Status of the REP experiment: Ce, Pr and Nd data

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Outline

- 1. Summary of the data.
- 2. Particle identification.
- 3. Fitting program methodology.
  - 3.1 Background.
  - 3.2 Beta efficiency calculation.
- 4. Fit Results.
  - 4.1 Fit Cesium.
  - 4.2 Fit Praseodymium
  - 4.3 Fit Neodymium.
- 5. Neutron correlated data, Overview.

1. Summary of data. *

- Mergerd files: merged_cleanedPID_a5_
- Files missing:

merged_cleanedPID_a5_R5_71	(Only .csv)
merged_cleanedPID_a5_R5_165	(Only .csv)
merged_cleanedPID_a5_R5_493	(Not Found)
merged_cleanedPID_a5_R5_567	(Only .csv)
merged_cleanedPID_a5_R5_638	(Not Found)

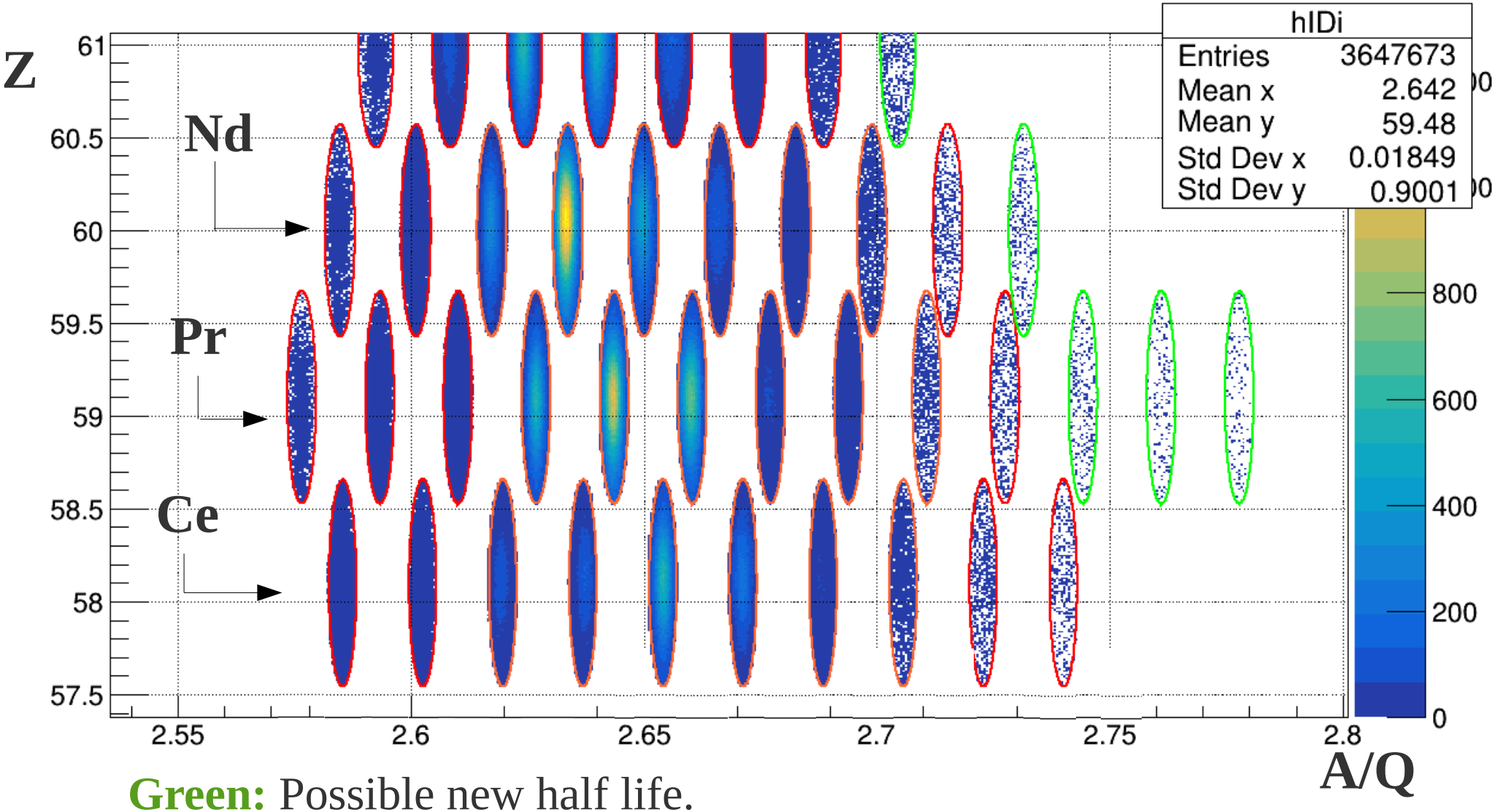
- Degraders:

  From Aida run R5_14 to R5_179 → F11 3 mm
  From Aida run R5_191 to R5_200 → F11 2.3 mm
  From Aida run R5_ 202 to R5_642 → F11 2.8 mm
- Total hours: ~ 60h
- AIDA sort: Lucky Doll
- Anamerger: Anamerger_Reloaded.

  Vetoes in F11: ((*beta).vectorOfAnc.at(ia).ID == 102 || (*beta).vectorOfAnc.at(ia).ID == 103 || (*beta).vectorOfAnc.at(ia).ID == 106)

  106: Aida plastic
  102: F11_PL_R
  103: F11_PL_L

2. PID. UPC DATA: Ce, Pr, Nd



Green: Possible new half life.

3. Eurica Campaigns on the REP region.

94 β-Decay Half-Lives of Neutron-Rich $_{55}$Cs to $_{67}$Ho: Experimental Feedback and Evaluation of the *r*-Process Rare-Earth Peak Formation

J. Wu,[1,2,*] S. Nishimura,[2] G. Lorusso,[2,3,4] P. Möller,[5] E. Ideguchi,[6] P.-H. Regan,[3,4] G. S. Simpson,[7,8,9] P.-A. Söderström,[2] P. M. Walker,[4] H. Watanabe,[10,2] Z. Y. Xu,[11,12] H. Baba,[2] F. Browne,[13,2] R. Daido,[14] P. Doornenbal,[2] Y. F. Fang,[14] G. Gey,[7,15,2] T. Isobe,[2] P. S. Lee,[16] J. J. Liu,[11] Z. Li,[1] Z. Korkulu,[17] Z. Patel,[4,2] V. Phong,[18,2] S. Rice,[4,2] H. Sakurai,[2,12] L. Sinclair,[19,2] T. Sumikama,[2] M. Tanaka,[6] A. Yagi,[14] Y. L. Ye,[1] R. Yokoyama,[20] G. X. Zhang,[10] T. Alharbi,[21] N. Aoi,[6] F. L. Bello Garrote,[22] G. Benzoni,[23] A. M. Bruce,[13] R. J. Carroll,[4] K. Y. Chae,[24] Z. Dombradi,[17] A. Estrade,[25] A. Gottardo,[26,27] C. J. Griffin,[25] H. Kanaoka,[14] I. Kojouharov,[28] F. G. Kondev,[29] S. Kubono,[2] N. Kurz,[28] I. Kuti,[17] S. Lalkovski,[4] G. J. Lane,[30] E. J. Lee,[24] T. Lokotko,[11] G. Lotay,[4] C.-B. Moon,[31] H. Nishibata,[14] I. Nishizuka,[32] C. R. Nita,[13,33] A. Odahara,[14] Zs. Podolyák,[4] O. J. Roberts,[34] H. Schaffner,[28] C. Shand,[4] J. Taprogge,[35,36] S. Terashima,[10] Z. Vajta,[17] and S. Yoshida[14]

analysis allowed control of the purity of the ions, so that it could be accounted for in the half-life analysis. The β-decay half-life of an isotope of interest was extracted from the fit of the time distribution of electrons detected after the implantation of an ion, and correlated to them in position and time [20–24], employing the least-squared and unbinned maximum likelihood methods in a parallel analysis that included contributions from the decays of parent, daughters, granddaughters, as well as a constant background. In some cases, β-decay curves gated on β-delayed γ rays were used to confirm the previous results. The half-lives of daughter nuclei used in the fit were either measured in our experiment or taken from literature [25]. The β-delayed neutron emission probabilities (P_n) were taken from literature [25] if available. Whereas they were varied in the fit within a range up to

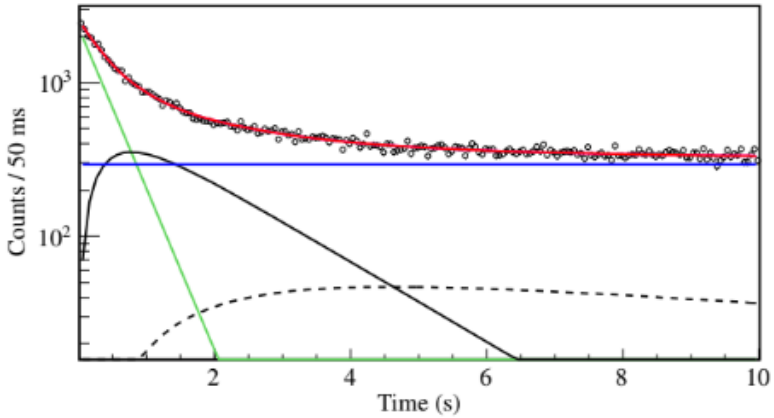


FIG. 2. Time distribution of ^{157}Pr β-decay events fitted to the sum of activities of several components: parent nuclei (solid green line), daughter nuclei (solid black line), granddaughter nuclei (dashed black line), as well as a constant background (solid blue line). The other components, including β-delayed daughter nuclei and β-delayed granddaughter nuclei, are not shown in this figure.

Ref: J.Wu. et. Al, 98 β Decay Half-Lives of neutron-rich $_{55}$Cs to $_{67}$Ho, Physical Review Letters, February 2017. Doi: 10.1103/PhysRevLett.118.072701

3. Fitting Program**. Methodology

- **Batteman Equations:**

$$\frac{dX_1}{dt} = -\lambda_1 X_1$$

$$\frac{dX_2}{dt} = -\lambda_{X2} + \lambda_1 X_1 P_{\beta 1}$$

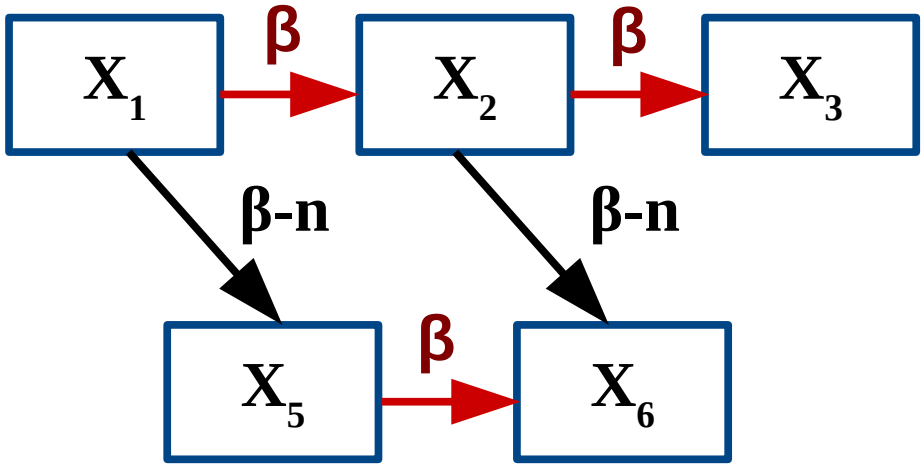
$$\frac{dX_3}{dt} = -\lambda_3 X_3 + \lambda_2 X_2 P_{\beta 2}$$

$$\frac{dX_5}{dt} = -\lambda_5 X_5 + \lambda_1 X_1 P_{n1}$$

$$\frac{dX_6}{dt} = -\lambda_6 X_6 + \lambda_5 X_5 P_{\beta 5} + \lambda_2 X_2 P_{n2}$$

- **Initial Conditions:**

$$X_1(t=0) = X_0,$$
$$X_i(t=0) = 0, \;\; i = 2, 3.$$



- From the fit we want to obtain:
  - T12 and X0

- Other parameters introduced as random variables

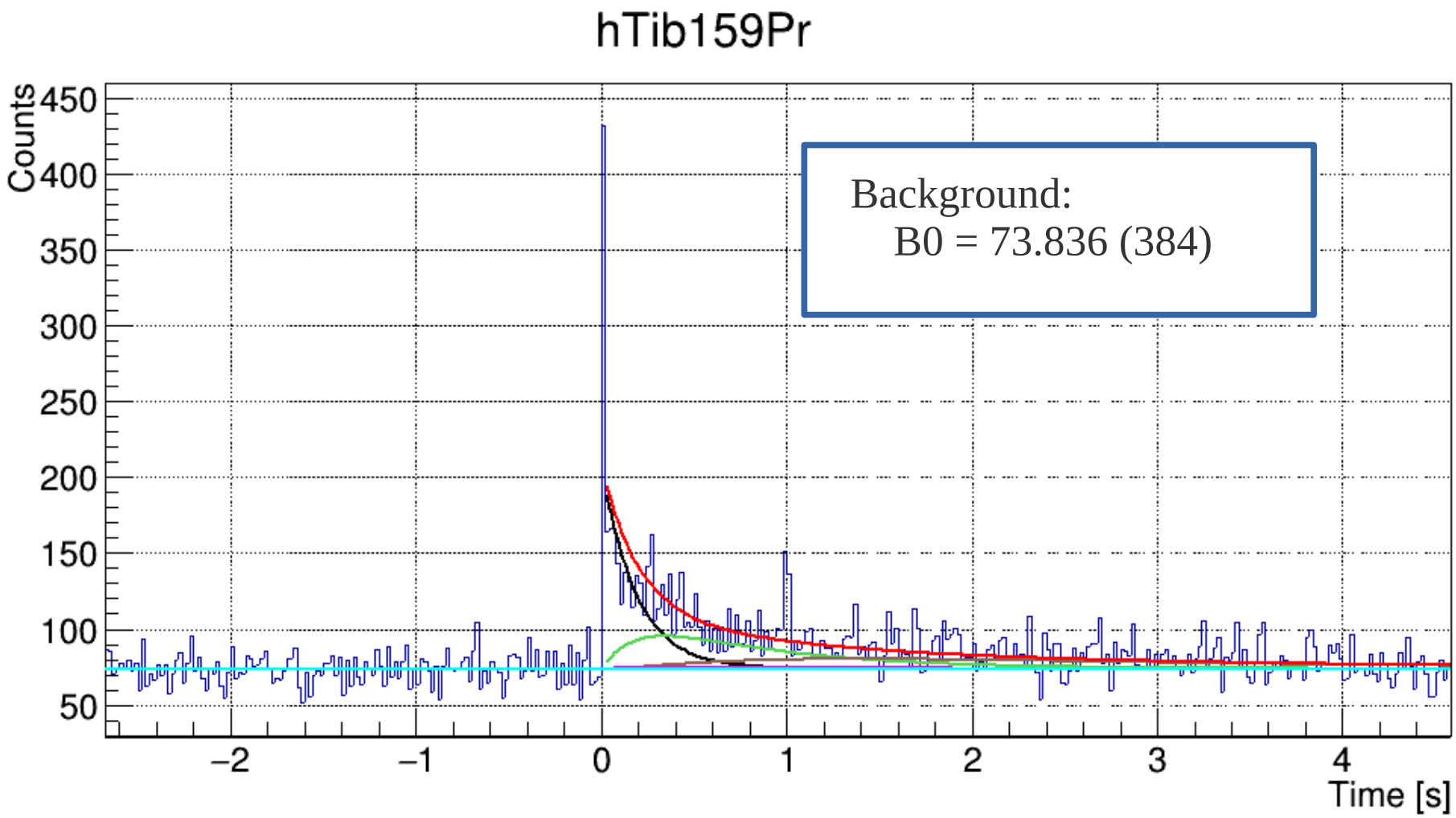
- Fit is done 1000 times.

- Final value of t12:
  - Mean of the results.

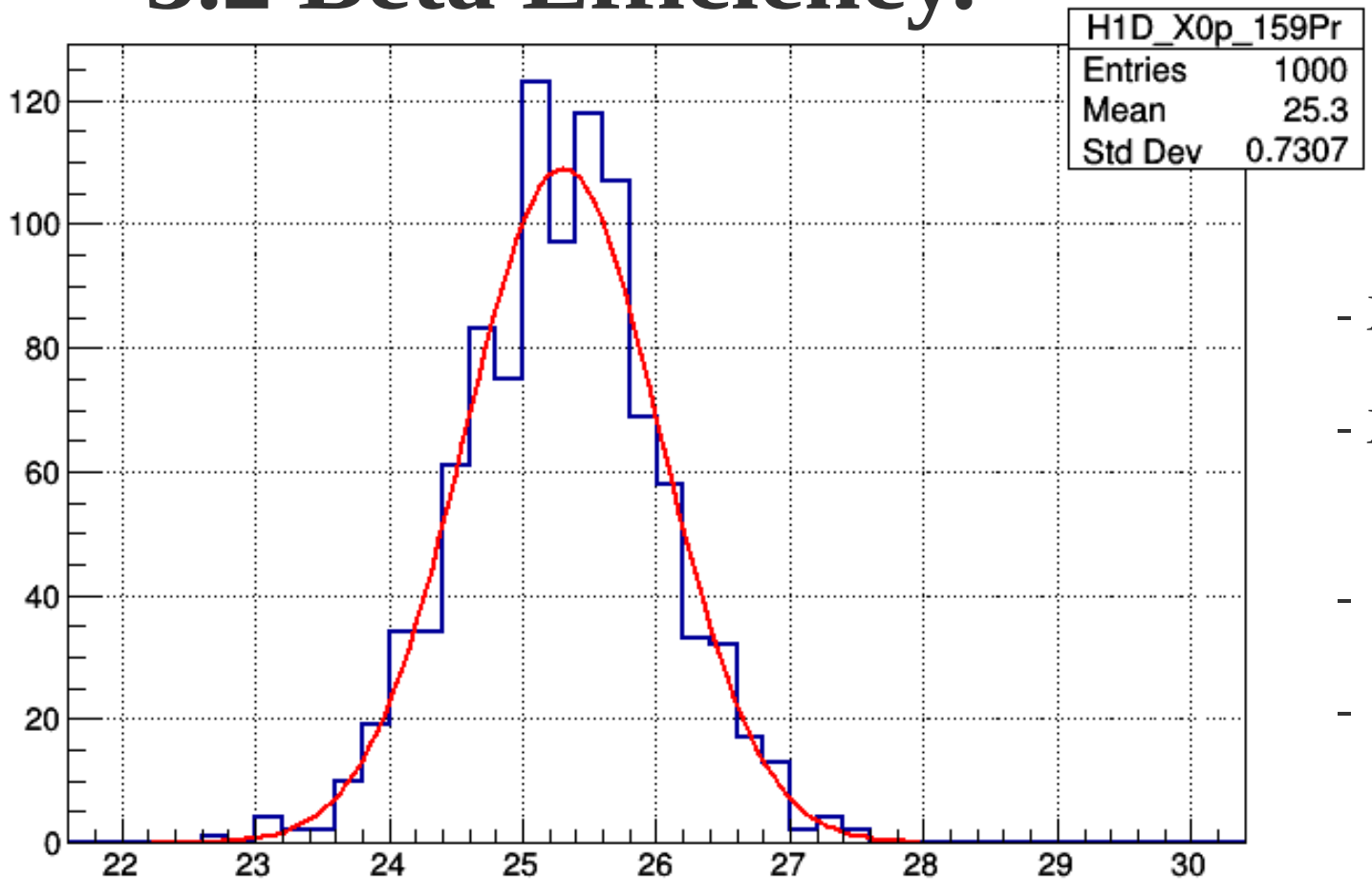
** A. Navarro, Masther thesis, U. Sevilla, coming soon...

3.1 Background.

- Constant Background: No anomalies detected.



3.2 Beta Efficiency.

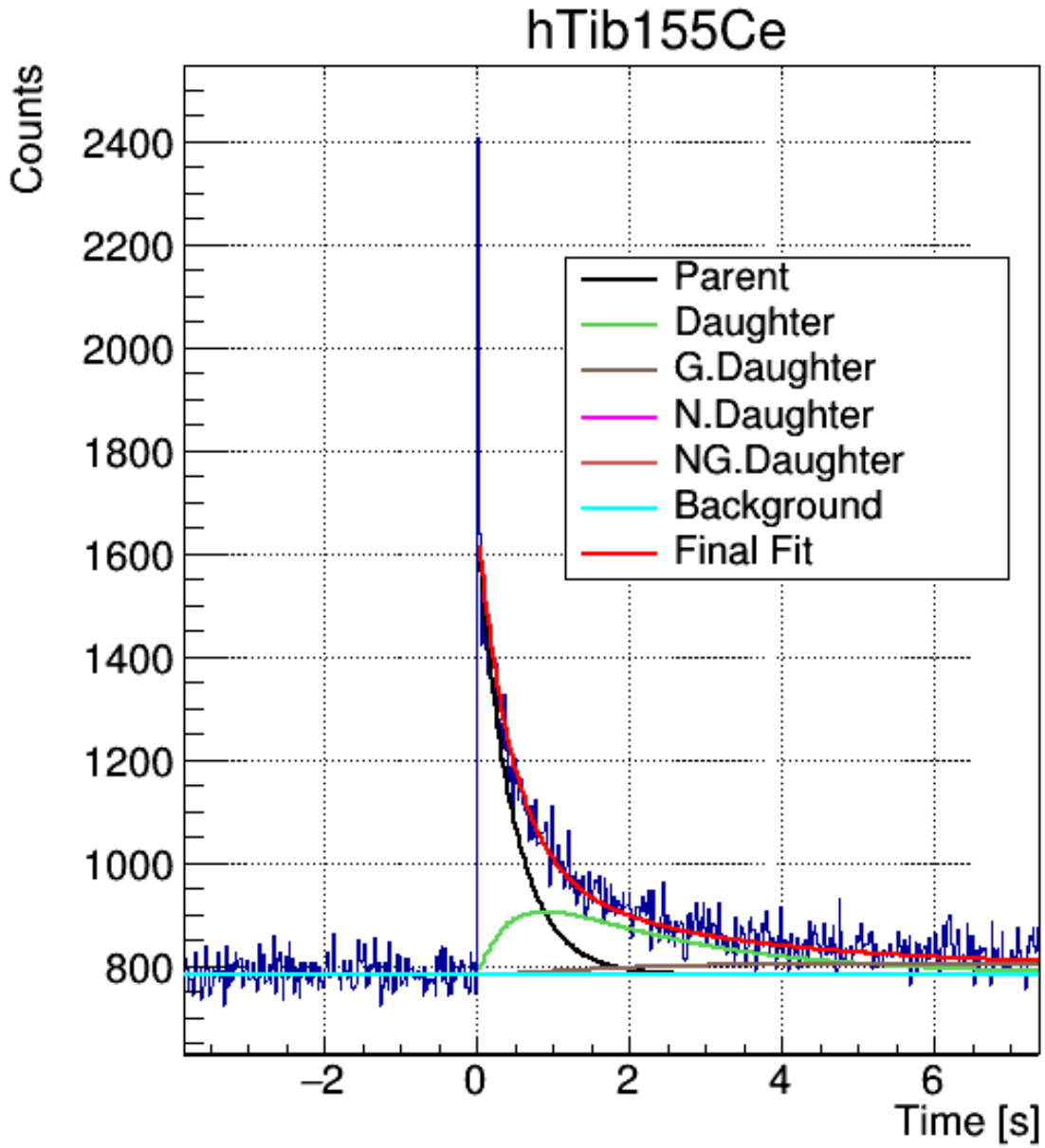


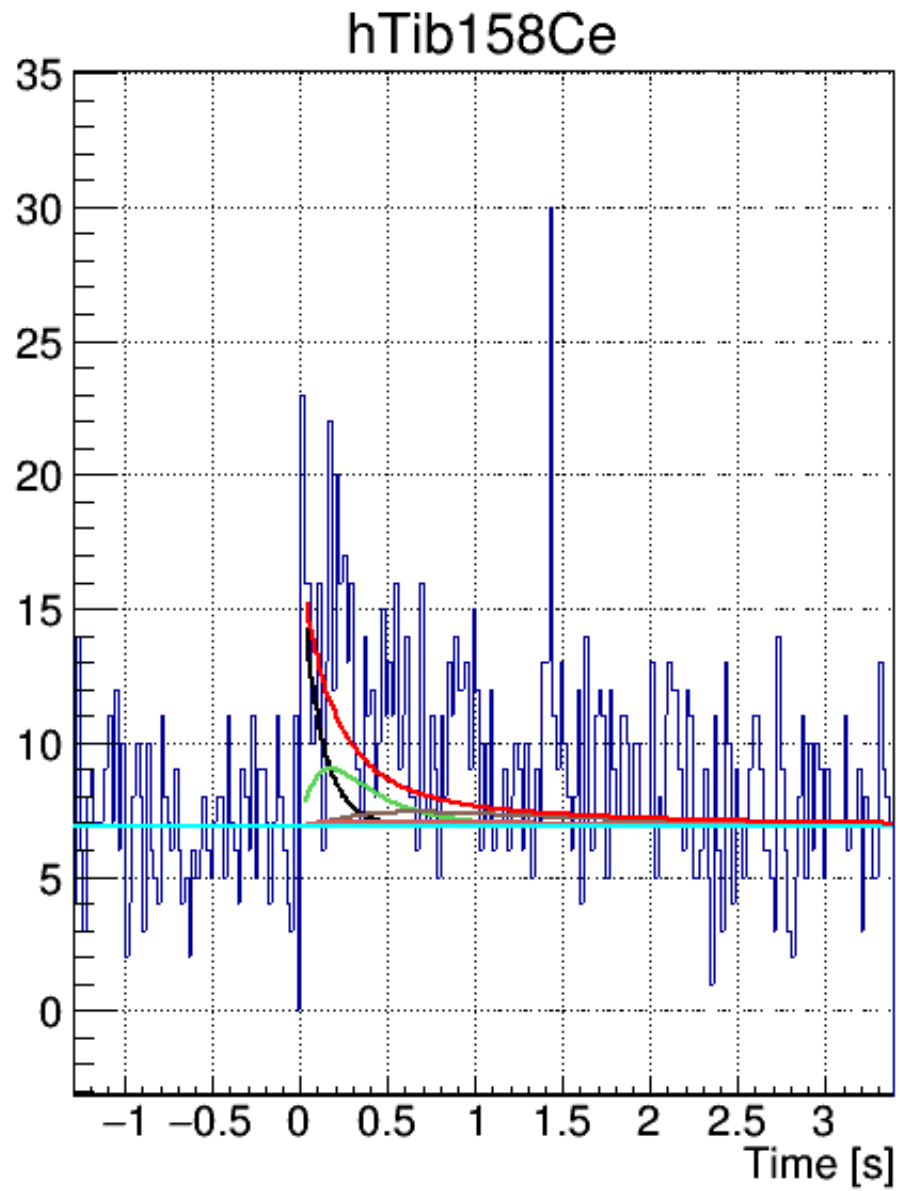
- X0: Activity*Bin_Width
- X0 is an output form the fit program.
- Error of X0: Std Dev.
- No Error in $N_{implants}$

