EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments
2007-2013

Sectoral Operational Programme
„Increase of Economic Competitiveness"
"Investments for Your Future"

Extreme Light Infrastructure – Nuclear Physics (ELI-NP)
Project co-financed by the European Regional Development Fund

Nuclear Physics Experiments with High-Power Lasers and Brilliant Gamma Beams at the ELI-NP Facility

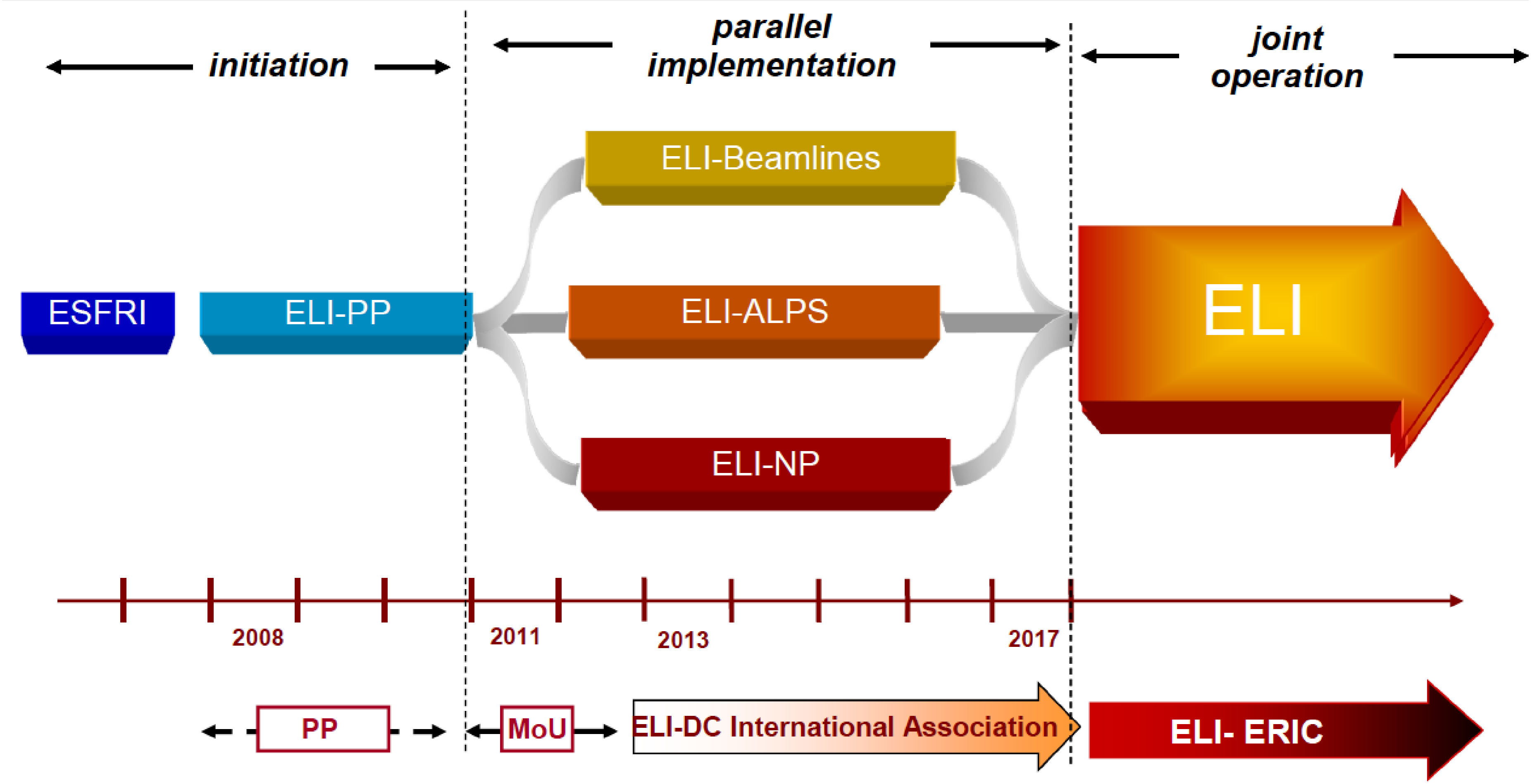
Dimiter L. Balabanski

Reflections on the Atomic Nucleus, Liverpool,
August 28th-30th, 2015

Extreme Light Infrastructure – Nuclear Physics

Mission: Nuclear Physics studies with high-intensity lasers and brilliant γ beams

ELI Road Map

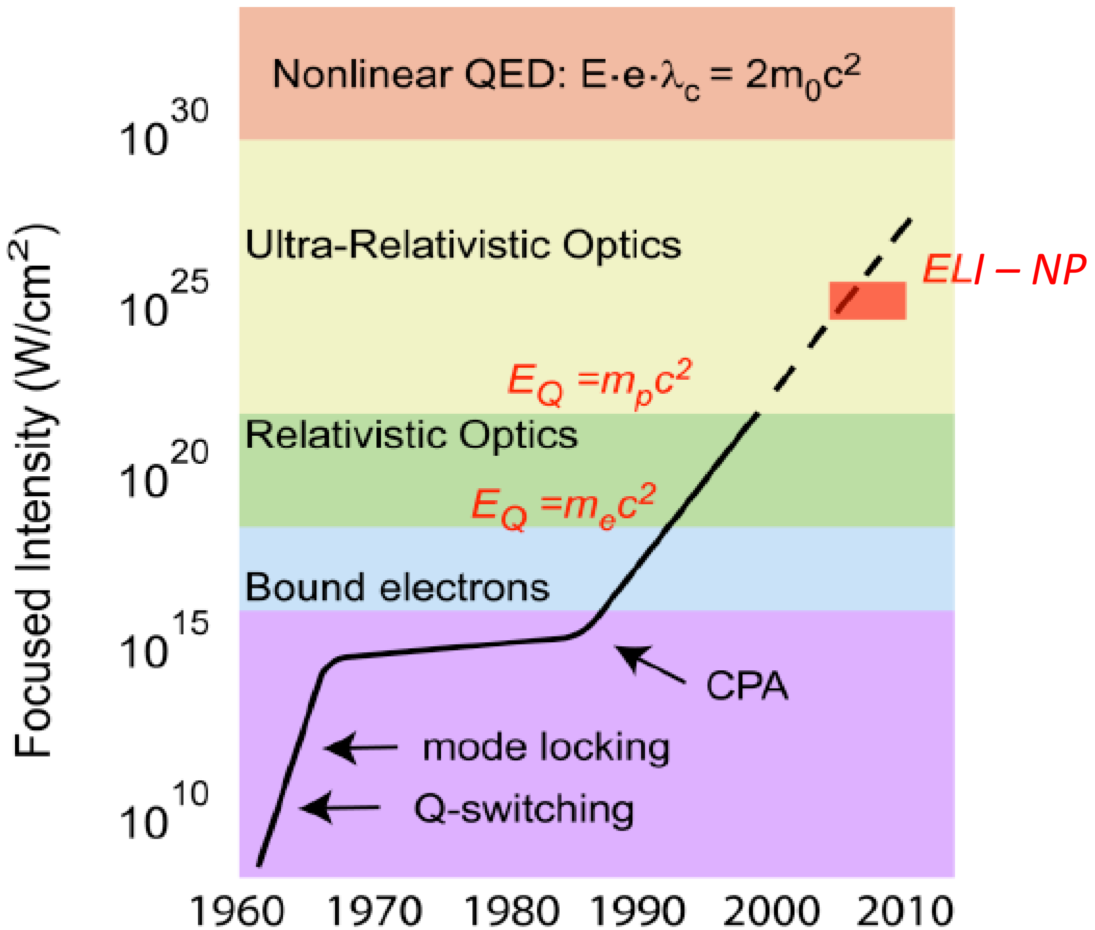


W. Sandner, ELI DC

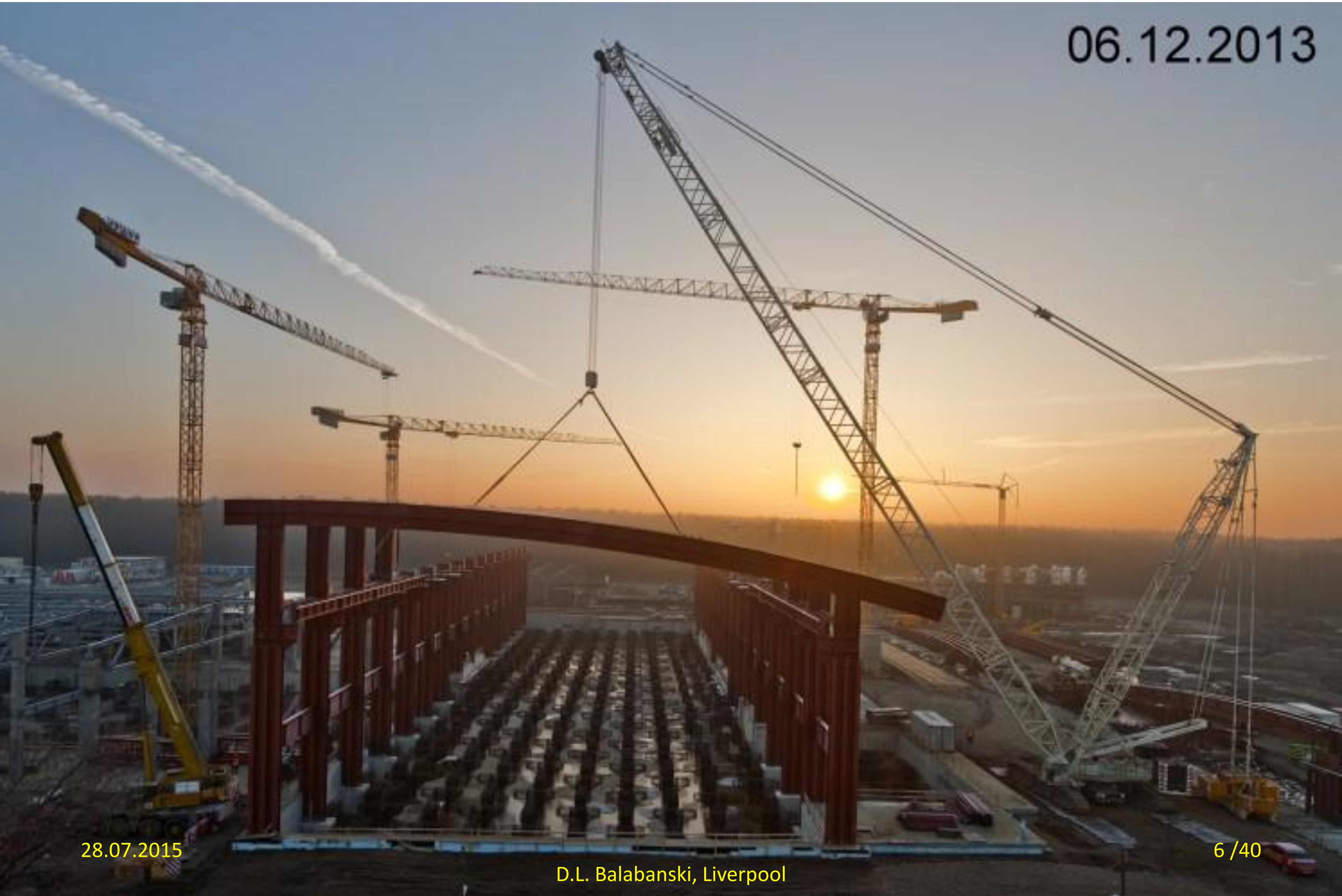
Extreme Light Infrastructure (ELI)

Gerard Mourou 1985: Chirped Pulse Amplification (CPA)

Strickland, Mourou, Opt. Commun. 56, 219 (1985)



