FATA2019

Fast Timing Applications for Nuclear Physics and Medical Imaging

Acireale 3-5 September 2019

INFN Istituto Nazionale di Fisica Nucleare

NArCoS project for nuclear physics and applications

PAGANO EMANUELE VINCENZO[1]

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[5] Dipartimento di Scienze MIFT, Universita' Messina, Italy

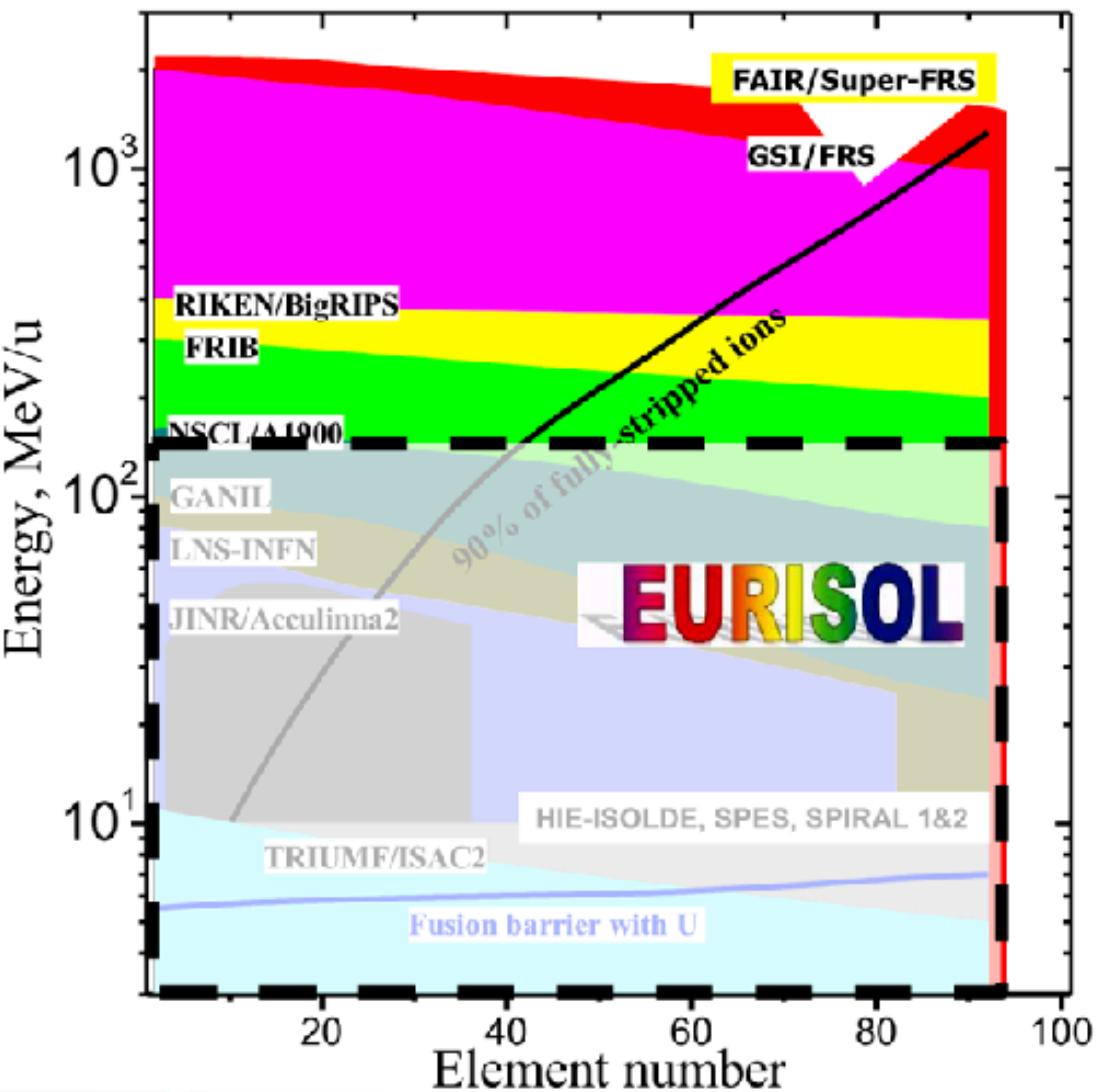
Project's motivations

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 with 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 ($\Delta t \leq 1$ 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)

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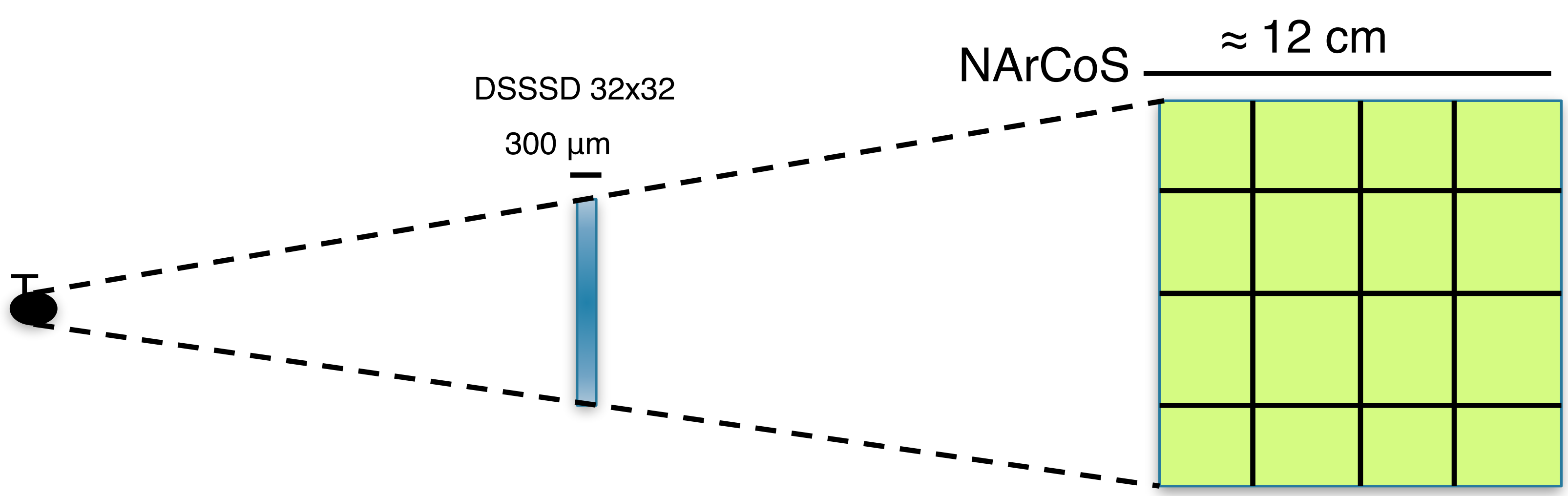

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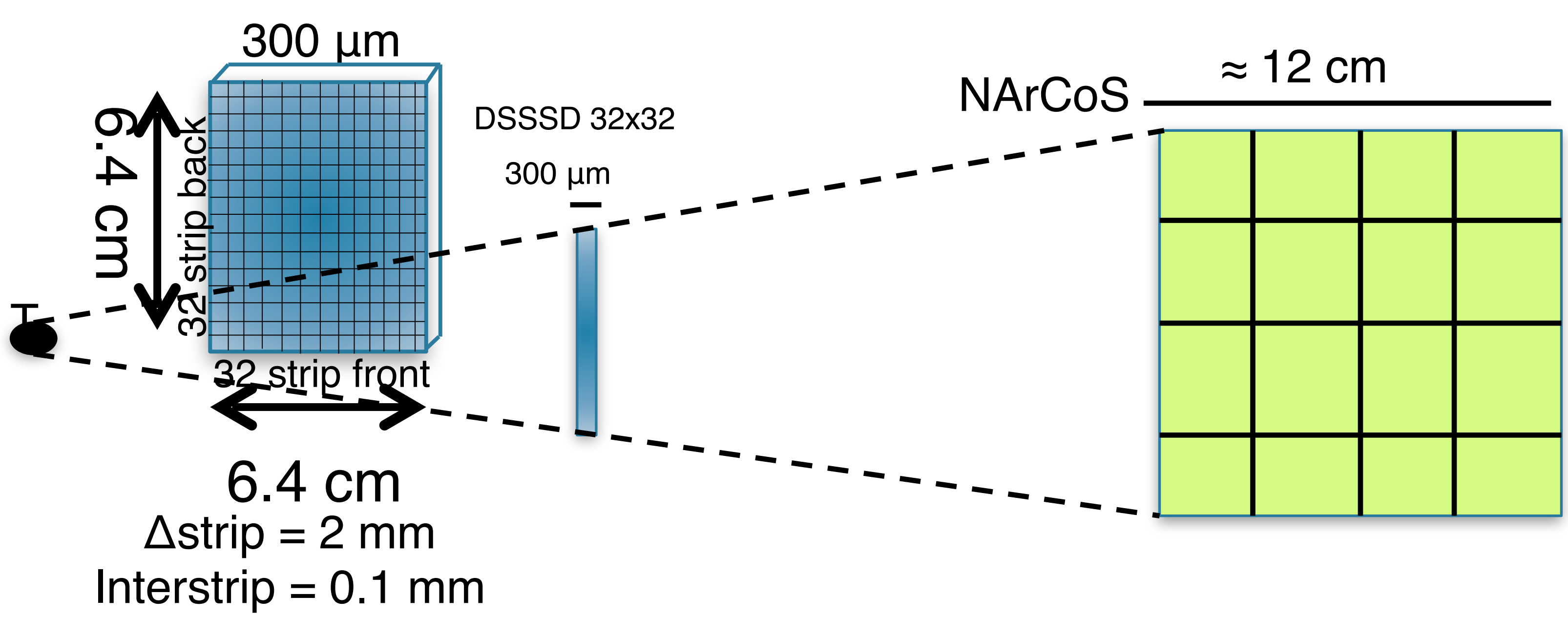

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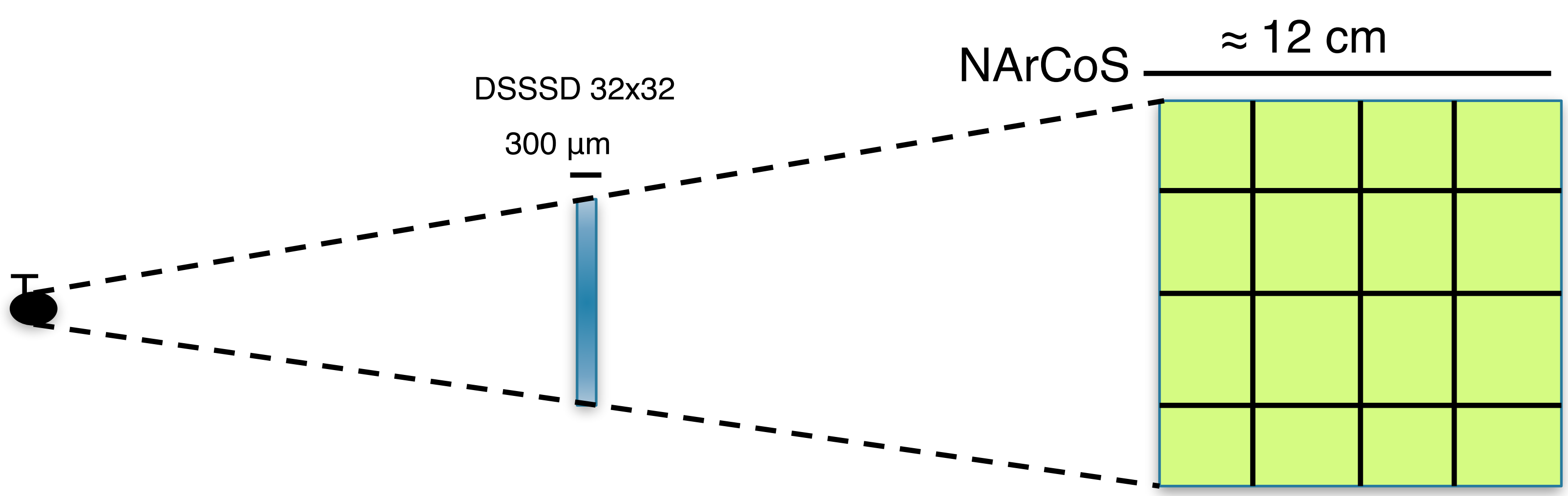

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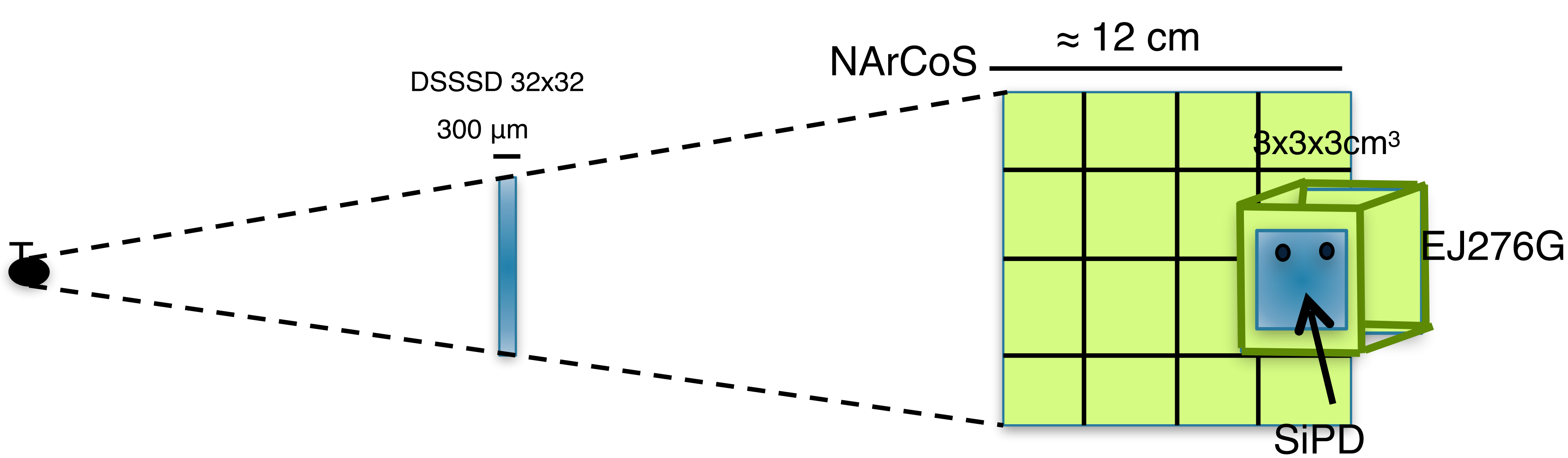

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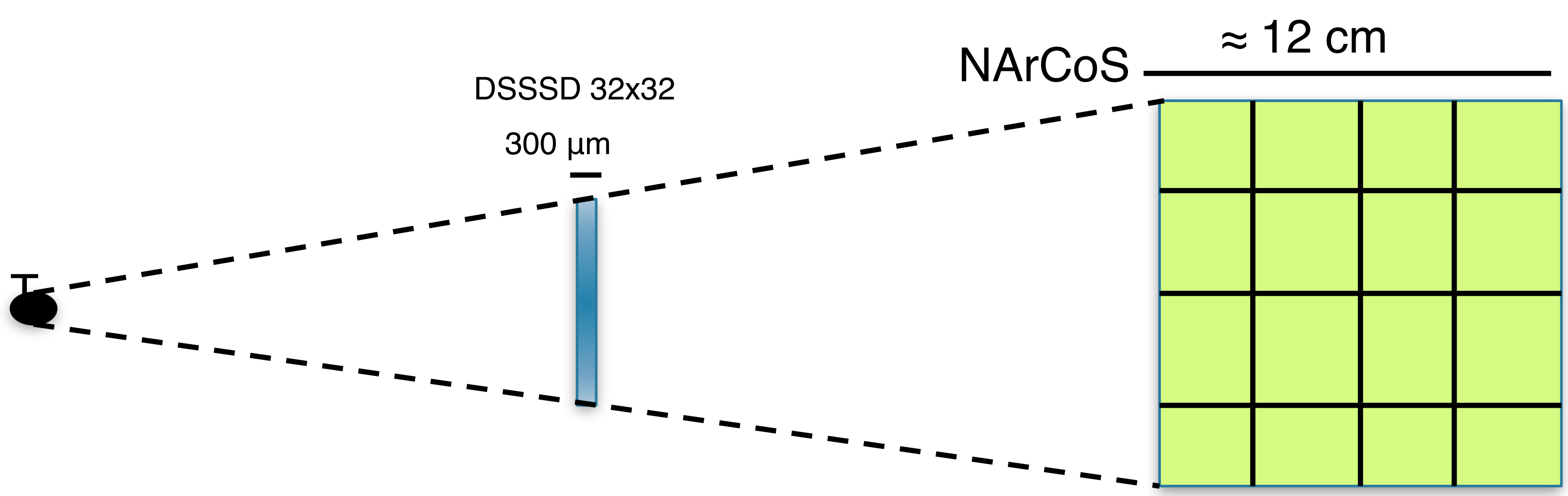

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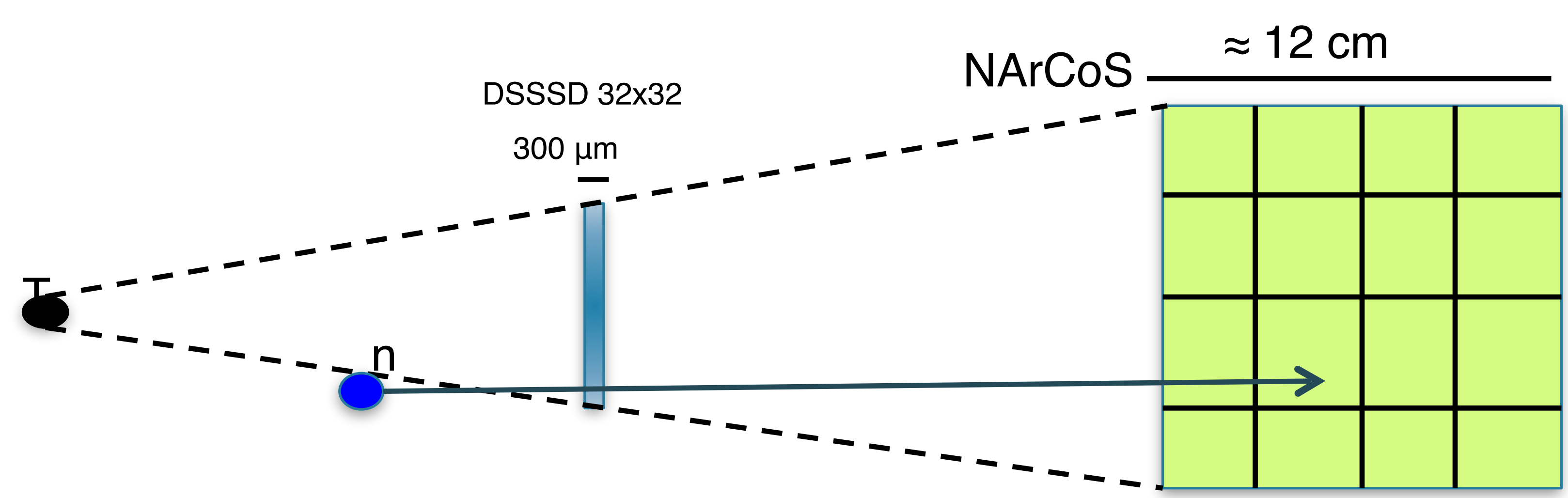

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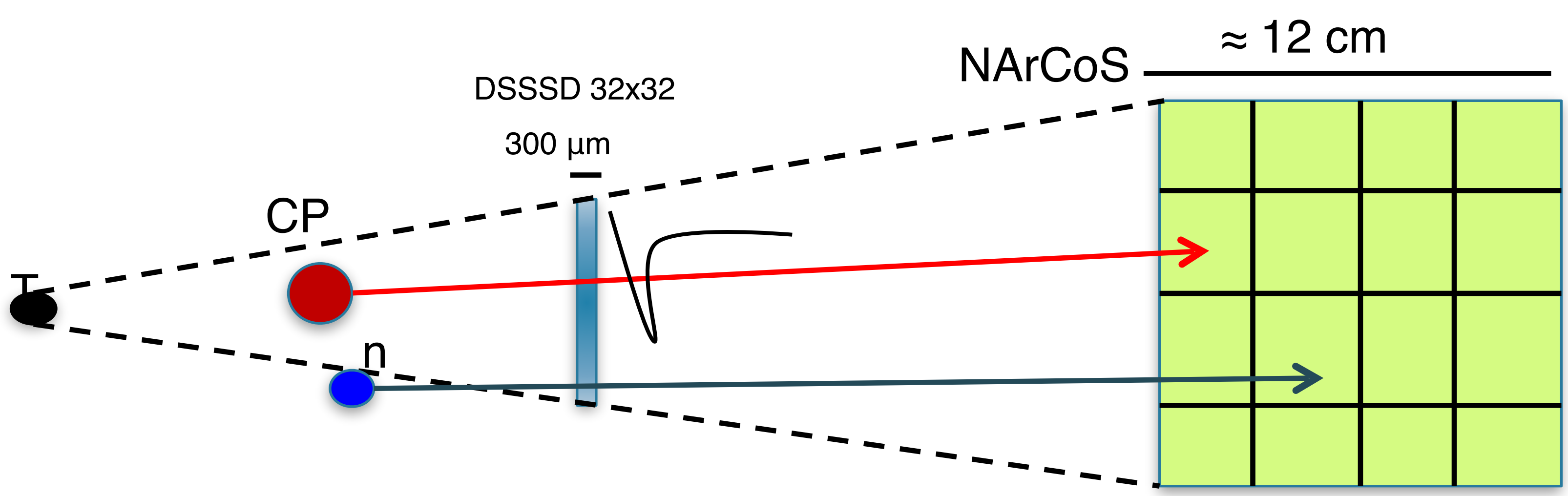

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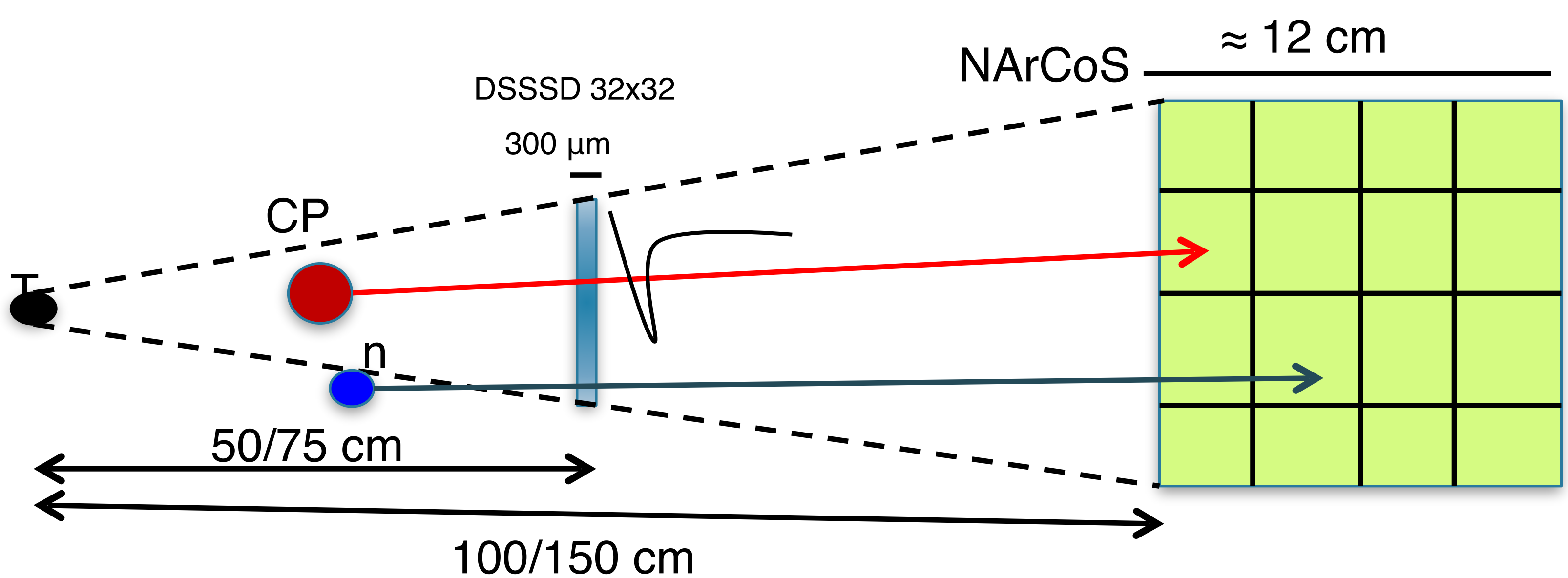

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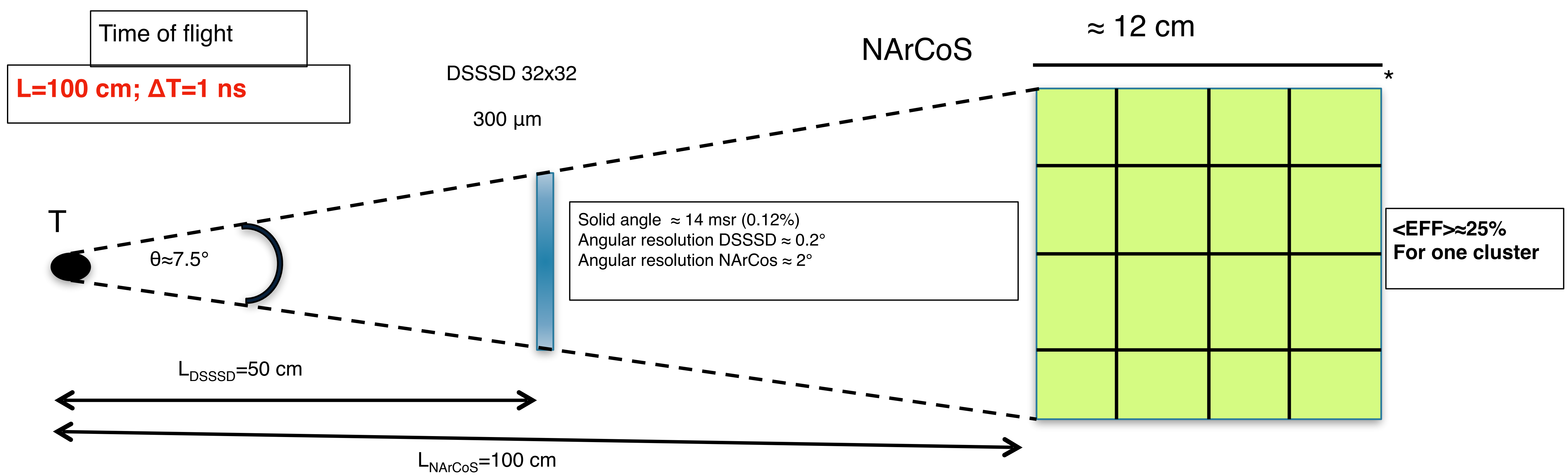

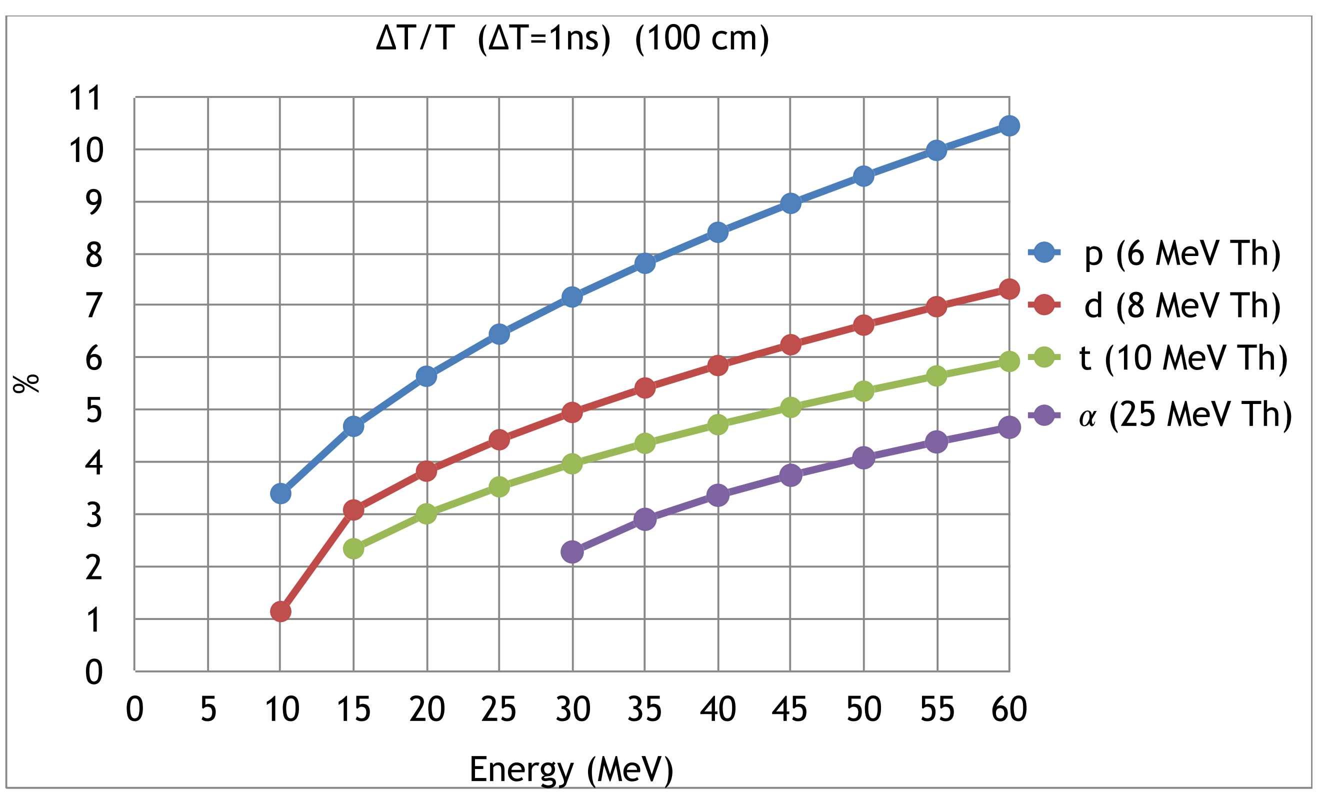

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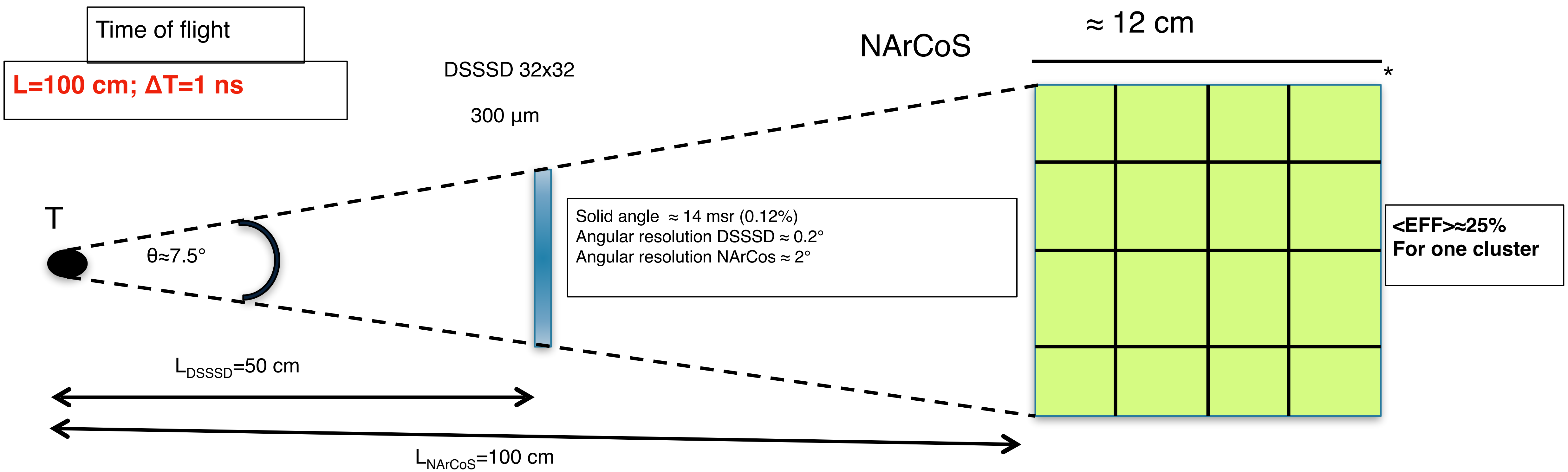

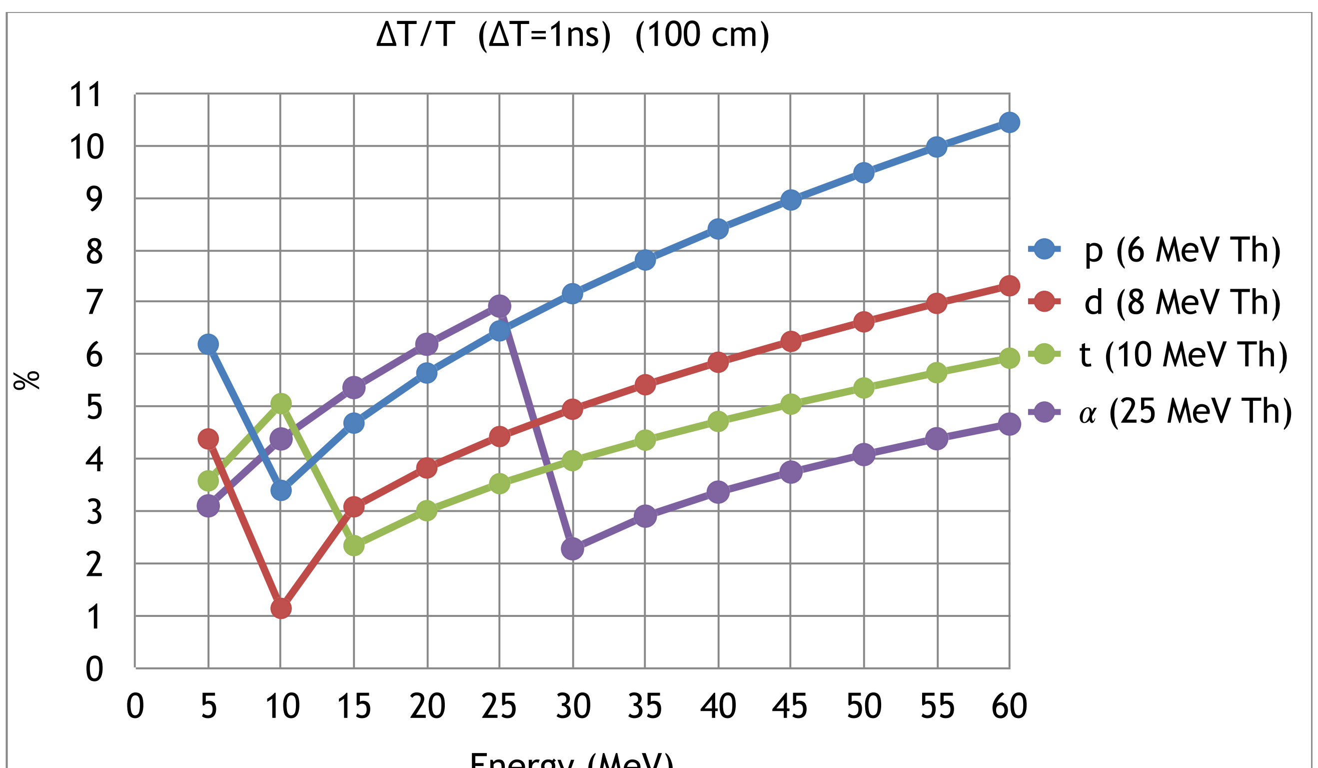

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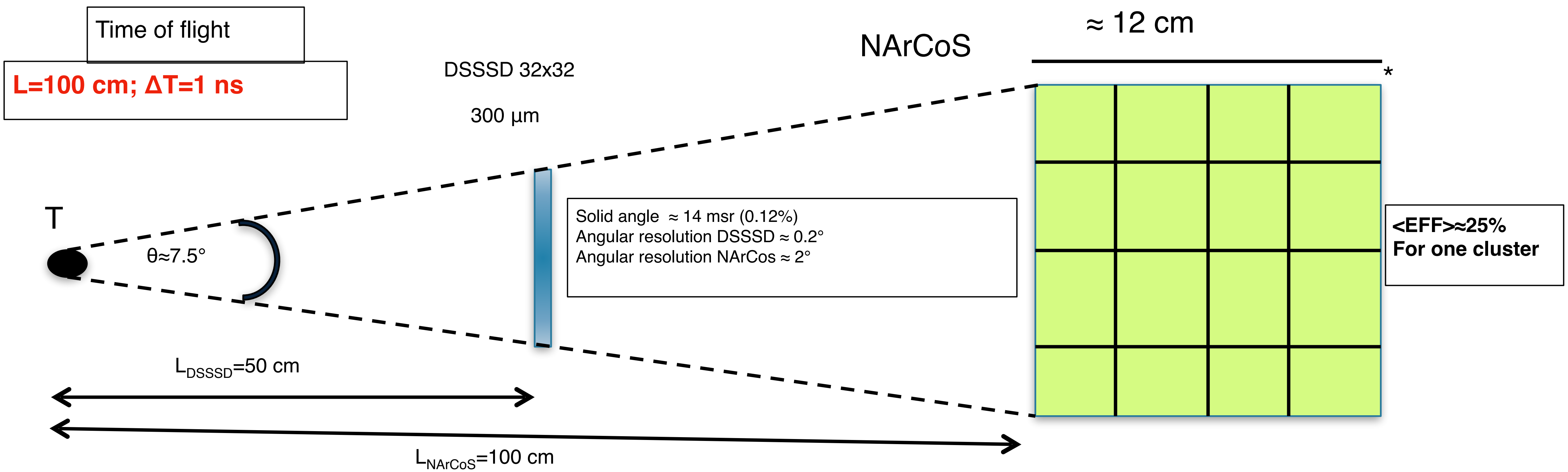

