Aspects of Lifetime Measurements in the LIBRA Framework

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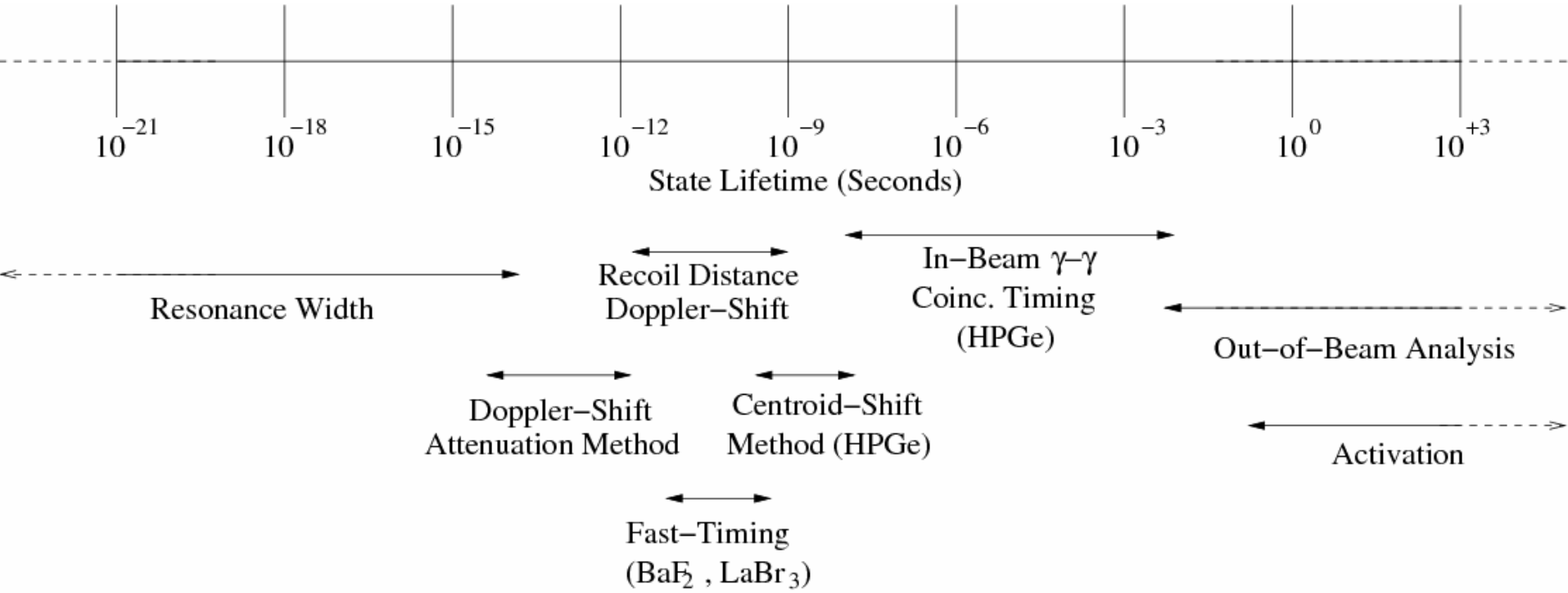
2nd Annual LIBRA Meeting, Athens Greece: November 9th 2009

Outline

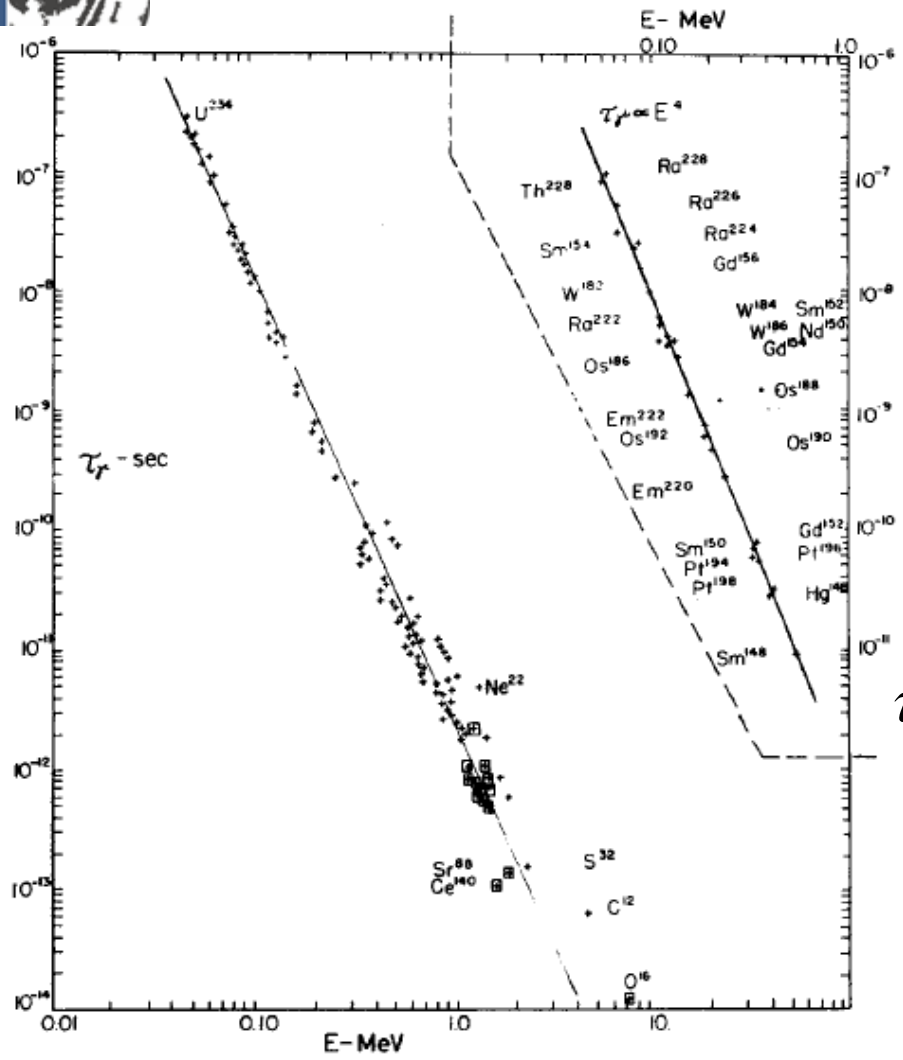
- Lifetimes of Excited States in Atomic Nuclei
  - Range and Their Importance to Nuclear Physics
- Picosecond Lifetime Determination
  - “Plunger” Apparatus and Recoil Distance Doppler Shift
  - The Current: RDDS by Fusion-Evaporation Reactions
  - The Future: RDDS by Coul.-Ex. in Inverse Kinematics
- sub-Picosecond Measurements at Demokritos
  - ECLIPSE@LIBRA
  - Commissioning Runs

LIBRA

Range of Lifetimes in Atomic Nuclei



The Picosecond Regime



L. Grodzins, Phys. Lett. **2** (1962) 88

Empirical relation between $\tau(2+)$ and $E(2+)$

$$T_\gamma = \frac{1}{\tau\left(2^+\right)} = \left(4 \pm 2\right) \times 10^{10} E^4 Z^2 A^{-1}$$

$E(2^+)$ in MeV and $\tau(2^+)$ in seconds

Updated relation given by

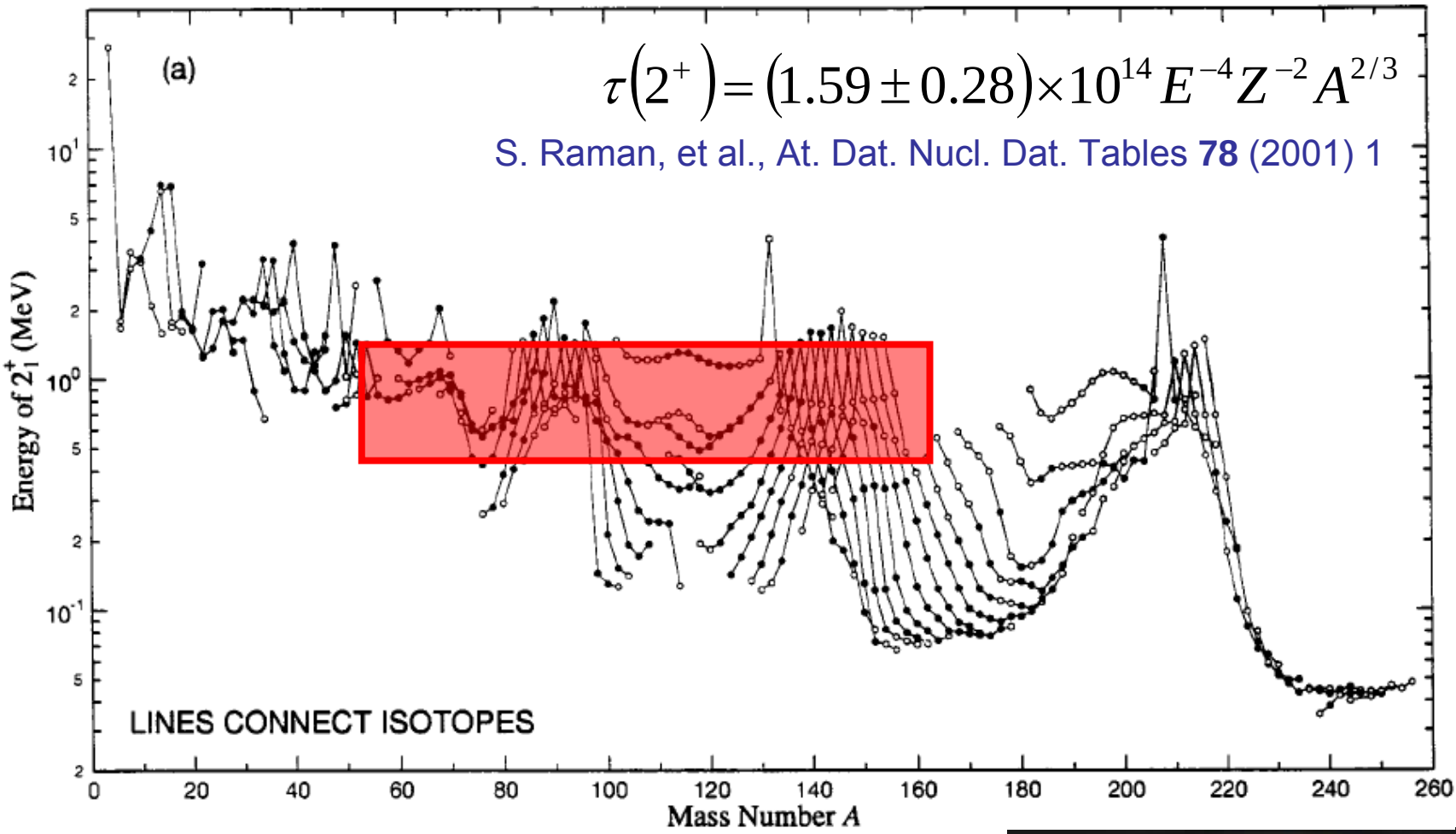
$$\tau\left(2^+\right) = \left(1.59 \pm 0.28\right) \times 10^{14} E^{-4} Z^{-2} A^{2/3}$$

