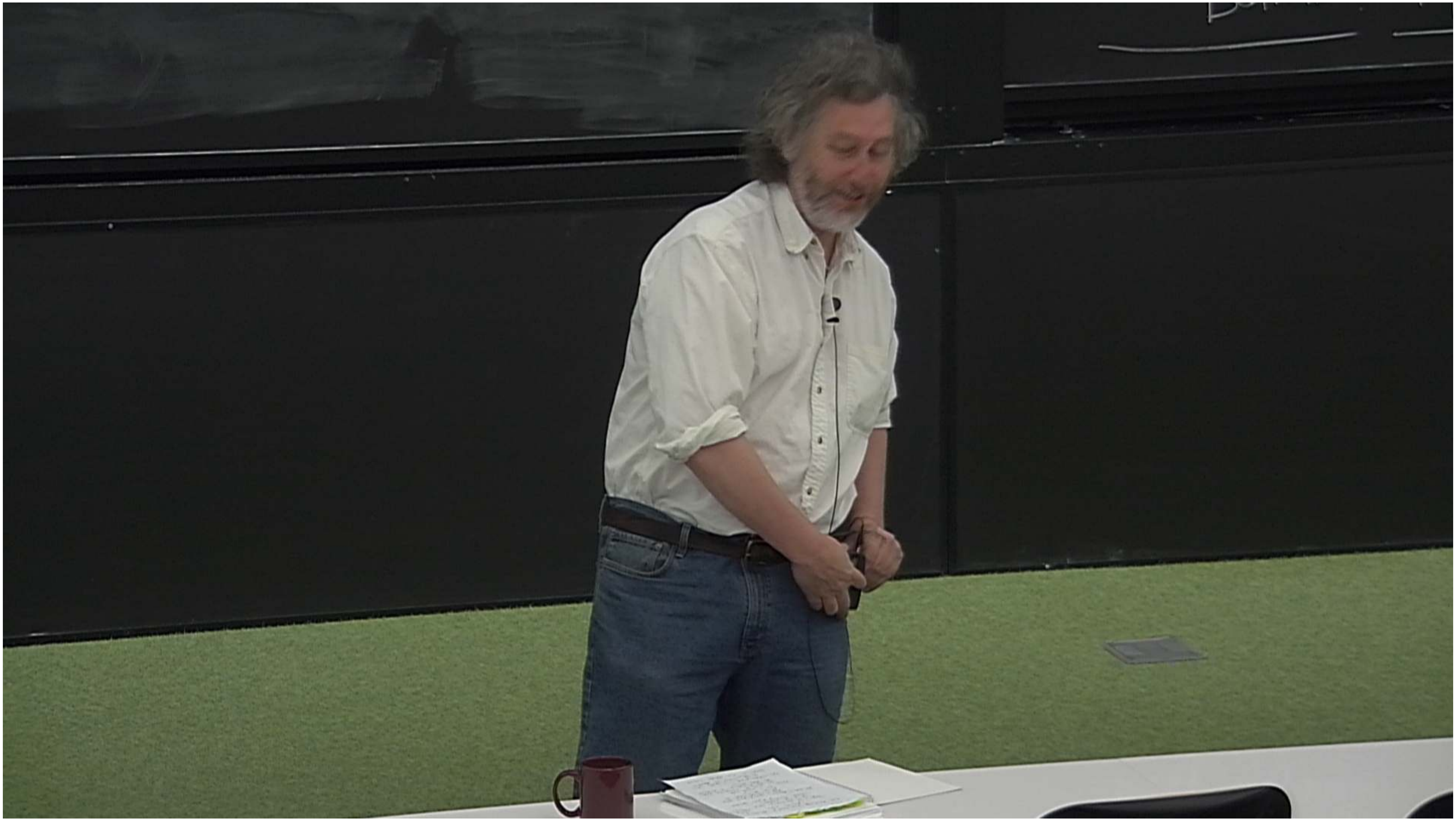
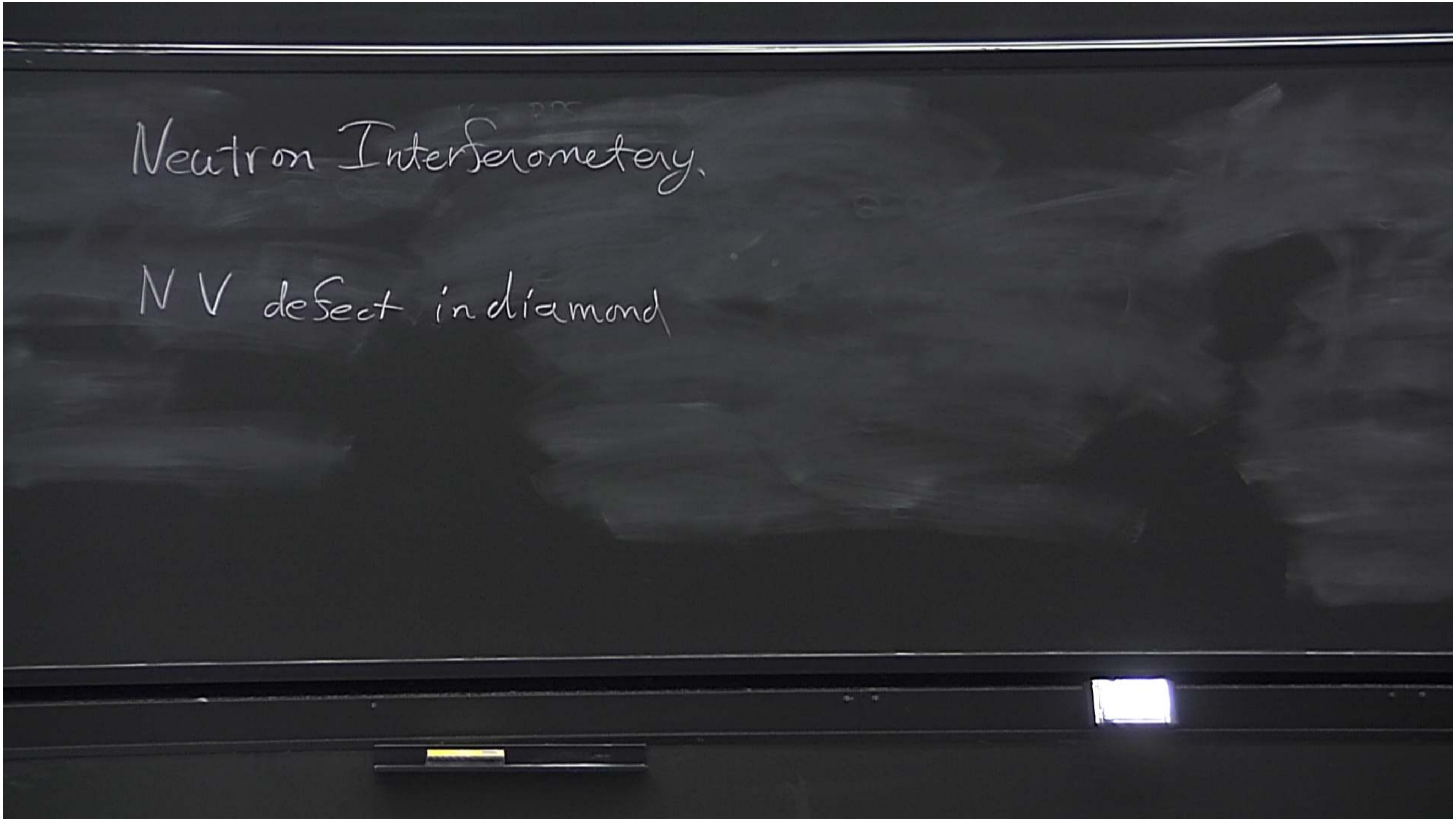
Title: Explorations in Quantum Information - Lecture 1

Date: Mar 12, 2012 09:00 AM

URL: http://pirsa.org/12030004

Abstract:

