Lawrence Livermore National Laboratory

Estimating Super Heavy Element Event Random Probabilities Using Monte Carlo Methods

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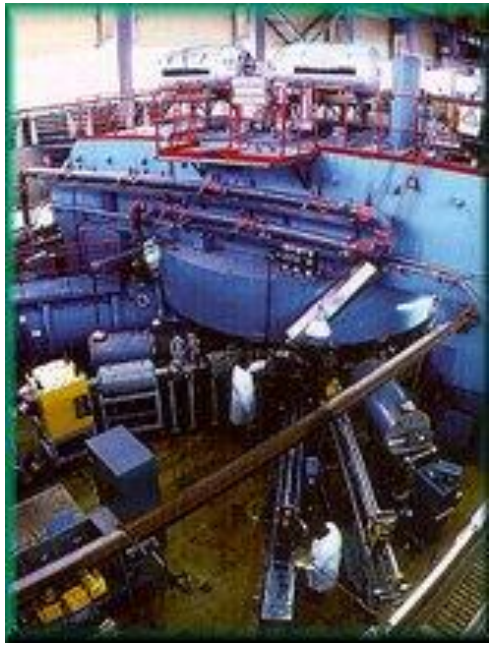
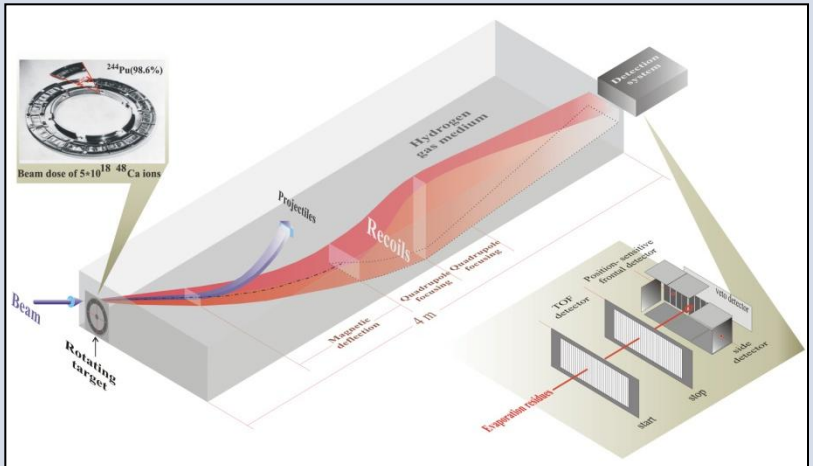
LLNL performs heavy element experiments at the Flerov Lab of Nuclear Reactions (JINR, Dubna, Russia)



- $^{48}Ca^{5+}$ beam supplied by the U400 Cyclotron with high intensities
- Total beam dose over the course of an experiment is ~ 10^{19} particles
- Thin (0.35 mg/cm^2) rotating actinide oxide targets electroplated onto 1.5-μm Ti backing

- Rapid separation allows for detection of half-lives from μs to days
- DGFRS suppression factors are $\geq 10^{15}$ and $\geq 10^4$ for beam- and target-like particles respectively

Dubna Gas-Filled Recoil Separator (DGFRS)



Transmission Efficiency = 35–40 % for Z = 114–118 nuclei

Detection of candidate events occurs in the focal plane detector

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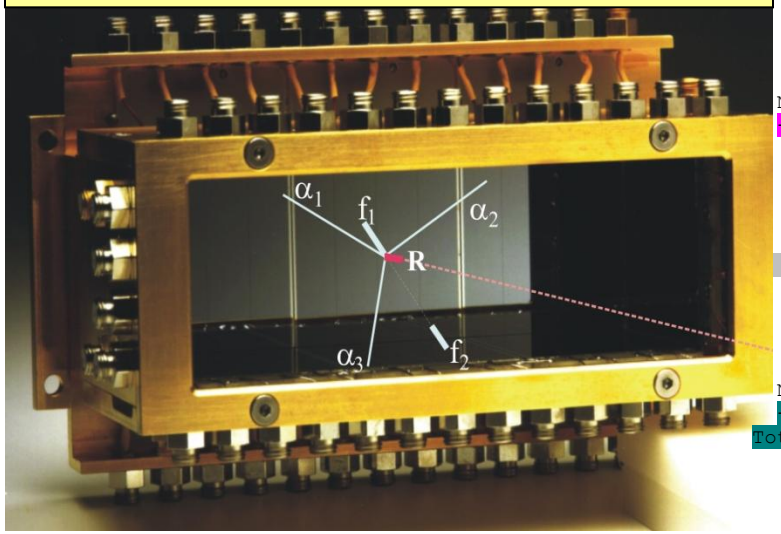
Position-sensitive silicon detector array



