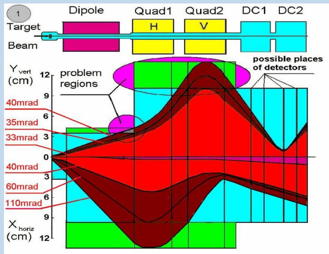
Measurements of $^{260-262}Rf$ produced in $^{22}Ne + ^{244}Pu$ fusion reaction at TASCA

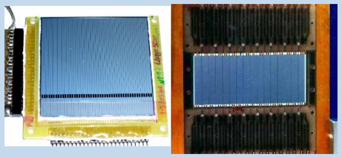
TECHNISCHE UNIVERSITÄT MÜNCHEN

Alexander Gorshkov, 12 October 2009
SEVENTH WORKSHOP ON THE CHEMISTRY OF THE HEAVIEST ELEMENTS

Commissioning phase was successfully accomplished:

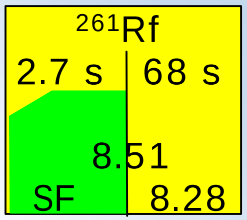


• **wide knowledge about separator settings**



• **2 types of focal plane detectors**

• **2 different chemical interfaces – Recoil Transfer Chambers (RTCs) for HTM and SIM**



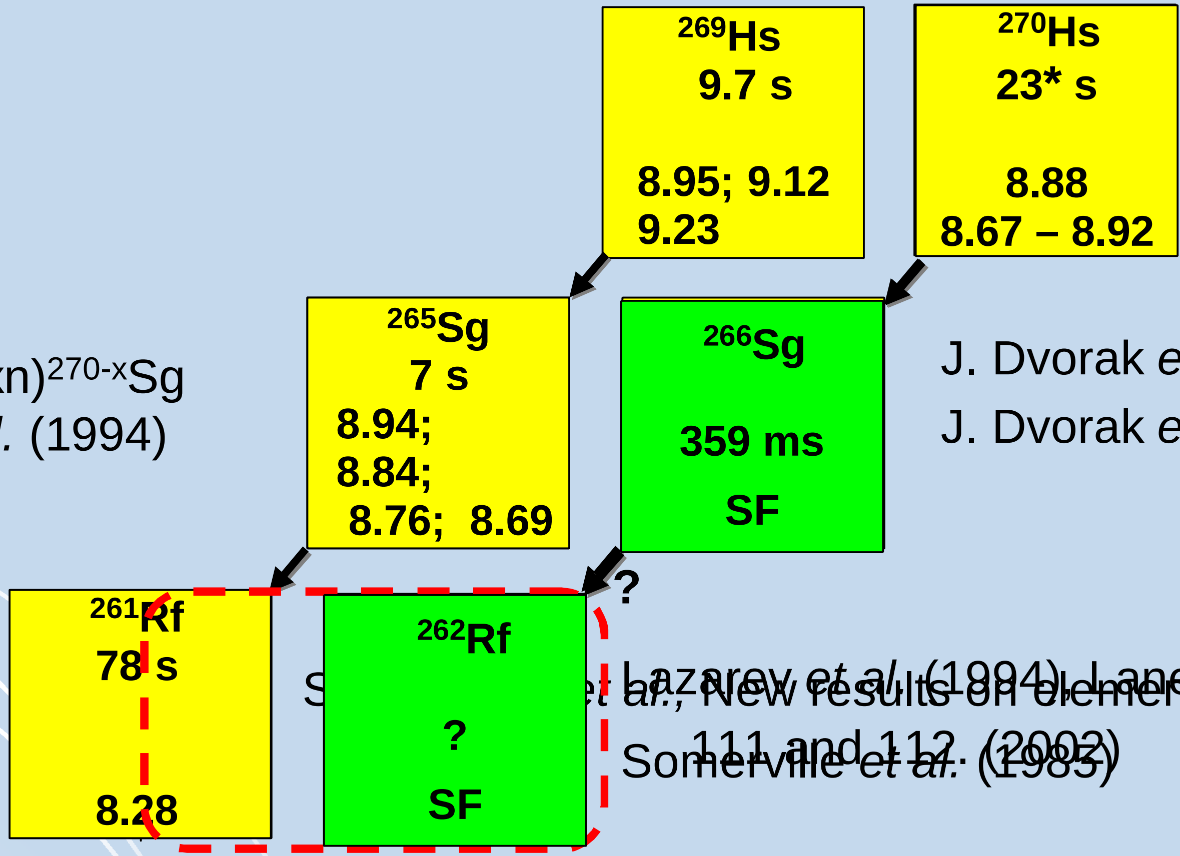
• **final experiment of the commissioning phase with first transactinide element Rf**

Motivation

Before 2002

After 2002

$^{248}Cm(^{22}Ne,xn)^{270-x}Sg$
Lazarev *et al.* (1994)



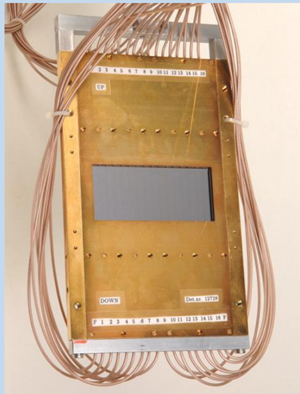
J. Dvorak *et al.*, (2006)
J. Dvorak *et al.*, (2008)

Lazarev *et al.* (1994), Lane *et al.* (1996)
Somerville *et al.* (1985)

S... *et al.*, New results on elements 111 and 112. (2002)

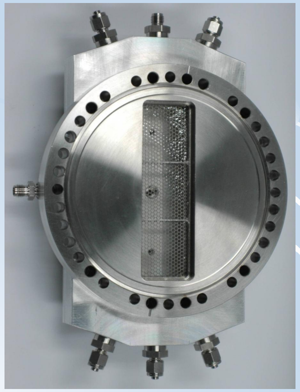
* Calculated value

Experimental approaches



$^{244}Pu(^{22}Ne,6n)^{260}Rf$ and $^{244}Pu(^{22}Ne,4n)^{262}Rf$

Short-lived SF decaying Rf isotopes could be detected in a Focal Plain Detector.



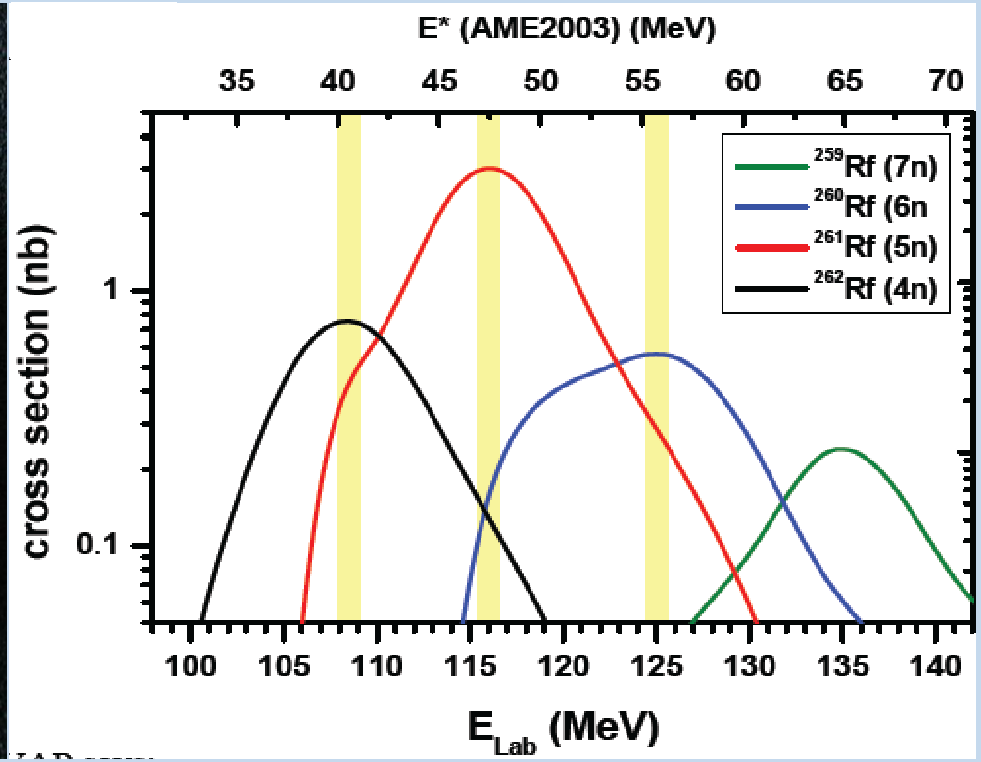
$^{244}Pu(^{22}Ne,5n)^{261}Rf$

To reduce background from Target Like Fragments

HTM RTC + ROMA combination was used.

