MINIWORKSHOP ON MACHINE AND PHYSICS ASPECTS OF
CLIC BASED FUTURE COLLIDERS August 30, 2004 CERN

CLIC*LHC Based FEL*Nucleus Collider

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Motivation

In principle, a FEL beam can be used for the excitations of any fully ionized relativistic nucleus beam to study Nuclear Spectroscopy...

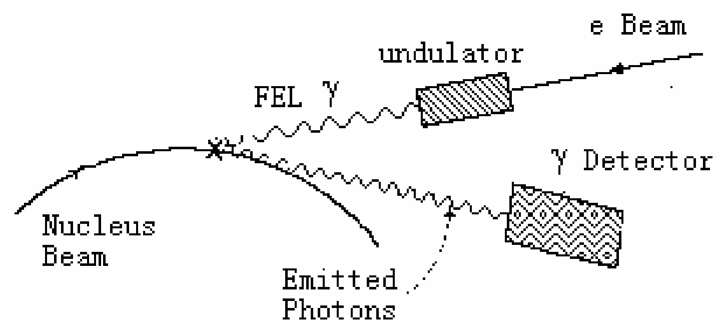
In such a FEL-Nucleus collider;

The accelerated fully ionized nuclei will "see" the keV energy photons as a MeV energy laser beam.

H. Aktas et al.
New tool for 'old' nuclear physics: FEL-Nucleus Colliders
Nuc. Instr. & Meth A428 (1999) 271-275

FEL*Nucleus Collider

- The main advantages compared to the traditional NRF methods are tunability, monochromaticity and high polarization of FEL beam.
- The advantages result in higher statistic and the possibility to investigate individual levels.



General schematic view of the proposed design

FEL*Nucleus Collider

The energy of FEL photons needed for excitation at the corresponding nuclei level can be expressed as

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

γ_p=7462 for LHC

- Due to good monochromaticity ($\Delta E\gamma/E\gamma < 10^{-3} \div 10^{-4}$) with the typical obtainable number of photons (10^{13} γ/bunch) and excellent tunability, this method can be successfully used to investigate nuclear excitations with low multipolarity (E1 and M1) in wide energy region.
- Especially, collective excitations of nuclei can be analyze in detail using the monochromaticity of FEL beam.

CLIC*LHC Based FEL-Nucleus Collider

- FEL beam can be obtained from CLIC drive beam...
- Nucleus beams from LHC ...
- CLIC*LHC Based FEL*Nucleus Collider !
- This collider allows to study Nuclear Spectroscopy precisely using tunable, monochromatic and coherent radiation FEL from CLIC which collide with LHC Nucleus beams (Pb, C, Sm, Au, Ce, Ba etc.)
- Luminosity: $L = \frac{n_\gamma n_{nuc}}{4\pi\sigma_x\sigma_y} f_c$
- Event rate: $R = L\sigma_{ave}$

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

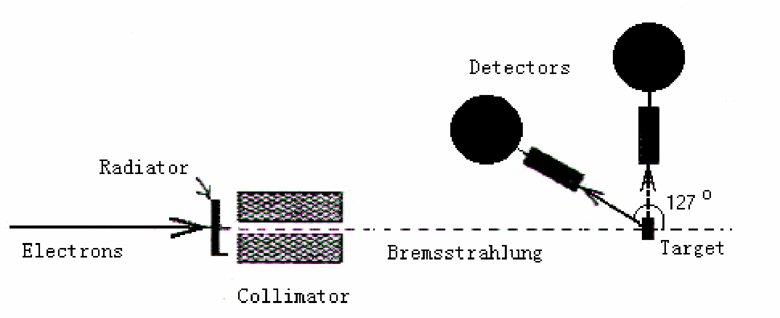
- High spectral intensity (I=N_γ /eV s)
- Good monochromaticity ($\Delta E_\gamma / E_\gamma$)
- Tunable in a broad energy range (IR - Hard X-ray)
- High degree of linear polarization (P_γ=100%)

