

# Atom trapping at (TRI $\mu$ P) KVI

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**TRI $\mu$ P Facility**



**Towards cooling of Heavy  
Alkaline Earth Elements (Ba, Ra)**

**Barium Spectroscopy**

**Next steps**



**TRI $\mu$ P**

NIPNET, HITRAP workshop, GSI, NOV 12-13, 2004



# TRI $\mu$ P - Trapped Radioactive Isotopes: $\mu$ -laboratories for fundamental Physics



AGOR  
cyclotron

Production  
Target

Magnetic  
Separator

Ion  
Catcher

RFQ  
Cooler

Atom  
Trap

Particle Physics

MeV

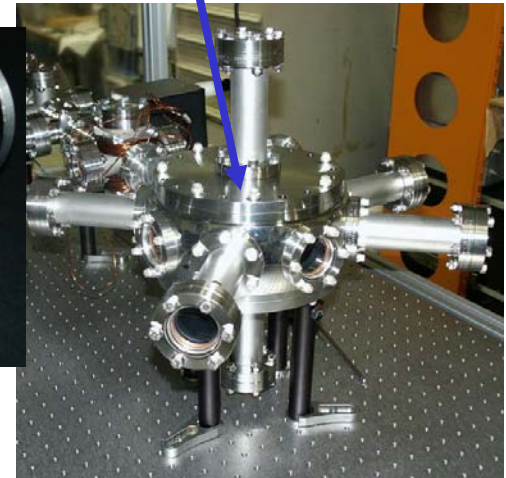
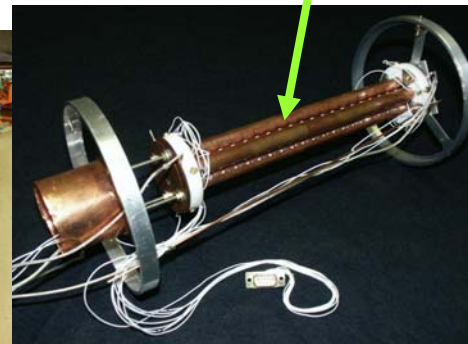
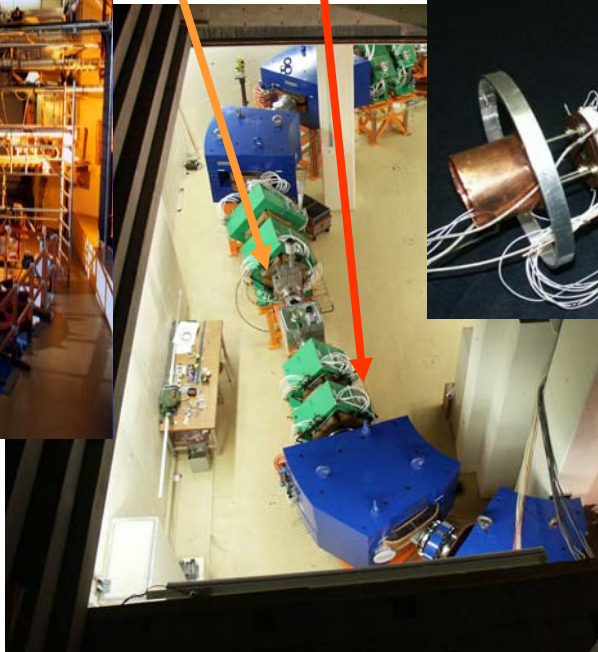
keV

