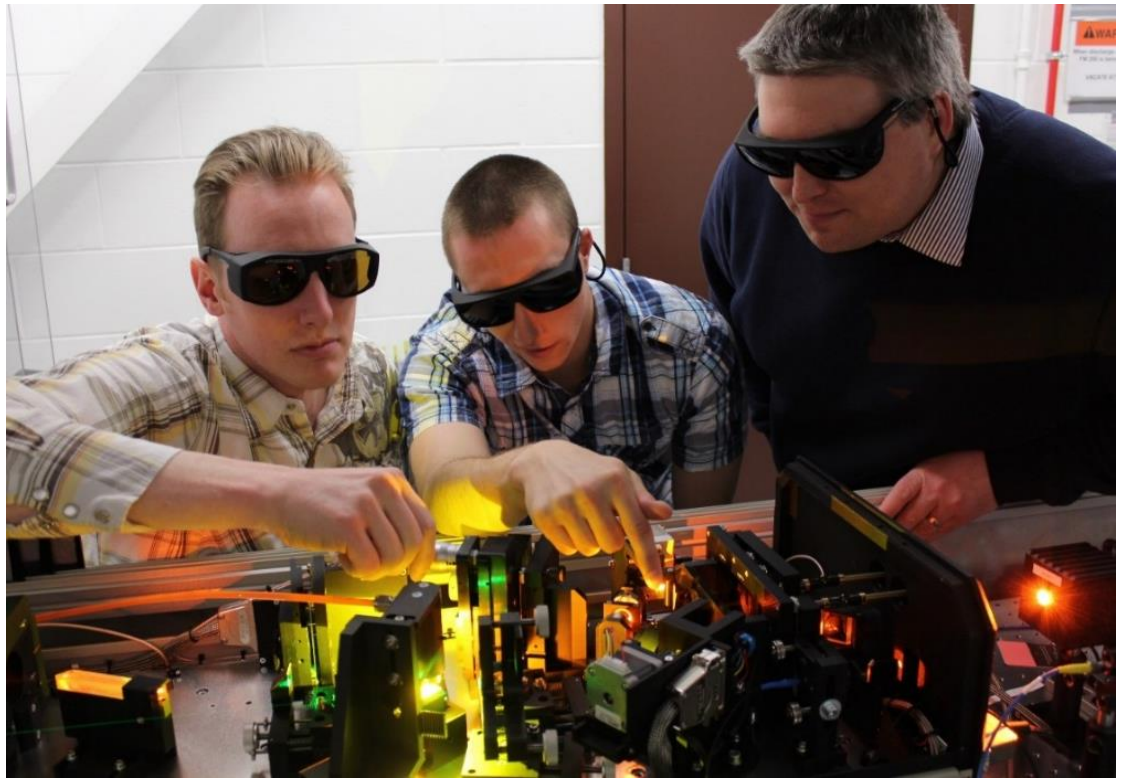
BECOLA facility; recent CLS studies on neutron-deficient K & Fe isotopes