- **alpha particle efficiency = 87%**
- **coincident fission fragment efficiency = 45%**

Some examples of data

No.	Type	Det.	Total Energy (MeV)	Side Energy (MeV)	Interval Time (ms)	Posit. (mm)	ToF8	ToF10	Block	NSTAT
1	EVR	2	19.229	0.000	0.00	18.56	0.	472.	733	17
2	alpha	2	9.014	0.000	1156.80	29.08	0.	0.	733	1
3	alpha	2	8.757	0.000	2180.10	20.29	0.	0.	734	1
4	alpha	2	8.865	0.000	9442.90	27.74	0.	0.	737	1
5	alpha	2	8.944	0.000	6643.10	30.94	0.	0.	739	1
6	fission	2	130.301	0.000	17500.00	24.01	0.	0.	743	1

No.	Type	Det.	Total Energy (MeV)	Side Energy (MeV)	Interval Time (ms)	Posit. (mm)	ToF8	ToF10	Block	NSTAT
Total Random correlations???										
1	EVR	9	12.580	0.000	0.00	26.19	0.	480.	2400	17
2	alpha	9	8.936	0.000	27263.80	22.37	0.	0.	2406	1
3	alpha	9	8.908	0.000	12812.80	26.42	0.	0.	2410	1
4	alpha	9	8.752	0.000	84924.70	31.25	0.	0.	2430	1
5	alpha	9	8.938	0.000	48007.20	29.55	0.	0.	2442	1
6	alpha	9	8.996	0.000	24534.30	27.75	0.	0.	2448	1
7	fission	9	109.404	0.000	18444.90	25.66	0.	0.	2453	1

The data consists of a time-stamped list of signals that can be decoded into alpha, fission or EVR implant events

Interpretation of the events into decay chains depends on position correlations

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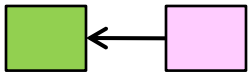
Poor position correlation

SF 26.7 mm

109 MeV

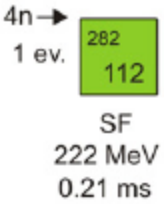


EVR 20.2 mm

11.3 MeV

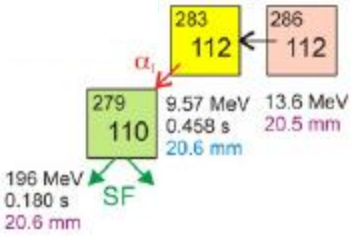
No position correlation results in random probability = 1

Position correlated



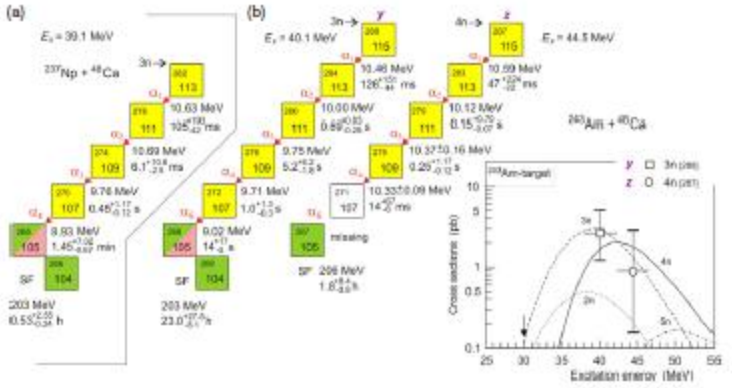
Because it is only a EVR – SF correlation, the probability for randomness is higher (~ 0.02-0.03)

Longer position correlated



Because it is a EVR – α – SF correlation, the probability for randomness is lower (~ 10^{-4})

No doubt?



