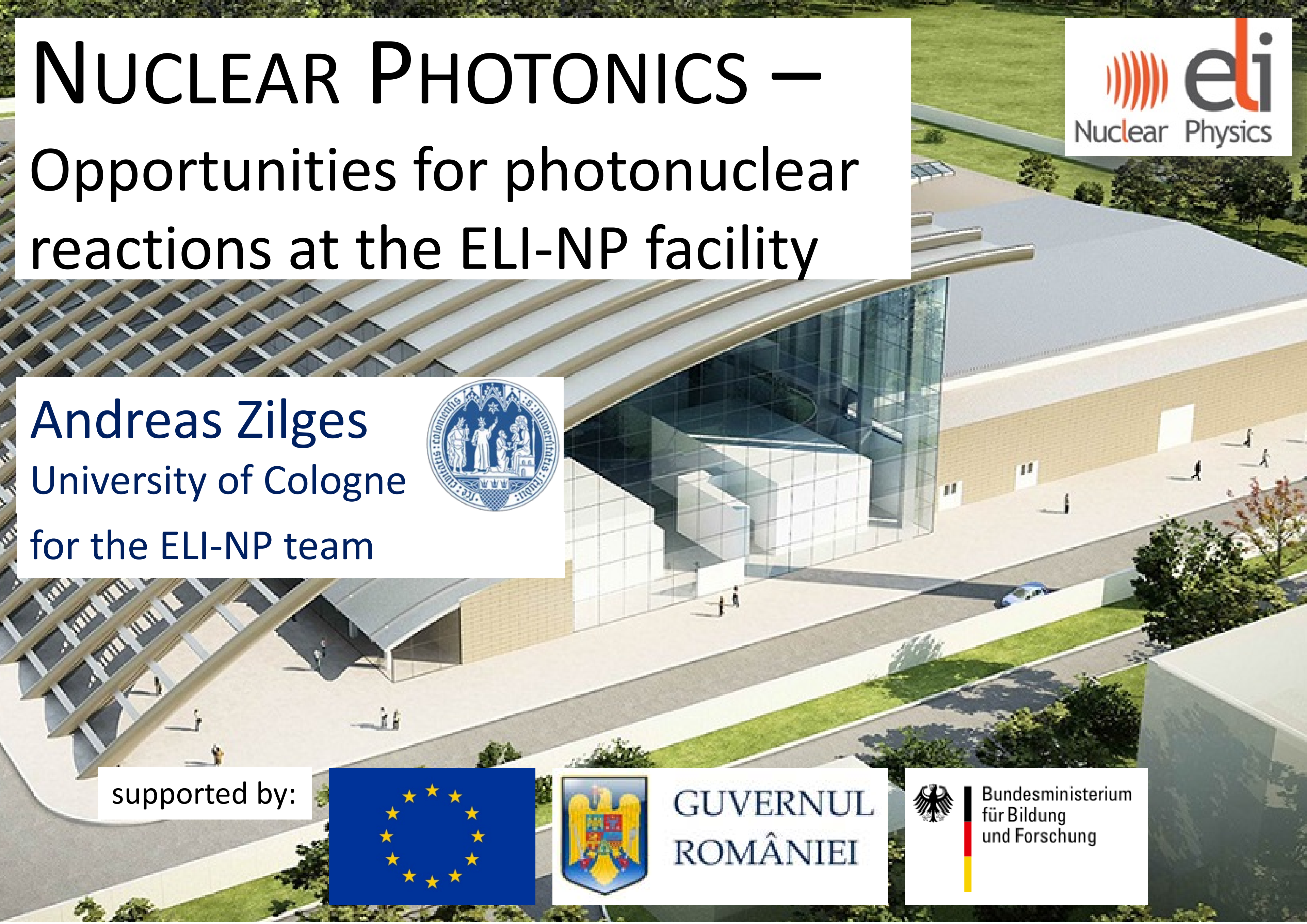


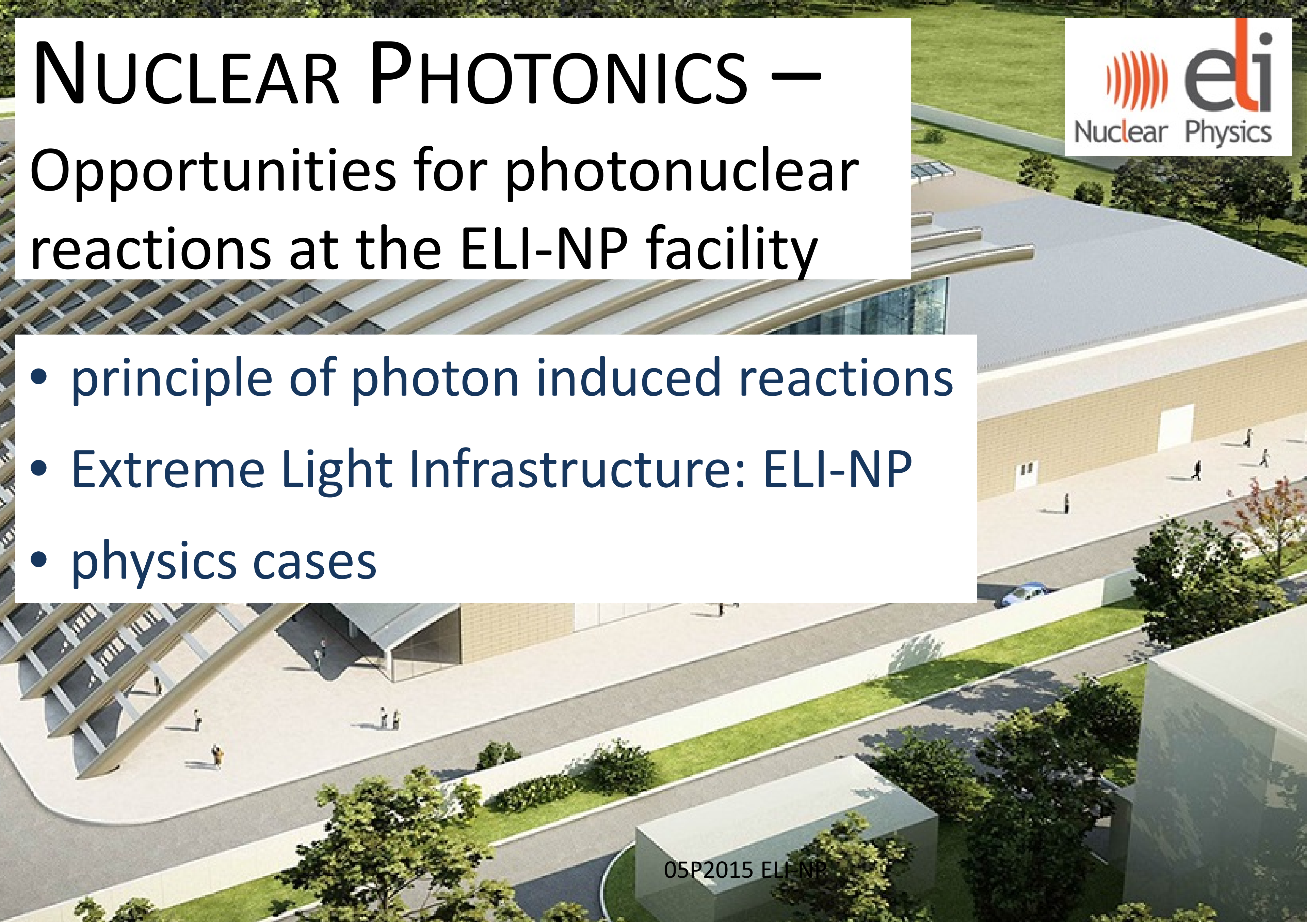
# Nuclear Photonics – Opportunities for photonuclear reactions at the ELI-NP facility

