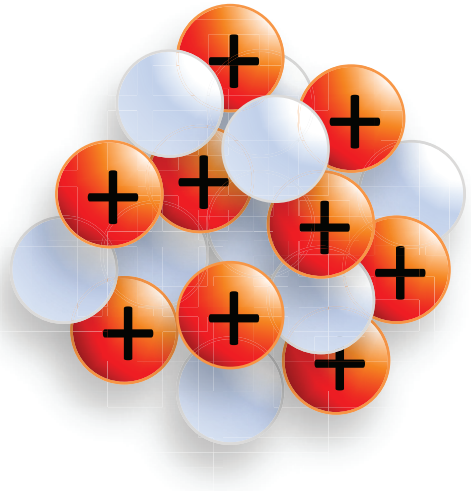
The Potential Use of X-ray FELs in Nuclear Studies

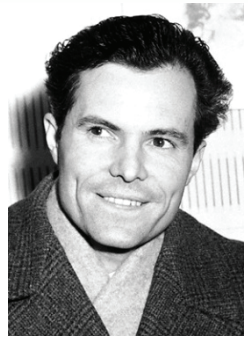


Wen-Te Liao 廖文德

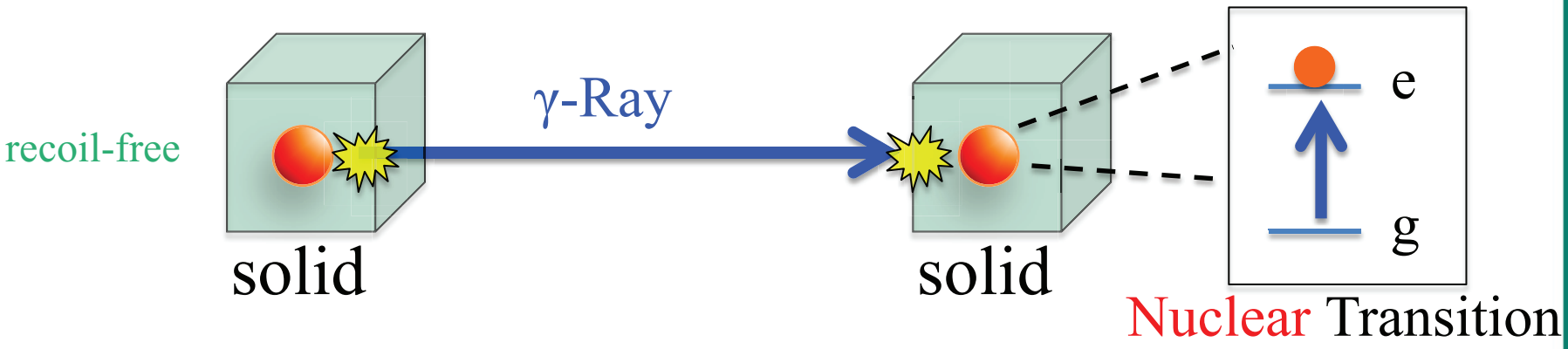
Max Planck Institute for Nuclear Physics
Heidelberg, Germany

29 August 2013 @ FEL2013

Mössbauer effect (1958)

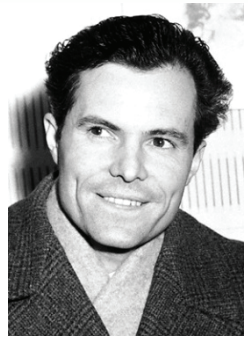


R. Mössbauer

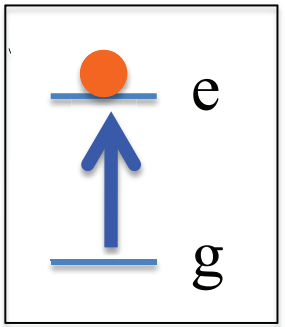


R. L. Mössbauer, Zeitschrift für Physik A 151, 124 (1958).

Mössbauer effect (1958)



R. Mössbauer



Nuclear Transition

Can we do
quantum control in nuclear systems?

What we can do with XFEL?

R. L. Mössbauer, Zeitschrift für Physik A 151, 124 (1958).

Two Examples

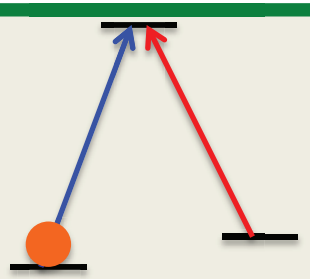
Iron Cage for X-Ray Photon

^{57}Fe nuclei and X-Rays

W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Rev. Lett. 109, 197403 (2012)

Nuclear STIRAP

many species of nuclei and XFEL



W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Lett. B 705, 134 (2011).
W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Rev. C 87, 054609 (2013).

Iron Cage for X-Ray Photons

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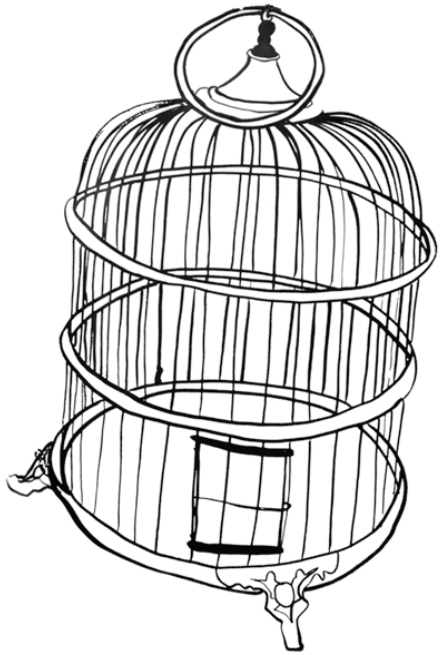
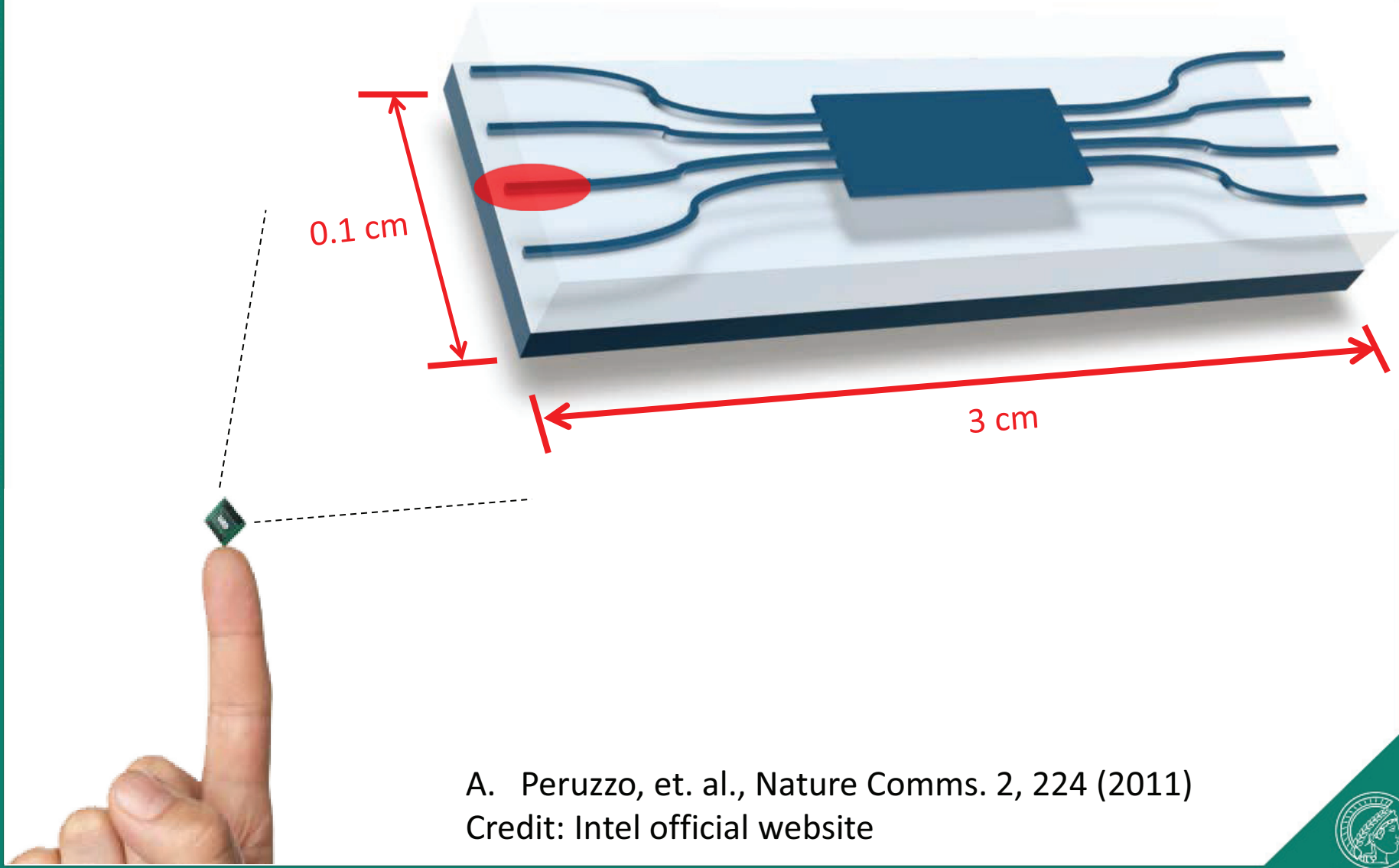


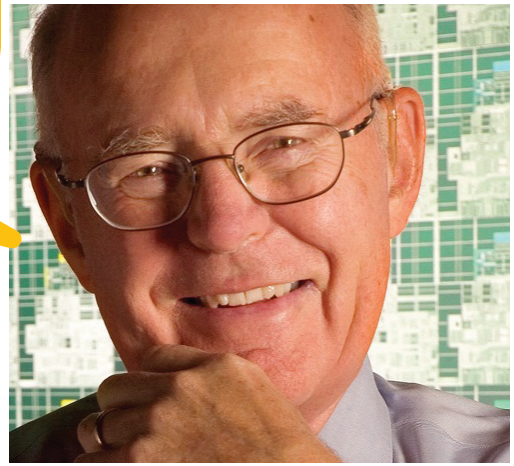
Quantum Photonic Circuit

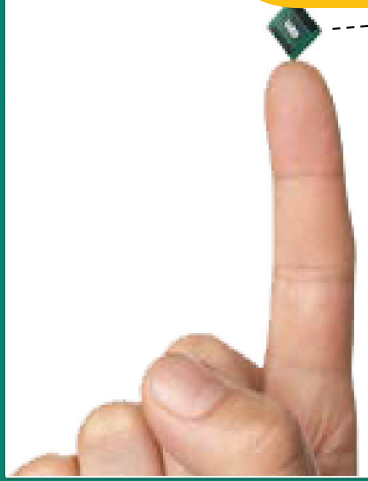


A. Peruzzo, et. al., Nature Comms. 2, 224 (2011)
Credit: Intel official website

Quantum Photonic Circuit

Sounds cool, but how about **Moore's Law**?





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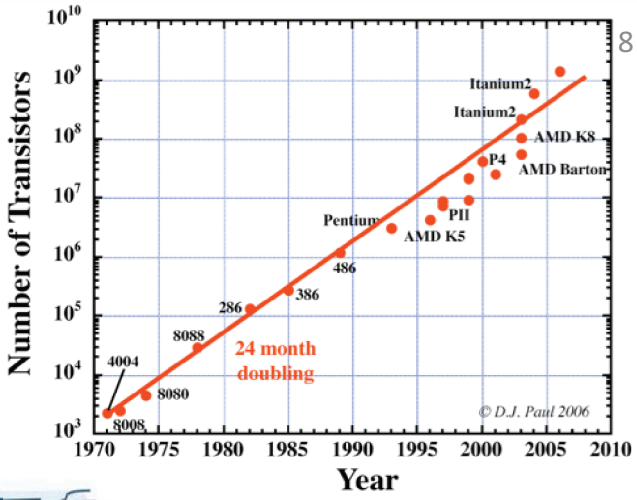
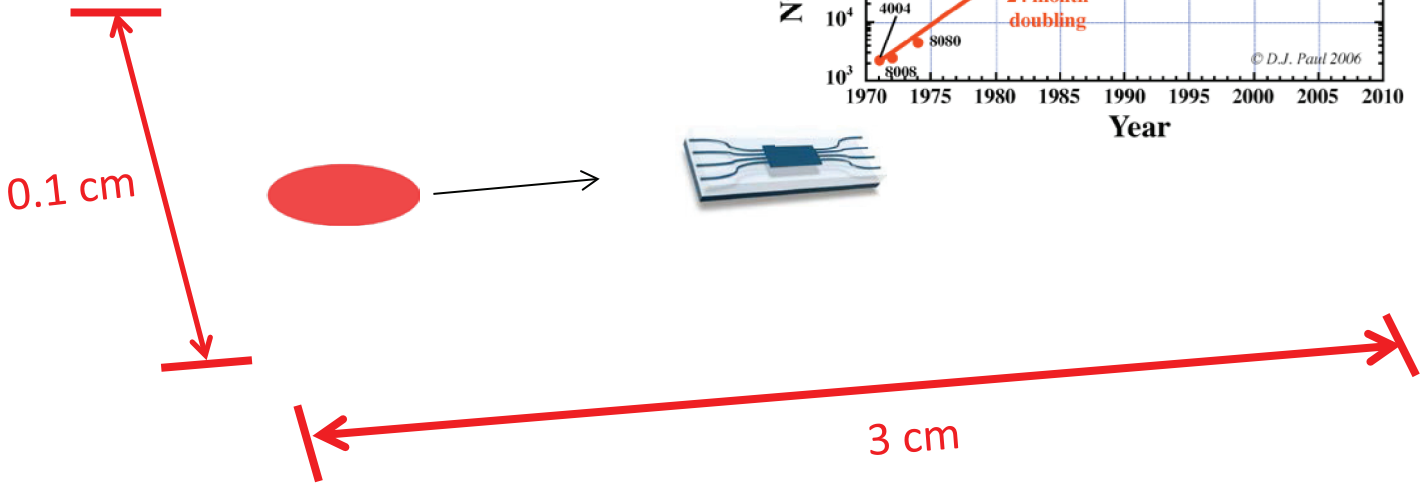
Credit: Intel official website

Trouble of Shrinking





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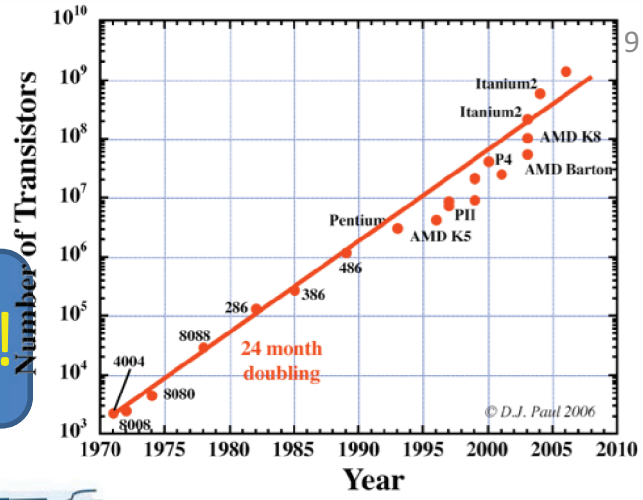

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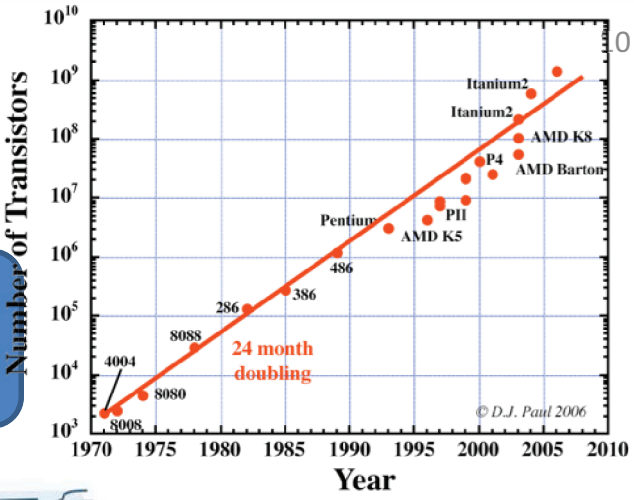
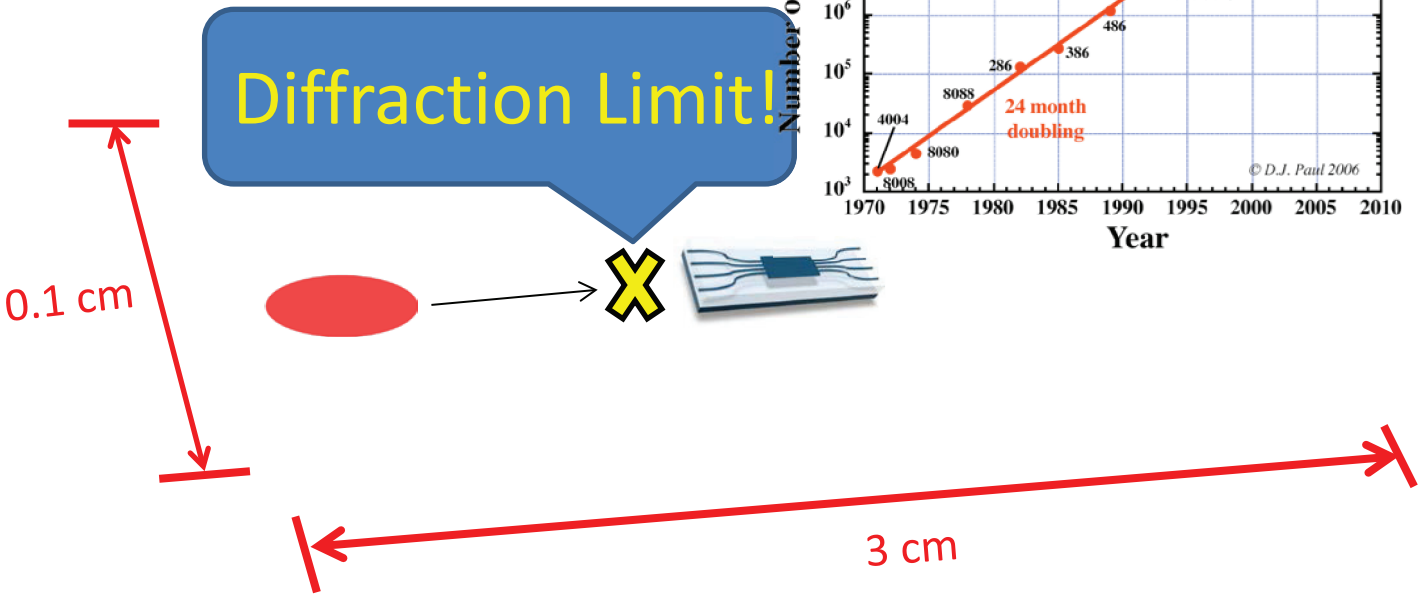
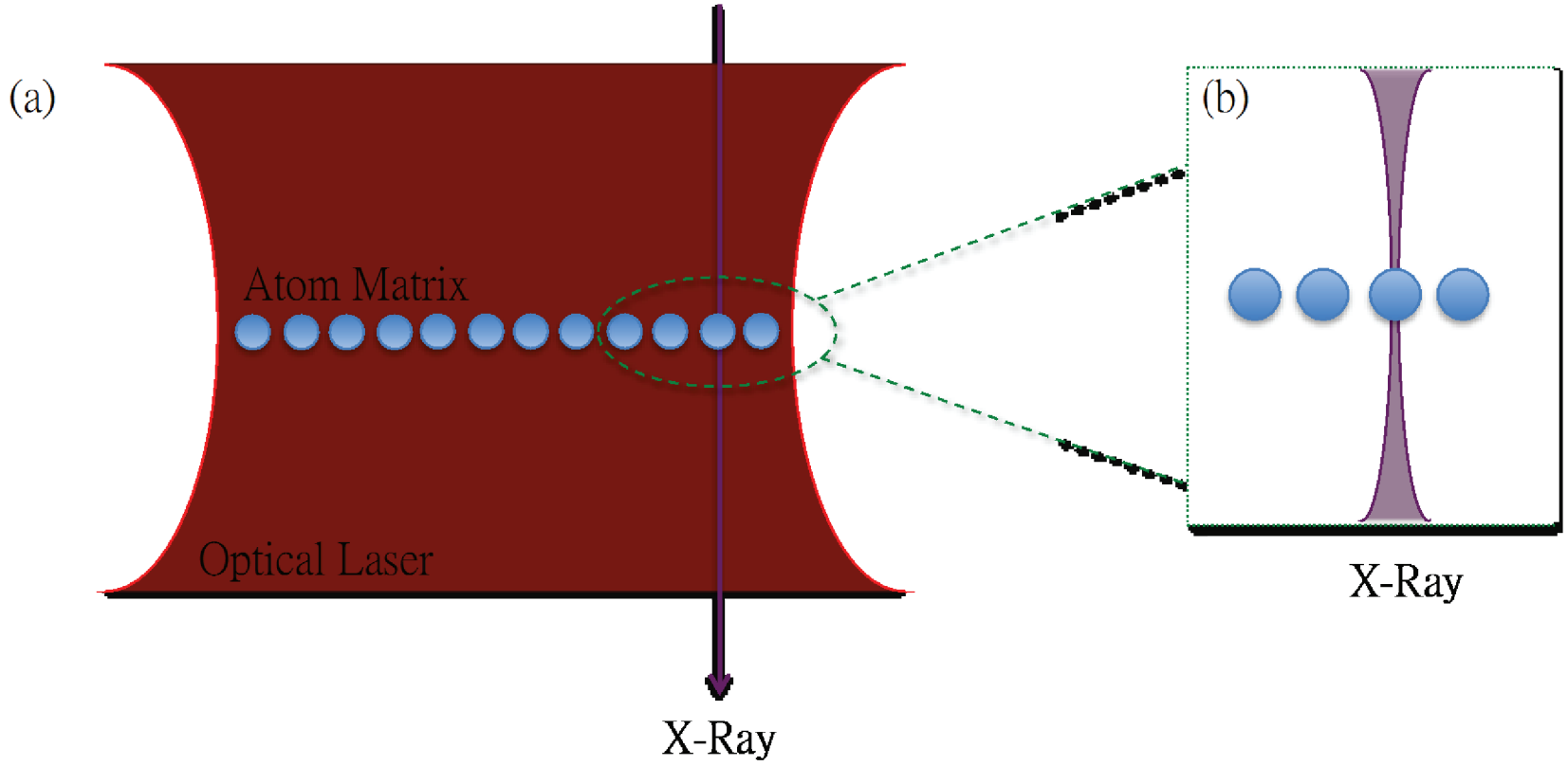


Trouble of Shrinking



Single Atom Memory



Control of single x-ray photon

Degree of freedom:

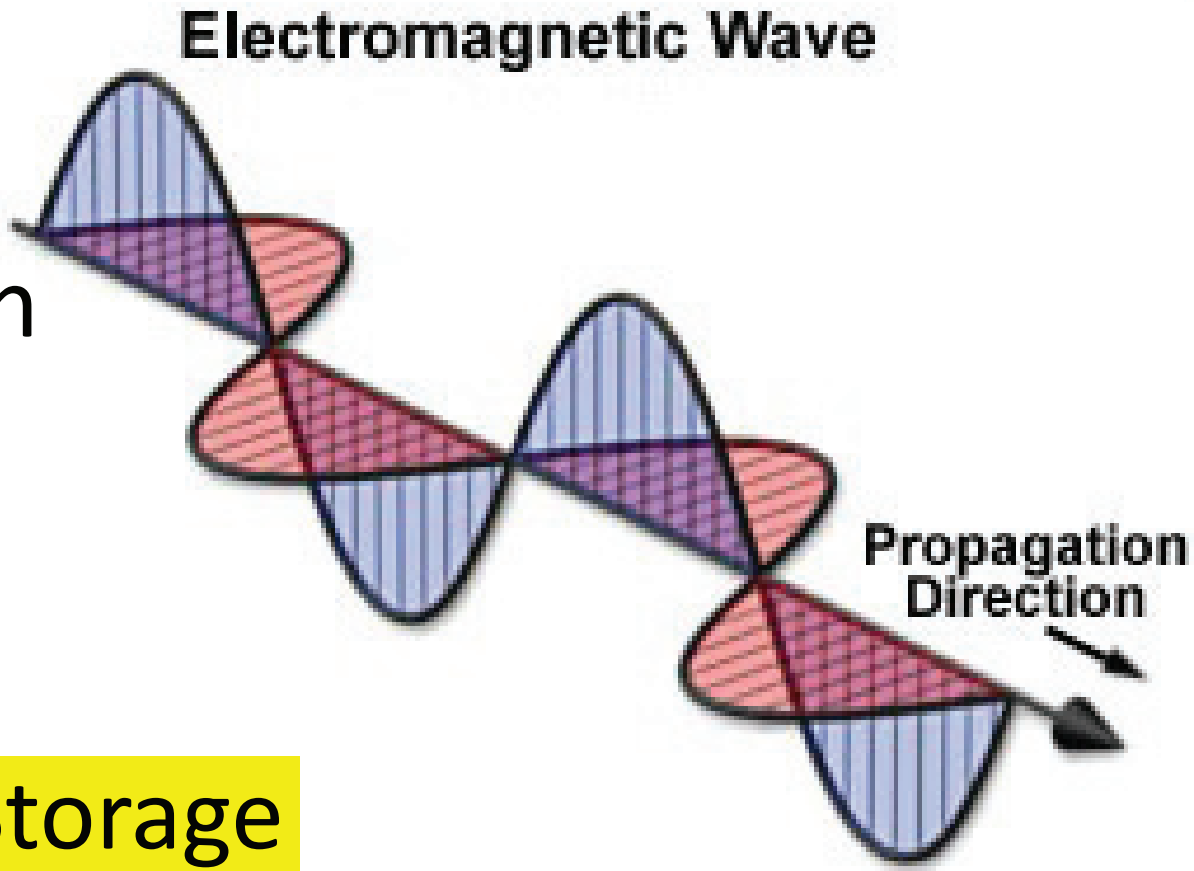
(1)Polarization

(2)Phase

(3)Amplitude

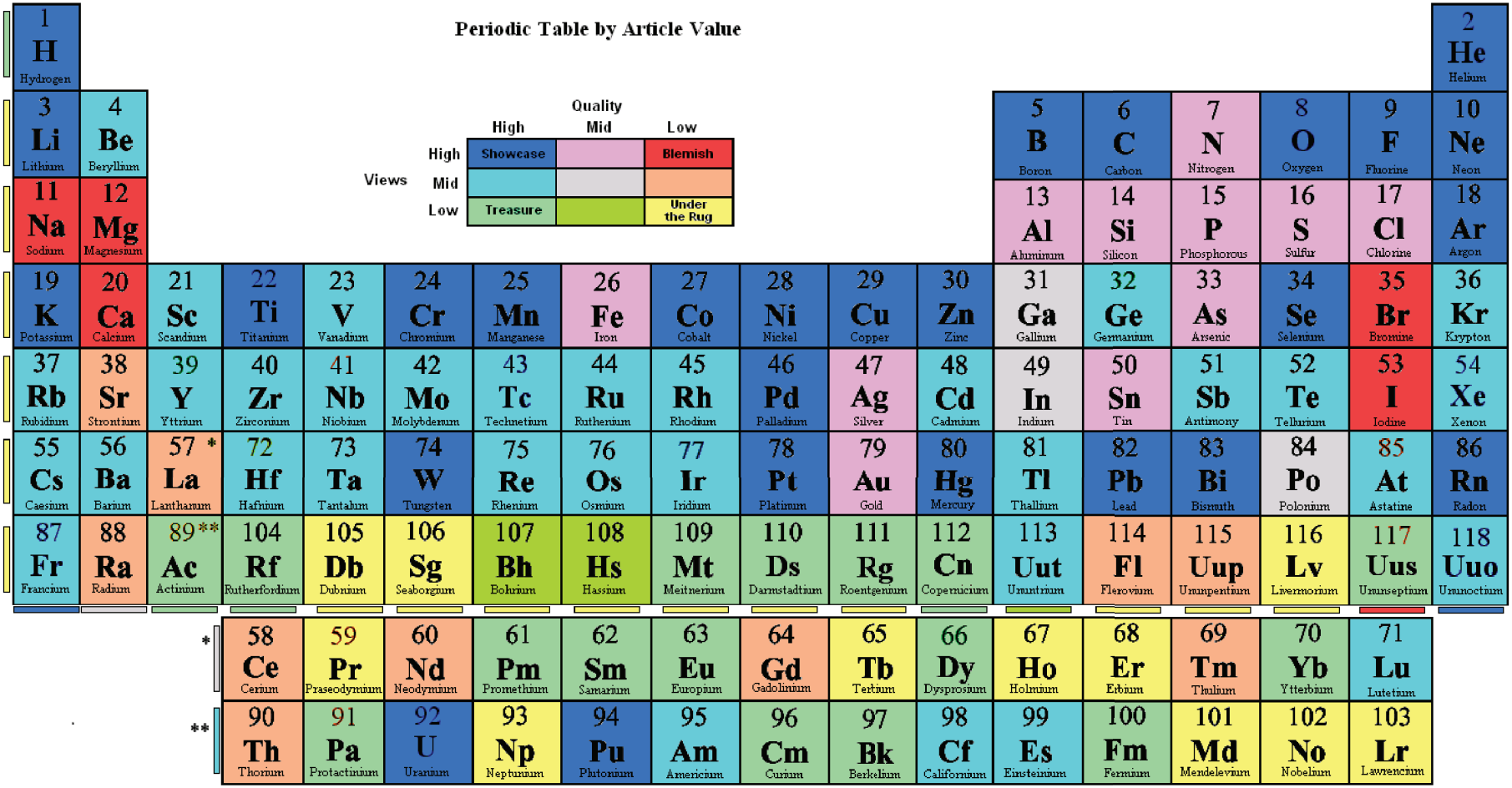
&

(4)Coherent Storage



Credit: Molecular Expressions website

^{57}Fe Nucleus



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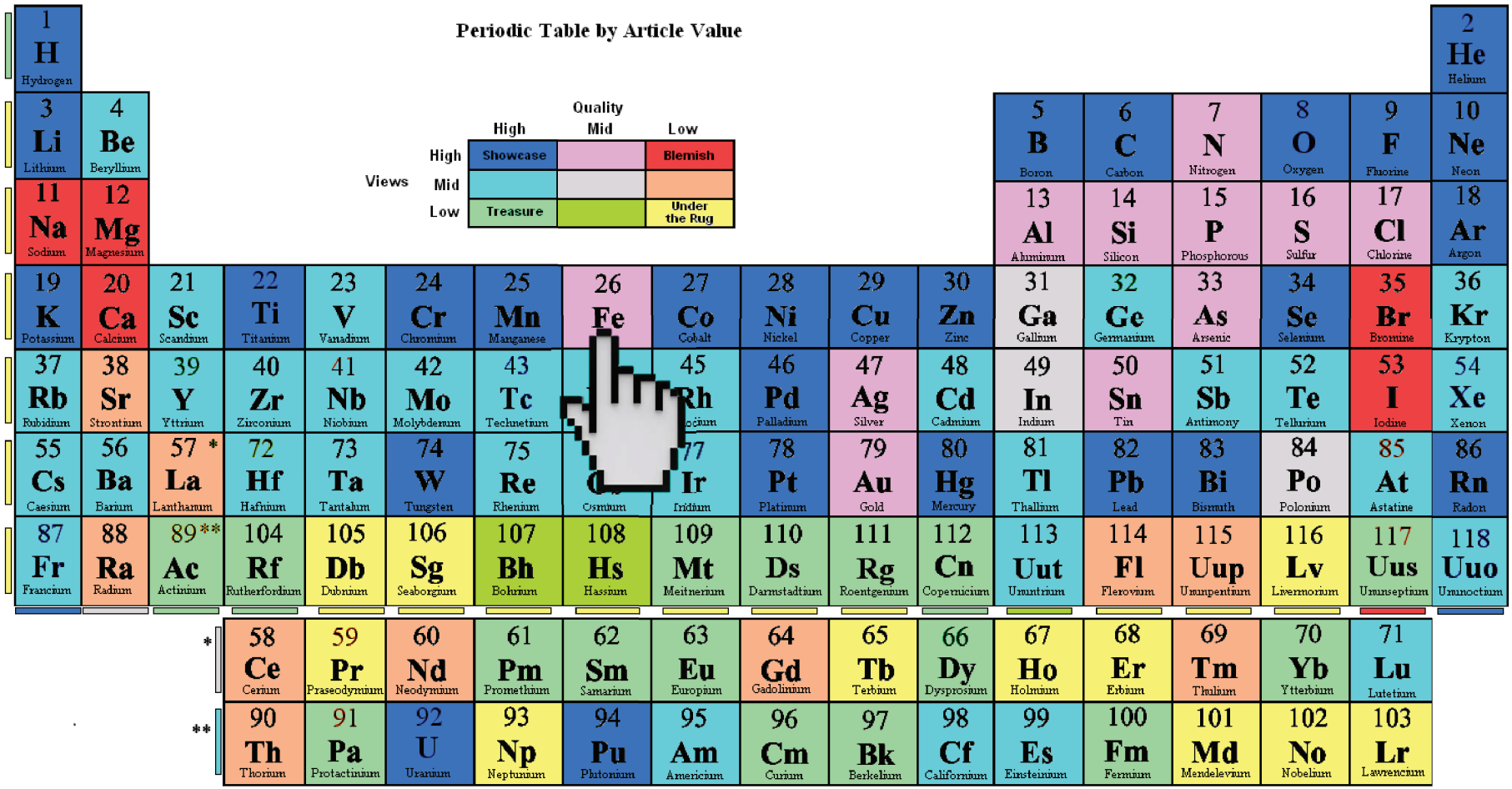