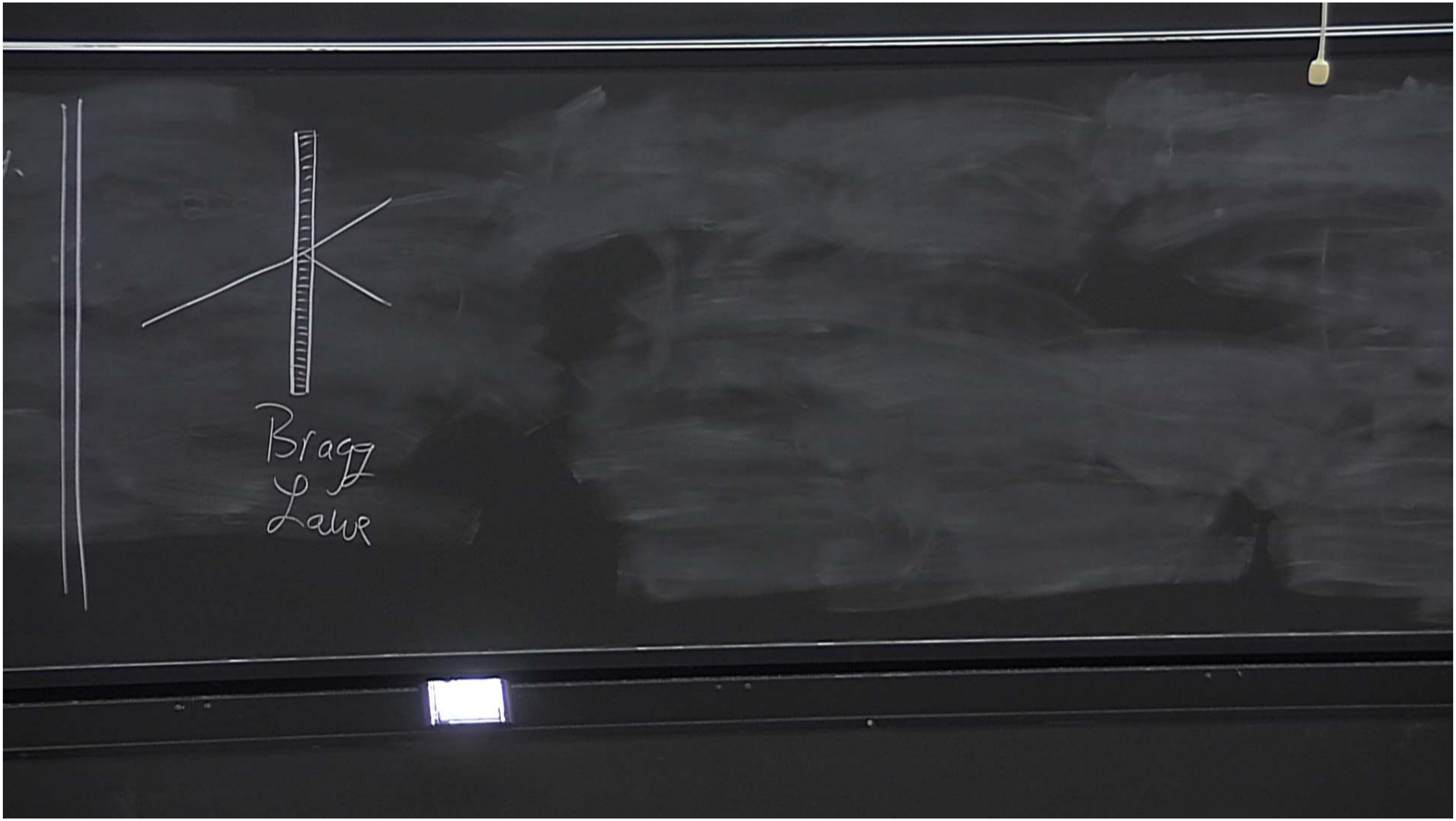


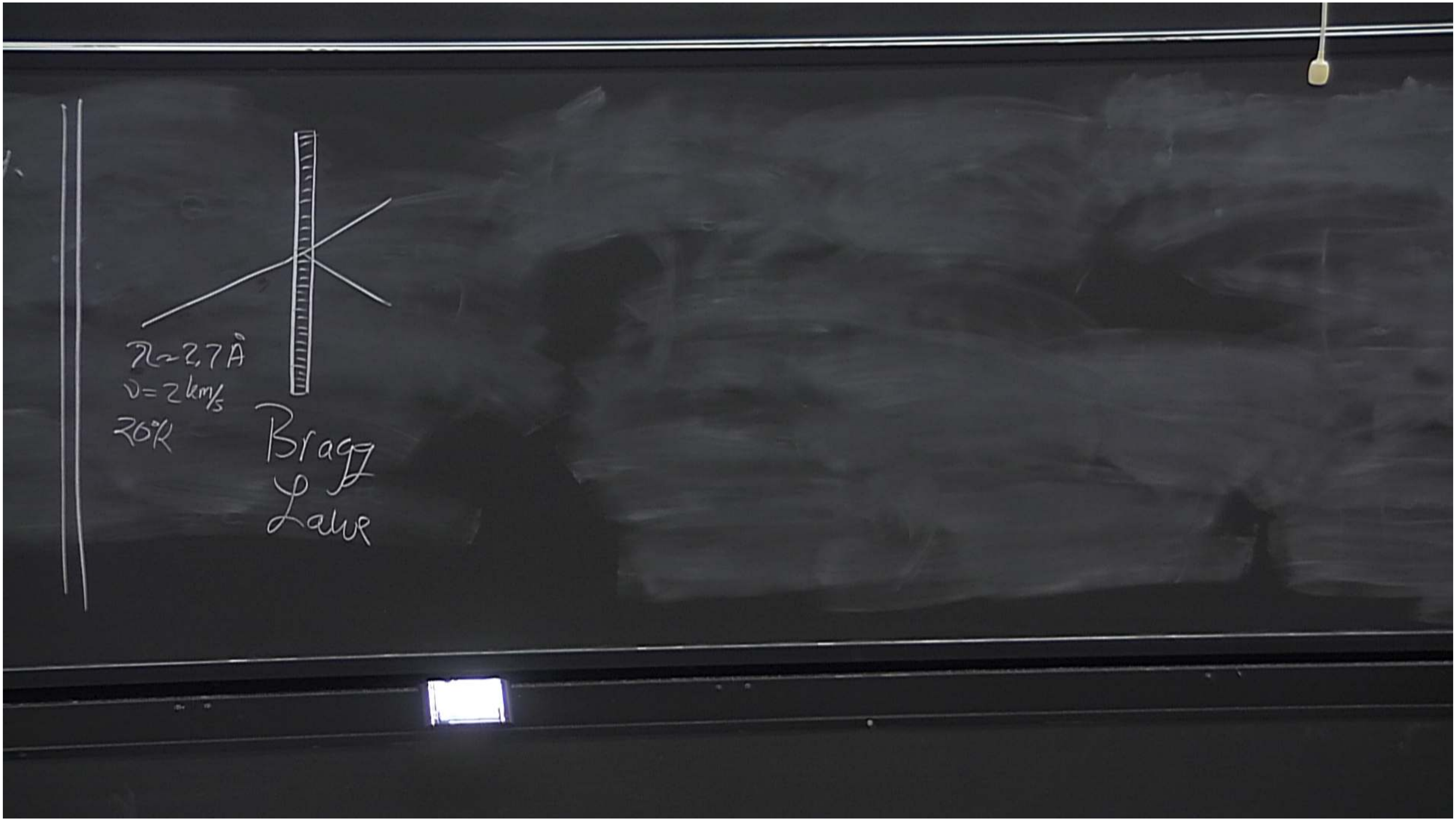

Neutron Interferometery.
N V defect in diamond

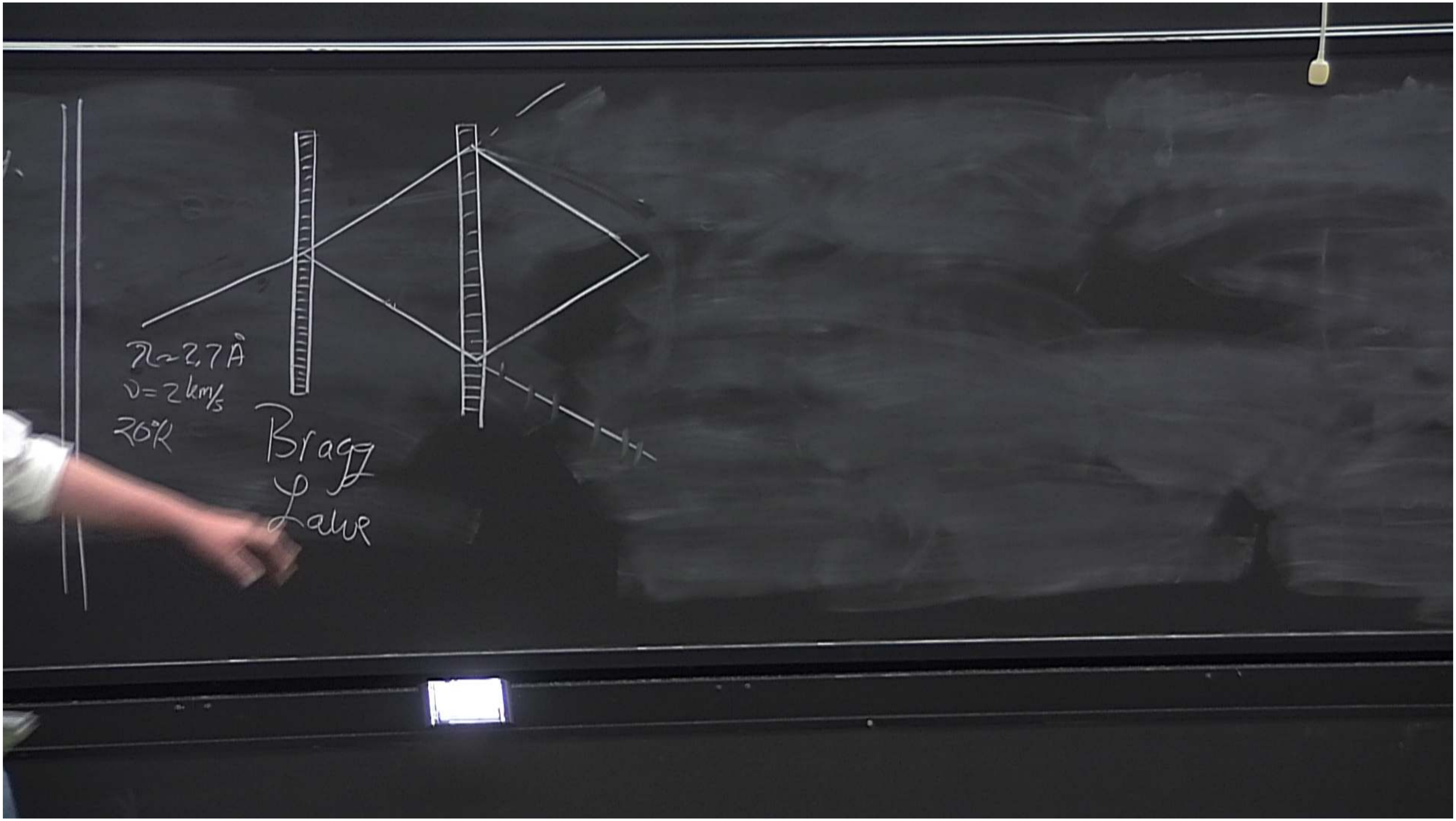
Neutron Interferometery.

