Chaires internationales de recherche Blaise Pascal

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gérée par la Fondation de l'École Normale Supérieure

The Fifth Blaise Pascal Lecture
Wednesday, March 10, 2010
Ecole Polytechnique

Photonuclear Physics

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Acknowledgments for Collaboration and advice: D. Habs, C. Barty, G. Mourou, J. Fuchs, C. Labaune, P. Mora, T. Hayakawa, R. Hajima, F. Krausz, M. Fujiwara, N. Nishimori, T. Esirkepov, S. Bulanov, W. Sandner, M. Borghesi, M. Gross, Y. Kato, A. Ogata, K. Kawase, R, Ruth, G. Wormser, J. Urakawa, N. Zamfir, D. Ursescu, K. Leddingham, P. Thirolf, N. Pietrall, J. Mizuki, S. Gales, F. Guir, Y. Fujiie, K. Homma, Y. Amano, H. Gies, T. Heinzl, R. Schuetzhold

Mountain of Radioactive Wastes of JAEA

Cleanup of the nuclear legacy
by γrays, we see and control nuclei

Nuclear Waste Unidentified

Handled by hand individually at this time
→ estimated cost $20B for JAEA, $200B for Japan

(JAEA)

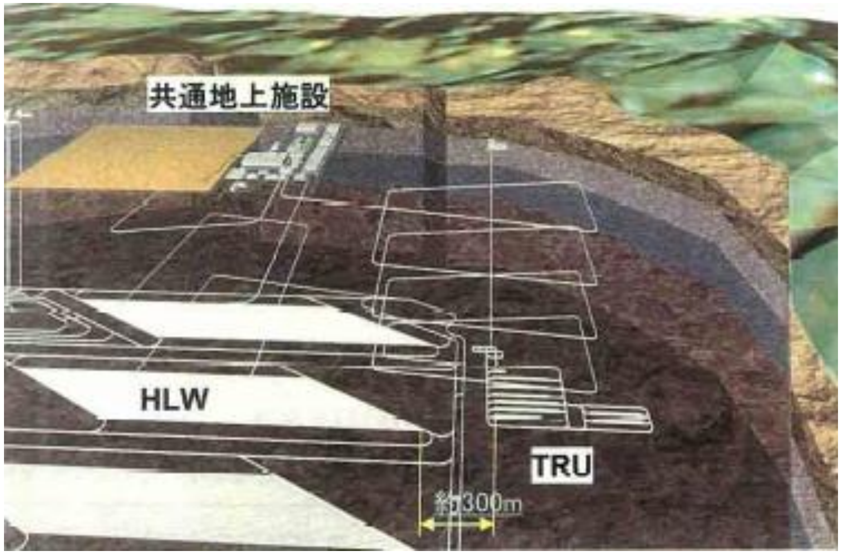
Germans move radioactive barrels

Long neglected ‘toilet side’ of nuclear energy, in contrast to its production (‘kitchen side’)

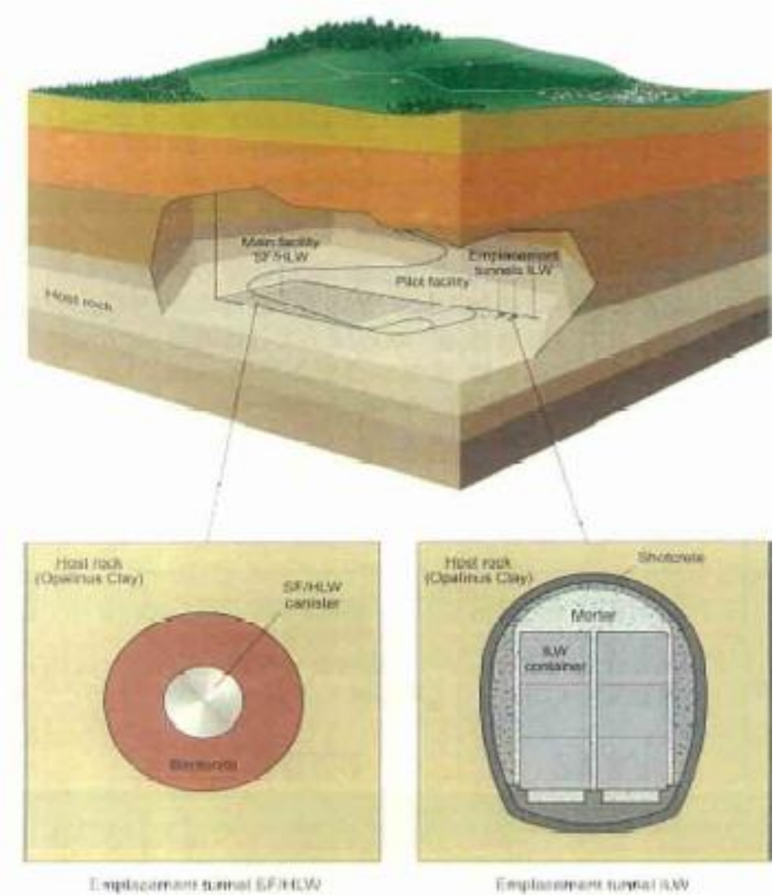
We need science (brain) of how to handle this; not just management (muscle)

Disposal of Nuclear Waste

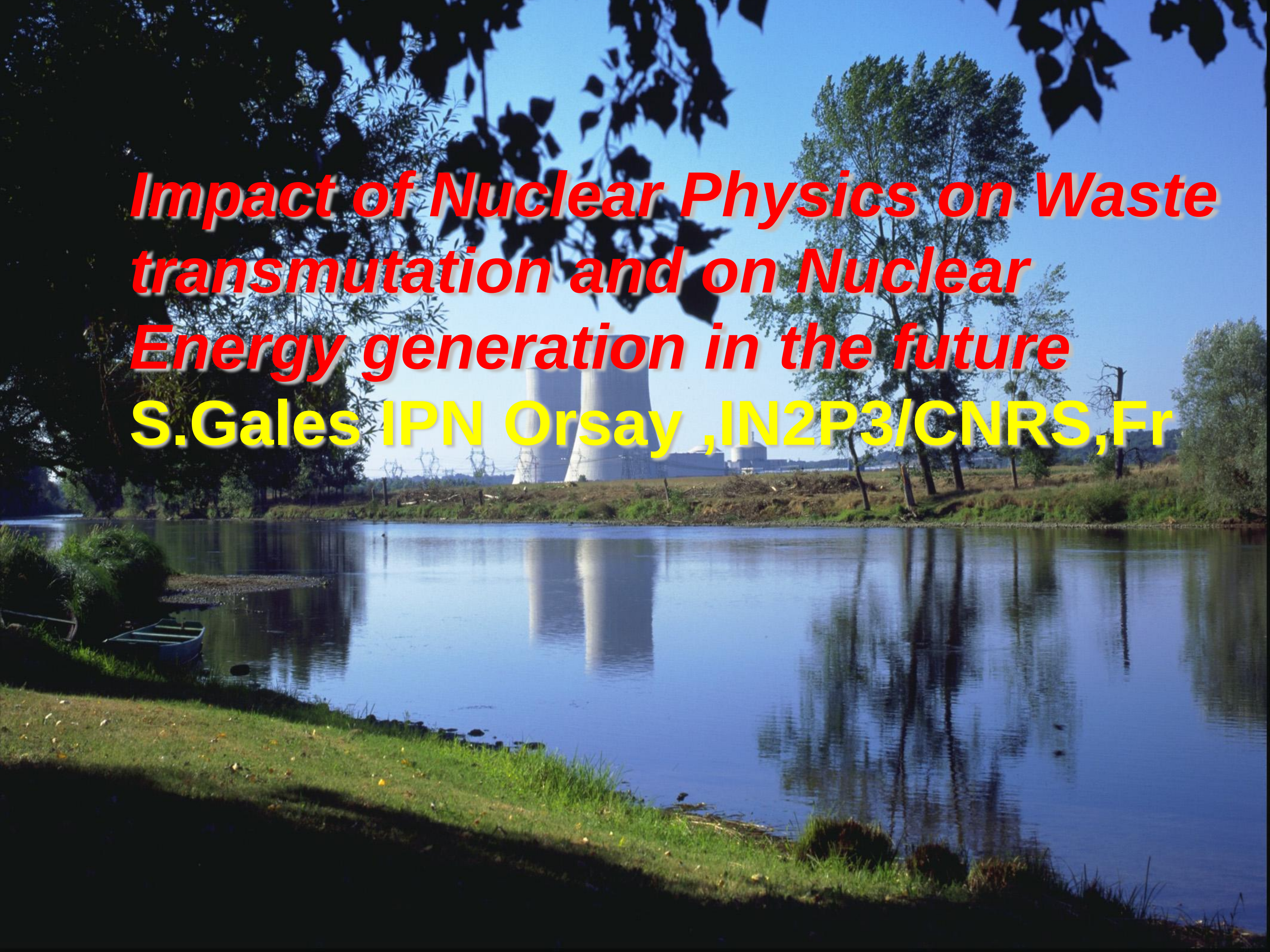
Underground burying



(Japan)



(Switzerland)



Impact of Nuclear Physics on Waste transmutation and on Nuclear Energy generation in the future

S.Gales IPN Orsay ,IN2P3/CNRS,Fr

Management of Nuclear waste:
Nuclear Data for Hybrid Reactors

(Gales)

Subcritical reactors:
- specific data, reactions induced by n or p,Fission,capture,residues,..
- Innovative fuels (Th,Am, Cm, …)

0.1 eV **20 MeV** **1 GeV**

Critical reactors

Subcritical reactors

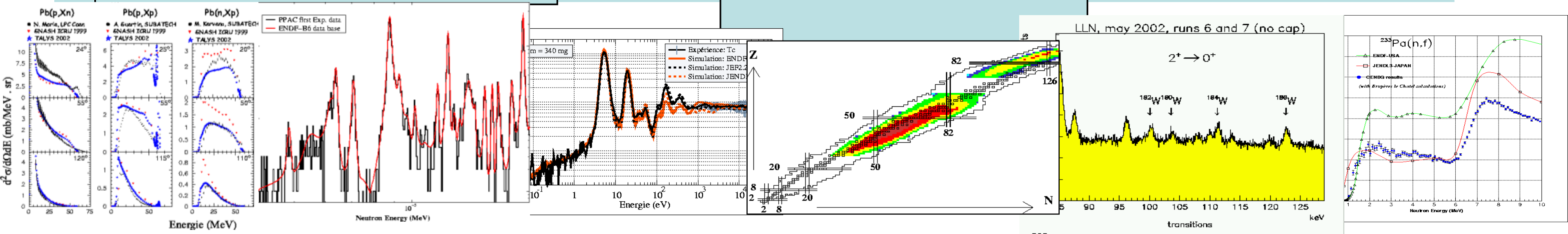
n-ToF CERN, thorium cycle, (n,fission), (n,xn)

VDG CENBG,
Tandem ORSAY,
thorium cycle,
(n,fission), (n,

GELINA Geel
(n,γ), fission products
transmutation (^{129}I)
(n,xn) thorium cycle

Louvain-la-Neuve
Uppsala, Groningen,
(n,xclp), (p,xn),
(p,xclp), Fe, Pb, U

GSI Darmstadt,
spallation residues,
inverse kinematics,
p + Fe, Xe, Pb, U



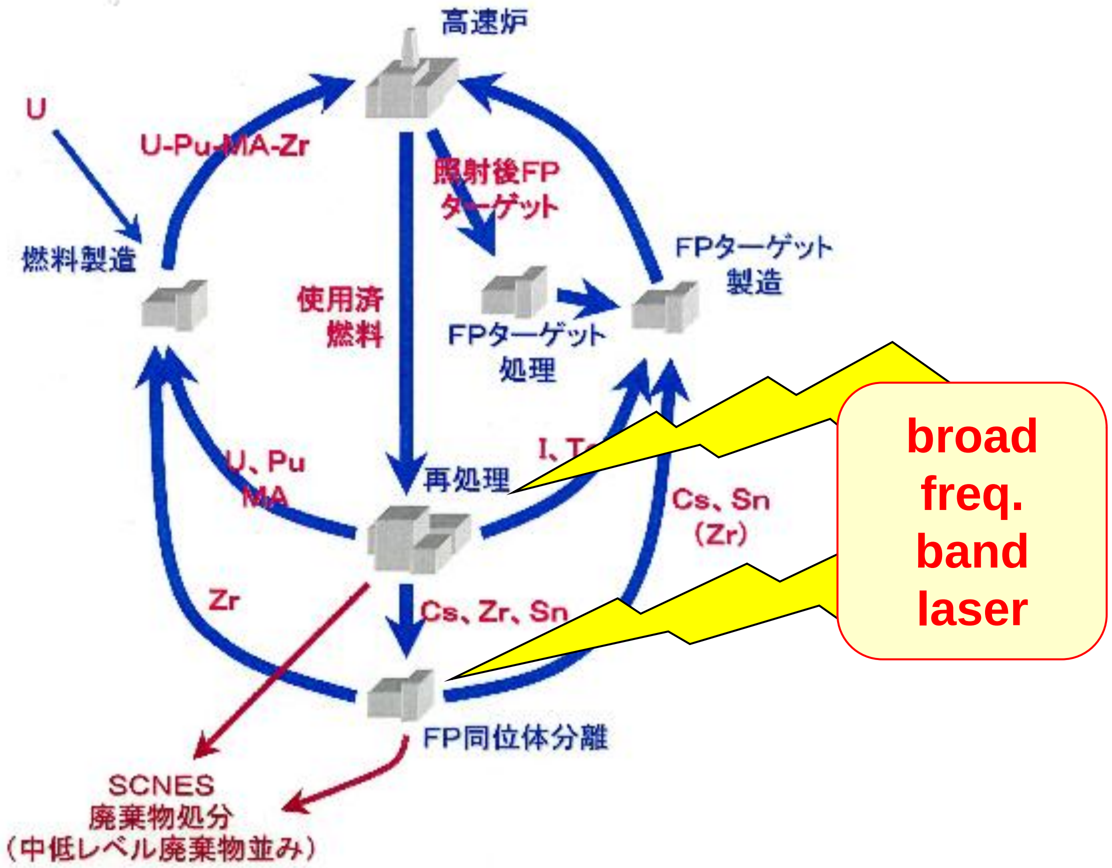
Some Conclusions

(Gales)

- *Nuclear energy does not appear any more to be a solved technical question*
  - *Overall (societal, economic) boundary conditions have evolved significantly since 1980 and will still do so in future*
  - *Innovation is and will be required . Evaluation of nuclear risk need more scientific input (not only though)!!*
  - **Basic research can contribute via :**
  - **Specific competences (improved data, accelerators, MC simulation)**
  - **More open approach to nuclear science (less short-term economically and technologically driven) ,multidiscip….**
  - **Basic training and formation**
- **Synergies exist with some basic science goals**
  - **Ex : Japan Joint Project, NSS,RIBF,ν beams , Accelerator target, Simulation…..**
- ***Academia via its competence and its independence can provide a unique contribution to the future of nuclear energy.***

Atomic Energy System Cyclable with Little Waste

Yoichi Fujiie (former Commissar, AEC of Japan: ‘Self-Contained Nuclear Energy System（ＳＣＮＥＳ）’



broad freq. band laser

Introduction of short-pulsed laser

laser quantum control

Invention of new time-domain separation/extraction of radioisotopes

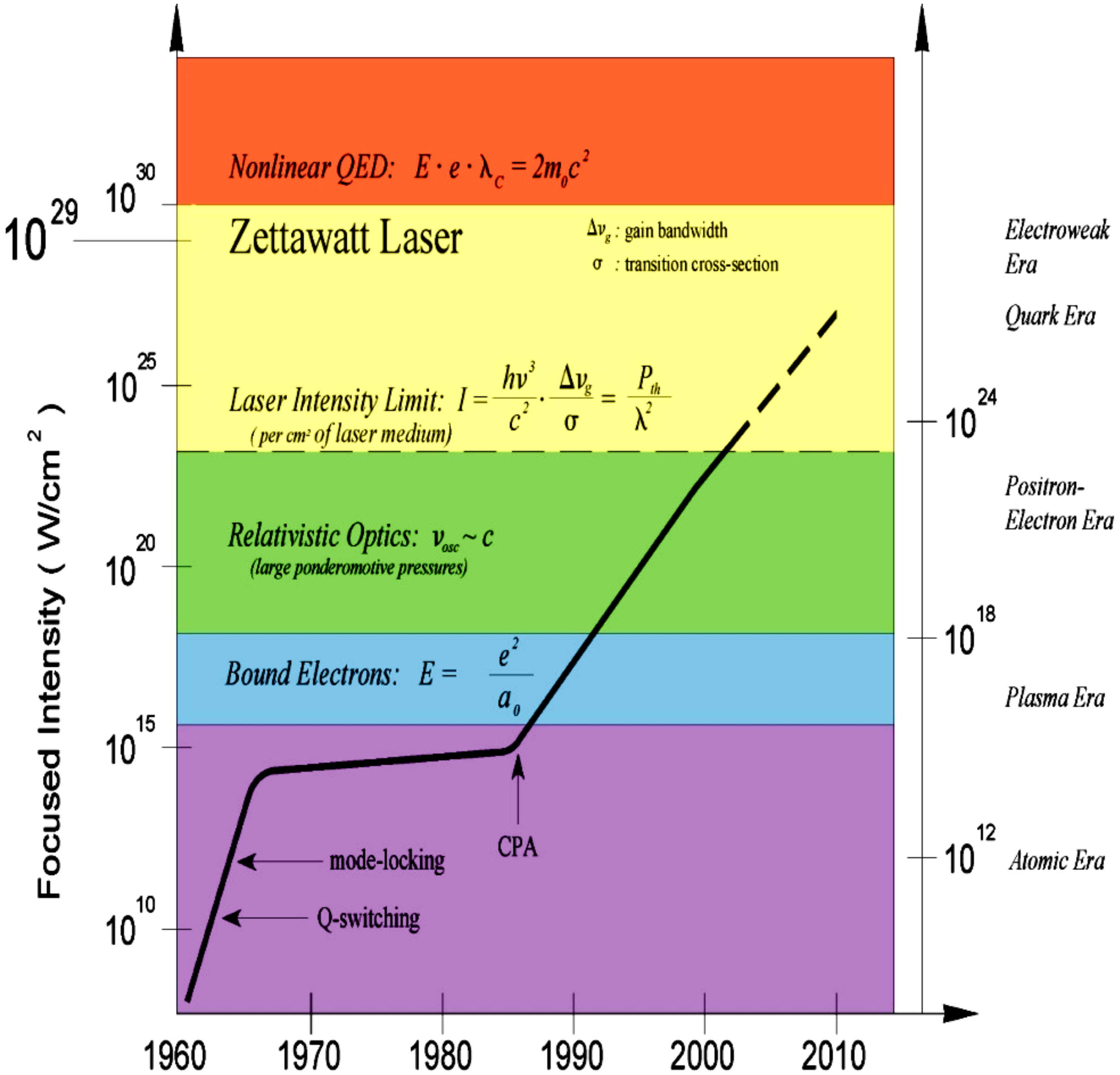
H. Yamada, K. Yokoyama, et al, Phy. Rev. A 72, 063404(2005)

- reprocessing of spent fuel
- treatment of **radioactive wastes**

large quantity of photons necessary

Atomic energy is ‘alchemistry’
Energy extracted through the ‘alchemistry’ process
We wish to put out only cyclable elements thru ‘alchemistry’

