Title: Standard Model - Review (PHYS 622) - Lecture 2

Date: Dec 01, 2009 09:00 AM

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Abstract:

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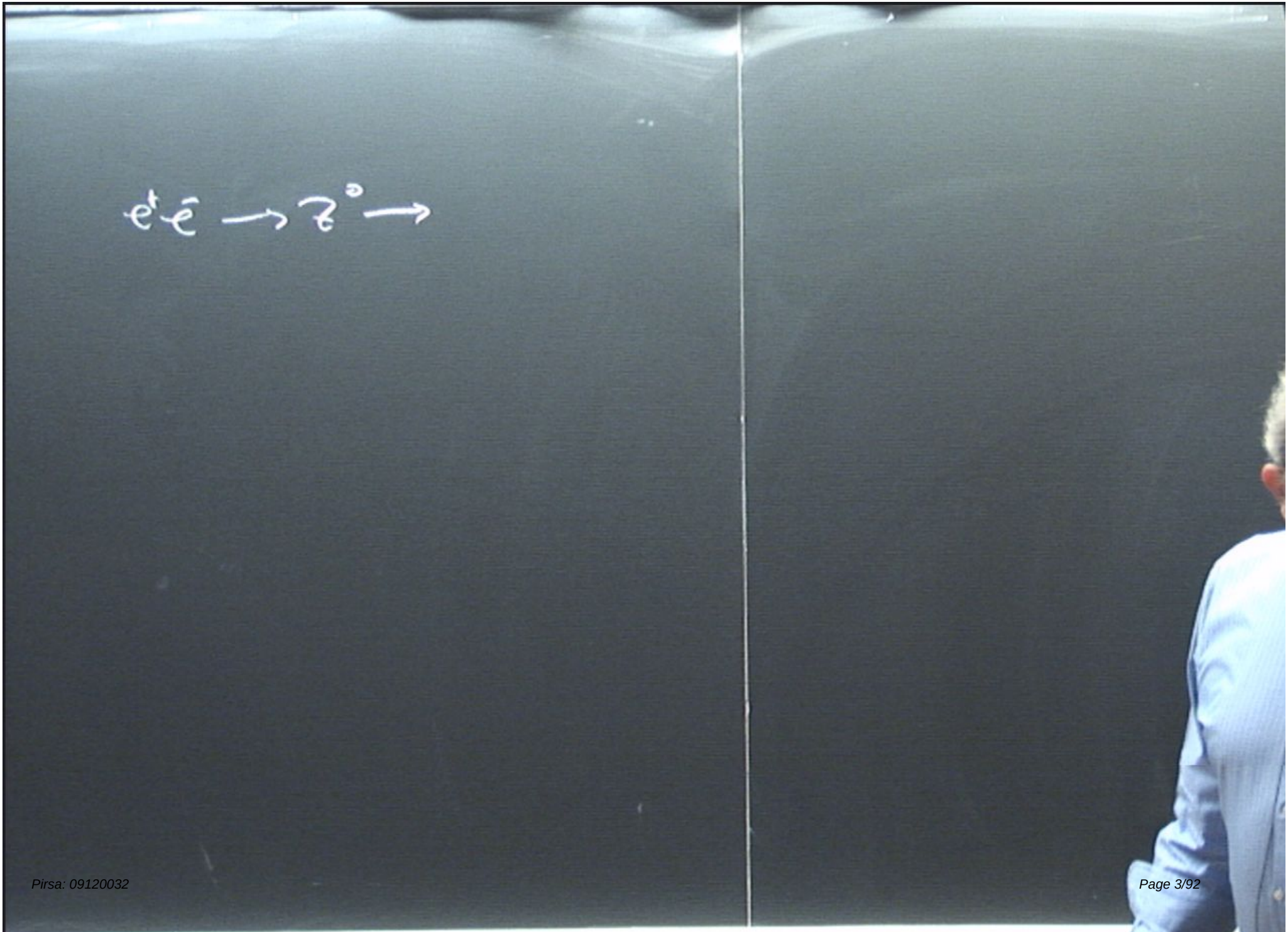
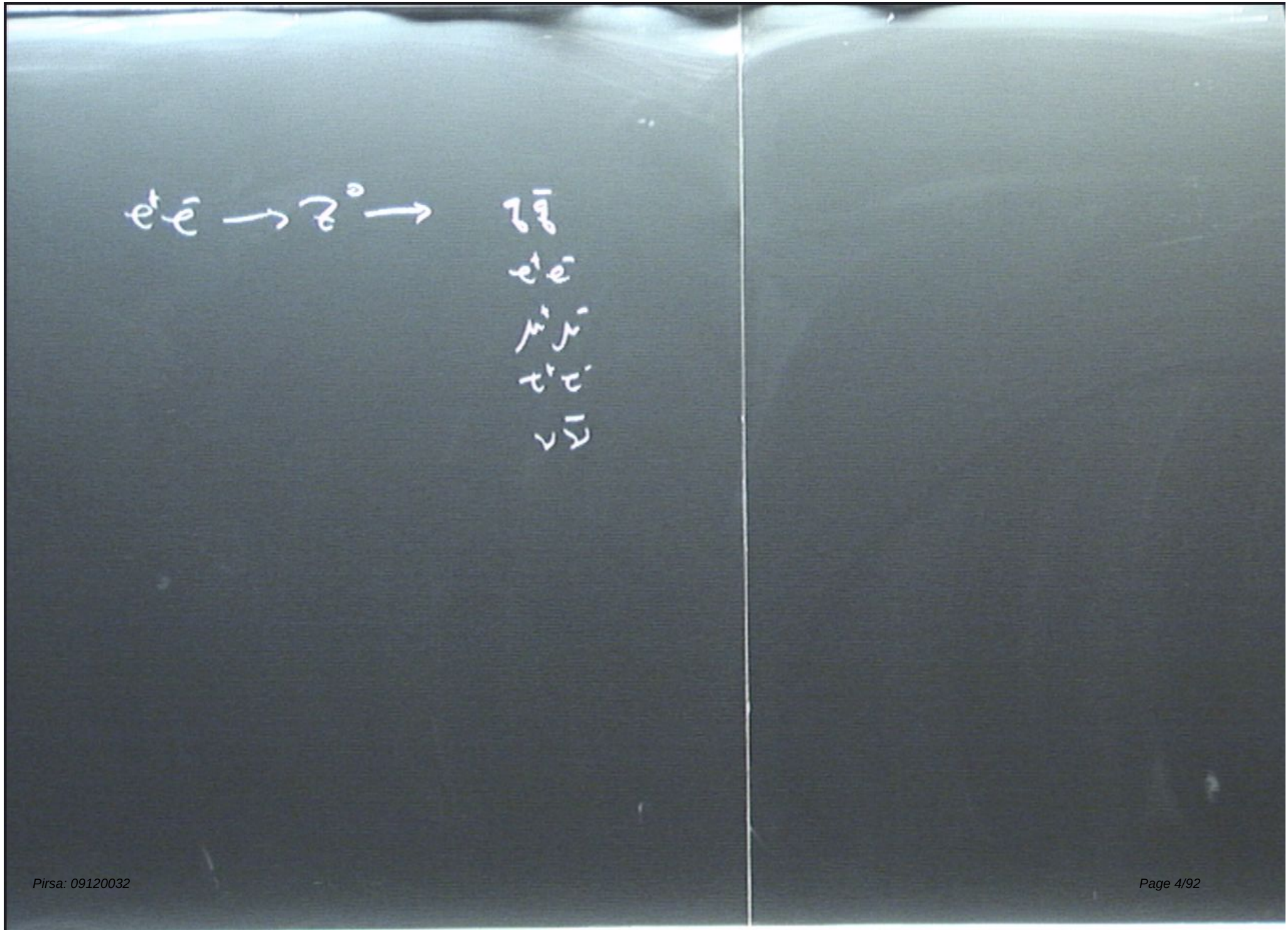