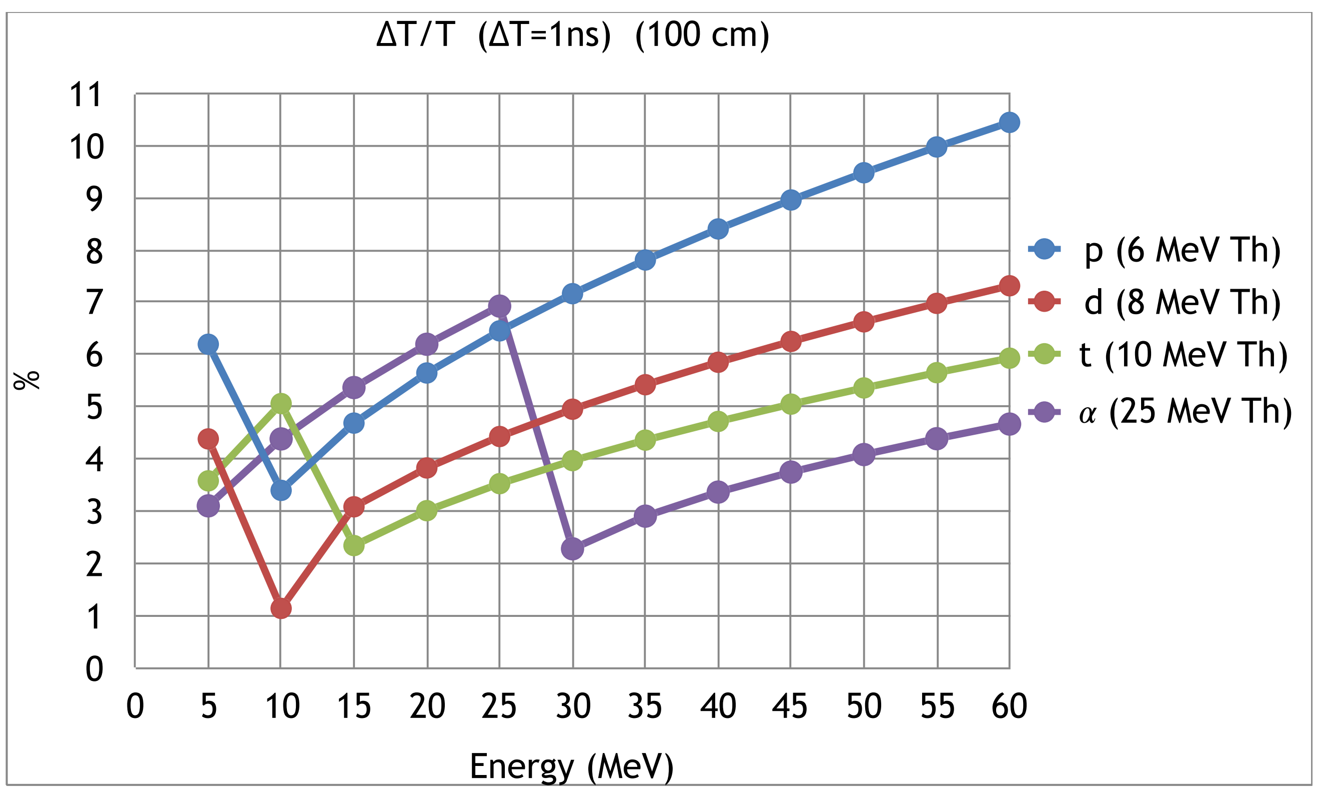

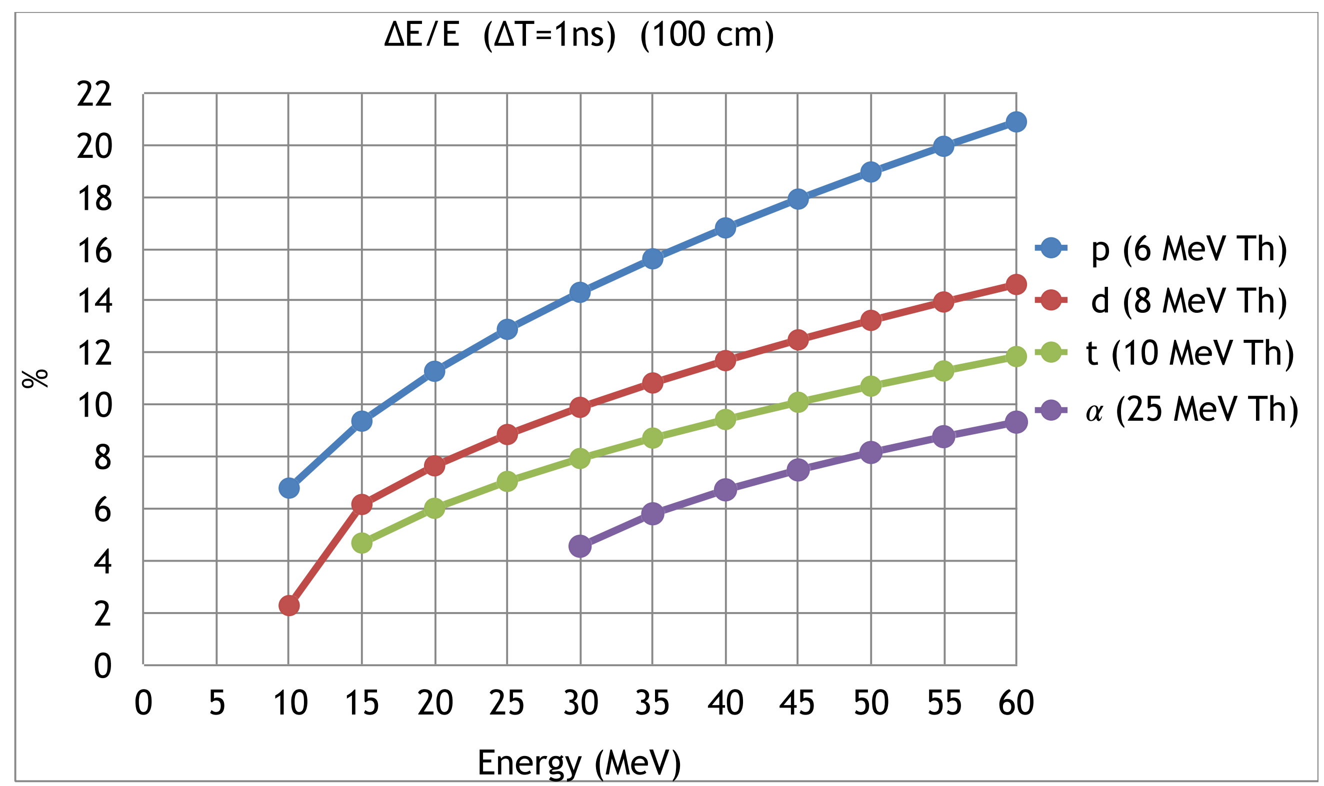

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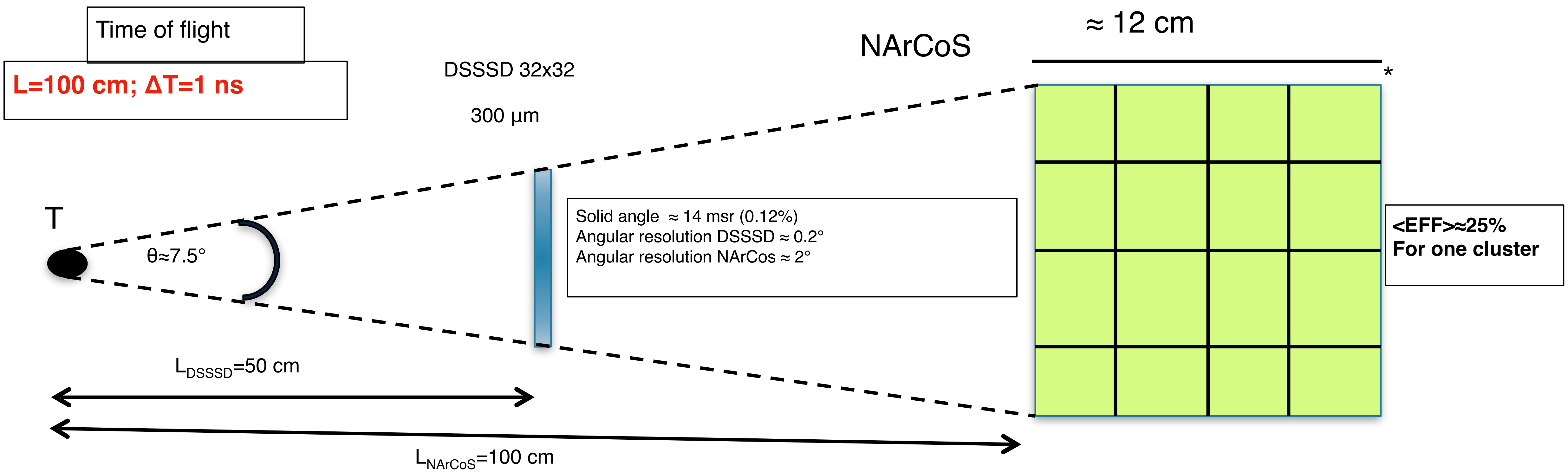

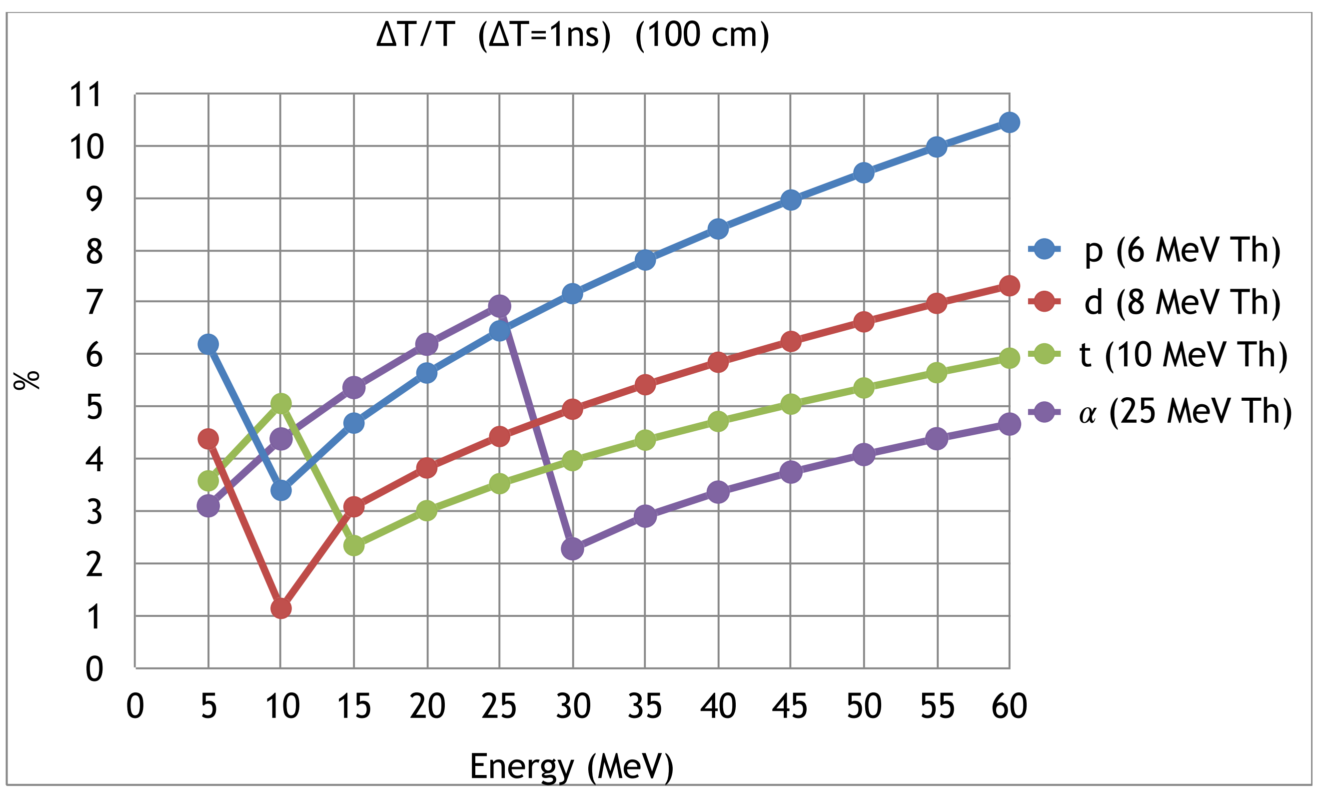

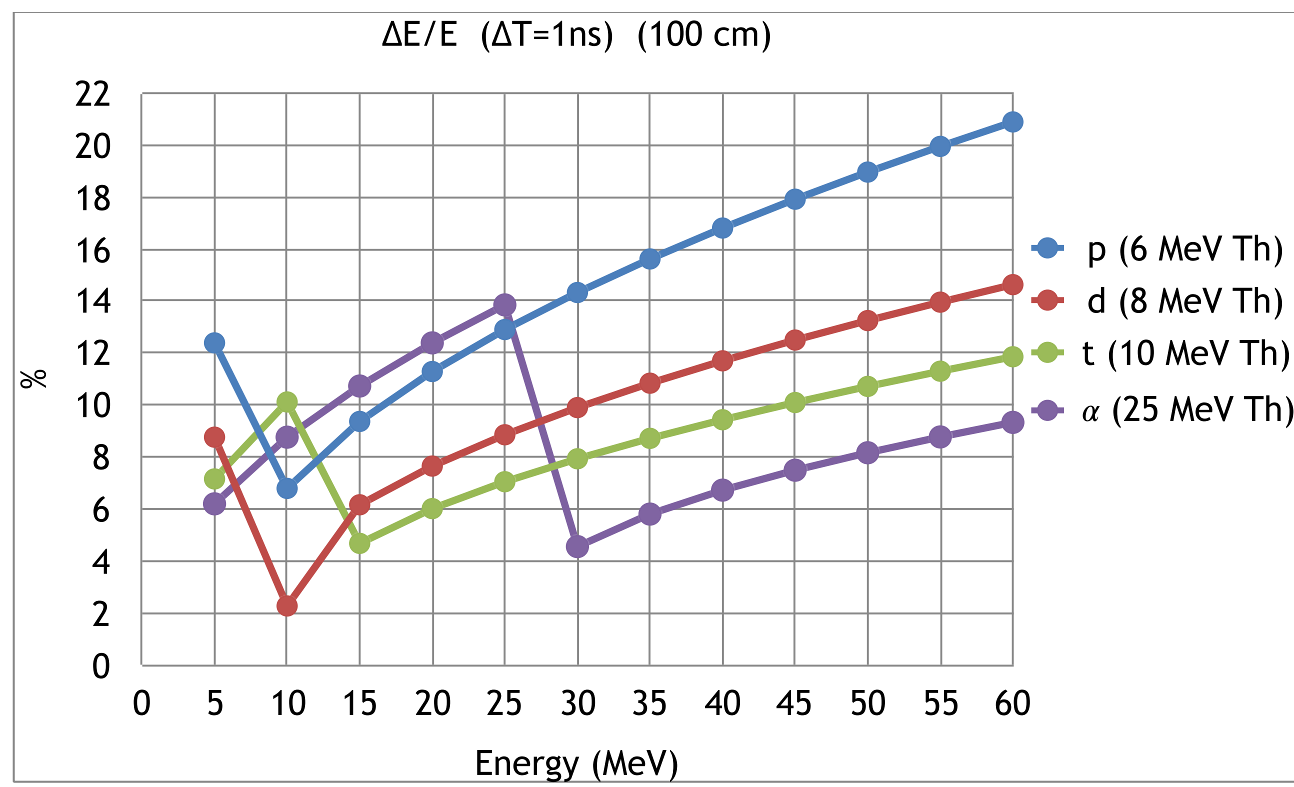

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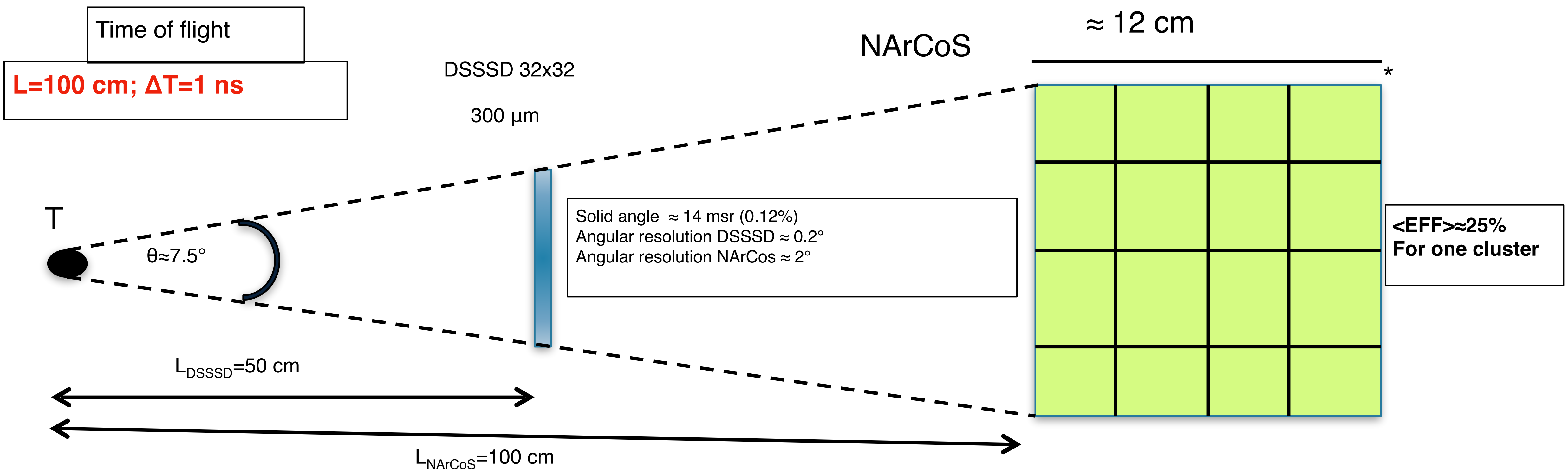

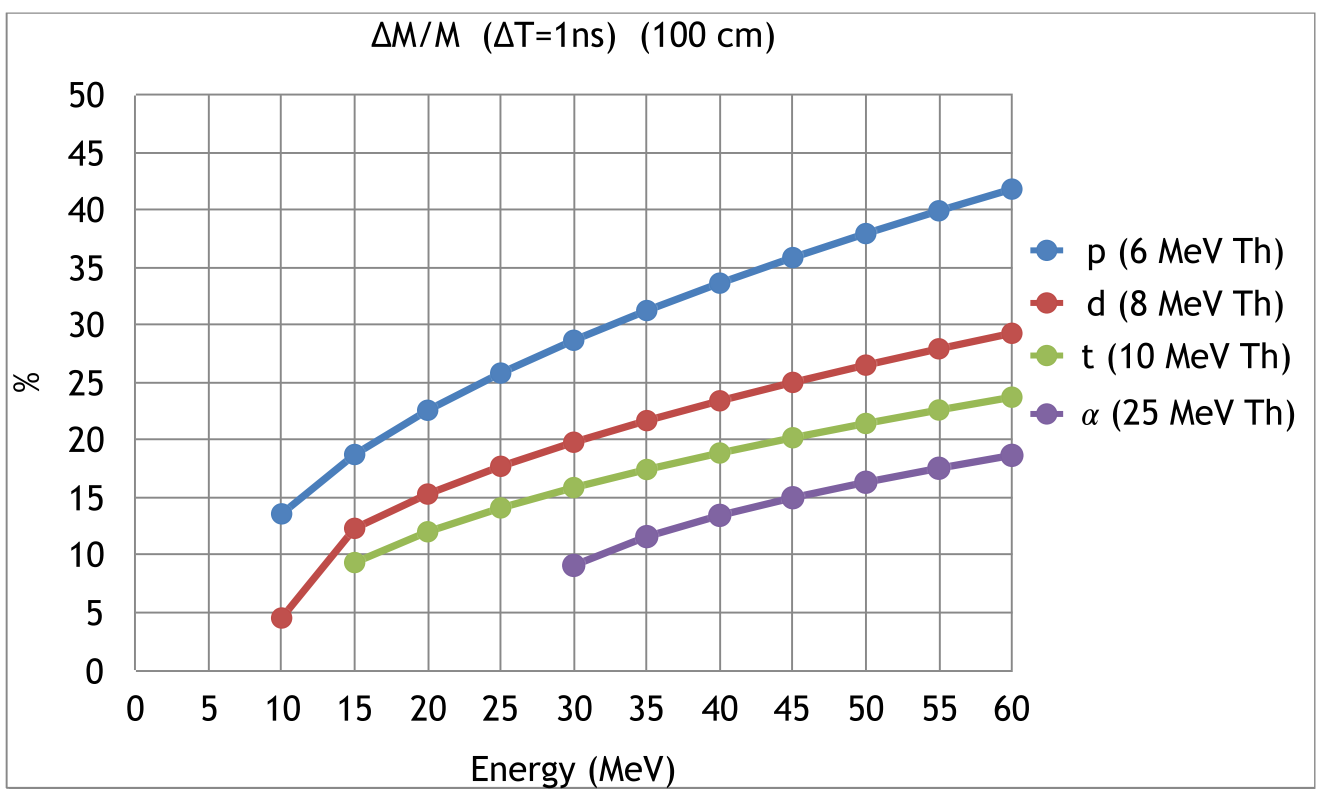

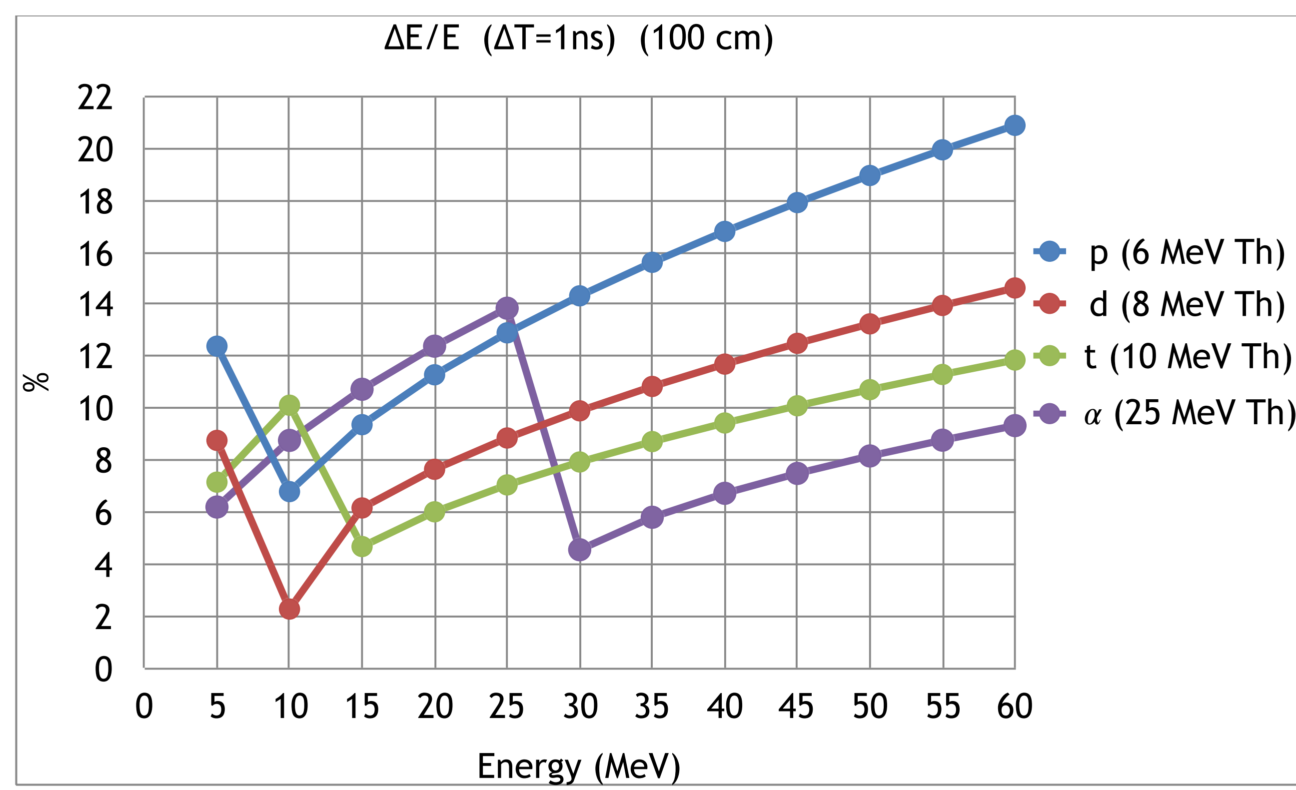

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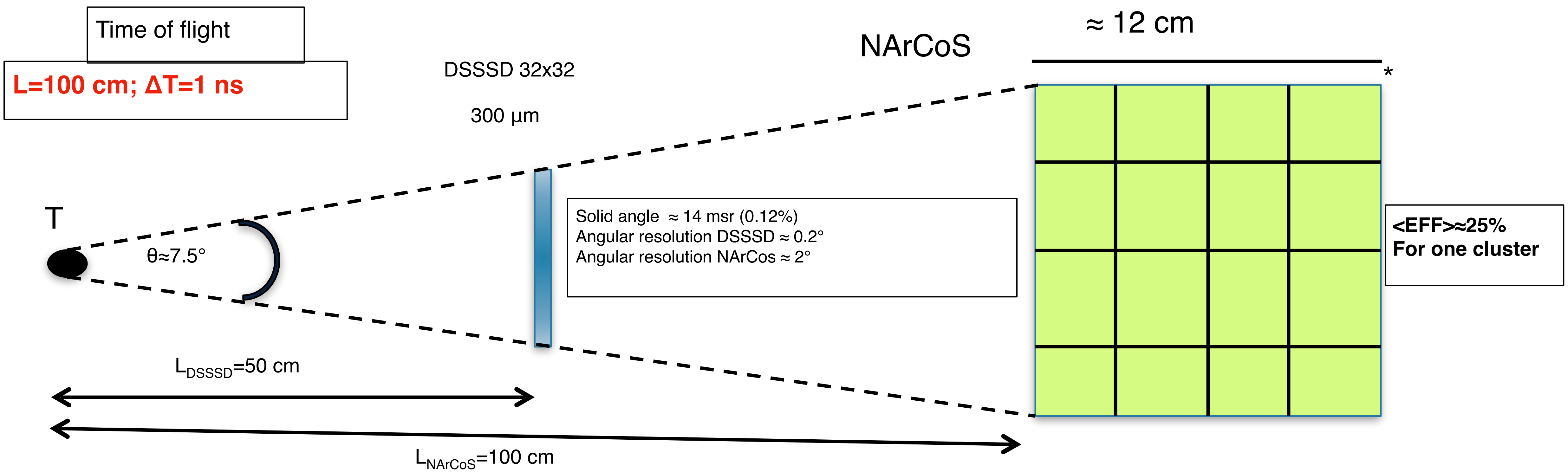

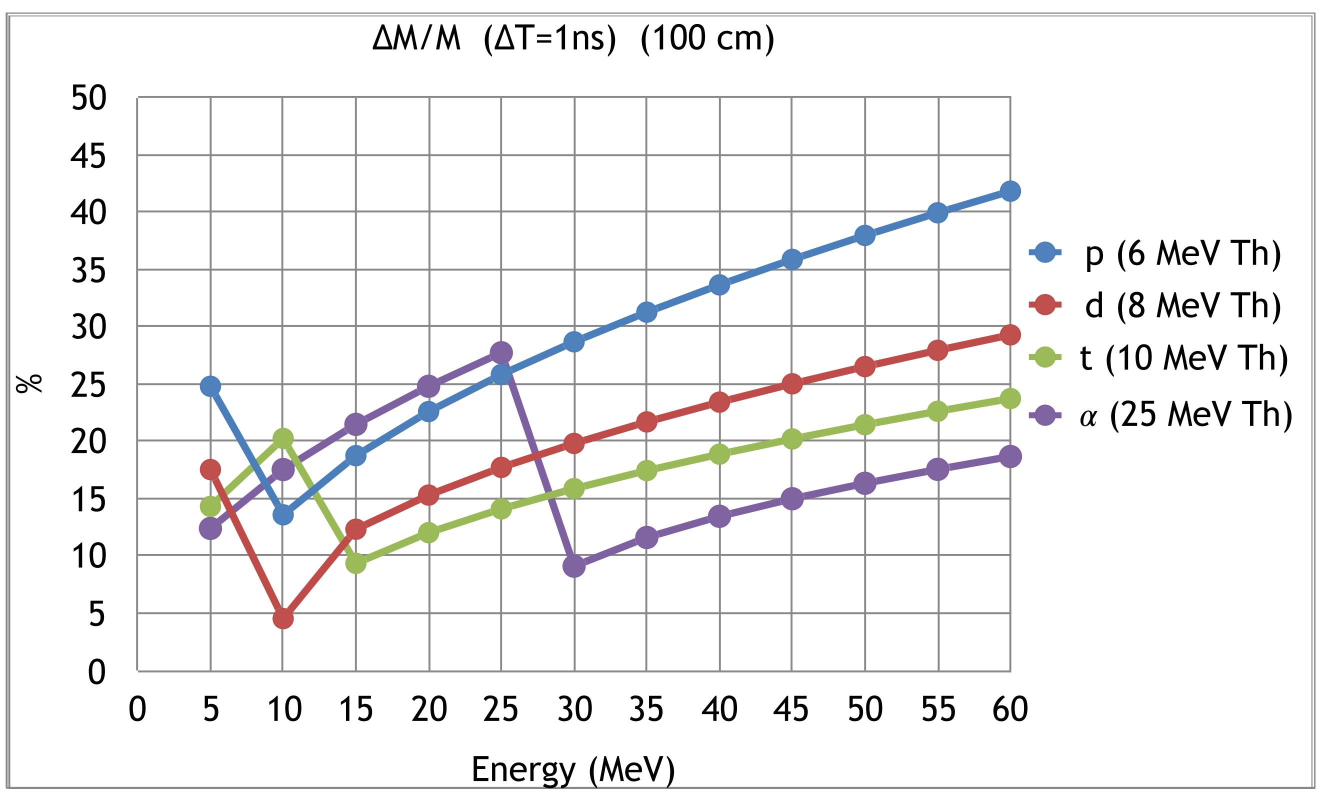

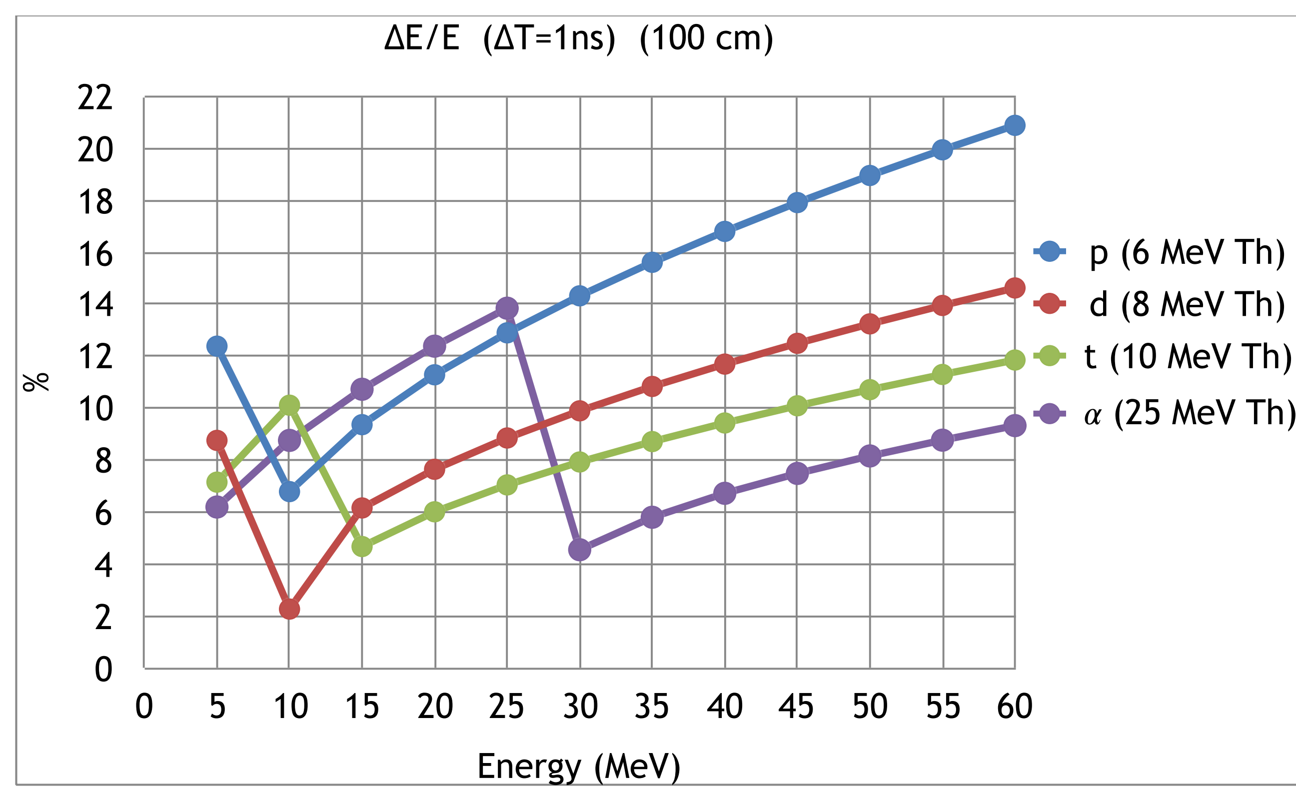

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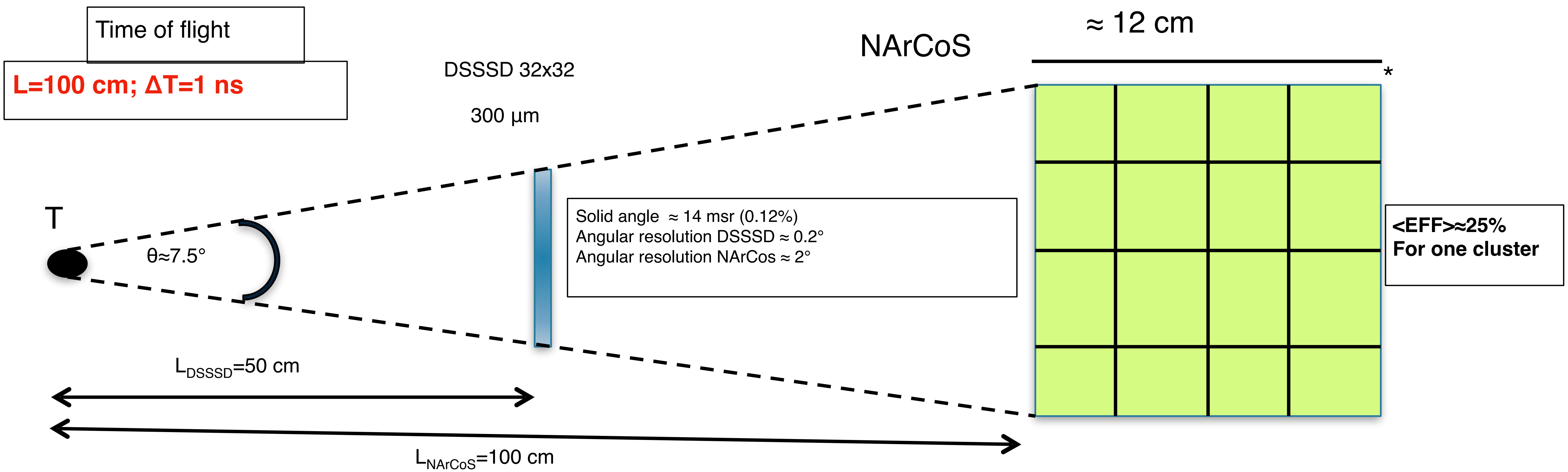

