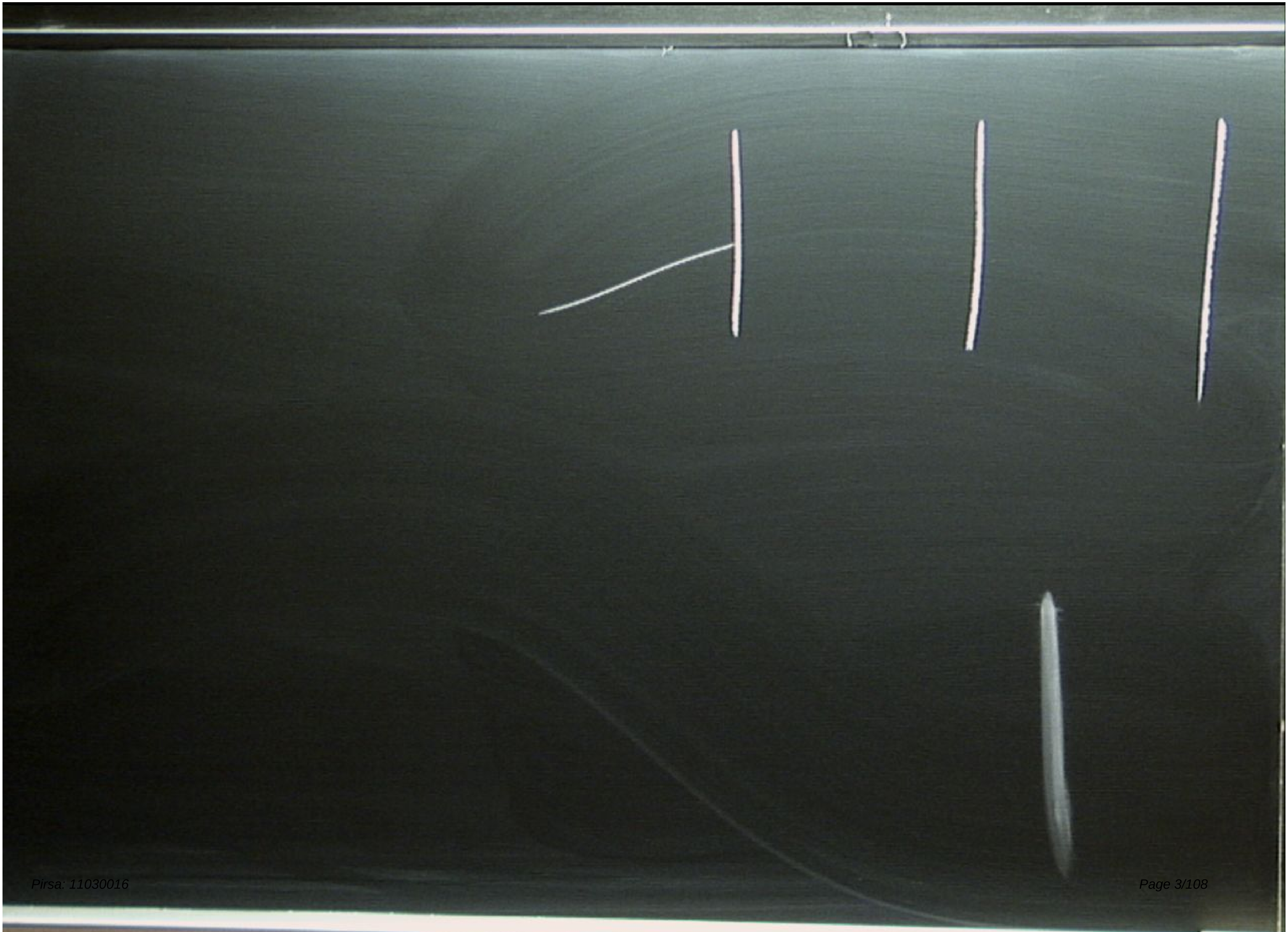
Title: Explorations in Quantum Information - Lecture 5

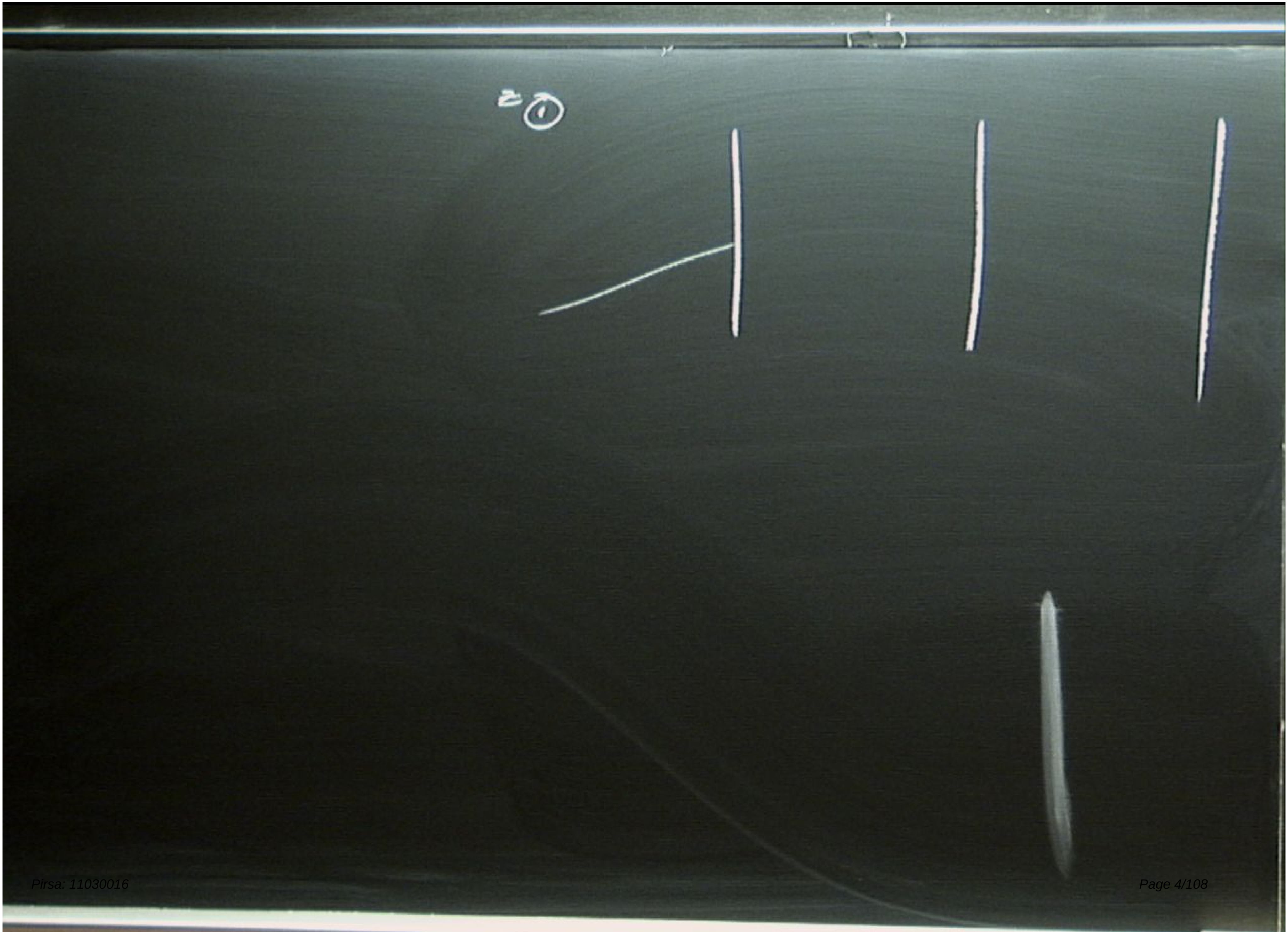
Date: Mar 18, 2011 09:00 AM

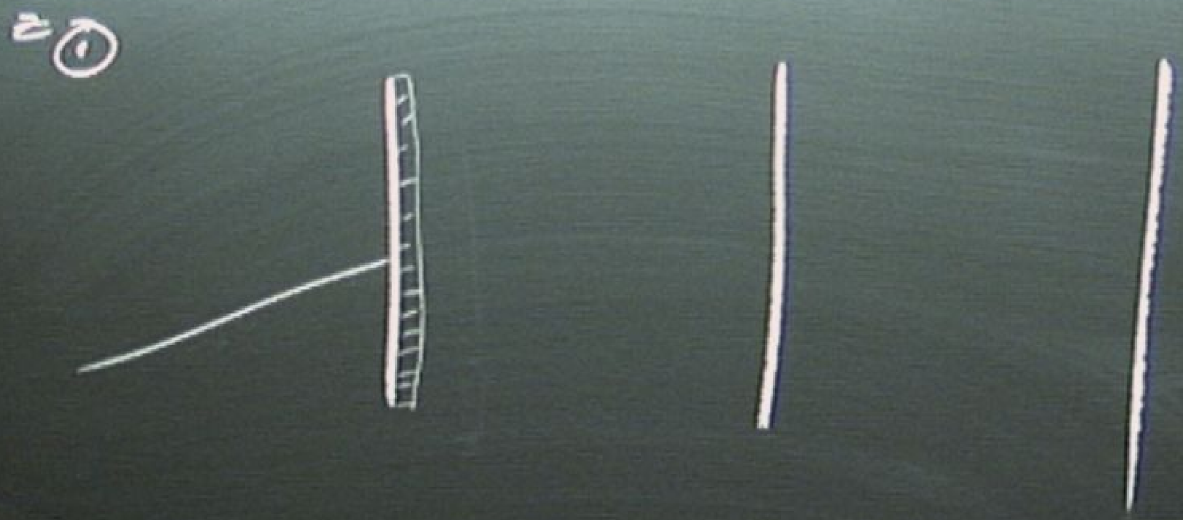
URL: http://pirsa.org/11030016

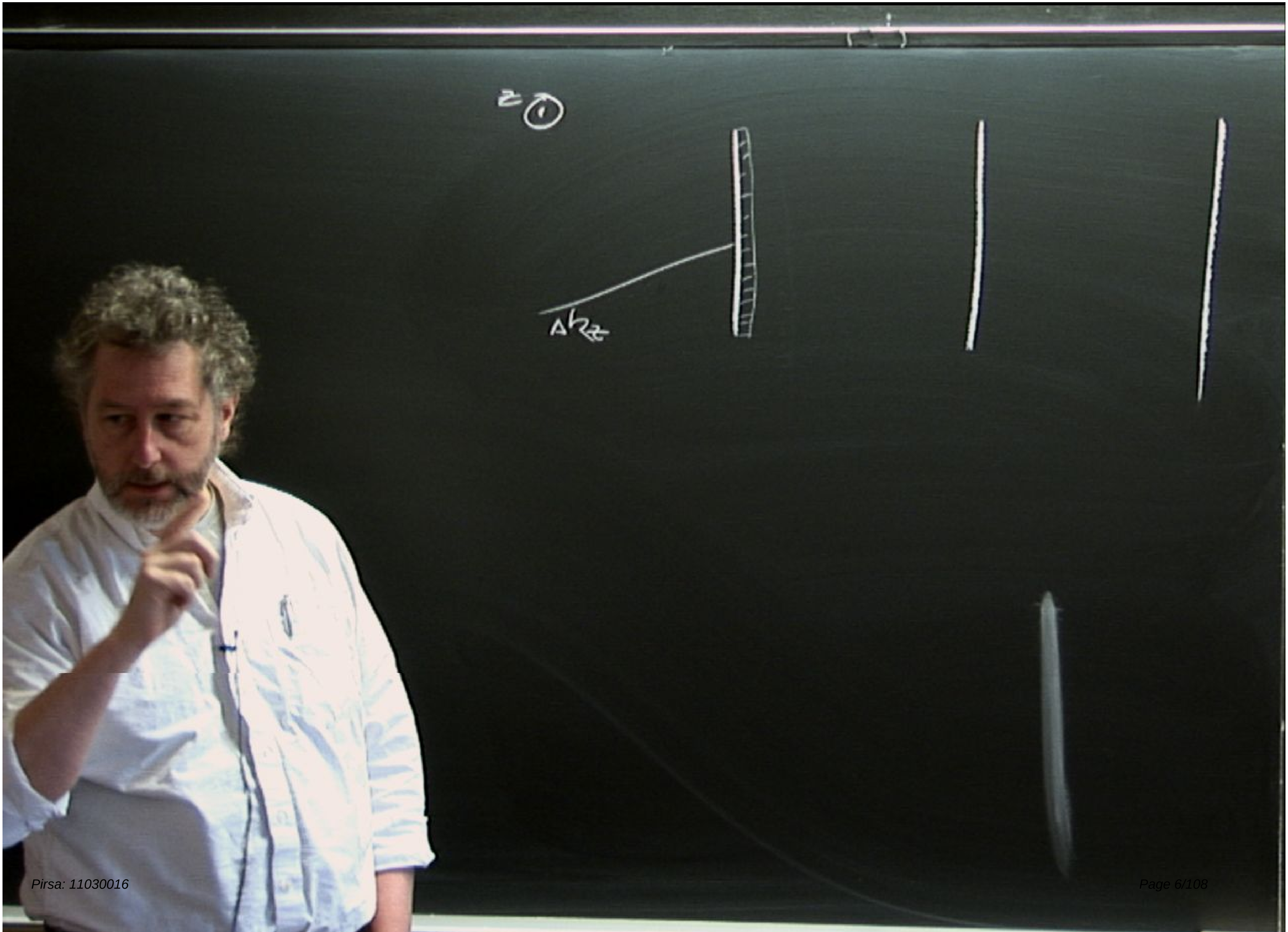
Abstract:

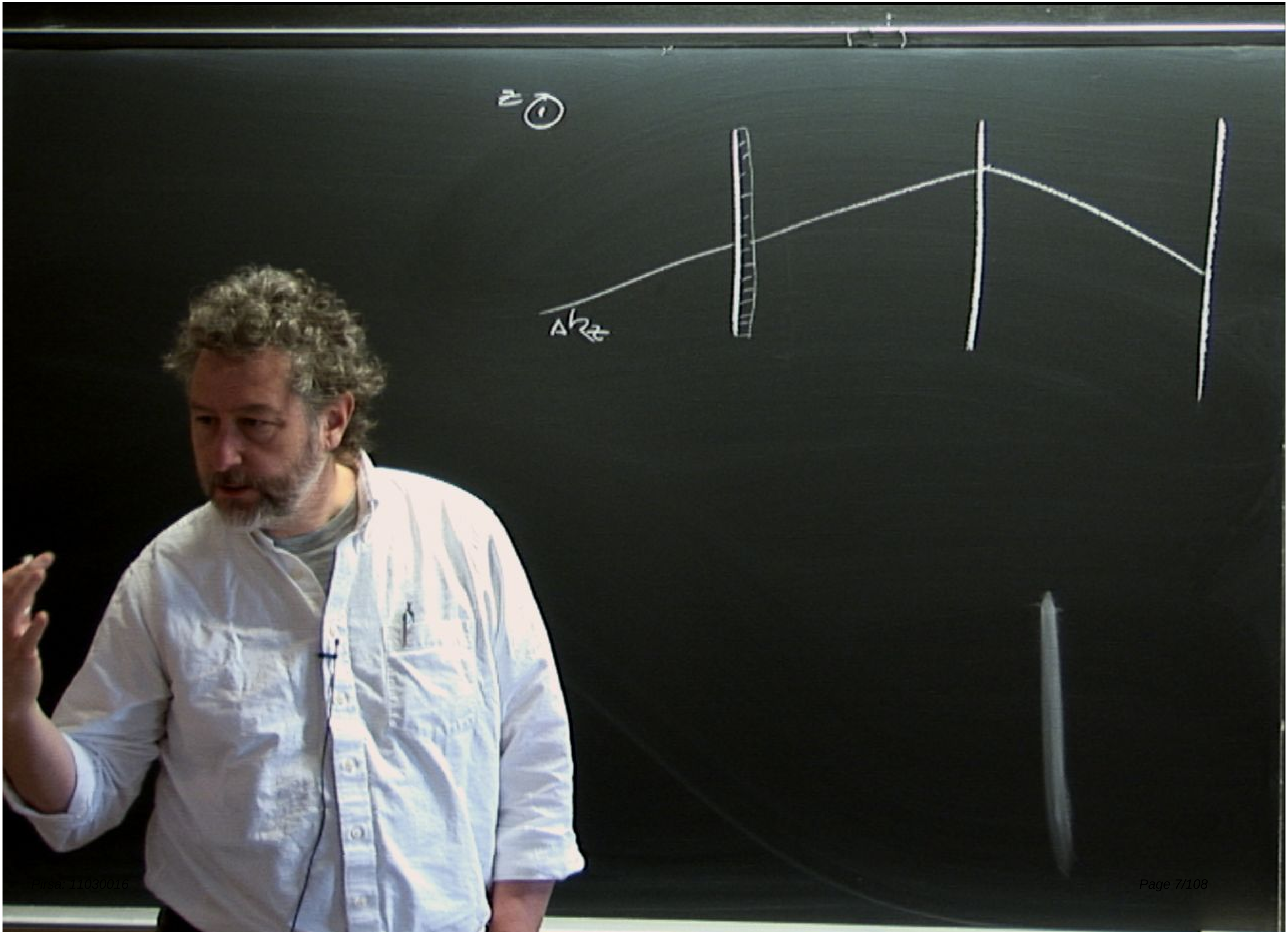
perimeter scholars
international

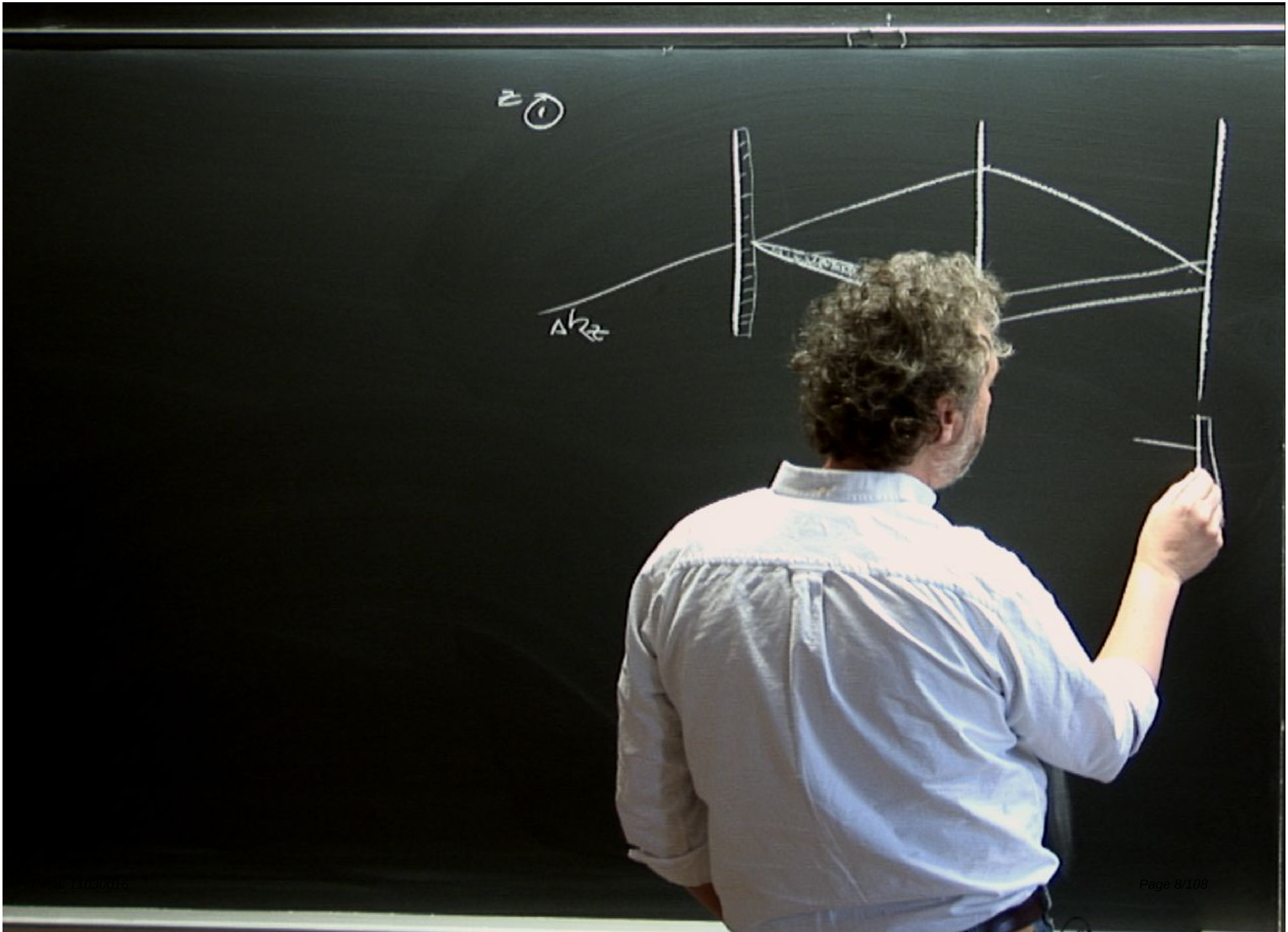


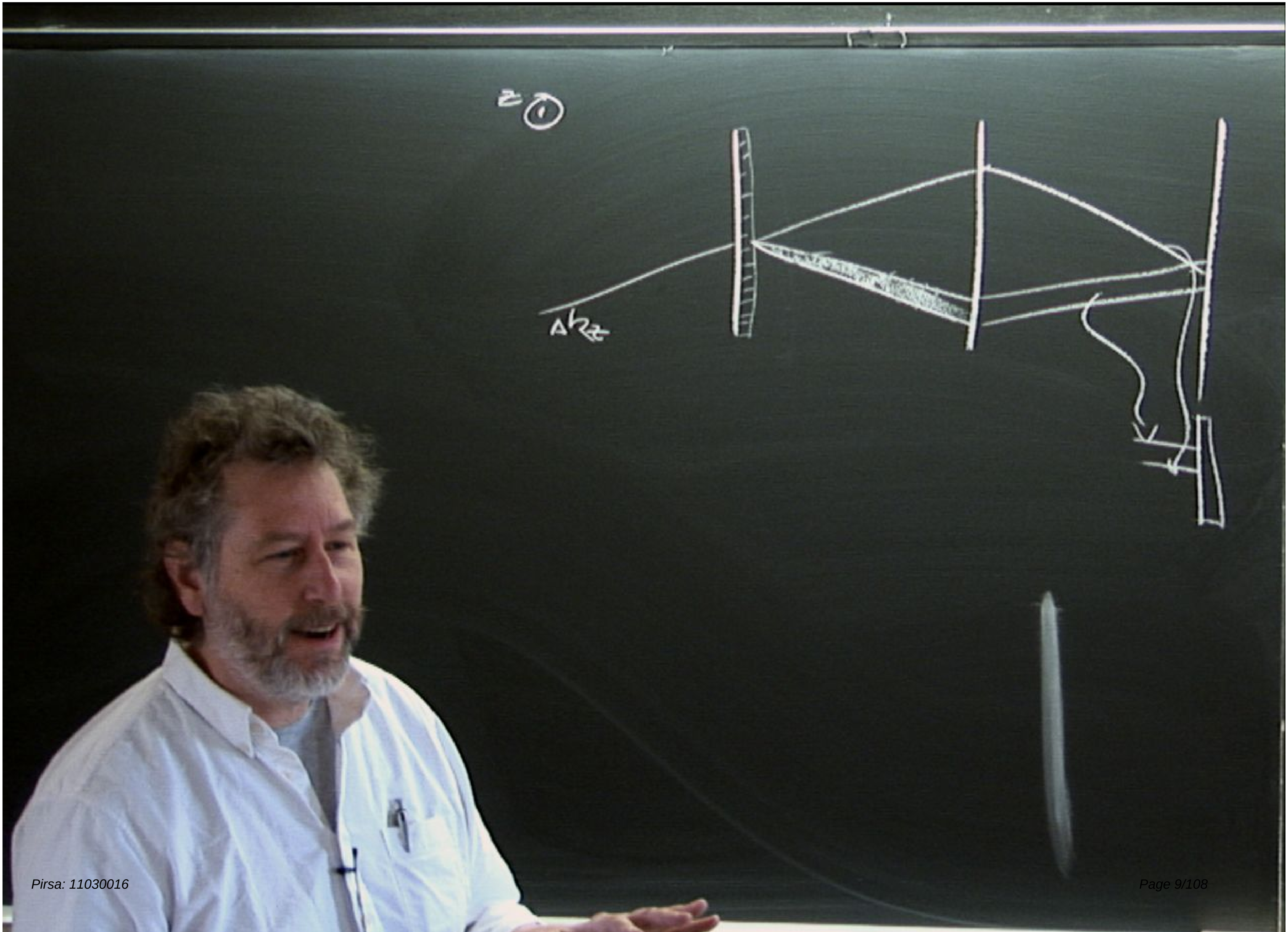

z ①

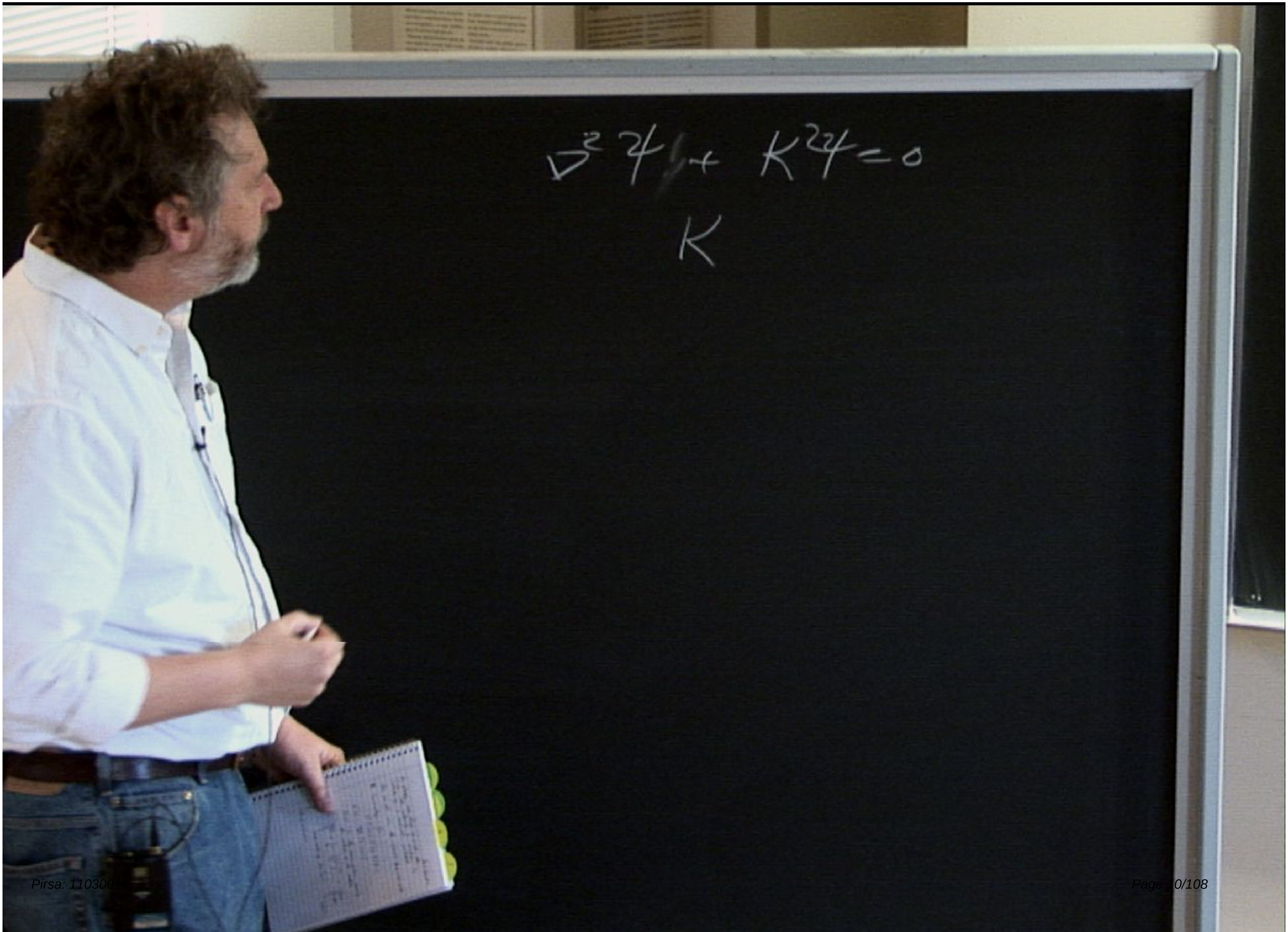

z ⊙

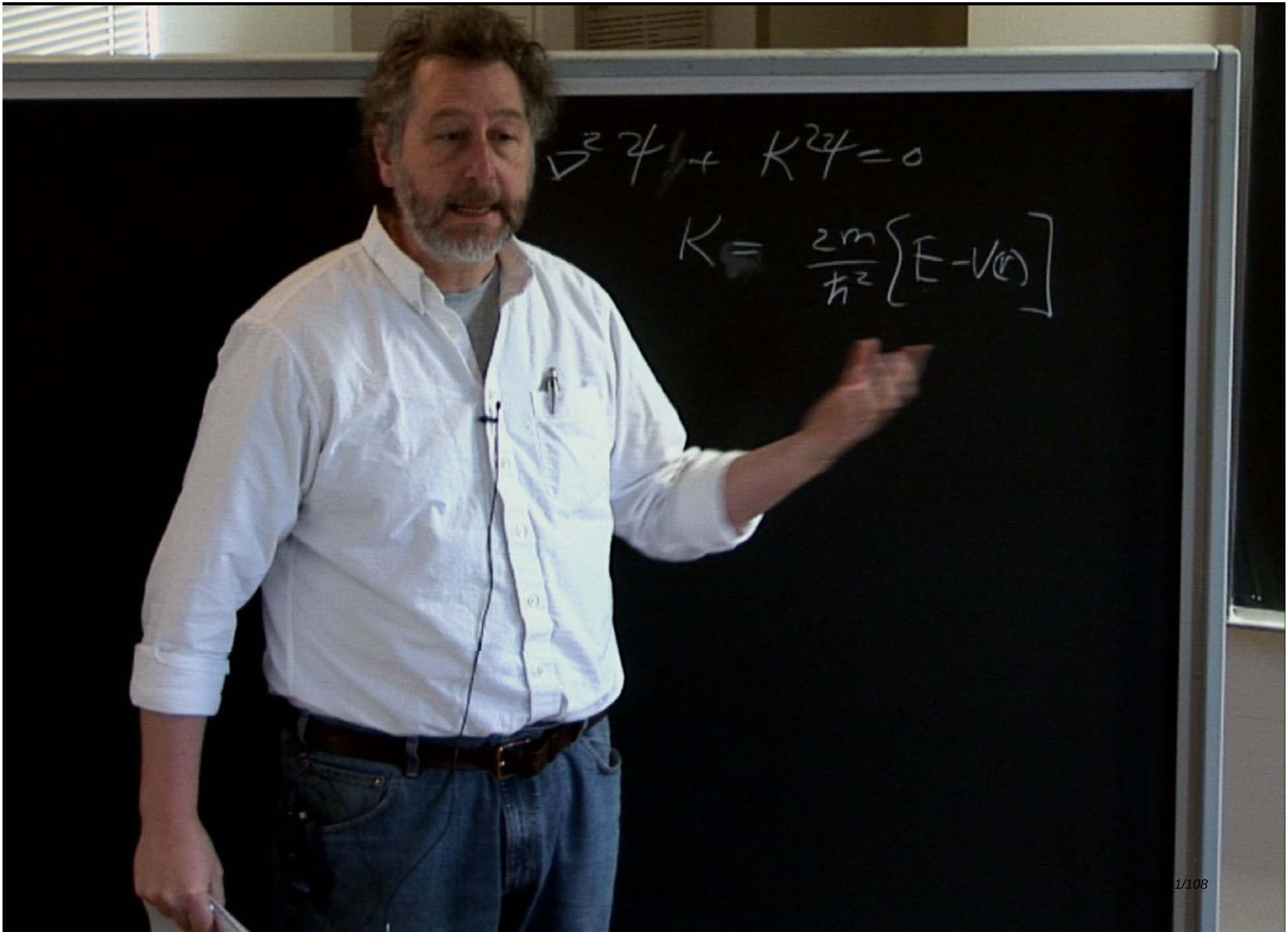

z ⊙
Δh_z

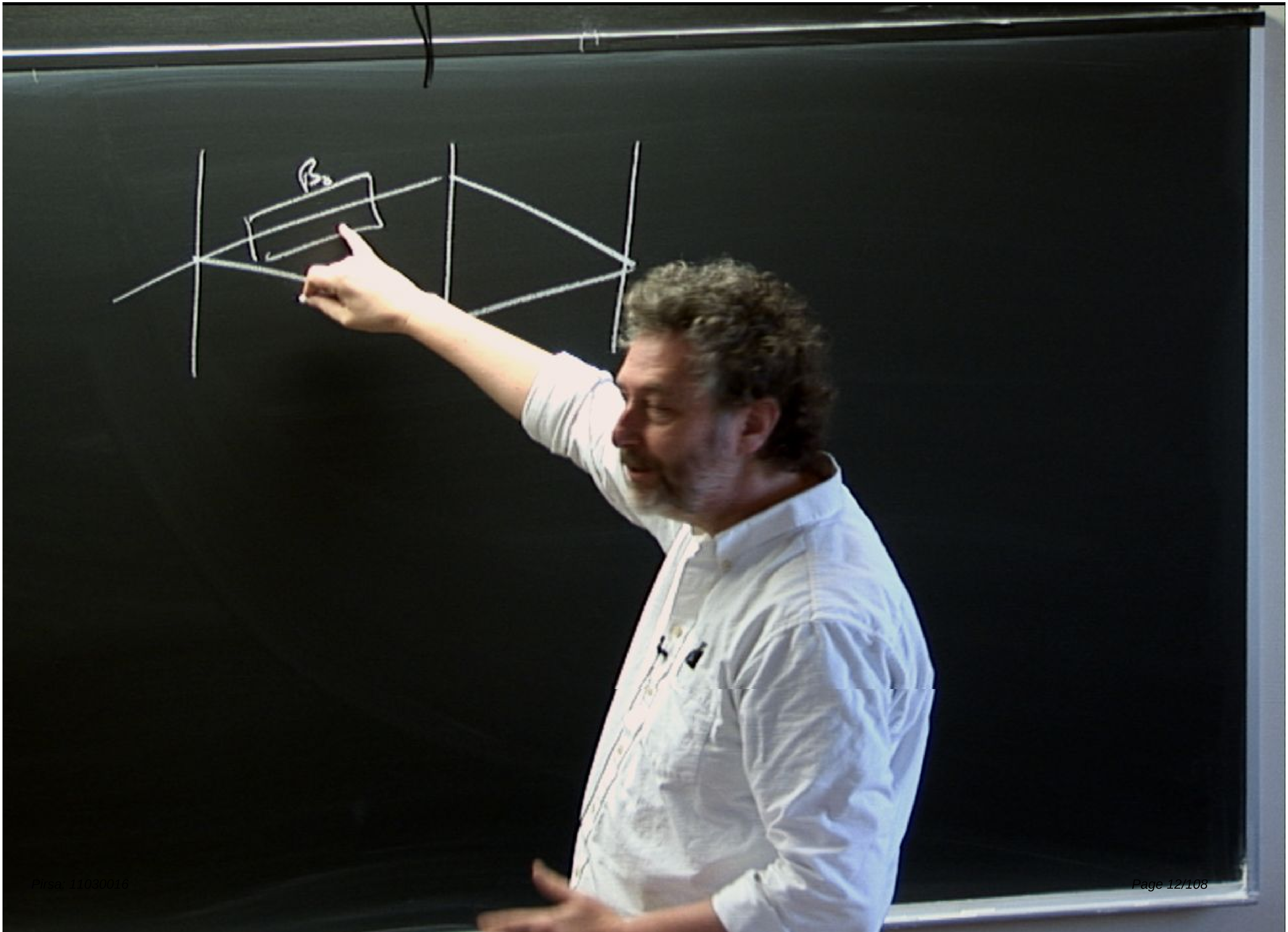

z ⊙
Δk_z

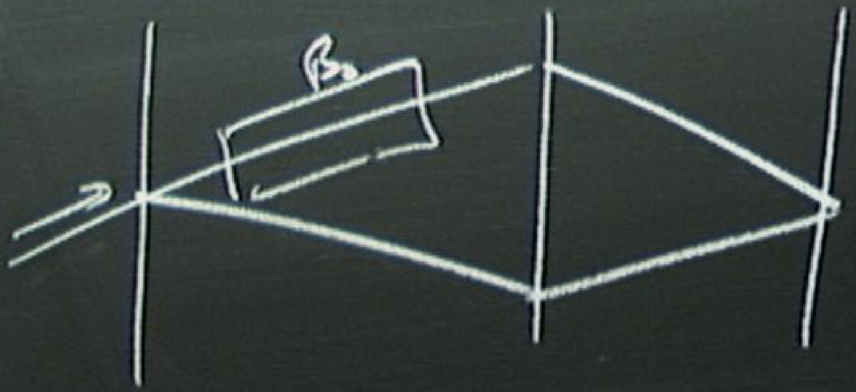

z ①
Δh_{zz}

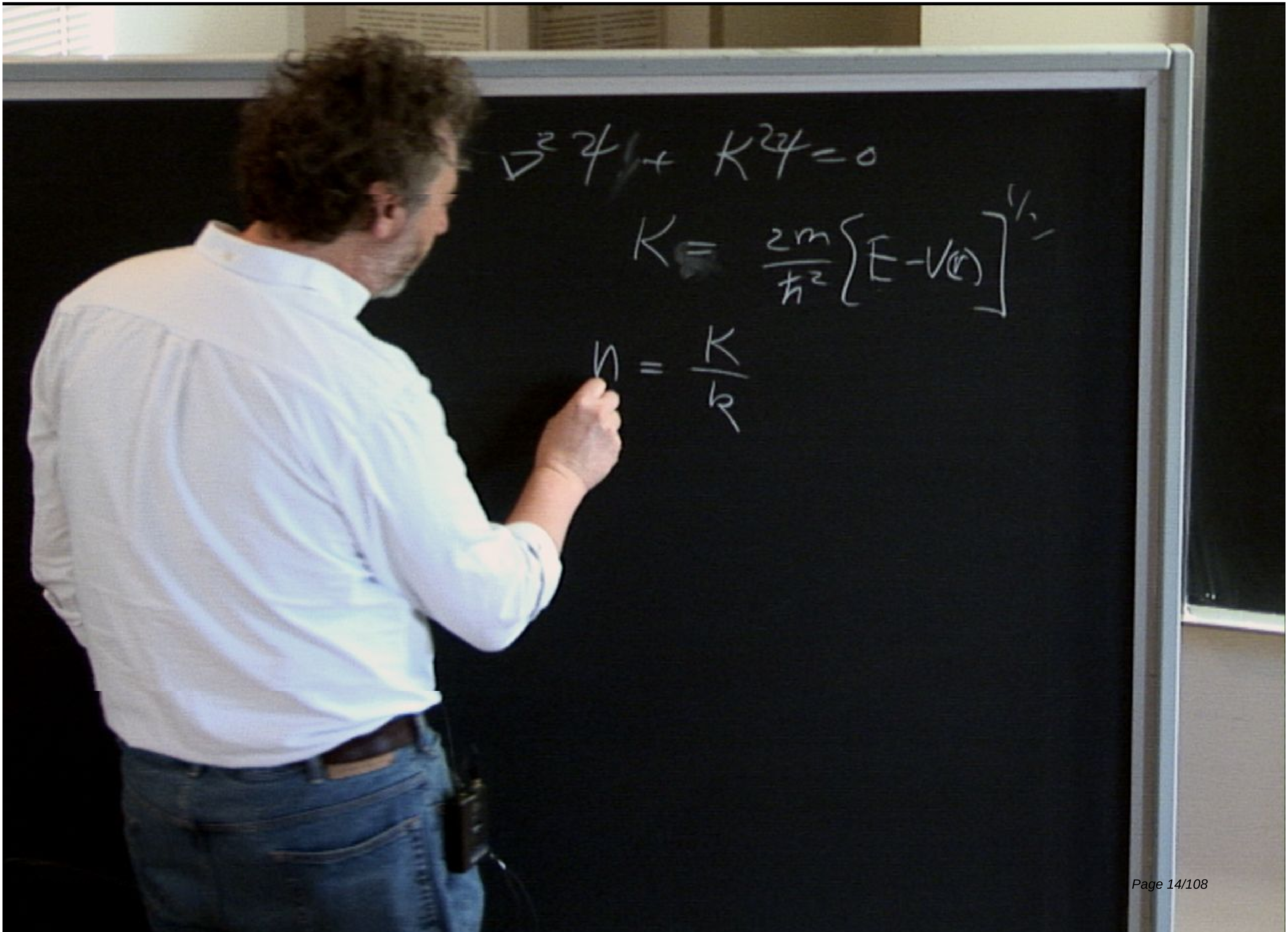

z ①
Δhz

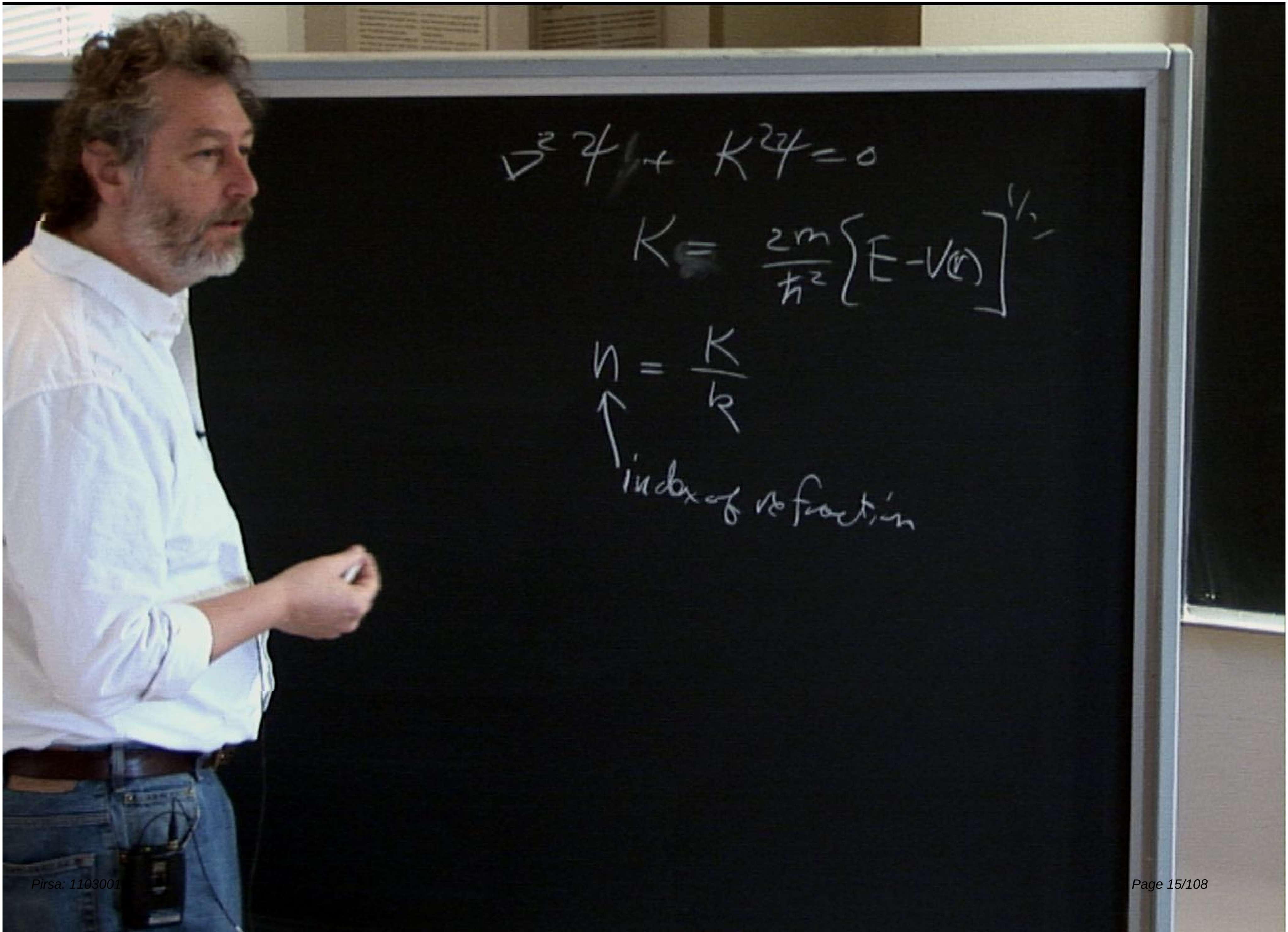

$\nabla^2\psi + K^2\psi = 0$
K


$\nabla^2\psi + K^2\psi = 0$
$K = \frac{2m}{\hbar^2}\left[E - V(r)\right]$


B_0


B_0


$\nabla^2\psi + K^2\psi = 0$
$K = \frac{2m}{\hbar^2}\left[E - V(r)\right]^{1/2}$
$n = \frac{K}{k}$

