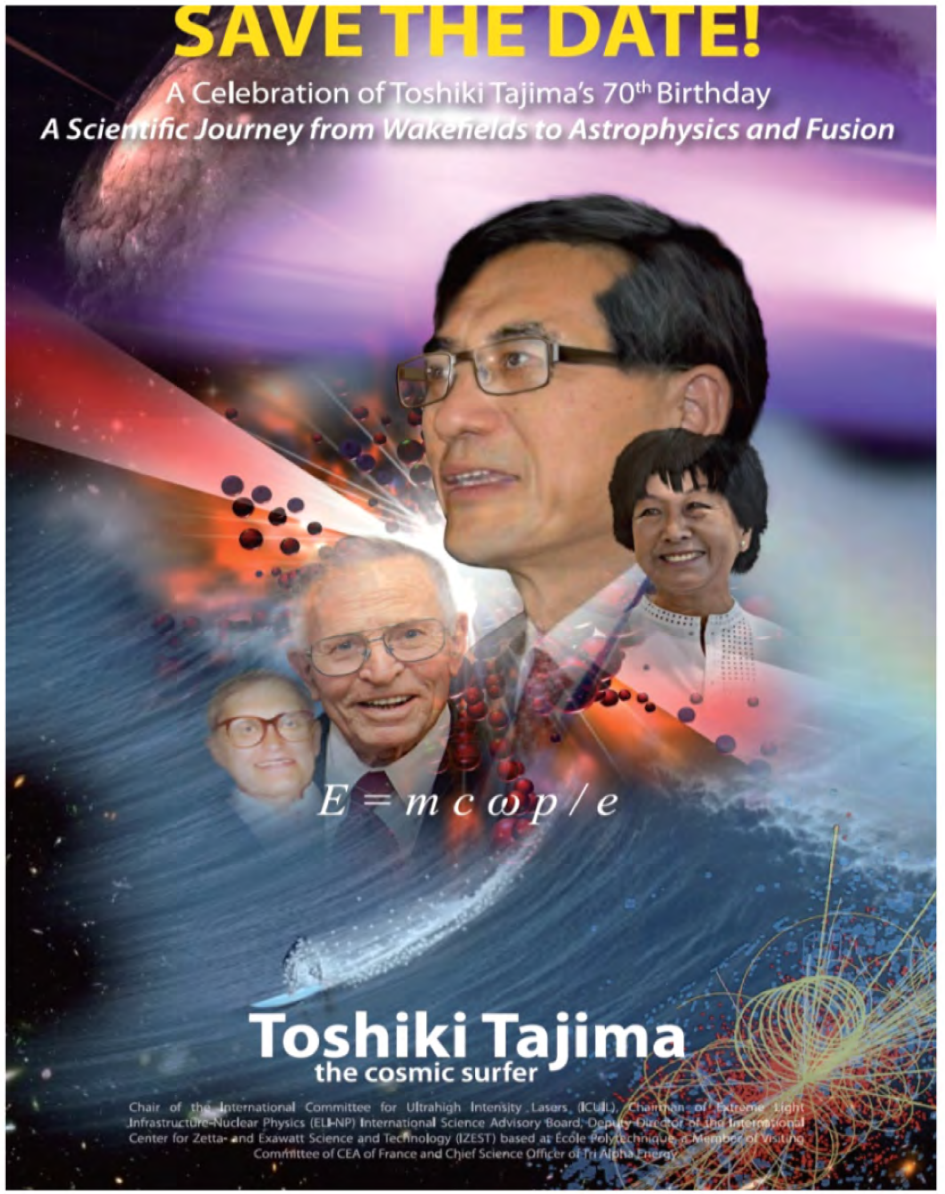
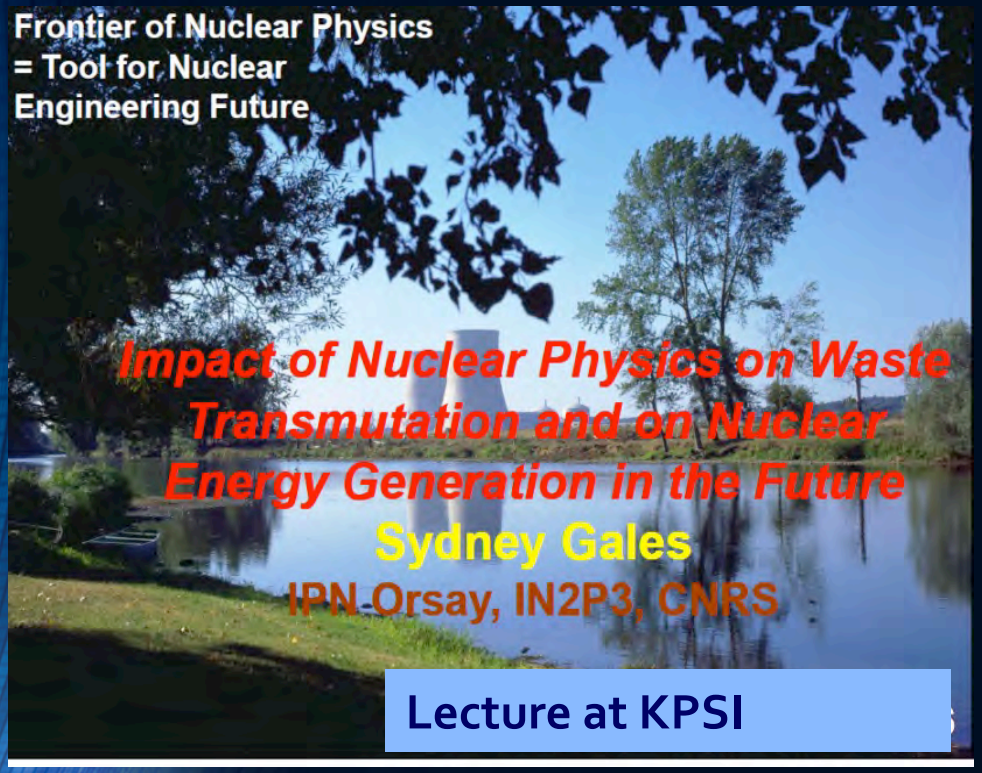
European Nuclear Physics Long range plan
Perspectives of Nuclear Science and its applications with Multi PW Lasers and Multi-MeV brilliant gamma beams.

Sydney Galés
IPN Orsay –IN2P3/CNRS(Fr)
&
ELI-NP



First encounter with Toshi at Kansai Institute 2004

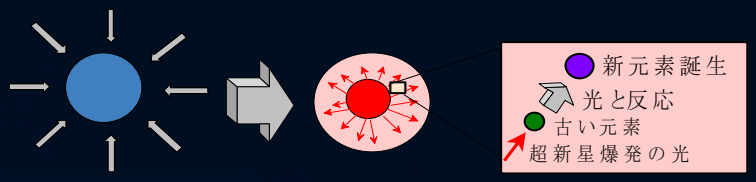


June 18, 2004

Marriage between Laser and Accelerator :
Frontier by the Merge of the Two

Toshi Tajima
Kansai Research Establishment
Japan Atomic Energy Research Instit

Nuclear Science using Laser



Collapse of heavy stars | SN explosion | Photonuclear synthesis

Transmutation by ADS and also by photonuclear processes

Then .....until 2013

Magurele, Bucarest ,RO on Jan 30 ,2013

ELI-NP Scientific Director position Interview
Selection Committee chaired by T.Tajima with G.Mourou

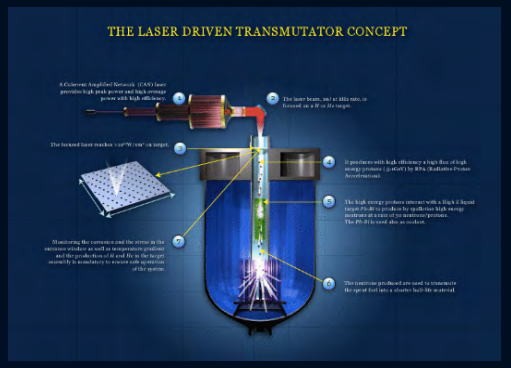
TDR's workshop and ISAB Chair –T. Tajima Reports 2015-2016

IZEST International Zeta-Exawatt Science Technology

IZEST Meetings Workshops

Laser and Accelerator

Transmutation of Nuclear Waste



Medical applications

What is NuPECC ?