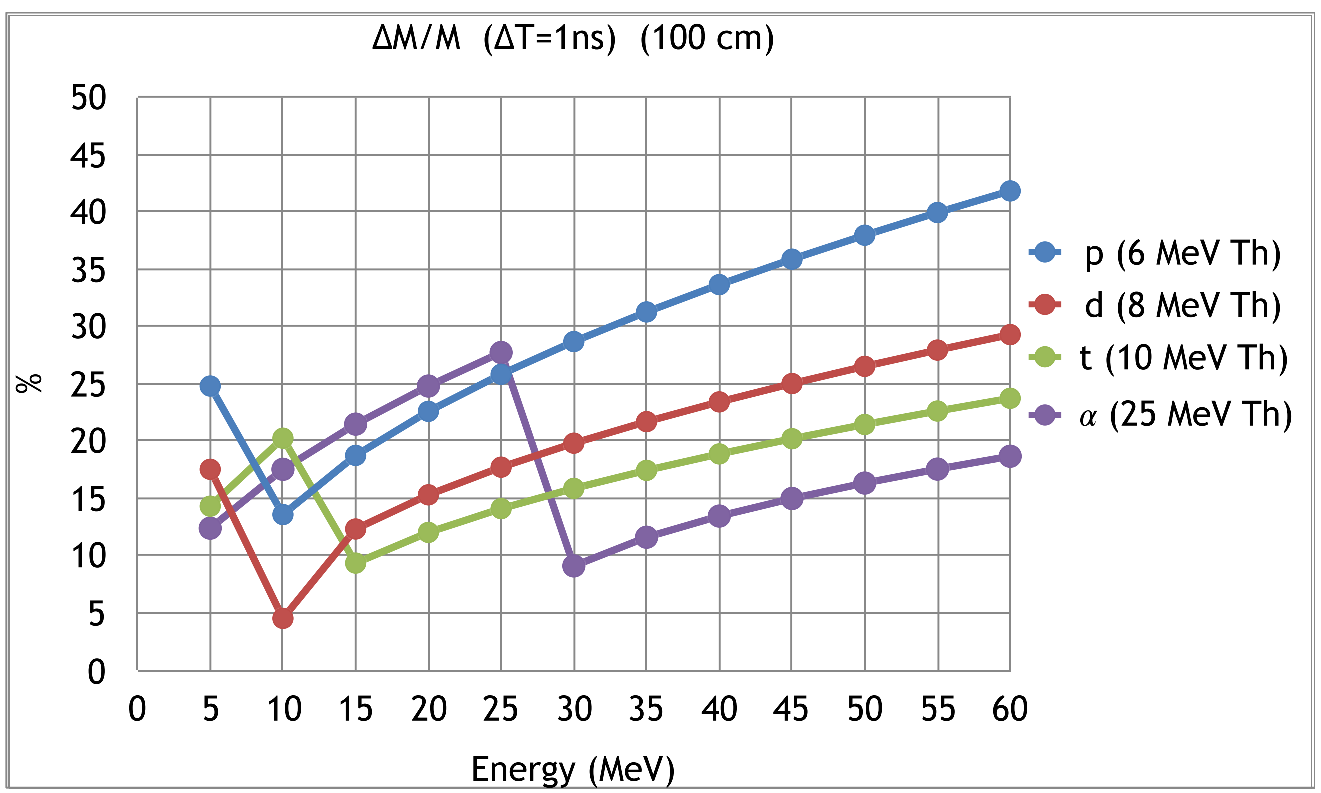

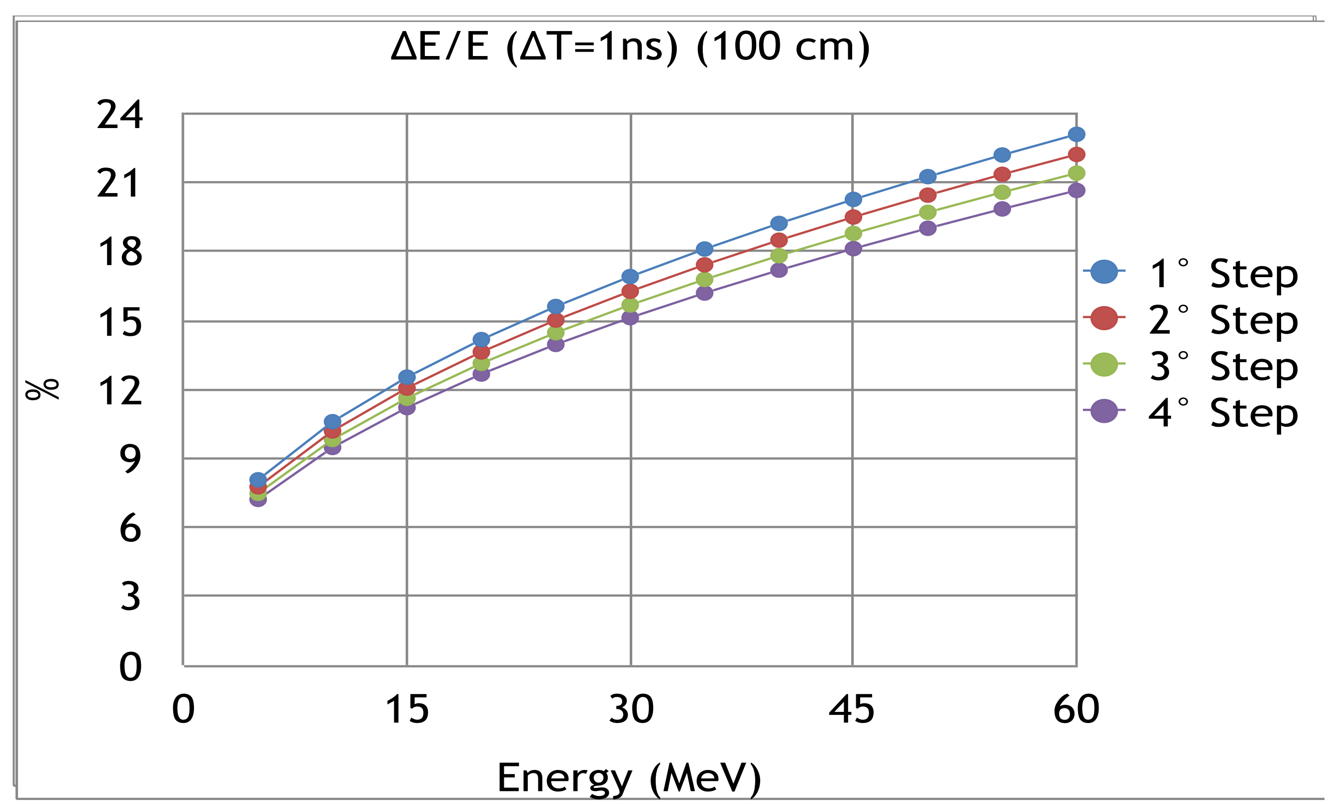

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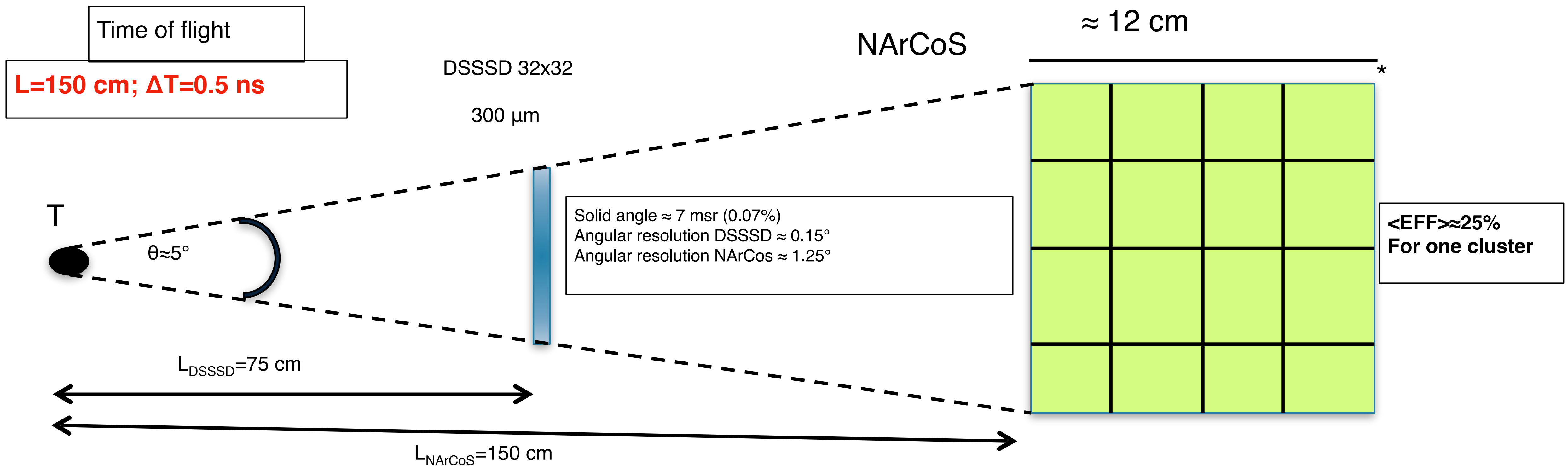

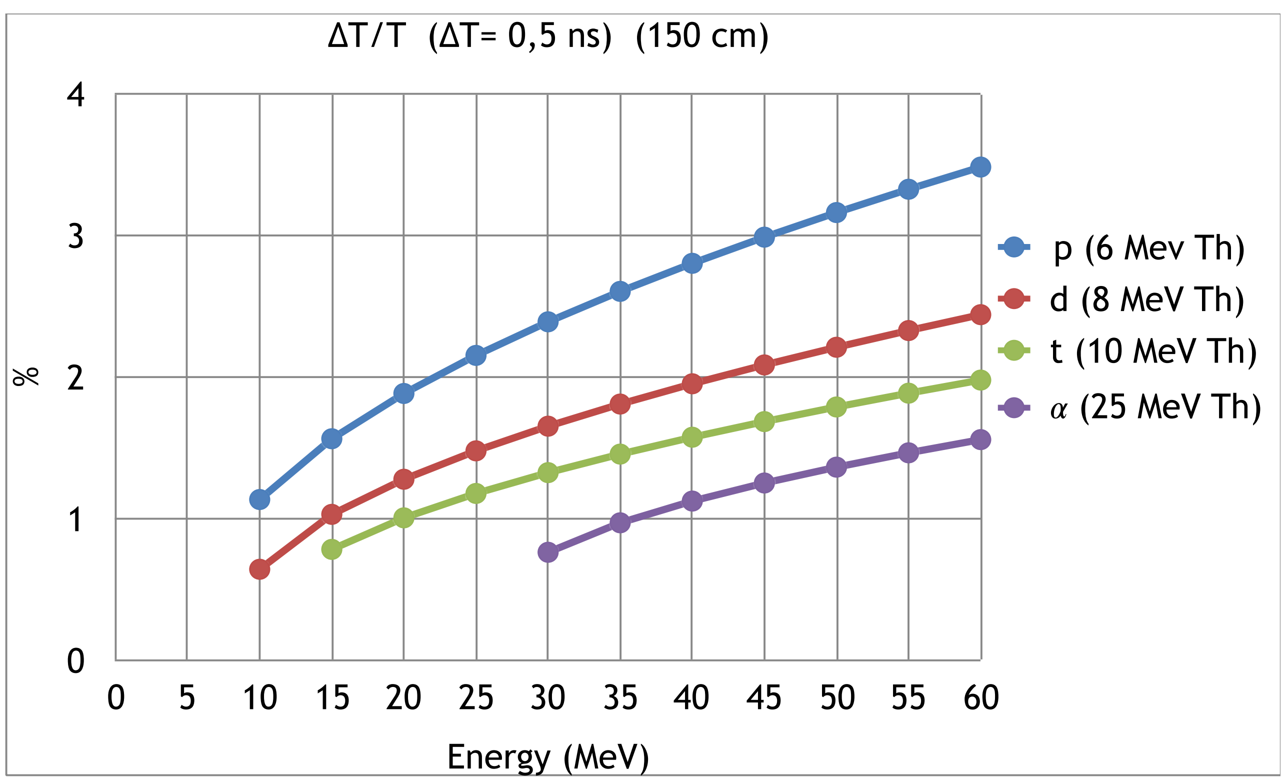

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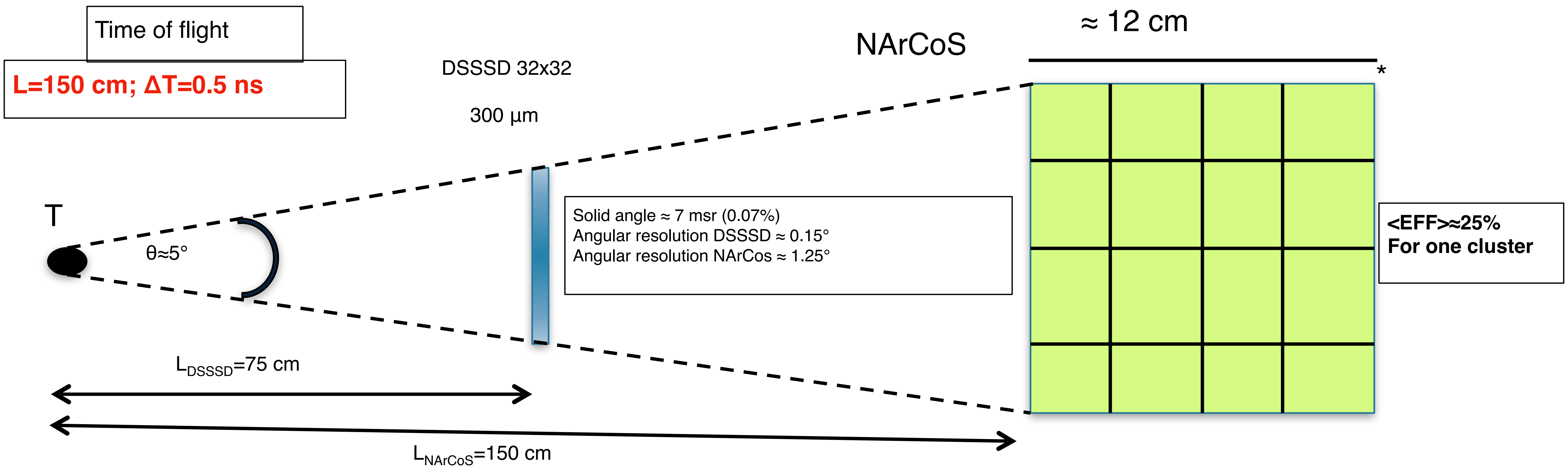

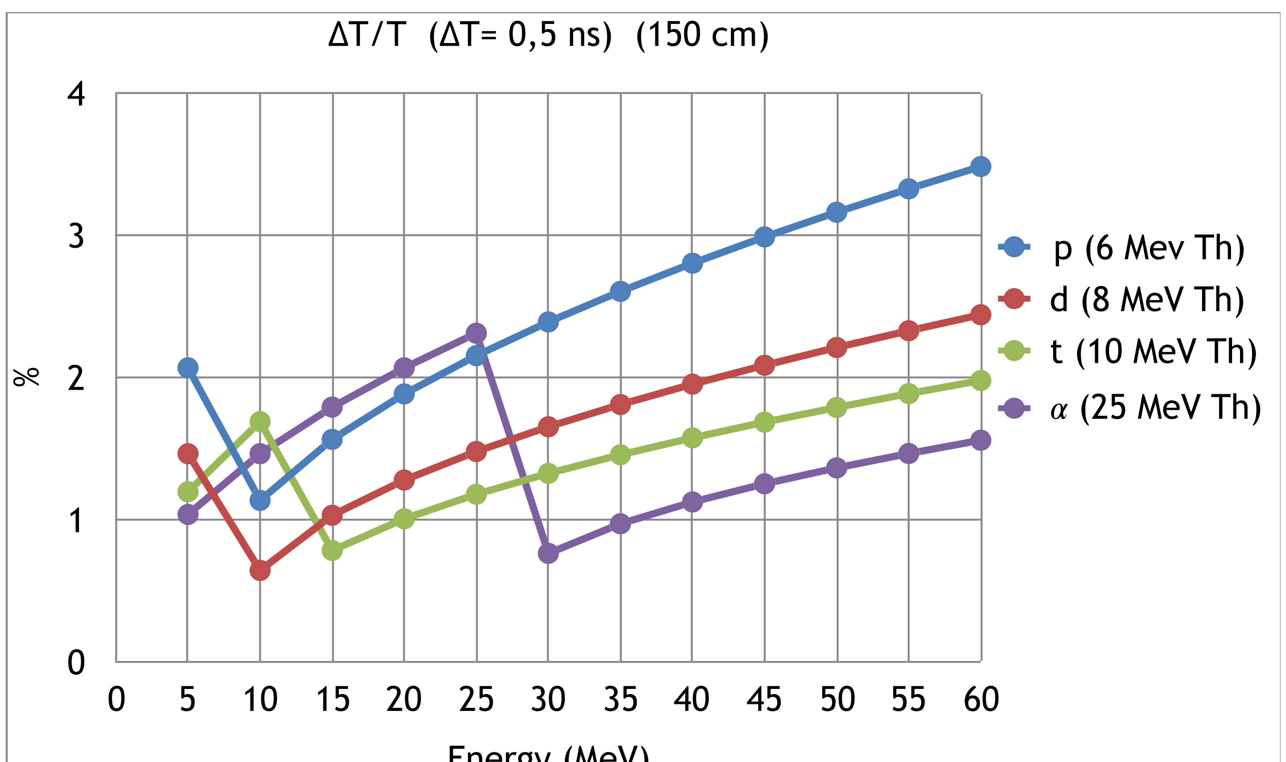

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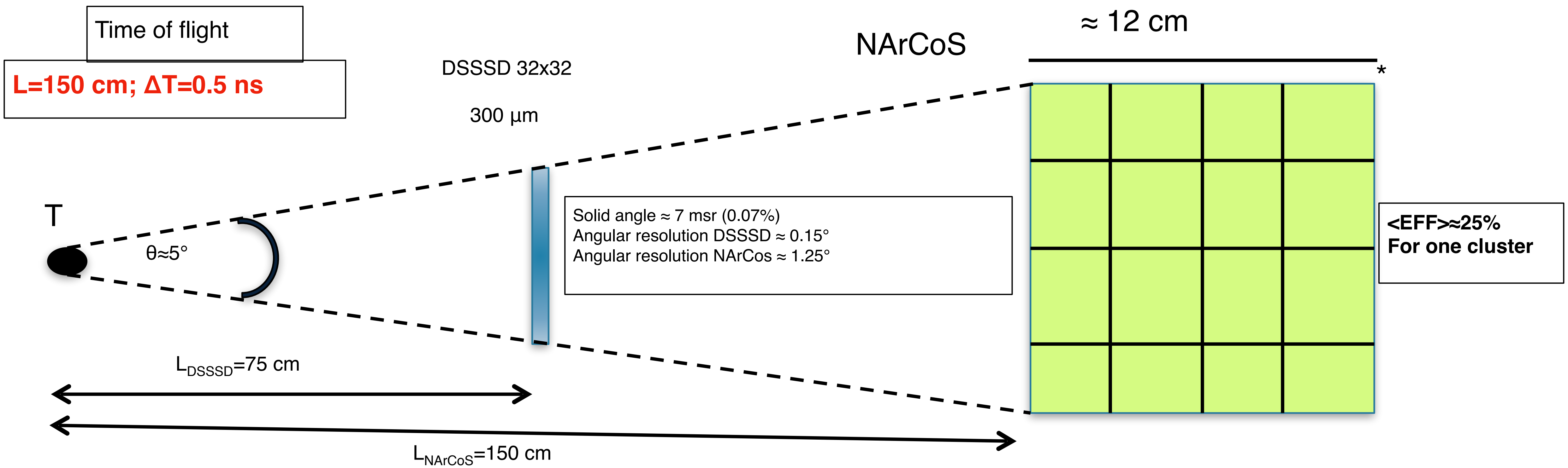

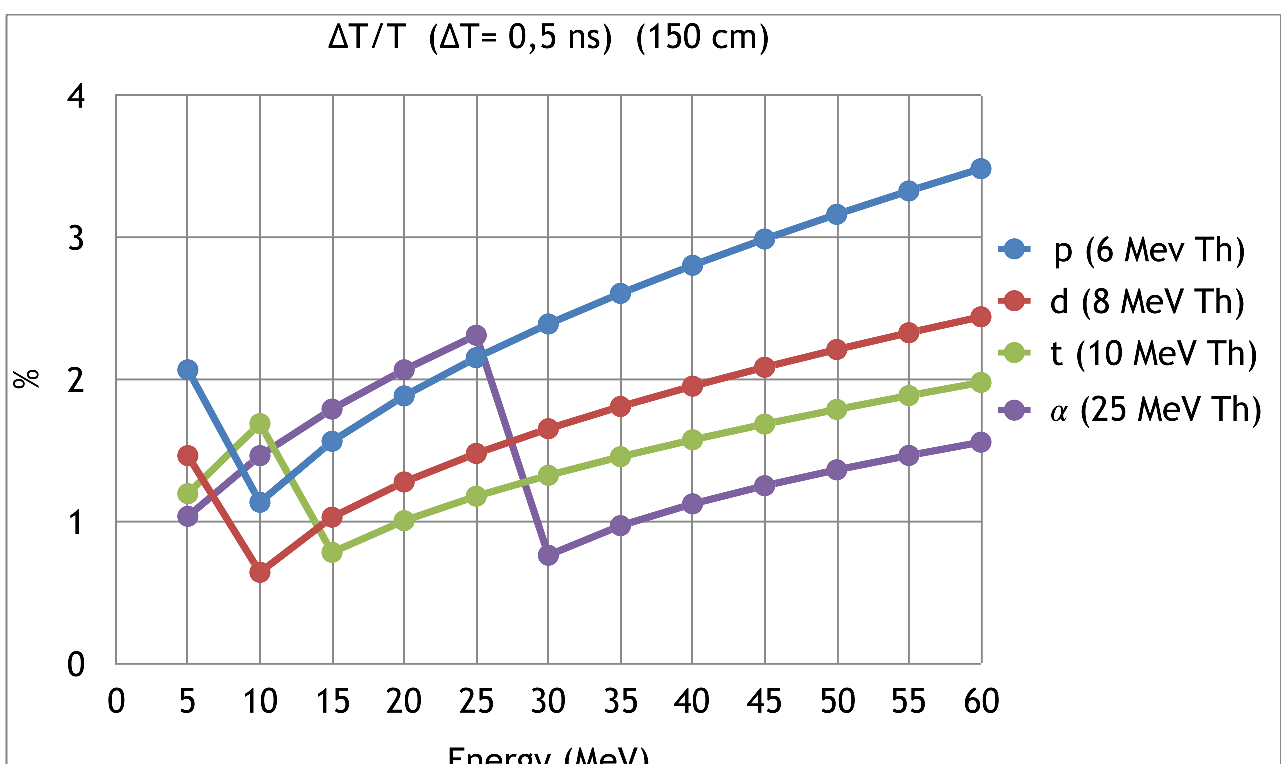

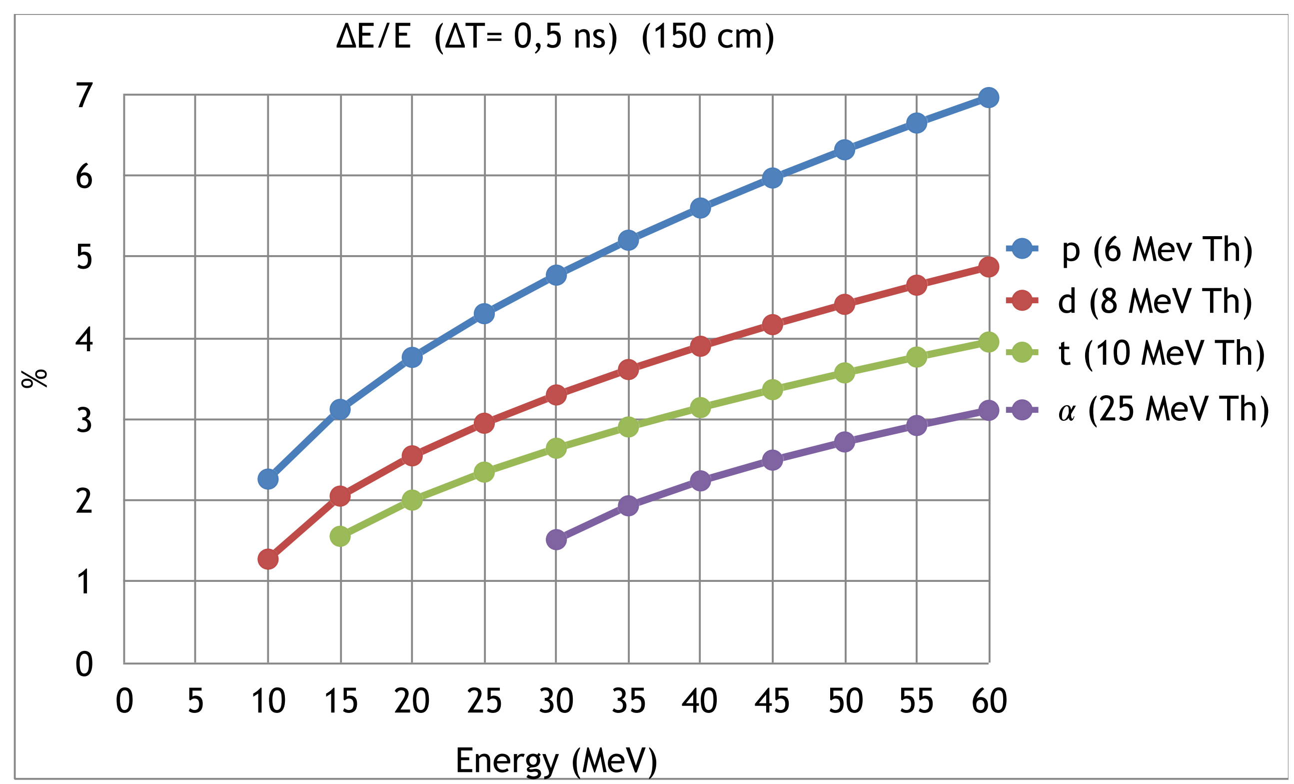

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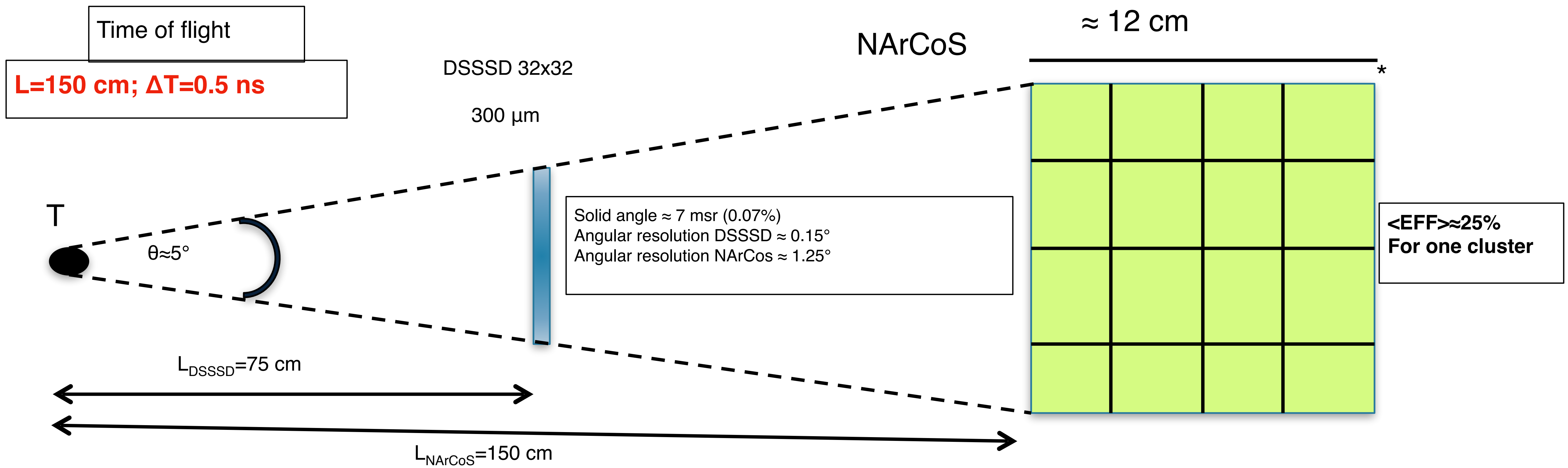

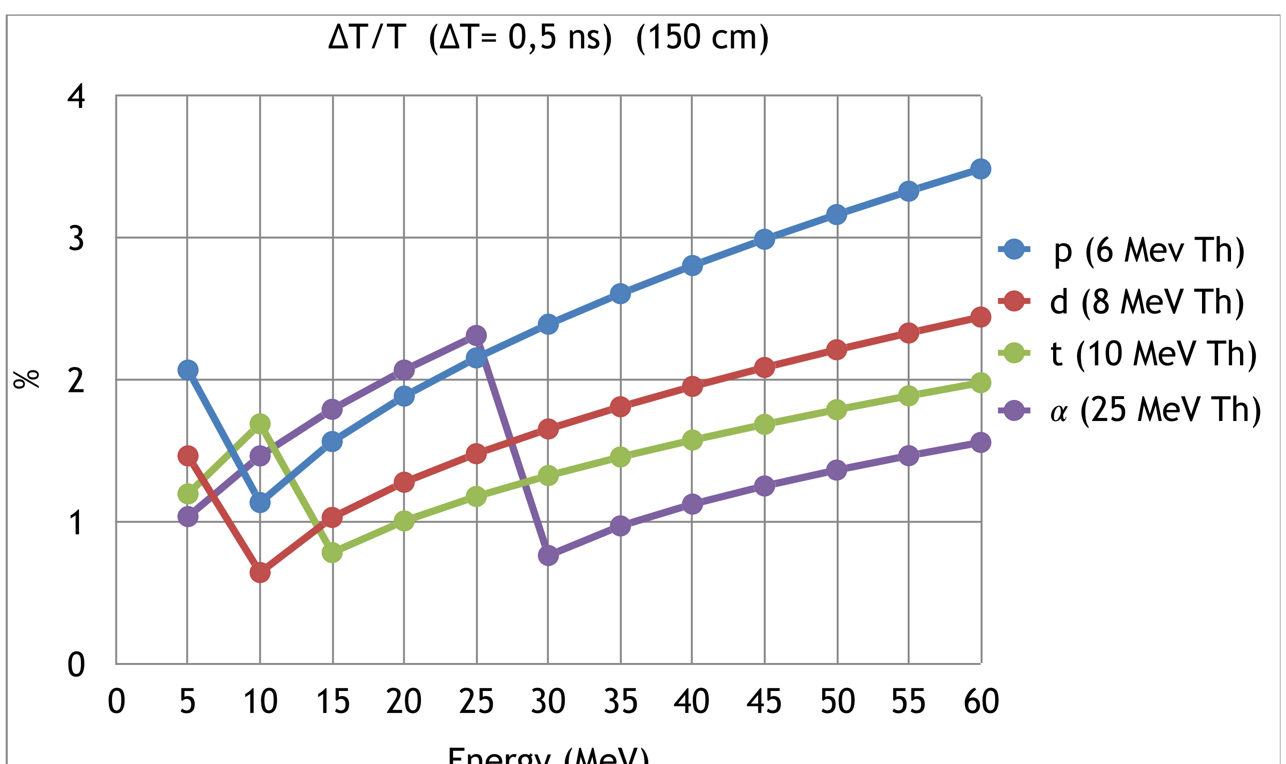

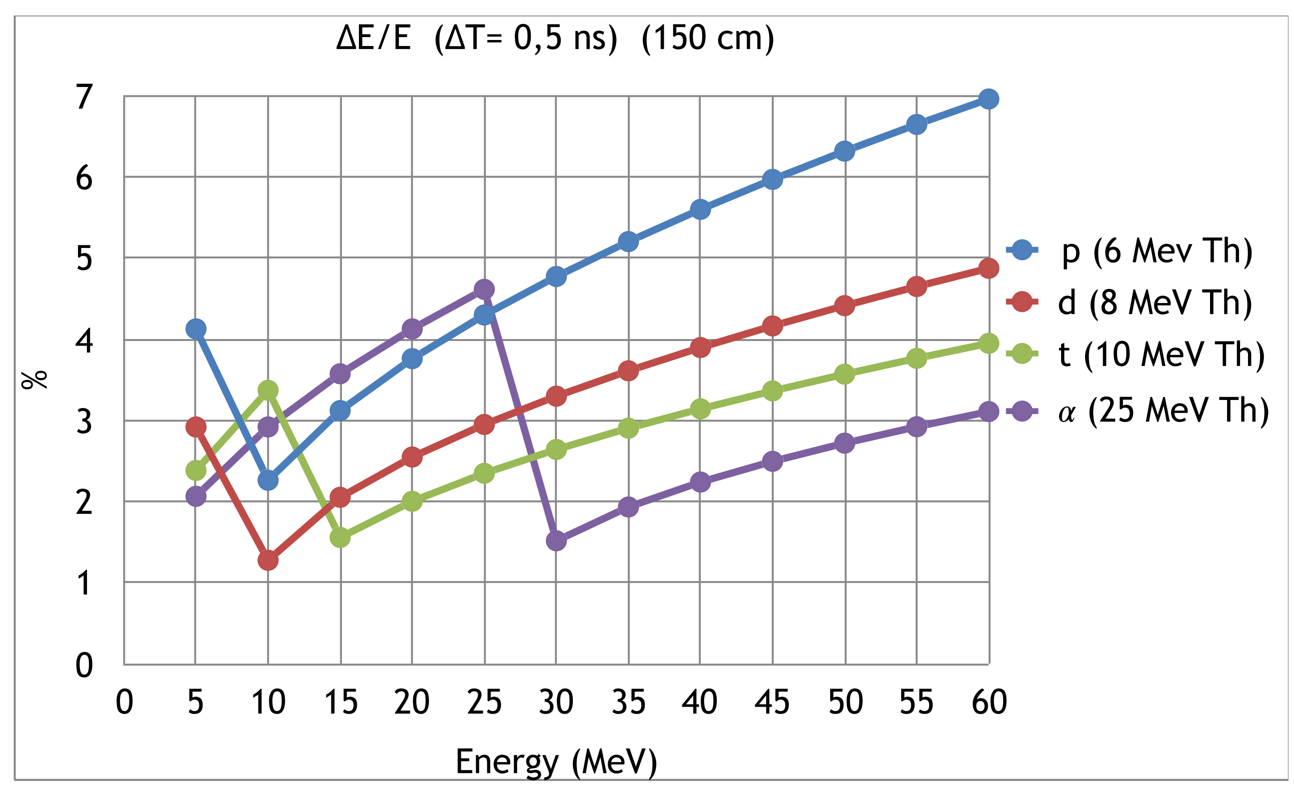

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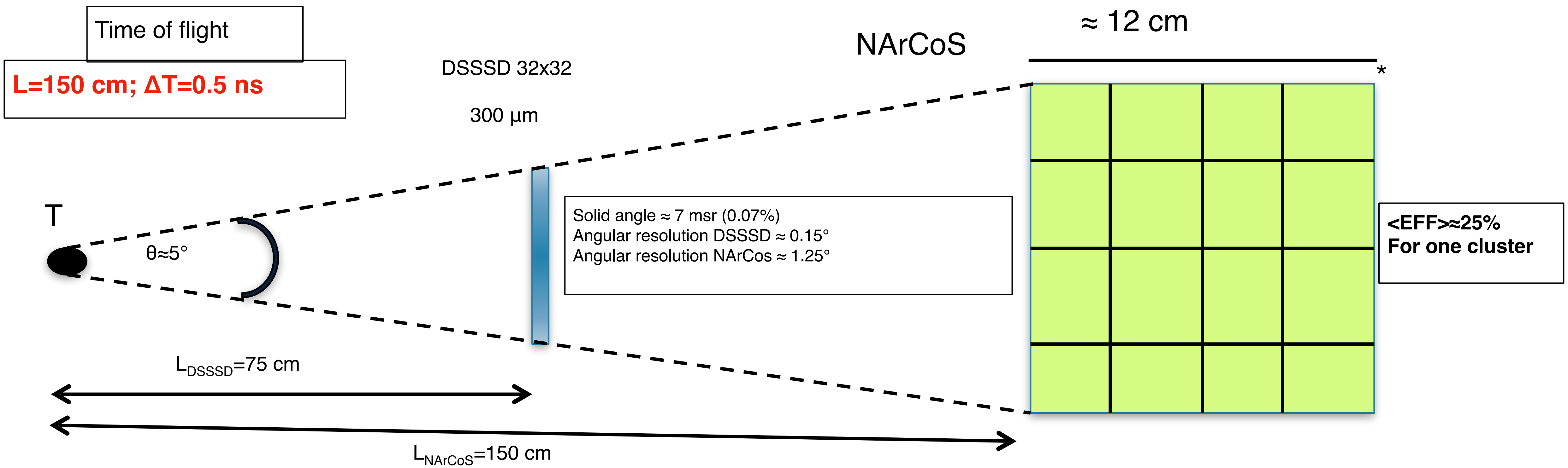