$E(2^+)$ in keV and $\tau(2^+)$ in picoseconds

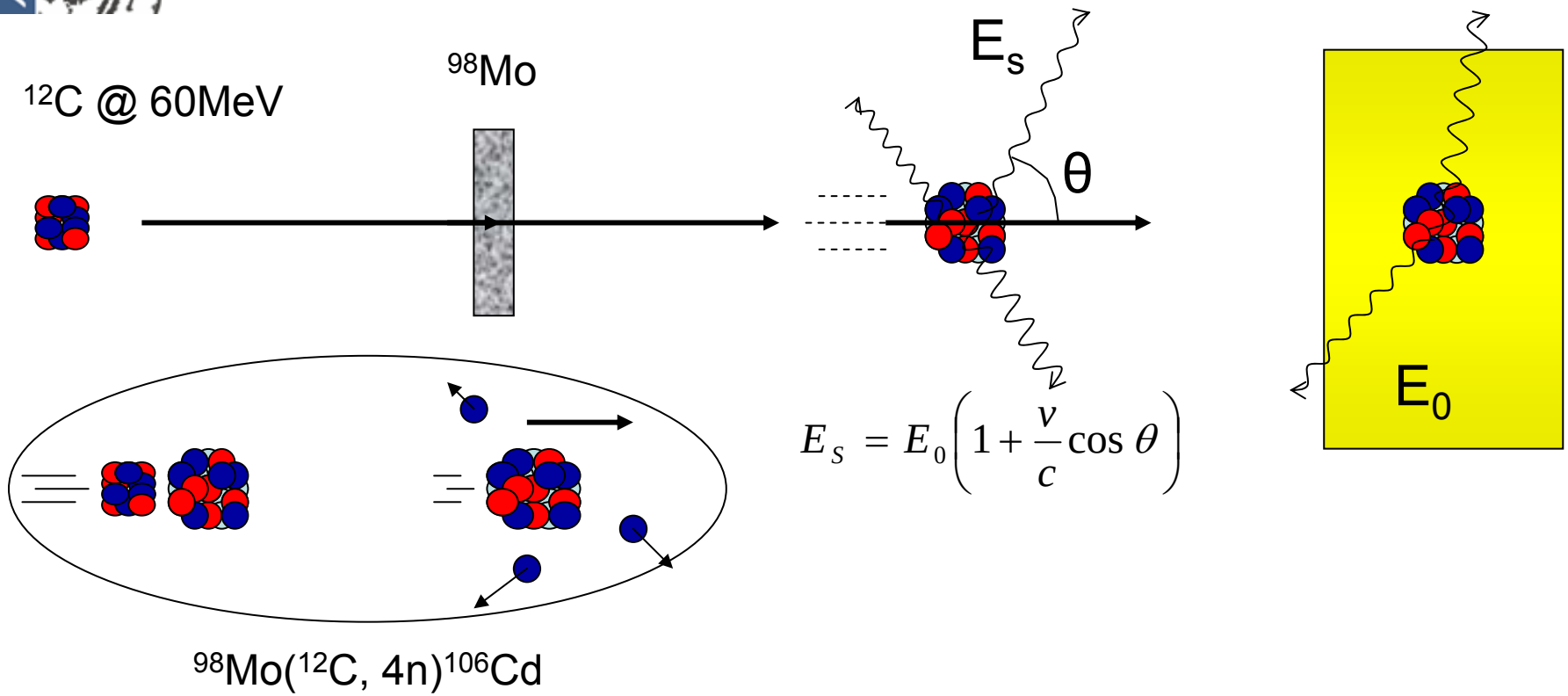
S. Raman et al., ADNDT **78** (2001) 1

The Picosecond Regime

Shaded region shows partial range of lifetimes (100 fs to 100 ps)

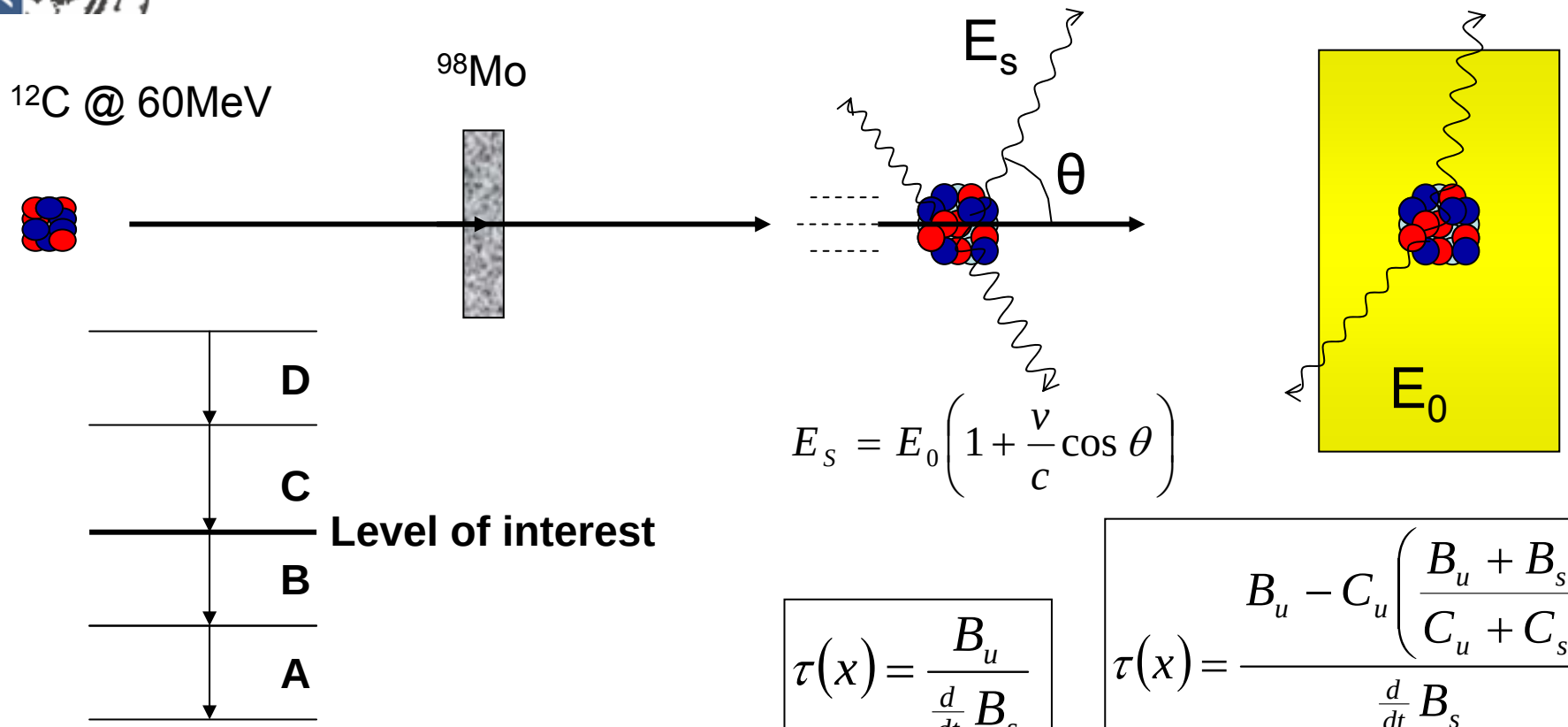


Recoil Distance Doppler Shift (1)



$$E_S = E_0\left(1 + \frac{v}{c}\cos\theta\right)$$

Recoil Distance Doppler Shift (1)



$$E_S = E_0\left(1+\frac{v}{c}\cos\theta\right)$$

$$B(E2) = \frac{1}{1.225\times10^{9}\,E_\gamma{}^{5}\,\tau}$$

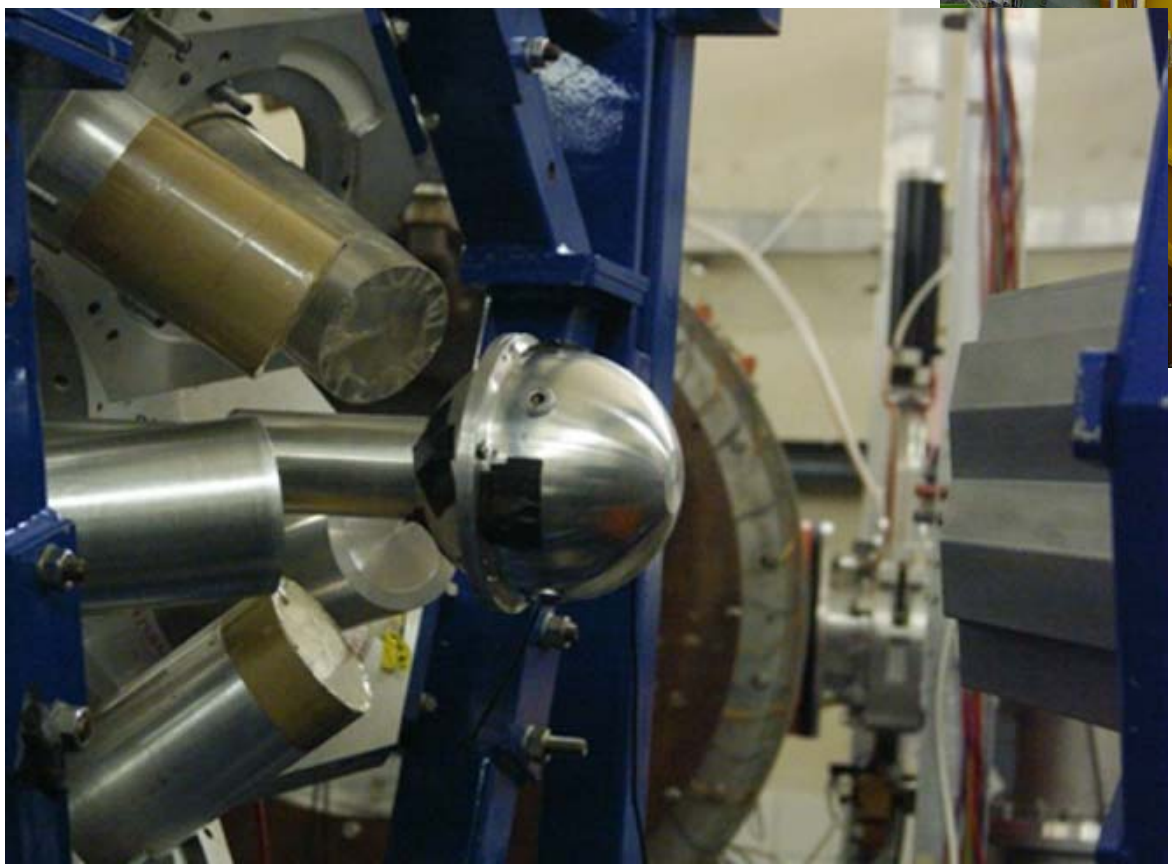
$$\tau(x) = \frac{B_u}{\frac{d}{dt}B_s}$$

