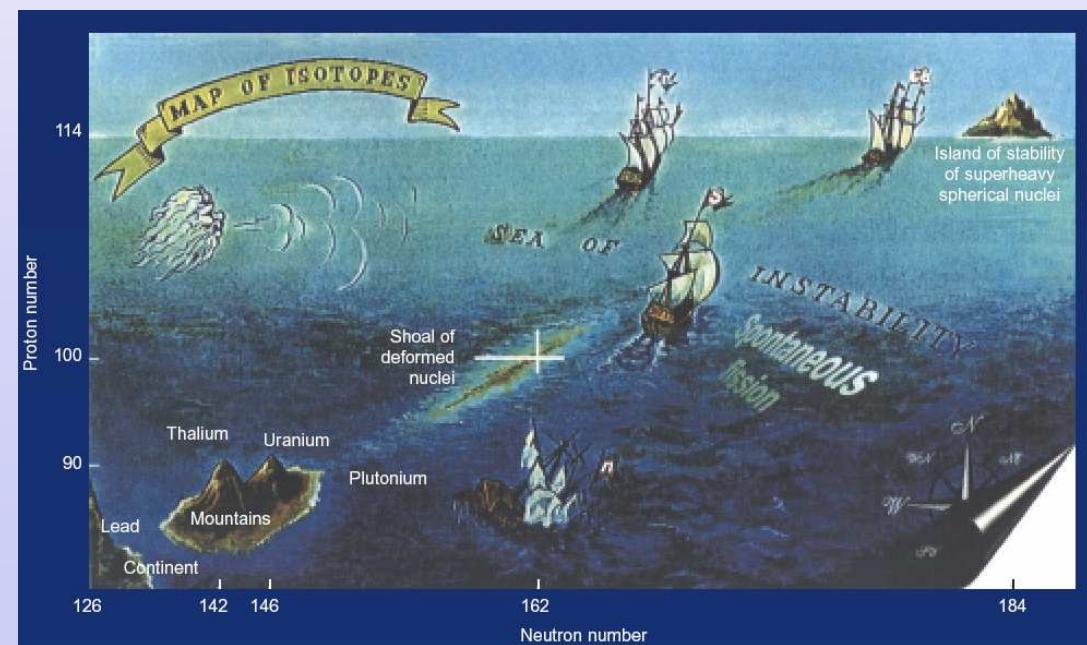


Measuring Masses with $Z \approx 104$ using MLLTRAP at DESIR

Peter G. Thirolf, LMU Munich

Outline:

- Motivation of (S)HE mass measurements
- Environment for studies with MLLTRAP at S³/DESIR
- Status of MLLTRAP system
- Status of transuranium mass measurements: SHIPTRAP results
- Identification of candidates for MLLTRAP
- Feasibility considerations
- Conclusion

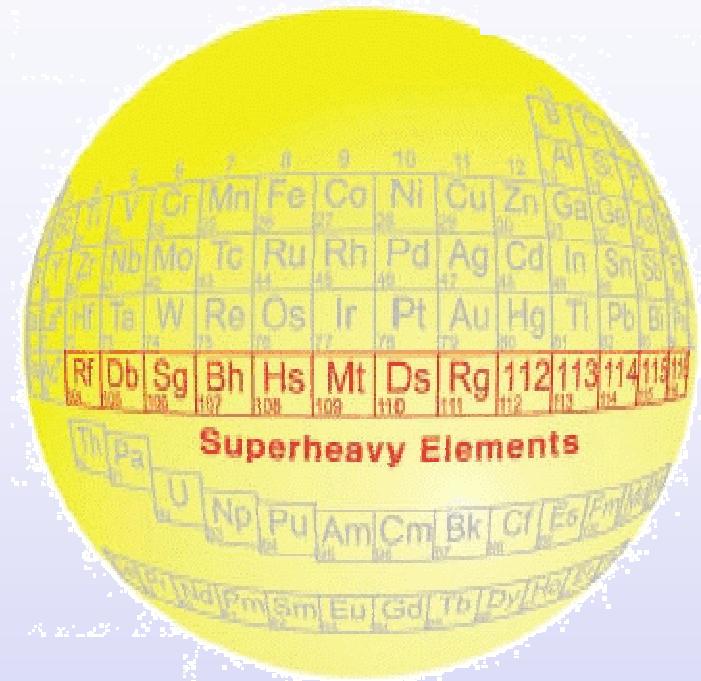
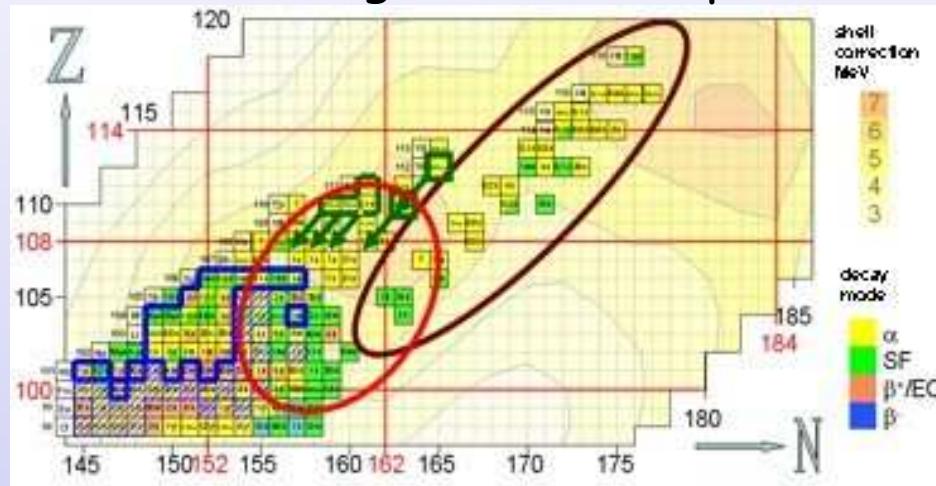


Mass Measurements of (S)HE

SHE: stabilized by shell effects

understanding fission barriers:

- > precise binding energies needed
- > contribution to fundamental knowledge of nuclear potential

