Exploring exotic nuclei via transition probabilities using the plunger technique

A. Dewald, University of Cologne

Outline:

- Plunger activities
- Plunger for deep inelastic reactions
- Plunger with radioactive beams
- ^{66}Fe at N=40
- New developments
- RDDS data analysis
- Target issues
- Summary

List of recent plunger measurements with the Cologne plunger group

Index	Jahr	Monat	Spokesperson	Institut	Kern	Reaktion
1	2008	March	Iwasaki	Köln	13B	7Li,p
2		Oct	Korten	GANIL	62,64Fe	deep inelastic
3		Oct	Dewald	LNL	180Os	Fusion Evaporation GASP
4		Nov	Joss, Grahn	JYFL	175Au	Fusion Evaporation, Jurogam, RITU
5		Dec	Harissopulos	JYFL	130Xe	Coulex
6	2009	Feb	Fallon	MSU	20C	
7		Feb	Adrich	NSCL	78Ni	
8		Feb	Clark	NSCL	16C	
9		Feb	Adrich	NSCL	18C	
10		Mar	Dewald	NSCL	62,64,66Fe	intermediate Coulex
11		Mai	Gladnishki	Köln	140Nd	Fusion Evaporatation
12		Oct	Möller, Franchoo	GANIL	73Cu	
14		Juli	Mengoni	LNL	51,53V	Fusion Evaporation GASP
15		Juli	Recchia, Gadea	LNL	112Te	Fusion Evaporation GASP
16		Juli	Valiente-Dobon	LNL	Cr	AGATA+Prisma+Alpi Stattgefunden???
17	2010	April	Nara Sing, Wadsworth	ANL	68Se	
18		April	Grahn, Scheck	ANL	184,186,188Hg	Fusion Evap
19		June	Görgen	LNL	72,74Zn	Agata+Prisma
20		Septembe r	Clement, Ljungvall	Ganil		
21		Septembe r	Görgen, Sahin, Doncel	Ganil	68,70,72Ni	tiefinealstisch, 238U + 70Zn --> 68,70,72Ni
22		Oktober	Fransen	Jyv	86Kr	inverse Coulex, 40Ca(86Kr, 86Kr*)40Ca*
23		Oktober	Konstantinopoulos	Jyv	130Xe	inverse Coulex, Fe(130Xe, 130Xe*)Fe*
24		Novembe r	Grahn	Jyv	182Pt	Compound, 154Sm(32S,4n)182Pt
25		Novembe r	Joss	Jyv	163,164W	Compound 106Cd(60Ni,2pn)163W
26		Nov/Dez	Cederwall	Jyv	108,110,112Te	54Fe(58Ni,2p2n)108Te, 54Fe(58Ni,2p)110Te, 56Fe(58Ni,2p)112Te
27		Dez	Cullen	Jyv	138Gd	Compound, 108Cd(36Ar,2p2n)138Gd
28	2011	April	Görgen	Ganil	insb. Ru,Pd Isotope	Fusion-Fragmentation 9Be(238U,-)-
29		May	Fransen	GSI	54Cr	Coulomb Excitation
30		Juni	Chapman	LNL	34Si,35P, 36S	36S(208Pb,-)-
31		July	Gadea	LNL	136Xe	

Cologne Plunger

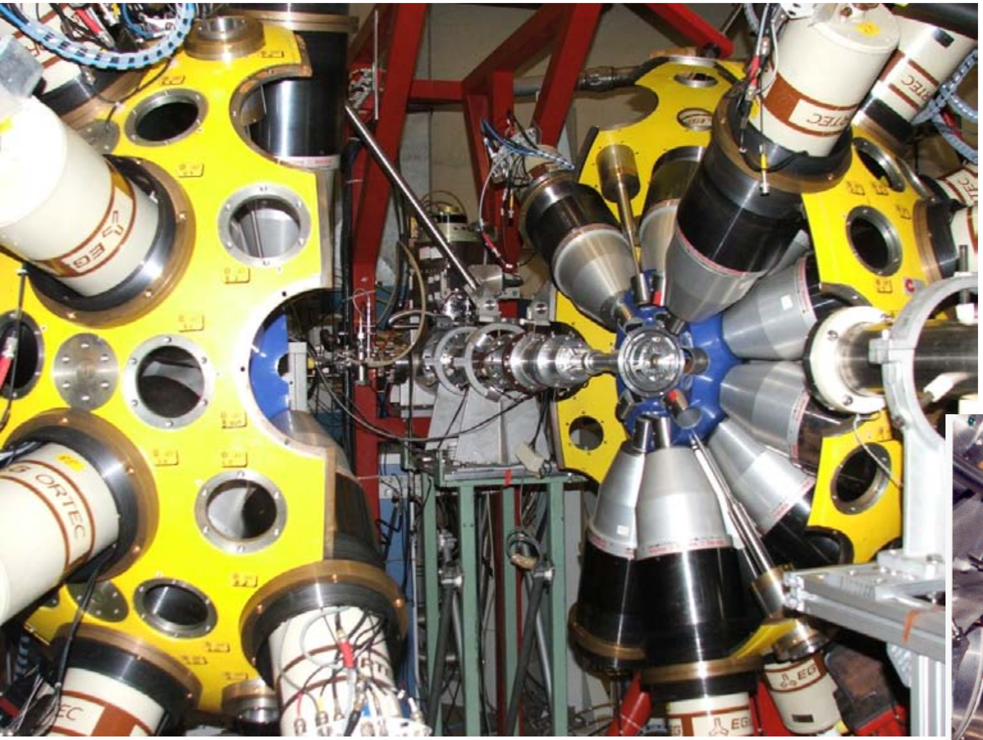
Copied by : Yale,
Bucharest,
Jyväskylä/ Manchester

Alternative design by Orsay group

New Plunger for MINIBALL@ CERN
S. Harissopulos (Athens), A. Blazhev (Cologne)

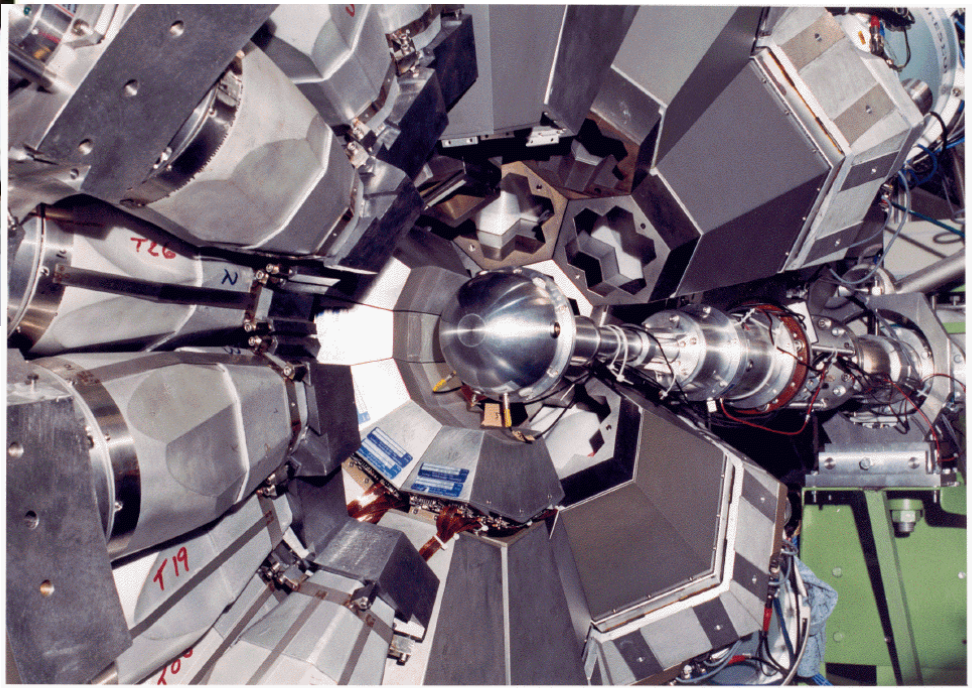
γγ Coincidence Plunger

GASP

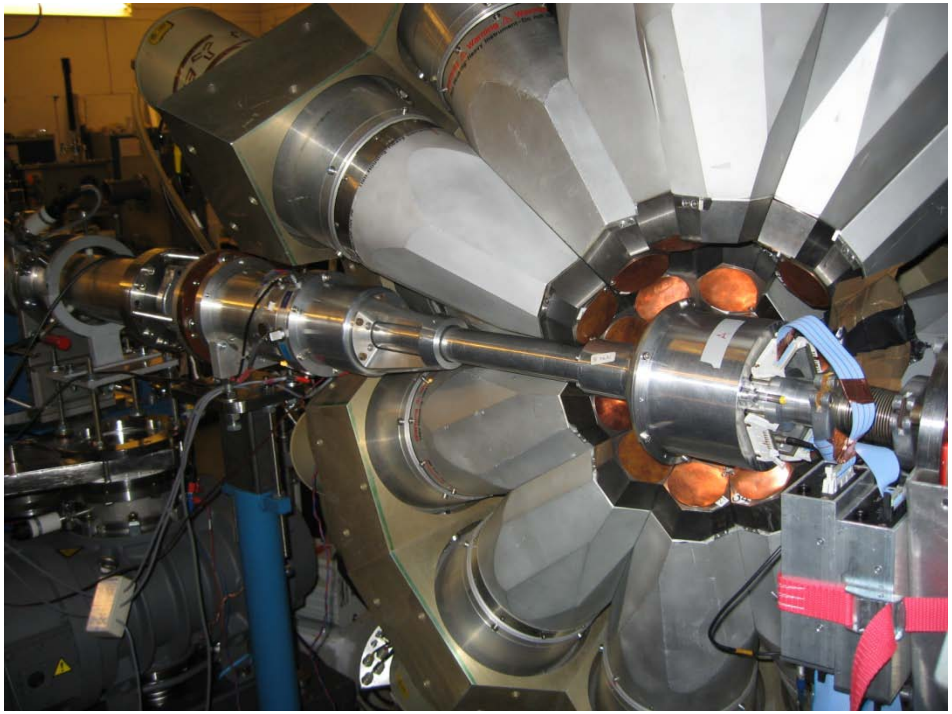


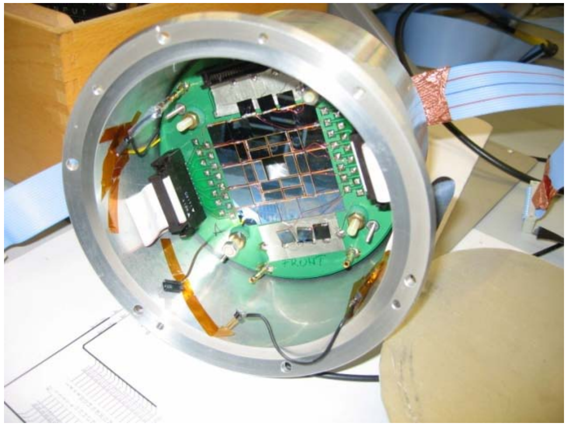
high precision: $\Delta\tau<3\%$

EUROBALL



Plunger with an array of photo-diodes @ JYFL / Jyväskylä



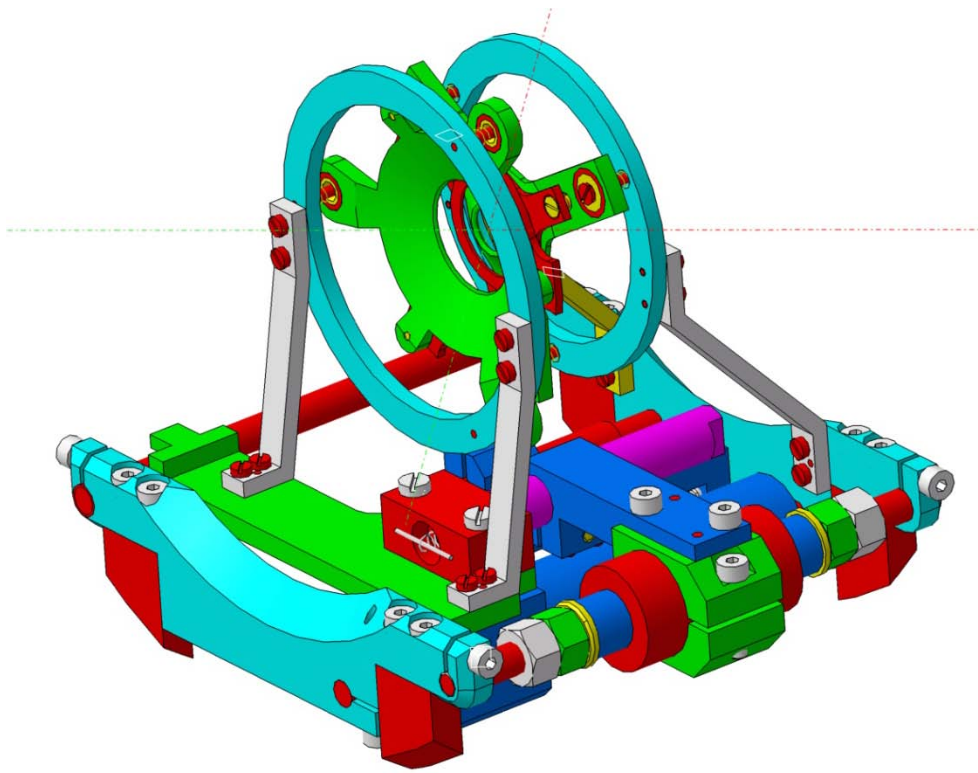


A new Recoil Distance Technique using low energy Coulomb Excitation in Inverse Kinematics