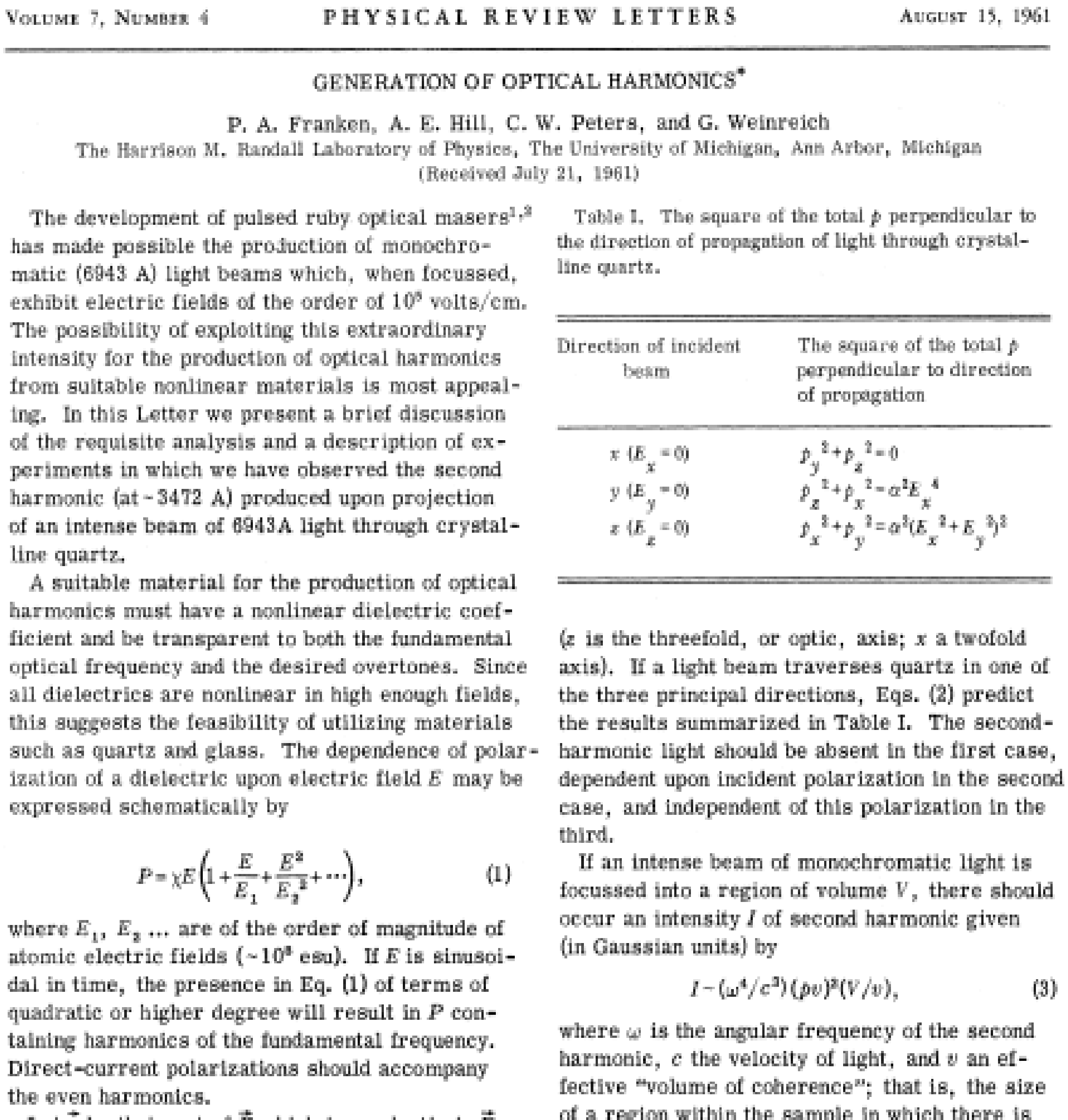
Lasers



(Tajima,Mourou,2002)

First Nonlinear Optics Work after Laser Invention

1961
by Franken et al.



VOLUME 7, NUMBER 4 PHYSICAL REVIEW LETTERS AUGUST 15, 1961

GENERATION OF OPTICAL HARMONICS*

P. A. Franken, A. E. Hill, C. W. Peters, and G. Weinreich
The Harrison M. Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan
(Received July 21, 1961)

The development of pulsed ruby optical masers[1,2] has made possible the production of monochromatic (6943 A) light beams which, when focussed, exhibit electric fields of the order of 10^5 volts/cm. The possibility of exploiting this extraordinary intensity for the production of optical harmonics from suitable nonlinear materials is most appealing. In this Letter we present a brief discussion of the requisite analysis and a description of experiments in which we have observed the second harmonic (at ~3472 A) produced upon projection of an intense beam of 6943A light through crystalline quartz.

A suitable material for the production of optical harmonics must have a nonlinear dielectric coefficient and be transparent to both the fundamental optical frequency and the desired overtones. Since all dielectrics are nonlinear in high enough fields, this suggests the feasibility of utilizing materials such as quartz and glass. The dependence of polarization of a dielectric upon electric field E may be expressed schematically by

$$P=\chi E\left(1+\frac{E}{E_1}+\frac{E^2}{E_2{}^2}+\cdots\right), \qquad (1)$$

where E_1, E_2 ... are of the order of magnitude of atomic electric fields (~10^8 esu). If E is sinusoidal in time, the presence in Eq. (1) of terms of quadratic or higher degree will result in P containing harmonics of the fundamental frequency. Direct-current polarizations should accompany the even harmonics.

Table I. The square of the total p perpendicular to the direction of propagation of light through crystalline quartz.

Direction of incident beam	The square of the total p perpendicular to direction of propagation
x $(E_x=0)$	$p_y{}^2+p_z{}^2=0$
y $(E_y=0)$	$p_z{}^2+p_x{}^2=\alpha^2E_x{}^4$
z $(E_z=0)$	$p_x{}^2+p_y{}^2=\alpha^2(E_x{}^2+E_y{}^2)^2$

(z is the threefold, or optic, axis; x a twofold axis). If a light beam traverses quartz in one of the three principal directions, Eqs. (2) predict the results summarized in Table I. The second-harmonic light should be absent in the first case, dependent upon incident polarization in the second case, and independent of this polarization in the third.

If an intense beam of monochromatic light is focussed into a region of volume V, there should occur an intensity I of second harmonic given (in Gaussian units) by

$$I\sim(\omega^4/c^3)(pv)^2(V/v), \qquad (3)$$

where ω is the angular frequency of the second harmonic, c the velocity of light, and v an effective "volume of coherence"; that is, the size of a region within the sample in which there is

First textbook on
Nonlinear optics
by Bloembergen
in 1965

What γ beam brings in to nuclear physics

- Rutherford approach (collider and particle beam)

high momentum penetrates deep interior of matter and scatters,

sees smallest detail of matter

$\lambda/a \leq 1$ (λ, a are probe and target sizes)

- ‘laser’ (and γ beam) approach

photon beam penetrates, but

not local real space structure,

excites the structure, induces

dynamics and spectroscopy,

possibly controls

$\lambda/a \sim 10^4$ (both for atoms and nuclei)

γ beam revolution of *nuclear physics*:

similar to laser revolution of *atomic physics* in’60s

γrays: opens new nuclear physics

-measurement of neutron cross section of rare nuclei by inverse process of (γ,n)

-*nuclear resonance fluorescence* and *spectroscopy*

-particular excitation

  *nuclear electroweak excitation such as parity measurement

  *isomer creation

  *particular excitation and interaction with inner-shell electrons

-manipulation of nuclei by more than one gamma pulse

  *consecutive excitation to higher levels

  *exploration of exotic nuclear states?

  *quantum control of nuclear states

-polarized positrons

-non-contact and fast detection of nuclear materials

-monitoring of nuclear reprocessing

-transmutation of nuclei with small neutron cross section

-materials research with nuclear resonance, Moessbauer

-cold neutron beam generation, etc. etc.

Dawn of Photonuclear Physics:

similar to the eve of the laser invention, spawning new atomic physics

Beginning of Photonuclear Physics International Work (Kizu,2006,-)

“2nd US-Japan Nuclear Photo-Science Workshop

Purple Orchid Inn, Livermore, July 26-27, 2007

- Opening Remarks, C.P.J. Barty (LLNL)

Presentations

- Nonlinear Thomson and JAEA interest, T. Tajima (JAEA)
- Energy Recovery Linacs (ERLs), N. Nishimori (JAEA)
- T-REX Status, C. Barty (LLNL)
- …..**”**

Now, -US-Japan governments seriously considering research on this subject

-IAEA

-ELI Nuclear Pillar

Can Laser Save (Help) Nuclear Energy?

- Challenge: to *safely* and *economically* identify and reduce nuclear waste
- Efficient Generation of High-Fluence Gamma Rays
- Accurate and safe detection and identification of isotopes
- Efficient Separation of bad nuclei
- Nuclear Transmutation of selected nuclei, e.g. I
- Is there a niche for laser?

NUCLEAR ENERGY :GLOBAL FACTS

A rather Young form of energy, of limited importance at the world level (7%),economically viable source of electricity (320GWe.y,16%)

Production concentrated in a few countries

(USA+FR+J)= 2/3 of the world

A passionately contested energy for

Its origin related to defense,

Its cost structure (high investments ,delayed returns)

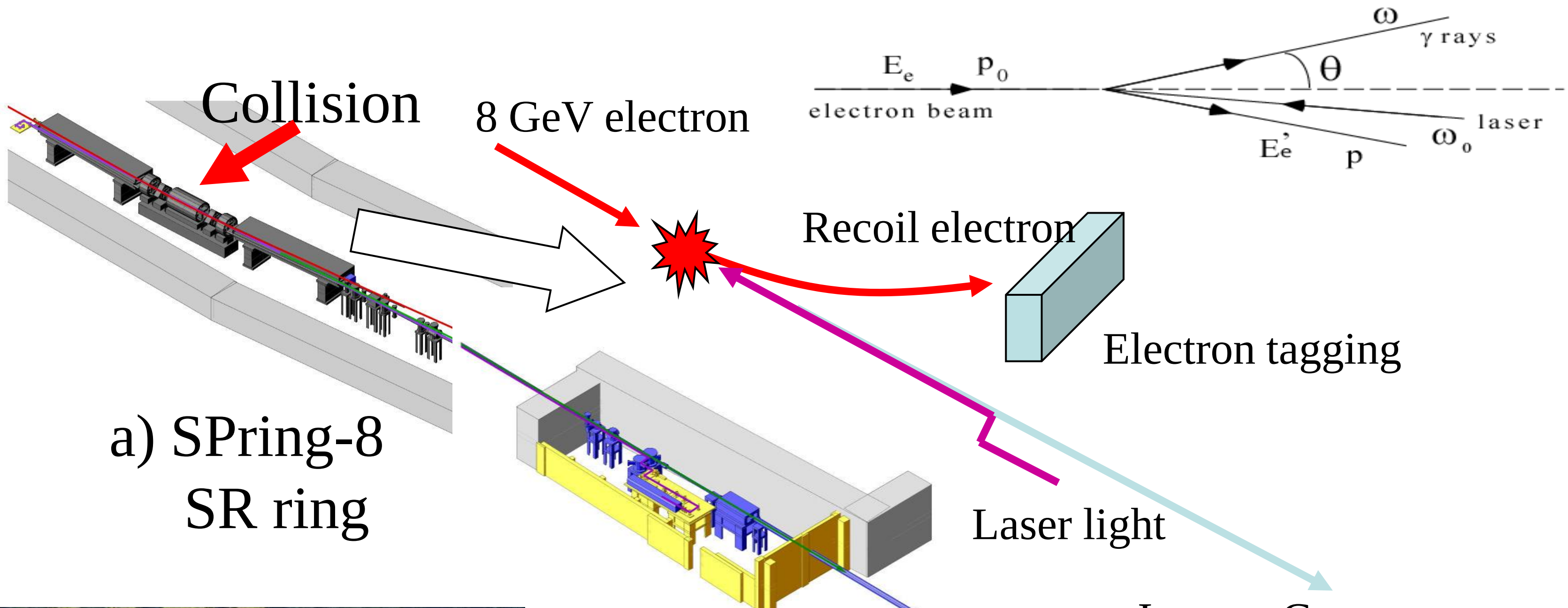
Questions insufficiently dealt with in the past

Proliferation (Pu mostly)

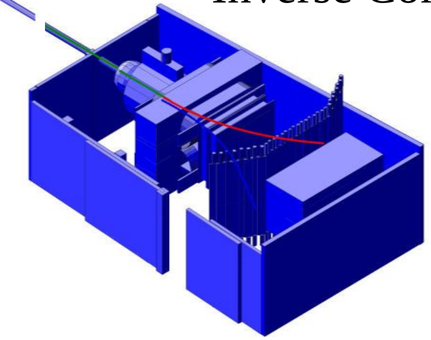
Nuclear waste management

These questions generate social concerns for the future

LEPS facility @Spring-8



laser hutch

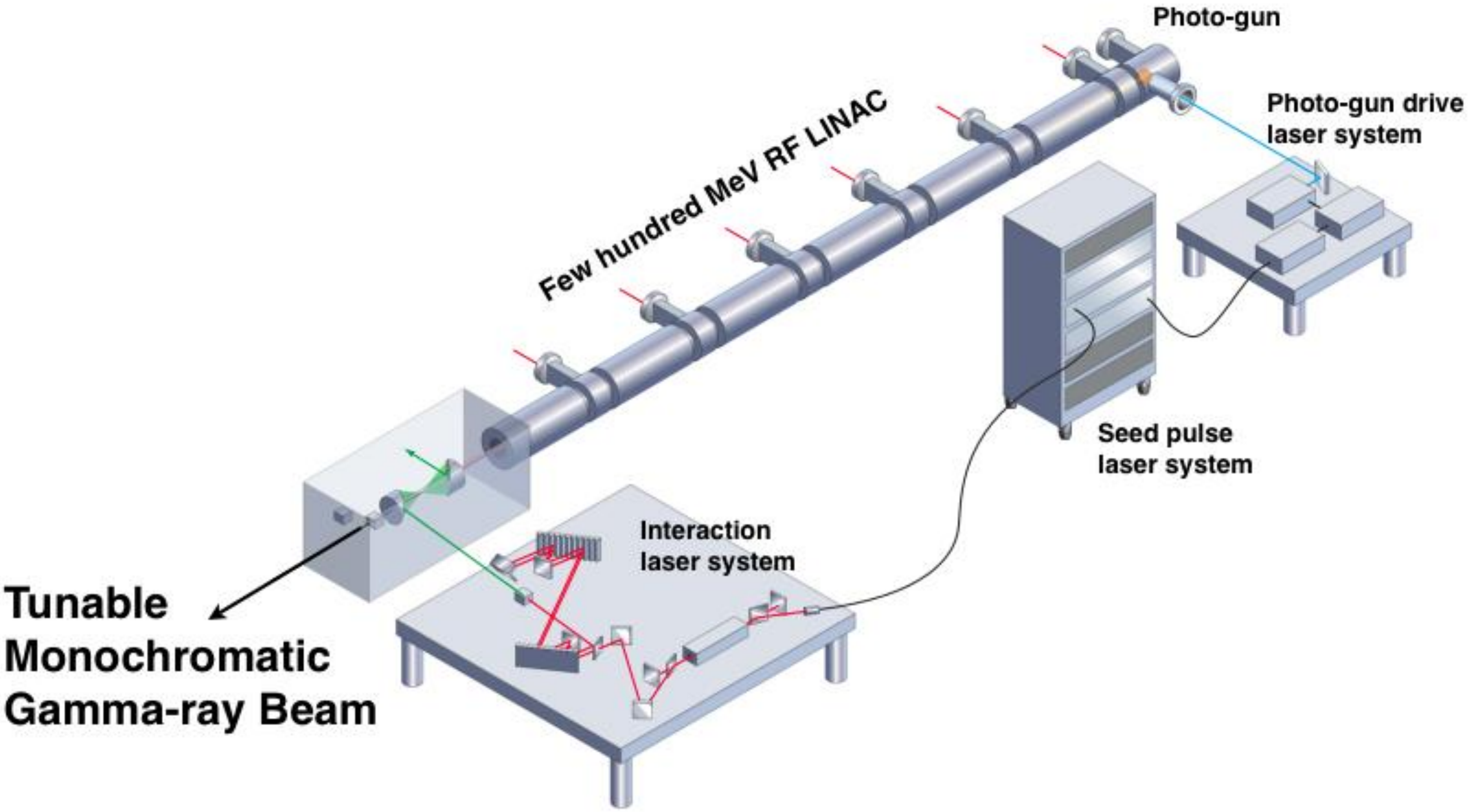


c) experimental hutch

RCNP、JAERI、JASRI collaboration

LLNL MEGAray Compton Source

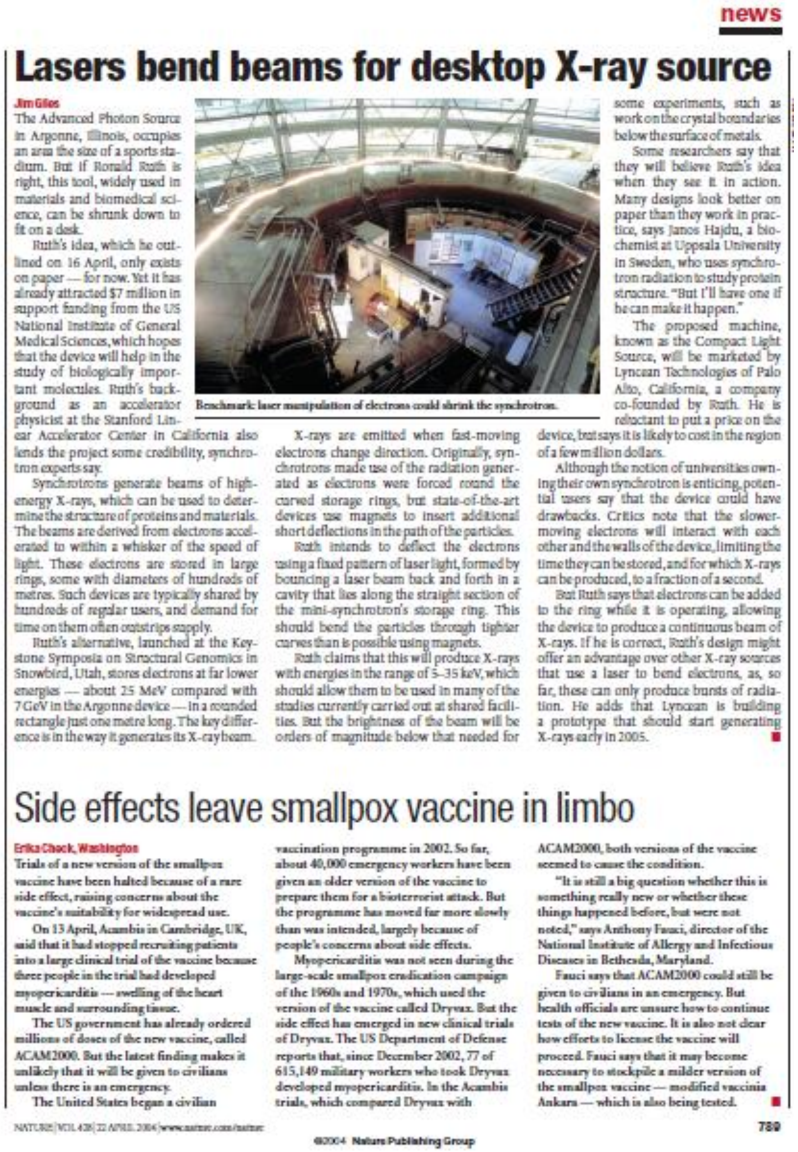
Mono-energetic Gamma rays



(C. Barty)

Table-top Synchrotron Laser Compton Source

Lyncean(Professor
Ron Ruth,SLAC)



news

Lasers bend beams for desktop X-ray source

Jim Giles

The Advanced Photon Source in Argonne, Illinois, occupies an area the size of a sports stadium. But if Ronald Ruth is right, this tool, widely used in materials and biomedical science, can be shrunk down to fit on a desk.