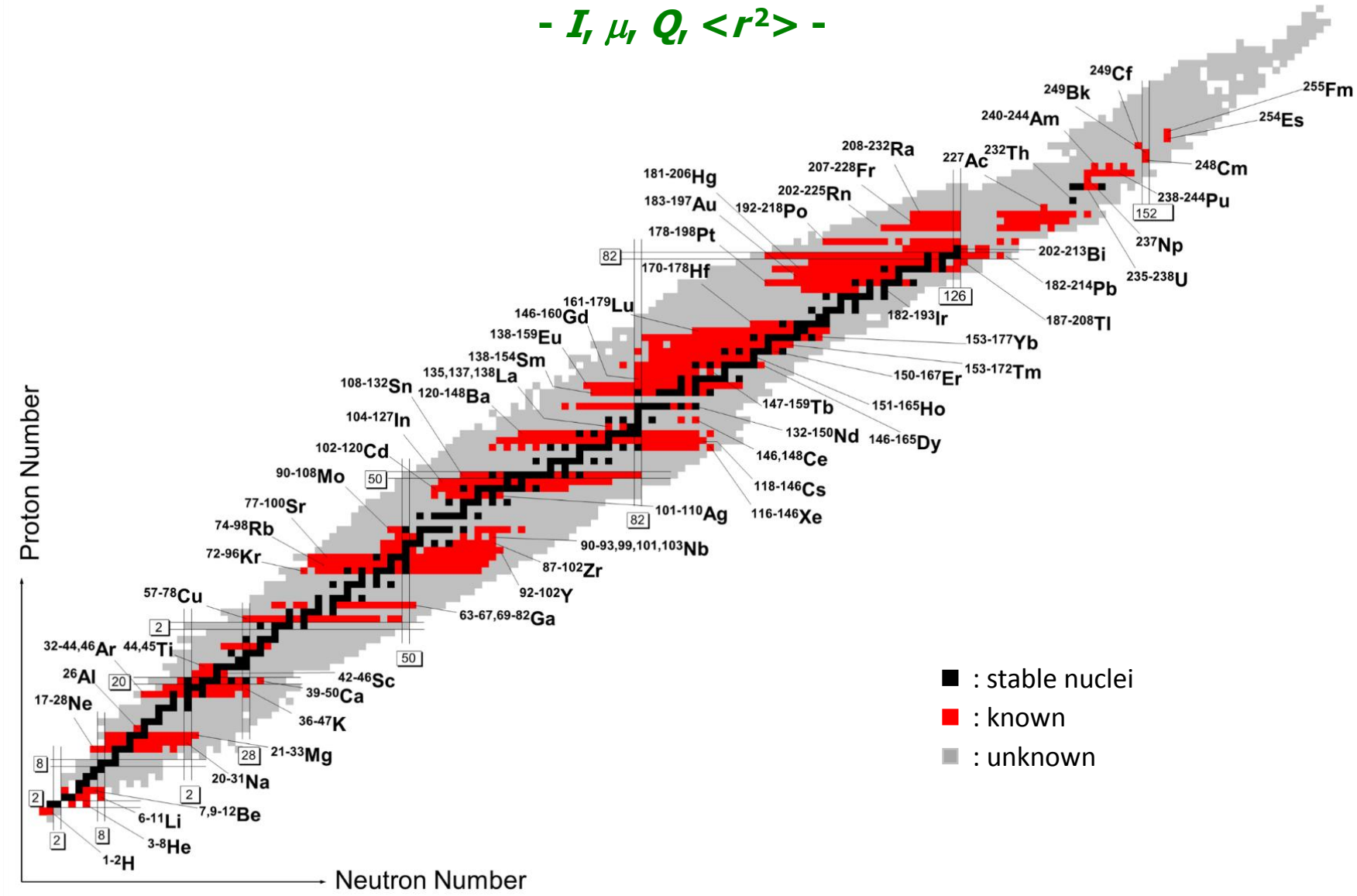


Kei Minamisono

NUSTAR annual meeting 2016, GSI, Germany, March 1-4, 2016

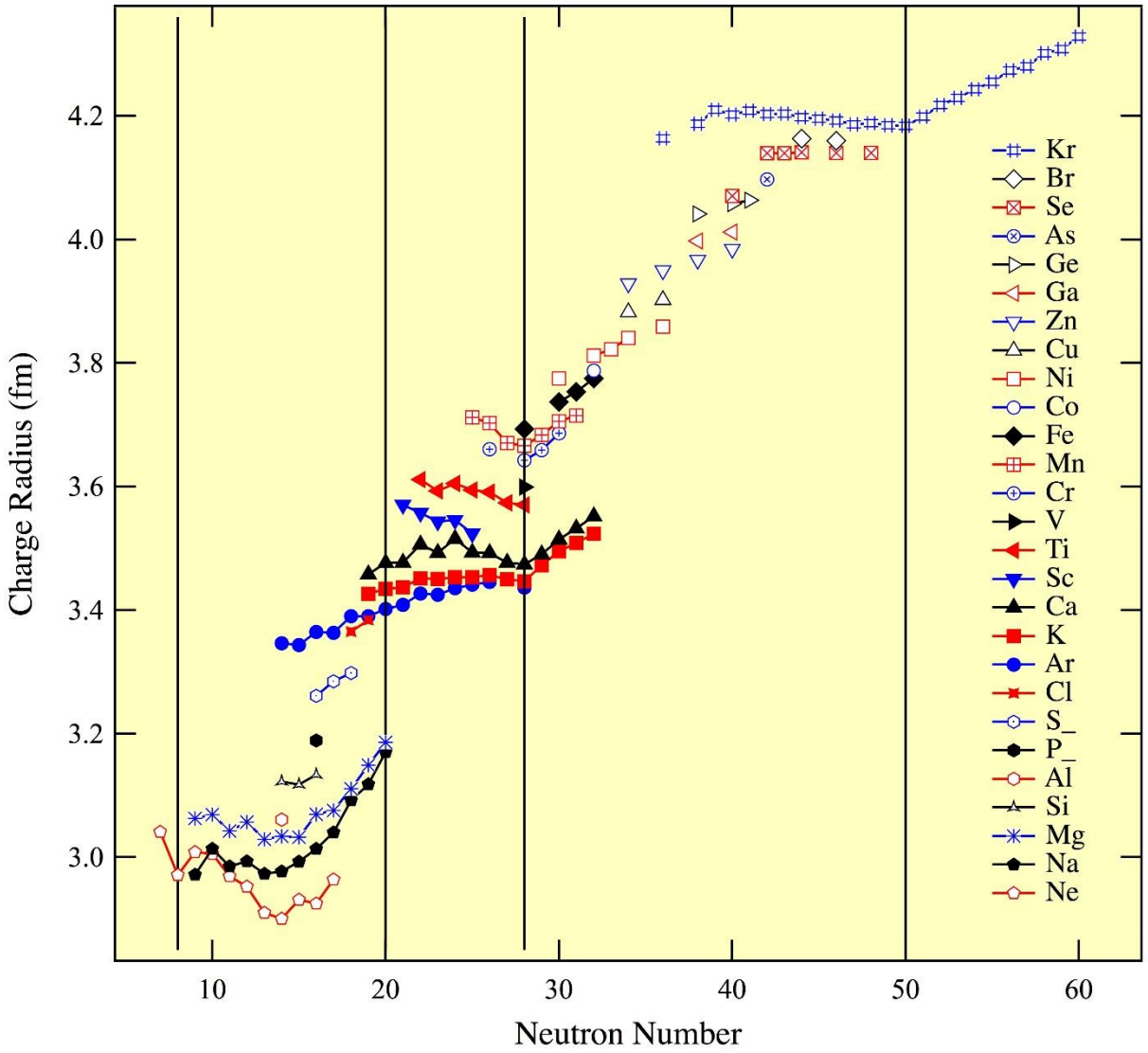
Laser spectroscopy measurements

- I, μ, Q, $\langle r^2 \rangle$ -



K. Blaum et al., PST152, 014017 (2013).

Charge radii: $_{10}$Ne-$_{36}$Kr

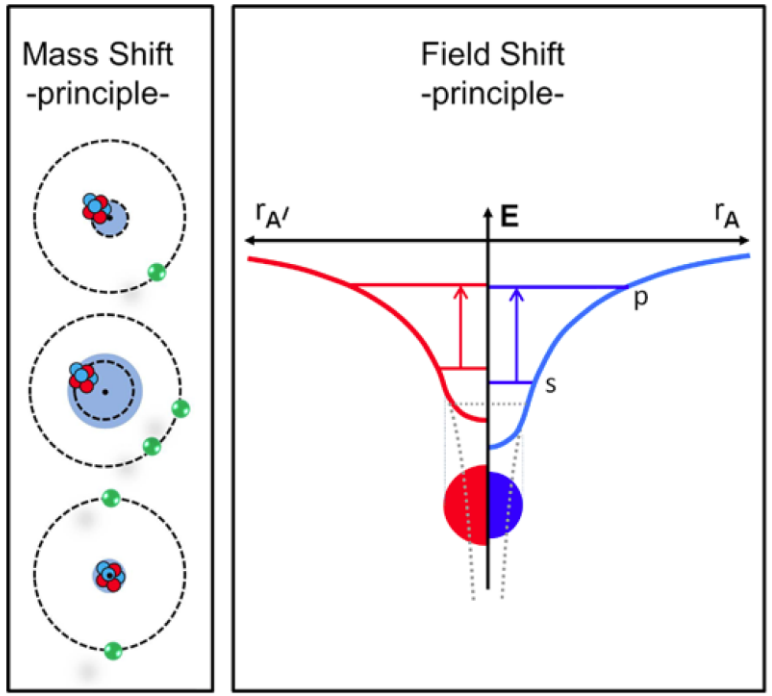


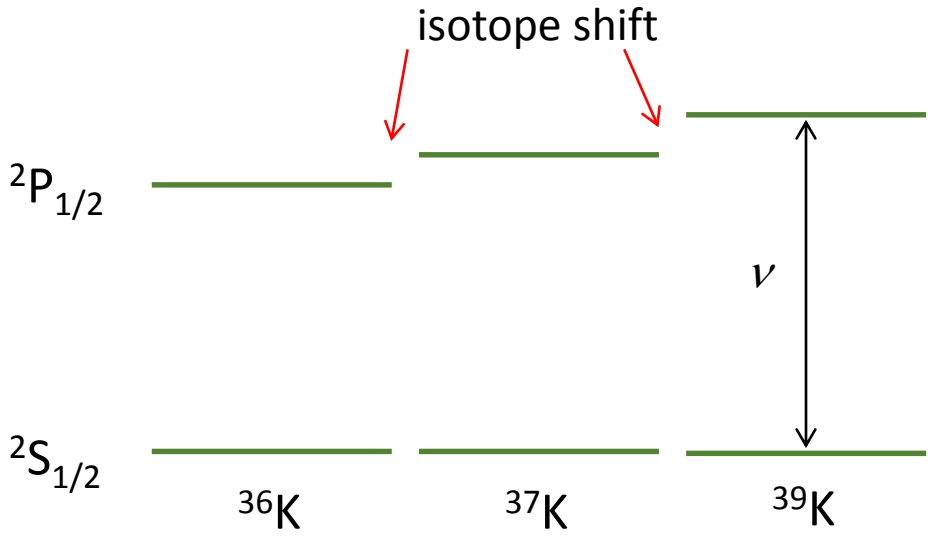
Data compilation: I. Angeli, K. P. Marinova, ADNDT 99, 69 (2013);
B. Cheal and K. T. Flanagan, JPG37, 113101 (2010);
and many newer publications.

Isotope shift

$$\delta\nu^{A,A'} = \nu^{A'} - \nu^{A}$$

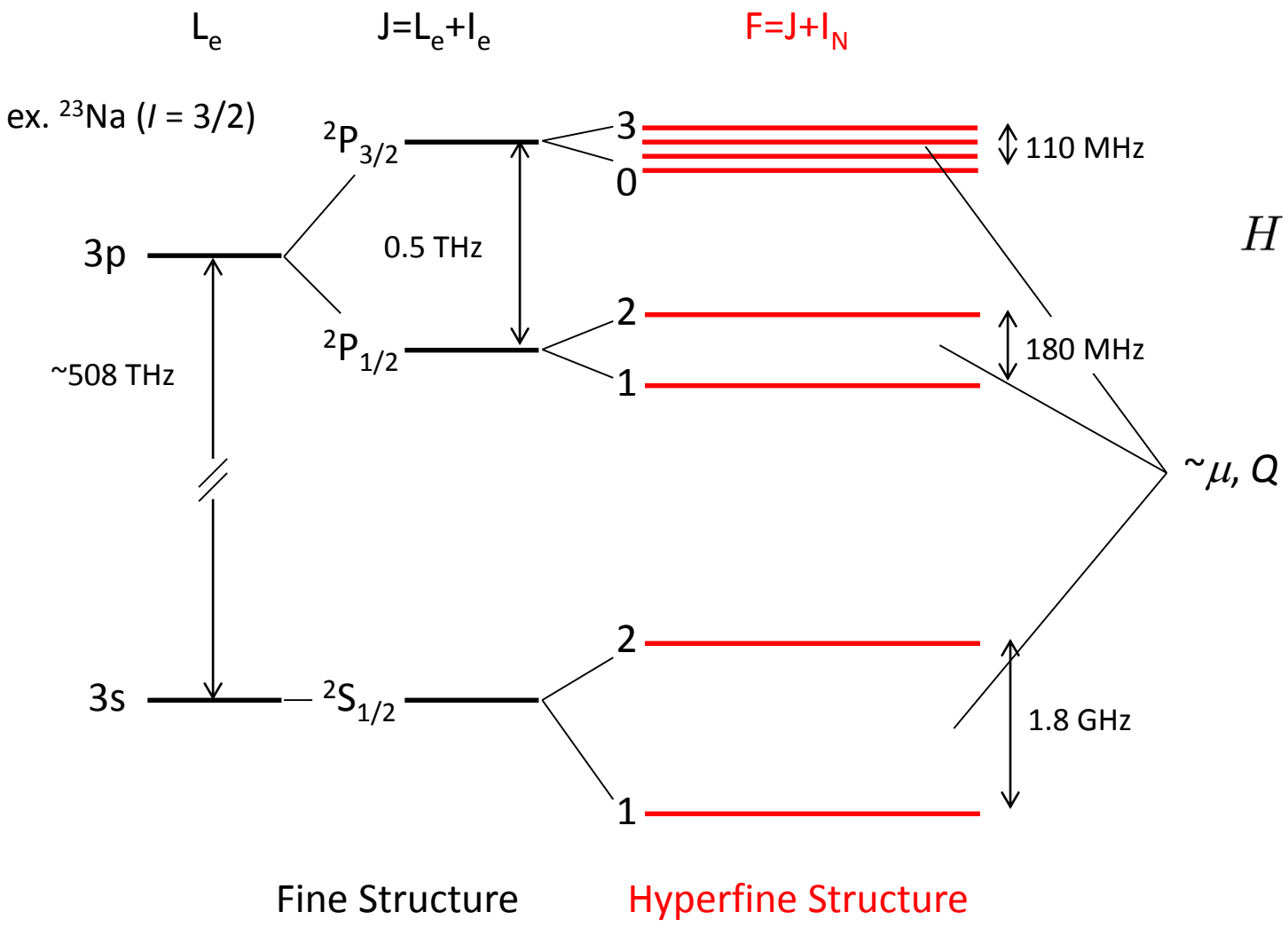
$$= k\frac{M' - M}{M'M} + F \times \delta\langle r^2 \rangle^{A,A'}$$





