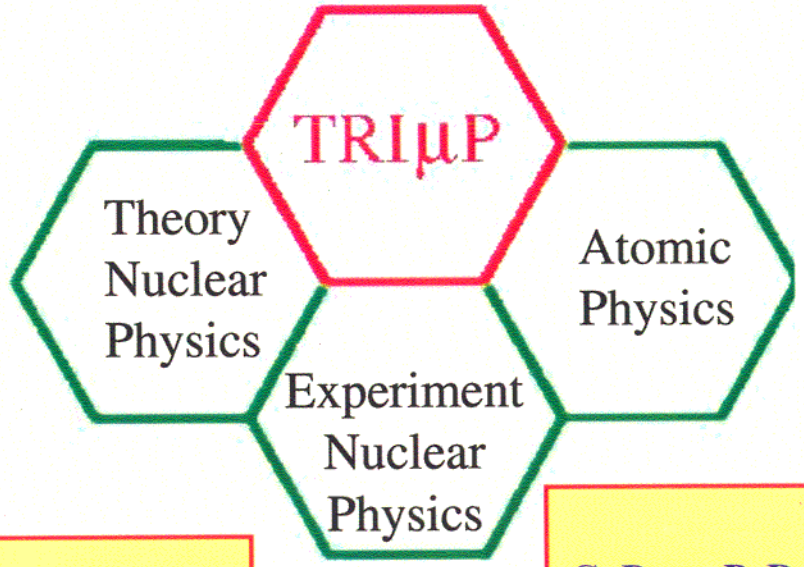
TRIμP

A new Facility to Investigate Fundamental Interactions with Optically Trapped Radioactive Atoms

Klaus Jungmann

ICHEP02, Amsterdam, 24-31 July 2002



funding:

FOM RuG

people :

G. Berg, P. Dendooven, O. Dermois, M. Harakeh, R. Hoekstra, S. Hoekstra, K. Jungmann, S. Kopecky, R. Morgenstern, R. Rogachevsky, M. Sanchez-Vega, , R. Timmermans, E. Traykov, S. Umakanth, M. van Veenhuizen, H. Warringa, L. Willmann, H. Wilschut

+ many more

project ⇒ program

2001 ⇒ 2013

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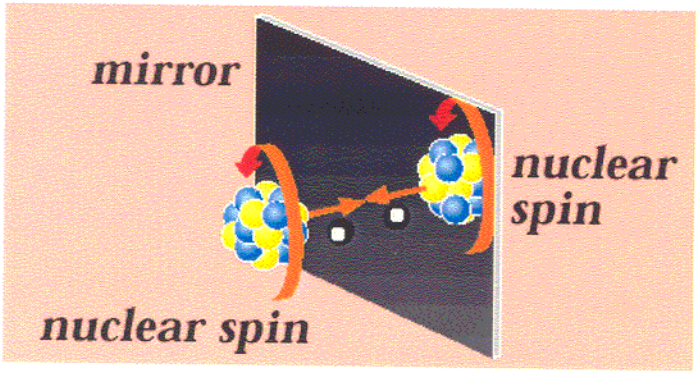
Some Questions related to TRIμP Physics

- **Origin of Parity Violation** in Weak Interactions

  - (nature prefers lefthandedness)

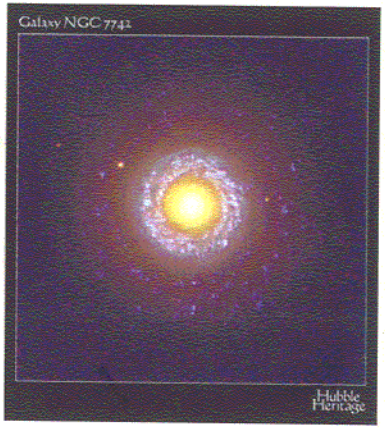
  ⇒ details of β-decays

  Na, Ne isotopes



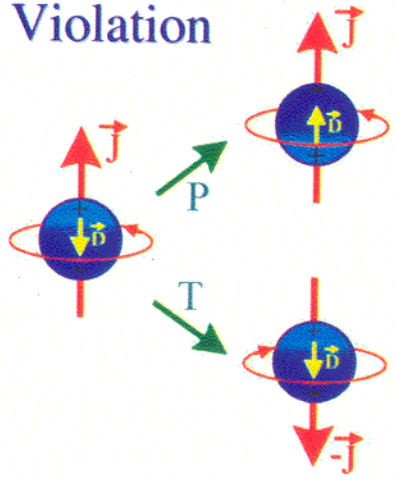
- **Dominance of Matter over Antimatter** in Universe ?

  CP - Violation, Time Reversal Symmetry, Parity Violation



⇒ permanent electric dipole moments ?

Ra isotopes



Exclusive measurements

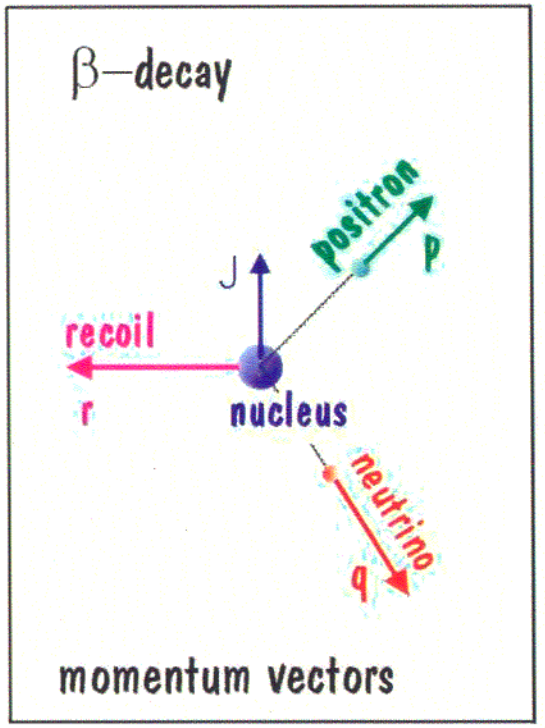
$$\frac{\mathrm{d}^2W}{\mathrm{d}\Omega_e\,\mathrm{d}\Omega_\nu} \sim 1 + a\frac{\boldsymbol{p}\cdot\hat{\boldsymbol{q}}}{E} + b\Gamma\frac{m_e}{E}$$

$$+ \langle \boldsymbol{J} \rangle \cdot \left[A\frac{\boldsymbol{p}}{E} + B\,\hat{\boldsymbol{q}} + D\frac{\boldsymbol{p}\times\hat{\boldsymbol{q}}}{E} \right]$$

