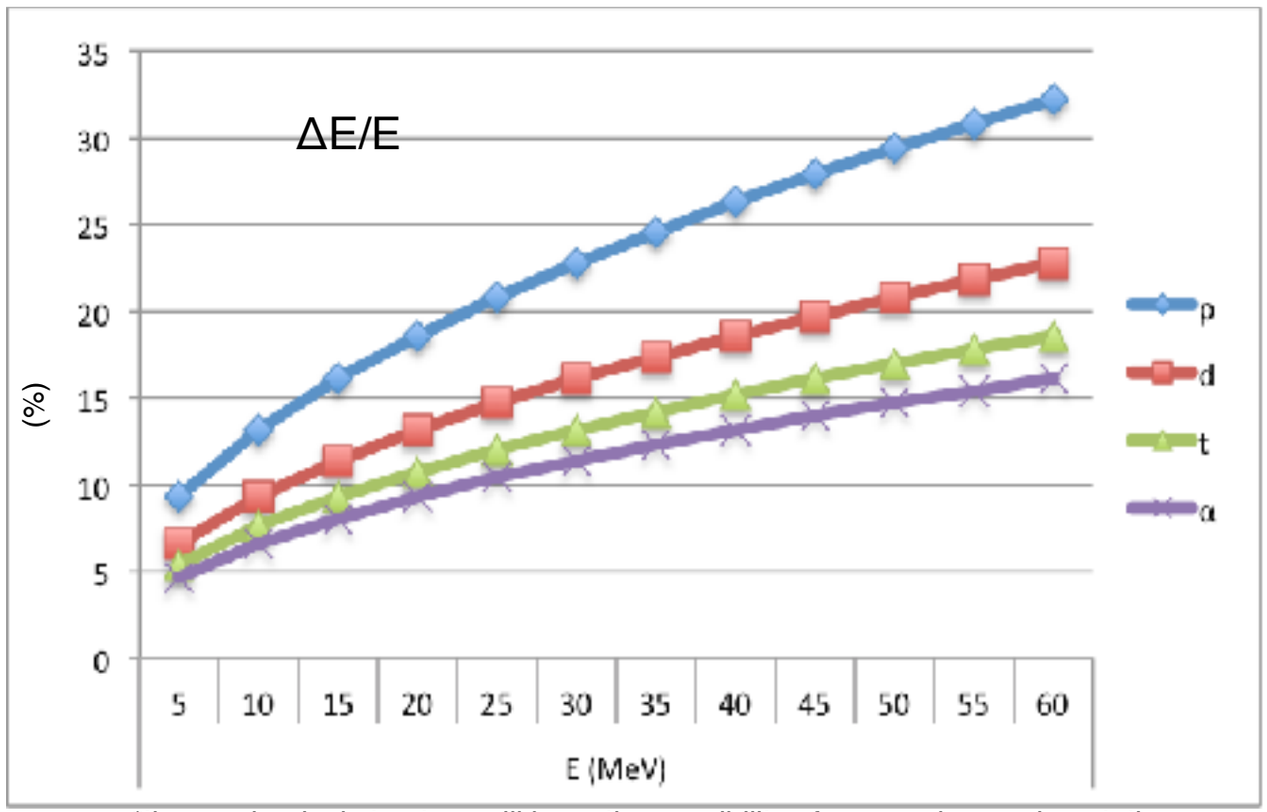

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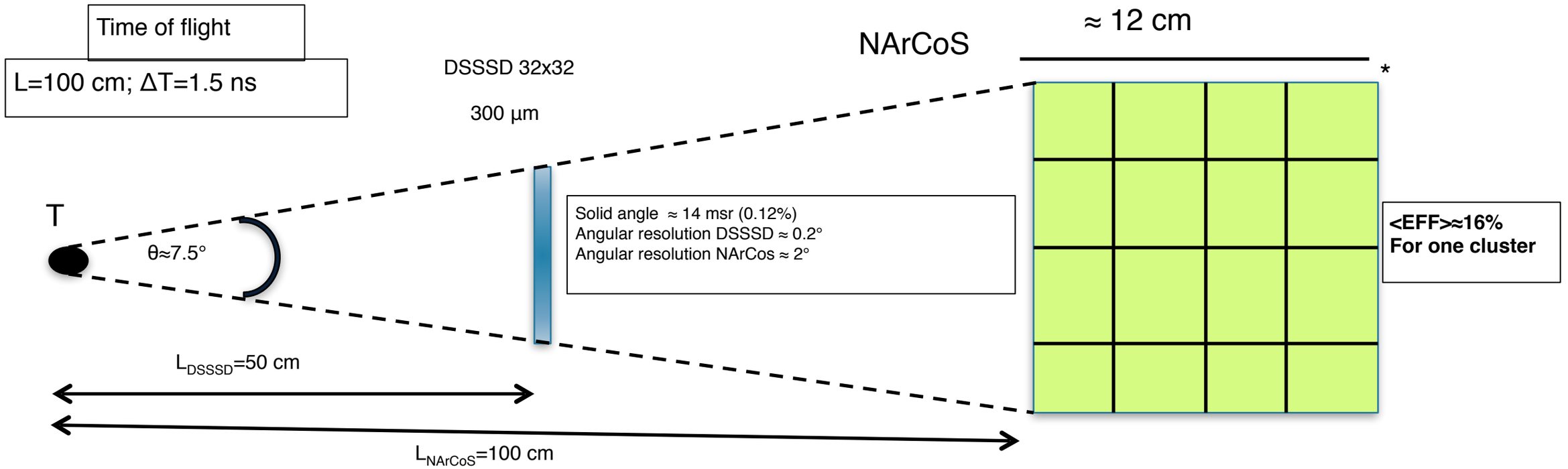

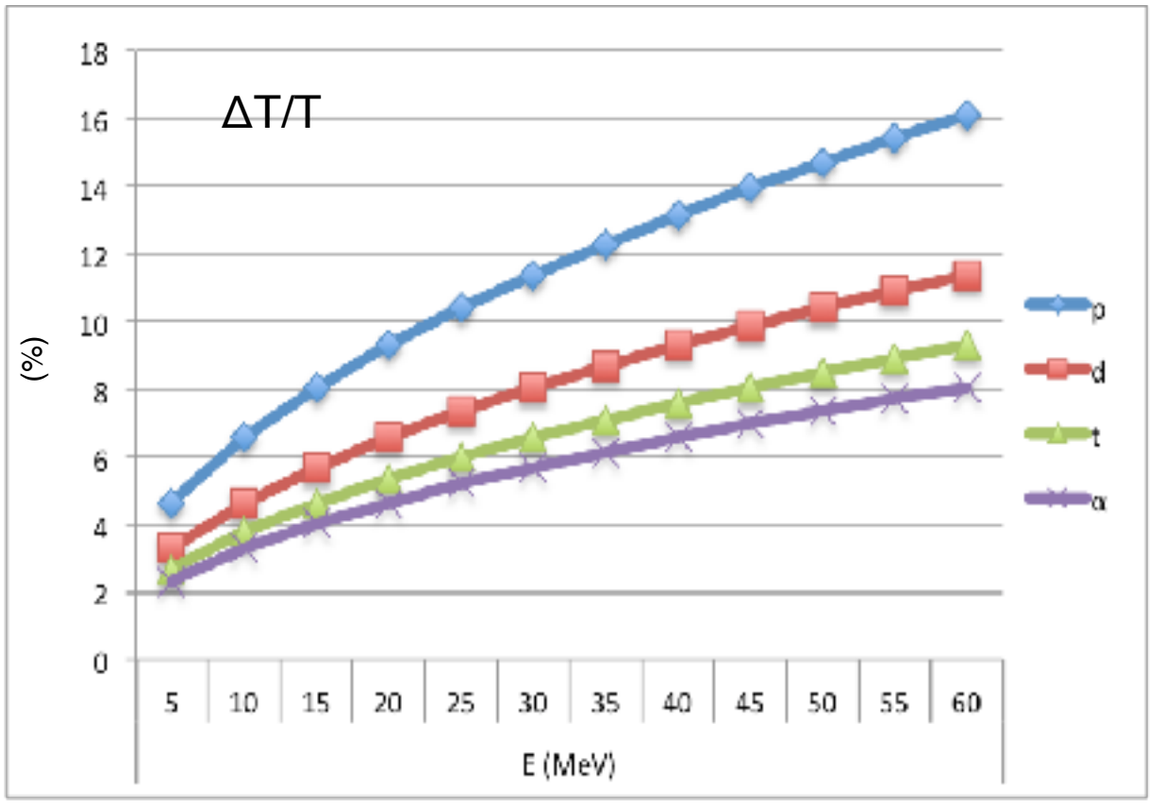

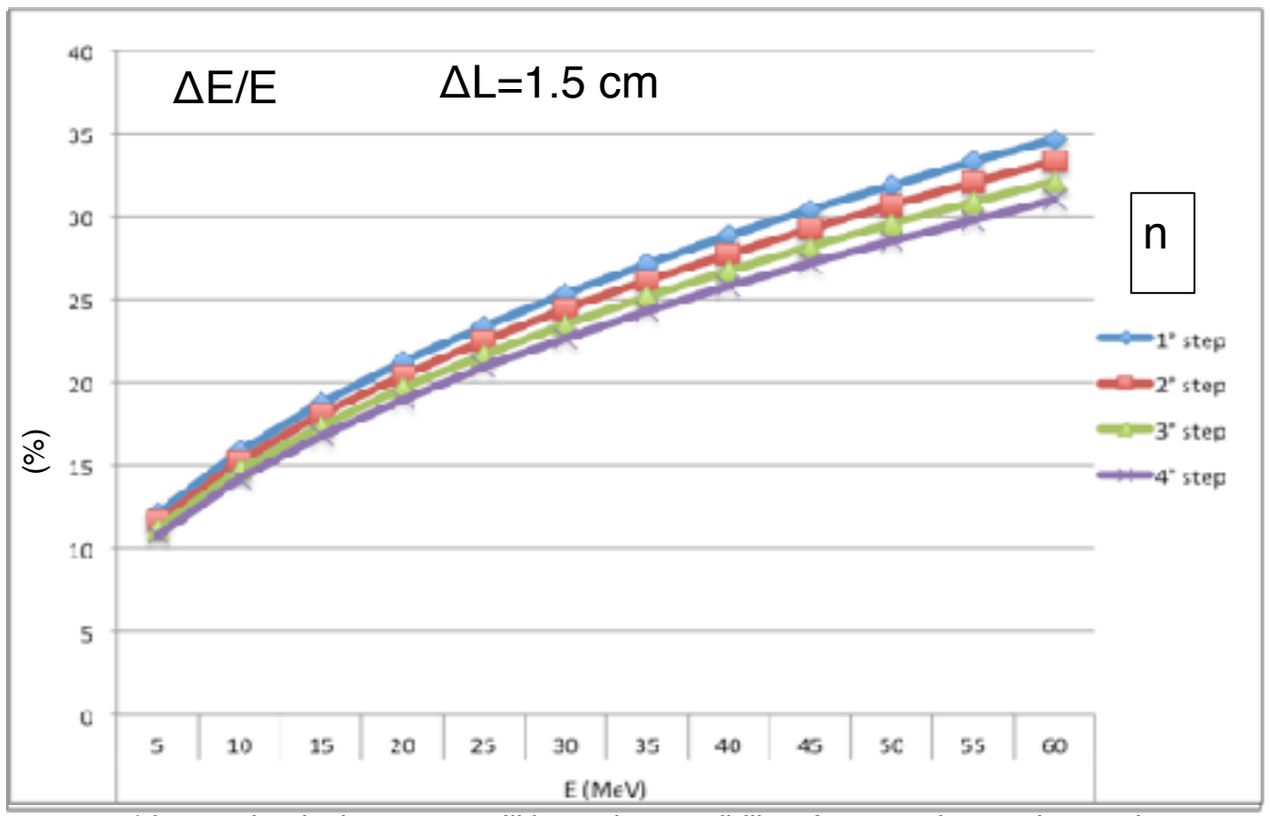

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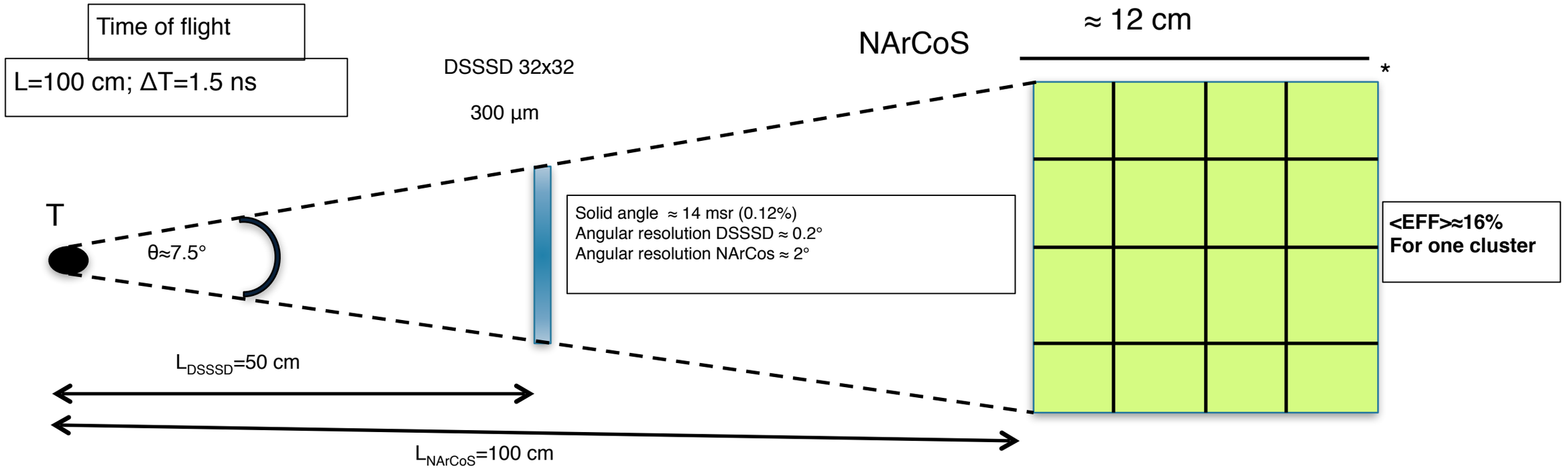

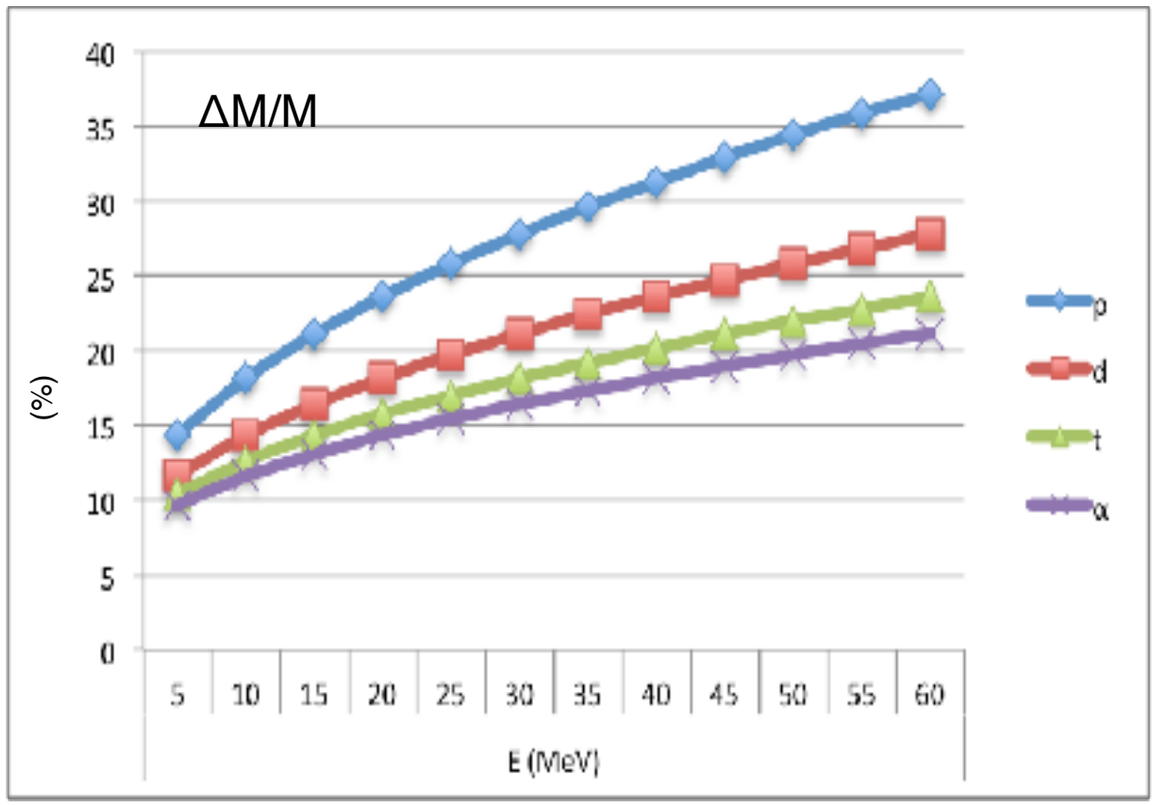

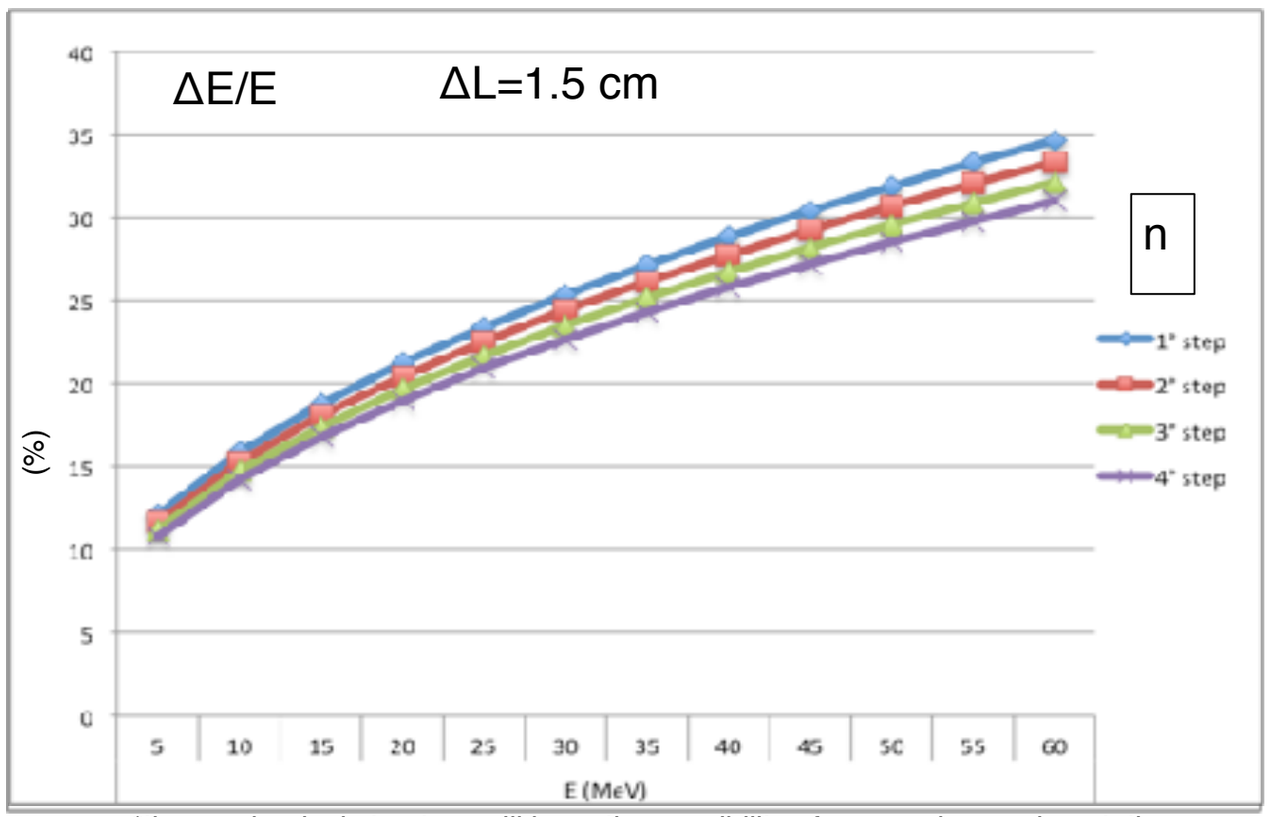

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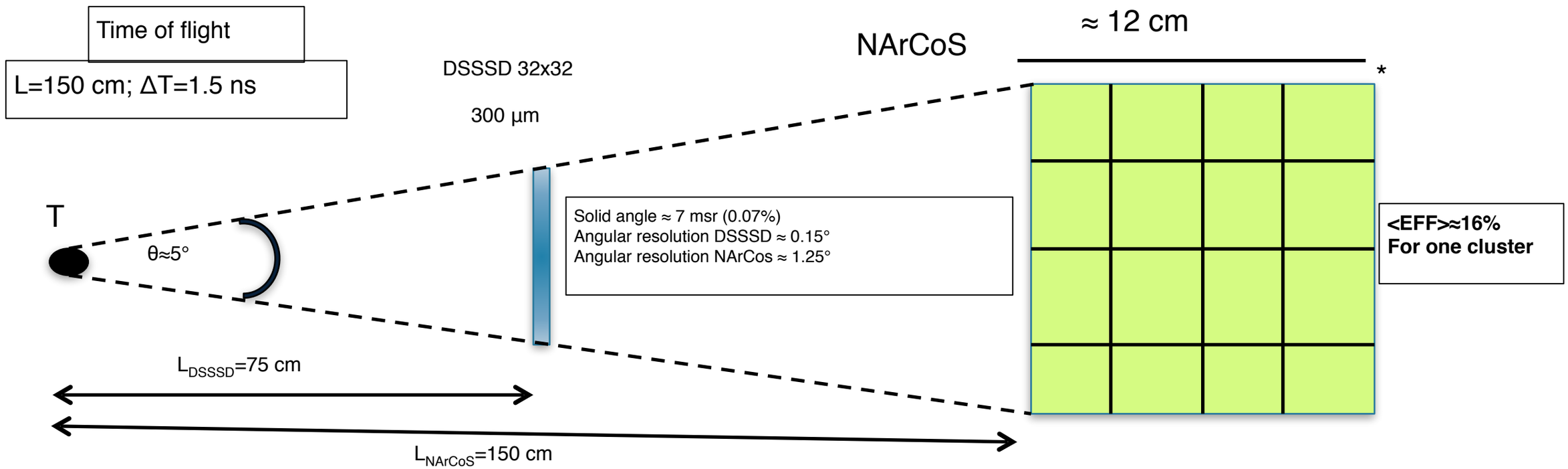

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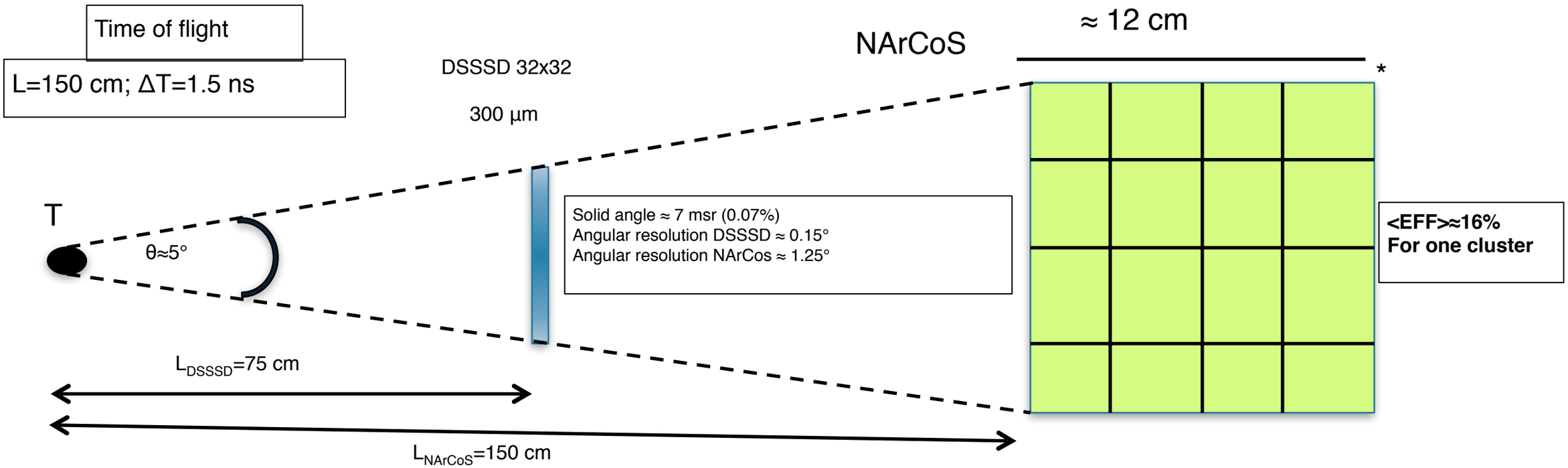