W. Nörtershäuser and Ch. Geppert, Lecture Notes in Physics 879 (2014).

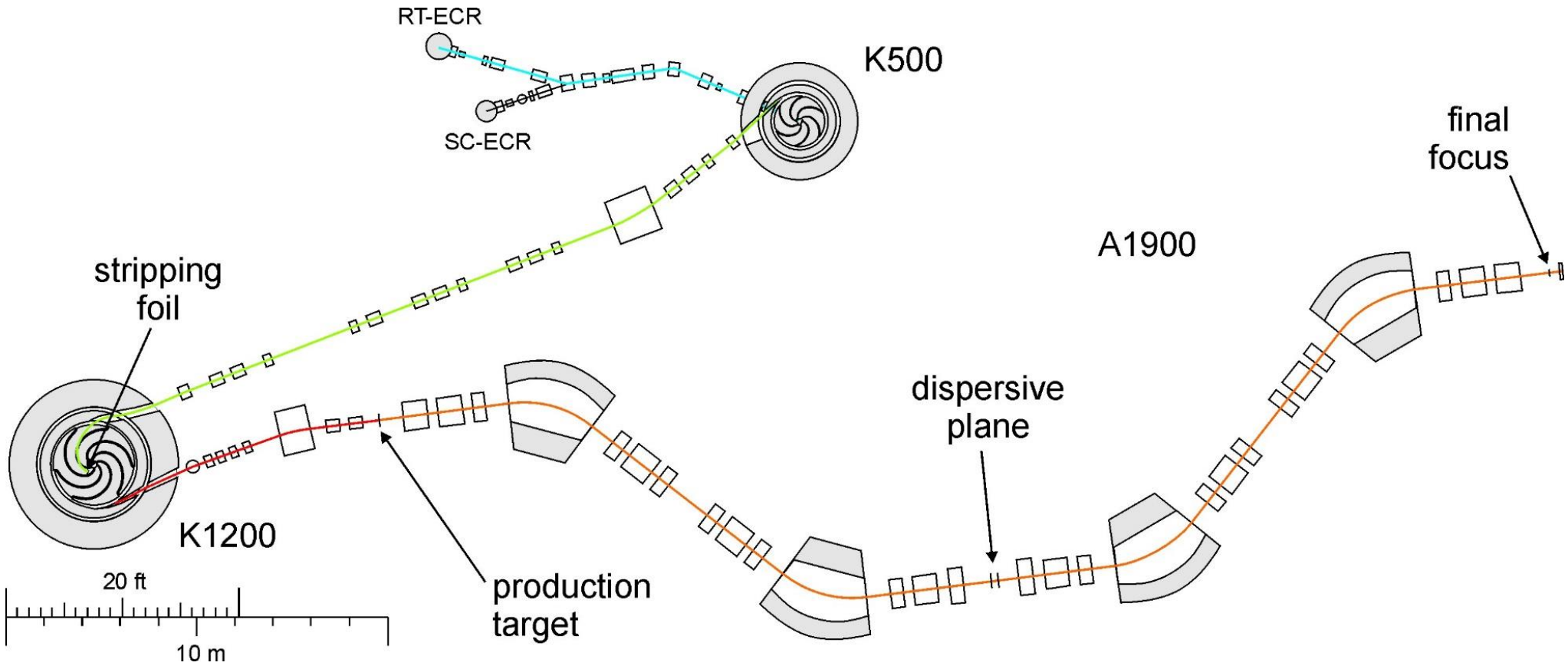
HFS: electromagnetic moments



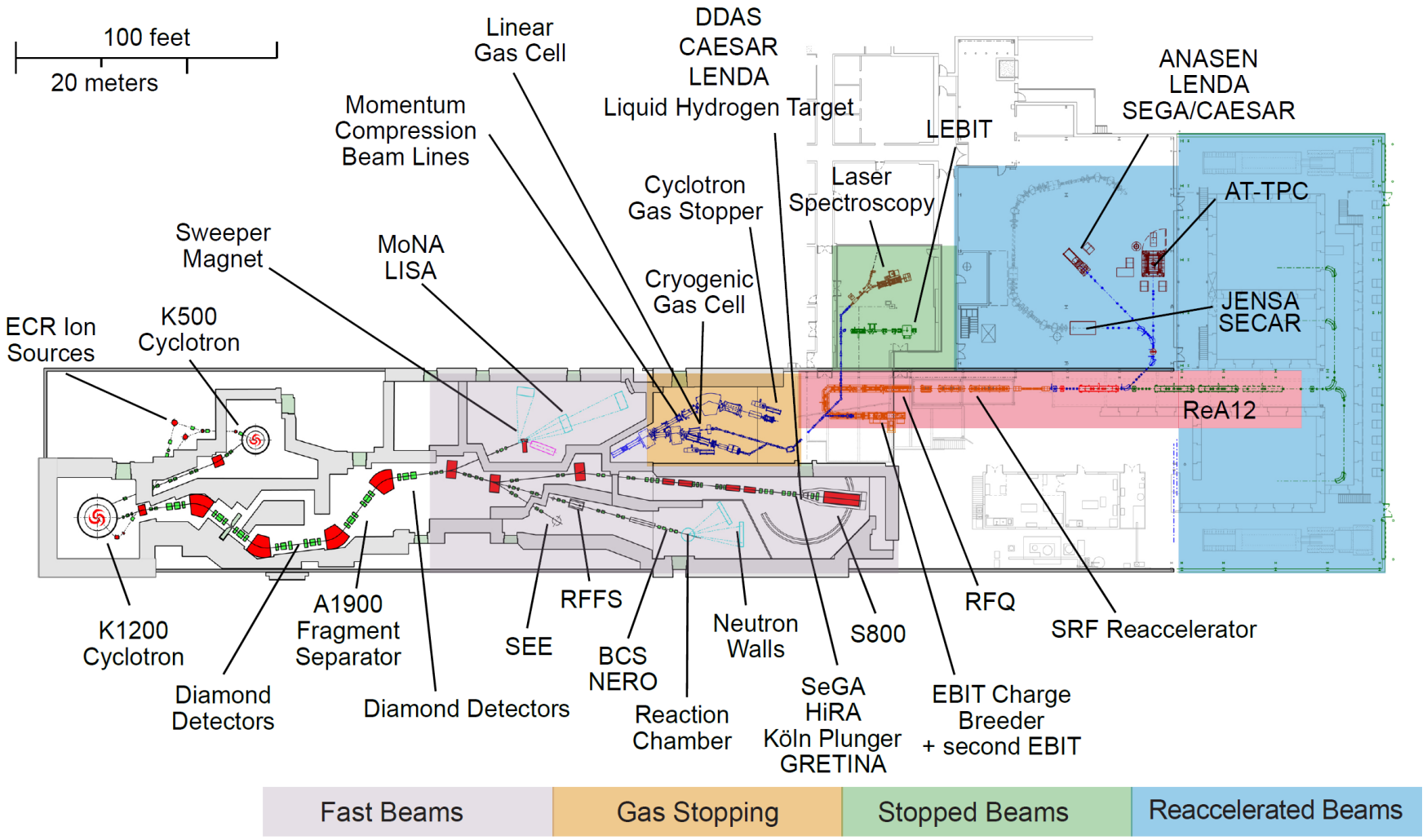
$$H \sim A\cos\left(\widehat{\boldsymbol{IJ}}\right) + B\frac{3\cos^2\left(\widehat{\boldsymbol{IJ}}\right) - 1}{2}$$

$$\begin{cases} A \sim \mu_I H \\ B \sim eqQ_I \end{cases}$$

Coupled cyclotron facility at NSCL

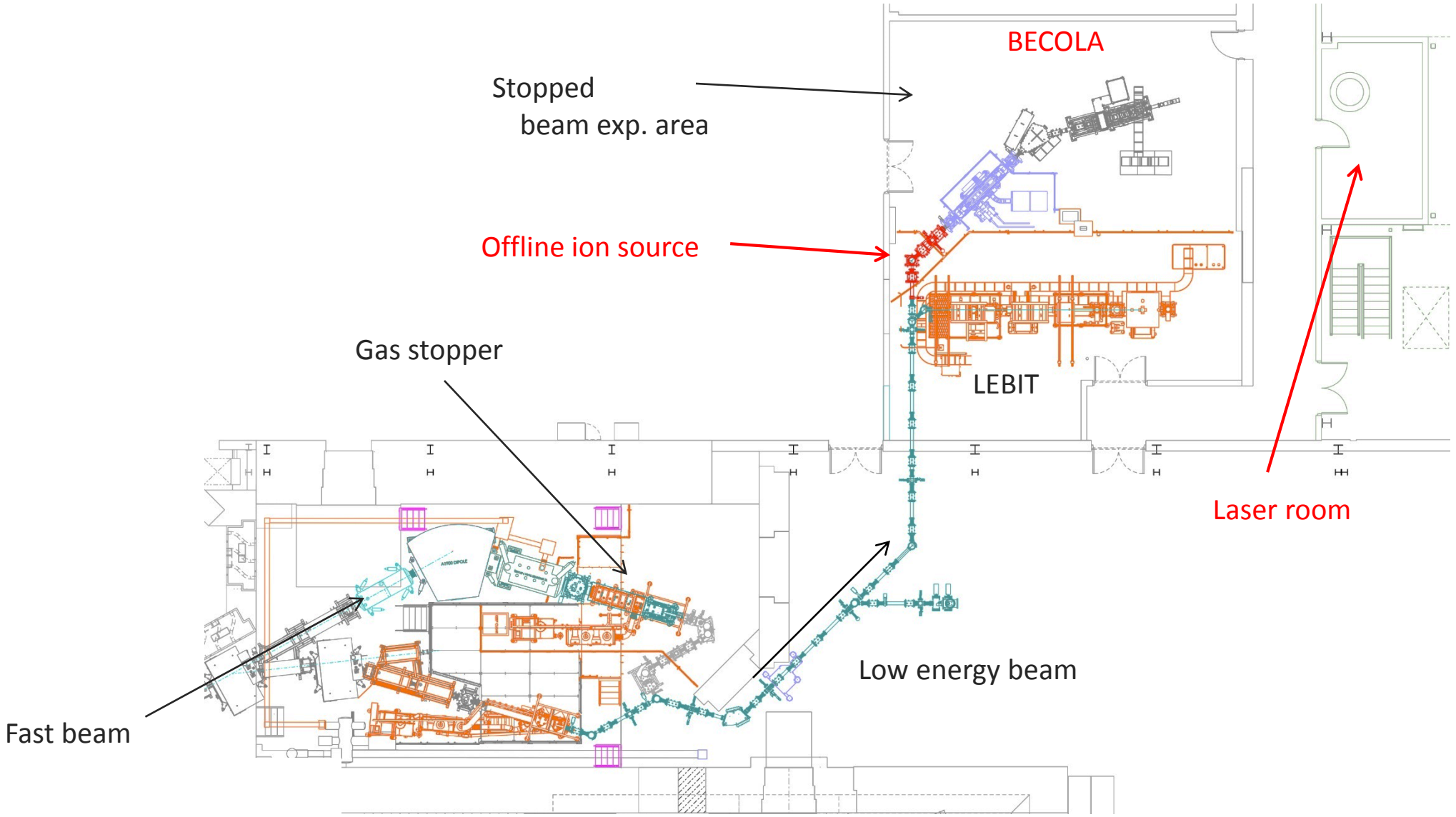


NSCL experiments



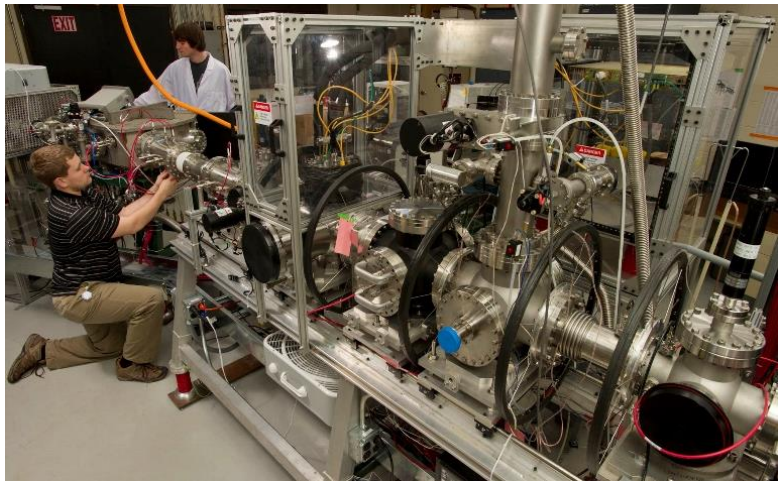
- Fast rare isotope beams
- Stopped rare isotope beams: fragmentation + gas stopping
- Reaccelerated rare isotope beams

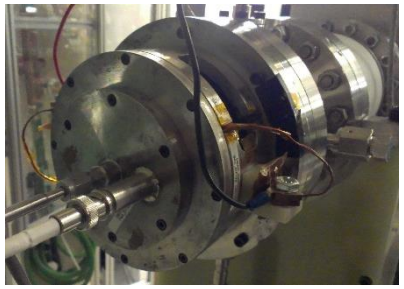
Gas stopping & transportation



gas stopper: K. Cooper et al., NIMA763, 543 (2014).

