B04: Electric dipole response and neutron equation of state

Dmytro Symochko

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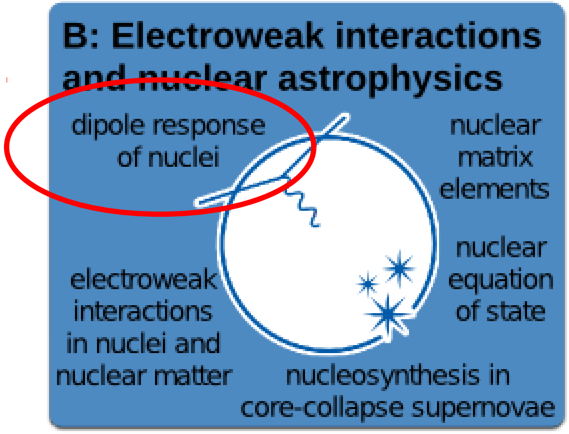

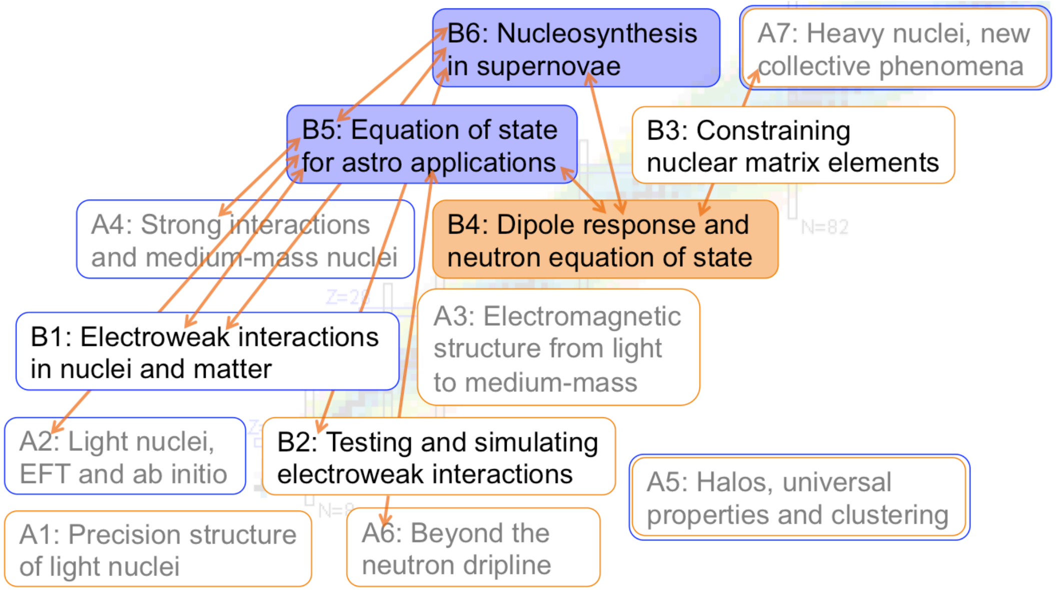

Supported by the Deutsche Forschungsgemeinschaft through grant SFB 1245

Dipole Response and Dipole Polarizability

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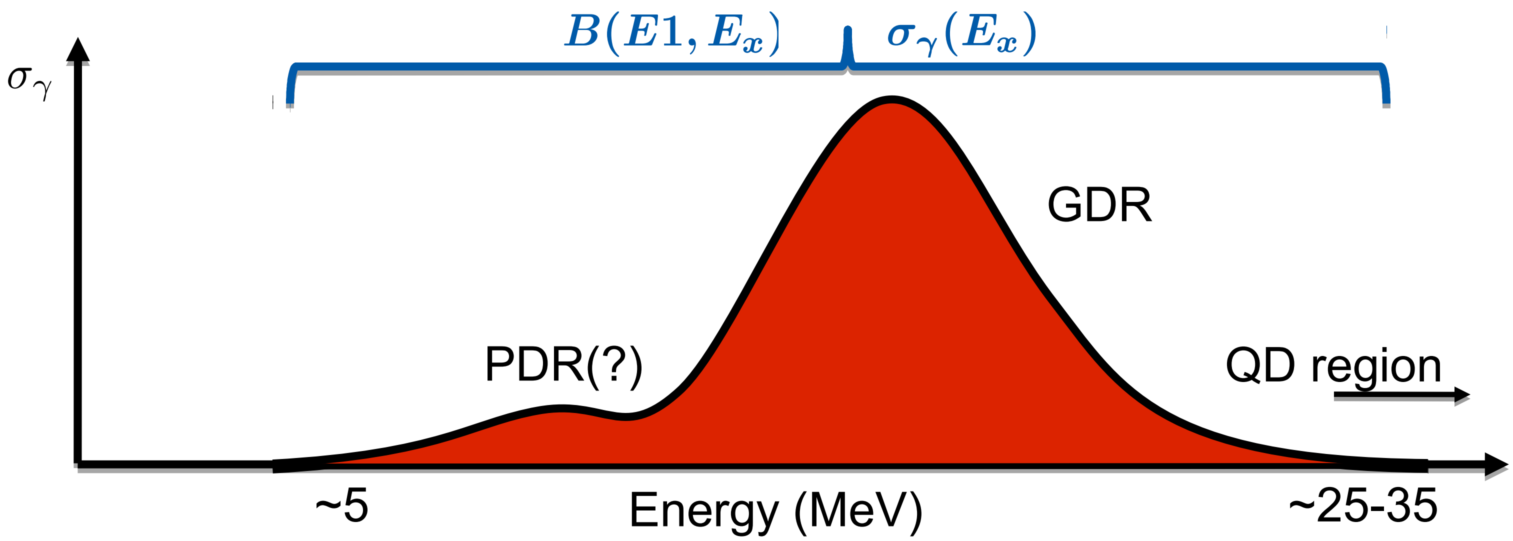
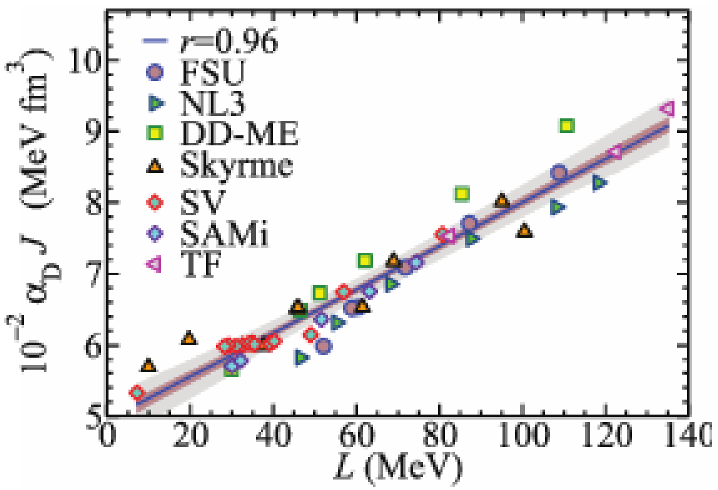


The electric polarizability is proportional to the inverse energy weighted sum rule (IEWSR) of the electric dipole response in nuclei

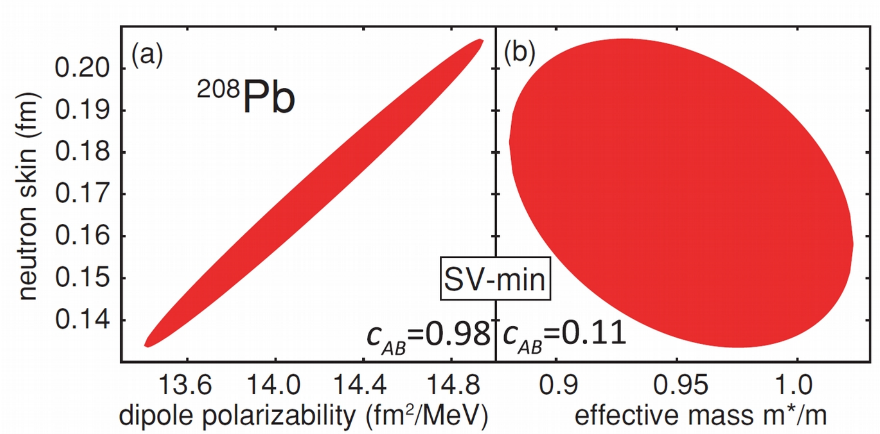
$$\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma_\gamma(E)}{E^2} dE = \frac{8\pi}{9} \int_0^\infty \frac{dB(E1)}{E} dE$$

Value of α_D observable

$$\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma_\gamma(E)}{E^2} dE = \frac{8\pi}{9} \int_0^\infty \frac{dB(E1)}{E} dE$$



X. Roca-Maza et al., PRC 92, 064304 (2015)



P.G. Reinhard and W. Nazarewicz,PRC 81 (2010) 051303

Additional value! Photoabsorption data is needed for modeling r- and p- processes.

Experimental approaches and aims in B04

Excitation by virtual photons – (p,p')

Experimental site – Grand Raiden spectrometer@RCNP (Osaka)

Excitation by real photons – (γ,γ'), (γ,γ'γ'),(γ,γ'n)...

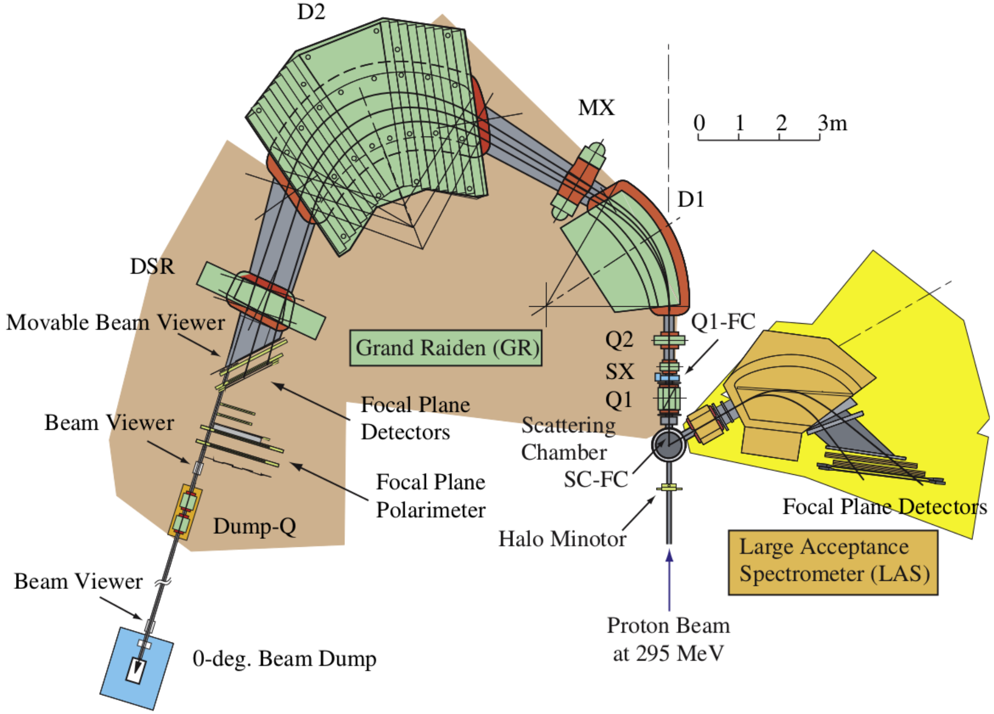
Experimental site – NEPTUN tagger@SDALINAC (Darmstadt)

