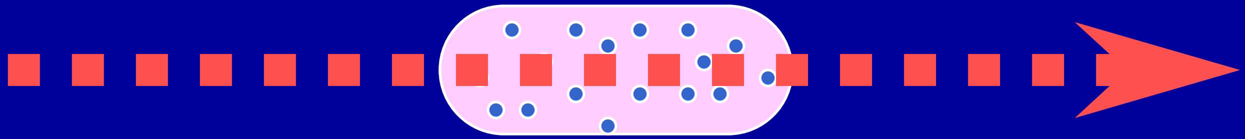
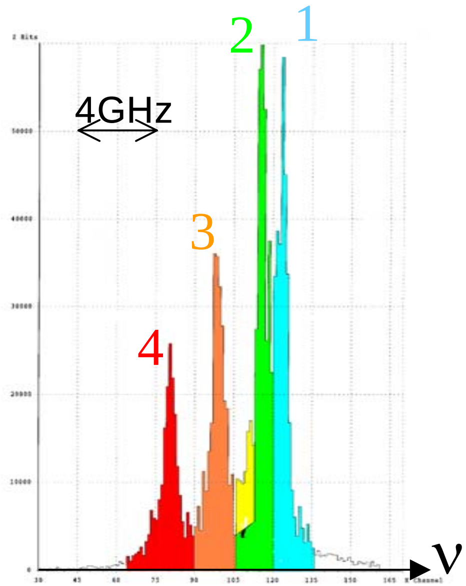
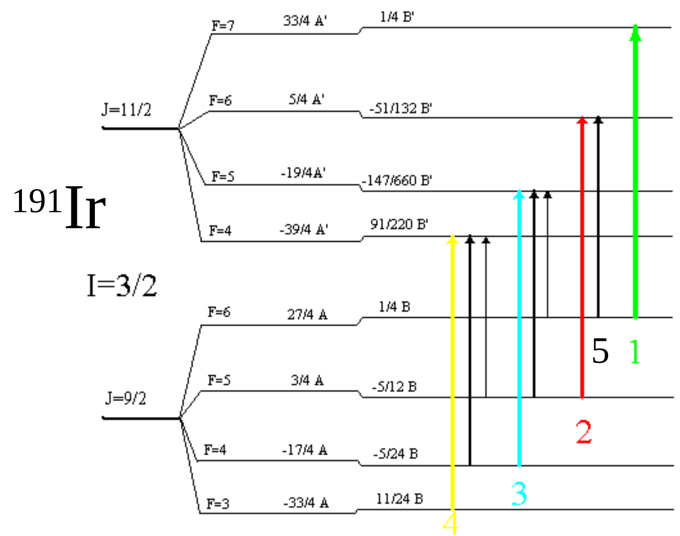
Collinear Laser Spectroscopy with Bunched Beams



J.E. Crawford
Titan Workshop
June 11, 2005

Hyperfine Interaction





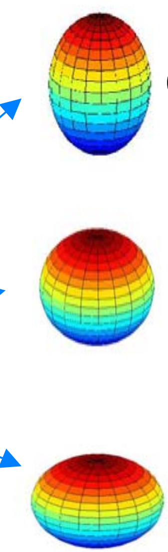
$$\vec{F} = \vec{I} + \vec{J}$$

$$\mathbf{A} = \frac{\mu_I \overline{H}_0}{IJ}$$

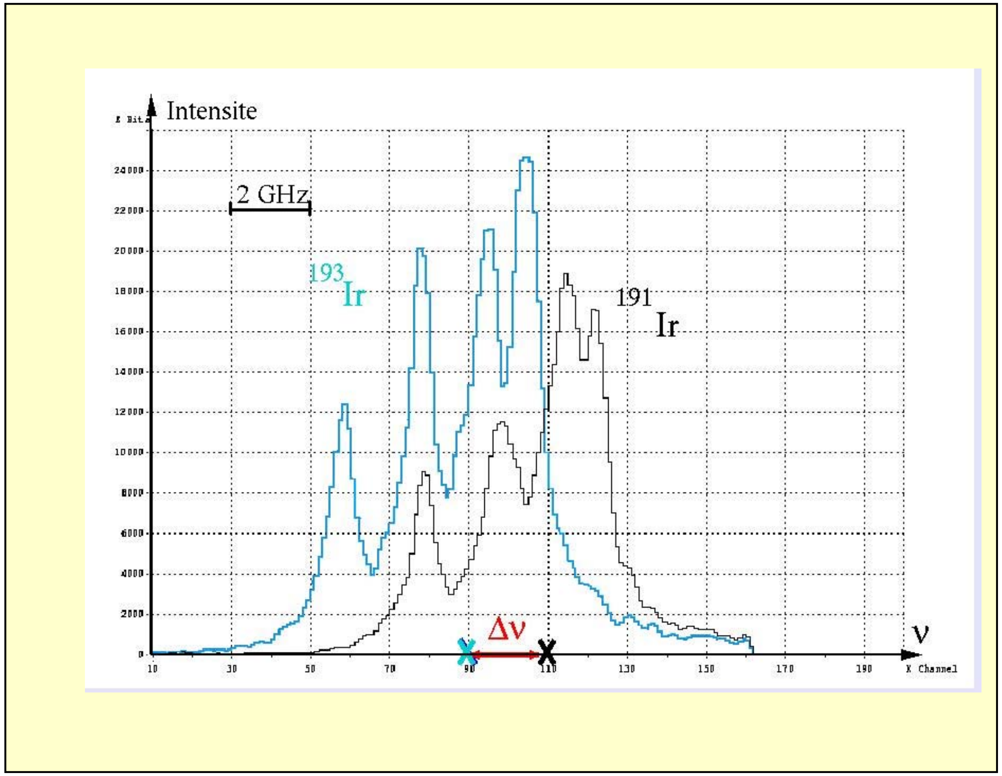
Nuclear Quantities

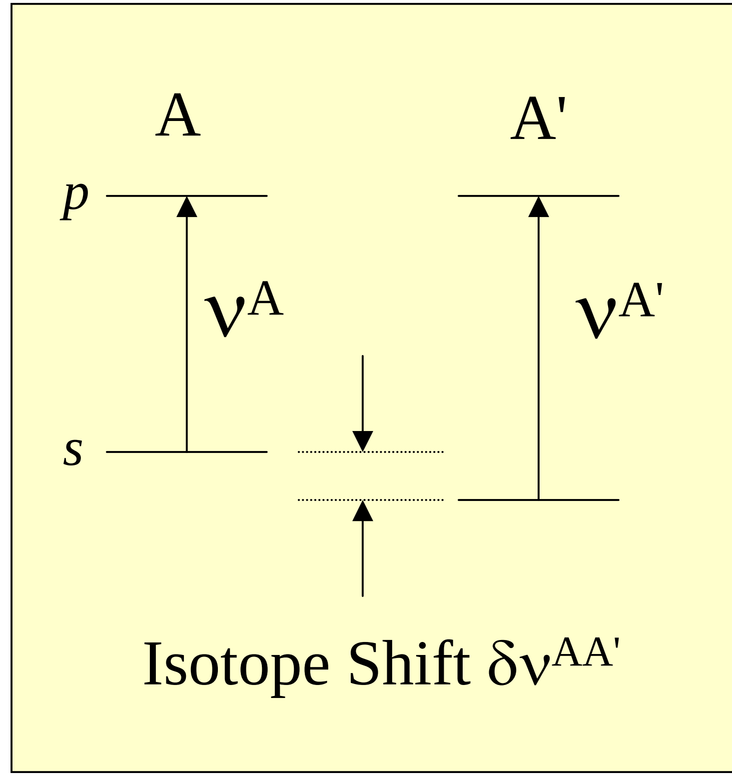
$$\mathbf{B} = e\, Q_S \overline{\Phi}_{JJ}(0)$$

$$Q_S = \frac{3K^2 - I(I+1)}{(I+1)(2I+3)} Q_0 \Longleftrightarrow \boxed{\beta_2}$$