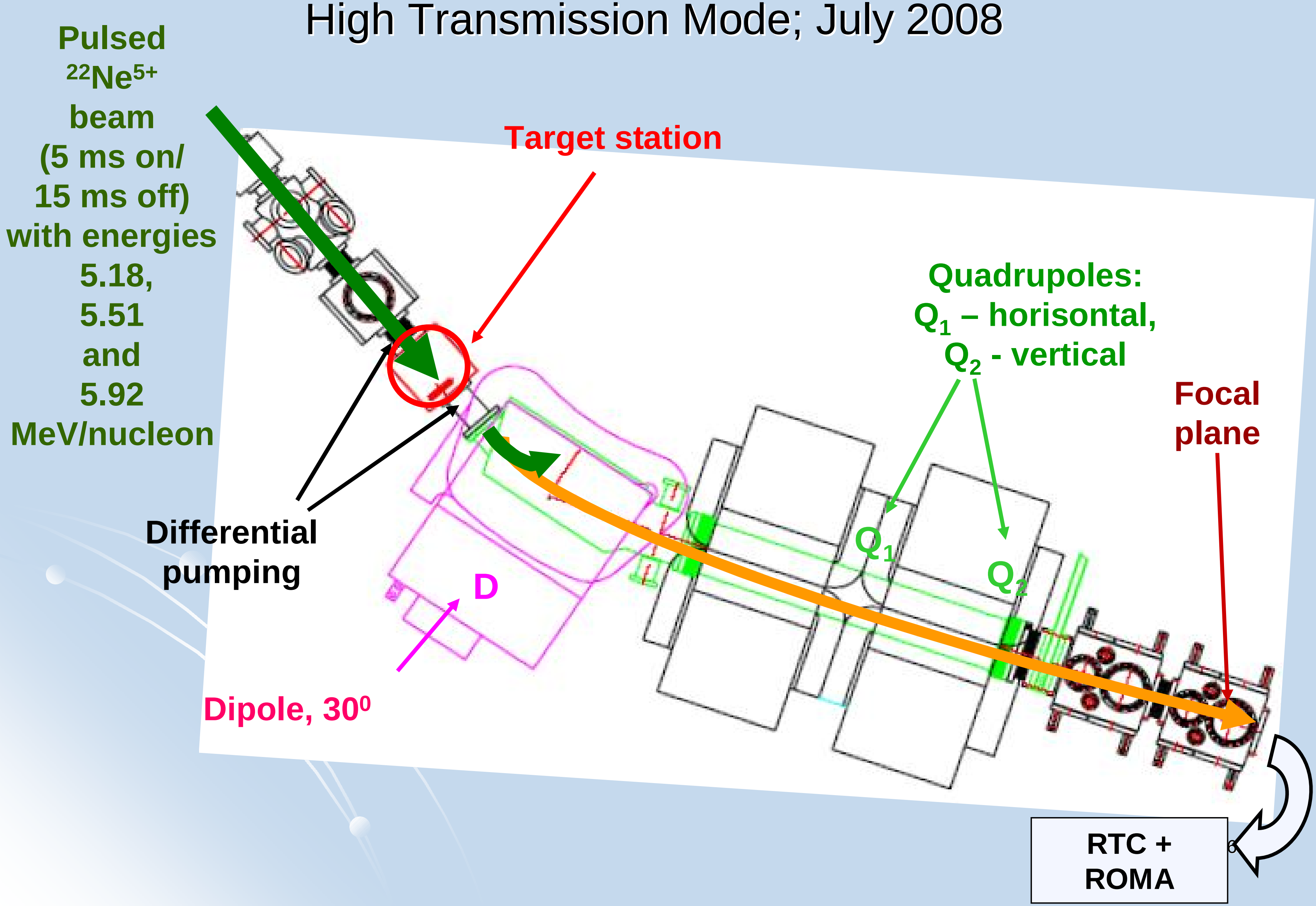
^{244}Pu target wheel

- A rotating target wheel with three banana-shaped segments was holding three ^{244}Pu targets (thickness:390 μg/cm², 481 μg/cm² and 502 μg/cm²).
- The target material was deposited on 2.2-μm thick Ti backing foils.



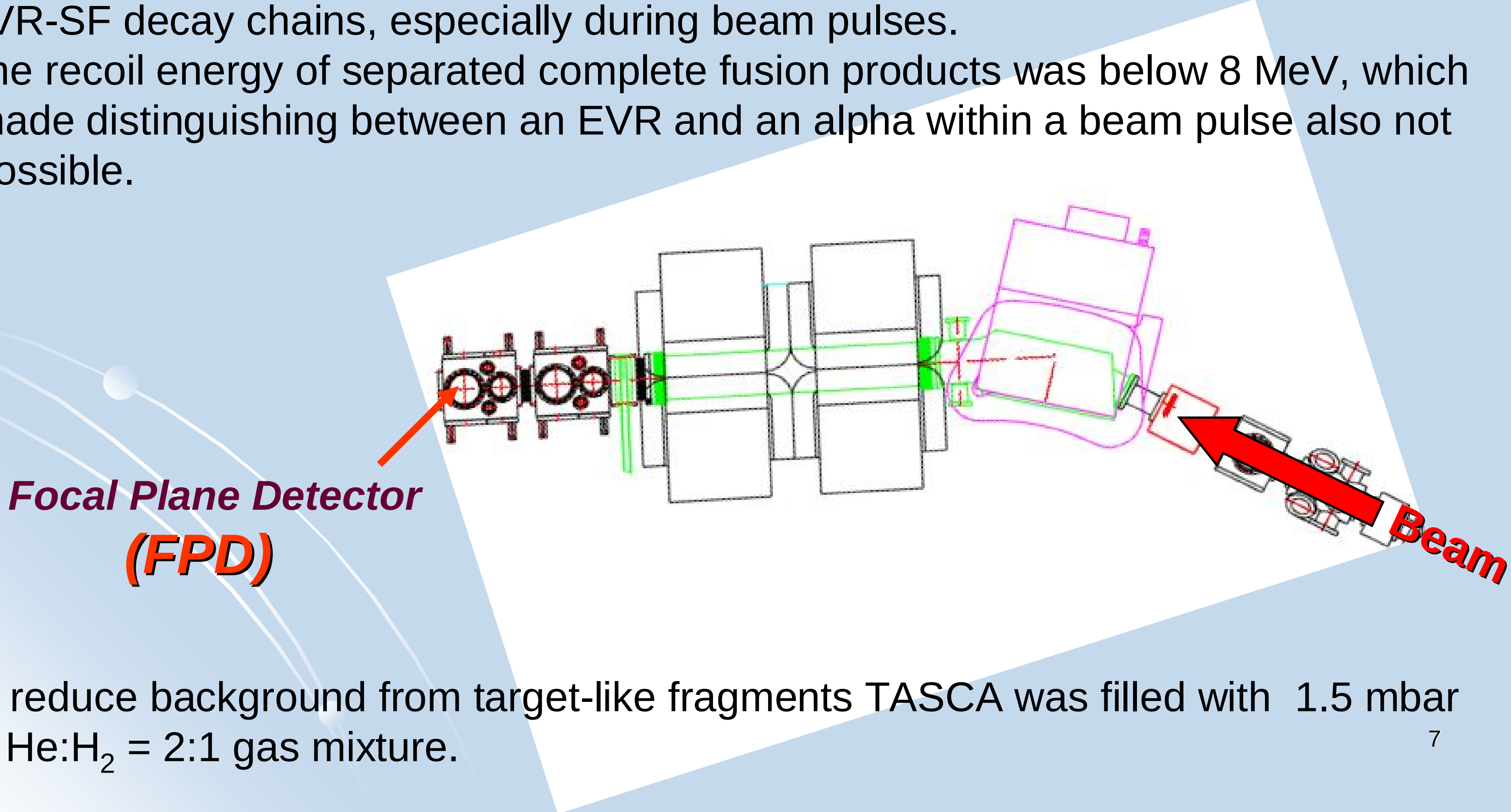
- The target wheel rotated synchronously with the beam macropulse structure.
- The beam energy in the center of the target was 109, 116, and 125 MeV.

TransActinide Separator and Chemistry Apparatus, High Transmission Mode; July 2008



Detection of short-lived $^{22}Ne(^{244}Pu,4n)^{262}Rf$ and $^{22}Ne(^{244}Pu,6n)^{260}Rf$ in the focal plane

- No *veto* detectors in TASCA were installed during the commissioning phase.
- A relative high counting rate from Target Like Fragments originated a high background, which negatively affected search limits for time- and position-correlated EVR-SF decay chains, especially during beam pulses.
- The recoil energy of separated complete fusion products was below 8 MeV, which made distinguishing between an EVR and an alpha within a beam pulse also not possible.

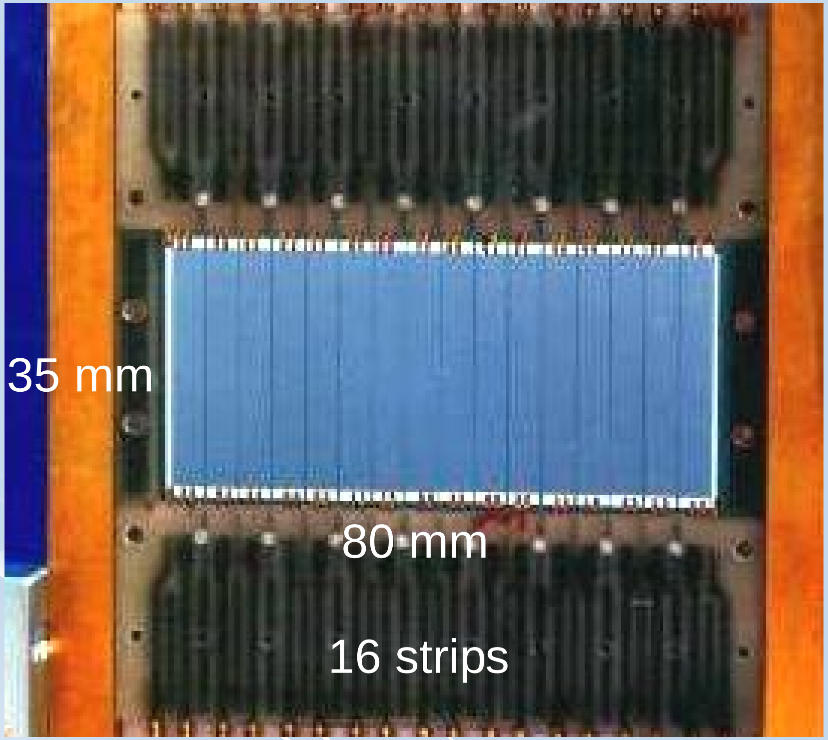


• To reduce background from target-like fragments TASCA was filled with 1.5 mbar of a He:H_2 = 2:1 gas mixture.