June 7th, 2013

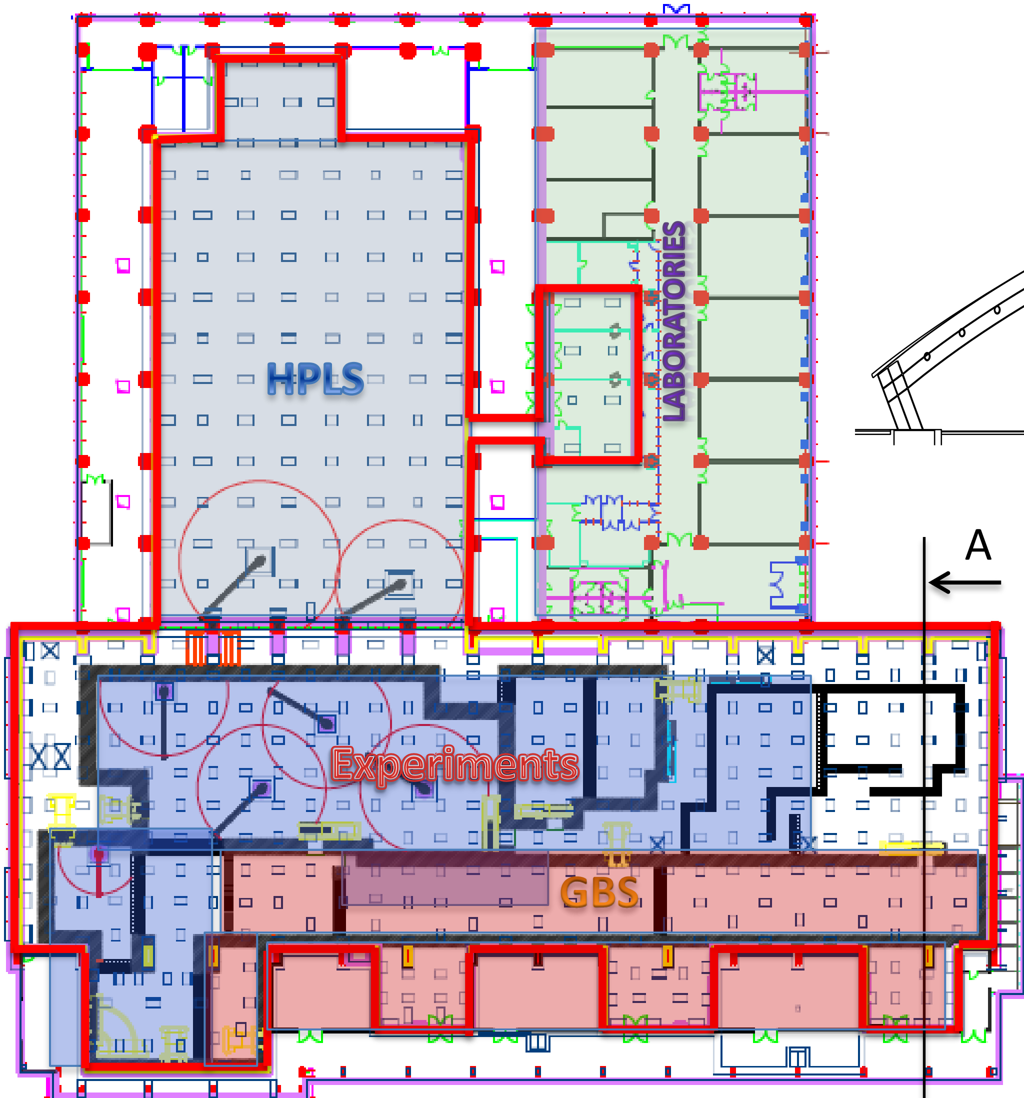

06.12.2013

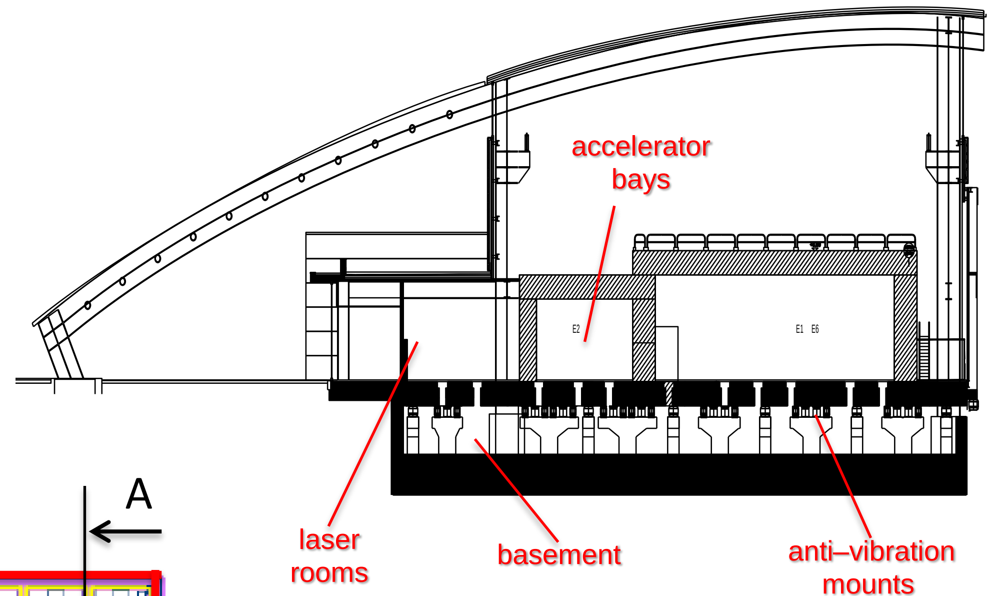

01.10.2014

Buildings – one contractor, 33000 m² total

- Experimental area building
- Office building
- Guest house
- Canteen

ELI–NP Building Structure

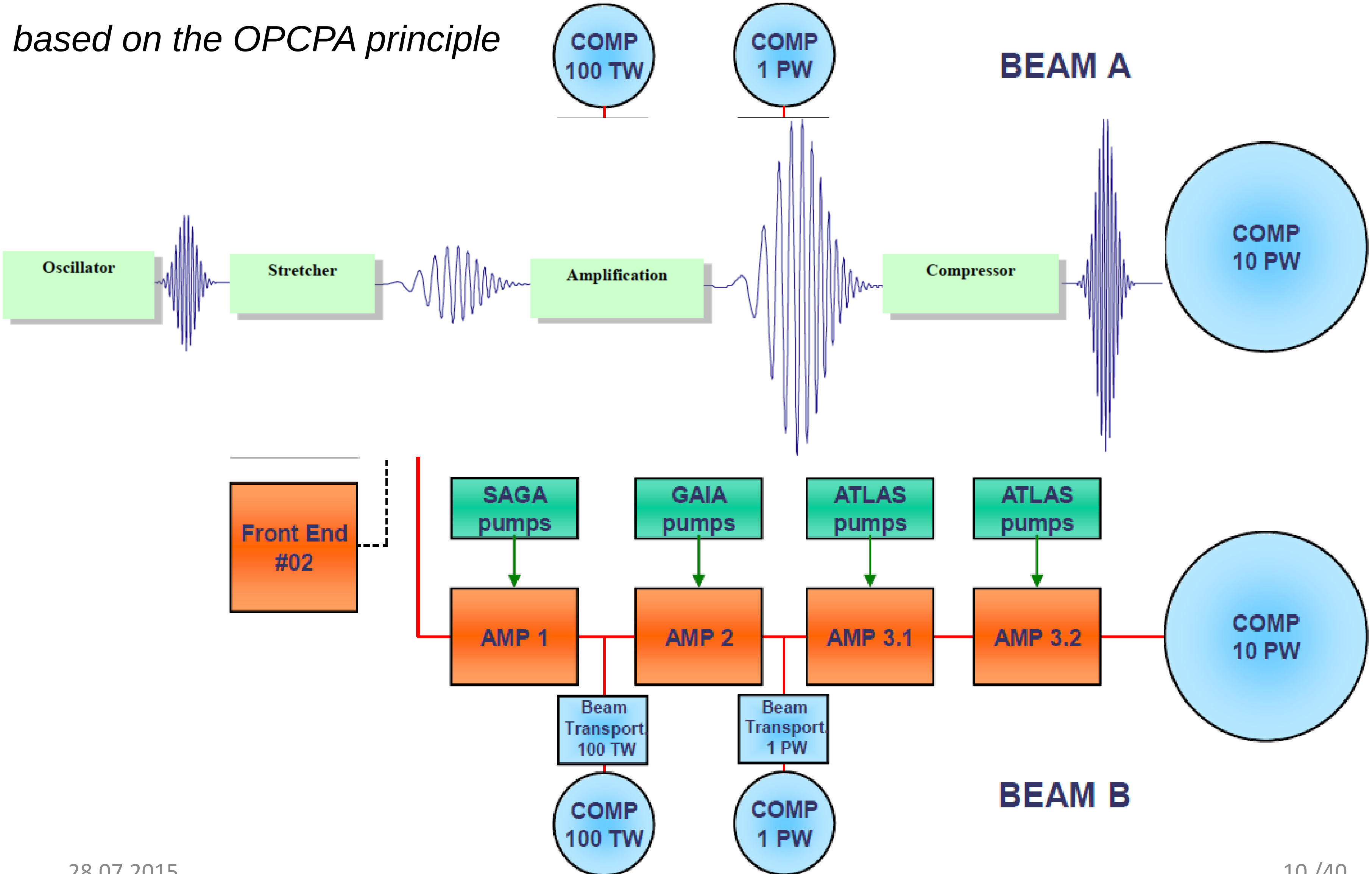




Platform supported on dampers

ELI-NP High Power Laser System (HPLS)

based on the OPCPA principle



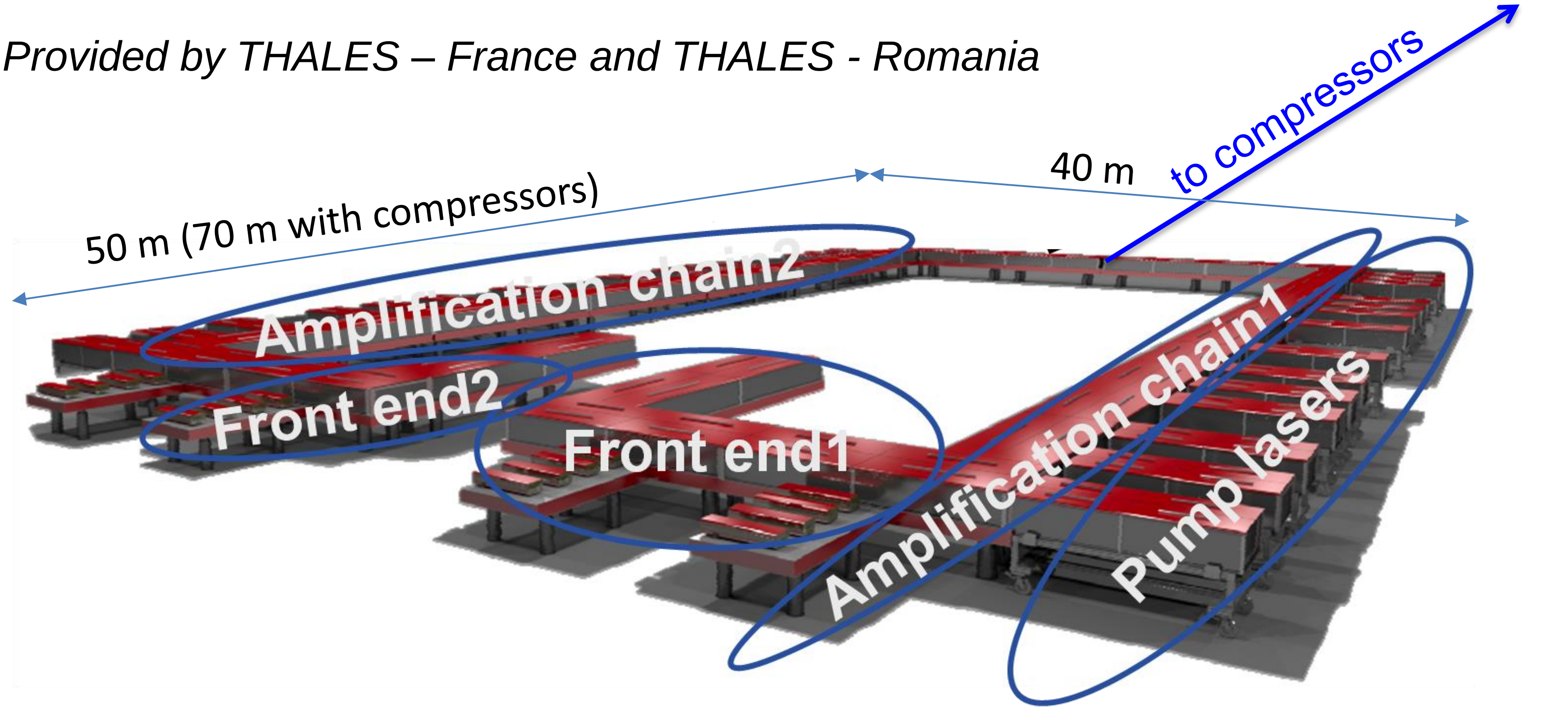
ELI–NP HPLS

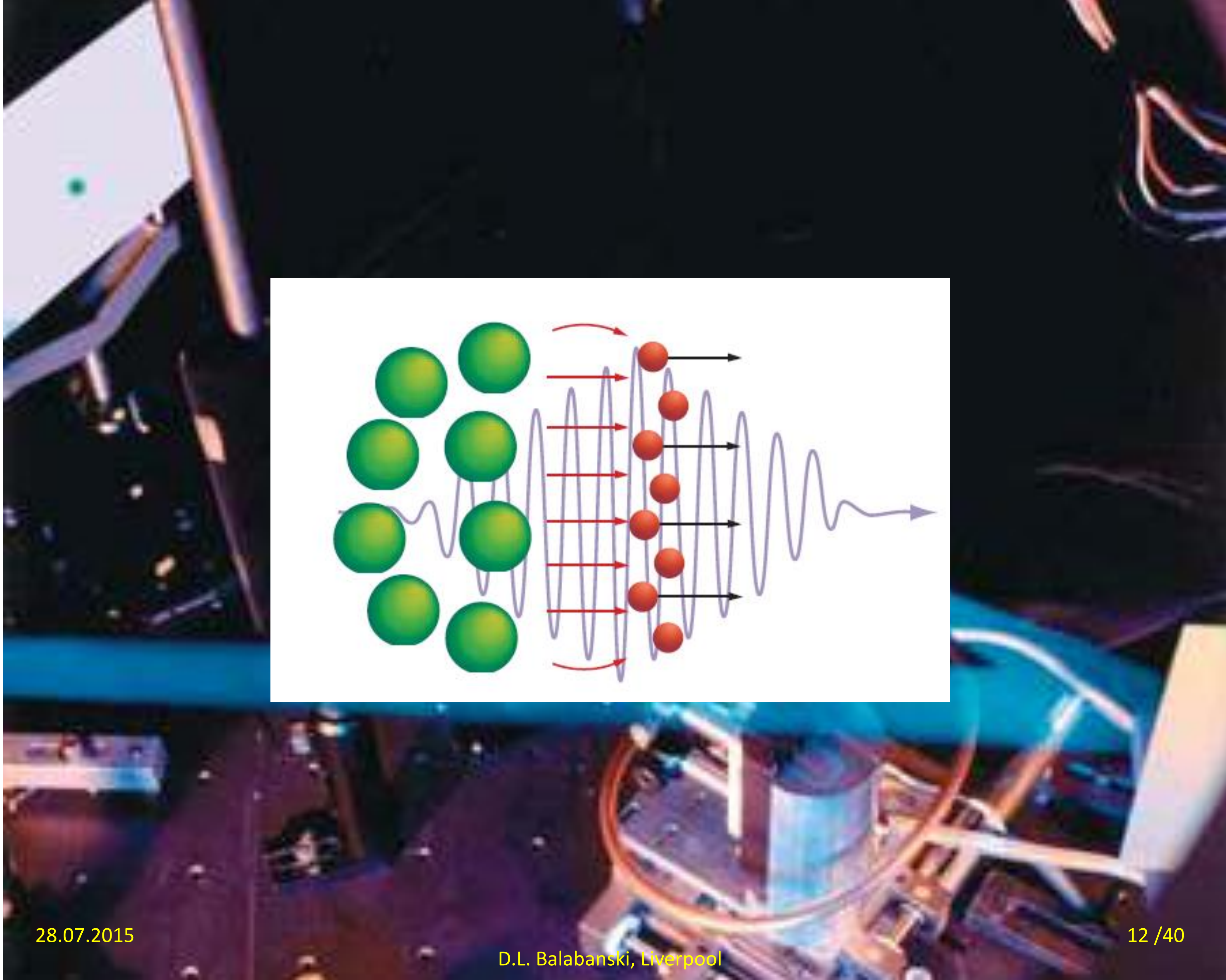
2 HPLS up to 10 PW – 6 output lines

2 x 0.1 PW
2 x 1 PW
2 x 10 PW

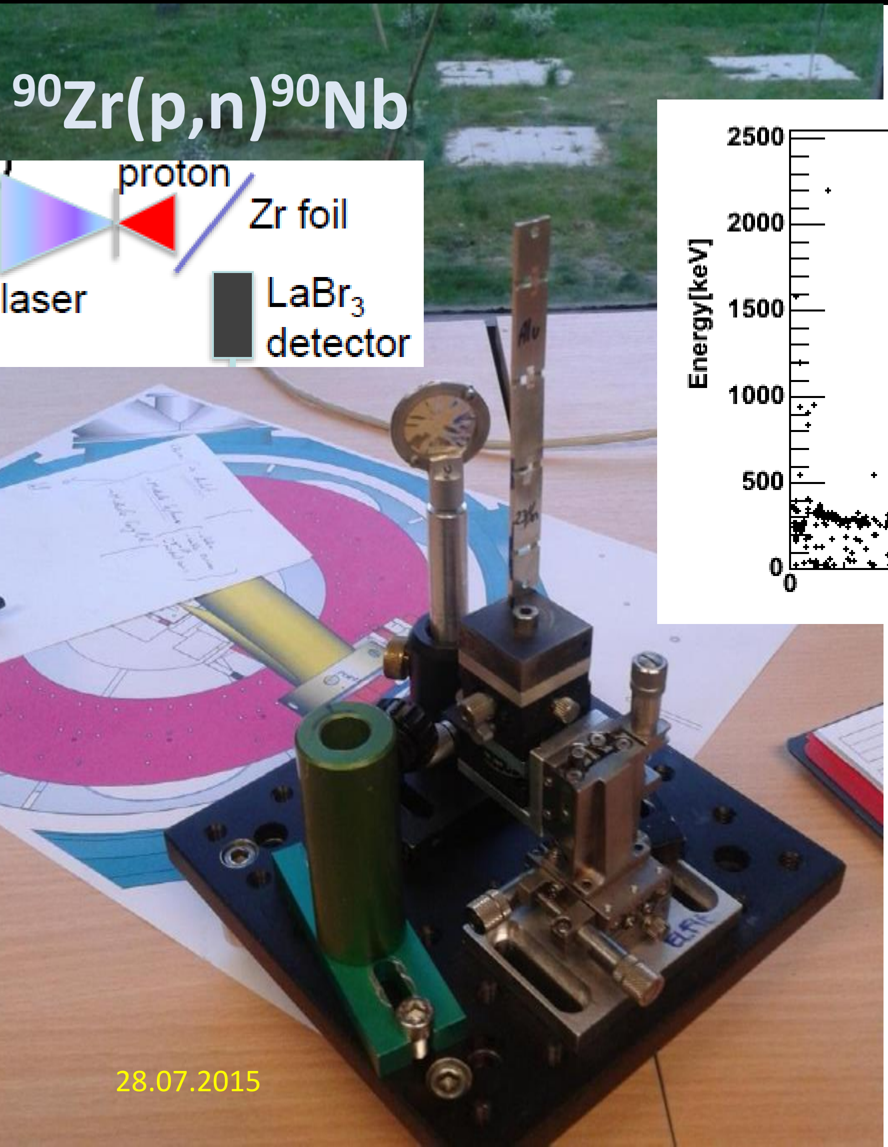
at present the most powerful lasers are 1 PW,
e.g. CETAL at Magurele (commissioned in 2015)

