Slow Neutron Optics for a Long-Distance Free-Flight

Hirohiko M. SHIMIZU
Neutron Science Division
KEK
hirohiko.shimizu@kek.jp

Vertical Setup for n-nbar Oscillation

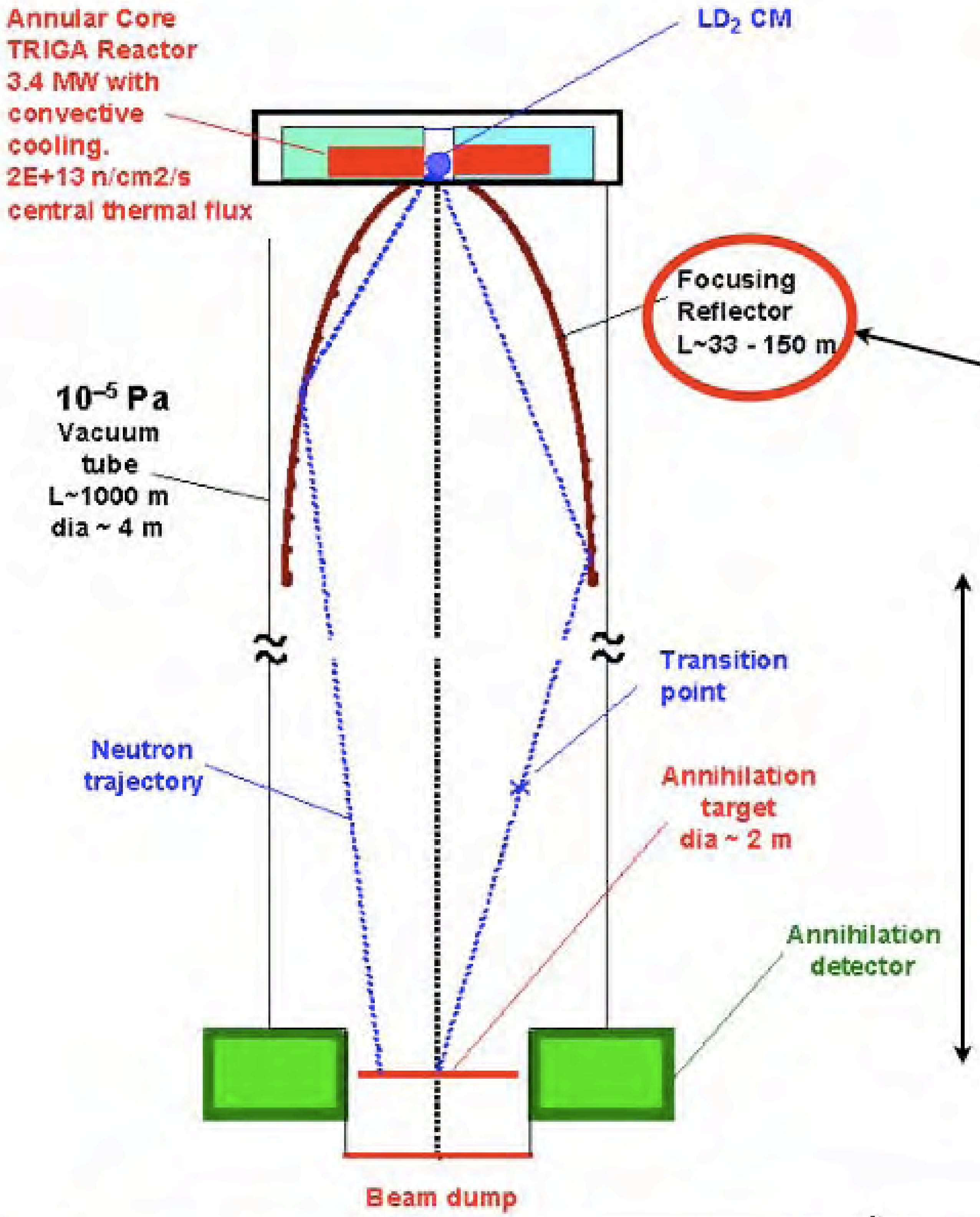
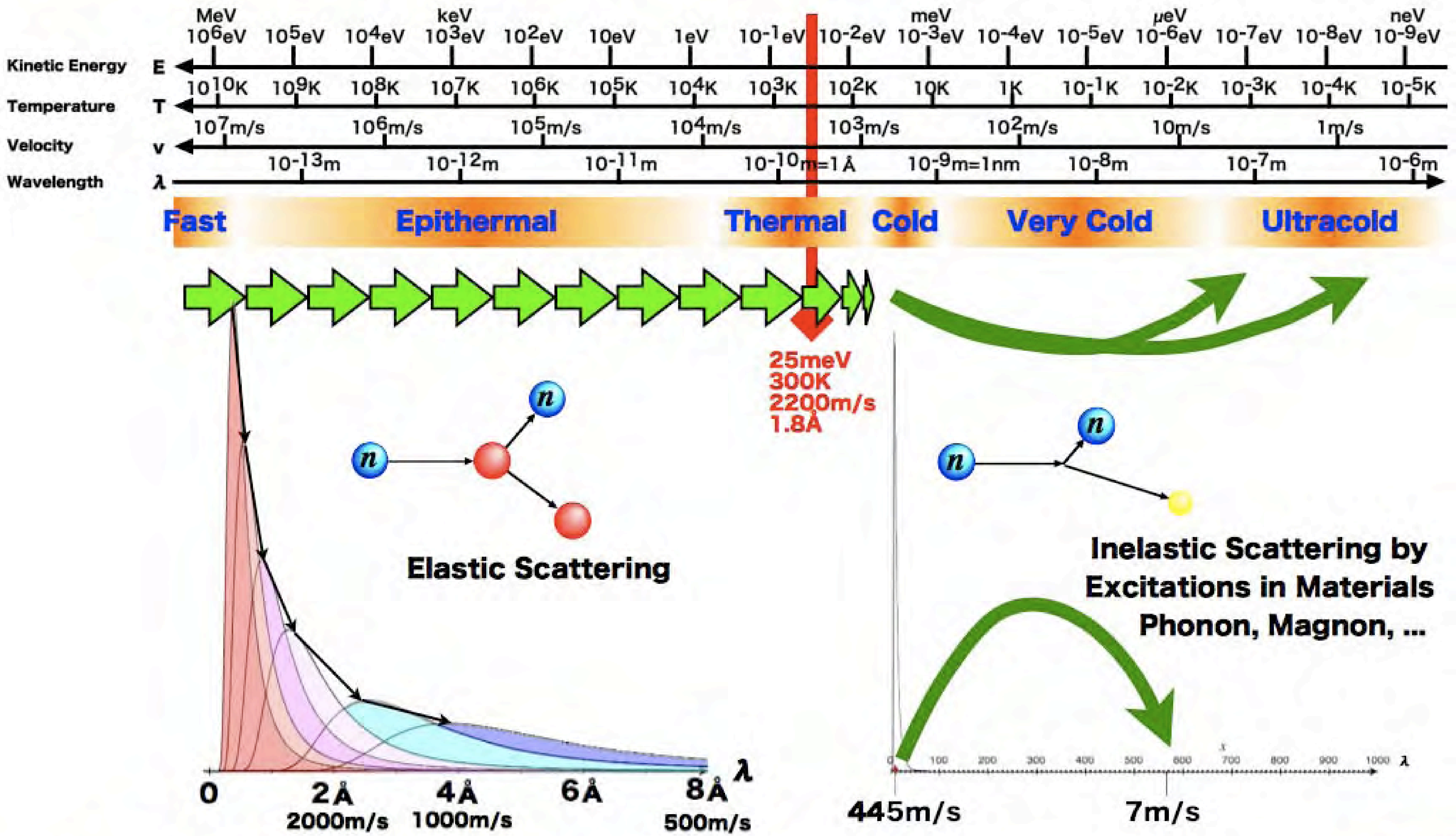


Figure of Merit ∝ N t^2

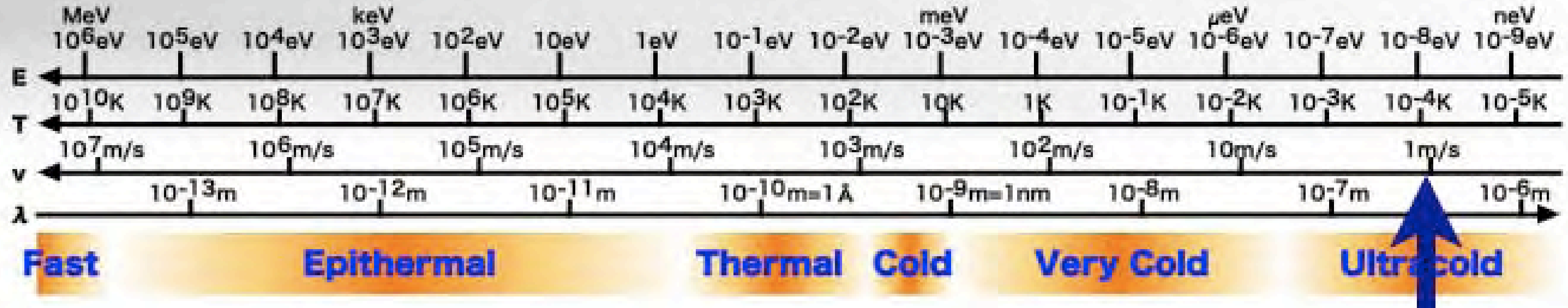
Focusing optics

for shooting the annihilation target without touching the boundary of the long free-flight path