**U.Kneissl et al. Prog.Part.Nucl. Phys. 37 (1996) 349*

Characteristics of the different photon sources

Photon Source	Spectral Intensity $[\gamma/s\cdot eV]$	$\Delta E_\gamma/E_\gamma$ [%]	$P\gamma$ [%]	Target Mass M [g]
Compton Backscattered	**0.15**	**2.7**	**100**	**70**
Bremsstrahlung (Polarised)	**20**	**Cont.**	**10-30**	**5**
Bremsstrahlung (Unpolarised) + CB	**1000**	**Cont.**	**10-20**	**5**
Bremsstrahlung (Unpolarised)	**1000**	**Cont.**	**0**	**1-2**
Free Electron Laser	**10^{17} MeV/E_{exc}**	**0.01**	**100**	**10^{-10}**

Nuclear Resonant Flouresance (NRF) Methods



The observables which can be obtained from NRF are*:

- The energy of the state
- The γ-decay branching ratios to the ground state and excited states,
- The multipolarity of the transition and the spin of excited states,
- The absolute transition strength or lifetime of the state if all decay branches are known,
- The parity of the state.

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*All these observables are independent from nuclear model

The experimental capacity of NRF methods are limited by many factors

- While the used photons energy increasing (> 4 MeV) the polarization of photons are decreases.

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

- Very long experiment time: For the 4-8 MeV spectra, the typical count rates in the Ge (HP) detectors are in order of a few thousands per second leading to typical measuring times of several hours.

- High energy background irradiation from evidence material

Energy Ranges

- Energy range for E1 and M1 dipole excitations :
  E_{exc} = 2-20 MeV

- Energy of nucleus beam of LHC:
  $E_A=\gamma_A m_A c^2$, $\gamma_A = \gamma_p Z/A$, $\gamma_p \sim 7462$

- Needed FEL energies:
  ω_{FEL} = 0.3 – 3 keV (for LHC nucleus beams)
  (4 – 0.4 nm) $E_{exc} = 2\ \gamma_A \omega_{FEL}$

- Needed electron beam energies from CLIC
  $E_{electron}$ = 1 – 4 GeV

Basic Requirements for SASE FEL Beam

- $\Delta E_e/E_e \sim \rho \sim 10^{-3}$ (ρ FEL Parameter)
- Normalized emittance $\varepsilon_x, \varepsilon_y \leq \lambda / 4\pi$
- Gain Length $l_g = \frac{\lambda_u}{4\pi\rho}$
- FEL Gain Parameter: $G = 4\pi\rho N_u$
- Power saturation: $P_{sat} = \rho P_{beam}$

CLIC*LHC based FEL-nucleus collider

Advantages of CLIC FEL:

- Compact linac
- Existing equipment (if CLIC is built)

Disadvantages of CLIC FEL:

- High-frequency RF ⇒ large energy spread (short range wakes)
- Normal conducting ⇒ difficult to match time structure of nucleus beam

CLIC*LHC based FEL-nucleus collider

- Possible solution:
- ⇒ Don’t use CLIC main beam (energy too high after damping ring, emittance too large before, large energy spread …)
- ⇒ Use additional drive beam pulses to power a dedicated linac -
- 15 GHz could be used, in order to obtain a smaller energy spread

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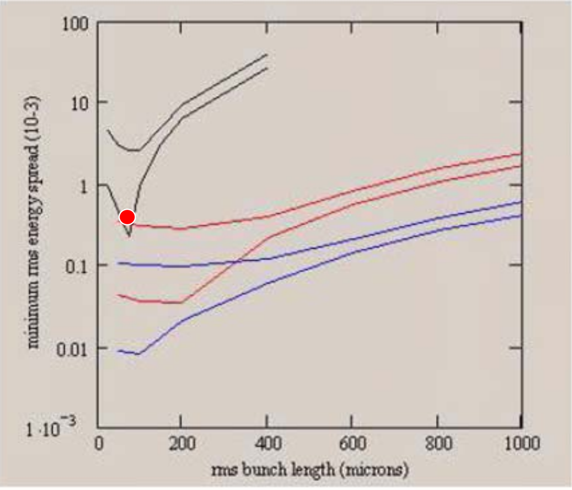


Minimum rms energy spread for 1.5 GHz (blue), 3 GHz (red), and 30 GHz (black) acceleration. The two lines for each colour correspond to a Gaussian (upper) and a uniform (lower) time profile of the bunch.