$$\tau(x) = \frac{B_u - C_u\left(\frac{B_u+B_s}{C_u+C_s}\right)}{\frac{d}{dt}B_s}$$

G. Böhm *et al.*, NIM A **329** (1993) 248

The Plunger: IKP, Universität zu Köln

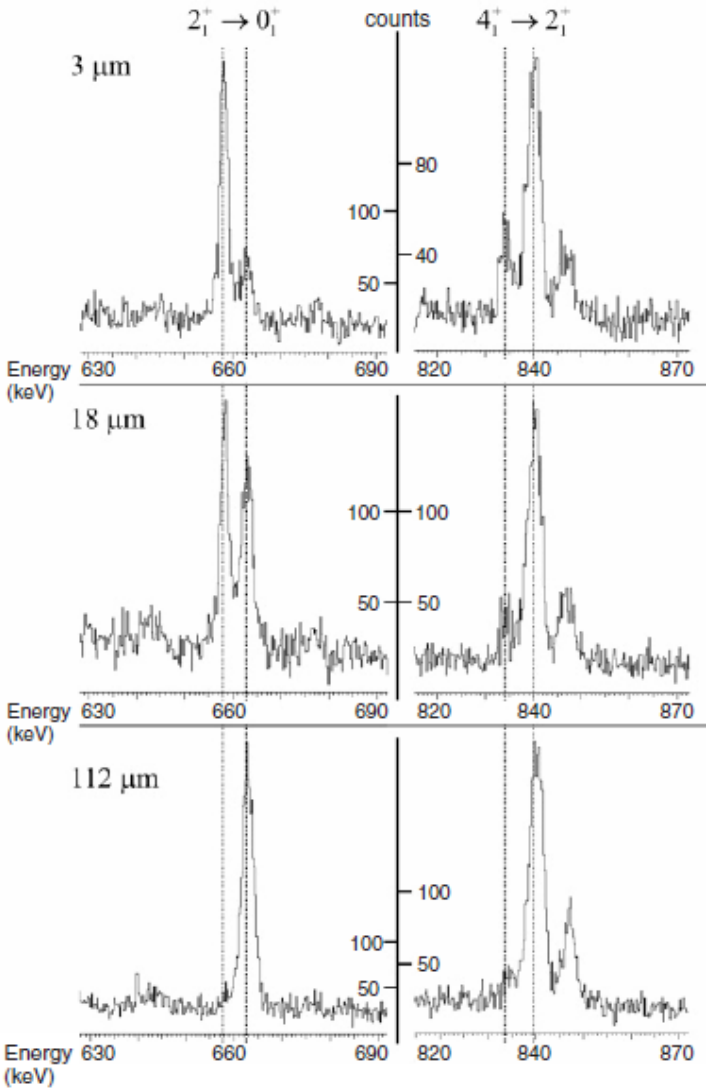
Köln plunger with 1 Euroball cluster det. and 5 HPGe dets.



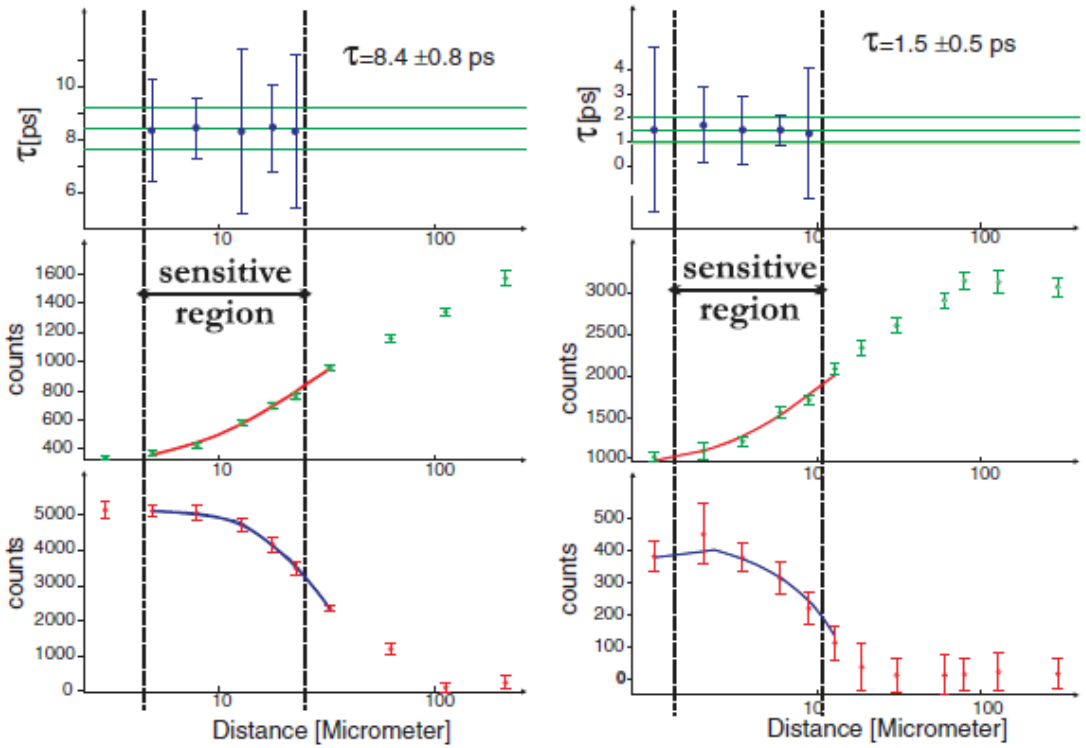
Köln 9MV FN
Tandem Van de Graaff

The Plunger: IKP, Universität zu Köln

N. Boelaert, et al., Phys. Rev. C **75** (2007) 054311



^{94}Mo(^{12}C,2n)^{104}Cd, E(^{12}C) = 42 MeV



$\tau(2^+)$ = 8.5(12) ps $\tau(4^+)$ = 1.5(5) ps

The Plunger: IKP, Universität zu Köln

N. Boelaert, et al., Phys. Rev. C **75** (2007) 054311

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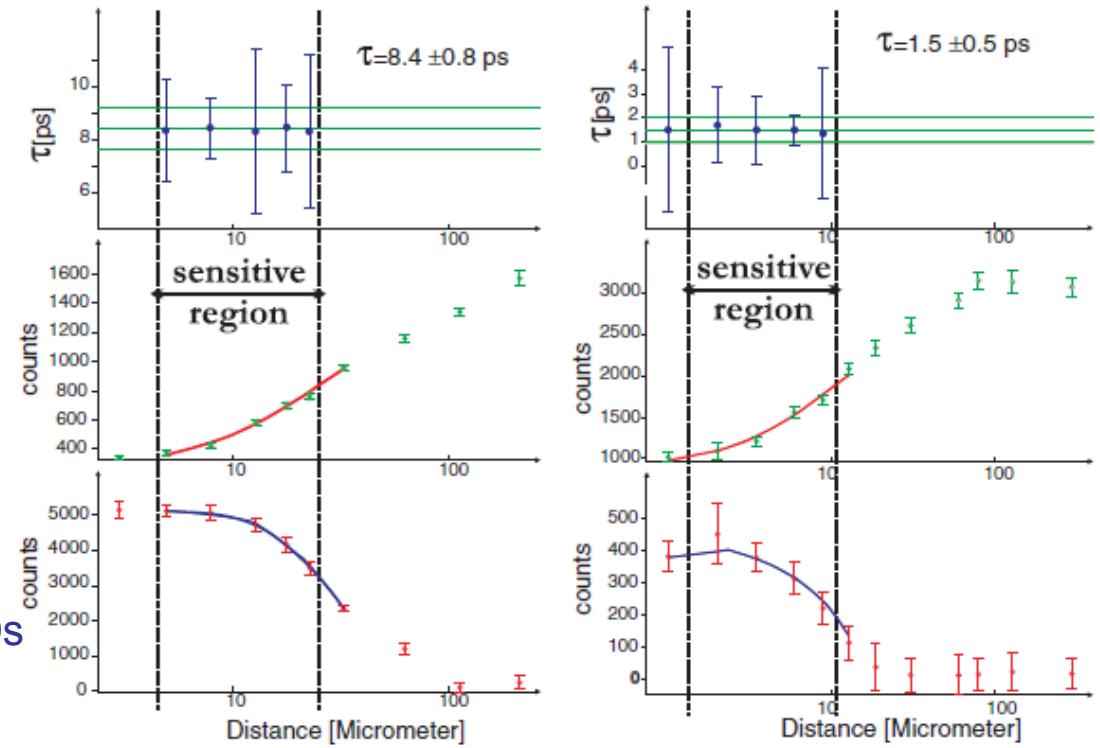


$\tau(2^+)$ = 8.5(12) ps $\tau(4^+)$ = 1.5(5) ps

Other recent measurements:

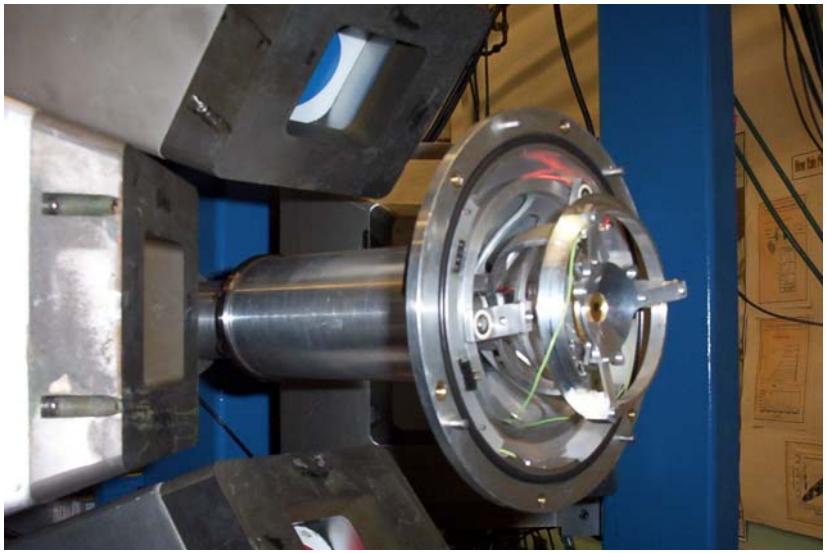
O. Möller, et al., ^{93}Nb(^{24}Mg,p2n)^{114}Te
E(^{24}Mg) = 90 MeV
Phys. Rev. C **75** (2005) 064324

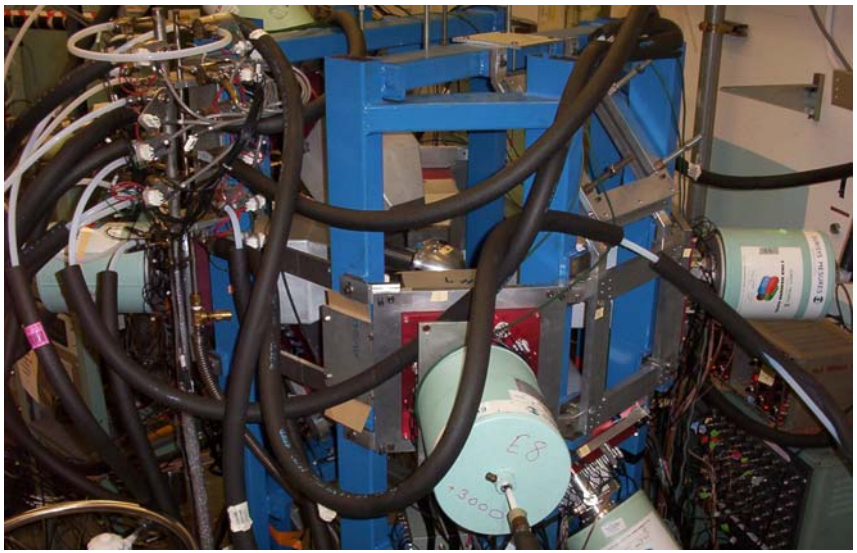
D. Tonev et al., ^{154}Gd(^{32}S,^{32}S*)
E(^{32}Se) = 110 MeV
Phys. Rev. C **69** (2004) 034334

O. Möller, et al., $^{164\text{-}168}$Er(^{16}O,4n)$^{176\text{-}180}$Os
E(^{16}O) = 80 MeV
Phys. Rev. C **72** (2005) 034306

Energy (keV)

The Plunger: WNSL, Yale University





Yale 20 MV ESTU Tandem Van de Graaff

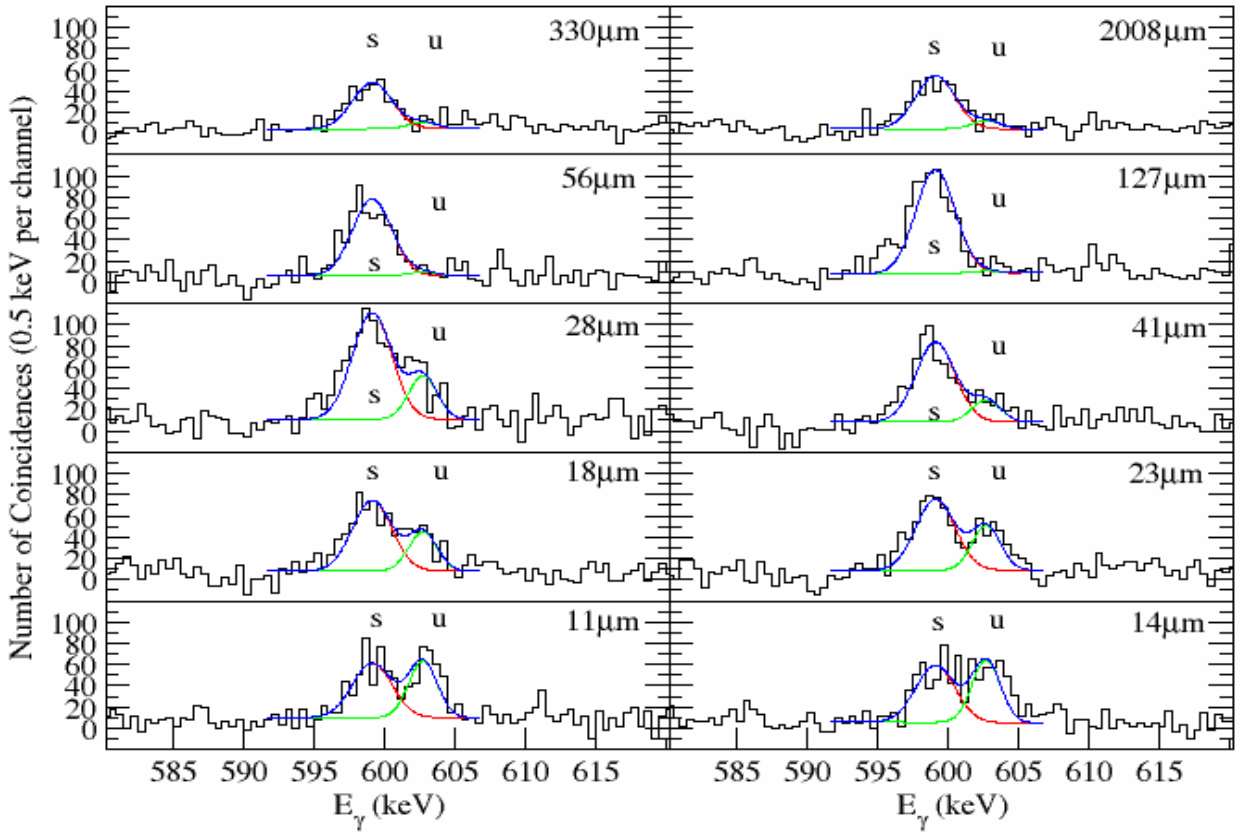
H.R. McK. Hyder et al., NIM A **268** (1988) 285

New Yale Plunger Device

R. Krücken, J. Res. Natl. Inst. Stand. **105** (2000) 53

The Plunger: WNSL, Yale University

) = 60 MeV

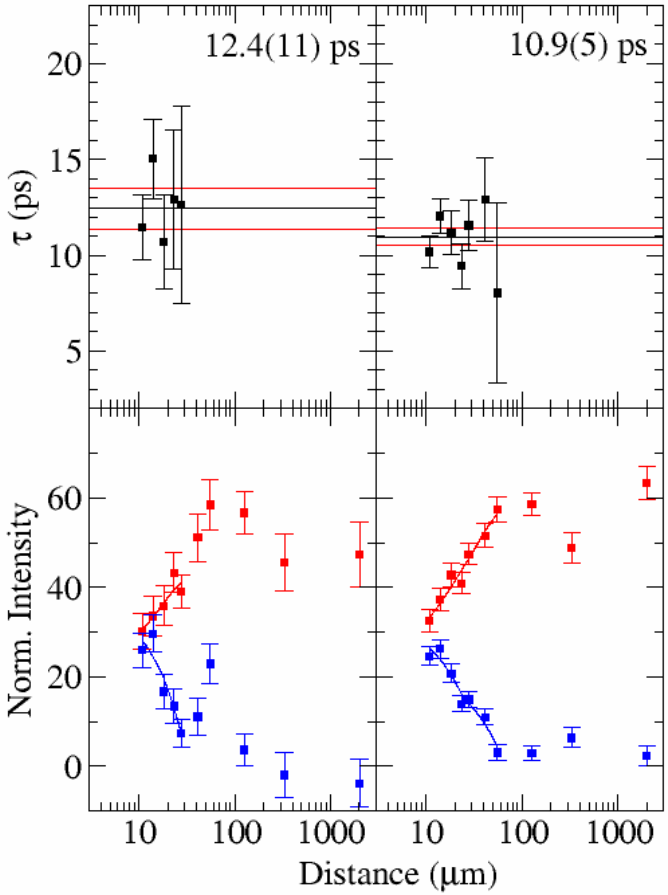


S.F. Ashley et al., Phys. Rev. C **76** (2007) 064302

2nd LIBRA Meeting, Athens Greece: November 9th 2009

The Plunger: WNSL, Yale University

$^{98}Mo(^{12}C,4n)^{106}Cd$, $E(^{12}C) = 60$ MeV



$\tau(12+) = 11.4(17)$ps
$B(E2) = 30.4(45)$ W.u.