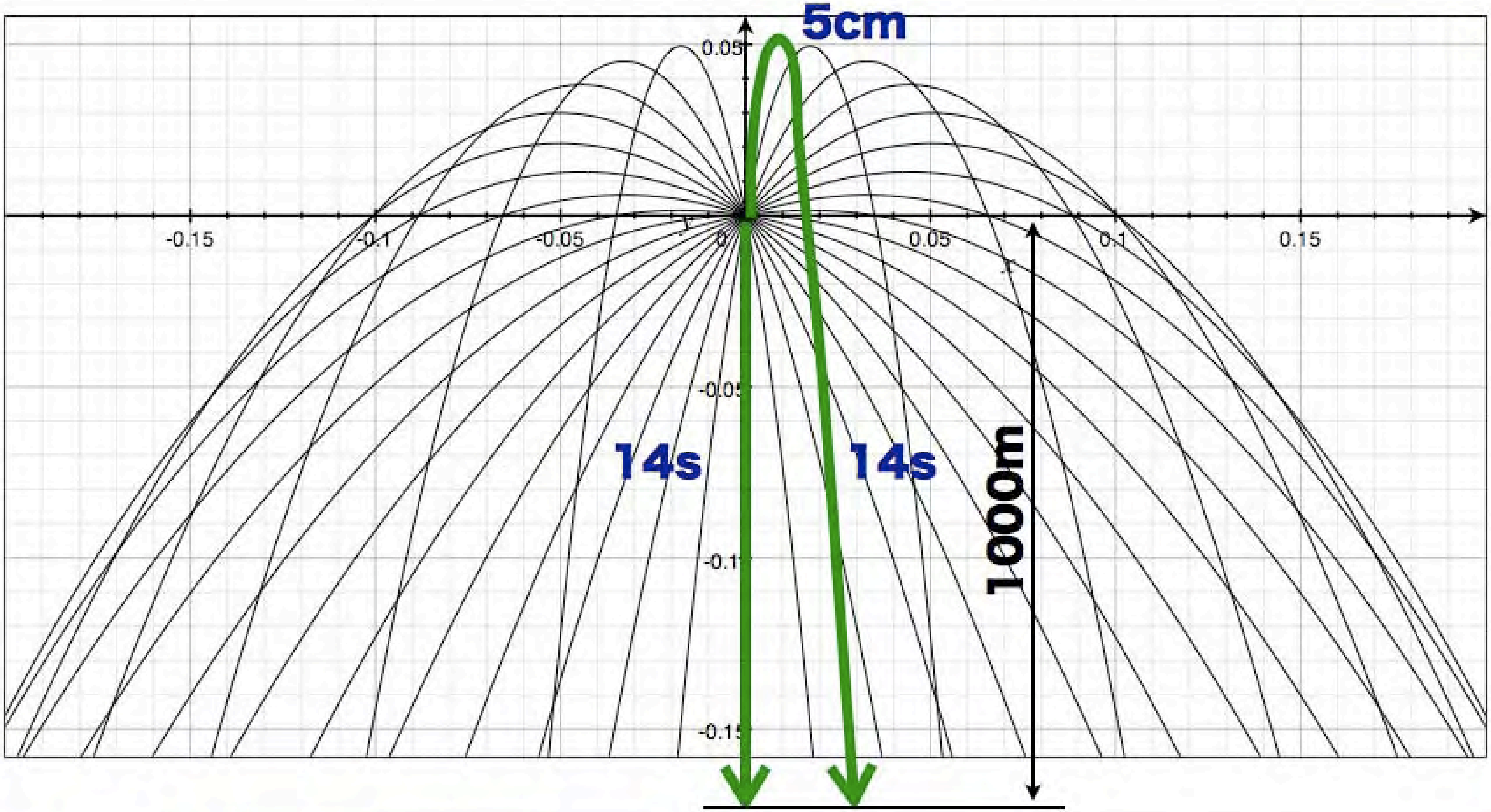
Neutron Deceleration



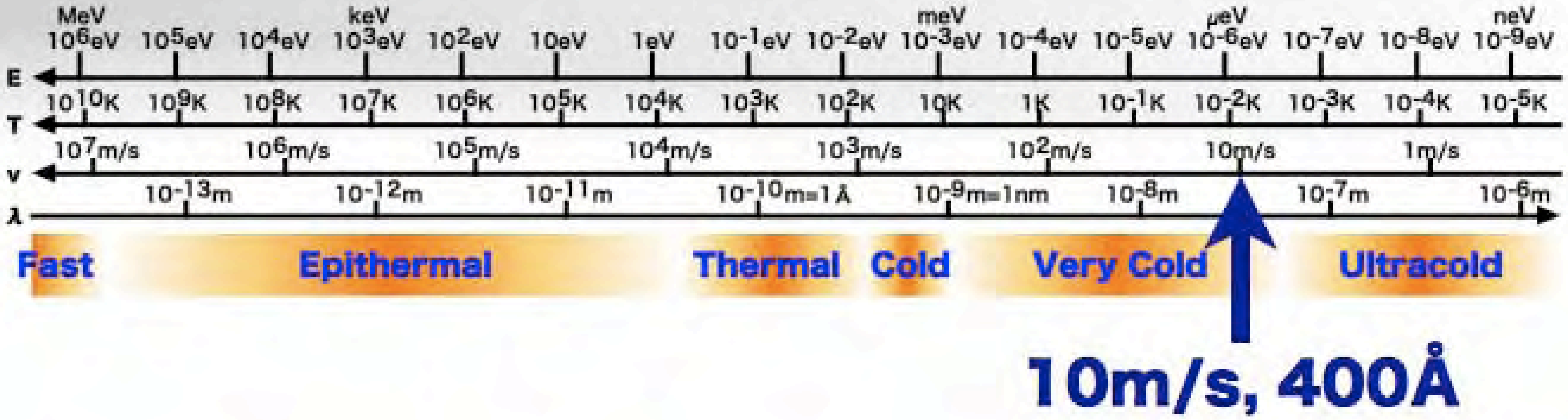
Ultracold Neutron

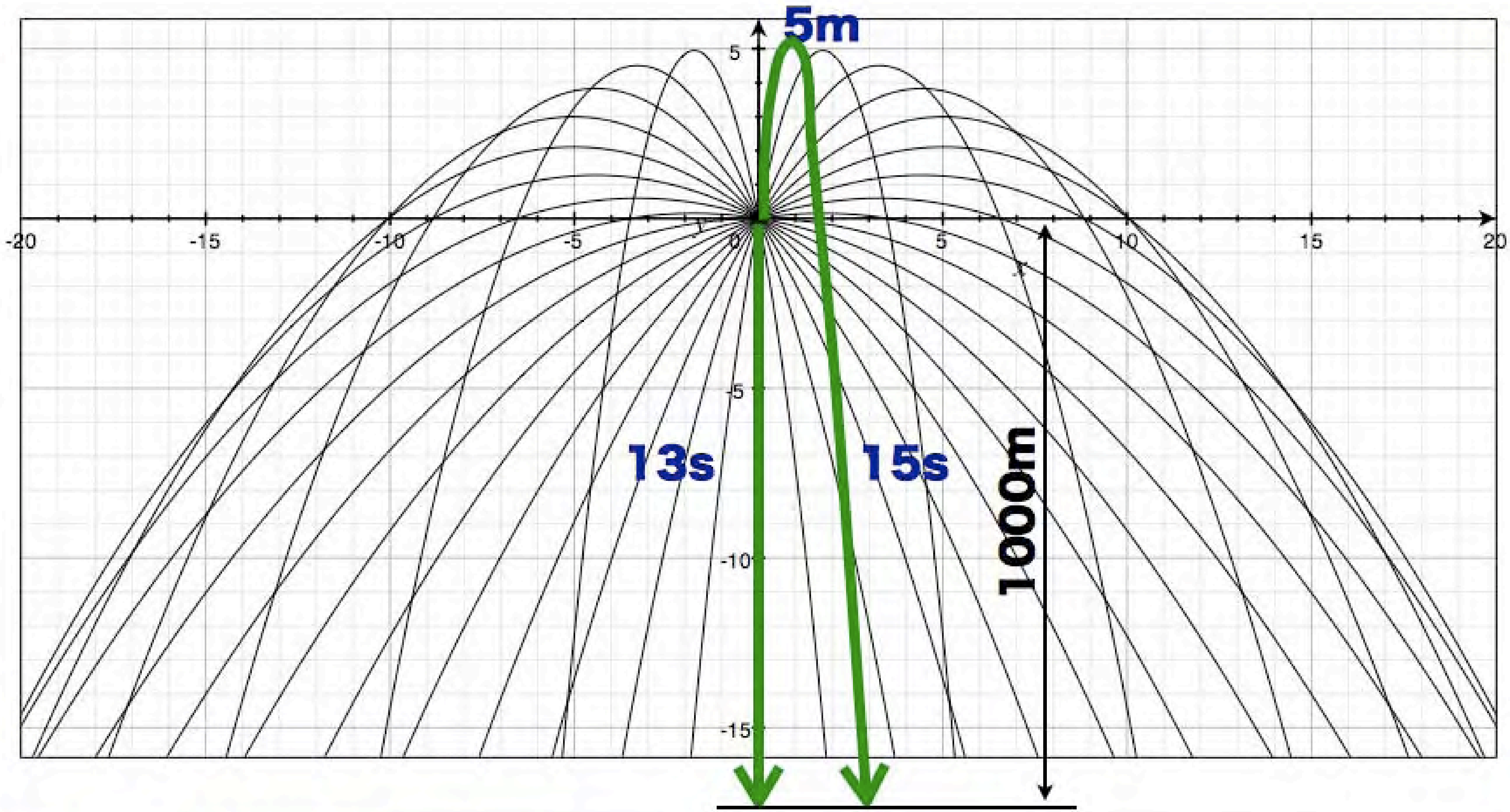


1m/s, 4000Å

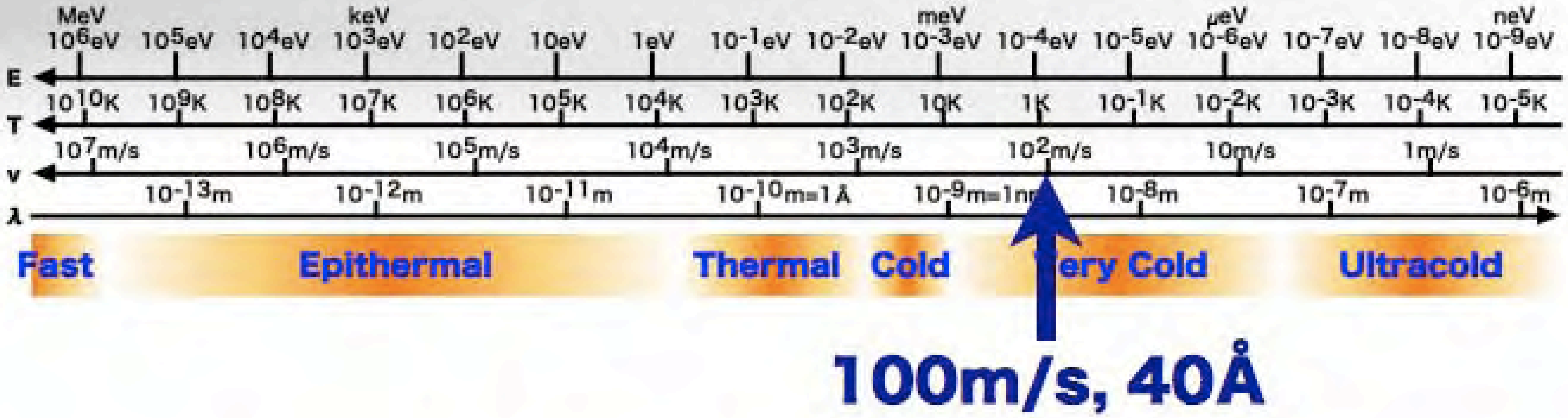


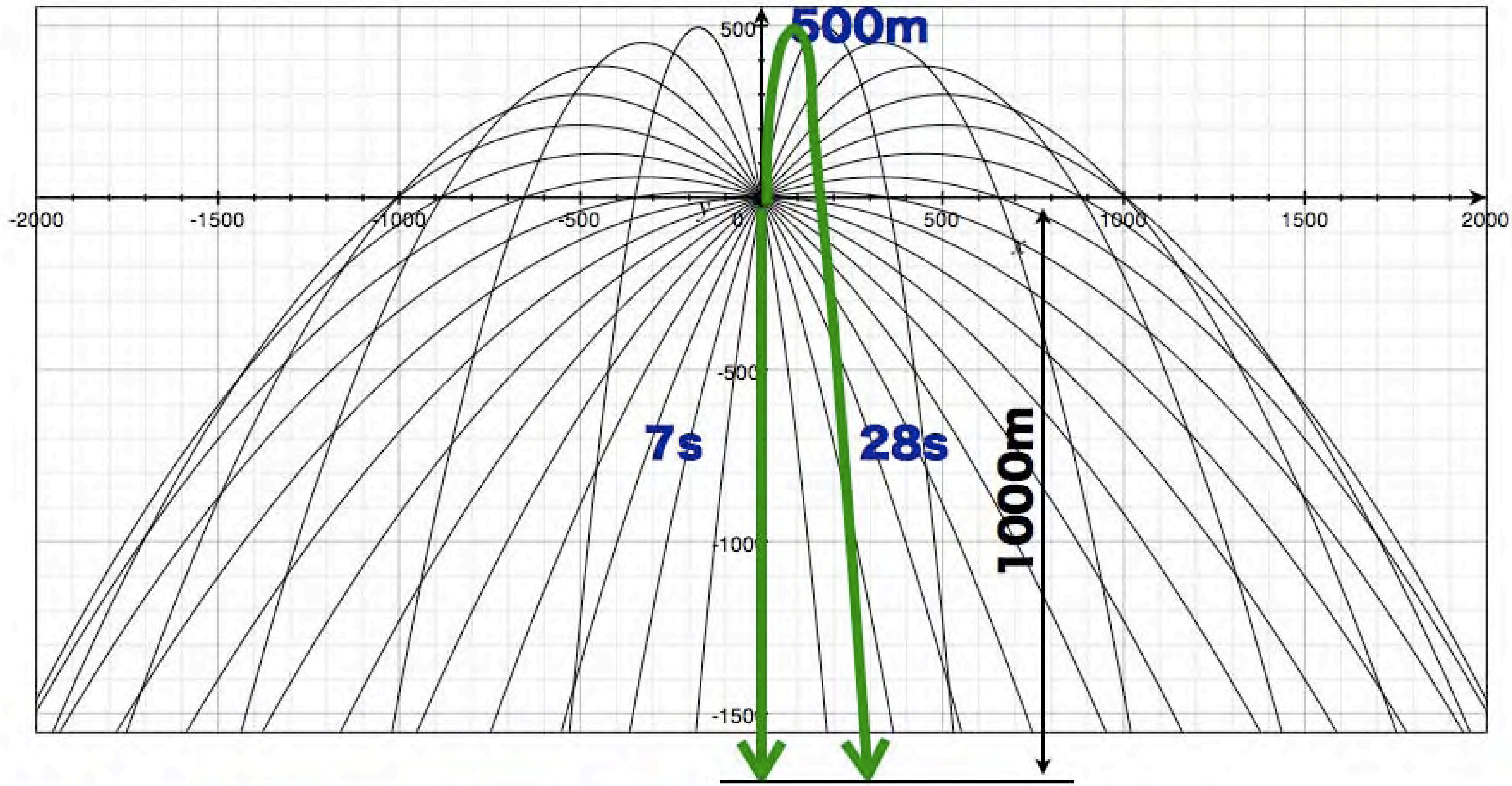
Ultracold Neutron



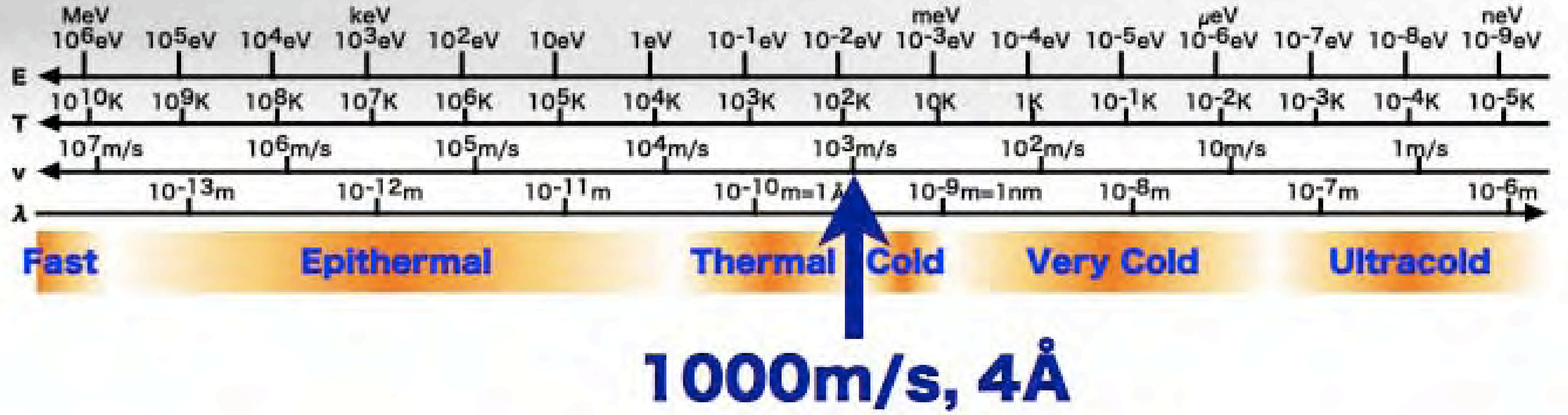


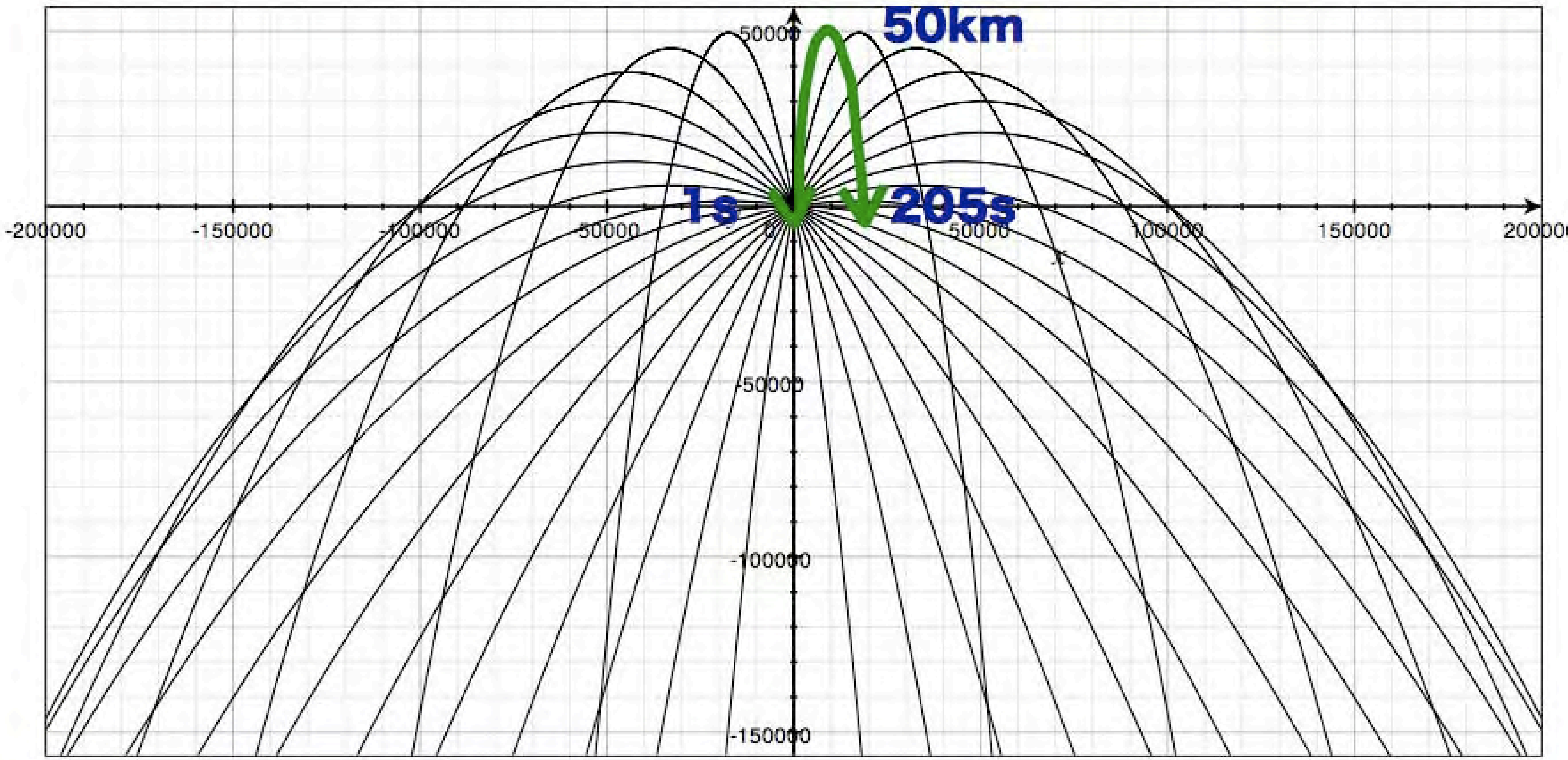
Very Cold Neutron



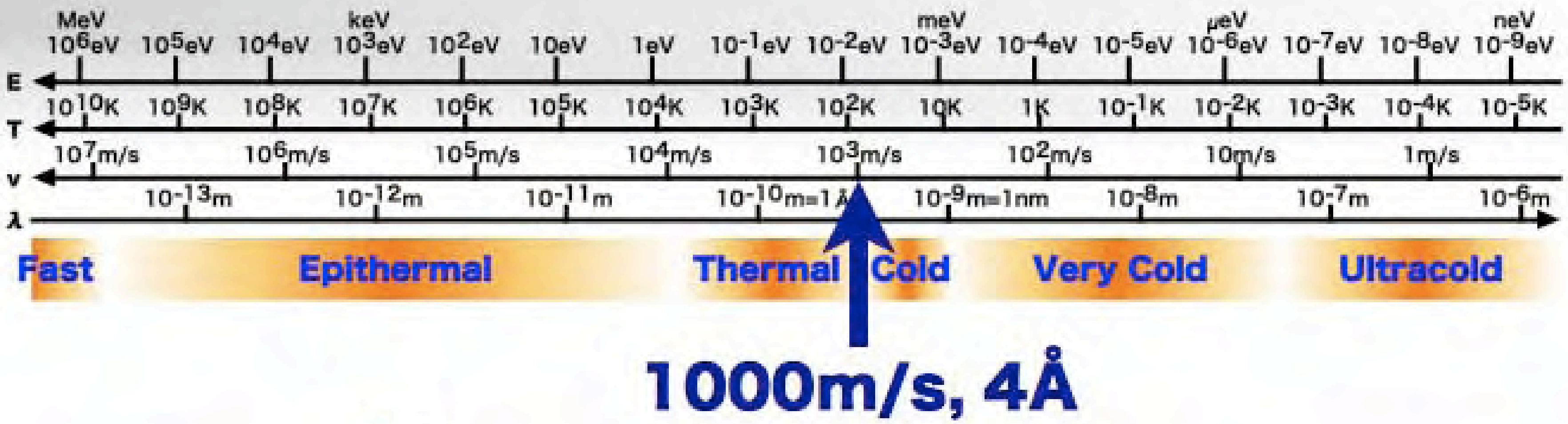


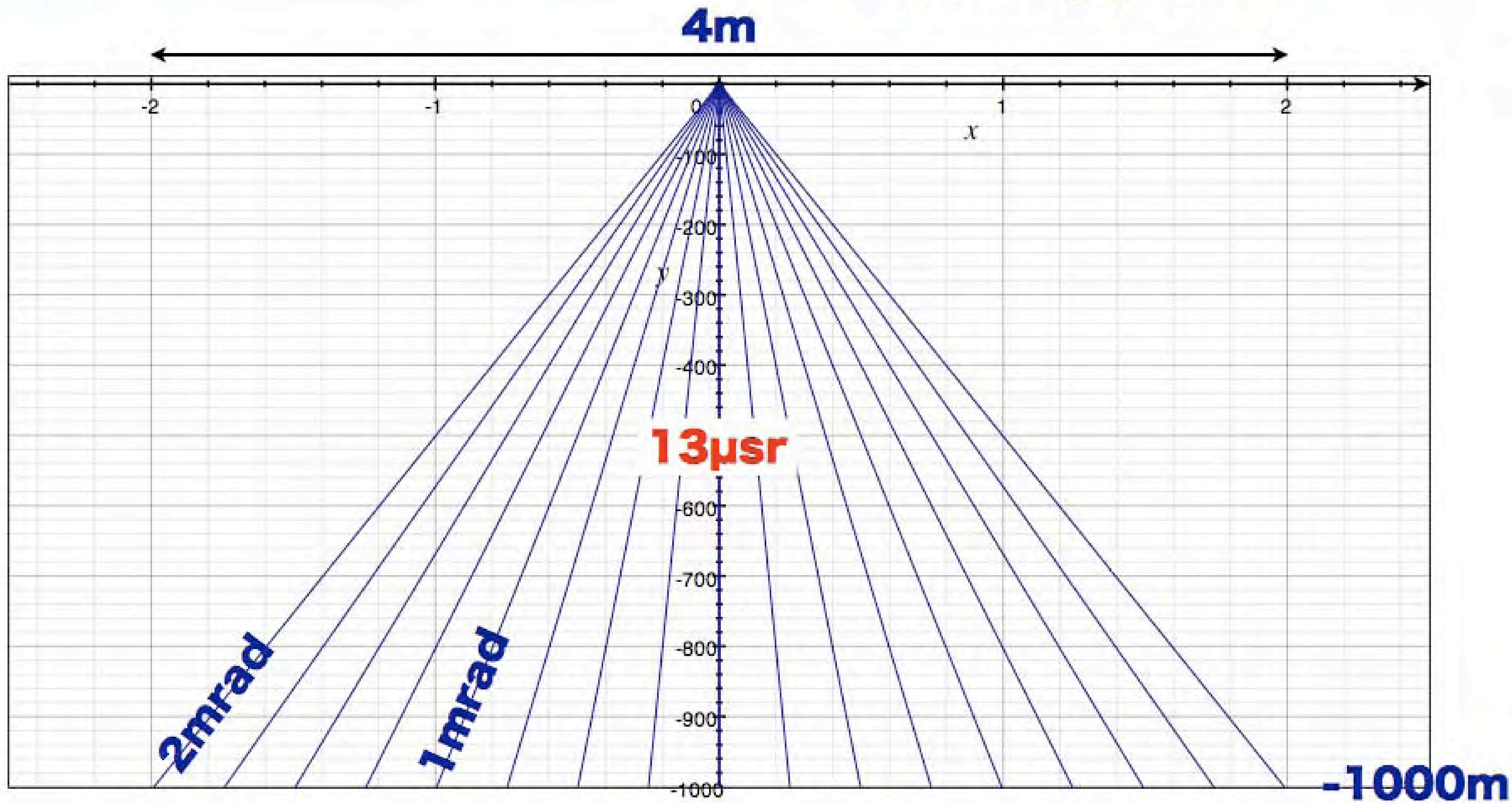
Cold Neutron



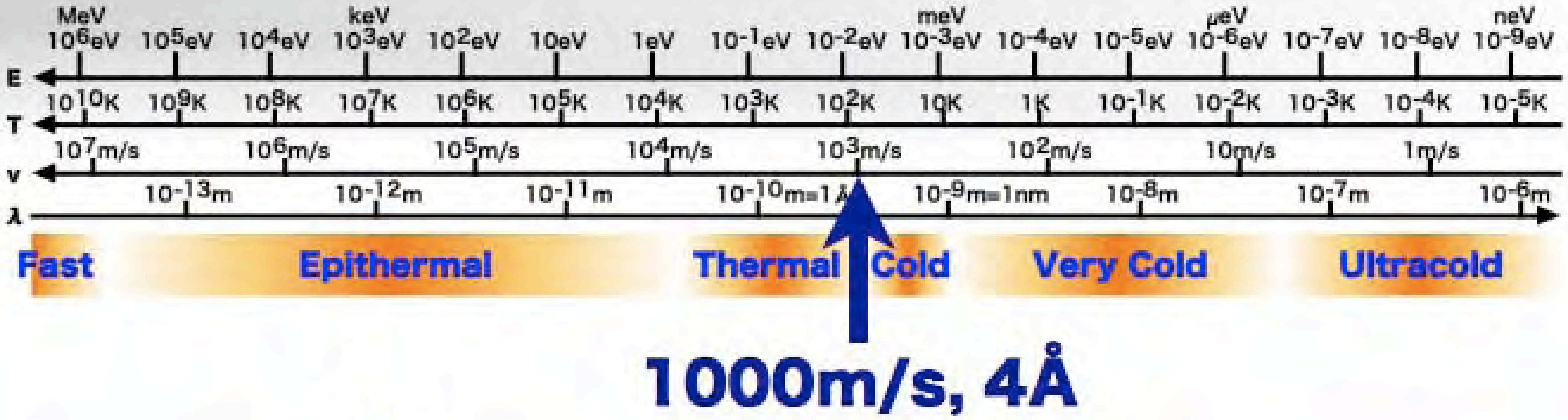


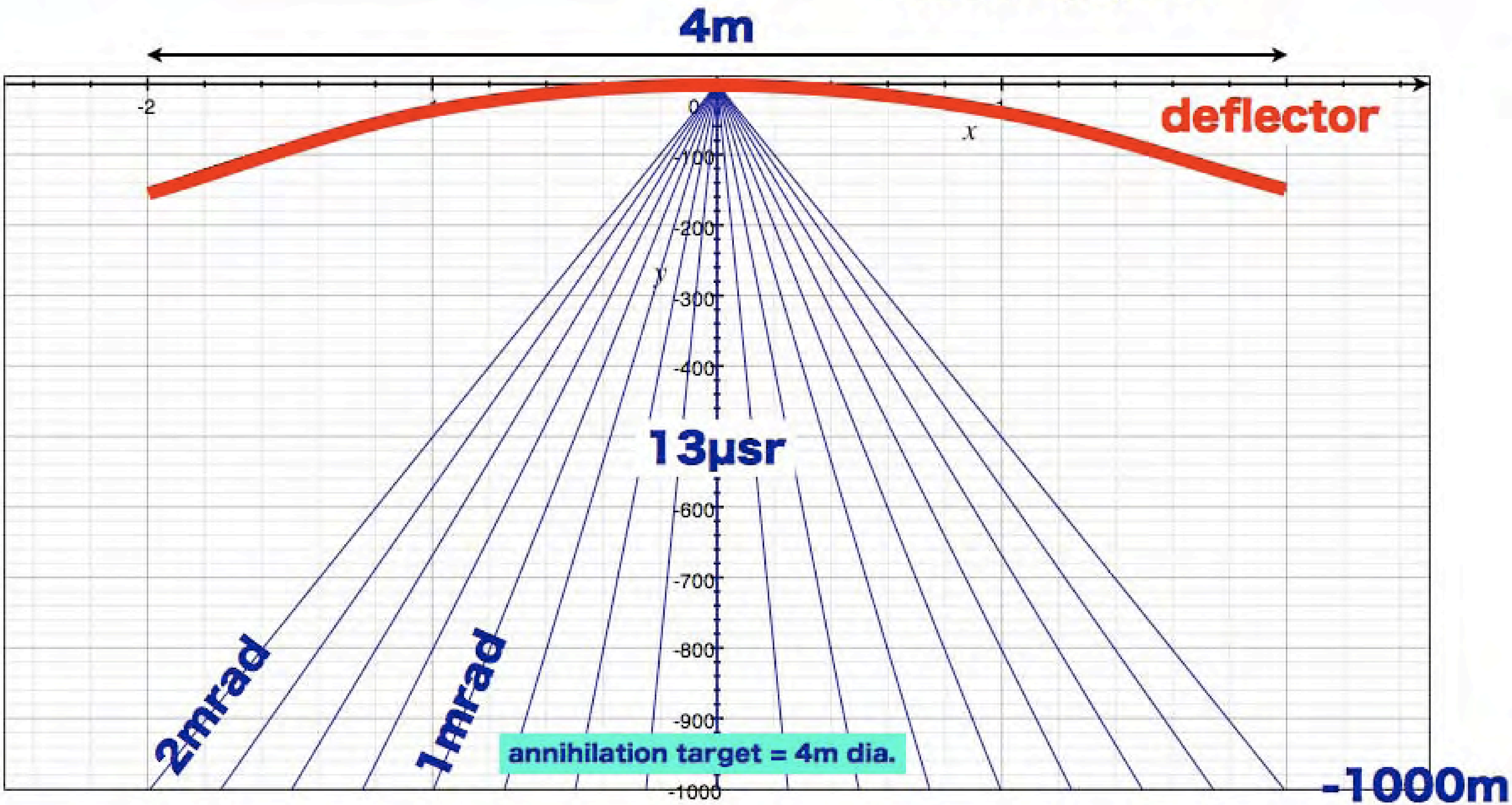
Cold Neutron