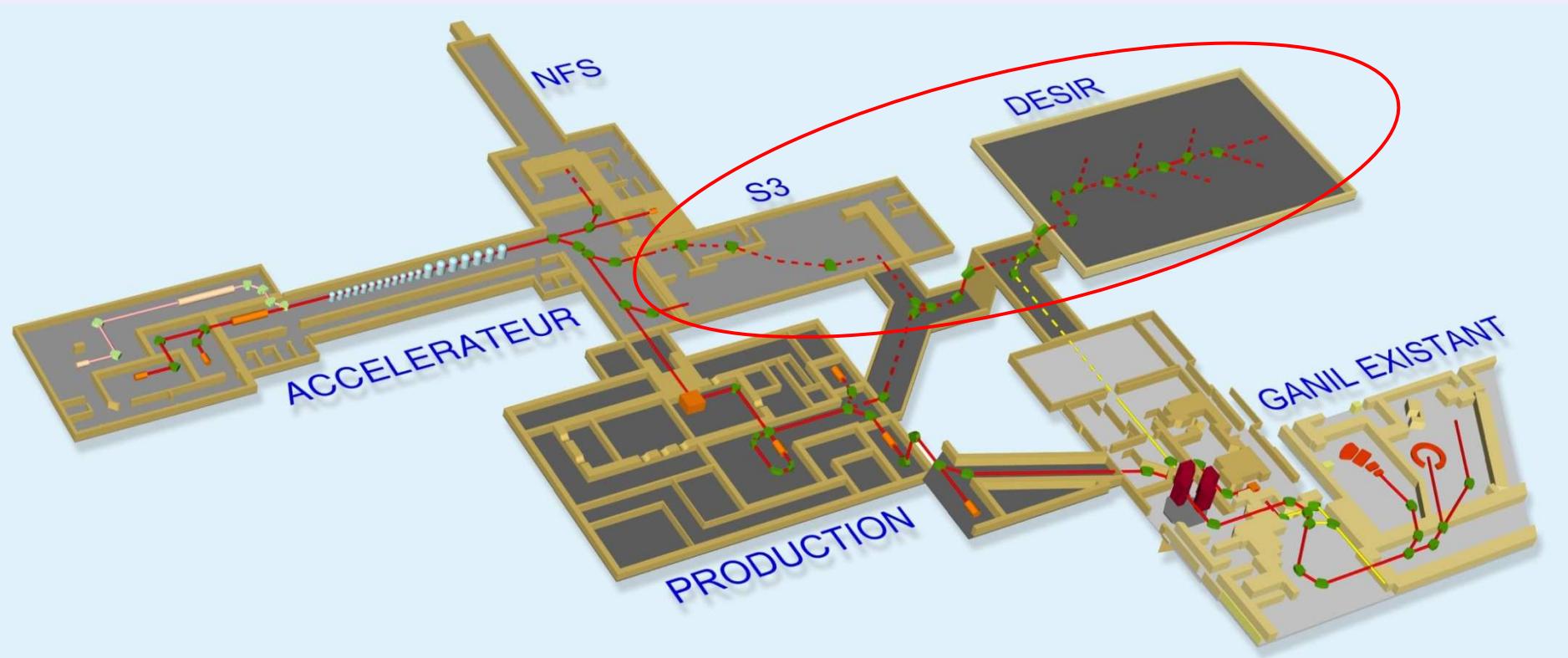


- so far: (S)HE masses from α decay chains to known masses
- odd nuclides: decay often to excited daughter levels
- direct mass measurements:
unambiguous data independent of nuclear level schemes

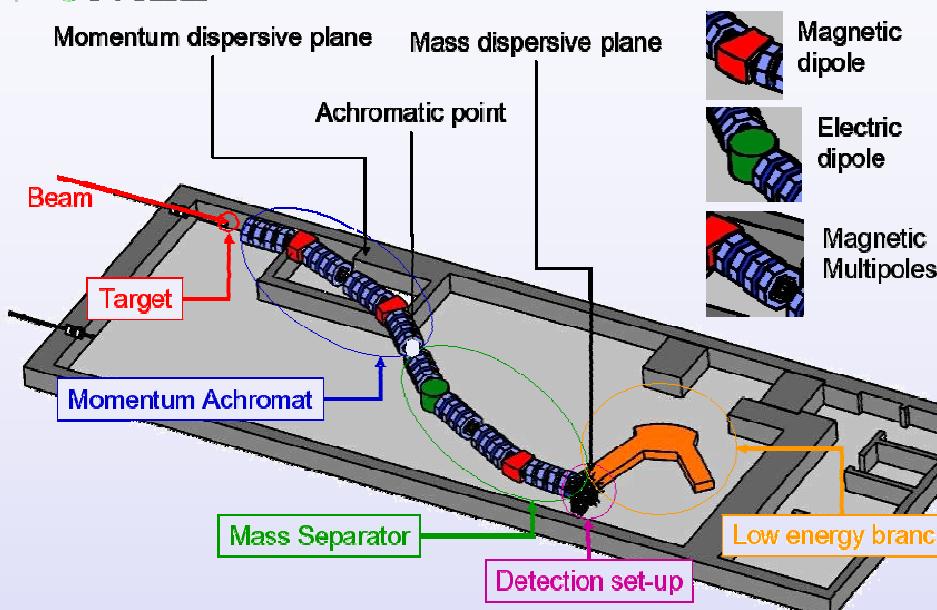
→ high precision Penning trap mass measurements

exploit synergies of S^3 and DESIR:

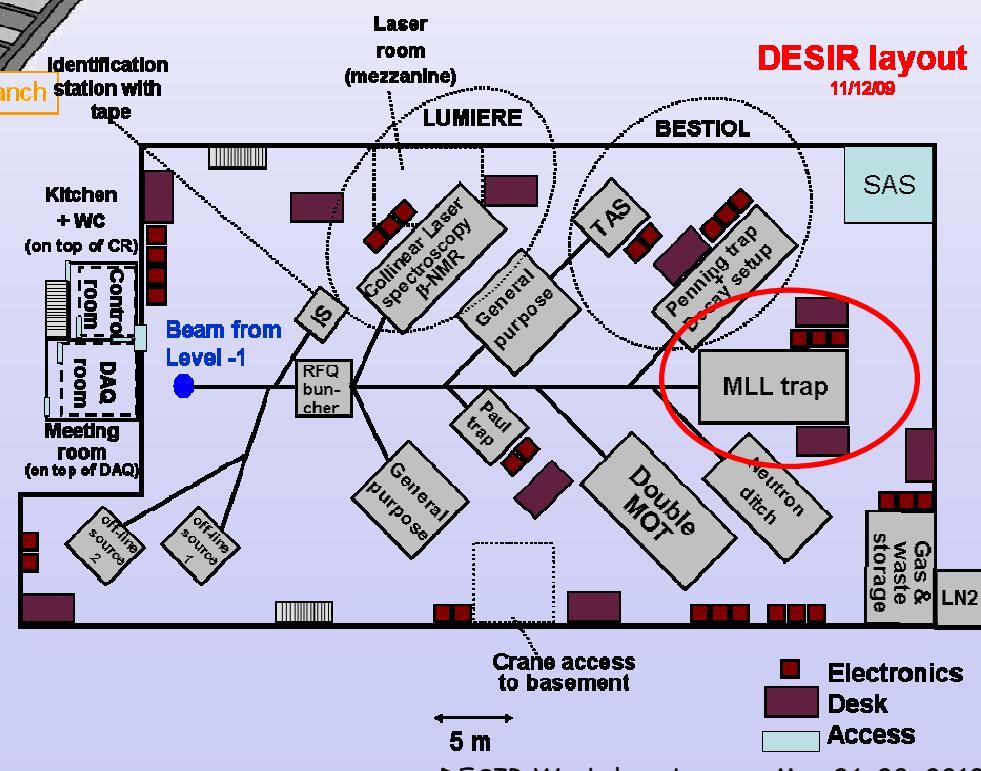
- high intensity stable primary beams
- highly efficient S^3 separator for fusion products
- experimental infrastructure at DESIR: mass measurements



