

Slow Neutron Optics for a Long-Distance Free-Flight

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Date(2007/09/22) by(H.M.Shimizu)

Title(Slow Neutron Optics for a Long-distance Free-flight) at(Berkeley)

Conf(Search for Baryon and Lepton Number Violations International Workshop)

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Vertical Setup for n-nbar Oscillation

Annular Core
TRIGA Reactor
3.4 MW with
convective
cooling.
 $2E+13$ n/cm²/s
central thermal flux

LD₂ CM

Figure of Merit $\propto N t^2$

10^{-5} Pa
Vacuum
tube
L~1000 m
dia ~ 4 m

Focusing
Reflector
L~33 - 150 m

Focusing optics

**for shooting the annihilation target
without touching the boundary of**

the long free-flight path

Neutron
trajectory

Transition
point

Annihilation
target
dia ~ 2 m

Annihilation
detector

Beam dump



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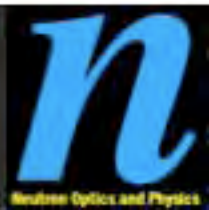
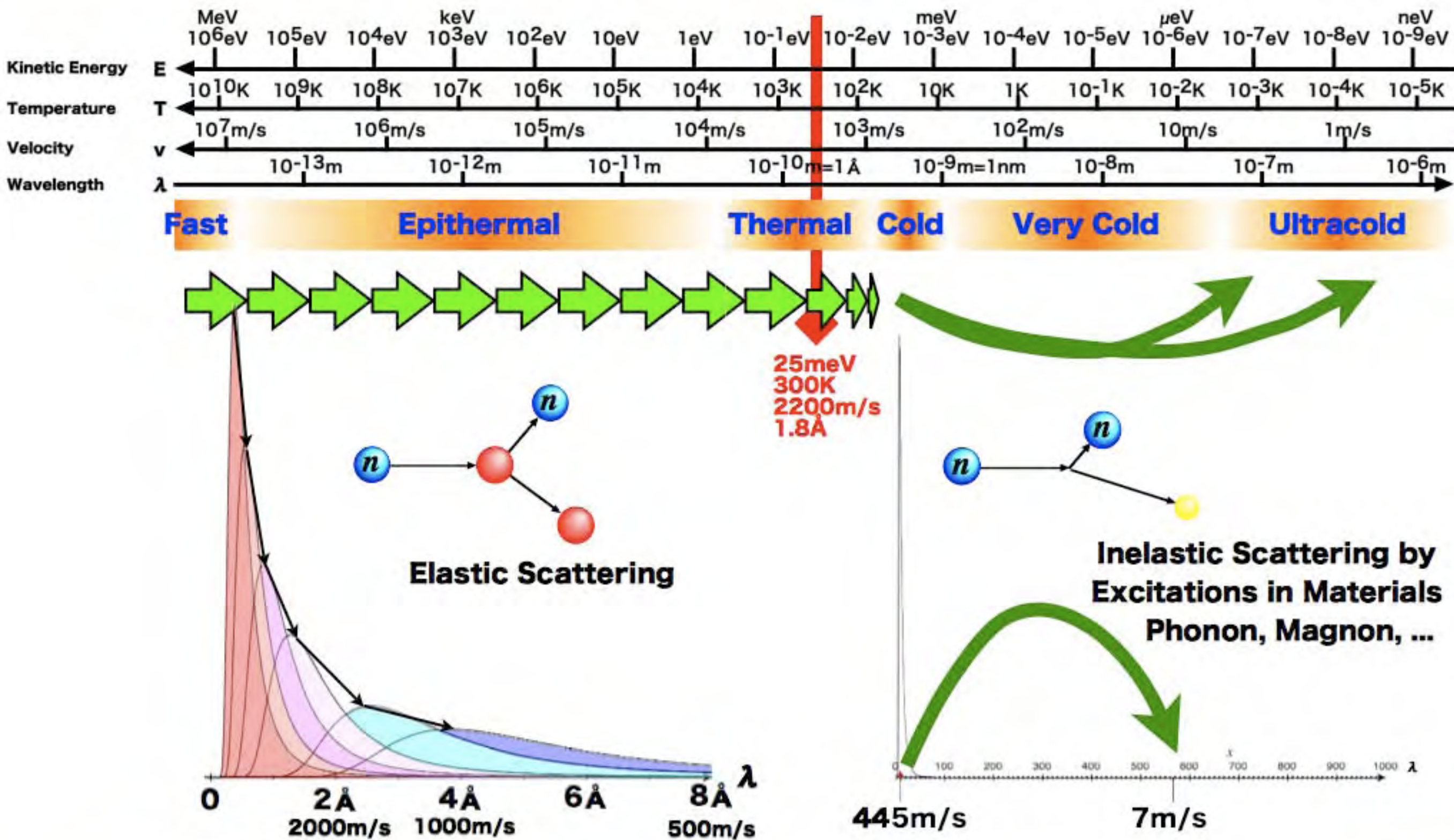
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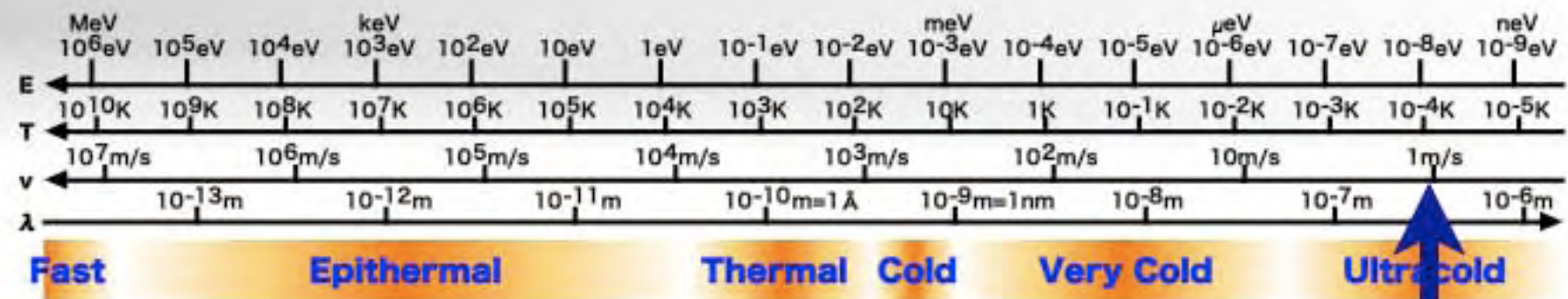
page 2



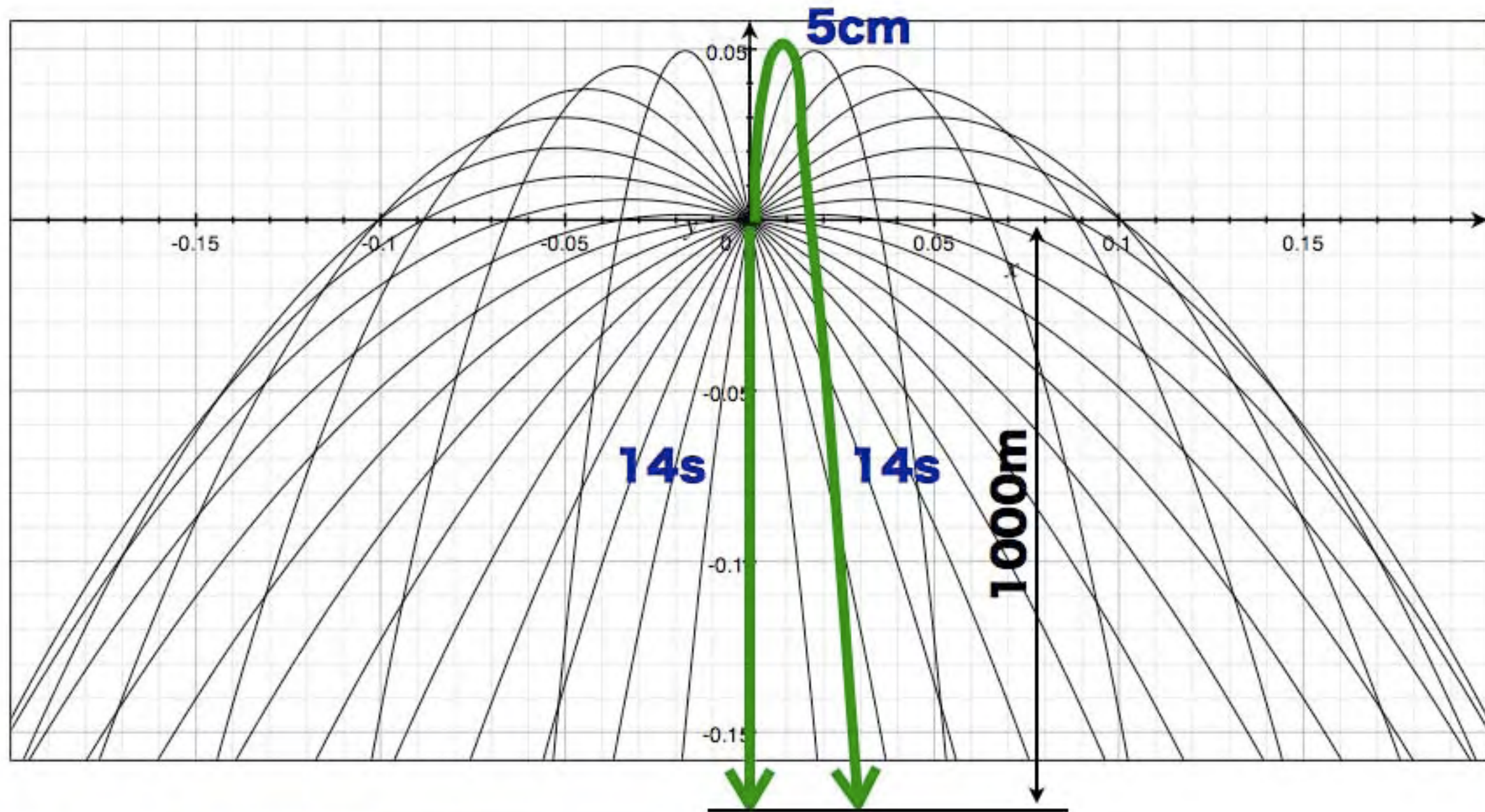
Neutron Deceleration



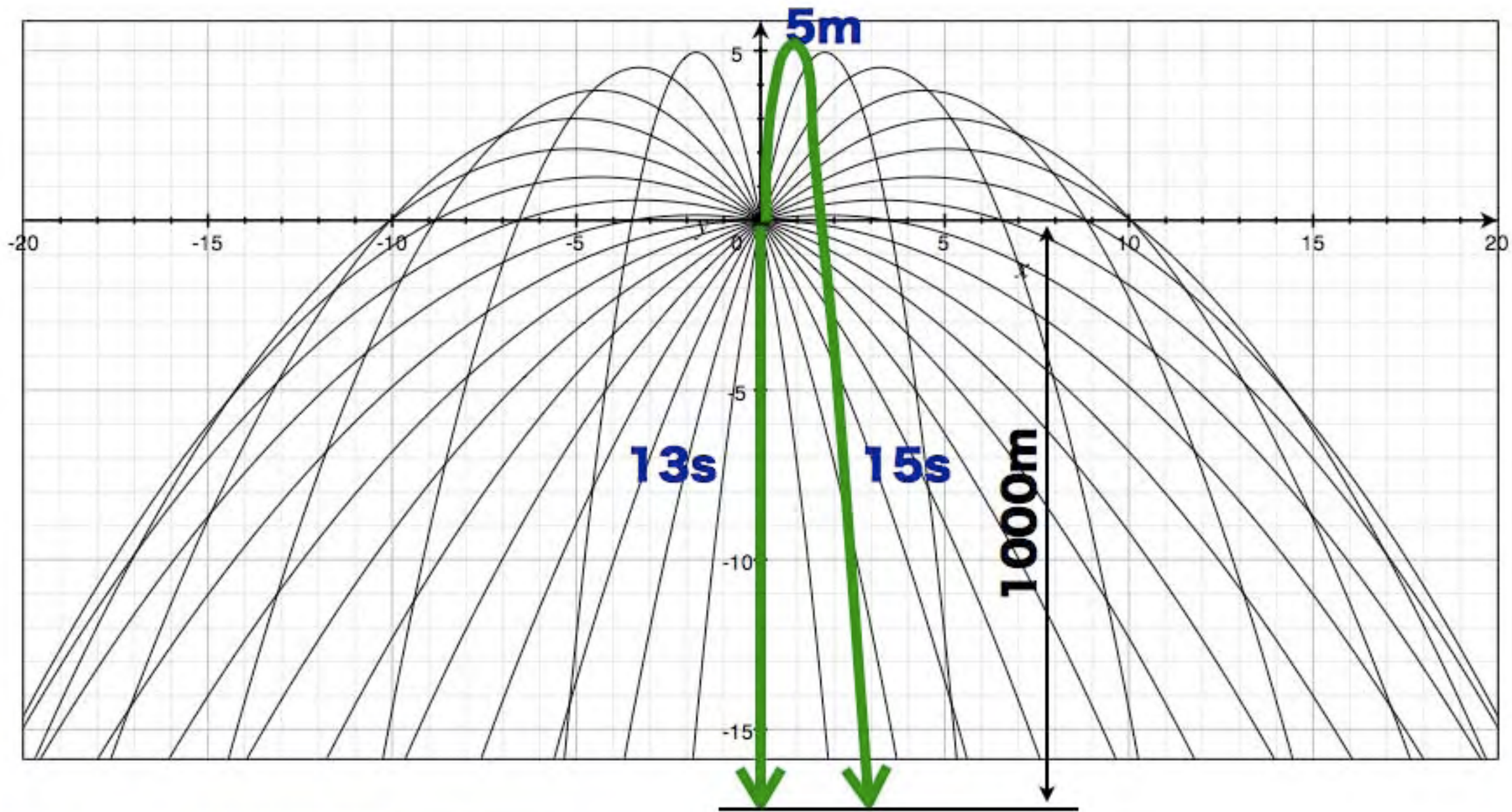
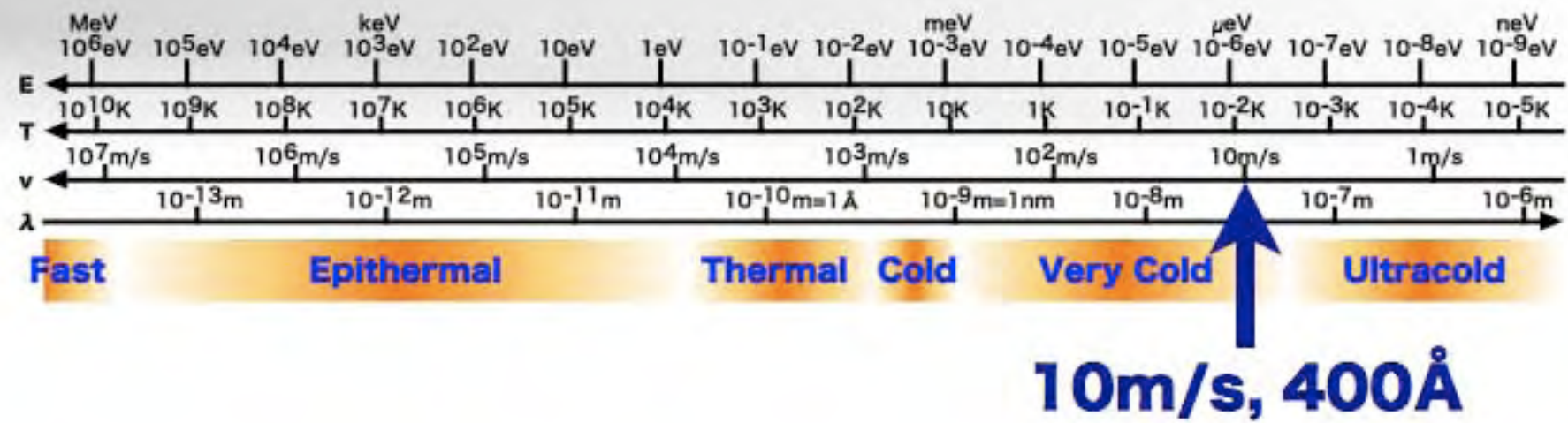
Ultracold Neutron