$$\beta_{eff} = \frac{X0_{mean}}{N_{implants} \cdot Bin_{width}}$$

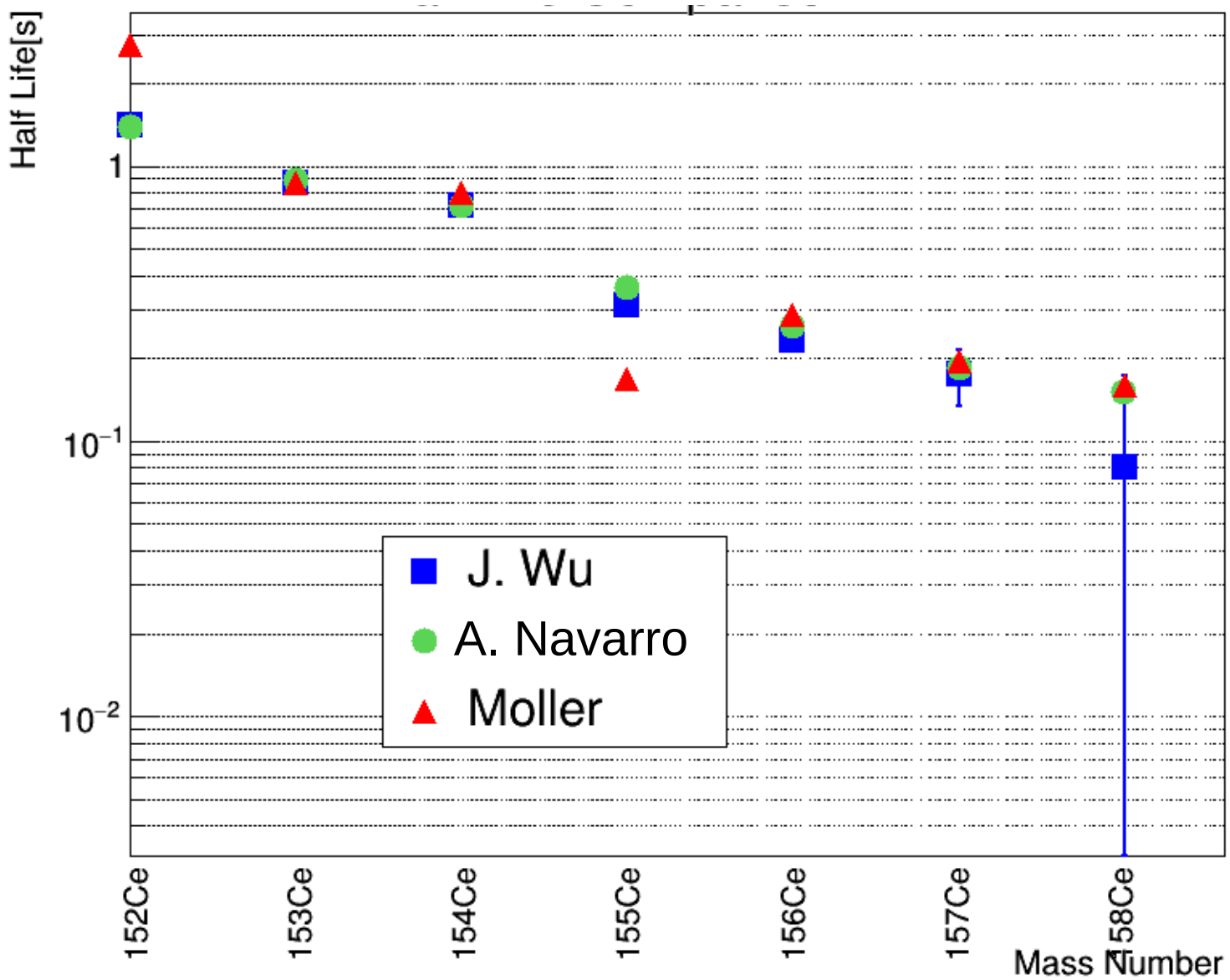
4. Some Results ...

4.1 T12 Fit Results: Ce (Cerium)





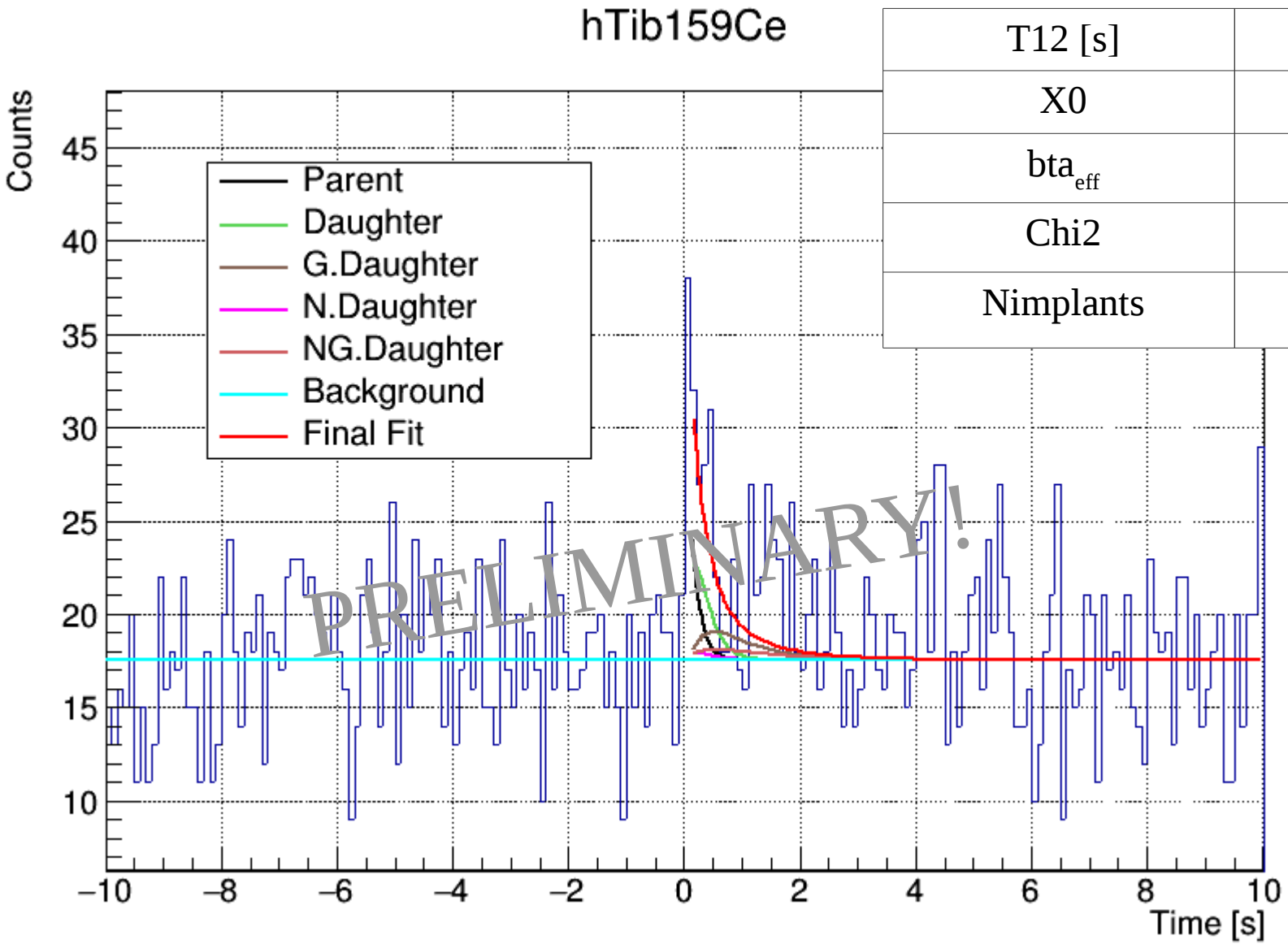
4.1 Summary T12 Ce



4.1 Summary T12 Ce

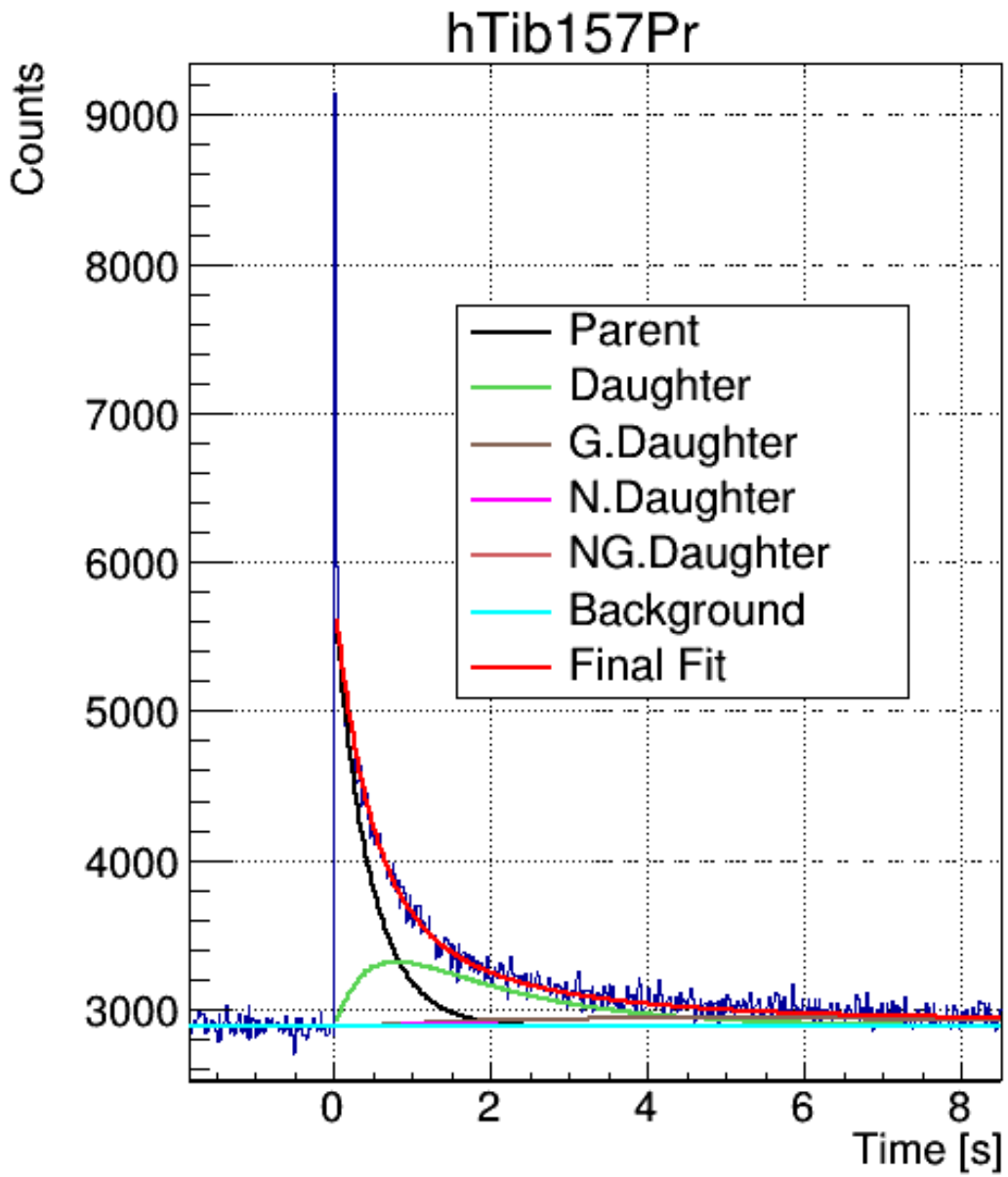
Nuclei	Background/ (counts/bin)	T12/s EURICA	T12/s BRIKEN	Beta Eff	Chi2/N
152Ce	292.42(76)	1.42(2)	1.393(24)	0.262(5)	0.523
153Ce	422.12(91)	0.865(3)	0.889(17)	0.242(5)	1.118
154Ce	1839.4(19)	0.722(14)	0.716(7)	0.262(3)	1.140
155Ce	781.8(12)	0.313(7)	0.362(17)	0.231(10)	1.050
156Ce	214.95(65)	0.233(9)	0.261(3)	0.216(2)	1.098
157Ce	20.43(20)	0.175(41)	0.185(11)	0.163(7)	1.040
158Ce	6.90(11)	0.09(9)	0.173(6)	0.16(5)	0.657

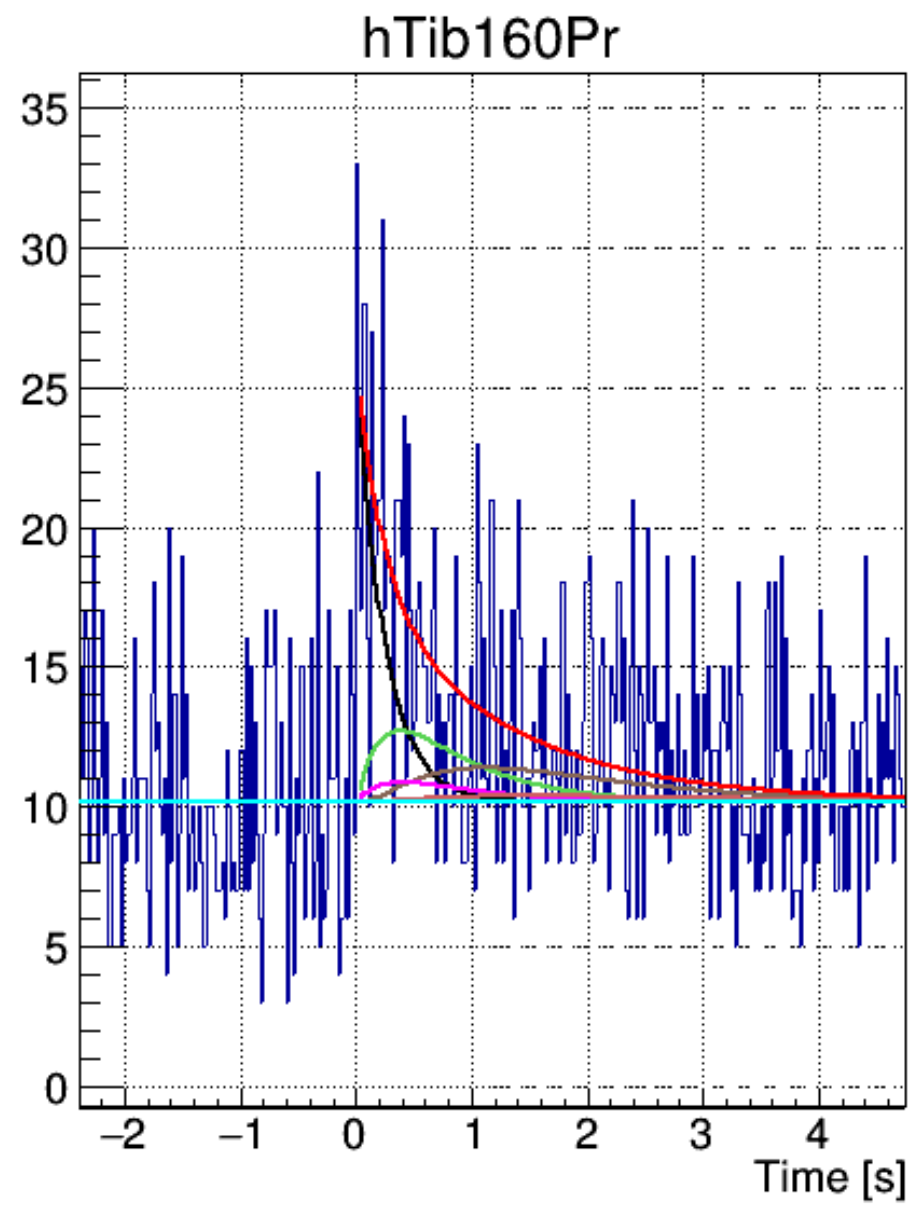
4.1 Cerium NEW T12



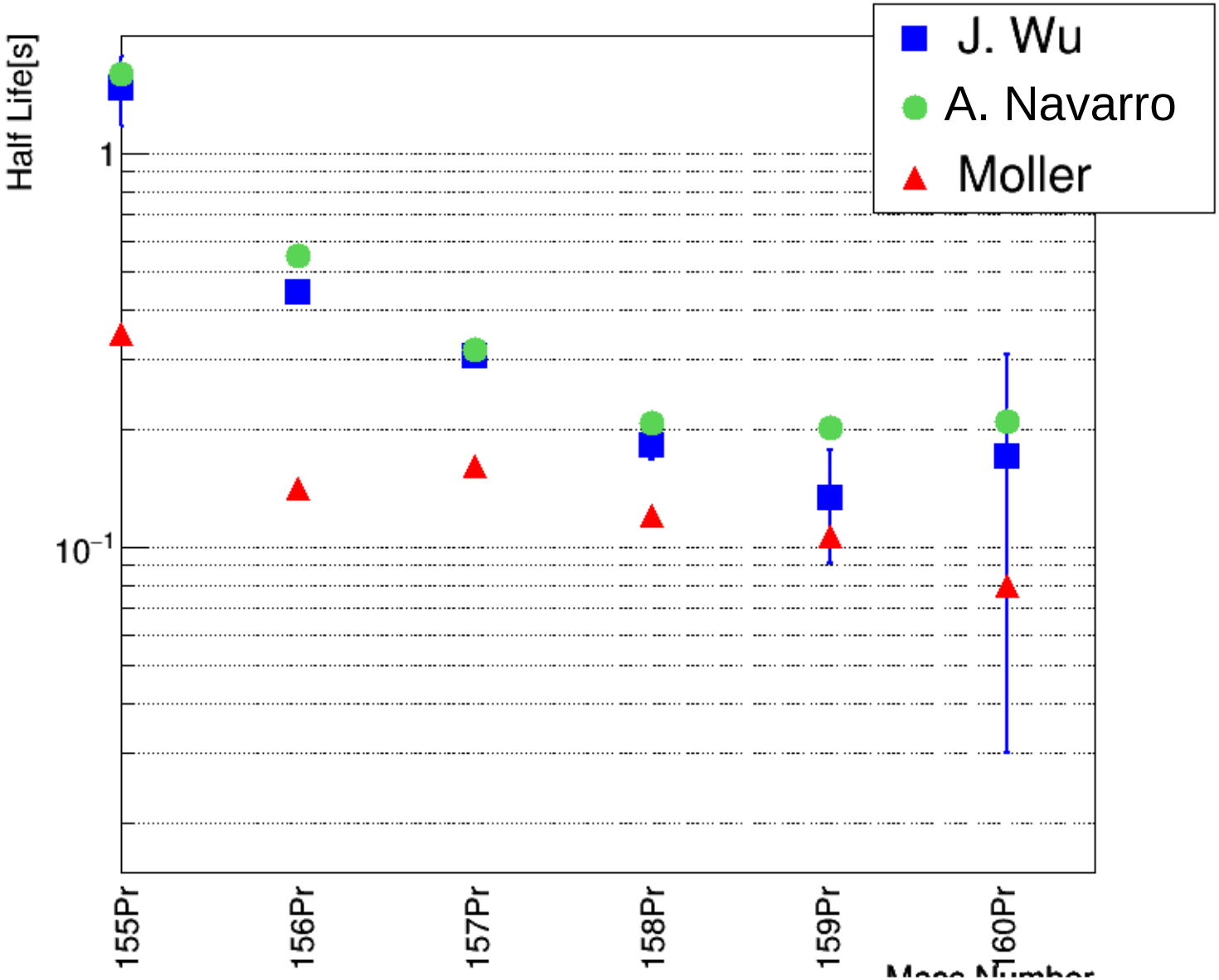
T12 [s]	0.147(50)
X0	2.6(20)
bta_{eff}	0.068(51)
Chi2	0.675
Nimplants	401

4. T12 Fit Results: Pr (Praseodymium)





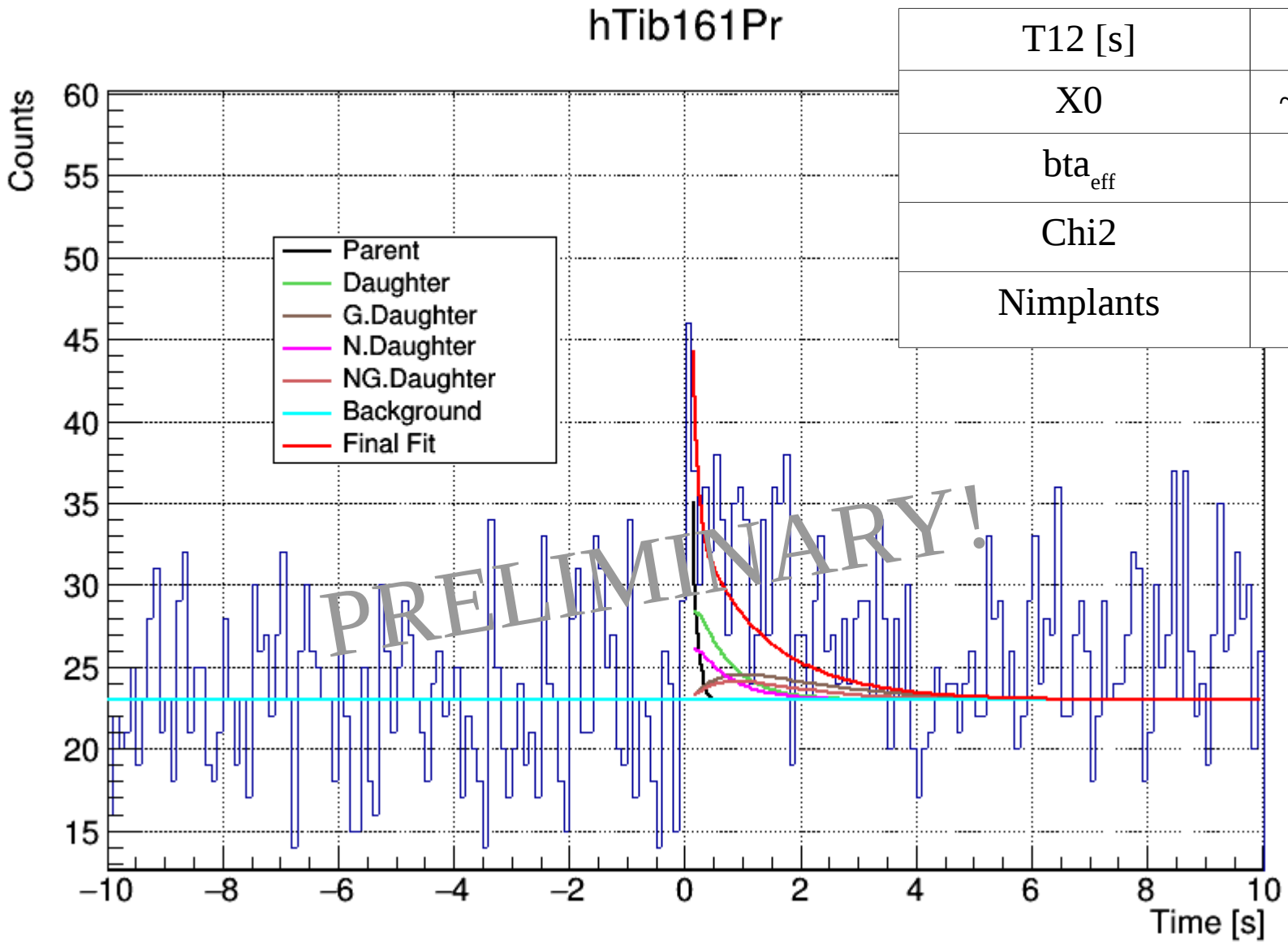
4.2 Summary T12 Pr



4.2 Summary T12 Pr

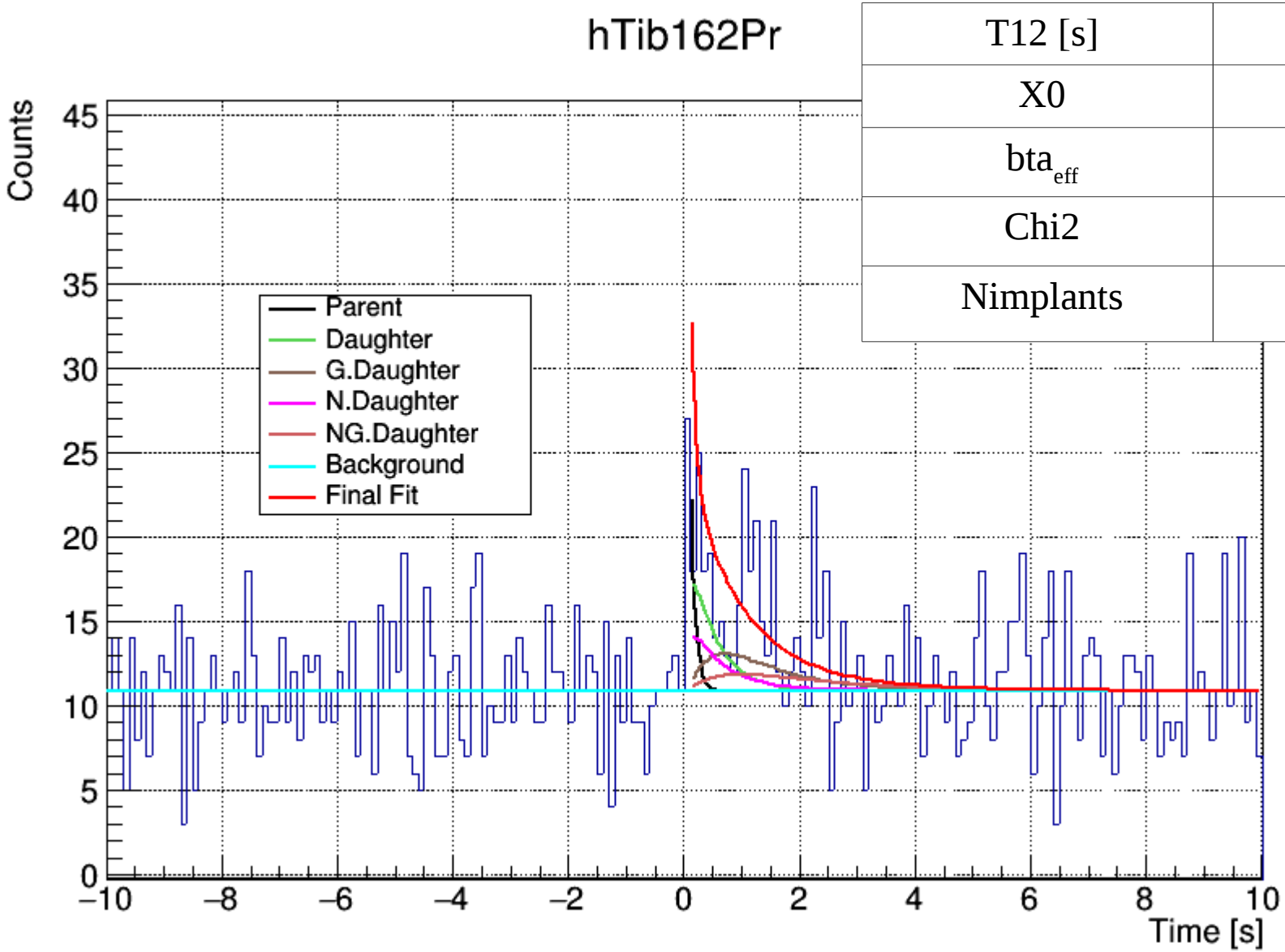
Nuclei	Background/ (counts/bin)	T12/s EURICA	T12/s BRIKEN	Beta Eff	Chi2/N
155Pr	2062(2)	1.47(30)	1.595(22)	0.264(4)	1.117
156Pr	3814(3)	0.444(6)	0.551(5)	0.247(2)	1.393
157Pr	2879(2)	0.307(21)	0.318(5)	0.220(5)	1.181
158Pr	290.7(7)	0.181(14)	0.206(3)	0.209(3)	1.112
159Pr	65.1(3)	0.134(43)	0.201(6)	0.185(4)	1.196
160Pr	10.1(1)	0.17(14)	0.208(10)	0.146(4)	1.155