Provided by THALES – France and THALES - Romania

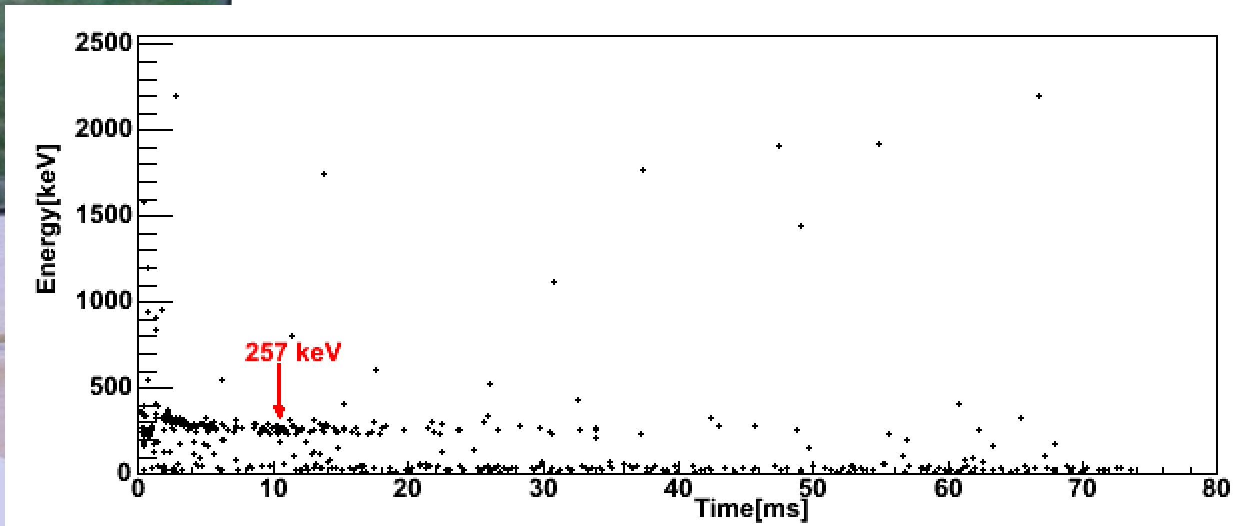


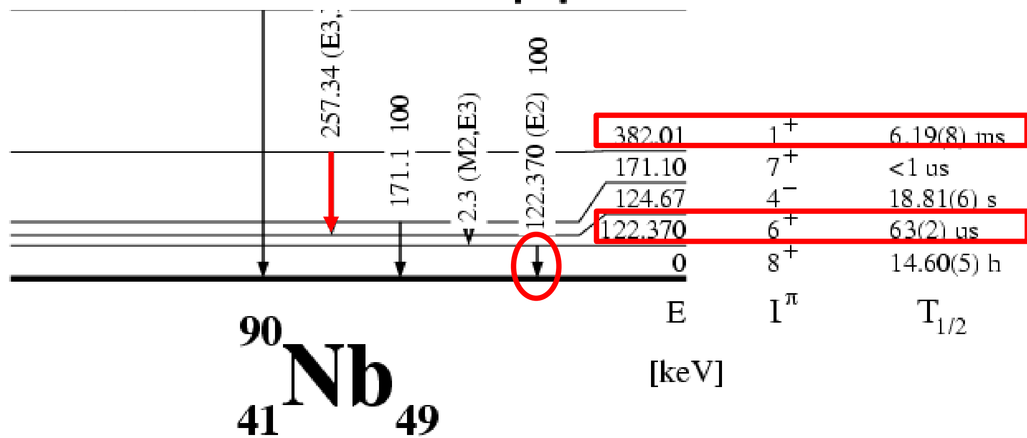


Nuclear isomer spectroscopy

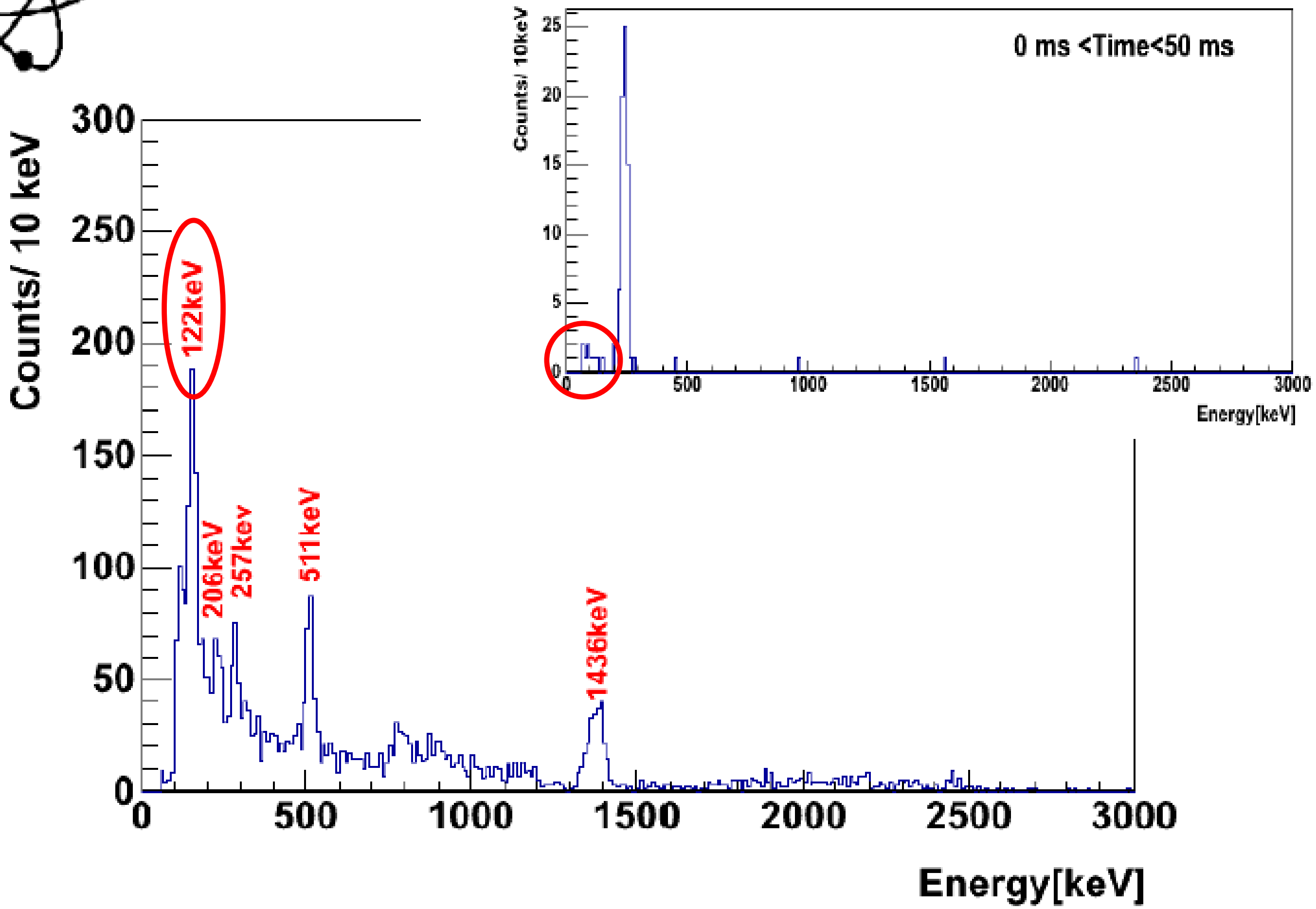


experiment of Florin Negoita @ LULI



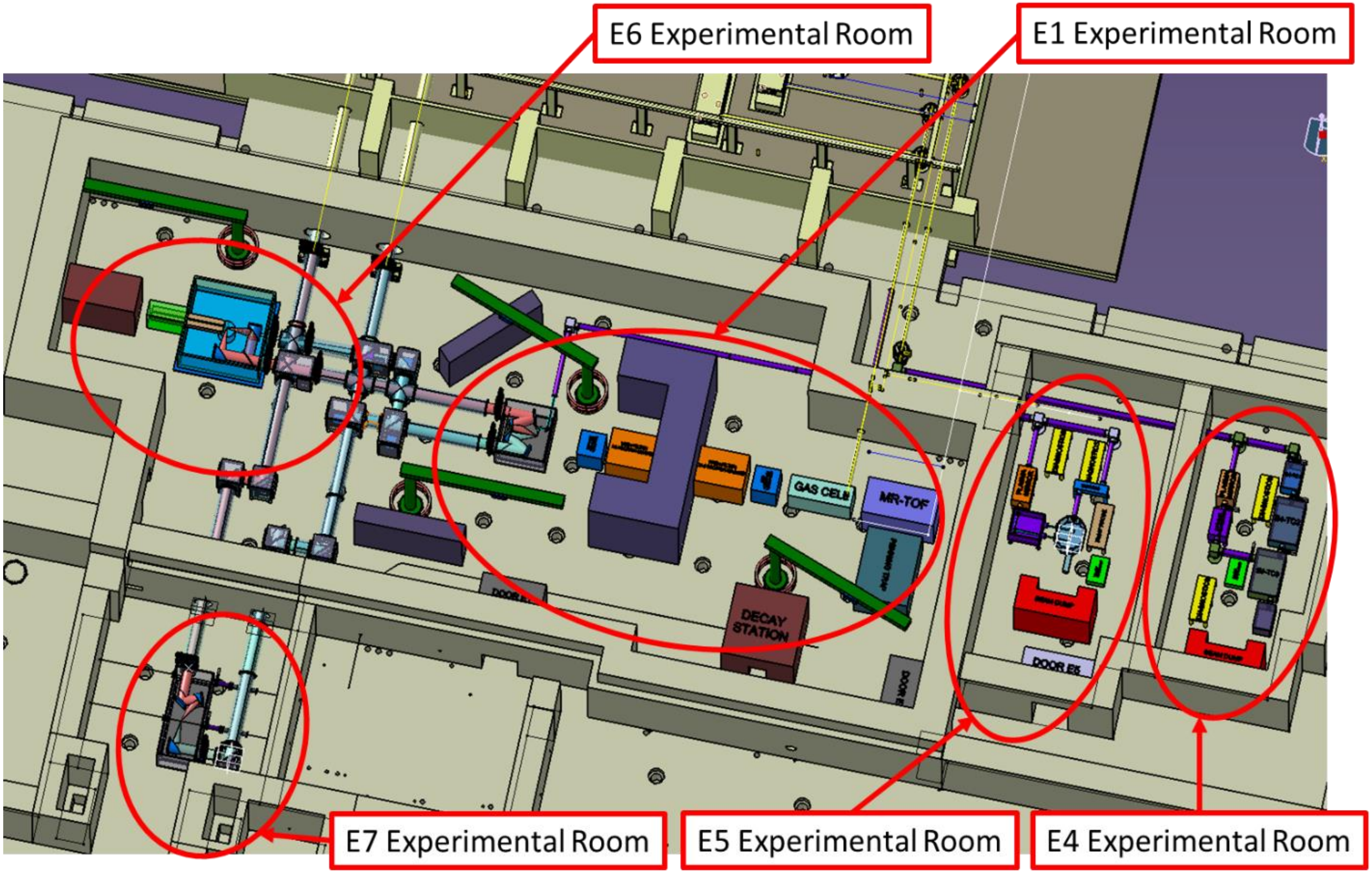


γ-ray spectra



courtesy Florin Negoita

ELI-NP Experiments Areas



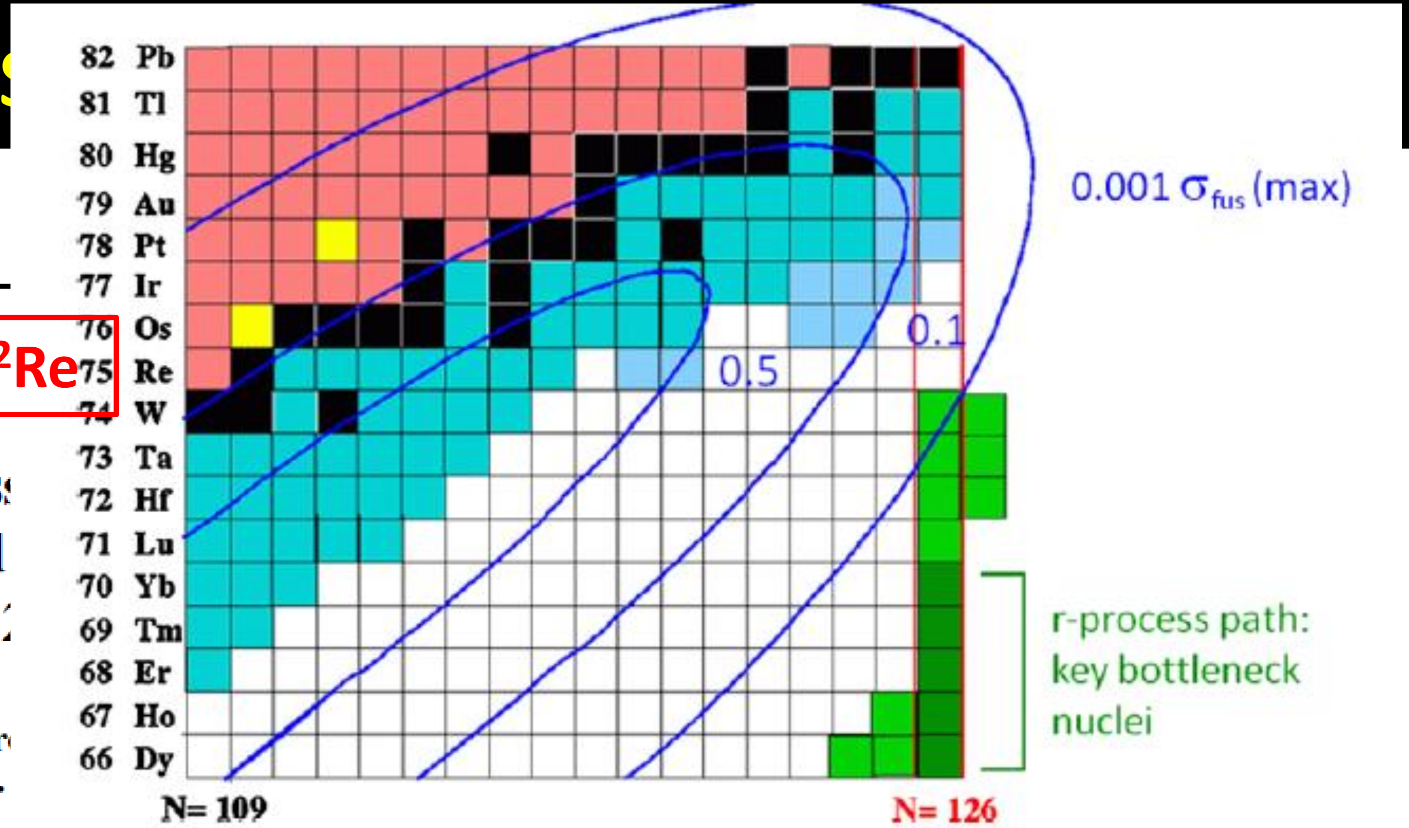
Las

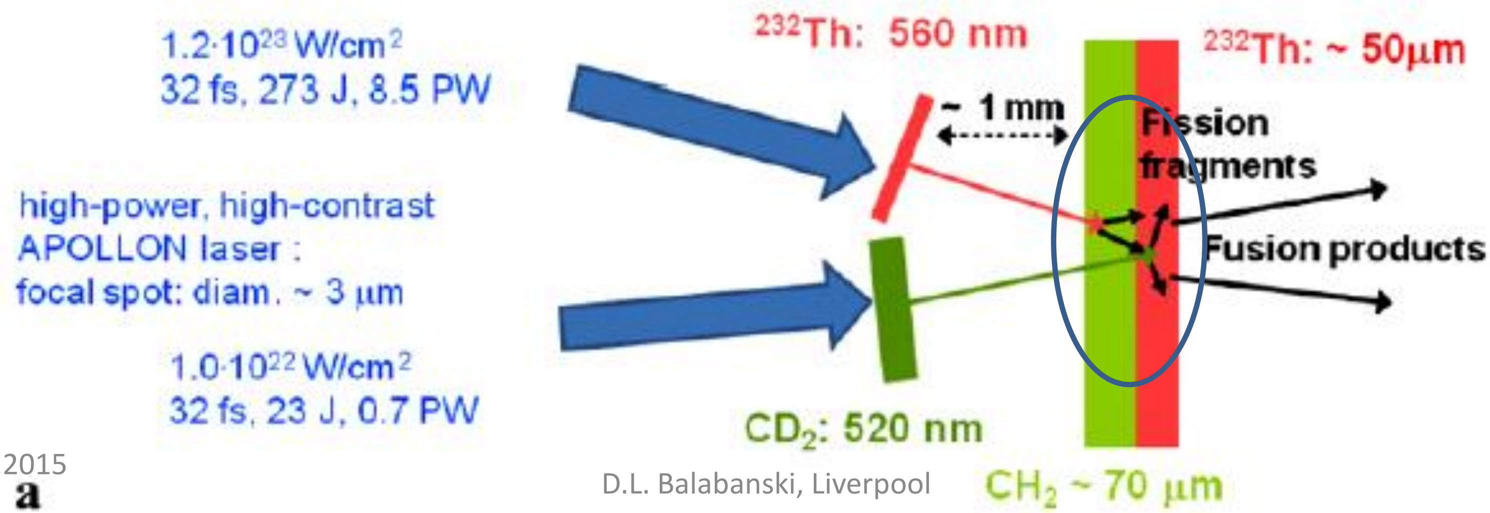
Appl Phys B (2011) 103: 471–484
DOI 10.1007/s00340-010-4261-x

