ICRM-LLRMT 2022

Best Poster Award

… and the winner is …

Direct measurement of the ionization quenching factor of nuclear recoils in germanium in the keV range

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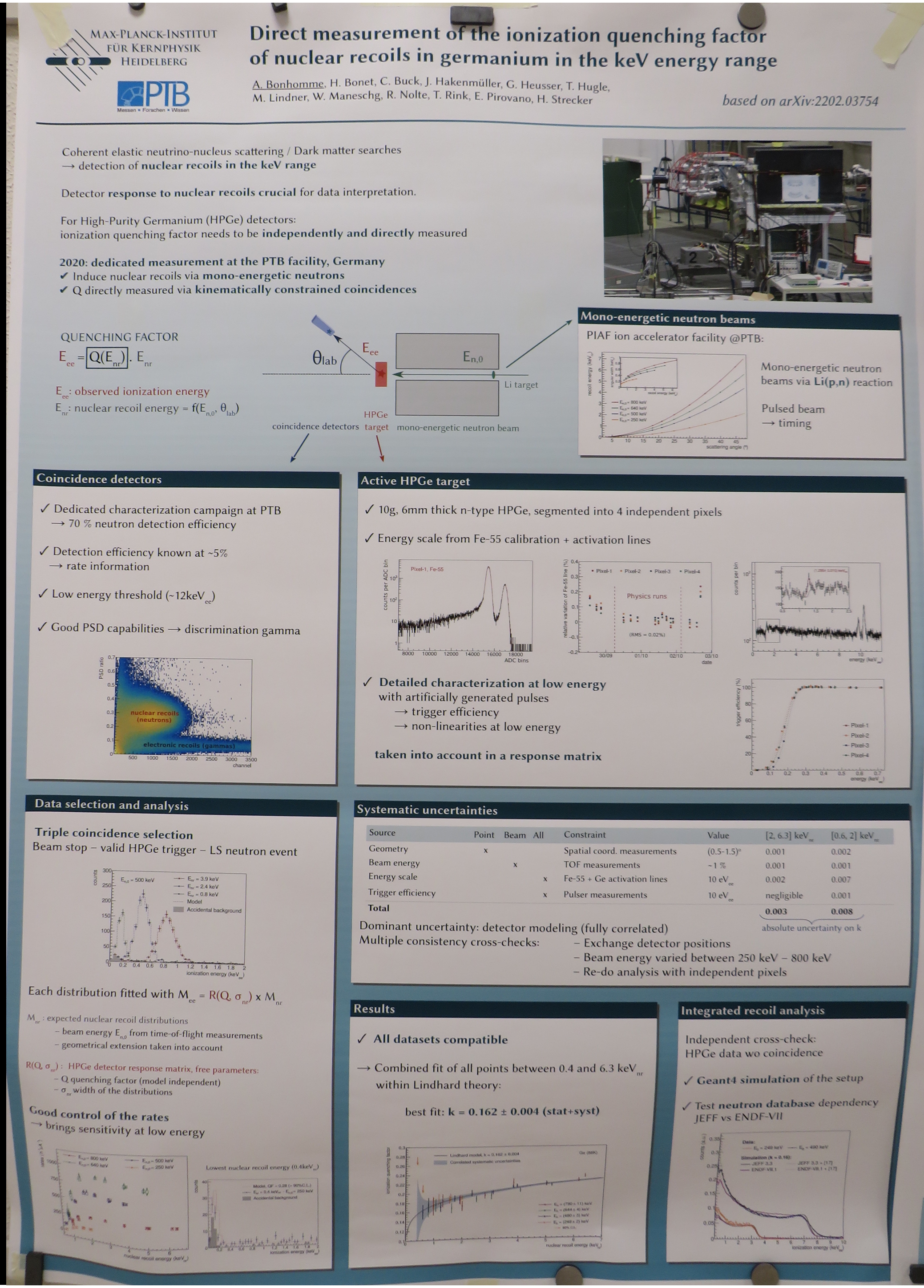
Poster #092

