Analysis update of $^{94}Nb(n,\gamma)$ cross section measurement

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AGENCIA ESTATAL DE INVESTIGACIÓN

nTOF

VNIVERSITAT DE VALÈNCIA

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

n_TOF collaboration meeting,Valencia 22th November 2023

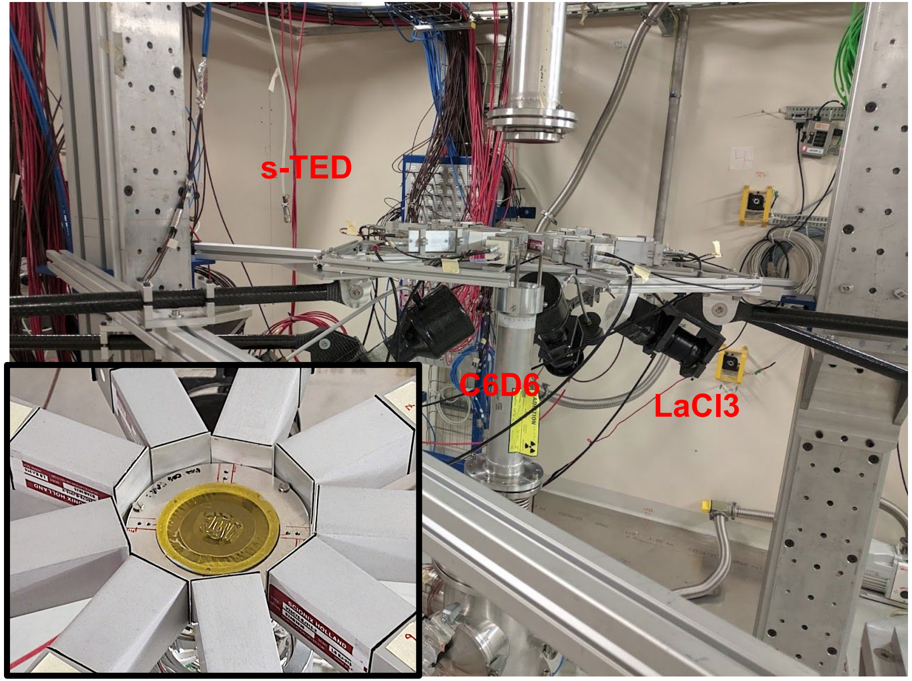
Experimental setup

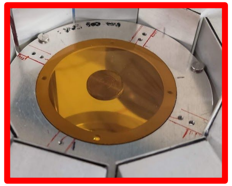
First (n,ɣ) measurement in **EAR2** for **2022** campaign:

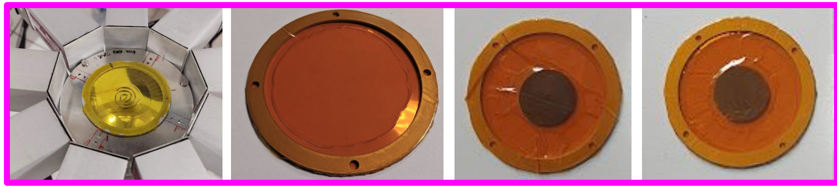
- Experiment performed between end of **March** and **April** of last year.

- Experimental setup:
  - **9 s-TEDs** in a ring configuration @ **4.5 cm**.
    →Main detectors for (n,ɣ) (~1 L of C6D6).
  - **2 C6D6** @ **17.5 cm** with the **new PMT+VD**
    →Validation.
  - **1 LaCl3** @ **9 cm**
    →Spectroscopic inf. & angular distribution.

- A total of **3.2**x10^{18} protons / **3.0**x 10^{18} INTC distributed in **several configurations** devoted to:
  - **Isotope** of interest
  - **Bkg** estimation
  - **Normalization** with a controlled geometry



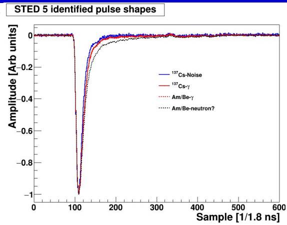


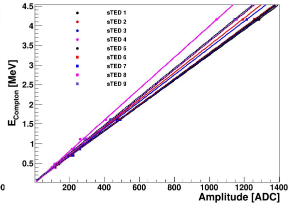


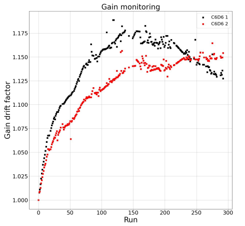
Brief summary

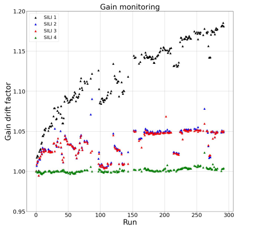
In previous meetings:

- Quality checks, calibrations and corrections for all detectors ✔
  (https://indico.cern.ch/event/1149528/)

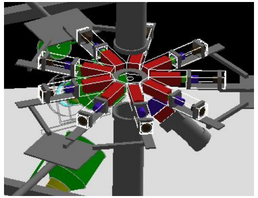




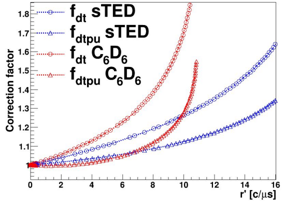




- Geant4 geometry model of 2022 EAR2 & Dead time model ✔
  (https://indico.cern.ch/event/1168514/contributions/)

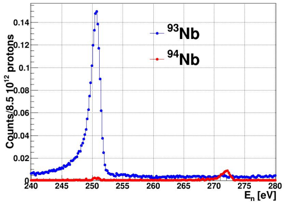


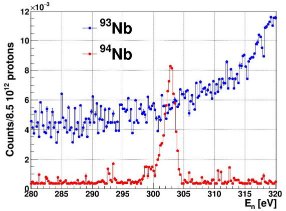
https://gitlab.cern.ch/ntof/geant4_simualtion



https://arxiv.org/abs/2311.01365

- Maximum likelihood yield calculation (Next meeting) ✔/?
  (https://indico.cern.ch/event/1168514/contributions/)





Outline

- Weighting function:
  - Calculation
  - Q-check on $^{197}Au(n,\gamma)$ & $^{93}Nb(n,\gamma)$