Isotope Shift



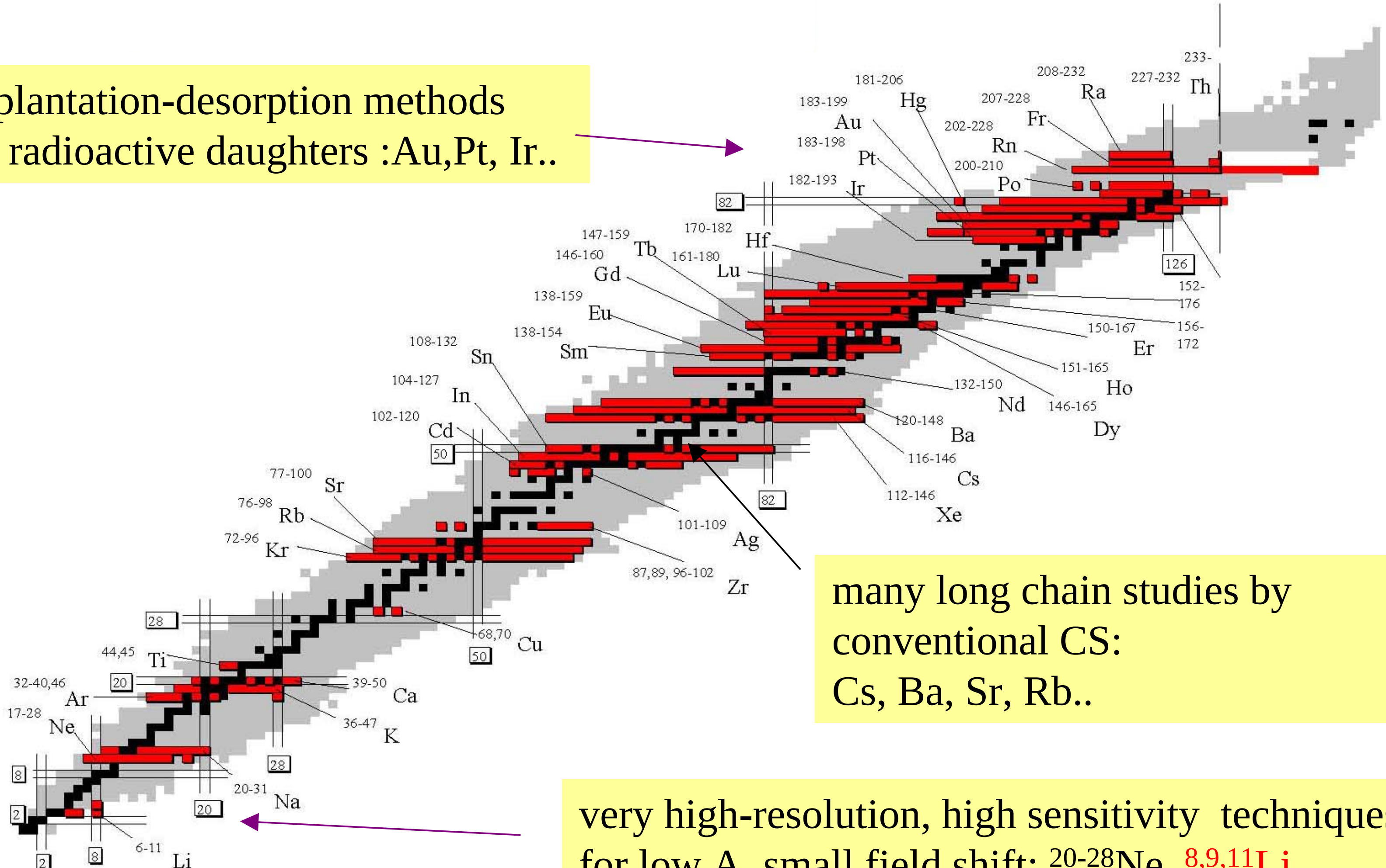


$$\Delta\nu_{(field)} = \text{constants x } \Delta\, |\psi(0)|^2 \;\; \delta\langle r^2\rangle$$

-easily detects a ~.01 fm change in size for 1 added neutron

Laser Spectroscopy on Long Isotopic Chains

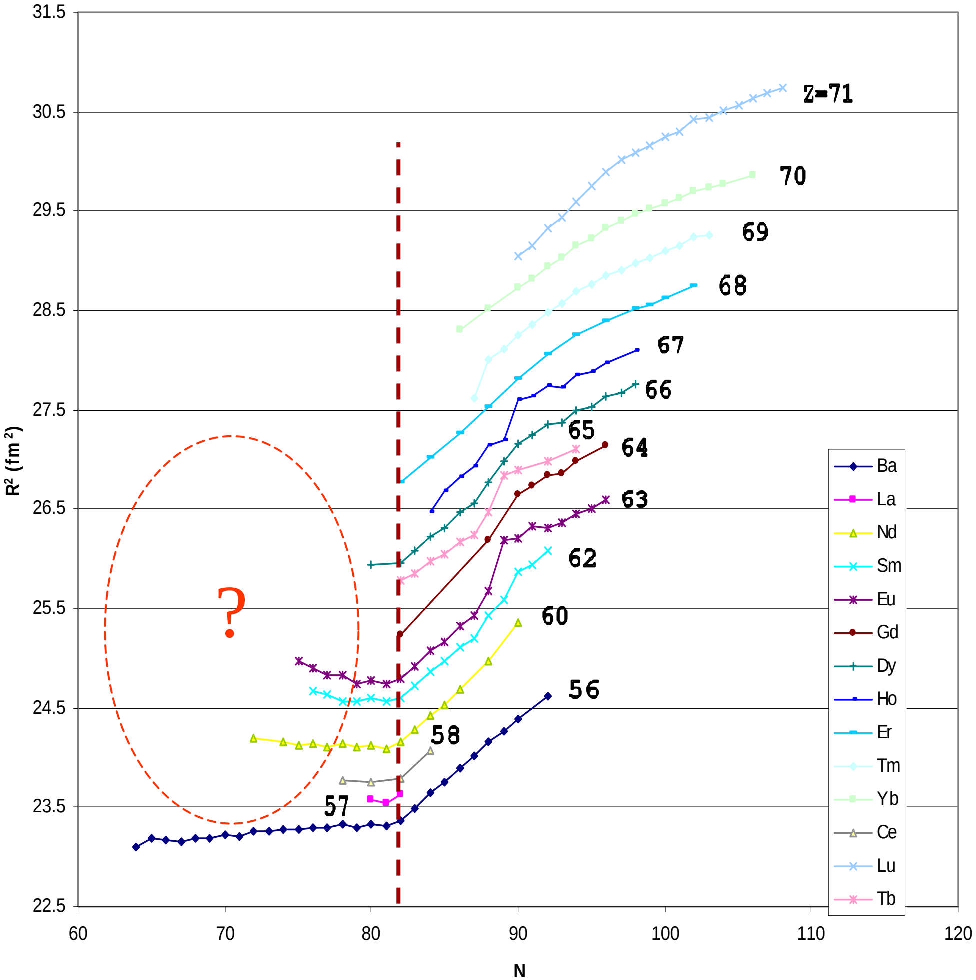
implantation-desorption methods
for radioactive daughters :Au,Pt, Ir..



many long chain studies by
conventional CS:
Cs, Ba, Sr, Rb..

very high-resolution, high sensitivity techniques
for low A, small field shift: $^{20-28}$Ne, ^{8,9,11}Li