Coupling between S³ and DESIR



transfer of mass separated heavy fusion products from S³ to DESIR



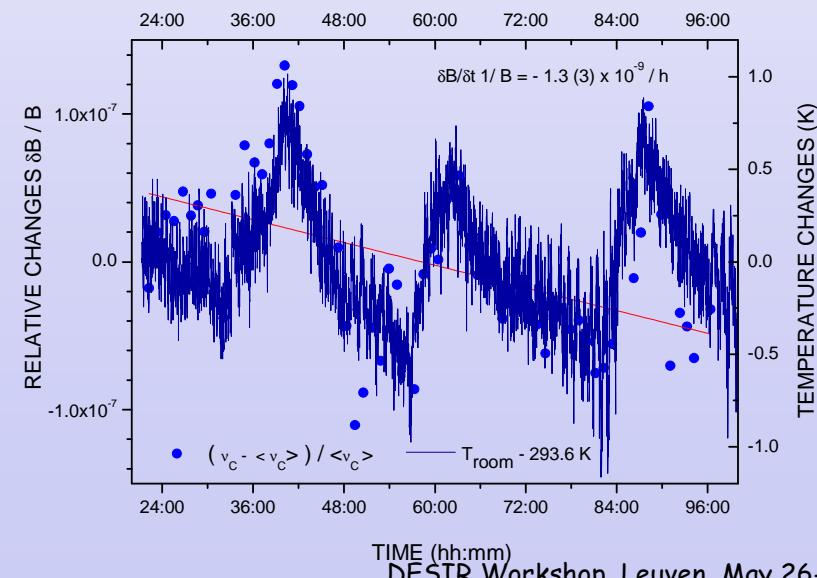
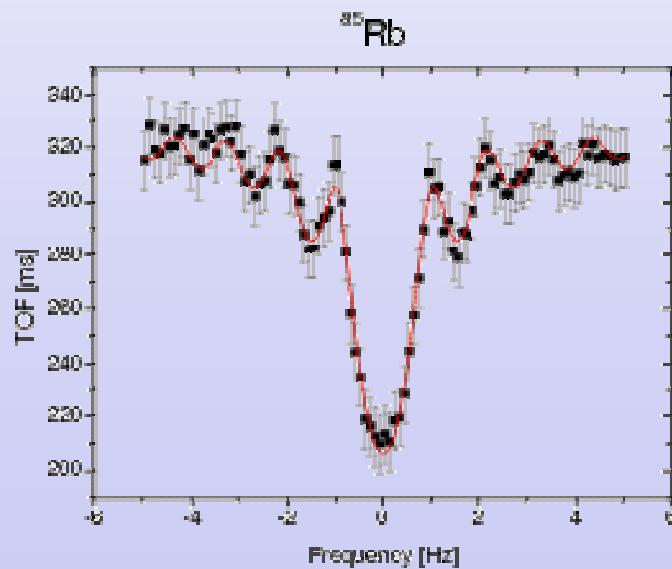
precision Penning trap mass measurements in MLLTRAP

Status of MLLTRAP

- 7T trap magnet, identical to SHIPTRAP, JYFLTRAP

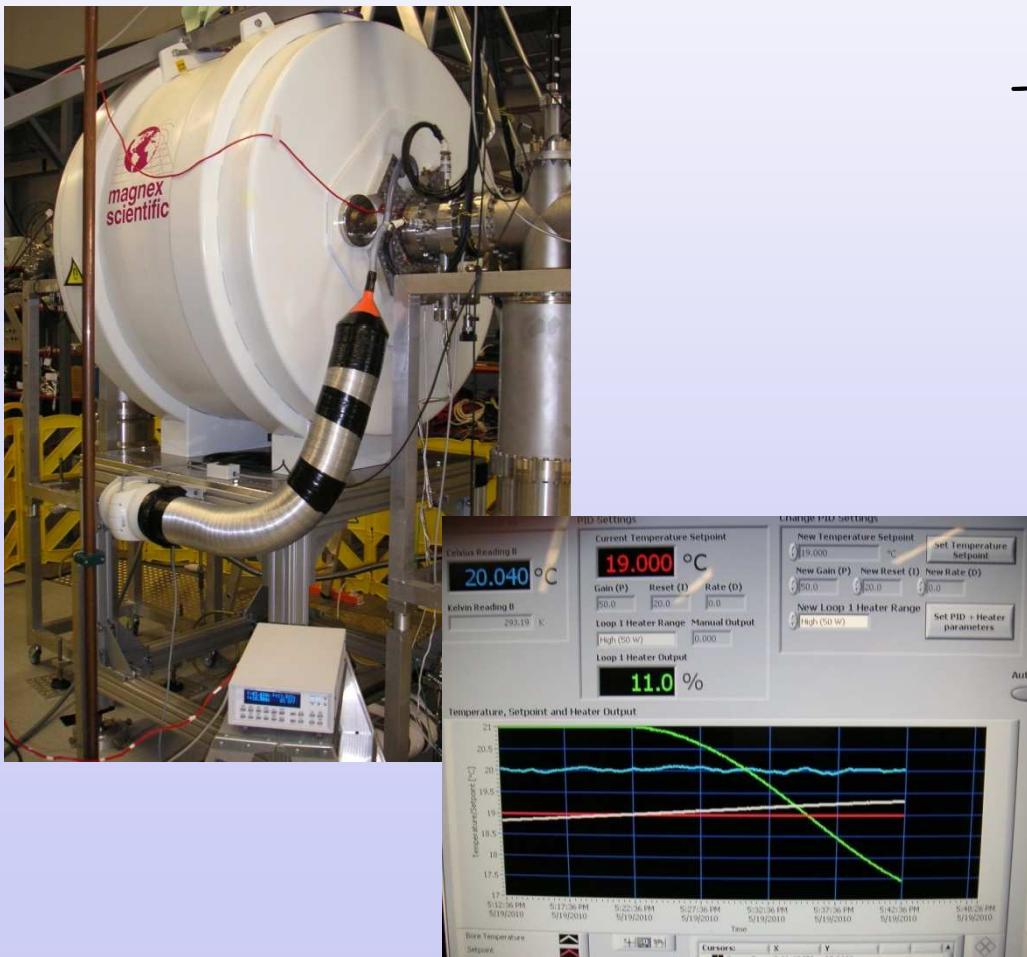
Status:

- operational with $\Delta m/m \sim 5 \cdot 10^{-8}$ (without systematic errors)
- systematic effects on B field studied



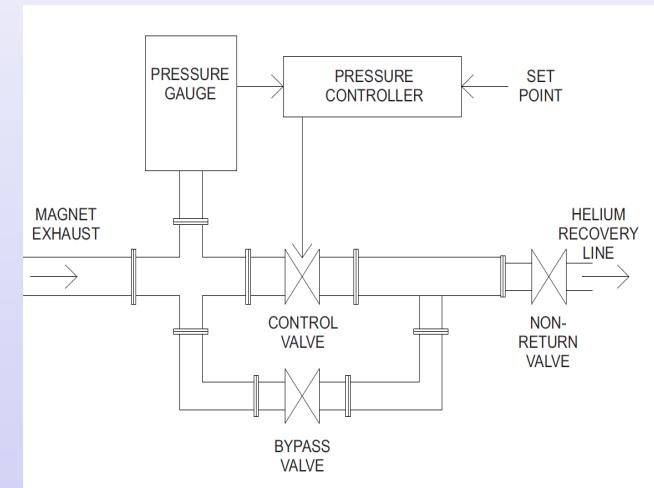
Temperature stabilization:

- blow warm air into magnet bore
- PID stabilization: goal $\approx \pm 10$ mK



Pressure stabilization:

- stabilize He reservoir pressure via controlled valve in helium exhaust line
- goal: ± 0.2 mbar



