Search for Scissor resonance in ^{182}Ta

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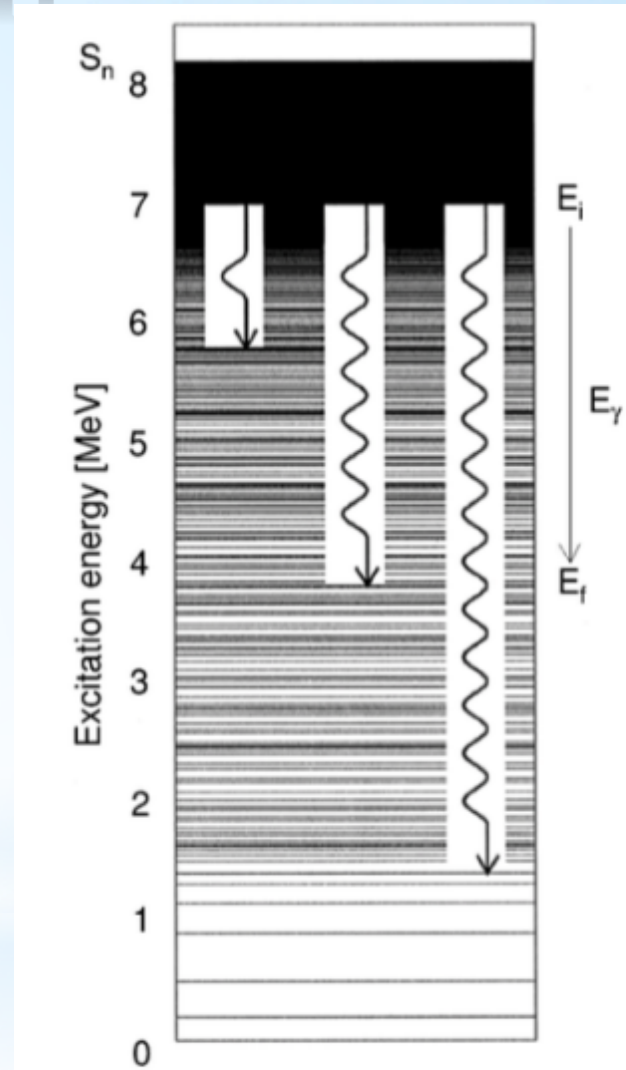
Christiaan Brits
iThemba LABS
University of Stellenbosch

NRF National Research Foundation
iThemba LABS Laboratory for Accelerator Based Sciences

Introduction

* The photon strength function (PSF) characterizes the average electromagnetic properties of excited nuclei. It is related to radiative decay and photo-absorption processes.
* The PSF is one of the critical input parameters for calculating reaction cross sections.
* The PSF is relevant to the design of future and existing nuclear power reactors, where simulations depend on the evaluated data of the many nuclear reactions involved.

[M.B. Chadwick et al., Nucl. Data Sheets 112, 2887 (2011).]

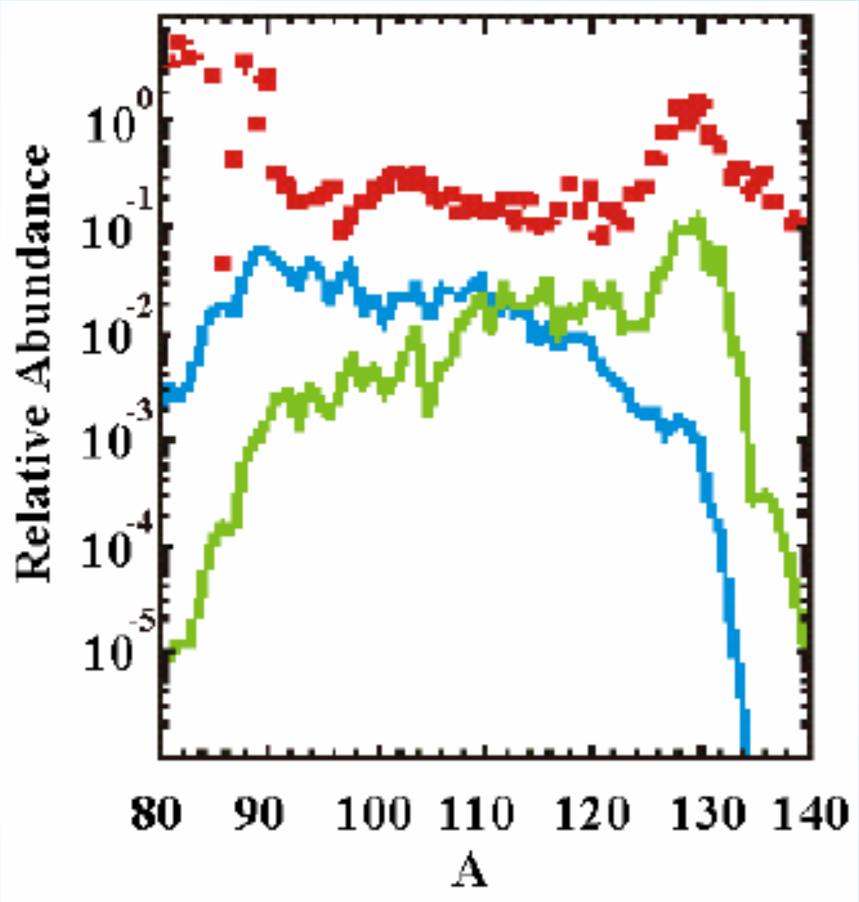


[A. Schiller et al., Nucl. Instrum. Methods Phys. Res. A 447, 498 (2000).]

Introduction

* The PSF also plays a central role in elemental formation during stellar nucleosynthesis
* Calculations have shown that relatively small changes to the overall shape of the PSF such as pygmy resonances can have an order of magnitude effect on the rate of elemental formation.

[M. Thoenessen from S. Goriely, Phys. Lett. B 436, 10 (1998).]

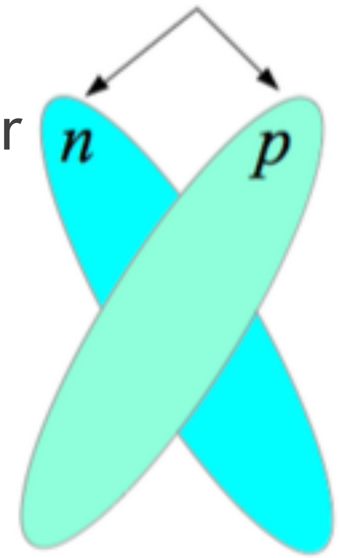


Observed relative abundance rates (Red)
Theoretical model without pygmy (Blue)
Theoretical model with pygmy (Green)

