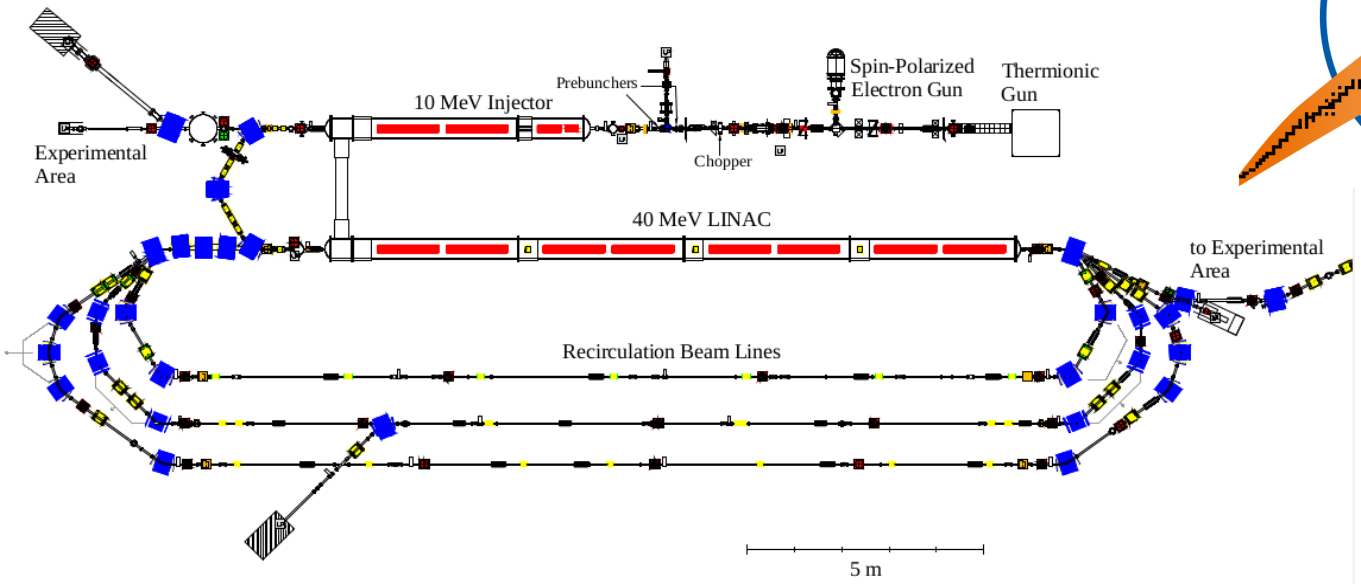
Report B03

Constraining nuclear matrix elements for fundamental symmetries

TECHNISCHE UNIVERSITÄT DARMSTADT

Philipp Ries



SFB 1245

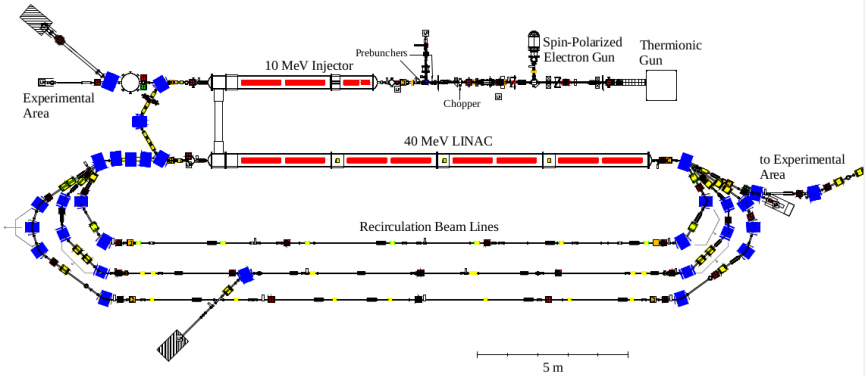
Outline

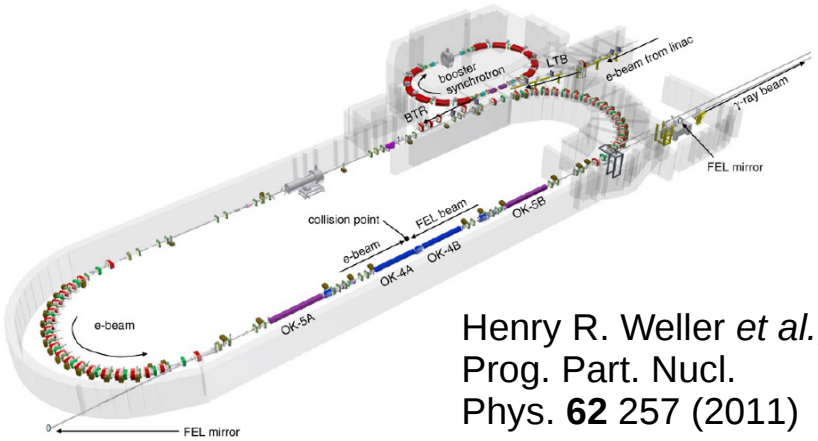
TECHNISCHE UNIVERSITÄT DARMSTADT

- Introduction
- Constraining nuclear matrix elements for $0\upsilon\beta\beta$-decay
  - Motivation
  - Scissors mode and shape mixing
  - Status
- Constraining WIMP-nucleus structure factors
  - Motivation
  - Status
- Summary

Introduction

- project B03 dedicated to test fundamental symmetries
- via key experiments at
  - Darmstadt superconducting linear electron accelerator S-DALINAC
  - High Intensity γ-ray Source HIγS, Duke University, NC, U.S.A.
- using electron scattering and nuclear resonance fluorescence
- providing crucial input for theoretical considerations