An EVR-α-α-α-α-α correlation results in extremely low random probability (< 10^{-9})

Let's illustrate the technique by examining several recent experiments

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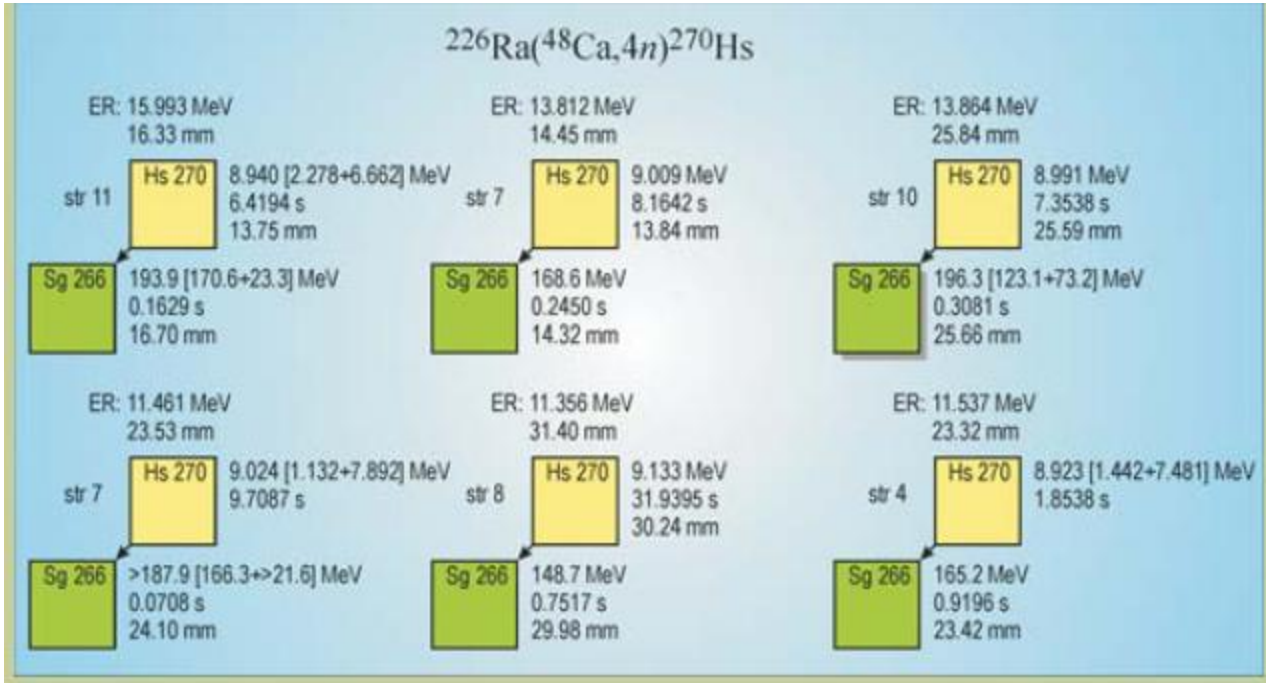
EVR – α – SF decay chains observed in ^{48}Ca + ^{226}Ra experiment



The Monte Carlo method artificially inserts events (of any type) into the actual data

