INVESTIGATIN NUCLEI IN FEL-NUCLEUS COLLIDER

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- The investigation of collective excitations, especially electric and magnetic dipole vibrations of nuclei play an important role in determination of nuclear structure. The data from these excitations have revealed exciting new insights into nuclear structure. The study of these excitations gives valuable information about nuclear structure and nucleon-nucleon forces at low energy.

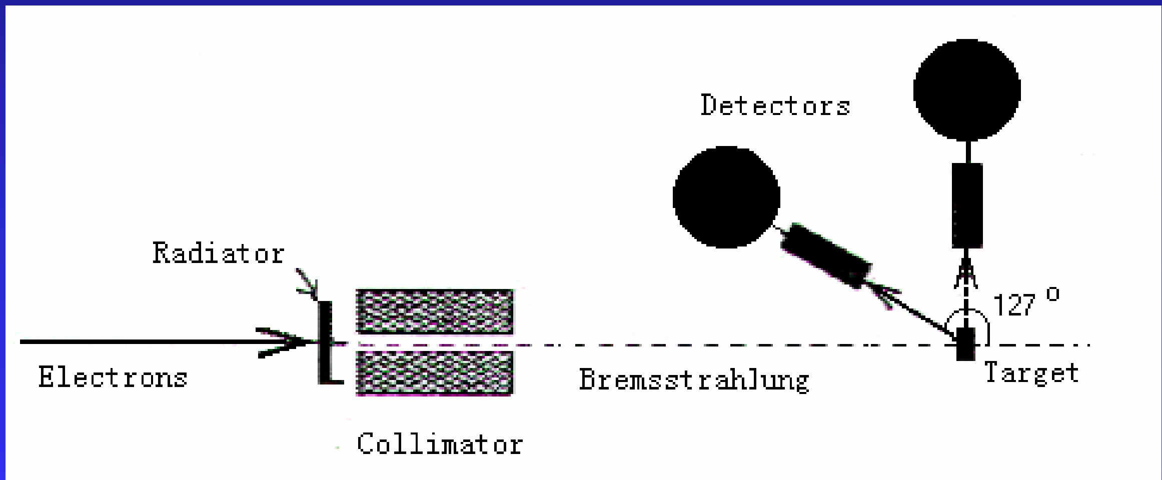
- Therefore, sensitive experimental tools are needed to investigate electromagnetic dipole and other higher order excitations

- Nuclear collective excitations have bin investigated in (e,e`), (p,p`) and (γ,γ`) scattering experiments.

- (γ,γ`) photon scattering experiment named Nuclear Resonance Fluoresances (NRF) is the most efficient method to study collective excitations.

Recently electro- magnetic dipole response E1 and M1 can be studied using real photons as projectiles. The photon scattering method gives complete and model independent information about dipole strength distributions.

Figure 1. *The principle NRF experiments using a bremsstrahlung beam*



The observable which can be obtained from this pure electromagnetic excitation method are*:

1. The energy of the state ;
2. The γ-decay branching ratios to the ground state and excited states;
3. The multipolarity of the transition and from this the spin of the excited state;
4. The absolute transition strength or lifetime of the state if all decay branches are known;
5. The parity of the states

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*All these observable are deduced model independent way

The capacity of NRF experiments limited by many factors:

1. Analyzing power of the Compton scattering process is energy dependent and approaches zero at energies more than *4 MeV*

2. The rather weak interaction between the photons and the target material. Therefore, one needs for typical obtainable photon currents of about 10^6 *c/(s keV)* at the target position large amounts of isotopically enriched target material (i.e. around *500 mg*)

3. The typical count rates in the Ge(HP) detectors is of the order of a few thousand events per second at electron bem currents of about 5 μA leading to typical measuring times of several hours for the spectra 4-8MeV