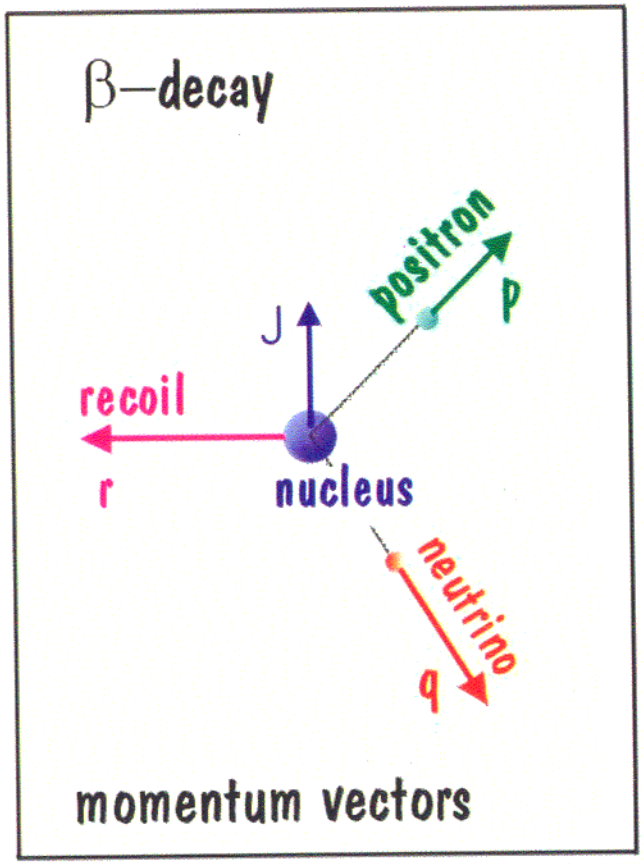
$$+ \langle \boldsymbol{\sigma} \rangle \cdot \left[G\frac{\boldsymbol{p}}{E} + Q\langle \boldsymbol{J} \rangle + R\langle \boldsymbol{J} \rangle \times \frac{\boldsymbol{p}}{E} \right]$$

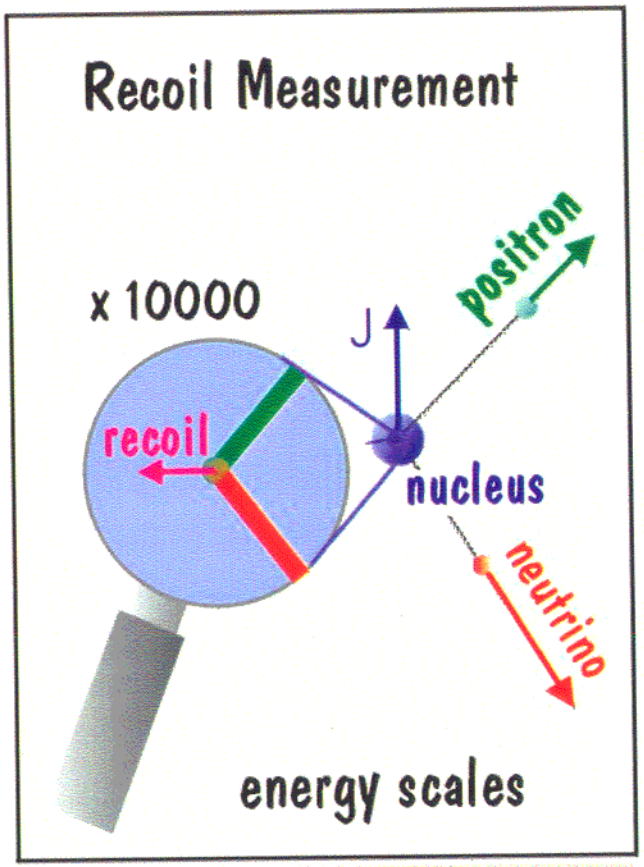
integrate over all spin variables
only a and b remain

$$dW = 1 + a\beta_e \cos\theta_{ev}$$



Why traps?





$$\langle \vec{J} \cdot \vec{p} \times \vec{q} \rangle \neq 0 \ ?$$

$$E_{recoil} = \frac{(\vec{p}+\vec{q})^2}{2M_{recoil}} < 100\,\text{eV}$$

Maximal experimental control

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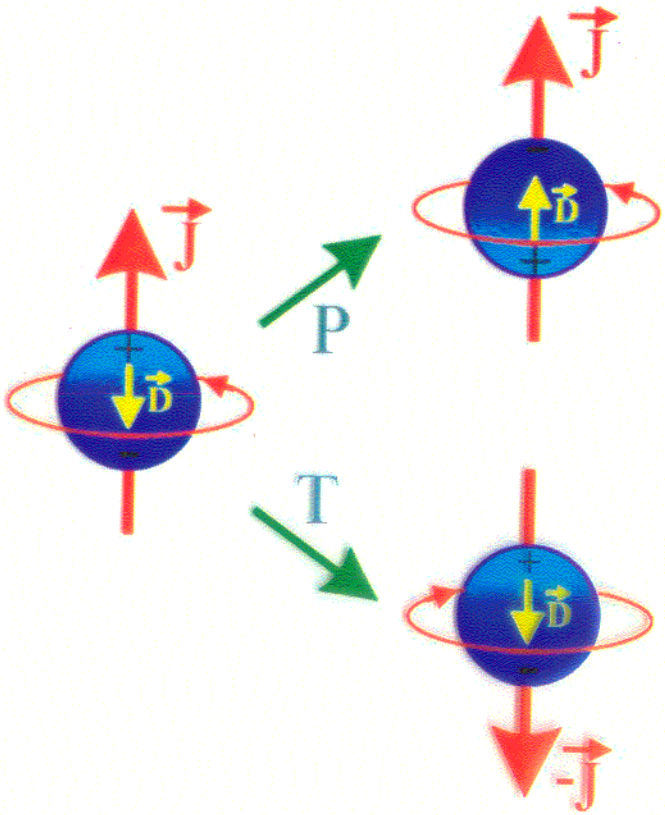
Experiments on β-Decays in Traps

