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

Fission Studies at the New ELI-NP Facility

Dimiter L. Balabanski

eli Nuclear Physics

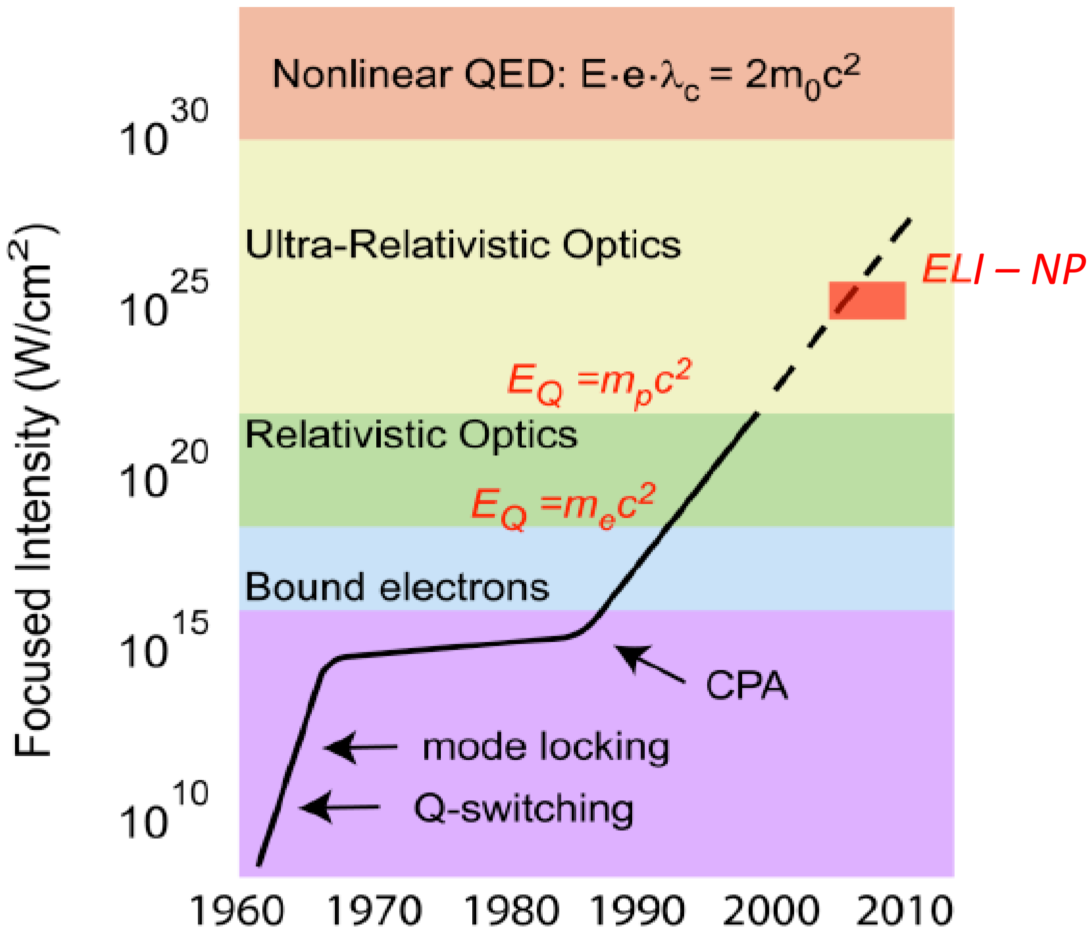
16th ASRC Workshop “Nuclear Fission and Structure Of Exotic Nuclei”, JAEA, Tokai, March 18th – 20th, 2014

IFIN-HH

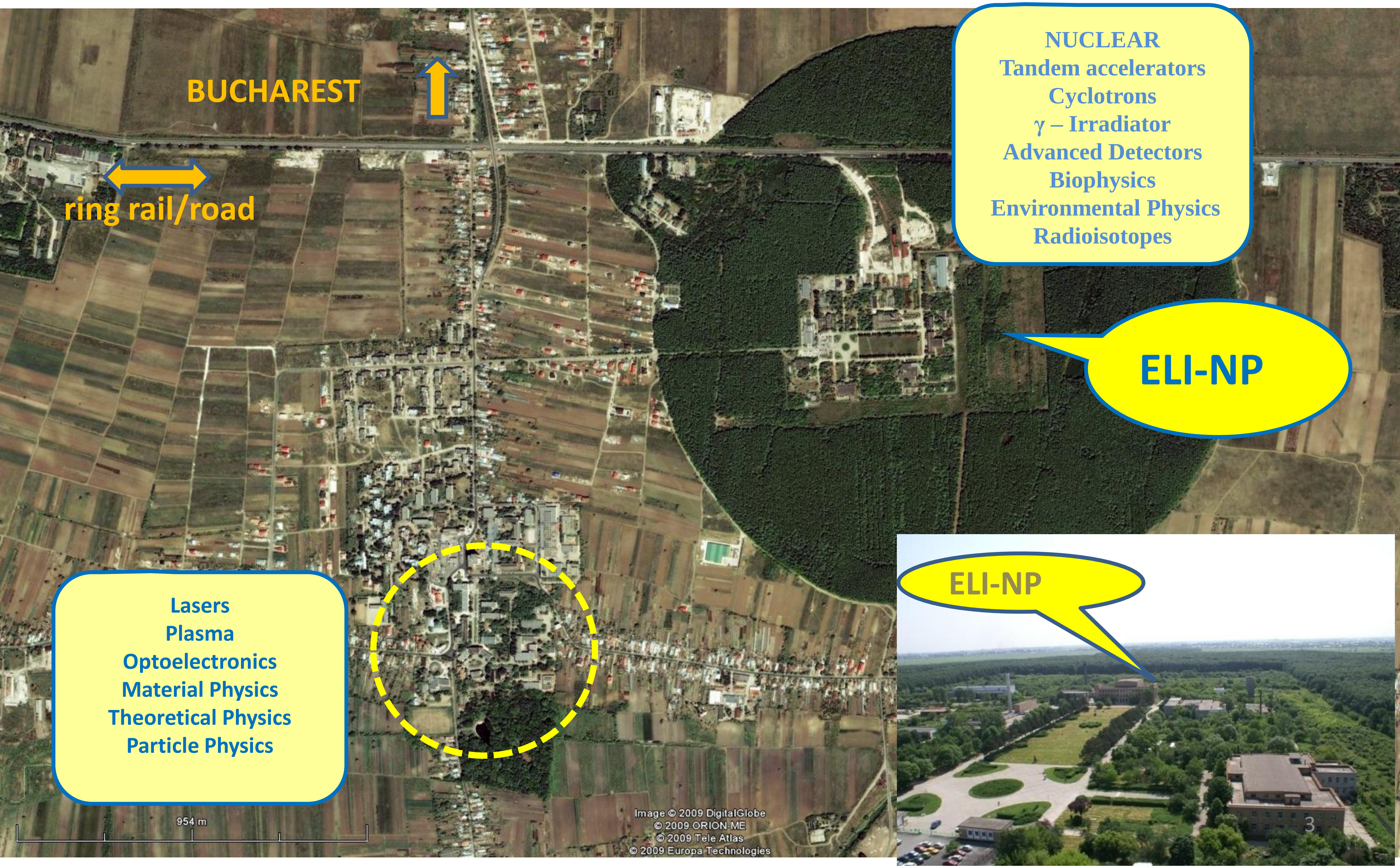
Extreme Light Infrastructure (ELI)

Gerard Mourou 1985: Chirped Pulse Amplification (CPA)

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



Bucharest-Magurele
National Physics Institutes



ELI-NP Milestones

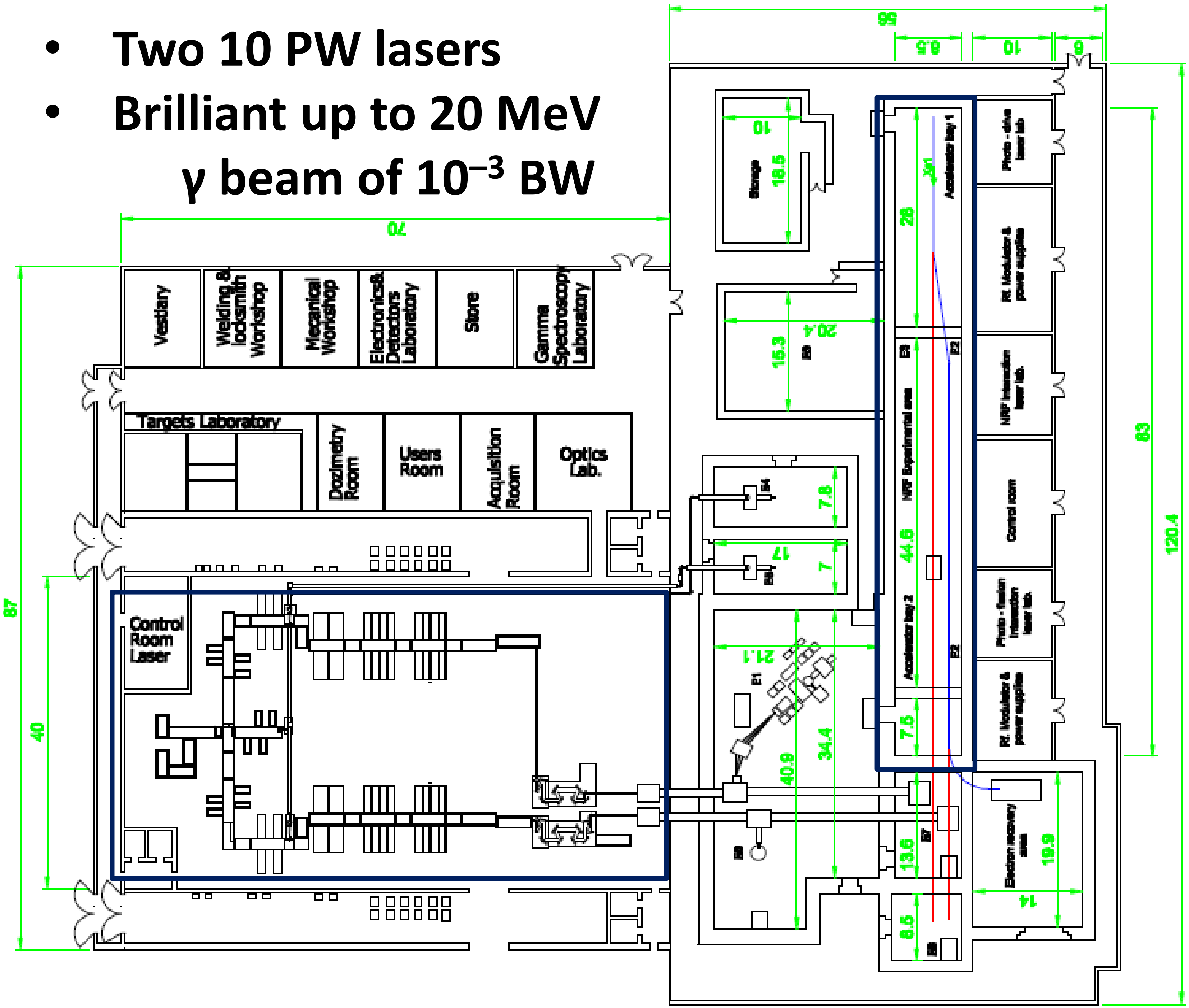
2005: *The ELI project was initiated*
2007: *Identified by the ESFRI Council as top priority research infrastructure*
EC supported a 36-month Preparatory Phase Project

May 2009: *Four main research topics were identified, among them ELI-NP*
December 2009: *Approval of the Competitiveness Council*

January 2012: *Project submitted to the EC*
July 2012: *Romanian Government Decision*
Construction of the New Research Infrastructure ELI-NP: 293 M€

September 2012: *EC Project Approval*
European Regional Development Fund
Operational Programme Increase of Economic Competitiveness
"Investments in your Future"
Financial Support (83%) of the First phase (2012-2015) 180 M€

- Two 10 PW lasers
- Brilliant up to 20 MeV γ beam of 10^{-3} BW



ELI-NP Status

December 2012: *Tenders for civil construction and major instrumentation*

May 2013: *Earth breaking*

Civil construction of the ELI-NP complex (2013 – 2015)

July 2013: *Laser-Beam System (LBS) contract signed*

Construction of the 2 x 10 PW Lasers (2013 – 2017)

March 2014: *Gamma-Beam System (GBS) contract signed*

Construction of 200 keV – 20 MeV gamma-beam system (2104 – 2018)

April 2013: *Science Division of ELI-NP was established*

Definition and preparation of experimental TDRs (due in early 2015)