$F_L + F_L \rightarrow \langle {}^{A}Z \rangle \approx {}^{192}Re$

Introducing the fis
a laser-accelerated
towards the $N = 1$

D. Habs · P.G. Thirolf · M. Gr
A. Henig · D. Kiefer · W. Ma ·

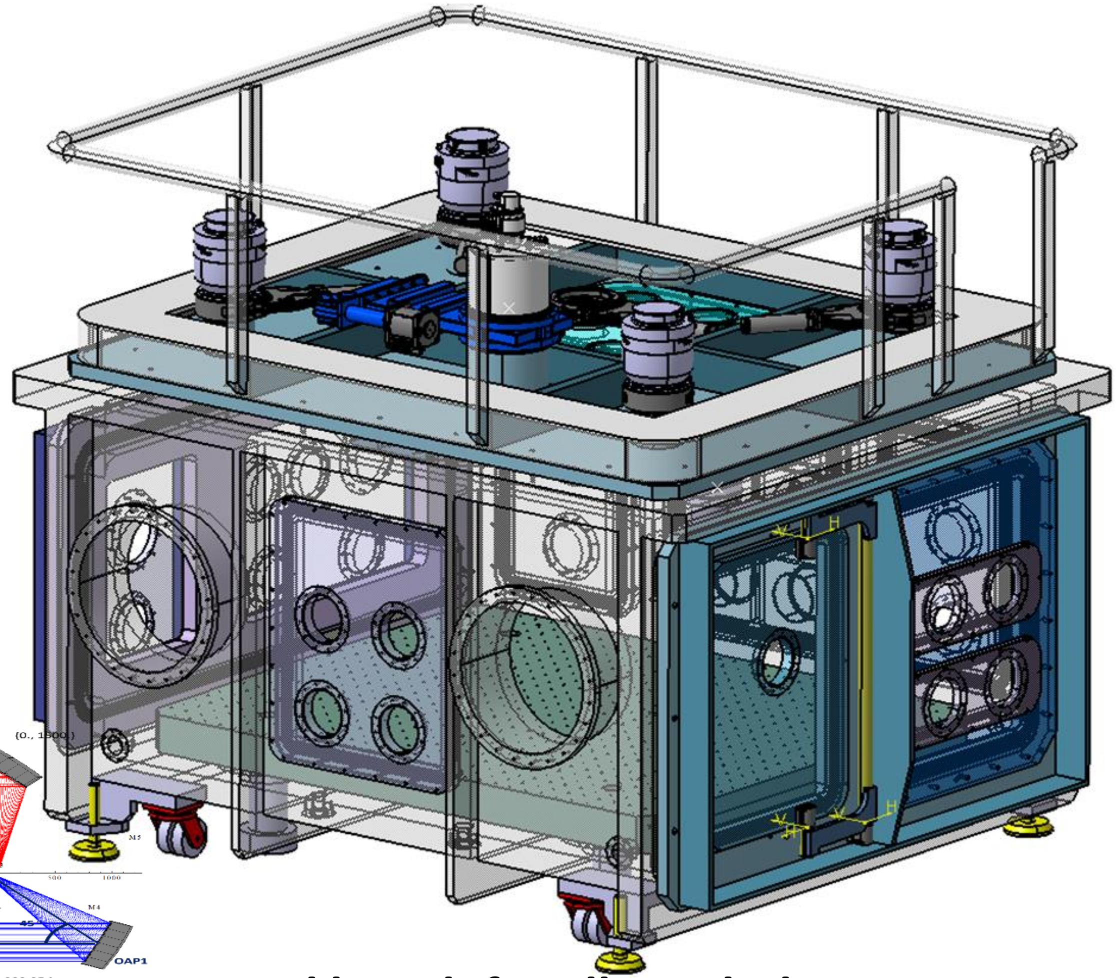


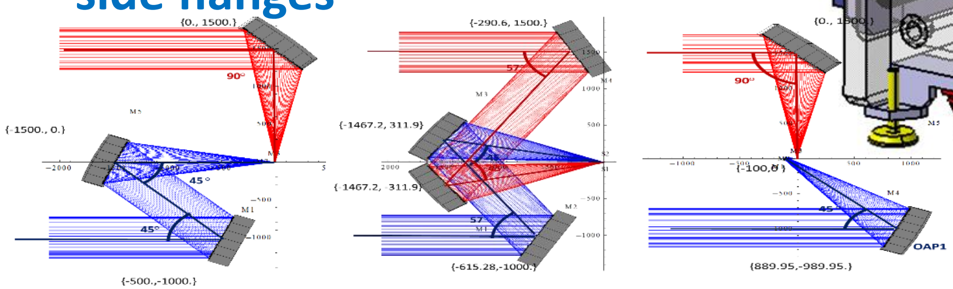


a

E1 Interaction Chamber (under construction)

- Shape: Rectangular
- Material: aluminium
- Volume: $3 \times 4 \times 2$ (=24) m^3
- Vacuum:
  10^{-6} mbar (empty chamber)
- Pump-down to
  $5x10^{-6}$ mbar: 45 min.
- Multiple flanges and ports
- Isolation of optical table
- Removable roof and
  side flanges



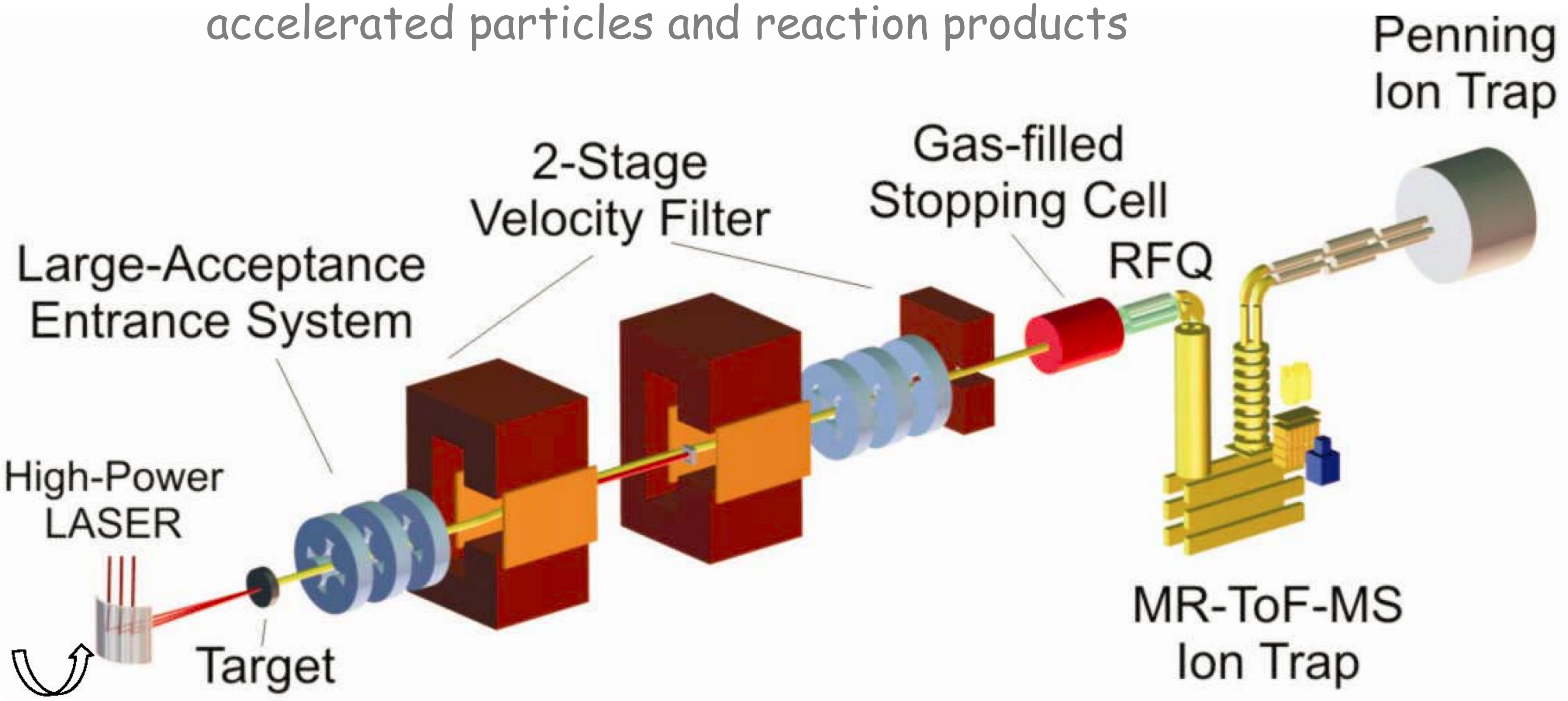


Focal length for all parabolas: 1500 mm

- Access on top for target exchange system
- Internal crane for heavy equipment (mirrors) manipulation
- Door for access inside through a cleanroom attached to the chamber (not shown)

In-flight separator for the ELI-NP laser-driven studies

concept proposed by H. Geissel (GSI/U Giessen)
for separation of nuclei of interest from all other
accelerated particles and reaction products

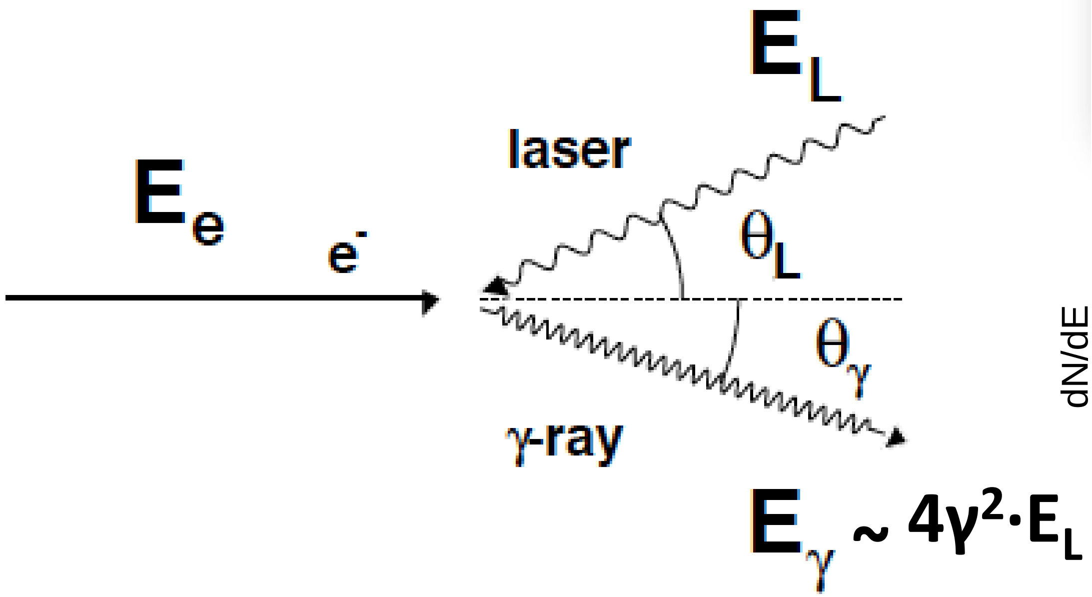


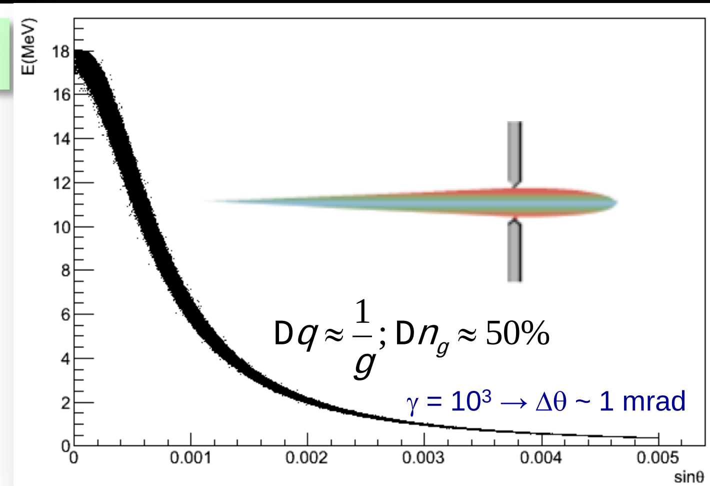
Measuring basic properties of N~126 nuclei: **masses**
lifetimes
decay modes

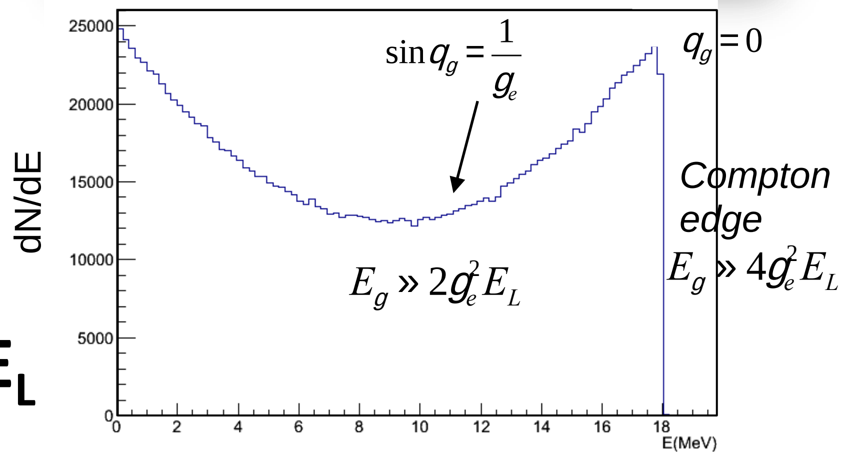
ELI-NP Gamma Beam System (GBS)

Strong forward focusing

$$E_\gamma = 2\gamma_e^2 \times \frac{1+\cos\theta_L}{1+(\gamma_e\theta_\gamma)^2 + a_0^2 + \frac{4\gamma_e E_L}{mc^2}} \times E_L$$



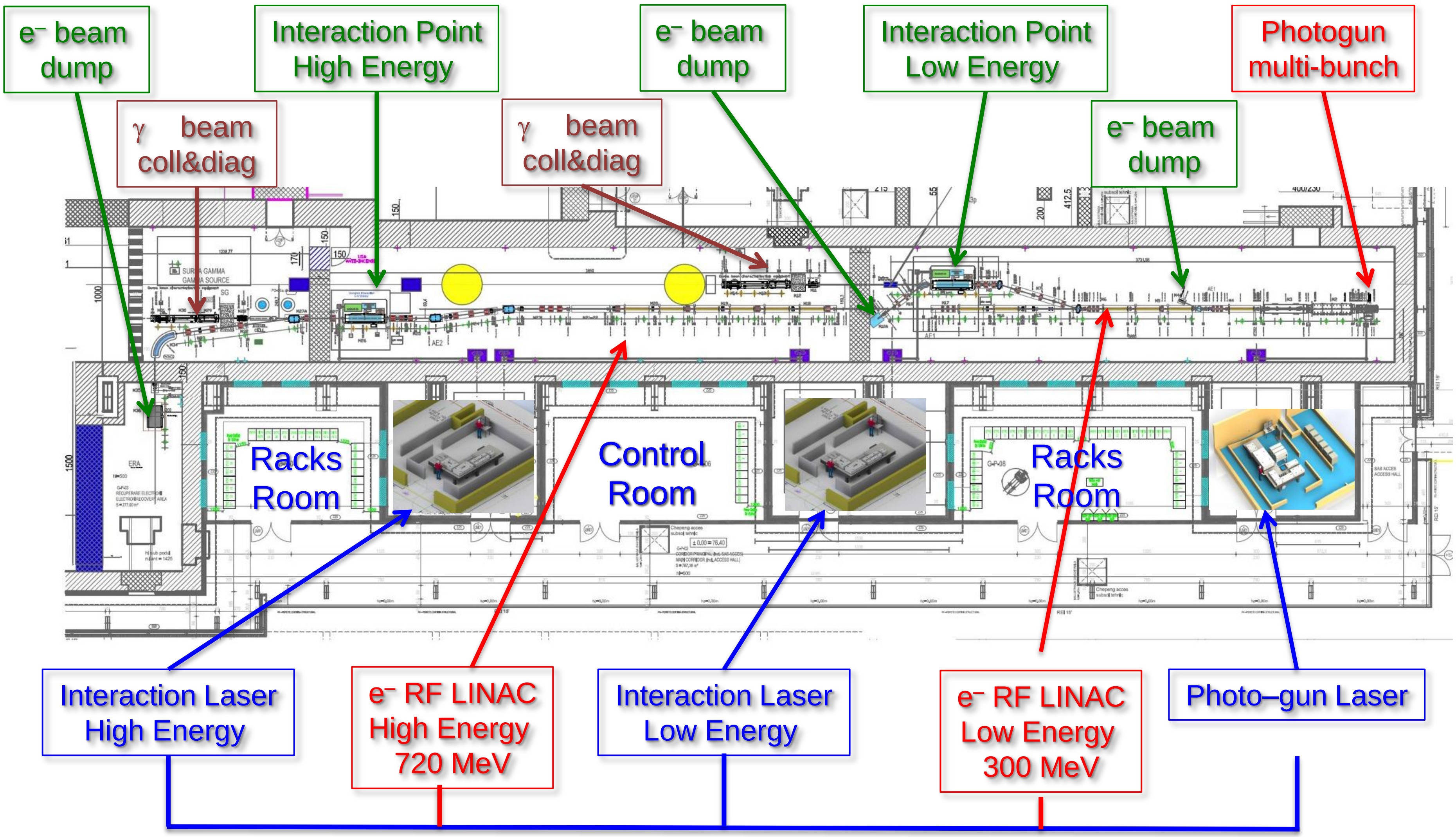




Laser Compton backscattering (LCB)