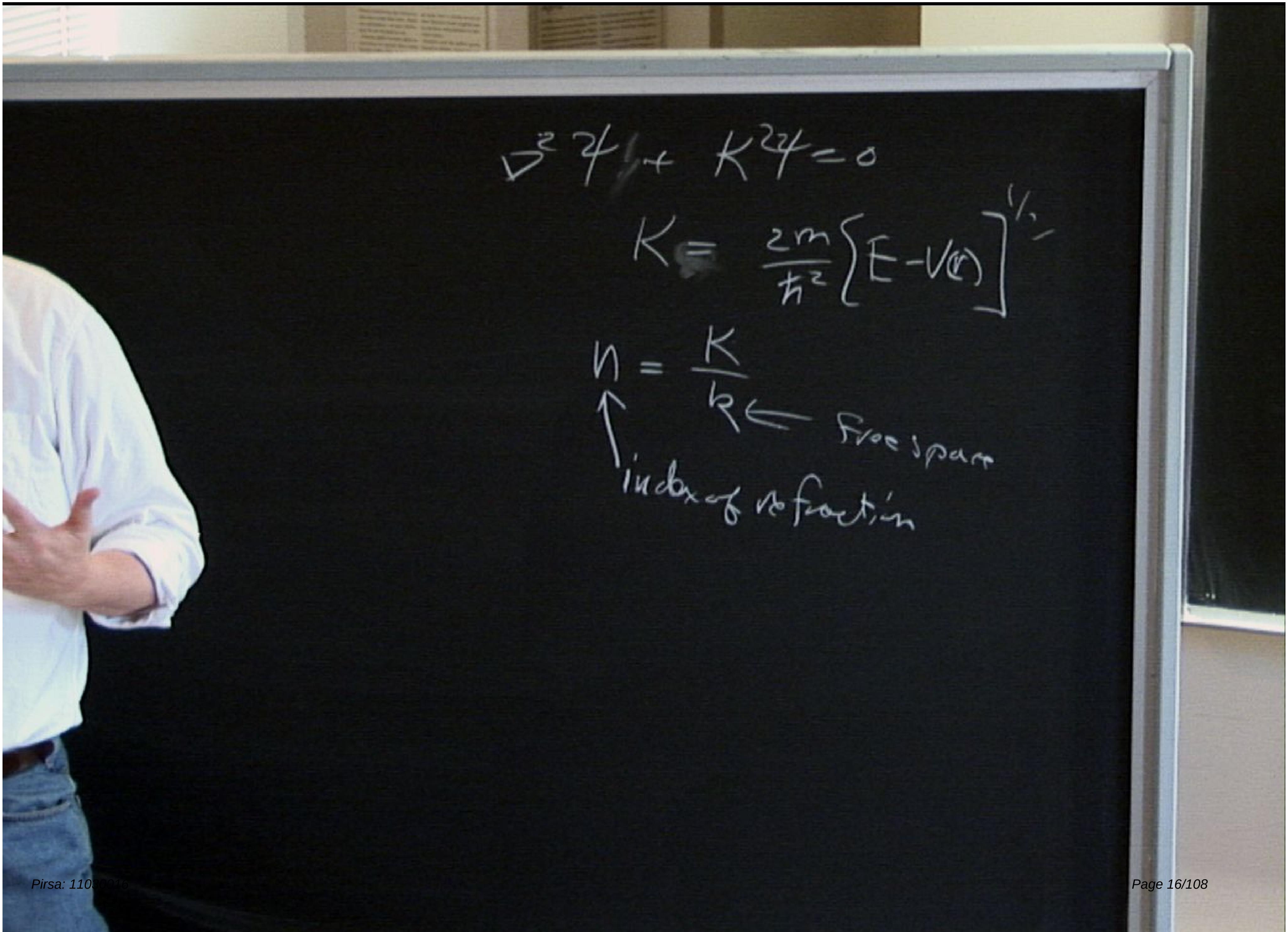


$$\nabla^2\psi + K^2\psi = 0$$

$$K = \frac{2m}{\hbar^2}\left\{E - V(r)\right]^{1/2}$$

$$n = \frac{K}{k}$$

↑ index of refraction



$$\nabla^2 \psi + K^2 \psi = 0$$

$$K = \frac{2m}{\hbar^2}\left[E - V(r)\right]^{1/2}$$

$$n = \frac{K}{k}$$

$k \leftarrow$ free space

$\uparrow$ index of refraction

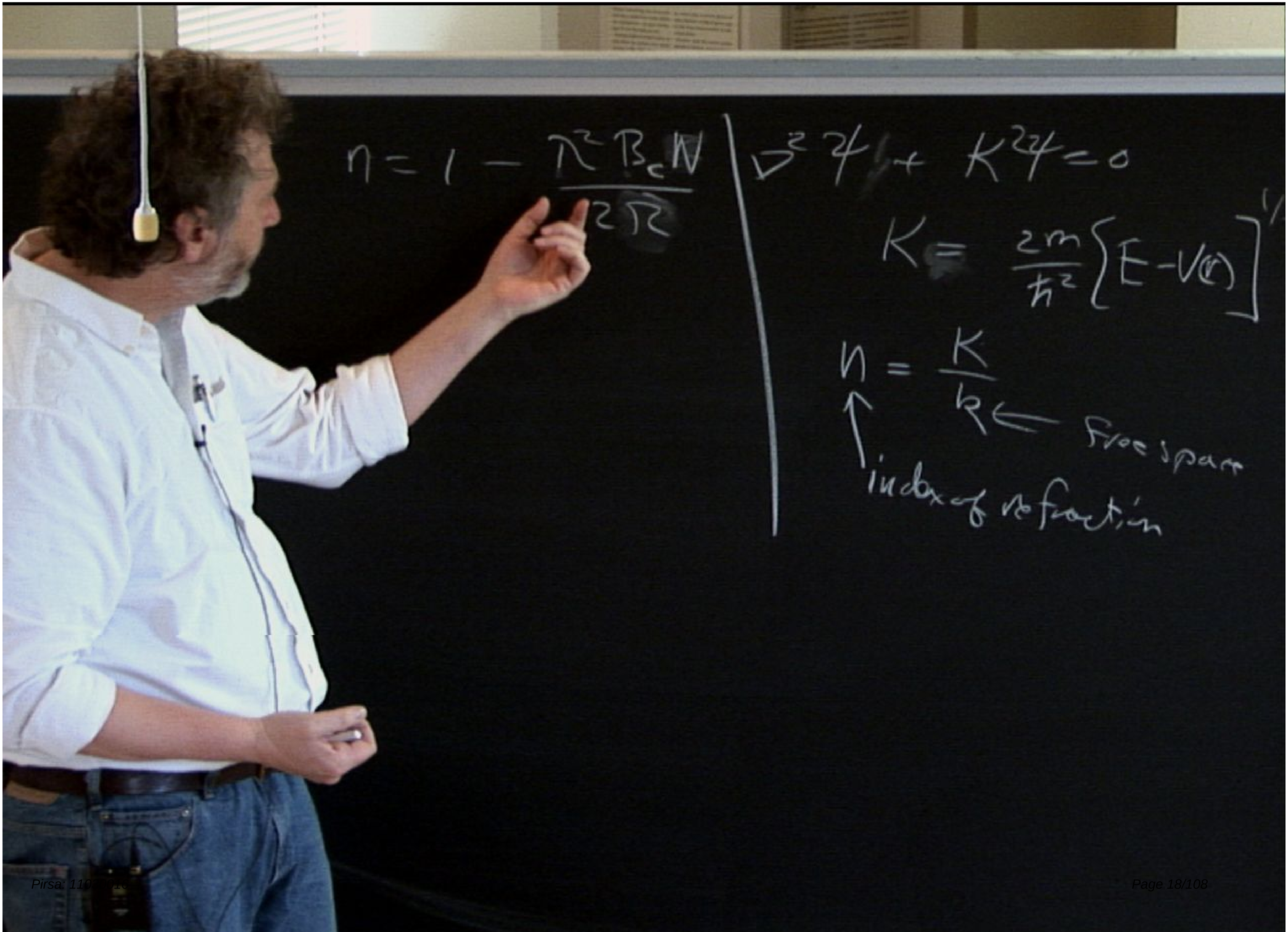
$$\nabla^2\psi + K^2\psi = 0$$

$$K = \left\{\frac{2m}{\hbar^2}\left[E - V(r)\right]\right\}^{1/2}$$

$$n = \frac{K}{k}$$

k ← free space

↑ index of refraction



$$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$$

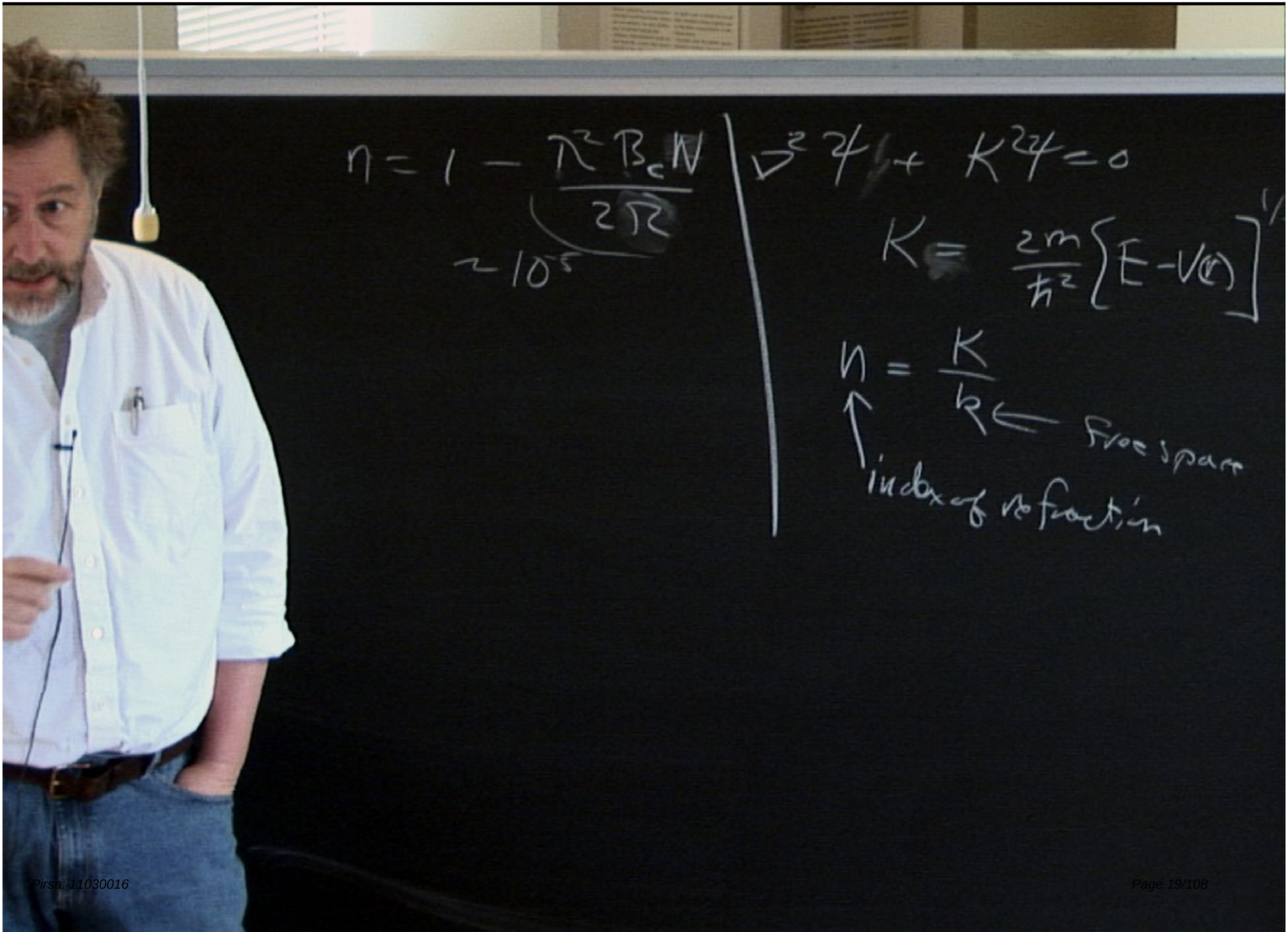
$$\nabla^2 \psi + K^2 \psi = 0$$

$$K = \left\{\frac{2m}{\hbar^2}\left[E - V(r)\right]\right\}^{1/2}$$

$$n = \frac{K}{k}$$

k ← free space

↑ index of refraction

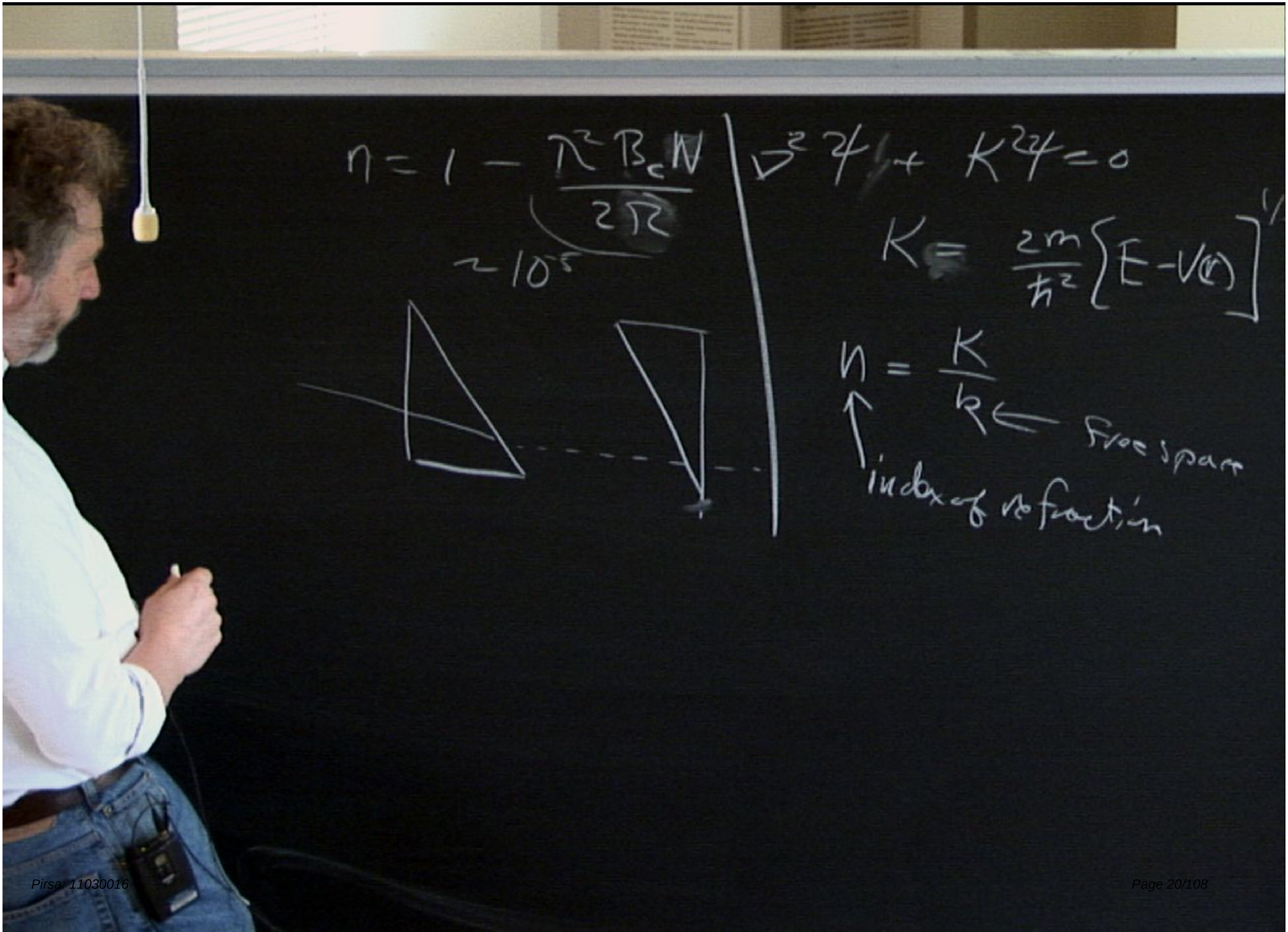


$$n = 1 - \underbrace{\frac{\lambda^2 B_c N}{2\pi}}_{\sim 10^{-5}}$$

$$\nabla^2 \psi + K^2 \psi = 0$$

$$K = \left[\frac{2m}{\hbar^2}\left\{E - V(r)\right\}\right]^{1/2}$$

$$\underset{\substack{\uparrow \\ \text{index of refraction}}}{n} = \frac{K}{k} \xleftarrow{} \text{free space}$$



$$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$$

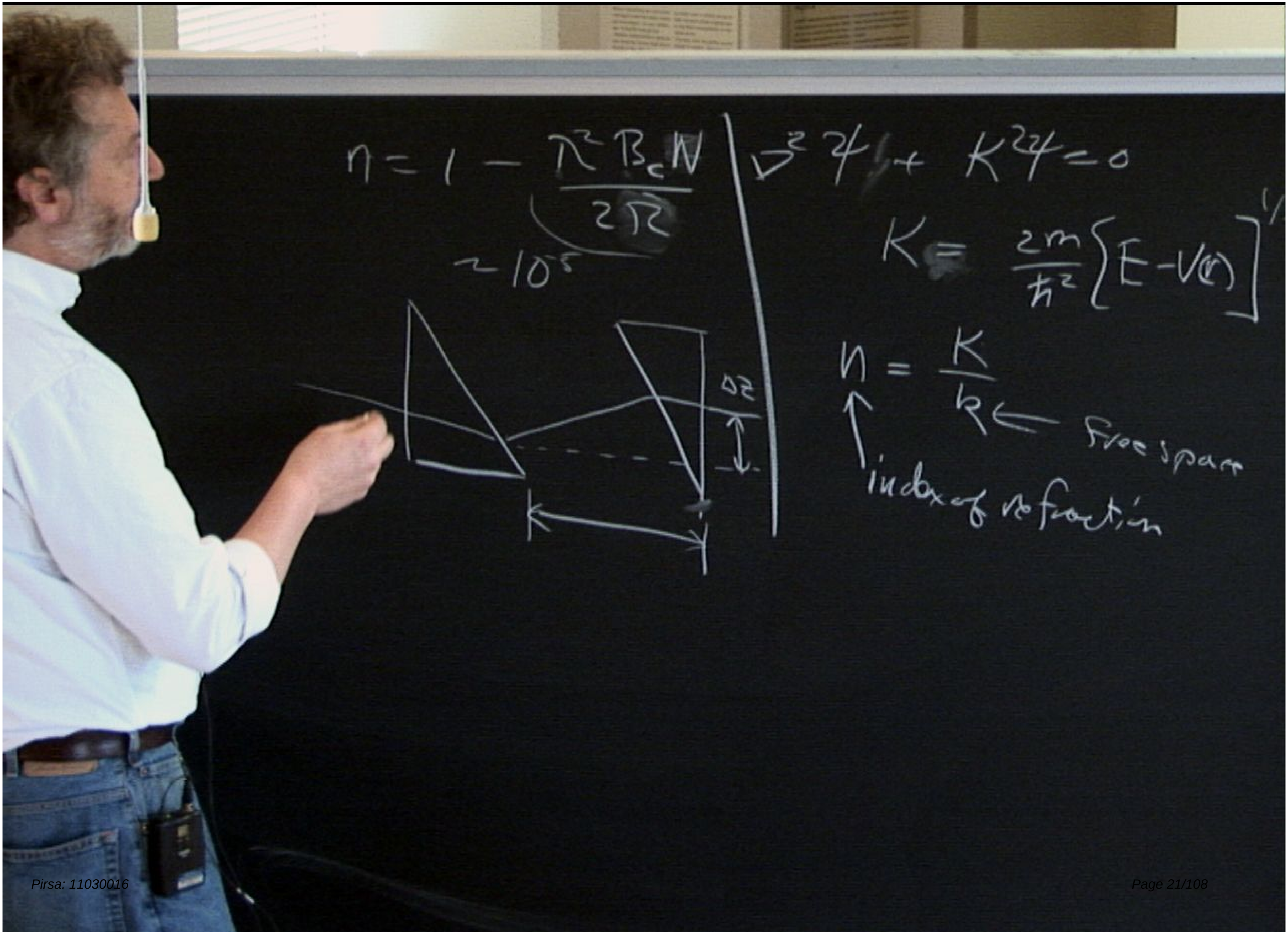
$\sim 10^{-5}$

$$\nabla^2 \psi + K^2 \psi = 0$$

$$K = \left[\frac{2m}{\hbar^2}\{E - V(r)\}\right]^{1/2}$$

$$n = \frac{K}{k} \leftarrow \text{free space}$$

$\uparrow$ index of refraction



$$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$$

$\sim 10^{-5}$

$$\nabla^2 \psi + K^2 \psi = 0$$

$$K = \frac{2m}{\hbar^2}\left\{E - V(r)\right]^{1/2}$$

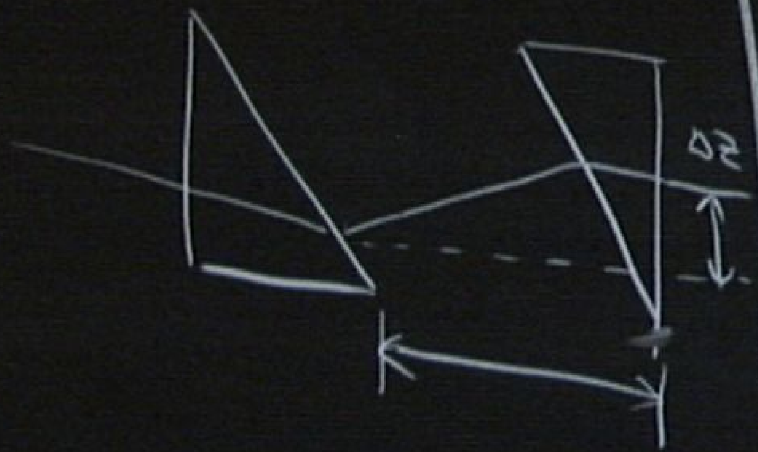
$$n = \frac{K}{k}$$

$k \leftarrow$ free space

$\uparrow$ index of refraction

$$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$$

$\sim 10^5$



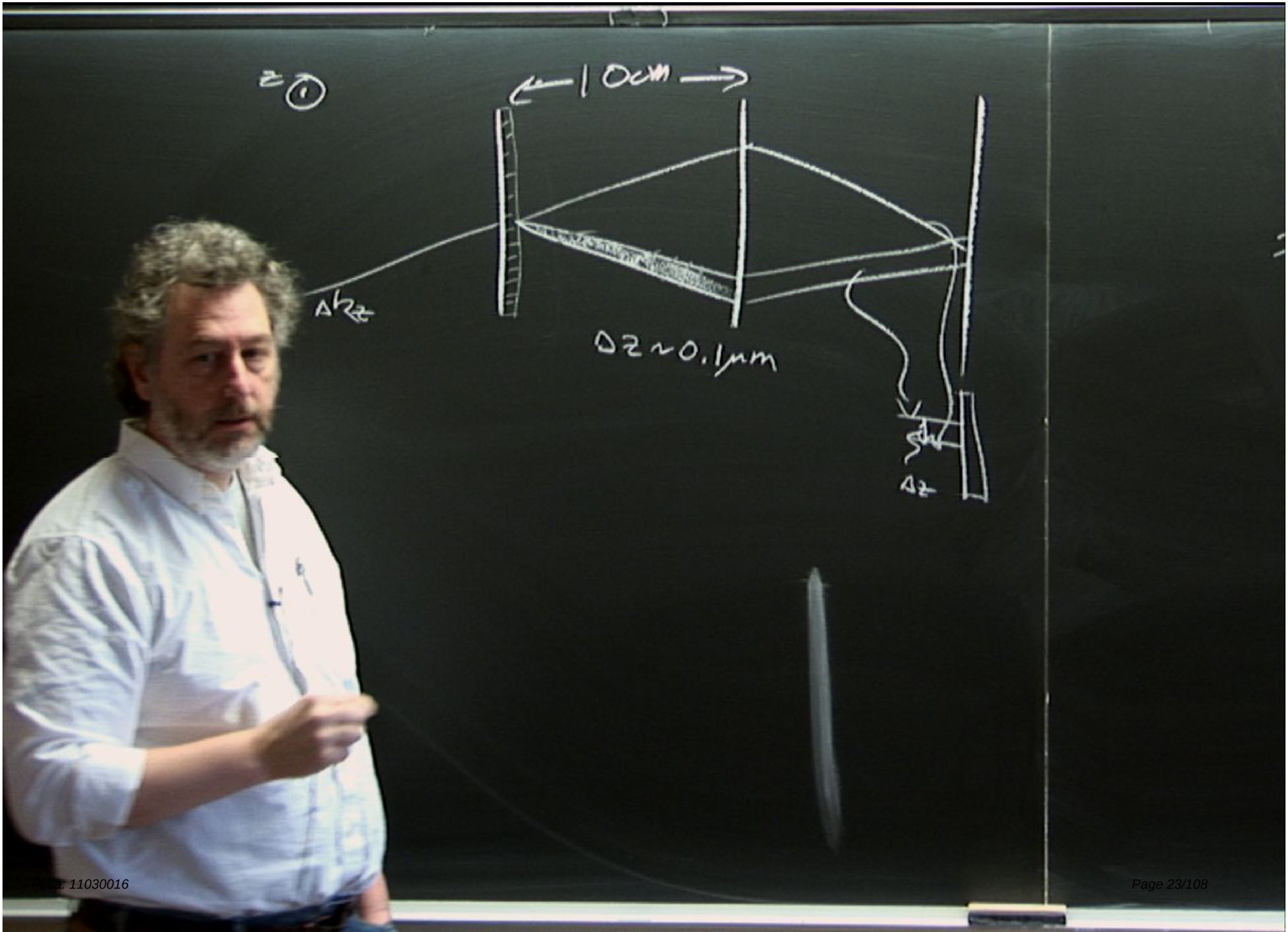
$$\nabla^2\psi + K^2\psi = 0$$

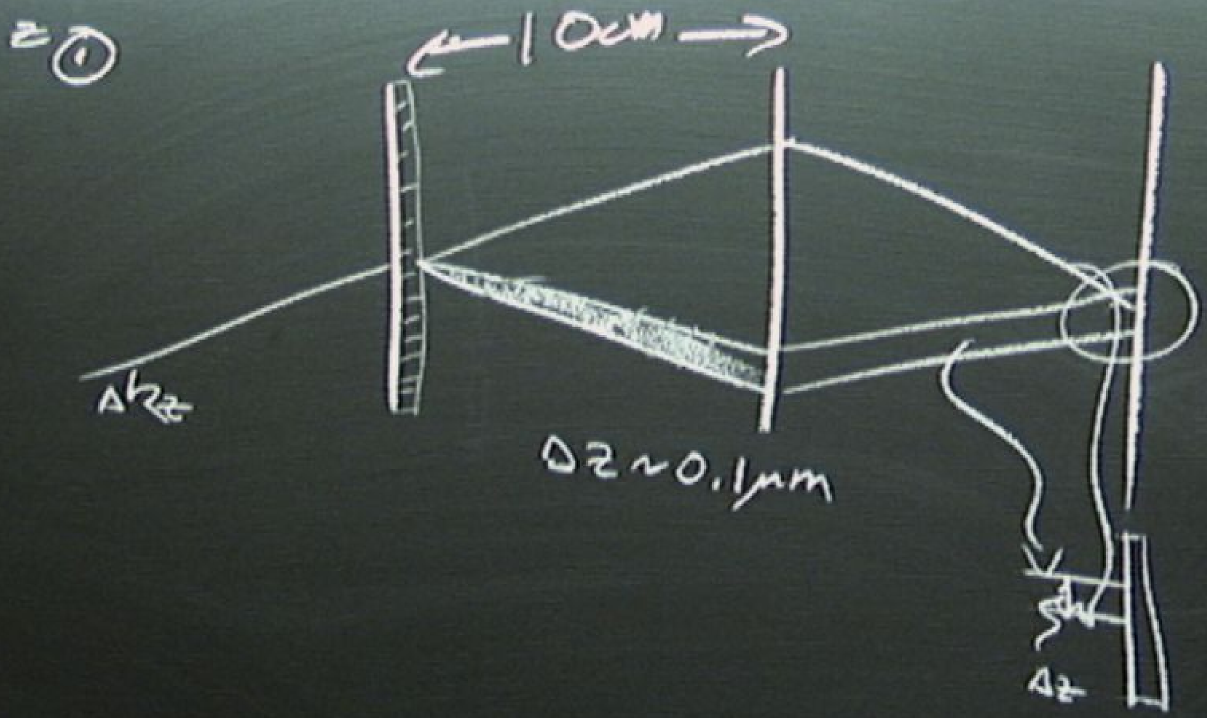
$$K = \left(\frac{2m}{\hbar^2}\left[E - V(r)\right]\right)^{1/2}$$

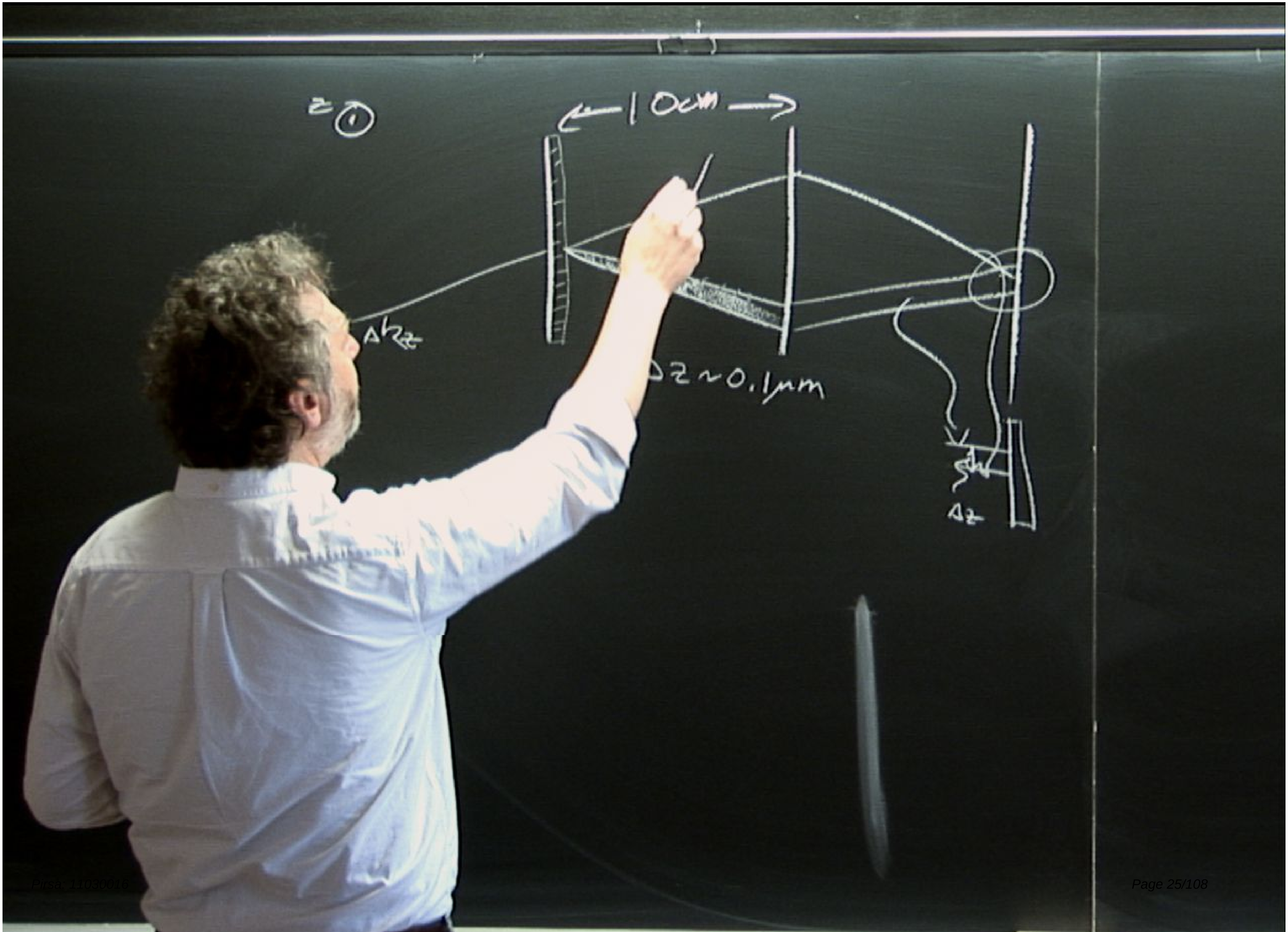
$$n = \frac{K}{k}$$

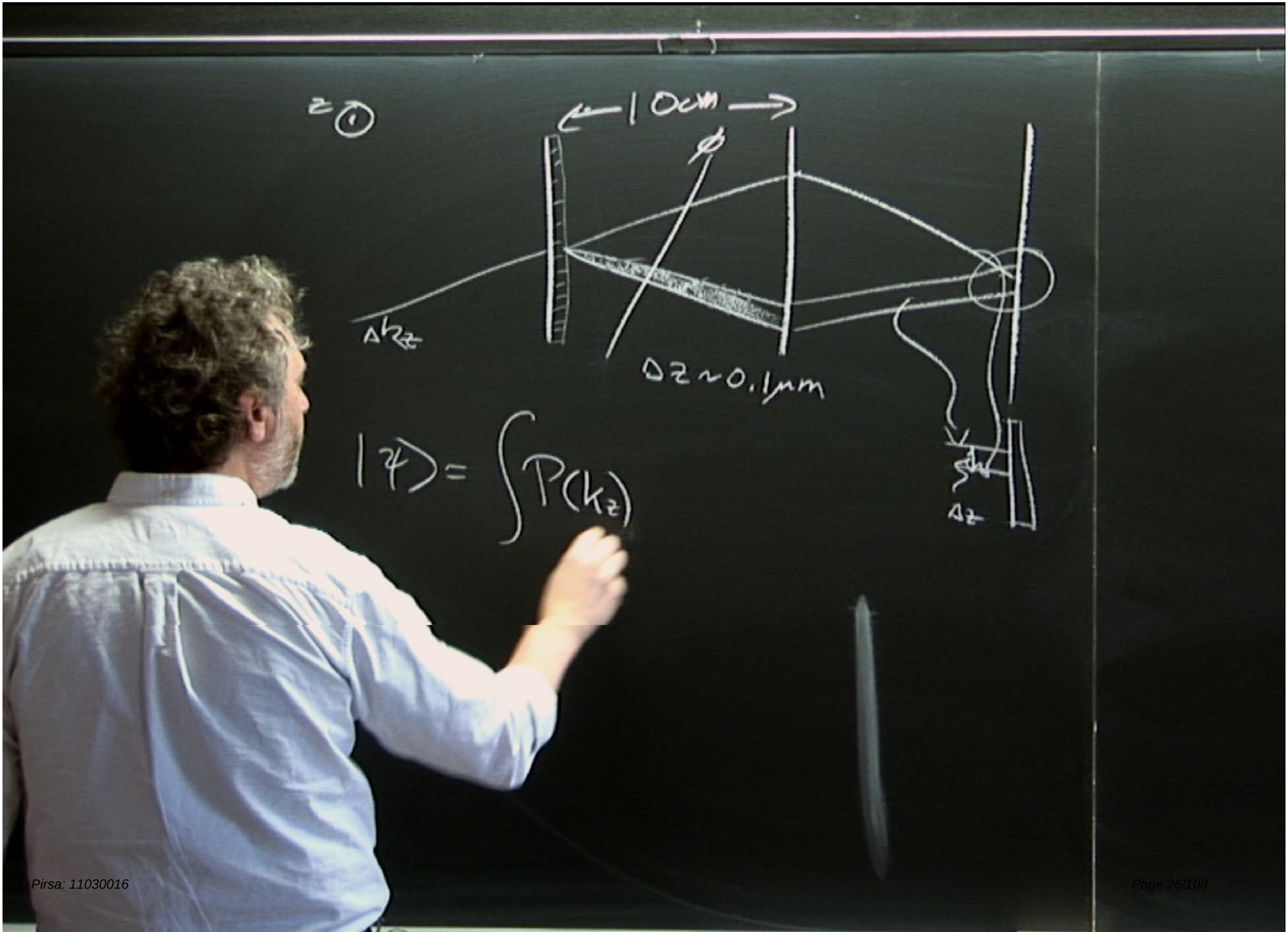
index of refraction

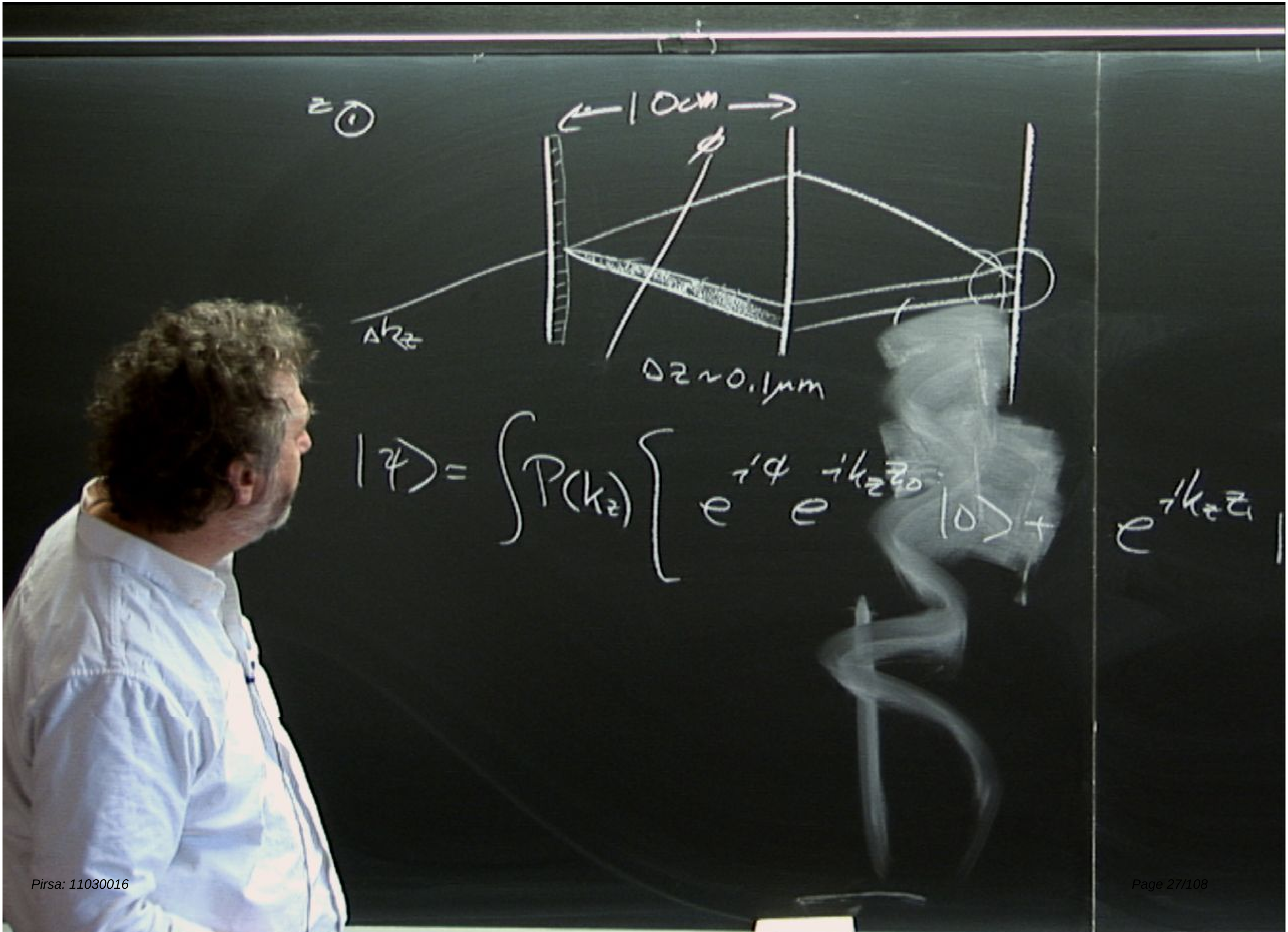
free space


z ①
10cm
Δz
Δz ~ 0.1μm
Δz

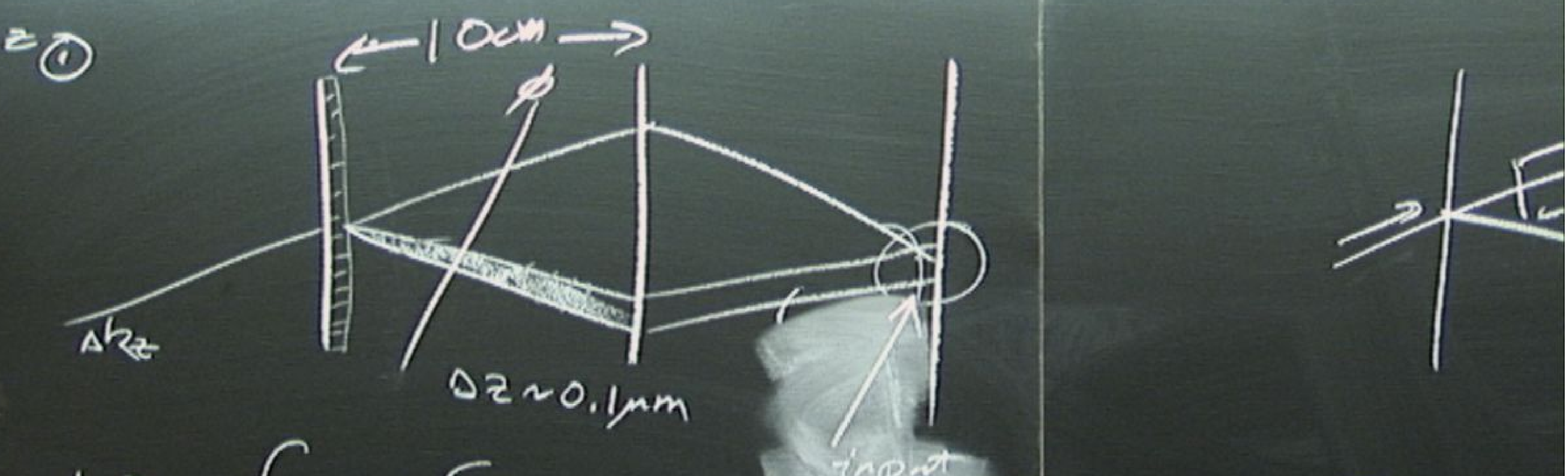

z ①
10cm
Δkz
Δz ~ 0.1μm
Δz


z ①
10cm
Δz
Δz ~ 0.1μm
Δz

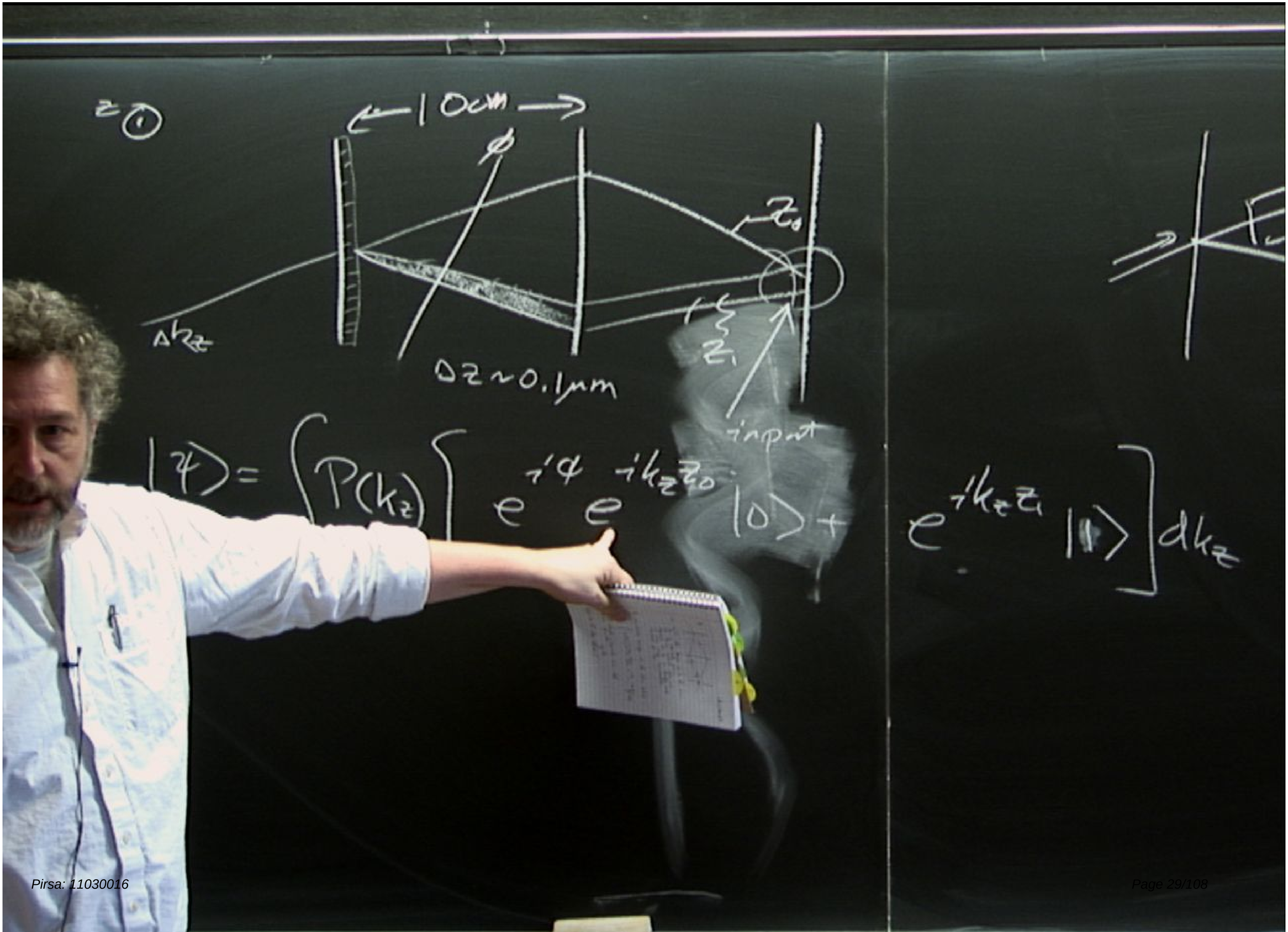

z ①
← 10cm →
φ
Δk_z
$\Delta z \sim 0.1 \mu m$
$|\psi\rangle = \int P(k_z)$
Δz



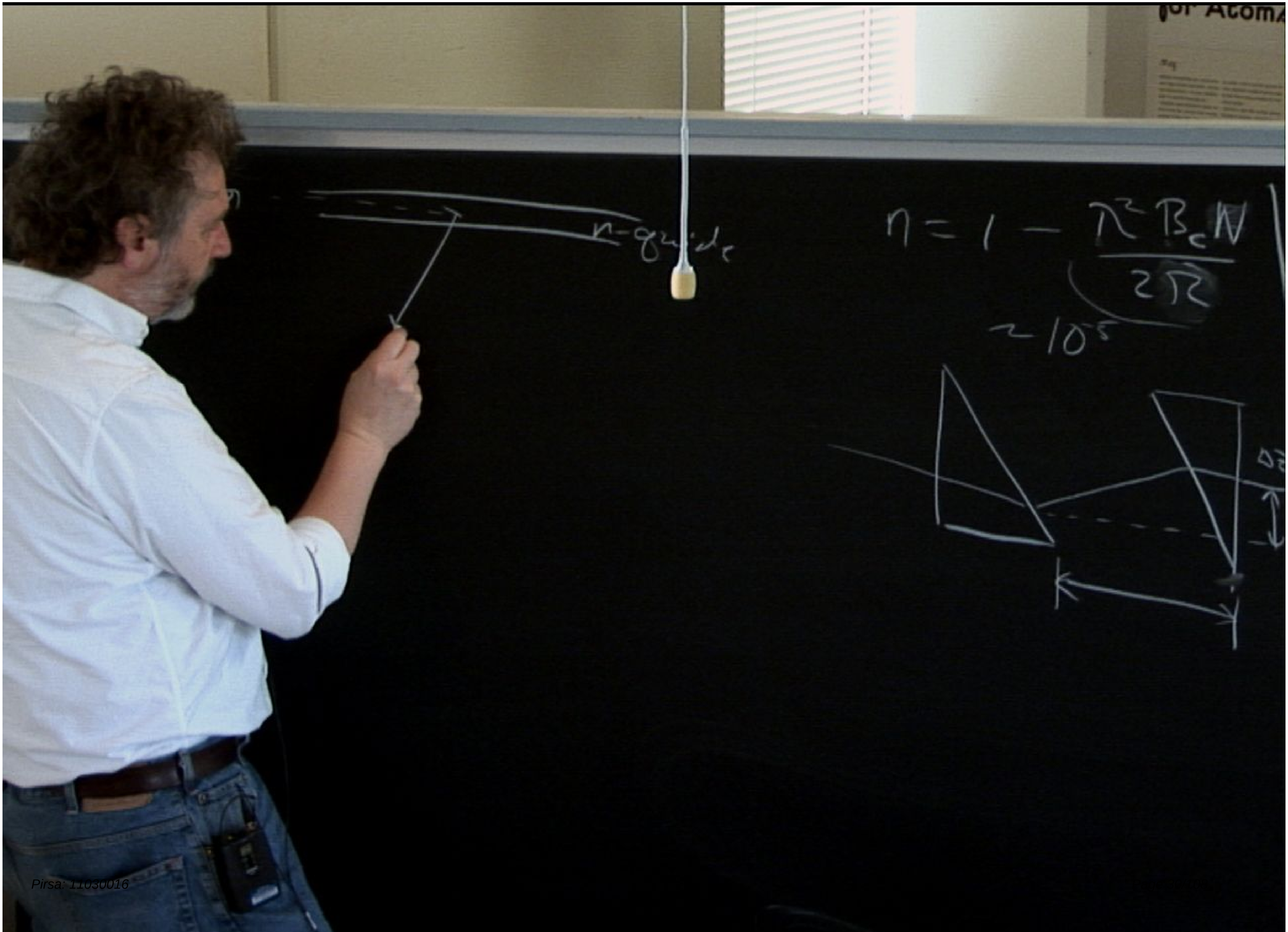
$$|\psi\rangle = \int P(k_z) \Big\{ e^{i\phi} e^{-ik_z z_0} |0\rangle + e^{ik_z z_1} |$$

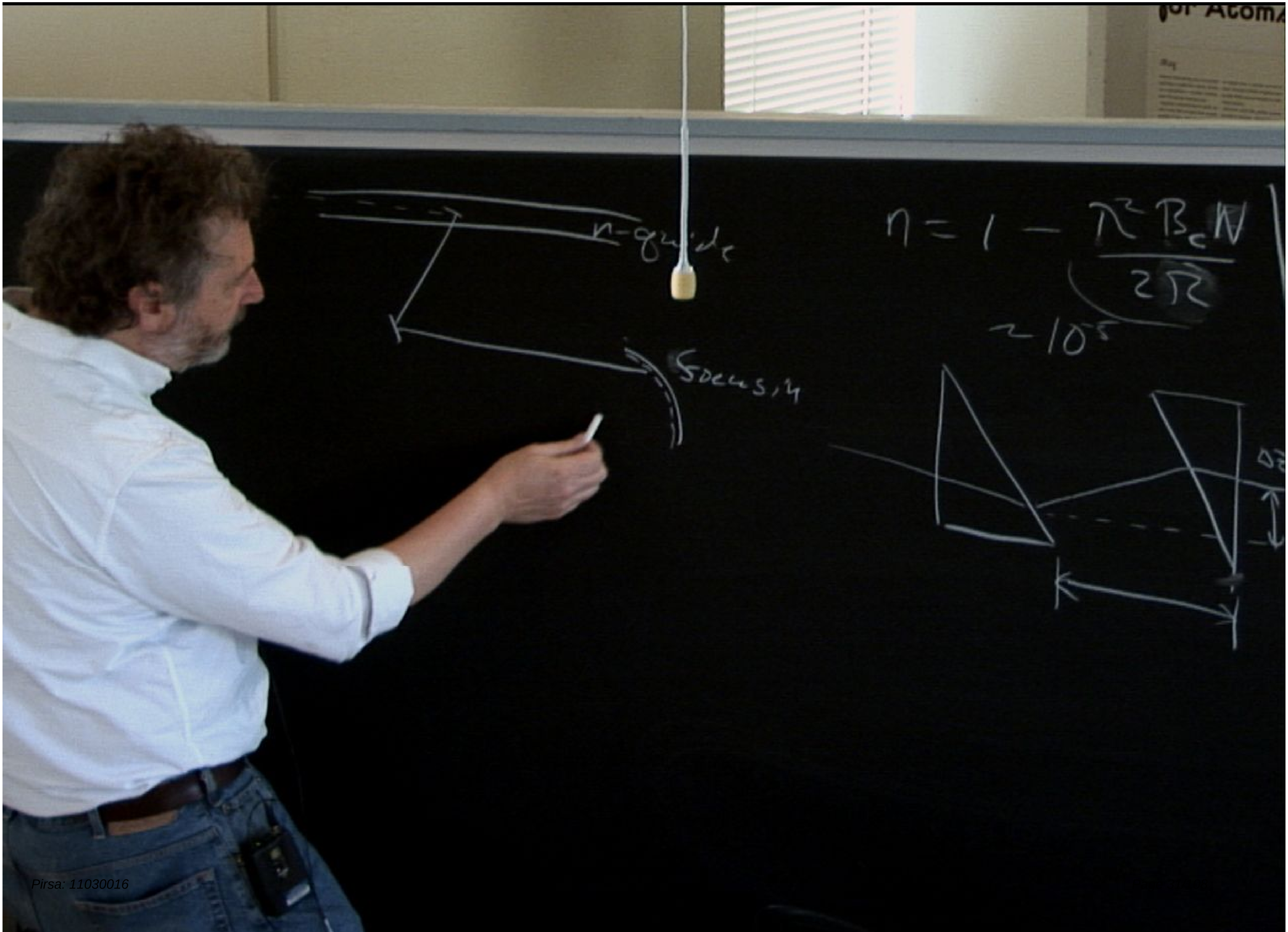


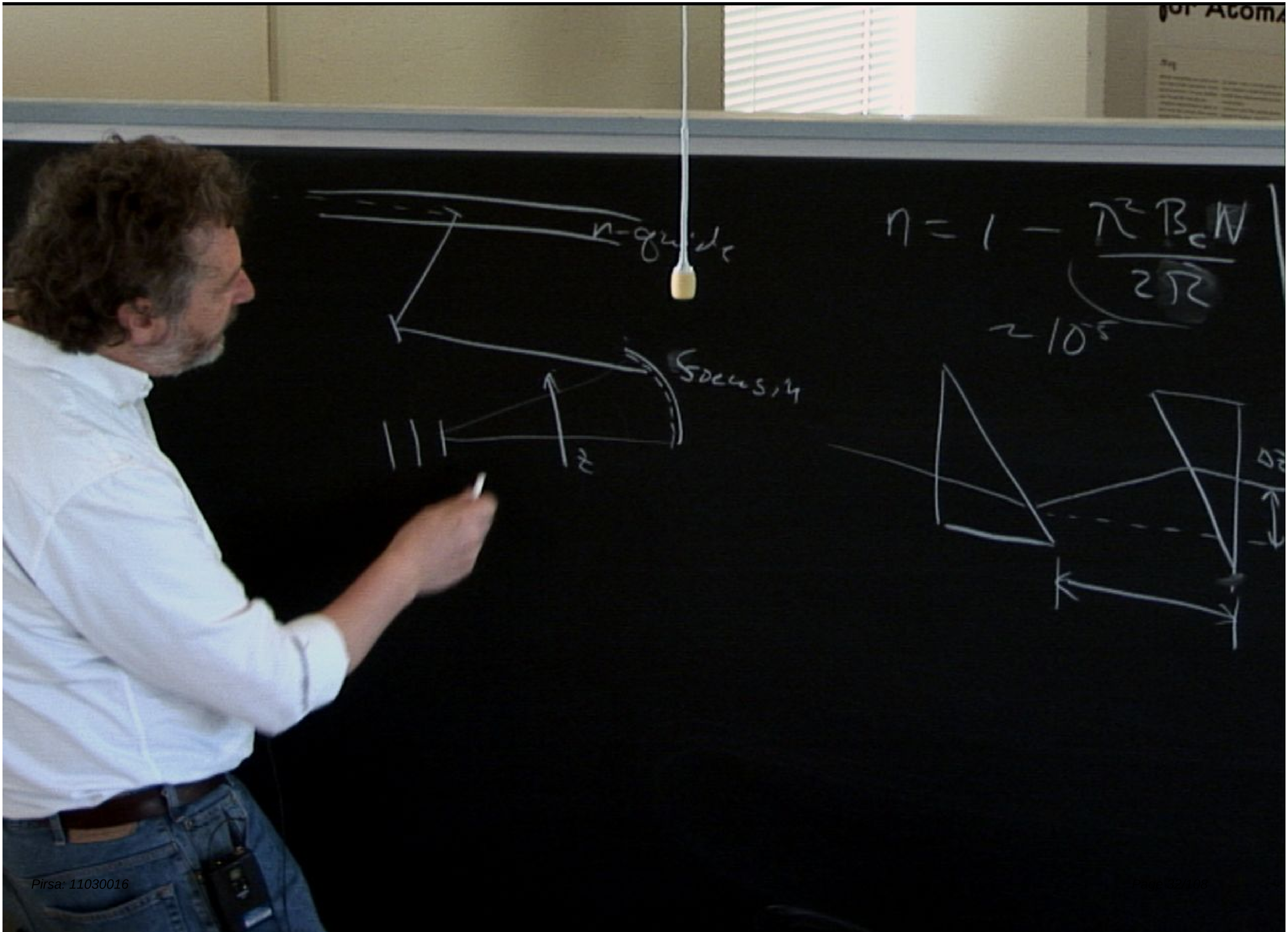
$$|\psi\rangle = \int P(k_z)\left[e^{i\phi}\, e^{ik_z z_0}\, |0\rangle + e^{ik_z z_1}\, |1\rangle \right] dk_z$$

