Is it Possible to Study $^{44}Ti(\alpha,p)^{47}V$ Reaction with Radioactive Target?

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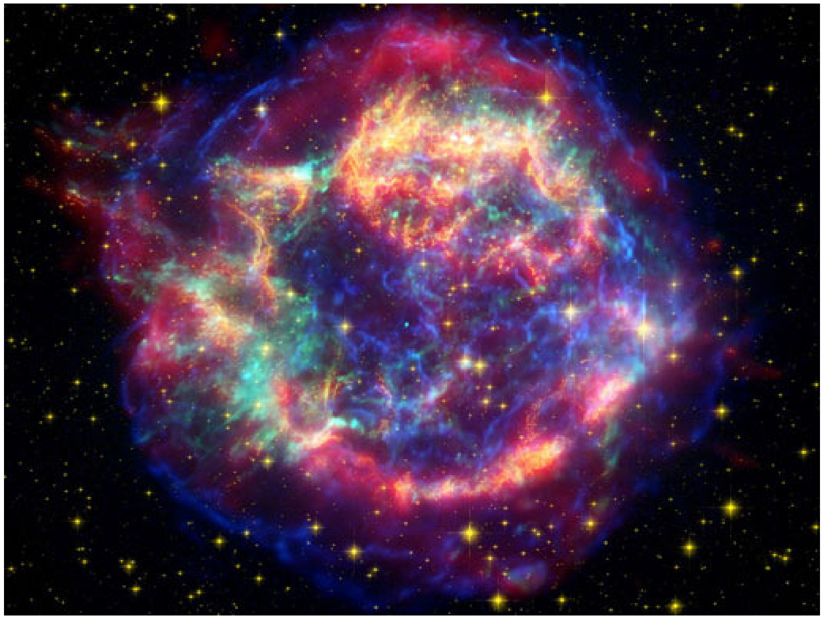
Mitglied von

Main Points

- The Importance of ^{44}**Ti** in Supernovae.
- The Reaction Rate for $^{44}\mathbf{Ti}(\alpha,p)^{47}\mathbf{V}$ at Astrophysical Energies.
- Problems with Radioactive ^{44}Ti Target.
- The Safety Concerns of the Experiment.
- Suggestions and Future Plans.



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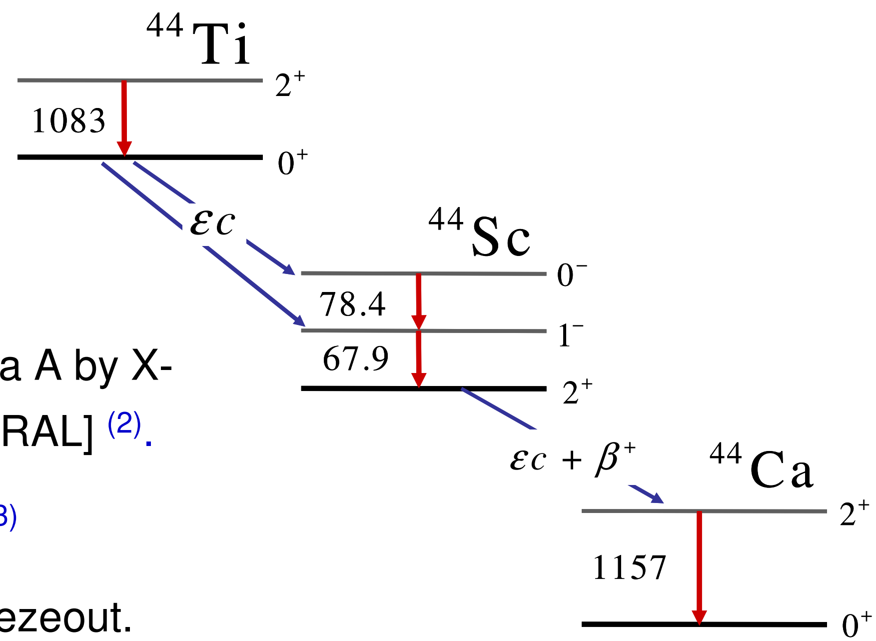
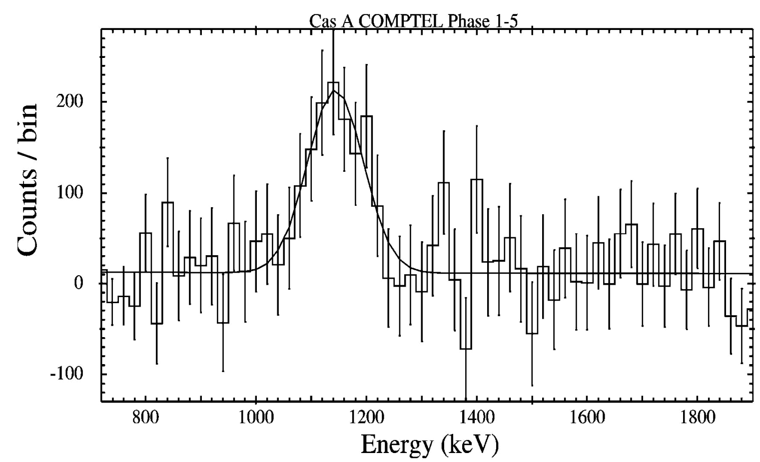
❑ The importance of ^{44}Ti in supernovae.

- ^{44}Ti, $t_{1/2}$=58.9 ± 0.3 yr(1).
- Its $^{44}\mathrm{Ti} \xrightarrow{EC} {}^{44}\mathrm{Sc}$, 78.4 & 67.9 keV.
- $^{44}\mathrm{Sc} \xrightarrow{\beta^+ + EC} {}^{44}\mathrm{Ca}$, γ-lines at 1157 keV.
- 1.157 MeV has been observed from Cassiopeia A by X-rays & γ-rays telescopes [CGRO, RXTE, INTEGRAL] (2).
- The ejected ^{44}Ti is estimated: $1.6^{+0.6}_{-0.3} \times 10^{-4} M_\odot$ (3)
- At T_9=4.3, its abundance grows after α-rich freezeout.
- The yield is sensitive to: $^{40}\mathrm{Ca}(\alpha,\gamma)^{44}\mathrm{Ti}$, $^{44}\mathrm{Ti}(\alpha,p)^{47}\mathrm{V}$, $^{44}\mathrm{Ti}(\alpha,\gamma)^{48}\mathrm{Cr}$, $^{45}\mathrm{V}(p,\gamma)^{46}\mathrm{Cr}$.
- L.-S. The(4): **^{44}Ti(α,p)^{47}V** is the most important reaction.





(1) I. Ahmad *et al*, PRC 74, 065803 (2006).
(2) A. f. Iyudin *et al*, Astron. Astrophys. 284, L1 (1994)
(3) M. Renaud *et al.*, Astrophys. J. 647, L41 (2006)
(4) L.-S. The *et al.*, Astropjys. J. 504, 500 (1998)

❑ The reaction rate for ^{44}Ti(α,p)^{47}V at astrophysical energies.

