# OSCAR calibration for an alpha beam and an oxidized $^{12}C$ target

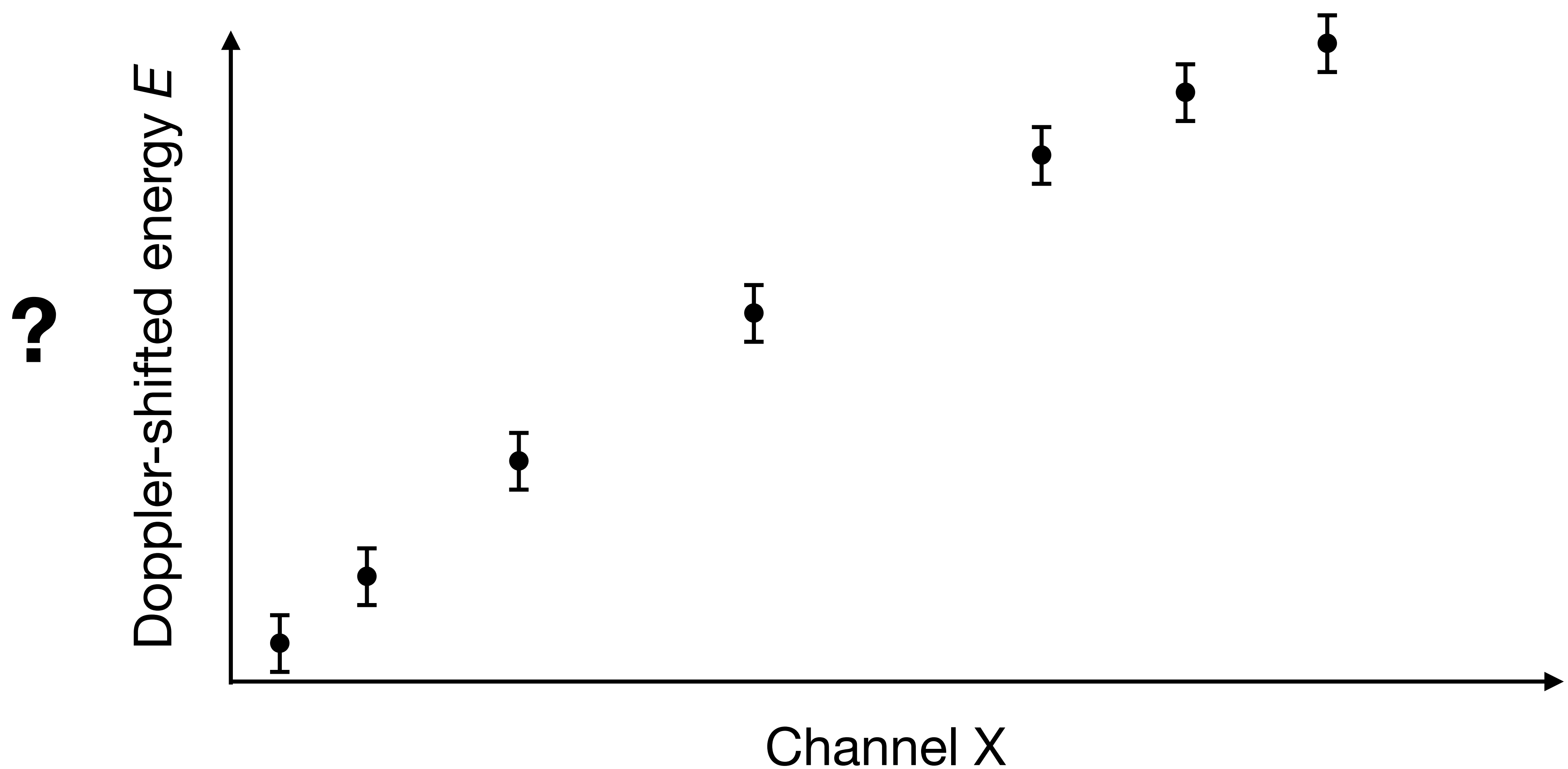
**Introduction:** In alpha beam experiments, a $^{12}C$ target contaminated with $^{16}O$ provides calibration lines from 110 keV to 7.3 MeV.

**Problem:** with an alpha beam of 24-26 MeV, and a light target ($^{12}C$ or $^{16}O$), the velocity of the recoil nucleus is in the order of 2-4%. For the high energy lines in $^{15}N$ (5-7 MeV), for example, the corresponding doppler shift is 150-200 keV.

**Doppler-shifted energies:**

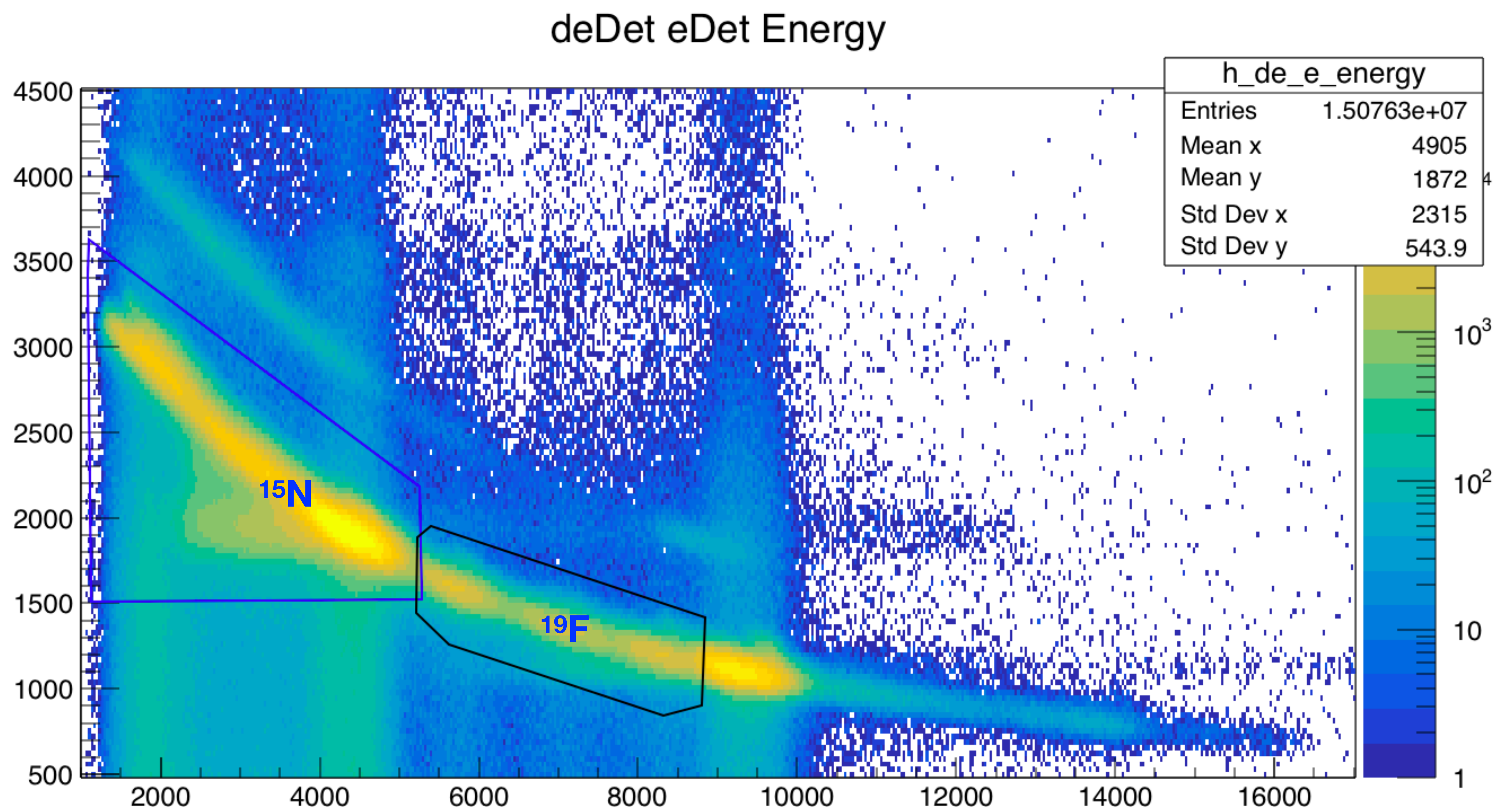
$E = E_0(1 + \beta cos\theta)$

The doppler-shifted energies *E* most be found to perform the calibration.



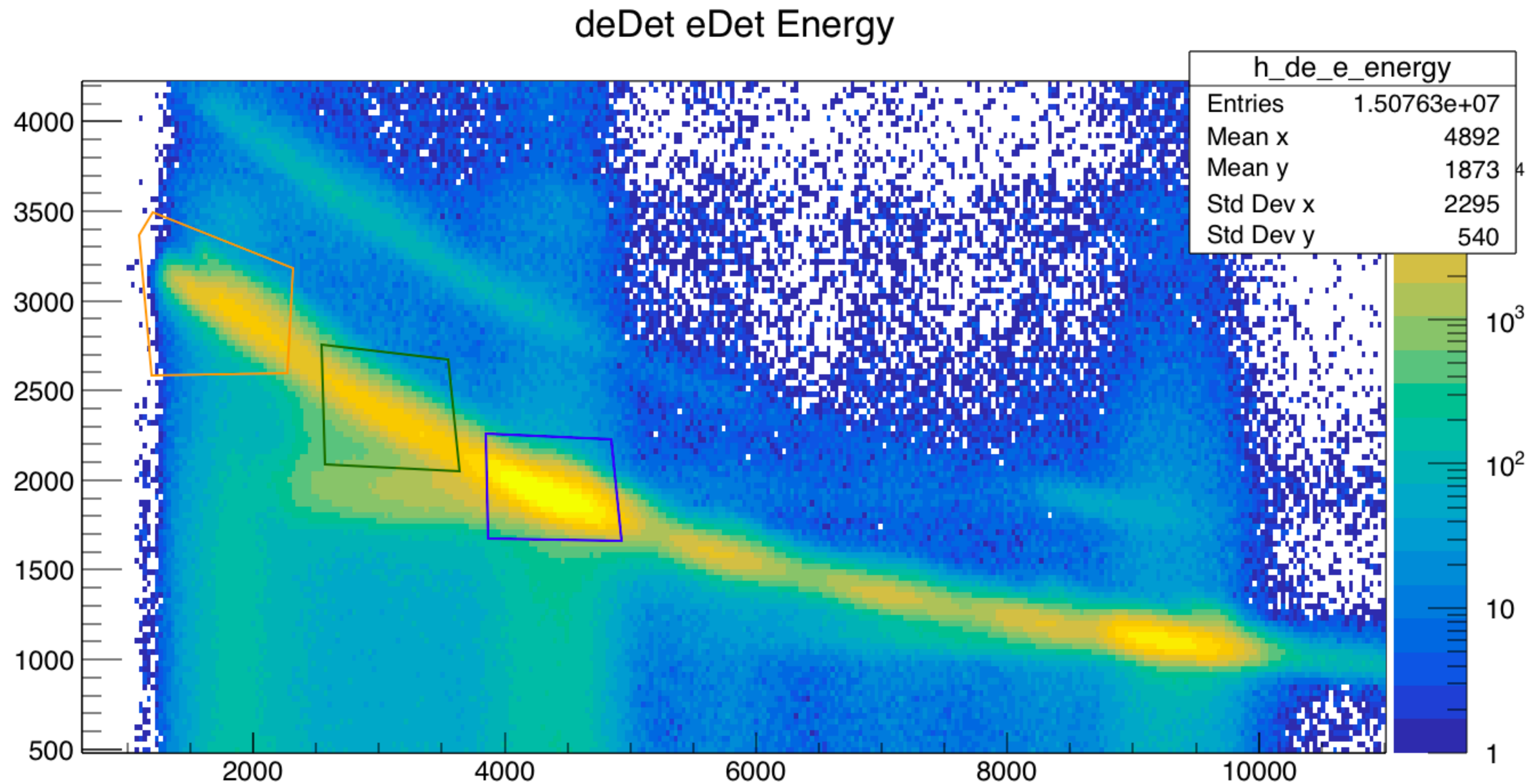
**My recommendation of cuts and calibration lines:**

**Obs!** This is for 26 MeV alphas in backwards. For other energies, other states can be populated (for example: for 30 MeV alphas, a 4.6 MeV 13/2+ state in $^{19}$F seems to show up strongly in the $^{15}$N cut shown below.)