$e^+e^- \to Z^0 \to$



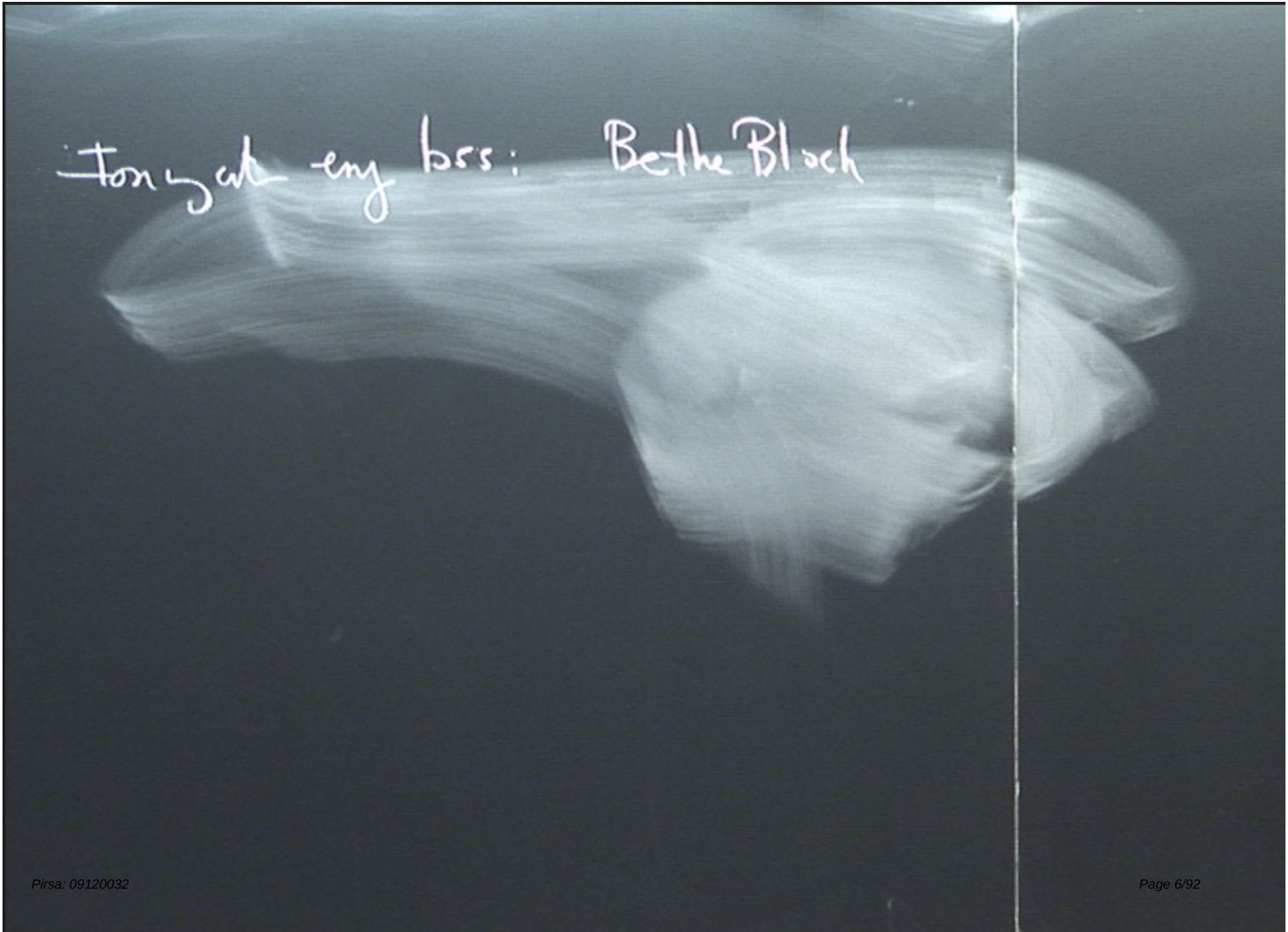
$e^+e^- \rightarrow Z^0 \rightarrow$ $q\bar{q}$