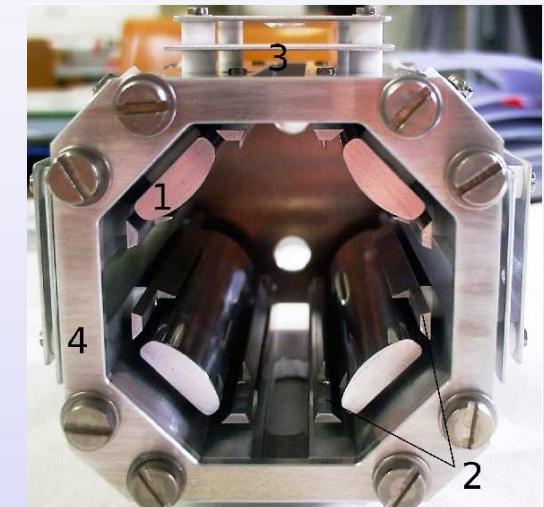
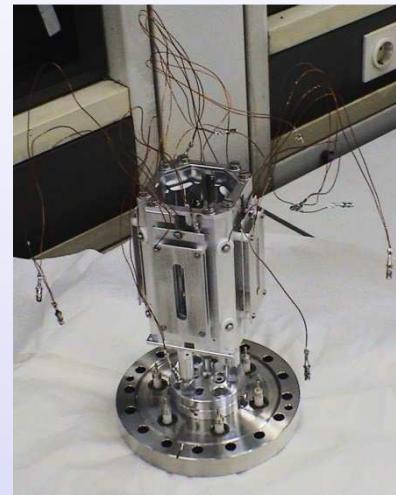
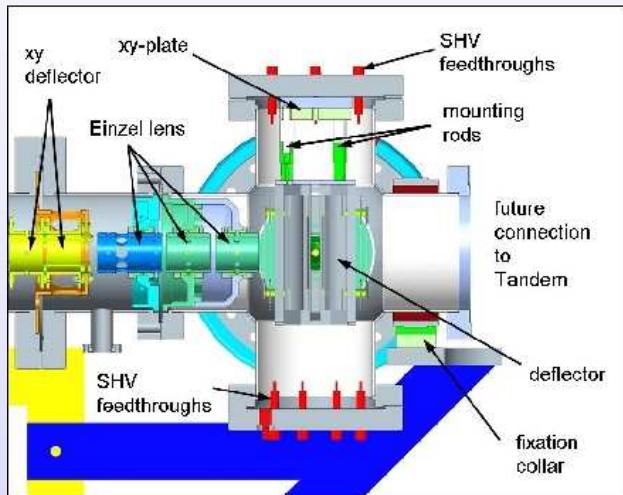
(work in progress)

diploma work: K. Krug (2010)

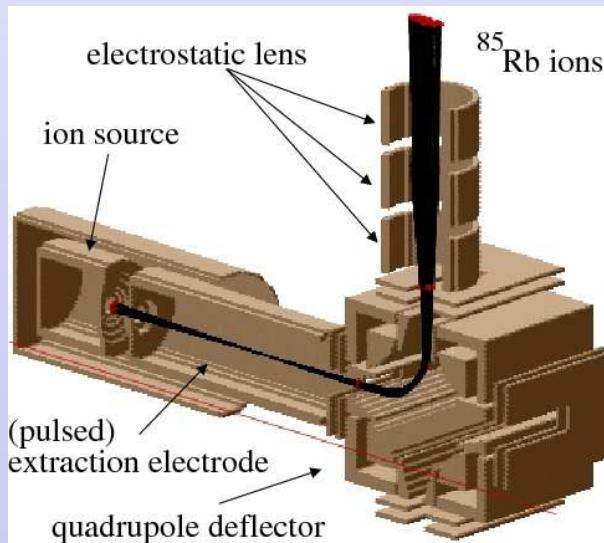
DESIR Workshop, Leuven, May 26-28, 2010

Quadrupole beam deflector

- electrostatic 4-way beam bender in injection line
- enables use of multiple ion sources



- ion trajectories (SIMION):



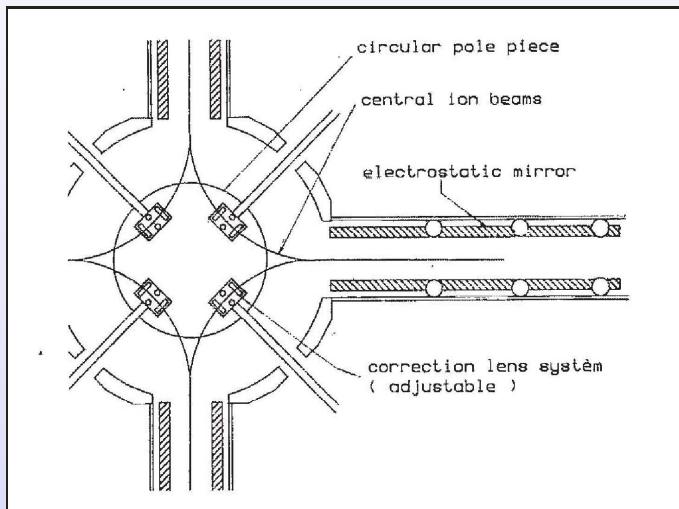
- measured transmission:
~ 80 %

diploma work: E. Gartzke (2009)

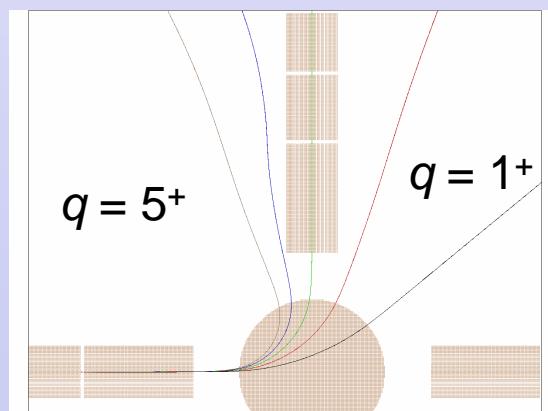
DESIR Workshop, Leuven, May 26-28, 2010

Multi-Passage Spectrometer (MPS)

prerequisite for future use of trap with highly charged ions:
q/A separator



SIMION studies (C. Weber):

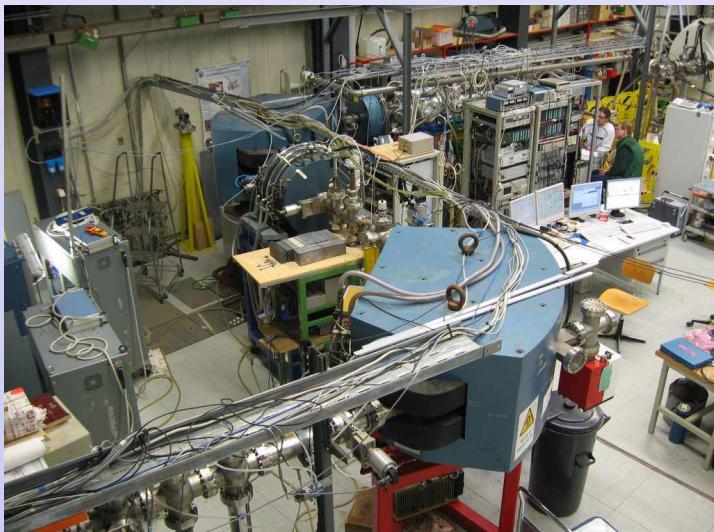


- fast cycling magnet: 0 - 1.2 T in 50 ms
(laminated yoke: 0.5 mm, SigmaPhi)
- round pole tip (diam. 250 mm)

