Coming developments

FLUKA Advanced Course

Vancouver, BC, Canada, September 16th-20th 2012

Developments in view of the release

- **Dynamic memory allocation** for the gfortran version!
- Ability to **change** a region material into whichever other for the radioactive product transport wrt the prompt radiation transport (presently only vacuum is allowed)
- New **generalized estimators**
- Ability to import **scans** in **DICOM** format automatically generating density correction factors and materials (for medical applications, through Flair)
- Flexible (number of estimators and number of bins) **DETECT** scoring

Recent physics developments in FLUKA

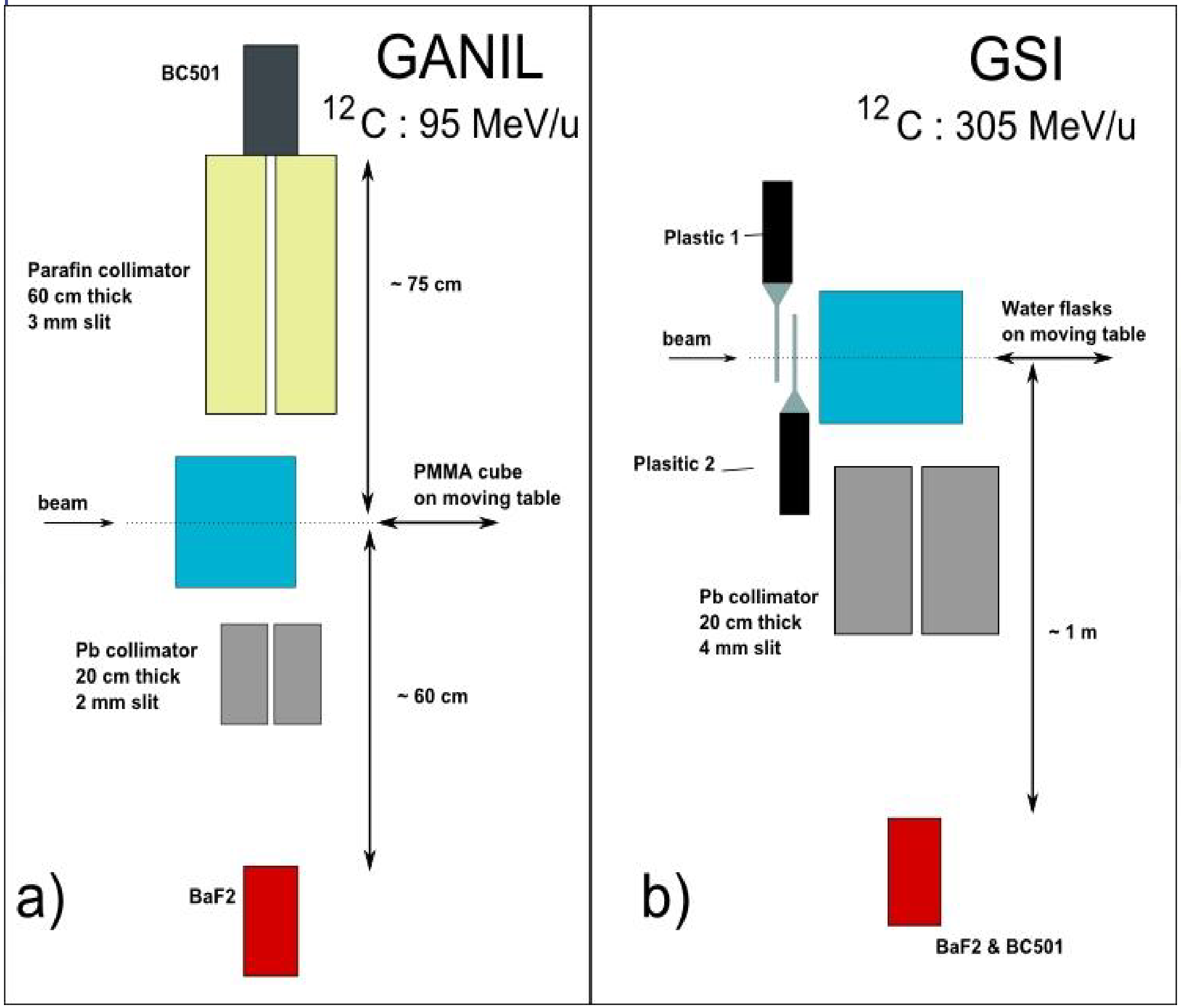
- Further **refinements in the (prompt) photon** emission modeling, accounting for spin-dependent angular distributions
- **Benchmarking of the (prompt) photon** emission part, see slides
- Development of a **physics-driven model for acolinearity in positron annihilation at rest** valid for all materials/compounds, see slides
- Improvements in **BME** (coupling with the PEANUT preeq)
- Initial extension of **BME** to **3-H** and **3-He** induced reactions
- **Alpha decays** now simulated if decay requested
- Improvements in PEANUT for **(p,d)** and **(n,d)** reactions
- $\rightarrow$ strong improvement in the prediction of the excitation curves for **11-C** and **15-O** production at low energies
- **Spin-parity** in Fermi break-up