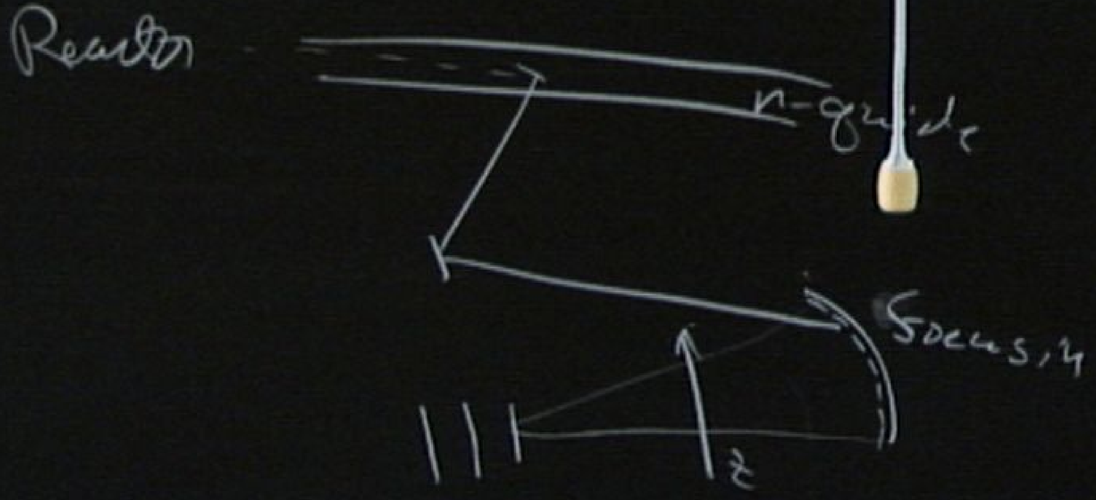


$$|\psi\rangle = \int P(k_z) \int e^{i\phi} e^{ik_z z_0} |0\rangle + e^{ik_z z_1} |1\rangle \Big] dk_z$$


n-guide
n = 1 − λ² B_c N / 2πc
~10^-5
Δz

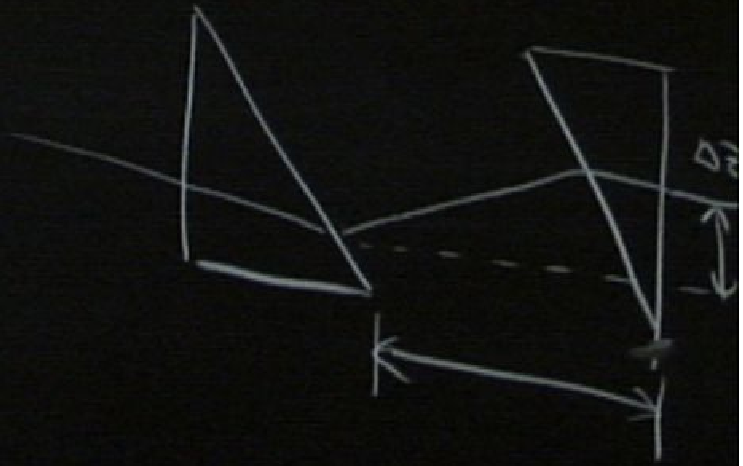

n-guide
focusing
n = 1 − λ²B_cN / 2π
~10⁵
Δz

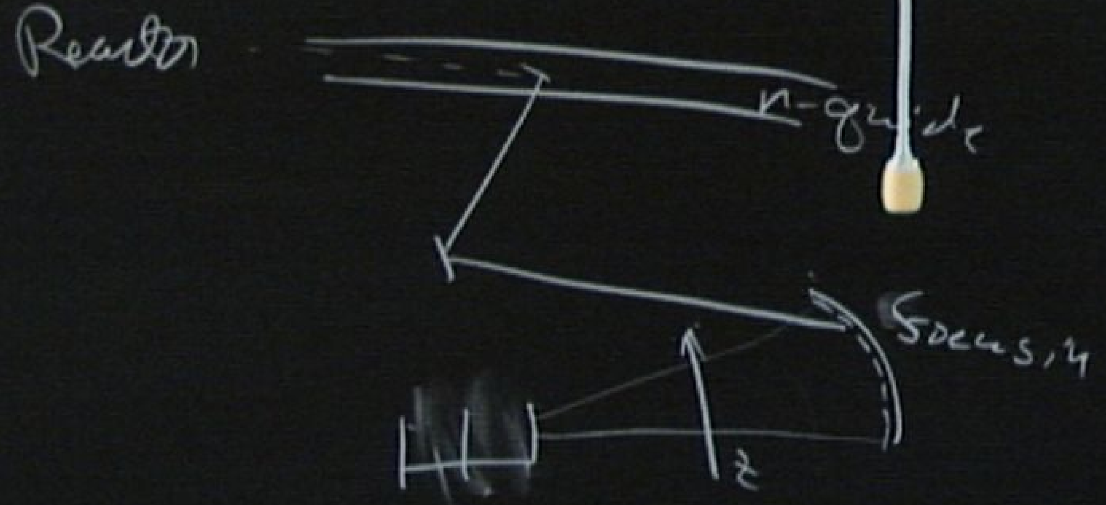

n-guide
focusing
z
$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$
$\sim 10^5$
Δz



$$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$$

$\sim 10^{5}$





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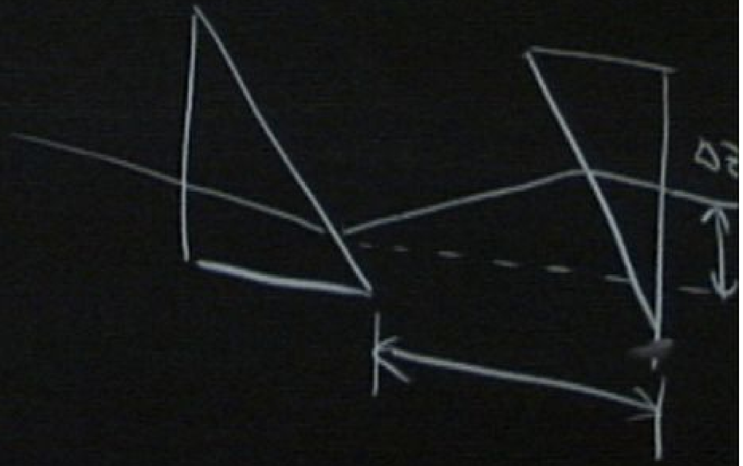
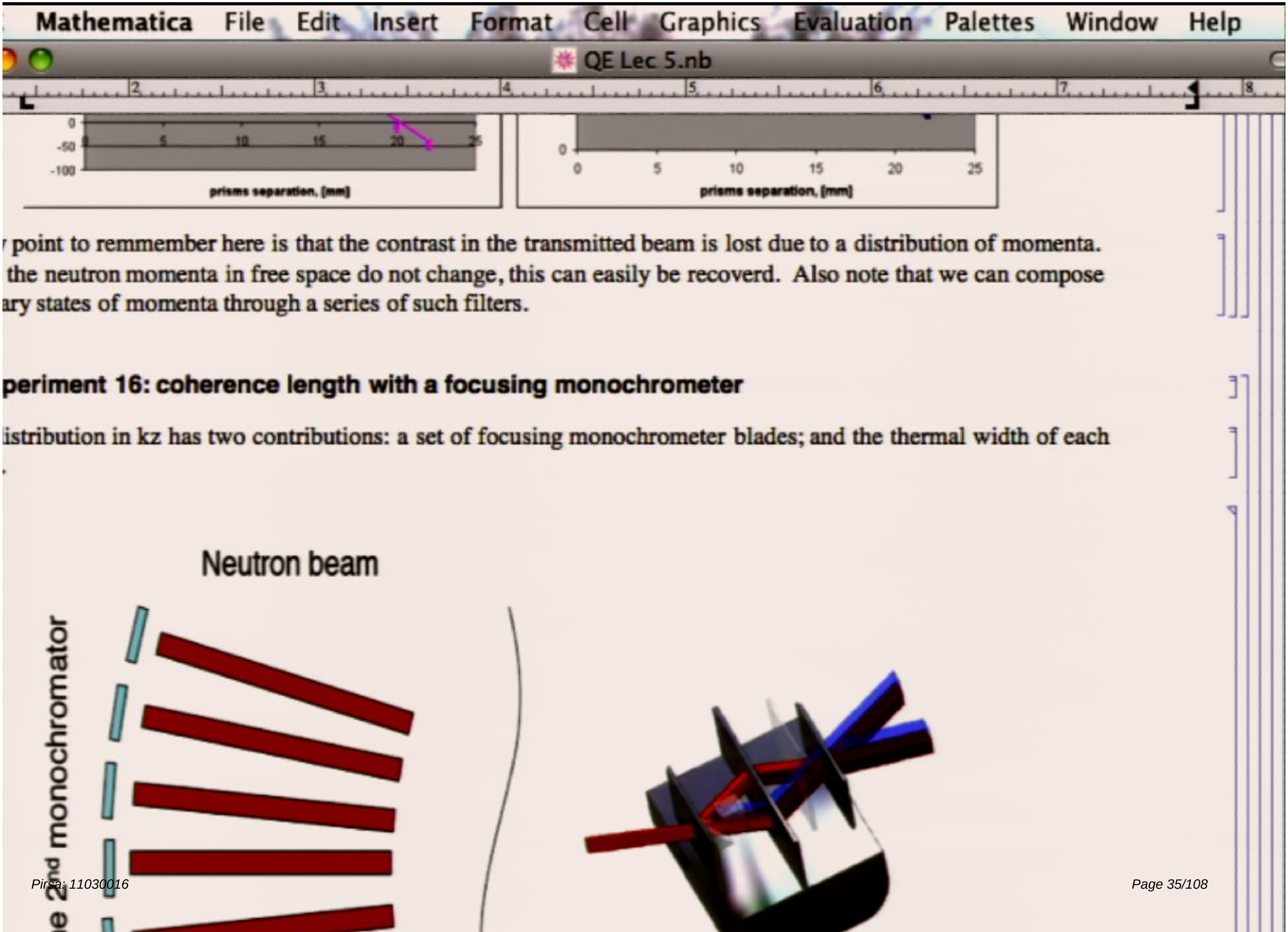
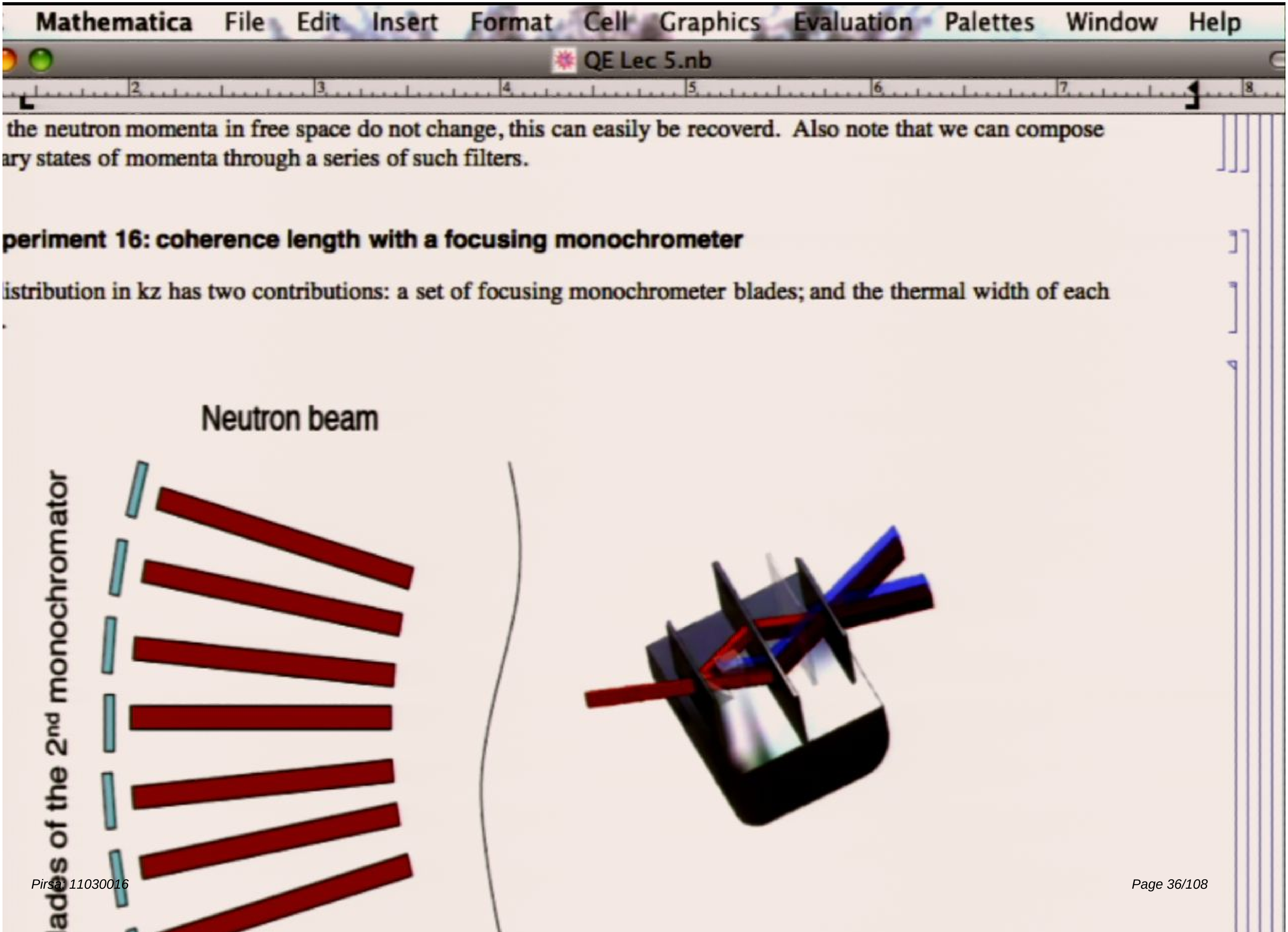




point to remmember here is that the contrast in the transmitted beam is lost due to a distribution of momenta. the neutron momenta in free space do not change, this can easily be recoverd. Also note that we can compose ary states of momenta through a series of such filters.

periment 16: coherence length with a focusing monochrometer

istribution in kz has two contributions: a set of focusing monochrometer blades; and the thermal width of each
.



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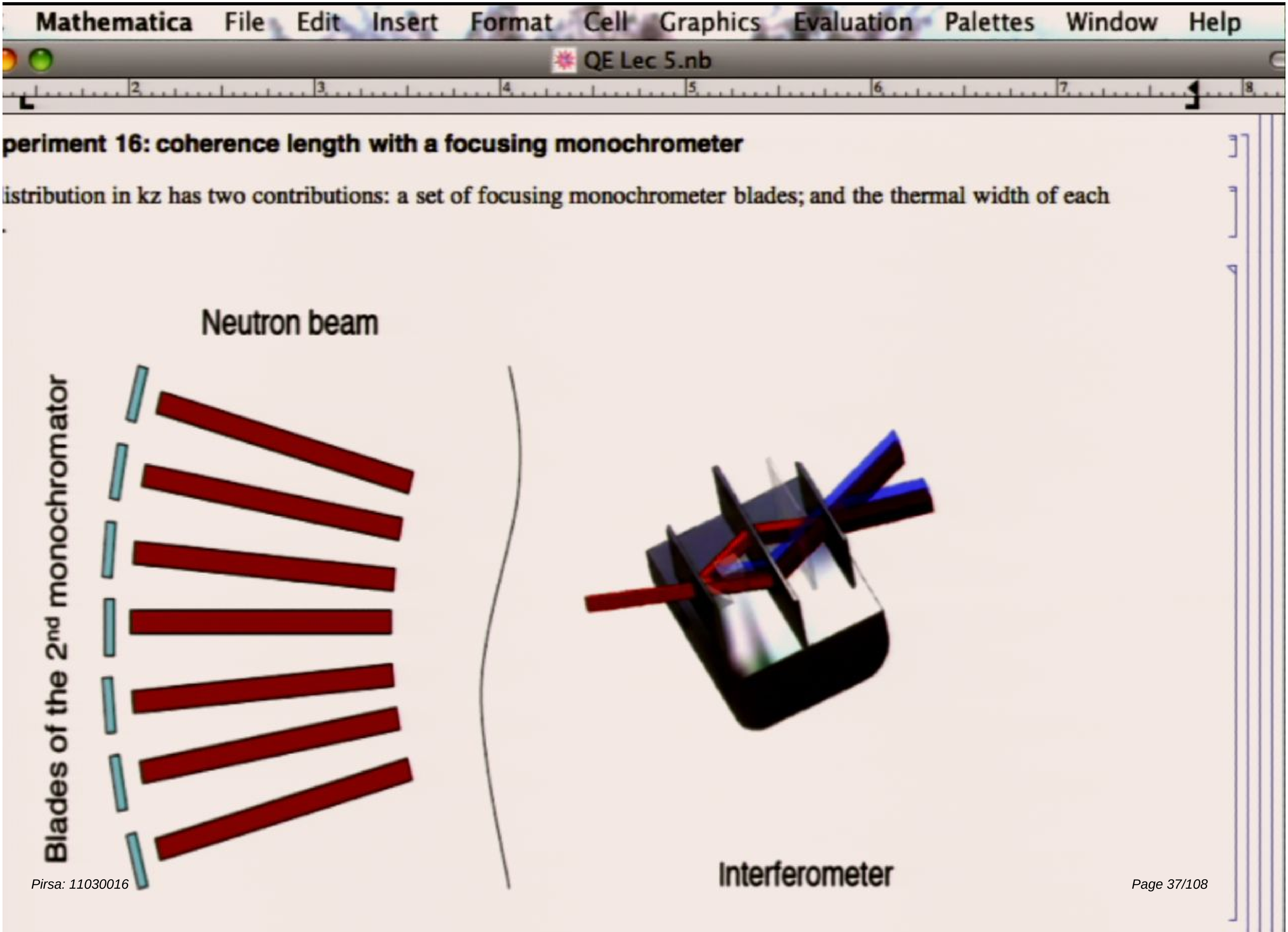

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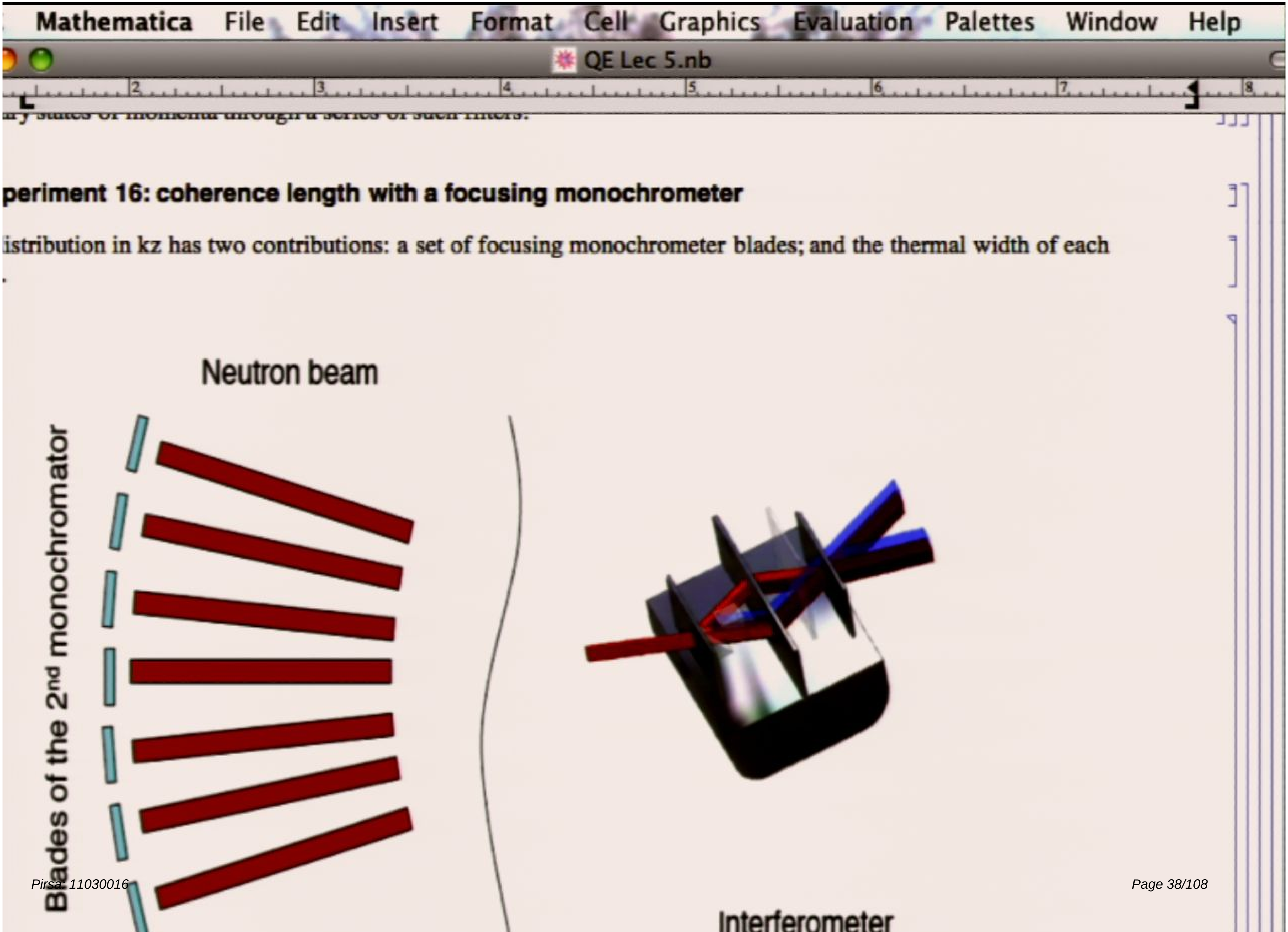

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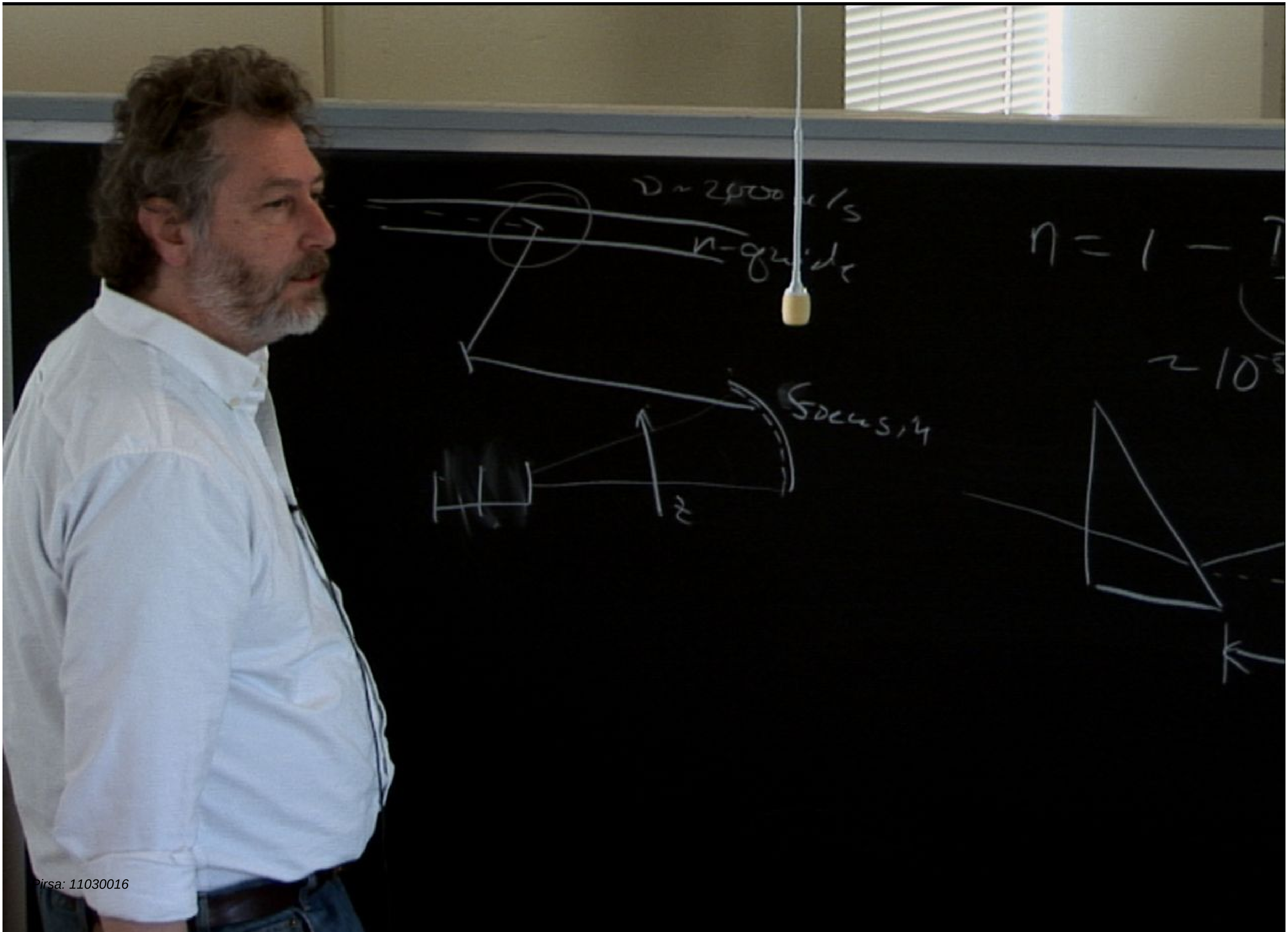
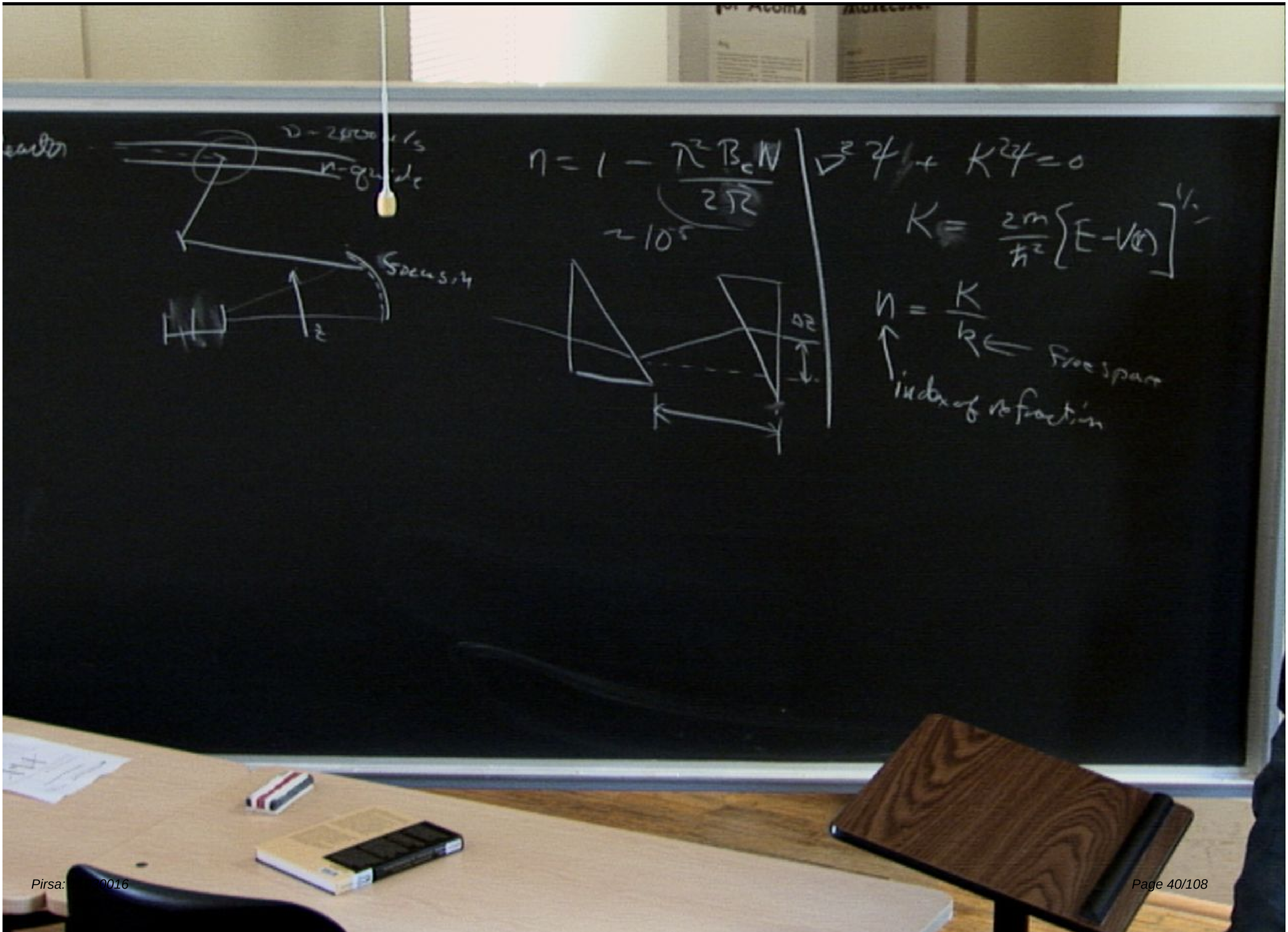
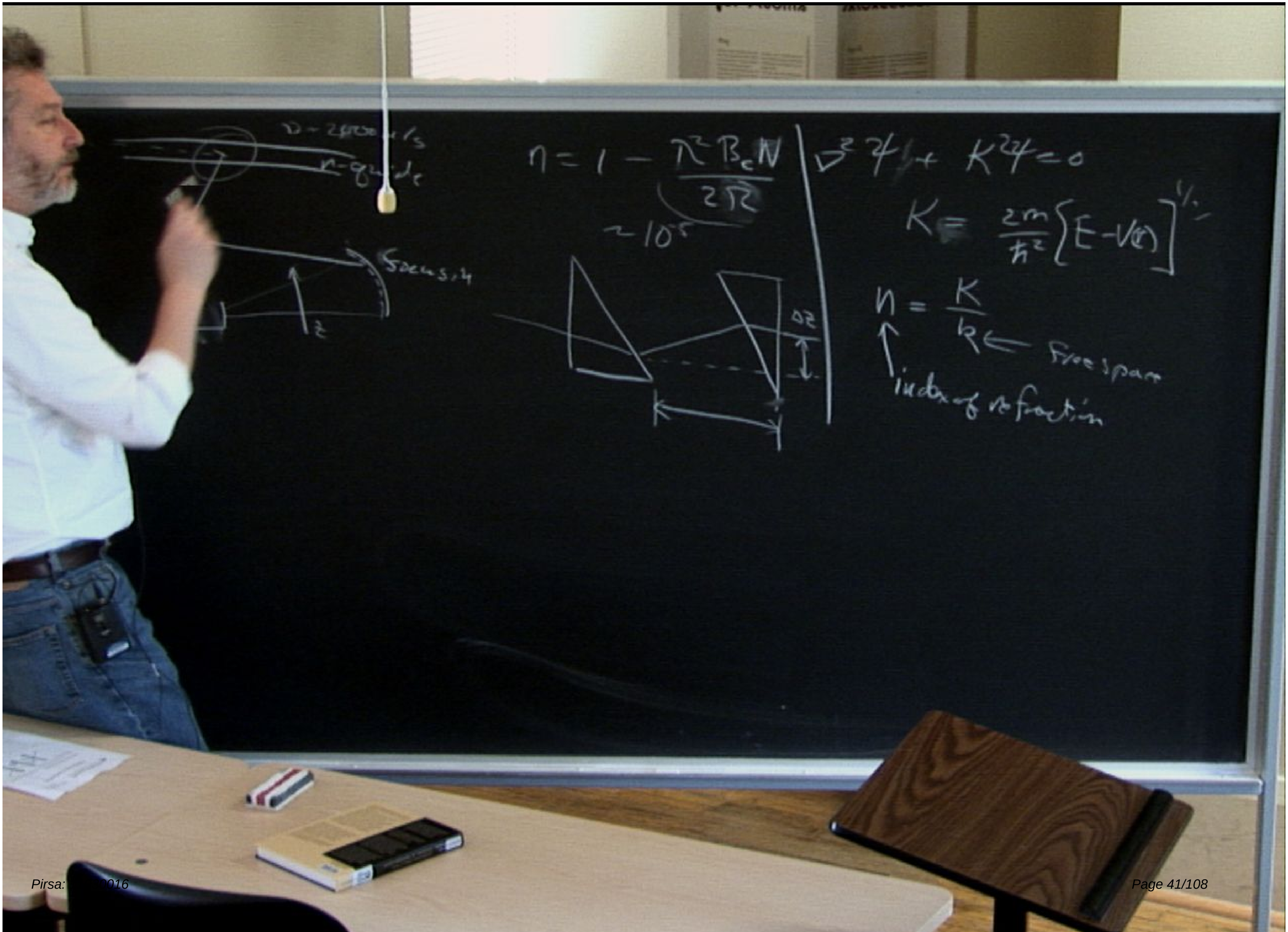
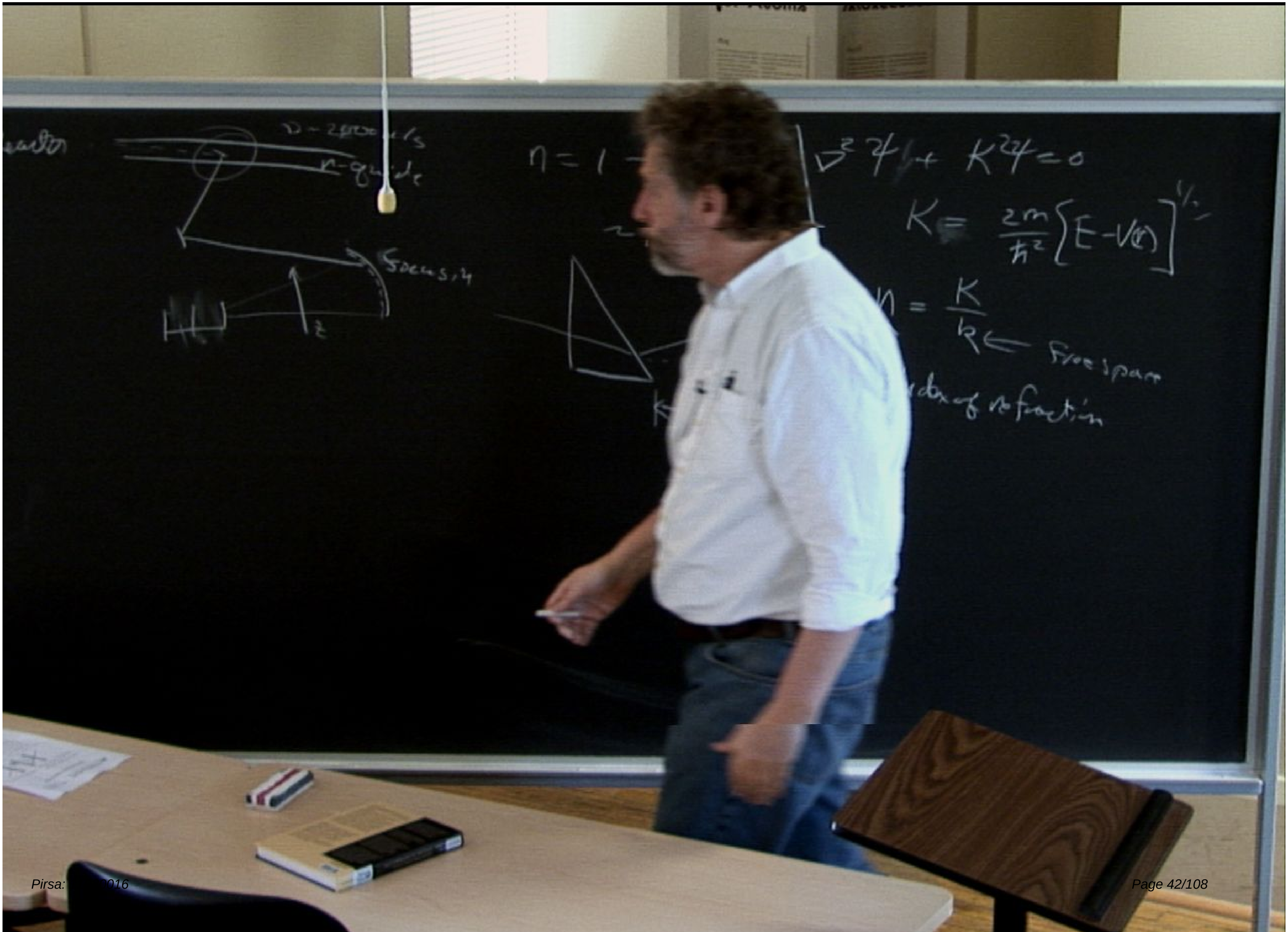
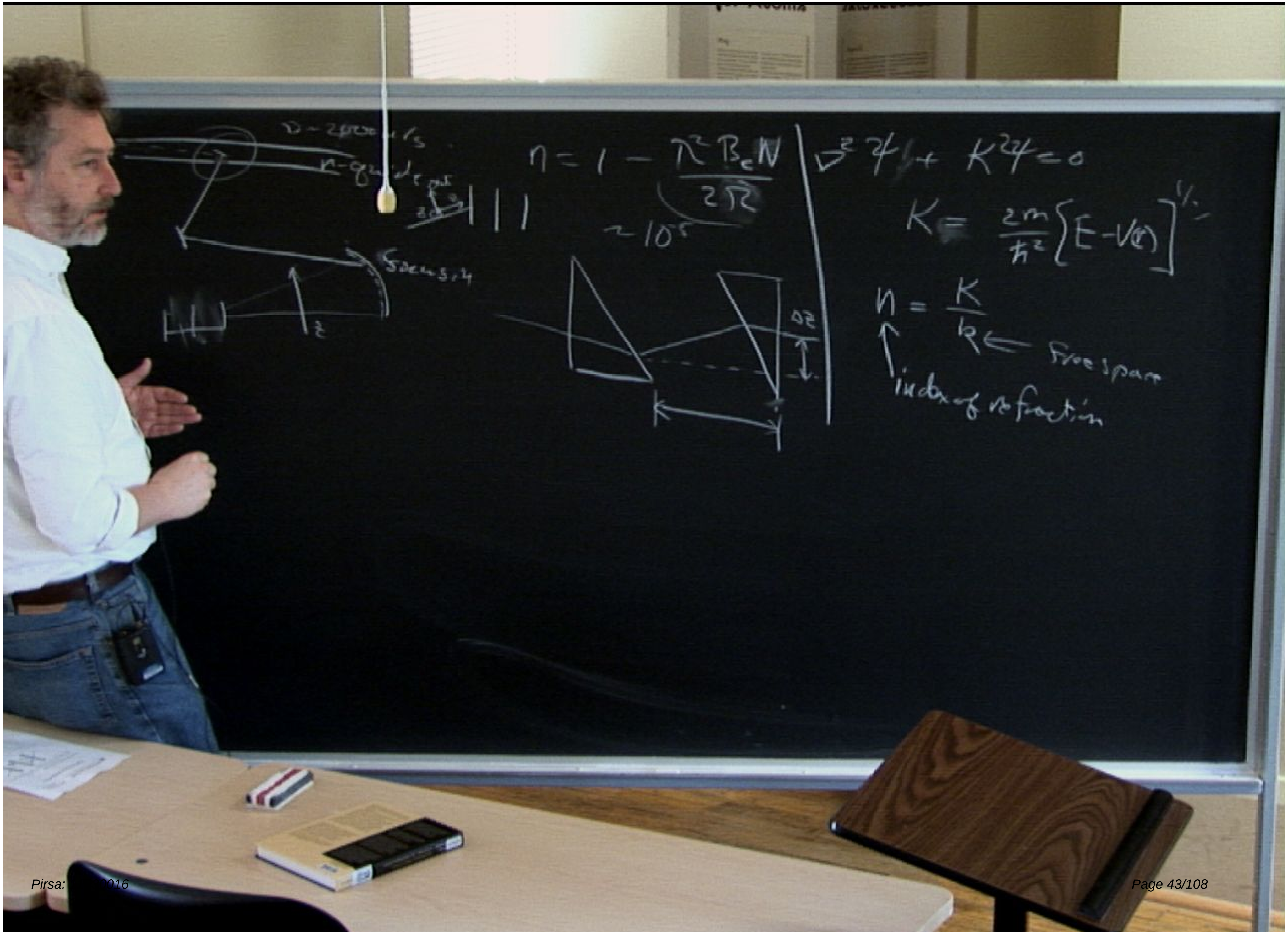

v ~ 2000 m/s
n-guide
n = 1 −
~10
focusing
z

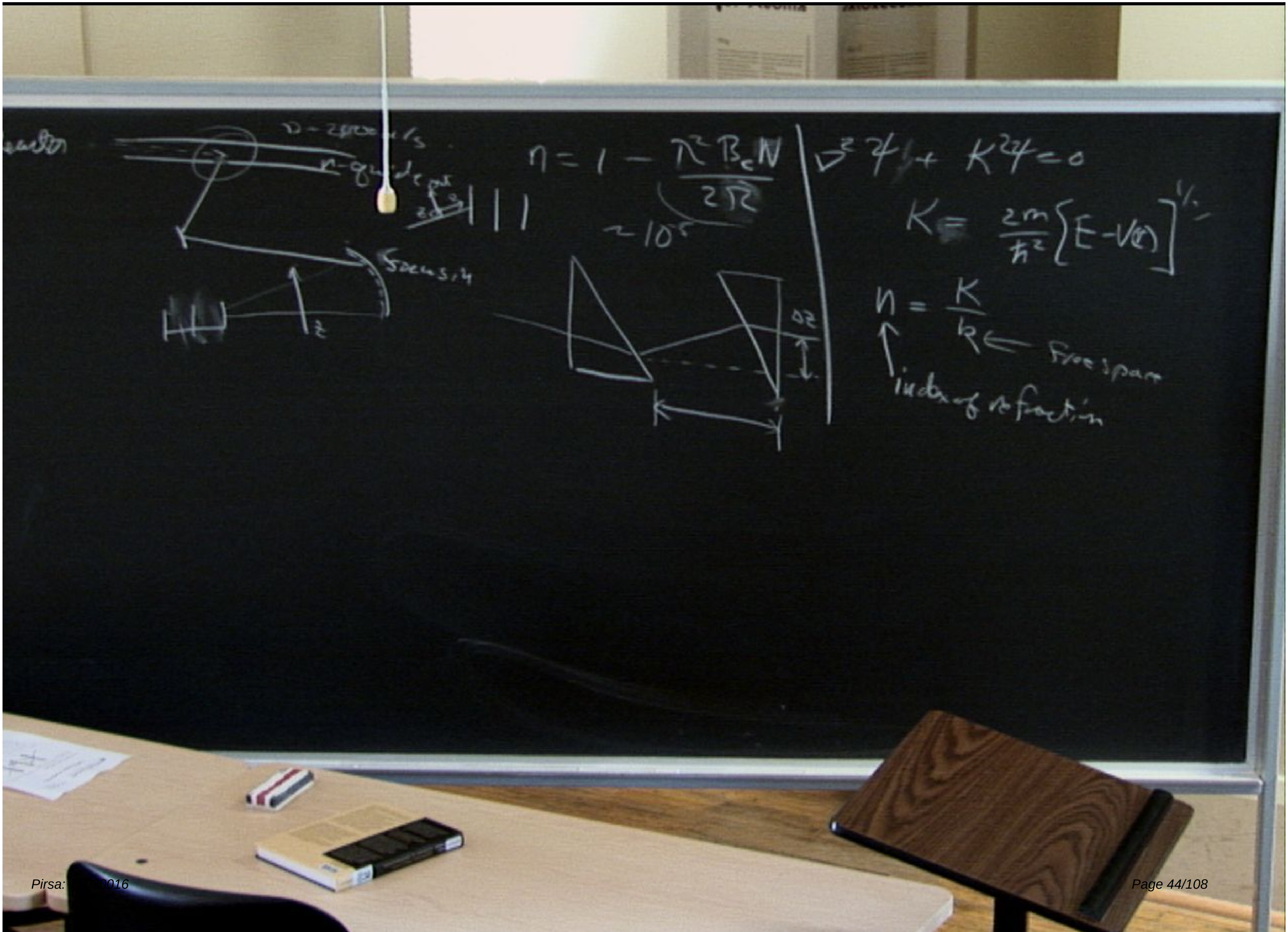


reactor
v ~ 2500 m/s
n-guide
focusing
z
$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$
~ 10^-5
Δz
$\nabla^2 \psi + K^2 \psi = 0$
$K = \frac{2m}{\hbar^2}\left[E - V(r)\right]^{1/2}$
$n = \frac{K}{k}$
free space
index of refraction


v ~ 2000 m/s
n-guide
focusing
z
$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$
$\sim 10^{-5}$
Δz
$\nabla^2 \psi + K^2 \psi = 0$
$K = \frac{2m}{\hbar^2}\left[E - V(r)\right]^{1/2}$
$n = \frac{K}{k}$
free space
index of refraction


v ~ 2000 m/s
n-guide
focus, 4
z
n = 1 −
∇²ψ + K²ψ = 0
K = 2m/ħ² [E − V(r)]^1/2
n = K/k ← free space
index of refraction


n-guide
Speeds, 4
z
n = 1 − λ²B_cN / 2π
~10⁵
Δz
∇²ψ + K²ψ = 0
K = 2m/ħ² [E − V(r)]^½
n = K/k
free space
index of refraction



$$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$$

$\sim 10^5$

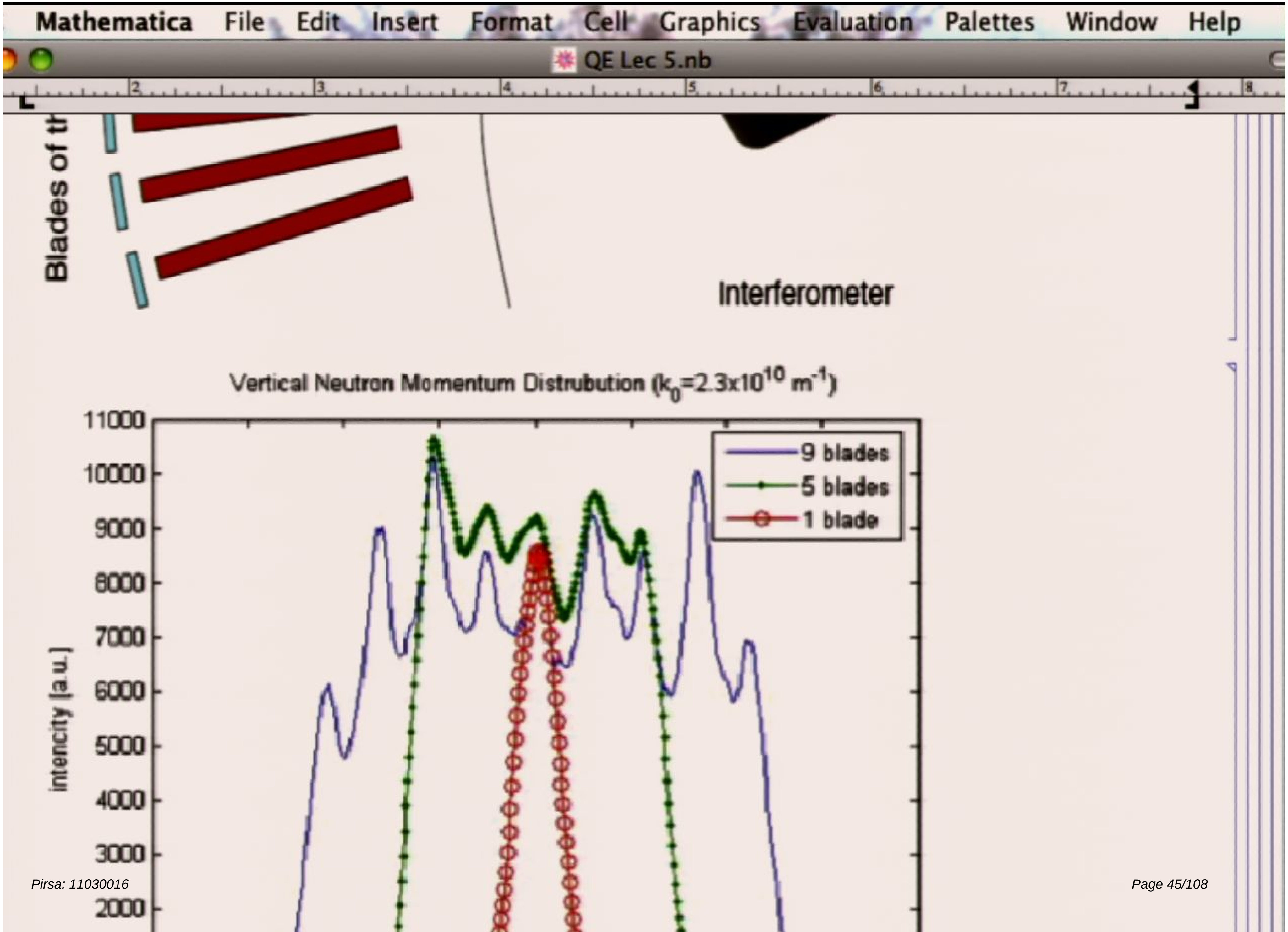
$$\nabla^2 \psi + K^2 \psi = 0$$

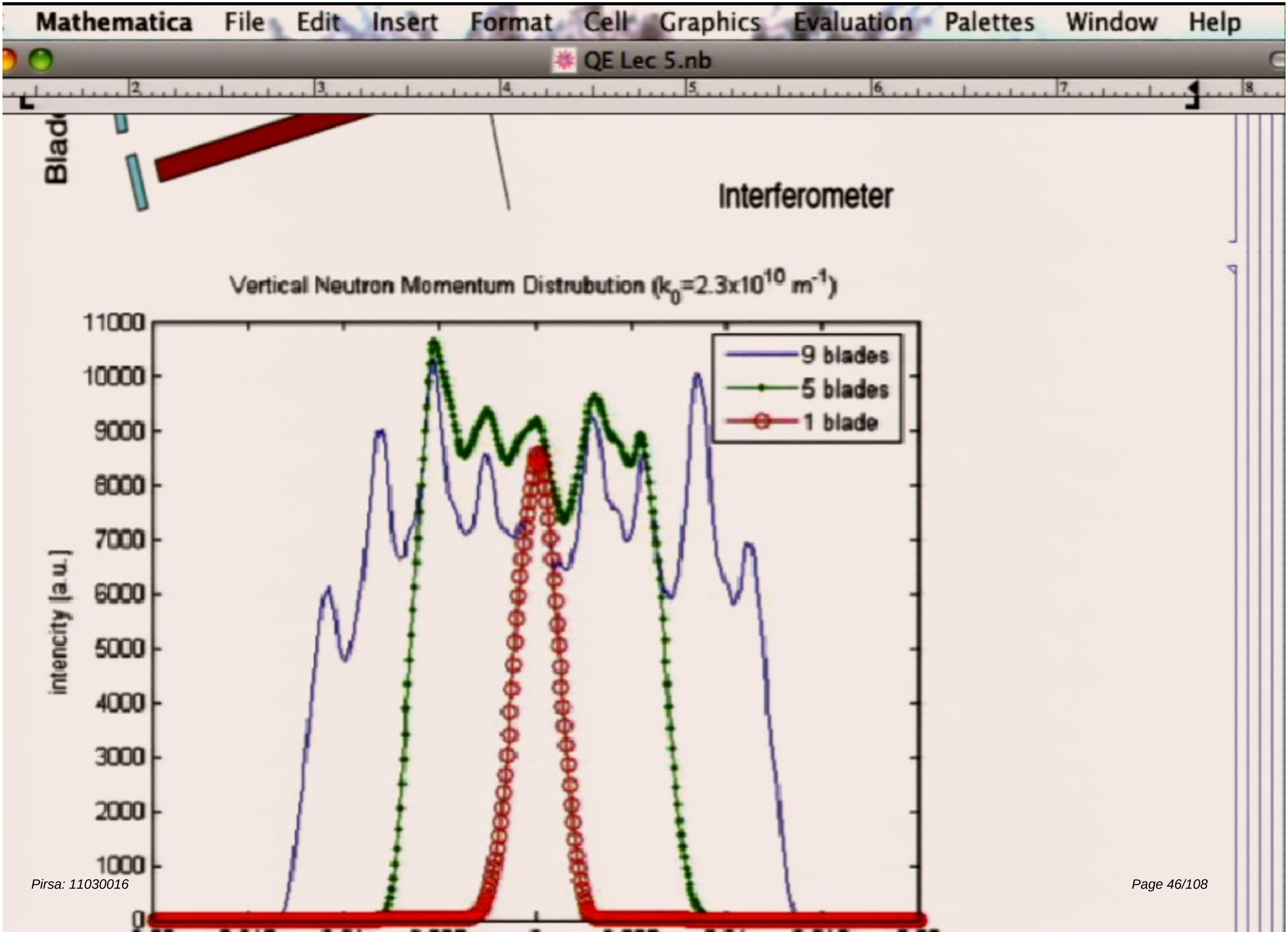
$$K = \frac{2m}{\hbar^2}\left\{E - V(r)\right]^{1/2}$$

$$n = \frac{K}{k}$$

free space

index of refraction


Mathematica
File
Edit
Insert
Format
Cell
Graphics
Evaluation
Palettes
Window
Help
QE Lec 5.nb
2
3
4
5
6
7
8
Blades of th
Interferometer
Vertical Neutron Momentum Distrubution (k_0=2.3x10^{10} m^{-1})
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
intencity [a.u.]
9 blades
5 blades
1 blade