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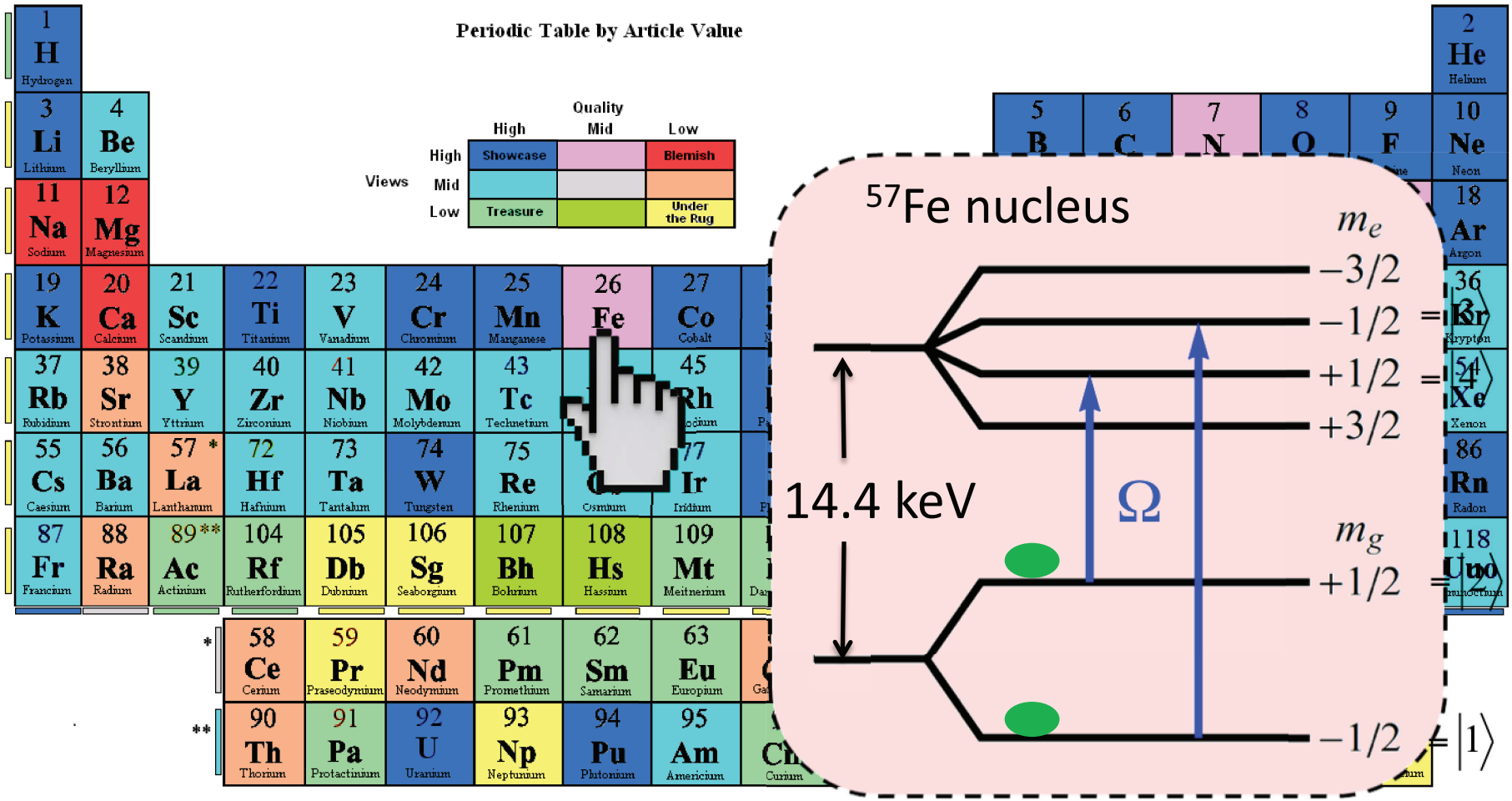
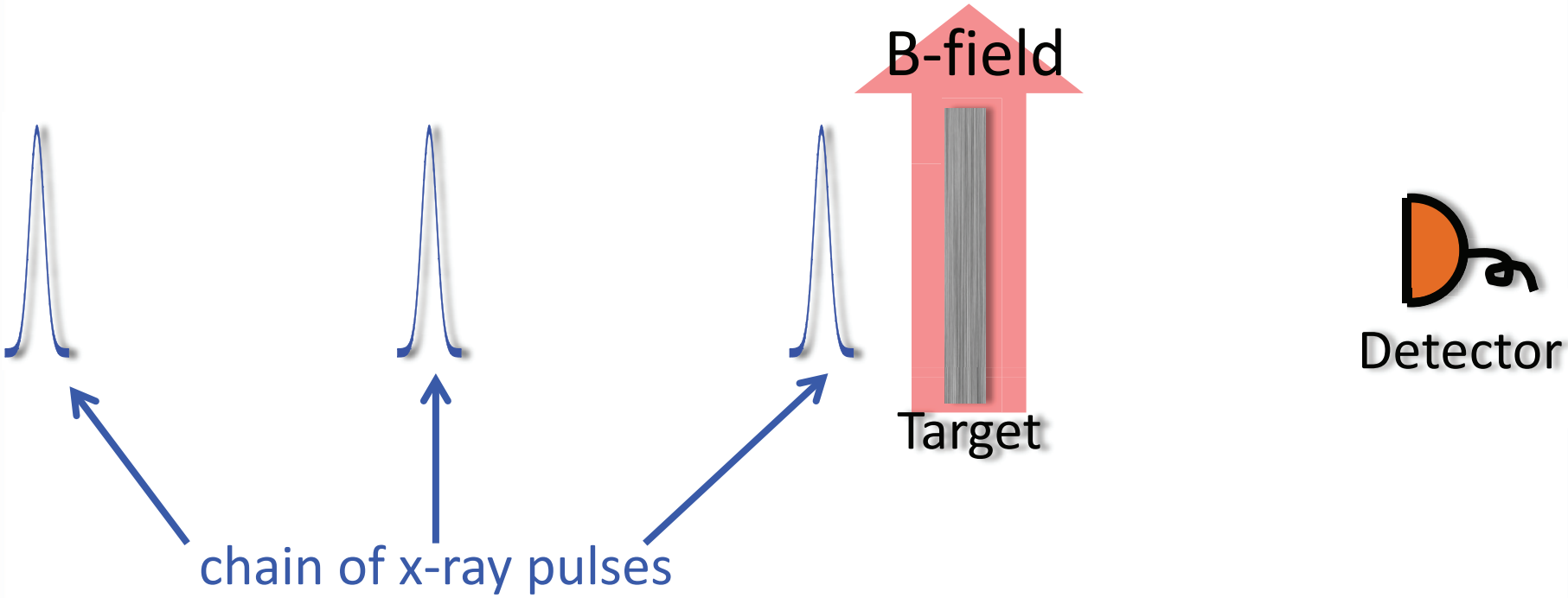
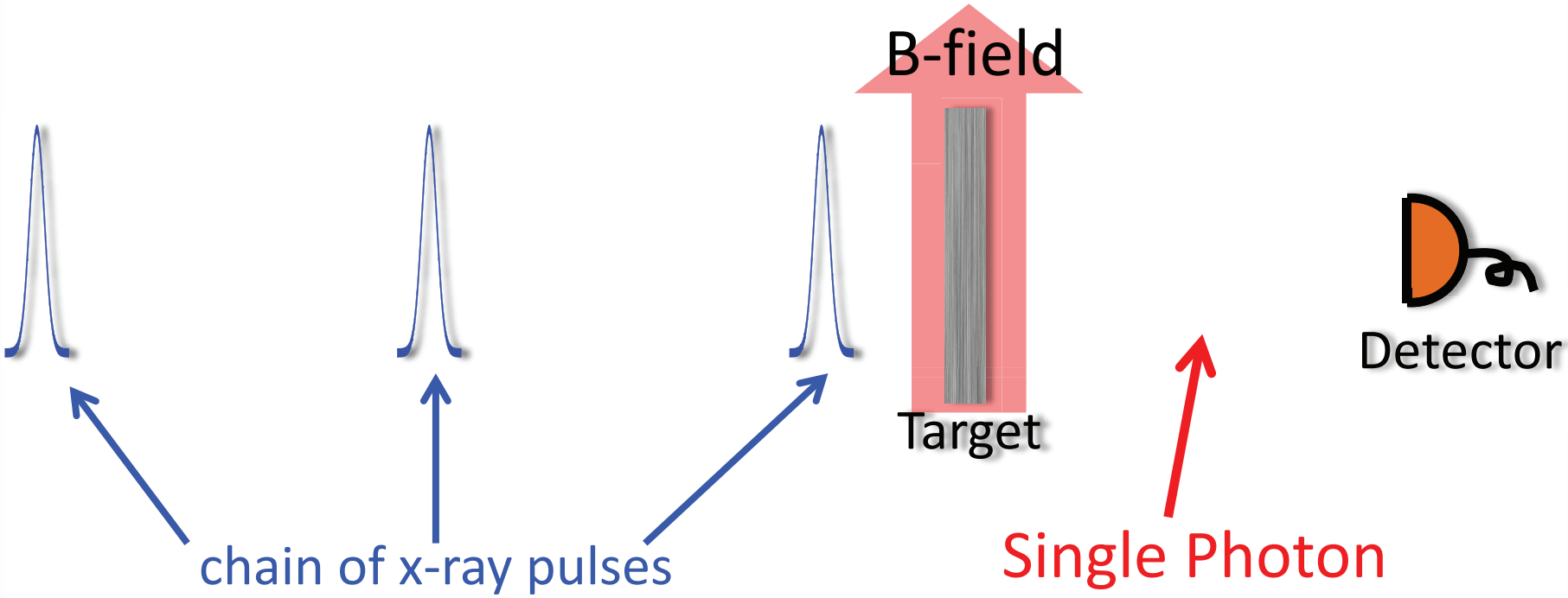


Nuclear Forward Scattering Time Spectrum



R. Röhlsberger, Book, Springer-Verlag (2004)

Nuclear Forward Scattering Time Spectrum



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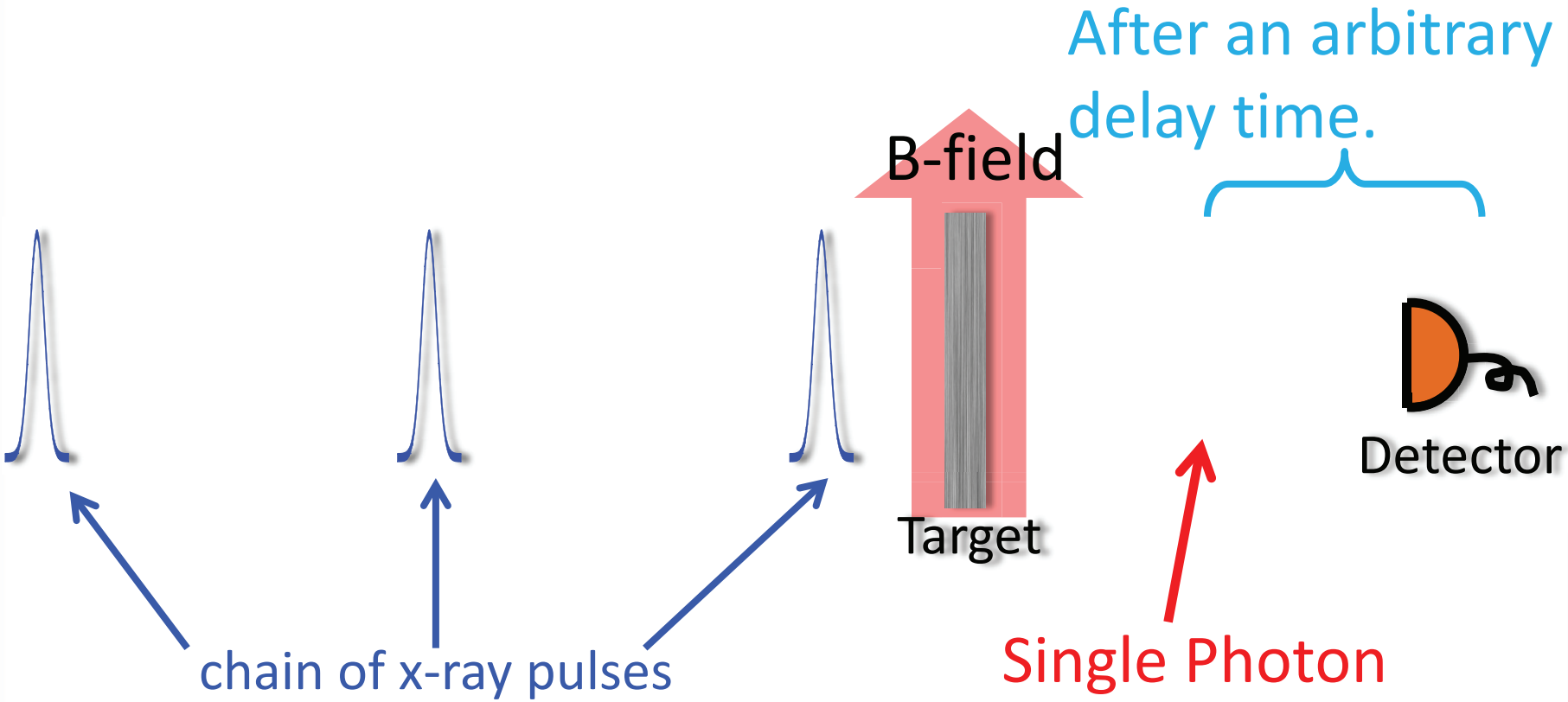
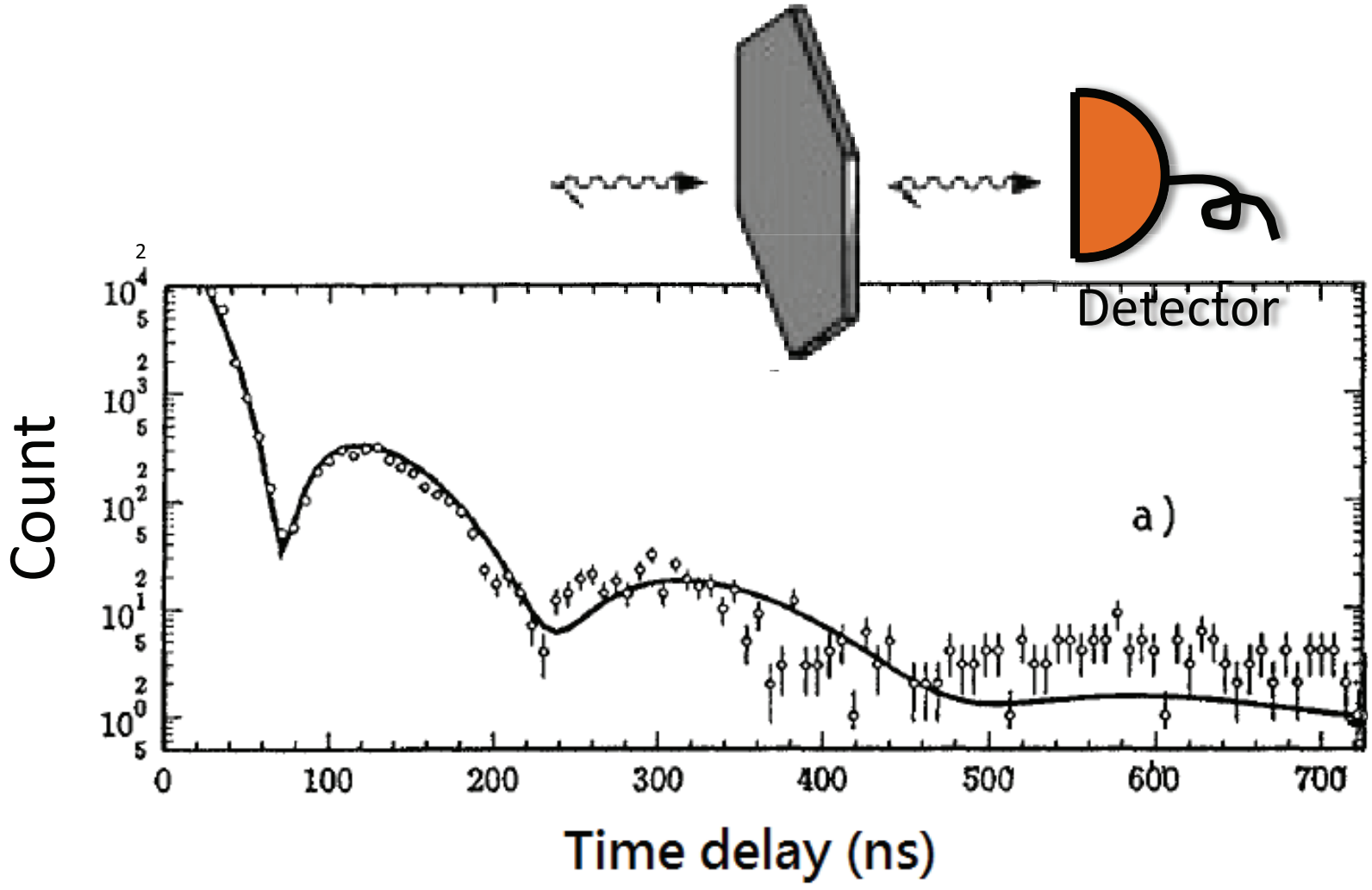
Nuclear Forward Scattering Time Spectrum



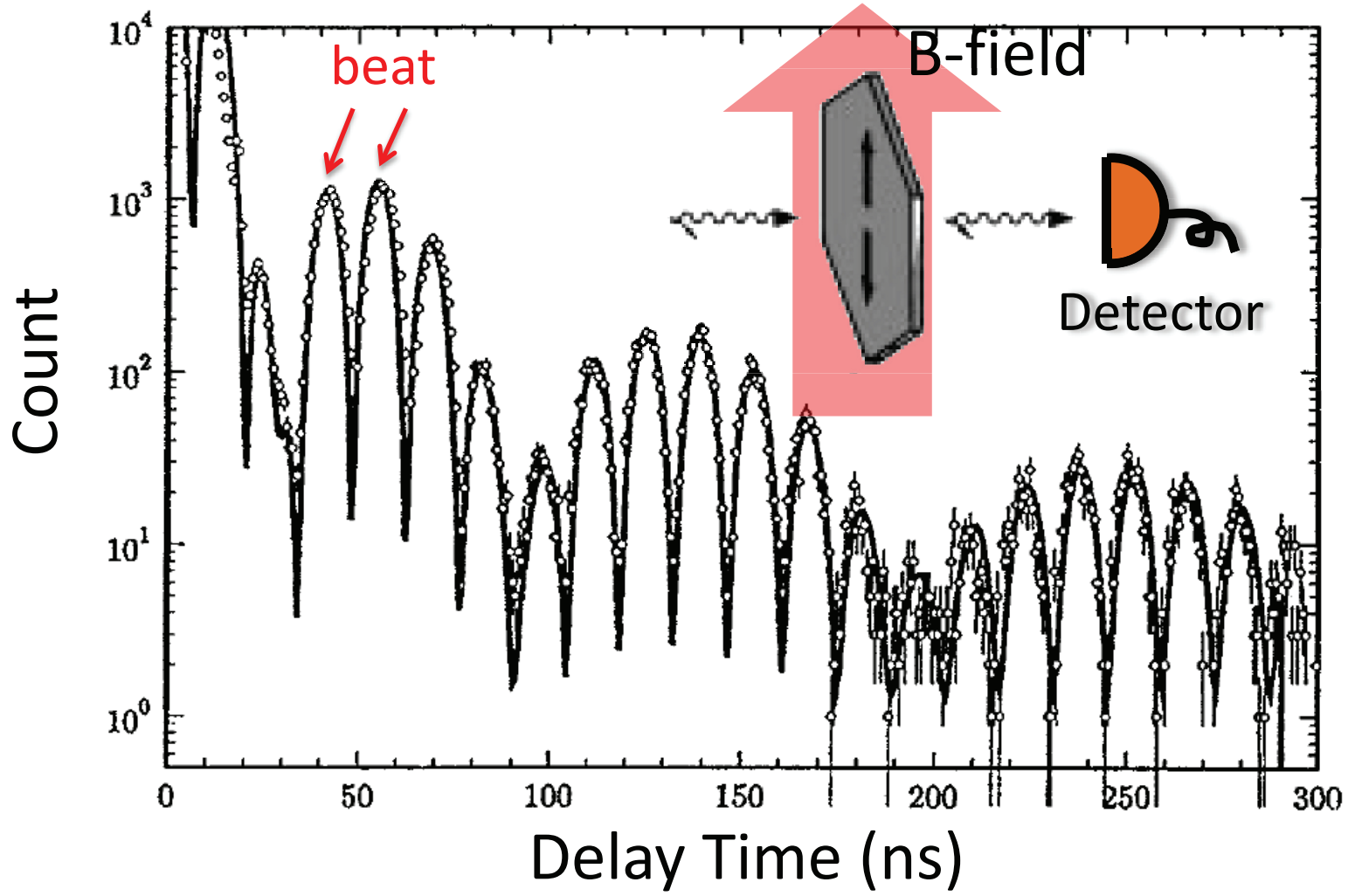
R. Röhlsberger, Book, Springer-Verlag (2004)

Time Spectrum without Hyperfine field



U. van Brück, Hyperfine Interact. 123, 483 (1999)

Time Spectrum with Hyperfine field



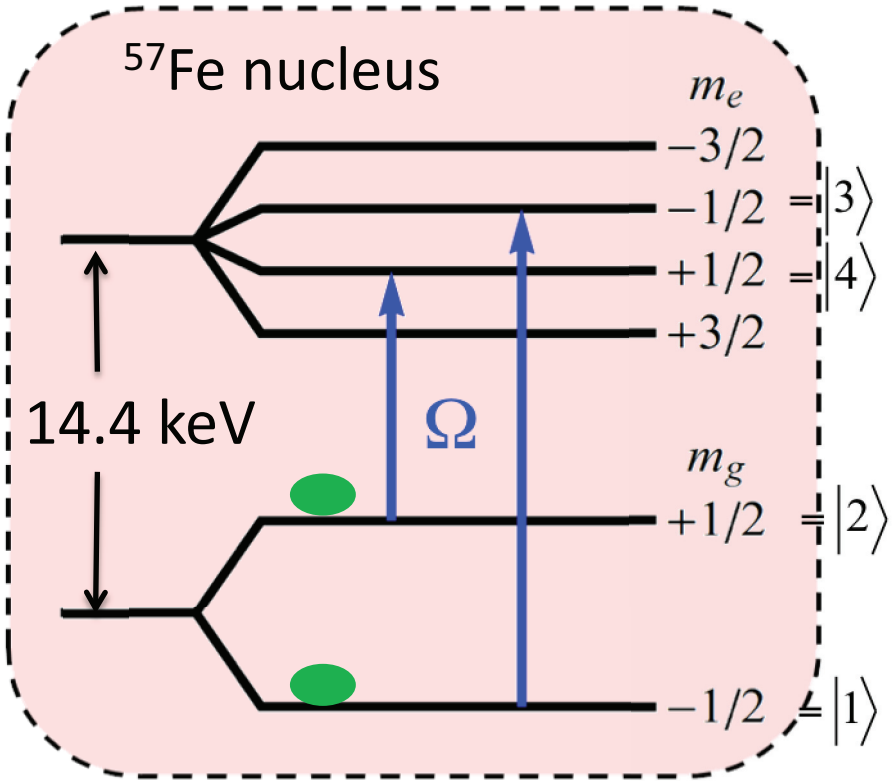
U. van Brück, Hyperfine Interact. 123, 483 (1999)

Maxwell-Bloch equations

$$\partial_t \hat{\rho} = \frac{1}{i\hbar}\left[\hat{H}, \hat{\rho}\right] + \hat{\rho}_s \,,$$

$$\frac{1}{c}\partial_t \Omega + \partial_y \Omega = i\eta\left(\rho_{31} + \rho_{42}\right)$$

Transition Currents



W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)

