Toward element 117

1) $^{48}Ca + ^{244}Pu \rightarrow ^{288}114 + 4n$

2) Element 117 search @ TASCA

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for upcoming *TASCA-117* collaboration

Presented on the 7th workshop on Recoil Separator for Superheavy Element Chemistry *TASCA 08*, October 31, 2008, GSI Darmstadt, Germany

The *TASCA-117* Collaboration

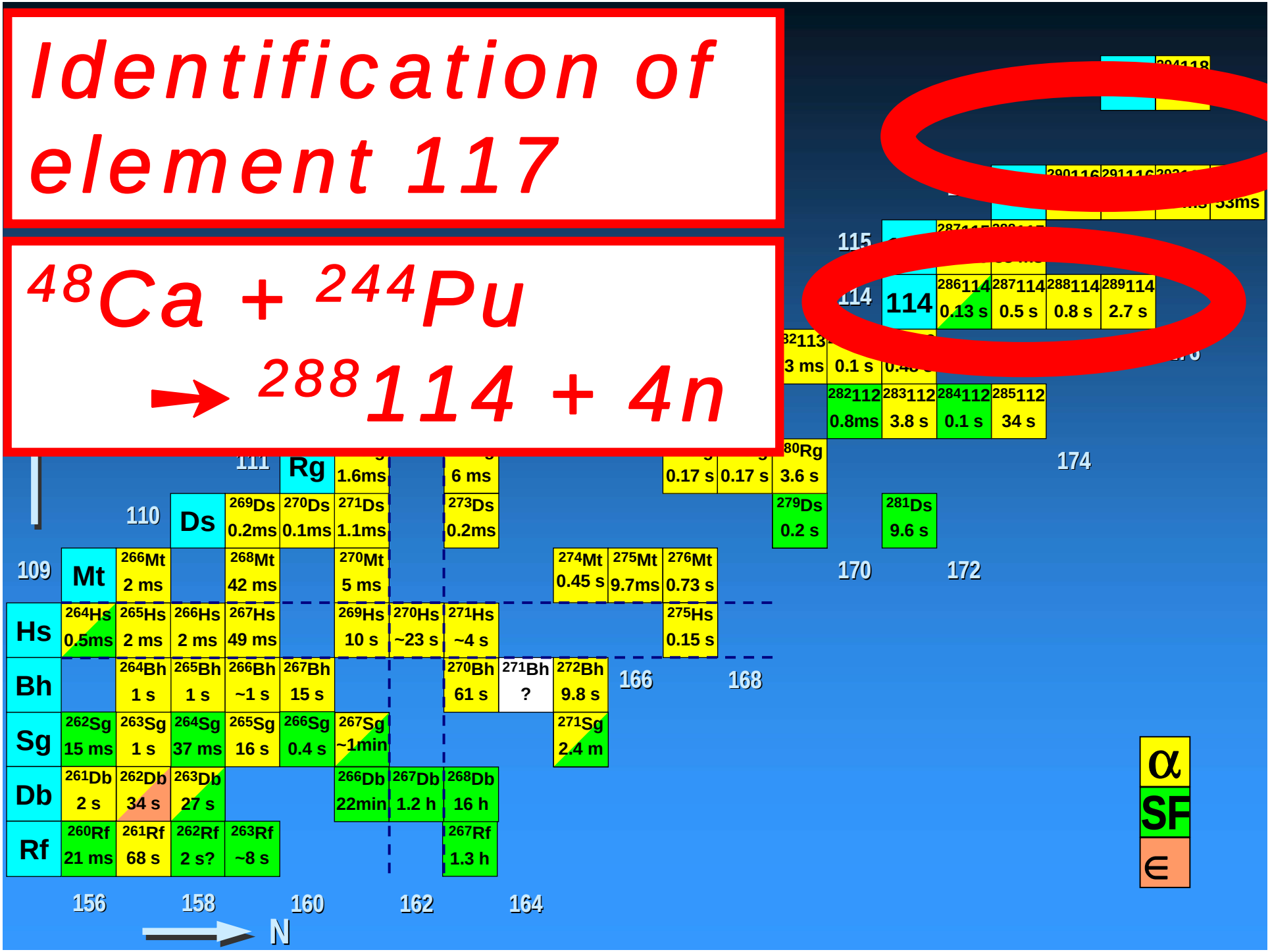
The Periodic Table

1												13	14	15	16	17	18
1 H	2																2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	3	4	5	6	7	8	9	10	11	12	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57+* La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84		86
87 Fr	88 Ra	89+" Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 ---	113 ---	114 ---	115 ---	116 --		1 -

*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	7 Yb	Lu
"	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Identification of element 117

$^{48}Ca + {}^{244}Pu \rightarrow {}^{288}114 + 4n$



SHE @ *TASCA*: What is needed?

Beam

Target

Magnet settings

Fill gas

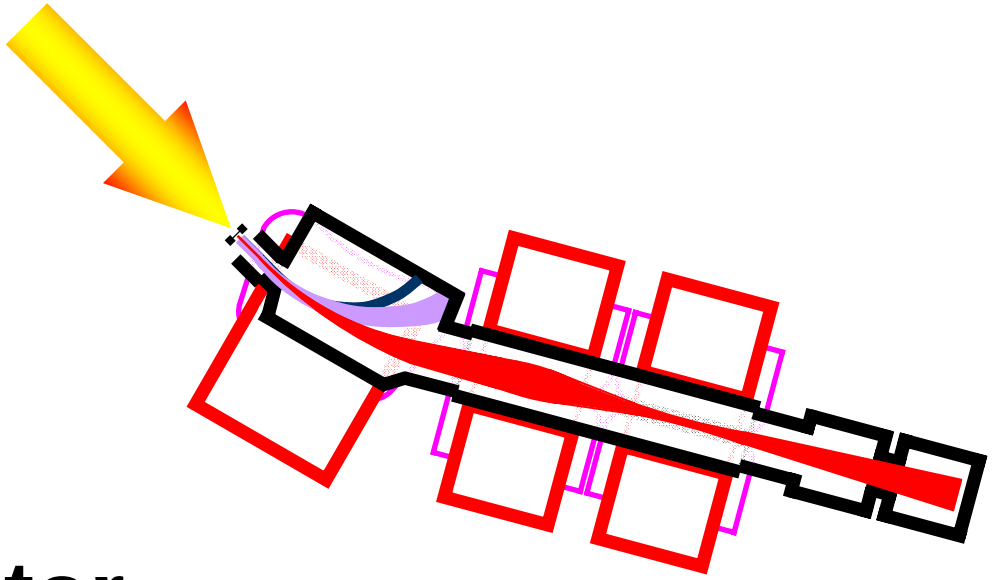
Recoil veto detector

Focal plane detector

DAQ

Beamtime / Proposal

Manpower



Step 1:
^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114

Step 2:
Element 117 search

Step 1

$^{244}Pu(^{48}Ca,xn)^{292-x}114$

^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114 @ *TASCA*: What is needed?

Beam ^{48}Ca ✓

Target

Magnet settings

Fill gas

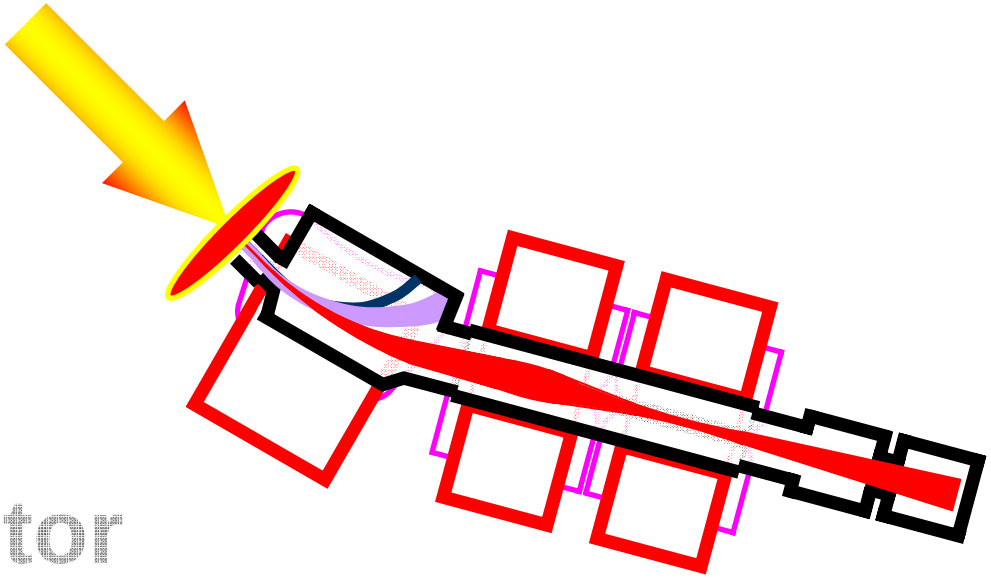
Recoil veto detector

Focal plane detector

DAQ

Beamtime / Proposal

Manpower



^{244}Pu target (~380 μg/cm^2)

History of this target:

-Produced in Mainz in summer 2008

-14-day ^{22}Ne irradiation for study of ^{244}Pu(^{22}Ne,x*n*)$^{266-x}$Rf

Intensity ~800 nA$_p$

-21-h ^{48}Ca irradiation to test target stability and background in TASCA (some main beam ~400 nA$_p$)

-Analysis of the target @ GSI

The target remained unchanged!

^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114 @ *TASCA*: What is needed?