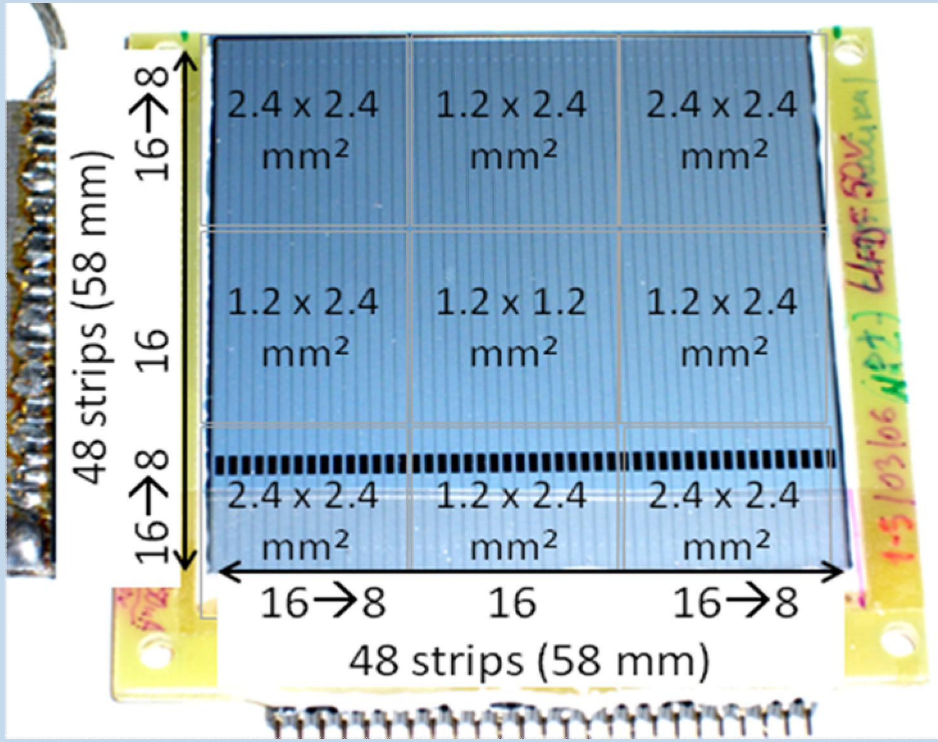
Two types of the focal plane detector

- (80 x 35) mm² 16-strip Position Sensitive silicon Detector (PSD) made by CANBERRA
- (58 x 58) mm² 48-strip Double-Sided Silicon Strip Detector (DSSSD) made in Zelenograd, Russia.

PSD



DSSSD



Thickness = 300 μm.
Bias = 40 V.
-35 °C

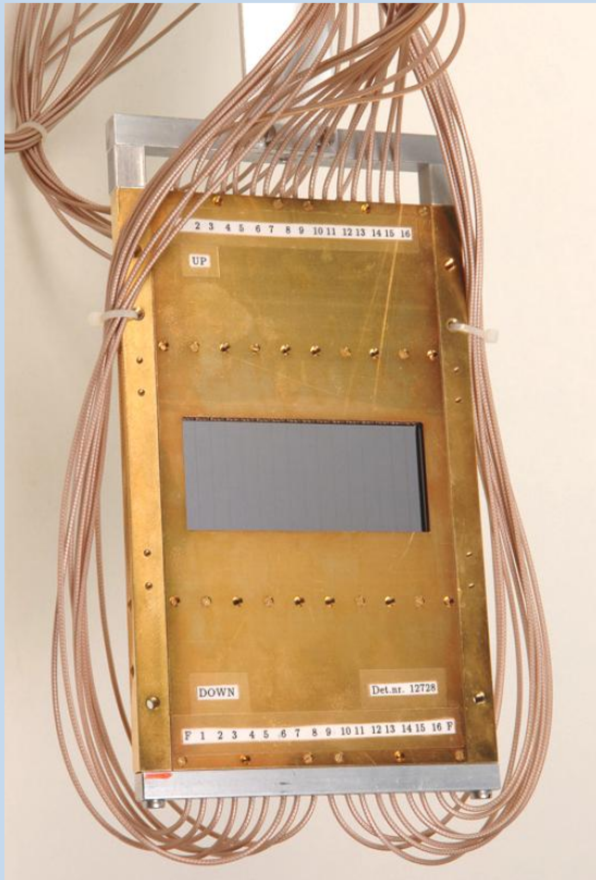
Thickness = 300 μm.
Bias = 50 V.
Room temperature.

Energy resolution FWHM for 5.8 MeV alpha particles ≈ **24 keV** for the both detectors

Detection of short-lived $^{22}Ne(^{244}Pu,6n)^{260}Rf$ in the **Position Sensitive Detector**

- Beam energy = 125 MeV in the center of the target.
- Nominal vertical position resolution is ± 0.2 mm.
- During search for position correlated chain members limits are ± 1 mm →
  → pixel size area about (5 x 2) mm^2.

The relatively large pixel size of the PSD didn’t allow detection of EVR-SF decay chains with a correlation time longer than 250 ms under the experimental conditions.

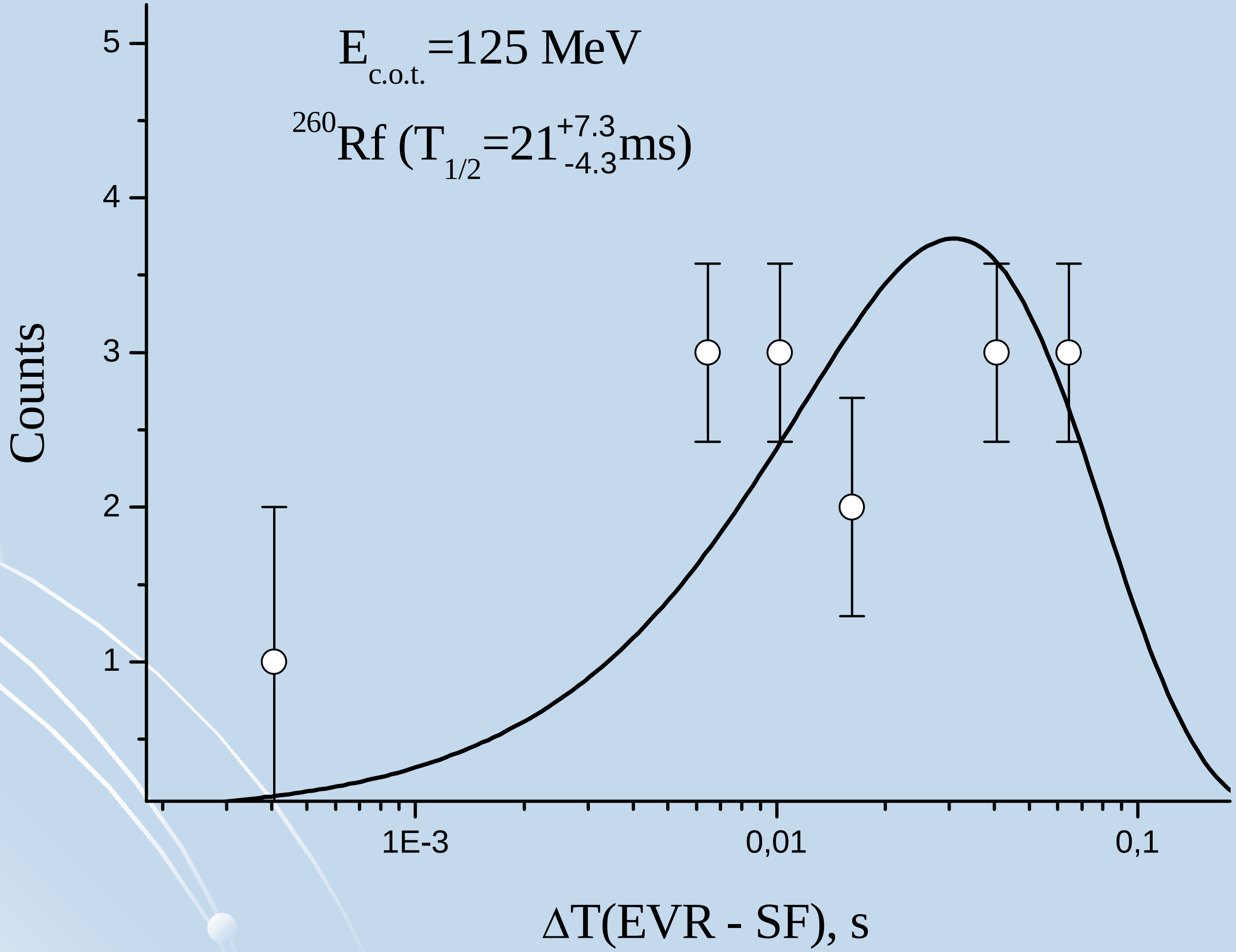


The detection efficiencies are:

- for an EVR near 100%
- for an alpha particle 50-55%
- for a SF fragment 100%.

Time distribution of observed EVR-SF correlations from ^{260}Rf

- 15 time and position correlated EVR-SF events
- Time window of $\Delta t \leq 250$ ms and a position window $\pm$ 1 mm.
- EVR-SF events with correlation time > 250 ms in the PSD could not be found, because of high probability to observe a random correlation.

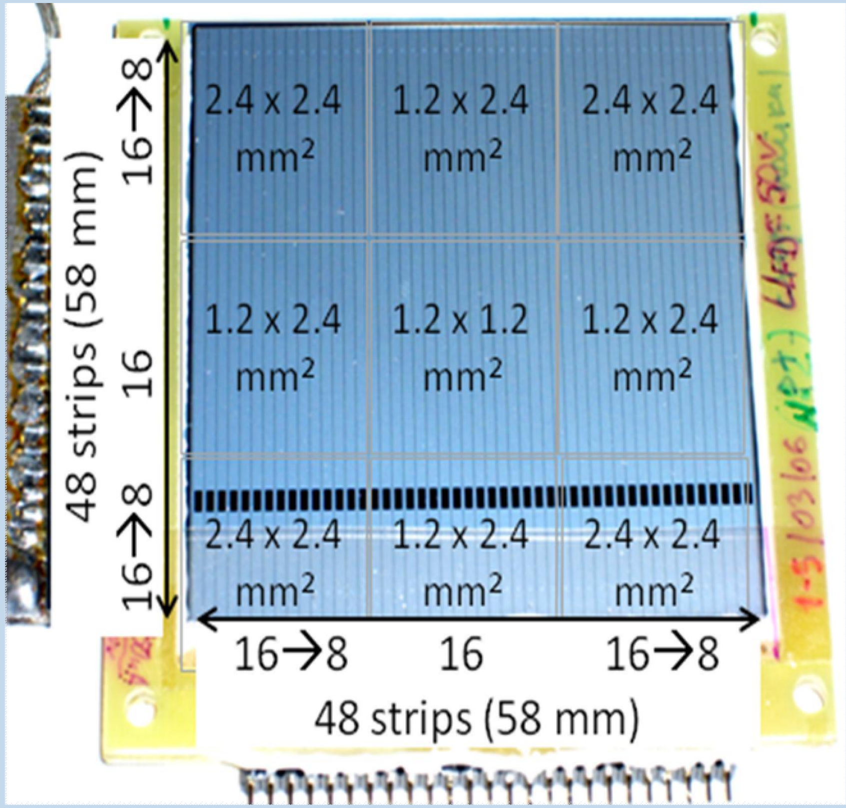


- $T_{½}$ is in good agreement with the half-life published by Somerville et all.,(1985).