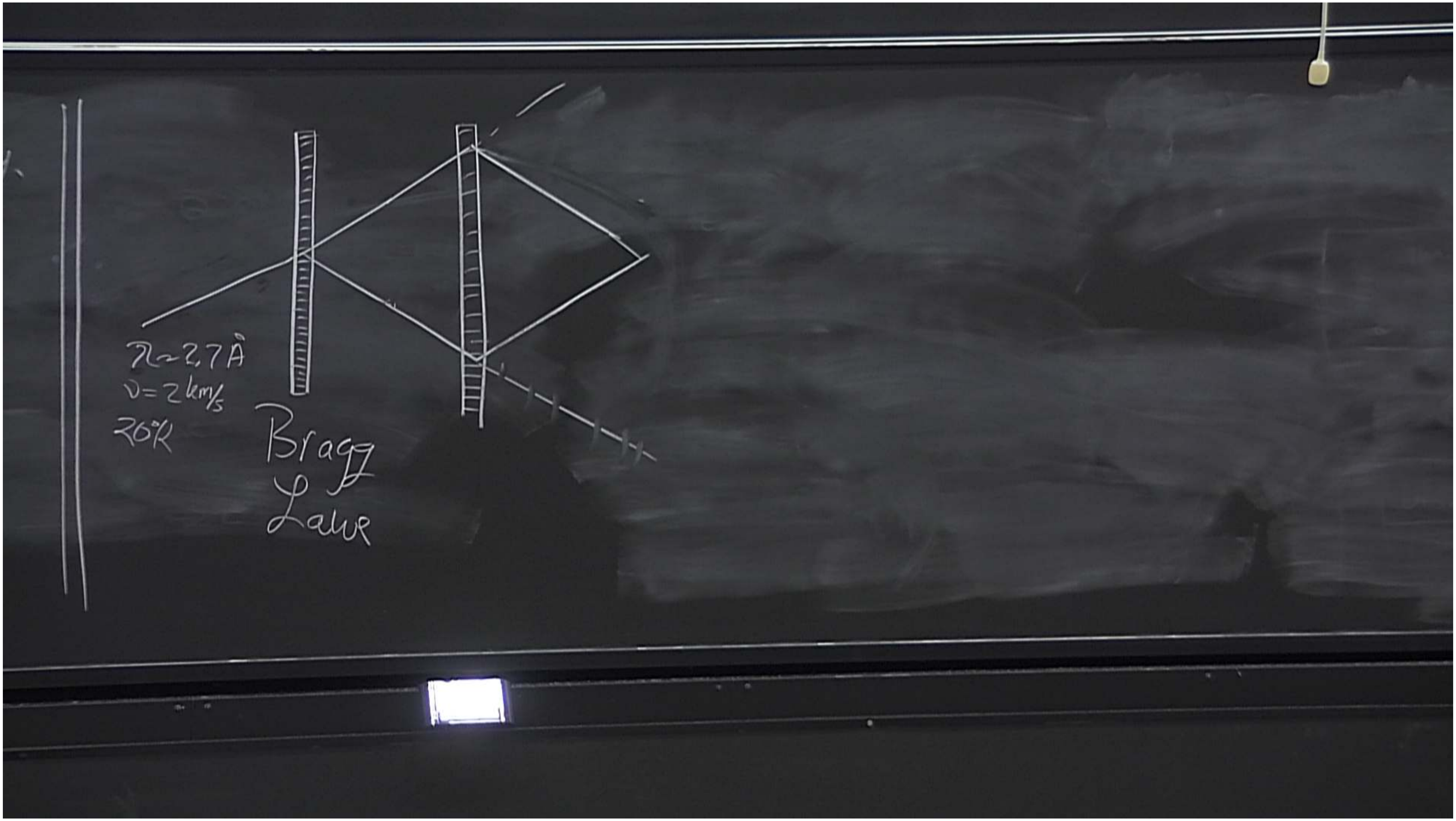
N V defect in diamond

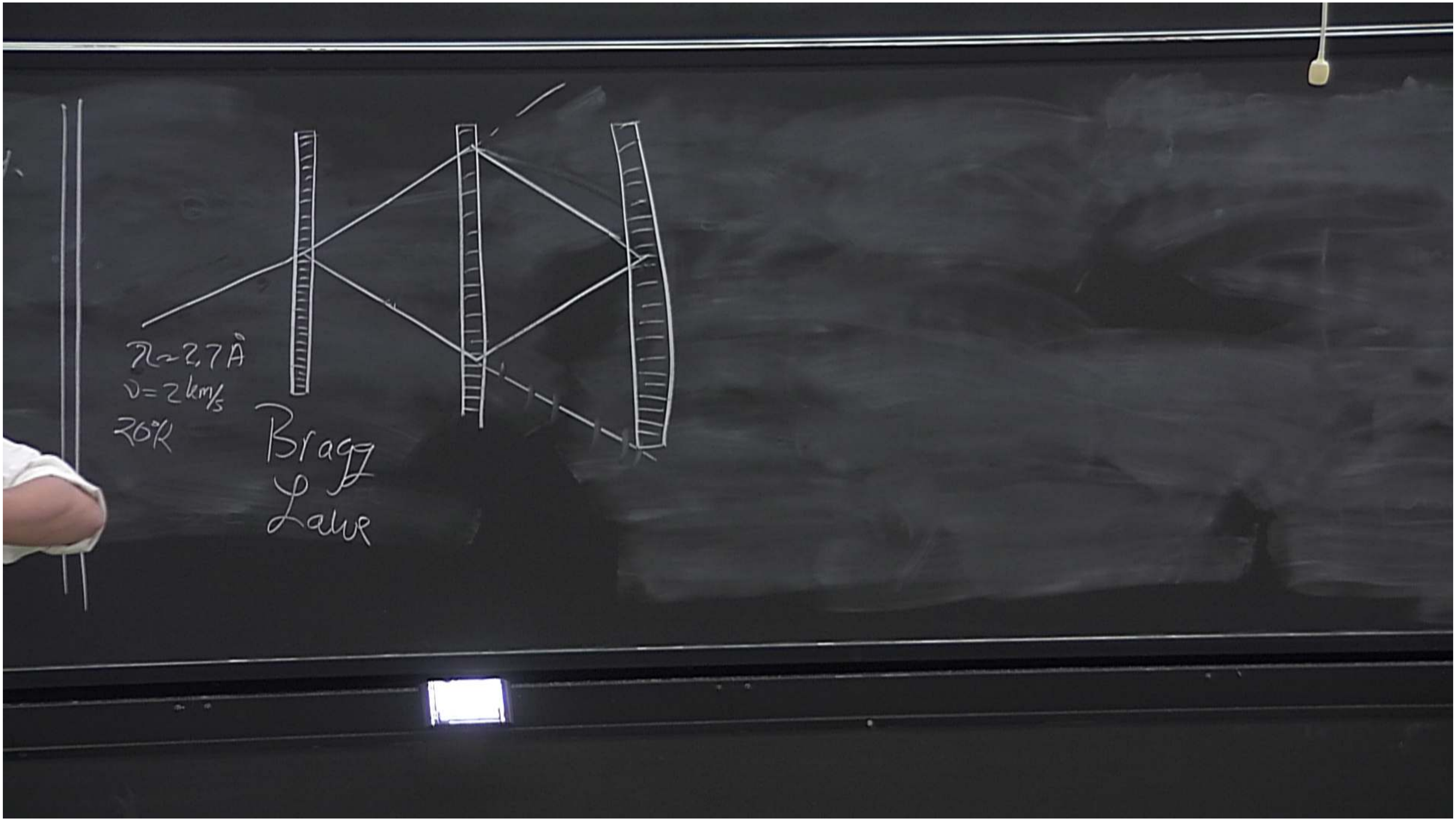
Superconducting circuits

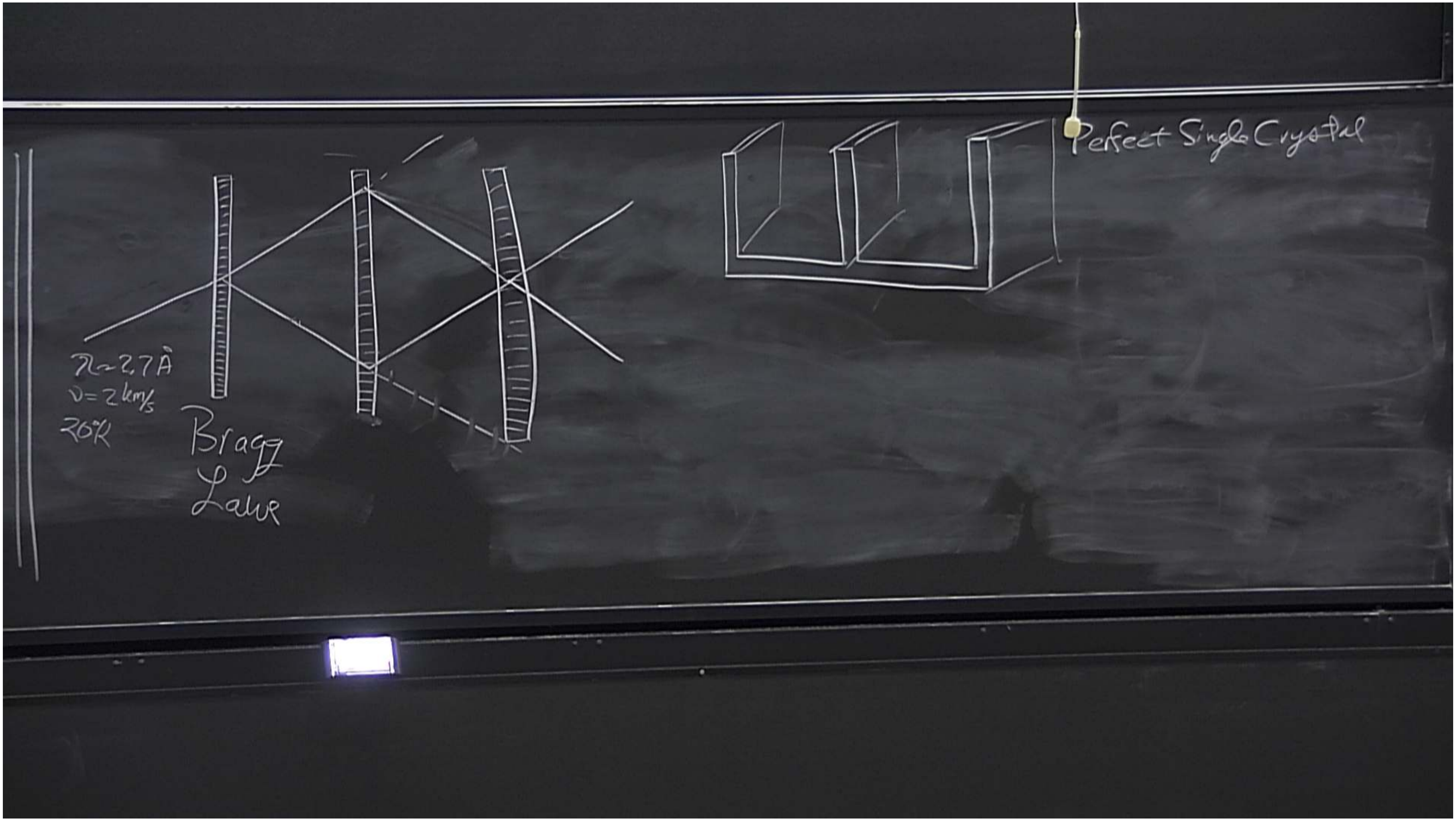

Bragg
& Laue

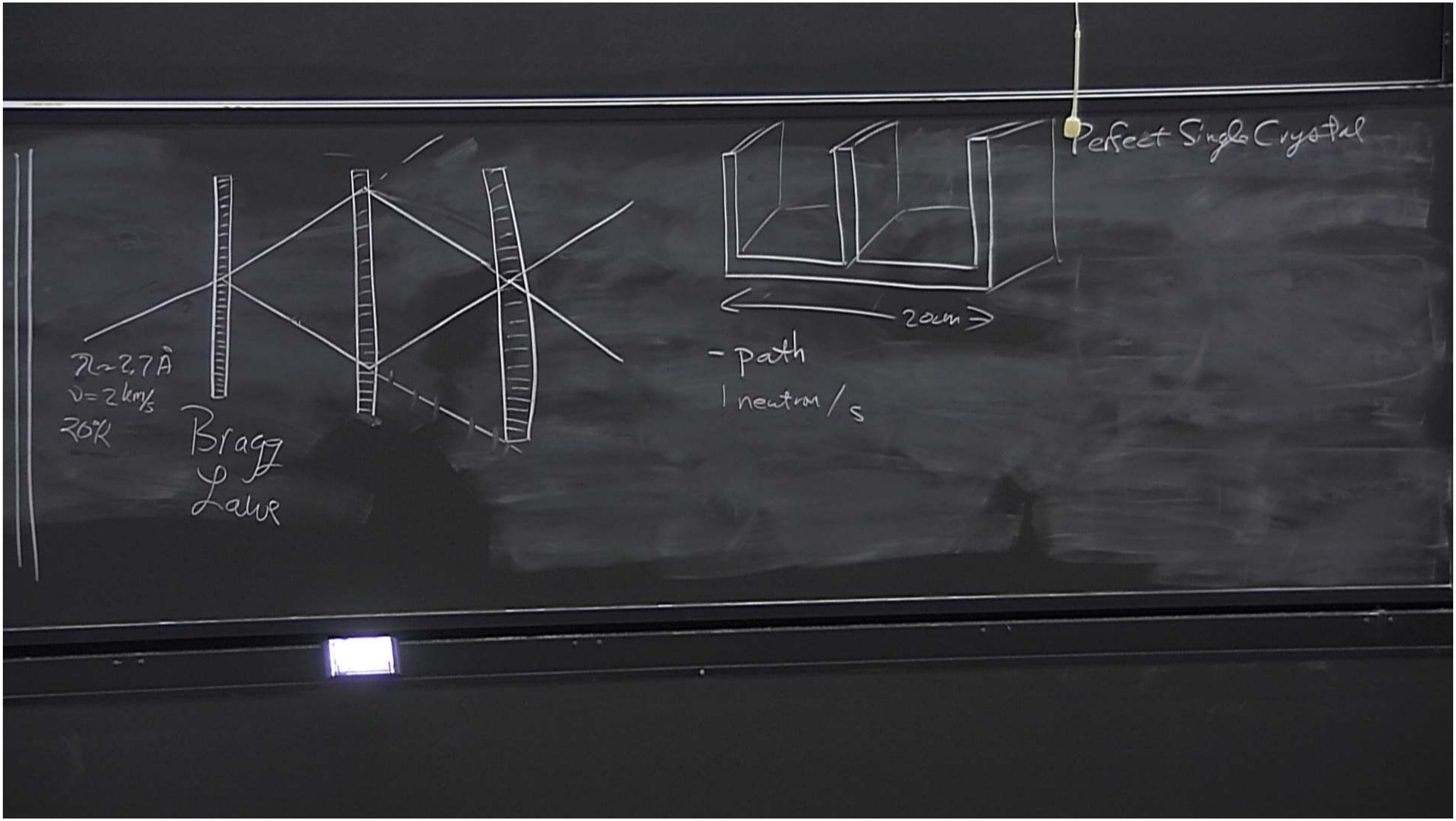

λ ≈ 2,7 Å
v = 2 km/s
20%
Bragg
&
Laue

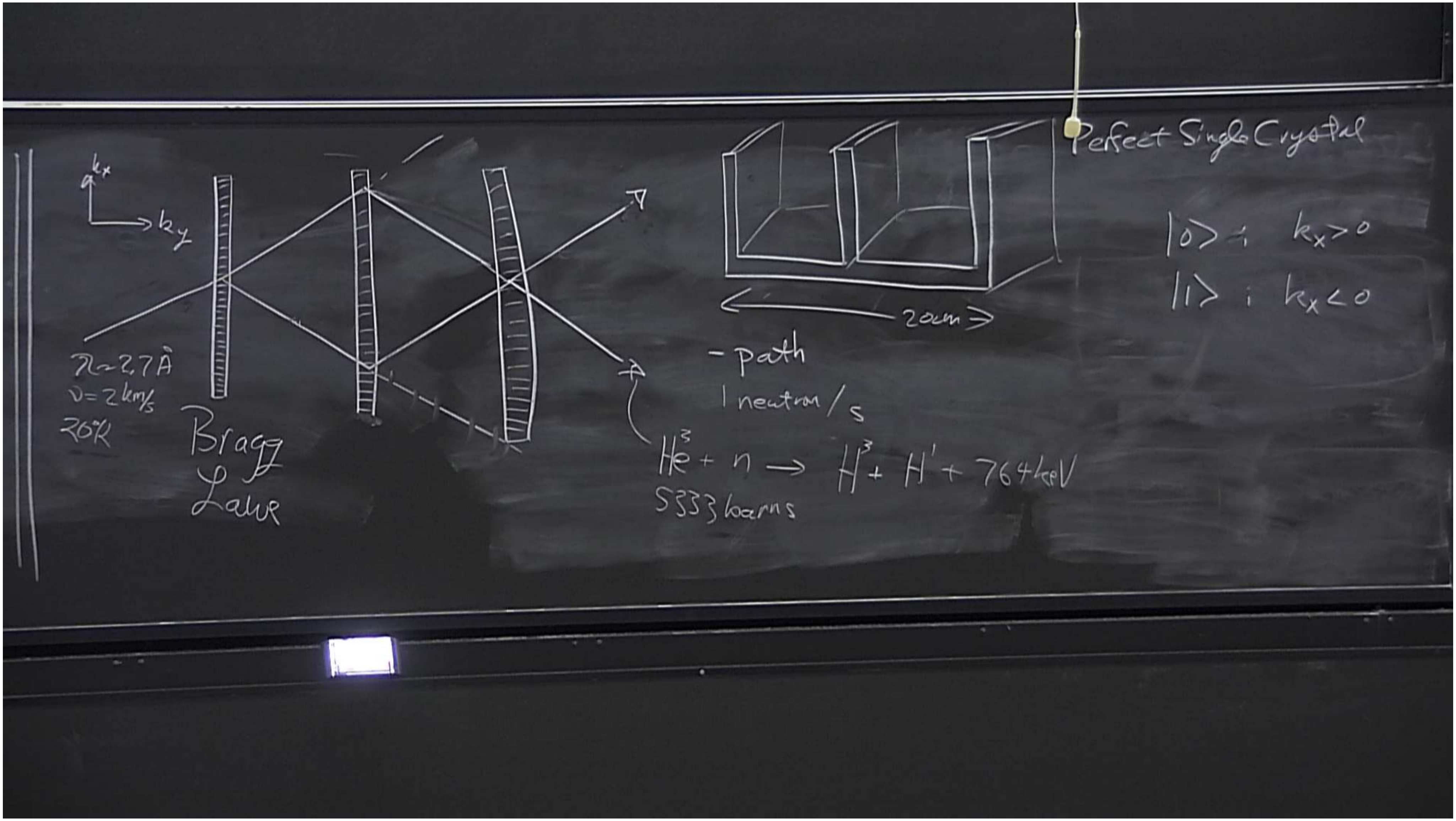

λ ≈ 2,7 Å
v = 2 km/s
20%
Bragg
Laue

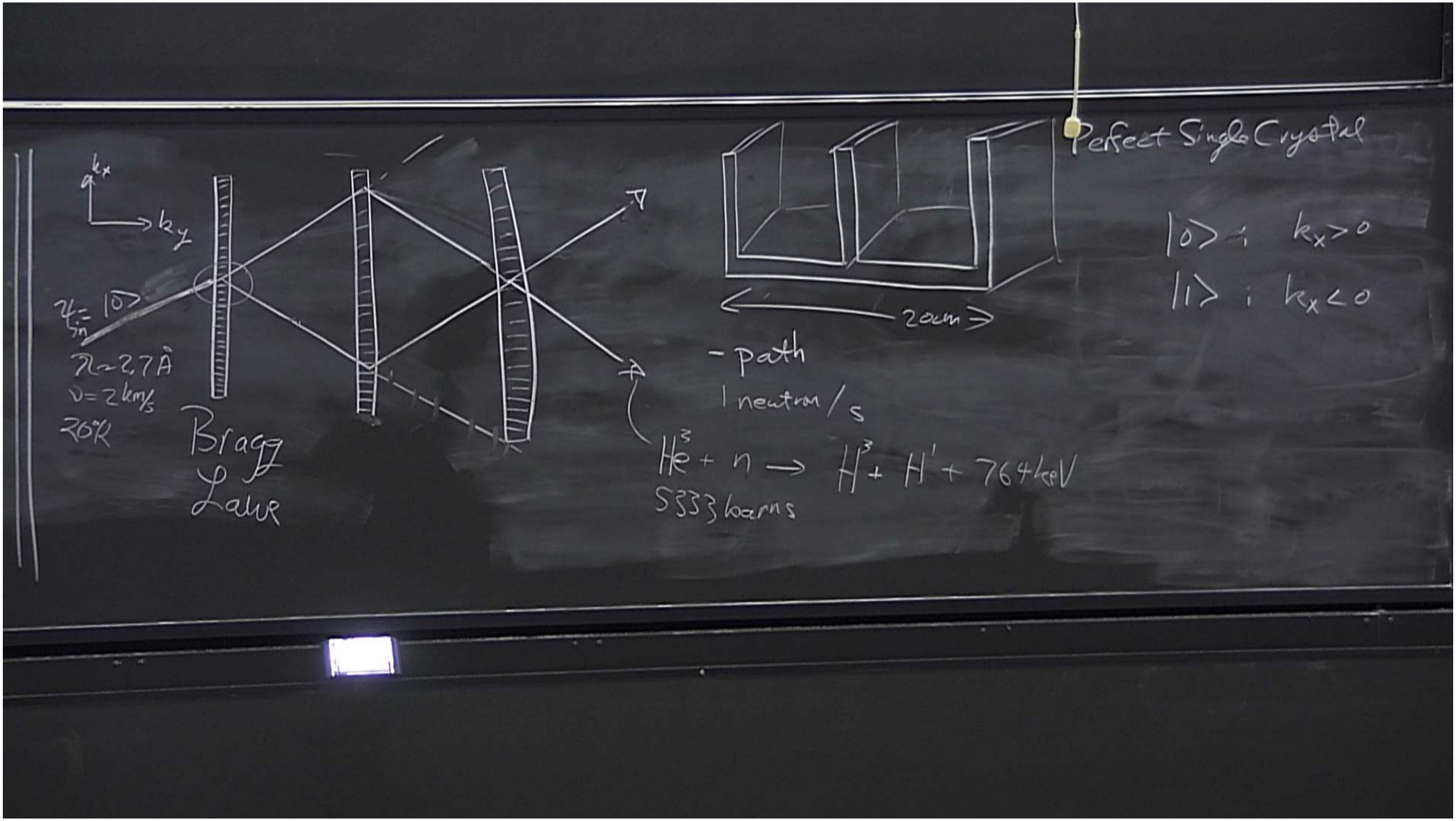

λ~2.7Å
v=2km/s
20%
Bragg
&
Laue


λ ~ 2,7 Å
v = 2 km/s
20%
Bragg
&
Laue


Perfect Single Crystal
λ≈2.7Å
v=2km/s
20%
Bragg
Laue

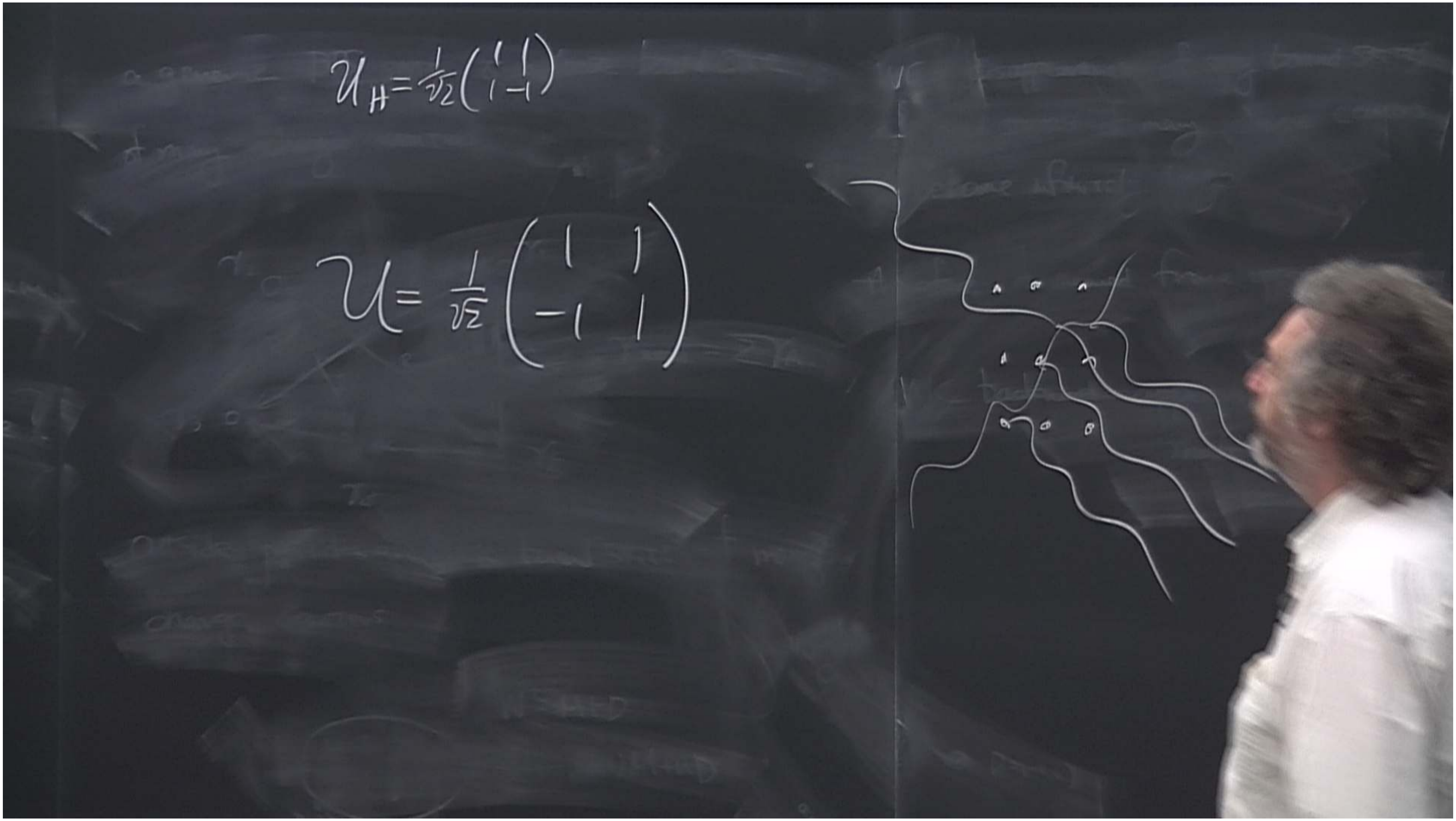

Perfect Single Crystal
λ≈2.7Å
v=2km/s
20%
Bragg
Laue
20cm
- path
1 neutron/s


Perfect Single Crystal
k_x
k_y
$\lambda \approx 2.7 Å$
$v = 2 km/s$
20%
Bragg
Laue
20cm
- path
1 neutron/s
$He^3 + n \rightarrow H^3 + H^1 + 764 keV$
