E 1112 proposal

Mass measurement of neutron-rich isotopes around N = 32 and N = 34

K, Ca, Sc RIB & TITAN

H. Savajols (GANIL/TRIUMF) & J. Dilling (TRIUMF)

Nuclear structure in neutron-rich nuclei

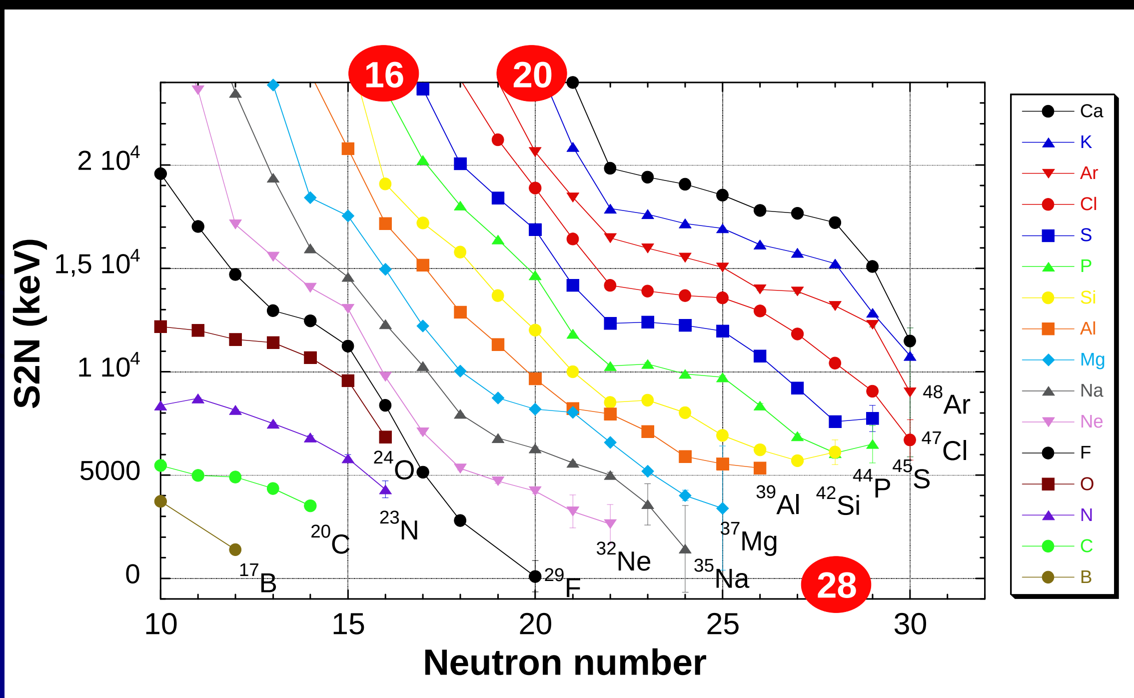
Mass measurement

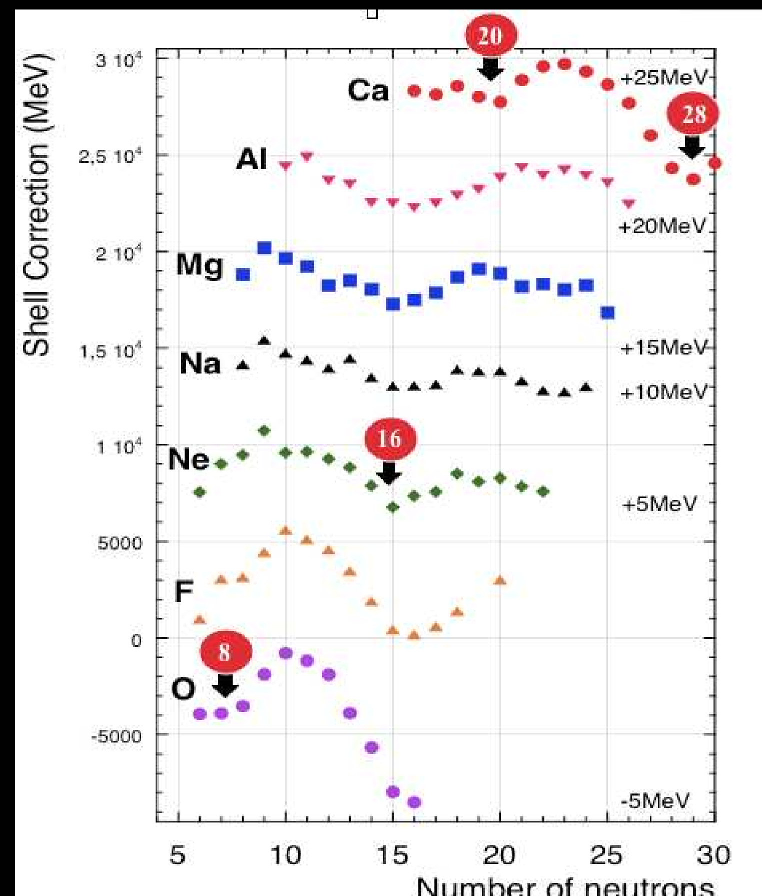
➲ a powerful nuclear structure probe

$$S_{2n}(A,Z) = M(A-2,Z) - M(A,Z) + 2M_n$$

$$\text{Shell Correction} = \Delta M_{exp} - \Delta M_{FRLDM}$$

P.Moller, J.R.Nix et al., Atomic Data and Nuclear Data Tables 59 (1995) 185