Ongoing developments for γ's:

- Extended database of known levels and transitions taken from RIPL-3 (IAEA)
- Discrete level treatment extended to evaporation stage
- (Partial) validation has been performed
- ***Up to this point inserted in the released FLUKA2011.2***

- … after the release (presently in the devel version)
- Photon angular distribution according to multipolarity and spin (→ effort to estimate residual spin value and direction in PEANUT, BME, rQMD)
- Account for discrete levels in BME (to be extended to rQMD and DPMJET)
- Special effort for 0→0 transitions (under implementation)
- Comparison with Lyon data (slides)
- Comparison with "IBA" data (slide)
- Comparison with data for ^{12}C @ 80 MeV/n taken at LNS

Prompt photons: benchmarks [I]



[figures and exp. data taken from
F. Le Foulher et al, IEEE TNS 57 (2009),
E. Testa et al, NIMB 267 (2009) 993]

Prompt photons measured during irradiation of water and PMMA phantoms with C ions.

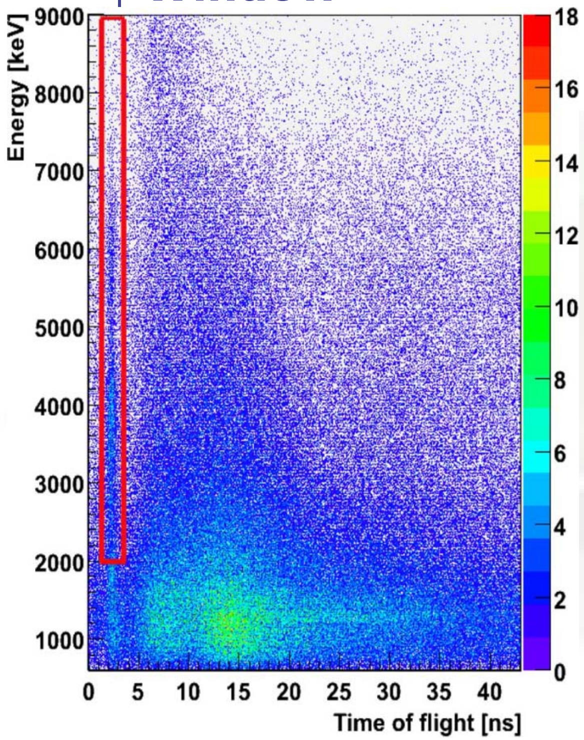
Photon spectra measured at 90^{0} wrt beam

Time-of-flight to discriminate neutron background

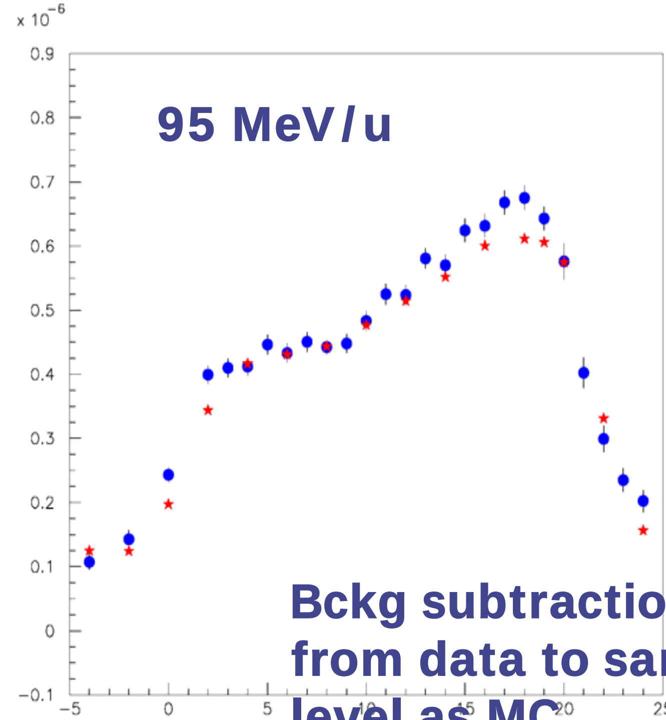
Threshold at 2 MeV to discriminate photons from secondary photons, bremsstrahlung etc.