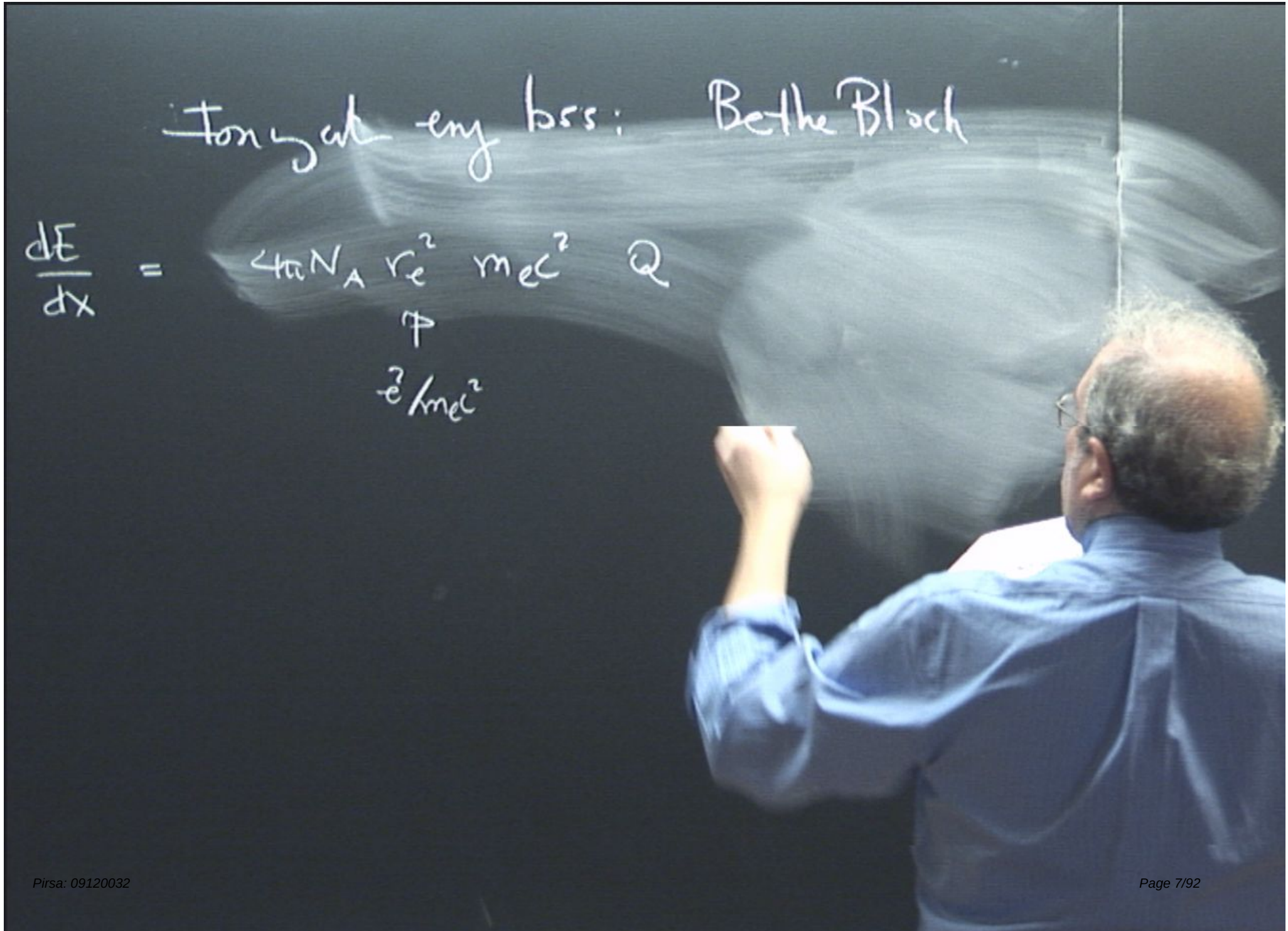
e^+e^-

$\mu^+\mu^-$

$\tau^+\tau^-$

$\nu\bar{\nu}$

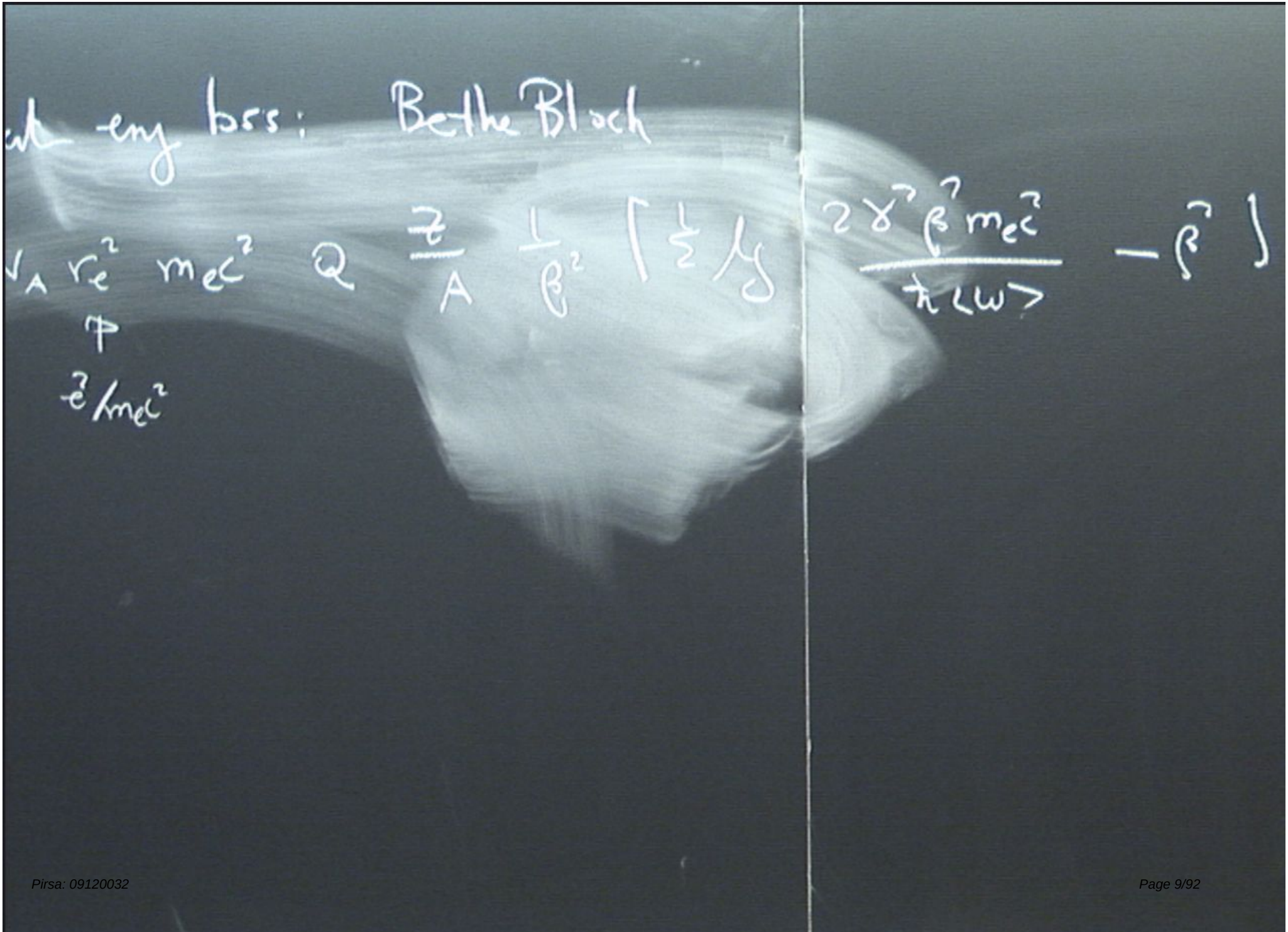

Ionization energy loss: Bethe Bloch


Ionization energy loss: Bethe Bloch
$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q$
$\uparrow$
$e^2/4\pi\epsilon_0$

Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2}$$

$r_e = e^2/m_e c^2$


Bethe Bloch
$\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2\gamma^2\beta^2 m_e c^2}{\hbar\langle\omega\rangle} - \beta^2\right]$
$\hbar$
$e^2/m_e c^2$

Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{I \langle \omega \rangle} - \beta^2 \right]$$