Ruth's idea, which he outlined on 16 April, only exists on paper — for now. Yet it has already attracted $7 million in support funding from the US National Institute of General Medical Sciences, which hopes that the device will help in the study of biologically important molecules. Ruth's background as an accelerator physicist at the Stanford Linear Accelerator Center in California also lends the project some credibility, synchrotron experts say.

Synchrotrons generate beams of high-energy X-rays, which can be used to determine the structure of proteins and materials. The beams are derived from electrons accelerated to within a whisker of the speed of light. These electrons are stored in large rings, some with diameters of hundreds of metres. Such devices are typically shared by hundreds of regular users, and demand for time on them often outstrips supply.

Ruth's alternative, launched at the Keystone Symposia on Structural Genomics in Snowbird, Utah, stores electrons at far lower energies — about 25 MeV compared with 7 GeV in the Argonne device — in a rounded rectangle just one metre long. The key difference is in the way it generates its X-ray beam.

X-rays are emitted when fast-moving electrons change direction. Originally, synchrotrons made use of the radiation generated as electrons were forced round the curved storage rings, but state-of-the-art devices use magnets to insert additional short deflections in the path of the particles.

Ruth intends to deflect the electrons using a fixed pattern of laser light, formed by bouncing a laser beam back and forth in a cavity that lies along the straight section of the mini-synchrotron's storage ring. This should bend the particles through tighter curves than is possible using magnets.

Ruth claims that this will produce X-rays with energies in the range of 5–35 keV, which should allow them to be used in many of the studies currently carried out at shared facilities. But the brightness of the beam will be orders of magnitude below that needed for some experiments, such as work on the crystal boundaries below the surface of metals.

Some researchers say that they will believe Ruth's idea when they see it in action. Many designs look better on paper than they work in practice, says Janos Hajdu, a biochemist at Uppsala University in Sweden, who uses synchrotron radiation to study protein structure. "But I'll have one if he can make it happen."

The proposed machine, known as the Compact Light Source, will be marketed by Lyncean Technologies of Palo Alto, California, a company co-founded by Ruth. He is reluctant to put a price on the device, but says it is likely to cost in the region of a few million dollars.

Although the notion of universities owning their own synchrotron is enticing, potential users say that the device could have drawbacks. Critics note that the slower-moving electrons will interact with each other and the walls of the device, limiting the time they can be stored, and for which X-rays can be produced, to a fraction of a second.

But Ruth says that electrons can be added to the ring while it is operating, allowing the device to produce a continuous beam of X-rays. If he is correct, Ruth's design might offer an advantage over other X-ray sources that use a laser to bend electrons, as, so far, these can only produce bursts of radiation. He adds that Lyncean is building a prototype that should start generating X-rays early in 2005. ■

Benchmark: laser manipulation of electrons could shrink the synchrotron.

Side effects leave smallpox vaccine in limbo

Erika Check, Washington

Trials of a new version of the smallpox vaccine have been halted because of a rare side effect, raising concerns about the vaccine's suitability for widespread use.

On 13 April, Acambis in Cambridge, UK, said that it had stopped recruiting patients into a large clinical trial of the vaccine because three people in the trial had developed myopericarditis — swelling of the heart muscle and surrounding tissue.

The US government has already ordered millions of doses of the new vaccine, called ACAM2000. But the latest finding makes it unlikely that it will be given to civilians unless there is an emergency.

The United States began a civilian vaccination programme in 2002. So far, about 40,000 emergency workers have been given an older version of the vaccine to prepare them for a bioterrorist attack. But the programme has moved far more slowly than was intended, largely because of people's concerns about side effects.

Myopericarditis was not seen during the large-scale smallpox eradication campaign of the 1960s and 1970s, which used the version of the vaccine called Dryvax. But the side effect has emerged in new clinical trials of Dryvax. The US Department of Defense reports that, since December 2002, 77 of 615,149 military workers who took Dryvax developed myopericarditis. In the Acambis trials, which compared Dryvax with ACAM2000, both versions of the vaccine seemed to cause the condition.

"It is still a big question whether this is something really new or whether these things happened before, but were not noted," says Anthony Fauci, director of the National Institute of Allergy and Infectious Diseases in Bethesda, Maryland.

Fauci says that ACAM2000 could still be given to civilians in an emergency. But health officials are unsure how to continue tests of the new vaccine. It is also not clear how efforts to license the vaccine will proceed. Fauci says that it may become necessary to stockpile a milder version of the smallpox vaccine — modified vaccinia Ankara — which is also being tested. ■

NATURE | VOL 428 | 22 APRIL 2004 | www.nature.com/nature

789

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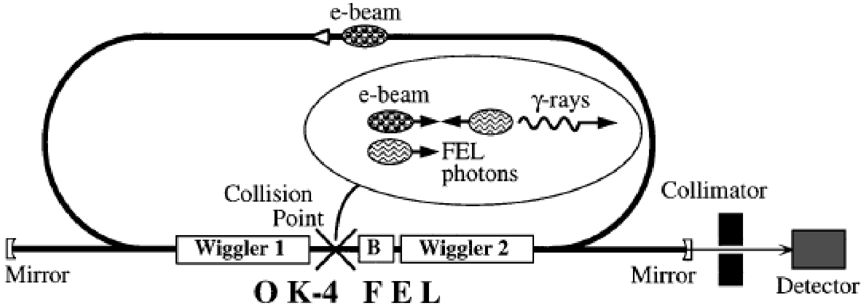
MeV LCS Facilities

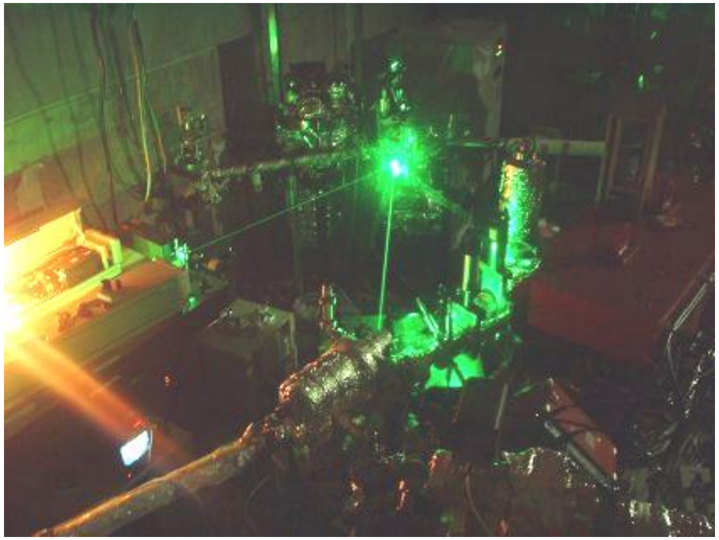
HIGGS facility, Duke University (US)
FEL+electrons



V. N. Litvinenko, PRL, 1997

- Energy 5~20MeV ?
- 10^7 photons/s: high flux
- dE/E is very sharp
- Good S/N ratio

AIST TERAS (Japan)

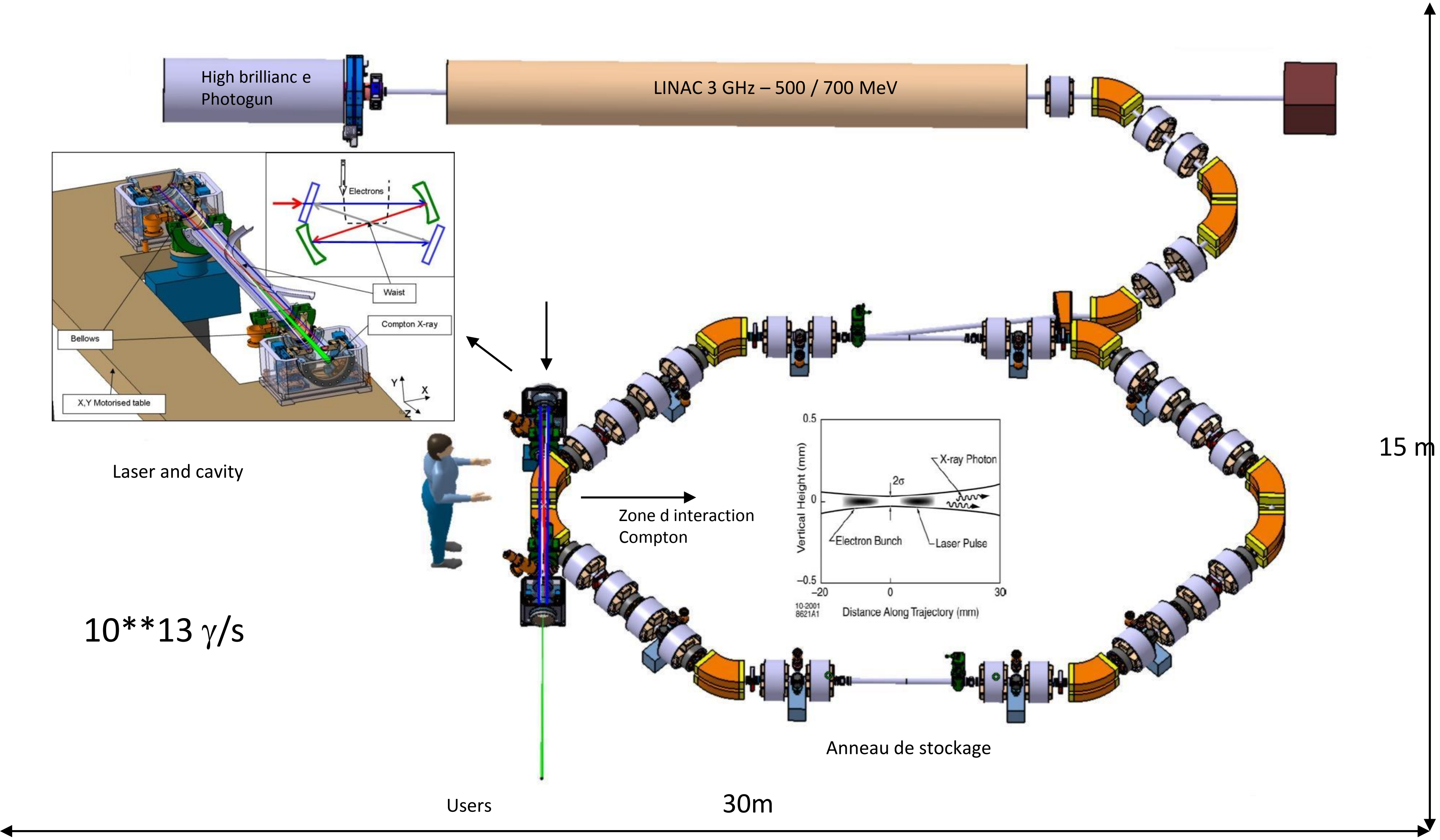


Nd/YVO_4 Laser + electrons in storage ring

- Energy 5~50 MeV
- 10^4 photons/MeV/s

However, the flux is too small to be used as the NRF assay method.

Detailed layout of the **THomX** machine



High brillianc e Photogun

LINAC 3 GHz – 500 / 700 MeV

Laser and cavity

Zone d interaction Compton

Anneau de stockage

Users

30m

15 m

10**13 γ/s

(G. Wormser)

JAEA concept of a high-flux γ-ray source

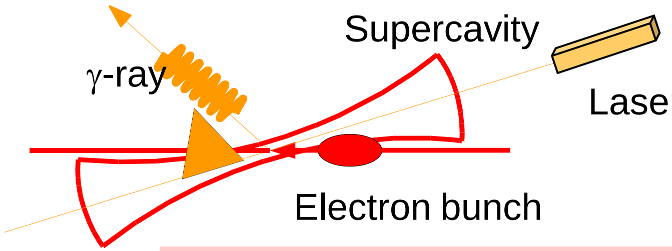
flux of LC γ-ray

$$F = \frac{f N_e N_L \sigma_C}{A}$$

f	collision frequency
N_e	number of electrons
N_L	number of laser photons
σ_C	scattering cross-section
A	effective sectional area

we need high repetition, tightly focused, high power, high current beams.

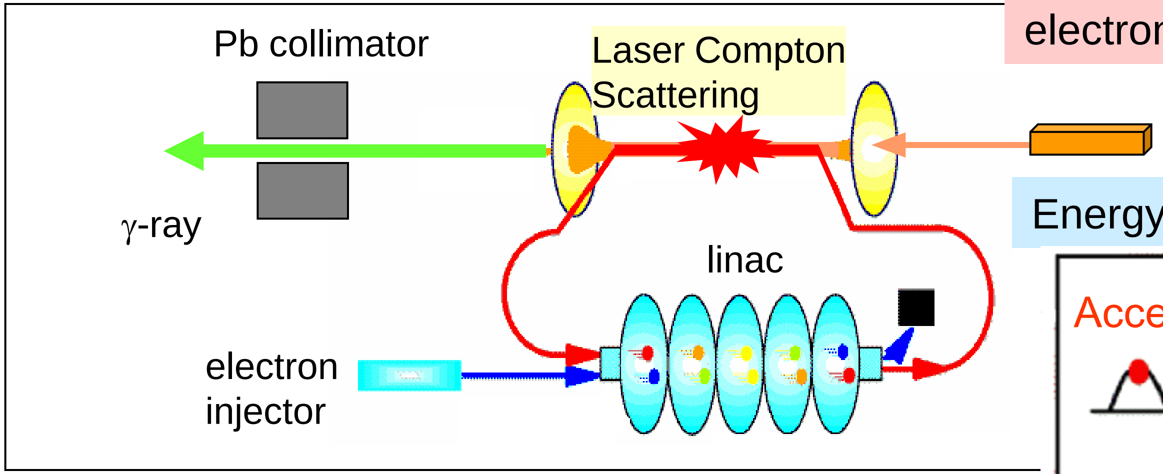
laser super cavity



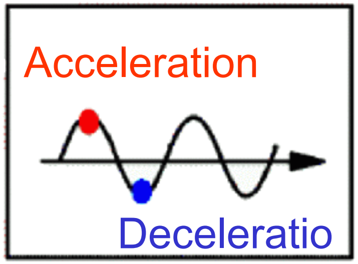
laser photons are recycled

high-flux γ-ray is available.

electron energy is recycled



Energy Recovery Linac



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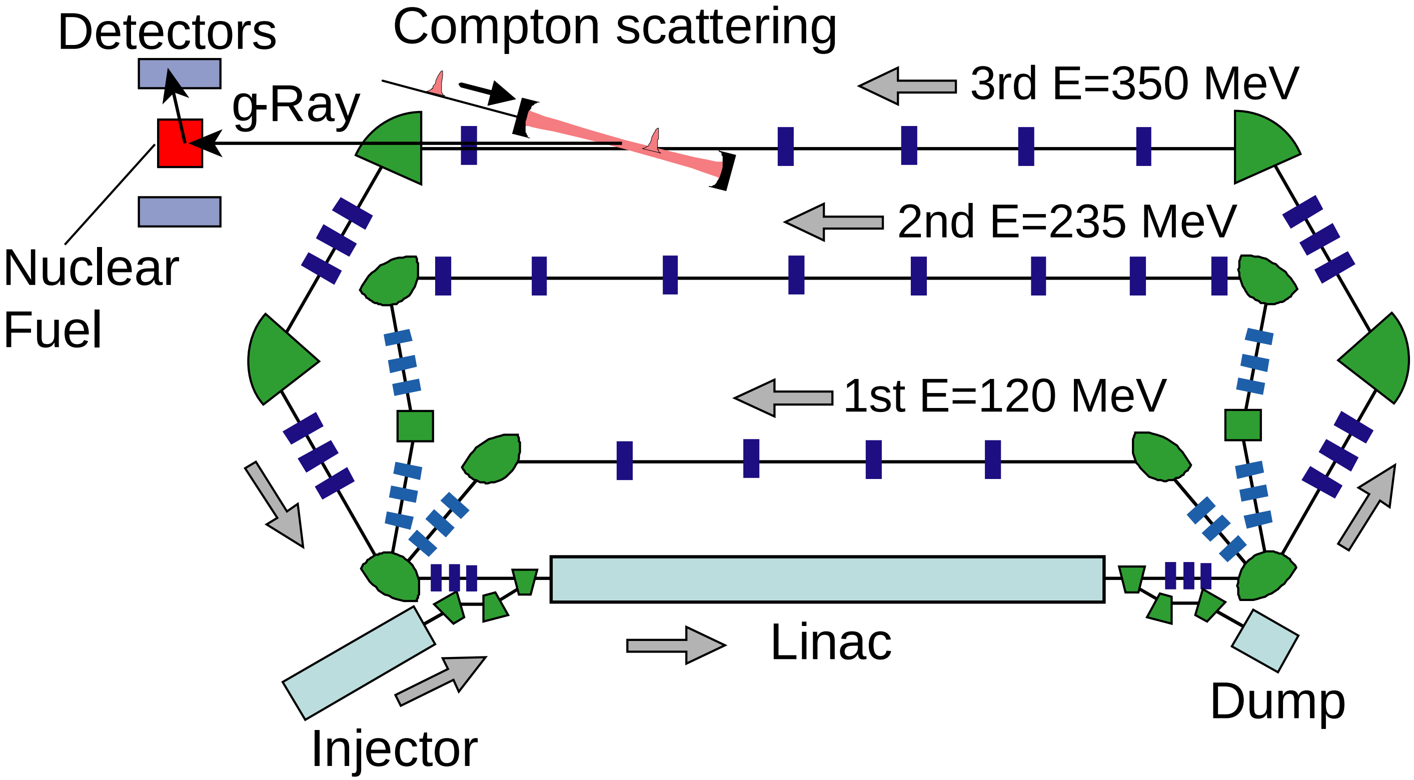
Proposal of a High-flux γ-ray source with a 3-loop ERL