Narrow bandwidth (≤0.3%) gamma-beams up to 19.5 MeV

Gamma Beam System – Layout



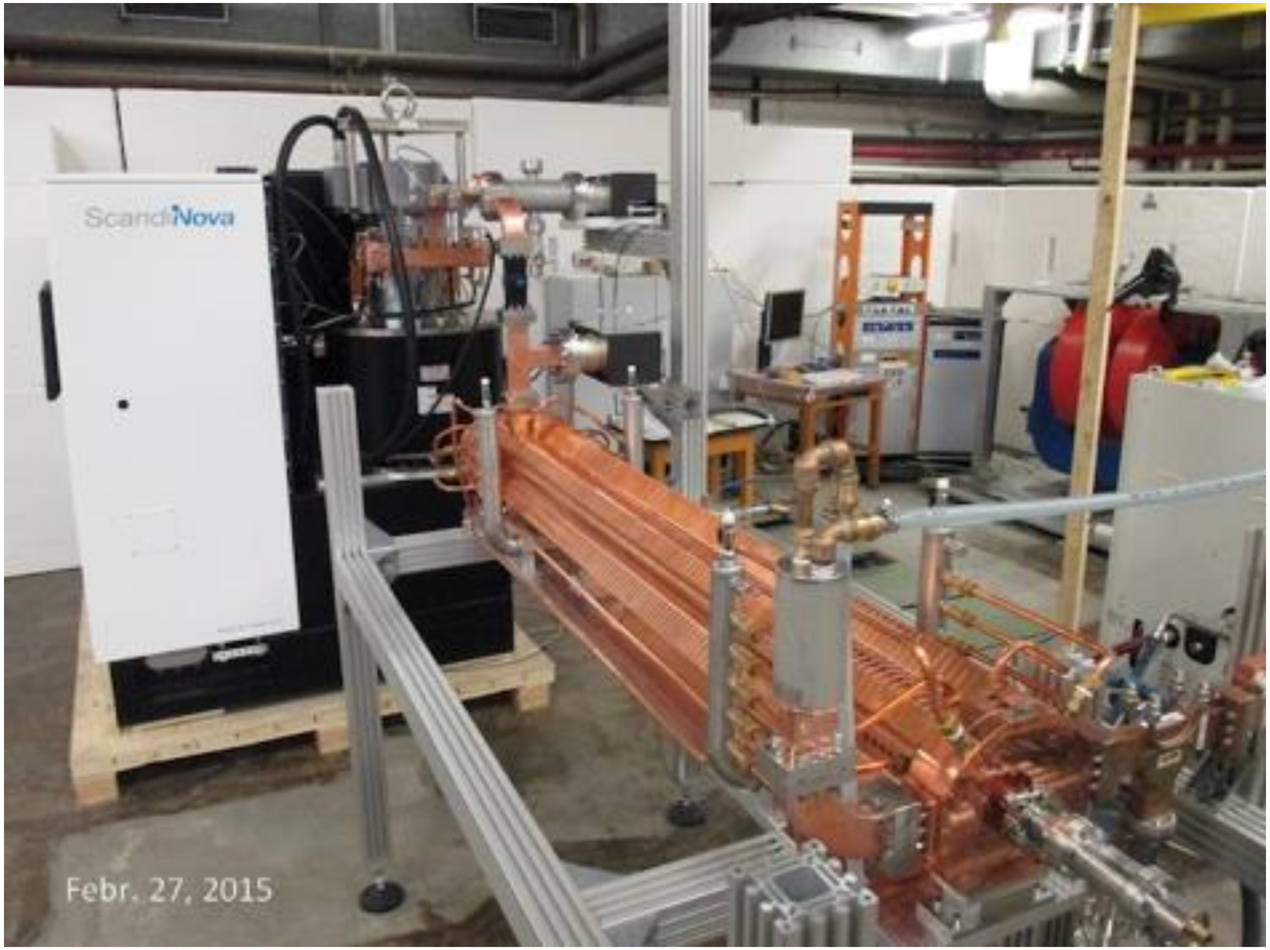
Master clock synchronization @ < 0.5 ps

High-Energy Stage: γ rays up to 19.5 MeV

Low-Energy Stage: γ rays up to 3.5 MeV

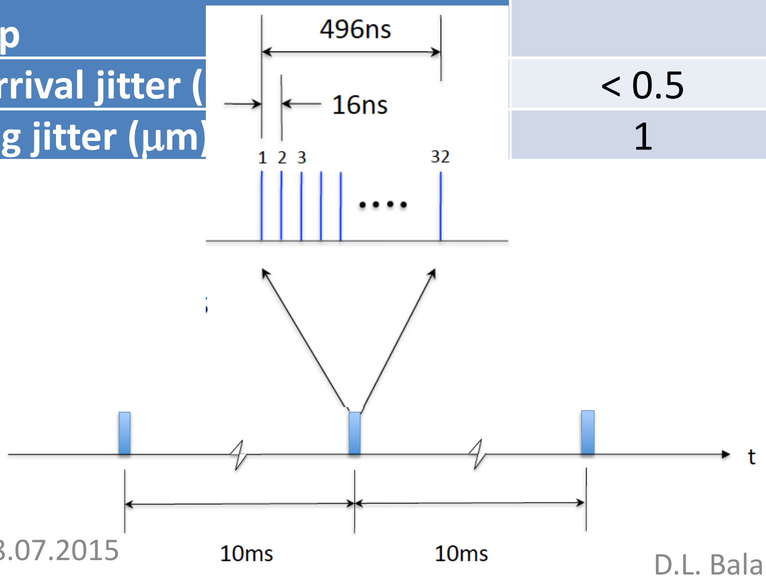
The Electron LINAC

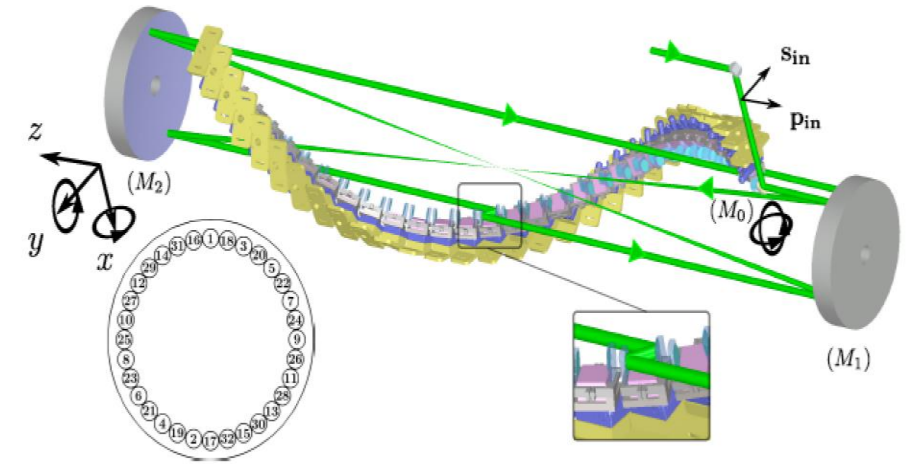
Factory Acceptance Tests – C–Band structure + Modulator



A r.t. RF linac *vs* pulsed laser source

Electron beam parameter at IP	
Energy (MeV)	180-750
Bunch charge (pC)	25-400
Bunch length (µm)	100-400
$\varepsilon_{n-x,y}$ (mm-mrad)	0.2-0.6
Bunch Energy spread (%)	0.04-0.1
Focal spot size (µm)	15-30
# bunches in the train	> 31
Bunch separation (nsec)	16
energy variation along the train	0.1 %
Energy jitter shot-to-shot	0.1 %
Emittance dilution due to beam breakup	< 10%
Time arrival jitter (	< 0.5
Pointing jitter (µm)	1



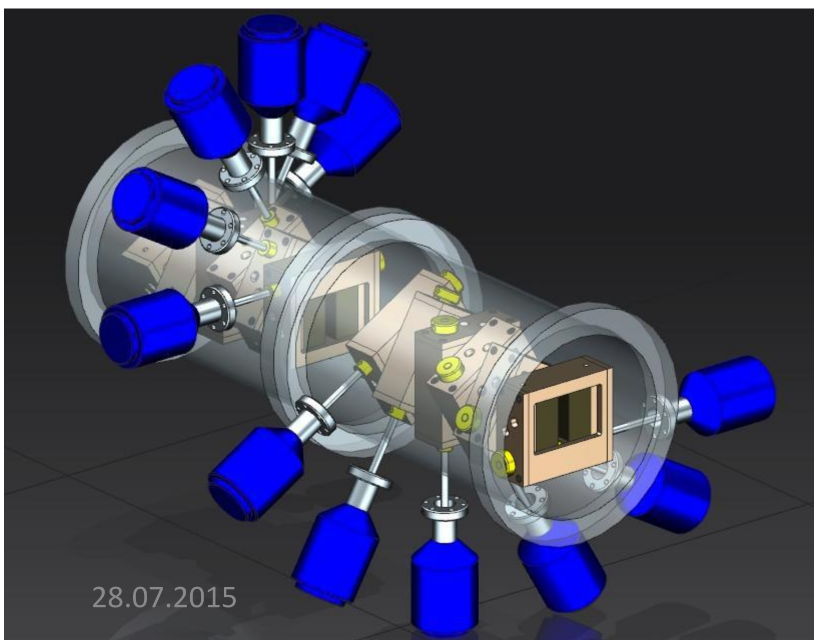


Pulse energy (J)	0.2	0.5
Wavelength (eV)	2.4	2.4
FWHM pulse length (ps)	2-4	2-4
Repetition Rate (Hz)	100	100
M^2	≥ 1.2	≥ 1.2
Focal spot size w_0 (µm)	> 25	25
Bandwidth (rms)	0.05 %	0.05 %
Pointing Stability (µrad)	1	1
Sinchronization to an ext. clock	< 1 psec	< 1 psec
Pulse energy stability	1 %	1 %

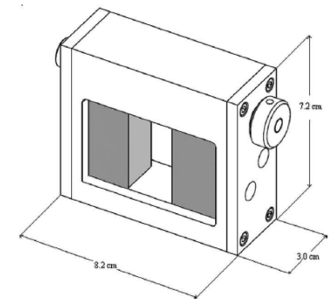
Gamma Beam Collimation

Main requirements are:

- **Low transmission of gamma photons** (high density and atomic number)
- **Continuously adjustable aperture** (to adjust the energy bandwidth in the entire energy range)
- **Avoid contamination of the primary beam** with production of secondary radiation



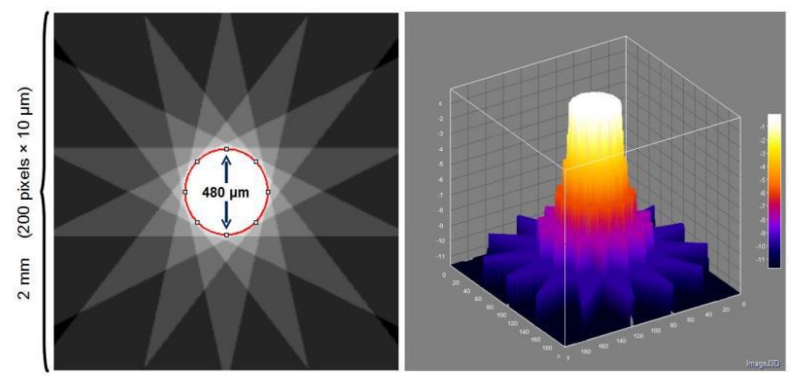
Collimation aperture varies from 20 mm to less than 1 mm, depending on the beam energy



Tungsten slits – 20 mm thick

Low–energy configuration:
12 independent slits with 30^{o} relative angle

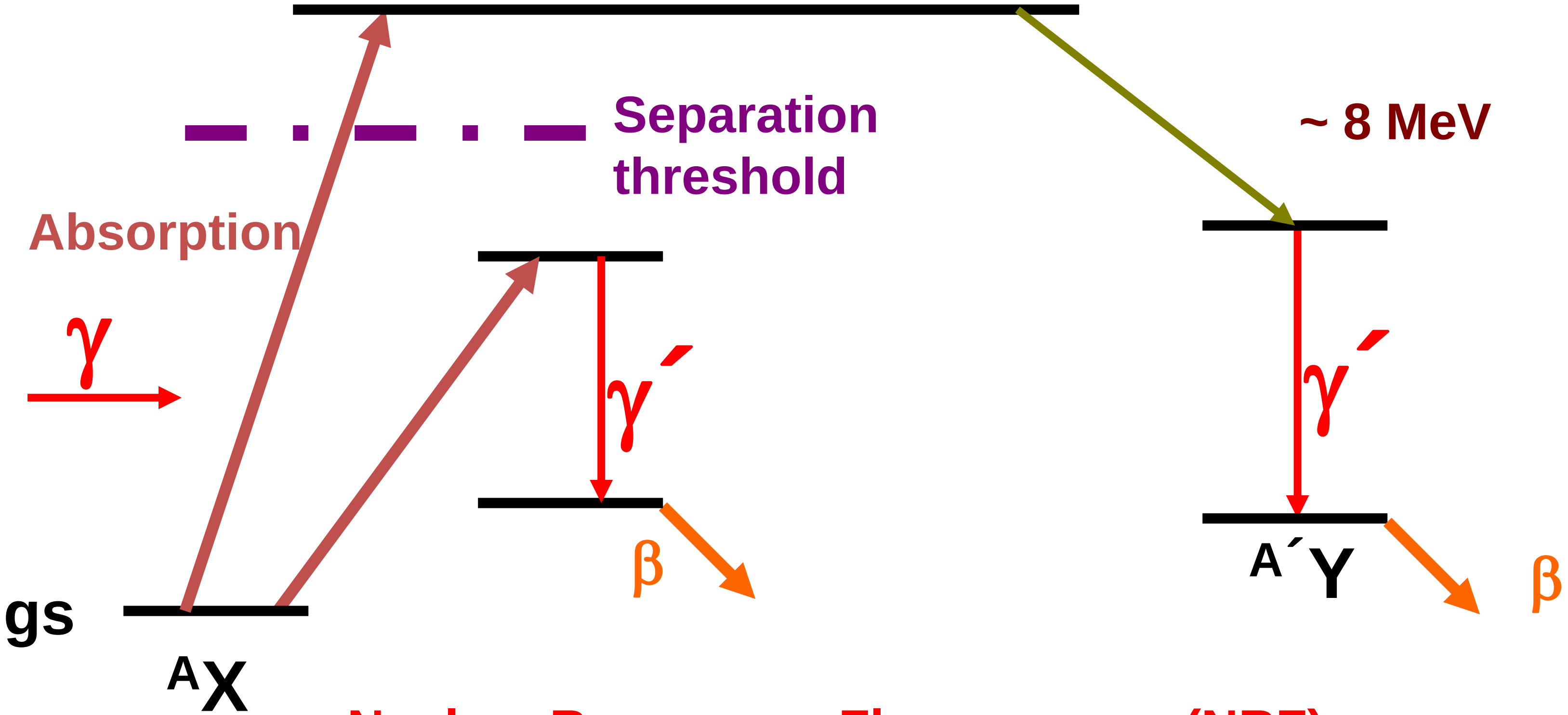
High – energy configuration:
14 independent slits with 25.7^{o} relative angle



Simulated radiography of the collimator assembly ($\log_{10}$ pixel values)

3D plot

Photonuclear Reactions



Nuclear Resonance Fluorescence (NRF)
Photoactivation
Photodesintegration (-activation)
Photofission