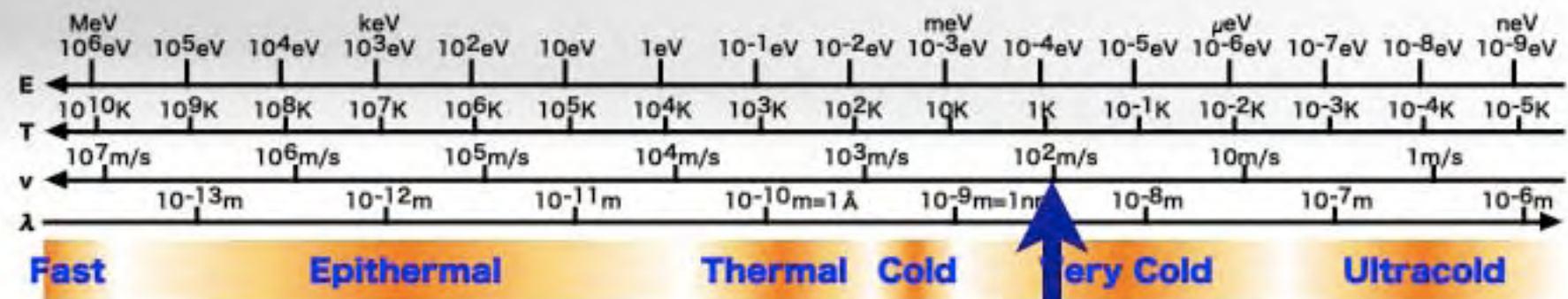
1 m/s, 4000 Å



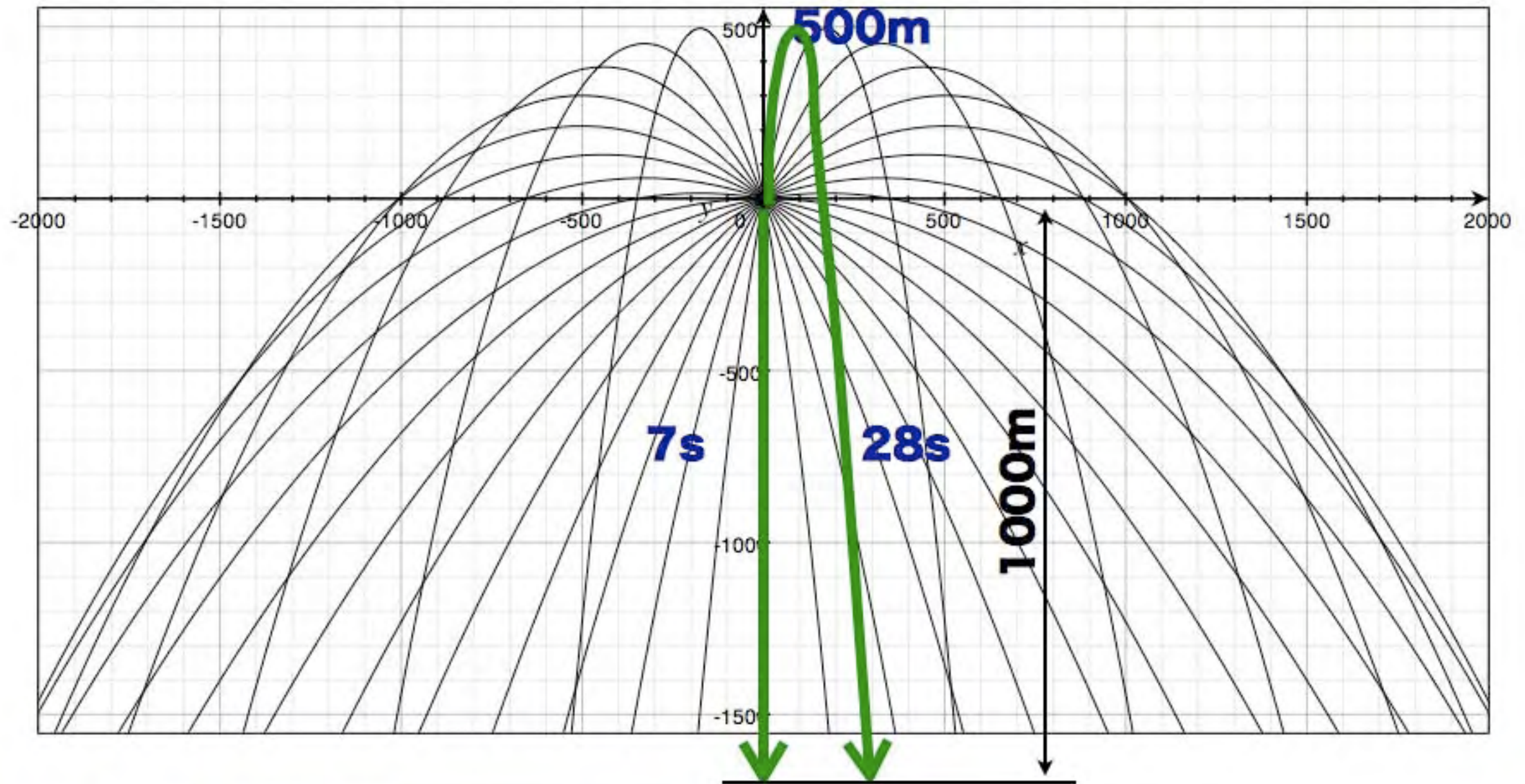
Ultracold Neutron



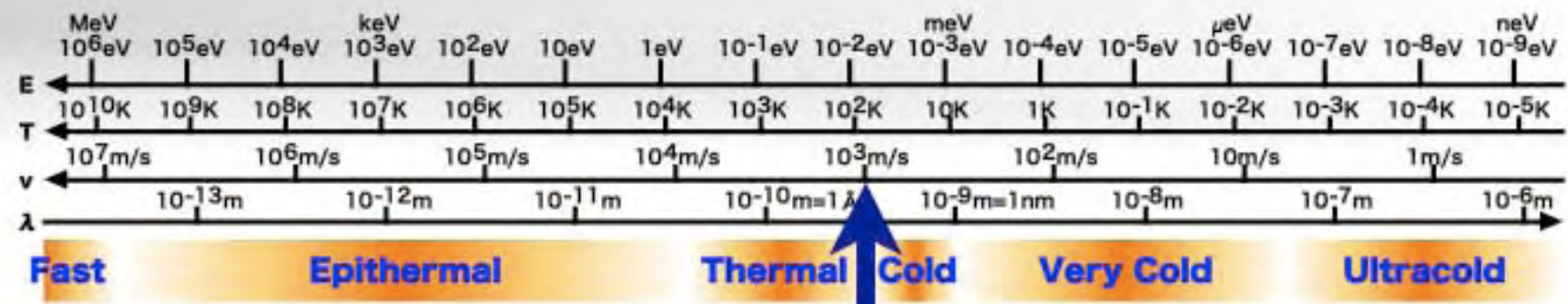
Very Cold Neutron



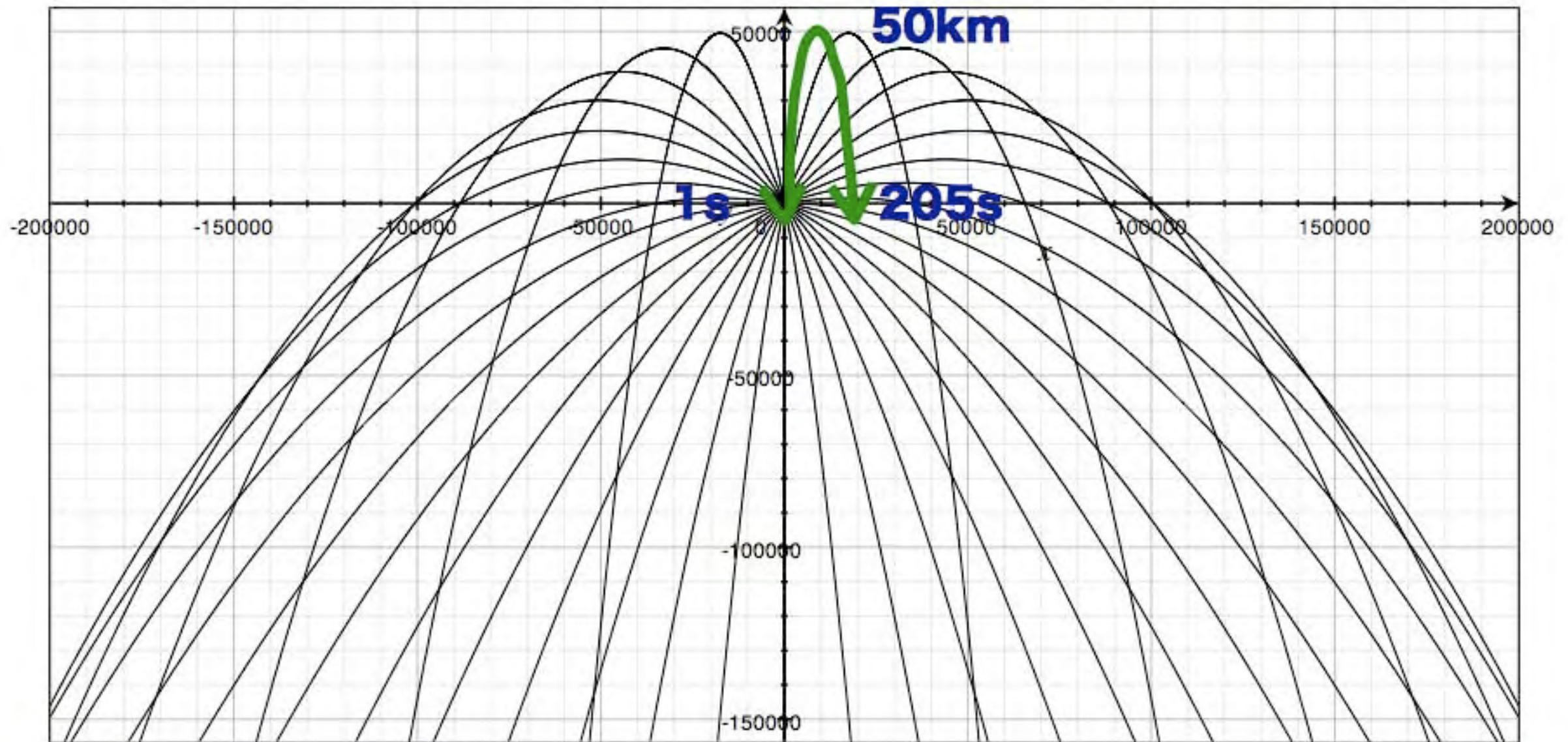
100m/s, 40Å



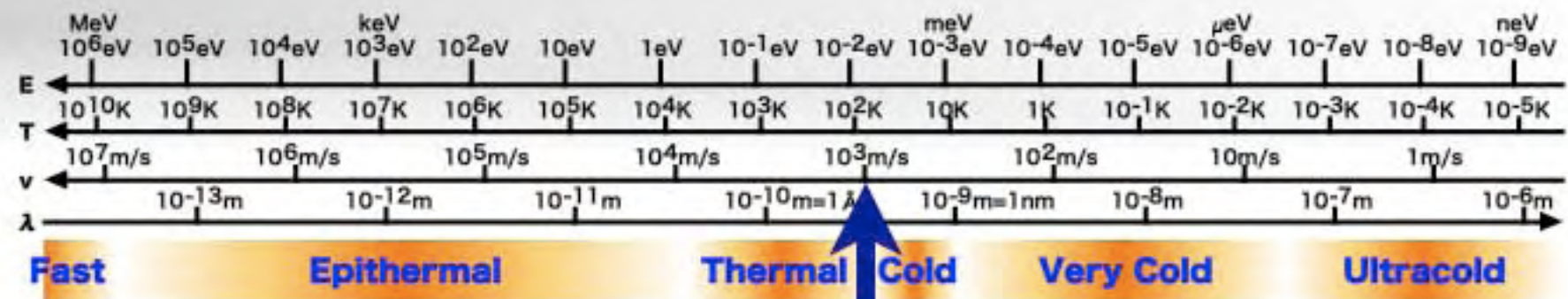
Cold Neutron



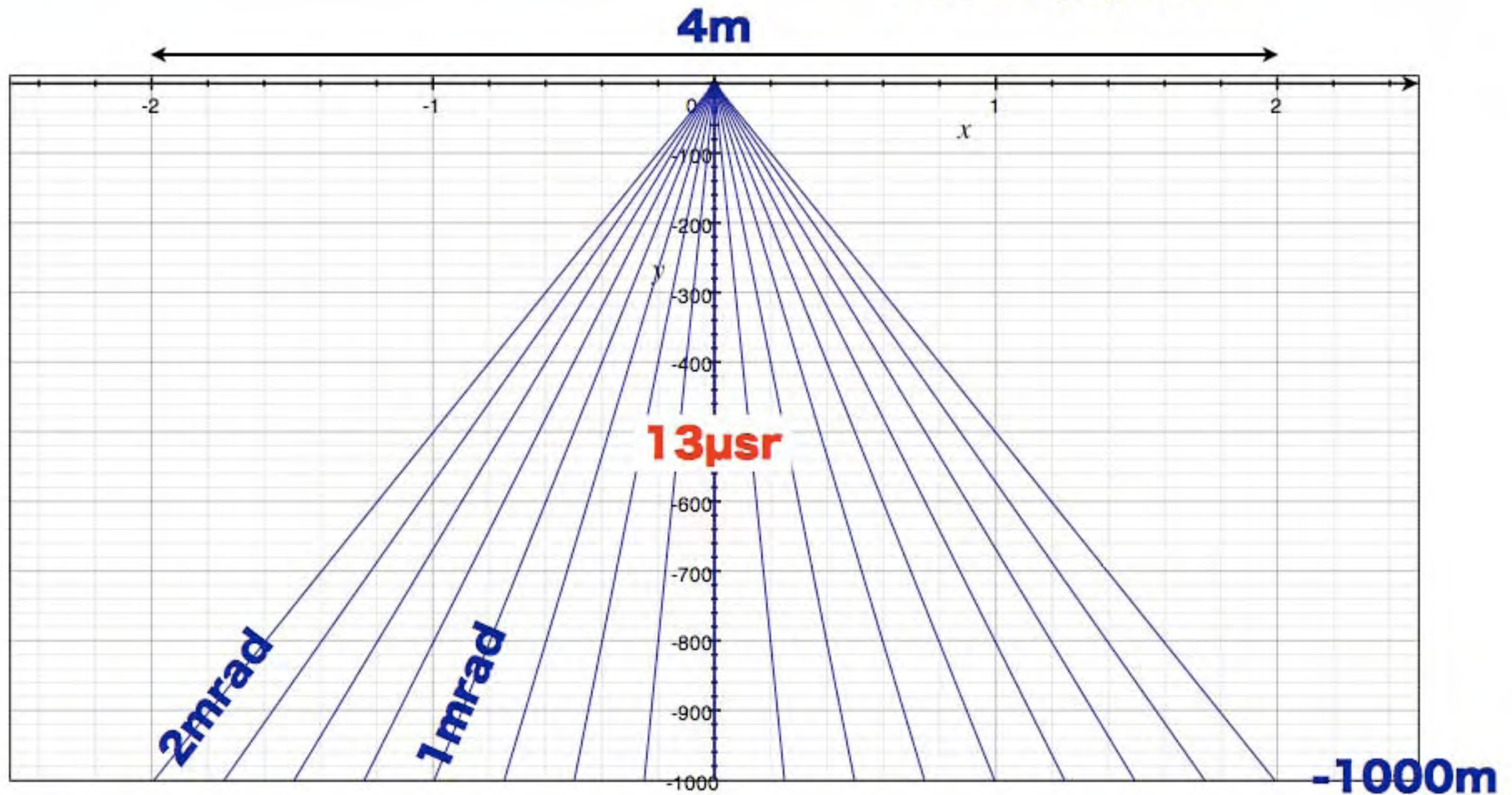
1000m/s, 4Å



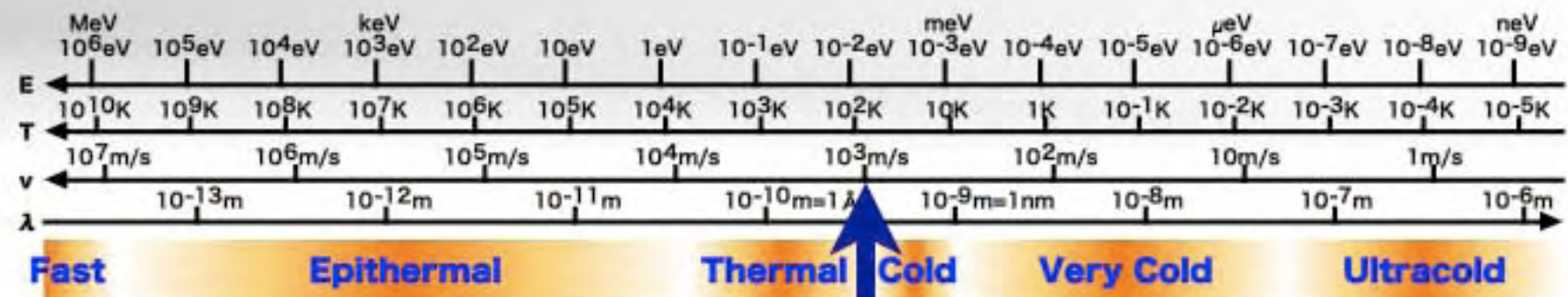
Cold Neutron



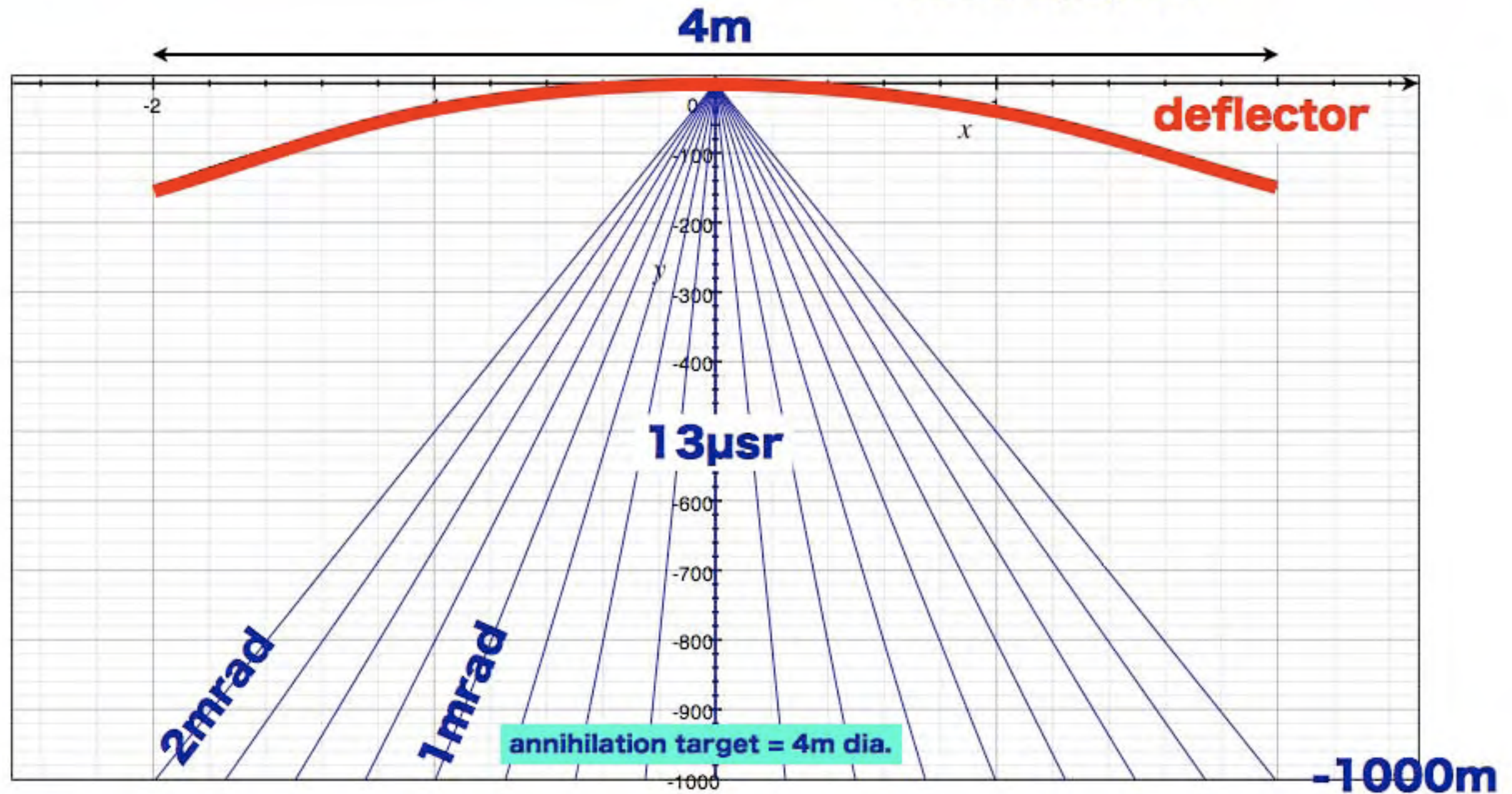
1000m/s, 4Å



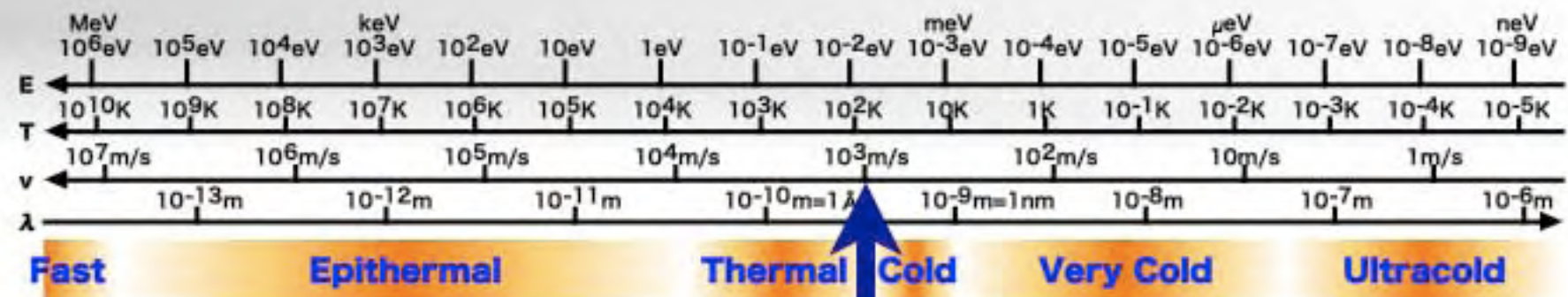
Cold Neutron



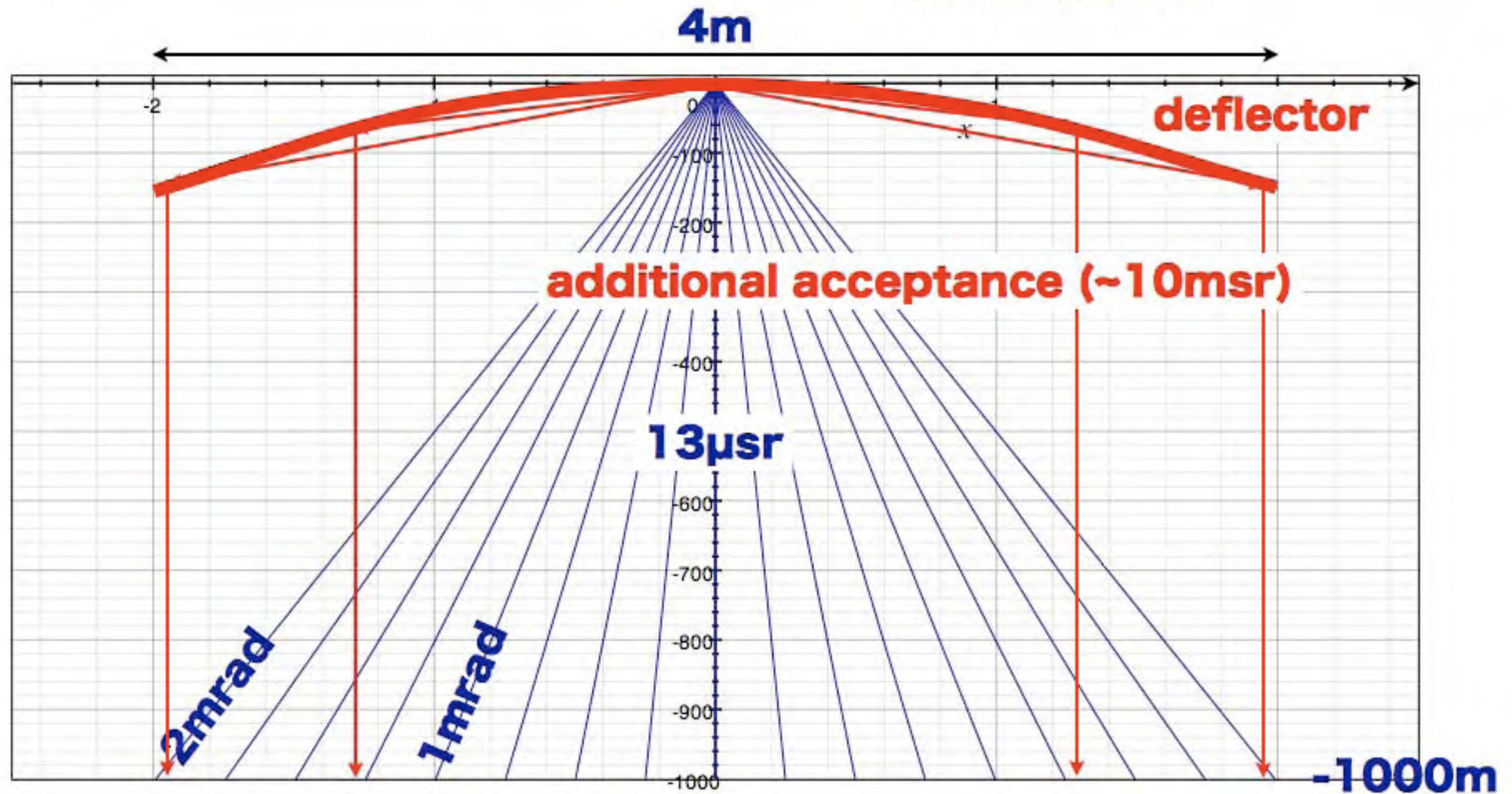