The European Expert Board
for Nuclear Physics
associated to ESF

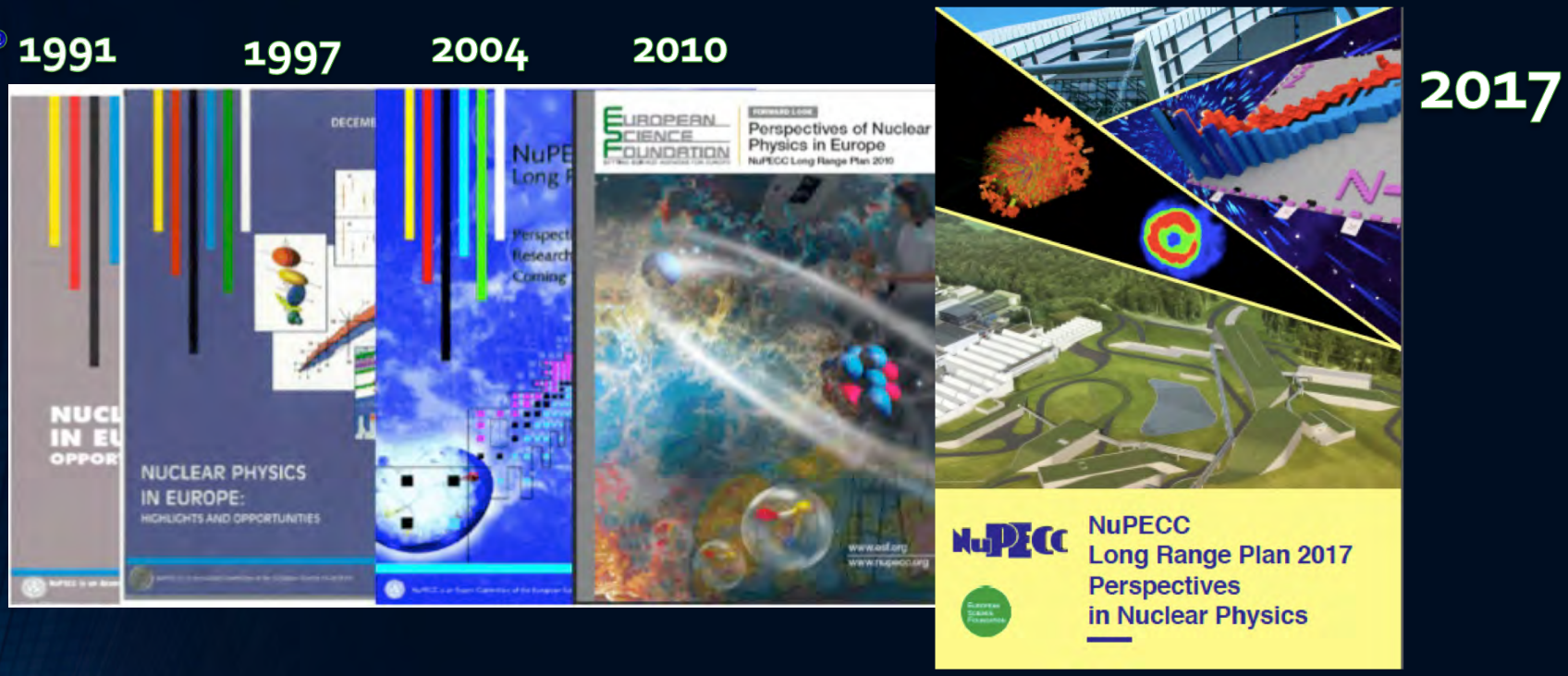
Representing
about 6000 scientists

Members: 31 institutions
from 21 countries
JINR Dubna also joined

Main mission is
strategy at European scale
for the field
Nuclear Physics news (4/years 6000 copies- 27 years)

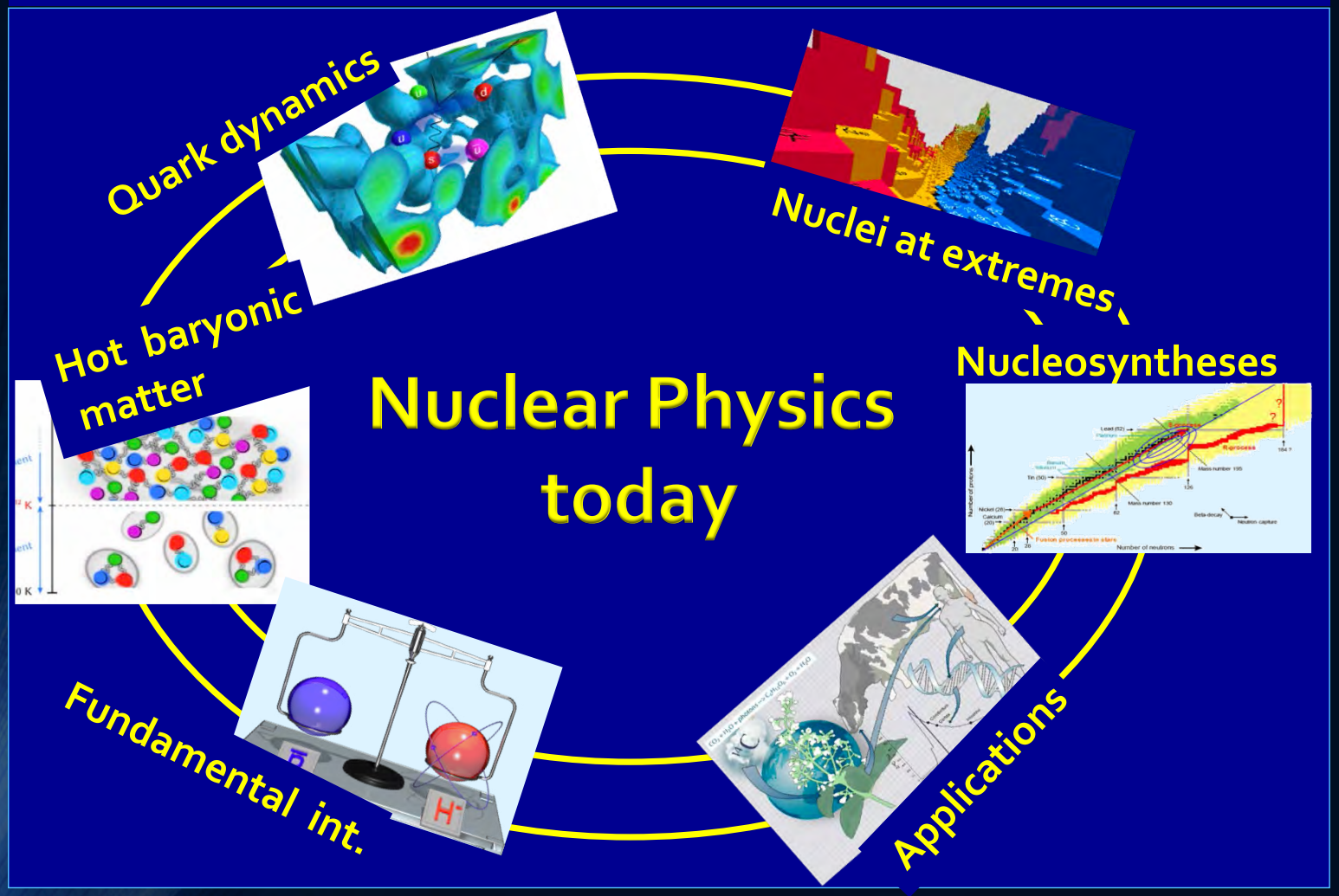
What is the Long range plan of NuPECC

LRP 1991 1997 2004 2010 2017



- The LPR **identifies opportunities** and priorities for the nuclear science in Europe
- The LRP **provides** the European Commission and national funding agencies with a **framework for coordinated advances** in nuclear science in Europe

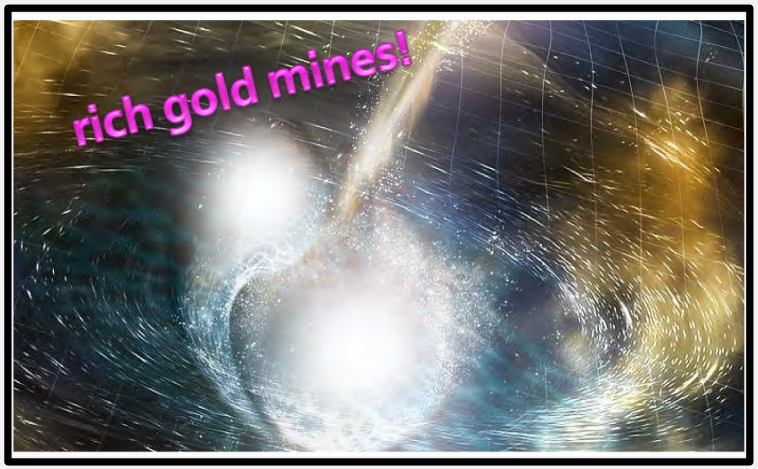
Study of nuclear matter in all its forms and exploring their possible applications

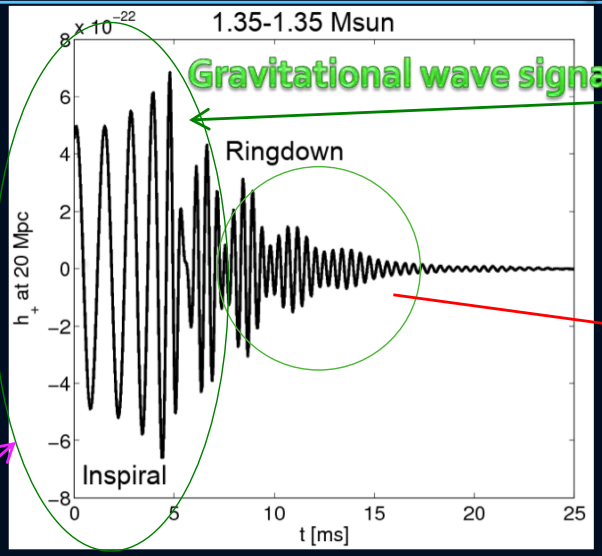


Nuclear physics is very broad !

Each area needs particular tools and technologies

Neutron star mergers: gravitational waves and production of heavy elements





Neutron star mass

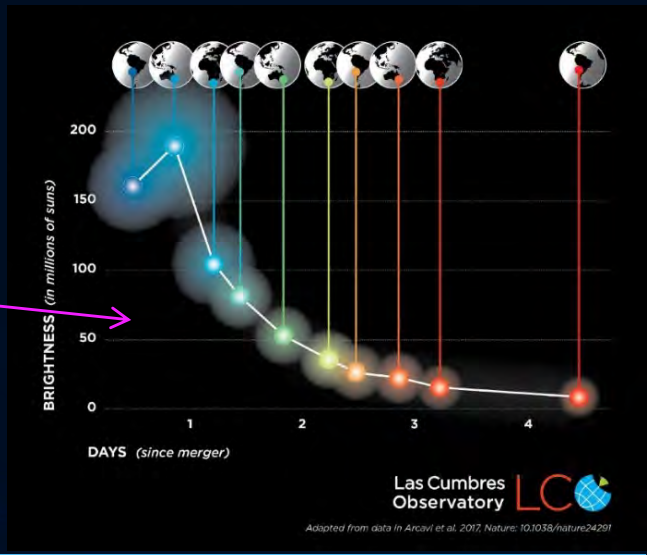
This depends on the Nuclear equation of state

The messengers from neutron star mergers :

- **Gravitational waves**
- **Electromagnetic signals characterizing the nuclei in the ejecta**
- **neutrinos**

Gravitational wave emission seen together with electromagnetic signals

Time evolution determined by the radioactive decay of r-process nuclei (science drive of facilities with RIB)