TRIUMF Expt. E920 - Lanthanum IS



HFBCS-1 Nuclear Mass Table

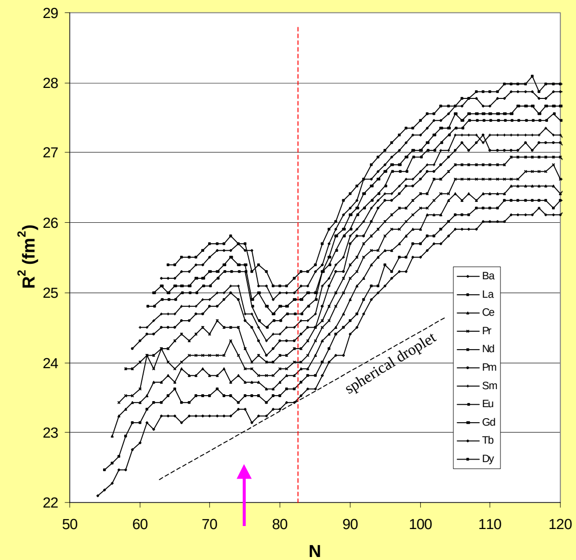
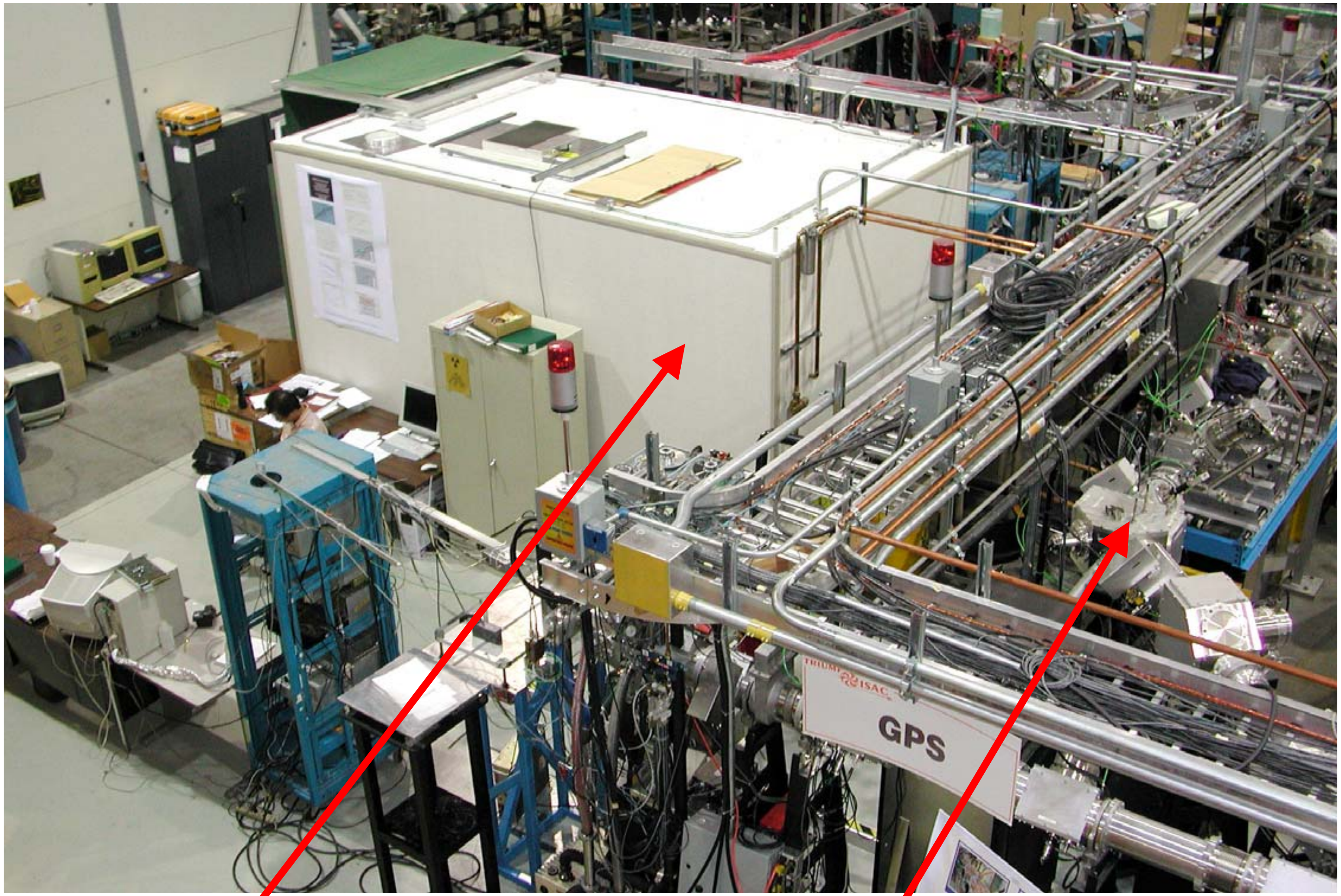


FIGURE 1. Charge radii from HF-BCS calculations

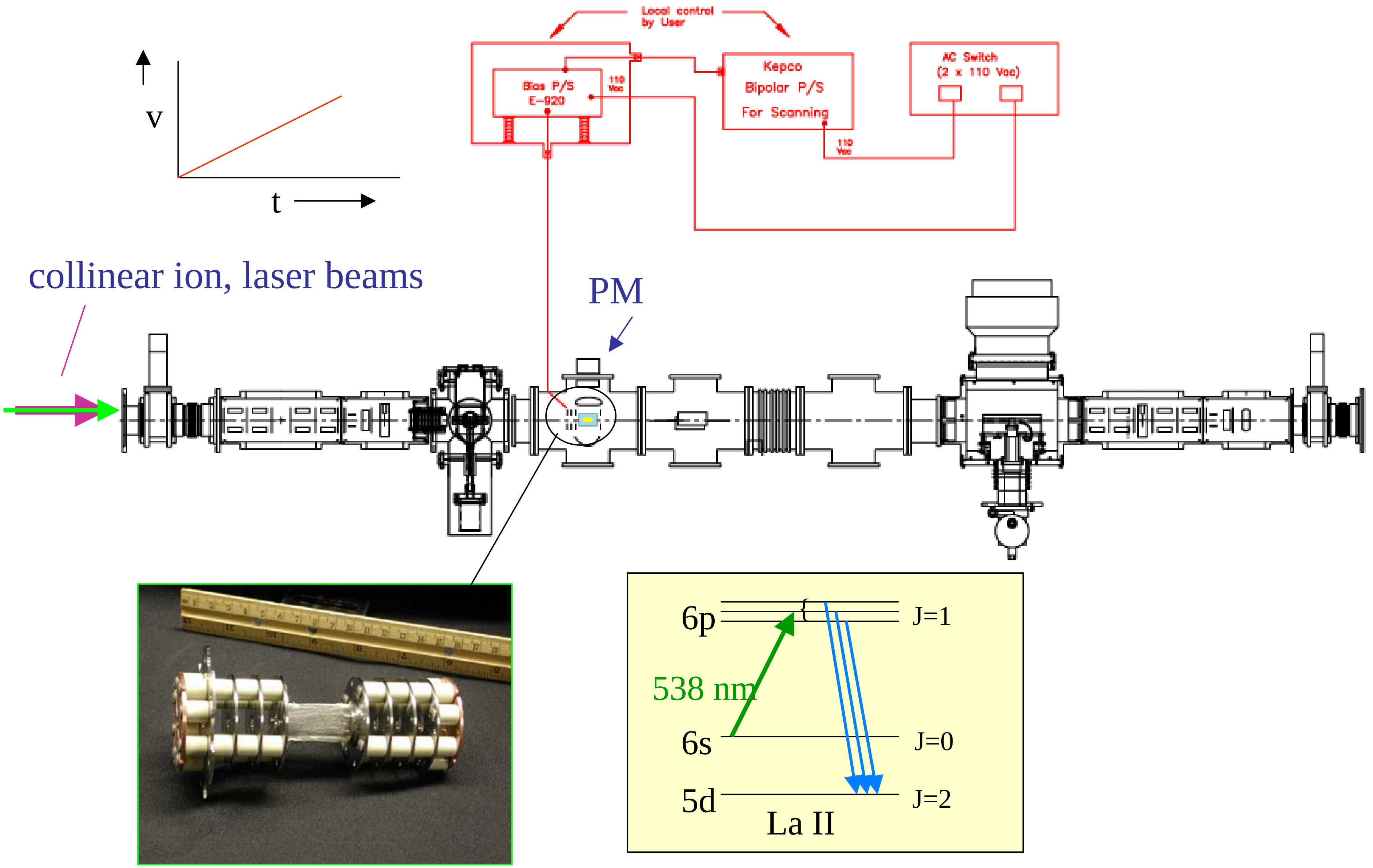
Goriely, Tondeur, Pearson,
At. Data & Nuc. Data Tables
vol. 77 (2001)