1000m/s, 4Å



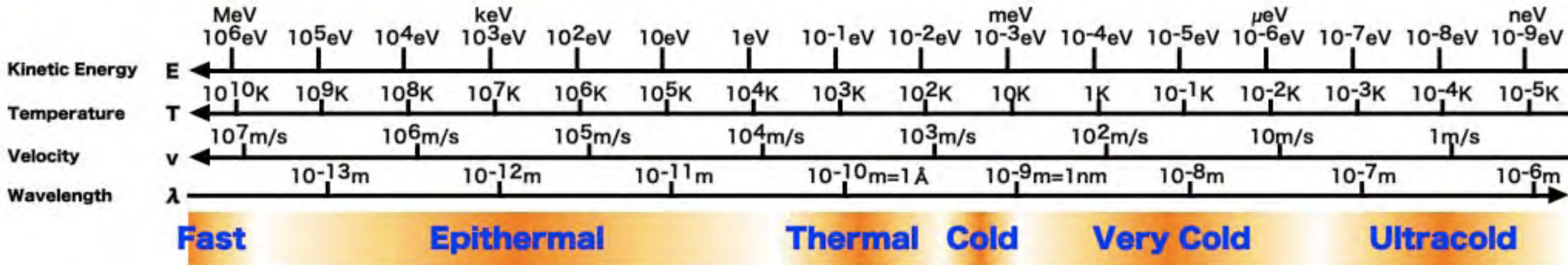
Cold Neutron



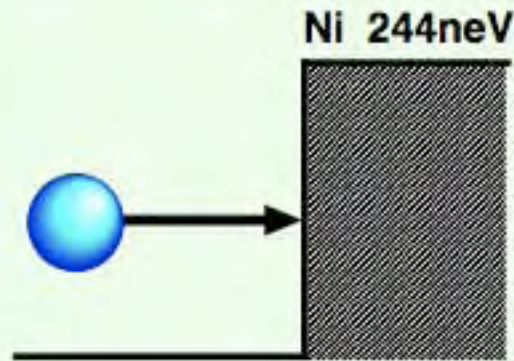
1000m/s, 4Å



Neutron Optics

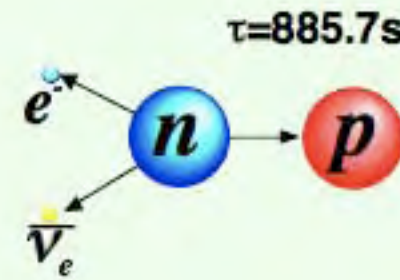


Strong Interaction



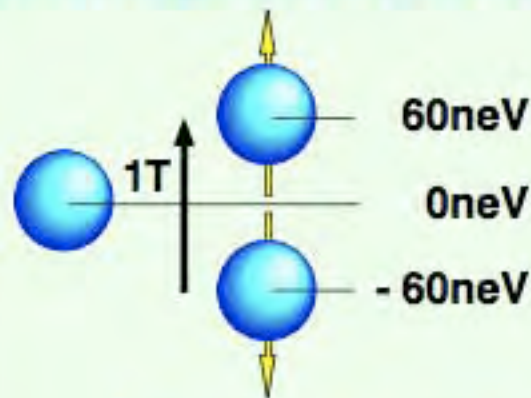
Strong Interaction

Weak Interaction



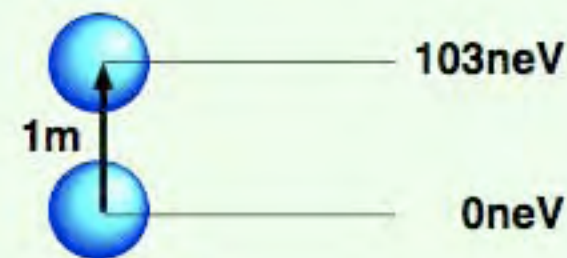
Weak Interaction

Electromagnetic Interaction



Electromagnetic Interaction

Gravitational Interaction



Gravitational Interaction



Neutron Optics

→ NIM A529 (2004)

Reflective Optics

M.Hino et al. (Kyoto Univ.)