Aims:

- **Systematic understanding of the electric dipole response in nuclei including the low-lying strength. Focus on Sn isotopes.**
- **Accurate determination of nuclear dipole polarizabilities**
- **Provide complete and consistent set of data for constraining the symmetry energy parameters**

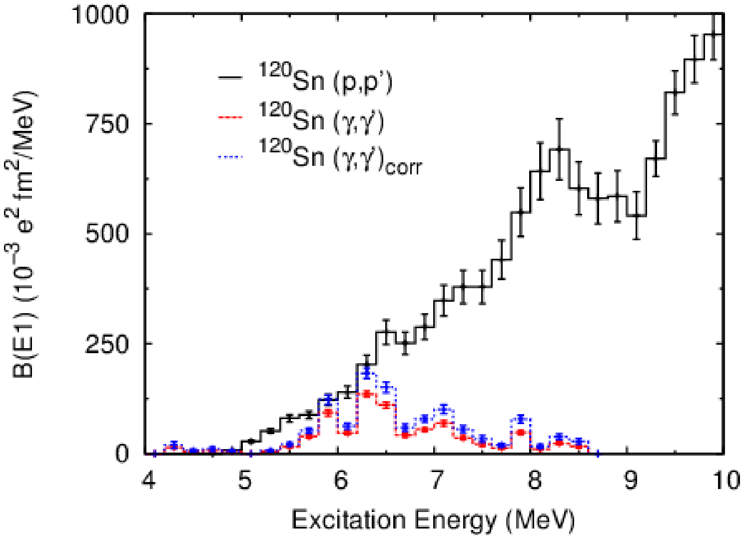
(p,p)'@RCNP (GRAND RAIDEN spectrometer)

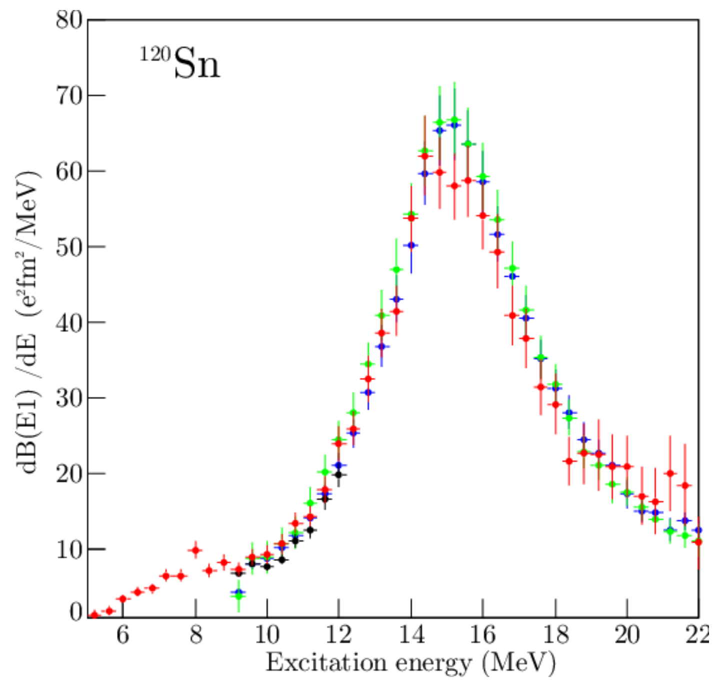
- 300 MeV proton scattering at and close to 0°
- strong Coulomb excitation of 1^- states: E1 strength up to 25 MeV
- high resolution: ΔE = 25 - 30 keV (FWHM)
- angular distributions: E1 / M1 separation by MDA



120Sn (p,p') data (SFB634)

A.M. Krumbholz et al., Phys. Lett. B 744 (2015) 7
T. Hashimoto et al., Phys. Rev. C 92 (2015) 031305

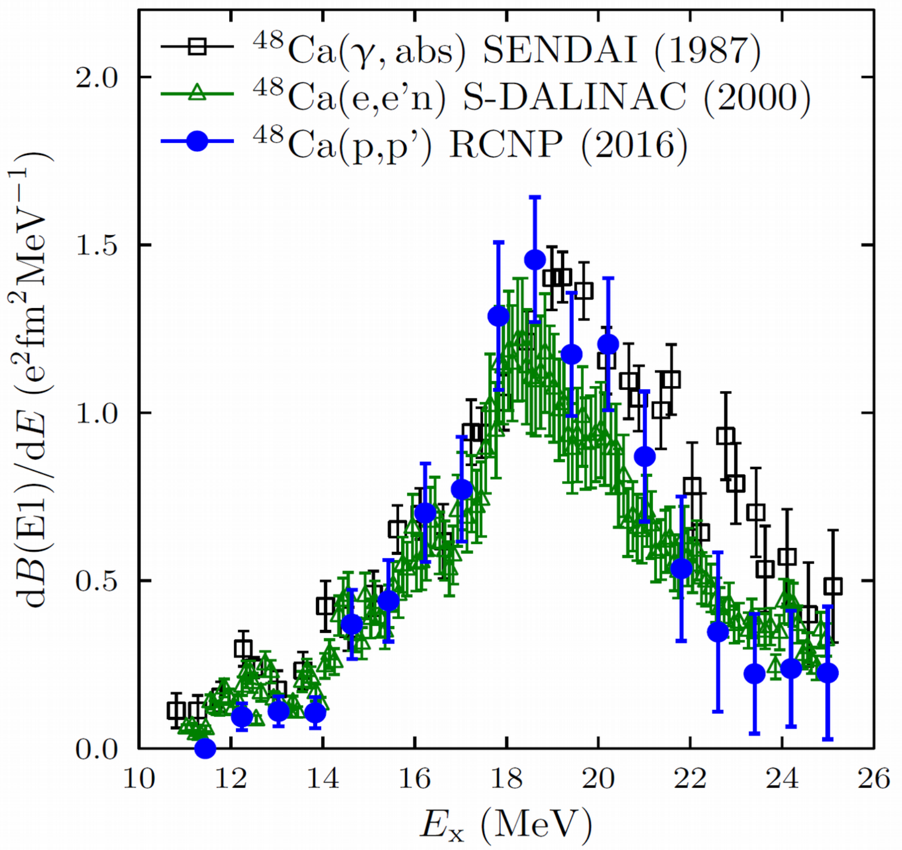




α_D=8.93 (36) fm^3

r_{skin}=0.148 (34) fm

B(E1) Strength in ^{48}Ca

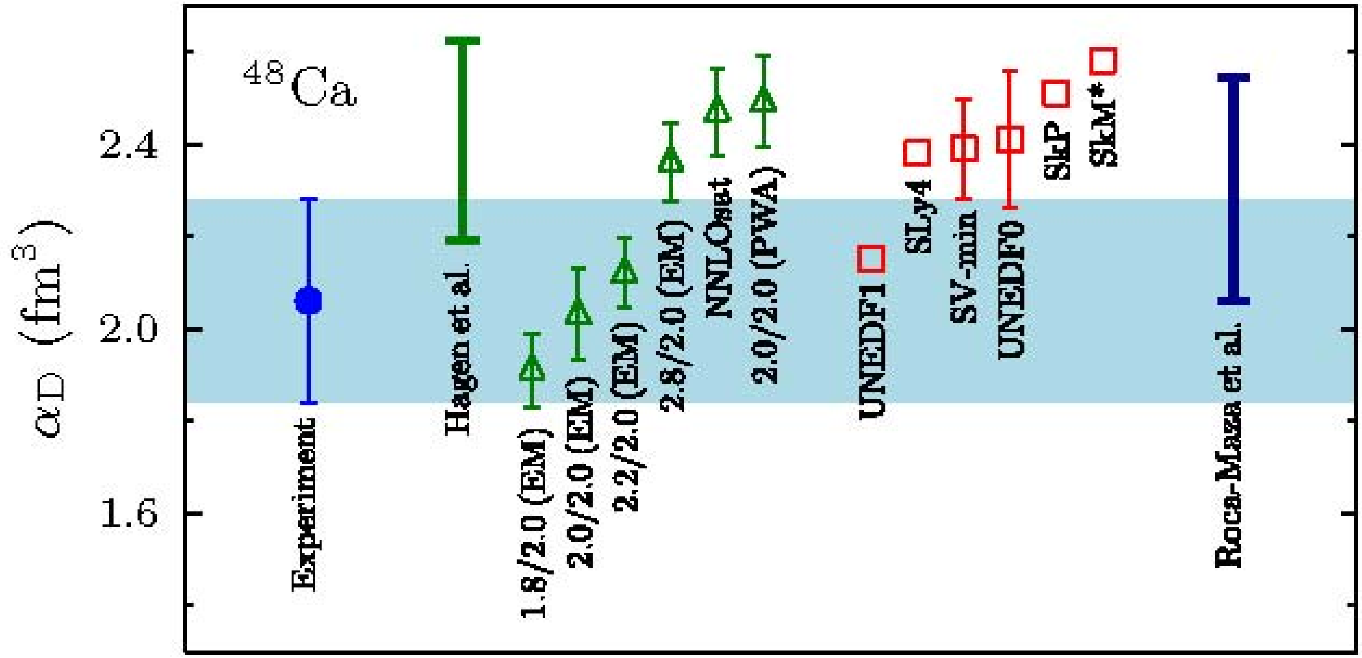


(γ, abs) - G.J. O'Keefe et al. Nucl. Phys. A 469, 239 (1987) – discarded because of the method

(e, e'n) - S. Strauch et al., Phys. Rev. Lett. 85, 2913 (2000) – does not include (e,e'p) chanel

Dipole Polarizability of ^{48}Ca

α_D=2.07 (22) fm^3



χEFT: G. Hagen et al., Nature Physics 12, 681 (2016)
EDFs: X. Roca-Maza et al., Phys .Rev. C 92, 064304 (2015)

Paper "Electric Dipole Polarizability of 48Ca and Implications for the Neutron Skin" by J. Birkhan et al. submitted to PRL this week