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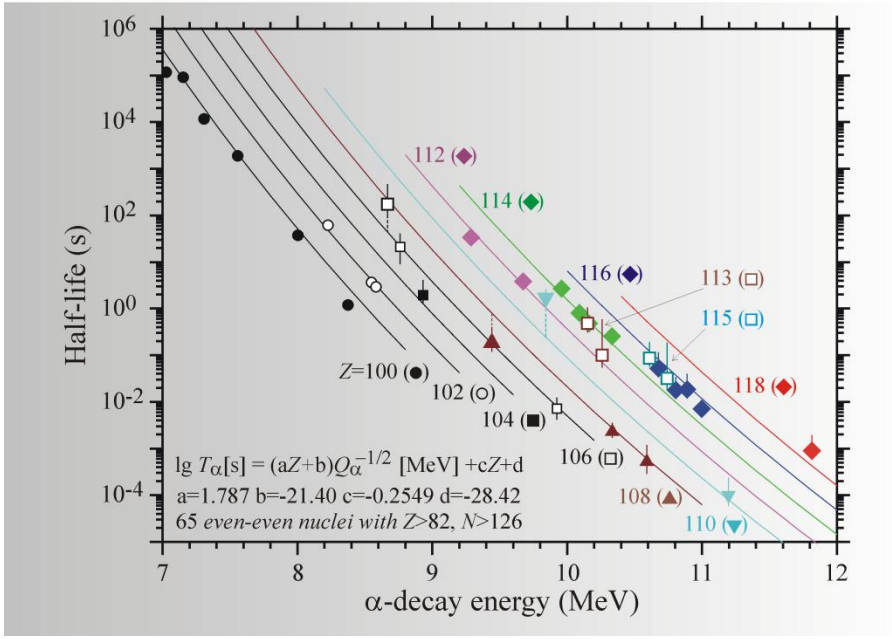
Preliminary results for $^{48}Ca + ^{226}Ra$ experiment

	EVR-SF	EVR-a-SF	EVR-xa-SF
First part	490680	1276	2
	4.91E-02	1.28E-04	2.00E-07
Second part	465237	1910	7
	4.65E-02	1.91E-04	7.00E-07
Third part	547096	1568	1
	5.47E-02	1.57E-04	1.00E-07
Fourth part	366787	1876	2
	3.67E-02	1.88E-04	2.00E-07
Fifth part	334443	1286	0
	1.67E-02	6.43E-05	0.00E+00
Total	**2204243**	**7916**	**12**
	3.67E-02	**1.32E-04**	**2.00E-07**
error	**0.1%**	**1.1%**	**28.9%**



- Searches performed just as you would look for correlated decay chains (position resolutions used)
- Method automatically takes into account beam intensity variations, time-dependent backgrounds, etc.
- Various random number generators tested
- Different event distributions tested (Gaussian, flat, removing top and bottom of strip, etc.)
- Different coincidence (correlation) conditions tested – also can apply Geiger-Nuttal conditions
- Different number of random events
- More conservative than other methods of estimating random probabilities based on event rates (GSI, Lazarev, etc.)

More details found in: N.J. Stoyer, et. al., NIMA 455 (2000) 433.

Element 117 was discovered using the $^{48}Ca + ^{249}Bk$ reaction at the DGFRS

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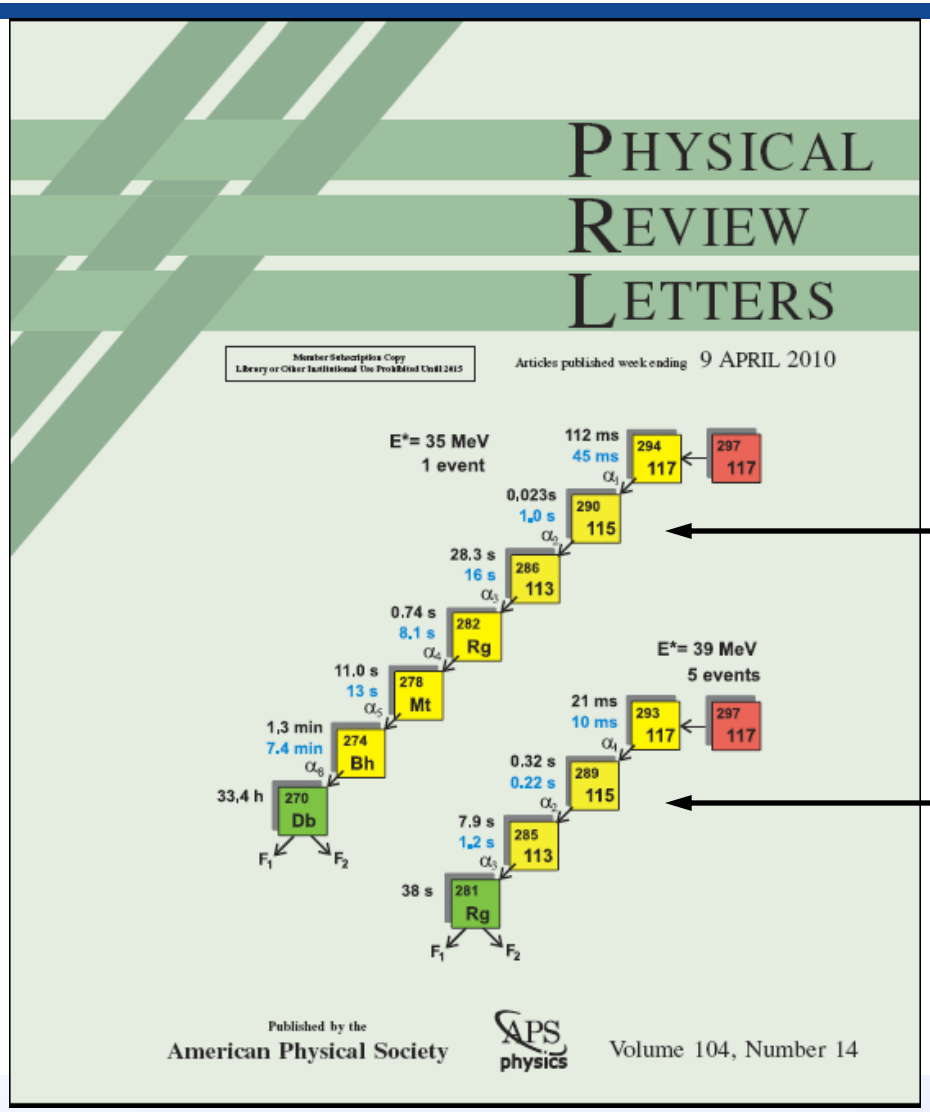