Detection of short-lived $^{22}Ne(^{244}Pu,4n)^{262}Rf$ in the **Double-Sided Silicon Stripe Detector**

- Beam energy was 109 MeV in the center of the target.
- Each two of 16 first and last strips on each side are connected to one channel.
- 3 different pixel sizes: (1.2 x 1.2) mm^2, (1.2 x 2.4) mm^2 , (2.4 x 2.4) mm^2 **.**

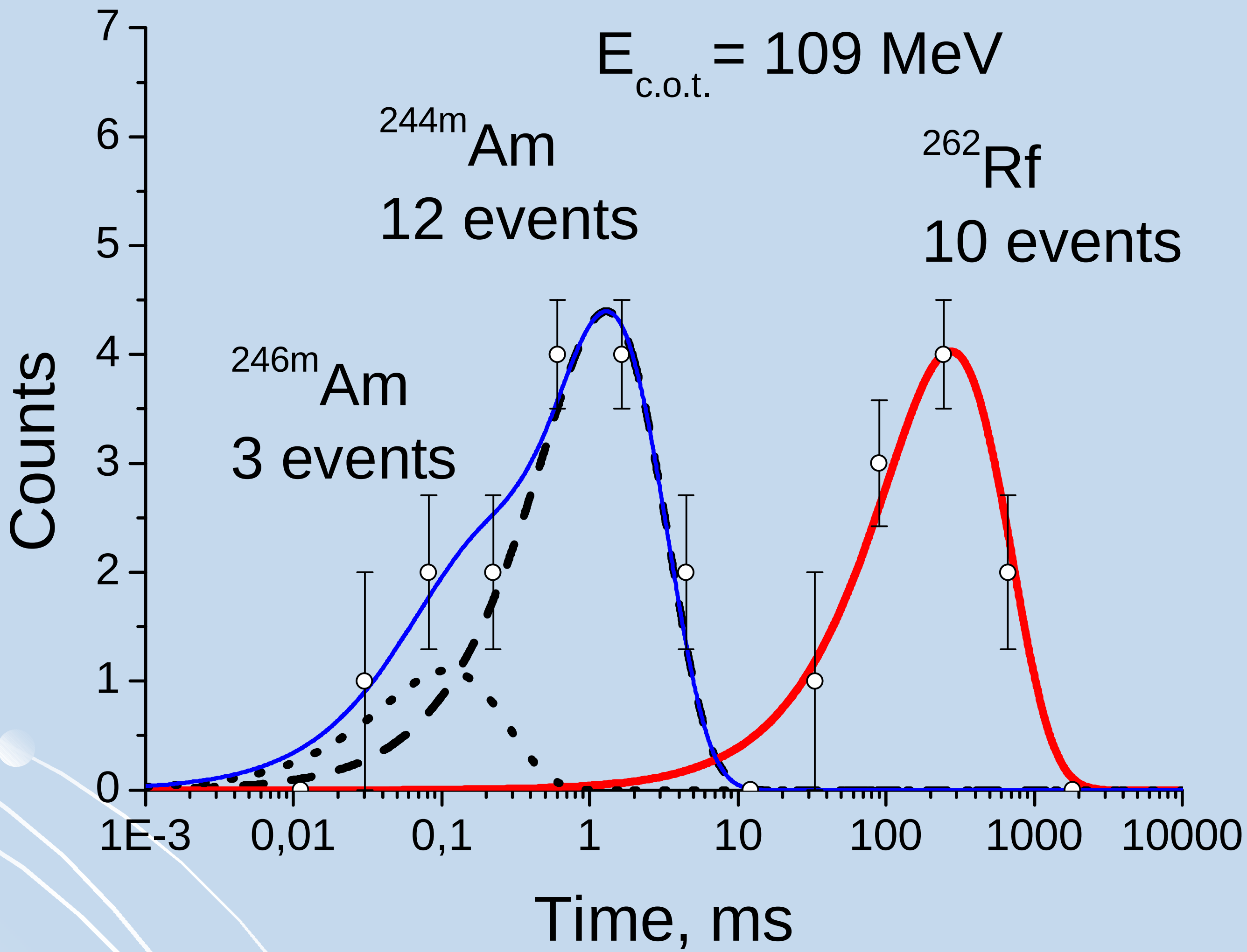
However, the largest pixel size in the DSSSD was only a half of the pixel size of the PSD.



The detection efficiencies are:

- for an EVR near 100%
- for an alpha particle 50-55%
- for a SF fragment 100%.

Time distribution of EVR-SF correlations from ^{262}Rf

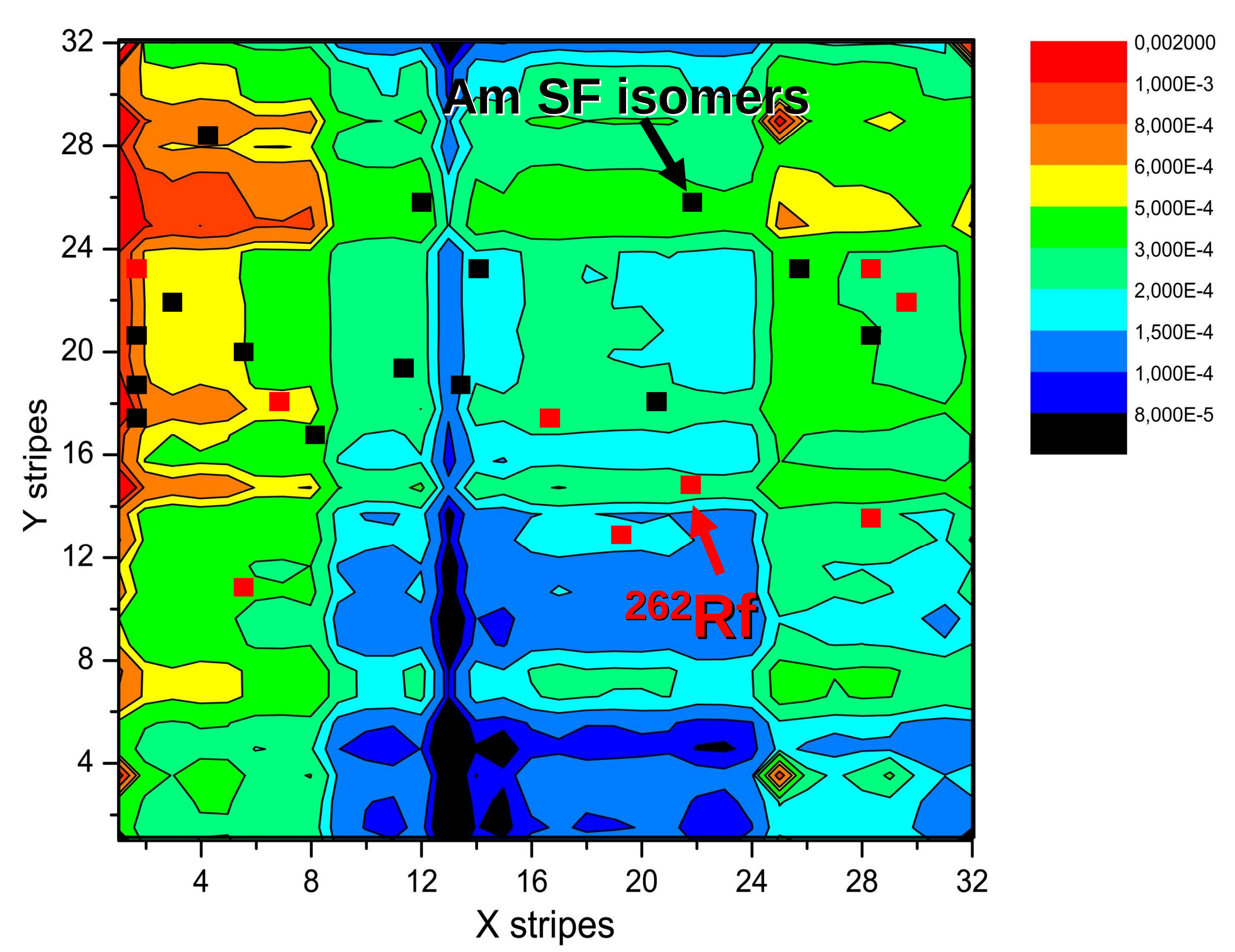


- 15 EVR-SF correlations with $\Delta t \leq 2$ ms and EVR energies of 7.5 ± 5.0 MeV. They were attributed to the decay of Am fission isomers:
  ^{244m}Am: $T_{1/2}$ = 0.9 ms (Nuclear Data Sheets 99, 197 (2003)
  ^{246m}Am: $T_{1/2}$ = 73 μs (Nuclear Data Sheets 84, 901 (1998).