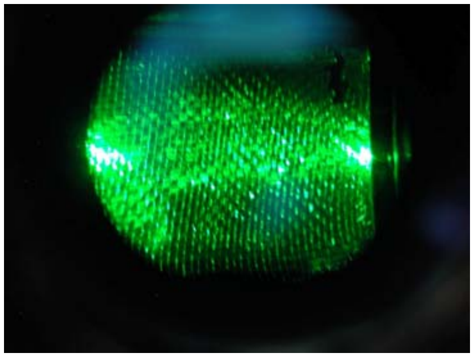
Laser hut
Ar-ion pump laser
CW tunable ring-dye laser
Data acquisition system

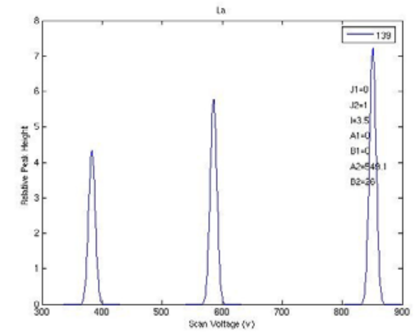
Collinear beam line = polarization beam line
2nd laser beam - polarization laser

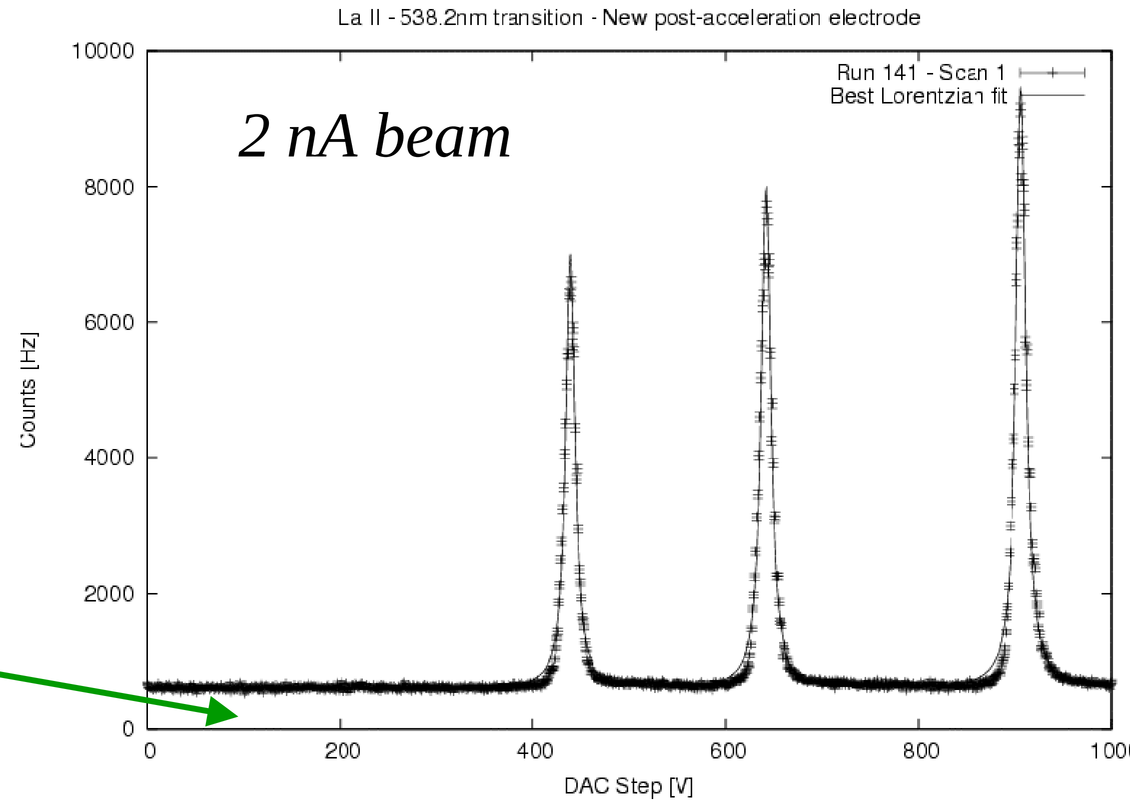
Doppler Tuning with a Retarding Voltage



Signal:Noise







Scattered light from mesh (+ PM dark current + scattering from gas in beamline)

Classical Collinear Spectroscopy

Good

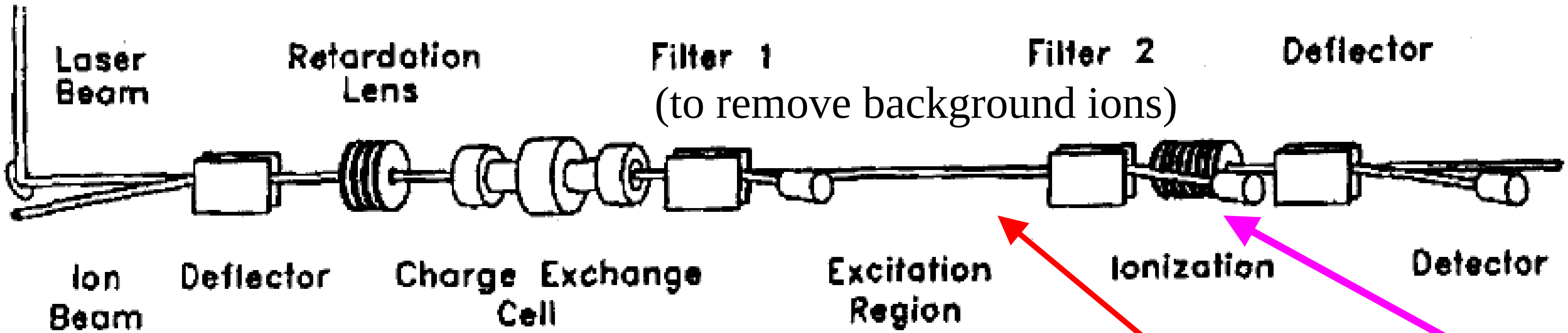
- direct use of ISOL beam
- complete spatial overlap
- reduction of Doppler broadening, giving resolutions of ~ 50 MHz
- spectroscopy of wide range of atoms or ions
- spectroscopy starting from excited states through charge exchange
- different transitions for excitation and detection
- fair sensitivity: efficiency ~ 10^{-5}