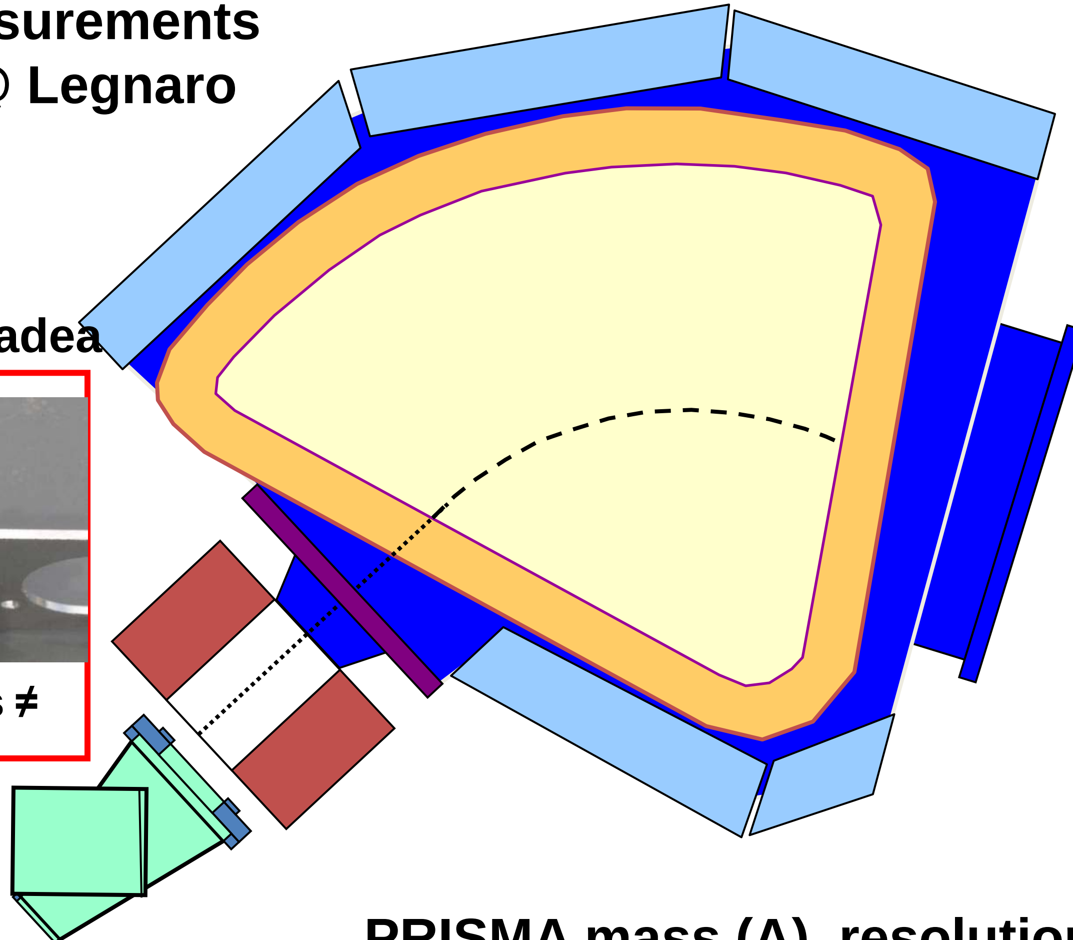
W. Rother et al. , NIM A, in press

Towards exotic nuclei

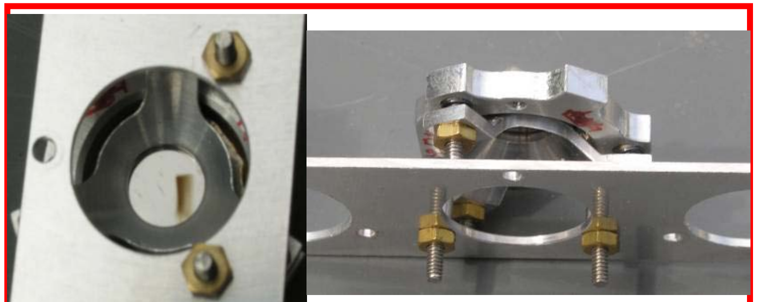
Plunger with DEEP INELASTIC REACTIONS



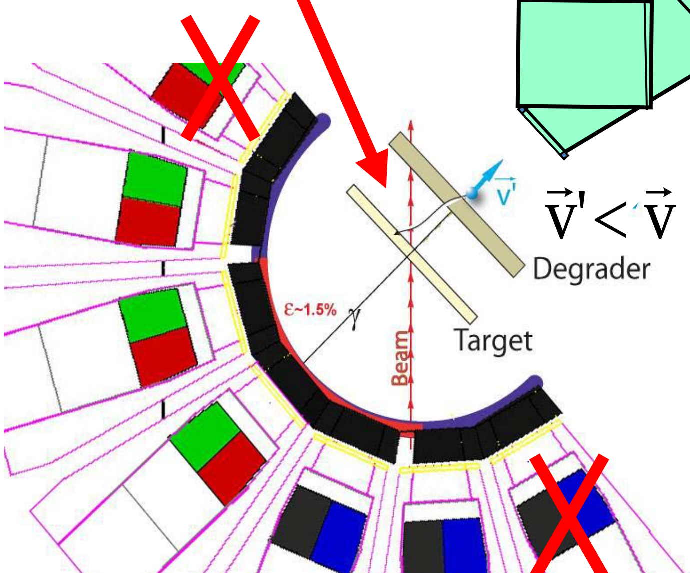
Differential RDDS Measurements with CLARA-PRISMA @ Legnaro



A,Dewald, N.Marginean, A.Gadea



Differential Plunger for angles ≠ 0º



PRISMA mass (A) resolution after degrader

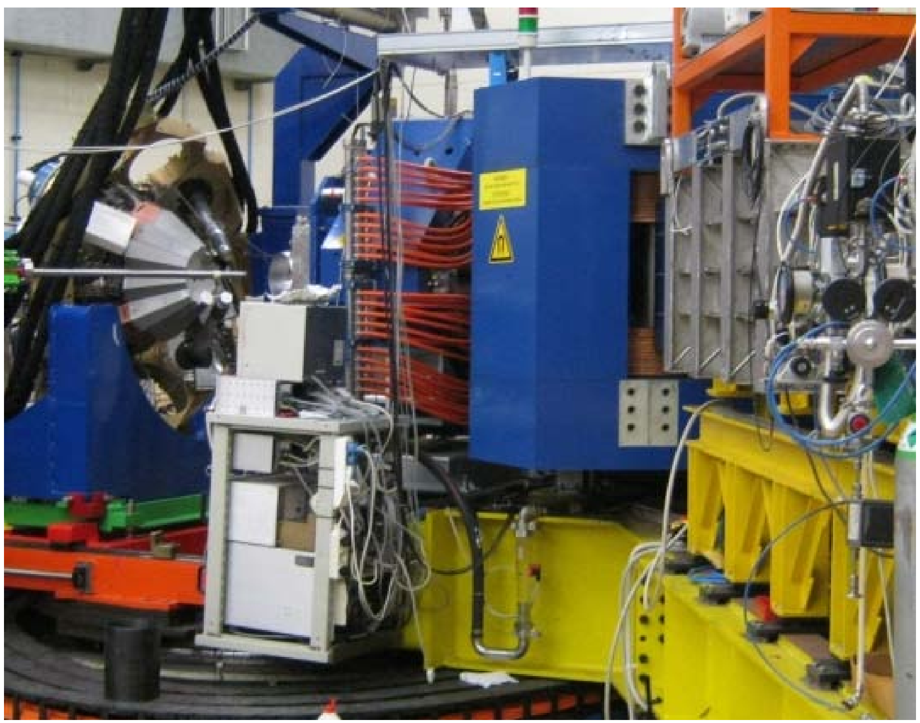
Plunger with deep inelastic reactions @ Legnaro

CLARA - PRISMA

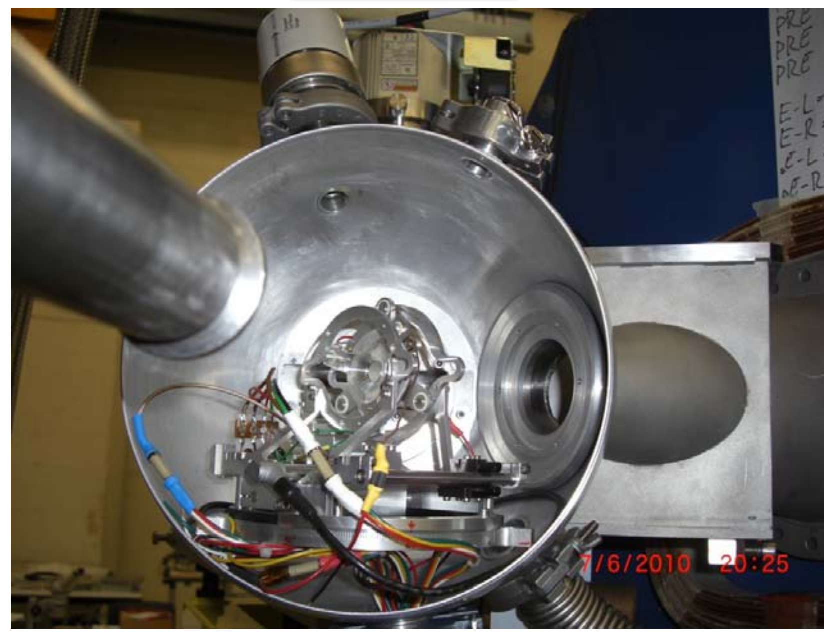
Lifetime Measurements of the Neutron-Rich N = 30 Isotones ^{50}Ca and ^{51}Sc: Orbital Dependence of Effective Charges in the fp Shell
J.J. Valiente-Dobon et al.
Phys.Rev.Lett. 102, 242502 (2009)

AGATA - PRISMA

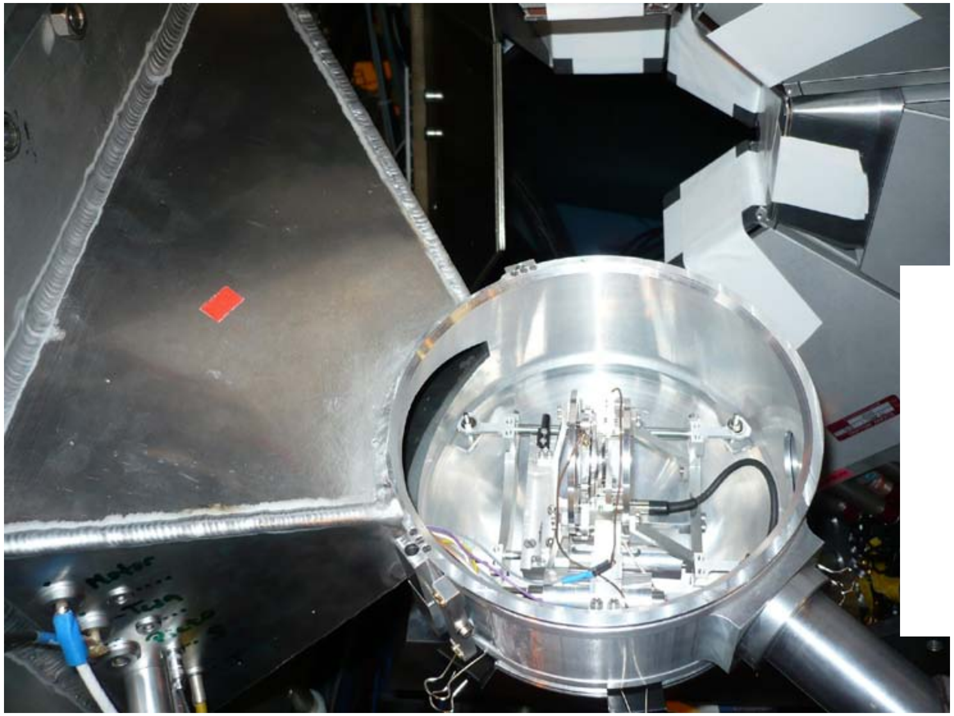
Lifetime measurements of excited states in neutron-rich $^{44, 46}$Ar populated via a multinucleon transfer reaction
D. Mengoni et al.
Phys.Rev. C 82, 024308 (2010)



PLUNGER



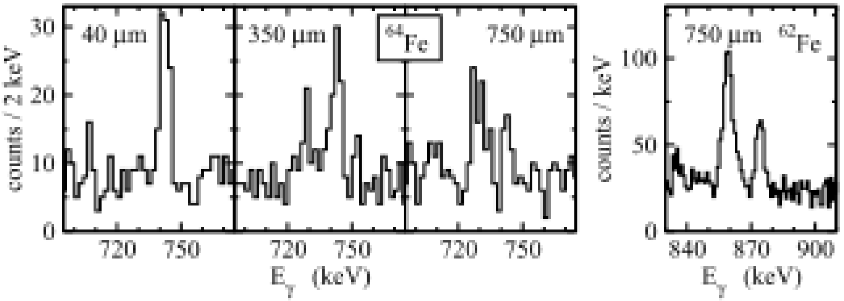
Plunger + VAMOS @ GANIL



J.Ljungvall et al.,
PRC81(2010)061301(R)