- **This reaction is measured in inverse kinematics by:**

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The ^{44}Ti(α, p) Reaction and its Implication on the ^{44}Ti Yield in Supernovae

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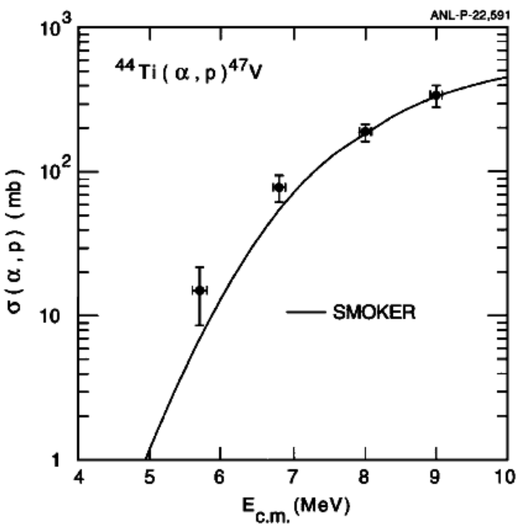
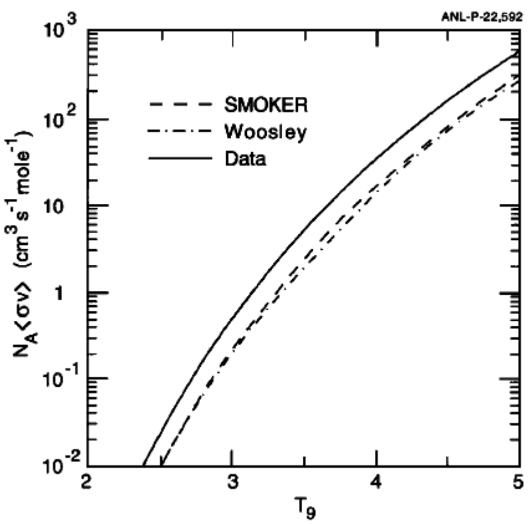
- **Energy range: 5.7 MeV ≤ $E_{c.m.}$ ≤ 9 MeV, using a beam of ^{44}Ti**





- **The estimated reaction rate is a factor of <u>*2*</u> greater than the theoretical calculations, with uncertainty of 37%.**

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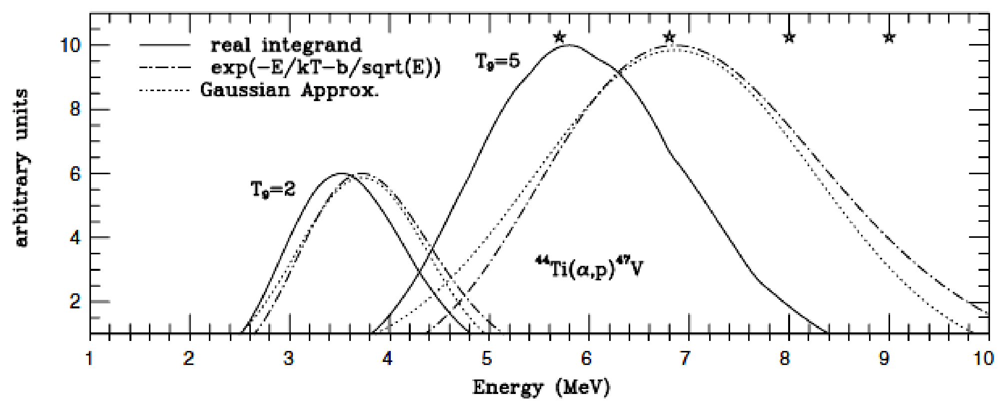
❑ The reaction rate for ^{44}Ti(α,p)^{47}V at astrophysical energies.

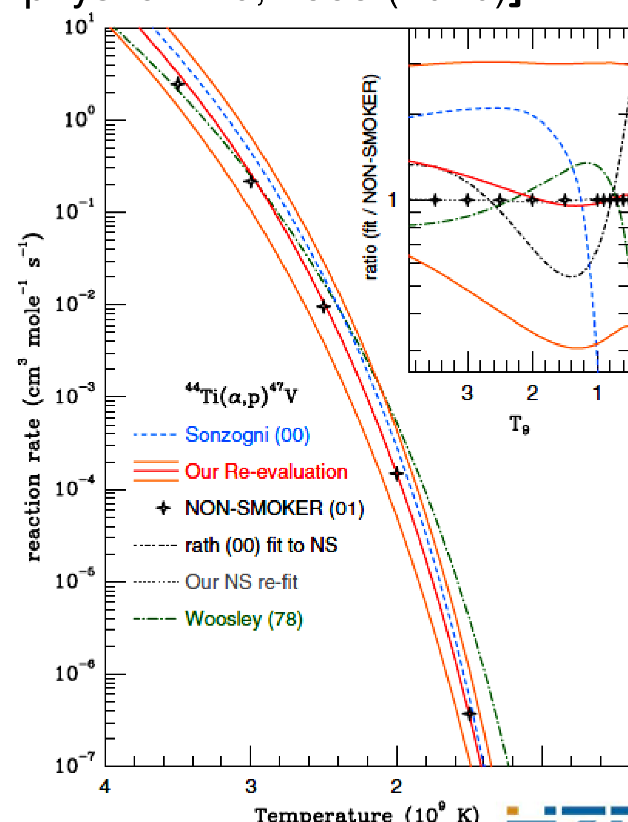
➢ **Old Gamow peak: An overlap between MB-distribution and Coulomb barrier penetration**
[Rauscher et al, PRC 81, 045807 (2010).

➢ **Not good if α-width is changing rapidly with the Coulomb barrier.**

➢ **The true Gamow Window** $N_A\langle\bar{\sigma}^{\mu}_{jk}v\rangle = \frac{3.732\times10^{10}}{\hat{A}_j^{1/2}T_9^{3/2}} \times \int_0^{\infty} \bar{\sigma}^{\mu}_{jk}E^{\mu}_j \exp\left(-11.605E^{\mu}_j/T_9\right)dE^{\mu}_j,$ (4)

➢ **The reaction rate is re-evaluated R. D. Hofmann; [**Astronphys. J. 715, 1383 (2010)**].**





- **The most relevant temp. range is 1 ≤ T_9 ≤ 5.**
- **Cross sections at lower energies dominate both the rates and uncertainties.**
- **Larger uncertainty in the rate (±3) ➔ large uncertainty in ^{44}Ti synthesis**

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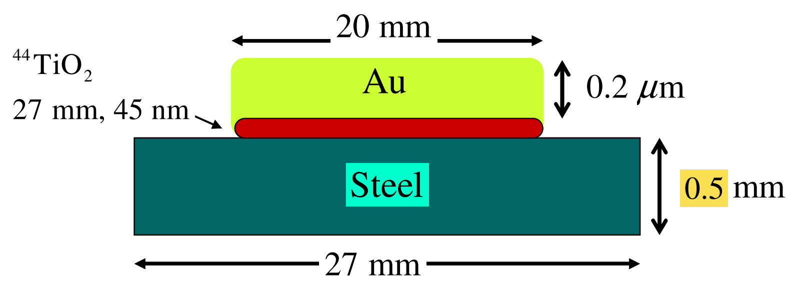
The planned radioactive ^{44}Ti target.