Red point corresponds to drive beam with 15 GHz acceleration

FEL & e- beam parameters

- Photon (FEL) energies: 0.3-3.4 keV
  $\Rightarrow \lambda =$ 4 - 0.4 nm
- Electron beam energies: E_b = 1 - 4 GeV
- Wiggler
  λ_W= 2.3 cm, B_W = 0.38 T, a_W = 0.8
- Q_b = 1 nC, $\Delta p/p \sim 10^{-3}$, $\varepsilon_{norm,rms} \sim 2\ 10^{-6}$,
  l_{bunch} = 50 μm
- Photon beam size (transverse) < 50 μm

FEL & e- beam parameters

- Need dedicated source (photoinjector), staged bunch compressor
- Assuming 15 GHz, 60 MV/m gradient & fill factor 0.75:
-
- linac length < 70 m
- wiggler length < 20 m

- **Time structure:**

- “minimum” scenario: single bunch, 100 Hz rep rate:

Luminosity (Single Bunch Scenario)

$$L := \frac{(n_\gamma \cdot n_{nuc})}{4 \cdot \pi \cdot \sigma_x \cdot \sigma_y} \cdot n_b \cdot f_{rep}$$

$\sigma_x := 40 \cdot 10^{-6}$ $\quad n_\gamma := 4 \cdot 10^{13}$ $\quad f_{rep} := 100$

$\sigma_y := 40 \cdot 10^{-6}$ $\quad n_{nuc} := 0.94 \cdot 10^{8}$ $\quad n_b := 1$

$L = 1.87 \cdot 10^{27}$

Time structure matching

Drive Beam "Double pulse" scheme

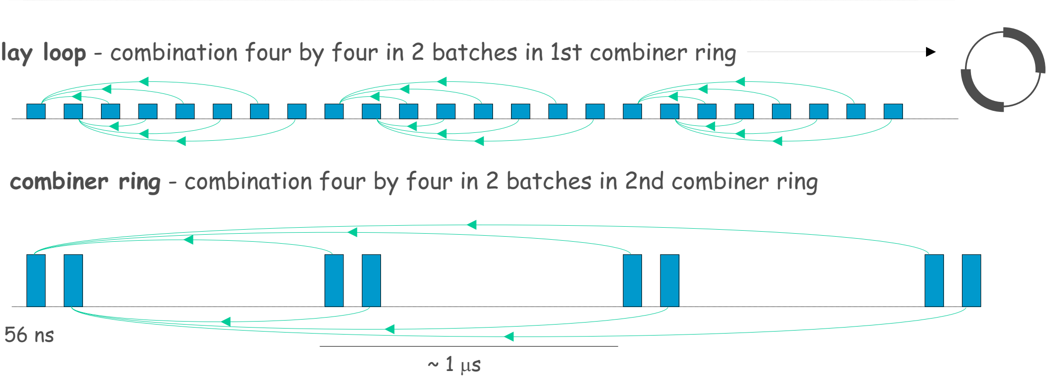
(new parameter set*)

* http://clic-meeting.web.cern.ch/clic-meeting/par-table.html

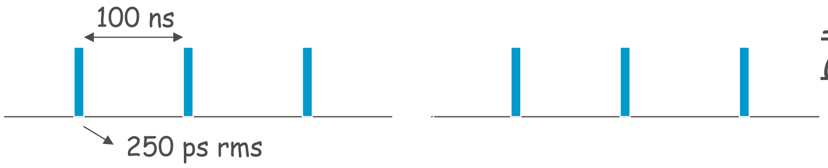
From DBA – **56 ns** long "sub-pulses"

After delay loop - combination four by four in 2 batches in 1st combiner ring

After 1st combiner ring - combination four by four in 2 batches in 2nd combiner ring



- Use drive beam pulses after delay loop
- Use **50 ns** long sub-pulses, **100 ns** between pulses (special delay loop ?)
- Can cover 10 ion bunches every 1μs additional DB pulse length