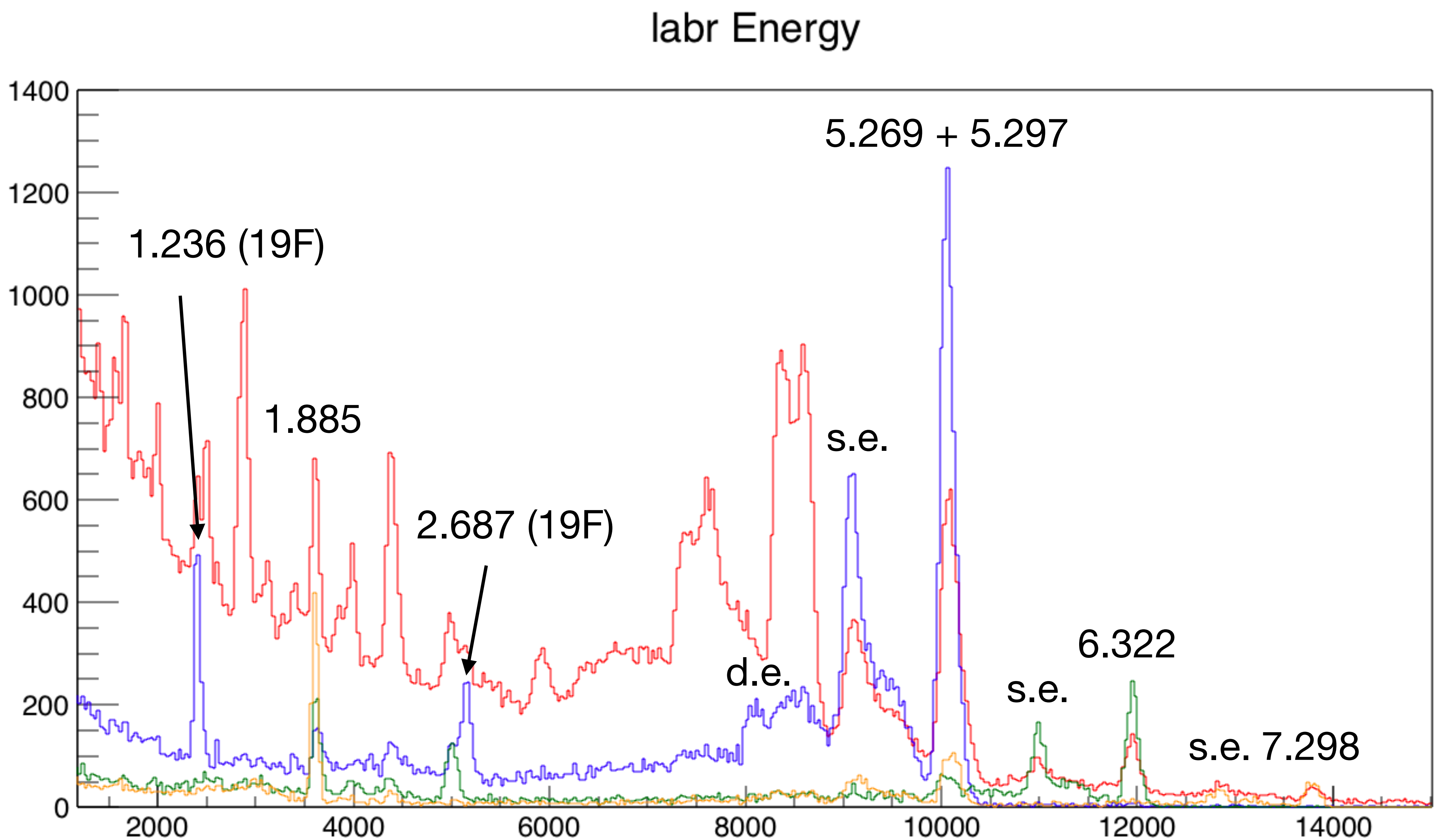


deDet eDet Energy
h_de_e_energy
Entries 1.50763e+07
Mean x 4905
Mean y 1872
Std Dev x 2315
Std Dev y 543.9
15N
19F
4500
4000
3500
3000
2500
2000
1500
1000
500
2000
4000
6000
8000
10000
12000
14000
16000
10^3
10^2
10
1

**Blue:** **(α,p) gated ($^{15}$N 5.2 MeV (two states!))**
**Green:** **(α,p) gated ($^{15}$N 6.3 MeV)**
**Orange:** **(α,p) gated ($^{15}$N 7.3 MeV)**