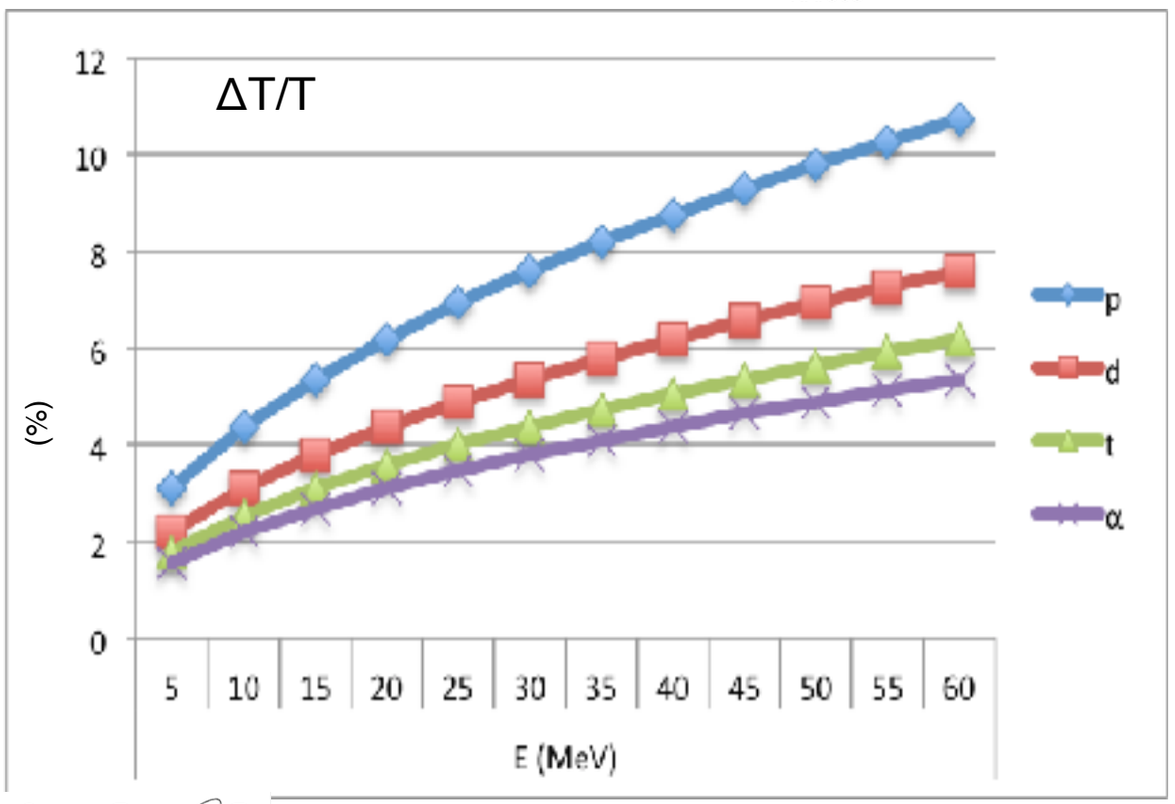

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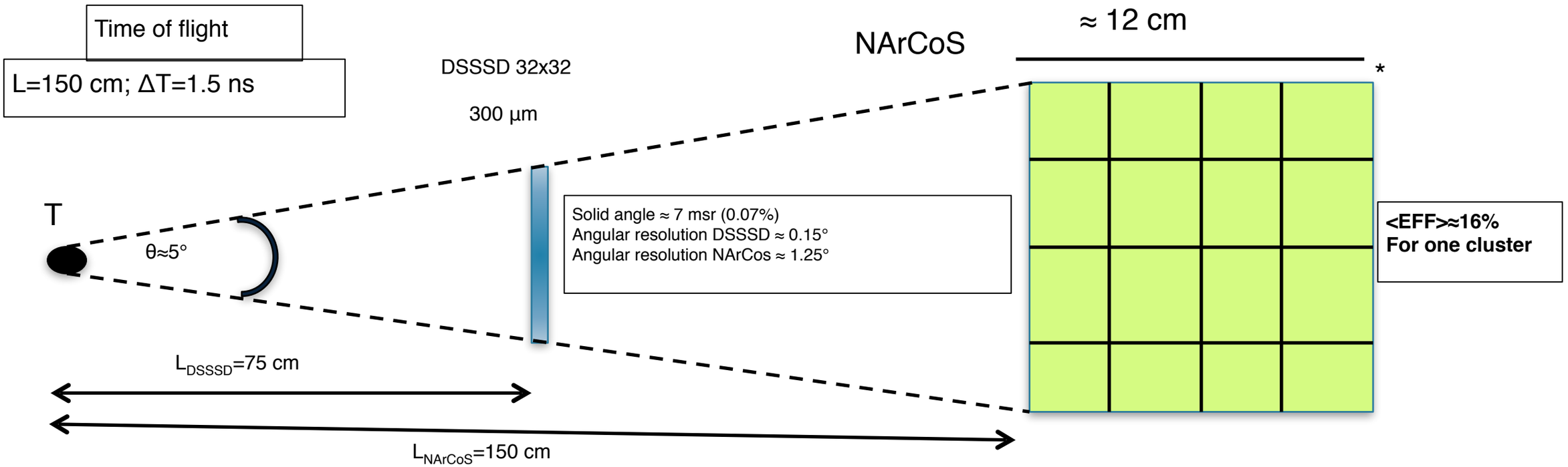

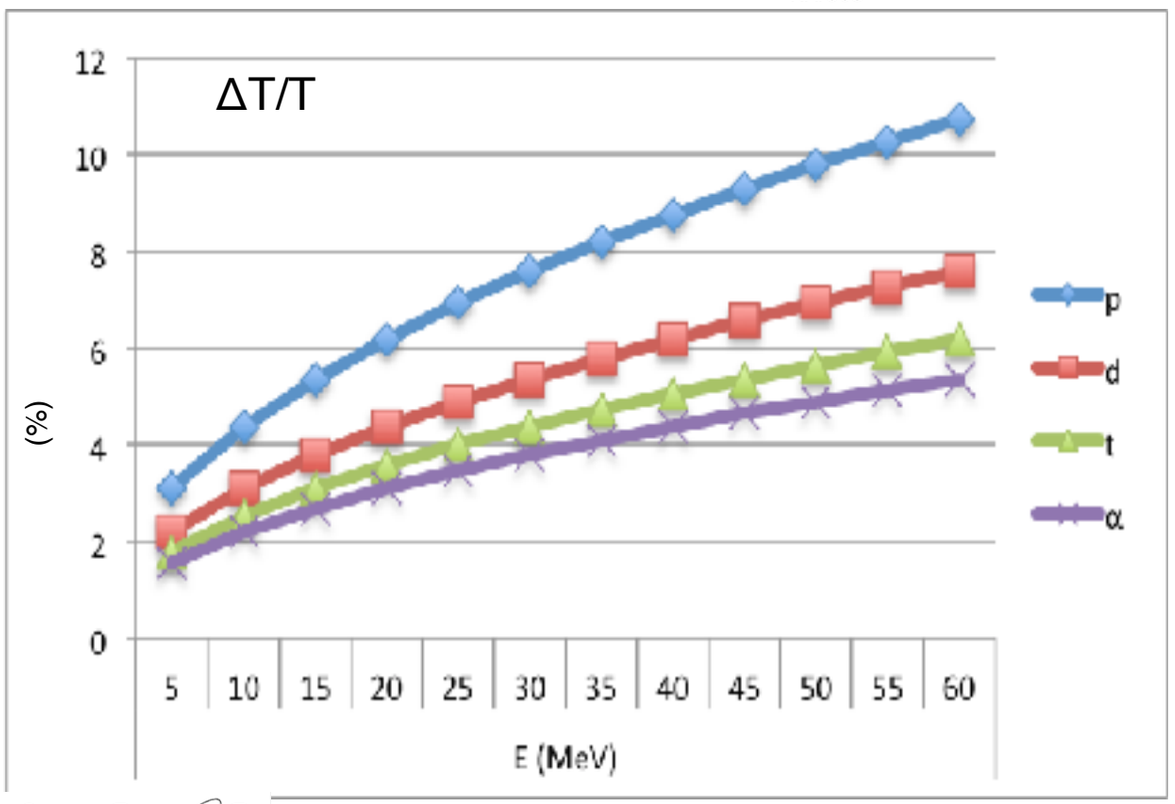

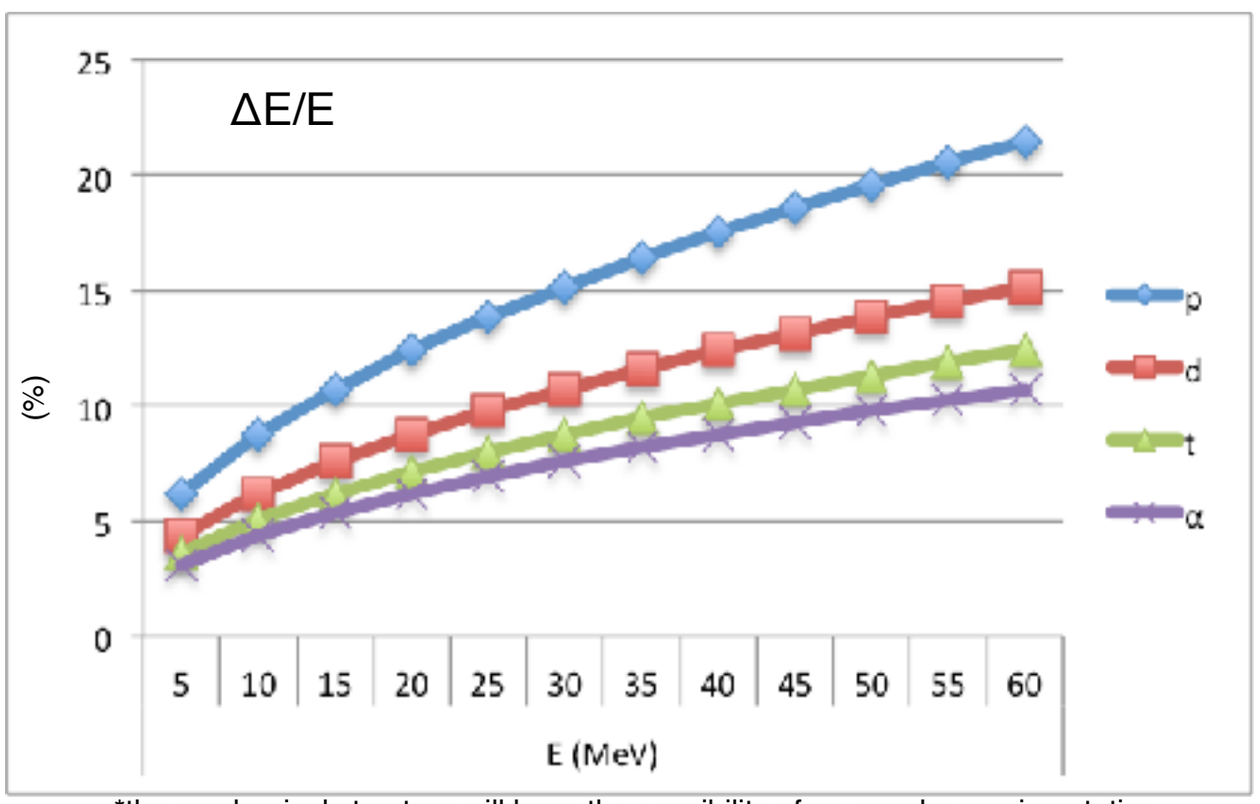

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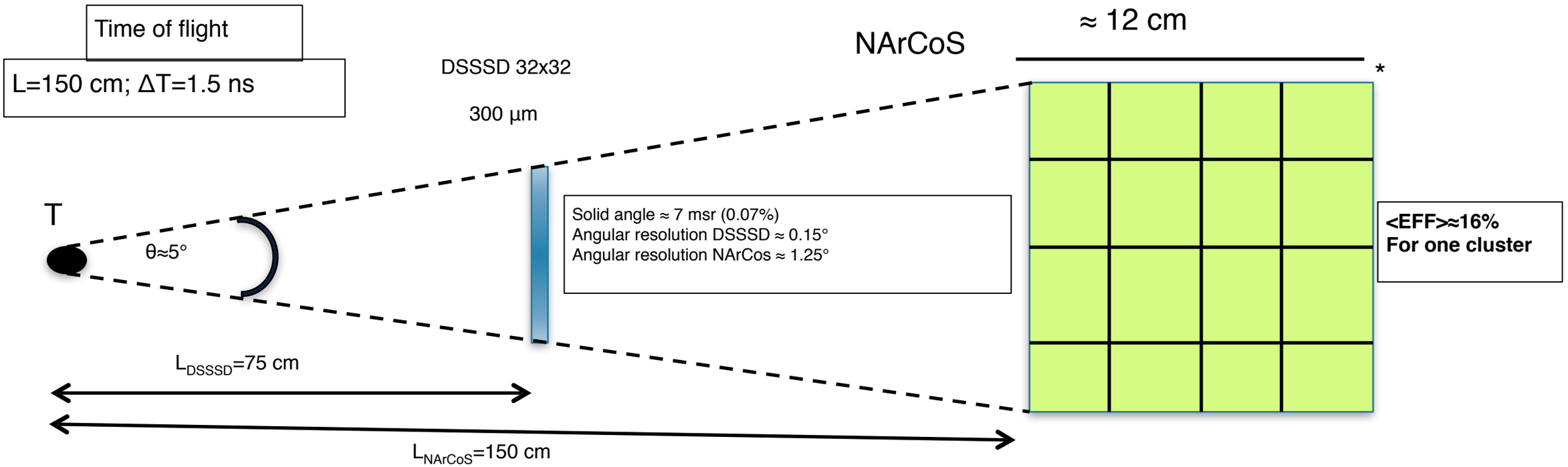

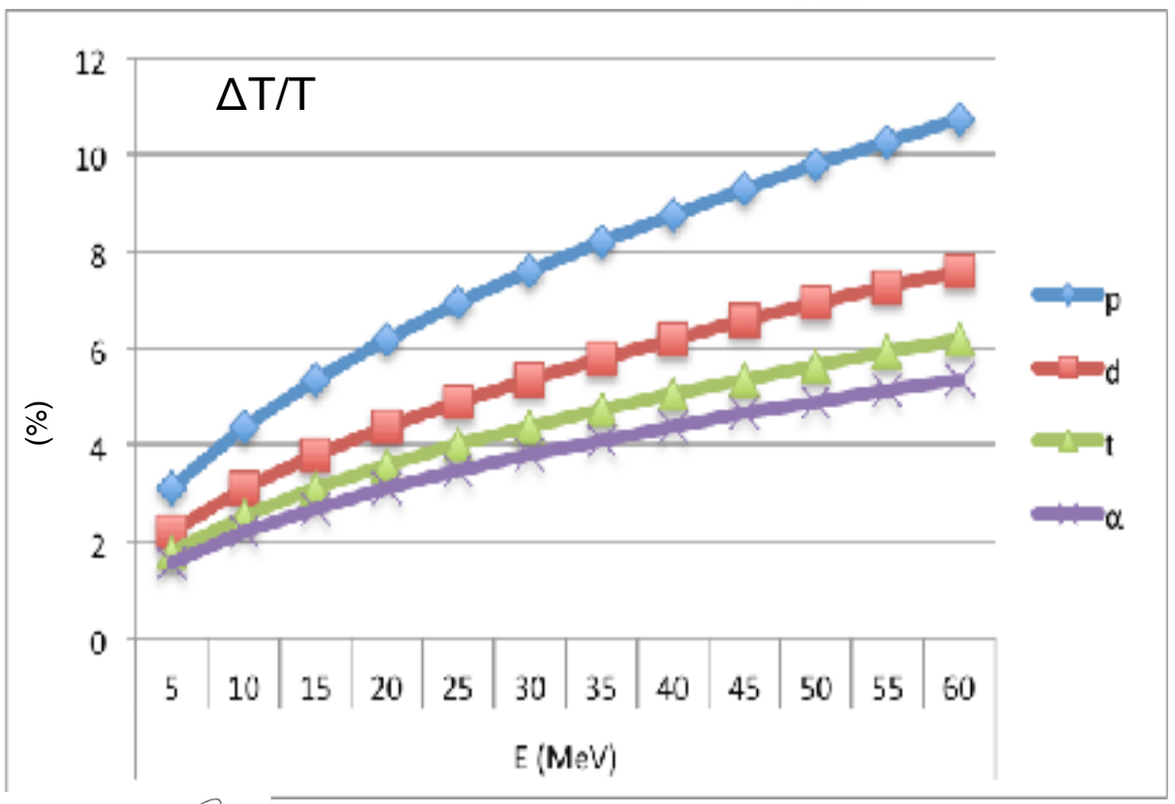

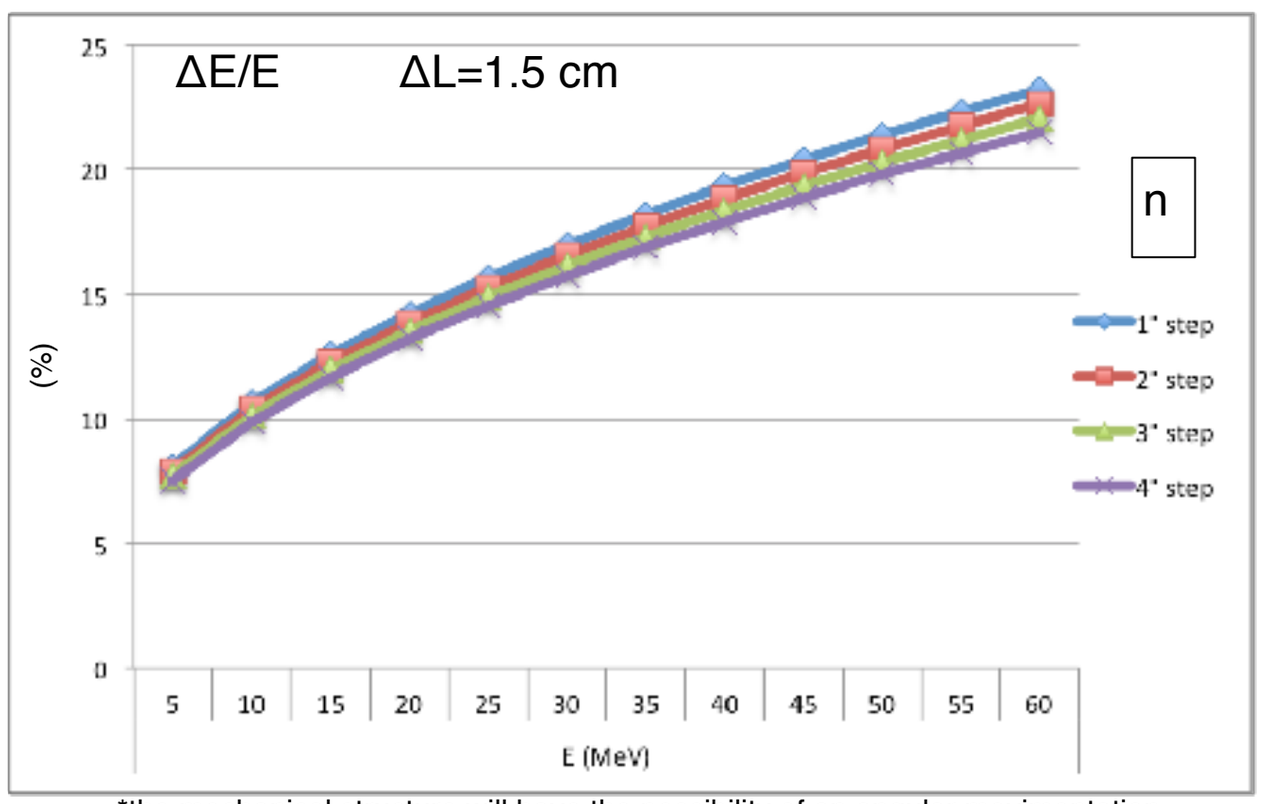

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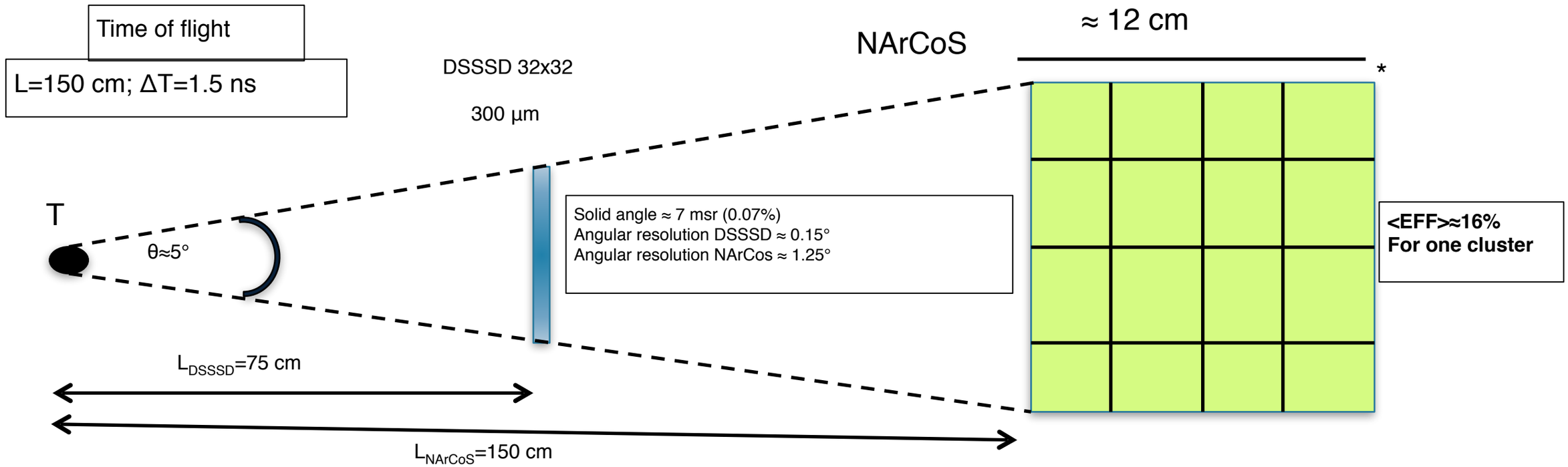

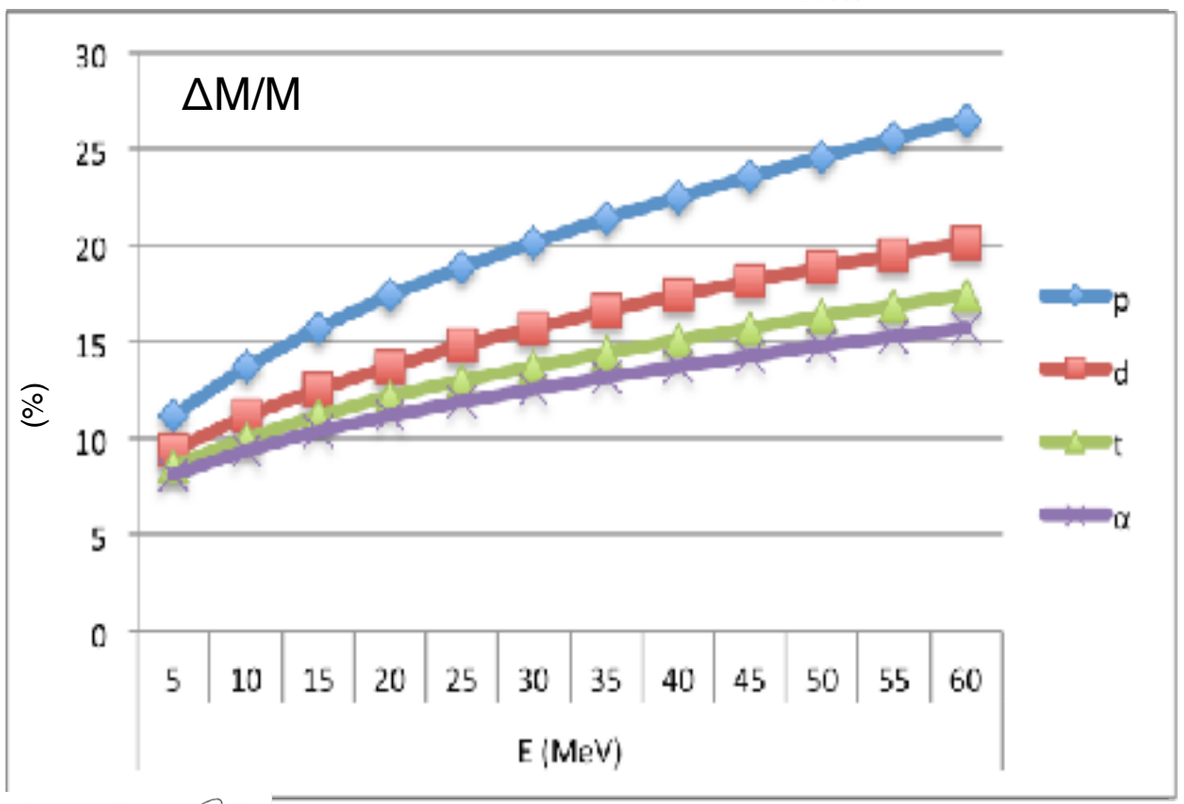

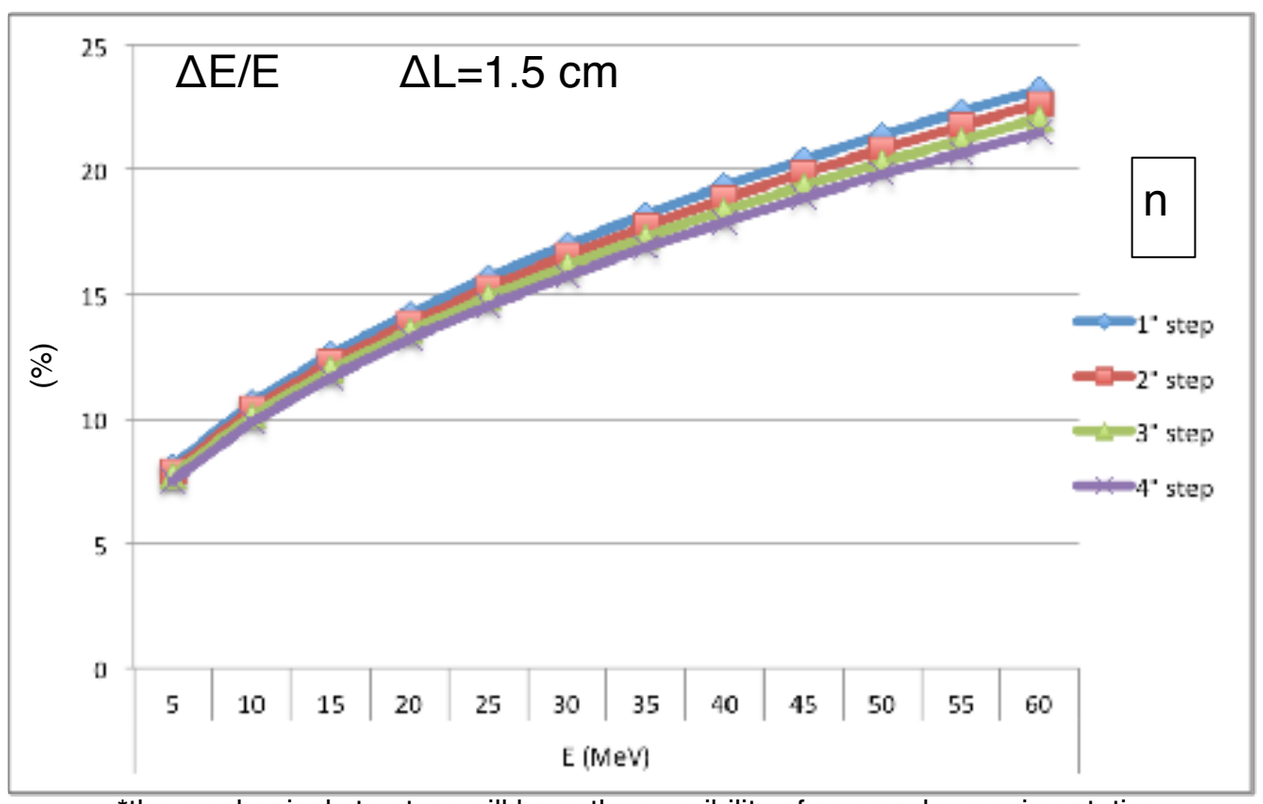

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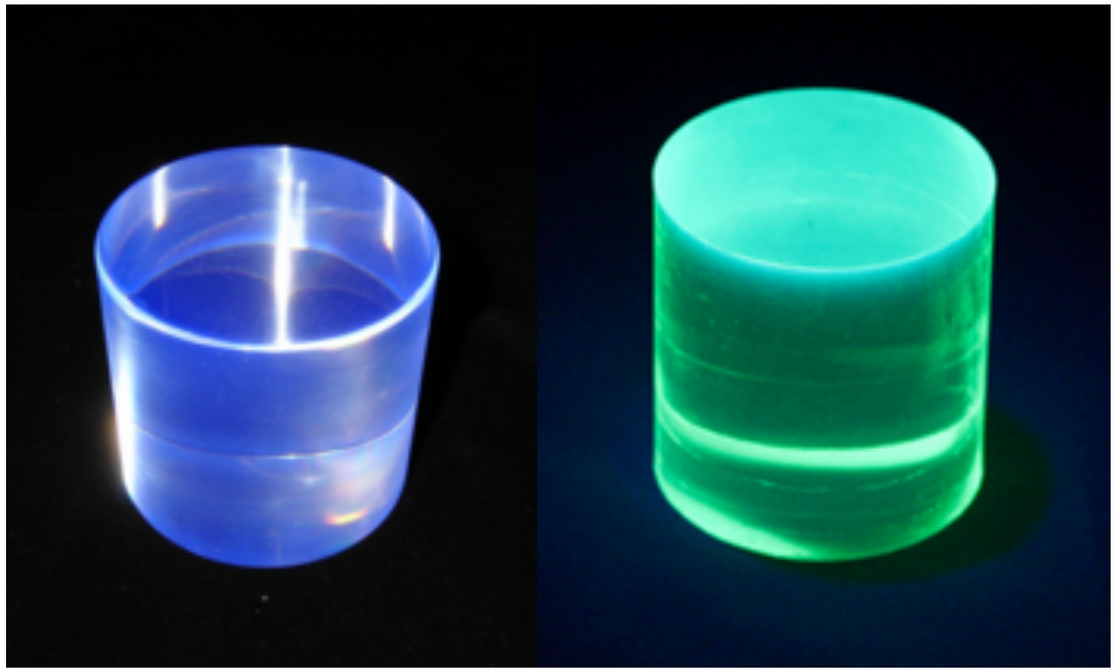
L’EJ276