Henry R. Weller *et al.*, Prog. Part. Nucl. Phys. **62** 257 (2011)

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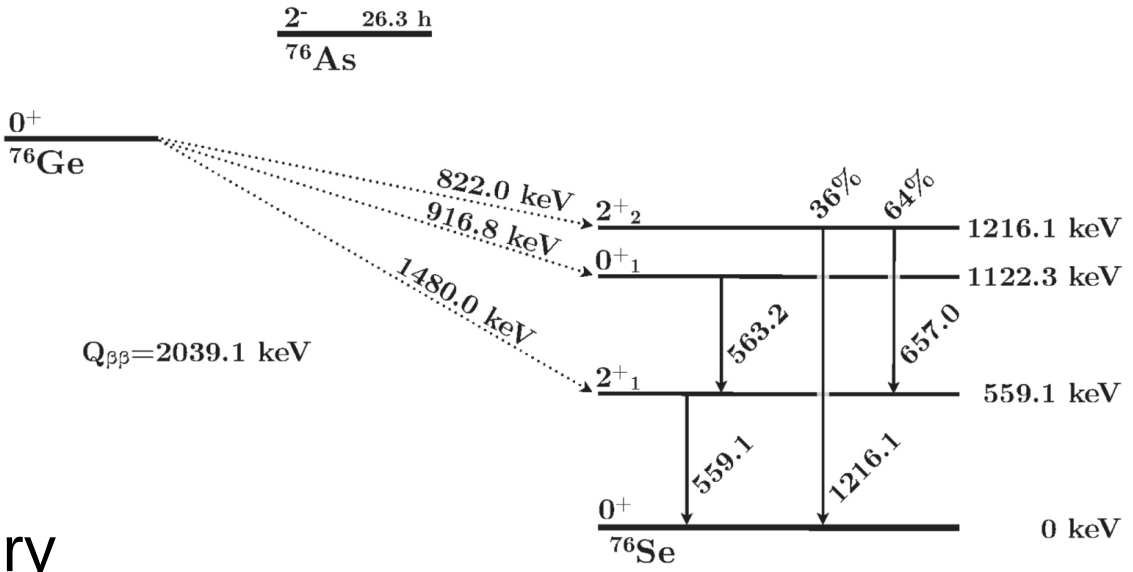
Motivation

- observation of 0υββ-decay implies Majorana character of neutrinos
  - virtual neutrinos annihilate during process
- NME proportional to neutrino masses

$$\Gamma = G \ |M|^2 \ |m_{\beta\beta}|^2$$

- NME only from theory

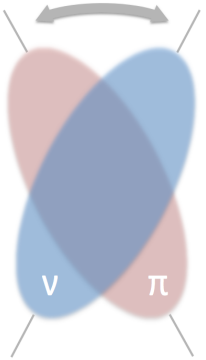


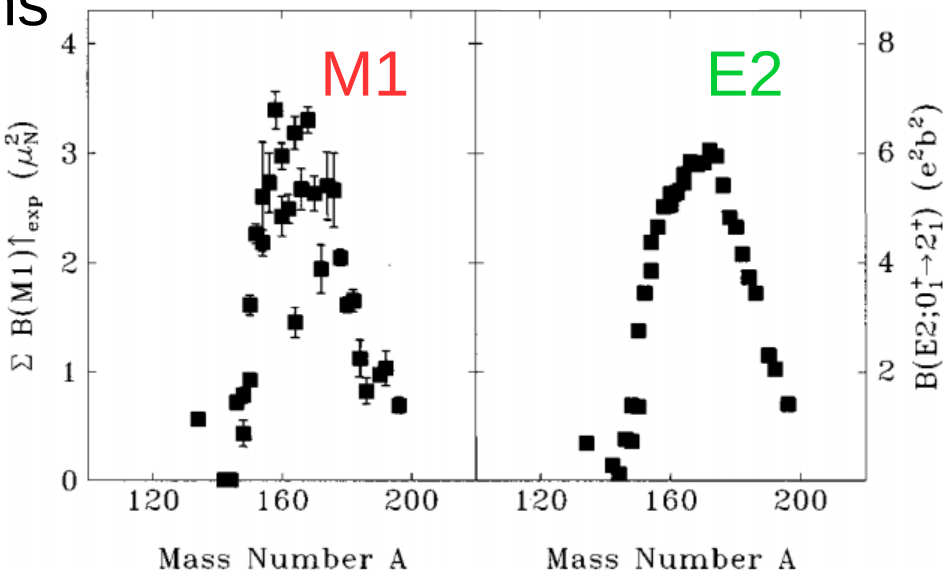
J.Phys. G42 (2015) no.11, 115201

Scissors Mode...

- first applicable prediction within IBM-2 in 1981 by Iachello
- isovector rotational mode of valence proton and neutrons
- excited via *M1* transition
- quadrupole collective
- correlated to *E0* transition strength