Ion beam (Pb)

592 bunches

Multi-pulse scenario, 100 Hz rep rate:

Matched
transverse beam
size

$\sigma_x := 16\cdot 10^{-6}$ $\quad n_\gamma := 4\cdot 10^{13}$ $\quad f_{rep} := 100$

$\sigma_y := 16\cdot 10^{-6}$ $\quad n_{nuc} := 7\cdot 10^{7}$ $\quad n_b := 50$

For 5 μs drive beam pulse
(about 5 % of CLIC total power consumption)

$$L := \frac{(n_\gamma \cdot n_{nuc})}{4\cdot\pi\cdot\sigma_x\cdot\sigma_y}\cdot n_b \cdot f_{rep} \Rightarrow \boxed{L = 4.4\ 10^{29}}$$

Power balance, accelerating structures parameters:

Take 1.8 GeV drive beam
9 A drive beam current
Total power in DB: 16 GW
Assume total transfer DB to RF ~ 75 %
Get ~ 12 GW

Assume 60 MV/m ⇒ active length 50 m - Available 240 MW/m

Example structures:

NLC	11.4 GHz	50-65 MV/m for 75 MW input, 0.9 m long fill time 120 ns
SICA (CTF3)	3 GHz	~ 14 MV/m for 30 MW input, 1 m long fill time 100 ns

Scaling SICA at 15 GHz, one would get about 0.6 m length for 50 ns fill time, and 60 MW input power for a gradient of 60 MV/m

Would need only about 110 MW/m – large margin (but low power extraction efficiency from the drive beam) – the available power would be enough to drive the structures at about 90 MV/m

Main Parameters of LHC Pb Beam

Energy per nucleon (TeV/u)	2.76
# of ions per bunch (10^7)	7
# of bunches	592
Bunch seperation (ns)	99.8
Transverse beam size (μm)	15.9
Luminosity for Pb-Pb coll. ($cm^{-2}s^{-1}$)	10^{27} (ALICE Exp.)

- Energy ranges for FEL*Pb Collisions

$$E_e = 1.2\ GeV \quad ; \quad \omega_{FEL} = 0.34\ keV \quad ; \quad E_{exc.} = 2\ MeV$$

$$E_e = 4\ GeV \quad ; \quad \omega_{FEL} = 3.4\ keV \quad ; \quad E_{exc.} = 20\ MeV$$

$$E_{exc} = 2\gamma_{Pb}\,\omega_{FEL} \quad , \quad \gamma_{Pb} = 2941$$

Process Example for ^{208}Pb

The cross section for the resonant photon scattering is given by the well-known Breit –Wigner formula

$$\sigma(\gamma,\gamma`) = \frac{\pi}{E^2}\frac{2J_{exc}+1}{2(2J_0+1)}\frac{\Gamma^2}{(E-E_R)^2+\Gamma^2/4}$$

Where E is the c.m. energy of the incoming photon, J_{exc} and J_0 are spins of the excited and gorund states of the nucleus, E_R is the energy at the resonance and Γ is the total width of the excited nucleus. The number of the scattering events from the nuclei of ^{208}Pb has roughly been calculated below taking their excited state of 4842.2 keV respectively. One can easily obtain corresponding values for other excitations and other nuclei.

In this case ω_0= 808 eV and E_e=2.05 GeV. Substituting J_{exc}=1, J_0=0, $\Gamma \approx$ 5 eV. Using these value resonant cross section has been estimated as

$$\sigma_{res} \approx 3.1 \cdot 10^{-22}\, cm^2$$

and, consequently, with the same energy spreads given above, the average cross section as

$$\sigma_{av} \approx 0.3 \cdot 10^{-24}\, cm^2 \qquad \sigma_{av} \approx \sigma_{res}\frac{\Gamma}{\Delta E_\gamma}$$

Which corresponds to $2.1\text{x}10^8$ events per day for L= 4.4 10^{29} cm^{-2} s^{-1}