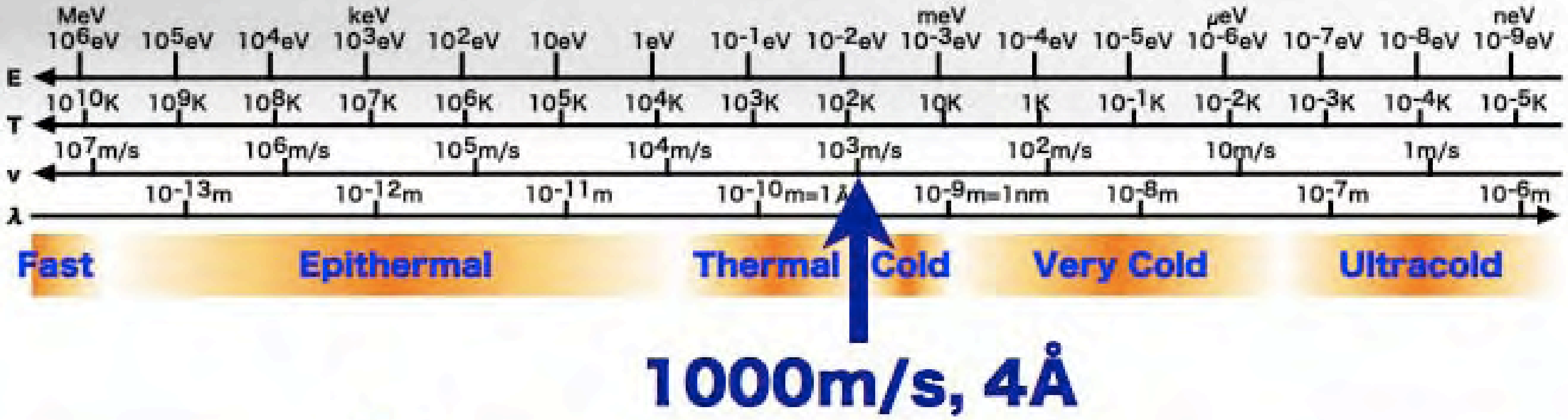


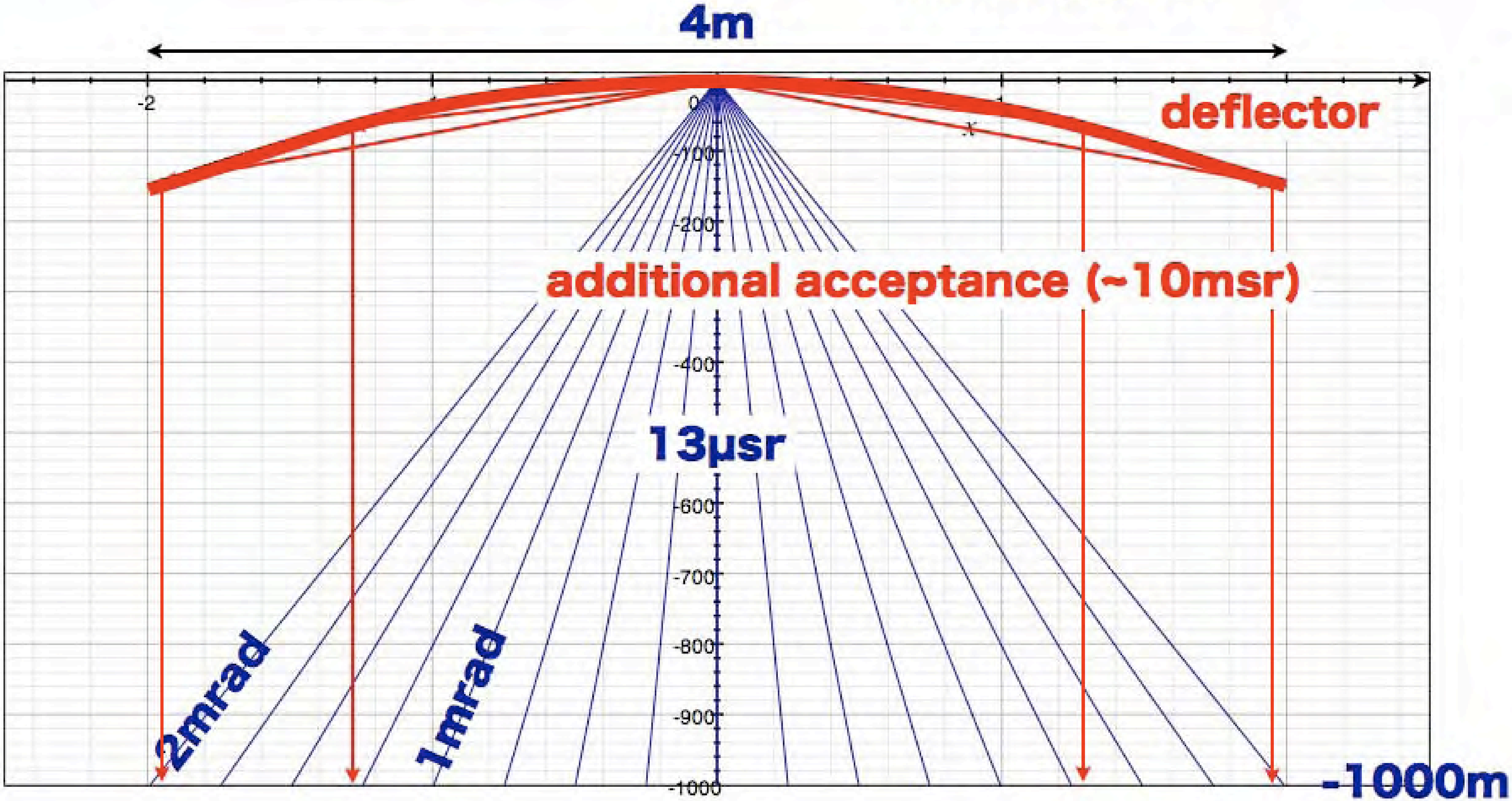
Cold Neutron



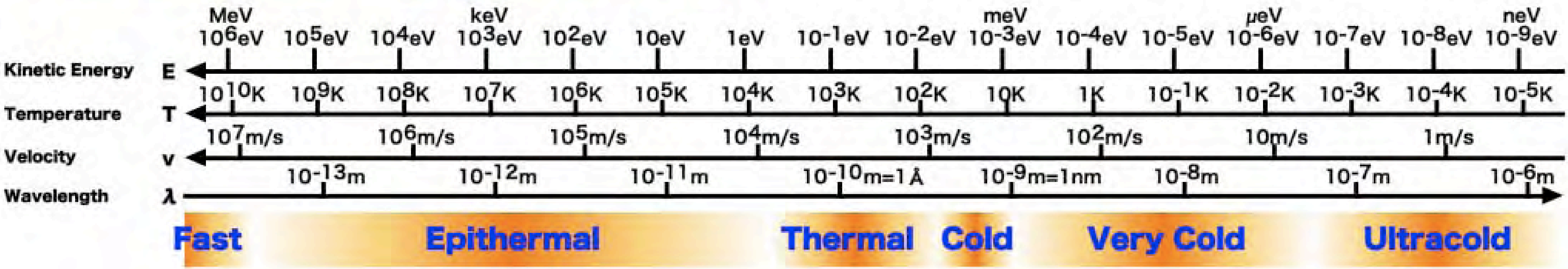


Cold Neutron

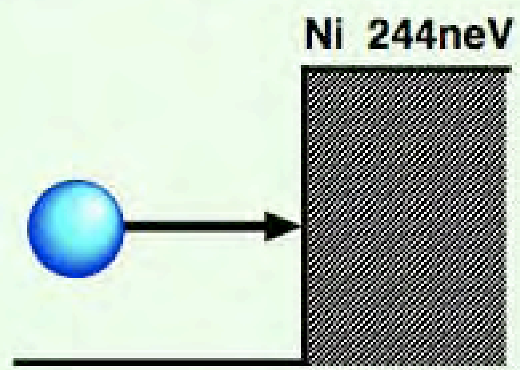




Neutron Optics

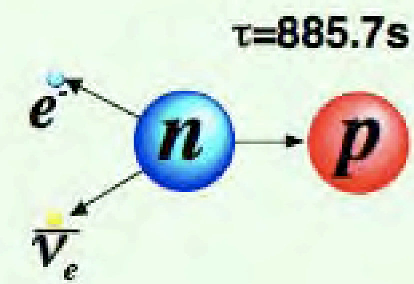


Strong Interaction



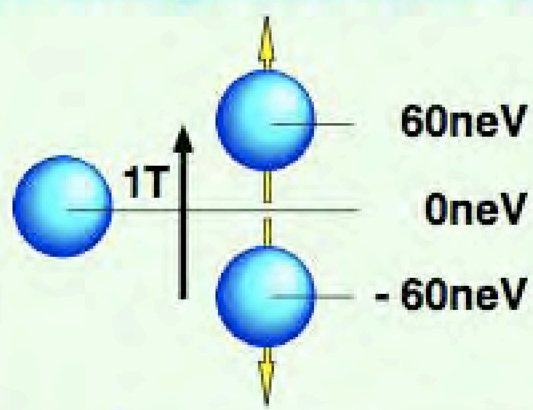
Strong Interaction

Weak Interaction



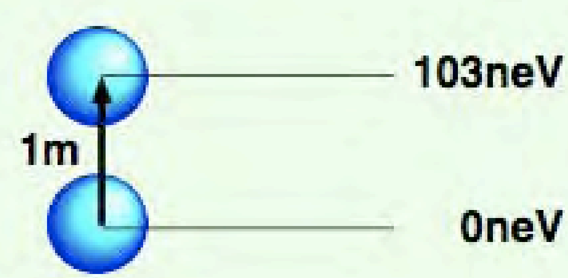
Weak Interaction

Electromagnetic Interaction



Electromagnetic Interaction

Gravitational Interaction



Gravitational Interaction

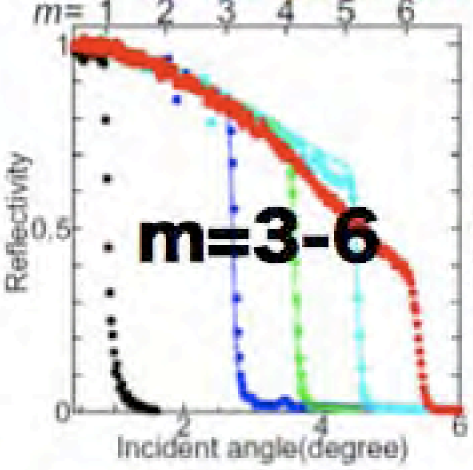
Neutron Optics

→ NIM A529 (2004)