S.F. Ashley et al., Phys. Rev. C **76** (2007) 064302

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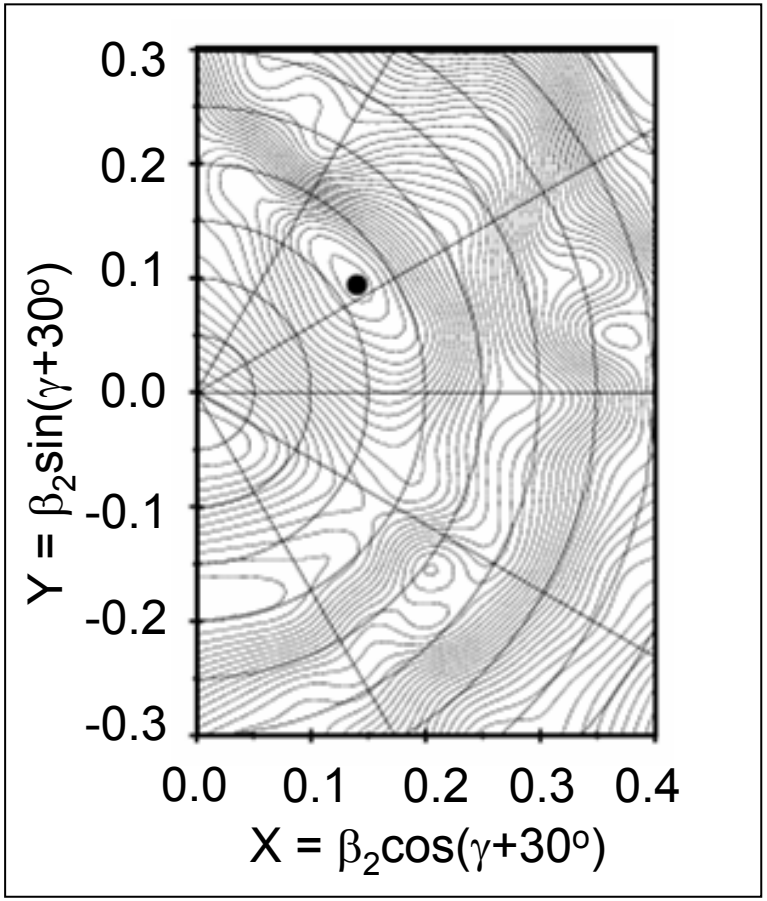

$\tau(12+) = 11.4(17)$ps
$B(E2) = 30.4(45)$ W.u.

$\beta_2 = 0.14(1)$

TRS Calculation:
(F.R. Xu, Priv. Comm.)
$\beta_2 = 0.17(1)$

Calc. ground state def.:
(Möller – Nix)
$\beta_2 = 0.14$

S.F. Ashley et al., Phys. Rev. C **76** (2007) 064302

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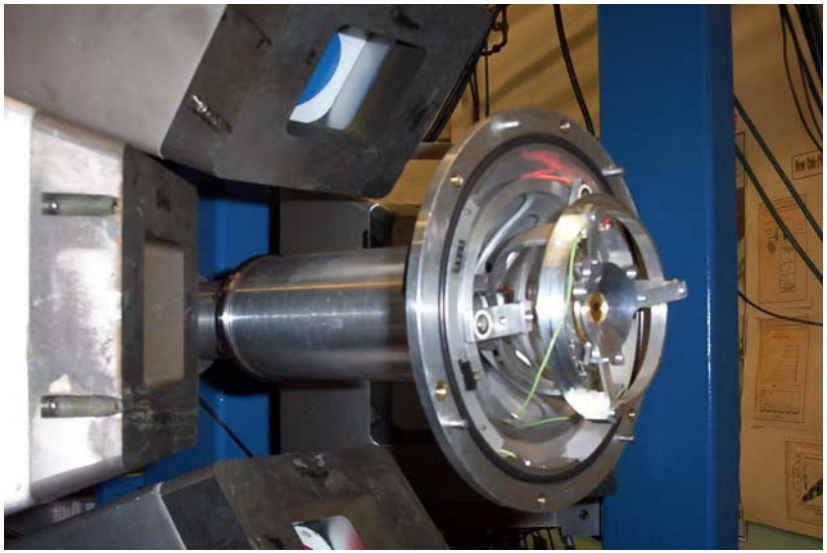
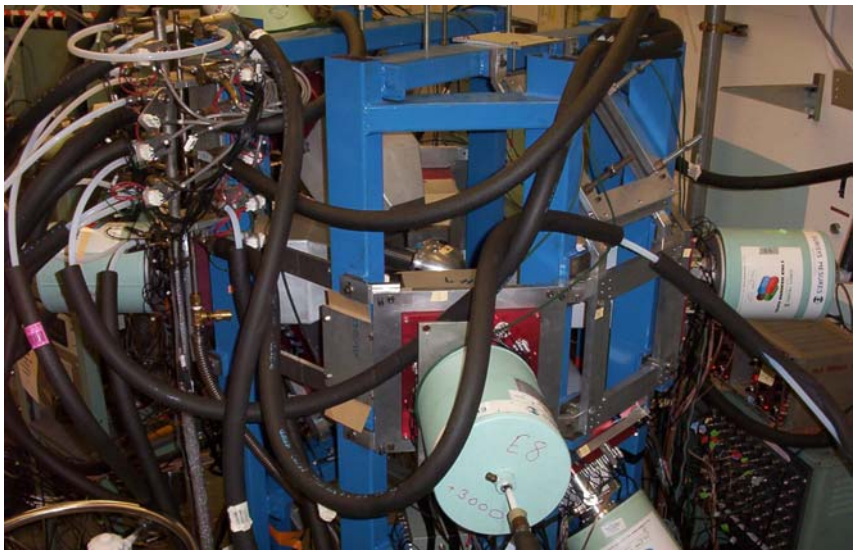
The Plunger: WNSL, Yale University





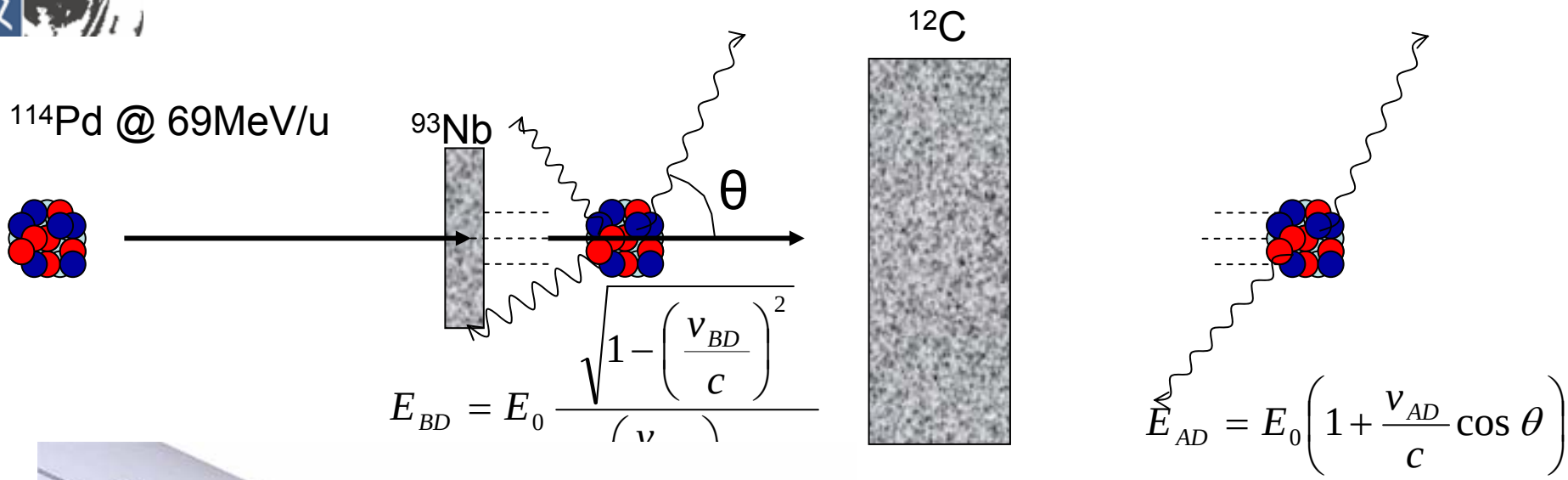
^{168}Hf: A. Costin, et al.,
Phys. Rev C **79** (2009) 024307

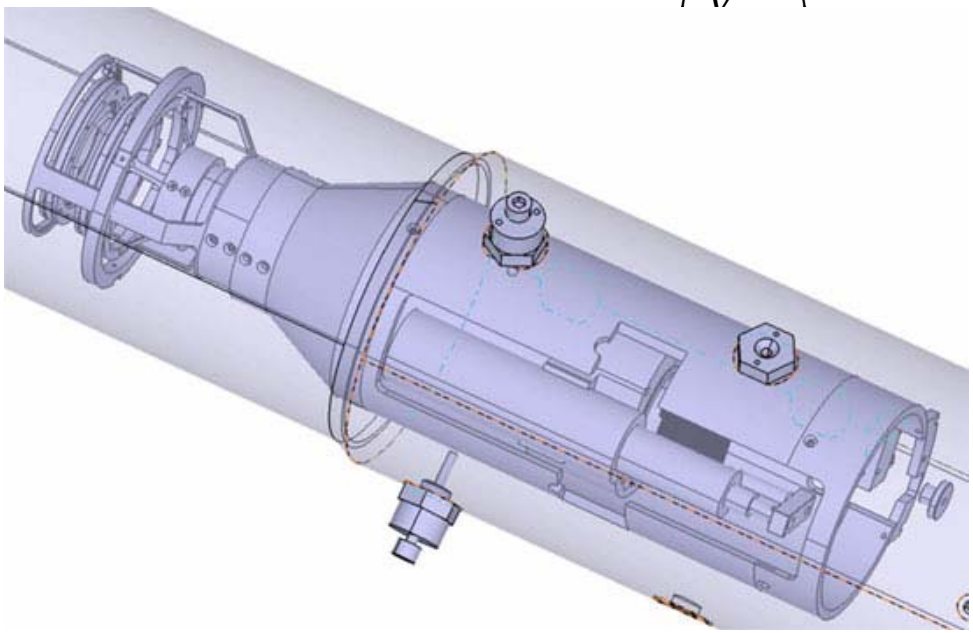
^{103}Pd, ^{106,107}Cd: S.F. Ashley, et al.,
Phys. Rev. C **76** (2007) 064302

^{162}Yb, ^{166}Hf: E.A. McCutchan, et al.,
Phys. Rev. C **75** (2006) 034303

^{128}Ce: D.L. Balabanski, et al.,
Int. J. Mod. Phys. **E15** (2006) 1735

Recoil Distance Doppler Shift (2)