2015: *Tenders for experimental instrumentation*

2017: *Commissioning experiments*


June 14th, 2013


Oct. 4th, 2013

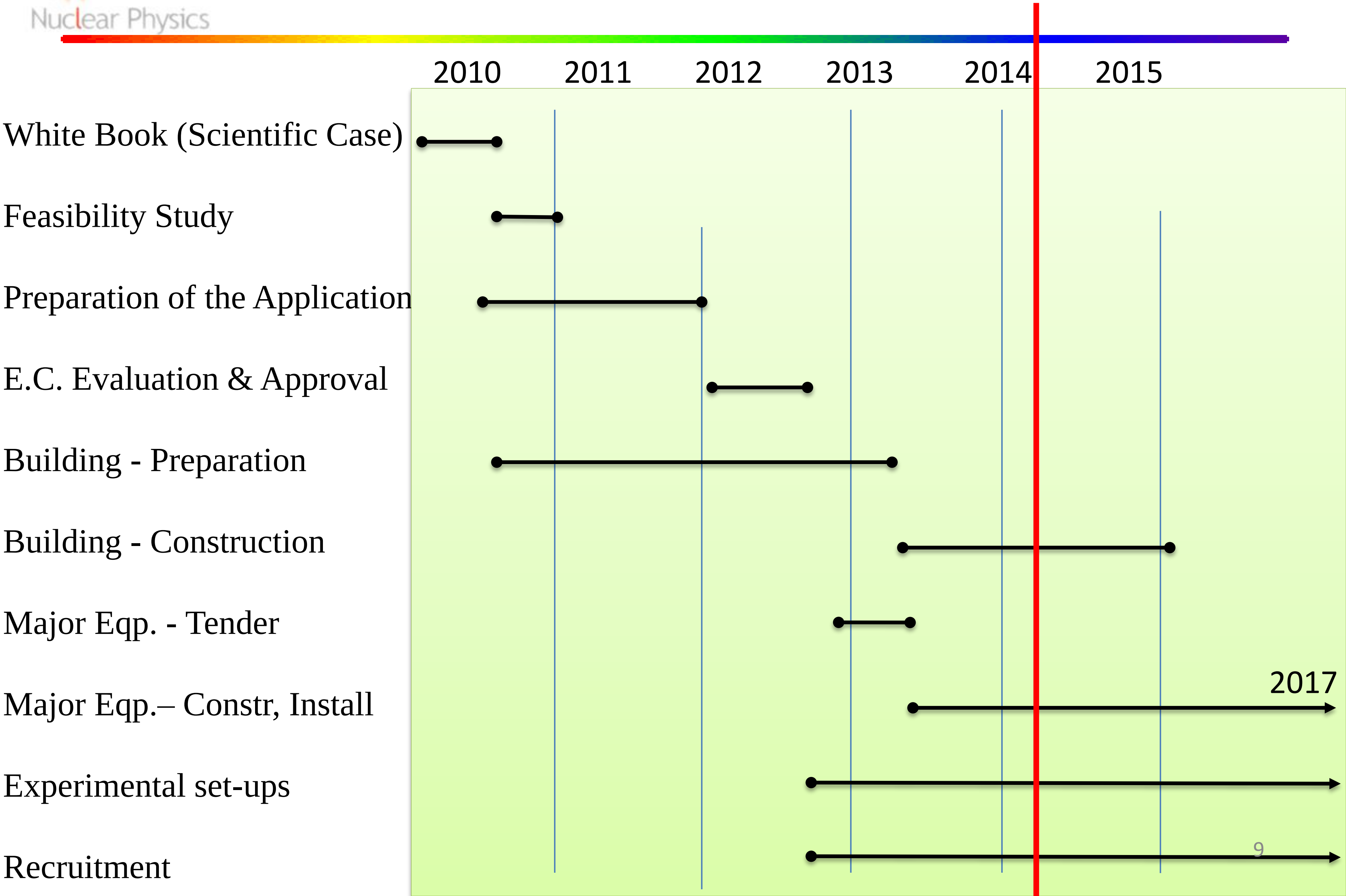
2x10PW Laser Contract

July 12th, 2013
Thales Optronique SAS and S.C. Thales System Romania SRL

2013-2017

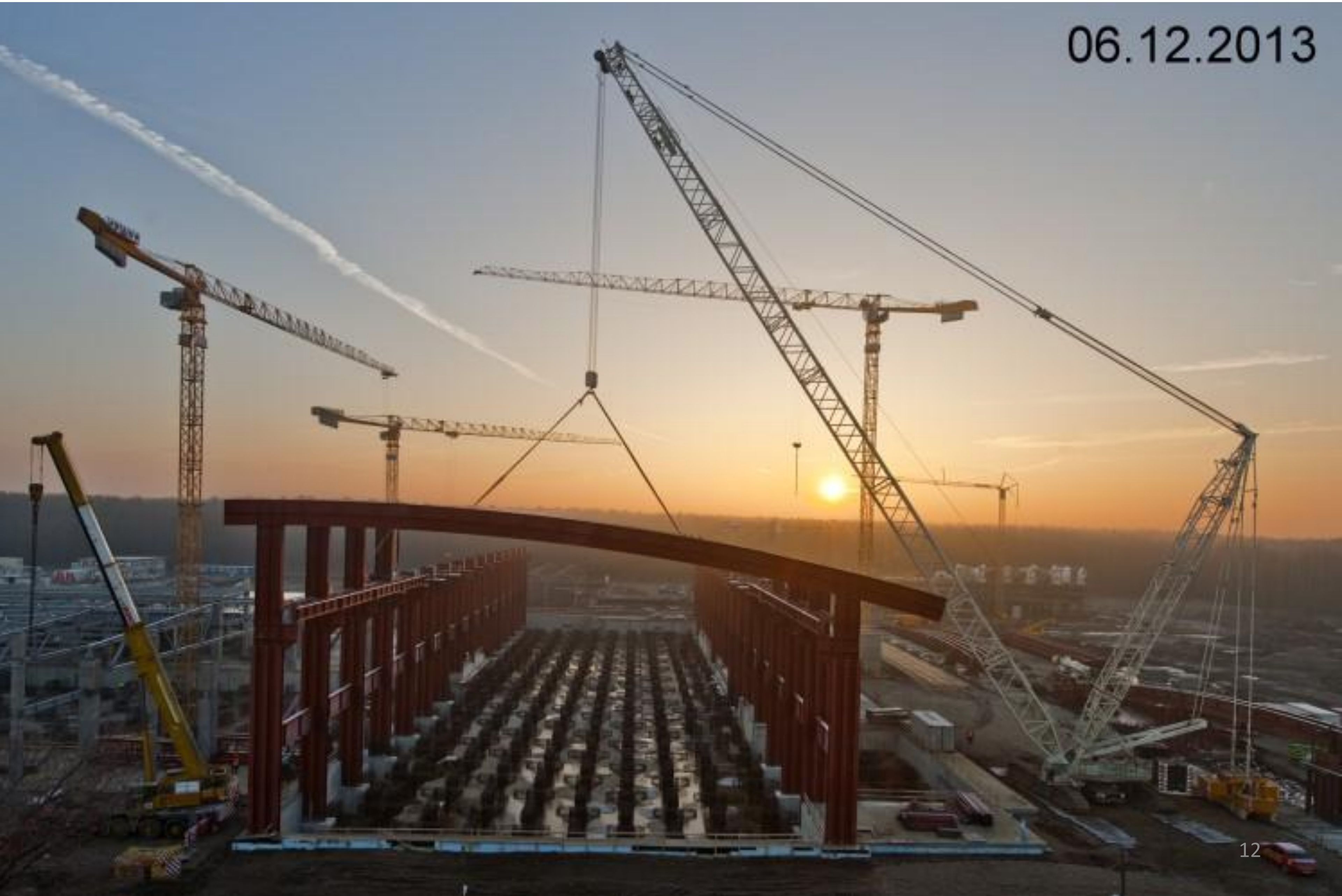
61.5 Meuro

Project implementation



June 7th, 2013

September, 2013


06.12.2013

current view

Buildings – one contractor, 33000 m² total

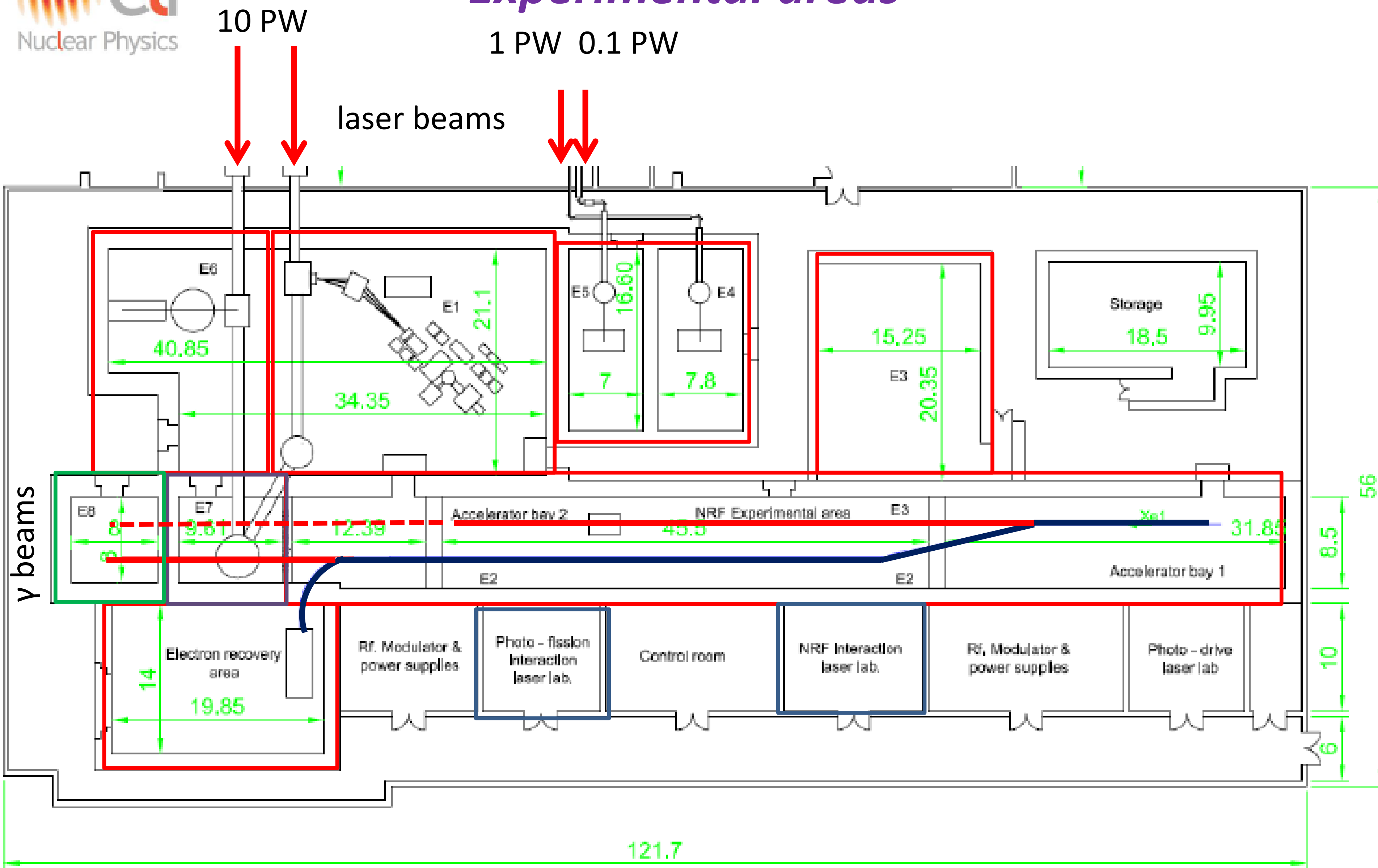
- Experimental area building
- Office building
- Guest house
- Canteen

Nuclear Physics

High-power laser source

Parameter	Range
Available outputs power and repetition rate	Two outputs with 0.1PW at 10Hz two outputs with 1PW at 1 Hz two outputs with 10PW at 1shot/min
Pulse duration	<50 fs
Strehl Ratio	>0.7
Pointing stability	<0.2 microrad
Temporal contrast in the nanosecond range	10^{11}:1 for the 0.1PW outputs 10^{12}:1 extrapolated for the 10PW outputs
Temporal contrast in the picosecond range	10^{11}:1 for the 0.1PW outputs 10^{12}:1 extrapolated for the 10PW outputs
External clock synchronization jitter	<200fs

Experimental areas



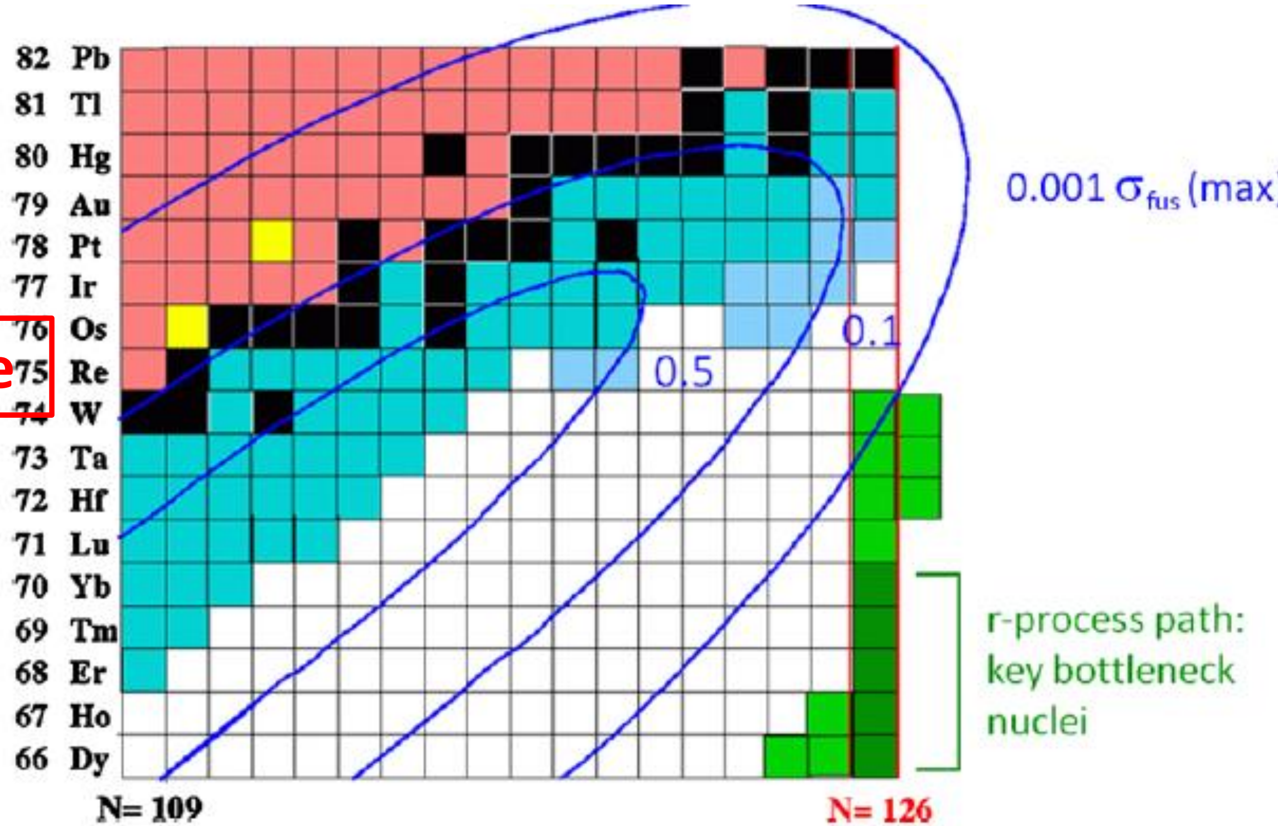
Laser-

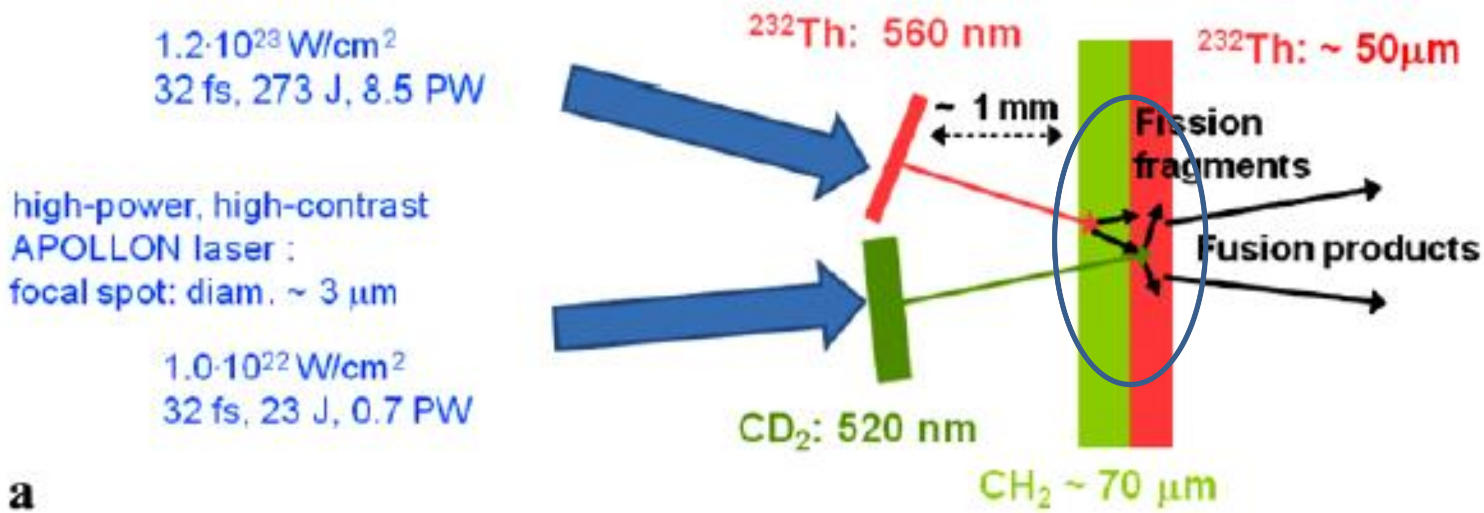
Appl Phys B (2011) 103: 471–484
DOI 10.1007/s00340-010-4261-x