^{64}Fe : $2^+ \rightarrow 0^+$

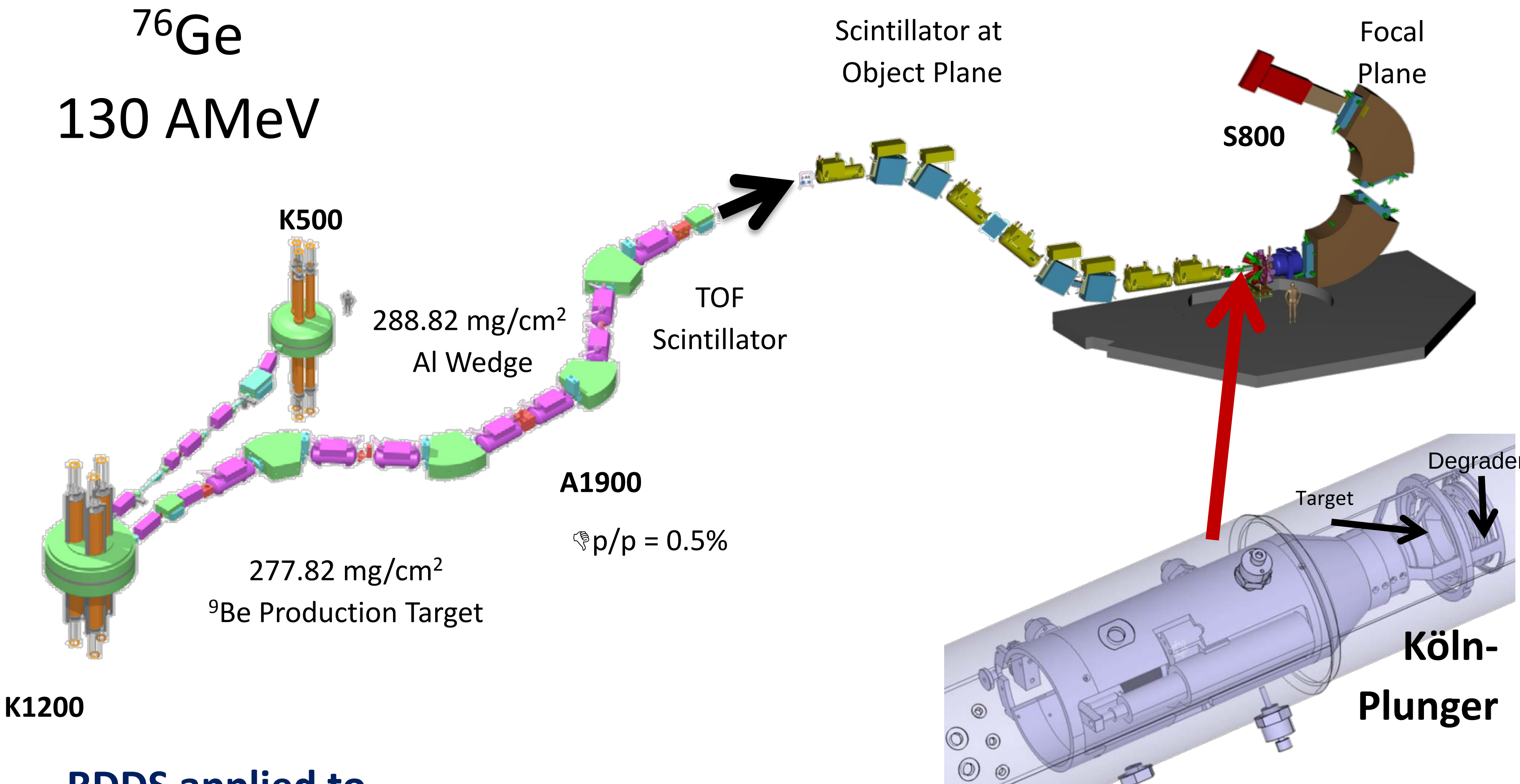
^{62}Fe



^{66}Fe at N=40

$^{62,64,66}Fe$ (2^+) lifetime measurement at NSCL

NSCL coupled cyclotron facility + A1900; MSU

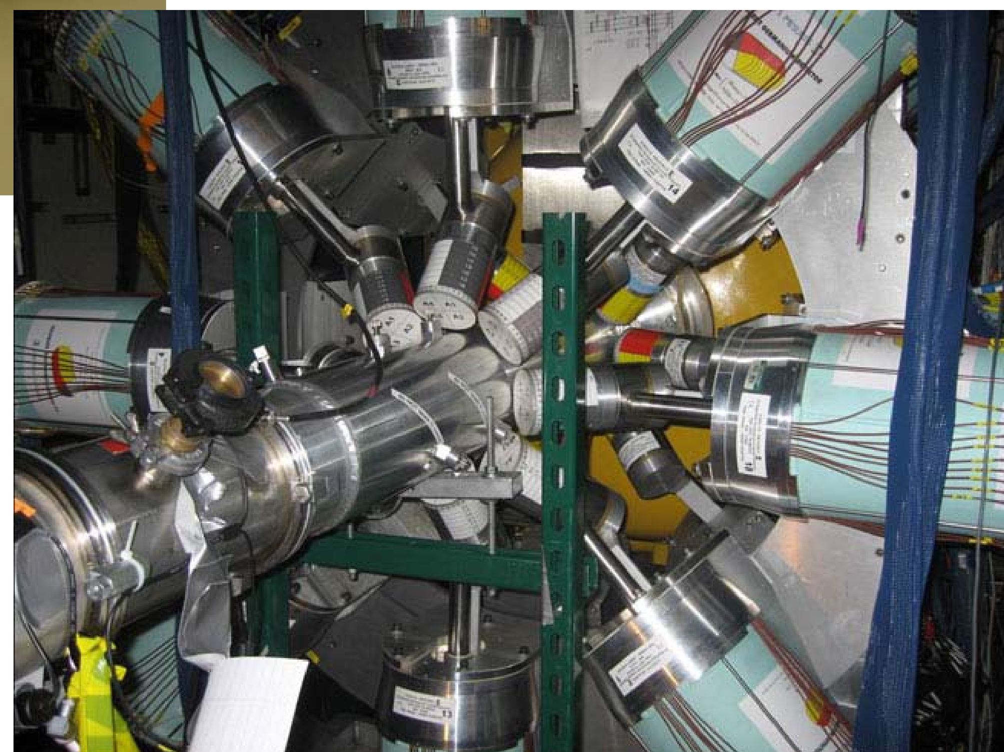


RDDS applied to
projectile ($^{62,64,66}Fe$) Coulomb excitation reactions
at intermediate energies (88-98 AMeV)

Setup

Köln/NSCL plunger

target/ degrader diameter: 4 cm
target/ degrader separations: 0-2,5 cm
precision : ~ 1 μm
target/ degrader thickness: ~1μm -1mm

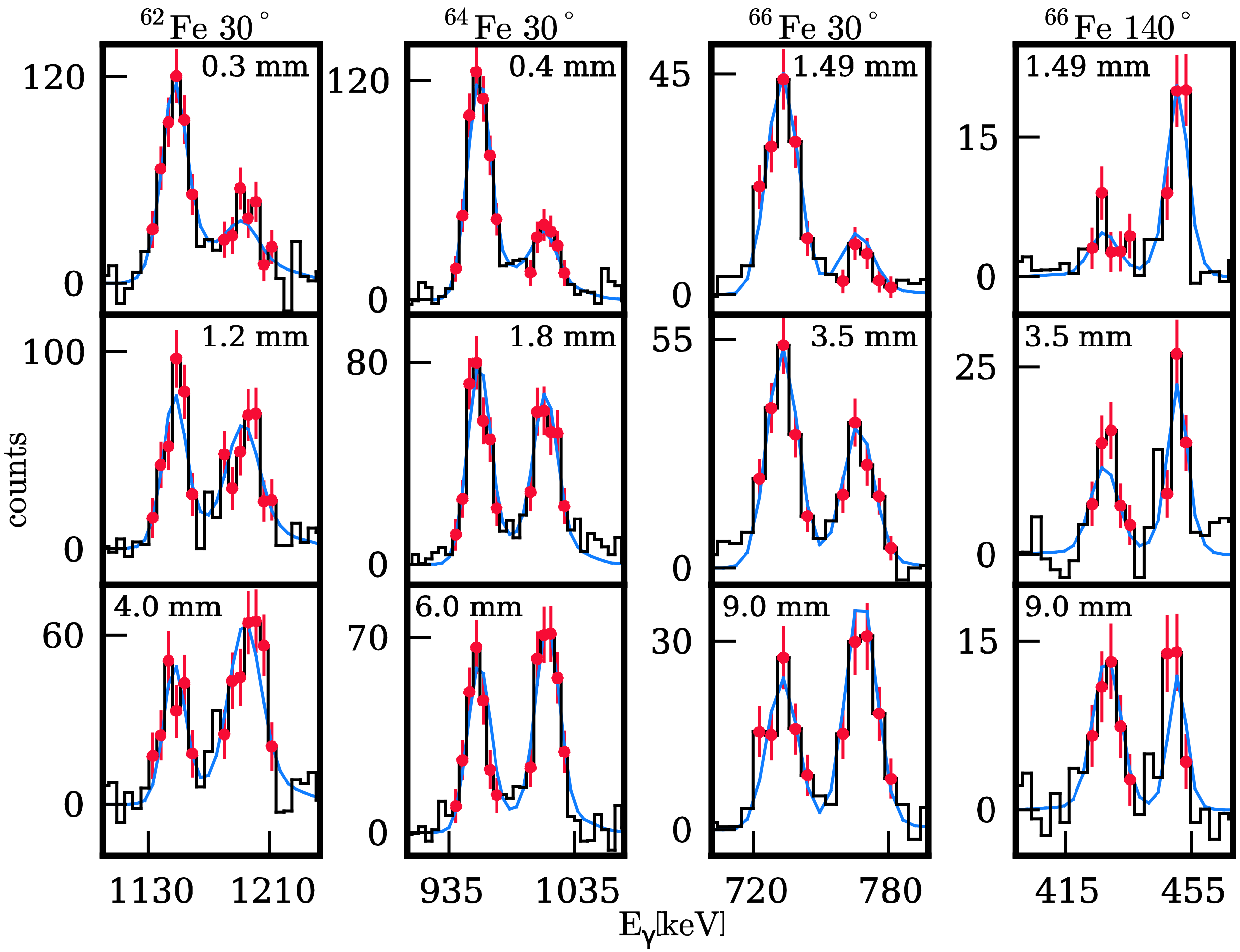


SeGA @ S800

7 detectors
at forward angles (30 deg.)
8 detectors
at backward angles (140deg.)

Line-shape analysis for lifetime determination

Lifetimes are obtained by simultaneous fits to data taken at different (5-7) target-degrader distances.