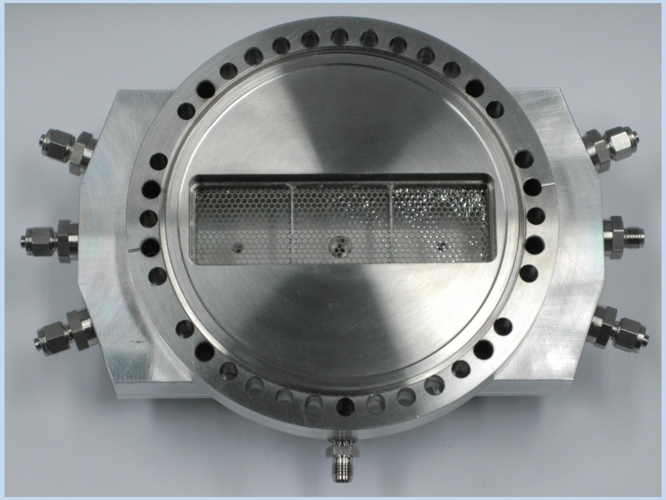
- 10 correlated EVR-SF events of ^{262}Rf (EVR = 1÷3.5 MeV, SF > 90 MeV)
  $T_{½}(^{262}Rf) = 190^{+100}_{-50}$ ms, in contradiction with values from Lane et al. (1996) and Somerville et al. (1985)

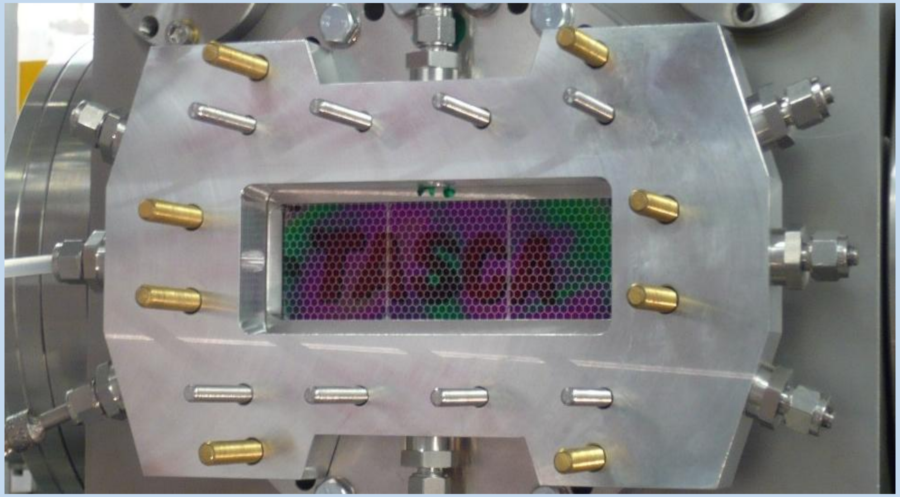
Observed EVR-SF events and random event analysis

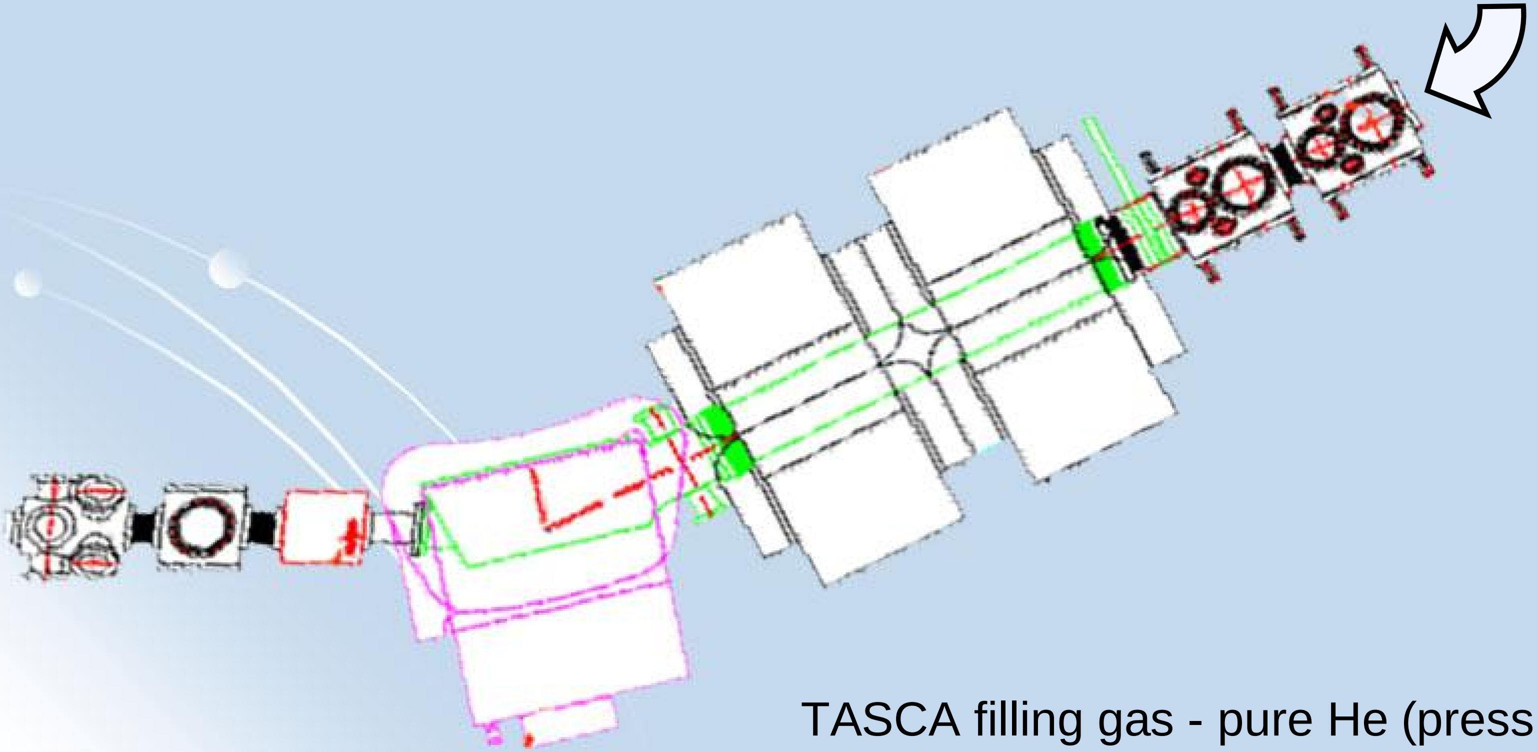
Number of random events in DSSSD within Δt of 1 s



Detection of long-lived ^{261}Rf

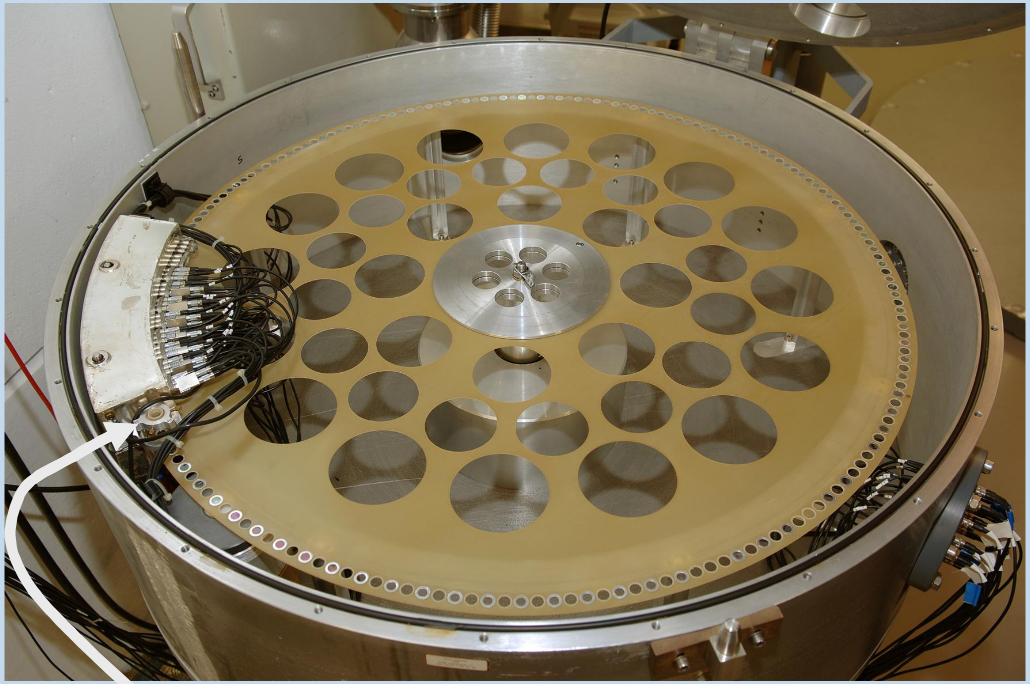




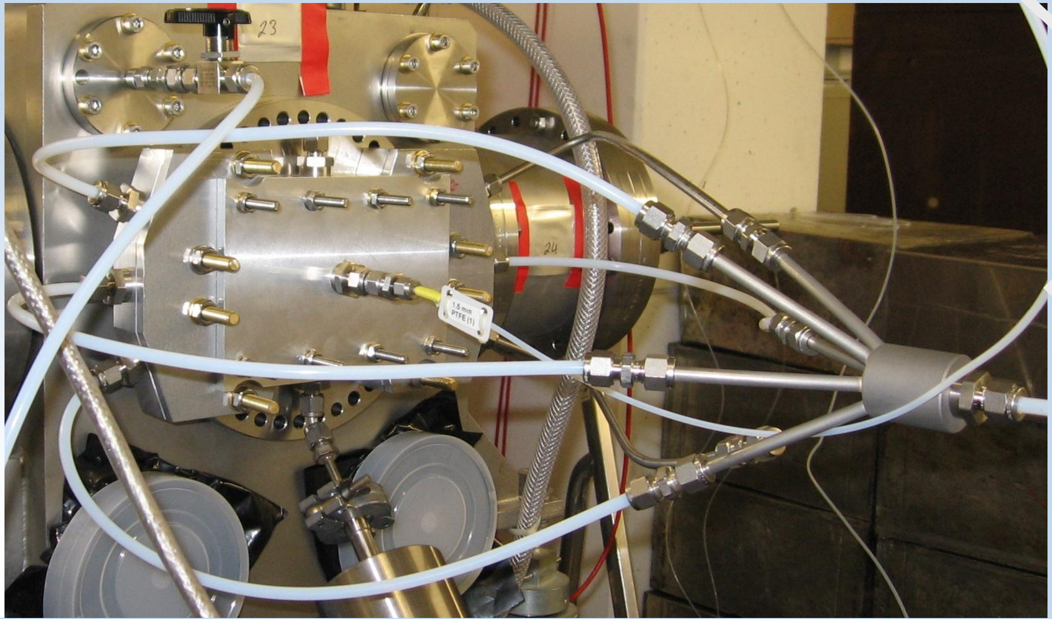


TASCA filling gas - pure He (pressure 0.4 mbar)

Detection of long-lived ^{261}Rf in ROMA

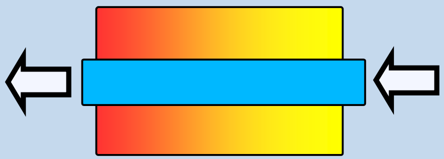


• Mylar window - 1.2 µm thick (140 x 40) mm^2
• 17 mm-deep RTC flushed with He jet



4 m PTFE capillary
(inner diameter: 2 mm)

Oven



He gas
Pressure ~1.2 bar
Flow rate: 3.45 l/min

KCl aerosol produced
by sublimation of KCl at 650 °C.