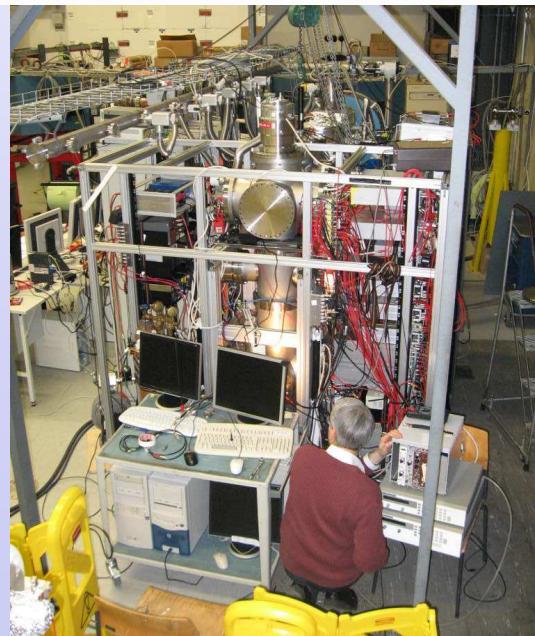
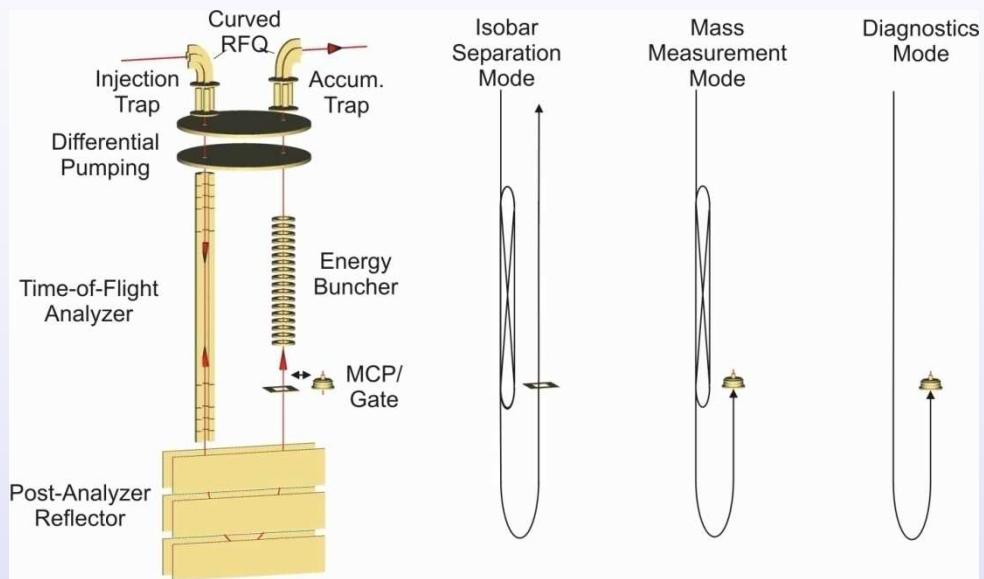
W. Plaß et al., Uni Giessen

- analyzer with 2 electrostatic reflectors
- length: ca. 0.5 m, short TOF: ~ 1 ms
- ca. 100 turns: $m/\Delta m > 10^5$ achievable
- efficiency > 50%
- setup in collaboration with Giessen team

beamtime march '09 at Garching:
prototype test of MR-TOF
 $\rightarrow m/\Delta m > 3 \times 10^5$



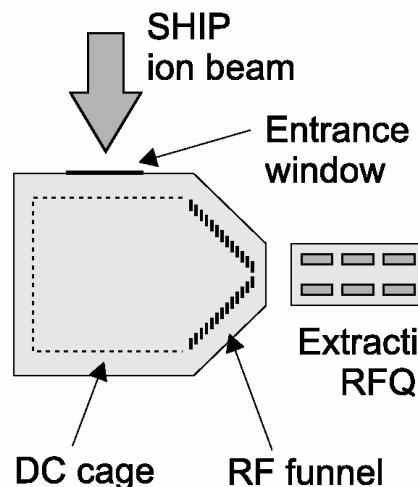
Peter G. Thirolf, LMU München



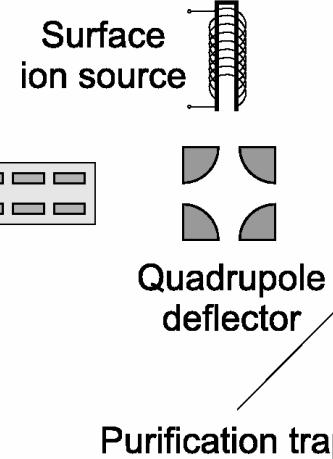
DESIR Workshop, Leuven, May 26-28, 2010

First direct Transuranium Mass Measurement: at SHIPTRAP

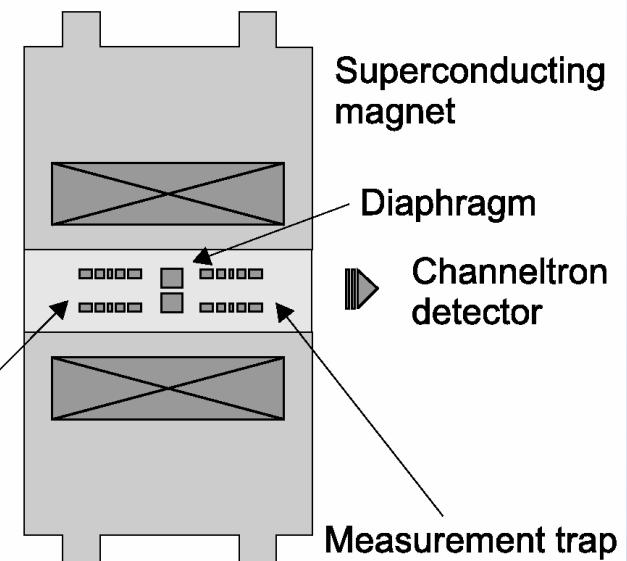
Gas Cell



Buncher



Penning Traps



252-254No Mass Measurements @ SHIPTRAP

➤ 206-208Pb(⁴⁸Ca,2n) 252-254No ($Z=102$):

- $E_{beam} = 4.55 \text{ MeV/u}$
- $E^* = 22 \text{ MeV}$
- $I_{beam} = 6 \cdot 10^{12} \text{ pps}$

isotope	$T_{1/2}(\text{gs})$	$T_{1/2}(\text{isomer})$	σ
²⁵⁴ No	2.44(4) s	110(10) ms	1.8 μb
²⁵³ No	1.62(15) min.	715(30) μs	1.0 μb
²⁵² No	51(10) s	266(2) ms	400 nb

→ production: ~ 1 atom/sec.

- $\varepsilon(\text{Shiptrap}) \sim 1-2\%$

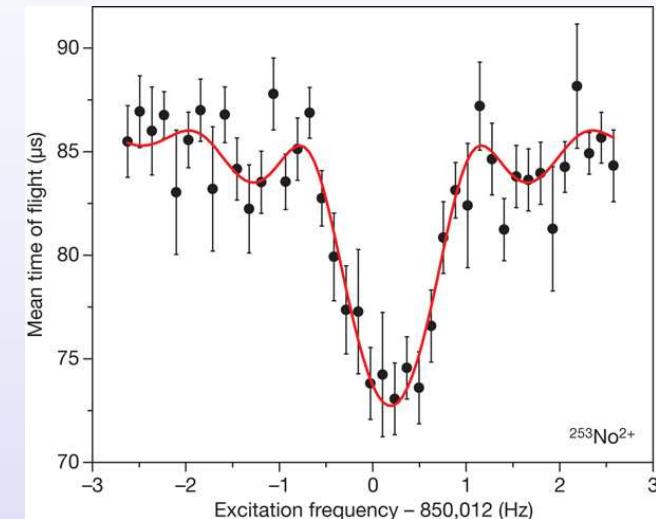
→ ca. 1 ion/min. detected behind trap

➤ present limit:

²⁵⁵Lr: ²⁰⁹Bi(⁴⁸Ca,2n) at 4.55 MeV/u:
 $\sigma \sim 200 \text{ nb}$

→ 0.3 ions/s detected in front of SHIPTRAP

→ ~ 10 ion/hour detected behind trap (May 2010)



accuracy:

$$\Delta m/m \sim 5 \cdot 10^{-8} - 10^{-7}$$

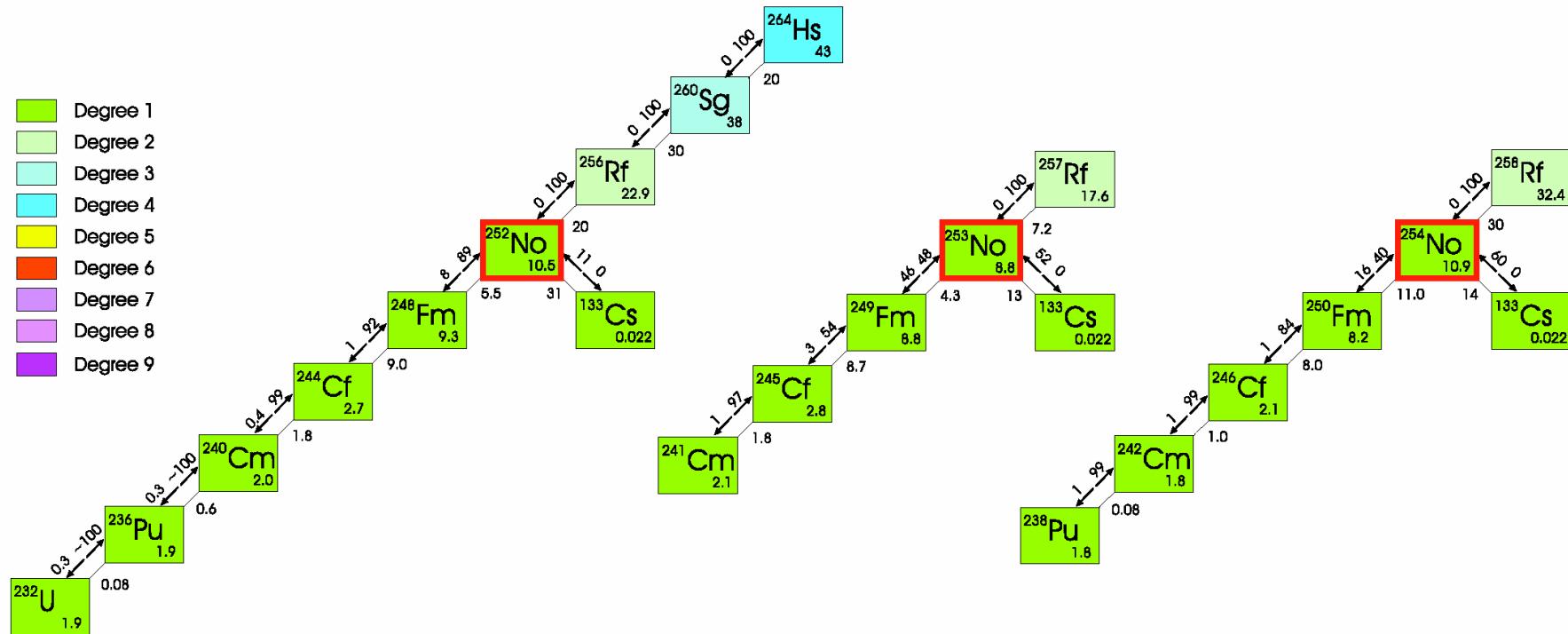
$$(\Delta m \sim 13-30 \text{ keV})$$

M. Block et al., Nature 463 (2010) 785

M. Dworschak et al., subm. to PRC

Updated Mass Evaluation

- before: No masses indirectly via Q_α values from decay spectroscopy
- new Nobelium masses: 'primary' nuclides in mass evaluation
- including new SHIPTRAP results:



Rf masses: ~ factor 2 less accurate than No

M. Dworschak et al., PRC in print

Candidates for measurements with $Z \geq 104$ @ MLLTRAP

➤ Sg-isotopes ($Z=106$):

K. Gregorich et al. (PRC 2006):

$$^{238}\text{U}({}^{30}\text{Si}, xn)^{268-x}\text{Sg} : 10 - 40 \text{ pb}$$

B. Streicher et al. (2007):

$$^{208}\text{Pb}({}^{54}\text{Cr}, 1n)^{261}\text{Sg} : 2.0(1) \text{ nb}$$

➤ Db, Rf isotopes ($Z=105, 104$):

i) Nagame et al. (JNRS 2002):

$$^{248}\text{Cm}({}^{18}\text{O}, 5n)^{261}\text{Rf} \text{ (94 MeV)}: 13(3) \text{ nb}$$

$$^{248}\text{Cm}({}^{19}\text{F}, 5n)^{262}\text{Db} \text{ (106 MeV)}: 1.3(4) \text{ nb}$$

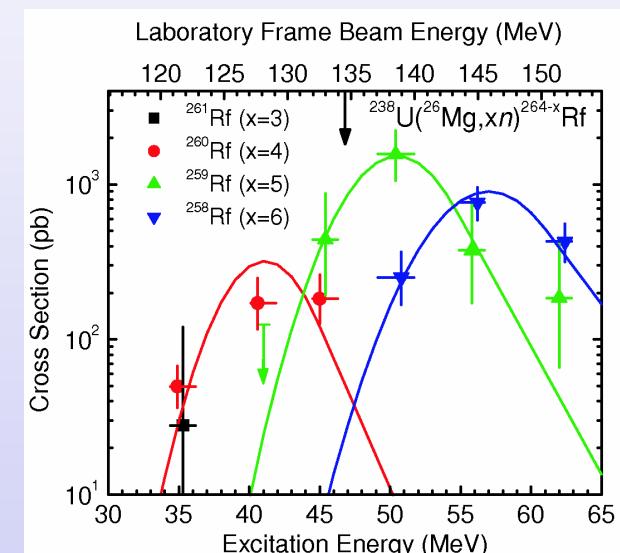
ii) Gates et al. (PRC 2008)

$$^{238}\text{U}({}^{26}\text{Mg}, 3n)^{261}\text{Rf} : \sim 28 \text{ pb}$$

$$^{238}\text{U}({}^{26}\text{Mg}, 4n)^{260}\text{Rf} : 180(80) \text{ pb} \quad (133.0 \text{ MeV})$$

$$^{238}\text{U}({}^{26}\text{Mg}, 5n)^{259}\text{Rf} : 1.56(50) \text{ nb} \quad (138.5 \text{ MeV})$$

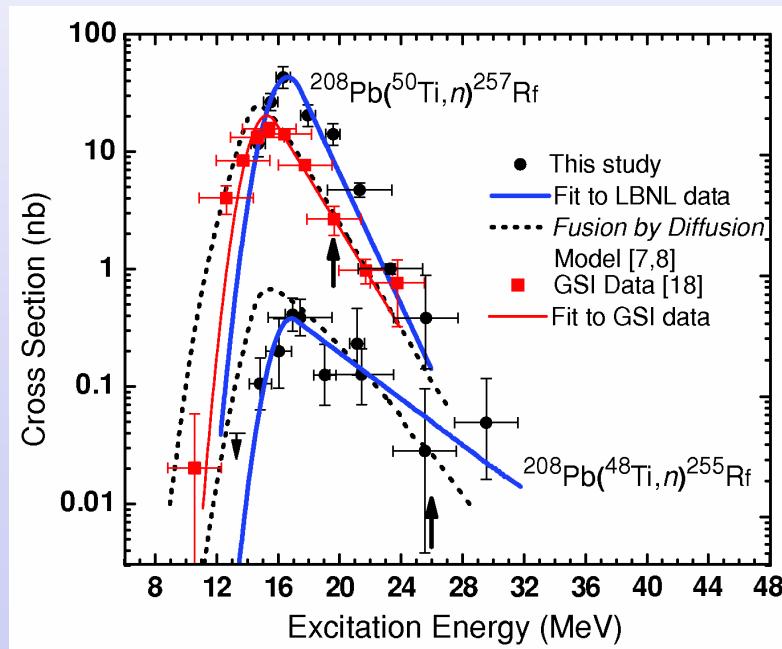
$$^{238}\text{U}({}^{26}\text{Mg}, 6n)^{258}\text{Rf} : 0.77(20) \text{ nb} \quad (144.5 \text{ MeV})$$