- A 10-50 MBq radioactive target will be prepared in PSI, [D. Schumann, ERAWAST-PSI].
- For 10 MBq, D=20 mm, $T_{1/2}$=58.9 yr, using

$$N = \frac{A}{L}, \qquad L = \frac{\ln 2}{T_{1/2}}$$



- → N= 2.68 x 10^{16}; ^{44}Ti
- The thickness of the ($^{44}TiO_2$) target is almost 45 nm, or 11 μg/cm^2.
- 0.2 μm-Gold will coat the radioactive area.
- Stainless steel support: 0.5 mm thick, 27 mm in diameter.
- High purity target is required, no impurities from $^{46\text{-}50}$Ti isotopes.

Ti (inert)-Target

^{44}Ti-Target

Ta-disk

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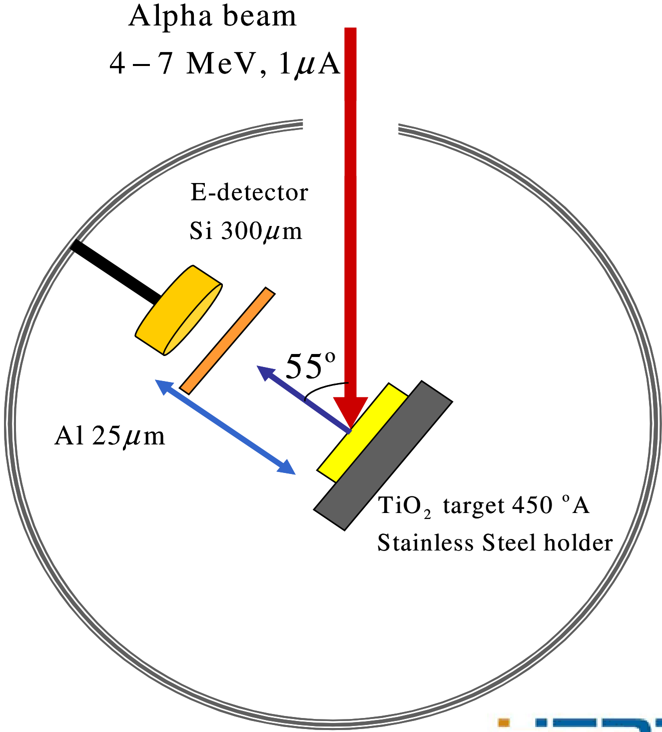
Possible Experimental Setup

- ION-Beam Center at HZDR.
- Q-Value = -- 0.41 MeV.
- α-beam at 4-7 MeV, Angle = 55°. Current = 1 μA for 1-2 weeks.
- 25 μm Al-foil is used to stop α-particles before the detector.
- 100-300 μm PIPS [Partially Implanted Passivated Silicon].



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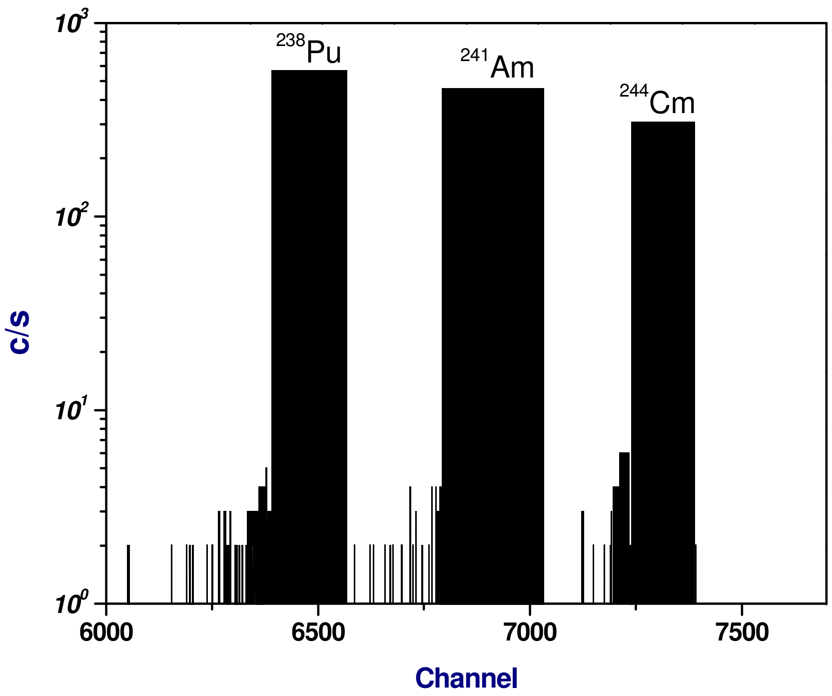
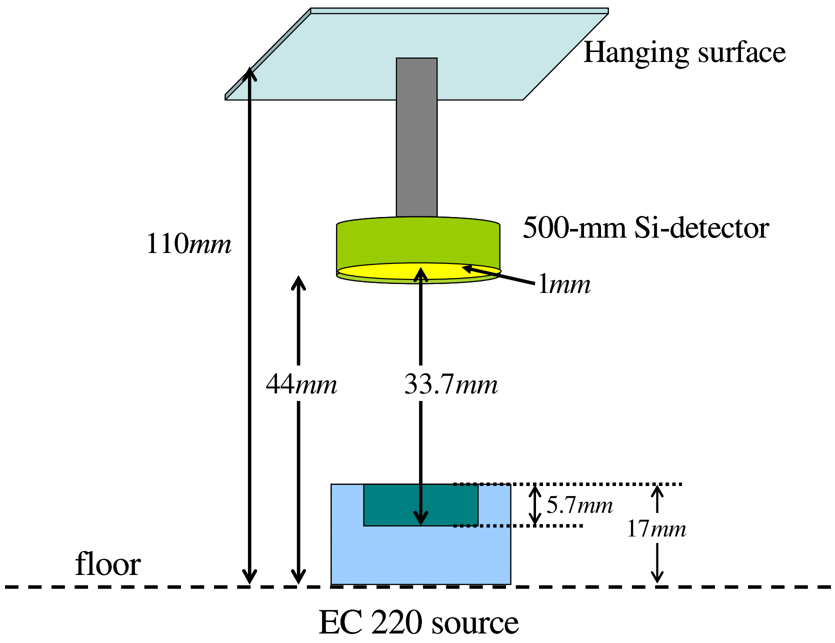
❑ Can $^{44}Ti(\alpha,p)^{47}V$ be performed?