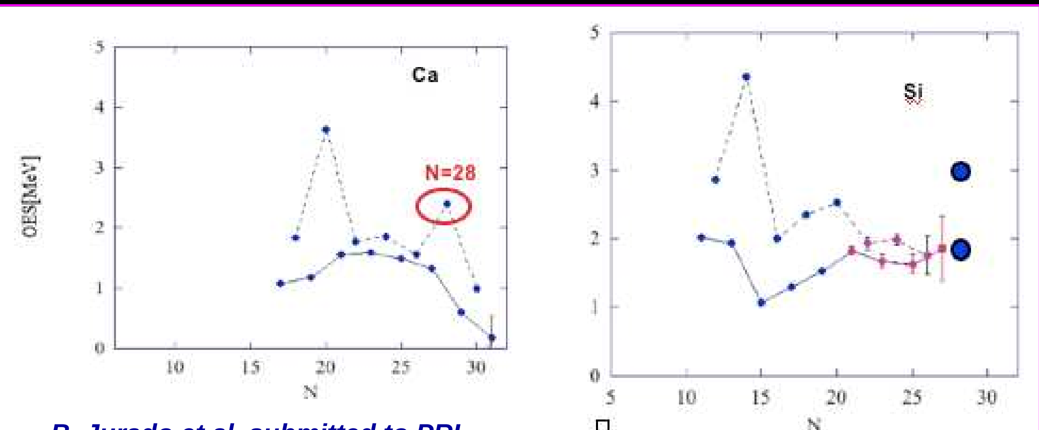
H. Savajols et al., Eur.Phys.J. A 25, 23 (2005)

Mass measurement ➲ a powerful nuclear structure probe

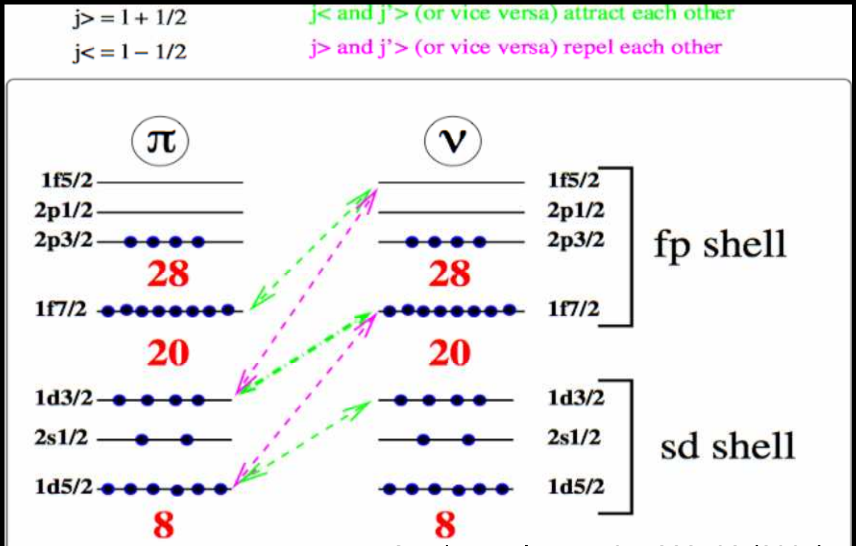
$$\Delta_3(N) = (-1)^N[M(N-1)+M(N+1)-2M(N)]c^2/2$$

- ❍ Pairing effects ⇩ Δ_3 at odd values of N
- ❍ Single particle spacing ⇩ difference of Δ_3 at adjacent even and odd values of N

Satula et al., PRL 81 (1998) 3599



B. Jurado et al. submitted to PRL.



T.Otsuka et al., PRL 95, 232502 (2005)