(γ,γ') scattering results for excitations of ^{208}Pb

E MeV	Γ (eV)	J^π	$\omega_{FEL,}$ keV	σ_{res} cm^2	σ_{ave} cm^2	R/s
4.0852	$7.83\cdot10^{-1}$	2^+	0.694	$7.3\cdot10^{-22}$	$1.39\cdot10^{-24}$	$6.1\cdot10^{5}$
4.8422	$99.72\cdot10^{-1}$	1^-	0.823	$5.23\cdot10^{-22}$	$1.07\cdot10^{-23}$	$4.7\cdot10^{6}$
5.2926	$13.16\cdot10^{0}$	1^-	0.899	$2.62\cdot10^{-22}$	$2.62\cdot10^{-24}$	$2.8\cdot10^{6}$
5.5122	$32.91\cdot10^{0}$	1^-	0.937	$2.41\cdot10^{-22}$	$0.14\cdot10^{-22}$	$6.1\cdot10^{7}$
5.8461	$11.54\cdot10^{-1}$	1^+	0.993	$21.5\cdot10^{-22}$	$4.25\cdot10^{-24}$	$1.8\cdot10^{5}$
5.9480	$10.12\cdot10^{-1}$	1^-	1.011	$2.07\cdot10^{-22}$	$3.52\cdot10^{-25}$	$1.5\cdot10^{4}$
6.2640	$10.12\cdot10^{-1}$	1^-	1.064	$1.87\cdot10^{-22}$	$3.02\cdot10^{-25}$	$1.3\cdot10^{4}$
6.3117	$36.56\cdot10^{-1}$	1^-	1.072	$1.06\cdot10^{-22}$	$1.06\cdot10^{-24}$	$4.6\cdot10^{5}$
6.3628	$10.44\cdot10^{-1}$	1^-	1.081	$1.81\cdot10^{-22}$	$2.96\cdot10^{-25}$	$1.3\cdot10^{4}$
6.7205	$10.97\cdot10^{0}$	1^-	1.142	$1.62\cdot10^{-22}$	$2.64\cdot10^{-24}$	$1.1\cdot10^{5}$
6.9800	$50.64\cdot10^{-1}$	-	1.186	-	-	-
7.0635	$28.61\cdot10^{0}$	1^-	1.200	$1.47\cdot10^{-22}$	$5.95\cdot10^{-24}$	$2.6\cdot10^{5}$
7.0834	$14.62\cdot10^{0}$	1^-	1.200	$1.46\cdot10^{-22}$	$3.62\cdot10^{-24}$	$1.5\cdot10^{5}$
7.2430	$15.67\cdot10^{-1}$	-	1.231	-	-	-
7.2780	$15.67\cdot10^{-1}$	-	1.237	-	-	-
7.2789	$14.00\cdot10^{-1}$	1^+	1.237	$1.38\cdot10^{-22}$	$2.65\cdot10^{-25}$	$1.1\cdot10^{4}$
7.3325	$38.71\cdot10^{-0}$	1^-	1.246	$1.36\cdot10^{-22}$	$7.18\cdot10^{-24}$	$3.1\cdot10^{5}$
7.6853	-	-	1.306	-	-	-
10.050	-	-	1.708	-	-	-
10.600	-	-	1.801	-	-	-
11.450	-	-	1.975	-	-	-

FEL-LHC (^{154}Sm example)

Existing $(\gamma,\gamma`)$ facilities are not suitable for investigation of excitations with $E_{exc} > 5$ MeV. On the other hand, theoretical models predicts a lot of levels in this region. Therefore here we present results obtained from experiment and from microscopic model used RPA approximation.

We studied the main parameters of FEL-LHC (Sm) collider considering TTF FEL like photon beam and obtained 10^{30} cm^{-2}s^{-1} luminosity (E. Guliyev et al. 2002). Following tables show the needed FEL energies, spin and parities of states and event rates.

Following first table show the results for experimentaly observed states ($E_{exc}< 3.844$). It is clear that spin and parity values of some levels had not determined with NRF experiments. Results for the only theoretically predicted levels can be seen in second table for the $E_{exc} > 5.155$ MeV.