BECOLA facility
- BEam COoling and LAser spectroscopy -



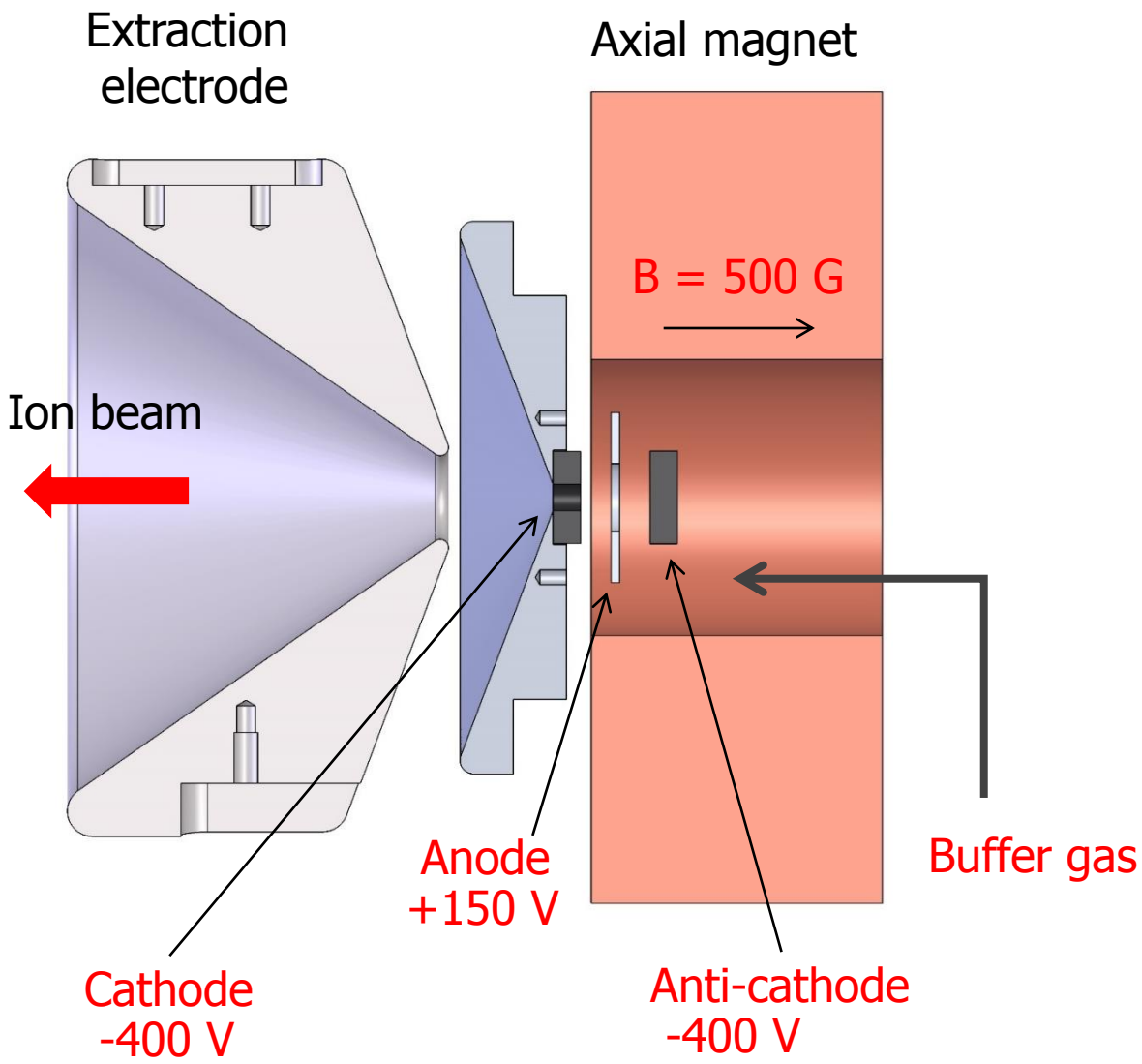


laser system

K. Minamisono et al, NIMA 709, 85 (2013).

Penning ionization gauge (PIG) ion source

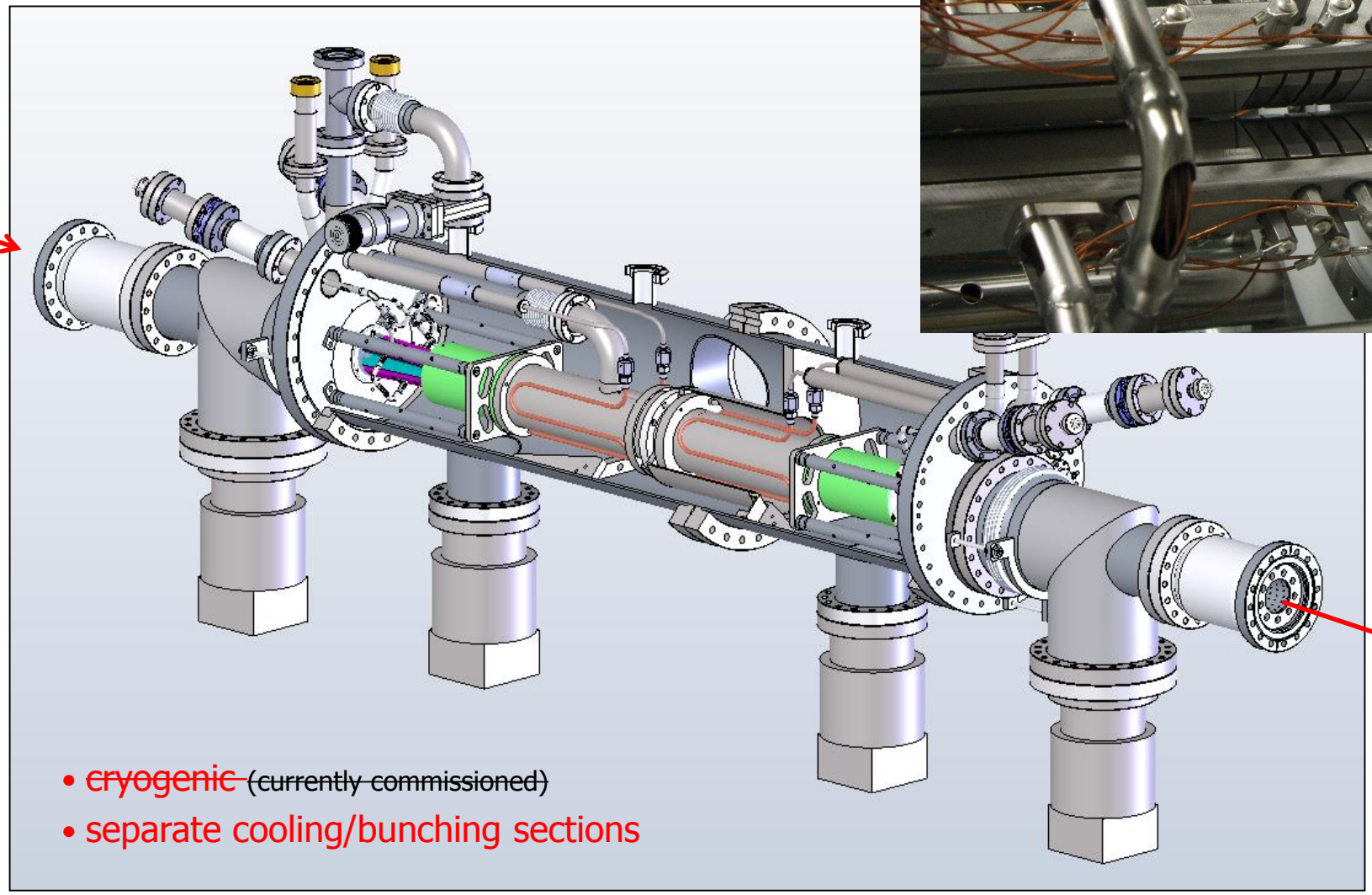
- plasma sputter source
- generates ions from
  - cathodes
  - buffer gas



C. A. Ryder, K.M. et al, Spectrochimica Acta B113, 16 (2015).

BECOLA cryogenic cooler/buncher

low energy beam



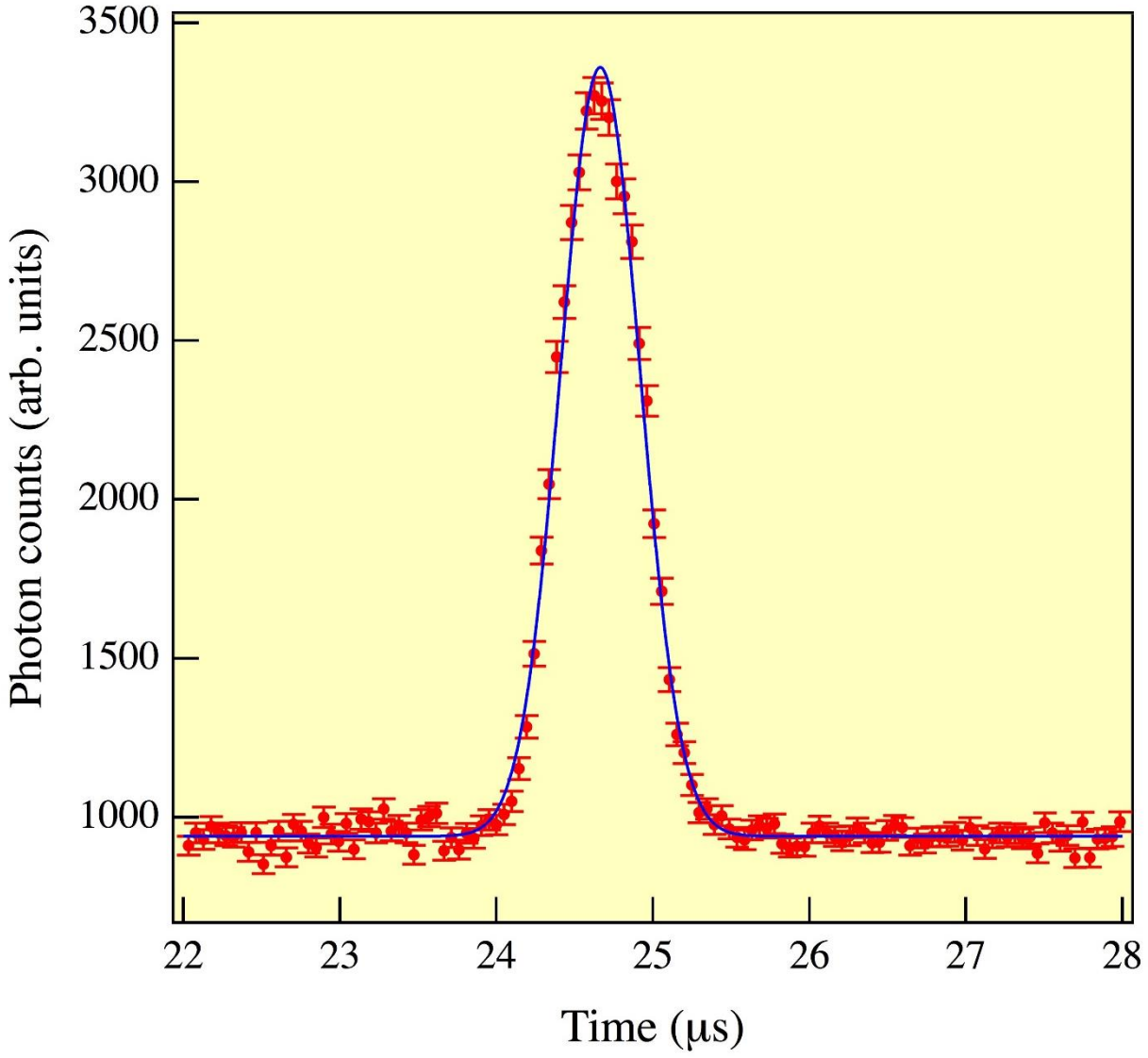
bunching section

to CLS beam line

- ~~cryogenic~~ ~~(currently commissioned)~~
- separate cooling/bunching sections