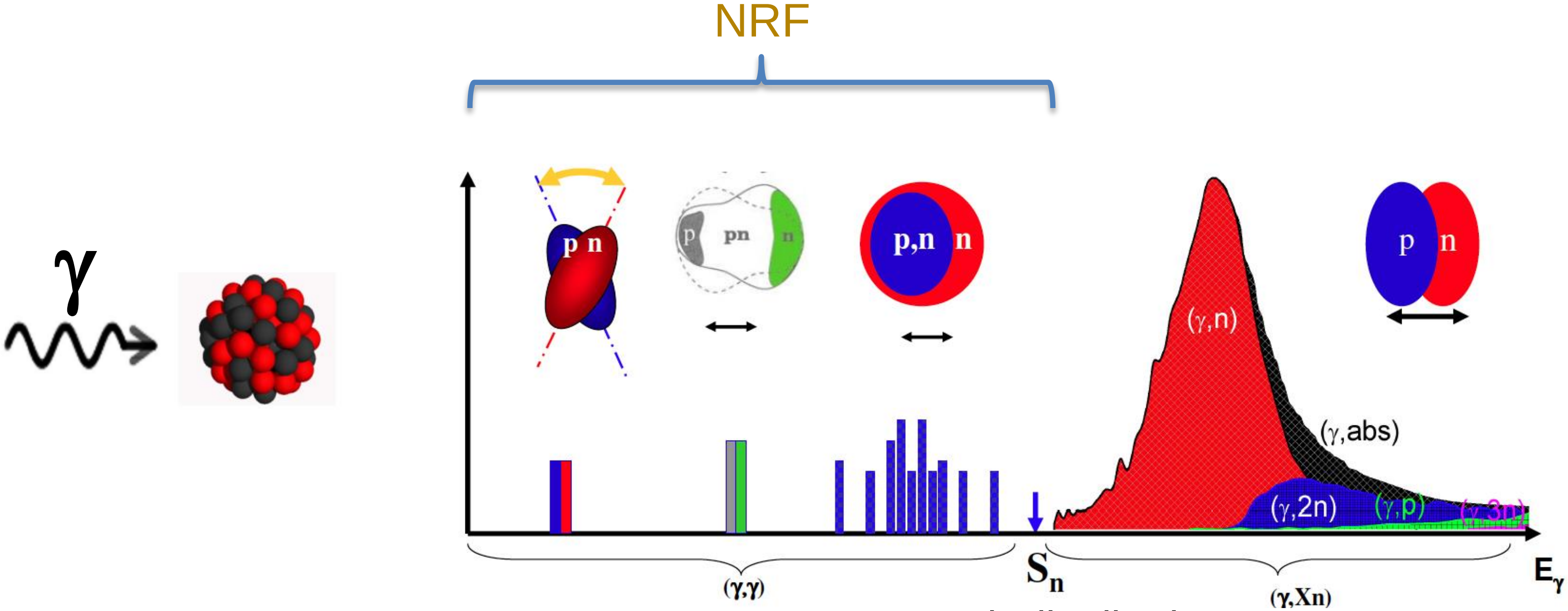
Nuclear Photonics

Electromagnetic dipole response of nuclei

Nuclear structure
- Modes of excitation below the GDR

Impact on nucleosynthesis
- Gamow window for photo–induced reactions in explosive stellar events

Understanding exotic nuclei
- E1 strength will be shifted to lower energies in neutron rich system

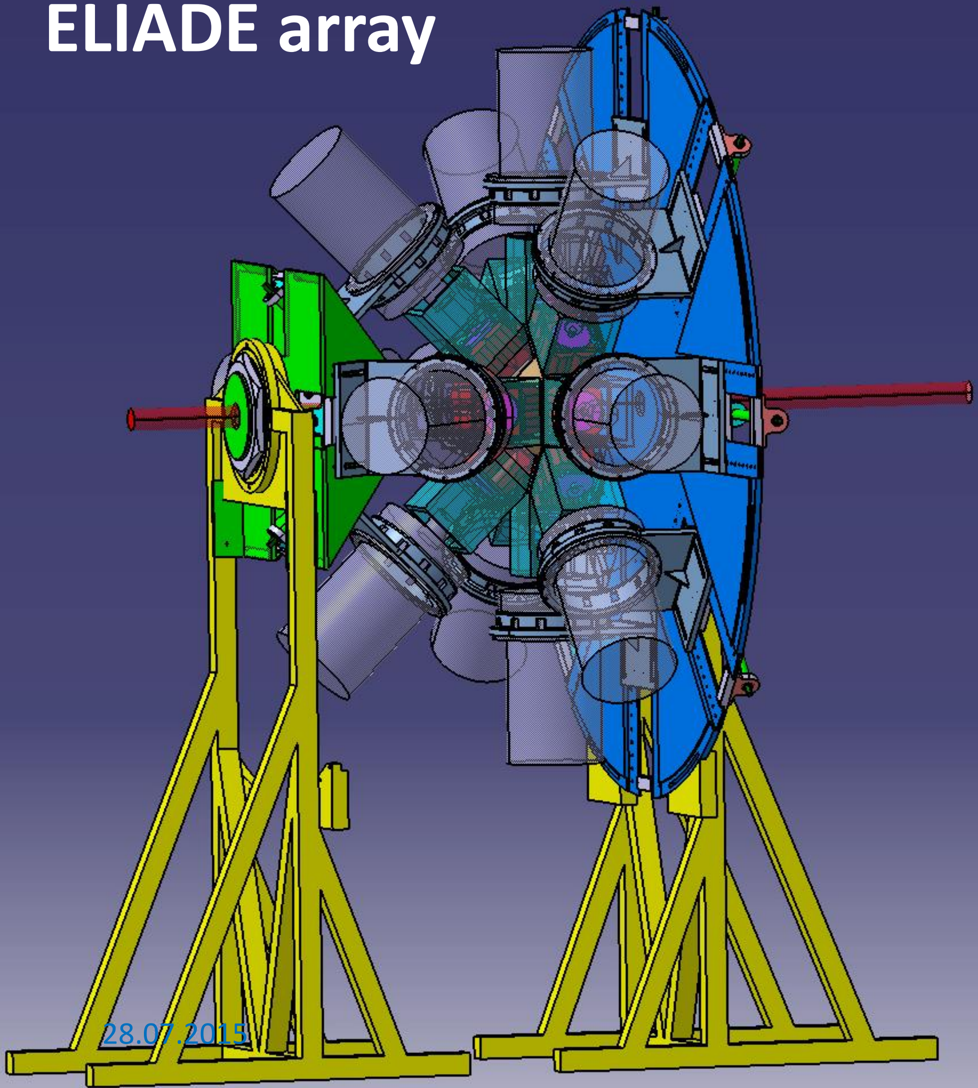


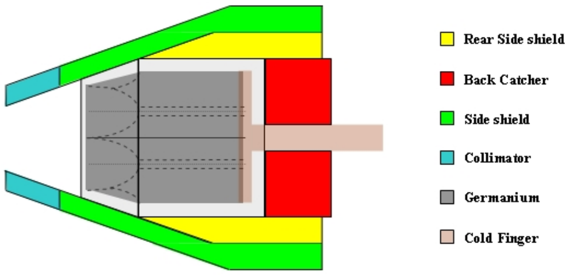
E1 strength distribution

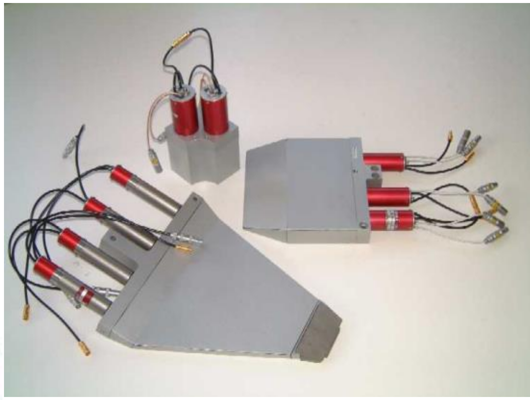
γ-ray spectroscopy

delivery of 4 Tigress-type Clovers and electronics is underway

ELIADE array

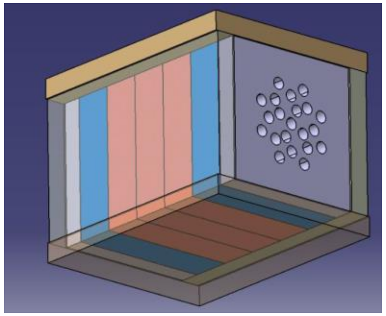




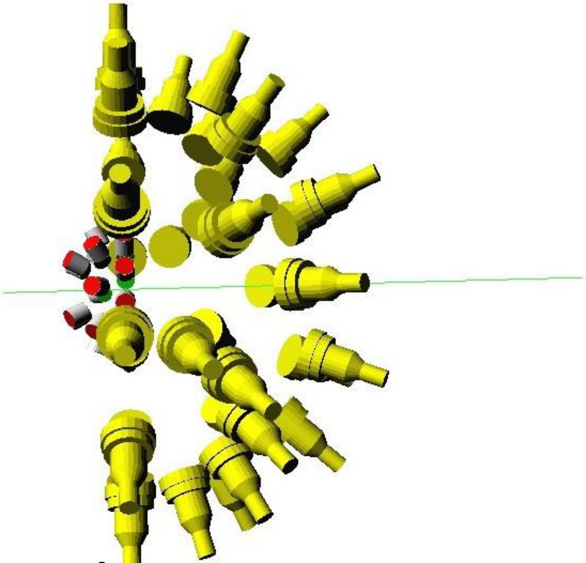


Physics above the neutron threshold

30 ^3He, 15 $LaBr_3$, 15 $CeBr_3$, 20 NE213 detectors and electronics



- Studies of GDR and PDR decay
- Studies of spin-flip M1 resonances
- (γ, n) cross section measurements, *e.g.* p process related measurements:
  - the $^{138}La(\gamma,n)\,^{137}La$ reaction,
  - the $^{180m}Ta(\gamma,n)^{179}Ta$ reaction.



<u>Instrumentation:</u>

(i) $LaBr_3$(Ce) array,

(ii) Fast-neutron detector array

(iii) NE213 liquid scintillator array

conveners: Hiroaki Utsonumiya and Franco Camera

liaison: Dan Filipescu

Nuclear Astrophysics

tender for 20 DSSD Si detectors is open

- Molecular states and symmetries in light nuclei
- The $^{16}O(\gamma,\alpha)^{12}C$ reaction
- The $^{24}Mg(\gamma,\alpha)^{20}Ne$ reaction
- The $^{22}Ne(\gamma,\alpha)^{18}O$ reaction
- The $^{19}F(\gamma,p)^{18}O$ reaction
- The $^{21}Ne(\gamma,\alpha)^{17}O$ reaction

$$\omega_A \frac{\sigma_A(X,\gamma)}{\lambda_\alpha^2} = \omega_B \frac{\sigma_B(\gamma,X)}{\lambda_\beta^2}$$

Day One experiment:

The ^{7}Li cosmological problem

ELI-NP will be the ideal cite to study the

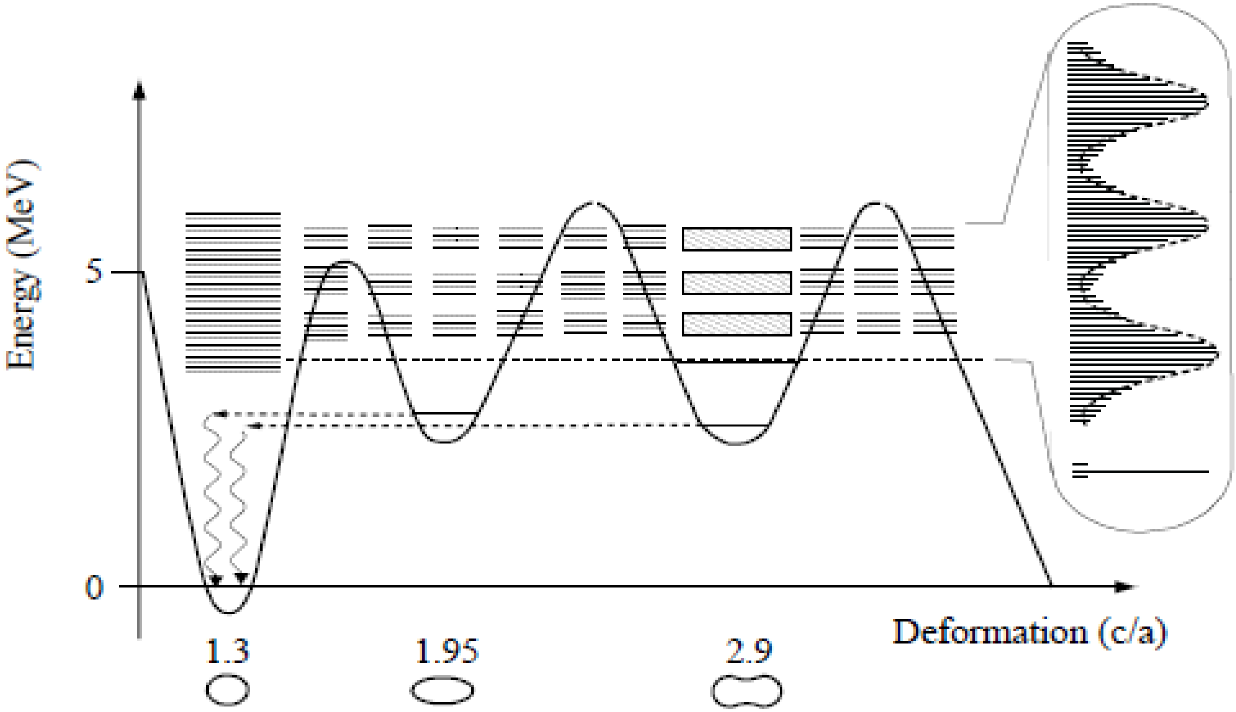
$^{7}Li(\gamma, \alpha)^{3}H$ reaction

Photofission

tenders for 5 BICs, 8 Si DSSD, THGEM array, electronics and support infrastructure are open or in preparation

1. Studies in the 2nd and 3rd minimum of the fission barrier: transmission resonances
2. Rare fission modes: ternary fission
3. Structure of neutron-rich nuclei: the rare-earth neutron-rich deformed region

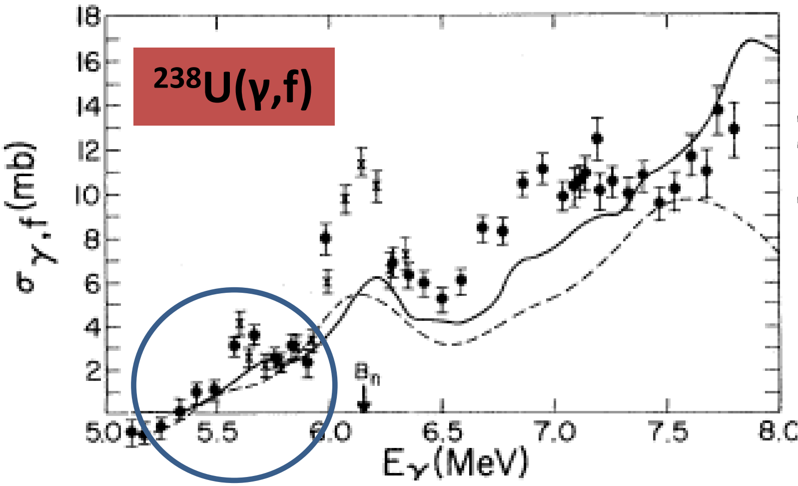
Studies of the 2nd and 3rd minimum

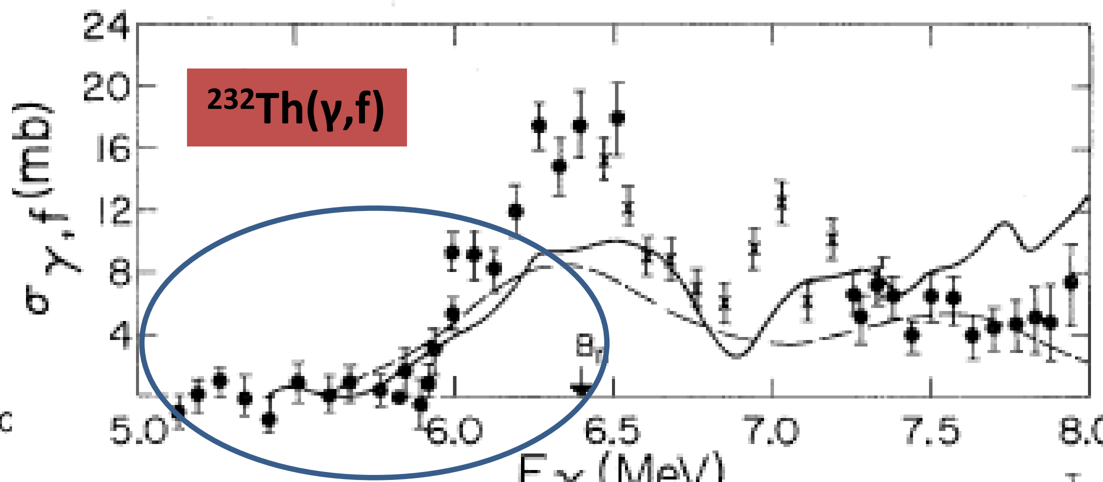


schematical description of the occurrence of transmission resonances

P.G. Thirolf et al., EPJ Web of Conferences 38, 08001 (2012)