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

E^*, MeV	Γ, eV	J^π	ω_{FEL}, keV	σ_{rez}, cm^2	σ_{ave}, cm^2	R/s
1.973	0.004	1^+	0.329	$0.189 \cdot 10^{-20}$	$0.328 \cdot 10^{-25}$	$0.765 \cdot 10^5$
2.443	0.010	1^+	0.407	$0.123 \cdot 10^{-20}$	$0.503 \cdot 10^{-25}$	$0.101 \cdot 10^6$
2.556	0.030	1^-	0.426	$0.112 \cdot 10^{-20}$	$0.132 \cdot 10^{-24}$	$0.264 \cdot 10^6$
2.617	0.036	-	0.436	$0.107 \cdot 10^{-20}$	$0.147 \cdot 10^{-24}$	$0.295 \cdot 10^6$
2.744	0.030	1^-	0.457	$0.975 \cdot 10^{-21}$	$0.107 \cdot 10^{-24}$	$0.213 \cdot 10^6$
2.778	0.007	1^-	0.463	$0.951 \cdot 10^{-21}$	$0.240 \cdot 10^{-25}$	$0.479 \cdot 10^5$
2.825	0.015	1^-	0.471	$0.920 \cdot 10^{-21}$	$0.488 \cdot 10^{-25}$	$0.977 \cdot 10^5$
2.842	0.025	1^-	0.474	$0.910 \cdot 10^{-21}$	$0.799 \cdot 10^{-25}$	$0.160 \cdot 10^6$
2.882	0.012	1^-	0.480	$0.884 \cdot 10^{-21}$	$0.368 \cdot 10^{-25}$	$0.736 \cdot 10^5$
2.907	0.017	1^+	0.485	$0.869 \cdot 10^{-21}$	$0.508 \cdot 10^{-25}$	$0.102 \cdot 10^6$
3.092	0.051	1^+	0.515	$0.768 \cdot 10^{-21}$	$0.127 \cdot 10^{-24}$	$0.253 \cdot 10^6$
3.117	0.036	1^+	0.520	$0.755 \cdot 10^{-21}$	$0.872 \cdot 10^{-25}$	$0.174 \cdot 10^6$
3.193	0.101	1^+	0.532	$0.720 \cdot 10^{-21}$	$0.228 \cdot 10^{-24}$	$0.455 \cdot 10^6$
3.339	0.014	-	0.557	$0.658 \cdot 10^{-21}$	$0.276 \cdot 10^{-25}$	$0.552 \cdot 10^5$
3.366	0.015	-	0.561	$0.648 \cdot 10^{-21}$	$0.289 \cdot 10^{-25}$	$0{,}578 \cdot 10^5$
3.371	0.021	1^+	0.562	$0.646 \cdot 10^{-21}$	$0.402 \cdot 10^{-25}$	$0{,}805 \cdot 10^5$
3.426	0.016	-	0.571	$0.625 \cdot 10^{-21}$	$0.292 \cdot 10^{-25}$	$0.584 \cdot 10^5$
3.492	0.016	1^+	0.582	$0.602 \cdot 10^{-21}$	$0.276 \cdot 10^{-25}$	$0.552 \cdot 10^5$
3.622	0.035	1^+	0.604	$0.559 \cdot 10^{-21}$	$0.541 \cdot 10^{-25}$	$0.108 \cdot 10^6$
3.746	0.032	-	0.624	$0.523 \cdot 10^{-21}$	$0.447 \cdot 10^{-25}$	$0.894 \cdot 10^5$
3.760	0.020	-	0.627	$0.519\ 10^{-21}$	$0.263\ \cdot 10^{-25}$	0.52510^5
3.801	0.040	-	0.634	$0.508\ 10^{-21}$	$0.535\ \cdot 10^{-25}$	0.10710^6
3.827	0.048	1^-	0.638	$0.501\ 10^{-21}$	$0.629\ \cdot 10^{-25}$	0.12610^6
3.837	0.014	-	0.639	$0.499\ 10^{-21}$	$0.182\ \cdot 10^{-25}$	0.36410^5
3.844	0.015	-	0.641	$0.497\ 10^{-21}$	$0.194\ \cdot 10^{-25}$	0.38810^5