Up-coming Facilities

In Bucharest :
one pillar of the distributed facility ELI (in the ESFRI list)

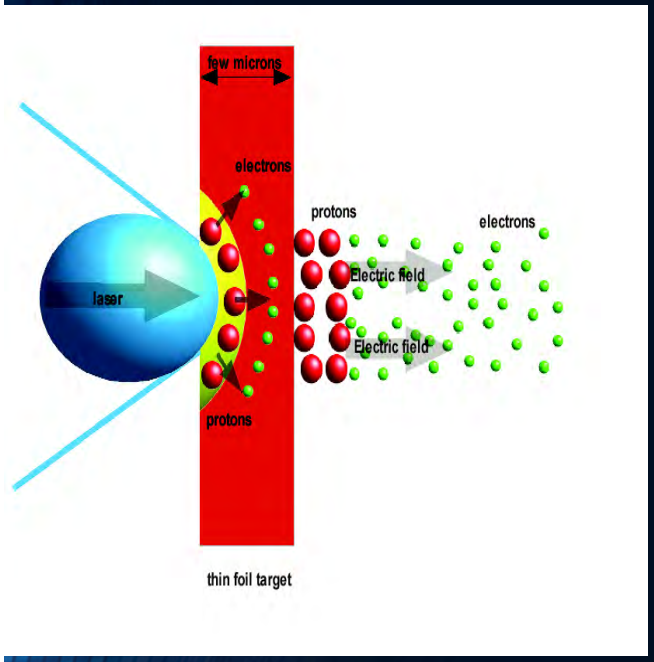
1) Ultra-short High power laser pulse
(25fs) 2 X1O PW, 1/mn

2) GAMMA beams high flux , monochromatic, Γ ~qqs10^{-3} ,
E= 0.2-19 MeV

Nuclear astrophysics-Nuclear structure-applications – **start in 2019-20**

Experimental set ups under construction-scientifique program with electromagnetic probes unique

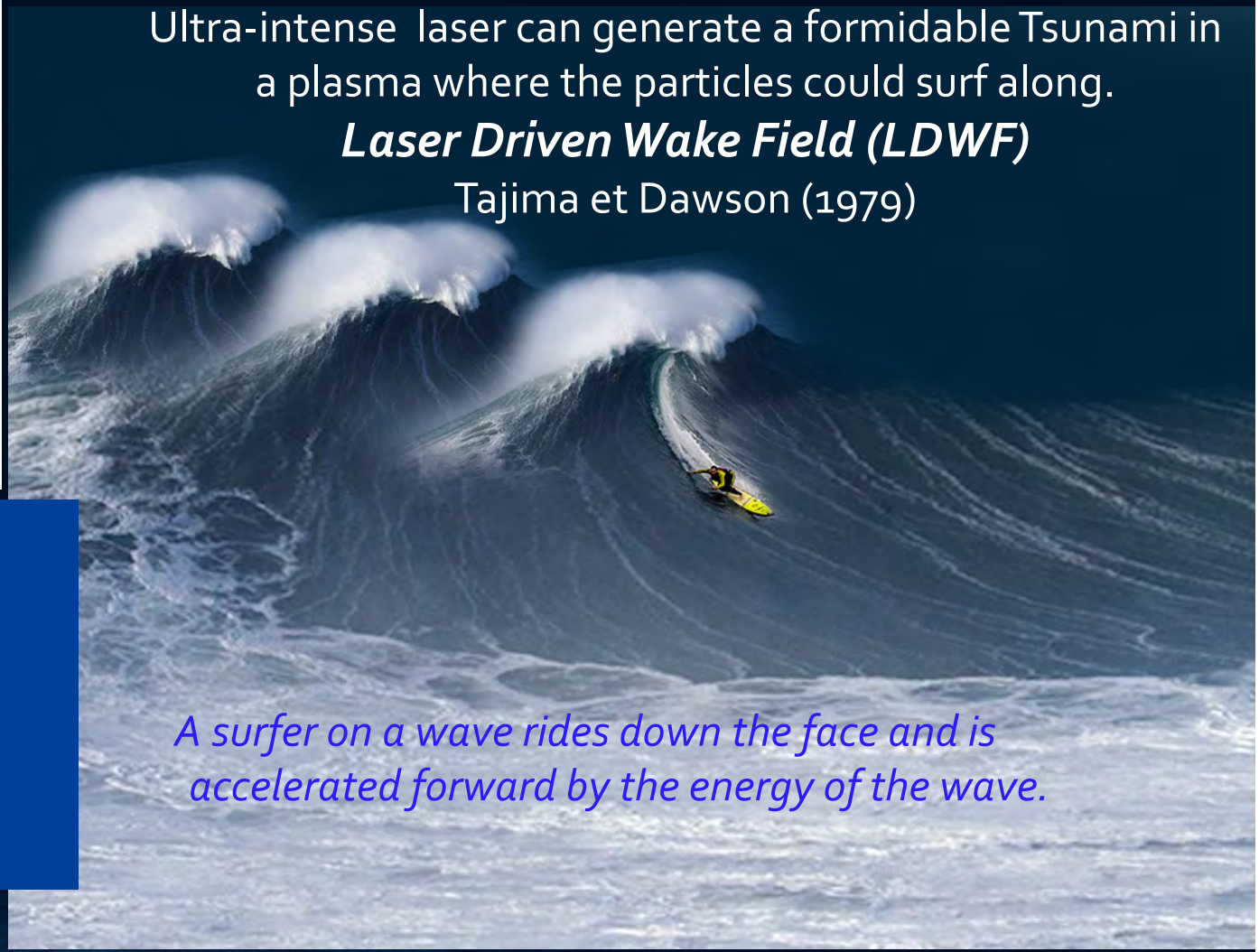
Laser Driven Nuclear Physics



Ultra-intense laser can generate a formidable Tsunami in a plasma where the particles could surf along.

Laser Driven Wake Field (LDWF)

Tajima et Dawson (1979)



A surfer on a wave rides down the face and is accelerated forward by the energy of the wave.

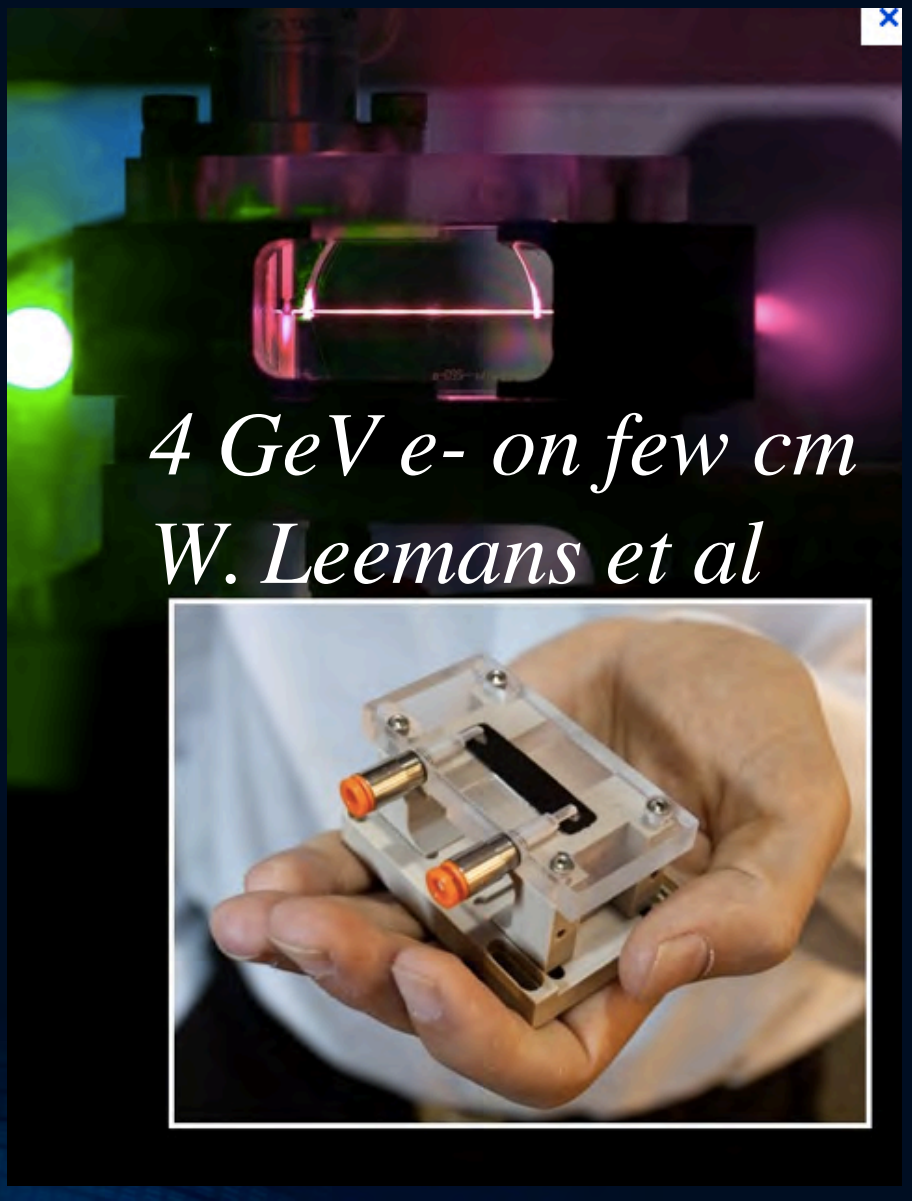
- **E -Field ~ TV/m**
- **E_e ~ Ten's of GeV in mm**
- **E_{ion} ≤ 150 MeV/u**
- **charge ~ 10's of pC**
- **DE/E ~ 1-2% (e^-)**

e~10^{-5} mm mrad

SLAC 50GeV, 3km long

Stanford Linear collider (USA)