➲ On neutron rich-side

N=16, N=20 and N=28

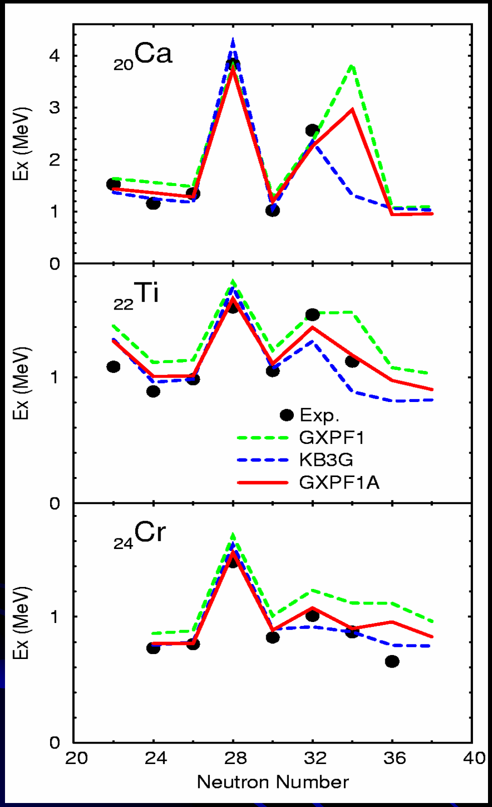
Clear evidences on the change in the shell structure

Manifestation of the tensor monopole part of the NN interaction in N/Z>>1 Nuclei ?

➲ Inversion of shell

Dependence of the ν–π interaction of their combination of their spin

E1112 : mass measurement around N=32 and N=34



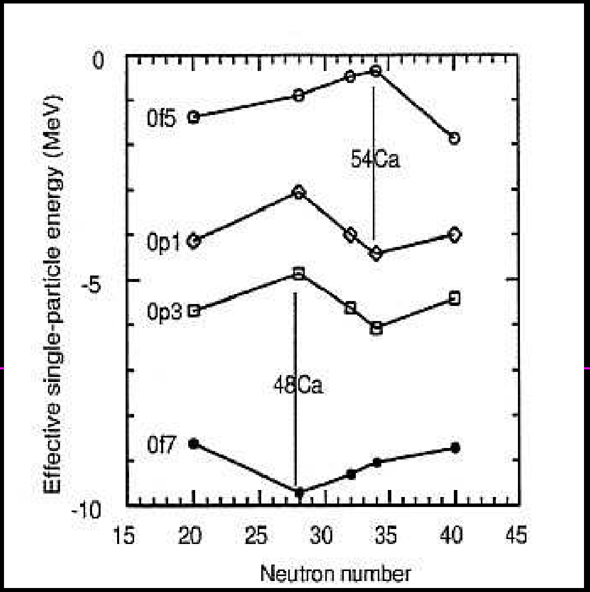
In the *pf* shell :

❍ The relative energy of the $p_{3/2}$, $p_{1/2}$ and $f_{5/2}$ orbits determine where sub shell closure take place

❍ Most of the shell model effective interaction predict a sub shell at N=32 for the Ca isotope

(confirm by β-decay measurement, B(E2), high spin of the even-even ^{56}Cr and ^{54}Ti)

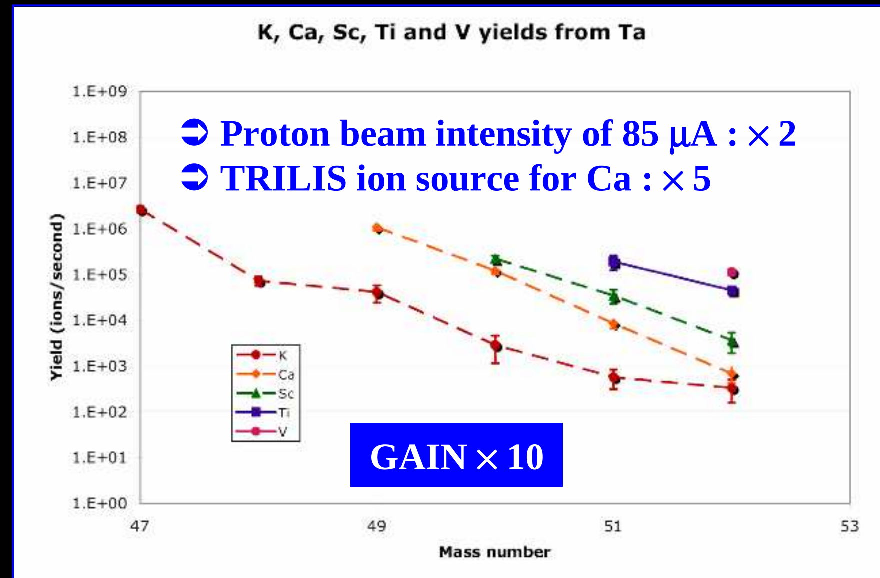
❍ New effective interaction :
GXPF1 *Homma et al. PRC65, (2002) 1301R*
Sizable energy gap between
$p_{1/2}$ and $f_{5/2}$ orbits ⇩ N=34
neutron proton interaction $\pi f_{7/2}$ - $\nu f_{5/2}$