Transitional Resonances: Status

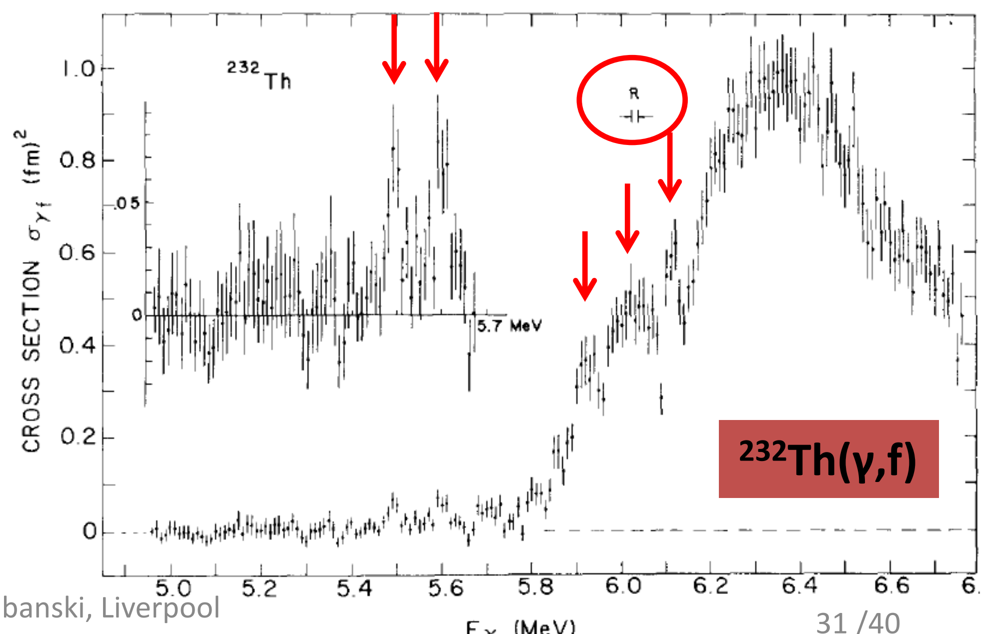




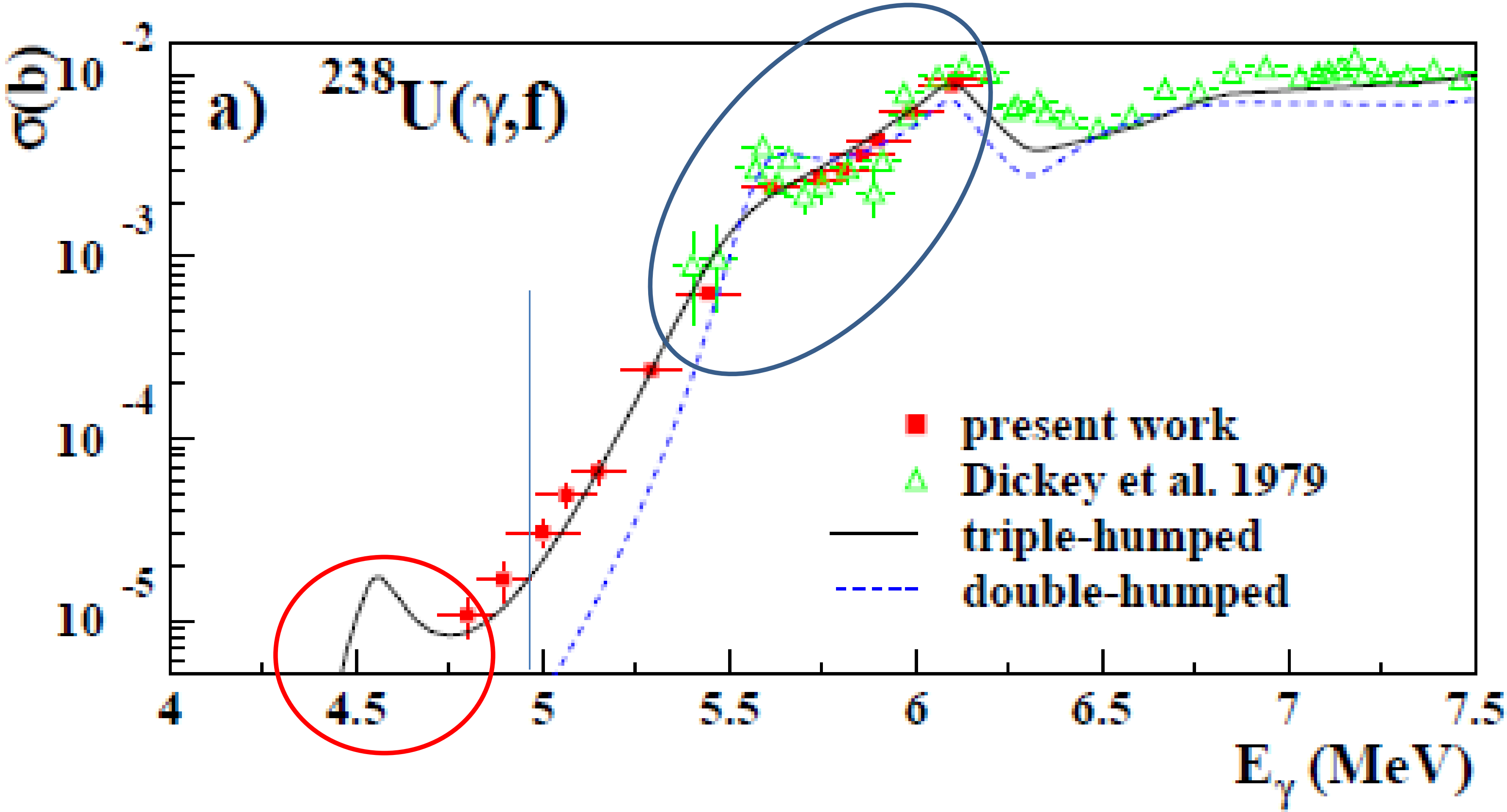
P. A. Dickey, P. Axel, PRL, 35, 501 (1975)

J. W. Knowles et al, PLB 116, 315 (1982)

bandwidth *R* = 12 – 14 keV

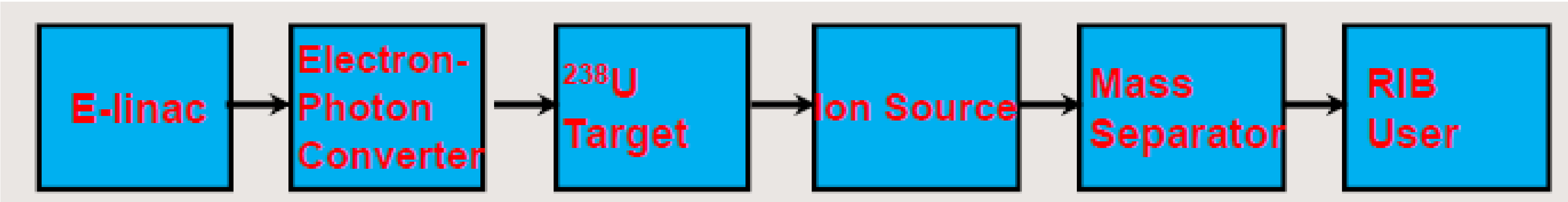


Transitional Resonances: Current studies

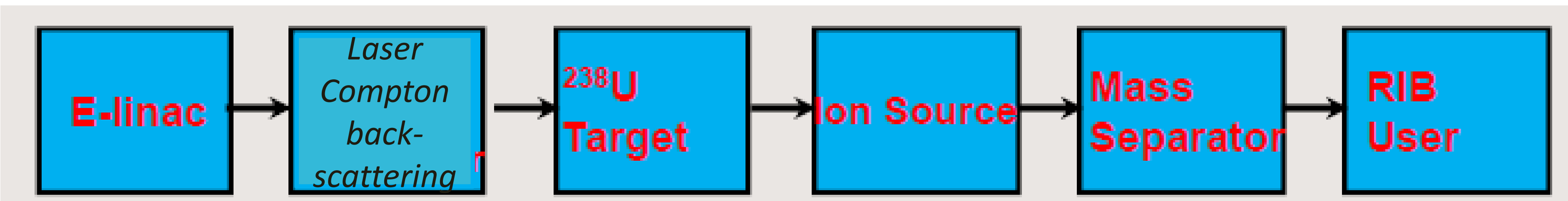


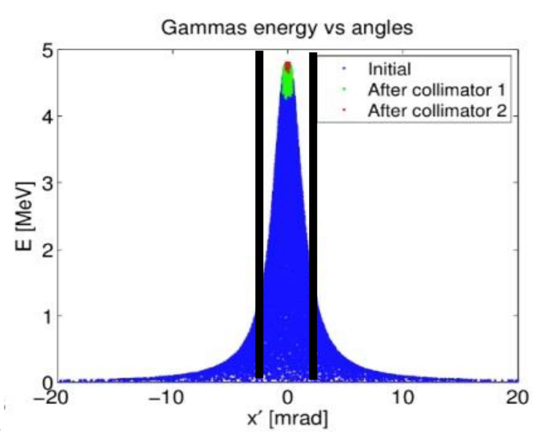
(γ,f) experiment at HIγS: Csige et al., Phys. Rev. C 87, 044321 (2013)

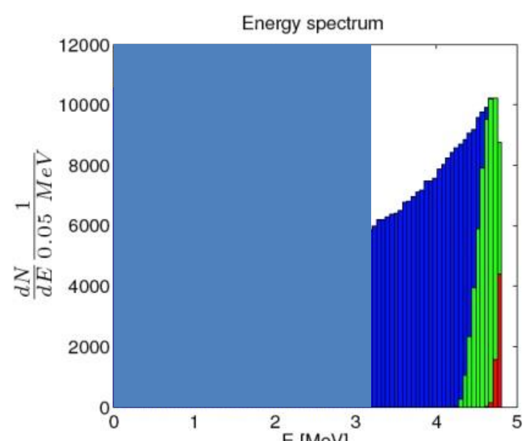
ALTO, ARIEL, etc.



ELI-NP





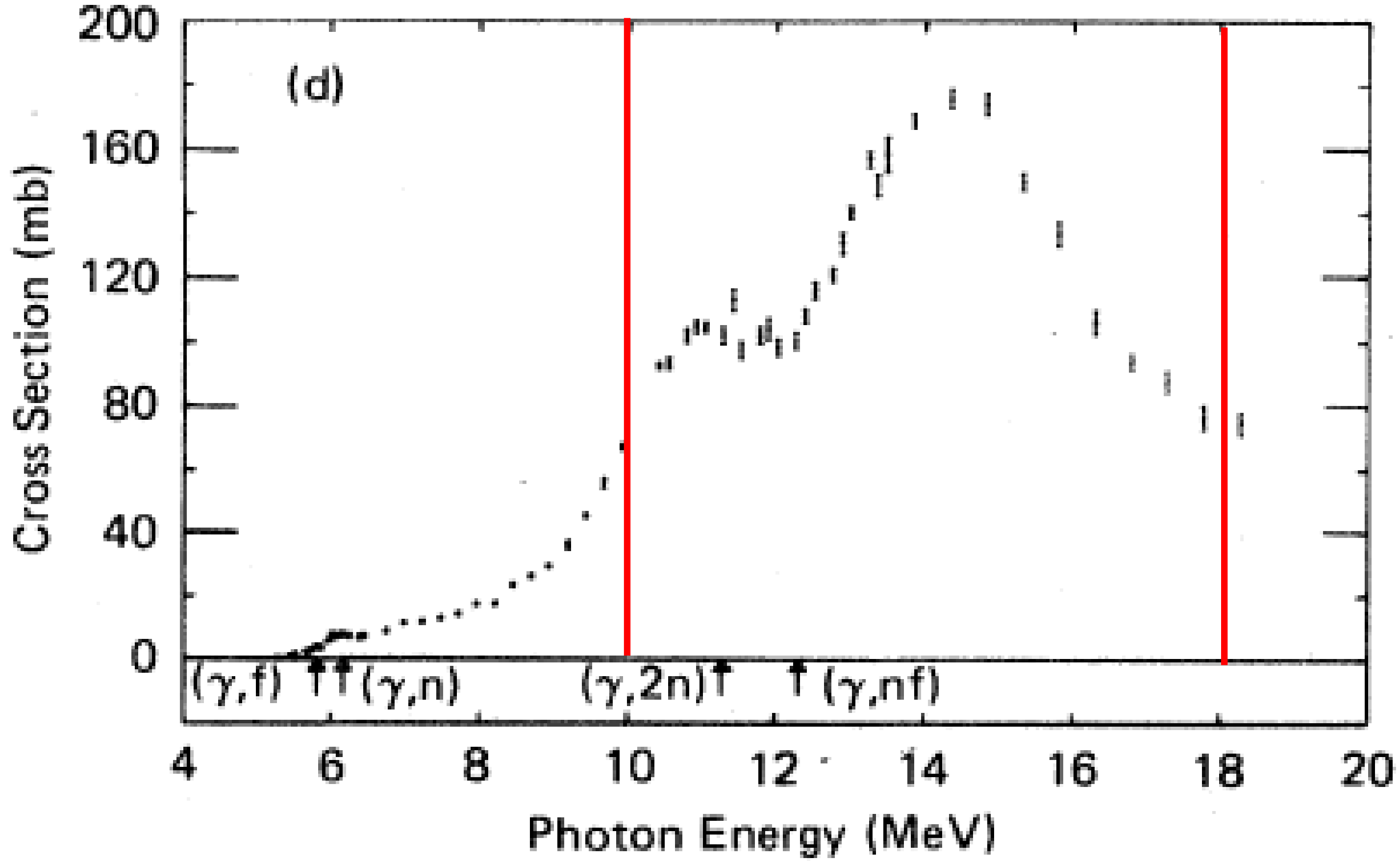


γ–beam spectrum at the IP (without collimator)