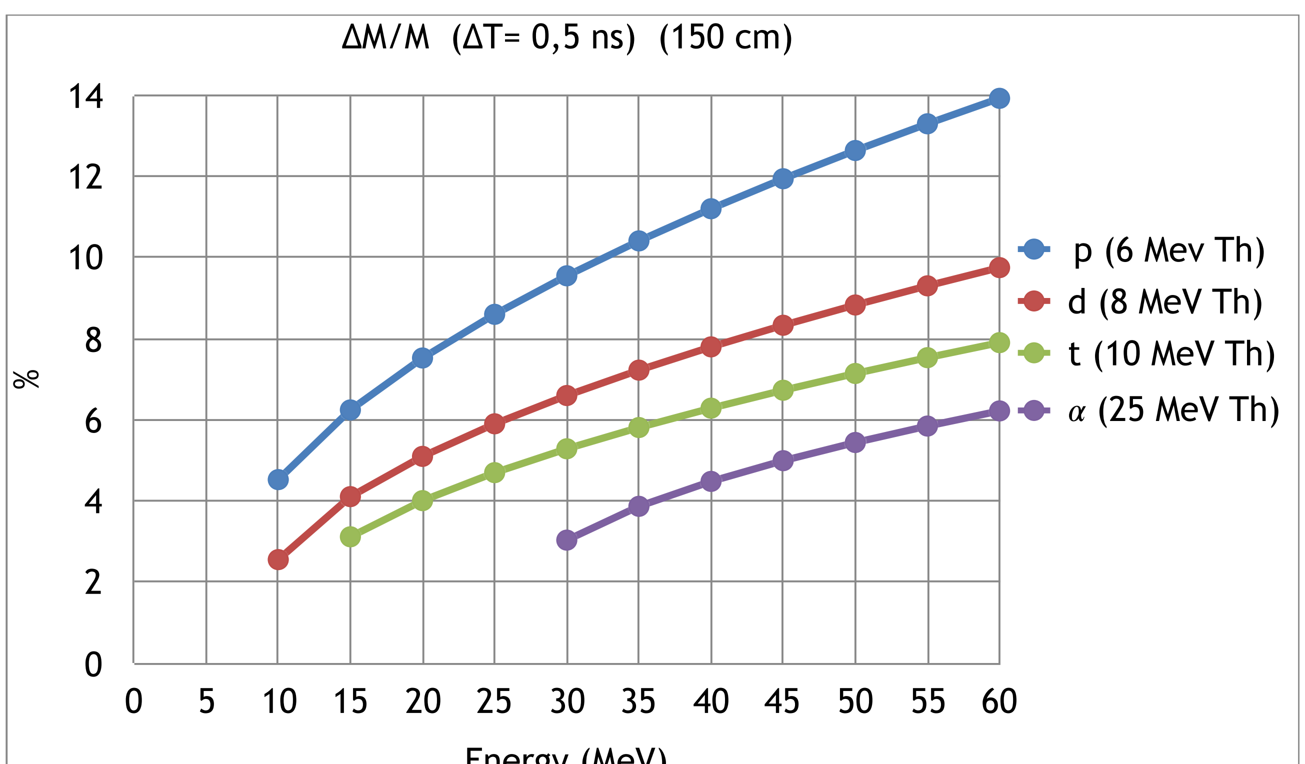

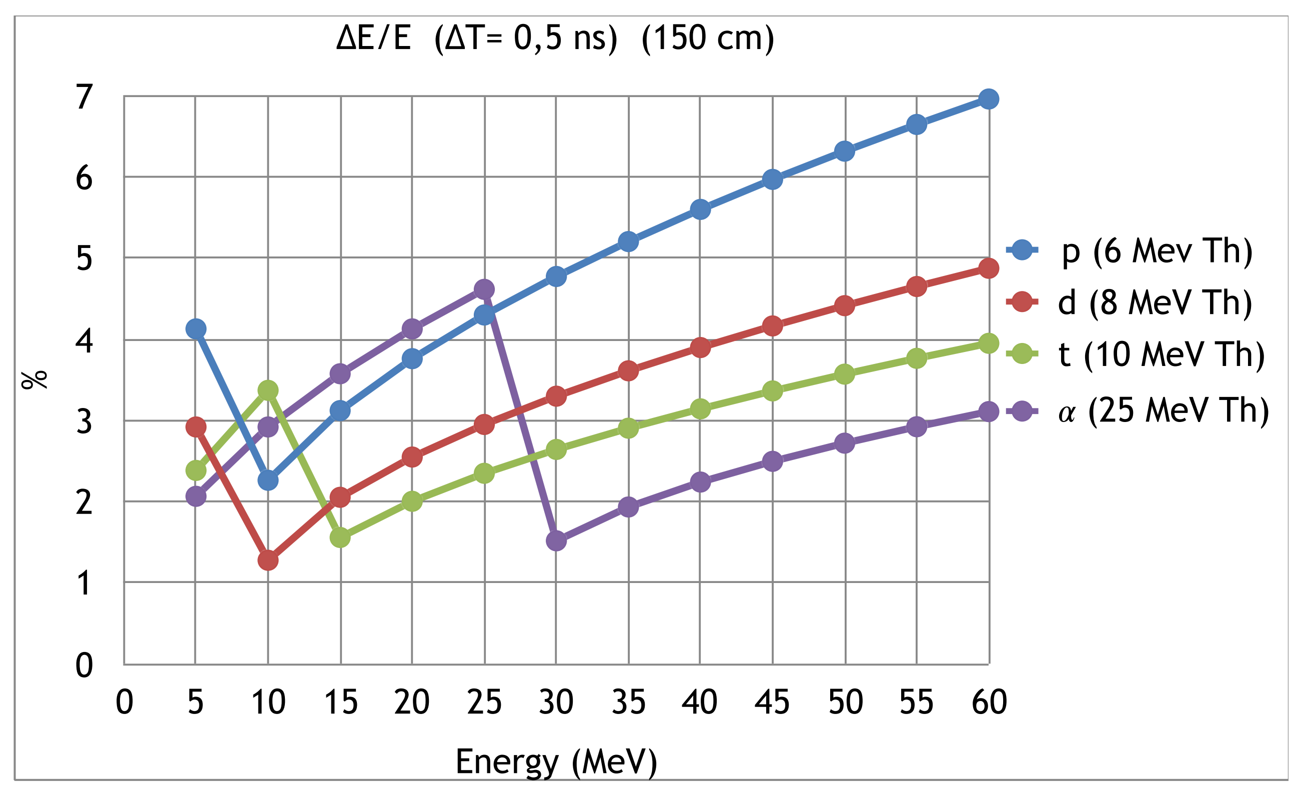

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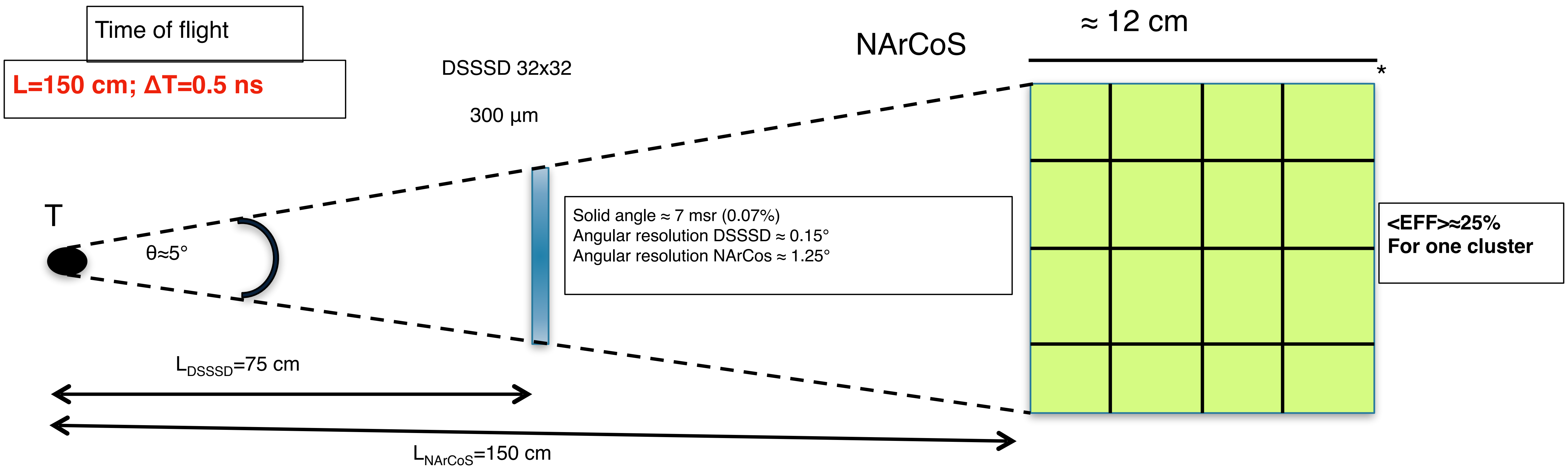

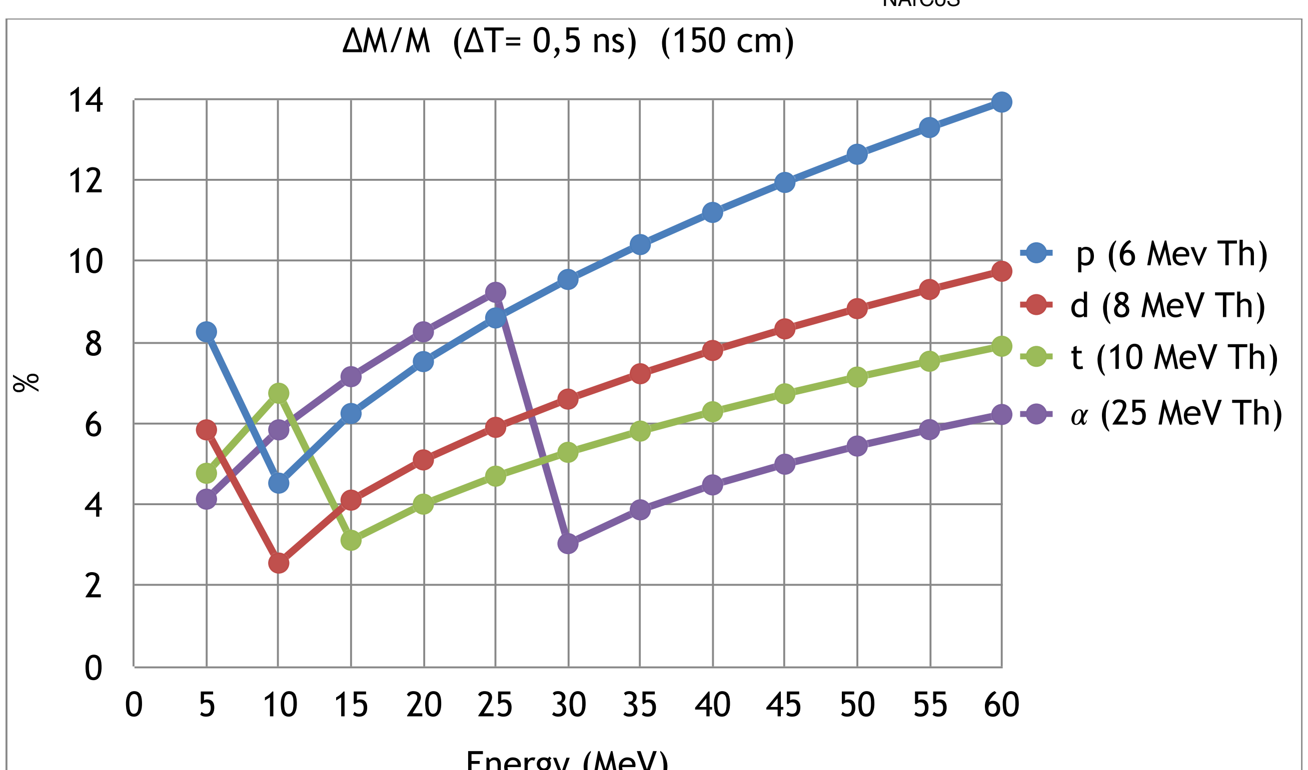

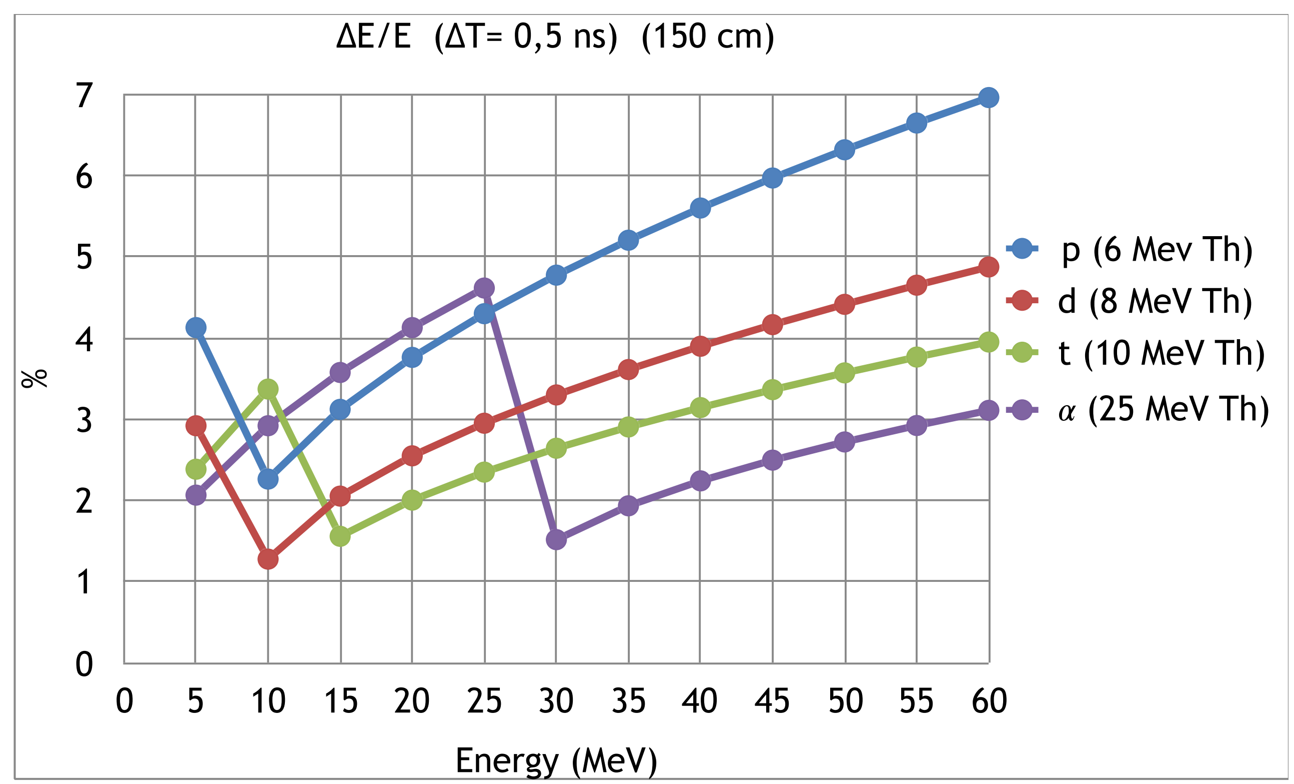

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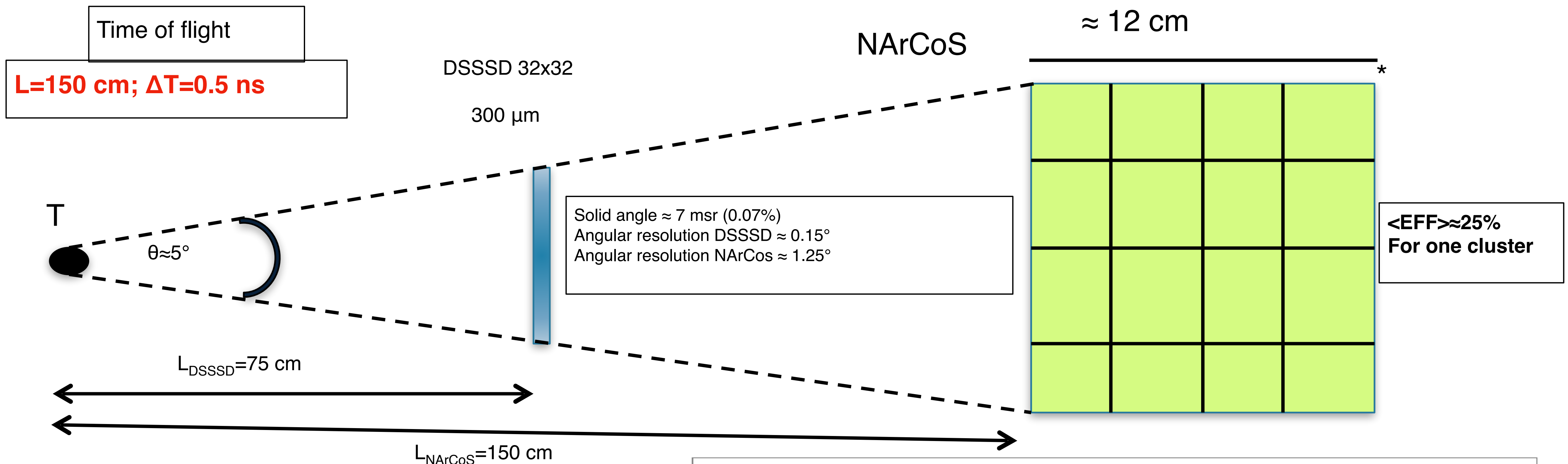

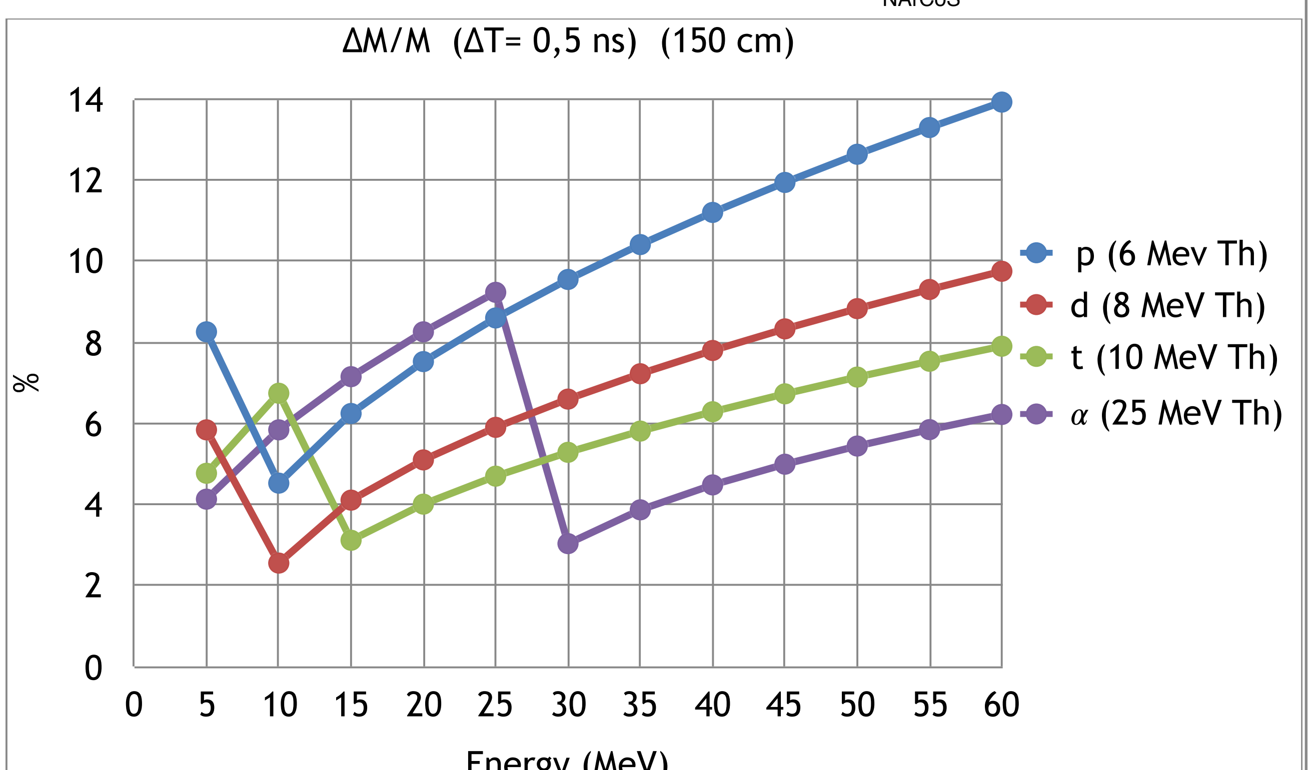

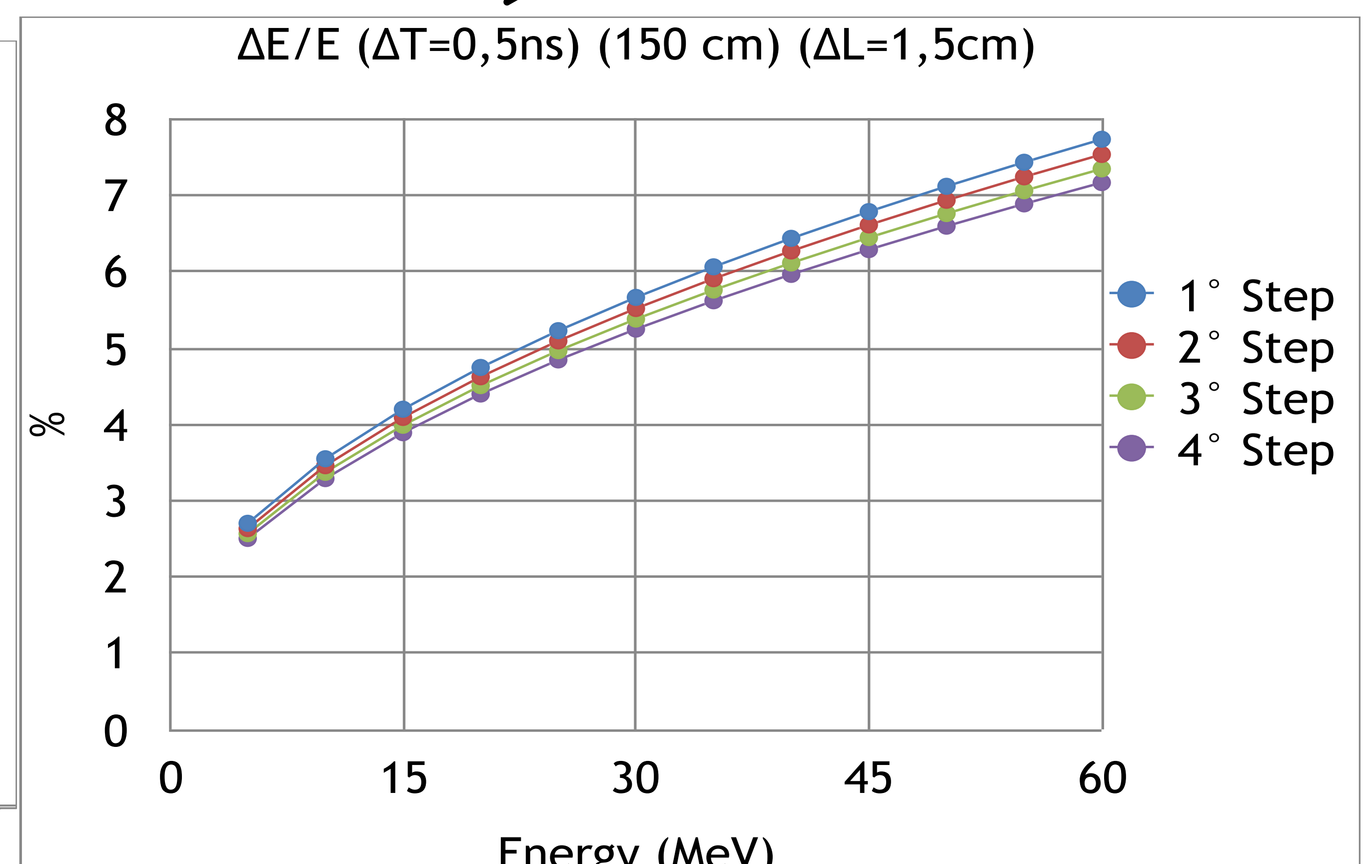

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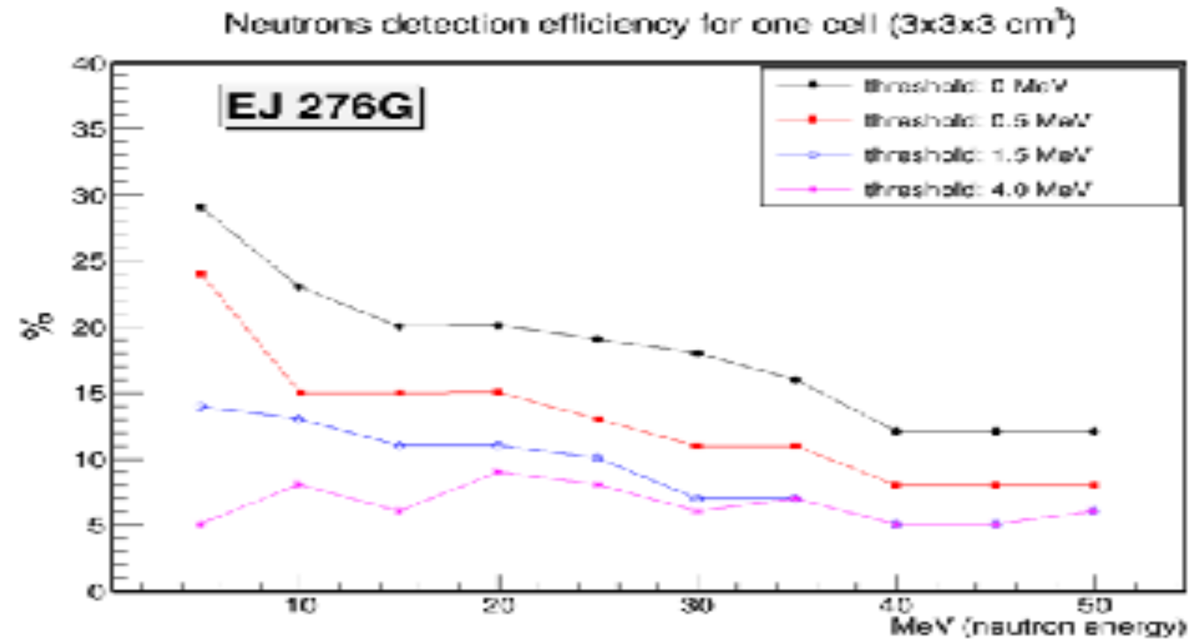
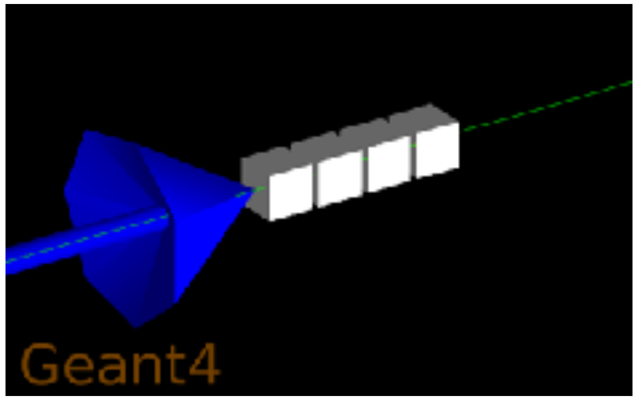
What about the neutron detection efficiency?

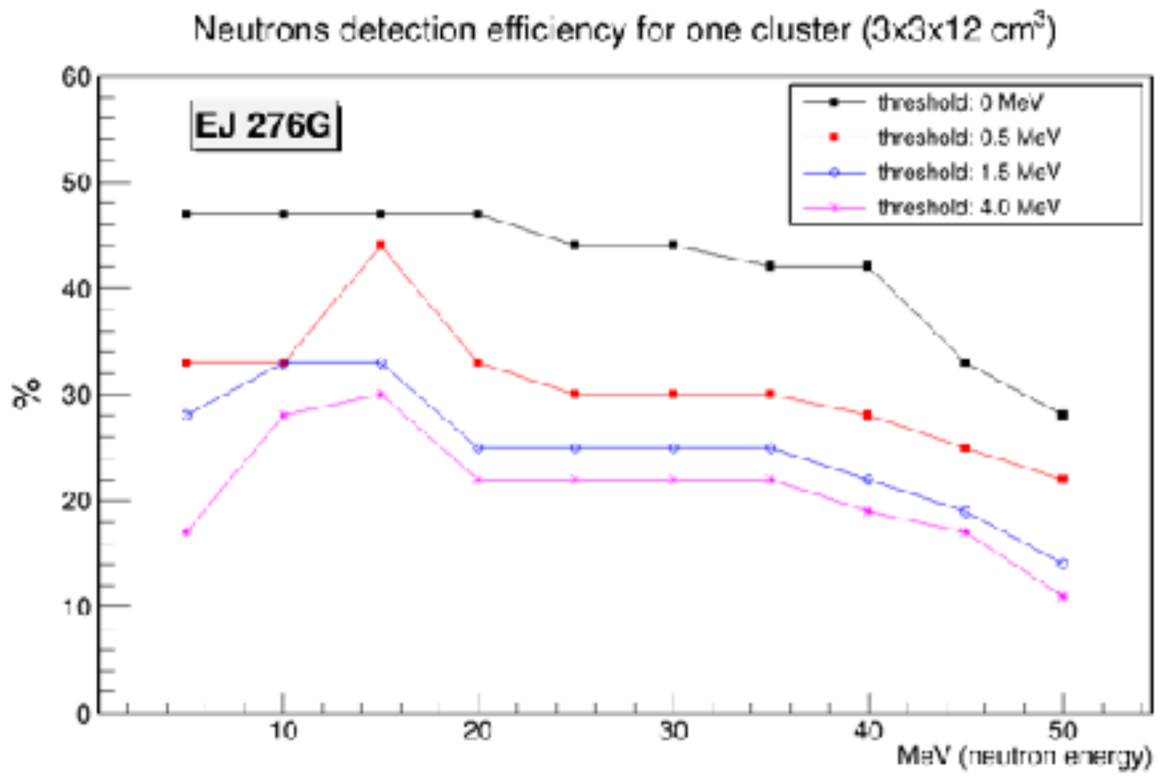
GEANT 4 simulation in order to estimate the neutron detection efficiency

Mean value for one detection cell (3x3x3 cm^3) ≅ 9%

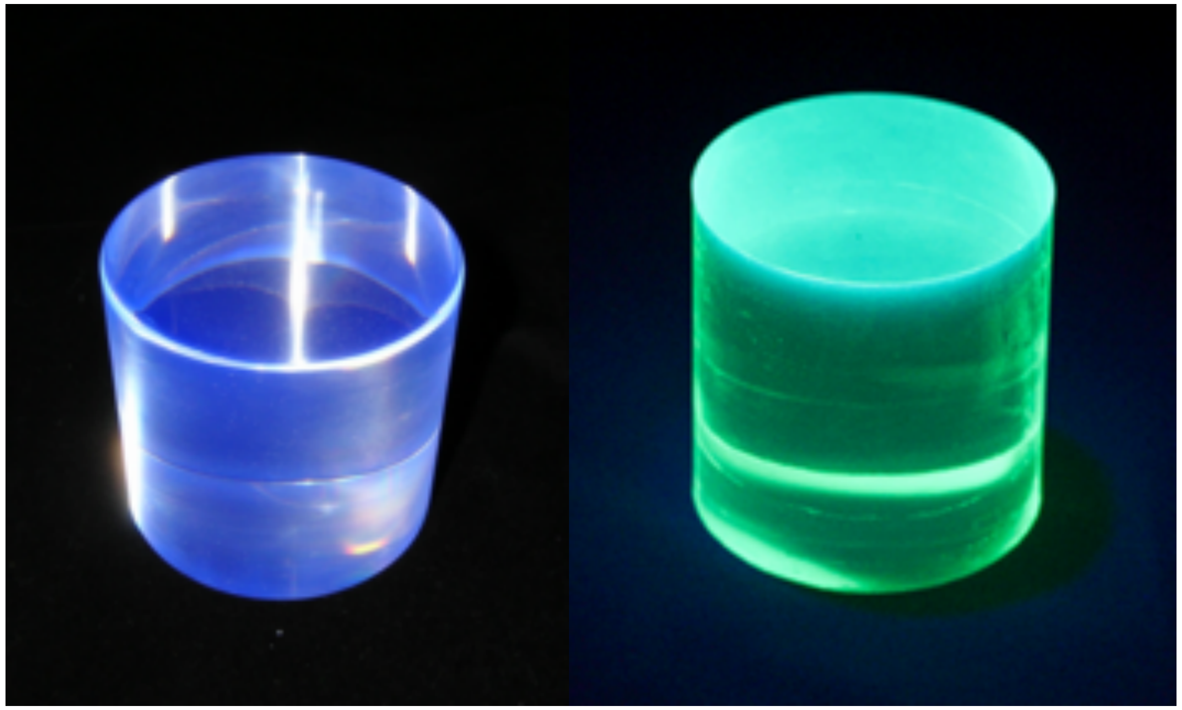


Mean value for one detection cluster (3x3x12 cm^3) ≅ 25%





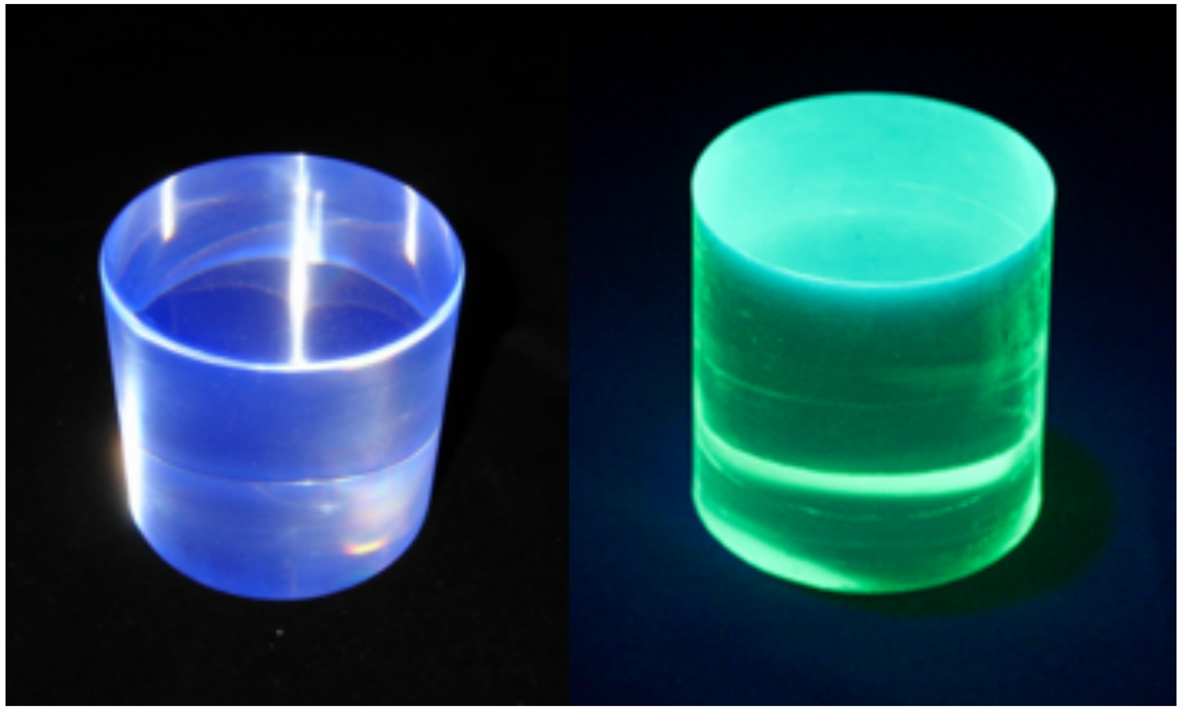
L'EJ276
(ex EJ-299-33)