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

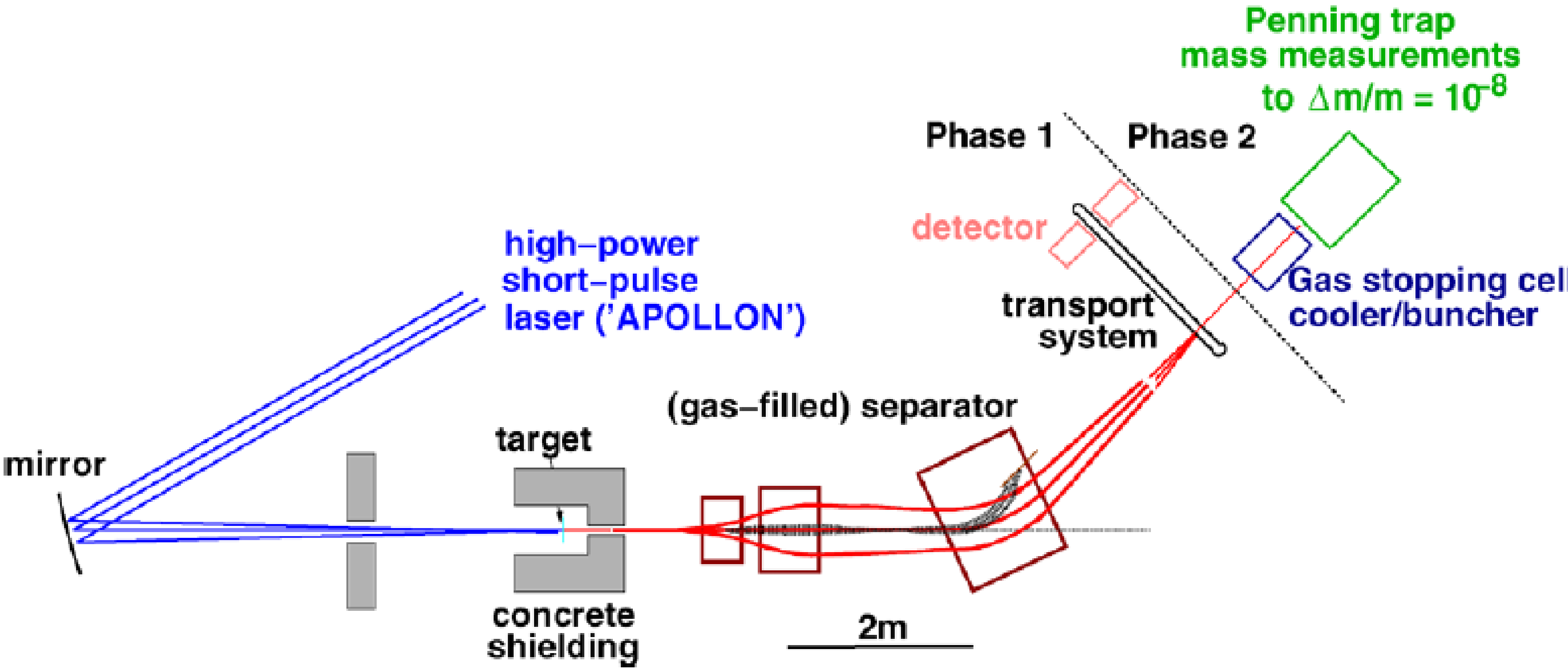
Introducing the fis
a laser-accelerated
towards the $N = 1$

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

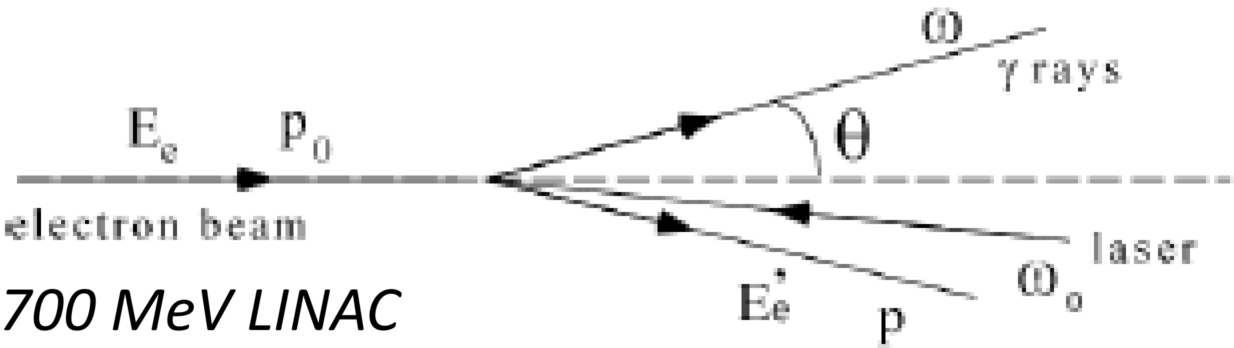




Experimental set-up @ ELI-NP



brilliant γ beam



700 MeV LINAC

Parameters of the gamma-beam

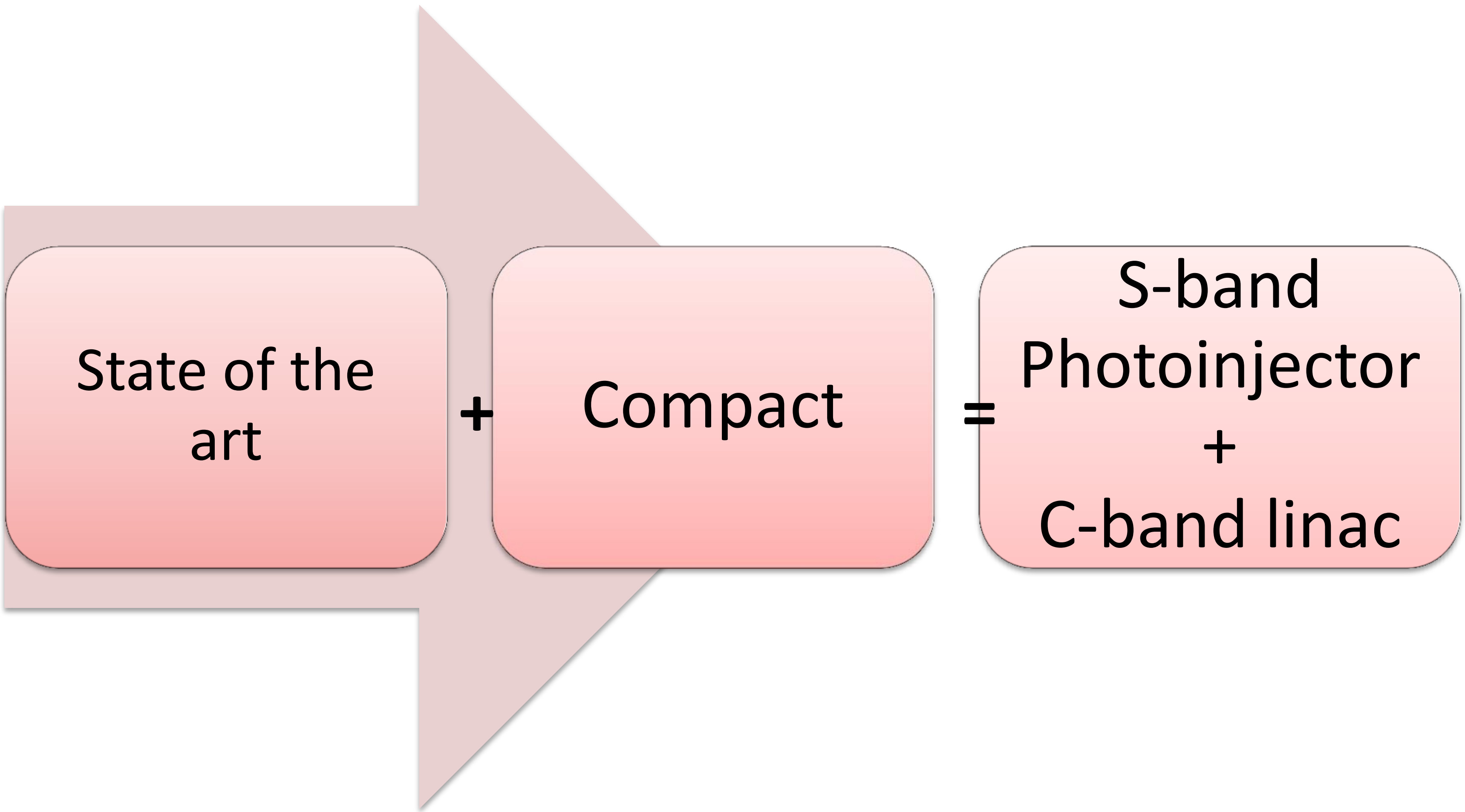
type	Units	Range
Photon energy	MeV	0.2 – 19.5
Divergence	Rad	$\leq 2.0 \times 10^{-4}$
Average Relative Bandwidth of Gamma-Ray Beam		$\leq 5.0 \times 10^{-3}$
Time-Average Spectral Density at Peak Energy	1/(s eV)	$\geq 5.0 \times 10^{3}$
Time-Average Brilliance at Peak Energy	1/(s mm² mrad² 0.1% $\eta_{,\gamma}$)	$\geq 1.0 \times 10^{11}$
Minimum Frequency of Gamma-Ray Macropulses	Hz	≥ 100

ELI-NP: the *F-I-UK* European proposal

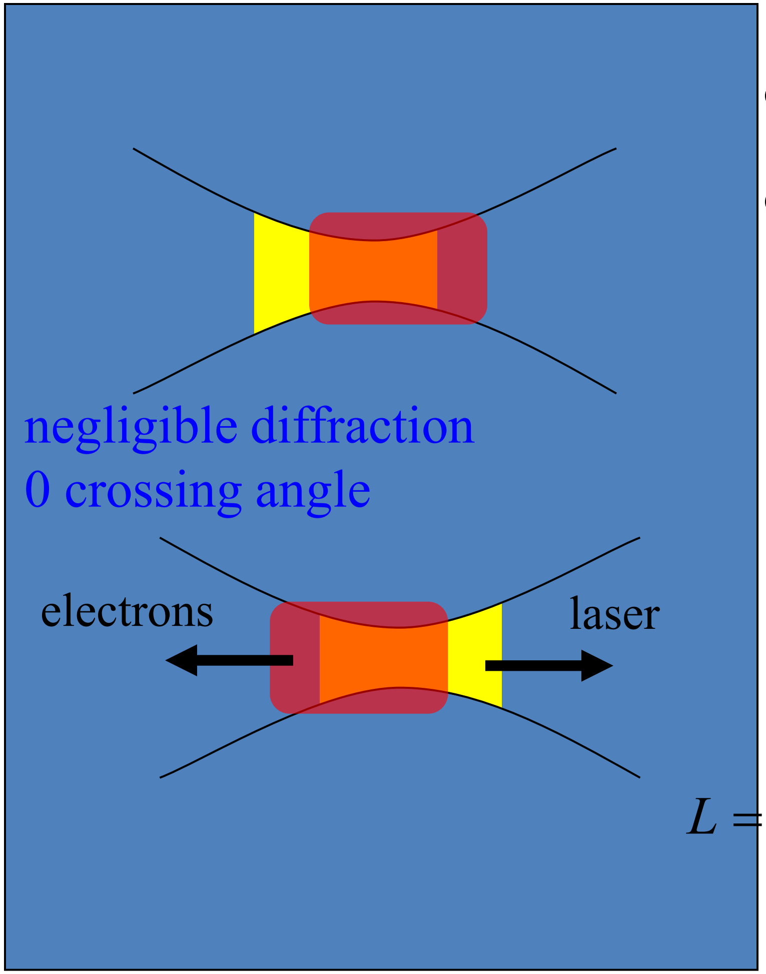
European Collaboration for the proposal of the gamma-ray source:

✓Italy: INFN,Sapienza
✓France: IN2P3, Univ. Paris Sud
✓UK: ASTeC/STFC
~ 80 collaborators elaborating the CDR/TDR

ELI-NP requirements:



Thomson/Compton Sources are electron-photon Colliders, based on the concept of *Spectral Luminosity*, *i.e.* Luminosity per unit bandwidth



$$\sigma_T = 0.67 \cdot 10^{-24} cm^2 = 0.67 \ \ barn$$

- Scattered flux $N_\gamma = \mathbf{L}\sigma_T$ $\quad \sigma_T = \frac{8\pi}{3} r_e^2$
- Luminosity as in HEP collisions
  - Many photons, electrons
  - Focus tightly
  - ELI-NP

$$\mathbf{L} = \frac{N_L N_{e-}}{4\pi\sigma_x^2} f$$

$$L = \frac{1.3 \cdot 10^{18} \cdot 1.6 \cdot 10^9}{4\pi(0.0015cm)^2} 3200(sec^{-1}) = 2.5 \cdot 10^{35} cm^{-2} sec^{-1}$$

cfr LHC 10^{34} SuperB-fac 10^{36}

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 (psec)	< 0.5
Pointing jitter (μm)	1

Yb:Yag Collision Laser	Low Energy Interaction	High Energy Interaction
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 %