Ni/Ti supermirrors

Fe/Si supermirrors

Fe/Ge supermirrors

K.Ikeda et al. (RIKEN)

Imaging Detector

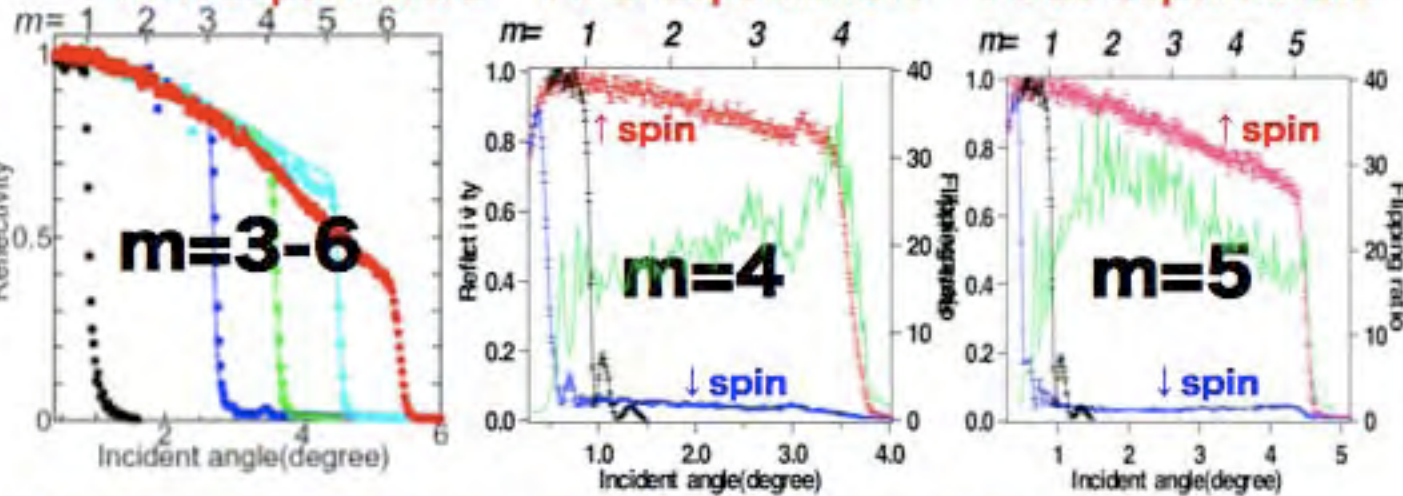
K.Hirota (RIKEN)

S.Sato (KEK) et al.

RPMT



FPPMT



Compound Refractive Optics

Biconcave

Fresnel-shape

Coaxial Double Biconcave

Microprism



T.Adachi et al. (RIKEN)

T.Shinohara et al. (RIKEN)

Magnetic Optics

Superconducting

Permanent

Pulsed

Variable Permanent

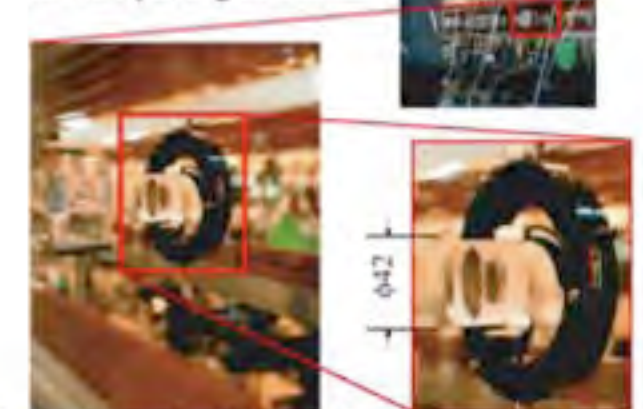


H.M.Shimizu (RIKEN), T.Oku, J.Suzuki (JAERI)

Y.Iwashita et al. (Kyoto Univ.)

Interference Optics

Beam Splitting Etalon



M.Kitaguchi et al. (Kyoto Univ.)



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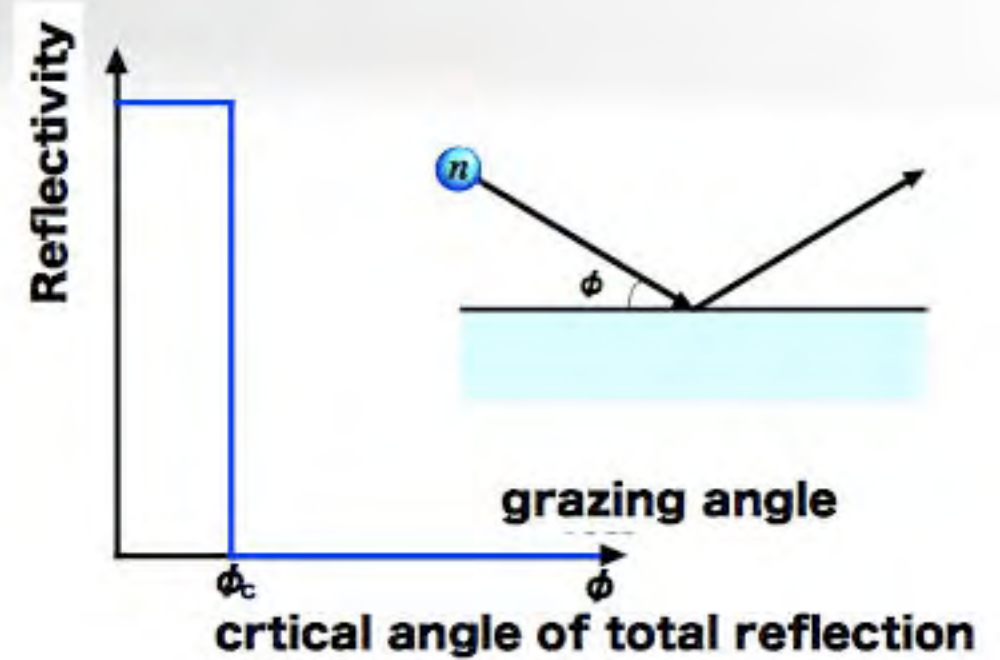
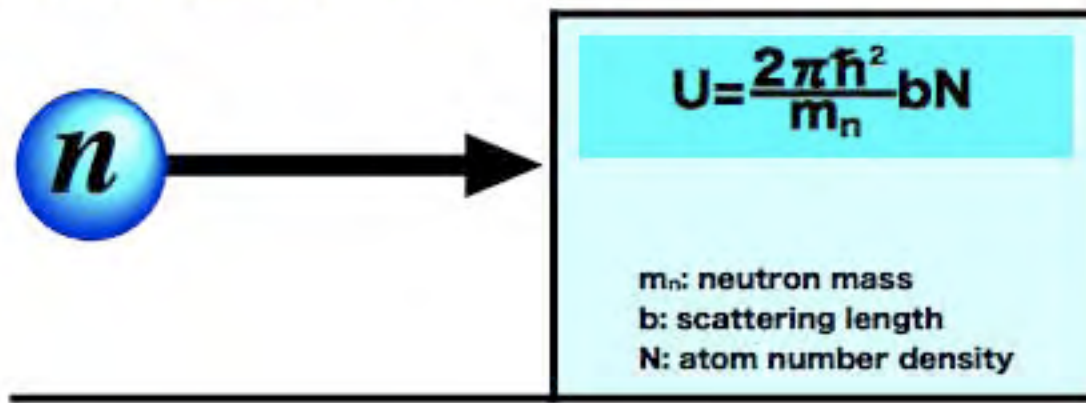
Conf(Search for Baryon and Lepton Number Violations International Workshop)

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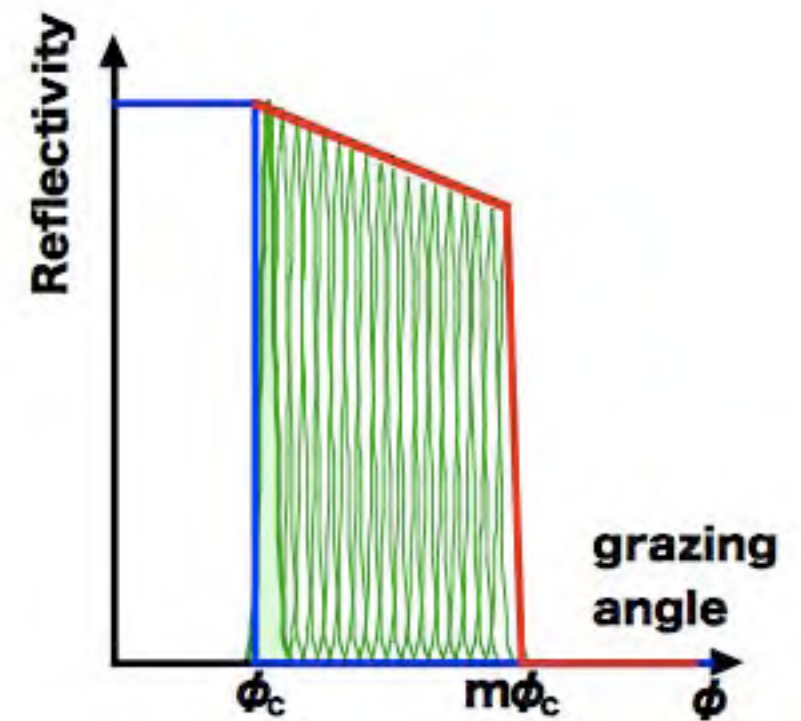
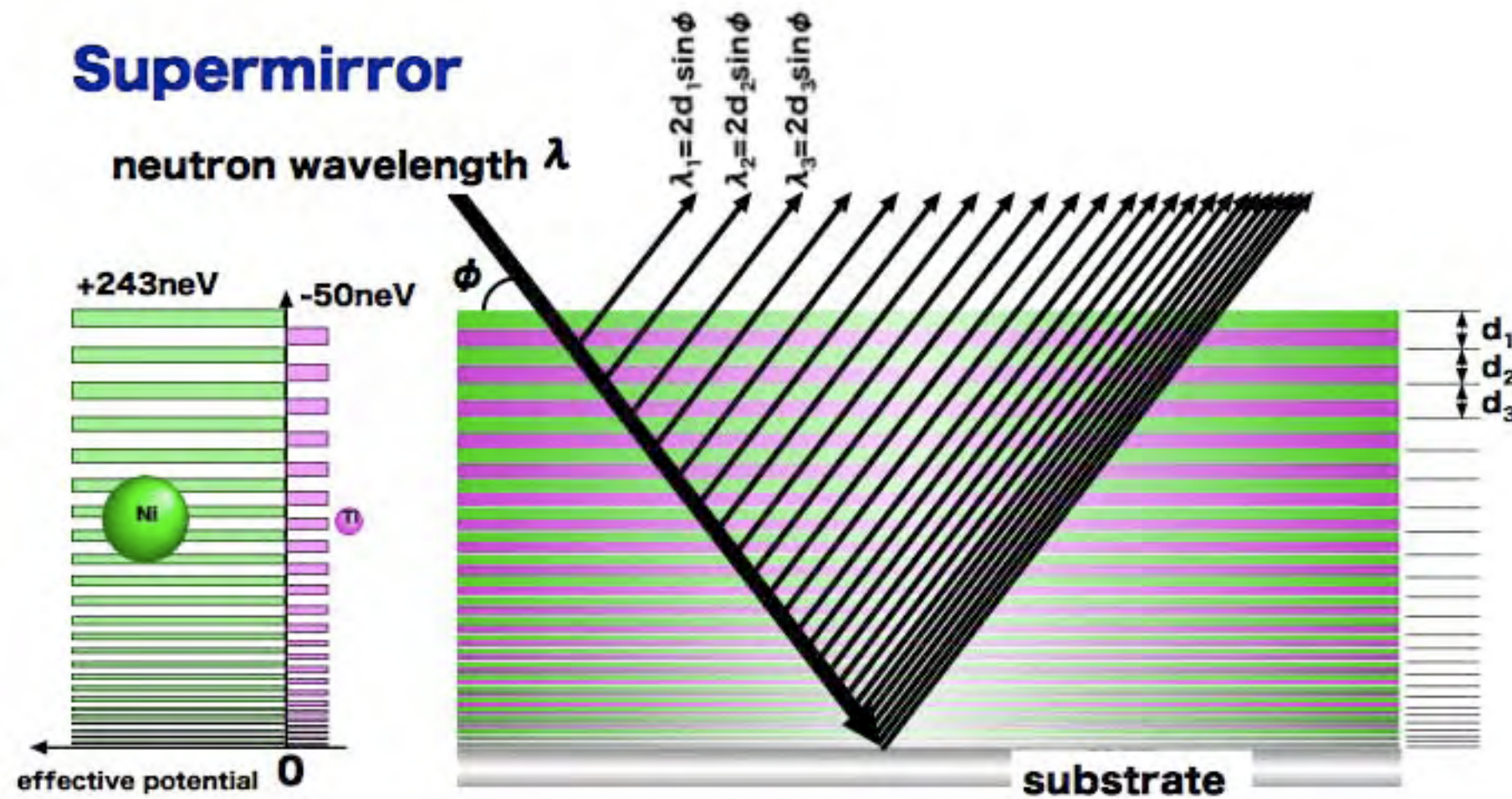
Reflective Optics

Neutron Reflection



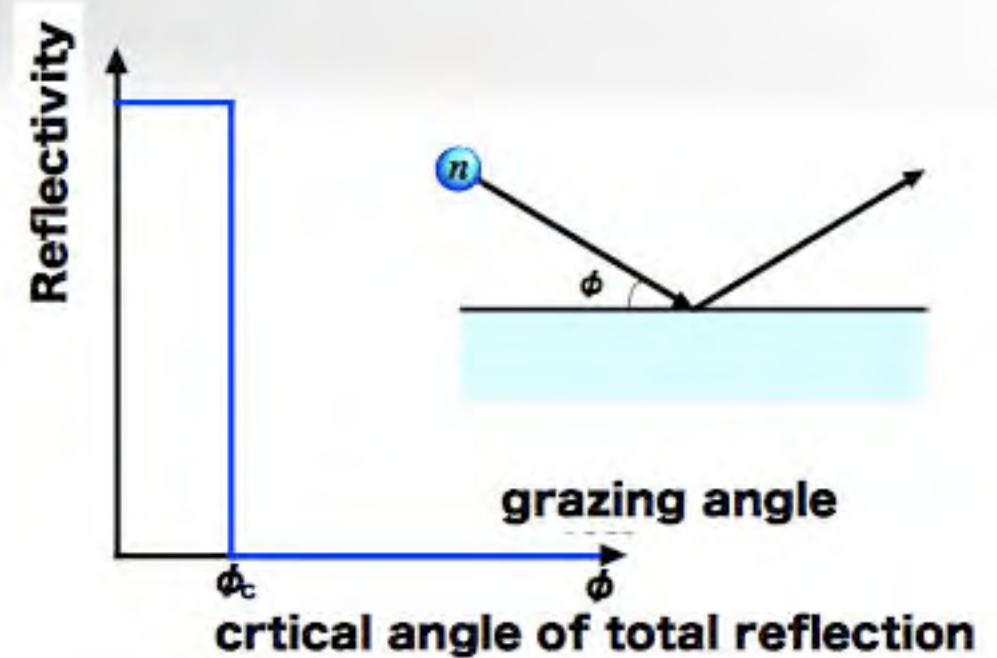
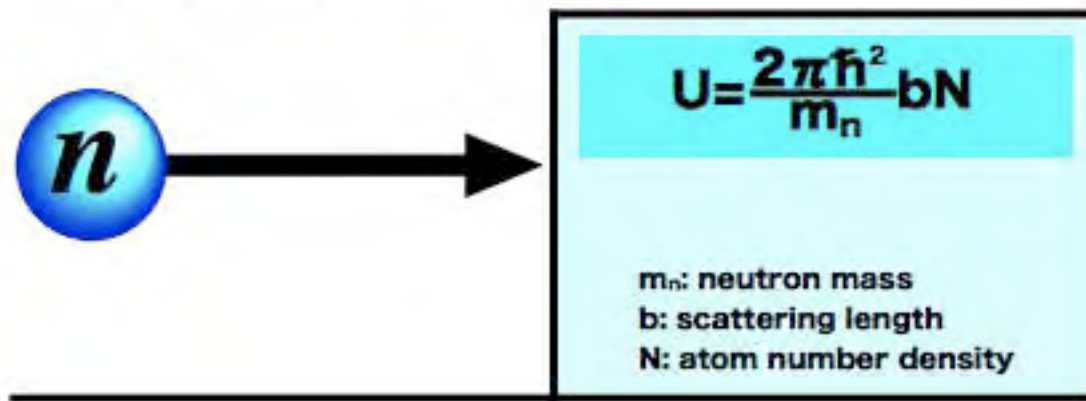
Supermirror