Ongoing analysis on Sn isotopes data by Sergej Bassauer

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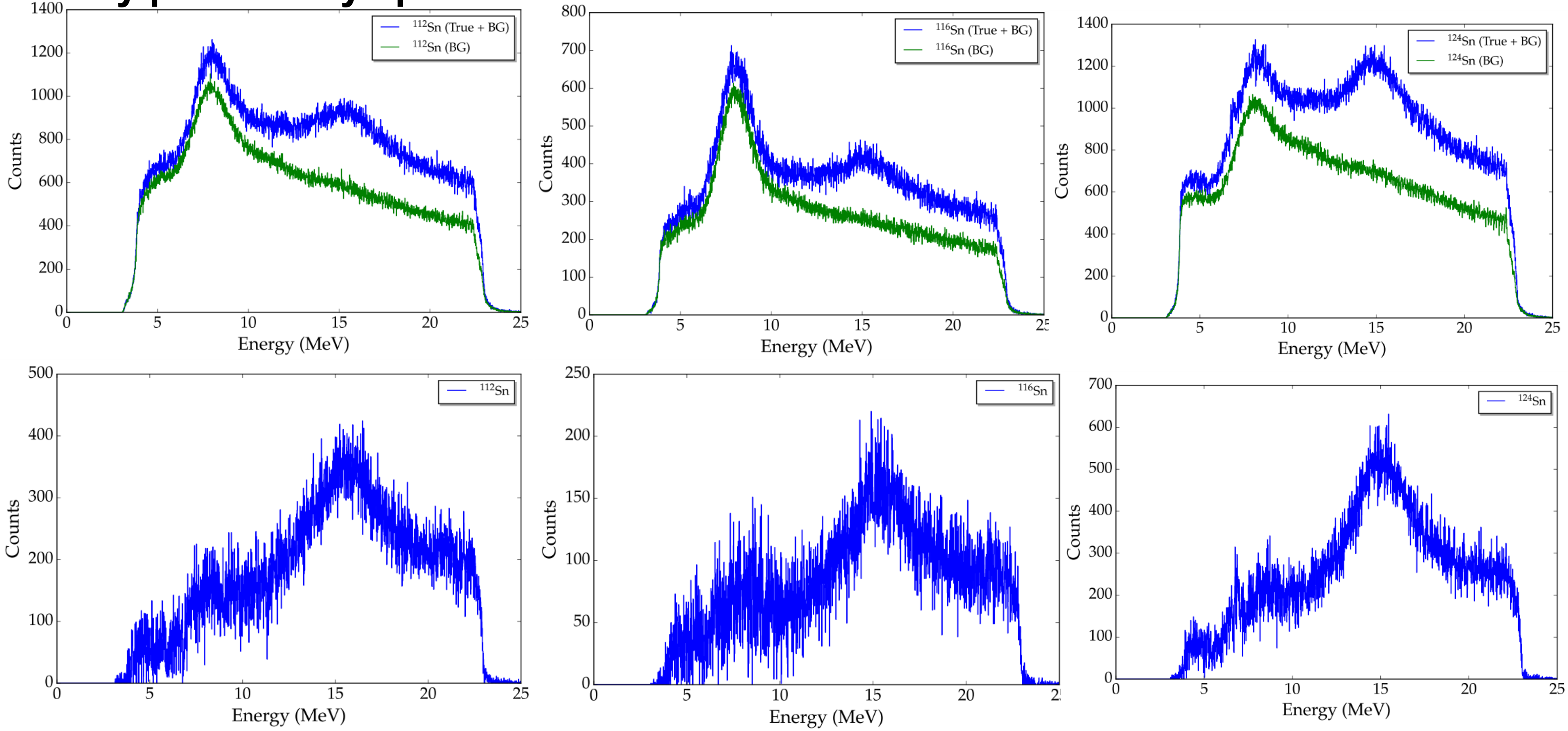
Done in 2016: angle and energy calibration, background subtraction.

Very preliminary spectrum!



(p,p') - plans for 2017

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Sn isotopes:

- Determine the double differential cross sections for all isotopes;
- Perform MDA;
- Determine dipole polarizability;
- Extract gamma strength functions and level densities.

40,44,48Ca:

- improved measurement of dipole polarizability by going to 400 MeV

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NEPTUN photon tagging facility at SDALINAC

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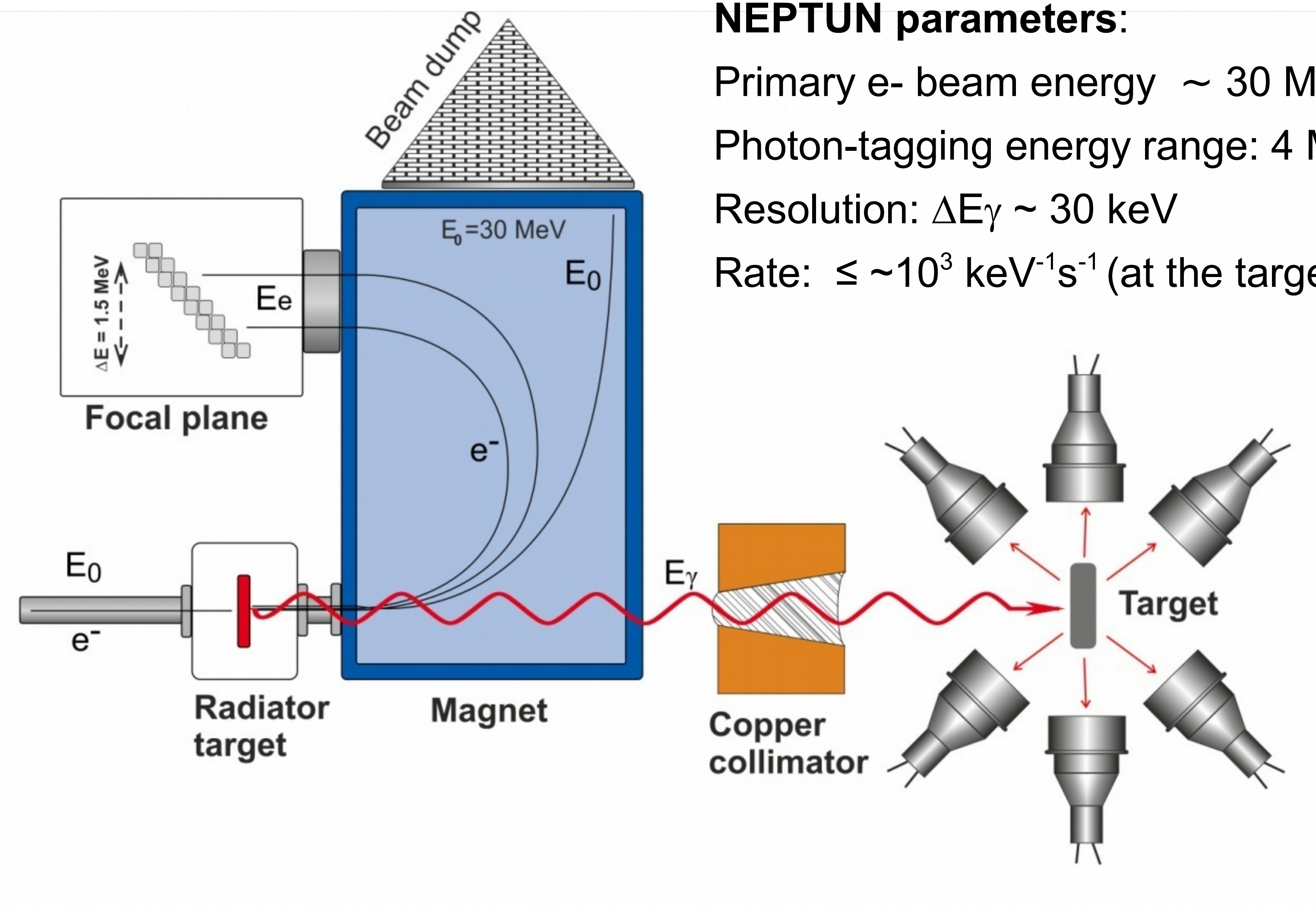

NEPTUN parameters:

Primary e- beam energy ~ 30 MeV

Photon-tagging energy range: 4 MeV – 20 MeV

Resolution: $\Delta E\gamma$ ~ 30 keV

Rate: ≤ ~10^3 $keV^{-1}s^{-1}$ (at the target)

NEPTUN detectors systems

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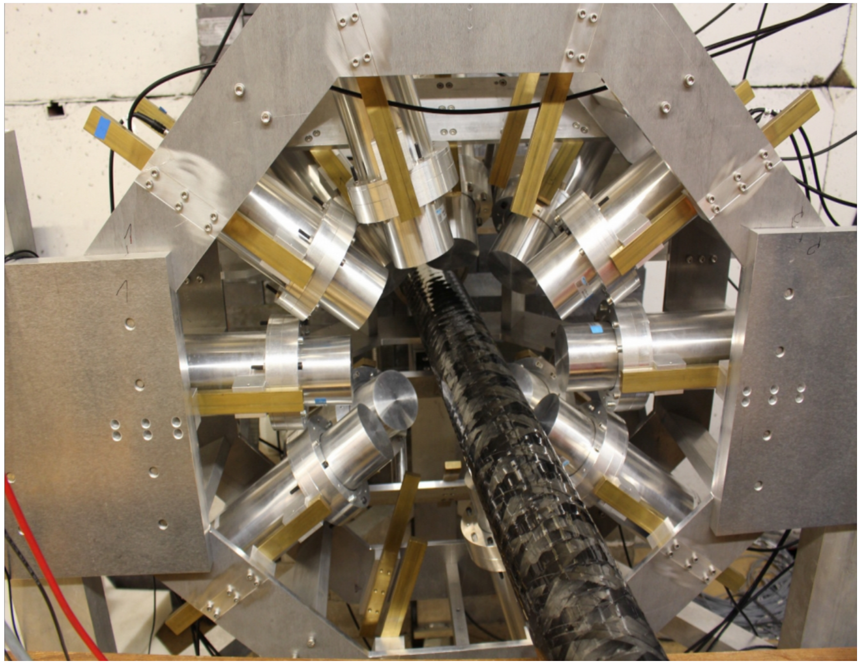


Detection systems:

γ:

GALATEA array

18 3"×3" **$LaBr_3$:Ce** crystals

2π coverage

neutrons:

Neutron Ball

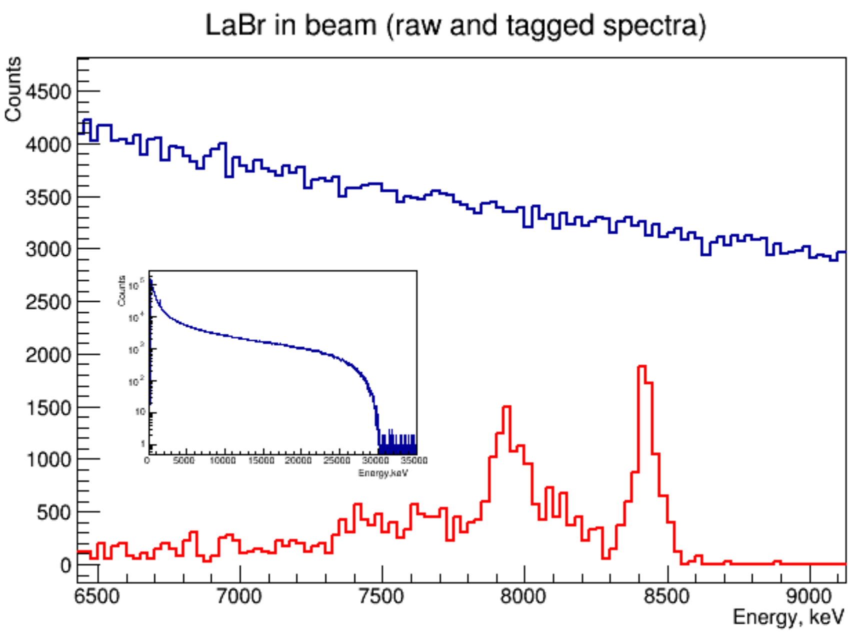
16 liquid-scintillator detectors

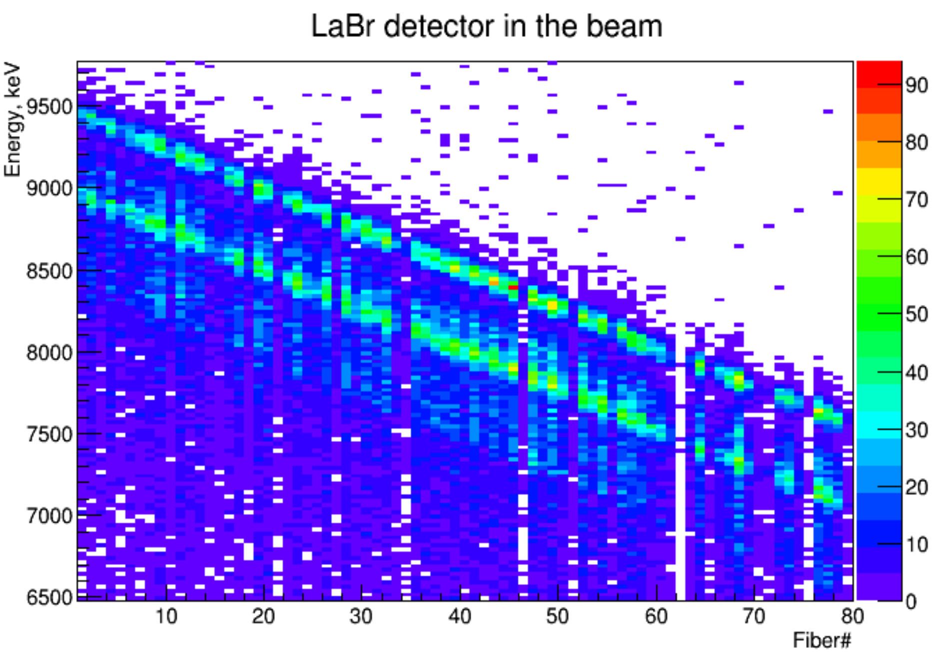
2π coverage

Digital DAQ built on the Multi-Branch System (GSI) and is based on Struck SIS3316 digitizers (250 MHz and 14 bit)

Tagged Bremsstrahlung spectrum

Positioning gamma detector directly in "tagged" beam and applying appropriate coincidence conditions shows the detector response to the quasimonochromatic gammas and allows the calibration of the focal plane detectors.





Commissioning results: first tagged transition

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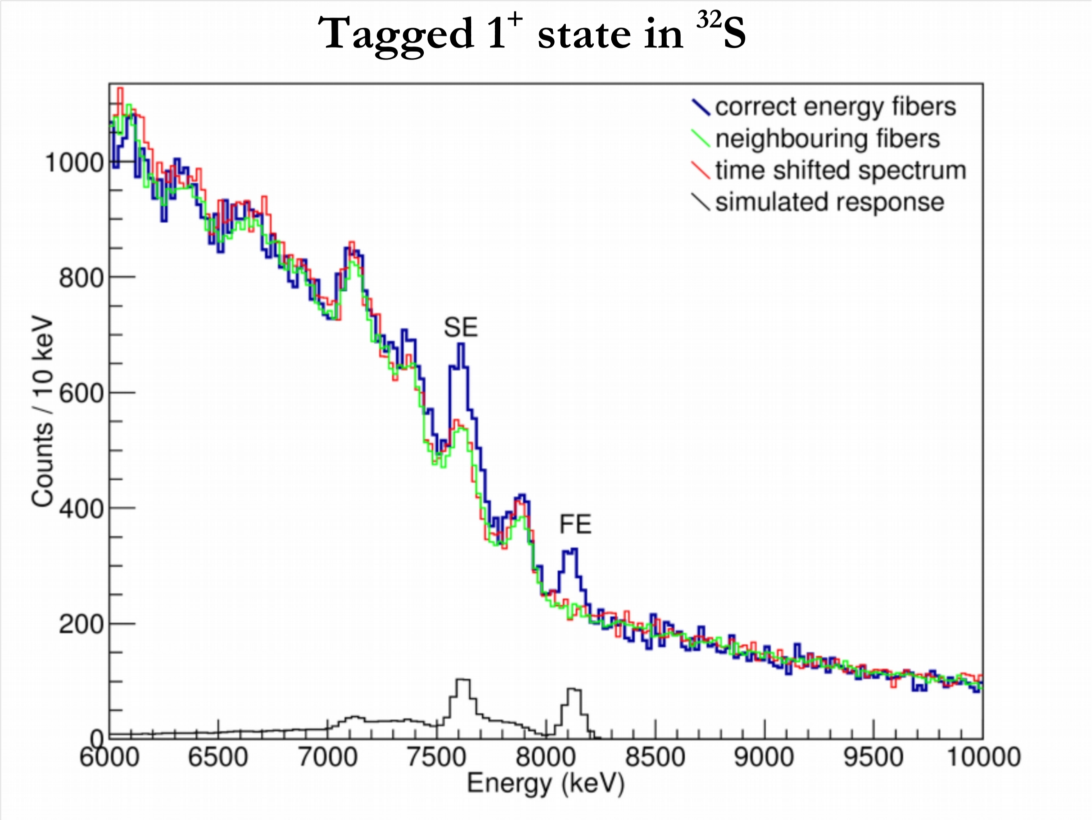
Transition in ^{32}S used for commissioning runs:

- $E\gamma$ = 8125.40 keV
- $J^{\pi} = 1^{+}$
- Γ = 3.2 eV



Obtained integrated cross-section: 760 (118) barn eV

Previously published value*: 573 (84) barn eV

**ENSDF data: weighted average from (pol γ,γ') Berg et al. Phys.Lett. 140B, 191 (1984)*
(γ,γ') Babilon et al. PRC 65, 03703 (2003)

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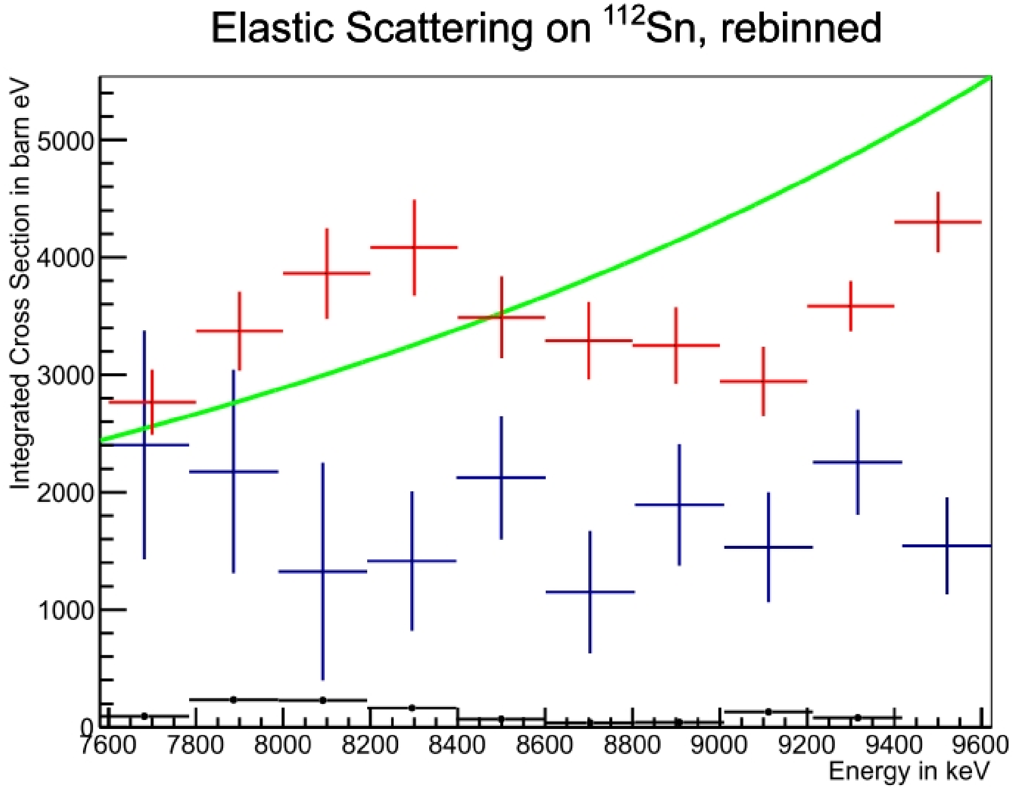
Results from ^{112}Sn target run

~30 hours of beam on the 112Sn (95% enrich.) target



NEPTUN data, Diego Semmler, PhD thesis, in prep.

112Sn NRF B. Özel-Tashenov et al. PRC C 90 024304 (2014)