4. High energy background irradiation from evidence material

Figure 1.*The principle NRF experiments using a bremsstrahlung beam*

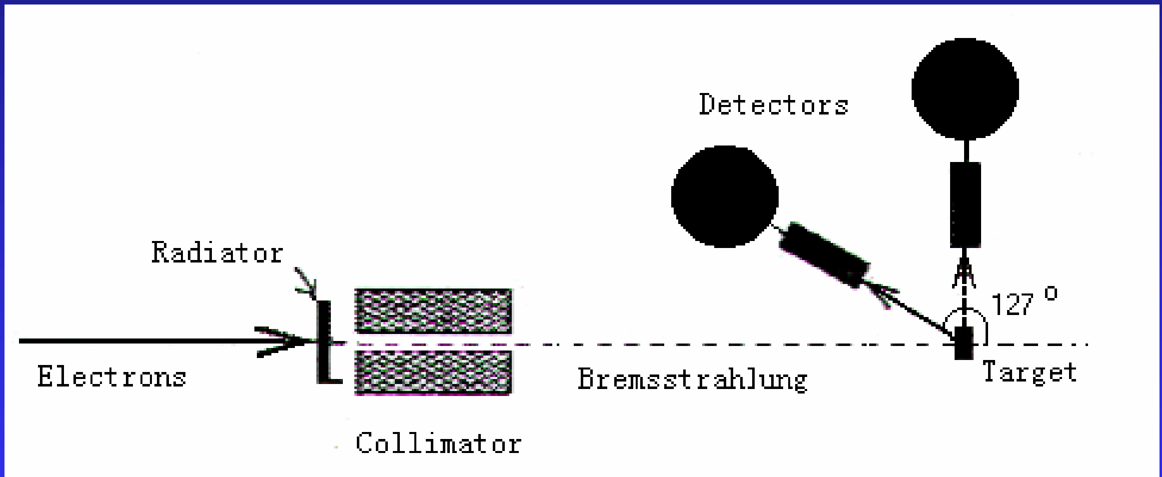


Table 1. *Materials wich have been used as radi-ators or collimators in NRF*

Isotope	Abundance (%)	Neutron separation energy (MeV)
^{54}Fe	5.8	13.4
^{56}Fe	91.7	11.2
^{57}Fe	2.2	7.6
^{58}Fe	0.3	10.0
^{63}Cu	69.2	10.9
^{65}Cu	30.8	9.9
^{180}Ta	0.01	6.6
^{181}Ta	99.99	7.6
^{197}Au	100	8.1
^{204}Pb	1.4	8.4
^{206}Pb	24.1	8.1
^{207}Pb	22.1	6.7
^{208}Pb	52.4	7.4

An ideal photon source used in (γ,γ') scattering experiments should have the following characteristics:

- High spectral intensity (I=N_γ /eV s)
- Good monochromaticity ($\Delta E_\gamma/E_\gamma$)
- Tunable in a broad energy range
- High degree of linear polarization (P_γ=100%)

Unfortunately up to now there are no such ideal sources available fulfilling all these requirements in every respect. Therefore, diverse photon sources have been applied in low energy photon scattering depending on the special experimental requirements and aims intended in the investigations. Therefore, only with the advent of the new generation of experimental facility with improved detection characteristics it is possible to investigate in detail the fine structure of the magnetic and electric response.

Table 2.*Characteristics of the different photon sources*

Photon Source	Spectral Intensit [γ/s·eV]	$\Delta E_\gamma/E_\gamma$ [%]	Pγ [%]	Target Mass M [g]
CF	0.15	2.7	100	70
BS_{pol}	20	Cont.	10-30	5
$BS_{unpol.}$+CF	1000	Cont.	10-20	5
$BS_{unpol.}$	1000	Cont.	0	1-2
FEL	$>10^{16}$	0.0001	100	10^{-10}

An ideal photon source can be free electron laser for nuclear spectroscopy experiments that is cover all of above characteristics.