Mathematica
File
Edit
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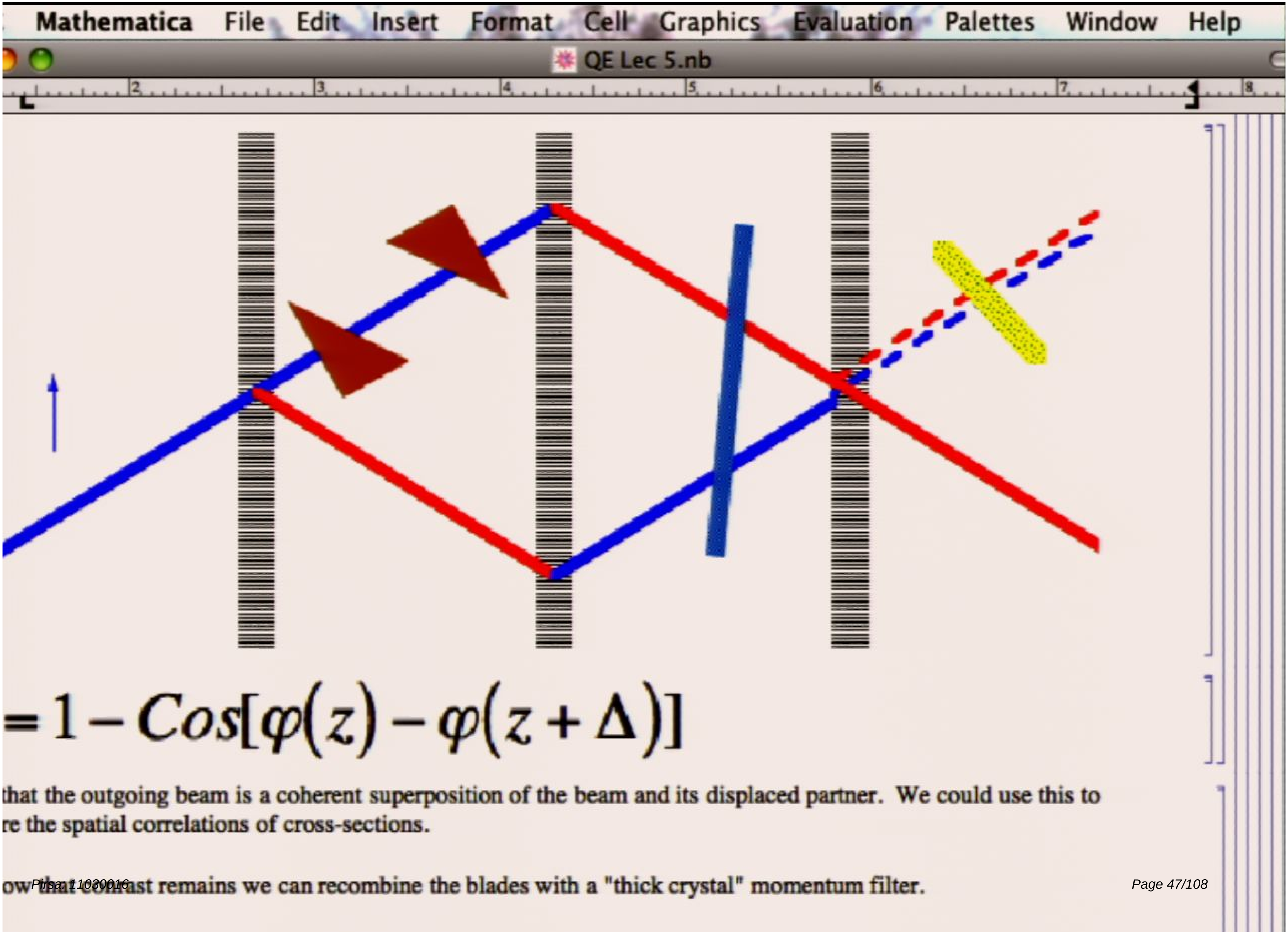
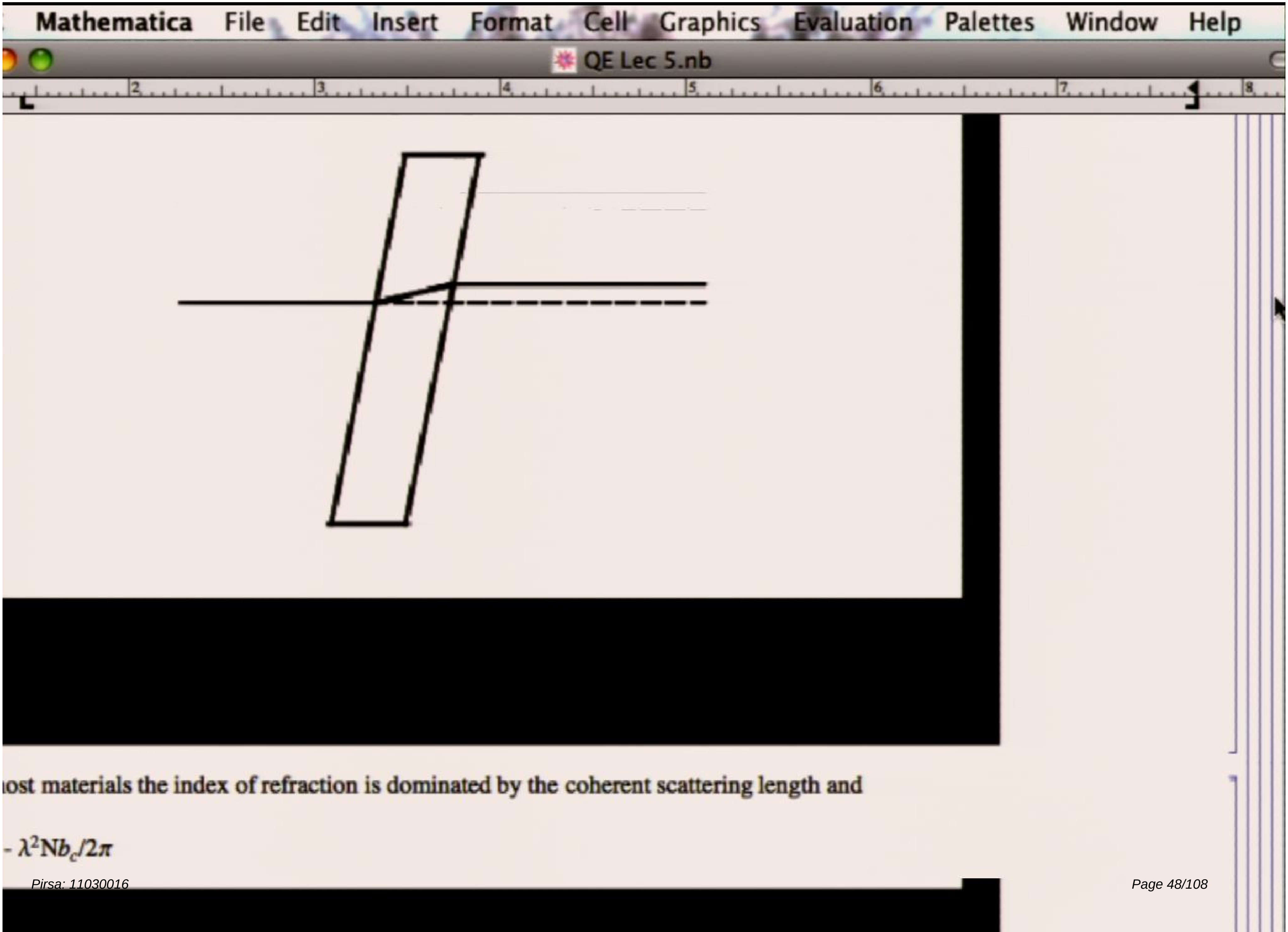
Format
Cell
Graphics
Evaluation
Palettes
Window
Help
QE Lec 5.nb
Blad
Interferometer
Vertical Neutron Momentum Distrubution (k_0=2.3x10^{10} m^{-1})
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
intencity [a.u.]
9 blades
5 blades
1 blade



$$= 1 - Cos[\varphi(z) - \varphi(z + \Delta)]$$

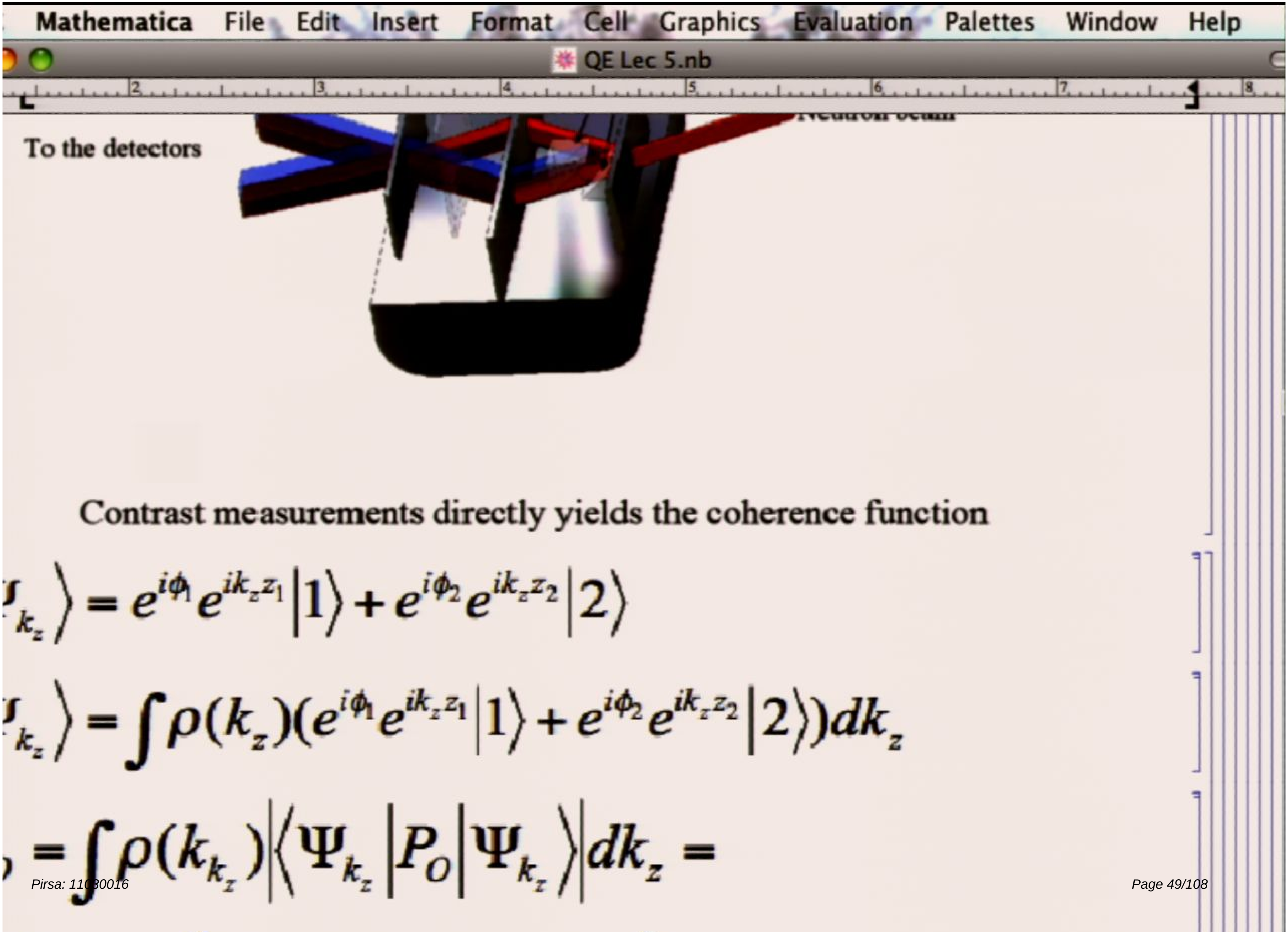
that the outgoing beam is a coherent superposition of the beam and its displaced partner. We could use this to
re the spatial correlations of cross-sections.

ow that contrast remains we can recombine the blades with a "thick crystal" momentum filter.



ost materials the index of refraction is dominated by the coherent scattering length and

- $\lambda^2 N b_c/2\pi$

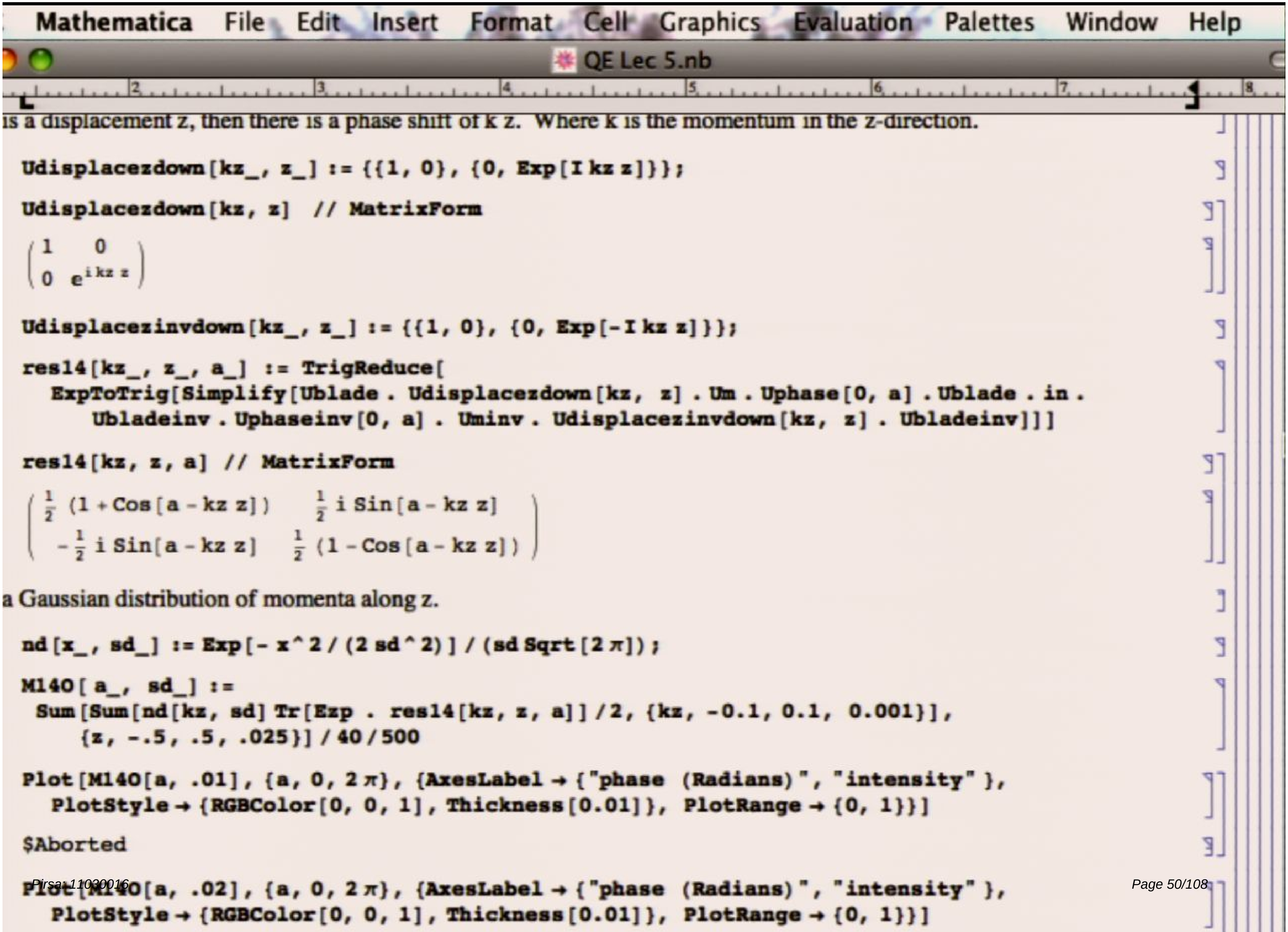


Contrast measurements directly yields the coherence function

$$\ _{k_z}\rangle = e^{i\phi_1}e^{ik_z z_1}\left|1\right\rangle + e^{i\phi_2}e^{ik_z z_2}\left|2\right\rangle$$

$$\ _{k_z}\rangle = \int \rho(k_z)(e^{i\phi_1}e^{ik_z z_1}\left|1\right\rangle + e^{i\phi_2}e^{ik_z z_2}\left|2\right\rangle)dk_z$$

$$= \int \rho(k_{k_z})\left|\left\langle \Psi_{k_z}\right|P_O\left|\Psi_{k_z}\right\rangle\right|dk_z =$$



is a displacement z, then there is a phase shift of k z. Where k is the momentum in the z-direction.

```
Udisplacezdown[kz_, z_] := {{1, 0}, {0, Exp[I kz z]}};
```

```
Udisplacezdown[kz, z]  // MatrixForm
```

$$\begin{pmatrix} 1 & 0 \\ 0 & e^{i\,kz\,z} \end{pmatrix}$$

```
Udisplacezinvdown[kz_, z_] := {{1, 0}, {0, Exp[-I kz z]}};
```

```
res14[kz_, z_, a_]  := TrigReduce[
  ExpToTrig[Simplify[Ublade . Udisplacezdown[kz,  z] . Um . Uphase[0, a] . Ublade . in .
     Ubladeinv . Uphaseinv[0, a] . Uminv . Udisplacezinvdown[kz,  z] . Ubladeinv]]]
```

```
res14[kz, z, a] // MatrixForm
```

$$\begin{pmatrix} \frac{1}{2}\,(1 + \mathrm{Cos}[a - kz\,z]) & \frac{1}{2}\,i\,\mathrm{Sin}[a - kz\,z] \\ -\frac{1}{2}\,i\,\mathrm{Sin}[a - kz\,z] & \frac{1}{2}\,(1 - \mathrm{Cos}[a - kz\,z]) \end{pmatrix}$$

a Gaussian distribution of momenta along z.

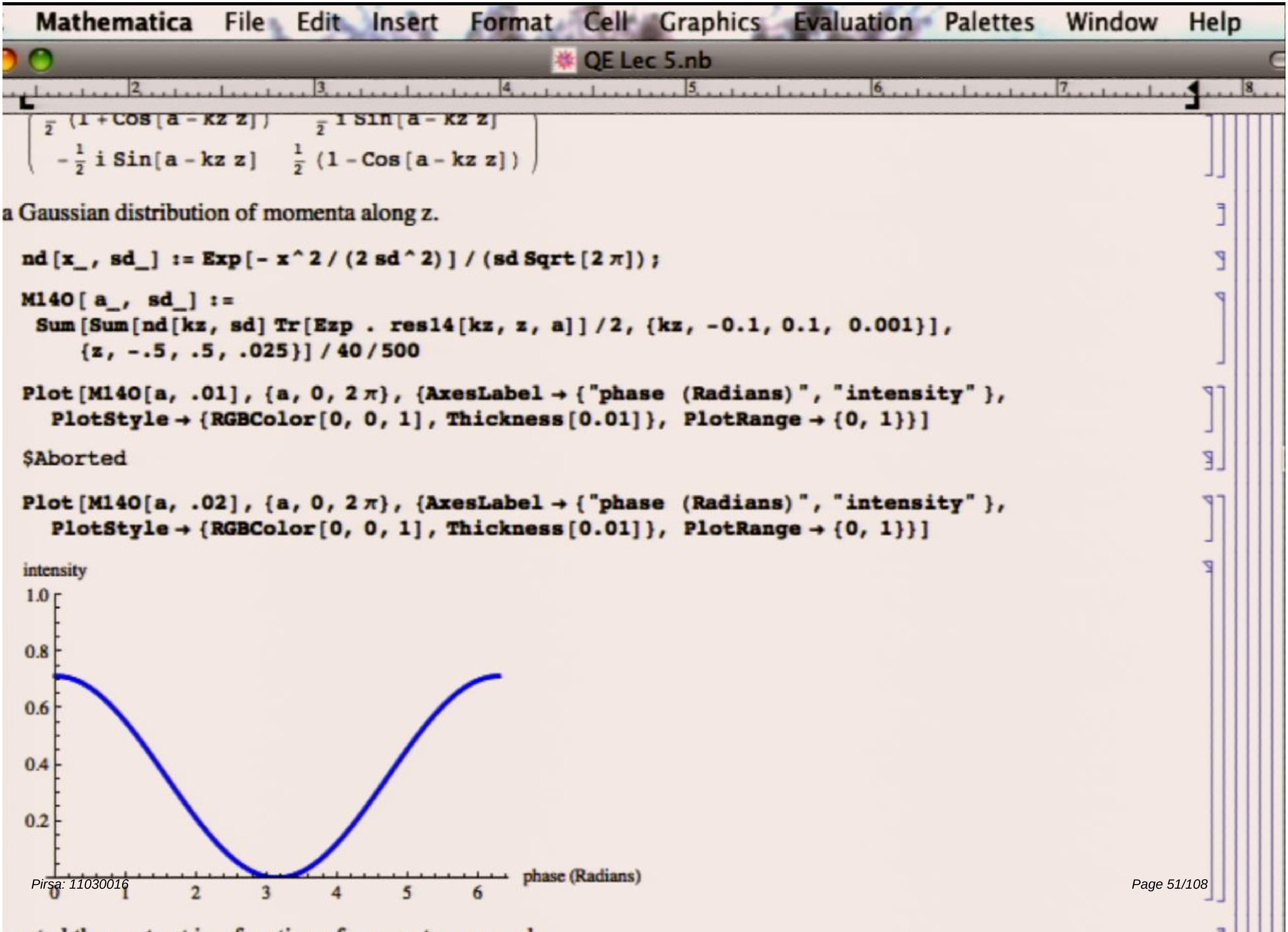
```
nd[x_, sd_] := Exp[- x^2 / (2 sd^2)] / (sd Sqrt[2 π]);
```

```
M140[ a_,  sd_] :=
 Sum[Sum[nd[kz, sd] Tr[Ezp . res14[kz, z, a]] / 2, {kz, -0.1, 0.1, 0.001}],
    {z, -.5, .5, .025}] / 40 / 500
```

```
Plot[M140[a, .01], {a, 0, 2 π}, {AxesLabel → {"phase  (Radians)", "intensity" },
  PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}]
```

```
$Aborted
```

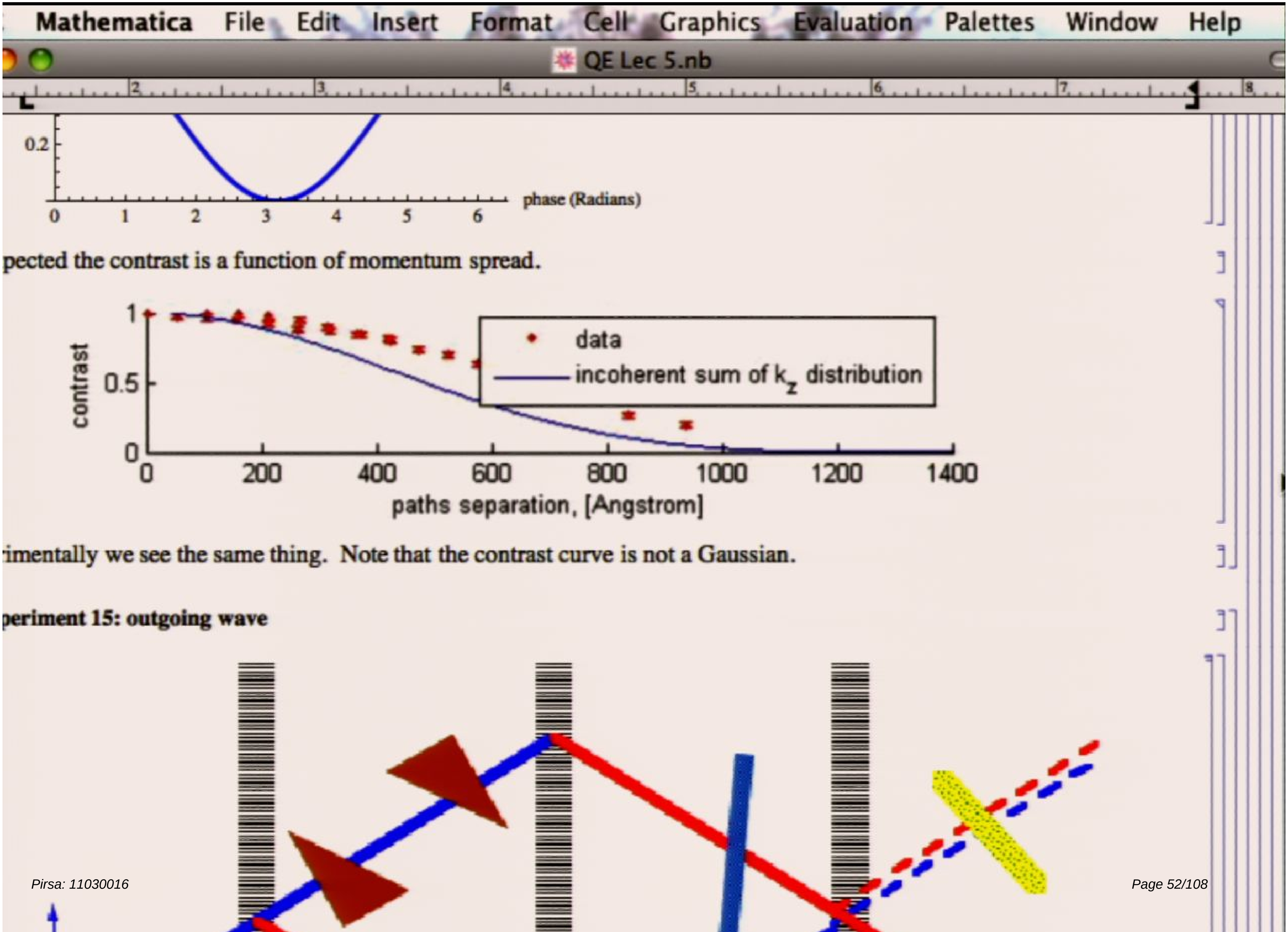
```
Plot[M140[a, .02], {a, 0, 2 π}, {AxesLabel → {"phase  (Radians)", "intensity" },
  PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}]
```



```
 ½ (1 + Cos[a - kz z])    ½ i Sin[a - kz z]
-½ i Sin[a - kz z]     ½ (1 - Cos[a - kz z])
```

a Gaussian distribution of momenta along z.

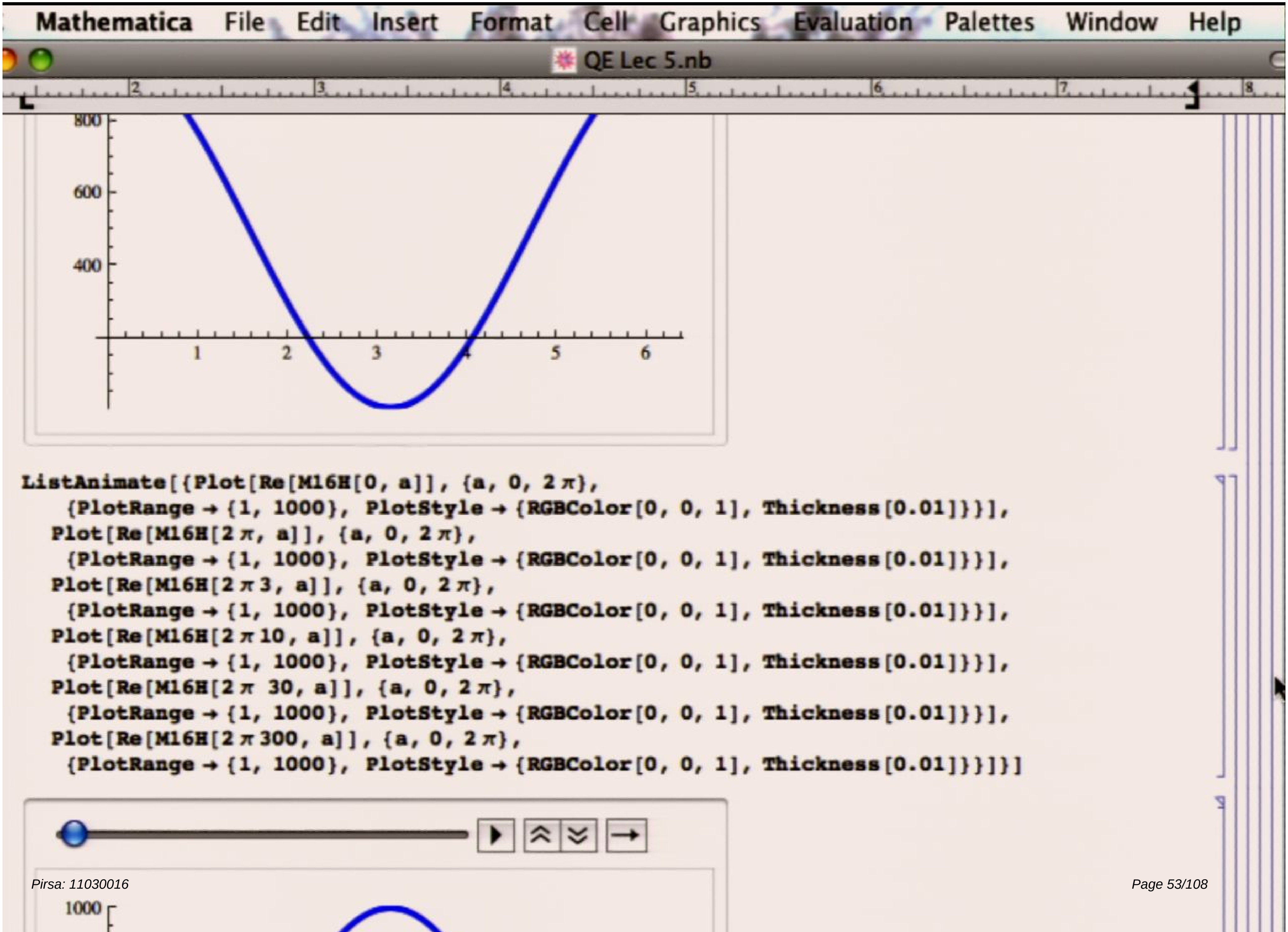
```
nd[x_, sd_] := Exp[- x^2 / (2 sd^2)] / (sd Sqrt[2 π]);

M14O[ a_, sd_] :=
 Sum[Sum[nd[kz, sd] Tr[Ezp . res14[kz, z, a]] / 2, {kz, -0.1, 0.1, 0.001}],
    {z, -.5, .5, .025}] / 40 / 500

Plot[M14O[a, .01], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity" },
  PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}]

$Aborted

Plot[M14O[a, .02], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity" },
  PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}]
```



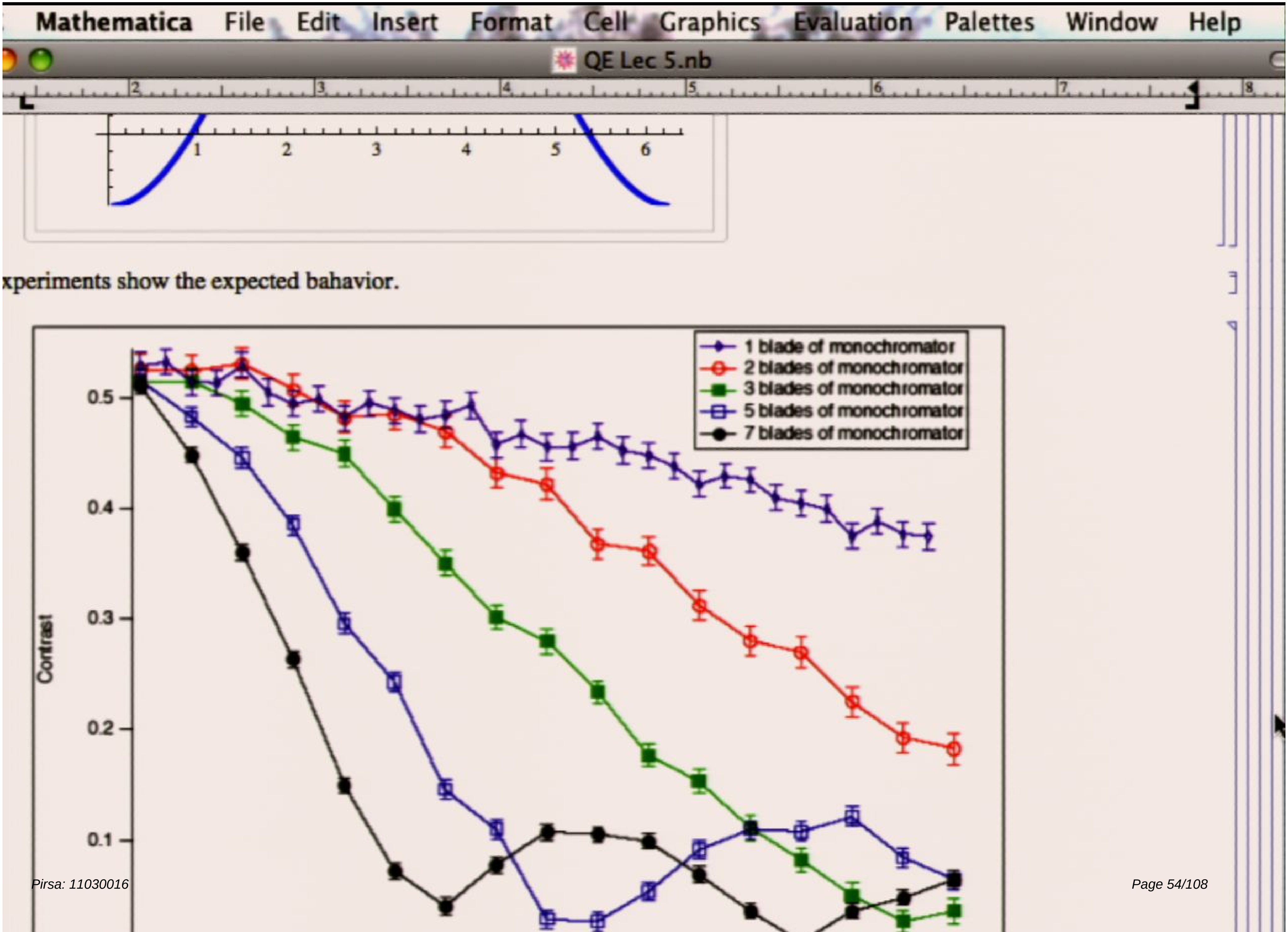
pected the contrast is a function of momentum spread.

imentally we see the same thing. Note that the contrast curve is not a Gaussian.

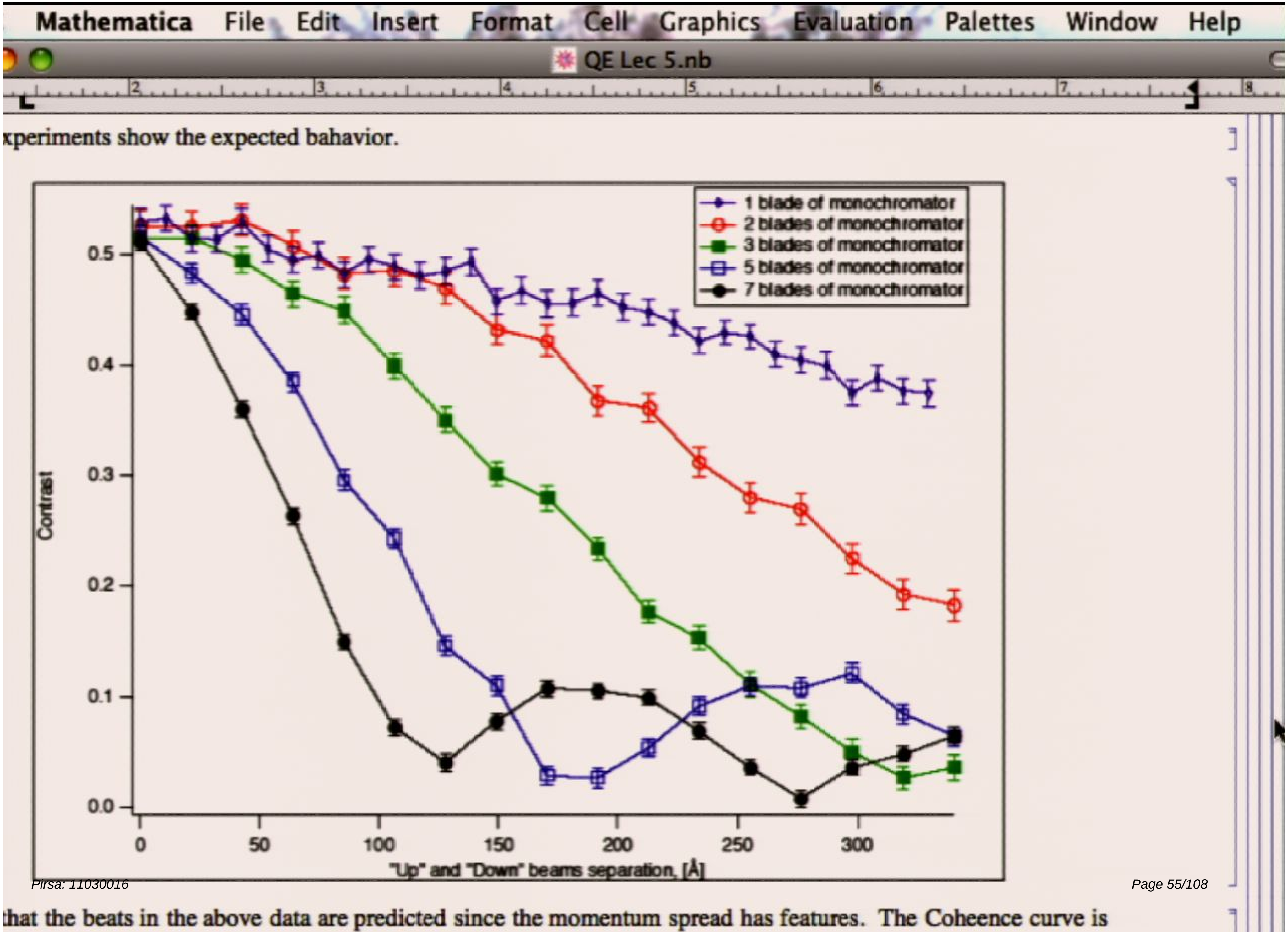
periment 15: outgoing wave



```
ListAnimate[{Plot[Re[M16H[0, a]], {a, 0, 2 π},
    {PlotRange → {1, 1000}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}}],
   Plot[Re[M16H[2 π, a]], {a, 0, 2 π},
    {PlotRange → {1, 1000}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}}],
   Plot[Re[M16H[2 π 3, a]], {a, 0, 2 π},
    {PlotRange → {1, 1000}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}}],
   Plot[Re[M16H[2 π 10, a]], {a, 0, 2 π},
    {PlotRange → {1, 1000}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}}],
   Plot[Re[M16H[2 π  30, a]], {a, 0, 2 π},
    {PlotRange → {1, 1000}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}}],
   Plot[Re[M16H[2 π 300, a]], {a, 0, 2 π},
    {PlotRange → {1, 1000}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}}]}]
```

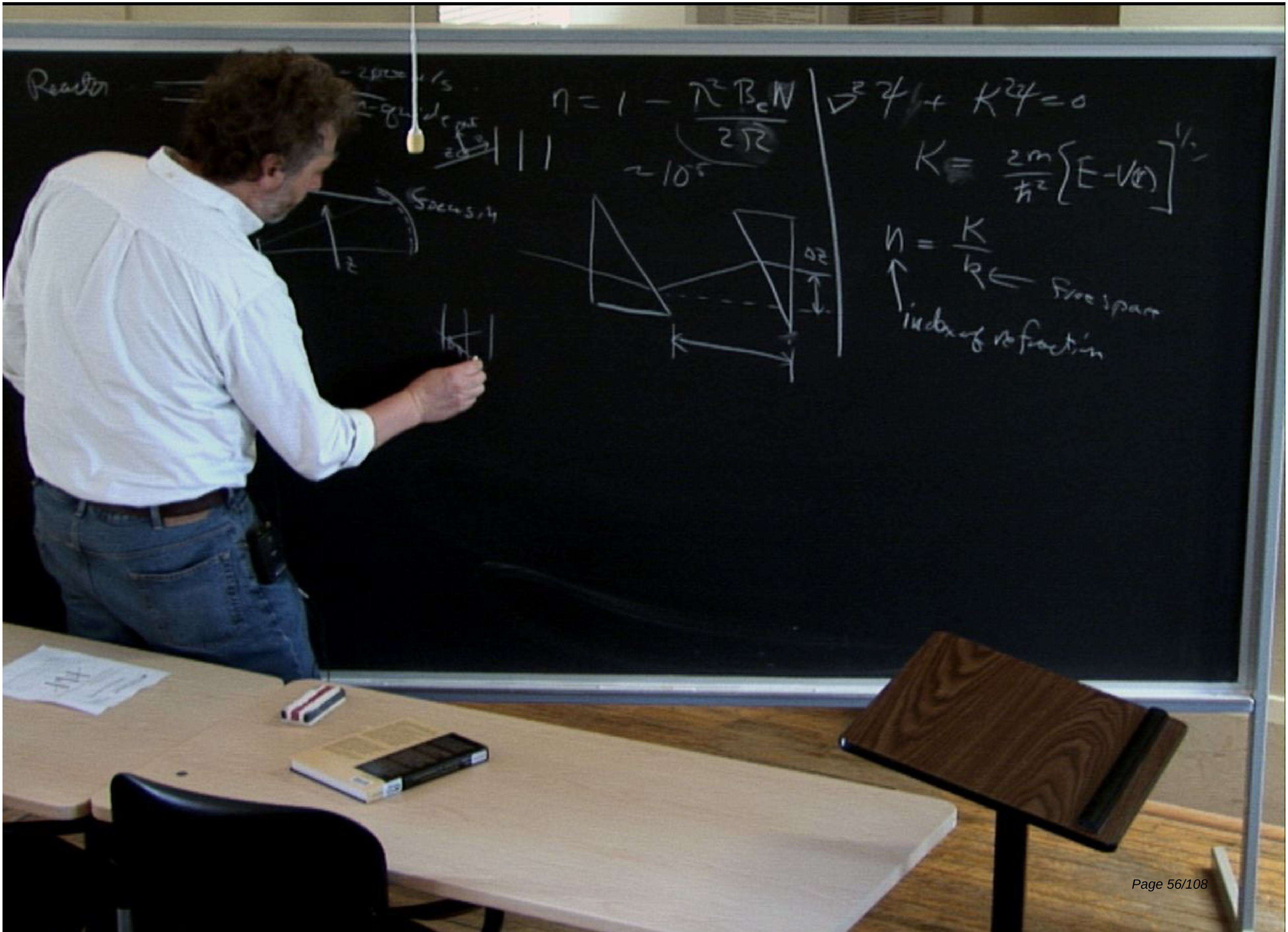


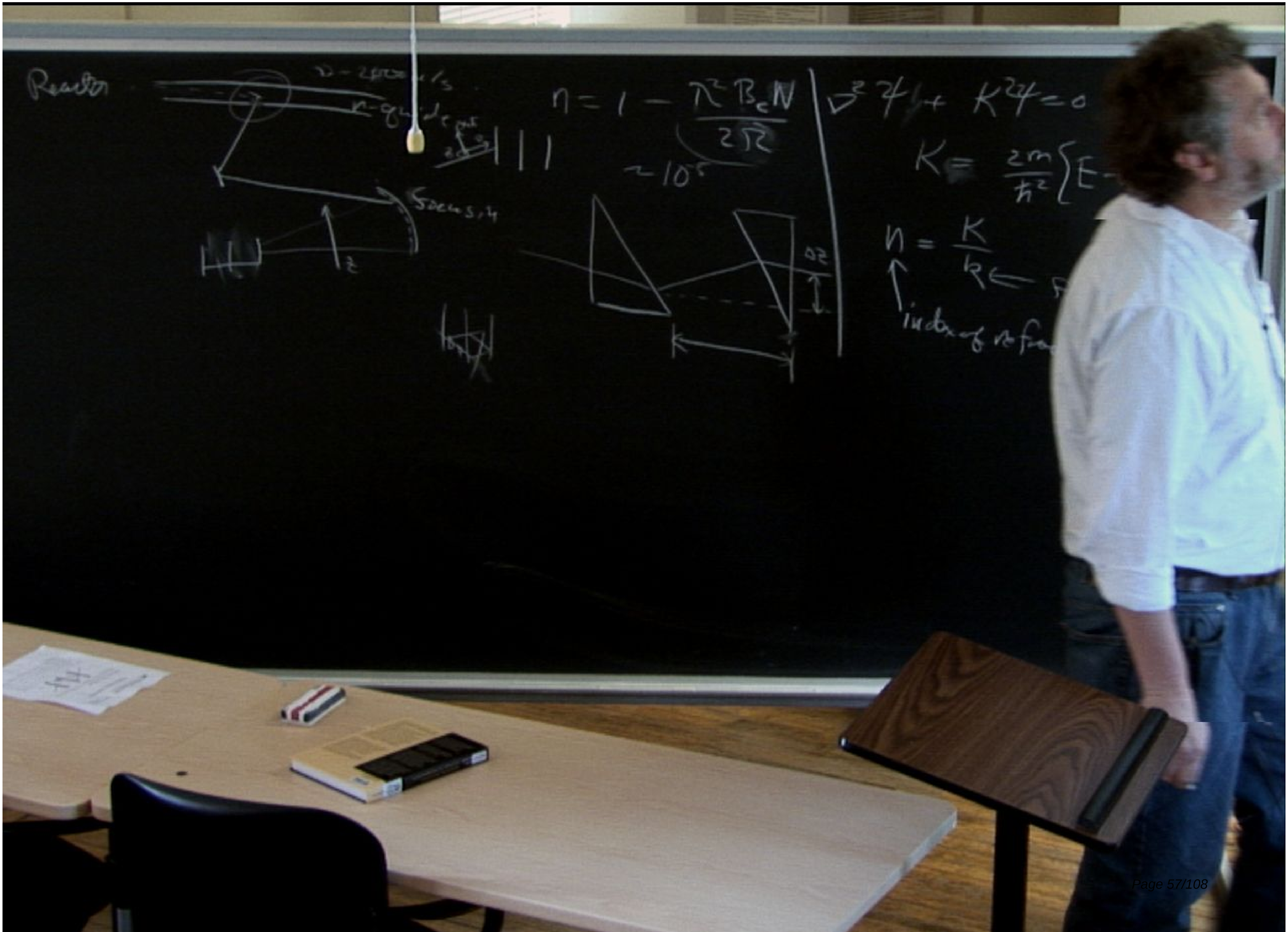
xperiments show the expected bahavior.