5333 barns
$|0\rangle : k_x > 0$
$|1\rangle : k_x < 0$



Perfect Single Crystal
k_x
k_y
$\psi_{in} = |0\rangle$
$\lambda \approx 2.7$ Å
$v = 2$ km/s
20%
Bragg
Laue
20cm
- path
1 neutron/s
$He^3 + n \rightarrow H^3 + H^1 + 764$ keV
5333 barns
$|0\rangle$; $k_x > 0$
$|1\rangle$; $k_x < 0$

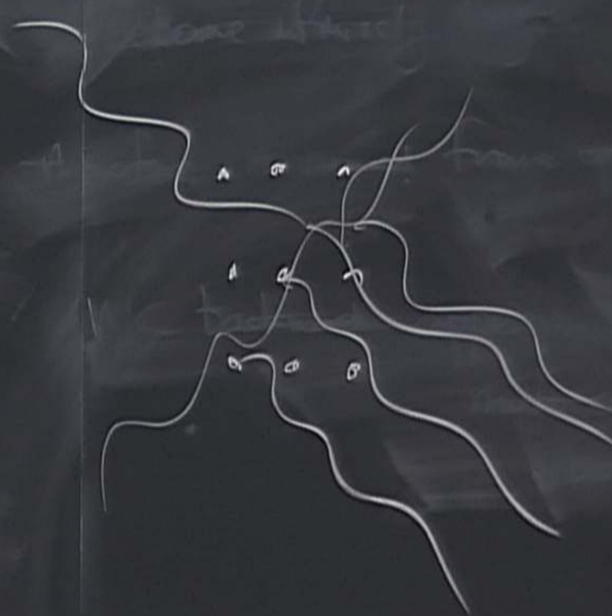
$$\mathcal{U} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}$$

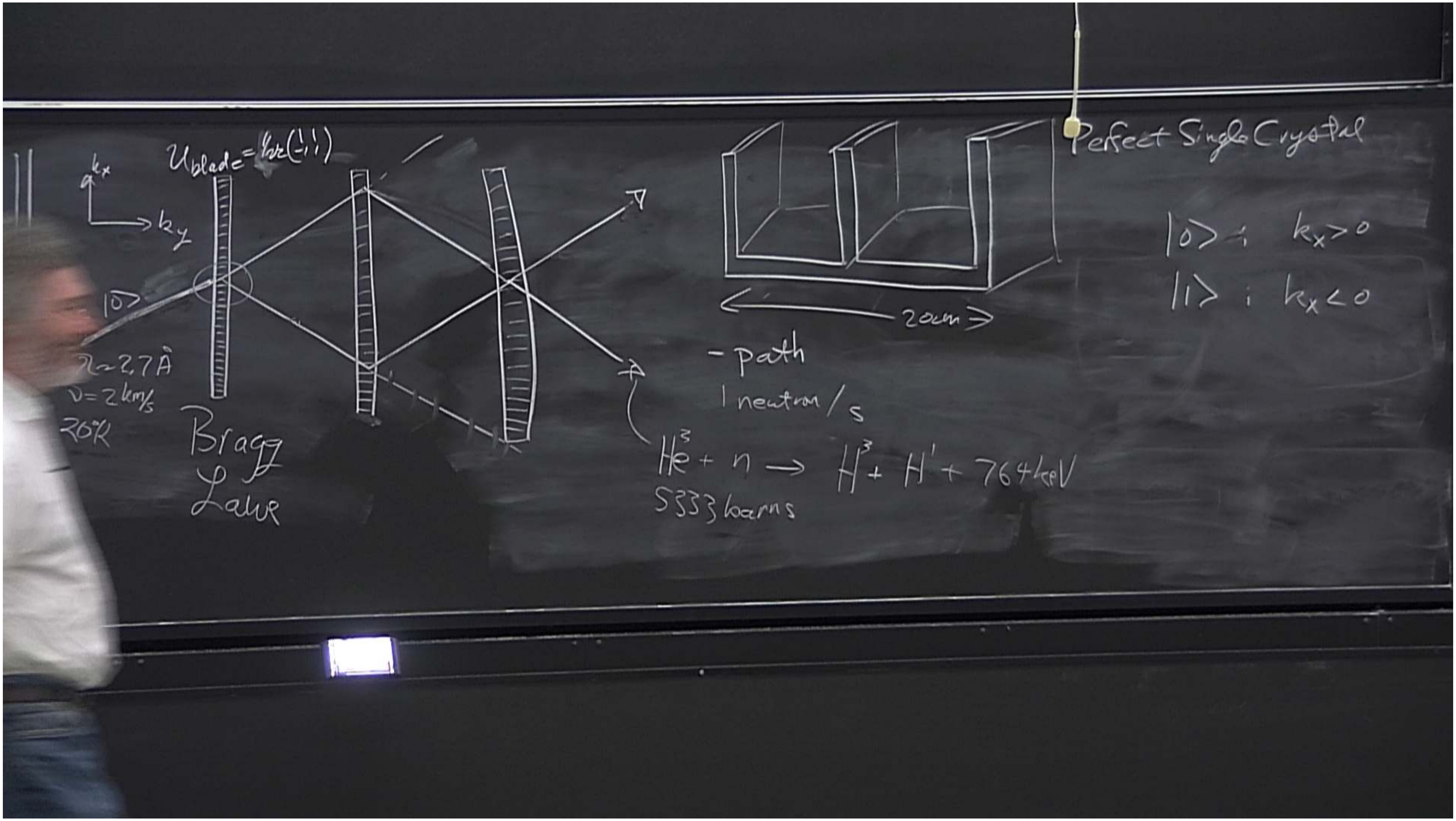

$\mathcal{U}_H = \frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix}$
$\mathcal{U} = \frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ -1 & 1\end{pmatrix}$

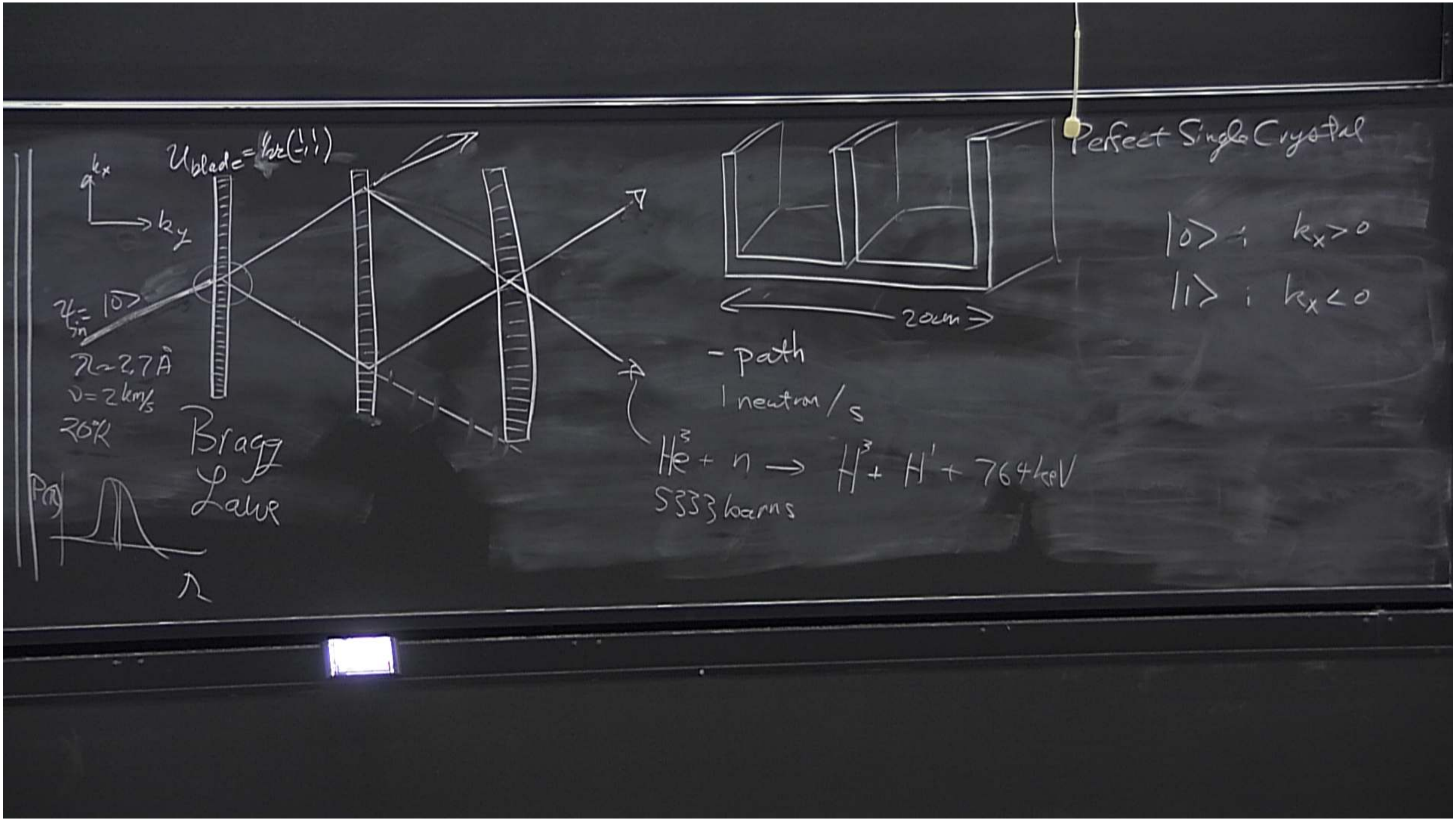
$$U_H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$U = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}$$