eV

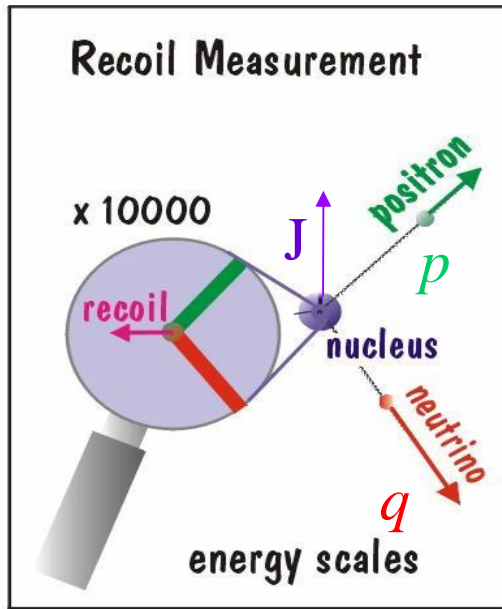
meV

neV

*Beyond the  
Standard Model  
TeV Physics  
EDM/ $\beta$ -decay*



# $\beta$ -decay

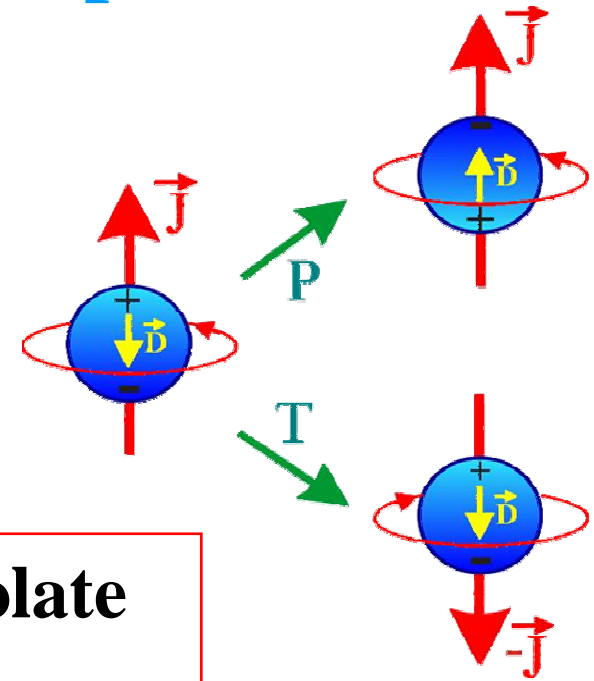


$$p, q \approx 1 \text{ MeV}/c \approx 260 \text{ a.u.}$$

$$E_{\text{recoil}} = (p + q)^2 / 2M_{\text{recoil}} < 100 \text{ eV} \approx 3.6 \text{ a.u.}$$

- $\beta$ - $\nu$  angular correlations in nuclear  $\beta$ -decay
- Suitable isotope  $^{21}\text{Na}$