(ex EJ-299-33)



N. Zaitsev et al., NIM A 668 (2012) 88.
N. P. Hawkes et al., NIM A729 (2013) 522
S.A. Pozzi et al., NIM A723 (2013) 19
E. V. Pagano et al. NIM A 889 (2018) 83-88
E. V. Pagano et al. NIM A 905 (2018) 47-52

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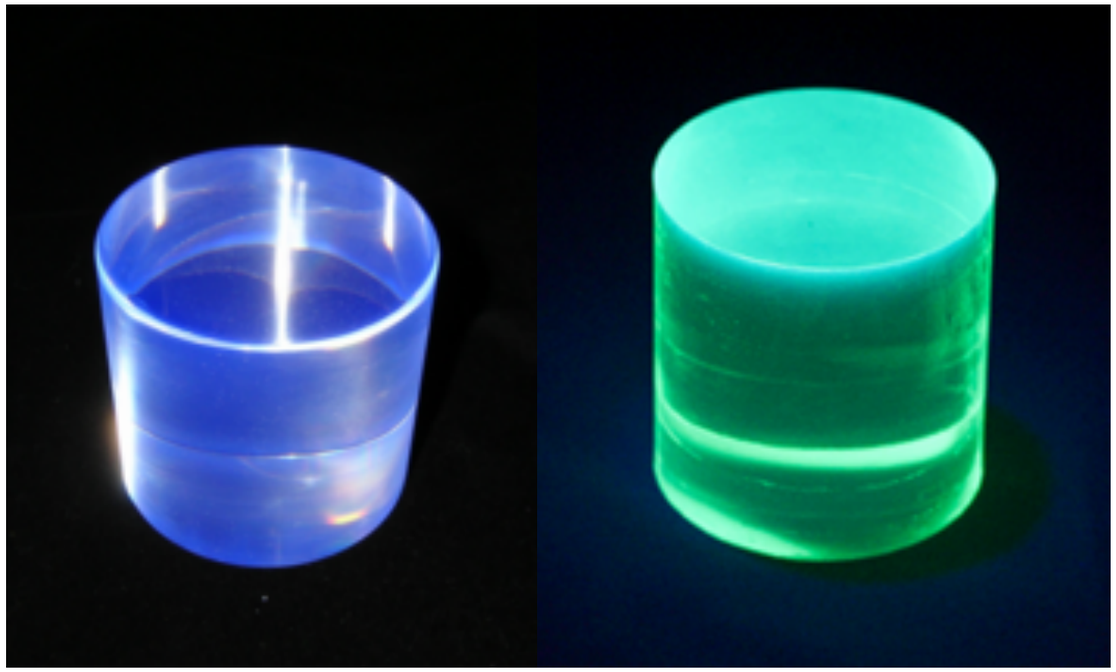

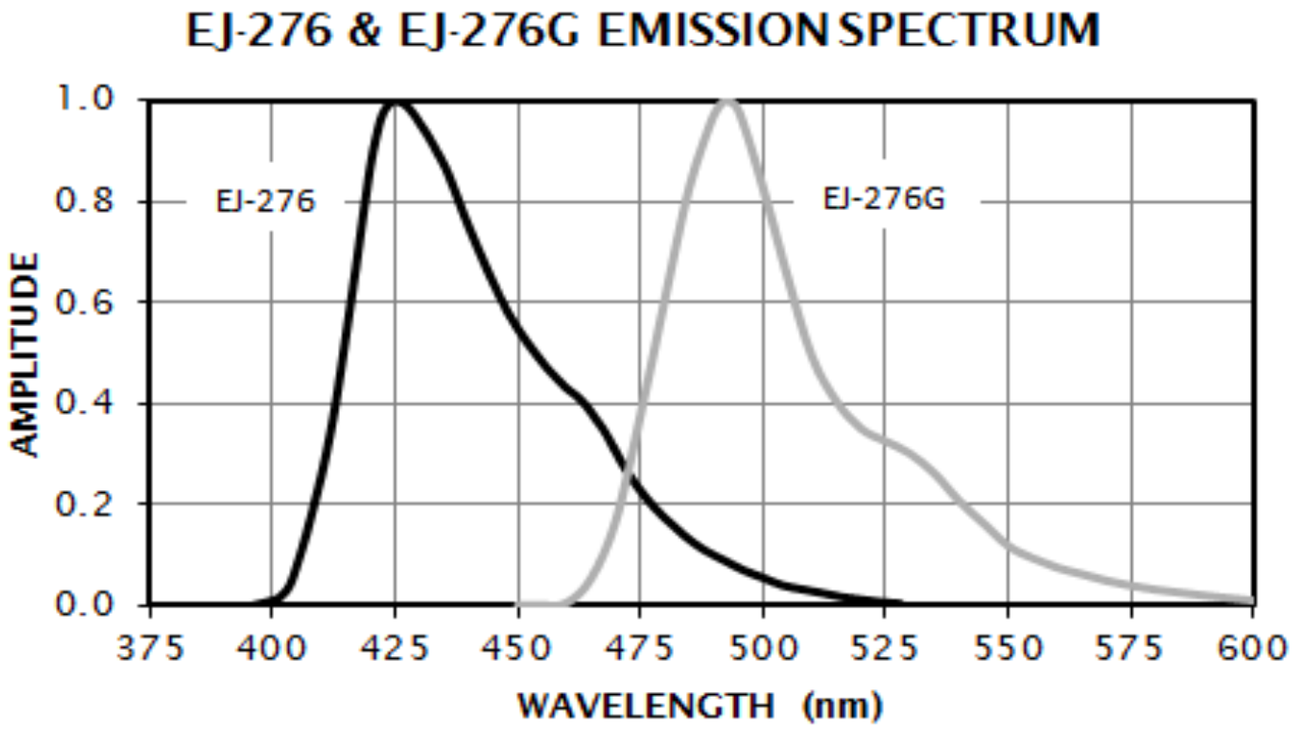

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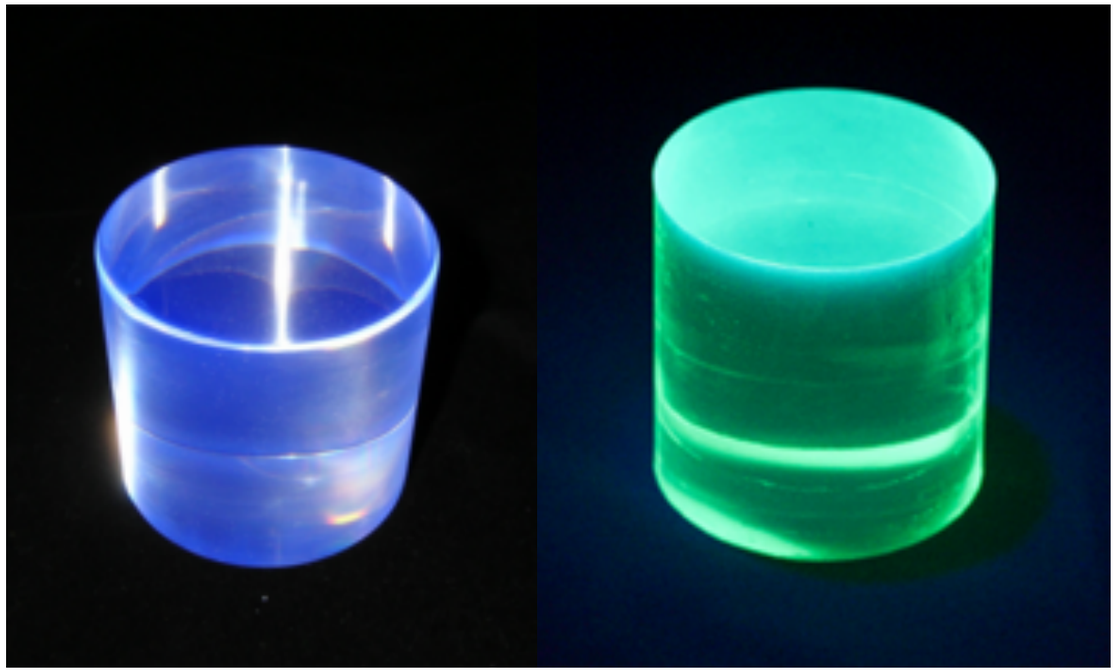

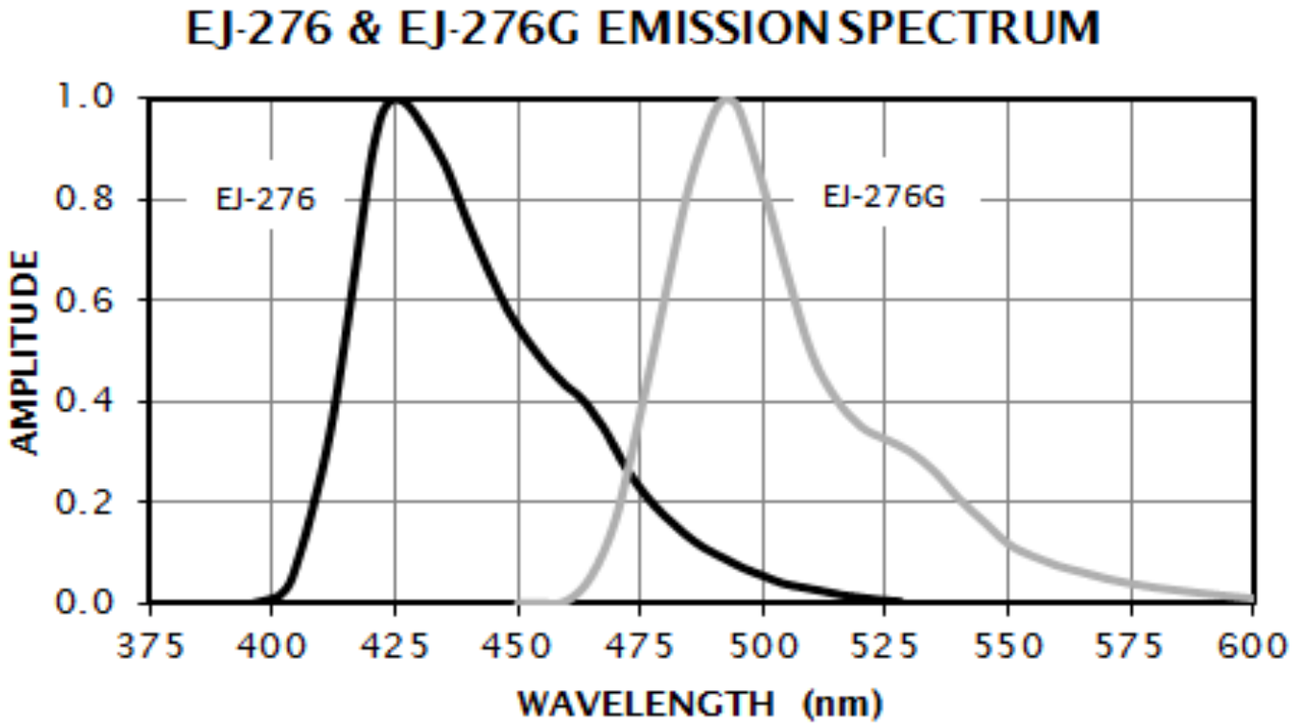

PROPERTIES		EJ-276	EJ-276G
Light Output (% Anthracene)		56	52
Scintillation Efficiency (photons/1 MeV e^-)		8,600	8000
Wavelength of Maximum Emission (nm)		425	490
No. of H Atoms per cm^3 ($x10^{22}$)		4.53	4.53
No. of C Atoms per cm^3 ($x10^{22}$)		4.89	4.89
No. of Electrons per cm^3 ($x10^{23}$)		3.52	3.52
Density (g/cm^3)		1.096	1.096
Approx. Mean Decay Times of First 3 Components (ns)	Gamma Excitation	13, 35, 270	—
	Neutron Excitation	13, 59, 460	—

L'EJ276

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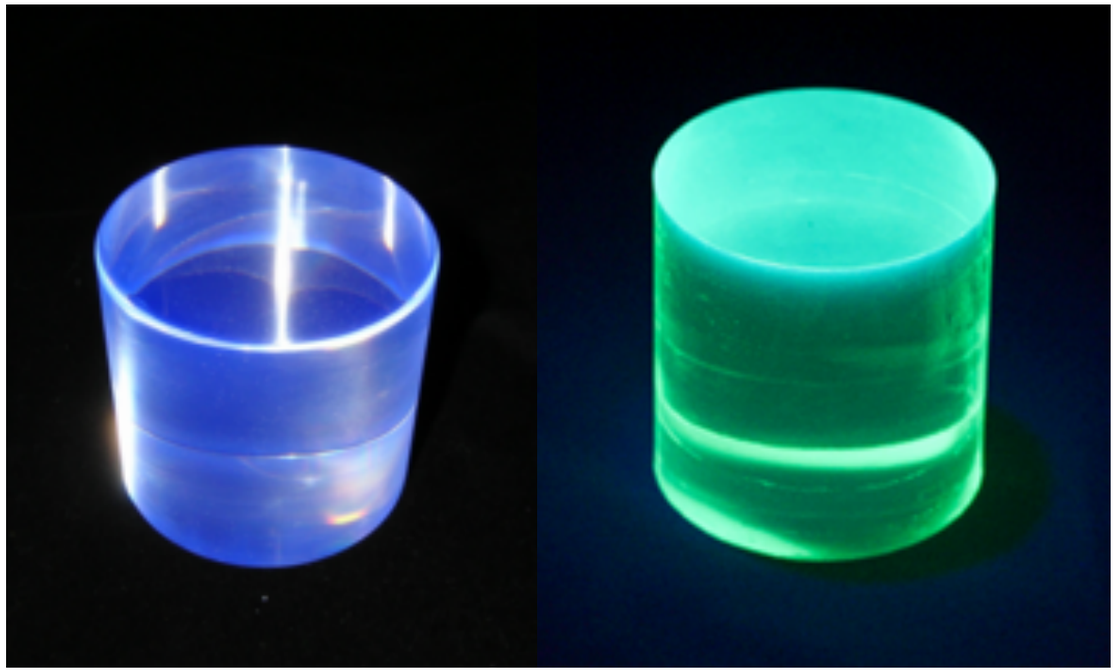

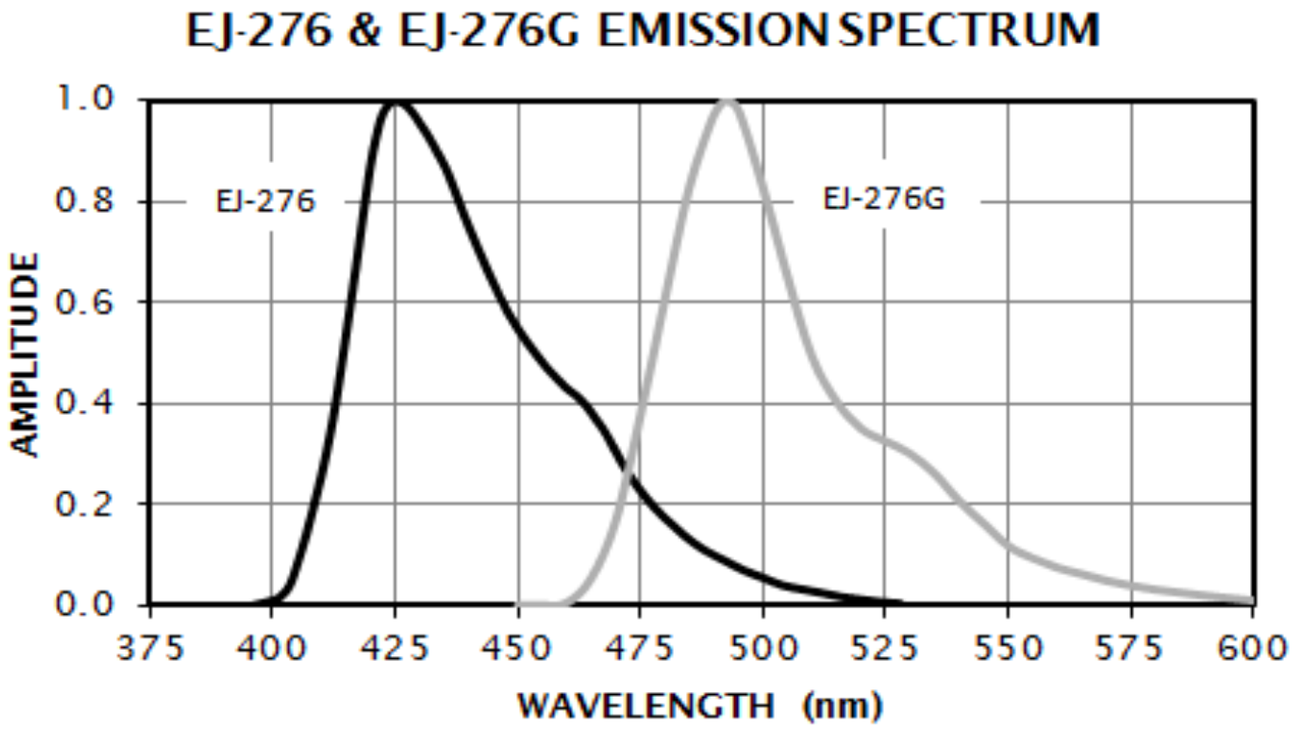

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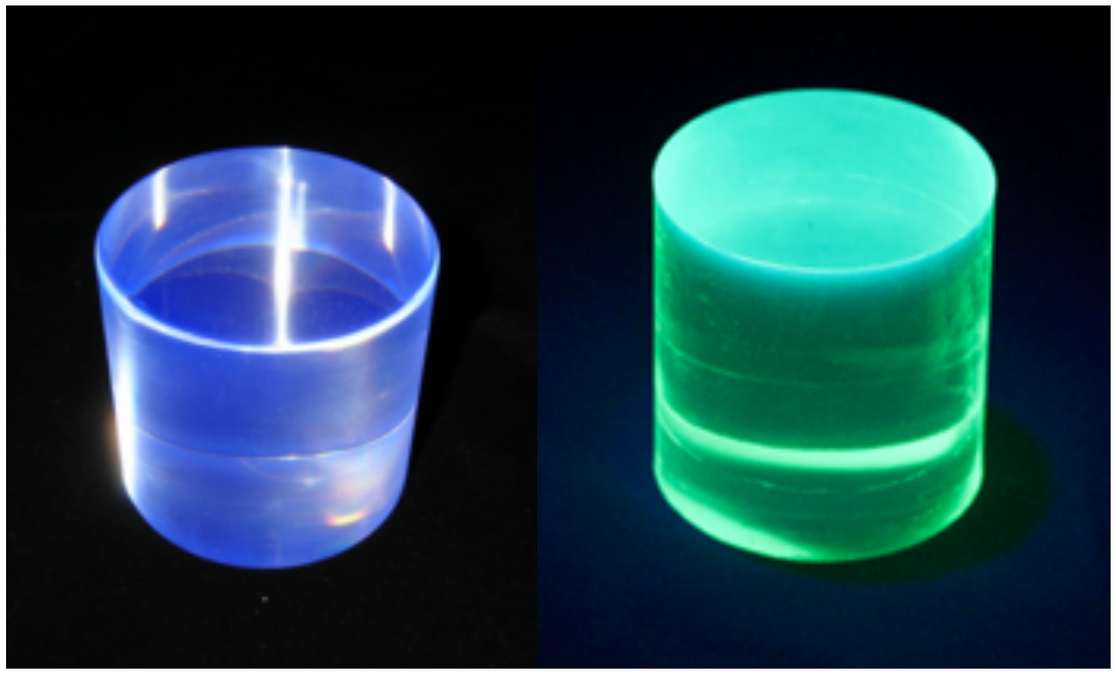
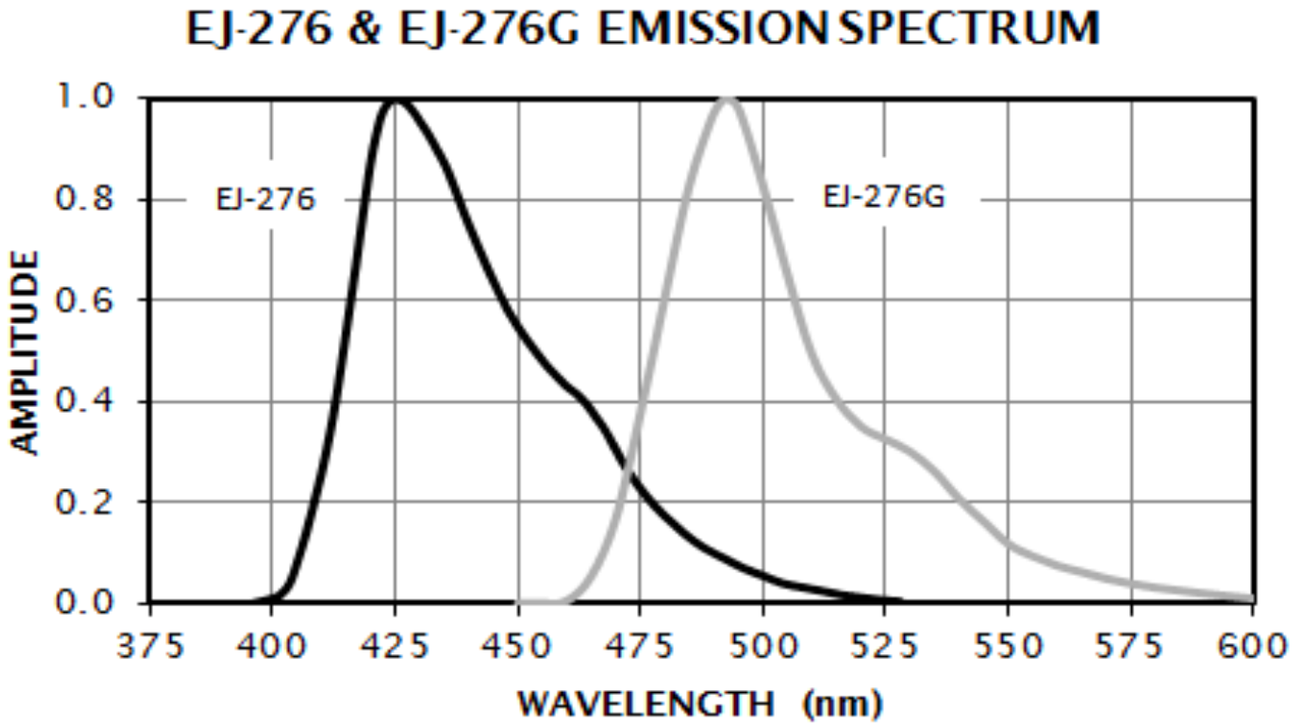
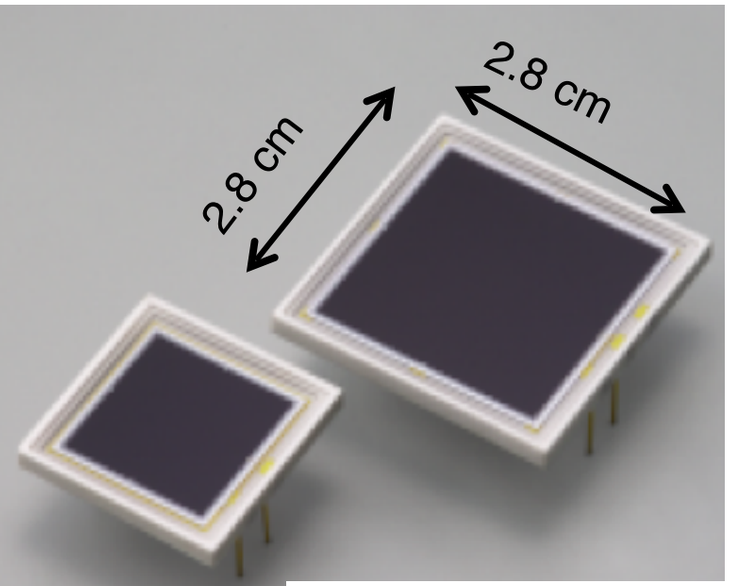