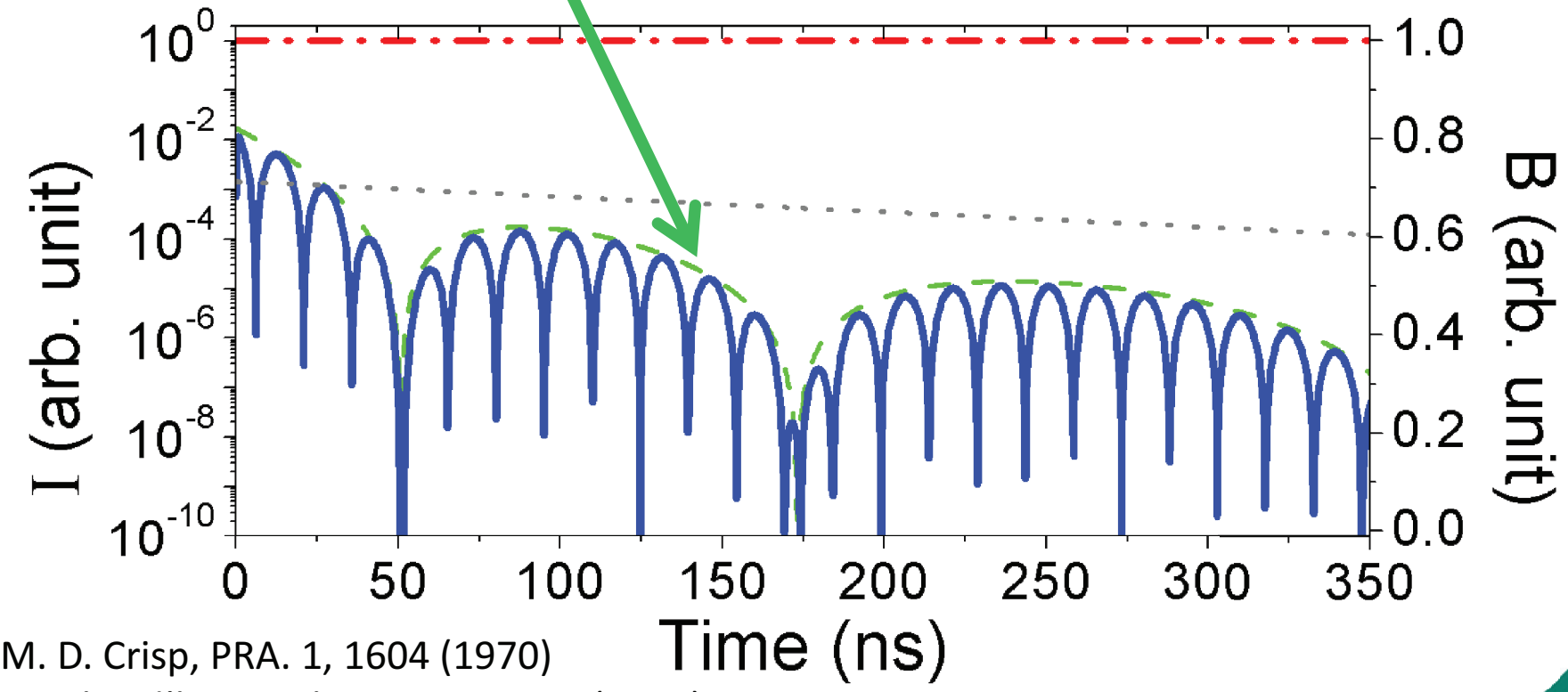
Solution

$$\left(\frac{\alpha}{\sqrt{\alpha\Gamma t}} J_1\left[2\sqrt{\alpha\Gamma t}\right]\right)^2 e^{-\Gamma t}$$

J_1: Bessel function of 1st kind

Γ: Spontaneous Decay Rate

α: Resonant Thickness



M. D. Crisp, PRA. 1, 1604 (1970)

Yu. Shvyd'ko, et. al, PRB. 59, 9132 (1999)

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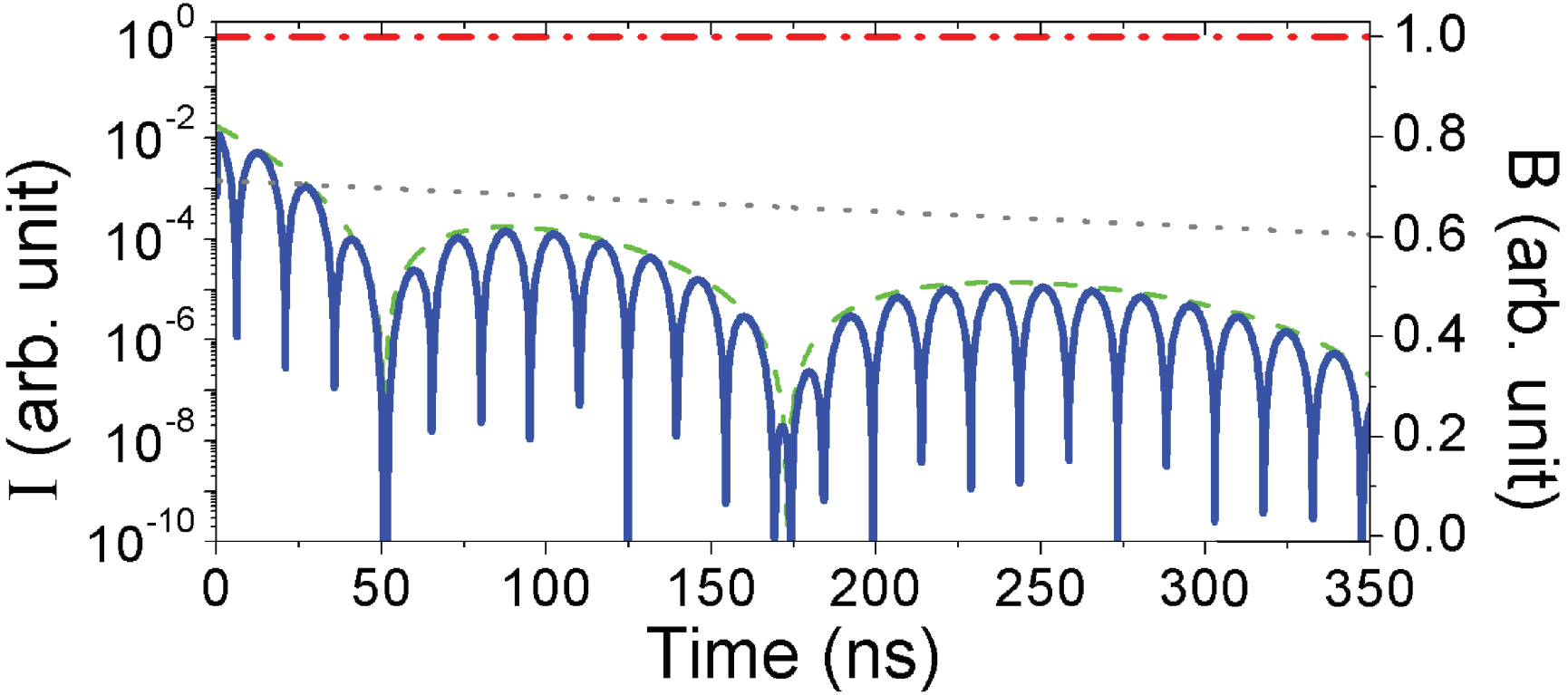
Why Beating?



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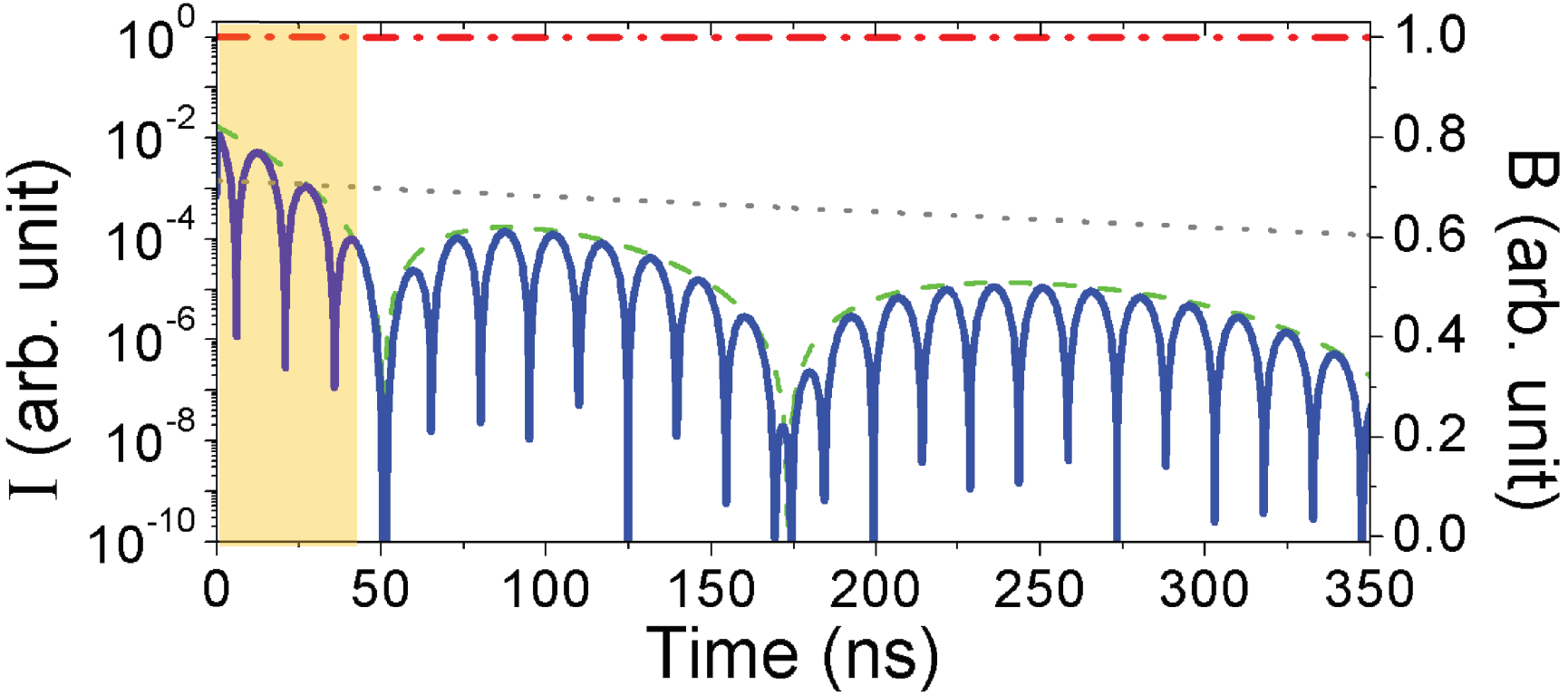

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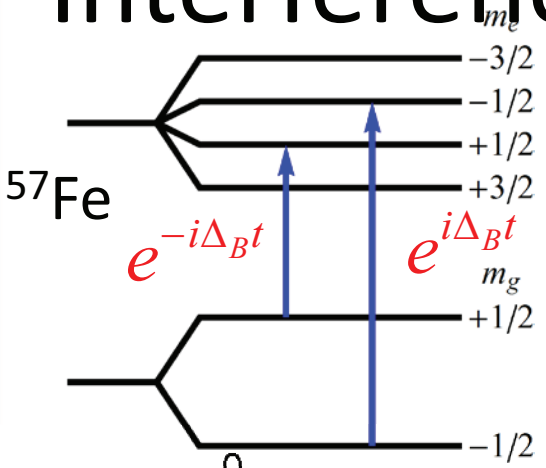
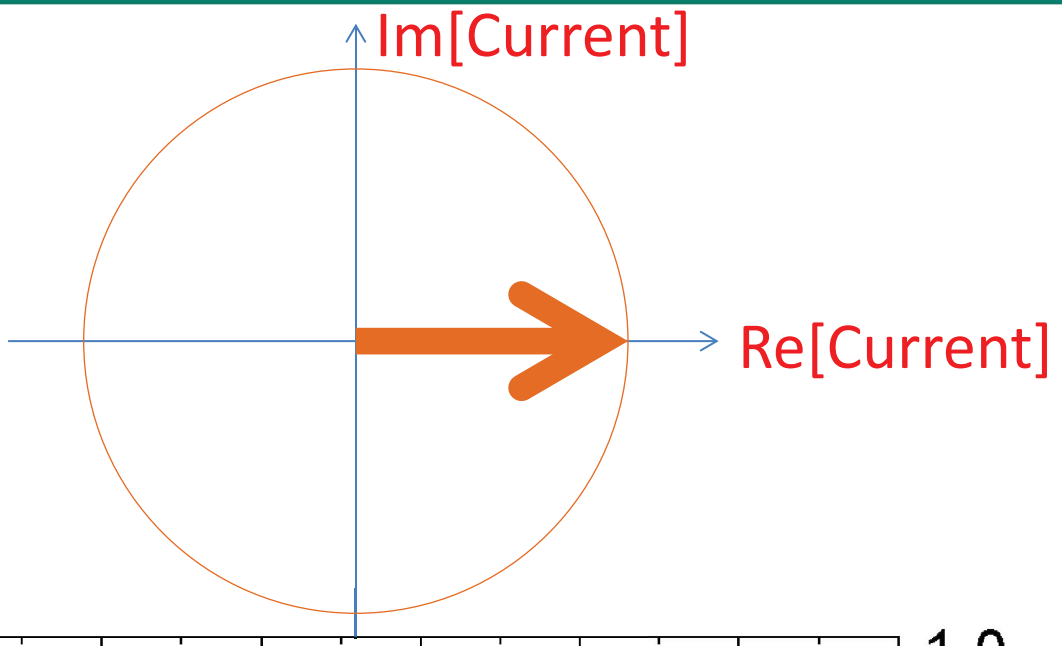
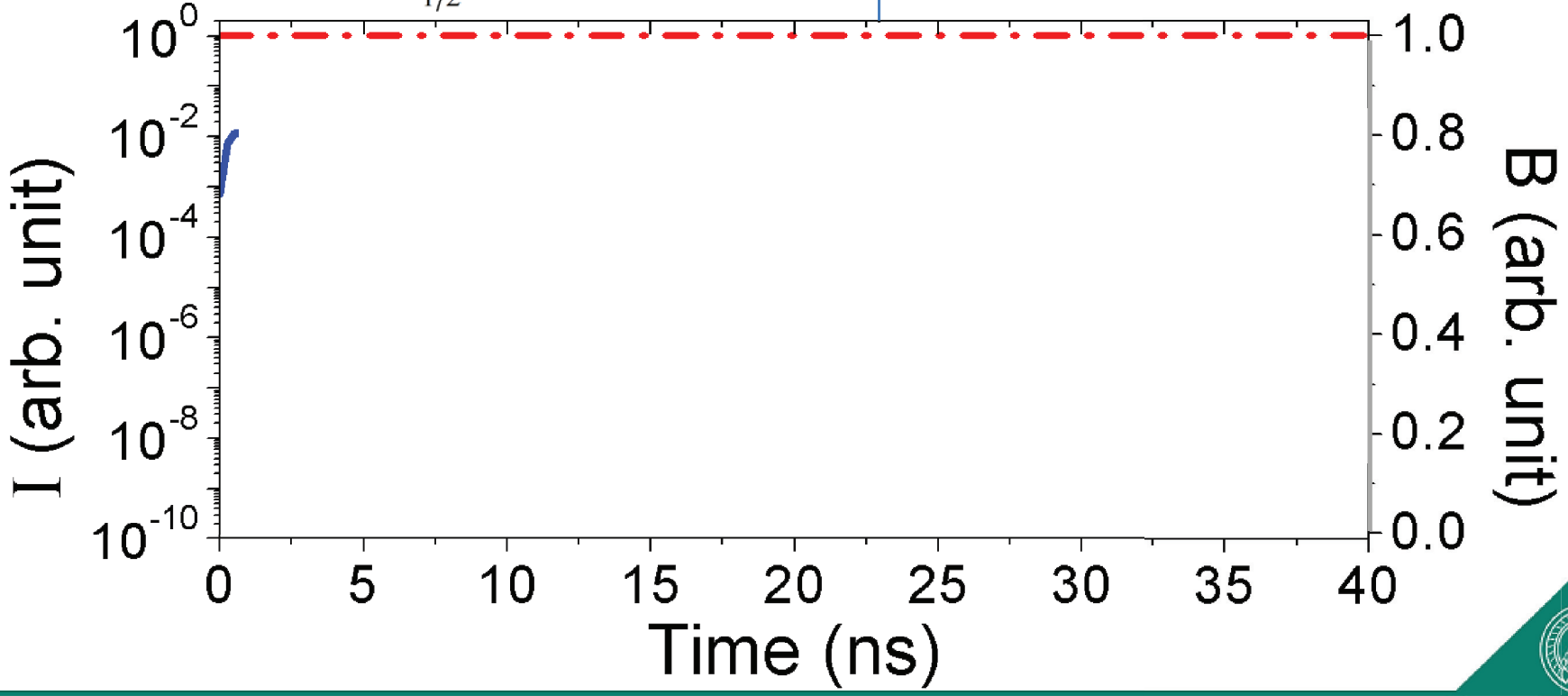
Interference







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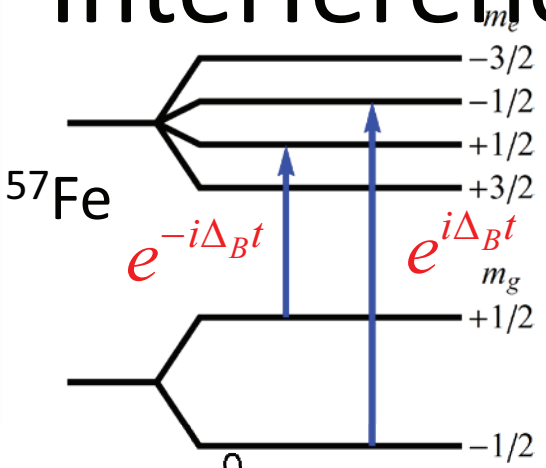

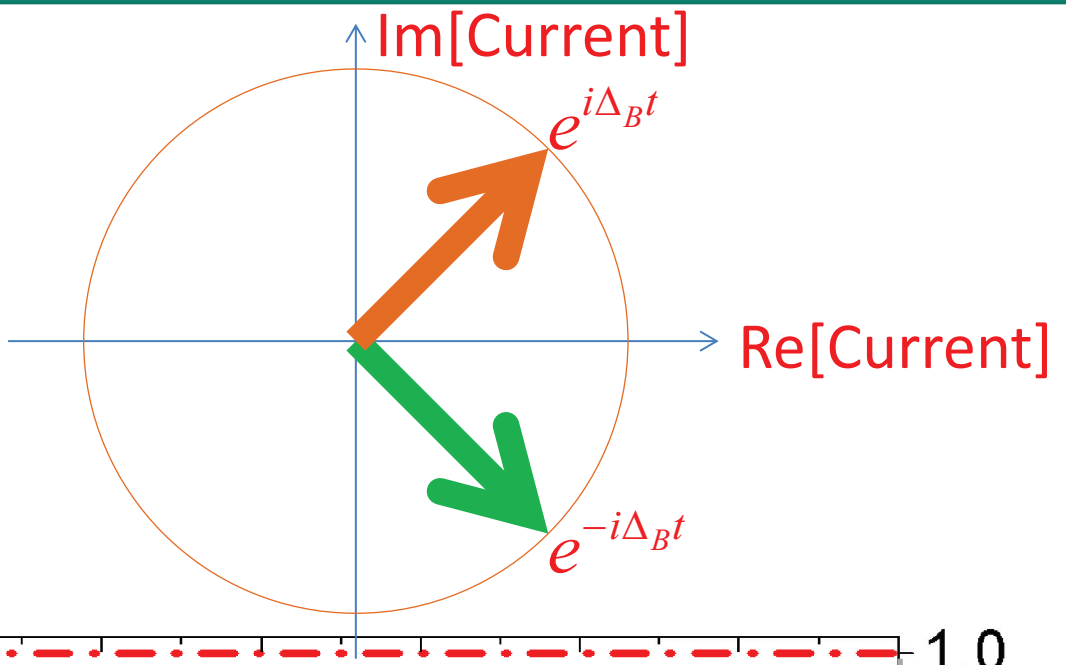

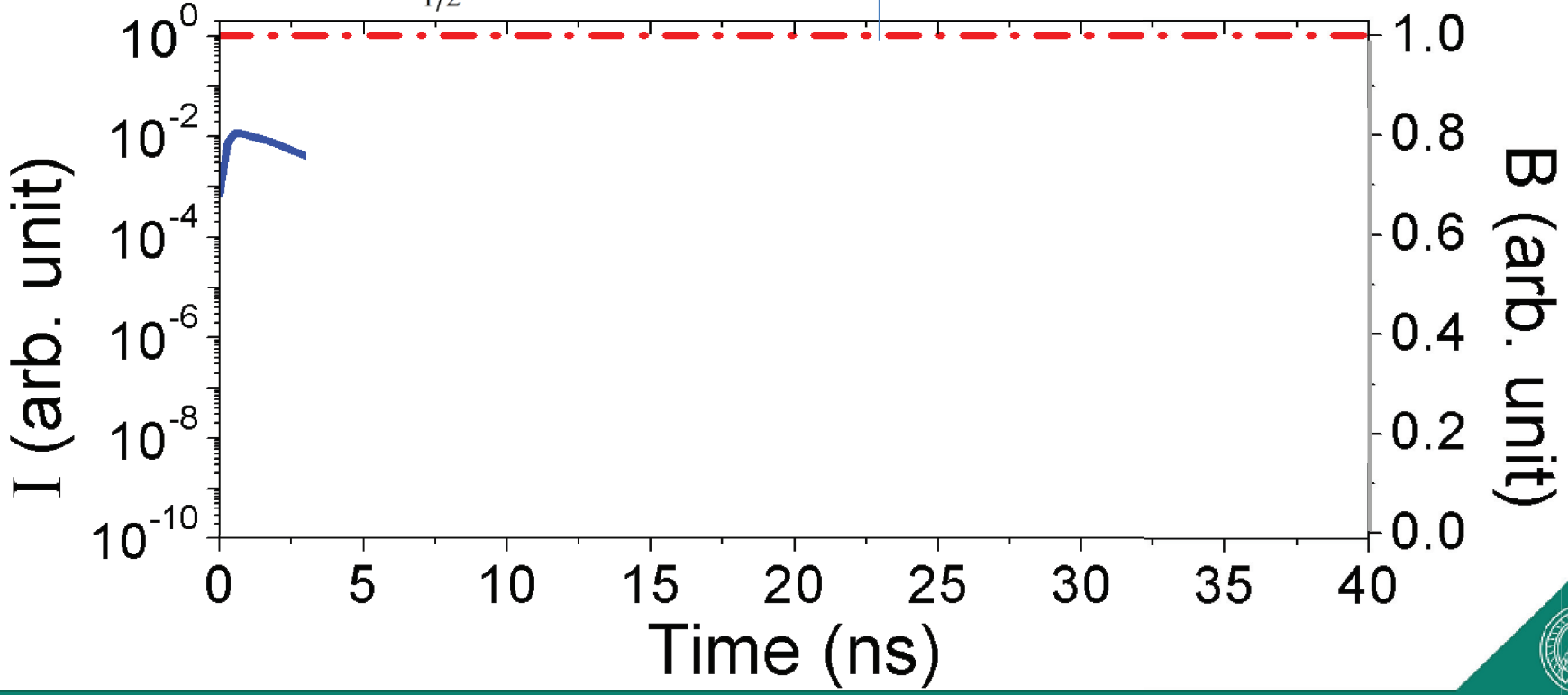

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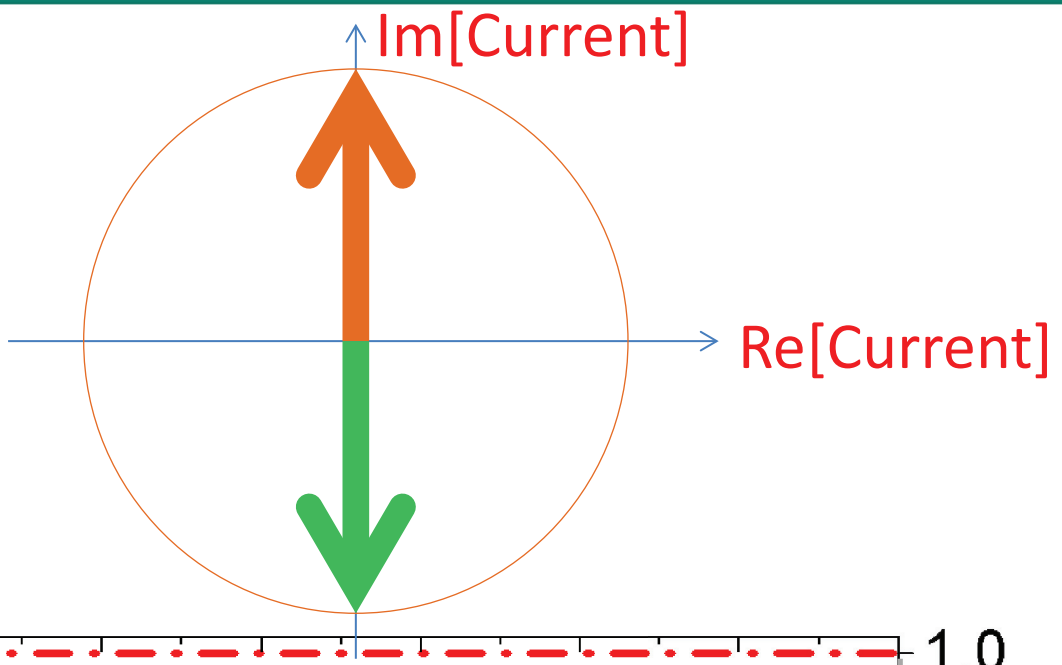

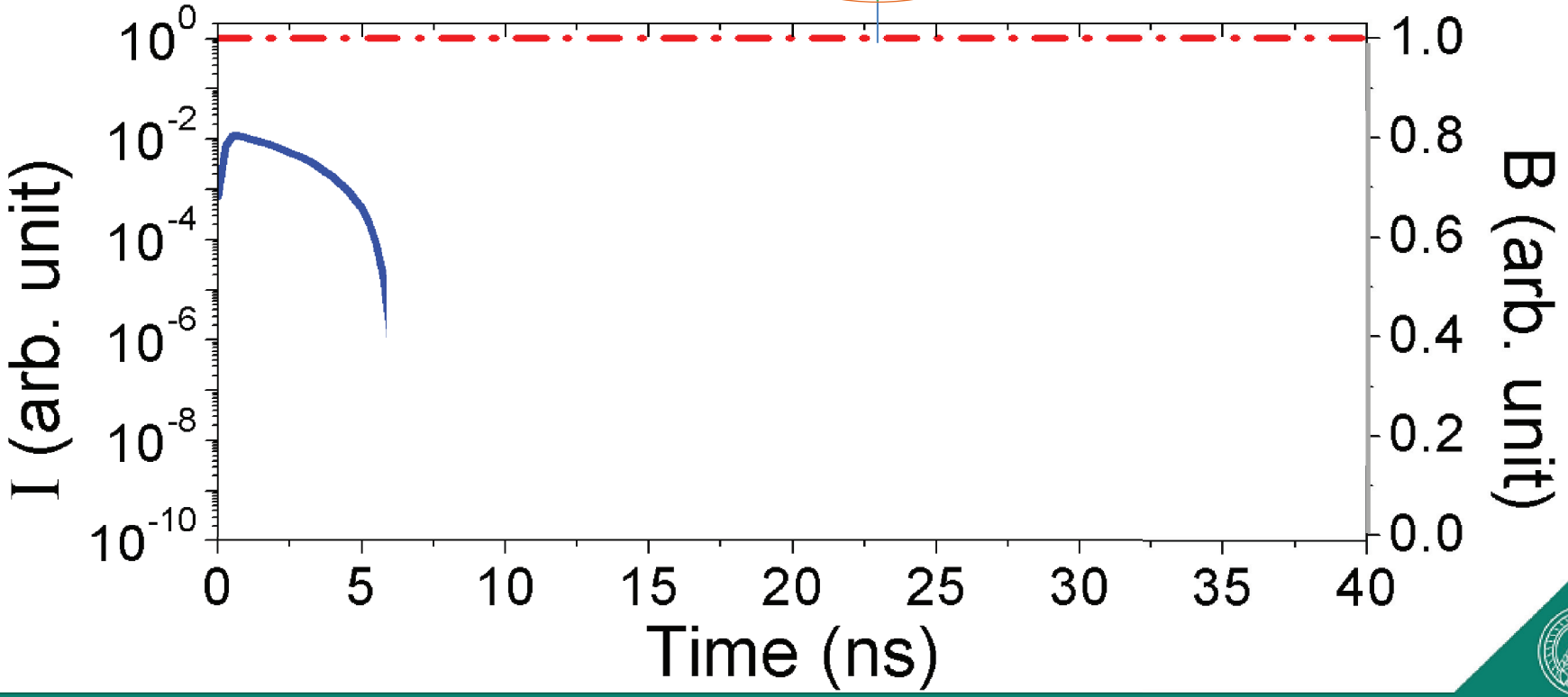

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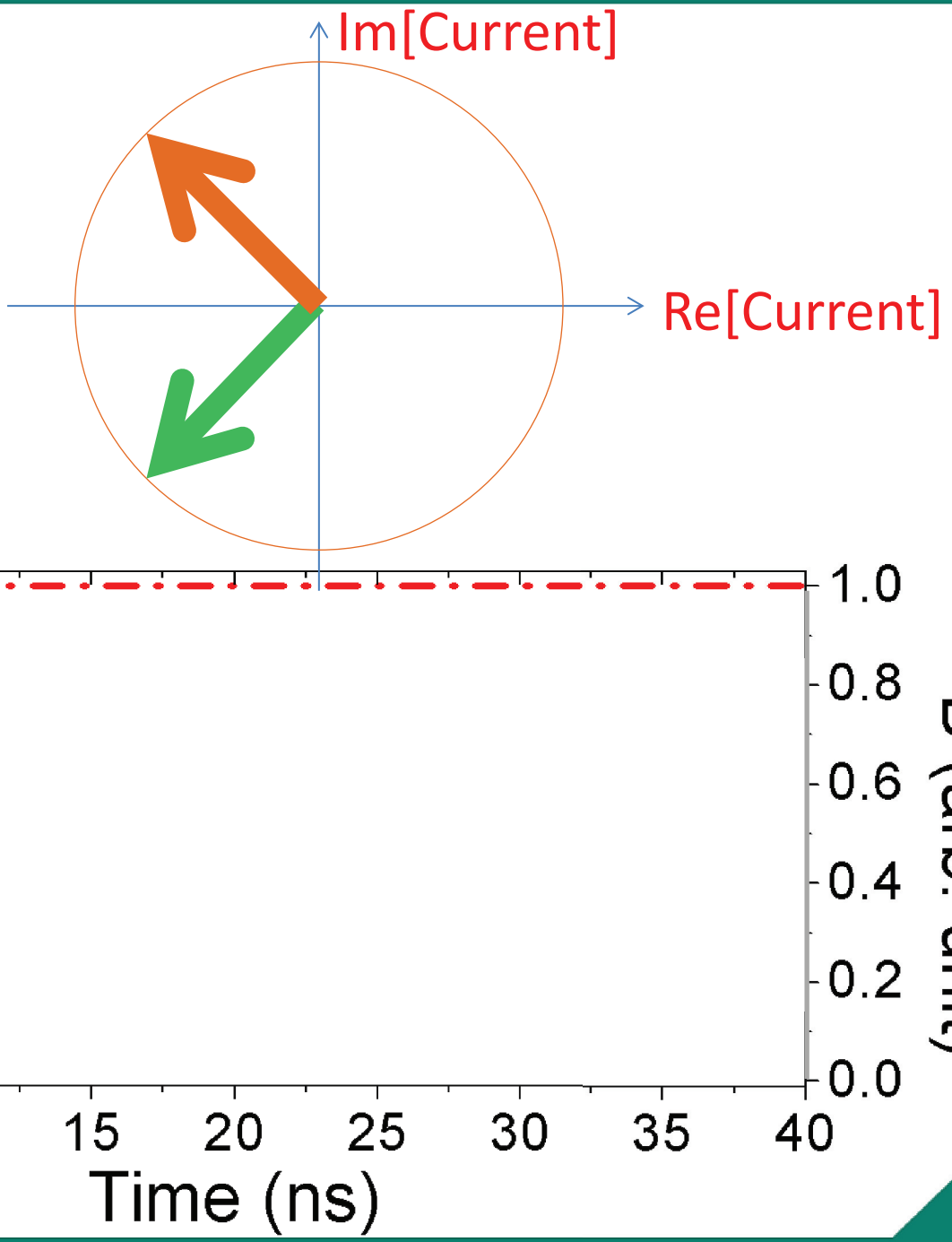