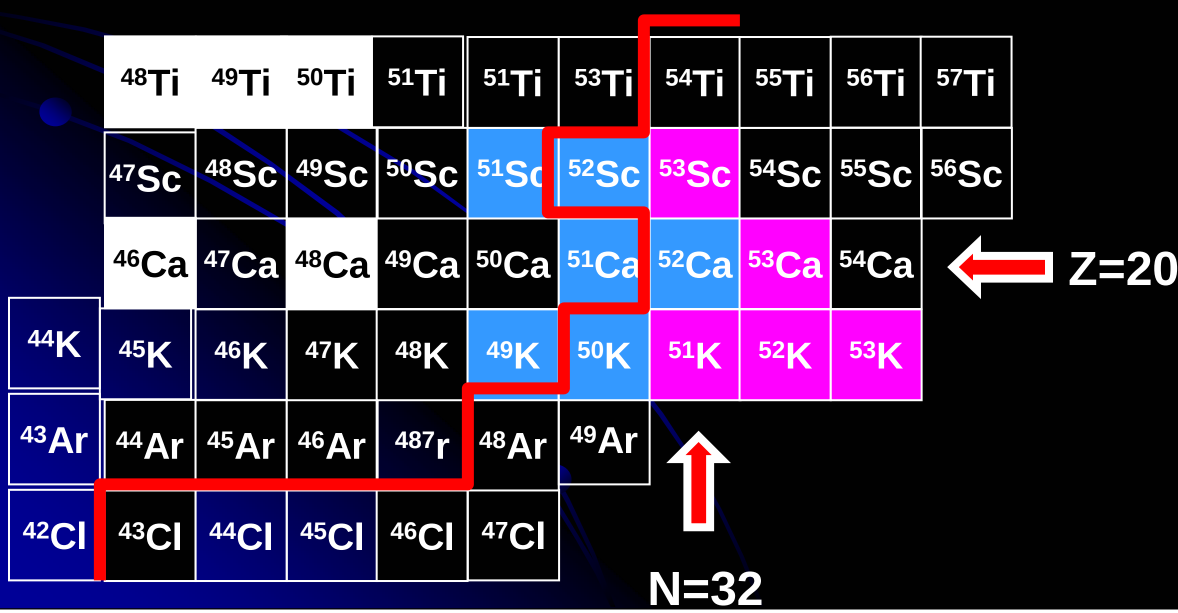


➲ Shell-structure evolution is expected to be reflected in mass measurements

Proposed experiment :

Isotope	*Half-live*	*(Expected)Yield*	*Ion source*
^{49}K	1.26 s	2×10^{5}	Surface
^{50}K	472 ms	1×10^{4}	Surface
^{51}K	365 ms	2×10^{3}	Surface
^{52}K	105 ms	1×10^{3}	Surface
^{53}K	30 ms	5×10^{2}	Surface
^{51}Ca	10 s	9×10^{4}	TRILIS
^{52}Ca	4.6 s	8×10^{3}	TRILIS
^{53}Ca	90 ms	7×10^{2}	TRILIS
^{51}Sc	12.4 s	1×10^{5}	Surface
^{52}Sc	8.6 s	8×10^{3}	Surface
^{53}Sc	> 3 s	1×10^{3}	Surface