4.1 Praseodymiun NEW T12



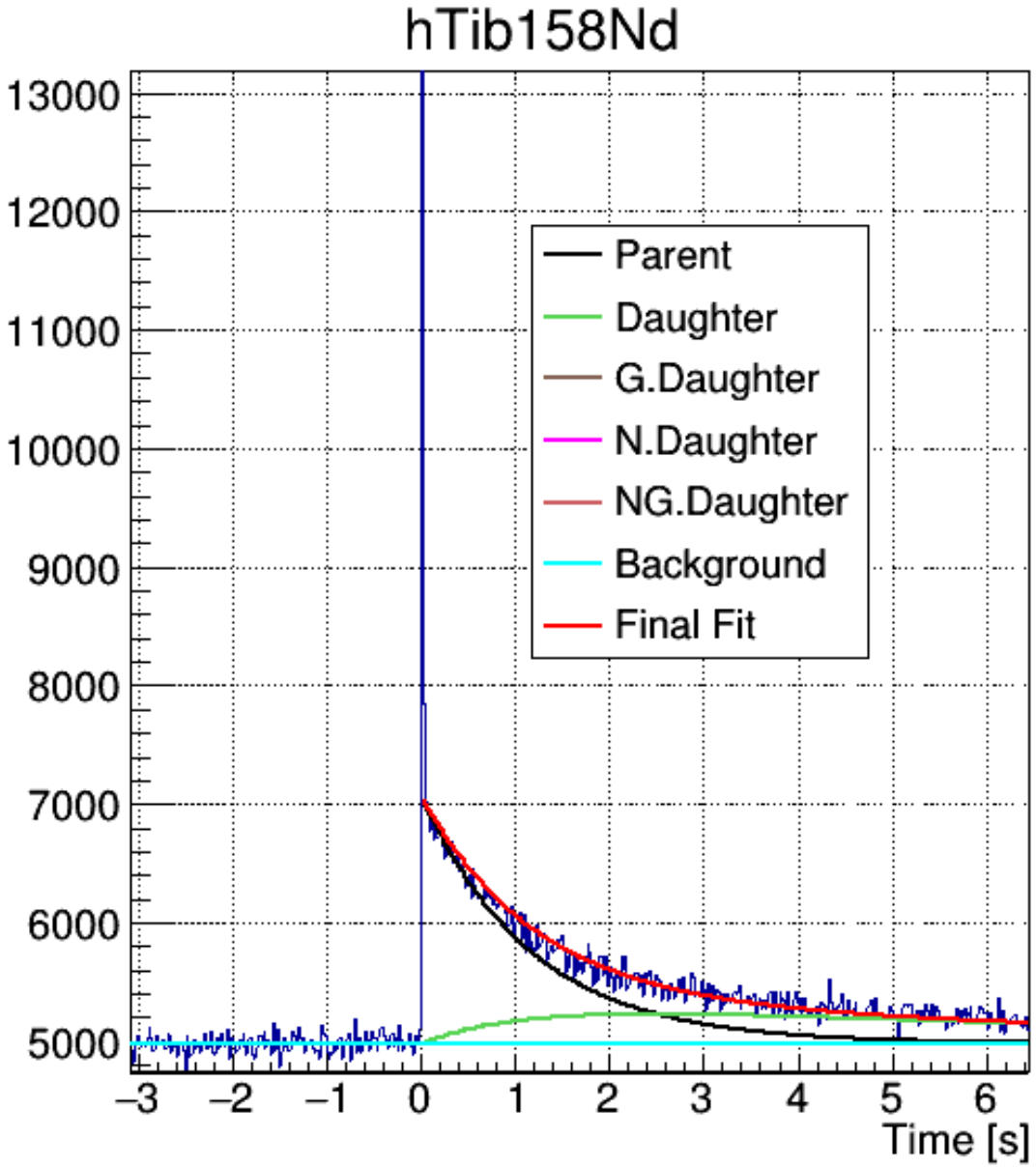
T12 [s]	0.029(3)
X0	~7 (Very Sensitive)
bta_{eff}	0.116
Chi2	0.91
Nimplants	602

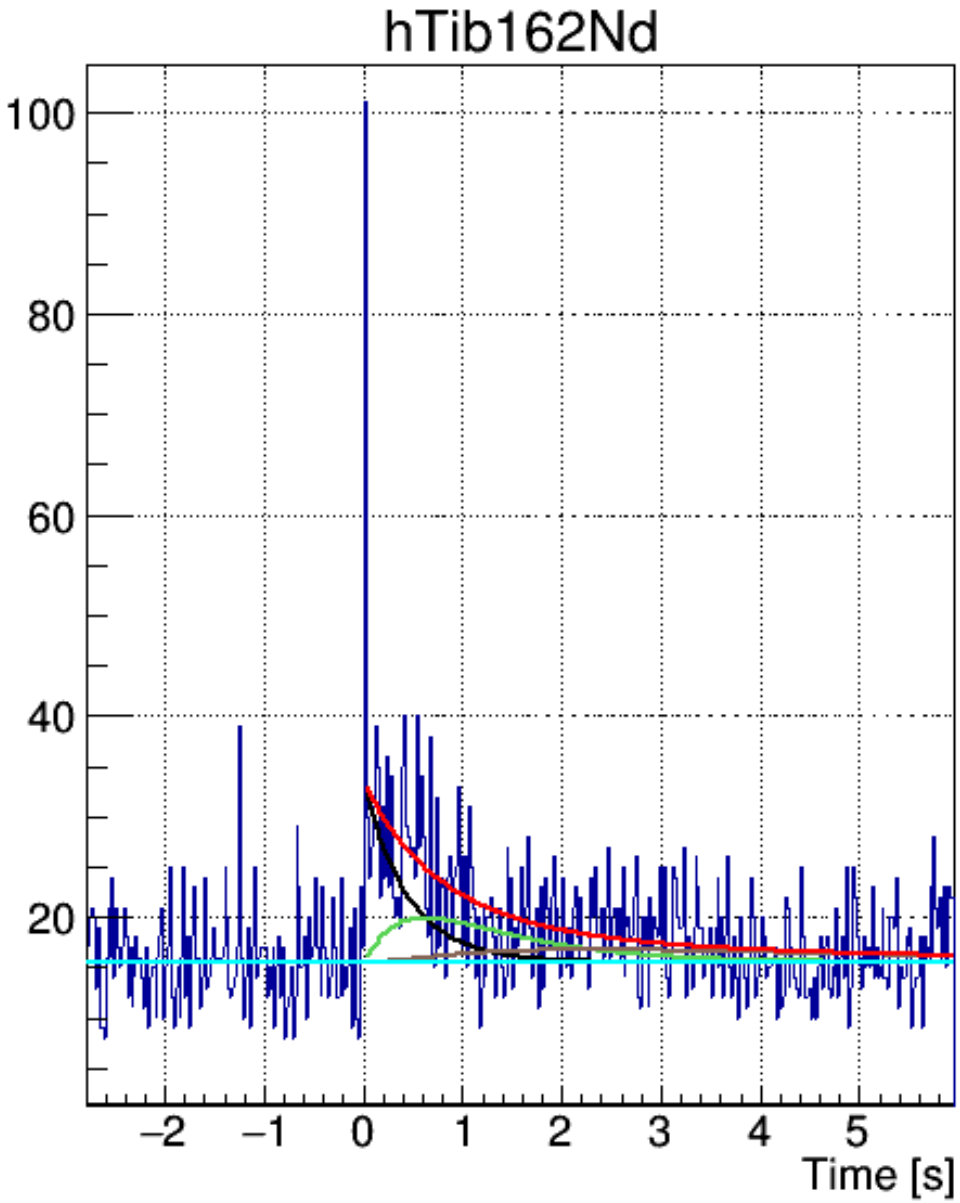
4.1 Praseodymiun NEW T12



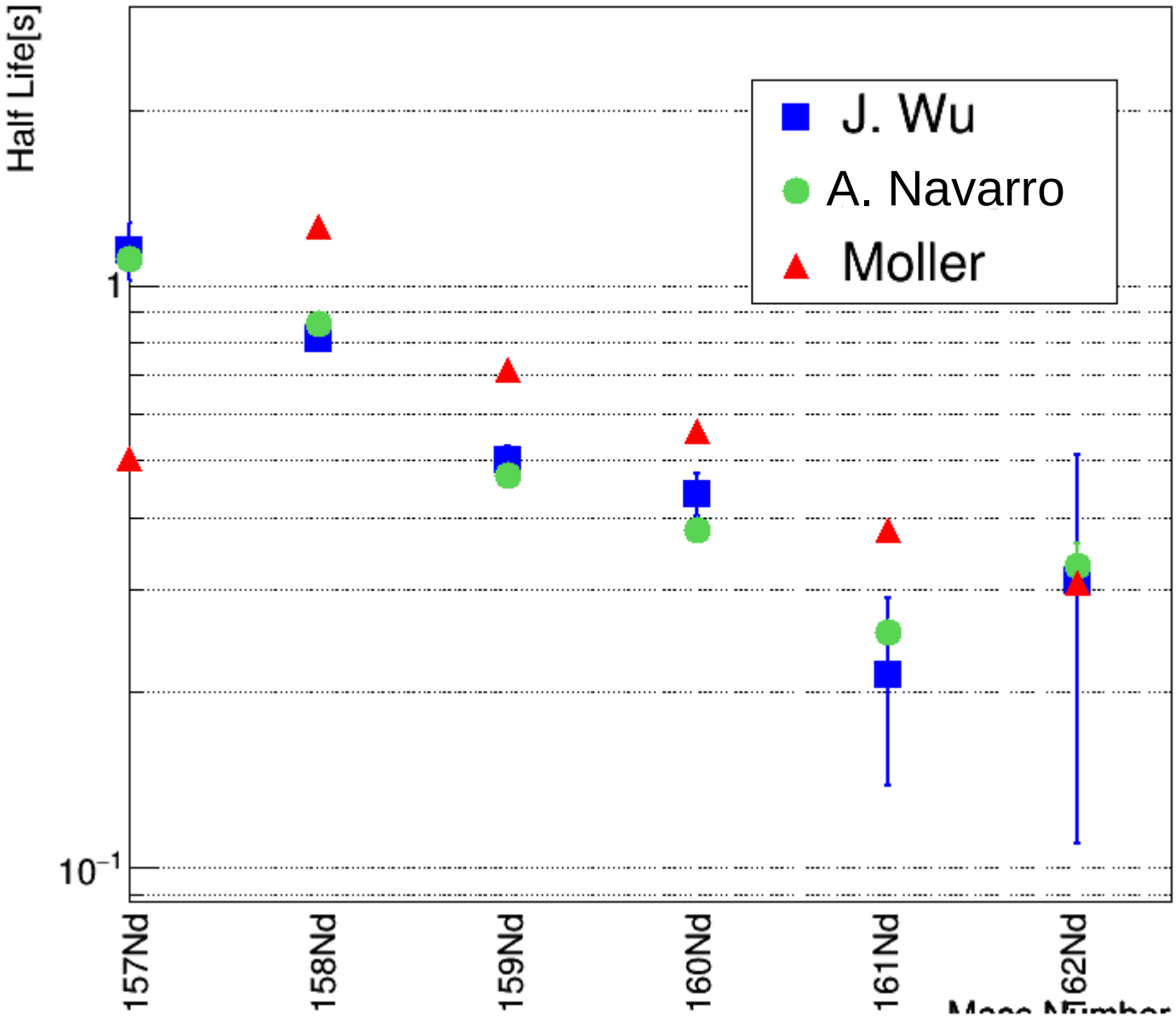
T12 [s]	0.014(83)
X0	6.56(84)
bta_{eff}	10.89(33)
Chi2	1.37
Nimplants	290

4. T12 Fit Results: Nd (Neodymium)





4.3 Summary T12 Nd

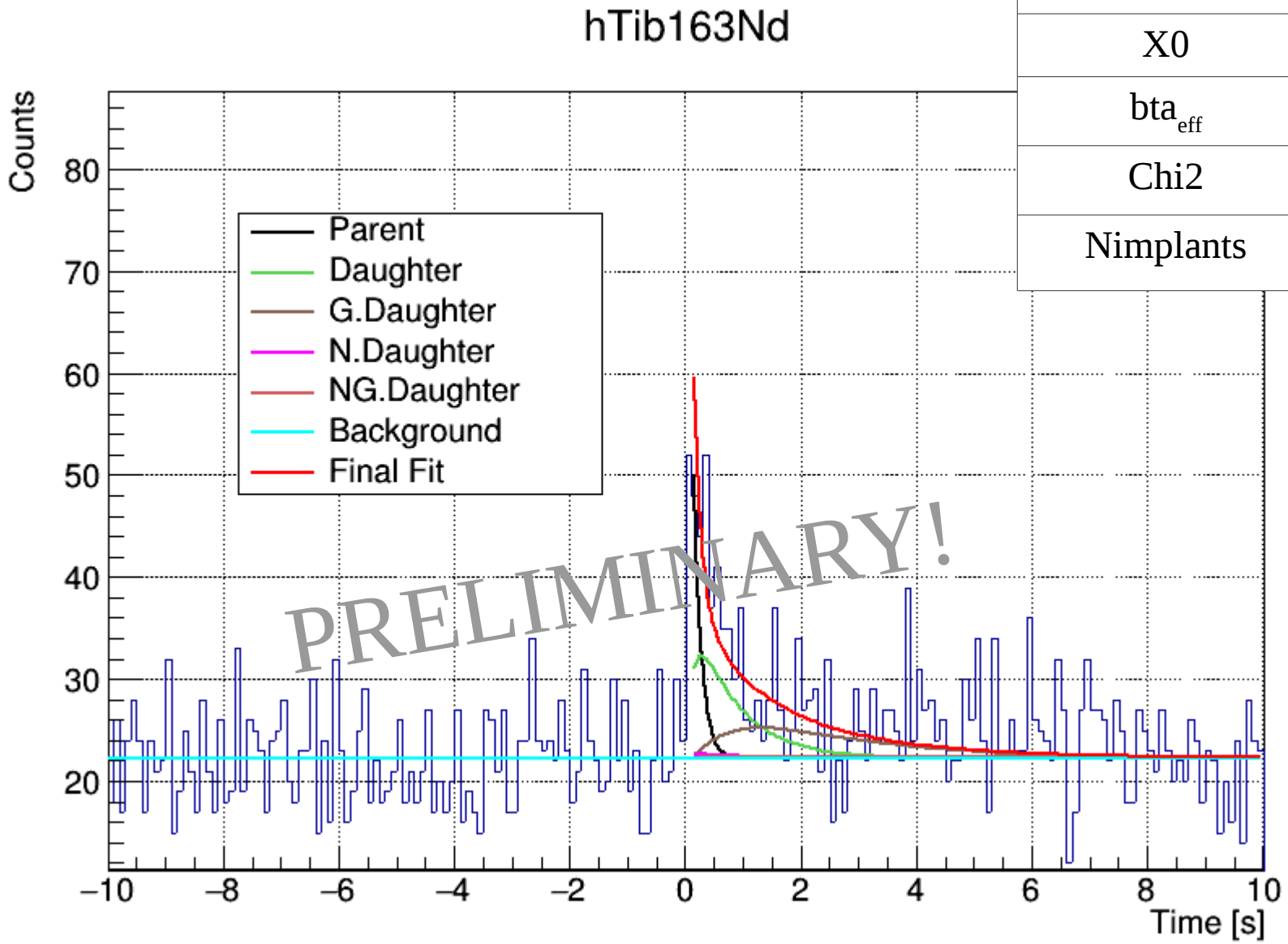


4.3 Summary T12 Nd

Nuclei	Background/ (counts/bin)	T12/s EURICA	T12/s BRIKEN	Beta Eff	Chi2/N
157Nd	1270(1)	1.15(13)	1.11(19)	0.222(4)	1.070
158Nd	4981(3)	0.81(3)	0.859(24)	0.247(6)	1.260
159Nd	1838(2)	0.50(3)	0.472(6)	0.215(4)	1.362
160Nd	521(1)	0.439(37)	0.380(5)	0.198(3)	1.481
161Nd	63.7(3)	0.215(76)	0.254(8)	0.193(7)	1.292
162Nd	15.5(2)	0.31(2)	0.330(29)	0.178(10)	1.170

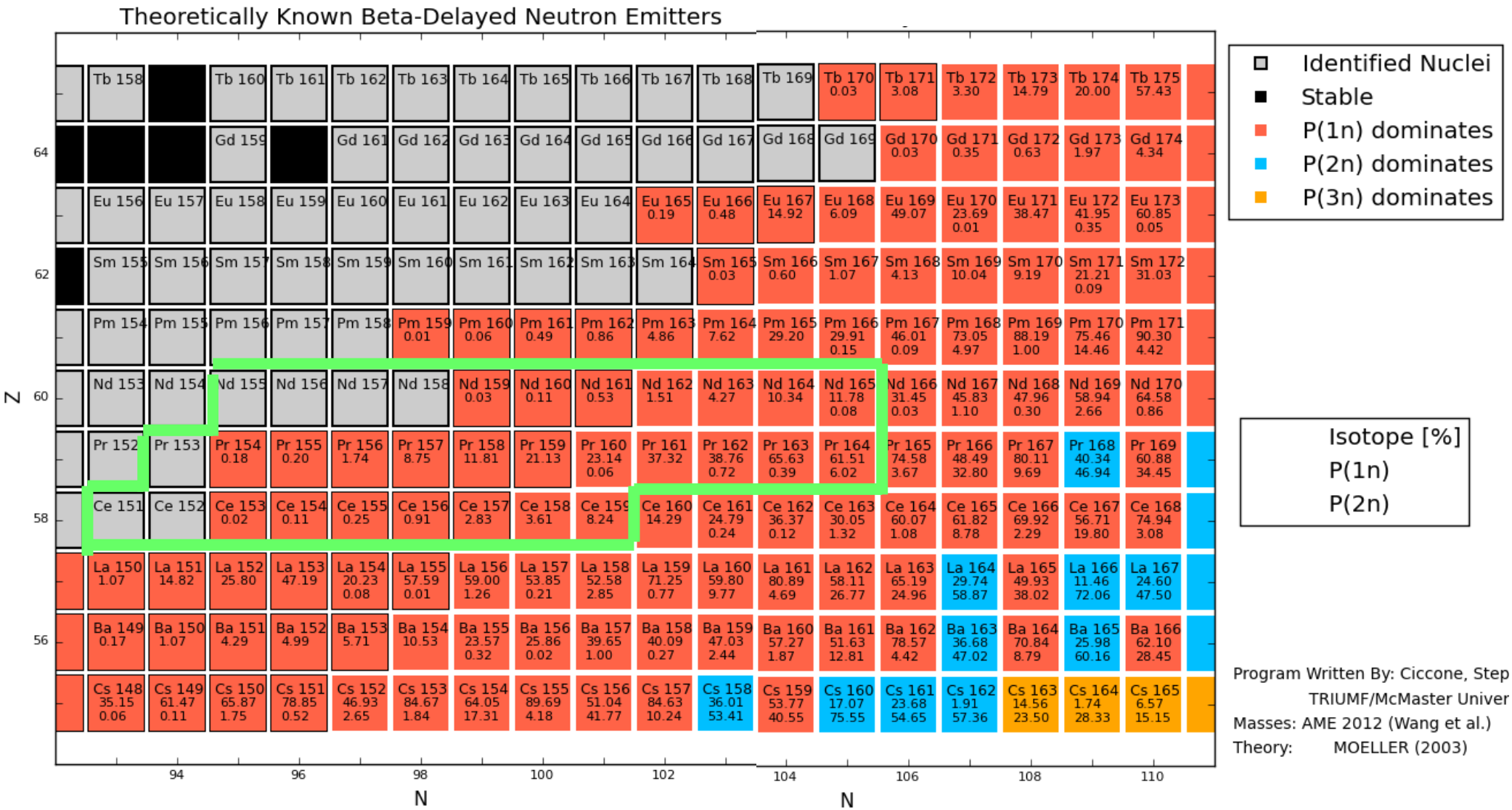
4.1 Neodymiun NEW T12

T12 [s]	0.23(4)
X0	11.4(17)
bta_{eff}	0.169(25)
Chi2	1.066
Nimplants	677



5.0 Pn Values, Overview

- Pn values in this region are only theoretical.
- **Green:** Möller's Pn values for Ce, Pr, Nd.



5.1 Pn Values, Overview REP run 2018

- Data used: Nearline Analysis.

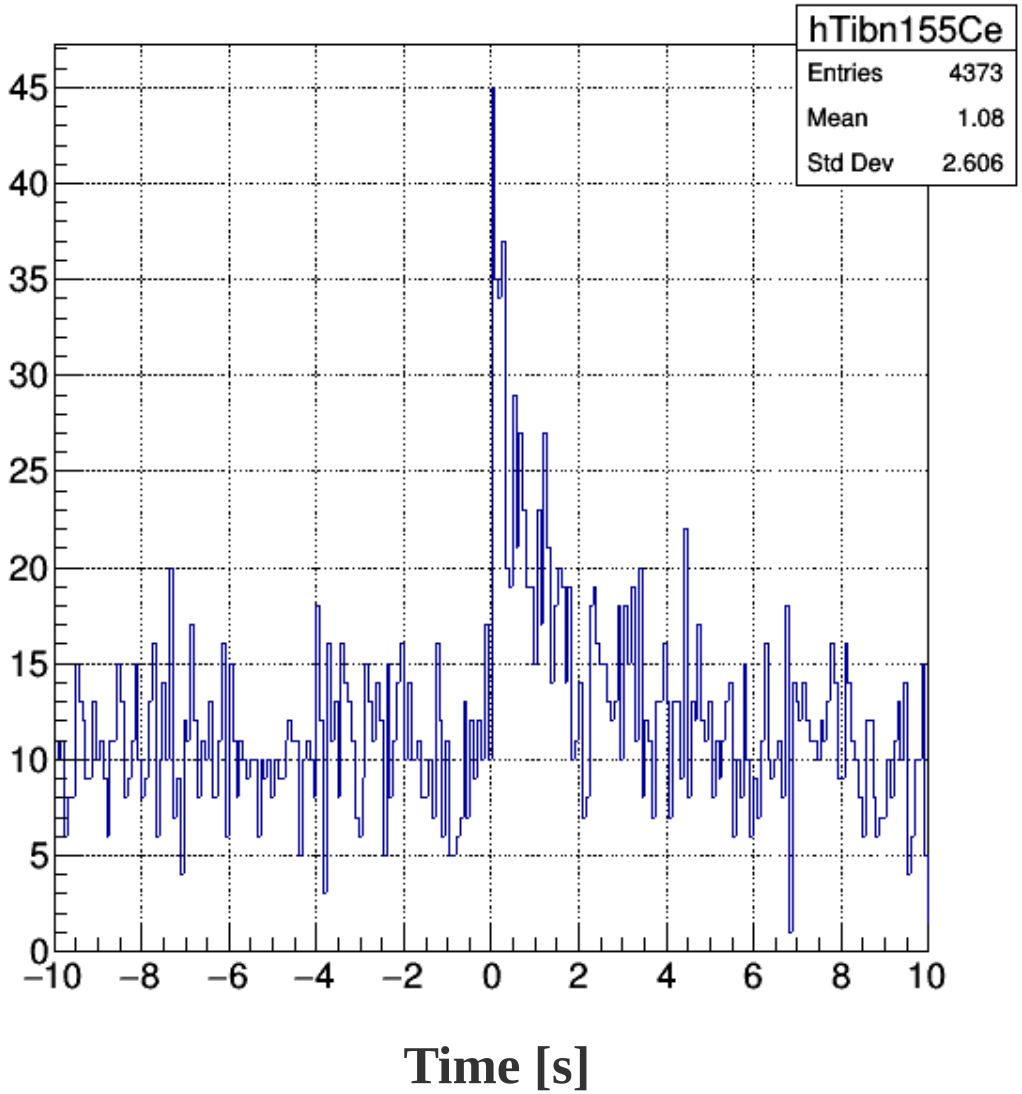
- Limited data from nearline mergers. There was an error in Briken's offline data.