- **Starting with simple setup [500 μm-Ortec Si-detector with AmCmPu source].**

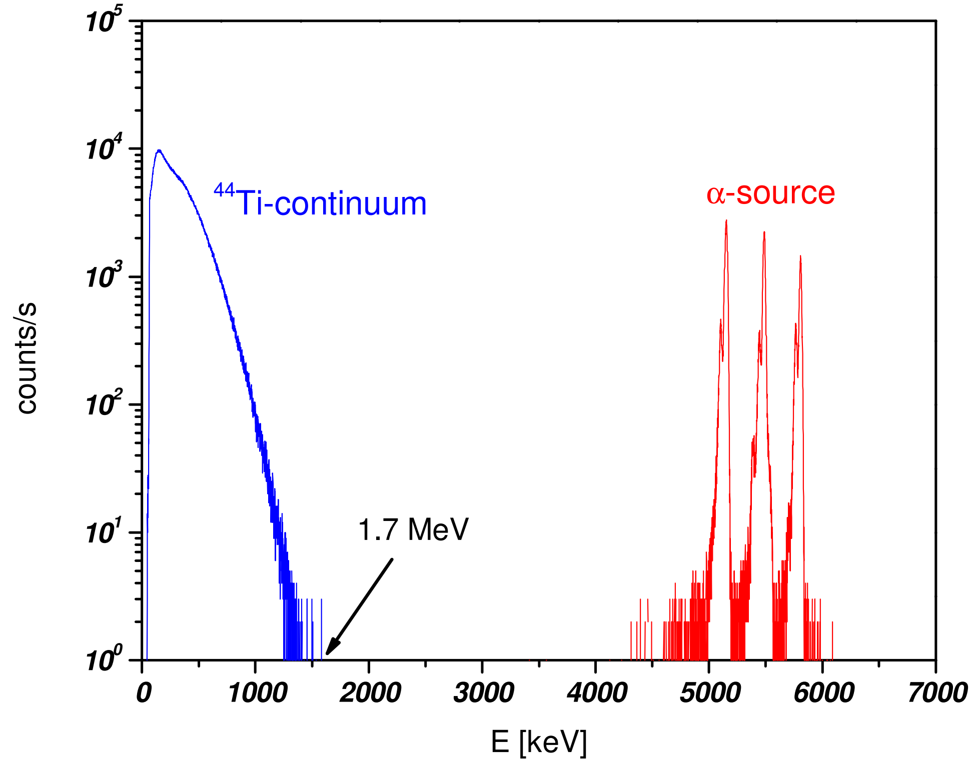


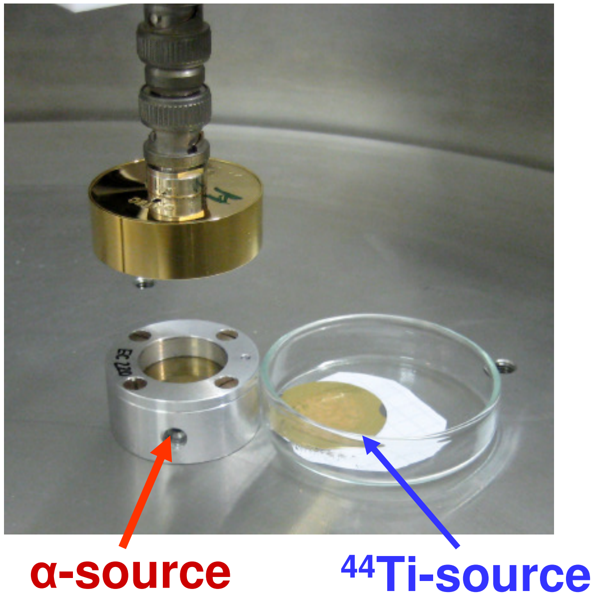


- **For ^{241}Am main peak, E = 5486 ± 21 keV.**

Can $^{44}Ti(\alpha,p)^{47}V$ be performed?

- **AmCuPu-source and ^{44}Ti (83 kBq) are both observed by the 500 μm Si-detector**





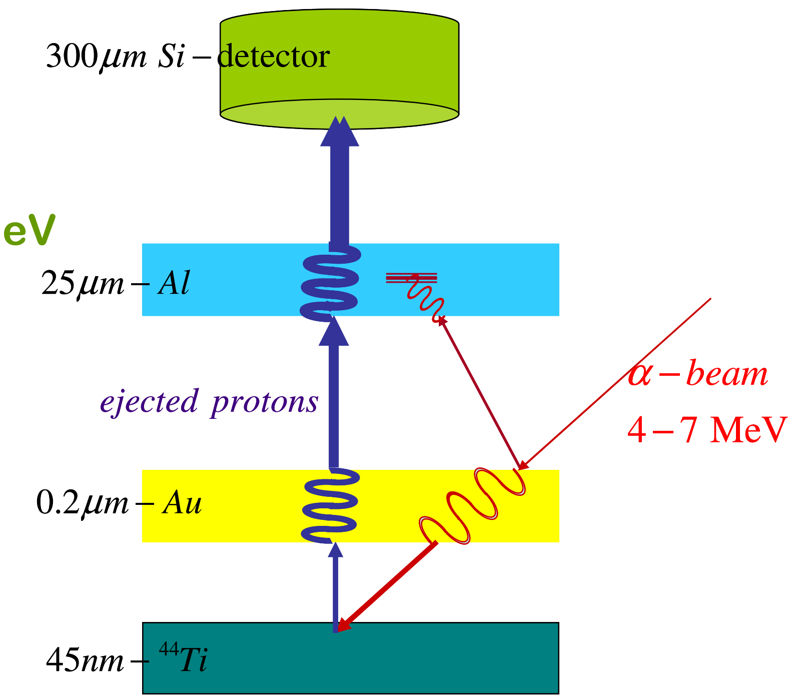
- **A strong increase in the background continuum; 1 % to 94 % counting rate.**
- **Continuum ends point is at almost 1.7 MeV.**
- **IS IT GOOD?**

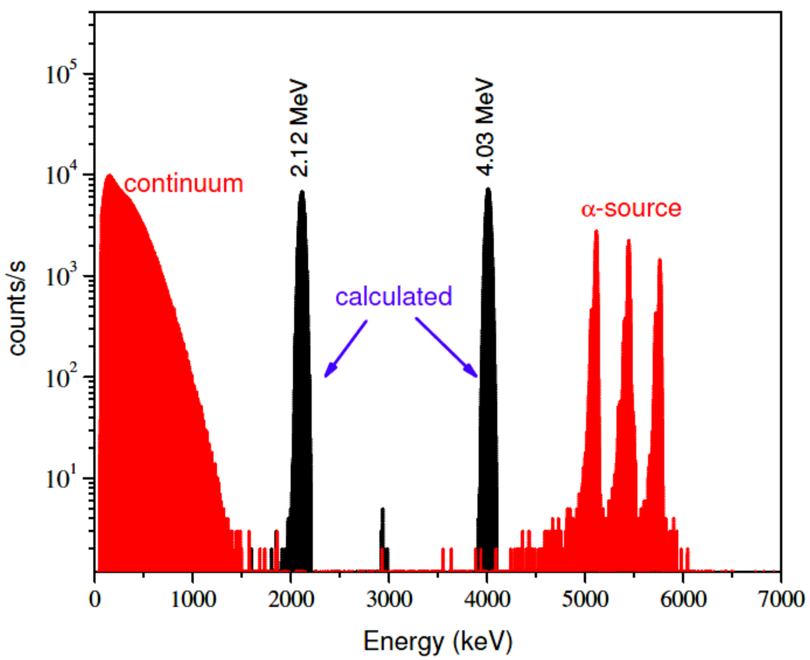
❑ Can $^{44}Ti(\alpha,p)^{47}V$ be performed?