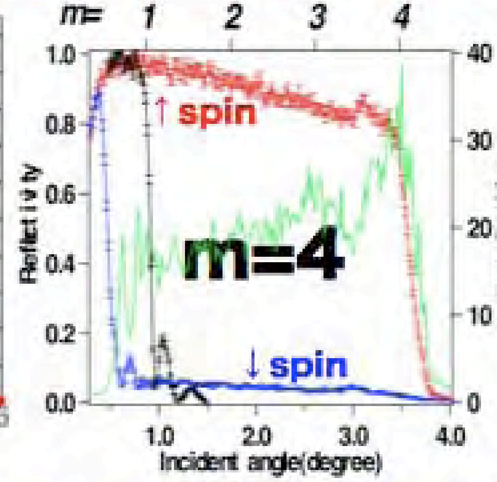
Reflective Optics

M.Hino et al. (Kyoto Univ.)

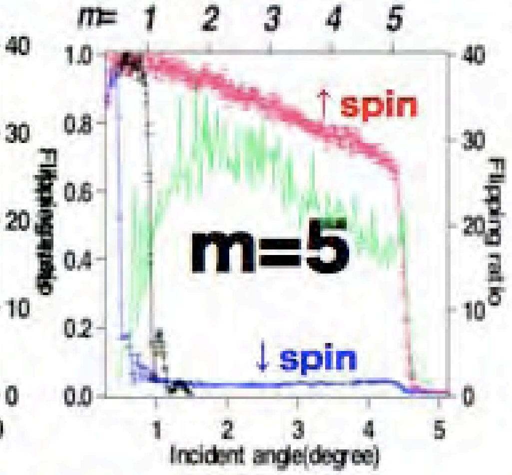
Ni/Ti supermirrors



Fe/Si supermirrors



Fe/Ge supermirrors

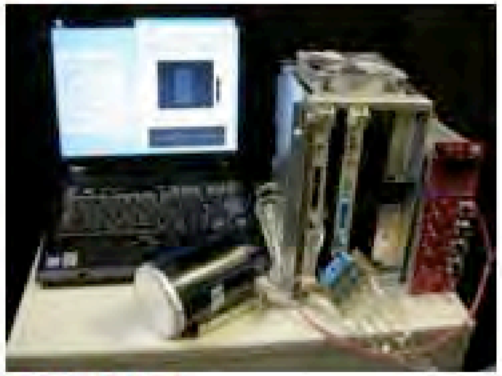


K.Ikeda et al. (RIKEN)

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

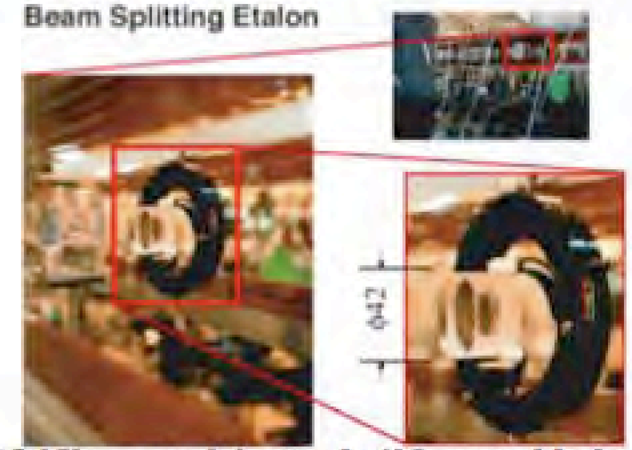
Pulsed

Variable Permanent

H.M.Shimizu (RIKEN), T.Oku, J.Suzuki (JAERI) Y.Iwashita et al. (Kyoto Univ.)

Interference Optics

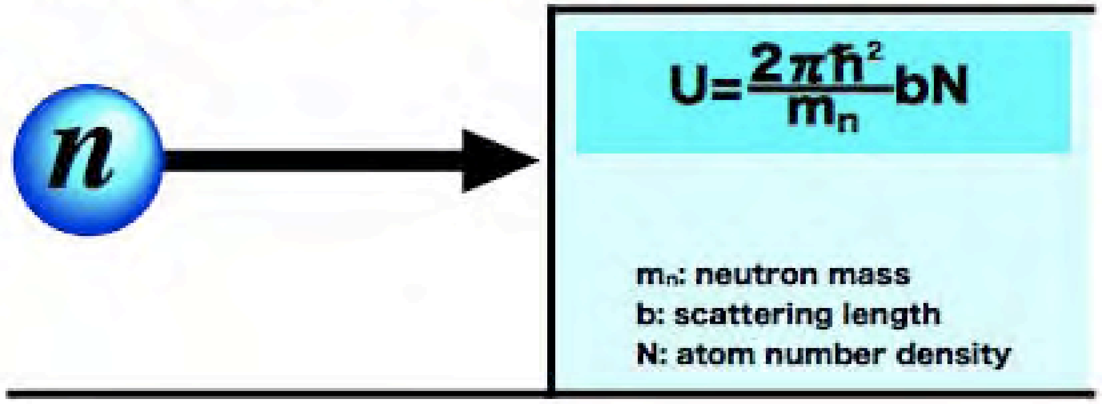
Beam Splitting Etalon

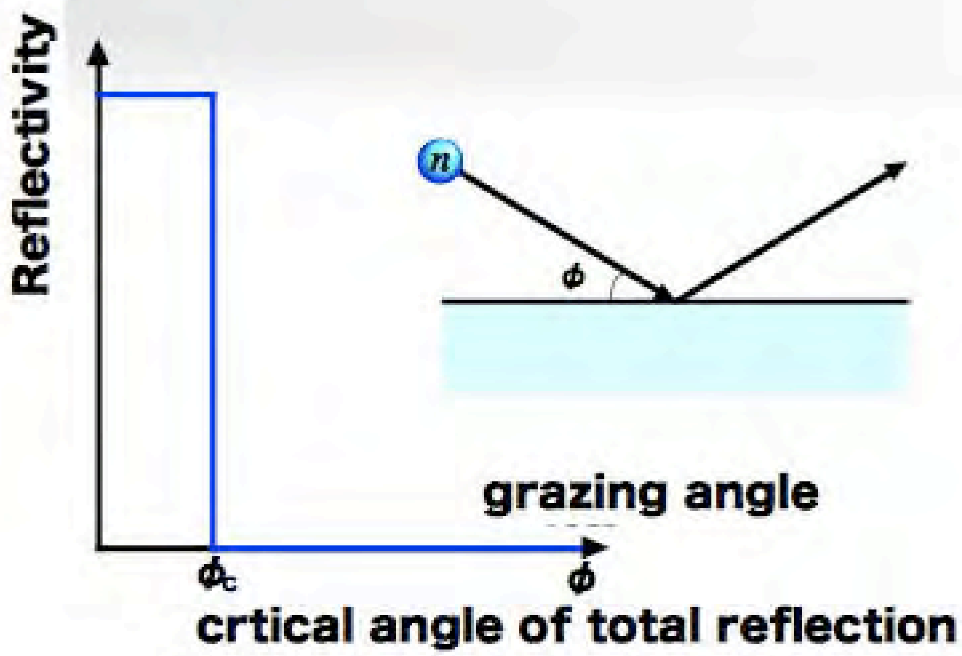


M.Kitaguchi et al. (Kyoto Univ.)