mean lifetime of the 2$^+$ states

^{62}Fe 8.0(10) ps

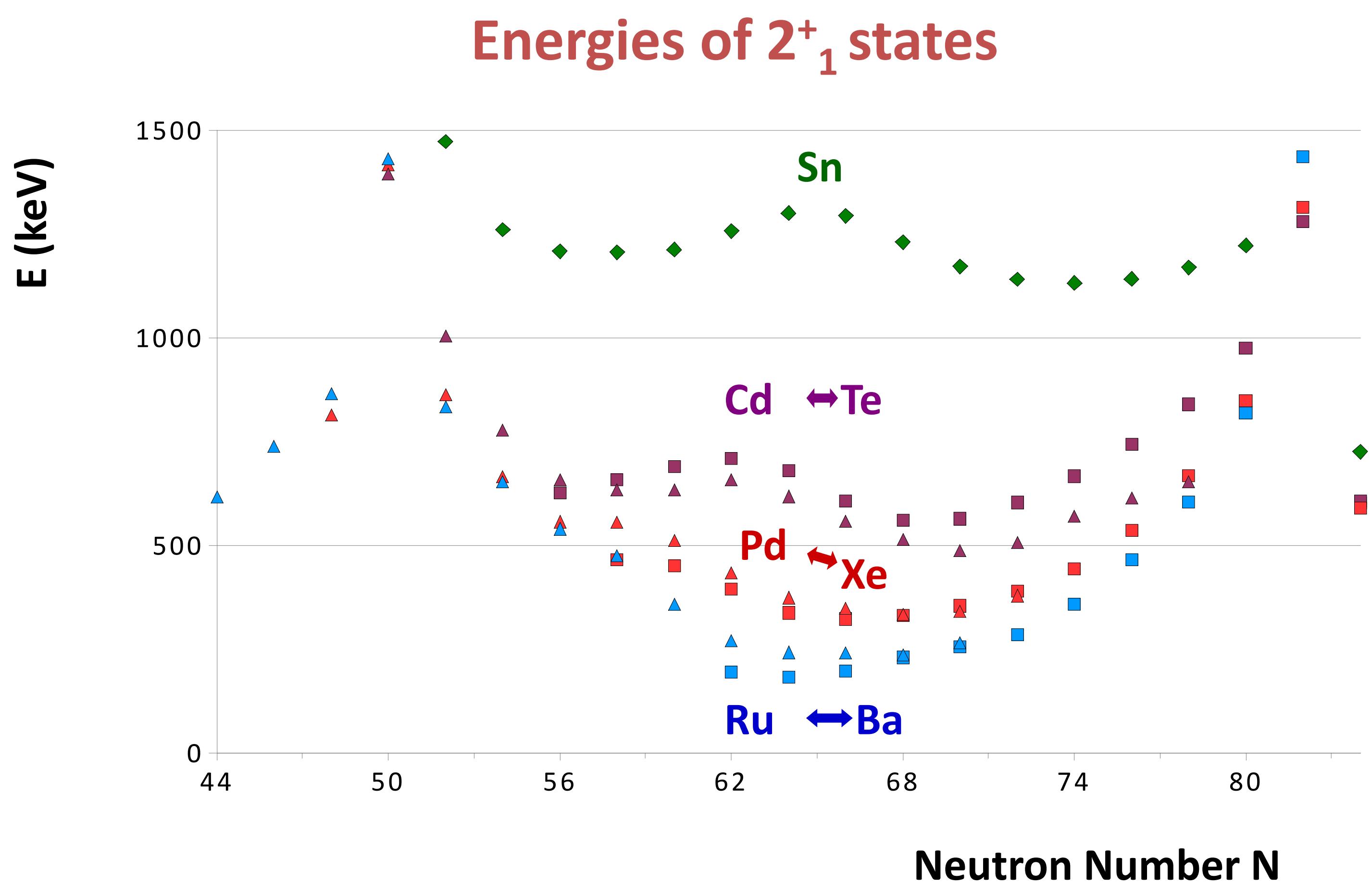
^{64}Fe 10.3(10)ps

^{66}Fe 39.4(40)ps

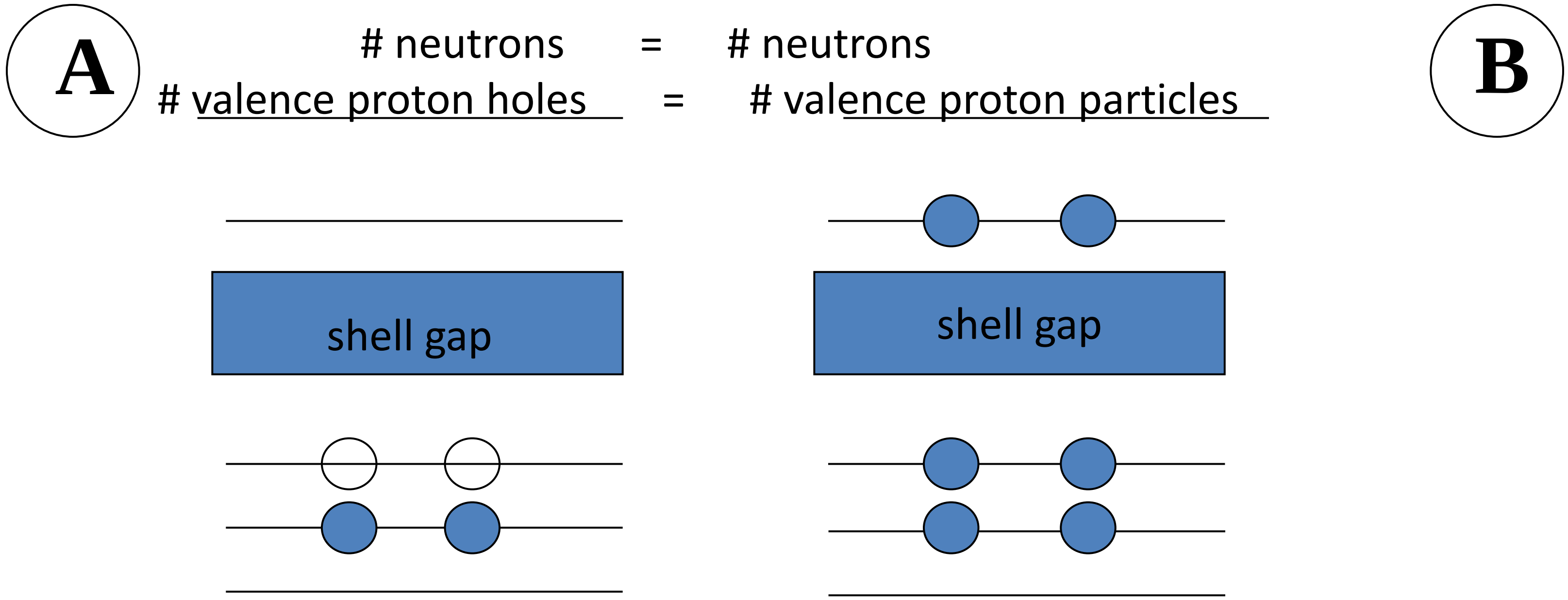
W.Rother et al., Phys. Rev. Lett. 106 (2011) 022502

^{62,64}Fe data agree with GANIL data J.Ljungvall et al., PRC81(2010)061301(R)

Valence Proton Symmetry



Valence Proton Symmetry (VPS)



VPS-pairs :

${}_{48}\mathrm{Cd} \leftrightarrow {}_{52}\mathrm{Te}$

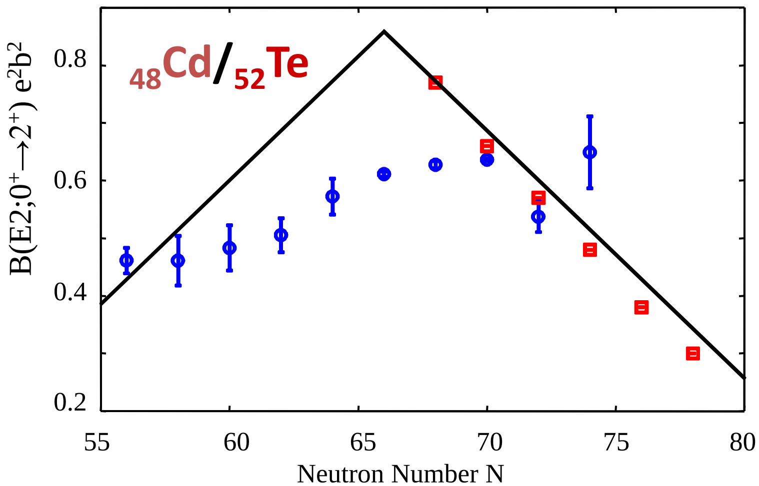
${}_{46}\mathrm{Pd} \leftrightarrow {}_{54}\mathrm{Xe}$

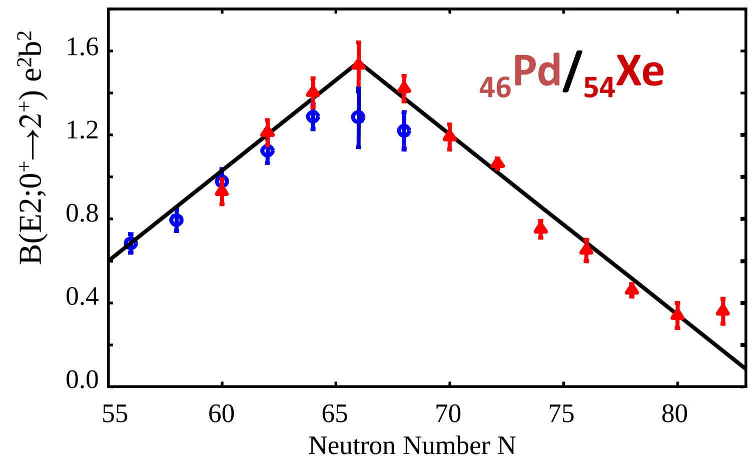
${}_{44}\mathrm{Ru} \leftrightarrow {}_{56}\mathrm{Ba}$

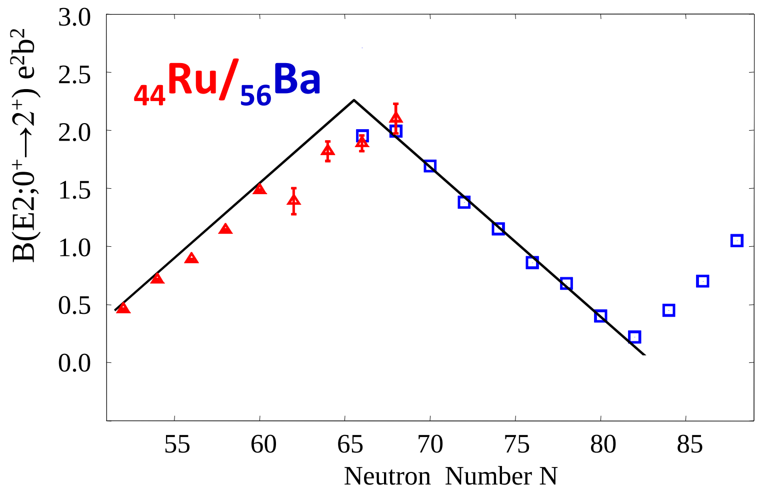
${}_{42}\mathrm{Mo} \leftrightarrow {}_{58}\mathrm{Nd}$

B(E2;$0^+ \rightarrow 2^+$) values of VPS pairs

Values of valence hole partners are scaled with factor **$S = (Z_p / Z_h)^2 \cdot (A_p / A_h)$**





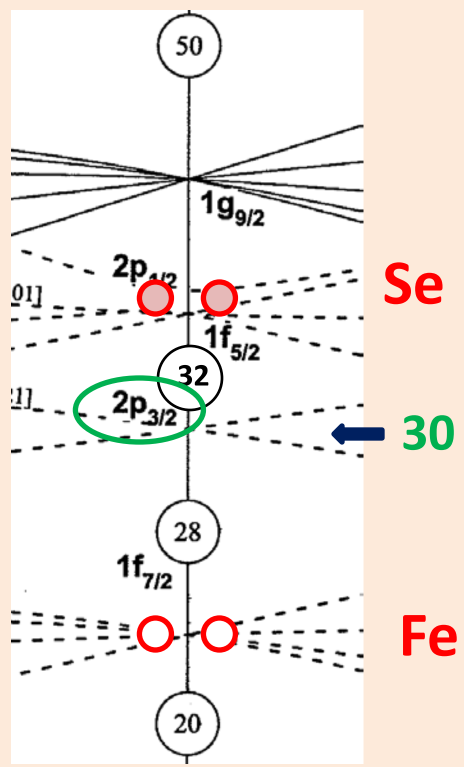


Solid lines are defined by the relation:

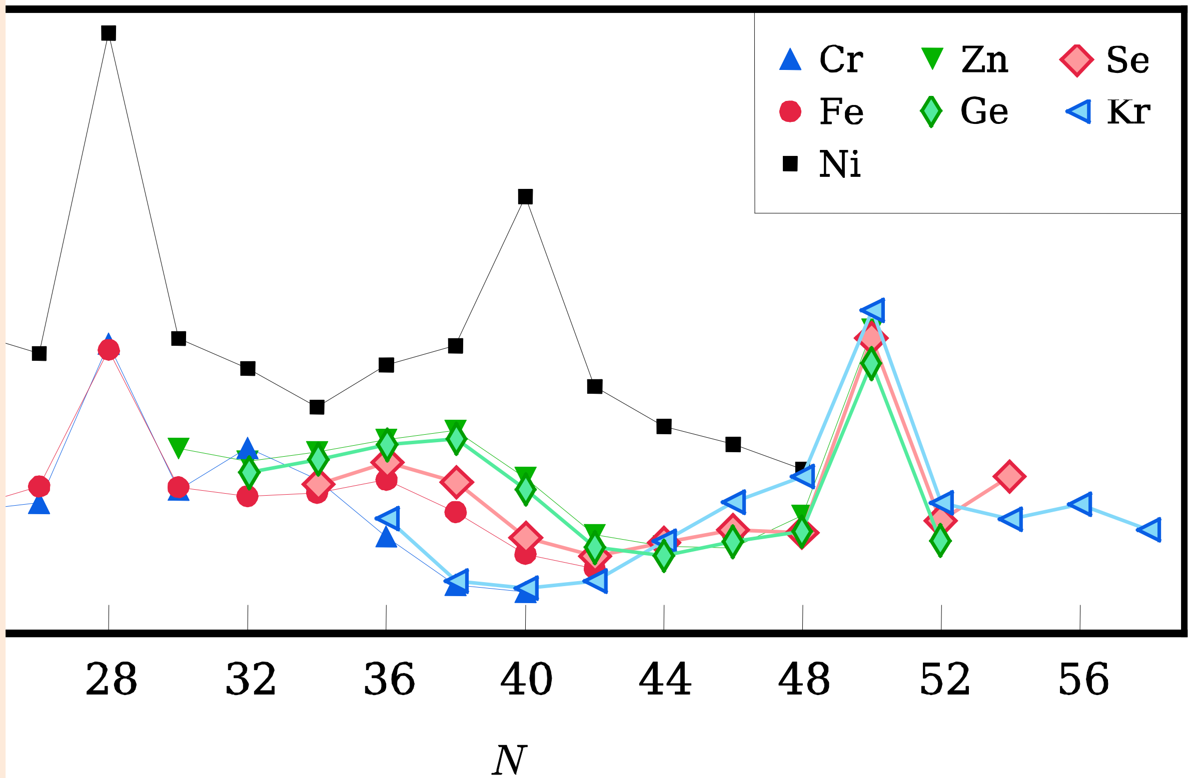
$$B(E2;0^+ \rightarrow 2^+) = 0.0215\ N_\pi N_\nu\ e^2b^2 + 0.17\ e^2b^2$$

The isotonic symmetry in E(2^+)

Symmetry with respect to Z ≈ 30



Proton orbits



Cr (Z = 24) — Kr (Z = 36)

Fe (Z = 26) ⟺ Se (Z = 34)