neutron wavelength λ



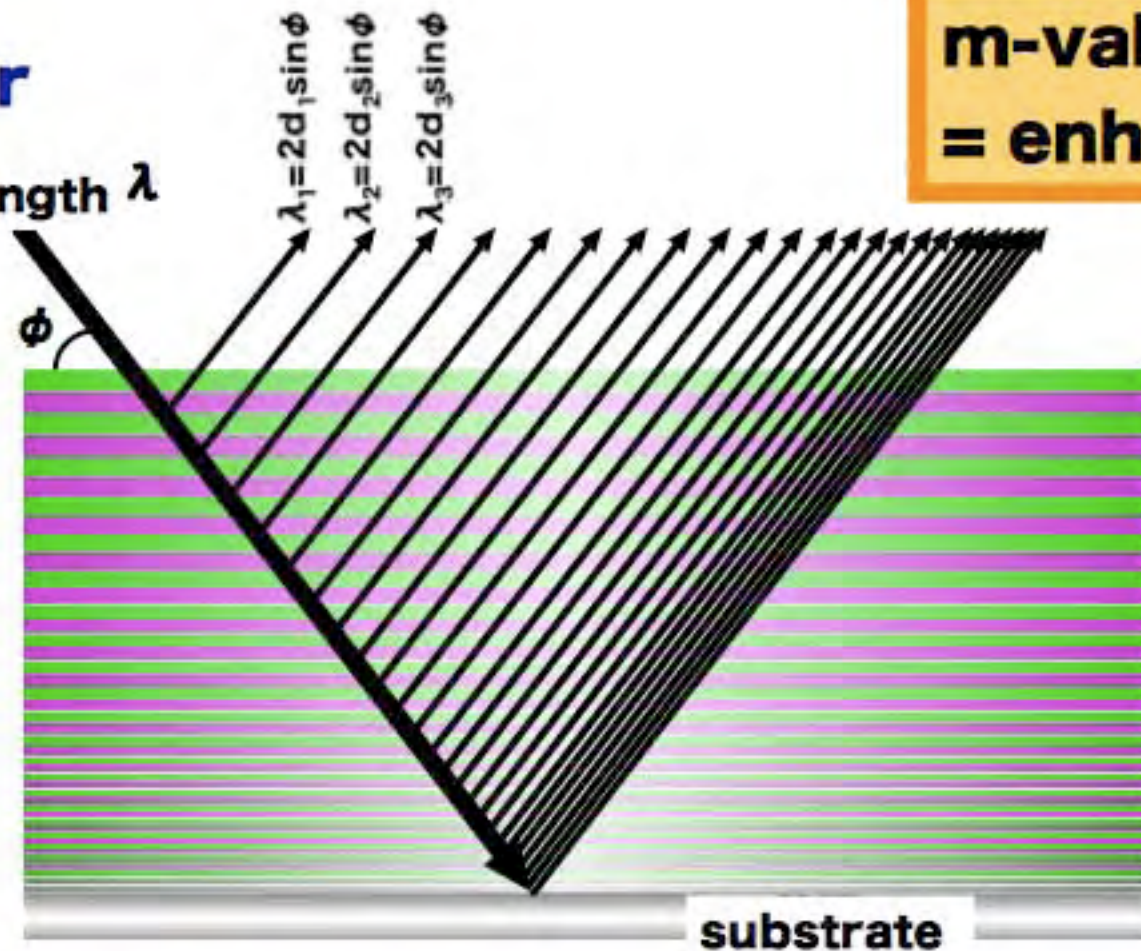
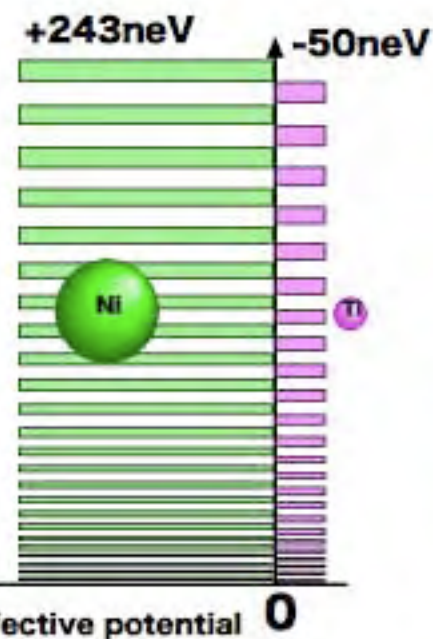
Reflective Optics

Neutron Reflection



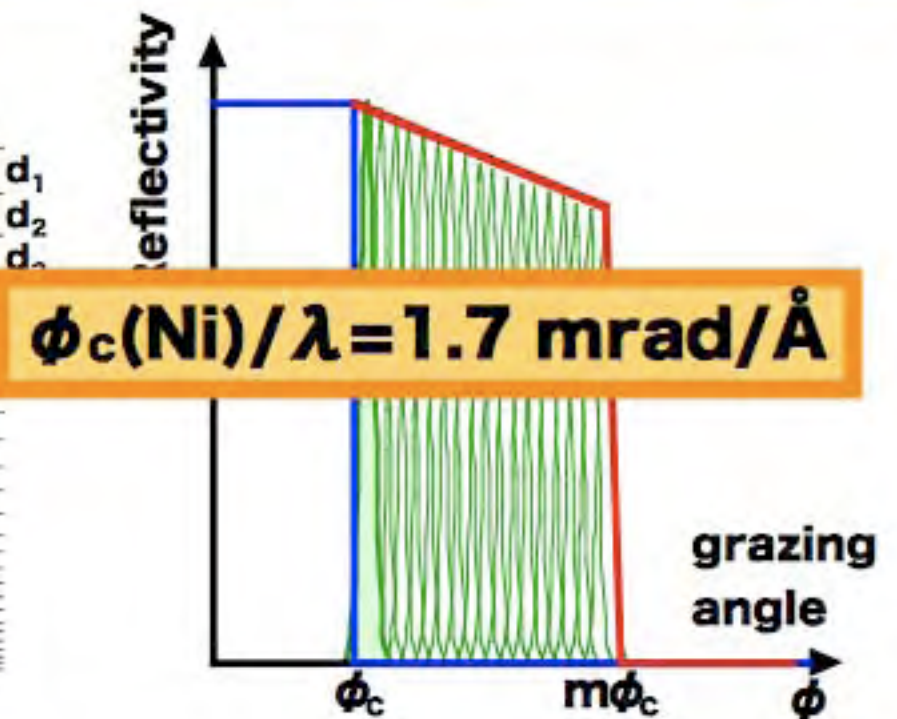
Supermirror

neutron wavelength λ



m-value

= enhancement of critical angle



$$\phi_c(\text{Ni}) / \lambda = 1.7 \text{ mrad/\AA}$$



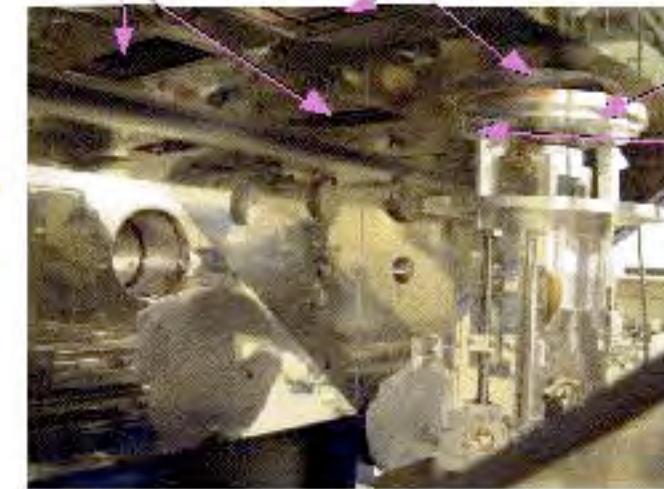
Supermirror Coaters

Magnetron Sputtering

$$m \leq 3.6$$

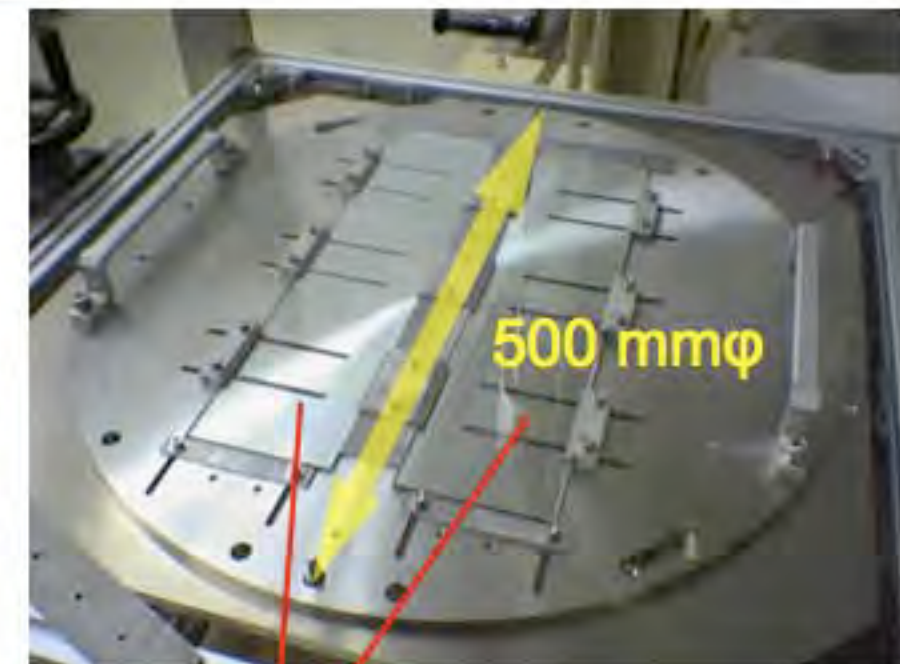
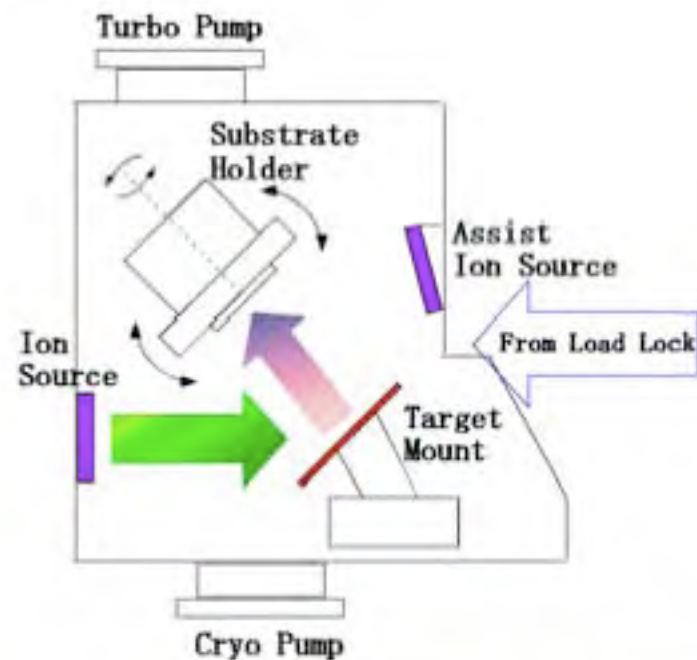


Facing Target Sputter Magnetron Sputter



Ion Beam Sputtering

$$m \leq 10$$



Float glass substrates (400 x 100 x 5 mm)

Photograph of new IBS instrument (L) and substrate holder with diameter of 500 mmφ (R).



Large-m Supermirrors

NiC/Ti(400, 1200, 3000layers)

$m=1$ 2 3 4 5

Ni200nm

$\sigma=5.5\text{\AA}$

$$R=R_0e^{-2M}$$

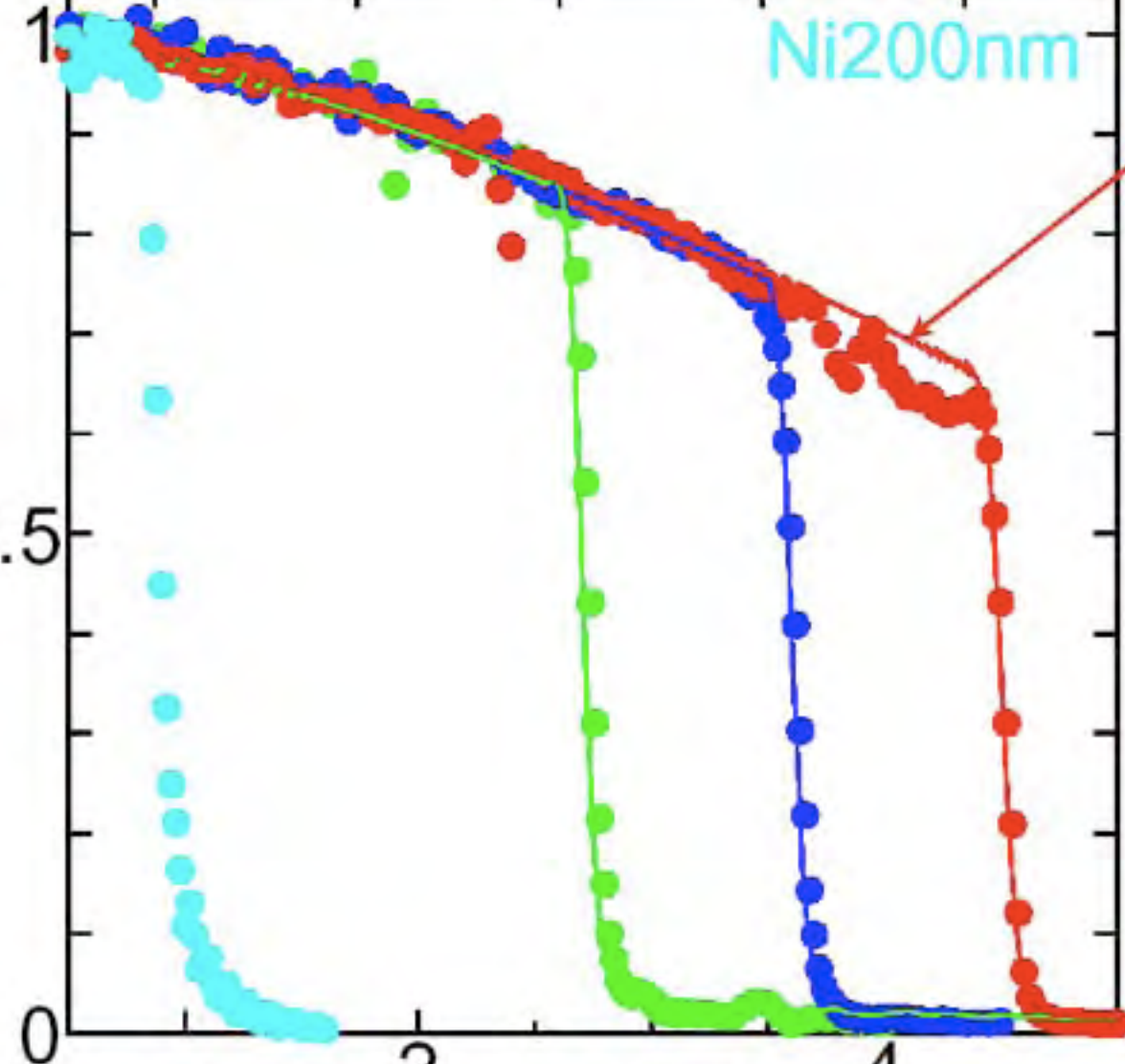
$$M=8\pi^2\sigma^2(\sin\theta/\lambda)^2$$

σ :interface roughness

single σ

no growth of interface roughness

Reflectivity



Incident angle(degree)

Incident wavelength 0.88nm(FWHM:2.4%)