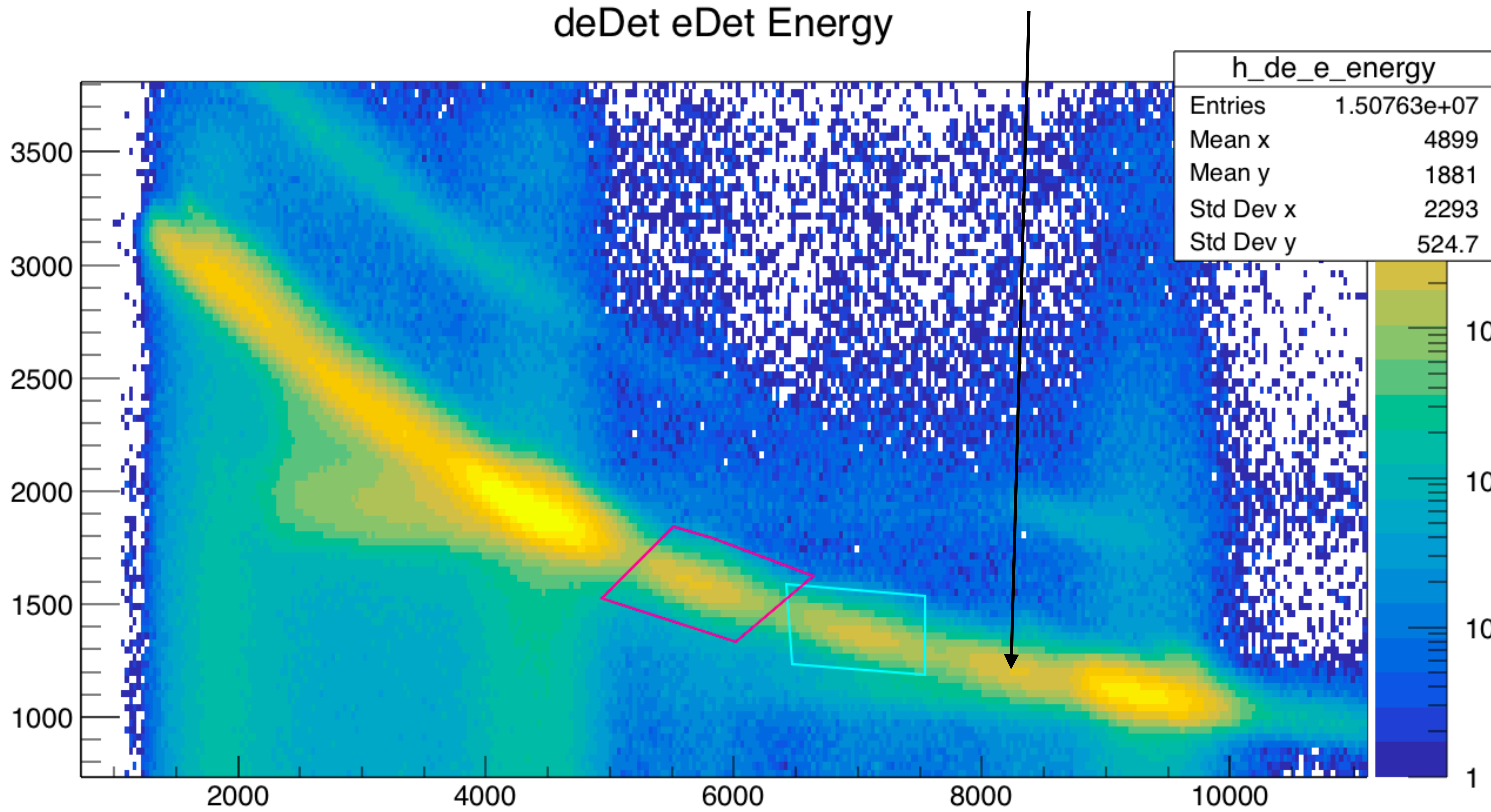


**Red:** Singles
**Blue:** (α,p) gated (5.2 MeV)
**Green:** (α,p) gated (6.3 MeV)
**Orange:** (α,p) gated (7.3 MeV)

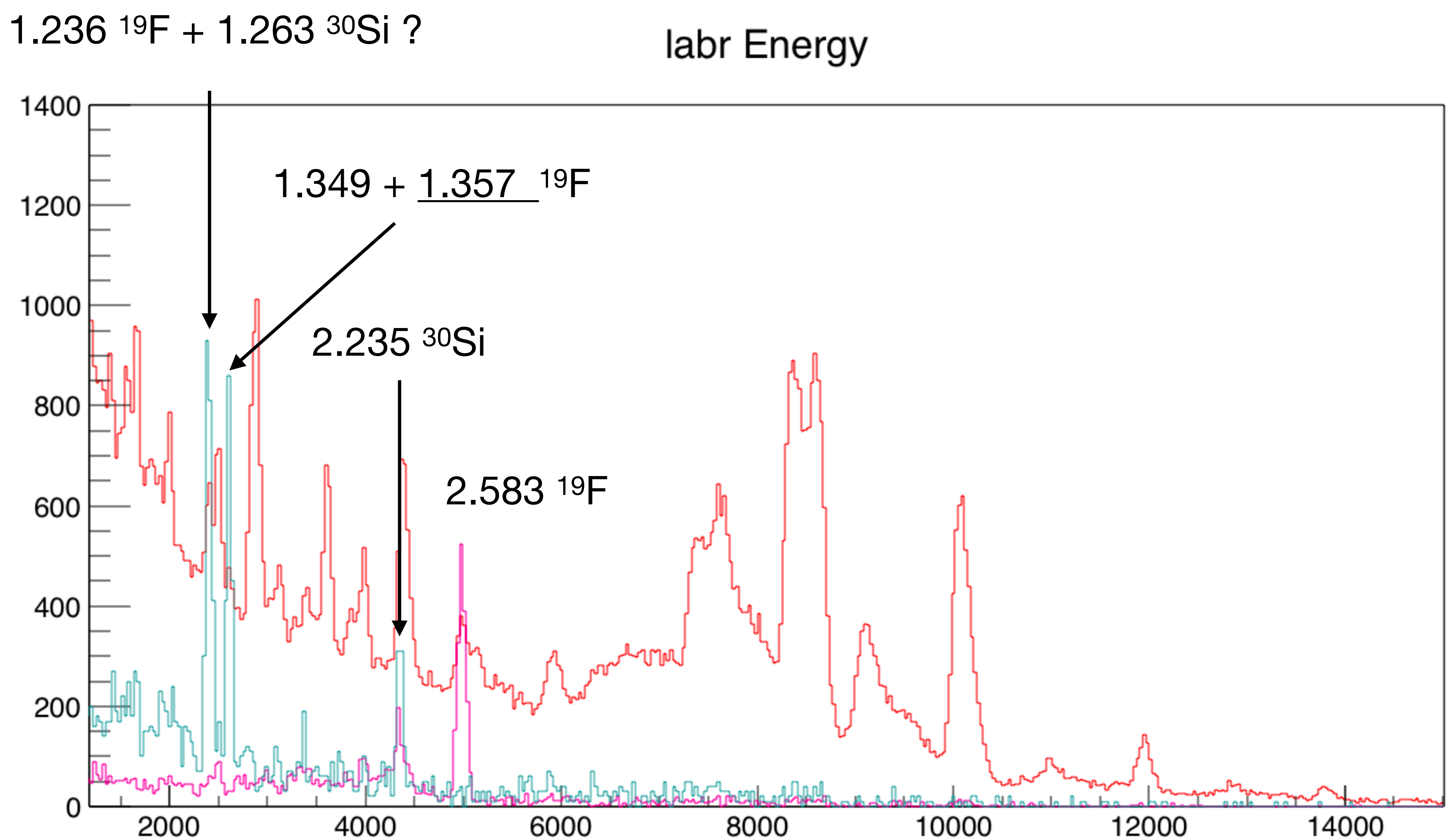


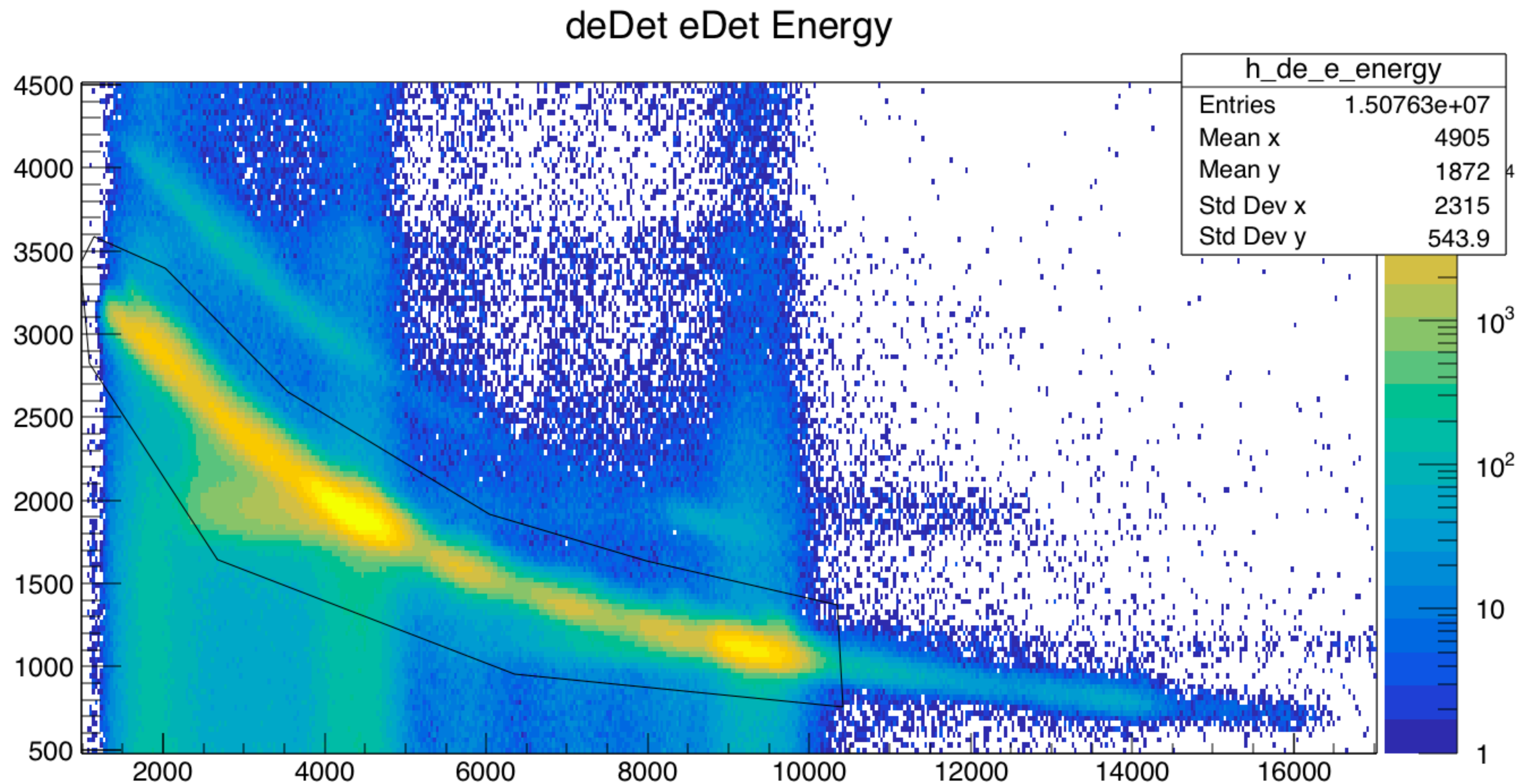
**Pink:** (α,p) gated ($^{19}F$ 2.7 MeV)
**Cyan:** (α,p) gated ($^{19}F$ 1.2 MeV)

$^{19}F$ 110 keV + 197 keV + g.s.



**Red:** Singles
**Pink:** (α,p) gated (2.7 MeV)
**Cyan:** (α,p) gated (1.2 MeV)





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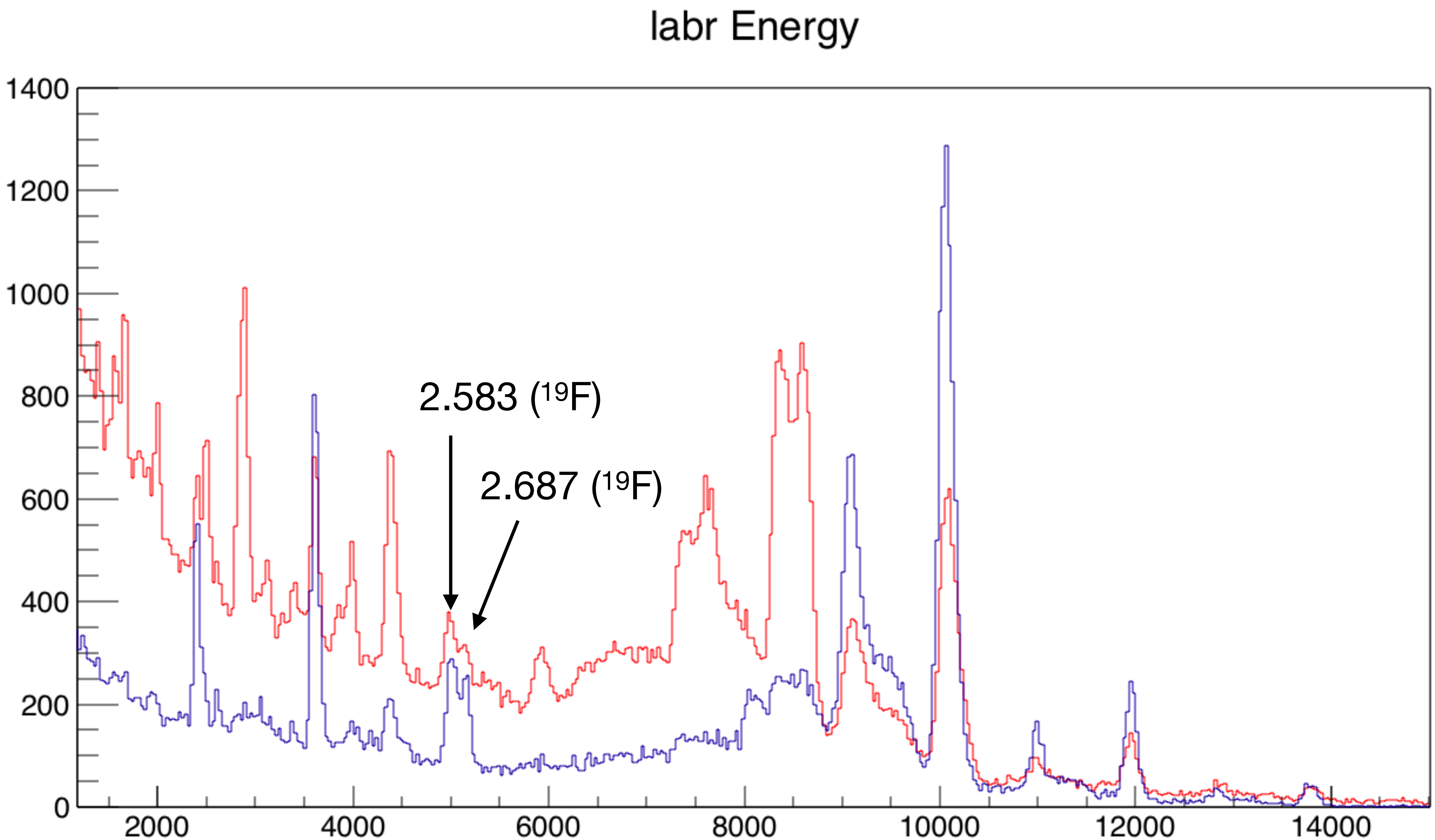
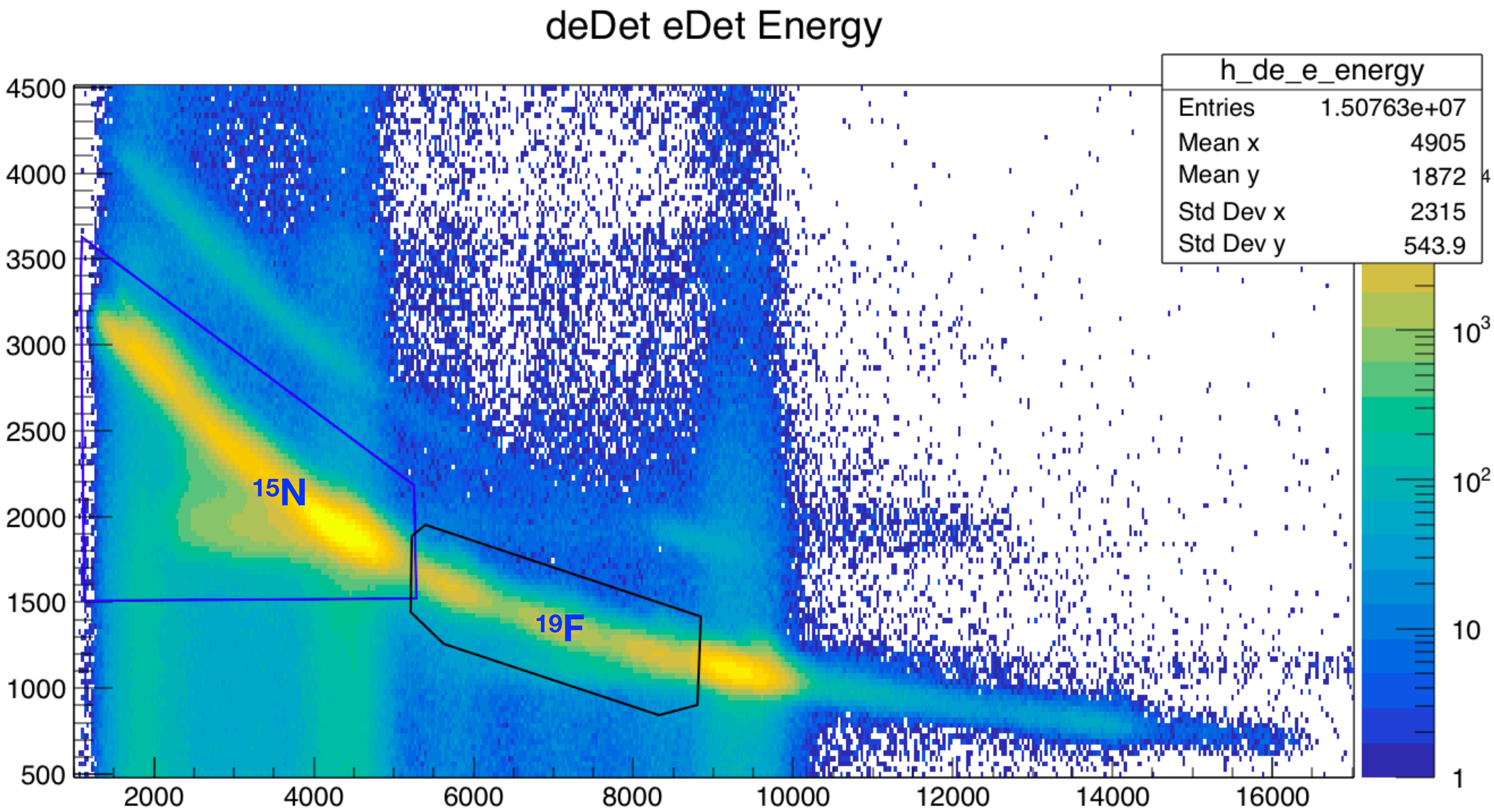
3000
2500
2000
1500
1000
500
2000
4000
6000
8000
10000
12000
14000
16000
$10^3$
$10^2$
10
1