PHOTODIODE

Si PIN photodiode
S3204/S3584 series

Large area sensors for scintillation detection



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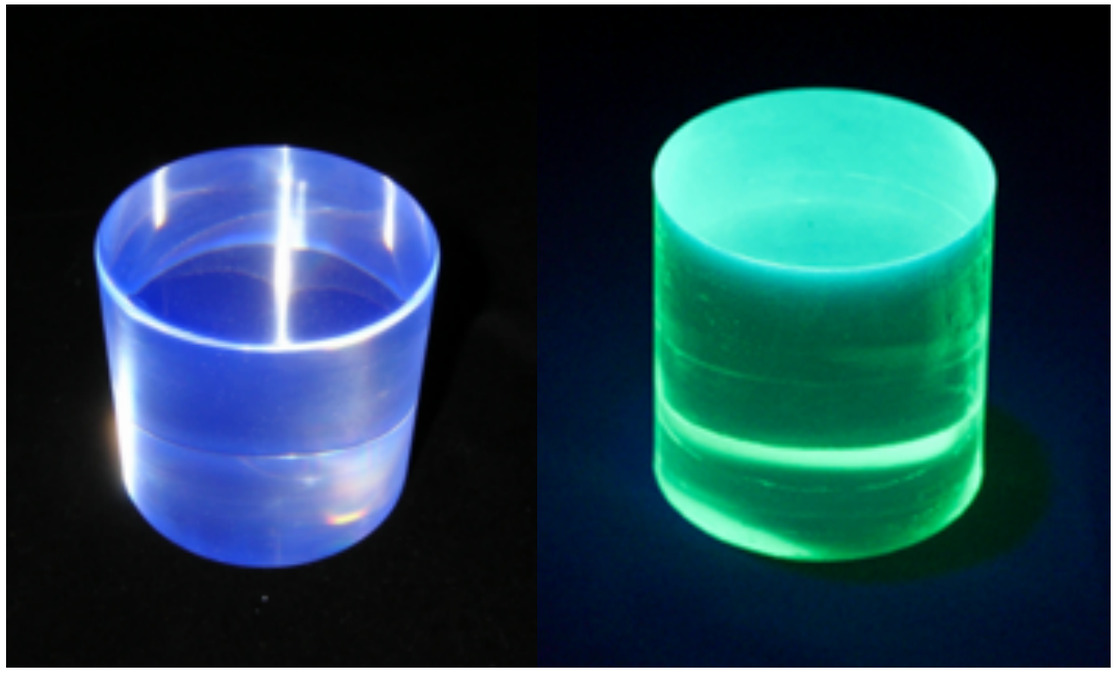
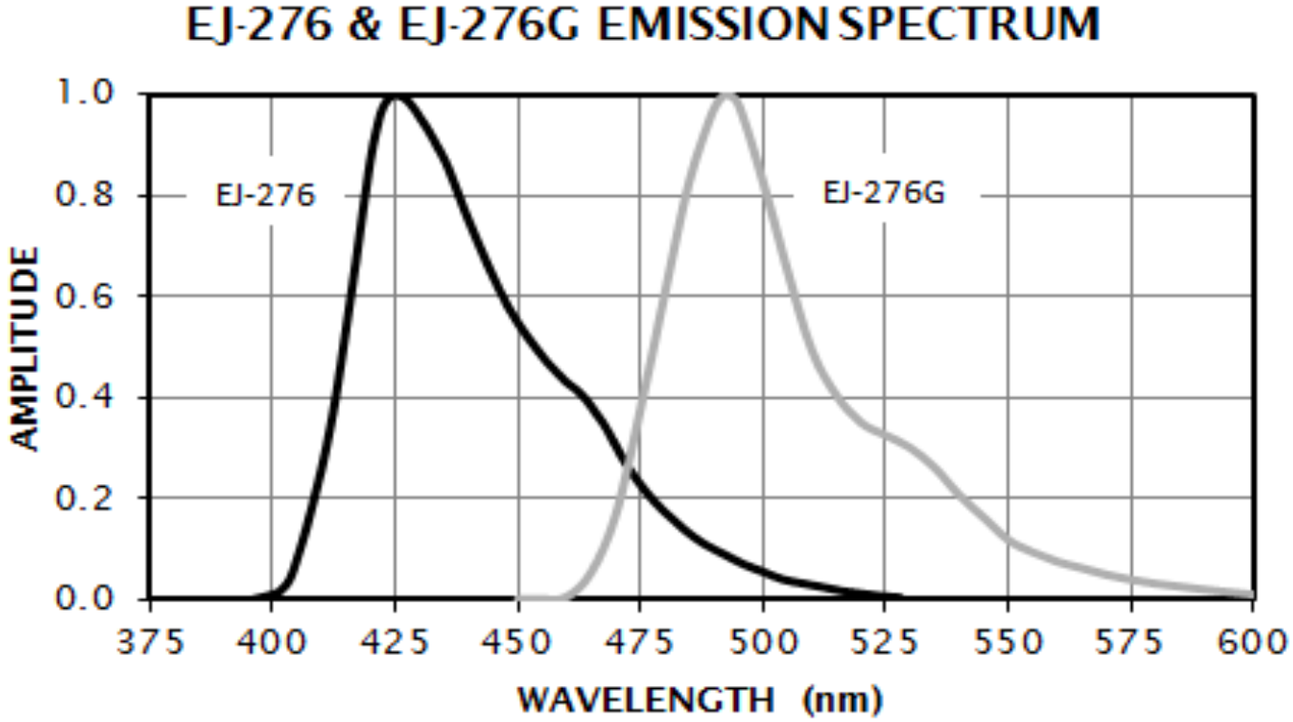
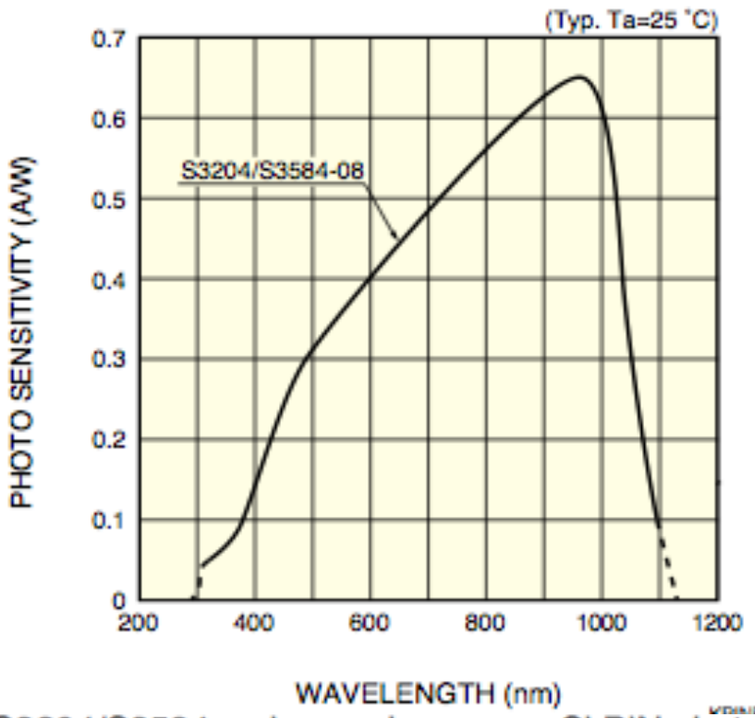
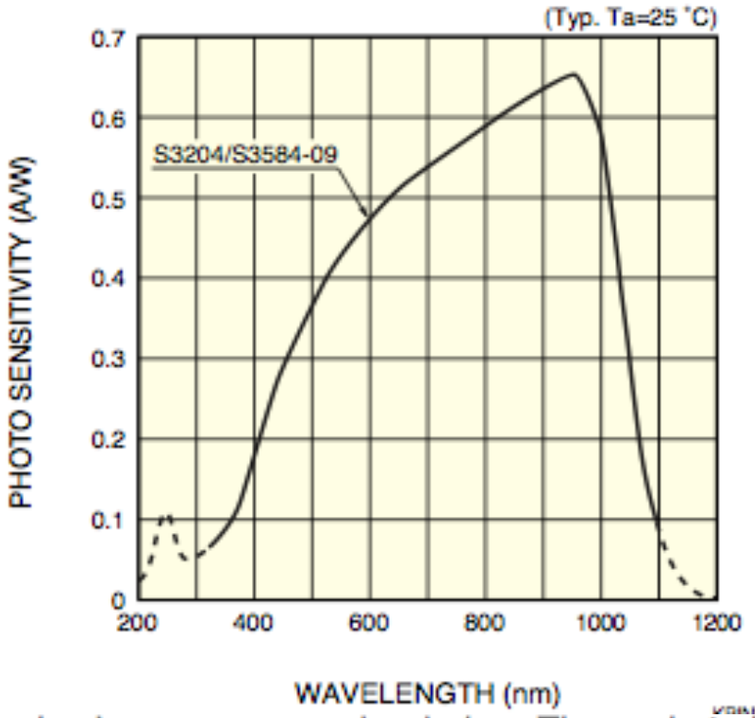


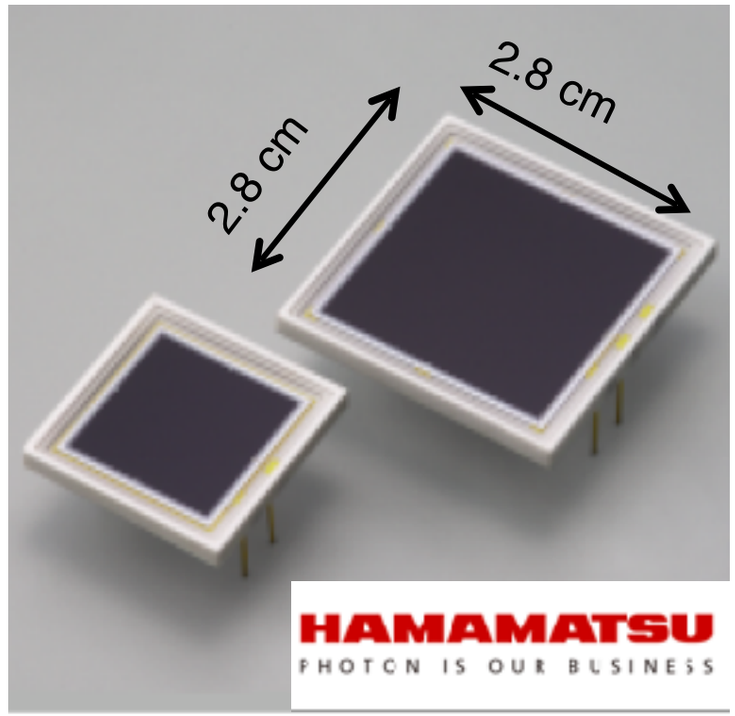


■ Spectral response



■ Spectral response (without window)





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Test using radioactive sources @ LNS

Dimention: 3x3x3 cm3
<neutron EFF> (MCNPX) ≈ 4%
Read by PM tube: EMI-9544QA
High Voltage: 1500-1700 V

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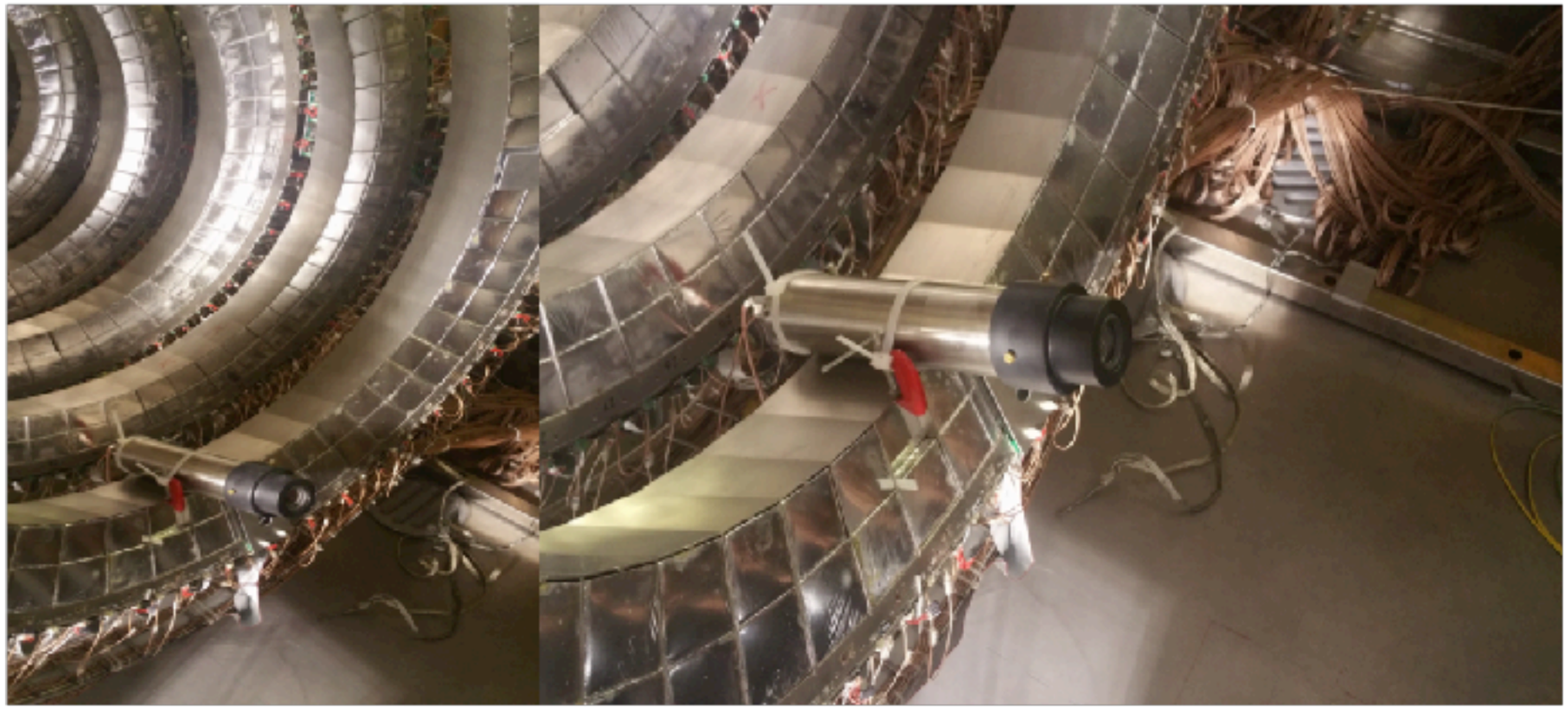

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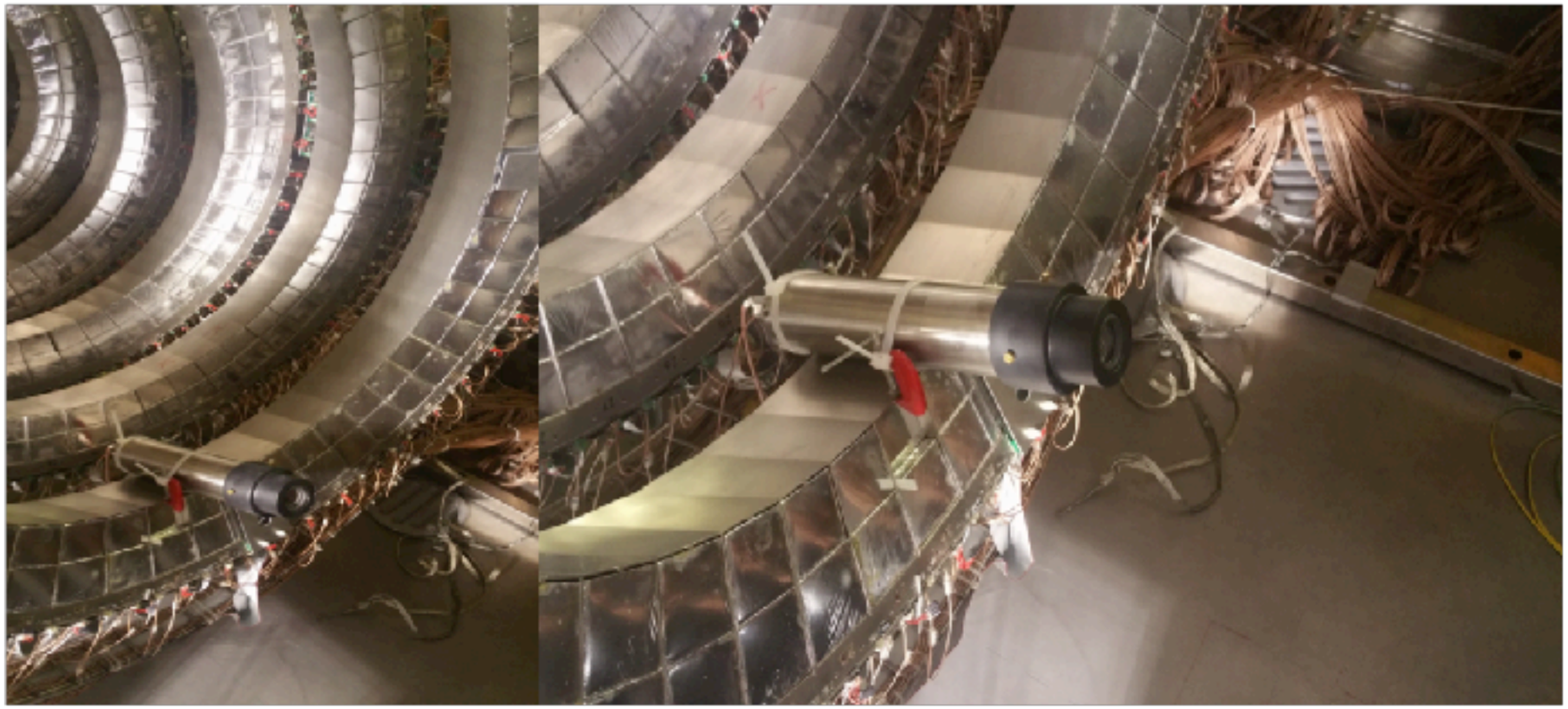

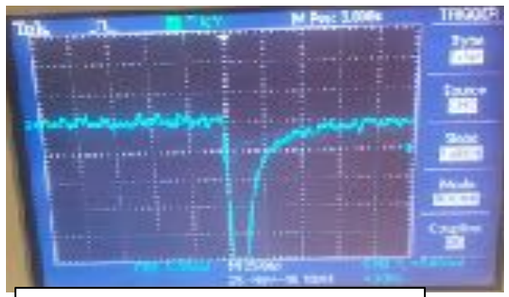

PM -EMI 9954QA
Like in ARGOS detector

G. Lanzanó, et al., NIM A 312, 3, (1992), 515-520

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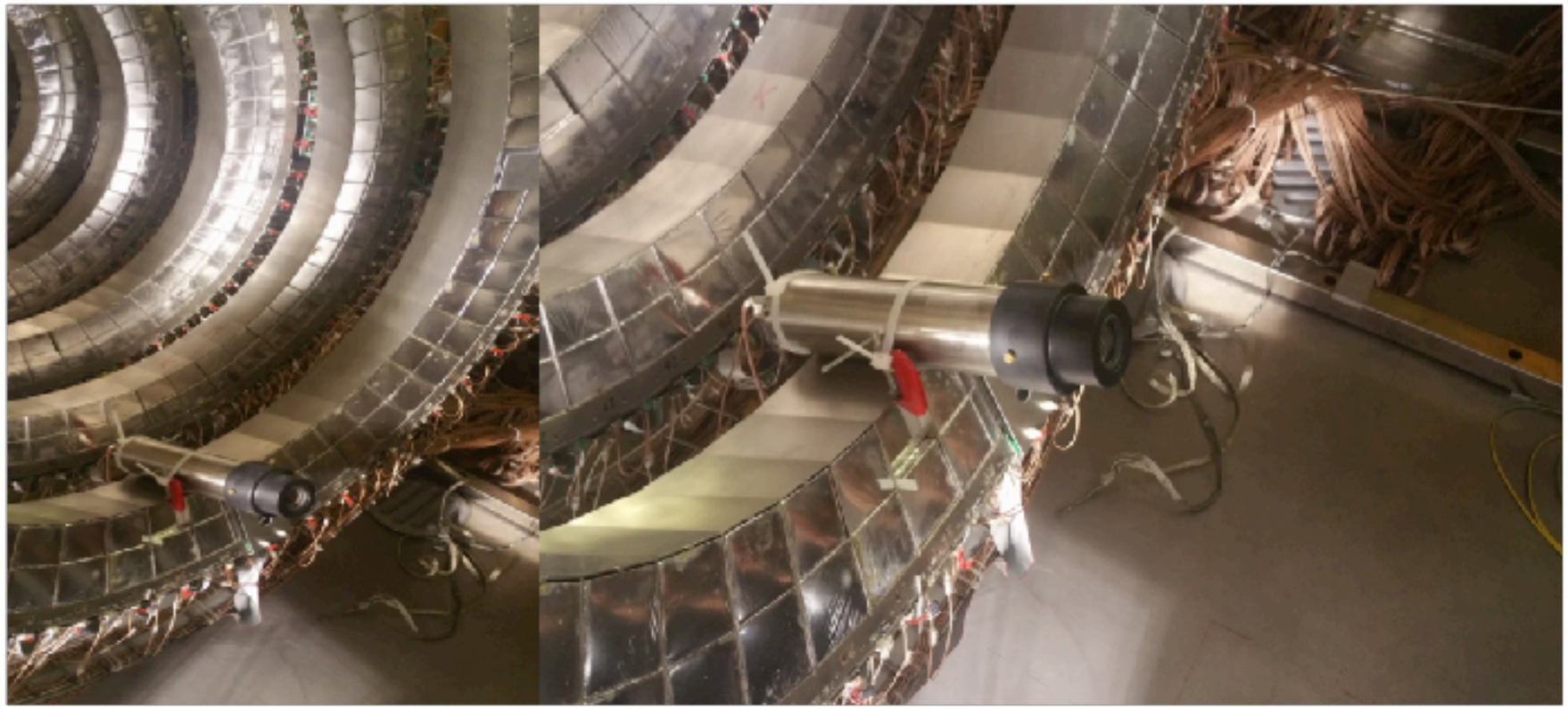

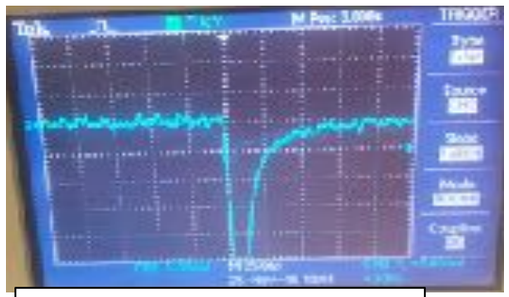

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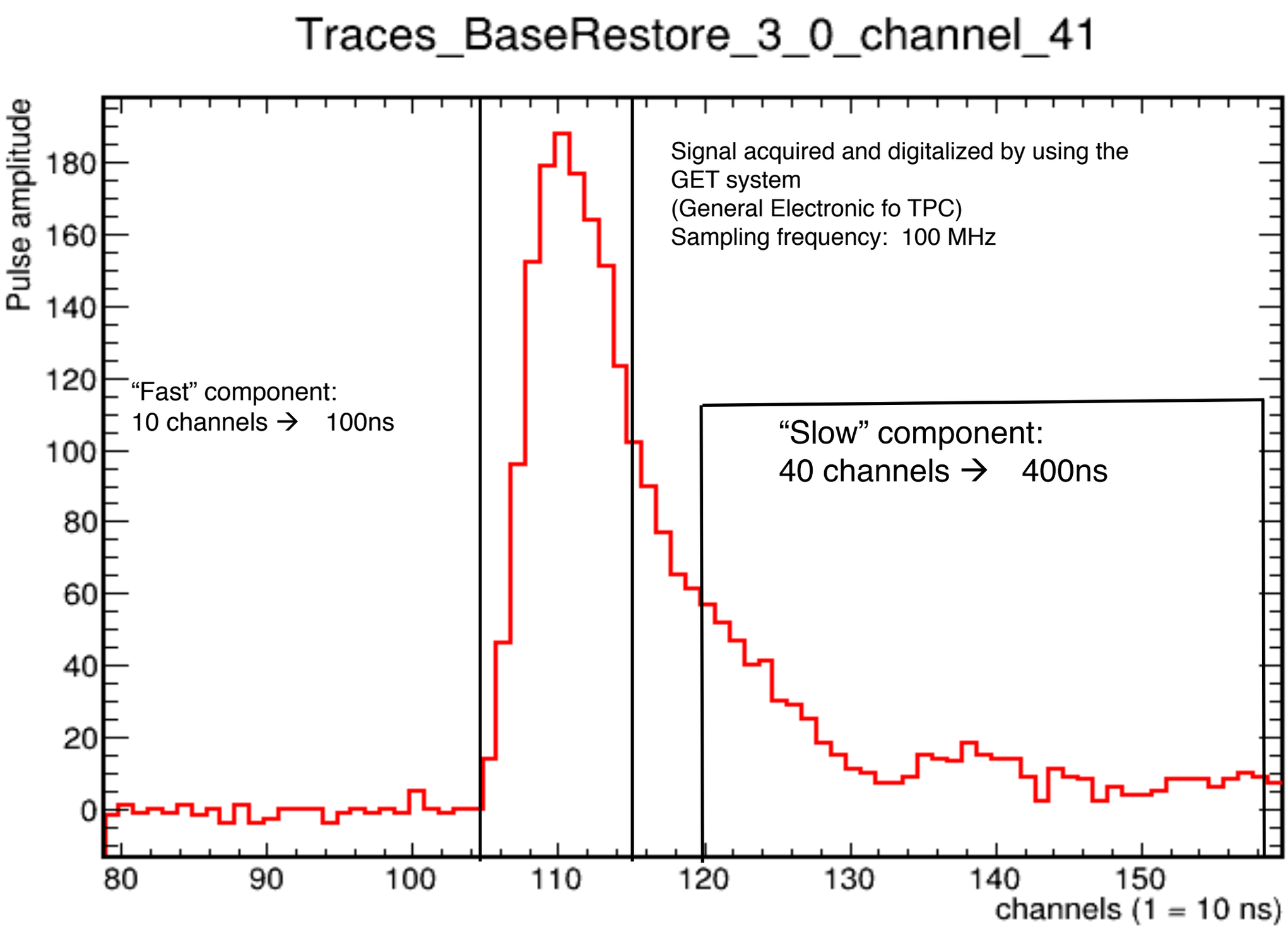
G. Lanzanó, et al., NIM A 312, 3, (1992), 515-520

Sources:
1)γ ^{60}Co
2)α ^{241}Am
3)α ^{232}Th
4) n e γ AmBe

Some results: the digitalized signal



Some results: A few of spectra

E. V. Pagano et al. NIM A 889 (2018) 83-88

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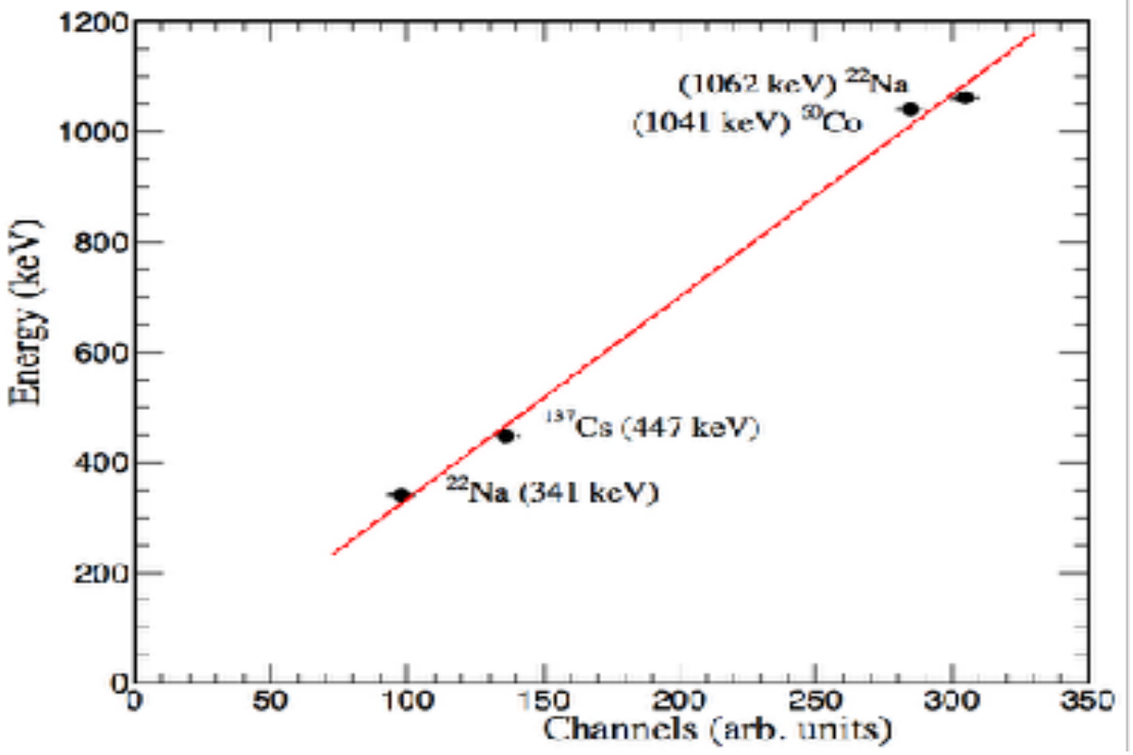