# Electric Dipole Moment



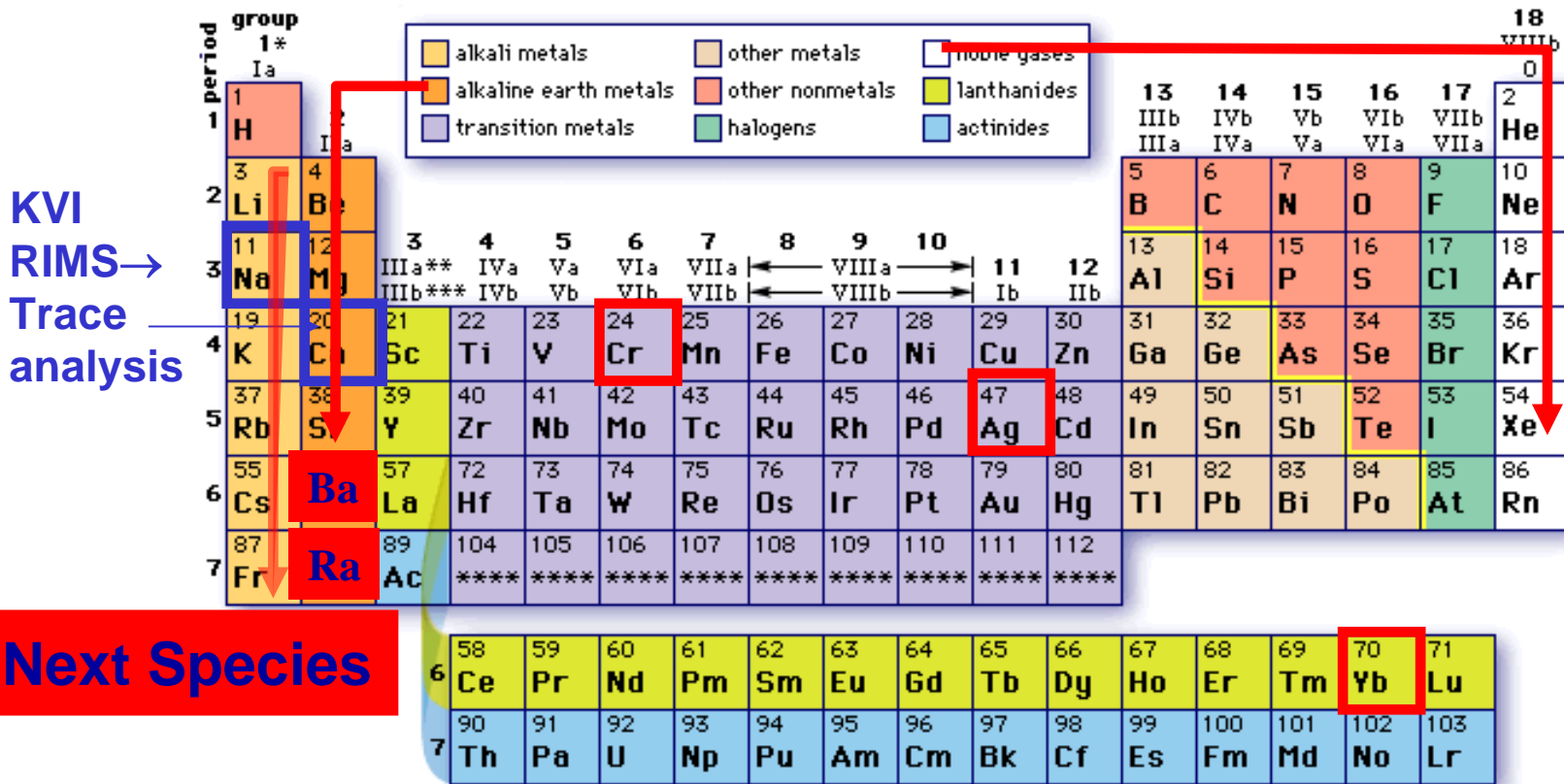
**EDMs violate**

- **Parity**
- **Time Reversal**

**Radium:** Excellent candidate

V. A. Dzuba et al. Phys. Rev.A61 062509(2000)

# Laser Cooling Chart



**Efficient production of cold atoms:  
Magneto Optical Trap**

**Other Possibilities: Buffer Gas loading into magnetic trap**  
J. Doyle, Harvard; A. Richter, Konstanz

# Neutral Atom Traps at KVI

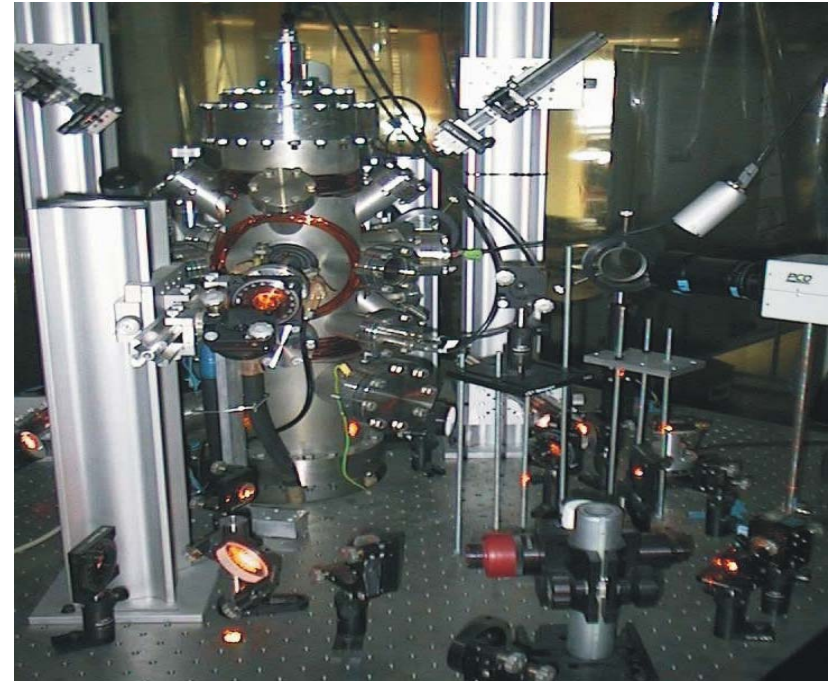
## Calcium(Ca) MOT



ALCATRAZ: Ultra sensitive isotope trap analysis of Calcium