- **Detecting the protons after the reaction.**
- **Using Lise & Trim codes.**
- **Starting at E_α = 4 MeV → Gold → E_α = 3.82 ± 0.04 MeV**
- **E_p = 2.8 MeV → Au & Al → E_p = 2.12 ± 0.08 MeV.**

Similarly for E_α = 6 MeV,

- **E_p = 4.49 MeV → Au & Al → E_p = 4.03 ± 0.08 MeV.**



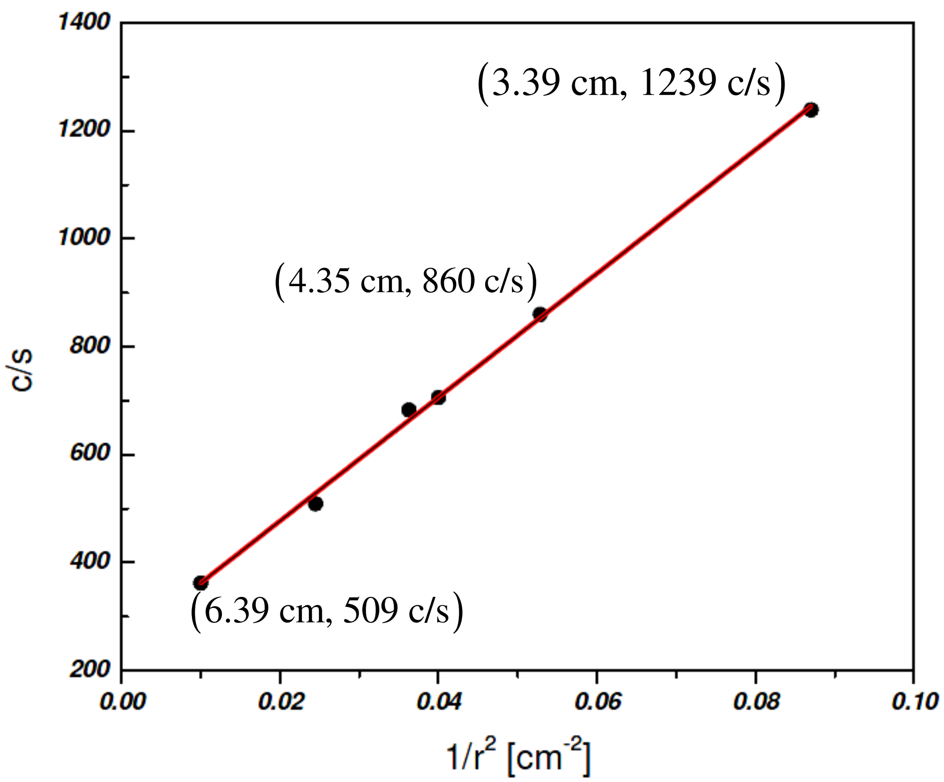


- **Protons peaks do not overlap with the continuum.**
- **PIPS detectors can be used.**
- **The height of the peaks is in random units.**

❑ Problems with radioactive ^{44}Ti target.

- **Using the 83-kBq ^{44}Ti source.**
- **The relation between the activity and the distance for the continuum background is:**