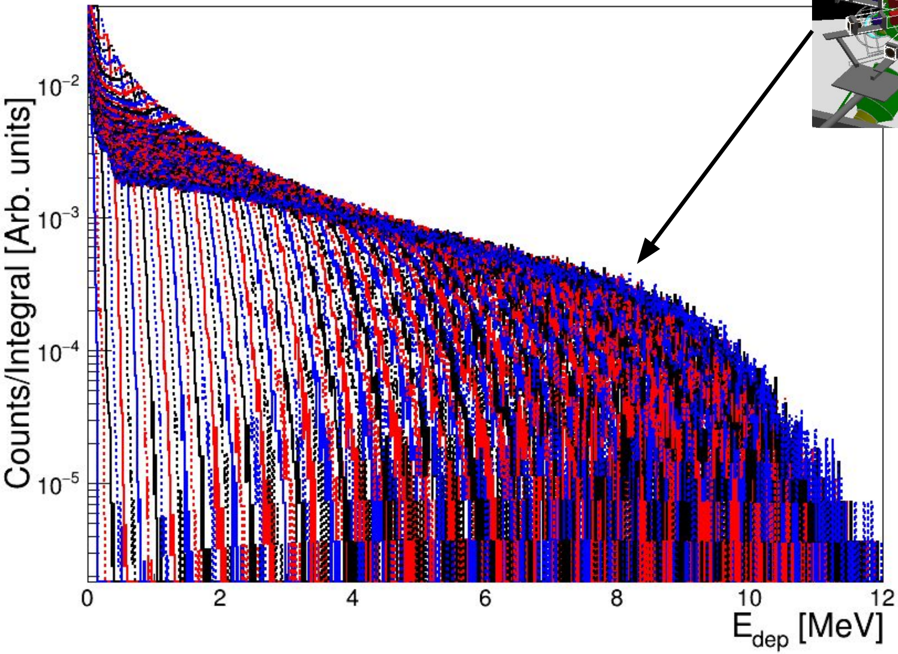
- Normalization:
  - $^{197}Au(n,\gamma)$
  - $^{93}Nb(n,\gamma)$ thick target yield

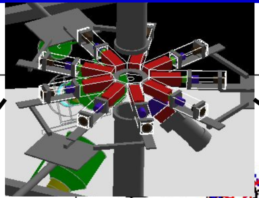
- MS and Self-shielding for Nb targets:
  - SAMMY & SAMMC
  - MC fast yield calculation code, validation and test

- Summary and outlook

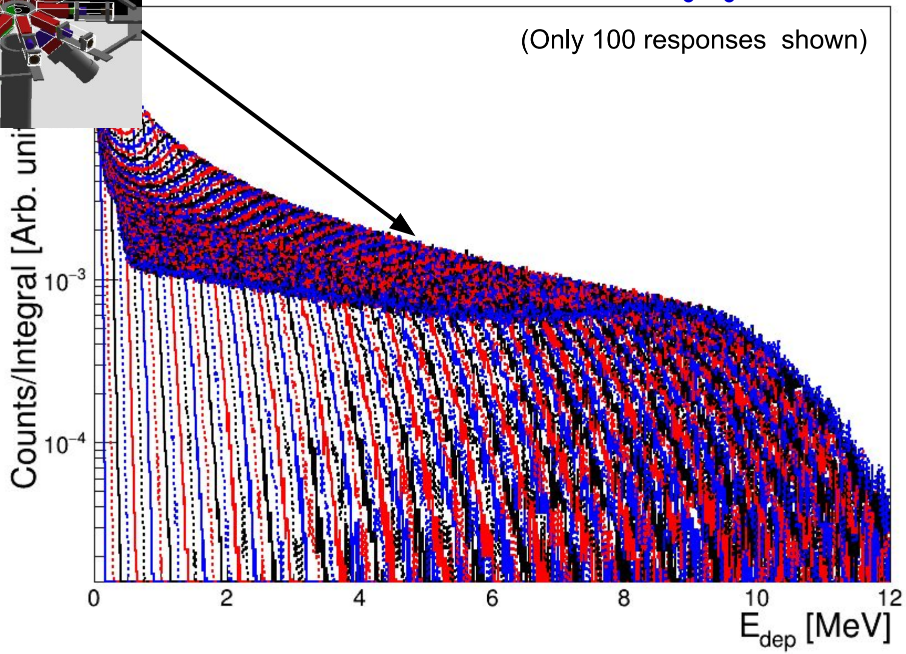
Weighting function calculation

Example response function **sTED** (1)





Example response function **C_6D_6** (1)

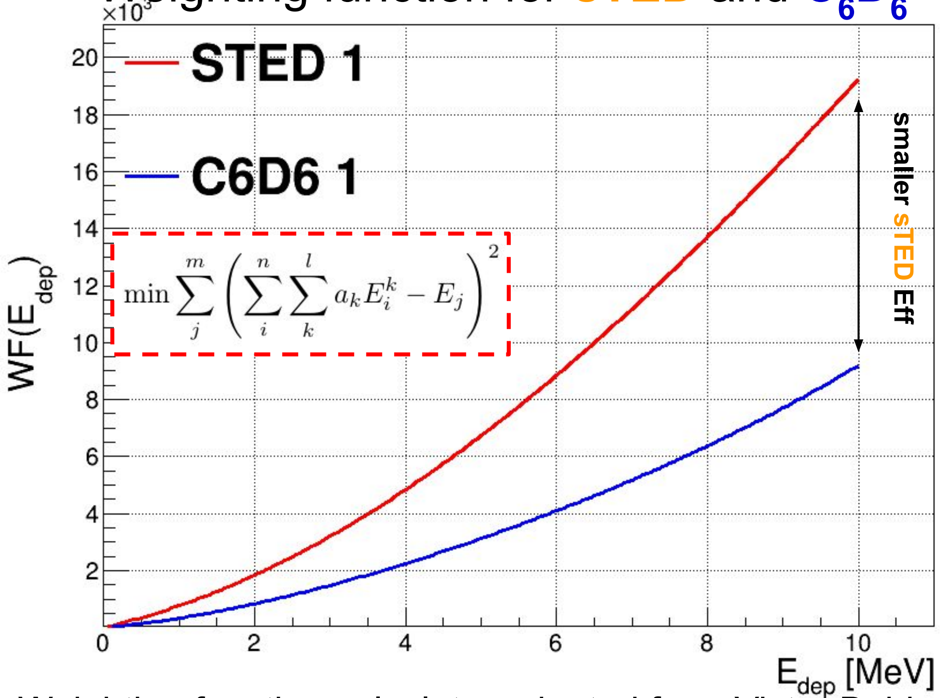


Response matrix calculation (2022) GEANT4 setup:

- **200** Monte Carlo **simulations** using **thin**(**thick**) **^{197}Au**(**^{93}Nb**) target + Gaussian 2D neutron flux shape
  - **50 keV - 10 MeV** range in **50 keV step**.
  - **10^9** γ-ray events/simulation.
  - **Detector response** modelization from comparison with **experimental** (https://indico.cern.ch/event/1168514/contributions/)