120Sn(p,p') A.M. Krumbholz et al., Phys. Lett. B 744 (2015) 7

112Sn GDR tail with parameters from Atlas of GDR by Varlamov et al

Upgrade of the bending dipole magnet

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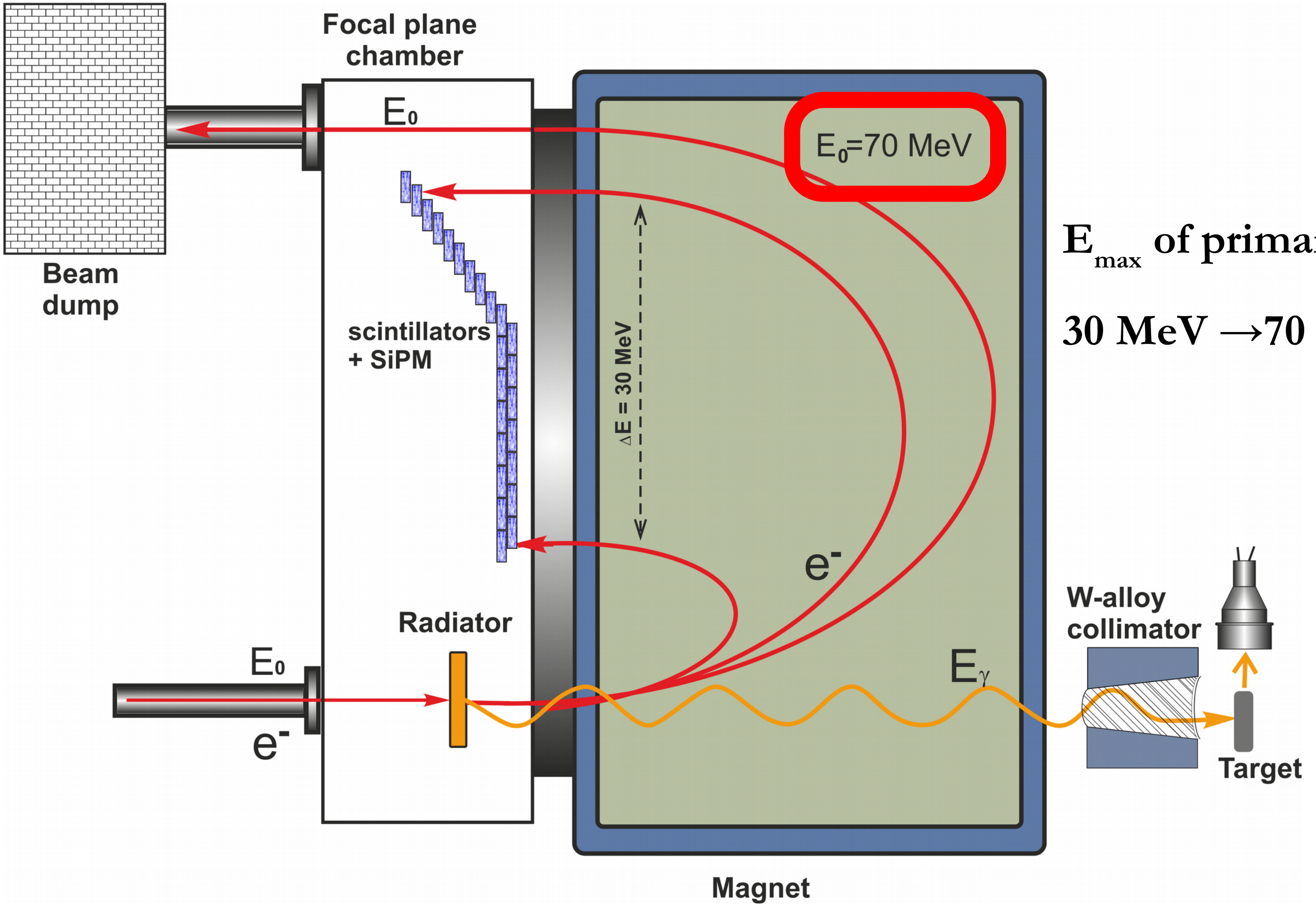
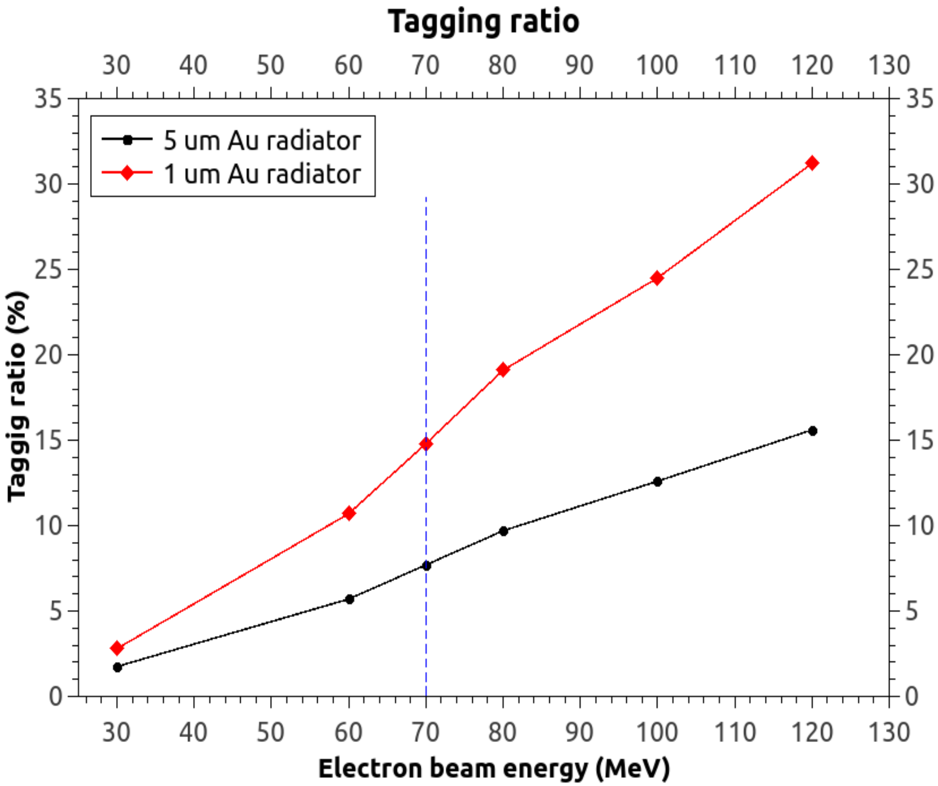


E_{max} of primary e- beam:

30 MeV →70 MeV

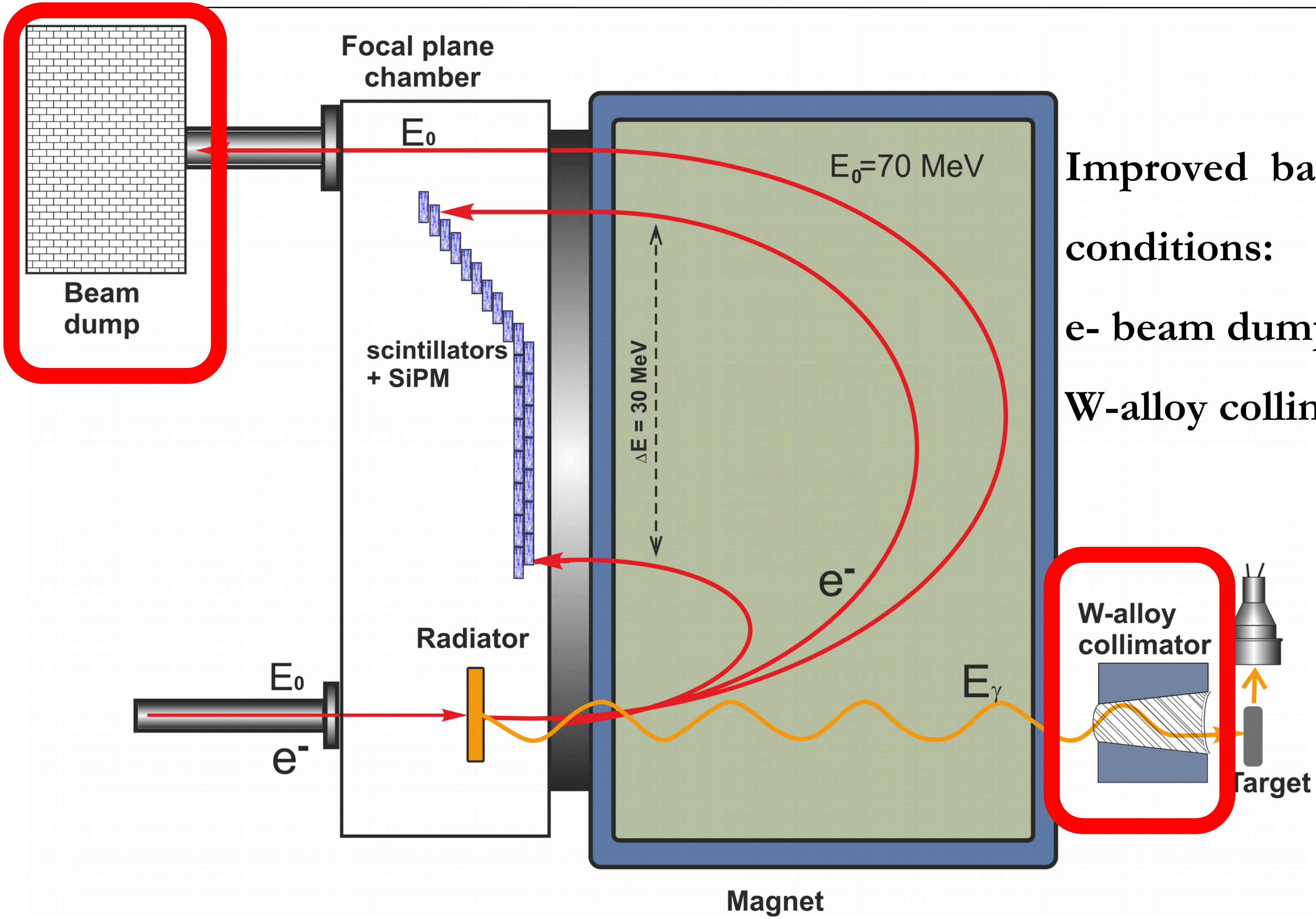
Magnet upgrade: improved "efficiency" (tagging ratio)

Tagging ratio = (Total number of emitted BS photons)/(Number of collimated BS photons)



Tagging ratio could be improved by factor 5

New electron beam dump and γ-collimator



Improved background conditions:

e- beam dump at 180°;

W-alloy collimator

Current background conditions

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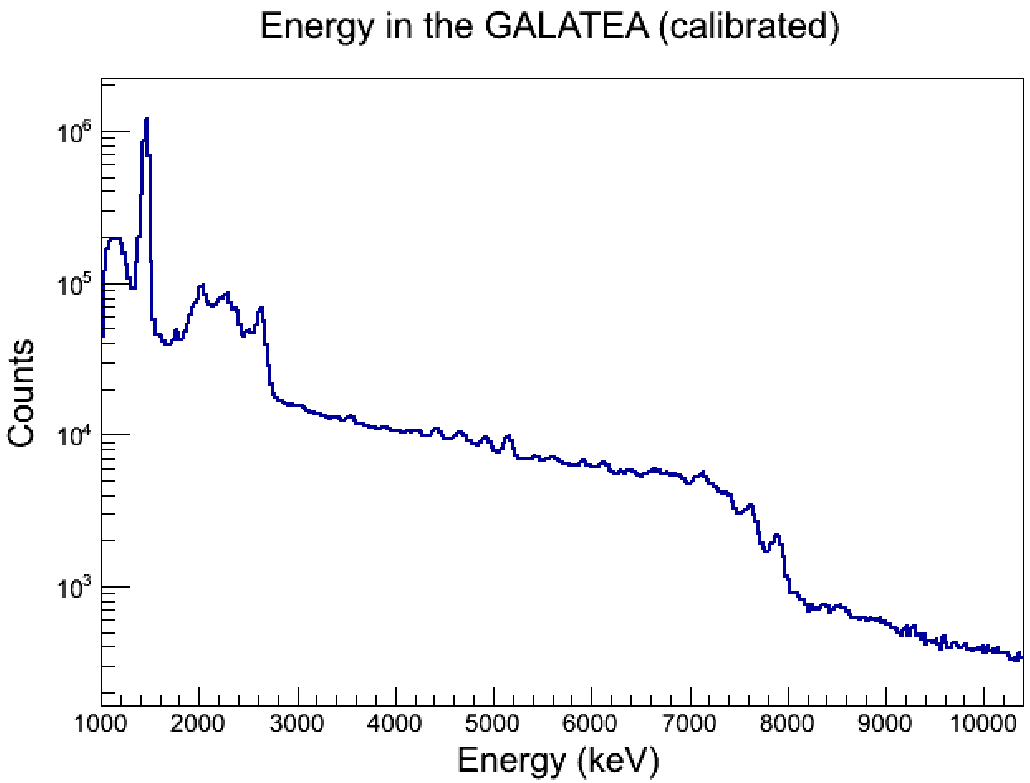
Runs without radiator show that main part of the beam correlated background comes from electron beamdump (mixed neutron/gamma background).