Nuclear Physics


Andreas Zilges
University of Cologne
for the ELI-NP team



supported by:
GUVERNUL ROMÂNIEI
Bundesministerium für Bildung und Forschung



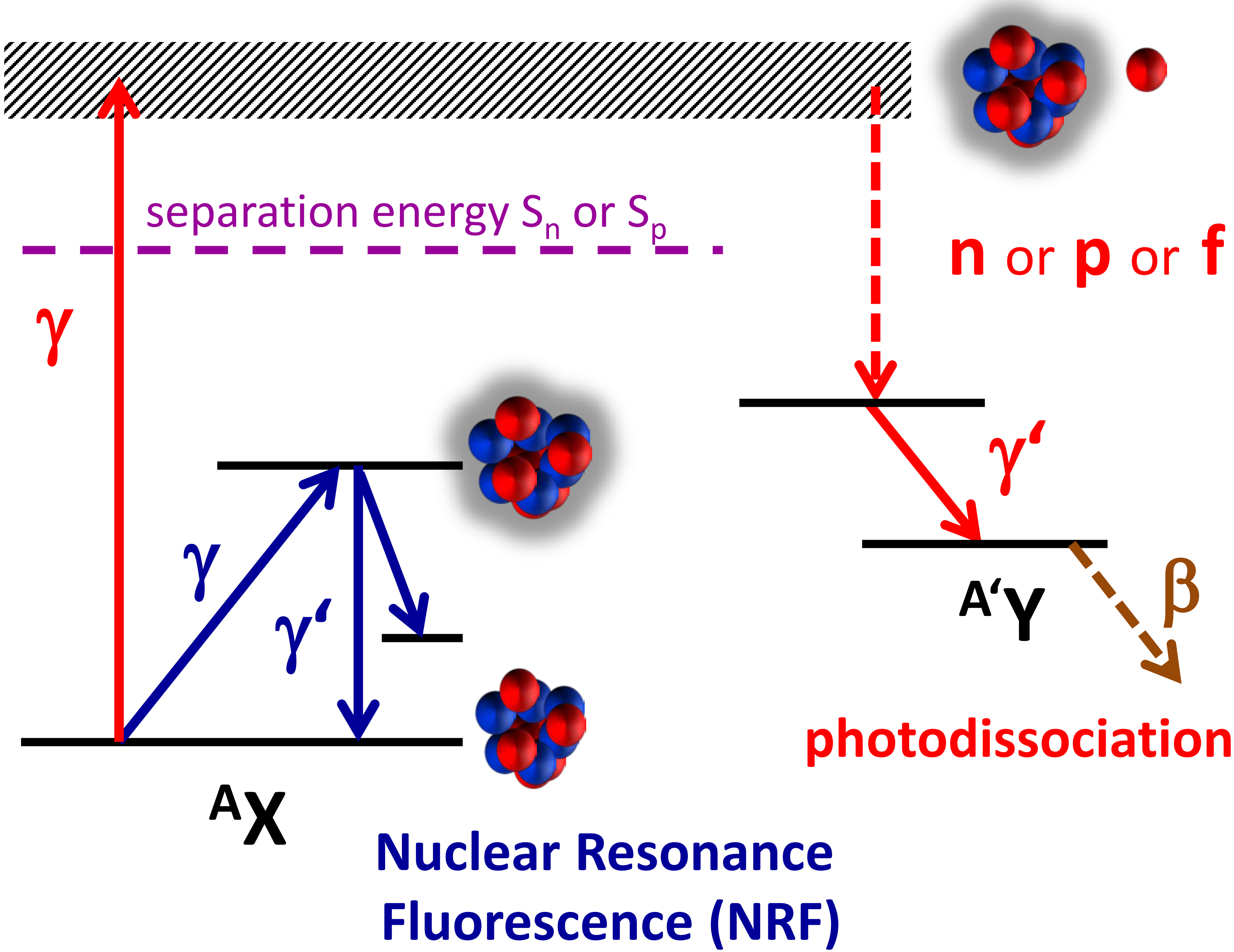
# Nuclear Photonics – Opportunities for photonuclear reactions at the ELI-NP facility

Nuclear Physics

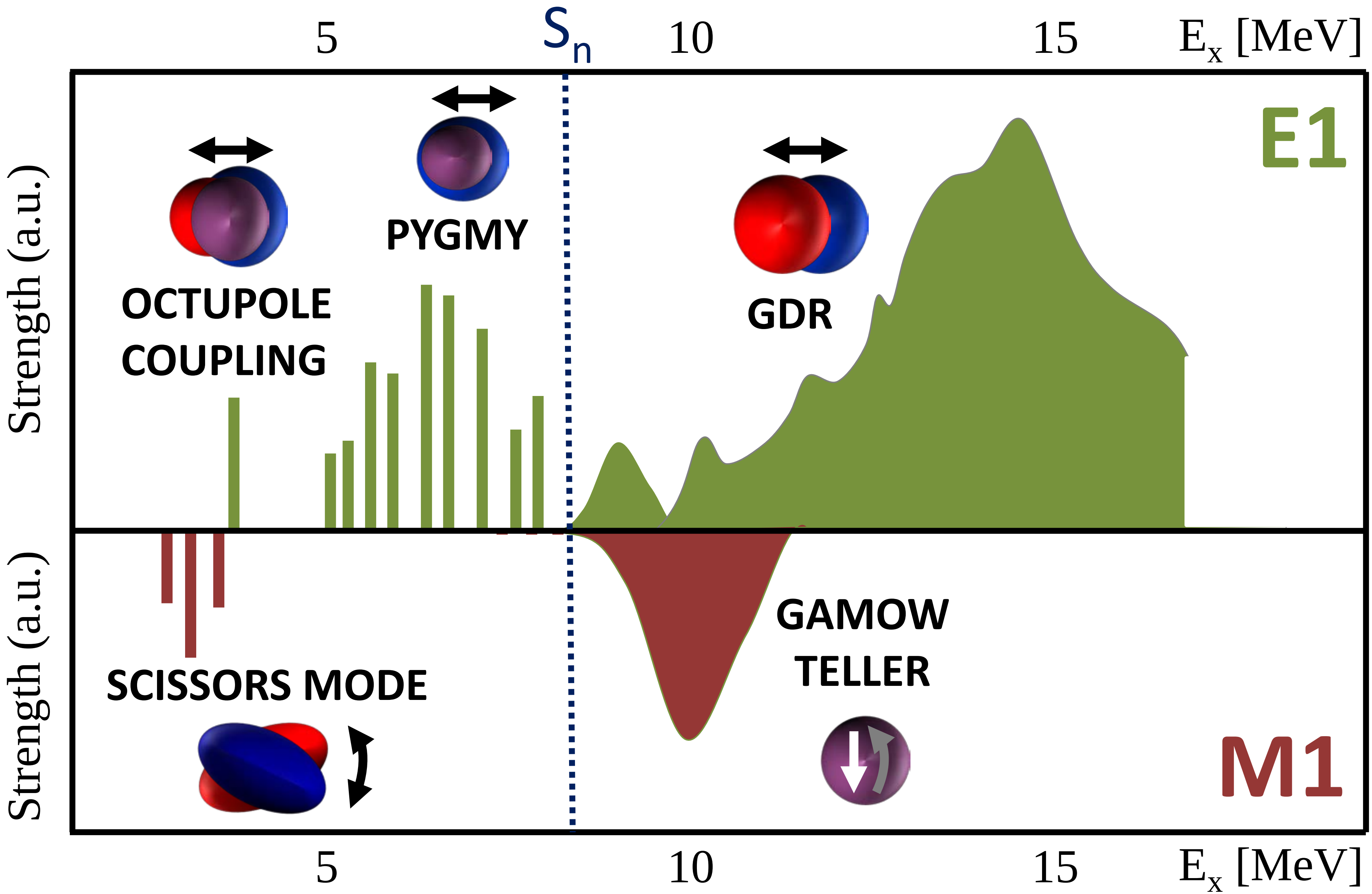
- principle of photon induced reactions
- Extreme Light Infrastructure: ELI-NP
- physics cases