Integral characteristics and theoretical results for 1^+ excitations of ^{154}Sm

E^*, MeV	Γ, eV	ω_{FEL}, keV	σ_{rez}, cm^2	σ_{ave}, cm^2	R/s
5.155	0.001	0.859	$0.276 \cdot 10^{-21}$	$0.658 \cdot 10^{-27}$	$0.131 \cdot 10^4$
5.385	0.068	0.898	$0.253 \cdot 10^{-21}$	$0.321 \cdot 10^{-25}$	$0.641 \cdot 10^5$
6.118	0.001	1.020	$0.196 \cdot 10^{-21}$	$0.431 \cdot 10^{-27}$	$0.233 \cdot 10^4$
6.807	0.575	1.134	$0.158 \cdot 10^{-21}$	$0.134 \cdot 10^{-24}$	$0.268 \cdot 10^6$
7.464	0.318	1.244	$0.132 \cdot 10^{-21}$	$0.562 \cdot 10^{-25}$	$0.303 \cdot 10^6$
7.588	0.002	1.265	$0.127 \cdot 10^{-21}$	$0.355 \cdot 10^{-27}$	$0.192 \cdot 10^4$
8.705	0.256	1.451	$0.969 \cdot 10^{-21}$	$0.285 \cdot 10^{-25}$	$0.154 \cdot 10^6$
8.798	0.004	1.466	$0.948 \cdot 10^{-22}$	$0.473 \cdot 10^{-27}$	$0.256 \cdot 10^4$
9.032	0.004	1.505	$0.900 \cdot 10^{-22}$	$0.409 \cdot 10^{-27}$	$0.221 \cdot 10^4$
9.226	0.897	1.538	$0.862 \cdot 10^{-22}$	$0.838 \cdot 10^{-25}$	$0.453 \cdot 10^6$
10.289	12.707	1.715	$0.693 \cdot 10^{-22}$	$0.856 \cdot 10^{-24}$	$0.171 \cdot 10^7$
10.499	0.006	1.750	$0.666 \cdot 10^{-22}$	$0.369 \cdot 10^{-27}$	$0.199 \cdot 10^4$
11.103	13.716	1.850	$0.595 \cdot 10^{-22}$	$0.736 \cdot 10^{-24}$	$0.147 \cdot 10^7$
11.413	0.018	1.902	$0.563 \cdot 10^{-22}$	$0.900 \cdot 10^{-27}$	$0.486 \cdot 10^4$
12.323	1.583	2.054	$0.483 \cdot 10^{-22}$	$0.621 \cdot 10^{-25}$	$0.124 \cdot 10^6$
12.753	0.013	2.125	$0.451 \cdot 10^{-22}$	$0.465 \cdot 10^{-27}$	$0.251 \cdot 10^4$
13.356	0.593	2.226	$0.411 \cdot 10^{-22}$	$0.183 \cdot 10^{-25}$	$0.986 \cdot 10^5$
13.466	0.020	2.244	$0.405 \cdot 10^{-22}$	$0.598 \cdot 10^{-27}$	$0.323 \cdot 10^4$
14.142	0.448	2.352	$0.369 \cdot 10^{-22}$	$0.602 \cdot 10^{-26}$	$0.325 \cdot 10^5$
14.488	0.013	2.415	$0.350 \cdot 10^{-22}$	$0.314 \cdot 10^{-22}$	$0.170 \cdot 10^4$

Detector Distances

The excited nucleus will turn to the ground state at a distance

$$l = \gamma_N \times \tau_N \times c \ ; \qquad \tau_N = \frac{6.582 \cdot 10^{-16}}{\Gamma}$$

As an example, for two levels of any nucleus we can obtained (probably for low and high decay widths) following value:

$$\Gamma = 4\, meV ; \qquad l = 0.36\, m$$

$$\Gamma = 2 \ \ eV \ ; \qquad l = 7.36 \cdot 10^{-7} m$$

As a result, one can say that for the detector size and position we have no any hardness.