Köln plunger at NSCL

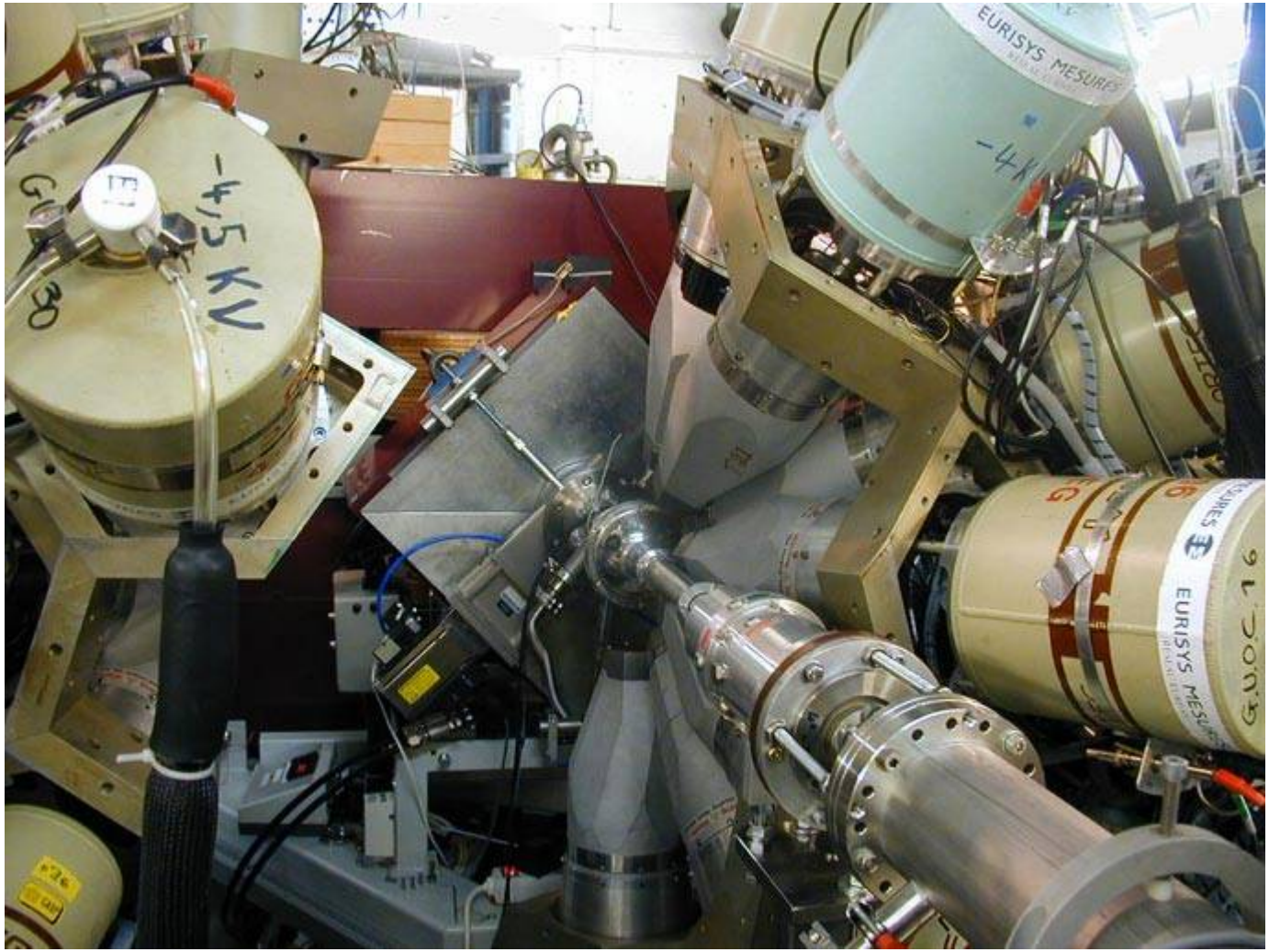
^{93}Nb(^{65}Ge,n)^{64}Ge

K. Starosta, et al., PRL **99** (2007) 042503

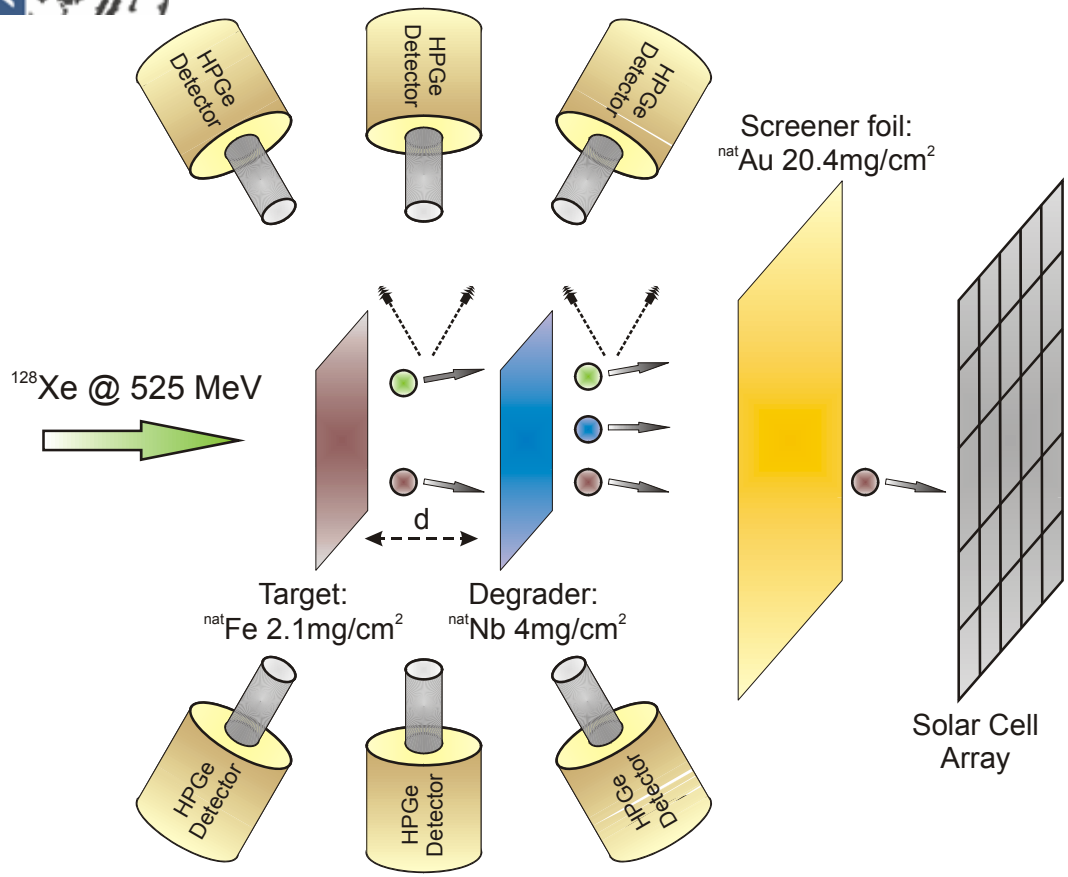
^{93}Nb(^{110,114}Pd,^{110,114}Pd*)

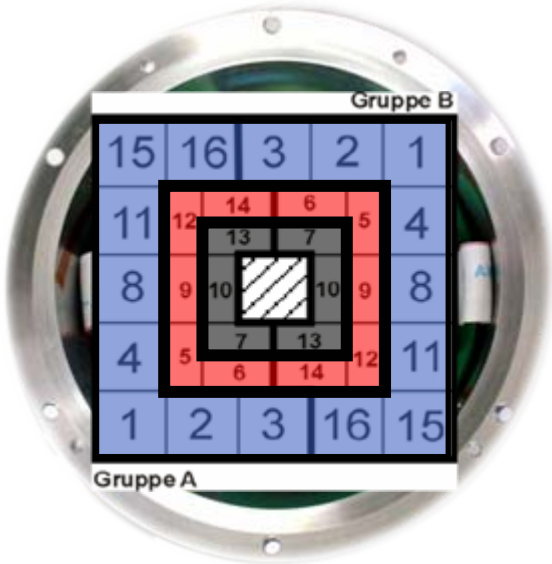
A. Dewald, et al., PRC **78** (2007) 051302R

The Plunger: JYFL, Jyväskylä



The Plunger: JYFL, Jyväskylä





Particle Coincidence Technique Characterisation

A. Dewald, M. Hackstein, W. Rother, et al., NIM A (In Prep.)

Figures courtesy of T. Konstantinopoulos

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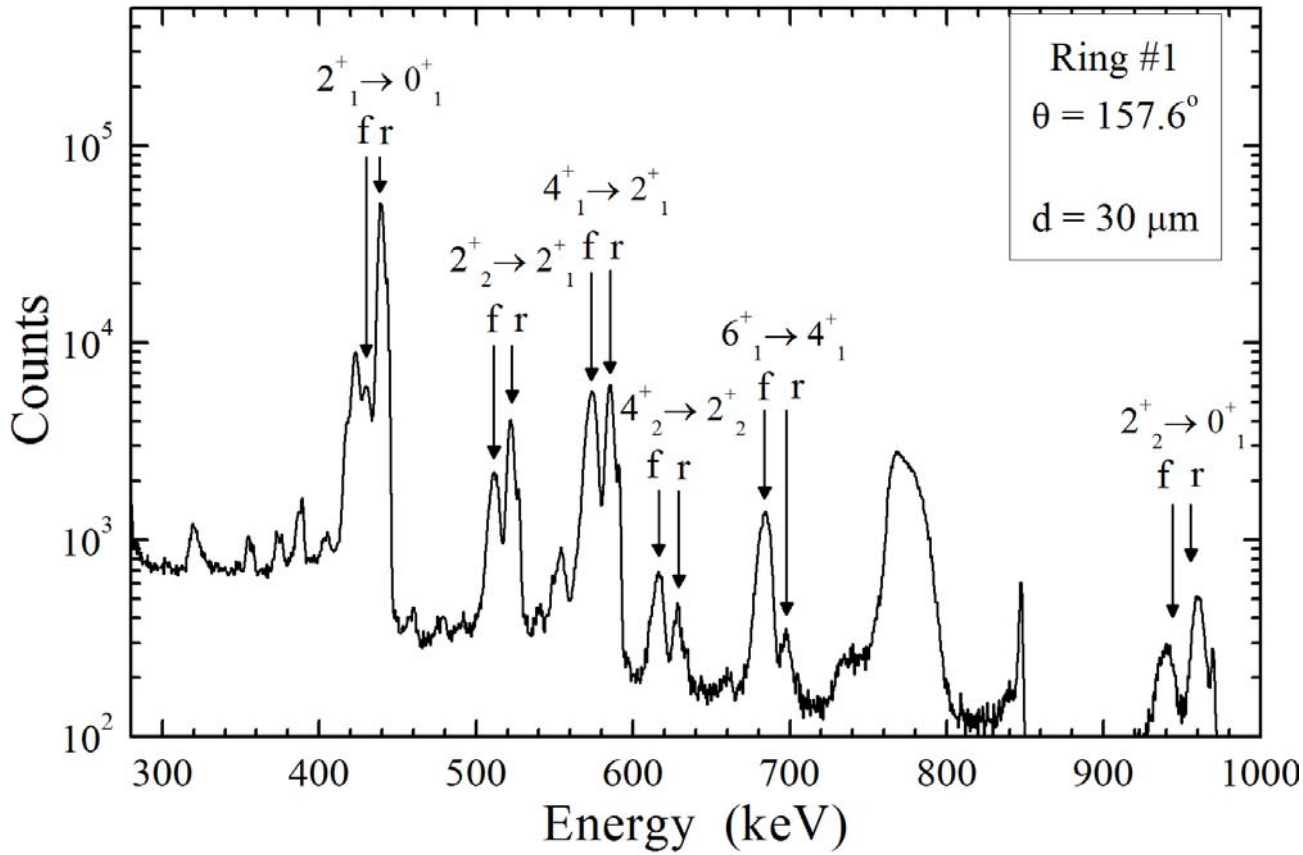
The Plunger: JYFL, Jyväskylä

