Accelerator Based Compact Neutron Sources

H.M.Shimizu
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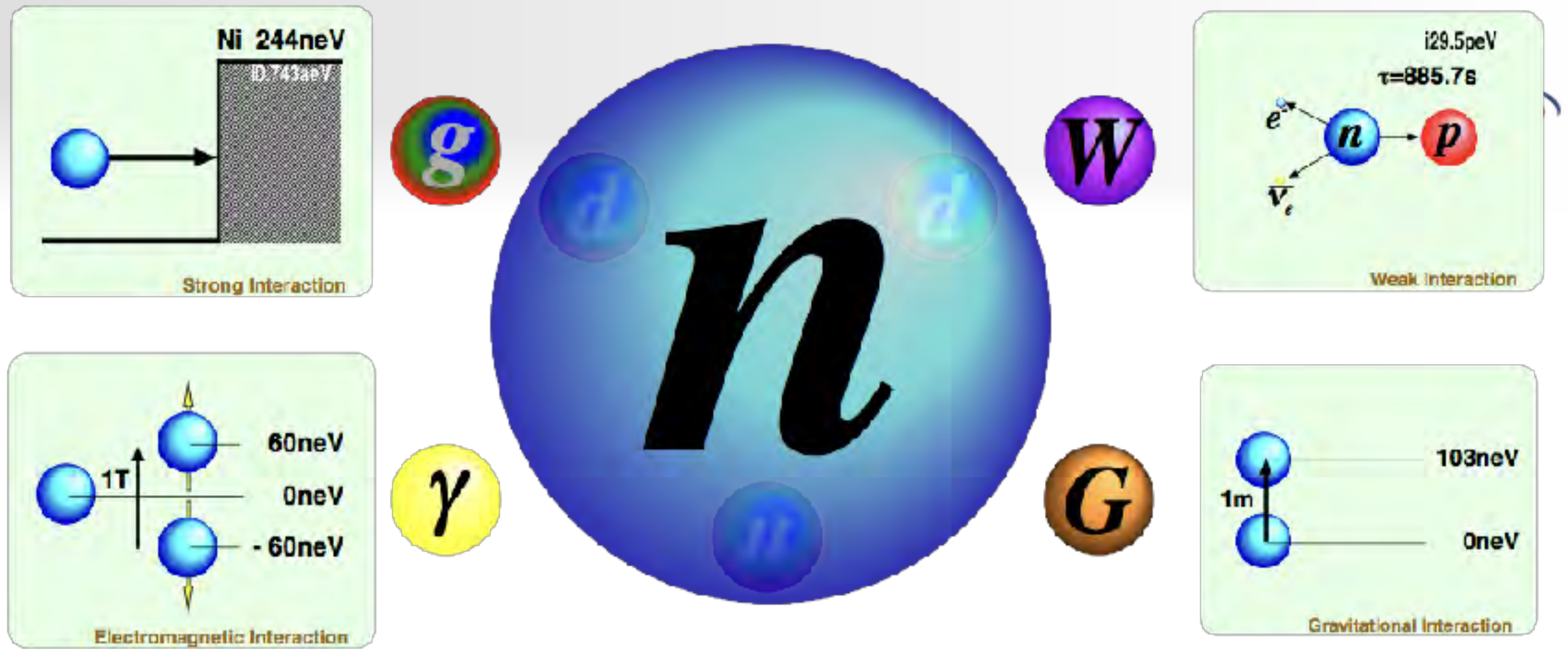
Neutron

- **penetrability** (←chargeless)
- **light element visualizability** (←nuclear process)
- **atom dynamics visualizability** (←atomic mass)



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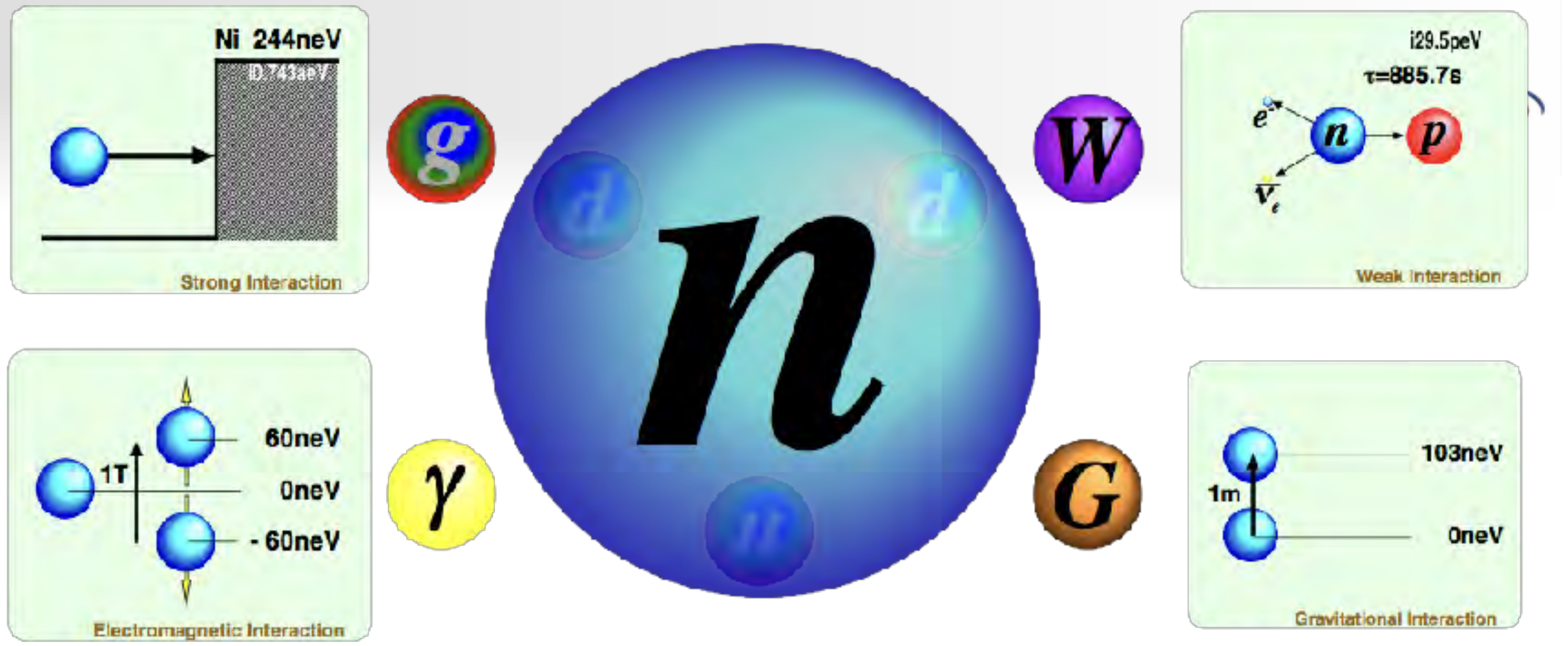
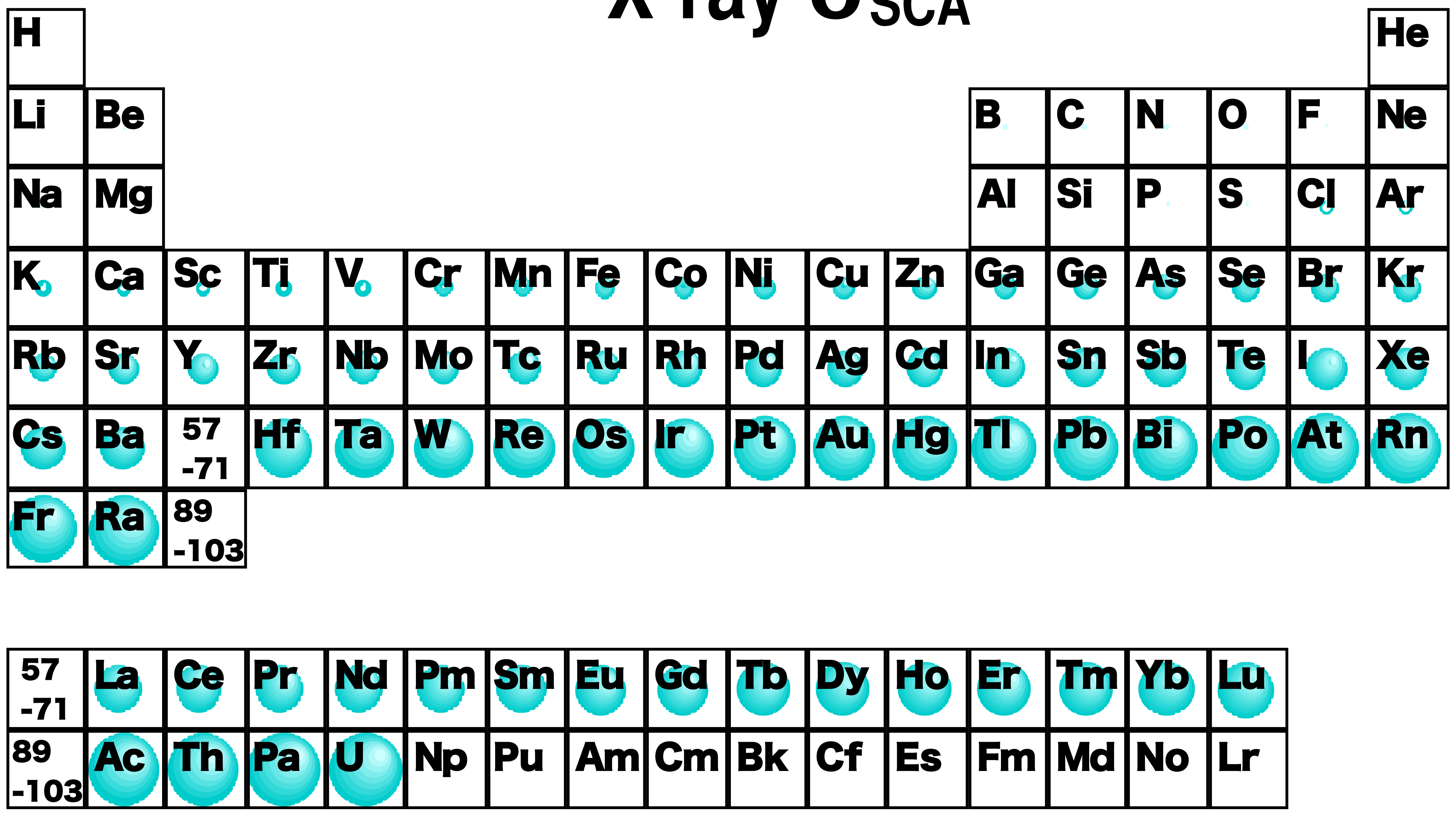


X-ray σ_{SCA}



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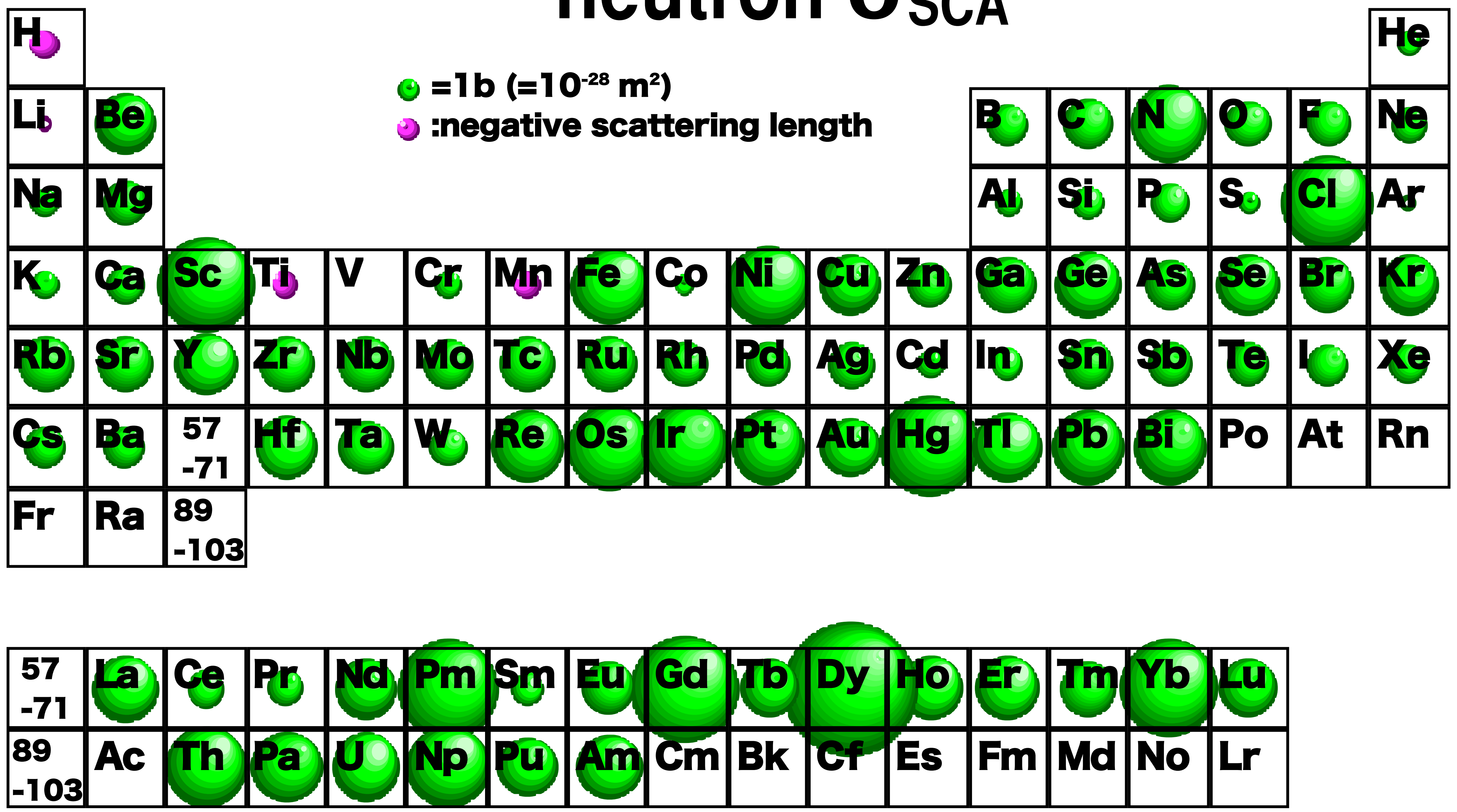

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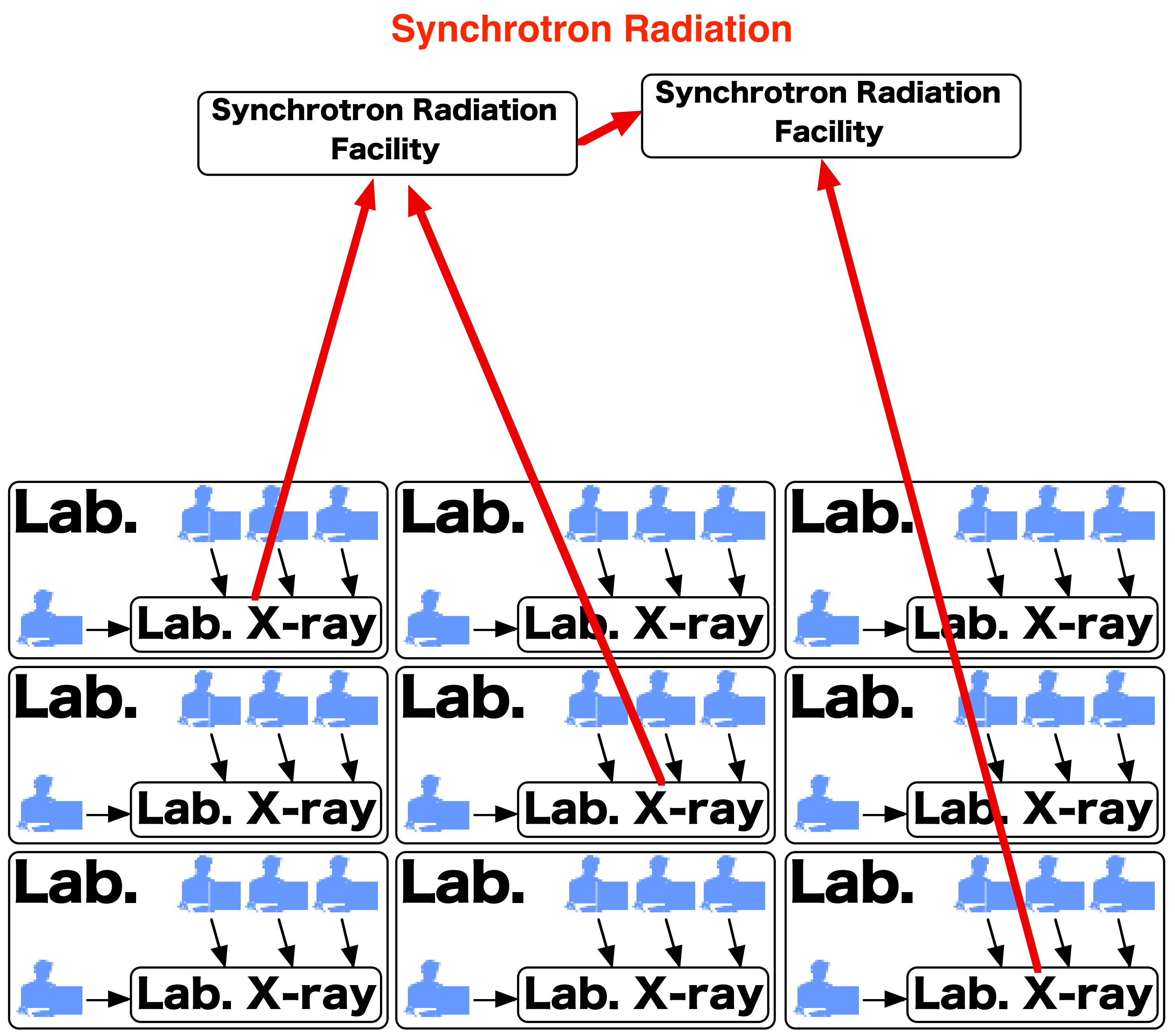
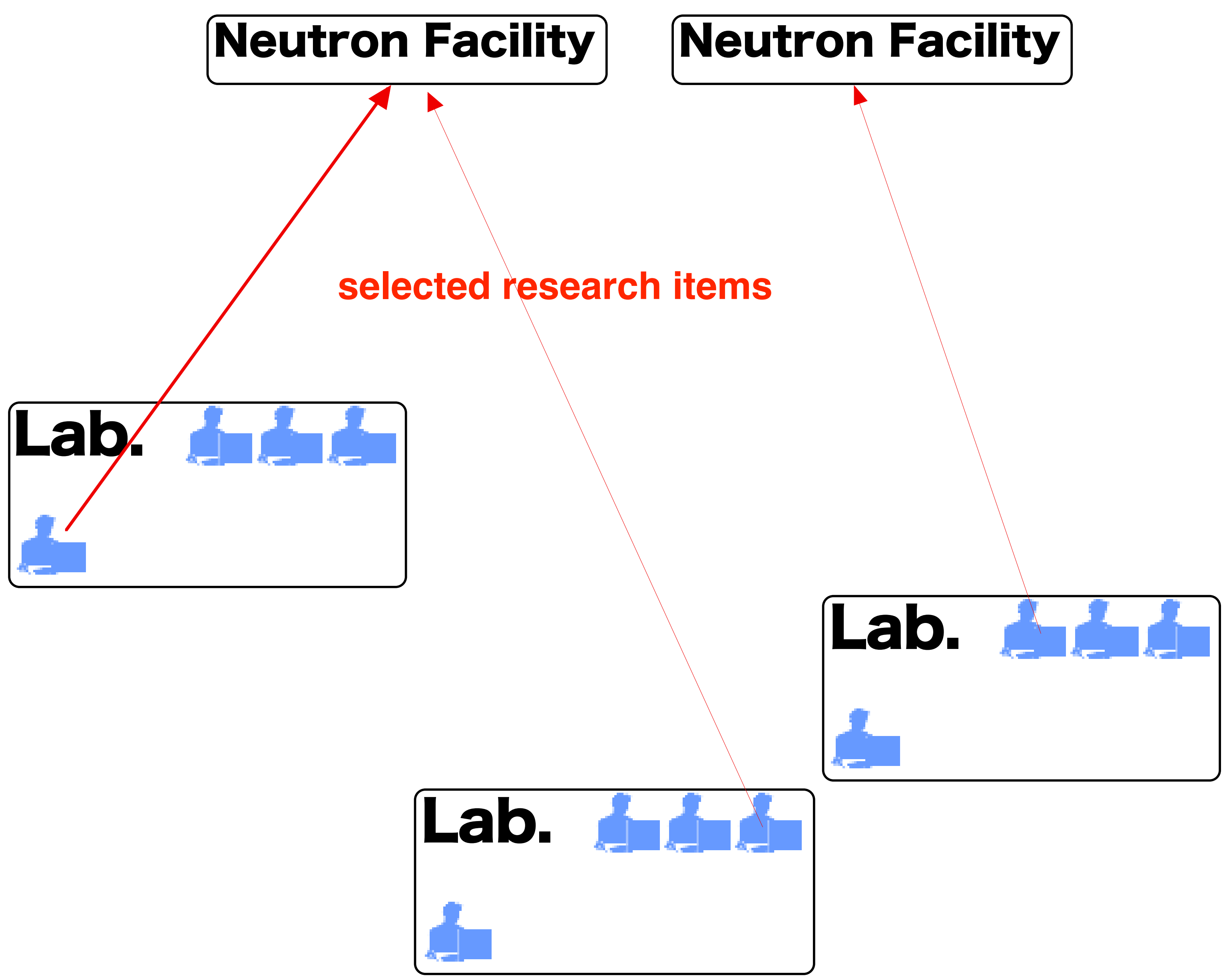
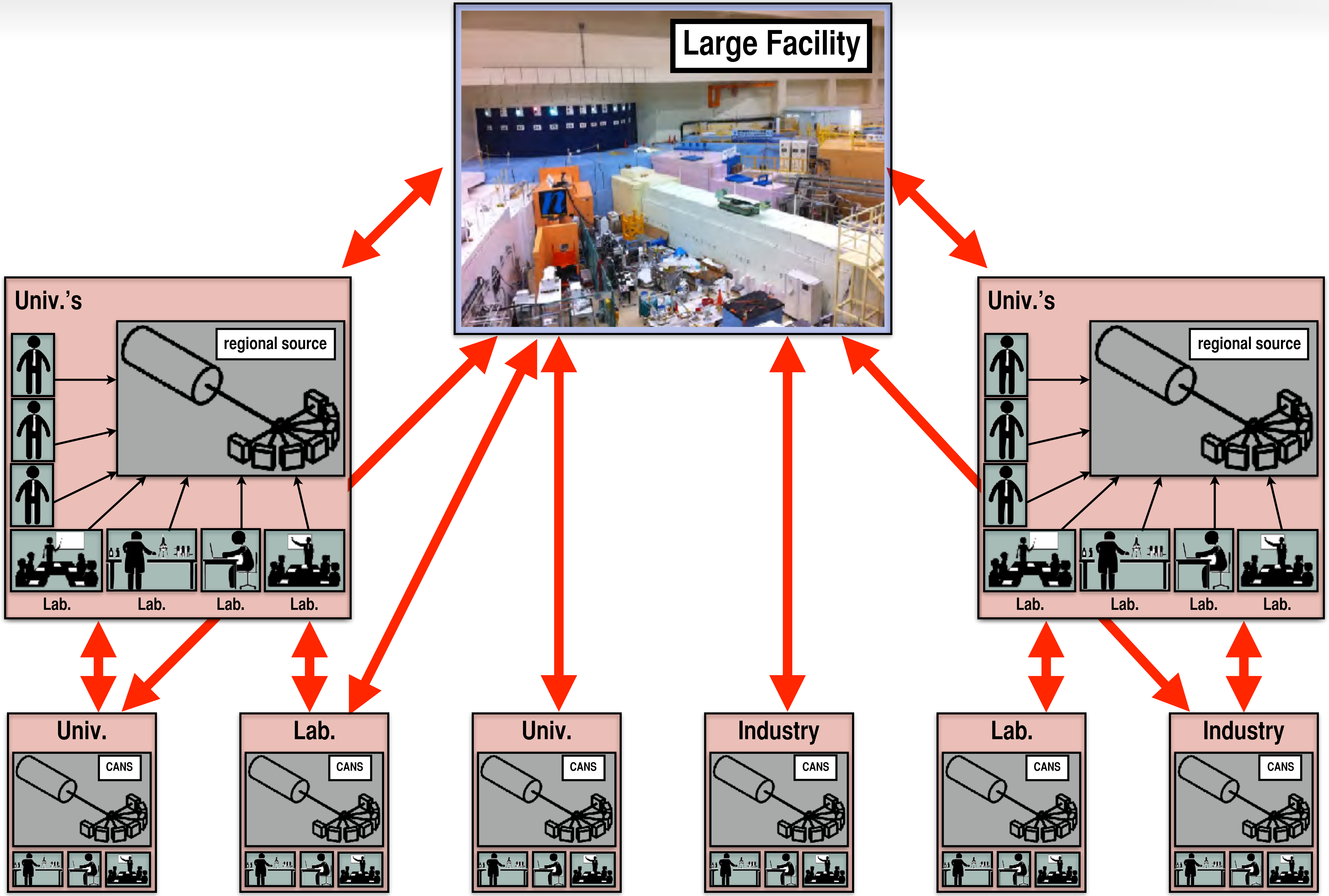