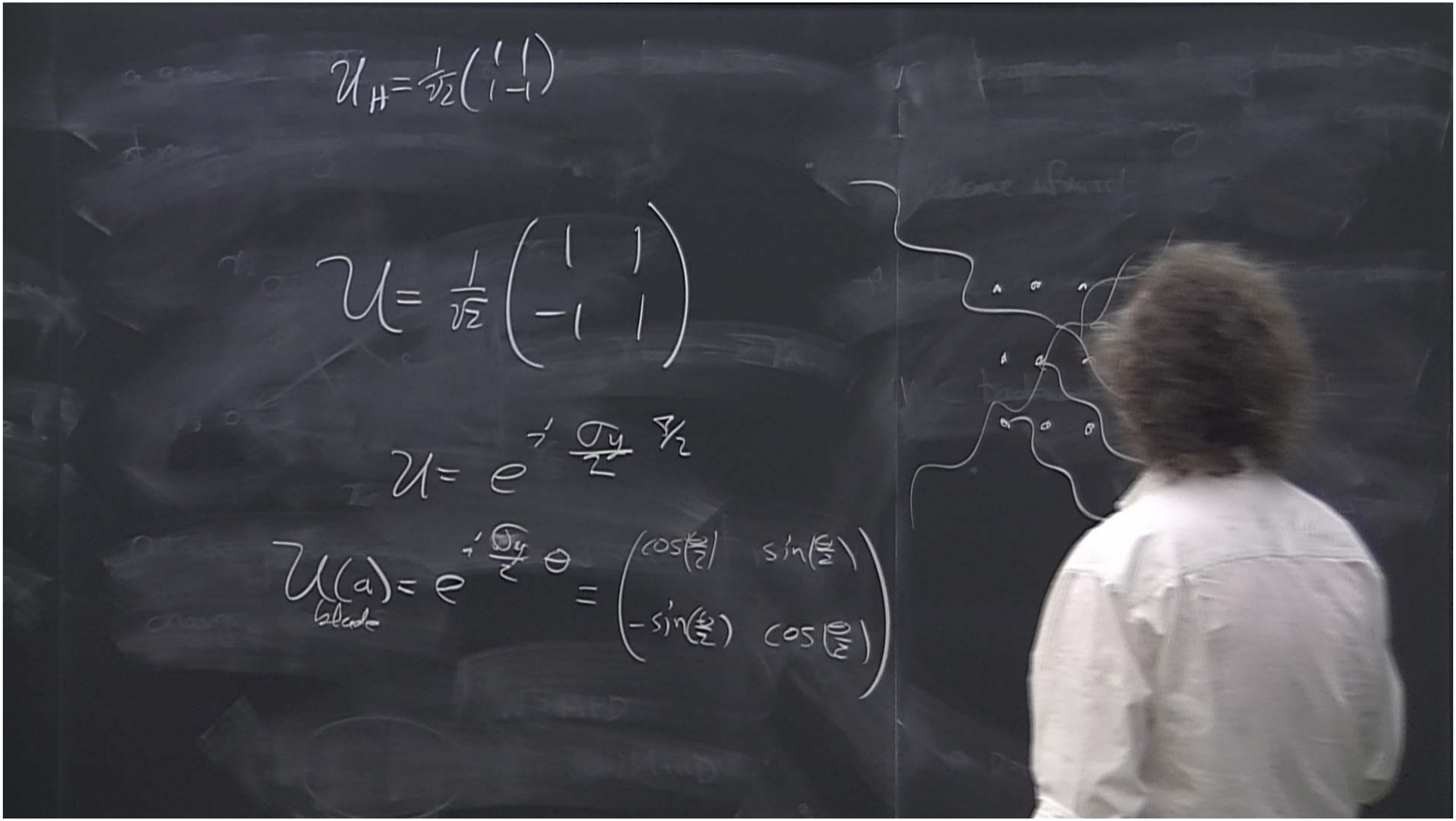
$$U = e^{-i \frac{\sigma_y}{2} \pi/2}$$

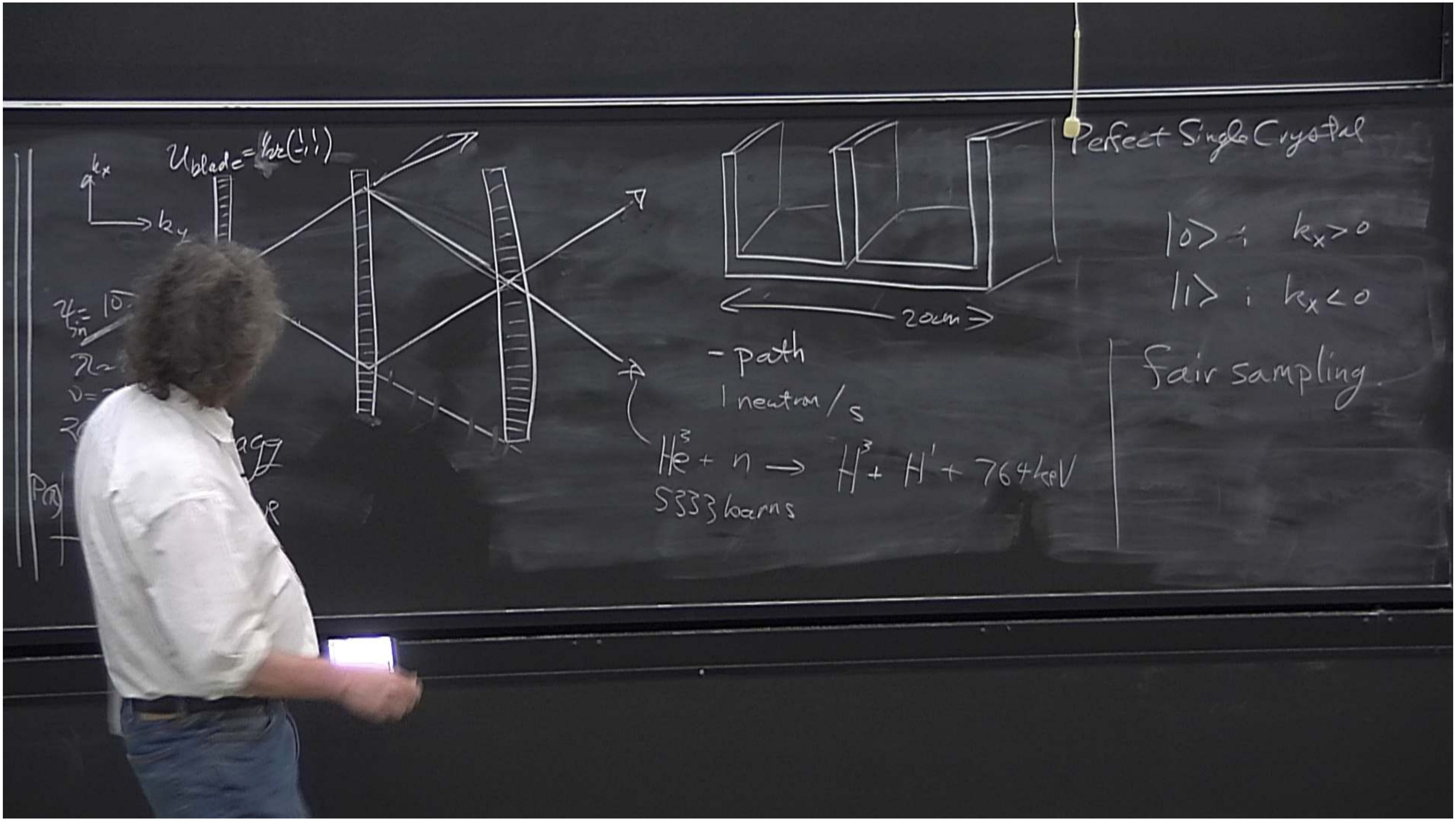


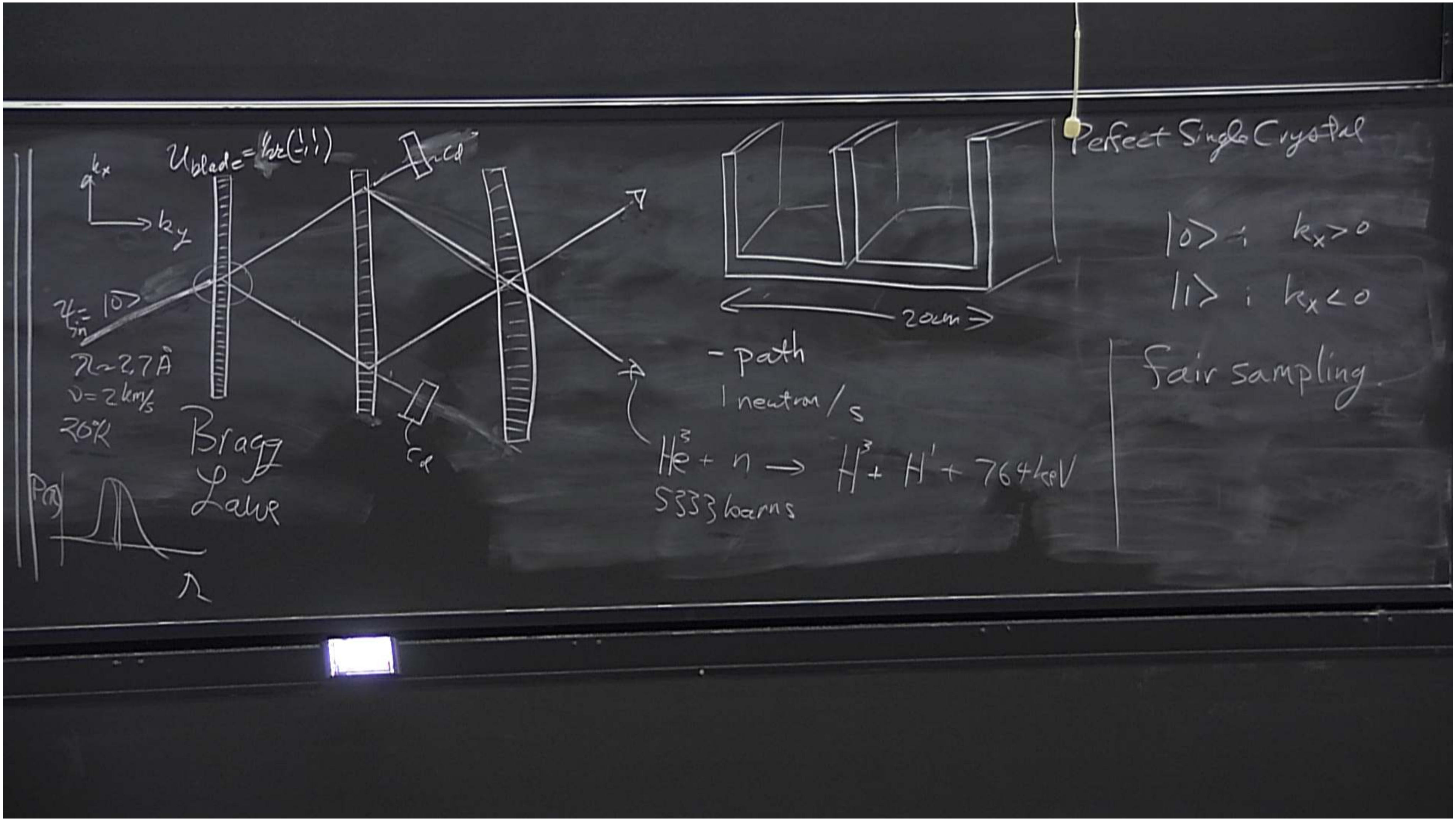

Perfect Single Crystal
$u_{blade} = \frac{1}{\sqrt{2}}\begin{pmatrix}1 & i \\ i & 1\end{pmatrix}$
k_x
k_y
$|0\rangle$
$\lambda \approx 2.7 Å$
$v = 2$ km/s
20%
Bragg
Laue
20cm
- path
1 neutron / s
$He^3 + n \rightarrow H^3 + H^1 + 764$ keV
5333 barns
$|0\rangle$: $k_x > 0$
$|1\rangle$: $k_x < 0$