**Red:** **Singles**
**Blue:** **(α,p) gated (all)**

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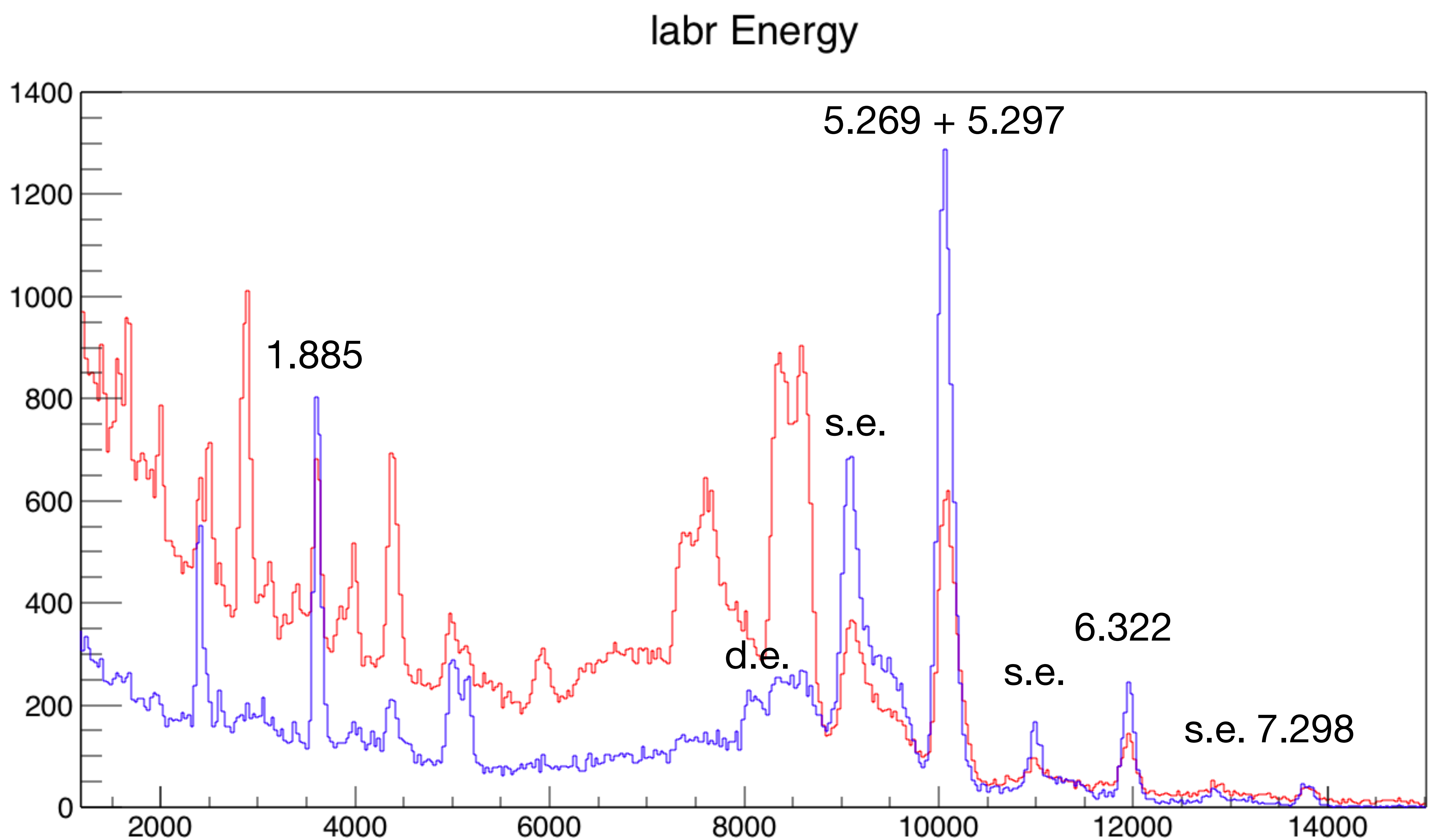
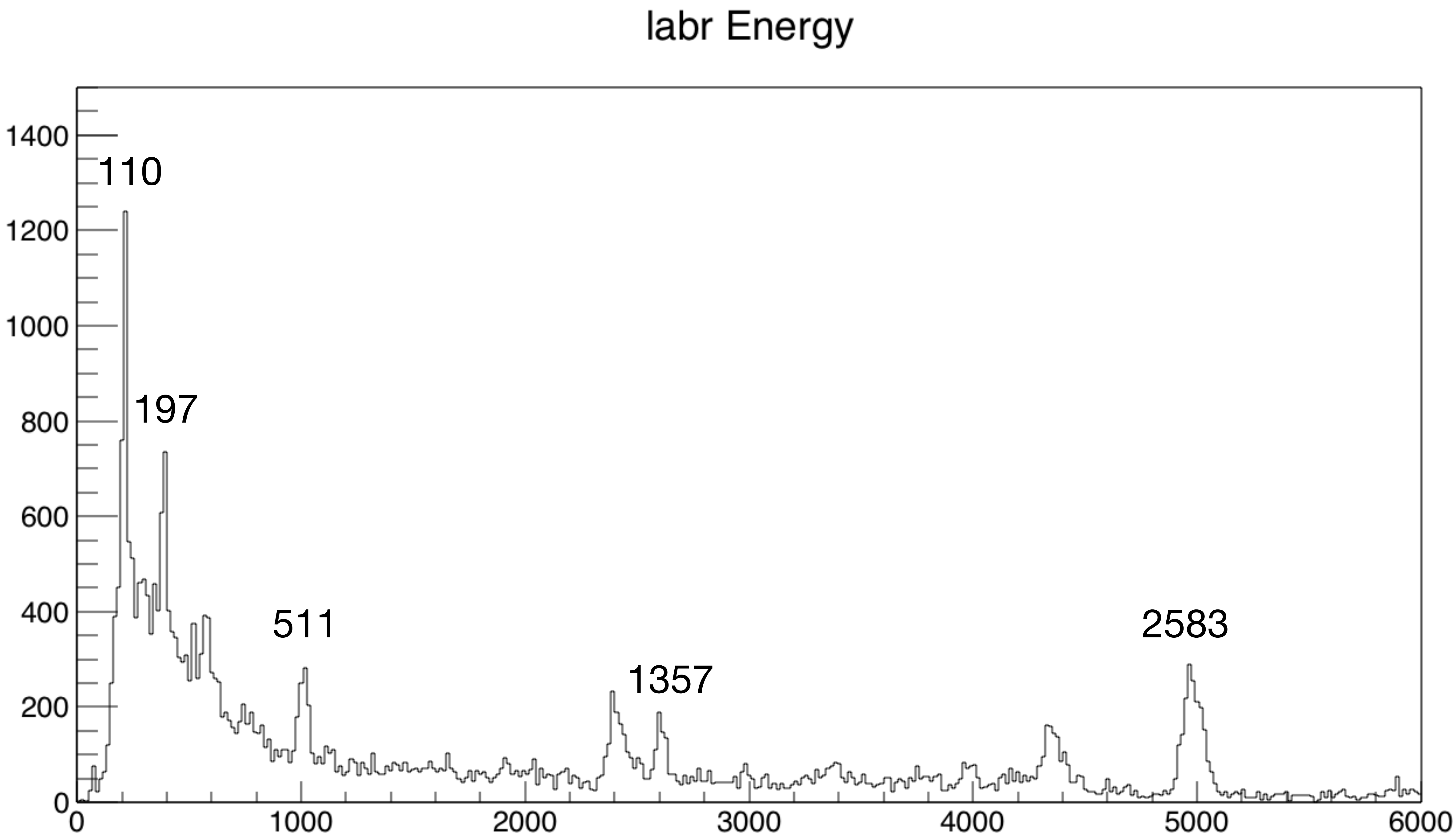
500
2000
4000
6000
8000
10000
12000
14000
16000
10^3
10^2
10
1

**Red:** Singles
**Blue:** (α,p) gated $^{15}N$



**Black: (α,p) gated $^{19}$F**



**Kinematics:**

**Obs!** I tried to obtain the doppler shifted energies directly from the spectrum without using the kinematic calculations to avoid possible systematics errors in the angles. That didn’t work. The energy resolution in not good enough to get the doppler shifted energies from the peak positions.

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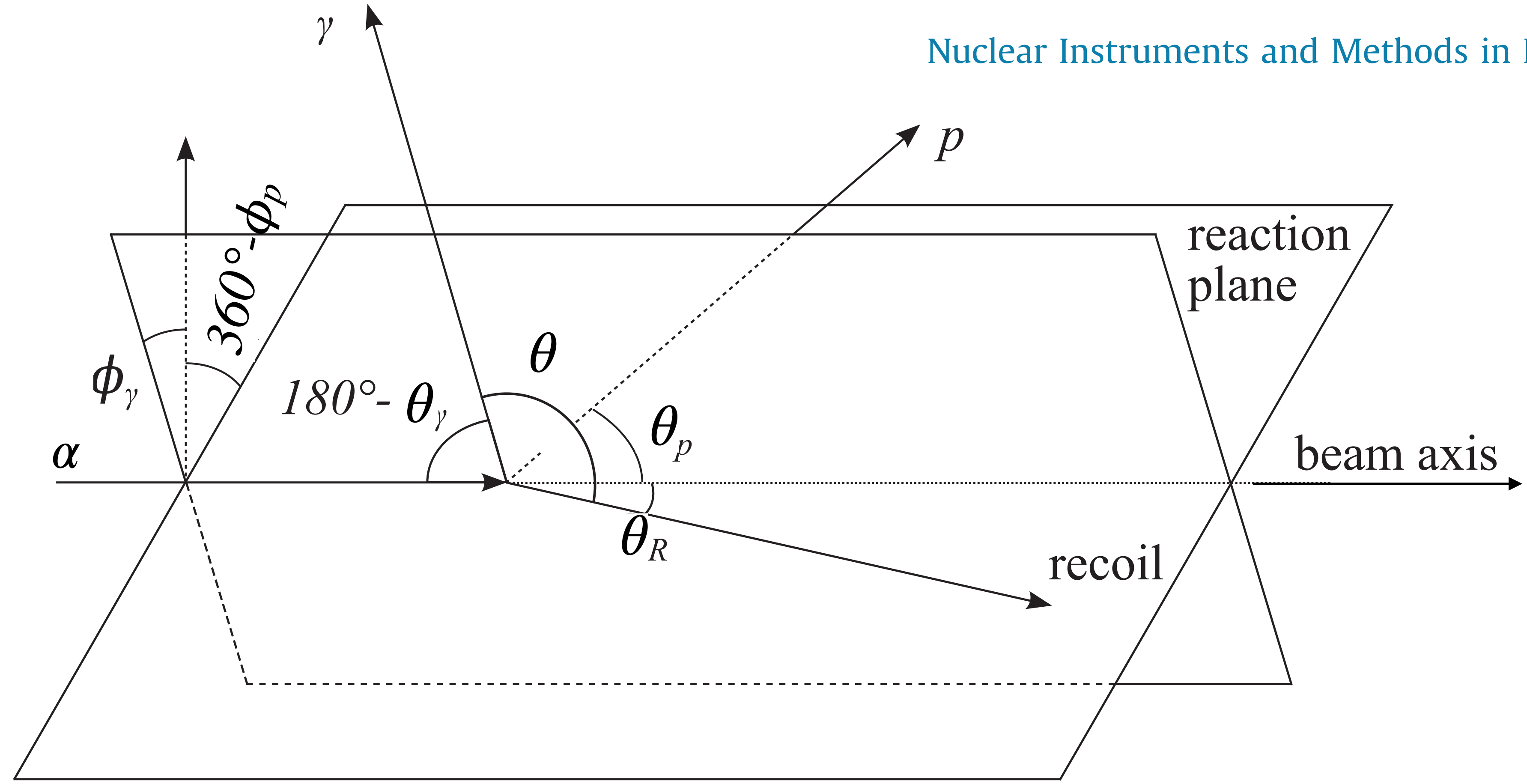


Oscar angle

Siri angle

$$\cos\theta = \frac{1}{\sqrt{1+x^2}}\left[\cos\theta_\gamma - x\cdot\sin\theta_\gamma\cos\left(\phi_\gamma-\phi_p\right)\right]$$

$$x \equiv \tan\theta_R = \frac{\sin\theta_p}{\sqrt{\frac{E_\alpha}{E_p}} - \cos\theta_p}.$$

Missing in the article!

Dependent on excitation energy and $\theta_p$

Angle between the recoil direction and the emitted photon

$$P_\alpha = P_p \cos\theta_p + P_R \cos\theta_R$$

$$0 = P_p \sin\theta_p - P_R \sin\theta_R$$

$$x \equiv \tan\theta_R = \frac{\sin\theta_p}{\sqrt{\frac{E_\alpha}{E_p}} - \cos\theta_p}.$$

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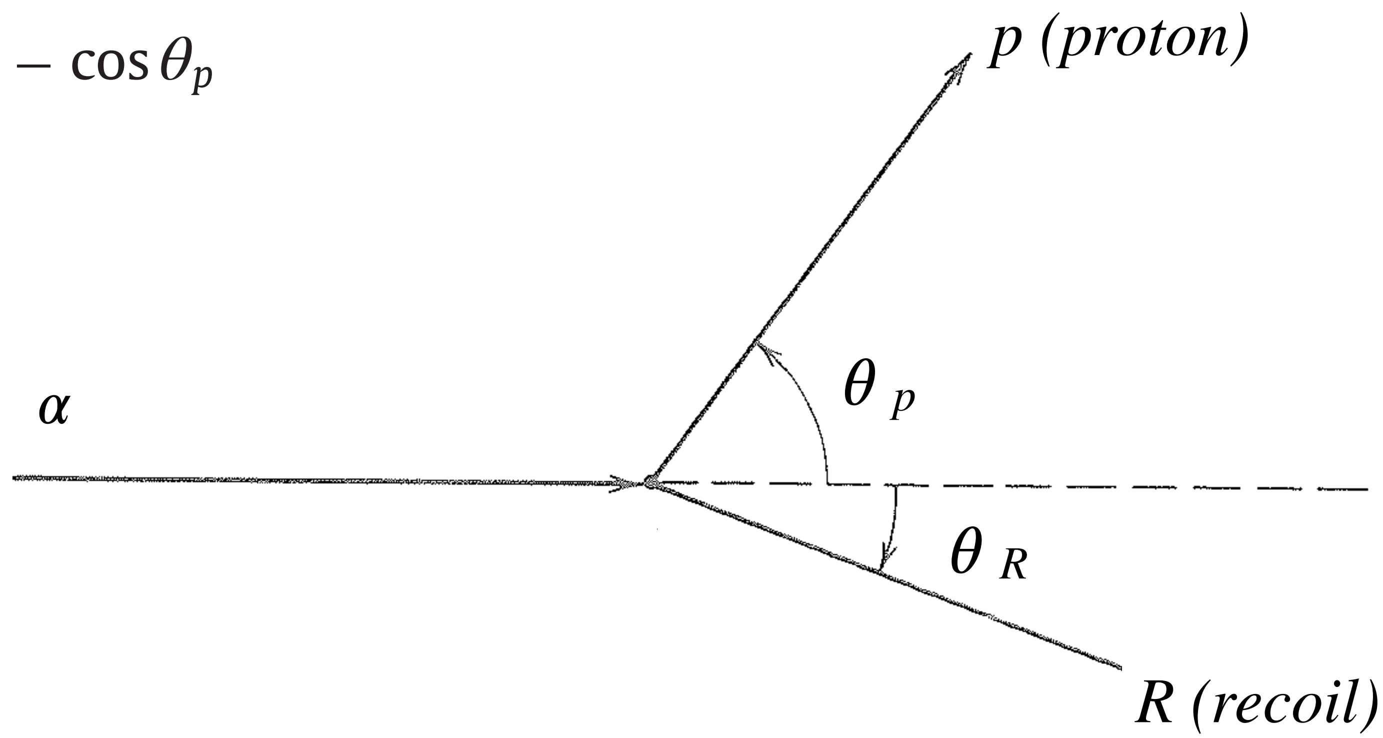
Oregon State University




$$\sqrt{E_p} = \frac{(m_\alpha m_p E_\alpha)^{1/2}\cos\theta_p + \{m_\alpha m_p E_\alpha \cos^2\theta_p + (m_R + m_p)[m_R Q + (m_R - m_\alpha)E_\alpha]\}^{1/2}}{m_R + m_p}$$

$$\cos\theta = \frac{1}{\sqrt{1+x^2}}\left[\cos\theta_\gamma - x\cdot\sin\theta_\gamma\cos\left(\phi_\gamma - \phi_p\right)\right]$$