β–ν Correlations	^{6}He, ^{14}O, ^{19}Ne, ^{35}Ar, ^{38m}K	GANIL, ANL, LBNL, ISOLDE, TRIUMF, KVI
β– Asymmetry	^{19}Ne, ^{20}Na, ^{21}Na, ^{37}K, ^{82}Rb	LBNL, TRIUMF, LANL, KVI

Experiments on Parity Violation in Traps

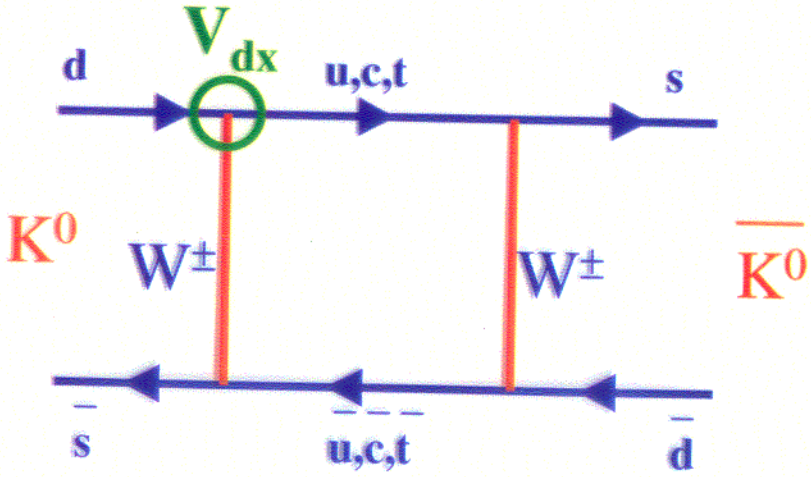
^{210}Fr, ^{211}Fr	Stony Brook, JILA, INFN

Time reversal violation and EDM



TRV is possible in the SM

CP or T violation in $K^0 \leftrightarrow \overline{K^0}$



immeasurably small otherwise

extensions SM have much larger EDM

EDM tool for theory selection

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Permanent Electric Dipole Moments

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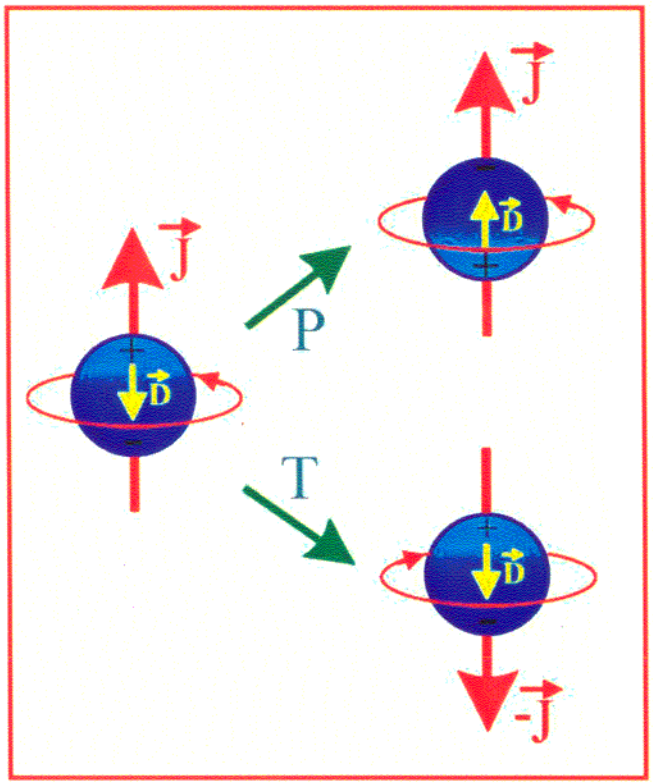


EDMs violate
- **P**arity
- **T**ime Reversal
- **CP** Symmetry

There can be only one vector in the system

$$\Rightarrow \quad \vec{D} = \eta \bullet \mu_x \bullet c^{-1} \bullet \vec{J}$$

Spin precession in an Electric Field E

$$\Rightarrow \quad \vec{\omega} = \frac{\vec{D} \bullet \vec{E}}{\hbar} \frac{\vec{E} \times \vec{J}}{|\vec{E} \times \vec{J}|}$$

Sensitivity of spin precession experiments proportional to:

$$\frac{1}{\text{Polarization}^2 \bullet \text{efficiency} \bullet \sqrt{\text{number}} \bullet \text{time}}$$

Enhancement Effects for Permanent Electric Dipole Moments

- Any quantum object cannot have a permanent electric dipole moment unless there is P, T and CP violation.

- "Polar" objects like molecules (ammonia) or nuclei do not have a permanent electric dipole moment, despite listings in tables! These objects don't have such thing like a shape in a well defined energy state !!!!!