Weighting function calculation

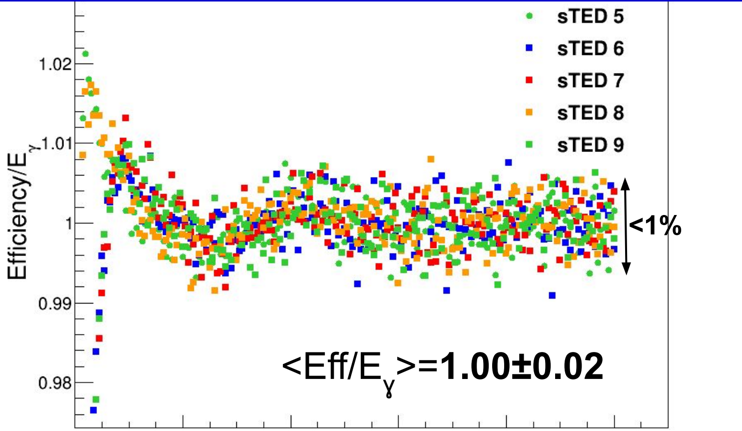
Weighting function for sTED and C_6D_6

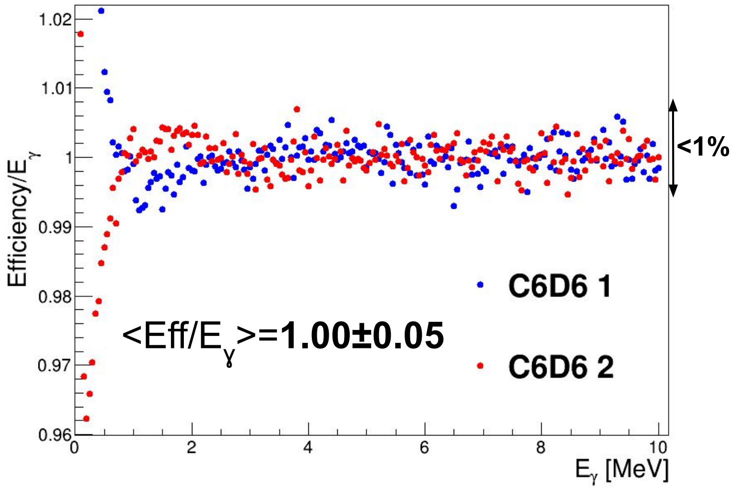


Weighting function calculator adapted from Victor Babiano’s code for the current MC code:

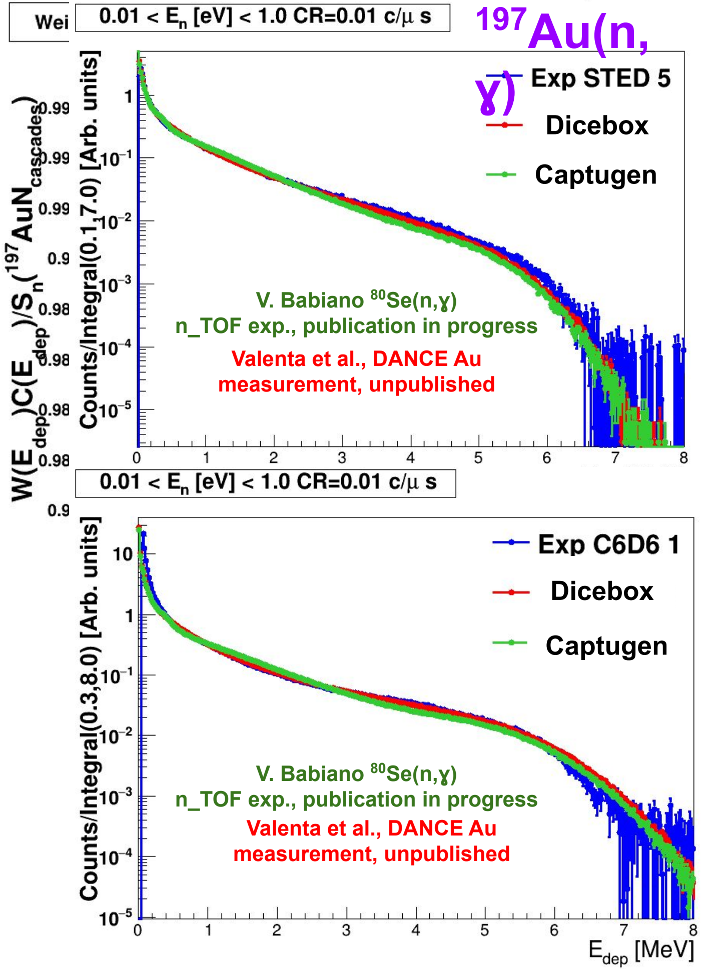
- Deposited energy threshold E_{th}=**0.0 MeV**
- Polynomial order **4**(5)

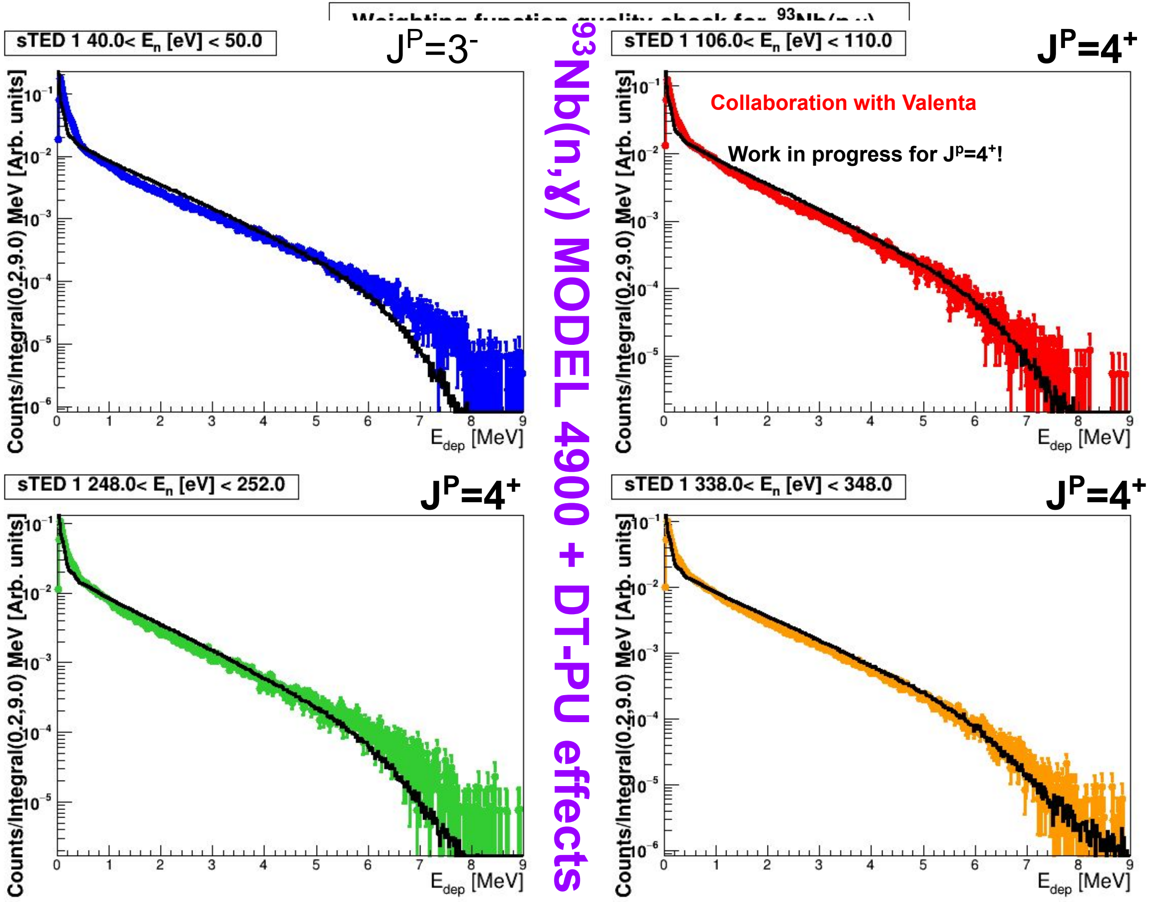
A **similar calculation** was performed for **thick** Nb target