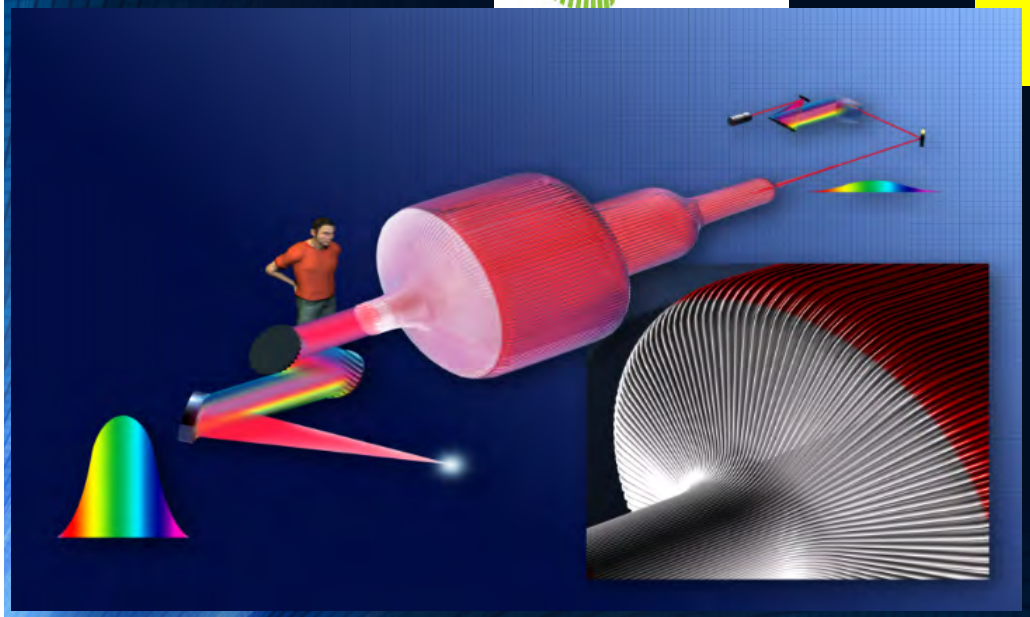
Enormous reduction in scale: GeV in the Palm



For the future, HPLS have still two handicaps
Efficiency at the grid
Repetition rate at high power

1PW HPLS Input 150KW
Output: 40J@1Hz = 40W
efficiency<10^{-3}

X-CAN
The Future is Fibre Accelerators (Nature Photonic April 2013)
IZEST(X-Polytech-CEA-ELI,…)



A Fiber Laser based CW driver would be a valuable first step !!

LASER DRIVEN Nuclear PHYSICS :

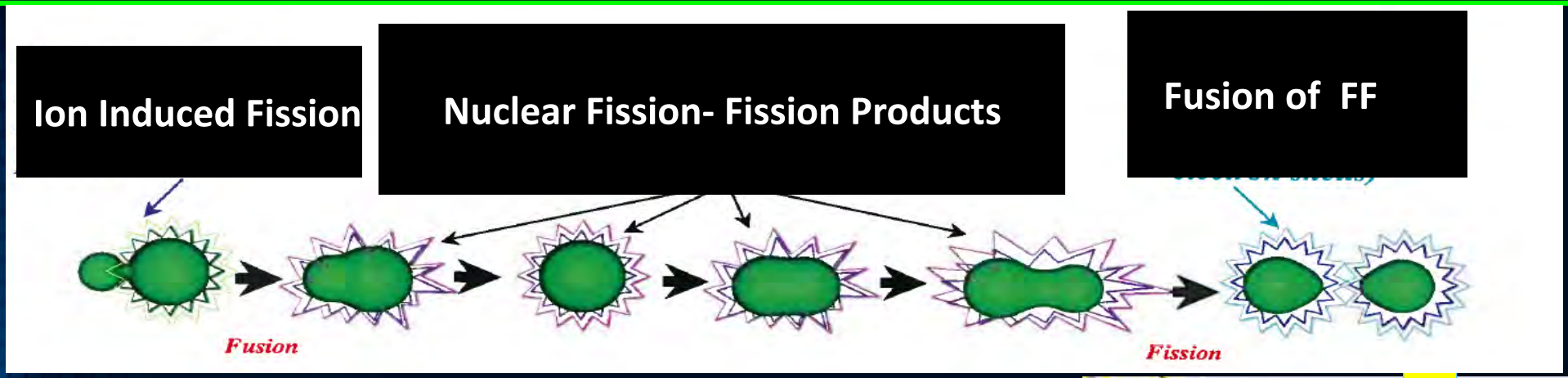
Science and Applications

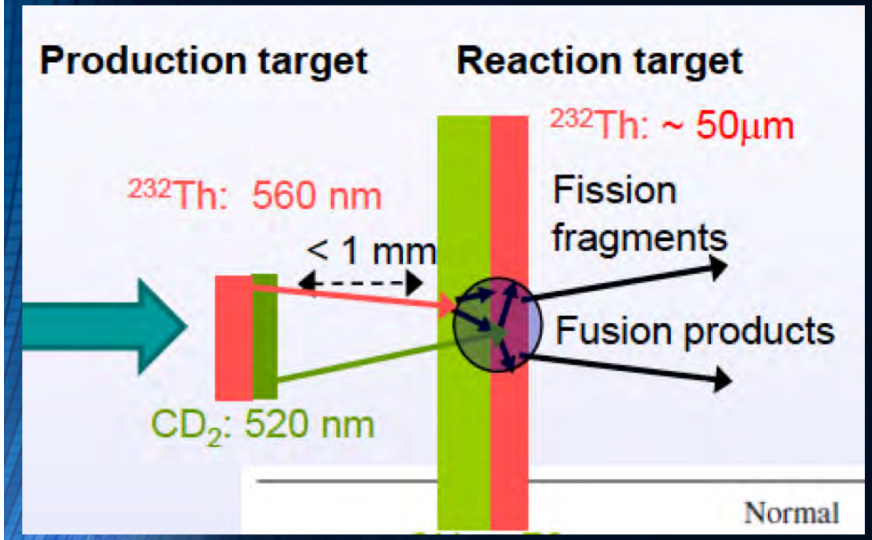
Nuclear reactions in Plasma

- interesting for astrophysics of light element nucleosynthesis (bare nuclei reactions as in stars)
- nucleosynthesis of heavy element
- lifetime changes (of isomer?) in the plasma and inverse electron capture
- Neutron production

Laser driven Fission-Fusion (Flagship expt @ELI-NP)

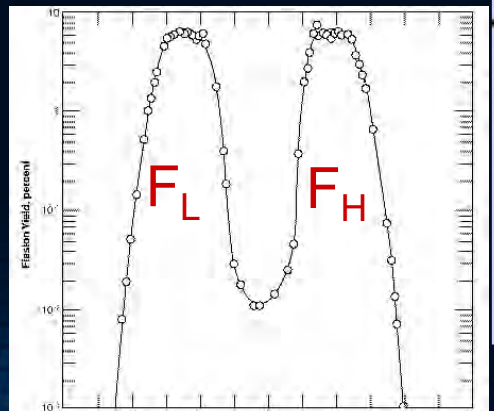
P.Thirof ,F.Negoita et al

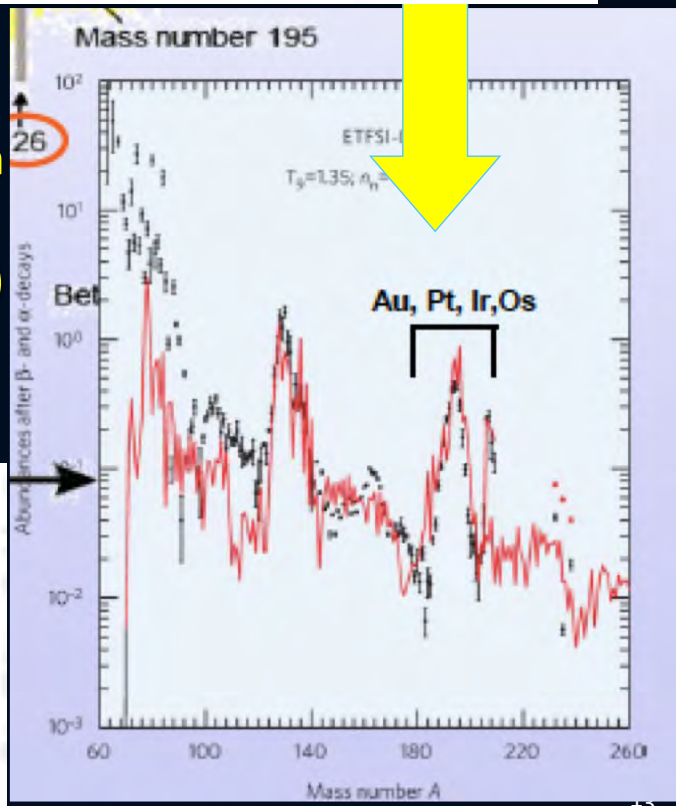




N= 126 waiting point bottleneck for

Fusion of (light) fission products : $F_L + F_L$ => (A~200, Z~70, N ~ 126)
Access to nuclei very far from stability