Background count rate at 7 MeV – 0.25 s^{-1} * 25 keV^{-1} (current NEPTUN resolution).



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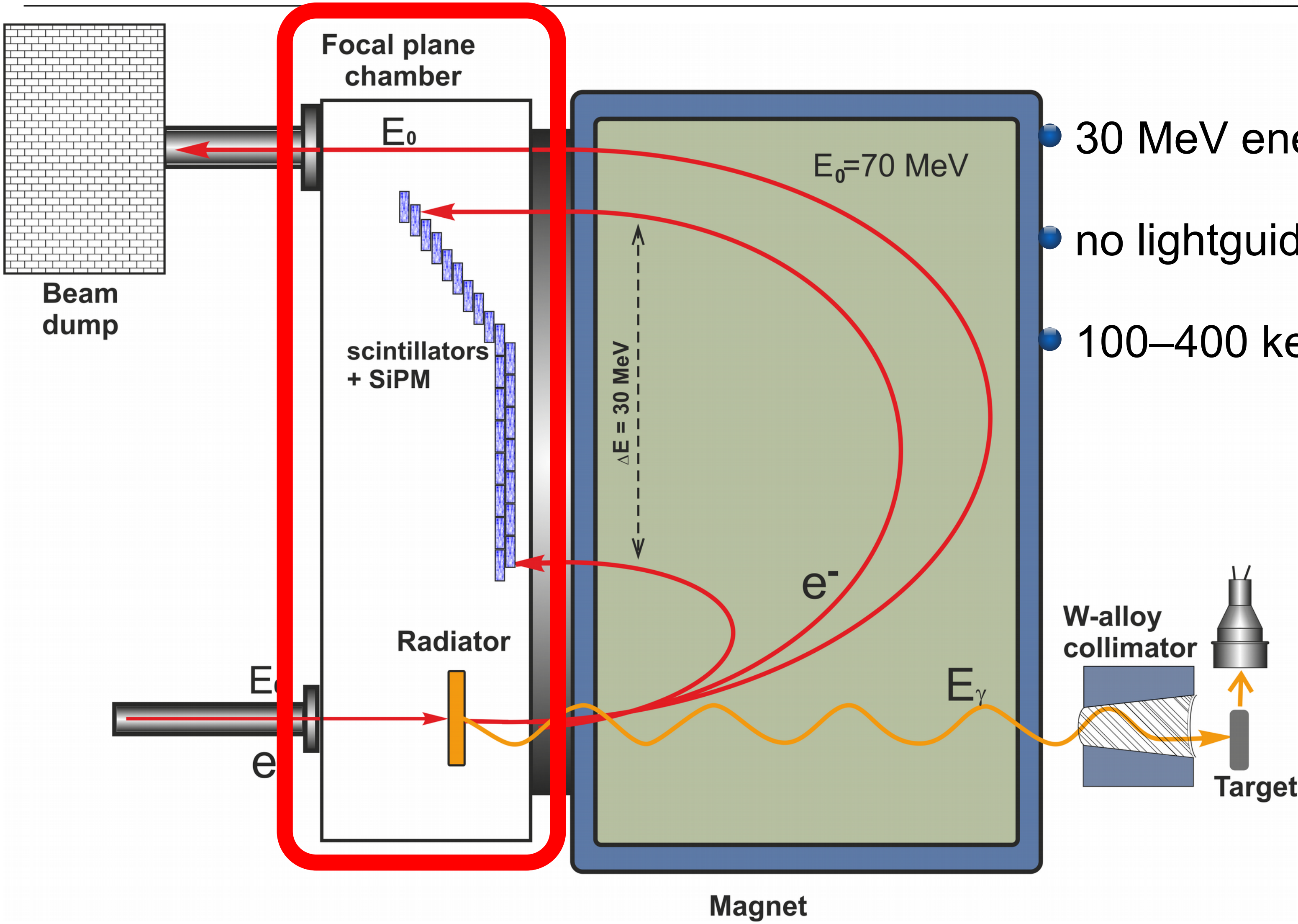
New focal plane detectors



- 30 MeV energy bite;
- no lightguides;
- 100–400 keV resolution

New focal plane detectors: large acceptance

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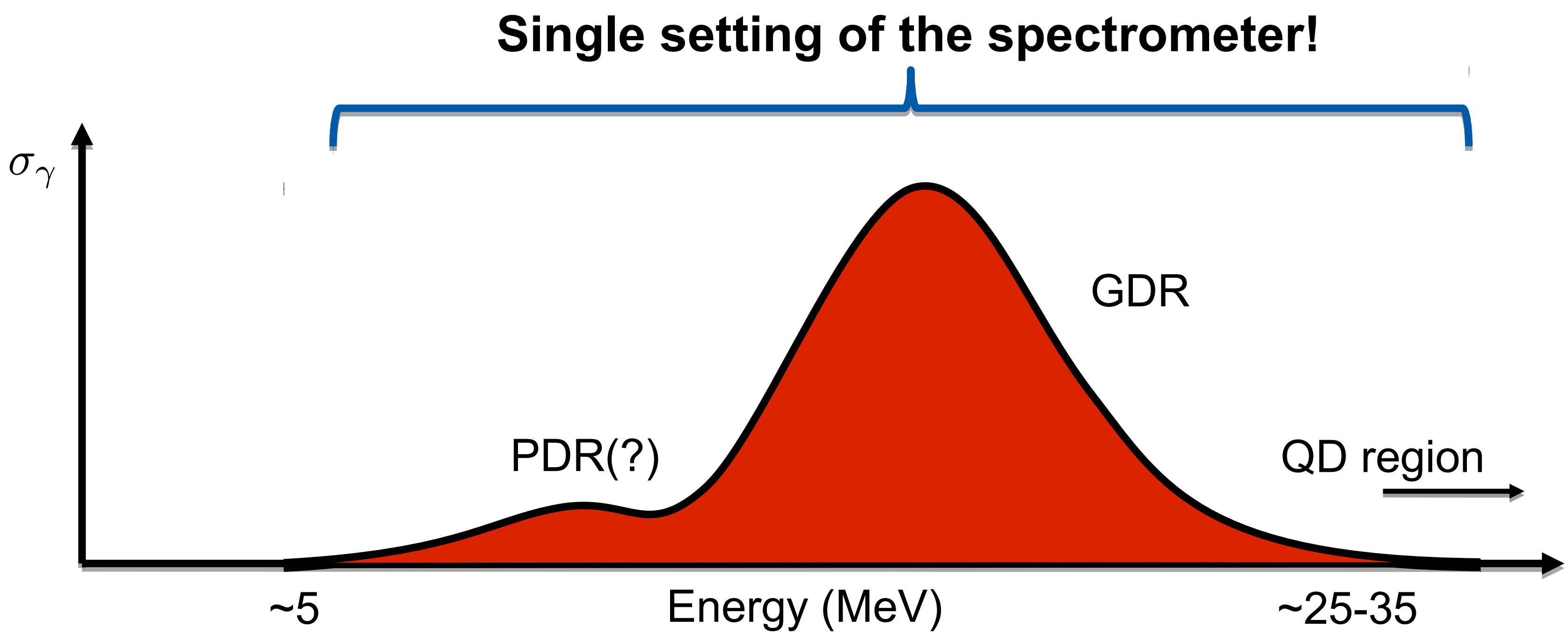
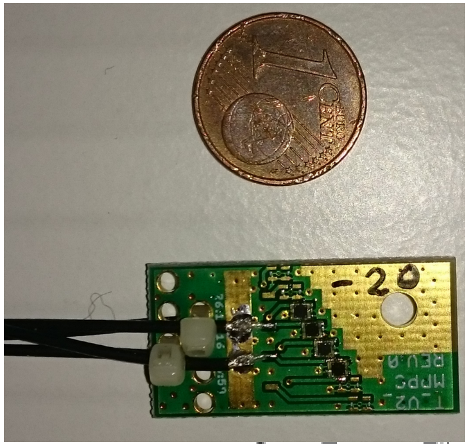
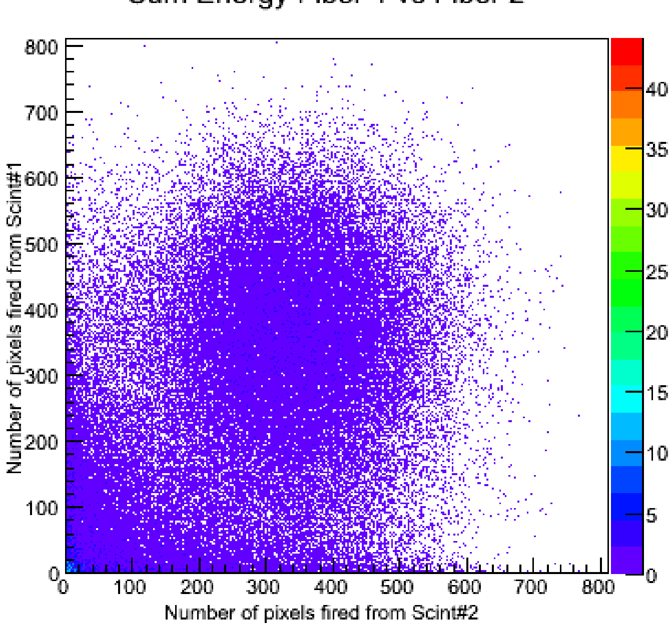
Current design has 1.5 MeV energy bite: at least 20 settings of the spectrometer are needed to cover 5-35 MeV γ energy range with near 5 days of beam on the target for each. Which sums up to ~100 days of beam for every target. Seems unrealistic!

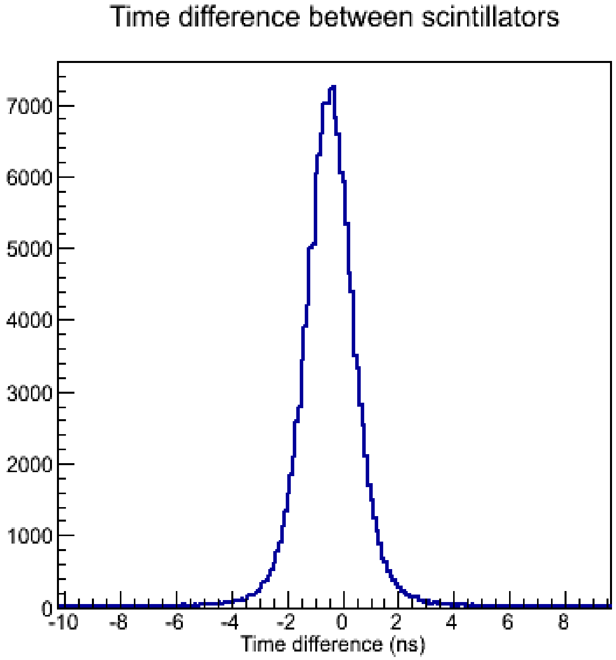


Focal plane upgrade: SiPM tests



Tests:
1x1 mm SiPM (SeNSL FC-10035)
Time resolution with LED pulser: 140 ps
Time resolution with Sr-90: 600 ps
Deposited energy could be separated from dark counts.