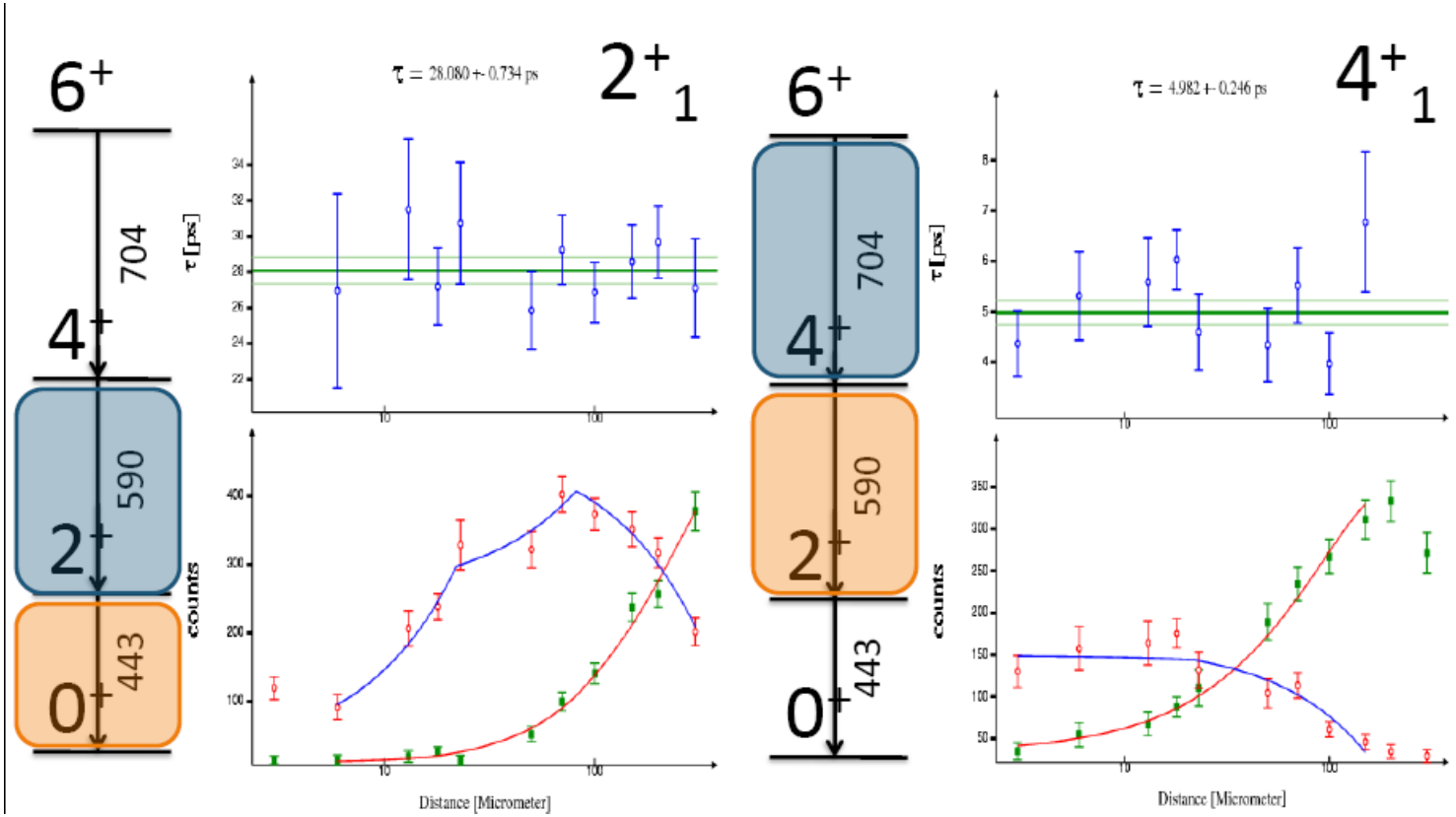


$^{nat}Fe(^{128}Xe, ^{128}Xe^*)$

W. Rother, M. Hackstein, et al., (In Prep.)

Figures courtesy of T. Konstantinopoulos

The Plunger: JYFL, Jyväskylä



$\tau(2^+) = 26.9(7)$ ps

$\tau(4^+) = 4.7(2)$ ps

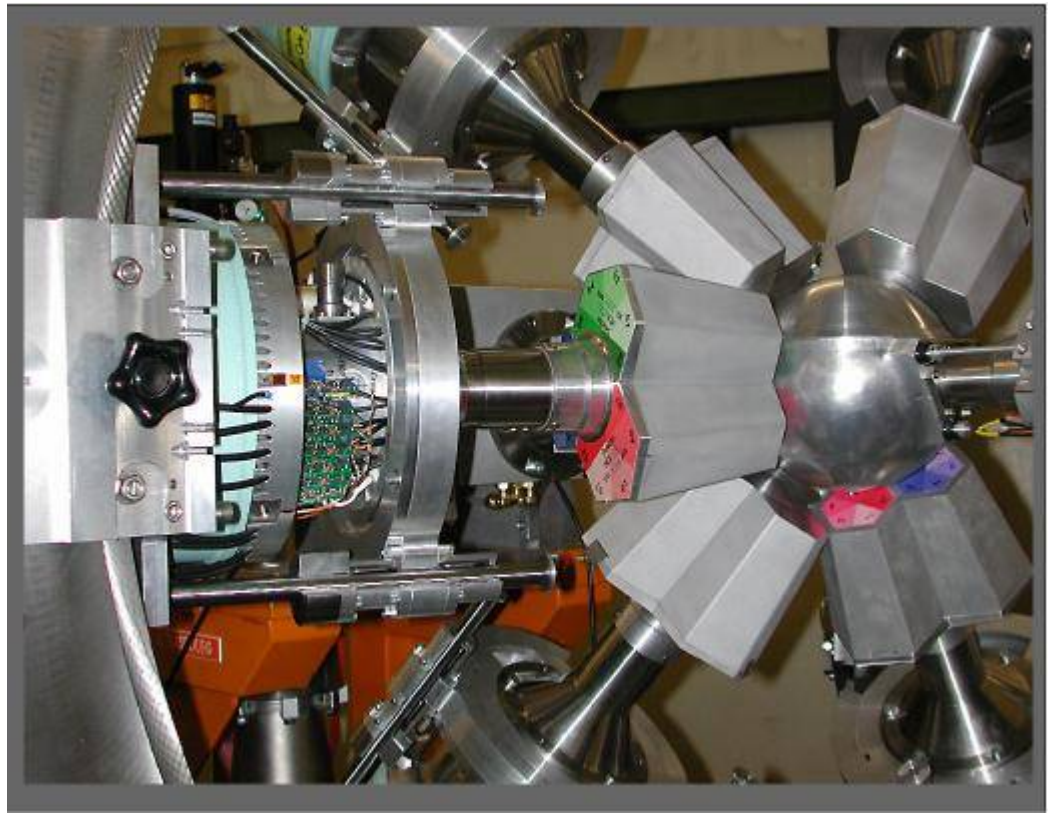
$^{nat}Fe(^{128}Xe, ^{128}Xe^*)$

W. Rother, M. Hackstein, et al., (In Prep.)

Figures courtesy of T. Konstantinopoulos

The Plunger: MINIBALL @ CERN

MINIBALL: J. Eberth, et al.,
Prog. Part. Nucl. Phys 46 (2001) 398



Recent Coul-Ex Expts.:

$^{74\text{-}80}$Zr: J. Van de Walle, et al.,
Phys. Rev. C **79** (2009) 014309

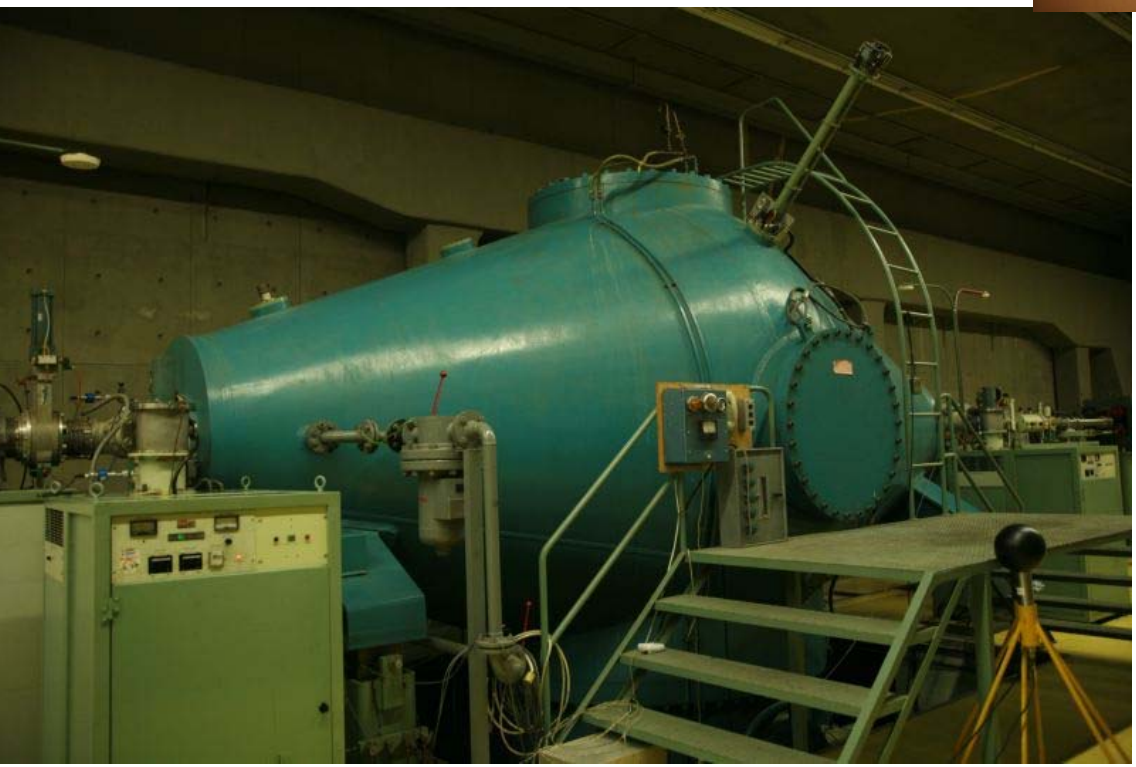
^{68}Ni: N. Bree, et al.,
Phys. Rev. C **78** (2008) 047301