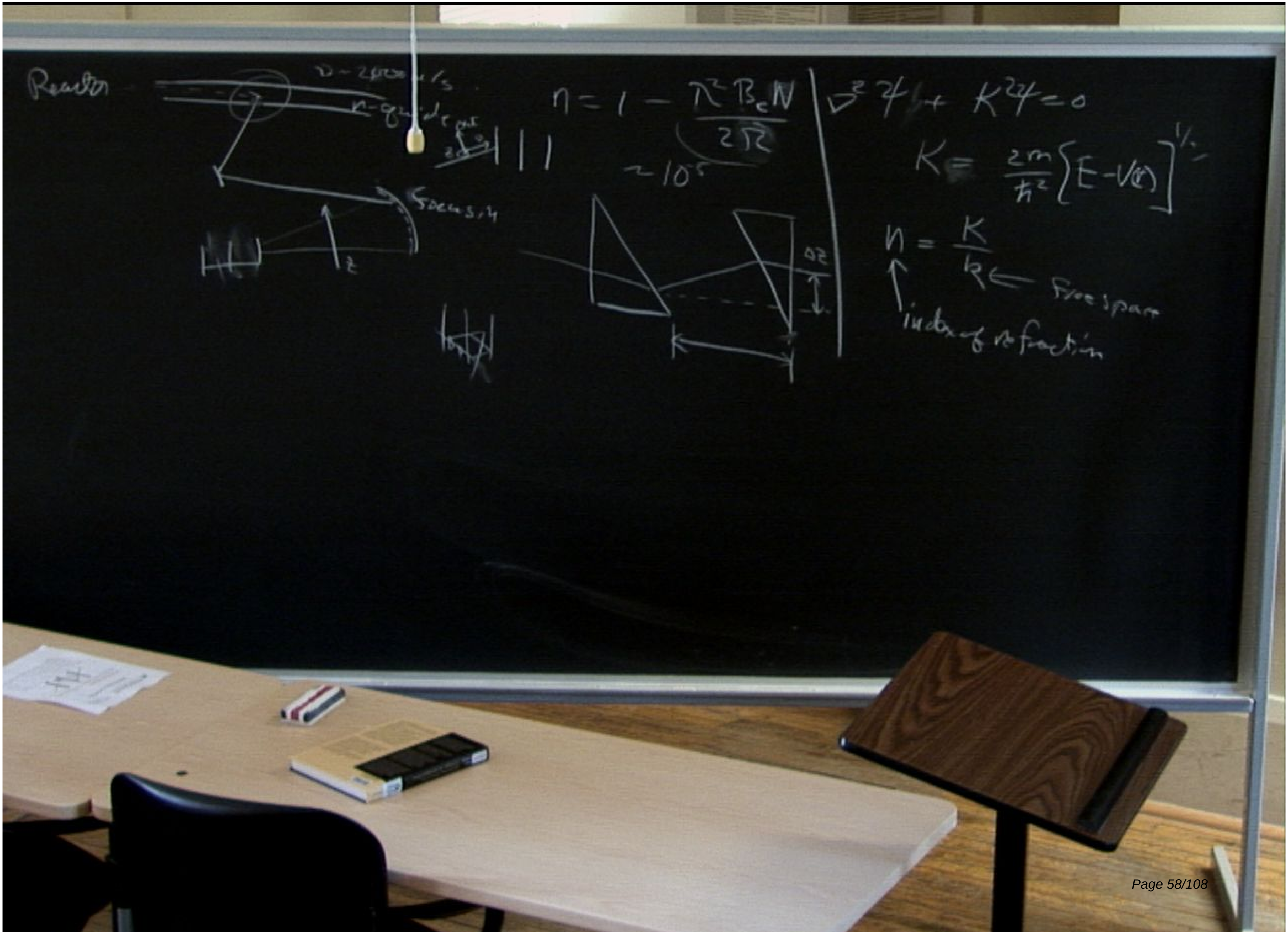


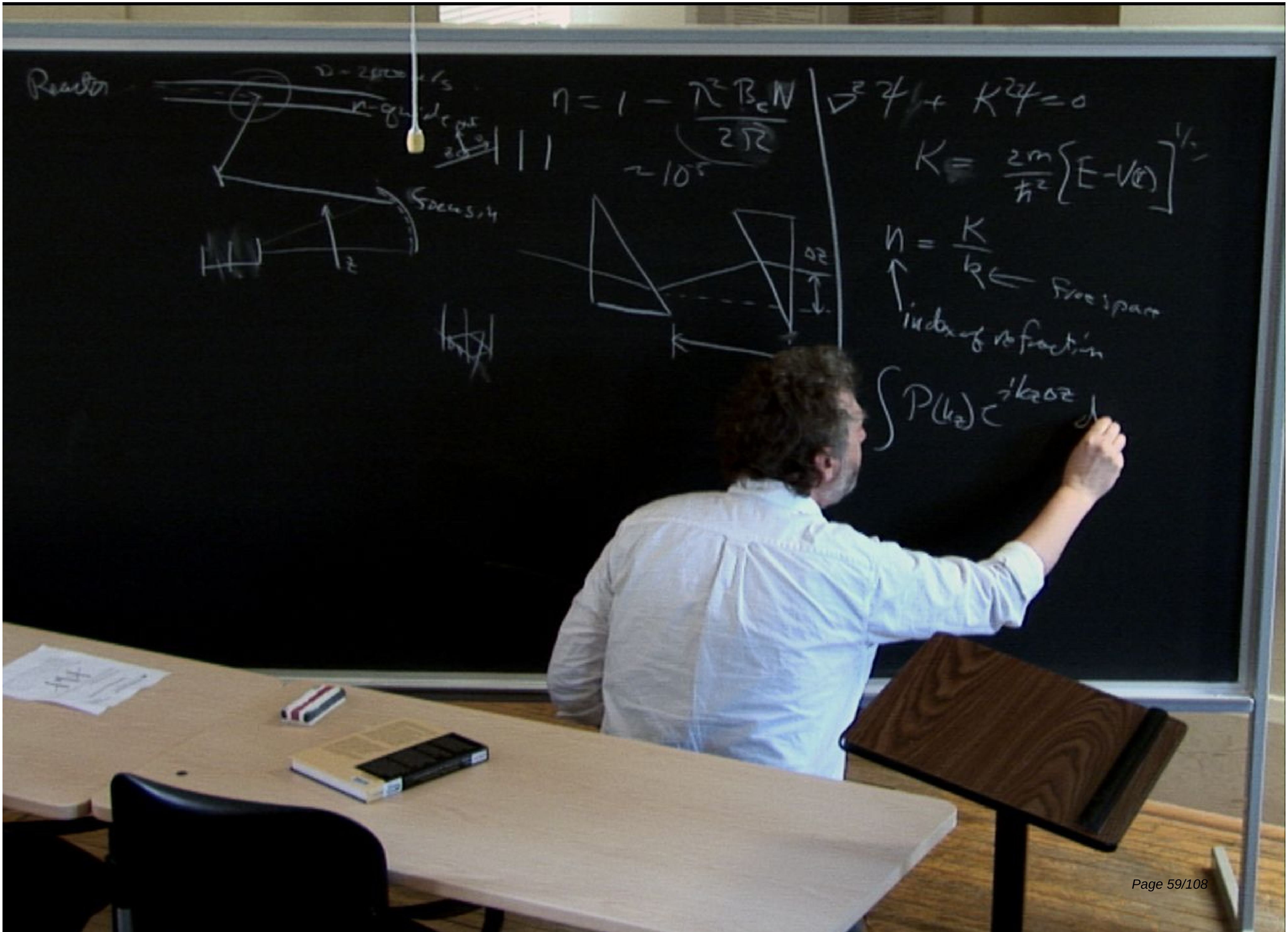
xperiments show the expected bahavior.

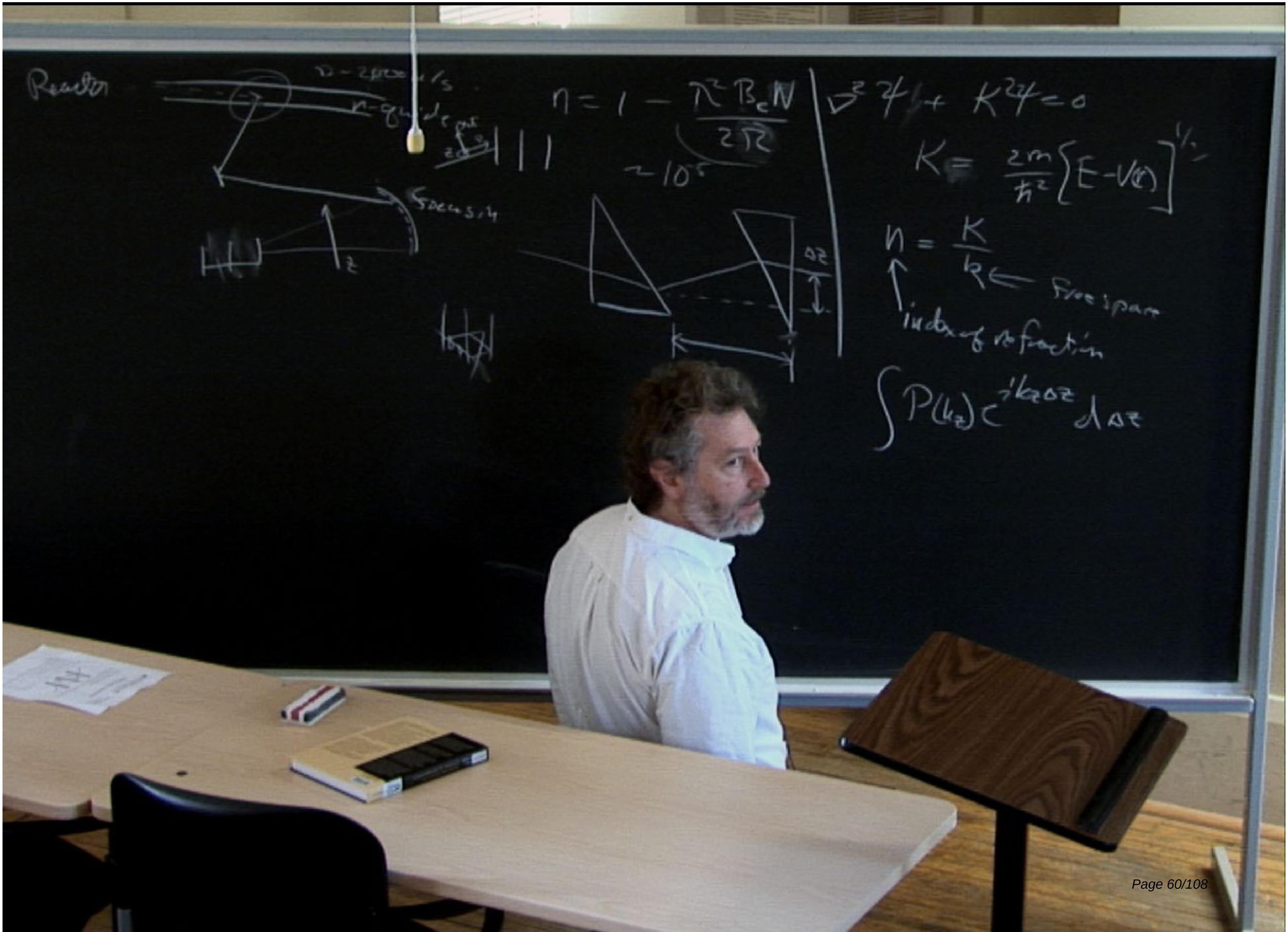
that the beats in the above data are predicted since the momentum spread has features. The Coheence curve is

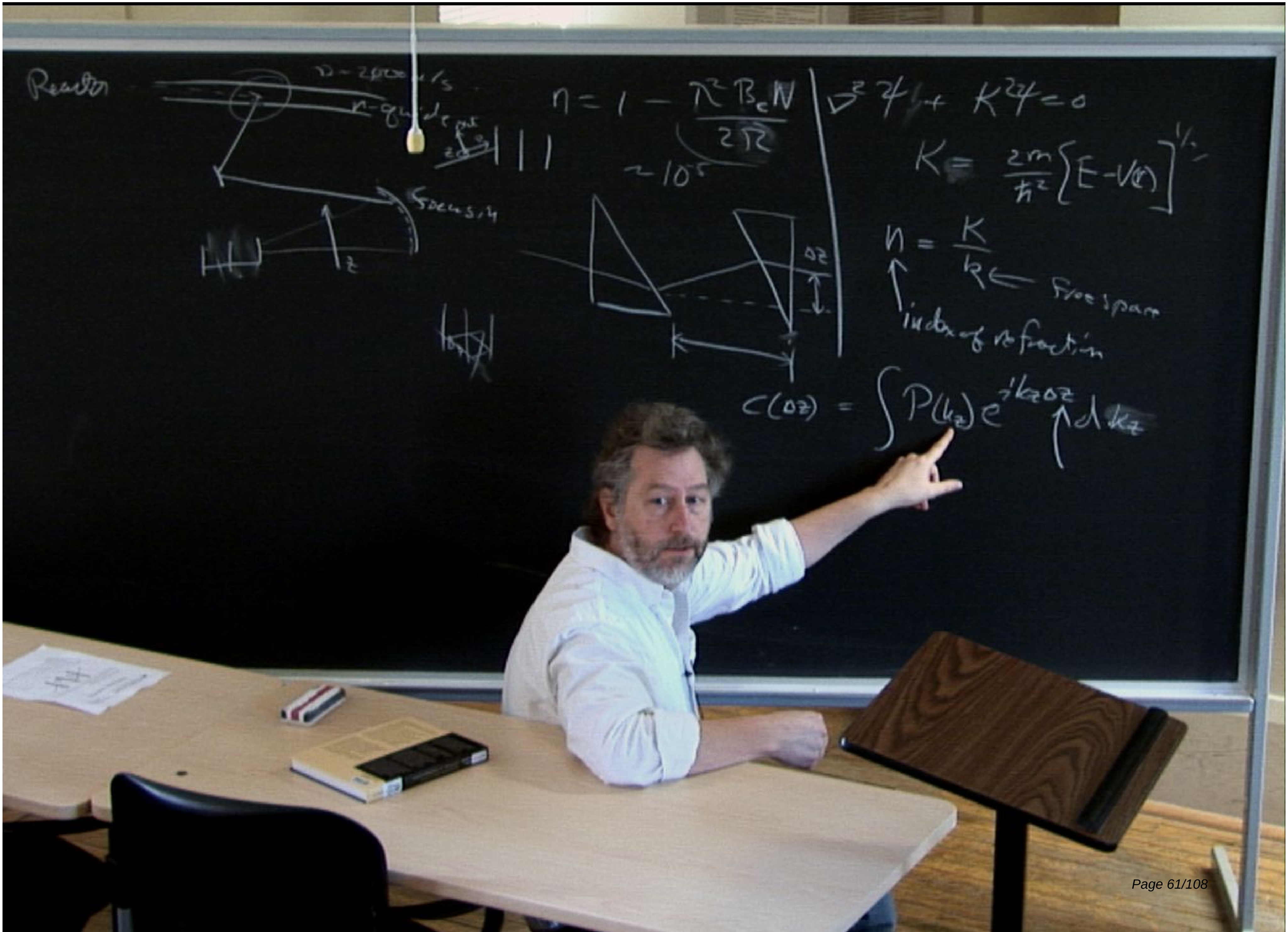

Reactor
n = 1 − π² B_c N / 2π
~10⁻⁵
∇²ψ + K²ψ = 0
K = 2m/ℏ² [E − V(r)]^½
n = K/k
free space
index of refraction
Δz
specular
z

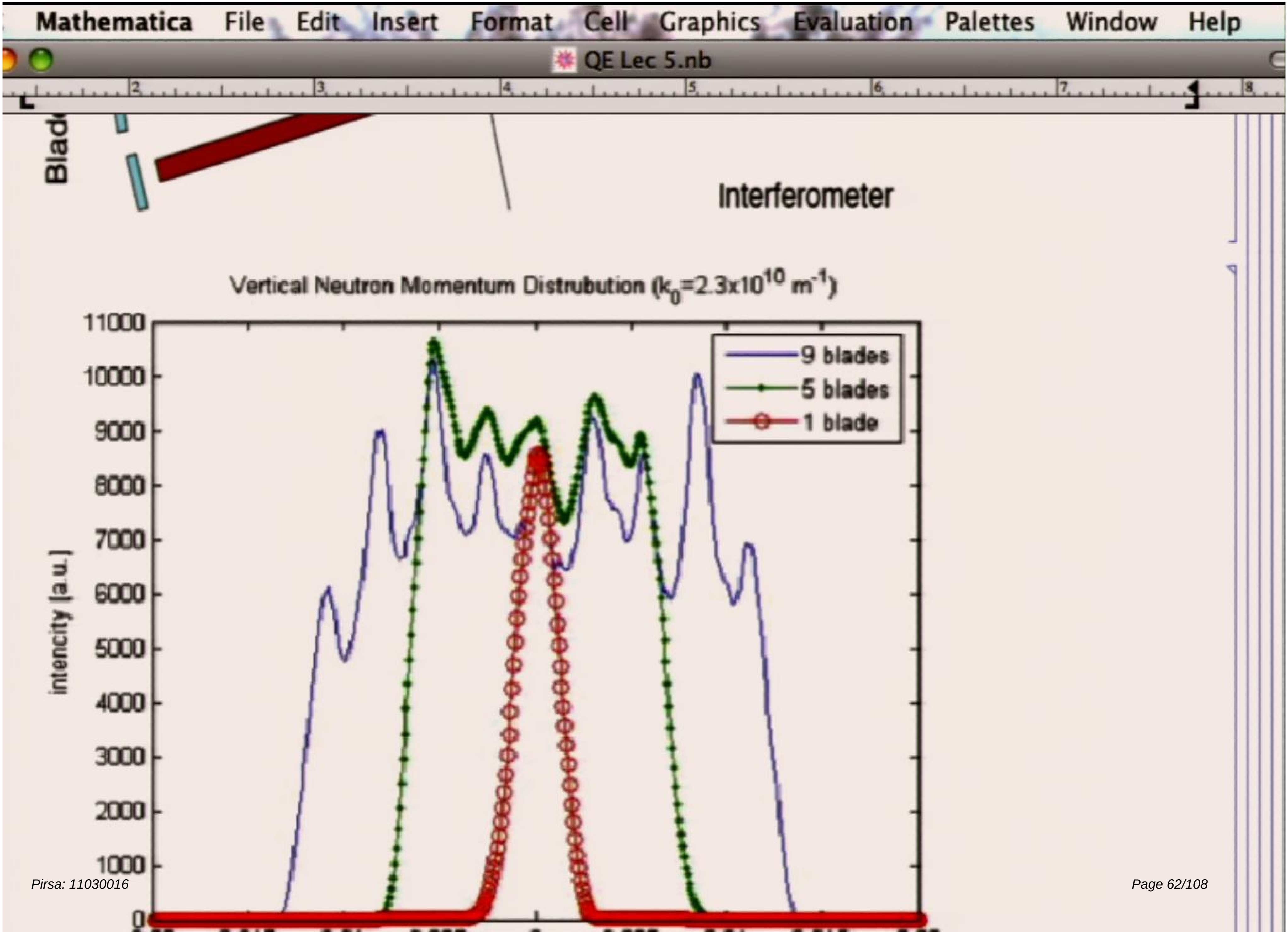

Reactor
v ~ 2800 m/s
n = 1 − λ²B_cN / 2π
~10⁵
∇²ψ + K²ψ = 0
K = 2m/ħ² {E −
n = K/k
index of refrac
Δz

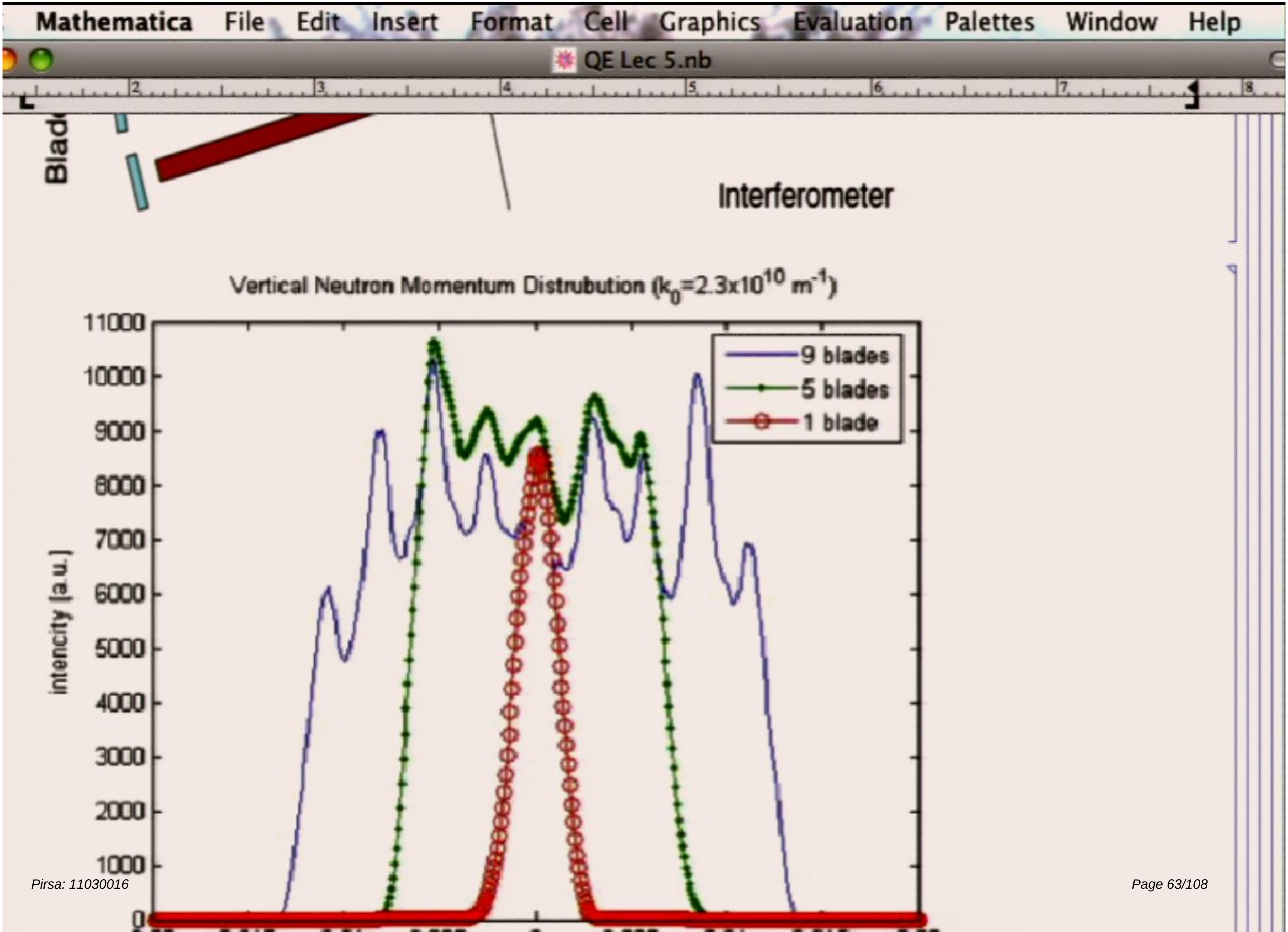

Reactor
$v \sim 2000$ m/s
n-guide
Specimen
z
$n = 1 - \frac{\lambda^2 b_c N}{2\pi}$
$\sim 10^5$
Δz
$\nabla^2\psi + K^2\psi = 0$
$K = \left[\frac{2m}{\hbar^2}\{E - V(r)\}\right]^{1/2}$
$n = \frac{K}{k}$
free space
index of refraction

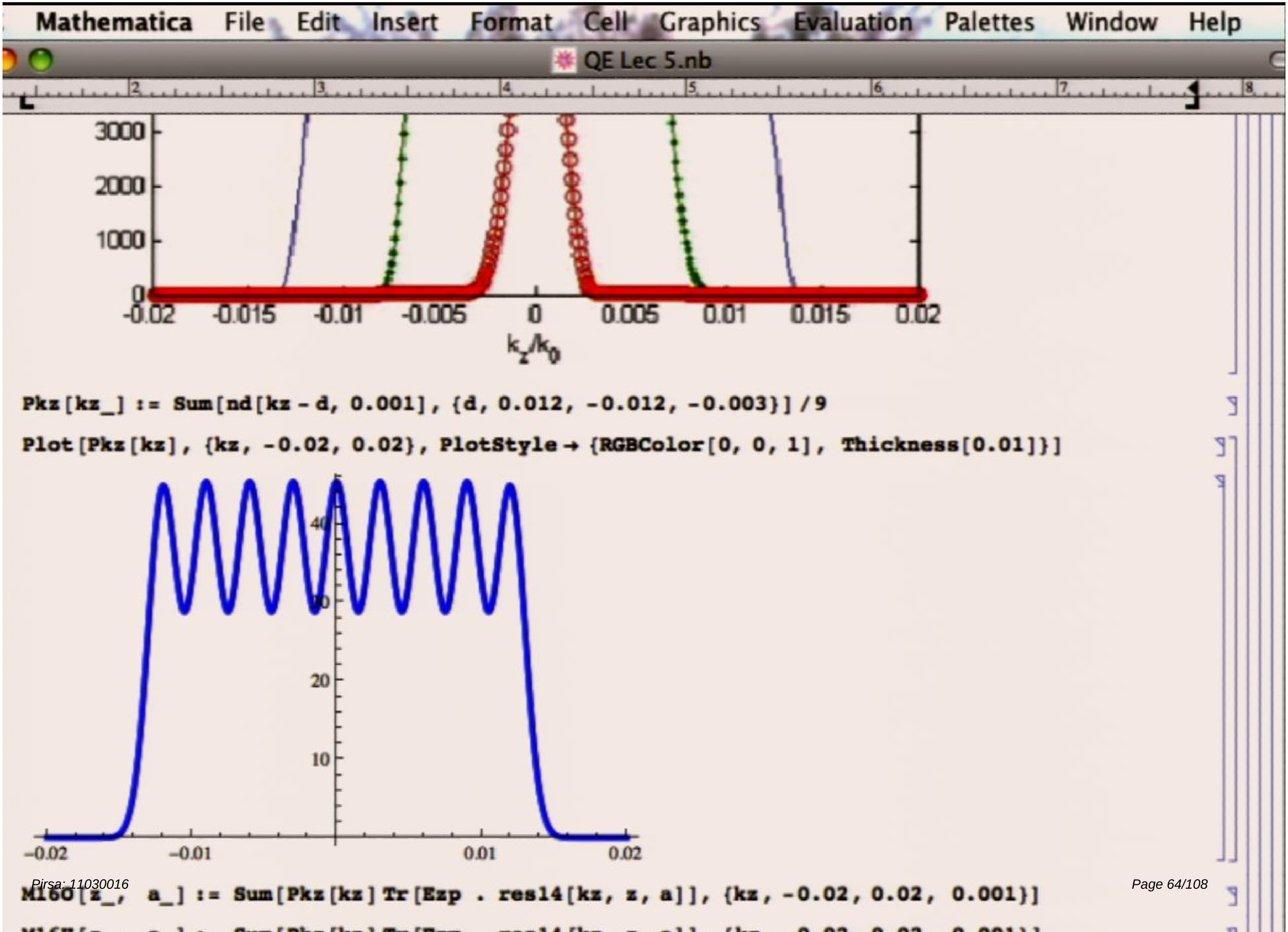

Reactor
v = 2200 m/s
n-guide
Specimen
z
$n = 1 - \frac{\lambda^2 B_c N}{2\pi}$
$\sim 10^{-5}$
Δz
k
$\nabla^2 \psi + K^2 \psi = 0$
$K = \left\{\frac{2m}{\hbar^2}\left[E - V(r)\right]\right\}^{1/2}$
$n = \frac{K}{k}$
free space
index of refraction
$\int P(k_z) e^{ik_z \Delta z} dk$


Reactor
v ~ 2000 m/s
n-guide
specimen
z
n = 1 − λ² B_c N / 2π
~10⁻⁵
Δz
∇²ψ + K²ψ = 0
K = 2m/ħ² [E − V(r)]^1/2
n = K/k
free space
index of refraction
∫ P(k_z) e^{ik_zΔz} dΔz


Reactor
v ~ 2500 m/s
n-guide
specimen
z
n = 1 − λ² B_c N / 2π
~10^5
Δz
∇²ψ + K²ψ = 0
K = 2m/ħ² [E − V(r)]^{1/2}
n = K/k
free space
index of refraction
C(Δz) = ∫ P(k_z) e^{ik_zΔz} dk_z

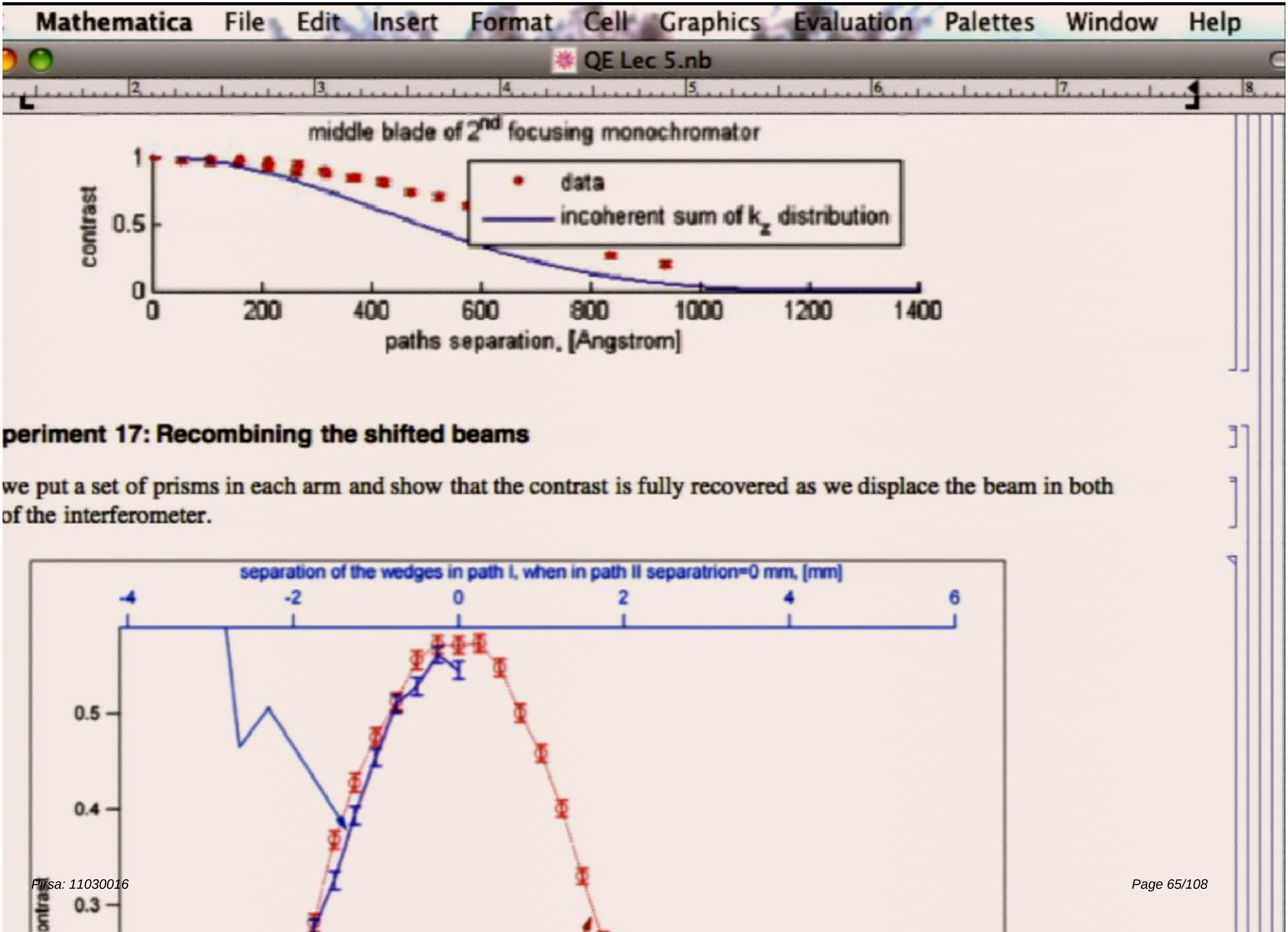

Mathematica
File
Edit
Insert
Format
Cell
Graphics
Evaluation
Palettes
Window
Help
QE Lec 5.nb
Blad
Interferometer
Vertical Neutron Momentum Distrubution (k_0=2.3x10^{10} m^{-1})
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
intencity [a.u.]
9 blades
5 blades
1 blade


Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
QE Lec 5.nb
Blad
Interferometer
Vertical Neutron Momentum Distrubution (k_0=2.3x10^{10} m^{-1})
intencity [a.u.]
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
9 blades
5 blades
1 blade



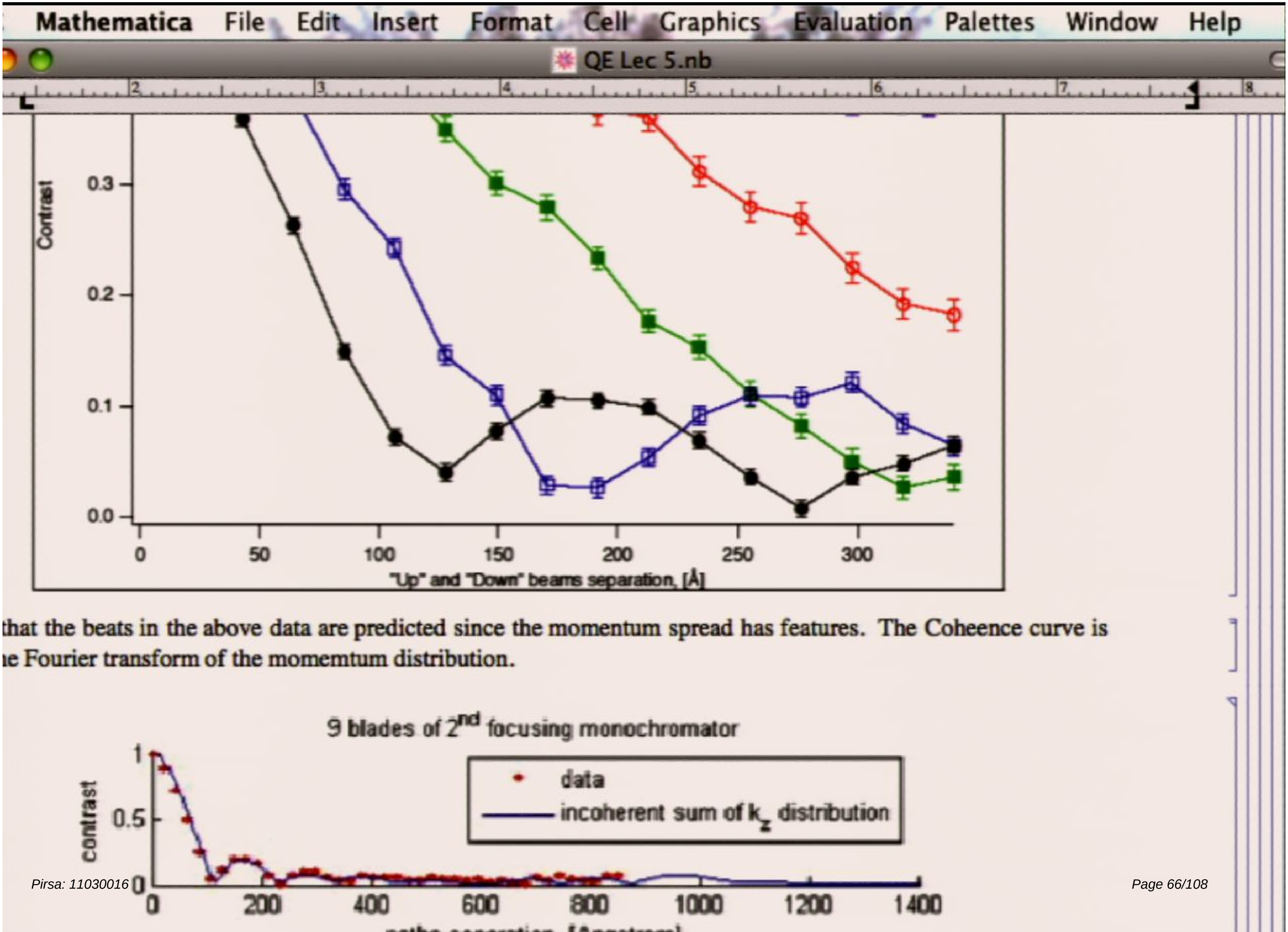
```
Pkz[kz_] := Sum[nd[kz - d, 0.001], {d, 0.012, -0.012, -0.003}] / 9
Plot[Pkz[kz], {kz, -0.02, 0.02}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}]
```

```
M16O[z_, a_] := Sum[Pkz[kz] Tr[Ezp . res14[kz, z, a]], {kz, -0.02, 0.02, 0.001}]
```



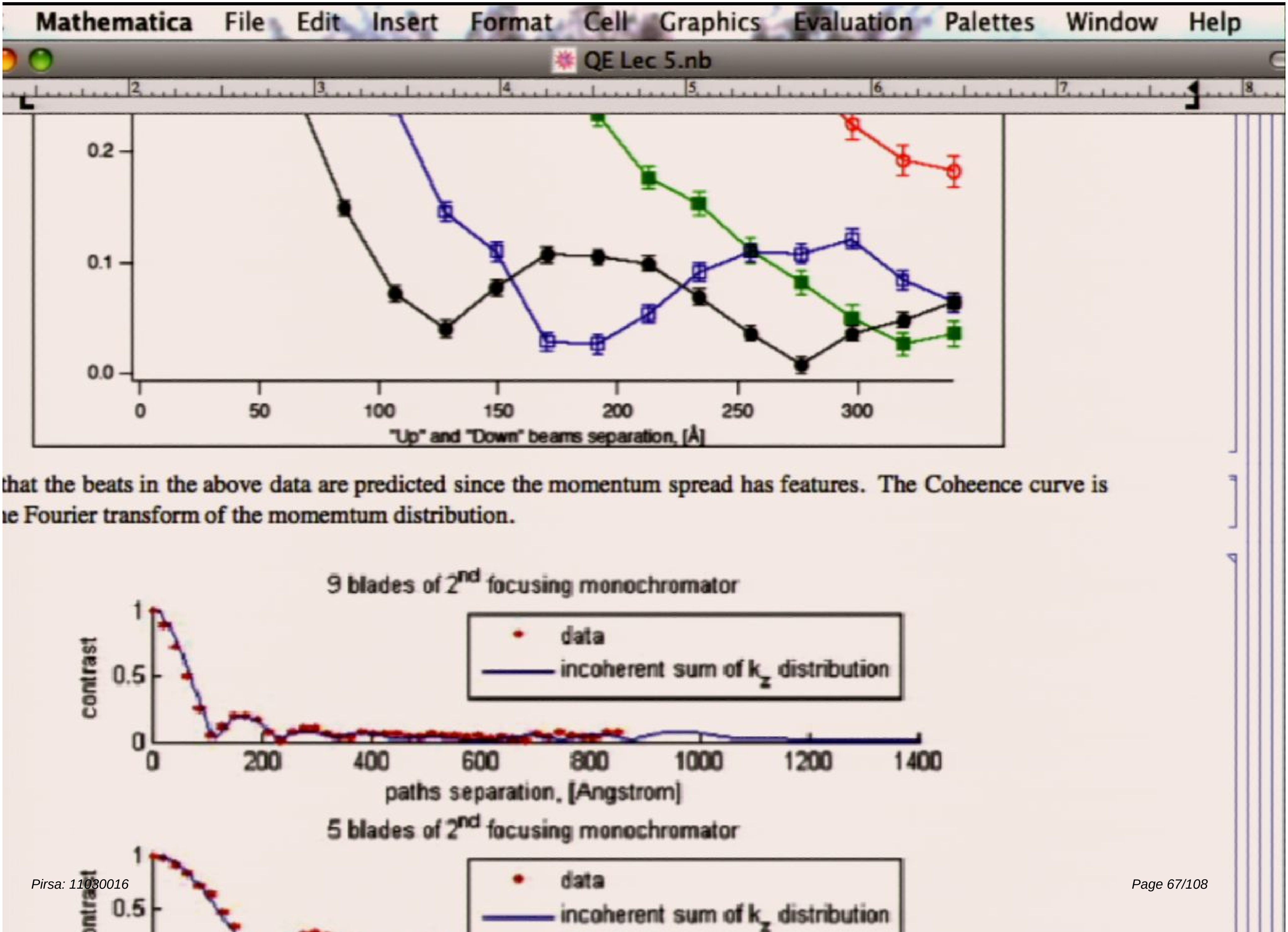
periment 17: Recombining the shifted beams

we put a set of prisms in each arm and show that the contrast is fully recovered as we displace the beam in both of the interferometer.

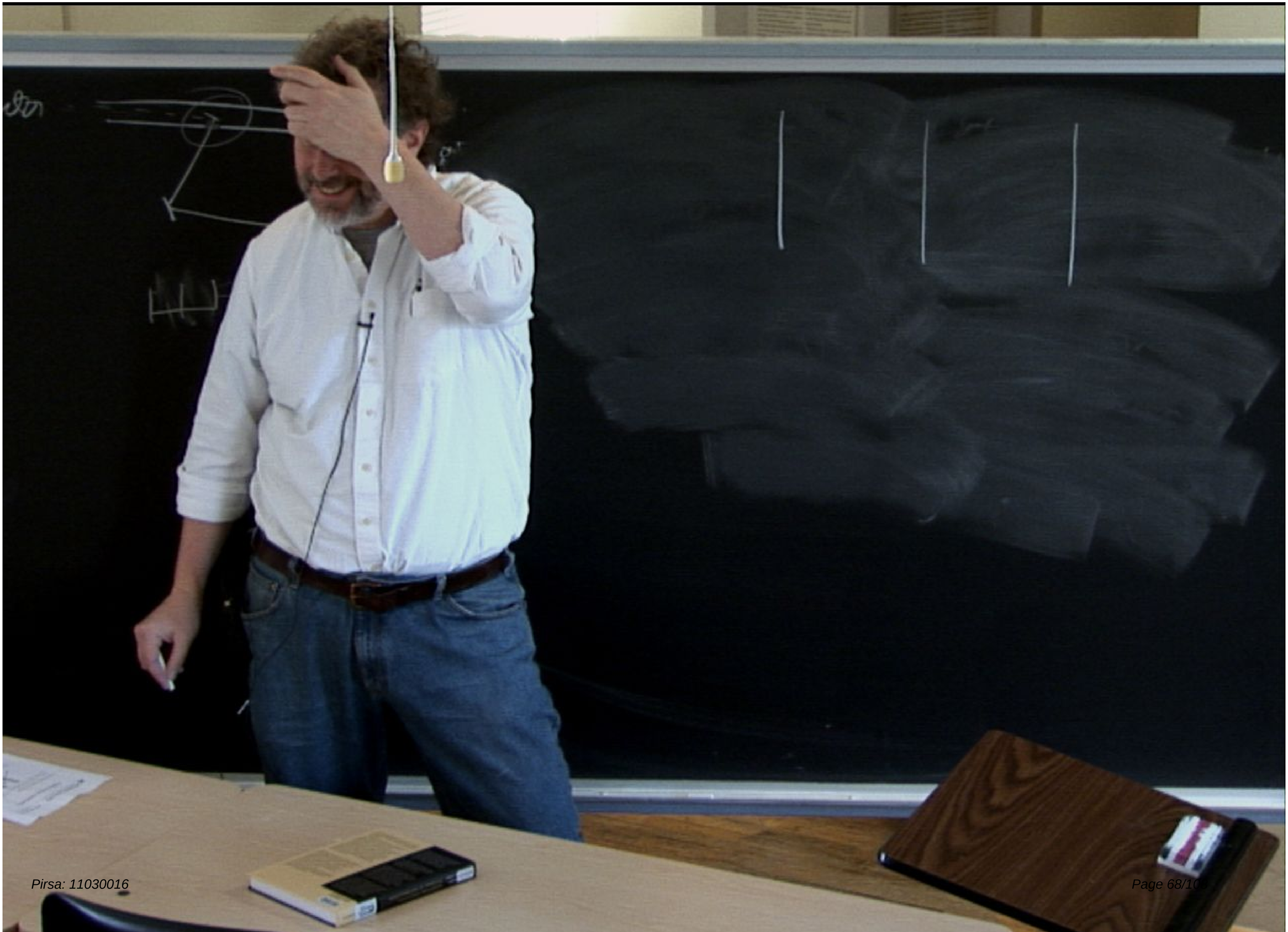


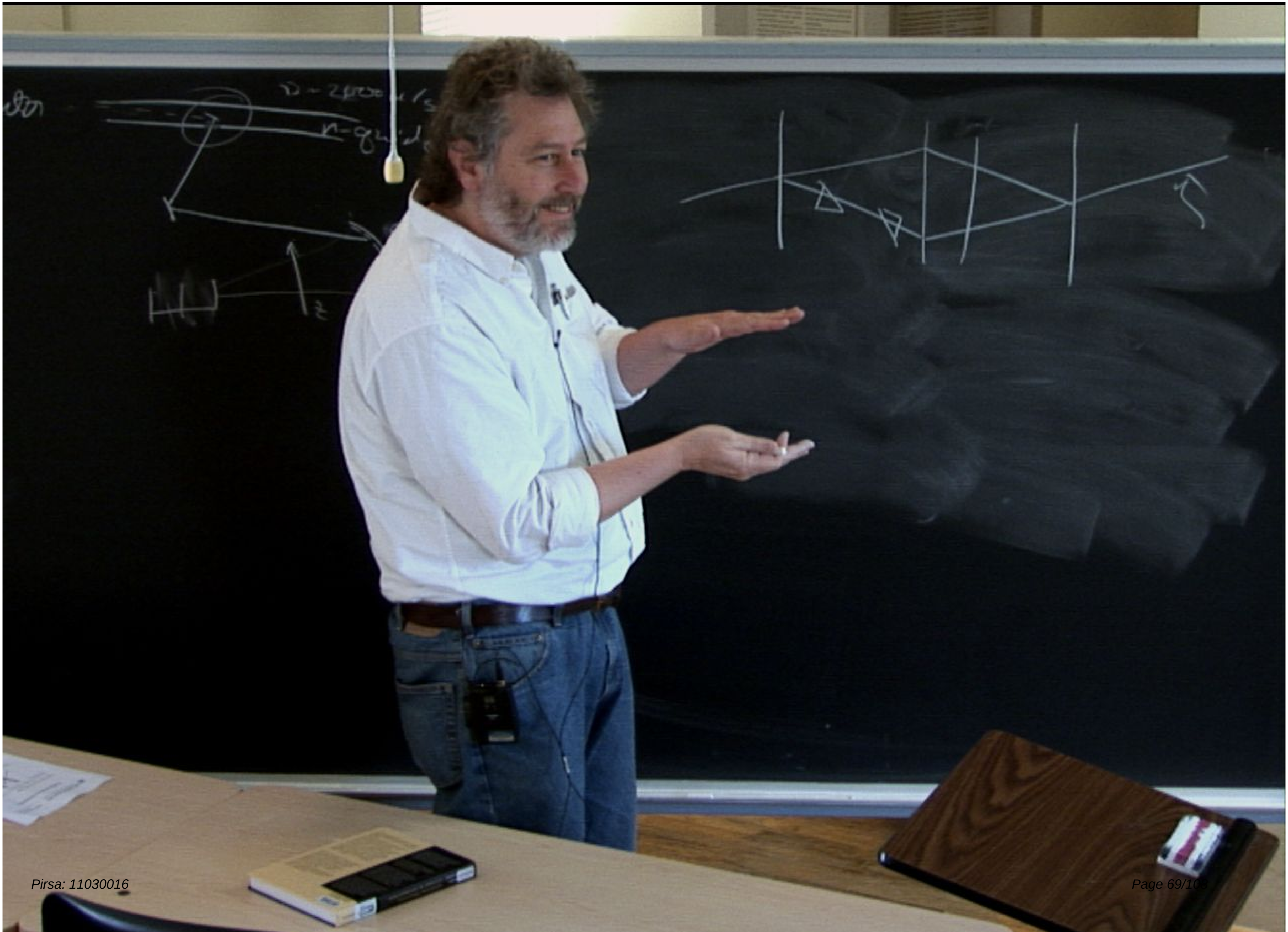
that the beats in the above data are predicted since the momentum spread has features. The Coheence curve is

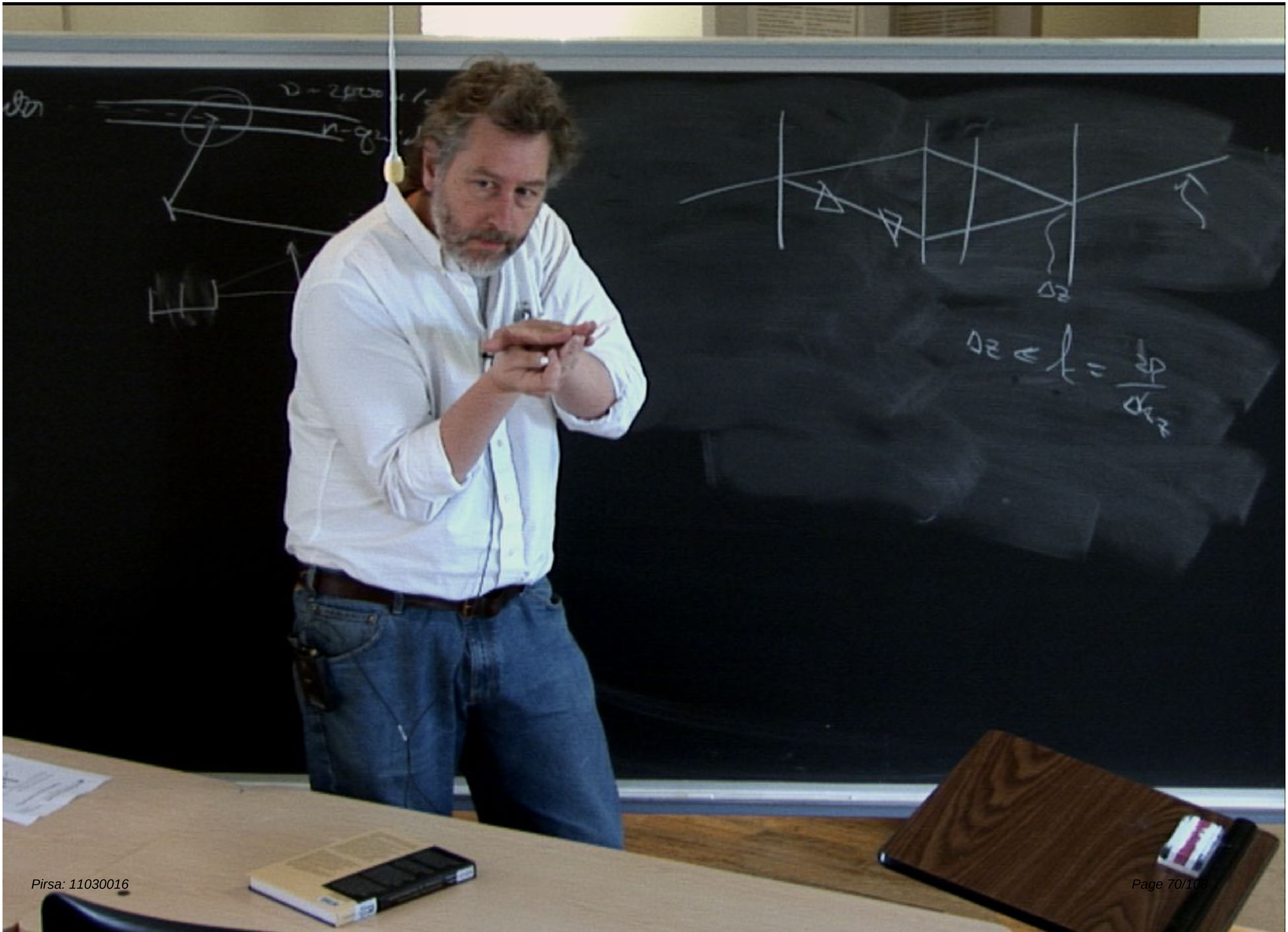
e Fourier transform of the momemtum distribution.

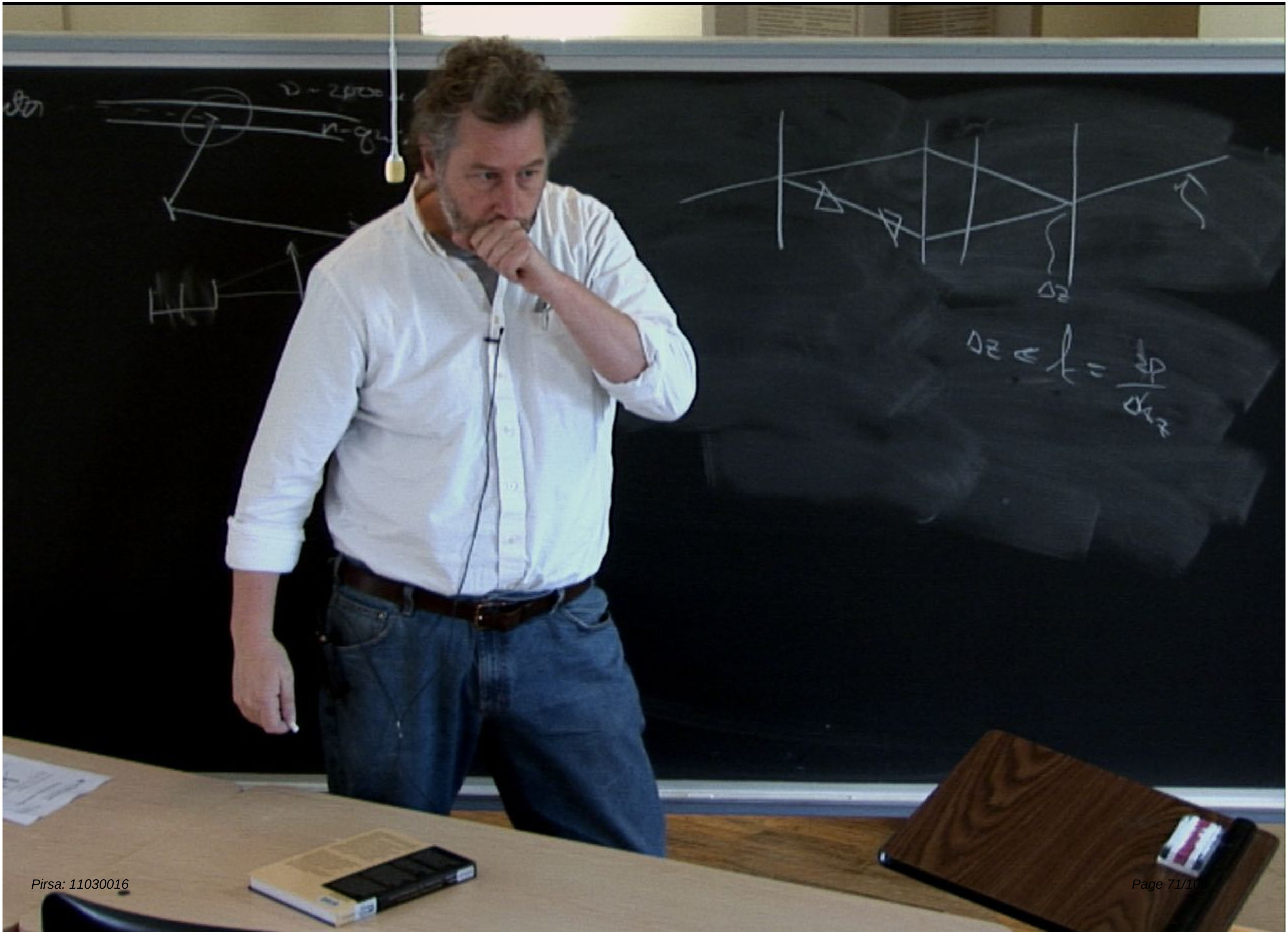


that the beats in the above data are predicted since the momentum spread has features. The Coheence curve is e Fourier transform of the momemtum distribution.