neutron



less opportunities to incubate new ideas, pioneering works and epoch-making break-through

Neutron Network



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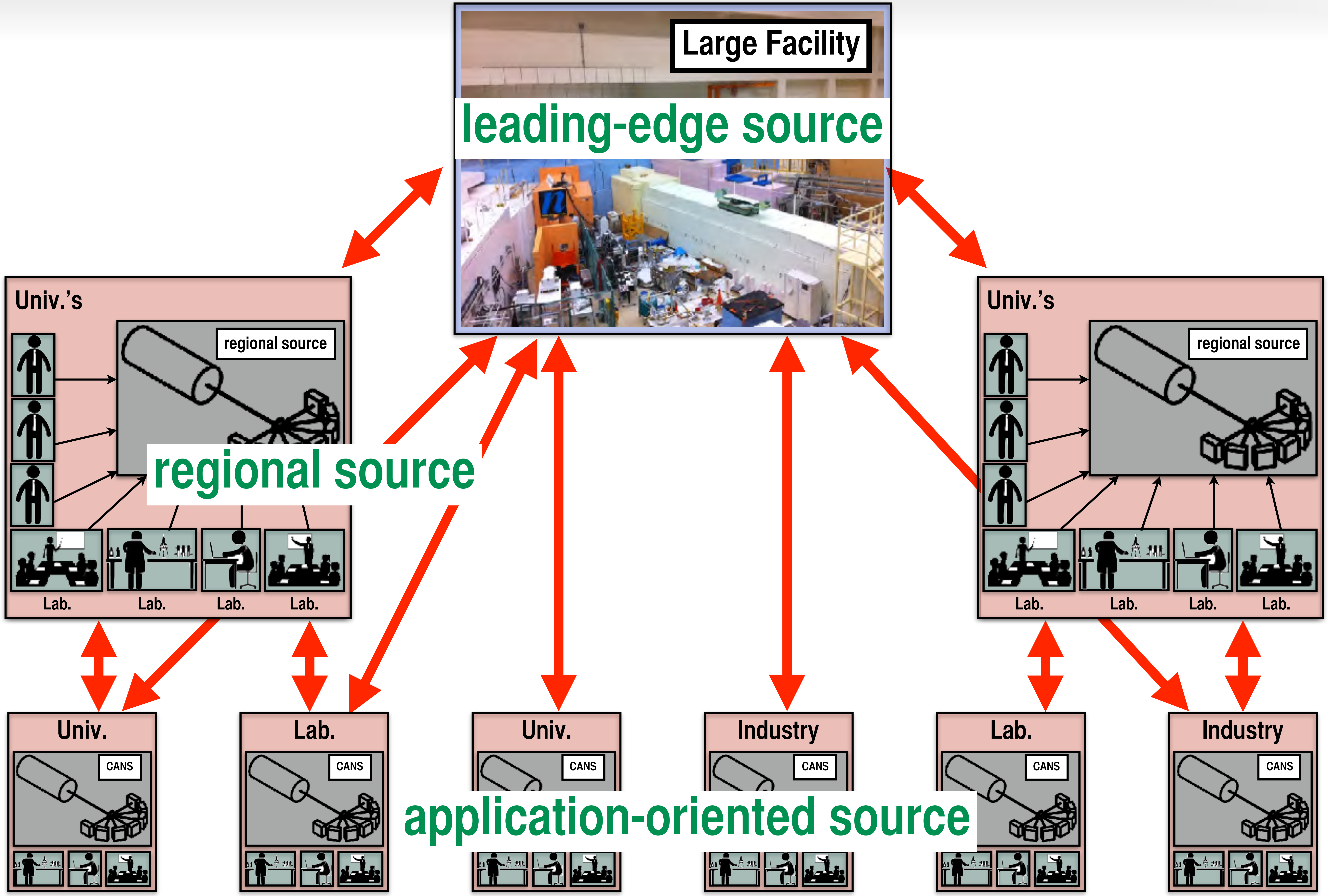
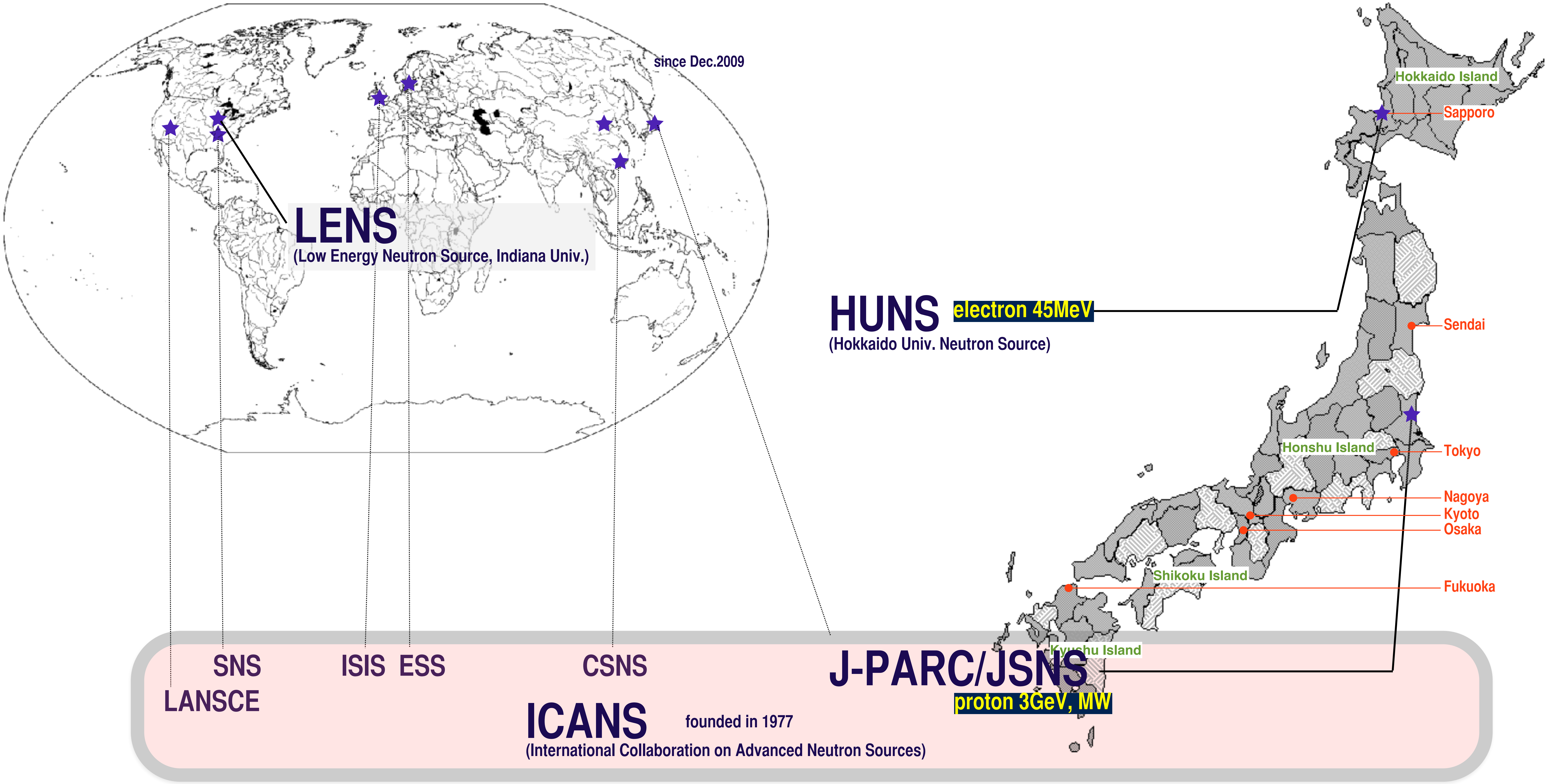


Accelerator-driven Neutron Sources for Science and their Networks



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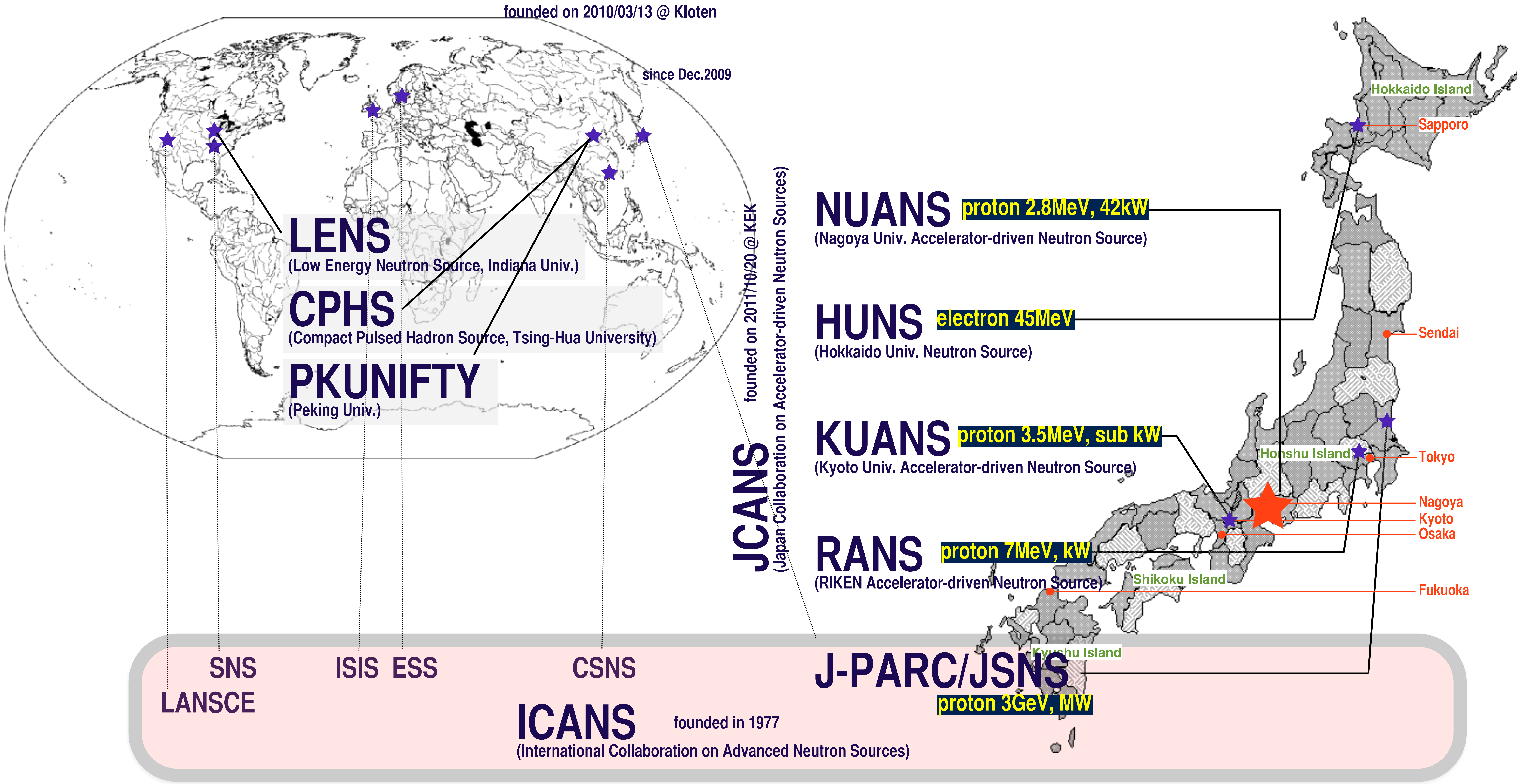

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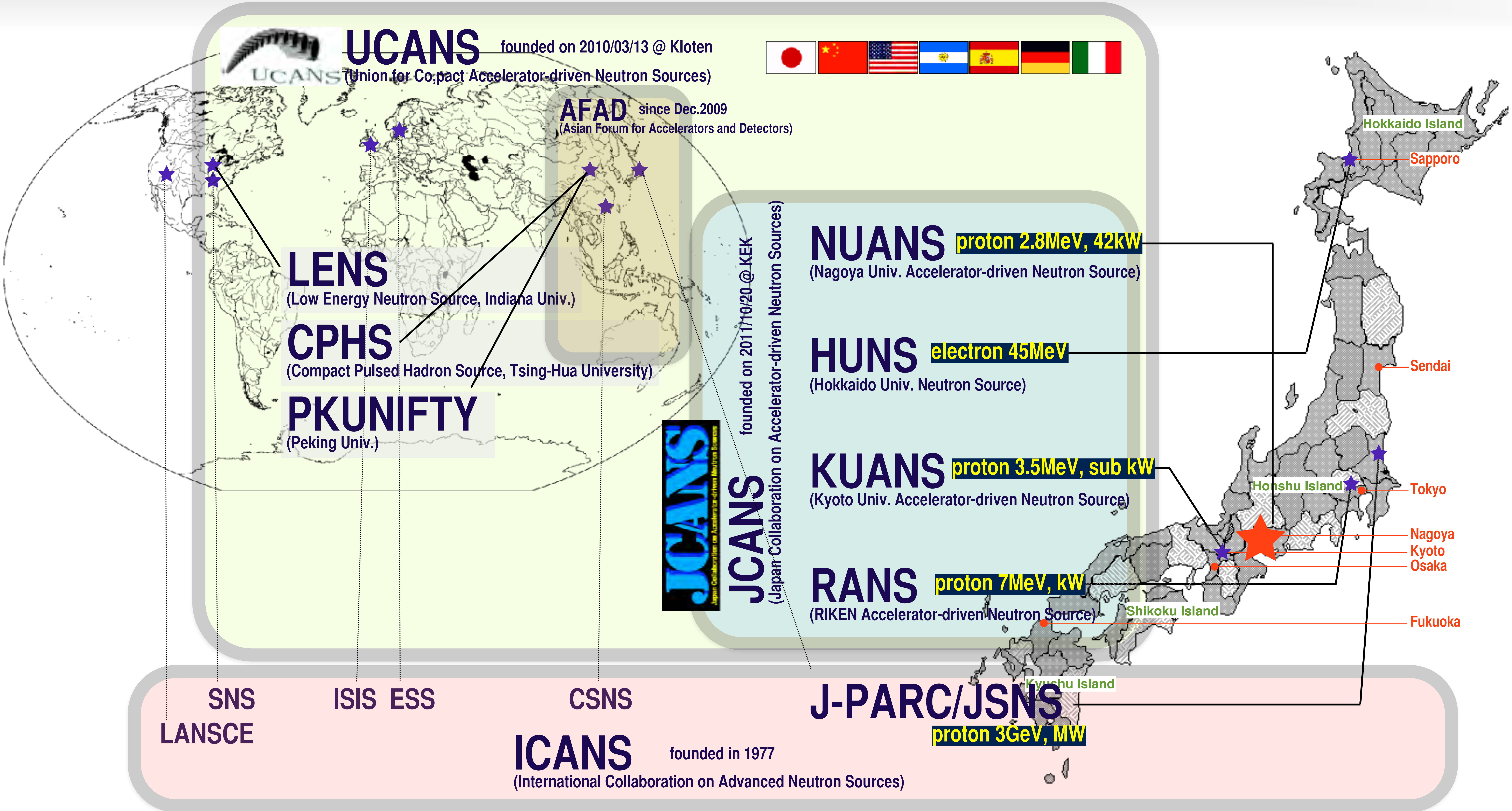