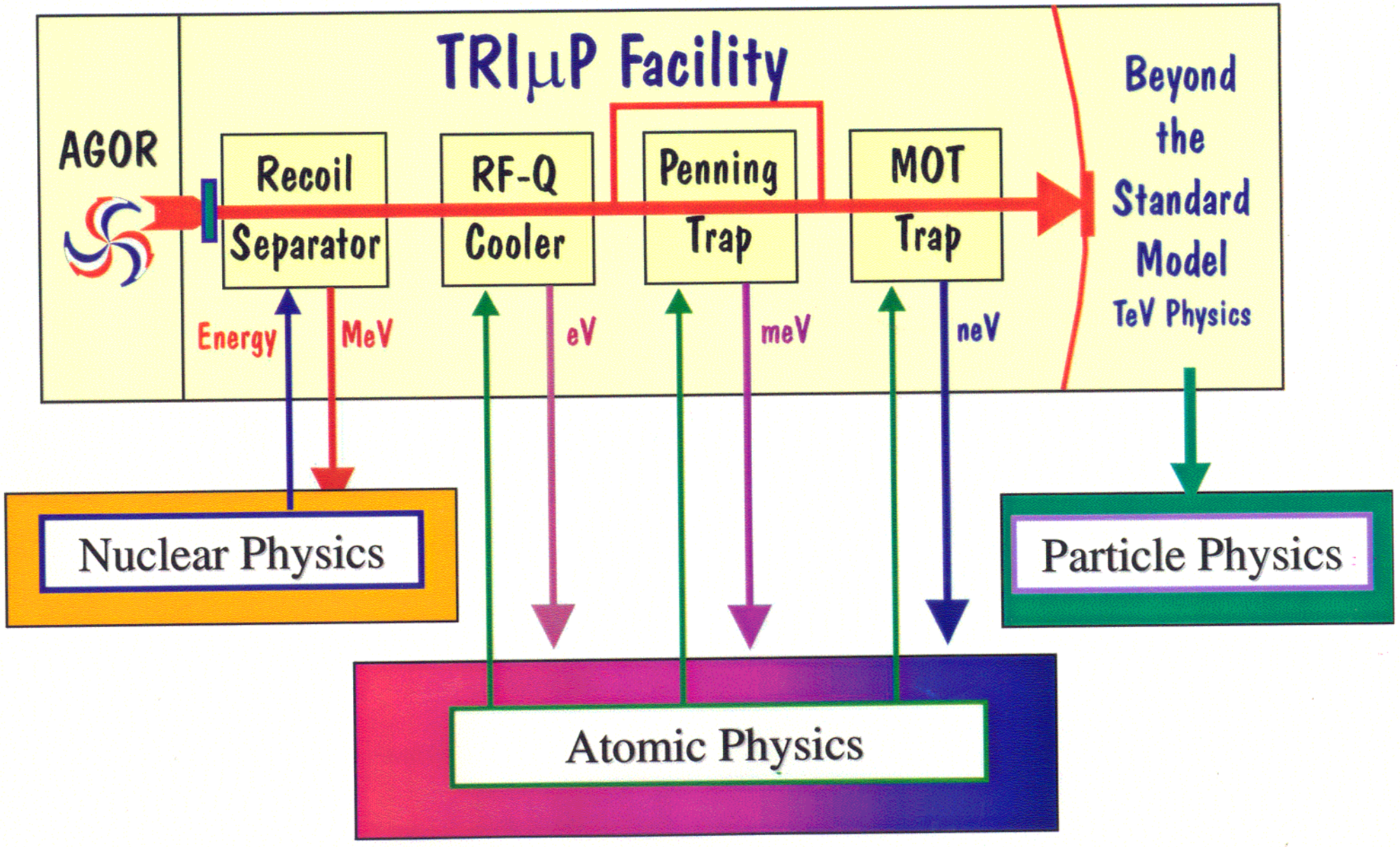
- A permanent electric dipole moment must be proportional to the spin

- Similar to atomic parity violation there is a Z^3 enhancement

- There is an an enhancement due to induced dipole moments

$$D_A = \sum_{n'} \frac{< nl | -d_e(\beta - 1)\vec{\sigma}\cdot\vec{E} | n'(l+1) >< n'(l+1) | -e\vec{r} | nl >}{E_{nl} - E_{n'(l+1)}} + \text{c.c.}$$

- Some enhancement factors: Tl -585, Fr 1150, Ra 40000, YbF 10^6


TRIμP Facility
AGOR
Recoil Separator
RF-Q Cooler
Penning Trap
MOT Trap
Beyond the Standard Model
TeV Physics
Energy
MeV
eV
meV
neV
Nuclear Physics
Particle Physics
Atomic Physics