Q check on ^{197}Au and ^{93}Nb

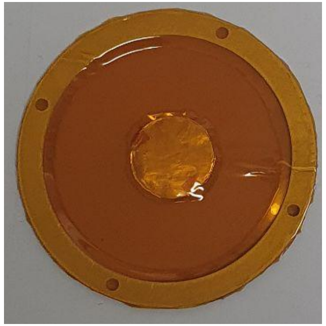




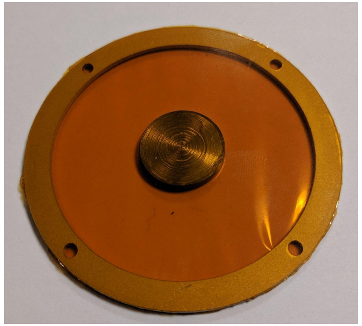
C_6D_6	1.01(4)	1.01(4)	1.01(4)	0.94(4)

Normalization procedure

^{197}Au(n,γ) → ^{93}Nb(n,γ) → ^{93}Nb(n,γ) → ^{93}Nb(n,γ)+^{94}Nb(n,γ)



Disk geometry
Saturated resonance



Disk geometry
^{93}Nb(n,γ) RP

Really **thick** target
DT corrections

^{93}Nb(n,γ) RP
Wire geometry

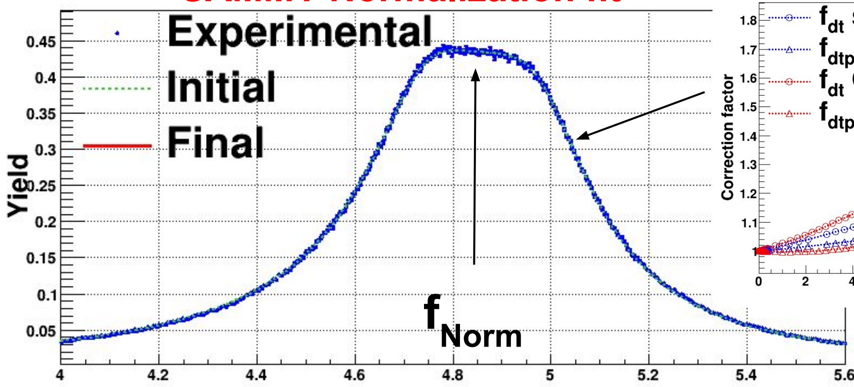
D=**1.0** mm

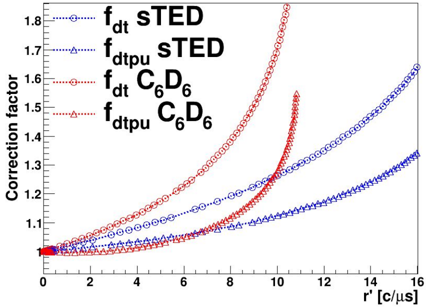
^{93}Nb(n,γ) RP
Wire geometry
^{94}Nb(n,γ) RP