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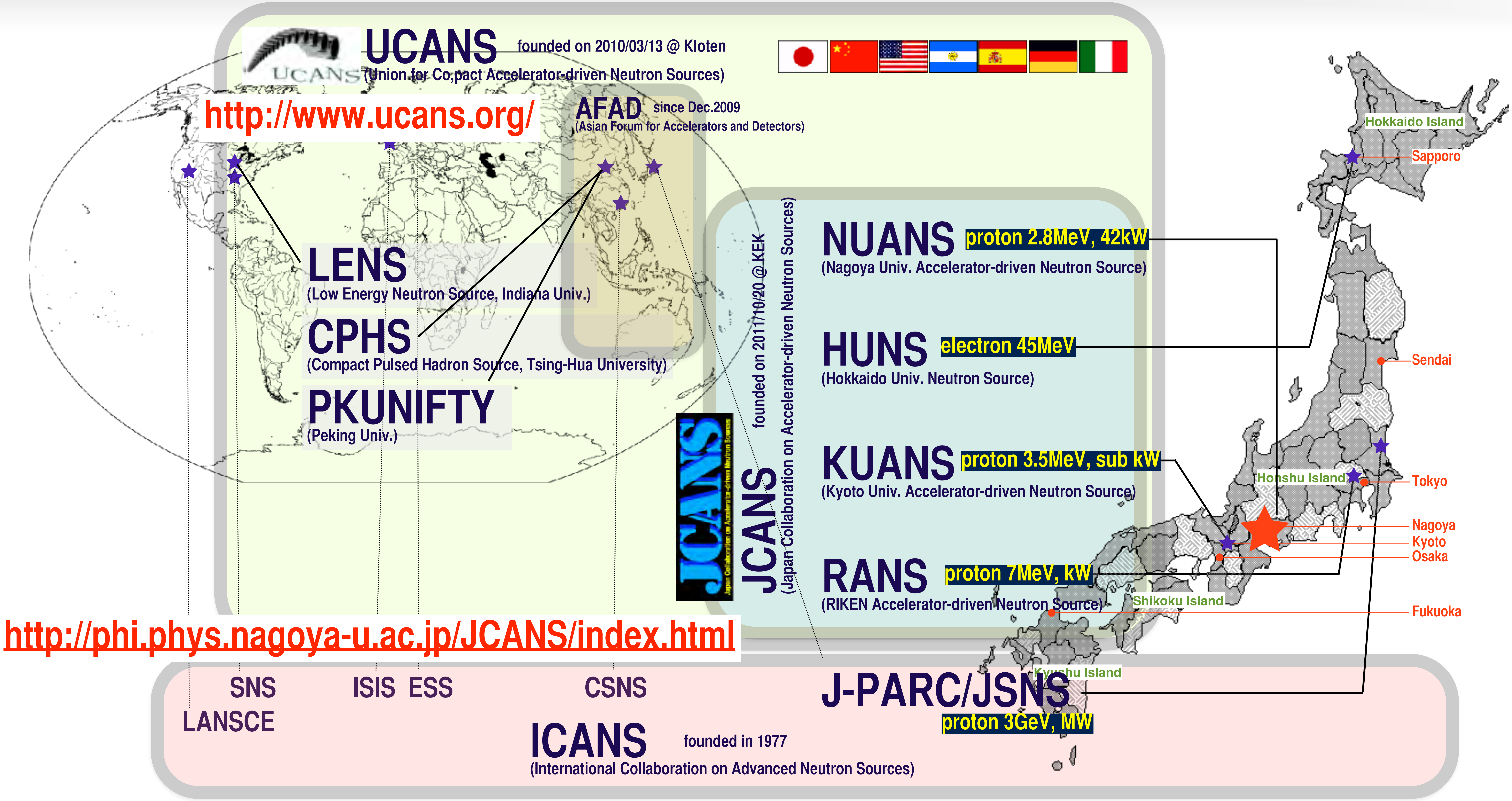

UCANS

UCANS-0	2010/03/13	Kloten	Switzerland
UCANS-I	2010/08/15–18	Beijing	China
UCANS-II	2011/07/05–08	Blooming	USA
UCANS-III	2012/07/31–08/03	Bilbao	Spain
UCANS-IV	2013/09/23–27	Sapporo	Japan
UCANS-V	2015/05/12–15	Padova	Italy
UCANS-VI	2016/10/25–28	Xian	China

UCANS VII — 11–15 March 2018, Bariloche, Argentina

Monday, March 12, 2018

8:30 – 8:55		**Opening Session** **Chair: Rolando Granada**	
		Session 1: CANS Projects and innovative instrumentation	
8:55 – 9:20		Christiane Alba-Simionesco	Update on SONATE, the French Compact Neutron Source Project
9:20 – 9:45		David V. Baxter	Update on LENS for 2018
9:45 – 10:10		Michihiro Furusaka	Upgrade of Hokkaido University neutron source (HUNS)
10:10 – 10:35		Ferenc Mezei	The industrial CANS project LvB at Martonvásár, Hungary
10:35 – 11:10		Coffee Break	
		Session 2: CANS Projects / Material Characterization	
11:10 – 11:35	I5	Javier Santisteban	LAHN: The Argentinean Neutron Beams Laboratory Project
11:35 – 12:00	G1	Yoshie Otake	RIKEN Accelerator driven compact neutron sources and its quantitative analysis methods
12:00 – 12:25		Rolando Granada	Neutron Scattering Kernels and Cross Sections for Cold Moderator Materials
12:30 – 13:55		Lunch	
		Session 3: Moderator neutronics / Optical devices	
14:00 – 14:25		Yannick Beßler	Engineering studies on second generation of ESS low dimensional cold moderator for full power operation
14:25 – 14:50	C3	Yutaka Yamagata	Development of cold neutron source using methyl-benzene derivatives for compact neutron source
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15:40 – 16:05			
16:10 – 16:50		Coffee Break + POSTER SESSION	
16:50 – 18:30		Round Table	

Tuesday, March 13, 2018

		Session 4: Accelerators and beam optics / Target radiation damage	
8:30 – 8:55	A1	Nicolas Chauvin	IPHI, a high intensity proton accelerator for neutron production
8:55 – 9:20		Valeri Shvetsov	Current status of the IREN resonance neutrons source
9:20 – 9:45	A3	Yoshiaki Kiyanagi	Present Status of Nagoya University Accelerator Driven Neutron Source, NUANS
9:45 – 10:10	A4	Tomohiro Kobayashi	Development of transportable neutron source prototype RANS-II
10:10 – 10:35	B1	Paul Zakalek	Mechanical stability of a target for a compact accelerator based neutron source
10:35 – 11:10		Coffee Break	
		Session 5: Neutron detectors	
11:10 – 11:35	L1	Yigang Yang	The progress of a honeycomb neutron convertor based neutron detector
11:35 – 12:00	F2	Seung Woo Hong	Detecting neutrons with a MICROMEGAS detector
12:00 – 12:25	L3	Valeri Shvetsov	Measurement of the energy dependence of the neutron counters sensitivity at the neutron beams of the electrostatic generator
12:30 – 13:55		Lunch	
14:00 – 20:30		Free Afternoon	
20:30 – 22:30		**Conference Dinner**	

Wednesday, March 14, 2018

		Session 6: CANS Projects and Innovative instrumentation	
8:30 – 8:55		Pierfrancesco Mastinu	The SPES project at the INFN- Laboratori Nazionali di Legnaro
8:55 – 9:20	F7	Yoshiaki Kiyanagi	Neutronic performance of a beam line for imaging at the electron Linac Facility in Kyoto University Research Reactor Institute
9:20 – 9:45		Thomas Gutberlet	NOVA ERA – A compact neutron source for universities
9:45 – 10:10	F9	János Füzi	Compact equipment for neutron source imaging
10:10 – 10:35	F10	Jianlin Ke	Conceptual design of an accelerator-driven 10-14MeV neutron source
10:35 – 11:10		Coffee Break	
		Session 7: Other aplications of CANS	
11:10 – 11:35	H1	Gentaro Funatsu	Progress in the ITU-T's standardization of Soft Error Test of network equipment using Compact Accelerator-driven Neutron Sources
11:35 – 12:00	H2	Hidenori Iwashita	Radioactivation characteristics evaluation of electronic equipment in soft error test using accelerator driven neutron sources
12:00 – 12:25	H3	Hiroki Mori	Evaluation of Acceleration Factor in a Soft Error Test Using 18MeV Proton Accelerator Facility
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		Session 8: Education / Neutron detection	
14:00 – 14:25	I1	Hirohiko M. Shimizu	An Effort to Improve the Terminology for Neutron Beam Users
14:25 – 14:50	E4	Roberto Mayer	Neutron Counting Absolute Method
14:50 – 15:15	E5	Shakir Zeinalov	Twin ionization chamber with position sensitivity for neutron induced fission investigations
15:15 – 15:40	E6	Ivan Sidelnik	Neutron detection capabilities of Water Cherenkov Detectors
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16:10 – 18:30		Coffee Break + POSTER SESSION	
18:30 – 20:30		Executive Committee Meeting	

Thursday, March 15, 2018

9:00 – 10:30	Round Table
10:30 – 11:00	Closing Session

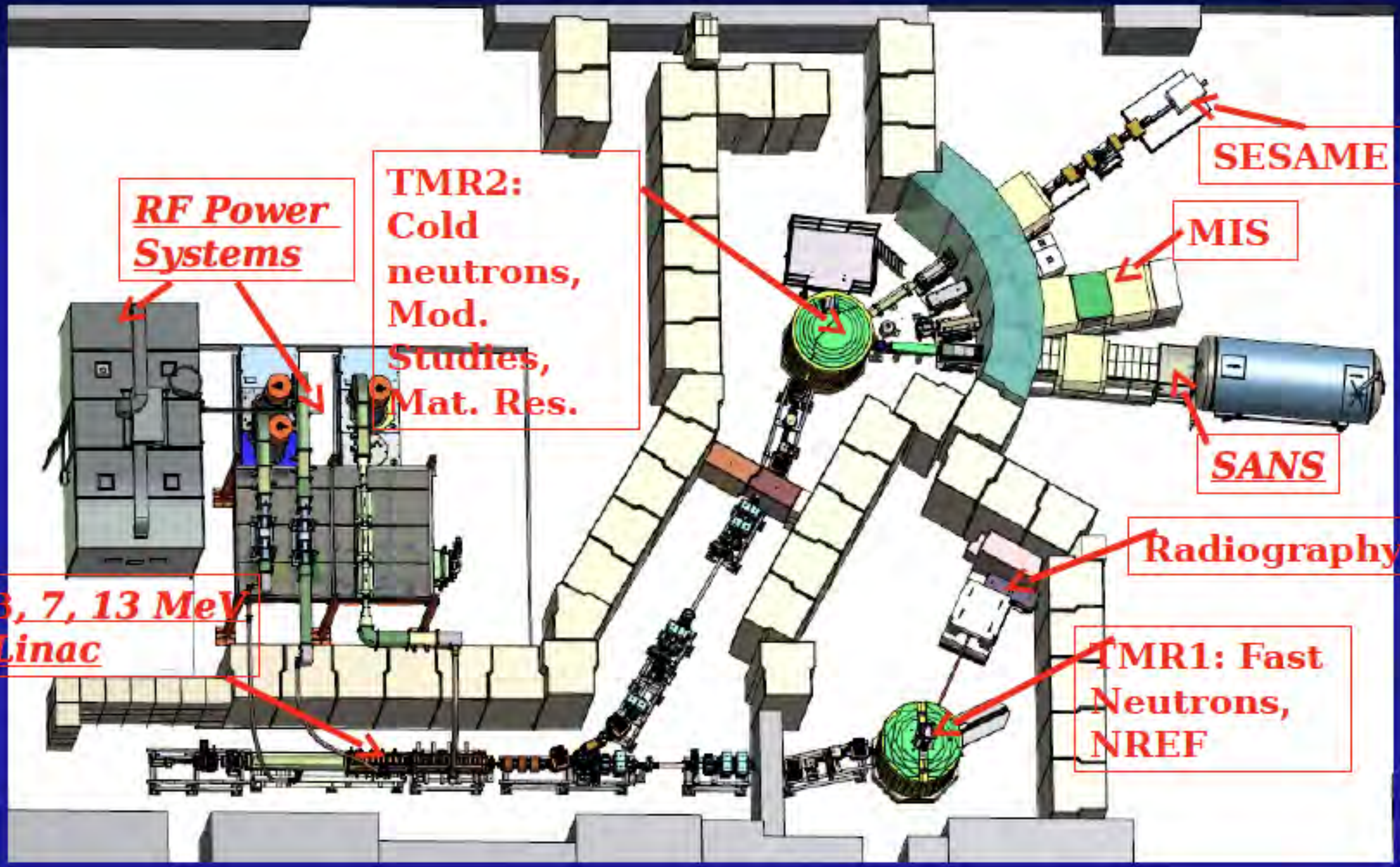
UCANS-VIII France

UCANS-0 2010/03/12 Kloten Switzerland
China
ing USA
Spain
ro Japan
a Italy
China

5 March 2018, Bariloche, Argentina

E_p=13MeV

LENS: 2018



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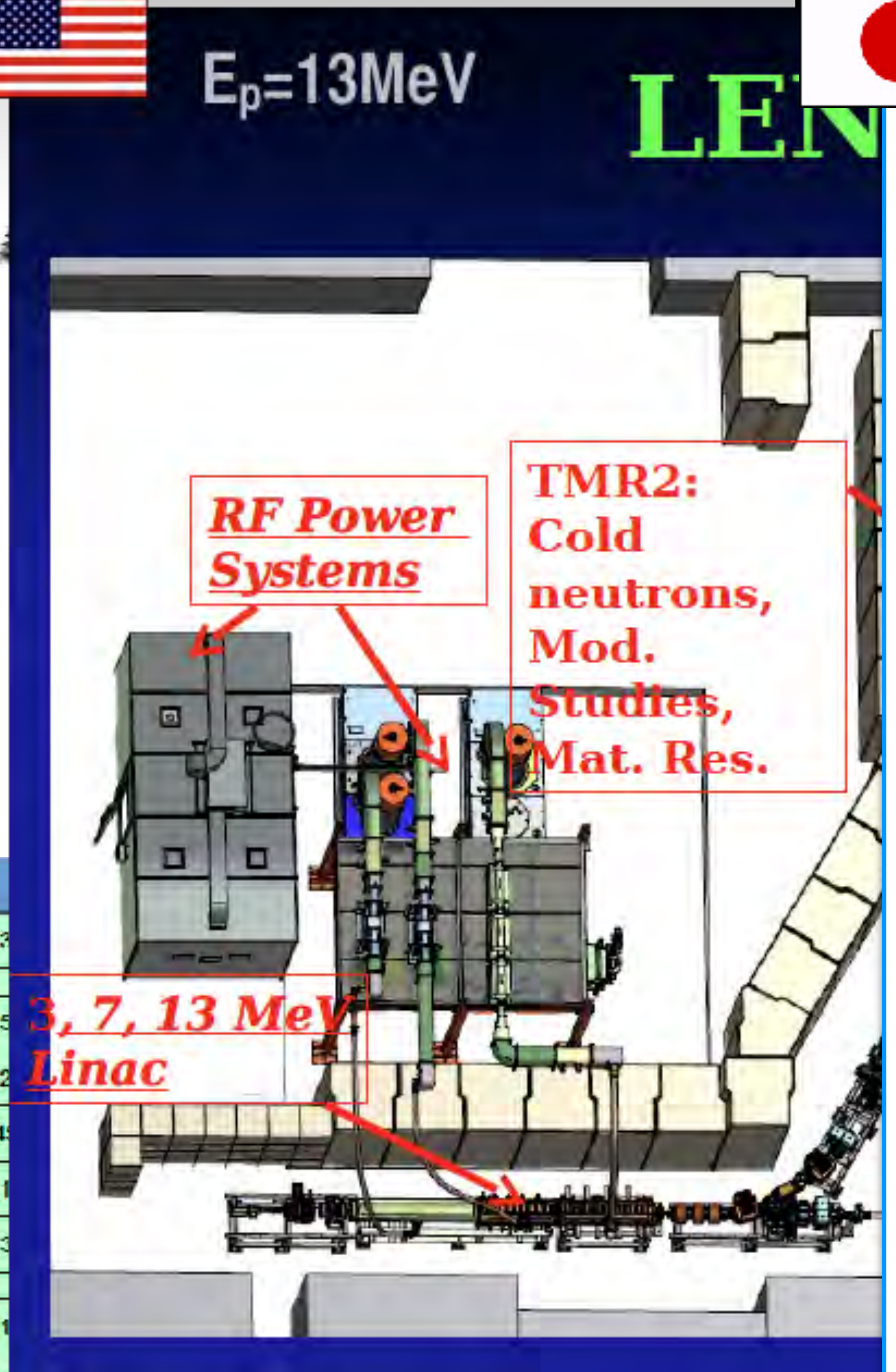
UCANS-VIII France



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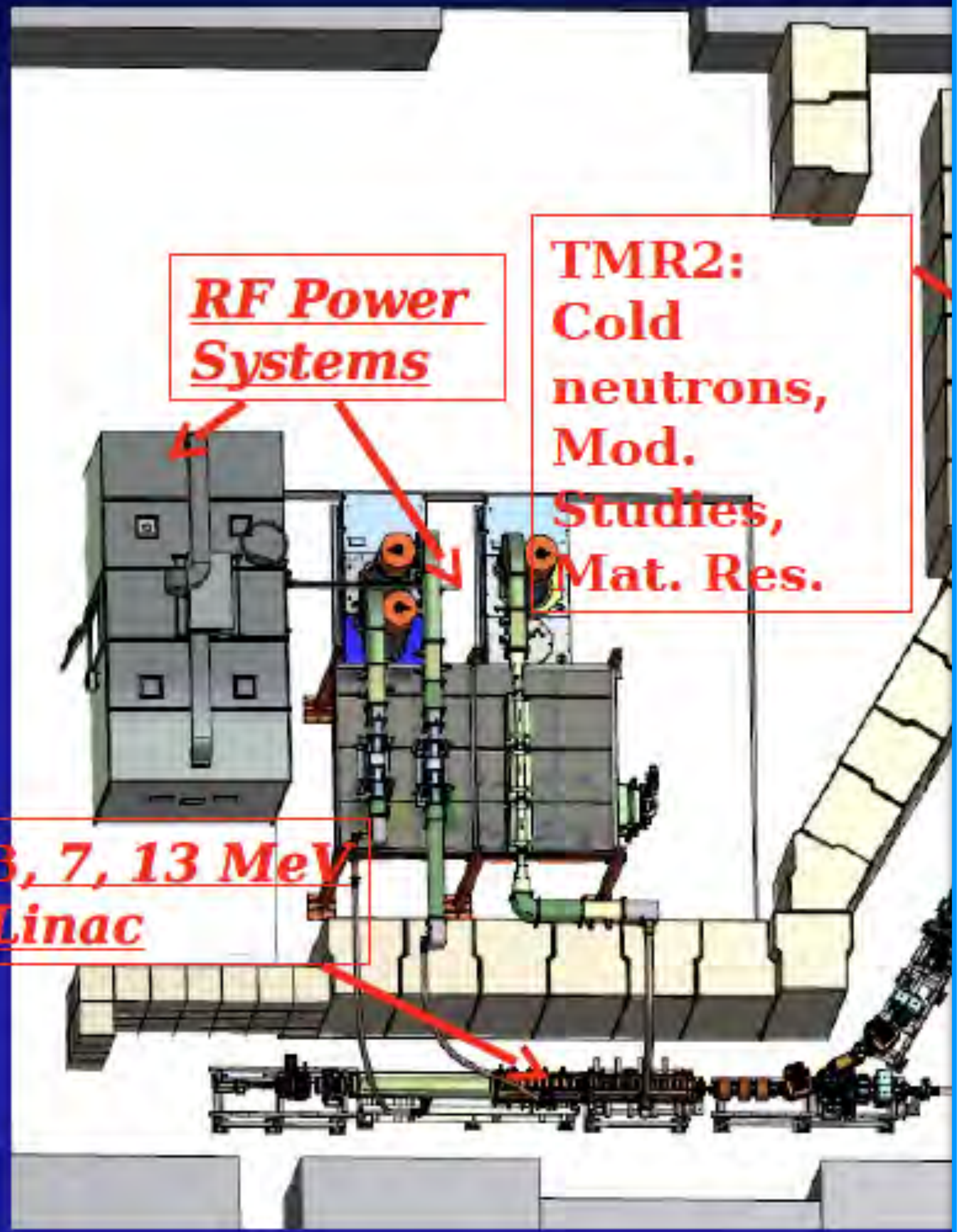
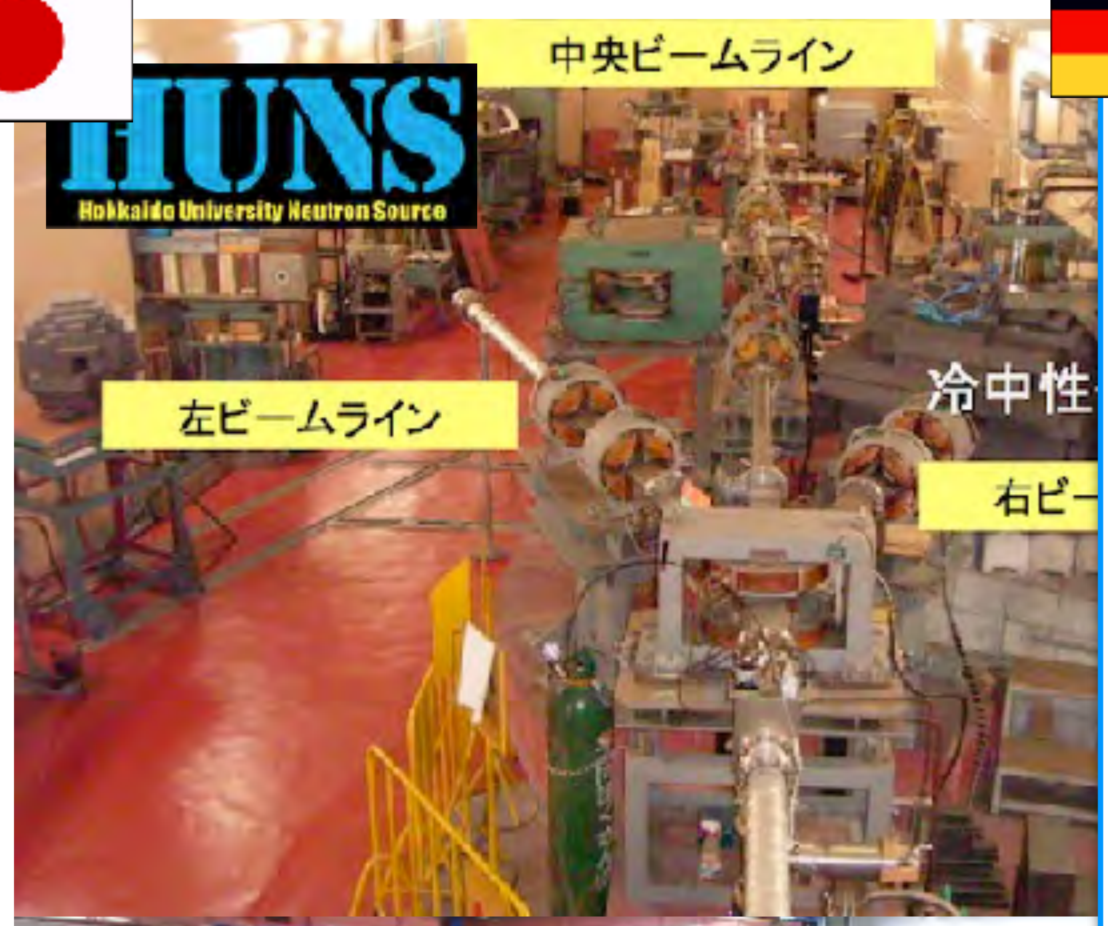
Ep=13MeV