B. R. Barquest, PhD thesis (advisor G. Bollen), MSU, 2014.

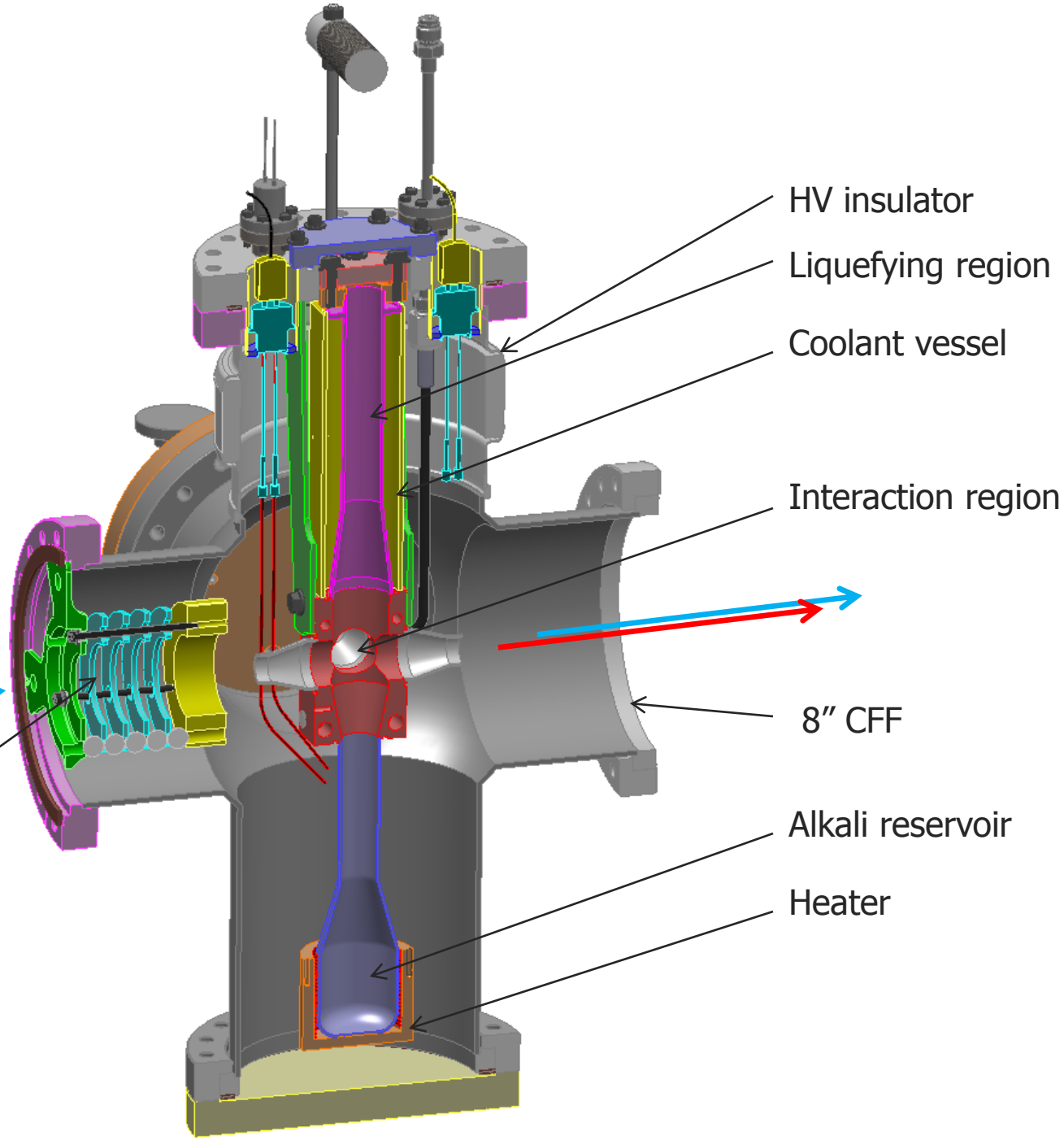
Time spectrum ^{53}Fe



^{53}Fe beam

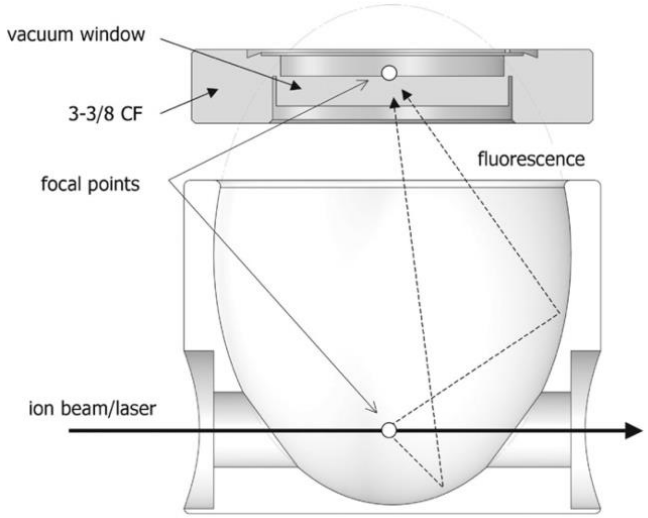
- 29.85 keV
- ~10^4 ions/bunch
- FWHM 850 ns
- ε_T = 2 π mm mrad
- dE ~ 5 eV (80 MHz)