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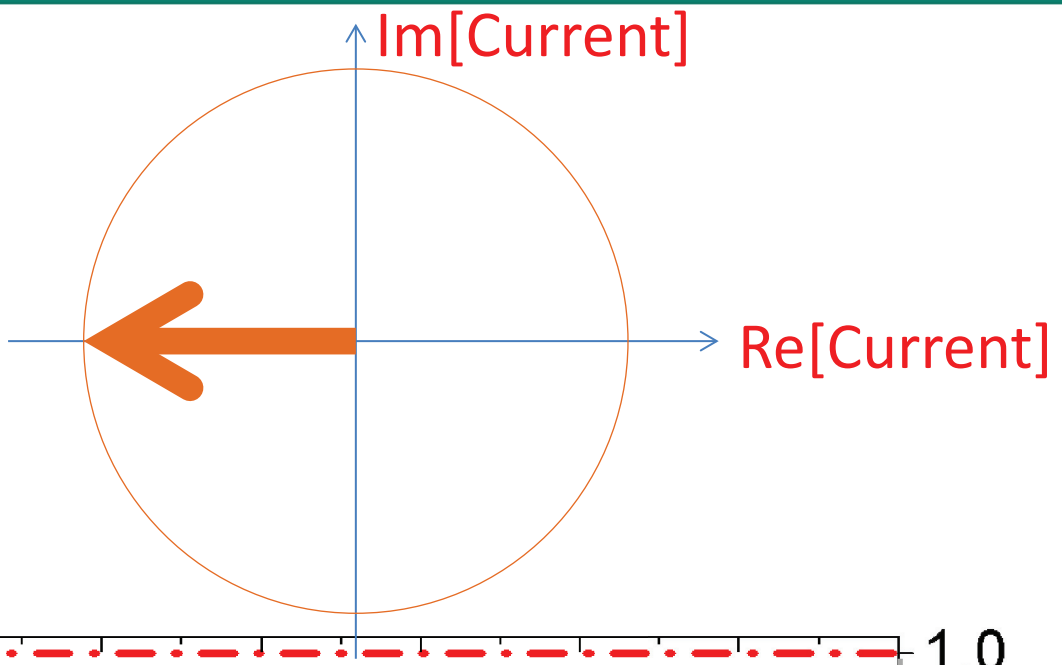

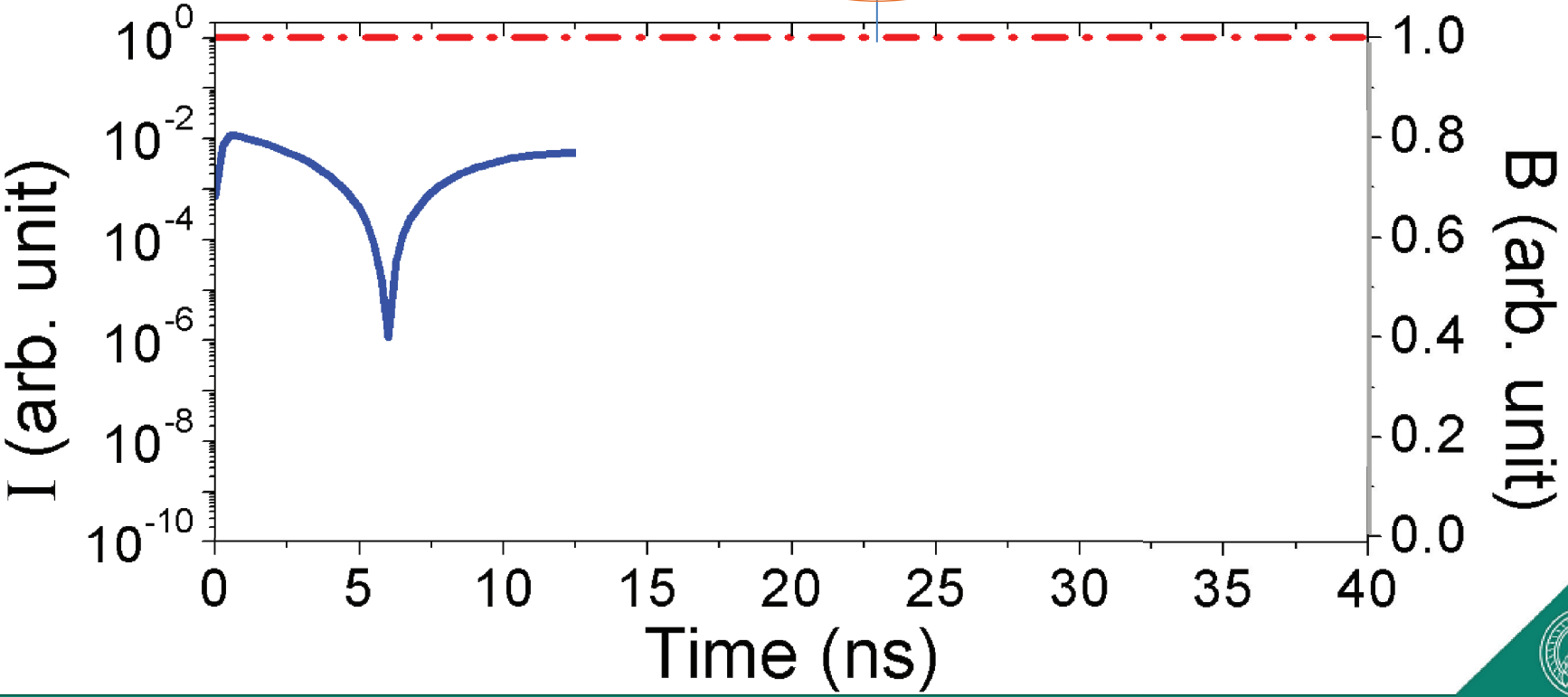

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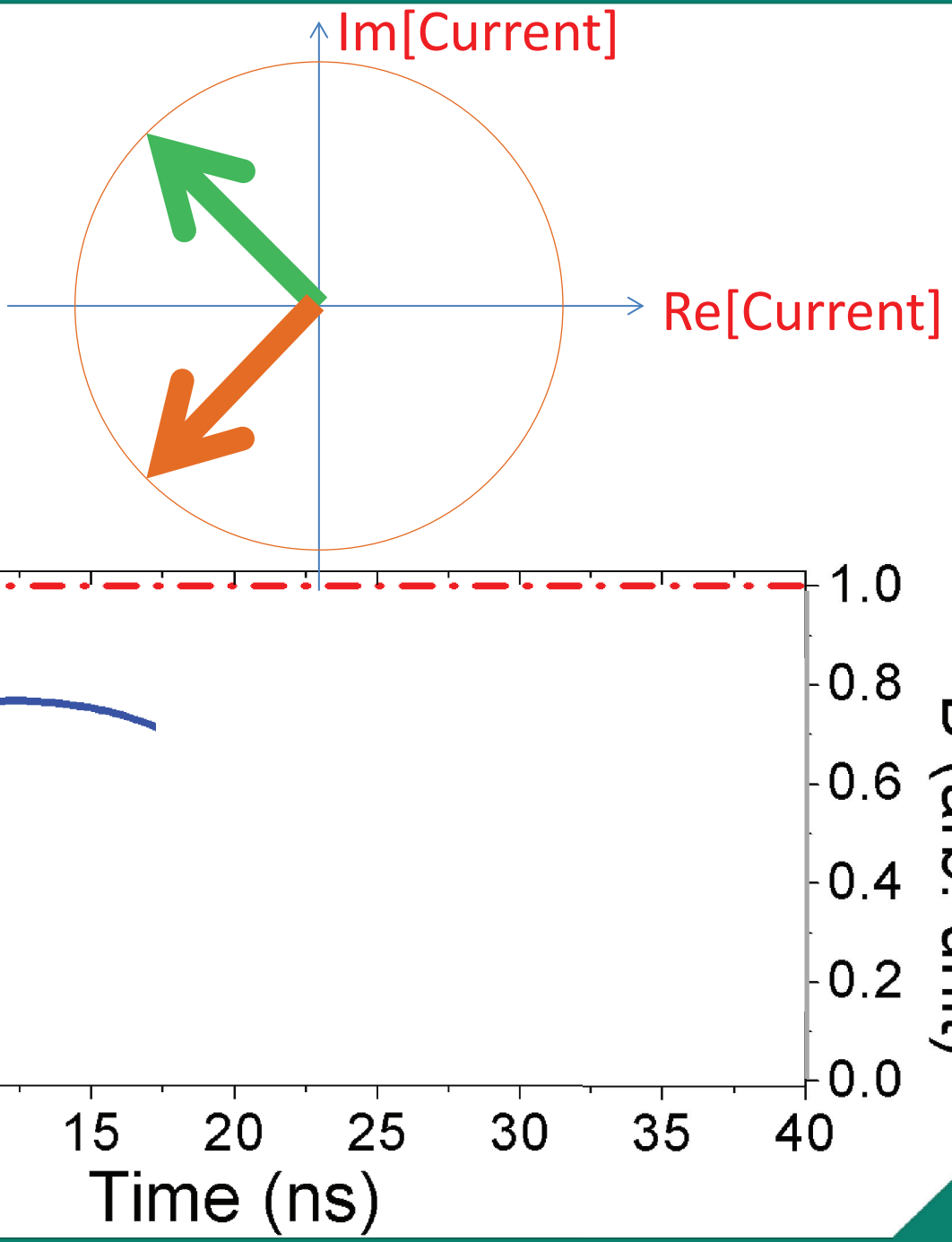

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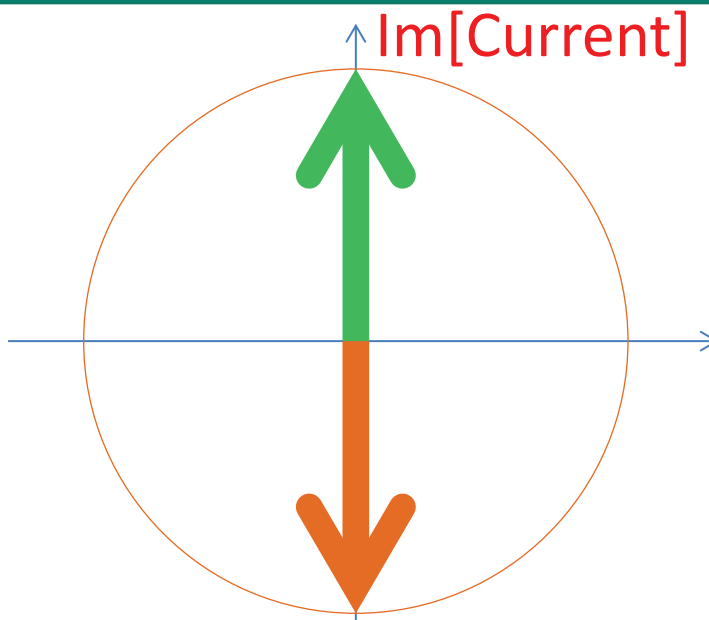
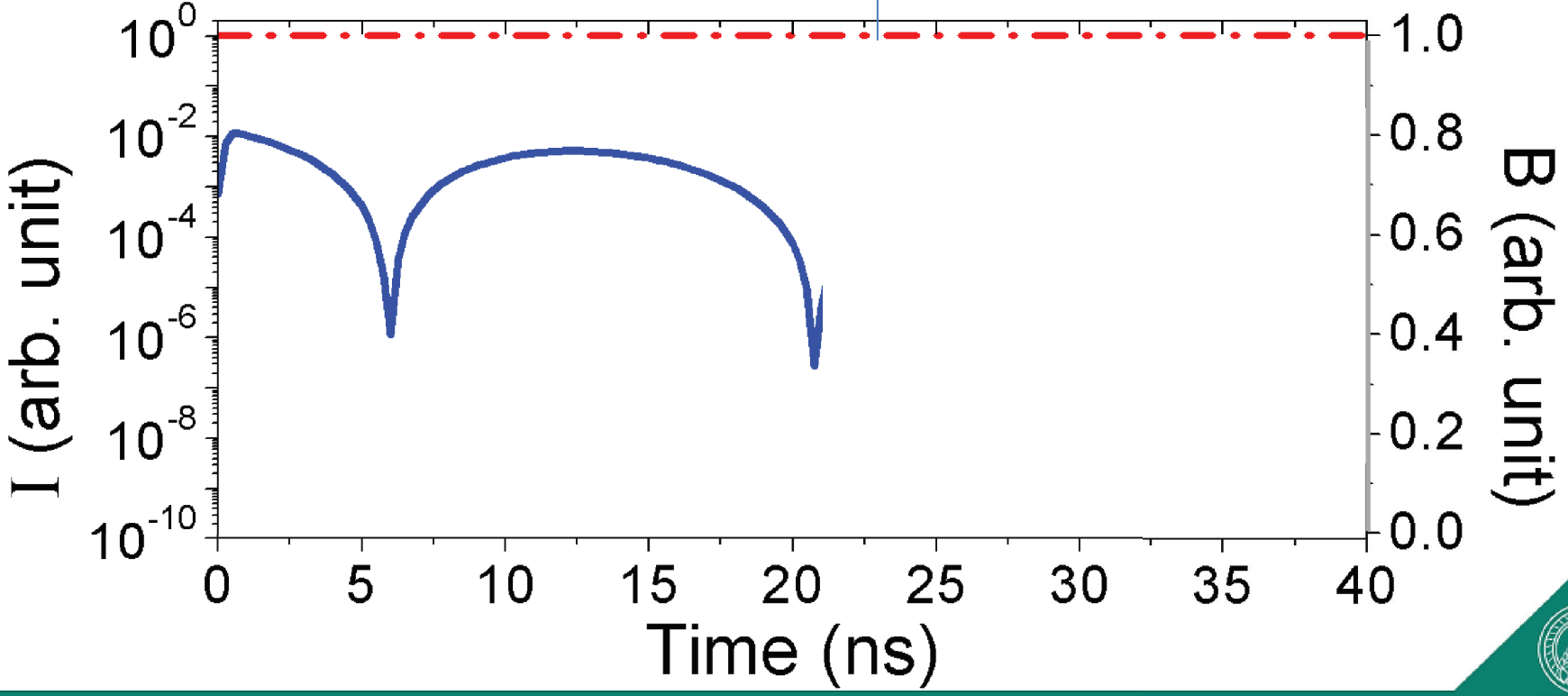
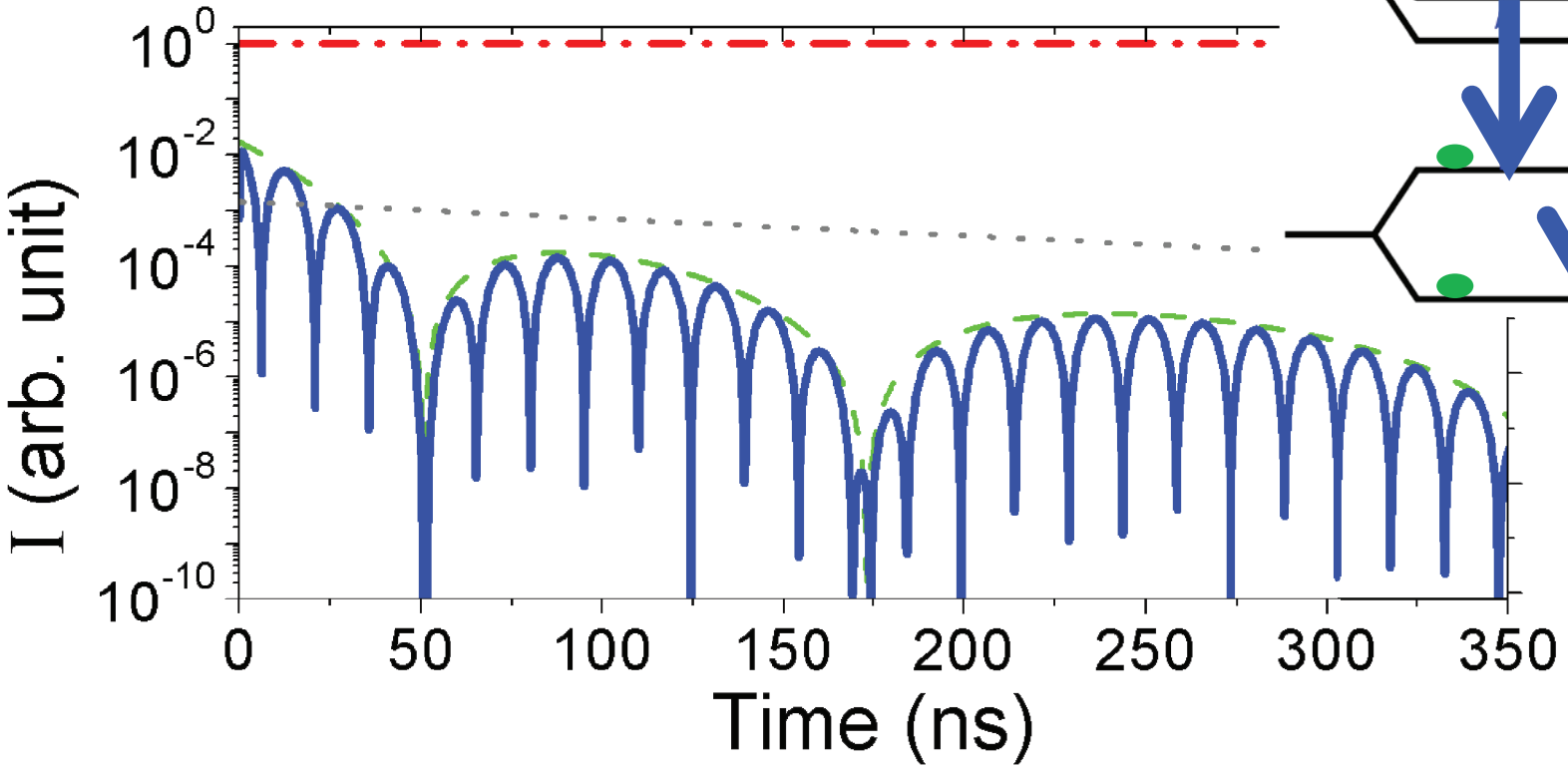
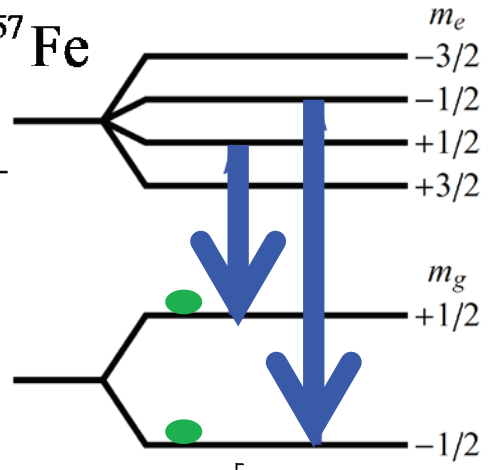




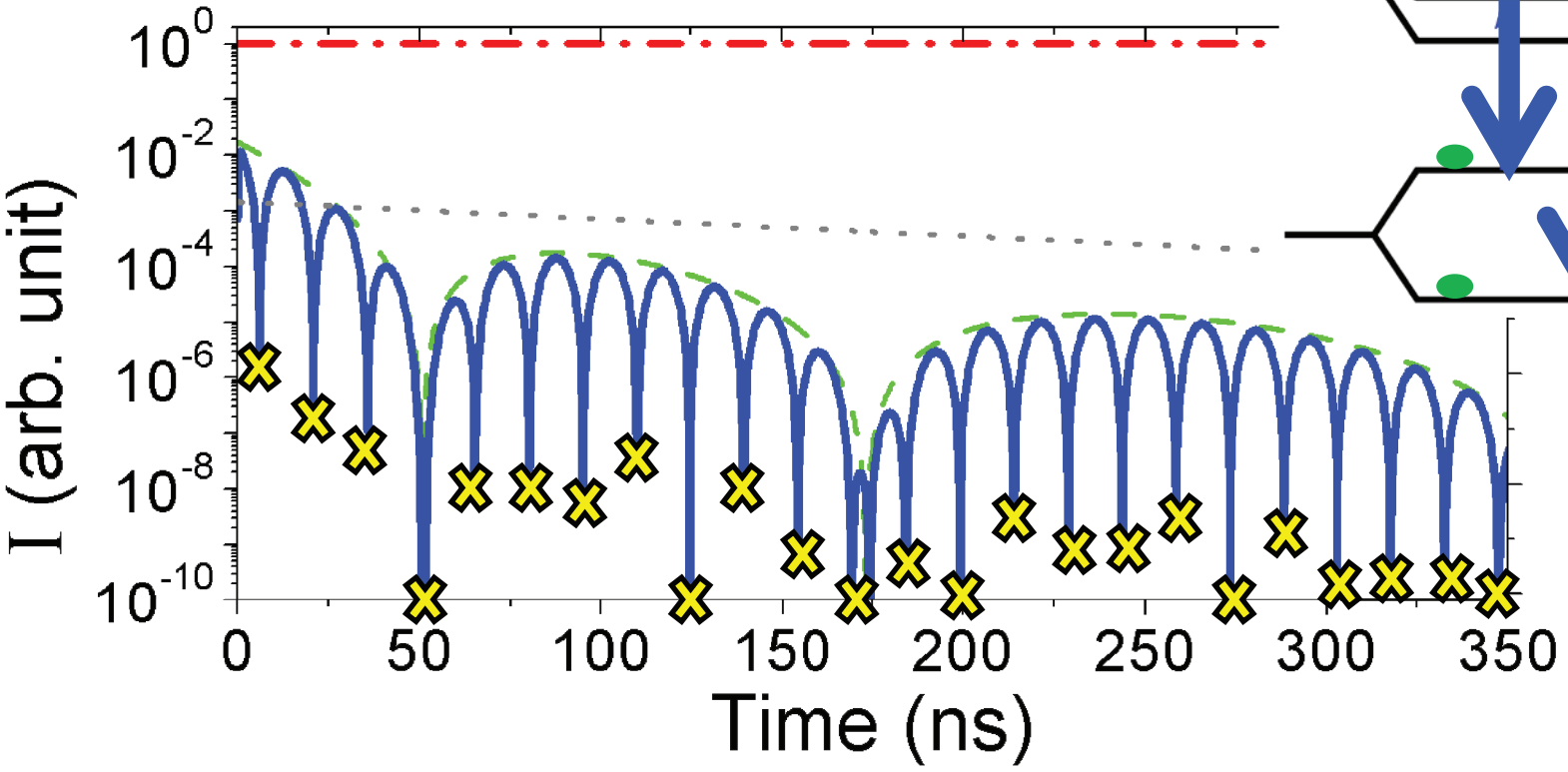
Coherent Storage-How?

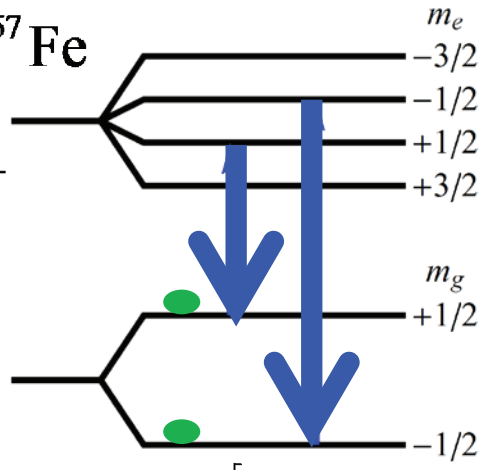




$$\frac{1}{c}\partial_t\Omega + \partial_y\Omega = i\eta\left(\rho_{31} + \rho_{42}\right)$$

Coherent Storage-How?





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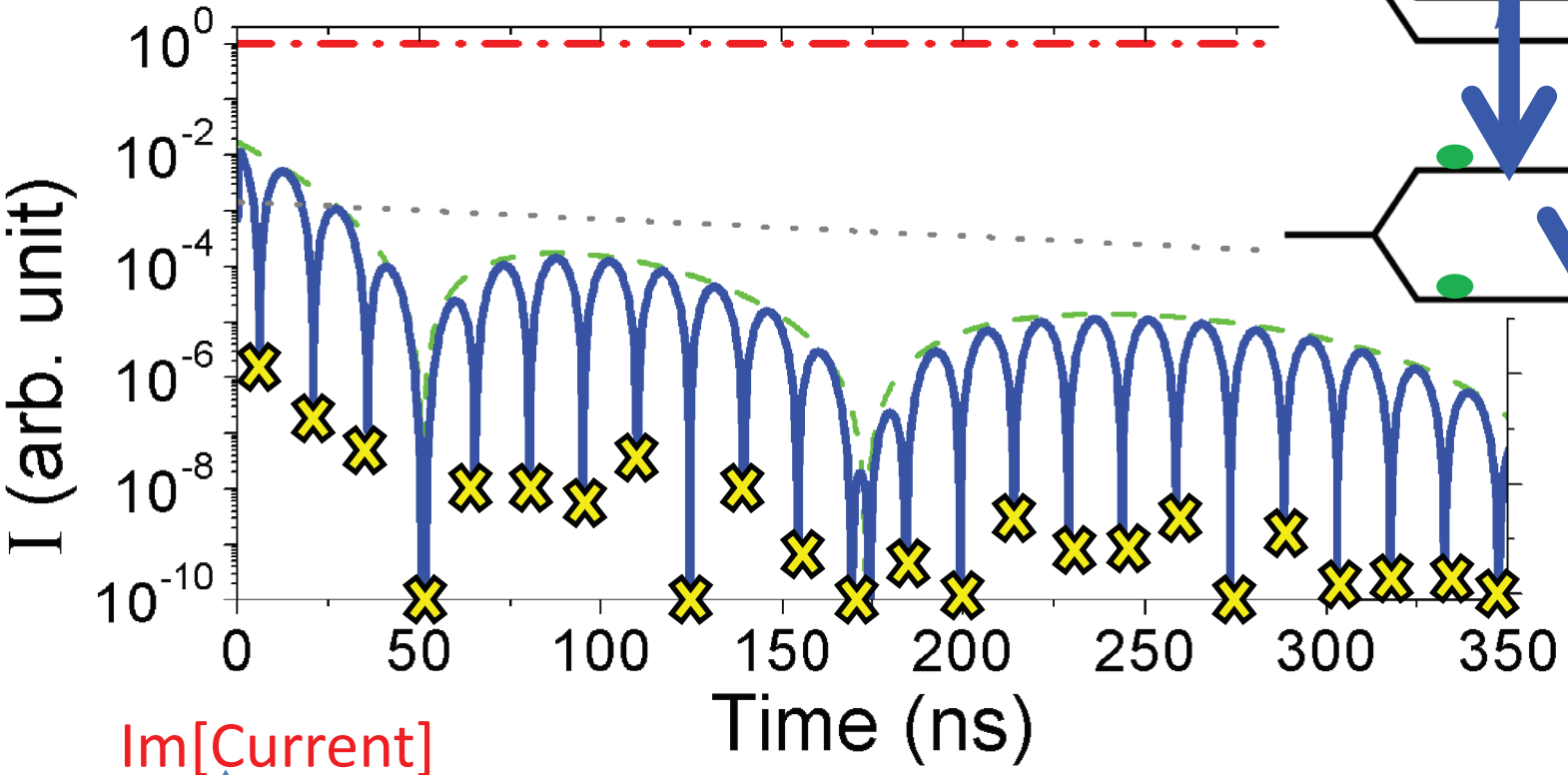