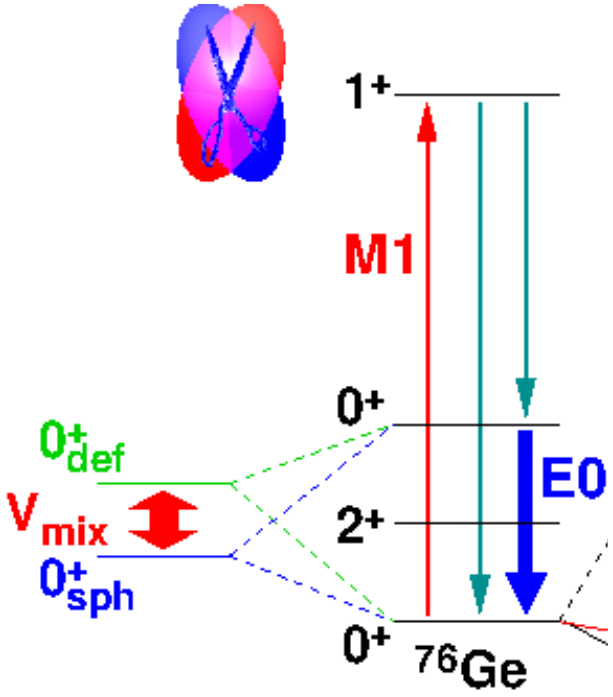
van Isacker, NDS 120 (2014) 119–122





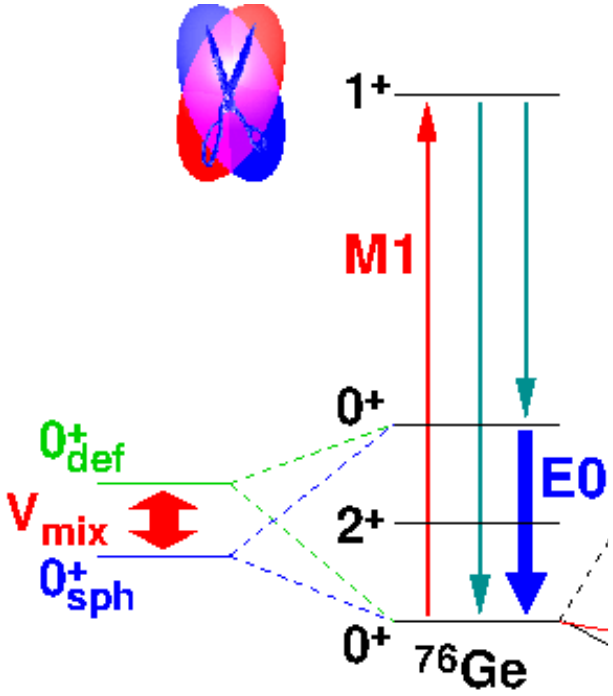
Pietralla *et al.*, Phys. Rev. C 58 (1998) 184

...and Shape Mixing

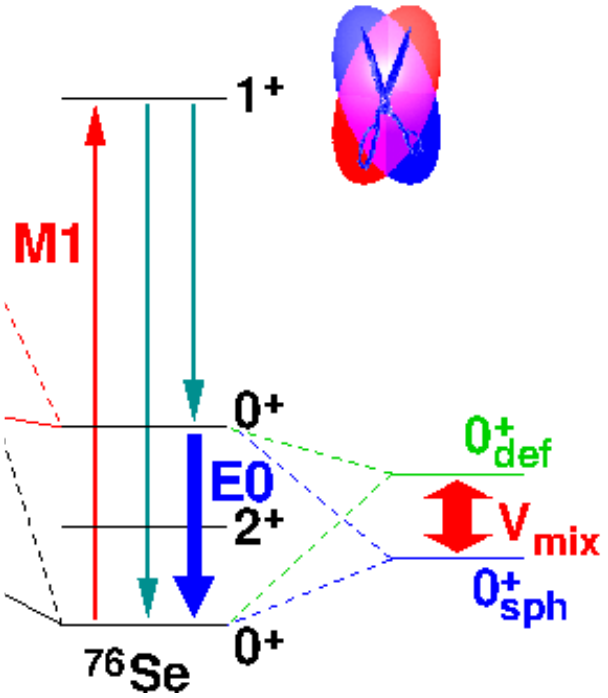


- significant contribution of deformation to gs wave function
- scissors mode excited from spherical-deformed mixed state
- search for scissors mode branching to excited 0^+ state
- E0 transition strength as complementary observable