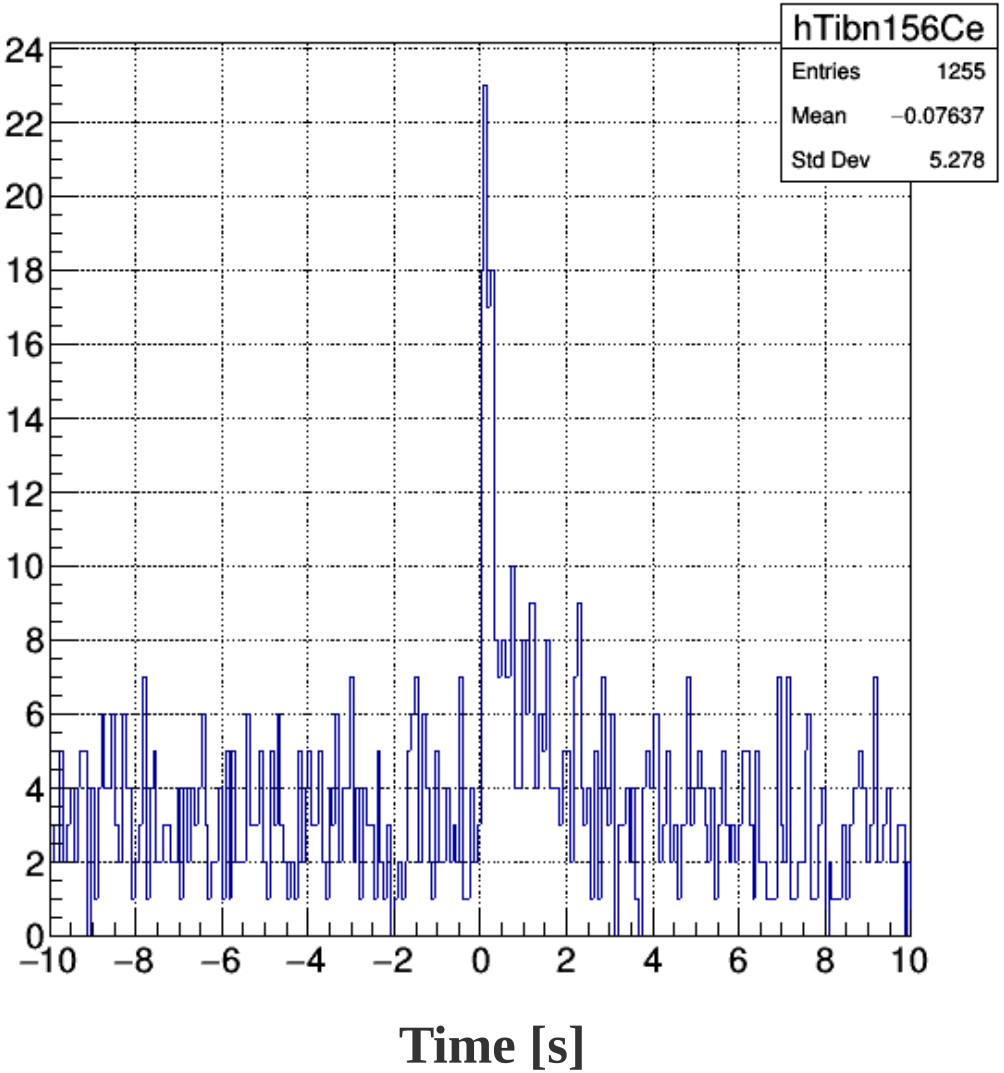
  - Smaller efficiency.
  - Not all the statistics are present in the following plots.

- Briken's REP data is being reprocessed.

5.2 Pn values, hTibn Ce

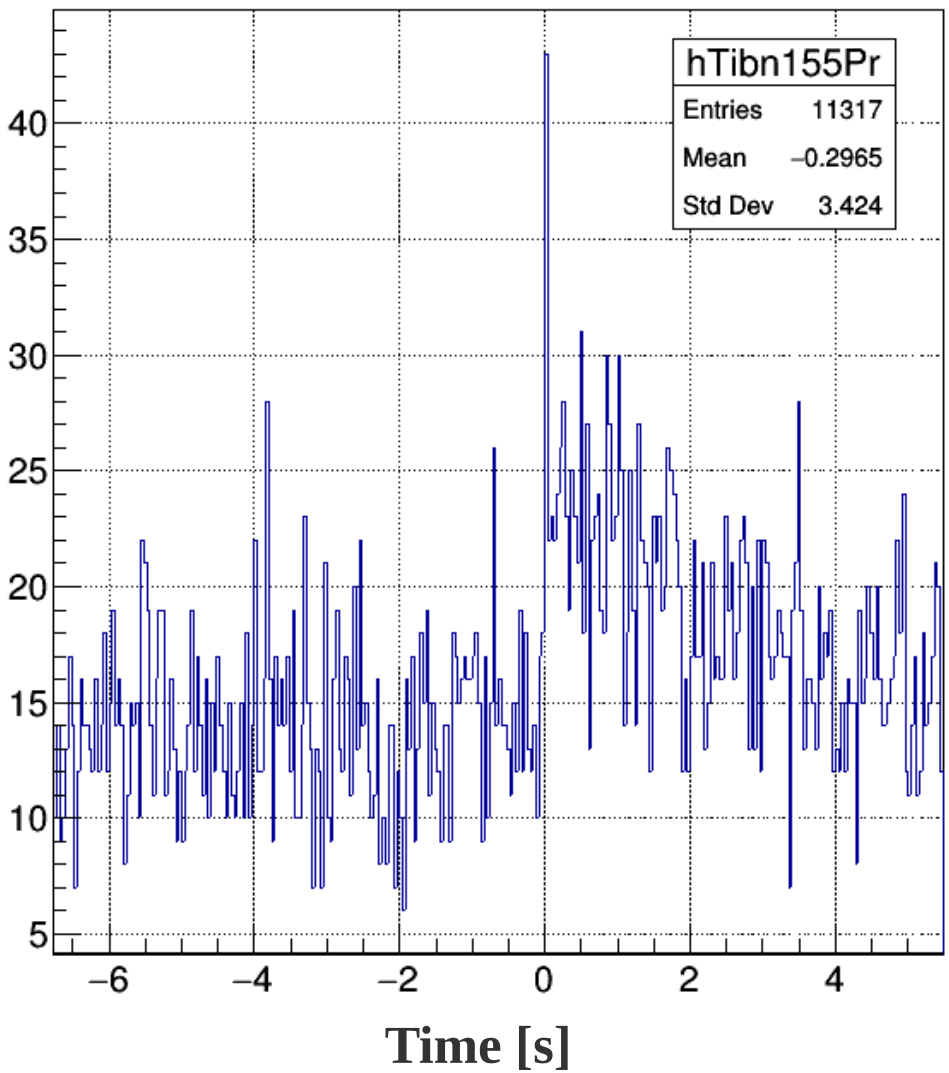
NEW!

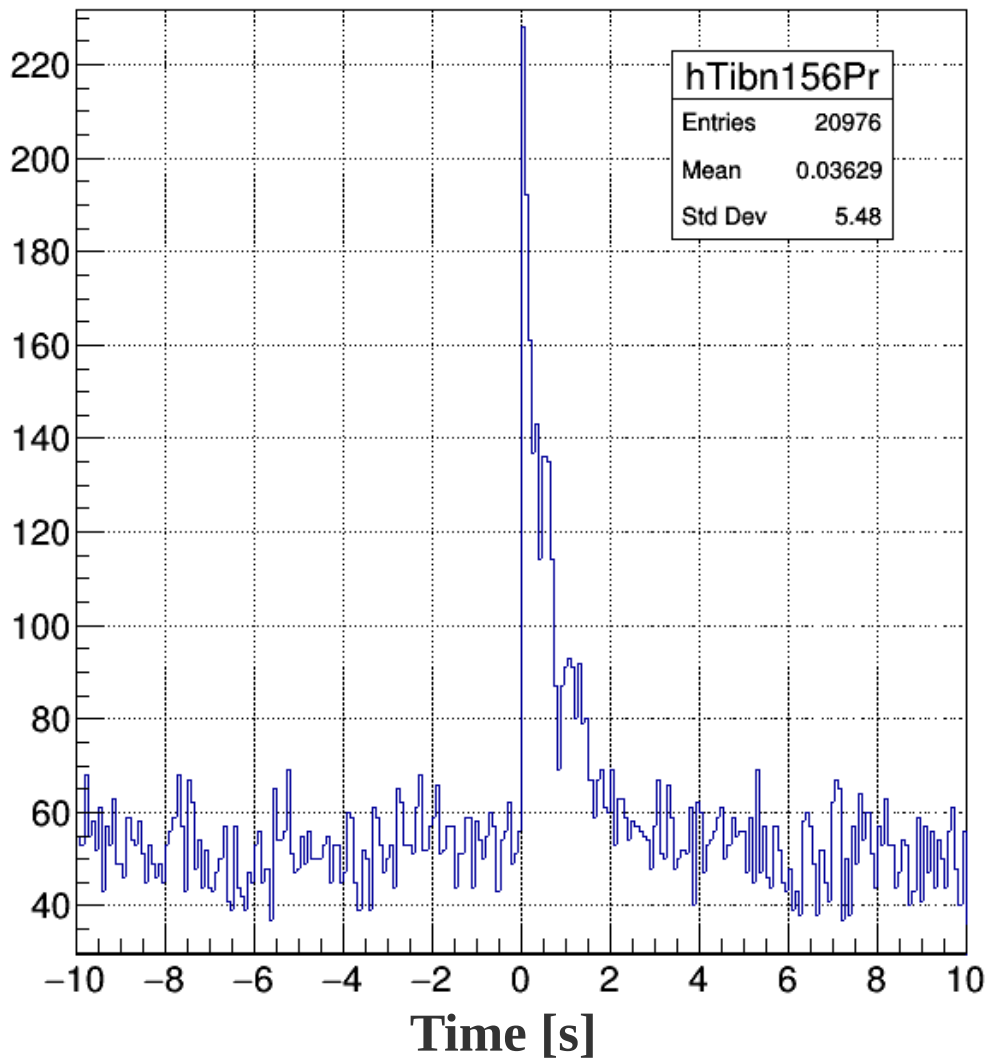




5.2 Pn values, hTibn Pr

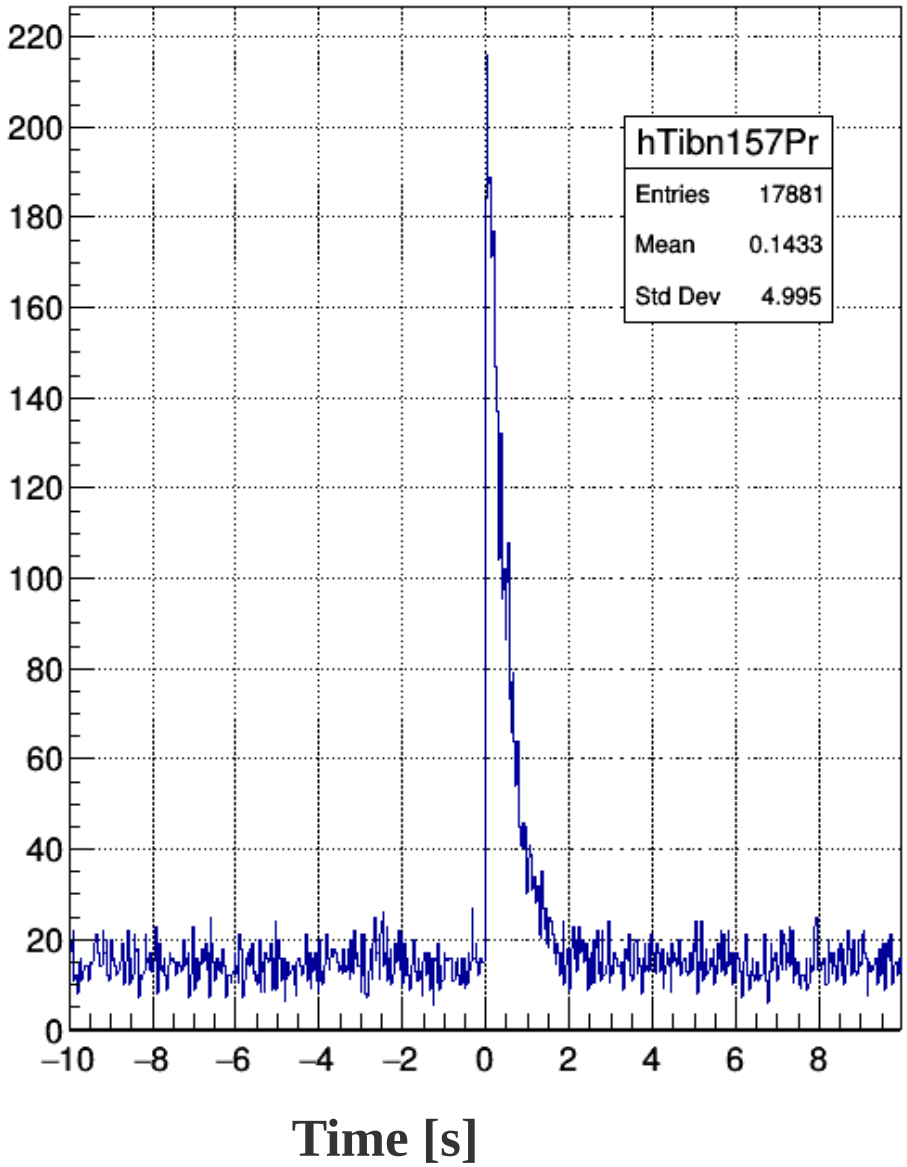
NEW!

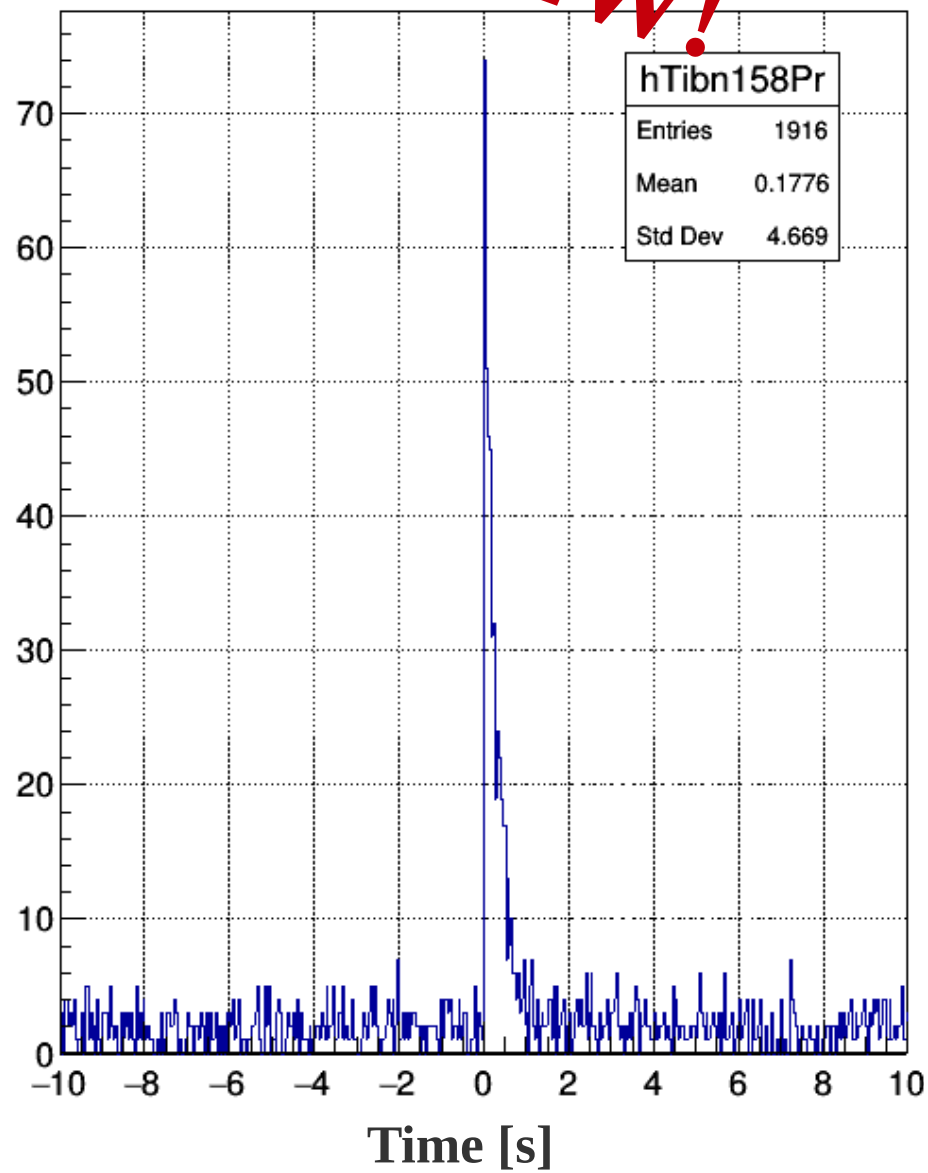




5.2 Pn values, hTibn Pr

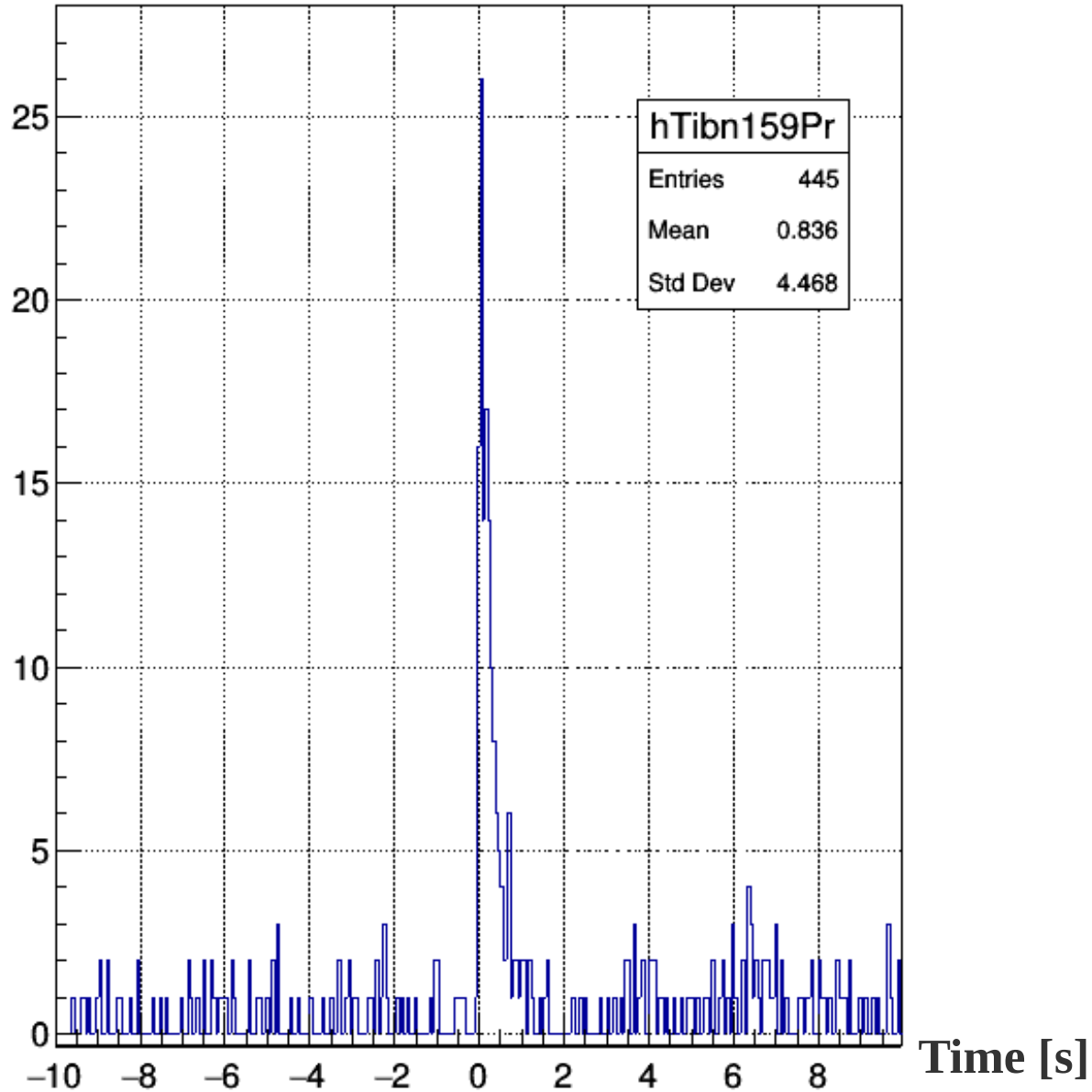
NEW!





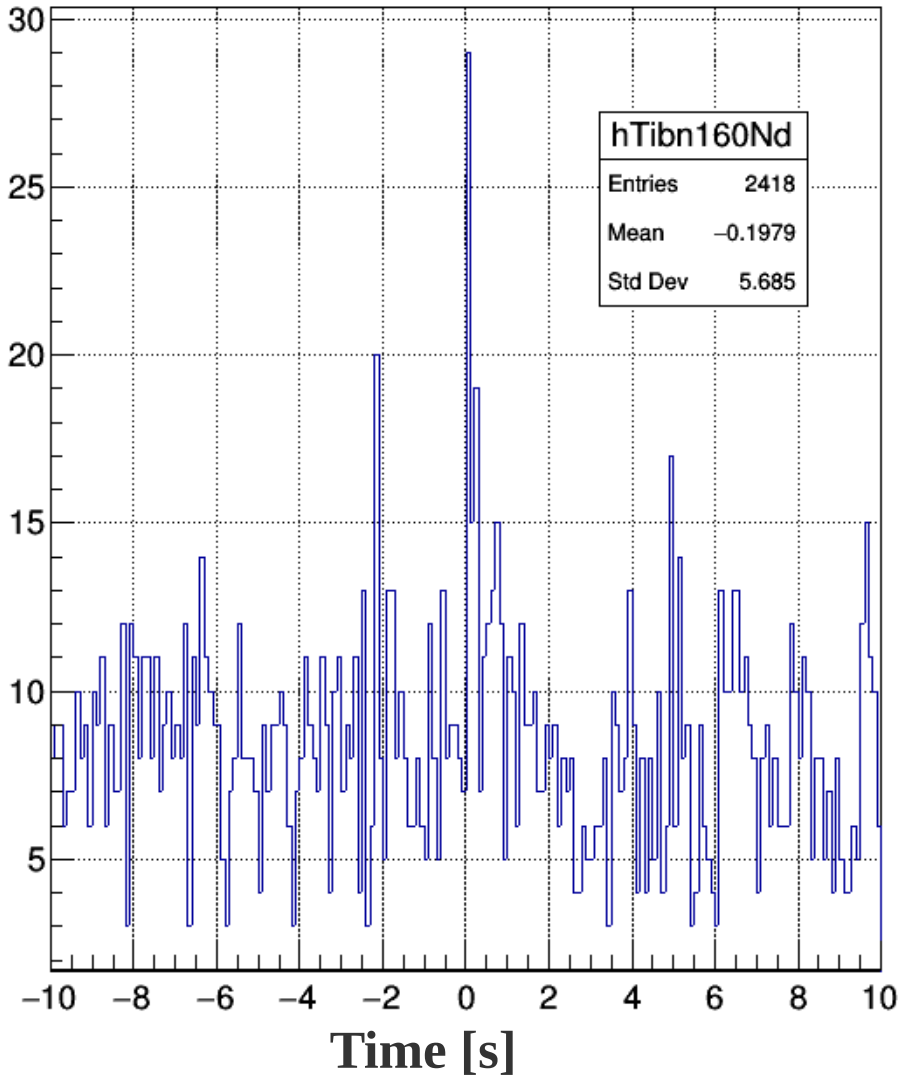
5.2 Pn values, hTibn Pr

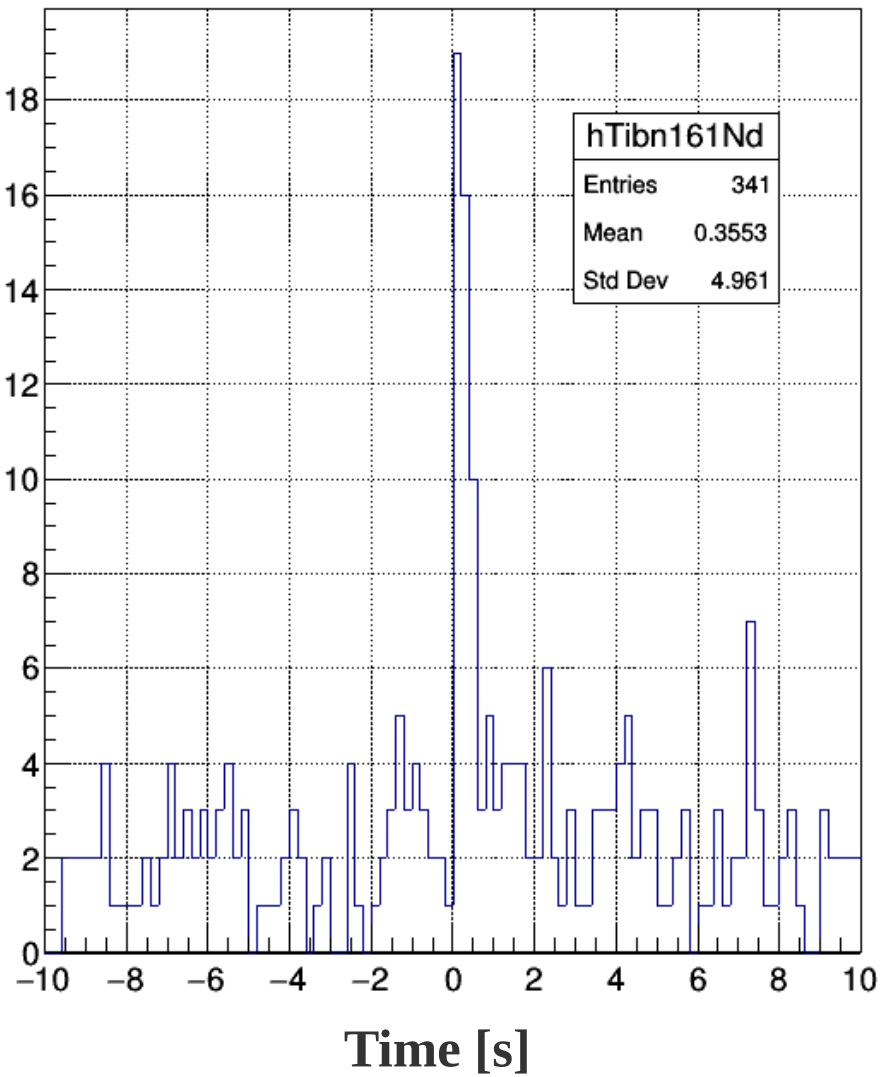
NEW!