Accelerator and Equipments in ELI-NP Building ELI-NP-GS

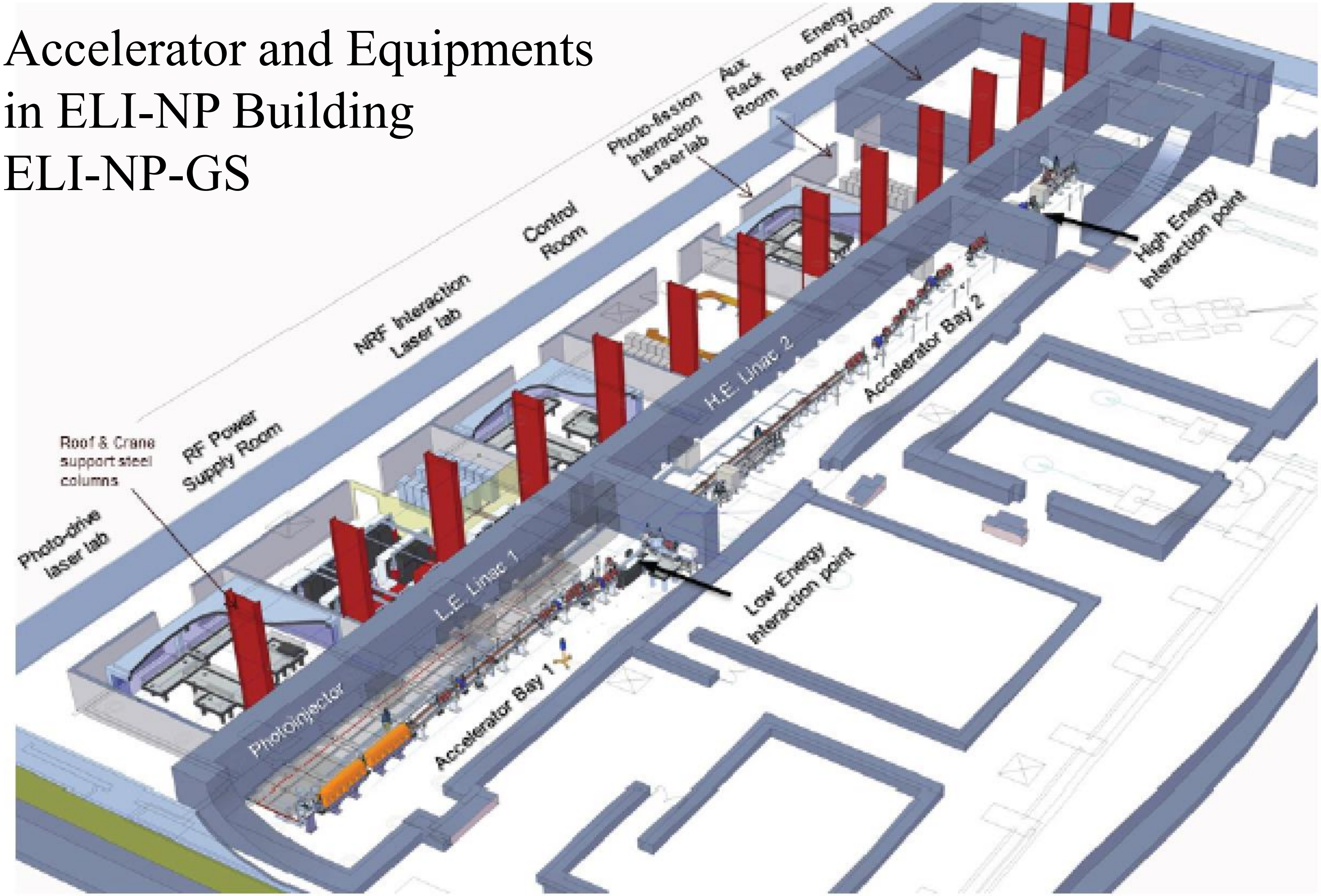
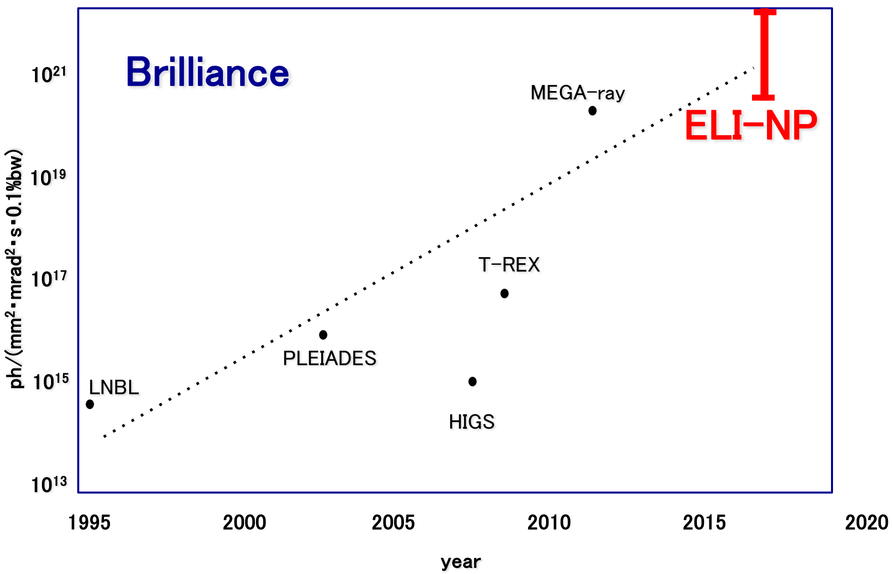
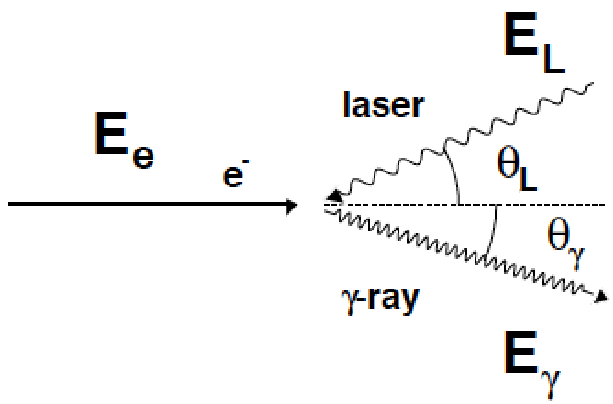


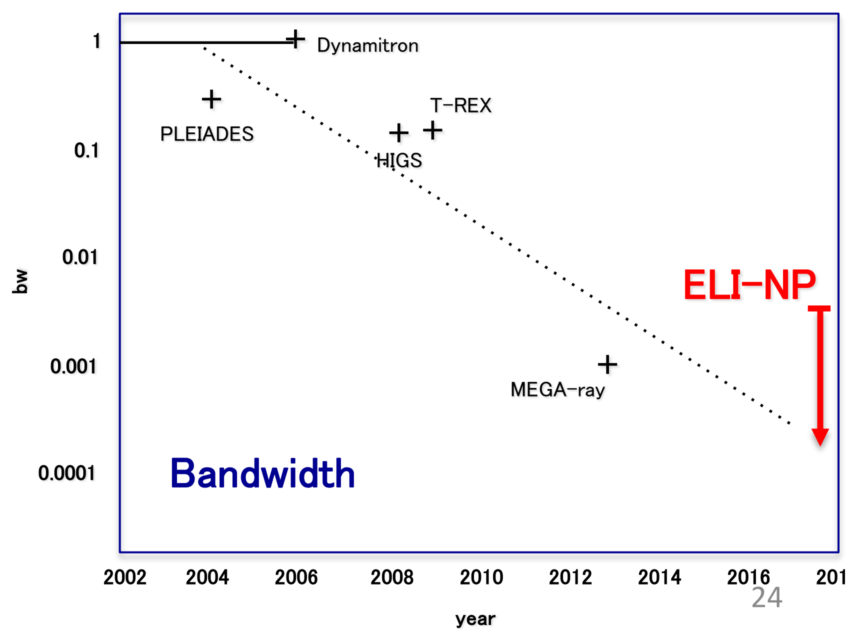
Fig. 197. Isometric 3D view of Building Layout of the Accelerator Hall & Experimental Areas

ELI–NP Gamma Beam System

Comparison with other LCB systems







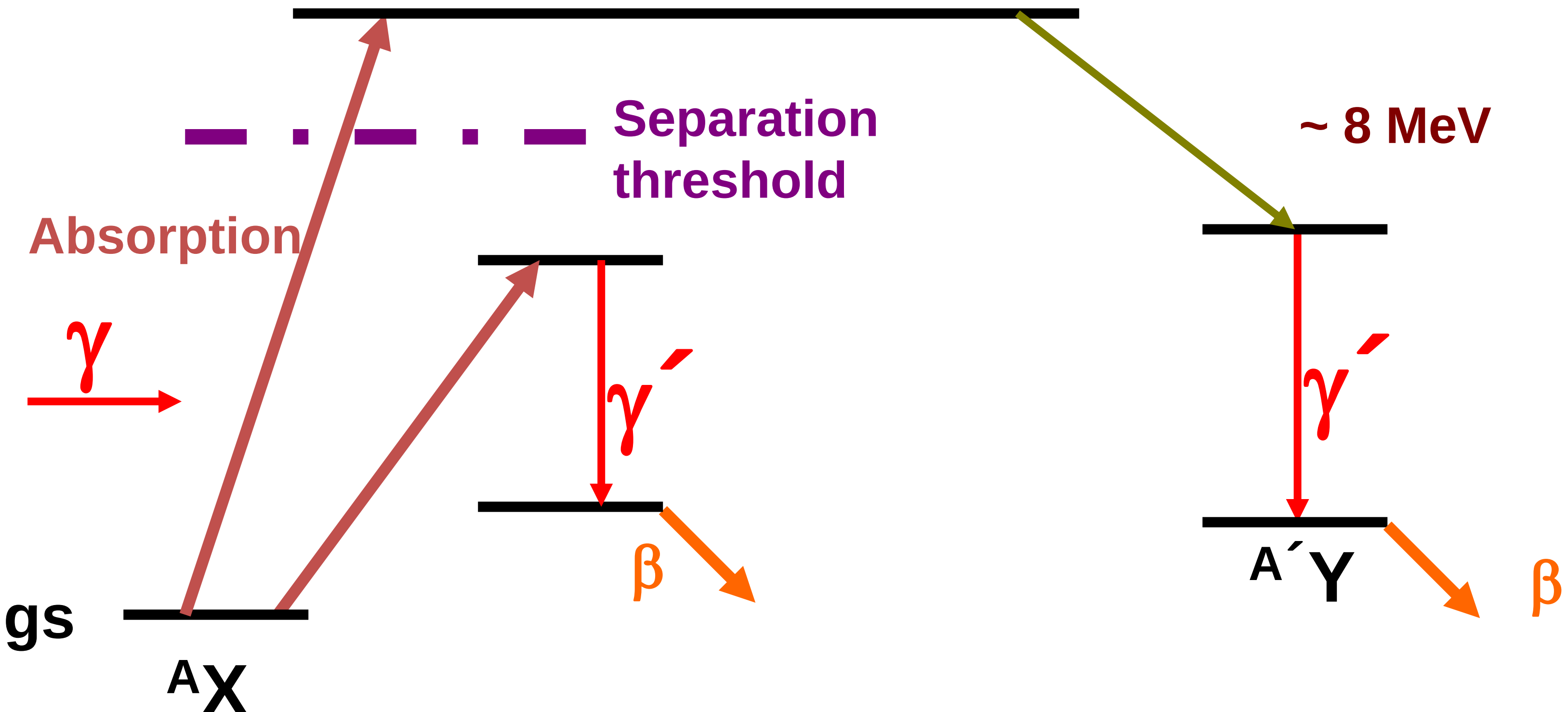
ELI–NP Gamma Beam System

- high intensity / small emittance e⁻ beam from a warm LINAC
- very brillant high rep. rate int. laser
- small collision volume

Table 1. Comparison of performance properties of existing and upcoming γ-beam facilities.

	HIγS	HIγS2	MEGa-Ray	ELI-NP
$E_\gamma [MeV]$	2-100	2-100	< 8	< 19
total flux [γ/s]	$\sim 10^9$	$5 \cdot 10^{12}$	10^{13}	10^{13}
$\Delta E/E$	$2\text{-}5 \cdot 10^{-2}$	$\leq 10^{-3}$	$\leq 10^{-3}$	$\leq 10^{-3}$
spectral density [γ/eVs]	10^2	$10^4\text{-}10^6$	$10^4\text{-}10^6$	$10^4\text{-}10^6$