Beam ^{48}Ca ✓

Target ^{244}Pu ✓

Magnet settings

Fill gas

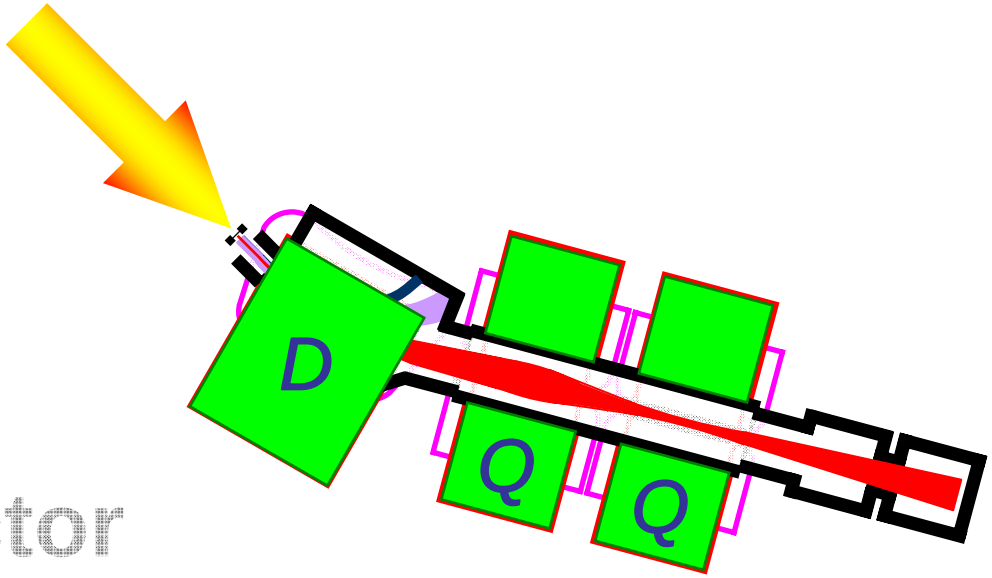
Recoil veto detector

Focal plane detector

DAQ

Beamtime / Proposal

Manpower



Deflection of ions TASCA governed by B·ρ

$$B\rho\,[T\cdot m] = \frac{m\cdot v}{\overline{q}\cdot e}$$

TASCA **example:**

$^{48}Ca+^{208}Pb$ in He

$B\cdot\rho_{pred} = 2.09$ T·m

$B\cdot\rho_{exp} = 2.08$ T·m

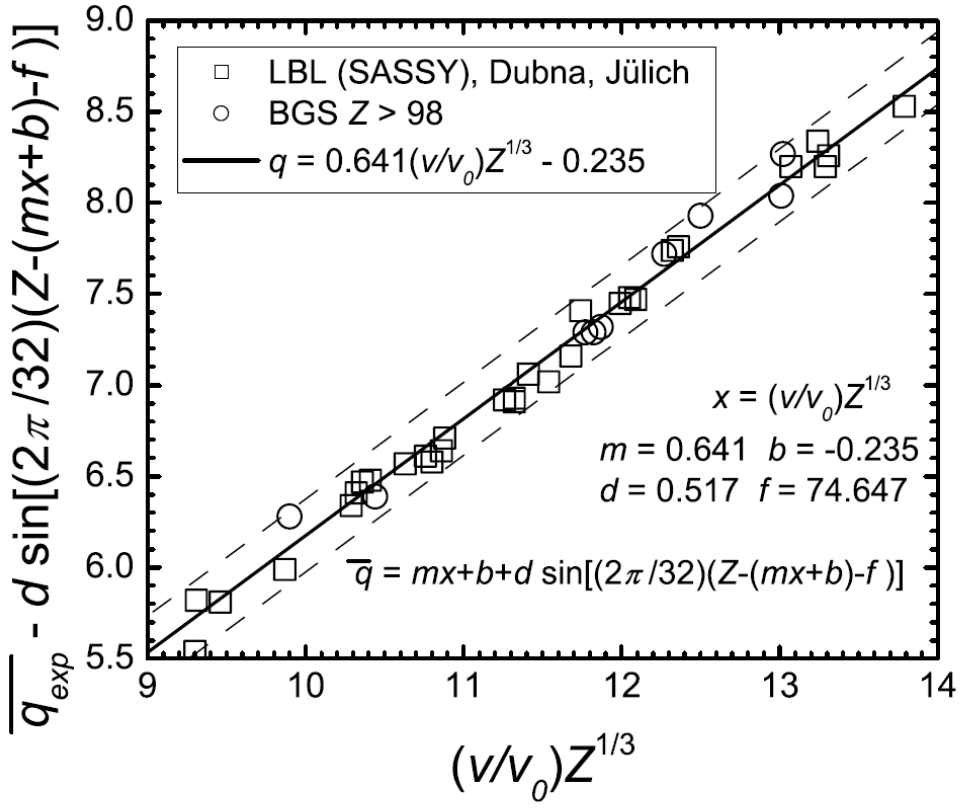


FIG. 1. Average charges of heavy ions passing through dilute He gas.

K.E. Gregorich et al., PRC 72 (2005) 014605

Based on FLNR Data, H_2 coefficients determined and tested at TASCA. Works, also for mixtures

^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114 @ *TASCA*: What is needed?

Beam ^{48}Ca ✓

Target ^{244}Pu ✓

Magnet settings

Fill gas

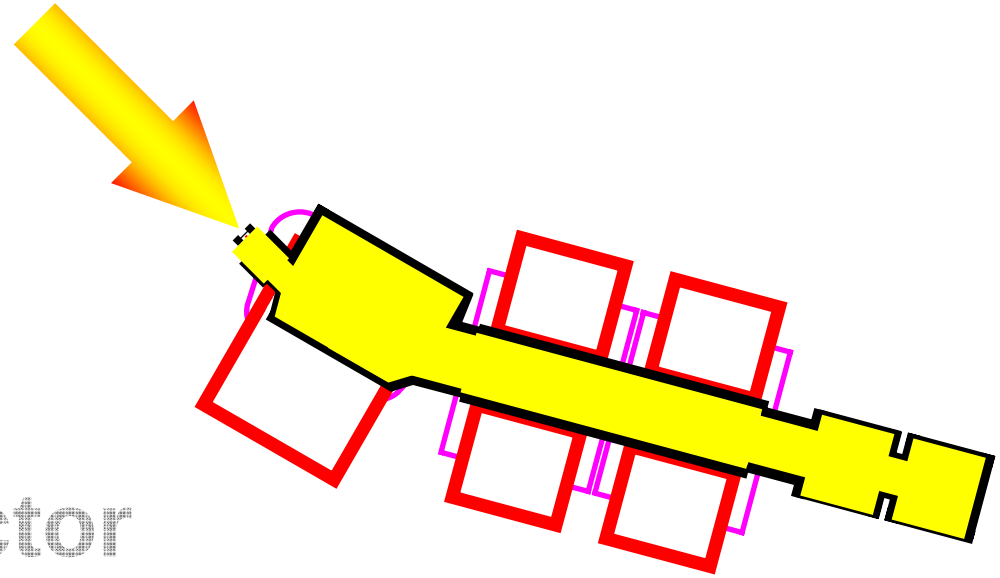
Recoil veto detector

Focal plane detector

DAQ

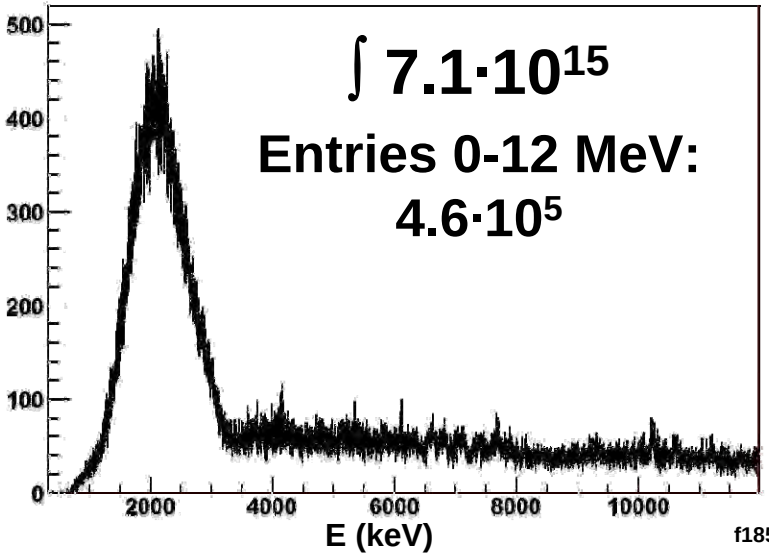
Beamtime / Proposal

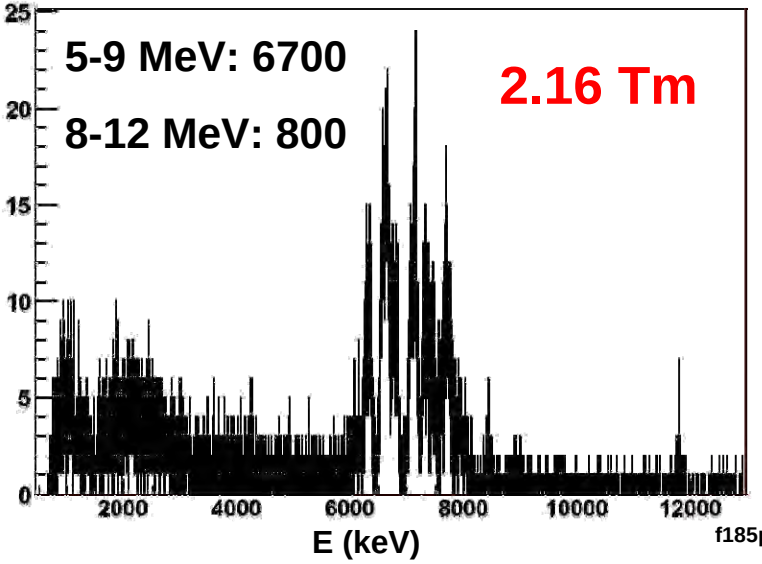
Manpower



$^{48}Ca + ^{244}Pu$ Background (1-hr runs)