Not so good

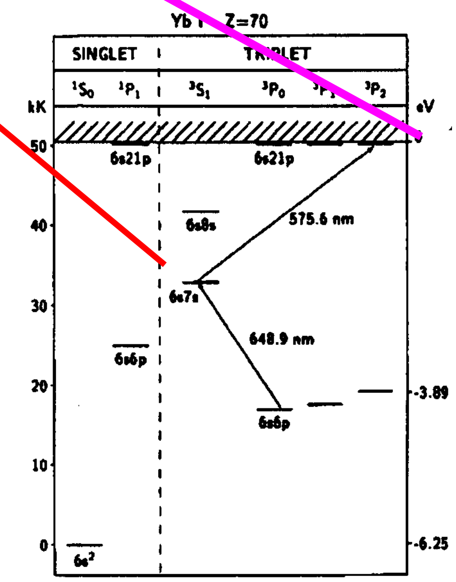
- low photomultiplier quantum efficiency
- small solid angle for detection
- background from laser stray light
- background from collisional excitation of gas in beamline
- background from radioactivity

So: Use PARTICLE detection instead of (or added to) photons

DC Ion Beam, Pulsed Lasers, Field Ionization



Charge exchange populates metastable level
Pulsed lasers excite to Rydberg state
Field ionization



Resonant stepladder → high selectivity
Gated particle detection → low background

but overall efficiency is still ~ 10 $^{-5}$

C. Schulz et al., J. Phys B24 (1991)4831

Efficiency

$$\eta = \varepsilon_{duty}\varepsilon_{pop}\varepsilon_{exc}\varepsilon_{ion}\varepsilon_{trans}$$

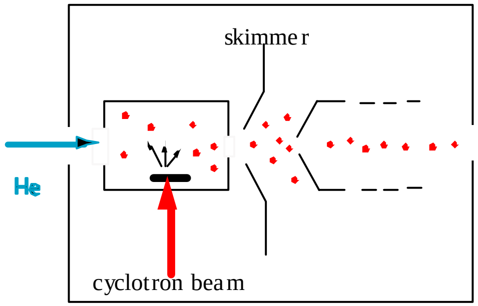
.03 .05 .03 .8 .7

Duty cycle = pulse rep. rate x time in interaction region
= 10^4 x 3x 10^{-6} = 3%

Problem: DC ion beams are not well adapted to pulsed lasers
"*Bunched beams* should give > order of magnitude improvement"

Solution: (Jyväskylä)
Accumulate ions in a trap for a time t_{acc} ; release in time t_{bunch}
Gate the detector to accept the bunch
Background suppressed by a factor $S = t_{acc}/t_{bunch}$

Jyväskylä 's IGISOL: CS with particle coincidence



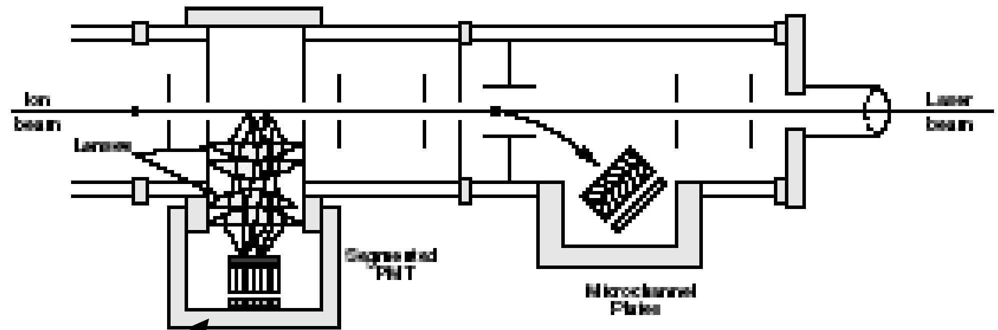
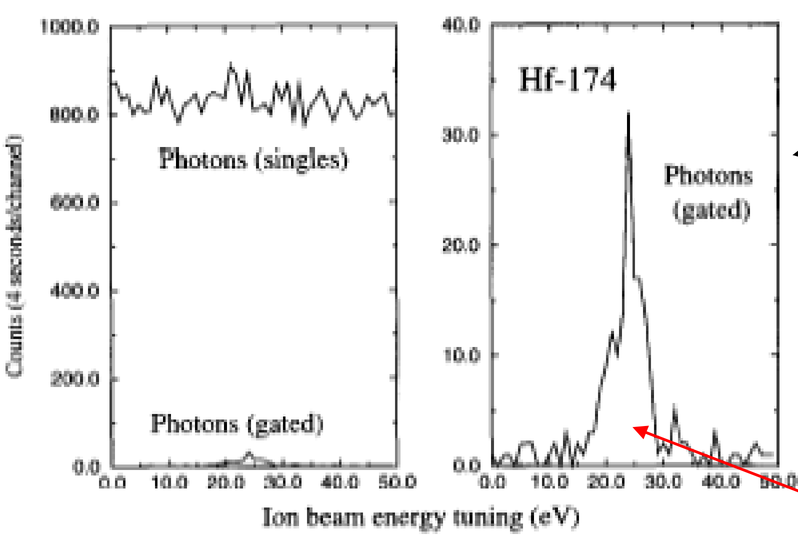


Figure 1. Schematic view of the laser spectroscopic station.

photon-ion coincidence with segmented PM⟶20 ns window



Ion current: 10^5/s
Collection time: 500 s
Linewidth: 70 MHz

Spectacular background reduction!
But: dependence on skimmer voltage, extraction efficiency
IGISOL spread ~ 10 eV