05P2015 ELI-NP

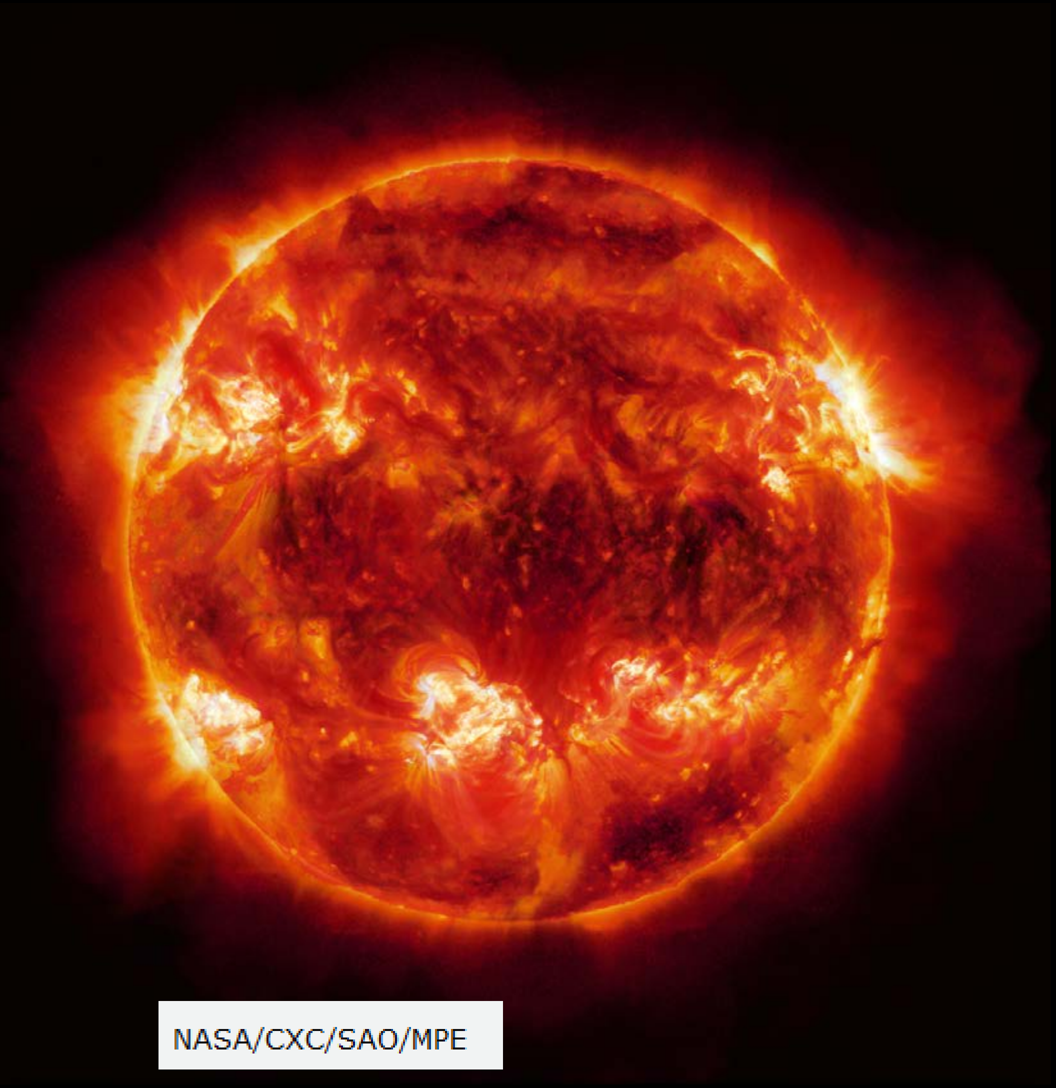
# Photonuclear Reactions

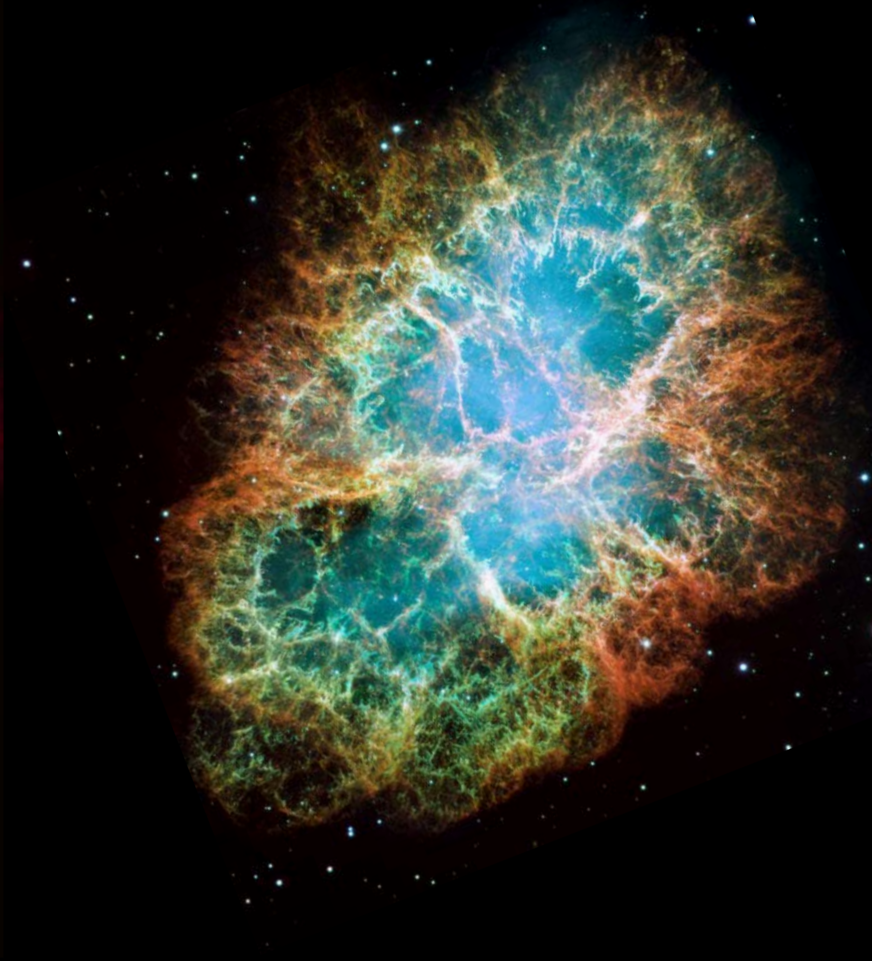


# Dipole photoresponse of atomic nuclei

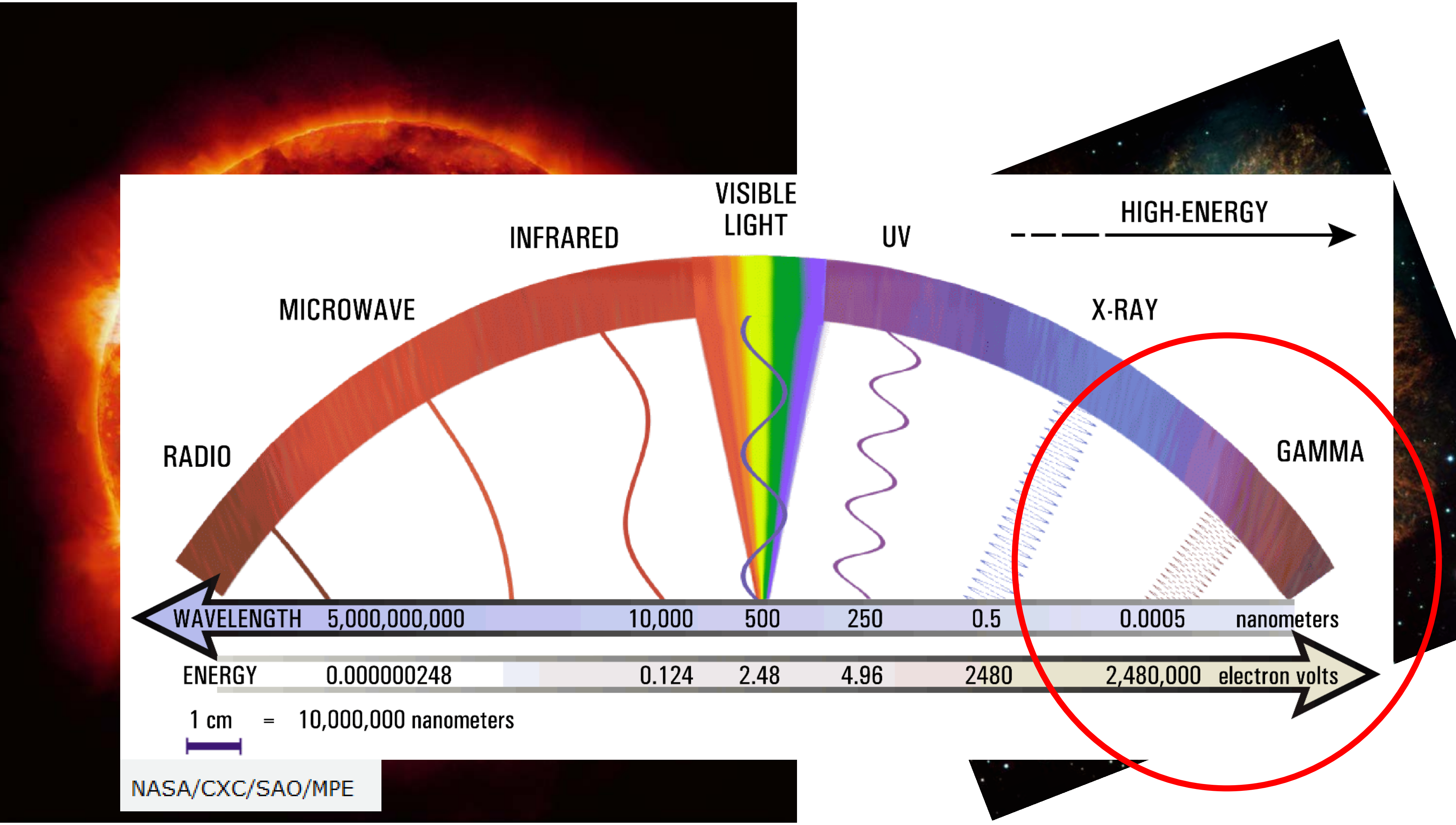


# Photons in the universe


NASA/CXC/SAO/MPE


*nasa.gov*

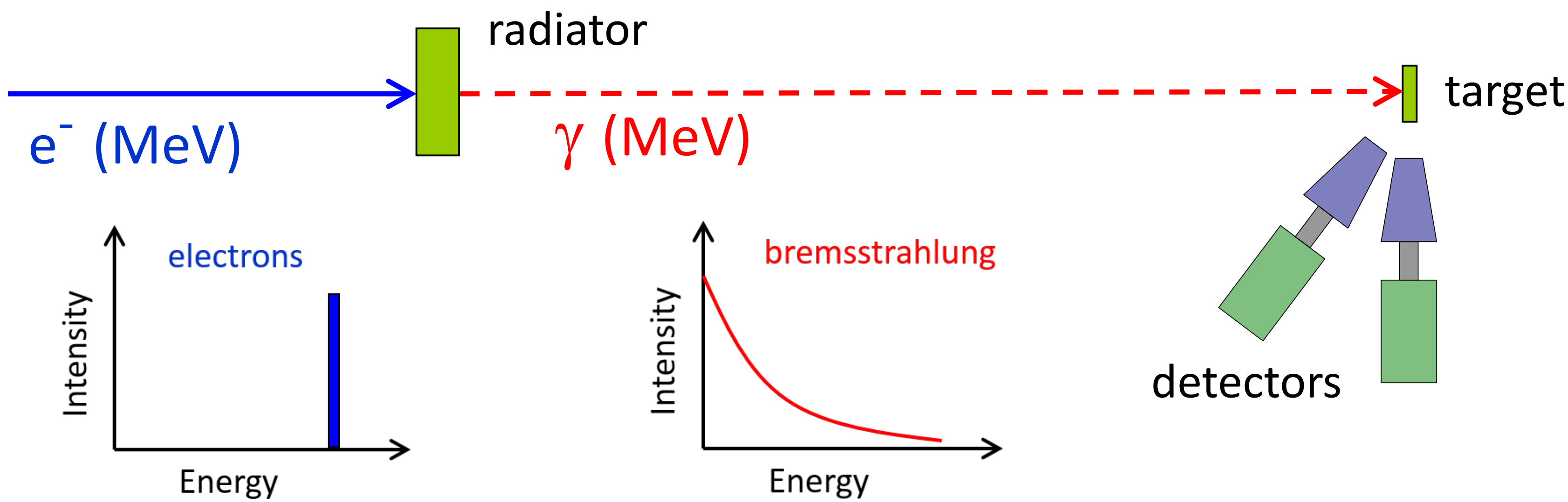
# Photons in the universe

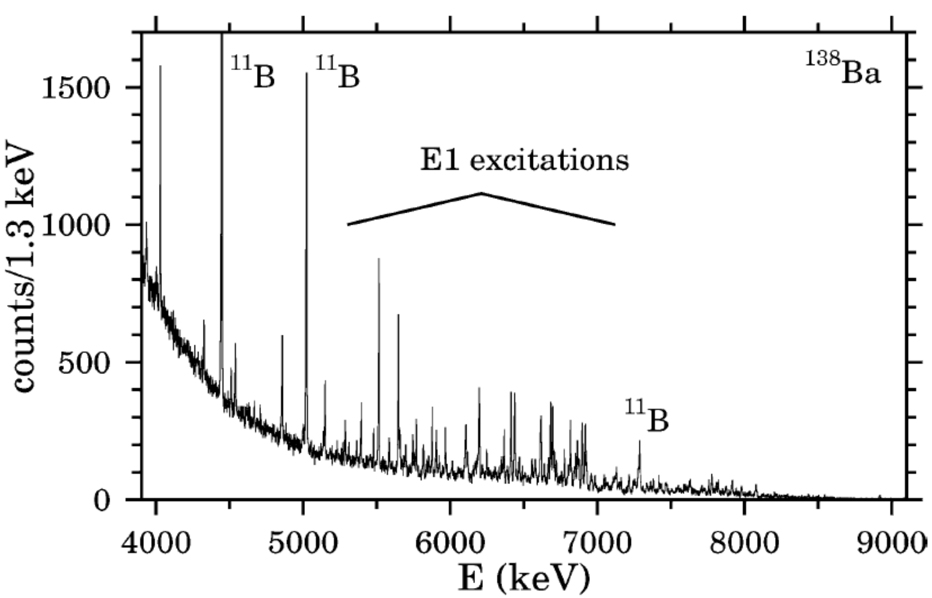


# Photonuclear Reactions

- pure EM interaction
- spin selectivity (mainly E1, M1, E2 transitions)
- strength selectivity
- **For $E_\gamma < S_n$ and $S_p$:**