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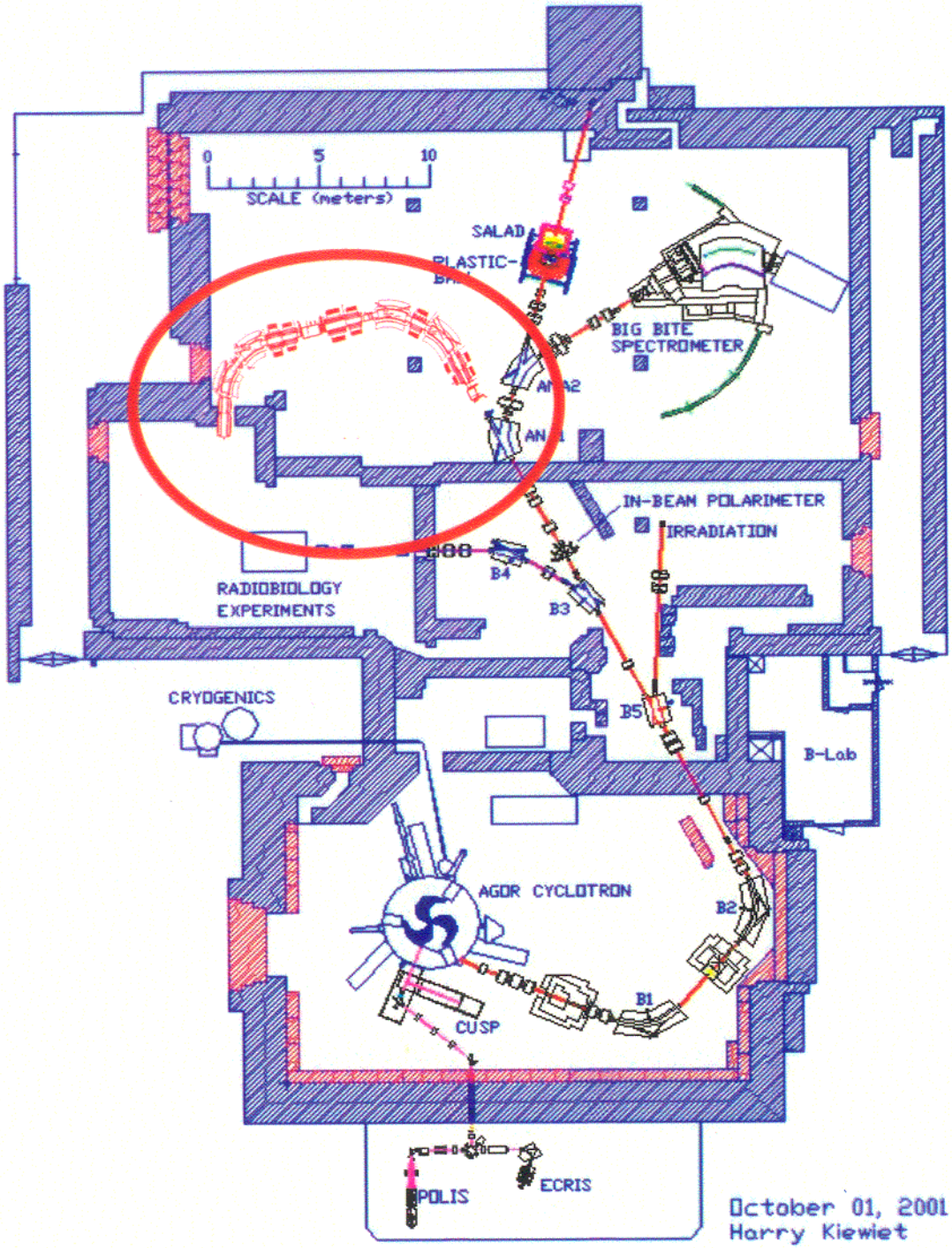
0
5
10
SCALE (meters)
SALAD
PLASTIC-
BIG BITE
SPECTROMETER
IN-BEAM POLARIMETER
IRRADIATION
RADIOBIOLOGY
EXPERIMENTS
B4
B3
B5
CRYOGENICS
B-Lab
AGOR CYCLOTRON
B2
B1
CUSP
POLIS
ECRIS
October 01, 2001
Harry Kiewiet

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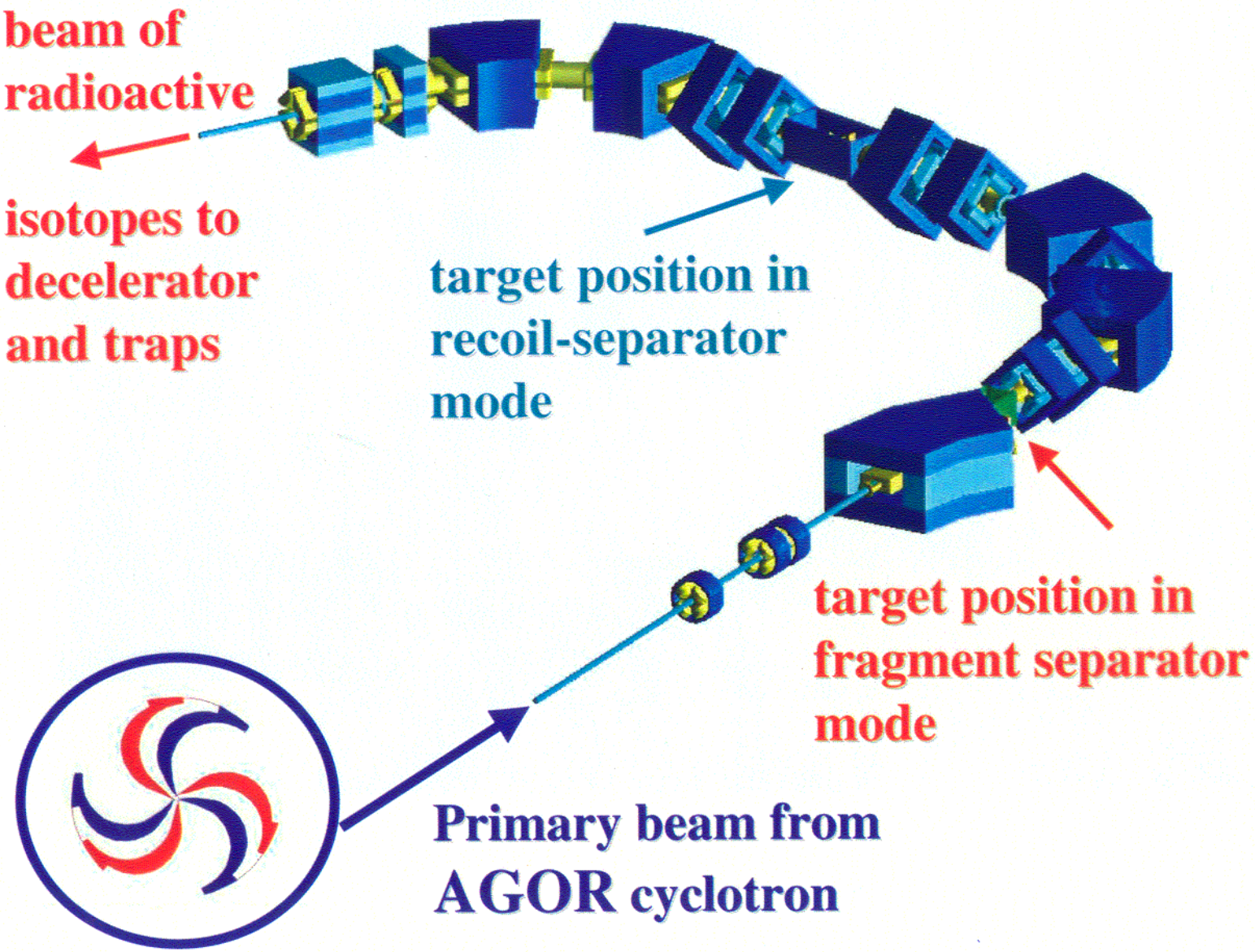
beam of
radioactive
isotopes to
decelerator
and traps
target position in
recoil-separator
mode
target position in
fragment separator
mode
Primary beam from
AGOR cyclotron