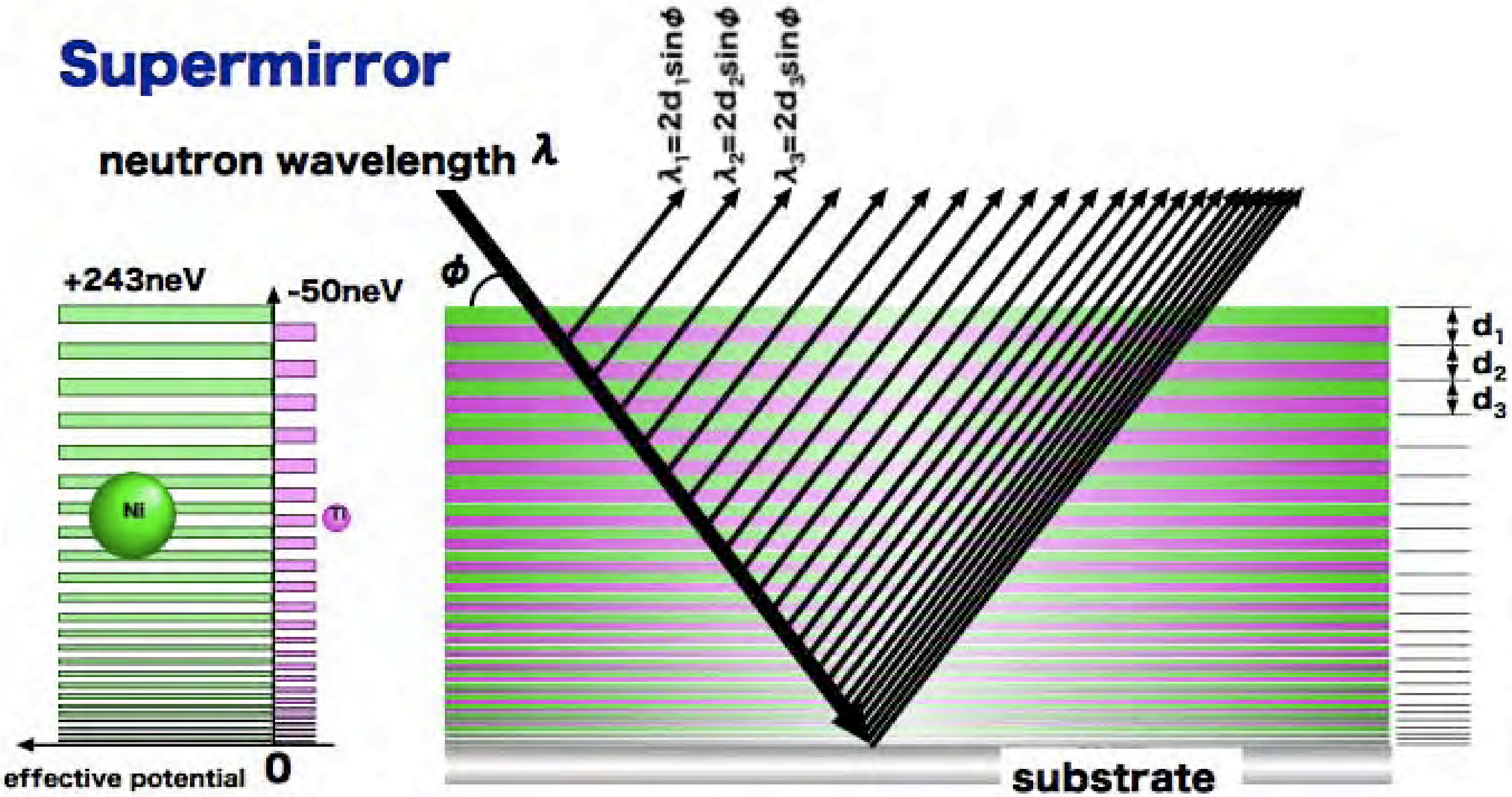
Reflective Optics

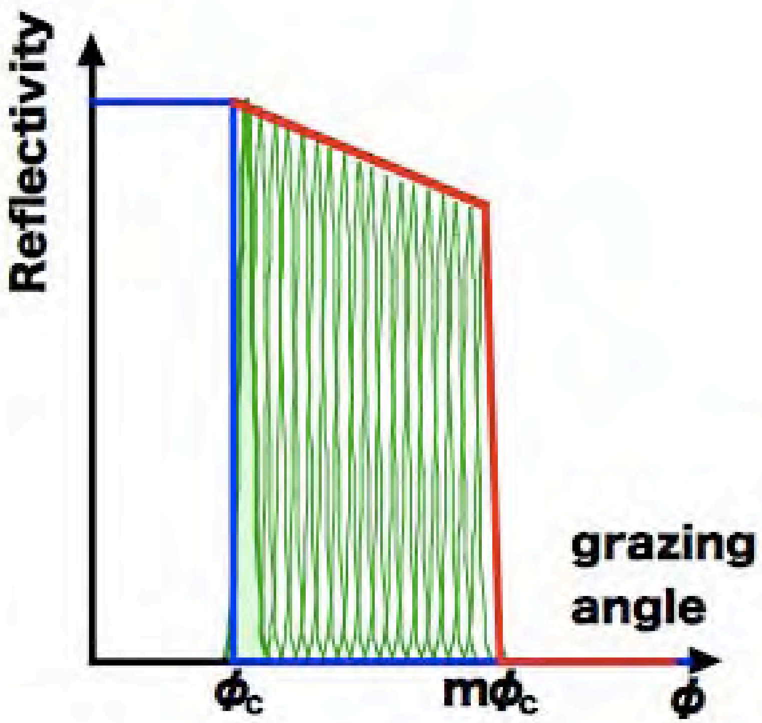
Neutron Reflection





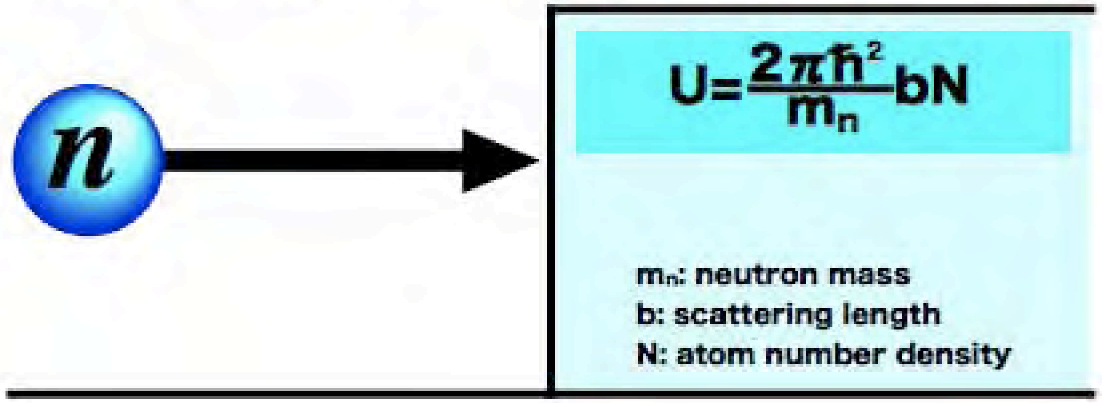
Supermirror

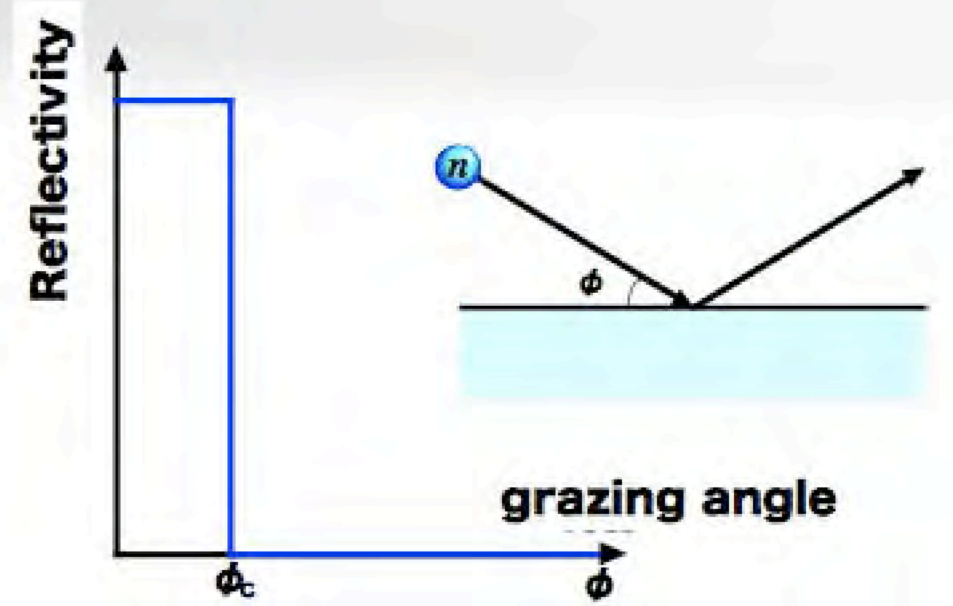




Reflective Optics

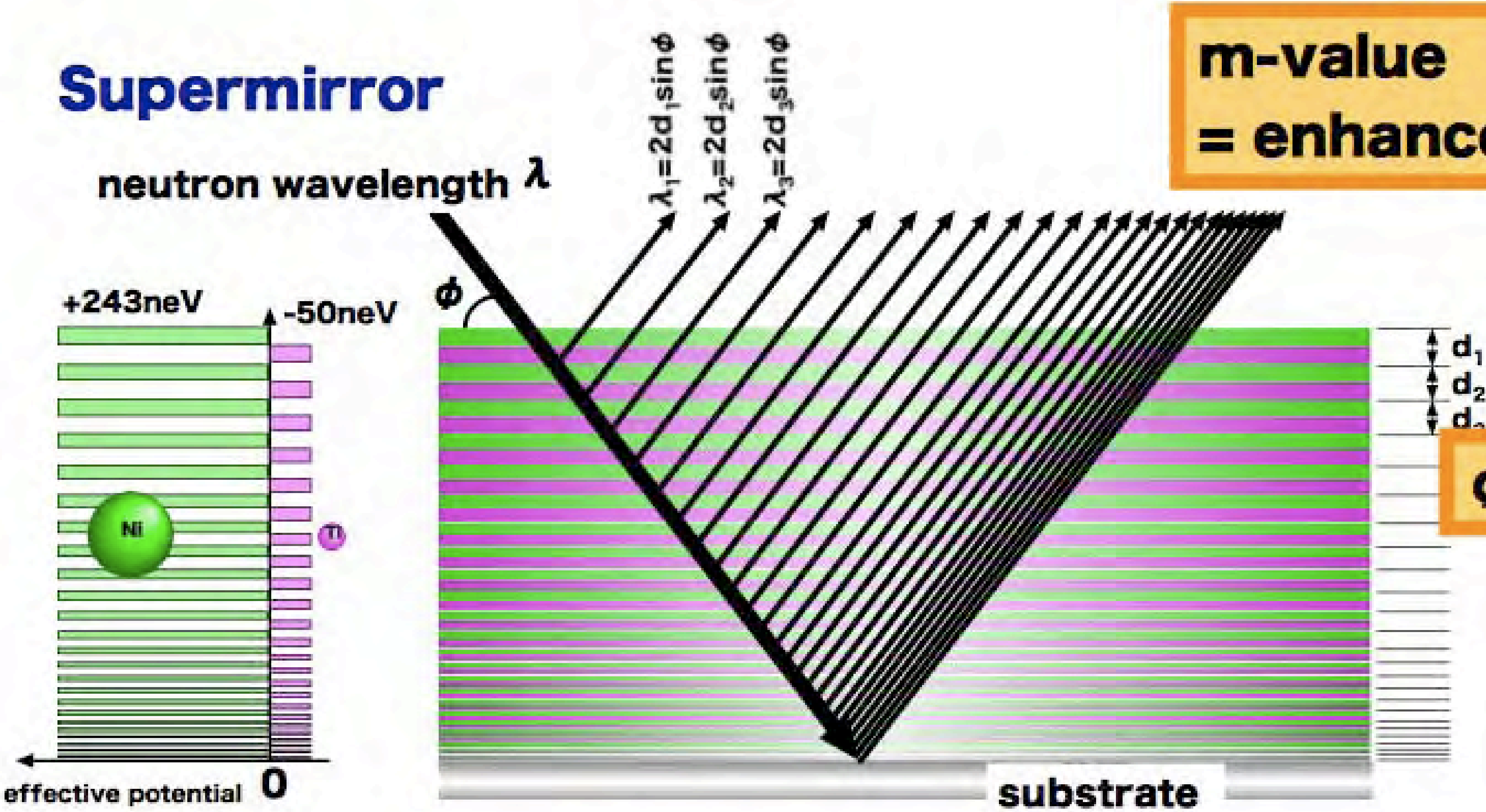
Neutron Reflection

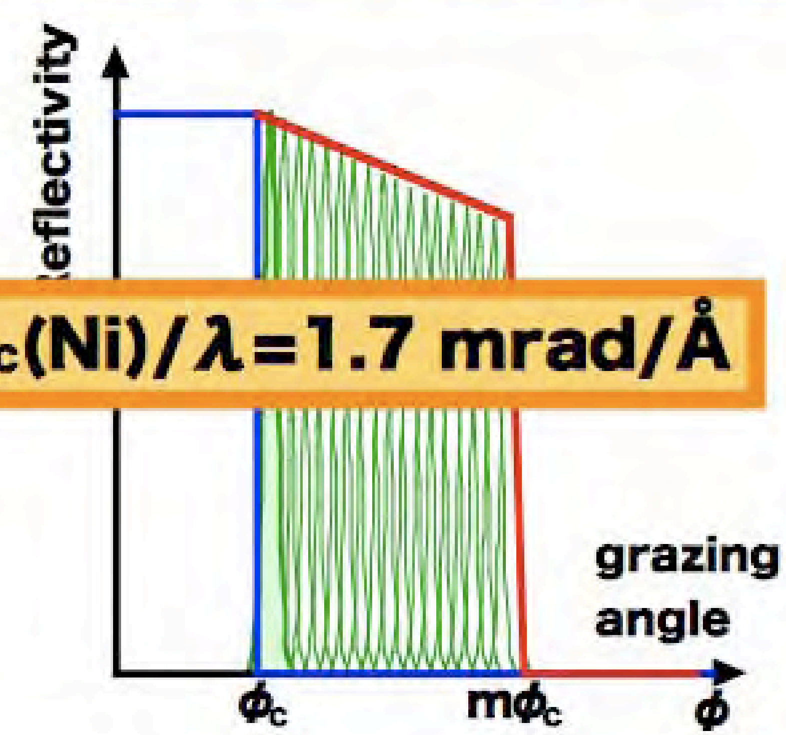




Supermirror

m-value
= enhancement of critical angle



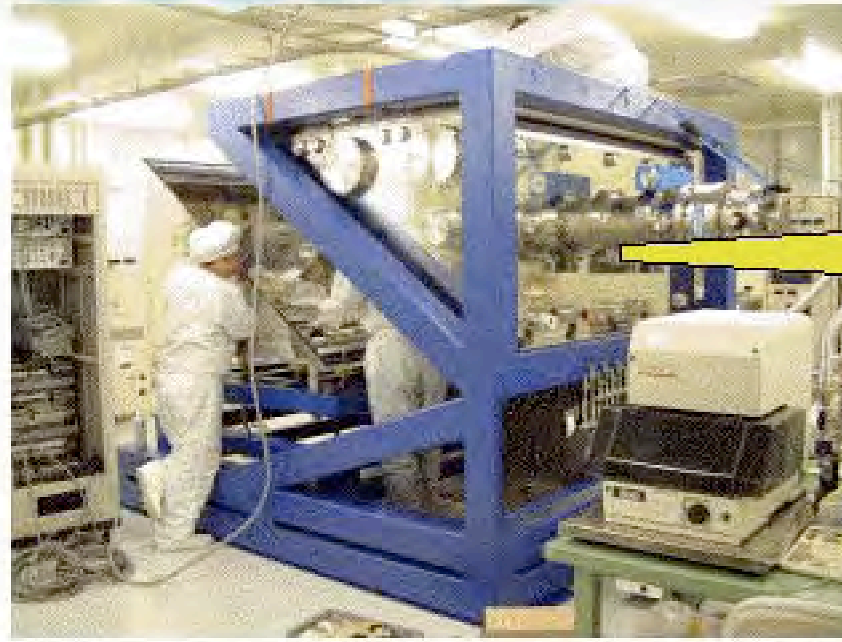


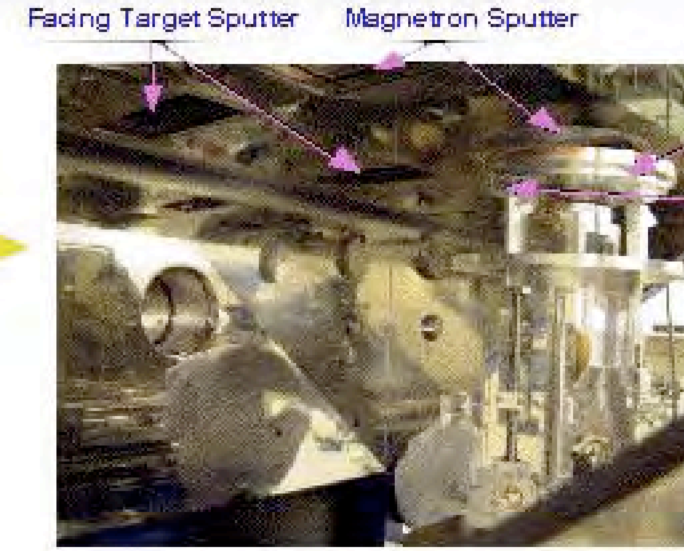
$\phi_c(Ni)/\lambda = 1.7$ mrad/Å

Supermirror Coaters

Magnetron Sputtering

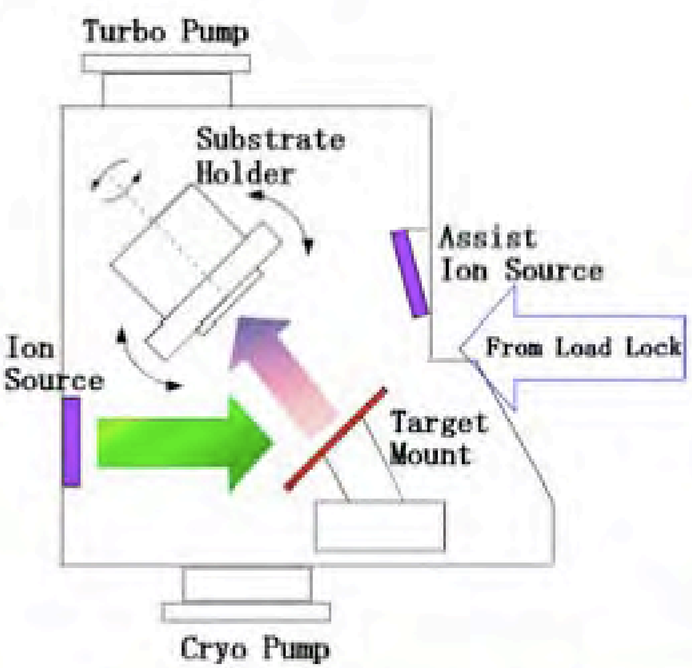
m≤3.6

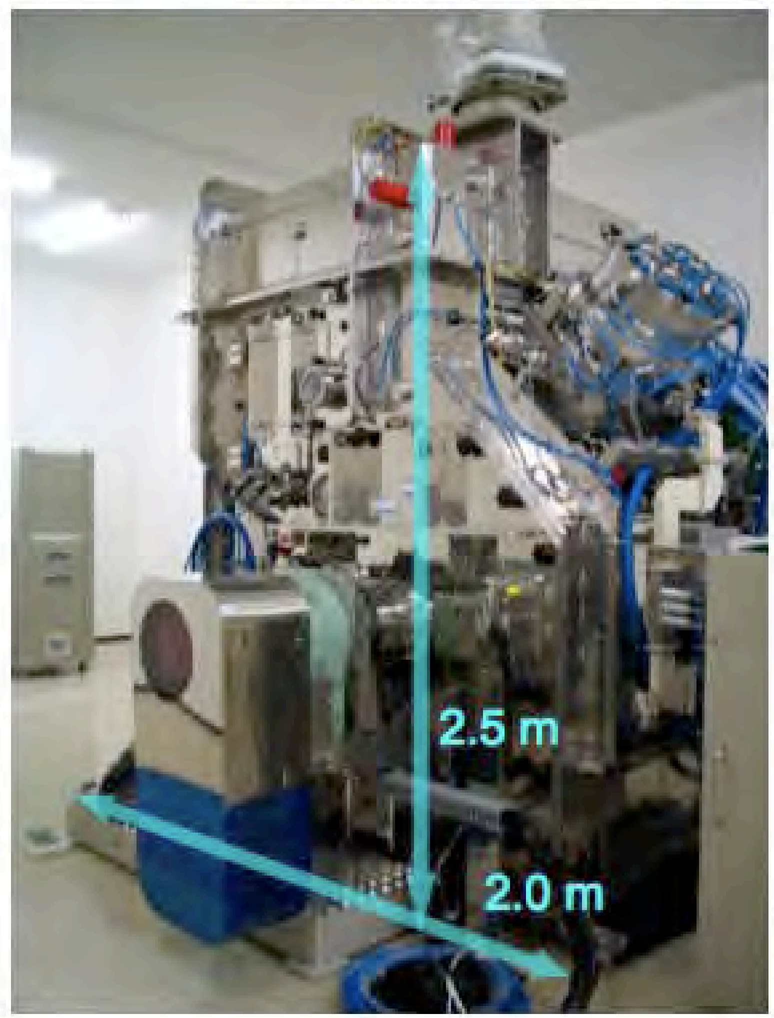


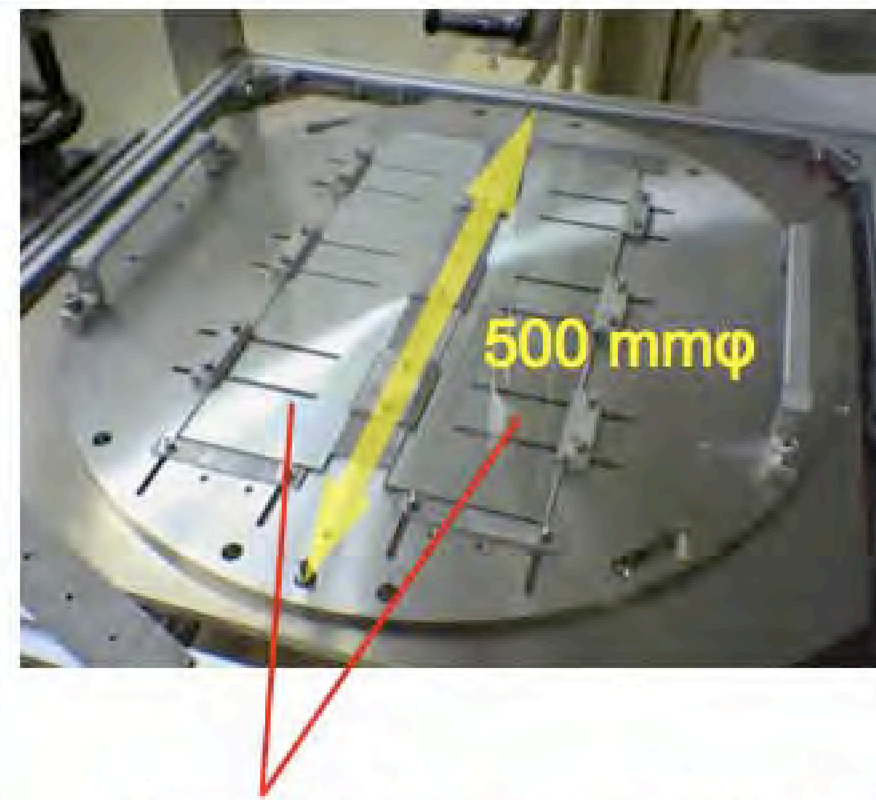