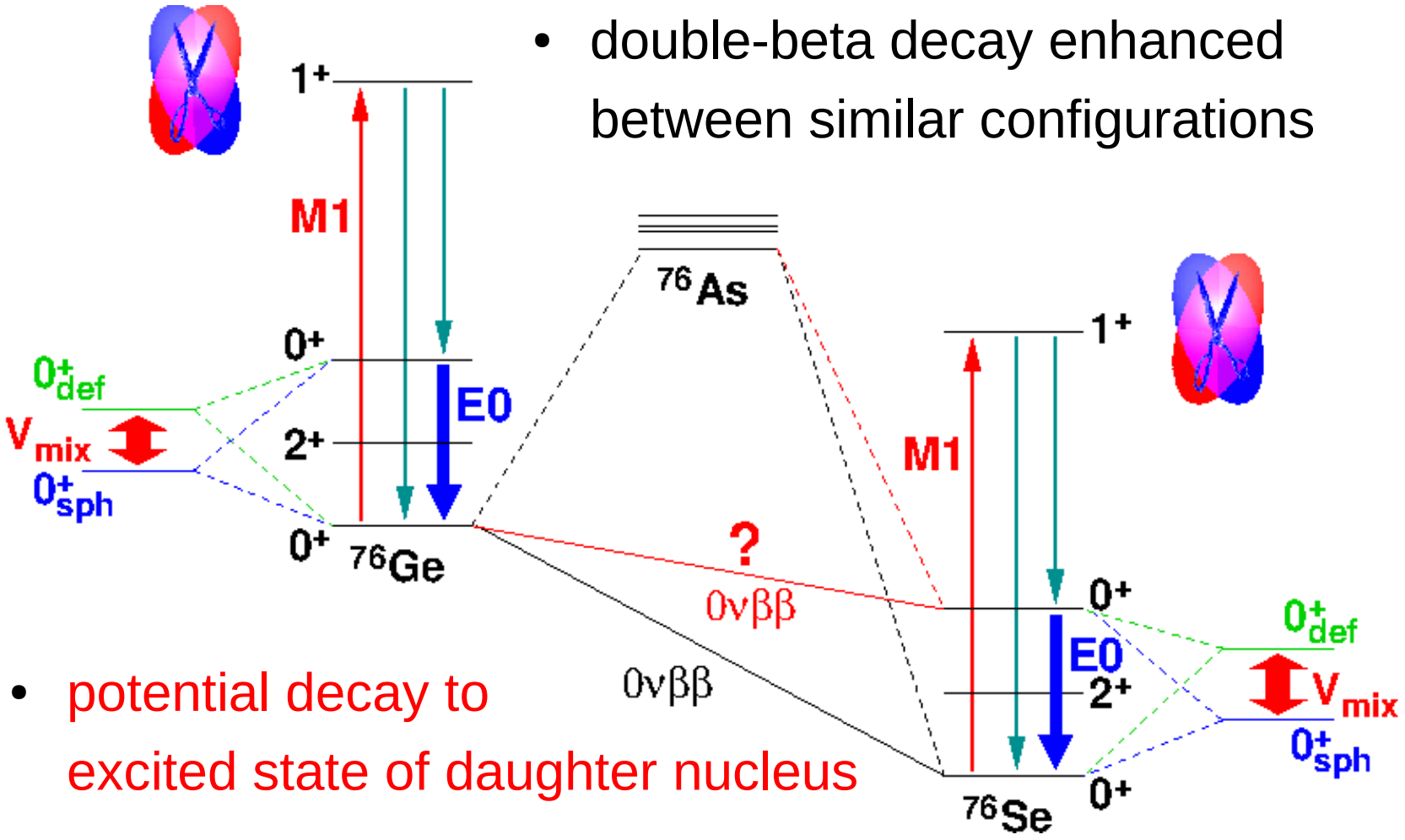
Scissors Mode and Shape Mixing II



- same happens for mother and daughter nucleus



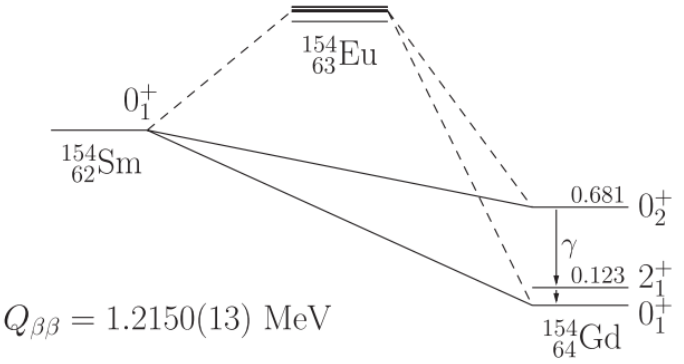
Scissors Mode and Shape Mixing III

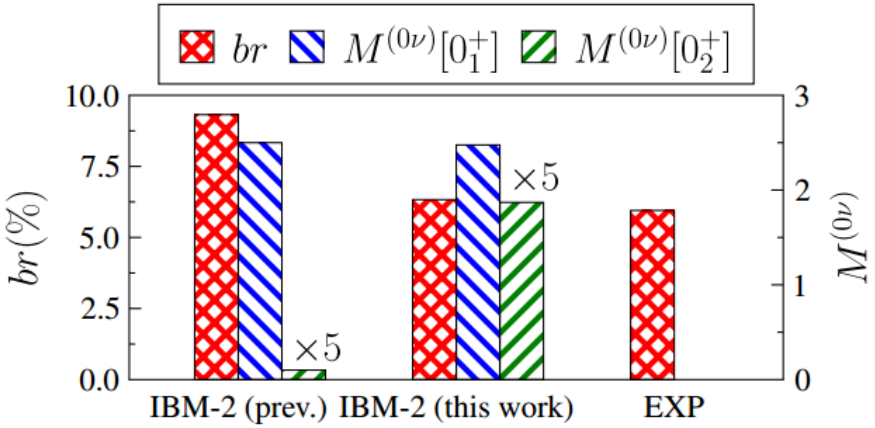


- double-beta decay enhanced between similar configurations
- potential decay to excited state of daughter nucleus

Nuclear Matrix Elements from IBM-2

- IBM-2 suitable to describe scissors mode by distinguishing protons and neutrons
- parameters fixed by branching ratio and excitation energy



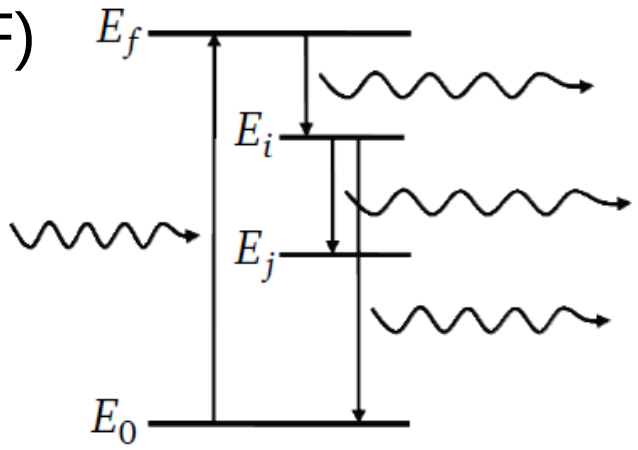


J. Beller *et al.*, Phys. Rev. Lett. 111, 172501 (2013)

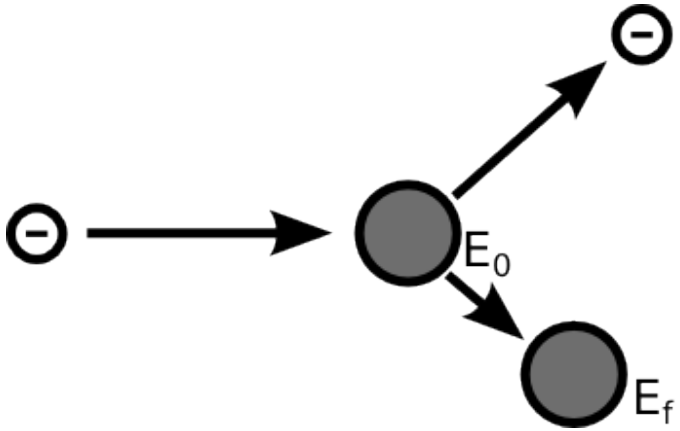
- new findings for corrections: 0υββ NMEs change