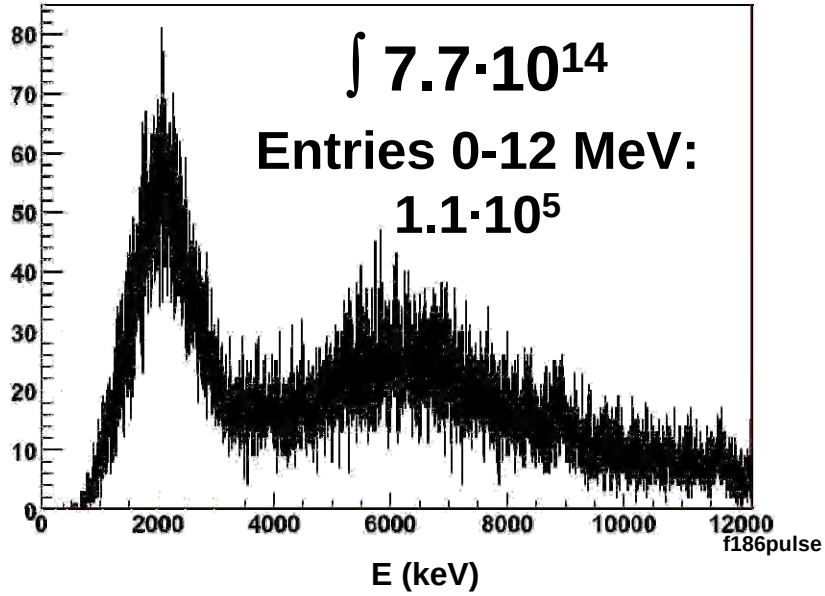
Pure He

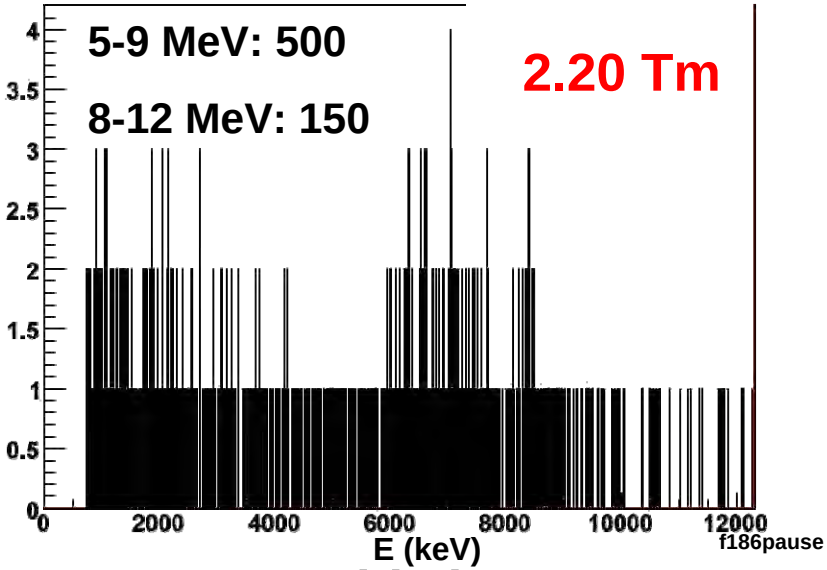




Main beam

He : H_2 mixture 2 : 1





Parasitic beam

^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114 @ *TASCA*: What is needed?

Beam ^{48}Ca ✓

Target ^{244}Pu ✓

Magnet settings

Fill gas

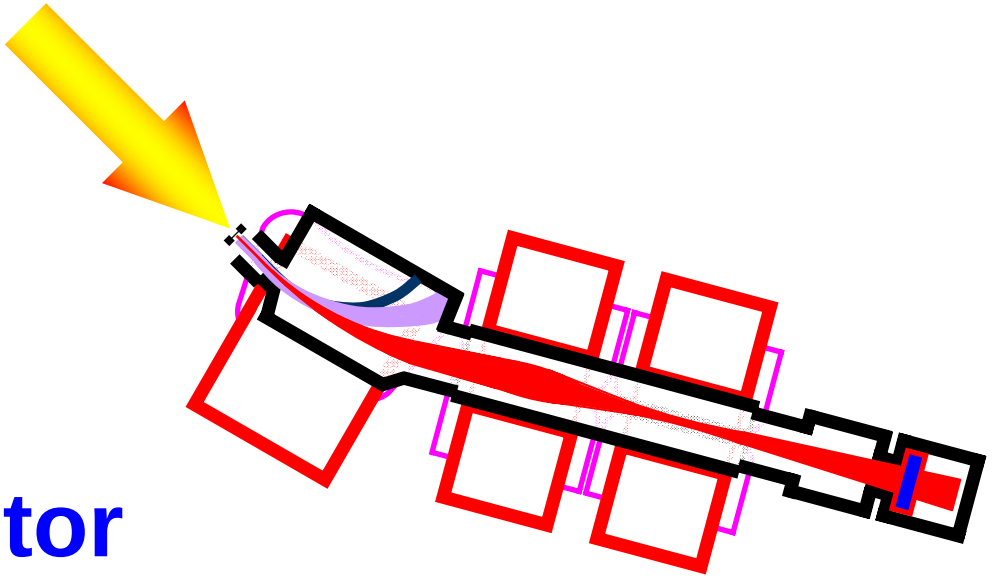
Recoil veto detector

Focal plane detector

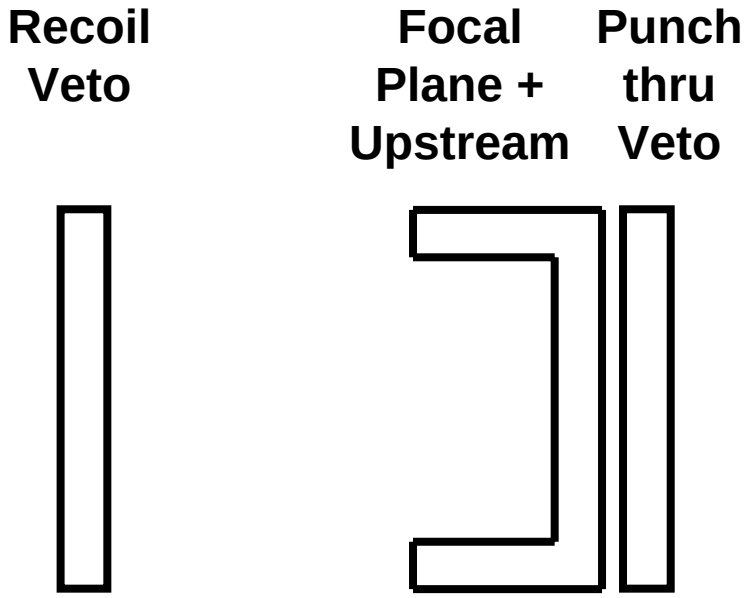
DAQ

Beamtime / Proposal

Manpower



Planned TASCA Detection System



Efficiency for **α-particles** **$\geq$ 72%**

SF **~100%**

Punchthrough for slow, low-ionizing particles

Recoil Veto Detector

-LBNL builds advanced MWPC prototype, will be tested in Dec. 2008

-LBNL agreed to adapt design + to build a copy matching TASCA FPD dimensions, respecting test results

Anticipated timeline:

Design:	Dec. 2008
Production:	Jan. 2009
Ready to implement:	Feb. 2009

^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114 @ *TASCA*: What is needed?