  derivation of excitation energies, spins, parities, decay energies, level widths, lifetimes, decay branchings, multipole mixing ratios, absolute transition strengths
  **completely model independently**

# NRF using bremsstrahlung



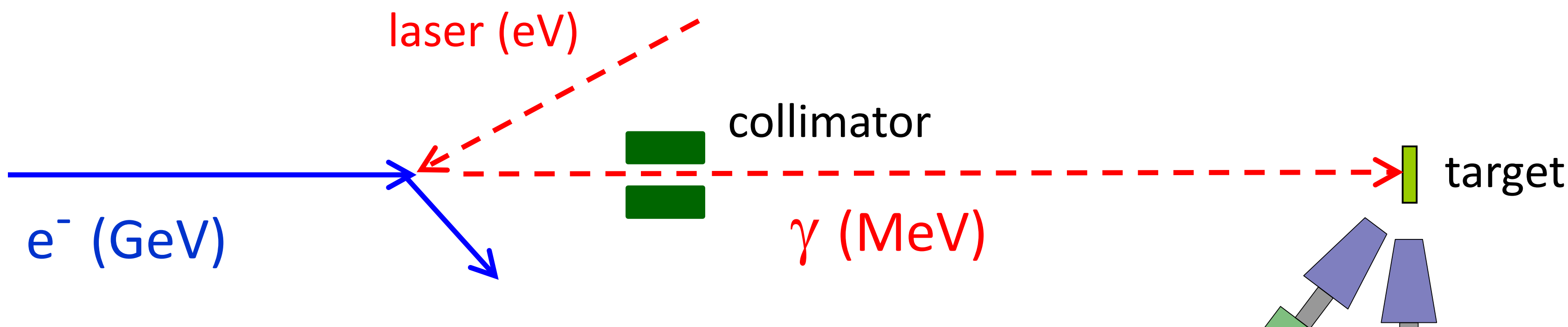



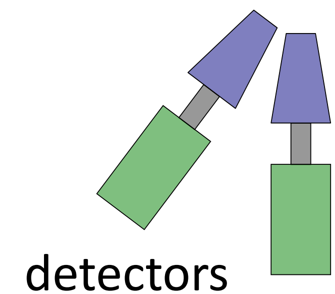

- “white“ photon spectrum
- wide energy region examined
- Background at low energies

*Review: U. Kneissl, H.H. Pitz, and A.Z., PPNP **37** (1996) 349*

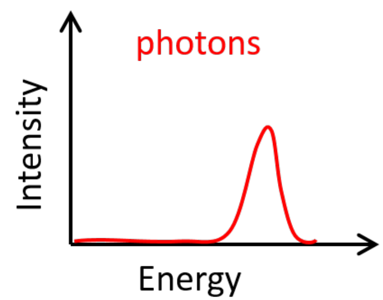
# NRF using monoenergetic photons

**Laser Compton Backscattering (LCB)**




Examples:
HIGS at TUNL (USA)
NewSUBARU (Japan)