**TRI $\mu$ P**

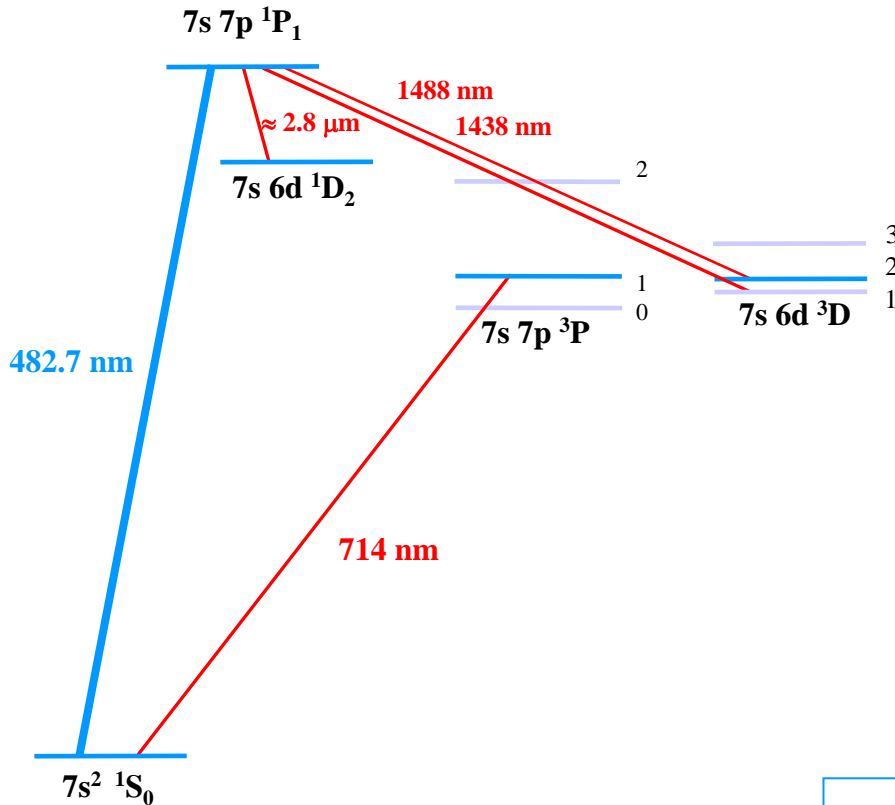
## Sodium(Na) MOT



MOTRIMS: Recoil Ion Momentum Spectroscopy



# Radium Atomic Structure



Energy level data:

E. Rasmussen, Z. Phys. 86, 24 (1933) and 87, 607 (1934);

H.N. Russel, Phys. Rev. 46, 989 (1934)

## Spectroscopy of P and D states

- Lifetime measurement
- Energy level spacing
- Hyperfine structure
- Needed for atomic structure calculations

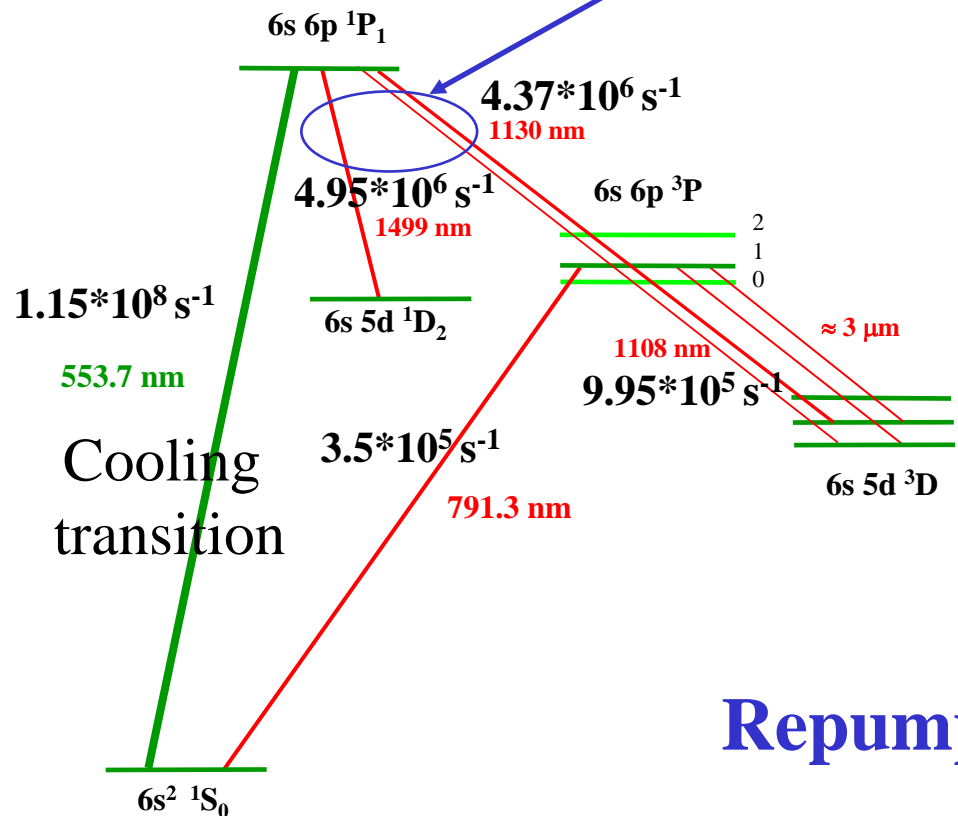
Calculations done by K Pachuki and Flaumbam, Dzuba et al.

But what about laser cooling of Radium?