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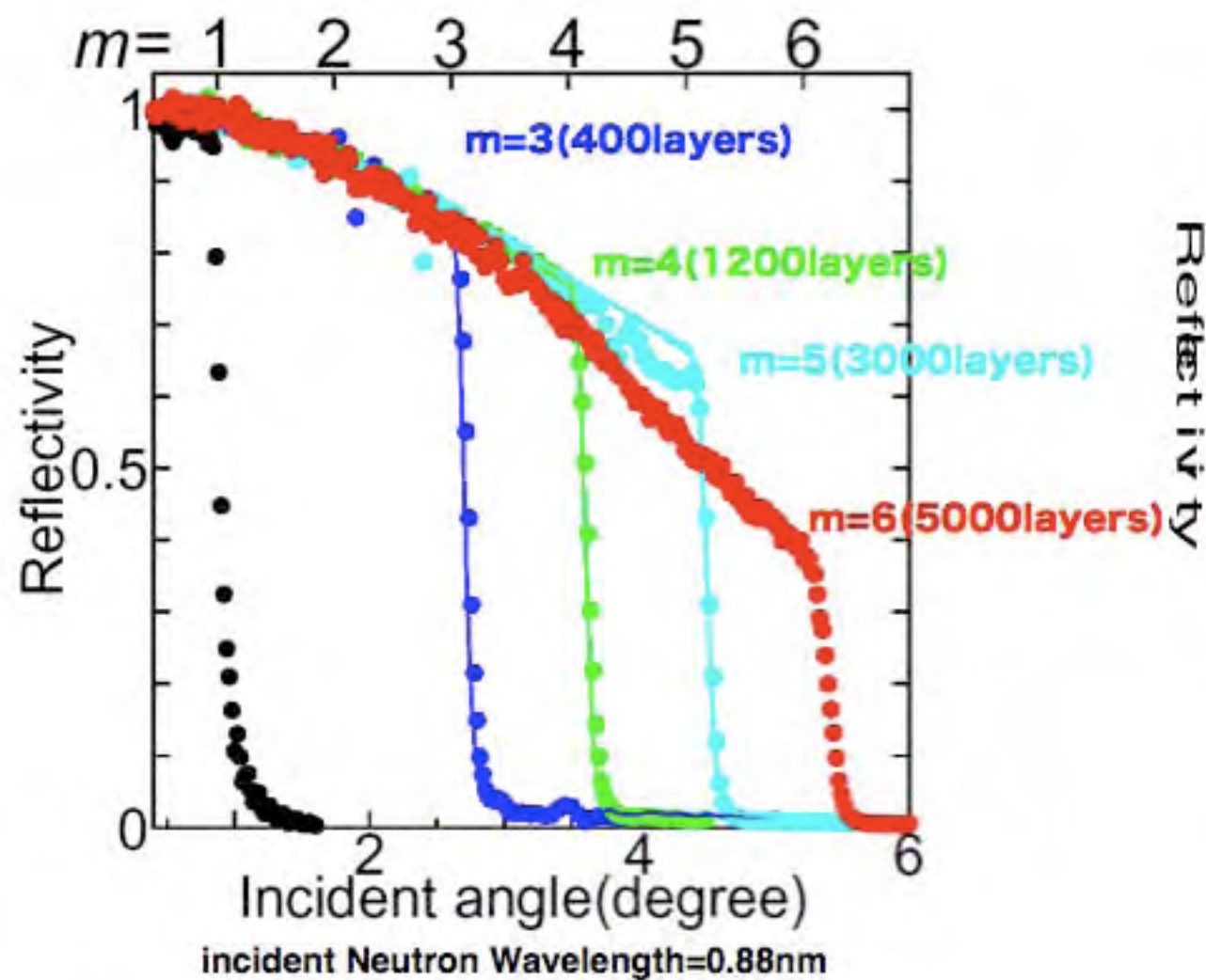
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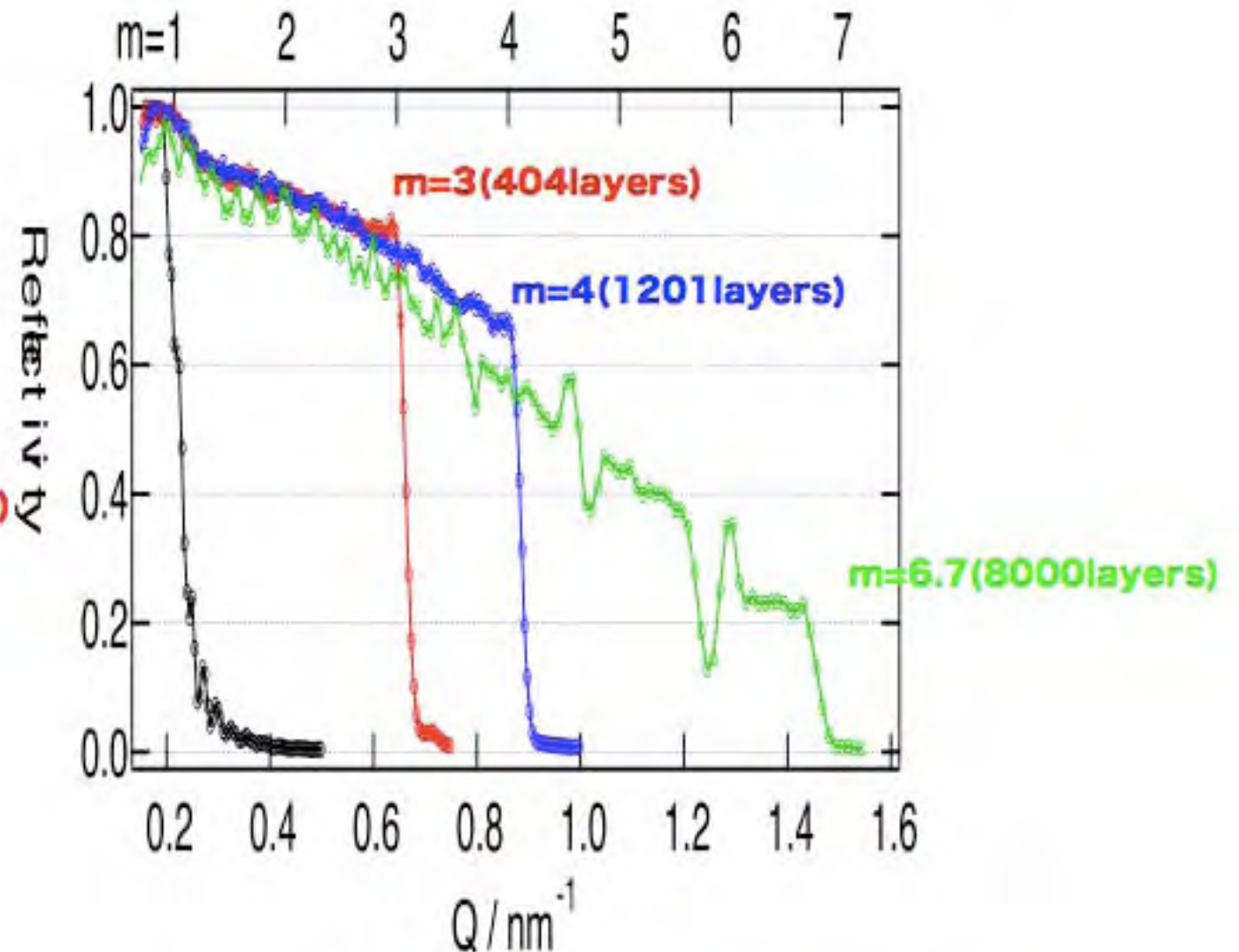
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Largest-m Supermirrors



M.Hino et al., Nucl. Instrum. Methods A529 (2004) 54



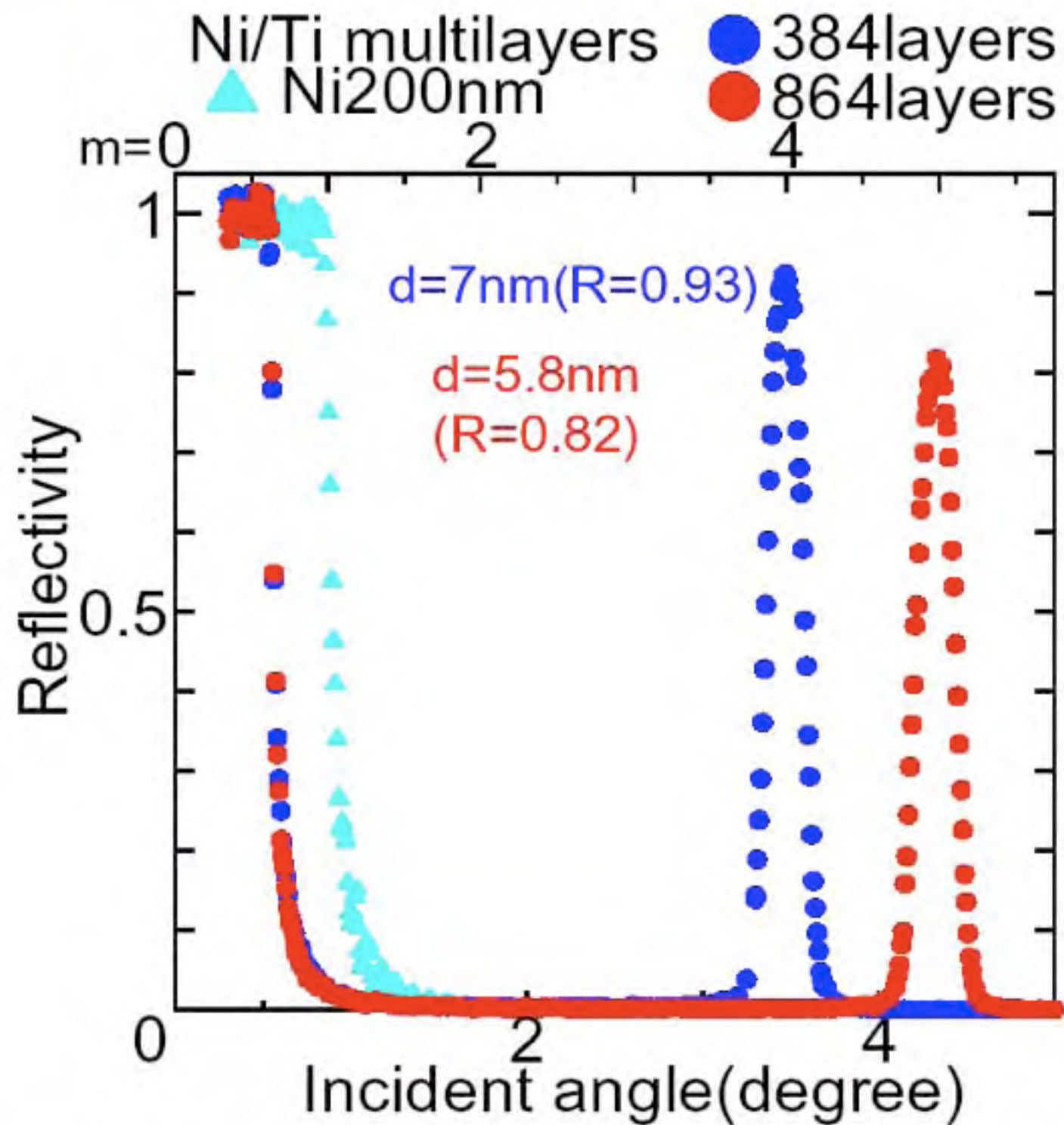
R.Maruyama et al., Thin Solid Films 515 (2007) 5704.

Reflectivity : **82%**($m=3$), **66%**($m=4$), **23%**($m=6.7$)

- Number of layers: 404($m=3$), 1201($m=4$), 8000($m=6.7$)
- Estimated interface roughness: 0.60 nm($m=3, 4$), 0.78 nm($m=6.7$) RMS



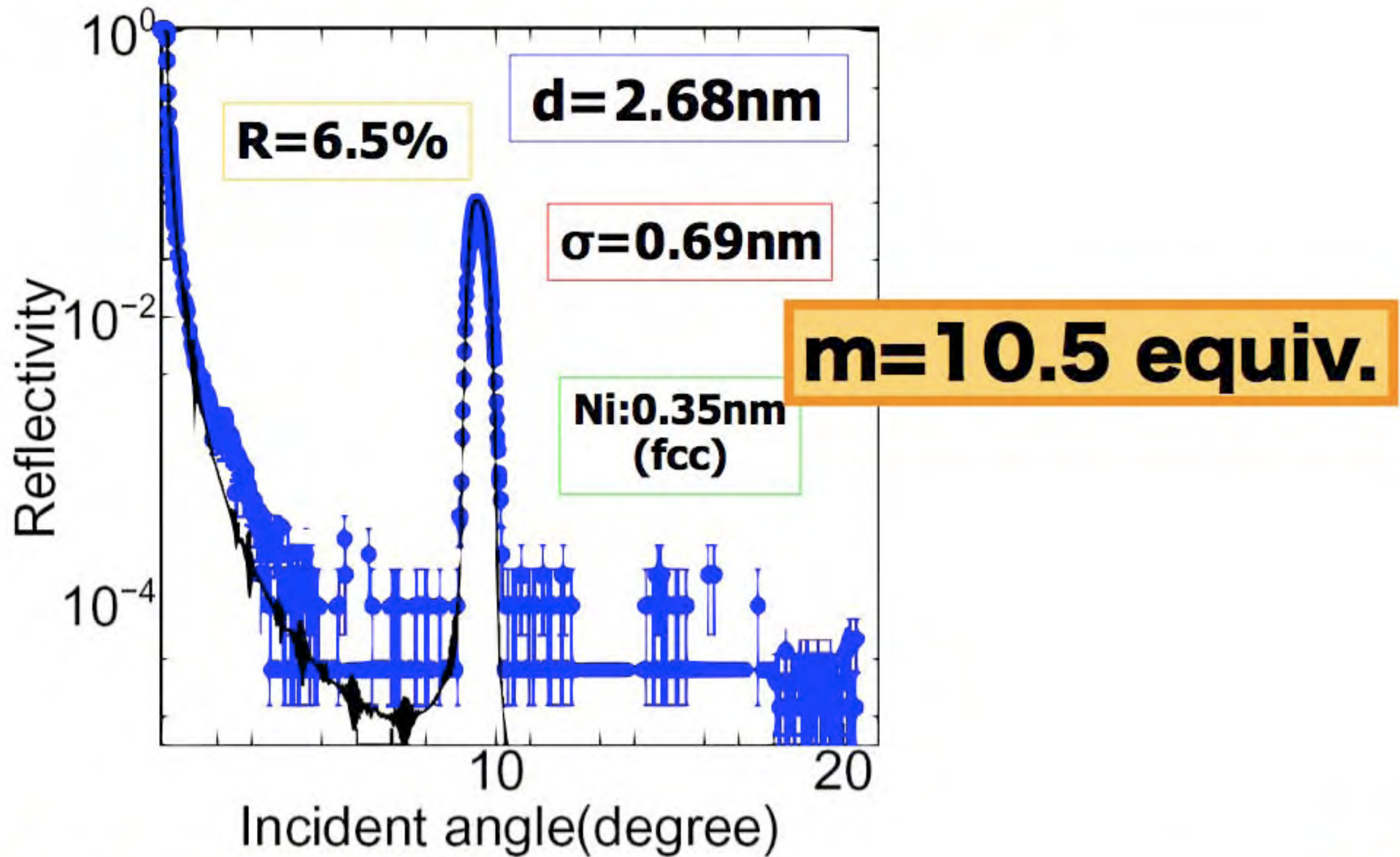
Multilayer Bender



Incident neutron wavelength 0.88nm(FWHM;2.5%)