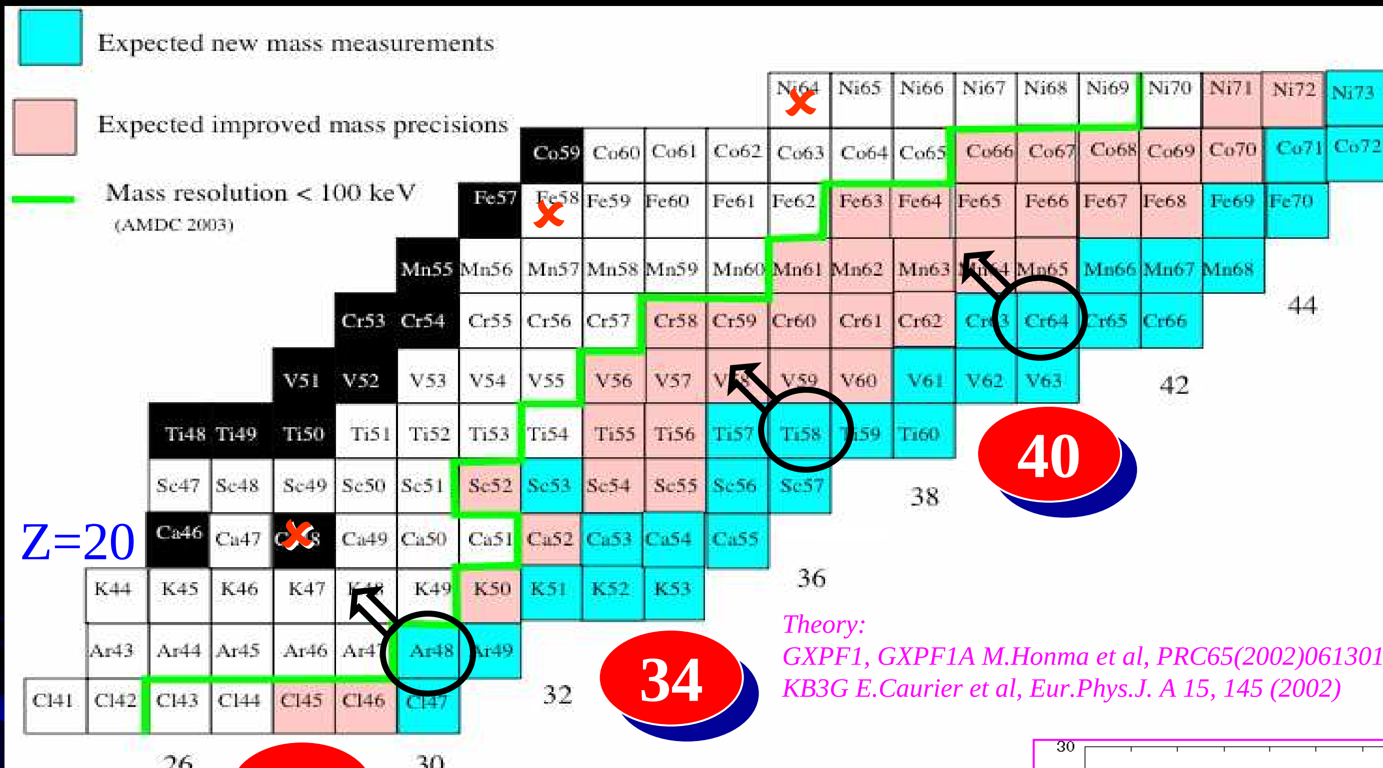
Expected improved mass precisions

Expected new mass precisions

Mass resolution < 100 keV (AMDC 2003)

11 new masses of very exotic nuclei
- 5 new masses
- 6 improved masses

E418a : measurements of 31 new masses and 37 improved masses



Theory:
GXPF1, GXPF1A M.Honma et al, PRC65(2002)061301
KB3G E.Caurier et al, Eur.Phys.J. A 15, 145 (2002)

➲ Astrophysical context

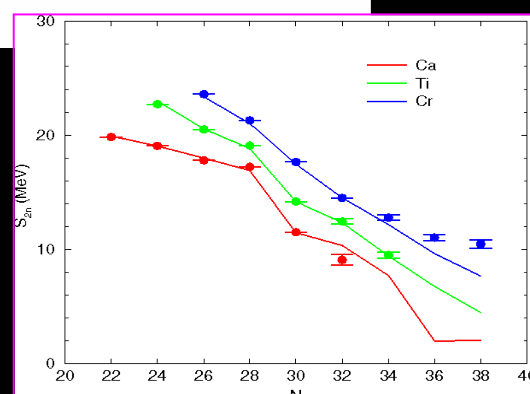
- S_n important to determine the r-process path
- turning points (t_β vs t_n)