# Barium - Testing ground for laser cooling and trapping of Radium

## Repump lasers

## Constraints

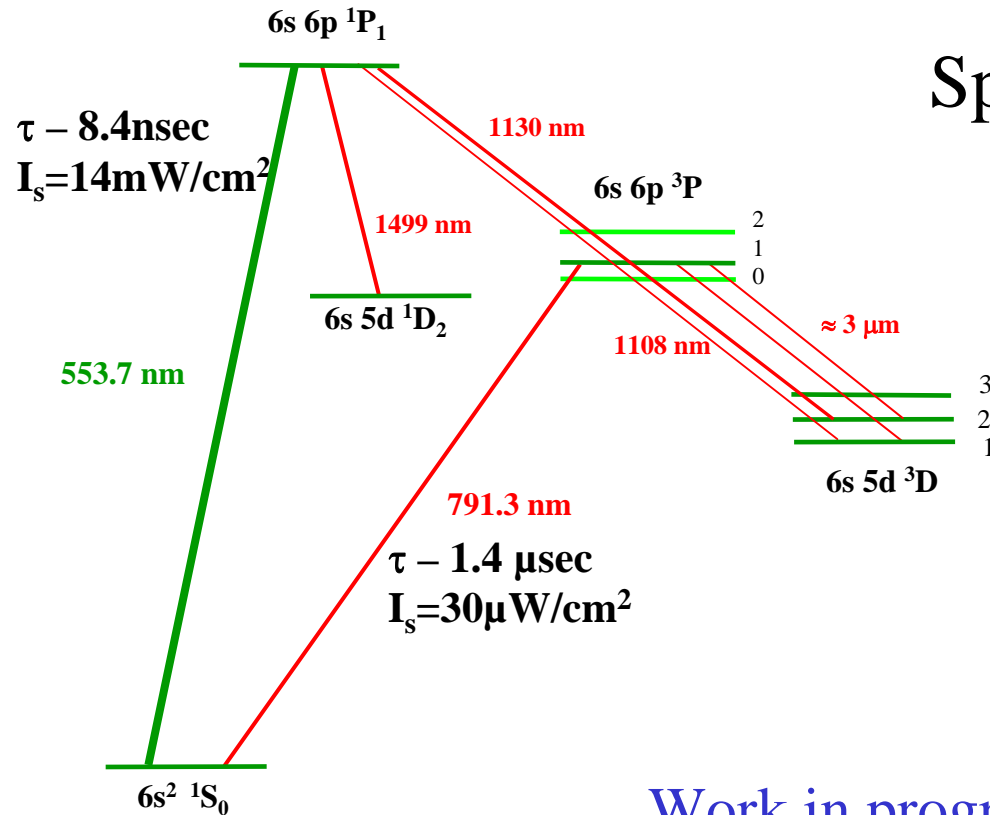


- Low lying meta-stable D states
- Leakage to D-states after interacting with  $\sim 340$  photons
- 3 Repumping lasers needed

Repump (Fiber) lasers ordered

# Spectroscopy of Barium

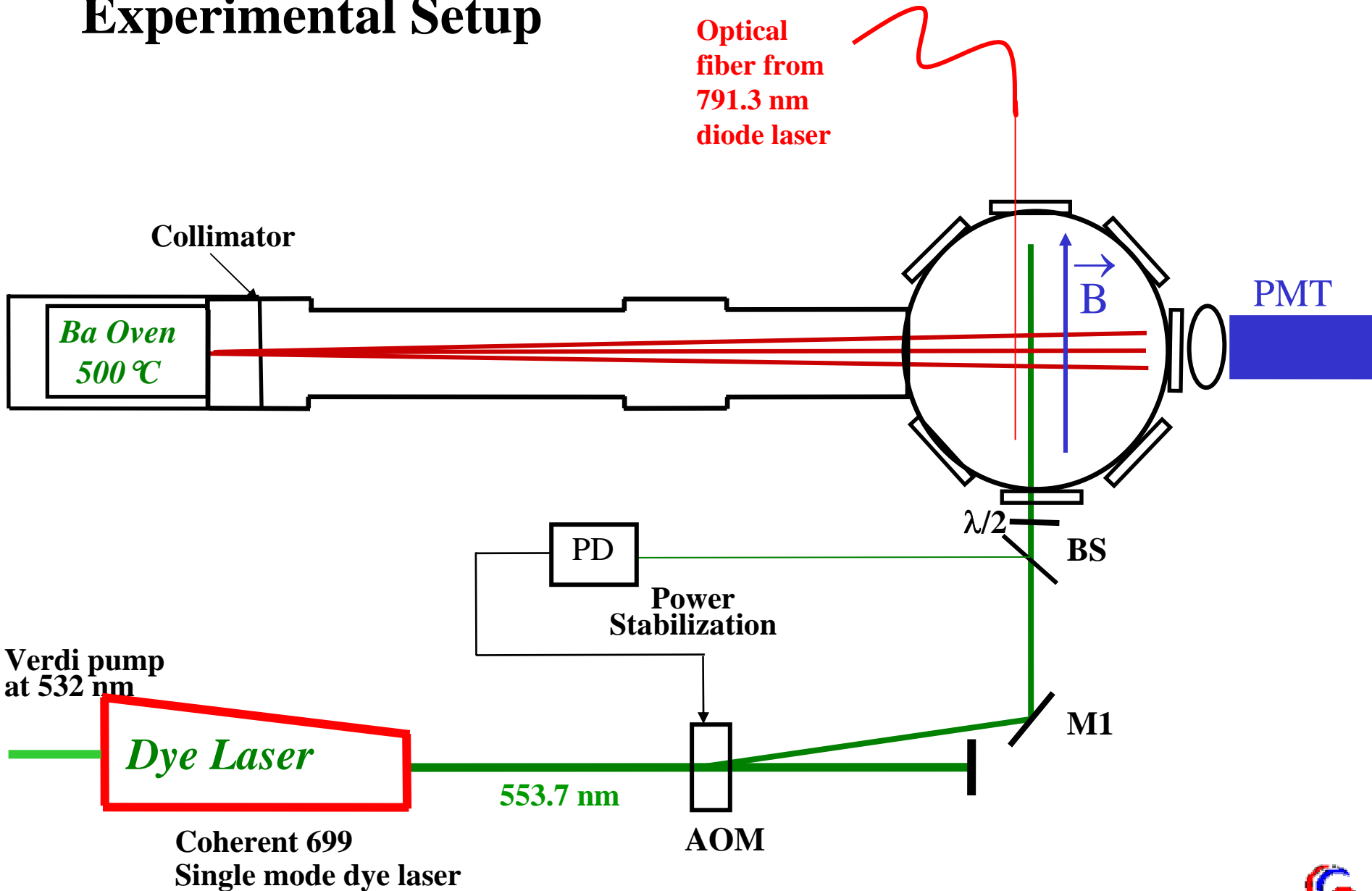
## Spectroscopy of **P** and **D** states