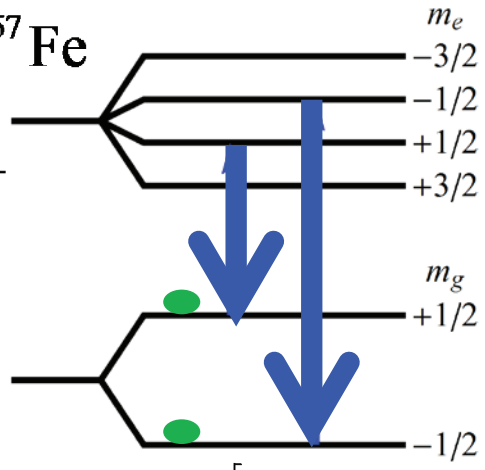

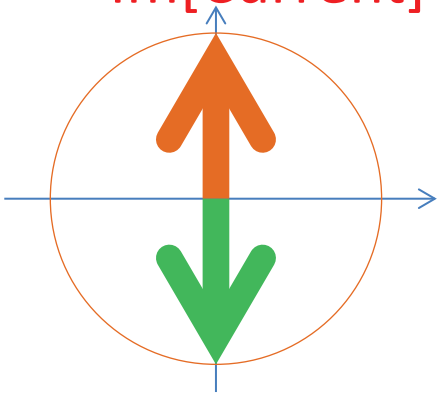

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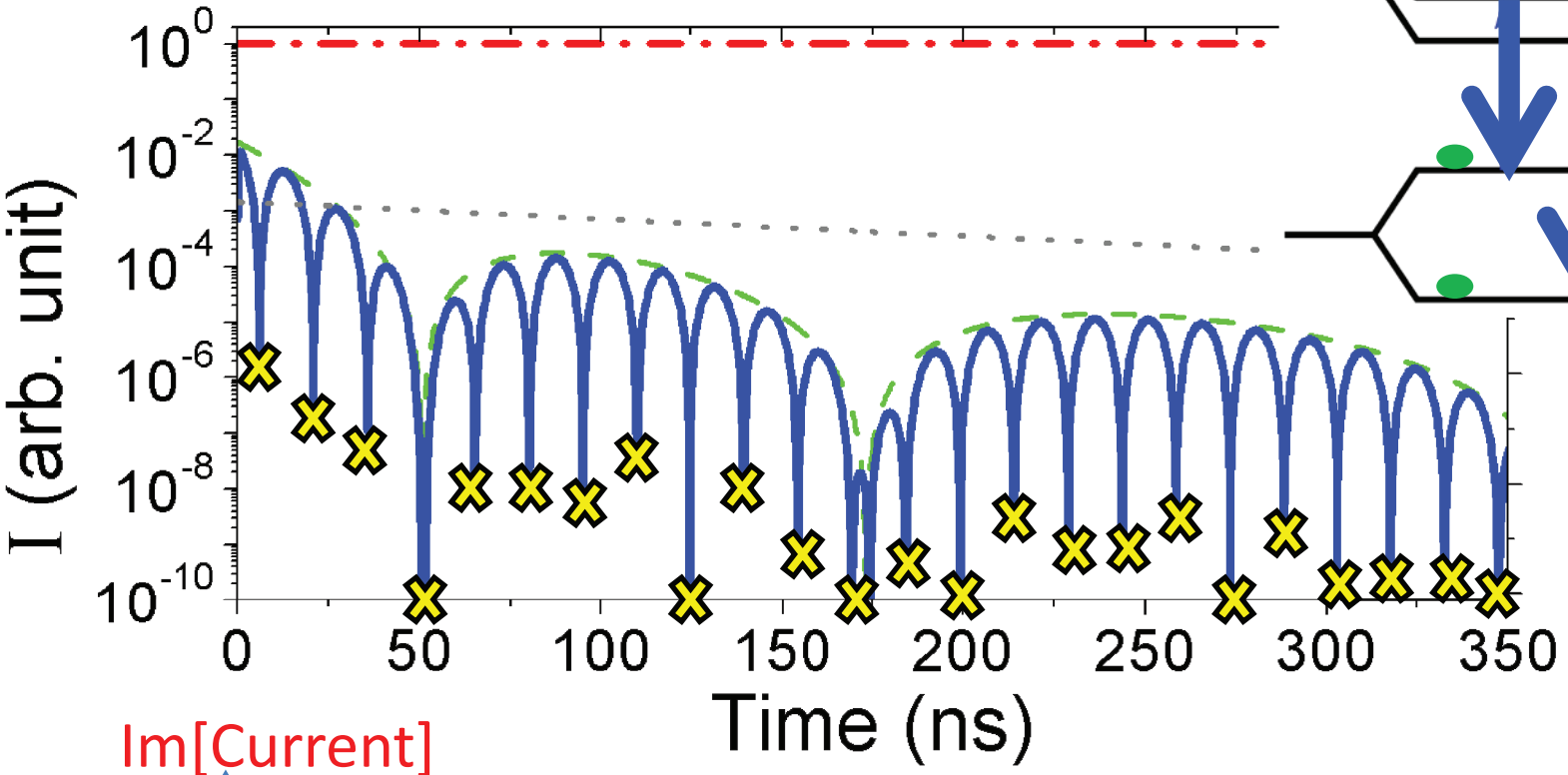
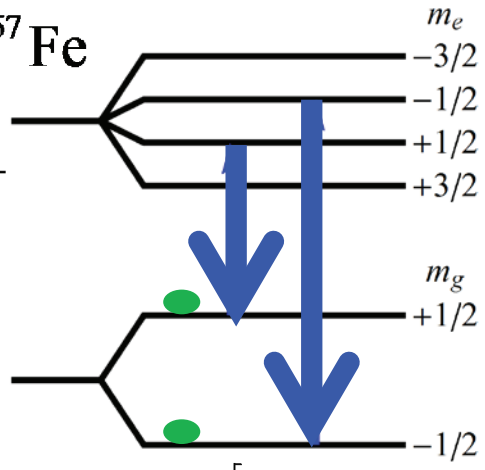
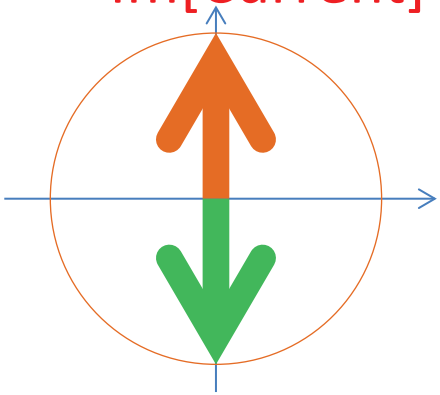
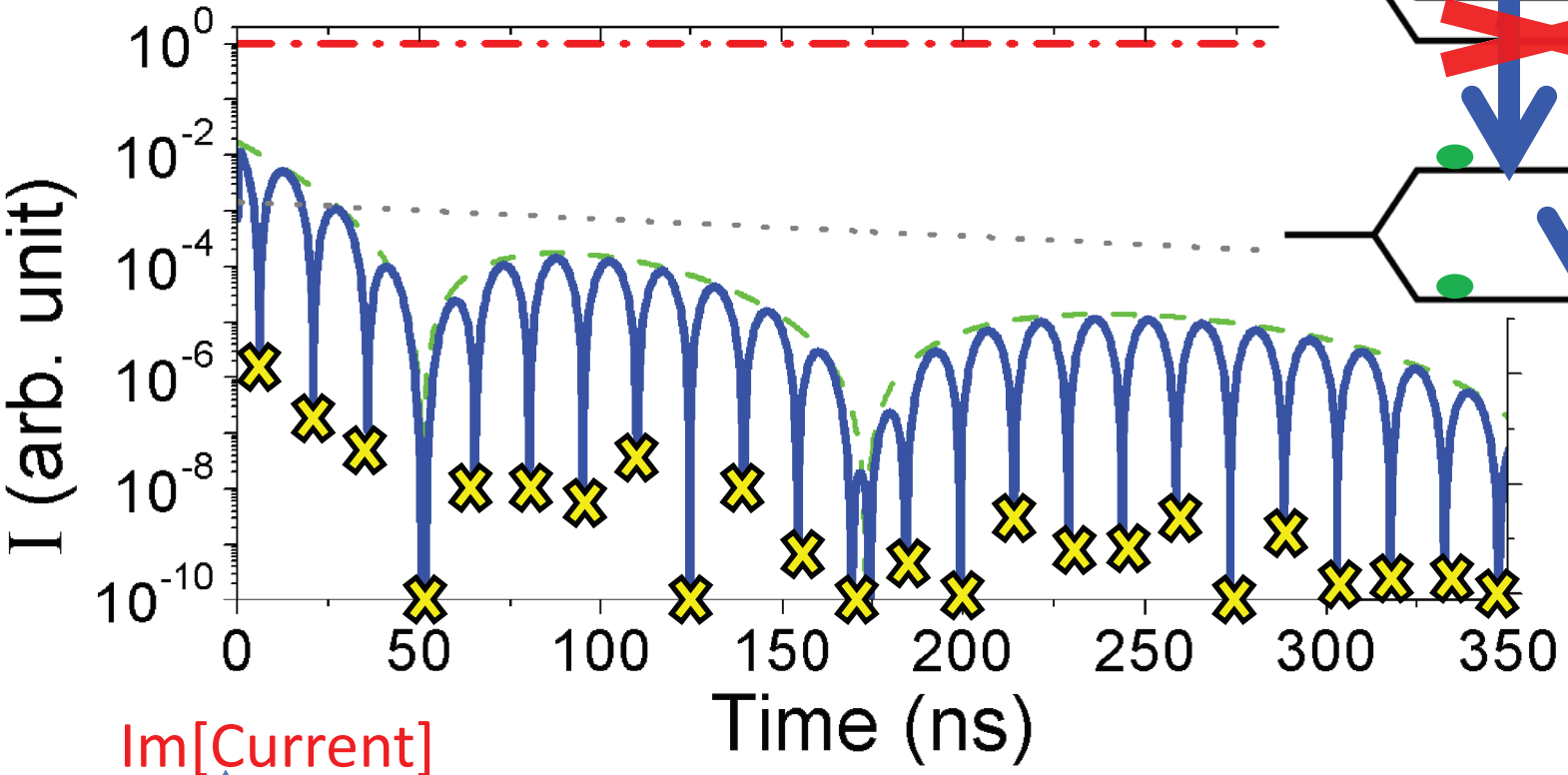


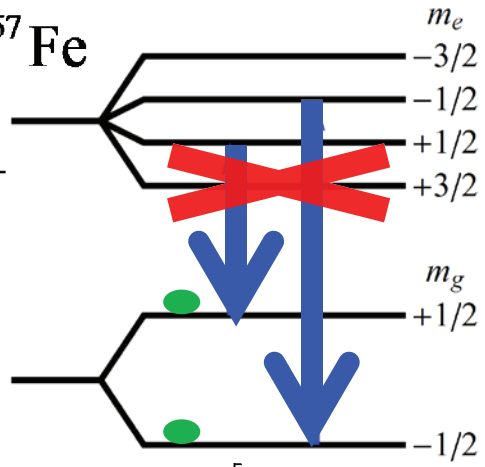


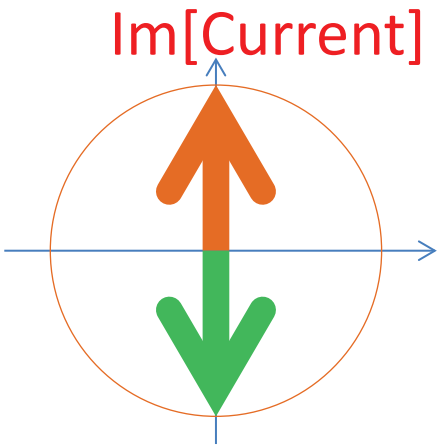


$$\frac{1}{c}\partial_t\Omega + \partial_y\Omega = i\eta\left(\rho_{31} + \rho_{42}\right)$$

Coherent Storage-How?

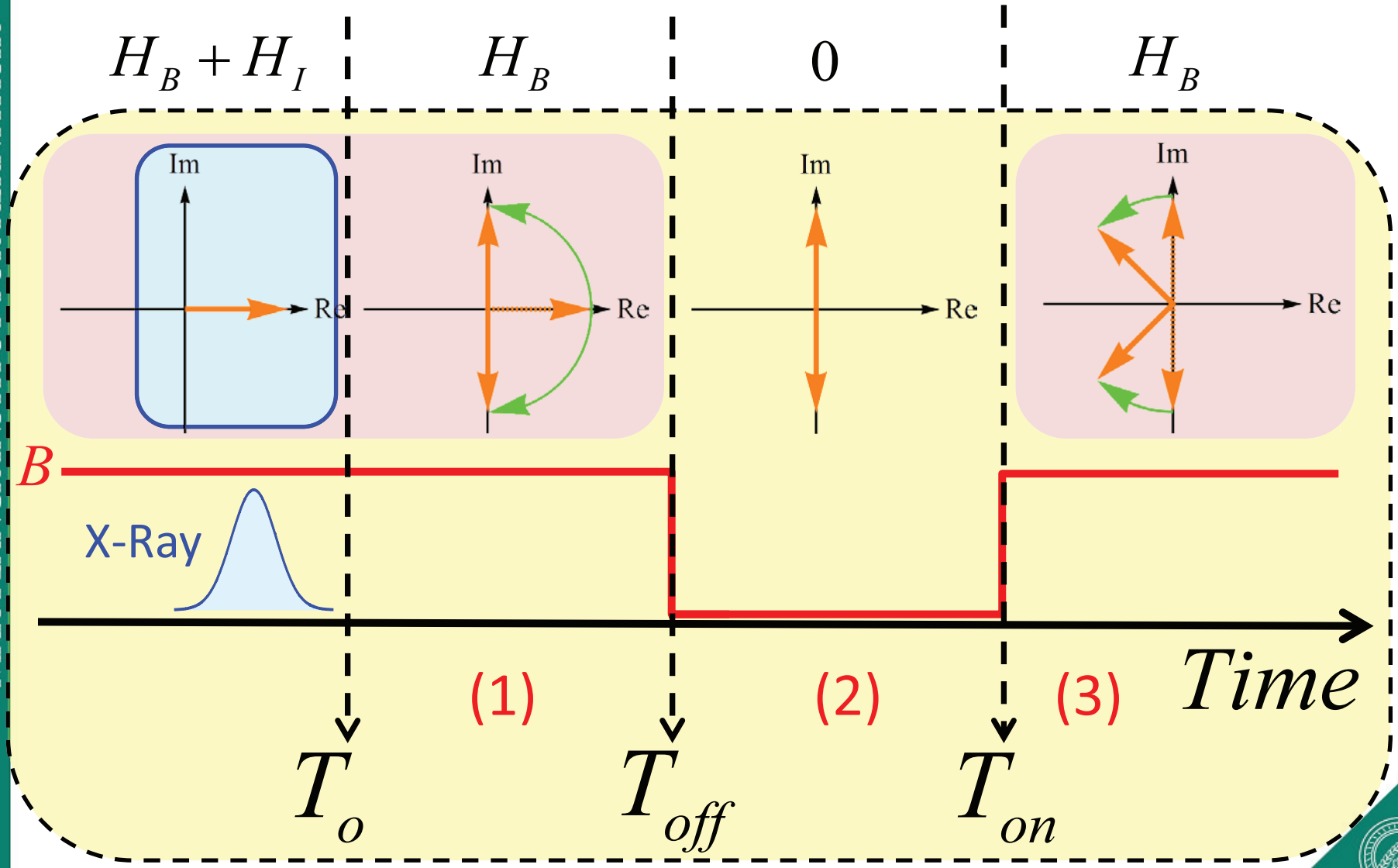






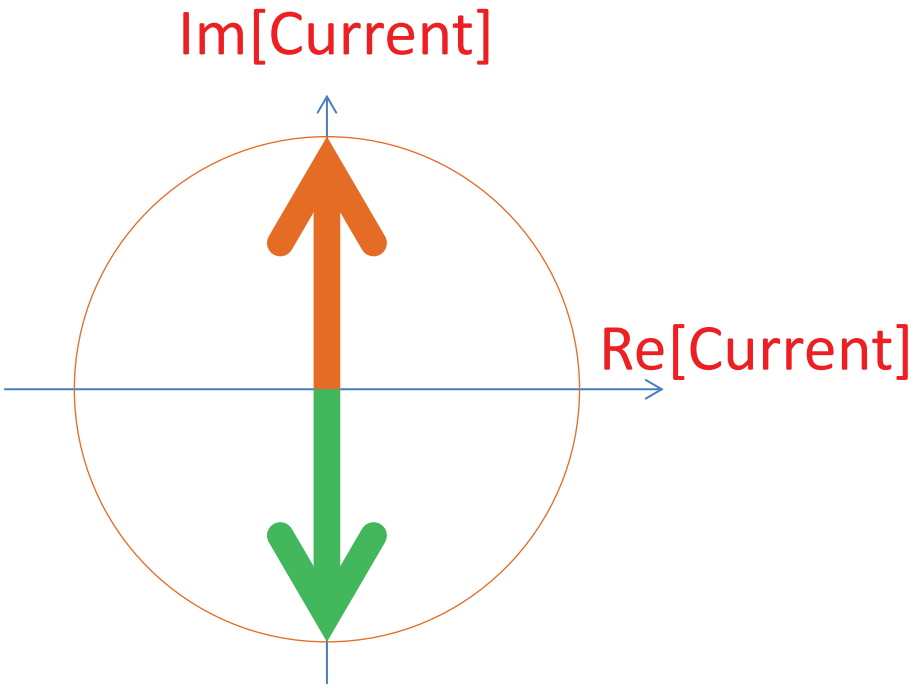
$$\frac{1}{c}\partial_t\Omega + \partial_y\Omega = i\eta\left(\rho_{31} + \rho_{42}\right)$$

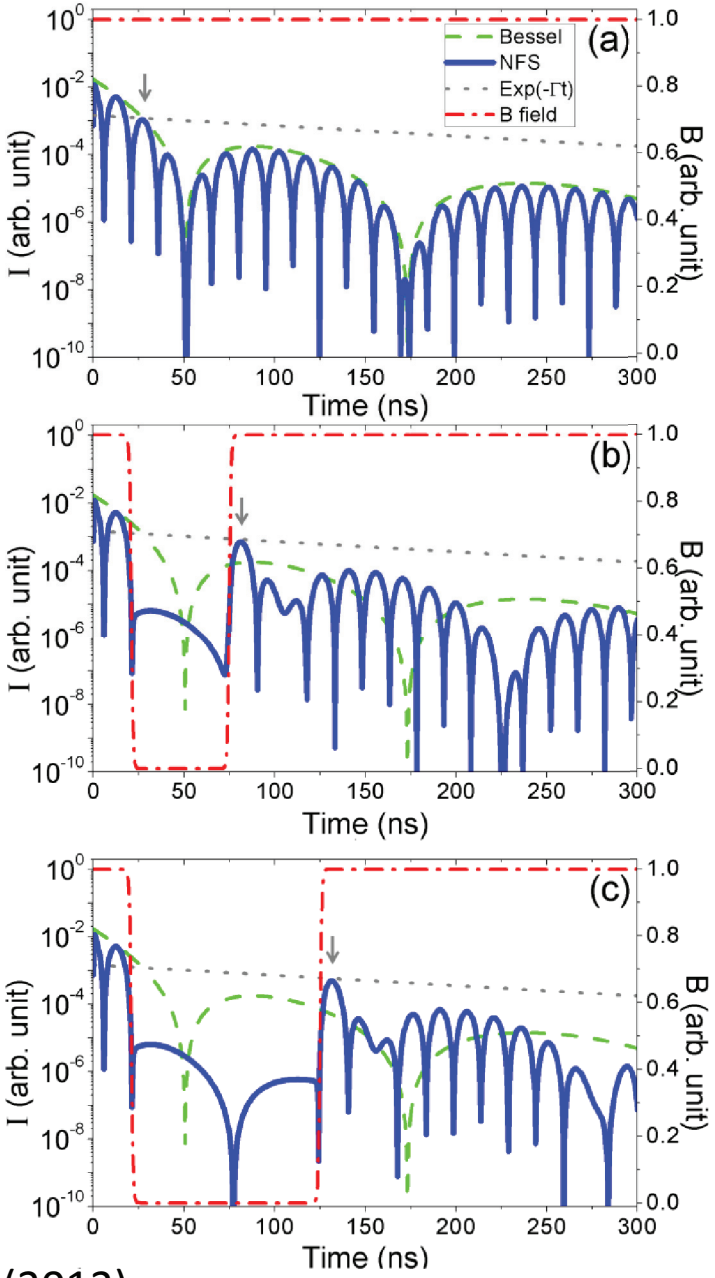
Coherent Storage-How?



Coherent Storage

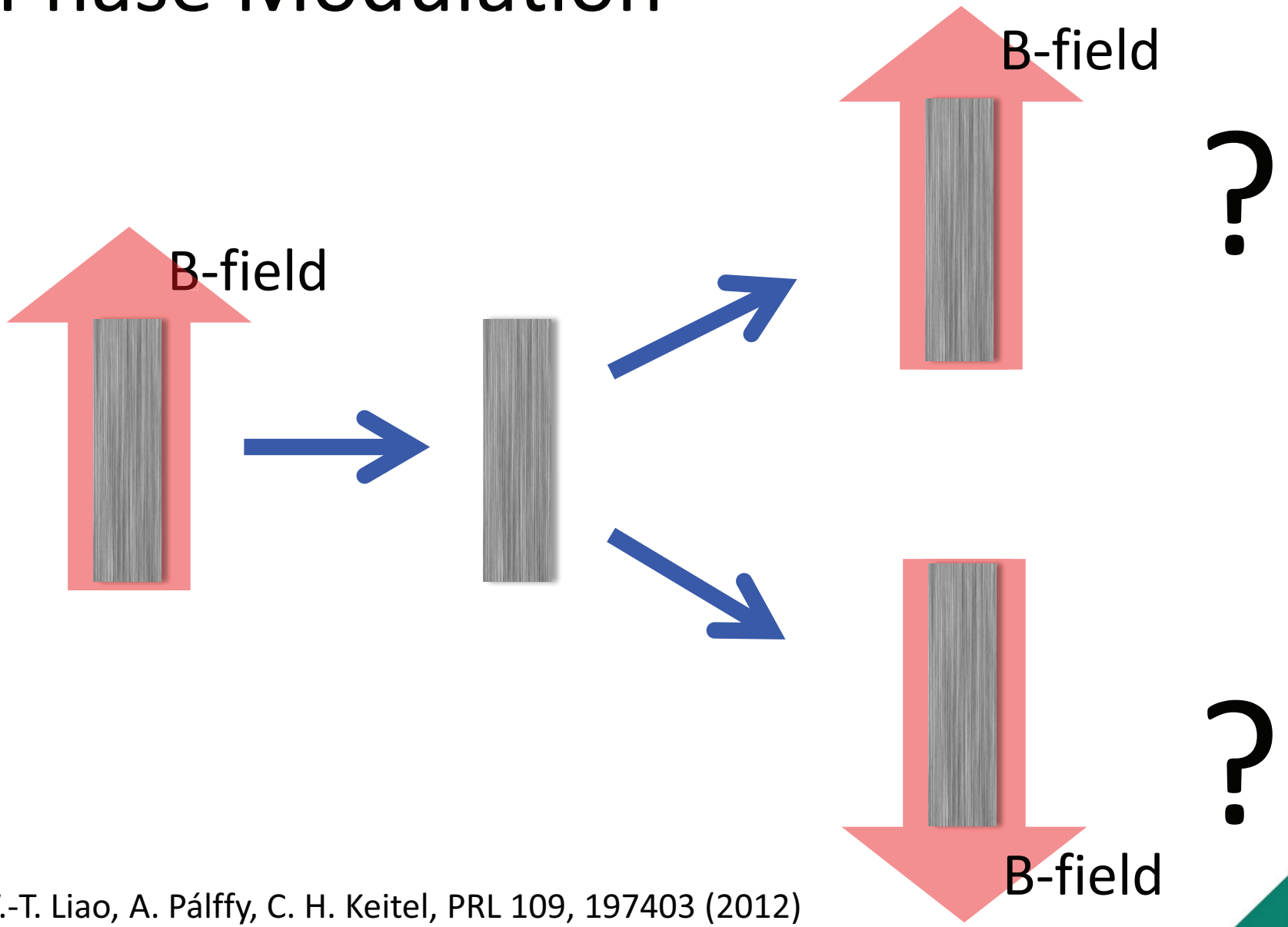
Phase and Polarization are Conserved!





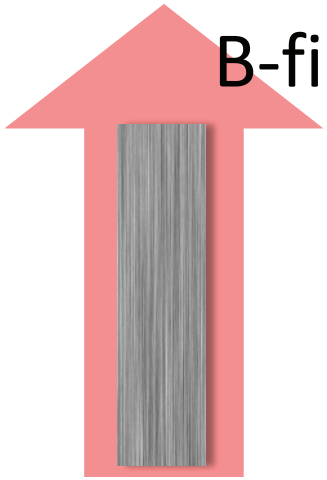
W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)

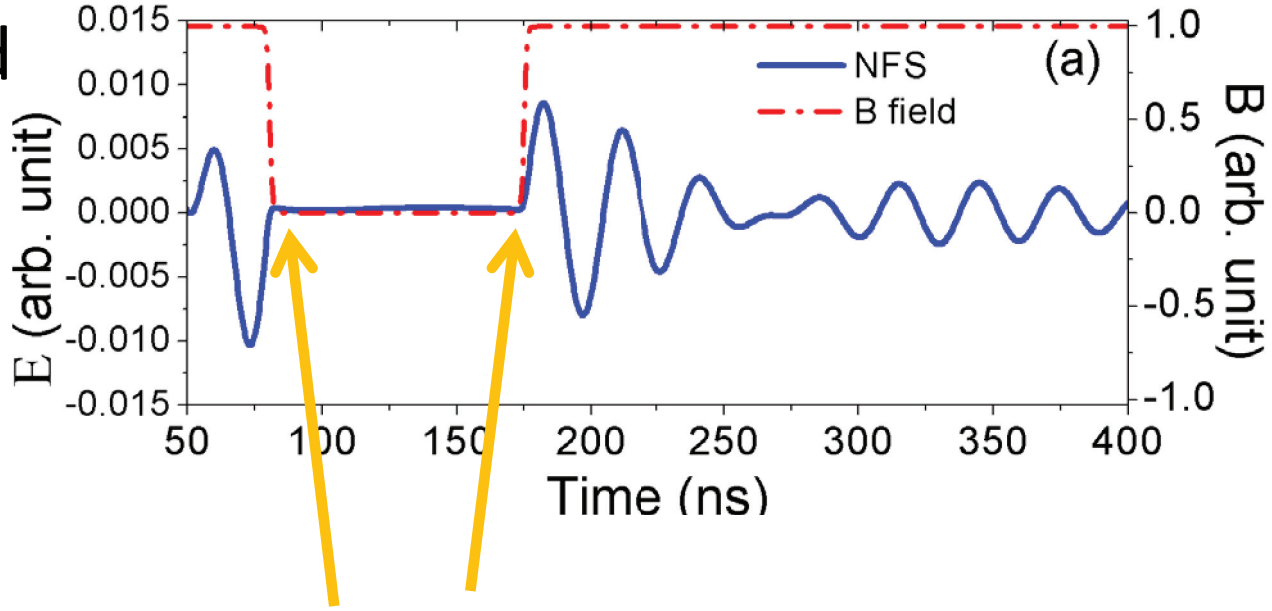
Phase Modulation



W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)

Phase Modulation

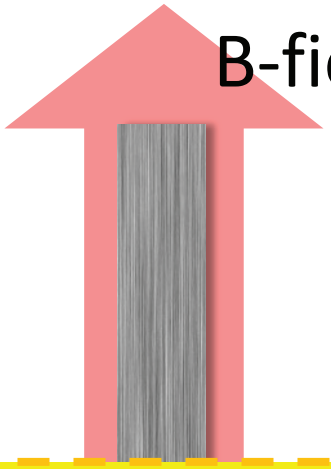


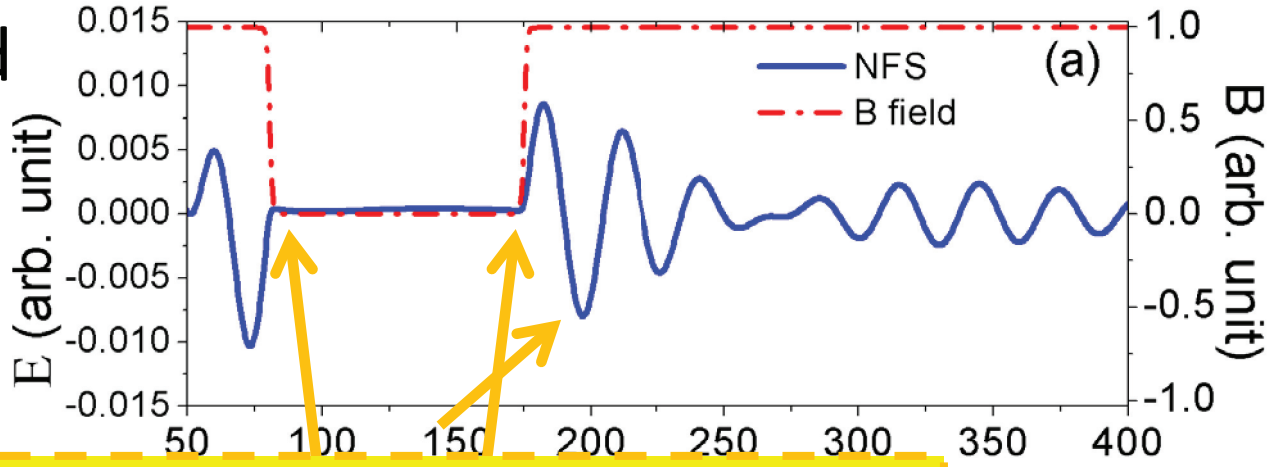


Phase is Conserved!