O.Sorlin et al., NPA A660 (1999) 3.
S.Grevy, private communication

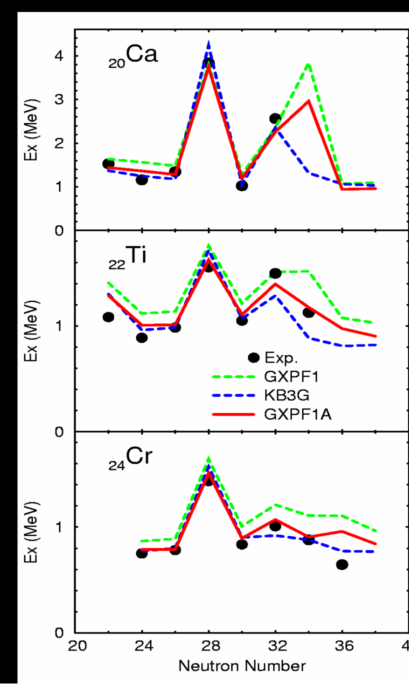
➲ Shell struture

- beyond N=28
- Around N=40
- New magic number N=34 ?

(neutron proton interaction $\pi f_{7/2}$ - $\nu f_{5/2}$)



T.Otsuka PRL 87 (2001) 082502-1
And private communication



TITAN device

Mass measurements on isotopes with short half-life $T_{1/2}$ 10 ms and low production yields (≈ 100 ions/s) with high precision $\delta m/m \approx 10^{-9}$.

Ideally, uniquely matched to isol-type production mode.

TITAN started April 2003, planned first on-line mass measurements will be in 2006.

ISAC ion beam → **RFQ cooler & buncher** → **EBIT charge breeder** → **m/q selection** → **Cooler Penning trap** → **Precision Penning trap**

① p ⇒HPTa @ 85 μA + Ion Source

② Linear cooler and buncher RFQ
cooled via interactions in a buffer gas
Eff ~ 60%

③ Electron Beam Ion Trap (EBIT)
Ions are stored and charge bred
Electron energy can be adjusted

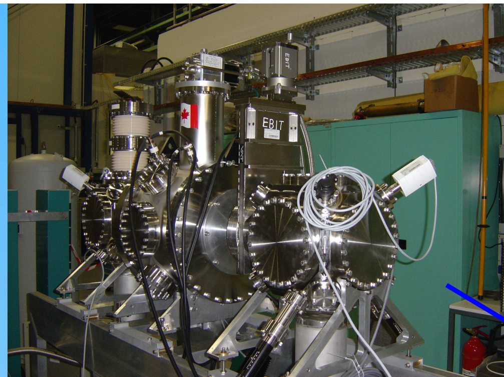
Eff ~ 60%

④ Wien filters

⑤ Penning trap combined with a TOF method
Eff cleaning ~ 80%

Eff measuring ~ 50%

J.Dilling et al., NIMB(2003) B294



EBIT built @ MPI-HD.
to TRIUMF April 2006.

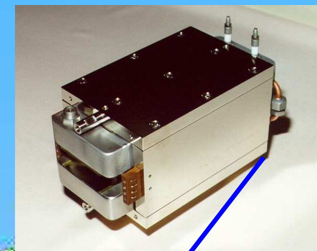
Max-Planck-Institut für Kernphysik

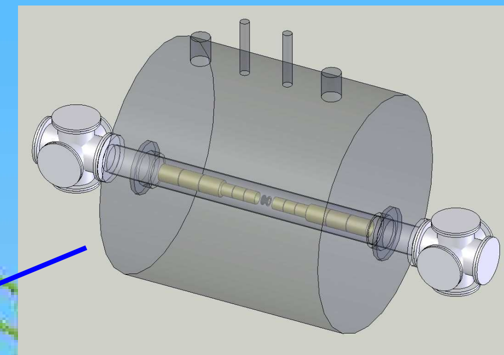
Cooler trap for HCI
(to be built in Manitoba,
CFI grant received)