Beam ^{48}Ca ✓

Target ^{244}Pu ✓

Magnet settings

Fill gas

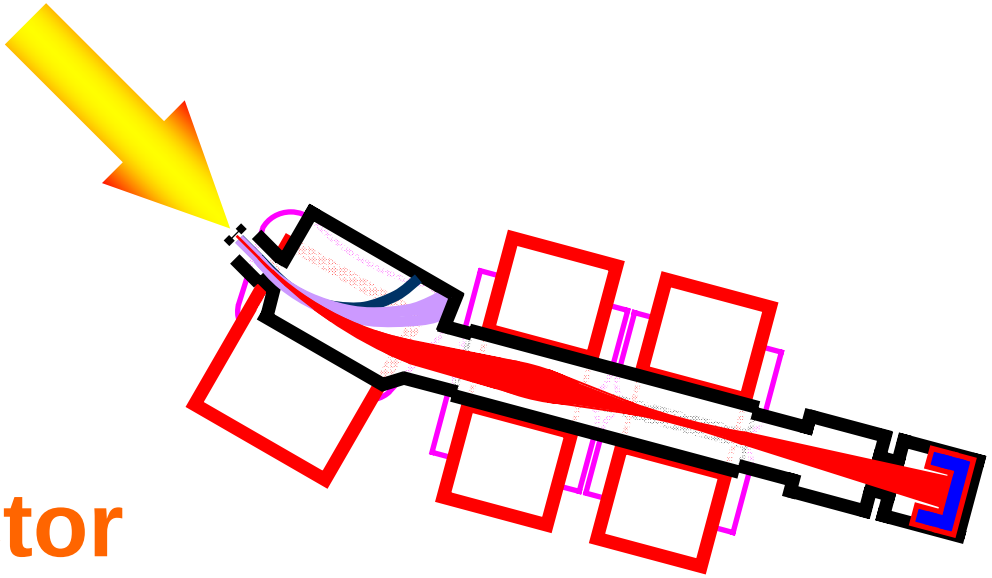
Recoil veto detector

Focal plane detector

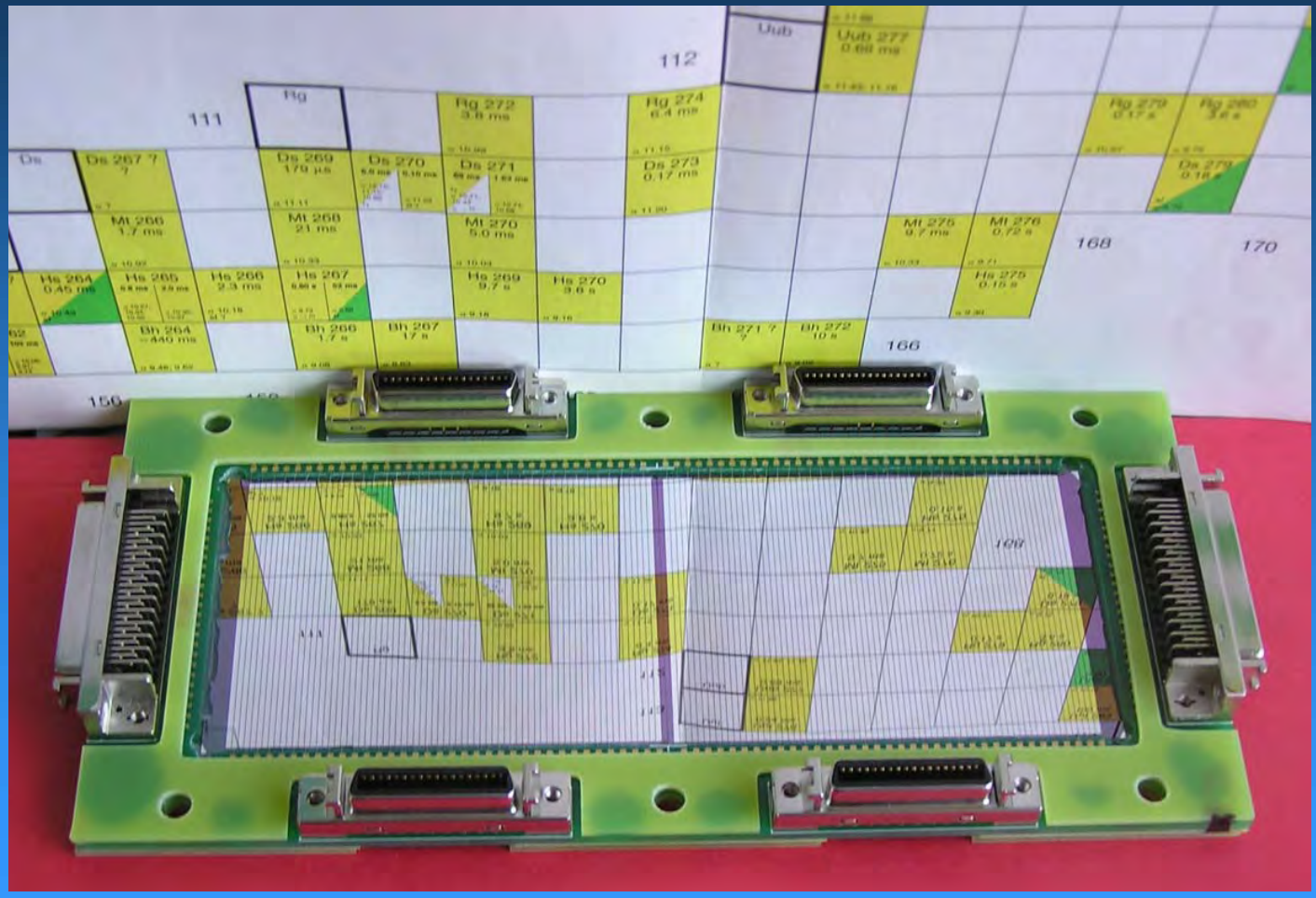
DAQ

Beamtime / Proposal

Manpower

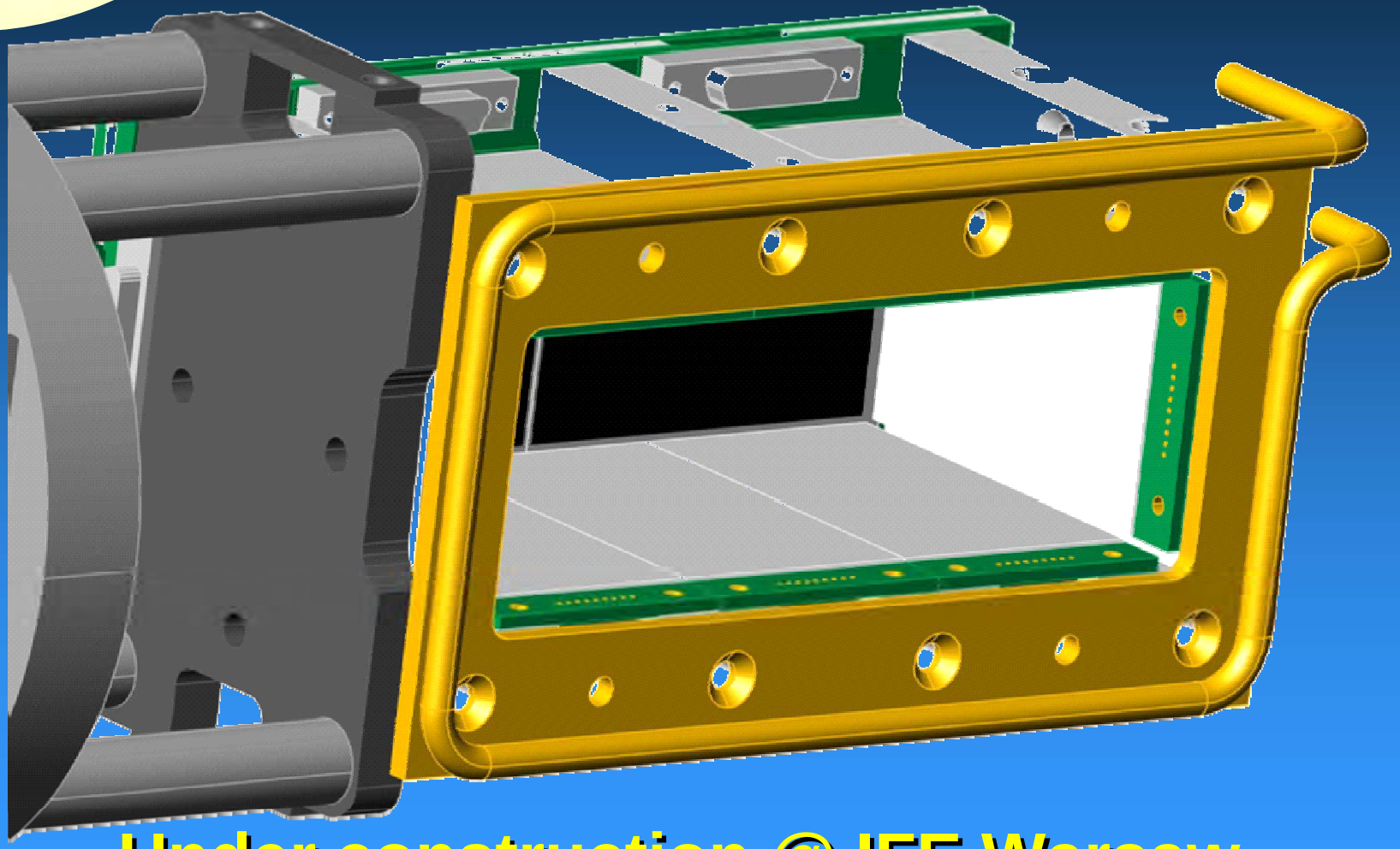


Focal pane detector: DSSD
Double Sided Strip Detectors



Tested @ *TASCA* during commissioning

Focal Plane+Upstream + Punchthrough Detector Box



Under construction @ IFE Warsaw

Delivery to TUM: end of 2008

^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114 @ *TASCA*: What is needed?