5.2 Pn values, hTibn Nd

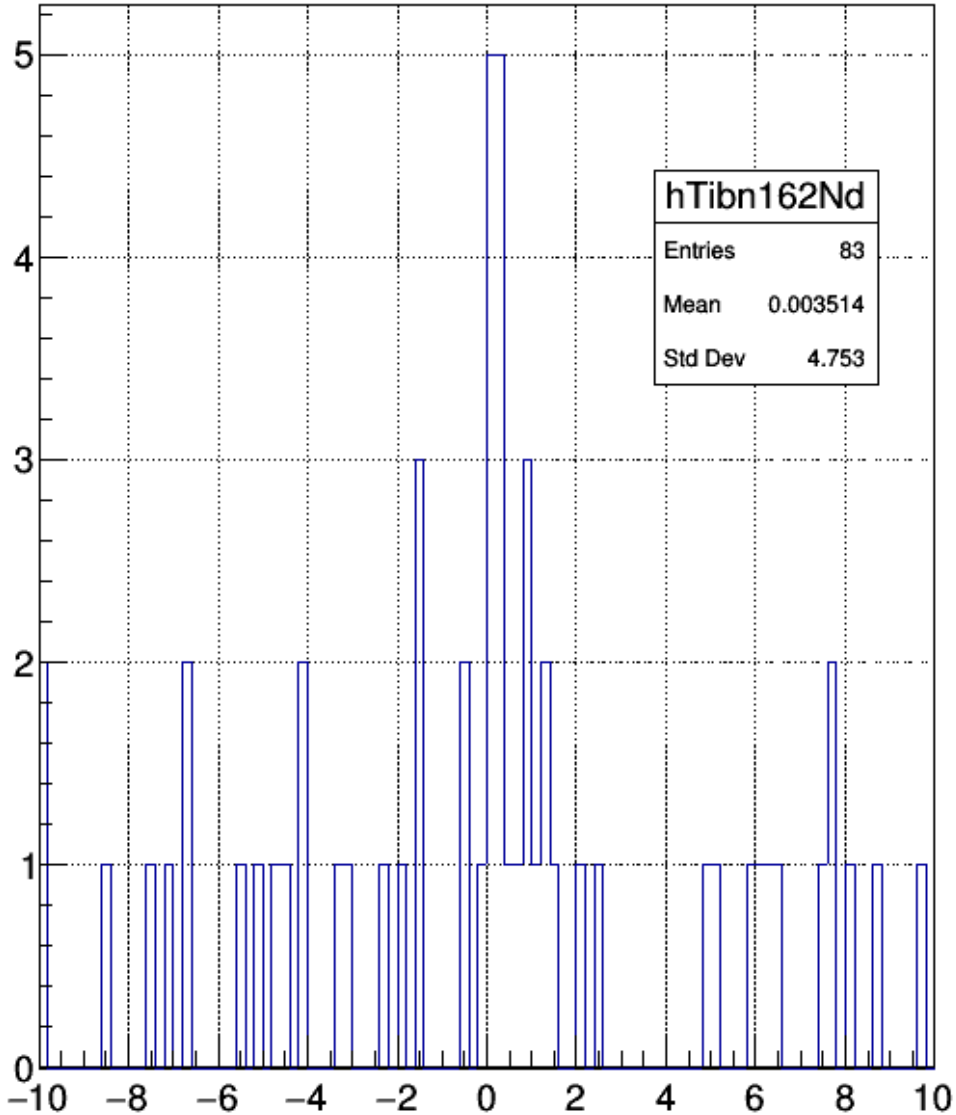
NEW!





5.2 Pn values, hTibn Nd

NEW!



Time [s]

Conclusion

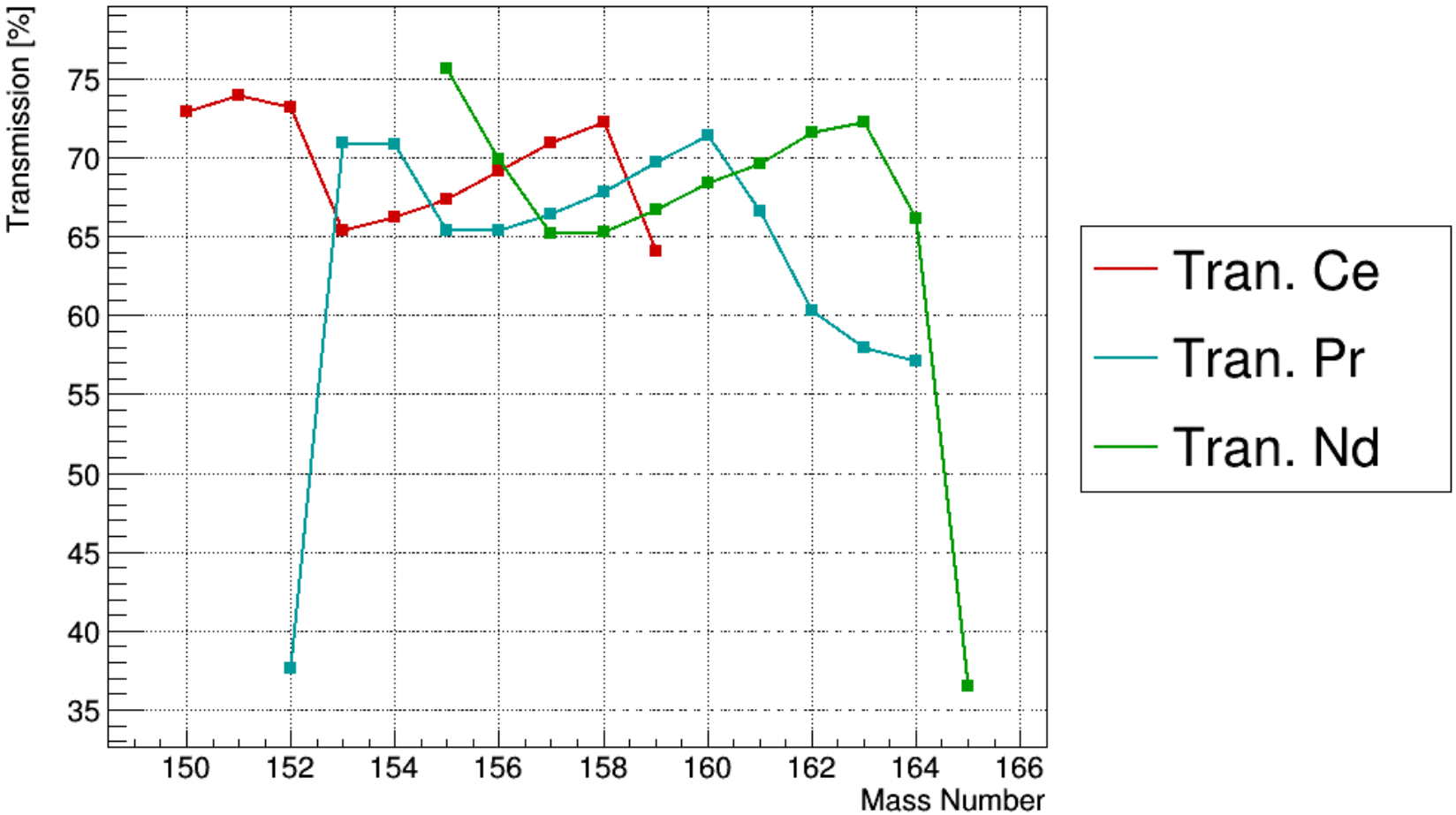
- Data from 2018's REP experiment looks very promising.
    - Half lives: ~ 4 new half lives.
    - Pn values: ~ 10 new pn values.

- There is still a lot of work to do.
    - Data is being reprocessed.
    - Evaluation of uncertainties ongoing.
    - We are working on the extraction of Pn.

Thanks for your attention.

Back up Slides

Transmission from ID point to Aida



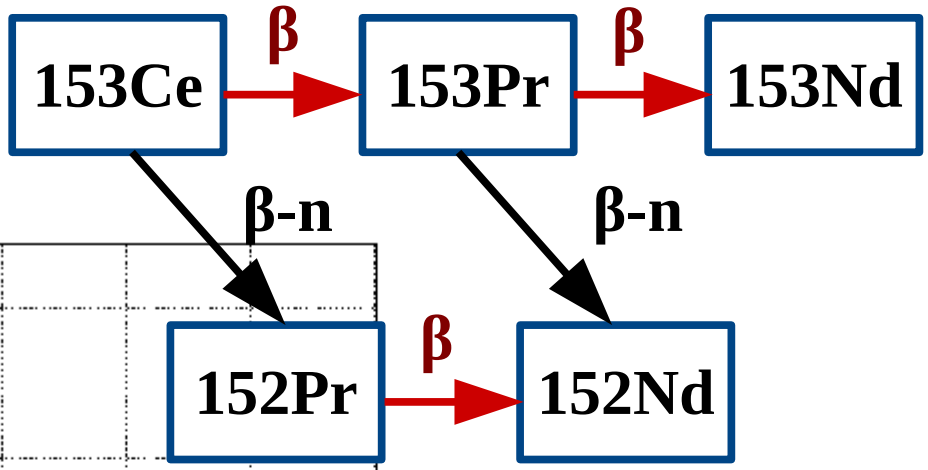
$$\text{Transmission} = \frac{\text{Integral PID merger}}{\text{Integral PID BigRips}}$$

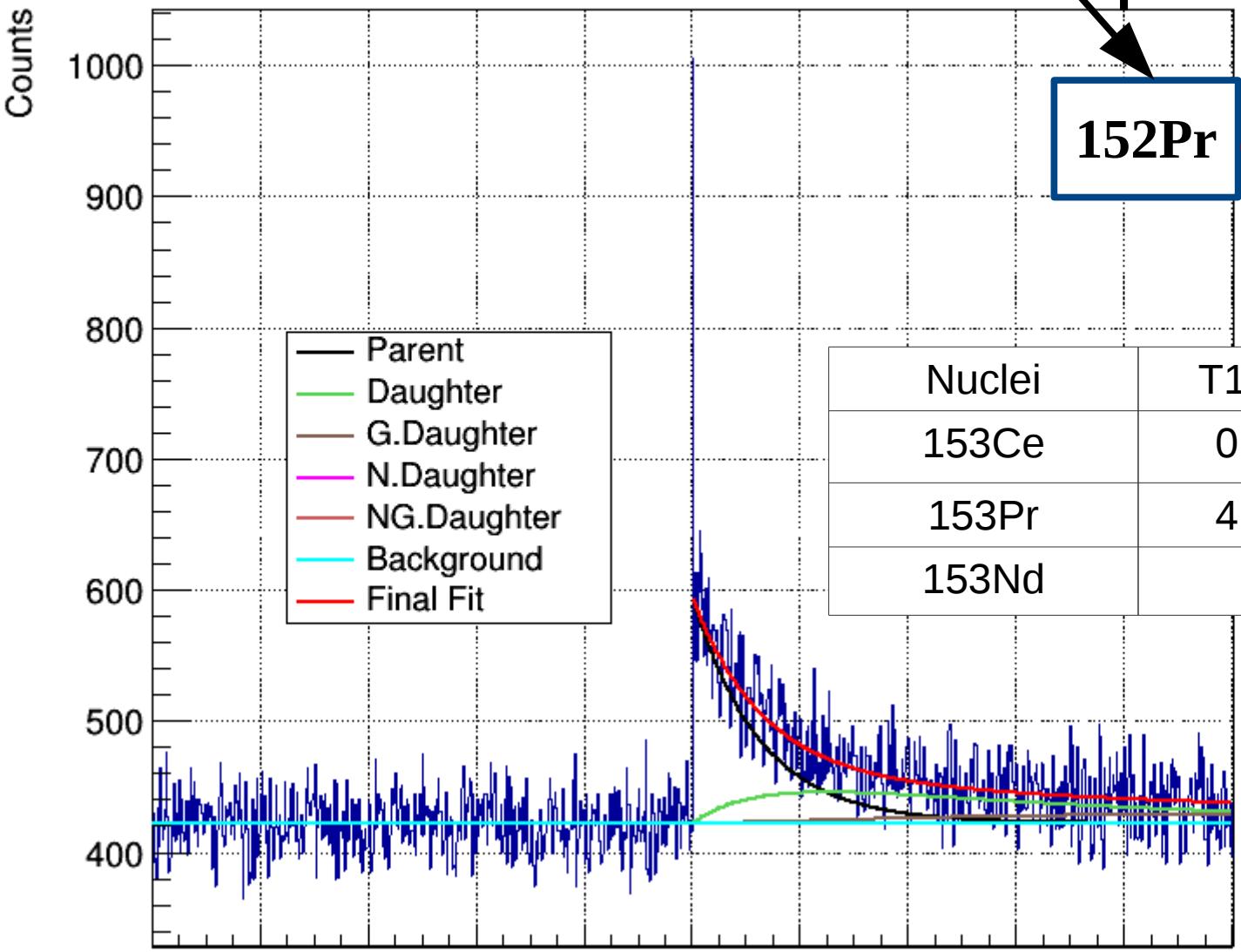
Independent Analysis

- All starting points are Möller's:

- Parameters to fit T12 all nuclei +X0

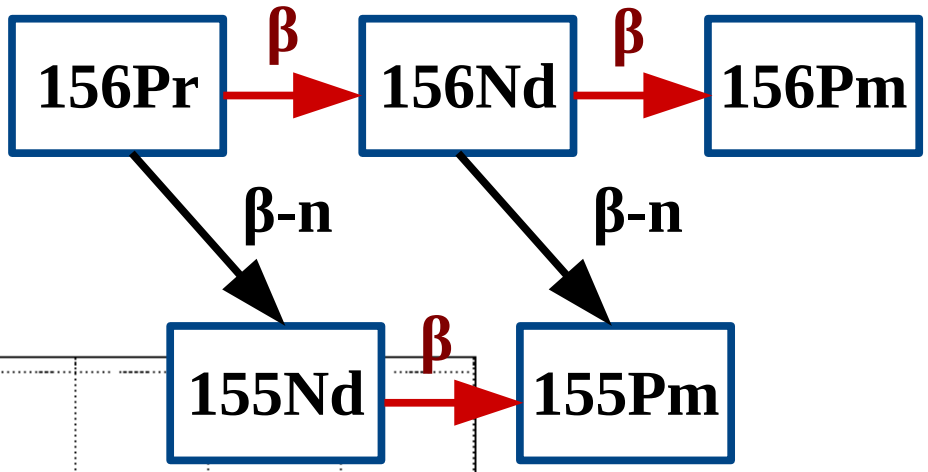
Example 153Ce

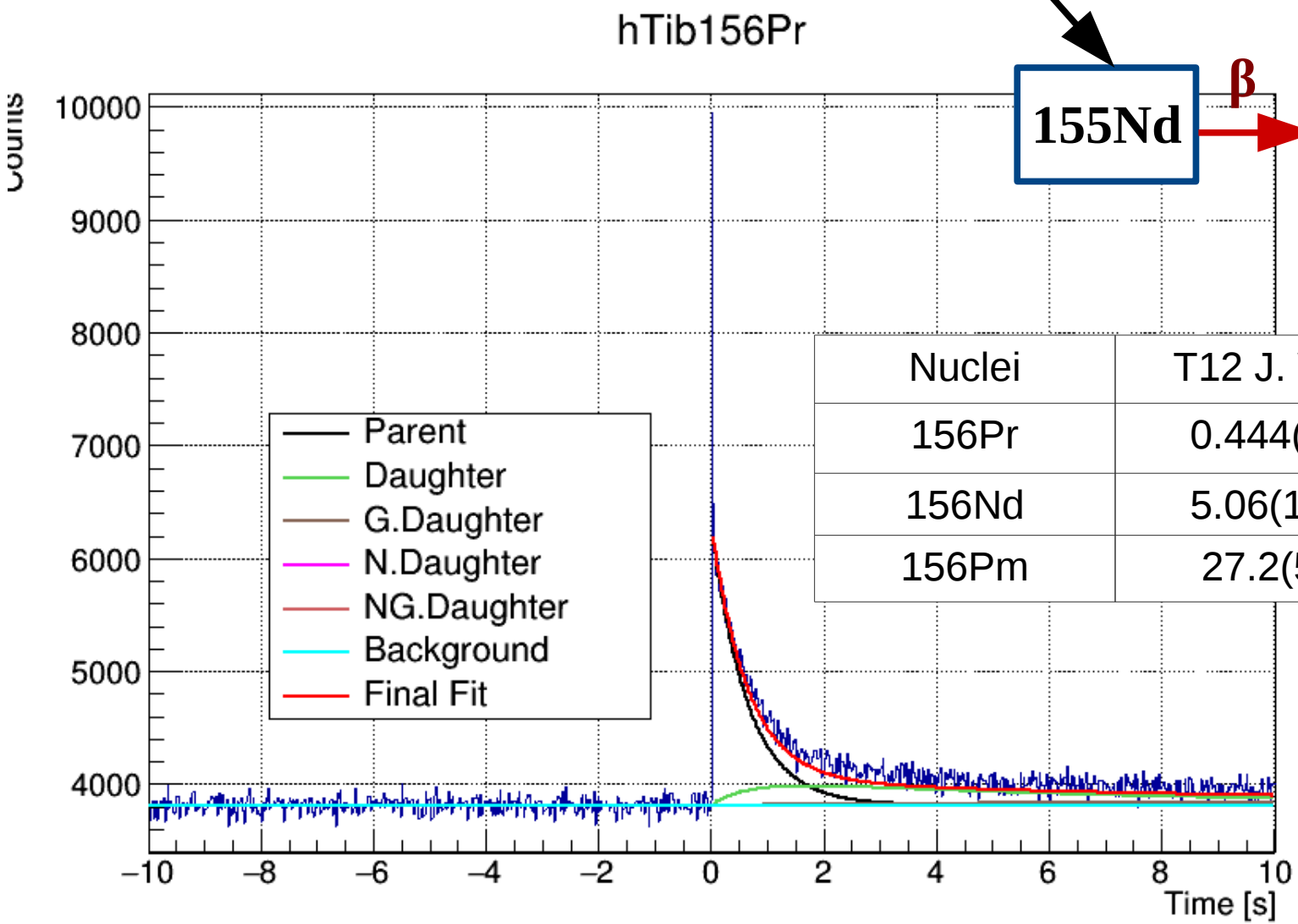




Nuclei	T12 J. Wu	T12 Fit 14.0
153Ce	0.865(2)	0.82(5)
153Pr	4.28(11)	3.484(65)
153Nd	31(1)	15(2)

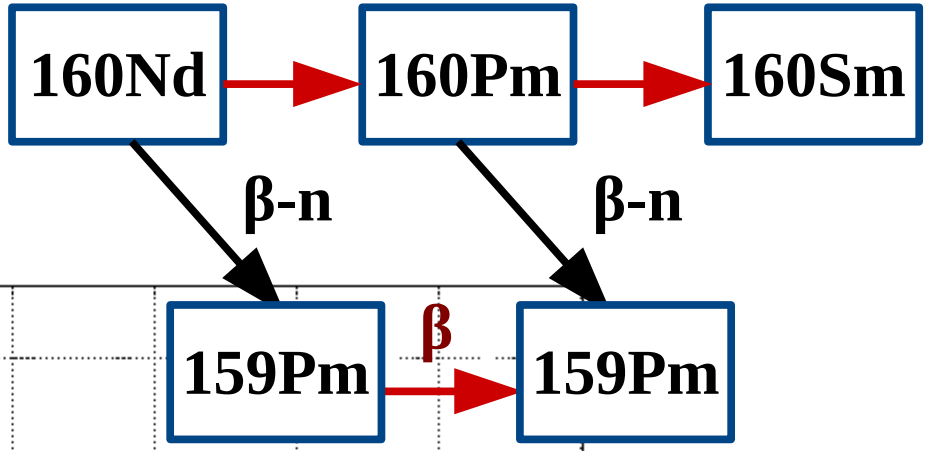
Example 156Pr

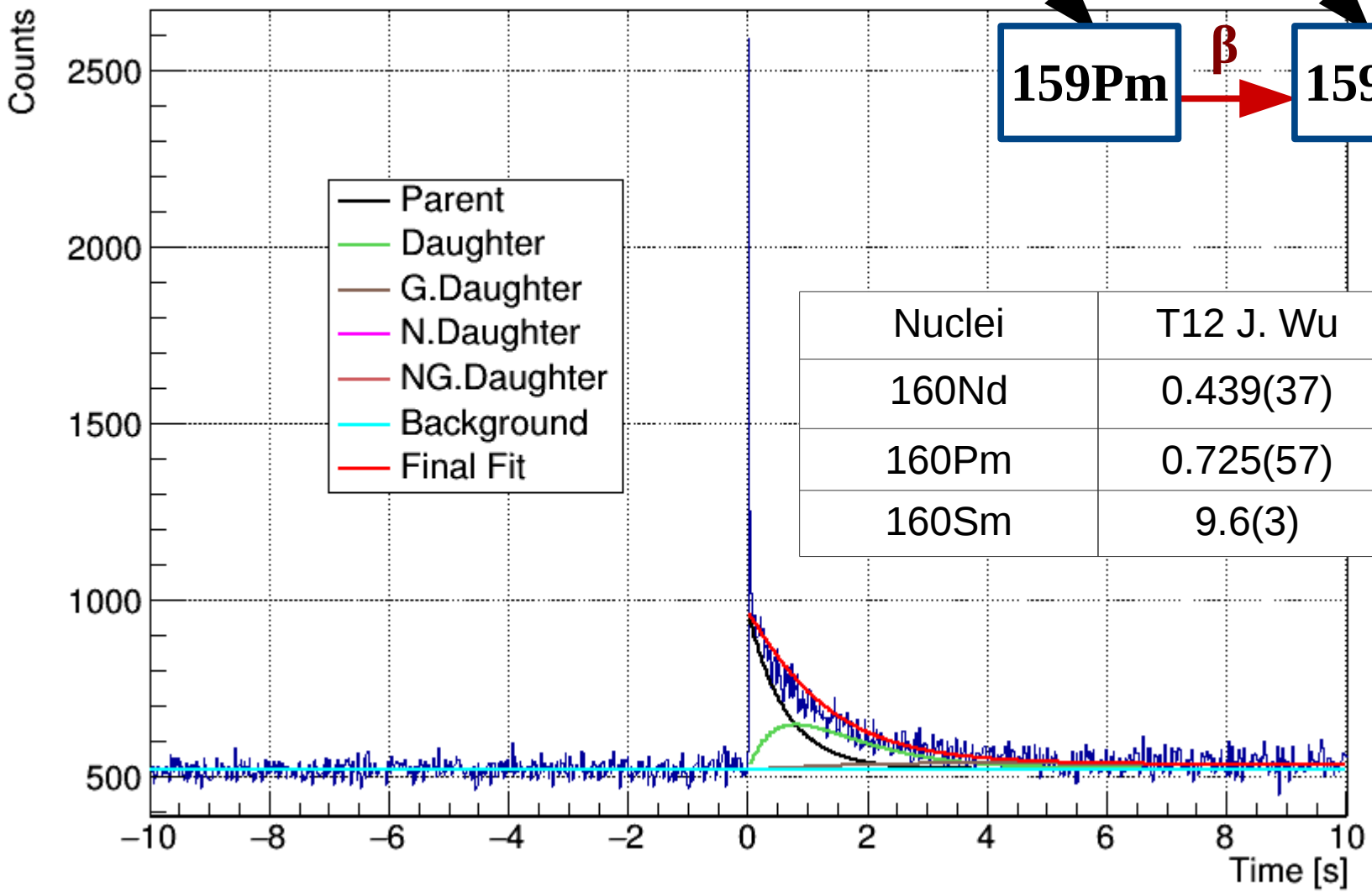




Nuclei	T12 J. Wu	T12 Fit 14.0
156Pr	0.444(6)	0.45(3)
156Nd	5.06(13)	3.47(4)
156Pm	27.2(5)	6.42(31)

Example 160Nd





Nuclei	T12 J. Wu	T12 Fit 14.0
160Nd	0.439(37)	0.39(8)
160Pm	0.725(57)	1.11(4)
160Sm	9.6(3)	8.91(94)

3.3 Error Calculation.

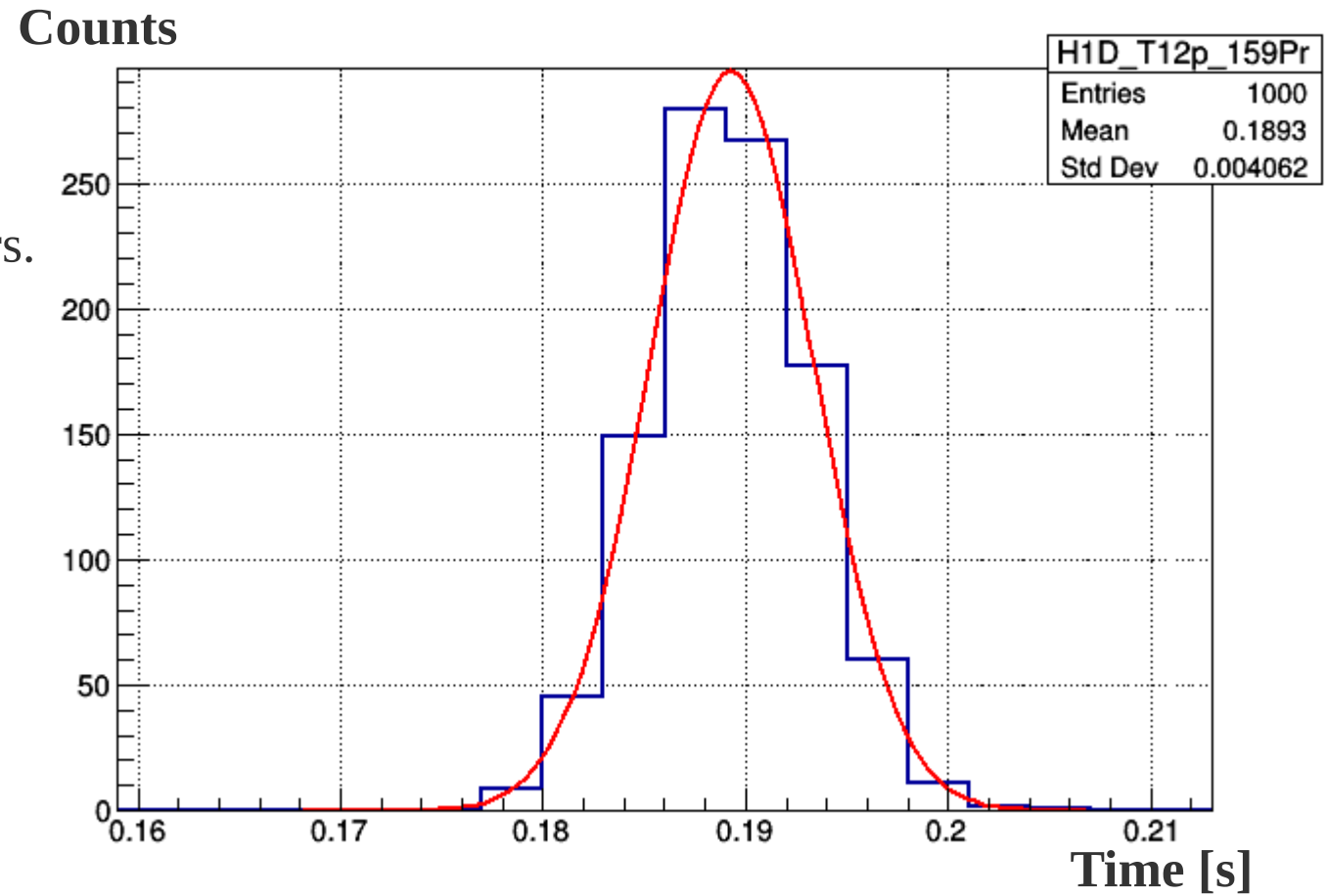
- From the fit:
  - T12 and X0

- Fit program has 9 parameters.
  - They are introduced as random variables.