Production of Light Rf Isotopes

iii) Dragojevic et al. (PRC 2008):

$$\begin{array}{lll} {}^{208}\text{Pb}(^{50}\text{Ti}, 2n) {}^{256}\text{Rf} : & 15.7(2) \text{ nb} & (E_{\text{beam}} = 239.0 \text{ MeV}) \\ \longrightarrow \quad {}^{208}\text{Pb}(^{50}\text{Ti}, 1n) {}^{257}\text{Rf} : & 43(10) \text{ nb} & (230.5 \text{ MeV}) \end{array}$$



crucial:
optimized target thickness

Candidates: Rf isotopes ($Z=104$)

➤ ^{257}Rf :

reaction : $^{50}\text{Ti} + ^{208}\text{Pb}$ (40 nb)

- S^3 transmission : 50-60%
- target: PbS (for high beam intensity)
- gas cell efficiency: ~ 10%-30%
- drawback : ^{50}Ti beam needs development (expected: 1-10 p μA)

➤ ^{259}Rf :

reaction : $^{26}\text{Mg} + ^{238}\text{U}$ (1.5 nb)

- S^3 transmission: ~ 15%
- target: UO_2 (will be tested)
- ^{26}Mg : high intensity (>10 p μA), available in 2013

→ clear preference for ^{257}Rf (via ^{50}Ti reaction)

Candidate: ^{257}Rf

		149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	
		Neutron number																	
Proton number	106	Rf253 48 ns	Rf254 2.3 ns	Rf255 1.8 s	Rf256 6.2 ms	Rf257 47 s	Rf258 14 ms	Rf259 3.1 s	Rf260 20 ms	Rf261 78/4.2 s	Rf262 4.7/2.1 ms	Rf263 15 m			Rf266 1.3 h	Rf267 1.3 h	Rf268 1.3 h		
	105	Db256 1.5 s	Db257 0.5/1.5 s	Db258 4.4 s	Db259 4.5 s	Db260 1.5 s	Db261 1.8 s								Db266 22 m	Db267 1.2 h	Db268 29 h		
	104 Rf	Lr252 0.4 s	Lr253 15/0.6 s	Lr254 13 s	Lr255 24.5 s	Lr256 25.9 s	Lr257 0.65 s	Lr258 3.9 s	Lr259 6.3 s	Lr260 3 m	Lr261 39 m	Lr262 3.6 h							
	103 Lr	No251 0.78 s	No252 2.3 s	No253 1.7 m	No254 12/55 s	No255 3.1 m	No256 2.91 s	No257 26 s	No258 1.2 ms	No259 58 m	No260 108 ms	No262 5 ms							
	102 No	Md250 52 s	Md251 4.0 m	Md252 2.3 m	Md253 6 m	Md254 70/20 m	Md255 27 m	Md256 1.30 h	Md257 5.52 h	Md258 57/51 d	Md259 95 m	Md260 31.8 d							
	101 Md	Fm249 2.6 m	Fm250 1.8/30 s	Fm251 5.3 h	Fm252 25.4 h	Fm253 3.0 d	Fm254 3.24 h	Fm255 20.1 h	Fm256 70/2.83 ms	Fm257 100 d	Fm258 0.38 ms	Fm259 1.5 s							
	99 Es	Es248 27 m	Es249 1.70 h	Es250 2.2/3.6 h	Es251 33 h	Es252 472 d	Es253 20.5 d	Es254 30/276 h	Es255 39.8 d	Es256 7.8/25.4 h									
	98 Cf	Cf247 3.11 h	Cf248 333 d	Cf249 351 a	Cf250 13.1 a	Cf251 898 a	Cf252 2.84 a	Cf253 17.8 d	Cf254 60.5 d	Cf255 1.4 h	Cf256 12.3 m								
	108	Ds264 11.8 ms			Hs265 0.8/1.7 ms	Hs266 2.3 ms	Hs267 59 ms			Hs269 9.7 s	Hs270 ~30 s	Hs271 ~10 s				Hs275 0.19 s			
	109	Mt266 1.7 ms			Mt268 42 ms		Mt270 5.0 ms								Mt274 0.44 s	Mt275 9.7 s	Mt276 0.72 s		
	110	Ds			Ds267 3.1 ms		Ds269 170 μ s	Ds270 100/5.0 μ s	Ds271 1.1/58 ms		Ds273 0.17 ms							Ds279 0.20 s	Ds281 11.1 s
	111	Rg					Rg272 1.6 ms		Rg274 6.4 ms						Rg278 4.2 ms	Rg279 0.17 s	Rg280 3.6 s		

SHIPTRAP:

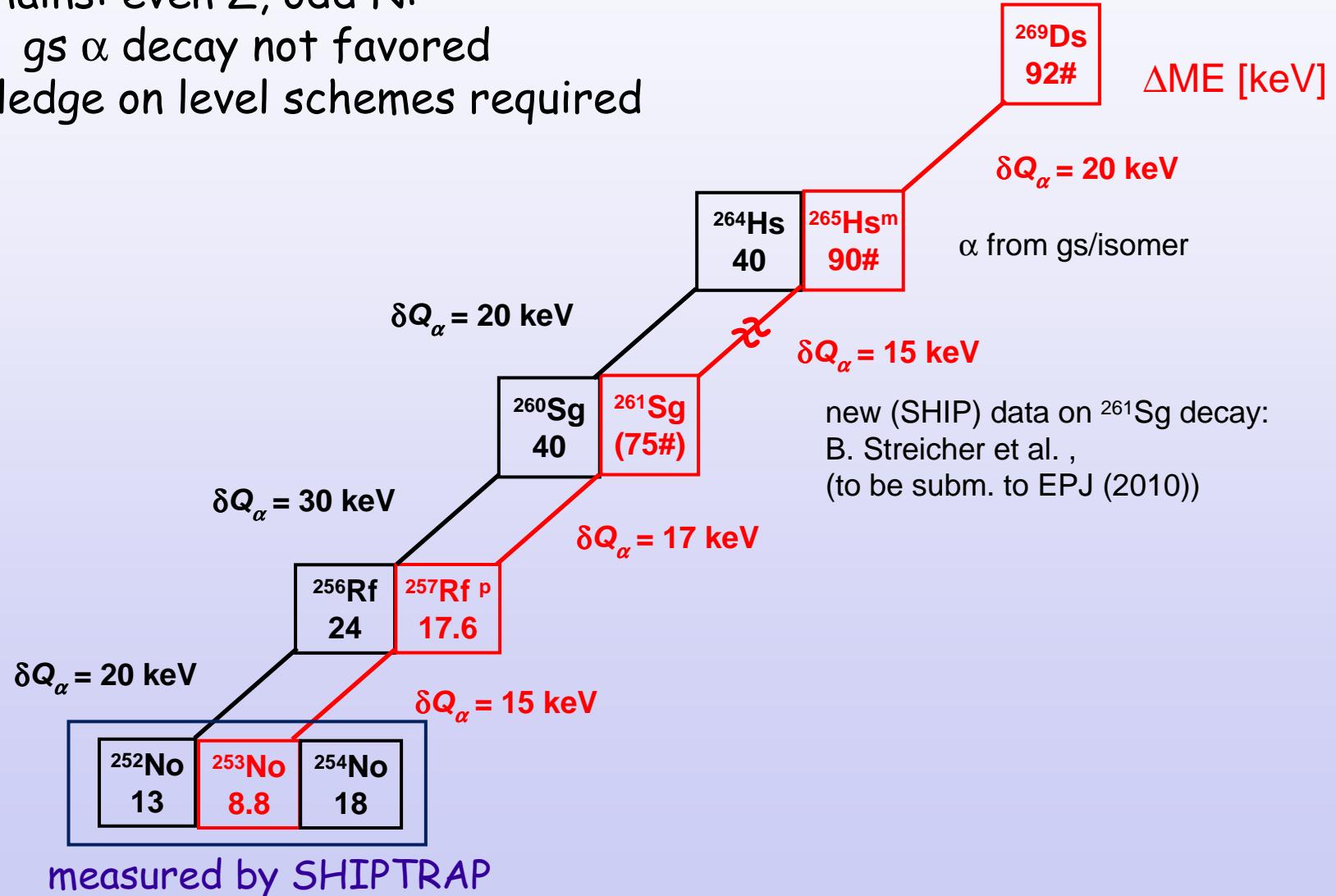
2010 : ^{255}Lr

$^{255}\text{No}, ^{256}\text{Lr} : \sim 100 \text{ nb}$

^{257}Rf : connecting α decay chains

decay chains: even Z , odd N :

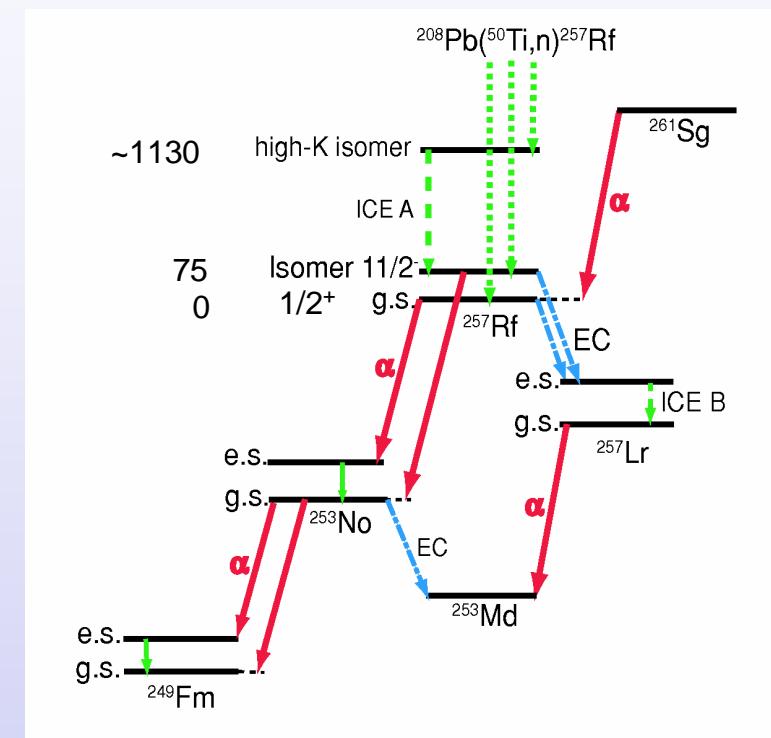
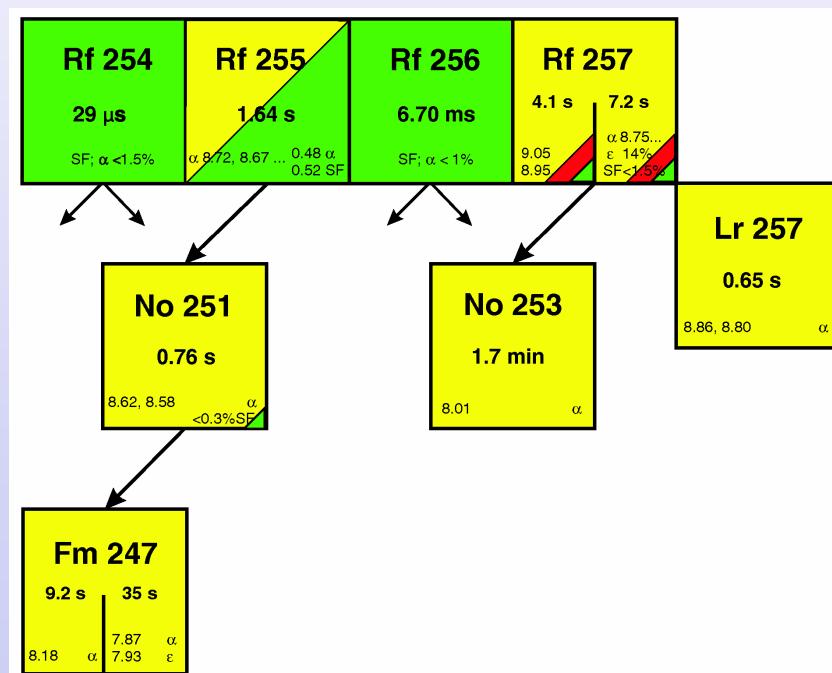
- gs \rightarrow gs α decay not favored
- knowledge on level schemes required



Decay Properties of ^{257}Rf

Qian et al. (PRC 2009):

- isomer in ^{257}Rf : $160(40)\ \mu\text{s}$
 $(t_{1/2}(^{257}\text{Rf}) \geq 4.1\ \text{s})$



Yield Considerations

Example: (from: P. Greenlees et al., S³ LoI 2009)

target: ^{238}U , 0.25mg/cm²

S³ transmission: 30%

primary beam intensity: 10 p μ A

α decay events detected at focal plane ($\varepsilon=0.55$):

10 nb \rightarrow 23460 events/week detected

\rightarrow ~ 43000 events/week at focal plane

^{257}Rf : - S³ transmission: $\varepsilon \sim 0.5$

- gas cell stopping: $\varepsilon \sim 0.3$

- 40 nb: $\sim 84000/\text{week}$ after gas cell

\rightarrow assume transport/bunching efficiency $\sim 15\%$

$\rightarrow 10000/\text{week}$ at trap : **$\sim 1/\text{min. at trap}$**

transport efficiency to MLLTRAP to be studied

Conclusion

- coupling between S³ and DESIR can be exploited for program on precise nuclear mass measurements of heavy elements
- high primary beam intensities, large separator efficiency: isotopes with Z≈104 within reach for Penning trap studies using MLLTRAP@DESIR
- candidate: ²⁵⁷Rf ($\sigma_{\max} \sim 40$ nb)
- staged approach:
 - day-1: commissioning with known Nobelium isotopes:
 $^{206-208}\text{Pb}(^{48}\text{Ca}, 2n)^{252-254}\text{No}$: 0.4- 1.8 μb
 - beam development: ⁵⁰Ti
 - day-2: $^{208}\text{Pb}(^{50}\text{Ti}, 1n)^{257}\text{Rf}$: ~ 40 nb

Thanks to ...



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Timo Dickel

Wolfgang Plaß

Martin Petrick