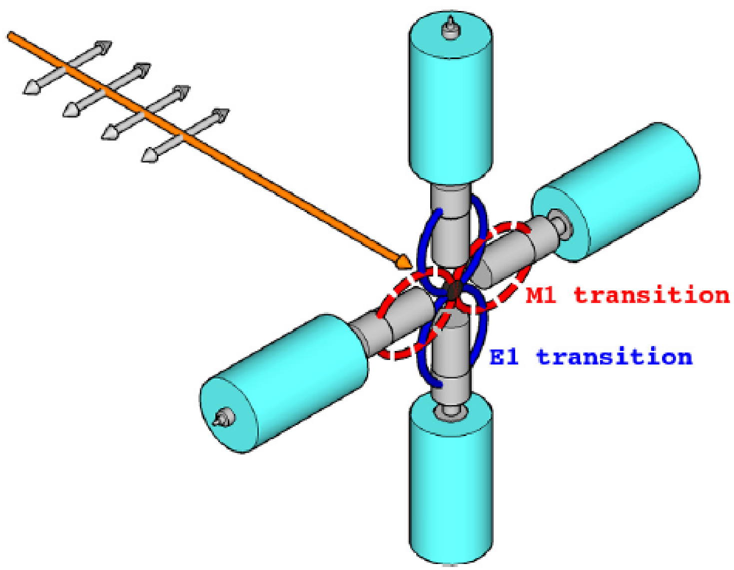

- ”monoenergetic“ photon spectrum
- tunable energy
- polarized beam

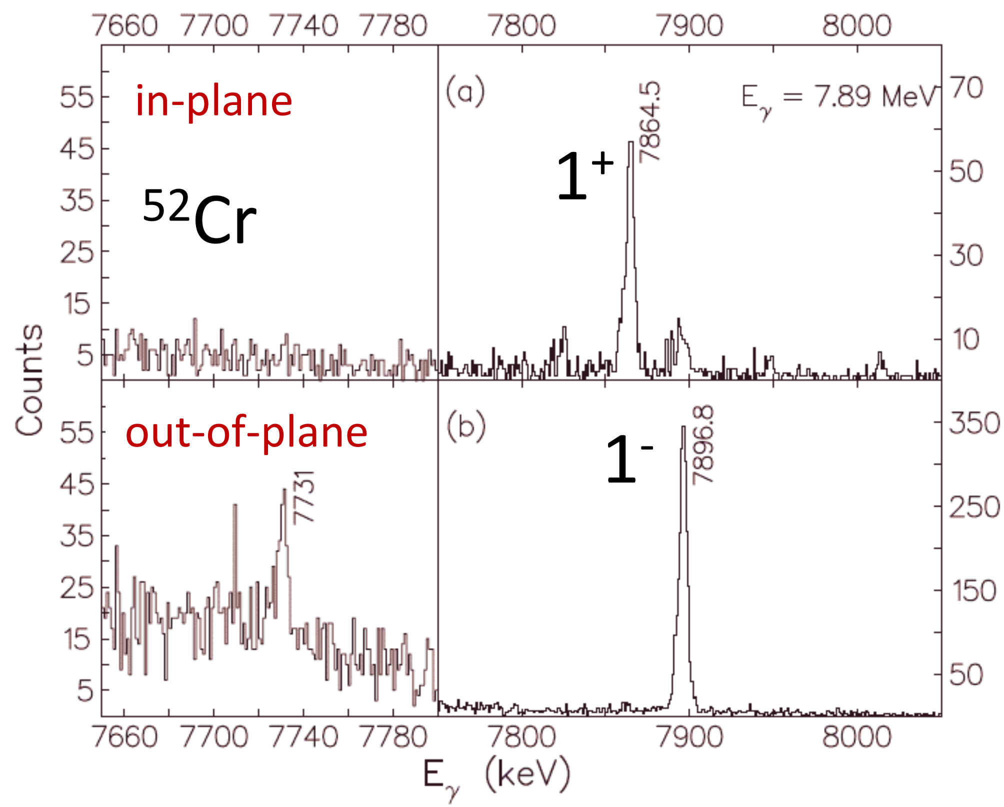
→ Nuclear Photonics

*H.R. Weller et al., PPNP **62** (2009) 257*

# NRF using monoenergetic photons

Parity determination by measuring asymmetries

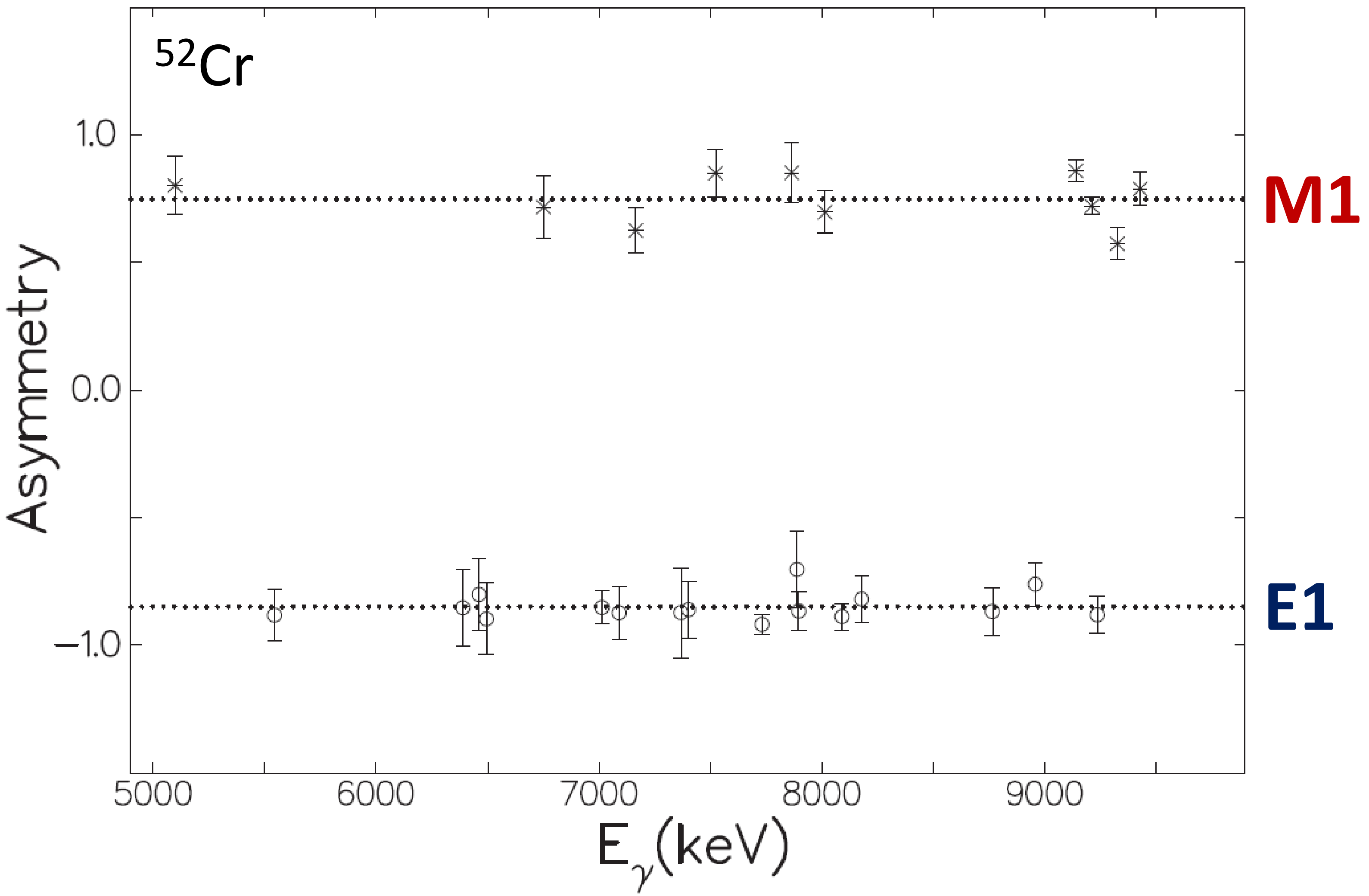



*J. Beller et al., PLB **741** (2015) 128*

*Krishichayan et al., PRC **91** (2015) 044328*

# NRF using monoenergetic photons

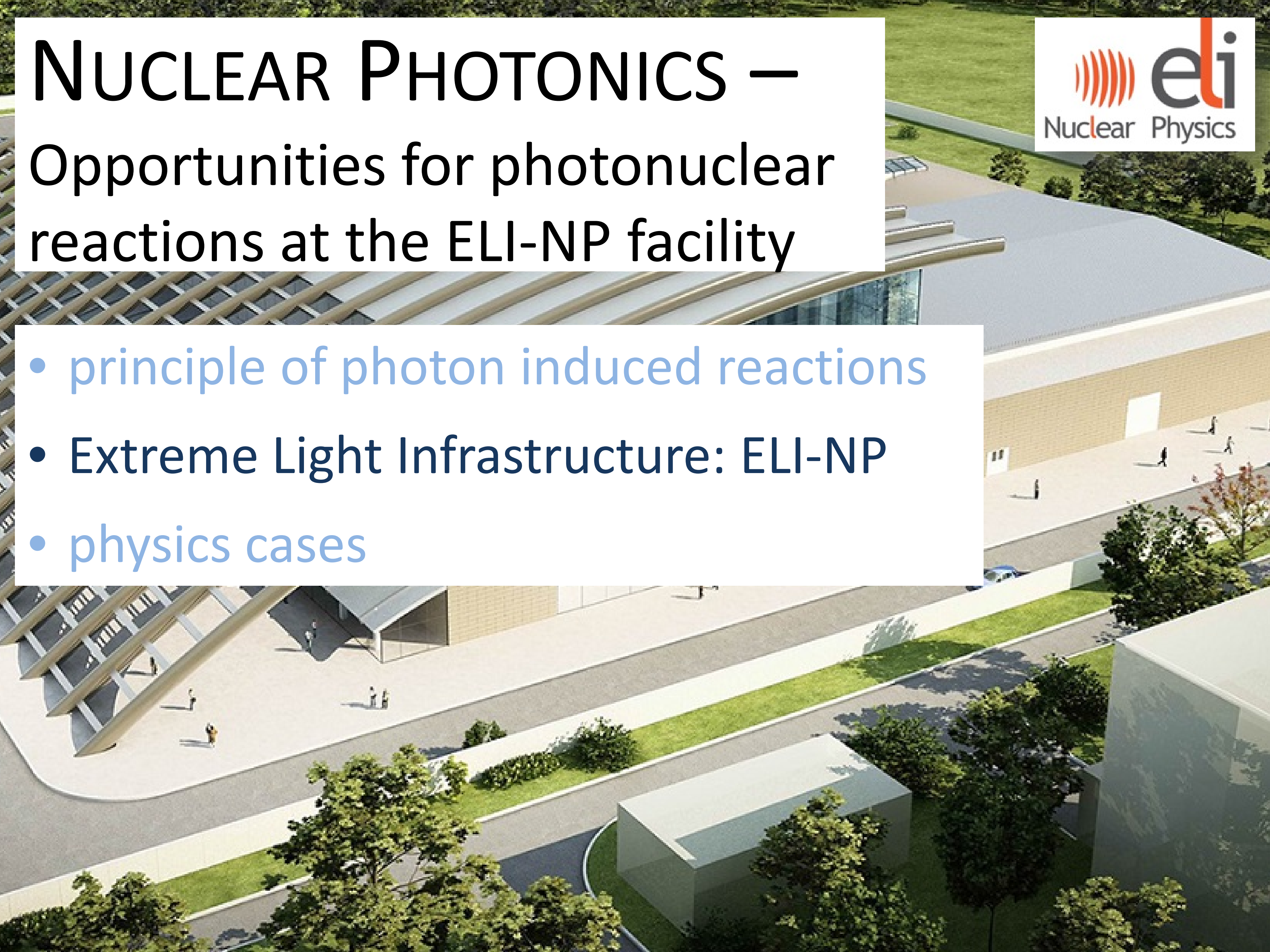



*Krishichayan et al., Phys. Rev. C **91**, 044328 (2015)*

# NUCLEAR PHOTONICS – Opportunities for photonuclear reactions at the ELI-NP facility

Nuclear Physics

- principle of photon induced reactions
- Extreme Light Infrastructure: ELI-NP
- physics cases



# The Extreme Light Infrastructure – Nuclear Physics

- High power laser system, 2 x 10 PW maximum power

  Thales Optronique SA and SC Thales System Romania

- High intensity gamma beam system **GBS**,
  0-20 MeV beam from laser Compton backscattering

  European Consortium **EuroGammaS** led by INFN Rome,
  subcontractors include STFC (UK)

- Eight experimental areas for laser, gamma, gamma&laser

Total investment 2013-2018: > 300 M€ (230 M£)
(mainly European Regional Development Fund)

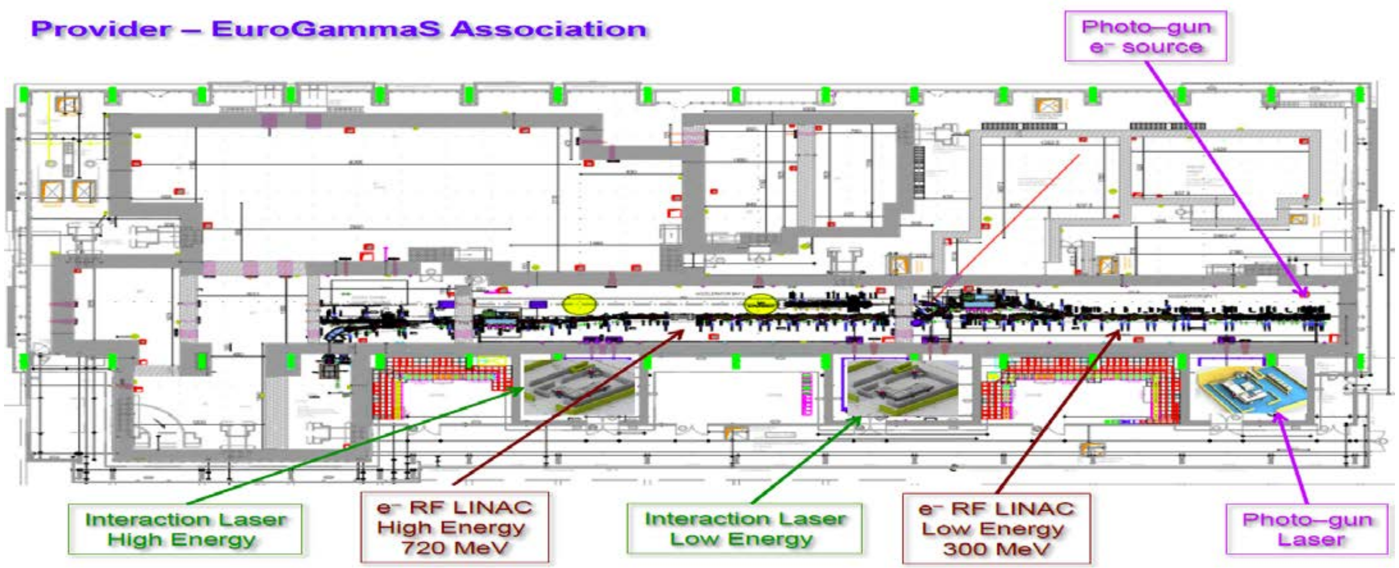
# Civil construction

33000 m$^2$ total:

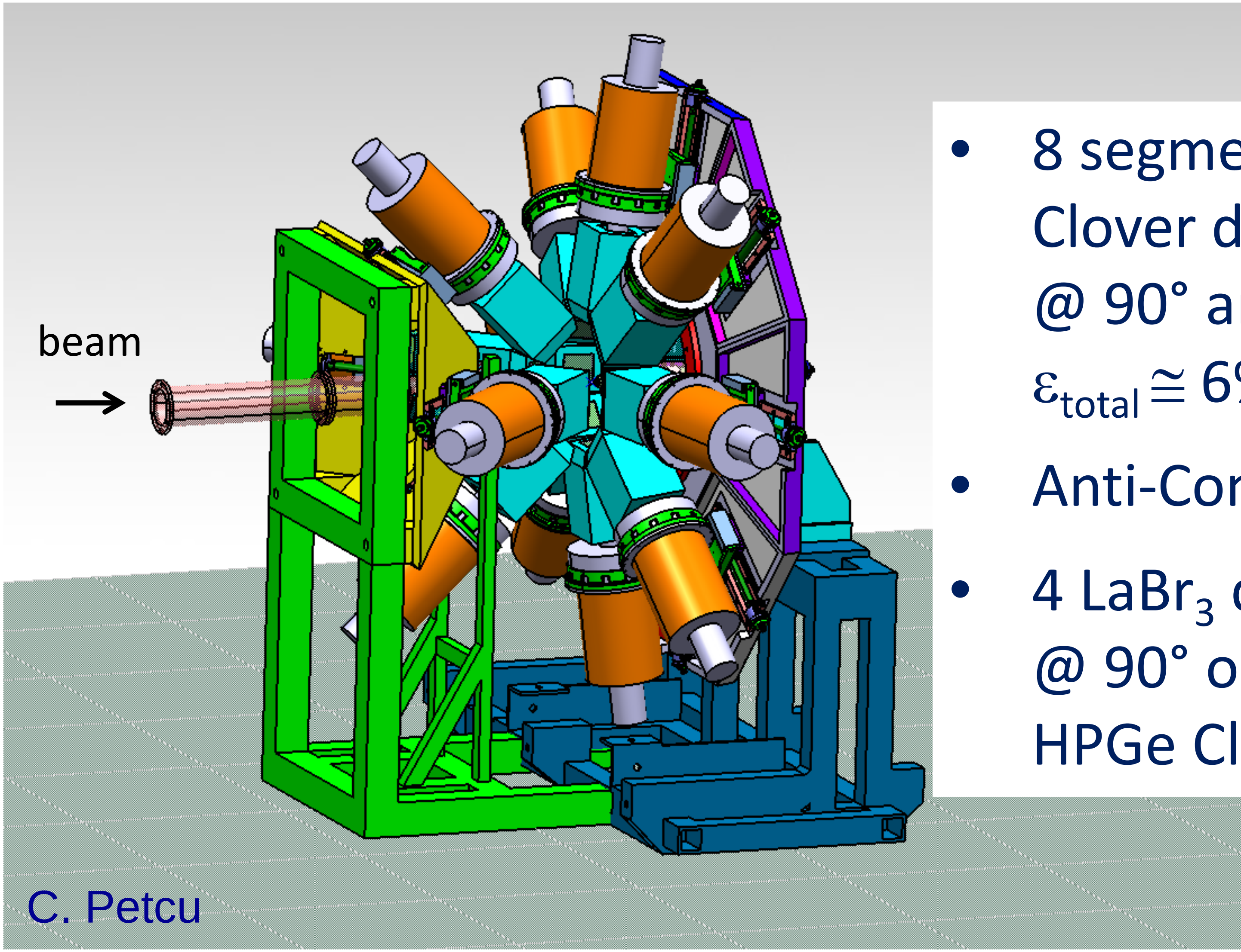
- experimental areas
- guest house
- office spaces

# The photon beam at ELI-NP

- very high intensity > $10^4$ $\gamma$/(s·eV) (HIGS: $10^2$ $\gamma$/(s·eV) )
- narrow bandwidth down to 0.5% (HIGS: 3%)
- small beam diameter in mm range (HIGS: cm range)
- high degree of polarization > 99% (HIGS: > 99%)
- low duty factor of 100 Hz (HIGS: MHz)



# ELIADE: ELI-NP Array of DEtectors




- 8 segmented HPGe Clover detectors @ 90° and 135°, $\varepsilon_{total} \cong 6\%$ @ 1.3 MeV
- Anti-Compton shields
- 4 $LaBr_3$ detectors @ 90° or 4 additional HPGe Clover

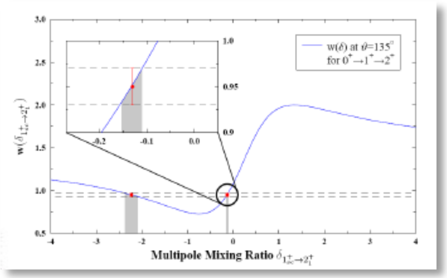
# Discovery frontiers for NRF at ELI-NP

## Availability frontier

(access to rare isotopes)

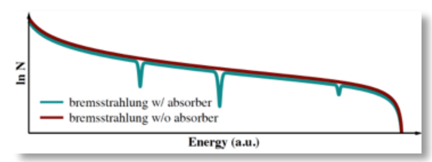
## Sensitivity frontier

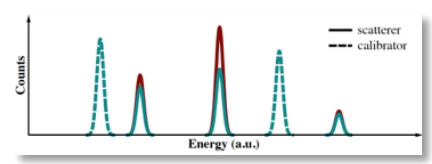
(weak channels)




## Precision frontier

(high statistics)