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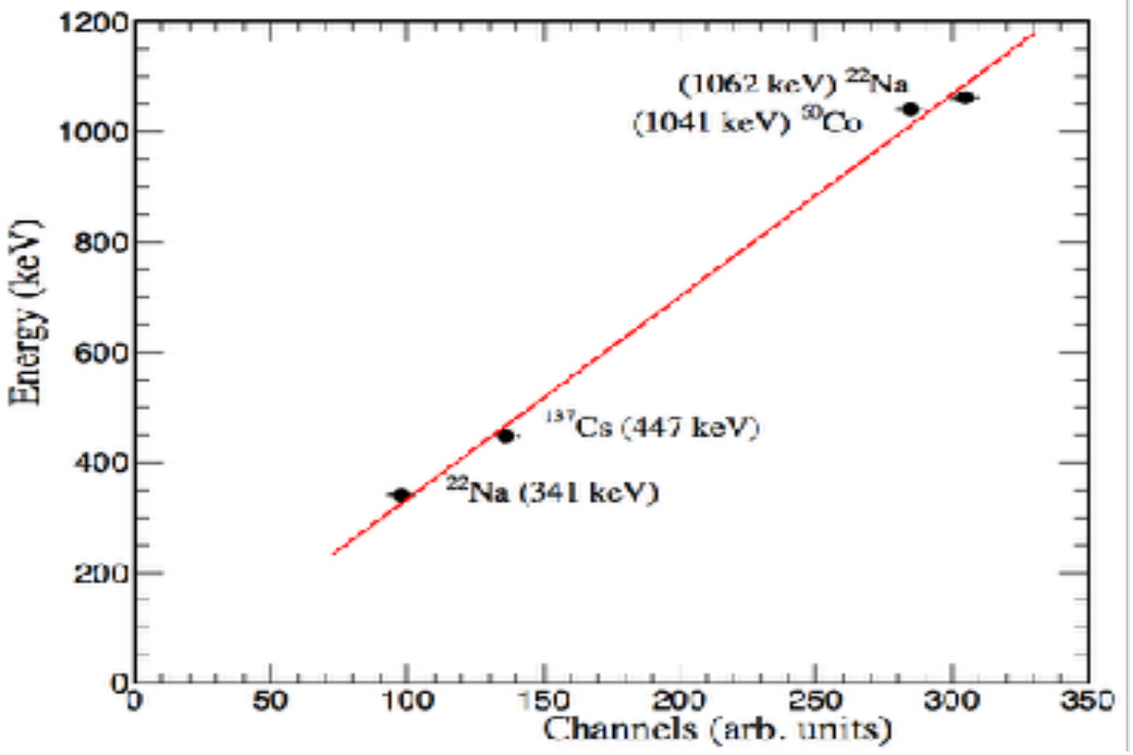

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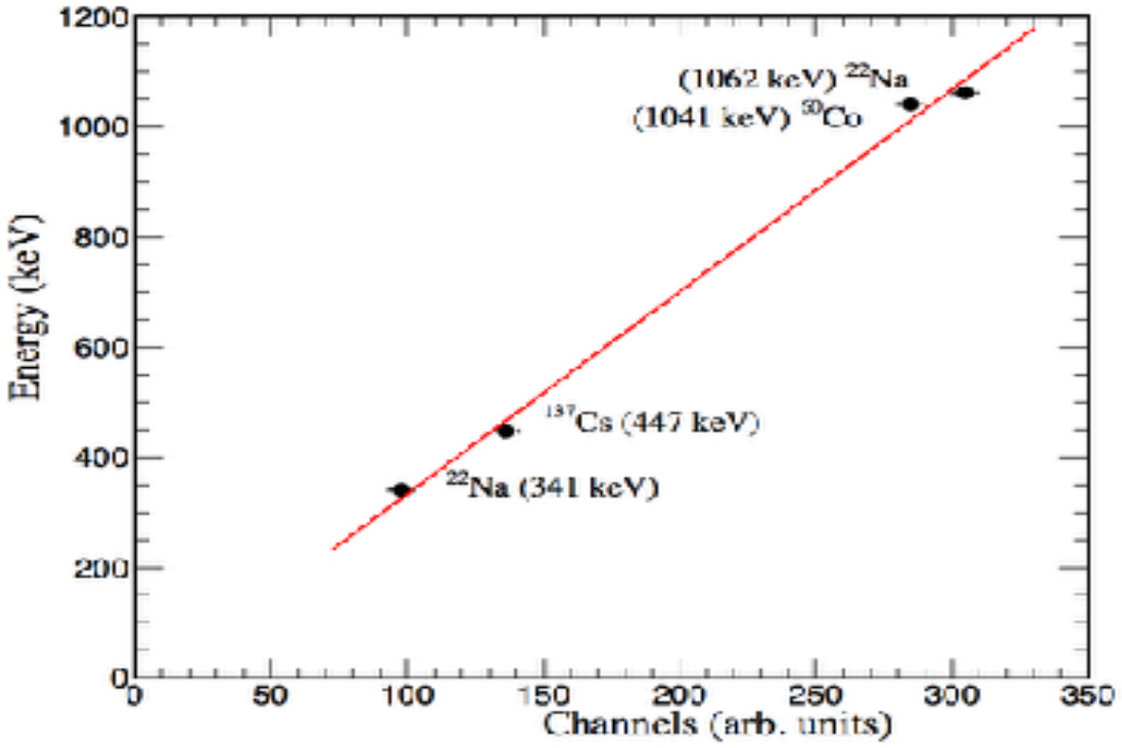

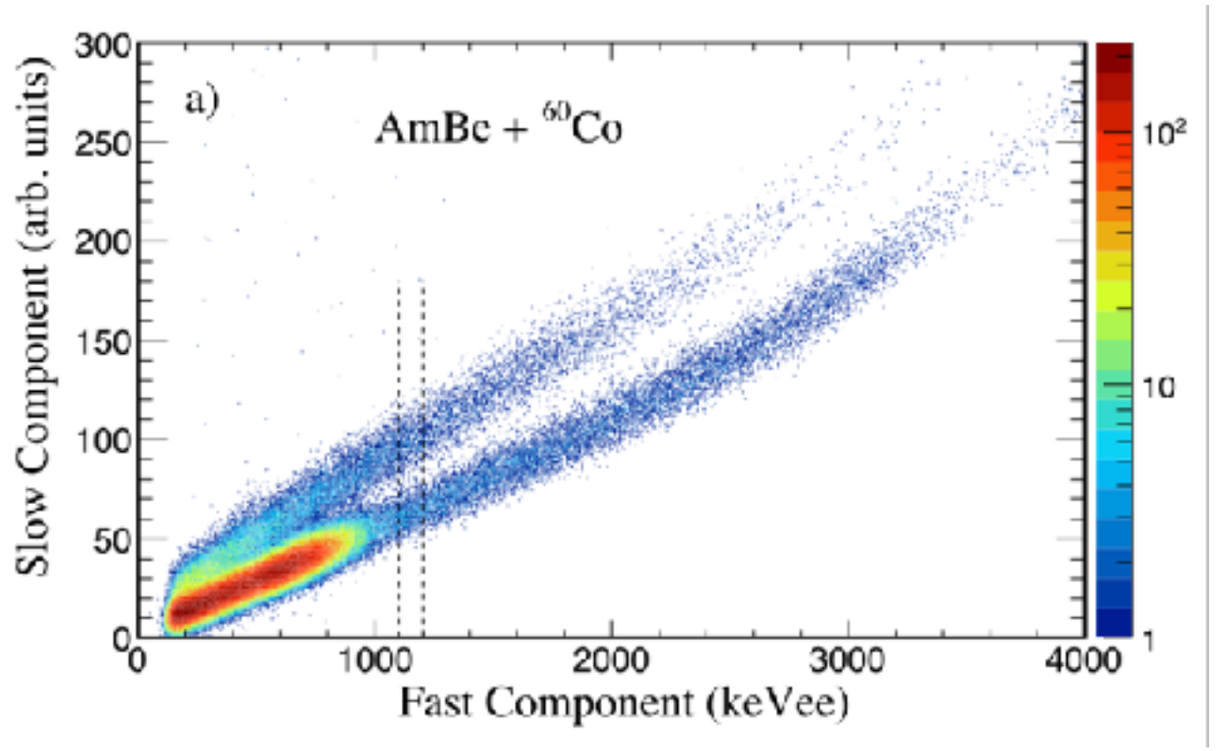

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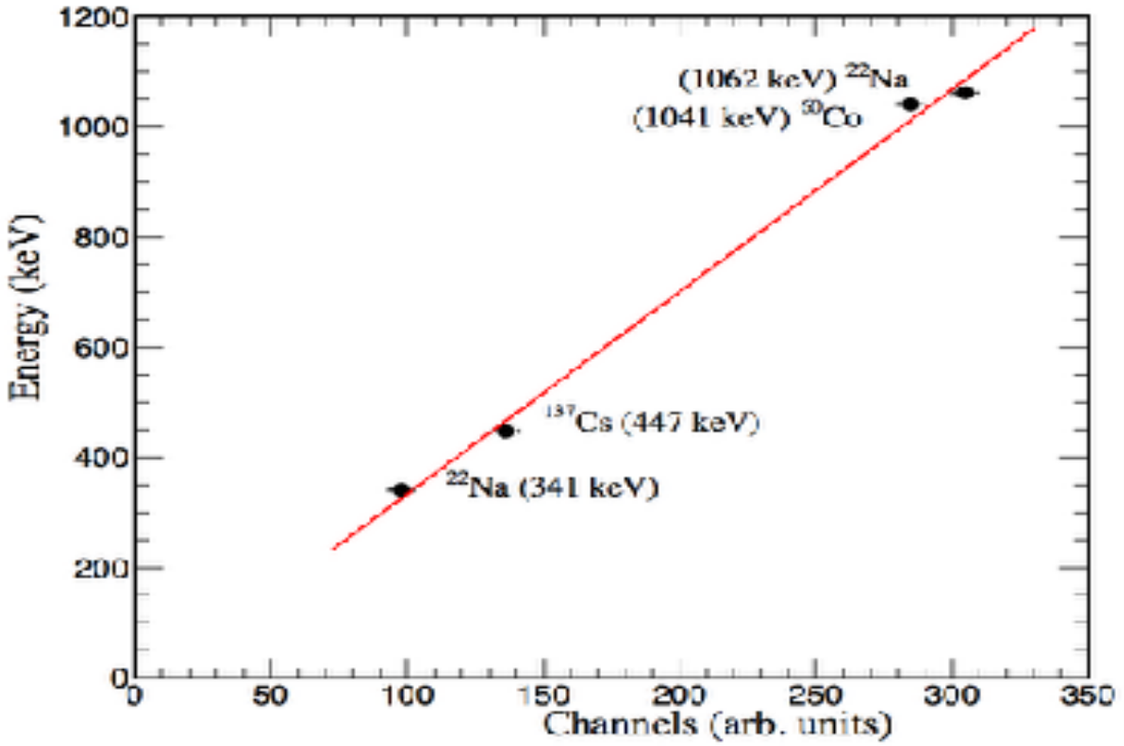

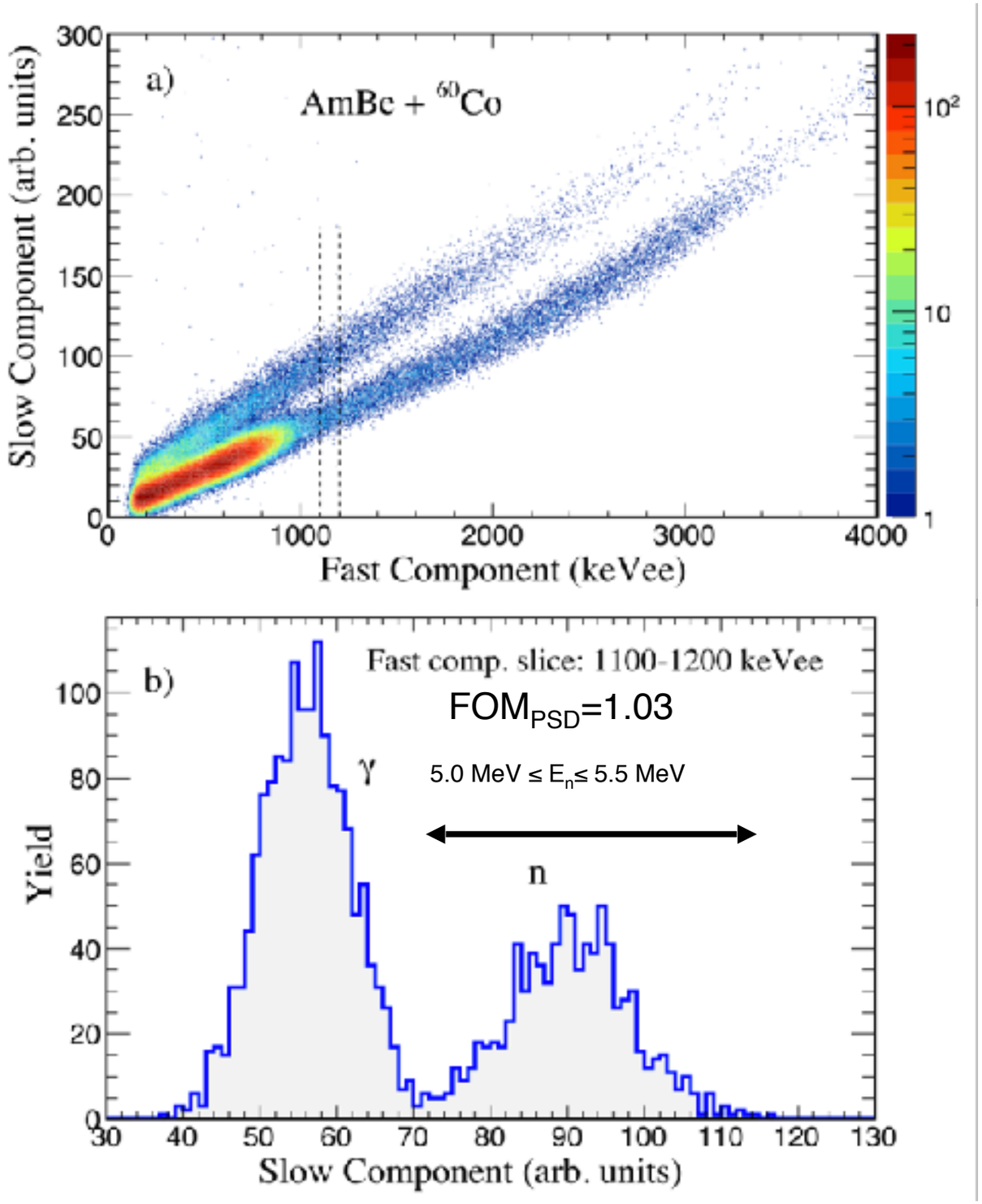

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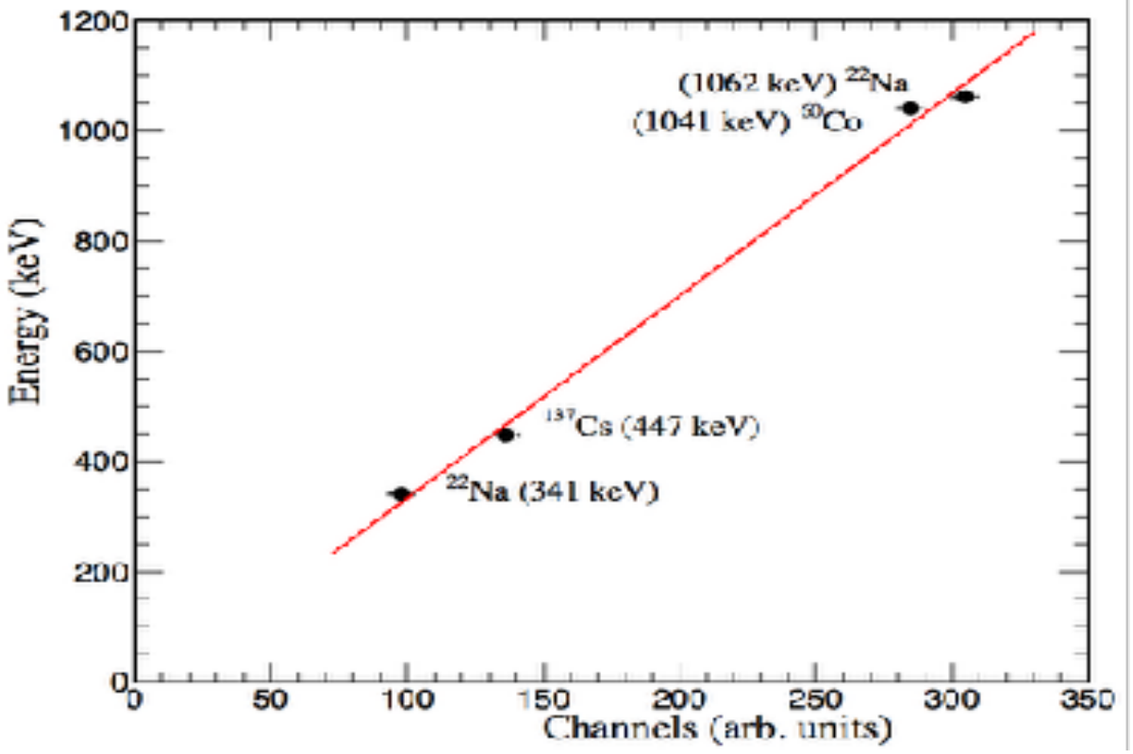
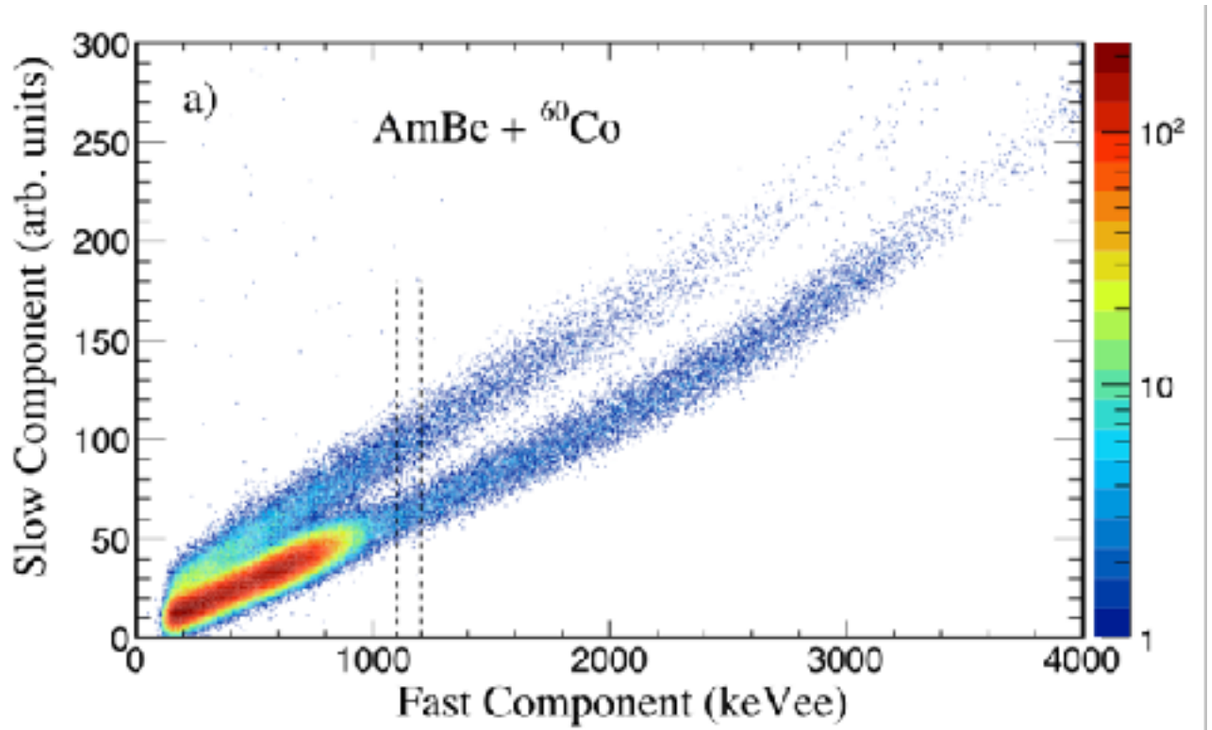
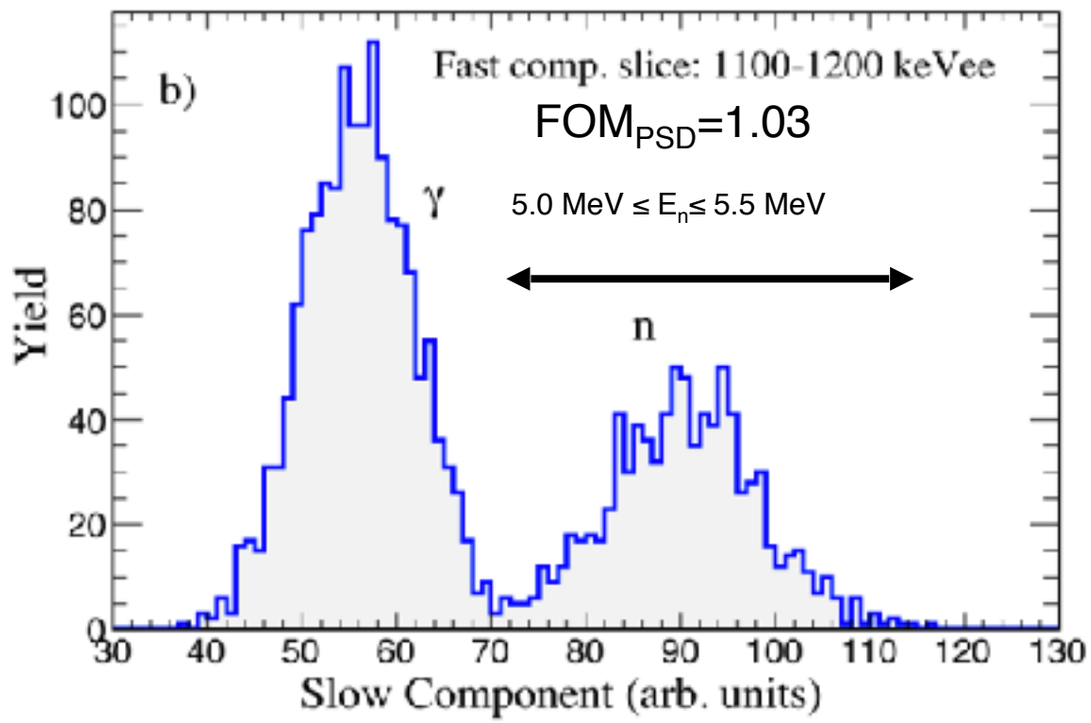






Detection threshold ≈ 0.7 MeV

Discrimination threshold ≈ 1.5 MeV (FOM$_{PSD}$=0.43)

$$L_{out} = A \cdot E_{dep} - B \cdot \left(1 - e^{-C \cdot E_{dep}}\right)$$

$A = 0.8 \quad MeVee \cdot MeV^{-1}$;

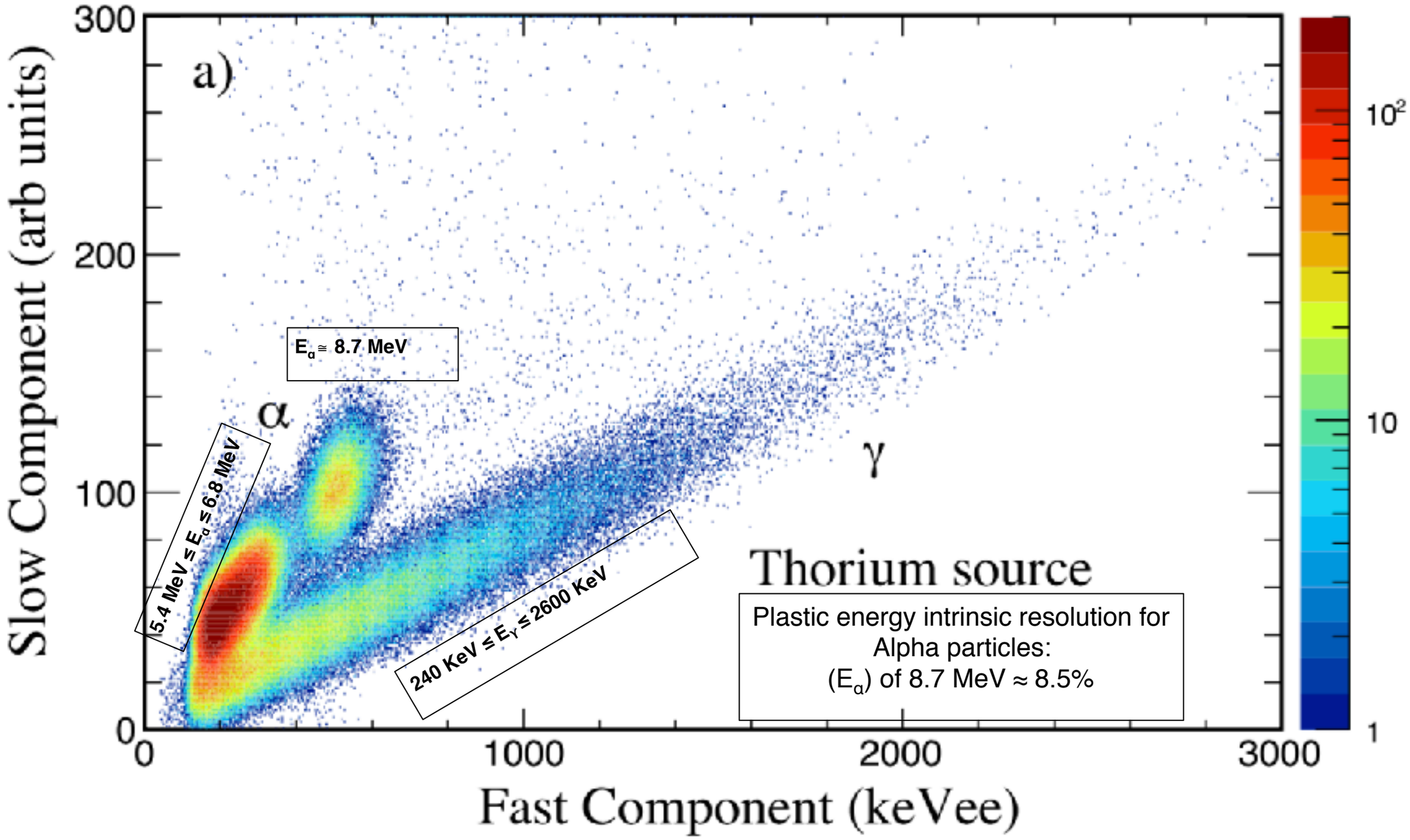
$B = 3.9 \quad MeVee$;