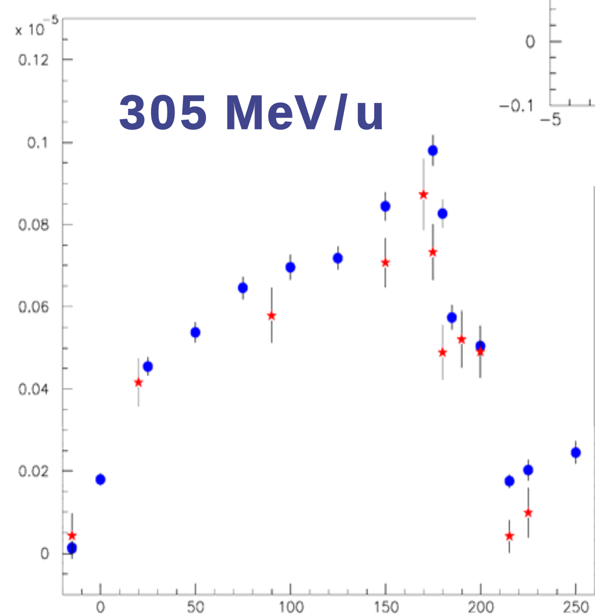
Prompt photons: benchmarks [II]

Exp. Energy/tof Distribution and Window



Counts/ion vs position along the phantom





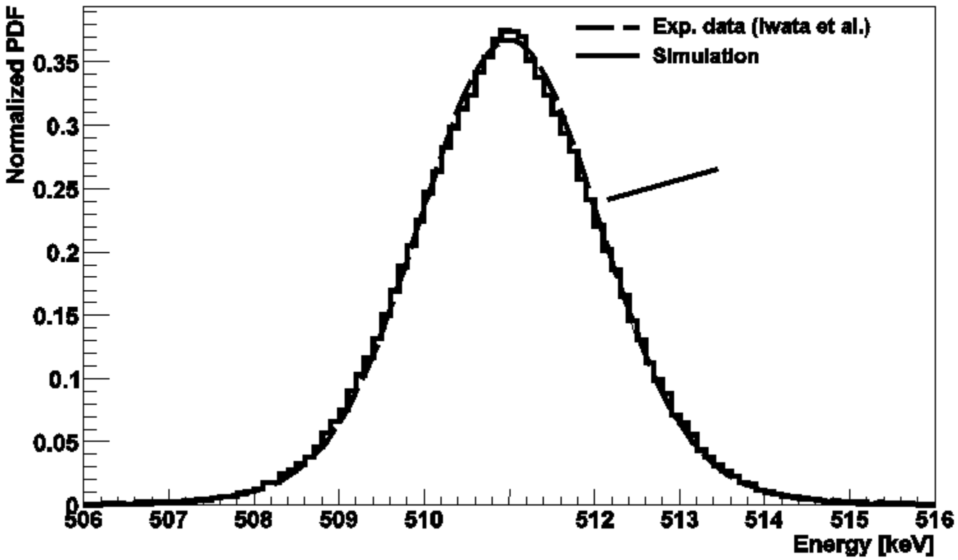
Bckg subtraction from data to same level as MC

Blue: FLUKA
Red: data

Compton and annihilation on bound electrons:

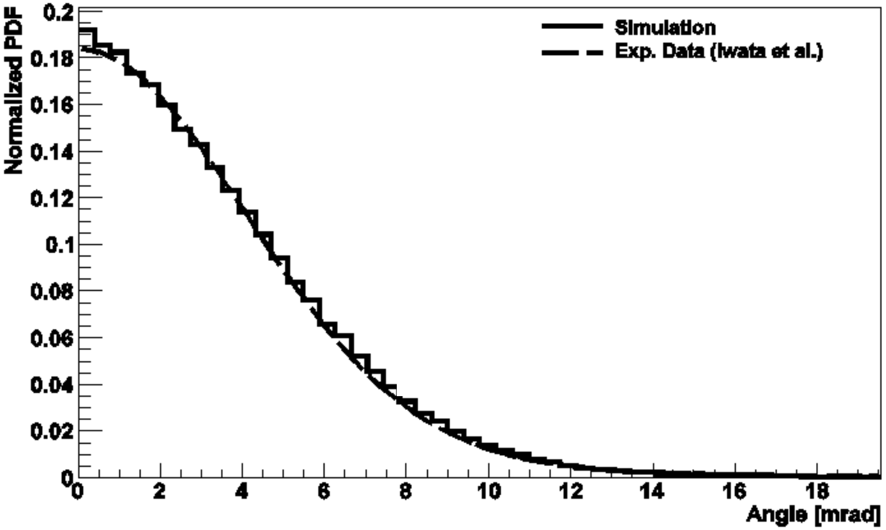
- **Bound electron momentum distributions** parameterized out of available (relativistic) Hartee-Fock calculations for all (sub)shells for all elements
- **Fermi momentum distribution** for conduction electrons in **metals**
- **Explicit bound-electron – photon kinematics for Compton scattering**, with full account for energy, momentum conservation (since 2008)
- Same approach for **(quasi) first-principle based acolinearity** description for **positron annihilation** at rest
- Paper in press in JINST