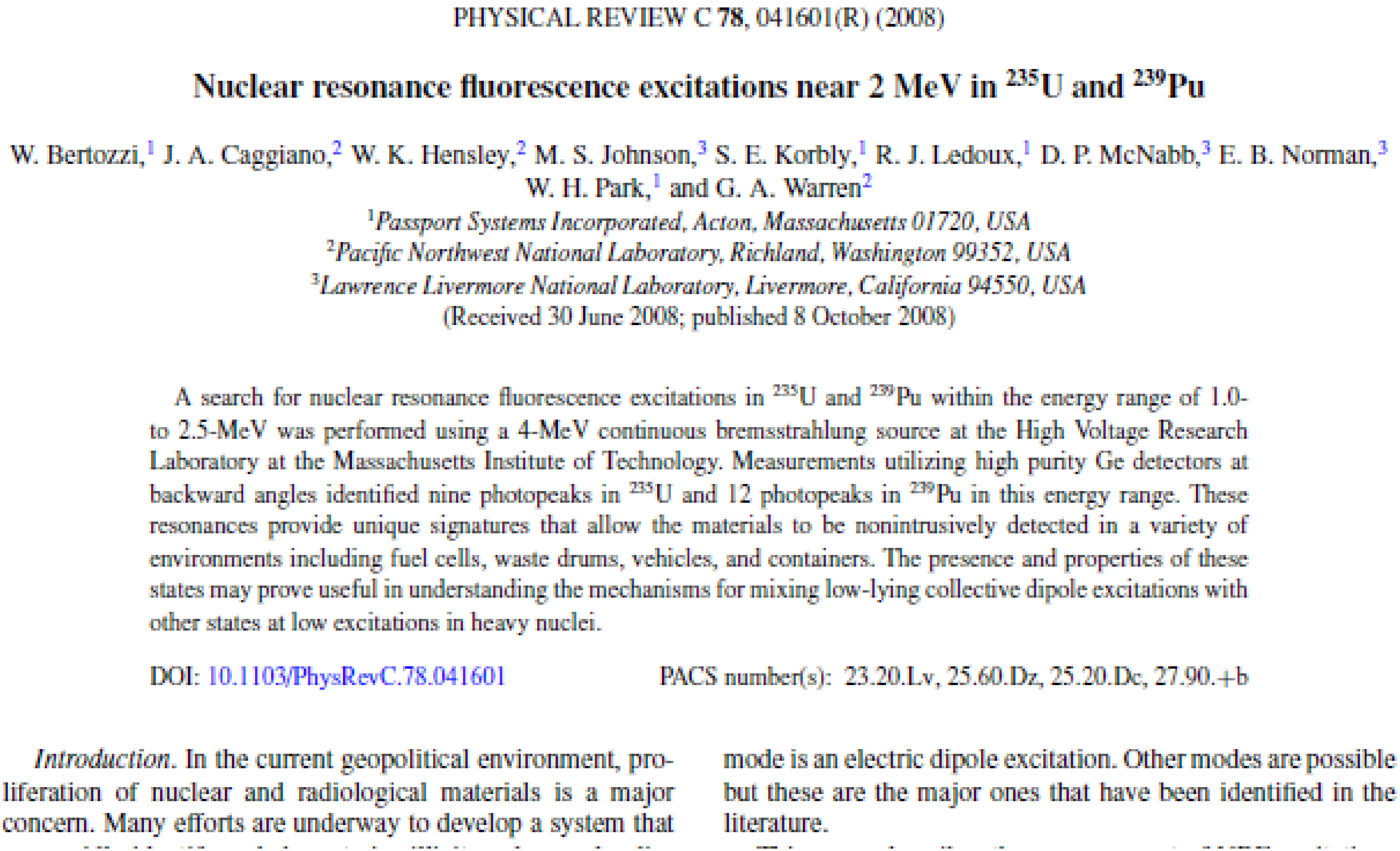


The electron beam is accelerated three times and decelerated three times.

(Hajima)

Isotope detection by γ

[redacted]



PHYSICAL REVIEW C **78**, 041601(R) (2008)

Nuclear resonance fluorescence excitations near 2 MeV in ^{235}U and ^{239}Pu

W. Bertozzi,[1] J. A. Caggiano,[2] W. K. Hensley,[2] M. S. Johnson,[3] S. E. Korbly,[1] R. J. Ledoux,[1] D. P. McNabb,[3] E. B. Norman,[3]
W. H. Park,[1] and G. A. Warren[2]
[1]*Passport Systems Incorporated, Acton, Massachusetts 01720, USA*
[2]*Pacific Northwest National Laboratory, Richland, Washington 99352, USA*
[3]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*

(Received 30 June 2008; published 8 October 2008)

A search for nuclear resonance fluorescence excitations in ^{235}U and ^{239}Pu within the energy range of 1.0- to 2.5-MeV was performed using a 4-MeV continuous bremsstrahlung source at the High Voltage Research Laboratory at the Massachusetts Institute of Technology. Measurements utilizing high purity Ge detectors at backward angles identified nine photopeaks in ^{235}U and 12 photopeaks in ^{239}Pu in this energy range. These resonances provide unique signatures that allow the materials to be nonintrusively detected in a variety of environments including fuel cells, waste drums, vehicles, and containers. The presence and properties of these states may prove useful in understanding the mechanisms for mixing low-lying collective dipole excitations with other states at low excitations in heavy nuclei.

DOI: 10.1103/PhysRevC.78.041601 PACS number(s): 23.20.Lv, 25.60.Dz, 25.20.Dc, 27.90.+b

Introduction. In the current geopolitical environment, proliferation of nuclear and radiological materials is a major concern. Many efforts are underway to develop a system that

mode is an electric dipole excitation. Other modes are possible but these are the major ones that have been identified in the literature.

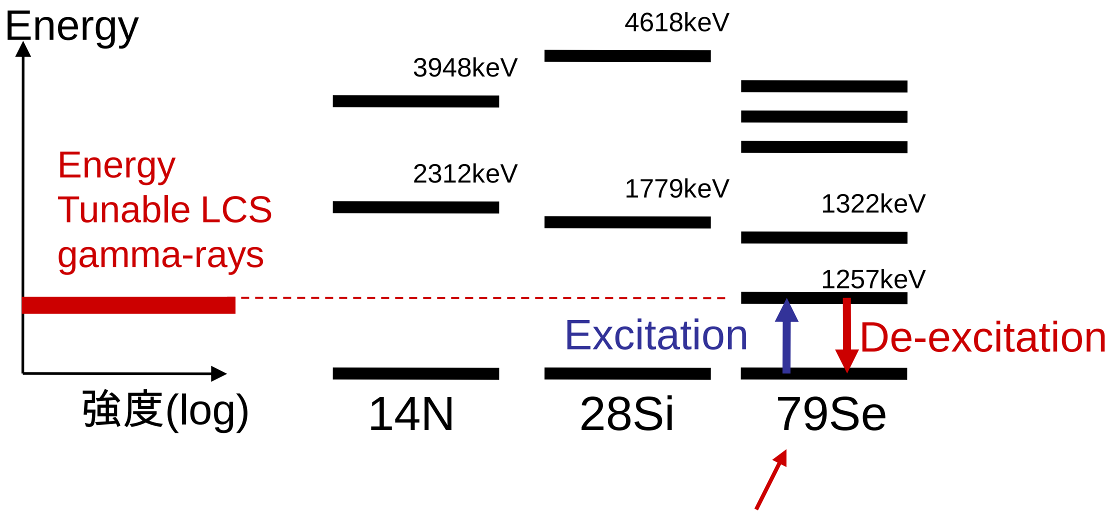
Proposal of Nondestructive Assay of Radionuclides

using nuclear resonant fluorescence technique

There are many minor actinoid (MA) and long-lived fission products (LLFP) in the nuclear waste drum.

How do detect such the MA and LLFP ?

A new Method



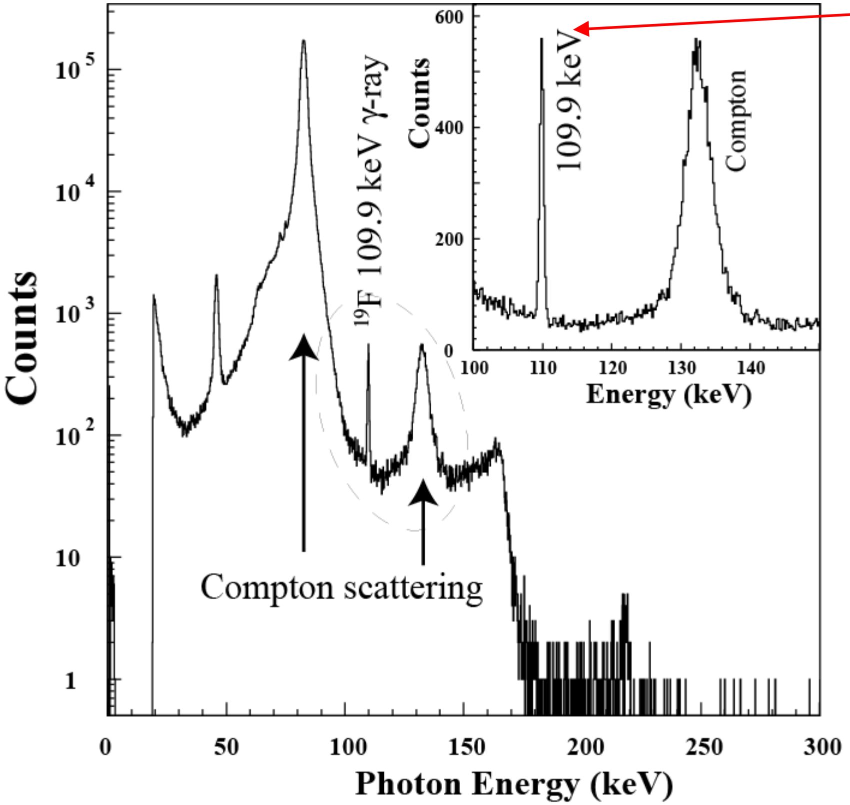
Only Nucleus of interest can be detected

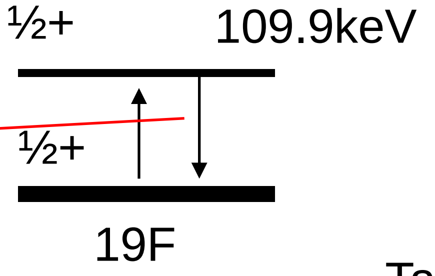
(Hajima)

- **This method can detect all radioactivities except ^{3}H**
- **However, this method require a very high-flux gamma-ray source.**

NRF experiment using Synchrotron Radiation at SPring-8 for Parity Mixing Measurement

(K.Kawase).





½+ 109.9keV

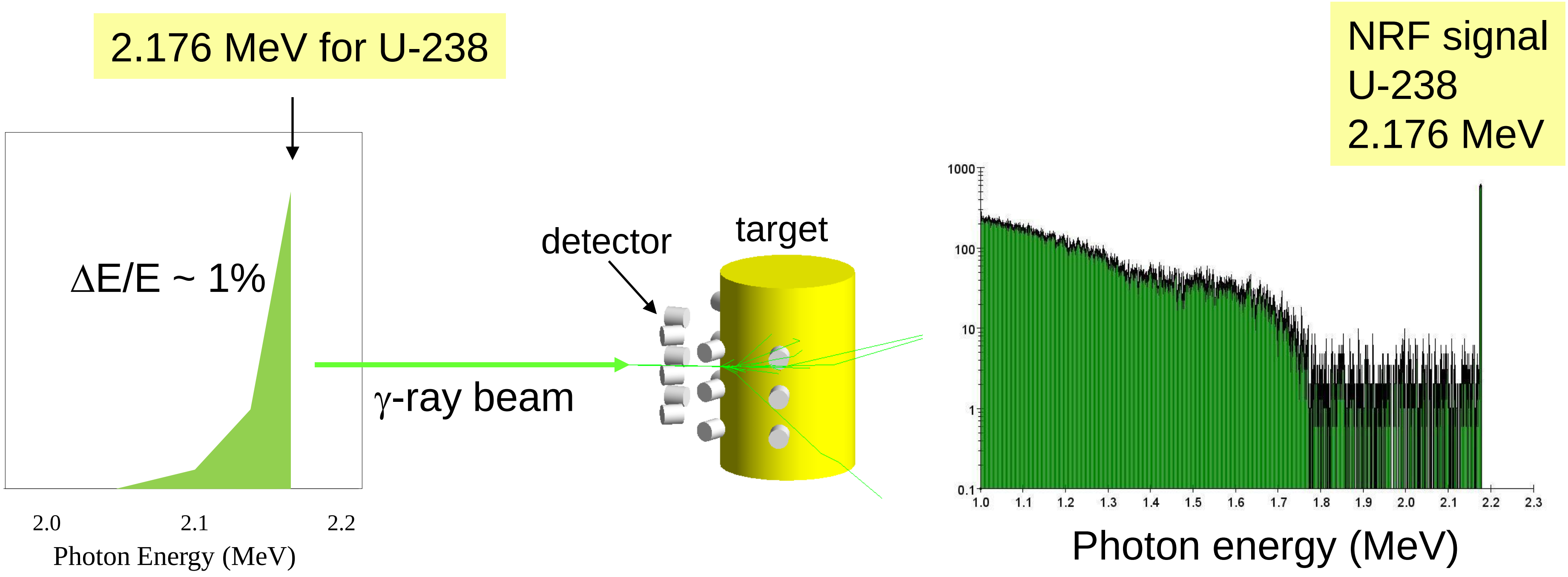
½+

19F

Target and detector

(Fujiwara, Kawase et al.)

Advantages of Nuclear Resonance Fluorescence detection



(1)Nondestructive detection of radioactive and stable nuclides

(2) Excellent signal-to-noise ratio in the energy-resolved gamma-ray detection

(3) Detecting many kind of nuclides by scanning the γ-ray energy

(4) Detection through a thick shield

(5) Full utilization of modern laser and accelerator technologies

(Hajima)

‘**Notch Filter**’: a method of fail-safe to detect specific nuclear matter

J. Appl. Phys. **99**, 123102 (2006)

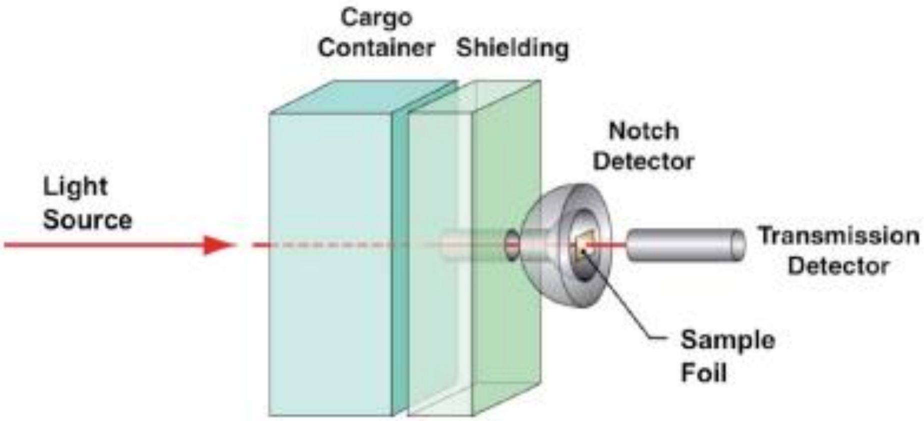
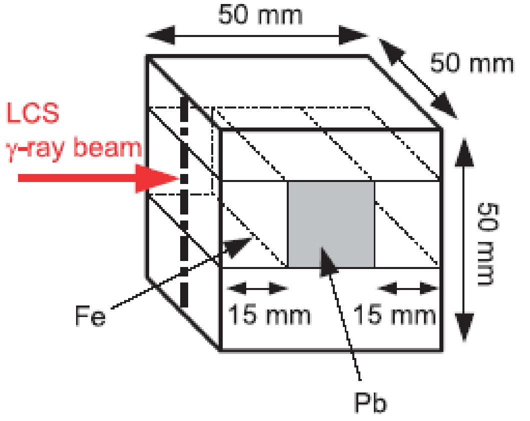


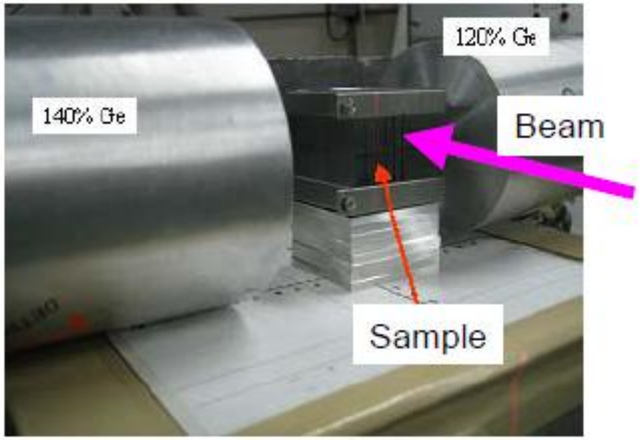
FIG. 2. (Color online) Schematic representation of the detection system studied here. A photon beam is sent to interrogation cargo. After passing through the container the flux of resonant and off-resonant photons is measured. Resonant flux is measured by “notch detectors” that observe NRF within a small sample foil made of the isotope that is being looked for. The flux of off-resonant photons is measured with a simple transmission or current detector.

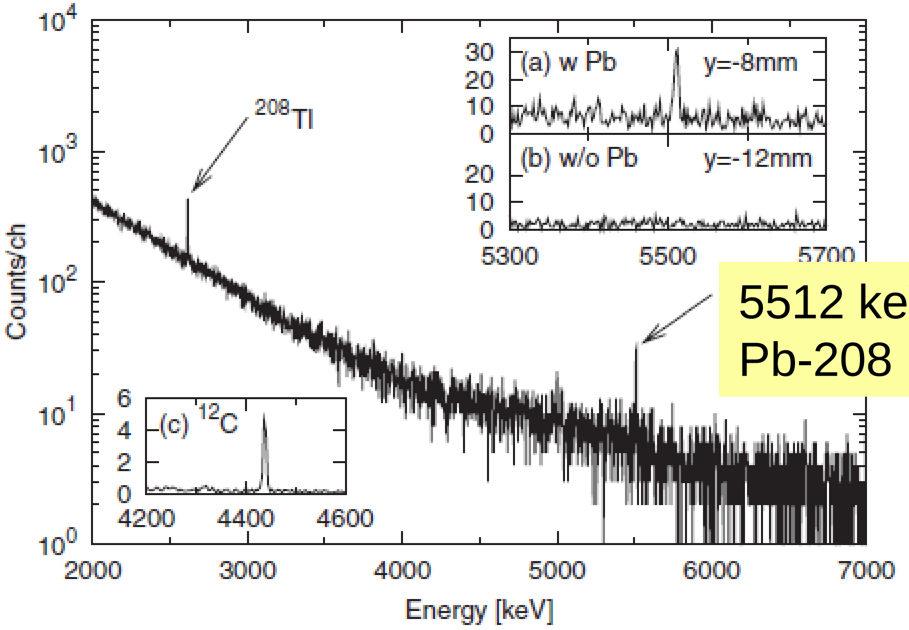
(Pruet,…Barty,2006)

Experiment of nondestructive detection of concealed isotope

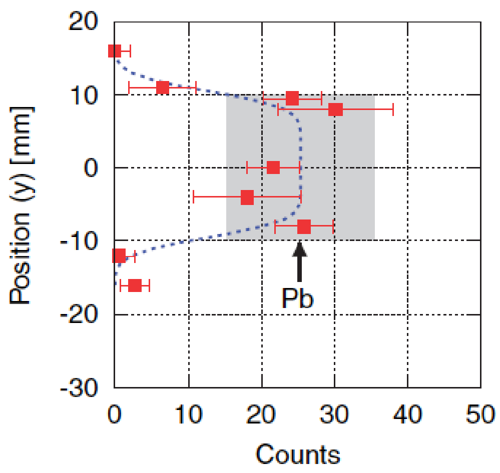


Pb block shielded by 15mm-thick iron box





5512 keV
Pb-208



Position and shape of the Pb block were clearly identified.

[2] N. Kikuzawa et al., Applied Physics Express 2, 036502 (2009).