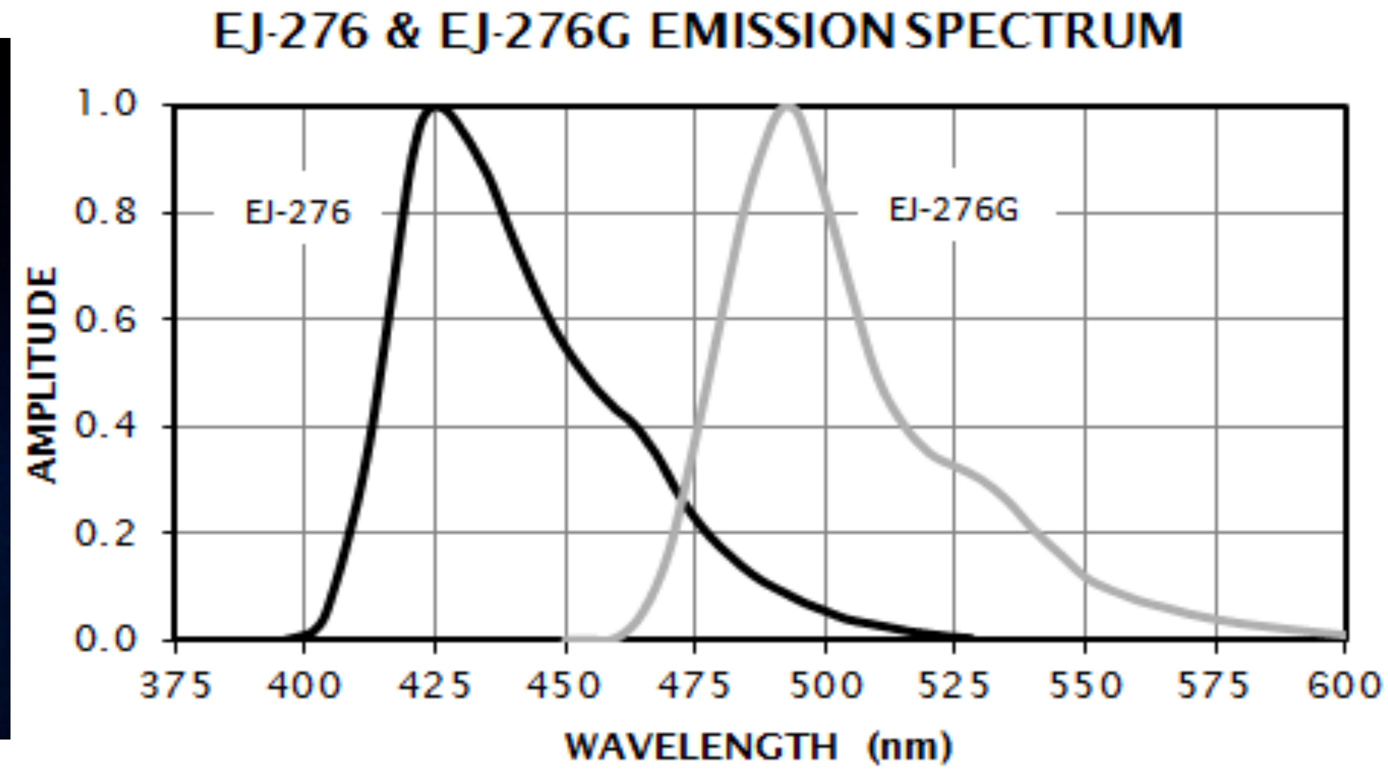


N. Zaitsev et al., NIM A 668 (2012) 88.
N. P. Hawkes et al., NIM A729 (2013) 522
S.A. Pozzi et al., NIM A723 (2013) 19
E. V. Pagano et al. NIM A 889 (2018) 83-88
E. V. Pagano et al. NIM A 905 (2018) 47-52

L'EJ276

(ex EJ-299-33)





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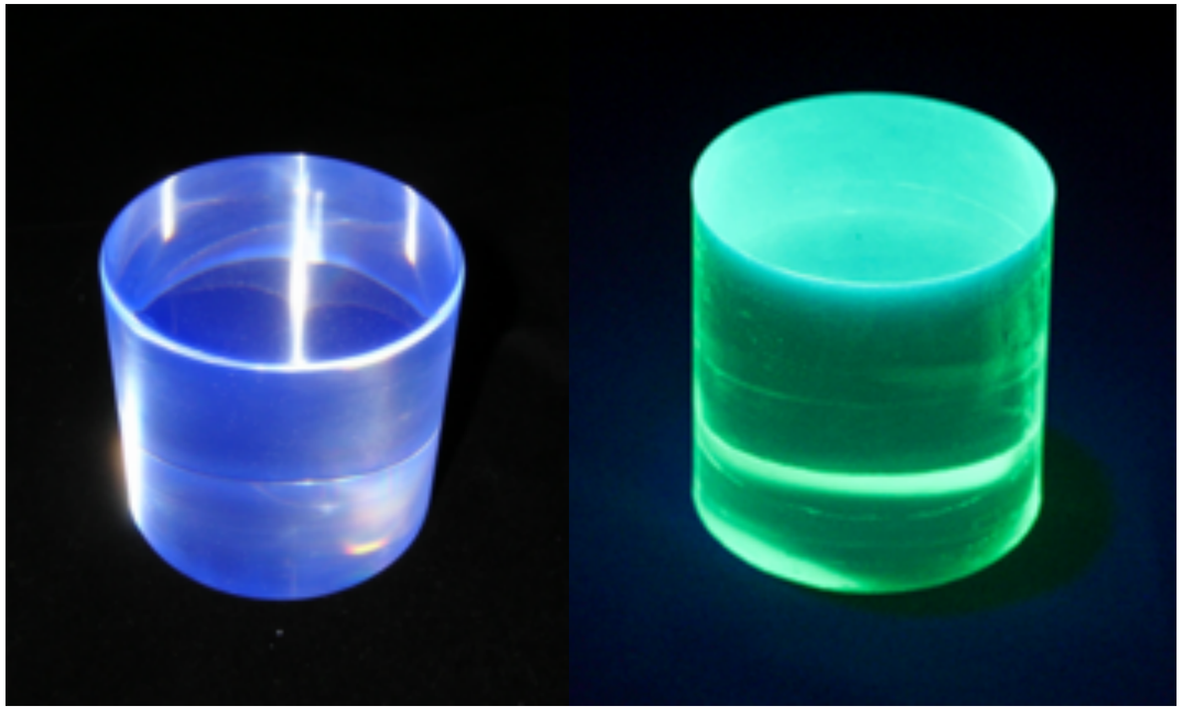
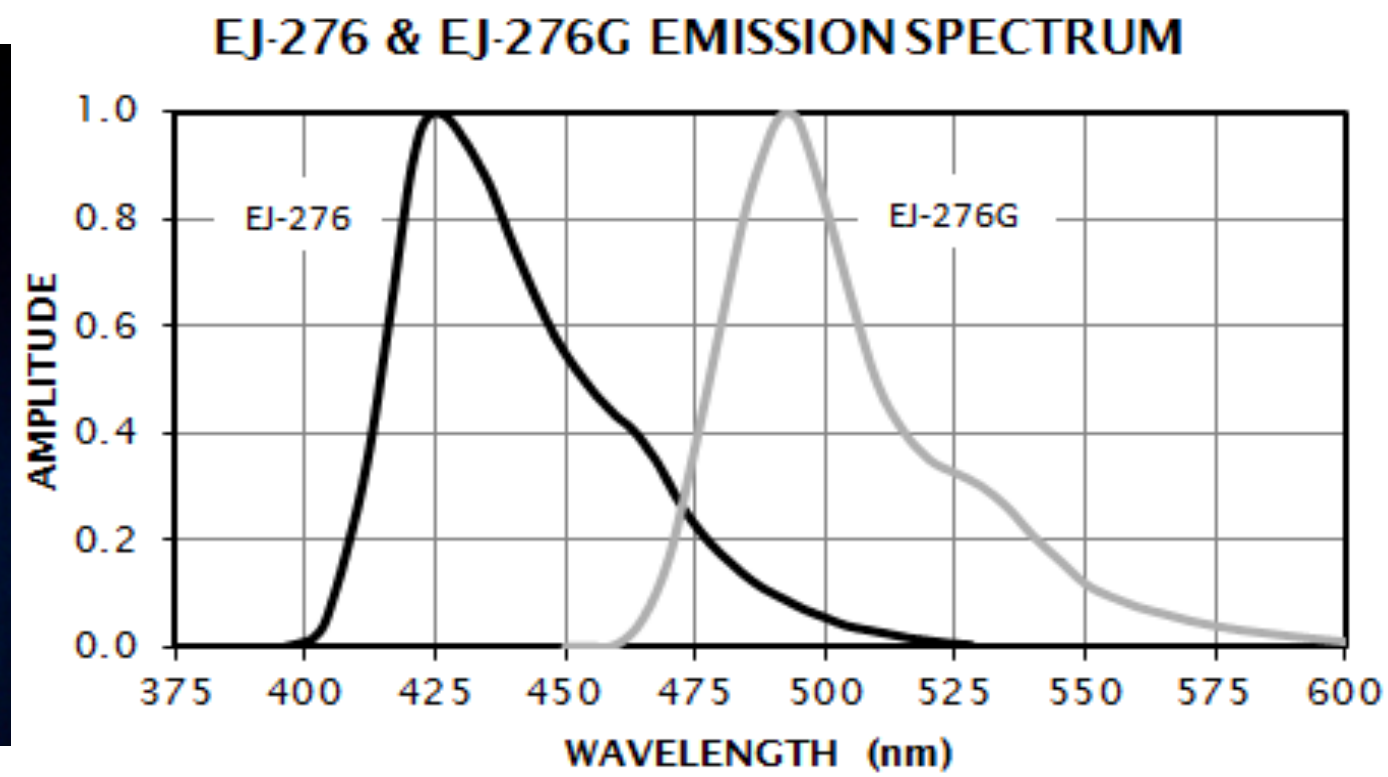
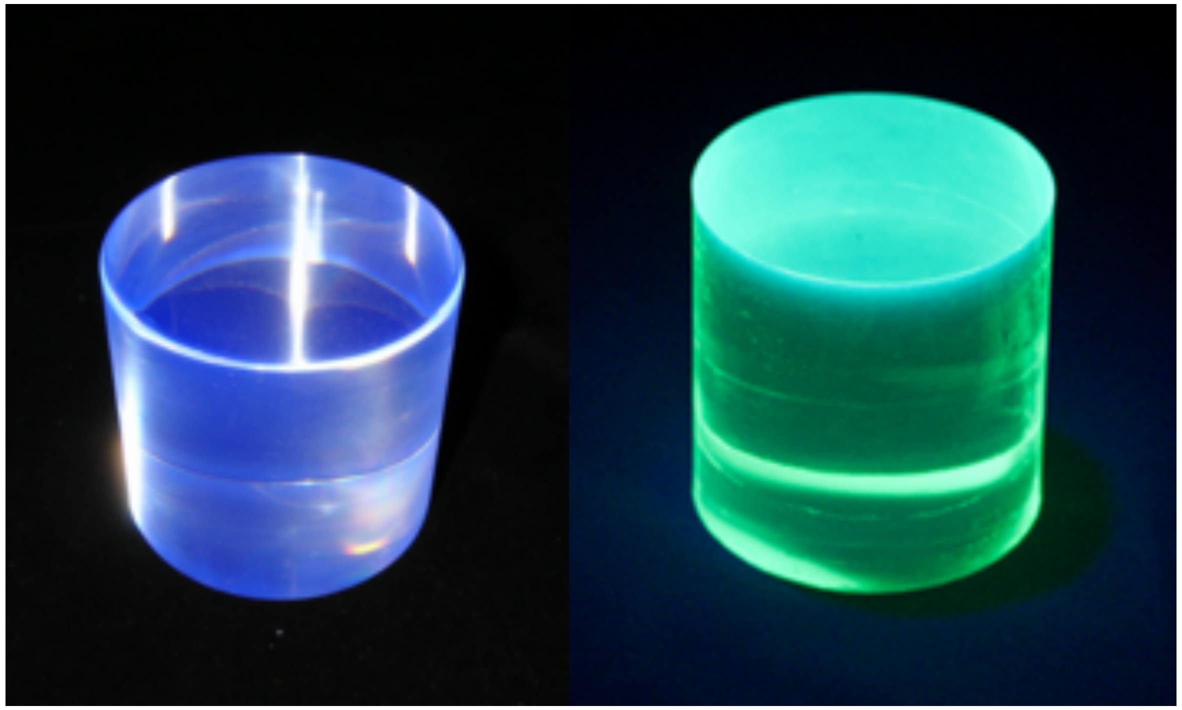


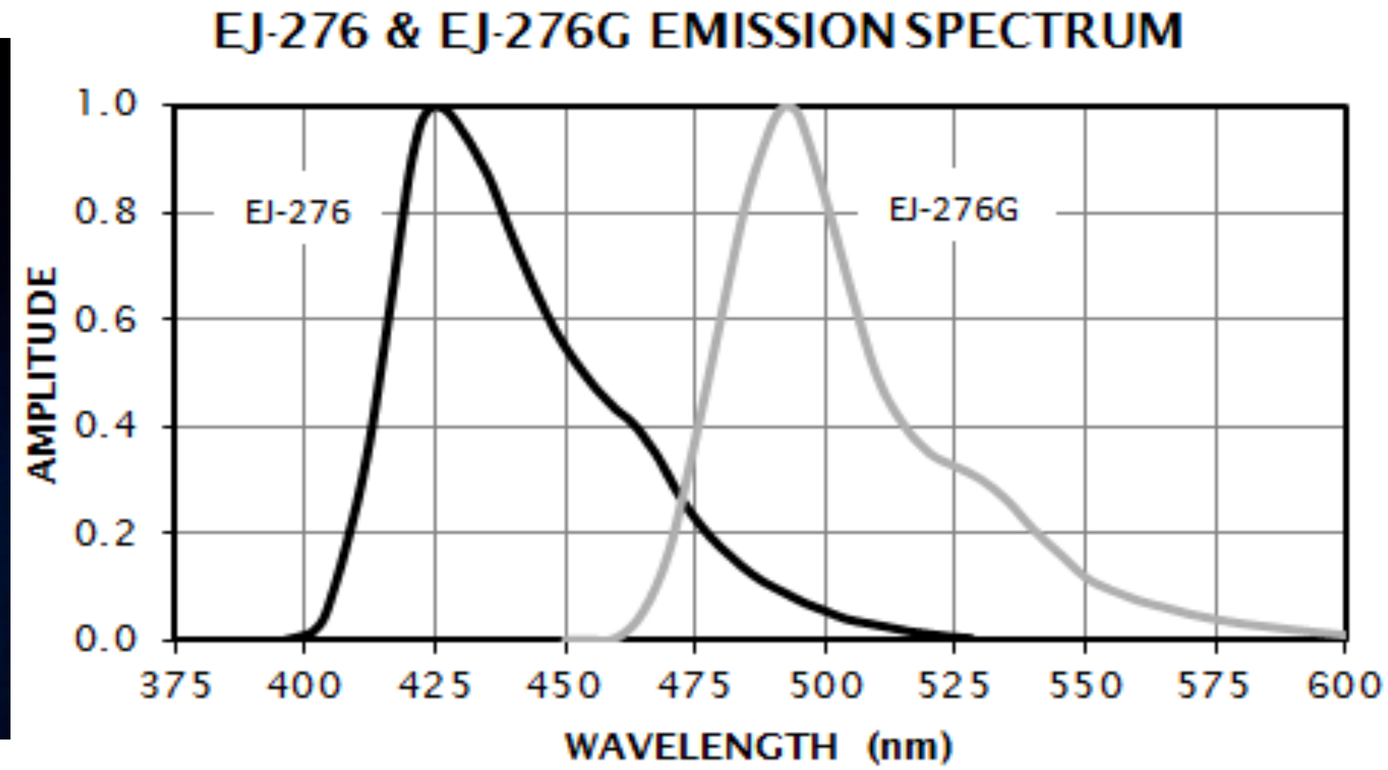


PROPERTIES		EJ-276	EJ-276G
Light Output (% Anthracene)		56	52
Scintillation Efficiency (photons/1 MeV e⁻)		8,600	8000
Wavelength of Maximum Emission (nm)		425	490
No. of H Atoms per cm^3 (x10^{22})		4.53	4.53
No. of C Atoms per cm^3 (x10^{22})		4.89	4.89
No. of Electrons per cm^3 (x10^{23})		3.52	3.52
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

(ex EJ-299-33)





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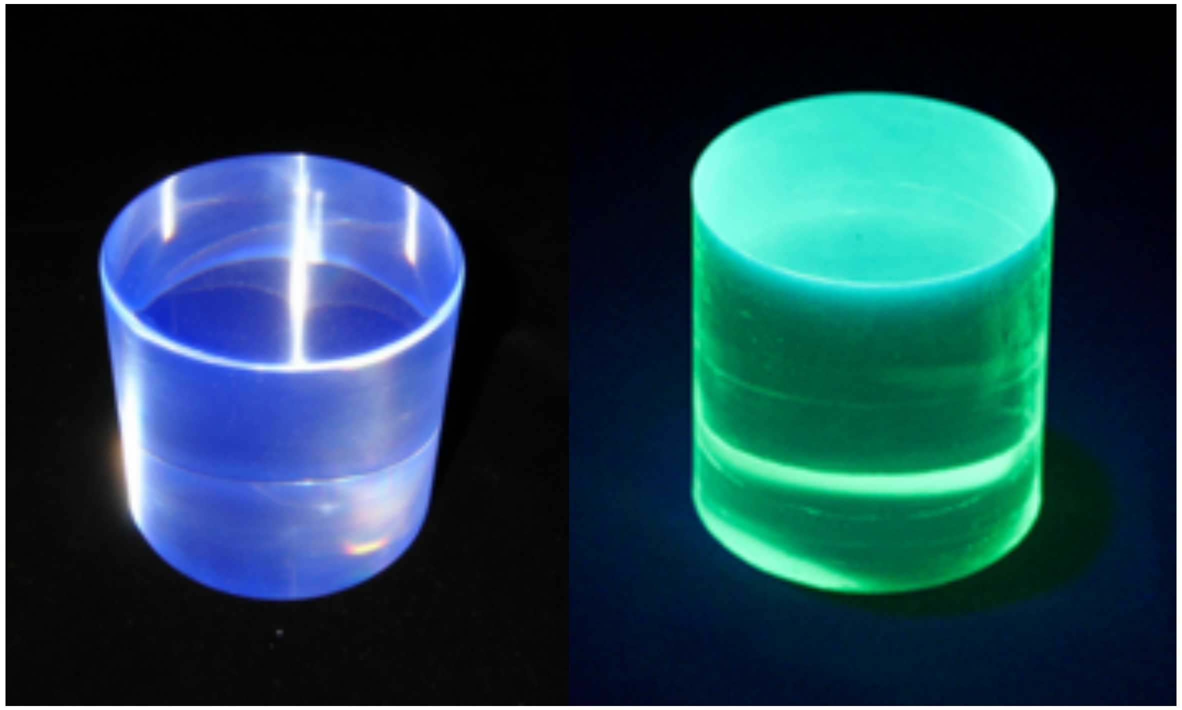
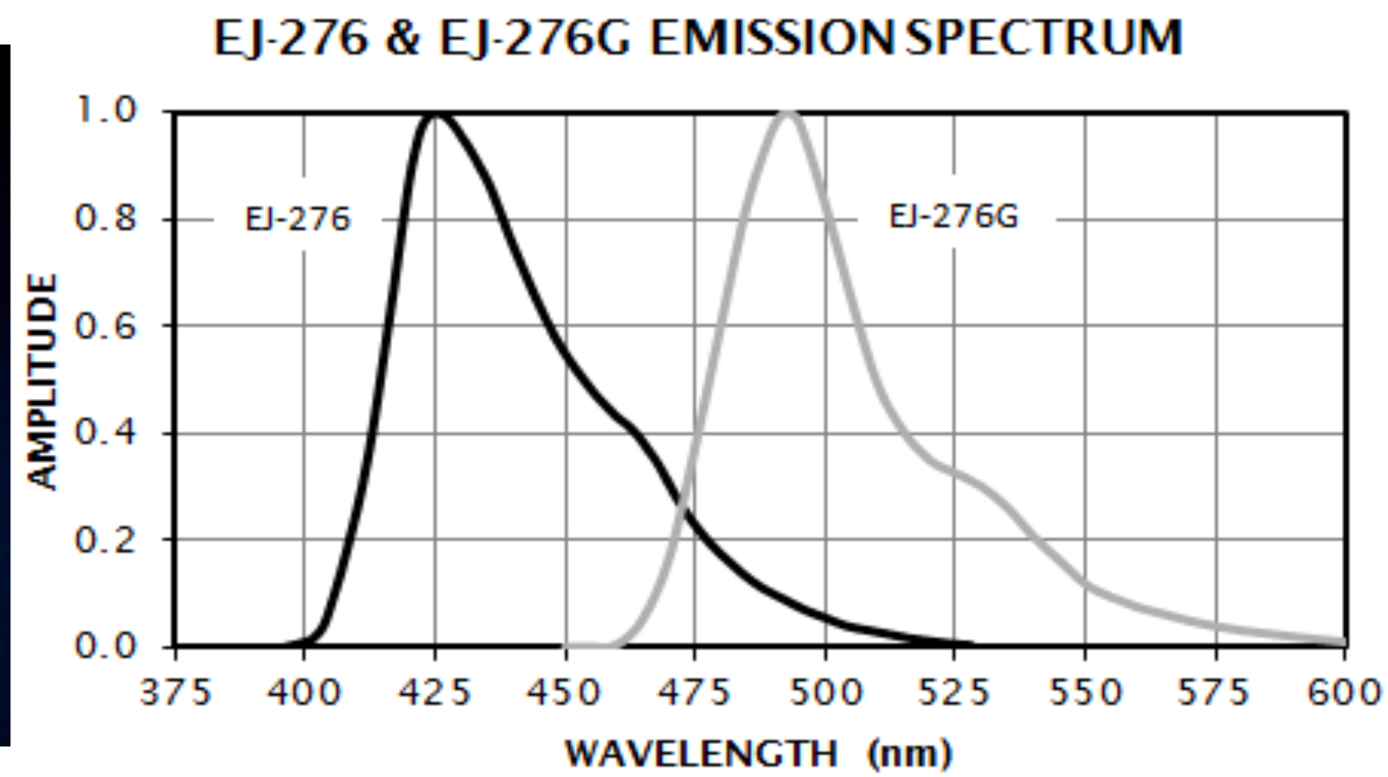
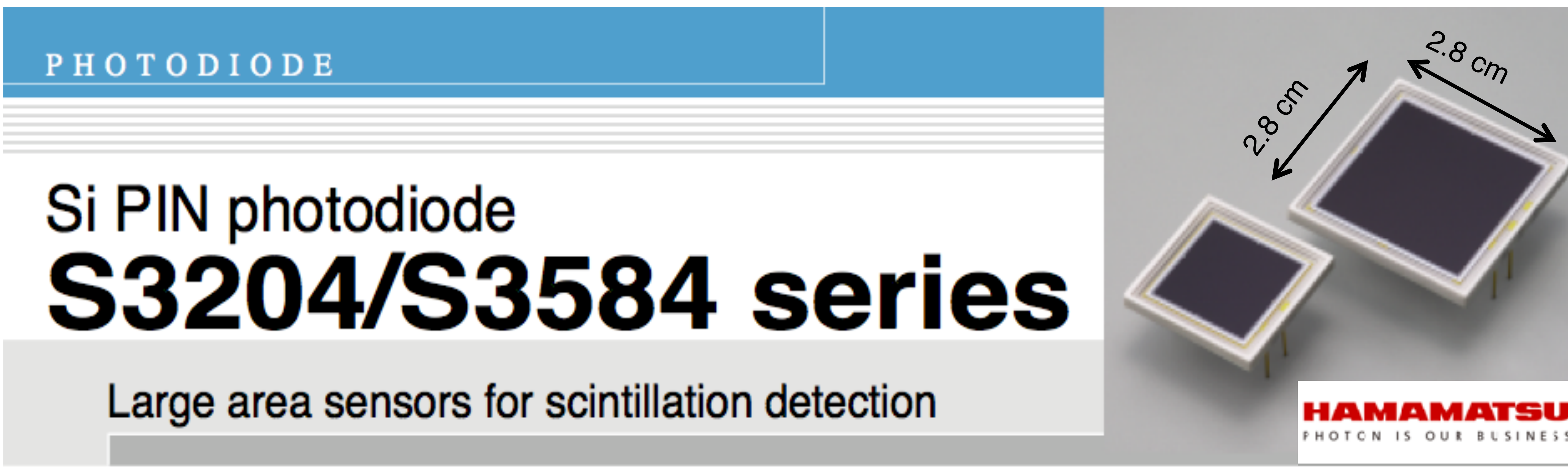
(ex EJ-299-33)

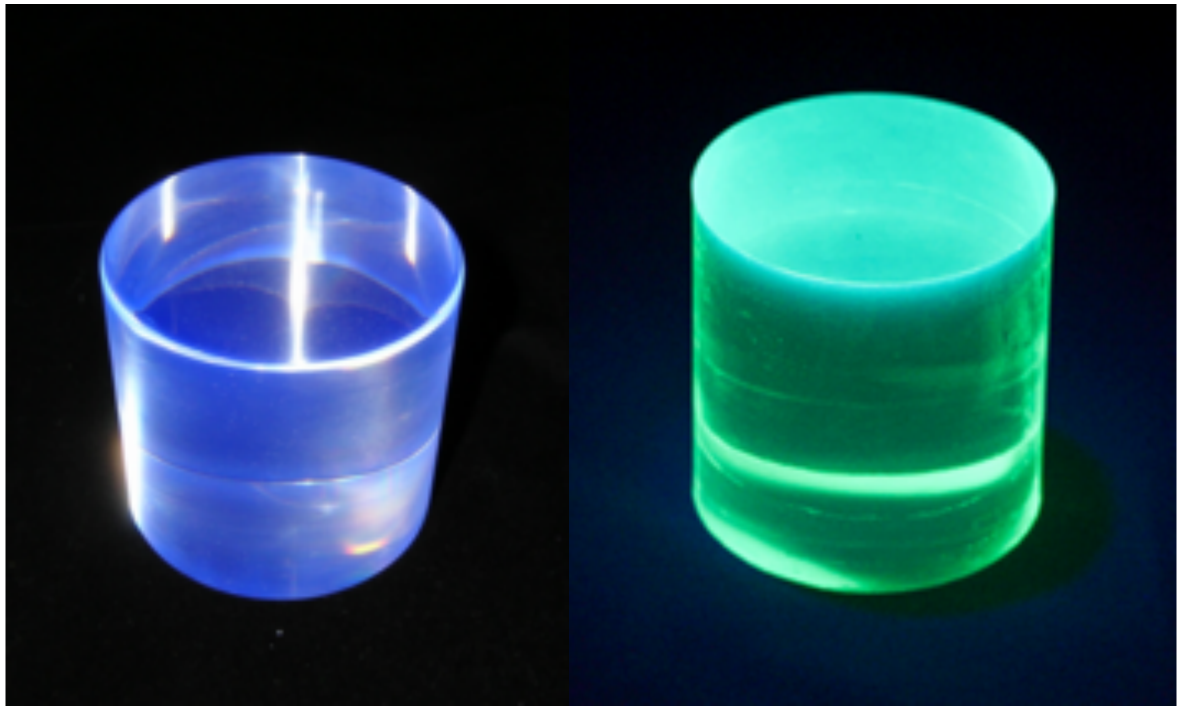


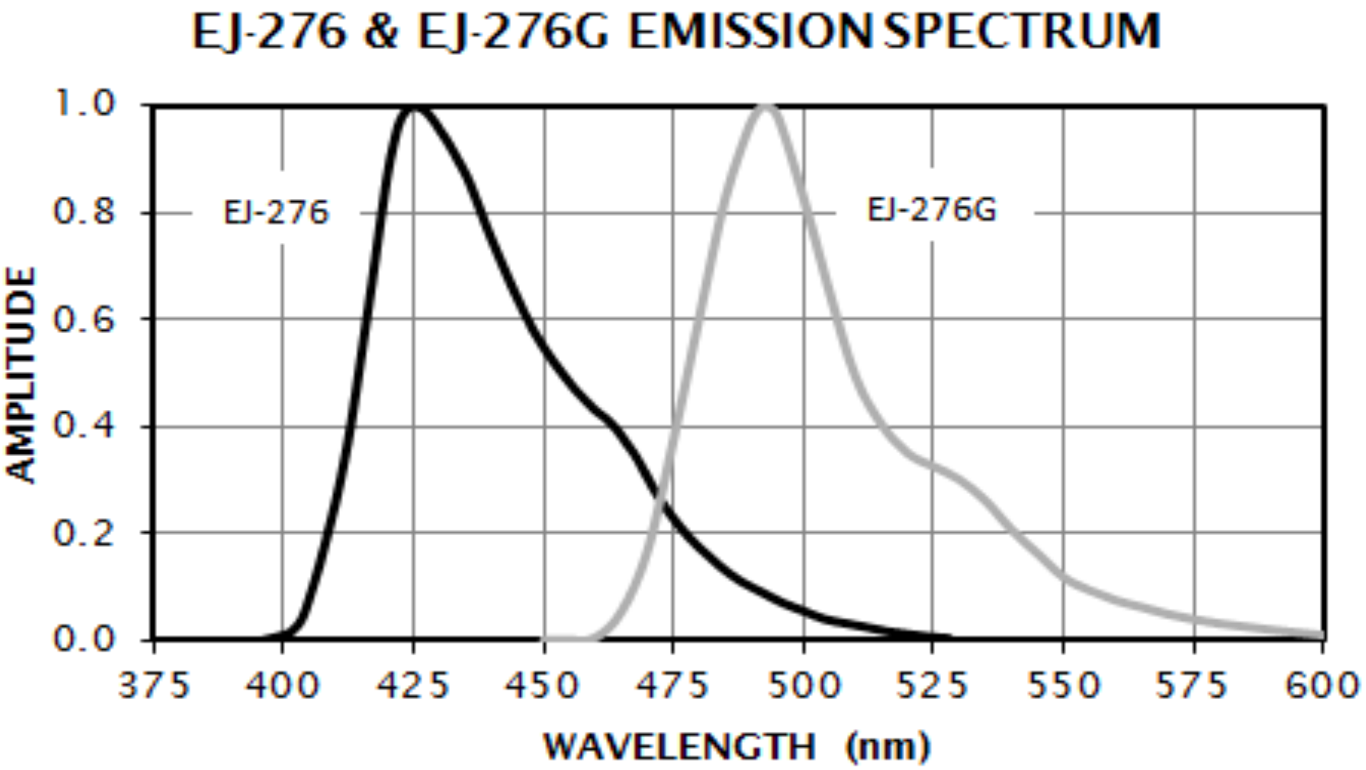




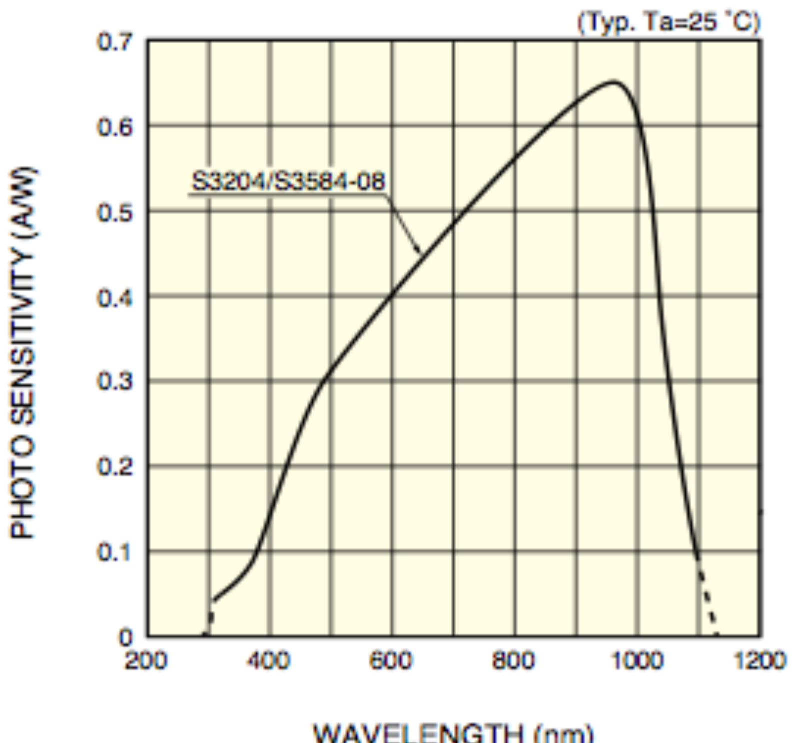
S3204/S3584 series are large area Si PIN photodiodes having an epoxy resin window. These photodiodes are also available without window.