D=**0.8** mm

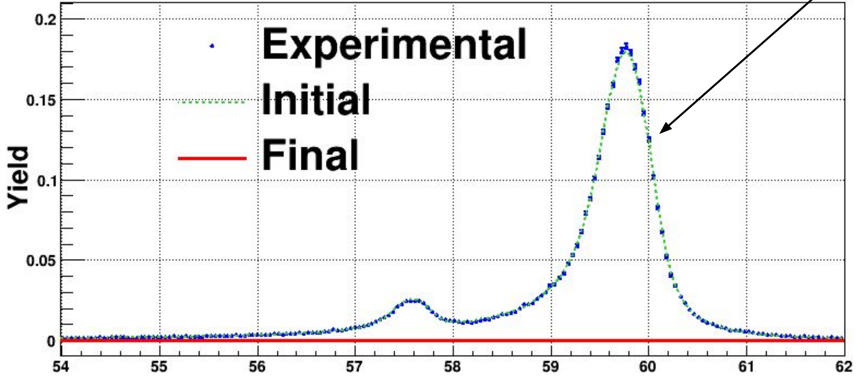
$^{197}Au(n,\gamma)$ sTED normalization

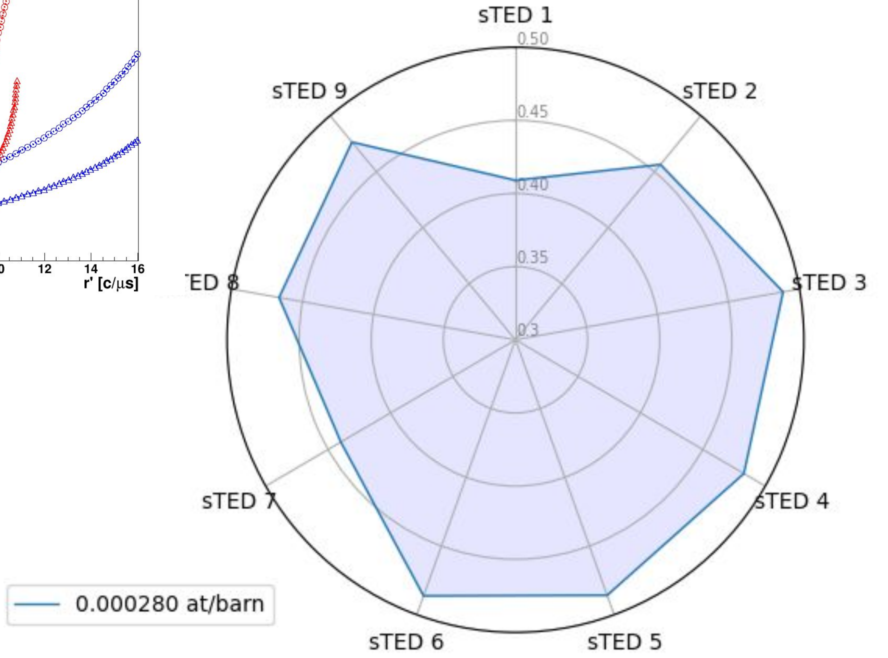
SAMMY Normalization fit





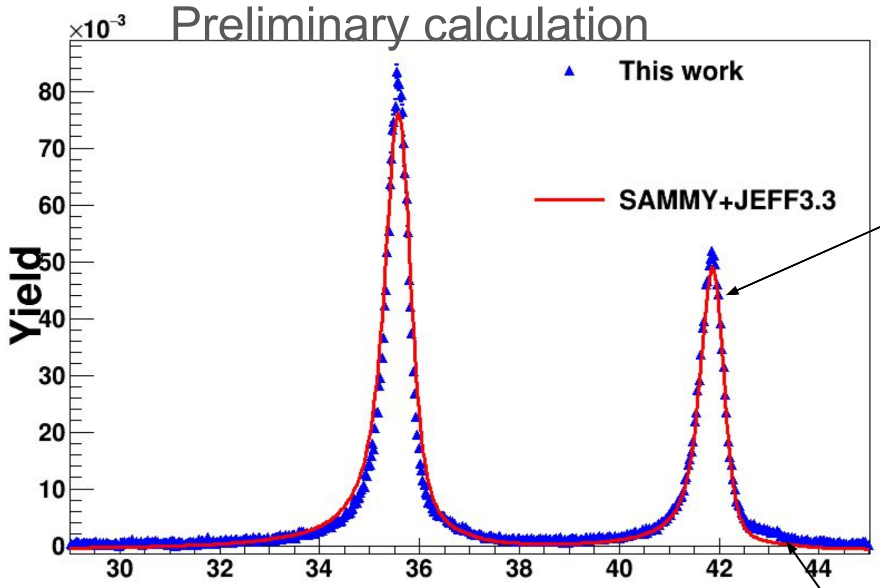
DT-PU check after normalization

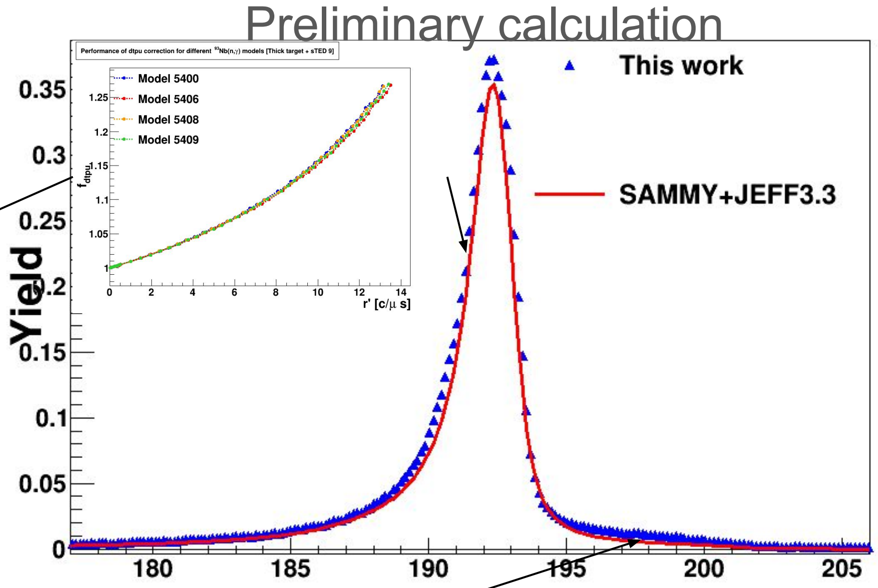




The ^{197}Au **normalization** taking into account **all sTED** detectors and threshold correction (**5%**): **f_{Norm}**=0.46775 (?)

Preliminary ^{93}Nb(n,ɣ) thick yield





The **calculated yield** is **similar** to **JEFF 3.3** after ^{197}Au **normalization** and **DT-PU** and **Th** (4%) corrections.

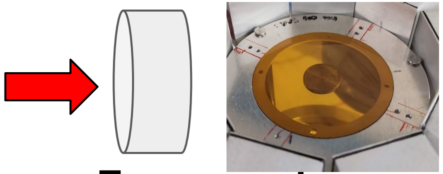
Multiple scattering and **Self-shielding** corrections are **limited** for such **thick target** (see backup En<1.3 keV)

SAMMY and SAMMC

SAMMY can not accurate account for **very thick** target corrections.

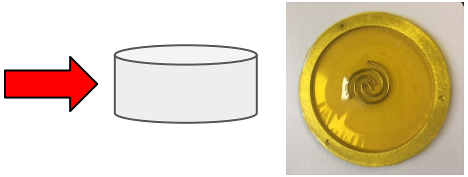
Instead, **SAMMC** code can calculate Y_0, Y_1 and Y_2 contributions via **Monte Carlo** simulations and **feed** SAMMY **fitting** procedure.
Geometries and **“irradiations”** are **limited** to:

- **Cylindrical** or **square** shapes
- Irradiation **transversal** axis



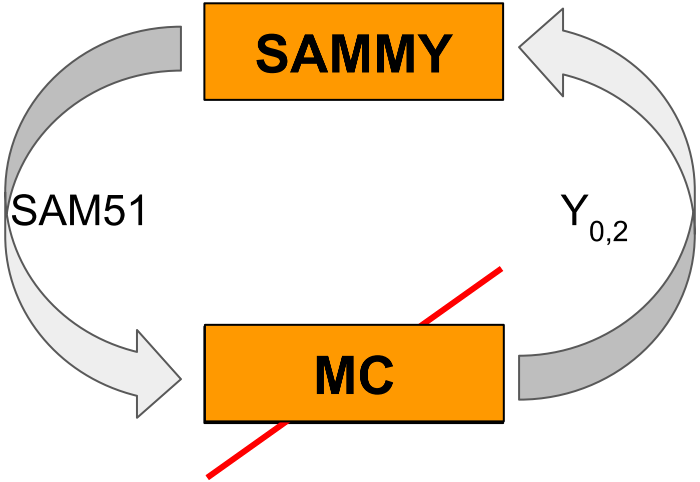
Transversal

Large BiF
“Thin” target



longitudinal

Small BiF
“Thick” target



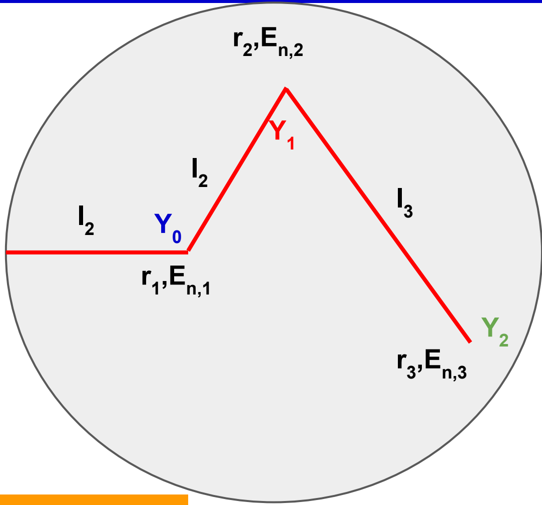
Replace SAMMC by a fast MC code that can deal with ^{93}**Nb**/^{94}**Nb geometries**

Neutron capture yield calculation

Neutron capture yield can be calculated as:

$$Y(E_n) = Y_0(E_n) + Y_1(E_n) + Y_2(E_n) + \mathcal{O}(\Sigma^4)$$

Y_0= capture
Y_1= scattering+capture
Y_2=scattering+scattering+capture



Every expansion term can be calculated solving the following equation:

Equation can be solved by means of MC integration techniques

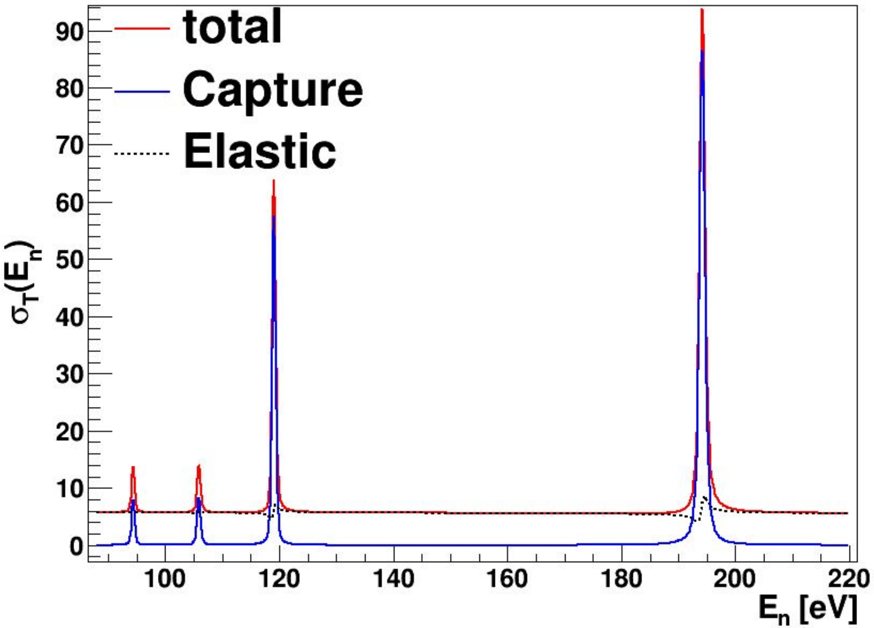
$$Y_n(E_n) = \prod_{i=0}^{n-1} \left[\int_0^{l_{max,i}} \Sigma e^{-\Sigma\sigma_T(E_{n,i})l_i} dl_i \int \frac{d\sigma_{nn}(E_n)}{d\Omega} d\Omega_i \right] \int_0^{l_{max,n}} \Sigma\sigma_\gamma(E_{n,n}) e^{-\Sigma\sigma_T(E_{n,n})l_n} dl_n$$

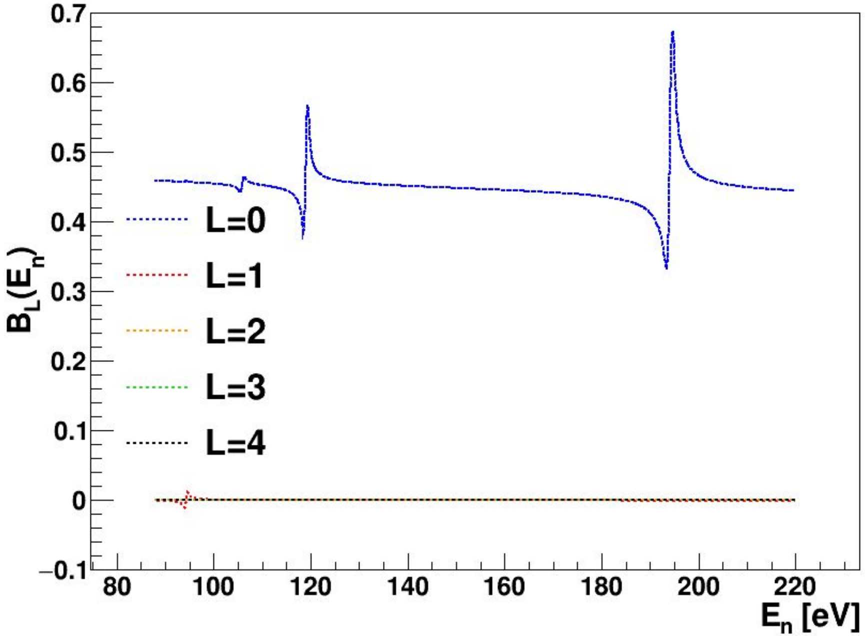
n-1 neutron **scattering**

neutron **capture**

SAMMY!

Total, elastic XS and partial waves





SAMMY provides a output file (**SAM51**) for **SAMMC** to perform the **MC yield calculation** (all isotopes):

- Doppler broadened **total** and **capture** cross section as a function of En.
- **Partial waves expansion** for **elastic** cross section in B formalism as a function of En.

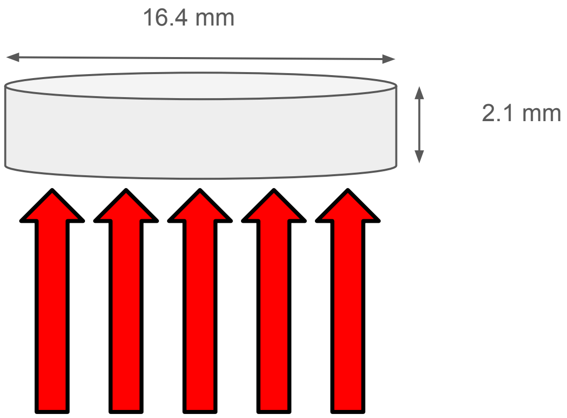
$$\frac{d\sigma_{nn}(E_{CM})}{d\Omega_{CM}} = K(E_n)\frac{d\sigma_{nn}(E_n)}{d\Omega_{lab}} = K(E_n)\sum_{l=0}^{L_{max}} B_l(E_n)P_l(cos\theta)$$

Validation on ^{93}Nb thick disk

Monte Carlo **methodology tested** against **SAMMY** (default) and **SAMMC** in a **controlled scenario** with **large corrections** (^{93}Nb disk):

Only ^{93}Nb isotope in the target:

n_s=**0.0109851** atms/barn m=92.9063781



Homogeneous irradiation

Two neutron **energy ranges** of interest for validation:

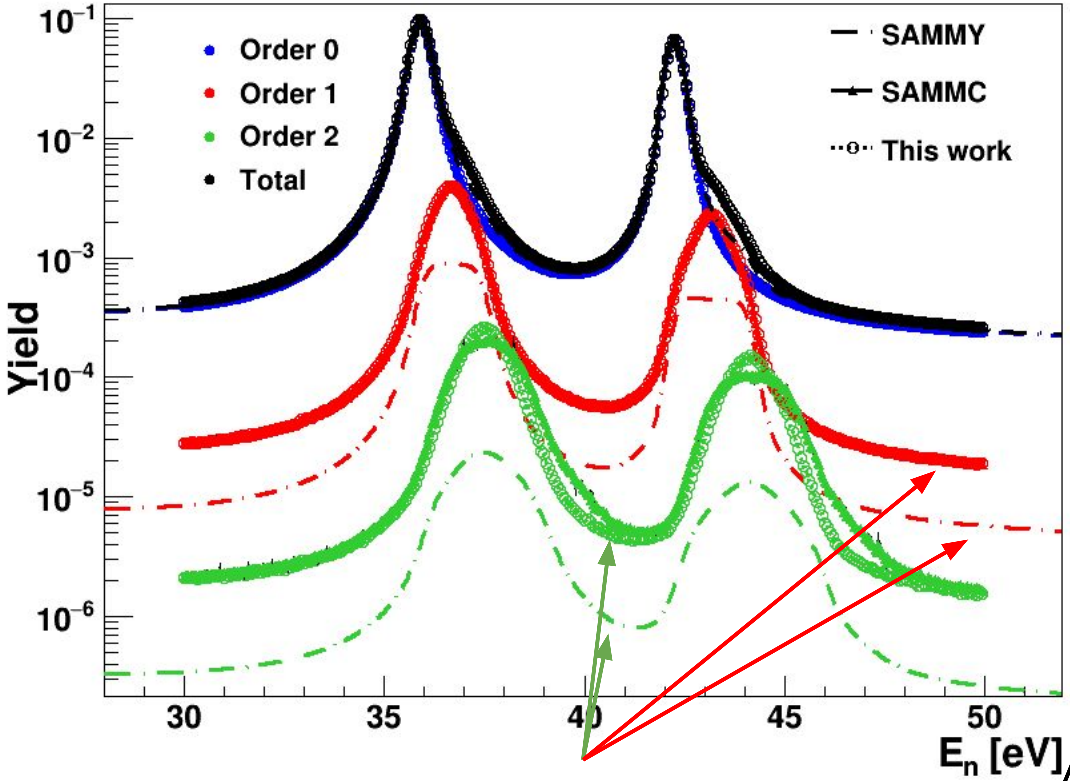
30.0 < En [eV] <50.0 [**Normalization** candidates]