CEC

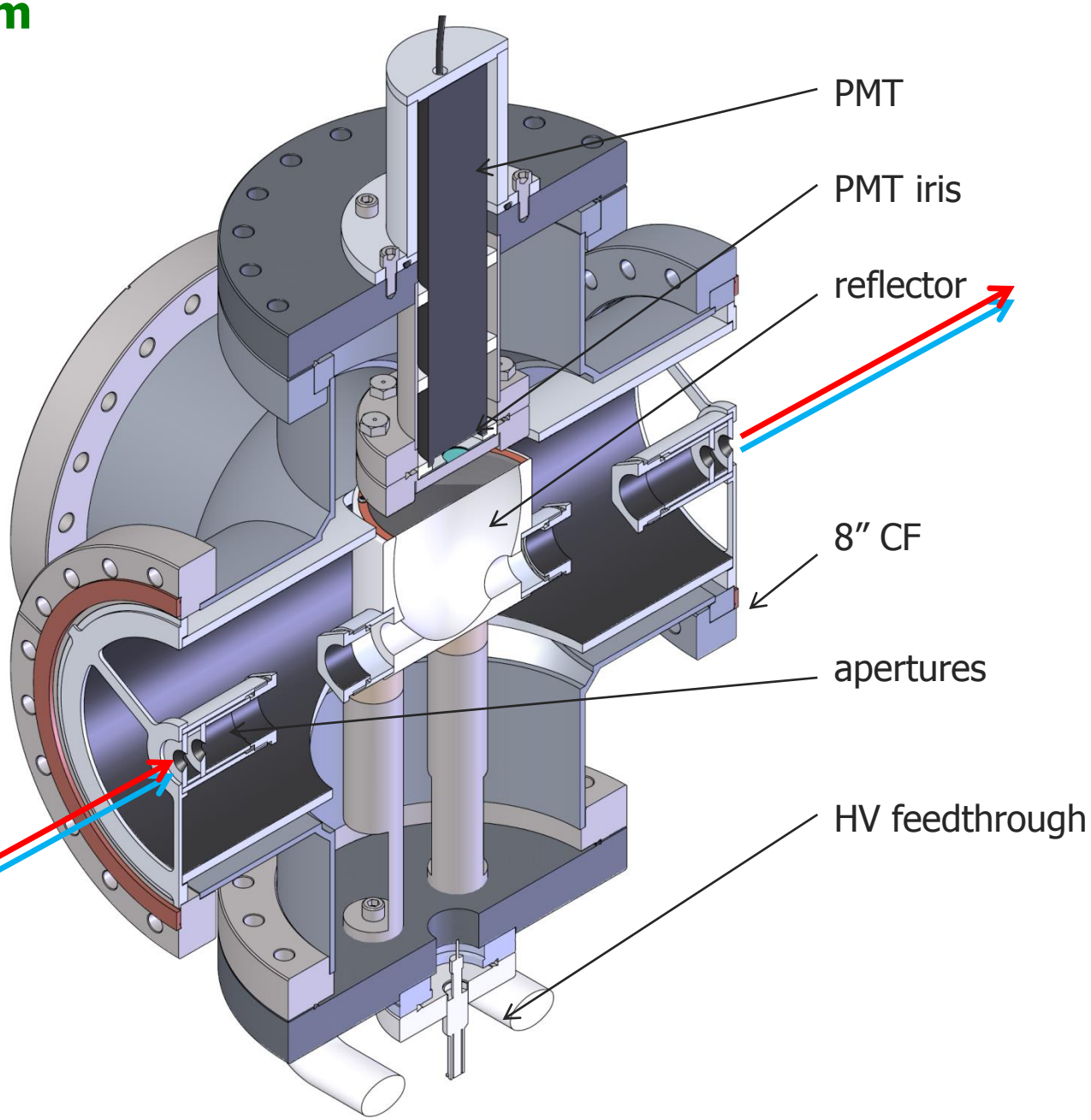


A. Klose, K.M. et al., NIMA678, 114 (2012).

Photon detection system



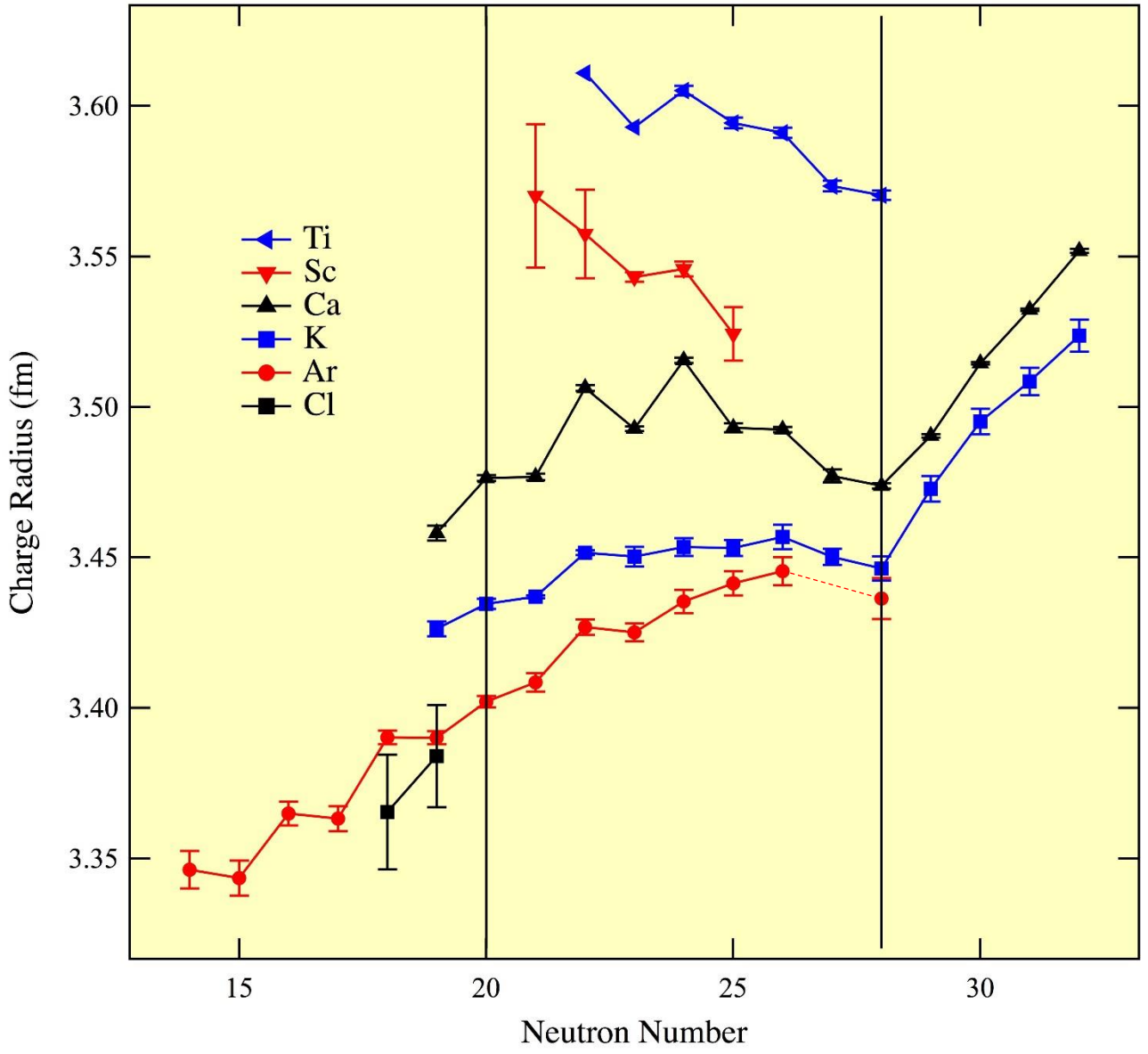
Ion beam/laser



K. Minamisono et al, NIMA 709, 85 (2013).

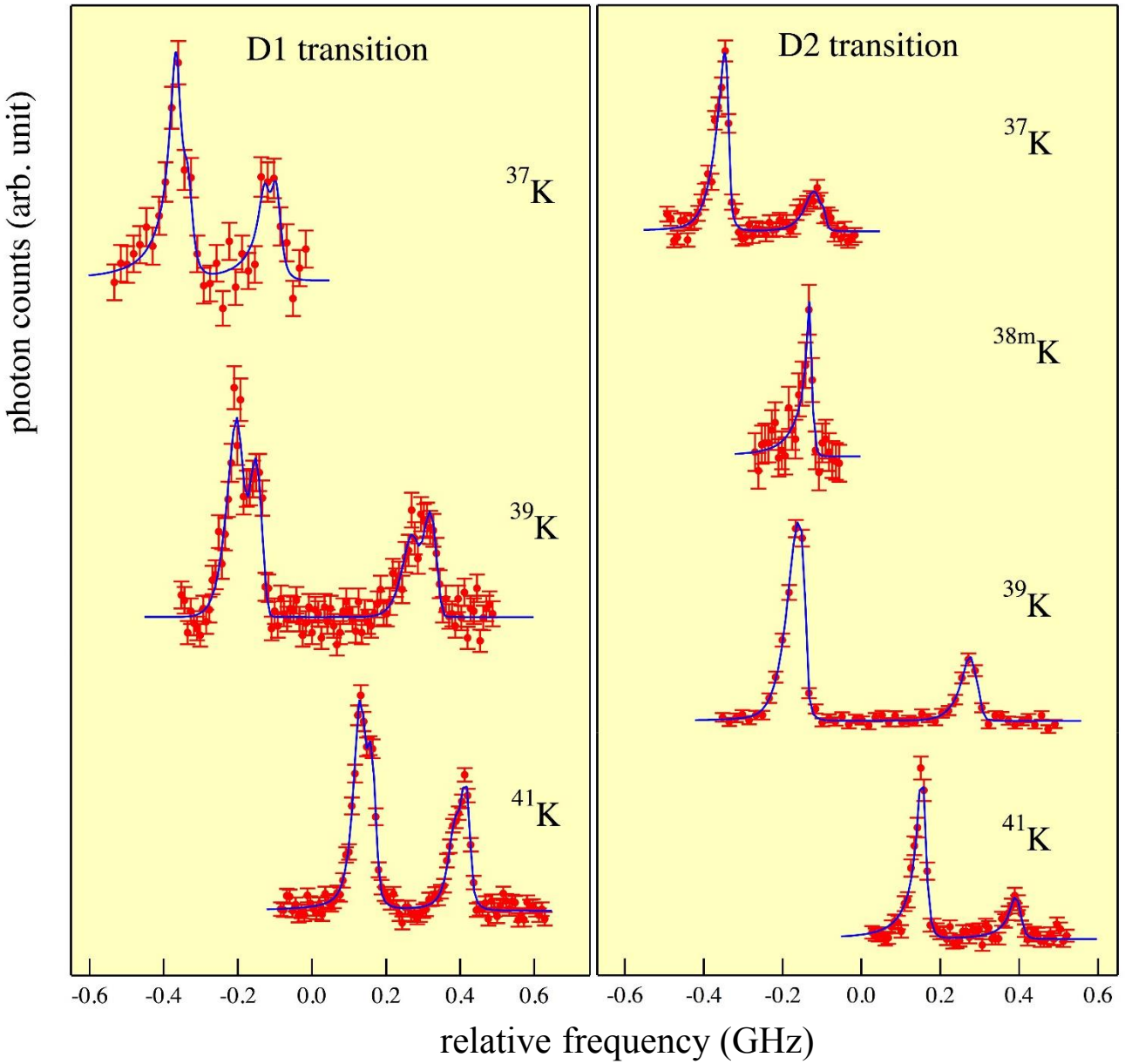
Charge radii around $N = 20$ for Ca region

- Disappearance of
  shell-closure signature at $N = 20$



for Ar isotopes: A. Klein et al., NPA607, 1 (1996).

Isotope shift of K isotopes: CLS with bunched beams

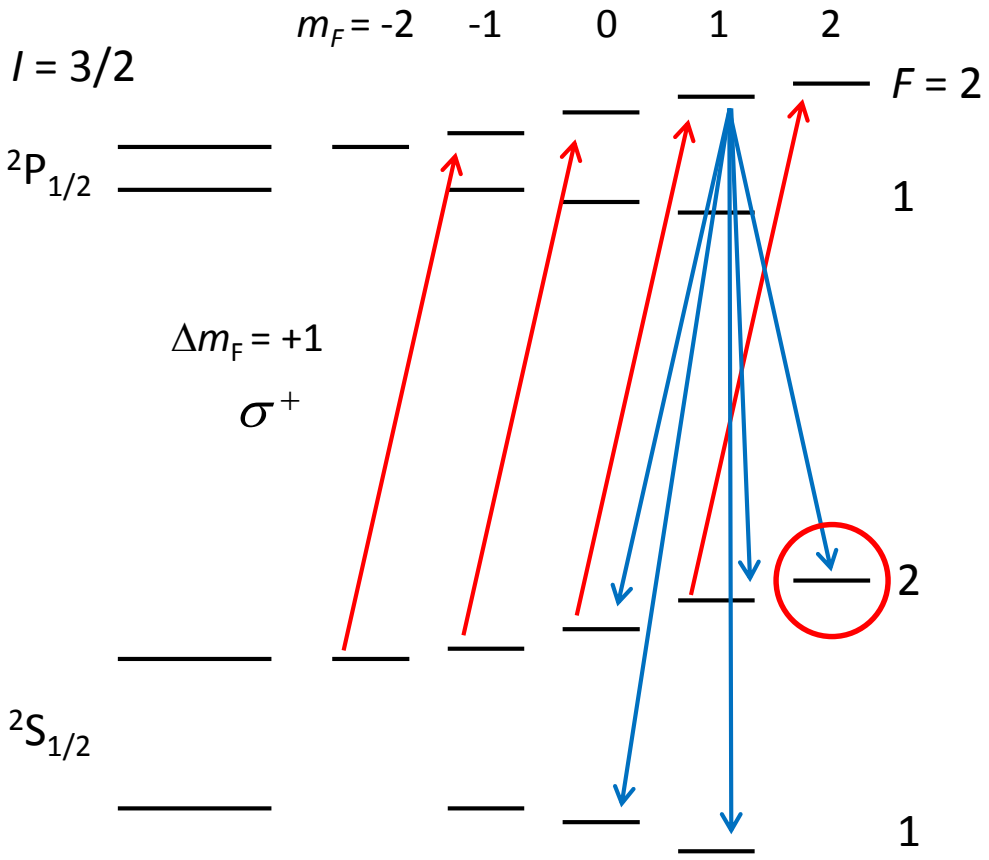


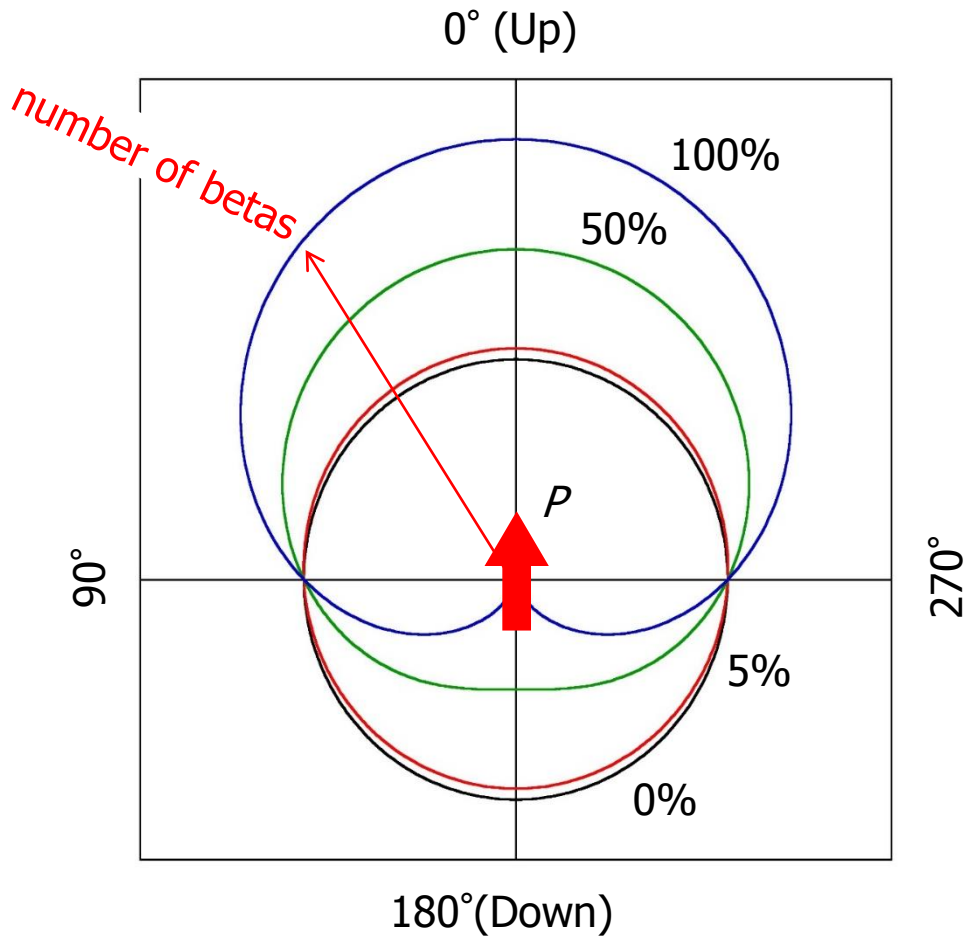
$\delta\nu^{39,37}$ = -264 ± 3 ± 3 (MHz)

c.f. $\delta\nu^{39,37}$ = -265± 4 (MHz)

J. A. Behr et al., PRL79, 375 (1997);
D. M. Rossi, K.M. et al., RSI85, 093503 (2014).

Optical pumping for nuclear polarization



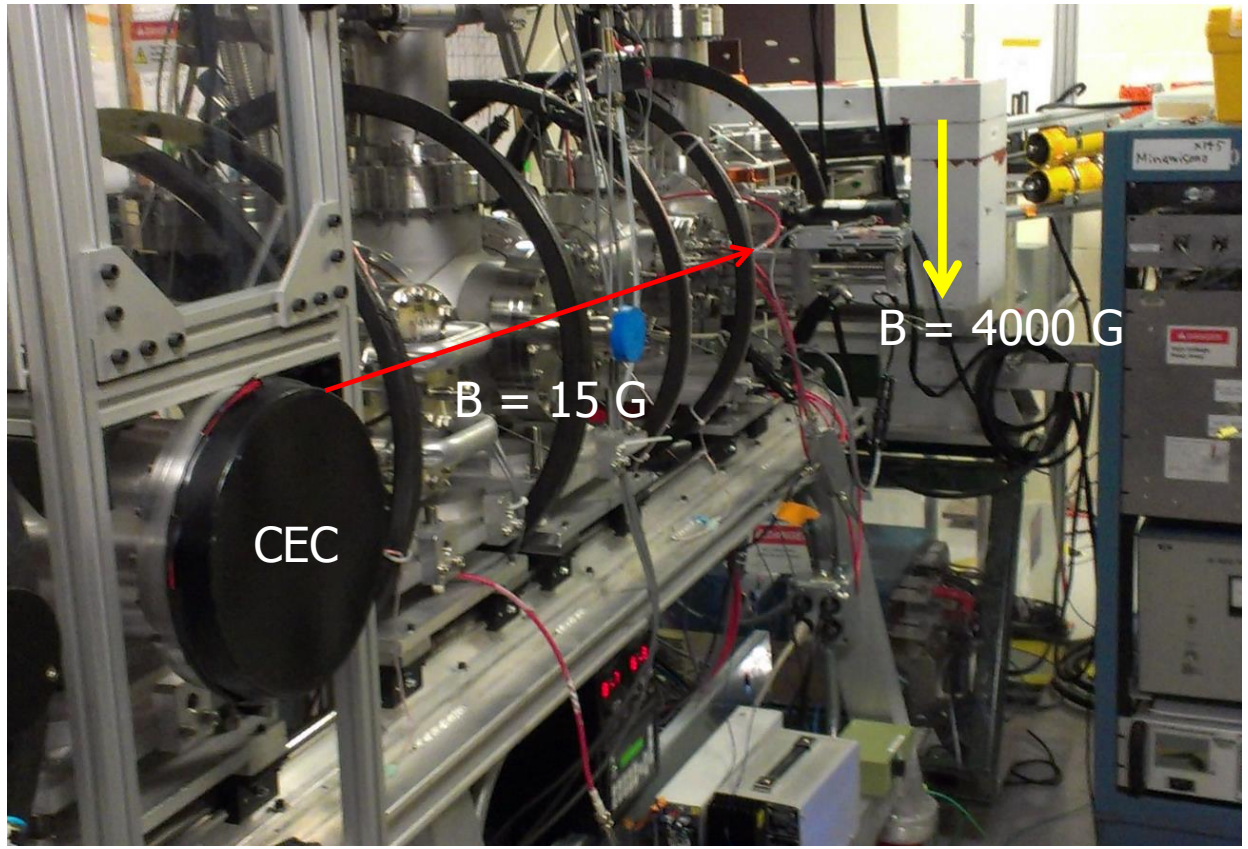


under weak external magnetic field

Eventually, $^2S_{1/2}$, F = 2, m_F=2 state will be heavily populated.