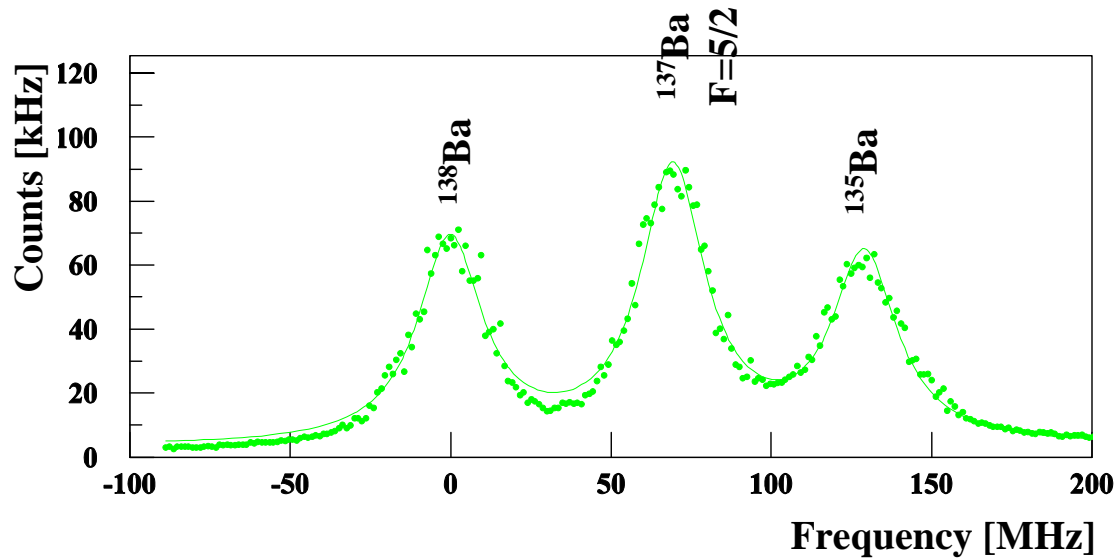
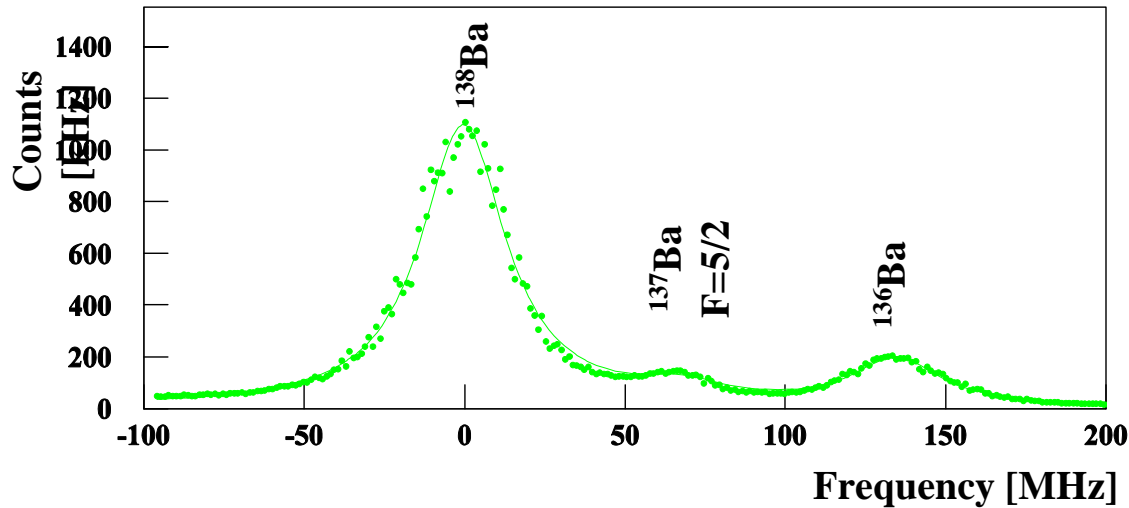
- Life time measurement
- Hyperfine structure