NEPTUN tagger - timeline

- Upgraded magnet is expected to return to IKP late summer 2017
- Before that date all possible construction work (Beam dump, shielding, chamber focal plane detectors, DAQ) should be finished
- Commissioning runs – end of 2017
- Test with well studied case (^{208}Pb)
- Production runs with ^{112}Sn-^{124}Sn targets – 2nd half of 2018

Double-gamma nuclear decay

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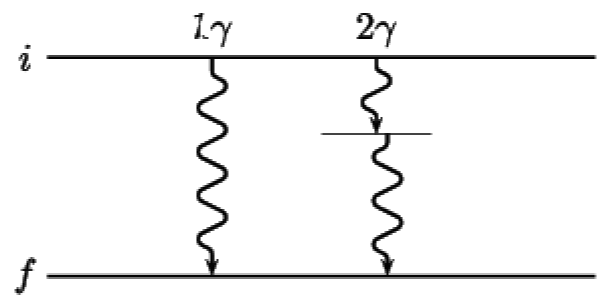
Double-gamma decay features:

- for 0+ → 0+ transitions:
- single photon decay strictly forbidden
- $\Gamma\gamma\gamma/\Gamma\gamma \sim 10^{-4}$
- $\Gamma \approx \Gamma$(internal pair production)



VOLUME 53, NUMBER 20 PHYSICAL REVIEW LETTERS 12 NOVEMBER 1984

Double Gamma Decay in ^{40}Ca and ^{90}Zr

J. Schirmer, D. Habs, R. Kroth, N. Kwong, D. Schwalm, and M. Zirnbauer
Max-Planck-Institut für Kernphysik and Physikalisches Institut der Universität Heidelberg, D-6900 Heidelberg, Federal Republic of Germany

Competitive double-gamma nuclear decay

Competitive double-gamma decay features:

- decay competing with allowed single gamma decay
- $\Gamma\gamma\gamma/\Gamma\gamma \ll 10^{-4}$
- $\Gamma \approx \Gamma\gamma$
- has never been observed,despite a few searches in last 30 years

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LETTER

doi:10.1038/nature15543

Observation of the competitive double-gamma nuclear decay

C. Walz[1], H. Scheit[1], N. Pietralla[1], T. Aumann[1], R. Lefol[1,2] & V. Yu. Ponomarev[1]

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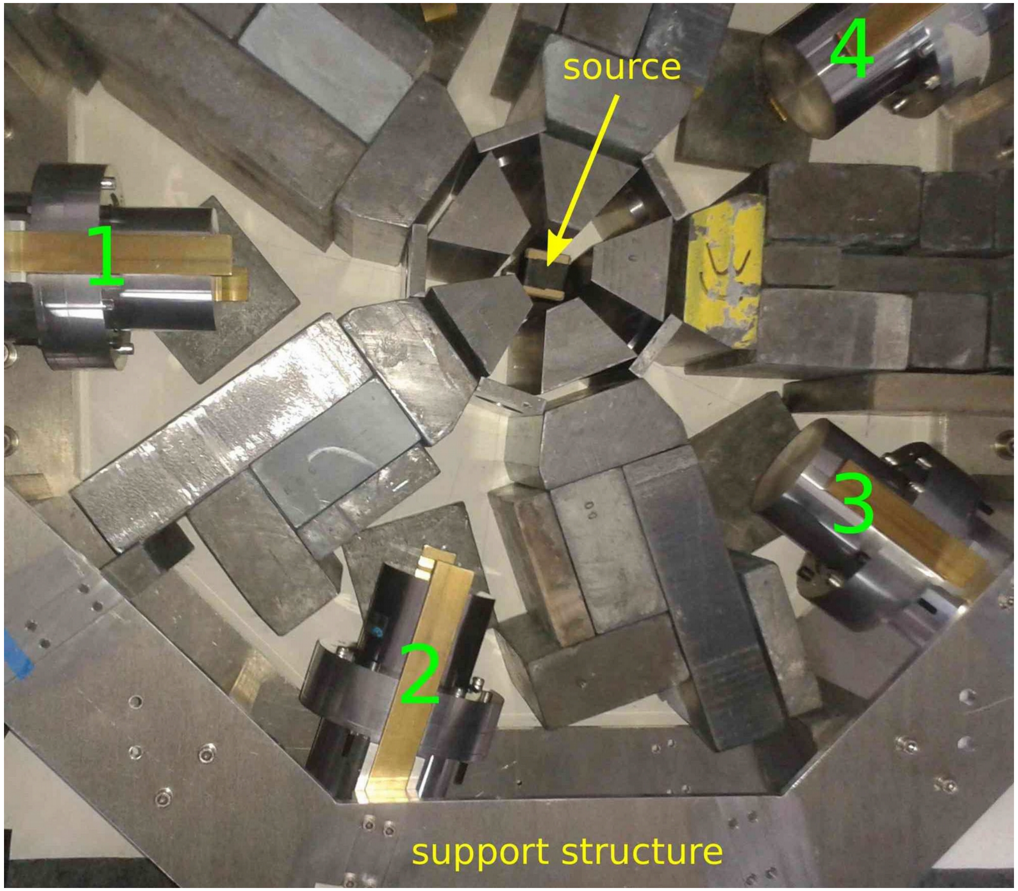
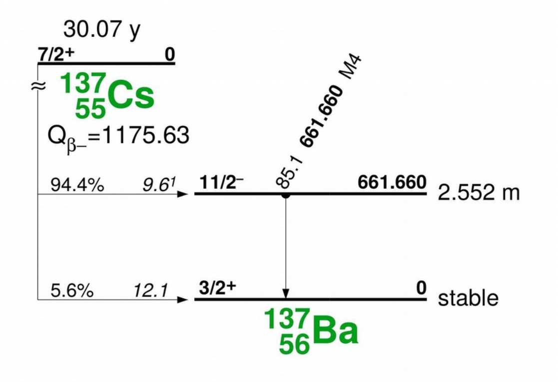
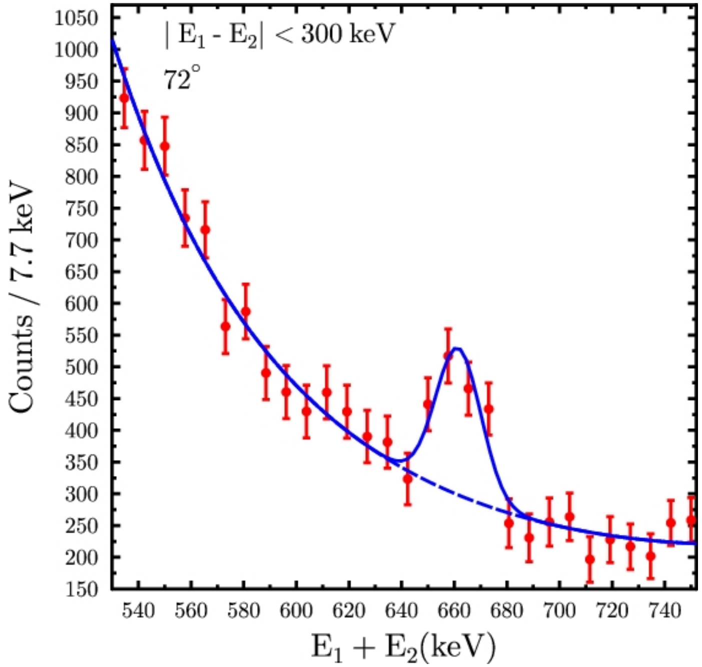
Experimental setup





- 5 $LaBr_3(Ce)$ detectors
- εFE(662 keV) = 1.5%
- $\varepsilon\gamma\gamma \approx 4 \cdot 10^{-4}$
- ΔE = 3% (FWHM)
- Δt = 1 ns (FWHM)
- data taking: 53 days
- source: ^{137}Cs (600 kBq)
- thick Pb blocks between detectors

Results



Connection to polarizability:

$$\alpha_{ii} \propto \frac{\sum_n \langle n|E1|i\rangle^2}{E_n} \propto \frac{\sum_n \langle i|E1|n\rangle\langle n|E1|i\rangle}{E_n}$$

$$\alpha_{ii} = \alpha_D$$

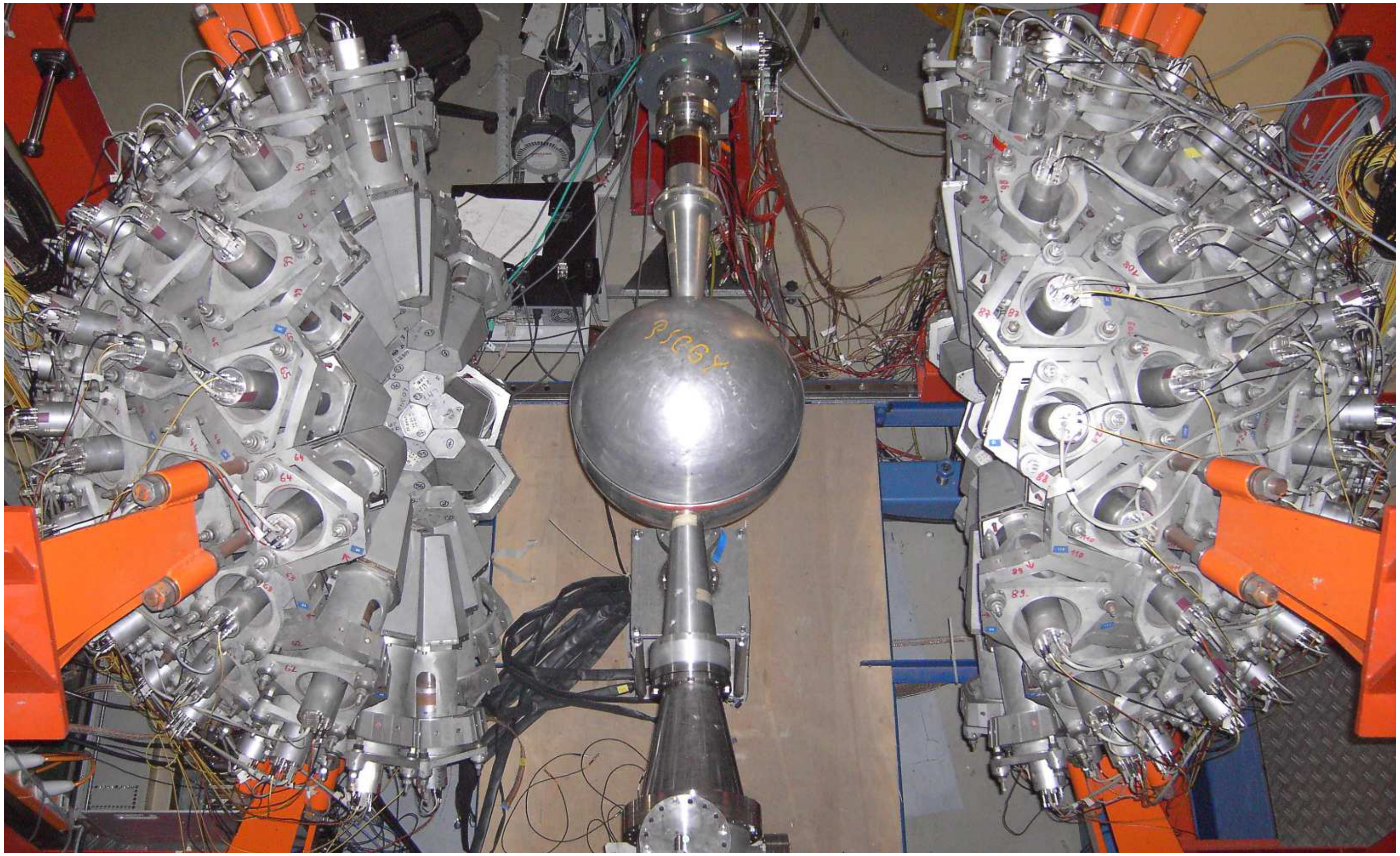
"Off-diagonal" or generalized polarizability