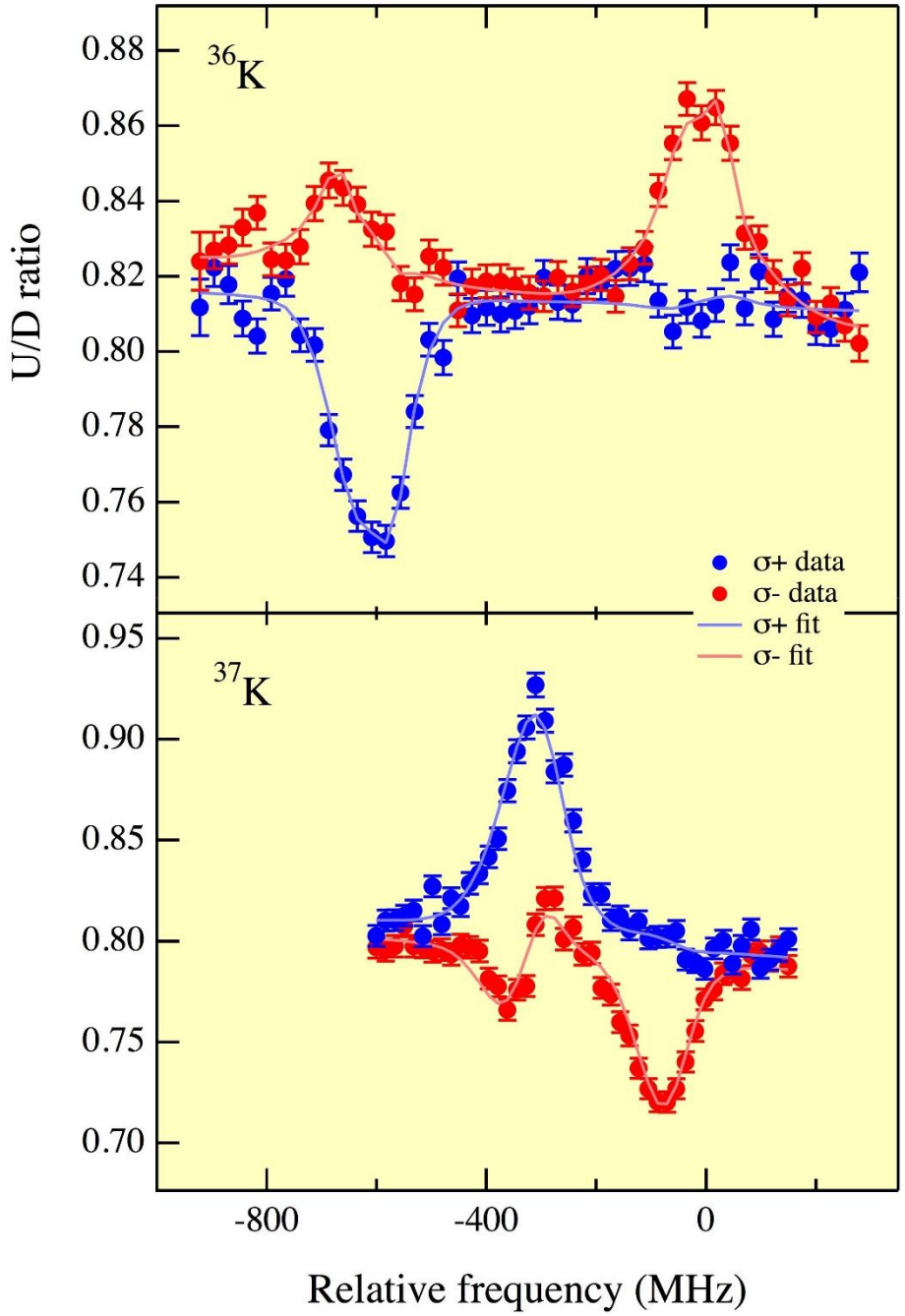
E. Arnold et al., PLB197, 311 (1087);
M. Keim et al., EPJA8, 31 (2000);
M. Kowalska et al., PRC77, 034307 (2008).

^{36}K optical pumping



- polarized ^{36}K by optical pumping
- implanted in KBr single crystal
- high magnetic field (~4 kOe)
- scan laser freq. (CEC voltage),
  measure change of β decay u/d ratio
  to determine HFS
- AP ~ 9% (max)
- ~500 atoms/s

K. Minamisono et al., NIMA589, 185 (2008).



^{36}K charge radius
optical pumping and β-asymmetry detection

- fit based on atomic rate equations
- simultaneous fits
- beta asymmetry parameters opposite sign
- magnetic moments same sign

$\delta\nu^{37,36}$ = -139 ± 4 ± 3 (MHz)

$\delta\nu^{39,37}$ = -264 ± 2 ± 3 (MHz)

$\delta\nu^{39,36}$ = -403 ± 5 ± 4 (MHz)

F = -110 ± 3 MHz/fm^2
k_{sms} = -15.3 ± 3.8 GHz u

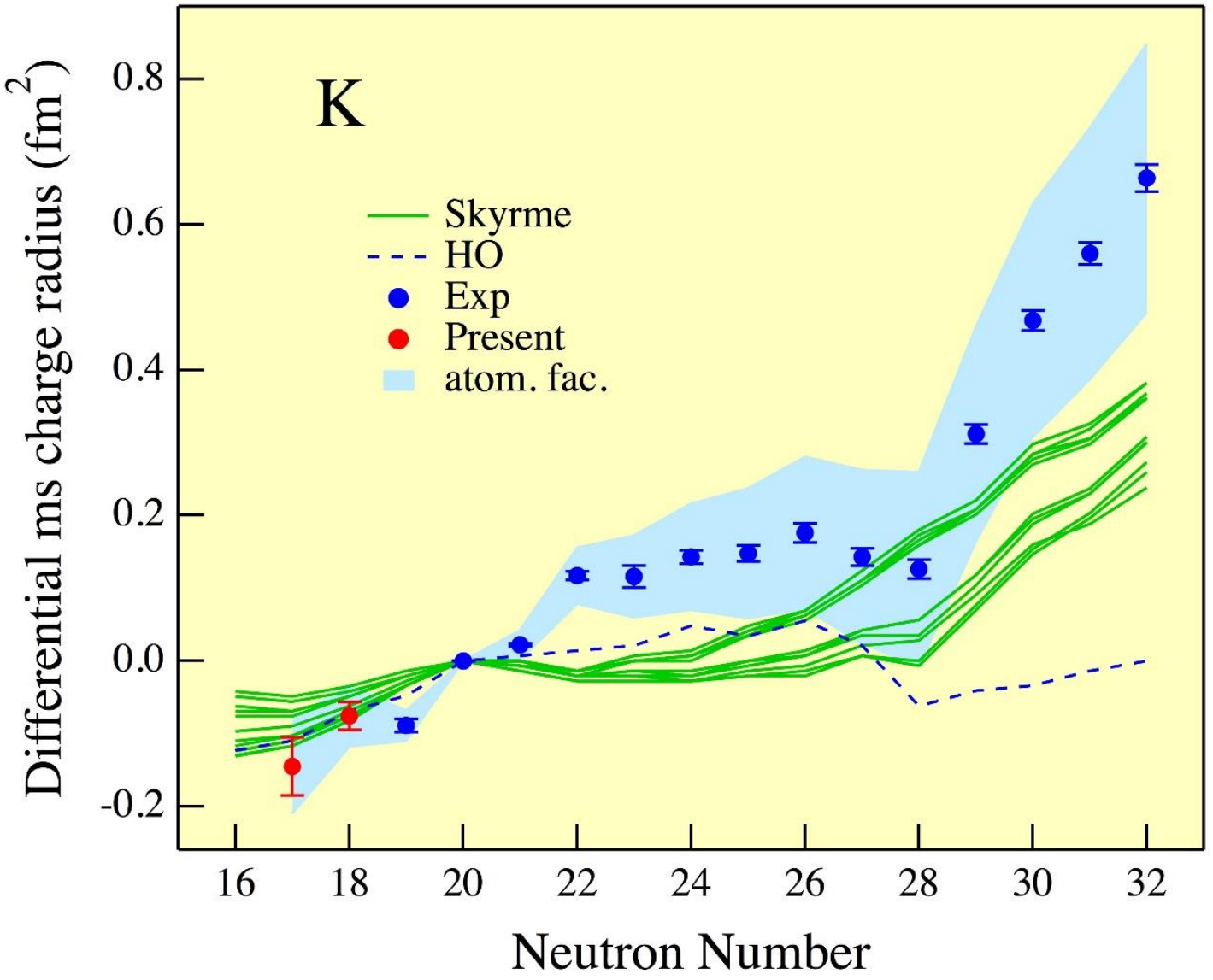
$\delta\langle r^2\rangle^{39,36}$ = -0.16 ± 0.05 ± 0.08 (fm^2)

atomic factor: A. -M. Martensson-Pendrill et al., JPB23, 1749 (1990).
M. Kowalska et al., PRC77, 034307 (2008);
D. M. Roissi, K.M. et al., PRC92, 014305 (2015).