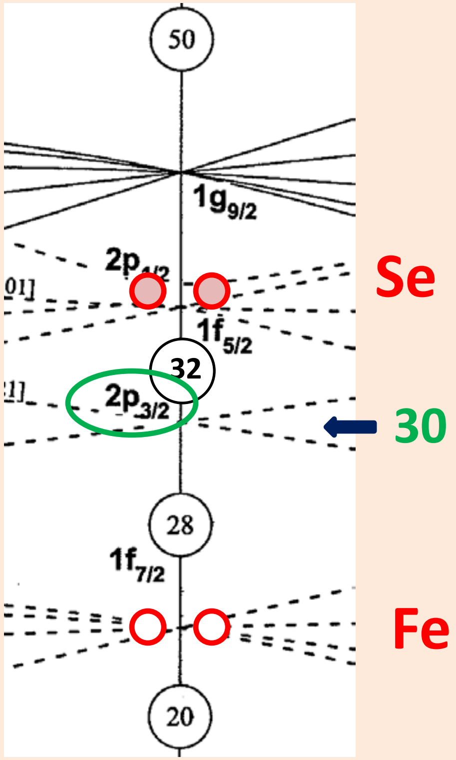
Zn (Z = 30) — Ge (Z = 32)

pairs

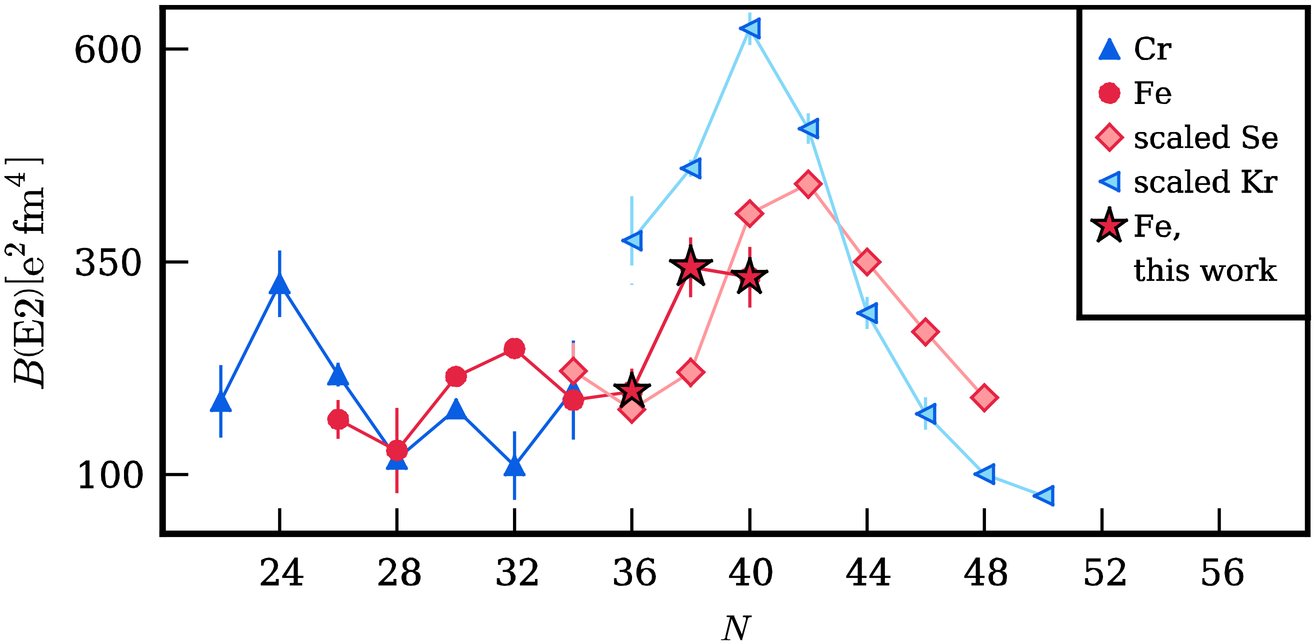
generalized scheme of Valence Proton Symmetry

VPS correlates
a pair of isotones that have the same number of valence protons and holes with respect to closed shells (same valence space results in similar collectivity)

VPS with respect to Z ≈ 30 (protons in $1f_{5/2}$, holes in $1f_{7/2}$)



Proton orbits

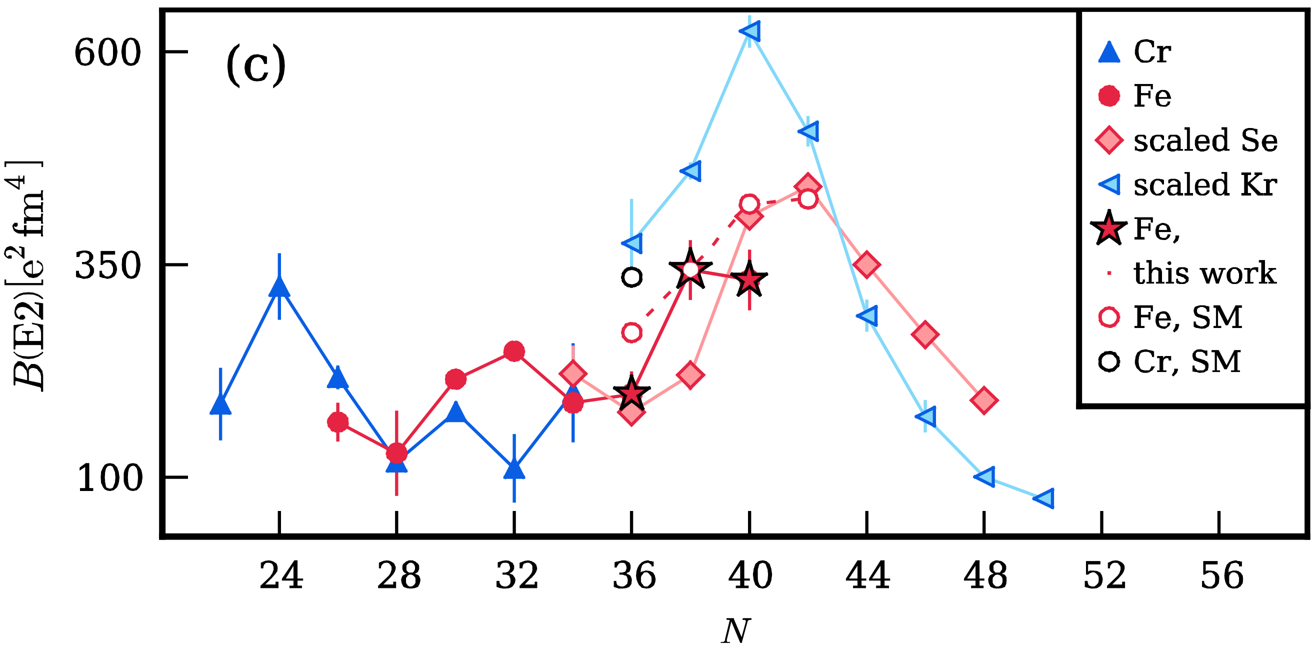


$S = (Z_L/Z_H)^2 \times (A_L/A_H)$, L(H) : Lighter(Heavier)pair

Comparison with shell model in the *fpgd* space

S.M.Lenzi, F.Nowacki,
A.Poves, K.Sieja,
PRC 82(2010) 054301

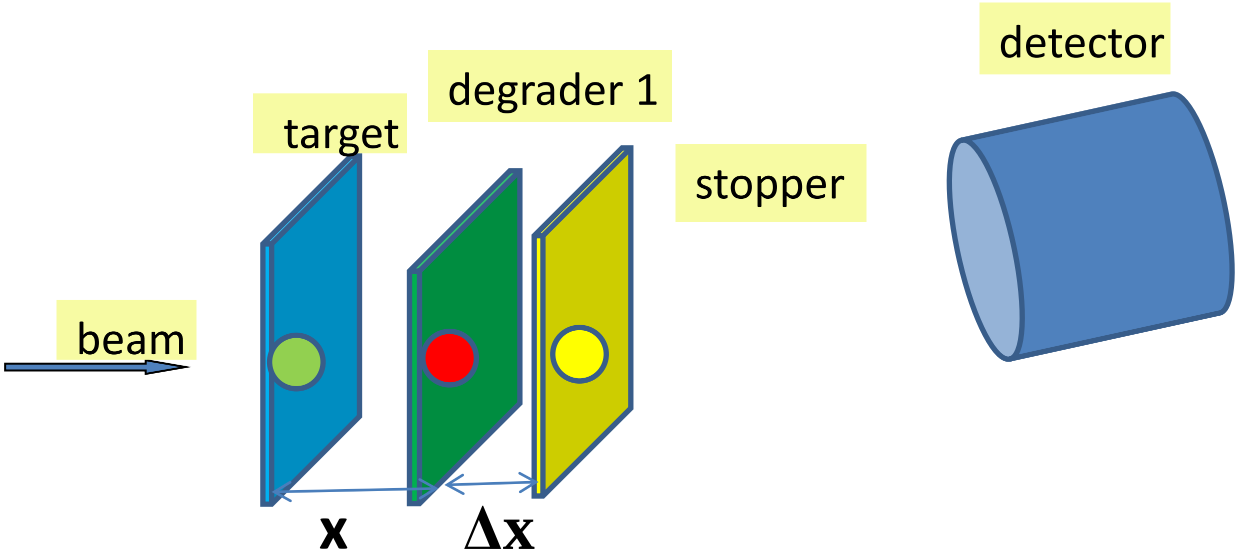
Recent shell model calculations with new effective LNPS interaction well explain the trends of B(E2) for $^{62,64,66}Fe$ at N=40

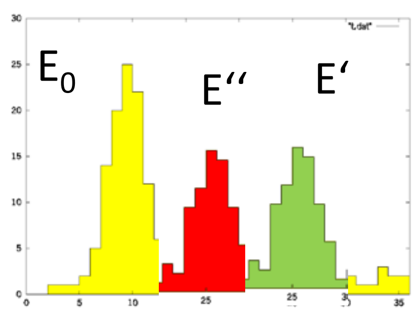


New Developments

The Differential Plunger

A. Dewald et al., Z.Phys. A334,1989

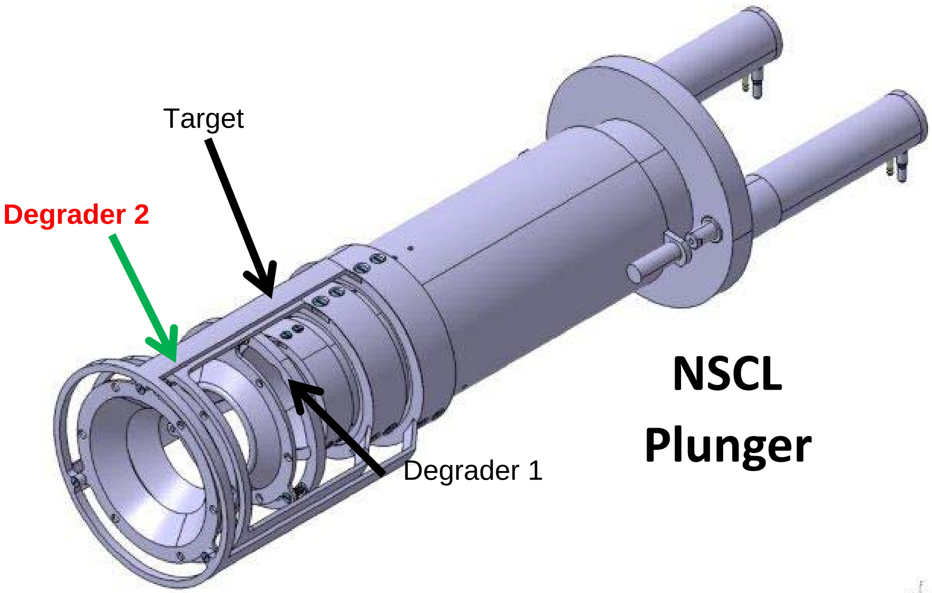




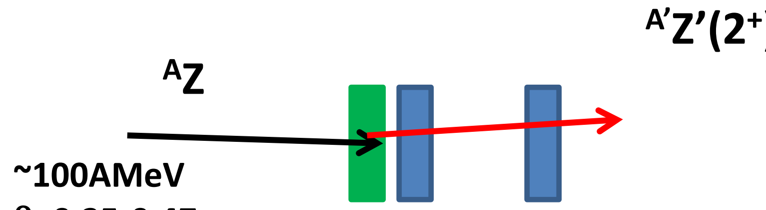
Concept of a new NSCL plunger
Köln/MSU

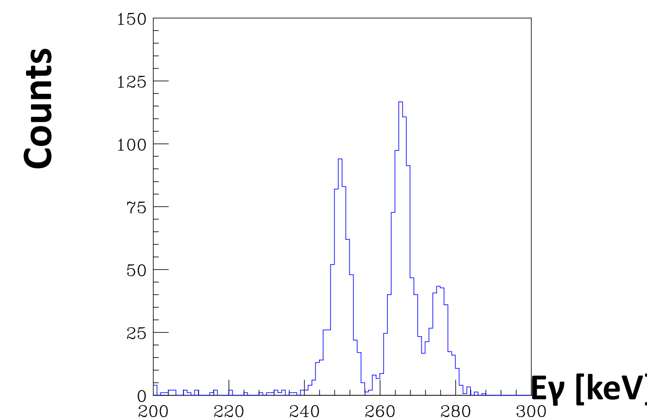
H. Iwasaki, NSCL/MSU

A new plunger with a " target – degrader - degrader " configuration



NSCL Plunger





Characteristic features

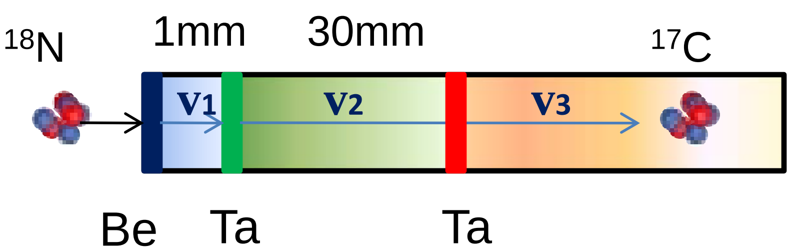
- 3 peak plunger … improve efficiencies in plunger measurements with slow, fast RI beams