Photonuclear Reactions



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

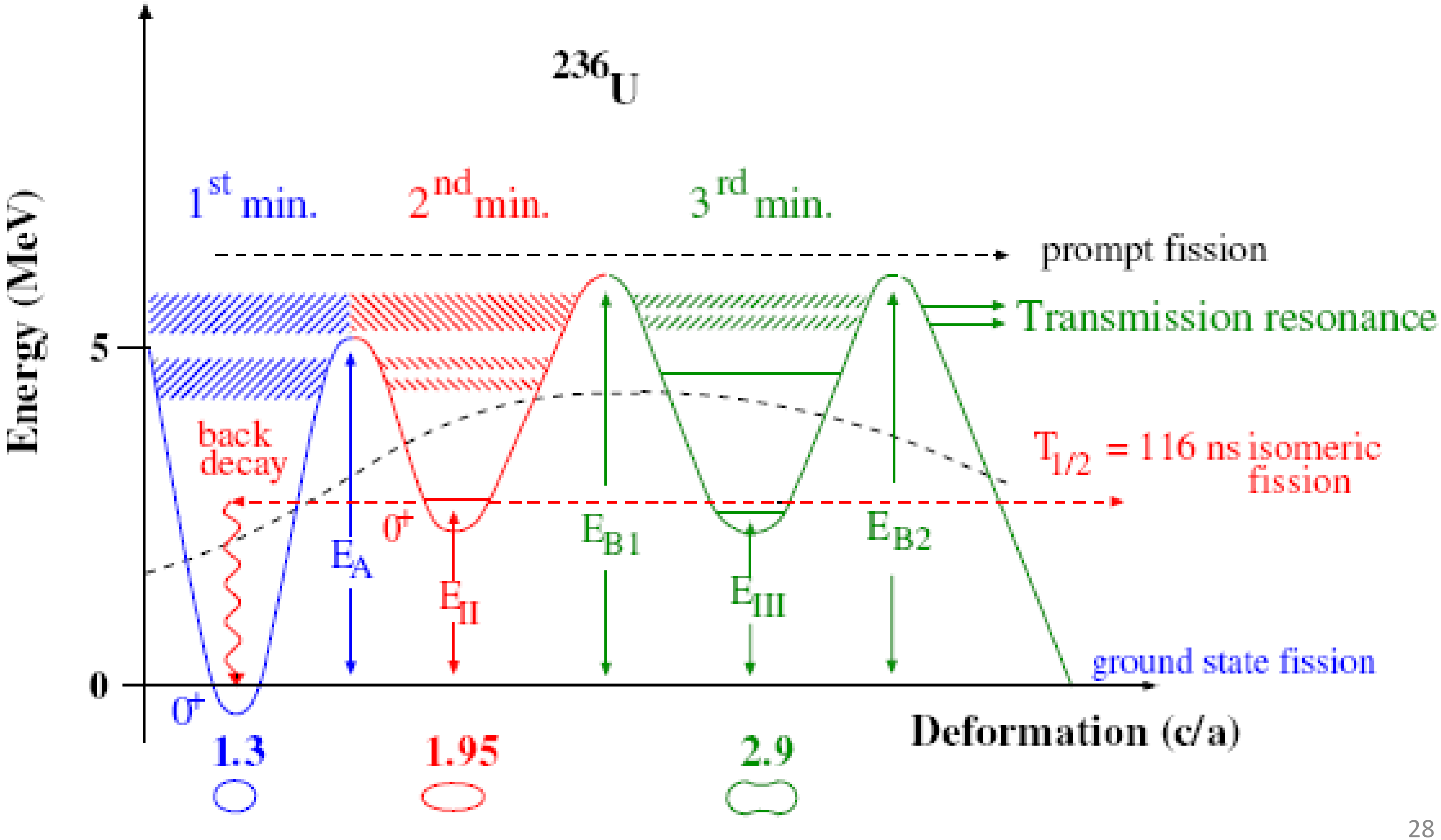
Photo-fission @ ELI-NP

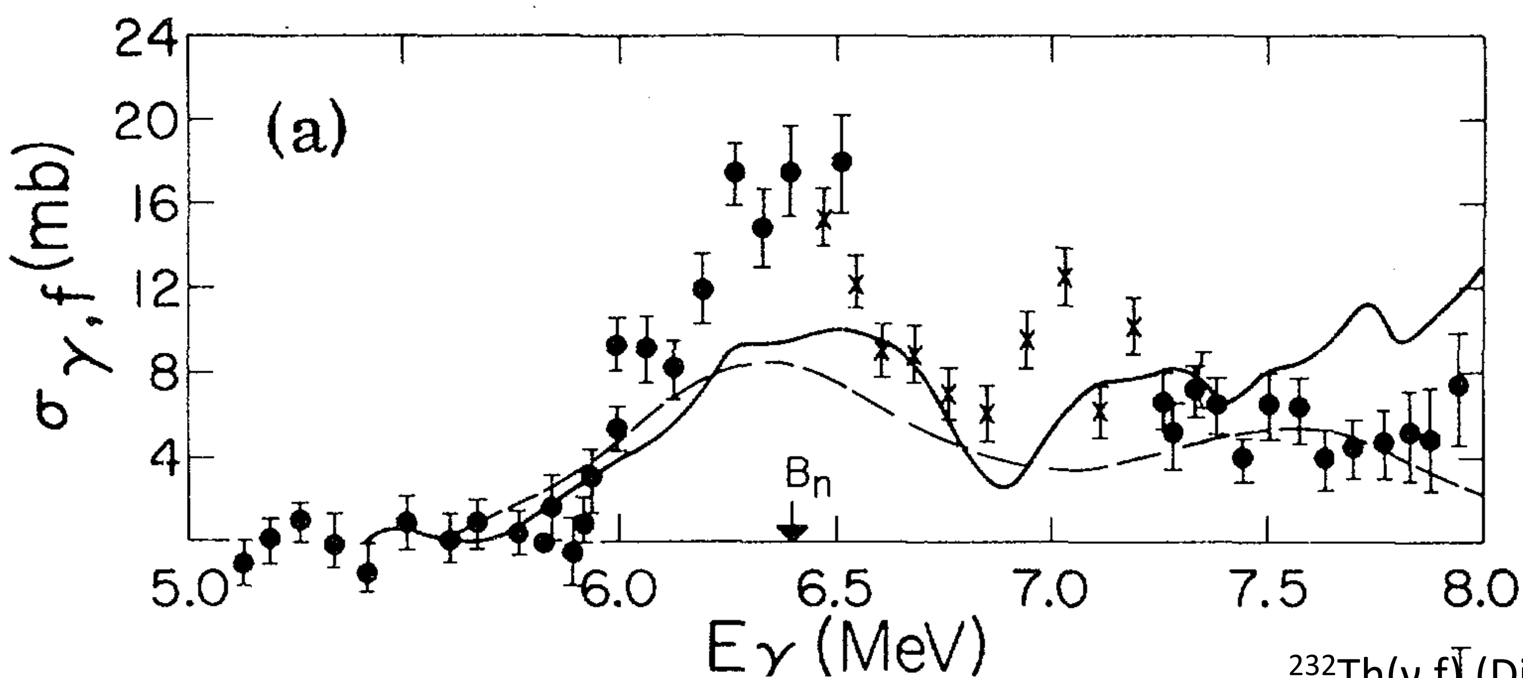
Attila Krasznahorkay (ATOMKI)

Fadi Ibrahim (IPN – Orsay)

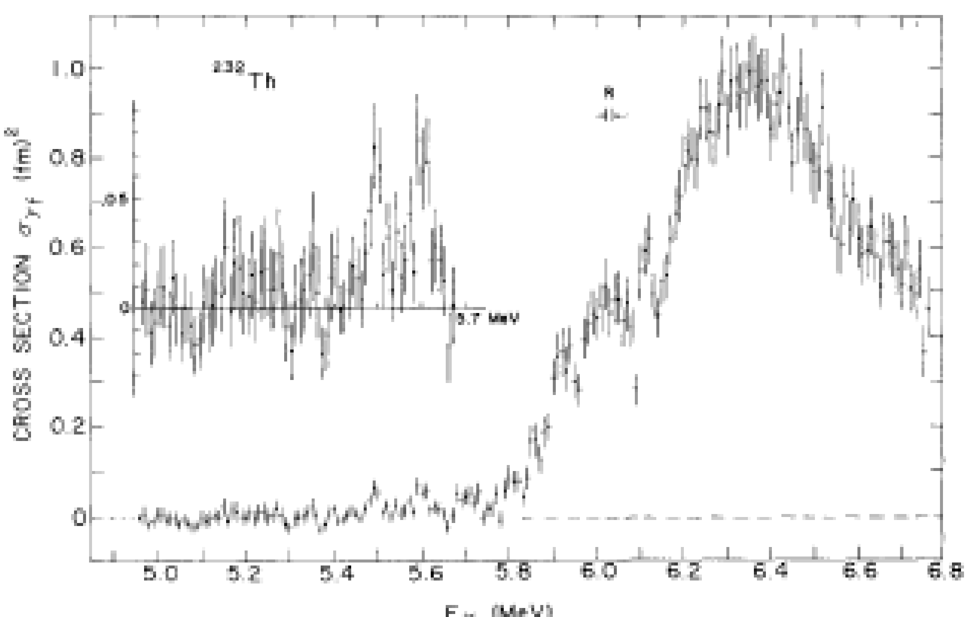
Dimiter L. Balabanski (ELI-NP)

Resonant tunneling through the triple humped fission barrier



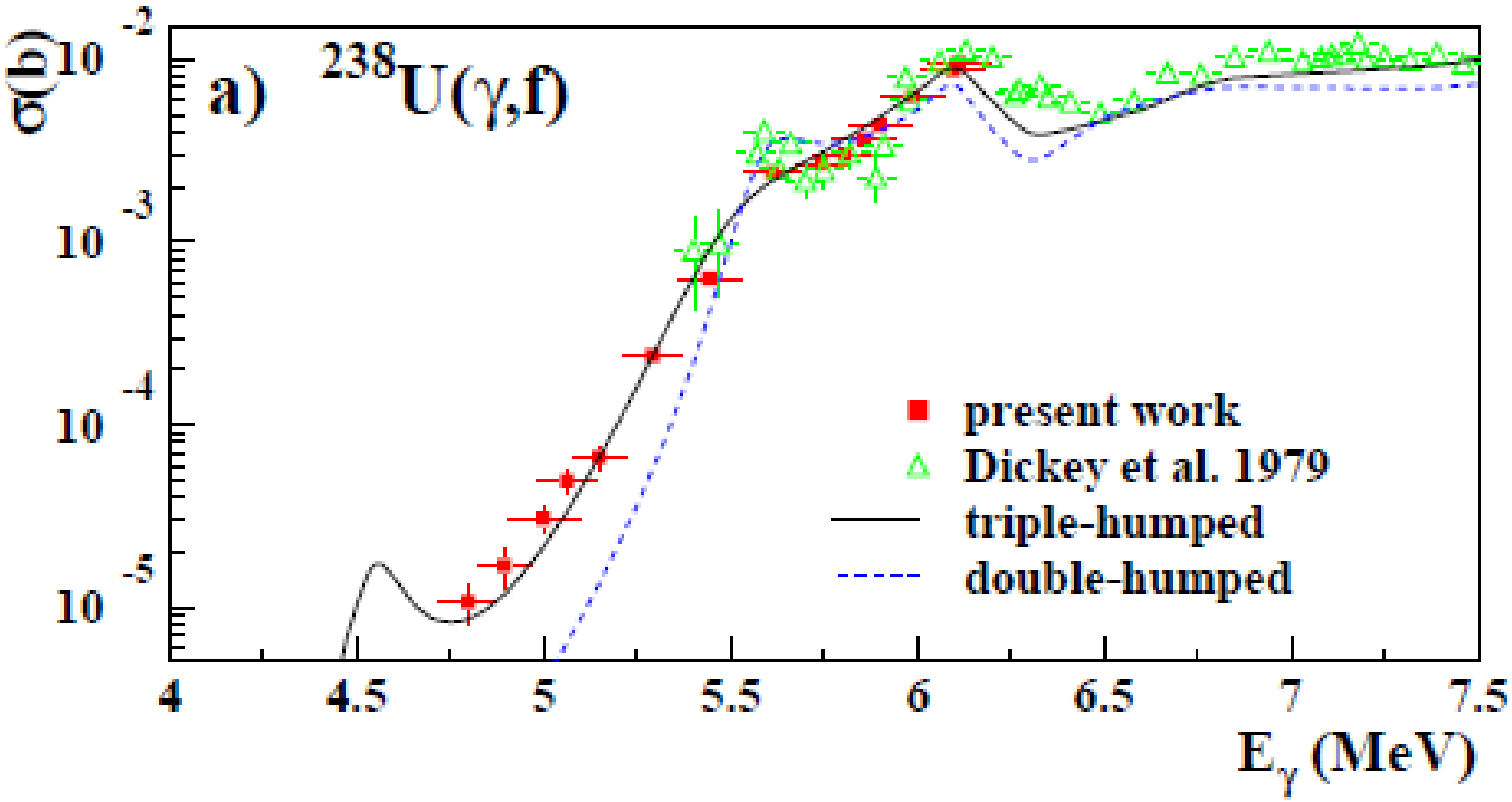


^{232}Th(γ,f) (Dickey 1975)

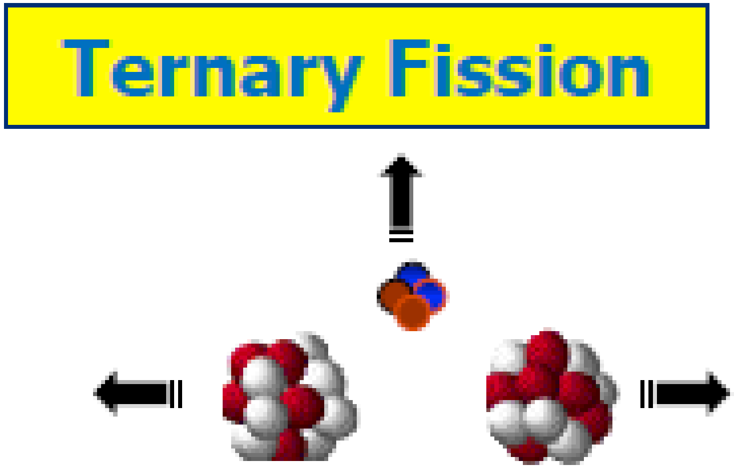


^{232}Th(γ,f) (Knowles 1982)
PLB 116B (1982) 315

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



Ternary fission studies with ELI-NP



The two heavy fragments are sometimes accompanied by a Light Charged Particle : Ternary fission

(roughly 2 to 4 times every thousand events depending on the mass of the fissioning nucleus)

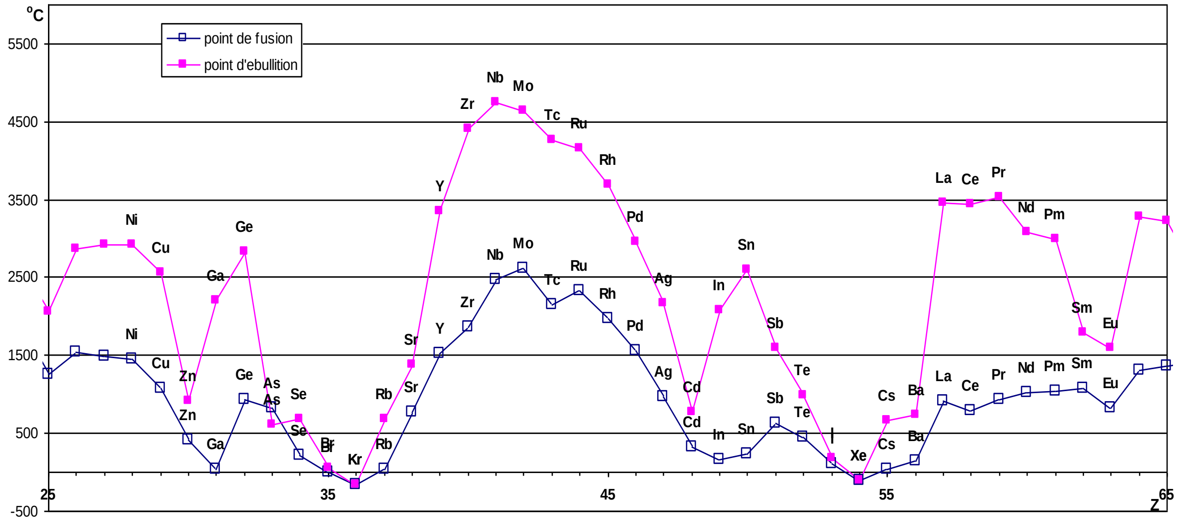
Let’s see what else we can squeeze from phot

In fission fragments share about 200 MeV and have angular momentum of 20ħ. The nuclear spin ensemble has oblate orientation with respect to the beam axis. The ions are emitted in a charge state around 20^+.

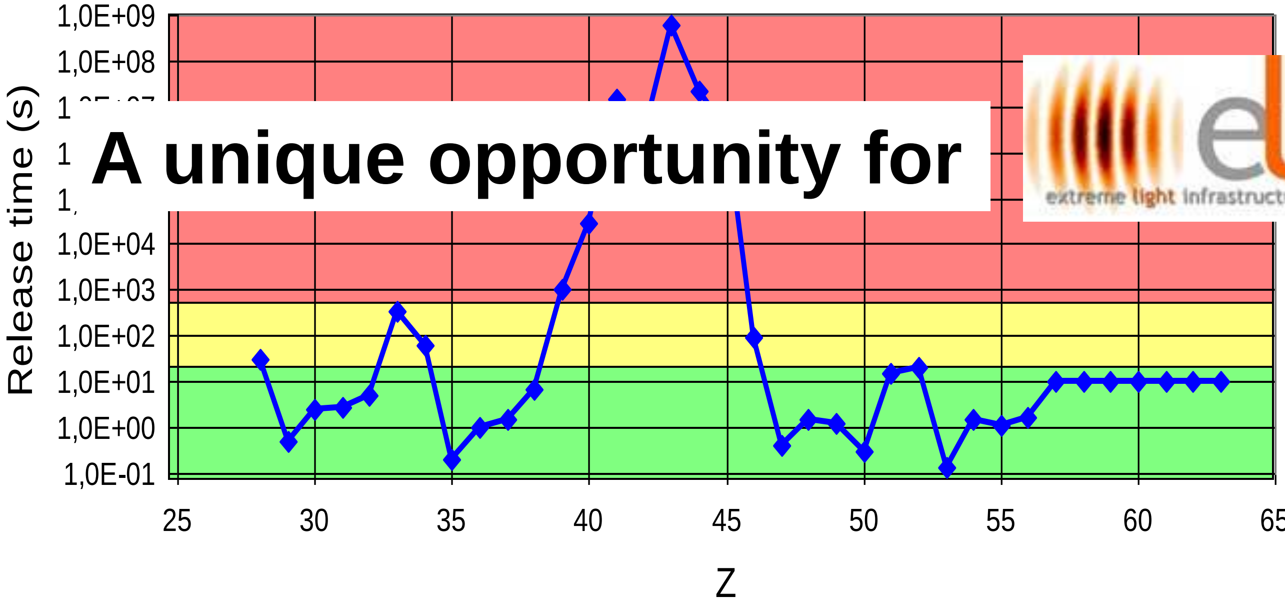
Designed experiments

- IGISOL studies of exotic nuclei
- γ-spectroscopy of exotic nuclei

What about the refractory elements ?