university of manitoba

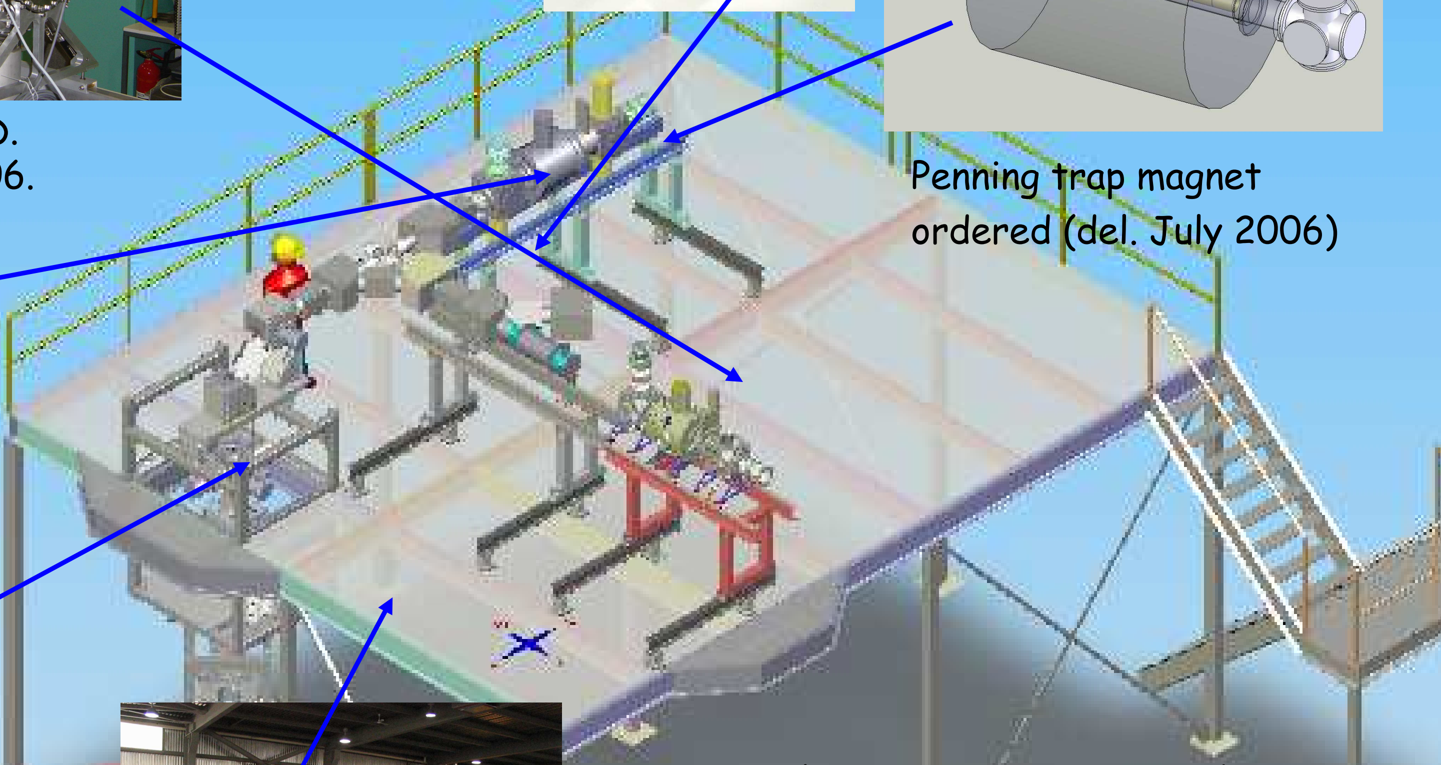
McGill

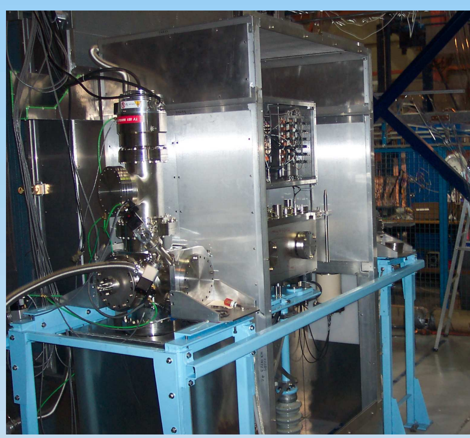
Wien filter
(R=500)





Penning trap magnet
ordered (del. July 2006)