W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)
Yu. Shvyd'ko, et. al, PRB. 52, R711 (1995)

Phase Modulation



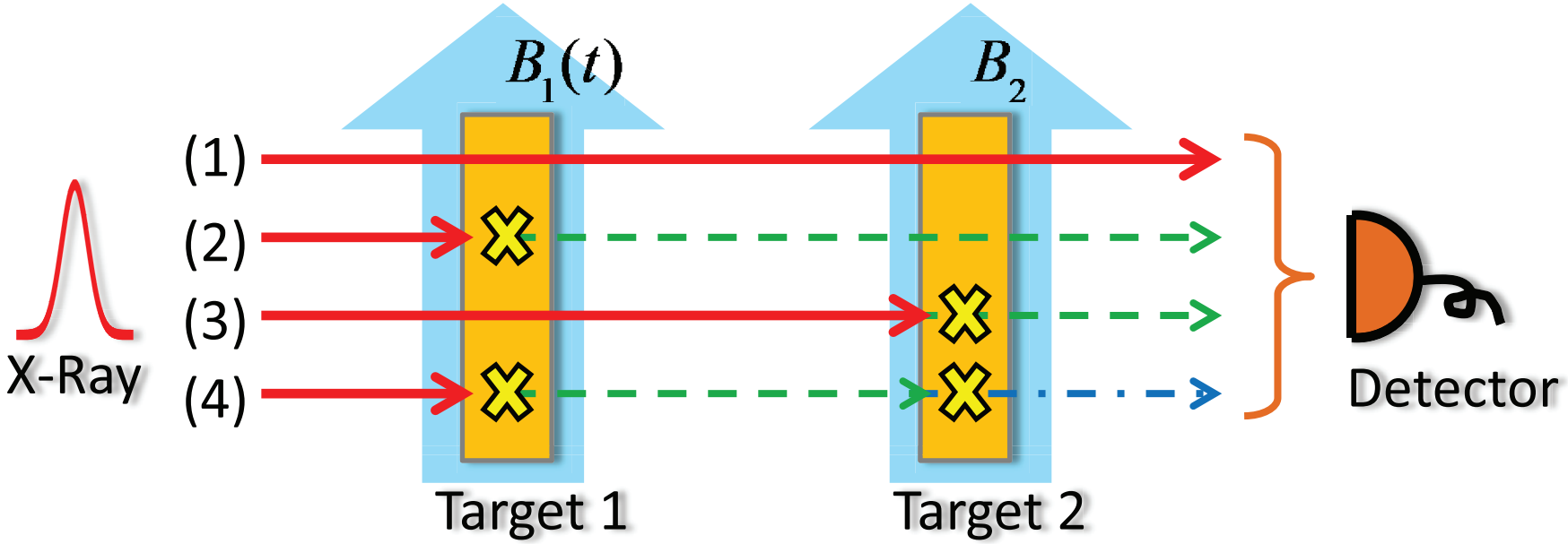


Phase is π modulated by ***time reversal***!

Phase is Conserved!

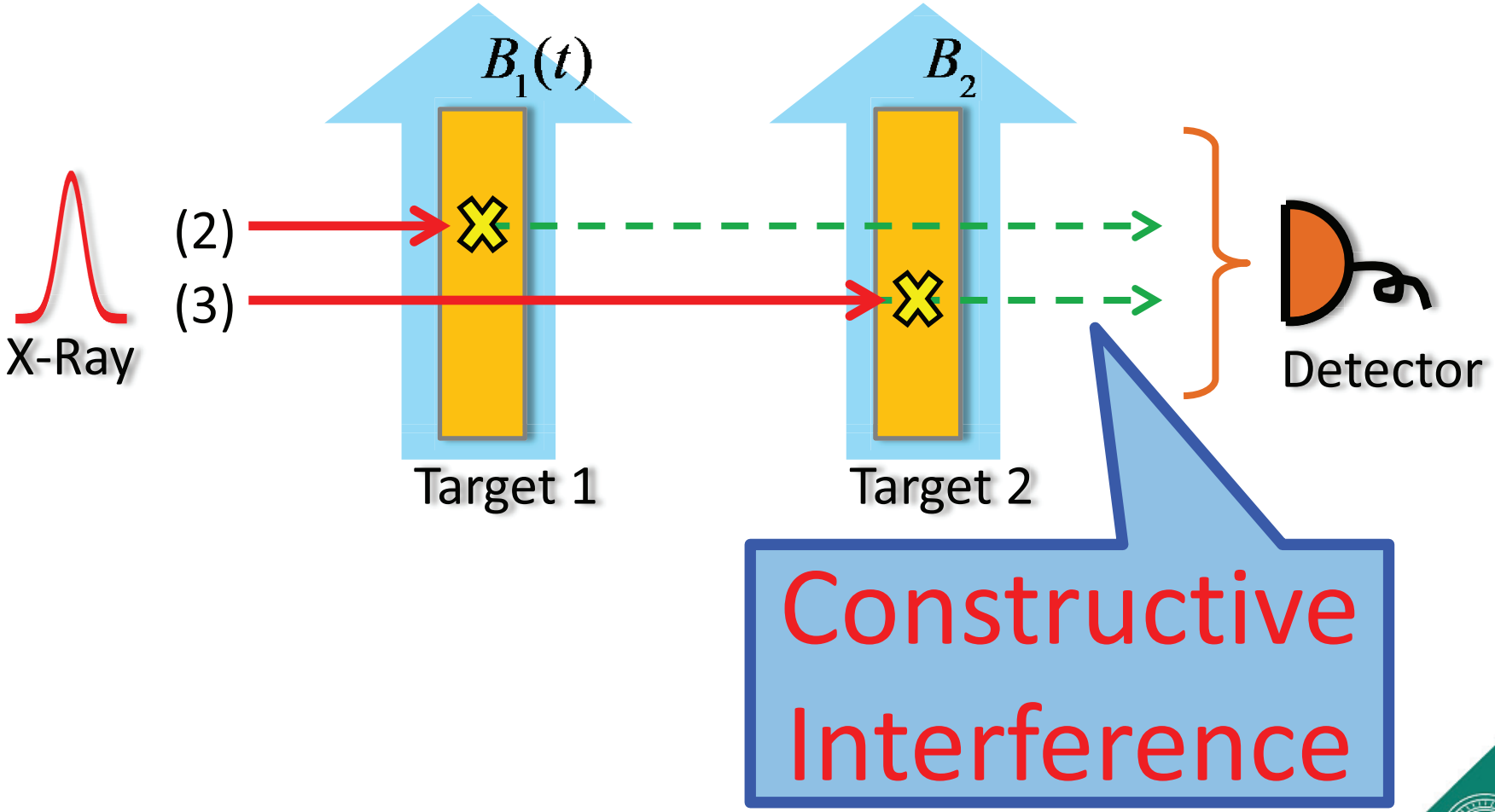
W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)
Yu. Shvyd'ko, et. al, PRB. 52, R711 (1995)

How to Measure the Phase?



W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)
G. V. Smirnov, et. al., PRA. 71, 023804 (2005)
G. V. Smirnov, et. al., PRL. 77, 183 (1996)
R. Röhlsberger, Book, Springer-Verlag (2004)

How to Measure the Phase?



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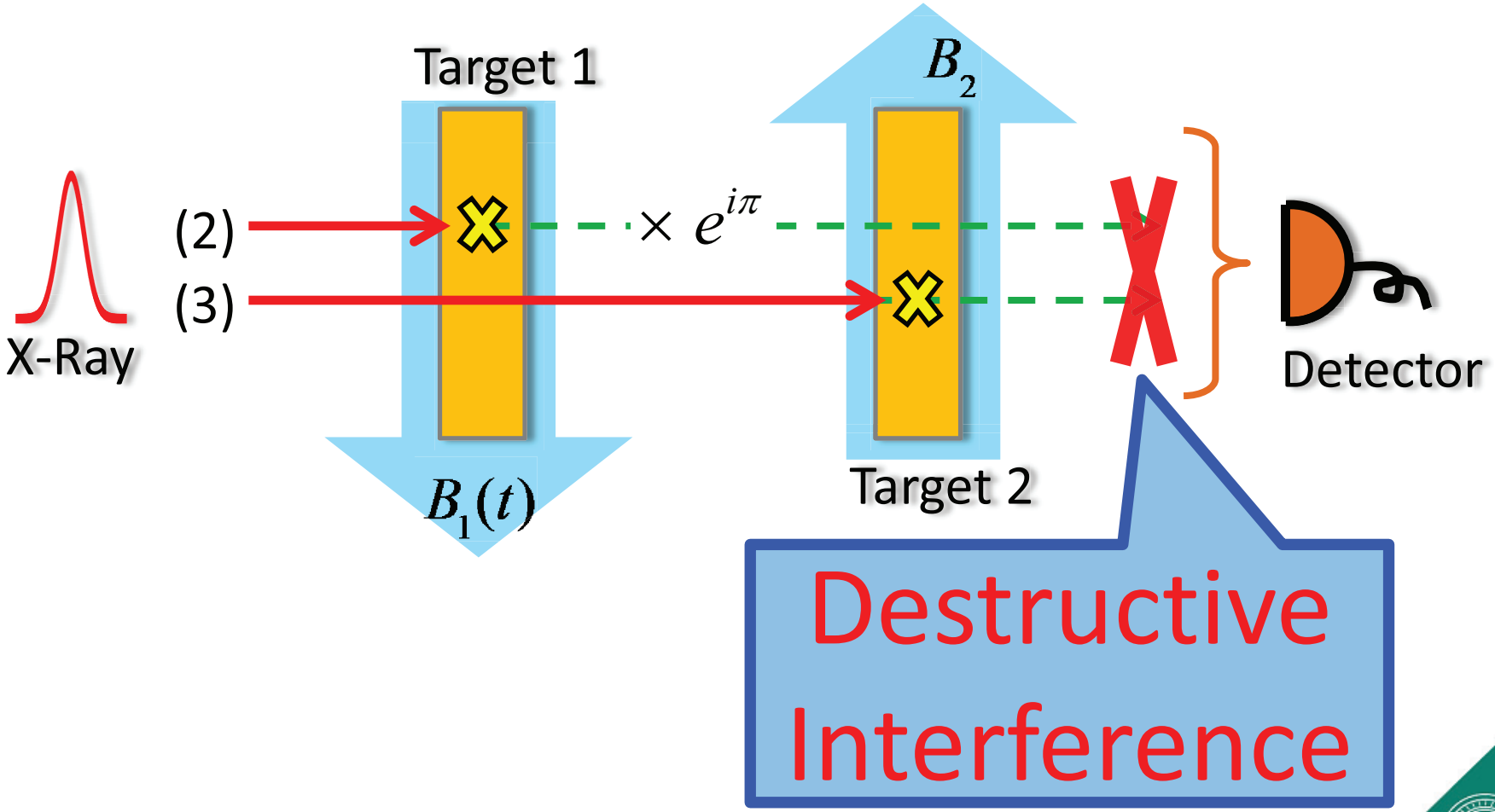

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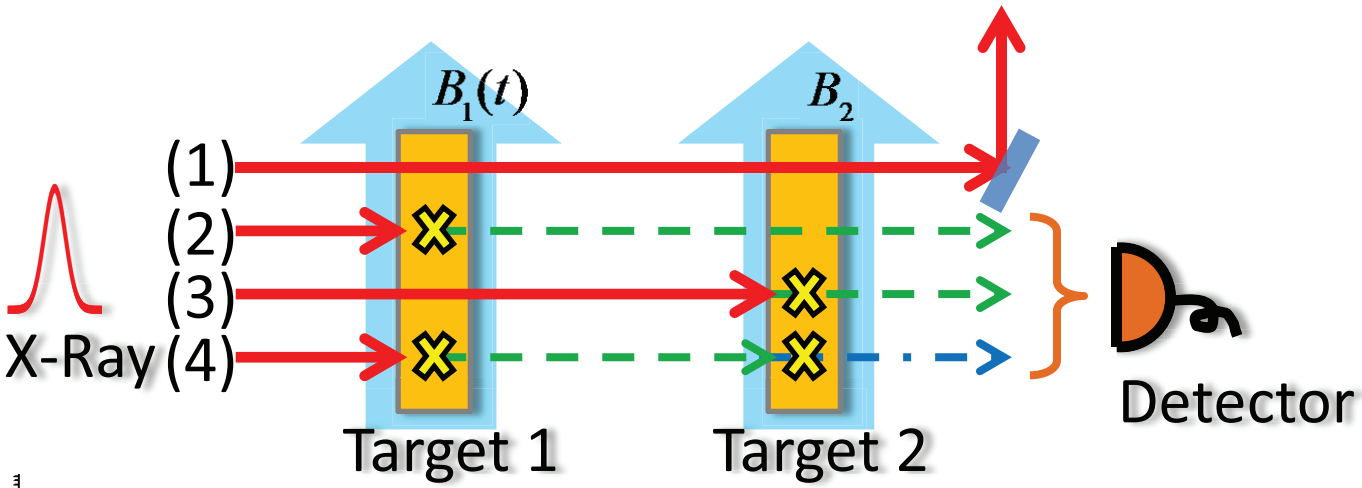

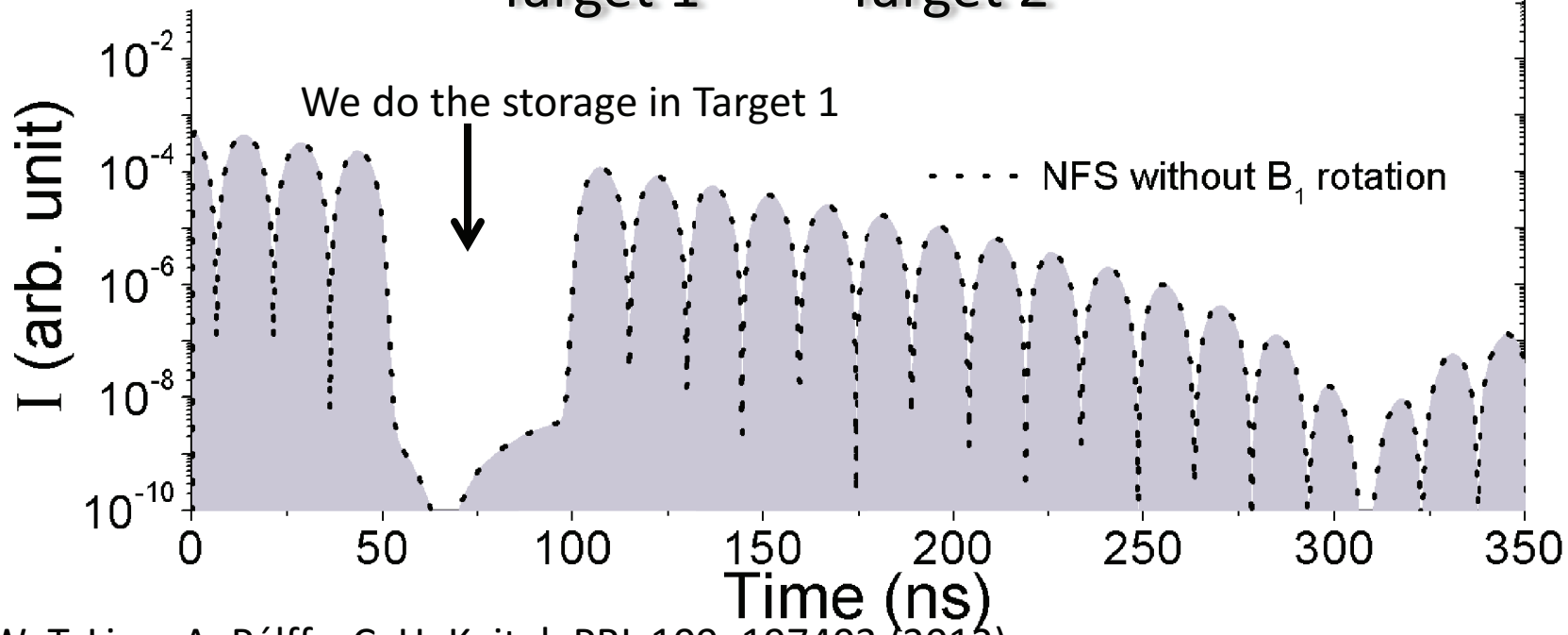

W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)

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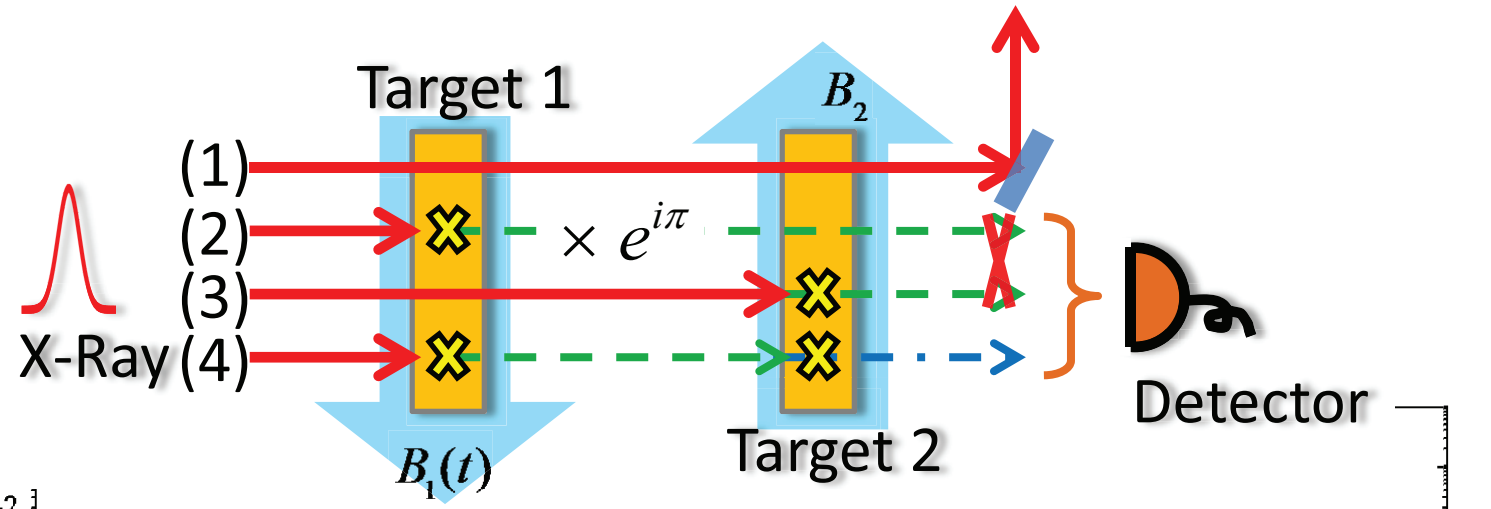

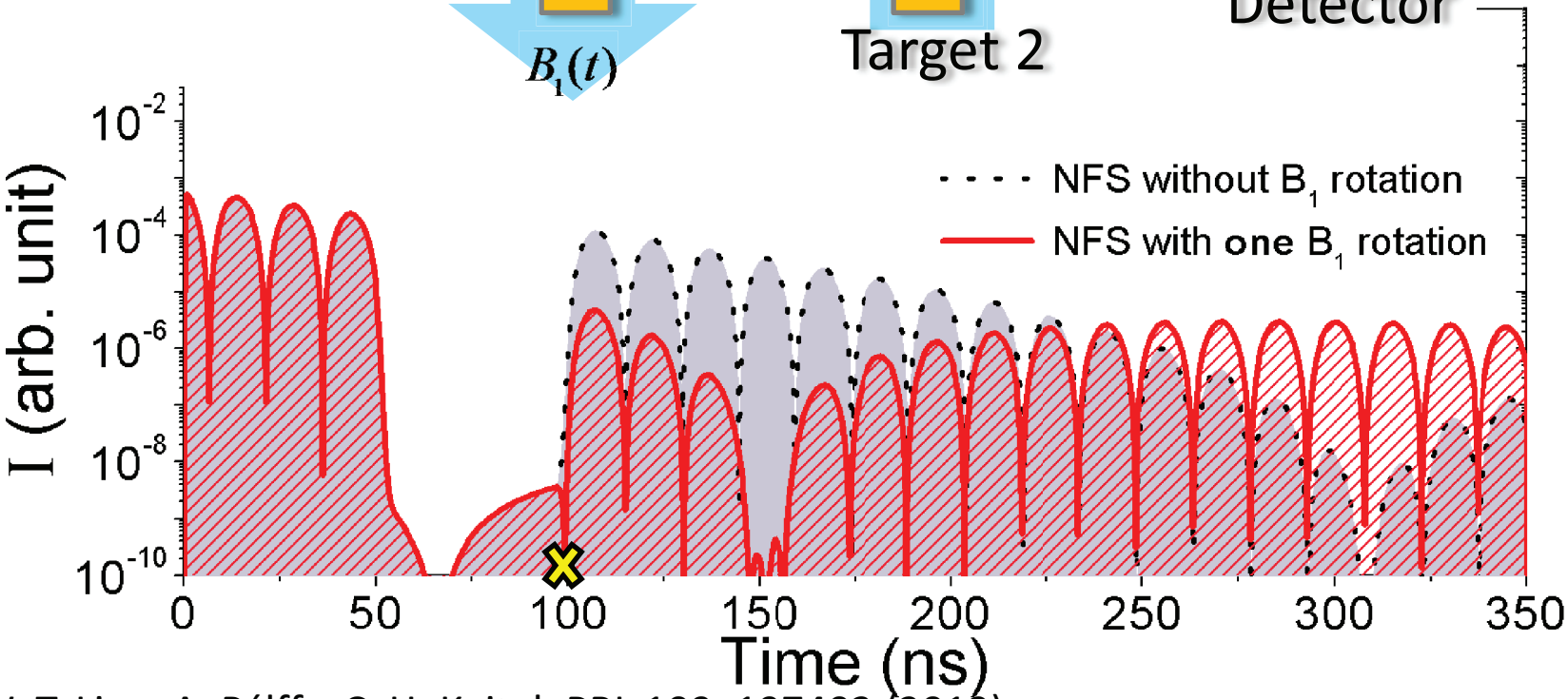

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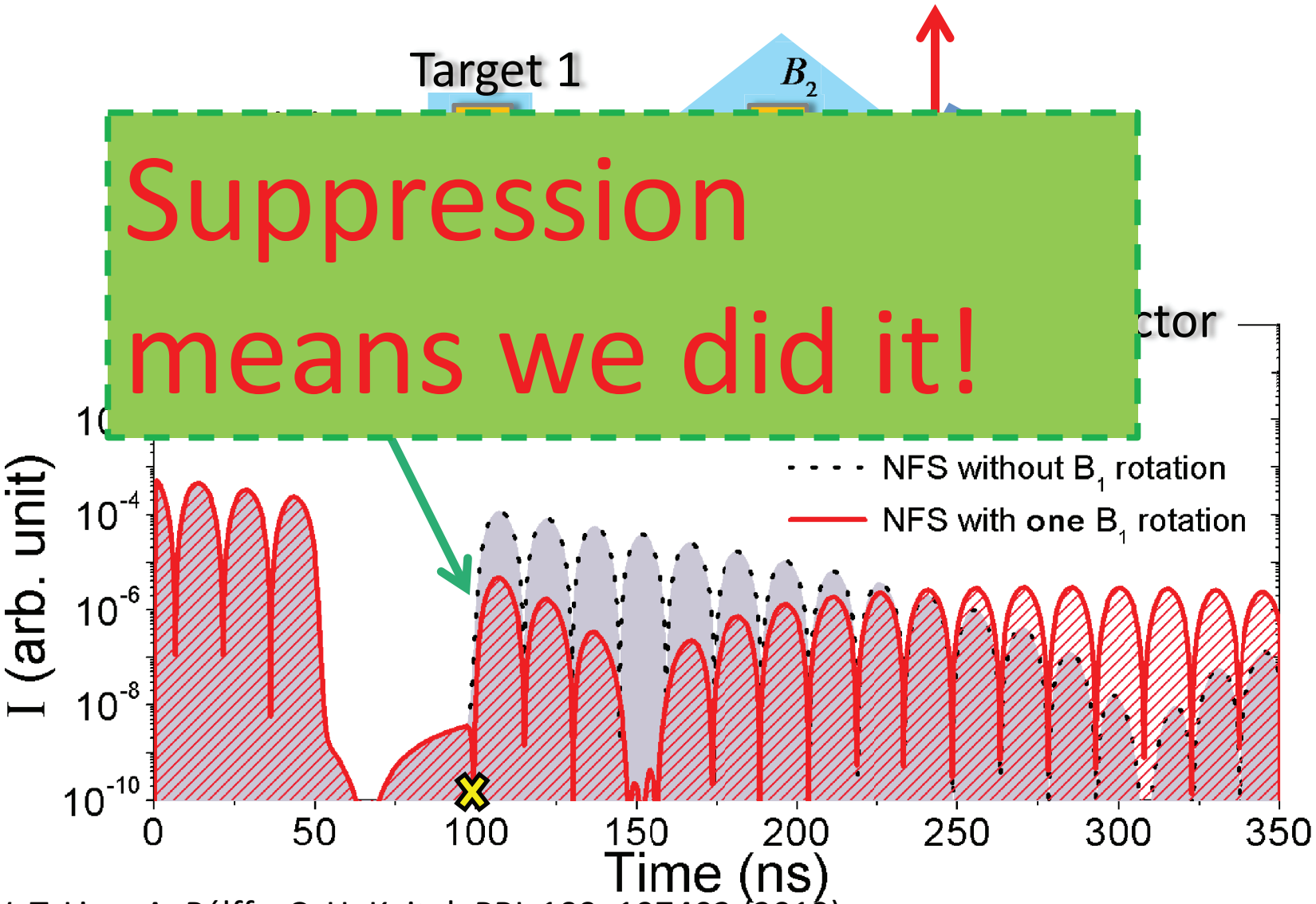

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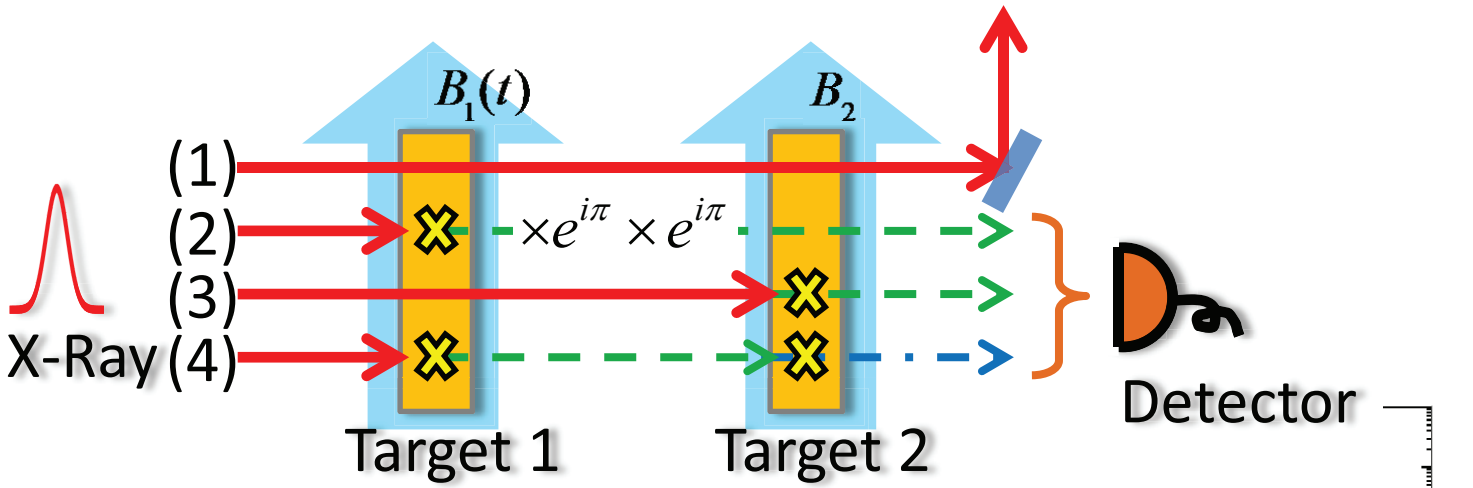
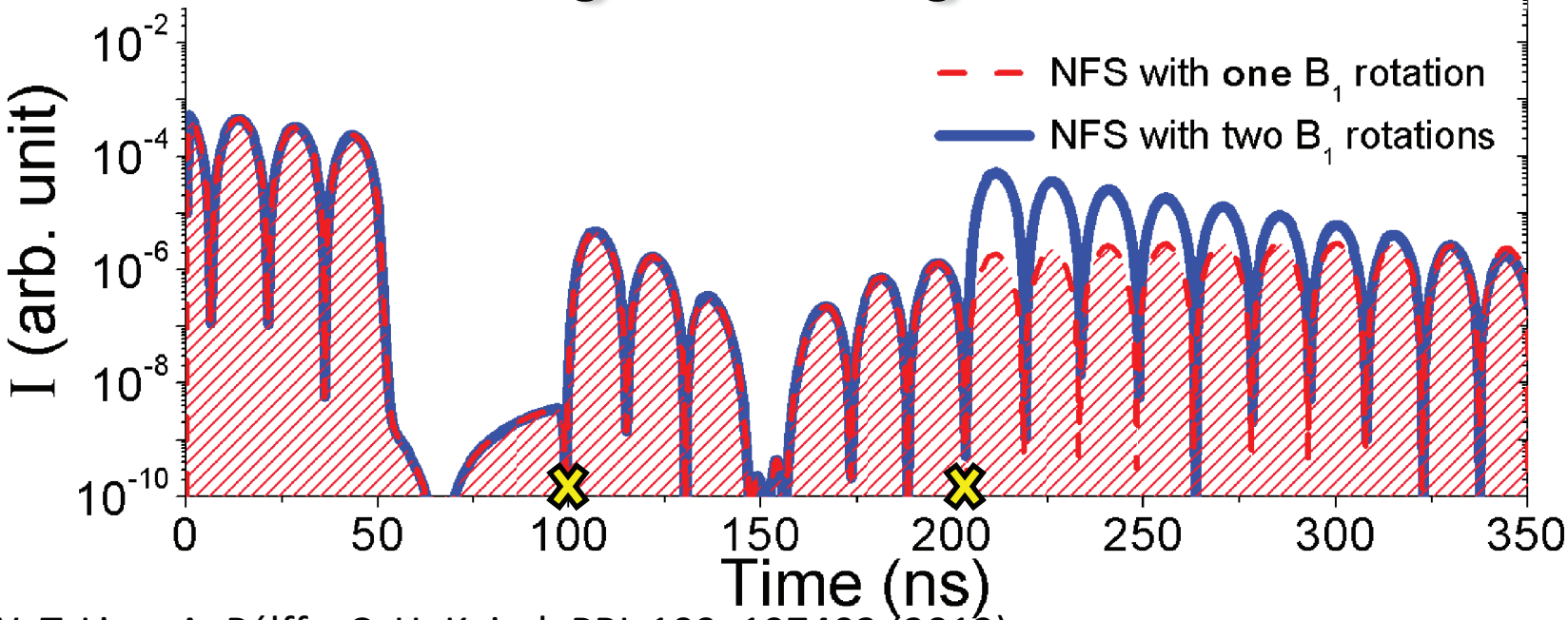
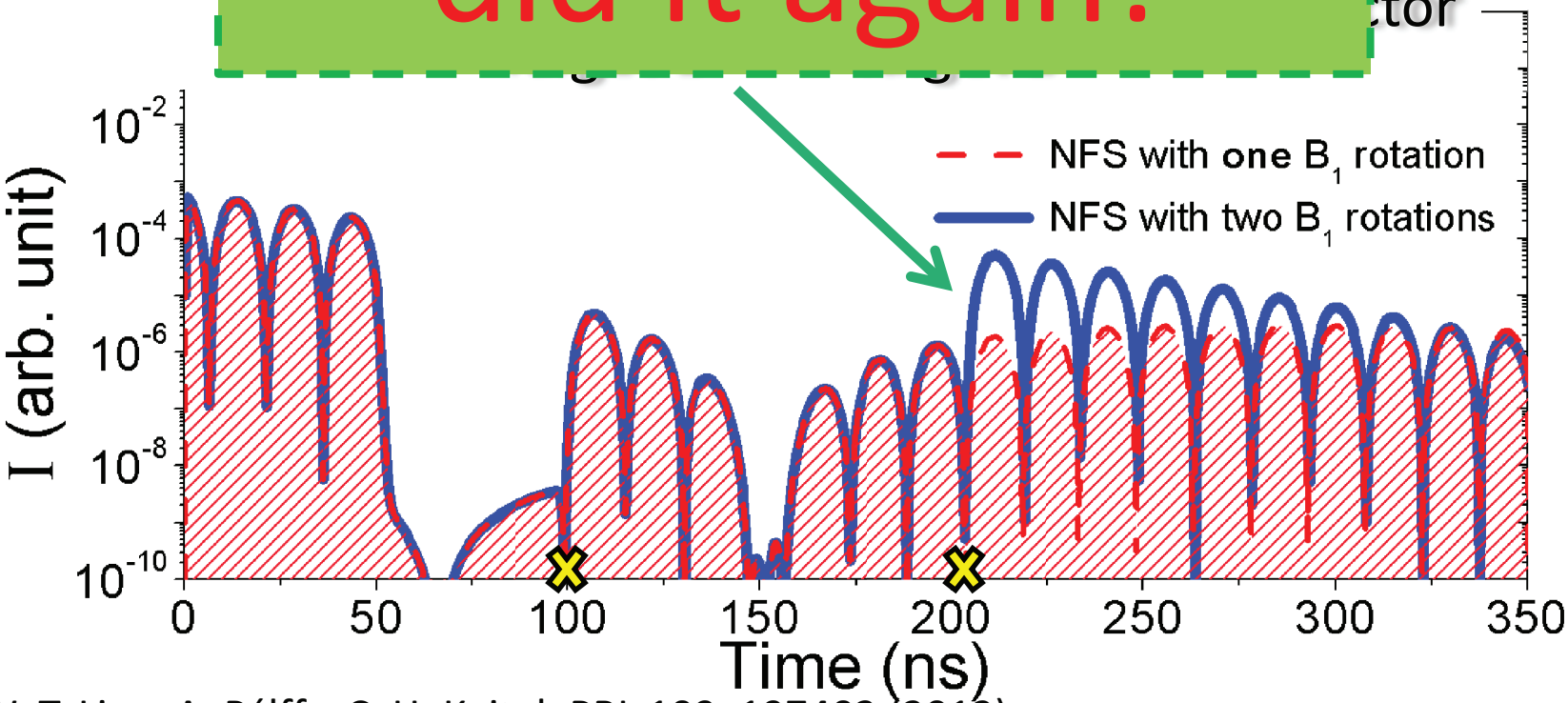




W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)

How to Measure the Phase?