Beam ^{48}Ca ✓

Target ^{244}Pu ✓

Magnet settings

Fill gas

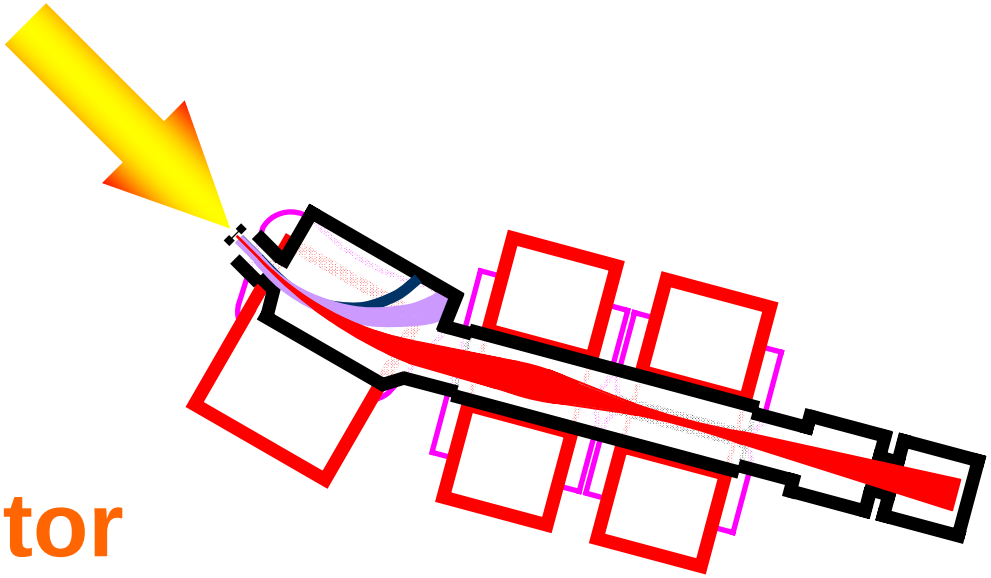
Recoil veto detector

Focal plane detector

DAQ

Beamtime / Proposal

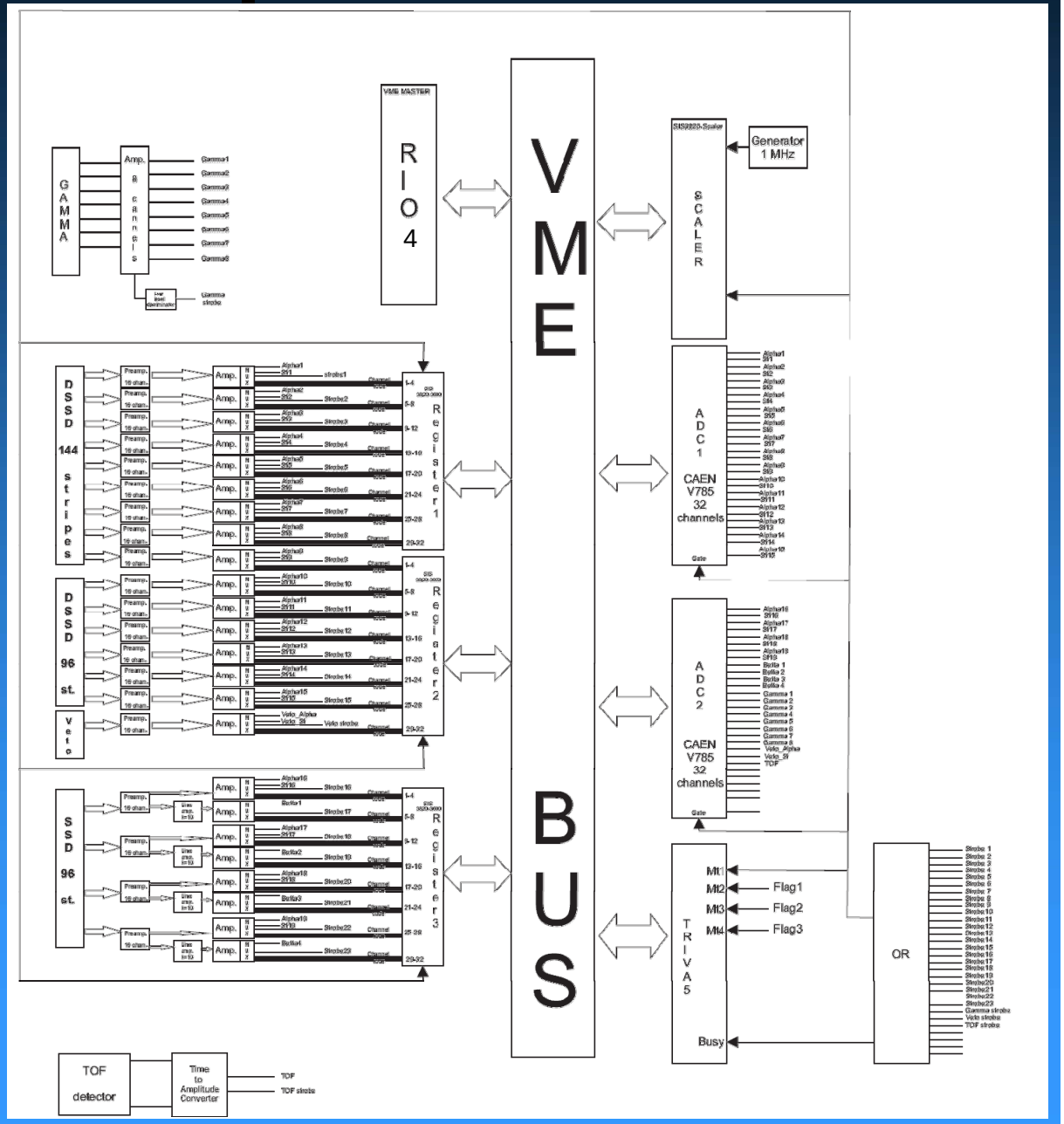
Manpower



Data Acquisition

Hardware design fixed, most components ordered

Based on GSI's RIO4/MBS & GO4



^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114 @ *TASCA*: What is needed?

Beam ^{48}Ca ✓

Target ^{244}Pu ✓

Magnet settings

Fill gas

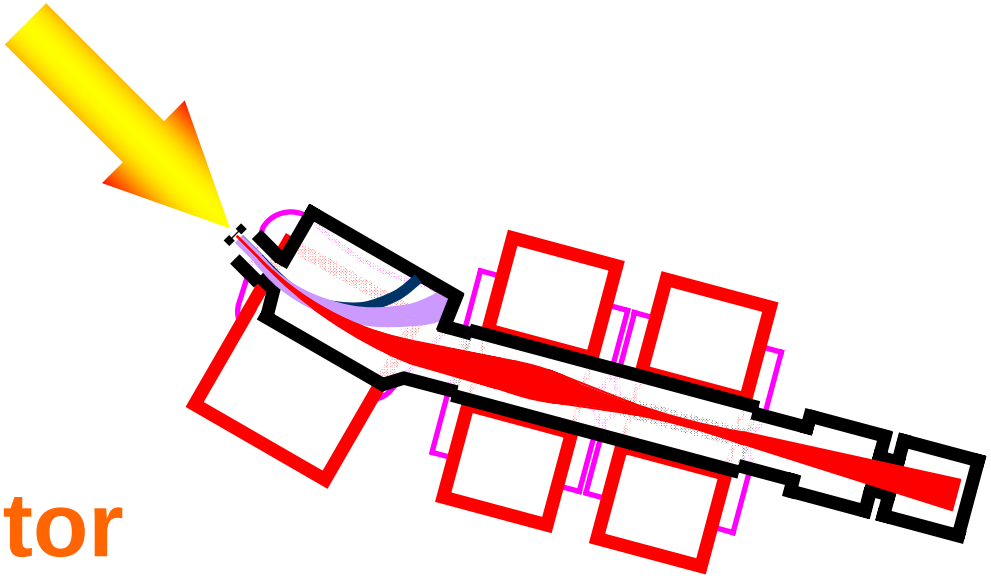
Recoil veto detector

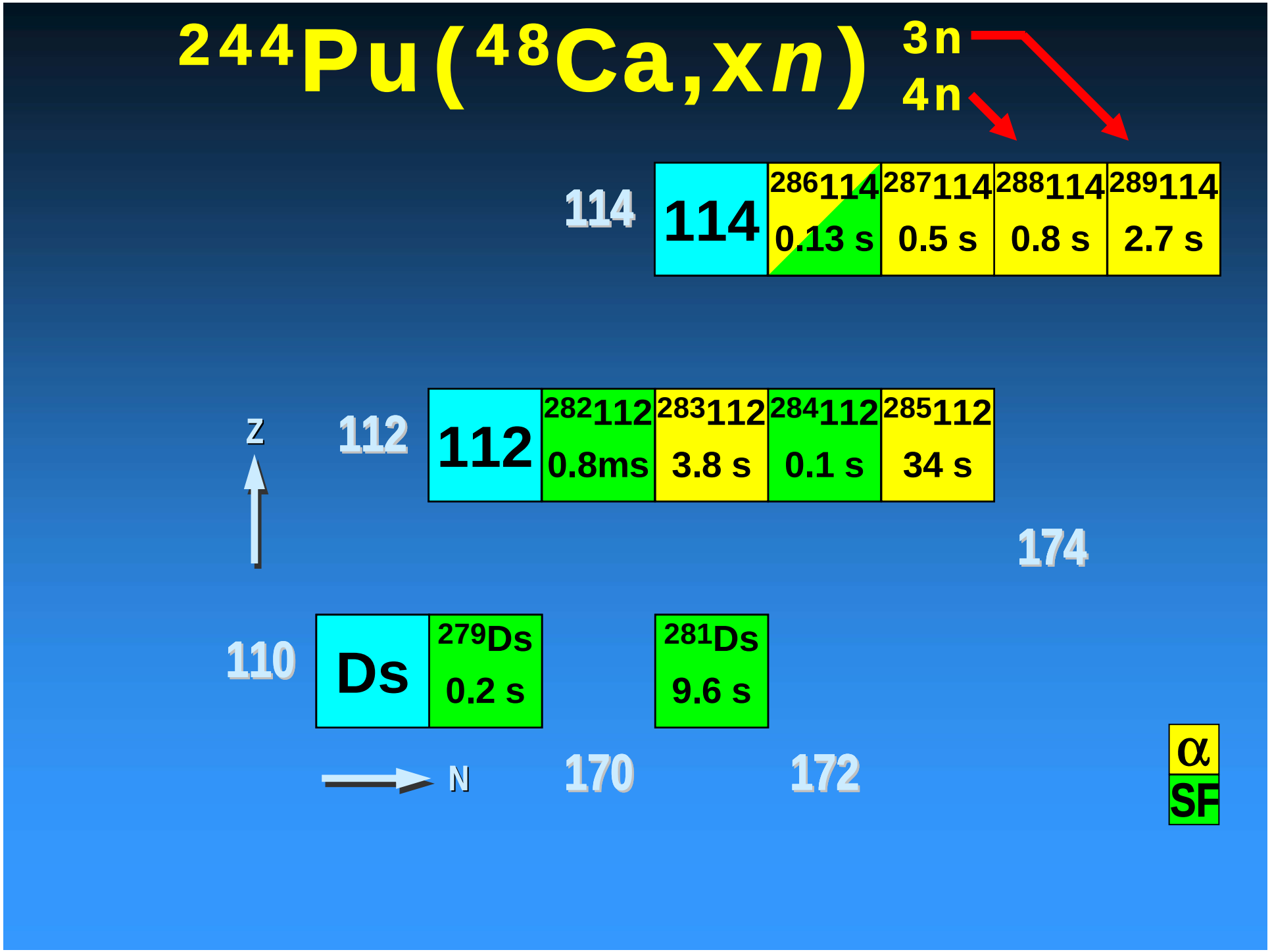
Focal plane detector

DAQ

Beamtime / Proposal

Manpower




^{244}Pu(^{48}Ca,xn)
3n
4n
114
114
^{286}114
0.13 s
^{287}114
0.5 s
^{288}114
0.8 s
^{289}114
2.7 s
Z
112
112
^{282}112
0.8ms
^{283}112
3.8 s
^{284}112
0.1 s
^{285}112
34 s
174
110
Ds
^{279}Ds
0.2 s
^{281}Ds
9.6 s
N
170
172
α
SF

$^{244}Pu(^{48}Ca,xn)$ 3n 4n

Excitation function (Dubna GFRS)

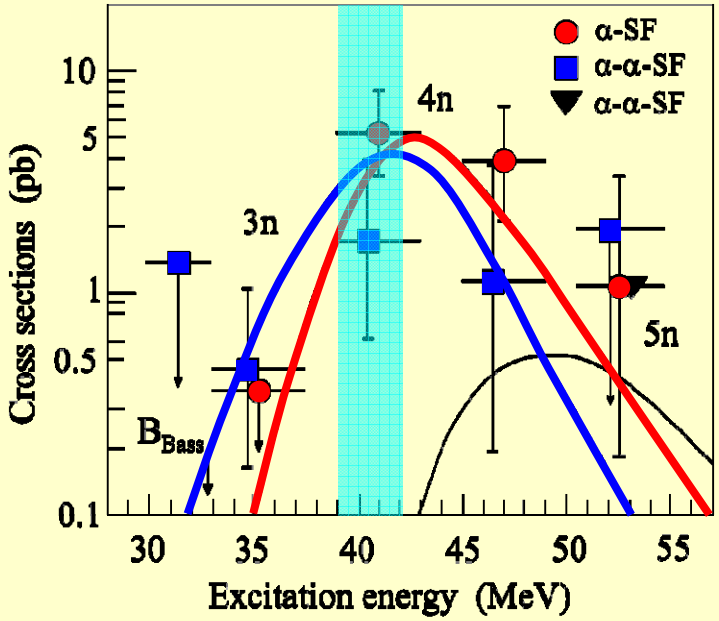


FIG. 1. Excitation functions for the 3*n* (■), 4*n* (●), and 5*n* (▼) evaporation channels from the complete-fusion reaction $^{244}Pu + ^{48}Ca$. The Bass barrier [8] is shown by an arrow. Lines show the results of calculations [9]. Error bars correspond to statistical uncertainties.