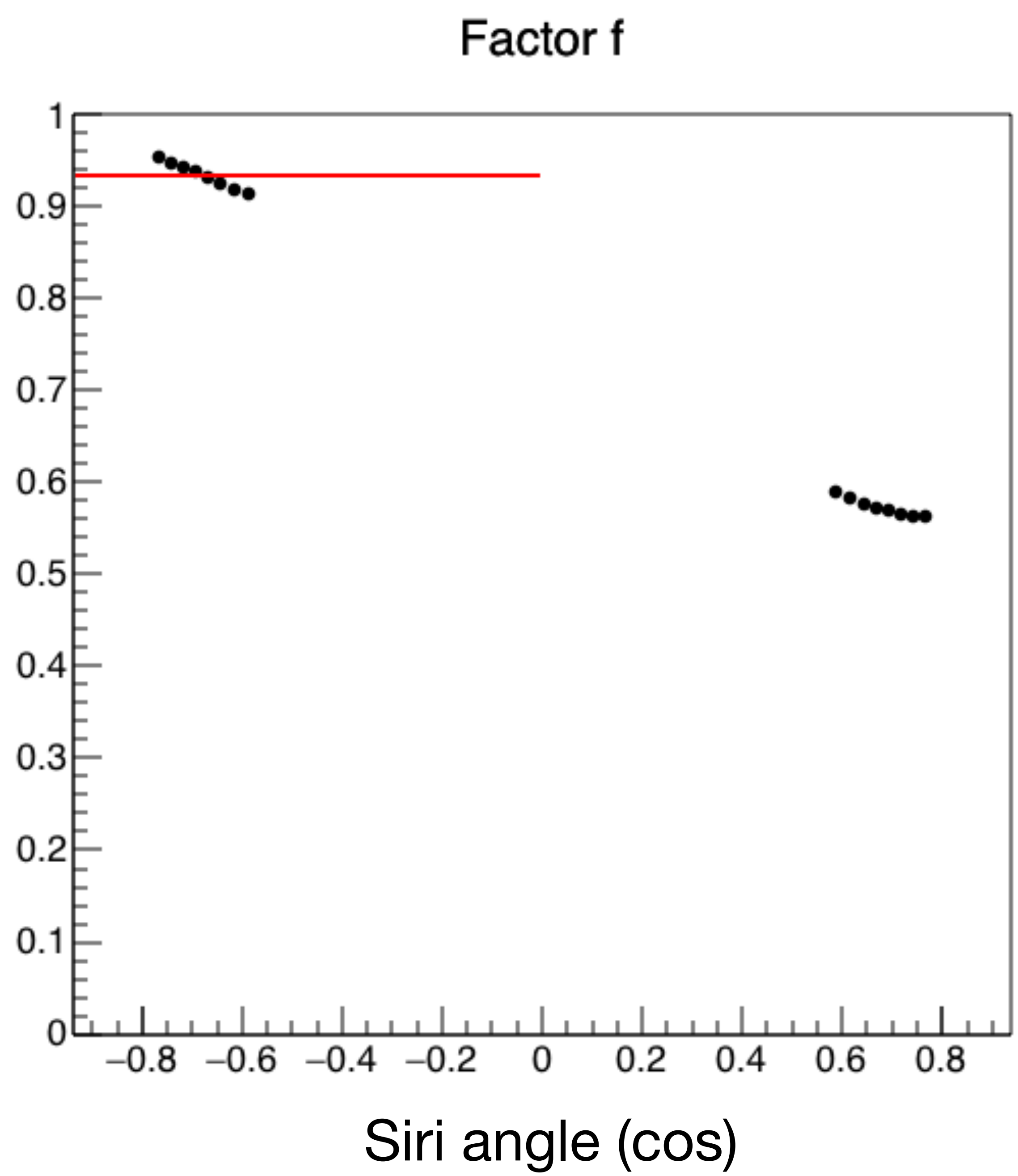
For gating on one SiRi ring:

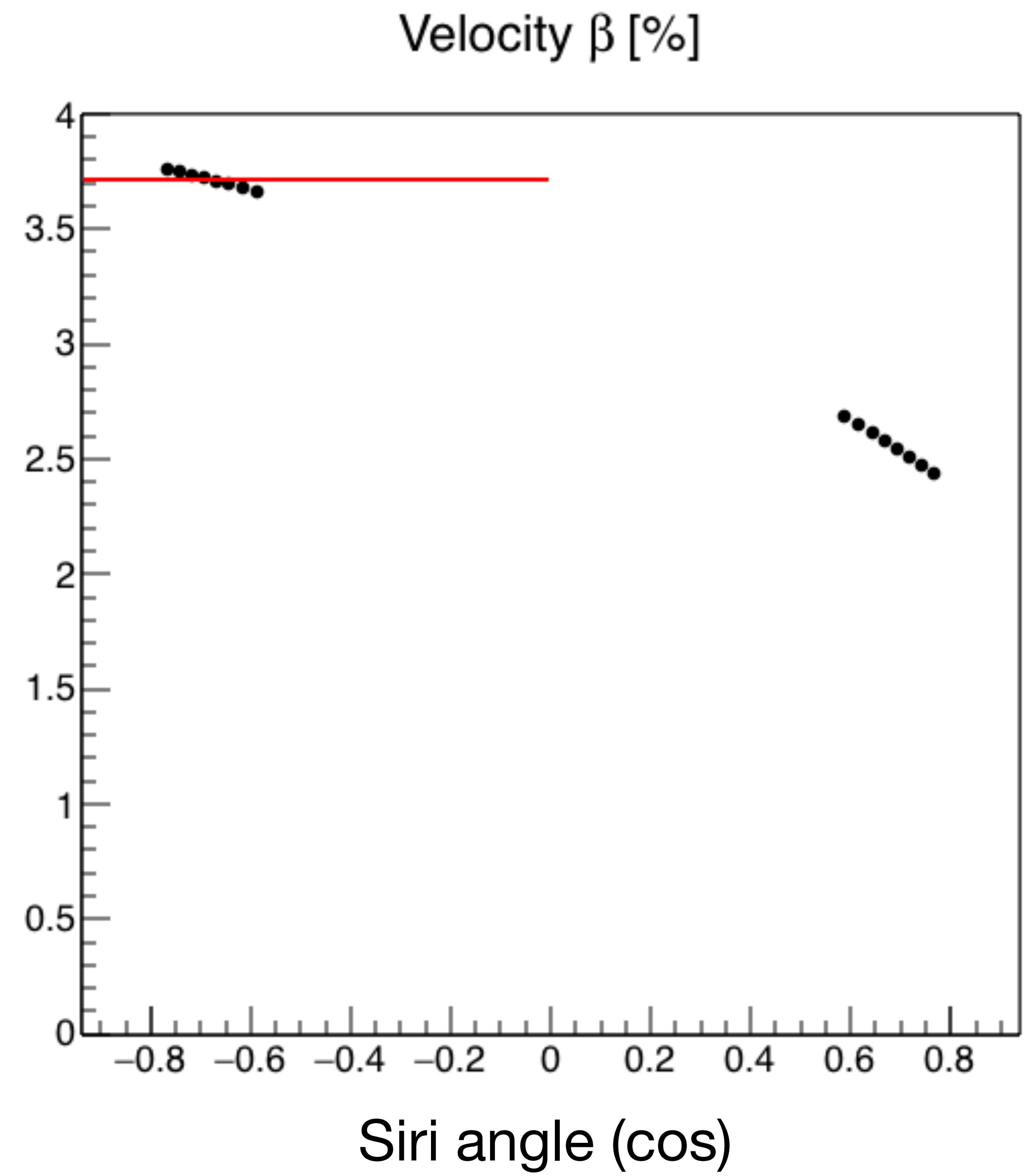
$$\overline{cos\theta} = \frac{1}{2\pi}\int_0^{2\pi} cos\theta\, d\phi_p = \frac{1}{\sqrt{1+x^2}}\, cos\theta_\gamma$$

$$E = E_0(1+\beta f cos\theta_\gamma) \qquad f = \frac{1}{\sqrt{1+x^2}} \qquad x = \tan\theta_R = \frac{\sin\theta_p}{\sqrt{\frac{E_\alpha}{E_p}} - \cos\theta_p}$$

I did the kinematic calculations in kinematics.C

For 5.2 MeV:



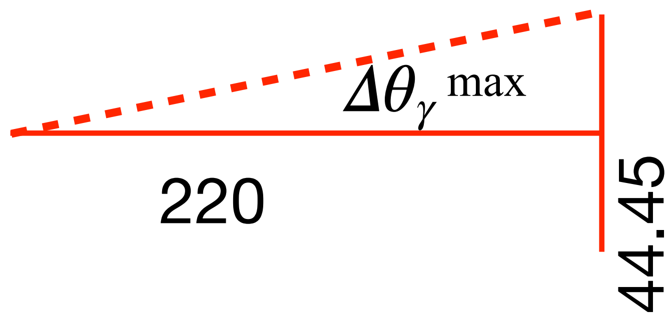

`f: 0.933 ± 0.020 (2.14%)`

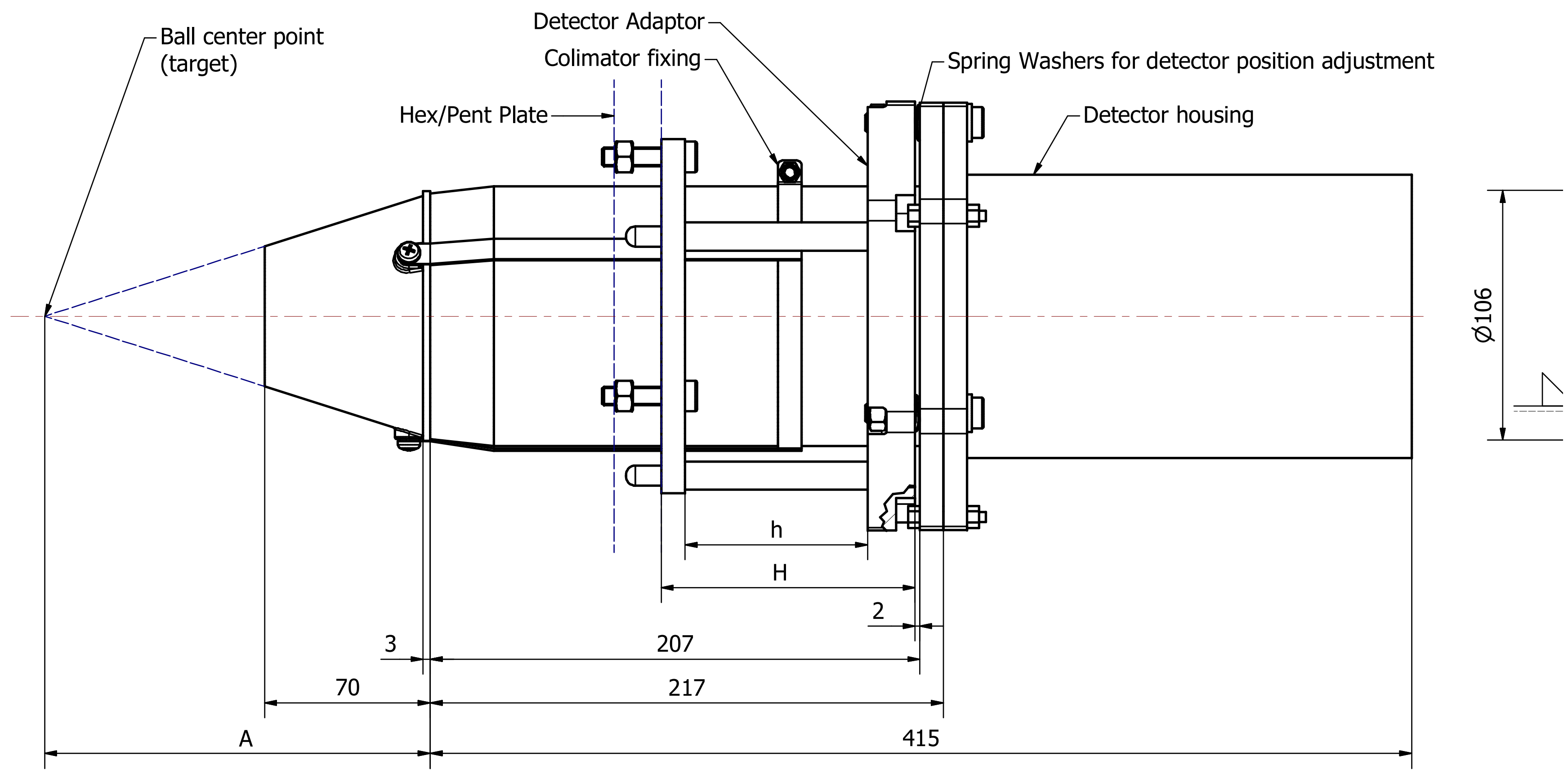
`beta: 3.713 ± 0.046 (1.25%)`

For the error I take the whole SiRi angular range.