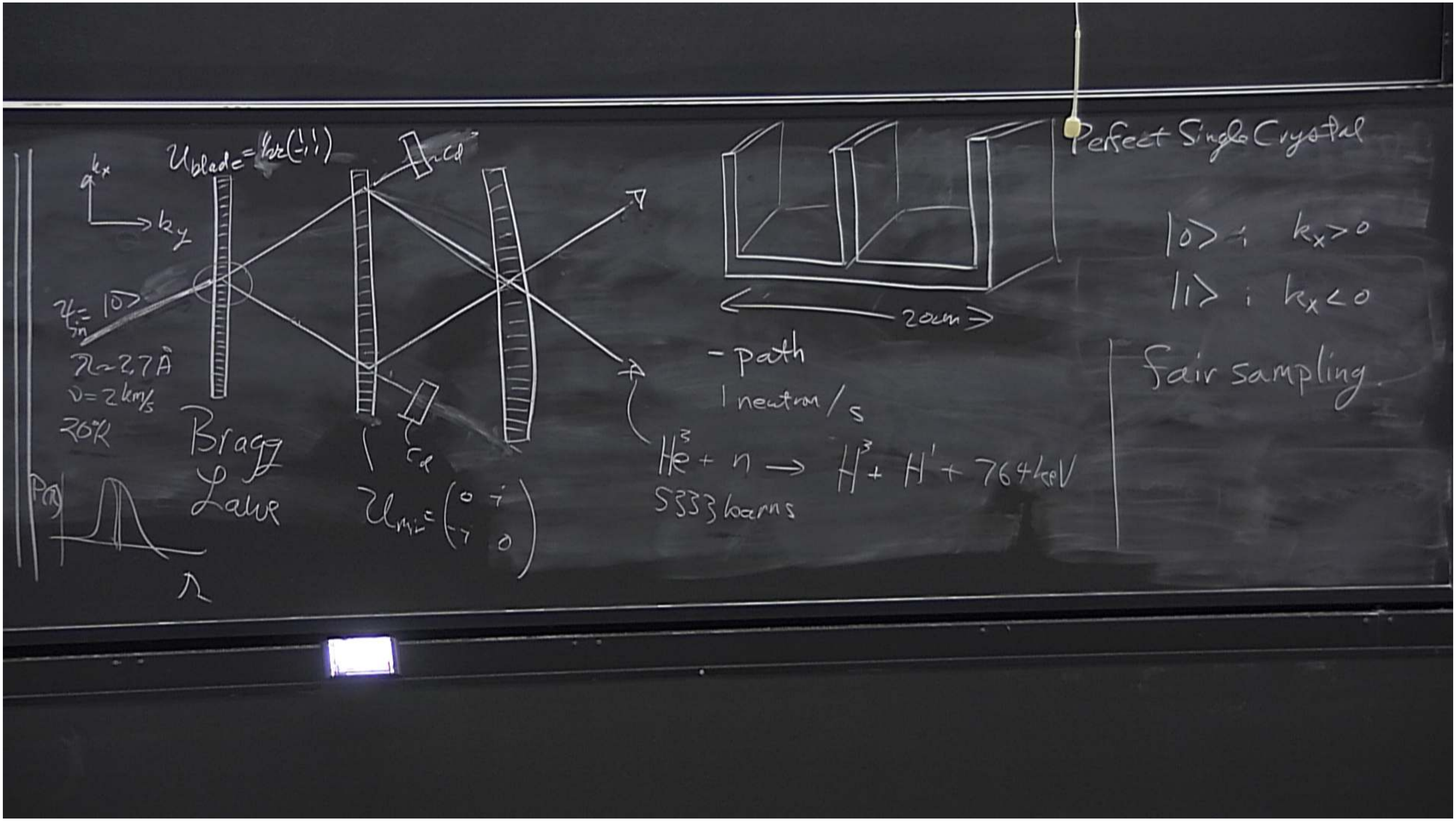


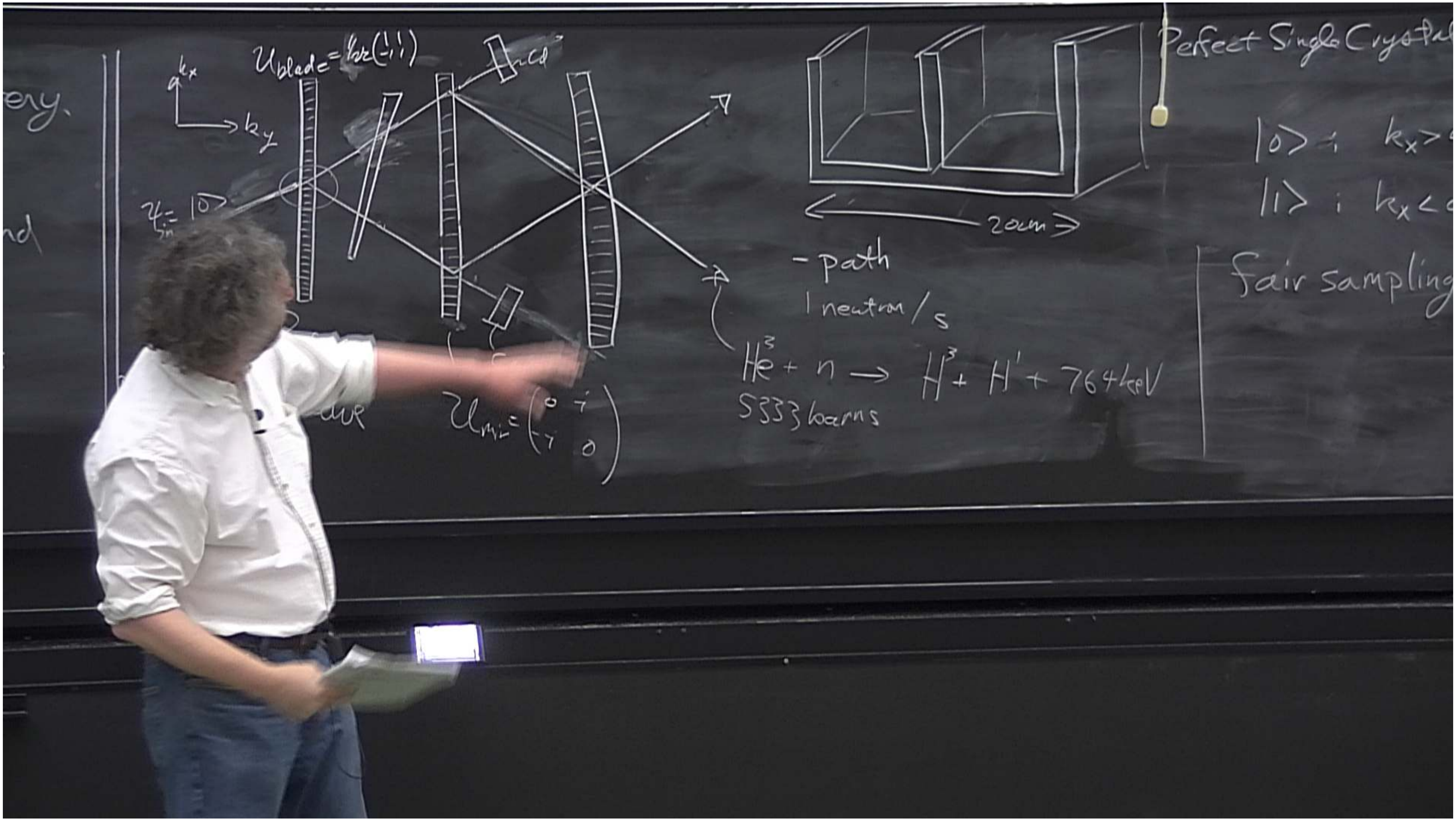
Perfect Single Crystal
$U_{blade} = \frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ -1 & 1\end{pmatrix}$
k_x
k_y
$\psi_{in} = |0\rangle$
$\lambda \approx 2.7$ Å
$v = 2$ km/s
20%
$P(\lambda)$
λ
Bragg
Laue
20cm
- path
1 neutron/s
$He^3 + n \rightarrow H^3 + H^1 + 764$ keV
5333 barns
$|0\rangle$: $k_x > 0$
$|1\rangle$: $k_x < 0$

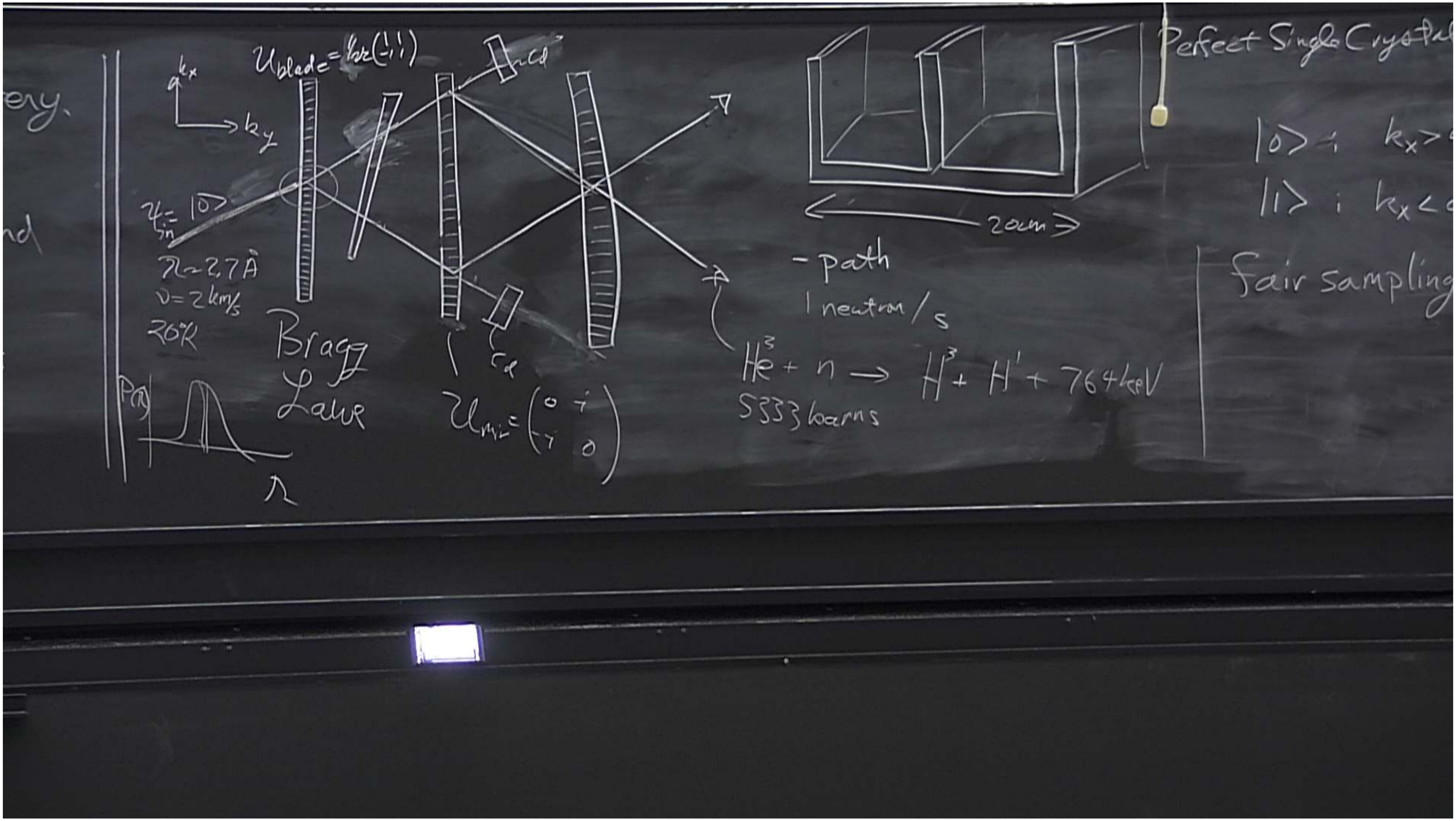

$U_H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$
$U = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}$
$U = e^{i \frac{\sigma_y}{2} \pi/2}$
$U(a) = e^{i \frac{\sigma_y}{2} \theta} = \begin{pmatrix} \cos(\frac{\theta}{2}) & \sin(\frac{\theta}{2}) \\ -\sin(\frac{\theta}{2}) & \cos(\frac{\theta}{2}) \end{pmatrix}$
blade


Perfect Single Crystal
20cm
- path
1 neutron/s
He3 + n → H3 + H1 + 764keV
5333 barns
|0> : kx>0
|1> : kx<0
fair sampling


Perfect Single Crystal
k_x
k_y
$U_{blade} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & i \\ i & 1 \end{pmatrix}$
Cd
$\psi_{in} = |0\rangle$
$\lambda \approx 2.7$ Å
$v = 2$ km/s
20%
Bragg
Laue
$P(\lambda)$
λ
Cd
20cm
- path
1 neutron/s
$He^3 + n \rightarrow H^3 + H^1 + 764$ keV
5333 barns
$|0\rangle$; $k_x > 0$
$|1\rangle$; $k_x < 0$
fair sampling


Perfect Single Crystal
|0> : kx > 0
|1> : kx < 0
fair sampling
20cm
- path
1 neutron/s
He + n → H + H + 764 keV
5333 barns
Bragg
Laue
2,7 Å
v = 2 km/s
20%
Cd


Perfect Single Crys
20cm
- path
1 neutron/s
fair sampling
He3 + n → H3 + H1 + 764 keV
5333 barns


Perfect Single Crystal
20cm
- path
1 neutron/s
5333 barns
Bragg
Laue
v = 2 km/s
20%
fair sampling

$$\mathcal{U}_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = \underbrace{e^{i\phi_1}}_{\text{global}} \begin{pmatrix} e^{i\overbrace{(\phi_0-\phi_1)}^{\Delta\phi}} & 0 \\ 0 & 1 \end{pmatrix}$$

$$U_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = \underbrace{e^{i\phi_1}}_{\text{global}} \begin{pmatrix} e^{\overbrace{i(\phi_0-\phi_1)}^{\Delta\phi}} & 0 \\ 0 & 1 \end{pmatrix}$$

$$U_{mix}\, U_{phase}\, U_{global} |\psi_{in}\rangle$$

$$\mathcal{U}_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = \underbrace{e^{i\phi_1}}_{\text{global}} \begin{pmatrix} \underbrace{e^{i(\phi_0-\phi_1)}}_{\Delta\phi} & 0 \\ 0 & 1 \end{pmatrix}$$

$$\mathcal{U}_{blade3}\,\mathcal{U}_{mir}\,\mathcal{U}_{phase}\,\mathcal{U}_{blade1}\,|\psi_{in}\rangle$$

$$\mathcal{U}_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = \underbrace{e^{i\phi_1}}_{\text{global}} \begin{pmatrix} \underbrace{e^{i(\phi_0-\phi_1)}}_{\Delta\phi} & 0 \\ 0 & 1 \end{pmatrix}$$

$$\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}$$

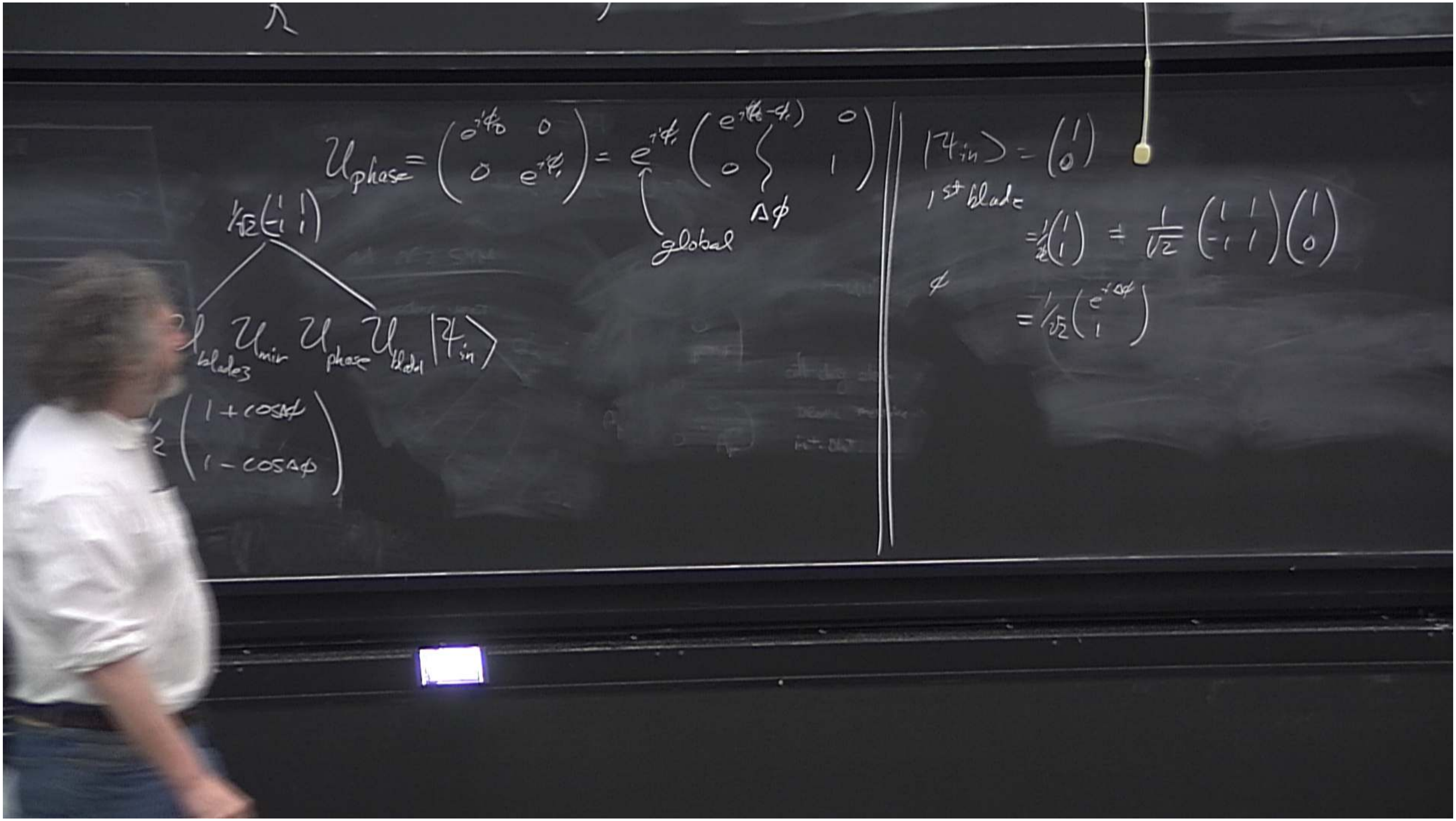
$$|\psi_{out}\rangle = \mathcal{U}_{blade3}\,\mathcal{U}_{mir}\,\mathcal{U}_{phase}\,\mathcal{U}_{blade1}\,|\psi_{in}\rangle$$

$$\mathcal{U}_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = \underbrace{e^{i\phi_1}}_{global} \begin{pmatrix} e^{i(\phi_0-\phi_1)} & 0 \\ 0 & 1 \end{pmatrix}$$