σ_{max} (3n)=$1.7^{+2.5}_{-1.1}$ pb

@ E*=41 MeV

EVR-α-α-SF (long)

σ_{max} (4n)=$5.3^{+3.3}_{-2.1}$ pb

@ E*=41 MeV

EVR-α-SF (short)

Yu. Oganessian et al. PRC 69 (2004) 054607

SF

Beamtime / Manpower $^{48}Ca + ^{244}Pu$

Assuming:

Target:	**380 μg/cm²**
Beam:	**500 nA_{part}**
Cross section:	**5 pb**
ε_{TASCA}:	**50%**
ε_{Det}:	**100%**
Beam-on-target time:	**80%**

TASCA efficiency:

$^{208}Pb(^{48}Ca,2n)^{254}No$:

520μg/cm² Target, into 80x35 mm² FPD:

Exp: 54%

MCS: 55%

Expect 3.5 events per 7-day week @ optimum conditions.

Allow for multiple E_{beam}, fill gases, B·ρ

➞ Six weeks of beamtime needed

^{244}Pu(^{48}Ca,x*n*)$^{292-x}$114 @ *TASCA*: What is needed?

Beam ^{48}Ca ✓

Target ^{244}Pu ✓

Magnet settings

Fill gas

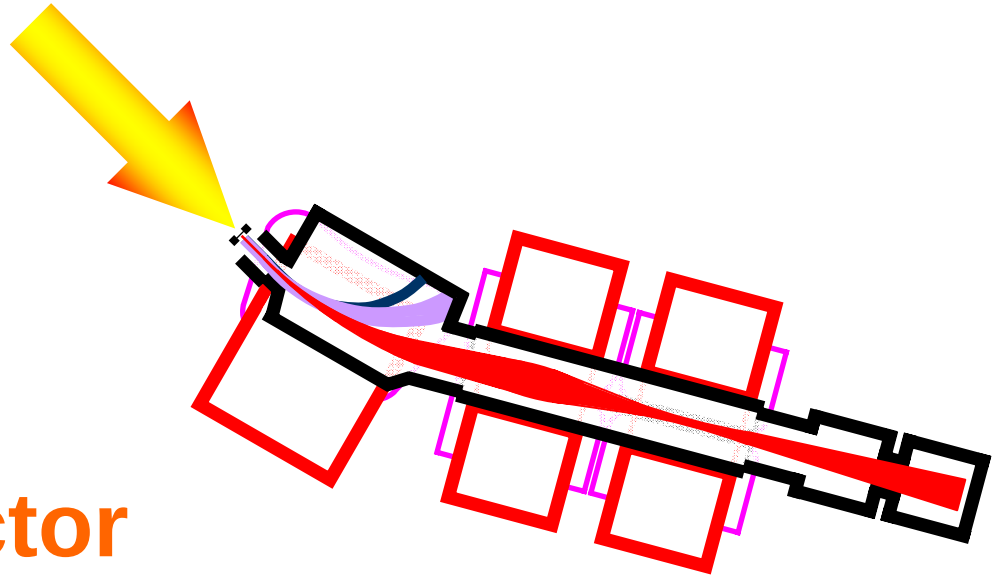
Recoil veto detector

Focal plane detector

DAQ

Beamtime / Proposal

Manpower → later



Step 2

Search for element 117

Search for element 117 @ *TASCA*: What is needed?

Beam

Target

Magnet settings

Fill gas

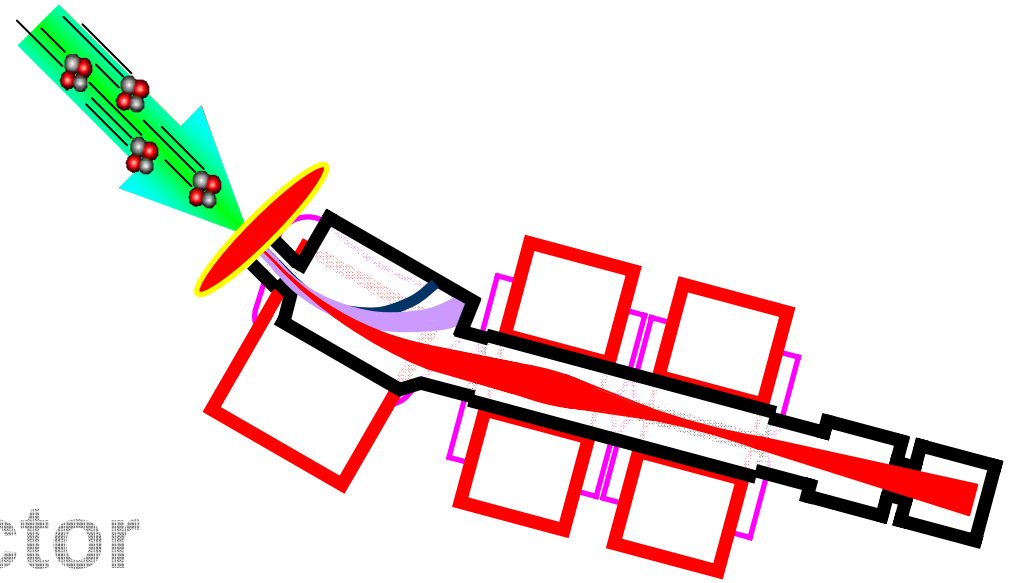
Recoil veto detector

Focal plane detector

DAQ

Beamtime / Proposal

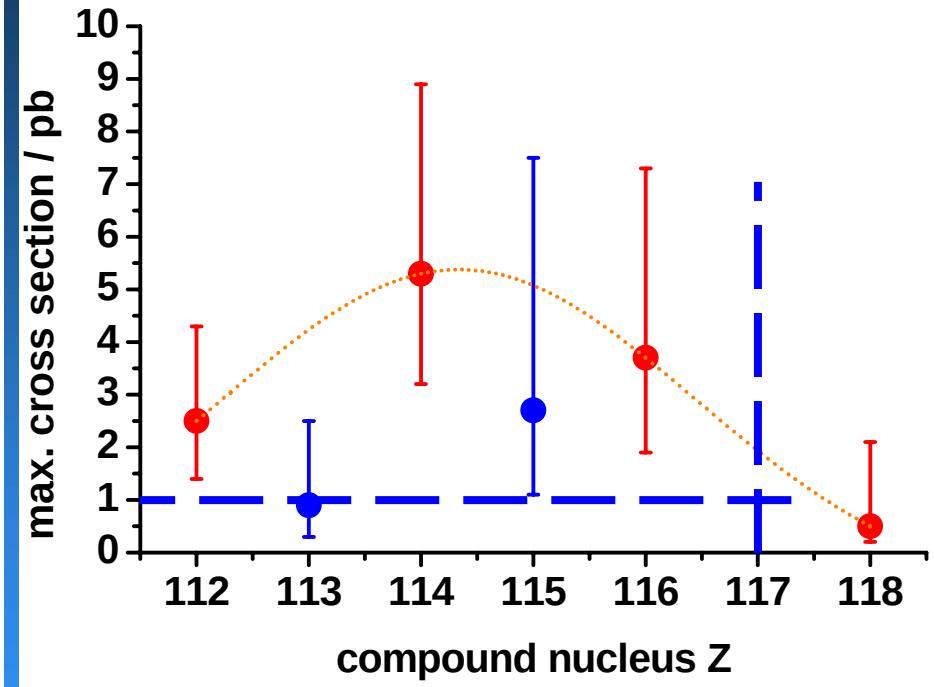
Manpower



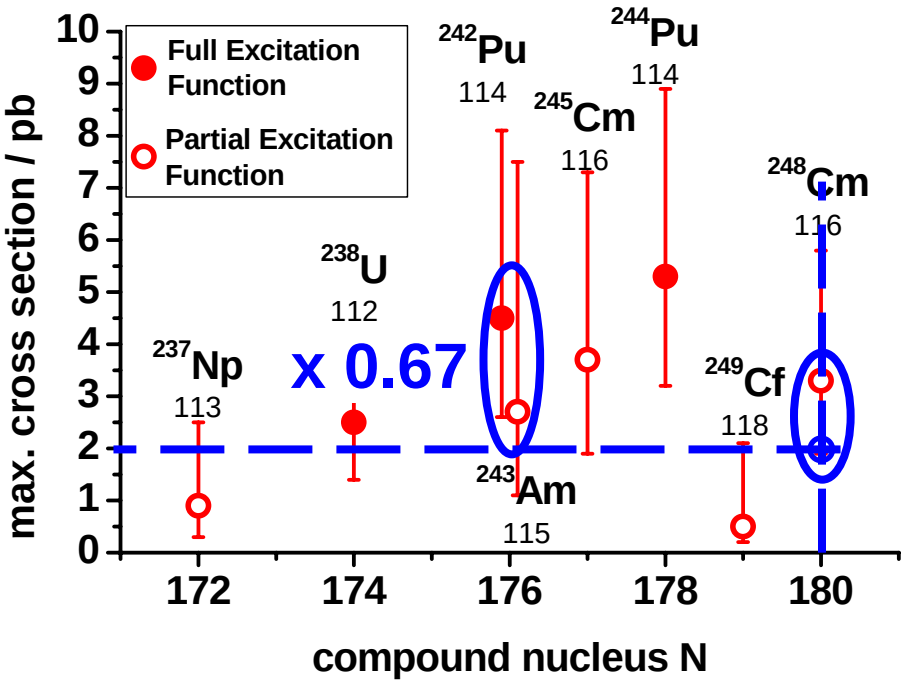
Which nuclear reaction?

Beam	Target	CN
^{41}K	^{249}Cf	$^{290}117$
^{48}Ca	^{249}Bk	$^{297}117$
^{45}Sc	^{248}Cm	$^{293}117$
^{50}Ti	^{243}Am	$^{293}117$
^{51}V	^{244}Pu	$^{295}117$
^{54}Cr	^{237}Np	$^{291}117$
^{55}Mn	^{238}U	$^{293}117$

Experimental cross section systematics ^{48}Ca+An (DGFRS)



^{48}Ca+^{249}Bk: ~1 pb?