For the error of OSCAR, I don't know what to take.

The entire angular opening $\Delta\theta_\gamma^{\ max}$ is 11.4°

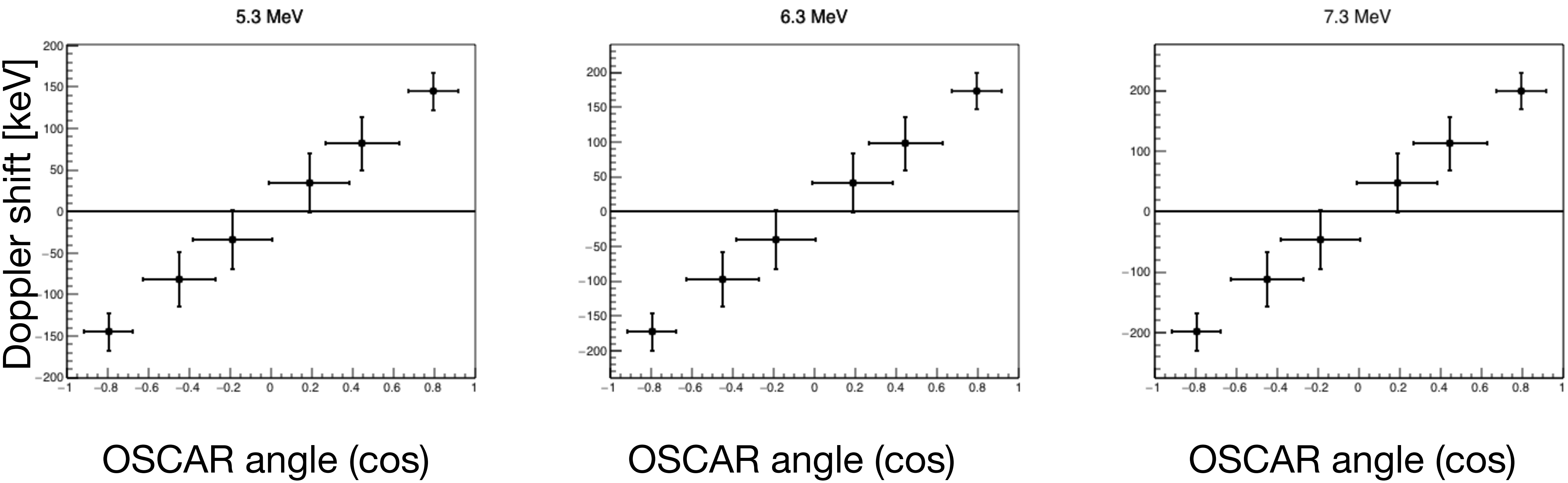


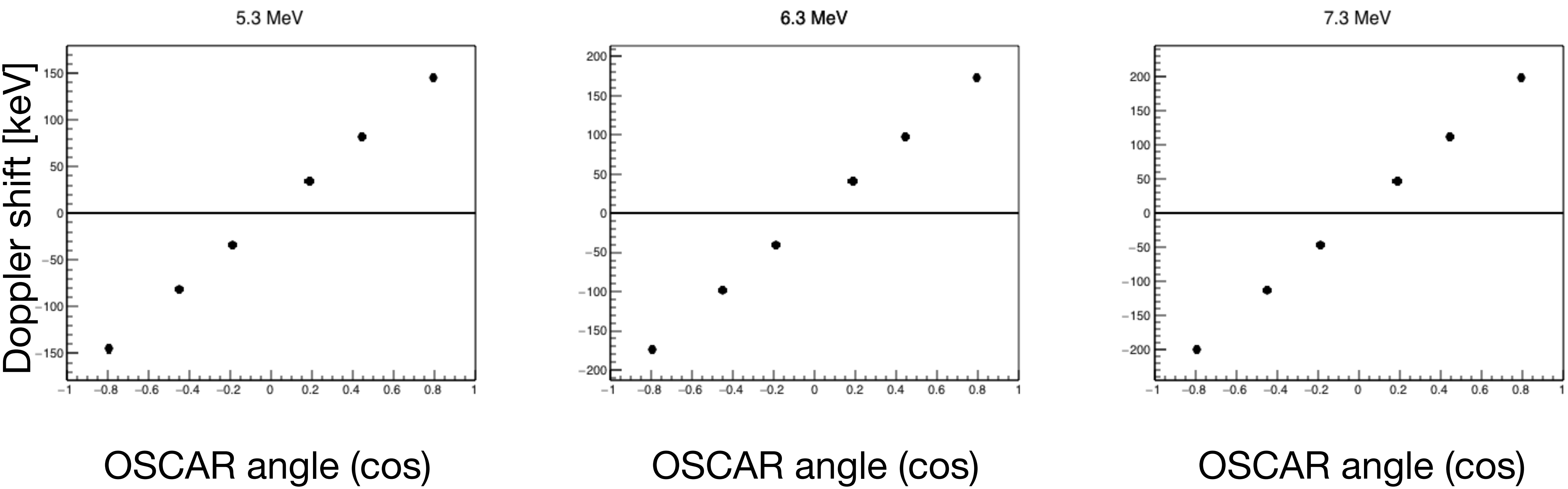

$$\tan \Delta\theta_\gamma = \frac{44.45}{220}$$

$$\Delta\theta_\gamma = 11.41$$

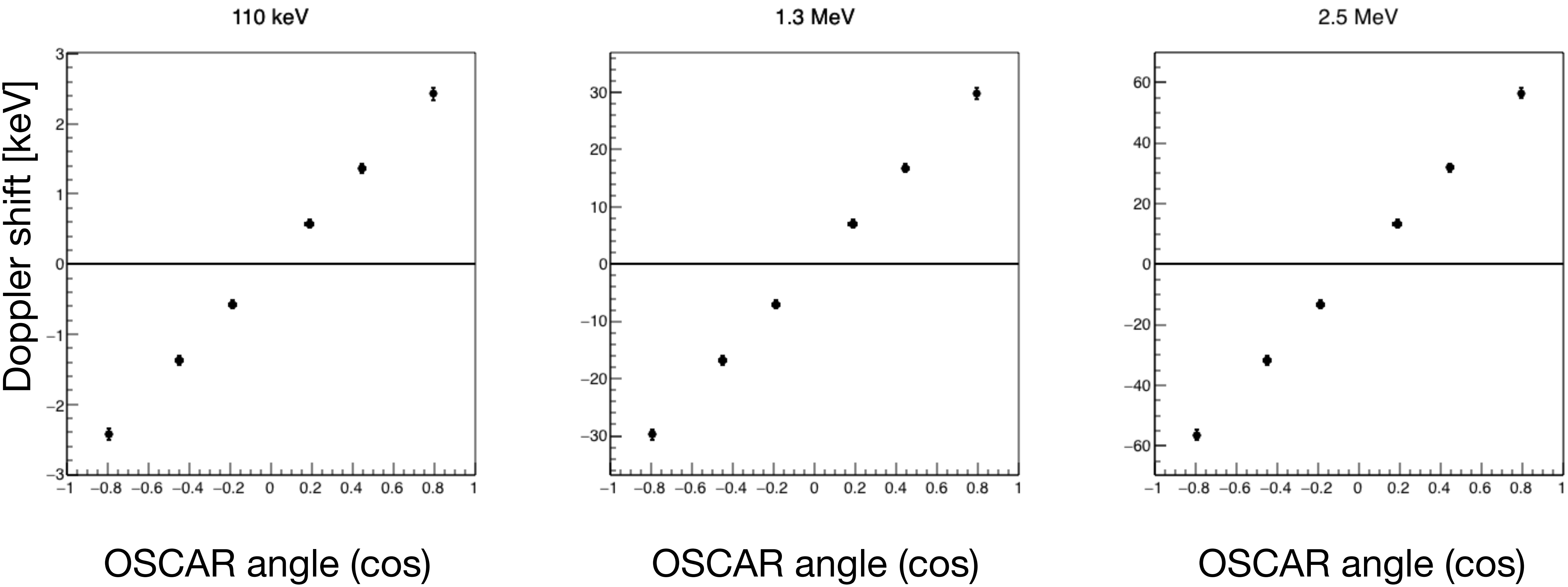
Doppler shift ($^{15}$N levels with $\Delta\theta_\gamma = 11.4°$ ):



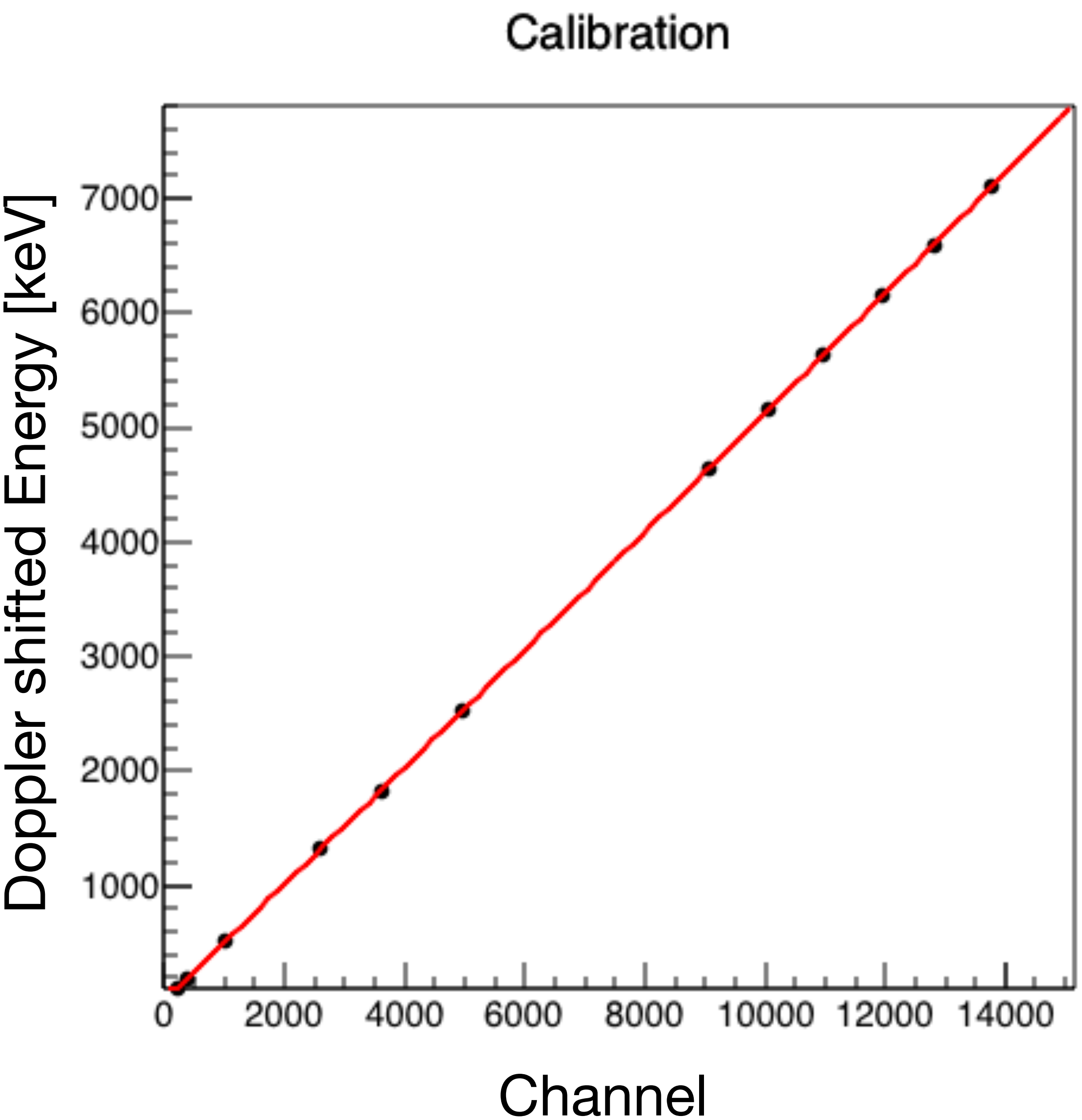
Doppler shift ($^{15}$N levels with $\Delta\theta_\gamma = 1°$ ):