$r_e = e^2/m_e c^2$

Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$$

$r_e \equiv e^2/m_e c^2$

Ionization energy loss: Bethe Bloch

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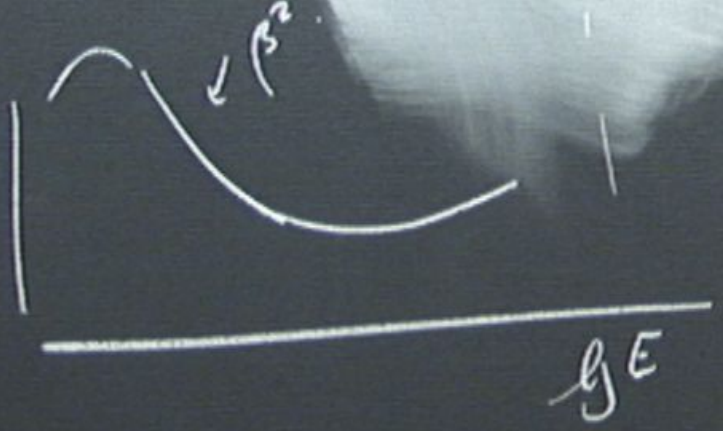
$r_e = e^2/m_e c^2$

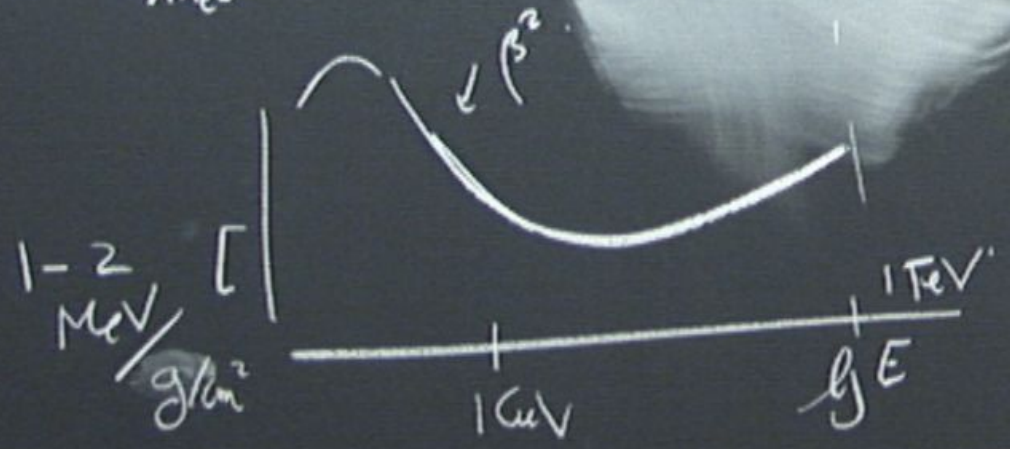


Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$$

Φ

e^2/mc^2



Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$$

β

z^2/mc^2

"minimum ionizing"

$\downarrow \beta^2$

1 - 2 MeV / g/cm²

1 GeV

1 TeV

$\ln E$

Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$$

$r_e = e^2/m_e c^2$

"minimum ionizing"

$\downarrow$

$1-2$ MeV/g/cm^2

$\downarrow 1/\beta^2$

1 GeV

1 TeV

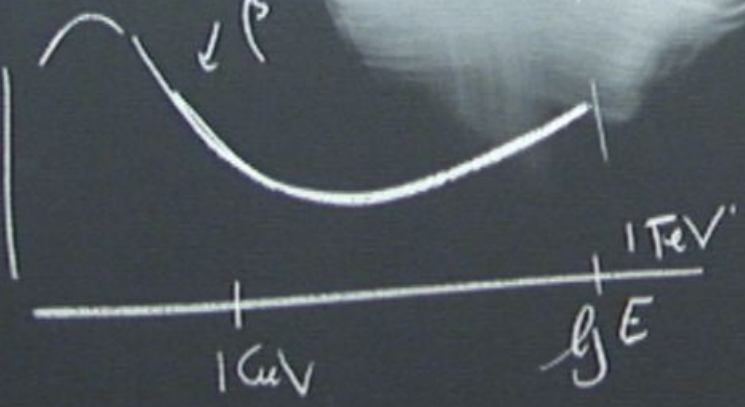
$\ln E$

Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$$

$r_e = e^2/m_e c^2$

- minimum ionization



Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$$

$\hbar$

$e^2/m_e c^2$

"minimum ionizing"