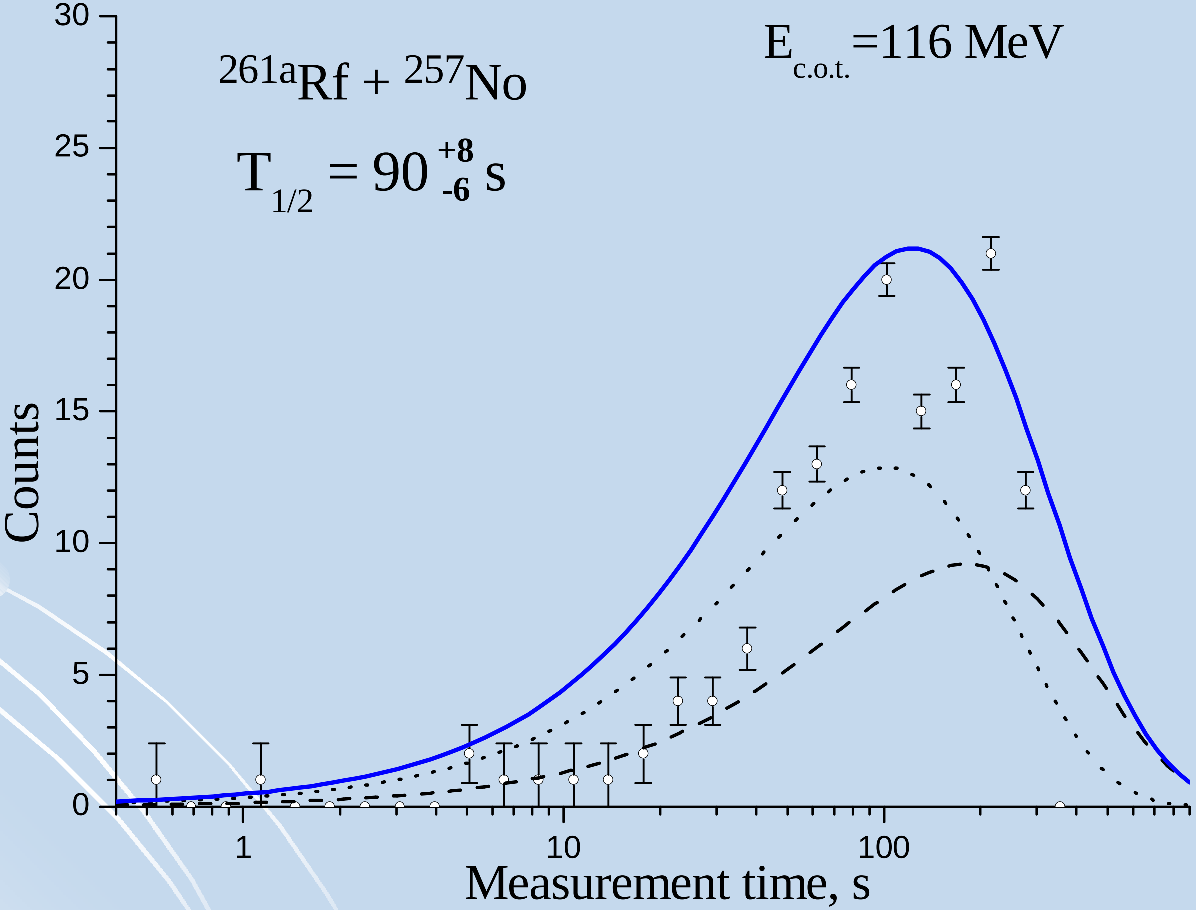
Rotating wheel On-line Multidetector Analyzer (ROMA)

- The particles were deposited on 40-µg/cm^2 thick polyethylene foils.
- ROMA wheel diameter = 85 cm.
- The wheel periodically stepped and transported the sample from collection position to eight counting positions equipped with (20 x 10)-mm^2 large PIN diodes.

- For measurements of ^{261a}Rf, a stepping time was 35 s.
- For ^{261b}Rf experiments were performed with a stepping time 1.5 s.

$^{22}Ne(^{244}Pu,5n)^{261a}Rf$ in ROMA

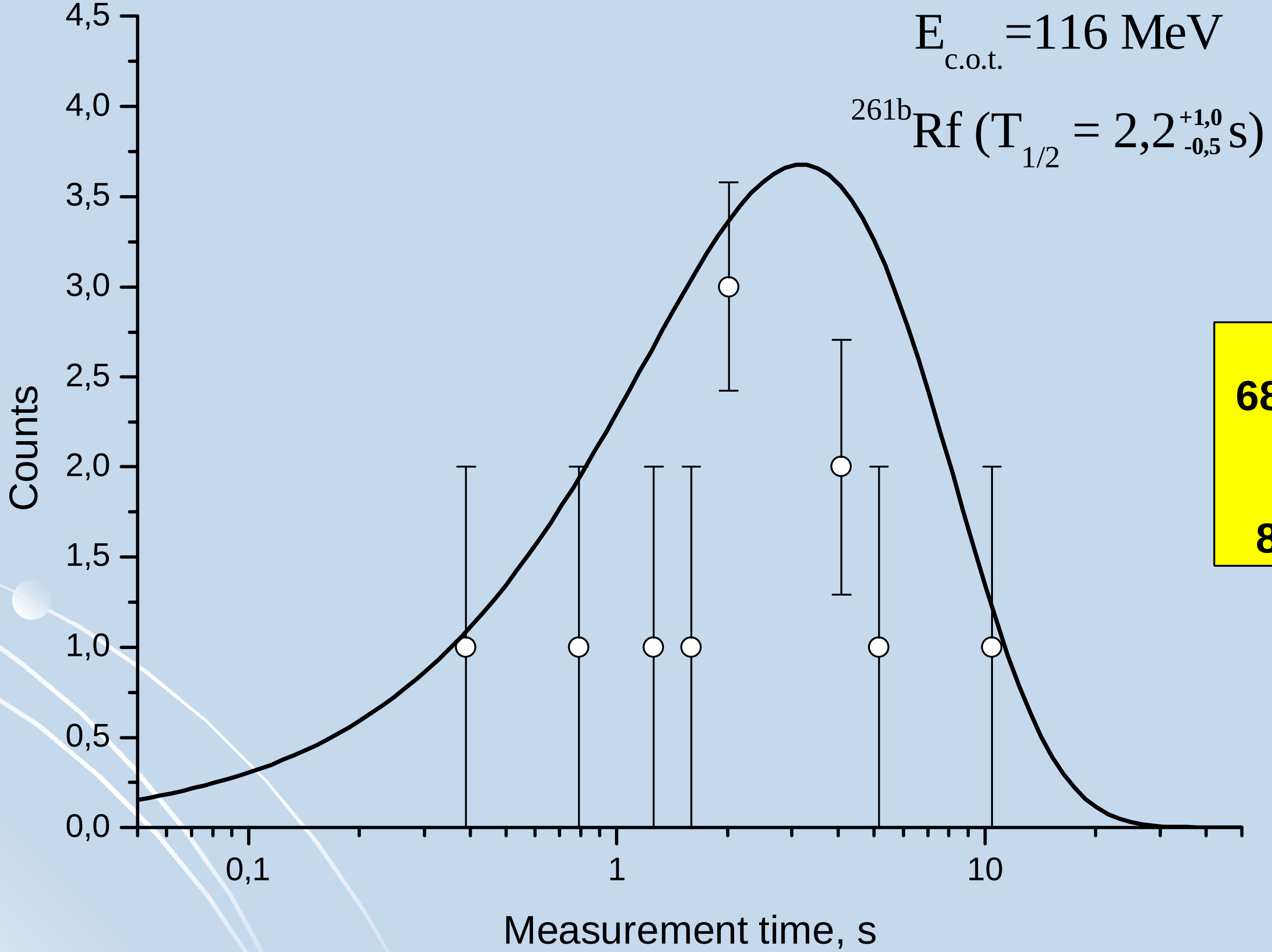
^{261}Rf was produced in the 5n channel at $E_{c.o.t}$ =116 MeV, t_{step} = 35 s.
149 single α-particles (E_{α} = 7.8 – 8.5 MeV) from ^{261a}Rf and ^{257}No were registered; among these 28 α-α correlations.

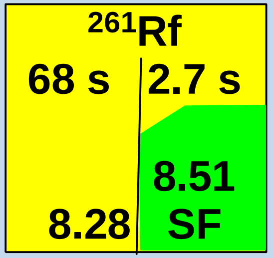


Time analysis of single alpha-particles and correlations confirmed, that detected events originated from ^{261a}Rf.

$^{22}Ne(^{244}Pu,5n)^{261b}Rf$ in ROMA

At the same beam energy 11 SF-events were registered and are attributed to ^{261b}Rf. The time analysis revealed $T_{1/2}(^{261b}Rf)$ of $2.2^{+1.0}_{-0.5}$ s. t_{step} = 1.5 s.