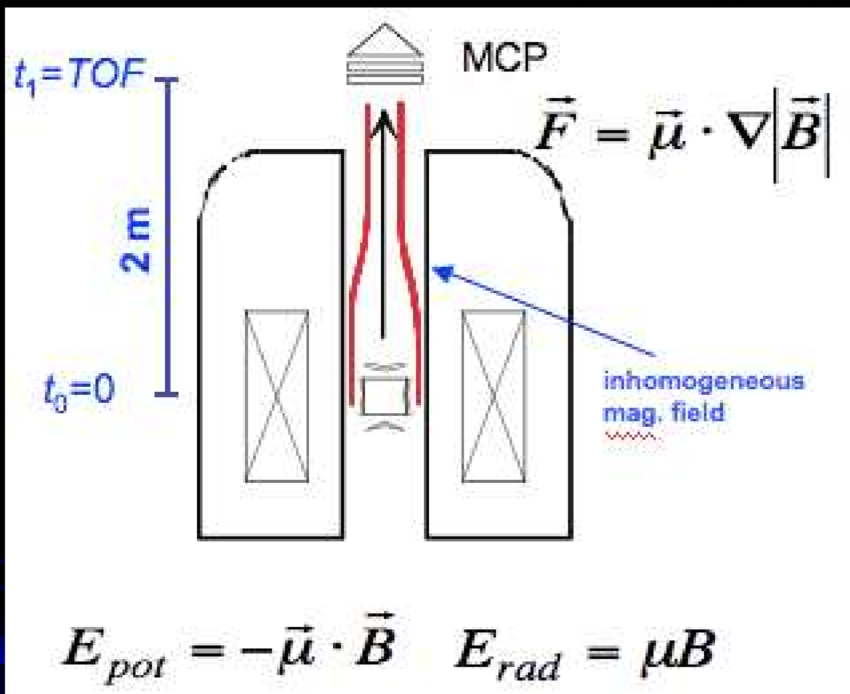
RFQ operational on test bench
Moved to ISAC, ready for tests

TITAN platform finished at ISAC

The TITAN system is under
construction and will be
operational for mass
measurements at ISAC/TRIUMF
in 2006.
Goal: $\delta m/m < 1 \cdot 10^{-8}$

TRIUMF ISAC

Mass measurement via time-of-flight

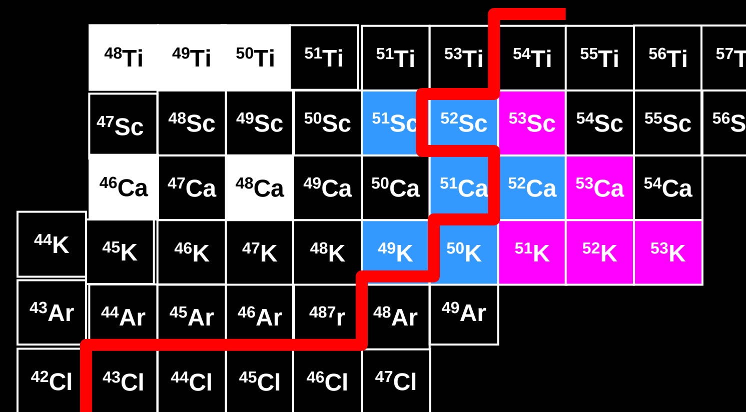


QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Determine atom mass from frequency ratio with a well known reference

Beam time request

Ions	Half-life	Intensity	Breeding to He like	e^- energy	Measuring	Resolution
^{53}Sc	0.9 s	700/s	Q = 19 - dt = 30 ms	4500 eV	100 ms	5.10^{-9}
^{53}Ca	90 ms	700/s	Q = 18 - dt = 30 ms	4100 eV	100 ms	5.10^{-9}
^{53}K	30 ms	500/s	Q = 17 - dt = 30 ms	3600 eV	30 ms	1.10^{-8}



Summarizing the duty cycle in the case of ^{53}Sc and for 700 incoming ions /s,

- **100 ms cooling × 60% efficiency × decay losses = 36 ions**
- **30 ms breeding × 60% efficiency × decay losses = 21 ions**
- **100 ms cleaning × 80% efficiency × decay losses = 14 ions**
- **100 ms measuring × 50% efficiency × decay losses = 6 ions**

➲ For ^{53}Ca & ^{53}K, the cycle has to be optimised to get 1 ion/cycle

1 ion/cycle → 3 ions/s
N = 3000
17 mn for one measurement !

- 3 shifts for the set-up of each elements
- 1 shift for each isotope

Total of 20 shifts

Collaboration

H. Savajols	GANIL/TRIUMF	Scientist	50 %
J. Dilling	TRIUMF	Scientist	50 %
P. Delheij	TRIUMF	Scientist	50 %
W. Mittig	GANIL	Scientist	20 %
P. Roussel-Chomaz	GANIL	Scientist	20 %
A.C.C. Villari	GANIL	Scientist	20 %
A. Chbihi	GANIL	Scientist	10 %
A. Gillibert	CEA/Saclay	Scientist	10 %
N. Orr	LPC/Caen	Scientist	10 %
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F.Sarazin	Colorado School of Mines	Professor	10 %
G. Gwinner	U. of Manitoba	Professor	10 %
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L.Gaudefroy	GANIL	Post-Doc	10 %
M.Smith	UBC	Student	50 %
M.Brodeur	UBC	Student	50 %
C.Champagne	McGill	Student	50 %
V. Ryjkov	TRIUMF	Post-Doc	50 %