Methods of Choice

- nuclear resonance fluorescence (NRF)
  - preferred method for extracting scissors mode observables
  - selectively sensitive to dipole excitation e.g. *M1*

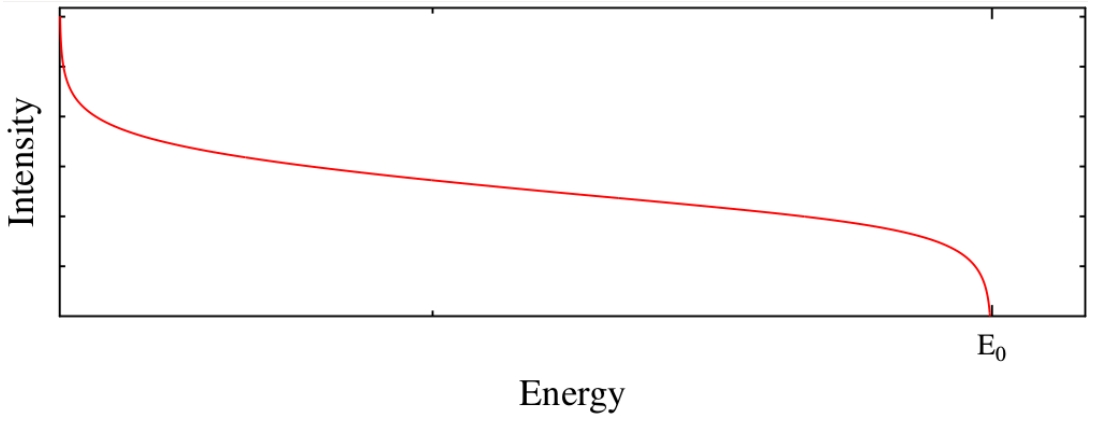


- electron scattering
  - sensitive to electric monopole transitions *E0*



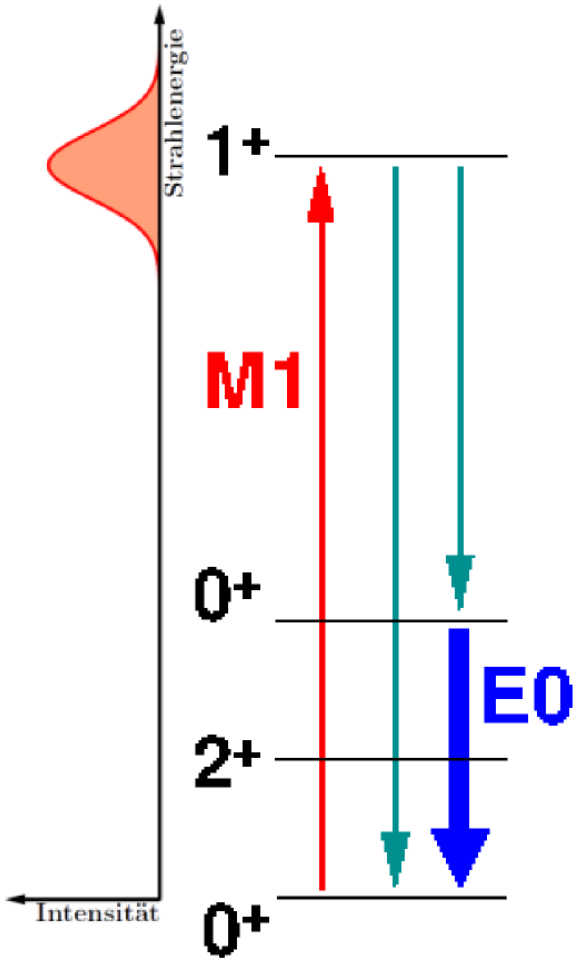
NRF Experiments at DHIPS

- measurements of $0\upsilon\beta\beta$ candidates ^{82}Se, ^{82}Kr and ^{150}Nd at DHIPS @ S-DALINAC
- utilizing high photon flux and energy range from bremsstrahlung
- extracting spin quantum numbers and transition strengths
- up to 4 weeks beam time



NRF Experiments at HIγS

- additional measurements HIγS
- utilizing quasi-monoenergetic polarized photon beam
- extracting parity quantum numbers
- and decay behaviour
- up to 2 weeks beam time



Status NRF Experiments

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- targets bought
- DHIPS beam time planned after commissioning of S-DALINAC and subsequent electron scattering campaign: summer 2017
- HIγS beam time currently running on ^{82}Se, ^{82}Kr and ^{150}Nd