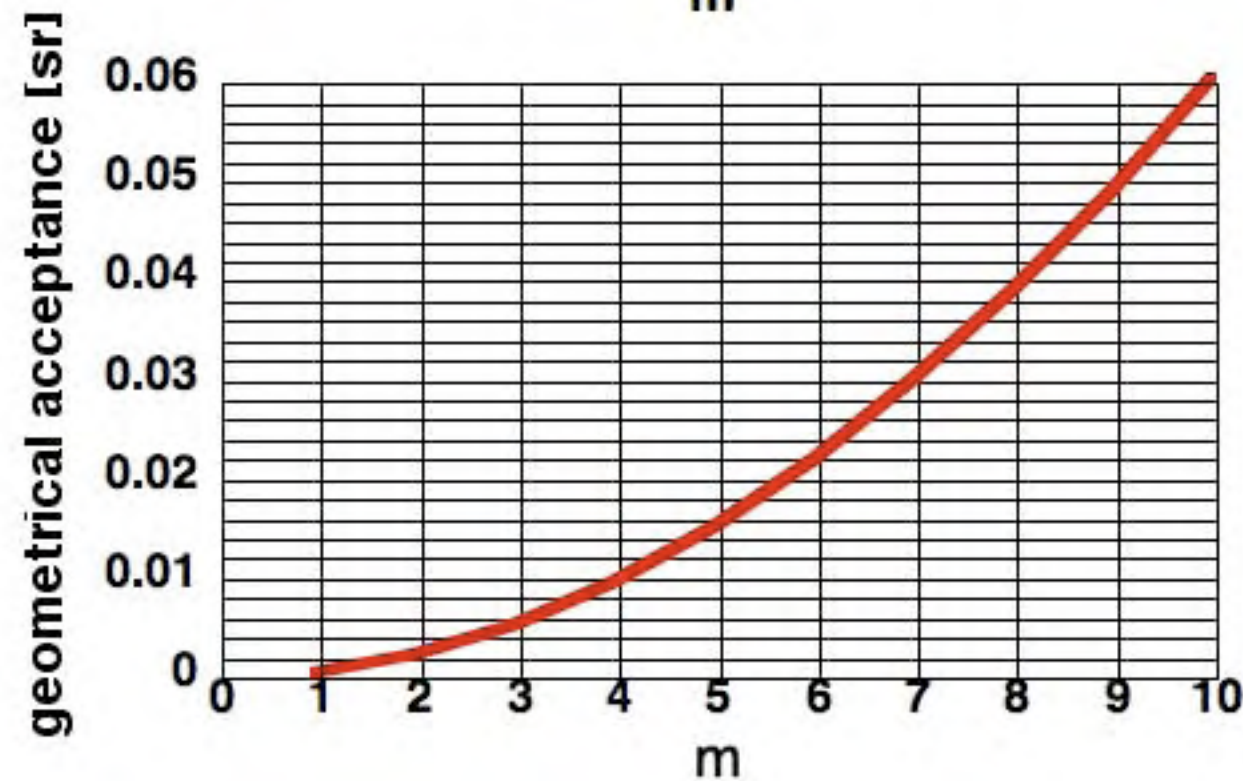
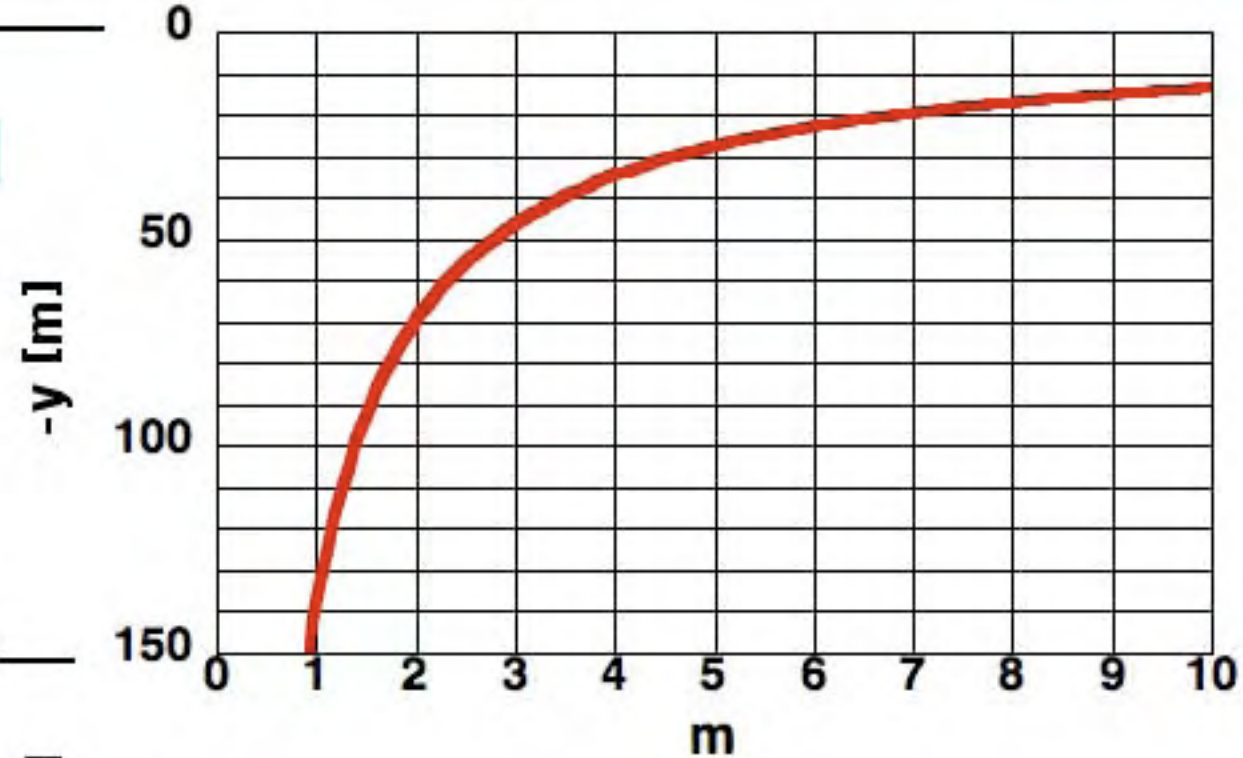
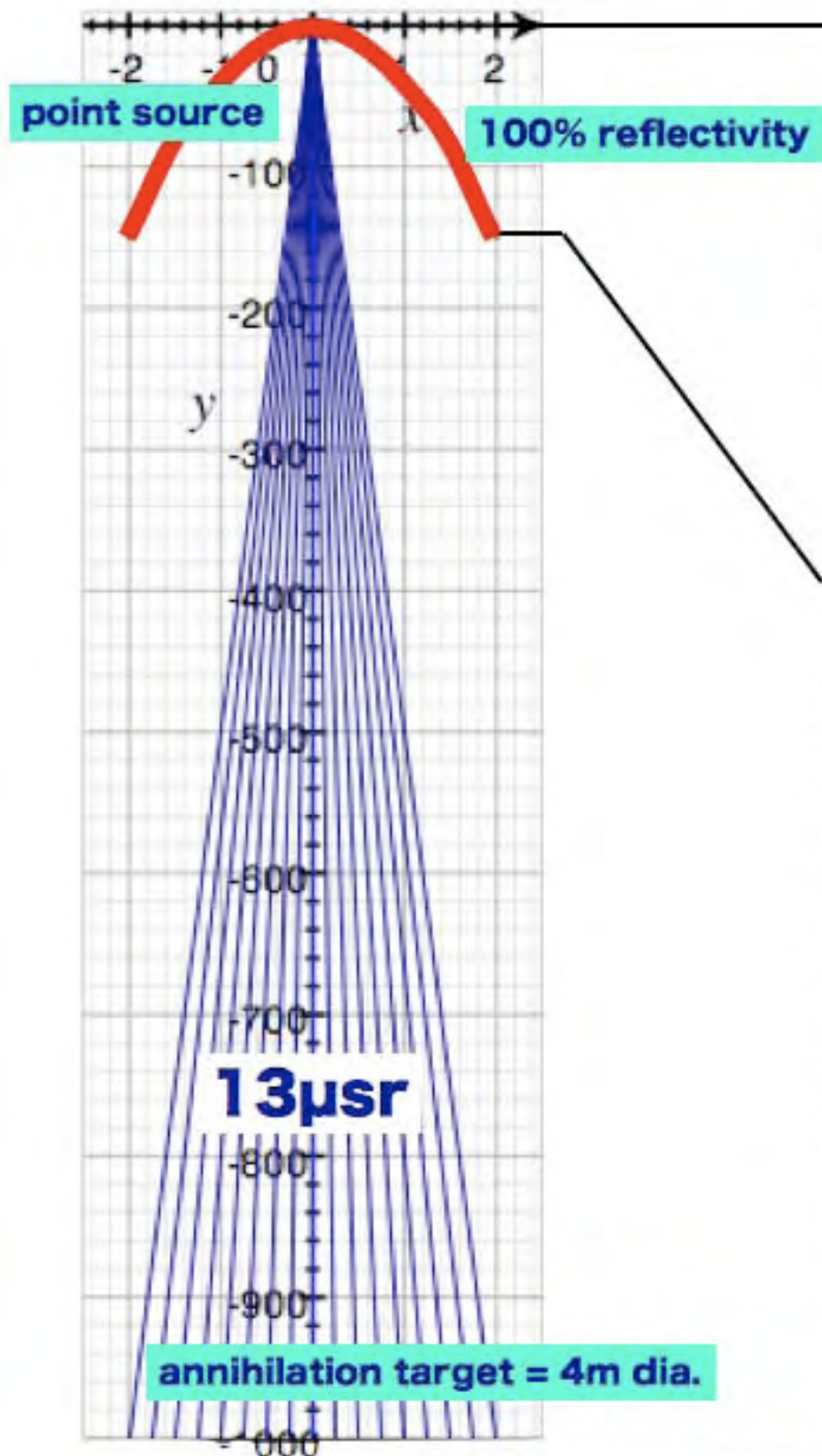
Largest-m Multilayer Bender



m-value Distribution and Geometrical Acceptance

$v=1000\text{m/s}$, $\lambda=4\text{\AA}$

$t \sim 1\text{s}$



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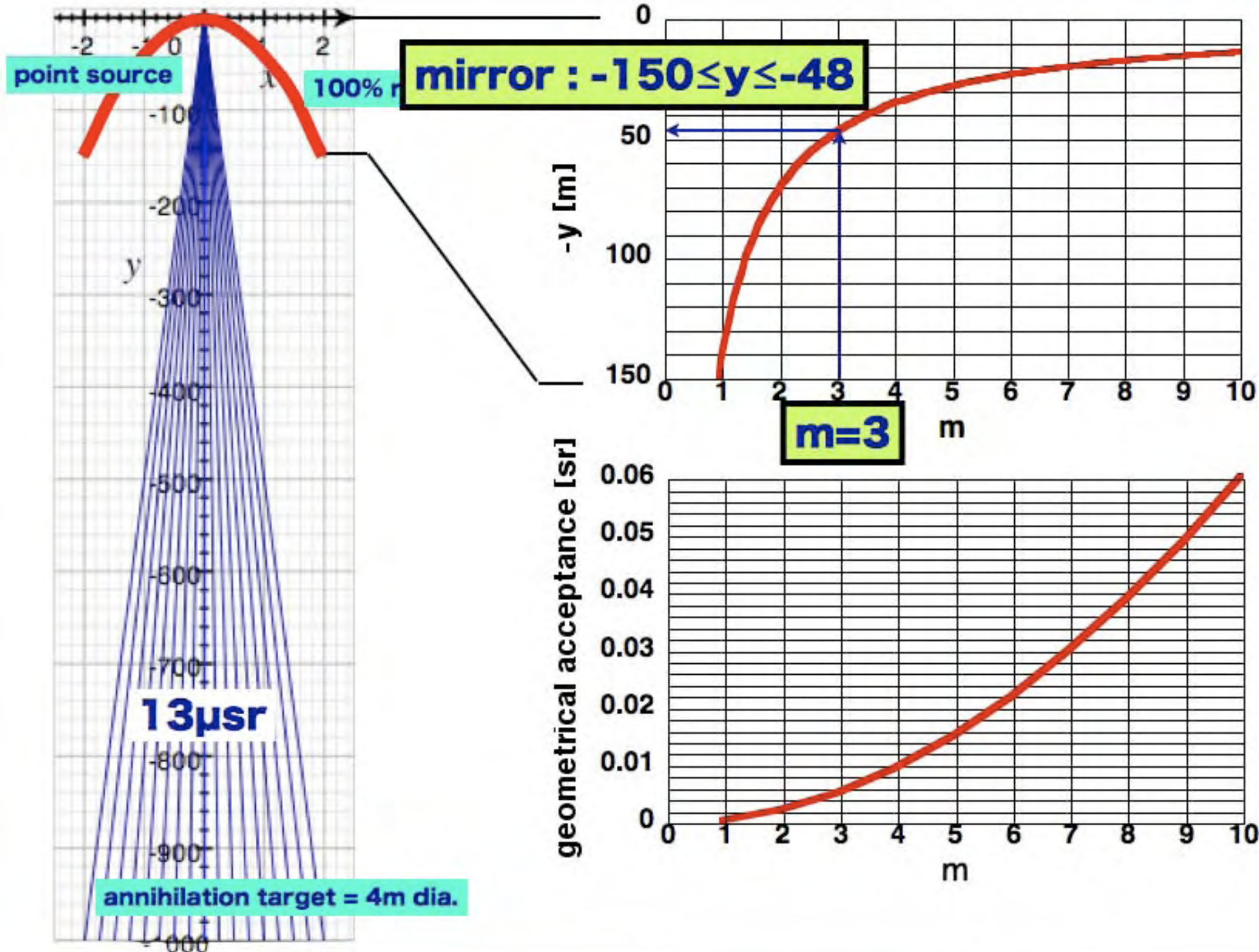
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m-value Distribution and Geometrical Acceptance