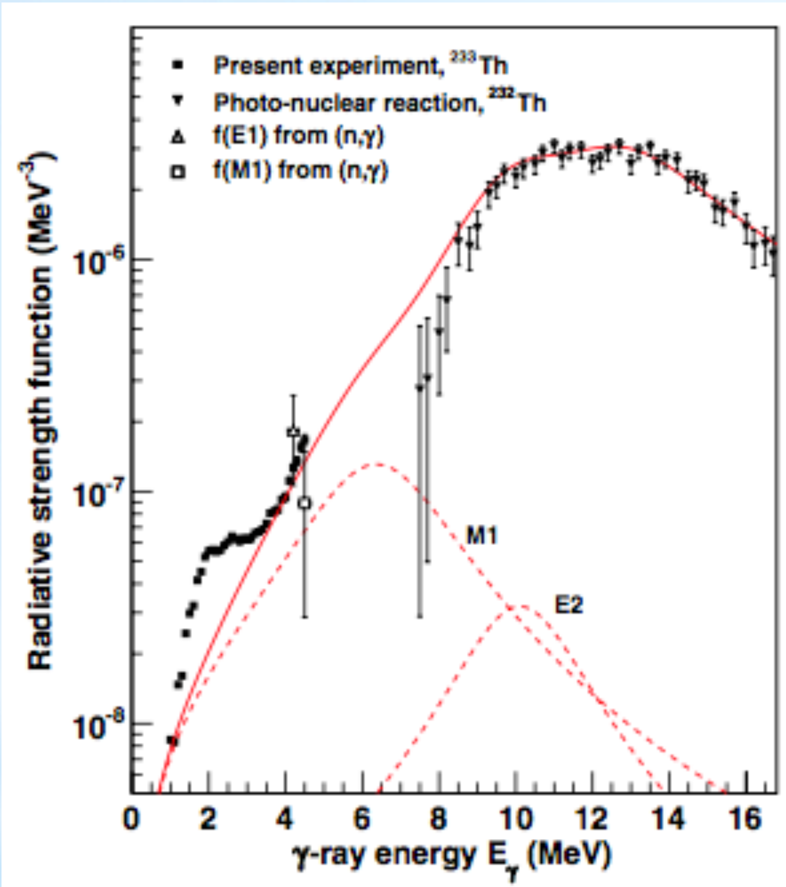
Scissor resonance

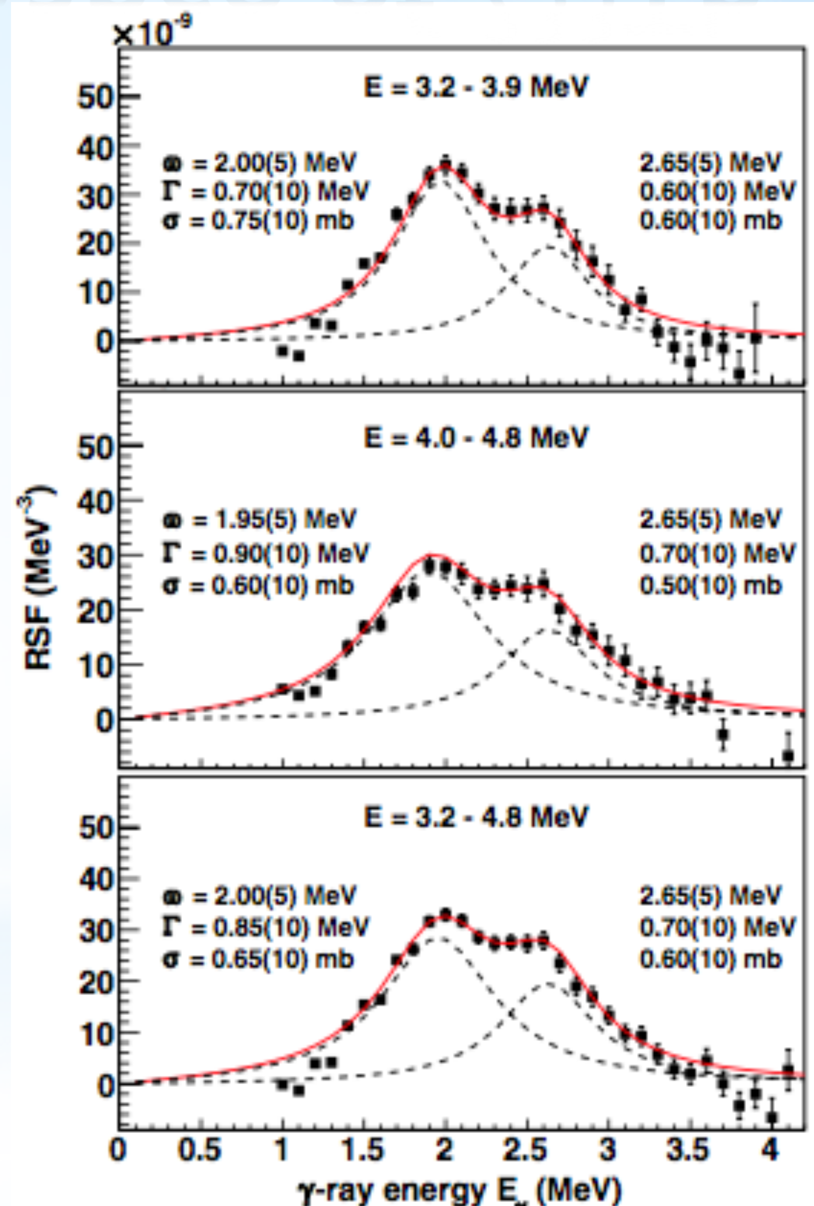
* The scissor resonance mode appears when the deformed proton and neutron cloud oscillates against each other like the blades of a scissor.
* Scissor resonance is found in several actinides with centroids around 2.2MeV.
* It is believed that the scissor resonance will appear for all deformed nuclei in this mass region
* The aim of this project is to look for the scissor resonance in ^{182}Ta

[M. Guttormsen et. al. Phys. Rev. Lett. 109 162503 (2012)]



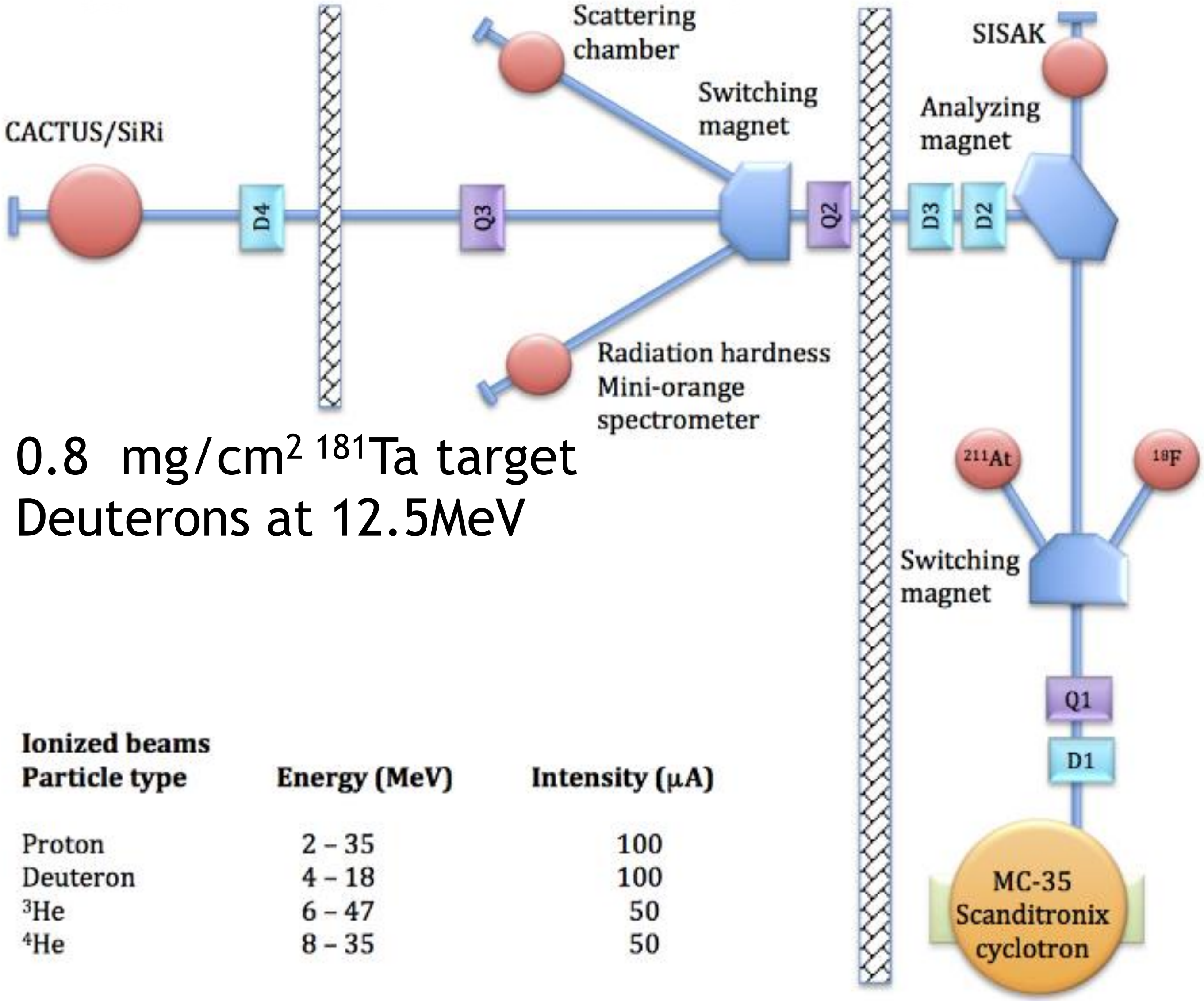
Scissor resonance of ^{233}Th





[M. Guttormsen et. al. Phys. Rev. Lett. 109 162503 (2012)]

Experimental setup

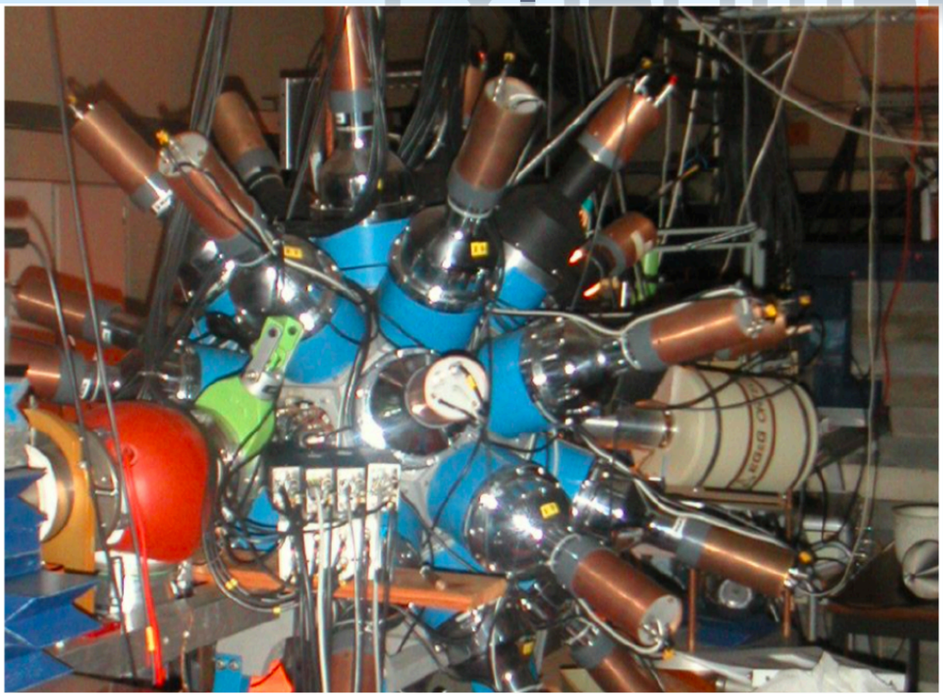


- 0.8 mg/cm^{2} ^{181}Ta target
- Deuterons at 12.5MeV

Ionized beams

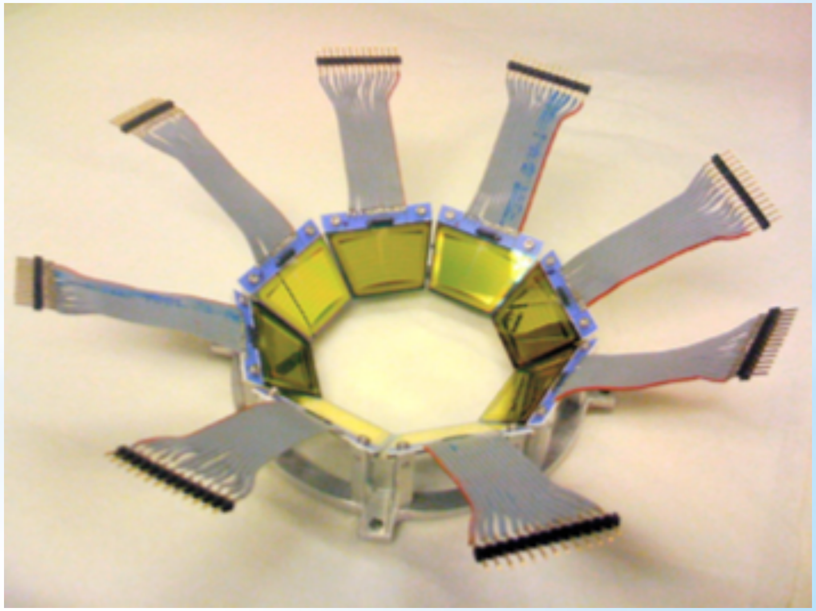
Particle type	**Energy (MeV)**	**Intensity (μA)**
Proton	2 – 35	100
Deuteron	4 – 18	100
^{3}He	6 – 47	50
^{4}He	8 – 35	50

Experimental setup



CACTUS array
- 26 NaI Detectors with 5”x5” crystal dimensions
- Solid angle of 17% of 4π sr.
- Efficiency of 14% at 1.3MeV

[A. C. Larsen, PhD thesis, University of Oslo, 2008.]