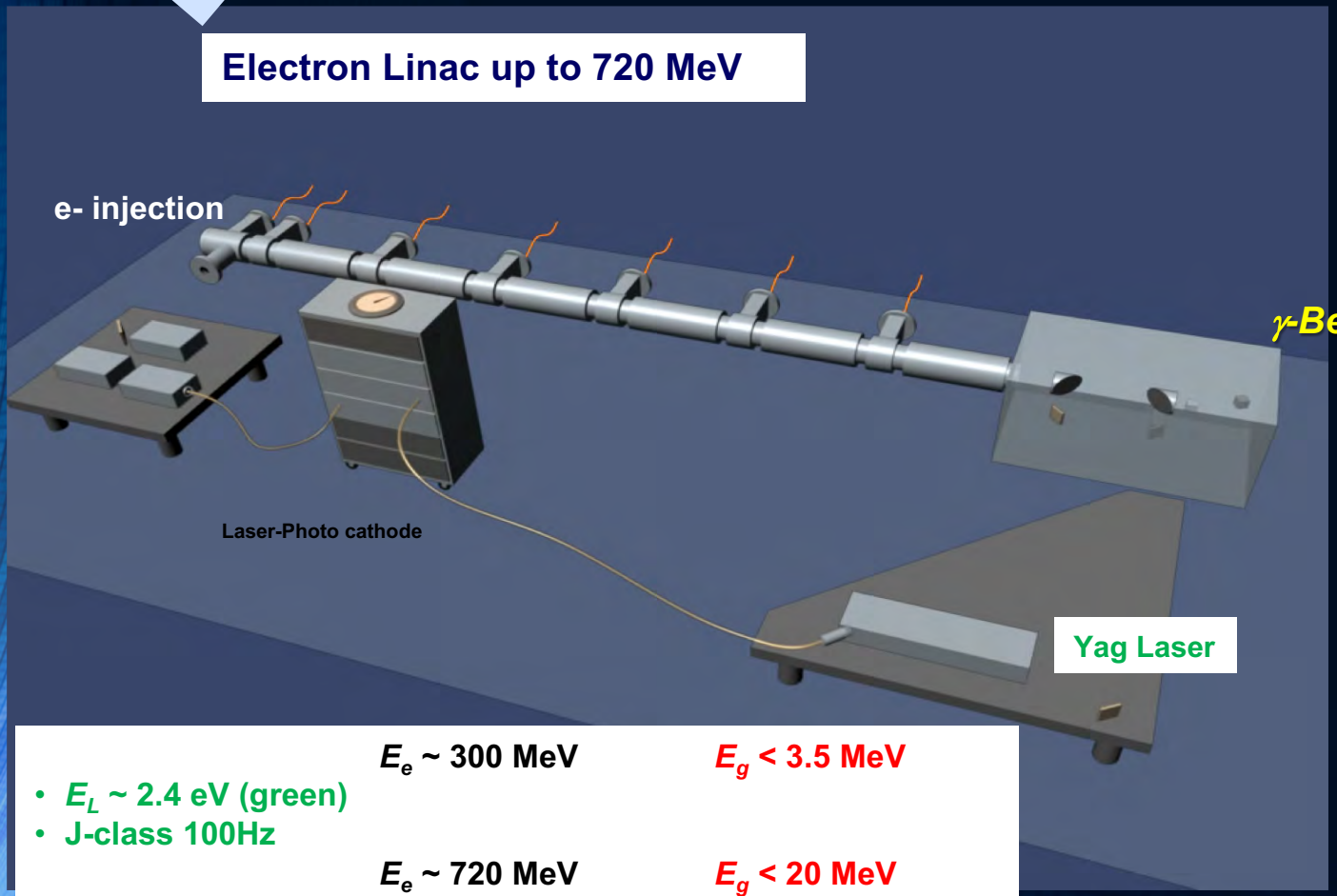
ELI–NP Gamma Beam System

A collider based on the *most advanced* components: electron accelerator and lasers ,unique in the world

Courtesy of C. Barty

EuroGammas Consortium

Istituto Nazionale di Fisica Nucleare, INFN Italy, CNRS France,Research Institutes and HighTech Companies from 8 EU Countries



- E_L ~ 2.4 eV (green)
- J-class 100Hz

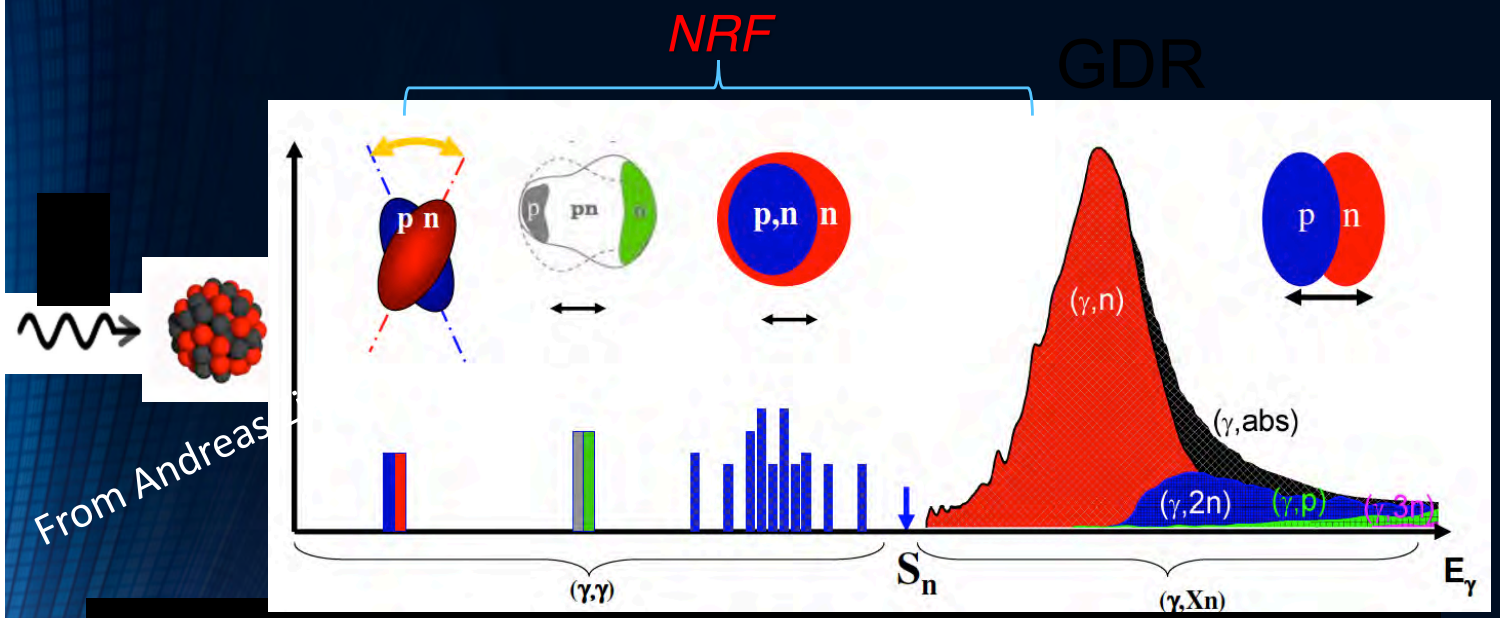
E_e ~ 300 MeV E_g < 3.5 MeV

E_e ~ 720 MeV E_g < 20 MeV

Energy (MeV)	0.2 – 19.5
Bandwidth rms (%)	≤ 0.5%
photons/sec within FWHM bdw.	≤ $8.3 \cdot 10^8$
Source rms size (mm)	10 – 30
Linear polarization (%)	> 99
Macro rep. rate (Hz)	100
# pulses per macro pulse	32
Pulse–to–pulse separation (nsec)	16

Experiments with high-brilliance gamma beams at ELI-NP

Electromagnetic dipole response of nuclei



From Andreas

Nuclear Resonance Fluorescence (NRF)

Giant/Pigmy Resonances (GANT) ; Decay channels

Photonuclear reactions (γ,n), (γ,p), (γ,α) and Astrophysics

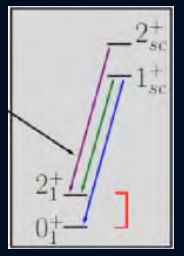
Photofission (γ,ff)

Availability frontier

***p*-nuclei and actinides**

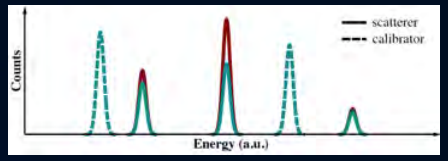
Sensitivity frontier

weak channels



Precision frontier

high statistics



Astrophysics on Earth@ELI-NP with Gamma Beams

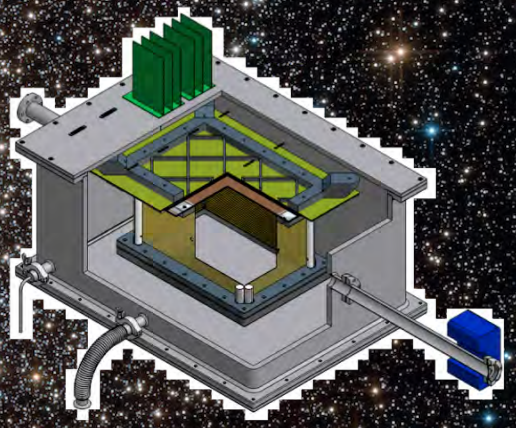
- **How the elements are made in the Cosmos**
- **–a central question for Astrophysics**

C,N,O elements essential for the emergence of life
Carbon Nuclear process 3 x 4He ------12C
Oxygen Nuclear reaction 12 C+4He---16O

Determination of the reaction rates by an absolute cross section measurement is possible in the lab with the **mono-energetic photon beams produced at ELI-NP**

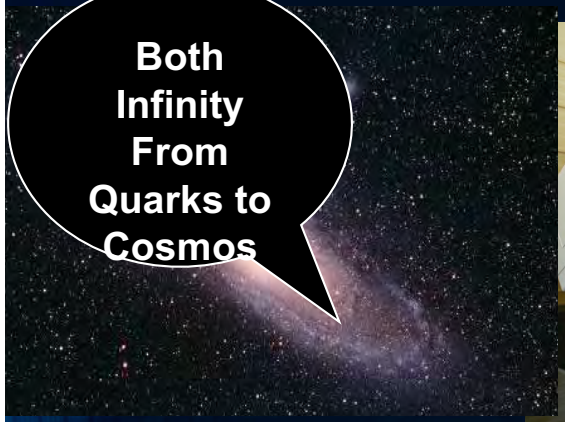
$\gamma + {}^{12}C \longrightarrow 3\,\alpha$

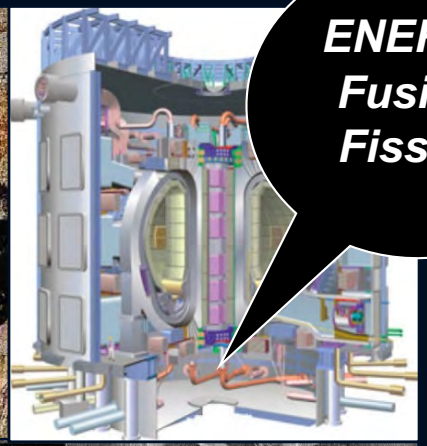
${}^{16}O + \gamma \longrightarrow {}^{12}C + \alpha$