Boiling point & Melting point

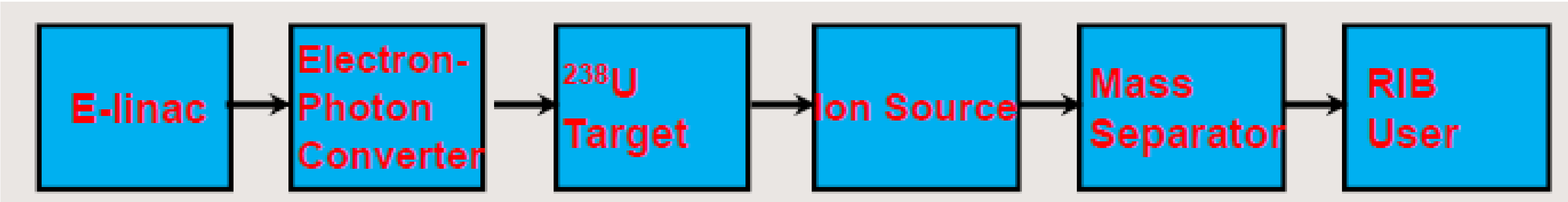


A unique opportunity for

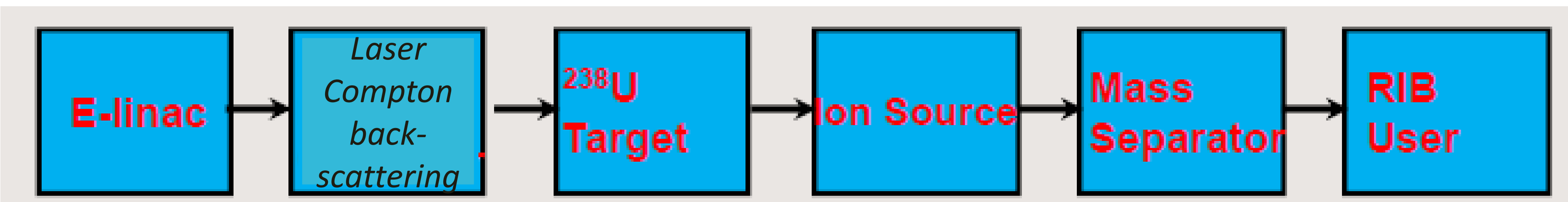
extreme light infrastructure

Taken from PIAFE project Report based on Studsvik measurements

ALTO, ARIEL, etc.



ELI-NP



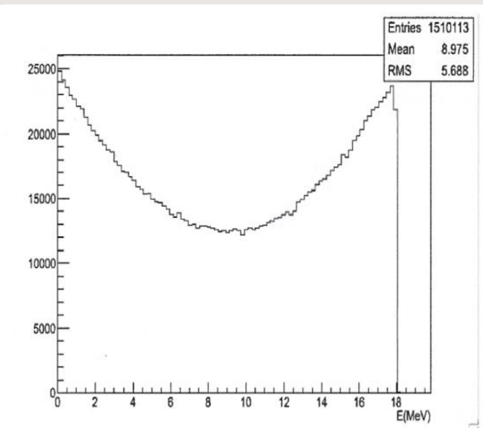
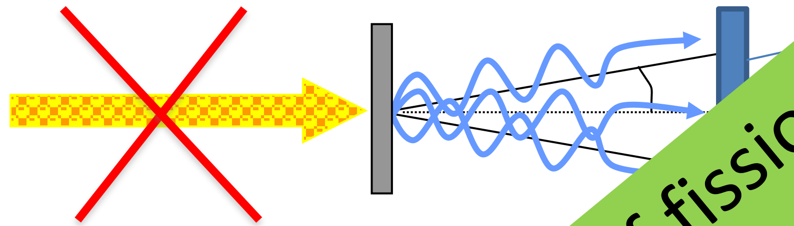


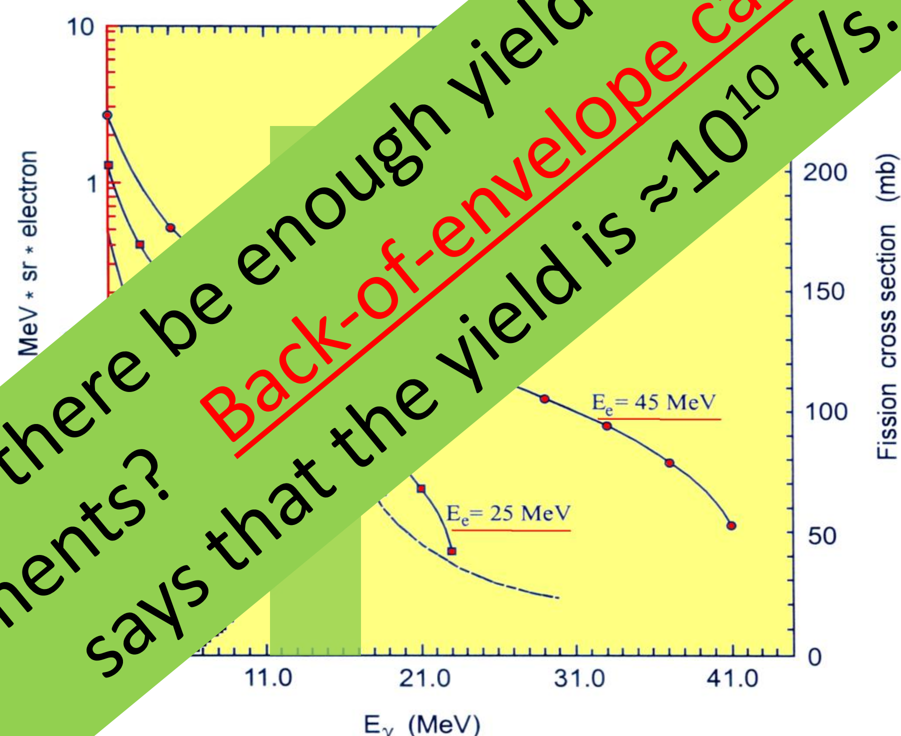
Fig. 182. Energy distribution for electron beam energy of 720 MeV at the IP

γ–beam spectrum at the IP
(without collimator)

Production of fission fragments by photo-fission at ELI



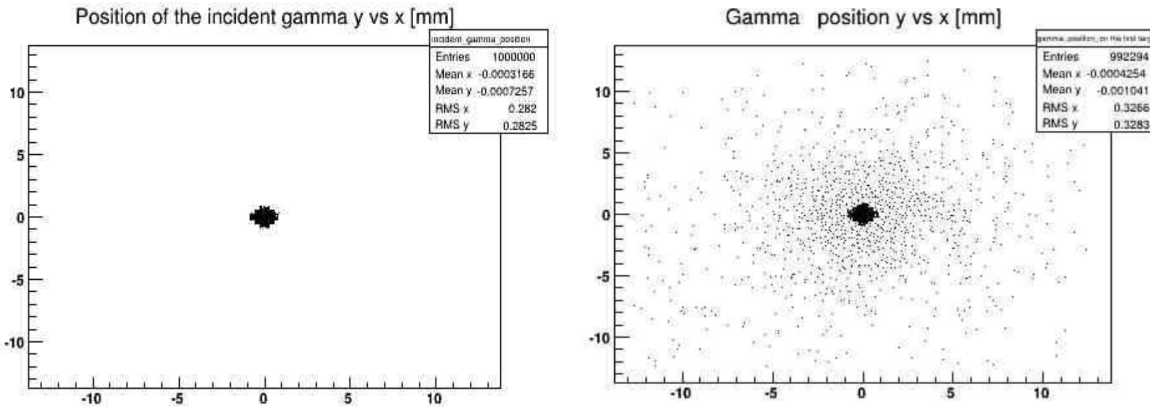
$\Phi = 1.4 \cdot 10^{12}$ γ/s

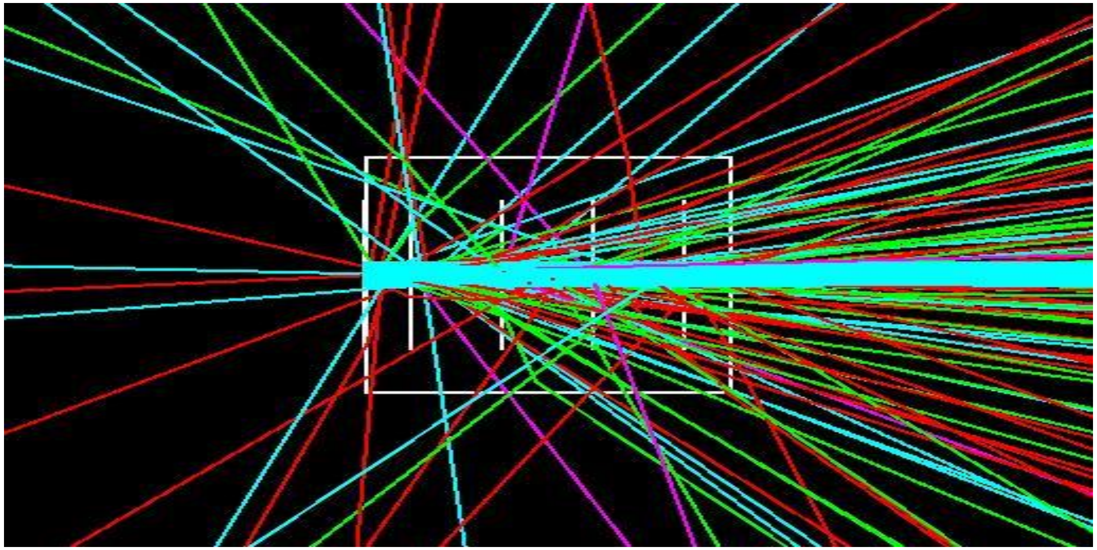


Will there be enough yield of fission fragments? Back-of-envelope calculation says that the yield is $\approx 10^{10}$ f/s.

Φ. s. N= Φ.6,4 10^{-3} f/s

Yield estimates





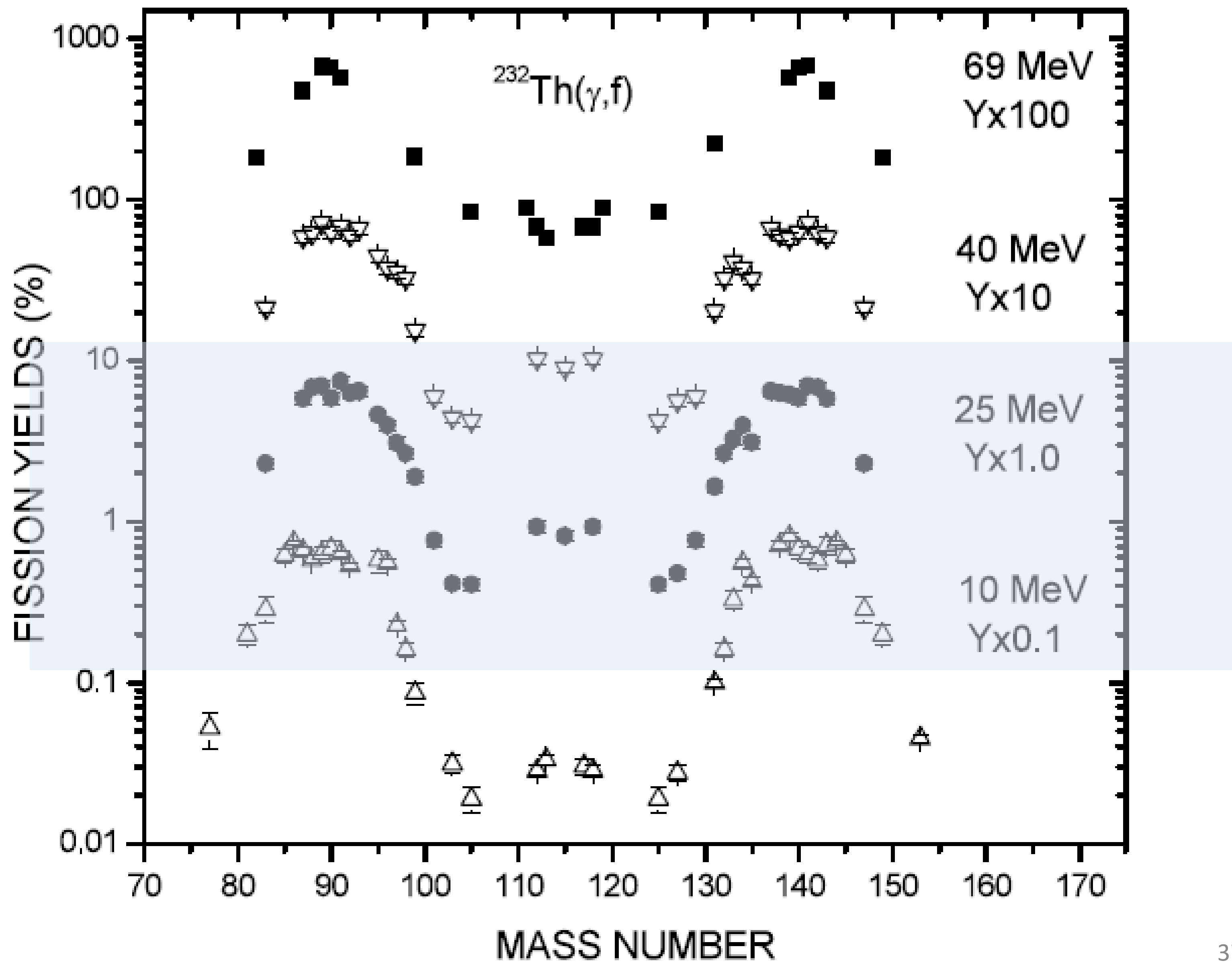
Yield: $6.2 \cdot 10^8$ f/s

with a stack of targets:

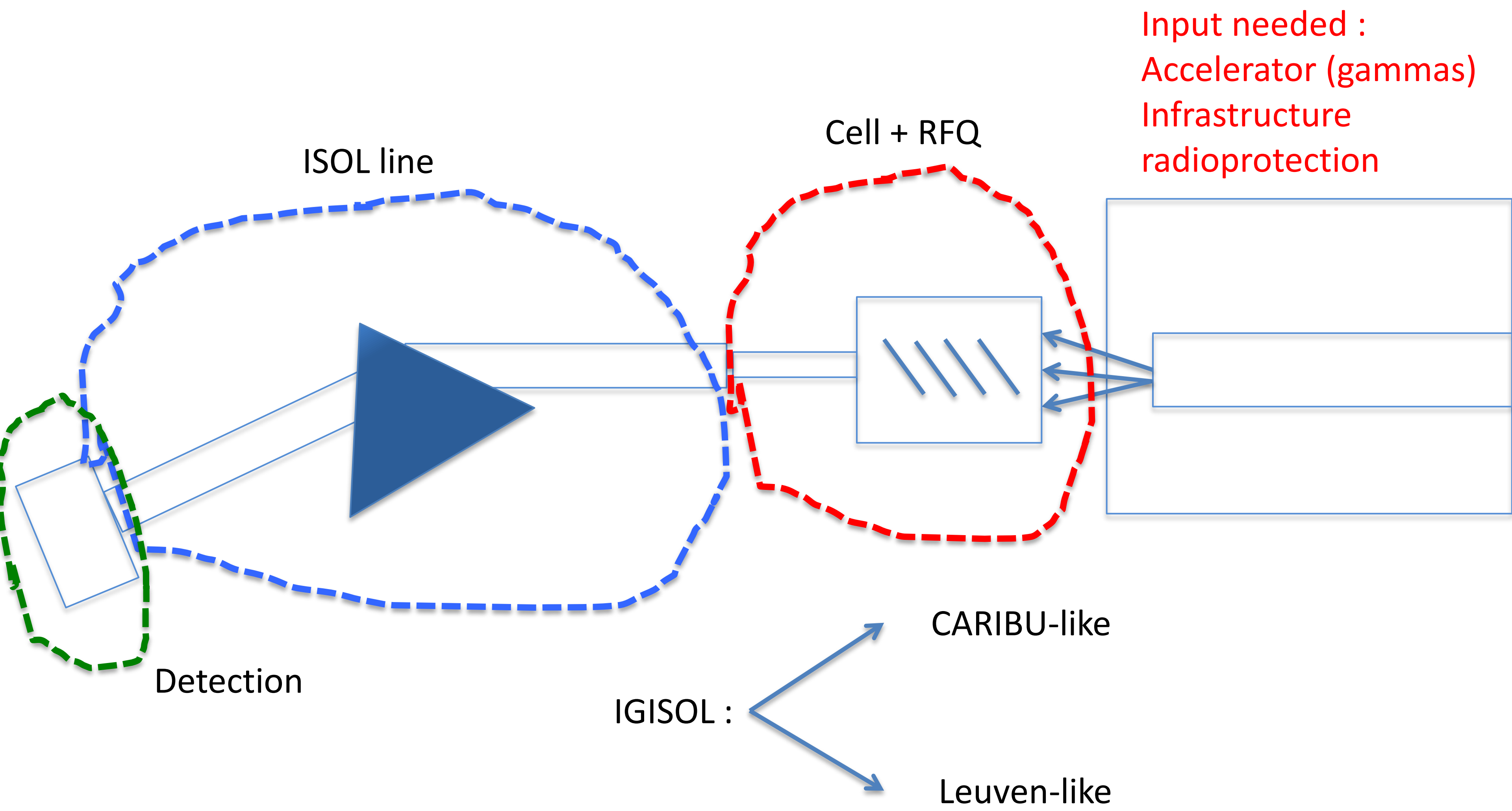
$\approx 10^{10}$ f/s

Al window 19.17 mg/sm^2
^{238}U targets of 19.1 mg/sm^2

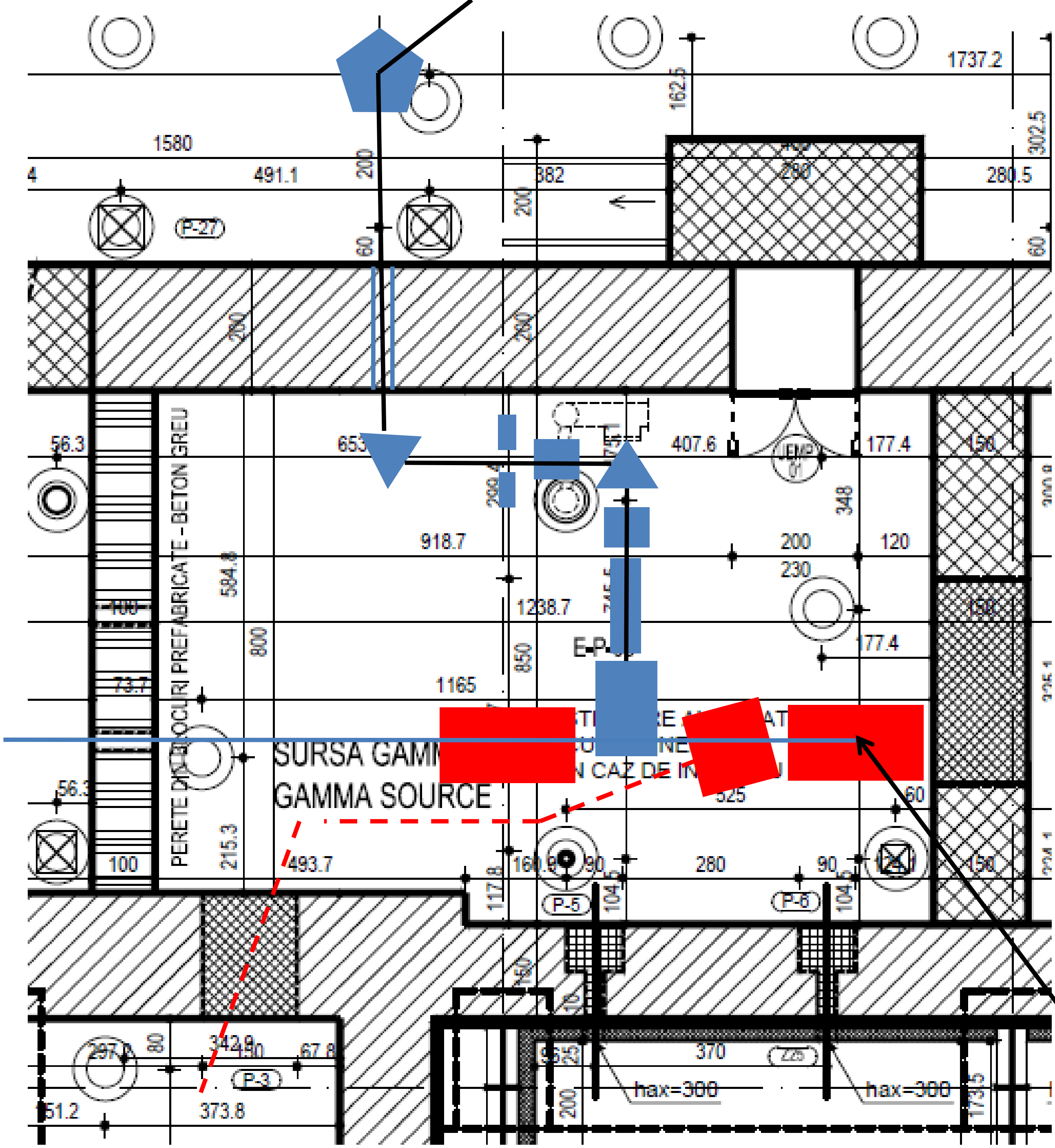
H. Naik et al. / Nuclear Physics A 853 (2011) 1–25



The IGISOL project



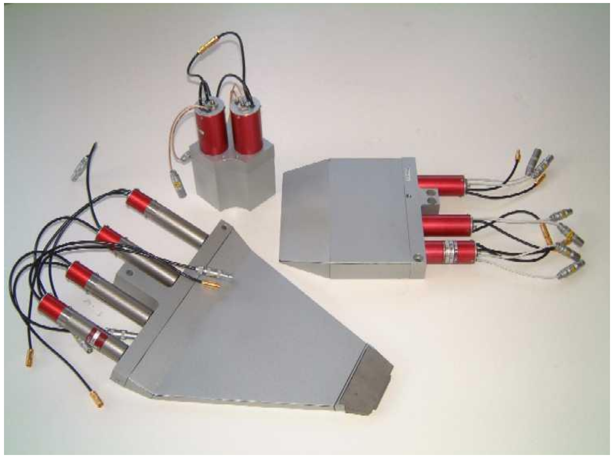
Phase 1

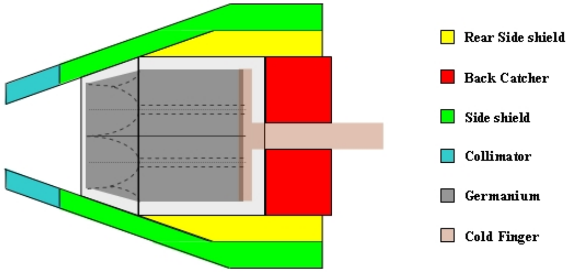


high-energy Interaction point

ELIADE – detector array

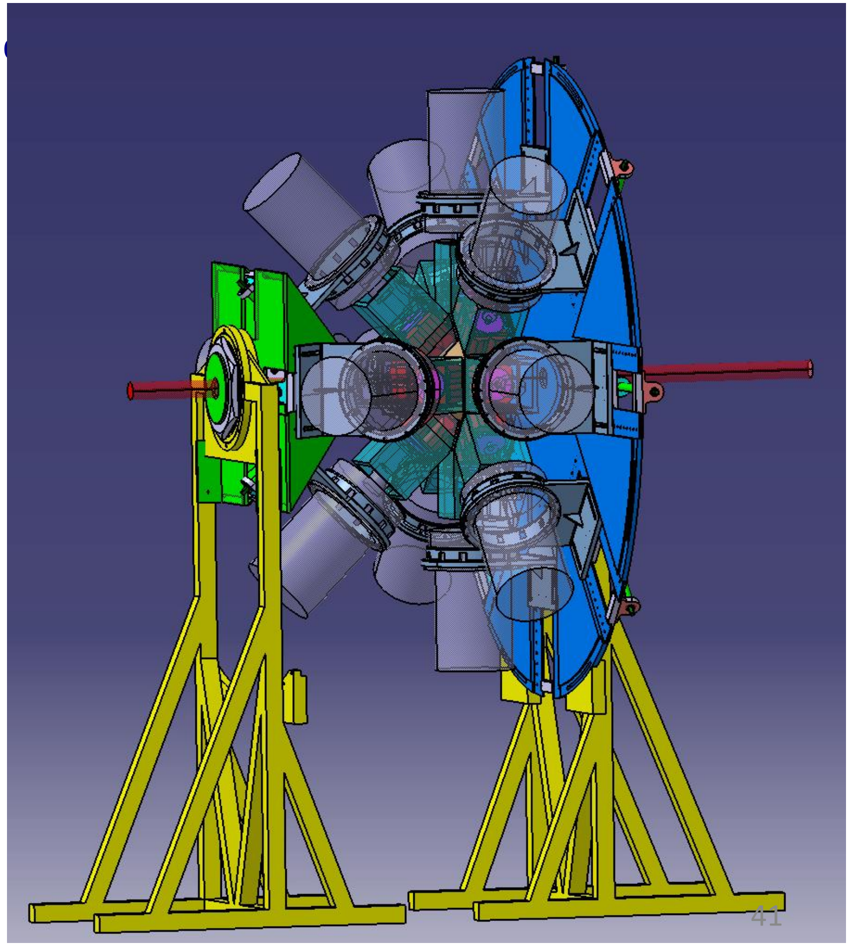
- *ELIADE* – **ELI**–NP **A**rray of **De**tectors
- Clover detector : 4 x crystals 60x90 cm (40% intrinsic efficiency)
  - EXOGAM type
  - AC shield 2 configurations





ELIADE – detector array

- *EXOGAM – like Configuration*
  - Most compact
  - Highest photopeak efficiency ~ 10
  - 4 Clovers @ 90 deg. @ 11 cm
  - 4 Clovers @ 135 deg. @ 11 cm
  - + 4 3”x3” $LaBr_3$ det. @ 90 deg.

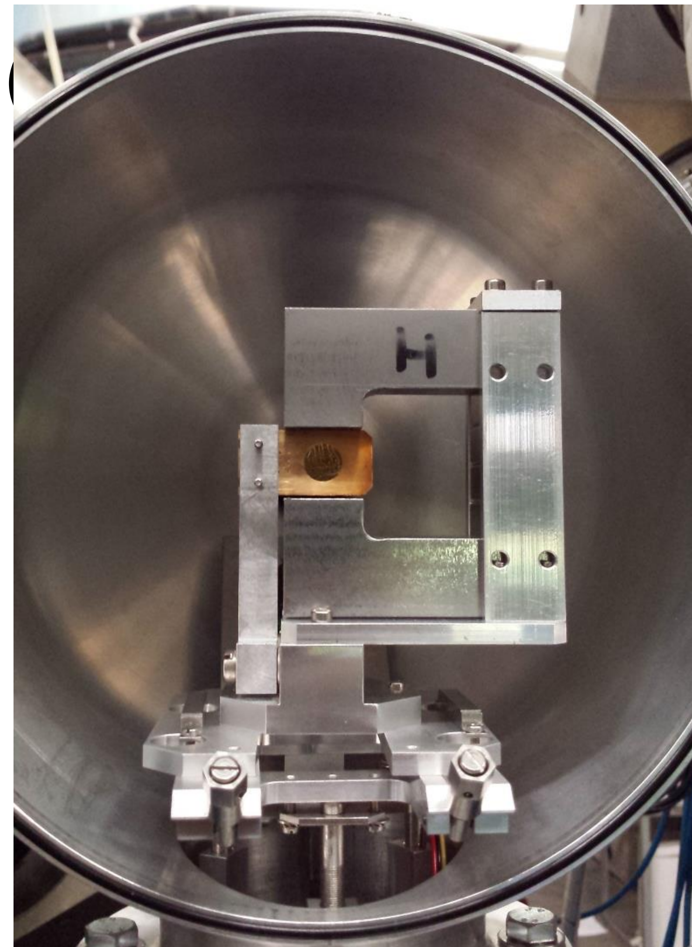


coupling to ancillary detectors:

- **fast timing with $LaBr_3$ det.**
- **selectivity with Bragg det.**
- **g-factors**

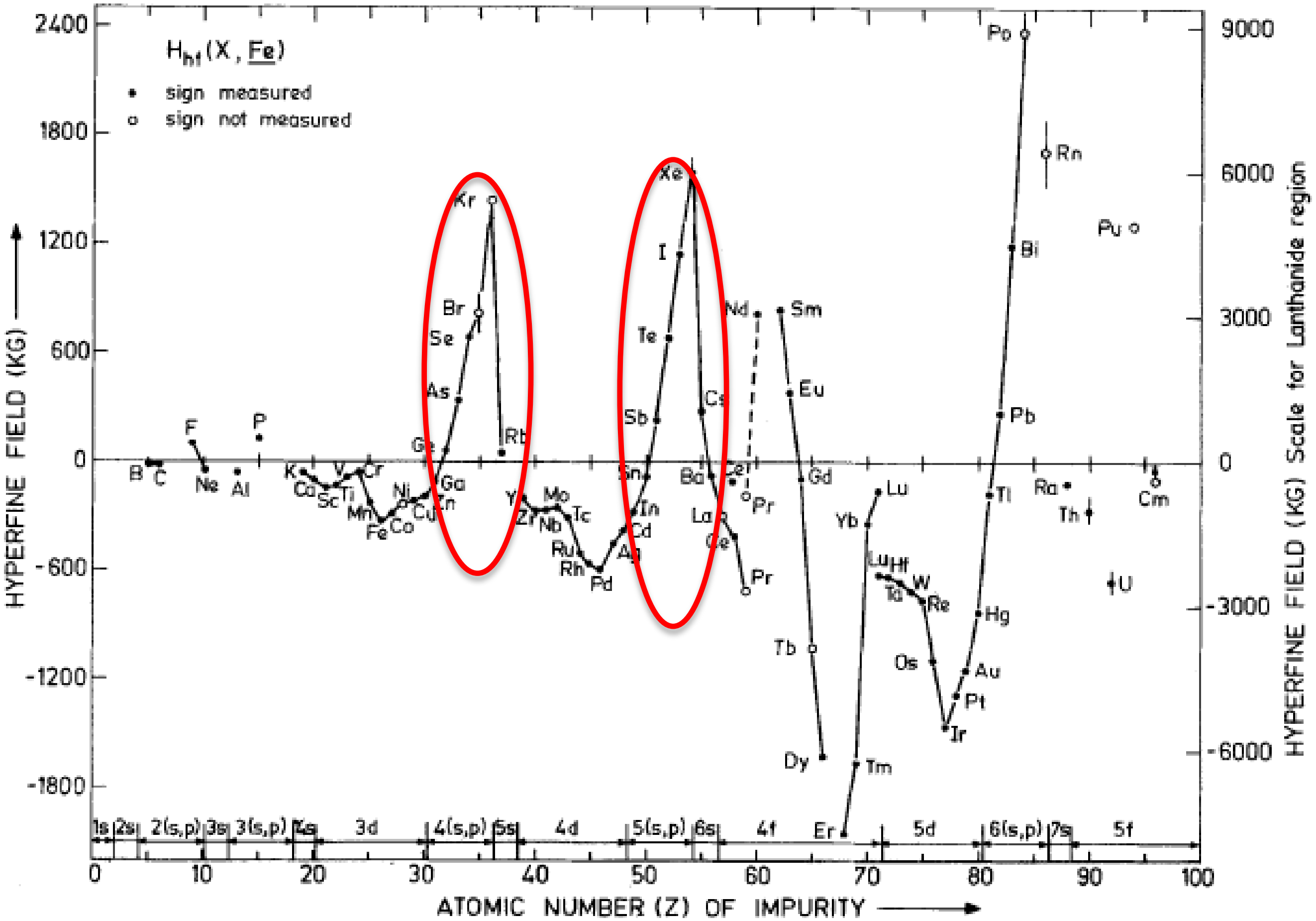
External magnetic fields – how?