^{48}Ca+^{249}Bk: ~2 pb?

Expectation for ^{48}Ca+^{249}Bk: 0.5 - 2 pb

Theory 2008

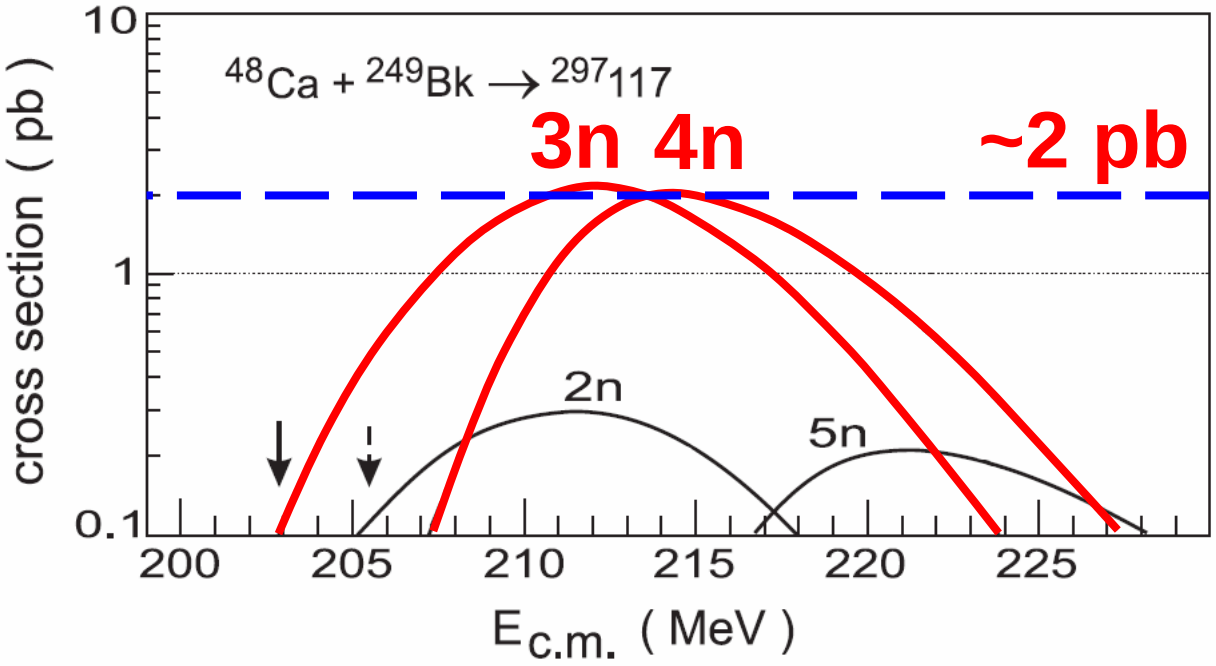
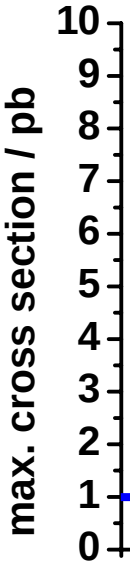
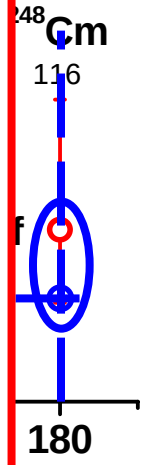


FIG. 8. Cross sections for production of the element 117 in the $^{48}Ca + ^{249}Bk$ fusion reaction (solid curves, $2n$, $3n$, $4n$, and $5n$ evaporation channels).

V. I. Zagrebaev + W. Greiner, Phys. Rev. C 78 (2008) 034610





Expectation for $^{48}Ca+^{249}Bk$: 0.5 - 2 pb

The U.S. Isotope Program
Availability of ^{249}Bk

- The isotope production program at Oak Ridge National Laboratory (ORNL) has essentially stopped since the beginning of 2008
- Responsibility for this program has been transferred within the DOE from "Nuclear Engineering (NE)" to "Nuclear Physics (NP)" (low energy) division
- NP has held a workshop in August 2008 on

  "The Nation's Needs for Isotopes: Present and Future to assess the Nation's need for isotopes"

  — the workshop had more than 70 participants from most National Labs, Government agencies, Universities and Industry

  — three 1 ½ working-day sessions found that there is a tremendous need and demand for stable and radioactive isotopes

The U.S. Isotope Program (2)
Availability of ^{249}Bk

- Three Working Sessions:
  - Stable and Enriched Isotopes
  - Radioisotope for Research and Development
  - Radioisotopes for Applications

- It was decided that the Nuclear Science Advisory Committee (NSAC) will form a sub-committee to further asses the Nation's isotope needs, which has been established
  - Chairs: Ani Aprahamian(Physics, U. Notre Dame) and Don Geesaman (ANL)

The U.S. Isotope Program (3)
Availability of ^{249}Bk

- **Charges to the Sub-committee**

  —1) to consider broad community input regarding how research isotopes are used and to identify compelling research opportunities using isotopes, and

  —2) study the opportunities and priorities for ensuring a robust national program in isotope production and development, and to recommend a long-term strategic plan that will provide a framework for a coordinated implementation of the National Isotopes Production and Applications Program over the next decade.

What does this mean to us?

- There are currently four production rods with ^{244}Cm in the core of the HFIR to breed ^{252}Cf.
- It is planned to remove them at the end of 2008 or early in 2009
  - — after a three-month cooling period they could be processed by the personnel who used to work in the Radiochemical Engineering Development Center (REDC) at ORNL to recover the ^{252}Cf
  - — the current uncertainty is if this processing will be authorized by DOE
  - — there is a good possibility that this may occur because there was a high demand from several costumers, especially from the petroleum industry

(When) will ^{249}Bk be available for an experiment ?

- After ^{252}Cf separation, further reprocessing to isolate ^{249}Bk would be required, charged to us on cost basis
  - — if the cost is reasonable LBNL would cover this, otherwise a joint solution has to be found
- Timeline: Uncertain at the moment, but….
  - — perhaps available in May/June 2009?
  - — Heino Nitsche (LBNL/UCB) is in contact with the decision makers at ORNL
  - — final decision whether ^{249}Bk will be available or not (and how much) is expected before the end of 2008
  - — Heino Nitsche would take care personally that shipment will actually leave ORNL
  - — receivers in Germany would guarantee the same

Search for element 117 @ *TASCA*: What is needed?

Beam

Target

Magnet settings

Fill gas as for E114

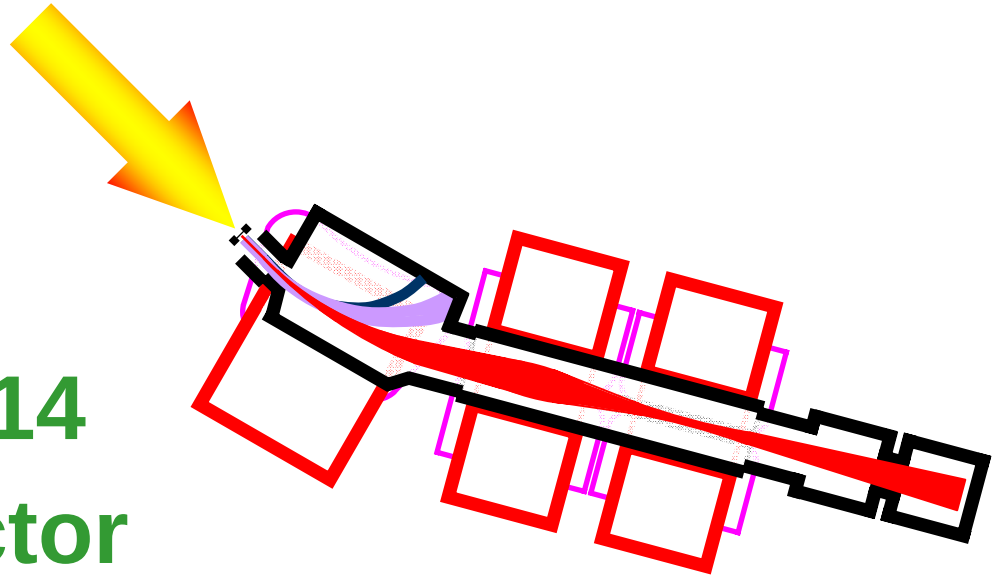
Recoil veto detector

Focal plane detector

DAQ

Beamtime / Proposal

Manpower



Beamtime $^{48}Ca + ^{249}Bk$ – Case 1

Rotating target wheel:	**400 μg/cm²**
Beam:	**500 nA_{part}**
Cross section:	**≥0.5 pb**
ε_{TASCA}:	**50%**
ε_{Det}:	**100%**
Beam-on-target time:	**80%**

Expect 1 event every 19 days.

In 9 weeks, expect 3.29 events.

Poisson probability to see ≥1 event when 3.29 are expected: 96.2%

→ Request: 210 shifts (10 weeks)

Beamtime $^{48}Ca+^{249}Bk$ – Case 2

Stationary 10mm ø target:	400 μg/cm²
Beam:	250 nA_{part}
Cross section:	≥0.5 pb
ε_{TASCA}:	50%
ε_{Det}:	100%
Beam-on-target time:	80%

Expect 1.8 events every 10 weeks.