LEN[S]



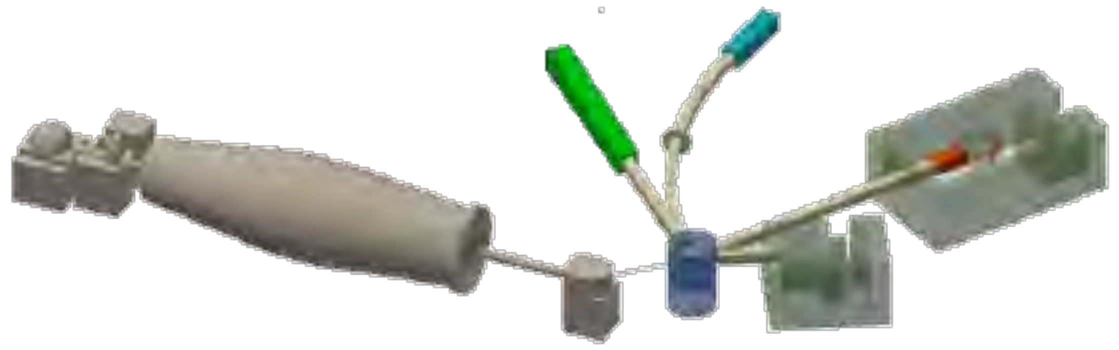


High Brilliance Neutron Source Project

Realisations

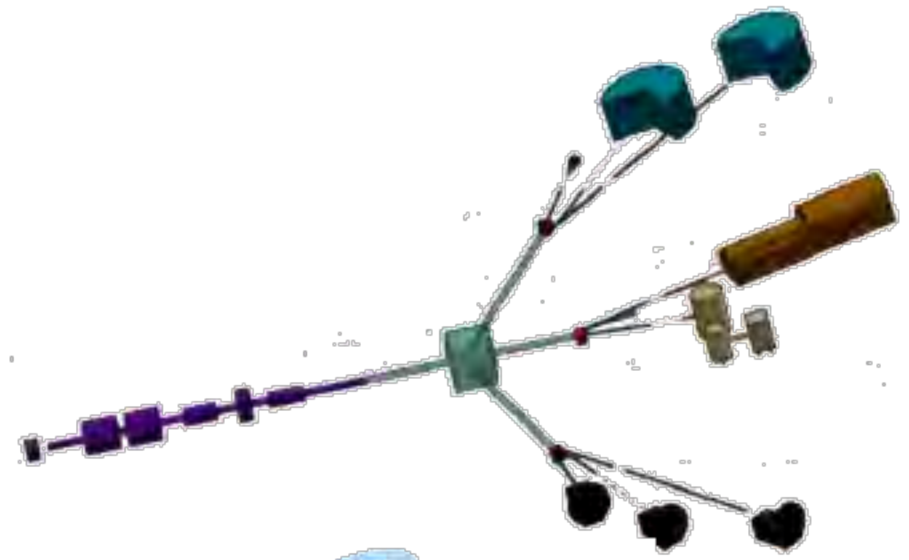
Laboratory facility: NOVA ERA

- small accelerator (~10 MeV)
  commercial tandetron
- single target station
- basic instruments for research, education and training



Large-scale facility: HBS

- linear accelerator (30-50 MeV)
- several target stations
- full suite of instruments with competitive performance



Mitglied der Helmholtz-Gemeinschaft

JCNS Jülich Centre for Neutron Science — JÜLICH Forschungszentrum

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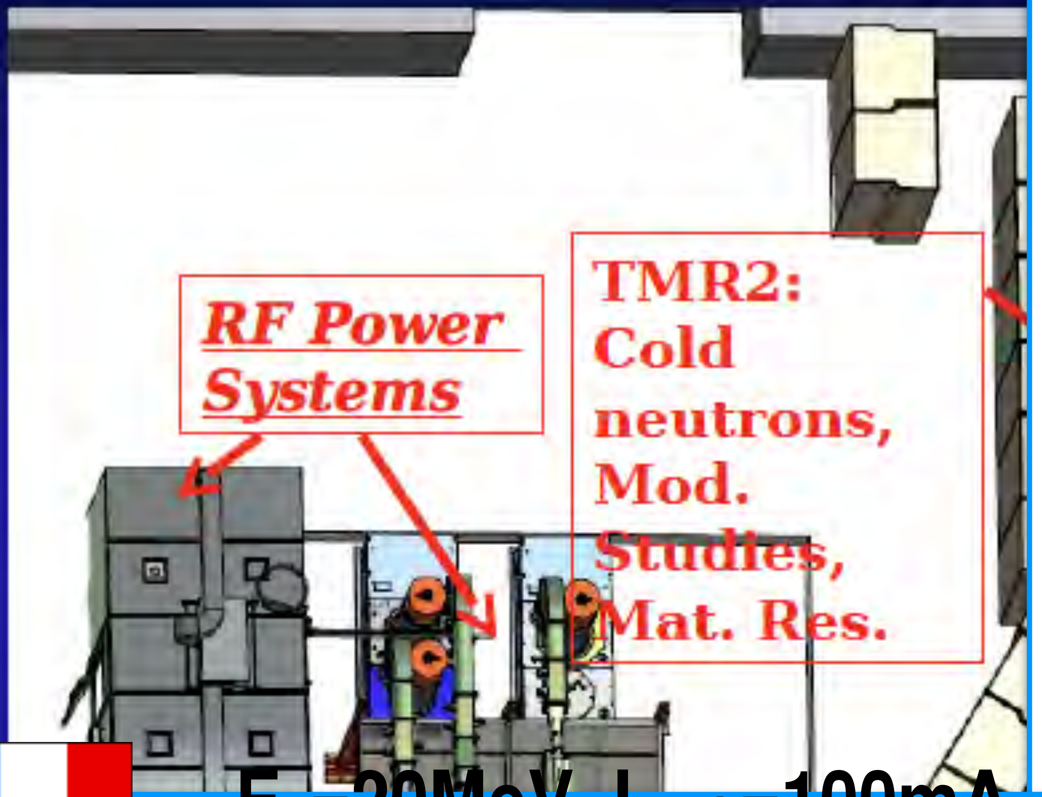
E_p=13MeV

LEN



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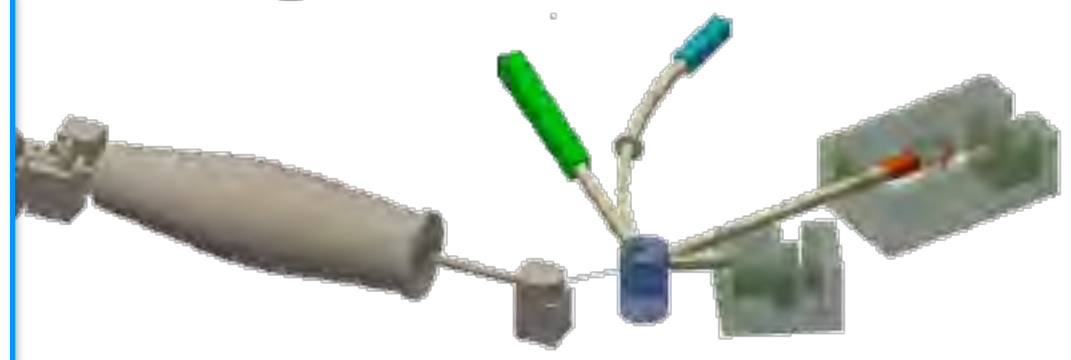

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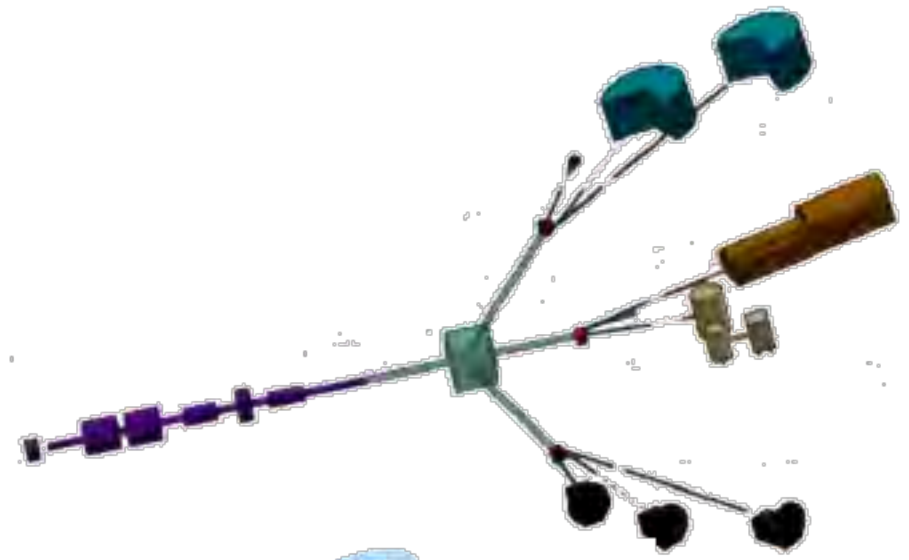
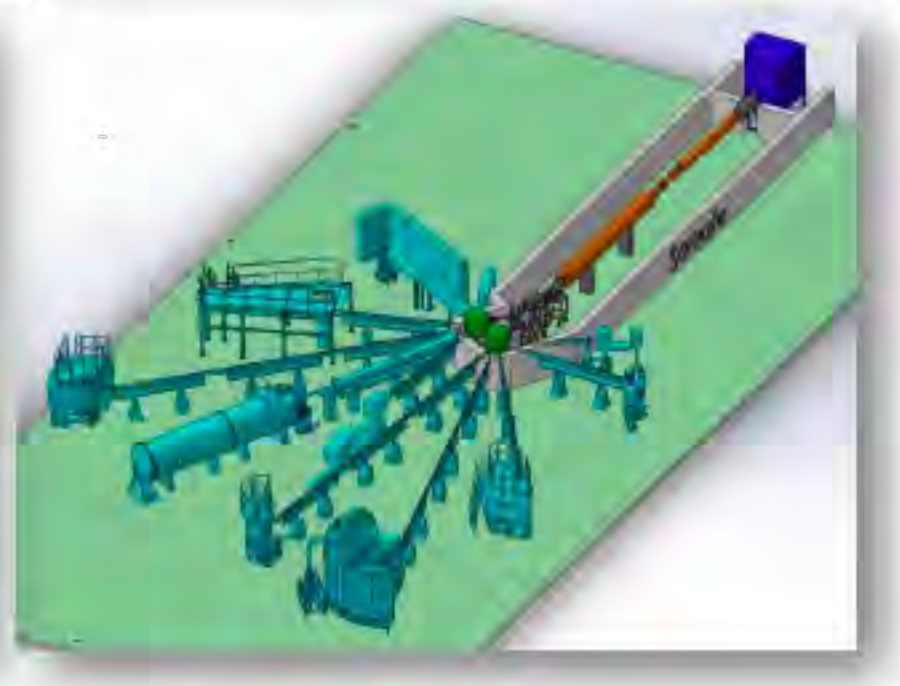


Helmholtz-Gemeinschaft

JCNS Jülich Centre for Neutron Science
JÜLICH Forschungszentrum

E_p=20MeV, I_{peak}=100mA, duty=4%, P=80kW
P=120kW (2 targets)



(Source cOmpacte de Neutrons s'Appuyant sur la Technologie des accélératEurs)

F. Ott, A.Menelle, C. Alba-Simionesco
Laboratoire Léon Brillouin, CEA-CNRS
CEA Saclay 91191 Gif sur Yvette
IRFU, CEA/DRF Saclay

cea cnrs université PARIS-SACLAY

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JCANS JSNS

E_p=13MeV

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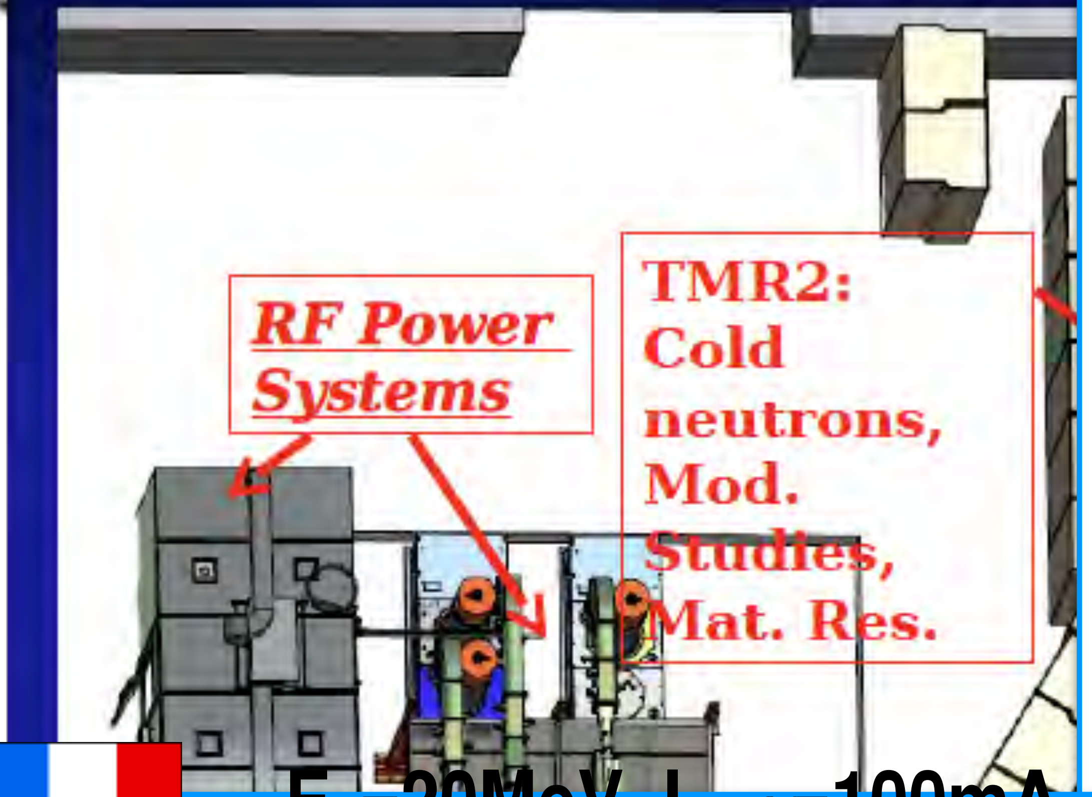

E_p=20MeV, I_{peak}=100mA, du
P=120

HUNS
Hokkaido University Neutron Source

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Sonate
NEUTRONS FOR MATERIALS SCIE

(Source cOmpacte de Neutrons s'Appuyant sur la Tec

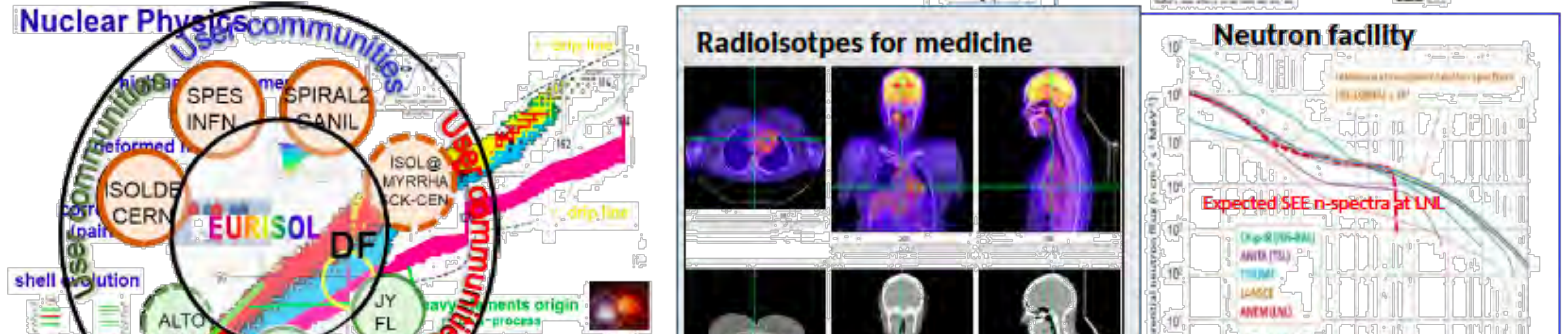
F. Ott, A.Menelle,
Laboratoire Léon
CEA Saclay 911
IRFU, CEA

cea cnrs université PARIS-SACLAY

neutron @ SPES

SPES project goals

1. **ISOL facility for nuclear physics: Production & re-acceleration of exotic beams. Neutron-rich ions from p-induced Fission on UCx (10^{13} f/s).**
2. Research and Production of **Radio-Isotopes for Nuclear Medicine**
3. Accelerator-based neutron source (**Neutron Facility for Applied Physics**)



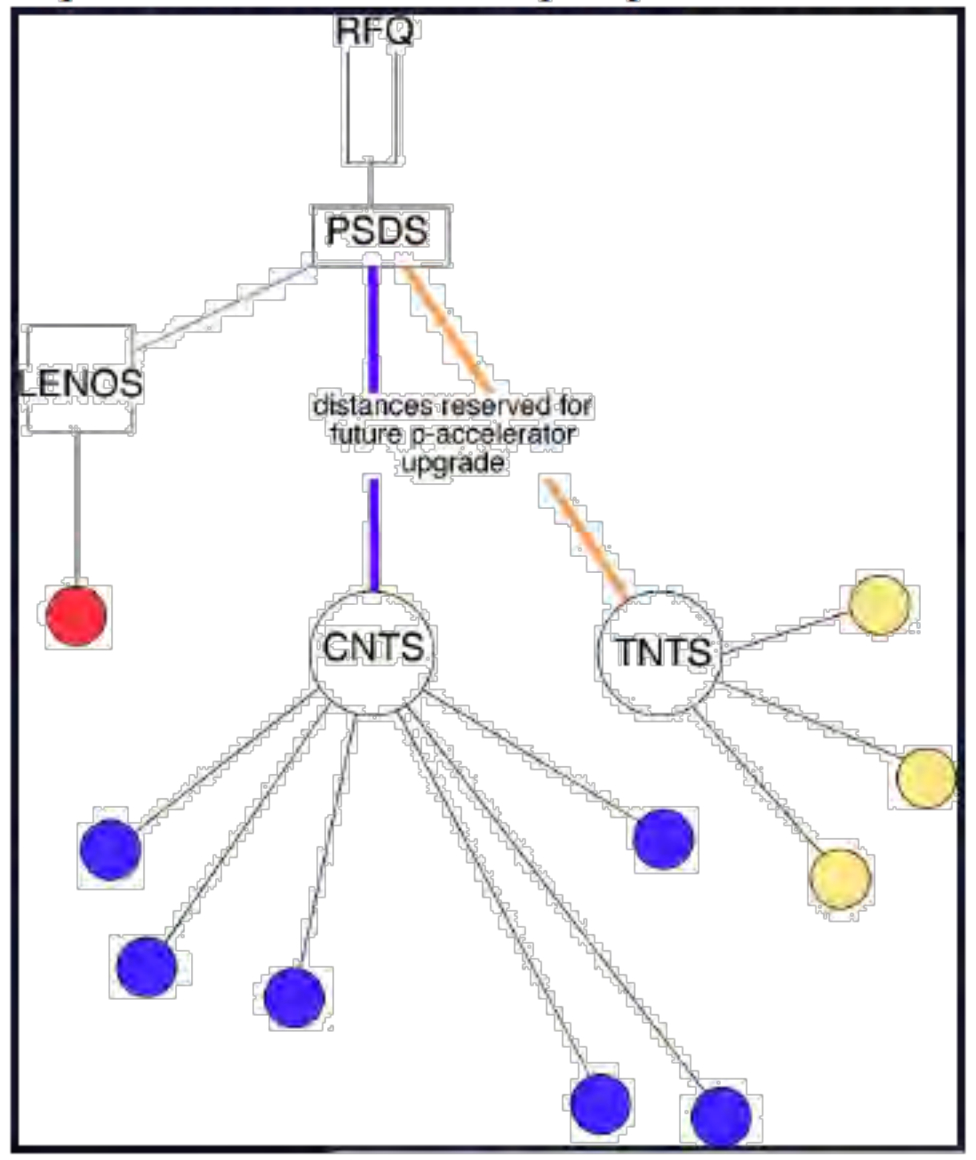
LENOS

Legnaro Neutron Source Driver

E_p=0.08–5MeV, I=30–50mA, P=150–250kW, CW

LENOS: Modular facility structur

Improve neutron facility capabilities with a High Power RFQ: TRASCO



Proton bea
(Pulse Selection and D

- CNTS (Cold Neutron Ta
  - Be target
  - Cryogenic moderato
  - Reflector (graphite
  - Up to 6 ports to exp
- TNTS (Thermal Neutro
  - Identical design to C (abient temperature
  - Initially three ports
- LENOS (astrophysics)