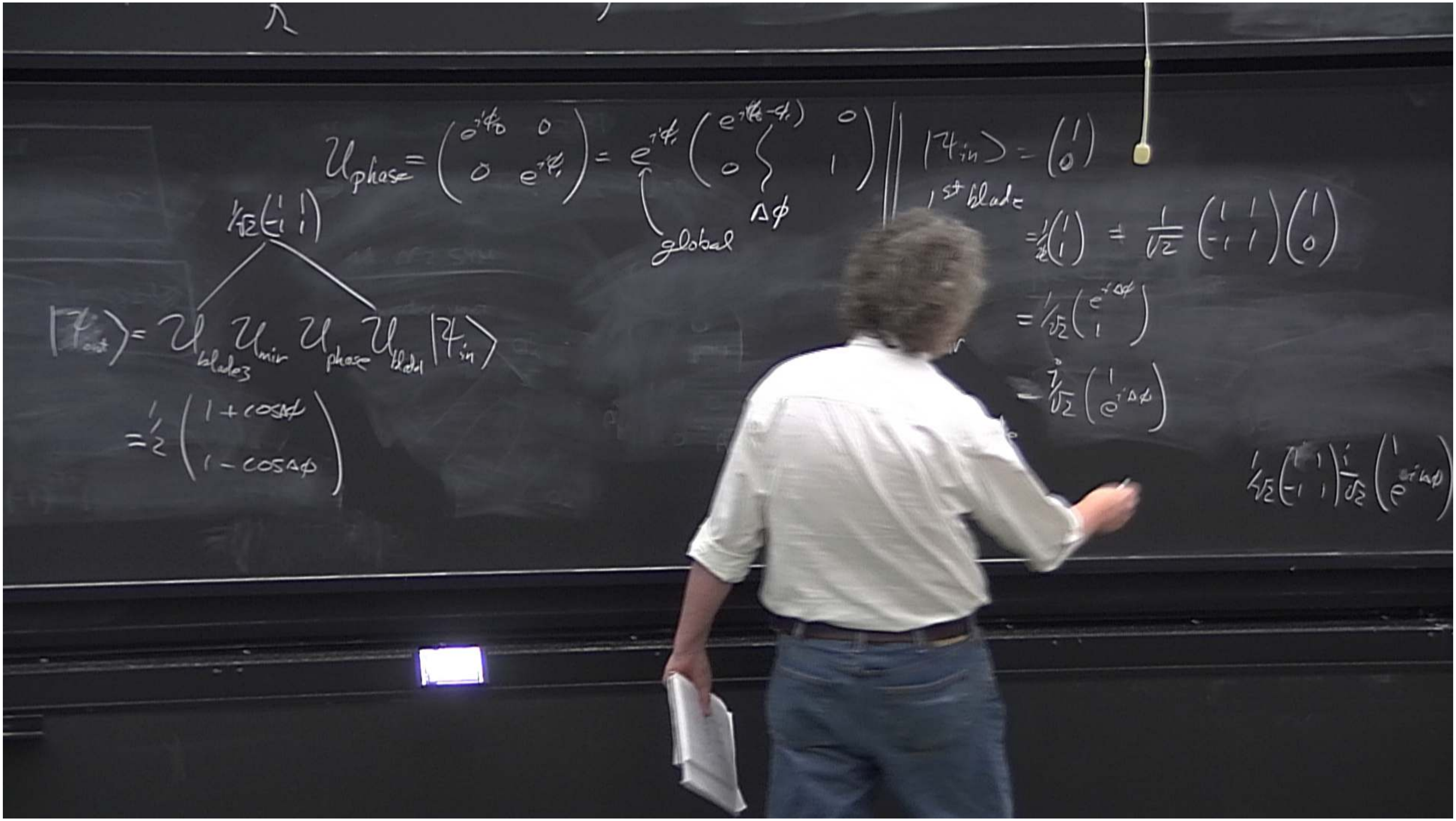
$$e^{i(\phi_0-\phi_1)}: \quad \Delta\phi$$

$$|\psi_{out}\rangle = \underbrace{\mathcal{U}_{blade 3}\,\mathcal{U}_{mir}\,\mathcal{U}_{phase}\,\mathcal{U}_{blade 1}}_{\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -i & i \end{pmatrix}} |\psi_{in}\rangle$$

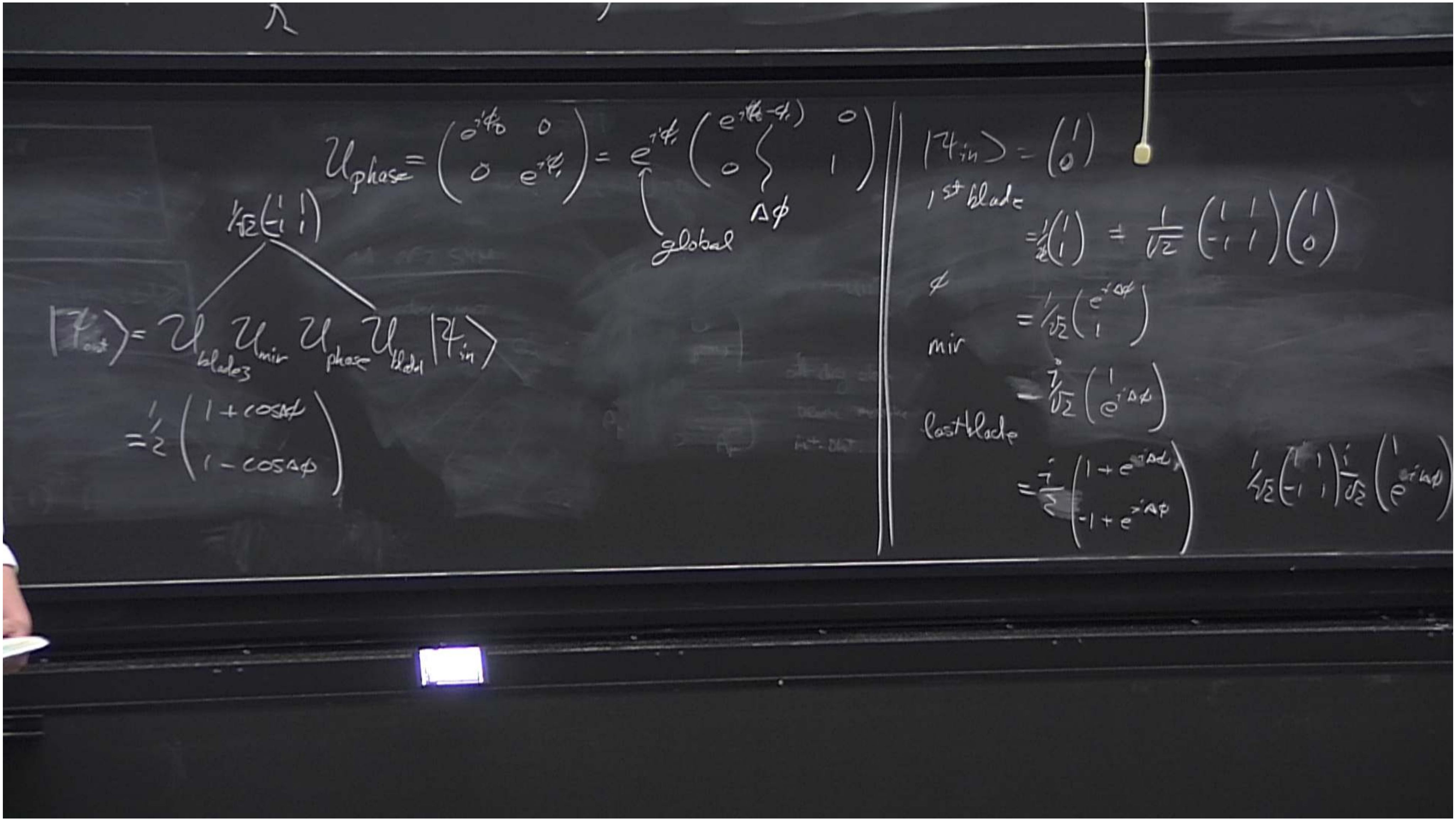
$$= \frac{1}{2}\begin{pmatrix} 1+\cos\Delta\phi \\ 1-\cos\Delta\phi \end{pmatrix}$$



$\mathcal{U}_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = e^{i\phi_1} \begin{pmatrix} e^{i(\phi_0-\phi_1)} & 0 \\ 0 & 1 \end{pmatrix}$
global
$\Delta\phi$
$\mathcal{U}_{blade3}\, \mathcal{U}_{mir}\, \mathcal{U}_{phase}\, \mathcal{U}_{blade1} |\psi_{in}\rangle$
$\begin{pmatrix} 1+\cos\Delta\phi \\ 1-\cos\Delta\phi \end{pmatrix}$
$|\psi_{in}\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$
1st blade
$= \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix}$
ϕ
$= \frac{1}{\sqrt{2}} \begin{pmatrix} e^{i\Delta\phi} \\ 1 \end{pmatrix}$



U_phase = (e^{iφ0} 0 ; 0 e^{iφ1}) = e^{iφ1} (e^{i(φ0−φ1)} 0 ; 0 1)
global
Δφ
|ψ_in> = (1 ; 0)
1st blade
1/√2 (1 ; 1) = 1/√2 (1 1 ; −1 1) (1 ; 0)
= 1/√2 (e^{iΔφ} ; 1)
|ψ_out> = U_blade3 U_mir U_phase U_blade1 |ψ_in>
= 1/2 (1 + cosΔφ ; 1 − cosΔφ)



U_phase = (e^{iφ0} 0 / 0 e^{iφ1}) = e^{iφ1} (e^{i(φ0-φ1)} 0 / 0 1)
global
Δφ
|ψ_out> = U_blade3 U_mir U_phase U_blade1 |ψ_in>
= 1/2 (1 + cosΔφ / 1 − cosΔφ)
|ψ_in> = (1 / 0)
1st blade
φ
mir
last blade

$$\mathcal{U}_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = \underbrace{e^{i\phi_1}}_{\text{global}} \begin{pmatrix} e^{\overbrace{i(\phi_0-\phi_1)}^{\Delta\phi}} & 0 \\ 0 & 1 \end{pmatrix}$$

$$\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -i & i \end{pmatrix}$$

$$|\psi_{out}\rangle = \mathcal{U}_{blade3}\,\mathcal{U}_{mir}\,\mathcal{U}_{phase}\,\mathcal{U}_{blade1}\,|\psi_{in}\rangle$$

O-detector ($+k_x$ detector) : $\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$

H-detector ($-k_x$ detector) : $\begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$