[M. Guttormsen et al., Nucl. Instrum. Methods Phys. Res. A 648, 168 (2011)]

SiRi particle telescope
- 8 E detectors, 8 segmented ΔE detectors
- 64 channels
- Resolution of 123keV
- ΔE E setup for particle identification
- 130 and 1550 μm thick

Overview of Oslo method

* By using the Oslo method the Nuclear level density (NLD) and PSF can be simultaneously extracted. The main steps are:

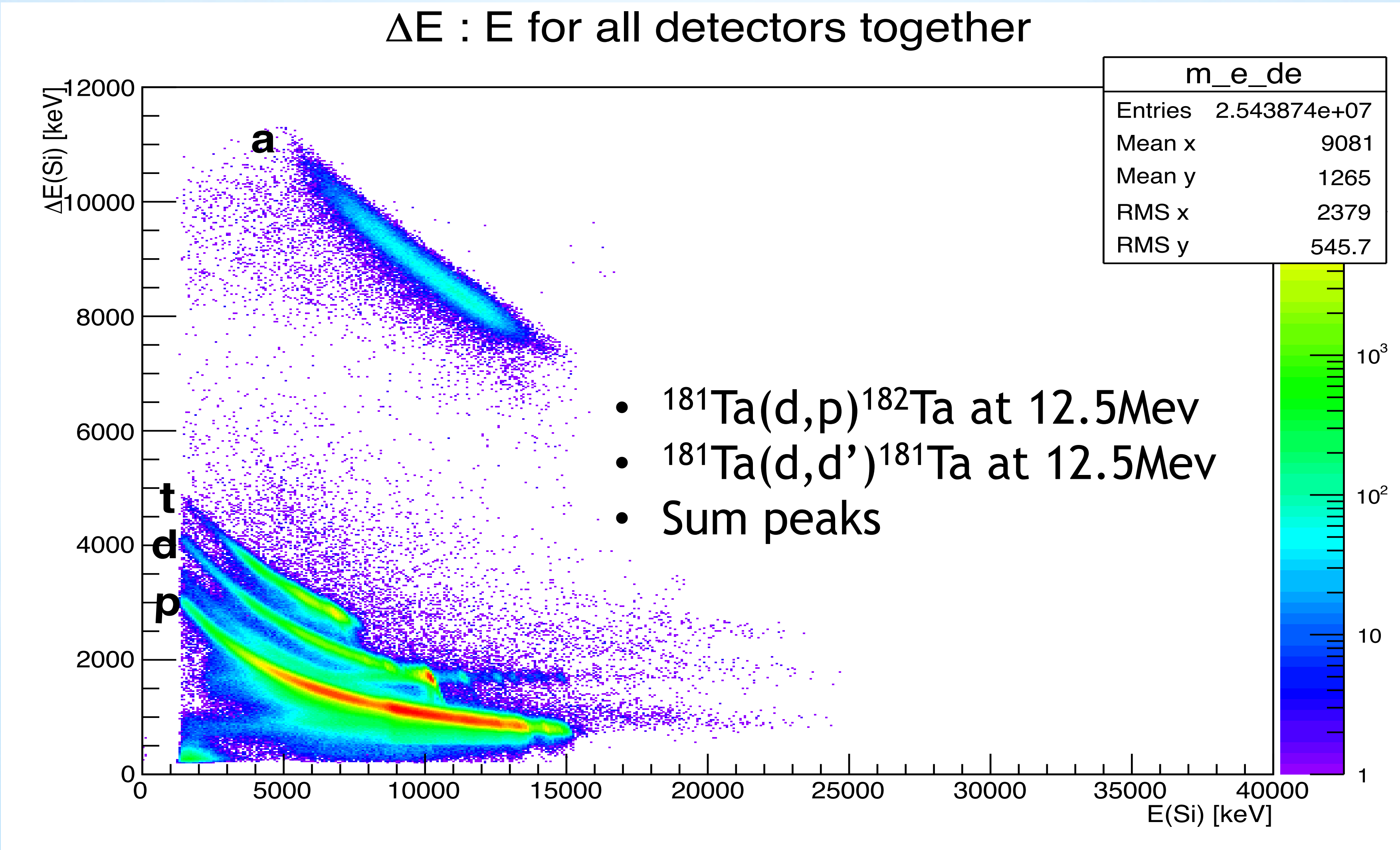
1. Calculate and remove the Compton background, effects from pair production, single and double escape peaks.
2. Extract the first generation gamma matrix.
3. Extract the NLD and PSF

* A detailed review of this method can be found in:

[Schiller et al., Nucl. Instrum. Methods Phys. Res. A 447, 498 (2000).]

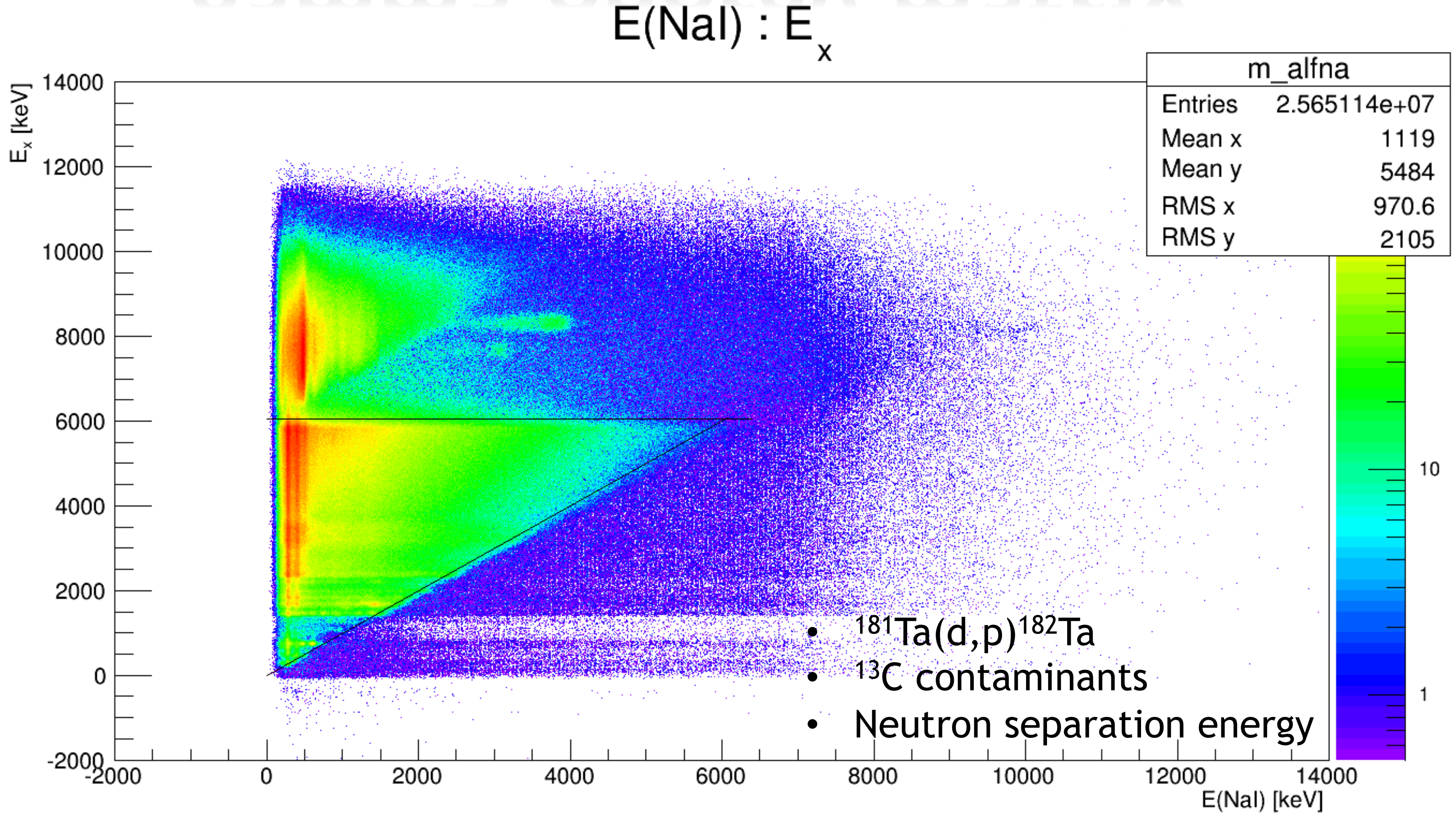
[A.C. Larsen et al., Phys. Rev. C 83, 034315 (2011).]