- **Modular structure**
- **Mild radioactivity** by low-energy protons (≤5 MeV)


IPAC18
E_p=13MeV
RF Power Systems
TMR2: Cold neutrons, Mod. Studies, Mat. Res.
HUNS
Hokkaido University Neutron Source
中央ビームライン
左ビームライン
右ビ
冷中性
Target station: Be target
proton
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E_p=20MeV, I_{peak}=100mA, du
P=120
NEUTRONS FOR
MATERIALS SCIE
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F. Ott, A.Menelle,
Laboratoire Léon
CEA Saclay 911
IRFU, CEA
cea
cnrs
université PARIS-SACLAY
neutron @ SPES
INFN
SPES project goals
1. ISOL facility for nuclear physics: Production & re-acceleration of exotic beams. Neutron-rich ions from p-induced Fission on UCx (10^{13} f/s).
2. Research and Production of Radio-Isotopes for Nuclear Medicine
3. Accelerator-based neutron source (Neutron Facility for Applied Physics)
Nuclear Physics
Radioisotopes for medicine
LvB
Accelerator to 5 – 8 MeV long (ms) pulsed
2.5 MeV accelerator CW or pulsed
MEBT
Bi-spectral "tube" moderator (above target)
Li target
Fast neutron beam
< 1 MeV neutron beam (investor option)
Beamlines with correlation chopper
Public procurement tender (mid 2018):
- ion source + LEBT
- 2.5 MeV accelerator (+ MEBT)
- accelerator 5 – 8 MeV (+ HEBT)
- RF amplifier
- integration

UCANS
Union for Compact Accelerator-driven Neutron Sources

reaction
(n,2n), ...

absorption
(n,γ)

diffraction

scattering

interference

confinement

neutron

moderation → conversion

fast · epithermal · thermal · cold · very-cold · ultracold

kinetic energy	MeV			eV			meV			μeV			neV
temperature	10^{10}K	10^{9}K	10^{5}K	10^{4}K	10^{3}K	100K	10K	1K	0.1K	0.01K	1mK	100μK	10μK
wavelength		100fm	0.01nm		0.1nm		1nm		10nm		100nm		1μm

reaction (n,2n), ...

absorption (n,γ)

scattering

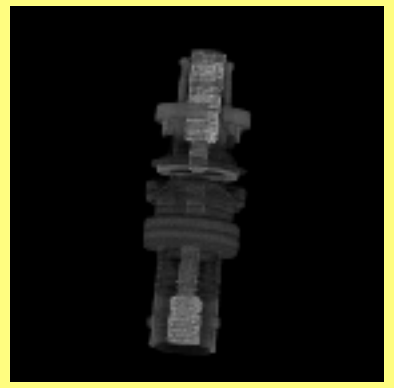
diffraction

interference

confinement

industry applications

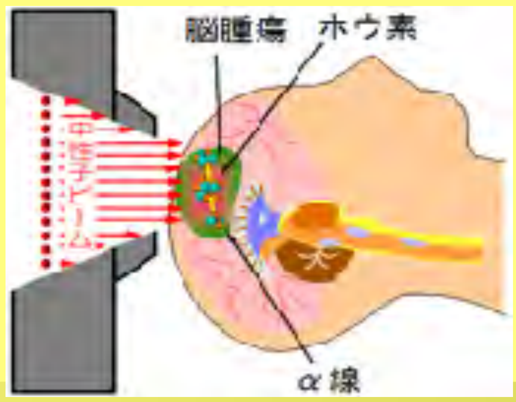
radiography

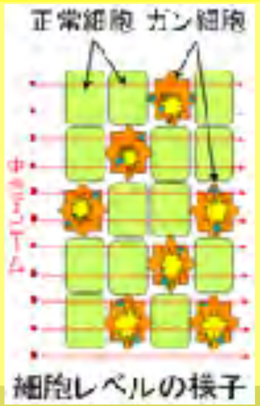


medical applications

RI production

Boron Neutron Capture Therapy

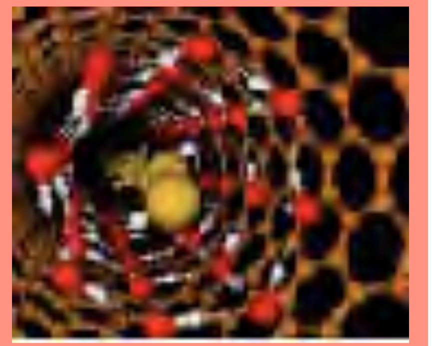




material science

diffraction

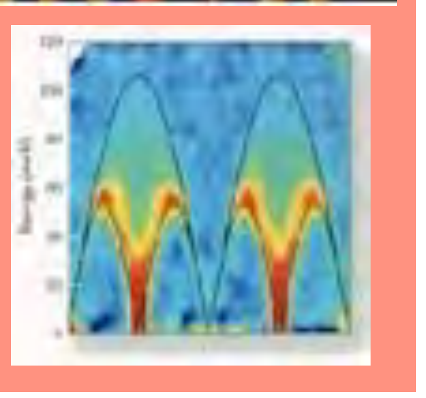
λ=0.1–10nm



spectroscopy

ΔE<100meV

t>10^{-13}s



fundamental physics

symmetry

$\delta_{NEW} = \frac{\Delta O_{NEW}}{O_{SM}} = \frac{\alpha}{\pi}\left(\frac{M}{\tilde{M}}\right)^2$

gravity

reaction (n,2n), ...

absorption (n,γ)

diffraction

scattering

interference

confinement

RI production

Reactor Engineering

Material Research

Fundamental Physics

Nuclear Transmutation Doping

Fundamental Physics

Boron Neutron Capture Therapy

Radiography

reaction (n,2n), ...

absorption (n,γ)

scattering

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Fundamental Physics

Boron Neutron Capture Therapy

Radiography

Production Rate

Flux

Conversion Efficiency


neutron
n
moderation
conversion
fast
epithermal
thermal
cold
very-cold
ultracold
kinetic energy
MeV
eV
meV
μeV
neV
temperature
10^{10}K
10^{9}K
10^{5}K
10^{4}K
10^{3}K
100K
10K
1K
0.1K
0.01K
1mK
100μK
10μK
wavelength
100fm
0.01nm
0.1nm
1nm
10nm
100nm
1μm
reaction
(n,2n), ...
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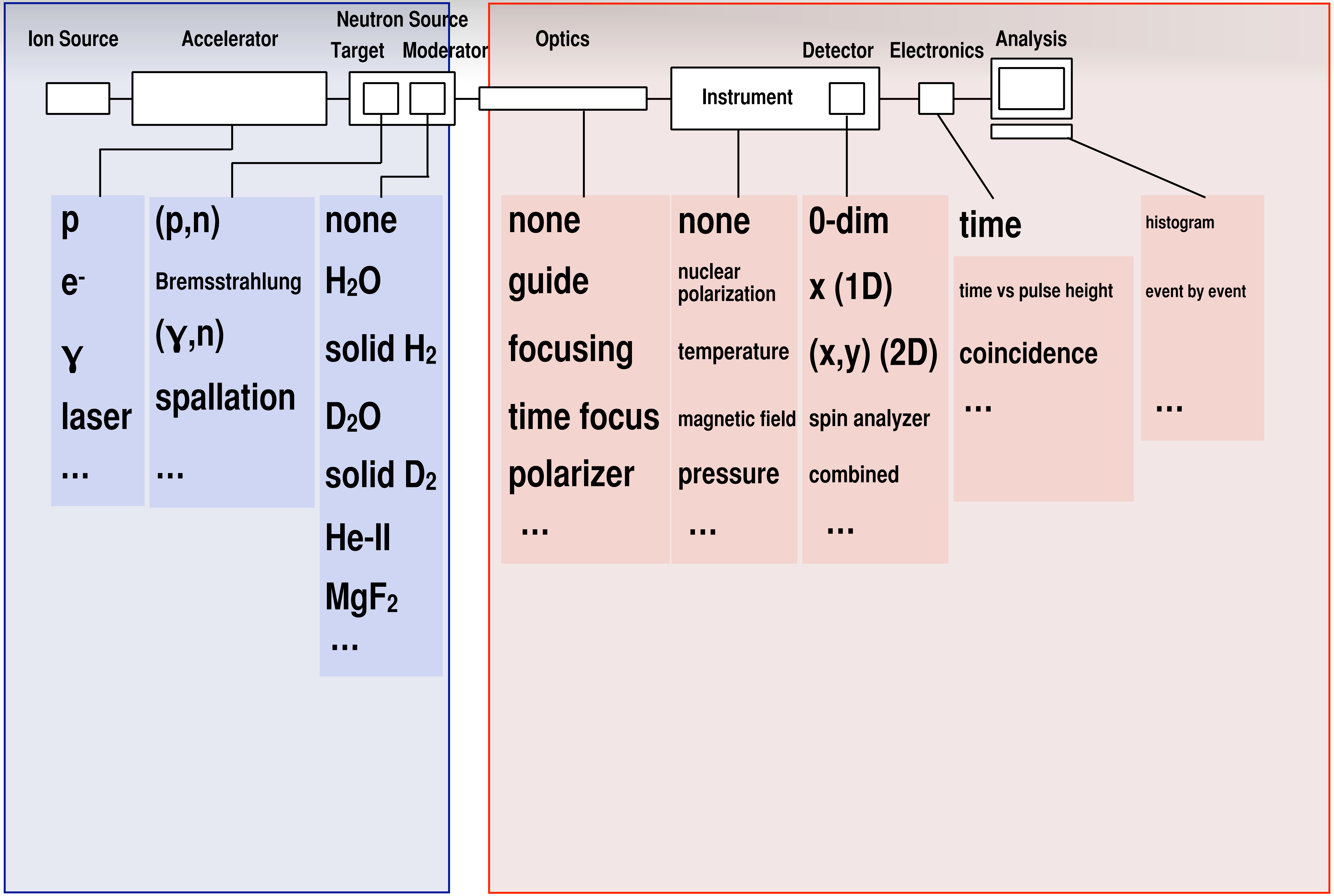
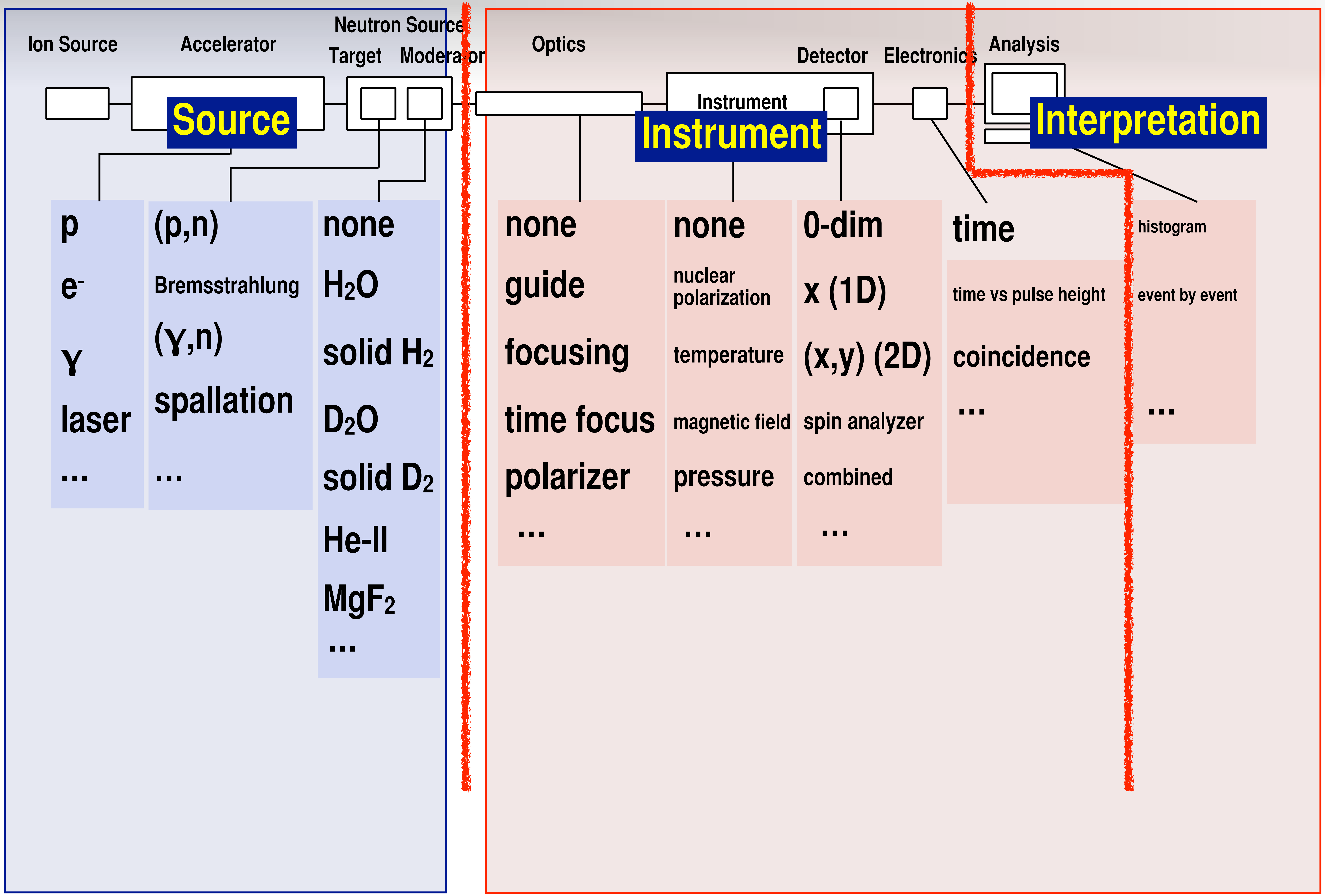
Boron Neutron Capture Therapy
Radiography
Production Rate
Flux
Conversion Efficiency


Ion Source
Accelerator
Neutron Source
Target
Moderator
Optics
Detector
Electronics
Analysis
Instrument
p
e-
γ
laser
…
(p,n)
Bremsstrahlung
(γ,n)
spallation
…
none
H_2O
solid H_2
D_2O
solid D_2
He-II
MgF_2
…
none
guide
focusing
time focus
polarizer
…
none
nuclear polarization
temperature
magnetic field
pressure
…
0-dim
x (1D)
(x,y) (2D)
spin analyzer
combined
…
time
time vs pulse height
coincidence
…
histogram
event by event
…



Ion Source
Accelerator
Neutron Source
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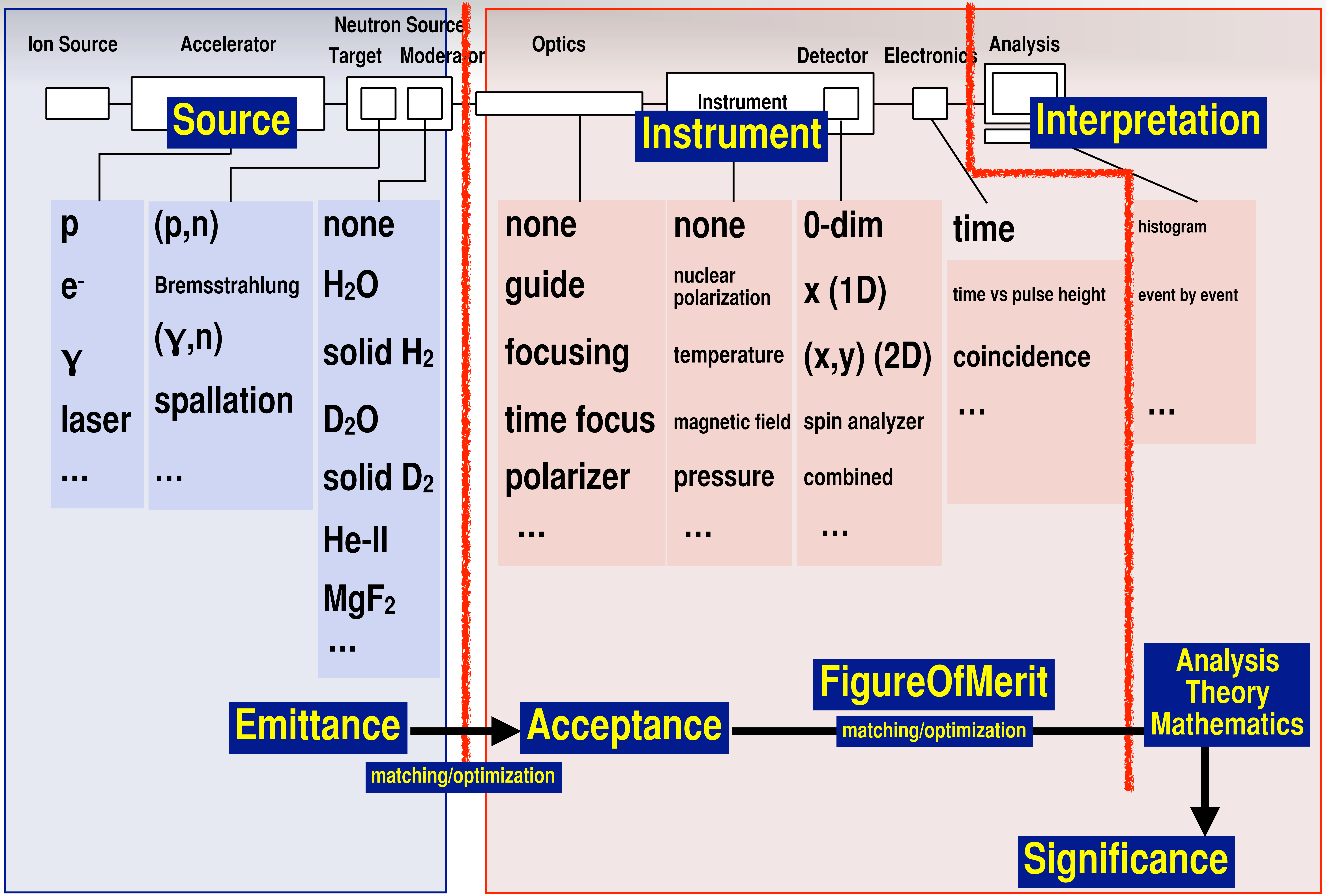
Ion Source
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MgF2
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spin analyzer
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…
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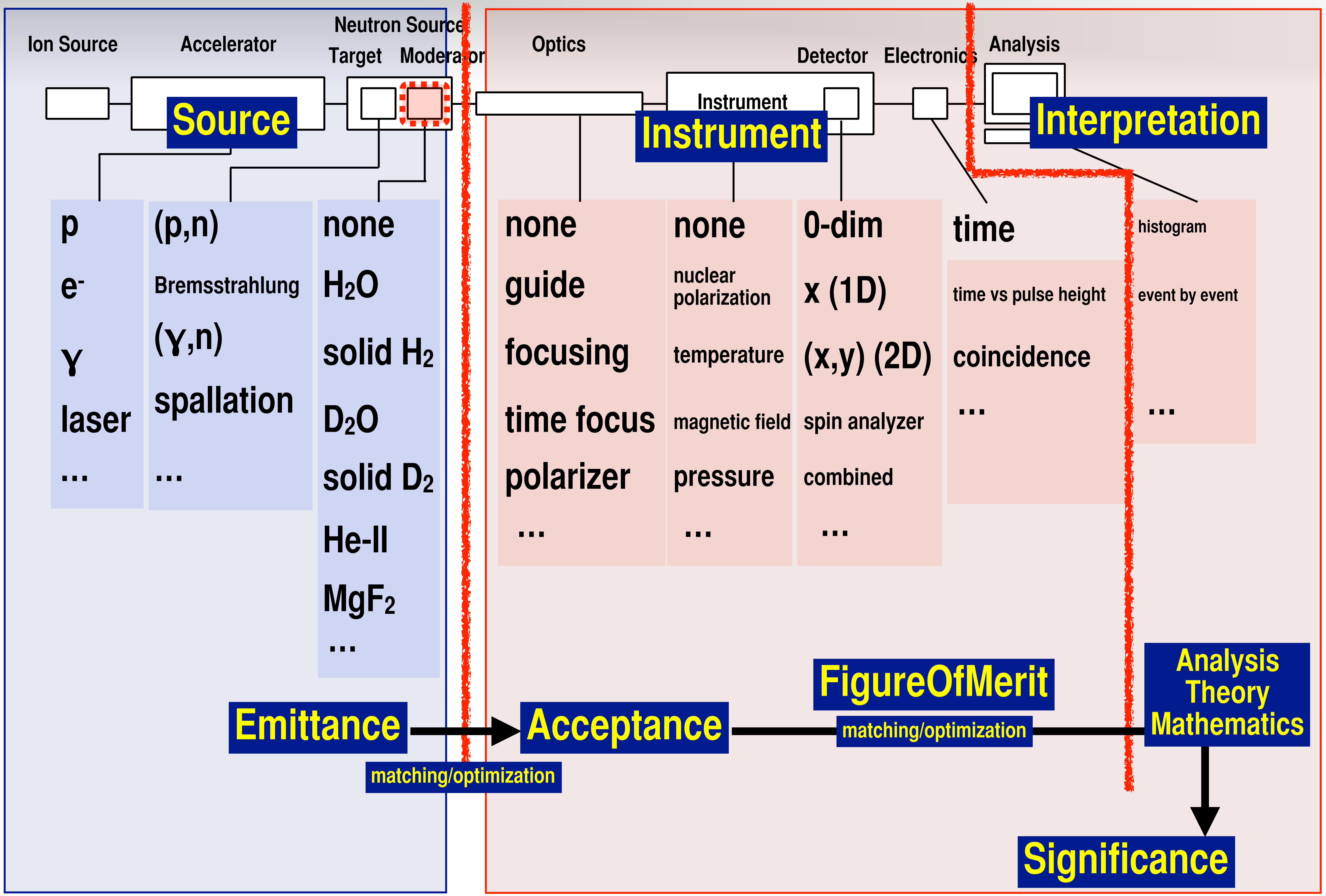
time vs pulse height
coincidence
…
histogram
event by event
…
Emittance
matching/optimization
Acceptance
FigureOfMerit
matching/optimization
Analysis Theory Mathematics
Significance