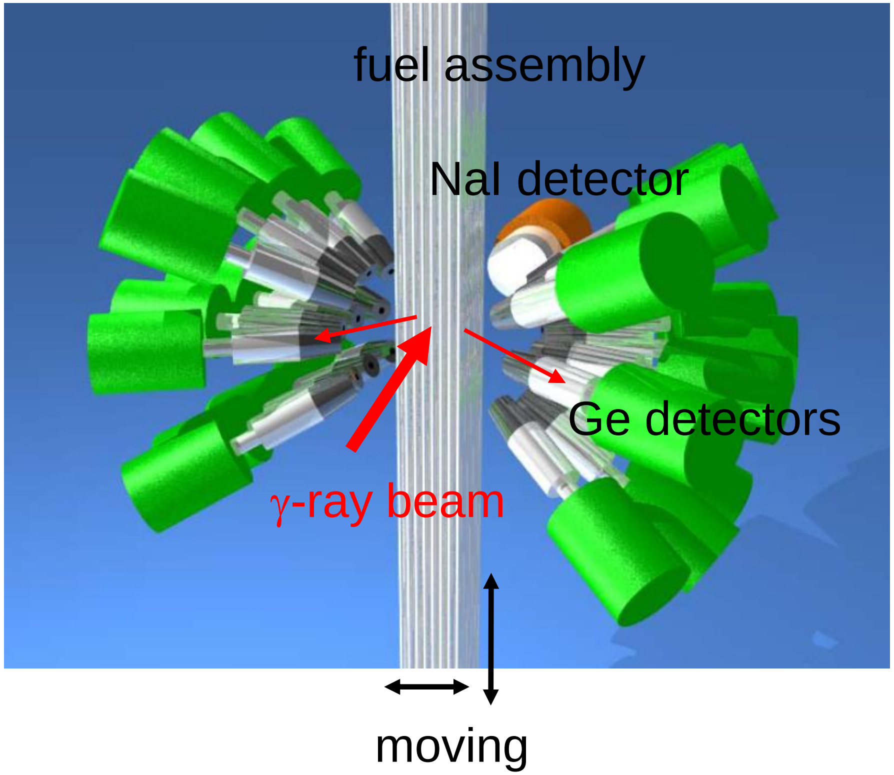
28

Safeguards technology based on mono-energetic γ-ray

Nuclear material accountability is an important issue for nuclear energy usage in the frame of Nuclear Non-Proliferation Treaty.

Nondestructive assay system of spent fuel assemblies
– U, Pu and MA.

Material accountability for operator
&
Safeguards verification for inspectorates

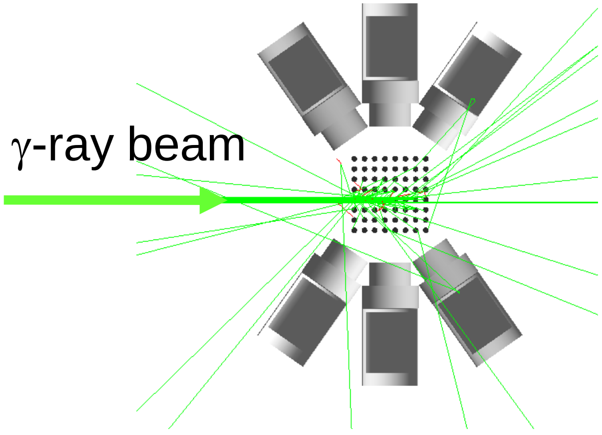


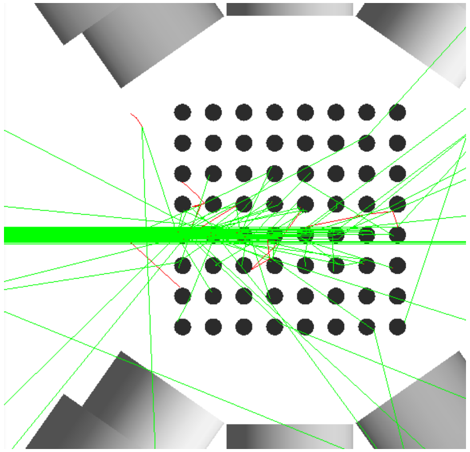
(Hajima)

Deep penetration of γ-rays in a fuel assembly

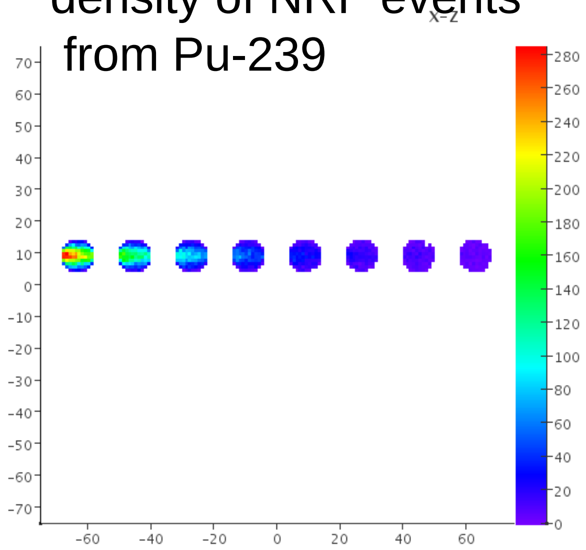
Ge detectors

γ-ray beam

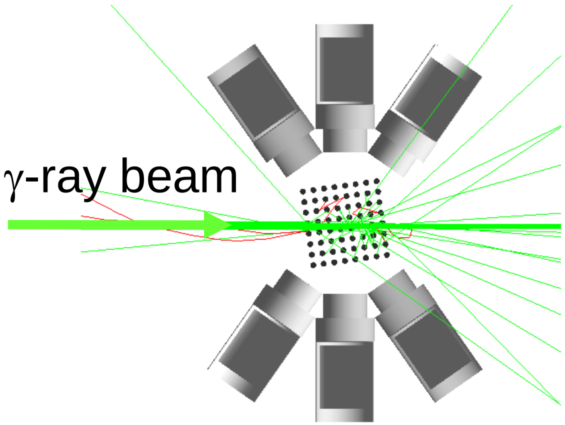


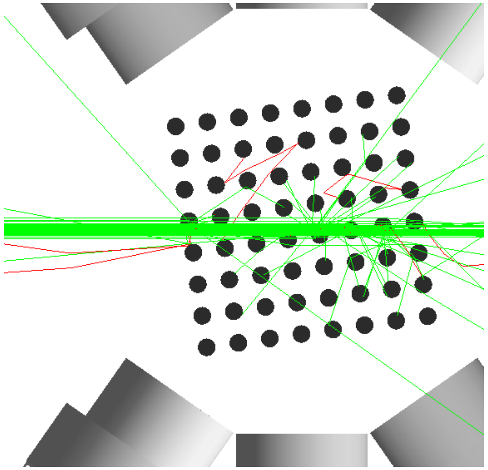


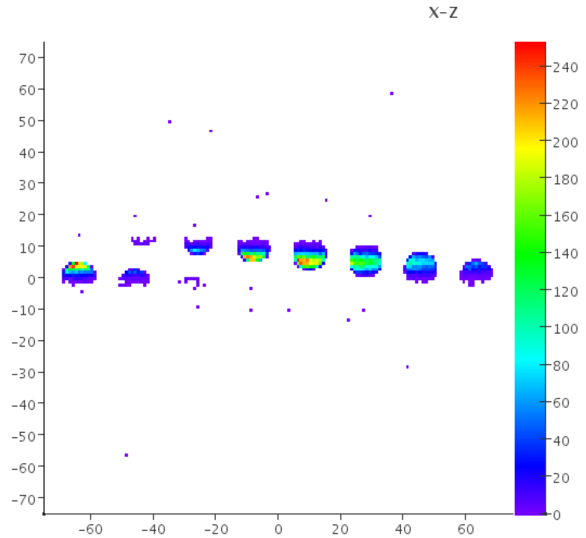
density of NRF events from Pu-239



γ-ray beam



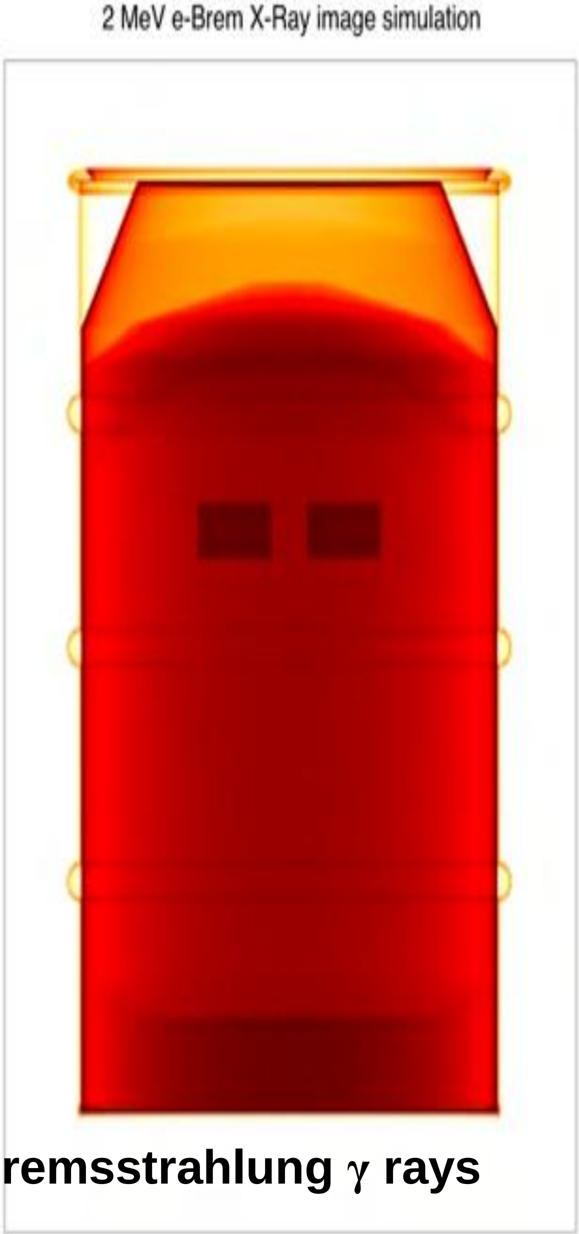




GEANT-4 based Monte Carlo code developed by Hajima's group.

Sharp discriminatory capability of monoenergetic γ rays

Nuclear Resonance fluorescence signal



Bremsstrahlung γ rays

vs

Laser Compton γ rays

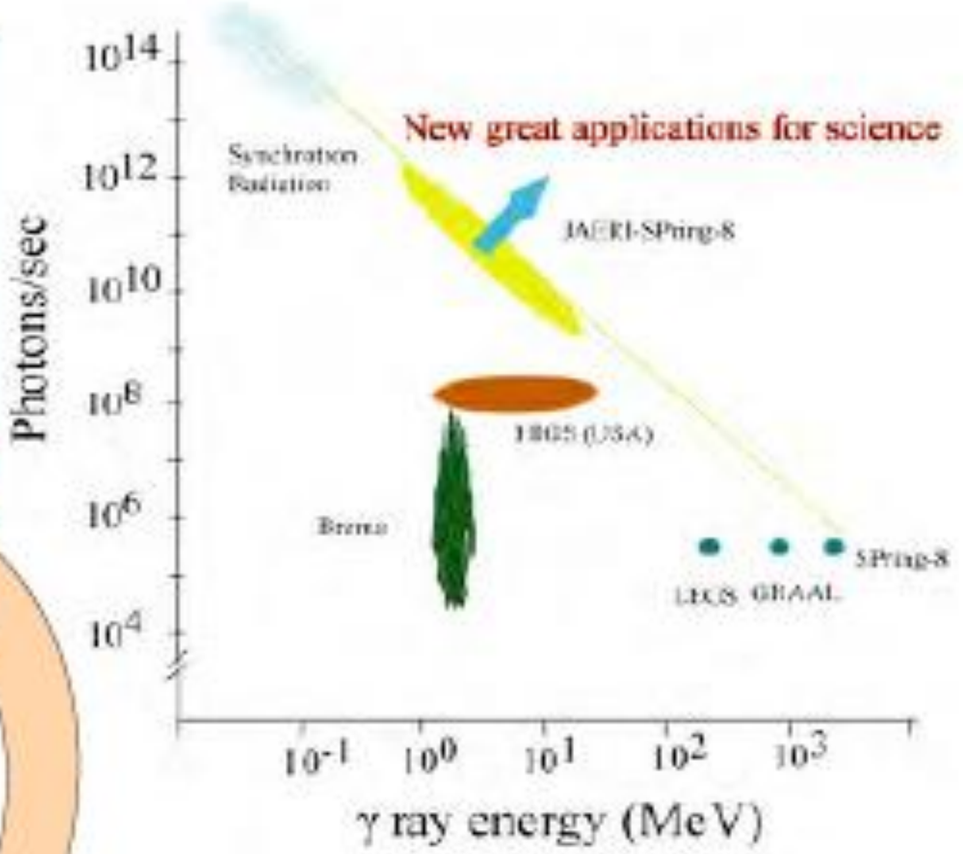
C. Barty and T. Tajima (2008)

Present status of MeV g-ray beam :

ation in Japan :
pring-8 (8 GeV electron storage ring (SR))
ERAS of AIST (National Institute of
dvanced Industrial Science and Technology)
)0 MeV—800 MeV SR
ew Subaru
EK SR
ga SR

Collaboration between Nuclear physics and Laser physics

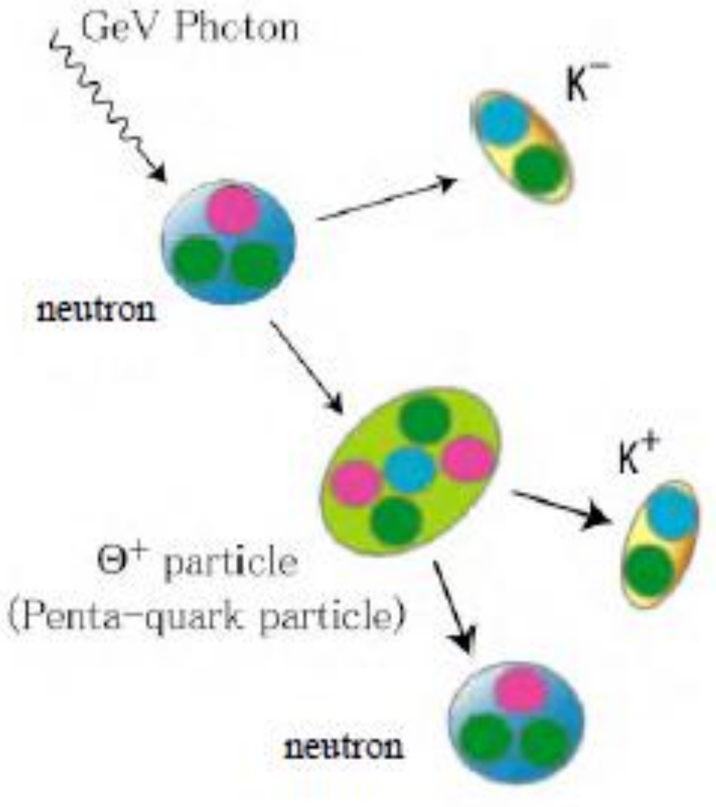
er Technology developments

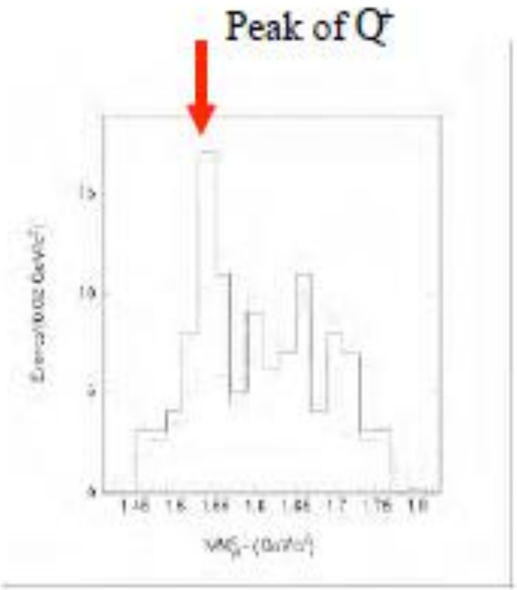


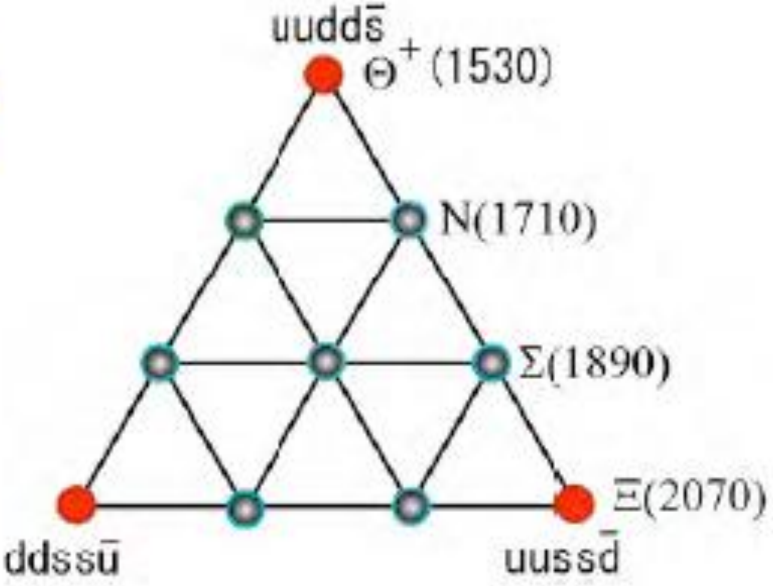
(M. Fujiwara)

Photonuclear processes

Nakano et al., PRL 91, 012002 (2003)







(Spring-8)

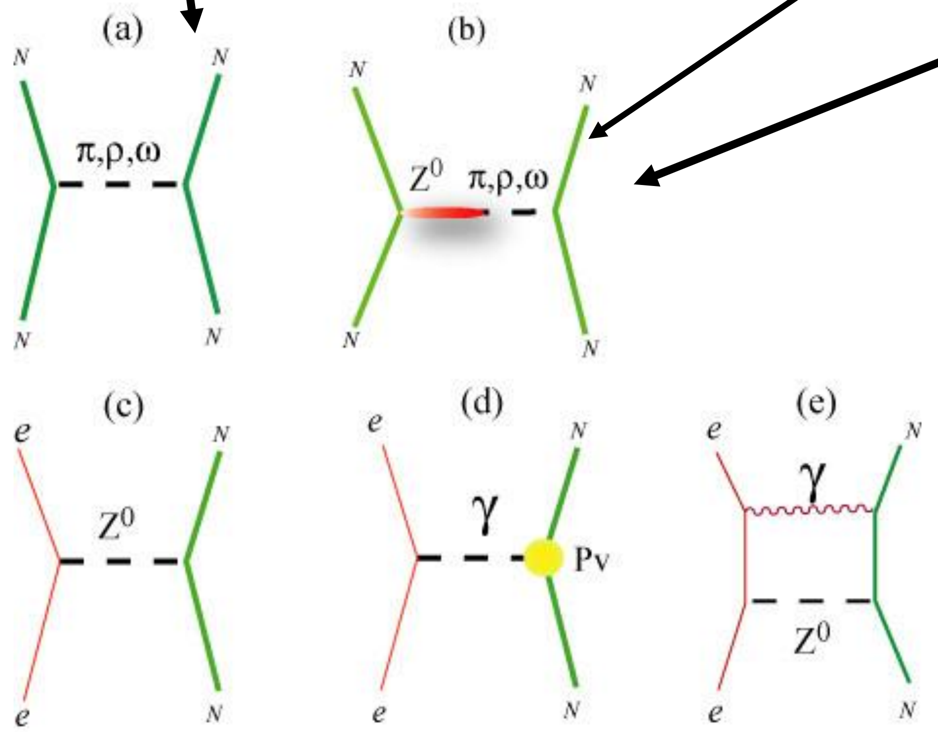
Parity Mixing in Nuclei

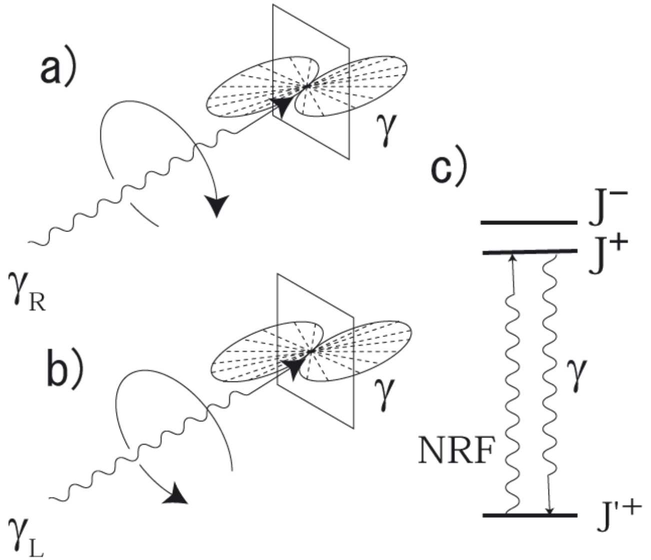
Interaction between Neutral Current Boson and Meson (Nucleon-Nucleon Interaction)

Z^0 : Neutral Current Boson

Standard Nucleon-Nucleon Interaction

Interaction between Z^0 and Mesons.