L'EJ276
(ex EJ-299-33)

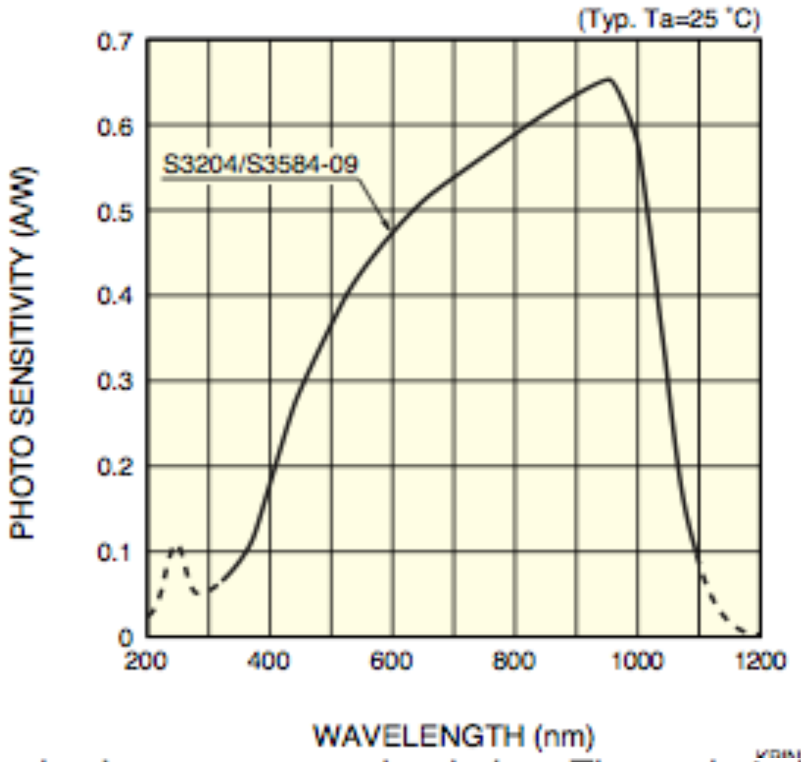


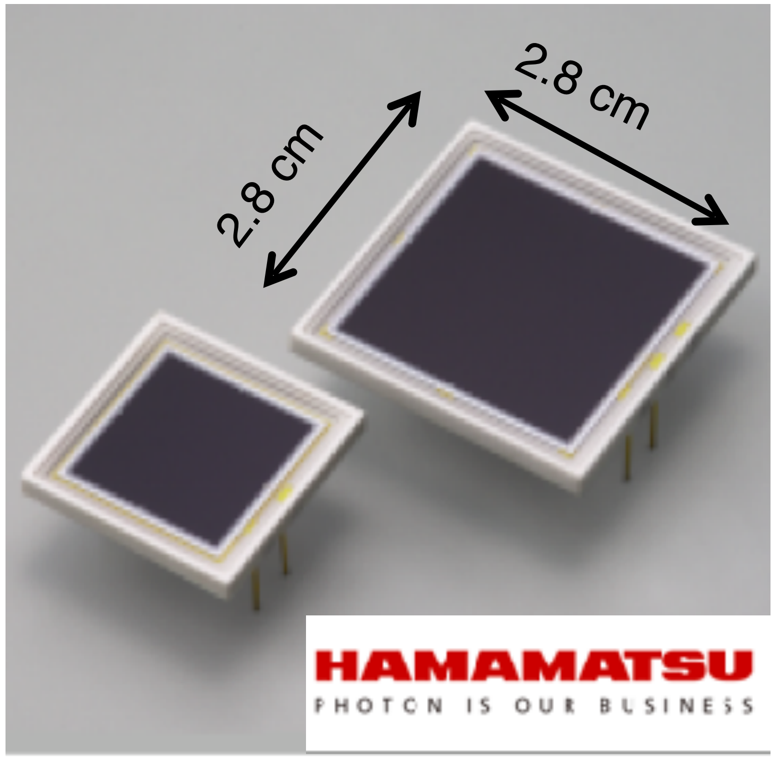


■ Spectral response



■ Spectral response (without window)





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Test using radioactive sources @ LNS

Dimention: 3x3x3 cm3
<neutron EFF> (GEANT4) ≈ 9%
Read by PM tube: EMI-9544QA
High Voltage: 1500-1700 V

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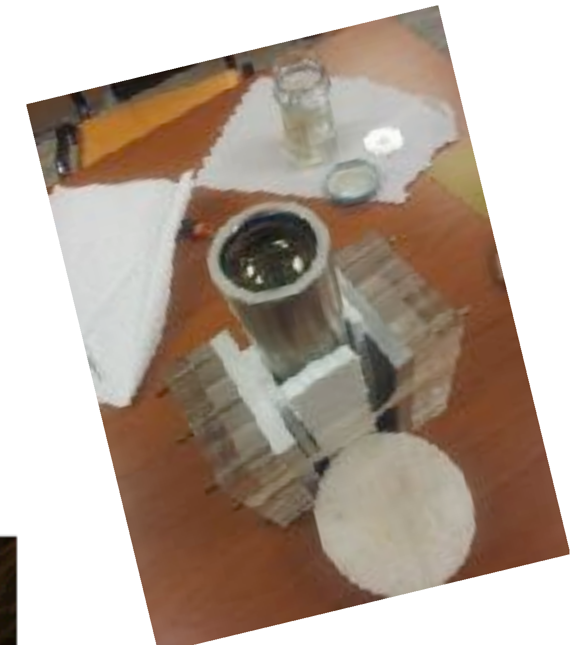

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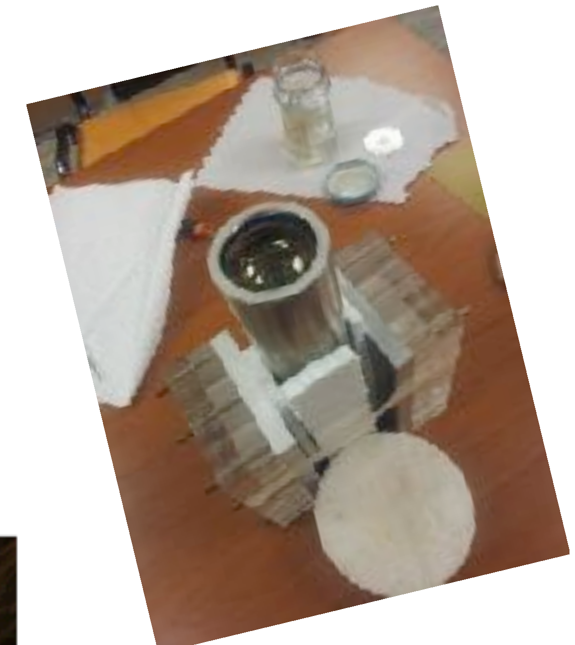

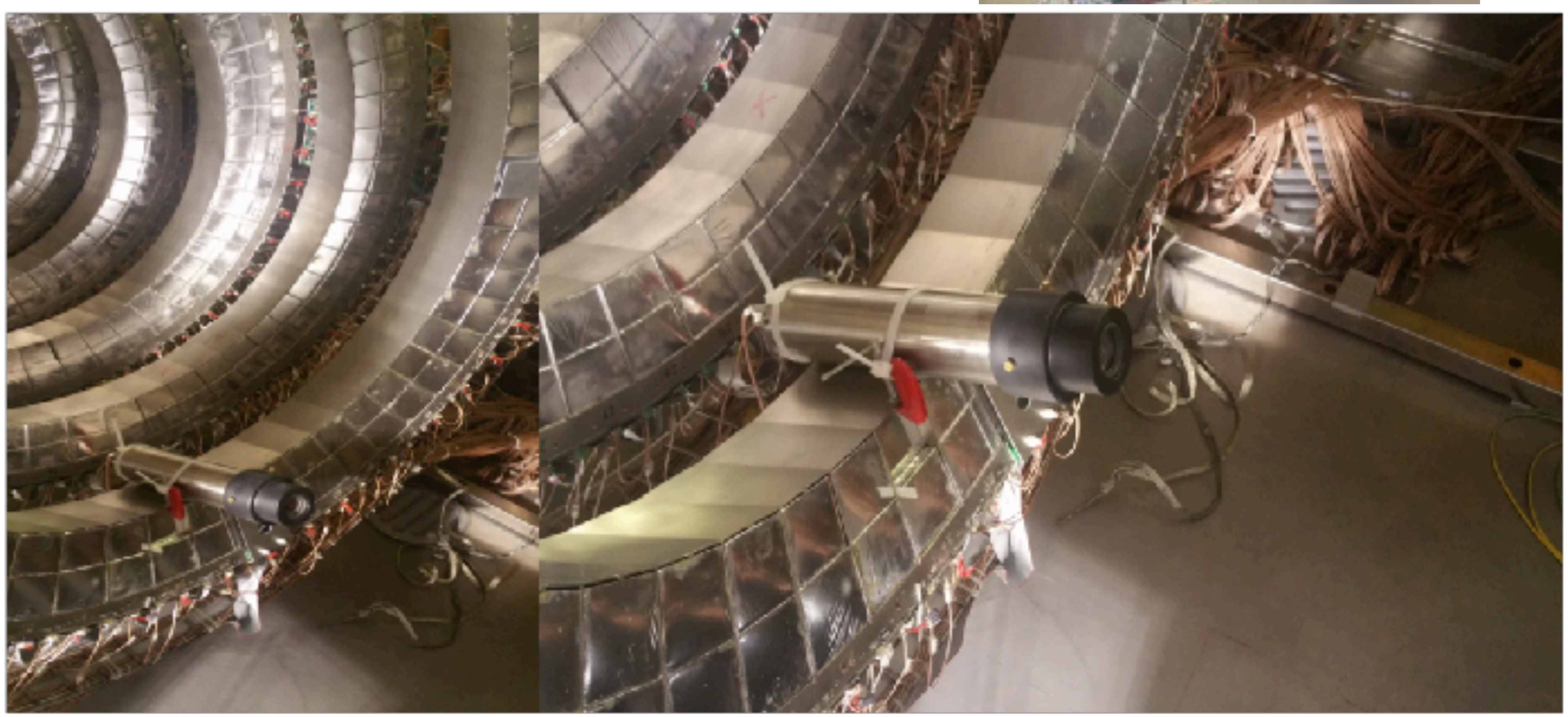

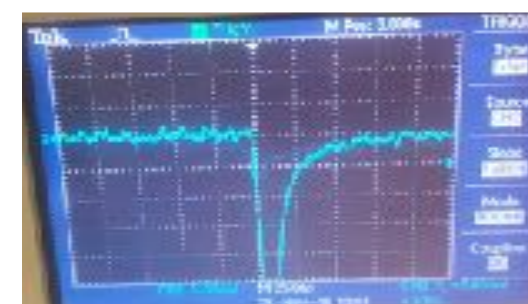

PM -EMI 9954QA
Like in ARGOS detector

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

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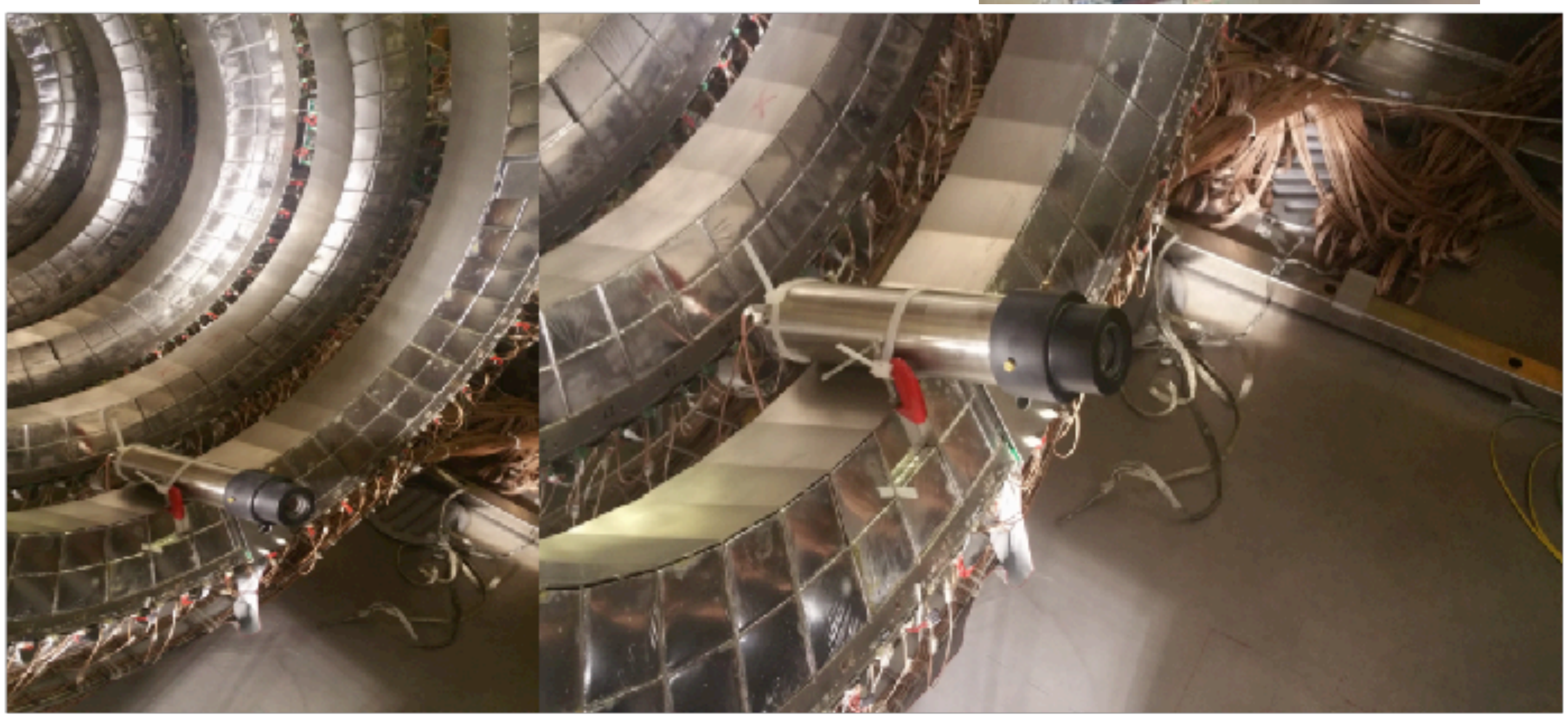
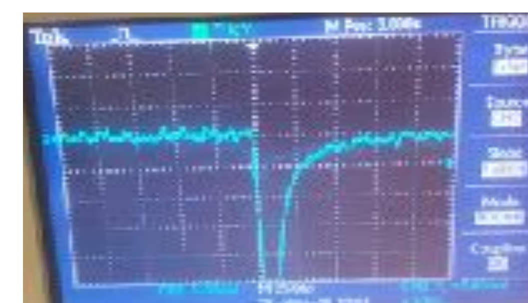


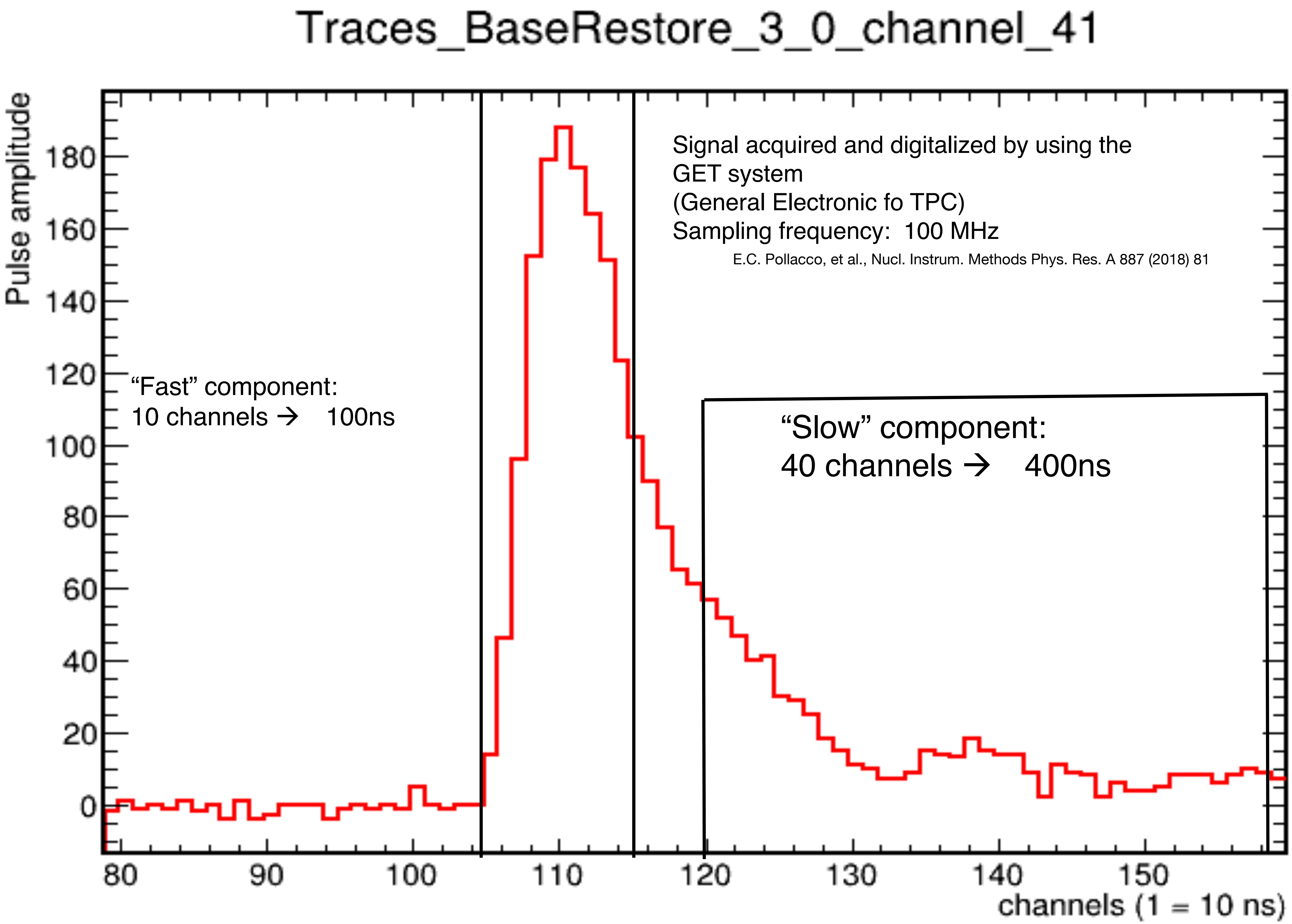


PM -EMI 9954QA
Like in ARGOS detector

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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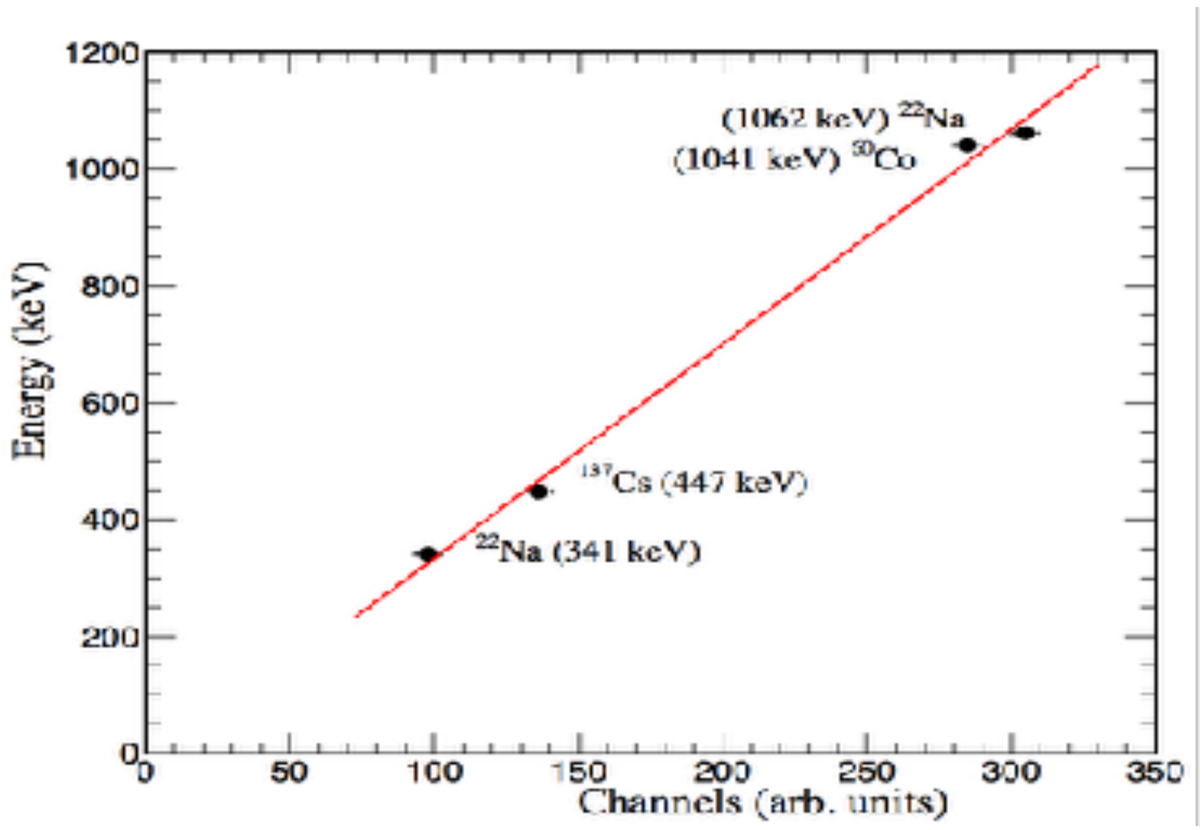

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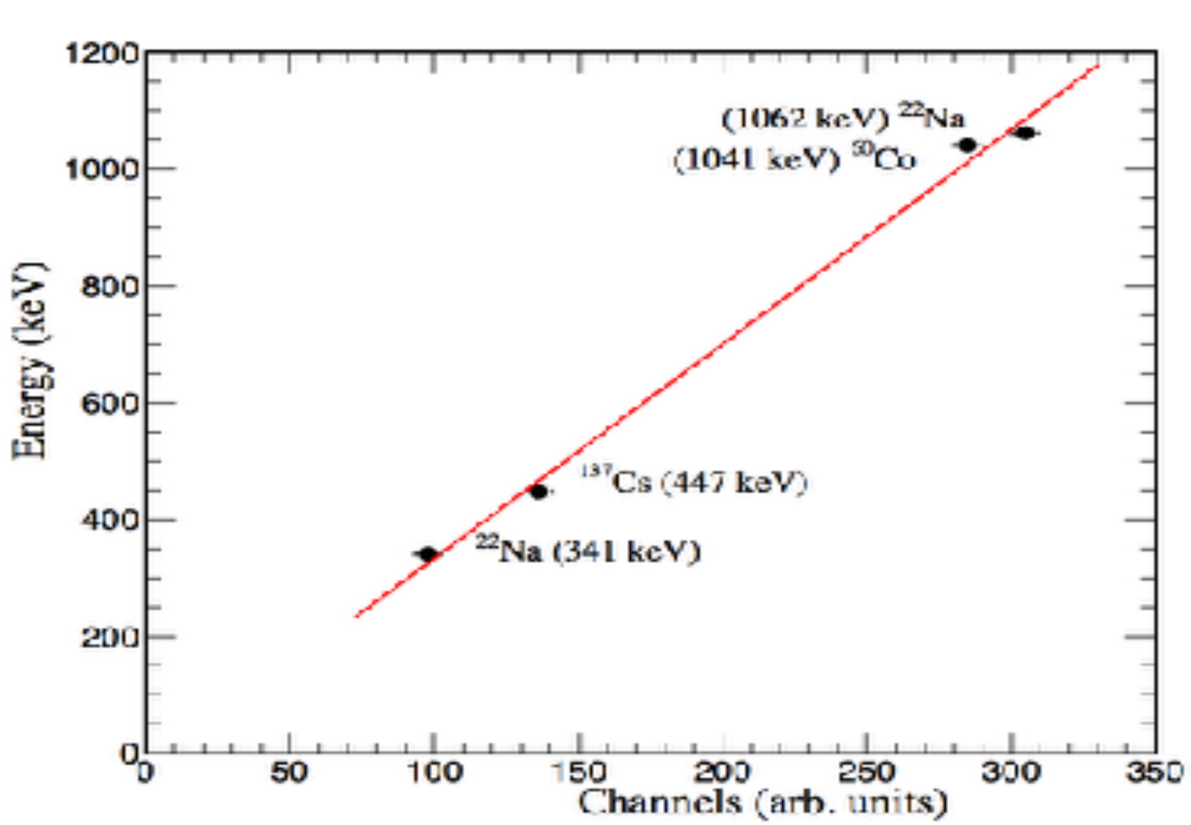

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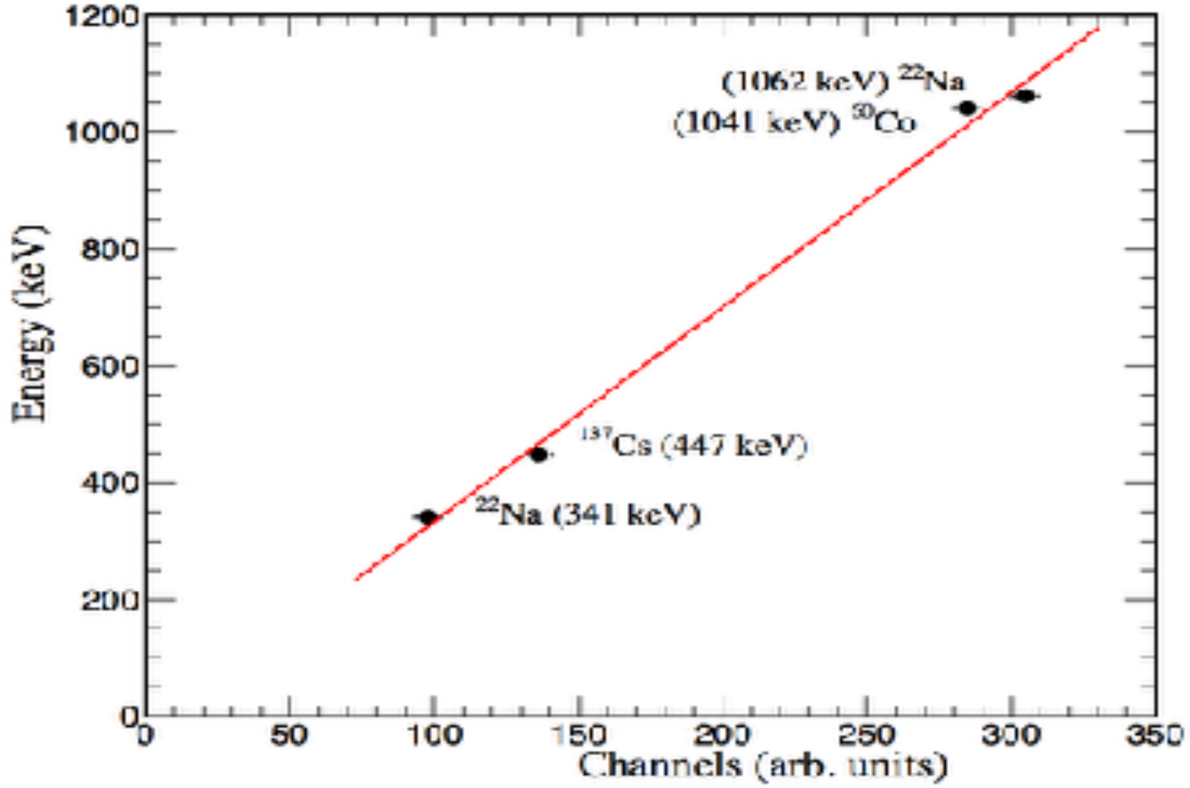

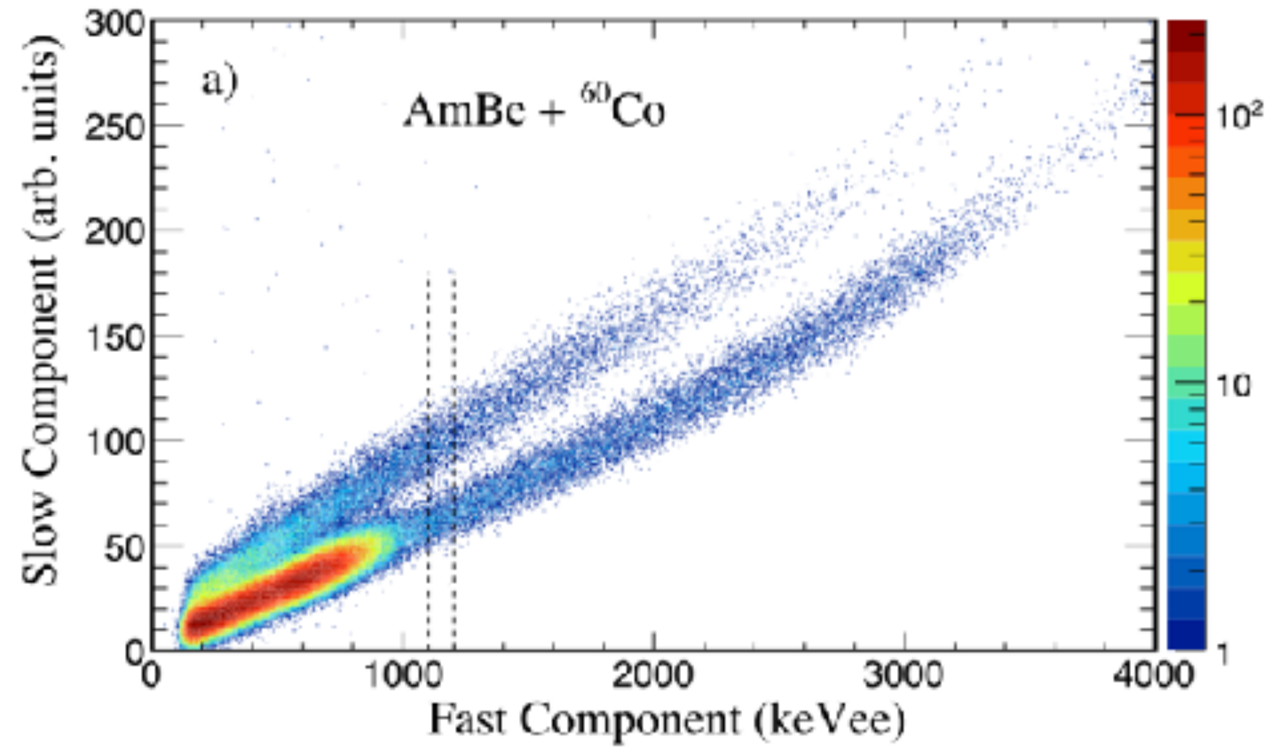

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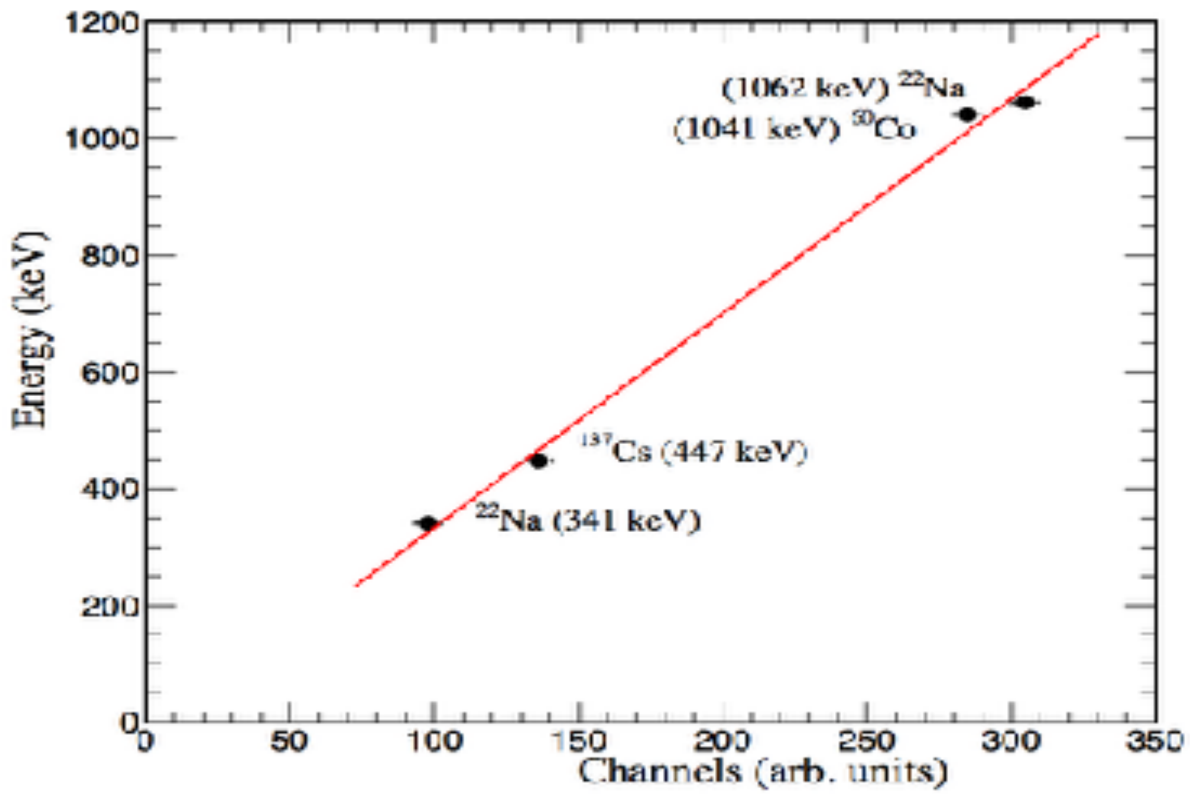

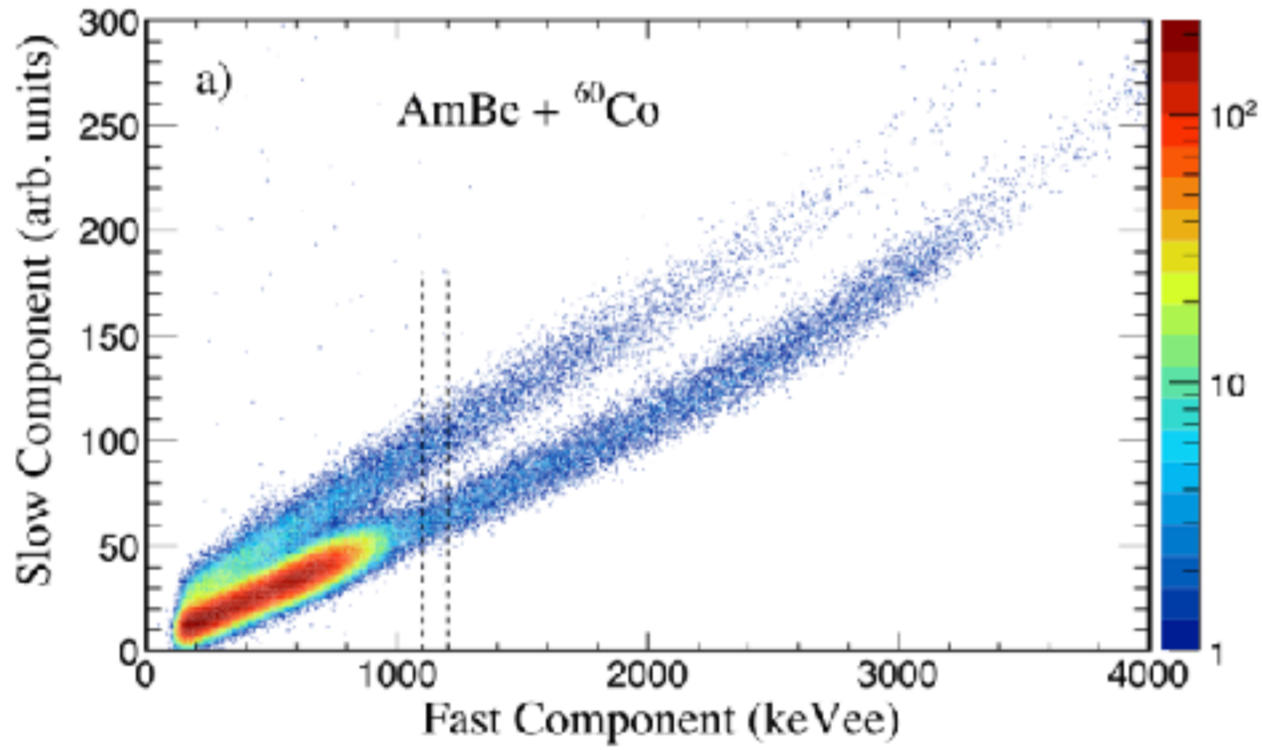

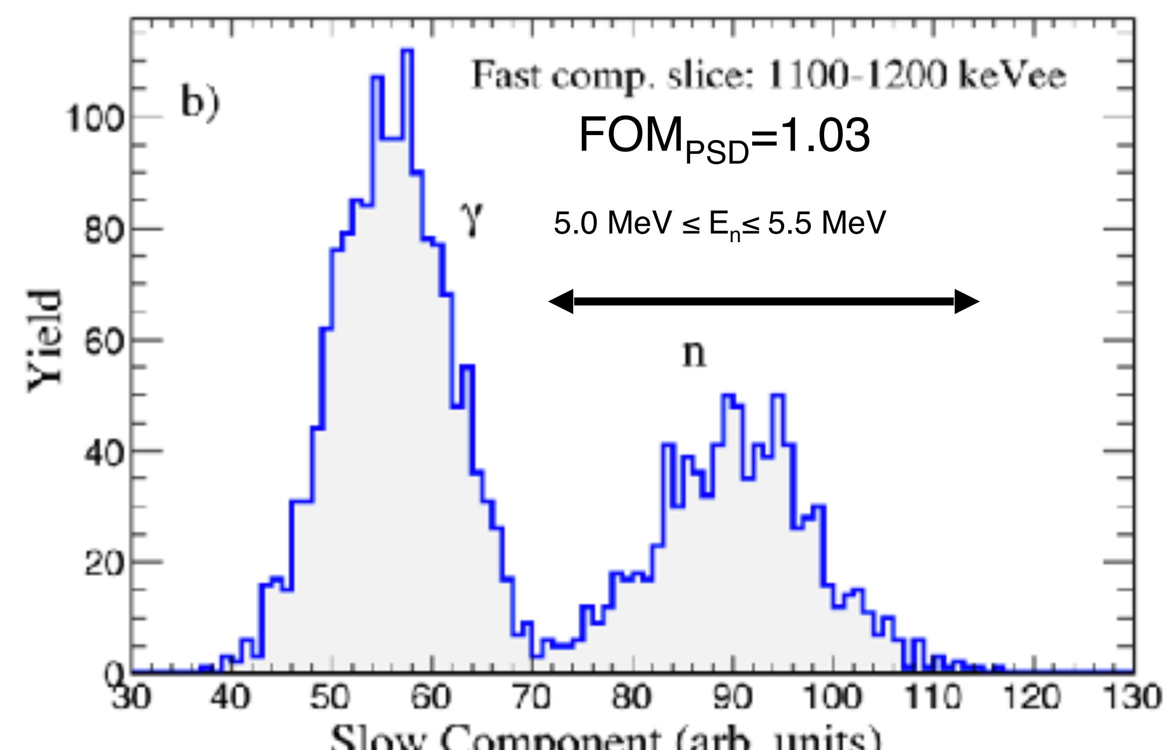

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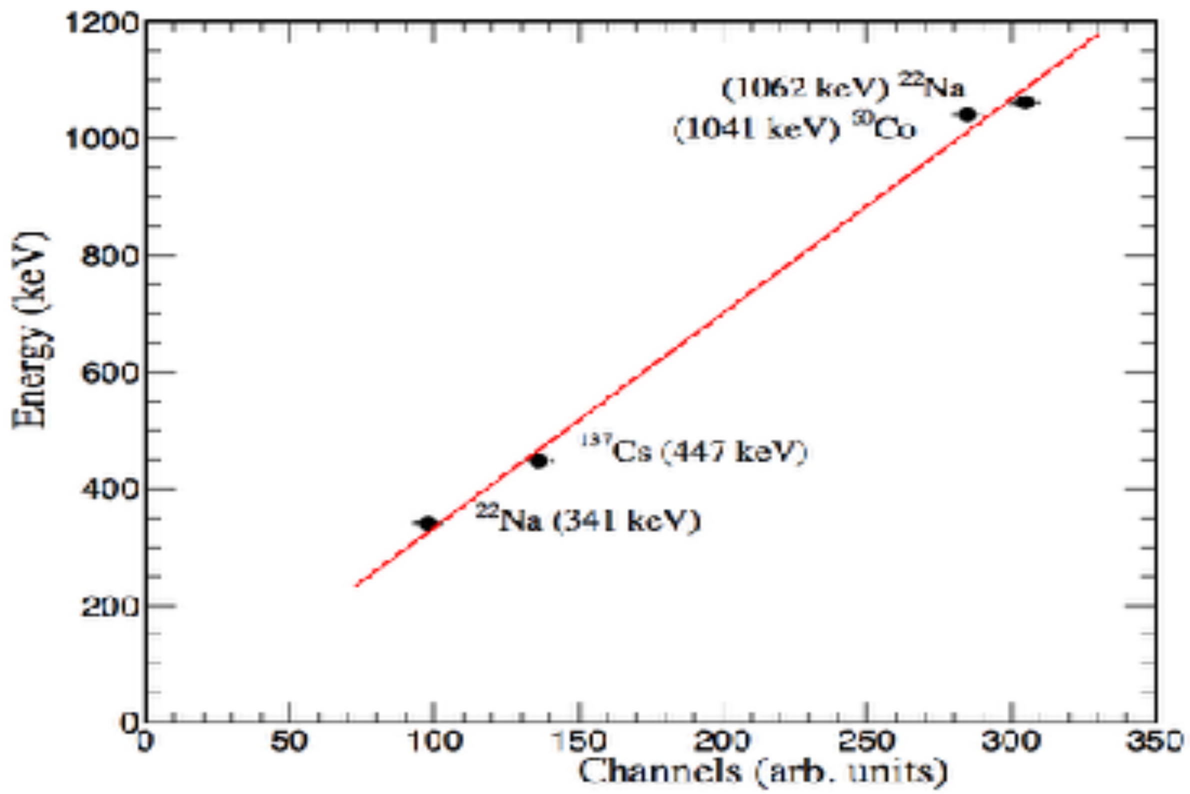