- Fit is done 1000 times.

- Final value of t12:
  - Mean of the results.

- Error of t12:
  - Sigma of the results.



Error = sqrt(t12_sigma^2 + t12_mean_error^2 + t12_sigma_error^2)

A. Navarro Vs A. Tolosa: 157Pr

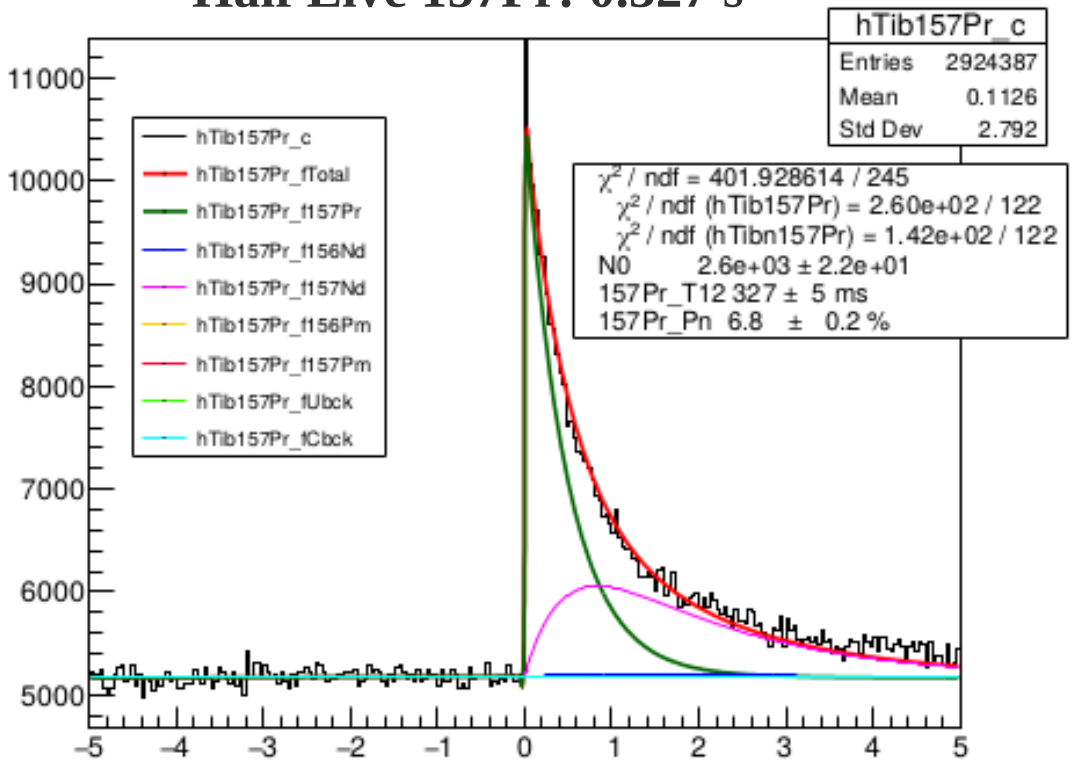
T12 with Alvaro's program

- Fit performed during experiment.
- Only 60% of Statistics.
- Before PID cleaning.

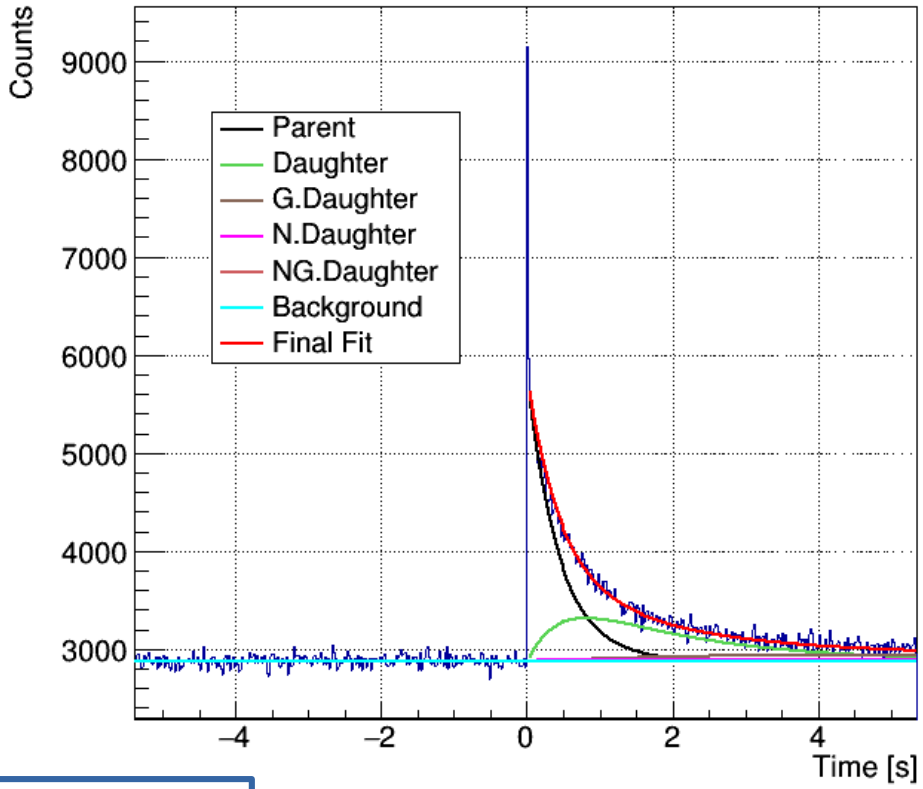
T12 with Araceli's program

- Aforementioned data.