In 4 months of beamtime, that is 3.17 events

(neglecting ^{249}Bk decay! After 4 months: 77% left)

Possion prob. to see ≥1 events: 95.8%

➔ Request: 365 shifts

Beamtime request for ^{244}Pu + ^{249}Bk

With a rotating ^{249}Bk target wheel

^{48}Ca+^{244}Pu: (6 weeks) 126 shifts

^{48}Ca+^{249}Bk: (10 weeks) 210 shifts

Total: 336 shifts

With a stationary ^{249}Bk target

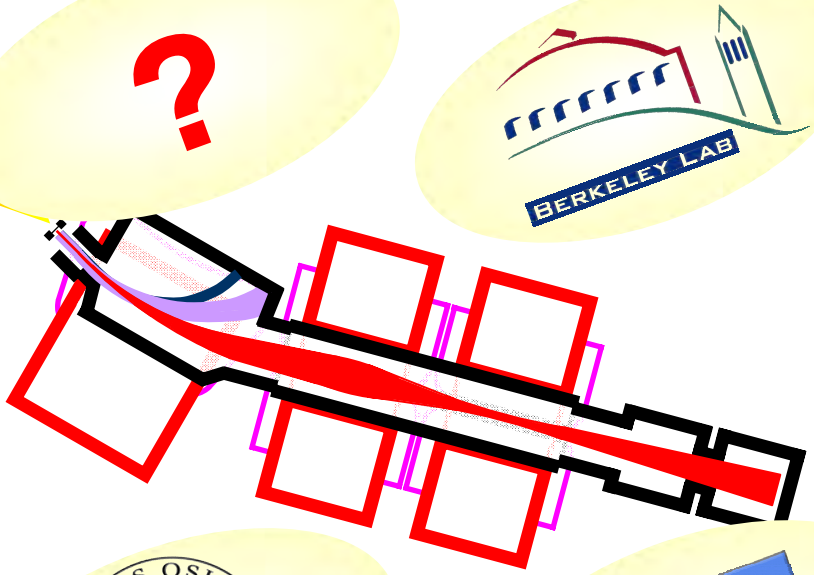
^{48}Ca+^{244}Pu: (6 weeks) 126 shifts

^{48}Ca+^{249}Bk: (4 months) 365 shifts

Total: 491 shifts

Search for element 117 @ *TASCA*: What is needed?

- Beam
- Target
- Magnet settings
- Fill gas as for E114
- Recoil veto detector
- Focal plane detector
- DAQ
- Beamtime / Proposal
- Manpower → YOU!!!



Manpower needs – Case 1

$^{48}Ca+^{244}Pu$: 126 shifts

$^{48}Ca+^{249}Bk$: 210 shifts

Needs: 1 person per shift, 21 shifts/week

On call: One TASCA expert

One DAQ/Hardware/Analysis expert

One person works five 8-hour shifts per week

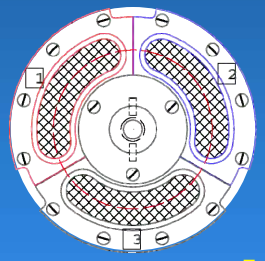
Manpower needs

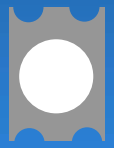
Needed per week:

5 people for shifts

1.5 people for TASCA

1.5 people for DAQ/HW/Analysis



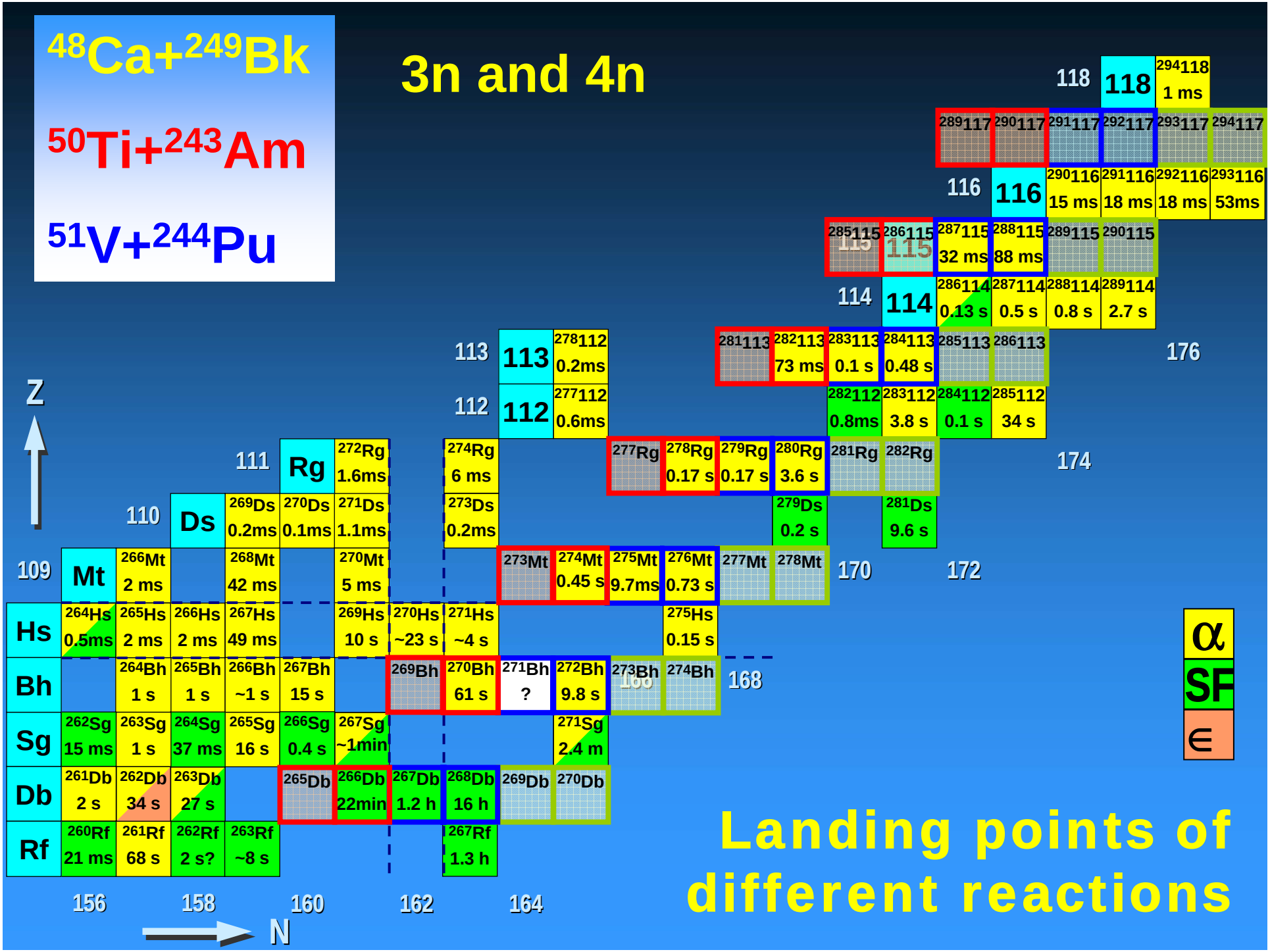


16 weeks		**~24 weeks**
80	**1-week slots for shifts**	**120**
24	**1-week slots TASCA**	**36**
24	**1-week slots DAQ**	**36**


What if there is no ^{249}Bk?

Which nuclear reaction?

Beam	Target	CN	comment
^{41}K	^{249}Cf	^{290}117	n-poor(?)
^{48}Ca	^{249}Bk	^{297}117	*1* ^{48}Ca; n-rich
^{45}Sc	^{248}Cm	^{293}117	(Target not ready)
^{50}Ti	^{243}Am	^{293}117	*2a* beam@GSI?
^{51}V	^{244}Pu	^{295}117	*2b* (✓)
^{54}Cr	^{237}Np	^{291}117	symmetric
^{55}Mn	^{238}U	^{293}117	symmetric


48Ca+249Bk
50Ti+243Am
51V+244Pu
3n and 4n
Landing points of different reactions
Z
N
α
SF
∈
Rf
Db
Sg
Bh
Hs
Mt
Ds
Rg
112
113
114
116
118
156
158
160
162
164
166
168
170
172
174
176
264Hs 0.5ms
265Hs 2 ms
266Hs 2 ms
267Hs 49 ms
269Hs 10 s
270Hs ~23 s
271Hs ~4 s
275Hs 0.15 s
264Bh 1 s
265Bh 1 s
266Bh ~1 s
267Bh 15 s
269Bh
270Bh 61 s
271Bh ?
272Bh 9.8 s
273Bh
274Bh
262Sg 15 ms
263Sg 1 s
264Sg 37 ms
265Sg 16 s
266Sg 0.4 s
267Sg ~1min
271Sg 2.4 m
261Db 2 s
262Db 34 s
263Db 27 s
265Db
266Db 22min
267Db 1.2 h
268Db 16 h
269Db
270Db
260Rf 21 ms
261Rf 68 s
262Rf 2 s?
263Rf ~8 s
267Rf 1.3 h
266Mt 2 ms
268Mt 42 ms
270Mt 5 ms
273Mt
274Mt 0.45 s
275Mt 9.7ms
276Mt 0.73 s
277Mt
278Mt
269Ds 0.2ms
270Ds 0.1ms
271Ds 1.1ms
273Ds 0.2ms
279Ds 0.2 s
281Ds 9.6 s
272Rg 1.6ms
274Rg 6 ms
277Rg
278Rg 0.17 s
279Rg 0.17 s
280Rg 3.6 s
281Rg
282Rg
278112 0.2ms
277112 0.6ms
281113
282113 73 ms
283113 0.1 s
284113 0.48 s
285113
286113
282112 0.8ms
283112 3.8 s
284112 0.1 s
285112 34 s
285115
286115
287115 32 ms
288115 88 ms
289115
290115
286114 0.13 s
287114 0.5 s
288114 0.8 s
289114 2.7 s
289117
290117
291117
292117
293117
294117
294118 1 ms
290116 15 ms
291116 18 ms
292116 18 ms
293116 53ms

$^{50}Ti + ^{243}Am$ (more asymmetric)	$^{51}V + ^{244}Pu$ (more symmetric)
Beam	
Development under way. Maybe ready by 01/2010	Ready
Target	
To be made, no problems expected	Ready
CN / Chains	
$^{293}117$	$^{295}117$
3n known from 113 on	3n/4n known from 115 on
Cross section	
Zagrebaev et al.: 85 fb	??? (Probably less)

If no ^{249}Bk becomes available, the collaboration has to deliberate which experiments are most attractive

Conclusion:
TASCA is a great device to search for E117!

Optimistic but realistic:

- Ready for $^{48}Ca+^{244}Pu$ by March/April 2008
  - Aspect 1: test Dubna results
  - Aspect 2: preparation for E117 search
  - Aspect 3: preparation for E114 chemistry @TASCA

  Six weeks of beamtime desirable.

- If ^{249}Bk becomes available, TASCA has a good chance to discover element 117 in a ten-week (or 4 month) run later in 2009.