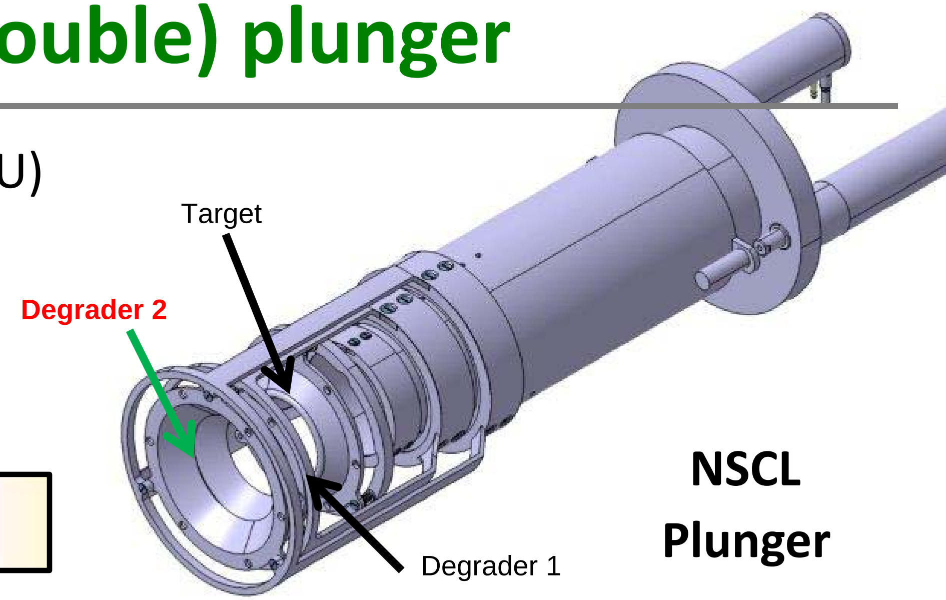
- Target-degrader- "stripper" configuration … reduce beam background (different *Q*)
improve collection efficiencies of reaction products

Differential (Double) plunger

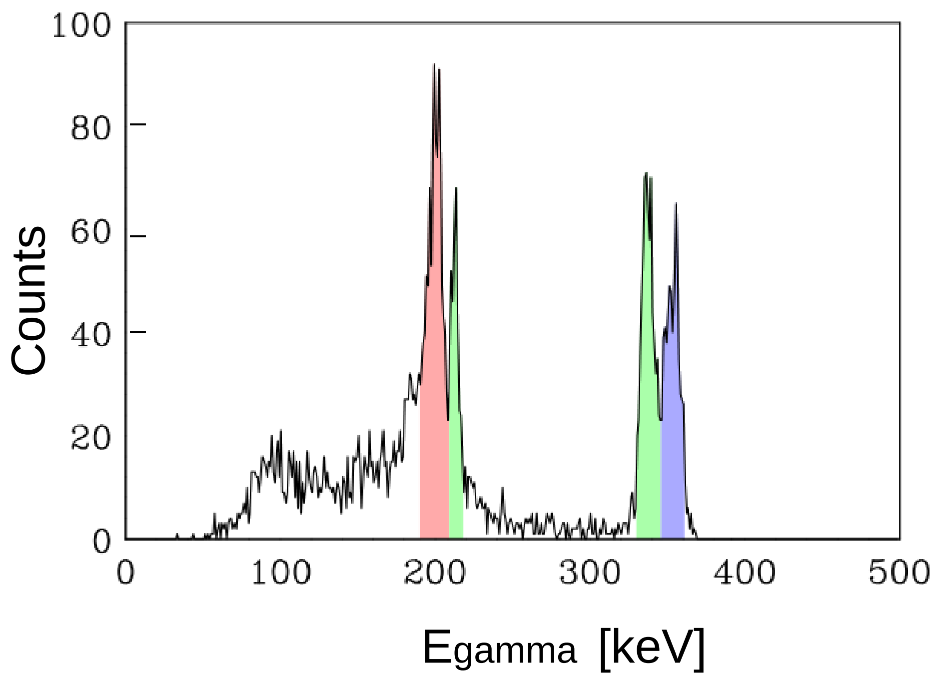
Example: ^{17}C ; (H. Iwasaki, NSCL/MSU)

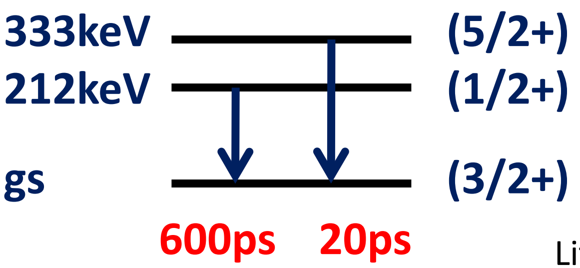
two excited states populated in ^{18}N one proton knockout





NSCL Plunger





Lifetimes from D.Suzuki et al., PLB666(08)222

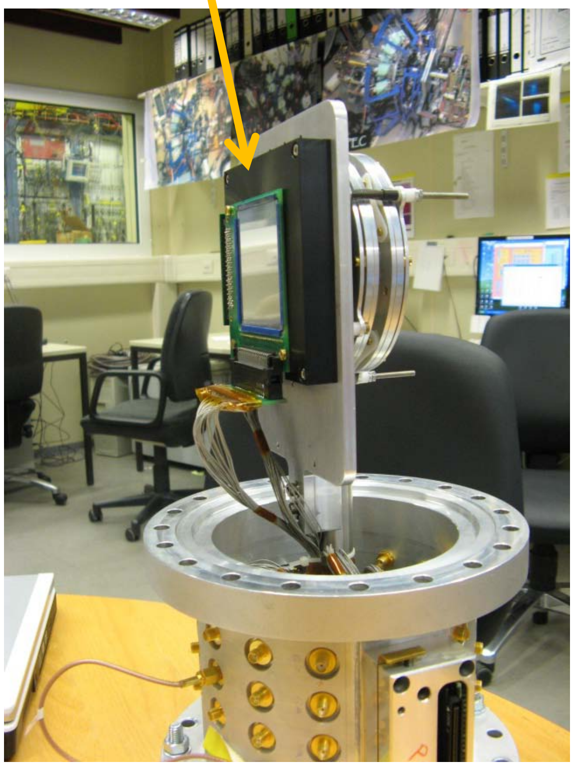
Towards
GRETINA
(better position resolutions)
FRIB
(larger beam range)

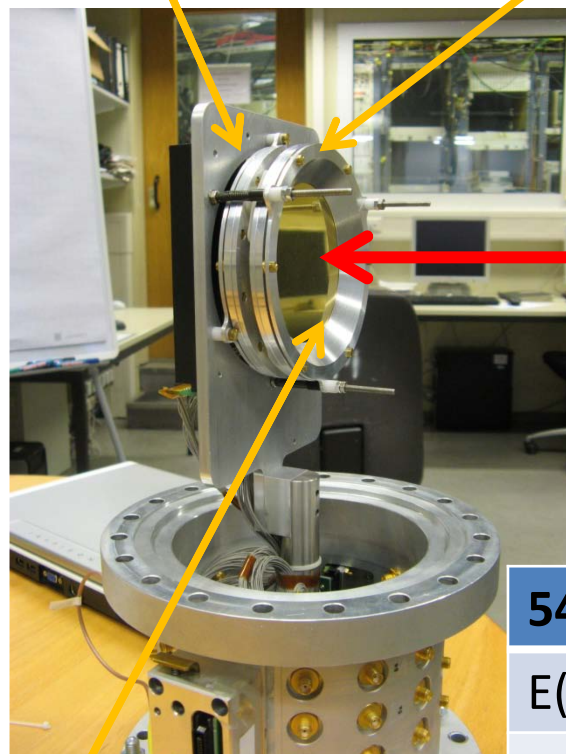
Plunger @ GSI

Target - DSSD

Ir Degrader (0.5 mm)

Au Target (1 mm)





Beam

^{54}Cr

(not actually in this room)

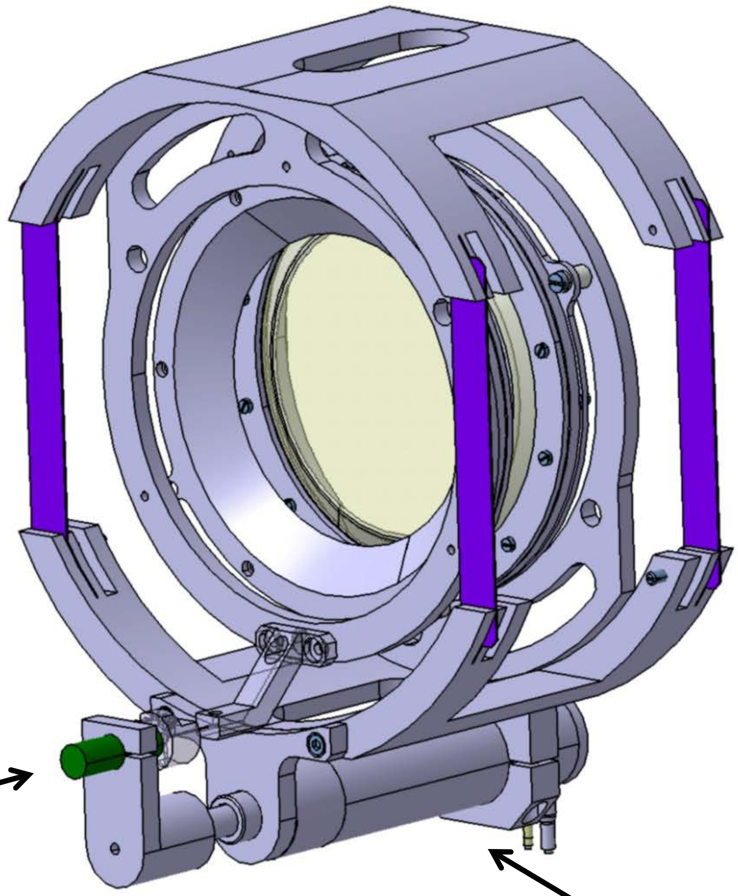
54Cr	
E(2+)	835 keV
$t_{1/2}$	7.9 ps
β	0.55

Separation 700 um

New plunger for PRESPEC/HISPEC

Construction:
S. Thiel, IKP, Cologne

Flat spring



Piezo crystal for feedback system

Piezo motor (Piezo Instruments)

Already built and mechanically tested:

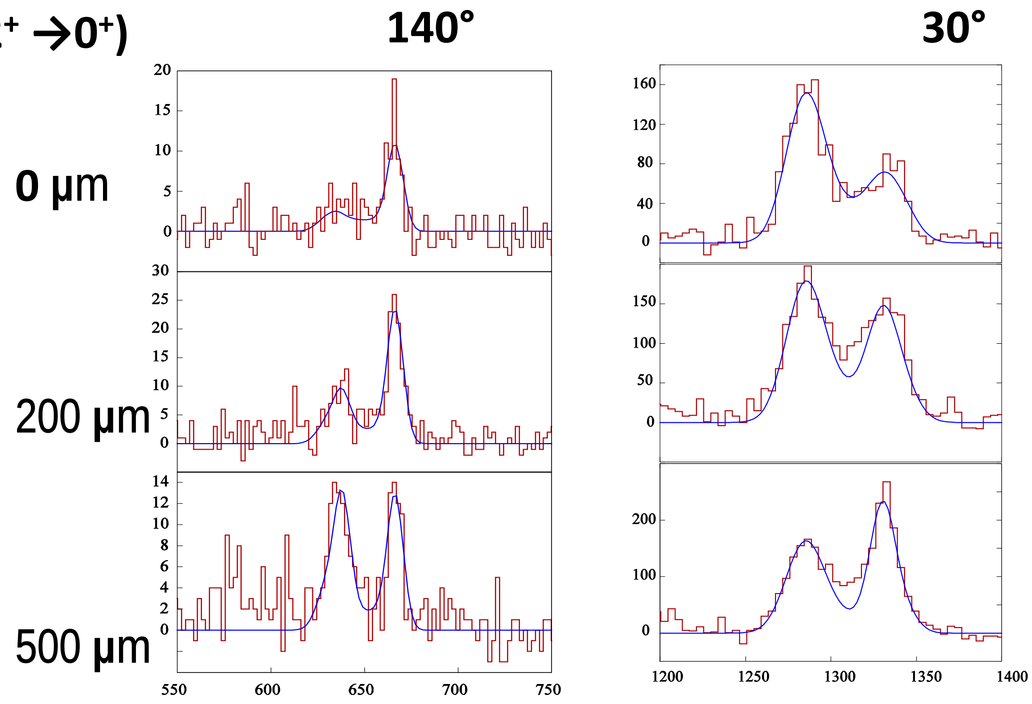
- Precision of about 0.1 mm (further improvement possible)
- Construction designed for use with feedback system.
- Maximum driving range: 30 mm (limited by inchworm)

RDDS Data Analysis

Lifetime determination from a lineshape analysis

Line shape important in cases of thick targets & short distances
(transition between RDDS and DSAM)

^{62}Zn : ($2^+ \rightarrow 0^+$)



Lifetime determined from a lineshape analysis
τ = 4.2(7) ps

Nucl.Data Sheets 91(2000)

τ = 4.2(3) ps

- Stopping power fixed by using velocities measured after the target and after the degrader
- Relativistic effects were considered
- Parameter: degrader excitation (40%)
  width of the velocity distribution
- Free parameter: lifetime, normalisation factor

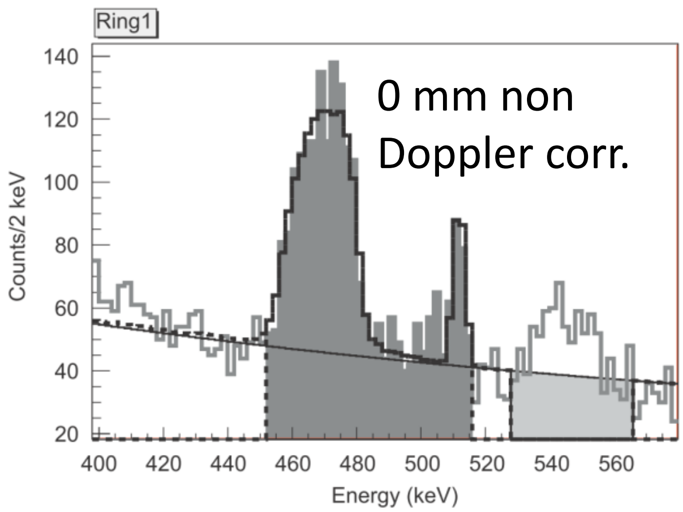
Simulation Tool for RDDS Measurements @NSCL with SEGA