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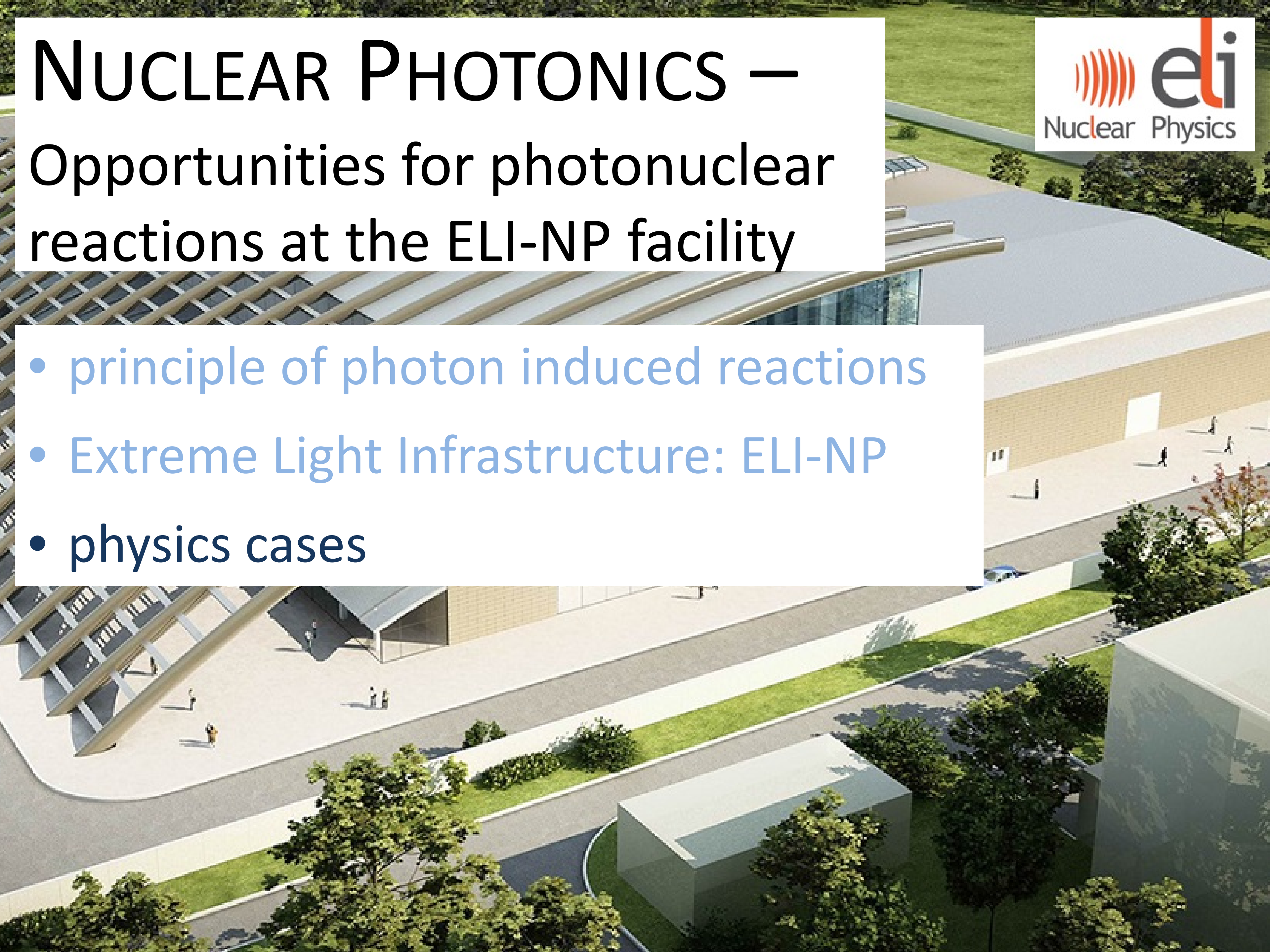
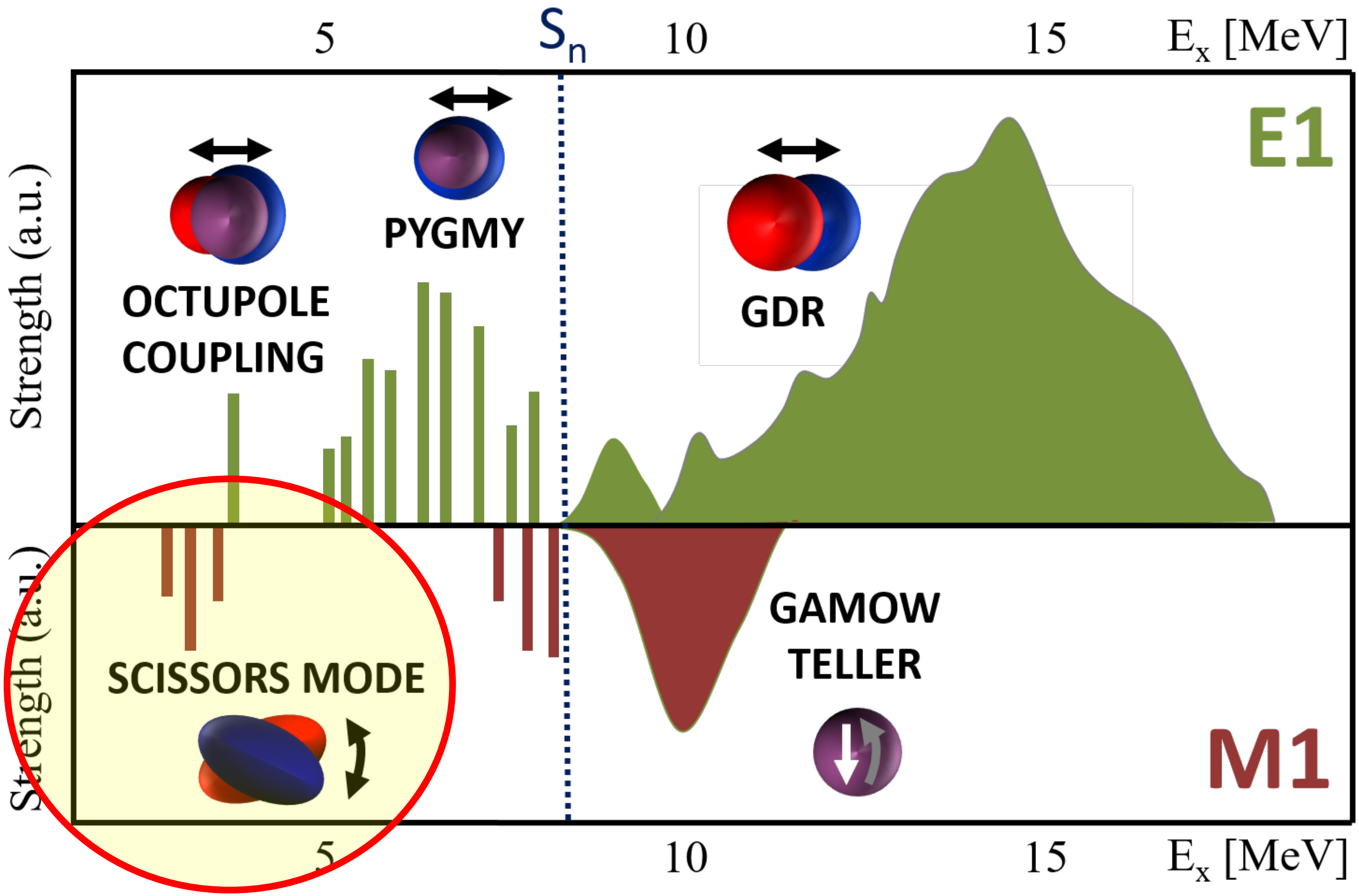


# Physics cases at ELI-NP: Examples

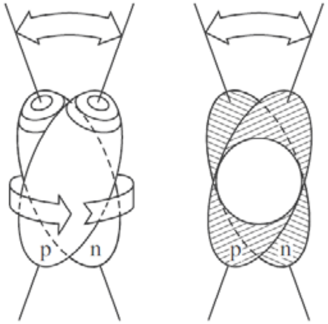
- constraints on **neutrinoless double-beta decay** matrix elements: A novel decay channel of the scissors mode

# Constraints on neutrinoless double-beta decay matrix elements: Decay channels of the scissors mode




*D. Savran, T. Aumann, and A. Zilges, Prog. Part. Nucl Phys.* ***70*** *(2013) 210*

# Constraints on neutrinoless double-beta decay matrix elements: Decay channels of the scissors mode




Branching ratios of the $1^+$ scissors mode are sensitive to parameters in certain nuclear structure models (e.g., IBM-2 Hamiltonian)

→ constrain nuclear matrix element in $0\nu\beta\beta$ transition rate

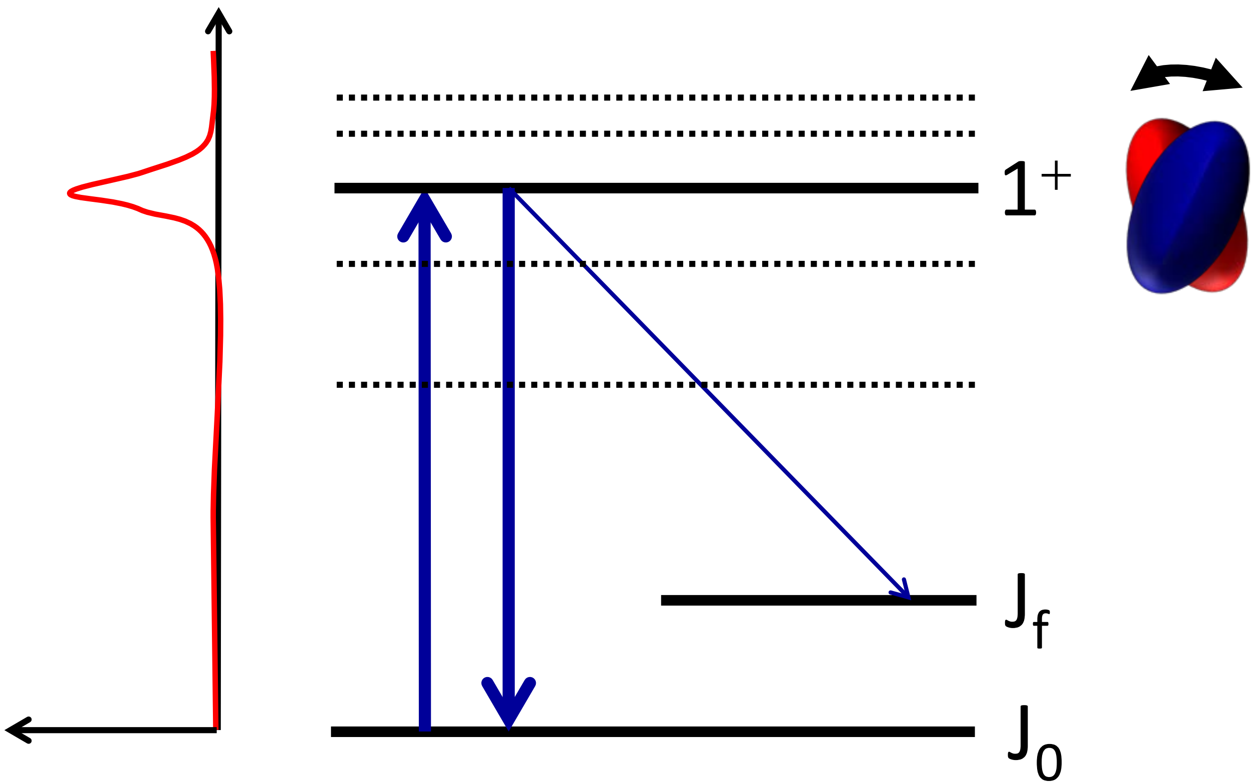
$$\lambda_{0\nu\beta\beta} = G_{0\nu} \left| M^{(0\nu)} \right|^2 \left( \frac{\langle m_\nu \rangle}{m_e} \right)^2$$

(see talks by Ben Kay, Stuart Szwec, Jonathan Entwisle)

# Constraints on neutrinoless double-beta decay matrix elements: Decay channels of the scissors mode

**ELI-NP:**

- narrow bandwidth allows selective excitation and detection of weak decay channels
- polarization allows to distinguish $1^+$ and $1^-$ states



# Physics cases at ELI-NP: Examples

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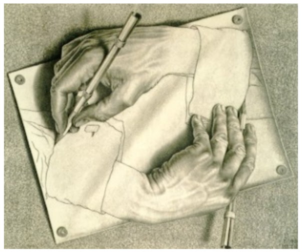
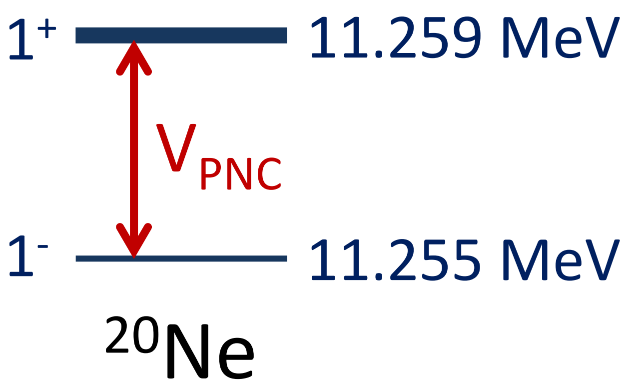
- **parity violation** in nuclear excitations: The case of $^{20}Ne$