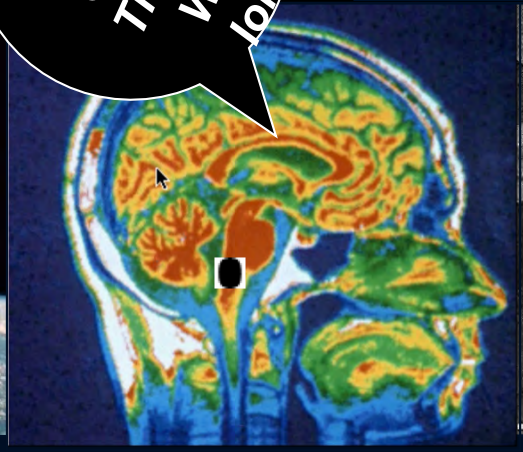


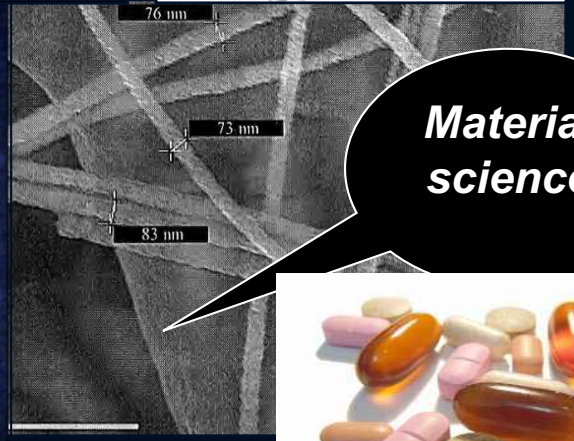
New 3D Camera to observe these processes

Tremendous advance to measure these rates directly- very high intense γ beam needed @ELI-NP



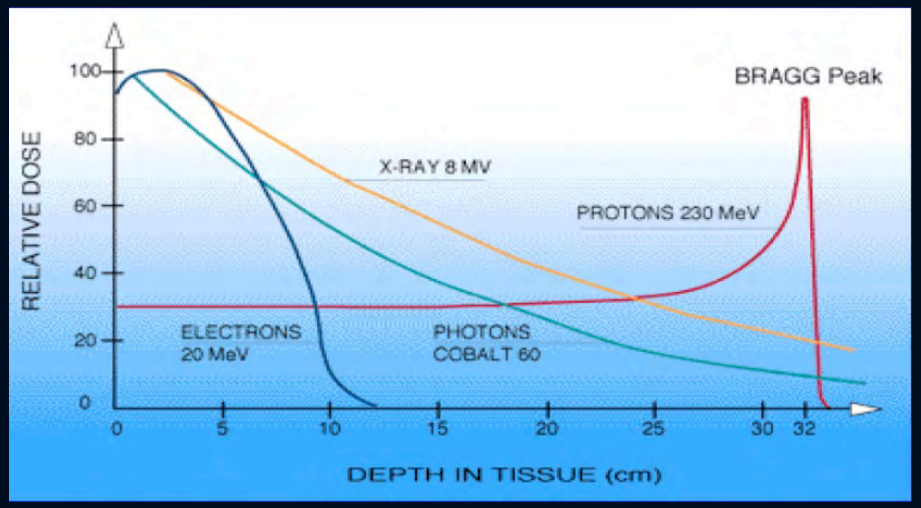




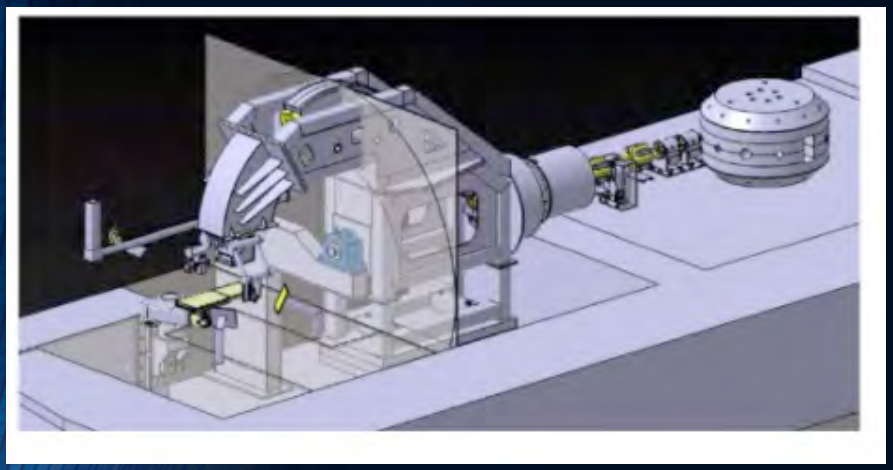


Multi-PW Lasers &Multi-MeV GBS like ELI-NP are Research Infrastructure Facilities where basic research as well as applied research are interacting to generate innovations for our daily life

Laser Driven Proton therapy

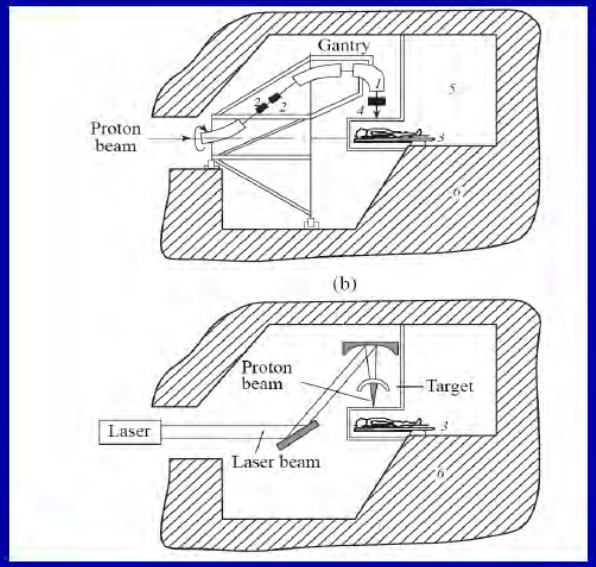


Sate of the art Proton cyclotron 250 Mev



Protheus one IBA 13X14X27 m3

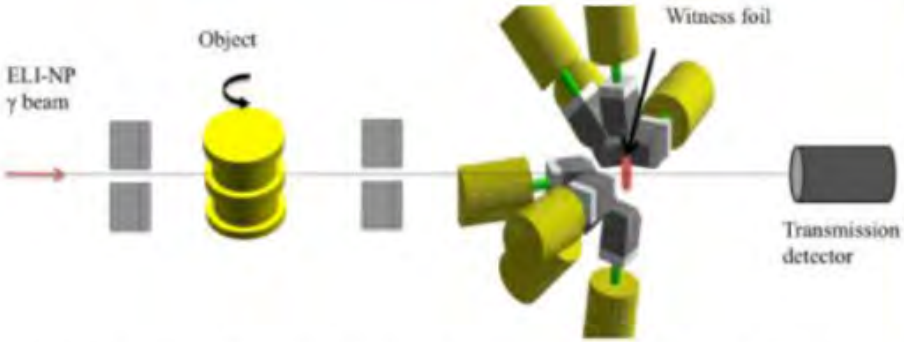
- If 200 MeV proton accelerators would be as cheap and small as the 10 MeV electron linacs used in conventional radiotherapy, at least 90% of the patients would be treated with proton beams.



Gantries for conventional accelerator 100 tons and an optical gantry which is very compact, light using mirrors

Security applications

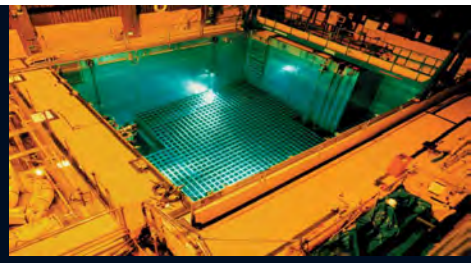
Need to enhance capabilities against CBRNE (chemical, biological, radiological, nuclear, explosives) threats



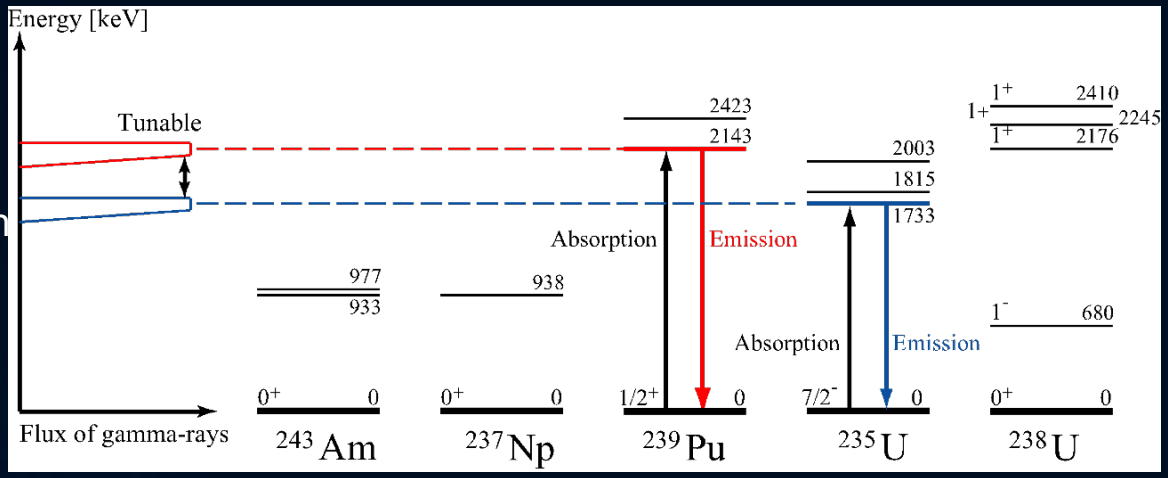
Detection of special nuclear materials hidden in high-density matrices could be achieved at ELI-NP in less than two minutes