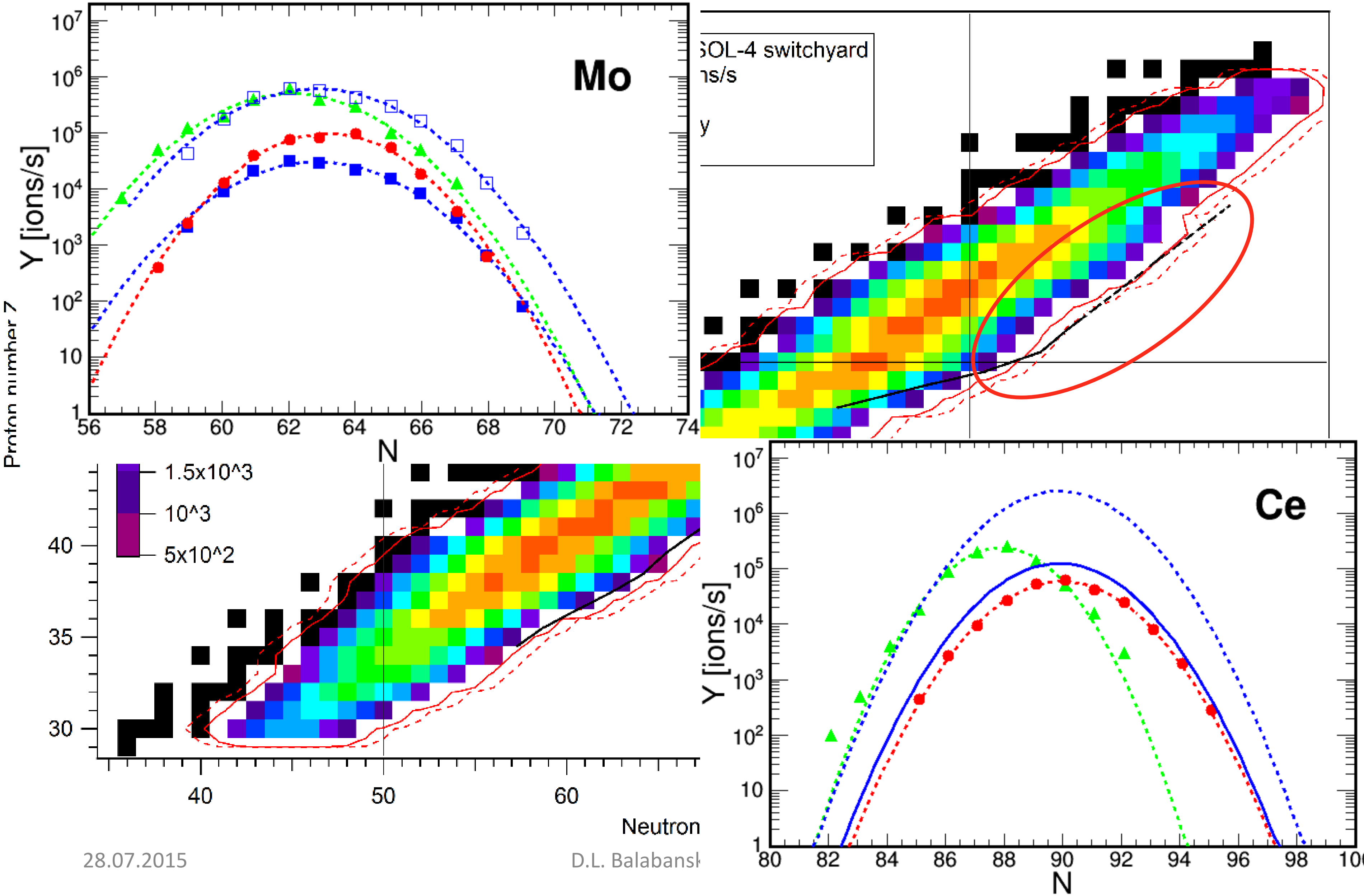
$\sim 10^{11}\ \gamma/s$

Photofission cross section for ^{238}U

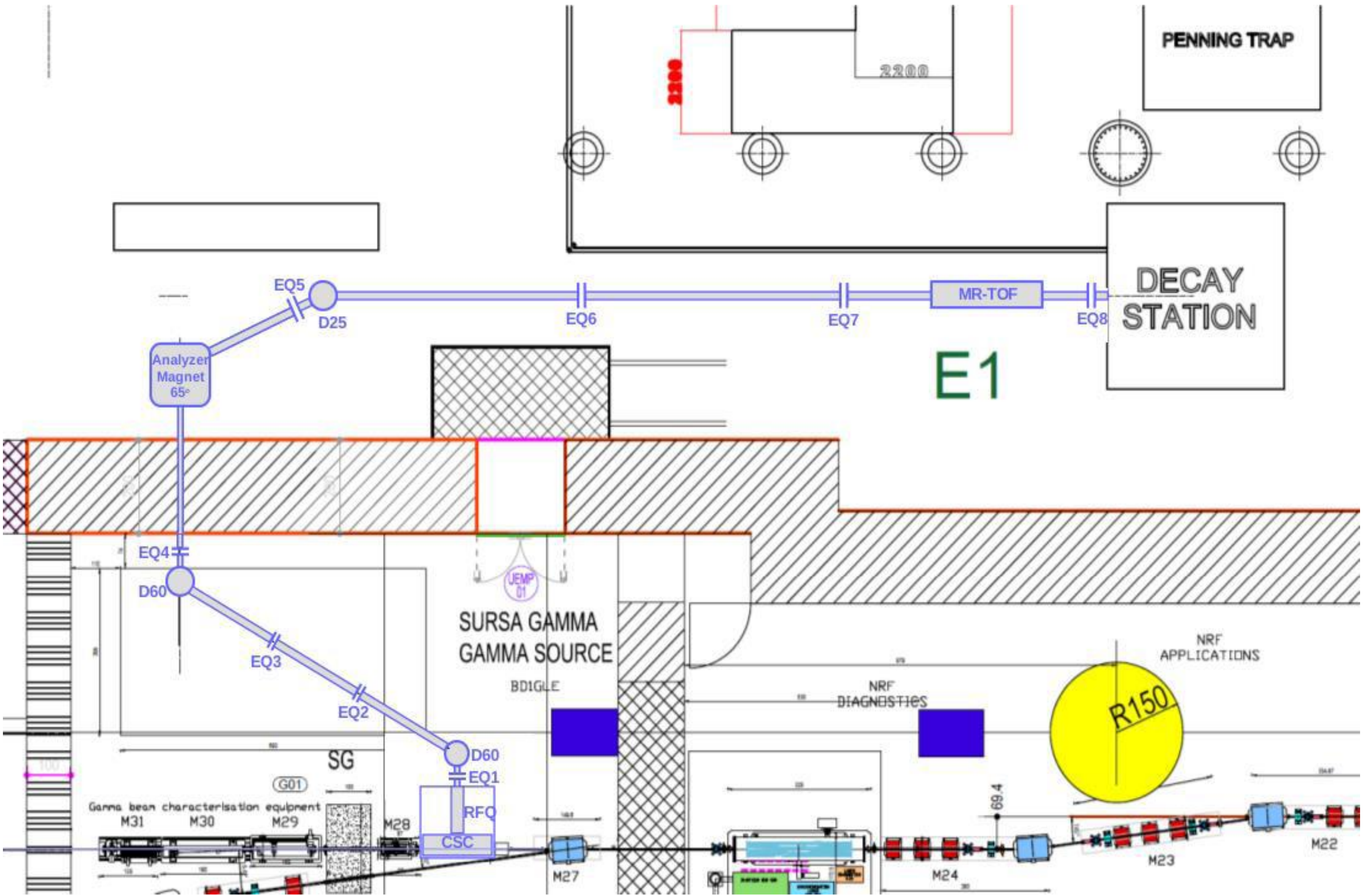
Caldwell *et al.*, Phys. Rev. C **21** (1980) 1215



Fragment Yields at the IGISOL-4 facility at JYFL



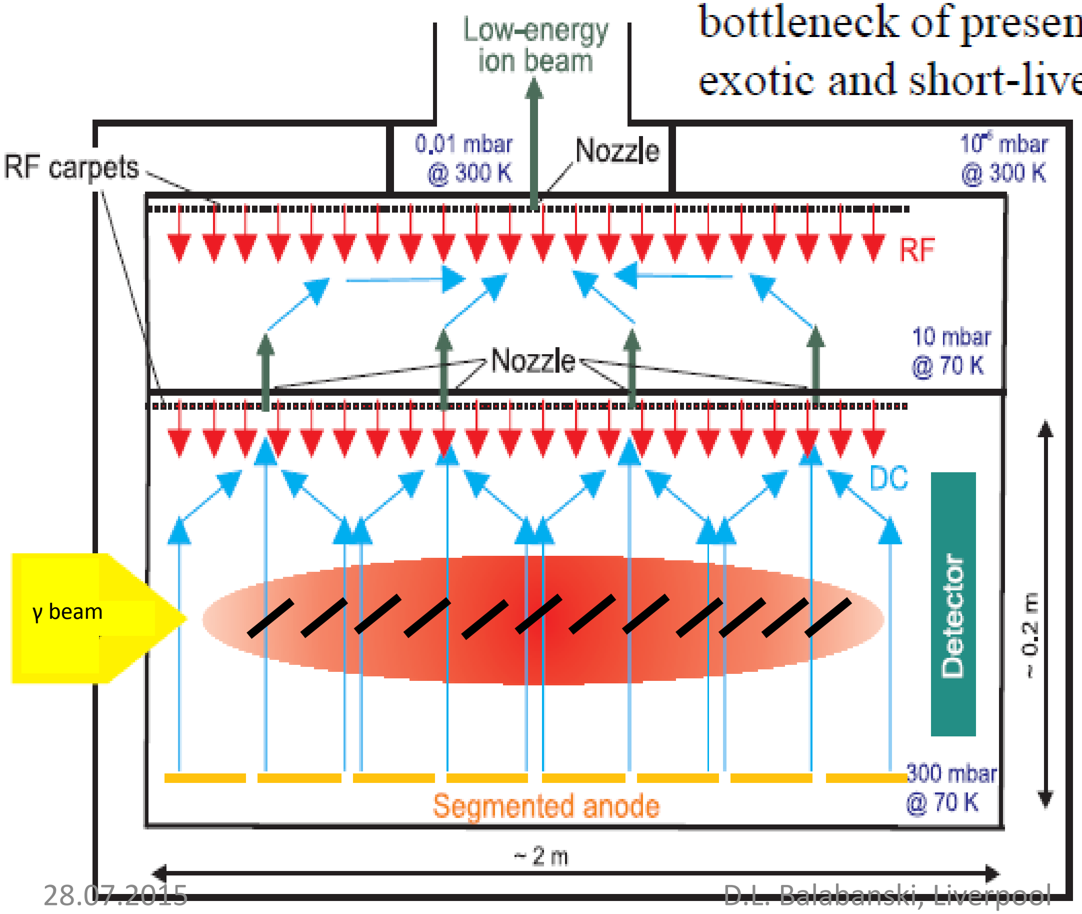
Location of the IGISOL beam line



ELI-NP Cryogenic Stopping Cell

50% efficiency,
5 ms extraction time
at a rate of ~ 10^7 ions/s

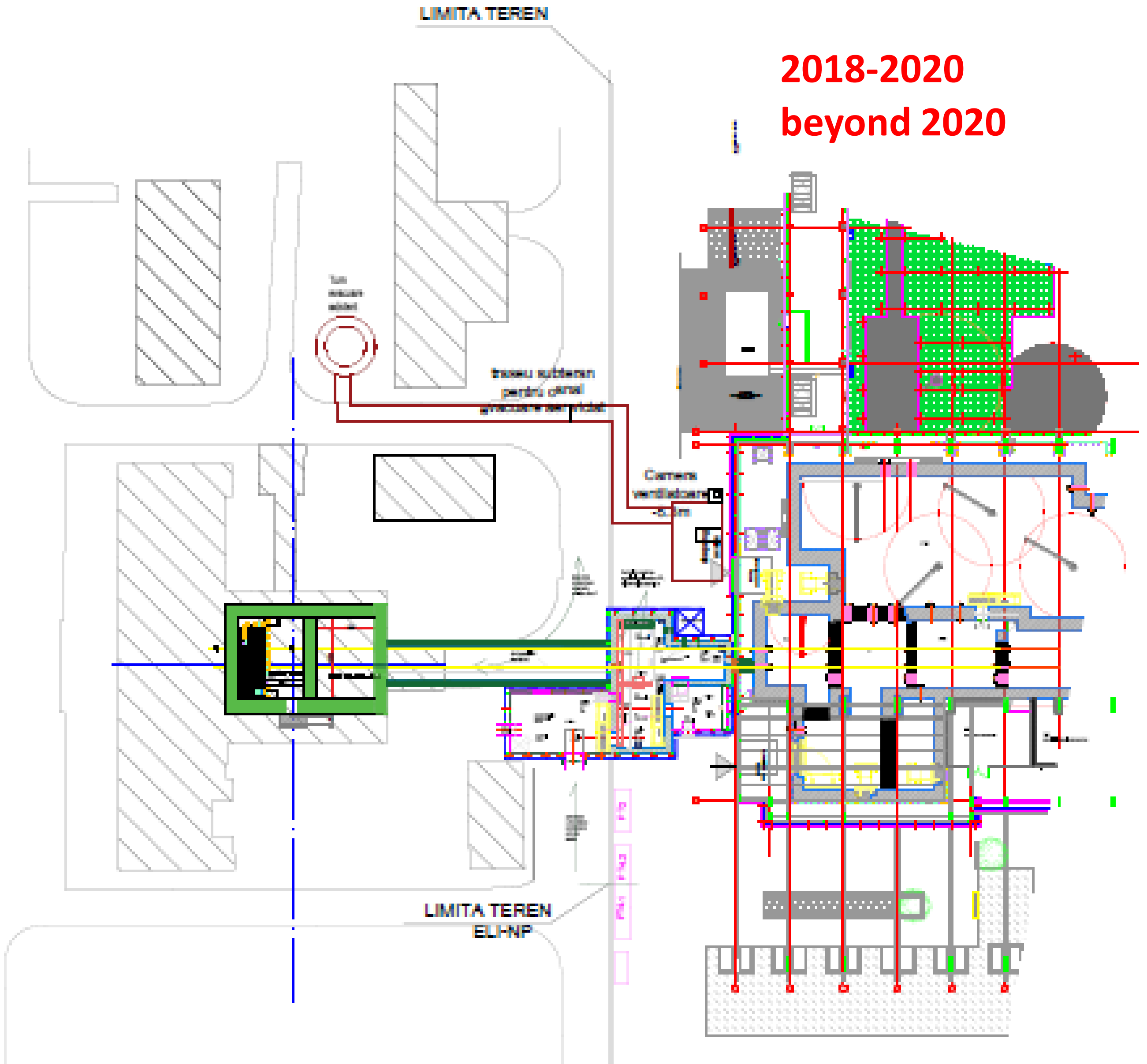
nuclei. Ion survival and extraction effciencies of better than 50% are expected. The extraction time of the ions will be about 5 ms, shorted by a factor of 5 compared to the present CSC. The novel CSC will thus remove the performance bottleneck of present stopping cells and give access to very exotic and short-lived nuclei available at the Super-FRS.



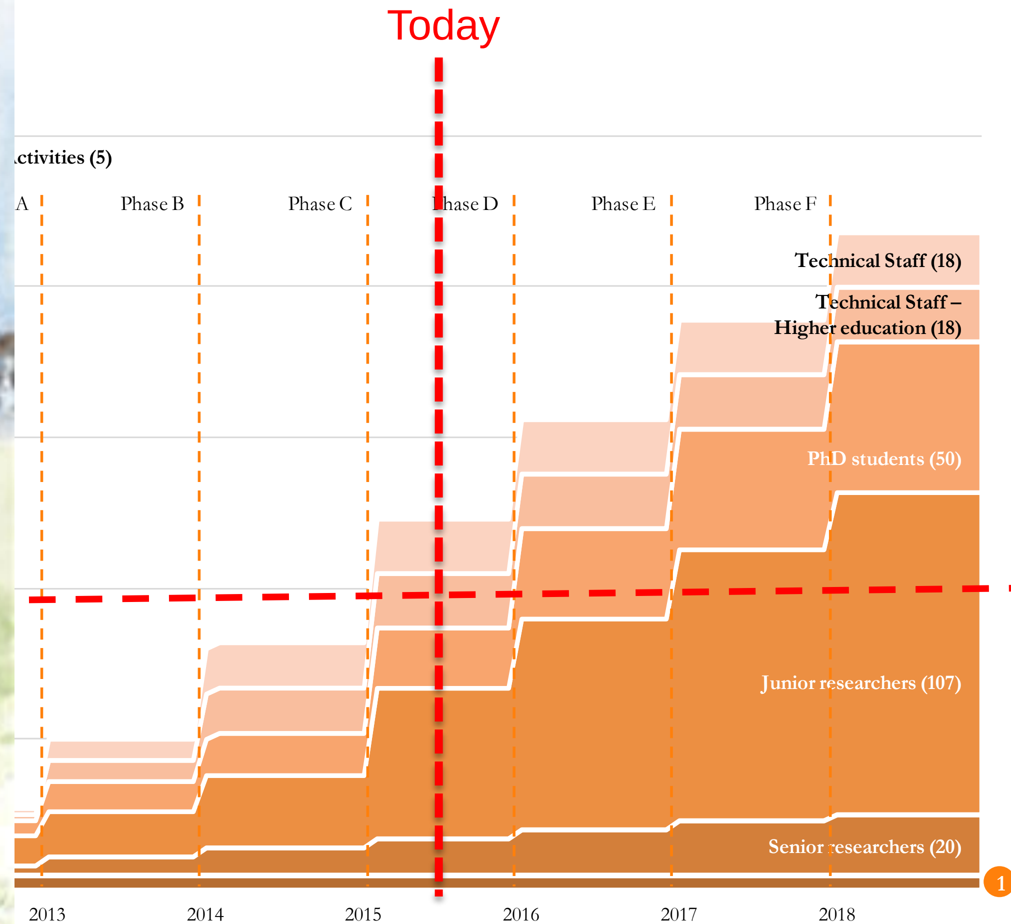
technical design
at GSI, Darmstadt

He gas @ 70 K
pressure 300 mb and 10 mb
> 100 V/sm DC field
RF carpet

Next phases of ELI-NP



Resources



http://www.eli-np.ro/jobs.php

Summary

- The laser-driven and gamma-beam science program at ELI-NP address key problems of present-day research.
- ELI-NP provides beyond-state-of-the-art gamma beams in terms of intensity, monochromaticity and polarizability, as well as intense laser pulses at much higher frequencies compared to existing facilities, which define experiments that cannot be done anywhere else.
- The facility will push ahead laser-driven research and photonuclear physics and their applications.

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Structural Instruments 2007-2013

Sectoral Operational Programme “Increase of Economic Competitiveness”

“Investments for Your Future!”

IFIN-HH

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) - Phase I

eli Nuclear Physics

www.eli-np.ro

Project co-financed by the European Regional Development Fund

Thank you!