The interaction can be determined by polarized LCS gamma-rays. Fujiwara, J. Phys. G (2006).

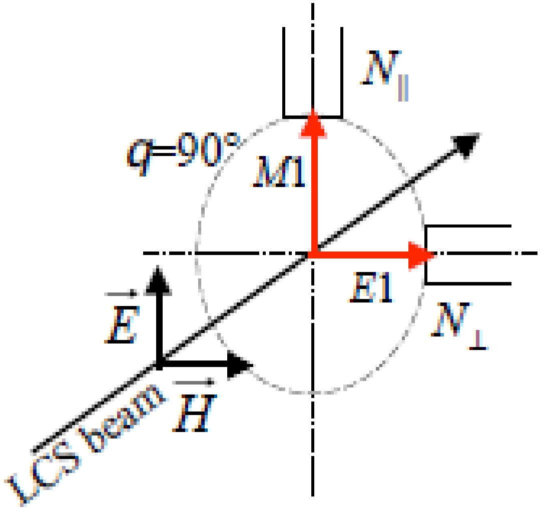
Parity Assignment

Asymmetry at q=90°

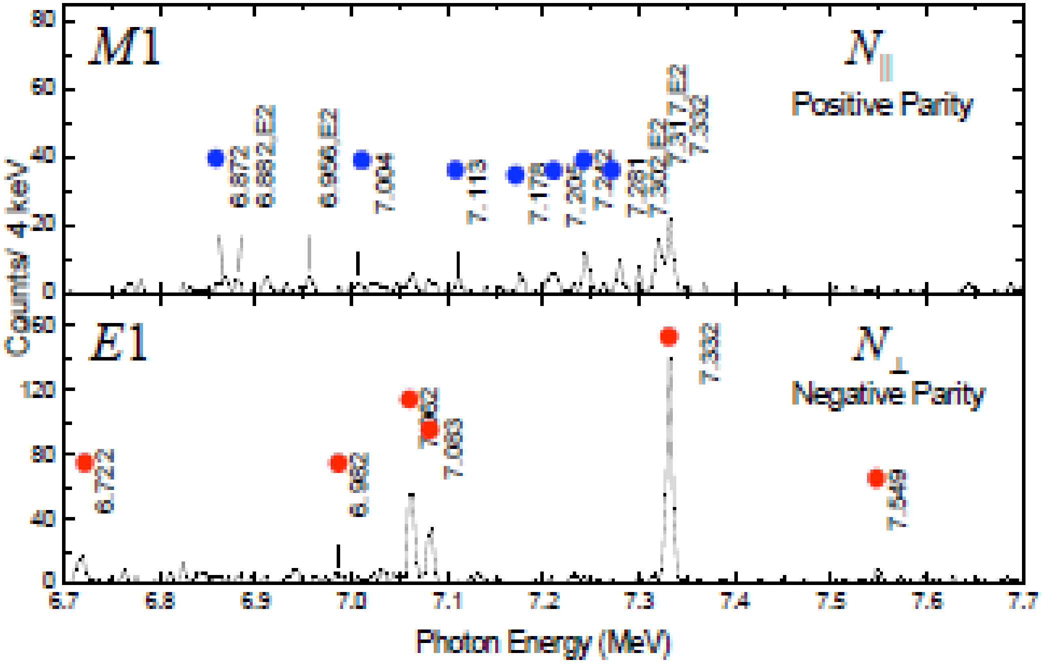
$$A = \frac{1}{P_\gamma}\frac{N_\parallel - N_\perp}{N_\parallel + N_\perp} \quad \xrightarrow{P_g = 1} \quad A = \begin{matrix} +1 \text{ for } M1 \text{ transitons} \\ -1 \text{ for } E1 \text{ transitions} \end{matrix}$$

P_g :Photon polarization

Linearly polarized photons



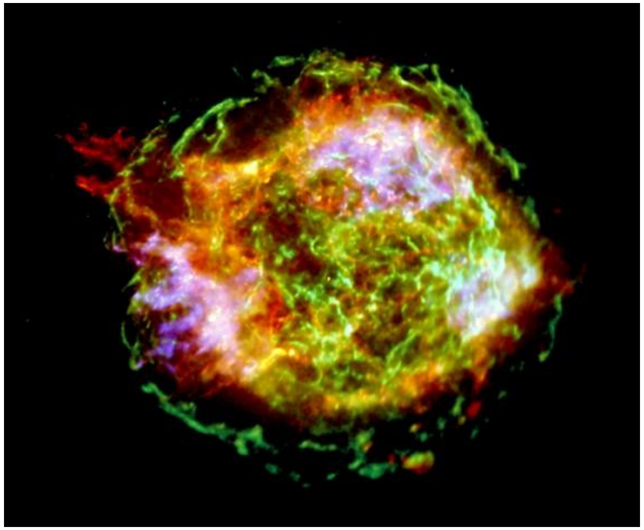
^{208}Pb(γ_{pol},γ), E_γ=7.8 MeV *Ohgaki et al.*



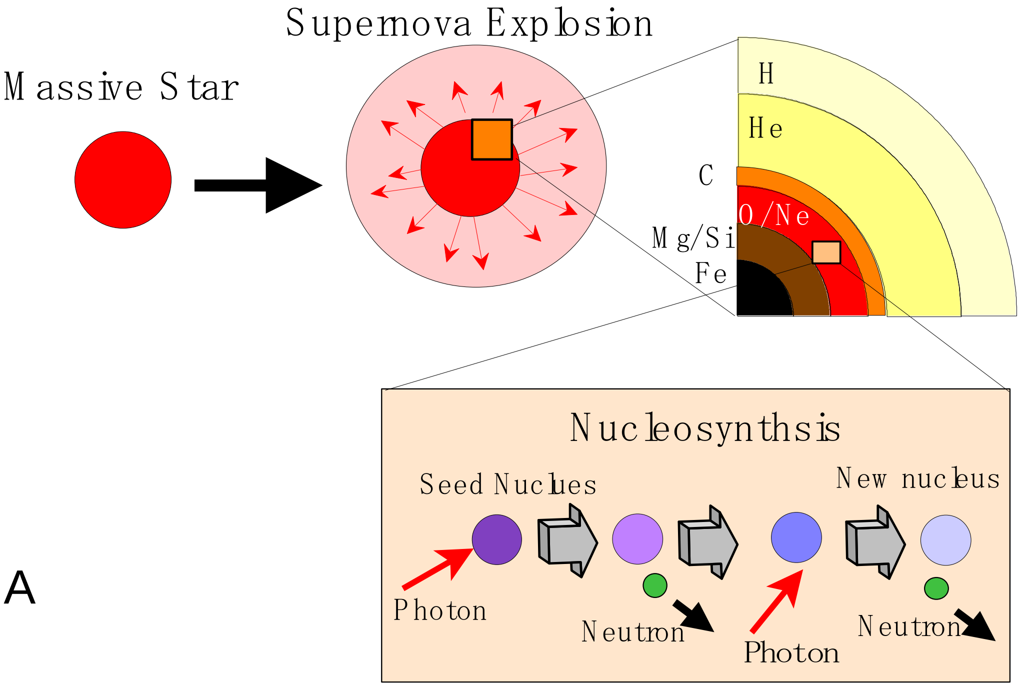
(M. Fujiwara)

Nuclear Astrophysics

High energy photons with 8-10 MeV create new isotopes



Supernova Residual: Cassiopeia A
There are many new isotopes.



JAEA-NAO team found a piece of evidence for such the nucleosynthesis.
Hayakawa, Phys. Rev. Lett. (2004)

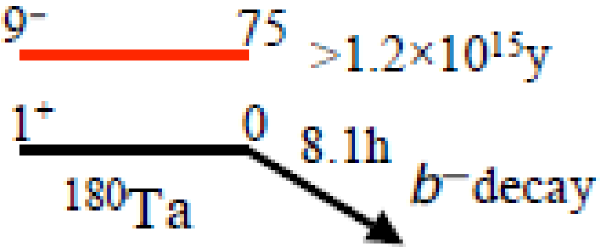
Photonuclear reaction rates are important for theoretical verification.

T.Hayakawa

Nucleosynthesis of the ^{180}Ta Isomer

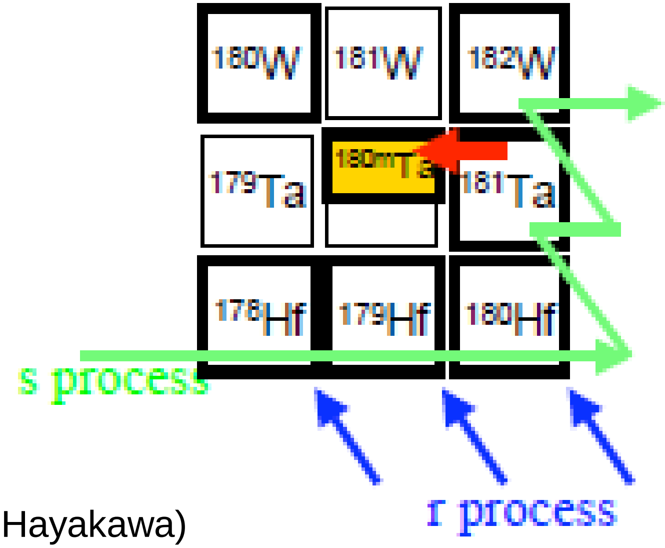
^{180m}Ta --- $T_{1/2}>1.2\times10^{15}$ y, E_x=75 keV

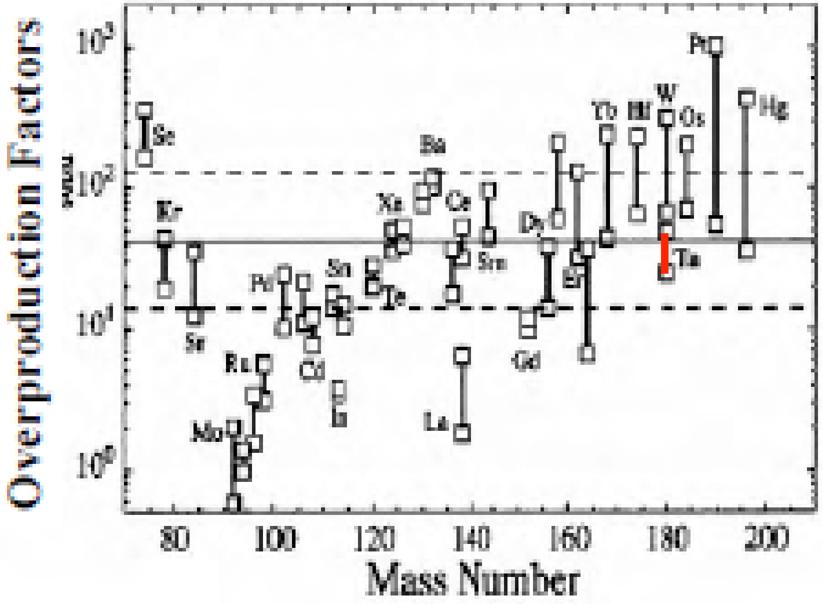
Only the naturally occurring isomer
Nature's rarest isotope
One of the *p* nuclei



Production process?

Photo-disintegration ^{181}Ta(g,n)^{180m}Ta

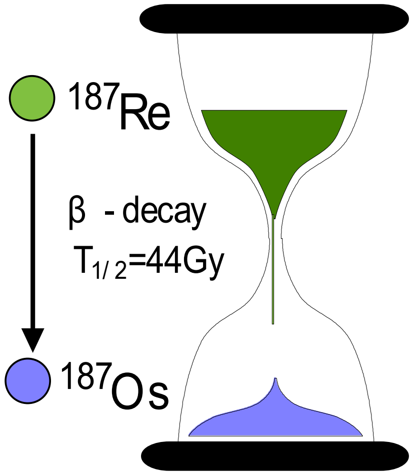




(T. Hayakawa)

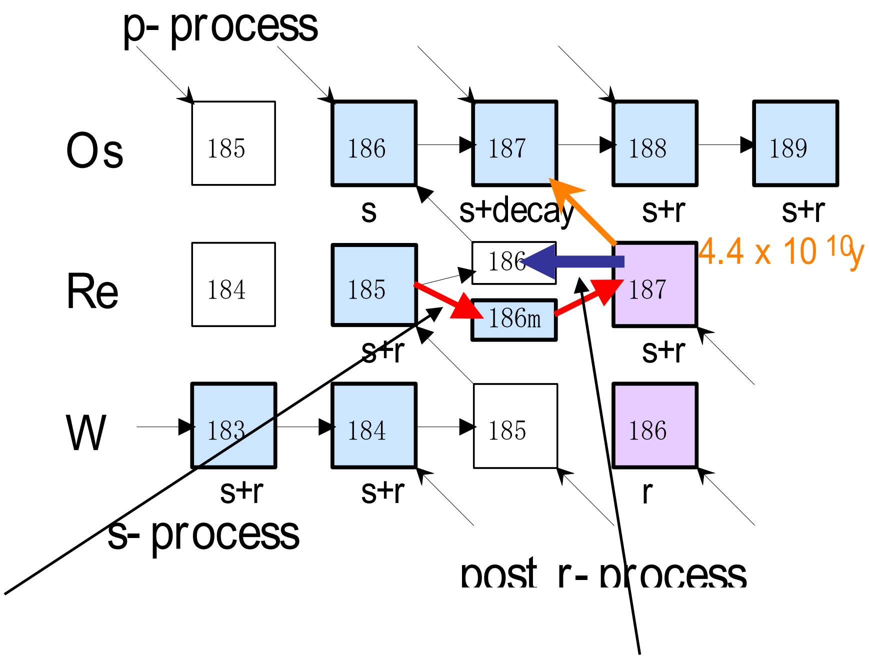
H. Utsunomiya et al.,
Phys. Rev. C67, 015807 (2003)

Nuclear Cosmochronometer



Method using long-lived radioactivity to measure time from material production to the present

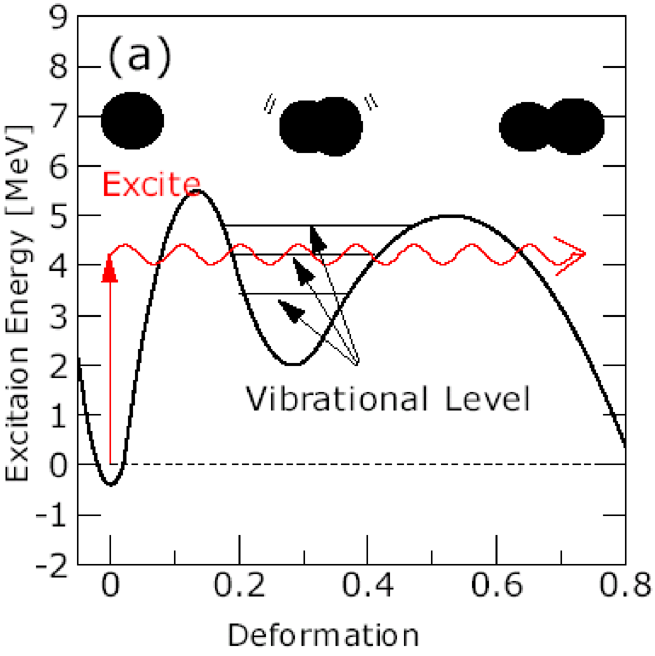
Reaction rates are important for evaluation of the initial abundance.



Neutron capture reaction rate using nuclear reactor
Hayakawa, Astrophys. J (2005).

Photonuclear reaction rate using LCS gamma-rays at AIST
Shizuma, Phys. Rev. C (2005).

Transmutation of actinide by photo-fission



Potential barrier and photo-fission

Horizontal axis: nuclear deformation,
Vertical axis: depth of potential.
We irradiate 4 MeV photons to a stable nucleus with a deformation 0. Then, the levels in the first potential with 0 deformation are excited. The excited levels couple to the vibration level in the second potential, inducing an abnormal photo-fission mode.

For example, the transmutation of Np by neutron induced nuclear fission, fission fragments with wide masses near A=120 remain. One serious RI is ^{129}I with a long half-life. Can we control the fission mode by selecting a special mode of fission ?

One possible route is to use Nuclear Resonance Fluorescence (NFR)

It is well known that there are the second-, and third-potential in addition to the first potential in actinide nuclei, when we consider the fission processes. One can use the coupling mechanism between the levels in the first- and second potentials. Theoretically, it is predicted that the mass distribution of the fission fragment is different from those of the usual neutron induced fission fragments.

Feasibility test by photon-beams from FEL Back-Compton photons are an interesting research subject.

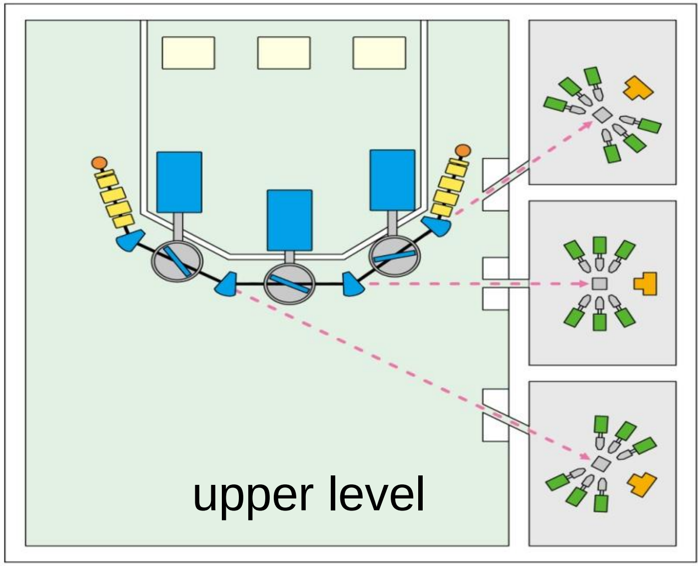
Parity mixing may also play a role !