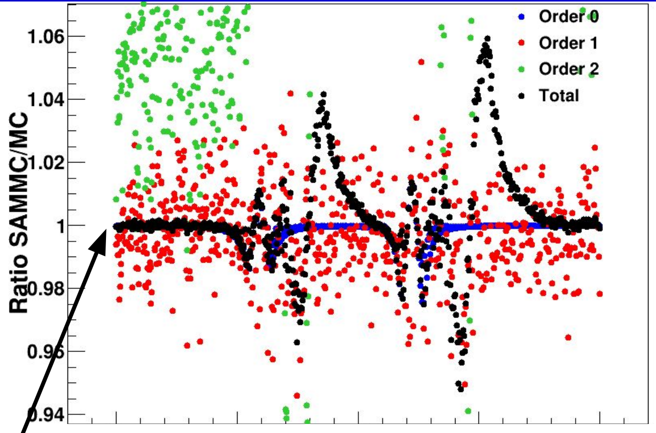
En [eV]	Γn	Γɣ	L
35.9	209.0	.101818200	0
42.3	222.0	.096111110	0

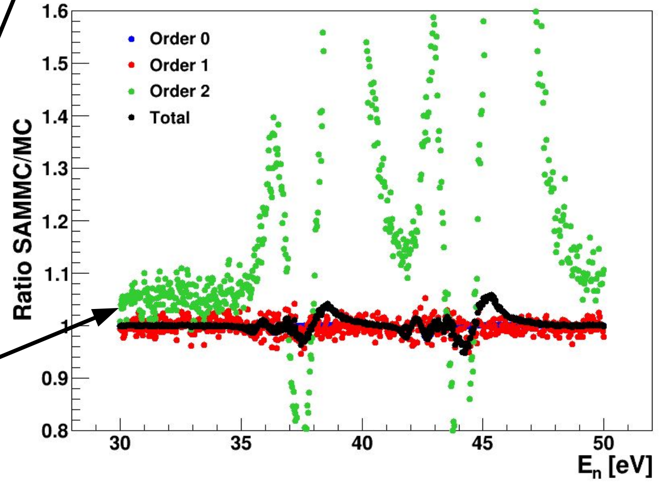
185.0 < En [eV] <220.0 [“**Big**” resonance]

En [eV]	Γn	Γɣ	L
193.8	134.0	33.8181800	0

30-50 eV comparison





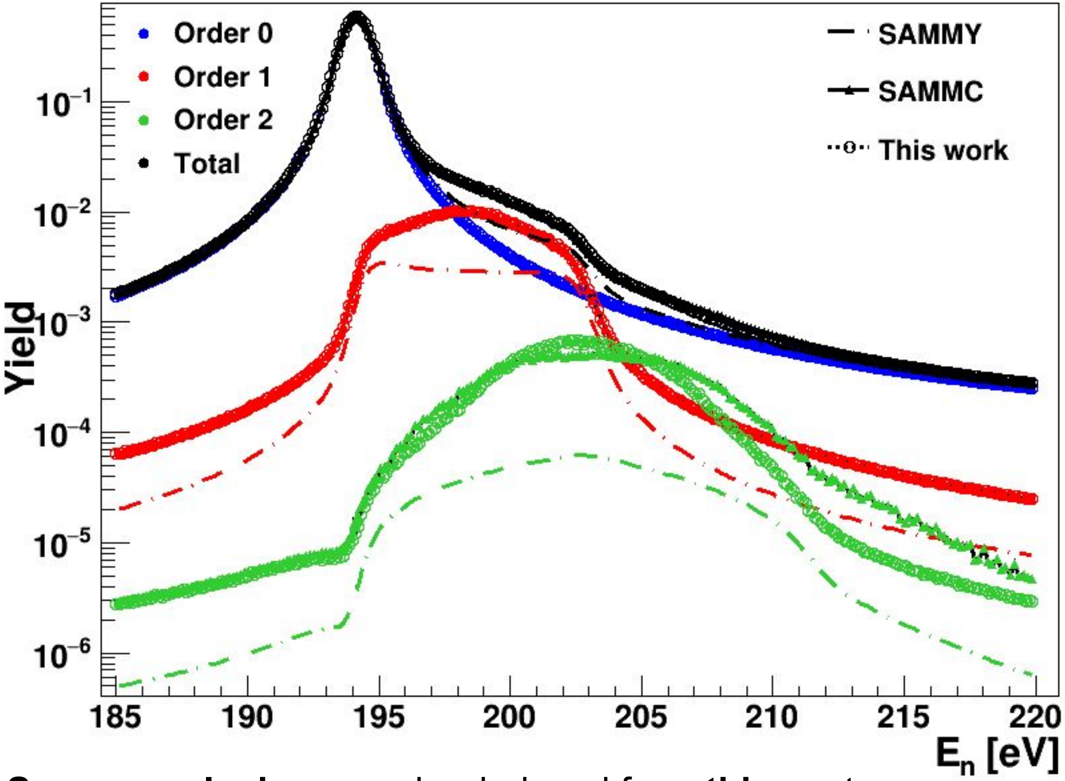


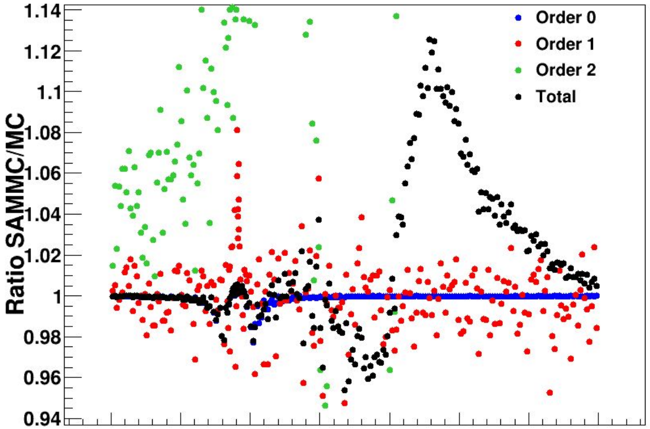
SAMMY and **SAMMC** have **large differences** for such thick target for Y_1 and Y_2