Plus a Bunching Trap

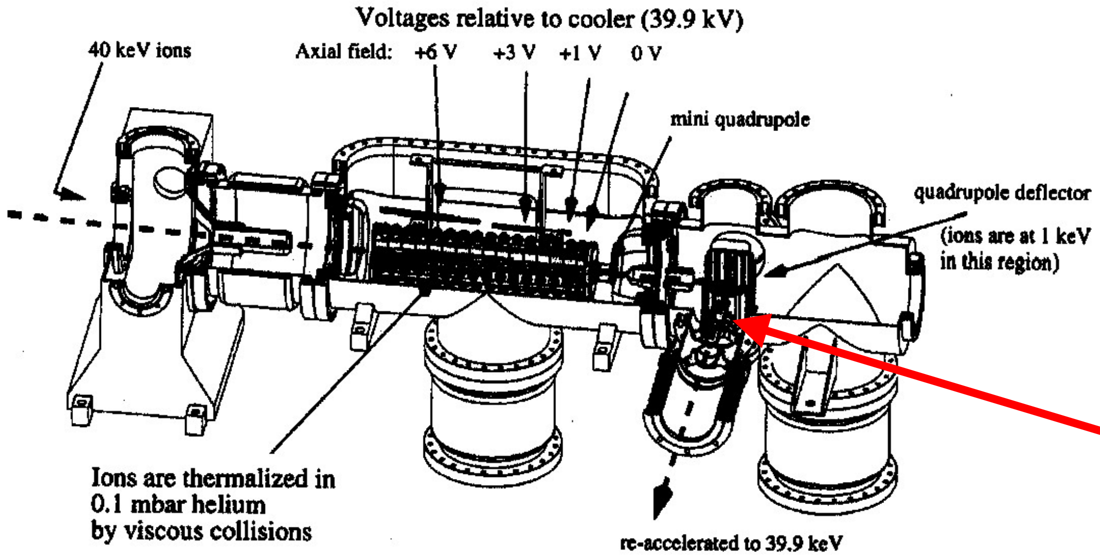
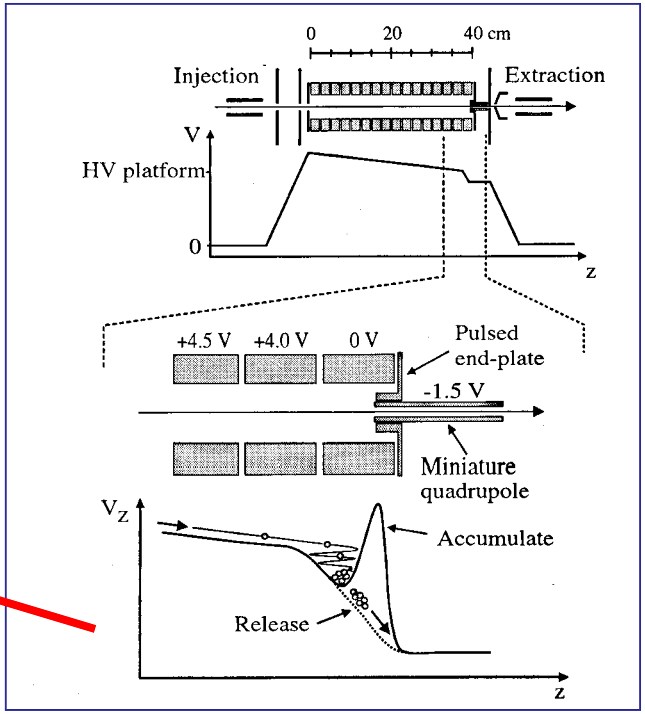
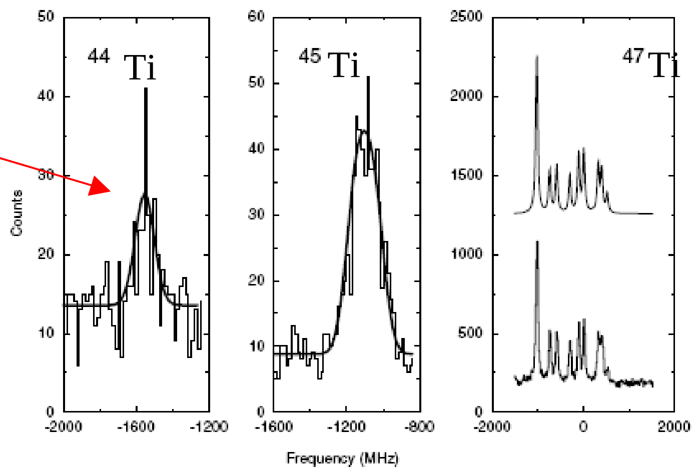
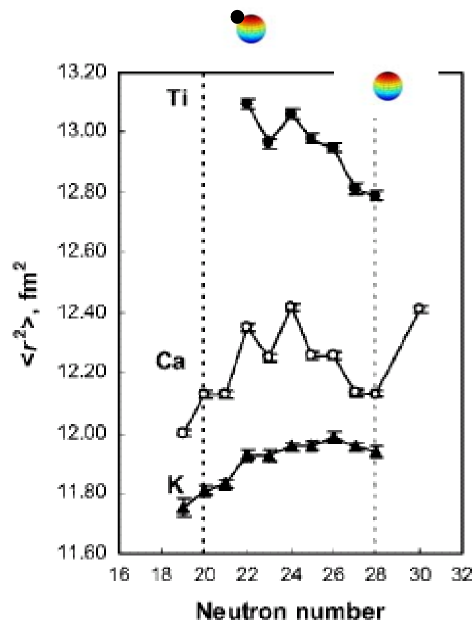


Figure 5. The gas-filled RFQ ion cooler.



~100/s !