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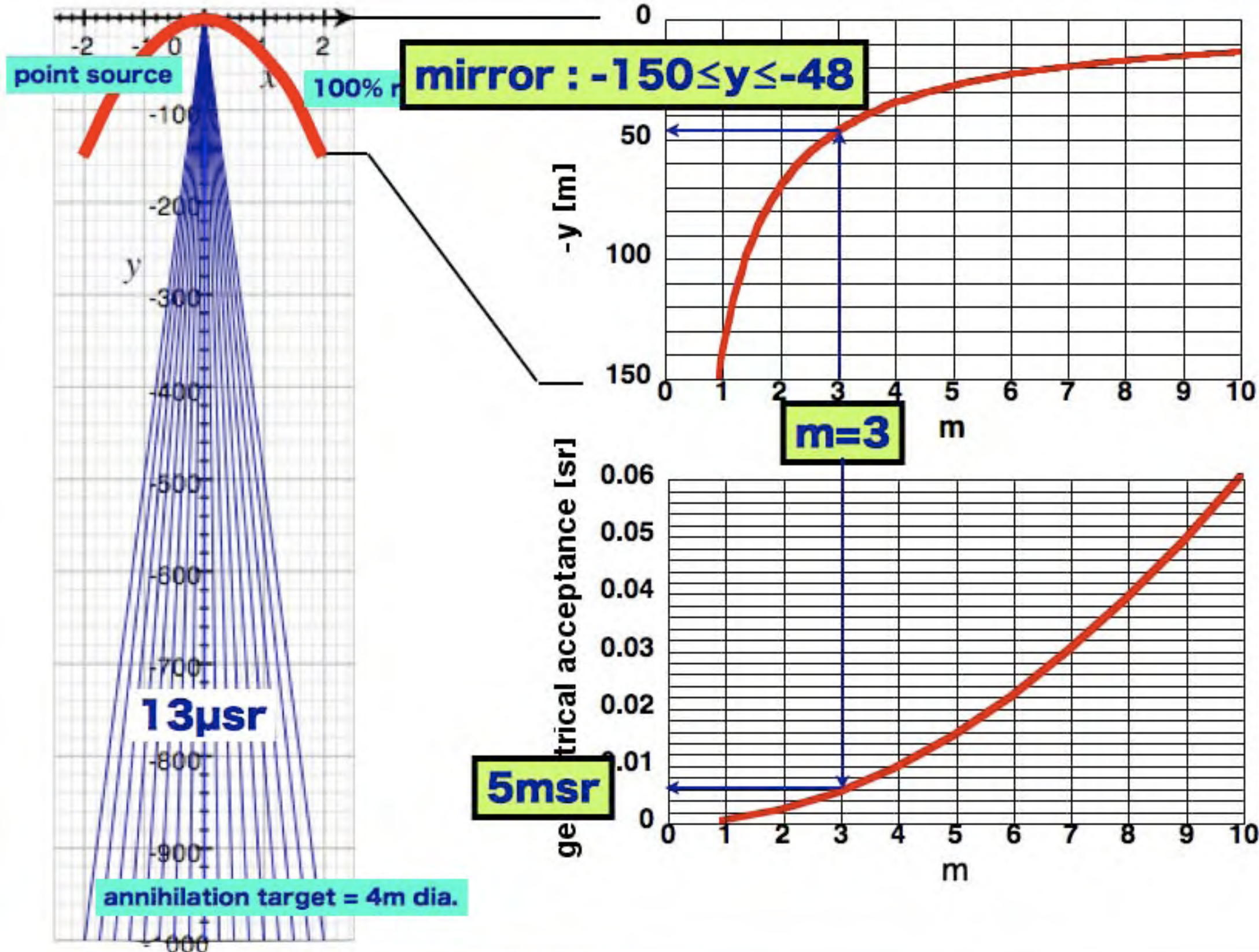
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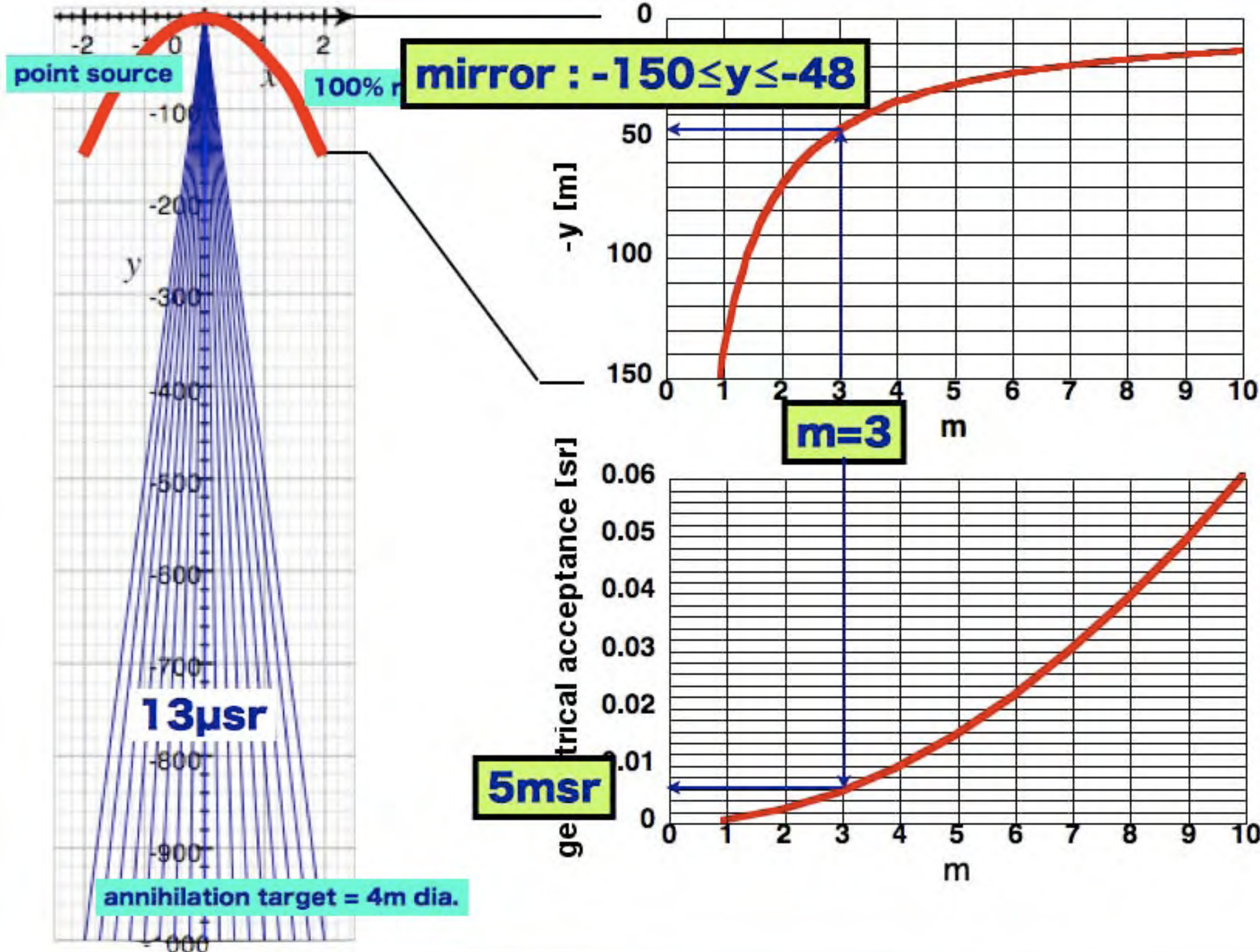
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m-value Distribution and Geometrical Acceptance

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$t \sim 1\text{s}$



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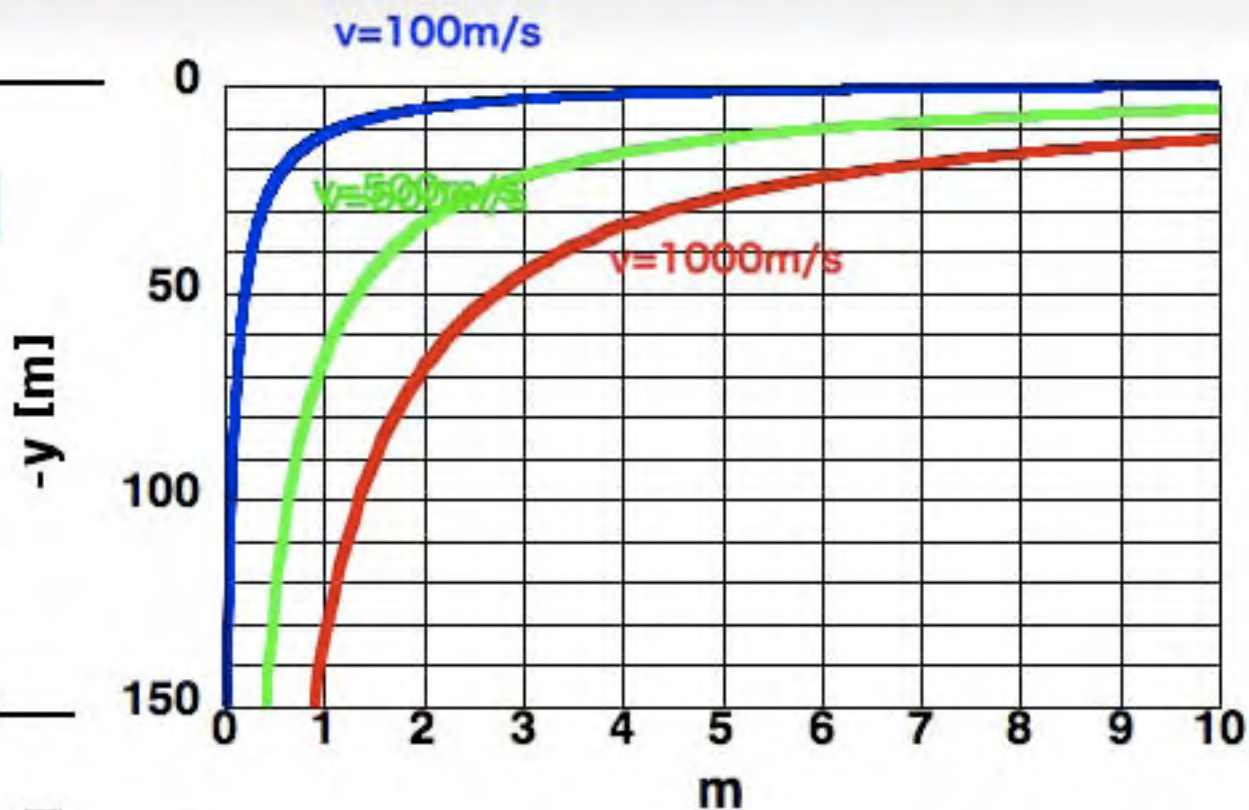
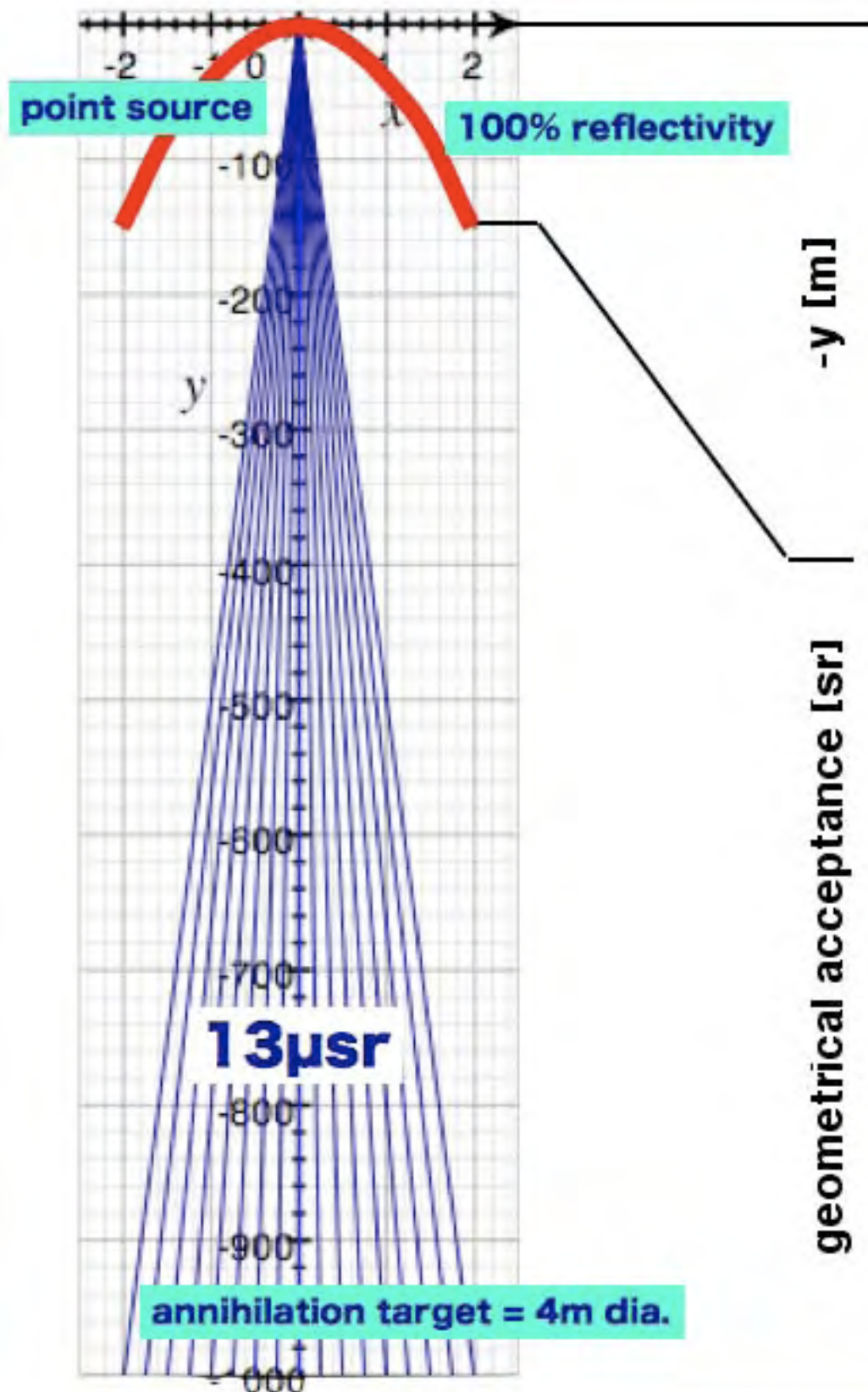
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m-value Distribution and Geometrical Acceptance



$v=1000\text{m/s}$
 $\lambda=4\text{\AA}$

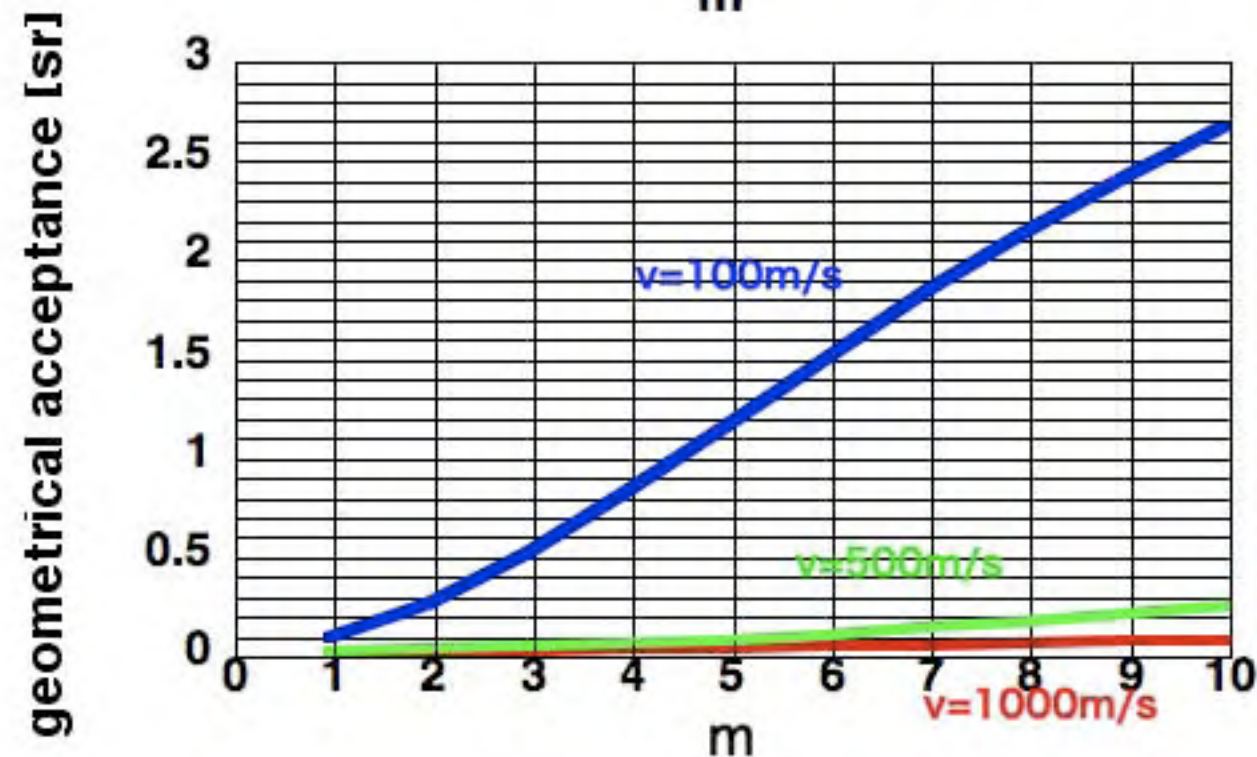
$t\sim 1\text{s}$

$v=500\text{m/s}$
 $\lambda=8\text{\AA}$

$t\sim 2\text{s}$

$v=100\text{m/s}$
 $\lambda=40\text{\AA}$

$t\sim 7\text{s}$



Summary

Multilayer-based reflective optics is suitable for the vertical flight path of n - $\bar{n}$ experiment.

Very large- m multilayer benders add more acceptance.

Deceleration process from cold region to very cold region is strongly desired. (This also enhances ultracold neutron flux.)