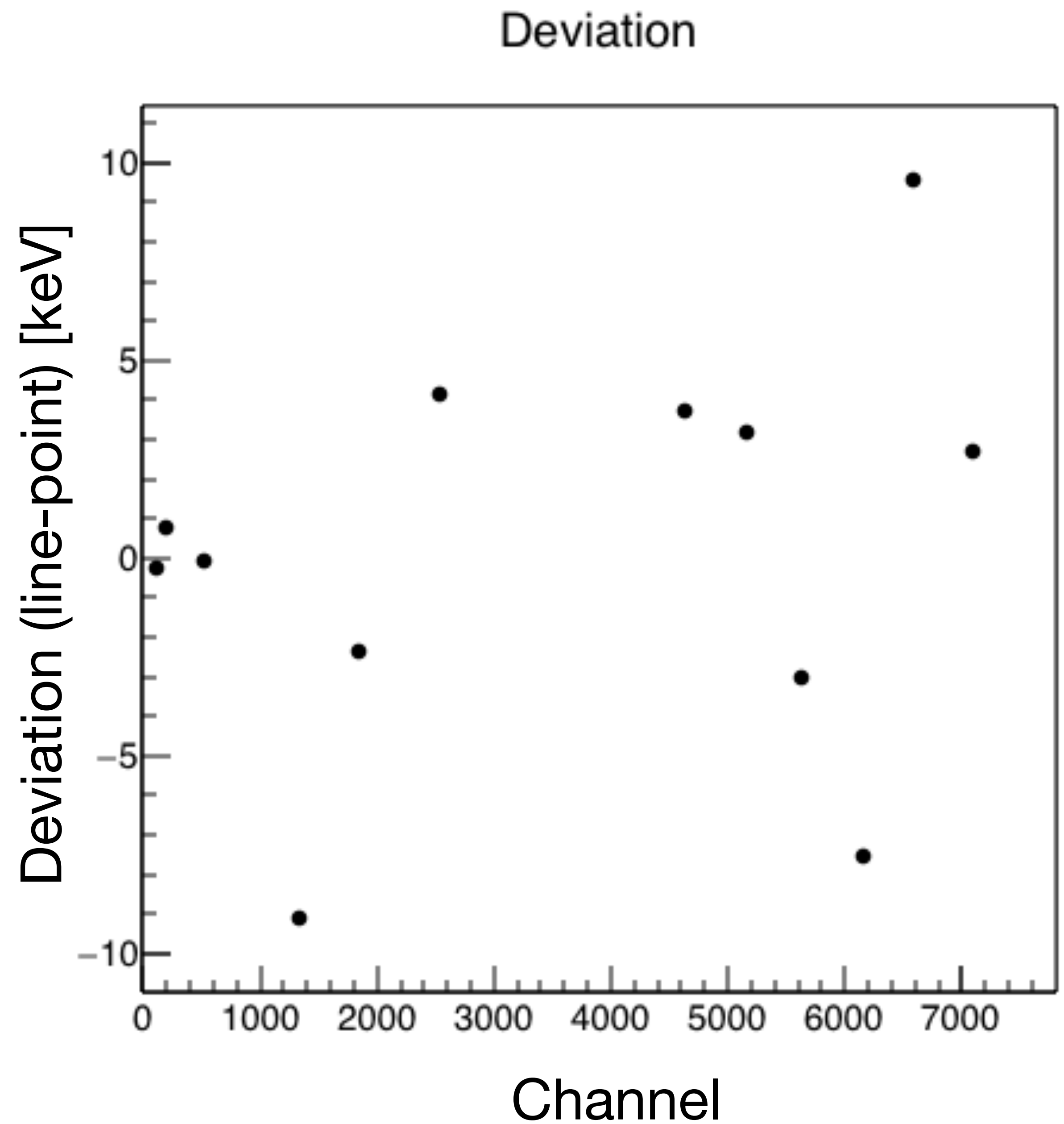


Doppler shift ($^{19}F$ levels):



## The calibration:



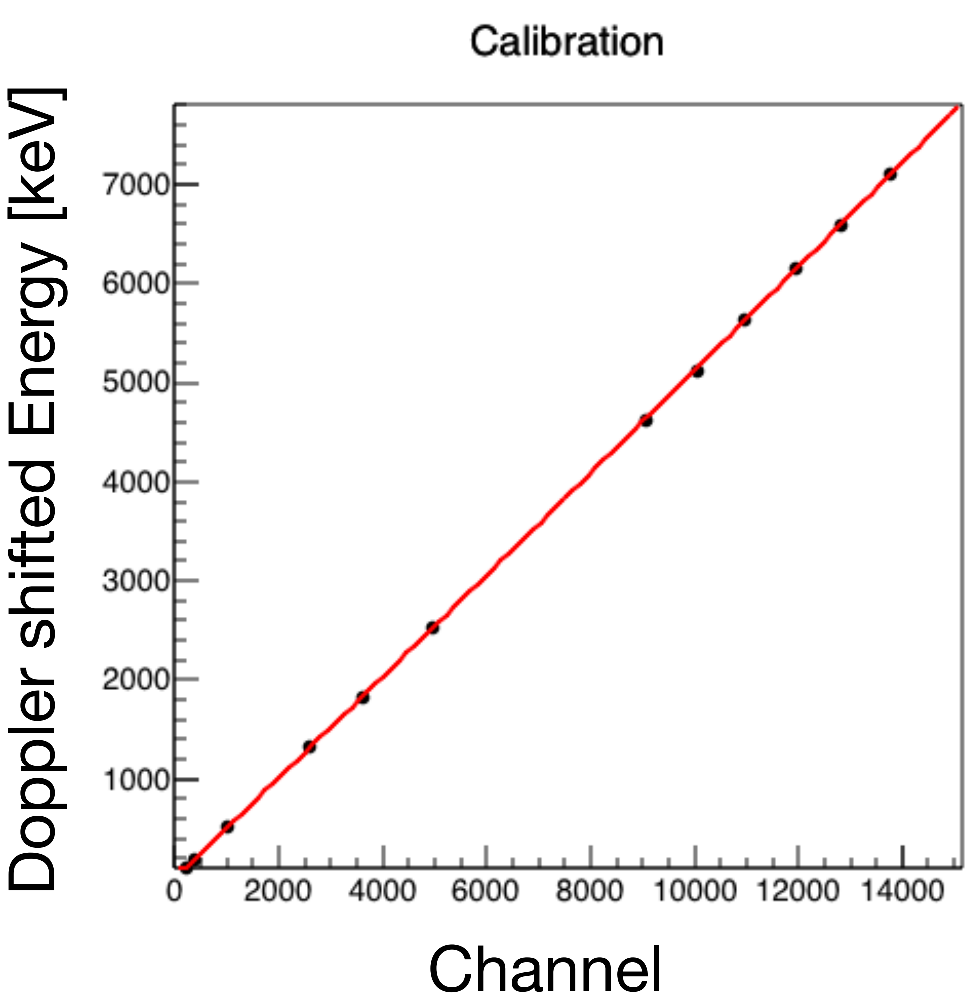



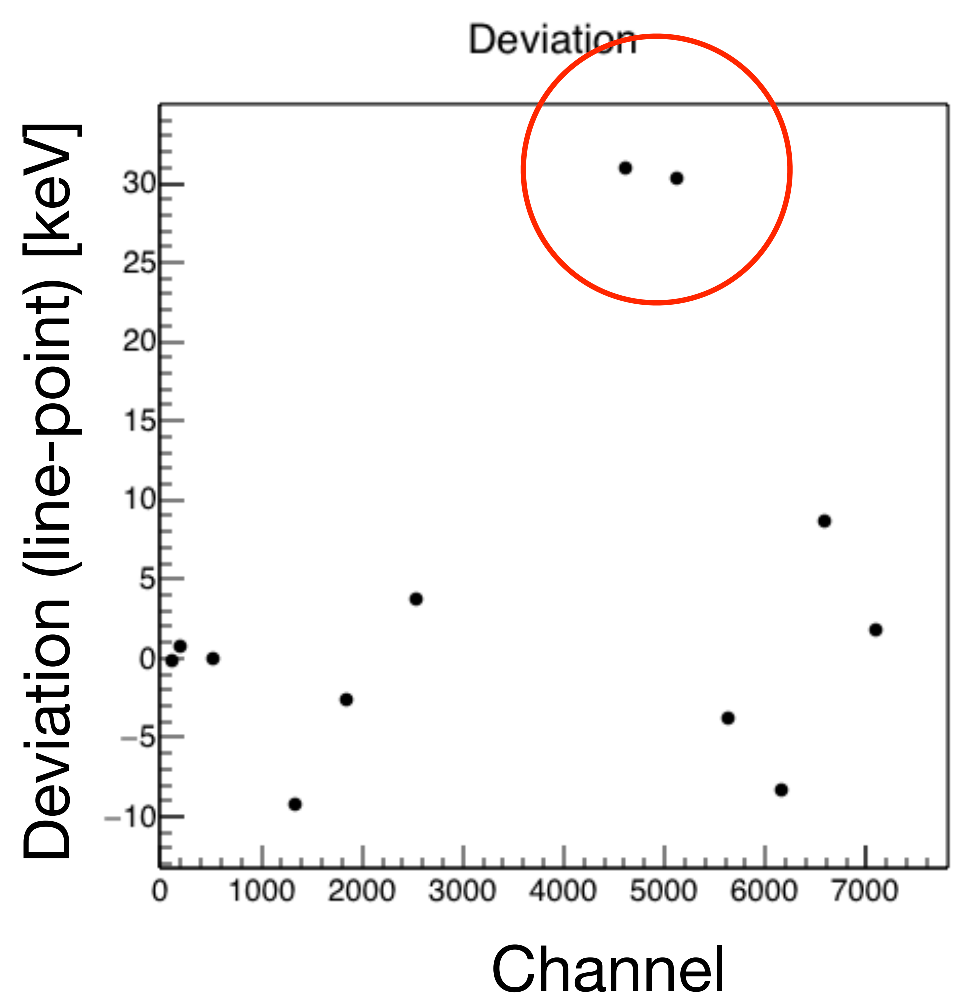

| NAME | VALUE | ERROR |
|---|---|---|
| p0 | 8.02135e−01 | 6.87625e−01 |
| p1 | 5.04581e−01 | 5.92953e−04 |
| p2 | 7.93935e−07 | 5.09800e−08 |

Notes: The 5.2 MeV state can be two states:

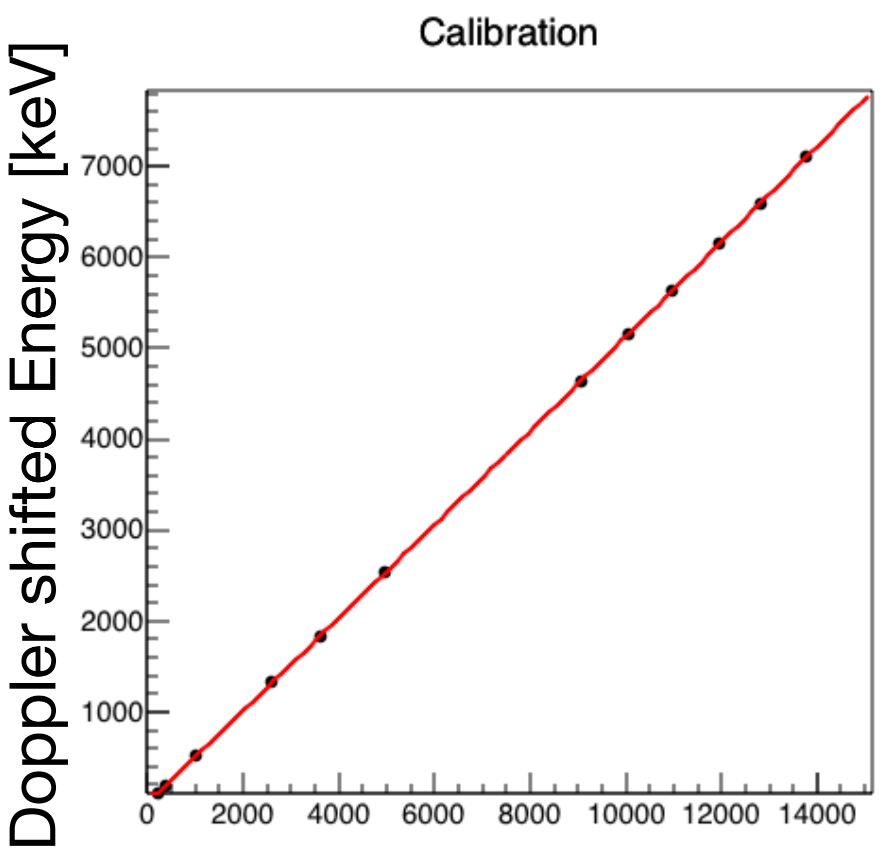
| E(level) (keV) | XREF | Jπ(level) | $T_{1/2}$(level) | E(γ) (keV) |
|---|---|---|---|---|
| 0.0 | ABCDE JKLMN PQRS UVWX Zabcdefghijk | 1/2- | STABLE | |
| 5270.155 *14* | CD LM O QR U WX abcdef h jk | 5/2+ | 1.79 ps *10* | 5269.161 *14* |
| 5298.822 *14* | A CD GHI L N QRS U WX ab def h jk | 1/2+ | 17 fs *5* | 5297.817 *14* |