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Optics
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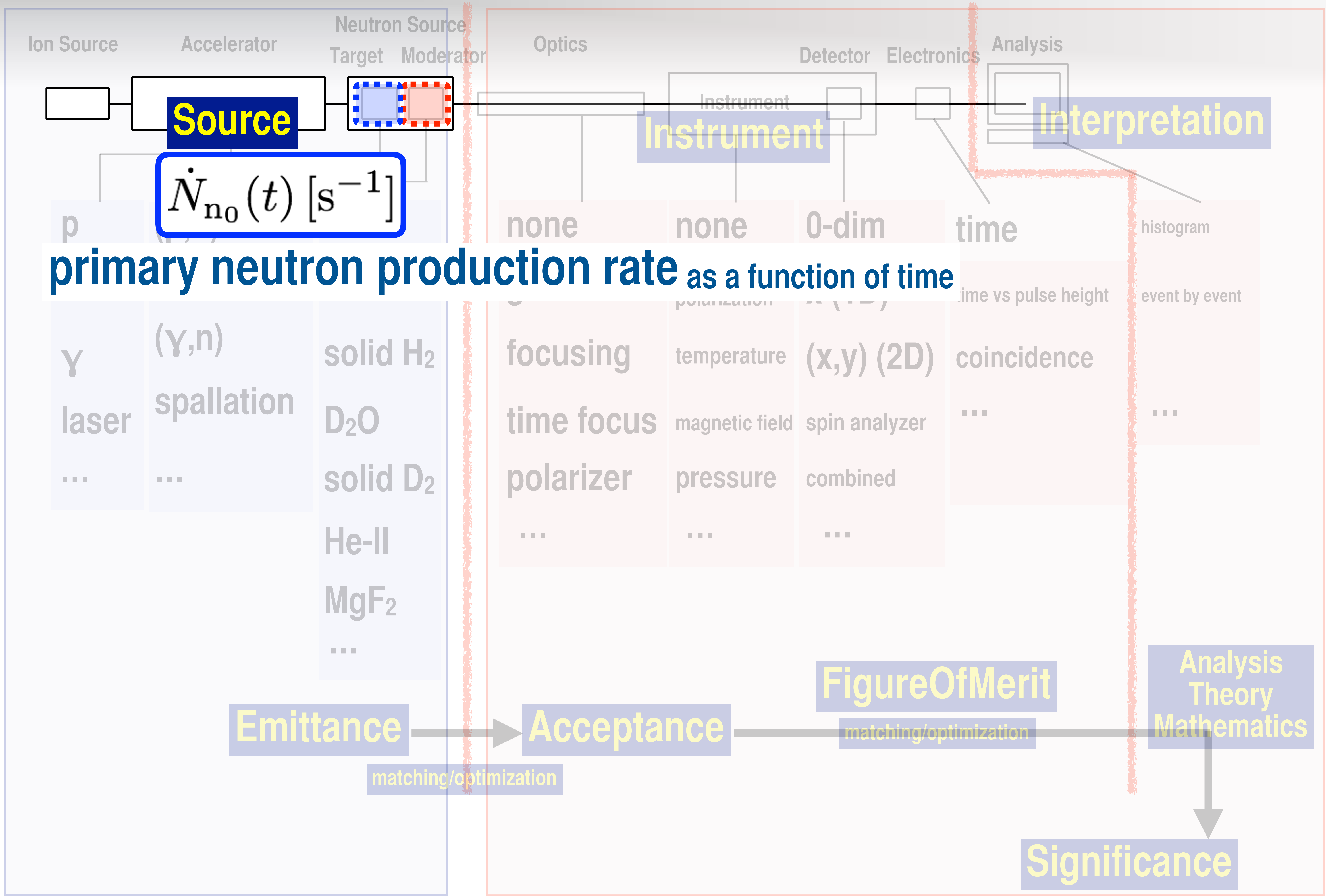


$\dot{N}_{n0}(t)\ [s^{-1}]$

primary neutron production rate as a function of time

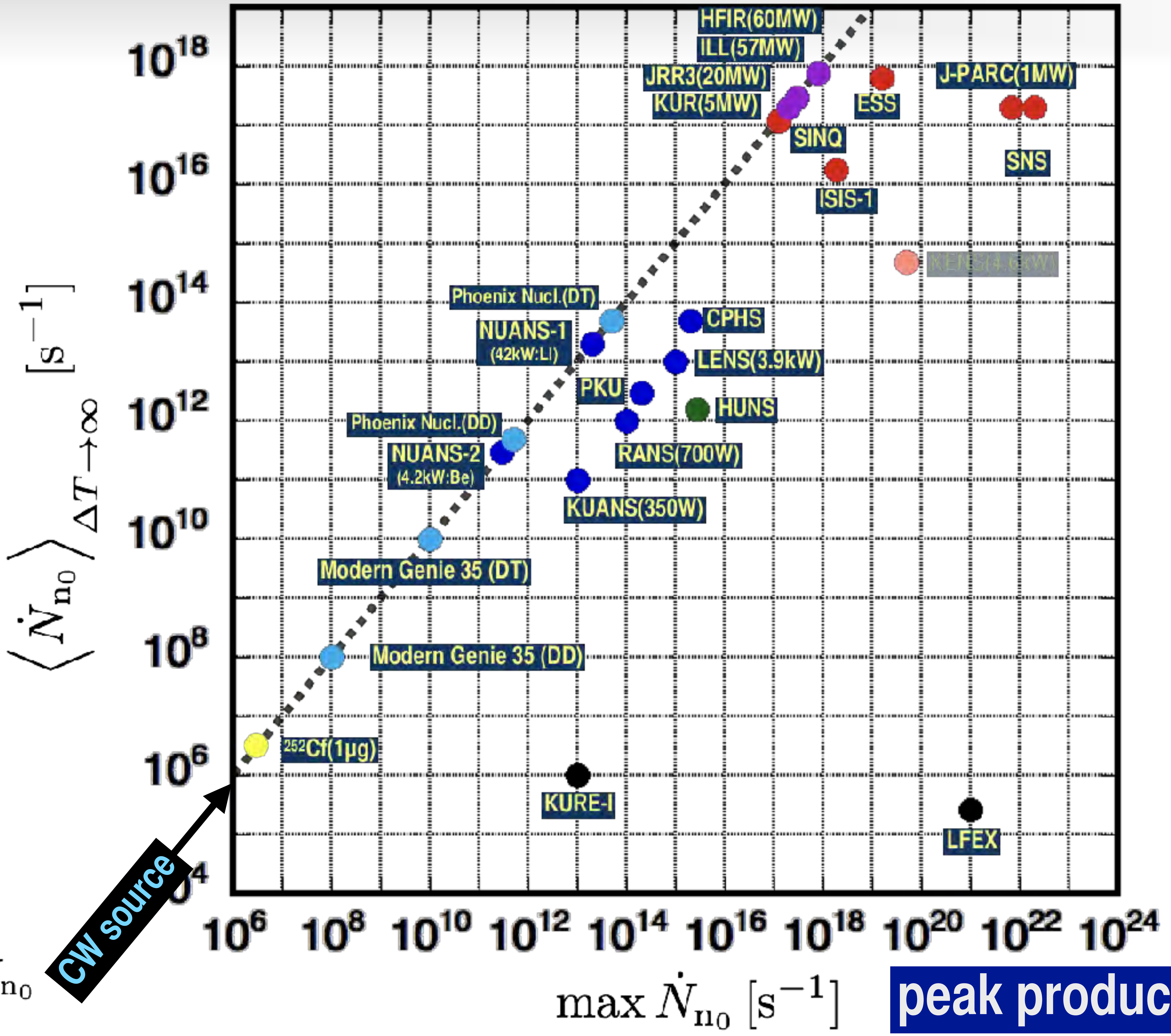
Neutron Production Rate

primary neutron production rate as a function of time

$$\left\langle \dot{N}_{\mathrm{n}_0}(t) \right\rangle_T = \frac{1}{T} \int_{t-T}^{t} \dot{N}_{\mathrm{n}_0}(t')\mathrm{d}t'$$

time-average of primary neutron production rate

average production rate



$$\left\langle \dot{N}_{\mathrm{n}_0} \right\rangle = \dot{N}_{\mathrm{n}_0}$$

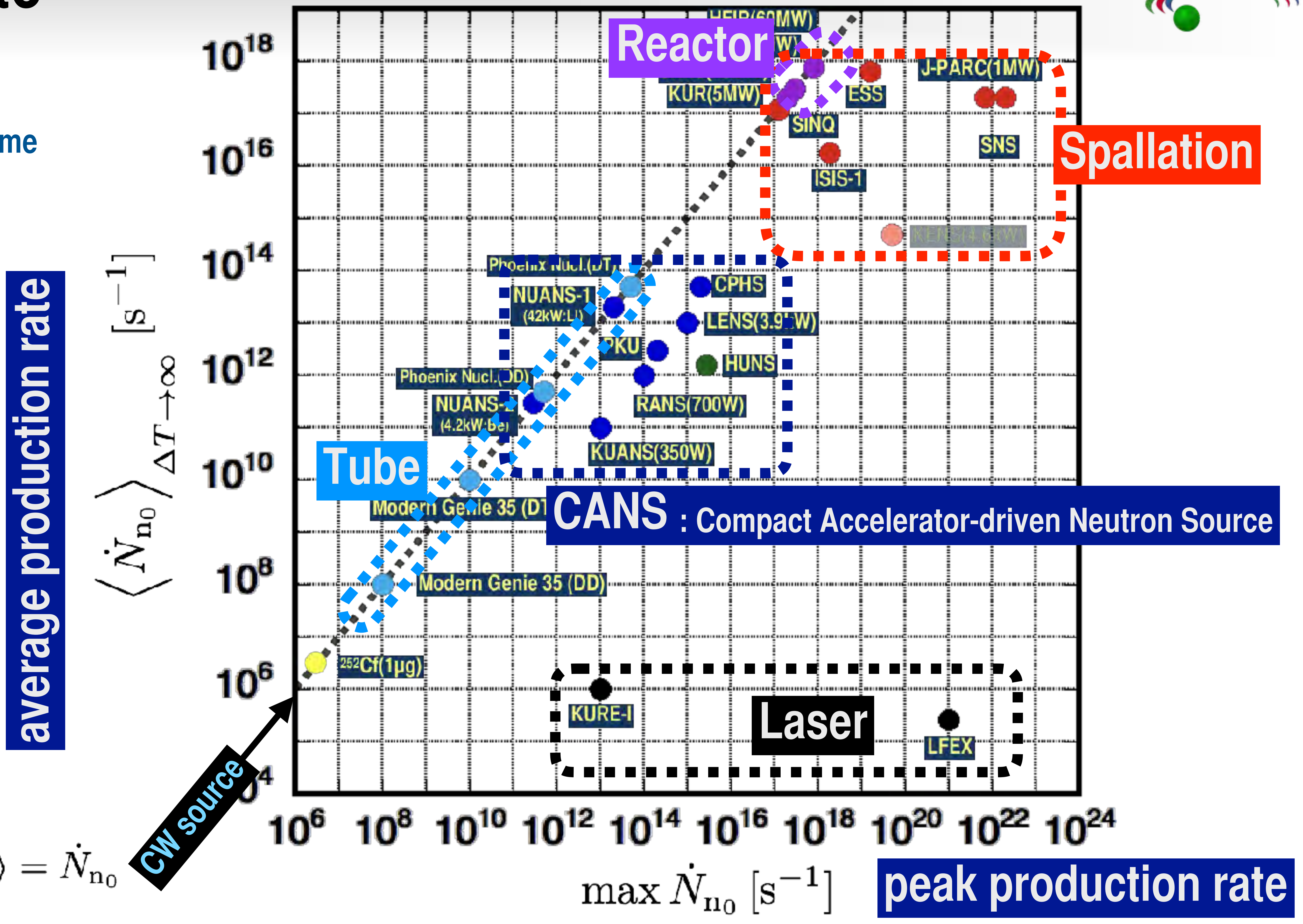
peak production rate

Neutron Production Rate

primary neutron production rate as a function of time

$$\left\langle \dot{N}_{\mathrm{n}0}(t) \right\rangle_T = \frac{1}{T}\int_{t-T}^{t} \dot{N}_{\mathrm{n}0}(t')\mathrm{d}t'$$

time-average of primary neutron production rate



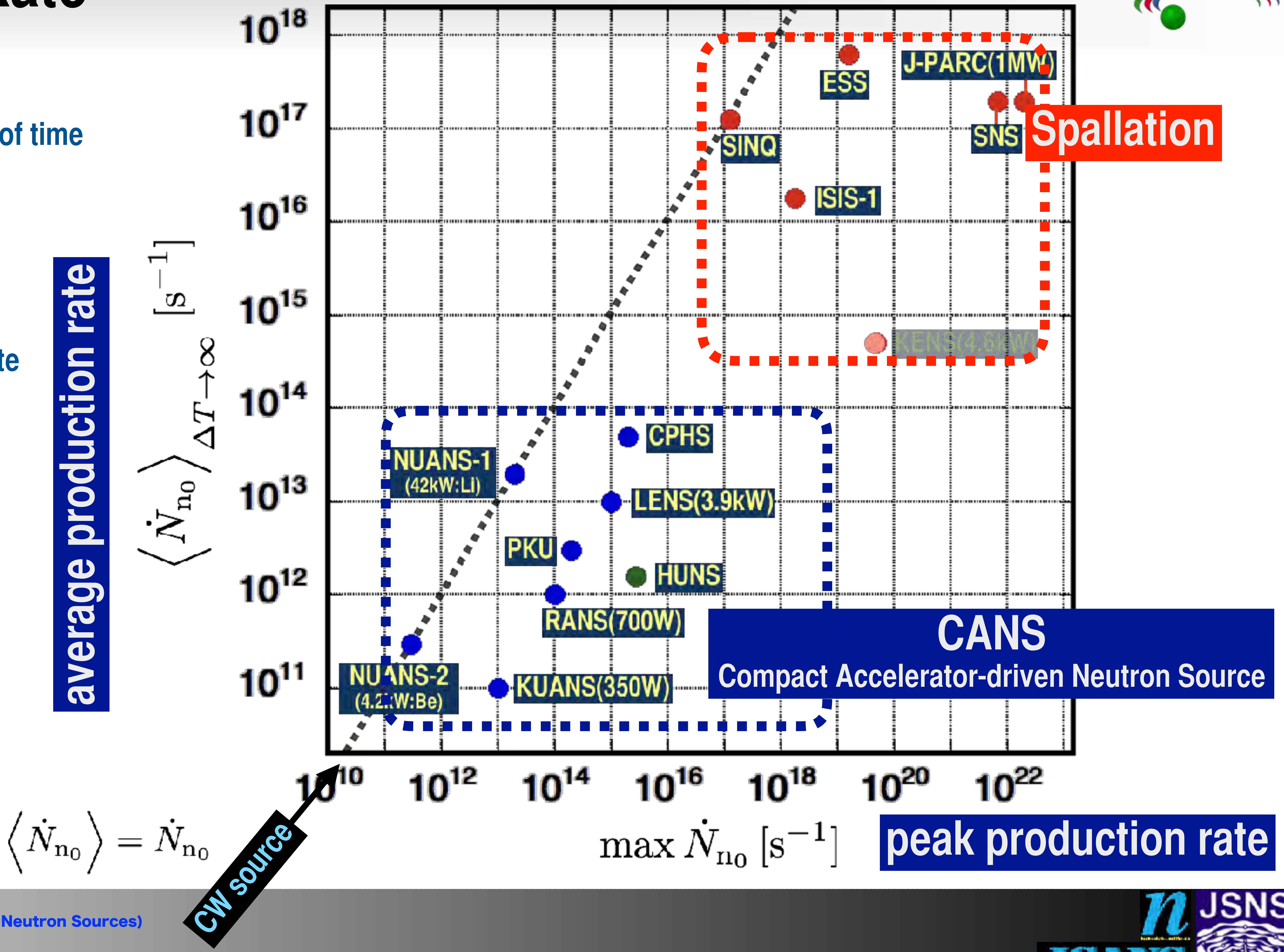
$$\left\langle \dot{N}_{\mathrm{n}0} \right\rangle = \dot{N}_{\mathrm{n}0}$$

Neutron Production Rate

primary neutron production rate as a function of time

$$\left\langle \dot{N}_{n_0}(t) \right\rangle_T = \frac{1}{T} \int_{t-T}^{t} \dot{N}_{n_0}(t')\mathrm{d}t'$$

time-average of primary neutron production rate



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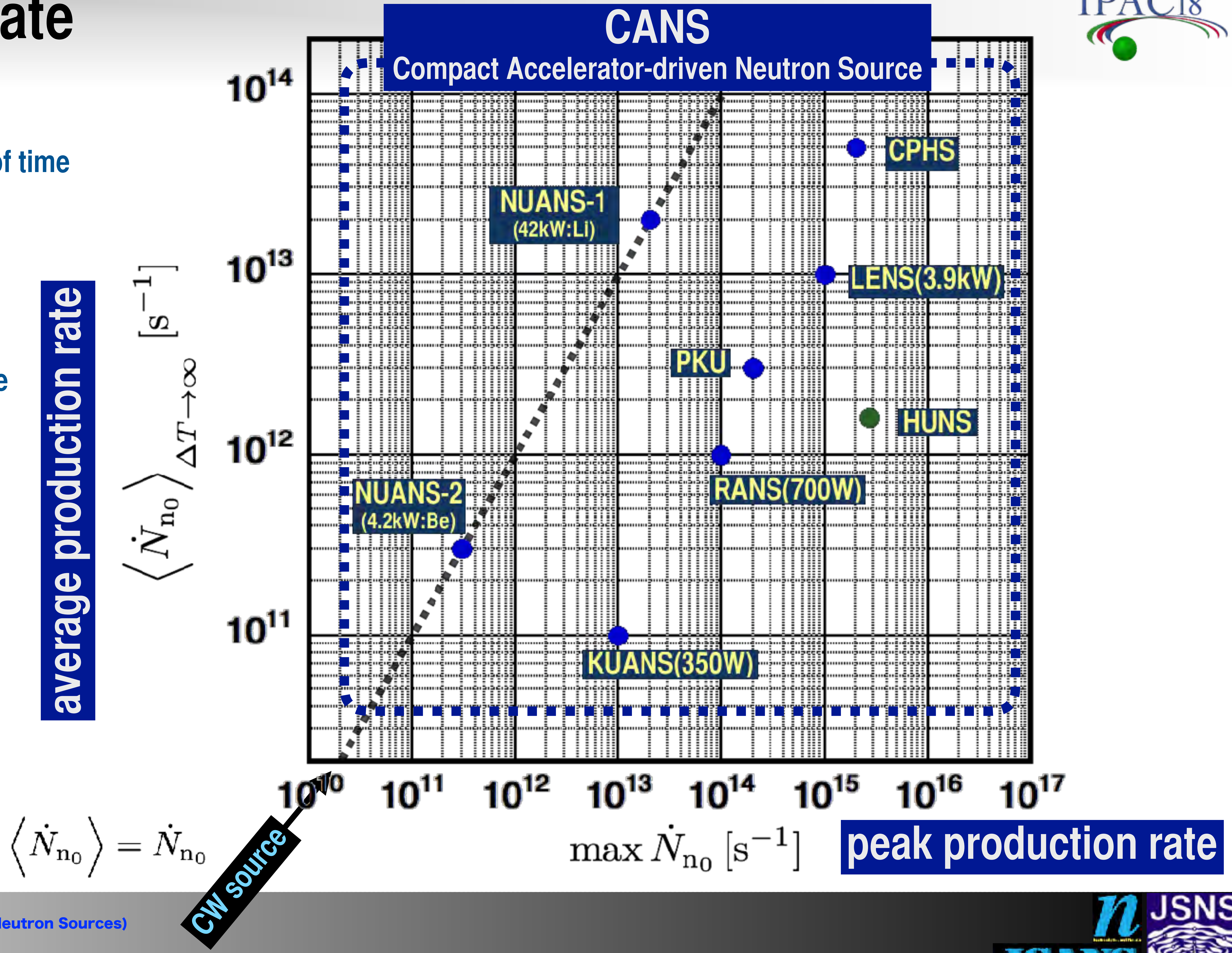