Half Live 157Pr: 0.327 s



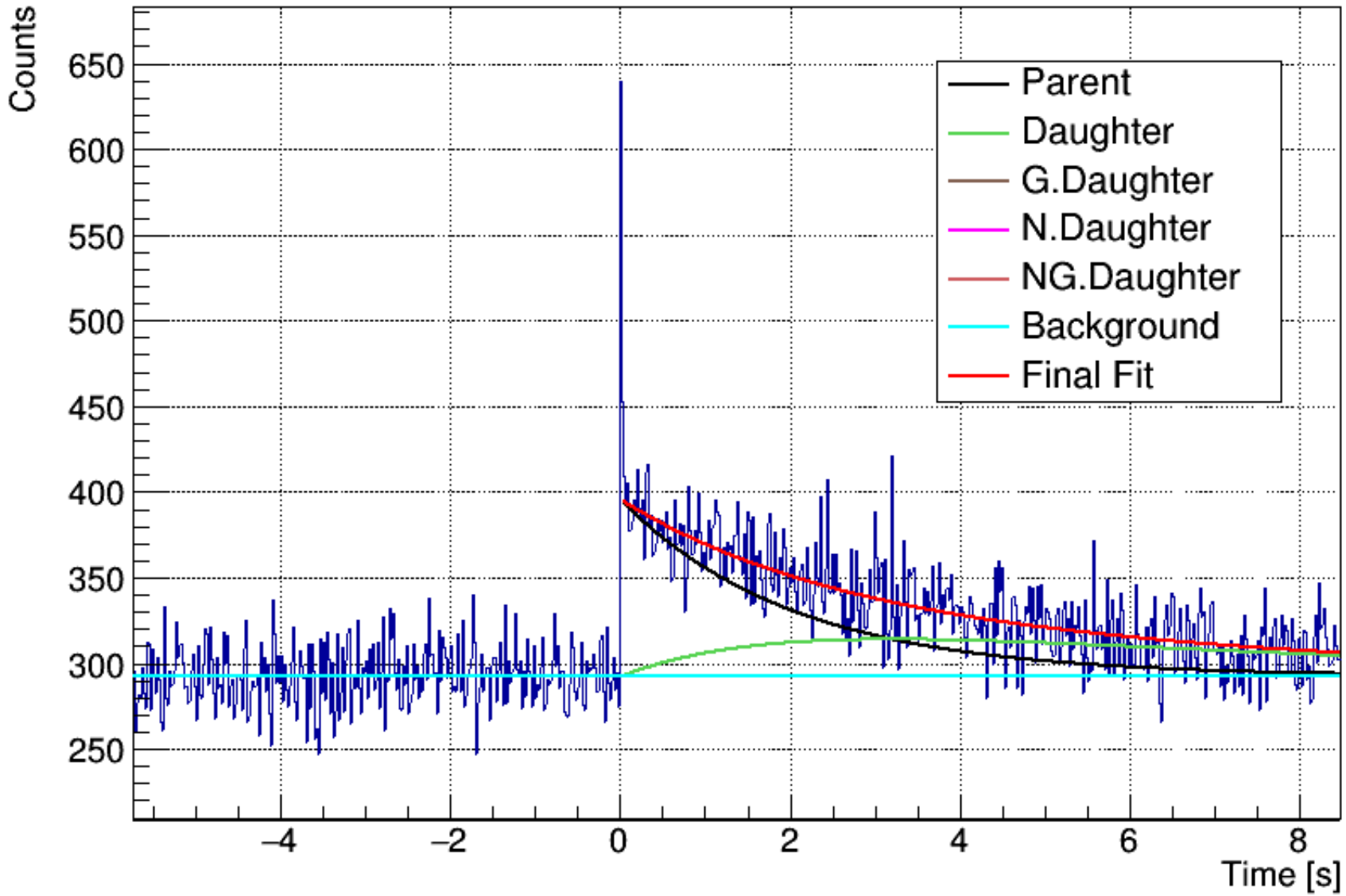
Half Live 157Pr: 0.318 s



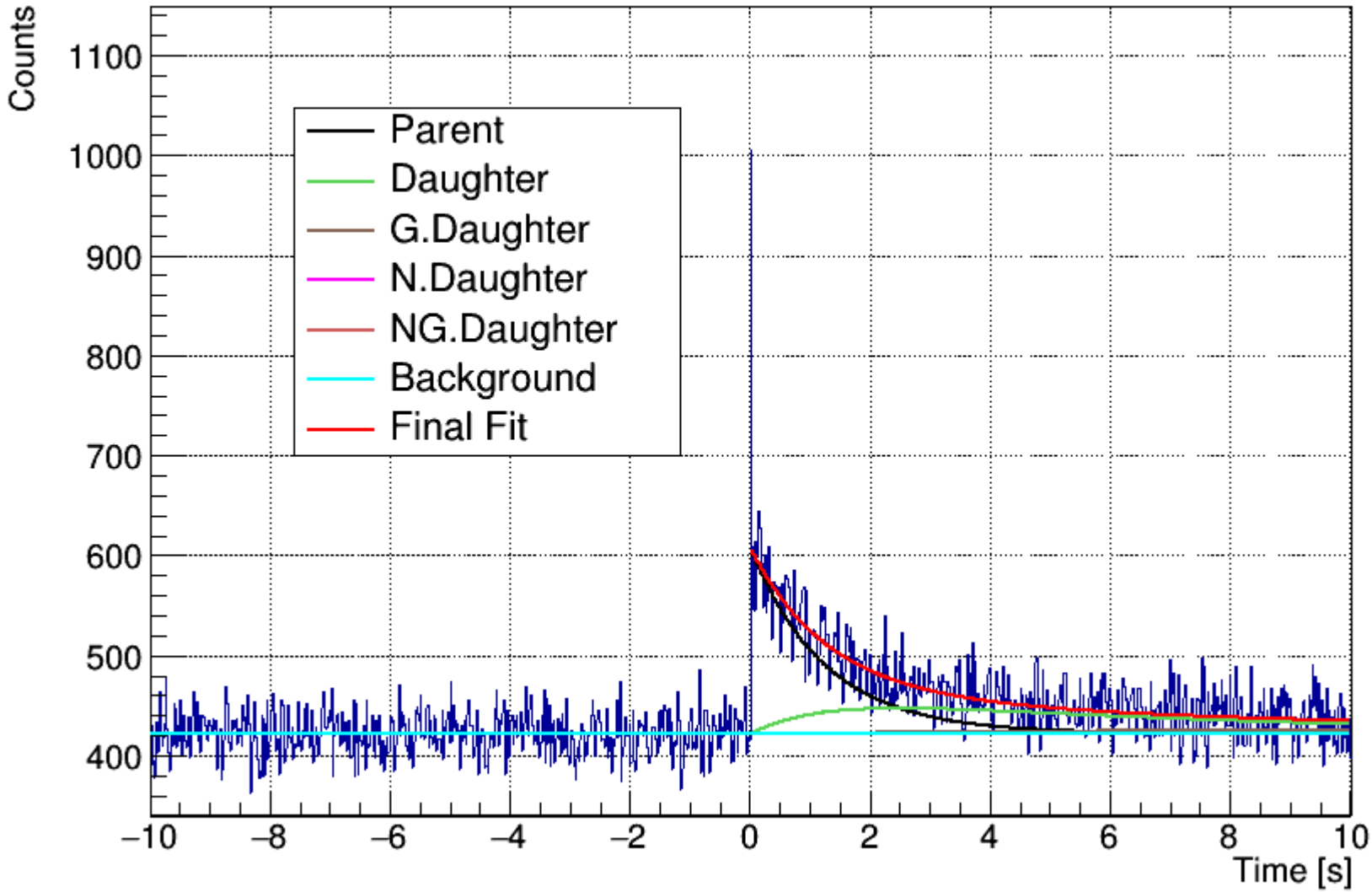
J. Wu: 0.295+-0.029 s

4. T12 Fit Results: Ce (Cerium)

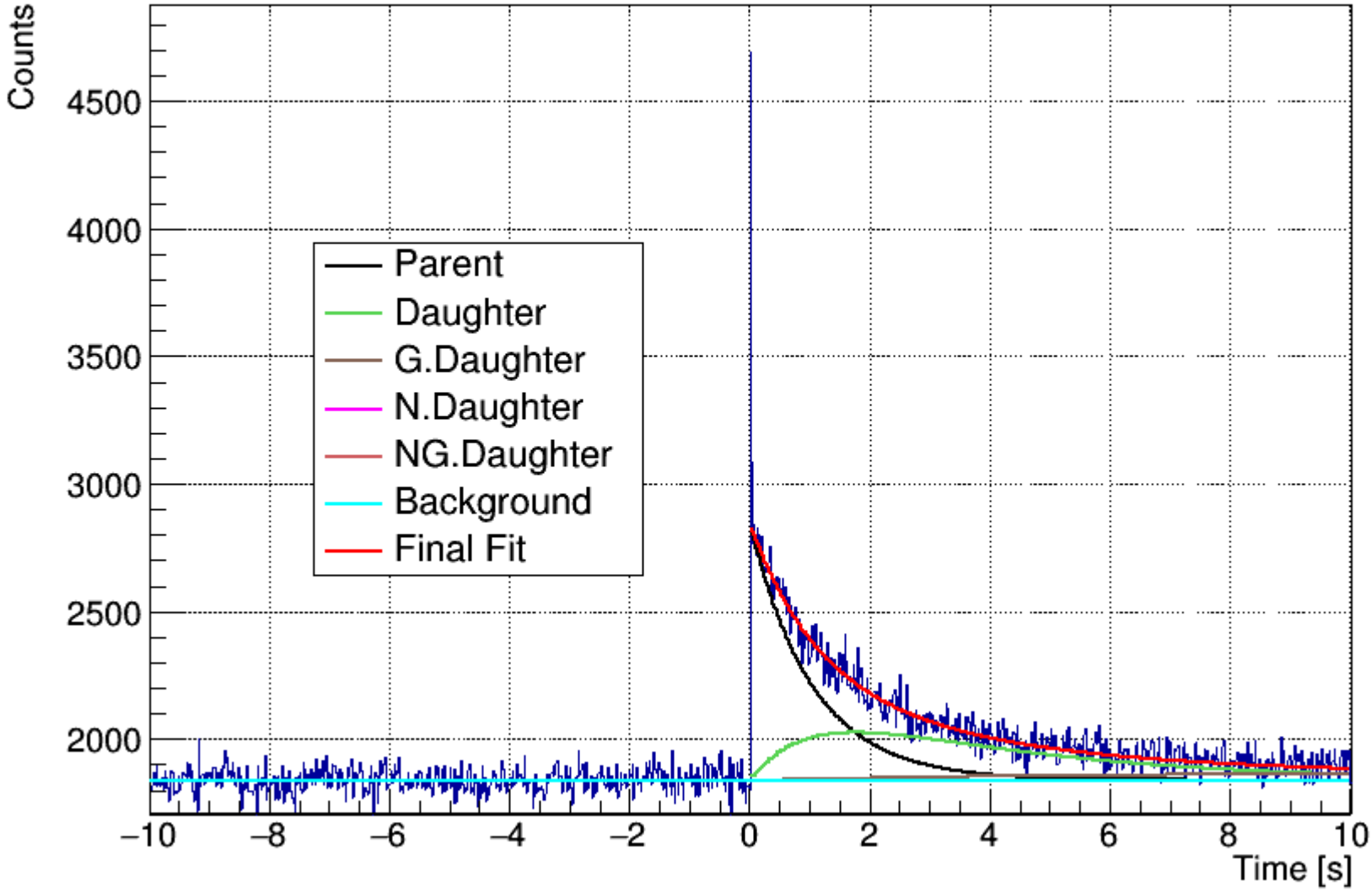
4.1 T12 Fit Results: 152Ce



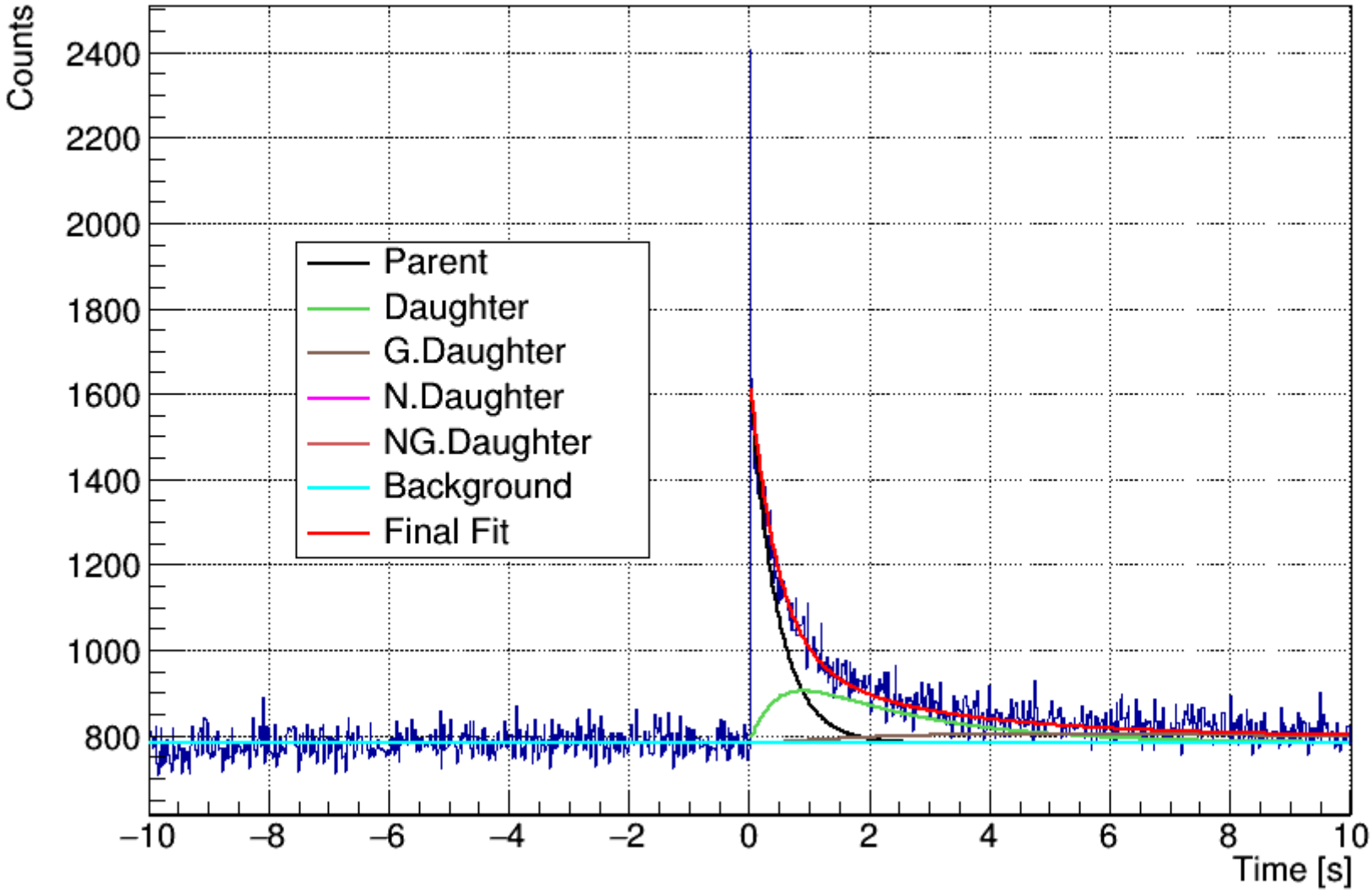
4.1 T12 Fit Results: 153Ce



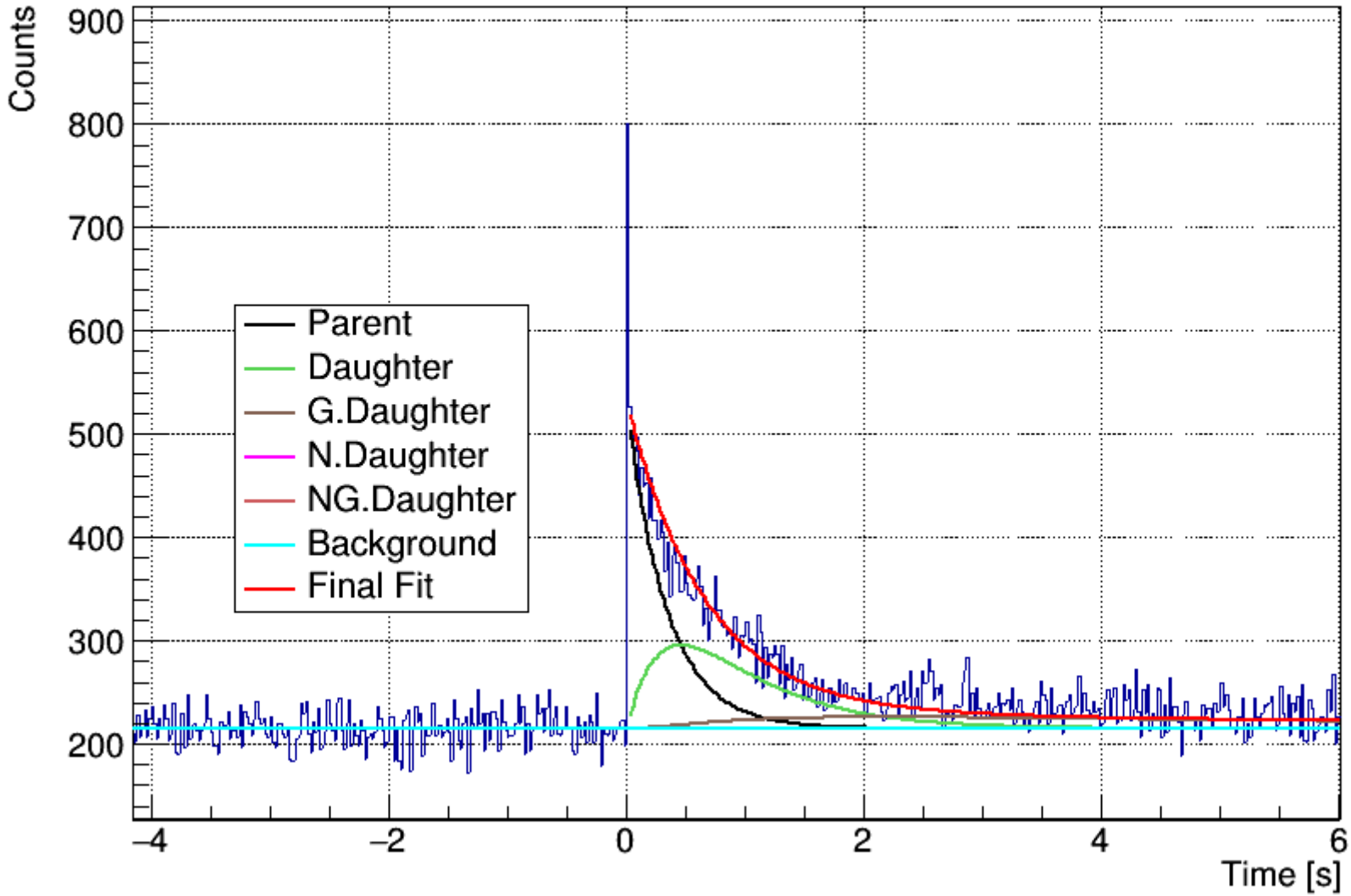
4.1 T12 Fit Results: 154Ce



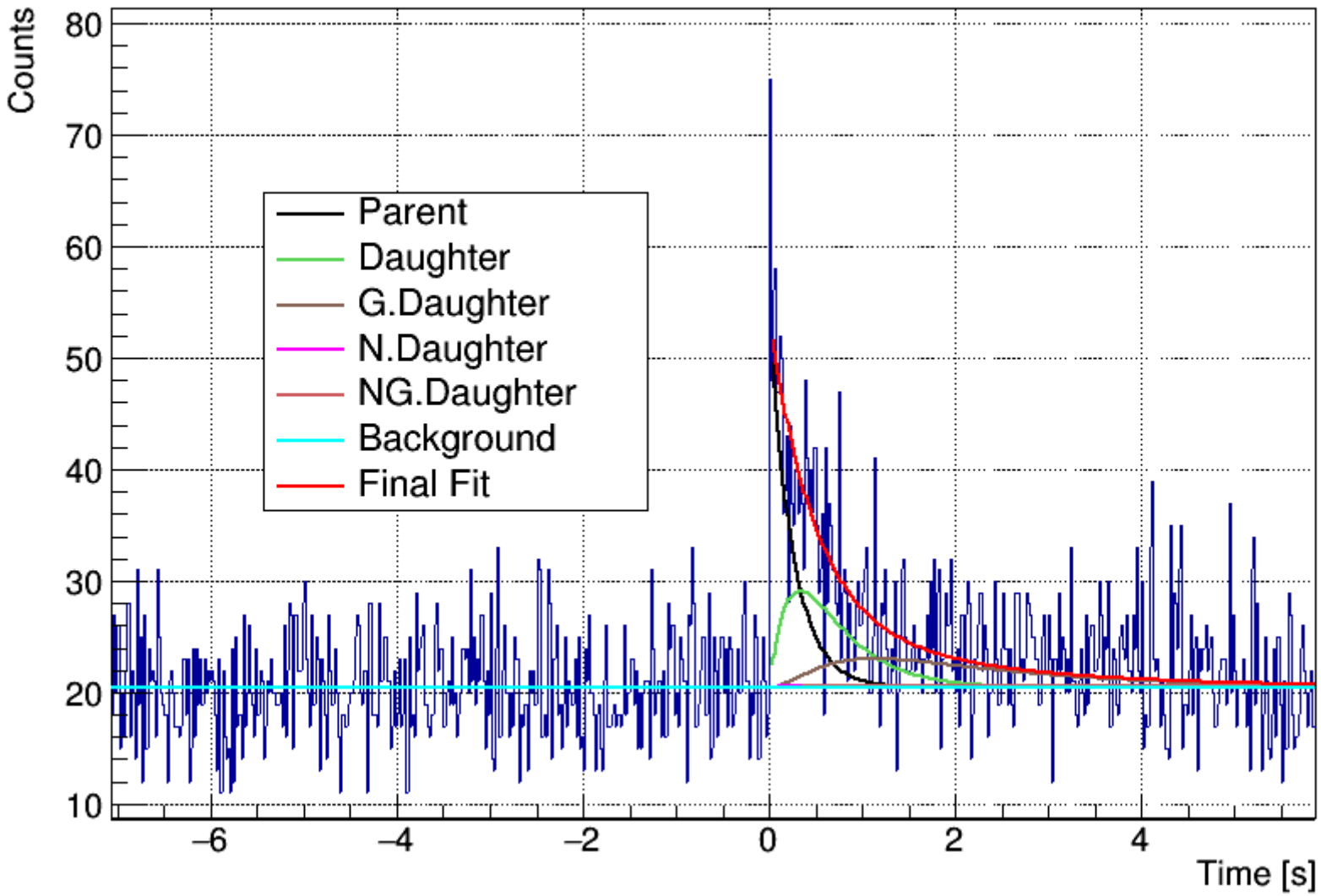
4.1 T12 Fit Results: 155Ce



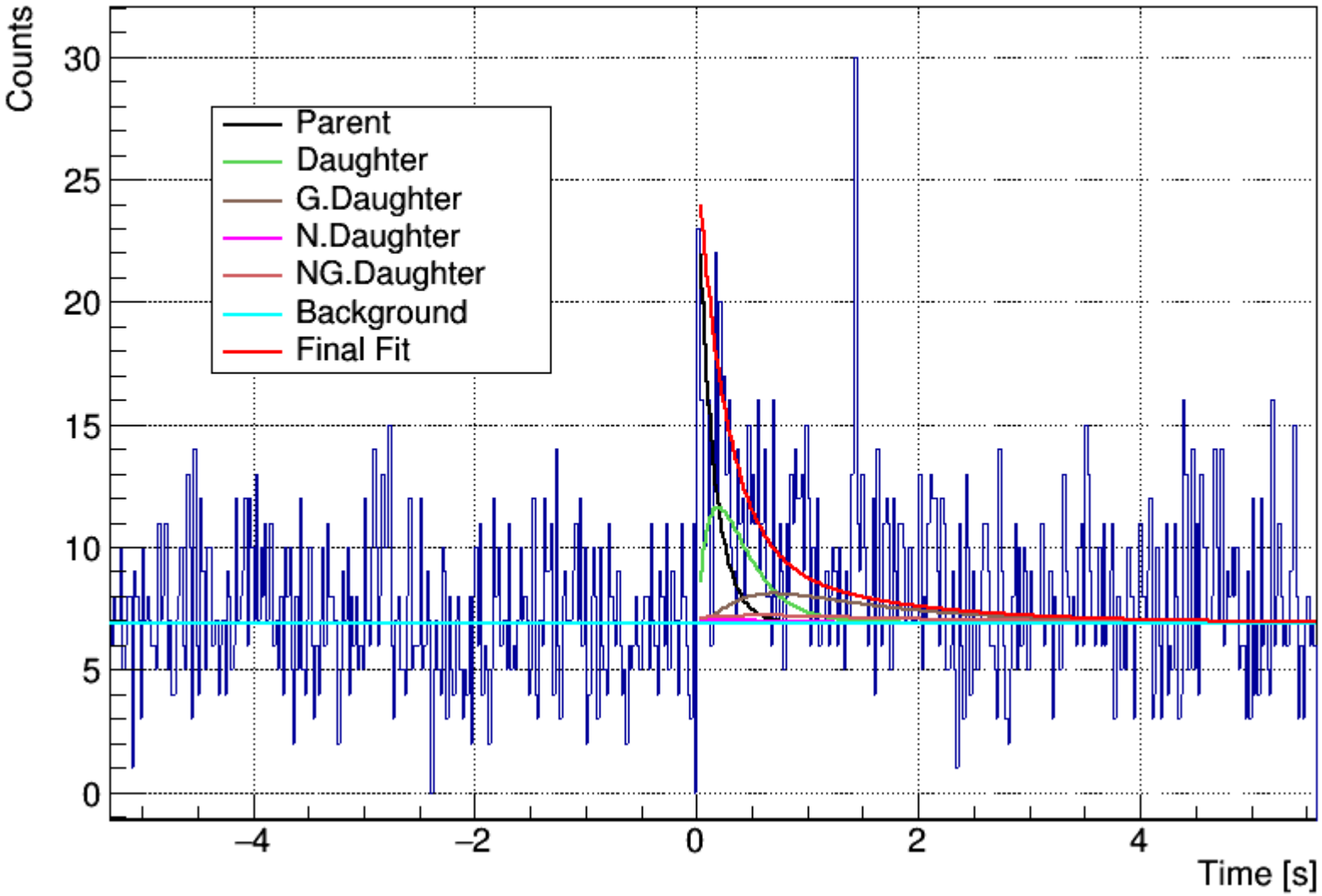
4.1 T12 Fit Results: 156Ce



4.1 T12 Fit Results: 157Ce

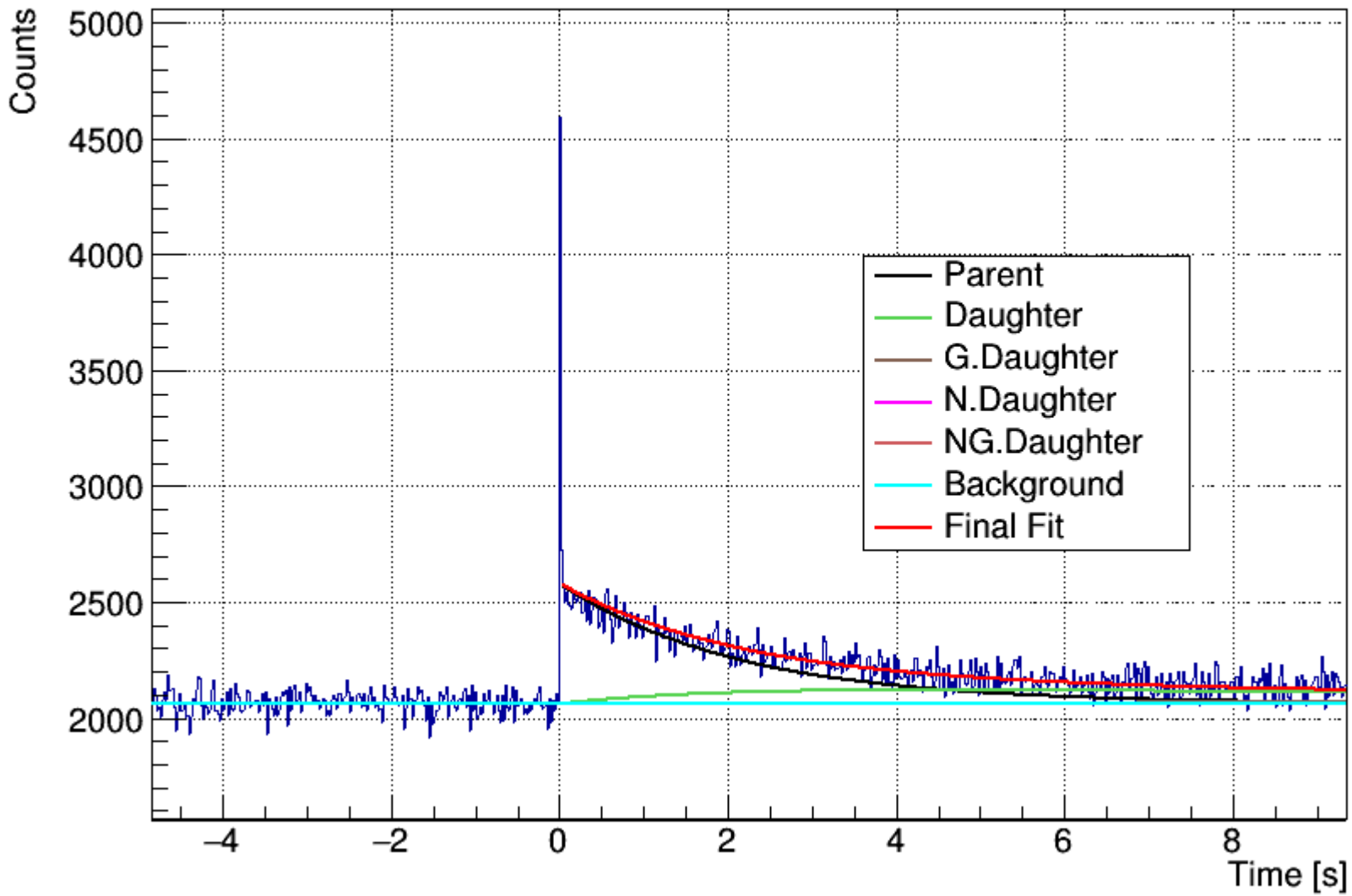


4.1 T12 Fit Results: 158Ce

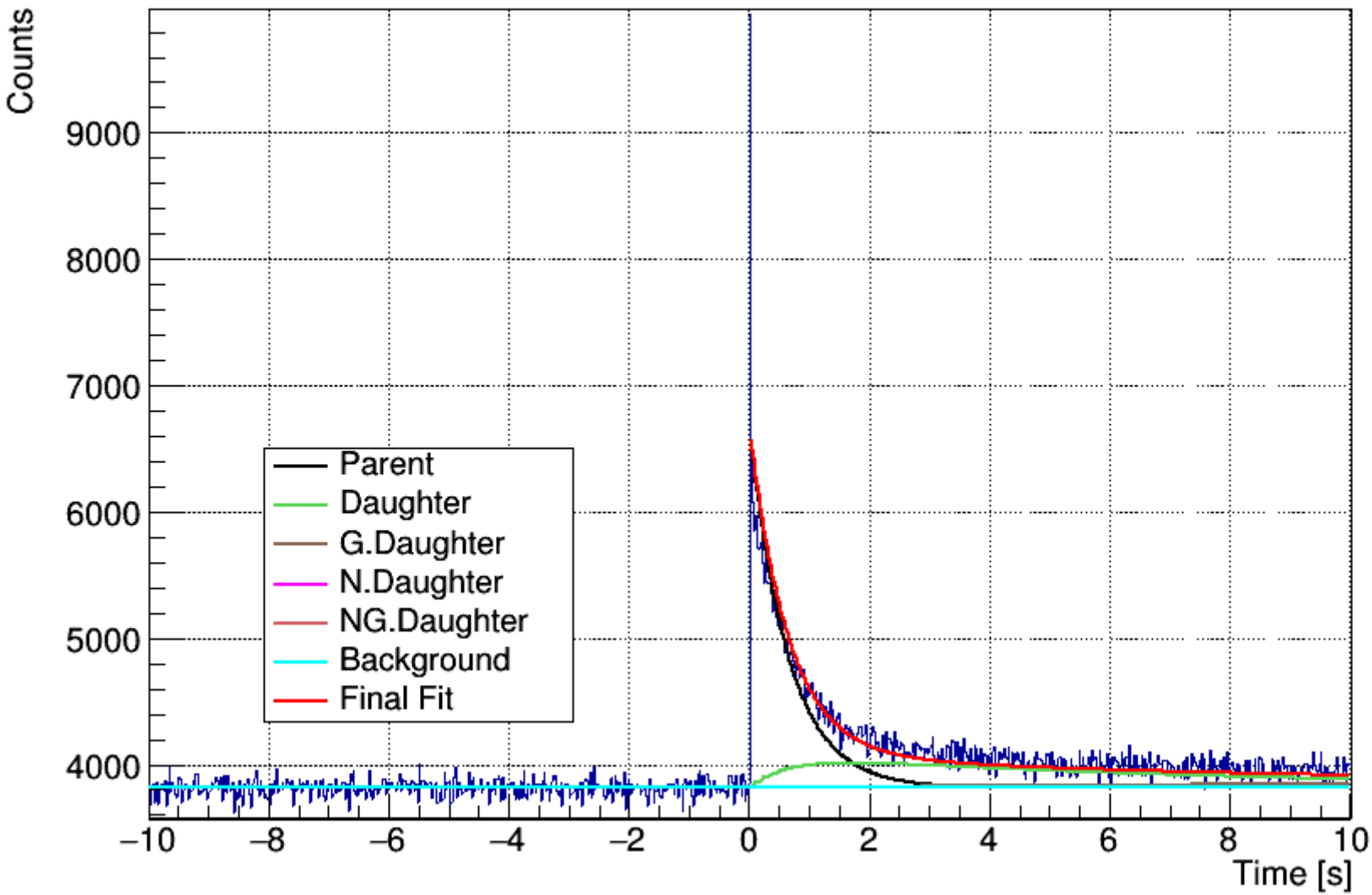


4. T12 Fit Results: Pr (Praseodymium)