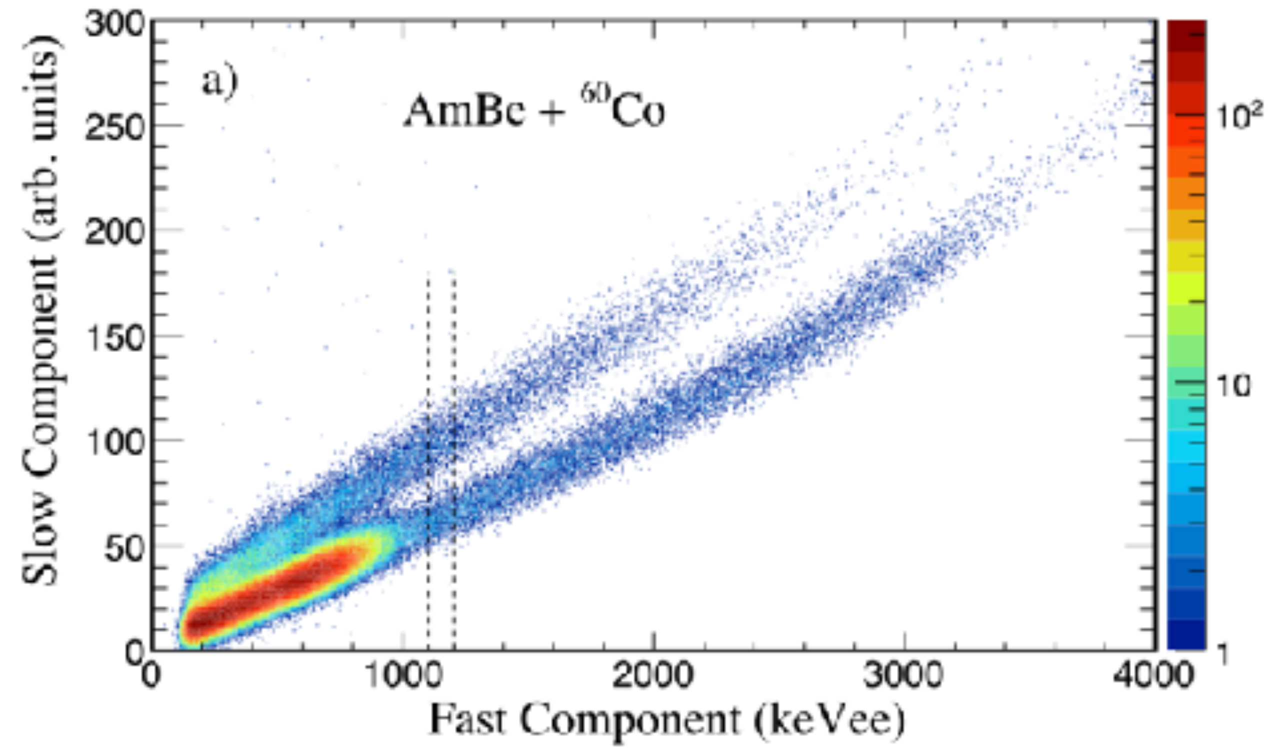

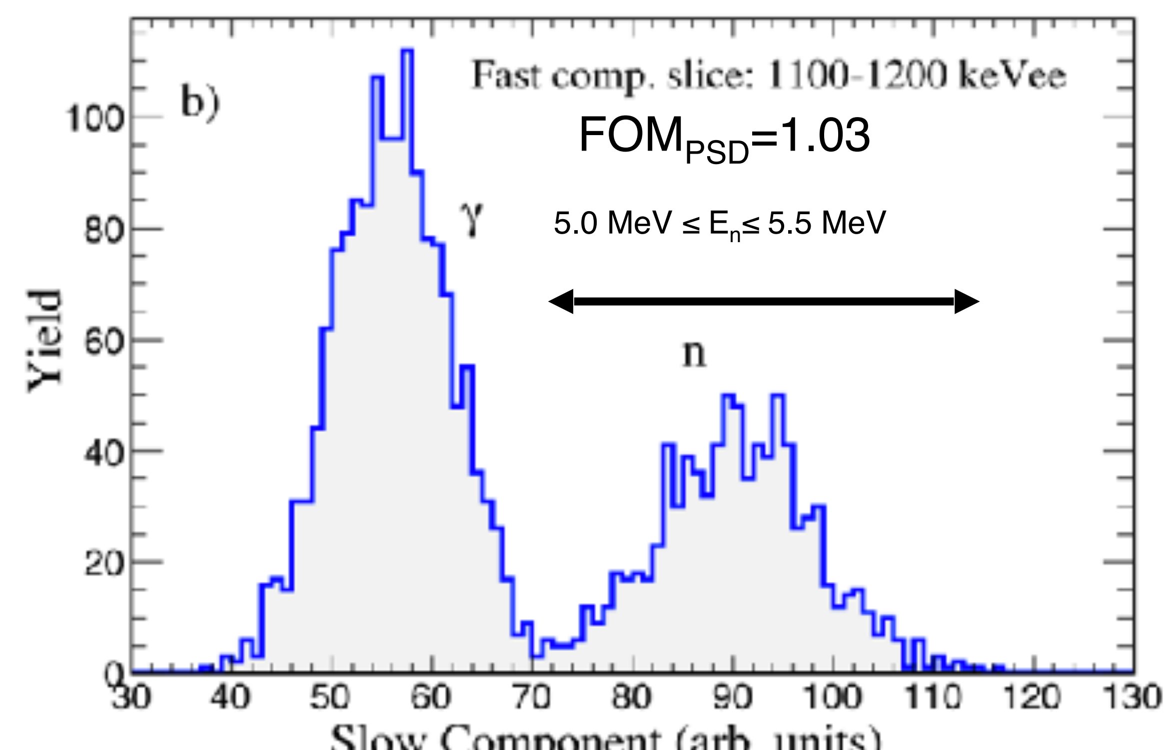

Detection threshold ≈ 0.7 MeV

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

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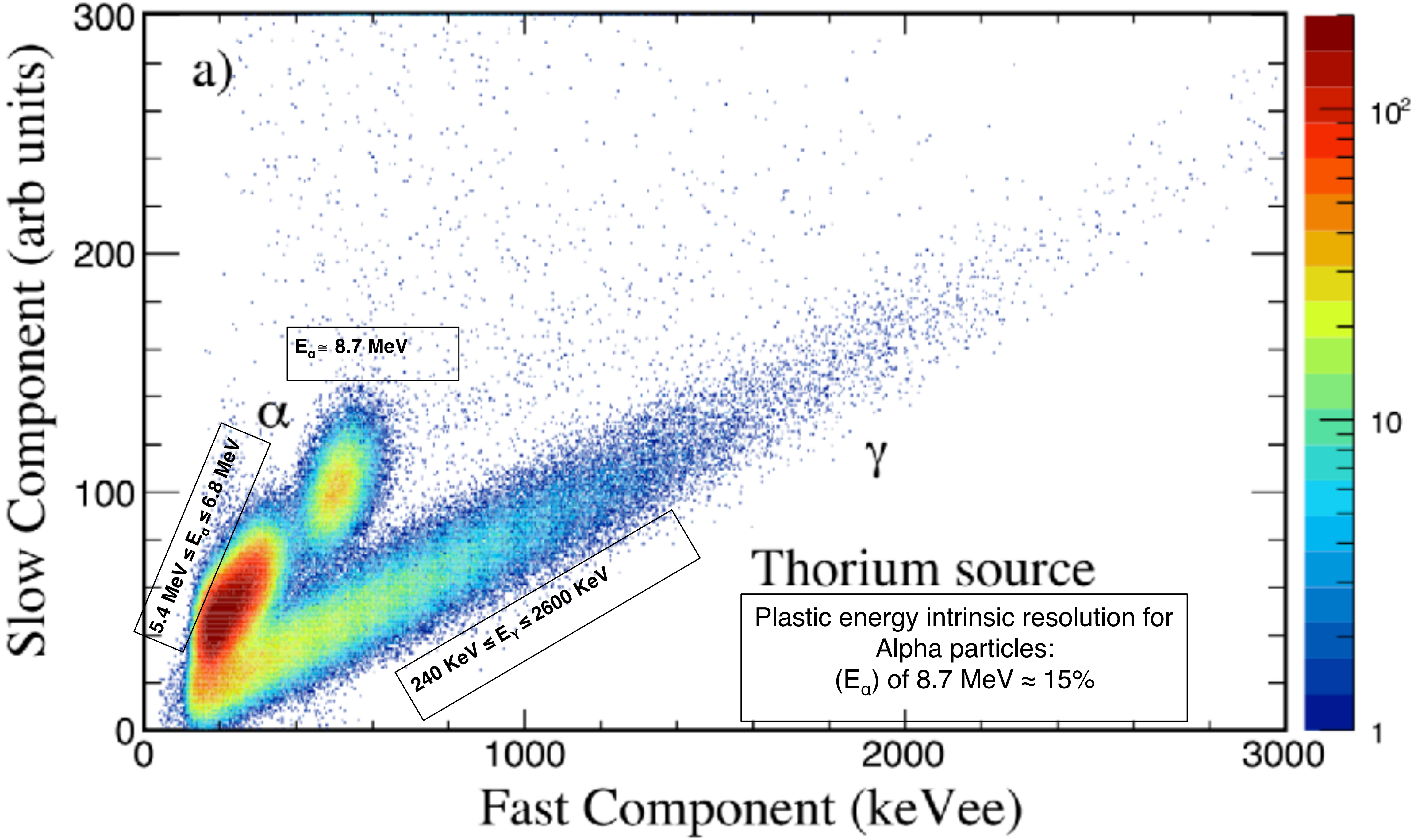
E. V. Pagano et al. NIM A 889 (2018) 83-88



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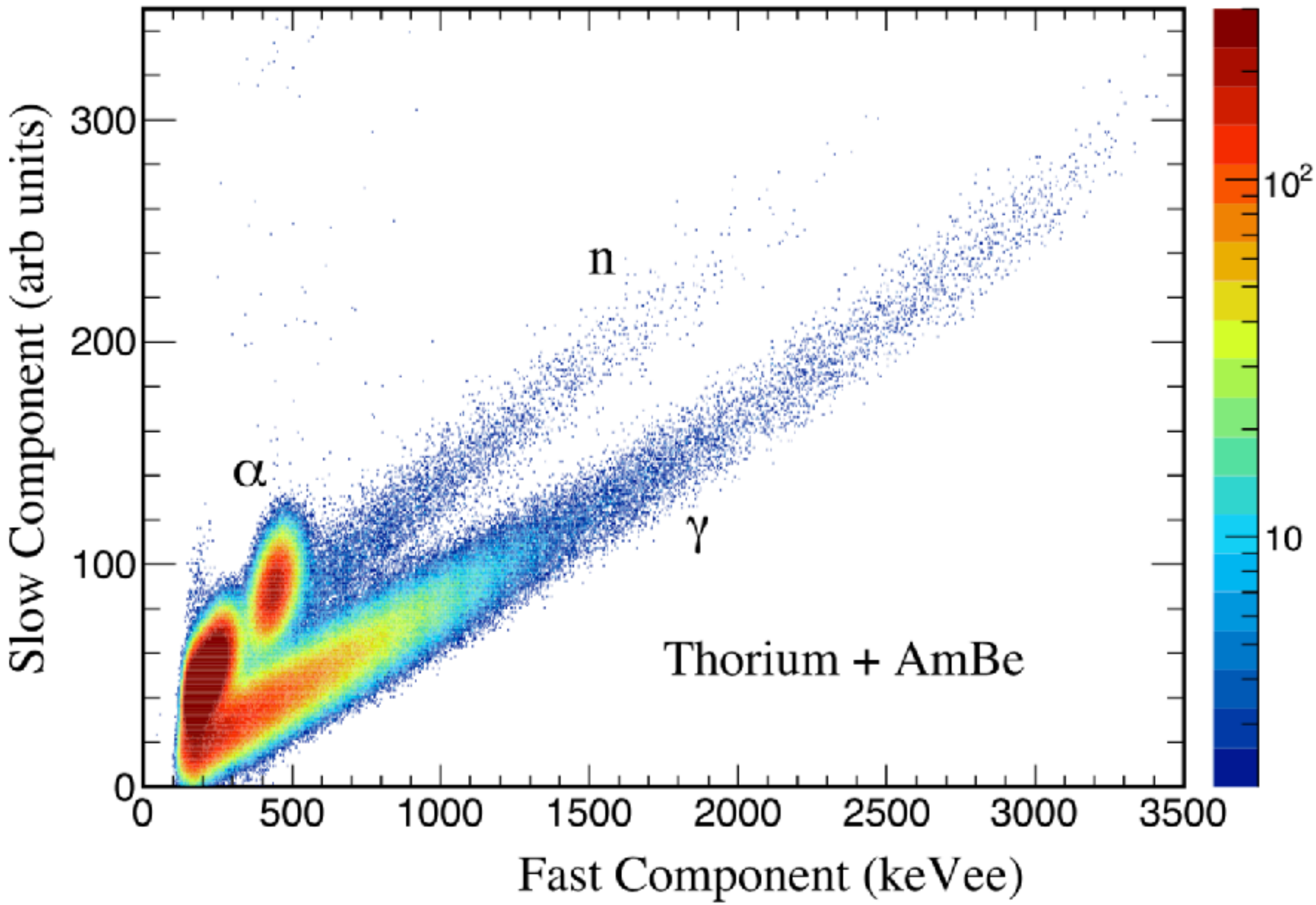
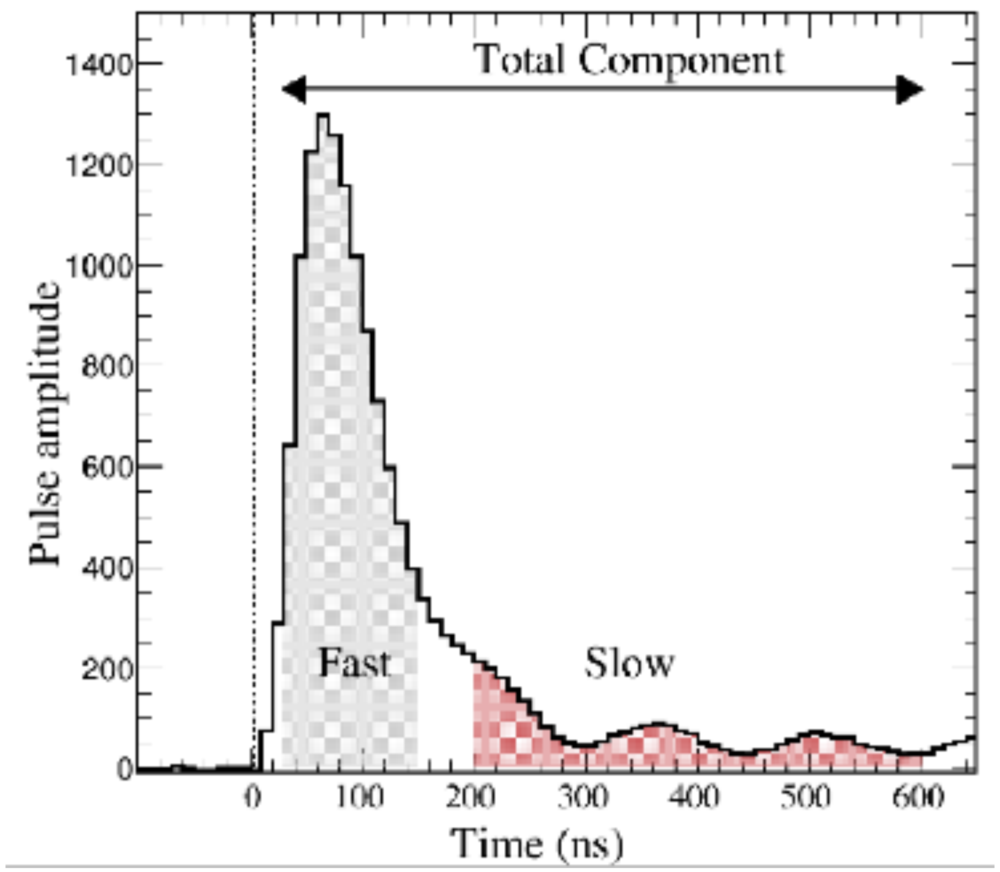


The latests resuls: tests in high background condition

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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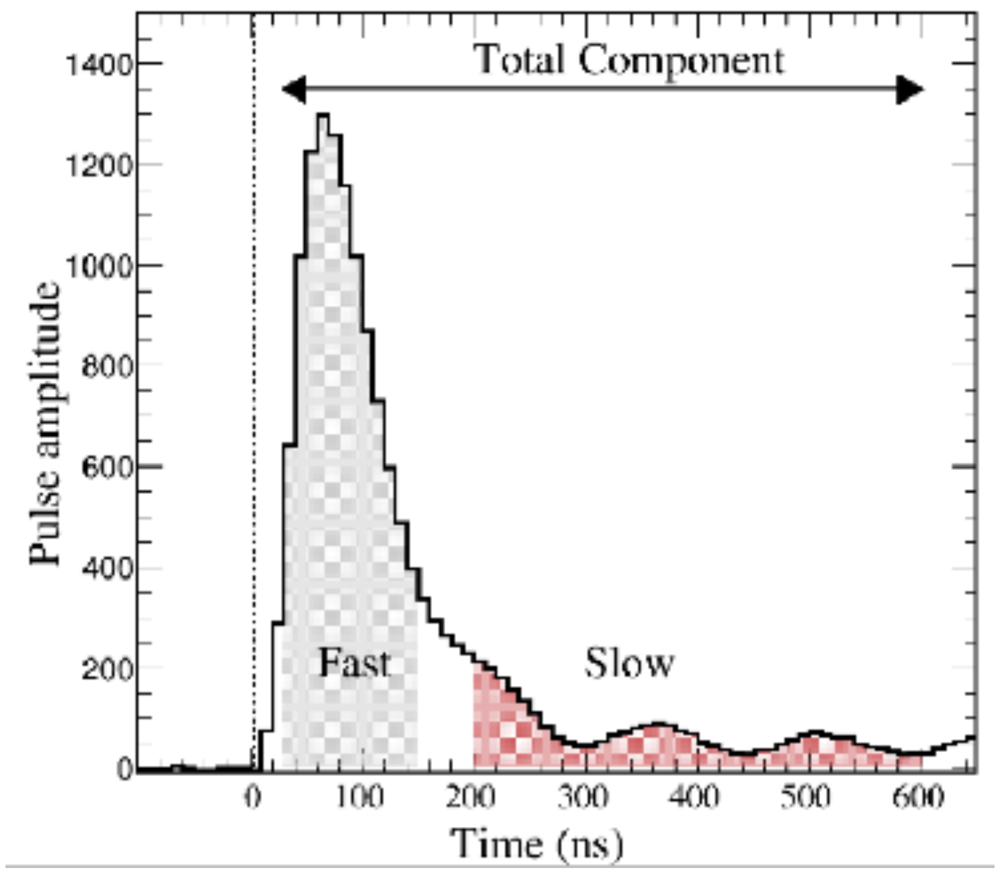

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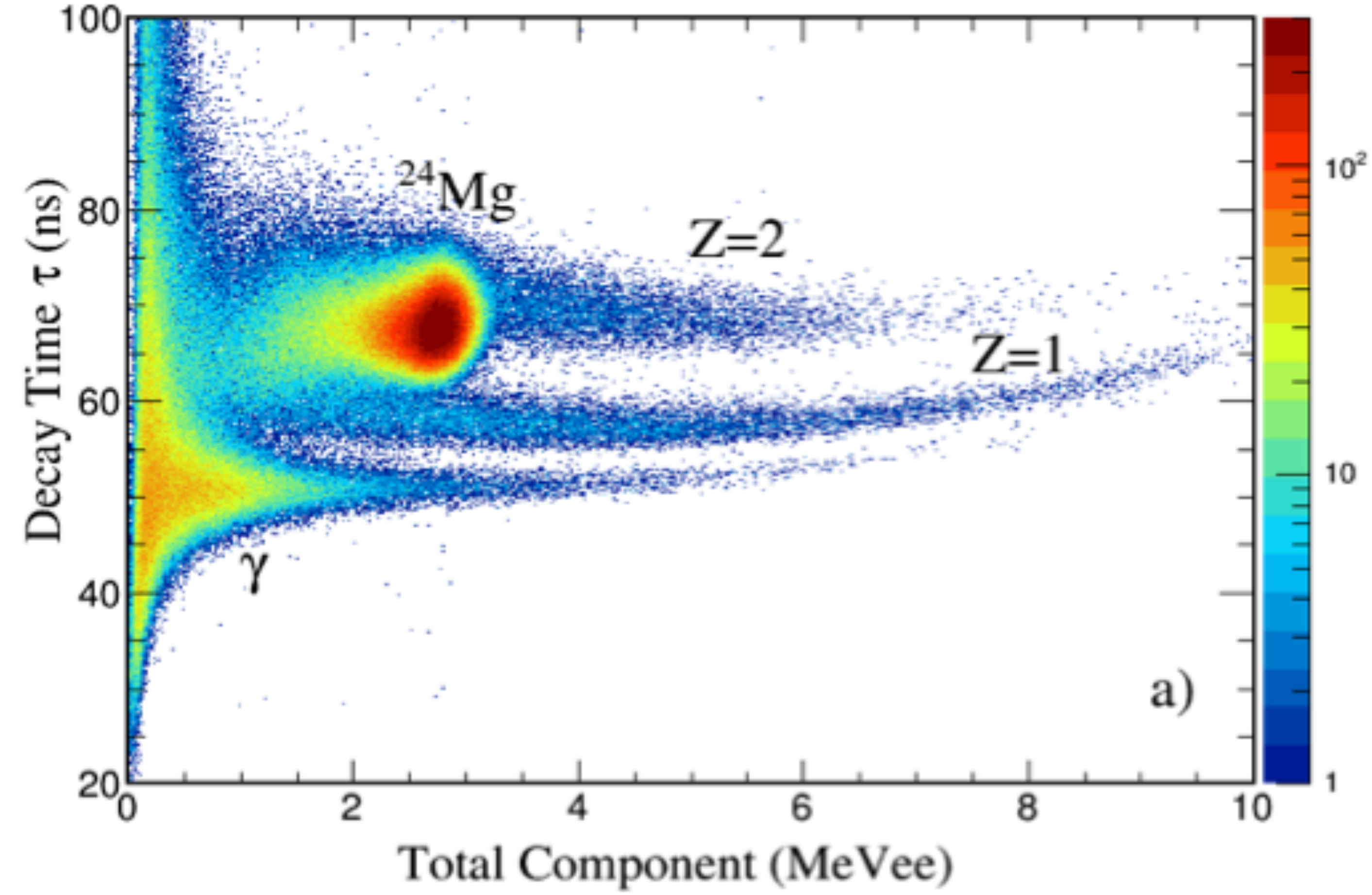

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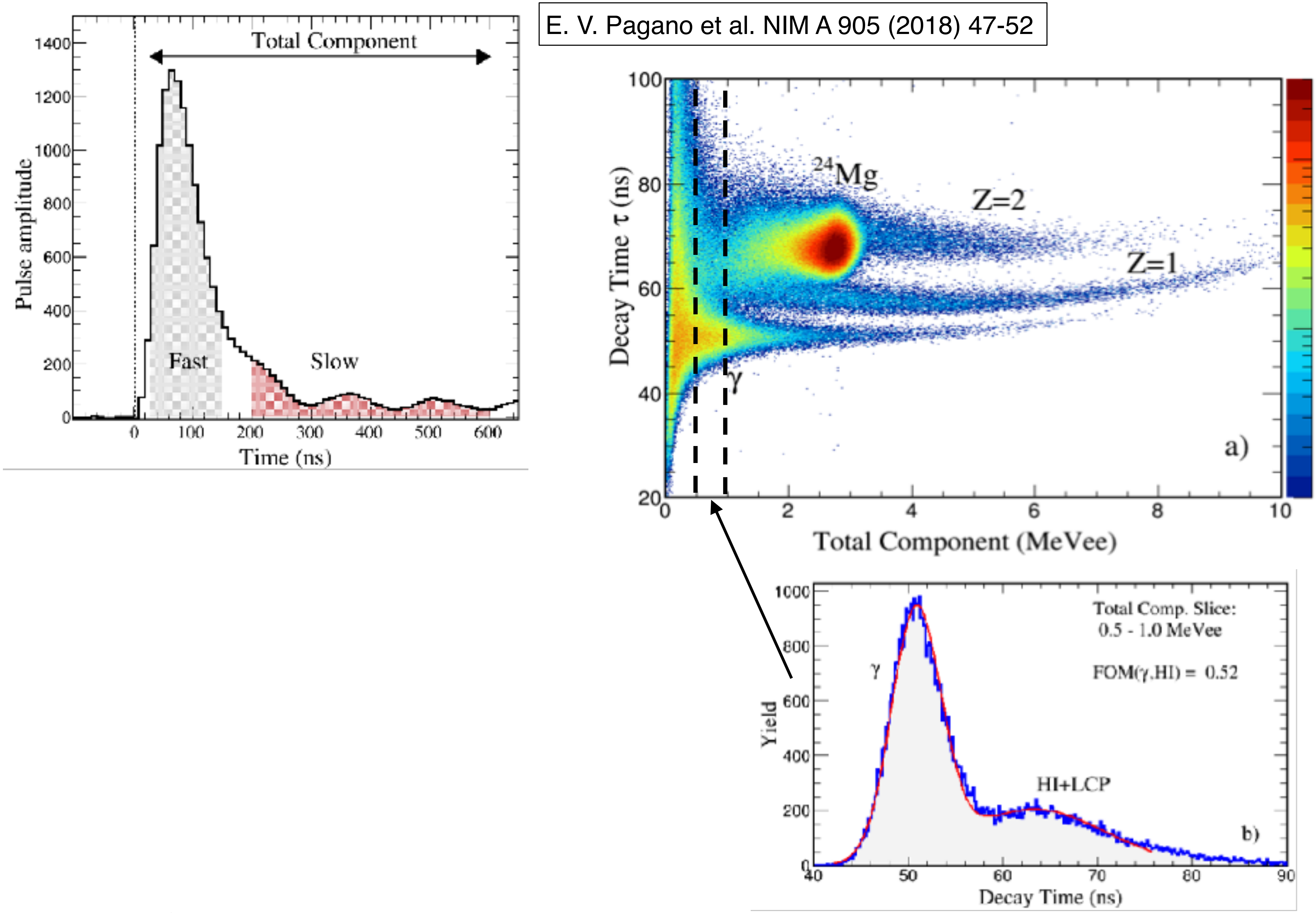

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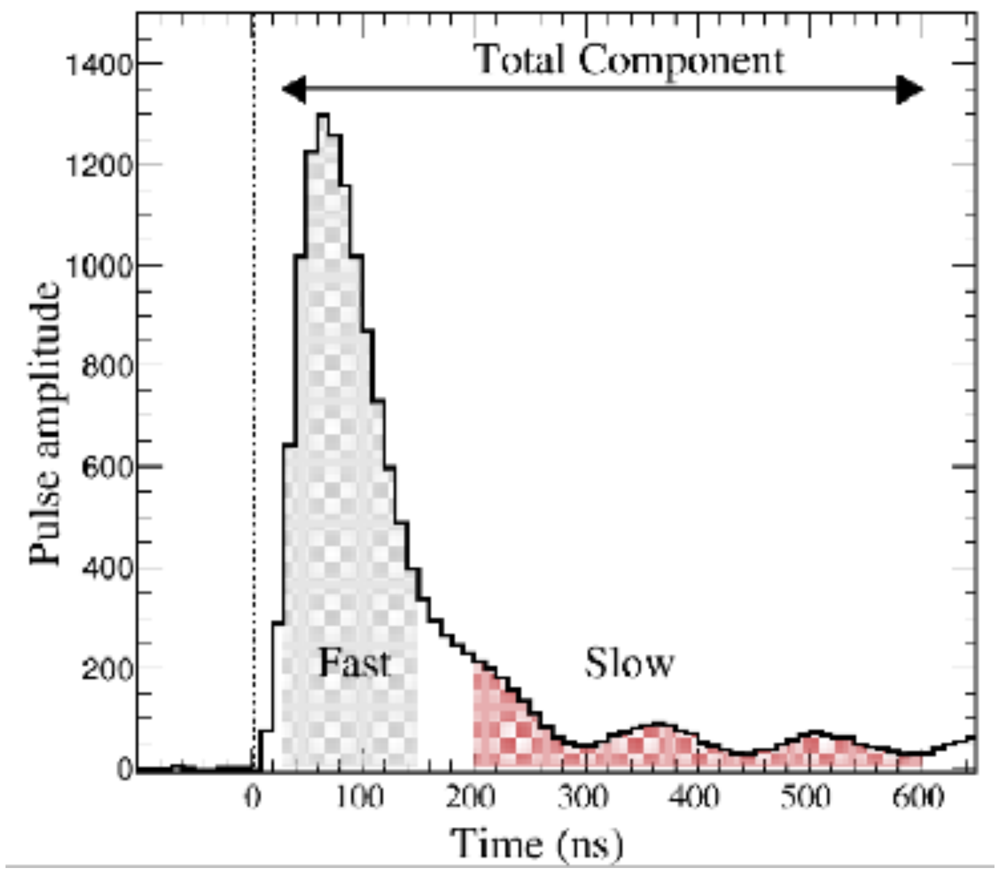