^{106,108}Sn: A. Ekstrom, et al.,
Phys. Rev. Lett. **101** (2008) 012502

$^{138\text{-}142}$Xe: T. Kröll, et al.,
Eur. Phys. J. Sp. Topics **150** (2007) 127

Closer to Home…

5.5 MV T11 HVEC Tandem Van de Graaff
G. Vourvopoulos, et al.,
Nucl. Instr. Meth. **220** (1984) 23

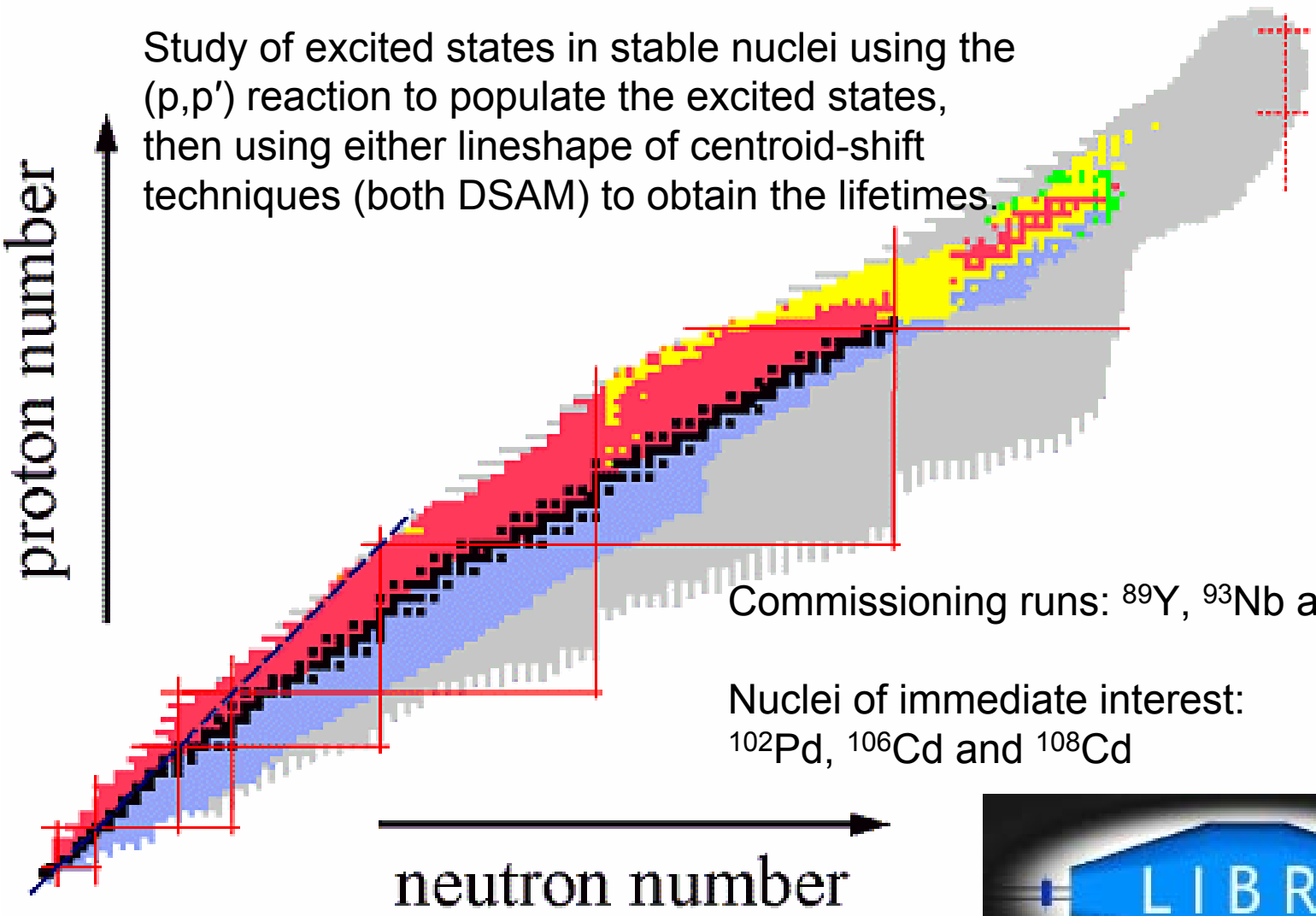


Scattering chamber set-up
in Red Expt. Hall

ECLIPSE @ LIBRA

Extra**C**tion of **L**ifetimes using **I**nelastic **P**roton **S**cattering **E**xperiments

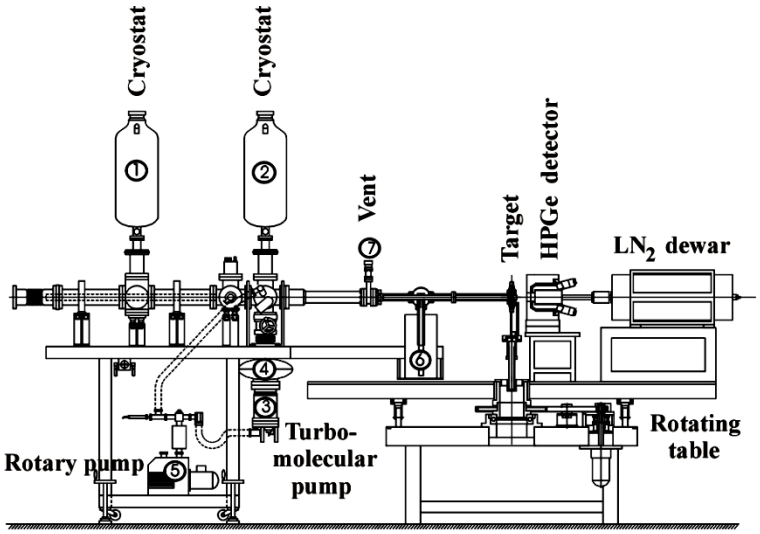
Study of excited states in stable nuclei using the (p,p′) reaction to populate the excited states, then using either lineshape of centroid-shift techniques (both DSAM) to obtain the lifetimes.

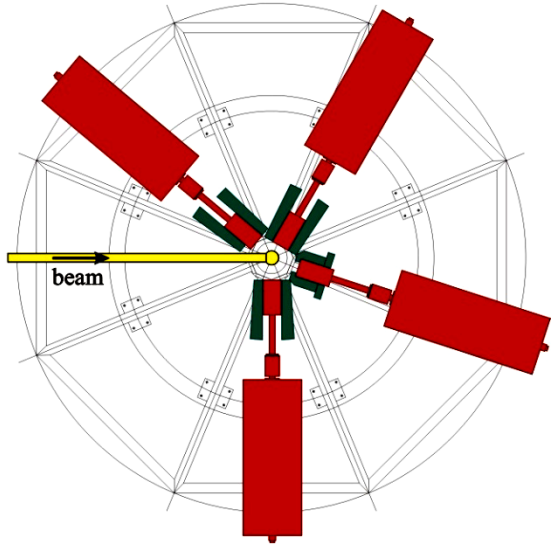


Commissioning runs: ^{89}Y, ^{93}Nb and ^{48}Ti

Nuclei of immediate interest:
^{102}Pd, ^{106}Cd and ^{108}Cd

ECLIPSE @ LIBRA



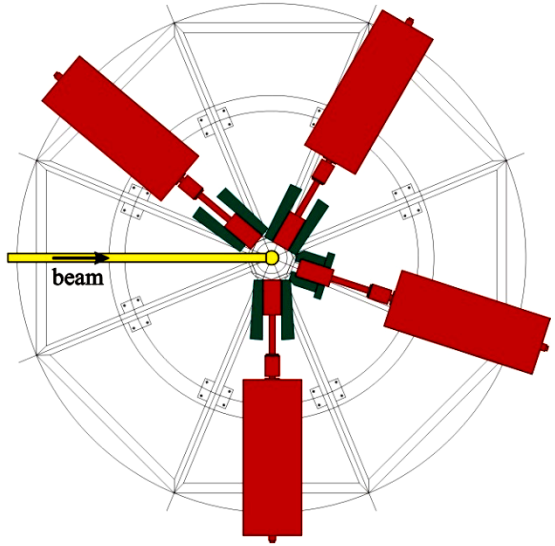


Former set-up at IfS, Stuttgart

Rotating table to arrive in mid-November

3 (100%) HPGe detectors to arrive in January

ECLIPSE @ LIBRA



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Concluding Remarks

- Extracting picosecond lifetimes of excited states are important to studies of nuclear structure
- Plunger unique tool for attaining these lifetimes
  - (Köln, Yale, Legnaro, JYFL and ANL)
    - Coulomb Excitation (normal kinematics, stable beam)
    - Fusion Evaporation
  - (JYFL and Yale)
    - Coulomb Excitation (inverse kinematics, stable beam)
  - (NSCL and CERN)
    - Coulomb Excitation (inverse kinematics, RIBs)
    - Knockout Reactions (RIBs)
- Proposed lifetime measurements at Demokritos