Preliminary Results



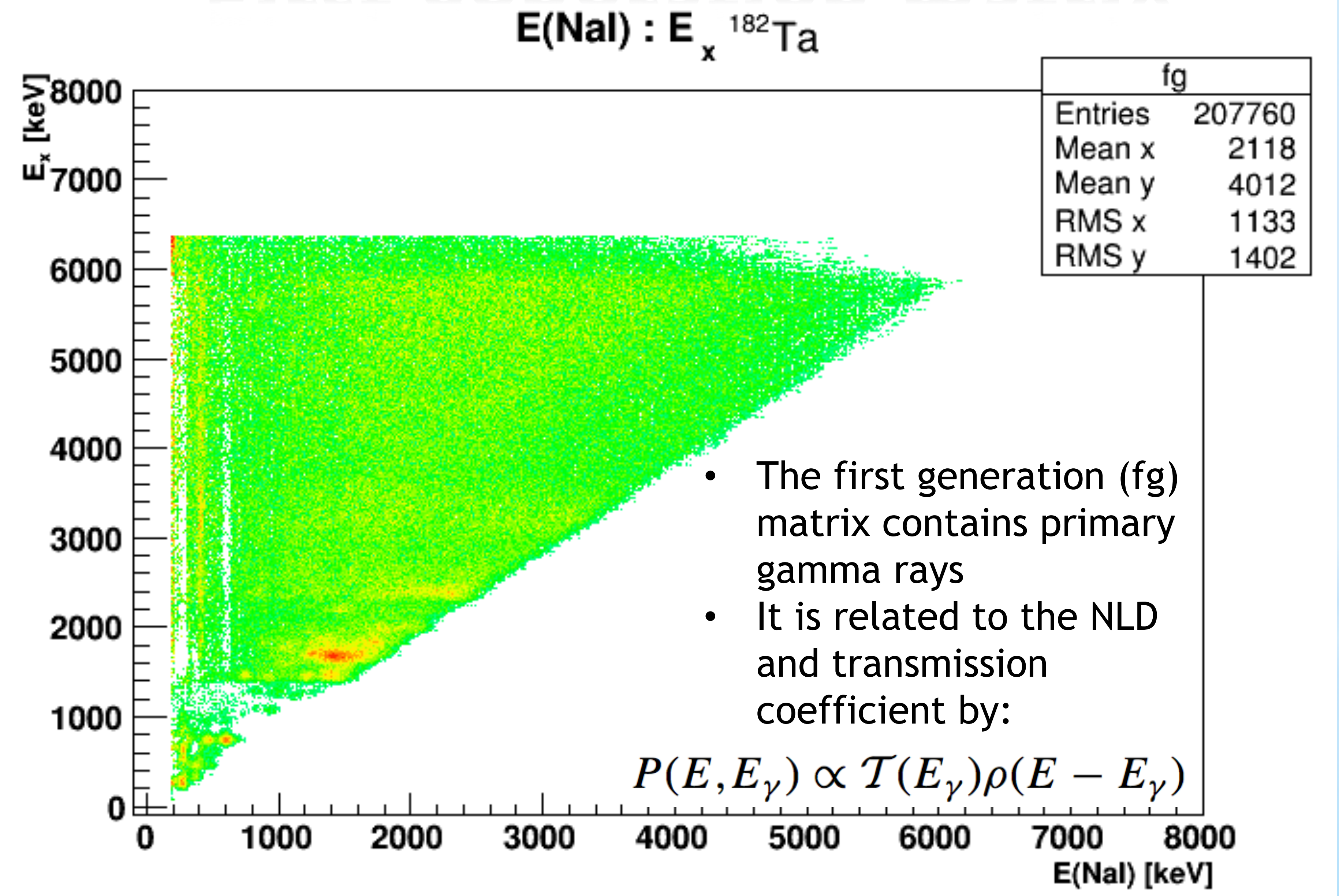
- ^{181}Ta(d,p)^{182}Ta at 12.5Mev
- ^{181}Ta(d,d')^{181}Ta at 12.5Mev
- Sum peaks

Excitation energy, gamma energy matrix



- $^{181}Ta(d,p)^{182}Ta$
- ^{13}C contaminants
- Neutron separation energy

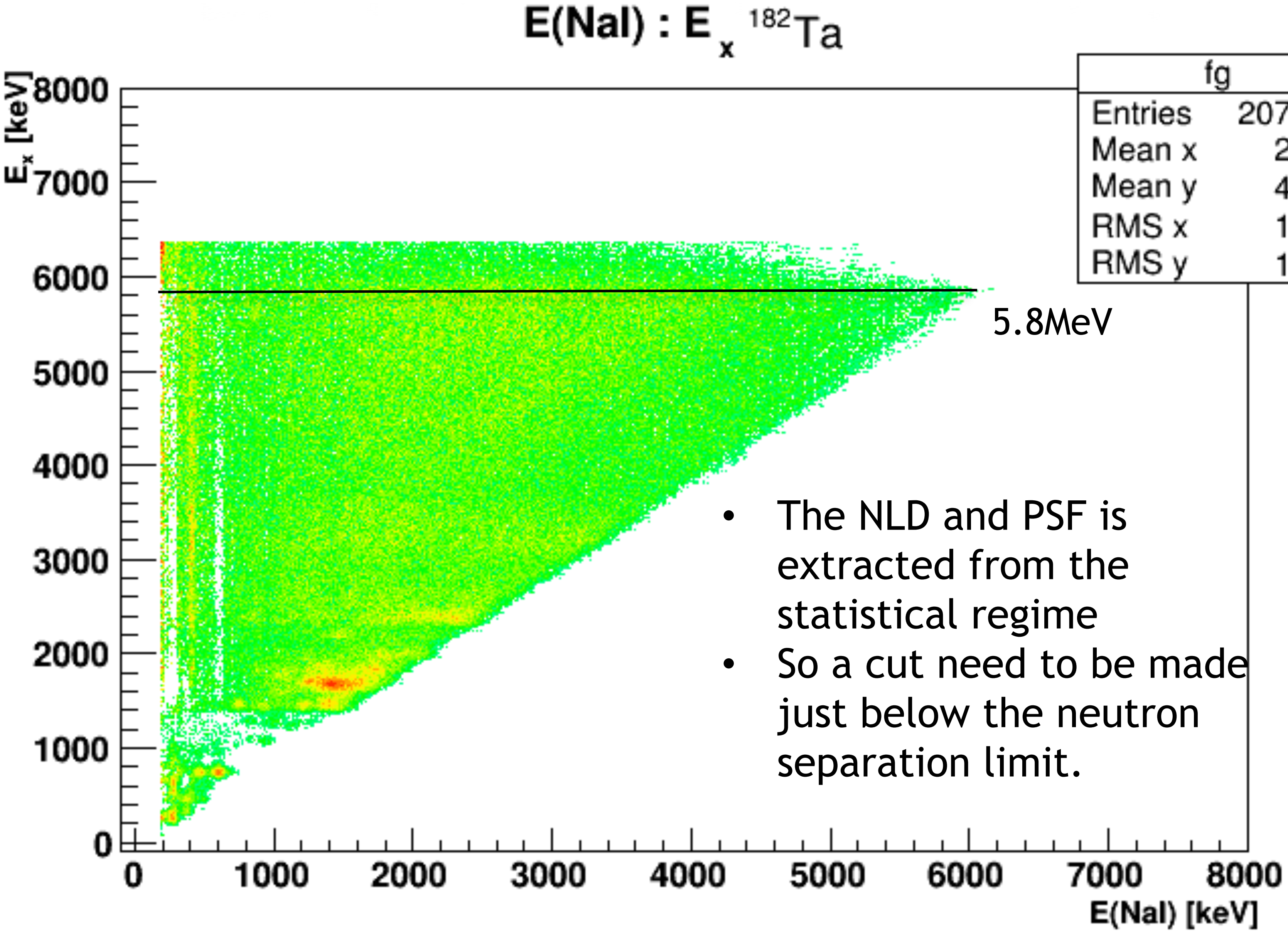
First generation matrix



- The first generation (fg) matrix contains primary gamma rays
- It is related to the NLD and transmission coefficient by:

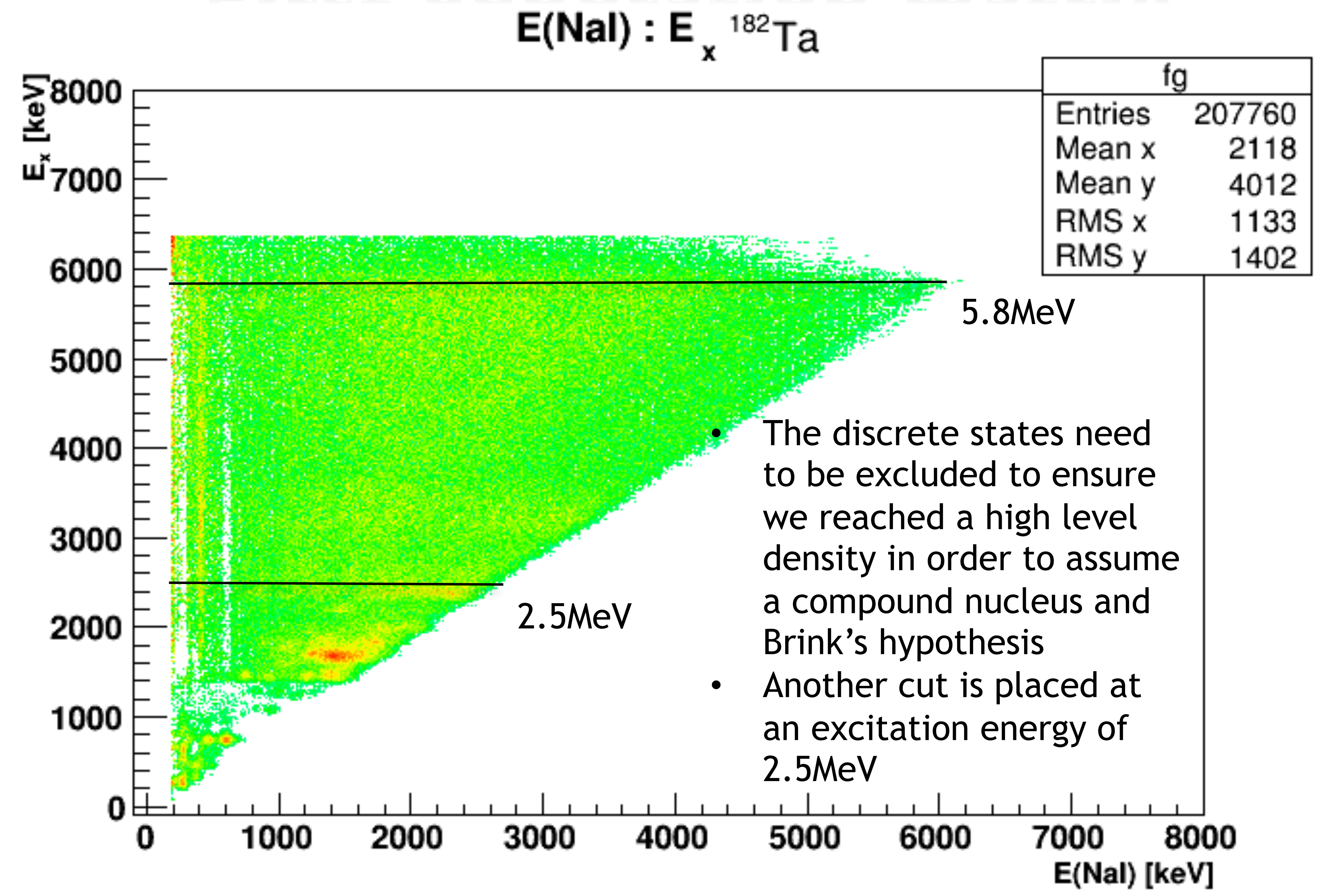
$$P(E, E_\gamma) \propto \mathcal{T}(E_\gamma)\rho(E - E_\gamma)$$