# Parity violation in nuclear excitations: The case of $^{20}$Ne



Study level mixing in $1^{+}/1^{-}$ parity doublets

$\rightarrow$ constrain weak meson-nucleon coupling

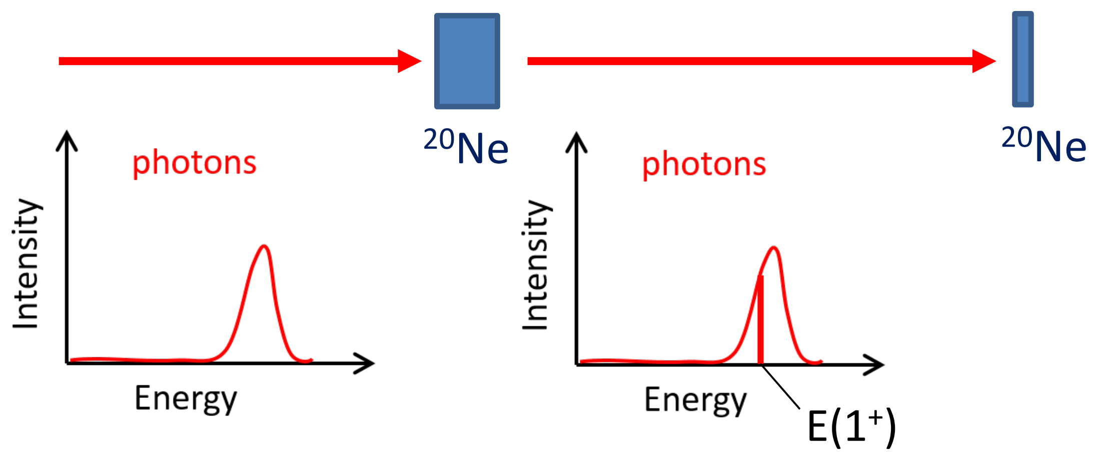


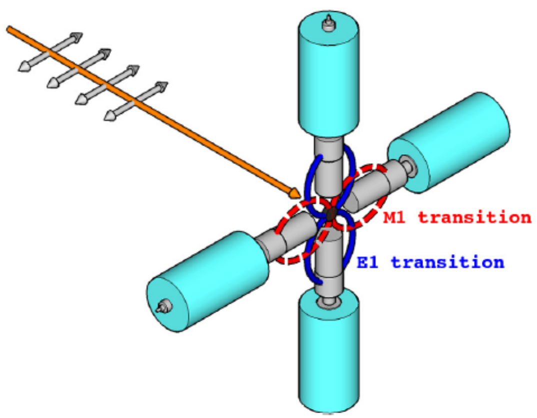

$V_{PNC} \equiv$ parity non-conserving interaction (about 1 eV)

# Parity violation in nuclear excitations

## ELI-NP:

- nearly 100% polarized $\gamma$ beam
- thick $^{20}$Ne absorber in front of target removes photons to excite broad $1^+$ state, because $\sigma(1^+) \approx 30 \bullet \sigma(1^-)$
- only $1^-$ state of doublet is excited by remaining photons
- measure M1 admixture to E1 excitation by analyzing NRF events in detector perpendicular to beam axis



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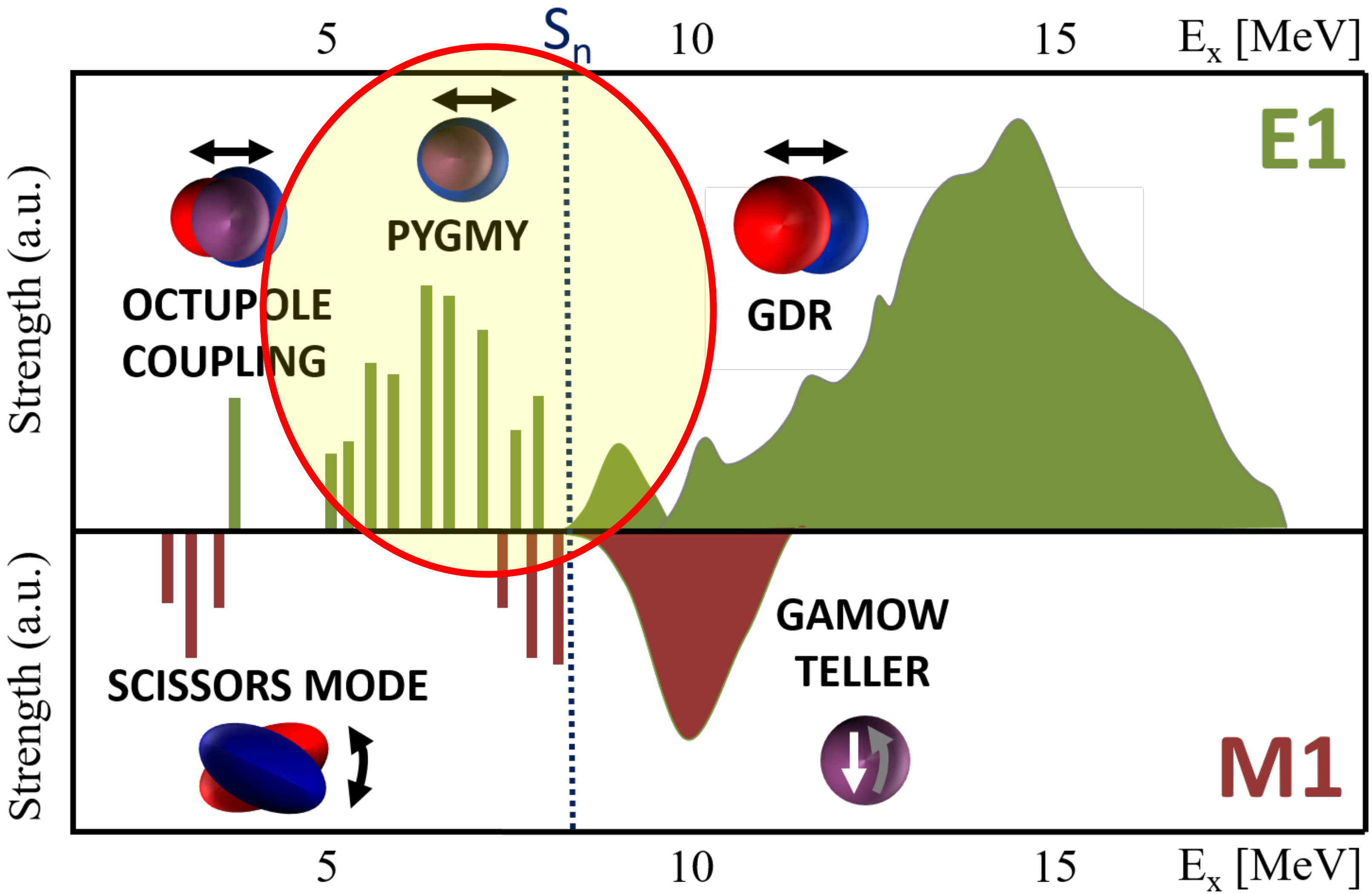
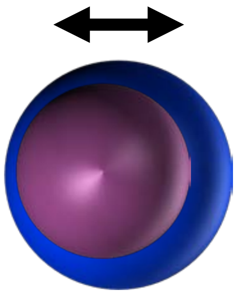
- **parity violation** in nuclear excitations: The case of $^{20}Ne$
- an access to the **equation of state** and to neutron-rich matter: Investigation of the Pygmy Dipole Resonance

# An access to the equation of state and to neutron-rich matter: The Pygmy Dipole Resonance




*D. Savran, T. Aumann, and A. Zilges, Prog. Part. Nucl Phys.* ***70*** *(2013) 210*

# An access to the equation of state and to neutron-rich matter: The Pygmy Dipole Resonance



Neutron skin oscillates against neutron/proton core

→ electric dipole mode (E1) around 5-10 MeV

→ impact on nucleosynthesis, EOS, neutron skin
(see talk by Dan Watts)

**ELI-NP:**

- narrow bandwidth allows single state excitation
  → measure, e.g., branching ratios to excited states
- high intensity and small beam diameter
  → study E1 distribution in rare isotopes

*D. Savran, T. Aumann, and A. Zilges, Prog. Part. Nucl Phys.* ***70*** *(2013) 210*

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- proton-neutron **symmetry breaking**: Rotational $2^+$ states of the nuclear scissors mode
- the **origin of matter**: Studies of the photoresponse of low-abundant *p* nuclei
- photons and **radioactive isotopes**: Electric and magnetic dipole response of unstable nuclei

# Applications of photonics at ELI-NP


**HEU Grand Challenge**
*detection of shielded material*


**Medical Imaging**
*low density & isotope specific*


**Waste Imaging & Assay**
*non-invasive content certification*

*Courtesy: Chris Barty (LLNL)*

# Nuclear Photonics – opportunities for photonuclear reactions at the ELI-NP facility

D. Balabanski, J. Beller, B. Boisdeffre, V. Buznea, F. Camera, M. Cernaianu, V. Derya, D. Filipescu, I. Kojouharov, B. Löher, C. Matei, C. Mihai, G. Pascovici, C. Petcu, N. Pietralla, C. Romig, D. Savran, G. Suliman, P. Thirolf, E. Udup, C.A. Ur, H. Utsunomiya, V. Werner, N.V. Zamfir, A.Z.

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