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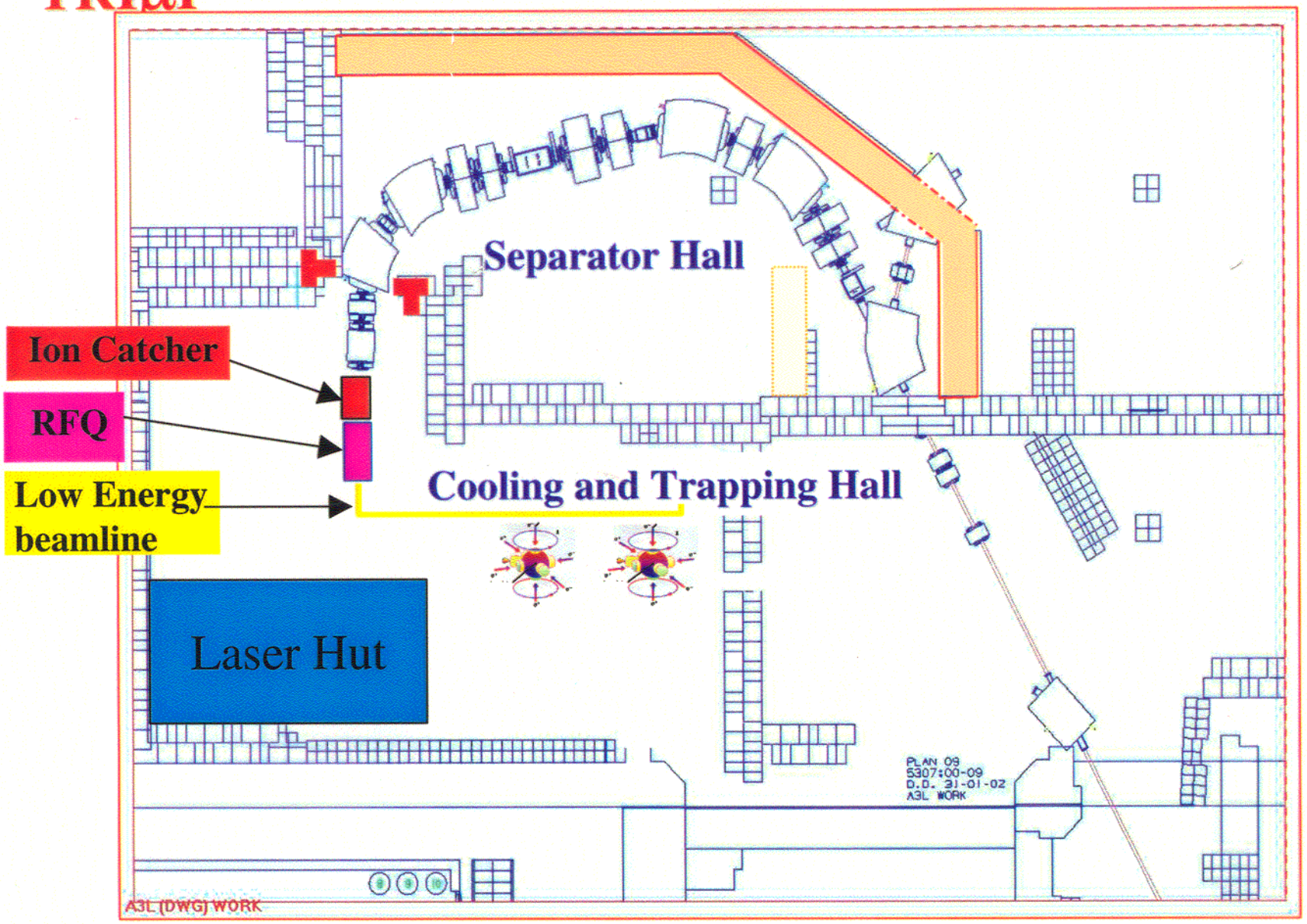
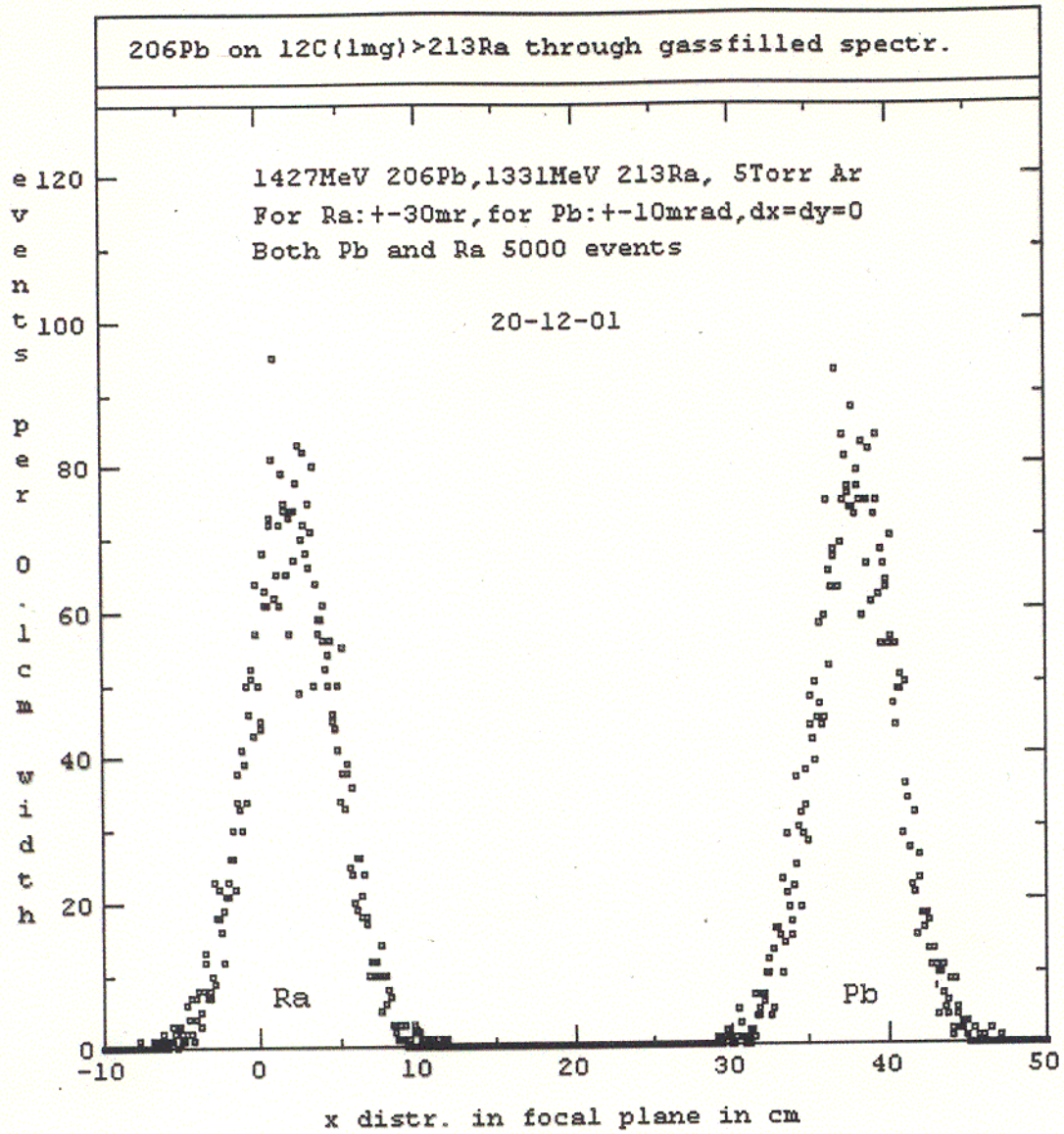