Ion Beam Sputtering

m≤10





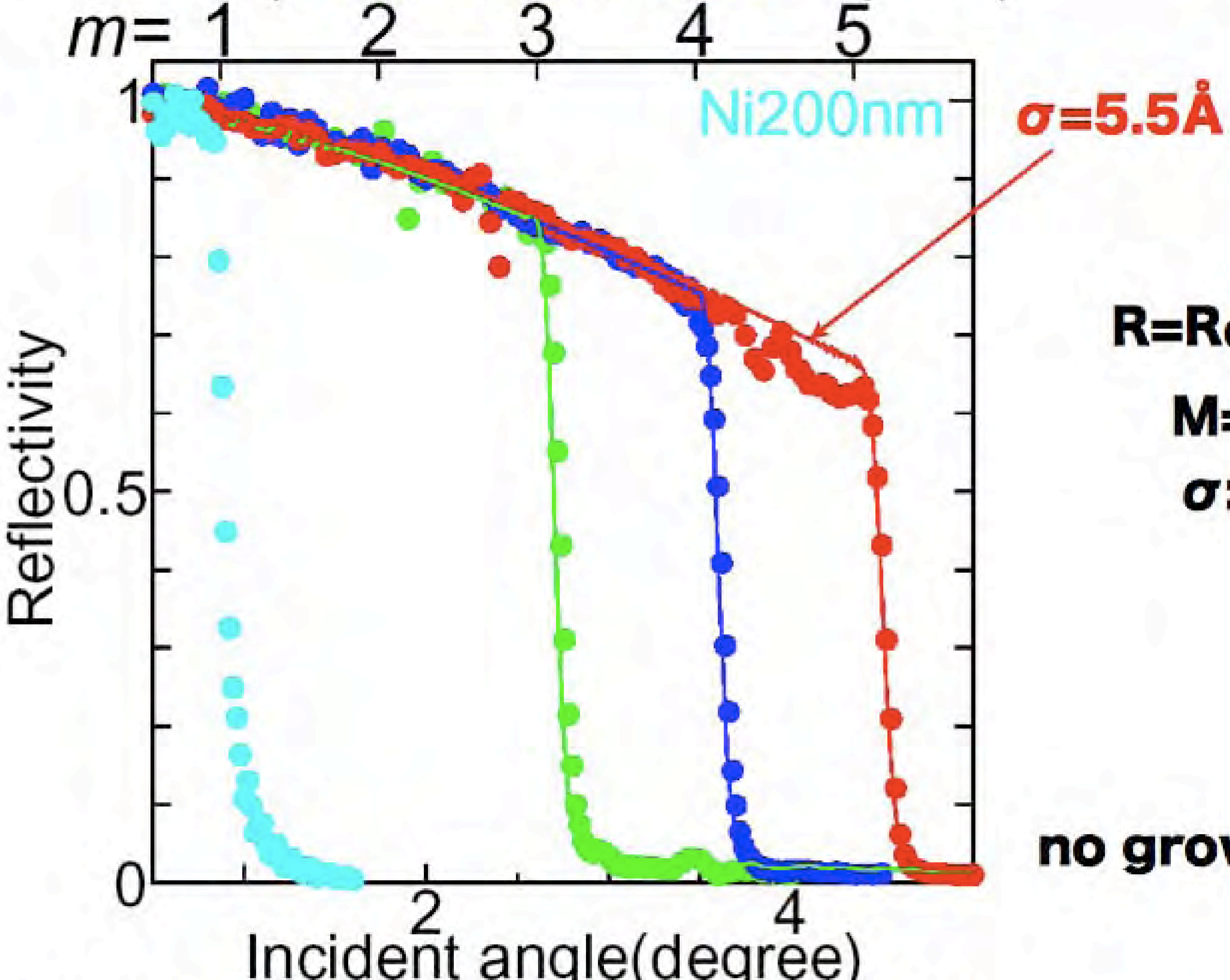


Float glass substrates (400 x 100 x 5 mm)

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

Large-m Supermirrors

NiC/Ti(400, 1200, 3000layers)



Incident wavelength 0.88nm(FWHM:2.4%)

$R=R_0e^{-2M}$

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

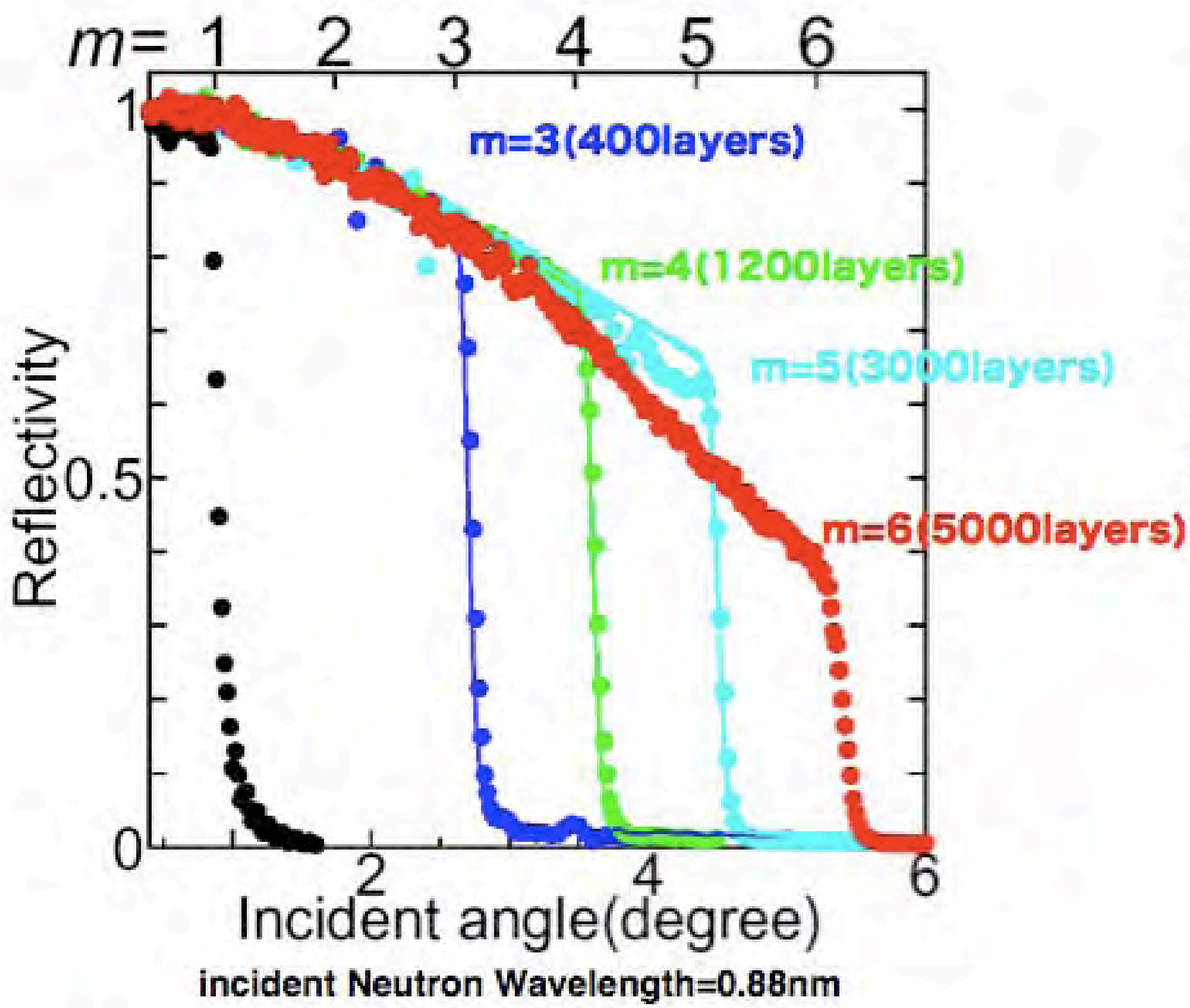
σ:interface roughness

single σ

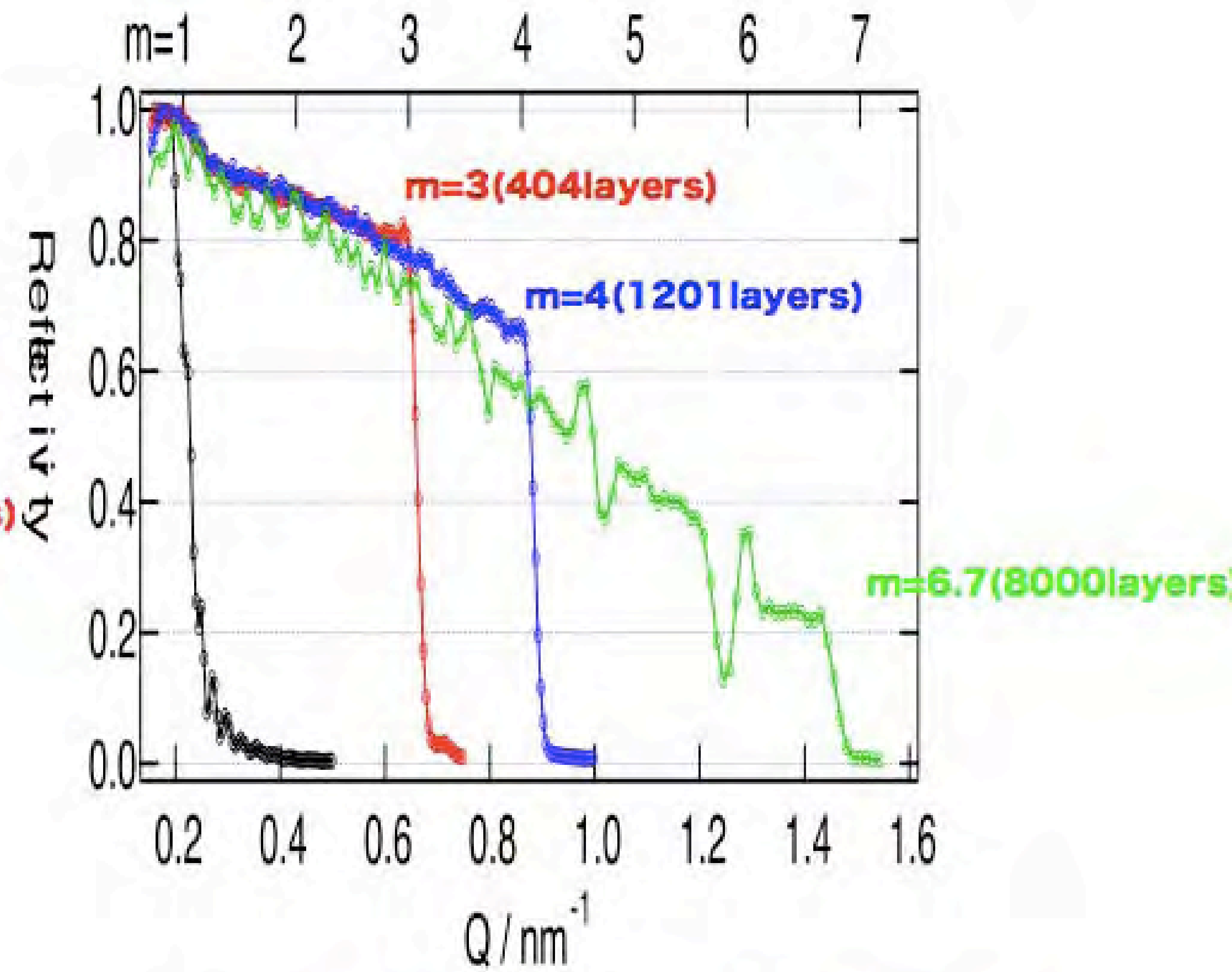
⇕

no growth of interface roughness

Largest-m Supermirrors



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

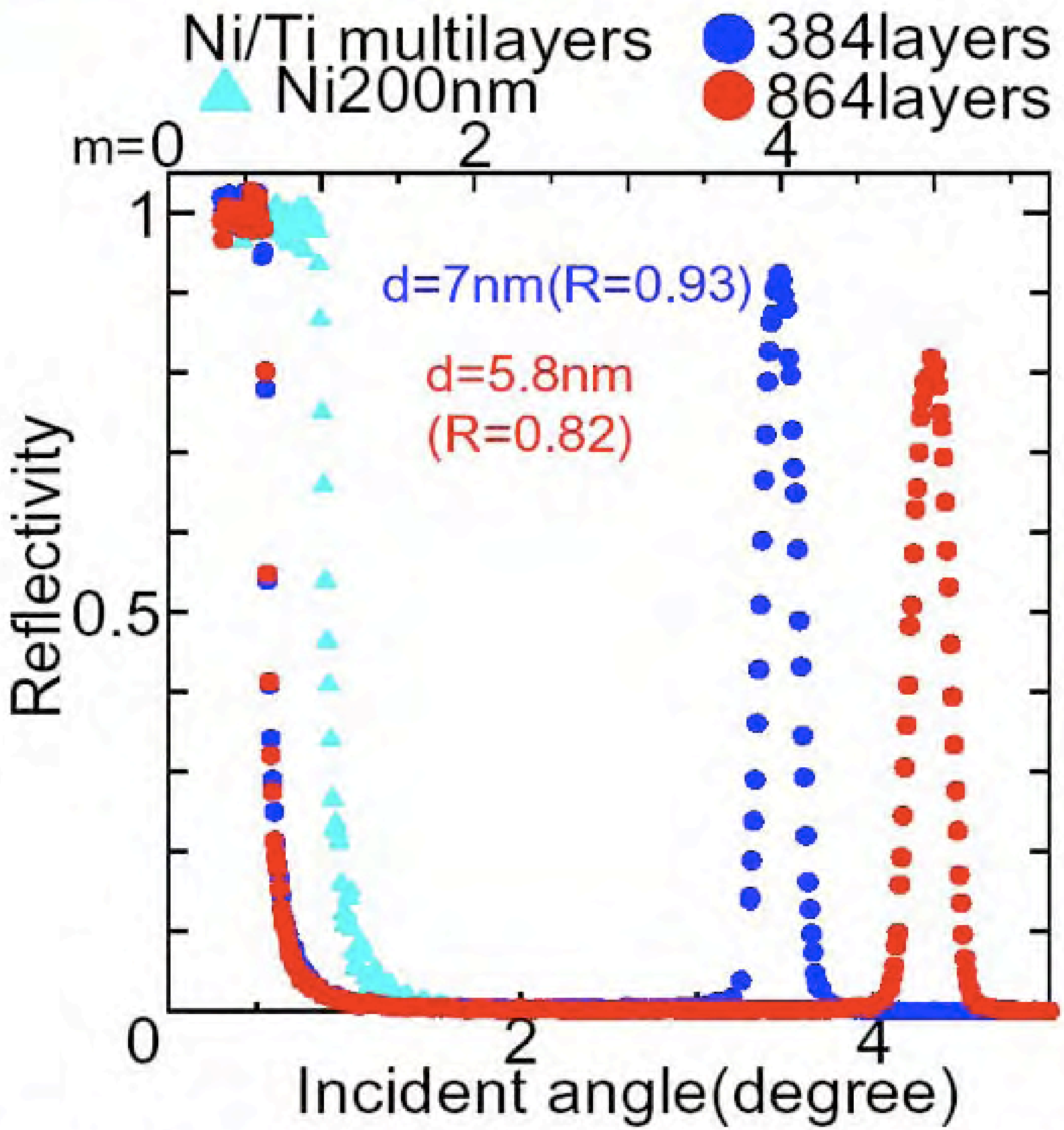


R.Maruyama et al., Thin Solid Films 515 (2007) 5704.