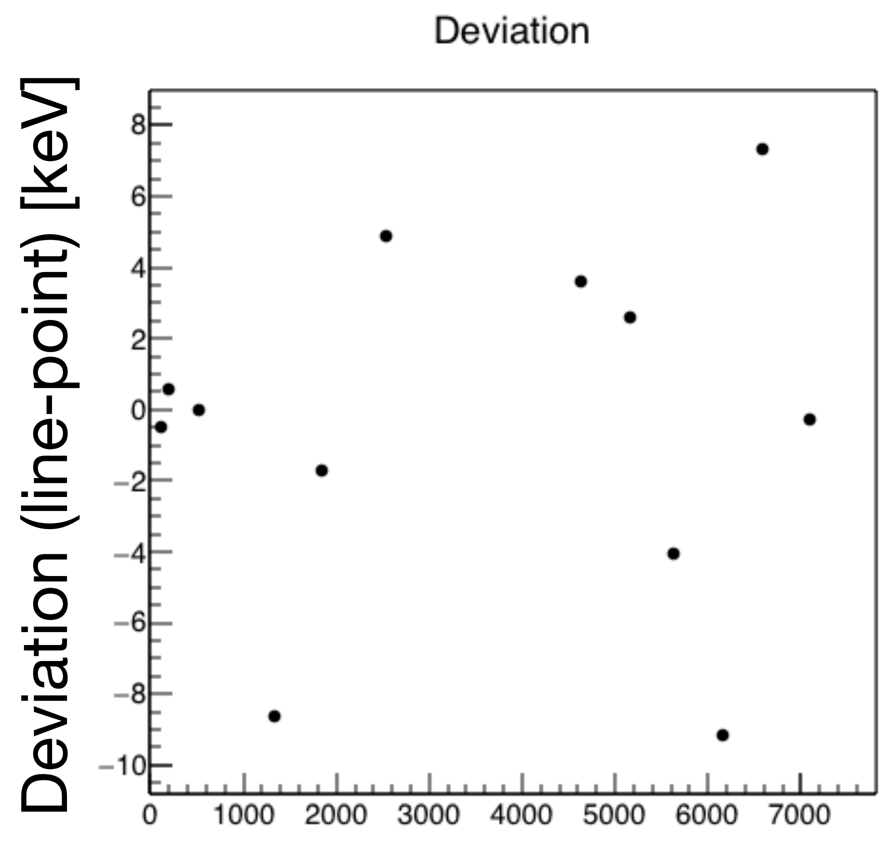
If I take 5270 keV that point lies below the calibration by 30 keV. If I take the 5299 KeV the point lies within 10 keV from the calibration line, as all the other points.
This seems to indicate that the state is the 1/2+?



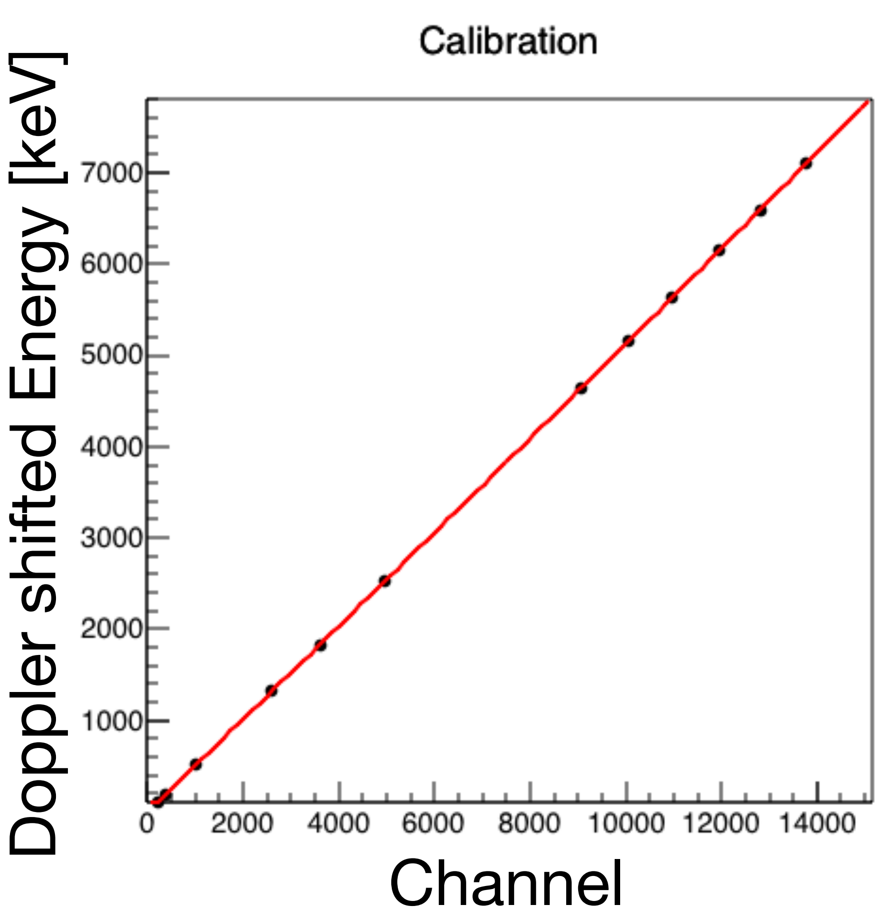
Notes: Using 1° or 11.4° for the angle error does not make a big difference in the calibration:

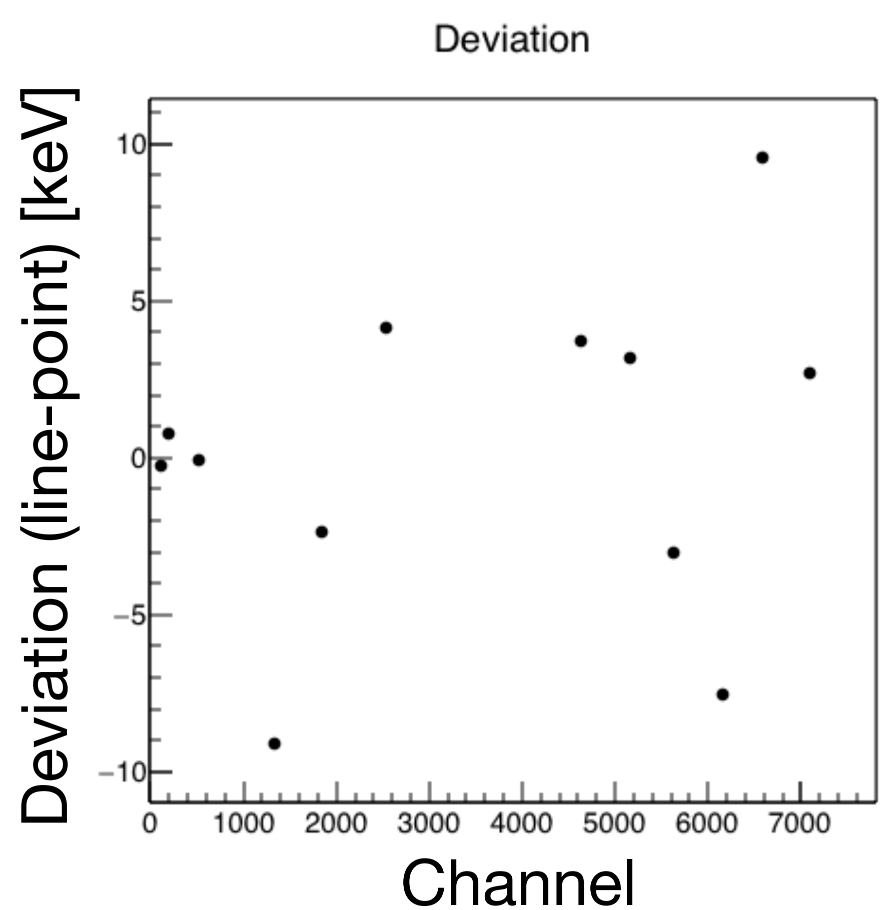



11.4° error

| NAME | VALUE | ERROR |
|---|---|---|
| p0 | 4.75908e-01 | 1.10090e+00 |
| p1 | 5.05015e-01 | 1.33309e-03 |
| p2 | 7.48410e-07 | 1.45982e-07 |

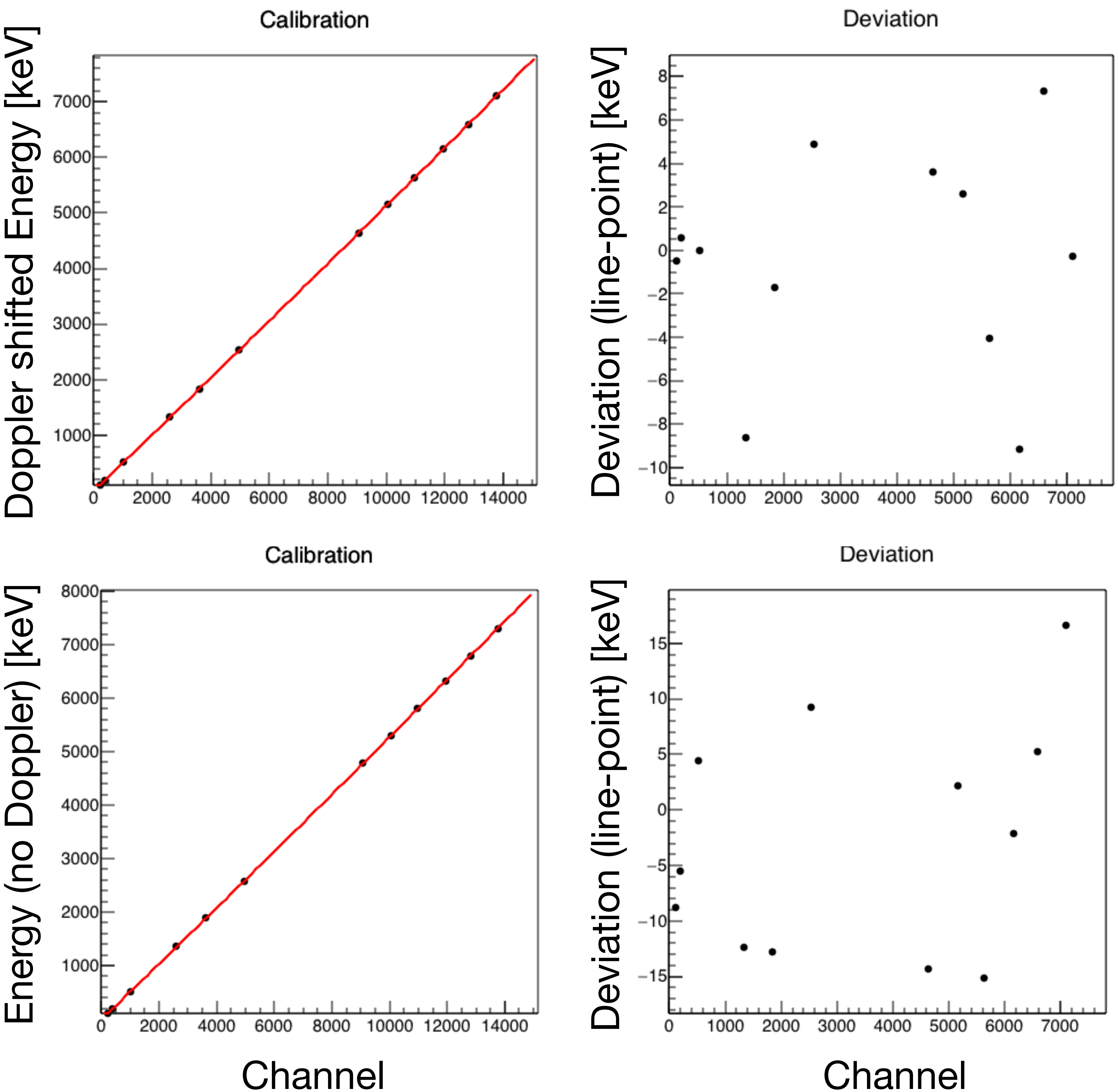



1° error

| NAME | VALUE | ERROR |
|---|---|---|
| p0 | 8.02135e-01 | 6.87625e-01 |
| p1 | 5.04581e-01 | 5.92953e-04 |
| p2 | 7.93935e-07 | 5.09800e-08 |

Notes: Without Doppler correction the calibration is less linear:




11.4° error
(with doppler)

| NAME | VALUE | ERROR |
|---|---|---|
| p0 | 4.75908e-01 | 1.10090e+00 |
| p1 | 5.05015e-01 | 1.33309e-03 |
| p2 | 7.48410e-07 | 1.45982e-07 |

11.4° error
(without doppler)

| NAME | VALUE | ERROR |
|---|---|---|
| p0 | -8.09833e+00 | 6.13484e-01 |
| p1 | 5.17632e-01 | 3.93435e-04 |
| p2 | 1.01596e-06 | 3.13769e-08 |