First generation matrix



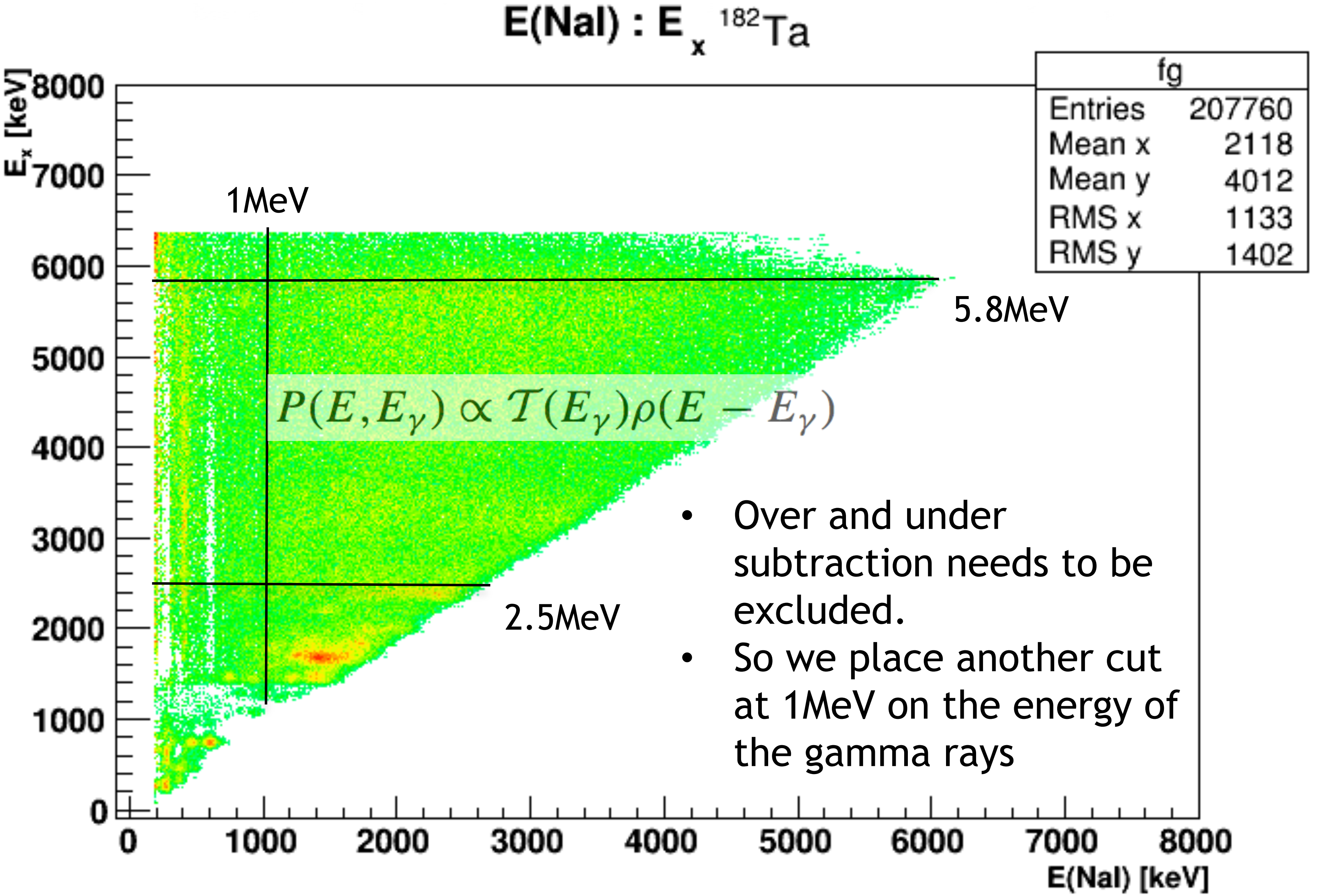
- The NLD and PSF is extracted from the statistical regime
- So a cut need to be made just below the neutron separation limit.

First generation matrix



- The discrete states need to be excluded to ensure we reached a high level density in order to assume a compound nucleus and Brink's hypothesis
- Another cut is placed at an excitation energy of 2.5MeV

First generation matrix



- Over and under subtraction needs to be excluded.
- So we place another cut at 1MeV on the energy of the gamma rays

First generation matrix

Since the fg matrix only depends on gamma energy a x^2 can be used to find the NLD and transmission coefficient.

$$\chi^2 = \frac{1}{N} \sum_{E_x} \sum_{E_\gamma} \frac{(P_{th}(E_x, E_\gamma) - P(E_x, E_\gamma))}{\Delta P(E_x, E_\gamma)}$$

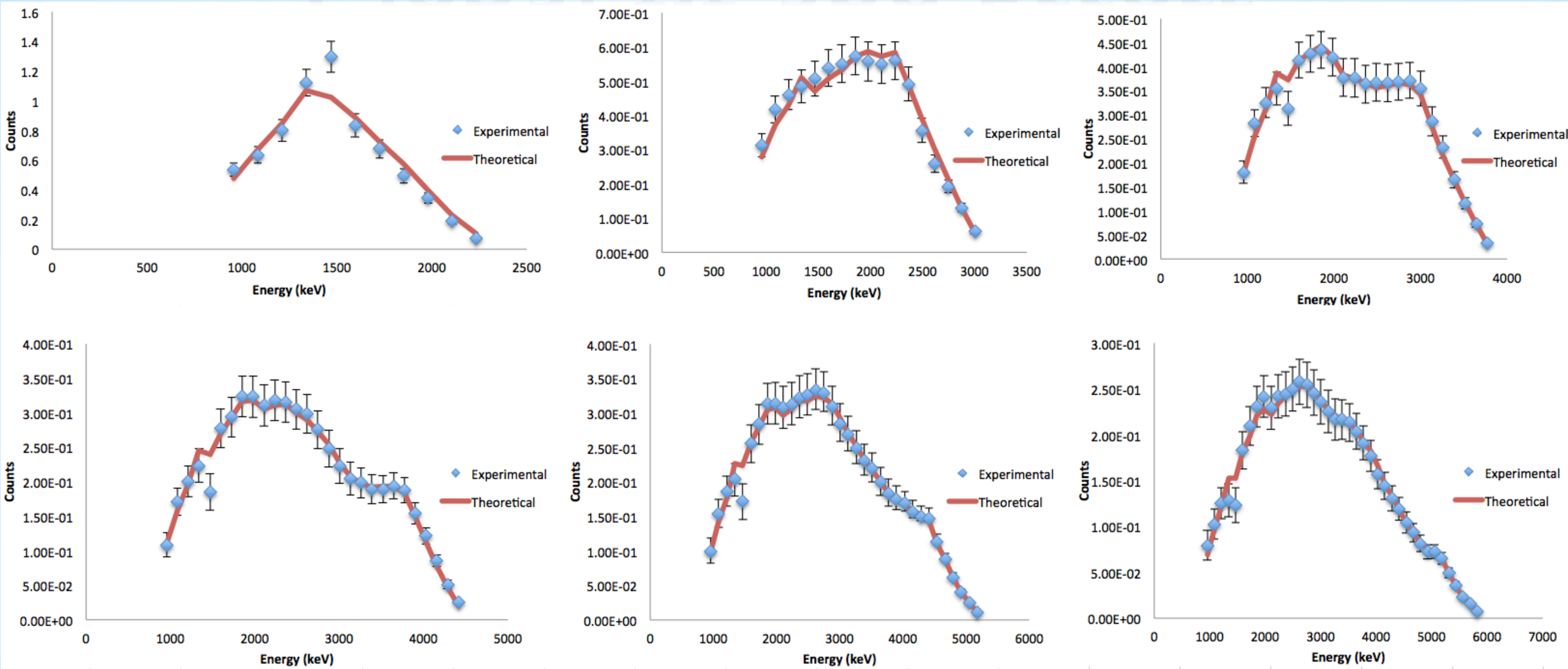
The NLD and transmission coefficient is then given by:

$$\tilde{\rho}(E - E_\gamma) = A \exp[\alpha(E - E_\gamma)]\rho(E - E_\gamma),$$

$$\tilde{\mathcal{T}}(E_\gamma) = B \exp(\alpha E_\gamma)\mathcal{T}(E_\gamma)$$

A and α can be found by normalizing to known level densities at low energies and to neutron resonance spacing at high energies. B can be found by reproducing the total gamma-radiative width from neutron resonance data.