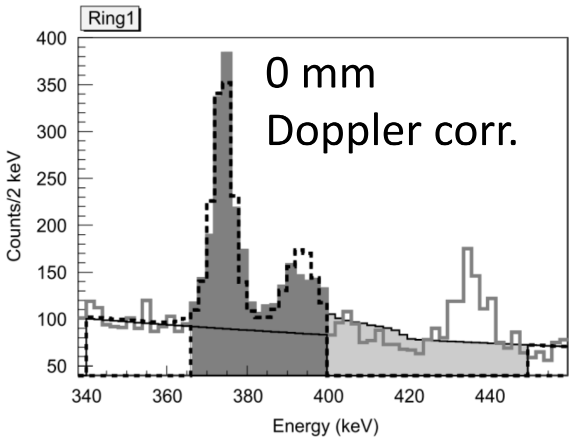
P.Adrich et al. , NIM A 598 (2009), 454

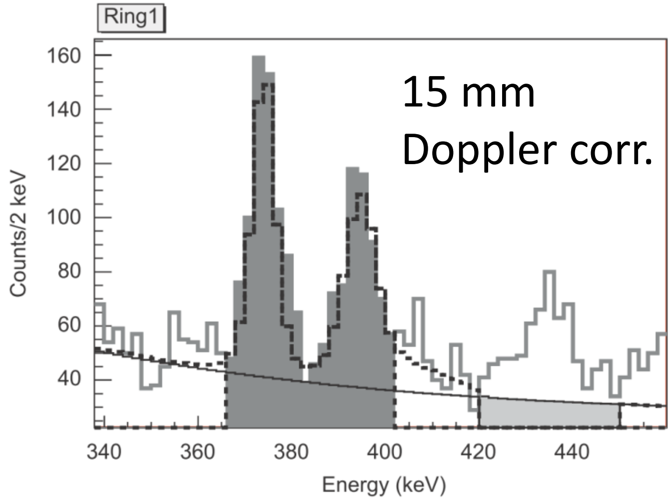
^{110}Pd; ($2^+ \rightarrow 0^+$)

Coulex @ intermediate energy
(70 MeV/u)
NSCL/MSU

v/c≈0.3





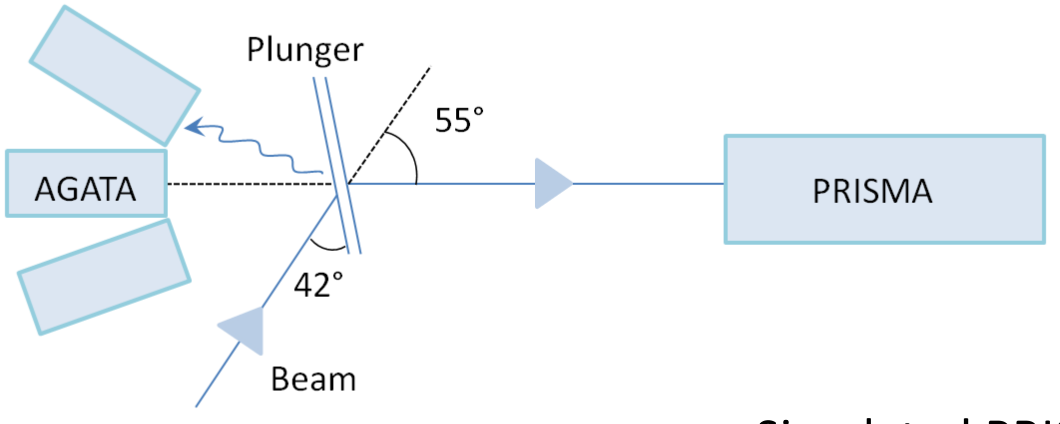


GEANT4 simulations of the AGATA Demonstrator coupled to PRISMA and the Cologne differential plunger:

comparison with experimental data (1)

C. Michelangoli

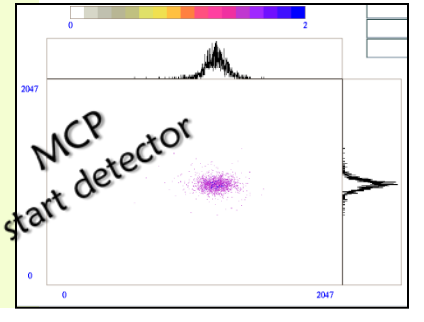
experiment performed in week 23 2010
(courtesy of C.Louchart)

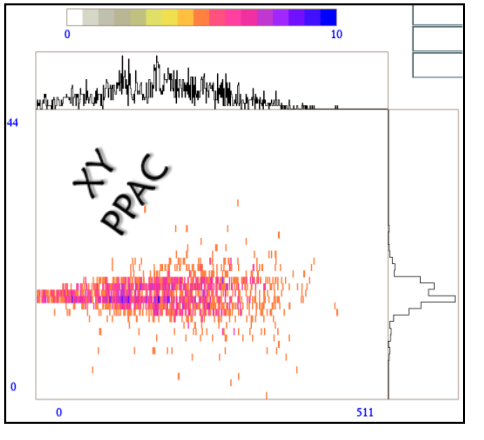


$^{76}Ge + ^{238}U$ @ 577 MeV
Nb degrader

Simulated PRISMA data:

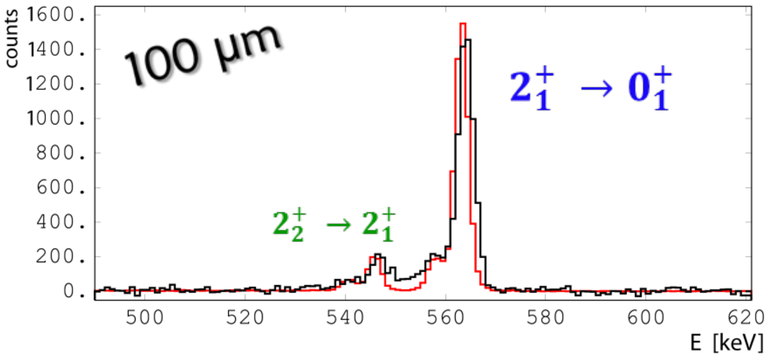
simulation of the ^{76}Ge channel
simplification : ^{76}Ge projectil-like emitted at a fixed direction (grazing angle, 55°)
monochromatic (417 MeV)

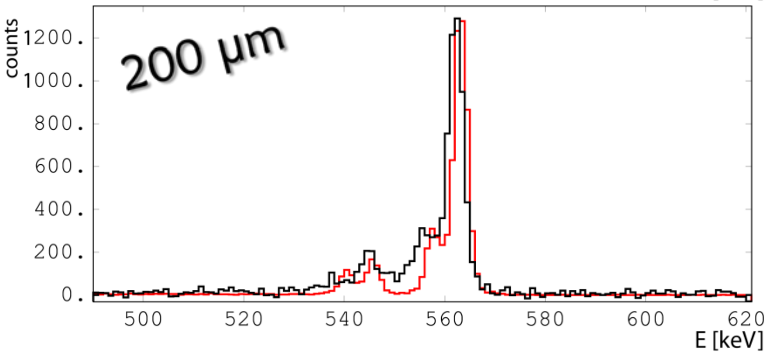


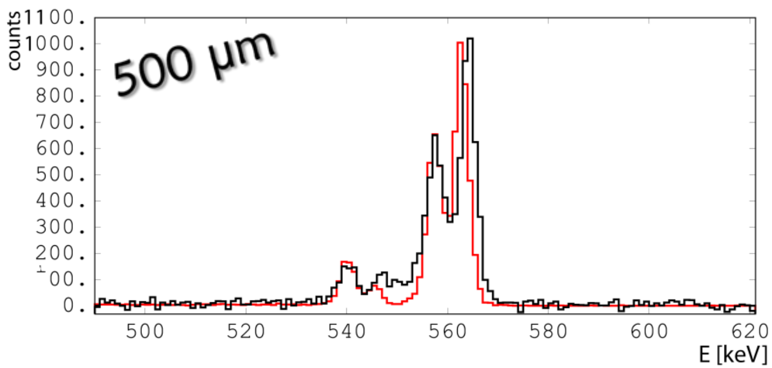


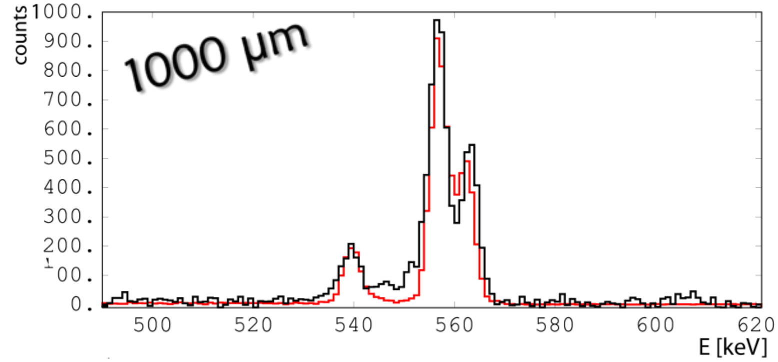
GEANT4 simulations of the AGATA Demonstrator coupled to PRISMA and the Cologne differential plunger:

comparison with experimental data (2)

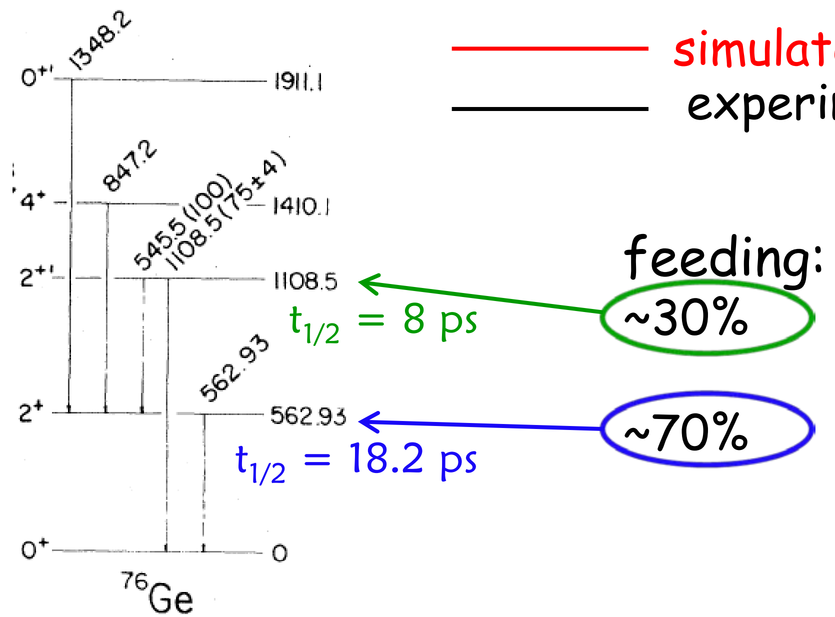








simulated
experim.



Conclusion

- **The plunger technique is an important technique in nuclear structure physics.**
- **At the moment there are many on-going plunger activities at different places.**
- **The plunger method can me adapted to the needs imposed by specific nuclear reactions.**
- **Work has still to be invested in the simulation of spectra for specific setups.**
- **Target production and test methods have to be further developed.**

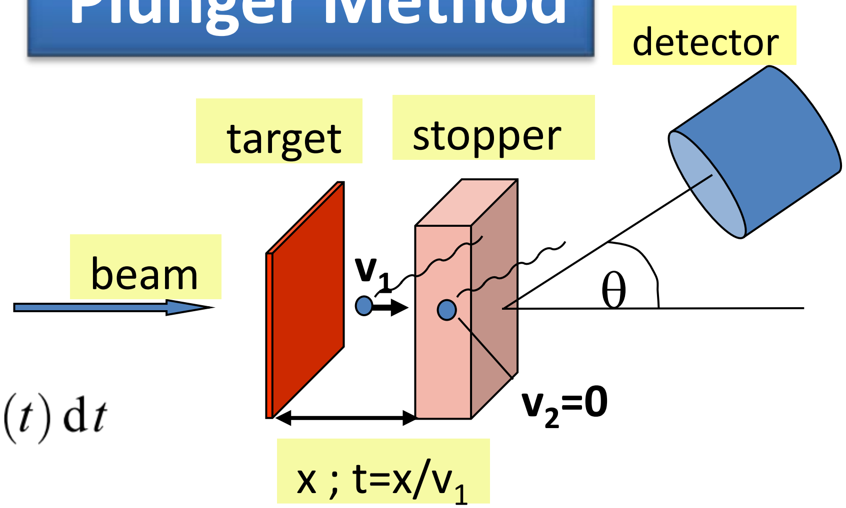
Targets issues

- flat surface (small target-degrader/stopper separations <10μm)
- enriched material, metal foils, radioactive targets
- thin(0.5 mg/cm^2)/thick(1-2 mm) targets
- small (1cm)/large (8cm) diameter

- avoid hot targets (cooling with He?)
- avoid carbon built-up (LN_2 baffle)
- test of mechanical properties by e-gun, ion beams prior to the experiment

- Need for absolute target-degrader/stopper separations?