$$A = 11473 \times \frac{1}{r^2} + 247 \quad [\mathrm{c/s}].$$

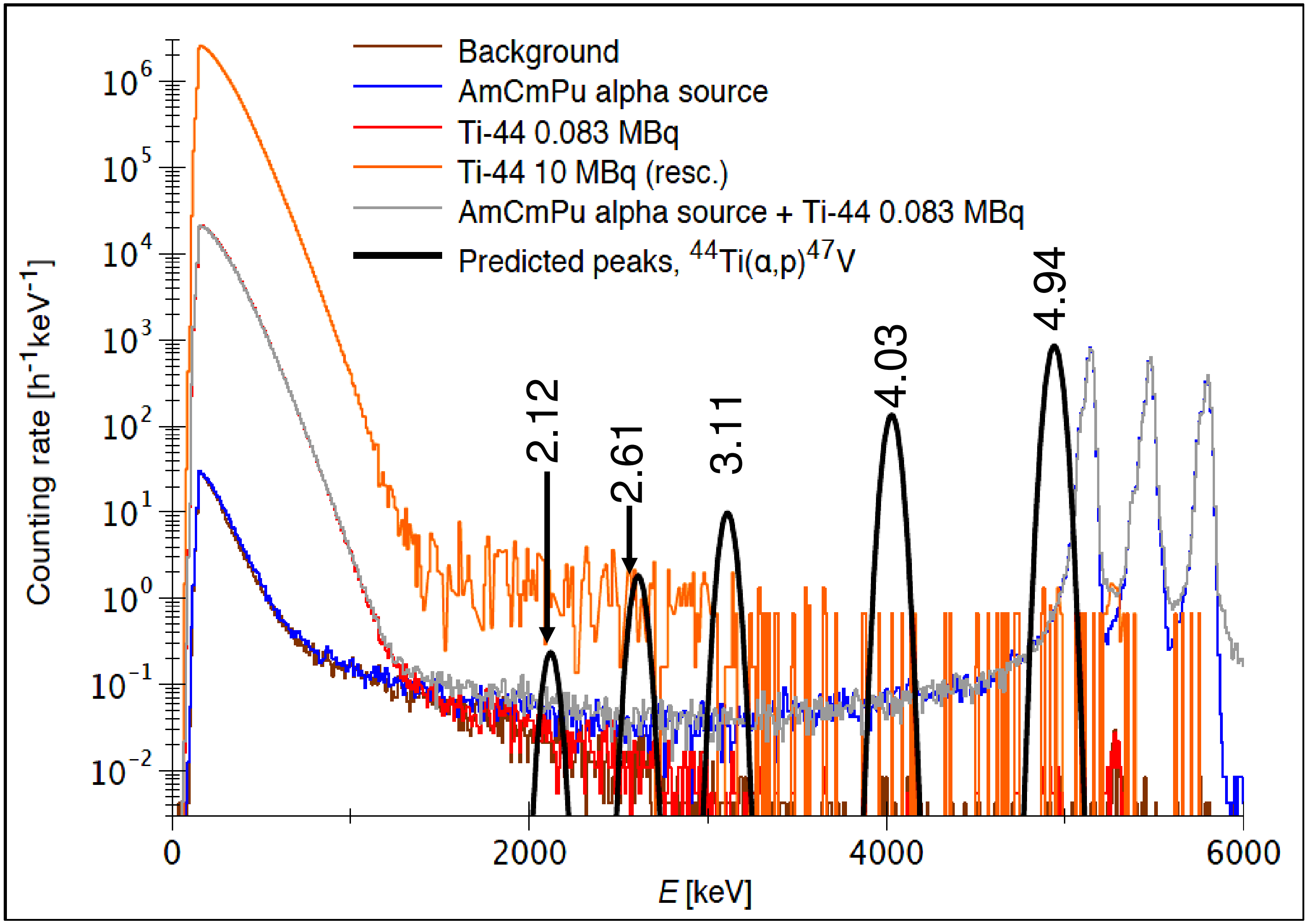


- **The estimated continuum background for 10MBq-target is:**

Dist. [cm]	Rate [c/s]	10 MBq [c/s]
5	706	5.5E+4
10	362	1.4E+4

❑ Problems with radioactive ^{44}Ti target.

- **Several runs with Am and ^{44}Ti sources are collected at the same geometry.**
- **Estimating the proton peaks in 300 μm Si-detector. E_α = 4 , 4.5, 5, 6, 7 MeV.**
- **The background from the cosmic rays hide peaks for $E_\alpha \leq$ 4.5 MeV.**



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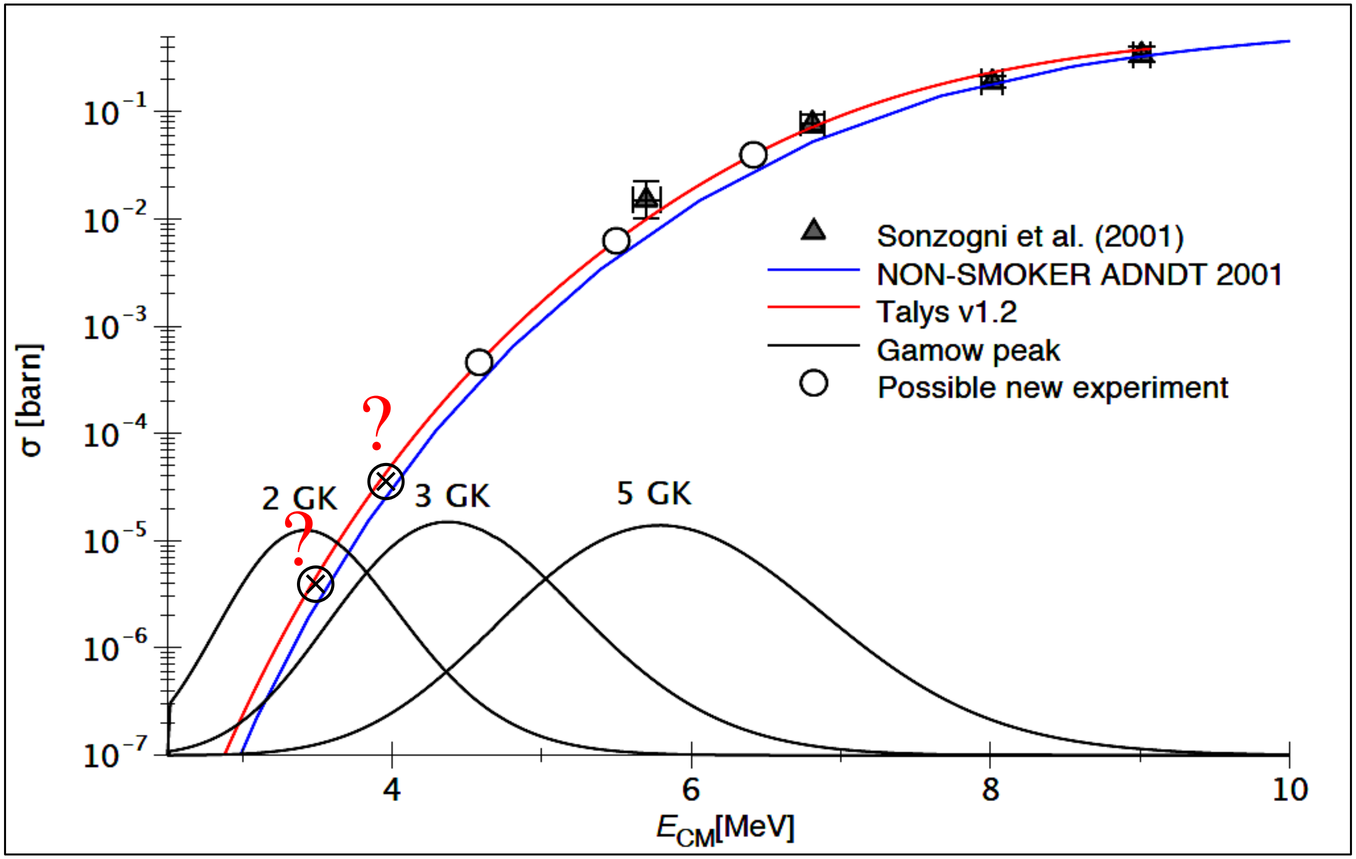
❑ The Feasibility of the $^{44}Ti(\alpha,p)^{47}V$!

- **Adopting Rauscher calculations,** PRC 81, 045807 (2010).
- **Gamow Windows are re-calculated for T_9 = 2, 3, 5.**
- **Talys code is used.** [A. J. Koning, AIP 769, 1154 (2005)]
- **Three new points are very probable to measure. Two more are question marks.**



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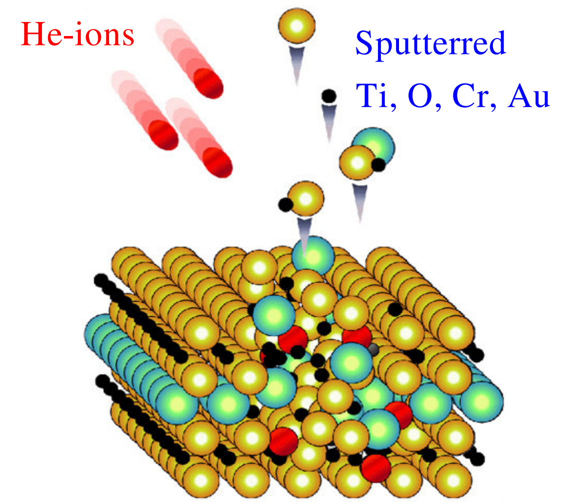
❑ Can $^{44}Ti(\alpha,p)^{47}V$ be performed?