Separator Hall
Ion Catcher
RFQ
Low Energy beamline
Cooling and Trapping Hall
Laser Hut
PLAN 09
5307:00-09
D.D. 31-01-02
A3L WORK
A3L (DWG) WORK


206Pb on 12C(1mg)>213Ra through gassfilled spectr.
1427MeV 206Pb,1331MeV 213Ra, 5Torr Ar
For Ra:+-30mr,for Pb:+-10mrad,dx=dy=0
Both Pb and Ra 5000 events
20-12-01
events per 0.1cm width
Ra
Pb
x distr. in focal plane in cm

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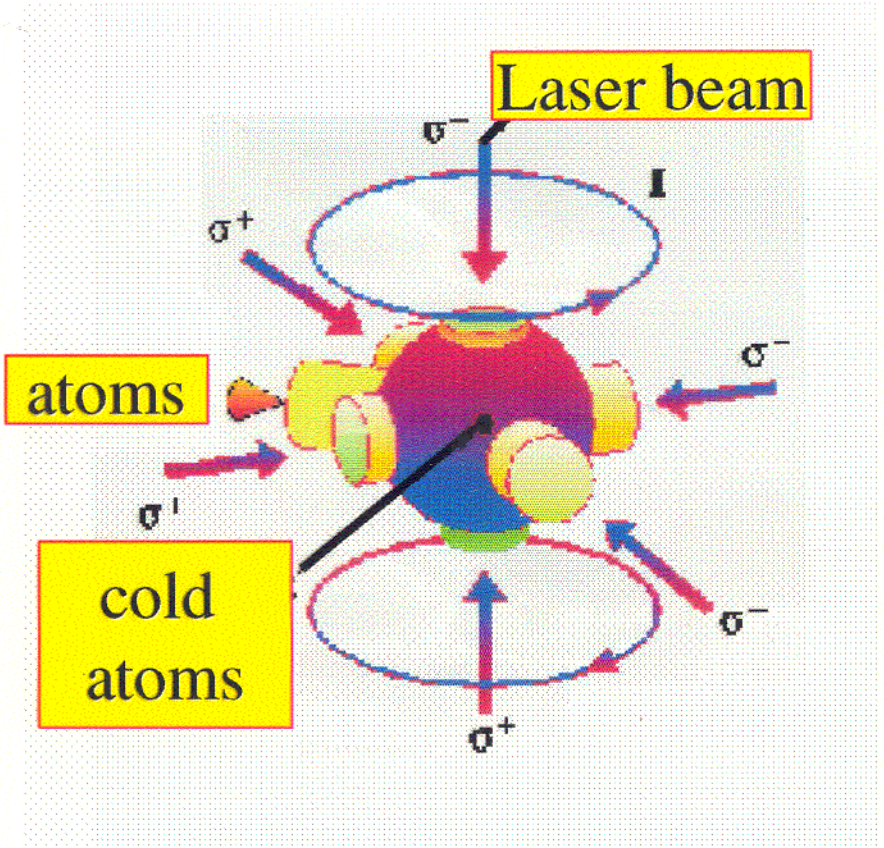
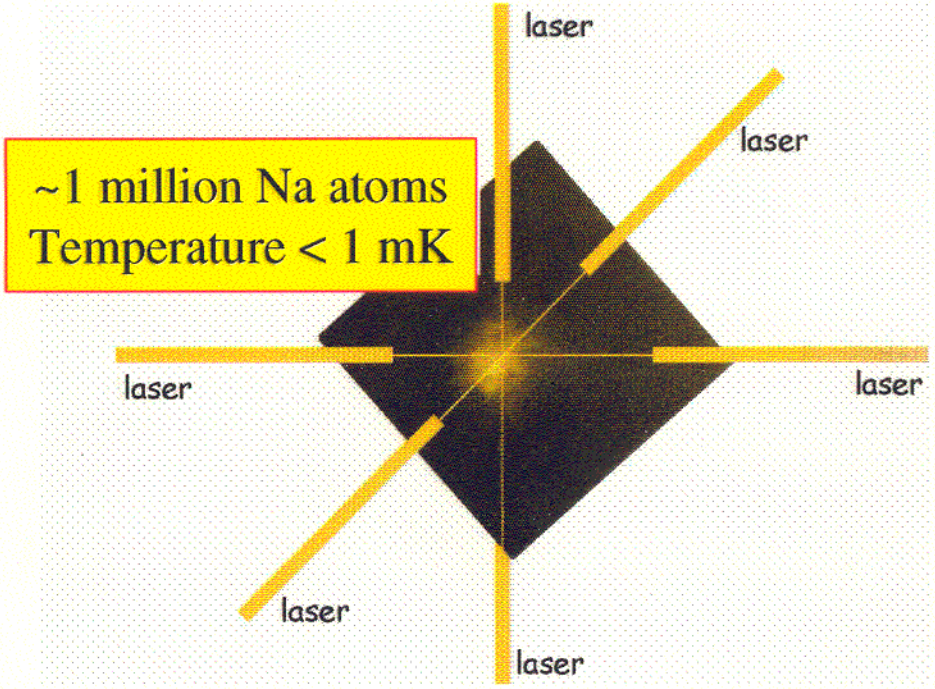
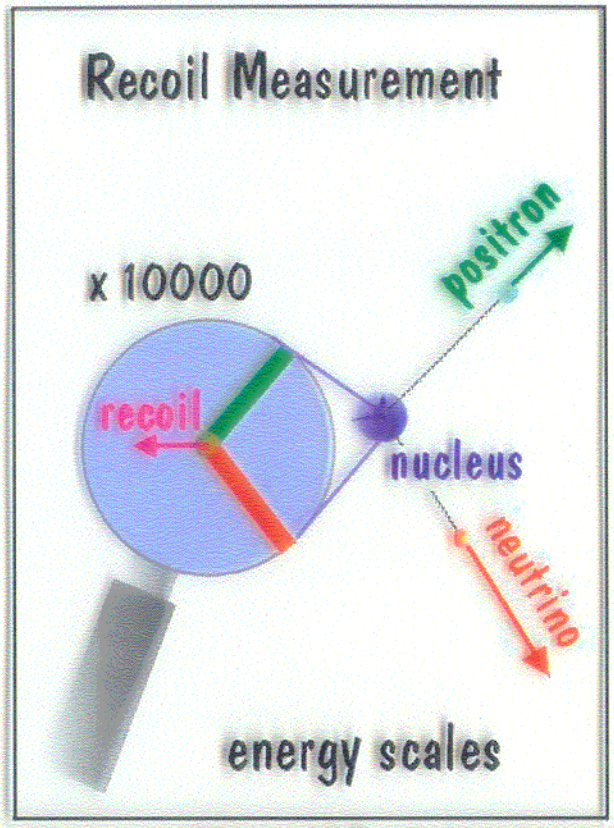
Magneto-Optical Trap (MOT)