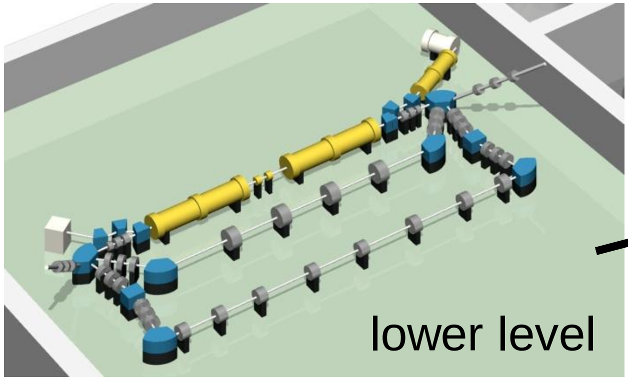
Idea comes from by Dr. Nishio of JAERI.

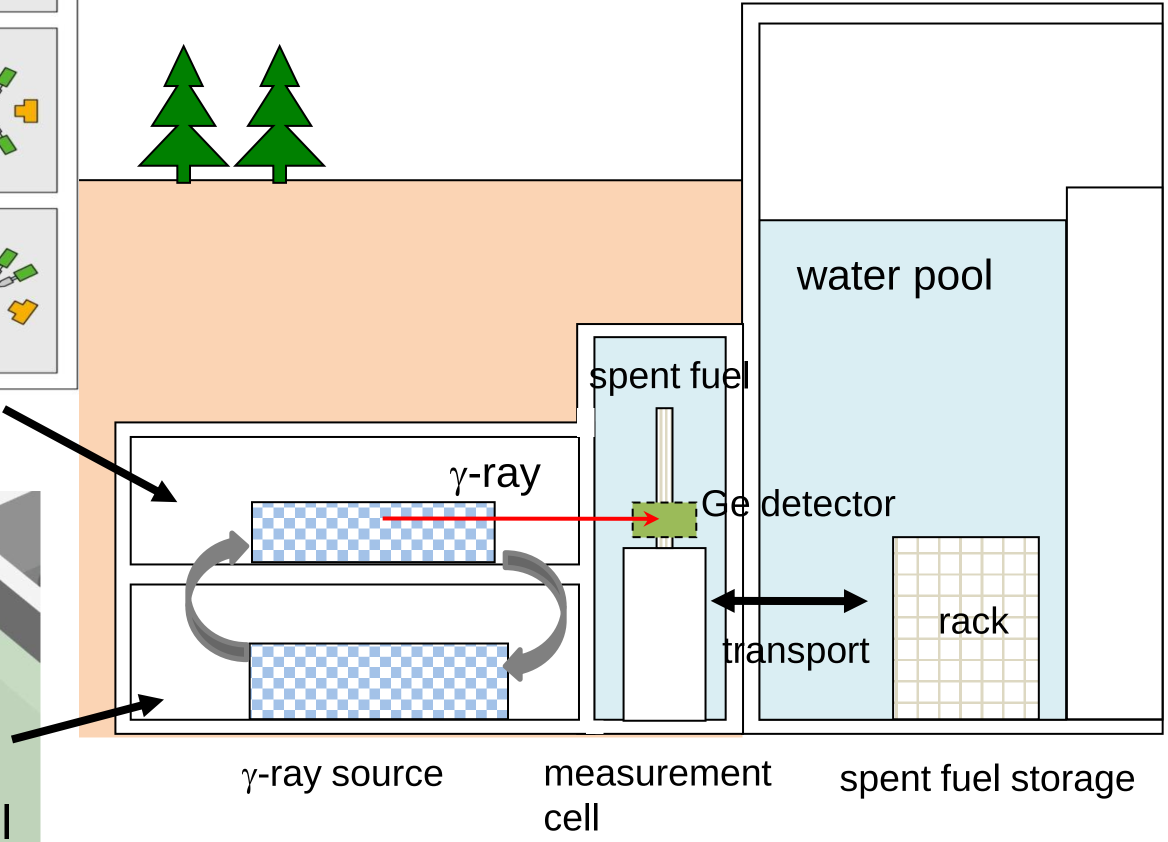
Shizuma

Possible layout in a nuclear fuel reprocessing plant

- ✓Fuel assemblies are transported from the storage to the measurement cell.
- ✓All the process is done in the water pool.





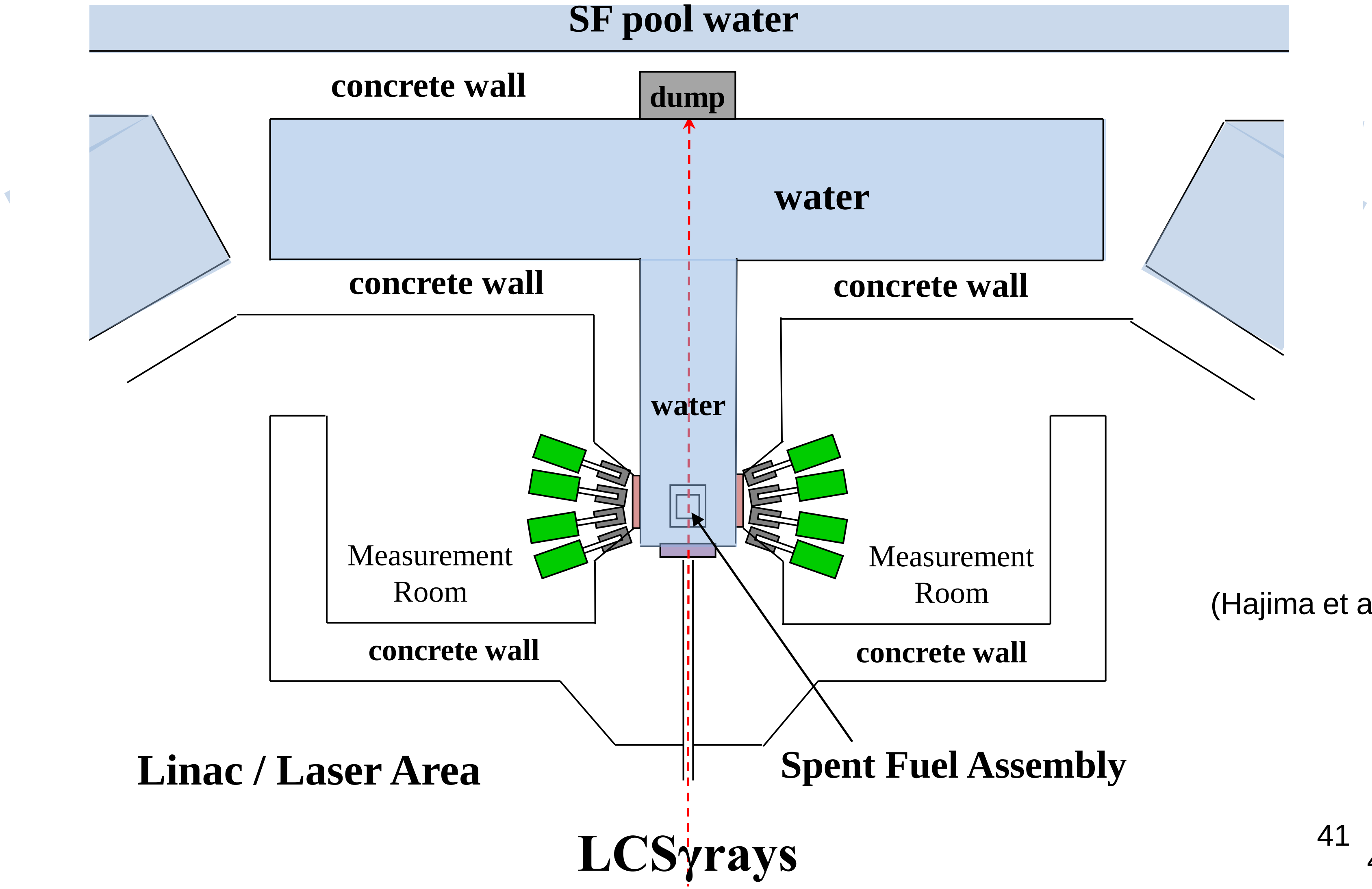


(Hajima et al)

40

Possible layout in a nuclear fuel reprocessing plant

Detectors are located outside the pool in measurement rooms where people can go inside when SF is not in the measurement point.



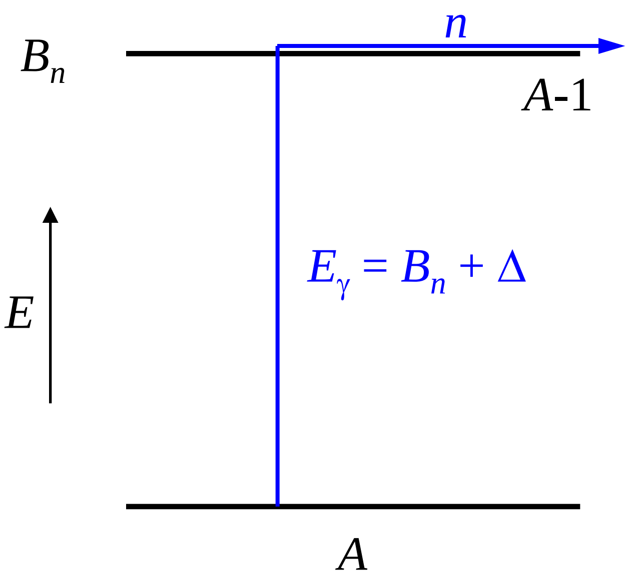
(Hajima et al)

41

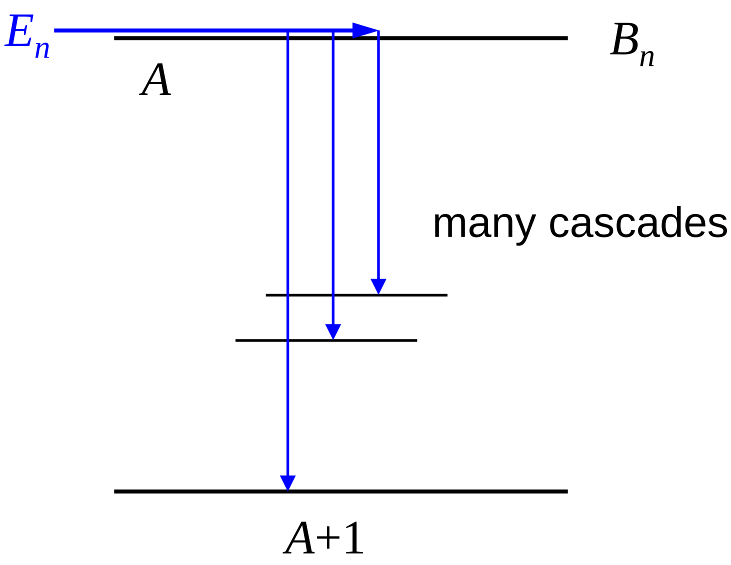
Gamma-driven Neutron beams
Photonuclear Reactions : Neutron yield

(γ,n) ↔ (n,γ)

(γ,n)



(n,γ)



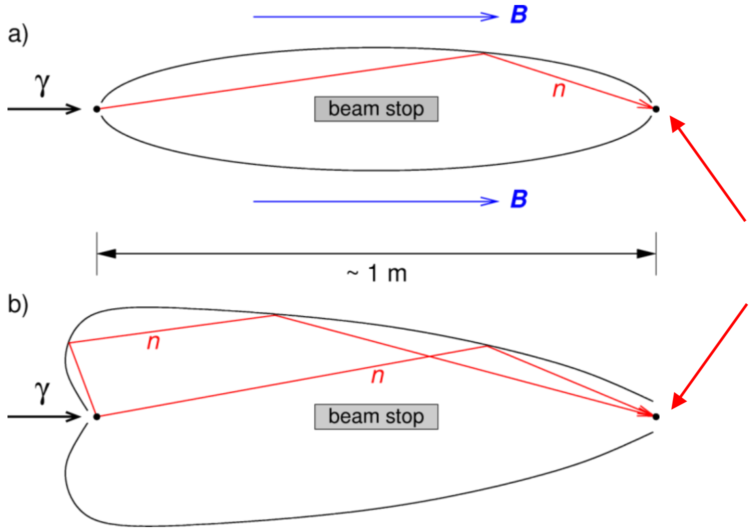
Cross sections and resonances unknown
Γ_n, Γ_γ

Many studies → level densities at B_n

(Habs)

Gamma-driven micro-neutron beams

$E_\gamma = 6$ MeV $A = 240$ $$E_{\text{rec}} = \frac{(6\,\text{MeV})^2}{2\cdot 240\cdot 10^3\ \text{MeV}} = 75\,\text{eV}$$



$$\frac{v}{c} = \frac{1}{4\cdot 10^4}, \qquad v = 7\cdot 10^3\,\frac{\text{m}}{\text{s}}$$

(compensate by fast centrifuge)

low background focus $E_n = 300$ meV

10 m elliptic mirror,
supermirrors: 10^4 Ni layers,
also for hot electrons

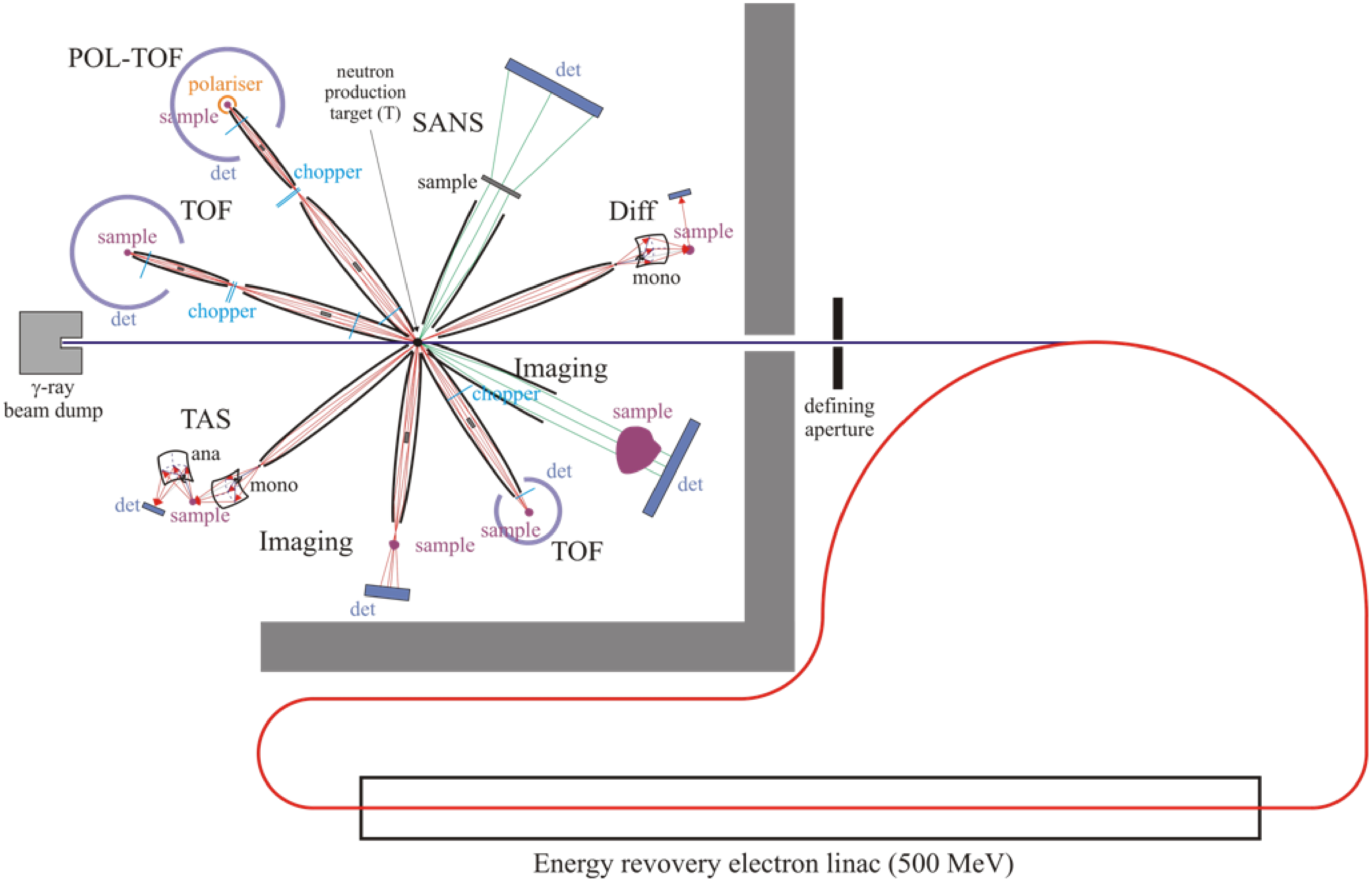
Expected optimum flux from reactor: 10^9 cm^{-2} s^{-1}, diameter ~ 1 mm
photo nuclear: 10^{14} s^{-1}, diameter ~ 10μm → 10^{18} cm^{-2} s^{-1}, diameter ~ 10 μm

Even 10^2 times higher flux would open up many new applications.