Electron Scattering Experiments at QCLAM

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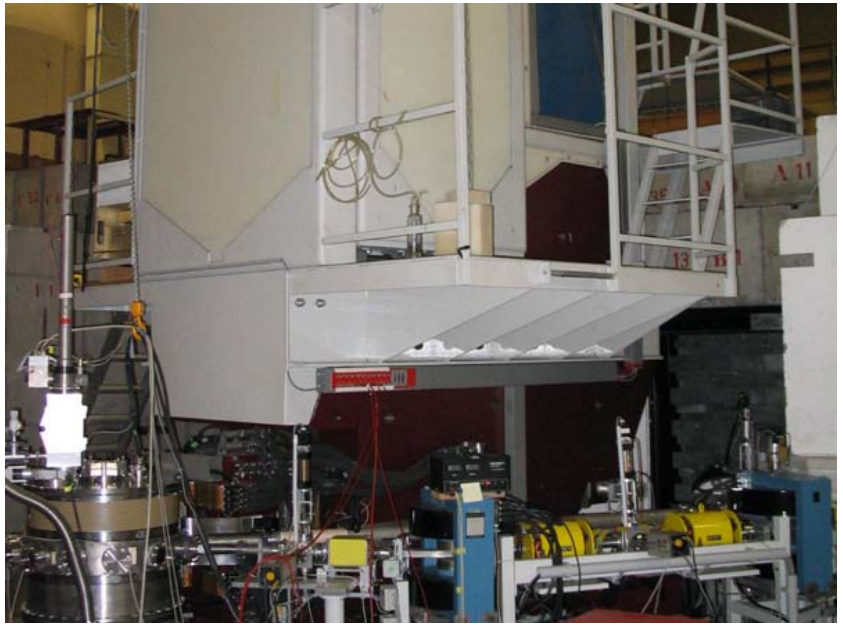
- measurements of $0\upsilon\beta\beta$ partners ^{76}Ge and ^{76}Se at QCLAM spectrometer at S-DALINAC
- utilizing large acceptance
- extracting form factors of 0^+_1 and 0^+_{gs}
- *E0* transition strength
- up to 3 weeks beam time



Status QCLAM Experiments

- QCLAM under reconstruction
  - new electronics ordered
- target production difficult due to geometric requirements and chemical properties:
  - desired target thickness 5-10 mg/cm²
  - ^{76}Se: powder, highly poisonous, low melting temperature
  - ^{76}Ge: powder
  - in contact with target laboratories at GSI and ELI-NP

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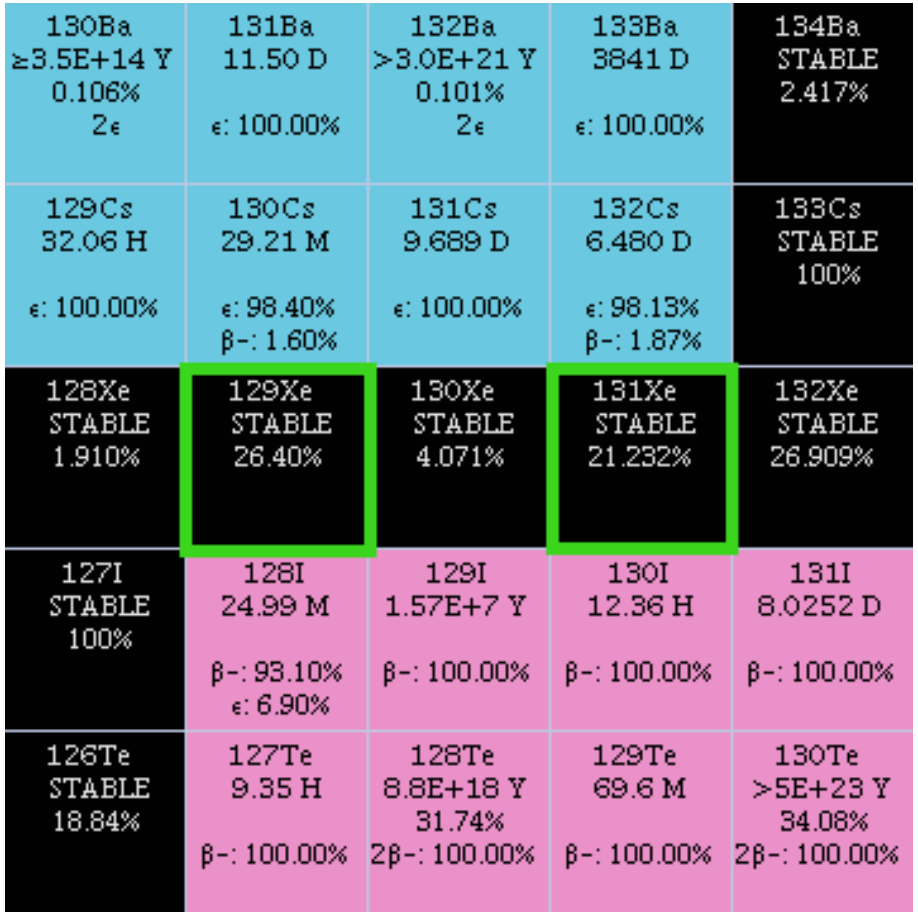
Motivation

- weakly interacting massive particles (WIMPs) as candidates for dark mater
- attempt to detect via elastic and inelastic scattering off nuclei
- promising detector material liquid xenon
- XENON100 collaboration provides limits for WIMP-nucleon cross section