The role of (optical) trapping



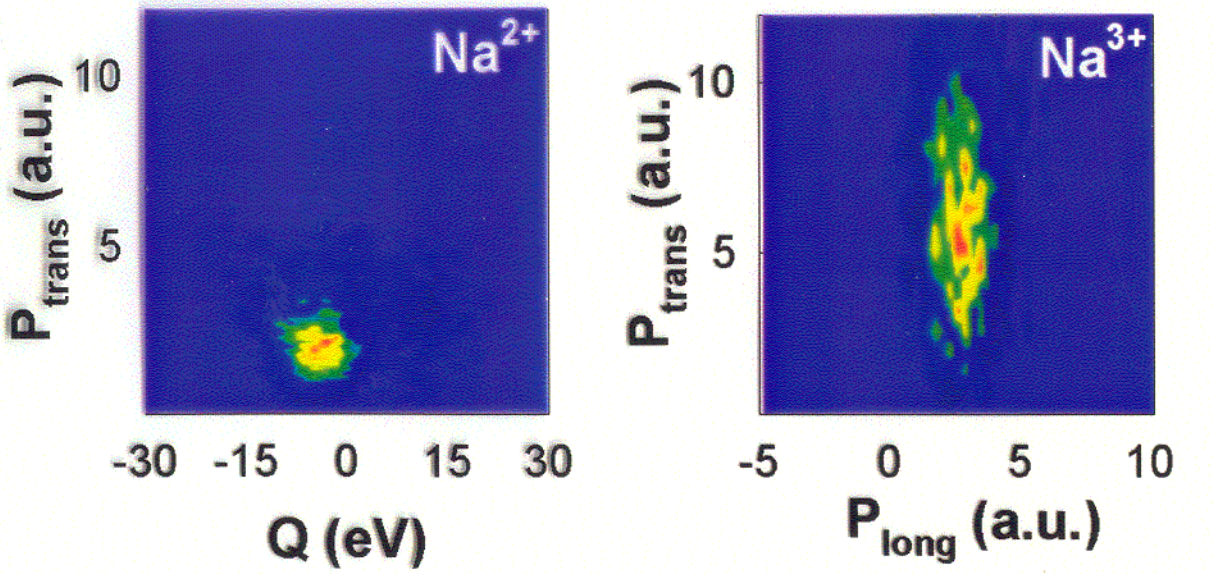
$$E_{recoil} = \frac{(\vec{p}+\vec{q})^2}{2M_{recoil}} < 100\,\text{eV}$$

Optical trap sample

- isotope selective, spin manipulation
- point source, no substrate
- recoil (ion) mass spectrometry

From KVI atomic physics: He^{2+} + Na

S. Knoop



1 a.u.=15 A·μeV

Ideal environment for precision experiments

Time Schedule

KVI

- Project started 2001
- Programme approved July 2001

- Separator, Cooler, RFQ, Optics Laboratory

  Orientation Phase in 2001 - now going to Design Phase
- Separator ready for bids - contract expected June 2002
- Magnet Delivery July 2003
- Separator Setup and Commisioning 2003/2004

- Ready for Experiments End 2004

- In the mean time: Preparatory Experiments,

  Isotope Production,Gas Stopping,Cooling, RFQ, base experiments,...