$$\alpha_{if} \propto \frac{\sum_n \langle i|E1|n\rangle\langle n|E1|f\rangle}{E_n - 1/2\,\Delta E_{if}}$$

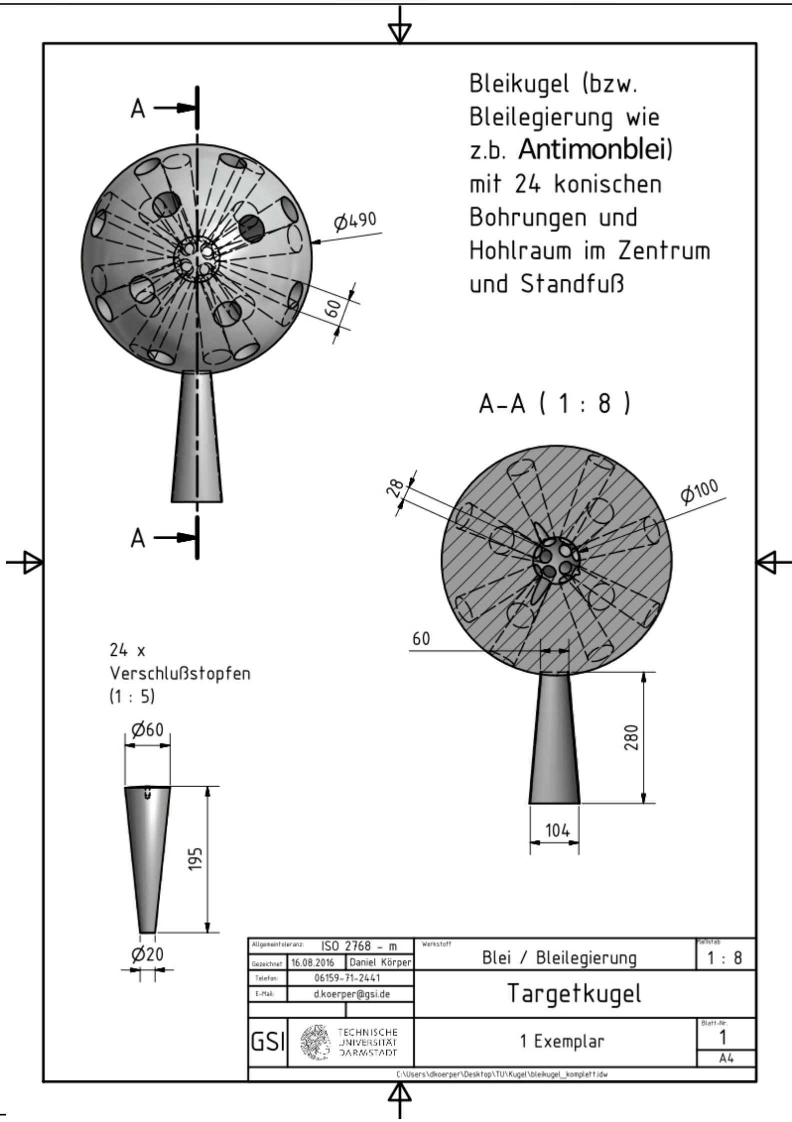
Parameter	Exp	QPM
$\Gamma_{\gamma\gamma}/\Gamma_\gamma$ (10^{-6})	2.05 (37)	2.69
αE2M2 (e^2 fm^4 MeV^{-1})	+33.9 (2.8)	+42.6
αM1E3 (e^2 fm^4 MeV^{-1})	10.1 (4.2)	+9.5

Active shielding

Heidelberg-Darmstadt Crystal- ball
full solid angle 4 π
162 NaI(TI) detectors



Passive shielding ("LeadBall")



Company: MTH Metal-Technik

Price: ~25.000 €

Competitive double-gamma decay – plans for 2017

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- Production and installation of LeadBall

- Construction and testing of DAQ for combined CrystallBall/Galatea system

- Comissioning full setup with 0+→0+ double-gamma decay measurements (e.g. 90Sr) and ^{137}Cs

- Search for cases dominated by E1E1 transitions (possible candidate 2+→0+ in ^{54}Ce, populated in the decay of ^{54}Mn)

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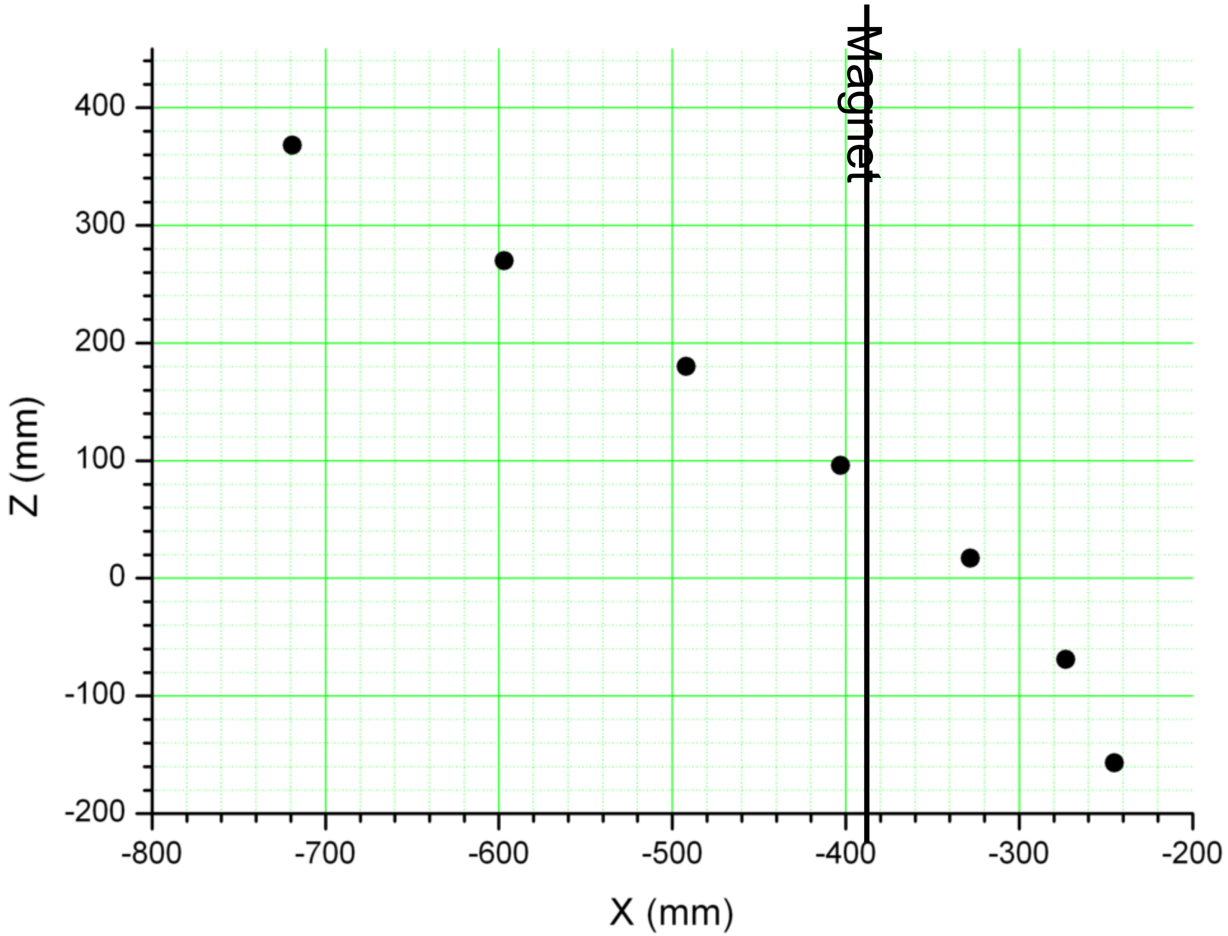
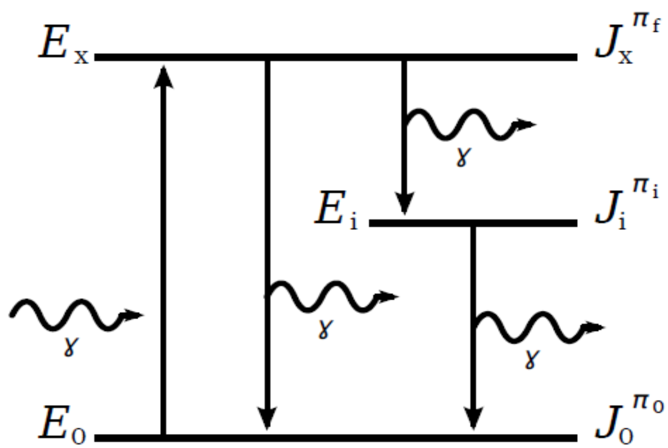
Thank You!


Magnet
400
300
200
100
0
-100
-200
Z (mm)
-800
-700
-600
-500
-400
-300
-200
X (mm)

Nuclear Resonance Fluorescence
Characterisation of transitions



- Transition $J_i^{\pi_i} \rightarrow J_f^{\pi_f}$
- Multipole order L given by $|J_i - J_f| \leq L \leq |J_i + J_f|$
- Character σ is electric for $\pi_i = (-1)^L \cdot \pi_f$ and magnetic for $\pi_i = (-1)^{L+1} \cdot \pi_f$
- Reduced transition probabilities are proportional to the reduced transition matrix element

  $B(\sigma L) \propto |\langle f \,\|\, M(\sigma L) \,\|\, i \rangle|^2$