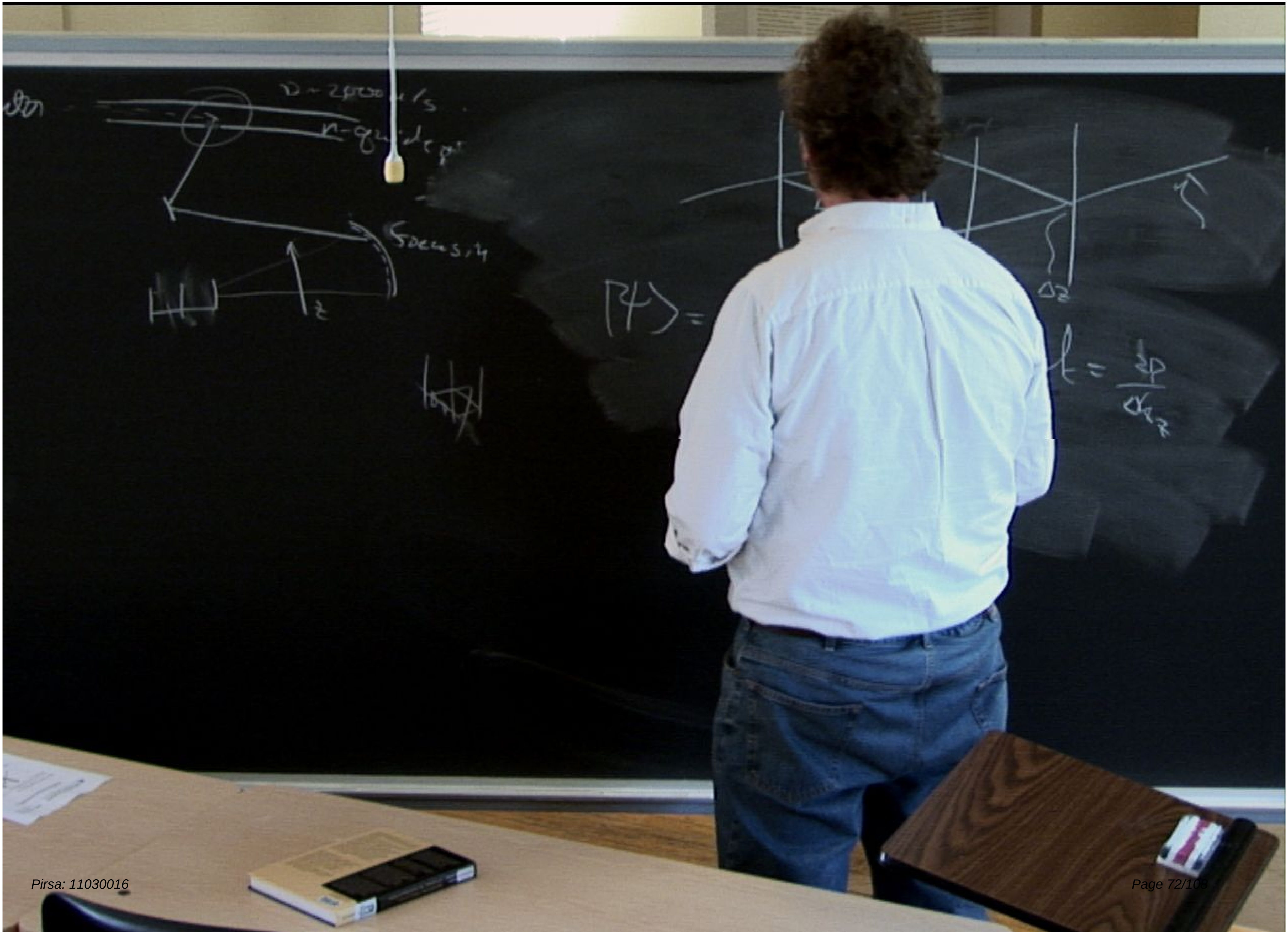


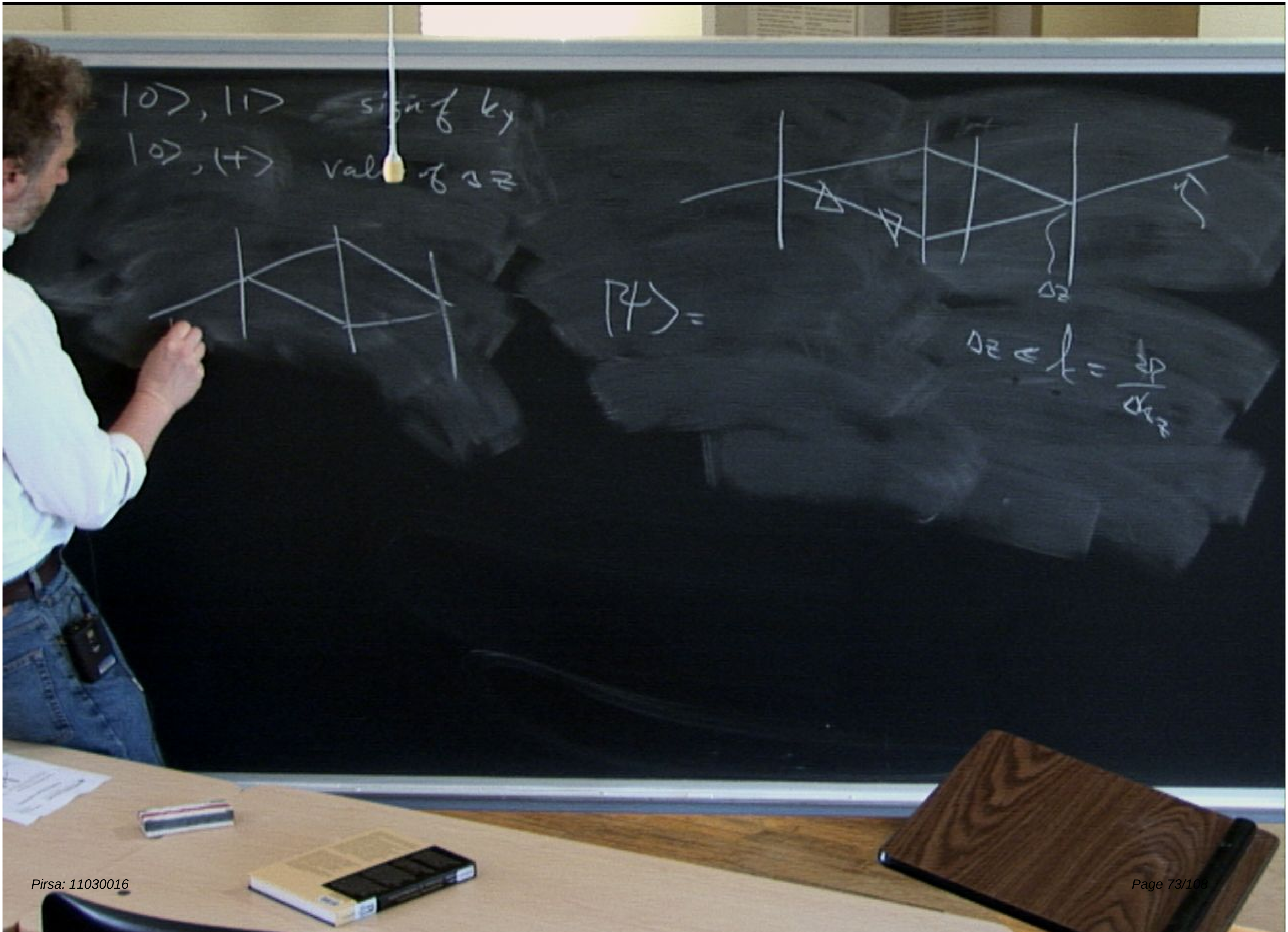


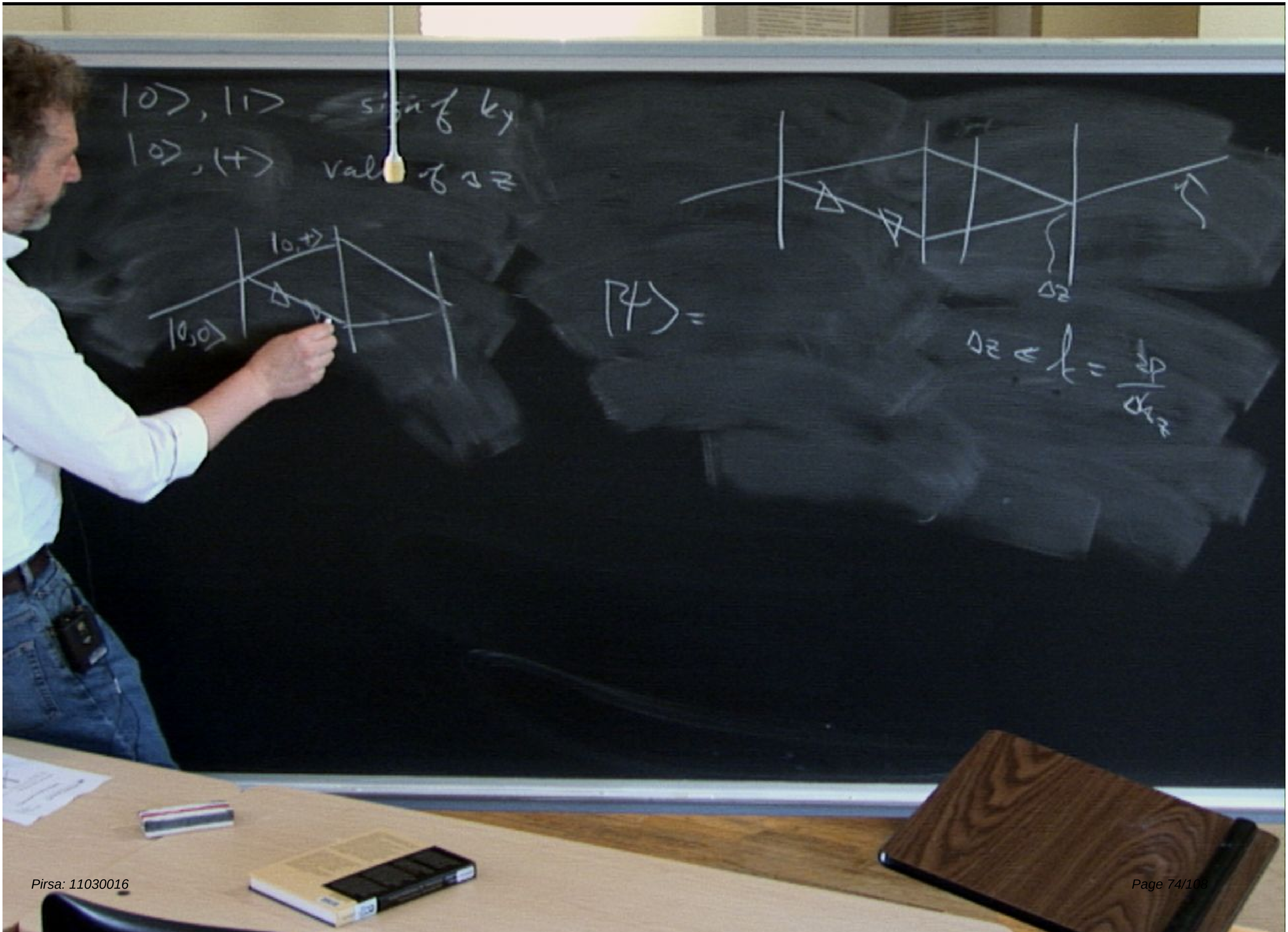

Δz
Δz ≤ ℓ = 2π / Δk_z

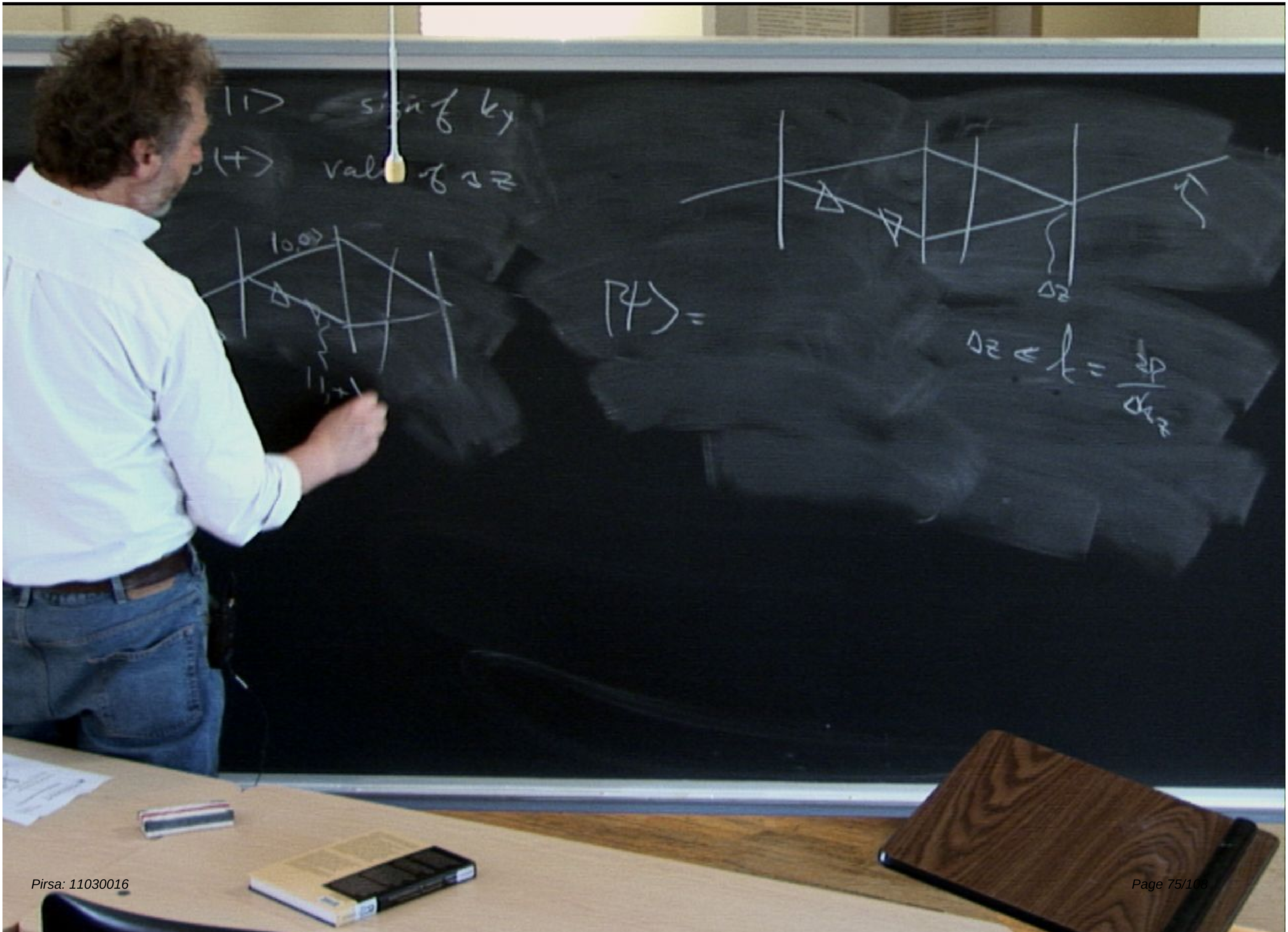


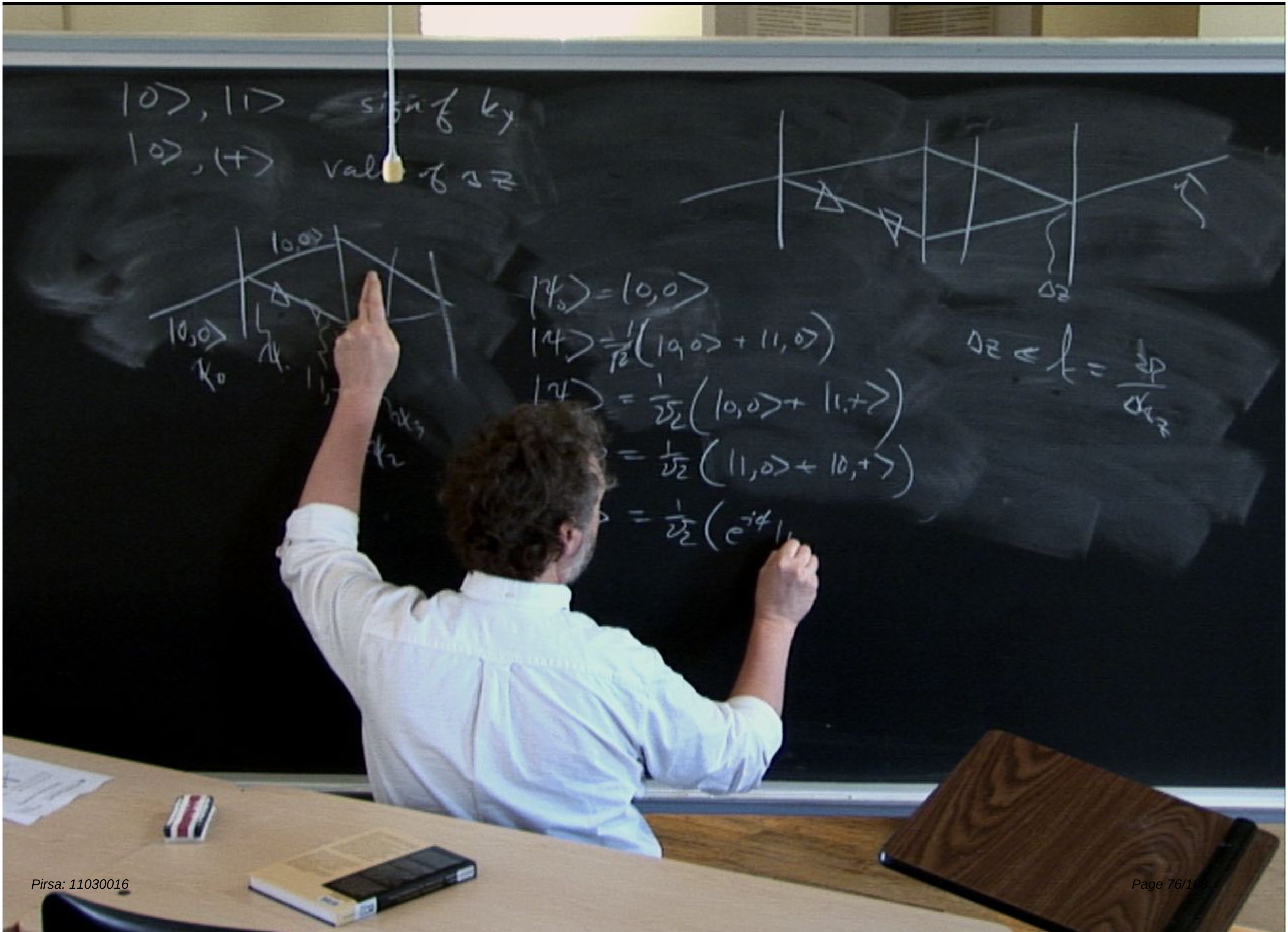
Δz
$\Delta z \leq \ell = \frac{d\phi}{dk_z}$

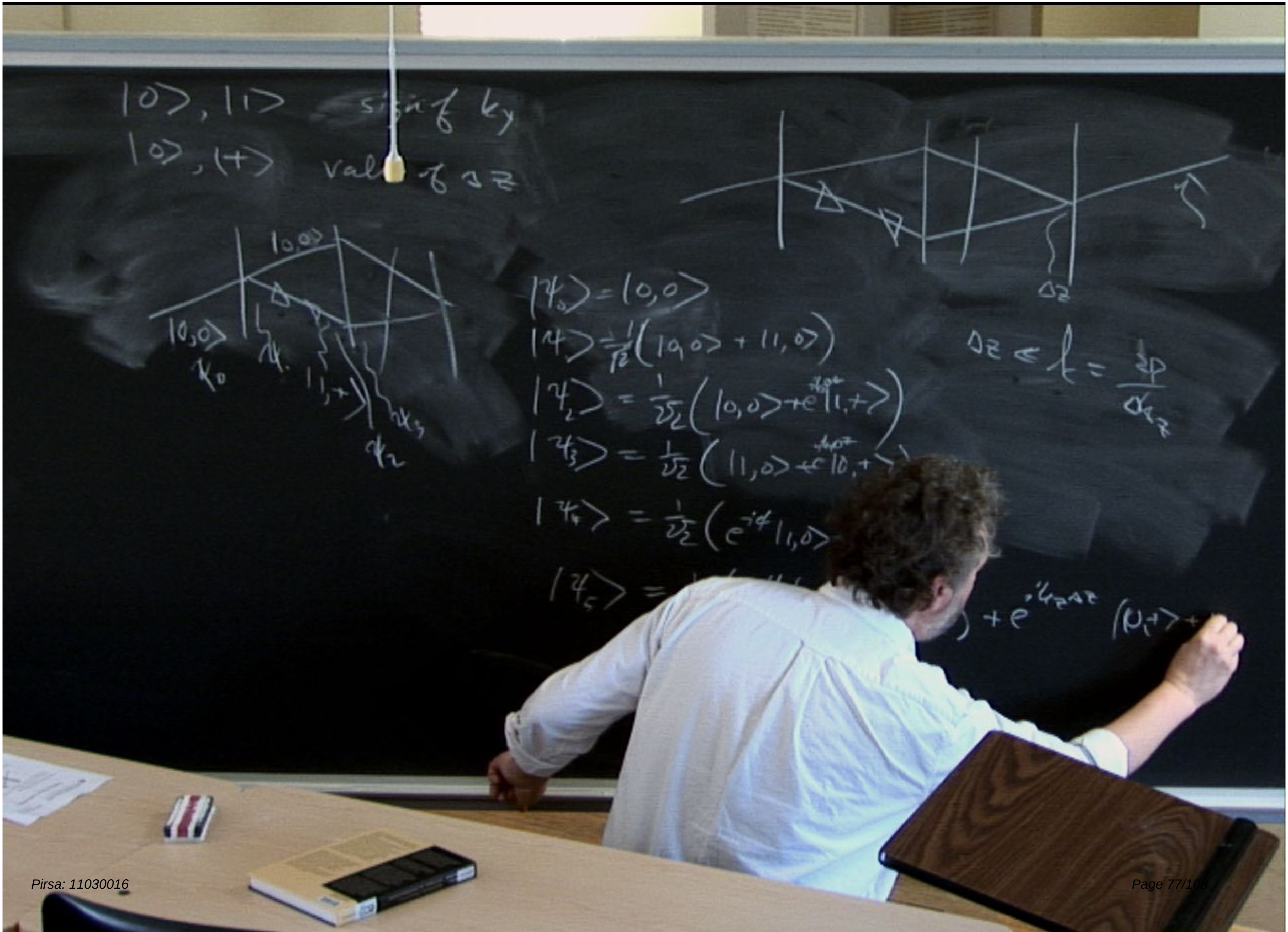

v ~ 2000 m/s
n-guide
Spacers
z
|ψ> =
Δz
f = ΔΦ / Δk_z

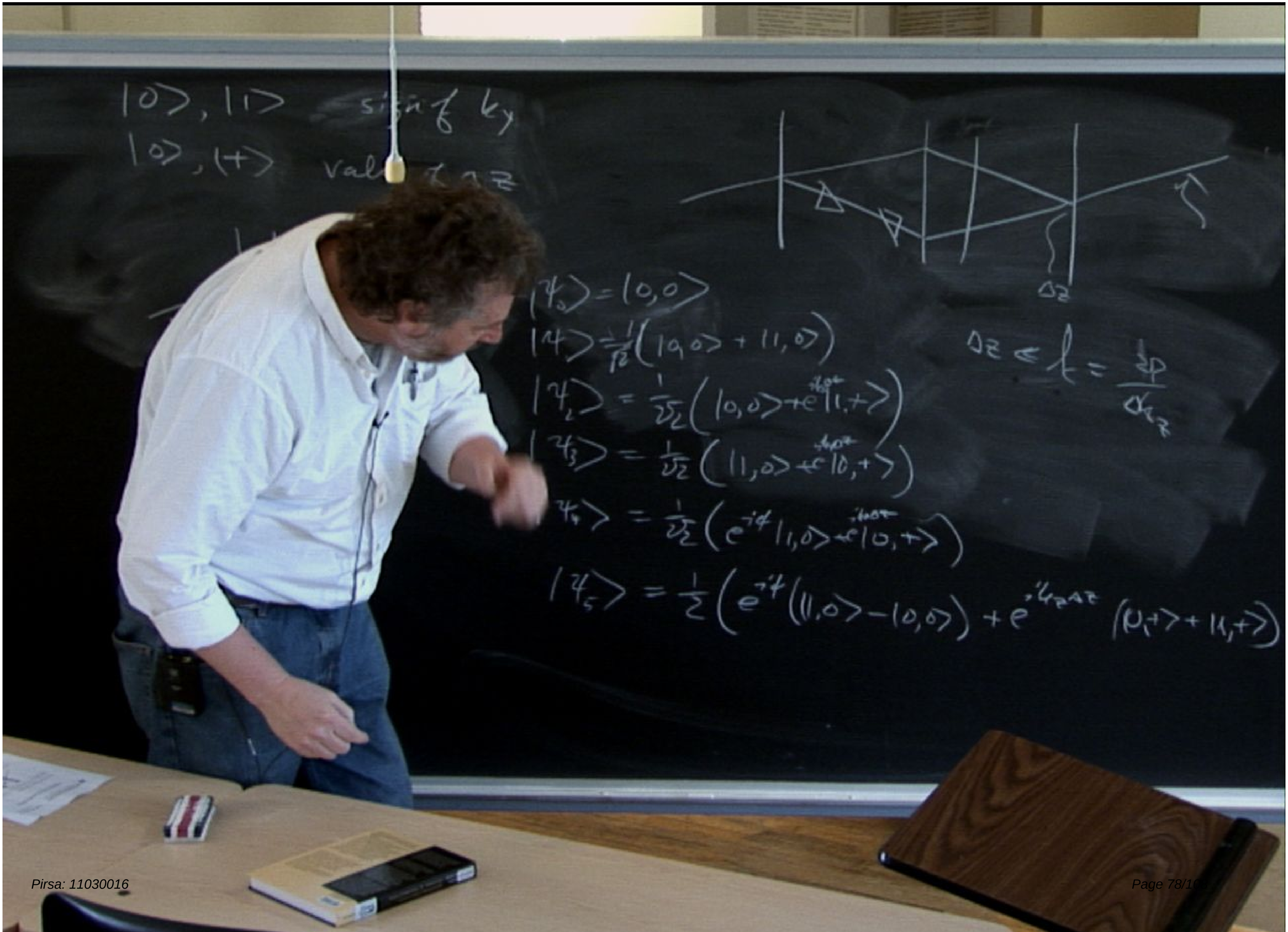

|0⟩, |1⟩ sign of k_y
|0⟩, |+⟩ val of Δz
|ψ⟩ =
Δz
$\Delta z \in f = \frac{d\phi}{dk_z}$

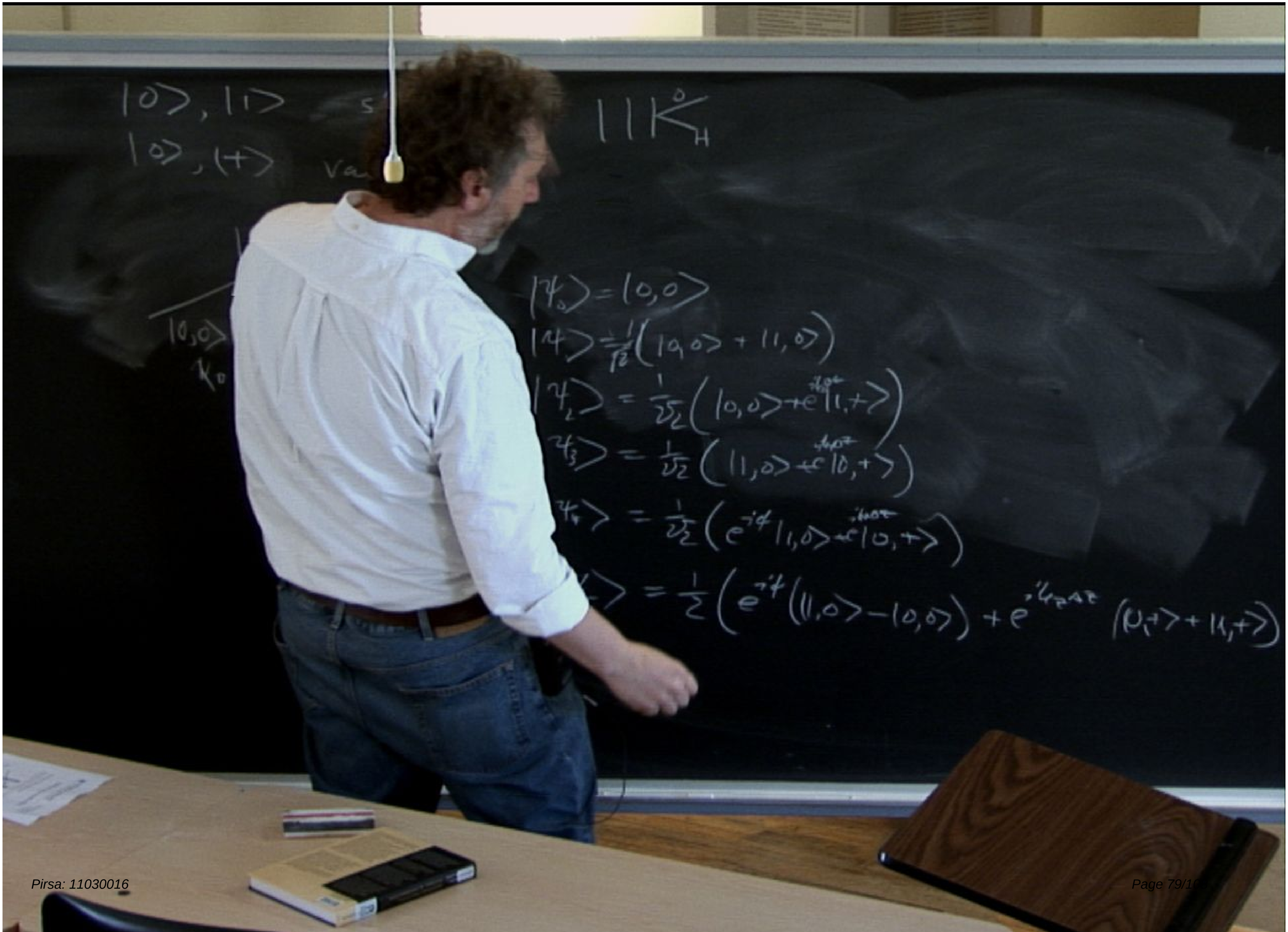

|0⟩, |1⟩ sign of k_y
|0⟩, |+⟩ val of Δz
|0,+⟩
|0,0⟩
|ψ⟩ =
Δz
Δz ∈ ℓ = dφ/dk_z

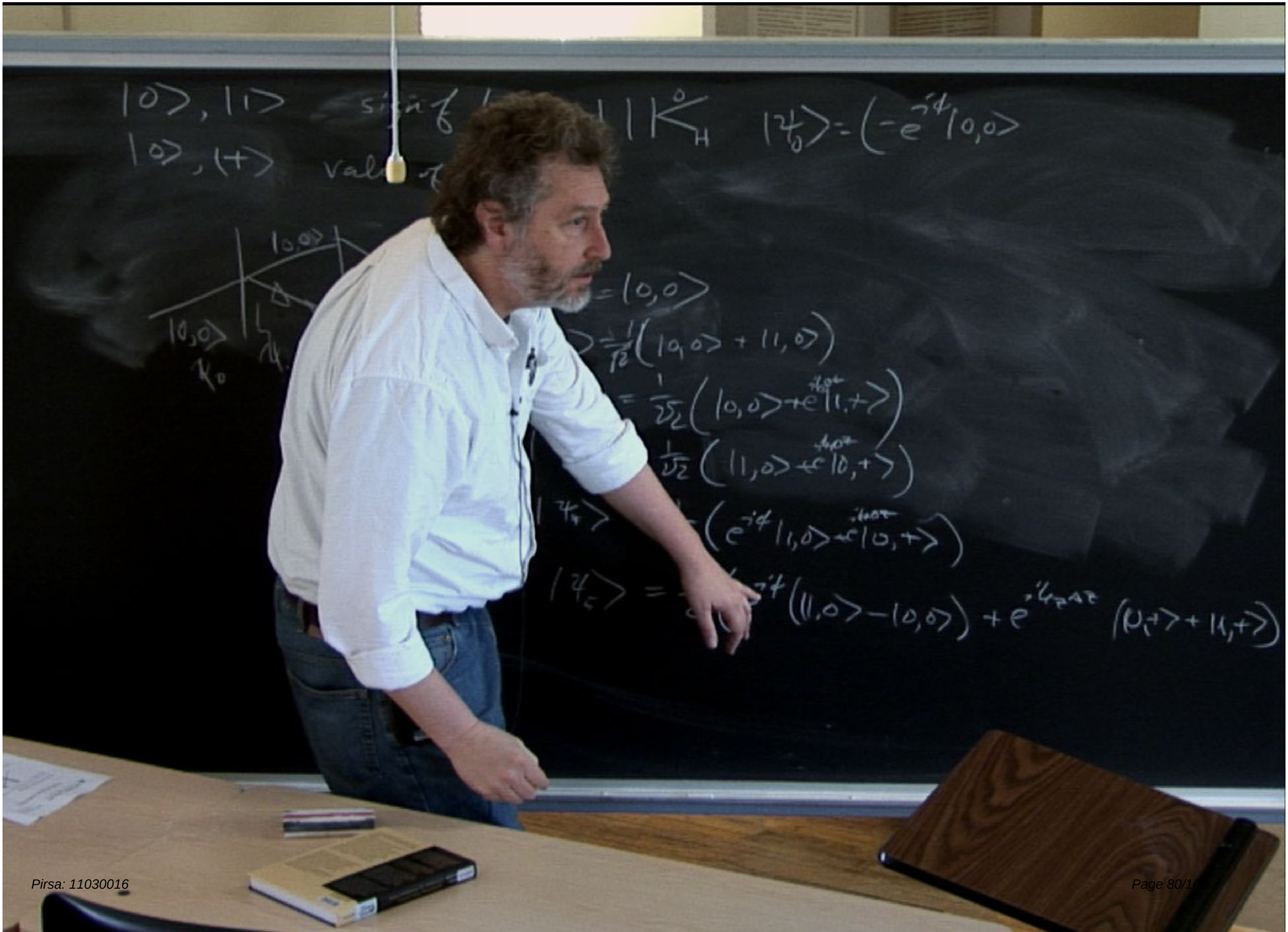

|1> sign of k_y
|+> val of Δz
|0,0>
|1,x>
|ψ> =
Δz
Δz ≪ ℓ = 2π/Δk_z

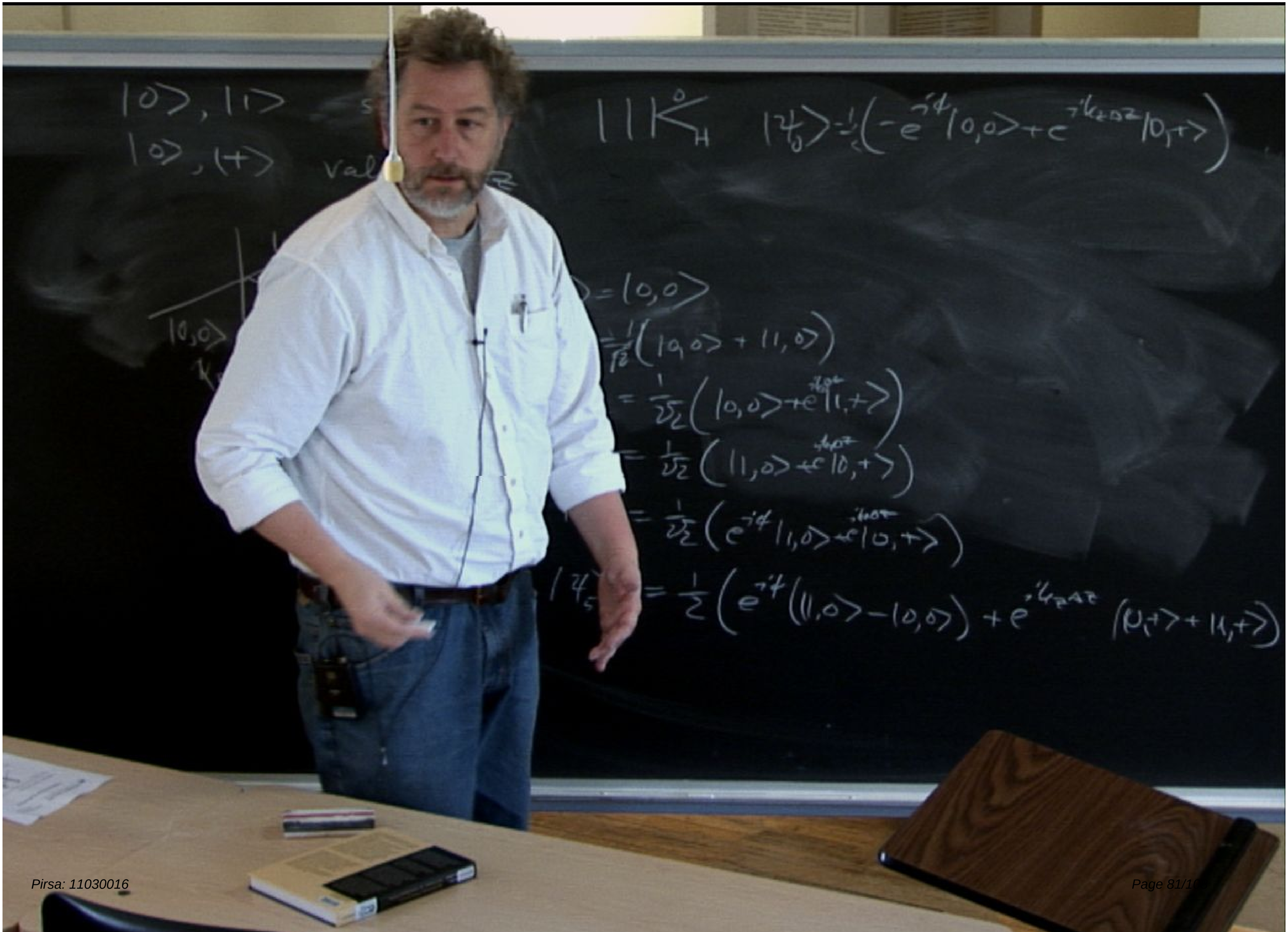

|0>, |1> sign of k_y
|0>, |+> val of Δz
|0,0>
|0,0>
|ψ_0> = |0,0>
|ψ> = 1/√2 (|0,0> + |1,0>)
|ψ> = 1/√2 (|0,0> + |1,+>)
= 1/√2 (|1,0> + |0,+>)
= 1/√2 (e^{iφ}|
Δz
Δz ∝ t = dp/dk_z

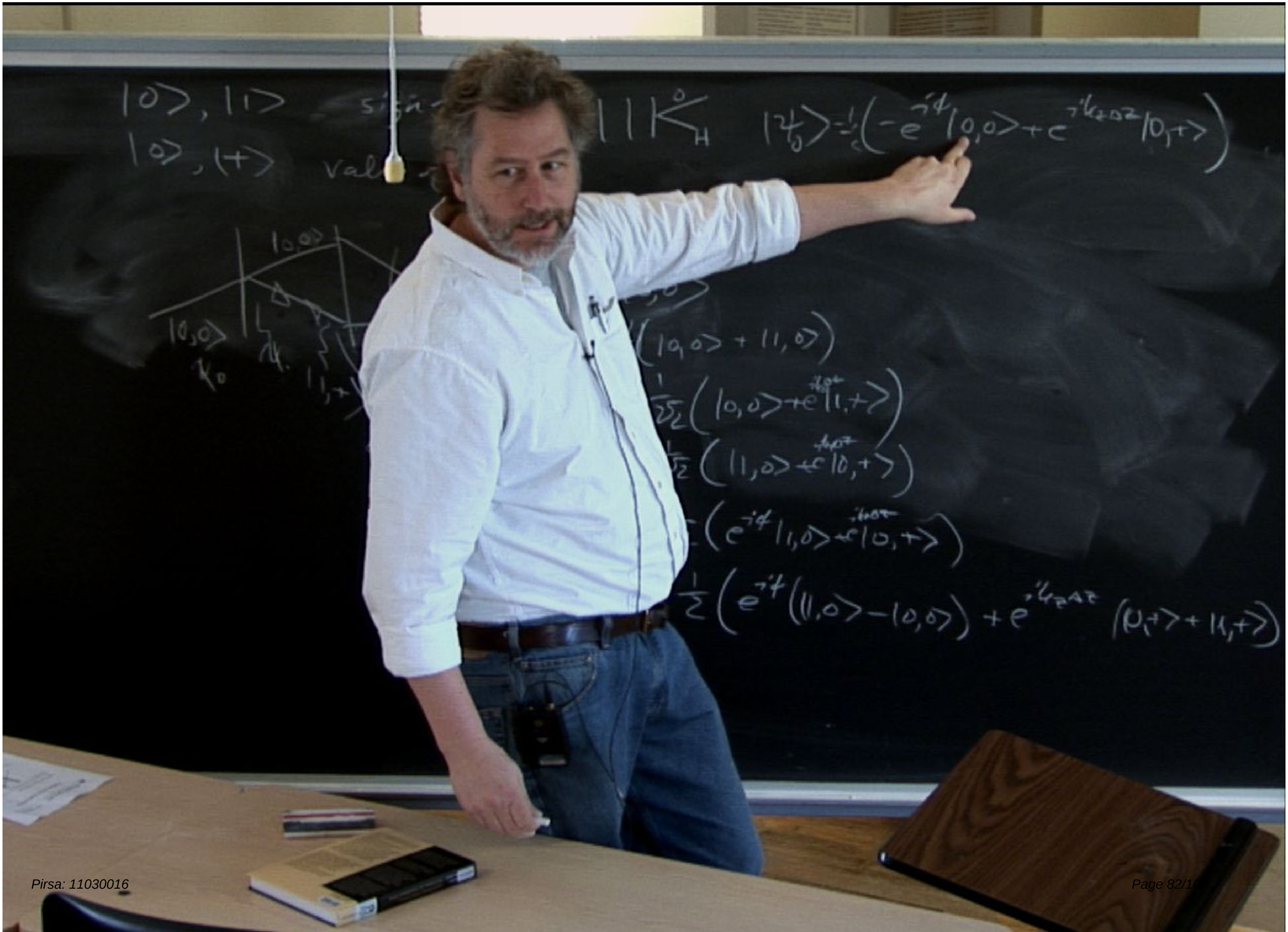

|0>, |1> sign of k_y
|0>, |+> val of Δz
|0,0>
|0,0>
ψ_0
ψ_1
|1,+>
ψ_2
ψ_3
|ψ_0> = |0,0>
|ψ_1> = 1/√2 (|0,0> + |1,0>)
|ψ_2> = 1/√2 (|0,0> + e^{iφ} |1,+>)
|ψ_3> = 1/√2 (|1,0> + e^{iφ} |0,+>)
|ψ_4> = 1/√2 (e^{iφ} |1,0>
|ψ_5> =
) + e^{ik_zΔz} (|0,+> +
Δz
Δz ≪ ℓ = ℏ/Δk_z

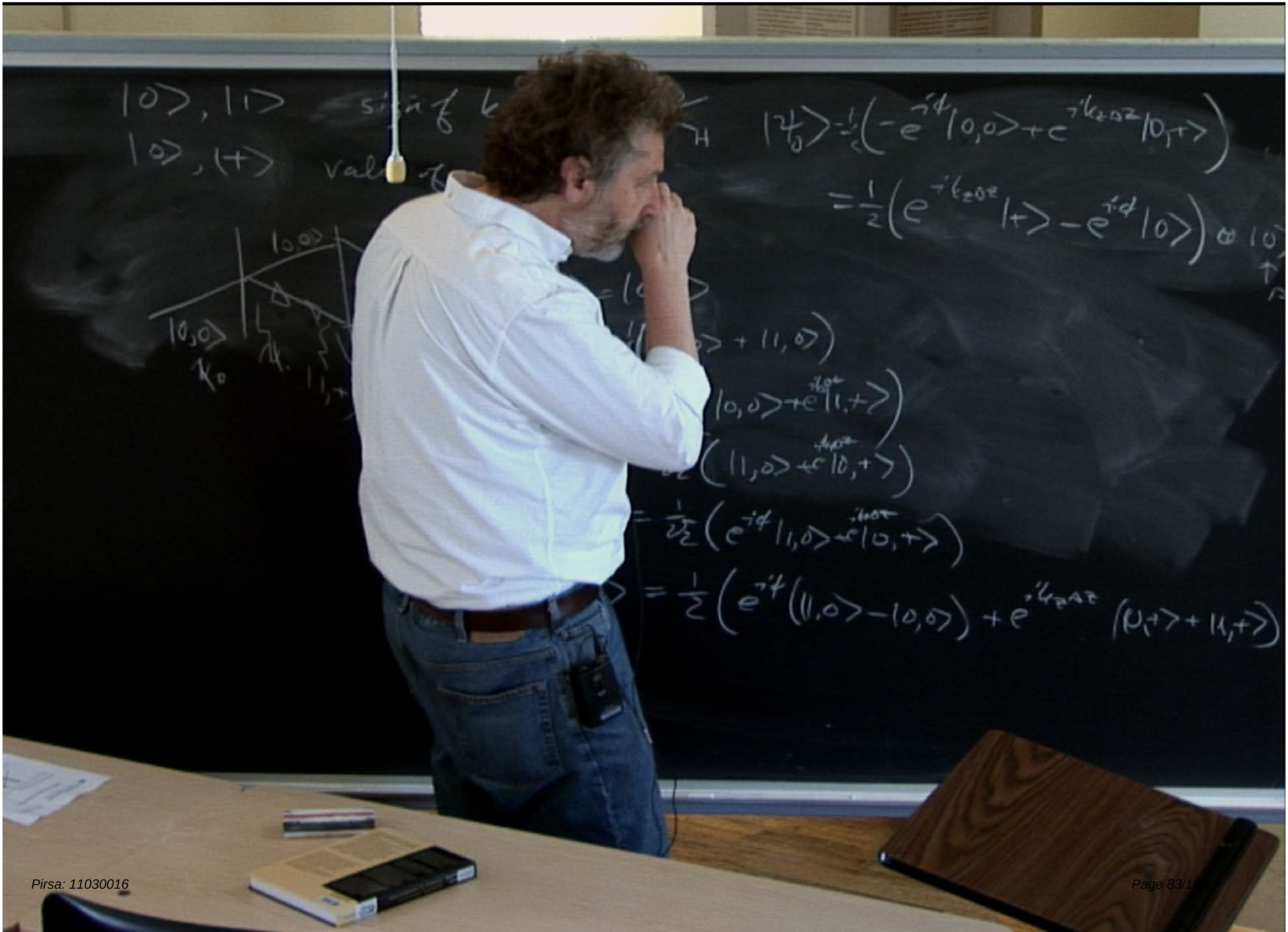


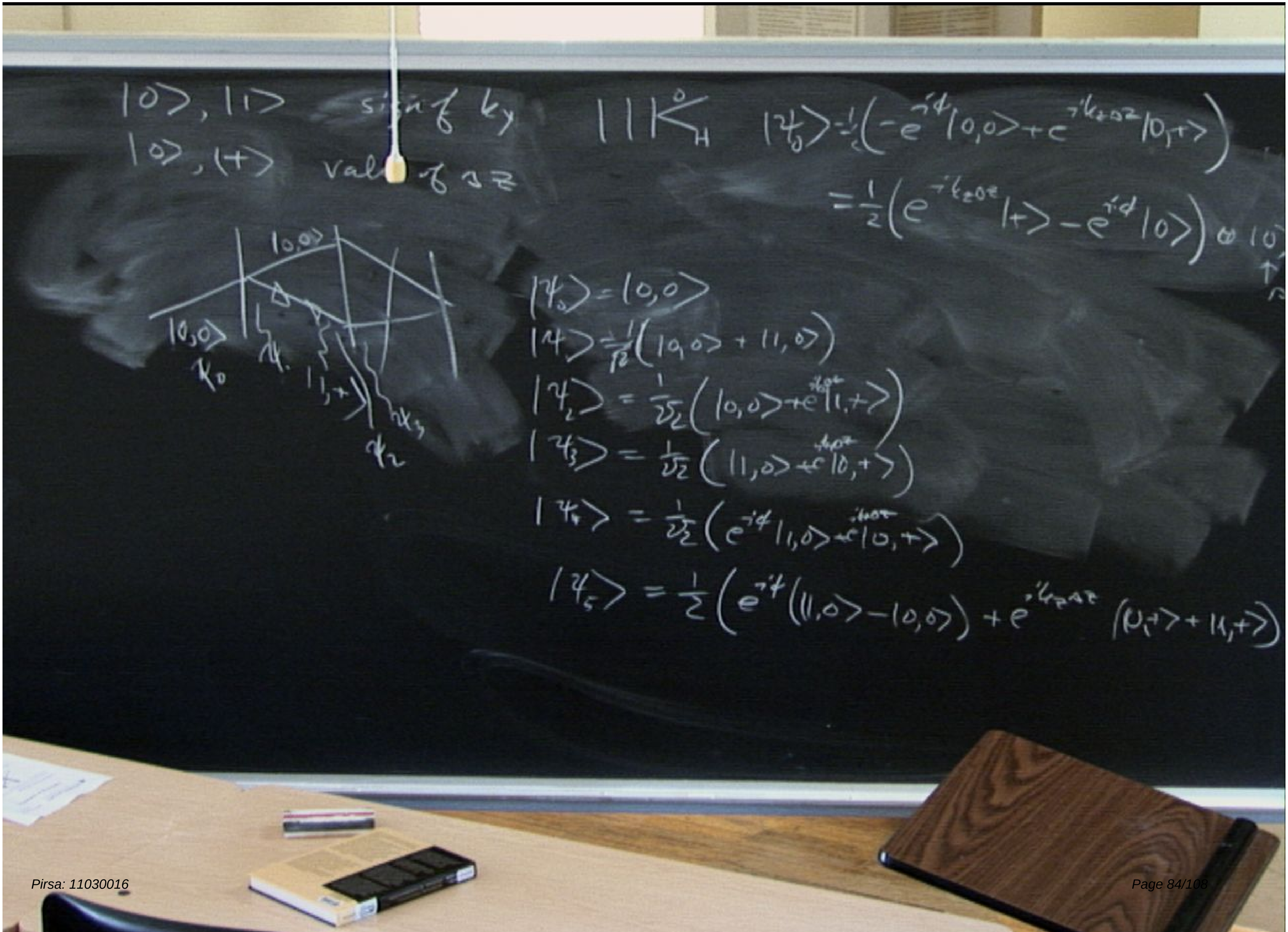

$|0\rangle, |1\rangle$ s
$|0\rangle, |+\rangle$ Va
$|1\rangle^{0}_{H}$
$|0,0\rangle$
K_0
$|\psi_0\rangle = |0,0\rangle$
$|\psi_1\rangle = \frac{1}{\sqrt{2}}(|0,0\rangle + |1,0\rangle)$
$|\psi_2\rangle = \frac{1}{\sqrt{2}}(|0,0\rangle + e^{i\omega_0 t}|1,+\rangle)$
$\psi_3\rangle = \frac{1}{\sqrt{2}}(|1,0\rangle + e^{i\omega_0 t}|0,+\rangle)$
$\psi_4\rangle = \frac{1}{\sqrt{2}}(e^{i\phi}|1,0\rangle + e^{i\omega_0 t}|0,+\rangle)$
$\rangle = \frac{1}{2}(e^{i\phi}(|1,0\rangle - |0,0\rangle) + e^{i\omega_0\Delta t}(|0,+\rangle + |1,+\rangle)$


|0>, |1>
|0>, |+>
|0,0>
|0,0>
|0,0>
|0,+>
|1,0>
|1,+>
|1,0> - |0,0>
|1,+>


|0>, |1>
|0>, |+>
|1K^0_H
|ψ_0> = 1/2 (−e^{−iφ}|0,0> + e^{−ik_zΔz}|0,+>)
= |0,0>
= 1/√2 (|0,0> + |1,0>)
= 1/√2 (|0,0> + e^{ik_zΔz}|1,+>)
= 1/√2 (|1,0> + e^{ik_zΔz}|0,+>)
= 1/√2 (e^{−iφ}|1,0> + e^{ik_zΔz}|0,+>)
|ψ_5> = 1/2 (e^{−iφ}(|1,0> − |0,0>) + e^{−ik_zΔz} (|0,+> + |1,+>)
|0,0>


|0>, |1>
|0>, |+>
|ψ_0> = ½(−e^{iφ}|0,0> + e^{ik_zΔz}|0,+>)
|0,0>
|1,+>
(|0,0> + |1,0>)
1/(2√2)(|0,0> + e^{ik_0z}|1,+>)
1/√2(|1,0> + e^{ik_0z}|0,+>)
(e^{iφ}|1,0> + e^{ik_0z}|0,+>)
½(e^{iφ}(|1,0> − |0,0>) + e^{ik_zΔz}(|0,+> + |1,+>)


|0>, |1> sign of k
|0>, |+> val. of
|Ψ_0> = 1/2 (−e^{-iφ} |0,0> + e^{-ik_zΔz} |0,+>)
= 1/2 (e^{-ik_zΔz} |+> − e^{-iφ} |0>) ⊗ |0>
|0,0>
|0,0>
k_0
|1,+>
= |0>
1/√2 (|0,0> + |1,0>)
|0,0> + e^{ik_0Δz} |1,+>
1/√2 (|1,0> + e^{ik_0Δz} |0,+>)
= 1/√2 (e^{-iφ} |1,0> + e^{ik_0Δz} |0,+>)
= 1/2 (e^{-iφ} (|1,0> − |0,0>) + e^{-ik_zΔz} (|0,+> + |1,+>)