Neutron Production Rate

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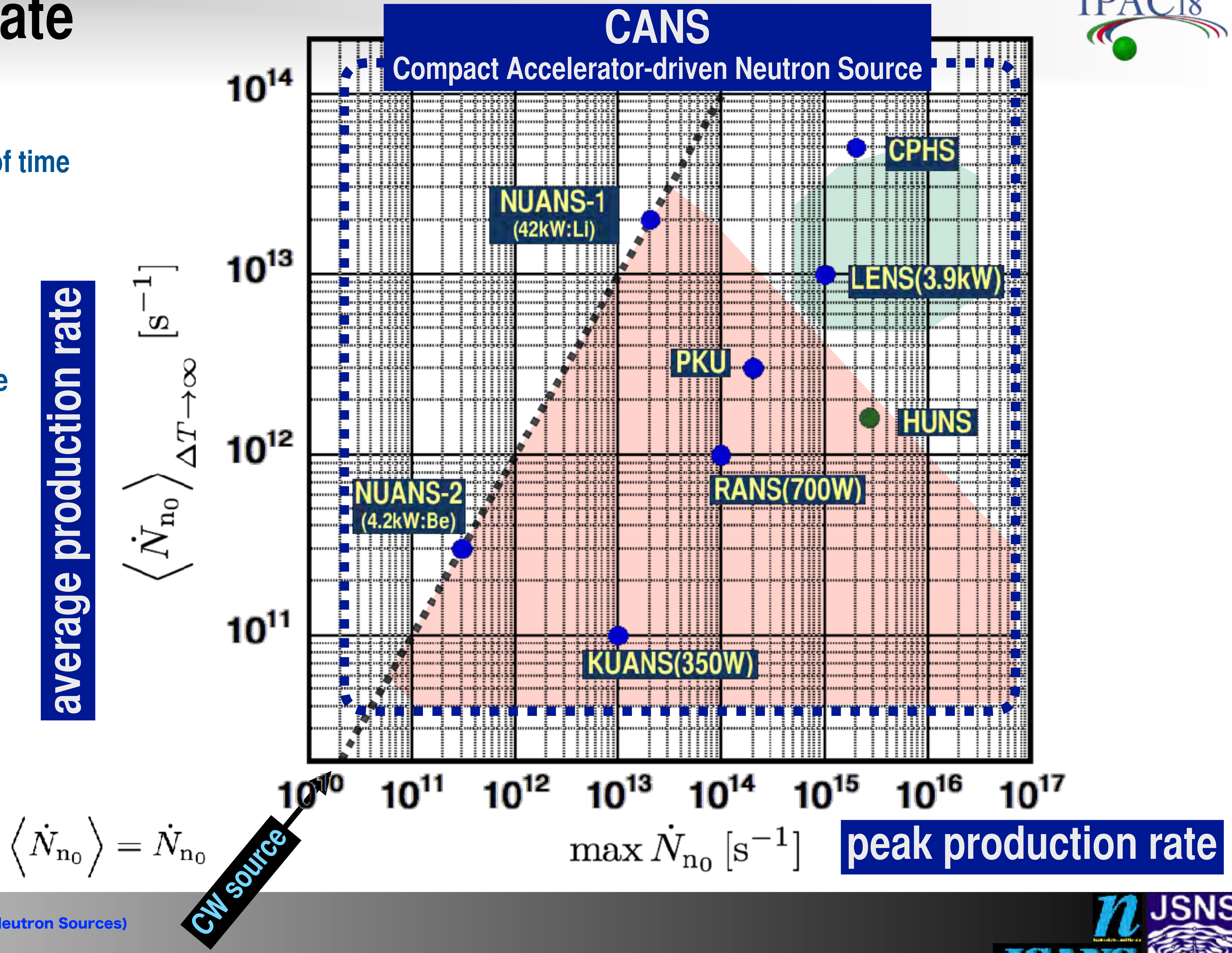

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primary neutron production rate as a function of time

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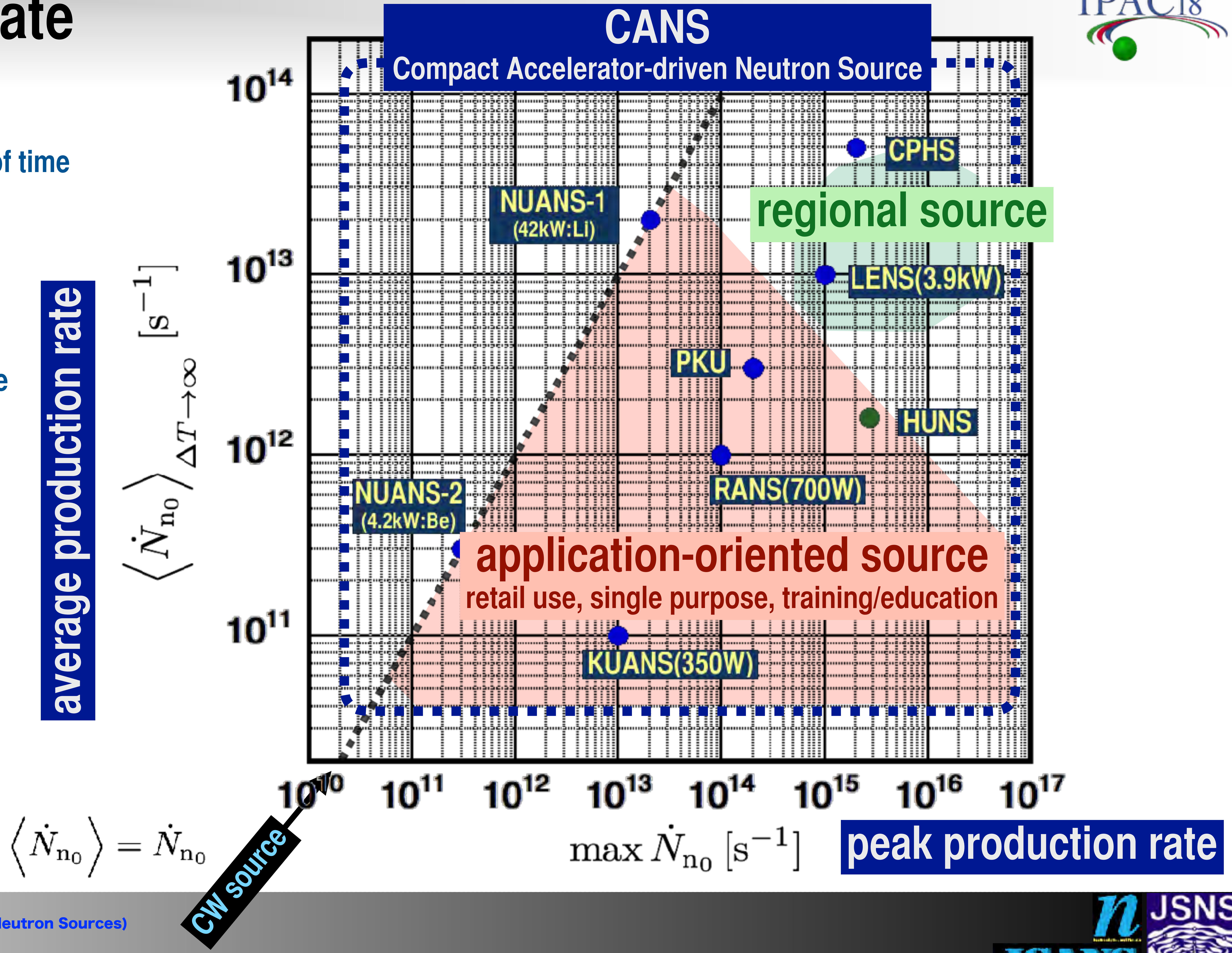

Neutron Production Rate

primary neutron production rate as a function of time

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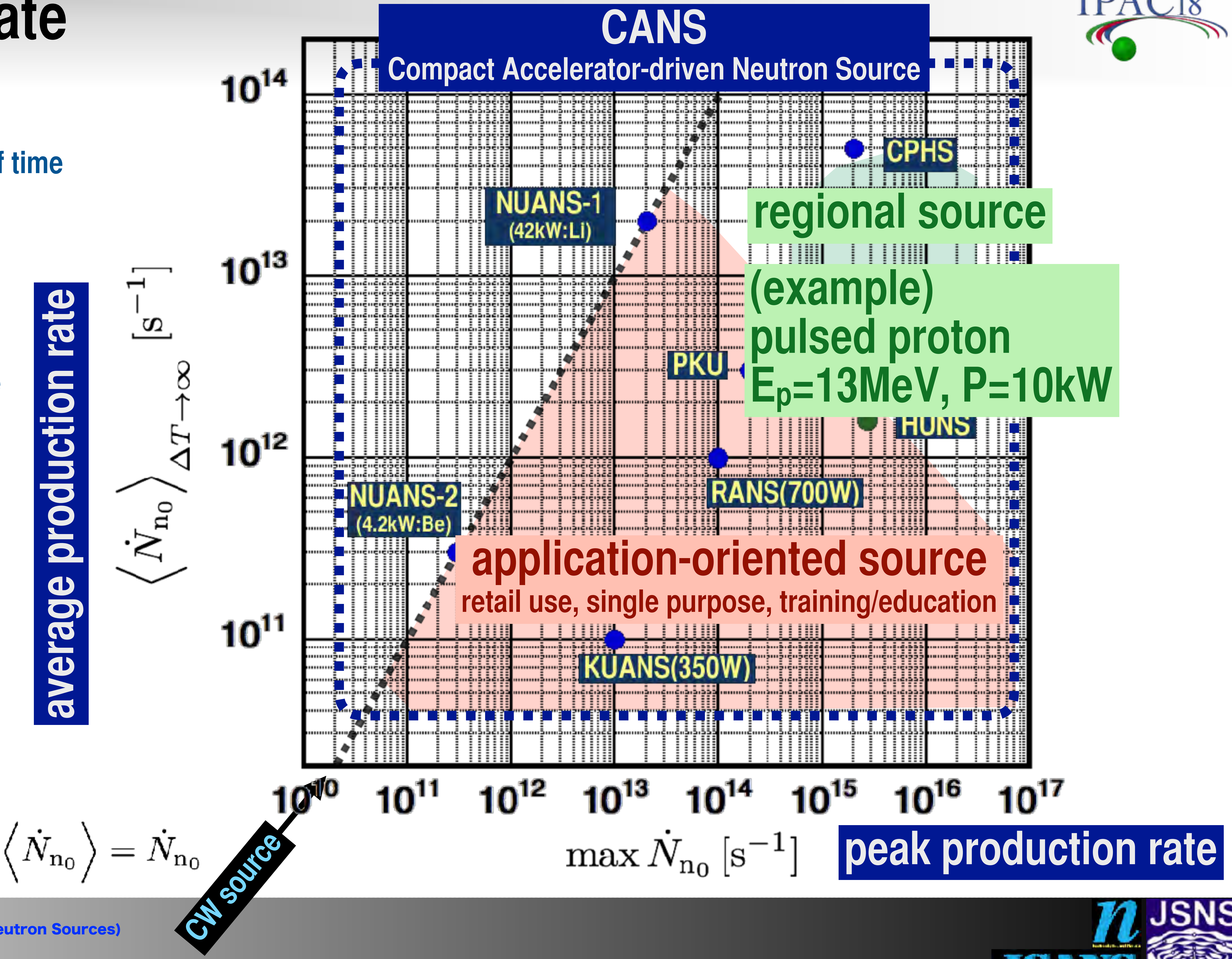
time-average of primary neutron production rate

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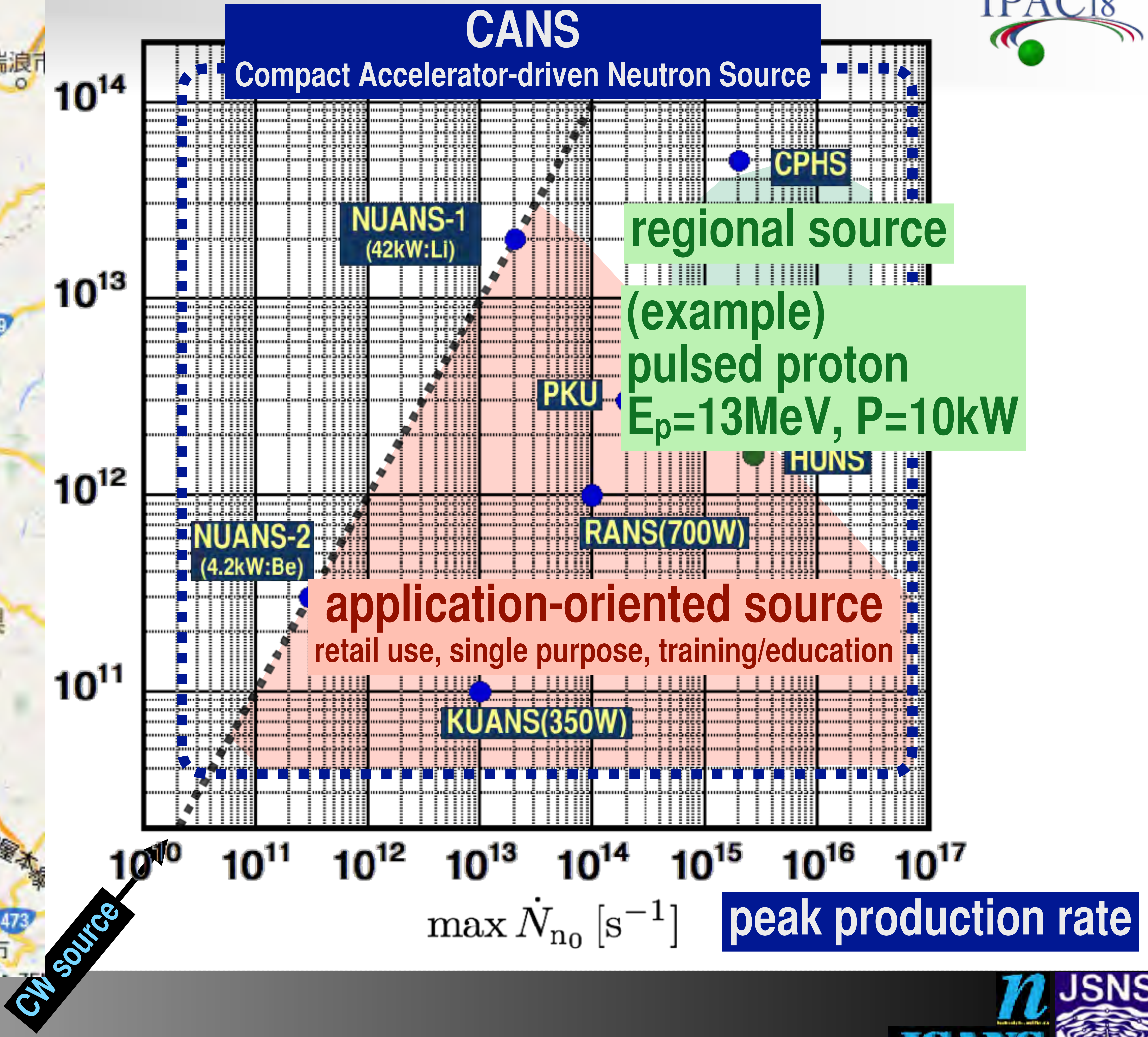
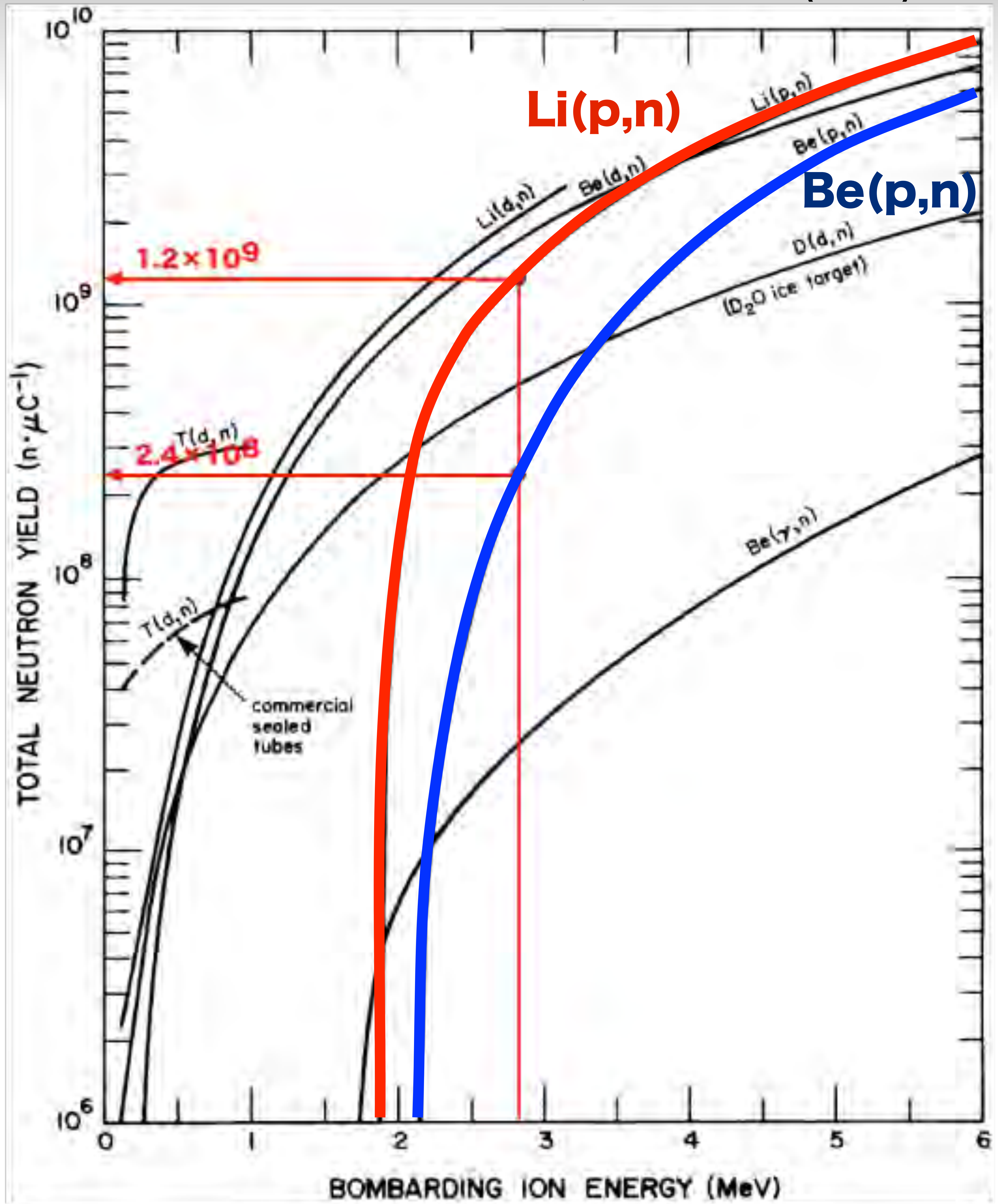
Nagoya University
NIPPON STEEL & SUMITOMO METAL
TOYOTA
JFE Steel Corporation
各務原市
犬山市
江南市
羽島市
一宮市
小牧市
稲沢市
北名古屋市
春日井市
瀬戸市
尾張旭市
津島市
長久手市
愛西市
日進市
弥富市
みよし市
豊田市
桑名市
豊明市
東海市
大府市
愛知県
知多市
刈谷市
知立市
安城市
岡崎市
高浜市
常滑市
西尾市
中部国際空港セントレア
蒲郡市
多治見市
土岐市
Google