- **Interrogation methods**
  - n or γ sources, muons
- **Improved radiation detection systems**
  - Detection of γ, prompt or delayed n
  - New high-light yield scintillators (ex $LaBr_3$, SrI_2…)
  - Lightweight detectors
- **Nuclear data**
  - Photonuclear reactions
- **AMS**

Gamma Beam Applications To Nuclear Materials

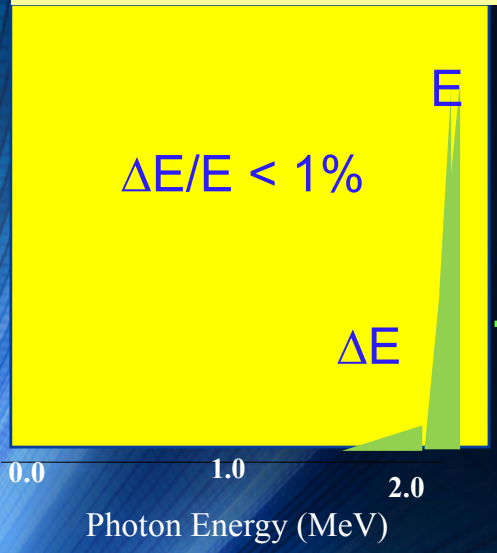


Mono-Chromatic Tunable GBS from ELI-NP

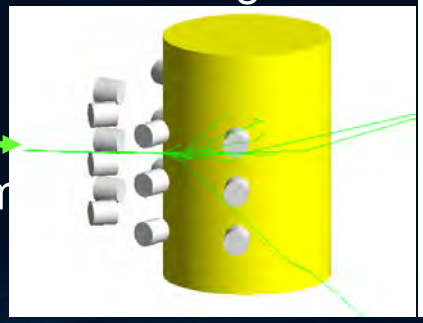


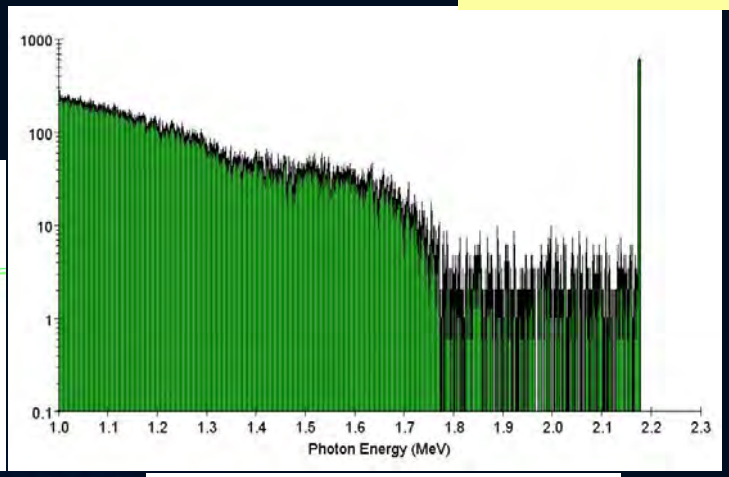
NRF signal U-238 2.176 MeV

2.176 MeV for U-238



γ-ray beam





Photon energy (MeV)

• *NUCLEAR ENERGY :GLOBAL FACTS*

A rather young form of energy, of limited importance at the world level (5%, 0.67GTeP),economically viable source of electricity (2400TWh,12%), Carbon free !!

Production concentrated in a few countries (USA+FR+J+Ru)

2/3 of the world

A passionately contested energy for

Its origin related to defense, Its cost structure (high investments ,delayed returns)

Questions insufficiently dealt with in the past:

Proliferation (Pu mostly) , Safety and Nuclear waste management

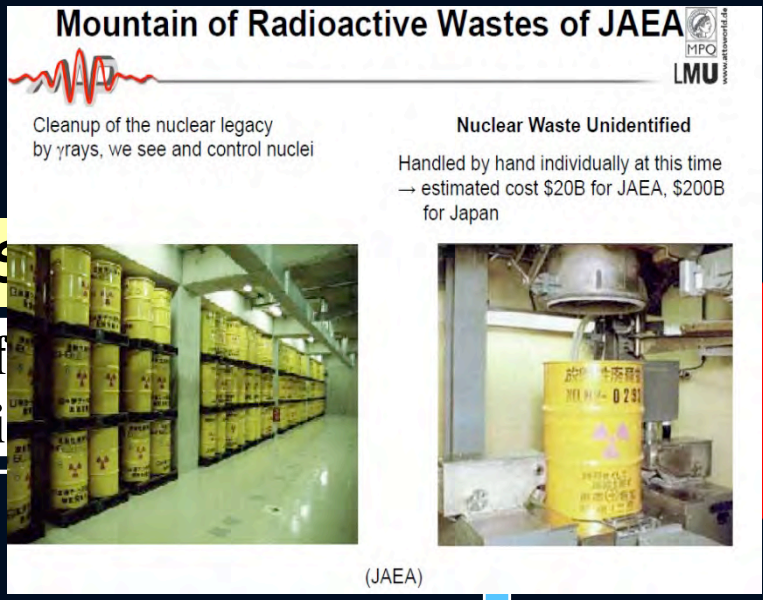
These questions generate social concerns for the future

Management of current waste
Two types of waste policies

U ore 200t → enriched U 30t → PWR

Once-through case (US

1GWe.yr=1t of fissioned materi



Geological storage of spent fuel ?????

U ore → enriched U → PWR

Pu recycling(Fr,J)

- Once-through Pu recycling
- possibility of multirecycling

U, Pu (MOX)

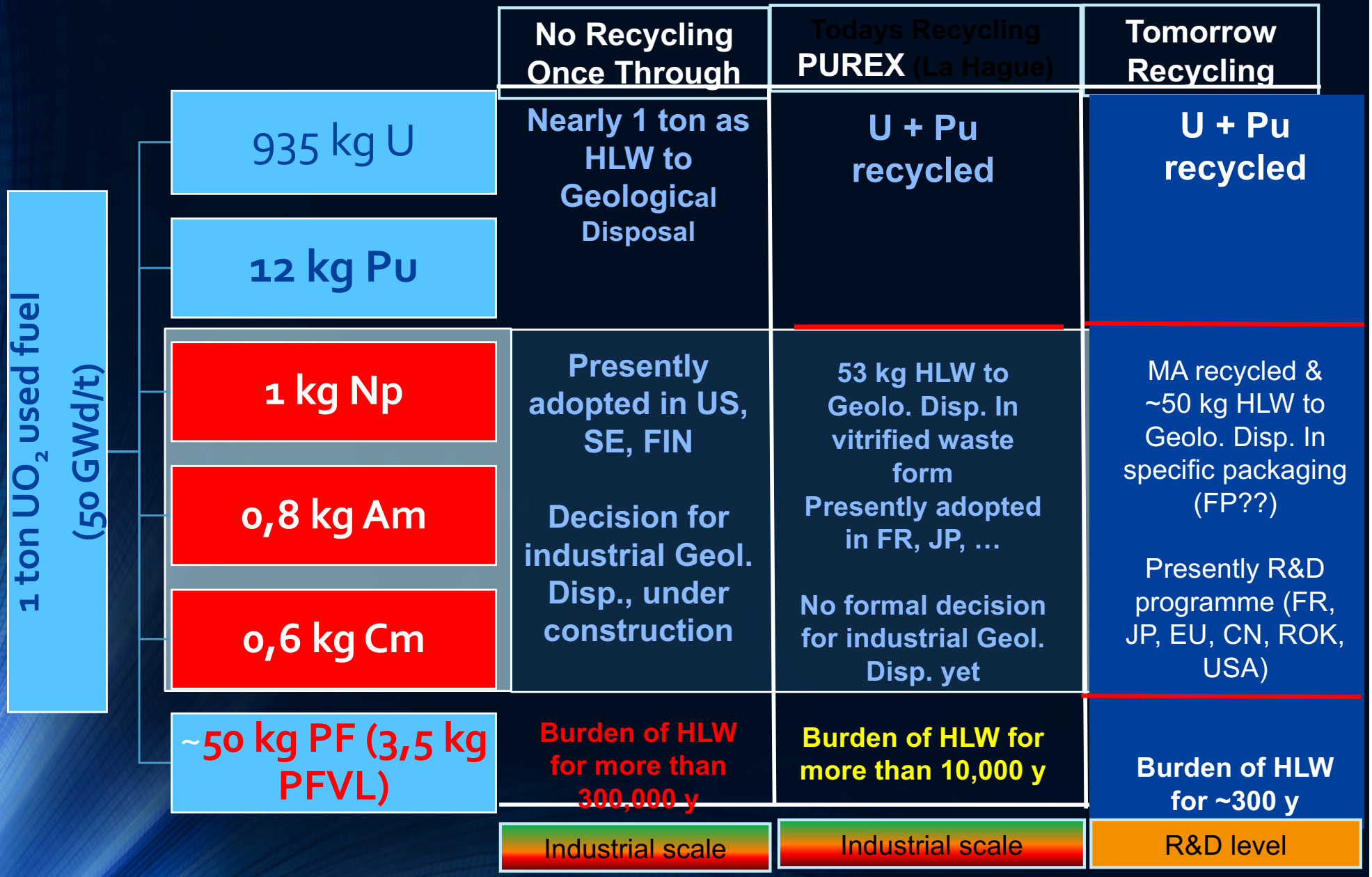
Reduction of final waste

U,Pu precious fuel!!!