$C = 0.19 \quad MeV^{-1}$;

C. C. Lawrence et al., NIM A759 (2014) 16

Some results: A few of spectra

E. V. Pagano et al. NIM A 889 (2018) 83-88



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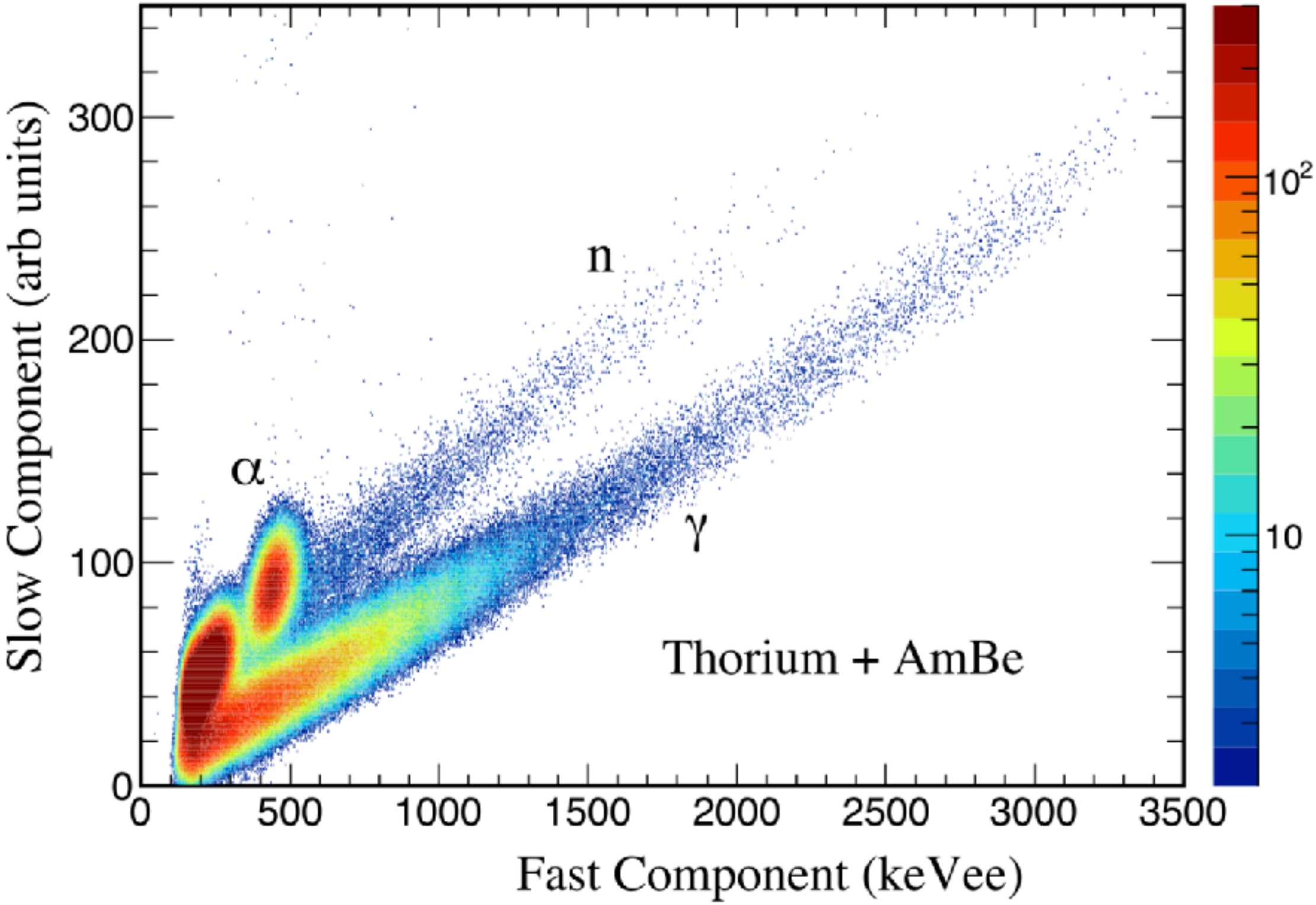
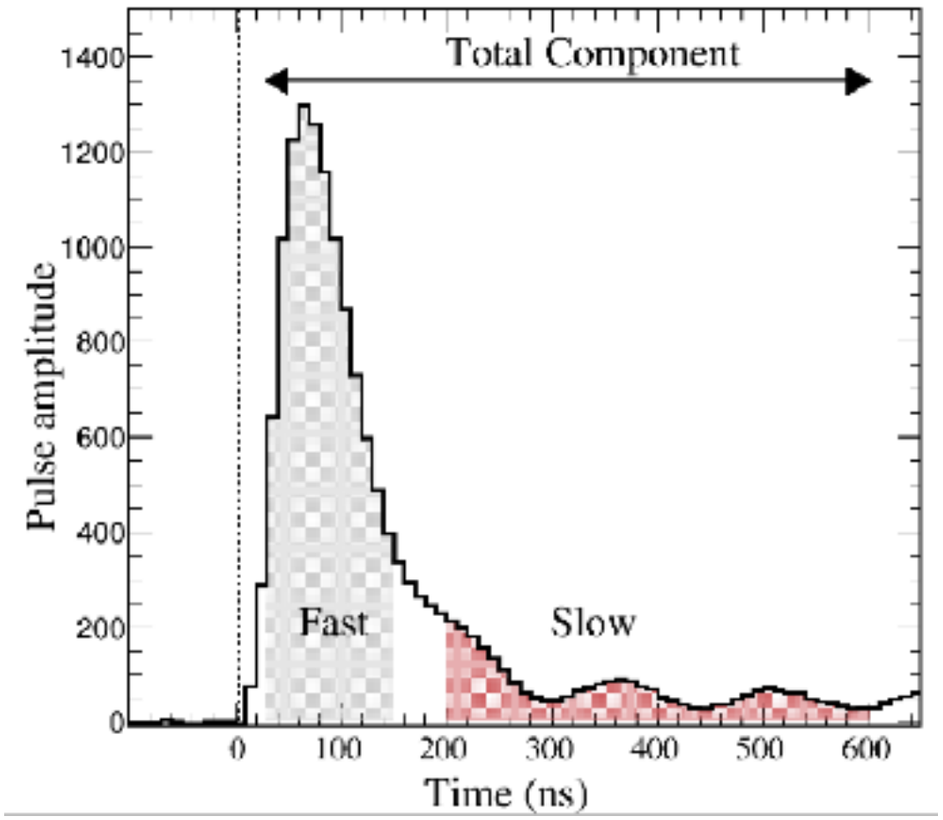


The latests resuls: tests in high background condition

The test was done during the Barrier experiment @ LNS $^{24}Mg+^{90,92}Zr$ @ 71.5MeV < E < 81 MeV



E. V. Pagano et al. NIM A 905 (2018) 47-52

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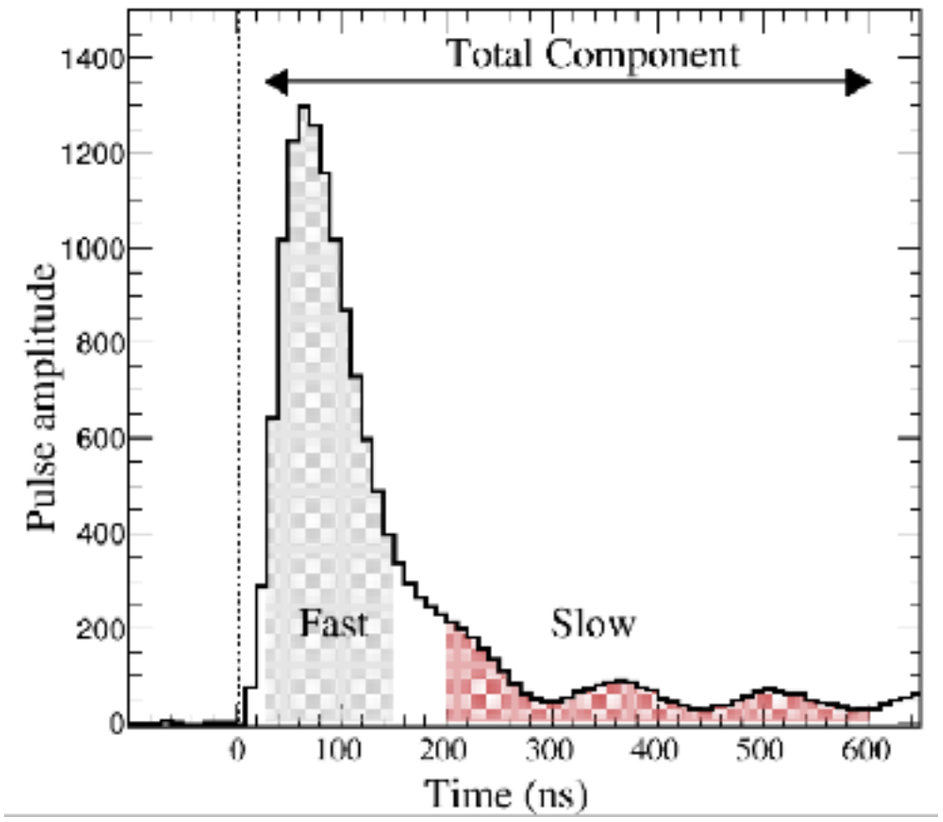

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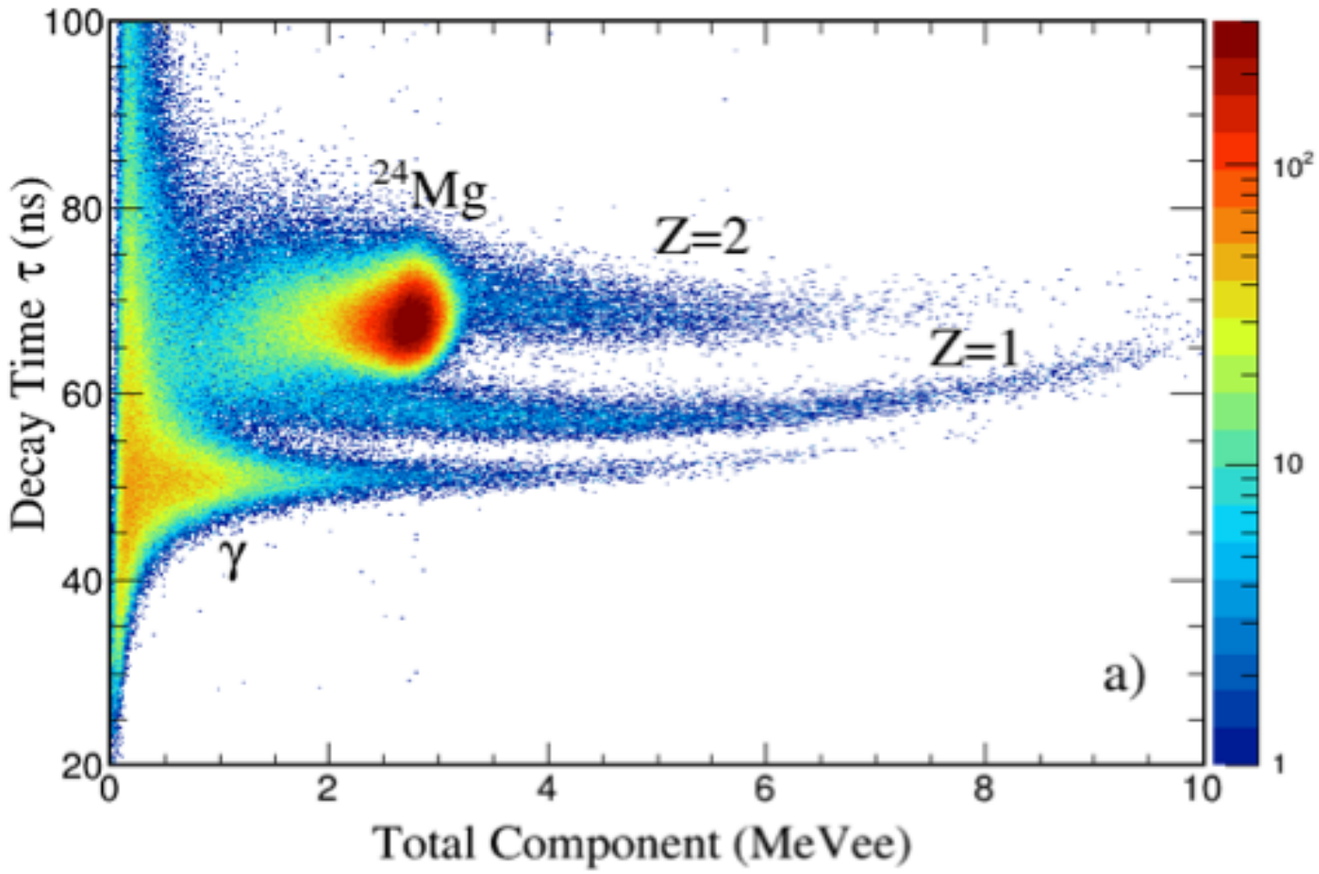

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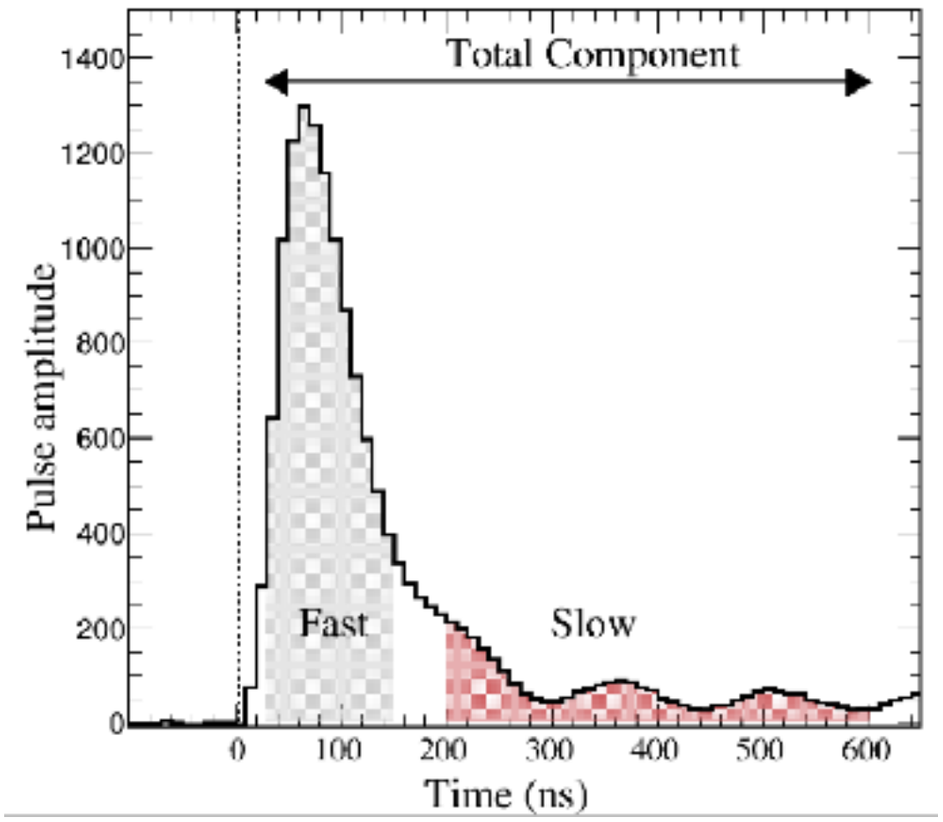

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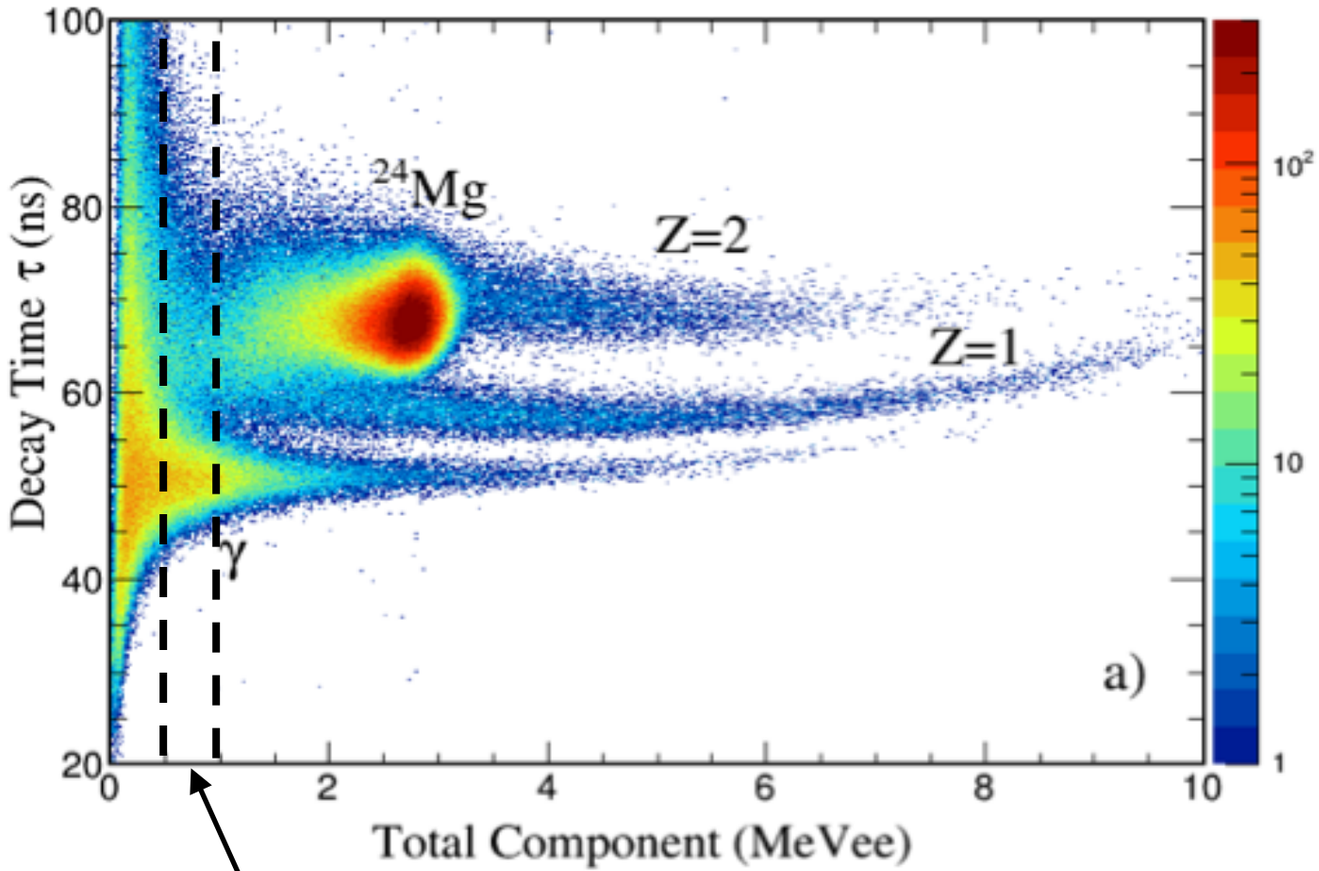

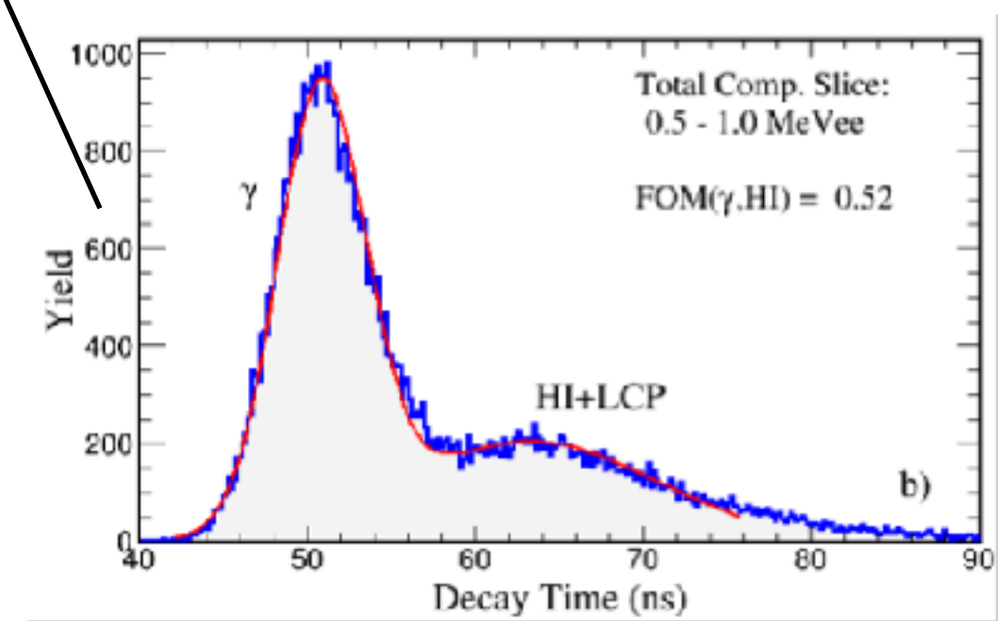

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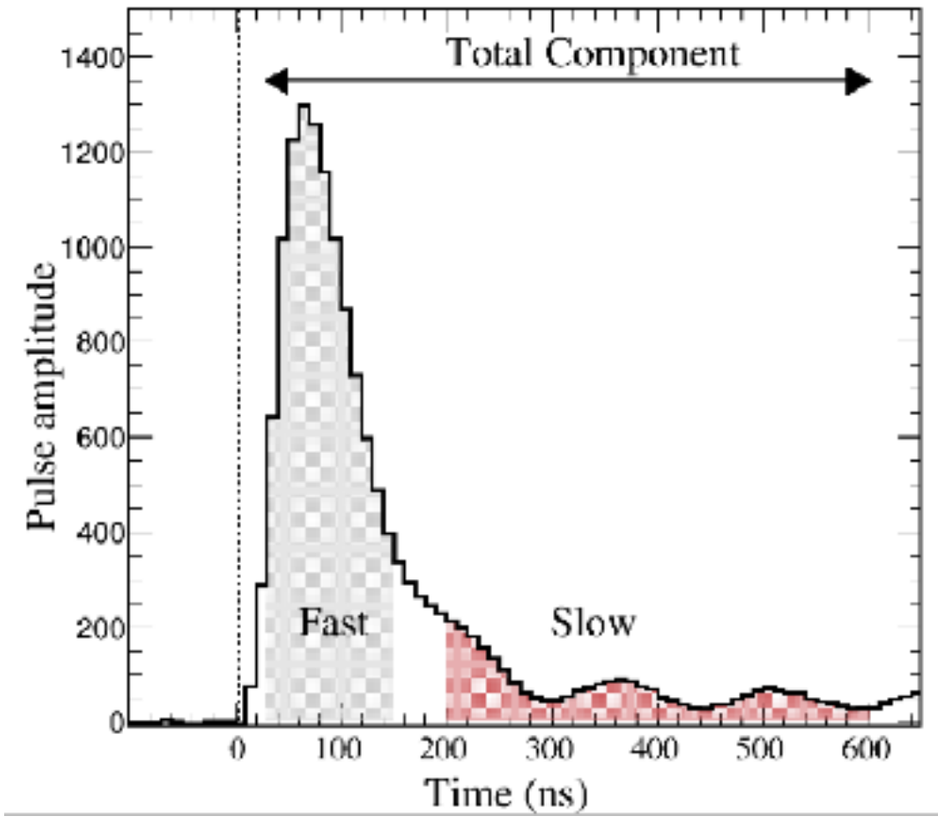

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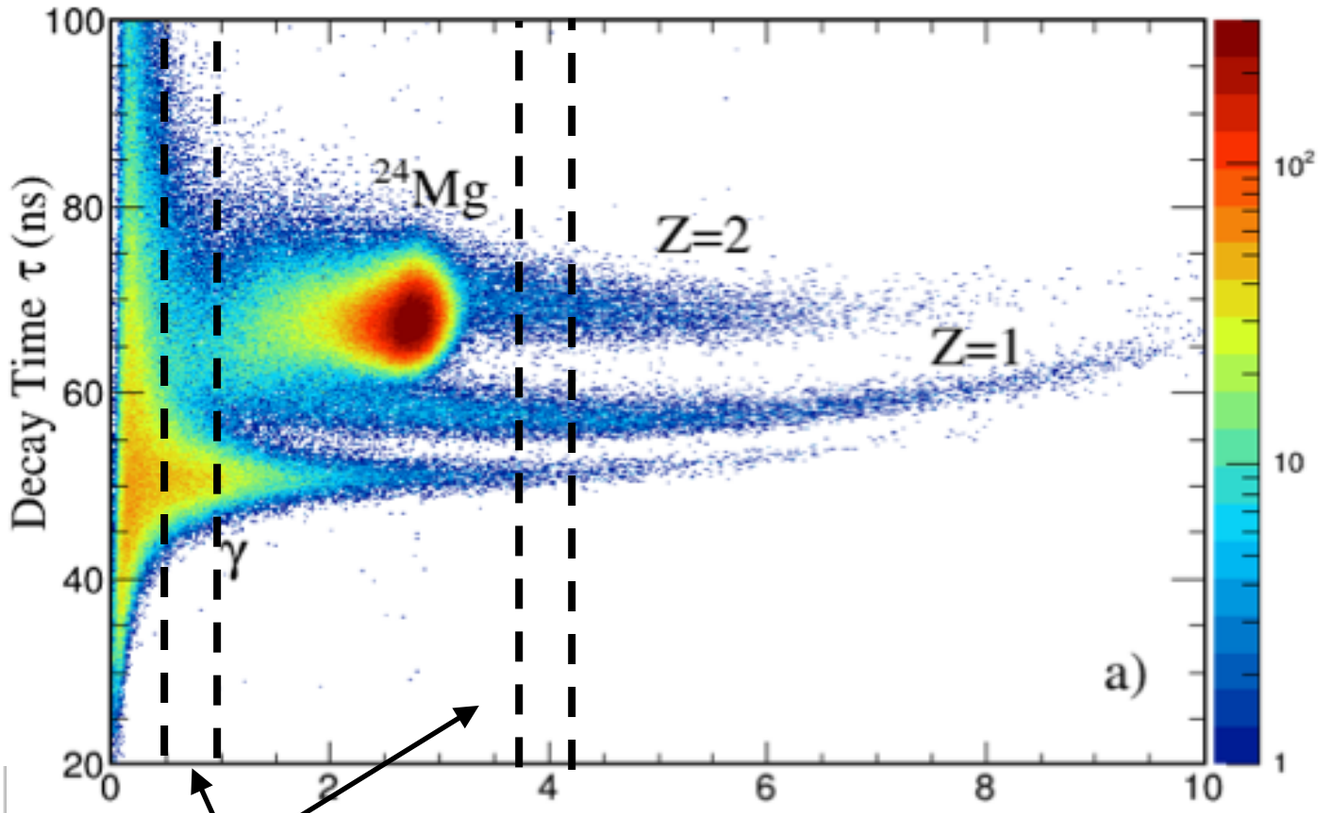