Annihilation on bound electrons: H_2O

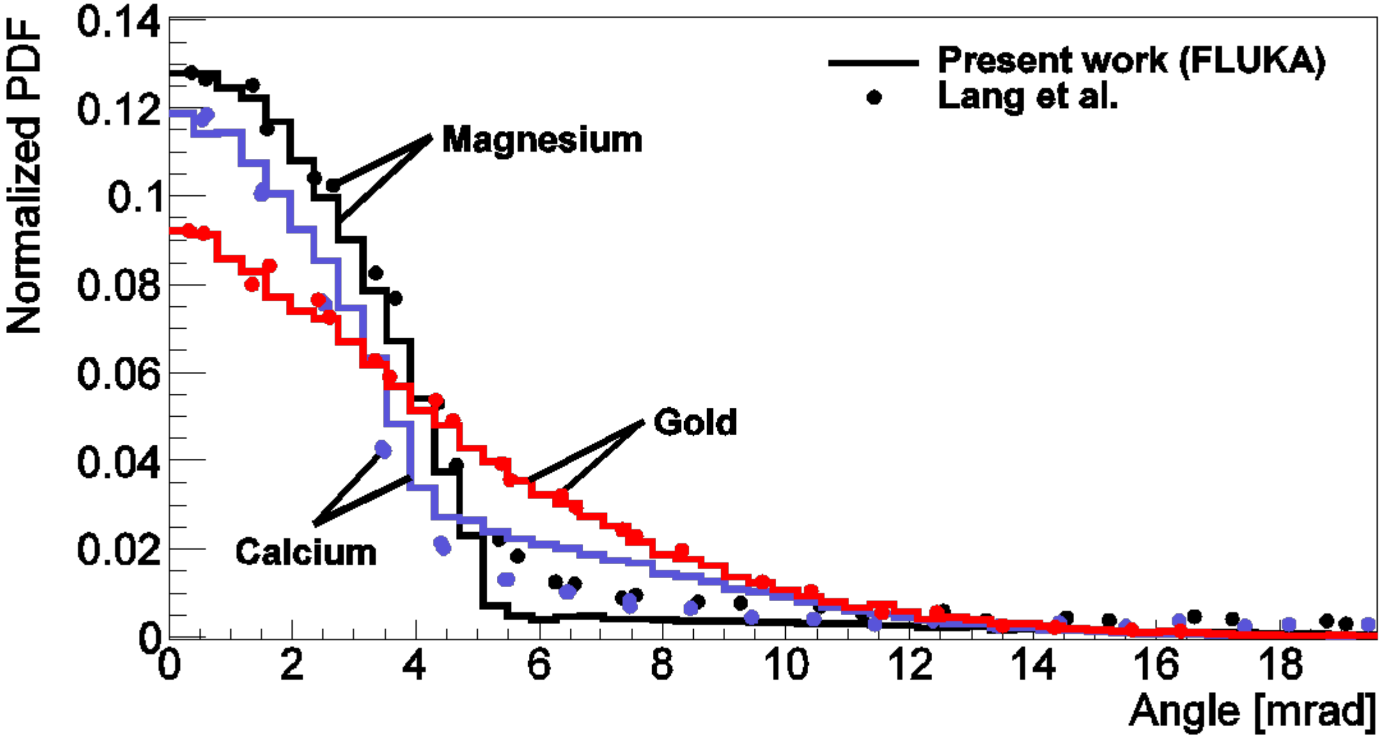


← Energy

Angle →



Annihilation on metals

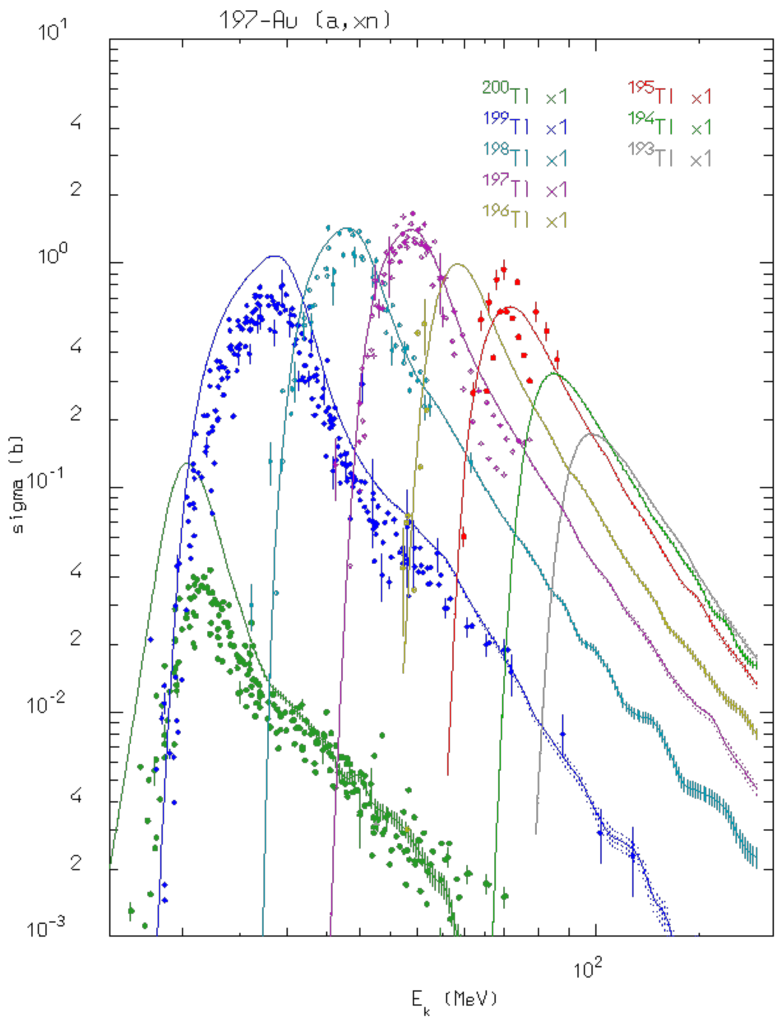


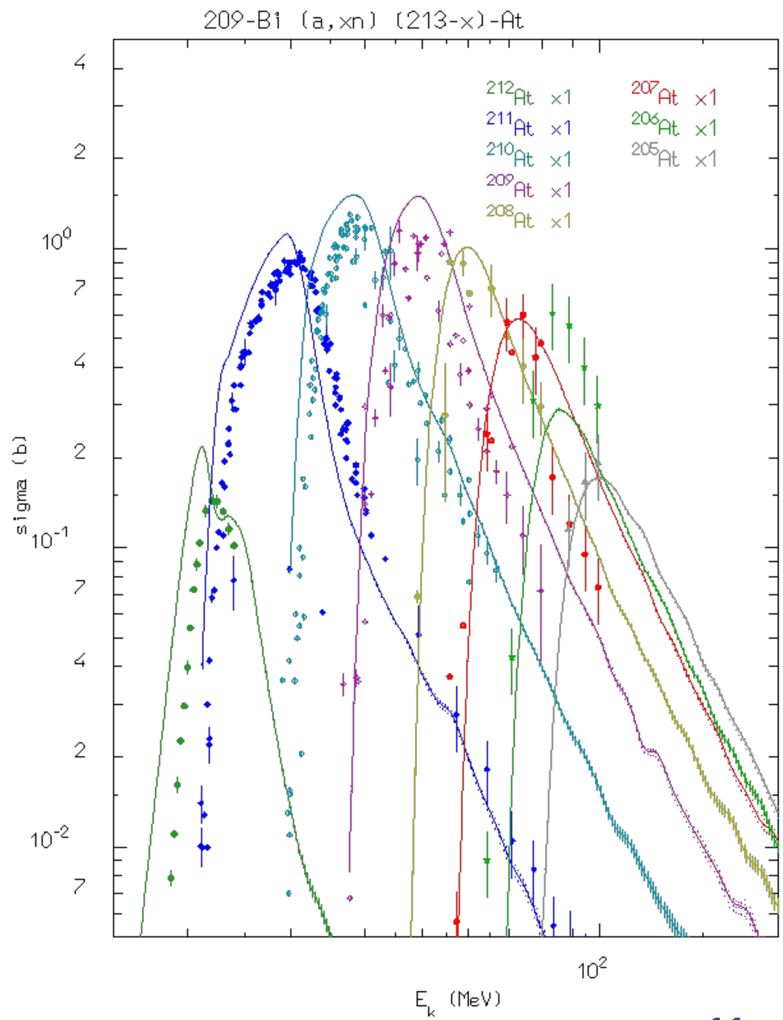
α-induced reactions, α-emitters

- ✓ Fragmentation tail in hadrontherapy beams
- ✓ Radiation damage to electronics
- ✓ Production of residual nuclei: On heavy targets, interactions of secondary α's can produce dangerous radioisotopes, for instance:
  - (α, Bi) → At : chemically reactive (halogen) α and β+ emitters. Eg, $^{210}_{85}$At has a mean life of 8.1 h, 5.6 MeV α decay and ε decay to $^{210}_{84}$Po
  - (α, Pb) → Po ...well known "problematic" α-emitters
- ✓ Some of these isotopes have exemption limits 3-4 order of magnitudes smaller than most other radioisotopes commonly produced at accelerators