P. Böni, NIM **A 586**, 1 (2008);
R. Valicu, P. Böni, "Focusing neutron beams to sub-mm size", NIM, to be published.

(Habs)

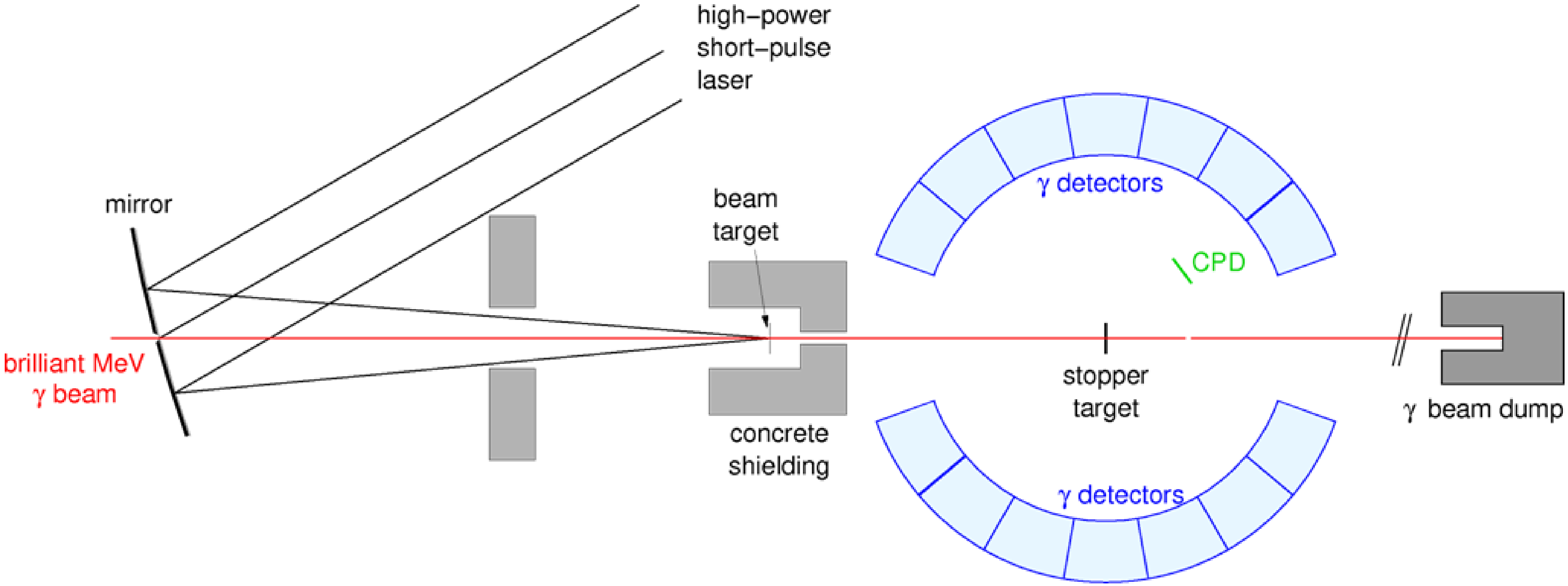
Laser-driven Cold Neutron experiments



(D. Habs)

NRF + radioactive nuclei

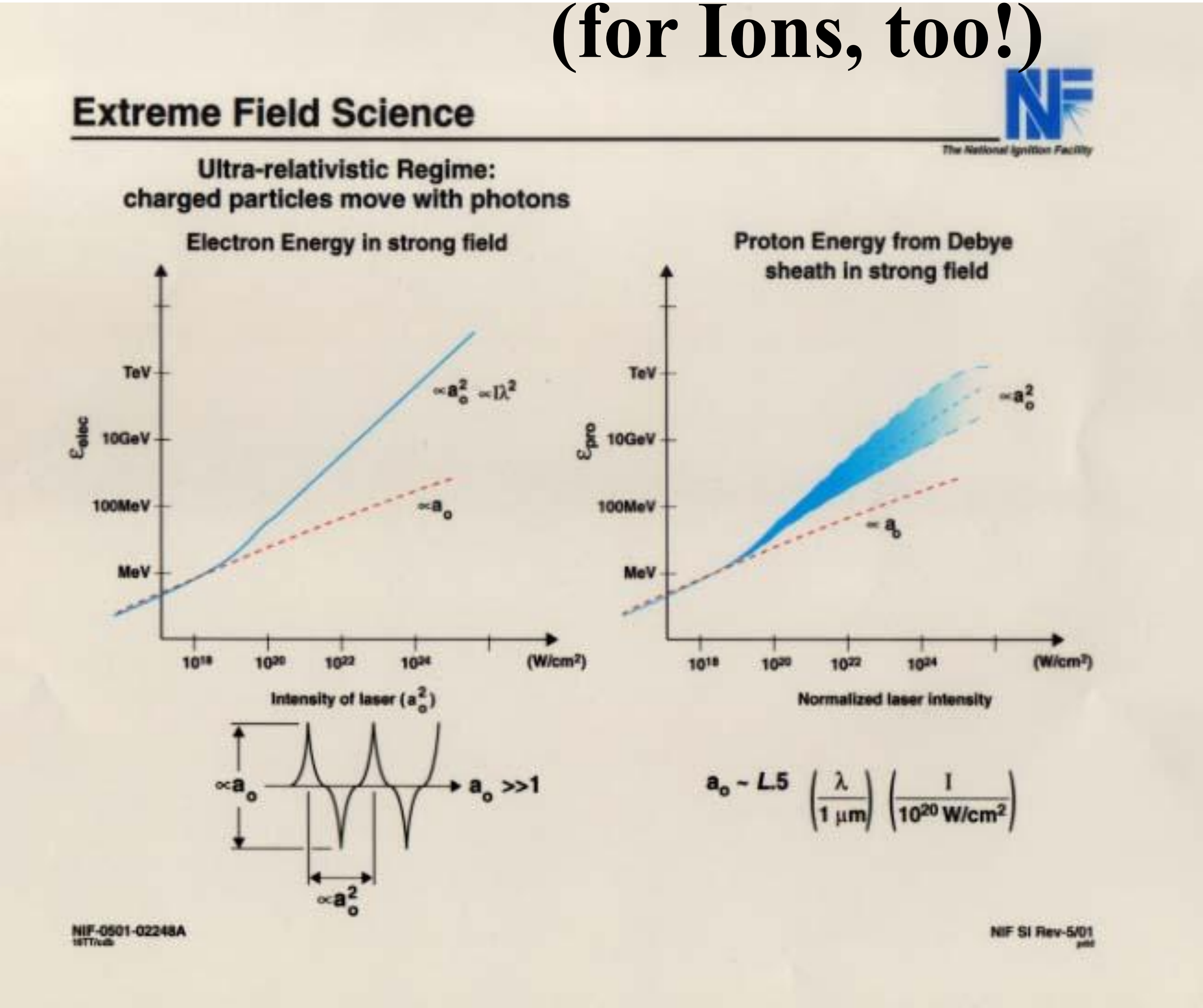
ELI (Extreme Light Infrastructure) Nuclear Pillar
APOLLON laser + γ beam



Dense radioactive target of neutron-deficient nuclei
$T_{1/2} \geq 1$ s

(D. Habs)

Relativity Helps Acceleration (for Ions, too!)



Extreme Field Science

The National Ignition Facility

Ultra-relativistic Regime:
charged particles move with photons

$$a_o \sim 1.5 \left(\frac{\lambda}{1\ \mu m}\right)\left(\frac{I}{10^{20}\ W/cm^2}\right)$$

NIF-0501-02248A
18TT/cdb

NIF SI Rev-5/01
pdd

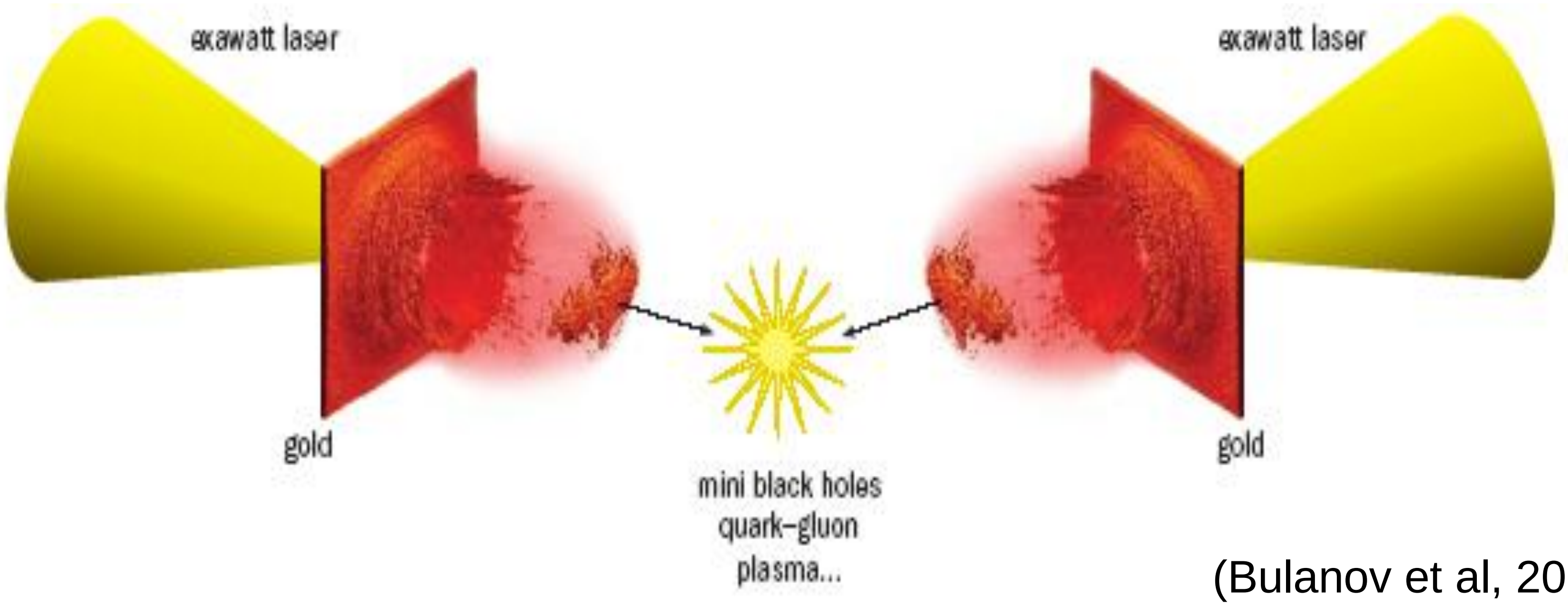
Strong fields:
rectifies laser
to longitudinal
fields

In relativistic regime,
photon x electrons
and even protons
couple stronger.

(Tajima, 1999 @LLNL; Esirkepov et al., PRL,2004)

Beyond intensity 10^{24}W/cm^2 ions move relativistically like e^-

Relativistic and monoenergetic ion beam may constitute compact colliders of ions
→ QCD vacuum exploration



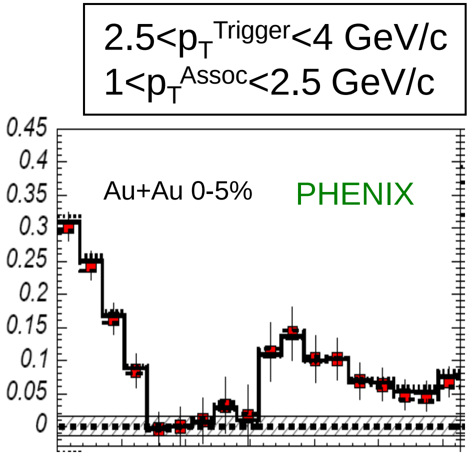
(Bulanov et al, 2004)

Nuclear wakefields

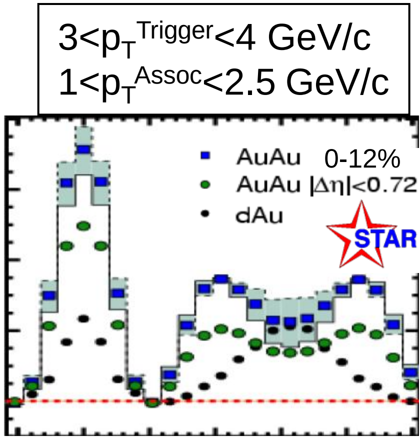
J. Ulery (2007)

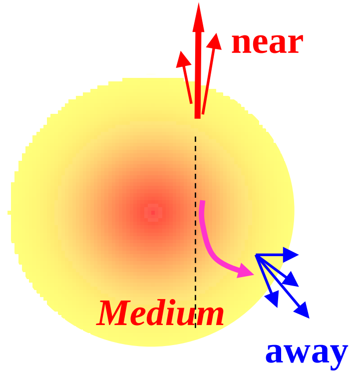
- Broadened and maybe double humped structure on the away-side in 2-particle correlations.
- Could be caused by:
  - Large angle gluon radiation (Vitev and Polsa and Salgado).
  - Deflected jets, due to flow (Armesto, Salgado and Wiedemann) and/or path length dependent energy loss (Chiu and Hwa).
  - Hydrodynamic conical flow from mach cone shock-waves (Stoecker, Casalderrey-Solanda, Shuryak and Teaney, Renk, Ruppert and Muller).
  - Cerenkov gluon radiation (Dremin, Koch).
- Three-particle correlations to distinguish them.

PHENIX PRL 97, 052301 (2006)

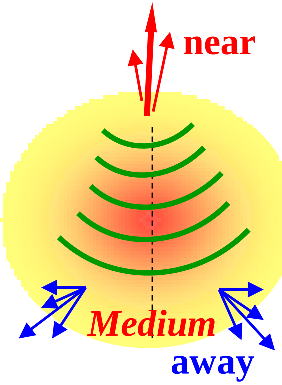


Horner (STAR) QM2006

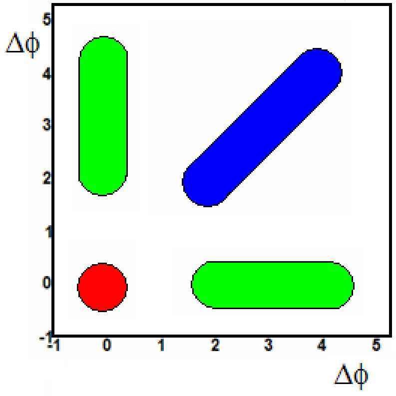


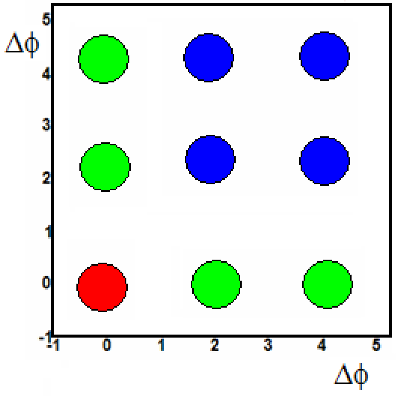


Deflected Jets



Conical Emission



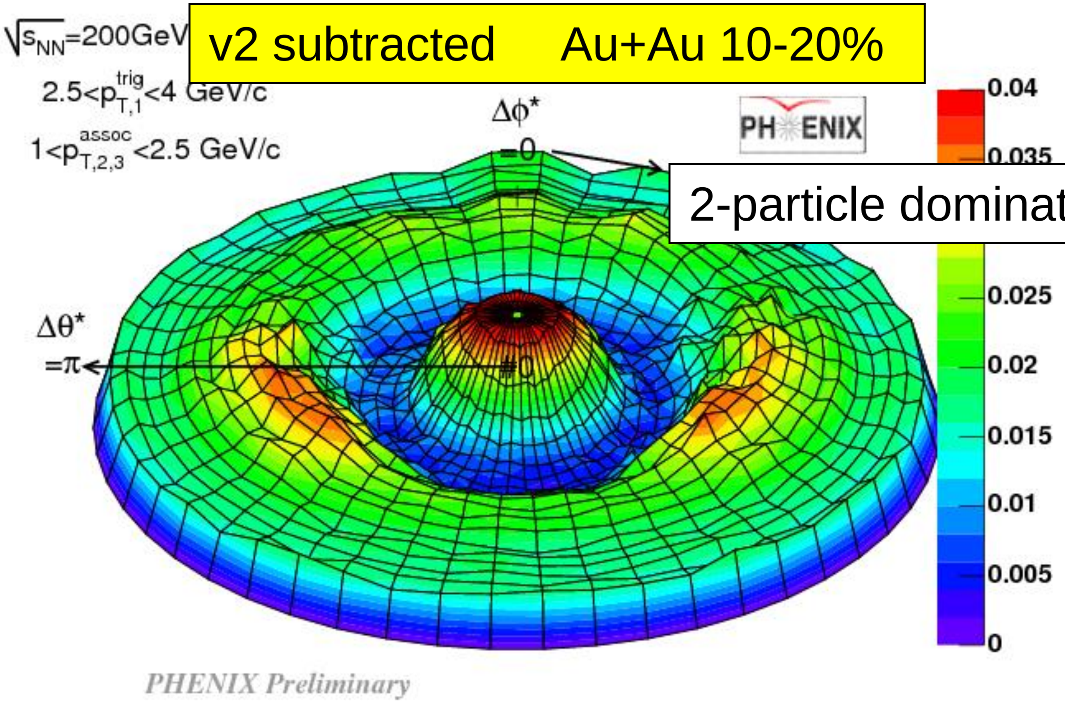


PHENIX Results: Nuclear Wake

$\Delta\phi^*$ Projections

J. Ulery (2007)

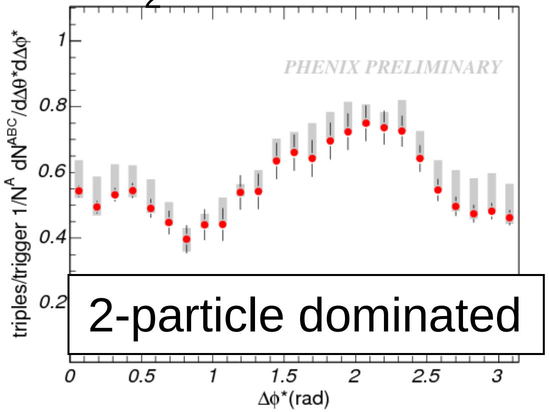
Ajitanand (PHENIX) HP06, IWCF'06



v2 subtracted Au+Au 10-20%

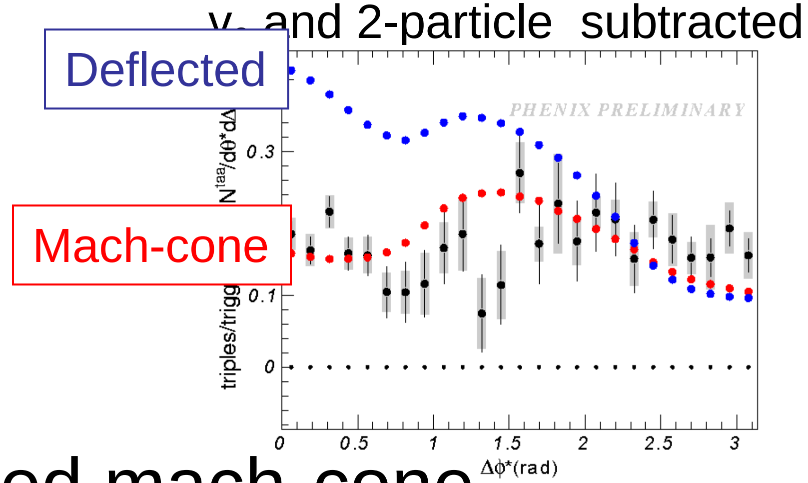
2-particle dominated

v_2 subtracted



2-particle dominated

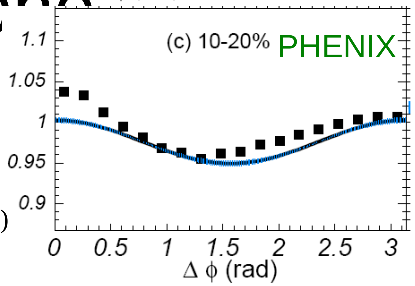
v_2 and 2-particle subtracted



Deflected

Mach-cone

- Shape consistent with simulated mach-cone
- 3-particle/2-particle ~ 1/3, very large
  - Residual background?



PRL 97, 052301 (2006)

summary

- Contemporary problems to solve in front of us
- Ultrfast intense laser: introduces new ways to revitalize nuclear physics
- Laser Compton γ-rays: first and main access to **photonuclear physics**
- Laser allows: pump and probe in zs regimes of nuclear reactions (‘streaking’ observation); laser and γbeams collaborate toward marriage of two disciplines of science for new nuclear physics
- Transform nuclear physics with clear specific control: basic science and applications
- γbeam can drive compact cold neutron beams
- New fundamental physics approach by the combination of intense laser + brilliant γbeam: s.a. vacuum physics
- Nuclear fuel monitoring and waste verification

Pascal Lecture Plan

(tentative, need your feedback)

- Oct.22: First Lecture (General) “ Laser Acceleration and High Field Science: 1979-2009”
- Nov.18: Second Lecture “Laser Electron Acceleration and its Future”
- Dec.9: Third Lecture “Laser Ion Acceleration”
- January 20,2010: “Relativistic Engineering”
- March 10: “Photonuclear Physics”
- April 14: “High Field Science”
- May: “Medical Applications”
- ……