$|0\rangle, |1\rangle$ sign of k_y

$|0\rangle, |+\rangle$ value of Δz

$||K^{0}_{H}$ $|\psi_0\rangle = \frac{1}{2}\left(-e^{-i\phi}|0,0\rangle + e^{-ik_z\Delta z}|0,+\rangle\right)$

$= \frac{1}{2}\left(e^{-ik_z\Delta z}|+\rangle - e^{-i\phi}|0\rangle\right) \otimes |0$

$|\psi_0\rangle = |0,0\rangle$

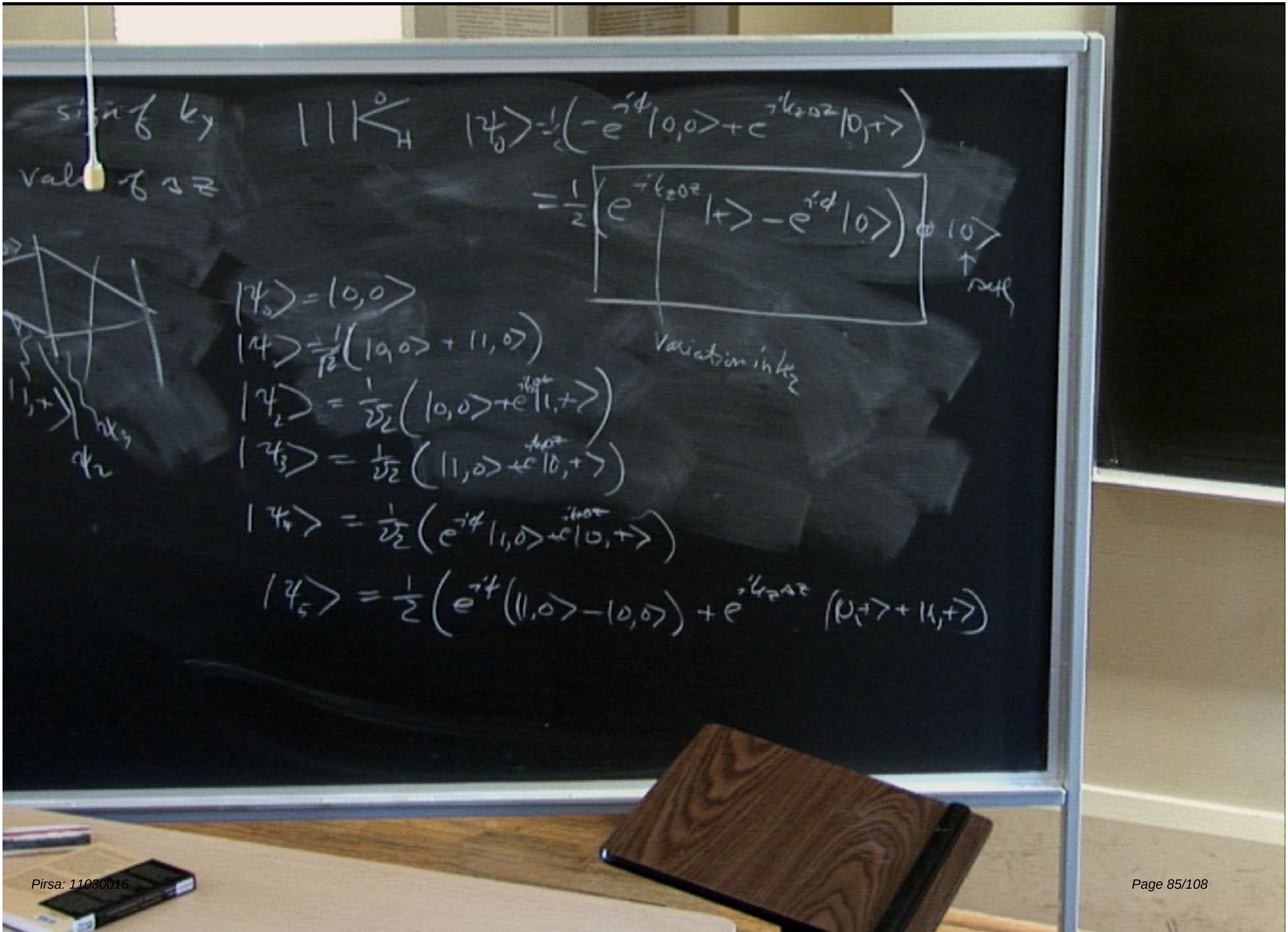
$|\psi_1\rangle = \frac{1}{\sqrt{2}}\left(|0,0\rangle + |1,0\rangle\right)$

$|\psi_2\rangle = \frac{1}{\sqrt{2}}\left(|0,0\rangle + e^{ik_z\Delta z}|1,+\rangle\right)$

$|\psi_3\rangle = \frac{1}{\sqrt{2}}\left(|1,0\rangle + e^{ik_z\Delta z}|0,+\rangle\right)$

$|\psi_4\rangle = \frac{1}{\sqrt{2}}\left(e^{-i\phi}|1,0\rangle + e^{ik_z\Delta z}|0,+\rangle\right)$

$|\psi_5\rangle = \frac{1}{2}\left(e^{-i\phi}\left(|1,0\rangle - |0,0\rangle\right) + e^{ik_z\Delta z}\left(|0,+\rangle + |1,+\rangle\right)\right)$



sign of k_y

value of Δz

$| \, | K^{0}_{H}$

$|\psi_6\rangle = \frac{1}{2}\left(-e^{-i\phi}|0,0\rangle + e^{-ik_z\Delta z}|0,+\rangle\right)$

$= \frac{1}{2}\boxed{\left(e^{-ik_z\Delta z}|+\rangle - e^{-i\phi}|0\rangle\right)} \otimes |0\rangle$

self

Variation in k_z

$|\psi_0\rangle = |0,0\rangle$

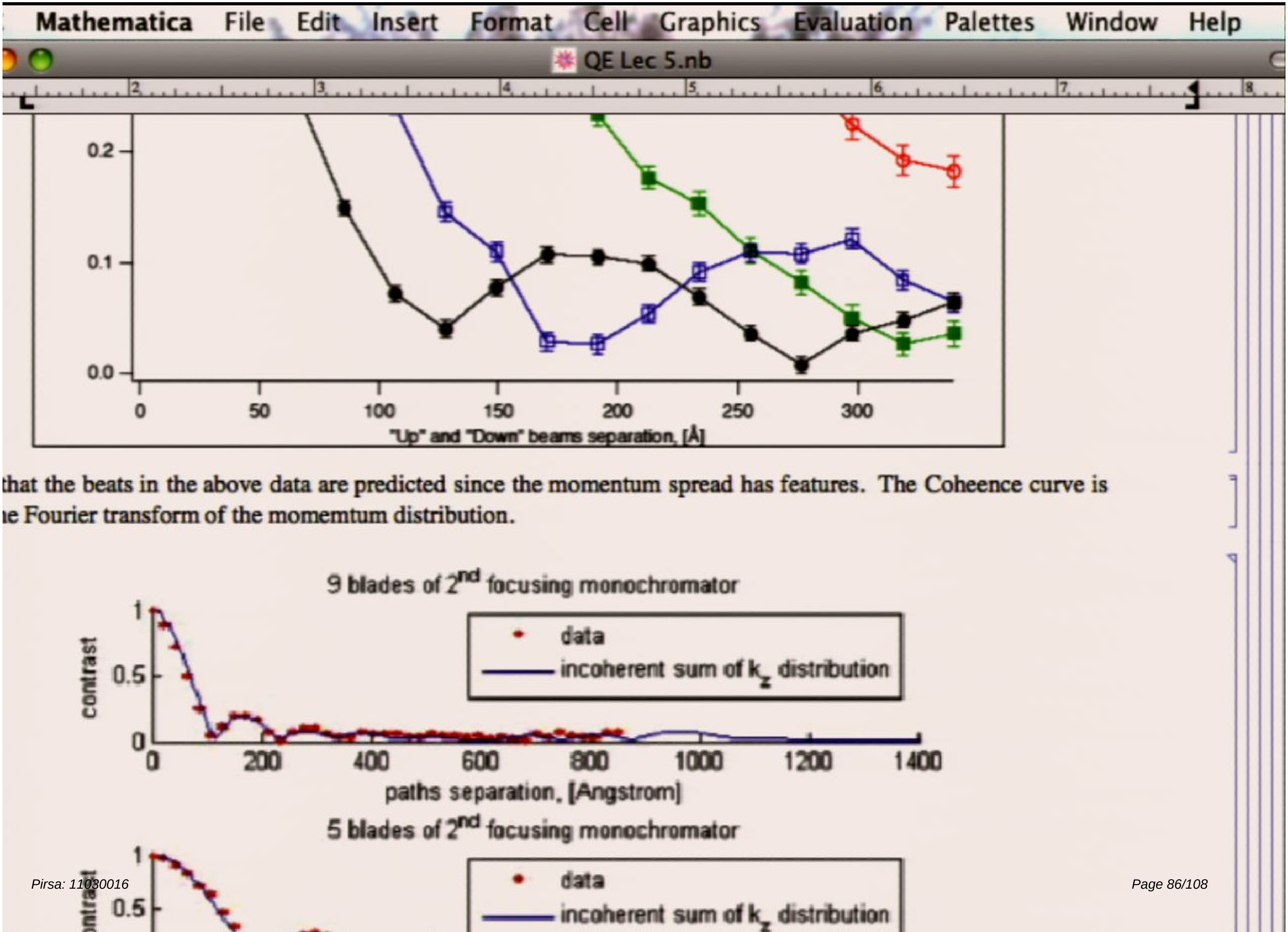
$|\psi_1\rangle = \frac{1}{\sqrt{2}}\left(|0,0\rangle + |1,0\rangle\right)$

$|\psi_2\rangle = \frac{1}{\sqrt{2}}\left(|0,0\rangle + e^{ik_z\Delta z}|1,+\rangle\right)$

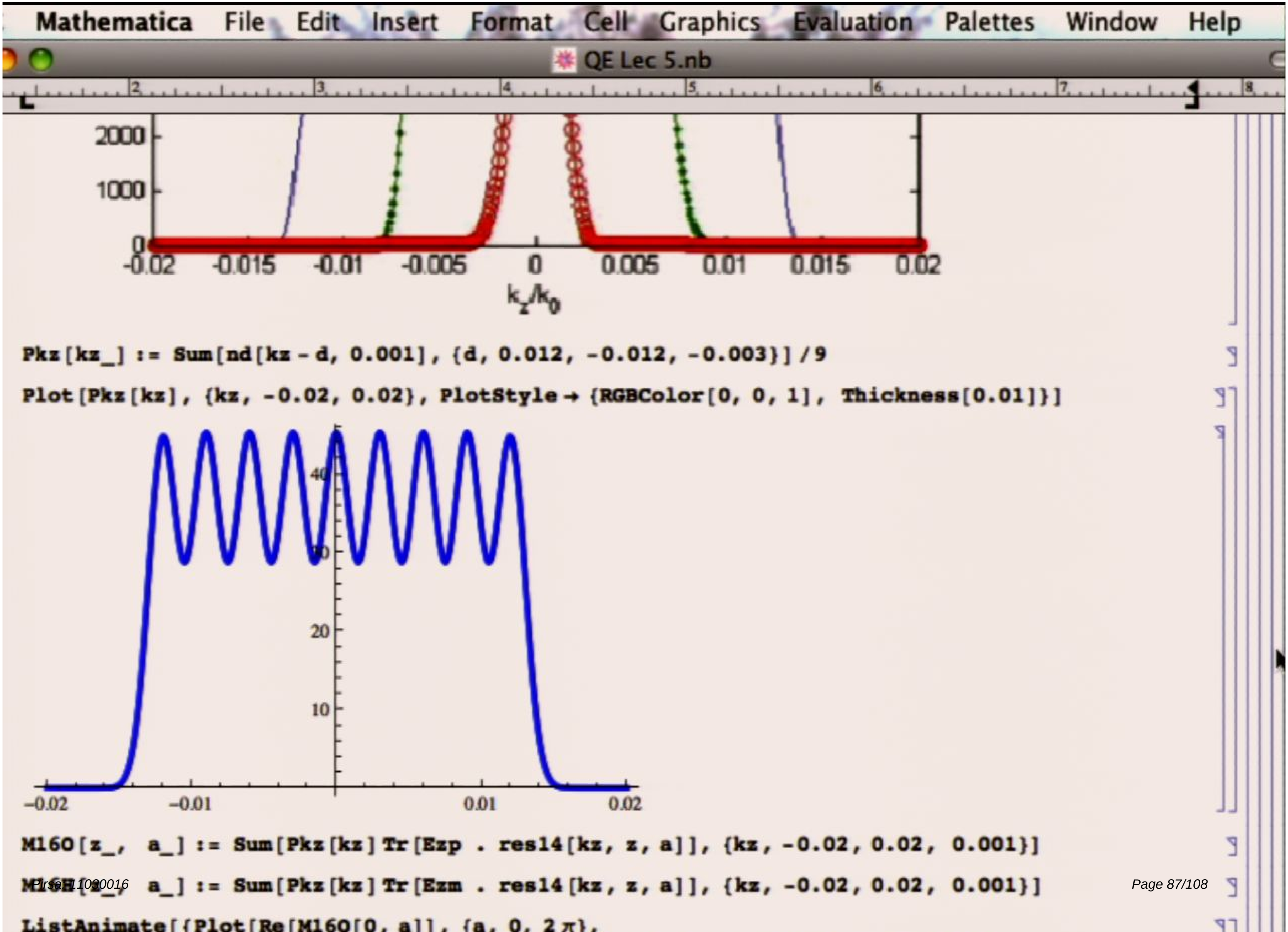
$|\psi_3\rangle = \frac{1}{\sqrt{2}}\left(|1,0\rangle + e^{ik_z\Delta z}|0,+\rangle\right)$

$|\psi_4\rangle = \frac{1}{\sqrt{2}}\left(e^{-i\phi}|1,0\rangle + e^{ik_z\Delta z}|0,+\rangle\right)$

$|\psi_5\rangle = \frac{1}{2}\left(e^{-i\phi}\left(|1,0\rangle - |0,0\rangle\right) + e^{-ik_z\Delta z}\left(|0,+\rangle + |1,+\rangle\right)\right)$



that the beats in the above data are predicted since the momentum spread has features. The Coheence curve is e Fourier transform of the momemtum distribution.



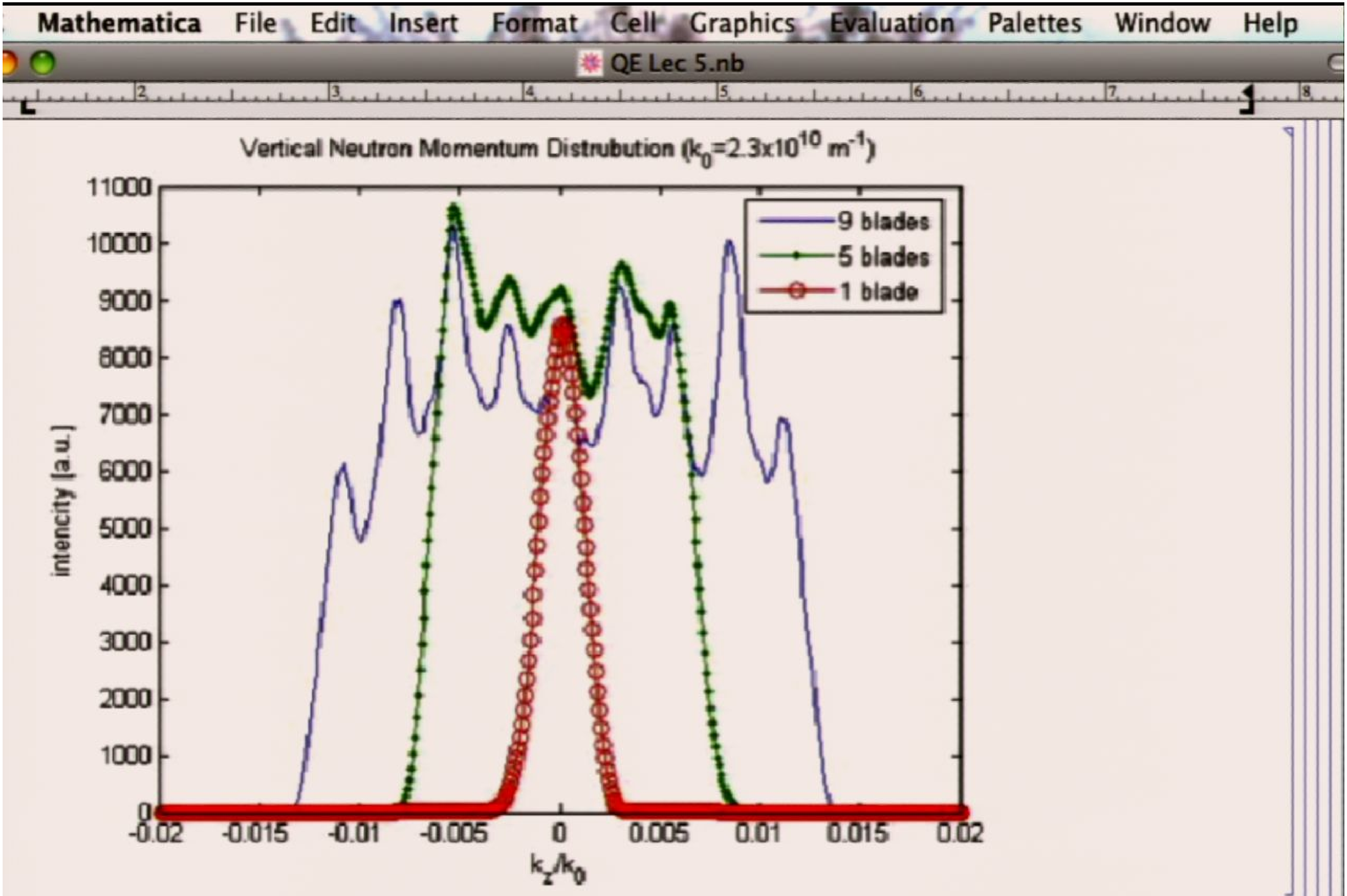
```
Pkz[kz_] := Sum[nd[kz - d, 0.001], {d, 0.012, -0.012, -0.003}] /9
```

```
Plot[Pkz[kz], {kz, -0.02, 0.02}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}]
```

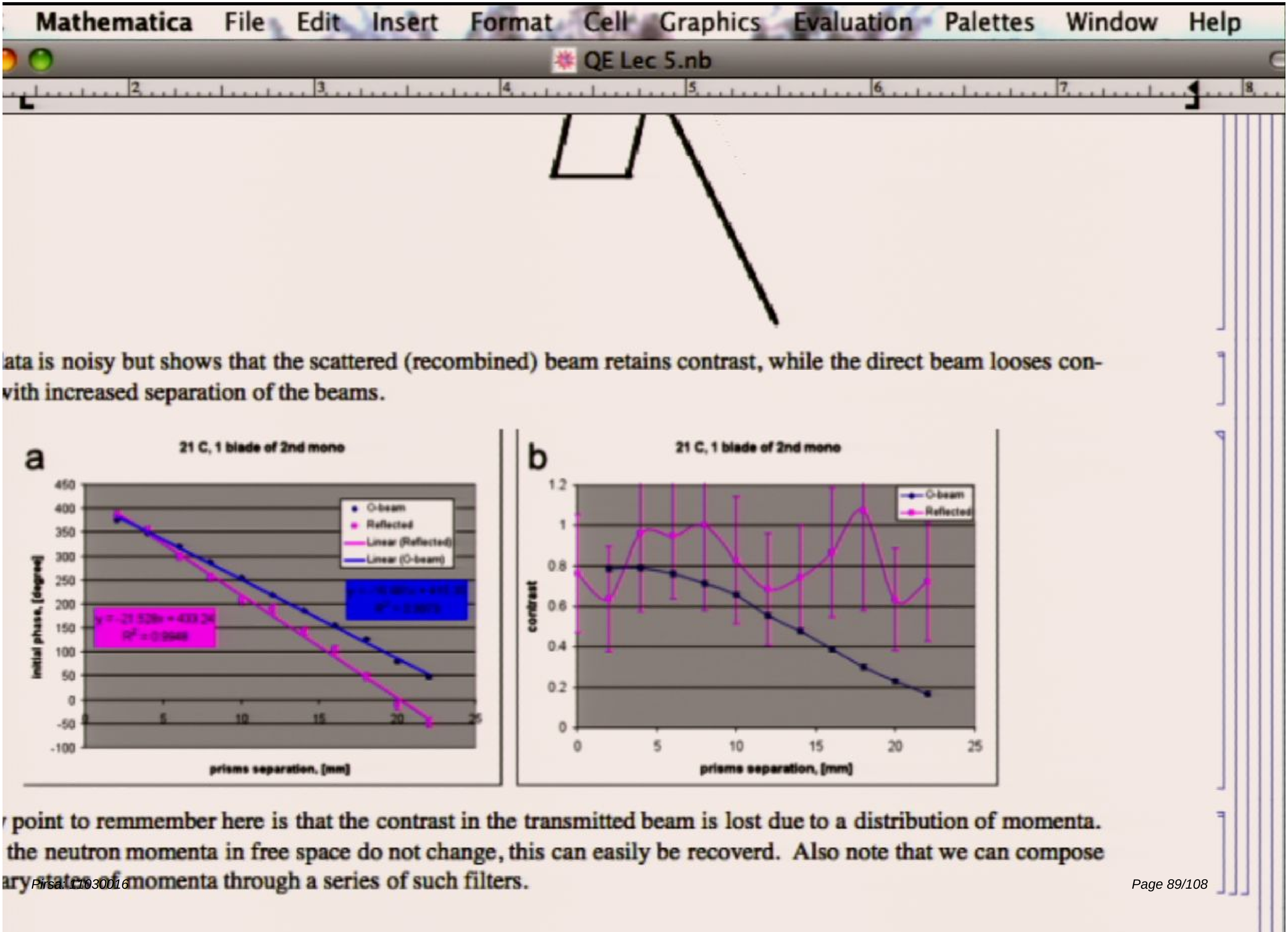
```
M16O[z_,  a_] := Sum[Pkz[kz] Tr[Ezp . res14[kz, z, a]], {kz, -0.02, 0.02, 0.001}]
```

```
M16H[z_,  a_] := Sum[Pkz[kz] Tr[Ezm . res14[kz, z, a]], {kz, -0.02, 0.02, 0.001}]
```

```
ListAnimate[{Plot[Re[M16O[0, a]], {a, 0, 2 π},
```

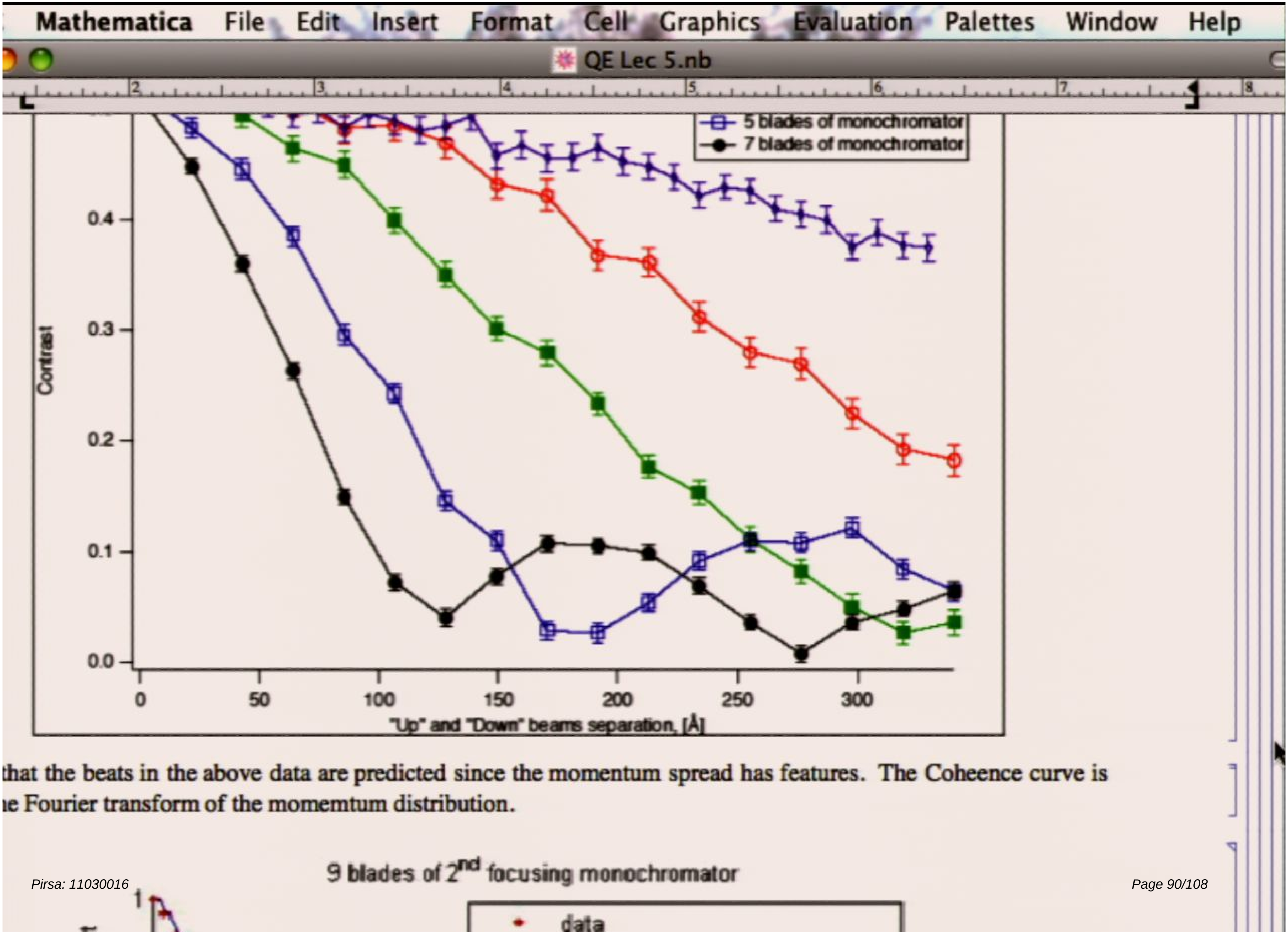


```
Pkz[kz_] := Sum[nd[kz - d, 0.001], {d, 0.012, -0.012, -0.003}] / 9
Plot[Pkz[kz], {kz, -0.02, 0.02}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}]
```

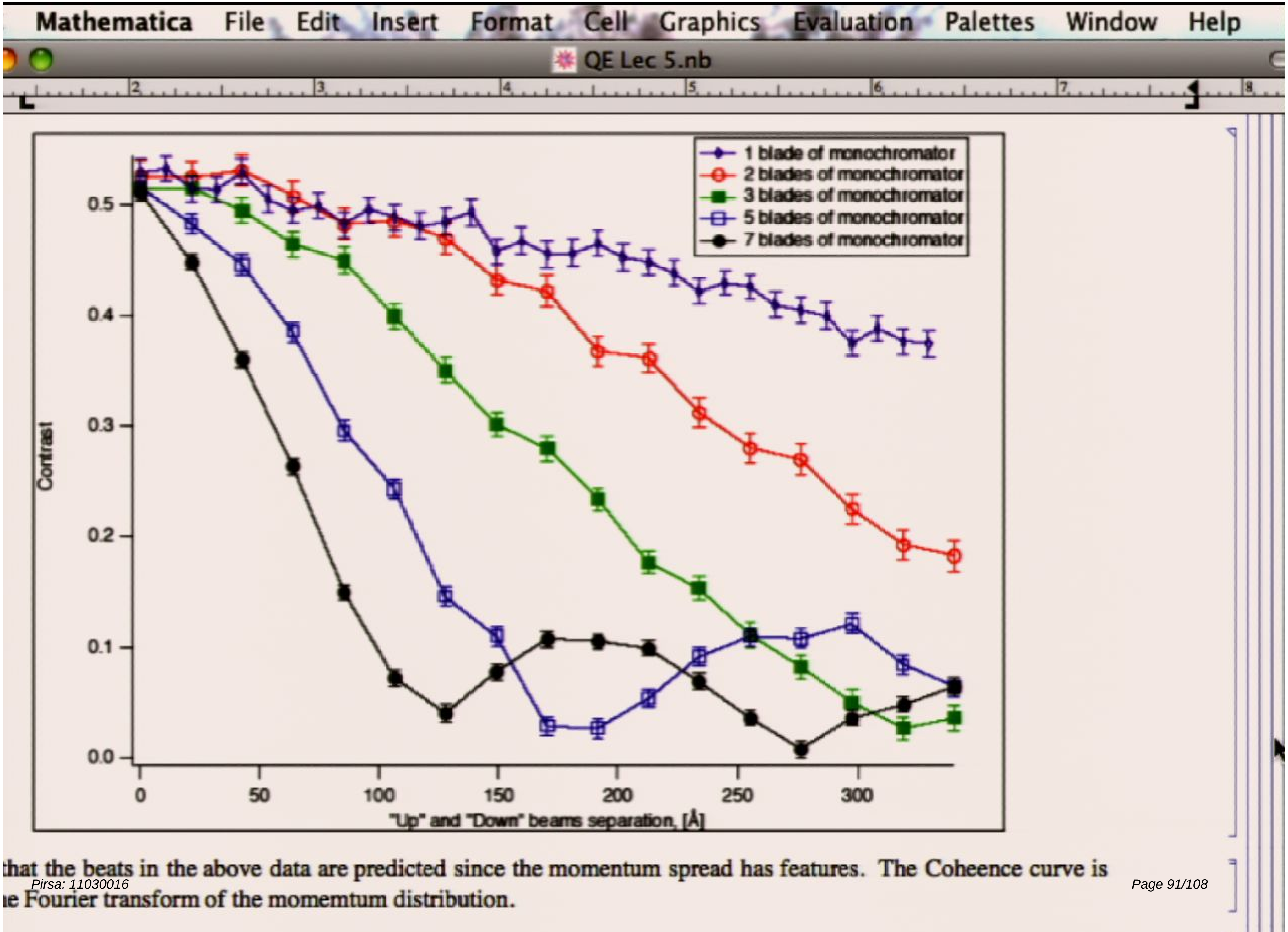


ata is noisy but shows that the scattered (recombined) beam retains contrast, while the direct beam looses con-
vith increased separation of the beams.

y point to remmember here is that the contrast in the transmitted beam is lost due to a distribution of momenta.
the neutron momenta in free space do not change, this can easily be recoverd. Also note that we can compose
ary states of momenta through a series of such filters.



that the beats in the above data are predicted since the momentum spread has features. The Coheence curve is e Fourier transform of the momemtum distribution.



that the beats in the above data are predicted since the momentum spread has features. The Coheence curve is
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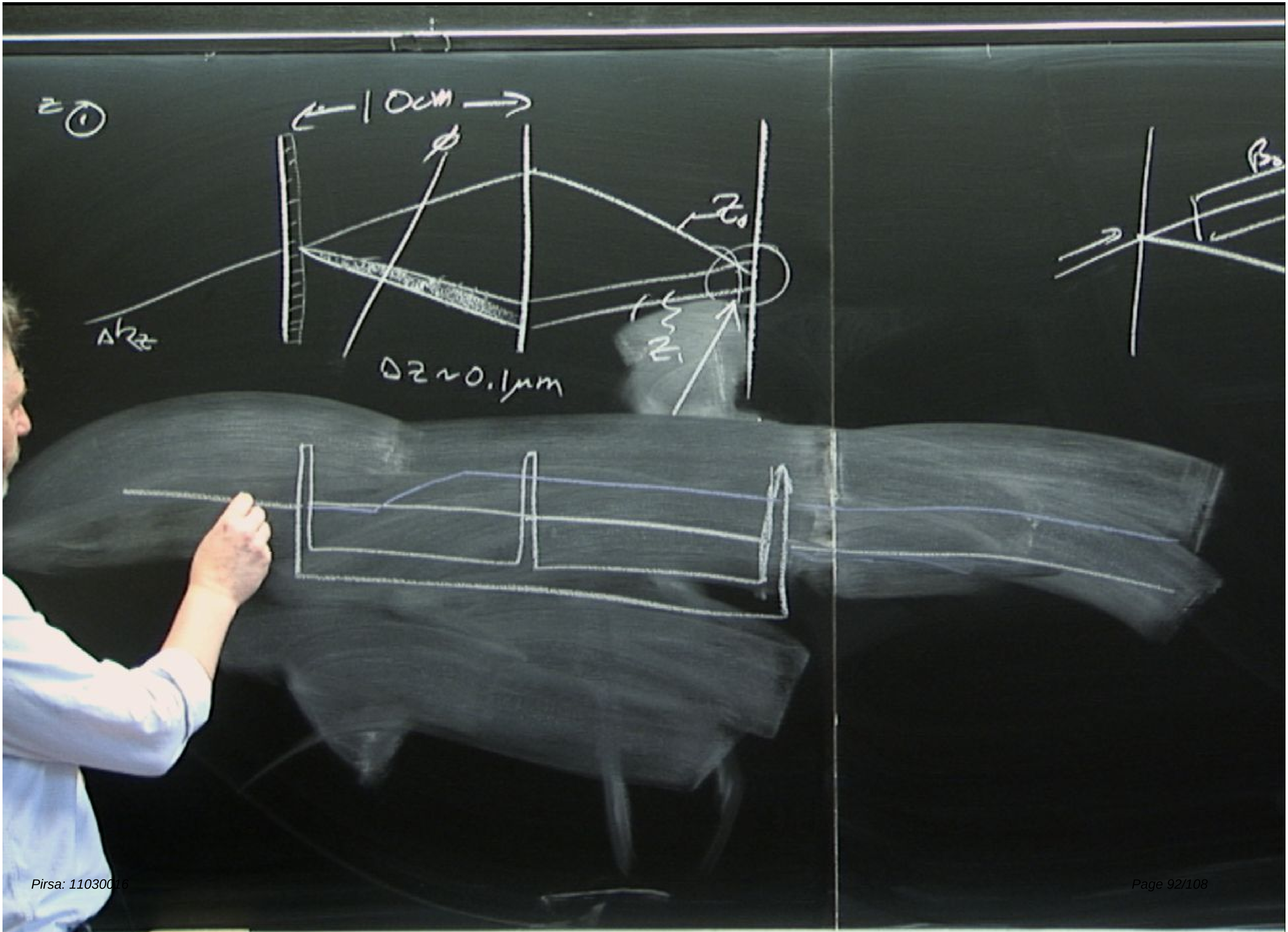
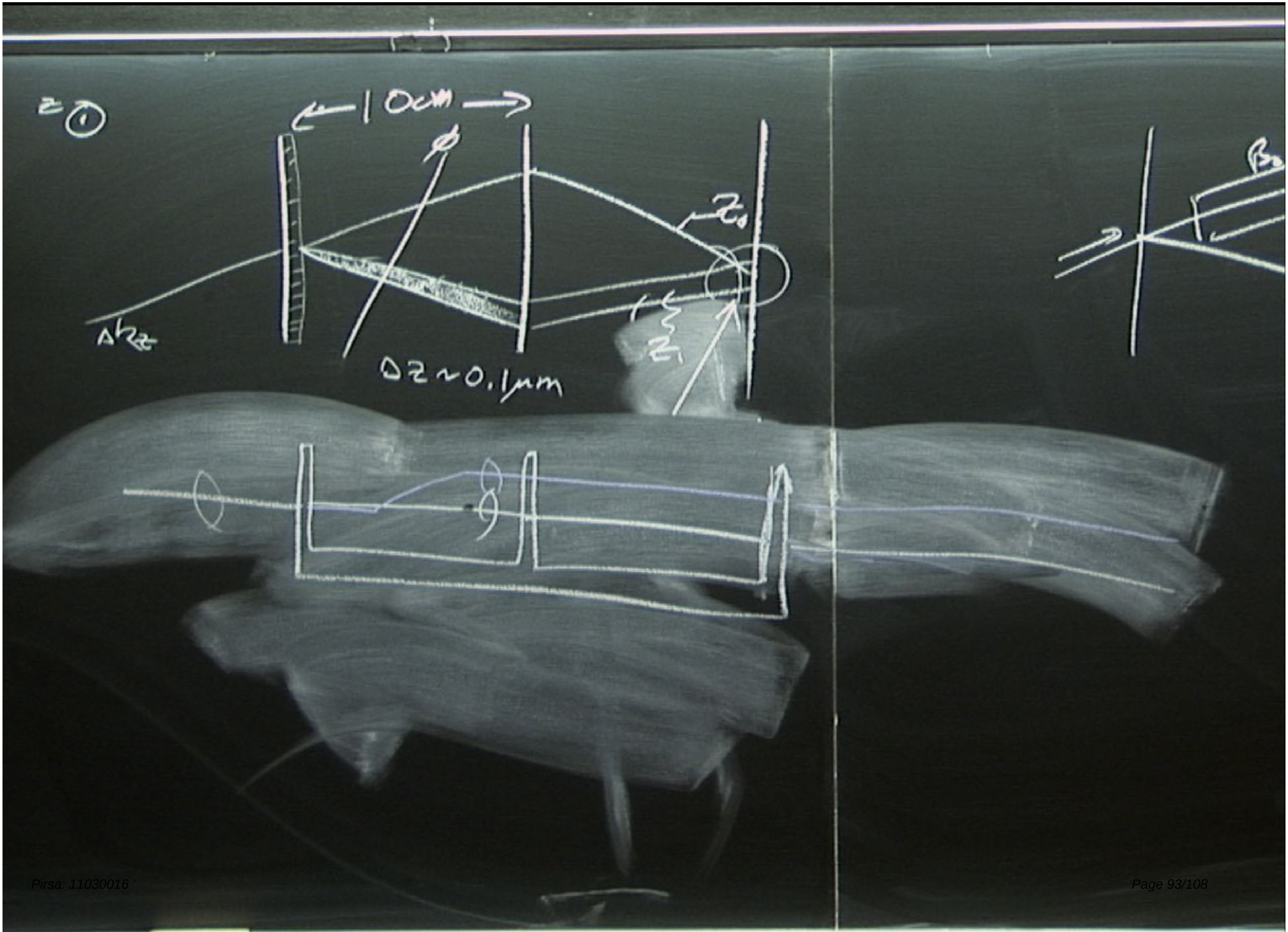
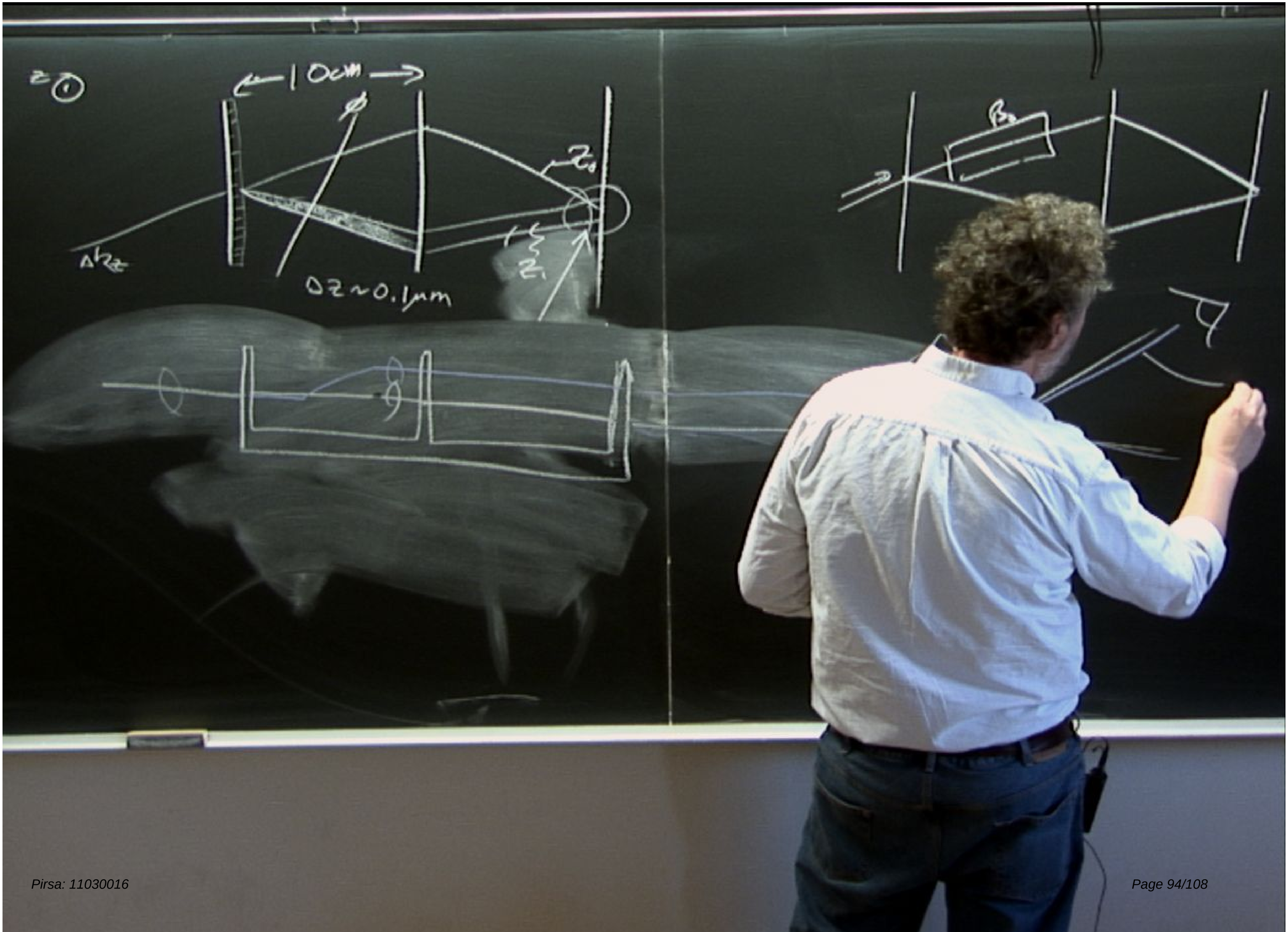
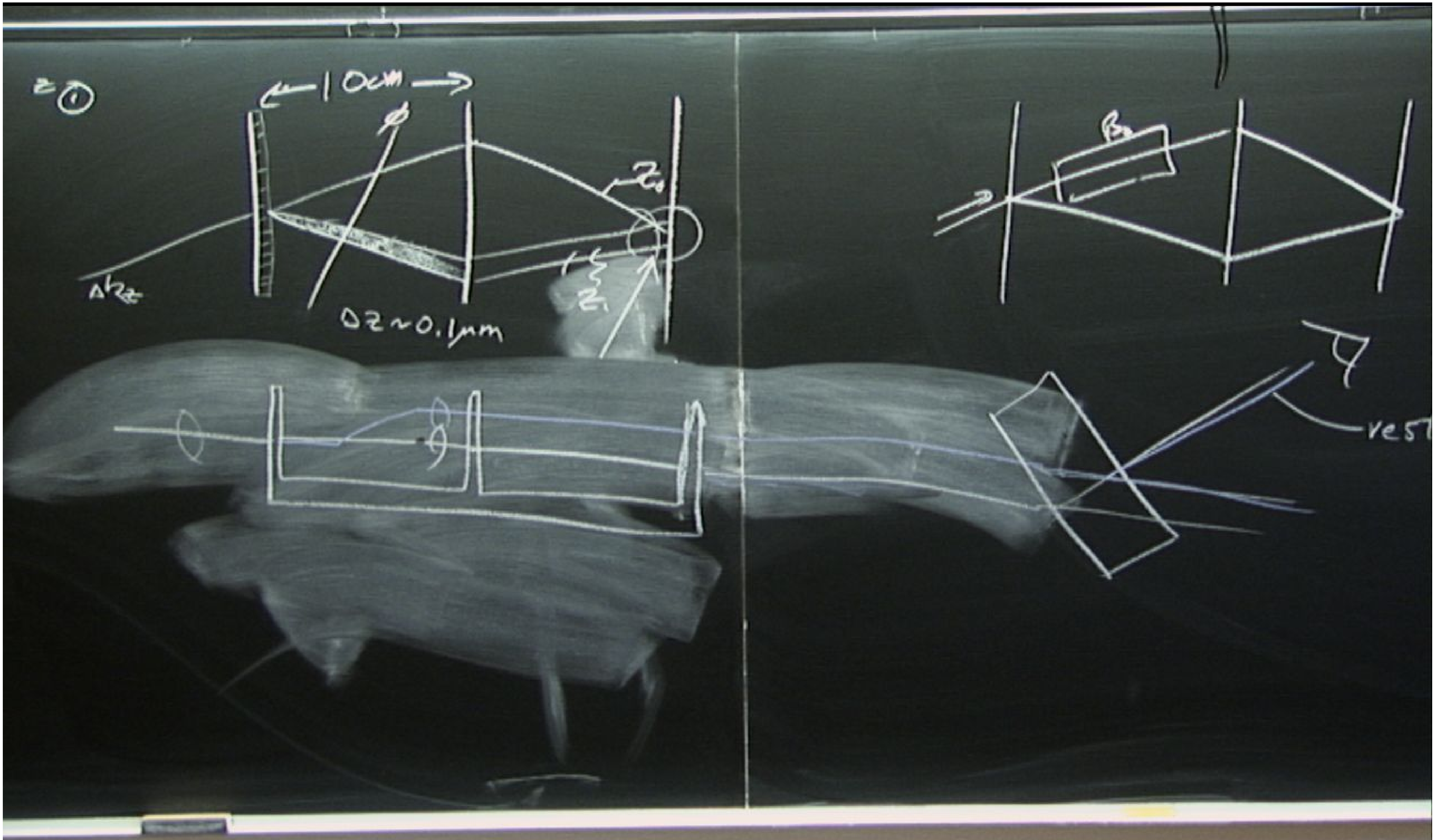