Global fit and Errors

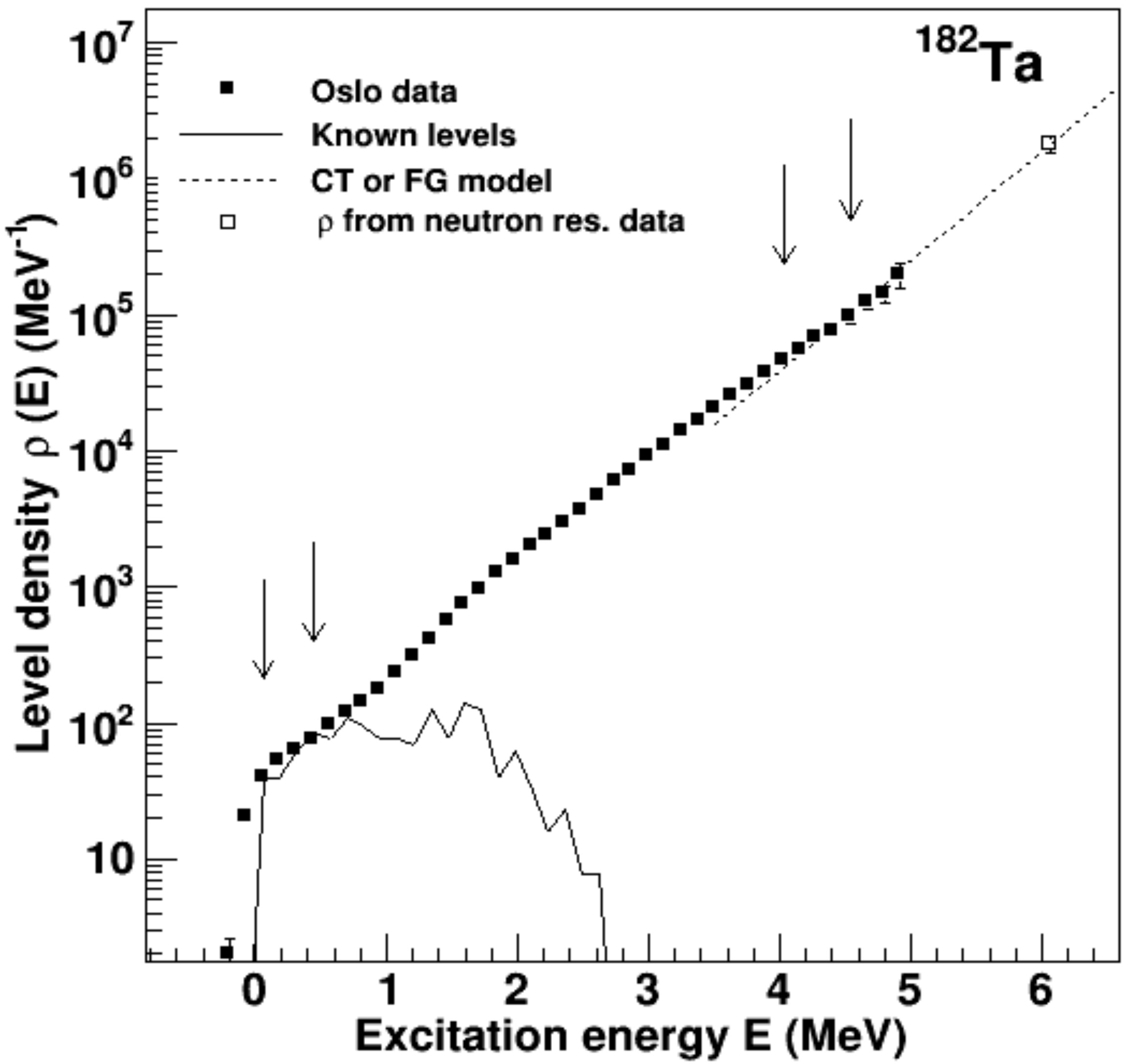


The theoretical first generation matrix is given by:

$$P_{th}(E_x, E_\gamma) = \frac{\rho(E_f)\mathcal{T}(E_\gamma)}{\sum_{E_\gamma}\rho(E_f)\mathcal{T}(E_\gamma)}.$$

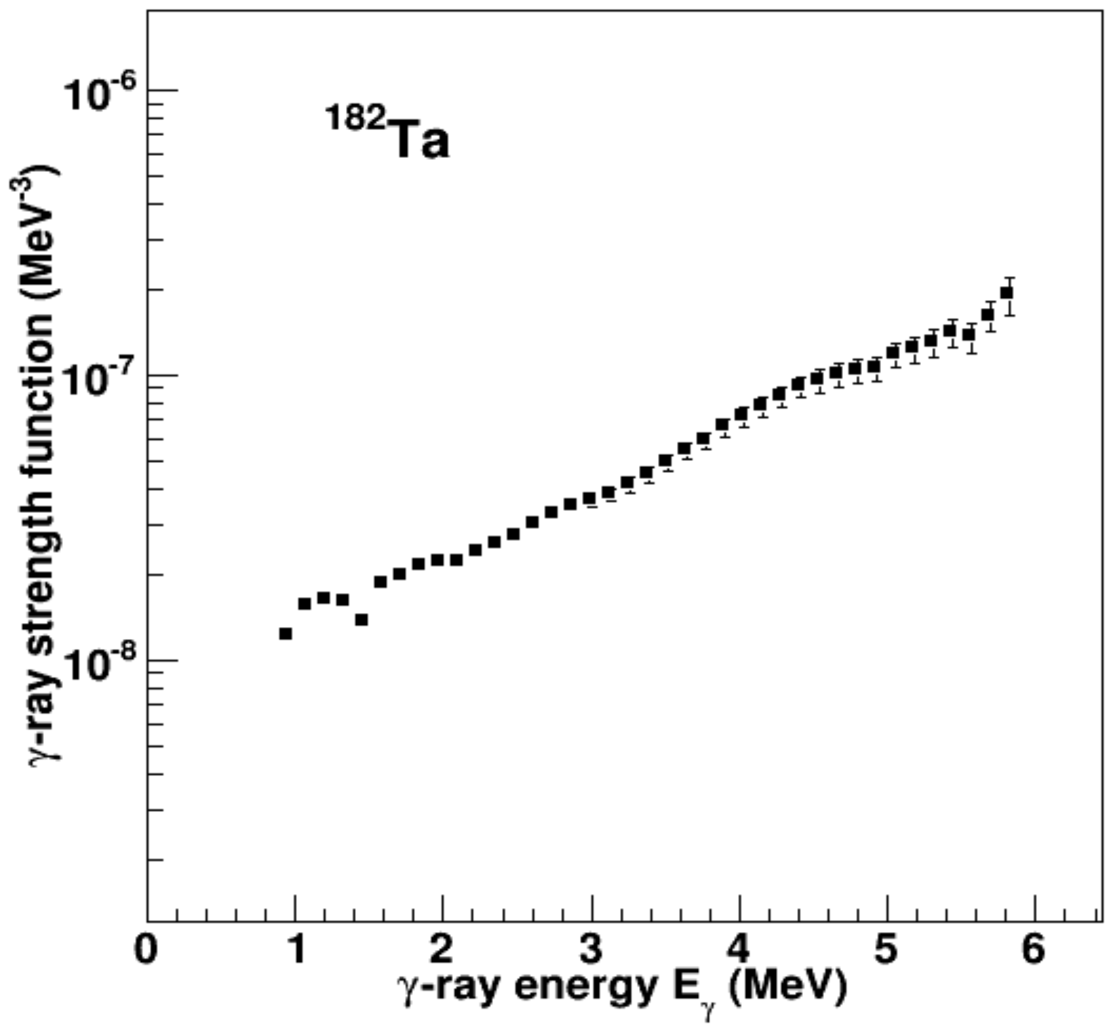
Comparing the gamma energy of the fg and theoretical fg we can see the statistical and systematical errors. The errors are small with an overall good extraction.

Nuclear level density



- NLD is the statistical amount of levels accessible at a given excitation energy, spin and parity.
- Most common model is the constant temperature, because all the energy is used to break the cooper pairs.
- The higher the excitation energy the harder it becomes to see all the discrete levels

Strength function



The strength function is given by:

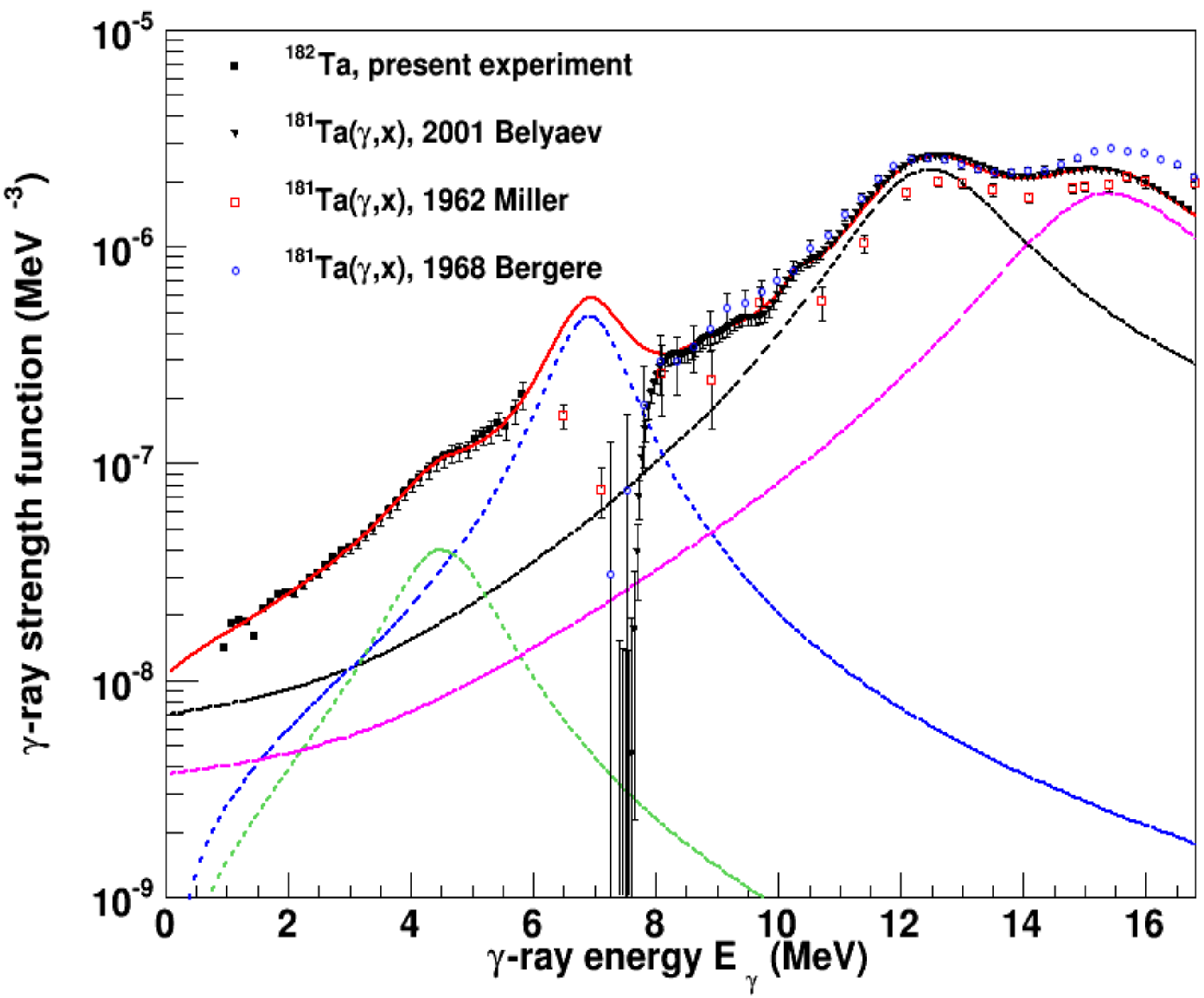
$$f(E_\gamma) = \frac{1}{2\pi}\frac{\tilde{\mathcal{T}}(E_\gamma)}{E_\gamma^3}.$$