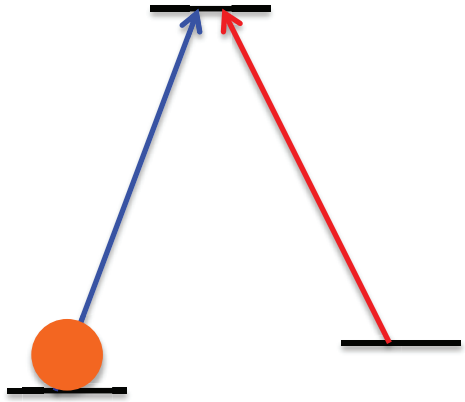
Echo means we did it again!



W.-T. Liao, A. Pálffy, C. H. Keitel, PRL 109, 197403 (2012)

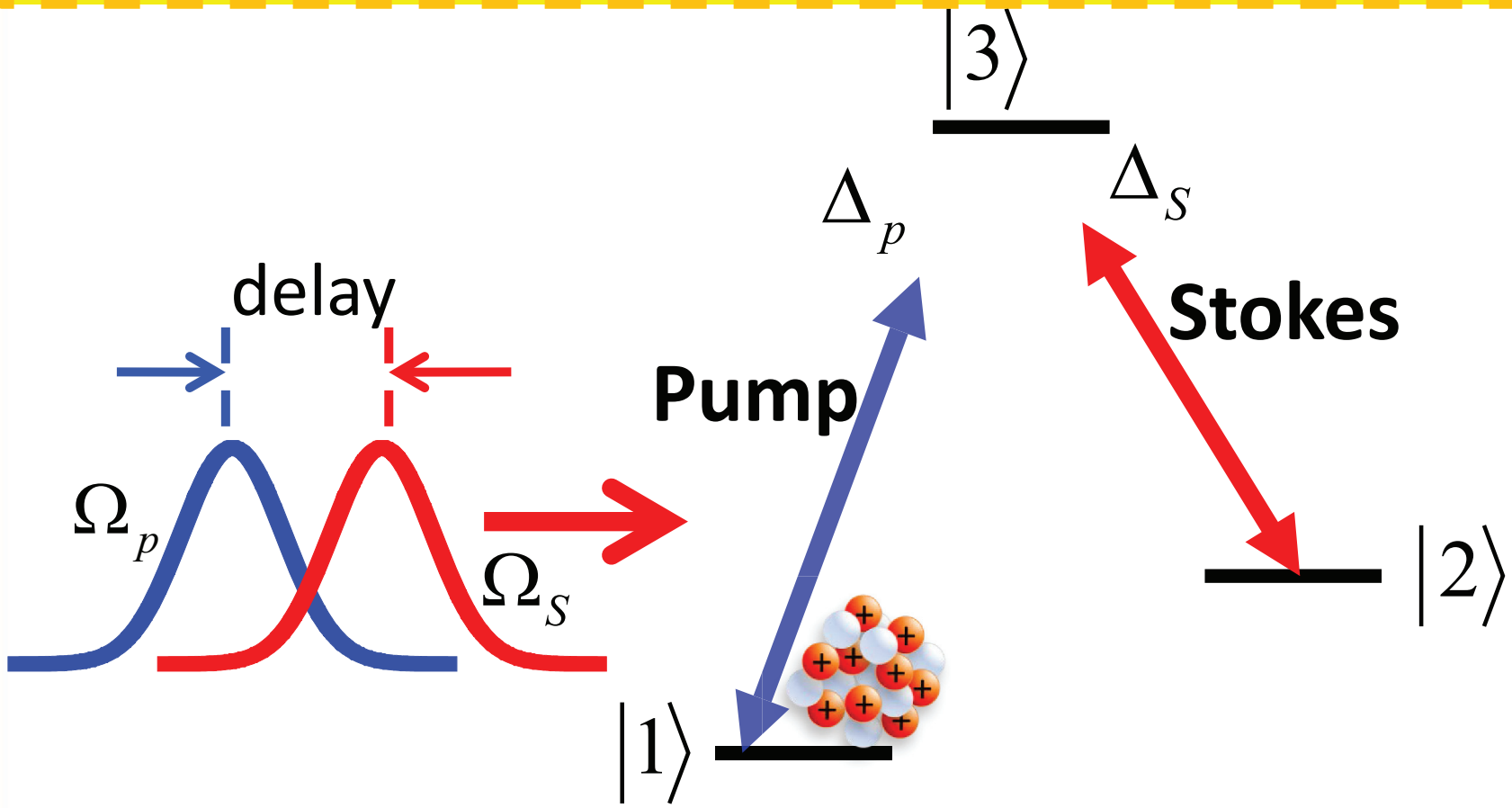
Nuclear STIRAP

W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Lett. B 705, 134 (2011).
W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Rev. C 87, 054609 (2013).



STIRAP

stimulated Raman adiabatic passage (STIRAP)



K. Bergmann, H. Theuer and B. W. Shore, RMP. 70, 1003 (1998).

STIRAP

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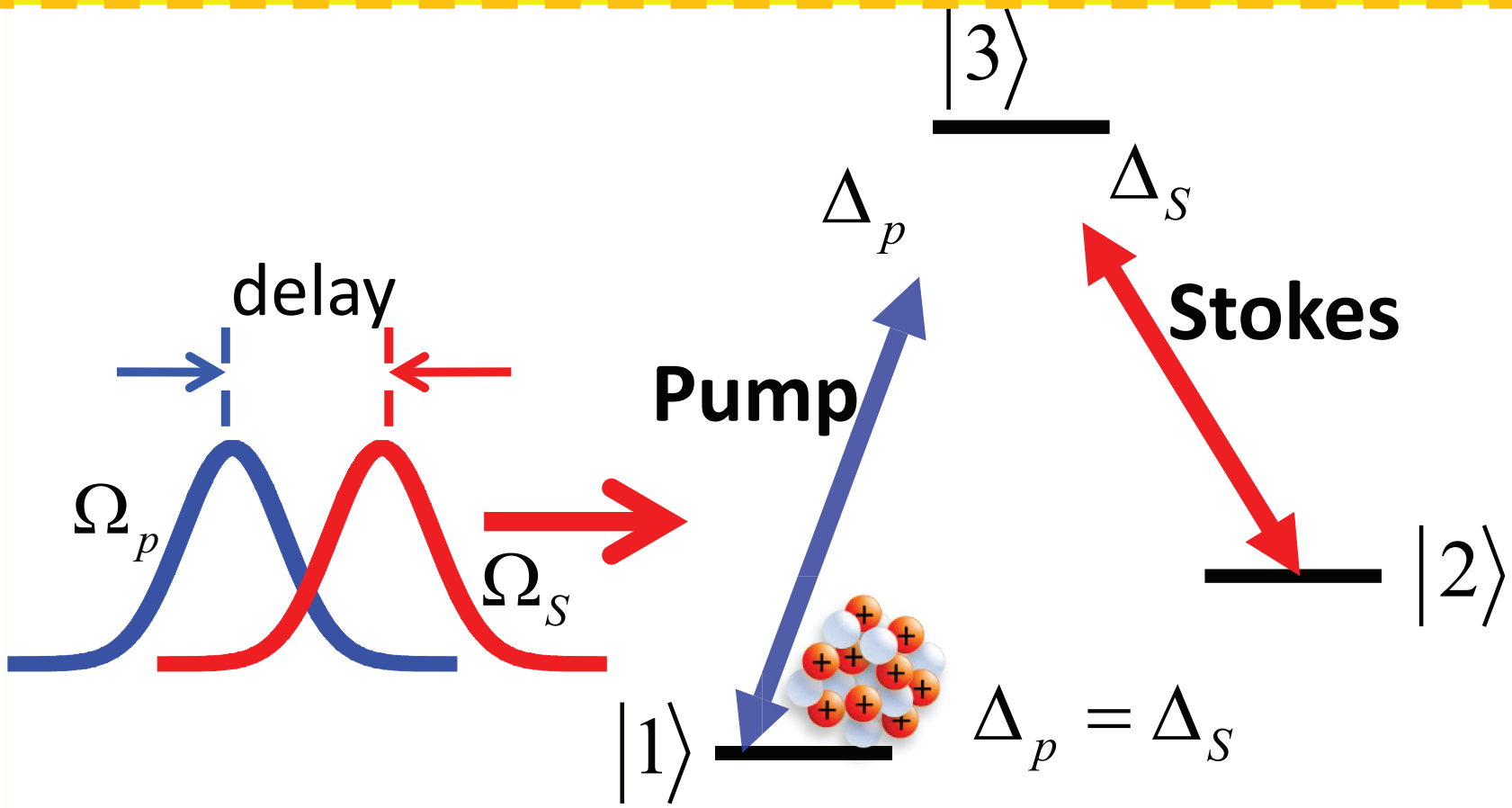
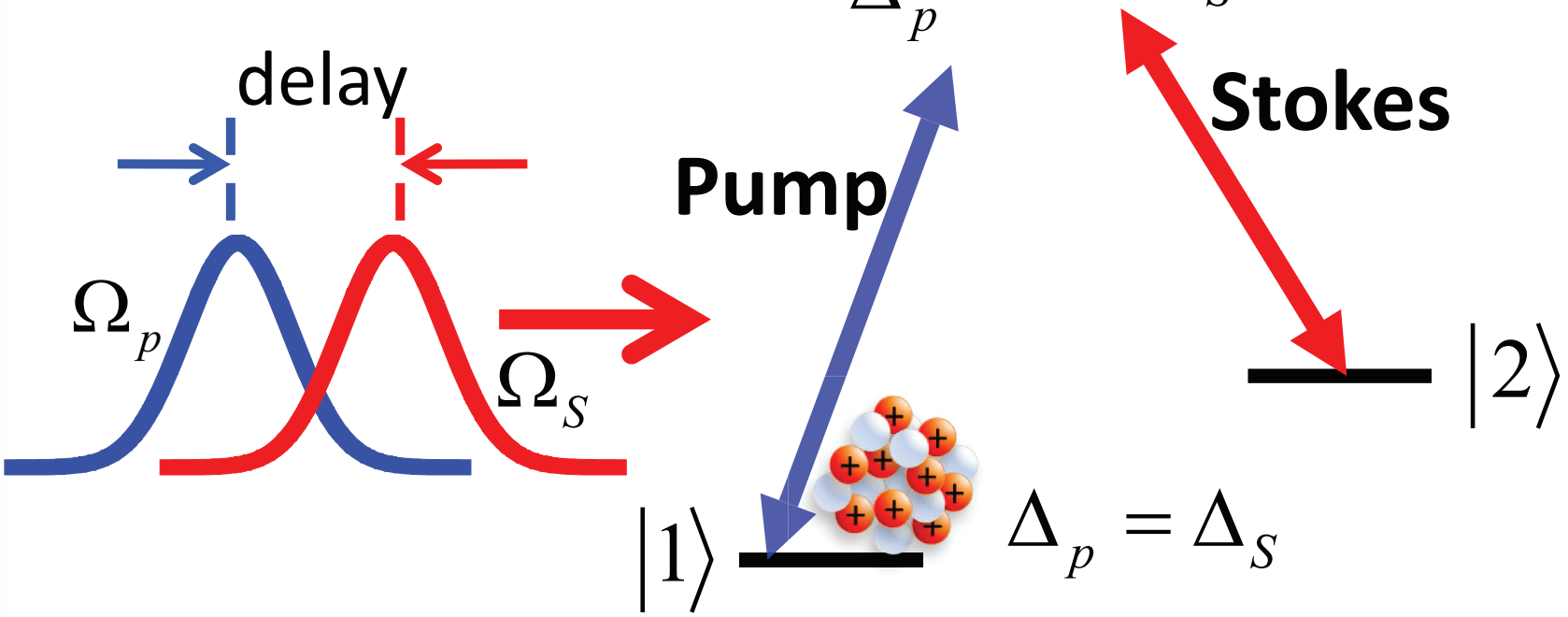


K. Bergmann, H. Theuer and B. W. Shore, RMP. 70, 1003 (1998).

STIRAP

stimulated Raman adiabatic passage (STIRAP)

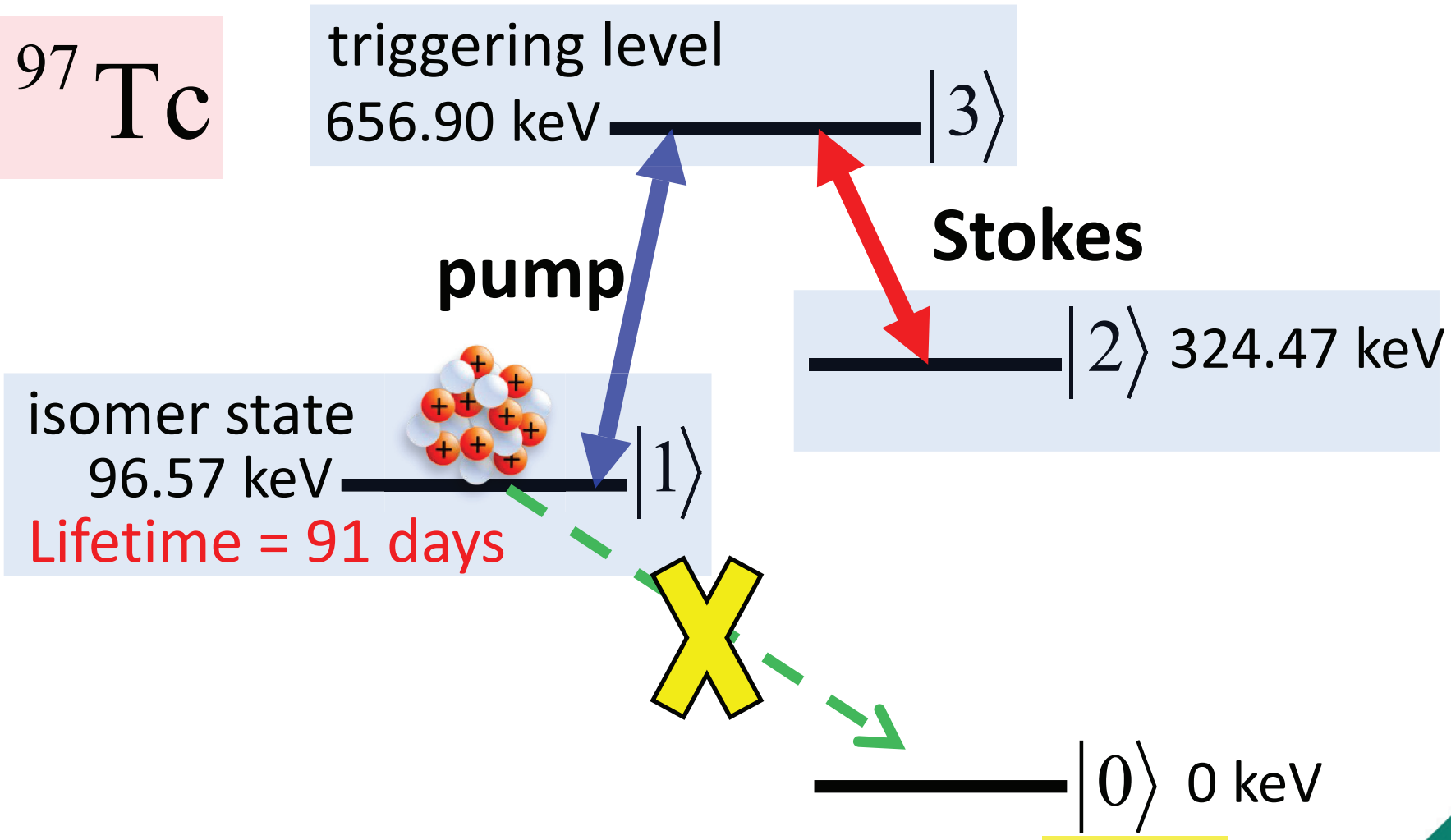
$$|D\rangle = \frac{\Omega_s}{\sqrt{\Omega_p^2+\Omega_s^2}}|1\rangle - \frac{\Omega_p}{\sqrt{\Omega_p^2+\Omega_s^2}}|2\rangle$$



K. Bergmann, H. Theuer and B. W. Shore, RMP. 70, 1003 (1998).

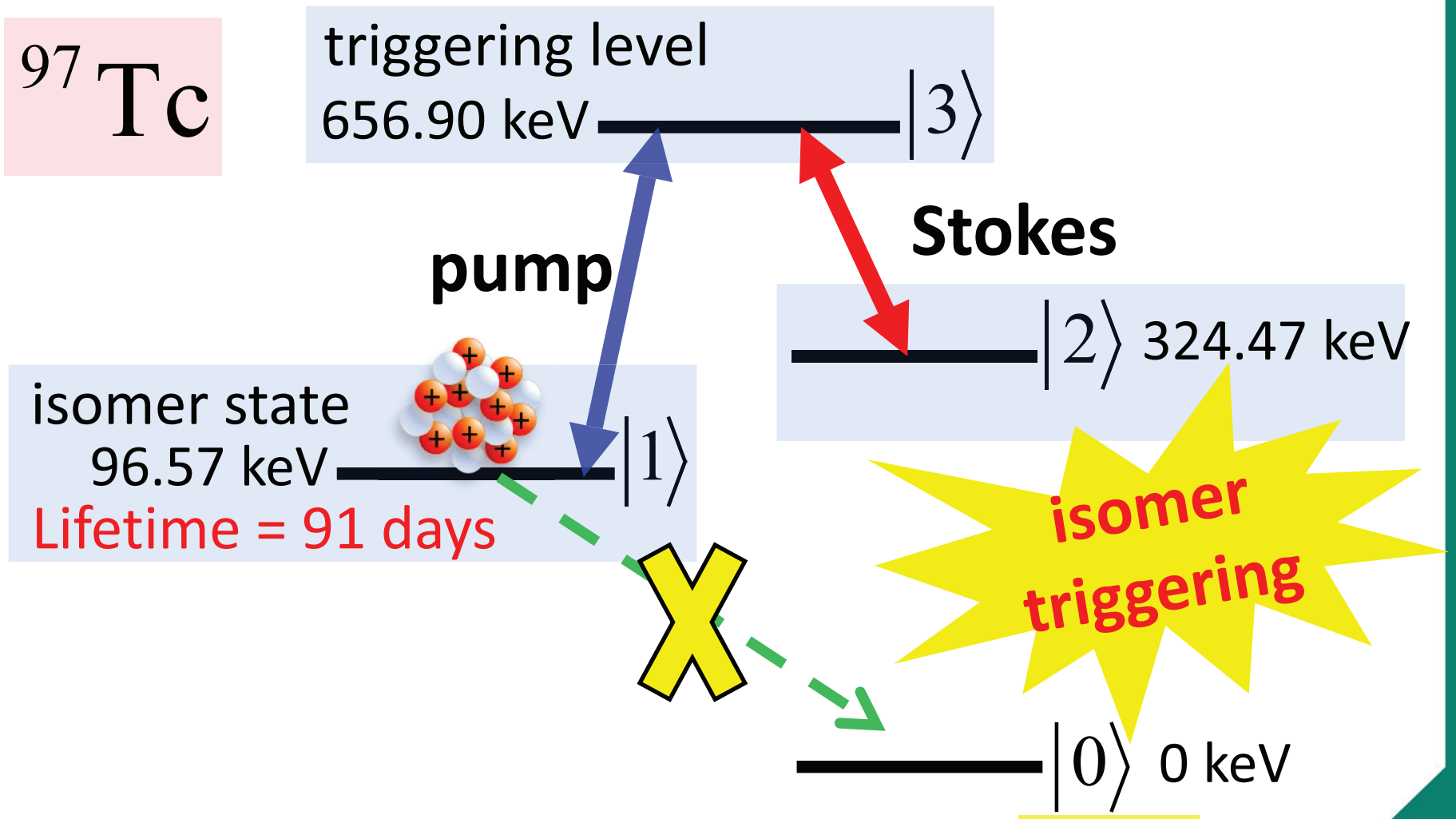
Motivation-Isomer Triggering

^{97}Tc



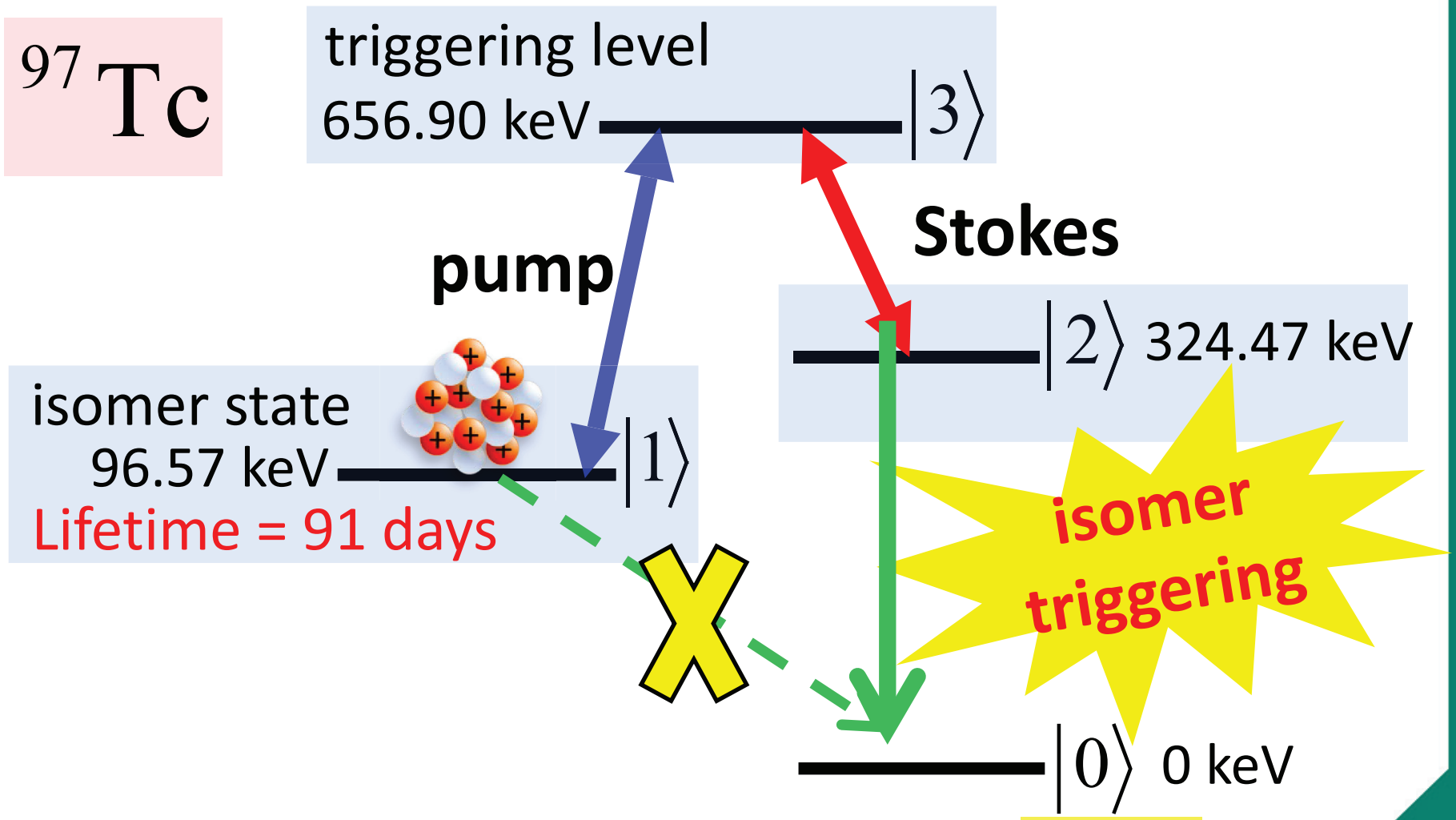
Nuclear Coherent Population Transfer (NCPT)