- Estimating the yield at **5 & 10 cm** between the target and the detector:.
- Efficiency: **5 cm → 9.6E-3, 10 cm → 2.4E-3.**
- The reaction is feasible for $E_{lab} \geq 4$ MeV.

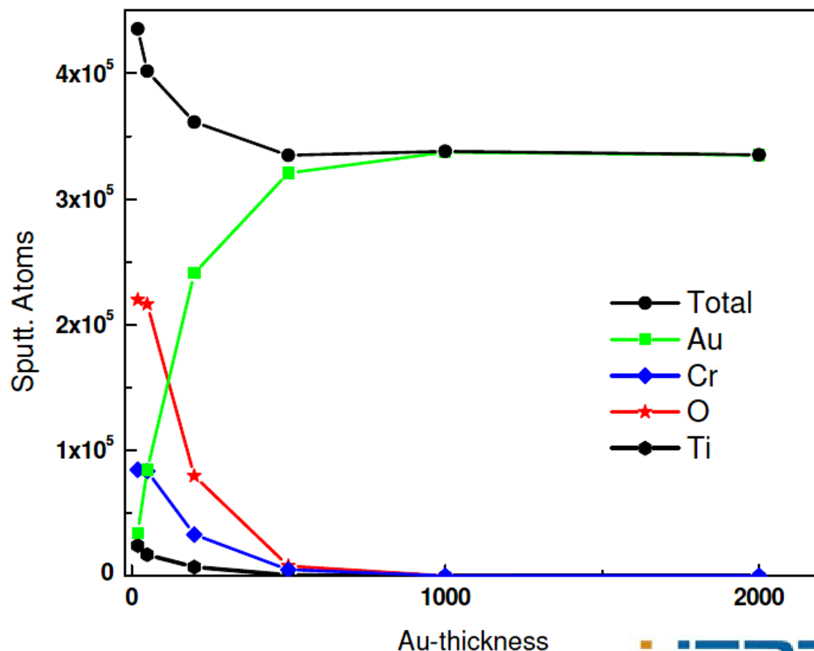
E_{lab} [MeV]	σ [mb]	Dist. 5-cm [Count/hr]	Dist. 10-cm [Count/hr]
3.5	8.96E-4	1.6	0.4
4	1.11E-2	20.3	5.8
5	4.59E-1	84.1	21.0
6	6.26E+0	1.15E+4	2.87E+3
7	3.79E+1	7.27E+4	1.82E+4

❑ The Safety Concerns of the Experiment.

- **The sputtering of the radioactive atoms from the target.**
- **Several calculations are made using TRIDYN_FZD code*. [*Dr. M. Posselt, HZDR*]** ***[W. Möller & W. Eckstein, NIM B 2, 814 (1984)].**
- **Parameters: Fluence = 10^{19} atoms/cm^2 [1 μA-10 days], NH = 10^8 [quality], E_α = 6.0 MeV @ 55°, TiO_2 [450 °A], Layers [Au varying, Cr = 50 °A]**

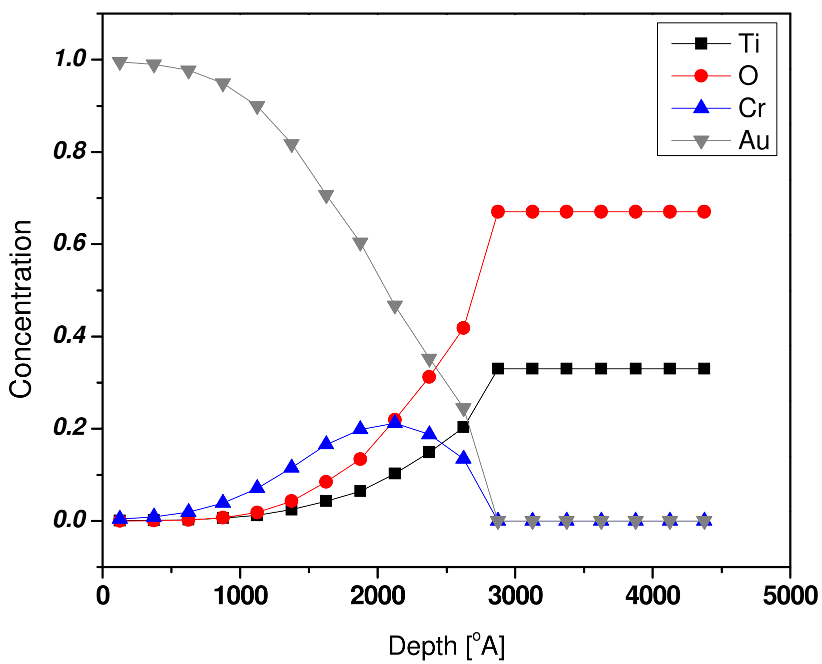


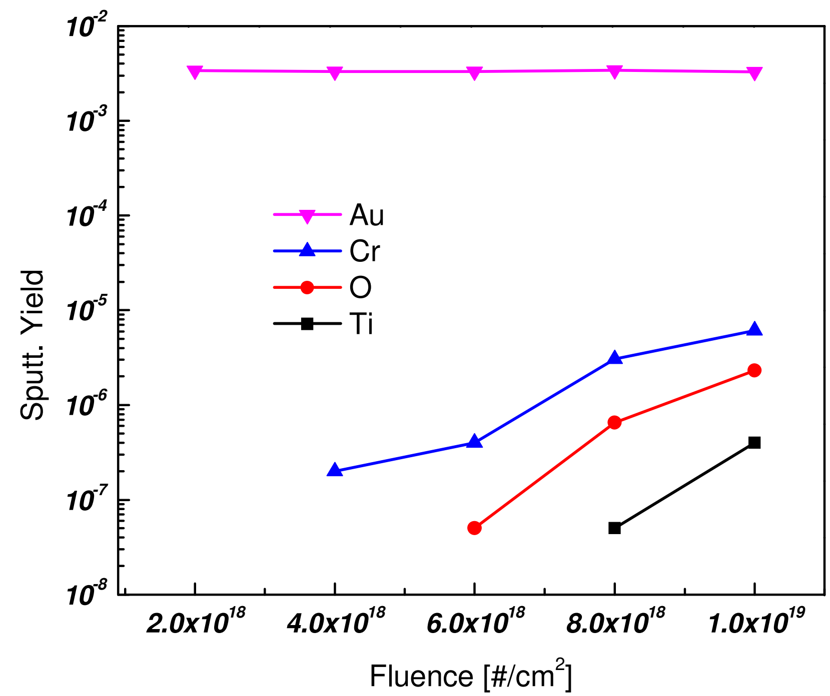
Au-Thick	20	50	200	500	1000	2000
Depth	-105.7	-91.2	-69.6	-58.7	-55.8	-38.8
Ti	24359	17058	7284	920	34	9
O	219922	216518	79827	8160	271	16
Cr	84656	83628	33066	5106	389	196
Au	34417	84578	241035	320695	337291	334982
Total	435354	401782	361212	334881	337985	335248



❑ The Safety Concerns of the Experiment.