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

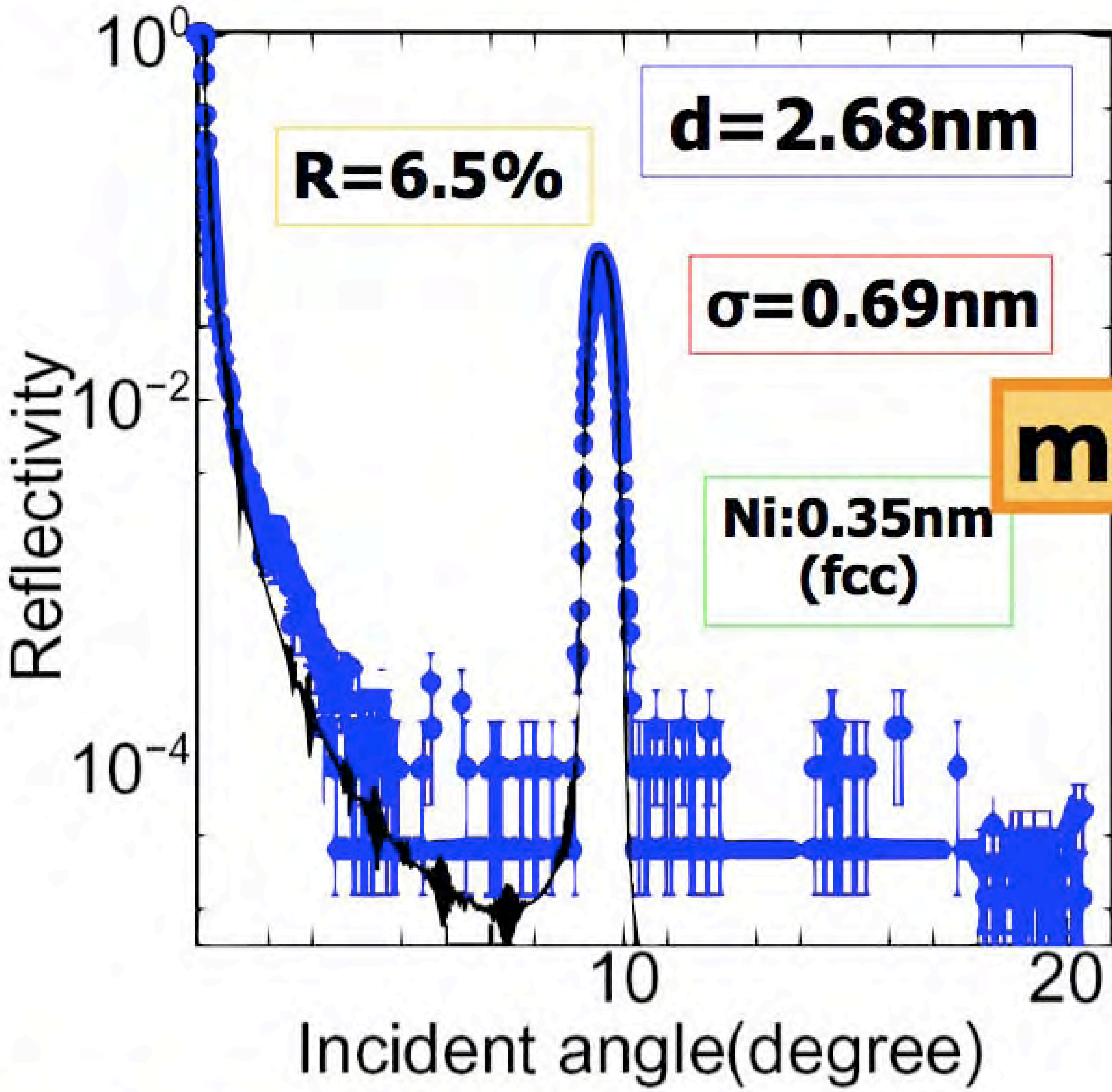
- Number of layers: 404(m=3), 1201(m=4), 8000(m=6.7)
- Estimated interface roughness: 0.60 nm(*m*=3, 4), 0.78 nm(*m*=6.7) RMS

Multilayer Bender



Incident neutron wavelength 0.88nm(FWHM;2.5%)

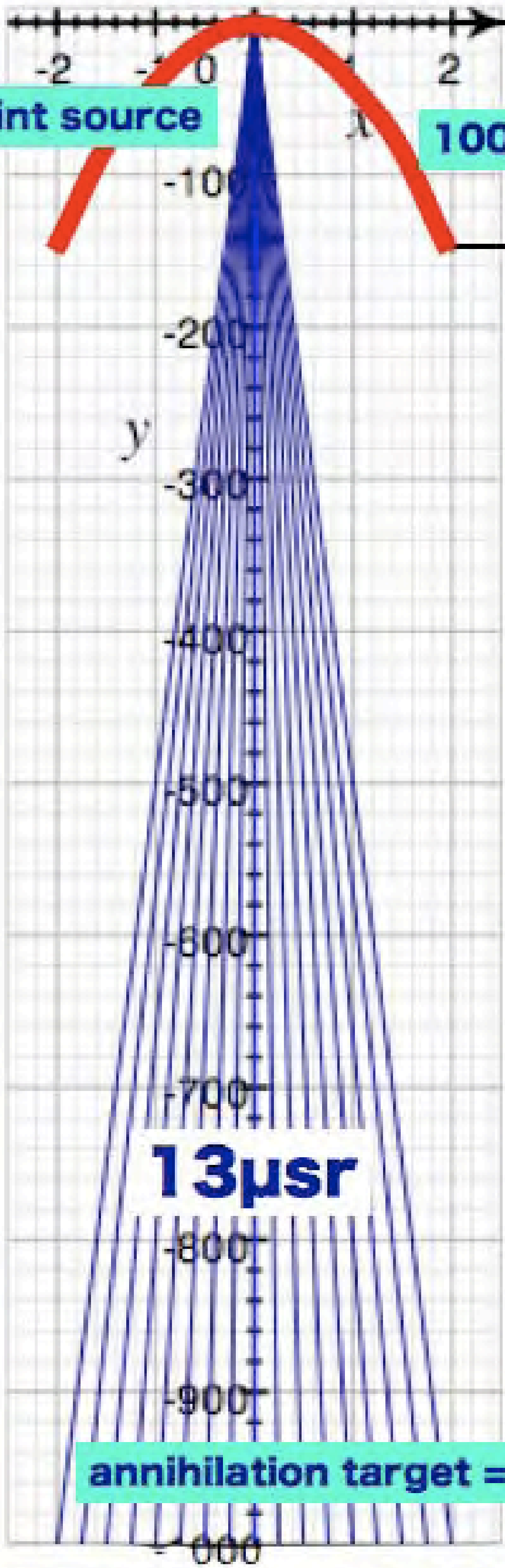
Largest-m Multilayer Bender

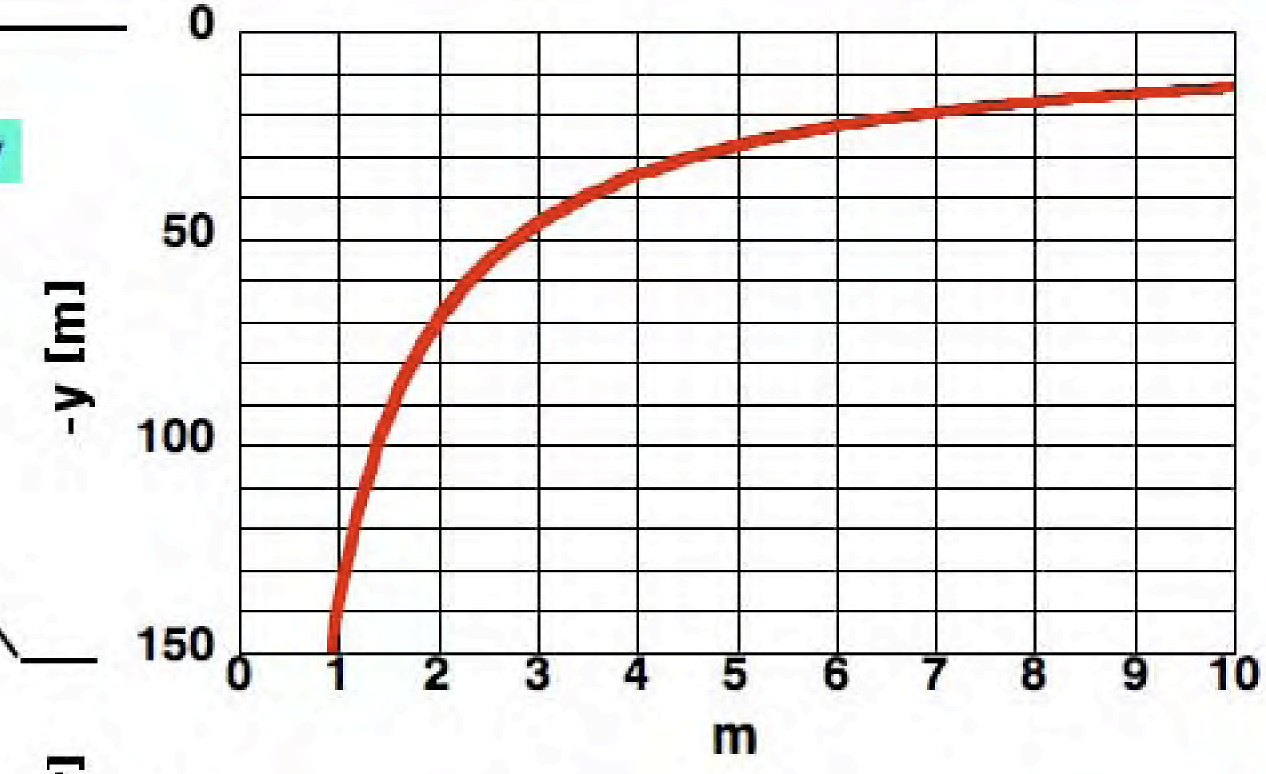


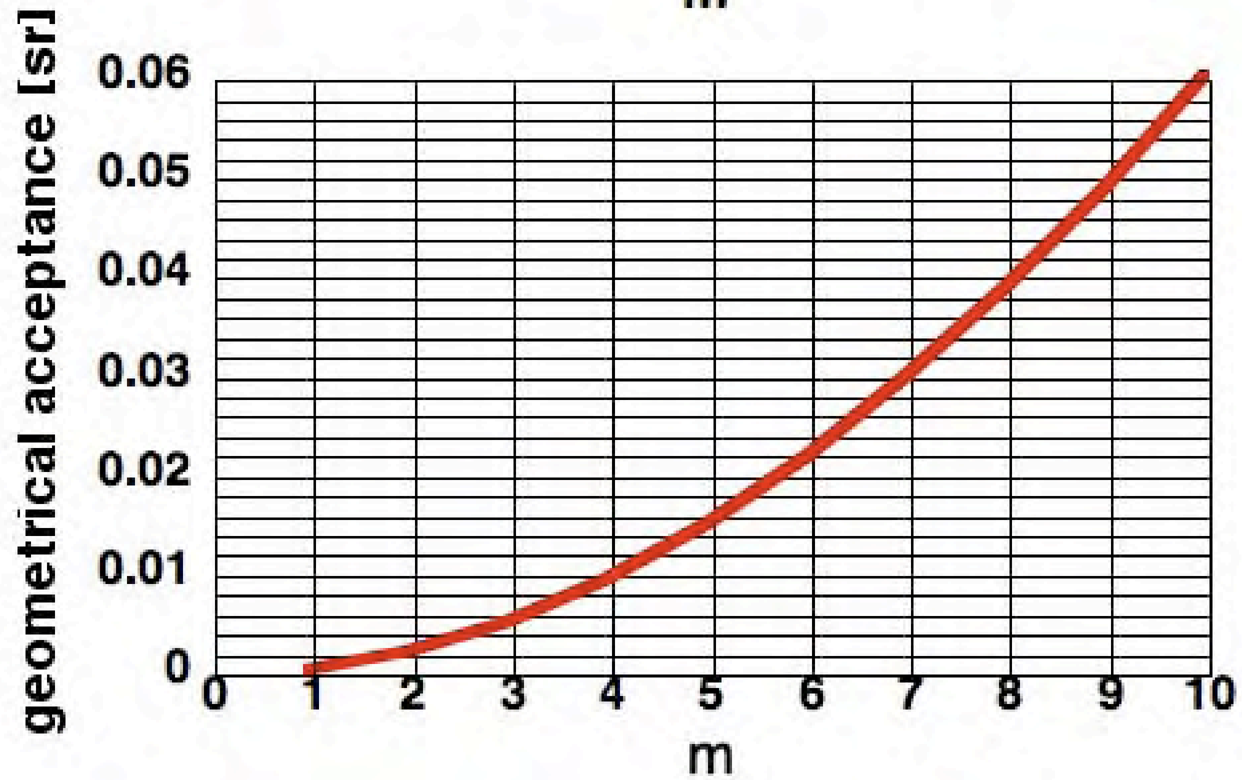
m=10.5 equiv.