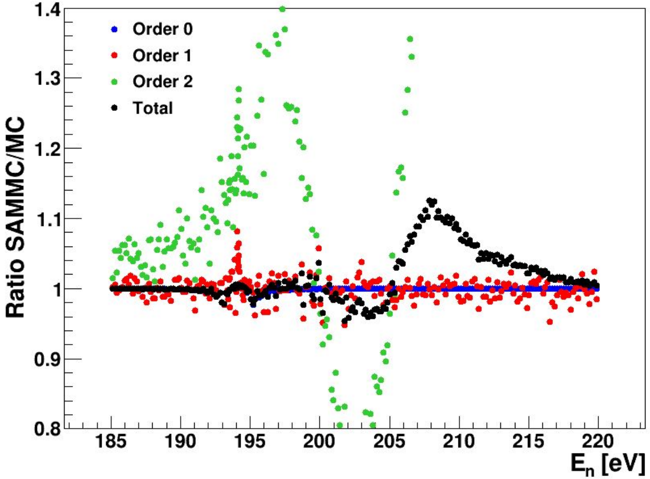
This work and **SAMMC** have differences for Y_0 and Y_1 **<2%**

This work and **SAMMC** have large differences for Y_2

185-220 eV comparison





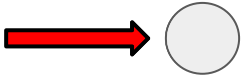


Same conclusions can be deduced from **this** neutron **energy range**

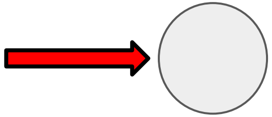
Since **Y_2** has a **larger contribution**, **Y_{total}** differences are **larger**

Wires/Equivalent Disk comparison

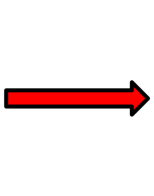
Wire 1 →D=0.8 mm, l=92 mm M=0.388452 g ns=0.500905 At/barn

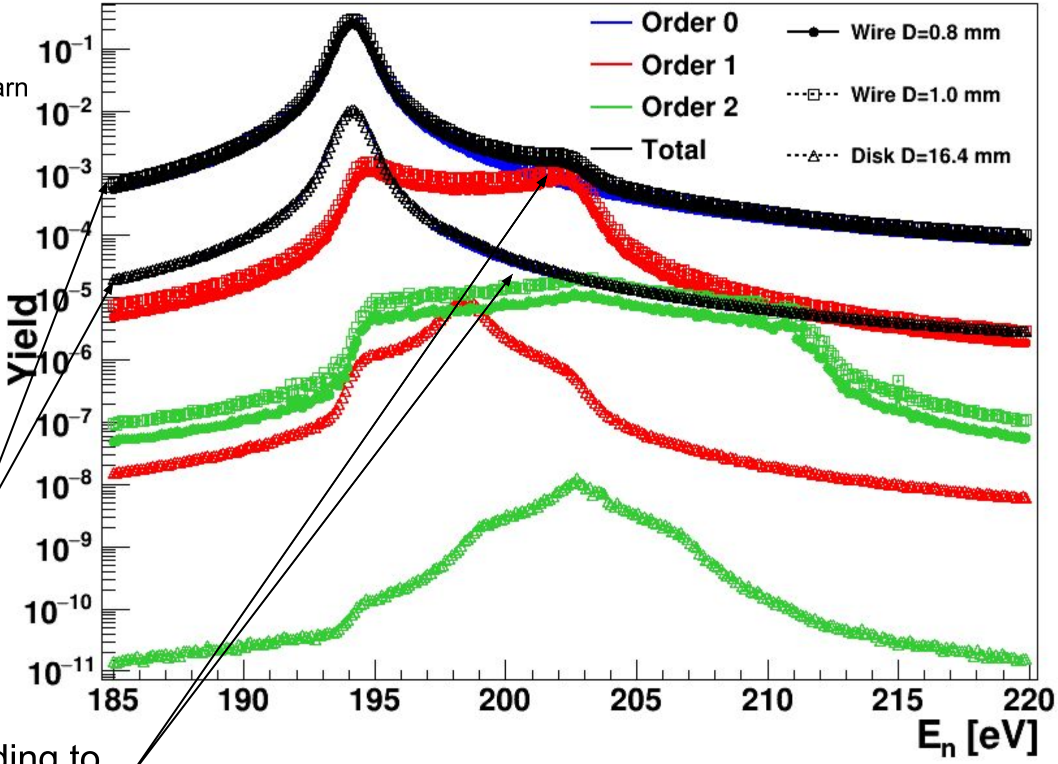


Wire 2→D=1.0 mm l=92 mm M= 0.606956 g ns=0.500905 At/barn



Disk-equivalent →D=16.4 mm l=0.22 mm M= 0.388452 g ns=0.000120073 At/barn





Disk equivalent is a **thin target** compared to wires cases as expected

All, Y_0, Y_1 and Y_2 have a **different shape** leading to a different neutron resonance Y_{tot} shape

Summary and outlook

Analysis on ^{94}Nb(n,ɣ) is **in progress**:

- **Weighting functions** for **thin** and **thick** targets are already **calculated.**
- **(n,ɣ) cascades** are in **progress**:
  - **^{197}Au(n,ɣ)** from **Standa** are **really good**!
  - **^{93}Nb(n,ɣ)** are in **progress**:
    - Very **difficult** for **controlled geometry** because of **DT-PU**.
    - Different **models** for **J^{π}=4^{+}** (reasonable reproduction for 4900 after DT-PU).
  - **^{94}Nb(n,ɣ)** is **on hold** until ^{93}Nb(n,ɣ) is finished.
- **Normalization** for ^{93}Nb ...
  - **^{197}Au** saturated re... **...lue**.
  - Very **preliminar** ^{93}... **...3**.
  - Deal with **unforeseen issues** is always problematic:
    - **DT-PU** corrections & **MS** for **controlled geometry**.
    - **Different** wires **diameters** (**MS**) between ^{93}Nb/^{94}Nb targets & **different BIF**.
- A **Monte Carlo** technique is being followed to **account** for **MS** and different **irradiation axis**:
  - Yield calculation **should be equivalent** to **SAMMC** calculation:
    - **SAMMY cross-sections** and **partial wave** expansion included in the calculation
  - There are **differences** in **Y_2** that I can not explain so far (**Did I forget something?**)
  - **Simplest approximation** to a **disk** would lead to a **misleading** change of **BIF**
  - In the following I will circle back the **output** from this calculation for **SAMMY fitting** as SAMMC do.

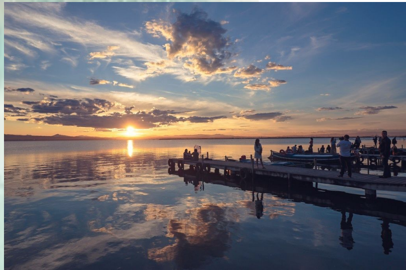
In summary,
work in progress!





Thank you very much for your attention!

Enjoy the city!

^{93}Nb(n,γ) thick target