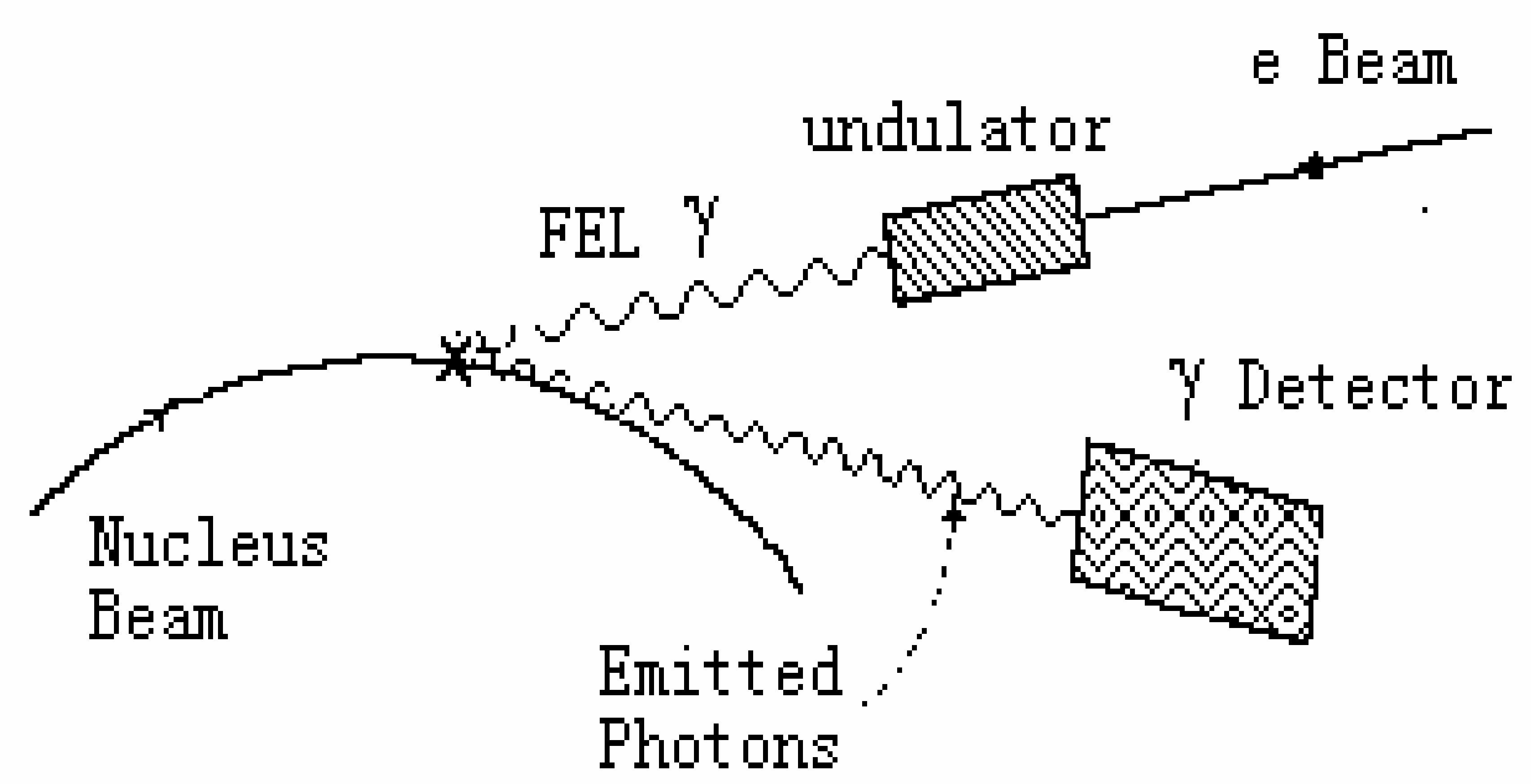
Comparison of traditionally used photon sources and FEL can be shown from Table 1. It is very clear that, FEL photons are best for all four basic requirements for NRF experiments.

FEL-Nucleus Colliders

Recently, a new method has been proposed to investigate the scattering reactions with photons on fully ionised nuclei, namely FEL-Nucleus colliders wich is free from the above-mentioned troubles.

[H.Aktas et al., Nuc. Instr. &Meth A428 (1999)271-275]

Figure 2. General schematic view of the proposed design



- In the nucleus rest frame the energy of FEL photon is multiplied by $2\gamma_N$, where γ_N is the Lorentz factor of the nucleus

- Due to good monochromaticity ($\Delta E/E<10^{-3}\div 10^{-4}$) with the typical obtainable number of photons of the order of 10^{13} γ/bunch and excellent tunability, this method can be successfully used to investigate nuclear excitations with low multipolarity in wide energy region.

The energy of FEL Photons needed for excitation at the corresponding nuclei level can be experessed as

$$\omega_{SEL} = \frac{E_{exc}}{2\gamma_N} = \frac{A}{Z}\frac{E_{exc}}{2\gamma_p}$$

$$\gamma_N = \frac{Z}{A}\gamma_p$$

for LHC : $\gamma_p = 7000$

The luminosity of the FEL γ- Nucleus collisions can be expressed as

$$L = \frac{n_\gamma n_{nuc}}{4\pi\sigma_x\sigma_y} f_c$$

Luminosity is obtained as $L=10^{28}$-10^{30} $cm^{-2}s^{-1}$

The number of the events :

$$R = L\sigma_{ave}$$

σ_{ave} is averaged cross sections .

Table 3.Main parameters of the TTF FEL beam.