Work in progress with a thermal atomic beam

# Experimental Setup



# Fluorescence at 553.7 nm from different Ba isotopes

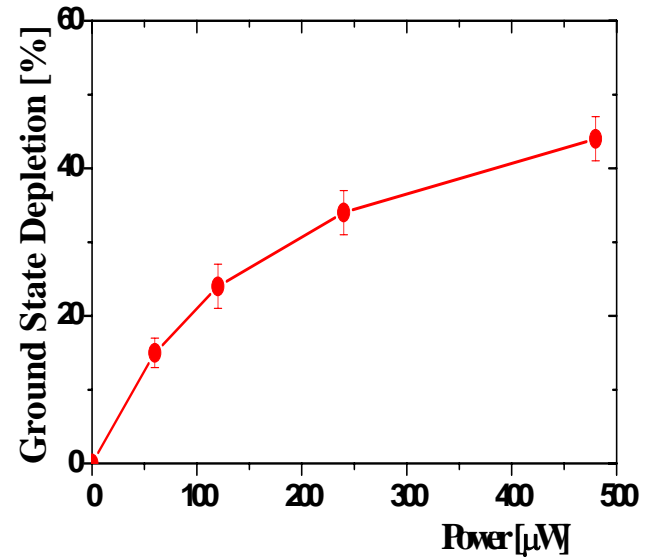
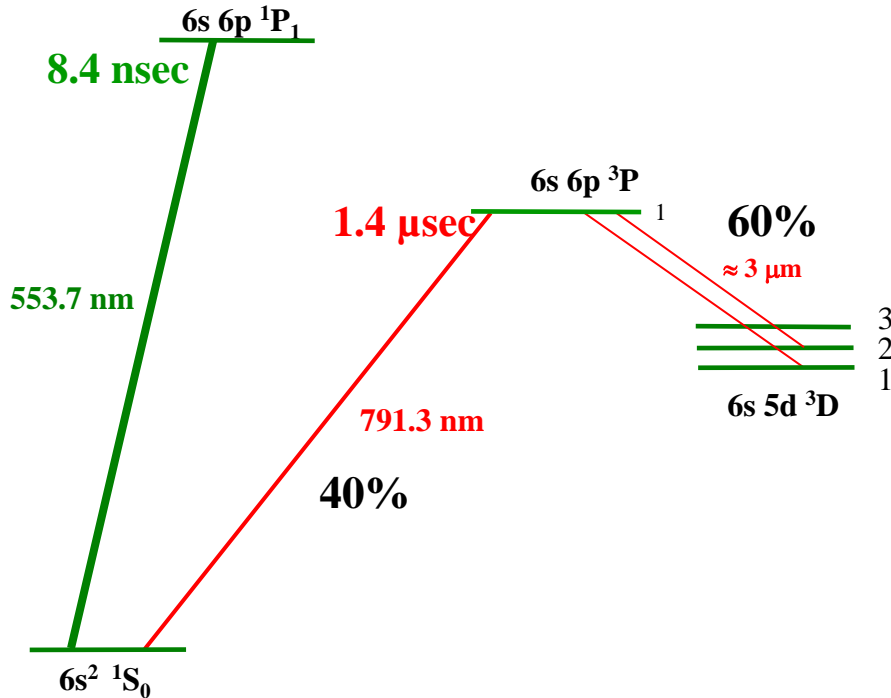


# Isotope shifts and Hyperfine Splitting of the $^1S_0 - ^1P_1$ transition in Barium

Isotope	IS (MHz)*	HFS (MHz)	F
138	<u>0</u>	— 151.67	5/2
137	<u>215.1</u>	— 138.75	
136	<u>128</u>		
135	<u>259.3</u>	— -59.46	3/2
134	----	— -64.14	
132	----		
130	----	— -334.37	1/2
		— -219.17	

\* W A van Wijngaarden & J Li,  
Can.J. Phys. **73**, 484-488(1995)