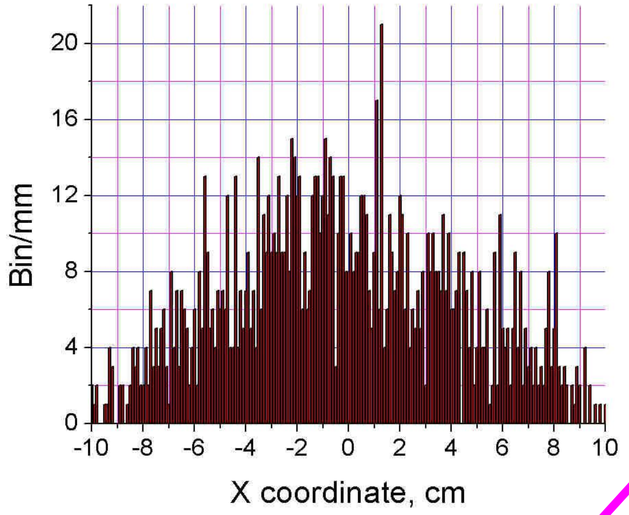




The SF activity assigned in Lane et al.(1996) to ^{262}Rf most likely originated from then unknown ^{261b}Rf.

Monte-Carlo simulation

$^{22}Ne(E_{lab}$ = 115 Mev CofT) + ^{244}Pu (400 mg/cm^2) -> ^{261}Rf + 5n

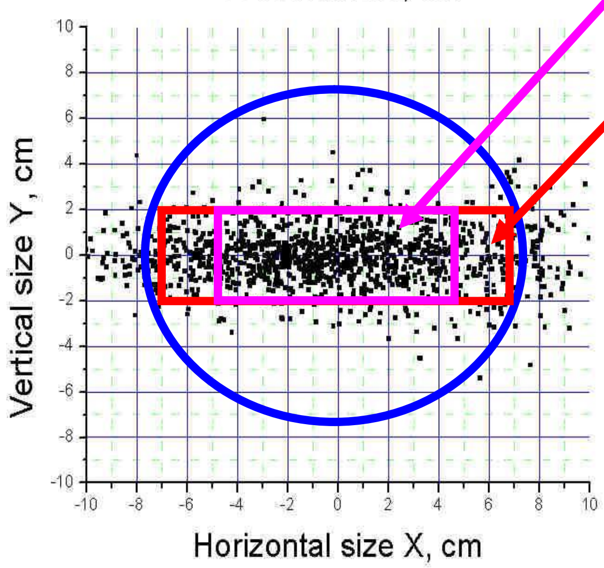


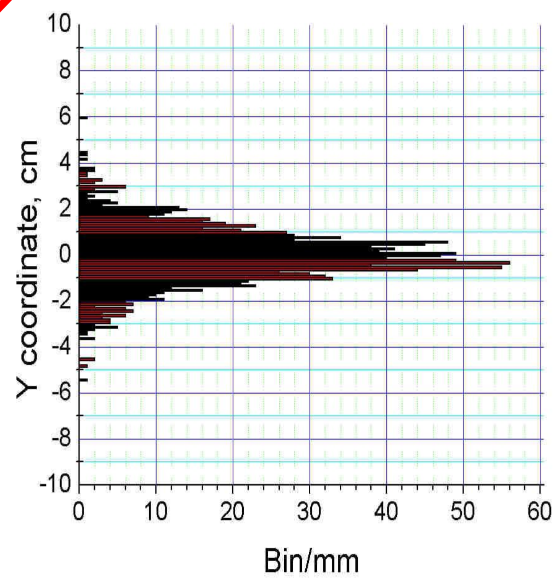
Pressure = 0.3 mbar

Transmission to the Focal Plane = 12.0%

53% inside 8 x 4 cm^2 PSD

81% inside 14 x 4 cm^2 RTC window





X coordinate	Fraction covered
±8 cm	99%
±7 cm	90%
±6 cm	80%
±5 cm	70%
±4 cm	60%
±3 cm	53%
±2 cm	33%
±1 cm	17%
Y coordinate	**Fraction covered**
±4 cm	99%
±3 cm	97%
±2 cm	90%
±1 cm	64%

*** Based on TRANSPORT ion-optic calculations (from A. Semchenkov)***

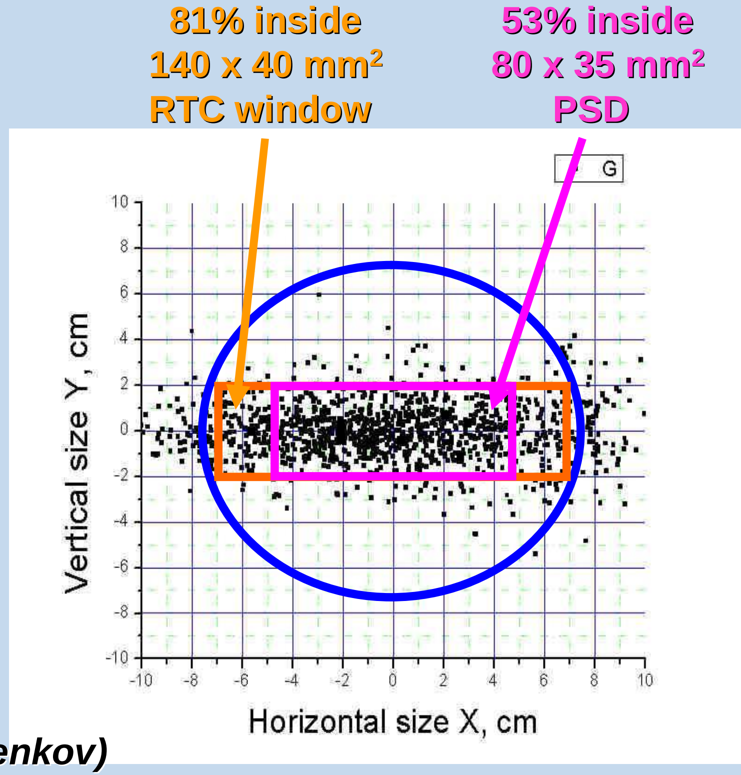
TASCA transmission for $^{22}Ne(^{244}Pu,xn)^{266-x}Rf$

$$E_{TASCA} = \frac{N_{measured}}{N_{produced} \cdot \varepsilon_{RTC} \cdot \varepsilon_{jet} \cdot \varepsilon_{decay} \cdot \varepsilon_{detection}}$$

From measured ^{261a}Rf event number, cross section of 4.4 nb from Lazarev et al. (2000), ε_{RTC} = 80 %, ε_{jet} = 60 % and ROMA detection efficiency transmission of Rf through TASCA to the Focal Plane is **10.5 %**.

Considering Monte-Carlo calculations, transmission of Rf through TASCA:

- to the RTC window 140 x 40 mm² is 8.5 %.
- to the PSD area 80 x 35 mm² is 5.3 %.
- to the DSSSD area 58 x 58 mm² is 5.1 %.



*** Based on TRANSPORT ion-optic calculations (from A. Semchenkov)***

HIVAP prediction for $^{22}Ne(^{244}Pu,xn)^{266-x}Rf$

4n channel: 0.75 nb @ 109 MeV

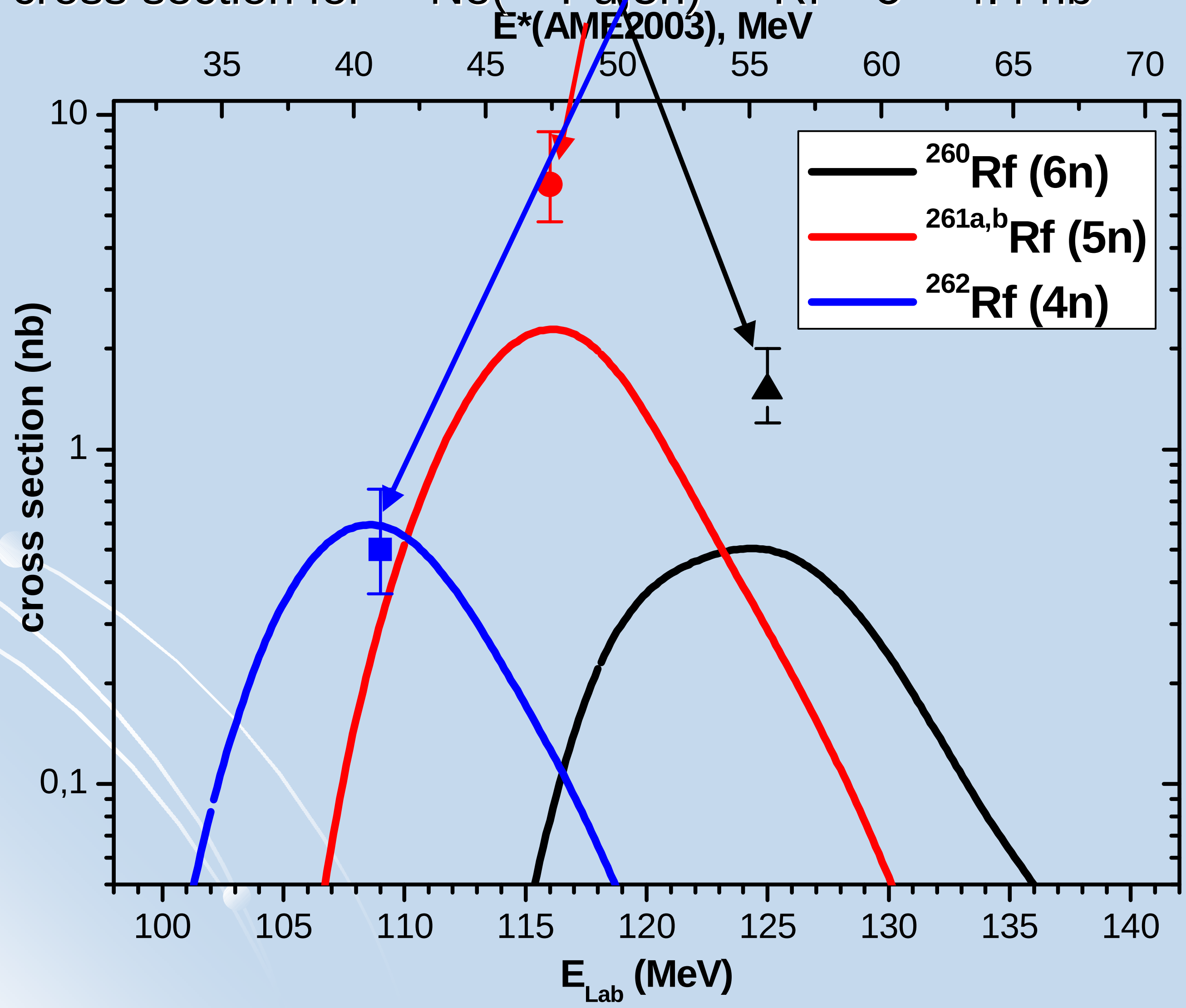
5n channel: 2.5 nb @ 116 MeV

6n channel: 0.55 nb @ 125 MeV

Cross section for $^{22}Ne(^{244}Pu,5n)^{261b}Rf$ $\sigma = 1.6^{+0.8}_{-0.5}$ nb,