Number of elctrons per bunch, n_e (10^{10})	1
Pulse length, μs	1000
Number of bunches per pulse, n_b	7200
Repetition rate, $f_{rep.}$ (Hz)	10
Number of photons per bunch, n_γ (10^{13})	4
Energy of FEL photons, ω (eV)	193
Energy spread of photons $\Delta E_{SEL}/E_{SEL}$ (10^{-3}-10^{-4})	1
Rms beam size, $\sigma_{x,y}$ (μm)	50

Table 4.Main parameters of nuclei beam at LHC

	LHC
Maximum beam energy , E (TeV)	7.0
Particles per bunch, n_{nuc} (10^8)	1.4
Normalized emittance, ε^N (mm mrad)	1.5
Amplitude function at IP , β^* (cm)	20
RMS beam size at IP, $\sigma_{x,y}$ (μm)	10
Number of bunches in FEL pulse, n^b (ns)	100

This facility allows the production of monochromatic photons with high density and the accelerated fully ionized nuclei see the few kev energy FEL photons as a ”laser” beam with MeV energy.

The potential of FEL-Nucleus colliders in search for collective $I^{\pi} = 1^{+}$ excitations of ^{12}C, ^{208}Pb ^{140}Ce, ^{154}Sm, and ^{180}Hf had been made.

Below we present some results for these nuclei:

Table 5. (γ,γ') scattering results for excitations of ^{154}Sm.

E*,MeV	J^{π}	Γ,eV	ω (keV)	σ_{ave}, cm^2	R/s (10^5)
1.973	1+	0.004	0.329	$0.328\ 10^{-25}$	0.765
2.443	1+	0.010	0.407	$0.503\ 10^{-25}$	1.01
2.556	1-	0.030	0.426	$0.132\ 10^{-24}$	2.64
2.617	-	0.036	0.436	$0.147\ 10^{-24}$	2.95
2.744	1-	0.030	0.457	$0.107\ 10^{-24}$	2.13
2.778	1-	0.007	0.463	$0.240\ 10^{-25}$	0.479
2.825	1-	0.015	0.471	$0.488\ 10^{-25}$	0.977
2.842	1-	0.025	0.474	$0.799\ 10^{-25}$	1.60
2.882	1-	0.012	0.480	$0.368\ 10^{-25}$	0.736
2.907	1+	0.017	0.485	$0.508\ 10^{-25}$	1.02
3.092	1+	0.051	0.515	$0.127\ 10^{-24}$	2.53
3.117	1+	0.036	0.520	$0.872\ 10^{-25}$	1.74
3.193	1+	0.101	0.532	$0.228\ 10^{-24}$	4.55
3.339	-	0.014	0.557	$0.276\ 10^{-25}$	0.552
3.366	-	0.015	0.561	$0.289\ 10^{-25}$	0.578
3.371	1+	0.021	0.562	$0.402\ 10^{-25}$	0.805
3.426	1-	0.016	0.571	$0.292\ 10^{-25}$	0.584

Table 6. (γ,γ') scattering results for excitations of ^{180}Hf

E*,MeV	J^{π}	Γ,eV	ω_{SEL}(ke)	$\sigma_{ave,}$ cm^2	R/s (10^5)
2.582	1	0.017	0.433	0.712 10^{-25}	1.420
2.617	1	0.032	0.438	0.013 10^{-25}	2.640
2.715	1	0.013	0.455	0.484 10^{-25}	0.968
2.892	1	0.016	0.484	0.470 10^{-25}	0.941
2.947	1	0.025	0.494	0.720 10^{-25}	1.440
3.068	1	0.018	0.514	0.465 10^{-25}	0.930
3.559	1	0.018	0.596	0.298 10^{-25}	0.596
3.584	1	0.025	0.600	0.394 10^{-25}	0.788
3.614	1	0.030	0.605	0.473 10^{-25}	0.945
3.766	1	0.032	0.631	0.438 10^{-25}	0.877
3.774	1	0.025	0.632	0.341 10^{-25}	0.683
3.786	1	0.027	0.634	0.361 10^{-25}	0.722
3.836	1	0.025	0.643	0.319 10^{-25}	0.637
3.851	1	0.035	0.645	0.451 10^{-25}	0.902
3.889	1	0.036	0.651	0.453 10^{-25}	0.906
3.967	1	0.025	0.665	0.293 10^{-25}	0.585
3.978	1	0.05	0.666	0.641 10^{-25}	1.280