Constraining WIMP-

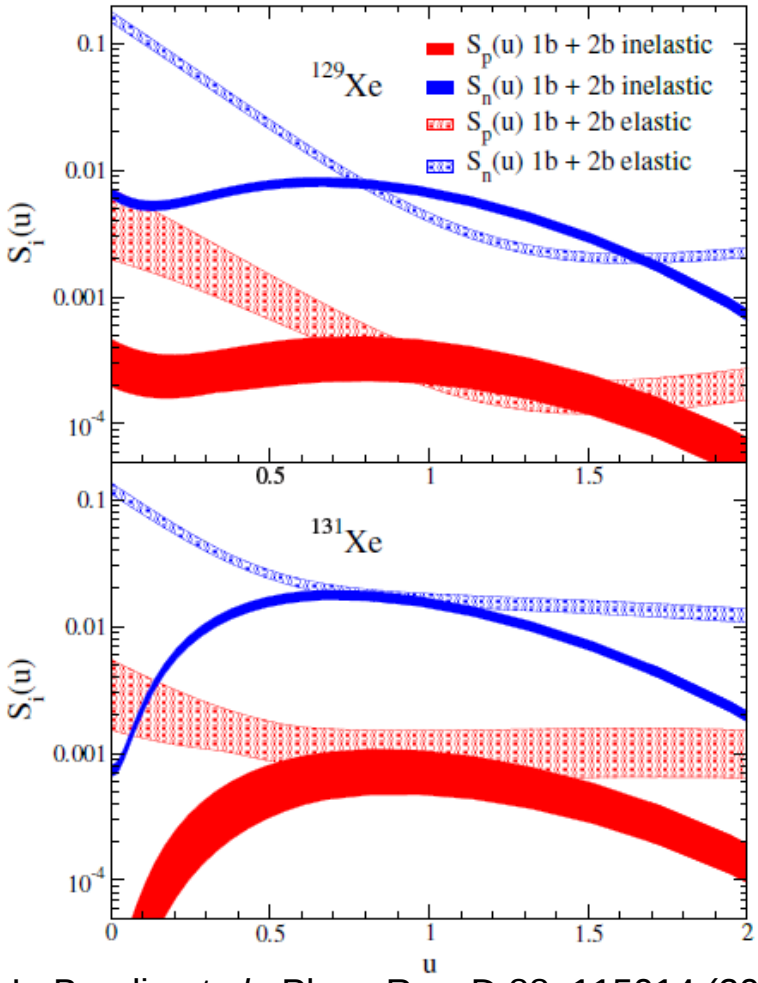
- measurement of form factors in ^{129}Xe and ^{131}Xe
- providing crucial information for dark matter detection



http://www.nndc.bnl.gov/

Spin-dependent Cross Section

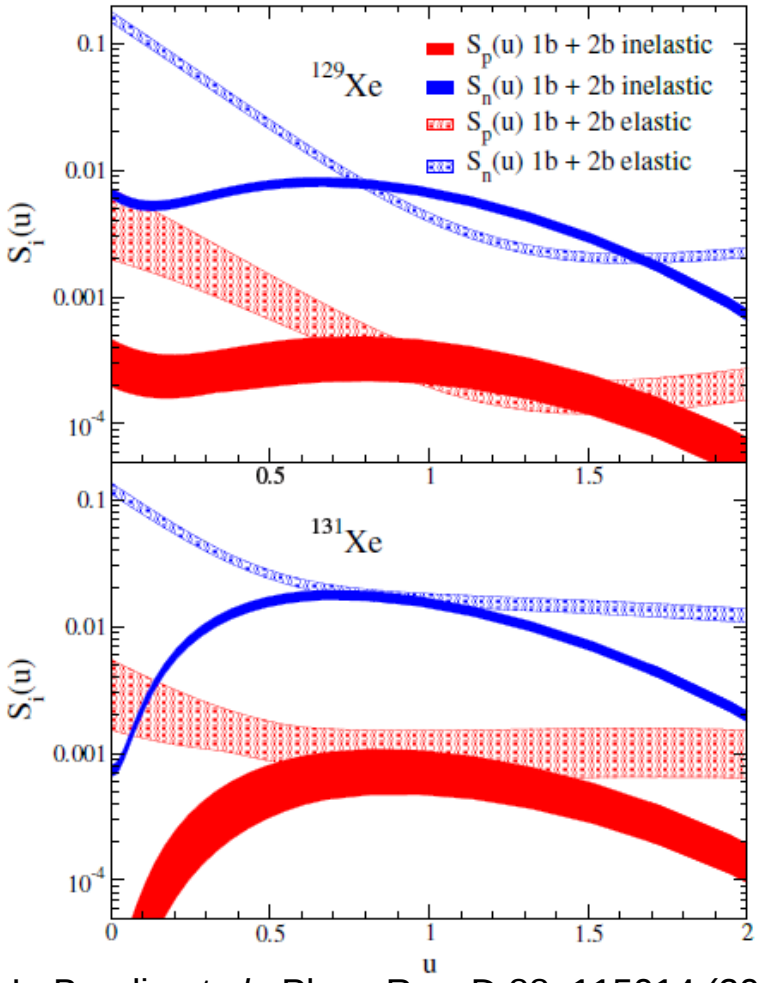
- spin-dependency of WIMP interaction unknown
- only odd mass number Xe isotopes interact
- large-scale shell-model calculations
- form factors for spin-dependent interaction



L. Baudis *et al.,* Phys. Rev. D 88, 115014 (2013)

Spin-dependent Cross Section II

- significant contribution from *inelastic* WIMP-nucleon scattering
- at low momentum transfer ~100MeV
- range of operation of S-DALINAC



L. Baudis *et al.,* Phys. Rev. D 88, 115014 (2013)

Electron Scattering Experiments at LINTOTT

- utilizing exceptional energy resolution in energy-loss mode of LINTOTT-spectrometer
- measuring form factors for gs and first excited states in ^{129}Xe and ^{131}Xe at 40 and 80 keV resp.
- beam energies at 50, 65 and 80 MeV
- angles from 69° to 165°
- up to 5 weeks beamtime

Status LINTOTT Experiments

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- LINTOTT-spectrometer ready for operation
- ^{129}Xe and ^{131}Xe targets ready
- planned for electron scattering campaign end of winter

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- motivation of the research program in B03
- contributing to exciting and recent research
  - neutrinoless double-beta decay
  - dark matter detection
- status report on B03
  - HIγS measurements up and running
  - first electron scattering experiments ready for operation