Motivation-Isomer Triggering



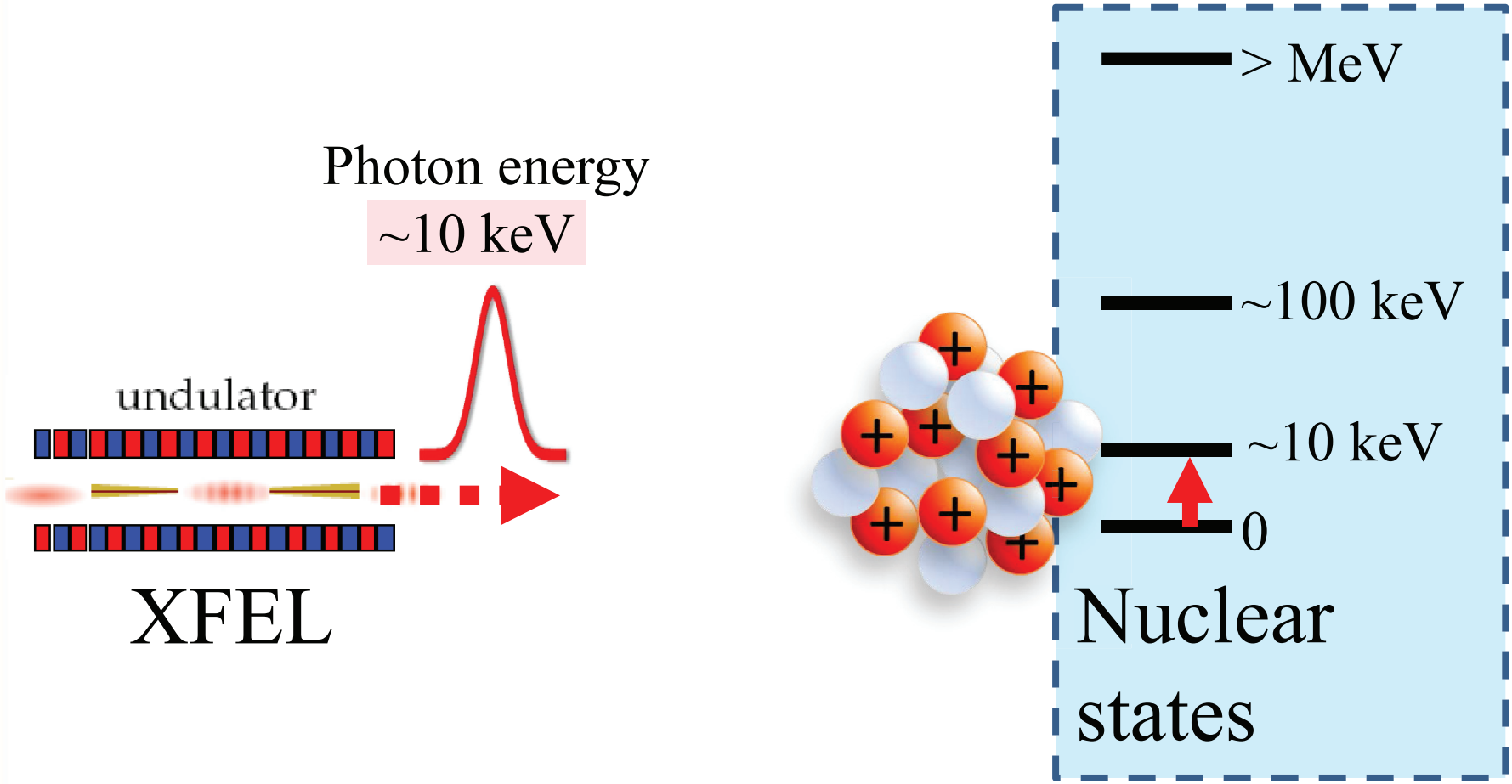
Nuclear Coherent Population Transfer (NCPT)

Motivation-Isomer Triggering



Nuclear Coherent Population Transfer (NCPT)

Drive MeV transition with 10keV photon



T. Tajima, *Report on the ELI Science*, p.14 (2009).
T. J. Bürvenich, J. Evers and C. H. Keitel, PRL 96, 142501 (2006).
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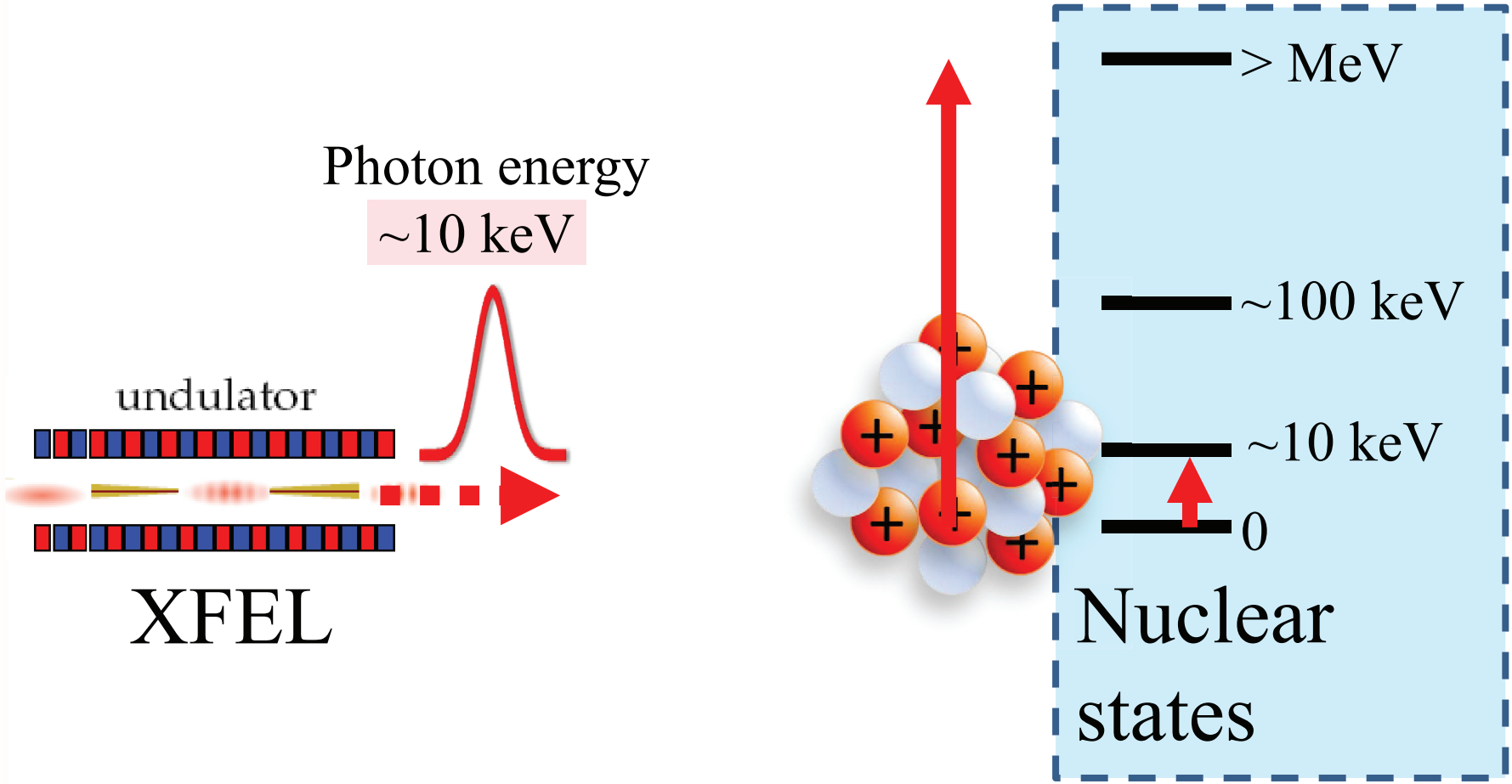

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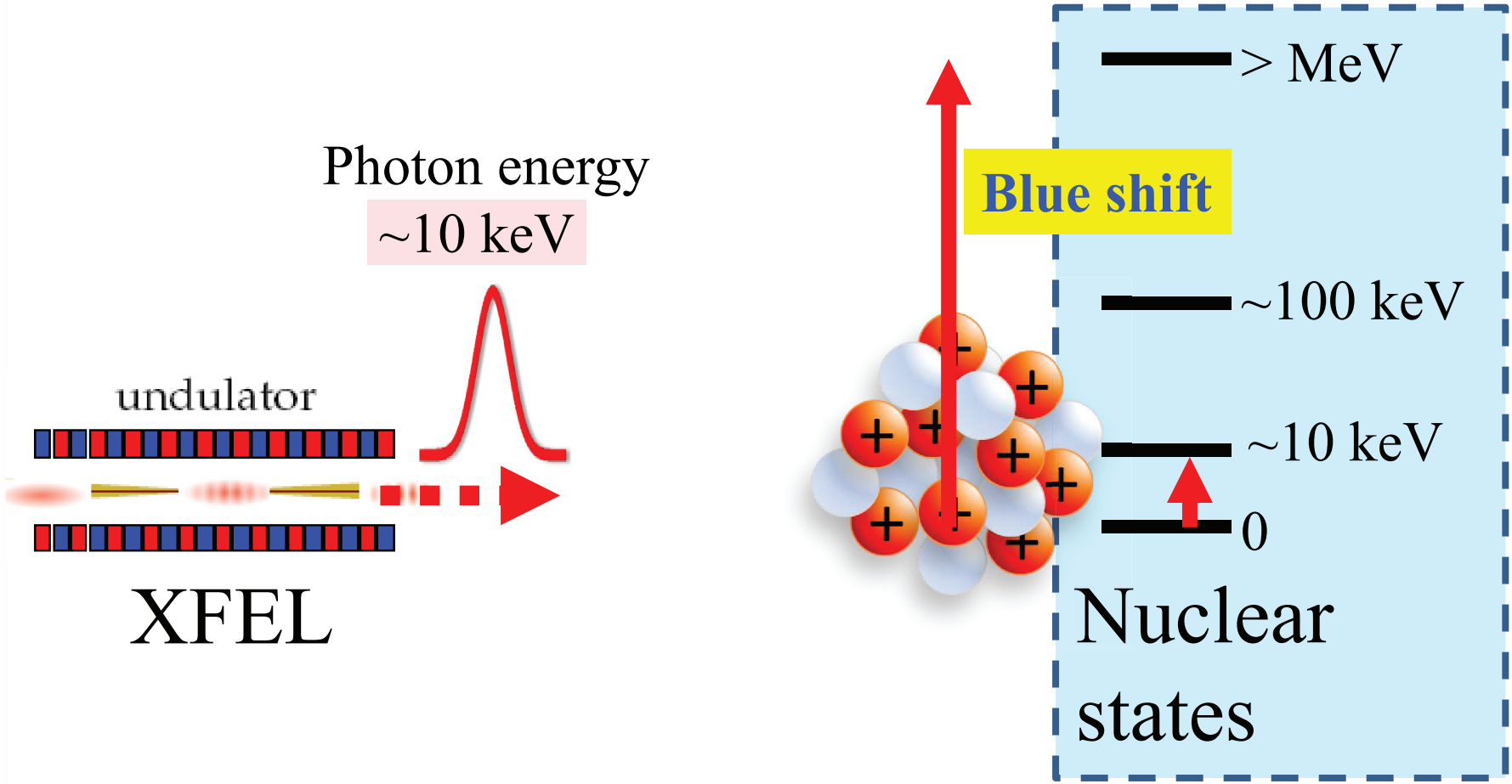

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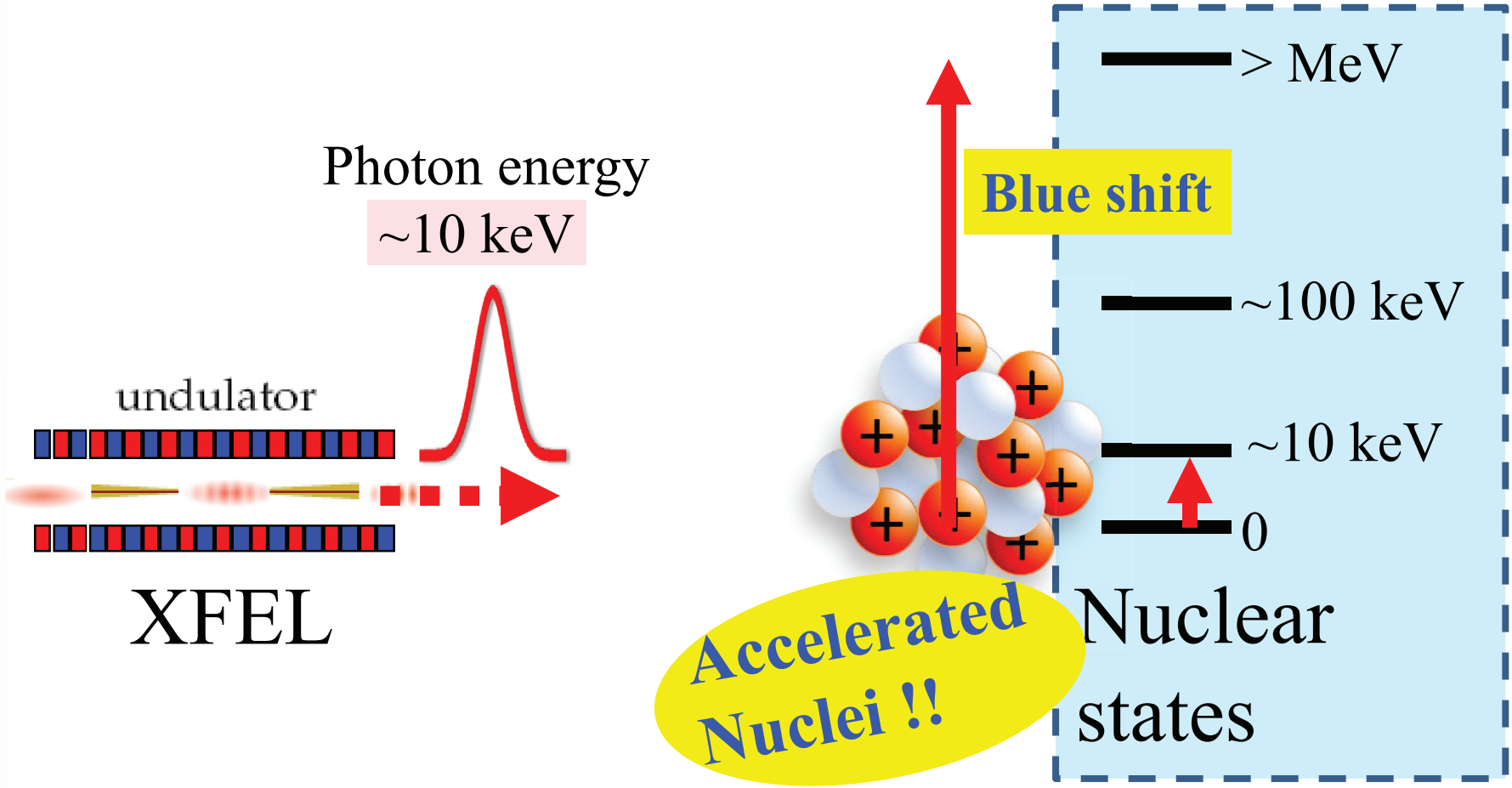

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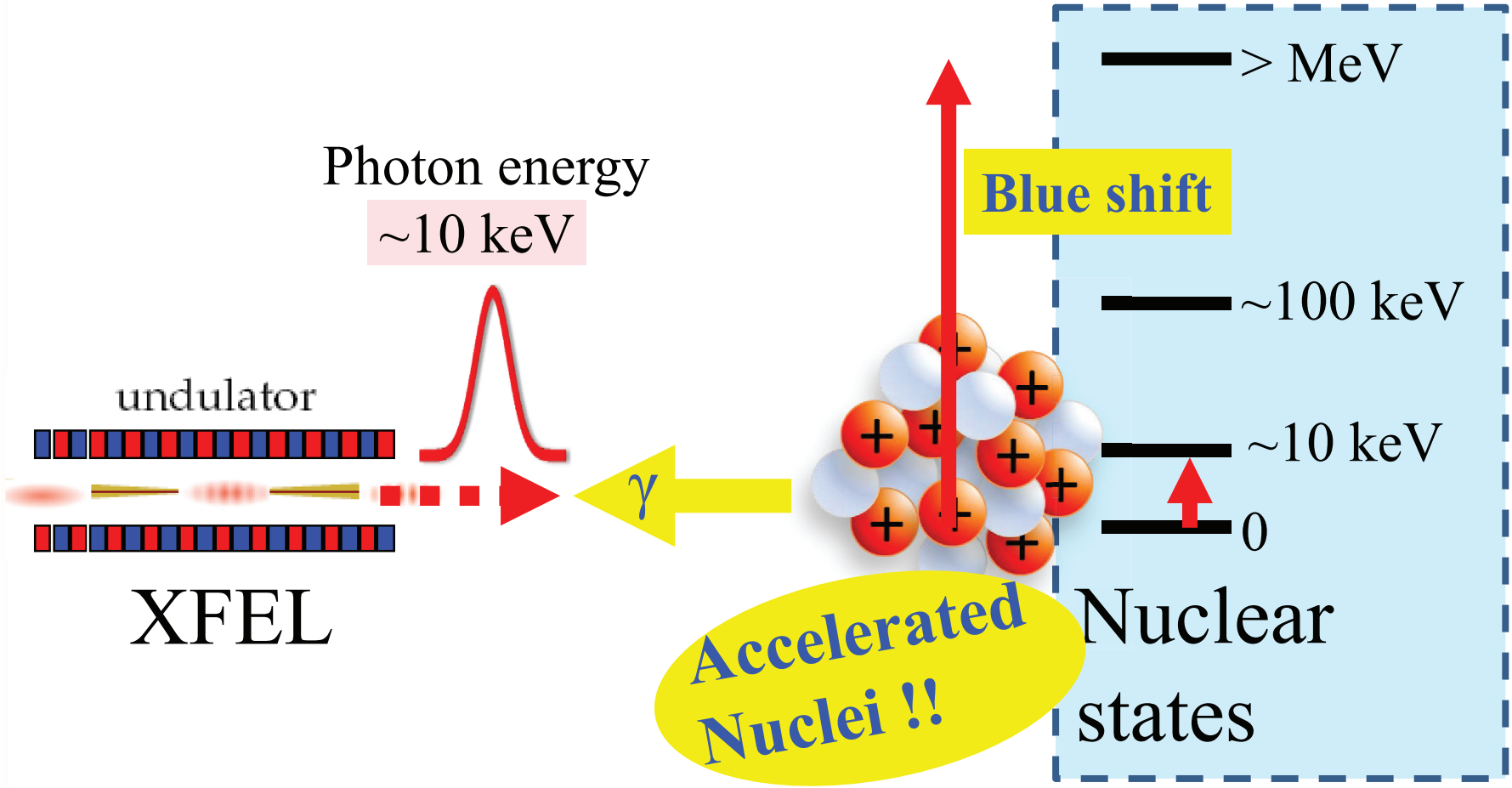

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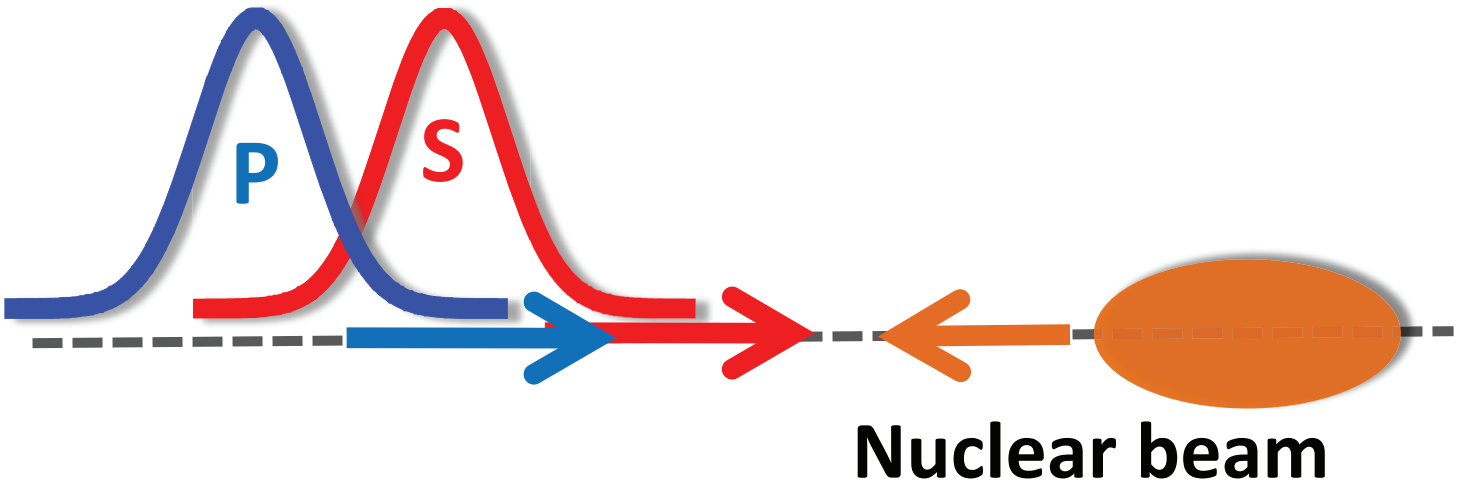
Three beams Setup



W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Lett. B 705, 134 (2011).
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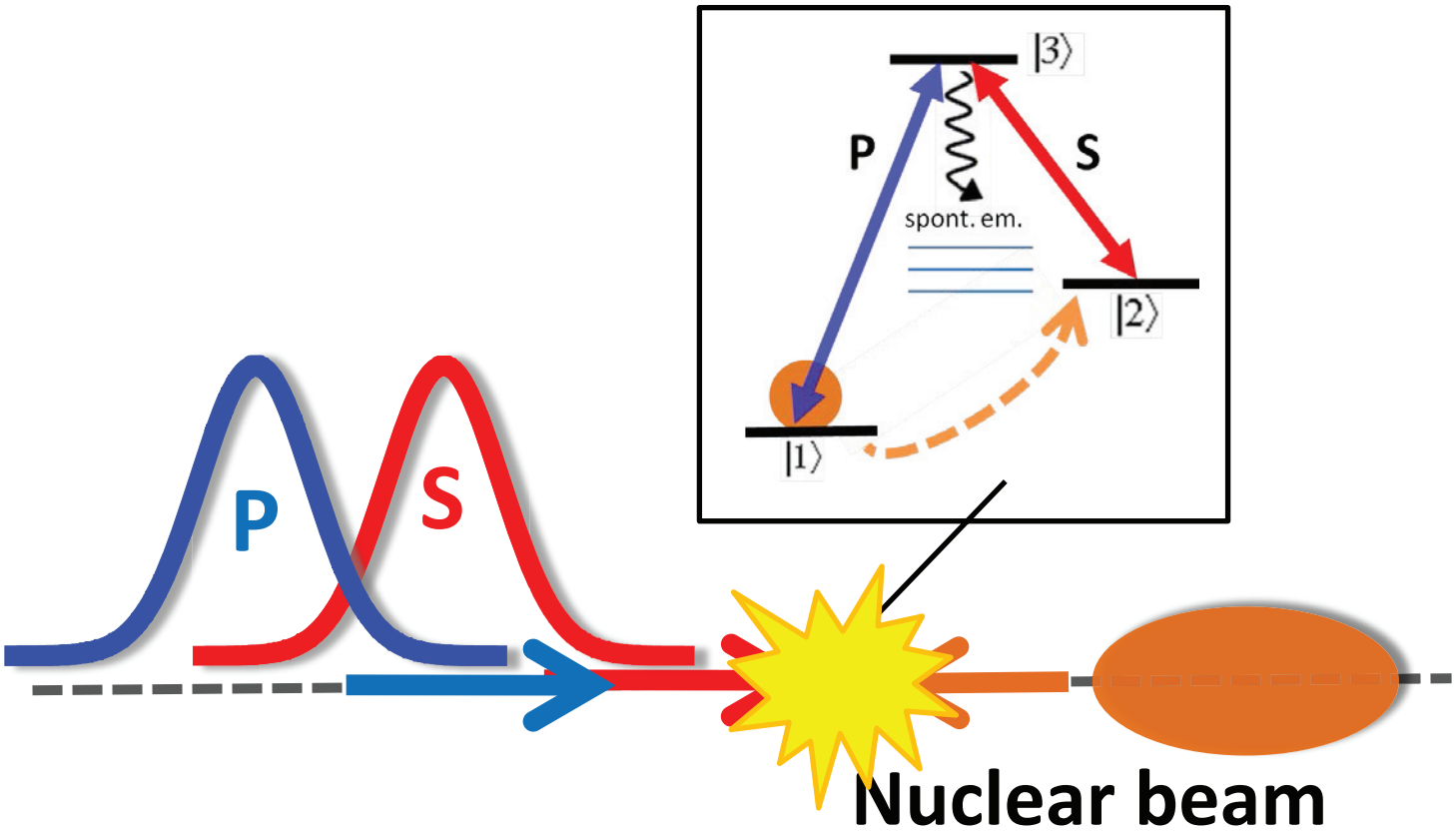

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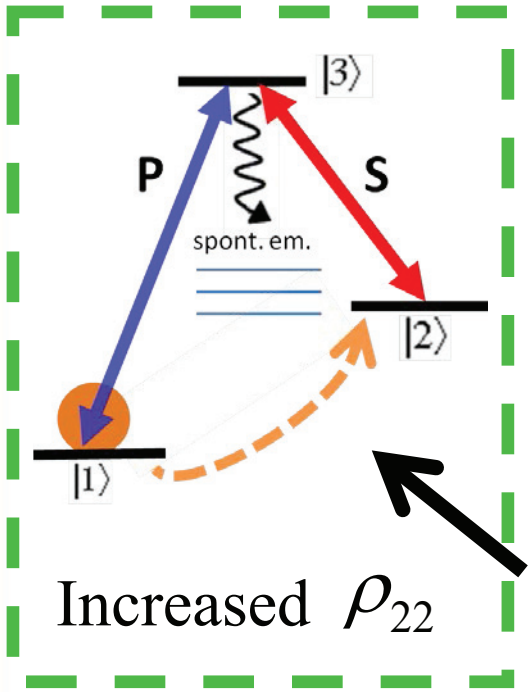
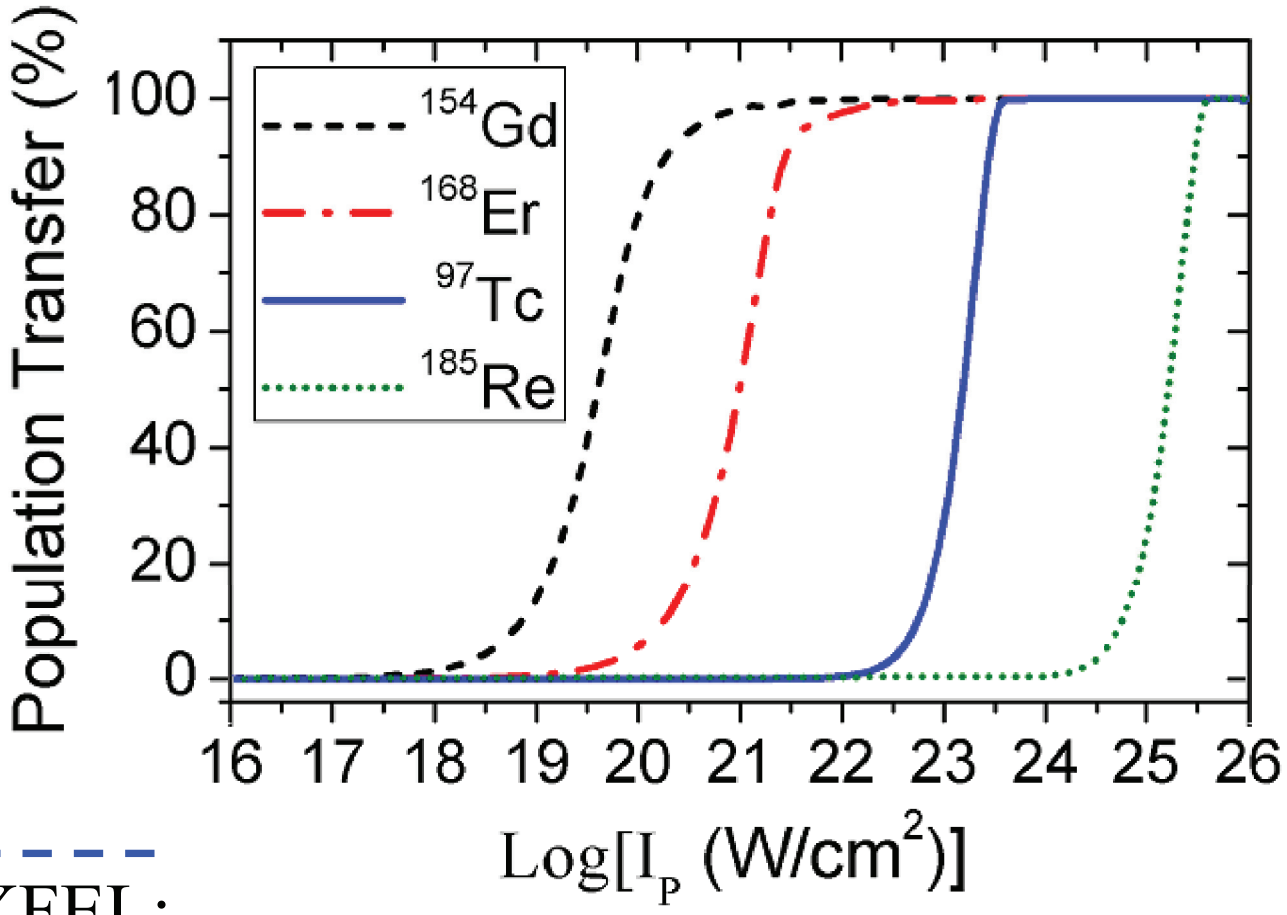
W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Rev. C 87, 054609 (2013).

Results





$11 < \gamma < 72$

Fully coherent XFEL:

Photon energy = 12.4 keV

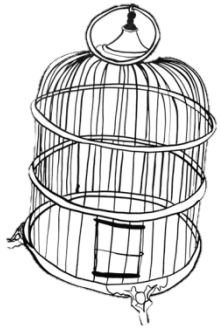
Bandwidth = 10 meV

$$\frac{I_p}{I_S} = \frac{I_p^{\pi}}{I_S^{\pi}}$$

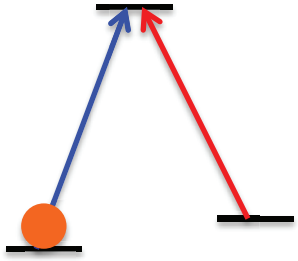
W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Lett. B 705, 134 (2011).
W.-T. Liao, A. Pálffy, C. H. Keitel, Phys. Rev. C 87, 054609 (2013).

Summary

1. Iron memory for x-ray photons.



2. mechanics-free method of changing x-ray phase.



3. NCPT can be observed with XFEL peak intensity $> 10^{18}\left(W/cm^2\right)$.

Acknowledgement

Prof. Christoph H. Keitel
MPIK, Heidelberg

Dr. Adriana Pálffy
MPIK, Heidelberg

Dr. Ralf Röhlsberger
DESY, Hamburg