Waste:
- Fission products
- 0.1% Pu
- 100% Np, Am, Cm

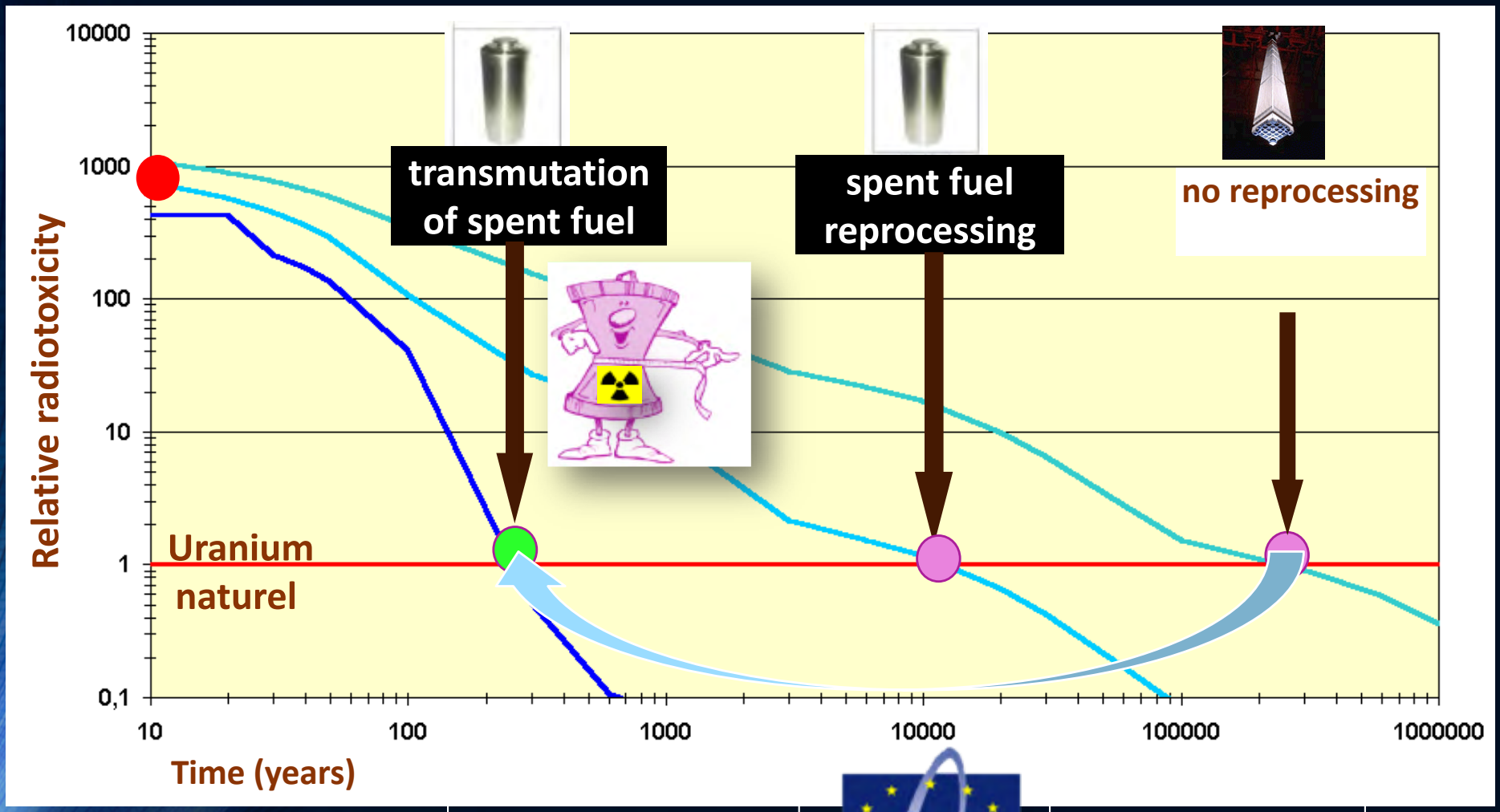
Partition &Transmutation

Fuel Cycle for High Level Waste ??



Nuclear Energy
Motivation for transmutation

1GWe.yr=1t of fissioned material



Duration Reduction 1.000x

Volume Reduction 100x

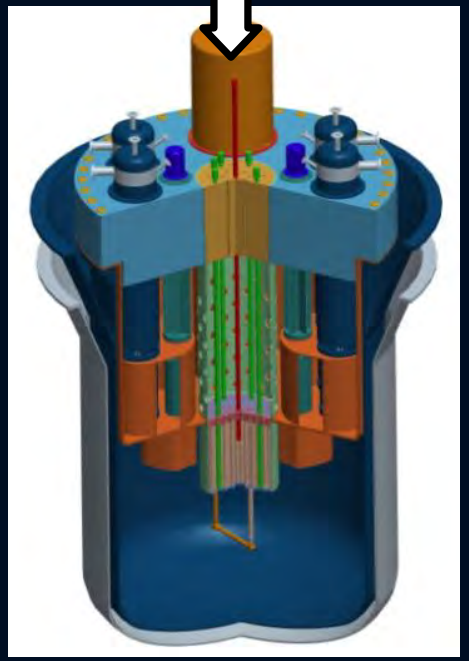
MYRRHA - Accelerator Driven System
ESFRI List EU-Roadmap 2010

Accelerator	
particles	protons
beam energy	600 MeV
beam current	2.4 to 4 mA
mode	CW
MTBF	> 250 h

Reactor	
power	~85 MW_{th}
k_{eff}	0.95
spectrum	fast (flexible)
fuel	30 to 35% Pu MOX
coolant	LBE

- Demonstrate the **ADS concept** (coupling accelerator + spallation source + power reactor)
- Demonstrate **Transmutation** (experimental fuel assemblies)
- Fast neutron source

Target	
main reaction	spallation
output	**$2 \cdot 10^{17}$ n/s**
material	LBE (coolant)
power	2.4 MW



Transmutation independent of Nuclear Energy future
(Go on , Stop, New , all needs to deal with the waste!!)
ADS system is very demanding , 400 m Long 1 -2 B€!!

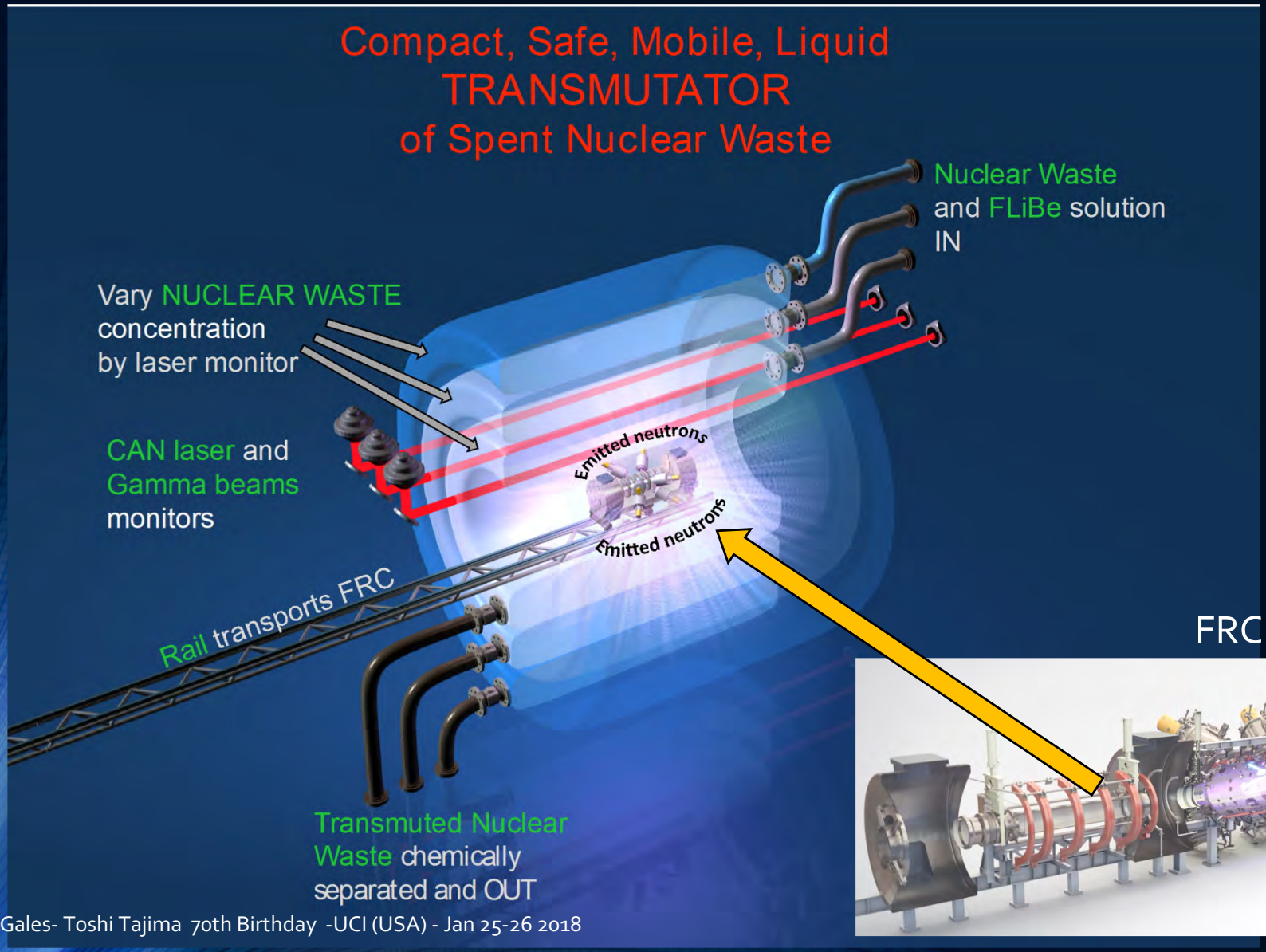
A new concept for transmutation
T. Tajima, A. Necas, S.Gales, G. Mourou, M.Leroy,...

Introduce TAE fusion neutron generation technology:
compact, cheap, mobile
Combine with: monitoring by laser and gamma
in transparent liquid transmuation process

T. Tajima 2017

Fusion-triggered Liquid-phased Transmutator Monitored and Controlled Real-time by CAN Laser and Gamma beams

- A. Necas, T. Tajima, S. Gales, K. Hatfield, G. Mourou, M. LeRoy, J. Tanner and the Entire TAE Team



Toshi
Happy Birthday !
My best wishes for the next decades of creative and successful life among your dear ones