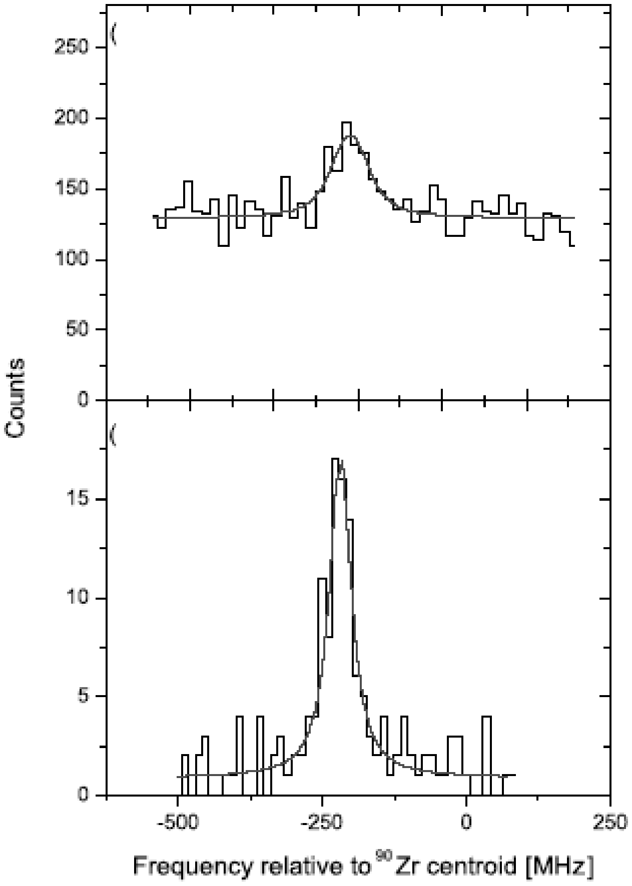


Gangrsky et al., J.Phys. G 30(2004)1089

Advantage of Cooling

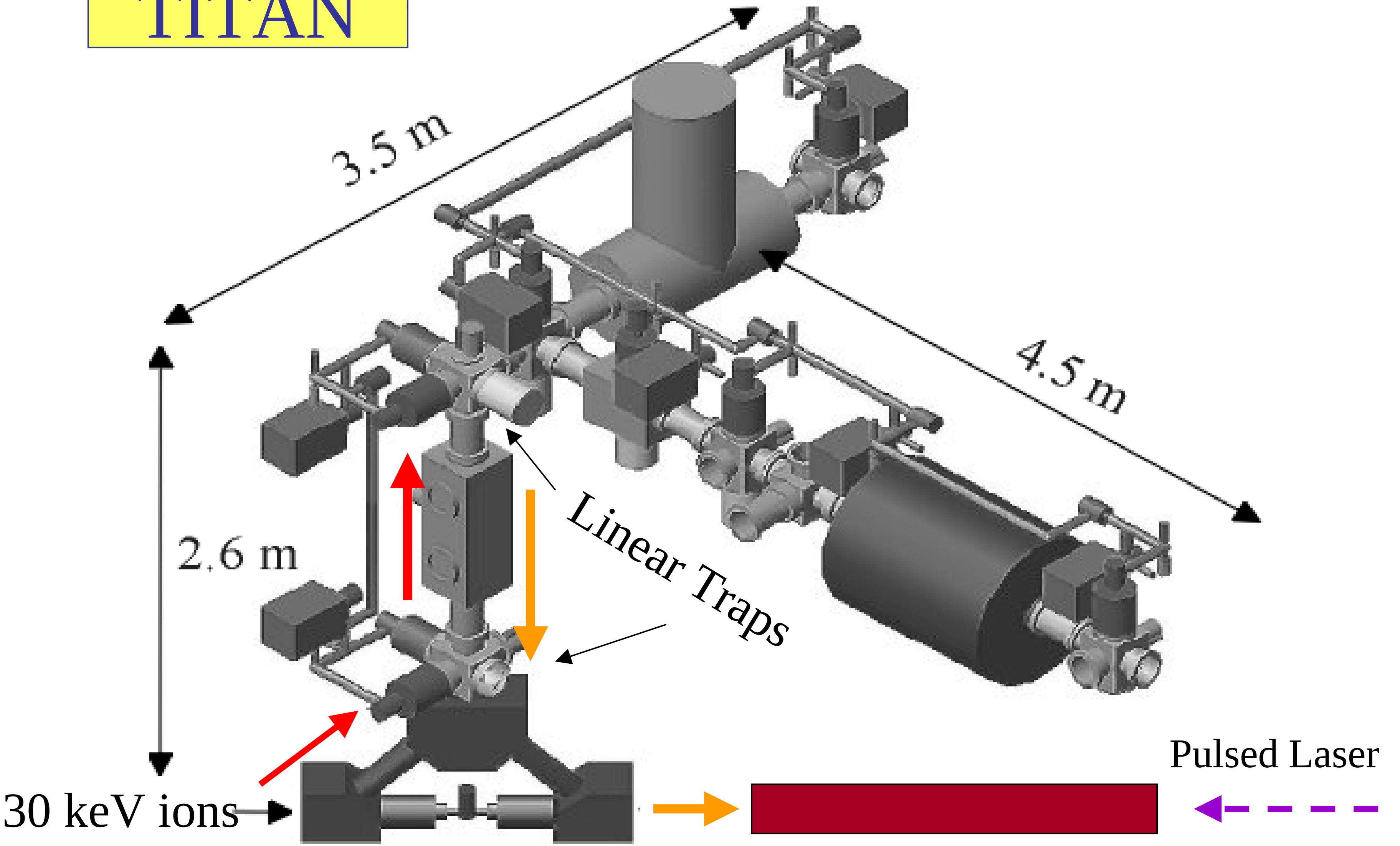
No cooling
12000 ions/s
5.25 hours

Cooled and bunched
2000 ions/s
45 min. collection



A. Nieminen et al., Nucl. Inst. And Meth. B 204 (2003) 563

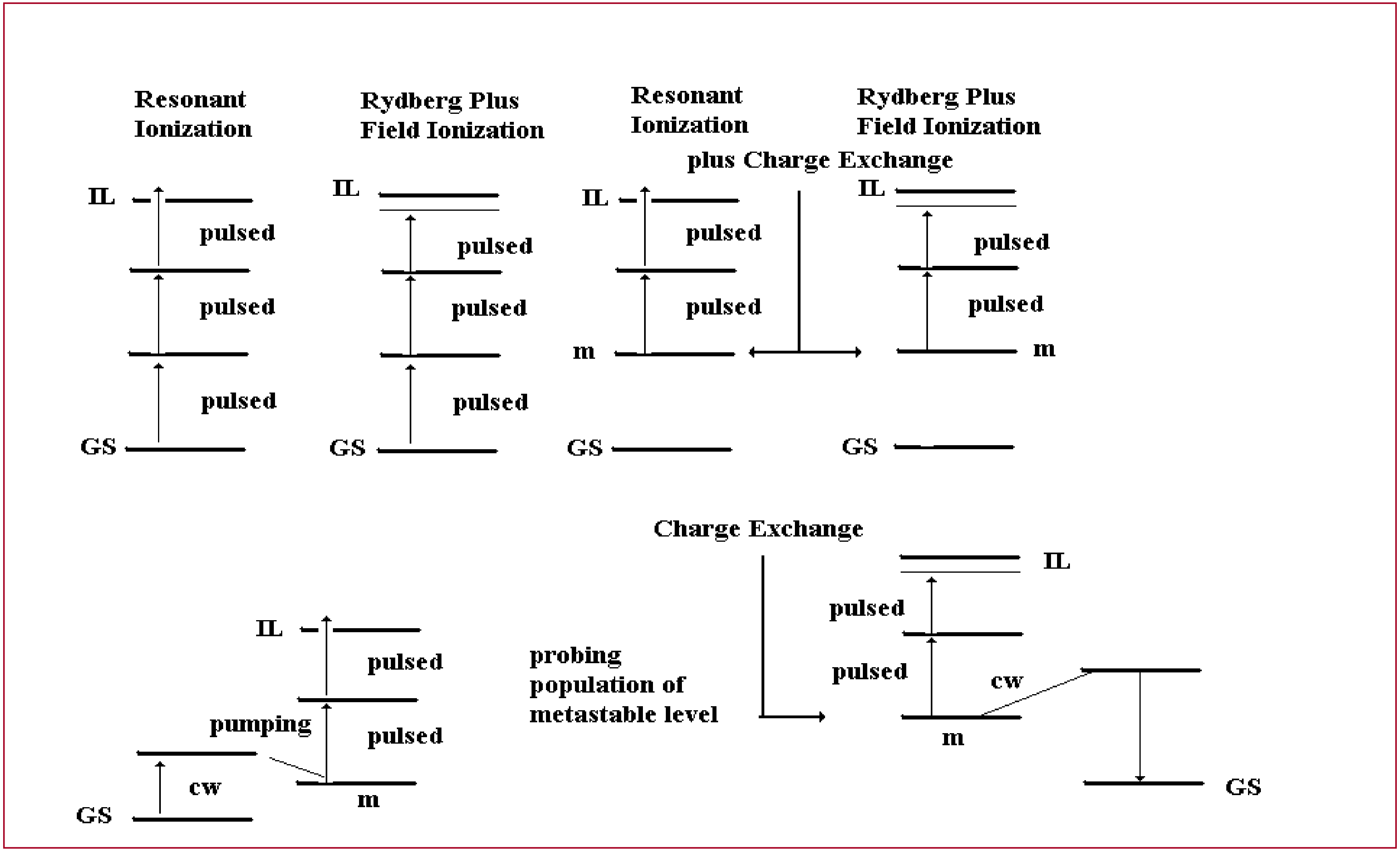
TITAN



~ π mm-mrad, ~10^5 ions/bunch

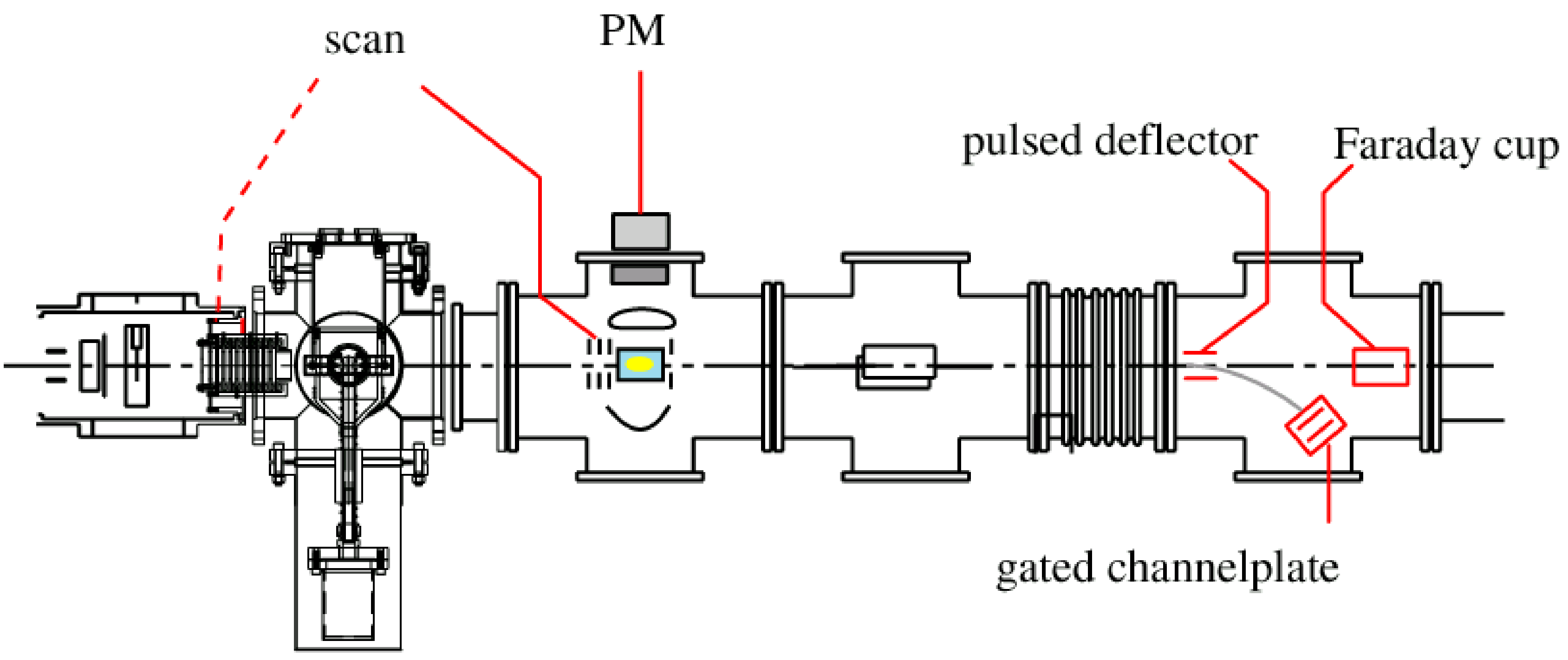
Multistep Ionization Processes

- applicable to nearly all elements with conventional lasers
- one of the steps with narrow bandwidth for spectroscopy