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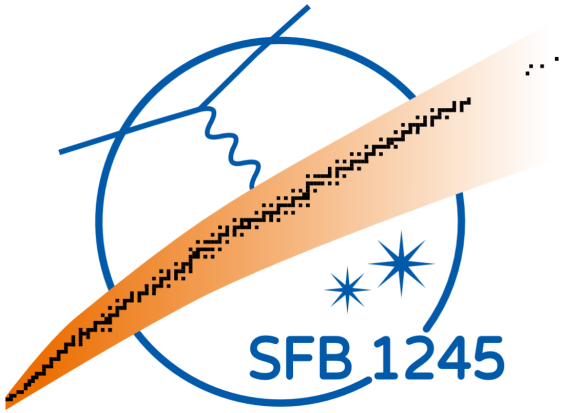
Thank you for your attention



QCLAM Experiments

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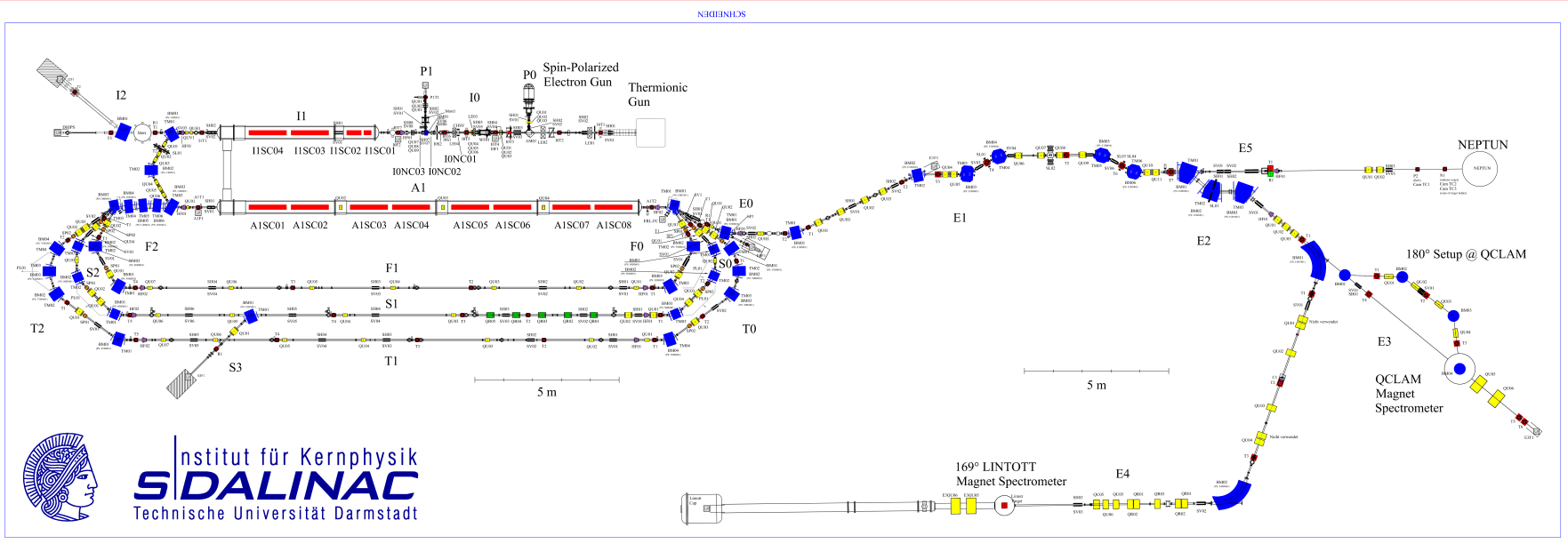
- measurement of double beta decay partners ^{76}Ge and ^{76}Se at QCLAM spectrometer
- form factor for gs and first excitet 0^+ states
- both *E0* Transition strengths $0^+_1 \rightarrow 0^+_{gs}$

76Br 16.2 H ε: 100.00%	77Br 57.036 H ε: 100.00%	78Br 6.46 M ε ≥ 99.99% β-≤ 0.01%	79Br STABLE 50.69%	80Br 17.68 M β-: 91.70% ε: 8.30%
75Se 119.79 D ε: 100.00%	76Se STABLE 9.37%	77Se STABLE 7.63%	78Se STABLE 23.77%	79Se 2.95E+5 Y β-: 100.00%
74As 17.77 D ε: 66.00% β-: 34.00%	75As STABLE 100%	76As 1.0942 D β-: 100.00%	77As 38.83 H β-: 100.00%	78As 90.7 M β-: 100.00%
73Ge STABLE 7.76%	74Ge STABLE 36.73%	75Ge 82.78 M β-: 100.00%	76Ge 1.78E+21 Y 7.83% 2β-	77Ge 11.30 H β-: 100.00%
72Ga 14.095 H β-: 100.00%	73Ga 4.86 H β-: 100.00%	74Ga 8.12 M β-: 100.00%	75Ga 126 S β-: 100.00%	76Ga 32.6 S β-: 100.00%

http://www.nndc.bnl.gov/

S-DALINAC


I2
I1
I0
P1
P0
Spin-Polarized
Electron Gun
Thermionic
Gun
I1SC04 I1SC03 I1SC02 I1SC01
I0NC01
I0NC03 I0NC02
A1
A1SC01 A1SC02 A1SC03 A1SC04 A1SC05 A1SC06 A1SC07 A1SC08
E0
E1
E2
E5
NEPTUN
180° Setup @ QCLAM
E3
QCLAM
Magnet
Spectrometer
169° LINTOTT
Magnet Spectrometer
E4
F0
F1
F2
S0
S1
S2
T0
T1
T2
S3
5 m
5 m
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