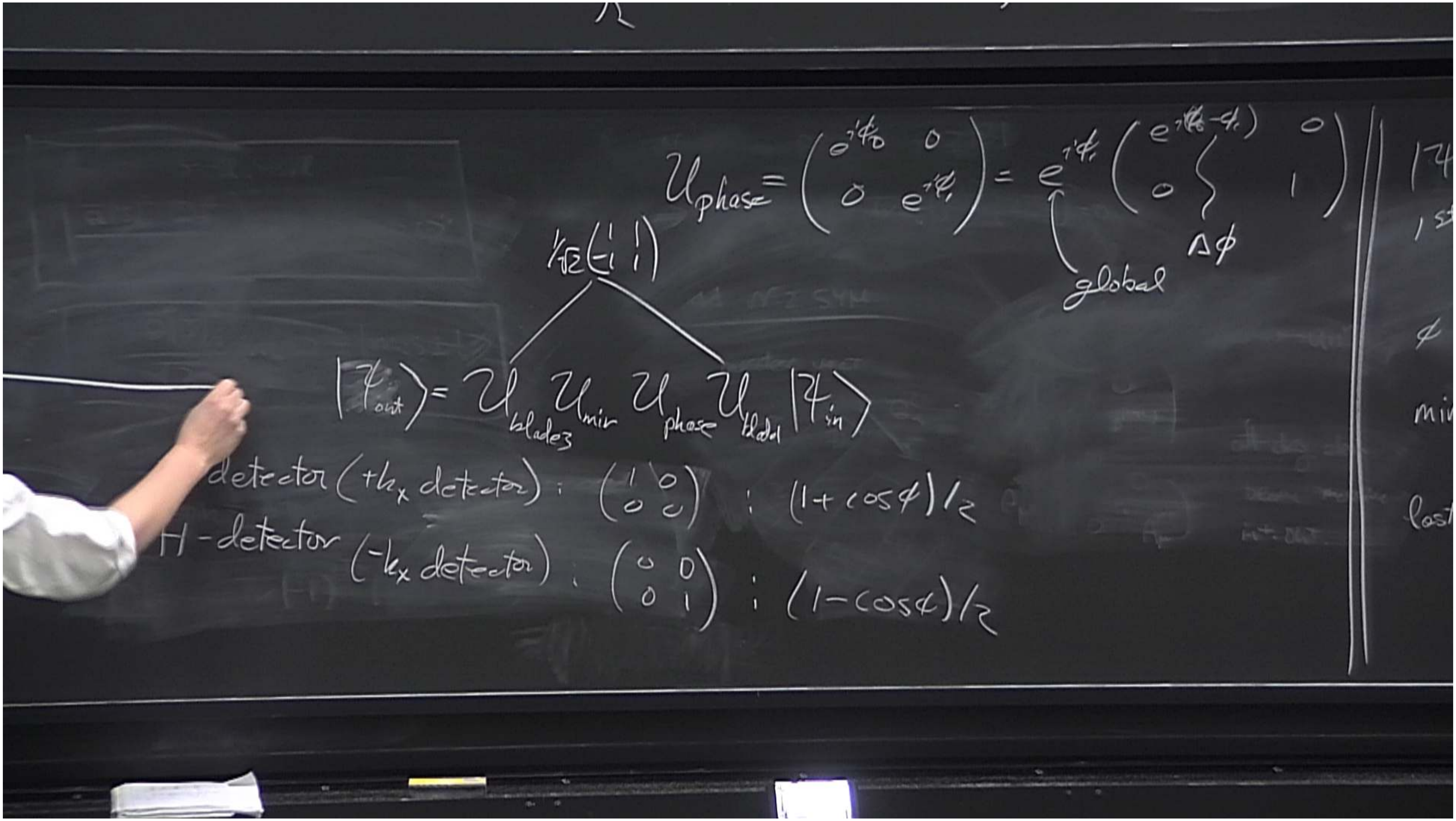
$|\psi$

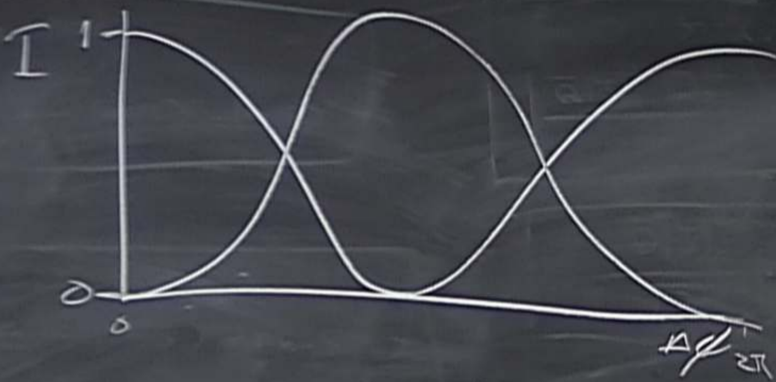
, st

ϕ

mi

las


$\mathcal{U}_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = e^{i\phi_1} \begin{pmatrix} e^{i(\phi_0-\phi_1)} & 0 \\ 0 & 1 \end{pmatrix}$
global
$\Delta\phi$
$\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & i \\ -i & 1 \end{pmatrix}$
$|\psi_{out}\rangle = \mathcal{U}_{blade3}\,\mathcal{U}_{mir}\,\mathcal{U}_{phase}\,\mathcal{U}_{blade1}\,|\psi_{in}\rangle$
detector ($+k_x$ detector) : $\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$: $(1+\cos\phi)/2$
H-detector ($-k_x$ detector) : $\begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$: $(1-\cos\phi)/2$



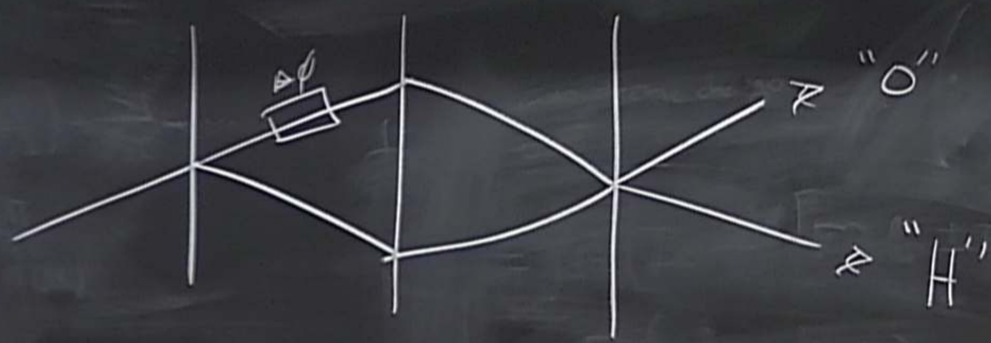
$$\mathcal{U}_{phase} = \begin{pmatrix} e^{i\phi_0} & 0 \\ 0 & e^{i\phi_1} \end{pmatrix} = e^{i}$$

$$\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}$$

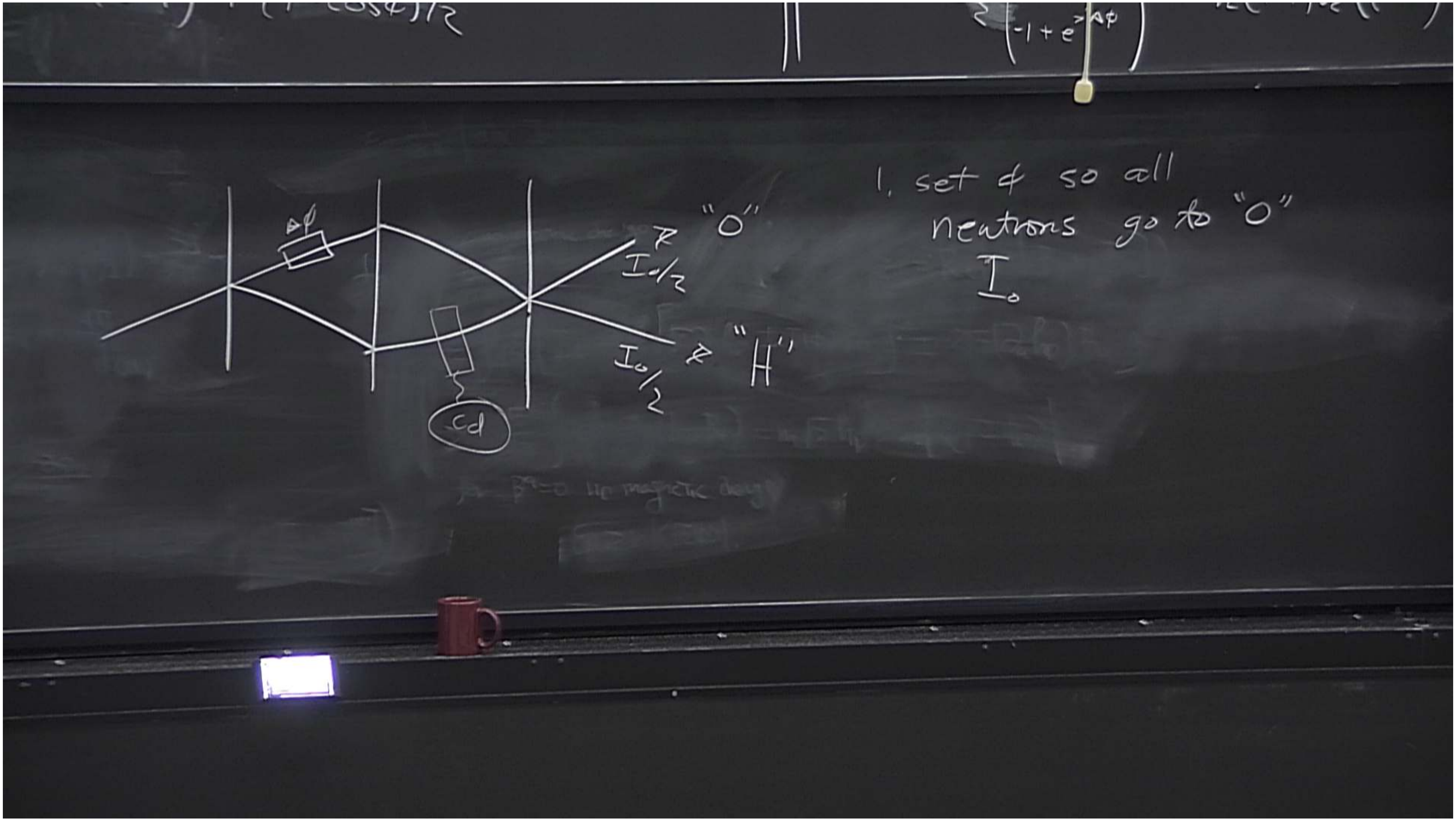
$$|\psi_{out}\rangle = \mathcal{U}_{blade3}\,\mathcal{U}_{mir}\,\mathcal{U}_{phase}\,\mathcal{U}_{blade1}\,|\psi_{in}\rangle$$

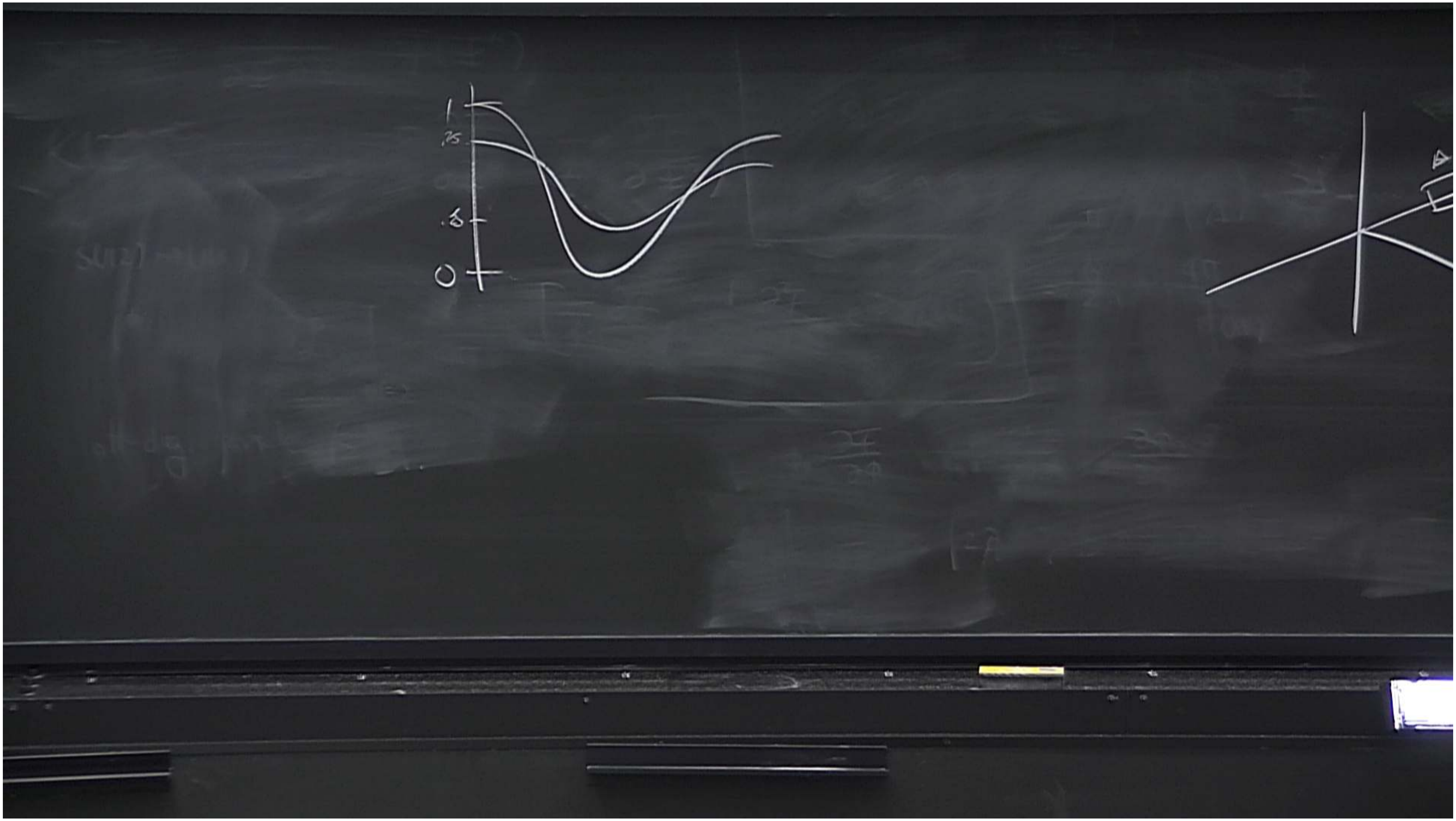
O-detector ($+k_x$ detector) : $\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$: $(1+\cos\phi)/2$

H-detector ($-k_x$ detector) : $\begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$: $(1-\cos\phi)/2$



1, set φ so all neutrons go to "O"


Δφ
"O"
I₀/2
"H"
I₀/2
Cd
1. set φ so all
neutrons go to "O"
I₀


1
.75
.5
0

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Mon 10:04 AM dcory

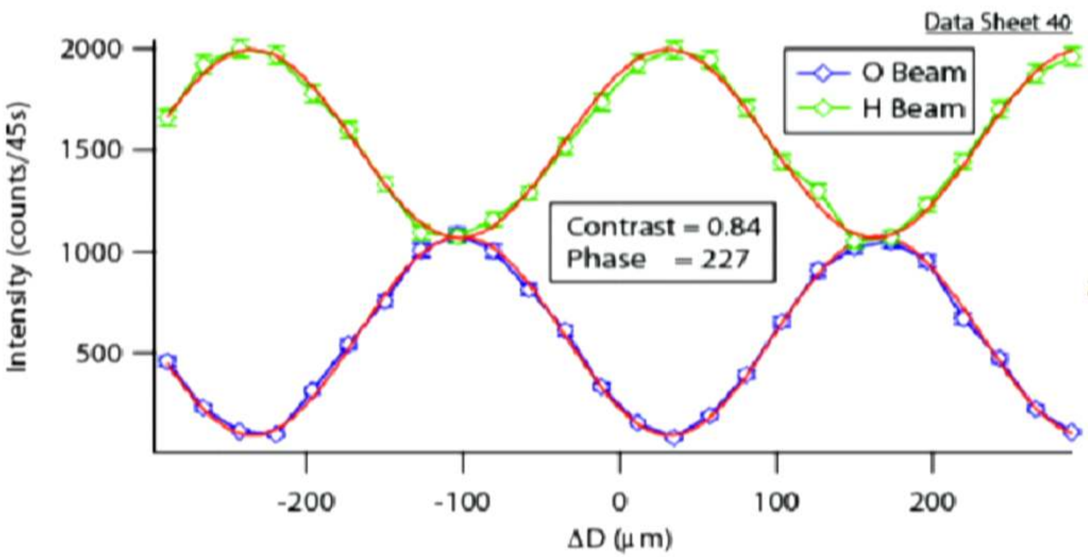
QE Lec 1.cdf

In[84]:= `Simplify[M1O[a] + M1H[a]]`

Out[84]= 1

- Problem 11: Here is a set of experimental data. The horizontal axis is given in terms of the difference in path length of silica blades placed in the two paths. What width of silica corresponds to a π phase shift in this experiment? Suggest a few possible reasons for the differences between the experiment and theory. We will explore some of these next.

In[85]:=



;

Note, all of the data on neutron interferometry was collected by Dr. Dmitry Pushin with the NIST setup.