K isotopes charge radii

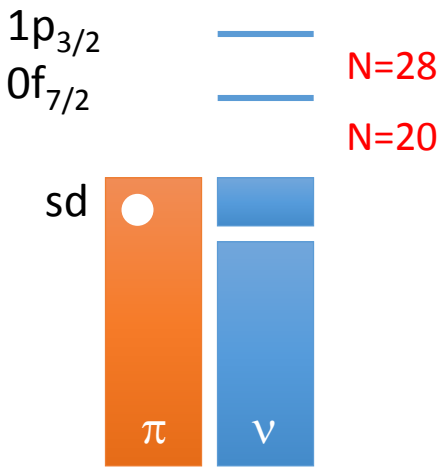
- mean-field calc. with Skyrme force
- nucleon occupation determined
  by CI shell-model calculation
- ZBM2 Hamiltonian
- excitation into $0f_{7/2}$ & $1p_{3/2}$ shells

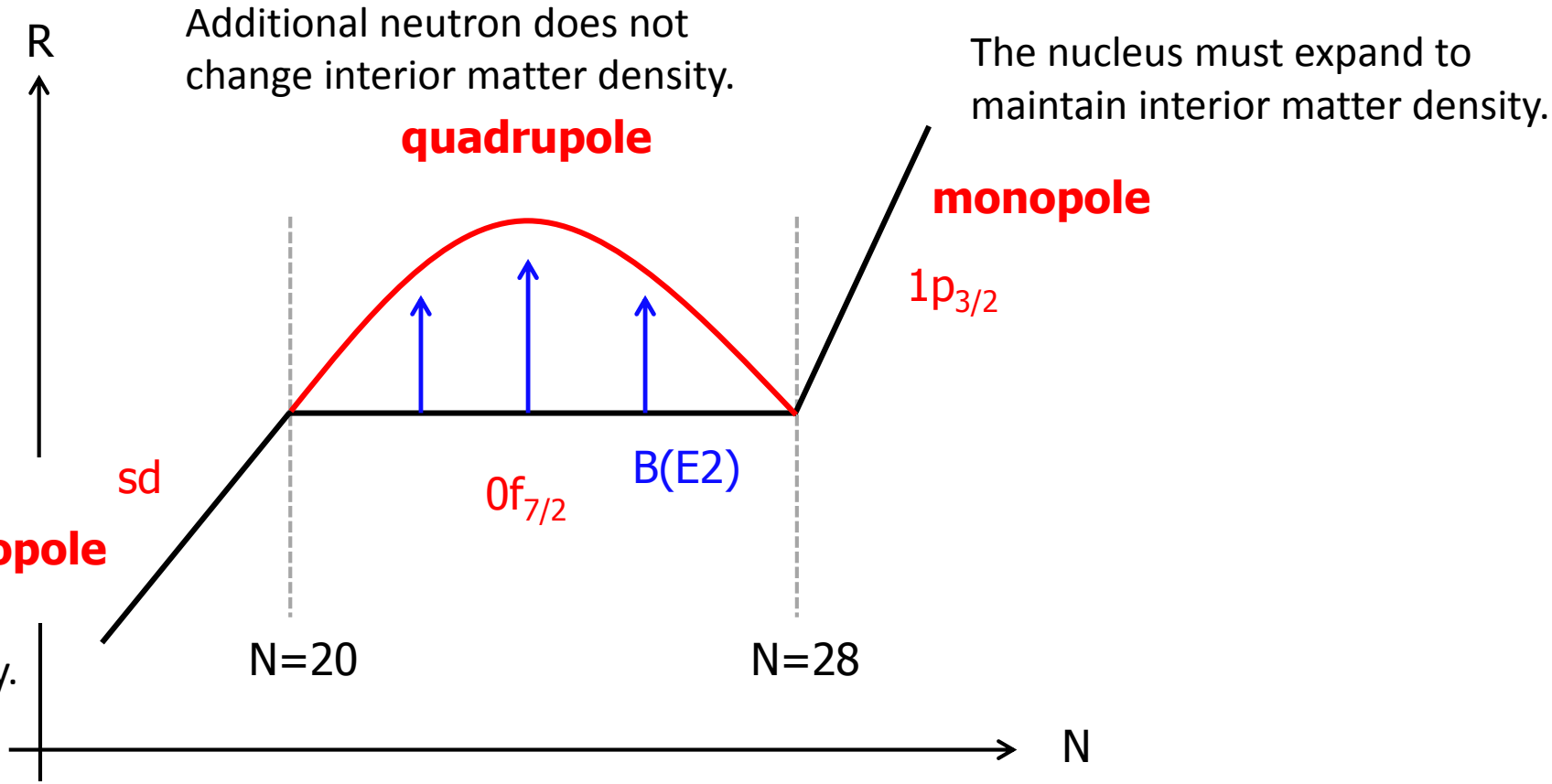
- discontinuity at $N = 28$
- smooth change at $N = 20$
- parabolic change in $0f_{7/2}$



D. M. Rossi, K.M. et al., PRC92, 014305 (2015);
A. Klein et al., PRC23, 533 (1981); K. Kreim et al., PLB731, 97 (2014).

Phenomenological interpretation

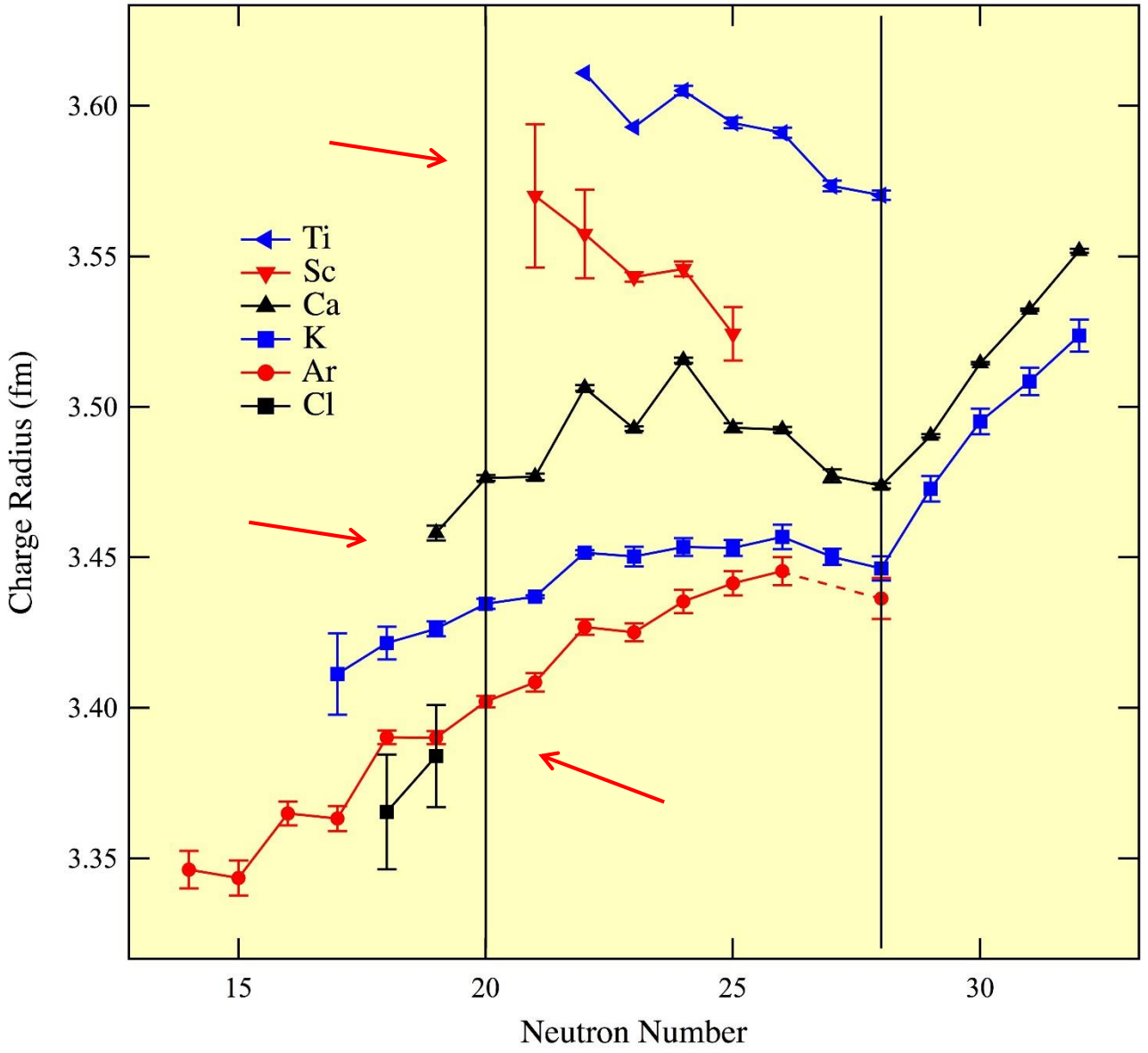




Ar isotope: A. Klein et al., NPA607, 1 (1996).

Disappearance of shell signature at N = 20

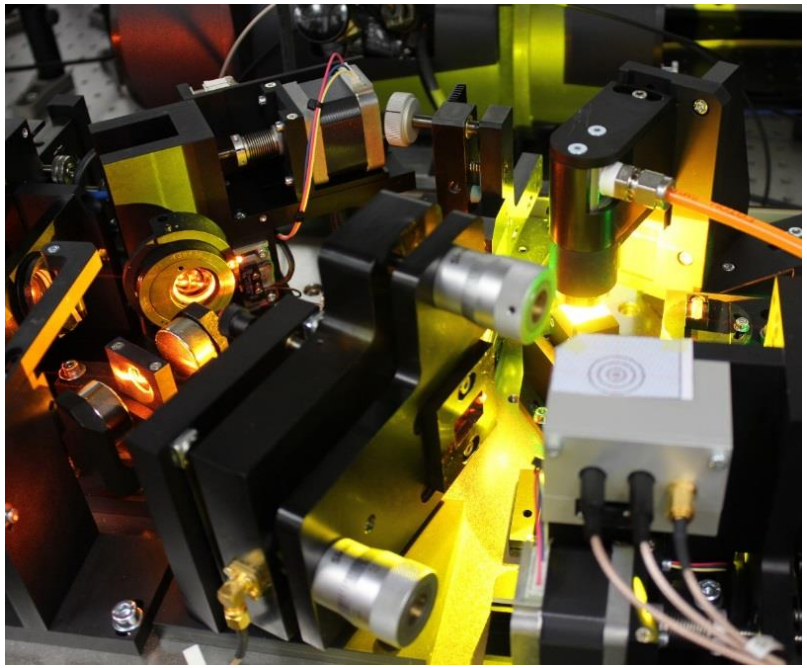
- seen for Ar, Ca and K isotopes
- balance between monopole and quadrupole effects
- why smooth connection?
- other neighboring systems?
- proposal on Ca and Sc isotopes submitted to the NSCL PAC40



Data compilation: I. Angeli, K. P. Marinova, ADNDT 99, 69 (2013).
Ar: A. Klein et al., NPA607, 1 (1996).
Sc: M. Avgoulea et al., JPG38, 025104 (2011).

Summary/Prospects

- BECOLA is a CLS facility at NSCL/FRIB
  - fully operational
- Fragmentation + gas stopping
  - neutron-deficient isotopes (transition, nonmetal elements)
- Neutron deficient K charge radii around $N = 20$
  - disappearance of shell signature at $N = 20 \rightarrow$ Ca, Sc isotopes
  - proposals submitted to NSCL PAC40
- Neutron-deficient Fe charge radii around $N = 28$
  - analysis underway
  - kink at $N = 28 \rightarrow$ neutron-deficient Ni isotopes
  - proposals submitted to NSCL PAC40
- Stay tuned



BECOLA collaboration

e11011/e14006

NSCL/MSU

K. Minamisono, G. Bollen, B. A. Brown, K. Cooper, D. Garand, K. Lund, P. F. Mantica, A. Miller, D. J. Morrissey, R. Ringle, J. A. Rodriguez, C. A. Ryder, C. Sumithrarachchi

e14006

TU Darmstadt

D. M. Rossi, W. Nörtershäuser, B. Maaβ

TRIUMF

M. Pearson

ORNL

Y. Liu

Augustana University

A. Klose

ANL

P. Müller

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THANK YOU.