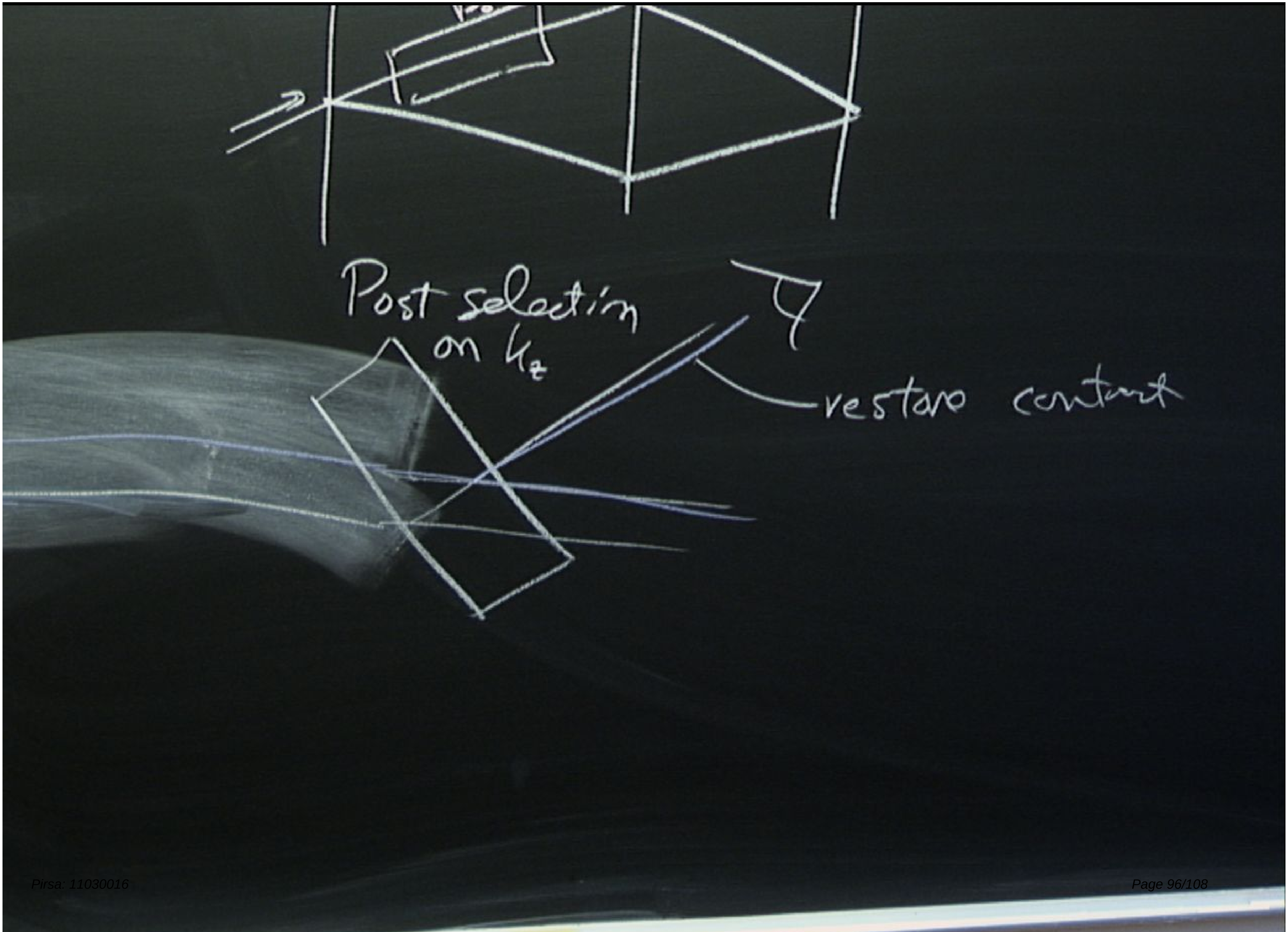
z ①
10cm
φ
z₀
z₁
Δkz
Δz ~ 0.1μm
B₀

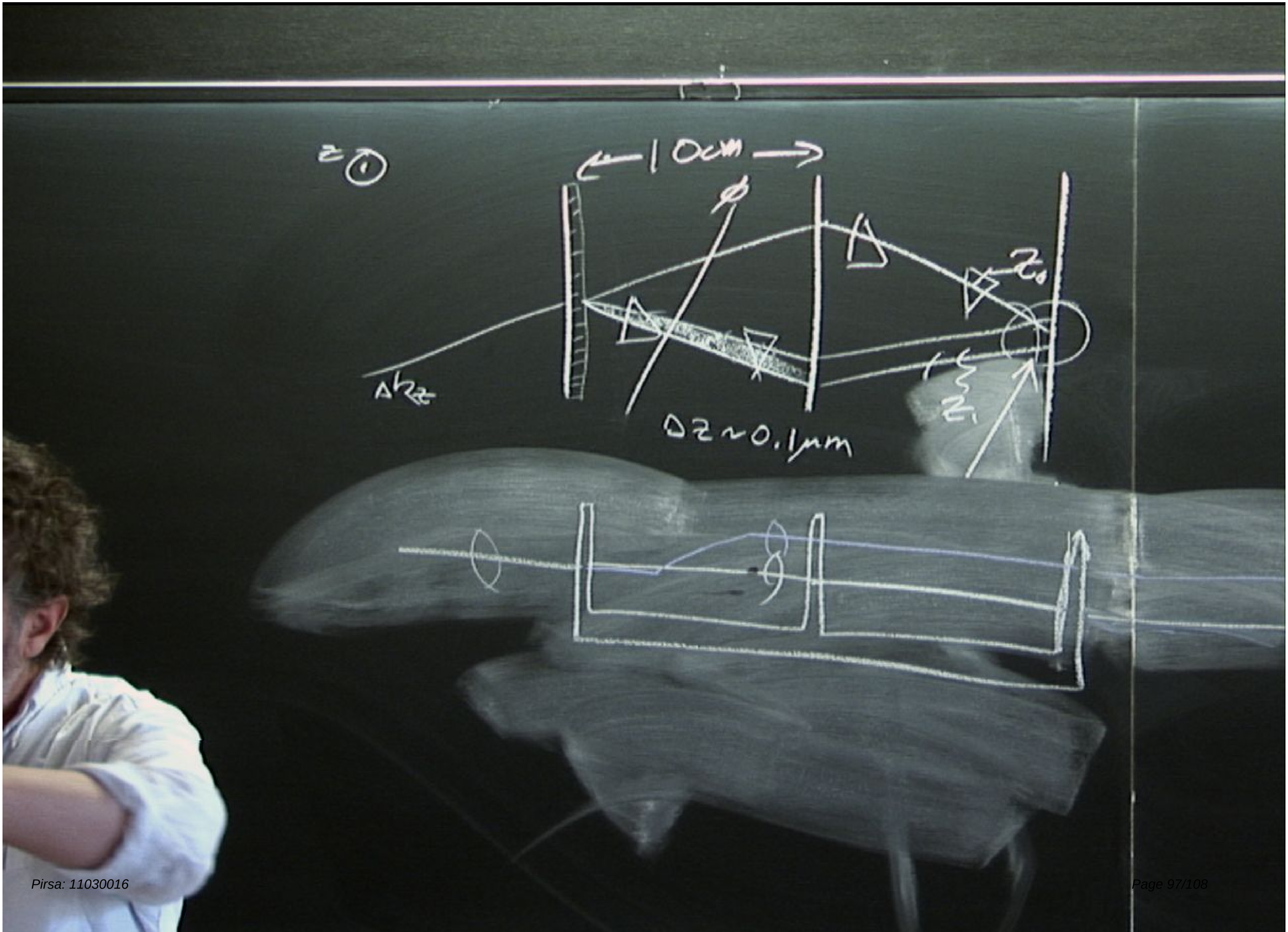


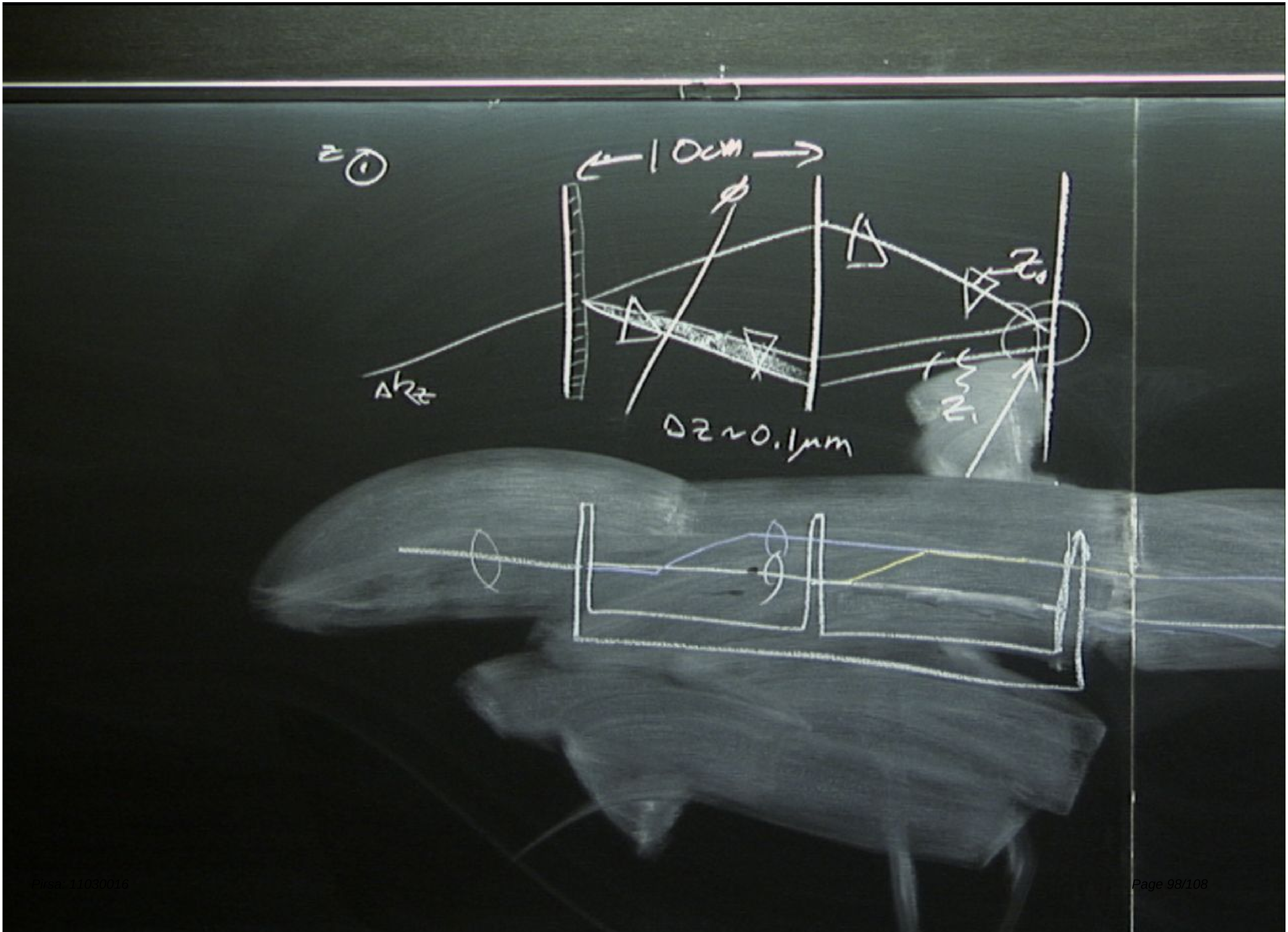
①
10cm
φ
z0
z1
Δz ~ 0.1μm
Δkz
B0

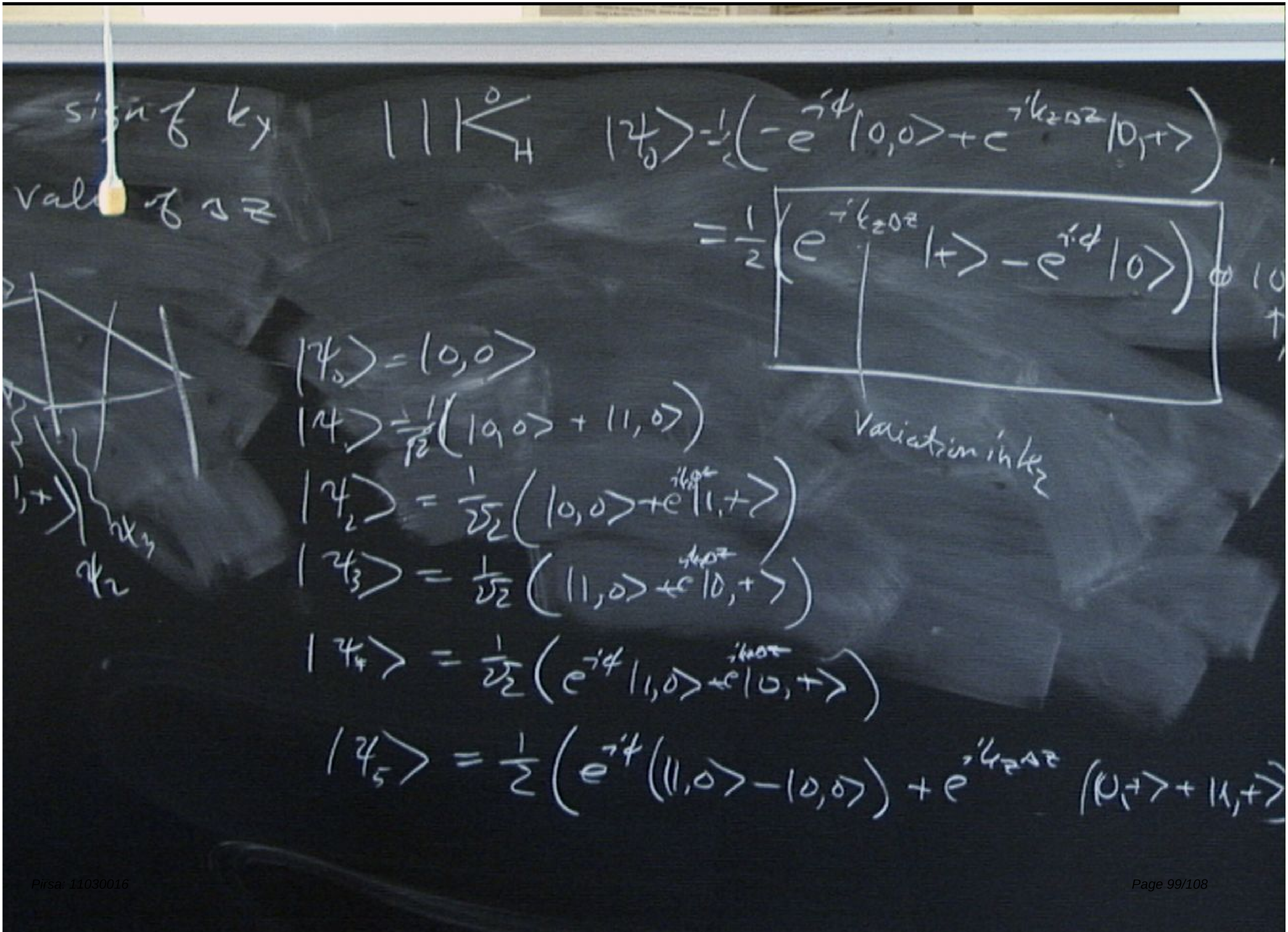

①
10cm
φ
z_0
z_1
$\Delta z \sim 0.1\mu m$
β_0


z ①
10cm
φ
z_0
z_1
Δhz
Δz~0.1μm
B_0
rest


Post selection
on k_z
restore contrast


z ①
10cm
ϕ
Z₀
Z₁
Δk z
Δz ~ 0.1μm


z ①
10cm
φ
Z_0
Z_1
Δk_z
$\Delta z \sim 0.1 \mu m$



sign of k_y

val of Δz

$\| K^{0}_{H}$

$|\psi_0\rangle = \frac{1}{2}\left(-e^{i\phi}|0,0\rangle + e^{ik_z\Delta z}|0,+\rangle\right)$

$= \boxed{\frac{1}{2}\left(e^{ik_z\Delta z}|+\rangle - e^{i\phi}|0\rangle\right)} \otimes |0$

Variation in k_z

$|\psi_0\rangle = |0,0\rangle$

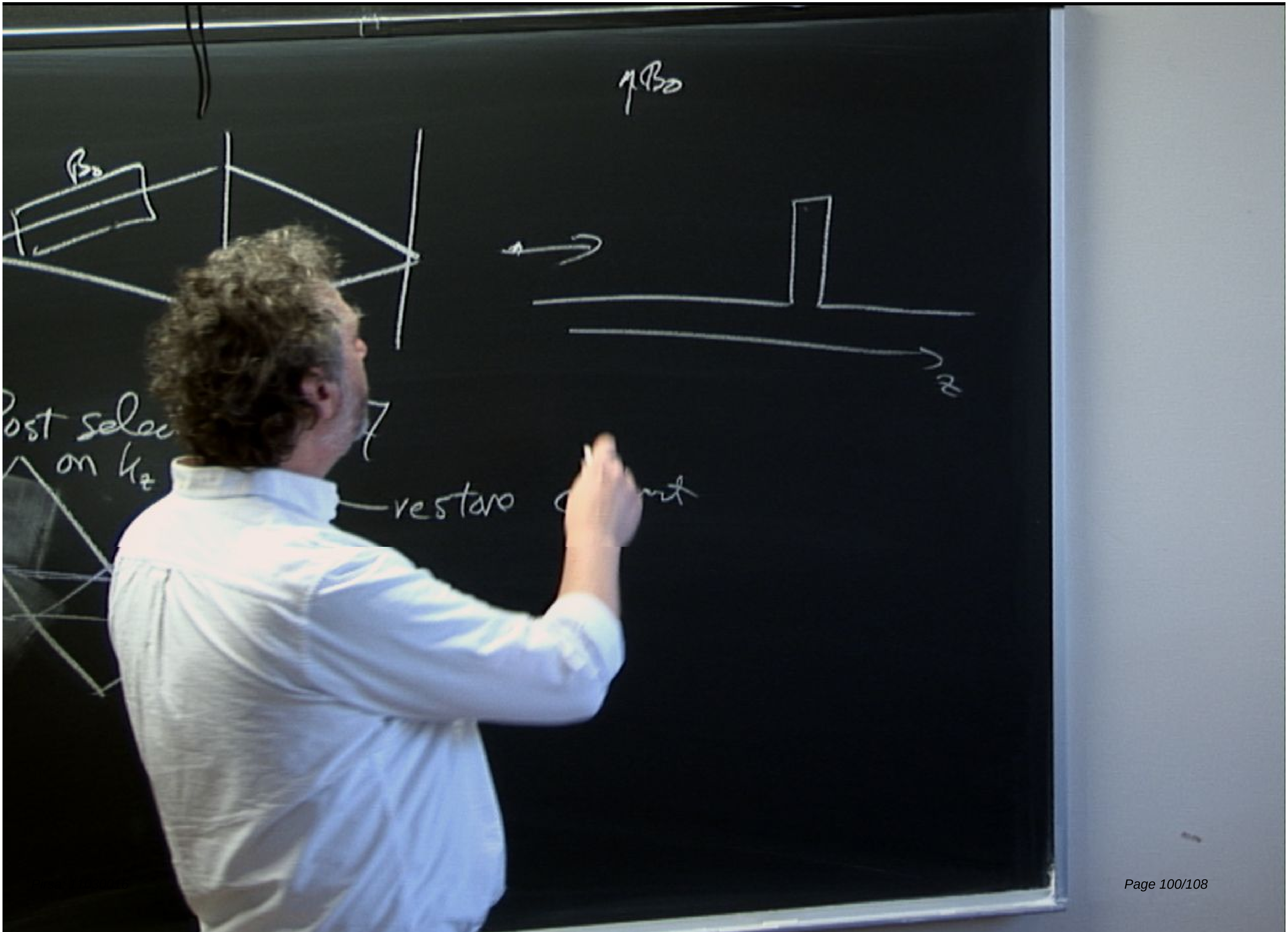
$|\psi_1\rangle = \frac{1}{\sqrt{2}}\left(|0,0\rangle + |1,0\rangle\right)$

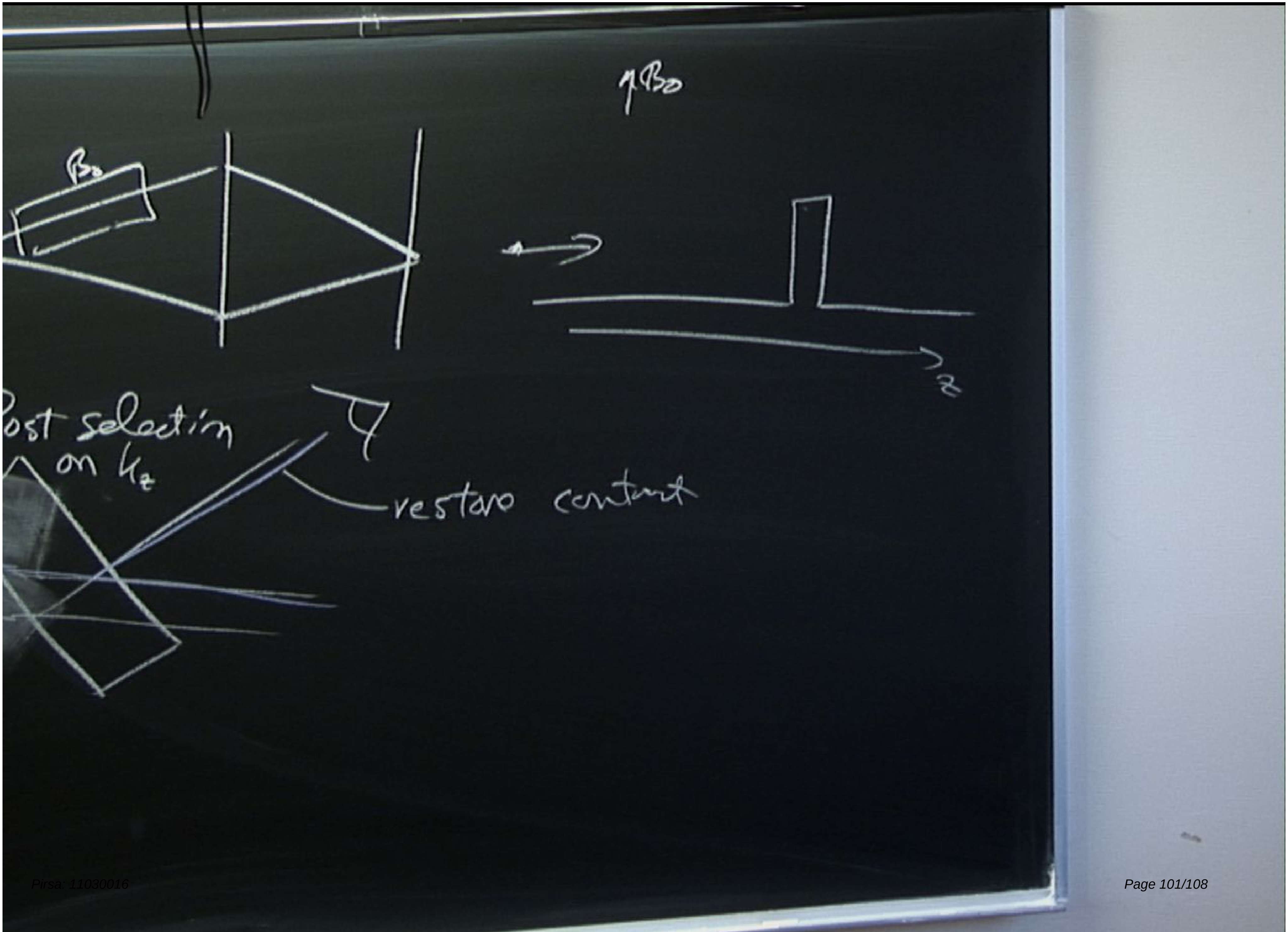
$|\psi_2\rangle = \frac{1}{\sqrt{2}}\left(|0,0\rangle + e^{ik_z\Delta z}|1,+\rangle\right)$

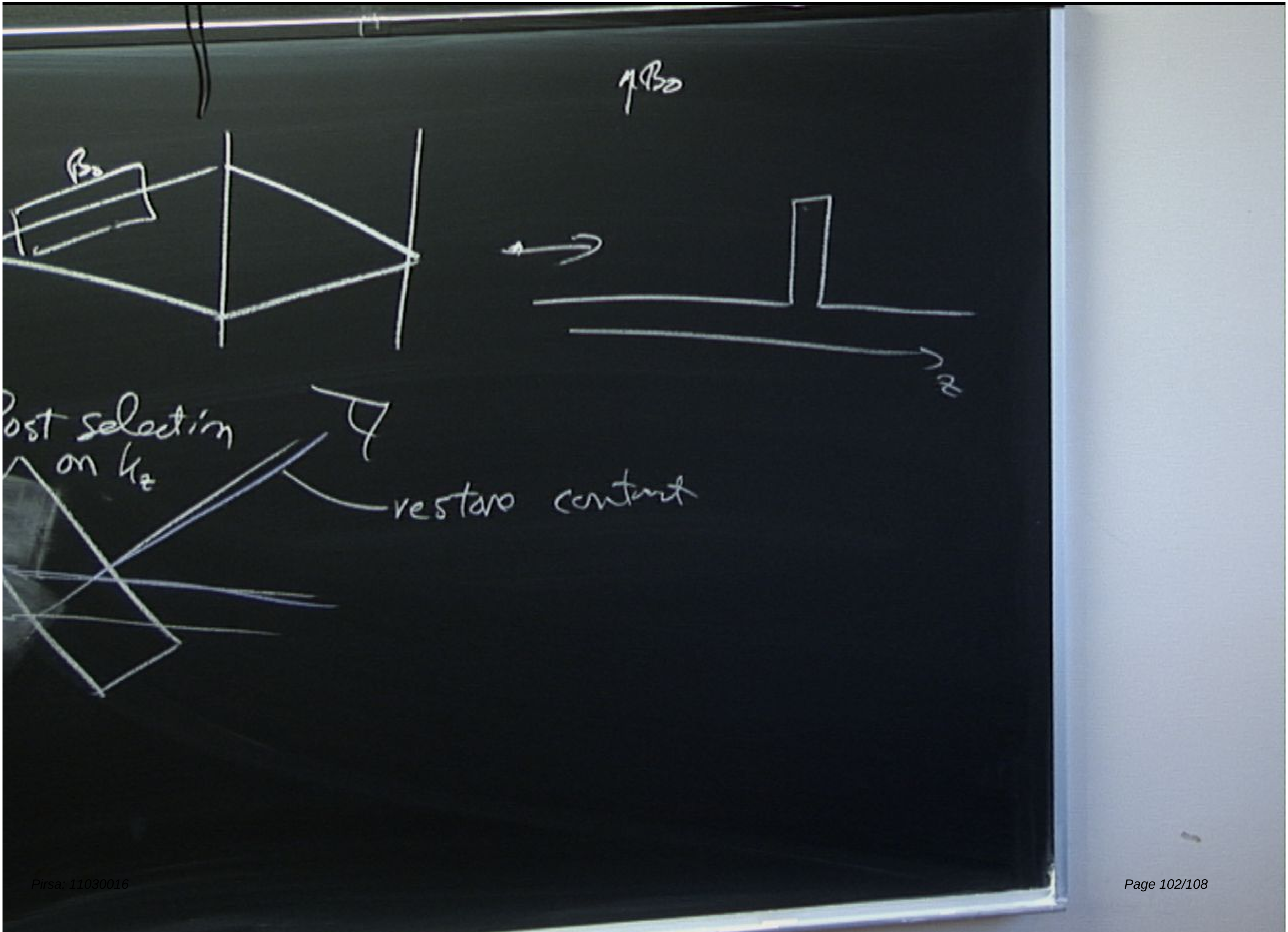
$|\psi_3\rangle = \frac{1}{\sqrt{2}}\left(|1,0\rangle + e^{ik_z\Delta z}|0,+\rangle\right)$

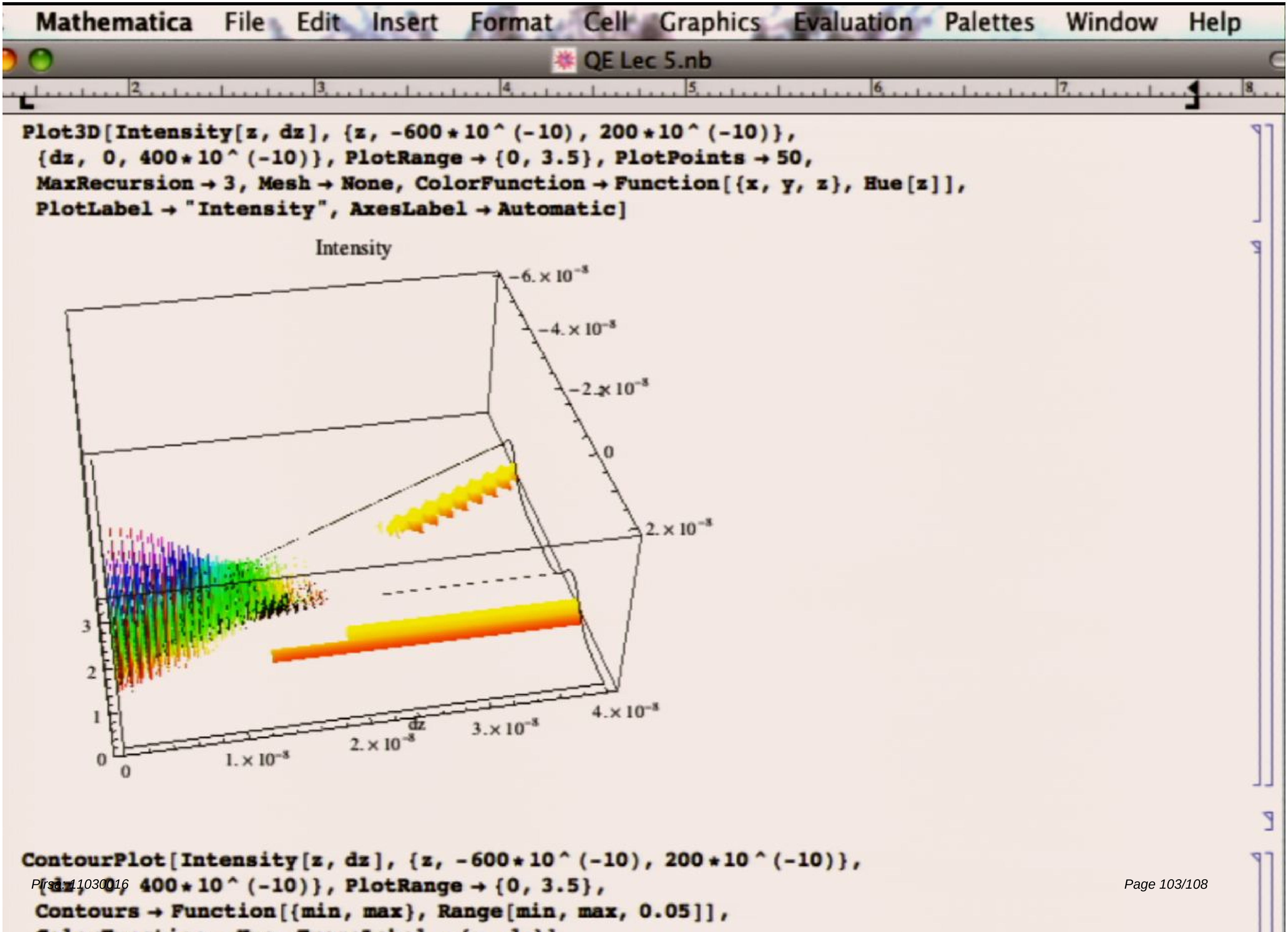
$|\psi_4\rangle = \frac{1}{\sqrt{2}}\left(e^{i\phi}|1,0\rangle + e^{ik_z\Delta z}|0,+\rangle\right)$

$|\psi_5\rangle = \frac{1}{2}\left(e^{i\phi}\left(|1,0\rangle - |0,0\rangle\right) + e^{ik_z\Delta z}\left(|0,+\rangle + |1,+\rangle\right.\right.$


μB₀
B₀
Post selec
on k_z
restore
z

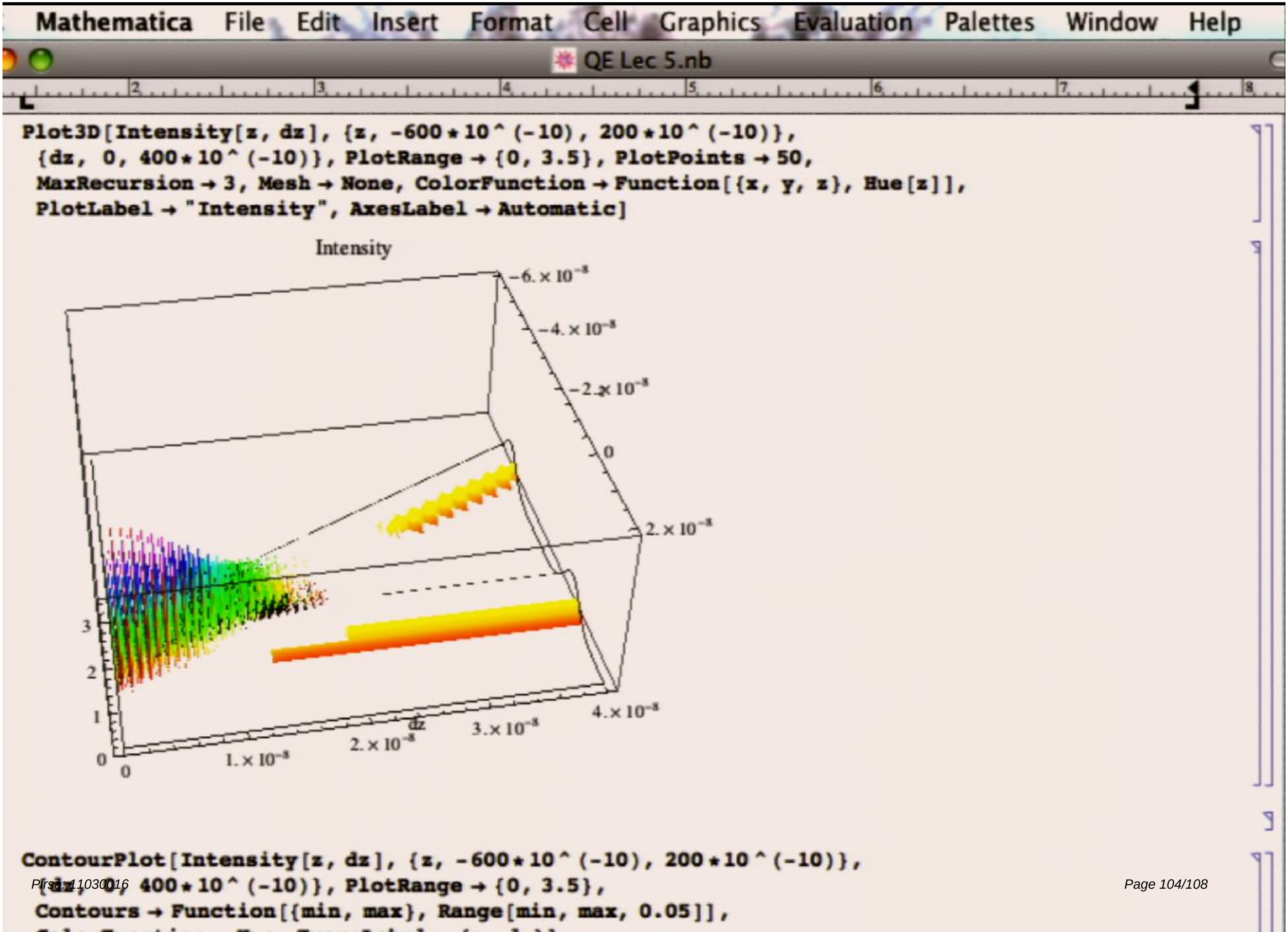

ηB_0
B_0
z
Post selection on k_z
restore contrast


ηB₀
B₀
z
Post selection
on k_z
restore contrast



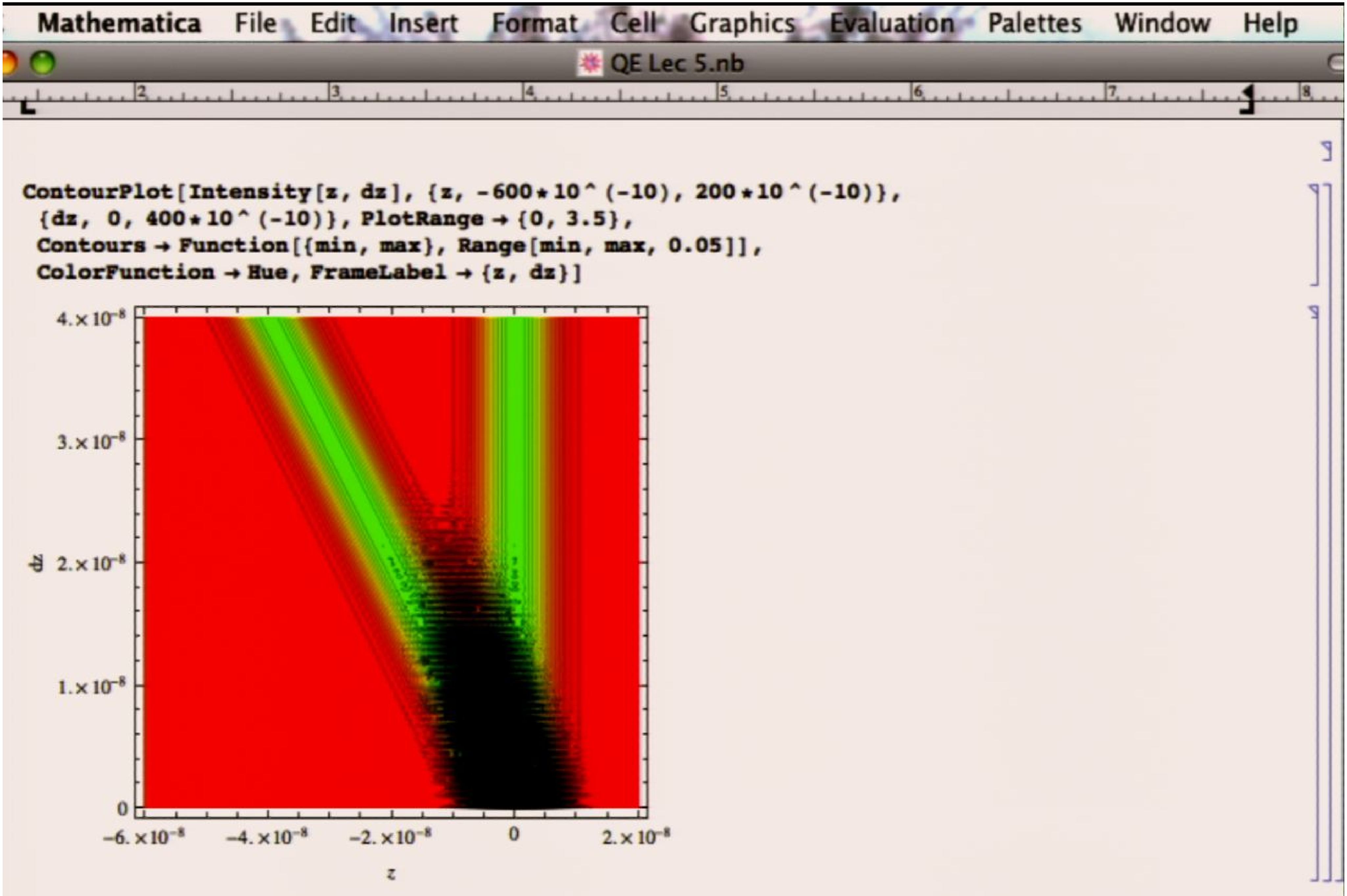
```
Plot3D[Intensity[z, dz], {z, -600*10^(-10), 200*10^(-10)},
 {dz, 0, 400*10^(-10)}, PlotRange → {0, 3.5}, PlotPoints → 50,
 MaxRecursion → 3, Mesh → None, ColorFunction → Function[{x, y, z}, Hue[z]],
 PlotLabel → "Intensity", AxesLabel → Automatic]
```

```
ContourPlot[Intensity[z, dz], {z, -600*10^(-10), 200*10^(-10)},
 {dz, 0, 400*10^(-10)}, PlotRange → {0, 3.5},
 Contours → Function[{min, max}, Range[min, max, 0.05]],
```

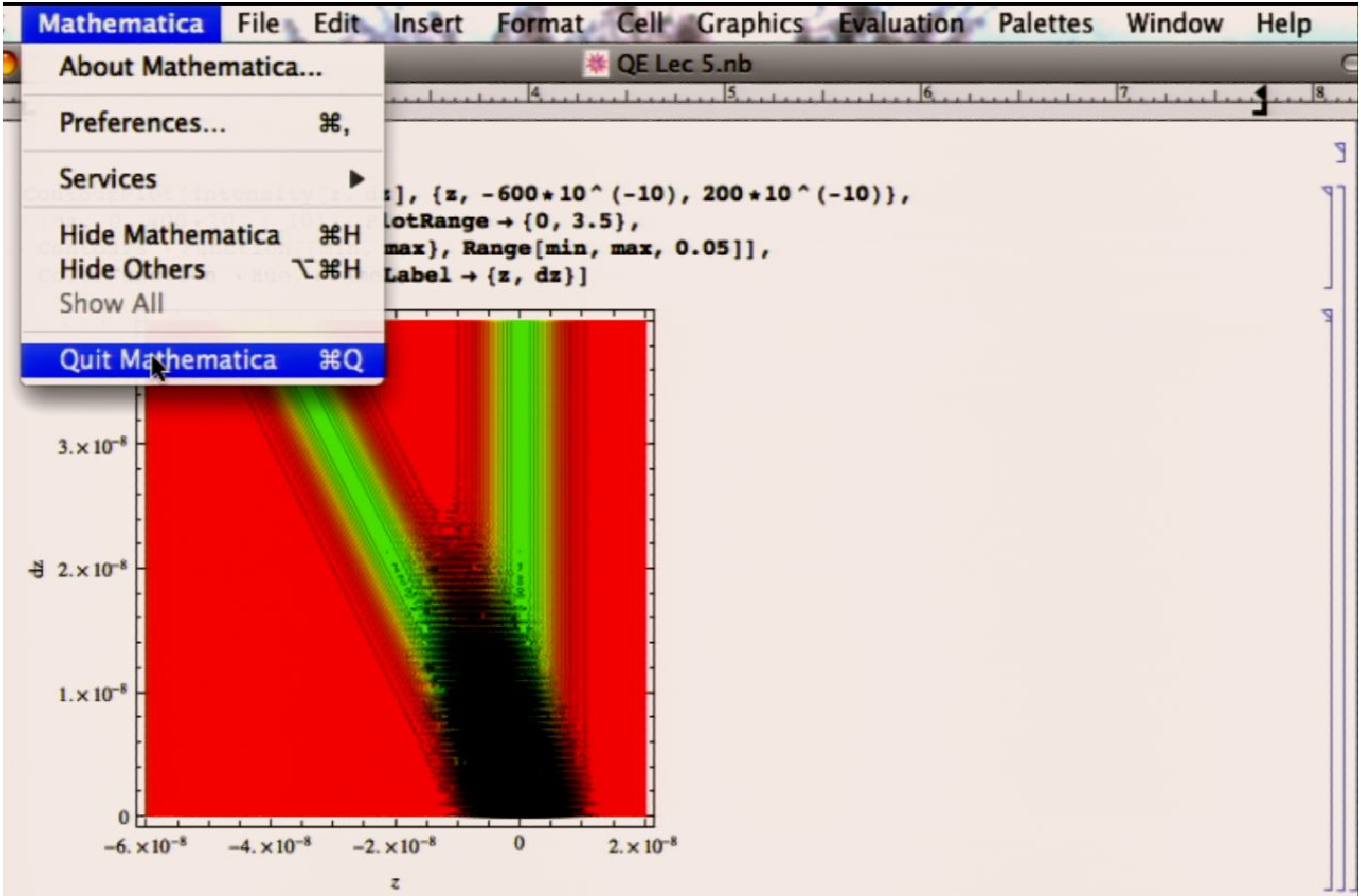


```
Plot3D[Intensity[z, dz], {z, -600*10^(-10), 200*10^(-10)},
 {dz, 0, 400*10^(-10)}, PlotRange → {0, 3.5}, PlotPoints → 50,
 MaxRecursion → 3, Mesh → None, ColorFunction → Function[{x, y, z}, Hue[z]],
 PlotLabel → "Intensity", AxesLabel → Automatic]
```

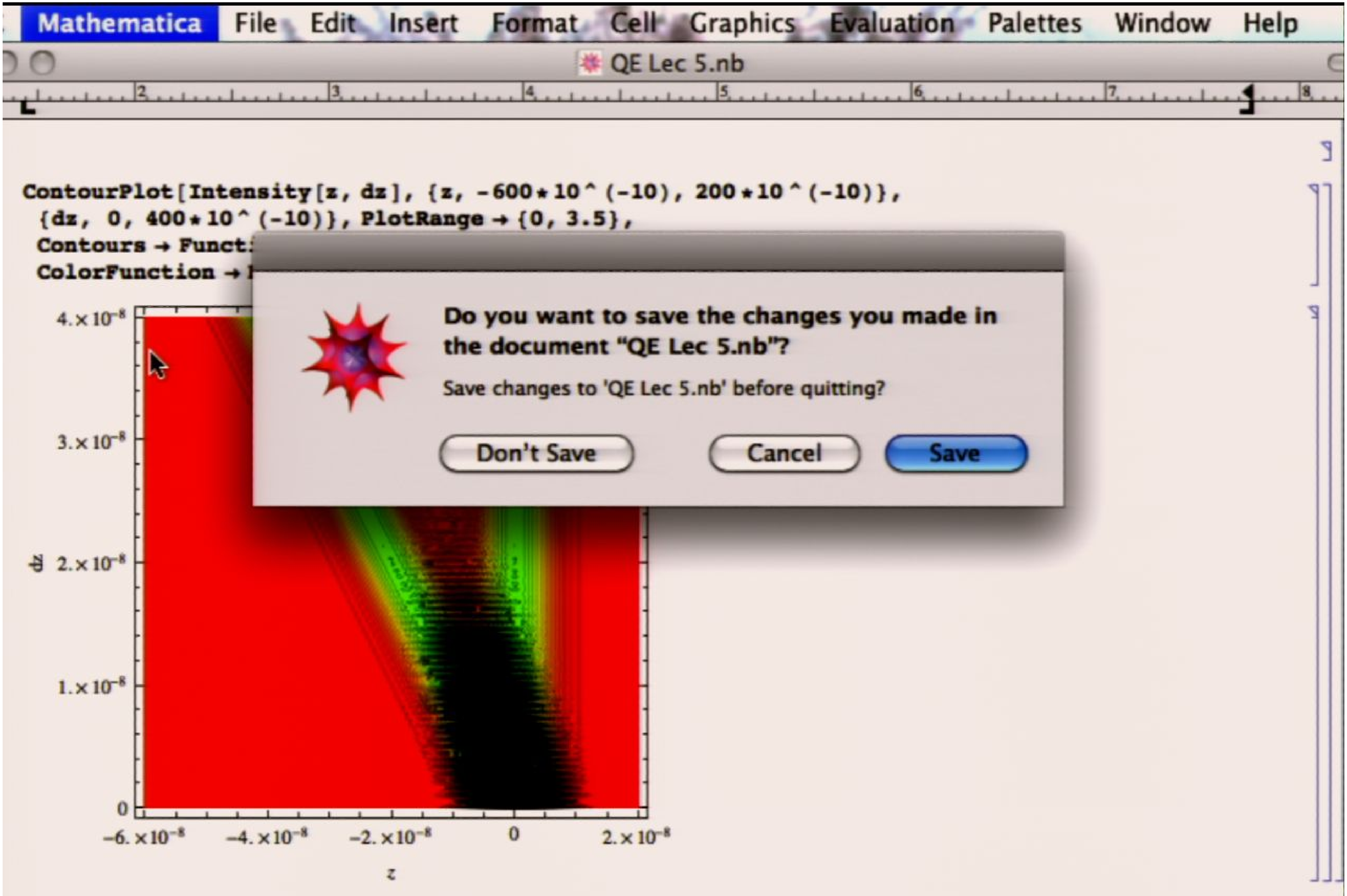
```
ContourPlot[Intensity[z, dz], {z, -600*10^(-10), 200*10^(-10)},
 {dz, 0, 400*10^(-10)}, PlotRange → {0, 3.5},
 Contours → Function[{min, max}, Range[min, max, 0.05]],
```



```
ContourPlot[Intensity[z, dz], {z, -600*10^(-10), 200*10^(-10)},
 {dz, 0, 400*10^(-10)}, PlotRange → {0, 3.5},
 Contours → Function[{min, max}, Range[min, max, 0.05]],
 ColorFunction → Hue, FrameLabel → {z, dz}]
```



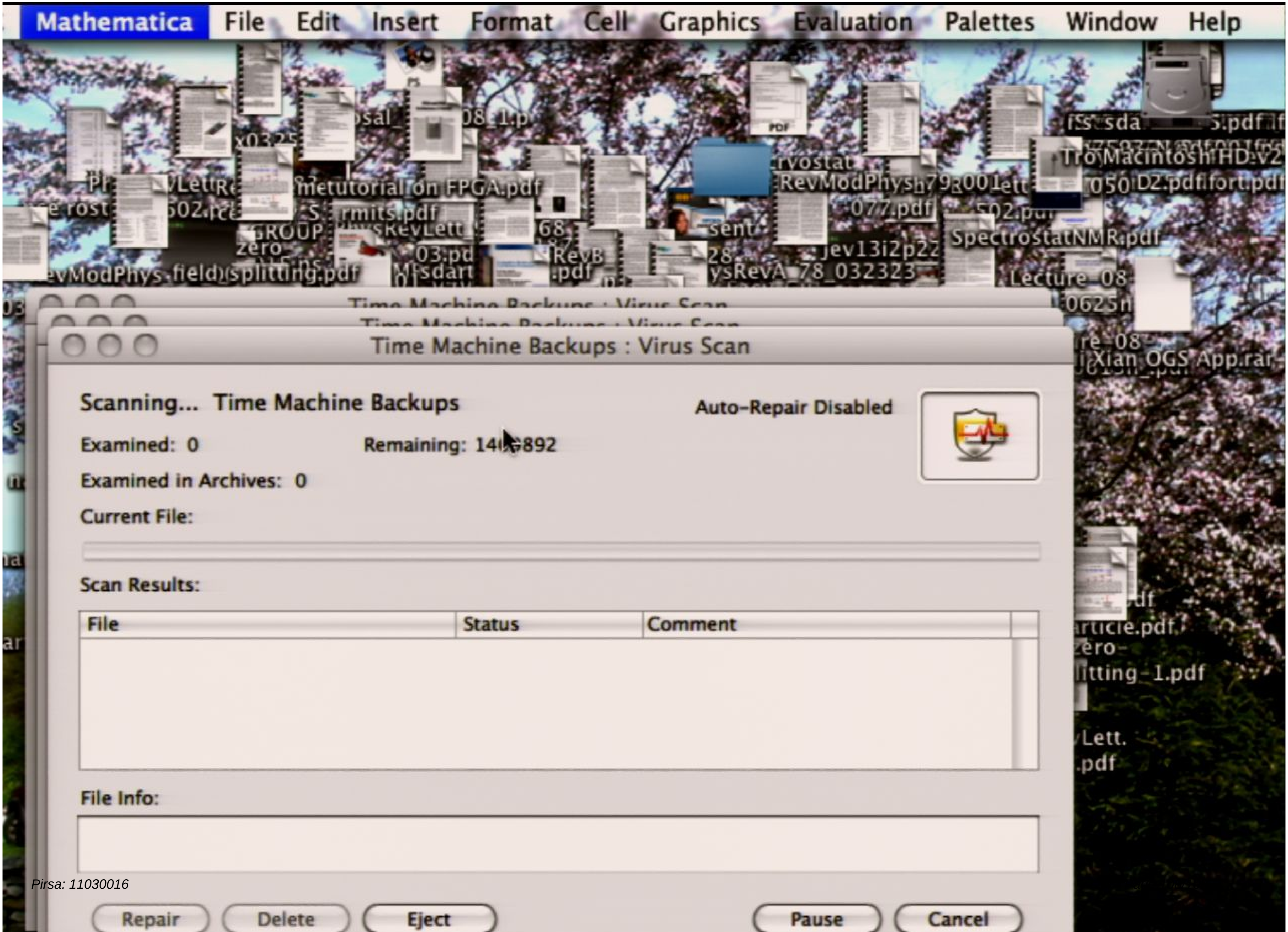
```
ContourPlot[Intensity[z, dz], {z, -600*10^(-10), 200*10^(-10)},
lotRange → {0, 3.5},
max}, Range[min, max, 0.05]],
Label → {z, dz}]
```



```
ContourPlot[Intensity[z, dz], {z, -600*10^(-10), 200*10^(-10)},
 {dz, 0, 400*10^(-10)}, PlotRange → {0, 3.5},
 Contours → Funct
 ColorFunction → 
```

Do you want to save the changes you made in the document "QE Lec 5.nb"?

Save changes to 'QE Lec 5.nb' before quitting?



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File	Status	Comment

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