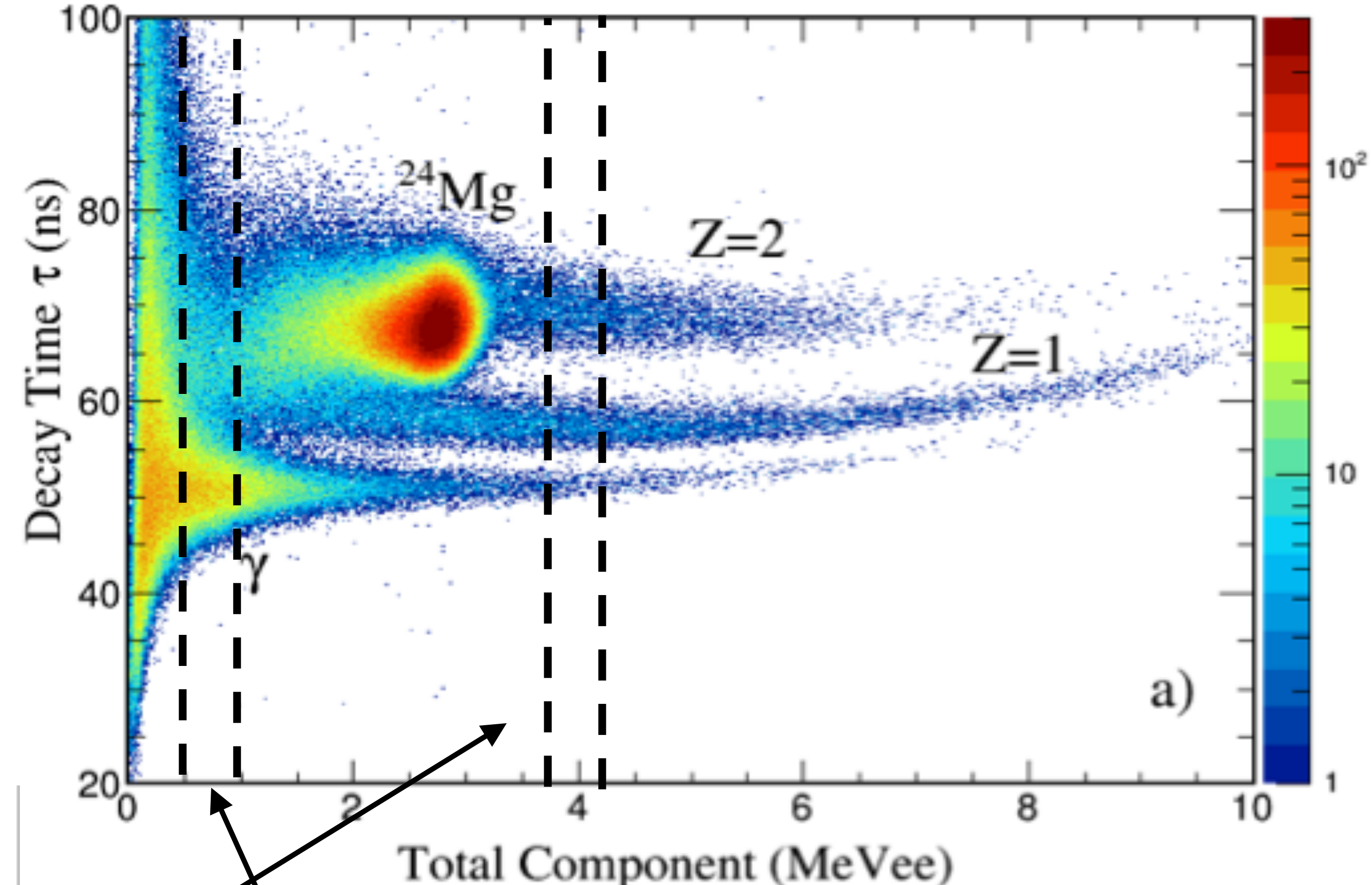

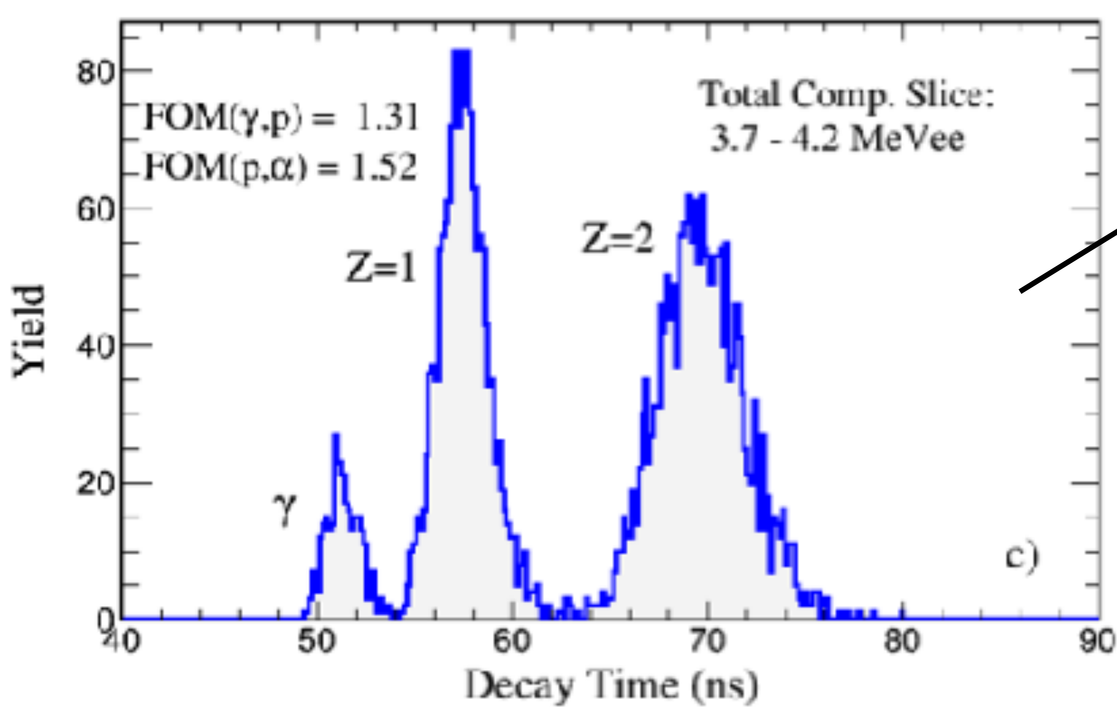

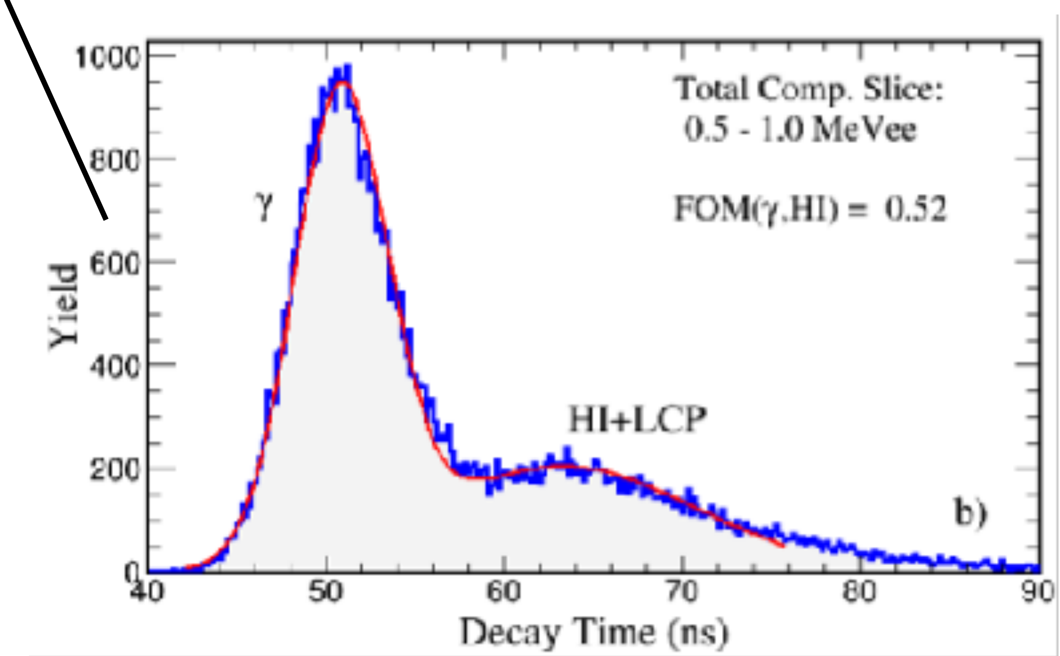

Purposes of the project

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)
- Homeland security

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

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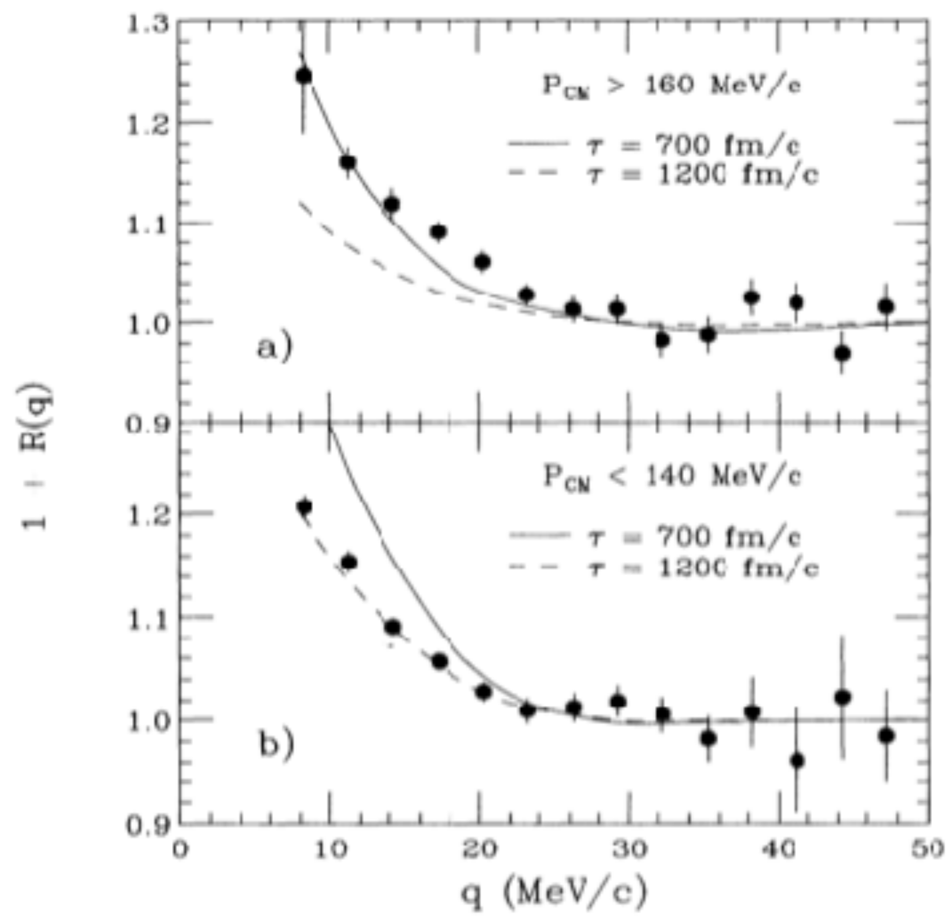

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FIG. 3. Angle-integrated correlation functions for two cuts on the total neutron pair momentum in the compound nucleus frame. The solid and dashed curves are results of theoretical calculations with the indicated emission time scales.

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

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

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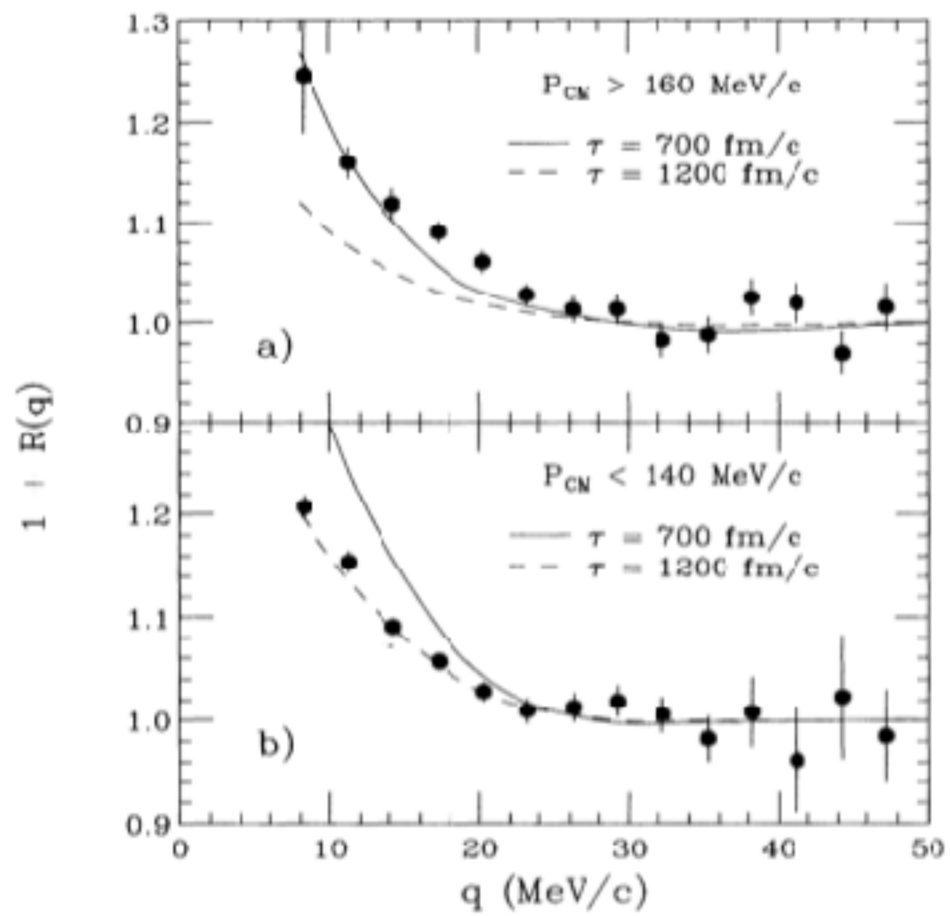

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R. Ghetti et al., PRL **87**, 10 (2001)

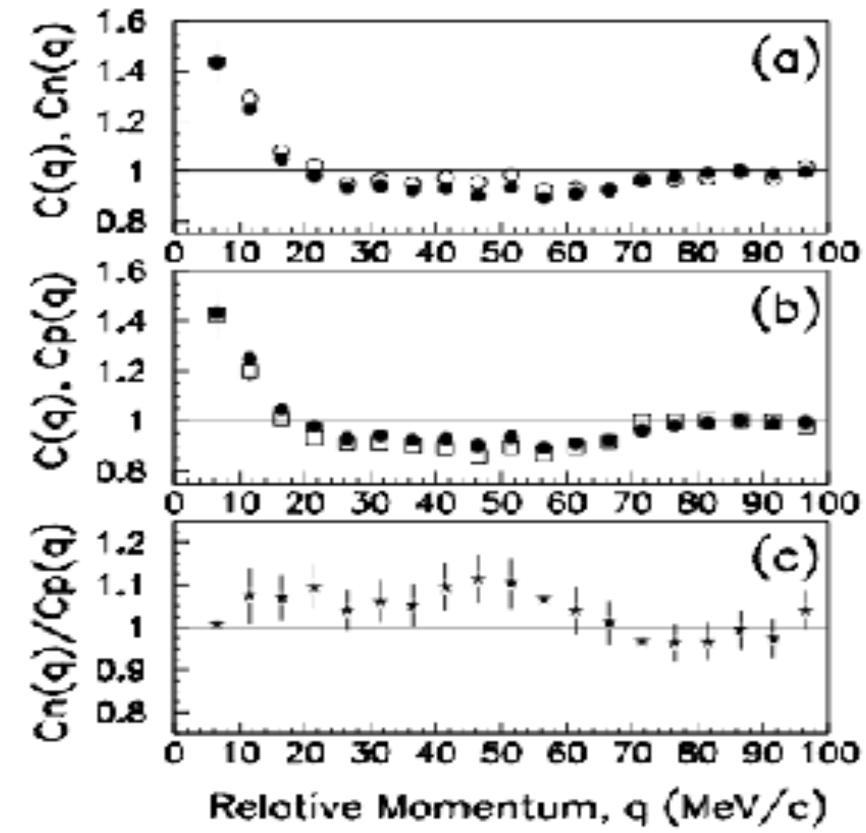

FIG. 2. Experimental ungated np correlation function $C(q)$, from the $E/A = 45$ MeV ^{58}Ni + ^{27}Al reaction [solid dots in panels (a),(b)] compared to panel (a), open circles: $C_n(q)$, constructed from pairs of type $E_n > E_p$, and panel (b), open squares: $C_p(q)$, constructed from pairs of type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

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

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

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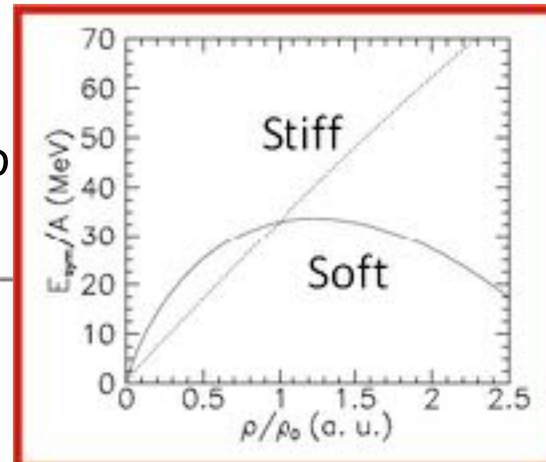
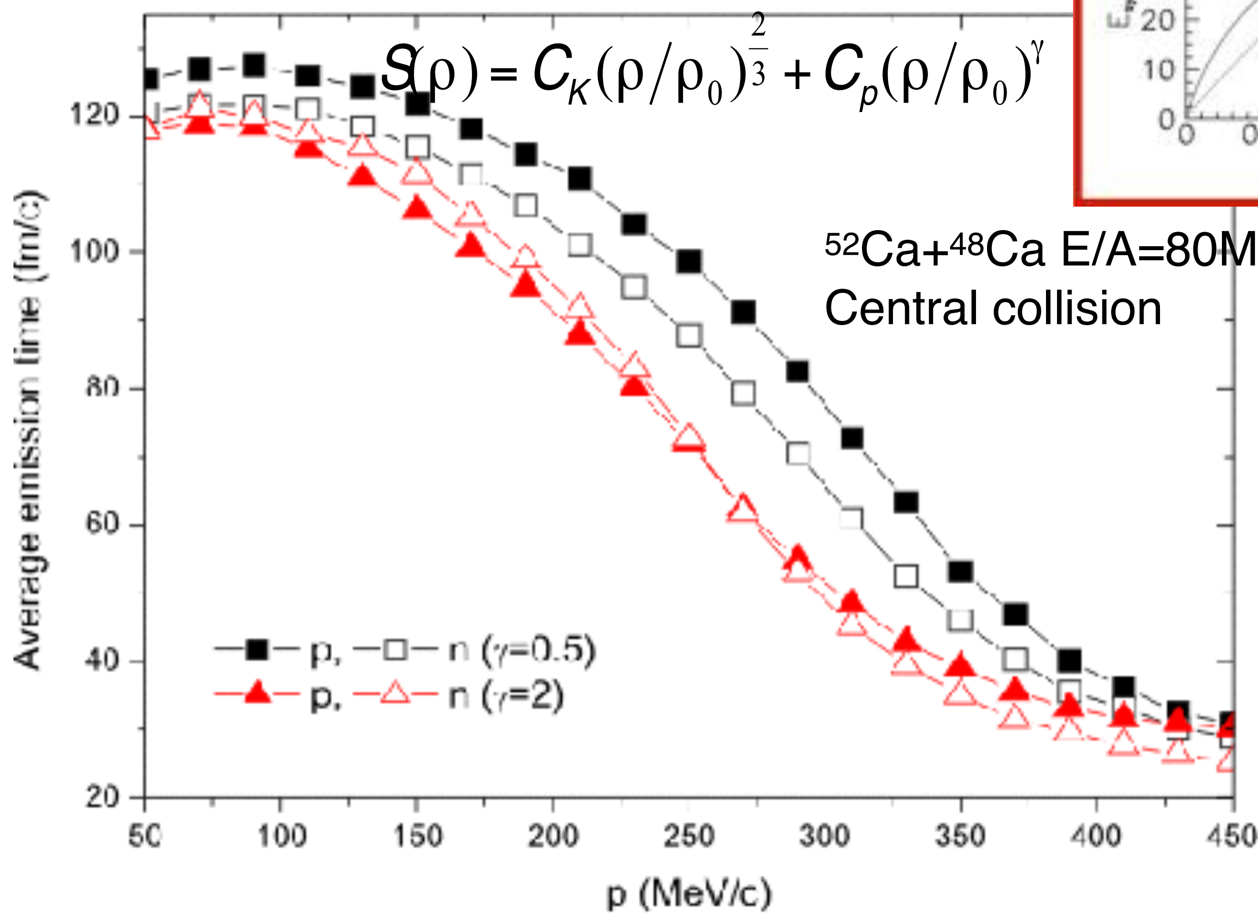
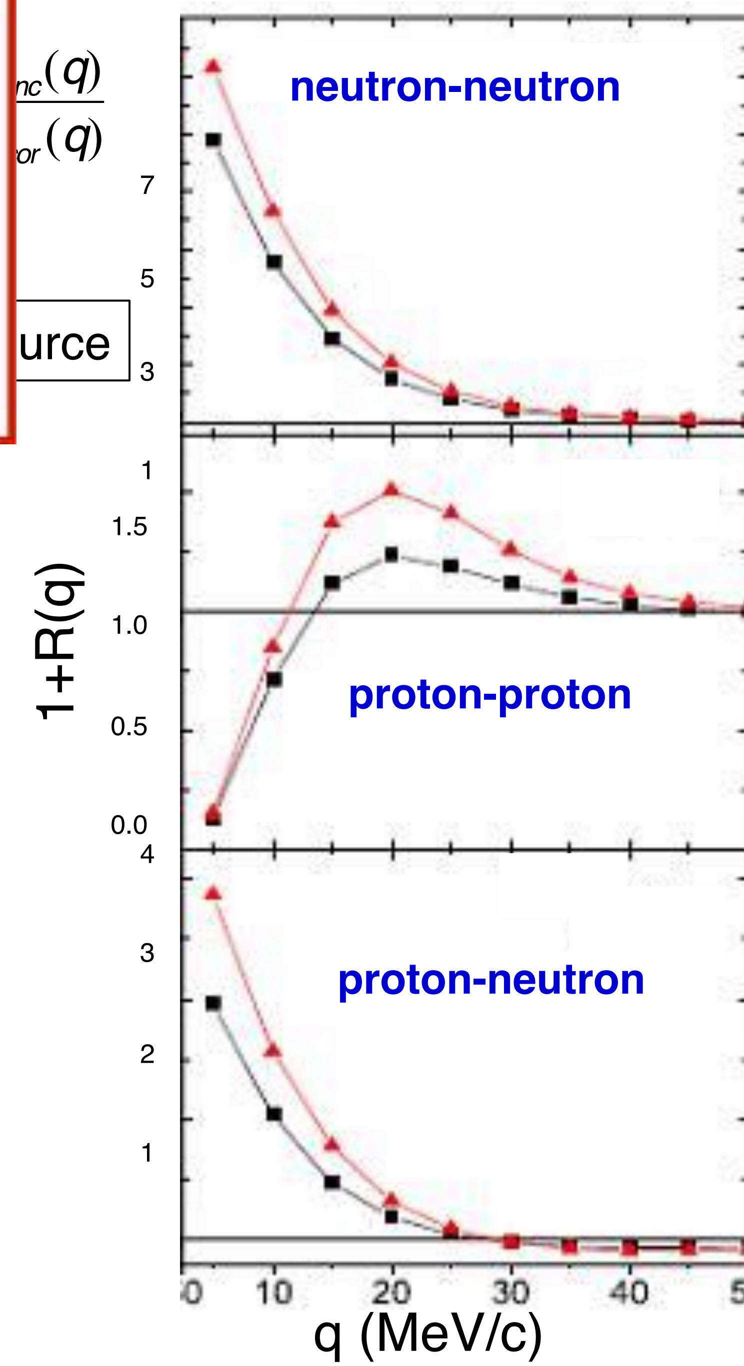


$$S(\rho) = C_K(\rho/\rho_0)^{\frac{2}{3}} + C_p(\rho/\rho_0)^{\gamma}$$

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



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



Purposes of the project: a few example applications

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

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Neutron Camera

Possible device for homeland security and health safety to be installed in airports, ports, etc...

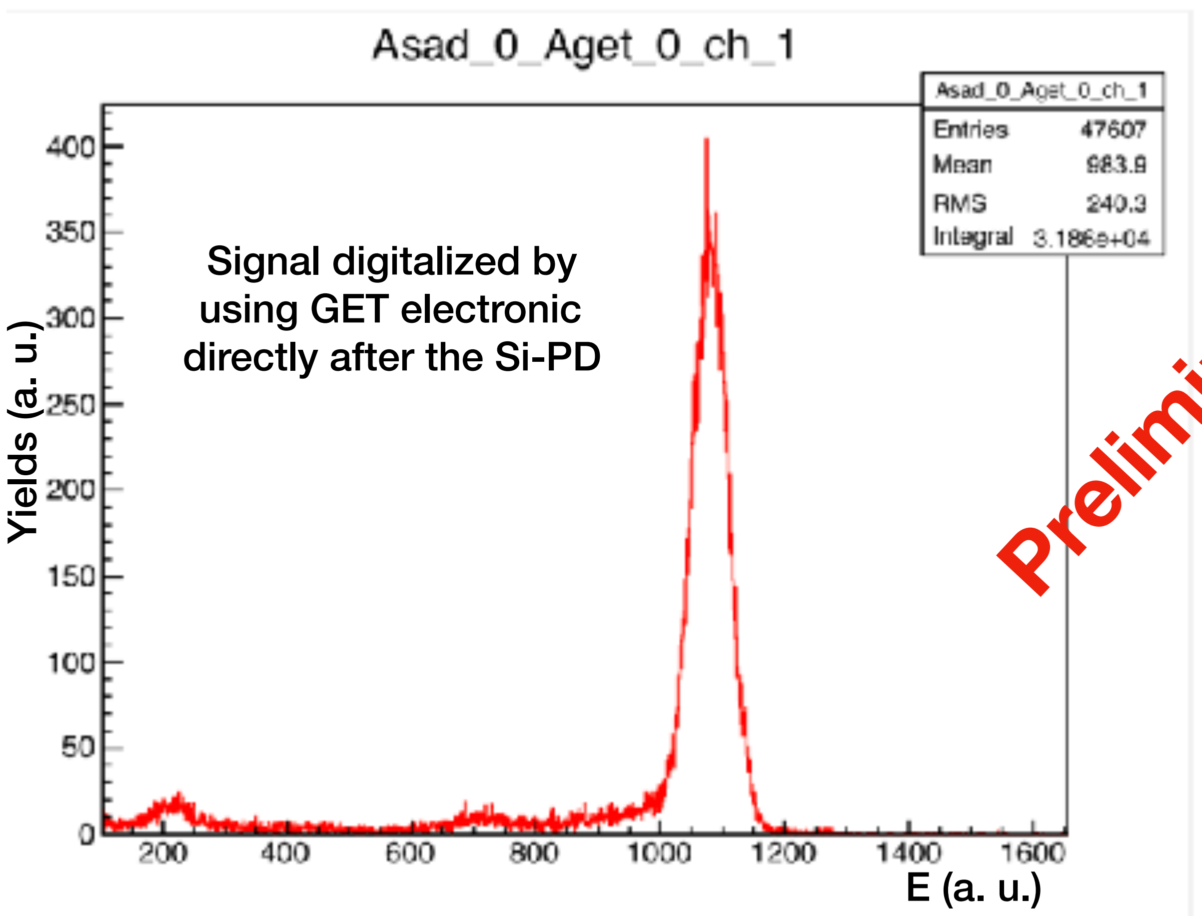
Conclusions and perspective

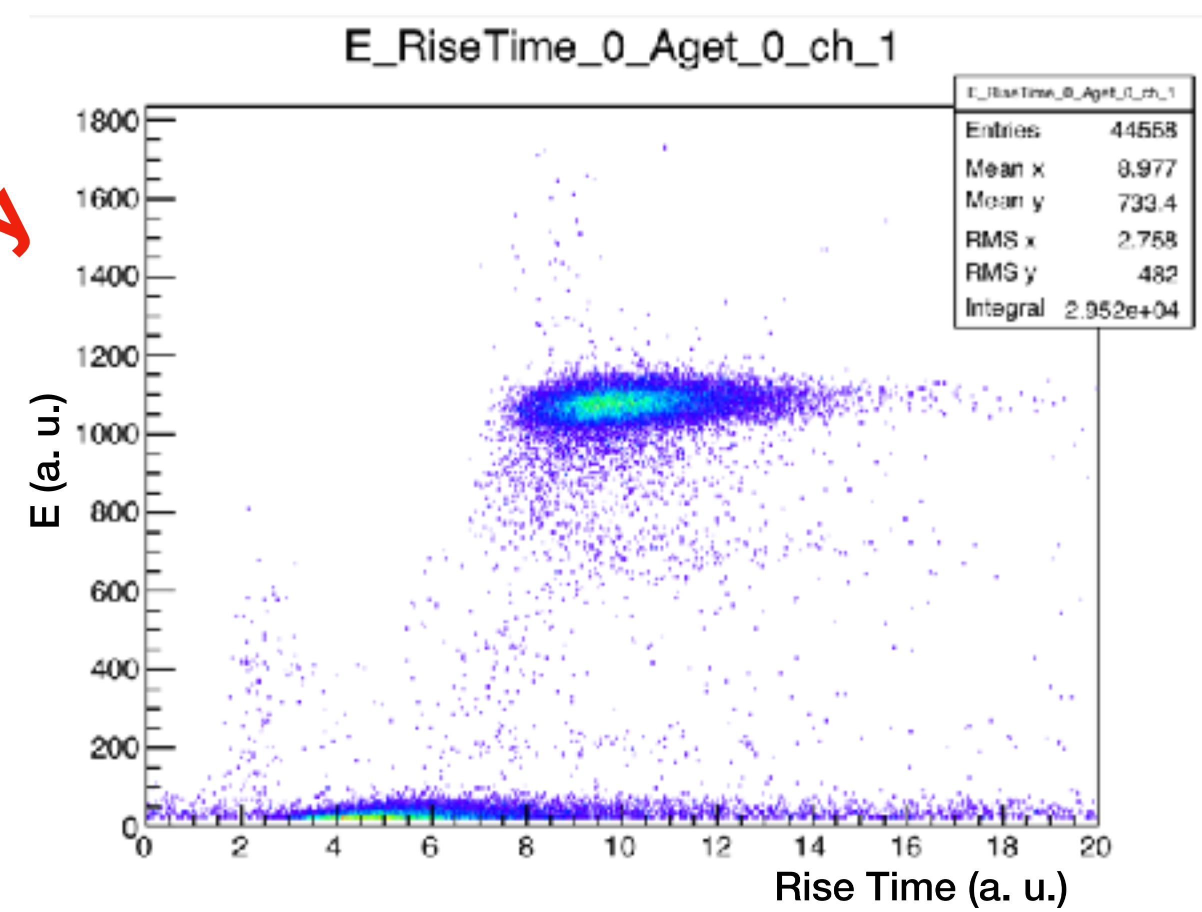
The results carried out so far are with EJ276 coupled by PM are encouraging. It seems possible to build a versatile and modular detector for neutrons and light charged particles with high angular and energy resolution, read by using silicon technology and signal digitalization. The studies of the background and of the cross-talk problems and theirs influence on the experimental results are going on using the GEANT4 software.

The studies on the timing properties of the EJ-276 green version and its PSD capability, performed by using silicon technology(PD, or SIMP) are going on.

FIRST RESULT ON EJ276 green coupled with PD *

Preliminary results during Hoyle exp. @ LNS July 2019.
α + Au total energy beam 64 MeV





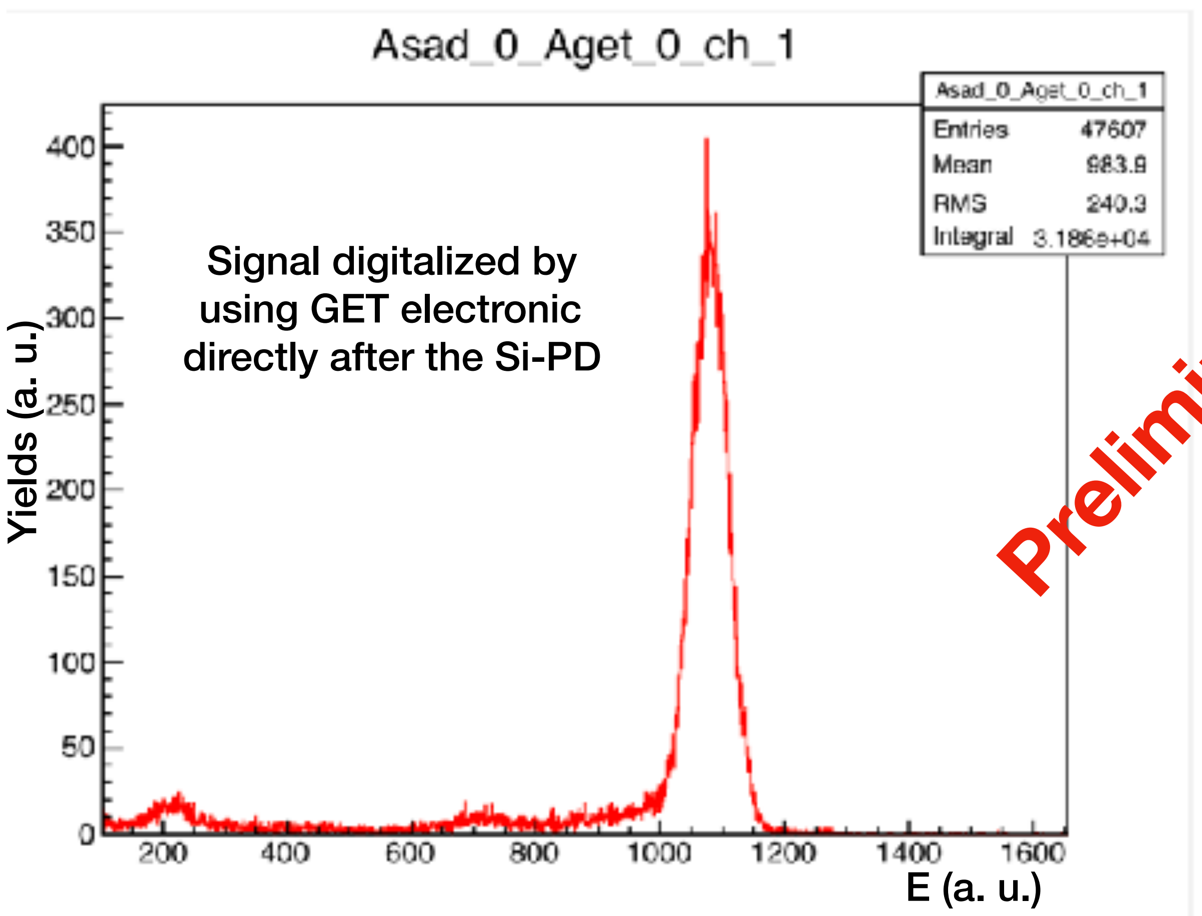
* Hamamatsu PIN photodiode 28X28 mm^2 (S3584 series)

Conclusions and perspective

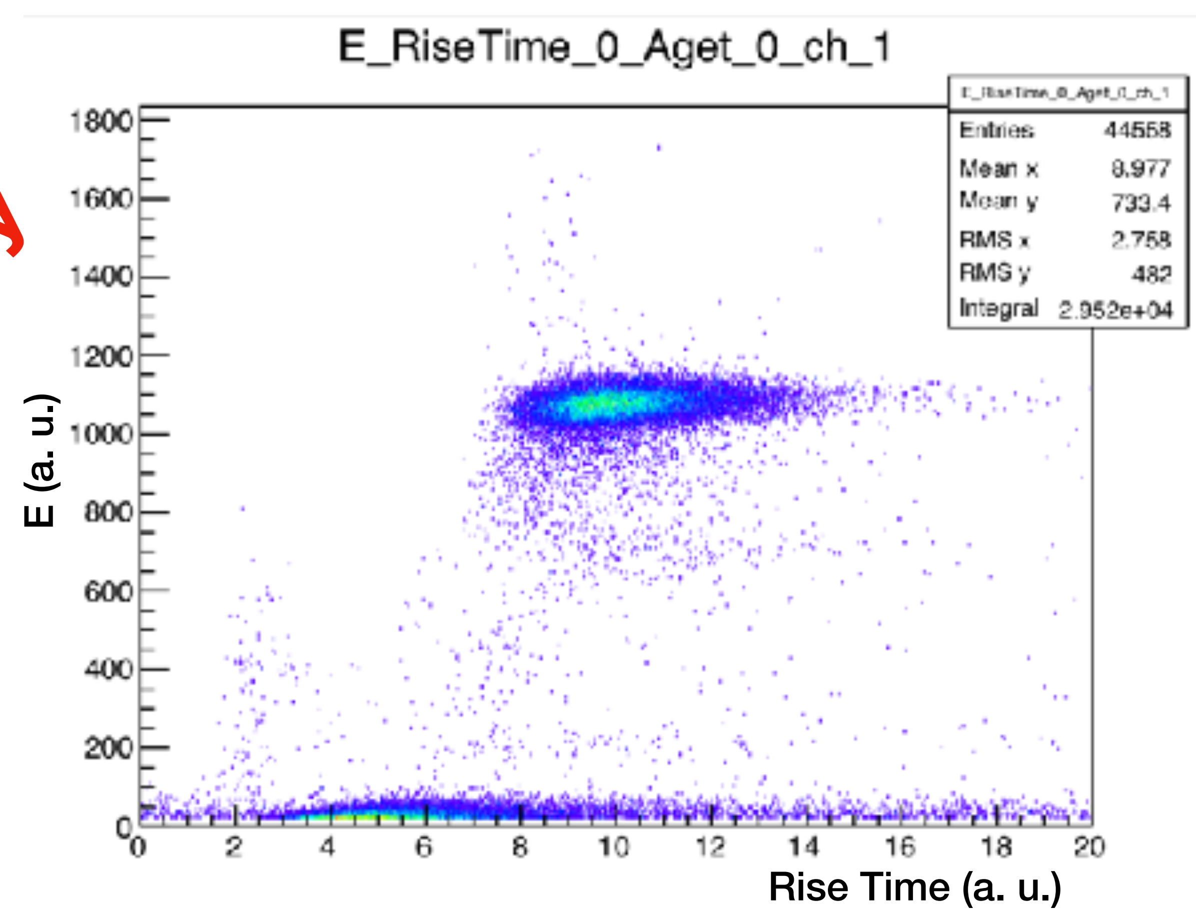
The results carried out so far are with EJ276 coupled by PM are encouraging. It seems possible to build a versatile and modular detector for neutrons and light charged particles with high angular and energy resolution, read by using silicon technology and signal digitalization. The studies of the background and of the cross-talk problems and theirs influence on the experimental results are going on using the GEANT4 software.

The studies on the timing properties of the EJ-276 green version and its PSD capability, performed by using silicon technology(PD, or SIMP) are going on.

FIRST RESULT ON EJ276 green coupled with PD *



Preliminary results during Hoyle exp. @ LNS July 2019.
α + Au total energy beam 64 MeV



* Hamamatsu PIN photodiode 28X28 mm^2 (S3584 series)

Thank you for the attention