- For our case: when the thickness of the Gold is 0.2 μm.
- The depth profiles of the components for 10^{19} ions/cm^2 fluence shows a strong mixing between the atoms at all depths.
- Decreasing the fluence will rapidly decrease the sputtered ^{44}Ti atoms.





In worst case, Au-20 ^oA thick FL = 10^{19}/cm^2, the sputtered ^{44}Ti is 25 k → 10 μBq.

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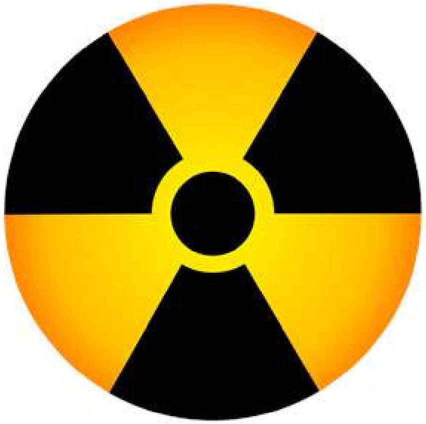
❑ The Safety Concerns of the Experiment.

Estimating the amount of the absorbed dose [Sv/h].



For 10 MBq $^{44}Ti/^{44}Sc$ source

Dose rate at 1 m distance from the source

$$4\ \frac{\mu Sv}{h} \Leftrightarrow 8\ \frac{mSv}{yr}$$ **Controlled Area**

In case of swallowing the source

10 MBq $^{44}Ti/^{44}Sc$ source

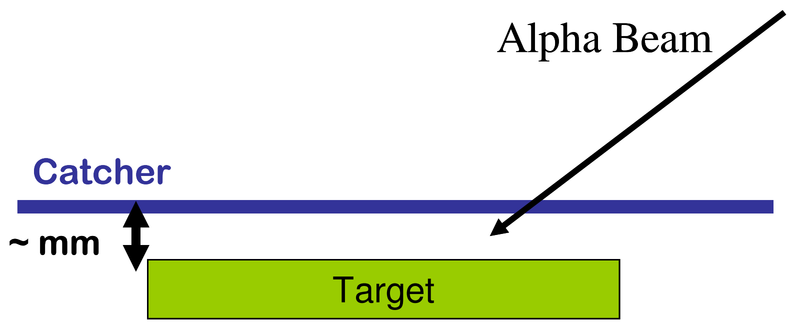
→ 66 mSv ⟷ total dose

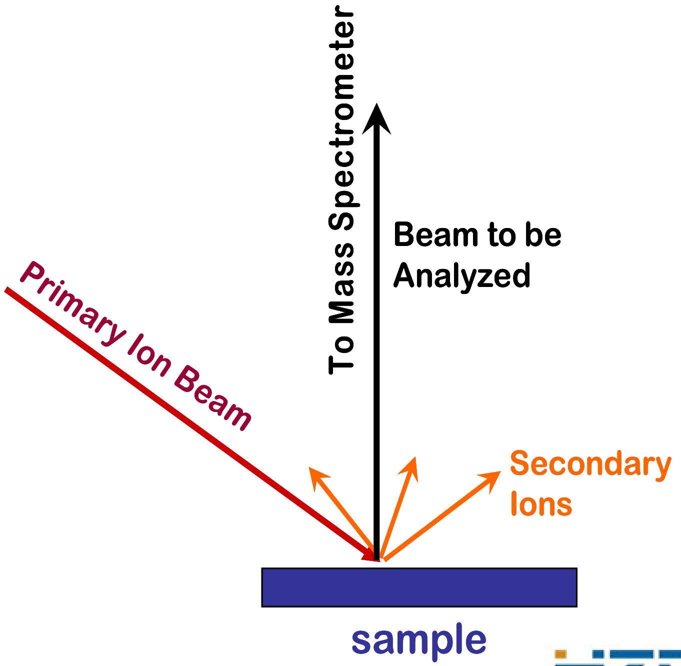
→ If it is not digested, the hazard is small.

❑ Suggestions and Future Plans.

- Measuring the sputtering yield experimentally with an inert target.
- An inert target is prepared and available, [D. Schumann, PSI].
- The target has same properties as the radioactive one.
- Sputtered atoms will be collected on a catcher, [^{12}C ,0.5-1 μm].
- A Secondary Ion Mass Spectroscopy (SIMS) technique.

→ Analyze the composition of the target surface and the catcher.





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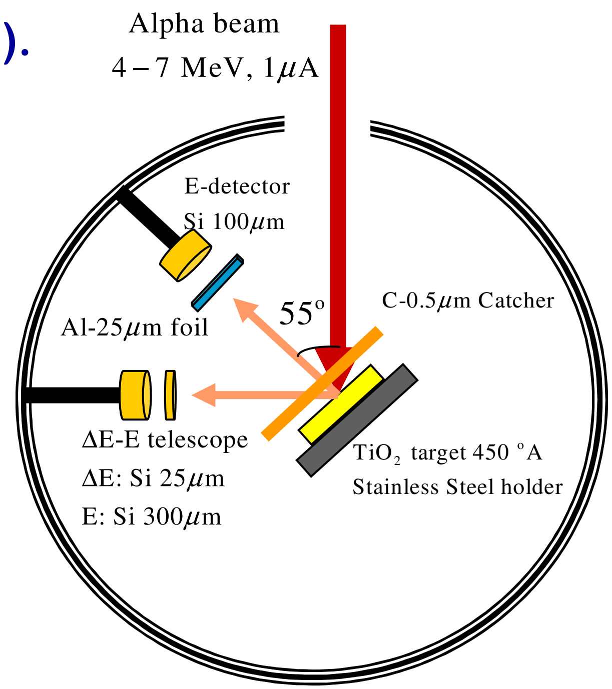
❑ Suggestions and Future Plans.

- **The continuum background from the cosmic rays can be reduced with using a telescope-detection system.**
- **Two particle detectors PIPS; ΔE (25 μm) & E (300 μm).**
- **More PIPS detectors inside the chamber at different reaction angles will be good.**



- **Monte-Carlo simulation; GEANT 4.**
- **Calculate the efficiency of the detectors.**
- **Estimate the height of the peaks.**
- **Reduce the background.**

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❑ Legitimacy!

- The experiment can not be performed until:
  - ➢ Getting the 10-50 MBq ^{44}Ti-target.
  - ➢ ~MBq is high ➔ several permissions and paper works.
  - ➢ Quite a few tools need to be available.
  - ➢ More than a few test runs must be made.

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❑ Summary & Conclusion

• The $^{44}Ti(\alpha,p)^{47}V$ reaction is possible with:

+

= $^{44}Ti(\alpha,p)^{47}V$

• Look for promising results that are better than those from radioactive beam facilities.

Thank you