Measure of unknown decay width

FEL Nucleus collider will give opportunity to measure unknown decay width using known ones. Indeed, decay width can be estimated using following relation[*]

$$\Gamma_{(1)} \cong \frac{E_\gamma^{(1)}}{E_\gamma^{(2)}} \cdot \frac{N_{(1)}}{N_{(2)}} \cdot \frac{\sigma_{res}^{(2)}}{\sigma_{res}^{(1)}} \cdot \Gamma_{(2)}$$

$$\sigma_{av} \approx \sigma_{res} \frac{\Gamma}{\Delta E_\gamma}$$

Where index 1 (2) correspond to level with unknown (known) decay width. For $N_{(1)}$ we can use 100 events per second as the observation limit.

As an example, if we use 4.085 MeV level, Γ=0.783 eV, σ_{res}=7.3 10^{-22} and $N_{(2)}$= 6.1 10^5 events/s, the upper limit for decay width of 11.45 MeV level (σ_{res} = 0.5 10^{-22} , J=1) is determined as Γ= 5.24 10^{-3} eV using 100 events per second as the observation limit.

*H.Koru et al. Int. J. of Mod. Phys. 12 (2003) 533.

Determination of the spin of state

In fixed target experiments the spin of excited nucleus can be determined using angular distribution of the emitted photons. In our case, this angular distribution will be transferred to the energy distribution in laboratory frame. For spin 1 and 2 cases, angular distributions in the rest frame are given by

$$W(\theta) = \frac{3}{4}(1 + \cos^2\theta)$$

$$W(\theta) = \frac{5}{4}(1 - 3\cos^2\theta + 4\cos^4\theta)$$

respectively. In laboratory system, these distributions will be seen by detector as energy distributions (for $\gamma >> 1$)

$$W(x) = \frac{3}{4}(x^2 - 2x + 2)$$

$$W(x) = \frac{5}{4}(4x^4 - 16x^3 + 21x^2 - 10x + 2)$$

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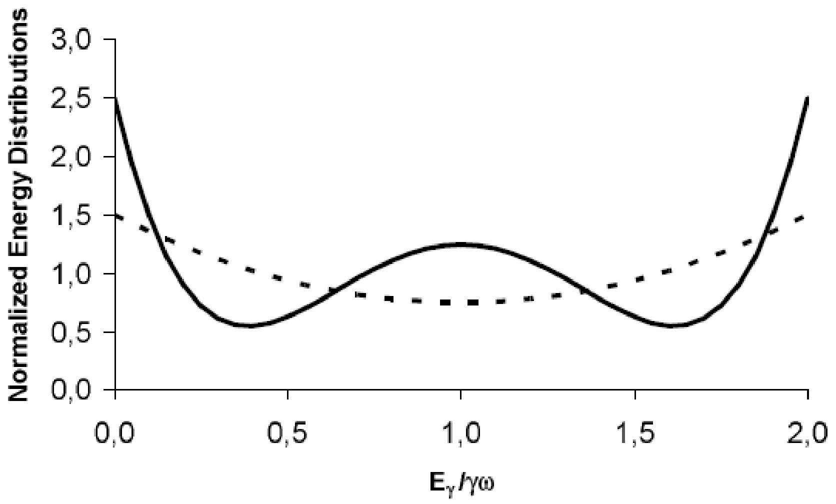
where $x = E_\gamma/\gamma_A\omega$. Here, x varies from 0 to 2 ($x = 0$ corresponds to $\theta = 180^0$ and $x = 2$ corresponds to $\theta = 0^0$). Fig. shows the x dependence of normalized energy distributions. Taking into account the high statistics, provided by proposed experiment, it is obvious that different spin values can be easily identified.



Normalized energy distributions of photons emitted by spin 1 (dashed curve) and spin 2 (continuous curve) excitations of the nucleus (Th example)

Feasibility of such a collider needs more R&D on…

- Bunch and pulse structures of electron, FEL and nucleus beams…
- SASE FEL optimization…
- Luminosity optimization…
- Open problems of nuclear spectroscopy…
- Ion program of LHC (Pb, Ce, Sm, Ba, C etc.)...
- Detector design for scattered high energy photons…

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