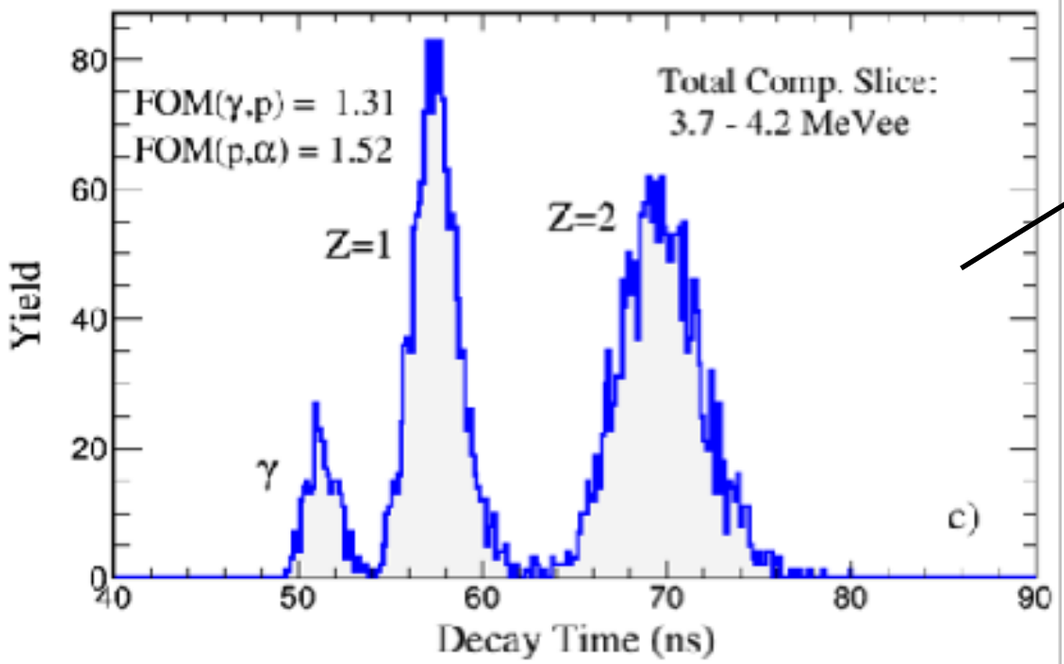

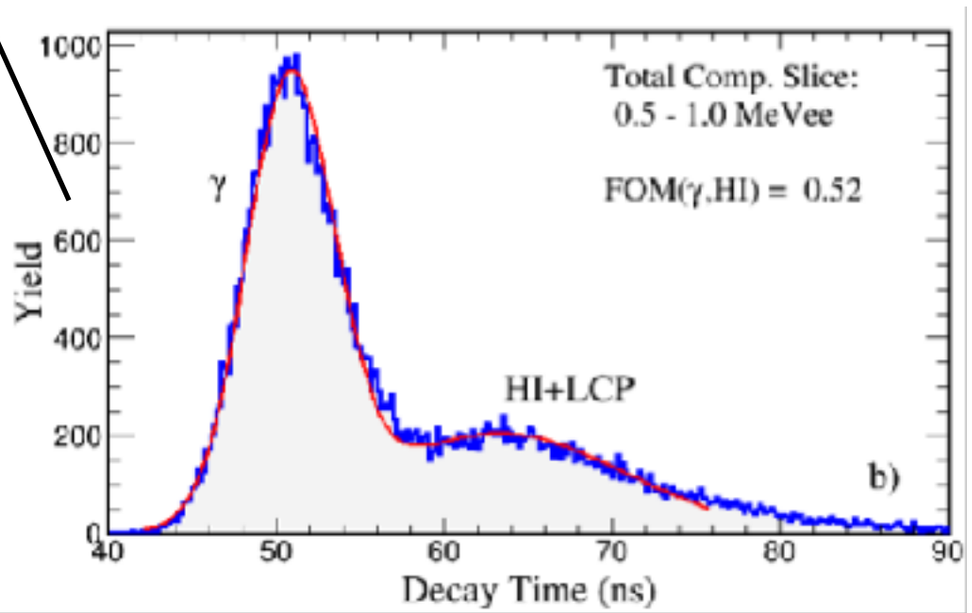

Purposes of the project

Energy of interest: 5≤ E ≤100 AMeV (having particular attention to the Fermi regime)

Nuclear fundamental physics

- Intensity interferometry (HBT effect)
  n-n, n-p, n-LCP, n-IMF, n-TLF, n-PLF
- Studies related to the nuclear symmetry energy (EOS) and its dependence to the nuclear density
- Neutron stars (nuclear astrophysics)
- Reaction mechanism
- Reaction times
- Clustering
- Validation of nuclear dynamics model (BUU,QMD)
- Measurements of the neutron signal in the n-rich RIBs (SPES, SPIRAL2, FRIB, FAIR)

Some applications

- Radioprotection
- Measurement of neutron flux (single measurement, cross section)
- Validation of MC based code (GEAN4, MCNPX)

Purposes of the project: a few example for the fundamental nuclear physic

Intensity interferometry (HBT effect)

Correlation functions $$1 + R(q) = C\frac{Y_{Coinc}(q)}{Y_{Uncor}(q)}$$

Space-time characterization of the emitting source

Purposes of the project: a few example for the fundamental nuclear physic

Intensity interferometry (HBT effect)

N. Colonna et al., PRL **75**, 23 (1995) 4190-4193

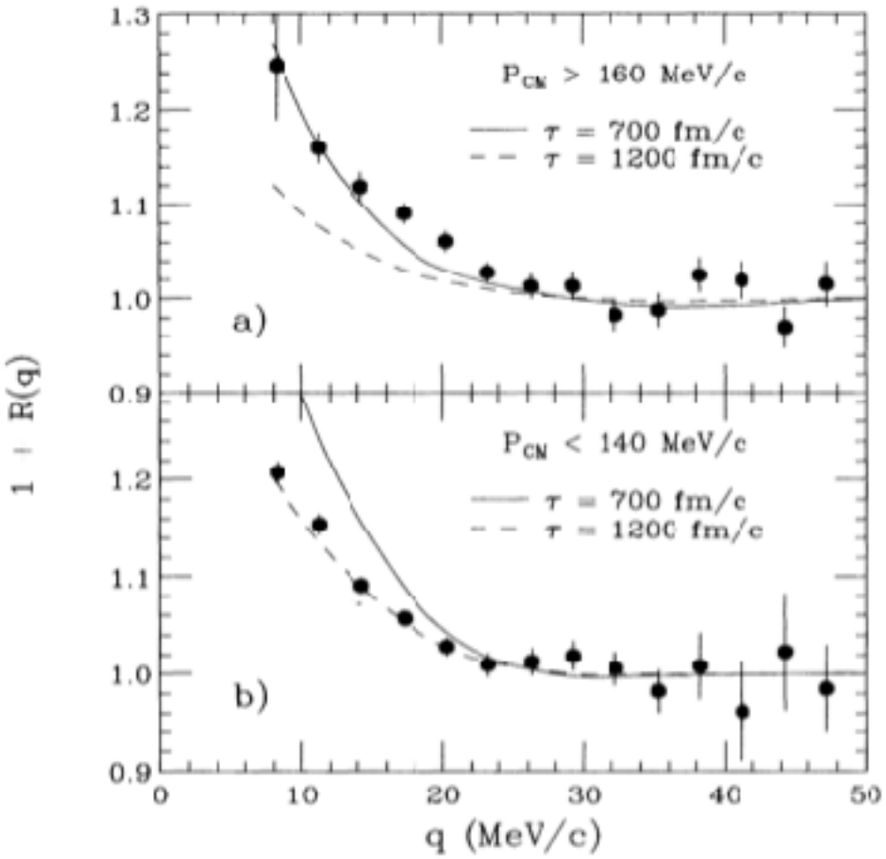

FIG. 3. Angle-integrated correlation functions for two cuts on the total neutron pair momentum in the compound nucleus frame. The solid and dashed curves are results of theoretical calculations with the indicated emission time scales.

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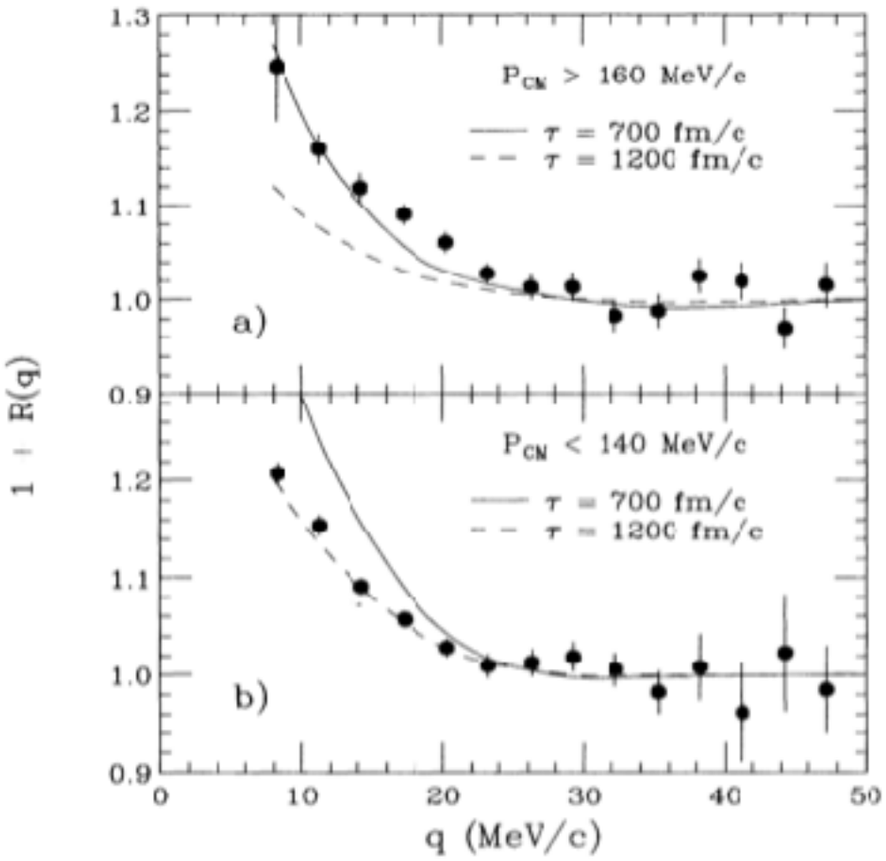

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R. Ghetti et al., PRL **87**, 10 (2001)

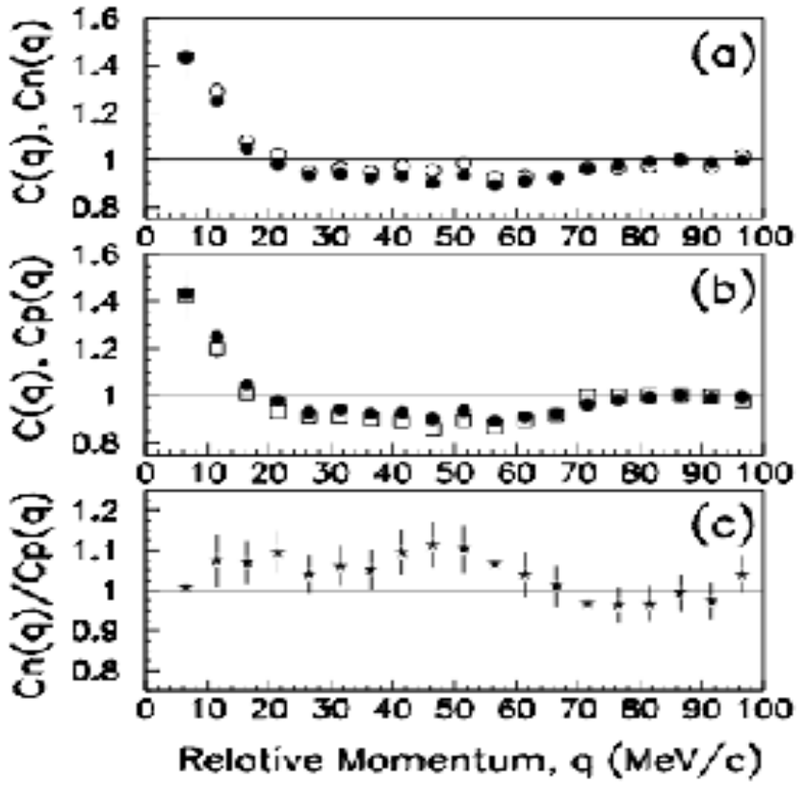

FIG. 2. Experimental ungated np correlation function $C(q)$, from the $E/A = 45$ MeV ^{58}Ni + ^{27}Al reaction [solid dots in panels (a),(b)] compared to panel (a), open circles: $C_n(q)$, constructed from pairs of type $E_n > E_p$, and panel (b), open squares: $C_c(q)$, constructed from pairs of type $E_n < E_p$. The ratio C_n/C_p is shown in panel (c).

Purposes of the project: a few example for the fundamental nuclear physic

Intensity interferometry (HBT effect)

Correlation functions $$1 + R(q) = C\frac{Y_{Coinc}(q)}{Y_{Uncor}(q)}$$

Space-time characterization of the emitting source

Purposes of the project: a few example for the fundamental nuclear physic

Intensity interferometry (HBT effect)

Correlation functio

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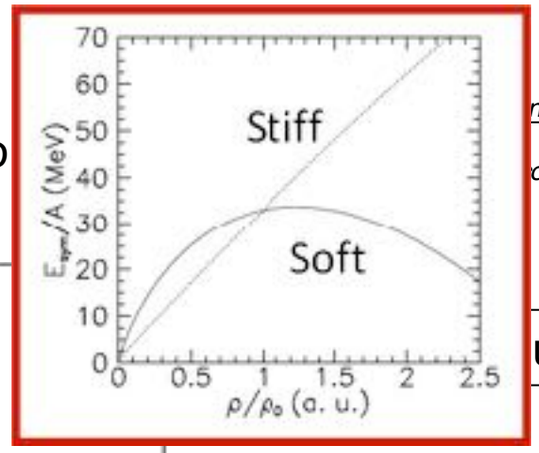
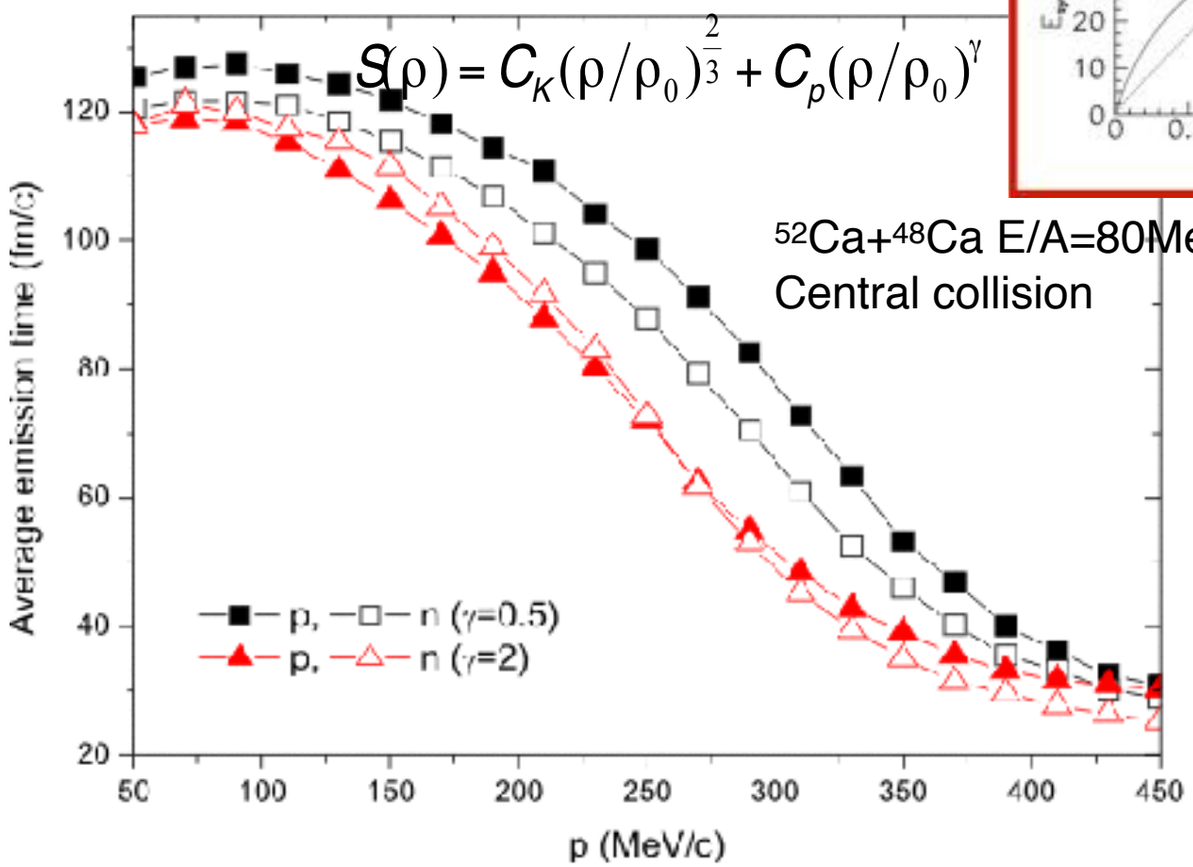
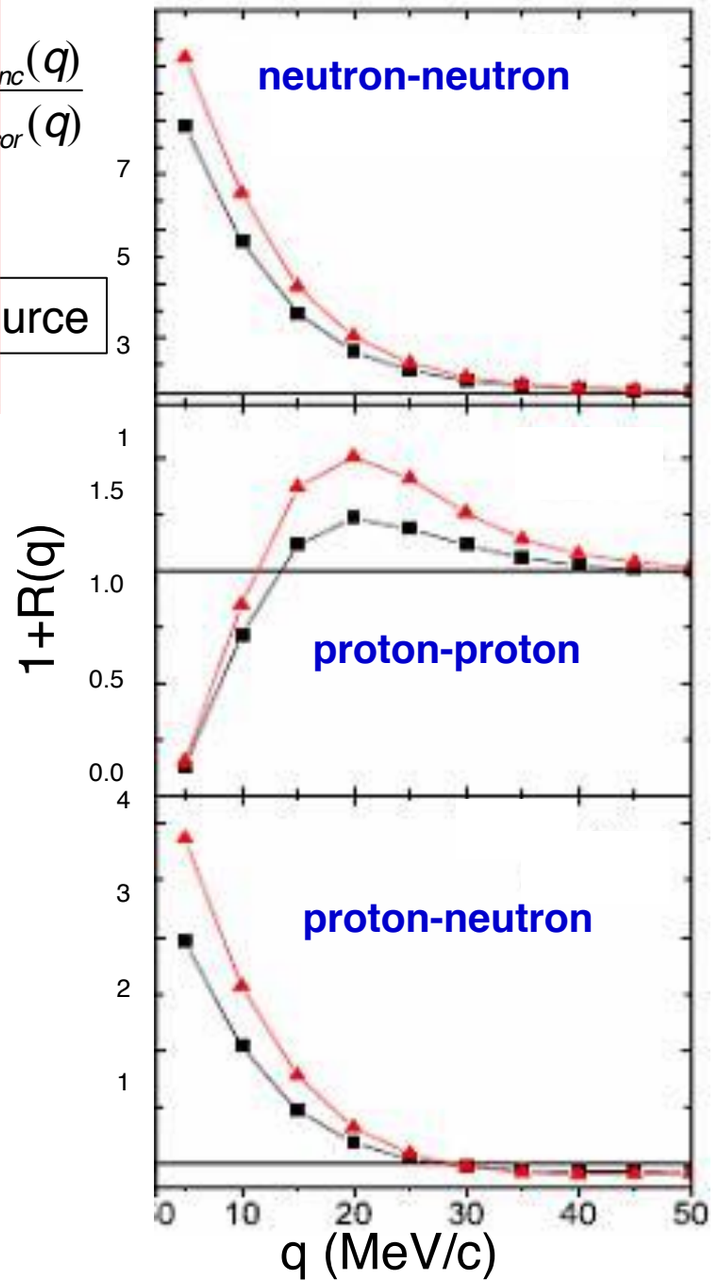


$$S(\rho) = C_K(\rho/\rho_0)^{\frac{2}{3}} + C_p(\rho/\rho_0)^{\gamma}$$

^{52}Ca+^{48}Ca E/A=80MeV
Central collision



Lie-Wen Chen et al., PRL (2003); PRC(2005)



Purposes of the project: a few example applications

M. De Simoni
Talk

Anti-cancer therapy:
Risk of secondary radio-induced cancers

In proton therapy, in particular in the pediatric one (but not only), the “damage” caused from the neutron to the healthy cells is one of the principal causes of the so called “ secondary radio-induced tumors” in particular if there are used degraders or collimators (passive technique)[1].

[1] Hall, E. J (2006) Intensity-modulated radiation therapy, protons, and the risk of second cancers.
Int J Radiat Oncol Biol Phys 65: 1-7.

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Validation of Monte Carlo codes

Measurement of cross sections ($d^2\sigma/d\theta dE$) have a huge interest for the validations of Monte Carlo code like GEANT4 in particular for neutrons in the Fermi energy regime

External interest for the project

External interest for the project

Science & Technology Facilities Council

Science and Technology Facilities Council

STFC Rutherford Appleton Laboratory
Harwell Campus
Didcot OX11 0QX
United Kingdom

Tel: +44 (0)1235 445000 Fax: +44 (0)1235 445808
www.stfc.ac.uk

Dr Emanuele Vincenzo Pagano
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and INFN Laboratori Nazionali del Sud
via Santa Sofia 62
95123 Catania
Italy

Direct line +44 (0)1235 445649
Mobile +44 (0) 7712403569
E-mail: triestino.minniti@stfc.ac.uk

Date: 10-July-2017

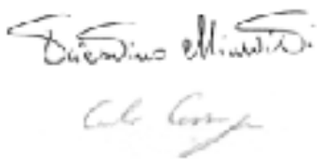
Research Project: Neutron Array for Correlations Studies (NArCoS)

The aim of the "Neutron Array for Correlations Studies" (NArCoS) research project focuses on the development of a neutron detector prototype for neutron spectroscopy. We believe that it will benefit from the experience about neutrons detection that is available at the ISIS spallation neutron source (UK) and from the availability of neutron beam time required for testing purpose. Moreover, this project can represent a further extension in neutron detection for applications at ISIS and in general for neutron spallation sources.

For these reasons, we are pleased to express with this letter our interest and research involvement.

Yours sincerely,

Dr. Triestino Minniti
Dr. Carlo Cazzaniga
Staff Scientist, STFC



External interest for the project

Prof. Salvatore Magazù
Full Professor of Experimental Physics
Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra
Università di Messina
Viale Ferdinando Stagno D'Alcontres n°31, S. Agata, P.O. Box: 55, 98166 Messina, Italy
Phone: +39 090 6765025
Fax: +39 090 395004

Messina, 6th July 207

DECLARATION

To whom it may concern, in charge of Full Professor of Experimental Physics since 2002 at the Department of Mathematical and Computer Science, Physical Sciences and Earth Sciences of the Messina University (Italy), of President of the Interuniversity Consortium for Applied Physics, of previous chairman of the Scientific Committee on Glass Forming Systems at the European Synchrotron Radiation Facility (ESRF, Grenoble), member of several Scientific Committees of synchrotron radiation and neutron scattering at ESRF and at Institute Laue Langevin (ILL, Grenoble), and member of the italian team for the neutron scattering project VESPA for the European Spallation Source, I strongly support the project leaded by Dr. Emanuele Pagano and I declare that the portable neutron source hosted at the Department of Mathematical and Computer Science, Physical Sciences and Earth Sciences of the Messina University is available for all the experimental tests requested in the project Dr. E. Pagano will be dealing with.

Prof. Salvatore Magazu'

Science and Technology Facilities Council

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Date: 10-July-2017

Research Project: Neutron Array for Correlations Studies (NArCoS)

The aim of the "Neutron Array for Correlations Studies" (NArCoS) research project focuses on the development of a neutron detector prototype for neutron spectroscopy. We believe that it will benefit from the experience about neutrons detection that is available at the ISIS spallation neutron source (UK) and from the availability of neutron beam time required for testing purpose. Moreover, this project can represent a further extension in neutron detection for applications at ISIS and in general for neutron spallation sources.

For these reasons, we are pleased to express with this letter our interest and research involvement.

Yours sincerely.