- Crucial for CEvNS/DM searches
- Direct measurement via kinematically constrained coincidences
  – Mono-energetic neutron beams @PTB
  – Dedicated thin HPGe target
  – LS based neutron detectors
- Careful treatment of systematics
- Data compatible with Lindhard theory in $[0.4, 6]\mathrm{keV}_{nr}$:

$$k = 0.162 \pm 0.004 \text{ (stat+syst)}$$

LNGS 2022 ICRM - LLRMT

Session: Fundamental Physics



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PTB
Direct measurement of the ionization quenching factor of nuclear recoils in germanium in the keV energy range
A. Bonhomme, H. Bonet, C. Buck, J. Hakenmüller, G. Heusser, T. Hugle, M. Lindner, W. Maneschg, R. Nolte, T. Rink, E. Pirovano, H. Strecker
based on arXiv:2202.03754
Coherent elastic neutrino-nucleus scattering / Dark matter searches
→ detection of nuclear recoils in the keV range
Detector response to nuclear recoils crucial for data interpretation.
For High-Purity Germanium (HPGe) detectors:
ionization quenching factor needs to be independently and directly measured
2020: dedicated measurement at the PTB facility, Germany
✓ Induce nuclear recoils via mono-energetic neutrons
✓ Q directly measured via kinematically constrained coincidences
QUENCHING FACTOR
E_ee = Q(E_nr) · E_nr
E_ee: observed ionization energy
E_nr: nuclear recoil energy = f(E_n,0, θ_lab)
θlab
E_ee
E_n,0
Li target
HPGe target
coincidence detectors
mono-energetic neutron beam
Mono-energetic neutron beams
PIAF ion accelerator facility @PTB:
Mono-energetic neutron beams via Li(p,n) reaction
Pulsed beam → timing
Coincidence detectors
✓ Dedicated characterization campaign at PTB → 70 % neutron detection efficiency
✓ Detection efficiency known at ~5% → rate information
✓ Low energy threshold (~12keV_ee)
✓ Good PSD capabilities → discrimination gamma
nuclear recoils (neutrons)
electronic recoils (gammas)
Active HPGe target
✓ 10g, 6mm thick n-type HPGe, segmented into 4 independent pixels
✓ Energy scale from Fe-55 calibration + activation lines
Pixel-1, Fe-55
Physics runs
✓ Detailed characterization at low energy with artificially generated pulses
→ trigger efficiency
→ non-linearities at low energy
taken into account in a response matrix
Pixel-1
Pixel-2
Pixel-3
Pixel-4
Data selection and analysis
Triple coincidence selection
Beam stop – valid HPGe trigger – LS neutron event
Accidental background
ionization energy (keV_ee)
Each distribution fitted with M_ee = R(Q, σ_nr) x M_nr
M_nr : expected nuclear recoil distributions
– beam energy E_n,0 from time-of-flight measurements
– geometrical extension taken into account
R(Q, σ_nr) : HPGe detector response matrix, free parameters:
– Q quenching factor (model independent)
– σ_nr width of the distributions
Good control of the rates
→ brings sensitivity at low energy
E_n,0 = 800 keV
E_n,0 = 640 keV
E_n,0 = 500 keV
E_n,0 = 250 keV
Lowest nuclear recoil energy (0.4keV_nr)
Systematic uncertainties
Source | Point | Beam | All | Constraint | Value | [2, 6.3] keV_nr | [0.6, 2] keV_nr
Geometry | x | | | Spatial coord. measurements | (0.5-1.5)° | 0.001 | 0.002
Beam energy | | x | | TOF measurements | ~1 % | 0.001 | 0.001
Energy scale | | | x | Fe-55 + Ge activation lines | 10 eV_ee | 0.002 | 0.007
Trigger efficiency | | | x | Pulser measurements | 10 eV_ee | negligible | 0.001
Total | | | | | | 0.003 | 0.008
absolute uncertainty on k
Dominant uncertainty: detector modeling (fully correlated)
Multiple consistency cross-checks:
– Exchange detector positions
– Beam energy varied between 250 keV – 800 keV
– Re-do analysis with independent pixels
Results
✓ All datasets compatible
→ Combined fit of all points between 0.4 and 6.3 keV_nr within Lindhard theory:
best fit: k = 0.162 ± 0.004 (stat+syst)
Integrated recoil analysis
Independent cross-check:
HPGe data wo coincidence
✓ Geant4 simulation of the setup
✓ Test neutron database dependency JEFF vs ENDF-VII