Assuming that the photo neutron cross section is dominated by dipole transitions it can be converted into a strength function by the following:

$$f_\gamma(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2}\frac{\sigma_\gamma}{E_\gamma}.$$

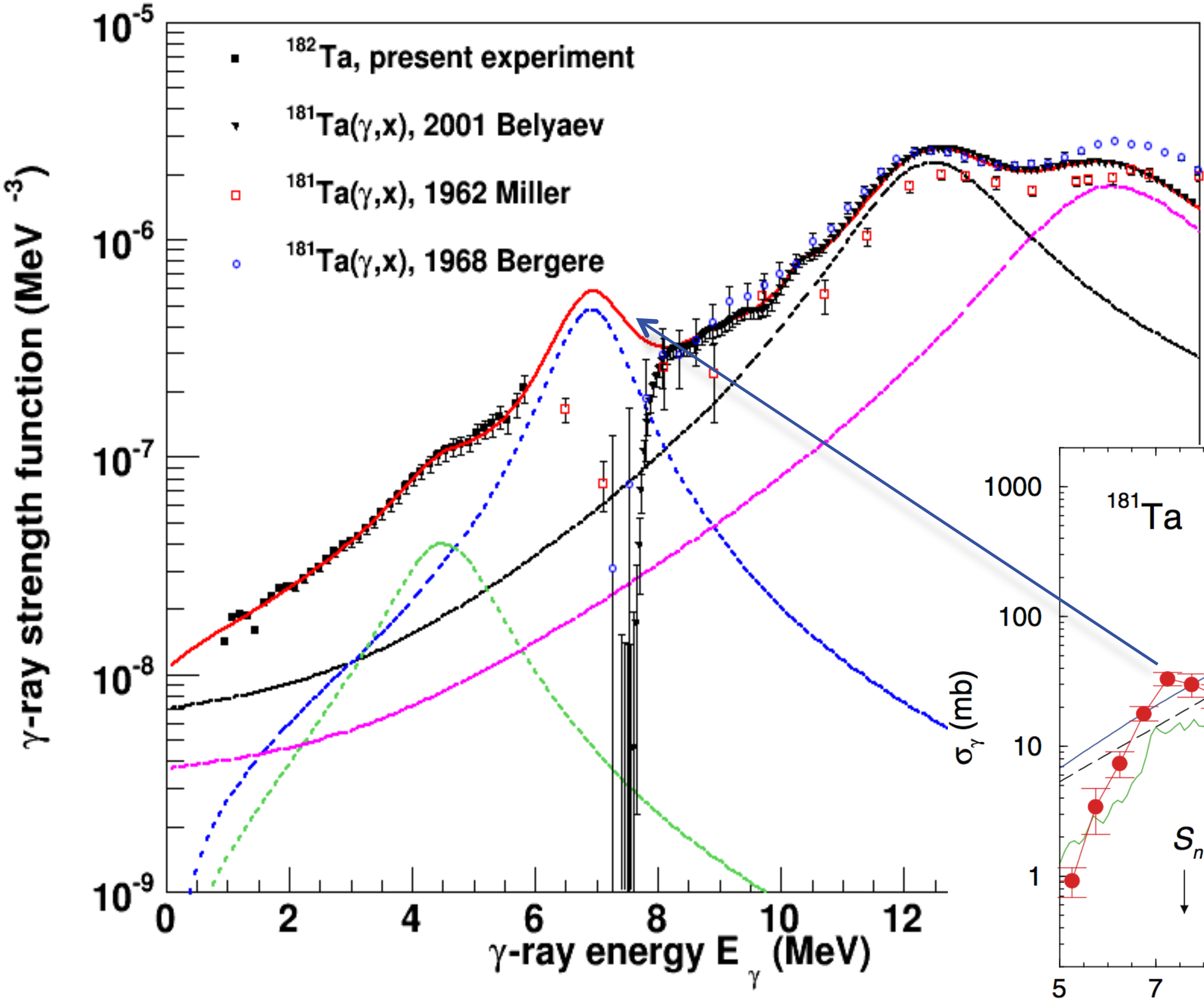
[A.C. Larsen et. al. *Transitional γ strength in Cd isotopes*]

Resonances of ^{182}Ta



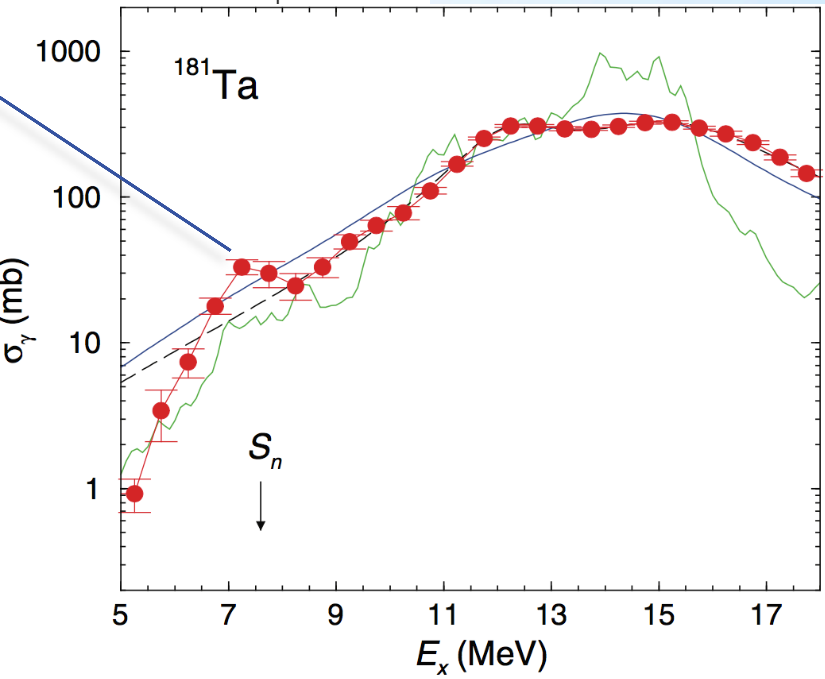
- The present data is plotted with known data from ^{181}Ta
- From the split in the GEDR we can see that the nucleus is deformed.
- We also see resonances that could be pygmy and spin-flip resonance

Resonances of ^{182}Ta

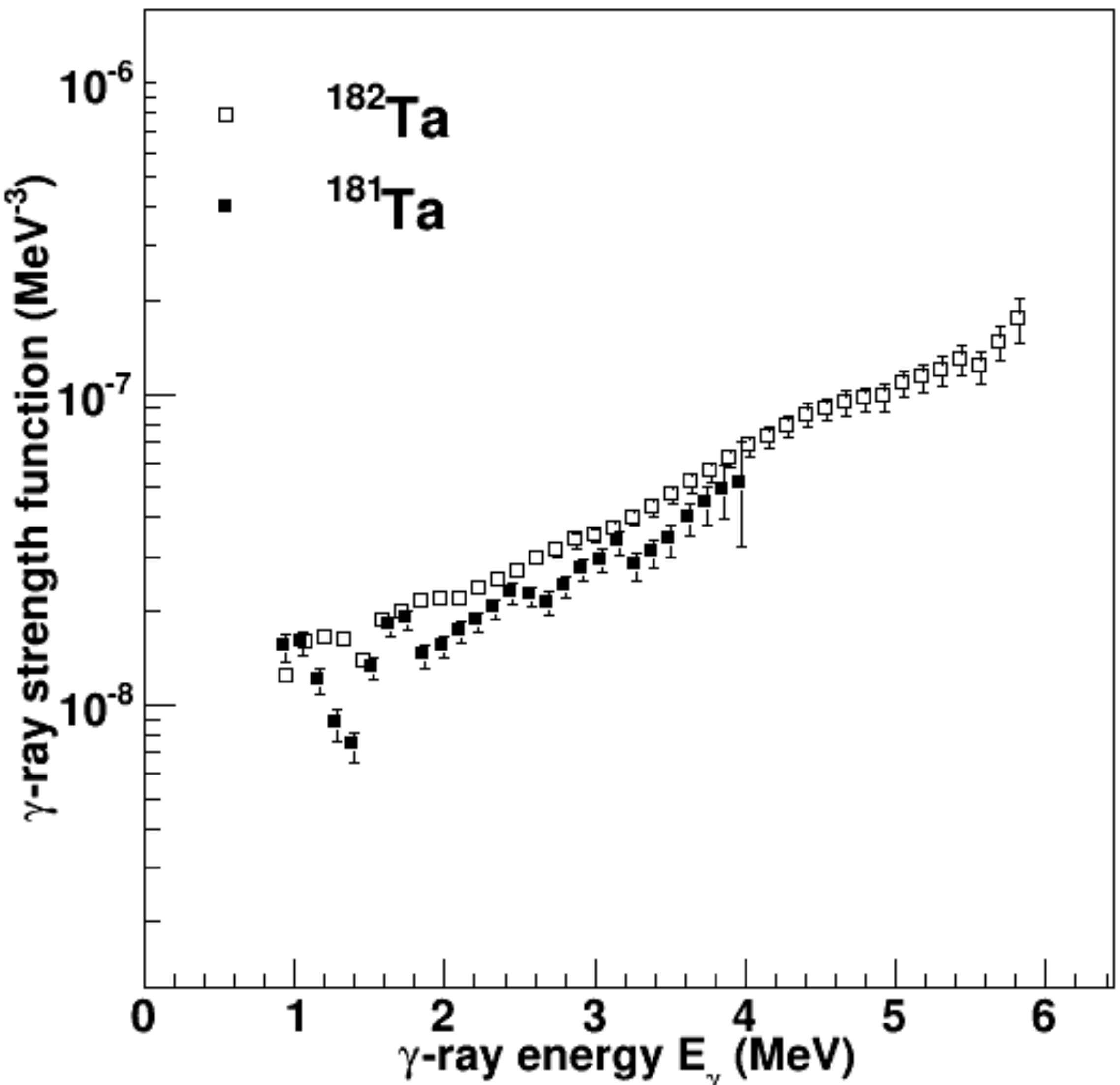


- Work done by A. Makinaga suggest a resonance at 7MeV

[A. Makinaga et al., Phys. Rev. C 90, 044301 (2014).]