Dr. Triestino Minniti
Dr. Carlo Cazzaniga
Staff Scientist, STFC

Conclusions and perspective

The results of the tests carried out so far are encouraging, seems possible to build a versatile and modular detector, which at the same time can detect neutrons and light charged particles with high angular and energy resolution, read by using silicon technology ad with the digitalization of the signal

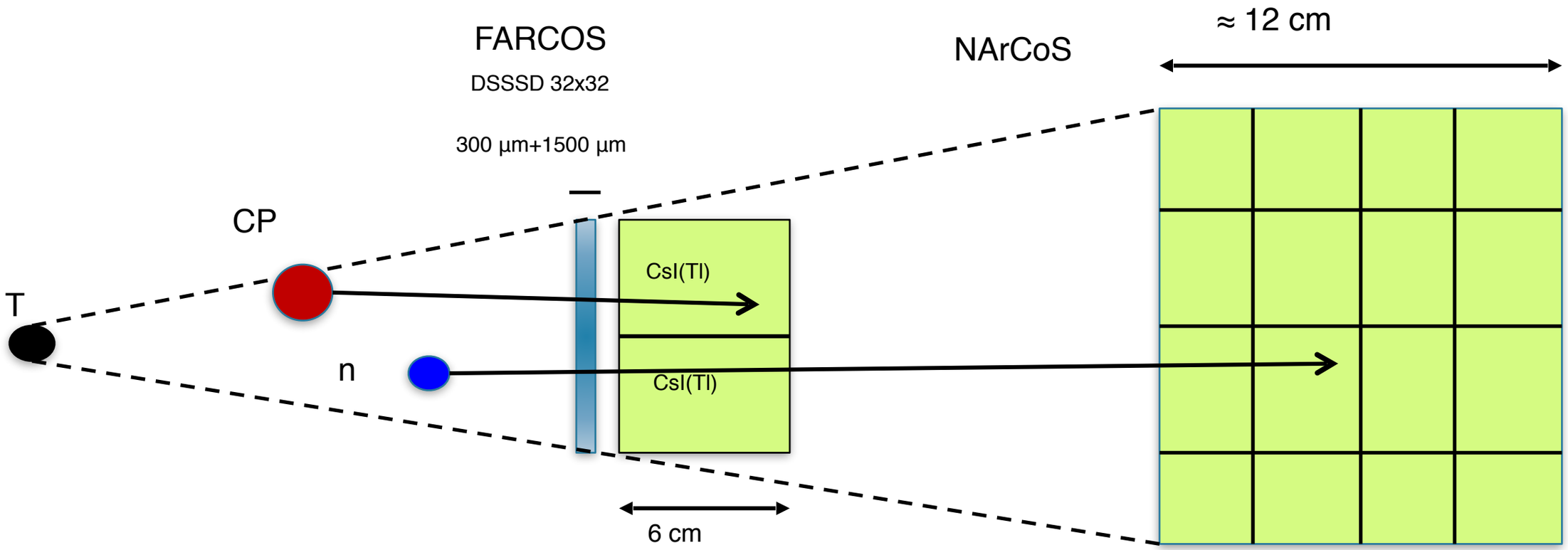
New tests need in order to study the cross-talk problem and the timing properties of the EJ-276 green version able to be read by using silicon technology

Thank you for the attention

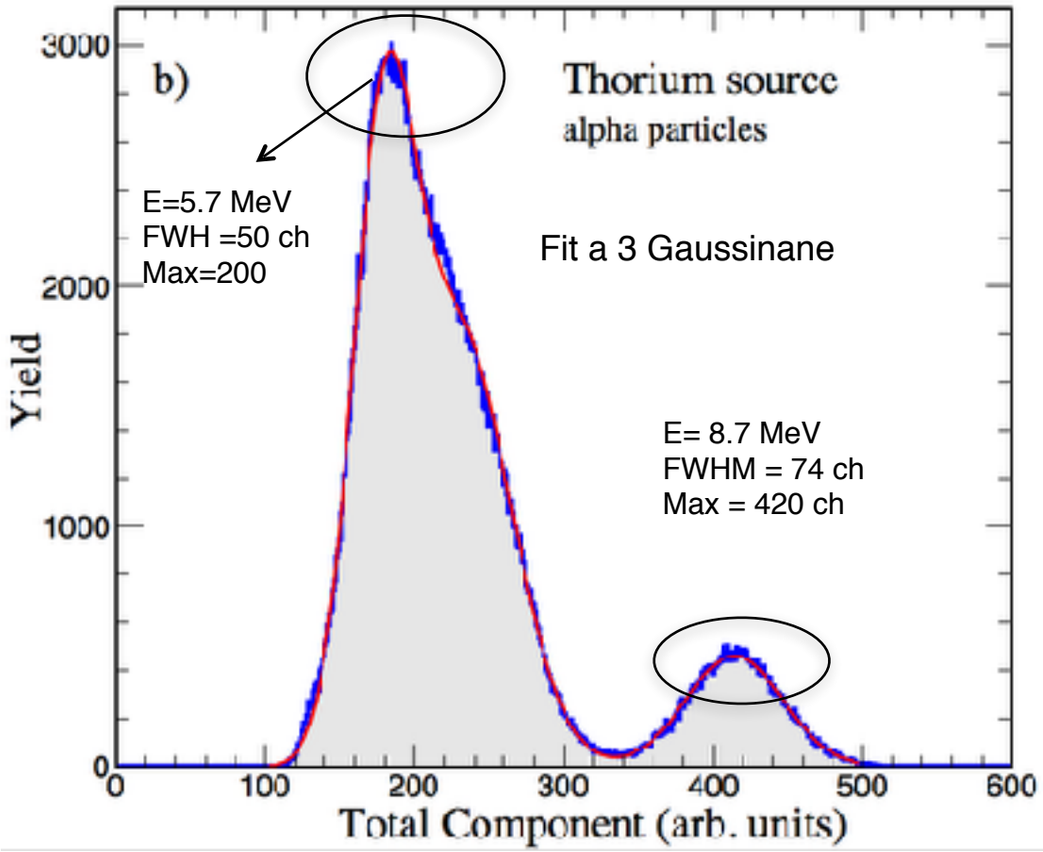
Backup Slides

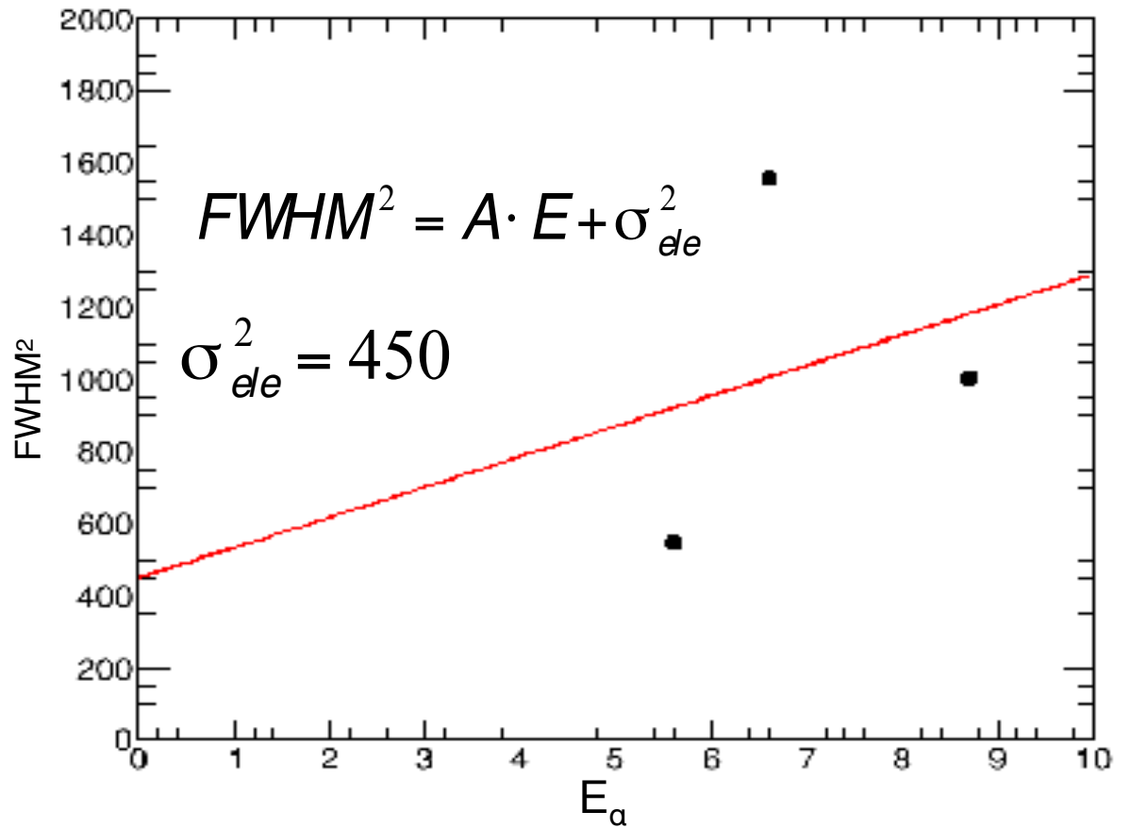
Esempio di accoppiamento con correlatore per particelle cariche

Accoppiamento FARCOS + NArCoS



Energy resolution of the 8,7 alpha peak





For E_α=8.7 MeV

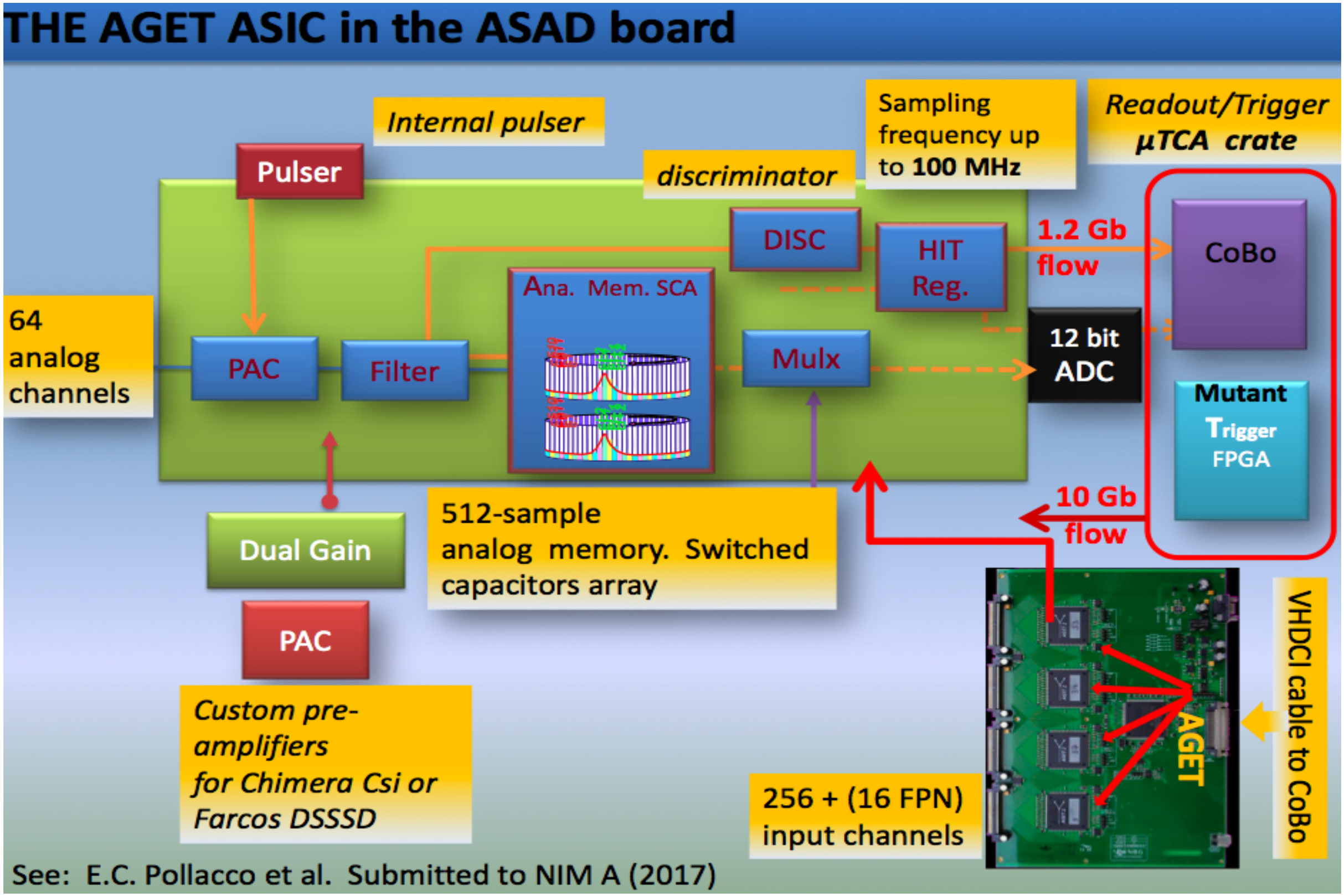
$$\sigma^2_{tot} = \sigma^2_{\text{int}} + \sigma^2_{ele} \rightarrow \sigma^2_{\text{int}} = \sigma^2_{tot} - \sigma^2_{ele} \rightarrow \sigma_{\text{int}} = \sqrt{\sigma^2_{tot} - \sigma^2_{ele}}$$

$$\sigma^2_{ele} = 450; \quad \sigma^2_{tot} = 1000 \rightarrow \frac{\Delta E_{tot}}{E} \approx 11\%$$

$$\sigma_{\text{int}} = 23 \rightarrow FWHM = 55$$

$$\Delta E_{bin} = 13.6\ {KeV}/{ch} \rightarrow \Delta E = 750\,KeV \rightarrow \frac{\Delta E_{\text{int}}}{E} \approx 8.5\%$$

THE AGET ASIC in the ASAD board



See: E.C. Pollacco et al. Submitted to NIM A (2017)

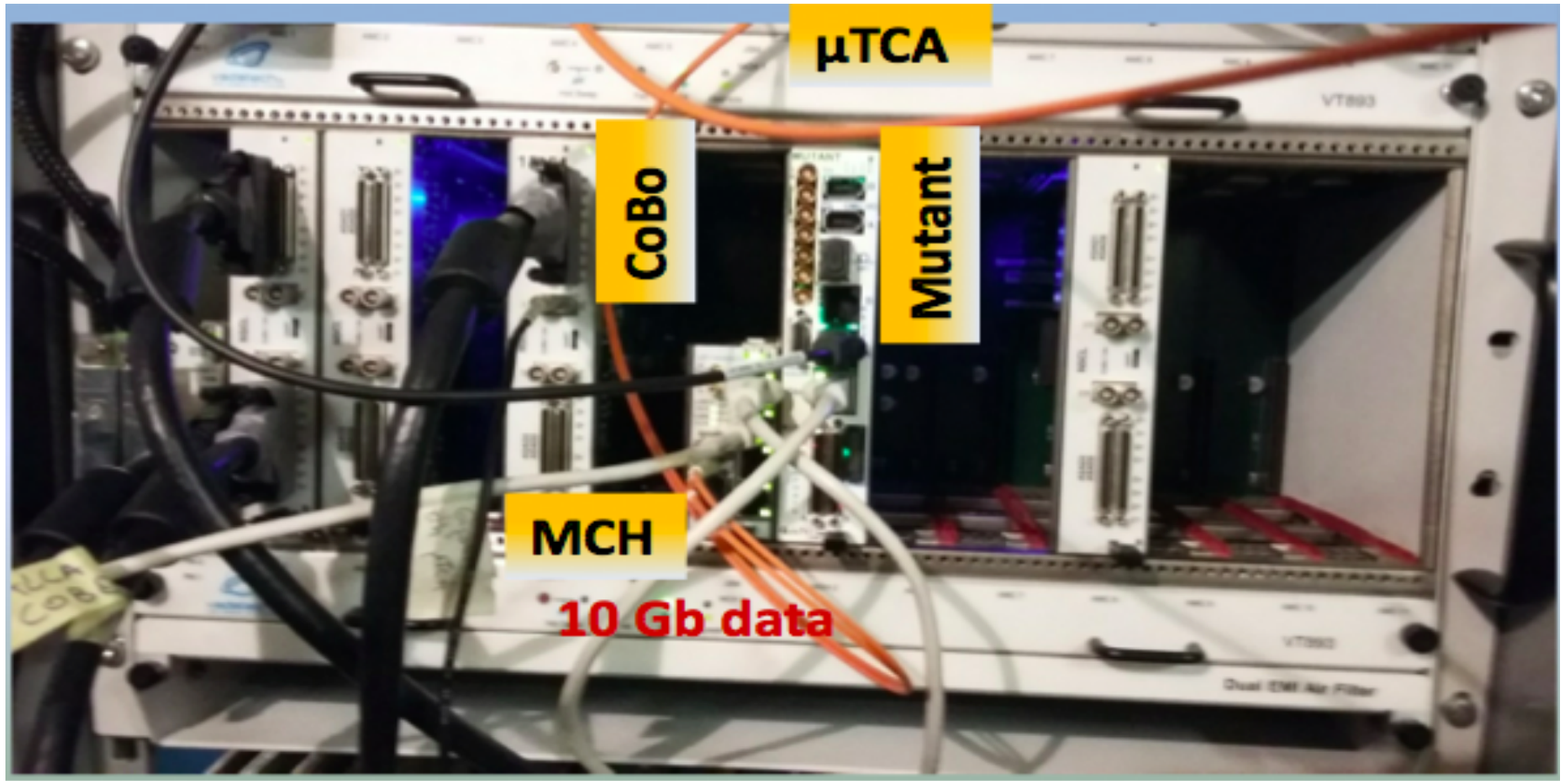
AGET: **A**sic for **GET** – 64 analog channels (+4 FPN) - 512 cells/channel

ASAD: **A**GET **S**upport for **A**nalog to **D**igital – 4 AGET

COBO: **CO**llection **BO**ard – 4 ASAD - 1024 digital channels

MUTANT: **MU**tiplicity, **T**rigger **AN**d **T**ime (3 trigger levels)

MicroTCA: **Micro** **T**elecommunications **C**omputing **A**rchitecture
MCH: **C**arrier **H**ub with 10 Gb and 1 Gb ethernet link



NArCOS prototype: 128 chs
2 AGET-> 0.5 ASAD!!!!

Cross talk

È un problema poco rilevante in misure in singola mentre non si può sottovalutare per misure in coincidenza e soprattutto a piccoli impulsi relativi!

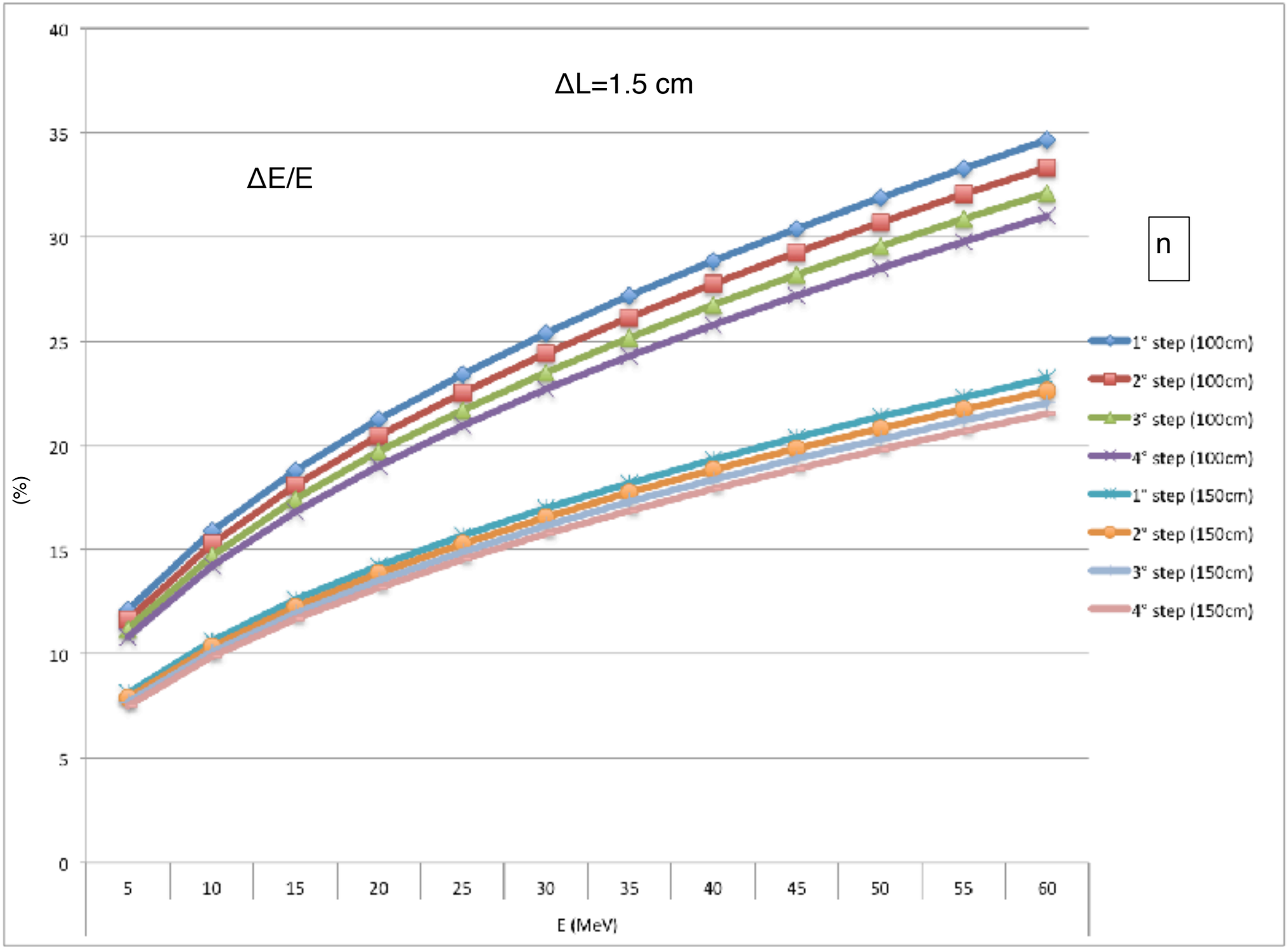
N. Colonna et al., NIM A 381 (1996) 472-480

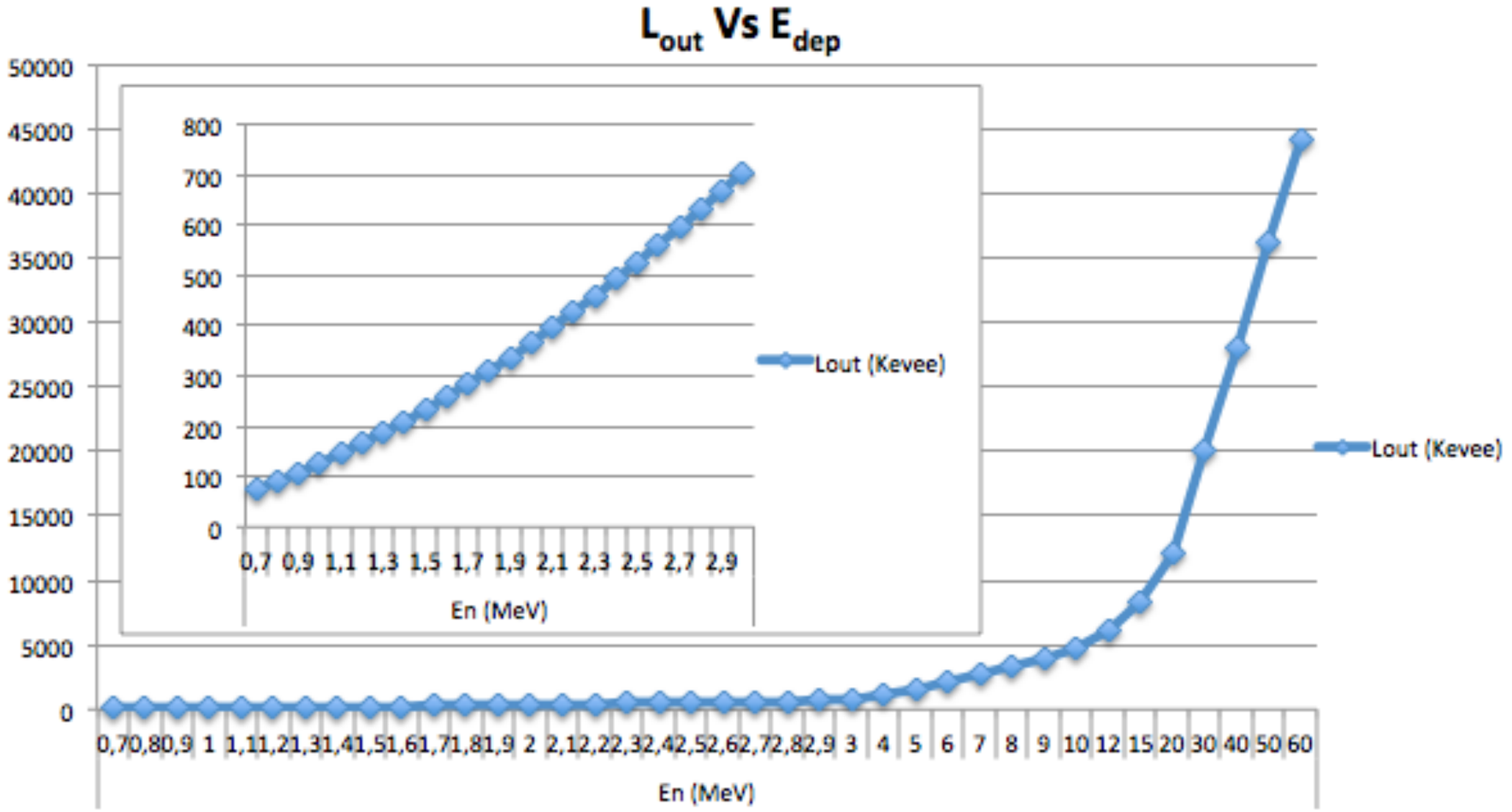
$$E_{diff} = E_1 - \frac{1}{2} m (d_{\min} / \Delta t)^2$$

E_1 è lenergia del neutroni più veloce
D_{min} è la minima distanza tra due rivelatori colpiti
Δt è la differenza temporale tra i due rivelatori colpiti
E_{diff} rappresenta l'energia persa dal neutrone le primo detector

L'energia minima che dovrebbe possedere il neutrone scatterato dal primo detector per raggiungere il secondo detector nel tempo Δt

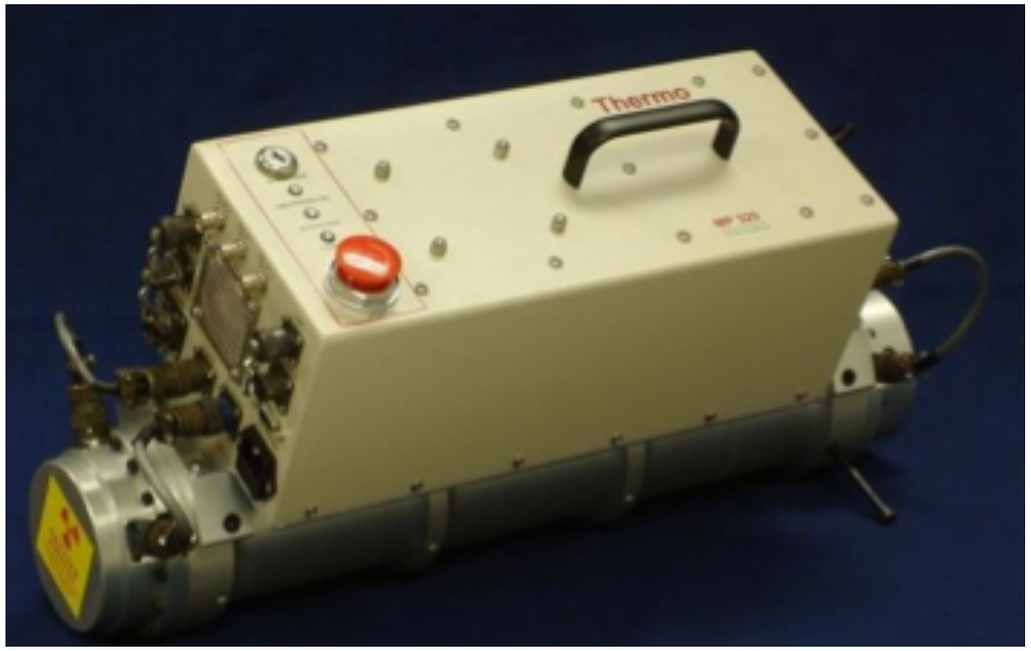
Se $E_{diff} < 0$ la coincidenza è reale
Se $E_{diff} > 0$ ulteriori analisi statistiche sono necessarie


ΔL=1.5 cm
ΔE/E
n
(%)
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
55
60
E (MeV)
1° step (100cm)
2° step (100cm)
3° step (100cm)
4° step (100cm)
1° step (150cm)
2° step (150cm)
3° step (150cm)
4° step (150cm)



C. C. Lawrence et al., NIM A759 (2014) 16

Sorgente portatile di neutroni (Messina)



reactions:
d+d -> n da 2.5 MeV 10^6 n/s
d+t -> n da 14 MeV 10^8 n/s

Attributes	MP 320
D-T Maximum Yield, n/s	1.0E+08
D-D Maximum Yield, n/s	1.0E+06
Maximum High Voltage, kV	-90
Typical Tube Life, Hrs	1,200
Operating Temperature, °C	50
Potential of Target	HV
Continuous Operation	Yes
Pulsing Range, kHz	0.50 to 20
Duty Cycle	5-95%
Minimum Pulse Width, µsec	5
Control	Digital
Keylock for Neutrons On/Off	Yes
HV Insulating Material	SF-6 Gas, 99.99% pure or better
Other Safety Interlocks	Yes
Input Power, Watts	< 75
Input Voltage	120/220 VAC or 24 VDC
Accelerator Head Weight, Kg	10
System Weight, Kg	12
Accelerator Head length and diameter, in.	22" L x 4.75" dia.