# Intercombination line $^1S_0 - ^3P_1$

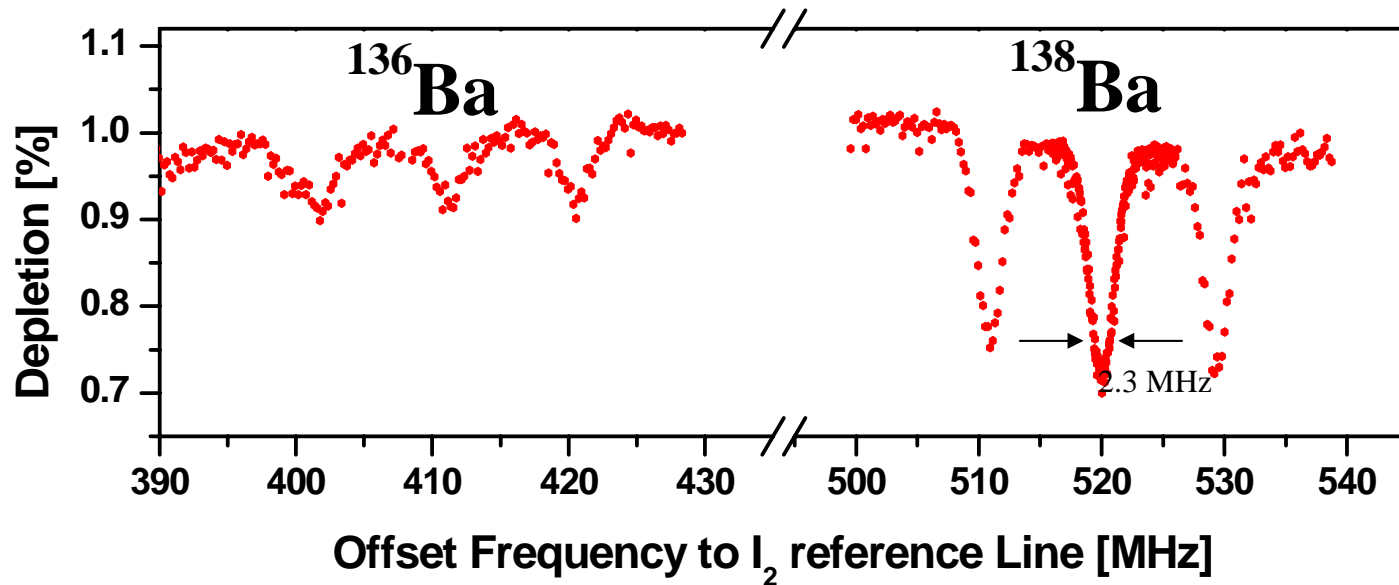


Creation of intense beam of meta-stable D-state atoms

# Hyperfine Splitting of $^1S_0-^3P_1$ transition in an External Magnetic field

$$\Delta\nu = g_J \mu m_J B$$

$$\Delta\nu_{IS} = ^{138}\text{Ba} - ^{136}\text{Ba} = 108.5 (3) \text{ MHz}$$



- Decay rate
- Branching into 3D states

# Isotope shifts and Hyperfine Splitting of the $^1S_0 - ^3P_1$ transition in Barium

Isotope	IS (MHz)	HFS (MHz)*	F
	<i>preliminary</i>		
138	<u>0</u>	— 1715.4	5/2
137	<u>375(5)</u>	— 1535.7	
136	<u>108.5(3)</u>		
135	<u>429(5)</u>		
134	----	— -1001.2	3/2
132	----	— -1109.0	
130	----	— -2604.6	1/2
		— -2928.5	

\* Zu Putlitz G, Z. Physik **175**, 543 (1963)

# Next steps

## Laser Cooling of Barium

- **Repump Lasers for**
  - $^1P_1 - ^1D_2$  transition @ 1500.4 nm
  - $^1P_1 - ^3D_2$  transition @ 1130.6 nm and
  - $^1P_1 - ^3D_1$  transition @ 1107.8 nm
- Delivery of Fiber lasers – January 2005
- Spectroscopy of meta-stable D-states

## Towards Radium

- Laser @482.5nm for  $^1S_0 - ^1P_1$  transition by frequency doubling Ti:Sapp Laser
- Production of Radium at TRI $\mu$ P
- Spectroscopy in a Radium beam

# TRI $\mu$ P Group:

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A. Young, L. Willmann, H.W. Wilschut

# Hanle effect

Life time of  $^1P_1$  state

$P_{\text{laser}} \perp B$  field

$$\tau_{\text{eff}} = h / (2\pi g_J \mu \Delta B_{1/2})$$

$$\tau_{\text{eff}} = 8 \text{ nsec} \pm 0.5 \text{ sec}$$