1 EVR – 6α –SF decay chain observed

5 EVR – α – α –α –SF decay chains observed

MCRP element 117 results

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- For EVR-3α-SF chain MCRP is 1.5×10^{-5} per fission for one decay chain
- The MCRP for 5 such decay chains is 3×10^{-24} per fission
- For the EVR-6α-SF chain MCRP is less than 2×10^{-8} per fission

Comparison of MCRP results with other methods for estimating random probabilities

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EVR – α – α – α– SF decay chains observed in ^{48}Ca + ^{244}Pu experiment

Method	Random Probability/ fission
GSI*	1.0×10^{-4}
Lazarev**	4.1×10^{-3}
MCRP***	5.8×10^{-3}
MCRP with Geiger Nuttal***	5.6×10^{-4}

*K.-H. Schmidt, C.-C. Sahm, K. Pielenz, H.-G. Clerc, Z. Phys. A, Atoms Nucl. **316** (1984) 19.

Yu.A. Lazarev et al., Phys. Rev. C **54 (1996) 620.

***N.J. Stoyer, et. al., NIMA **455** (2000) 433.

Comparison of MCRP results for a variety of experiments

Experiment	Element	DK chain length	MCRP (/fission)
$^{48}Ca + ^{226}Ra$	Hs	EVR-α-SF	1.3×10^{-4}
$^{48}Ca + ^{244}Pu$	114	EVR-3α-SF	5.6×10^{-4}
$^{48}Ca + ^{243}Am$	115	EVR-5α-SF	$<1.0 \times 10^{-7}$
$^{48}Ca + ^{245}Cm$	116	EVR-3α-SF	5.0×10^{-7}
$^{48}Ca + ^{248}Cm$	116	EVR-3α-SF	$<1.0 \times 10^{-6}$
$^{48}Ca + ^{249}Bk$	117	EVR-3α-SF	1.5×10^{-5}
$^{48}Ca + ^{249}Bk$	117	EVR-6α-SF	$<2.0 \times 10^{-8}$
$^{48}Ca + ^{249}Cf$	118	EVR-α-SF	7.0×10^{-6}

For most correlated decay chains, the random probability is $< 10^{-5}$

Conclusions

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- MCRP method developed at LLNL is useful for calculating the probability that an decay chain is due to random events
- Comparisons with other methods indicate MCRP may be a little more conservative
- Comparisons between different experiments (data sets) indicate the flexibility of the method
- We envision performing some random probability calculations for the $^{48}Ca + ^{248}Cm$ and $^{54}Cr + ^{248}Cm$ experiments at GSI to compare with Dubna experiments

Spasibo for your attention!