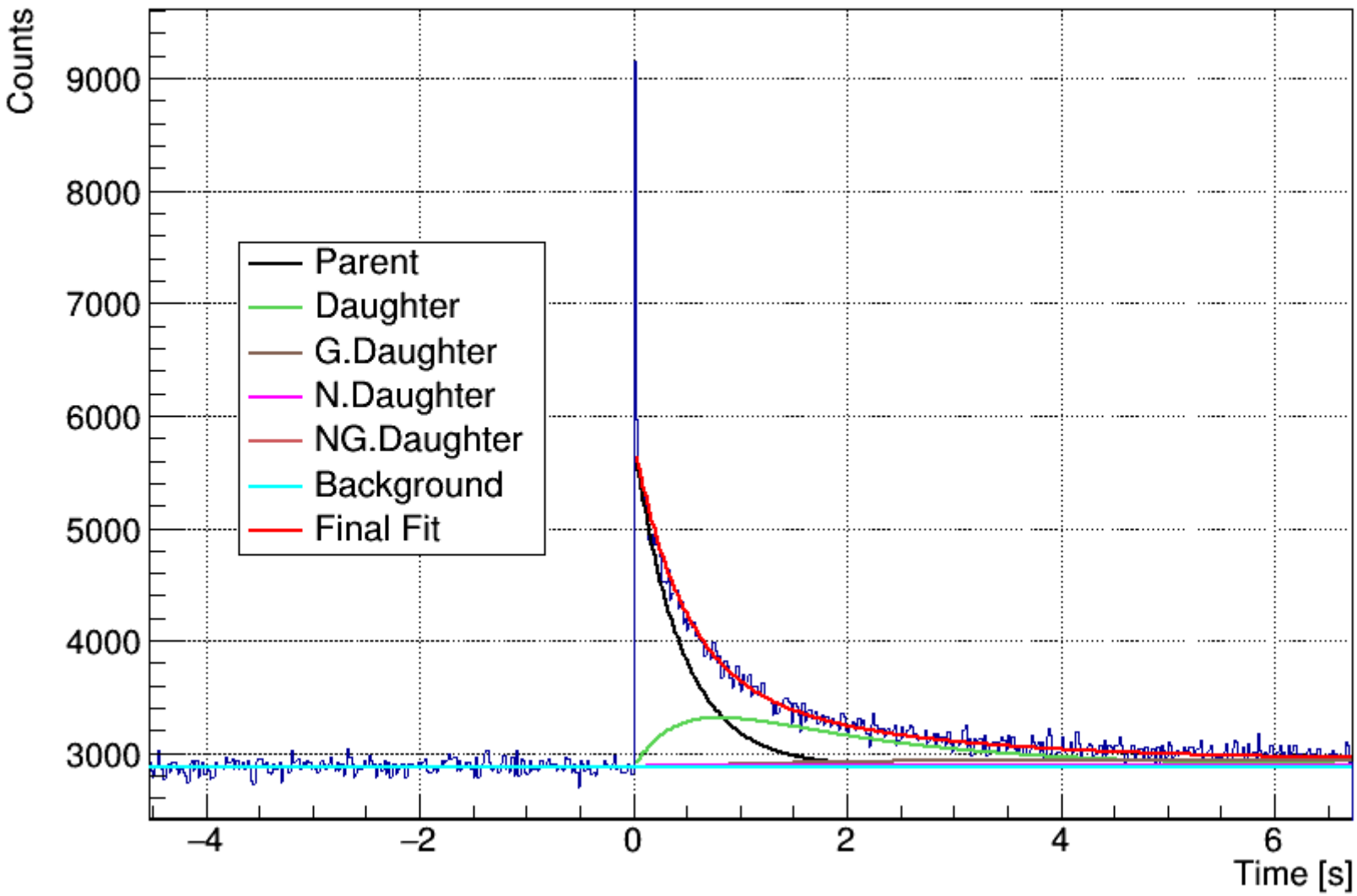
4.2 T12 Fit Results: 155Pr



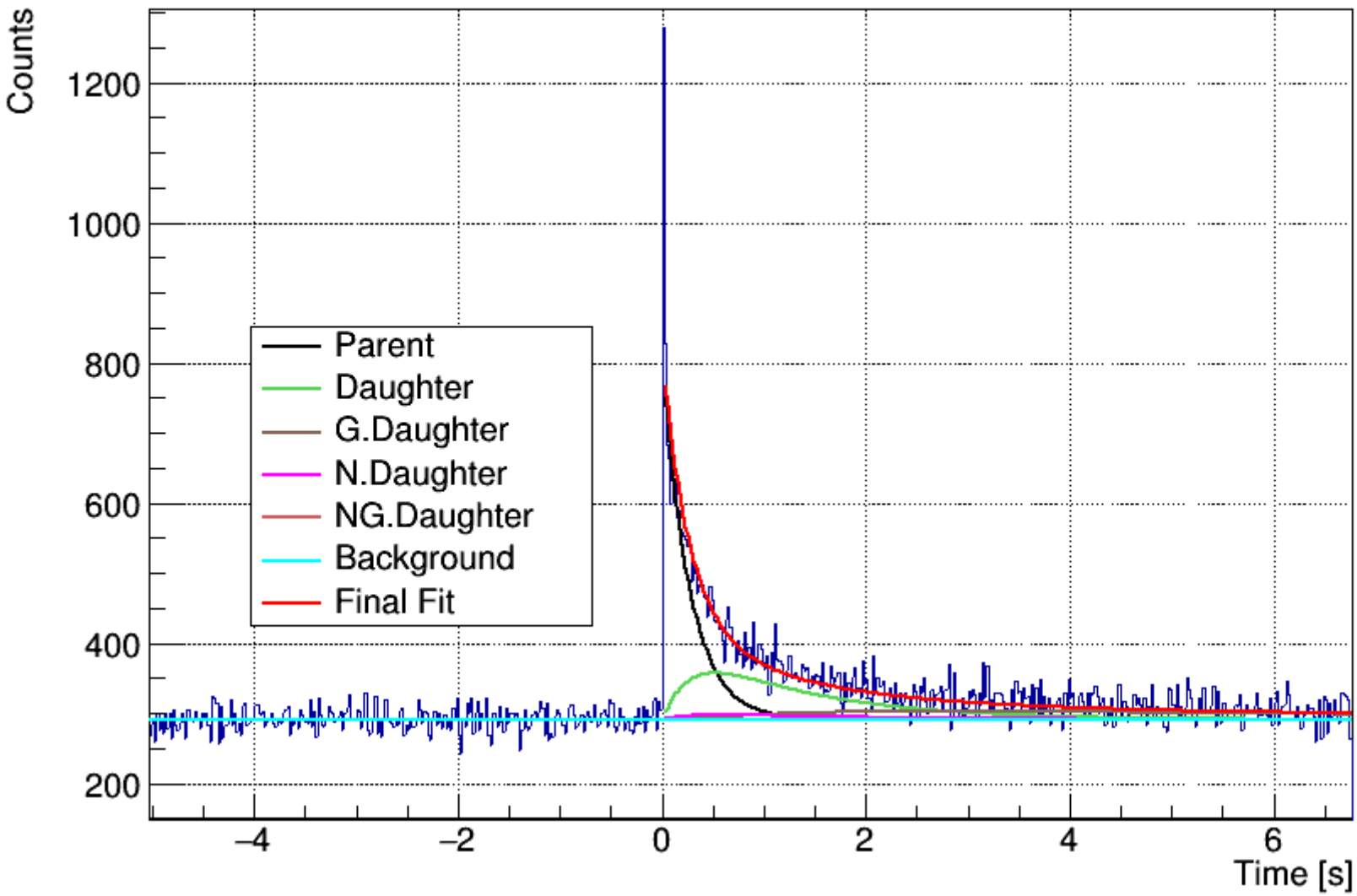
4.2 T12 Fit Results: 156Pr



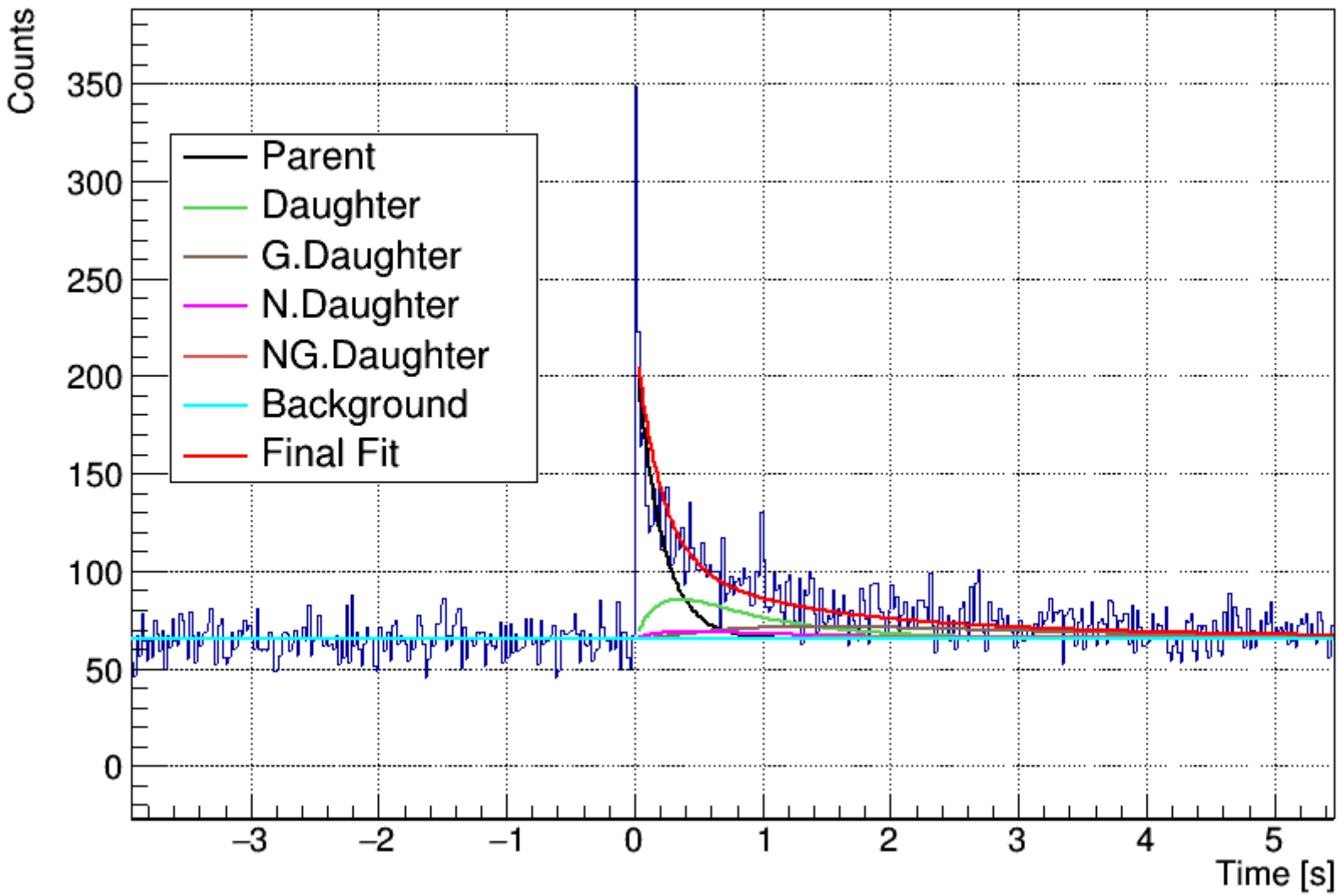
4.2 T12 Fit Results: 157Pr



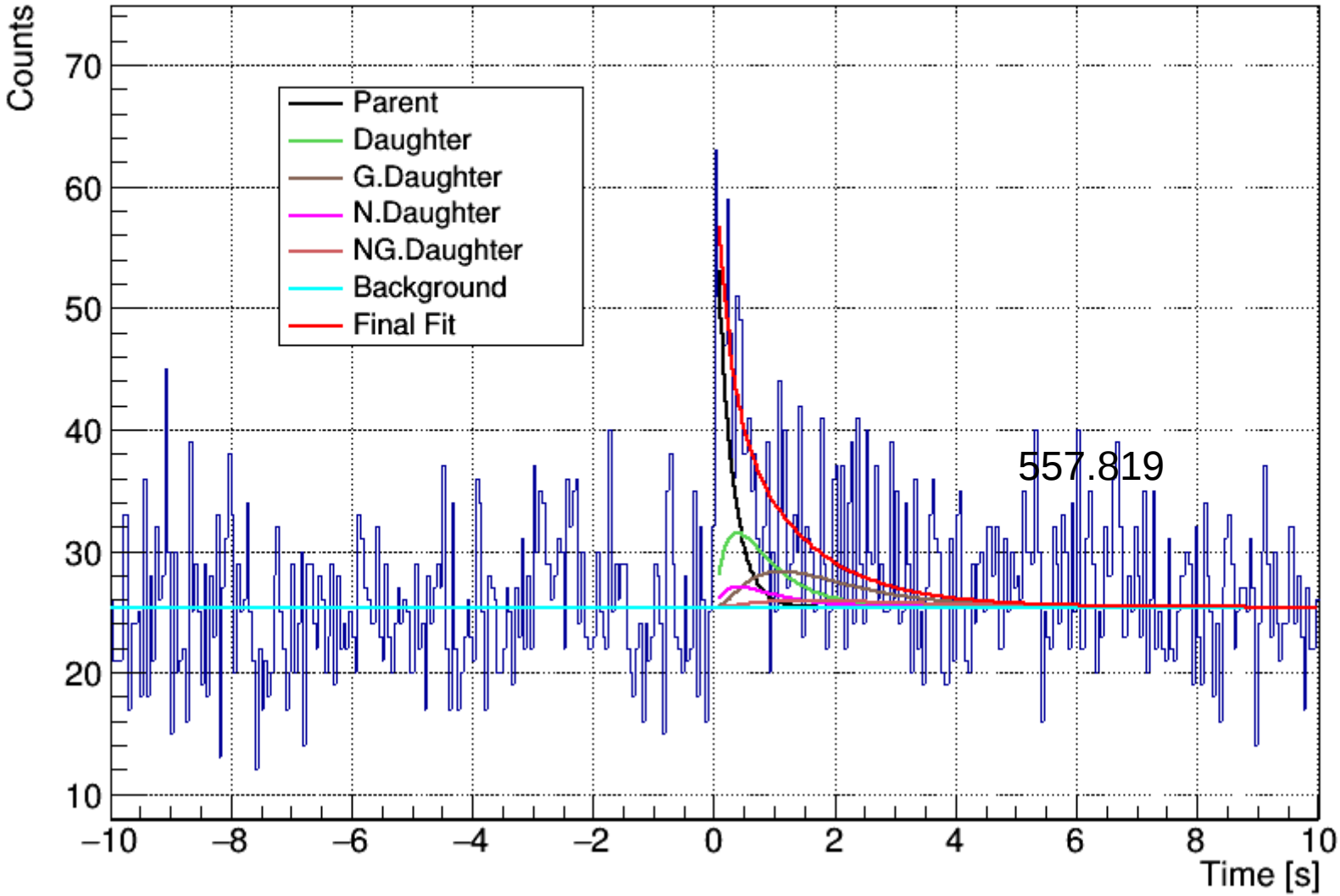
4.2 T12 Fit Results: 158Pr



4.2 T12 Fit Results: 159Pr

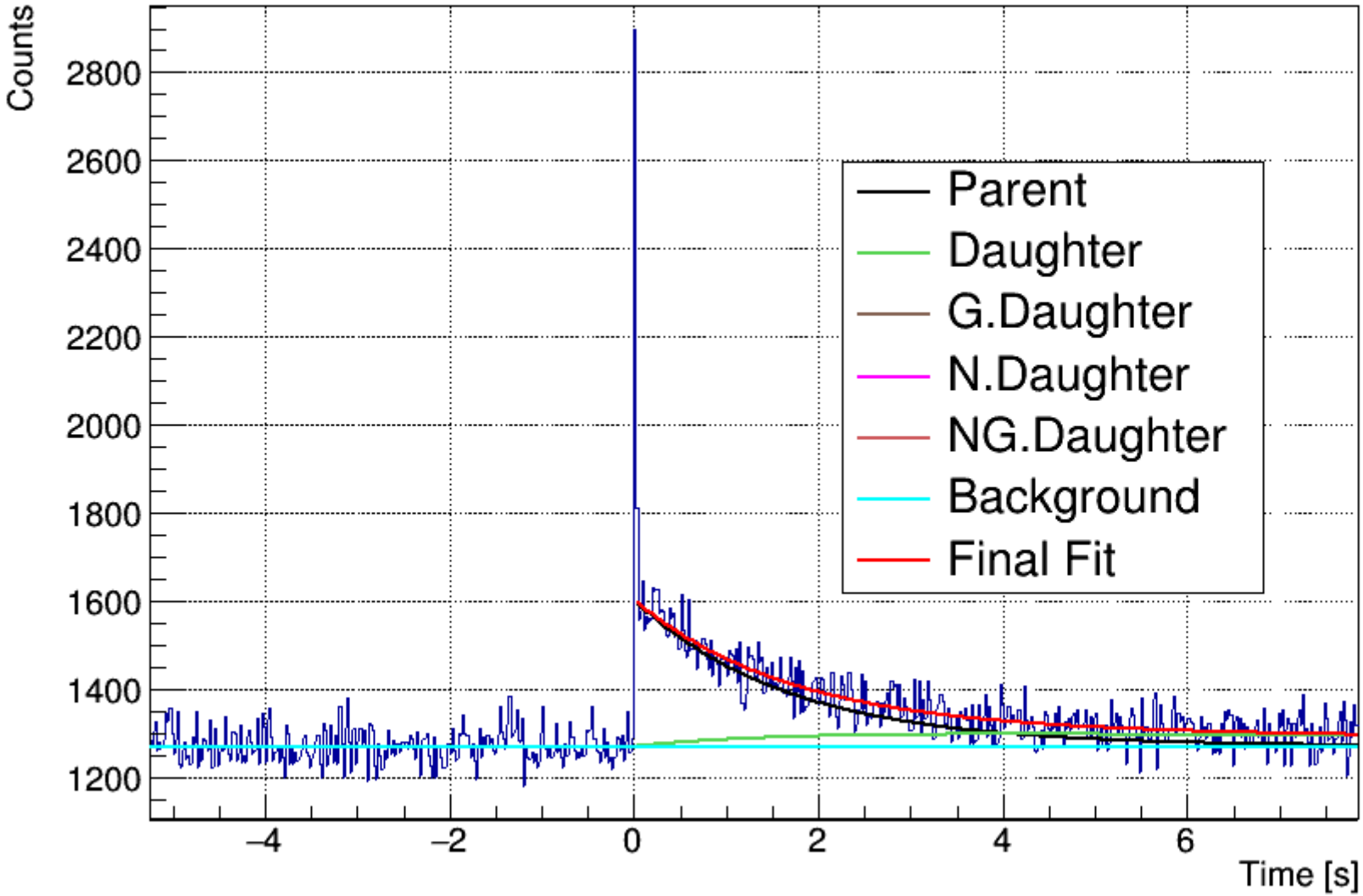


4.2 T12 Fit Results: 160Pr

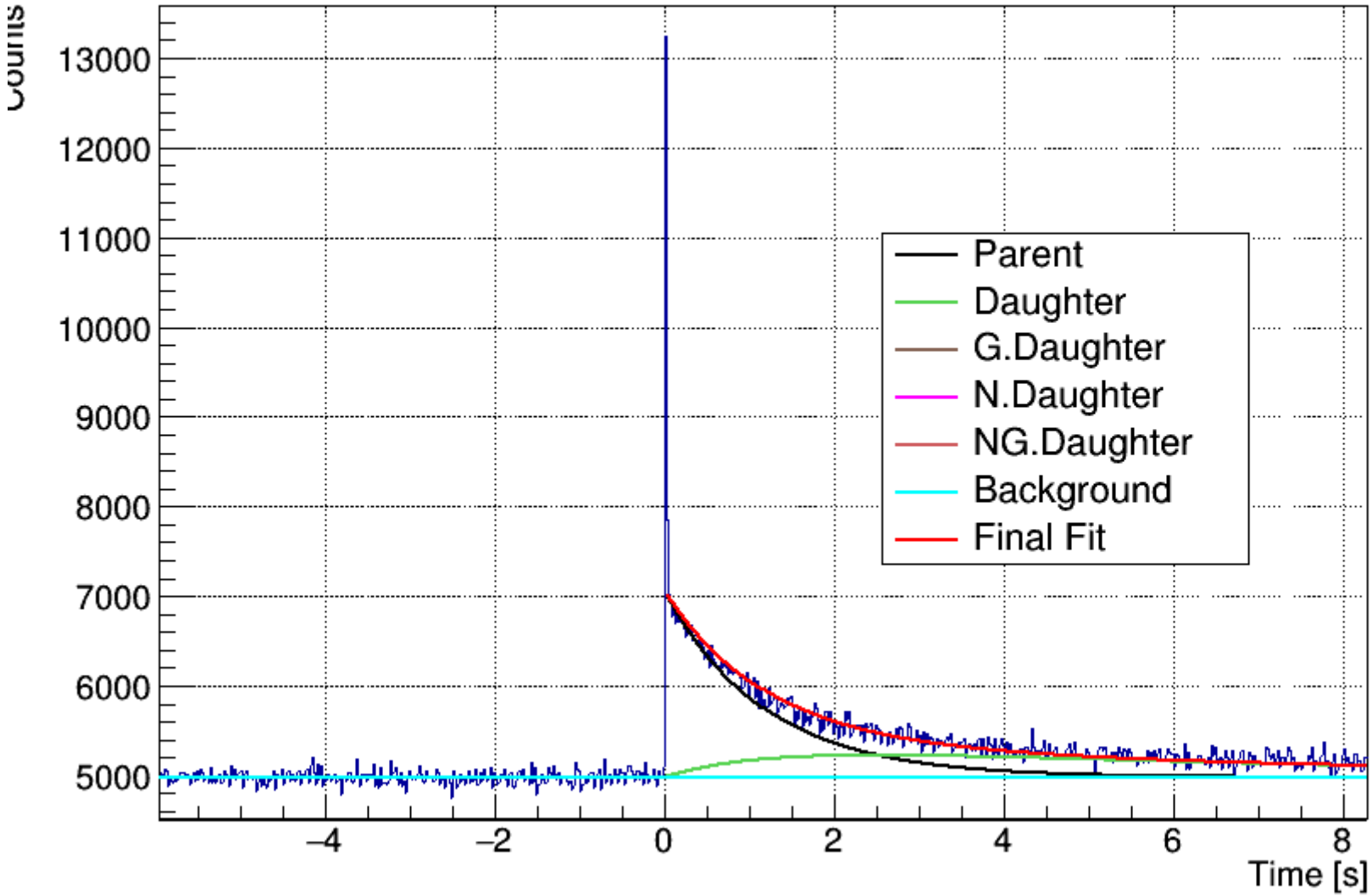


4. T12 Fit Results: Nd (Neodymium)

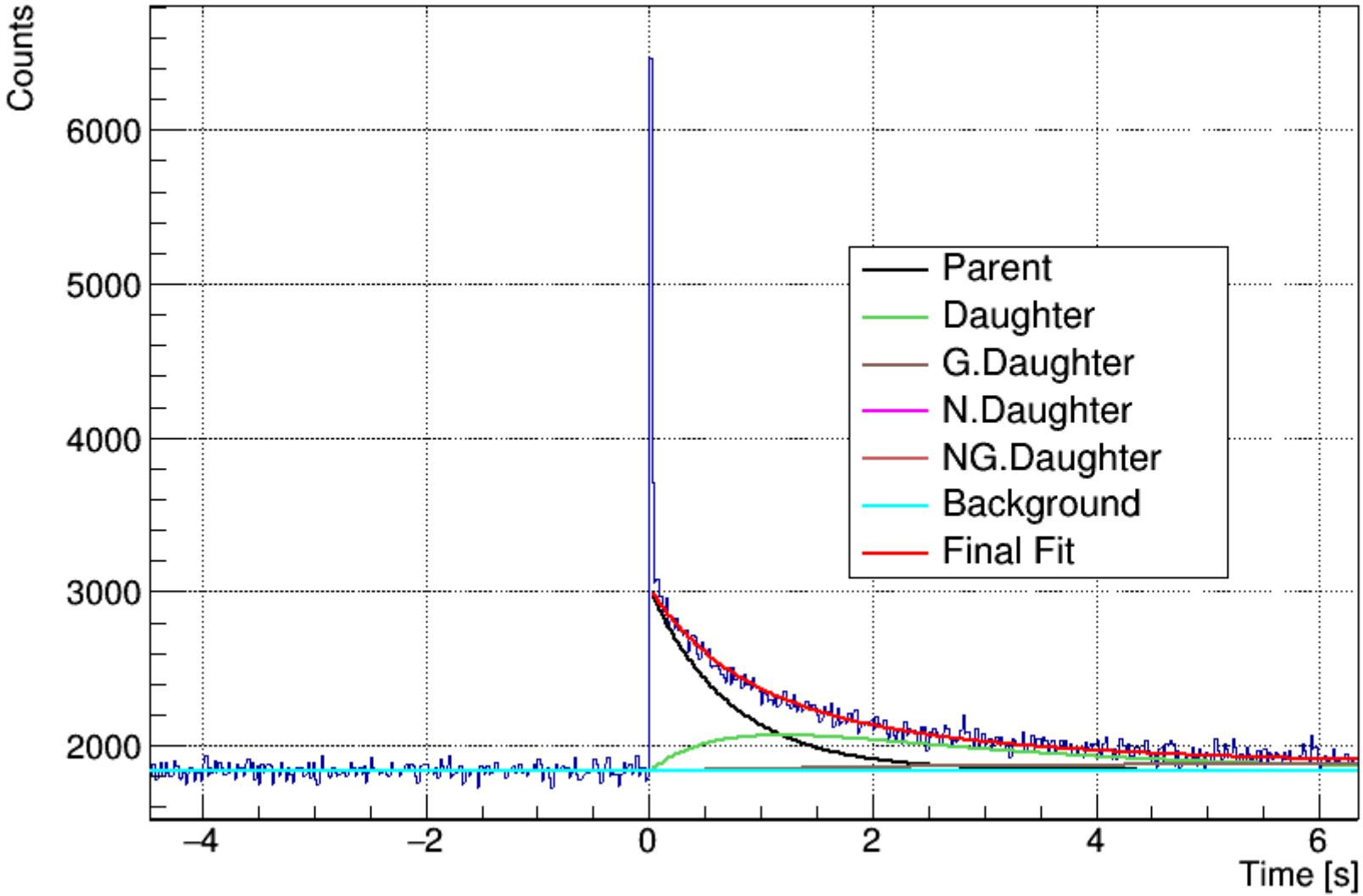
4.3 T12 Fit Results: 157Nd



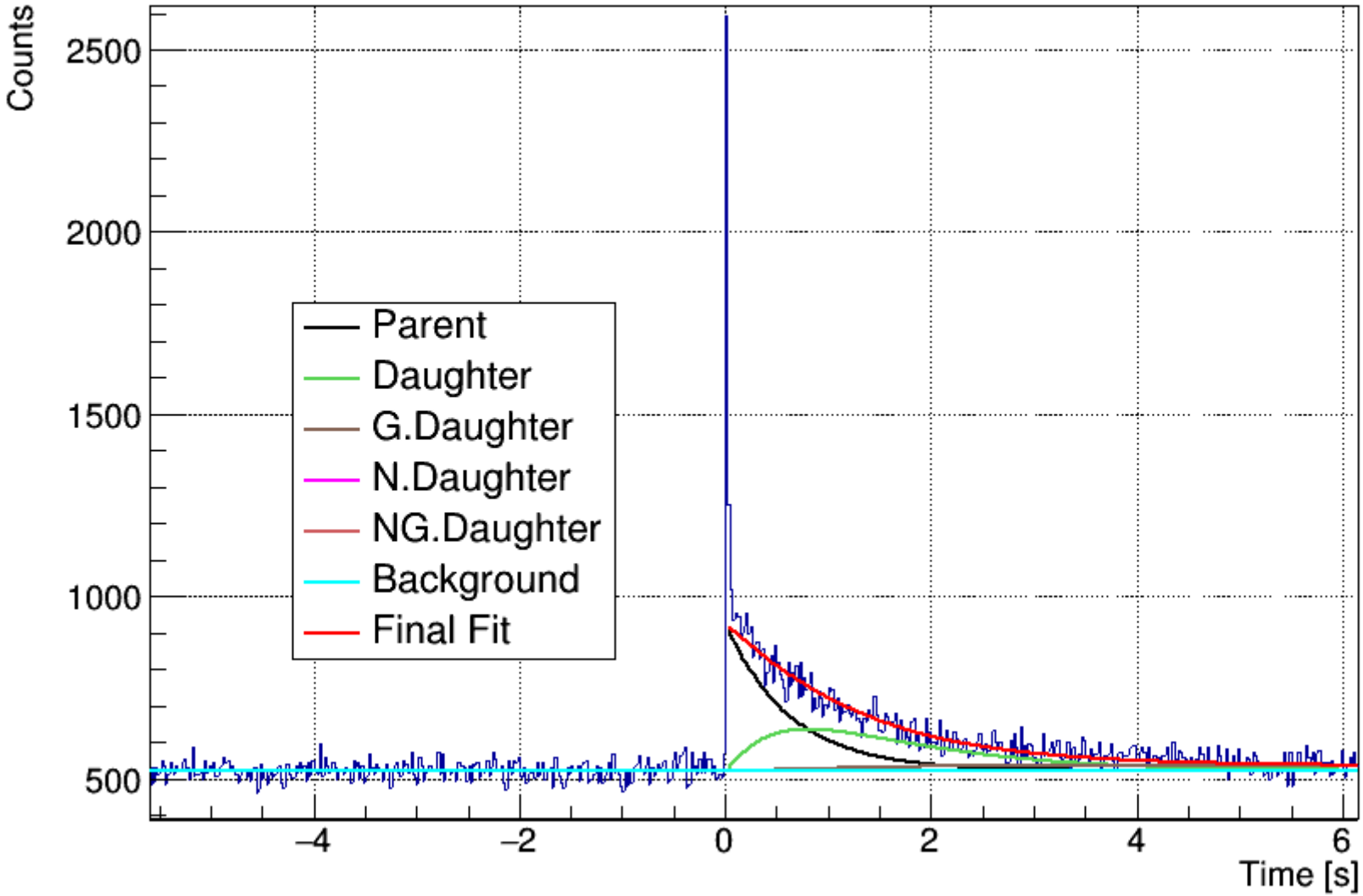
4.3 T12 Fit Results: 158Nd



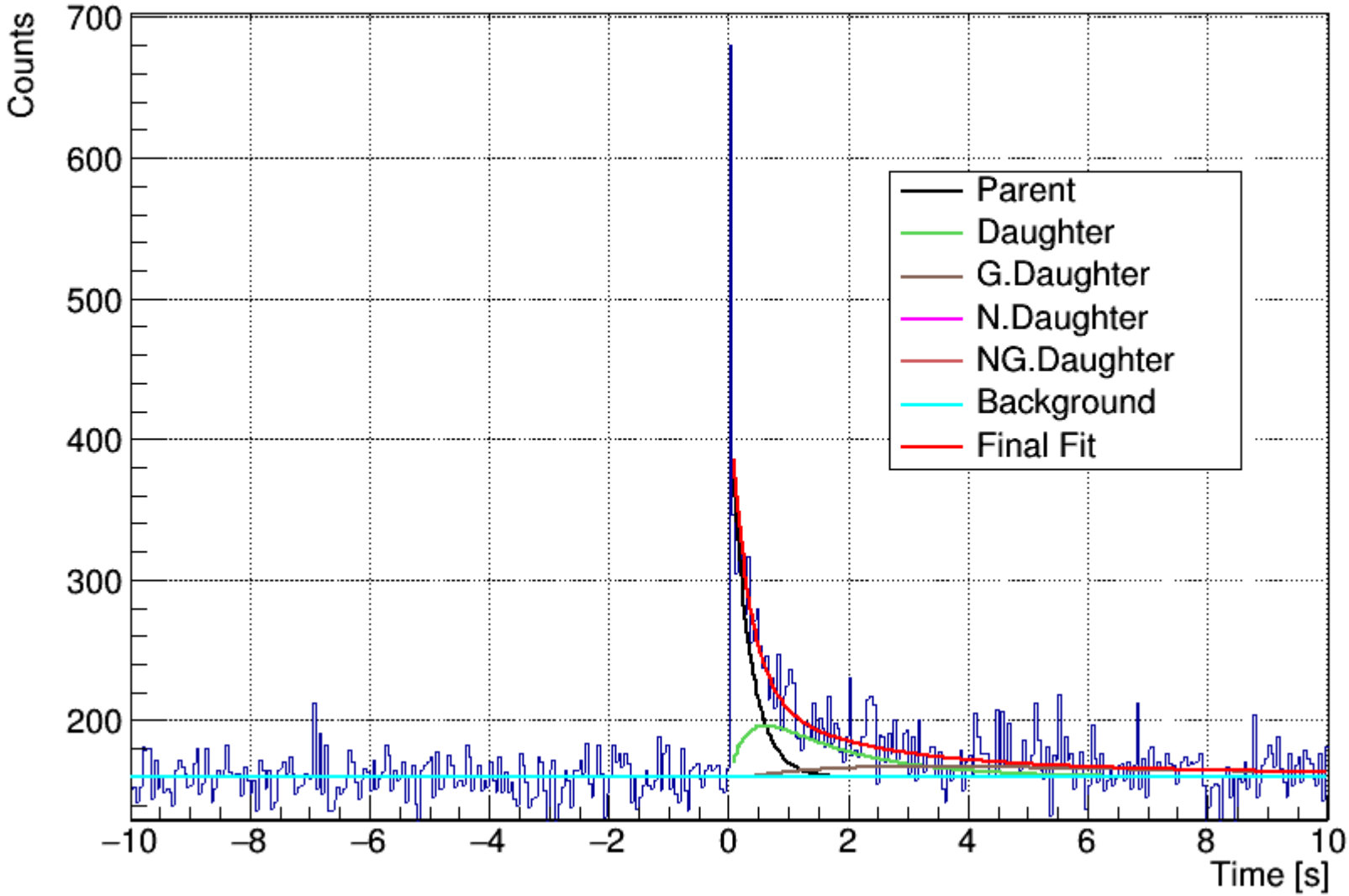
4.3 T12 Fit Results: 159Nd



4.3 T12 Fit Results: 160Nd



4.3 T12 Fit Results: 161Nd



4.3 T12 Fit Results: 162Nd