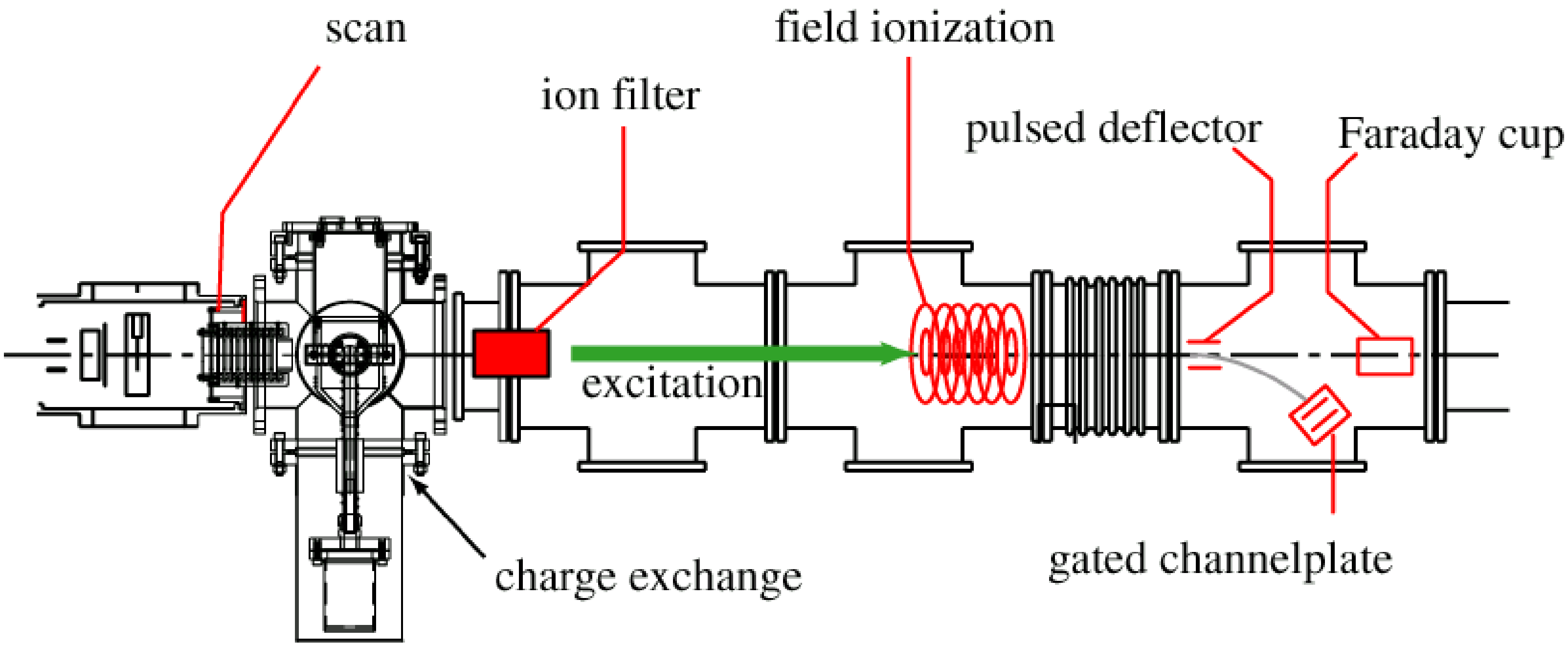
Modifying the Polarizer Beamline (1)

CS with particle coincidence - with or without ion bunching



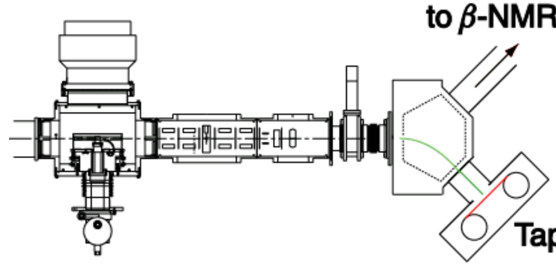
Modifying the Polarizer Beamline (2)

CS with bunched beams, RIS, particle coincidence



Isotope, Isomer Separation

RIS separated isomer



doublet?

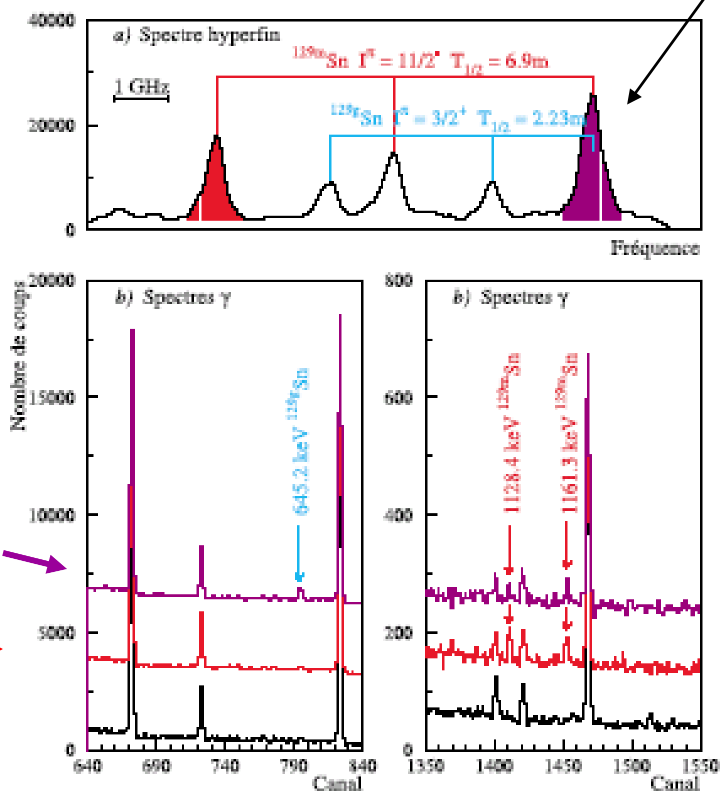
m	———	(11/2-)
g	——— ^{129}Sn	3/2+ (1/2+?)

1/2+ g.s. → 5 HF lines (2+3)

3/2+ g.s. → 6 HF lines (3+3)

RIS separation (blue peak) →isomer + ground

RIS separation (red peak) → only isomer



COMPLIS test (2002)

Conclusions

- ISAC: high yields
- *But* collinear laser systems must have
  - excellent sensitivity, selectivity, signal:noise
  - high duty cycle
- Achieved by cooled, bunched beams and pulsed lasers
- TITAN's cooler will produce pulsed beams with excellent emittance (~π mm-mrad) energy spread (~ 1 eV) and high intensity - *ideal* for collinear laser studies
- Relatively simple modifications to the beamline
- High-power pulsed lasers can excite weak transitions

  and can be doubled, tripled for UV

E920 Collaboration

H. Schuessler	*Texas A&M*
F. Buchinger T. Cocolios J.E. Crawford S. Gulick J.K.P. Lee	*McGill*
P. Levy M. Pearson	*TRIUMF*
S.D. Rosner	*UWO*
H. Iimura	*JAERI*
R. Thompson	*Calgary*