Strength function



- ^{181}Ta's data did not reach the neutron separation energy
- The strength function for ^{181}Ta has the same slope and is similar to that of ^{182}Ta
- Data from ^{181}Ta is not sufficient to draw conclusions from

Conclusion

This is the first data on ^{182}Ta, however there is data on ^{181}Ta that was used for comparison. [S.N.Belyaev, et. al. Yadernaya Fizika Vol.42, p.1050]

Surprisingly the scissor resonance can not be seen in the data. There may still be a scissor mode, but we are not sensitive enough to observe it.

The contribution from the scissor resonance may be to small due to its deformation. Its deformation parameter is 0.25, while the deformation parameter for nuclei with observed scissor resonance is 0.3 and higher. It could also be some structure of the nucleus that is suppressing the scissor's mode

Collaborators

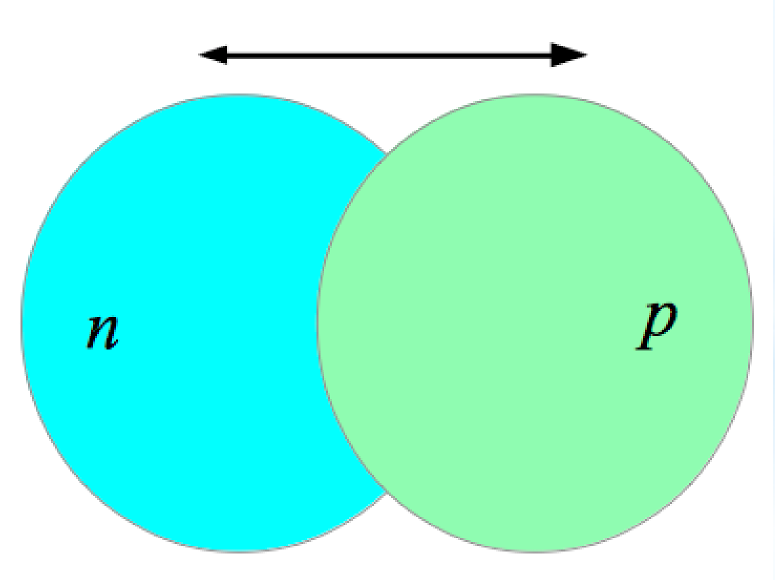
C.P. Brits[4], B.V. Kheswa[1], M.Wiedeking[1], F.L.Bello Garrote[2], D.L. Bleuel[3], F. Giacoppo[2], M. Guttormsen[2], A.Gorgen[2], K. Hadynska-Klek[2], T.W. Hagen[2], V. W. Ingeberg[2], M. Klintefjord[2], A.C.Larsen[2], H.T. Nyhus[2], P.Papka[1,4], T. Renstrom[2], S. Rose[2], E. Sahin[2], S. Siem[2], G. Tveten[2], F. Zeiser[2],

* 1 iThemba LABS, Faure, South Africa
* 2 University of Oslo, Oslo, Norway
* 3 Lawrence Livermore National Laboratory, Livermore, CA, USA
* 4 University of Stellenbosch, South Africa

GEDR

In the giant electric dipole resonance the neutron and protons vibrate out of phase. All of these resonance can be described by a Lorentzian function, in this case the EGLO or the GLO.

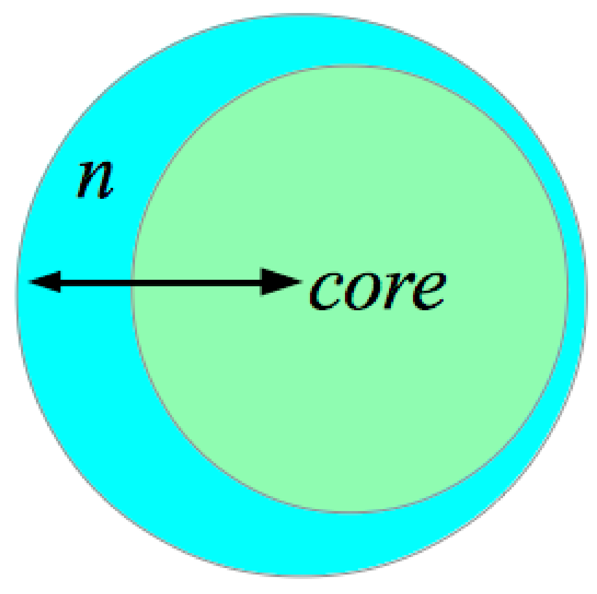
[J. Speth and J. Wambach, Electric and Magnetic Giant Resonances in Nuclei, (World Scientific Publishing Co. Pte. Ltd 7, 1991).]



Pygmy resonance

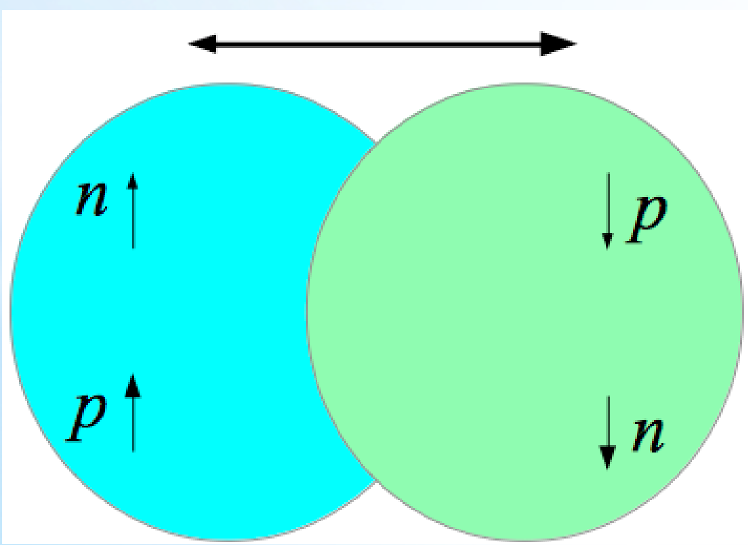
This resonance is due to the oscillation of the neutron skin against the proton-neutron core with isospin T=0. At the moment it is still impossible to investigate the nature of the pygmy resonance.

[D. Savran et al., Progress in Particle and Nuclear Physics 70, 2013 (210).]

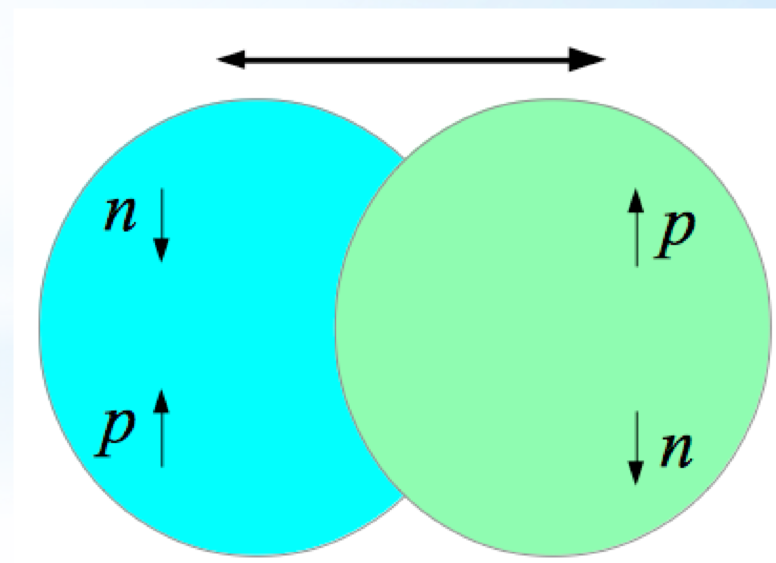


Spin-flip resonance

In this resonance the isoscalar mode neutrons with spin down oscillate against those with spin up. In the isovector mode protons with spin up oscillate against neutrons with spin down. [J. Speth and J. Wambach, Electric and Magnetic Giant Resonances in Nuclei, (World Scientific Publishing Co. Pte. Ltd 7, 1991).]



Isovector



Isoscalar

Models describing resonance

Resonance, like spin-flip and scissor resonance, can be described by the standard Lorentzian (SLO) function with an energy and temperature independent width:

$$f_{E1}^{SLO} = 8.68X10^{-8}\frac{\sigma_0 E_\gamma \Gamma_0^2}{(E_\gamma^2 - E_0^2)^2 + E_\gamma^2\Gamma_0^2}$$

where the Lorentzian parameters σ, Γ and E are the peak cross-section, resonance width and centroid energy, respectively.

There are different version like the generalized lorentzian and enhanced generalized lorentzian that is used in GEDR and other calculations.

[J. Kopecky and M. UHL, Phys. Rev. C. 41, 1941 (1990).]