Plunger Method

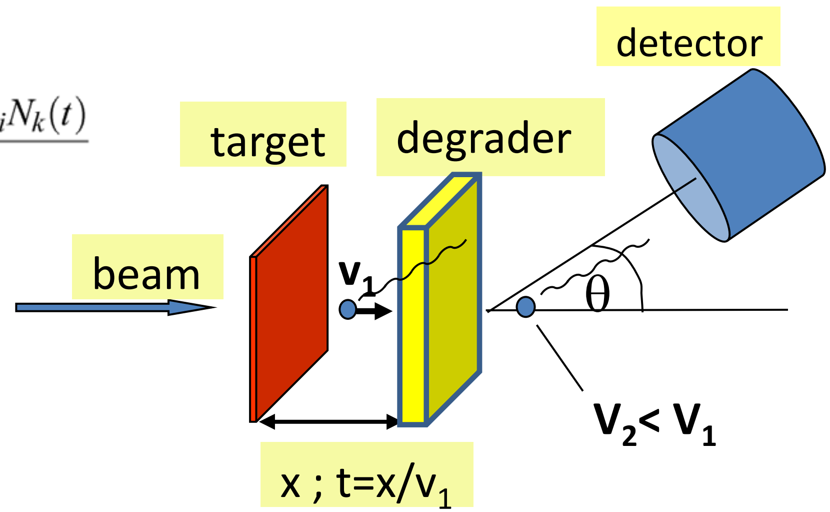


Decay curve:

$$N_{i/k}(t) = \int_t^{\infty} \lambda_{i/k} \cdot n_{i/k}(t)\,\mathrm{d}t$$

Differential Plunger Method

$$\tau_i(t) = 1/\lambda_i = \frac{-N_i(t) + \sum_k b_{ki} N_k(t)}{\frac{\mathrm{d}}{\mathrm{d}t} N_i(t)}$$



Approved experiments @ NSCL MSU:

SP: A. Dewald (Köln); **Collaboration:** Sofia, GSI Darmstadt, MSU, Padova, Legnaro
"Recoil-distance lifetime measurement in neutron rich Fe isotopes using intermediate energy Coulomb excitation"

SP: Roderick Clark(LBNL Berkeley); **Collaboration:** MSU, Köln, Legnaro, Kolkata, Bolpur, Goteborg
"Lifetime of the First Excited 2^+ State in ^{16}C"

SP: P. Adrich (NSCL MSU); **Collaboration:** MSU, Köln
"Lifetime of the first excited 2^+ state of ^{18}C measured with the relativistic plunger method"

Approved experiments @ GANIL:

SP: O. Möller (TU Darmstadt); **Collaboration:** Darmstadt, Orsay, Köln, GANIL, Legnaro, Bucharest, Sofia, Debrecen, Dubna

"Exploring single-particle and collective low-lying states in neutron rich nuclei towards 78-Ni with the plunger technique at GANIL: The case of ^{73}Cu"

SP: W. Korten (CEA Saclay); **Collaboration:** Saclay, Köln, GANIL, Legnaro, Padova, Cern-Isolde

"Shapes and collectivity in Neutron-Rich Nuclei around A=70 – Applying the Recoil-Distance Doppler-Shift Method to Deep-Inelastic Reactions."

Approved experiments @ Legnaro:

SP: D. Mengoni (Padova**): Collaboration:** Köln, Padova, Legnaro, Krakow, Milano, Firence, Valencia, Berlin
"Lifetime measurement around the doubly-magic ^{48}Ca nucleus"

Collaborators (for $^{62-66}$Fe at N=40)

IKP, University of Cologne

W.Rother, A.Dewald, C.Fransen, M.Hackstein, J.Jolie, Th.Pissulla, K.O.Zell

Dipartimento di Fisica, INFN, Padova

S.M.Lenzi, C.A.Ur

Simon Fraser University, Canada

K.Starosta

NSCL, Michigan State University

H.Iwasaki, D.Bazin, T.Baugher, B.A.Brown, H.L.Crawford, A.Gade, T.N.Ginter, T.Glasmacher, G.F.Gynyer, S.McDaniel, A.Ratkiewicz, P.Voss, K.A.Walsh, D.Weisshaar

Yale University

G.Ilie

University of Tennessee

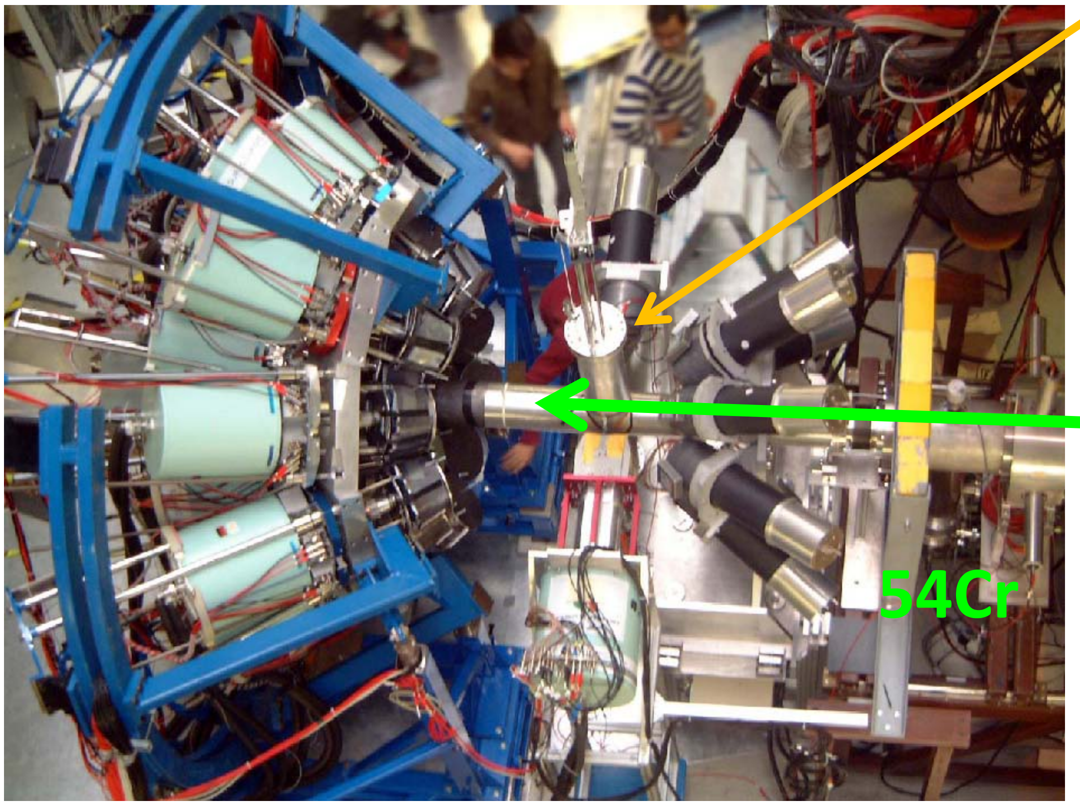
D.Miller

Institute for Nuclear Research and Nuclear Energy, Sofia

P.Petkov

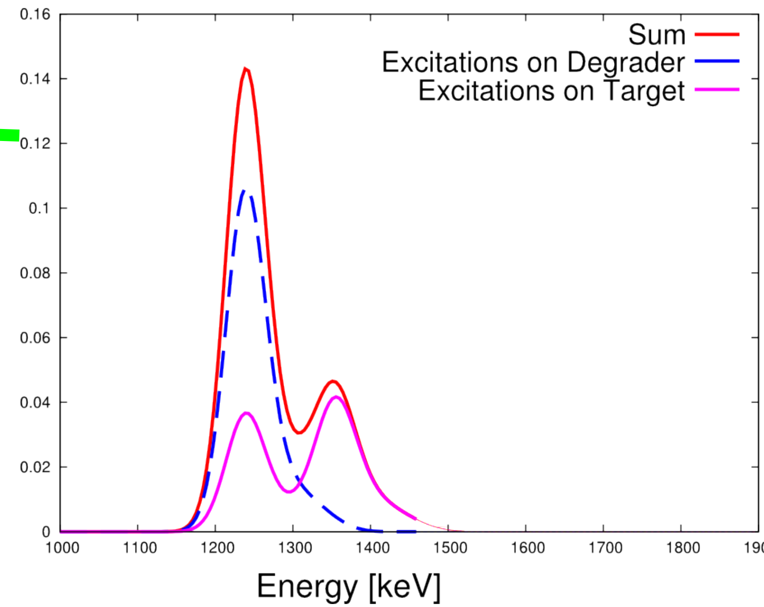
Plunger @ GSI

Target Position
(different Target chamber)



About 10 h Beamtime
We expect 700 good counts / peak
(inner Ge - Ring)

Expected Lineshape

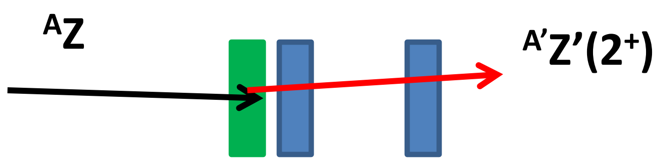


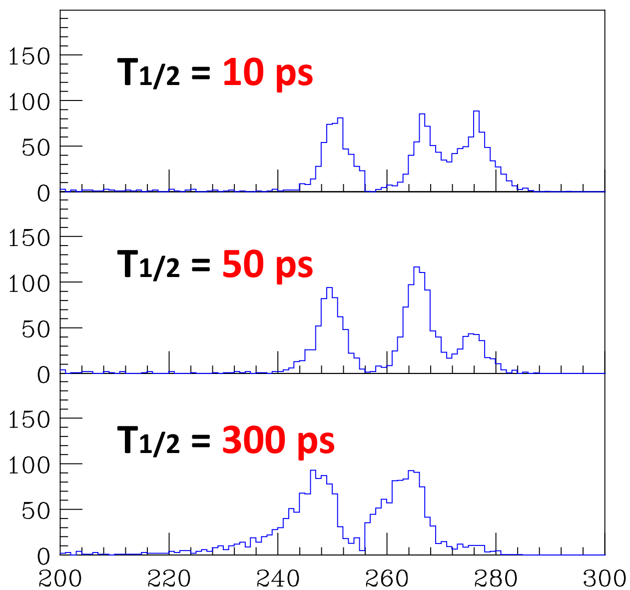
Analysis in progress…

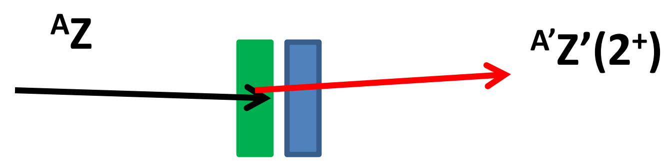
Gamma-plunger measurement

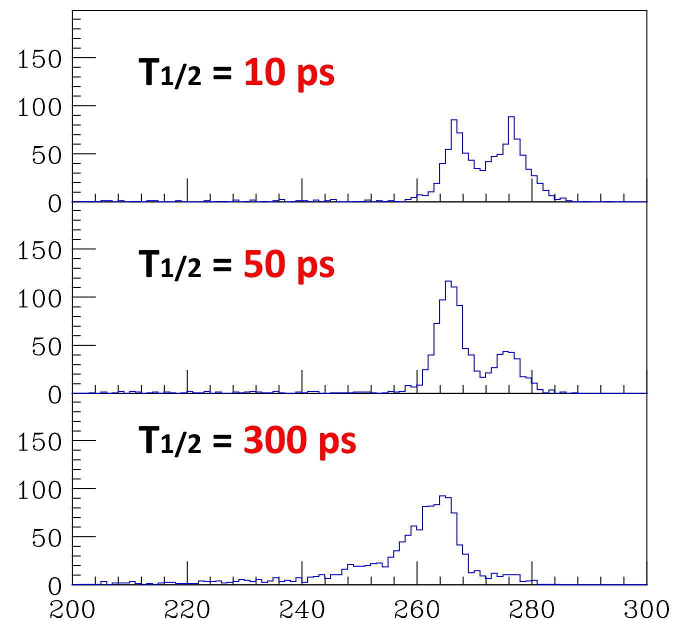
H. Iwasaki, NSCL/MSU

Comparison between 3-peak and 2-peak plunger measurements









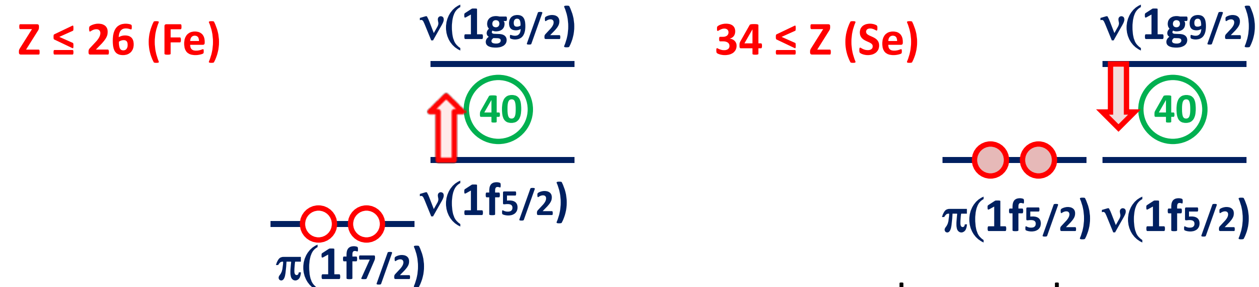
Towards

GRETINA (improvement in position resolutions)

FRIB (large beam range)

Comparison with shell model in the *fpgd* space

Symmetry with respect to Z ≈ 30, and shell evolution at N=40



proton-neutron monopole tensor int.

Recent shell model calculations with new effective LNPS interaction well explain the trends of B(E2) for ^{62,64,66}Fe at N=40

S.M.Lenzi, F.Nowacki, A.Poves, K.Sieja, PRC 82(2010) 054301