- Well known and controlled values
- Lower fields – suitable for longer-lived (
- Homogeneity – what do we need?
  ~1 % should be OK



- Permanent NdFeB magnets ;
- Homogeneity better than 1%;
- Field ~0.1 T with possibility of reaching > 0.5 T

Hyperfine fields in Fe



G.N. Rao, Hyp. Int. 24-26 (1985) 1119-1194

g-factors of deformed nuclei in the mass A = 140 region

- onset of deformation beyond the N = 82 shell
- single-particle states in odd-mass nuclei - reliable configuration assig
- rotat

isotope	N	I^{π}	E_i (keV)	$\tau_{1/2}$ (ns)	yield (%)
^{138}Xe	84	2^+	588.8	$2.1\cdot10^{-2}$	5.0
^{139}Cs	84		595.4		1.2
^{140}Ba	84	2^+	602.4	$9.7\cdot10^{-3}$	0.3
^{139}Xe	85	$(9/2^-)$	559.7	≤ 10	4.6
^{140}Cs	85	$1^-,0^-$	80.1	< 2.7	2.1
^{141}Ba	85	$(11/2^-)$	643.8		1.0
^{141}Cs	86		105.9 206.7	8.7 < 2.1	3.3
^{141}Xe	87	$(9/2^-)$	111.9		1.6
^{142}Cs	87	$I + 3(^-)$	x + 123	11	2.4
^{143}Cs	88	$9/2^-$	816.6		1.6
^{145}La	88	$(11/2^-)$	572.4		1.6
^{144}Cs	89	$(I + 1, I + 2)$	x + 108	≤ 8	0.2
^{146}La	89				0.9
^{147}Ce	89	$(9/2^+)$	483.6		1.0
^{147}La	90	$(9/2^-)$ $(3/2^+,5/2^+)$	229.7 167.4	 3.4	1.0
^{149}Ce	91	$(3/2^+)$ $(3/2^-)$	133.5 245.4	0.6 ≤ 0.12	0.7

g-factors around ^{132}Sn using the IPAC technique

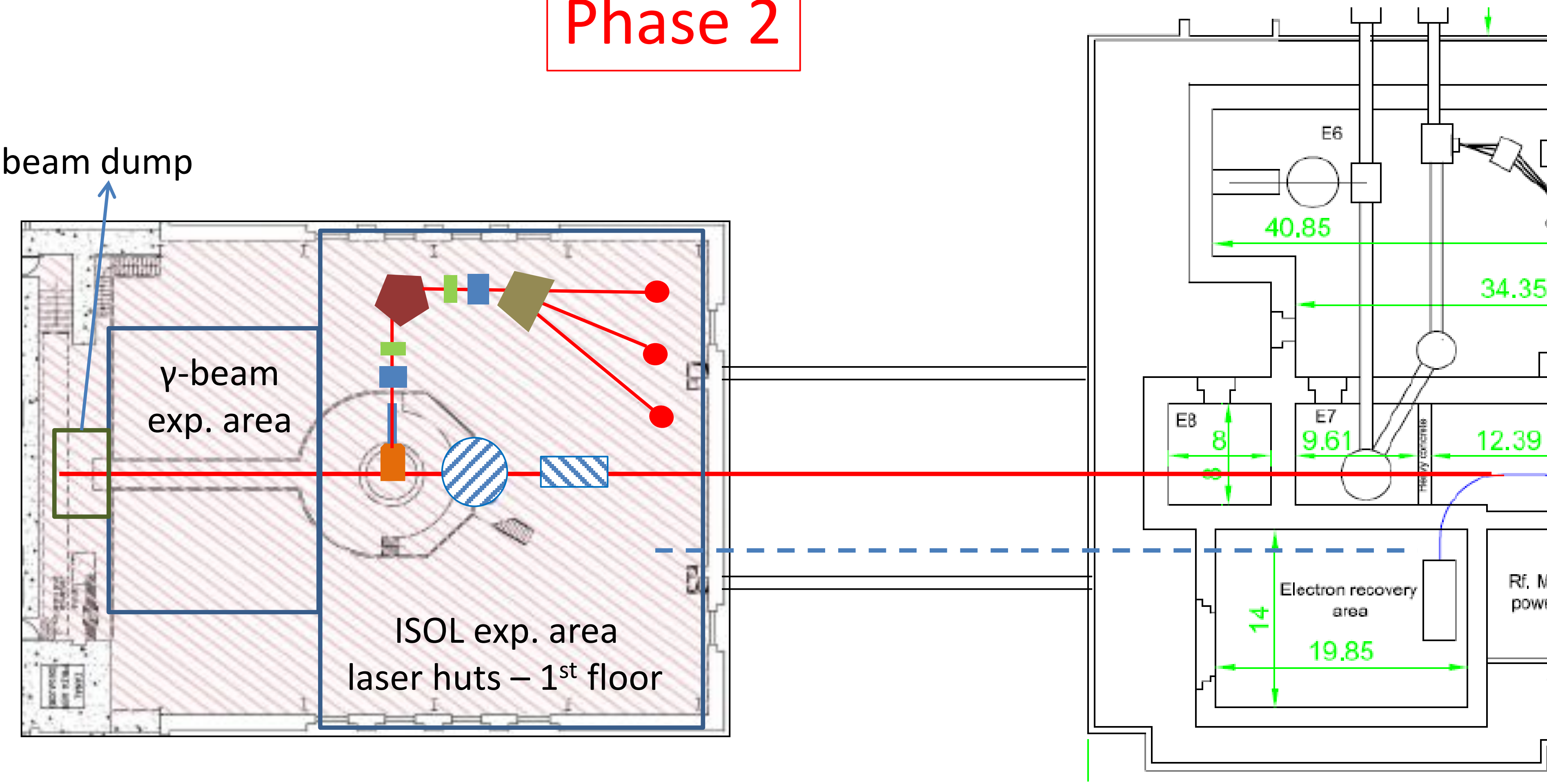
Fission rate (^{235}U)/s	Isotope	spin/parity	E-level [keV]	E-trans [keV]	M(λ)	$T_{1/2}$ [ns]	Possible configuration	B_{hyp} Fe [T]
1.3E-03	^{126}Sn	5^-	2161.5	111.8	E1	10.8	$\nu s_{1/2}h_{11/2}$	8.8
1.7E-03	^{128}Sn	5^-	2120.9	120.5	E1	8.6	$\nu s_{1/2}h_{11/2}$	8.8
2.4E-03	^{130}Sn	4^-	2214.6	129.8	M1	0.5	$\nu d_{5/2}h_{11/2}$	8.8
1.1E-03	^{132}Sn	7^+	4919.0	203.1	M1	0.062	$\nu f_{7/2}h_{11/2}^{-1}$	8.8
1.1E-03	^{132}Sn	4^-	4830.9	479.1	M1	0.026	$\nu f_{7/2}d_{3/2}^{-1}$	8.8
1.2E-02	^{132}Sb	2^+	426.1	340.5	M1(+E2)	0.015	$\pi g_{7/2}\nu d_{3/2}^{-1}$	23
1.2E-02	^{132}Sb	2_2^+	1078.3	992.7	M1+E2	0.026	$\pi d_{5/2}\nu d_{3/2}^{-1}$	23
2.3E-02	^{133}Sb	$11/2^-$	2791.3	2791.3	M2	0.0114	$\pi h_{11/2}$	23
1.6E-02	^{132}Te	2^+	974.2	974.2	E2	0.0018	$\pi g_{7/2}^2$	68
6.0E-02	^{134}Te	2^+	1279.1	1279.1	E2	6.40E-04	$\pi g_{7/2}^2$	68
6.0E-02	^{134}Te	6_2^+	2397.7	706.3	M1,E2	0.016	$\pi g_{7/2}d_{5/2}$	68
6.0E-02	^{134}Te	5_2^+	2727.1	1150.8; 329.3	(M1)	0.02	$\pi g_{7/2}d_{5/2}$	68
3.7E-02	^{135}Te	$11/2^-$	1179.9	1179.9	E2	0.3	$\nu h_{9/2}$	68
2.0E-02	^{136}Te	2^+	606.6	606.5	E2	4.16E-02	$\pi f_{7/2}^2$	68
5.0E-02	^{138}Xe	2^+	588.8	588.8	E2	2.10E-02	$\nu g_{7/2}^2\pi f_{7/2}^2$	155

g factors around neutron-rich N=60 using TDPAC

- shed light on the interplay of the proton-neutron interaction responsible

Fission rate (235U)/s	Isotope	spin/parity	E_x[keV]	T1/2[ns]	Possible configuration	Expected g factor	Bhyp Fe [T]	Osc. per $3xt_{1/2}$
2.2E-02	^{91}Rb	$9/2^+$	1134	17	$\pi g_{9/2}$	1.3	5.4	5
3.1E-02	^{92}Rb	7^+	1958	7	$\pi g_{9/2} X \nu d_{5/2}$	0.66	5.4	5
3.1E-02	^{92}Rb	3^-	284	54	$\pi p_{3/2} X \nu d_{5/2}$	0.2	5.4	3
3.0E-02	^{93}Rb	$27/2^-$	4423	111	$\pi g_{9/2} X \nu g_{7/2} h_{11/2}$	0.42	5.4	10
1.6E-02	^{94}Rb	8^+	1485	18	$\pi g_{9/2} X \nu g_{7/2}$	0.87	5.4	4
1.6E-02	^{94}Rb	10^-	2075	107	$\pi g_{9/2} X \nu h_{11/2}$	0.46	5.4	12
6.5E-03	^{95}Rb	$9/2^+$	810	95	$\pi g_{7/2} X d_{5/2}$	1.3	5.4	28
1.7E-03	^{96}Rb	10^-	1135	2000	$\pi g_{9/2} X \nu h_{11/2}$	0.46	5.4	220
1.2E-02	^{95}Y	$17/2^-$	3142	15	$\pi f_{5/2} X 6^+$	0.45	22.6	7
	^{95}Y	$21/2^-$	5022	65	$\pi g_{9/2} X \nu g_{7/2} h_{11/2}$	0.45	22.6	27

Phase 2



Research Reactor
(end of decommissioning 2017)

ELI –NP (commissioning 2017)

Instrumentation (gamma beams)

NRF set-up (the ELIADE array)

- rings of segmented HPGe detectors (8-12 Ge Clovers)
- good timing detectors

Nuclear structure set-up: modular and very flexible

- high resolution neutron detection
- gamma-ray detection with medium resolution (20 $LaBr_3$ det.)
- high-resolution γ-ray detection (in some cases)

THGEM + DSSD detector set-up for cross section measurements

Gas-filled Bragg spectrometers

4π DSSSD detector set-up

Gas-filled TPC

Bubble chamber

Production of RIB with IGISOL-type technique

Tape station and Ge array for decay studies

Multi-reflection trap

Collinear laser spectroscopy beam line

Extreme Light Infrastructure – Nuclear Physics

Nuclear Physics

Finally

1. There are many scientific and technical challenges ahead of us. However, time is short and we need to find solutions now.
2. ELI-NP is open for collaborations. We are building a user community. Formal collaborations to be established through MoUs.
3. Cooperation between nuclear and laser physicists needs to be established, e.g. first unify the language (!)

Job opportunities

The ELI-NP research teams will consist in **218 researchers, engineers and technicians** (5 heads of research and 20 senior researchers, 107 junior researchers, 50 research assistants (PhD students), 36 engineers and technicians) from 2018 on. 31 MSc and PhD students are also expected to receive some trainings with the equipment at ELI-NP every year.

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

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

eli Nuclear Physics

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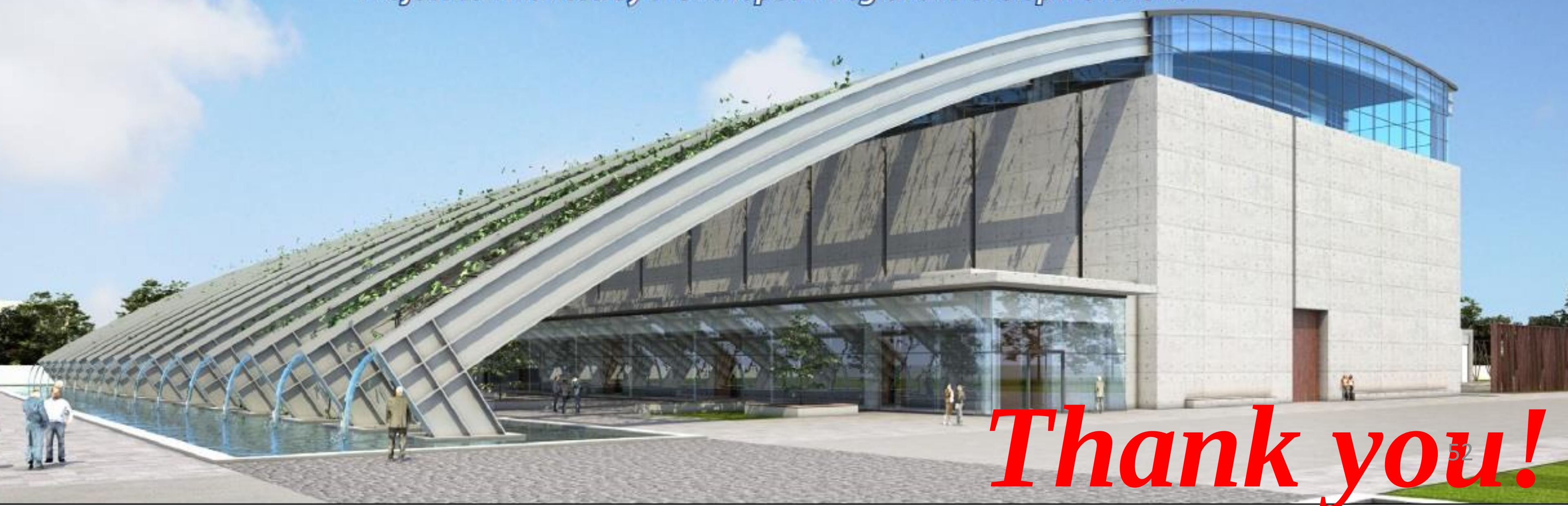
Project co-financed by the European Regional Development Fund



Thank you!