CANS
Compact Accelerator-driven Neutron Source
CPHS
regional source
NUANS-1
(42kW:Li)
(example)
pulsed proton
E_p=13MeV, P=10kW
PKU
HUNS
RANS(700W)
NUANS-2
(4.2kW:Be)
application-oriented source
retail use, single purpose, training/education
KUANS(350W)
CW source
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
max $\dot{N}_{n0}$ [s^{-1}]
peak production rate

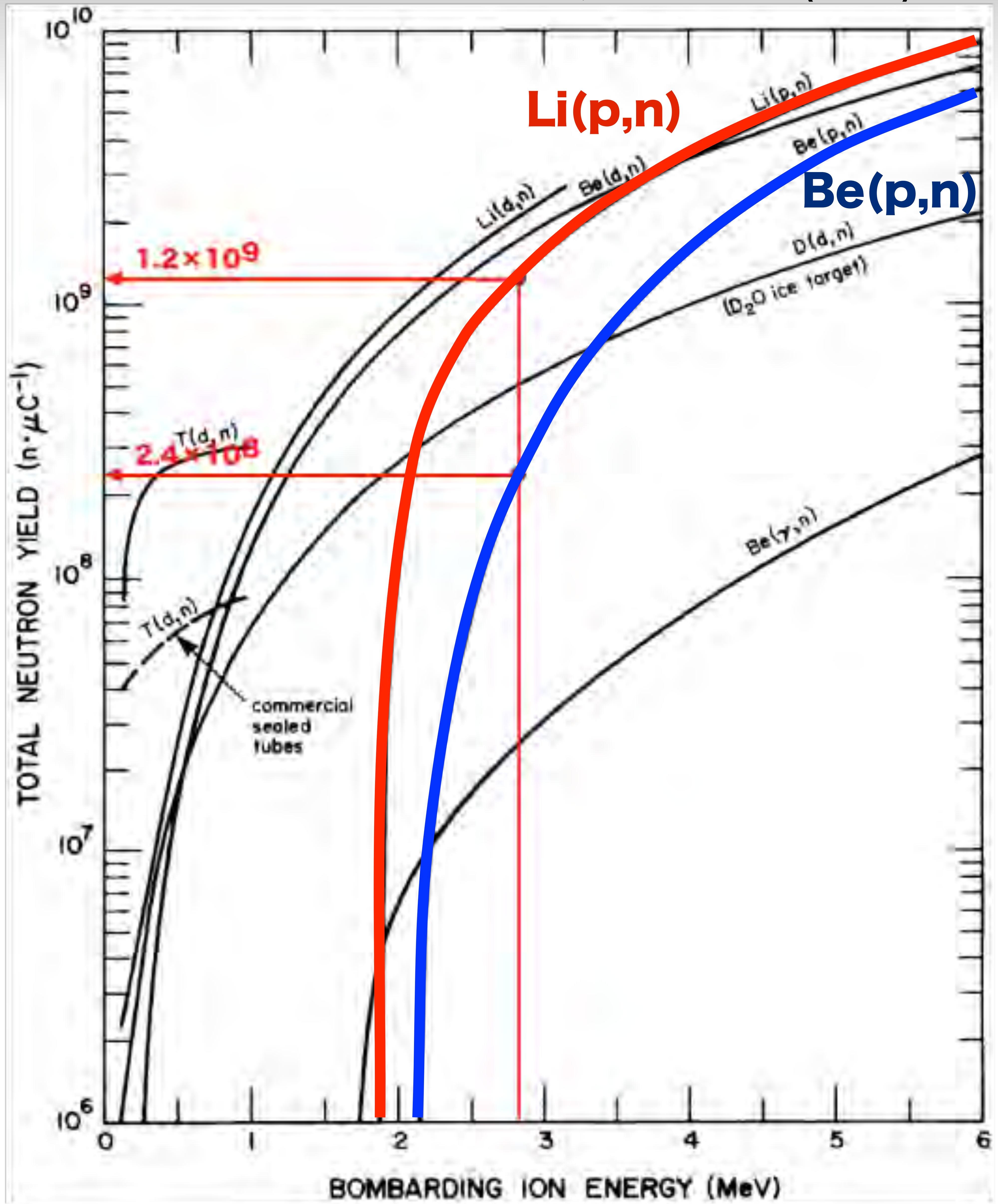


^{7}Li(p,n) ^{9}Be(p,n)

(example)
pulsed proton
E_p=13MeV, P=10kW

R.W.Hamm, SPIE 4142 (2000) 39 ←M.R.Hawkesworth, Atomic Energy Review 15 (1077) 169

IPAC18



dense heat deposit

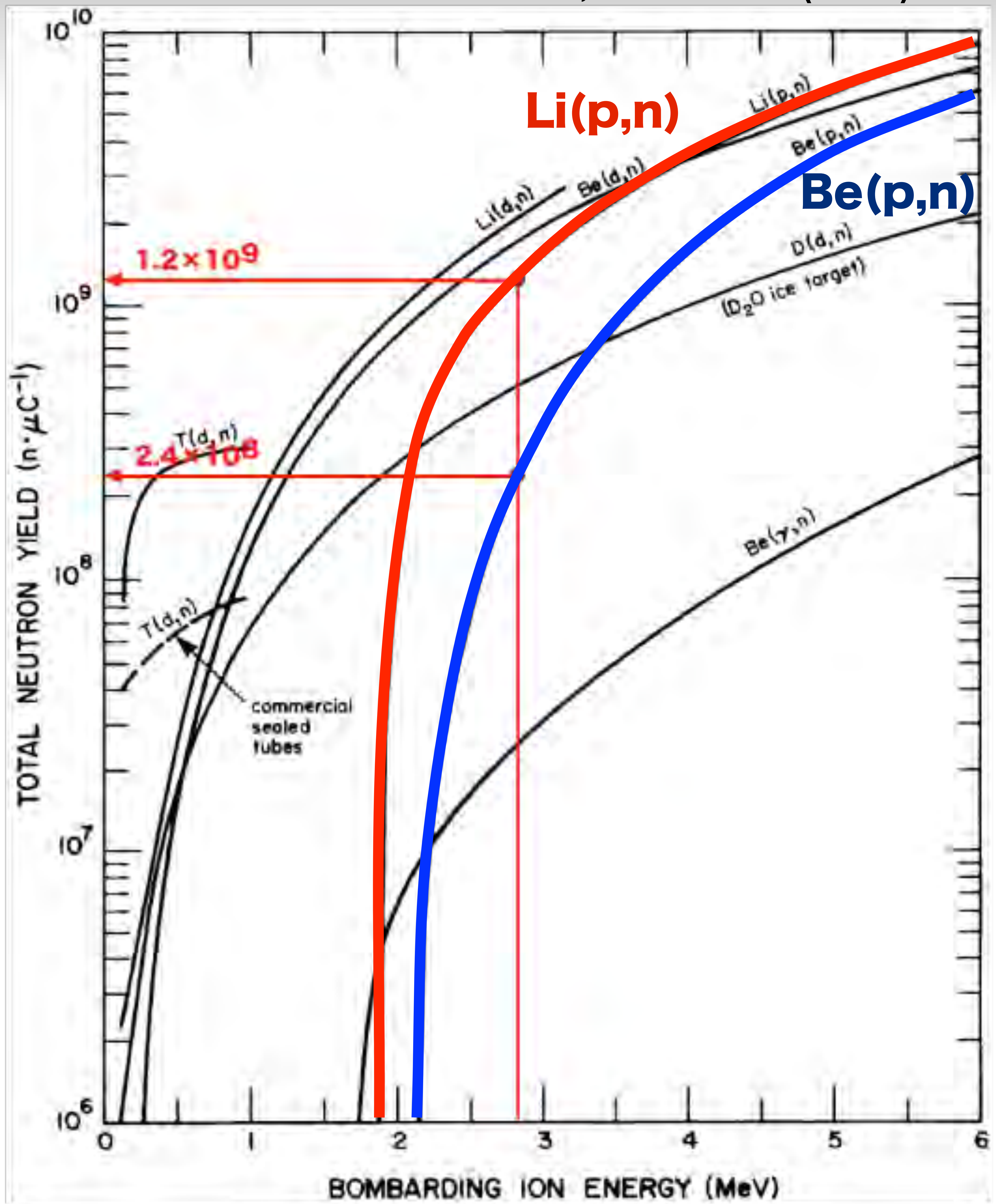
^{7}Li(p,n) ^{9}Be(p,n)

low melting point

chemical activity

blistering

(example)
pulsed proton
E_p=13MeV, P=10kW



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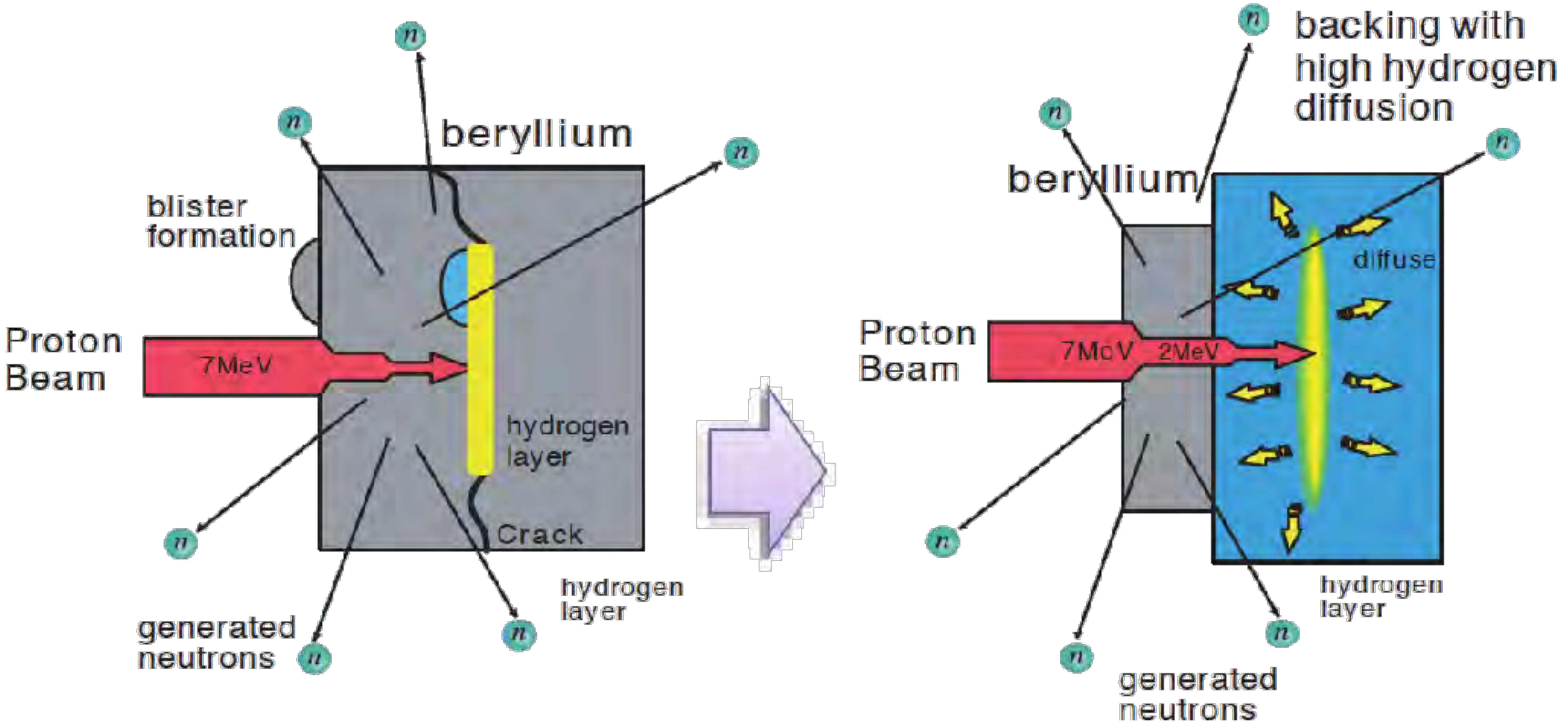

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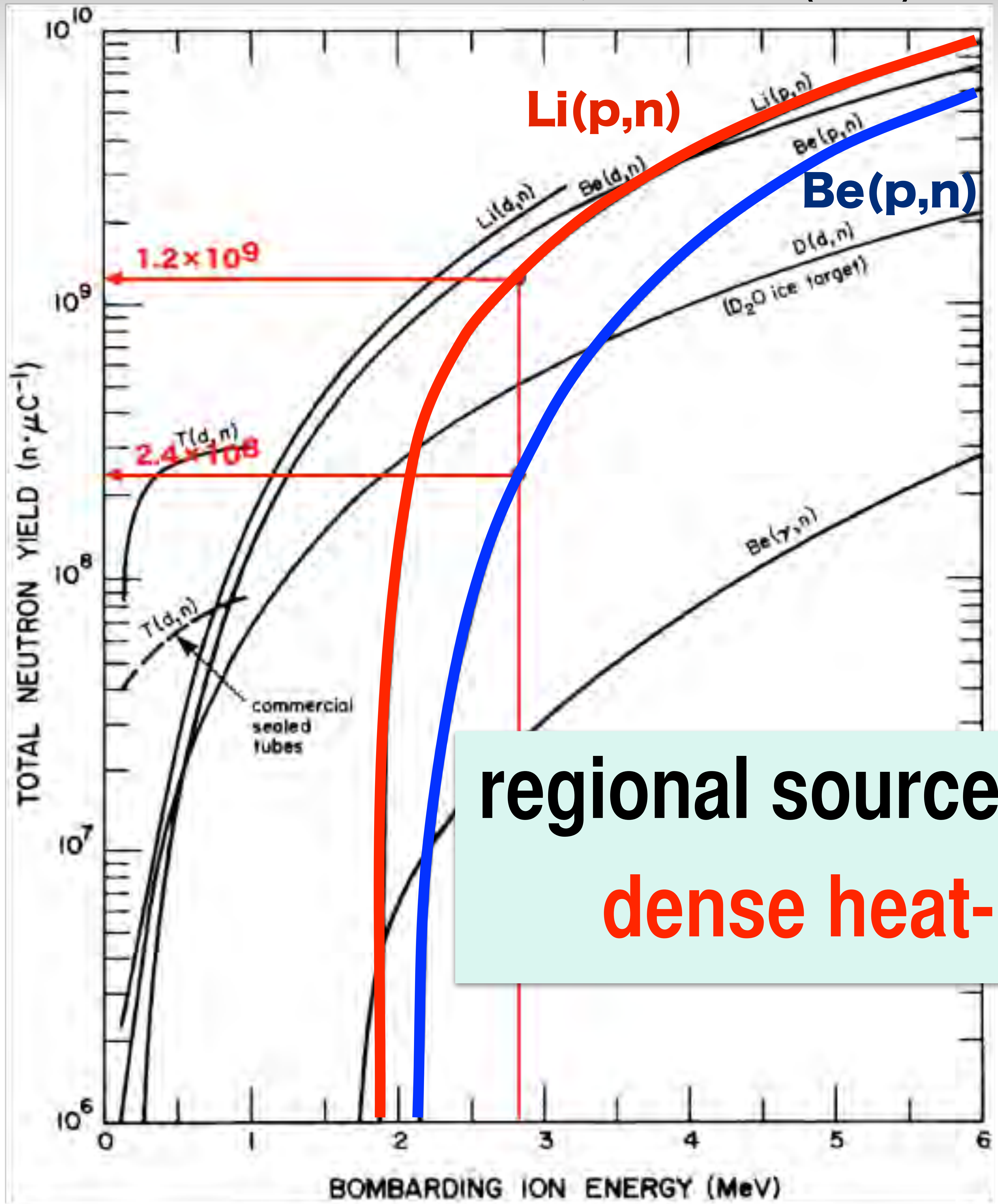

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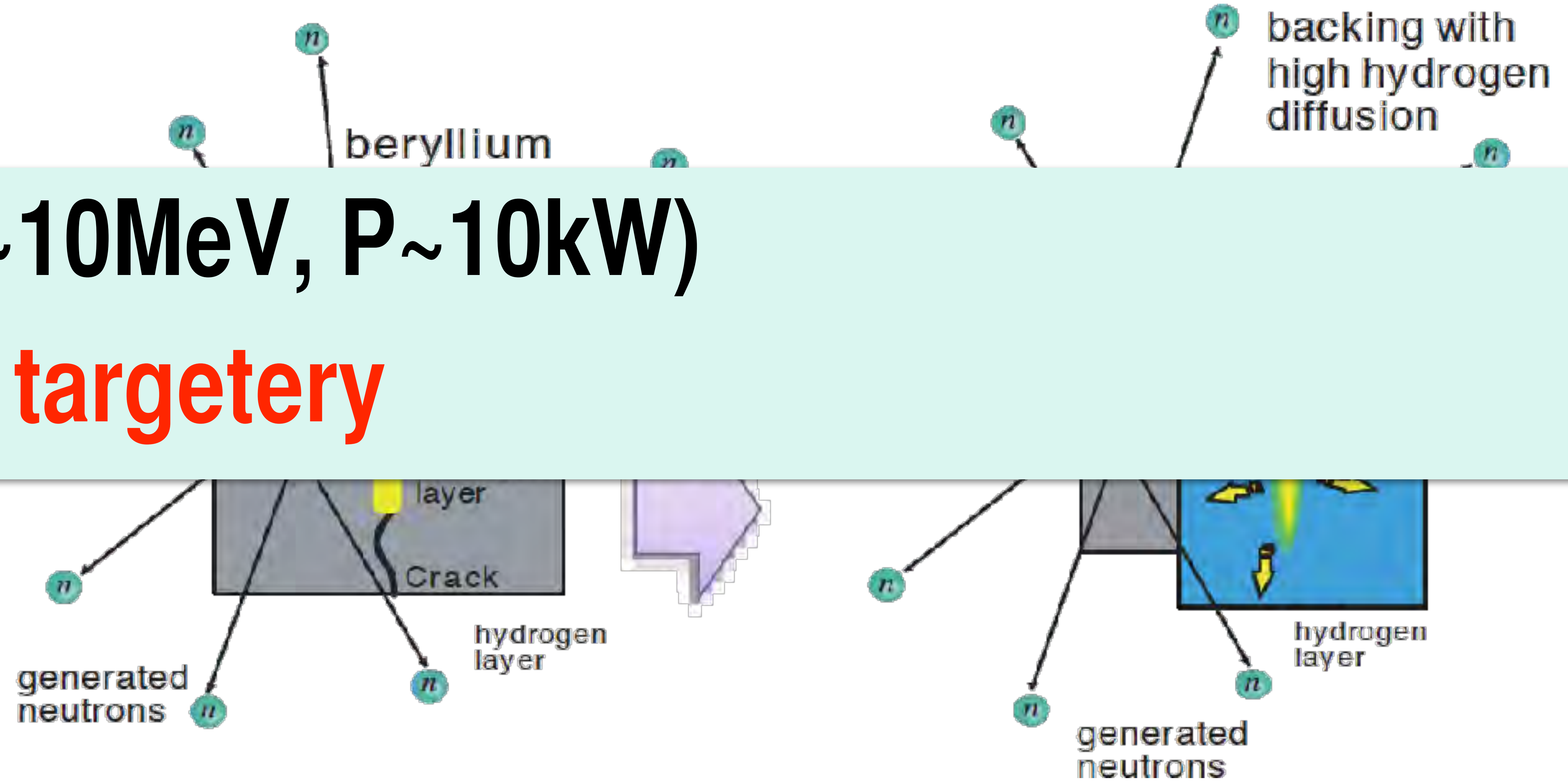
E_p=13MeV, P=10kW



regional source (E_p~10MeV, P~10kW)

dense heat-load targetery

present
front line

regional source (E_p~10MeV, P~10kW)

dense heat-load targetery

Summary

conceptual

compact accelerator-driven neutron sources (CANs)

- retail beam use for education/training
- on-demand access
- long-term occupation for innovation
- constant demands — "soft error" (secondary standard), radiography

present front line

regional source (E_p~10MeV, P~10kW)

- dense heat-load targetery

next

stable and user-friendly accelerator

- initial cost, maintenance cost, operators' skill

ご静聴ありがとうございました

숙박 경청 감사합니다.

感谢您的关注。

感謝您的關注。

Terima kasih atas perhatiannya.

ขอขอบคุณสำหรับความสนใจของคุณ.

आपकी तरह ध्यान देने के लिए धन्यवाद.

Thank you for your attention.

Gracias por su amable atención.

Danke für ihre Aufmerksamkeit.

Merci pour votre aimable attention.

Grazie per la cortese attenzione.

Благодарим вас за внимание.

Tack för din vänliga uppmärksamhet.

Köszönöm a kedves figyelmet.

Obrigado por sua amável atenção.

Kiitos ystävällisestä huomionne.