m-value Distribution and Geometircal Acceptance v=1000m/s, λ=4Å

t~1s



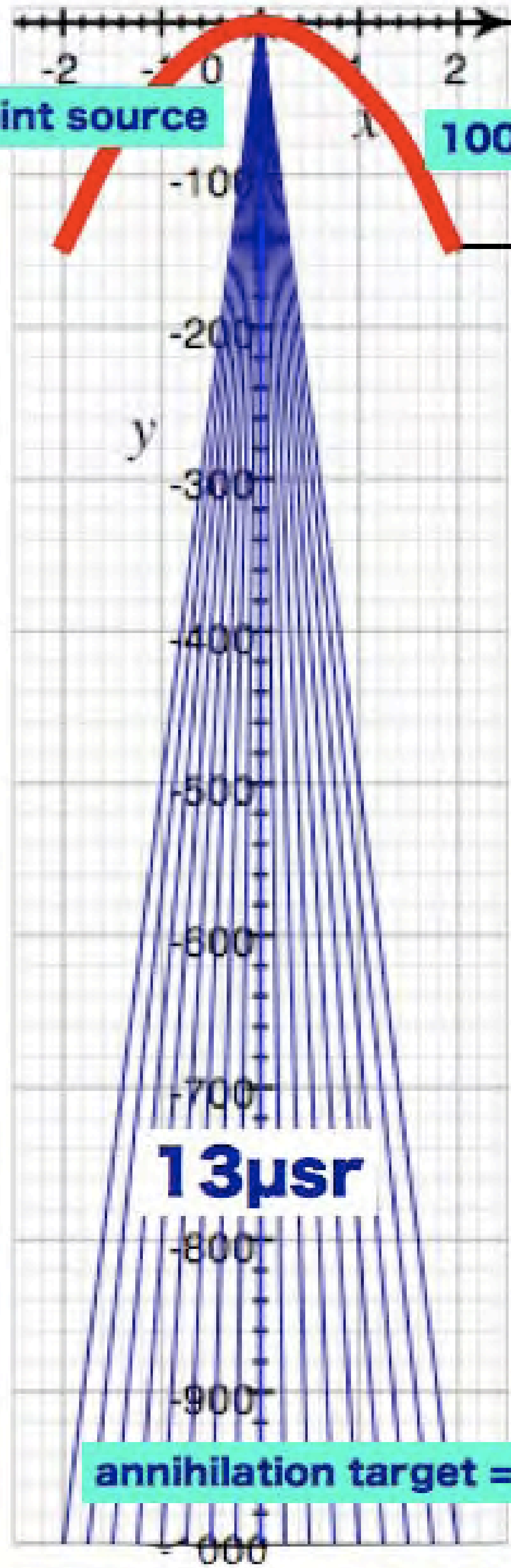


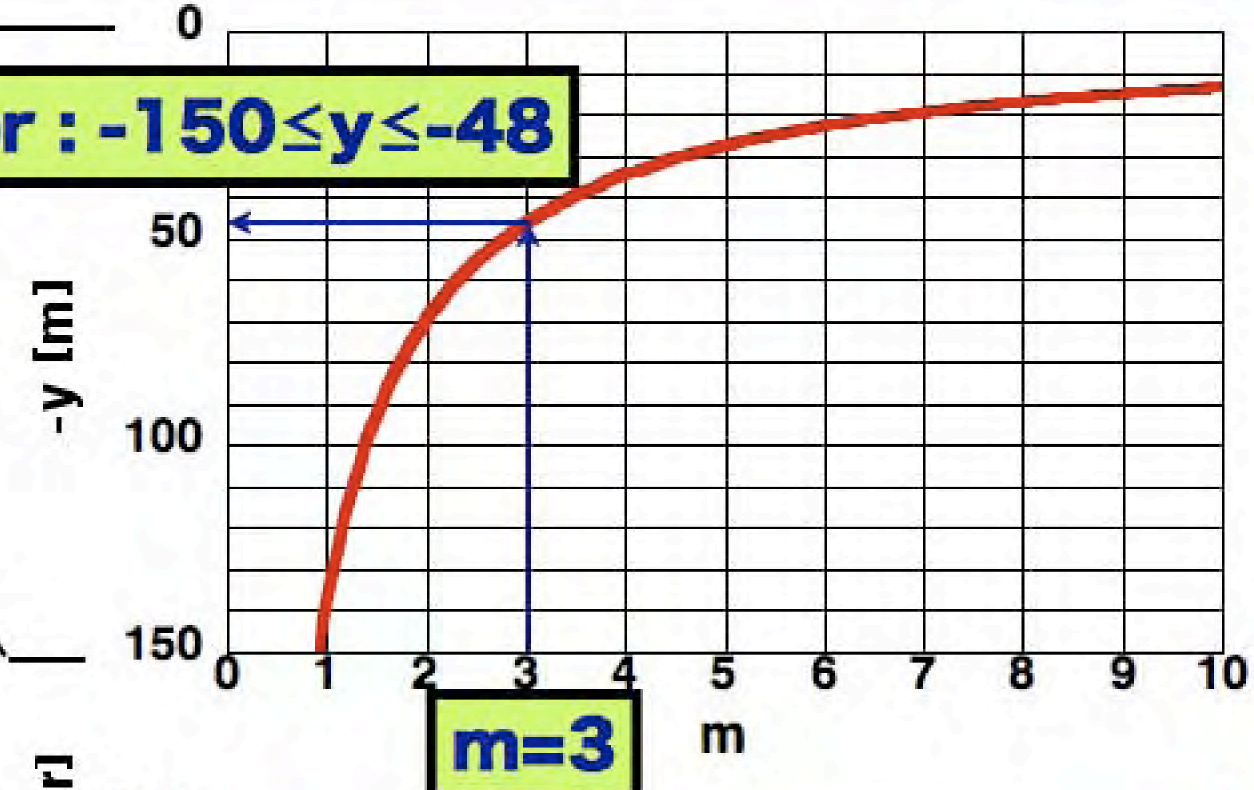


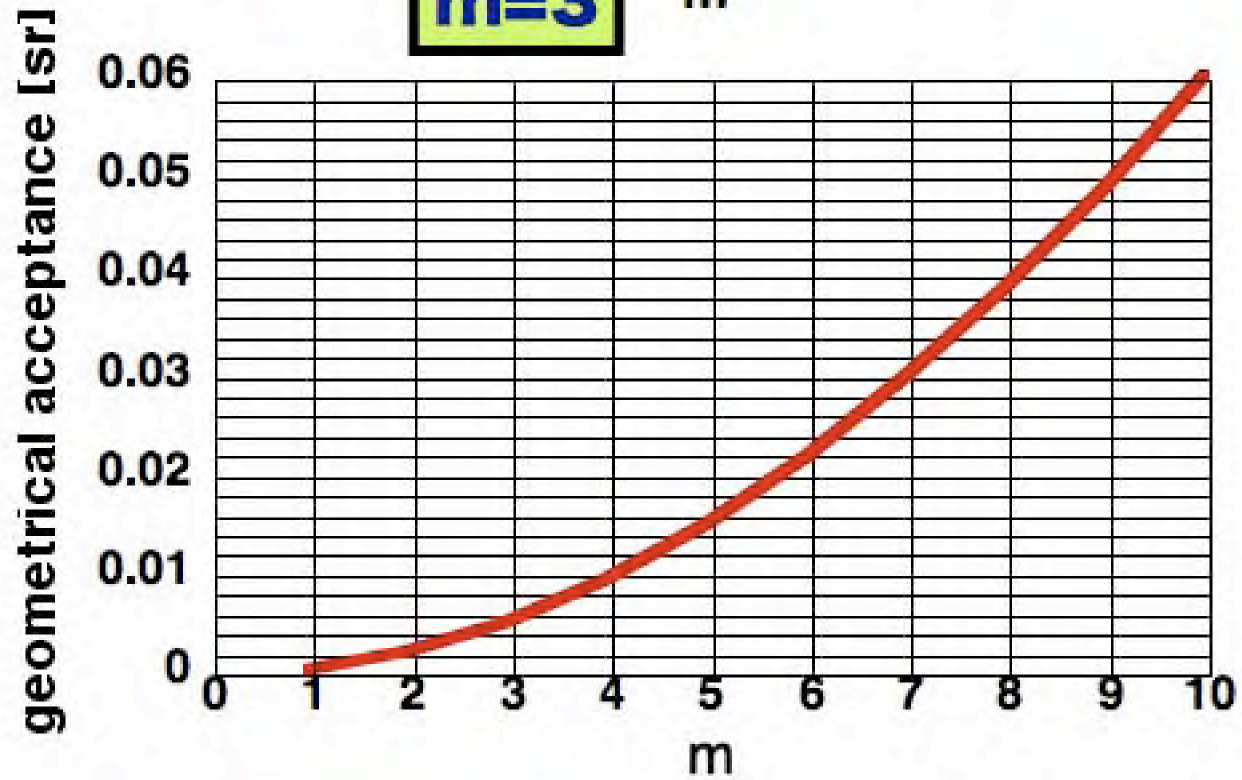
m-value Distribution and Geometircal Acceptance

v=1000m/s, λ=4Å

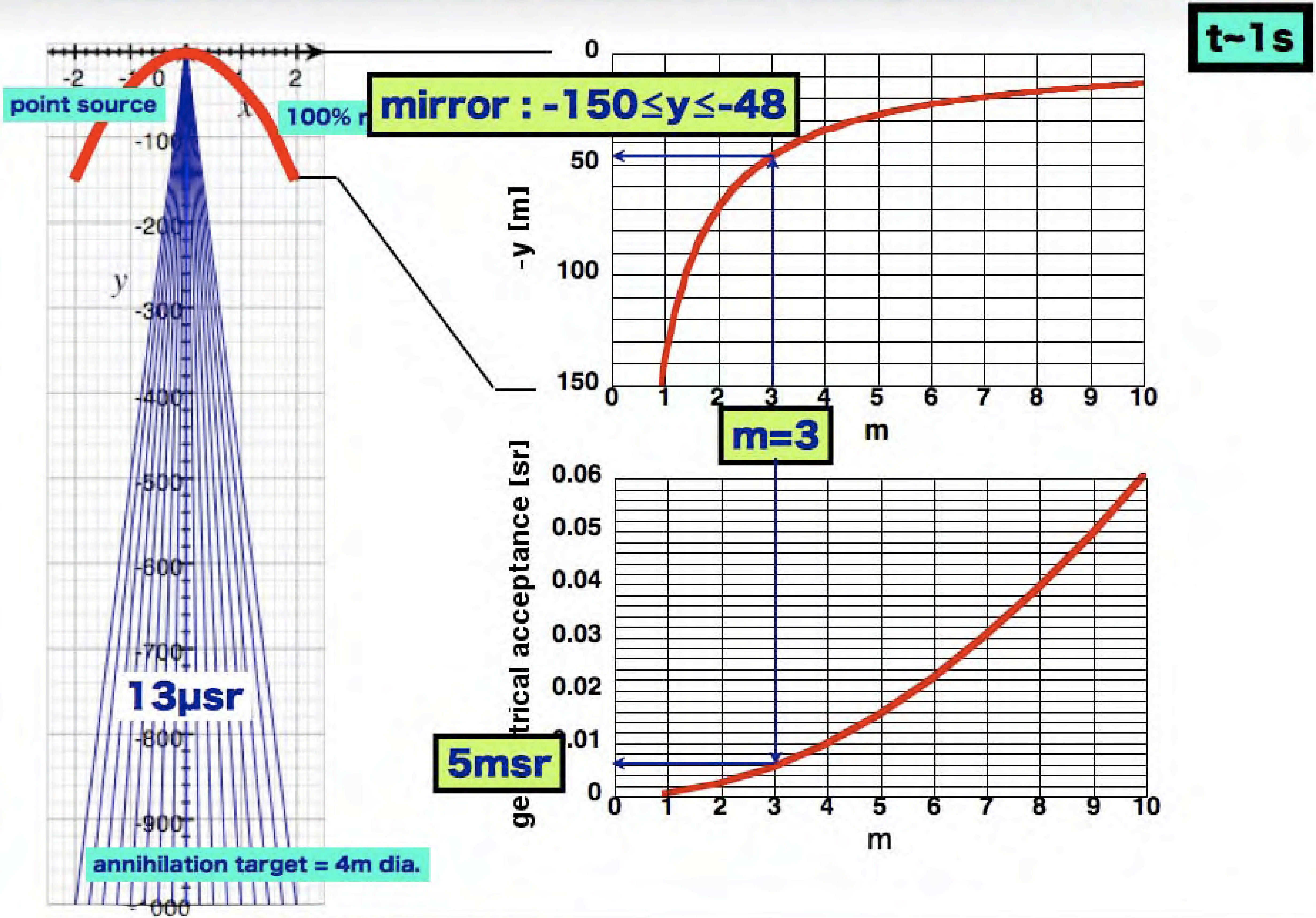
t~1s



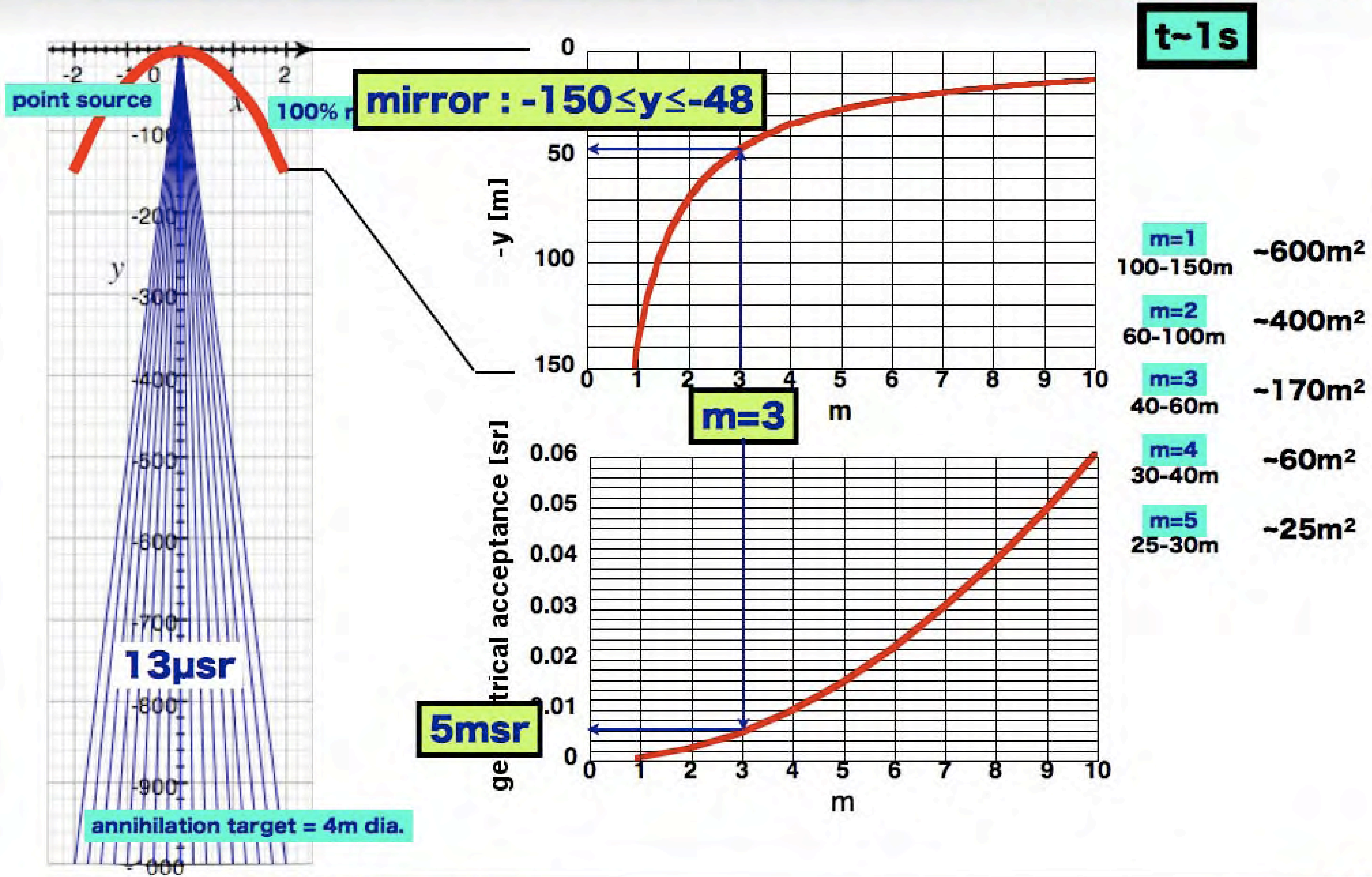




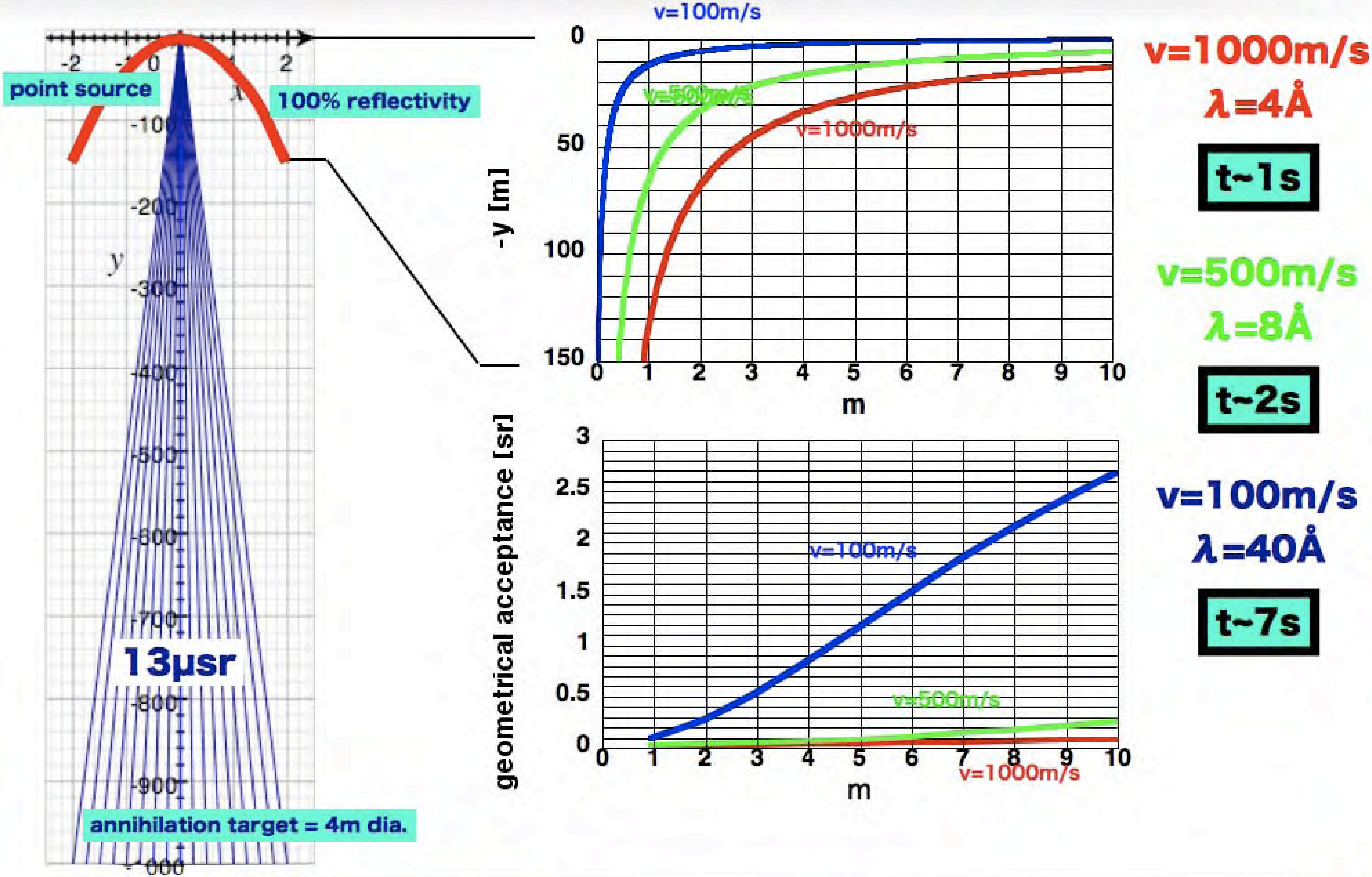
m-value Distribution and Geometircal Acceptance v=1000m/s, λ=4Å



m-value Distribution and Geometircal Acceptance v=1000m/s, λ=4Å



m-value Distribution and Geometircal Acceptance



Summary

Multilayer-based reflective optics is suitable for the vertical flight path of n-nbar 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.)