Cross section for $^{22}Ne(^{244}Pu,4n)^{262}Rf$ $\sigma = 0.5^{+0.26}_{-0.15}$ nb.

published cross section for $^{22}Ne(^{244}Pu,5n)^{261a}Rf$ $\sigma = 4.4$ nb



Conclusion

- $T_{½}$ for ^{260}Rf = $21^{+7.3}_{-4.3}$ s is in good agreement with the half-life published by Somerville et all.,(1985).
- Cross section for $^{22}Ne(^{244}Pu,6n)^{260}Rf$ $\sigma = 1.5^{+0.5}_{-0.3}$ nb. New!

- $T_{1/2}$ for ^{261b}Rf = $2.2^{+1.0}_{-0.5}$ s is in good agreement with the half-life published by Dvorak et all.,(2008).
- Cross section for $^{22}Ne(^{244}Pu,5n)^{261b}Rf$ $\sigma = 1.8^{+0.8}_{-0.4}$ nb. New!
- The production ratio of ^{261a}Rf : ^{261b}Rf = 2.5 : 1.

- Transmission of Rf through TASCA to the Focal Plane = **10.5** %.

- $T_{½}$ for ^{262}Rf = 190^{+100}_{-50} ms, in contradiction with values published by Lane et al. (1996) and Somerville et al. (1985). New!

- Cross section for $^{22}Ne(^{244}Pu,4n)^{262}Rf$ $\sigma = 500^{+260}_{-130}$ pb New!

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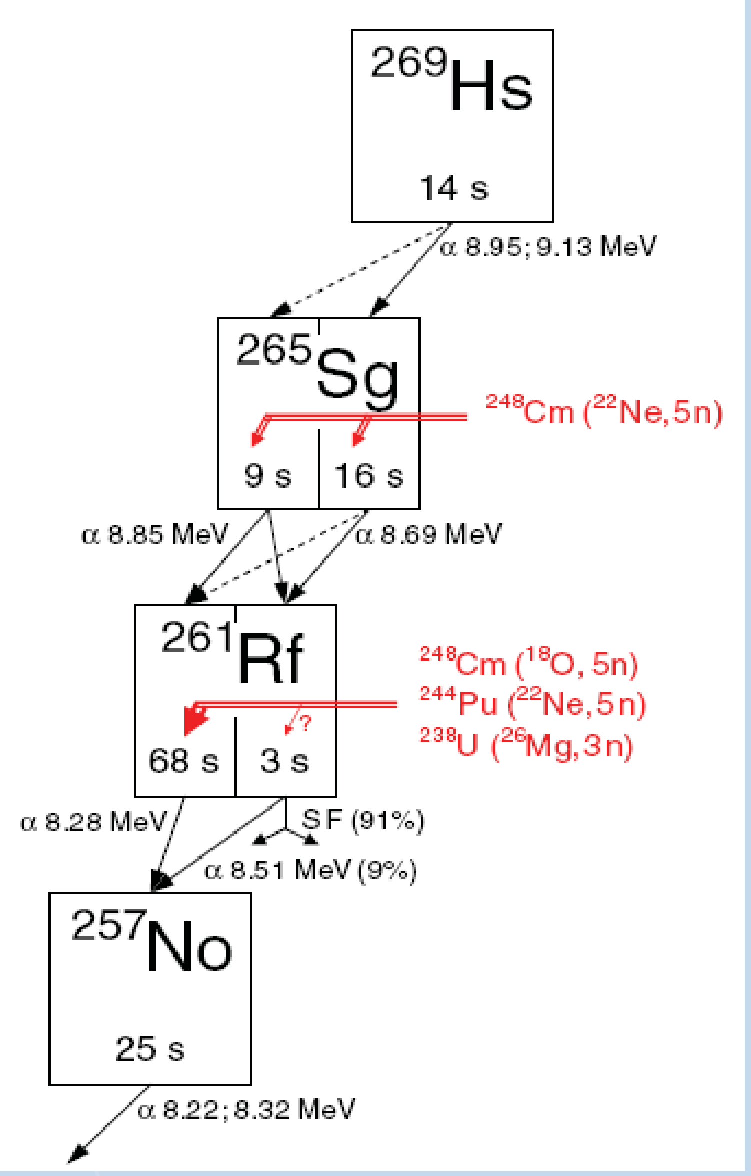
Thank you for your attention!

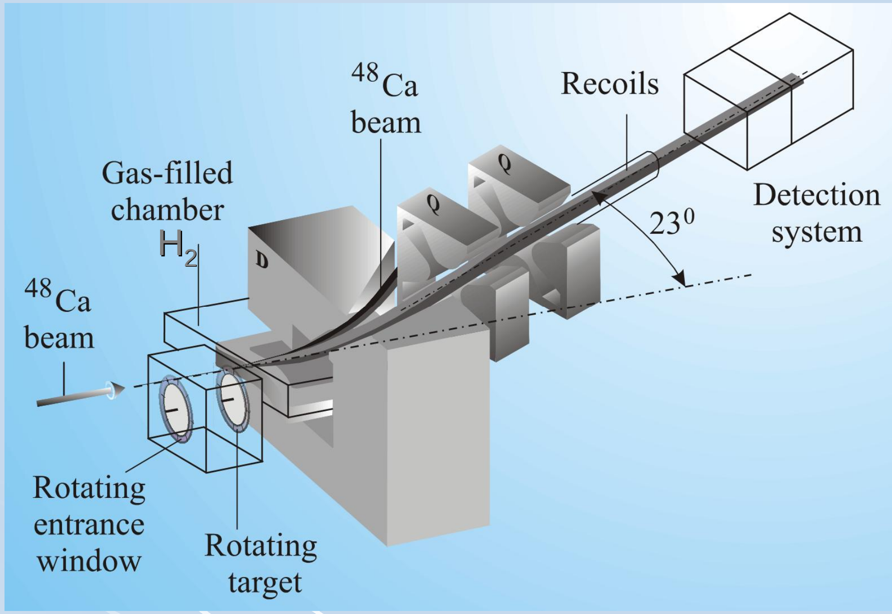
Current working hypothesis of the decay patterns observed in the chain $^{269}Hs \rightarrow ^{265}Sg \rightarrow ^{261}Rf \rightarrow (^{257}No \rightarrow)$

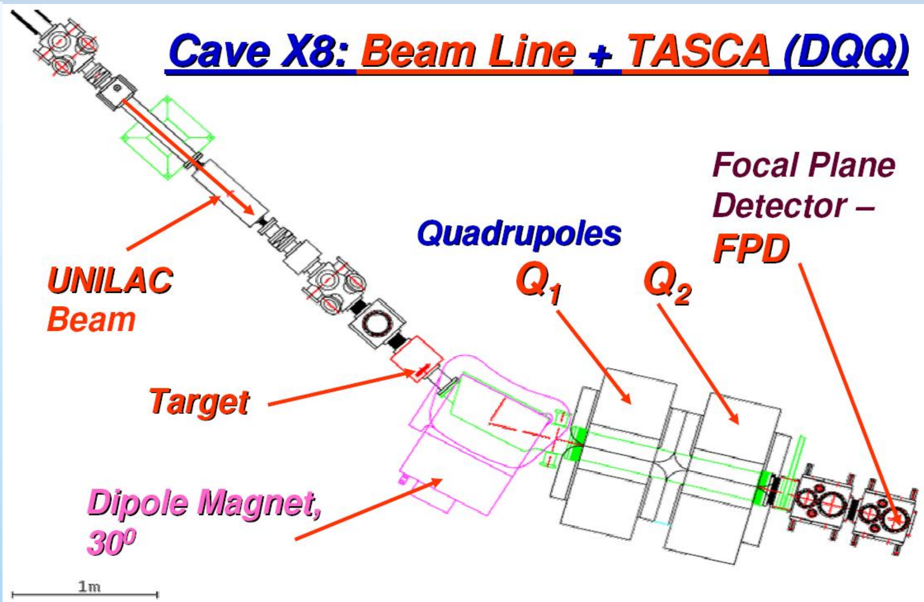


* Ch. E. Düllmann, A. Türler. Phys. Rev. C 77, 064320 (2008).

TASCA filling gas

- Predicted values of B·ρ of EVRs in the range of 1.90 T·m - 1.98 T·m.
- Predicted magnetic rigidities for elastically scattered ^{244}Pu nuclei recoiling from the target with twice the momentum of the beam are about 1.86 T·m.





Charge states of slow heavy EVRs in H_2 are much lower than in He -> high B· ρ values. DGFRS can reach B·ρ more than 3 T·m. TASCA - 2.4 T·m only, which is not enough to bend Rf EVRs from the reaction $^{22}Ne+^{244}Pu$. To reduce background from target-like fragments TASCA was filled with 1.5 mbar of a He:H_2 = 2:1 gas mixture.
As will be described in already prepared article of J. Khuyagbaatar the use of such gas mixtures indeed combines the advantages of both gas components.

Measured yield dependence from magnetic rigidity

Used settings: D= 555 A (1.99 T m), $Q_1 = Q_2 = 508$ A

Probable best settings: D= 535 A (1.94 T m), $Q_1 = Q_2 = 490$ A