- ➢ **New** in FLUKA: α - **induced** reactions at low energy (E < 150 MeV/A) through the BME model and the PEANUT pre-equilibrium

BME in FLUKA: (α,xn) examples

Excitation functions for the production of radioisotopes from α interactions on Au (left) and Pb (right) (Data: CSISRS, NNDC)





Spin-parity in Fermi-Break-up

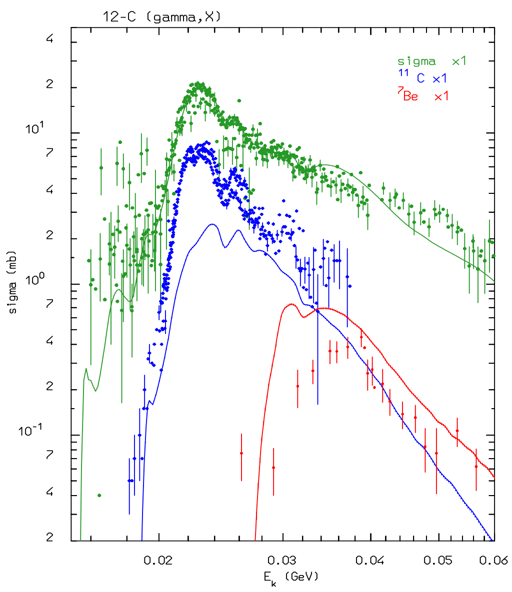
For A<17, evaporation is substituted by Fermi break-up

In cases where spin and parity of the residual nucleus are known, conservation laws, constraints on available configurations and centrifugal barrier (if L=0 is forbidden), are enforced in the fragment production

Straightforward example : photonuclear reaction in the GDR region

Effect : residual nuclei production

Application: background from induced activity in underground experiments



12C +γ in GDR

→J^{π} = 1^{-}

→ 3α and α + ^{8}Be impossible in L=0

→Factor 3 on ^{11}C production