↓

mip

1 - 2 MeV/g/cm²

β^2

1 TeV

1 GeV

$\ln E$

Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$$

β

z^2/mc^2

"minimum ionizing"

mip

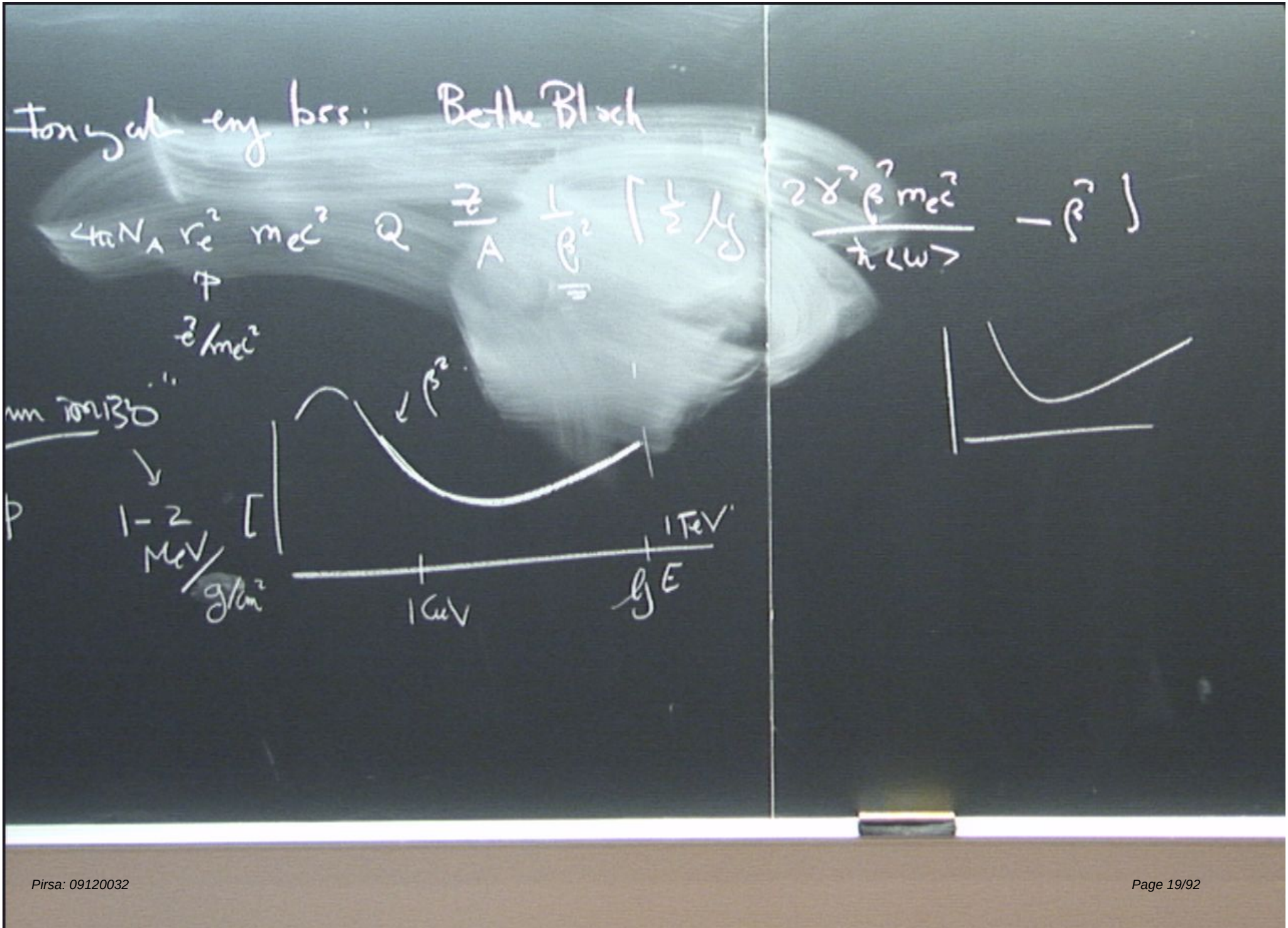
1 - 2 MeV / g/cm²

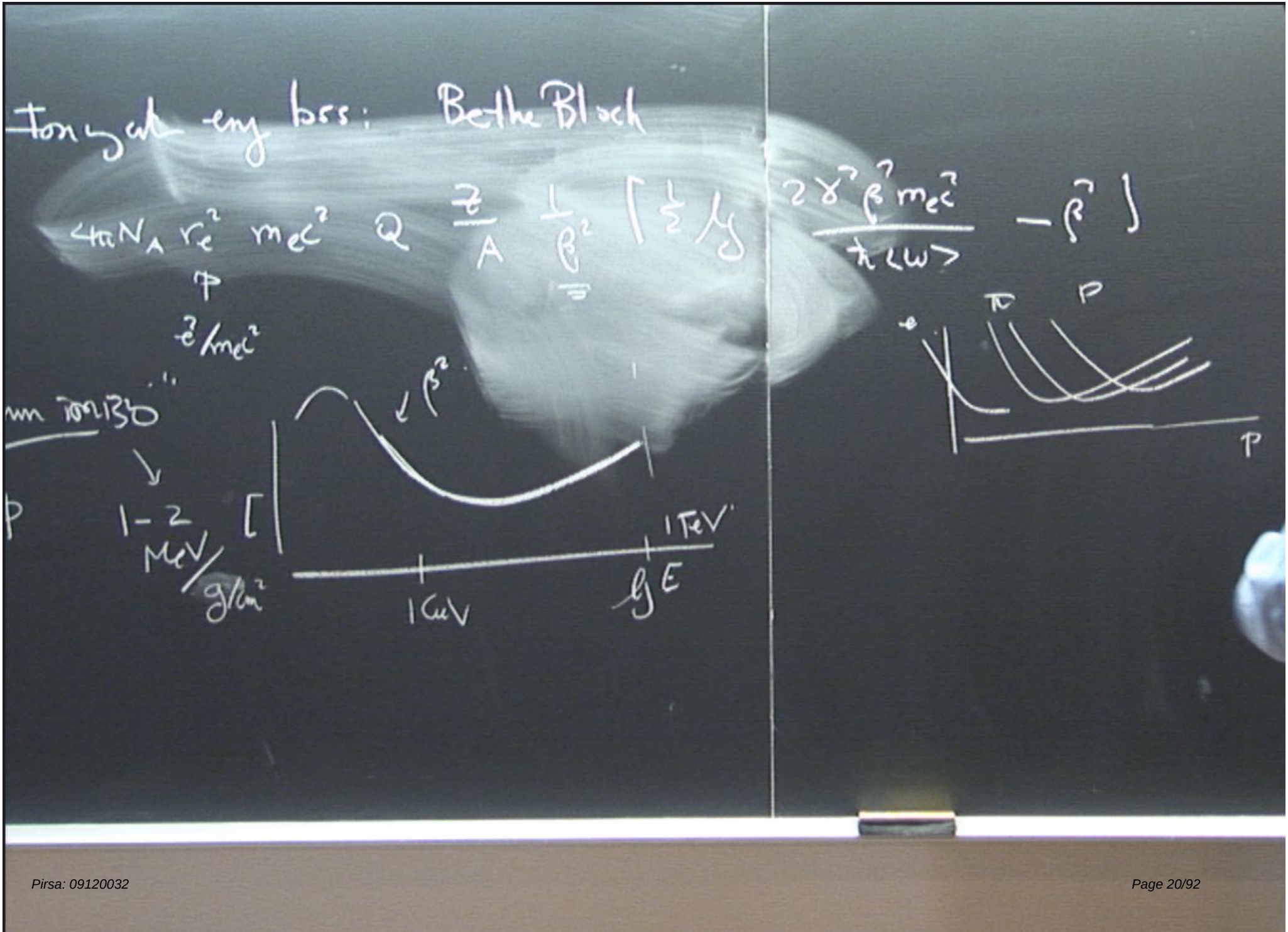
β^2

1 GeV

1 TeV

$\ln E$


Ionization energy loss: Bethe Bloch
$4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$
$\hbar^2/m_e c^2$
$1/\beta^2$
1-2 MeV/g/cm²
1 GeV
1 TeV
ln E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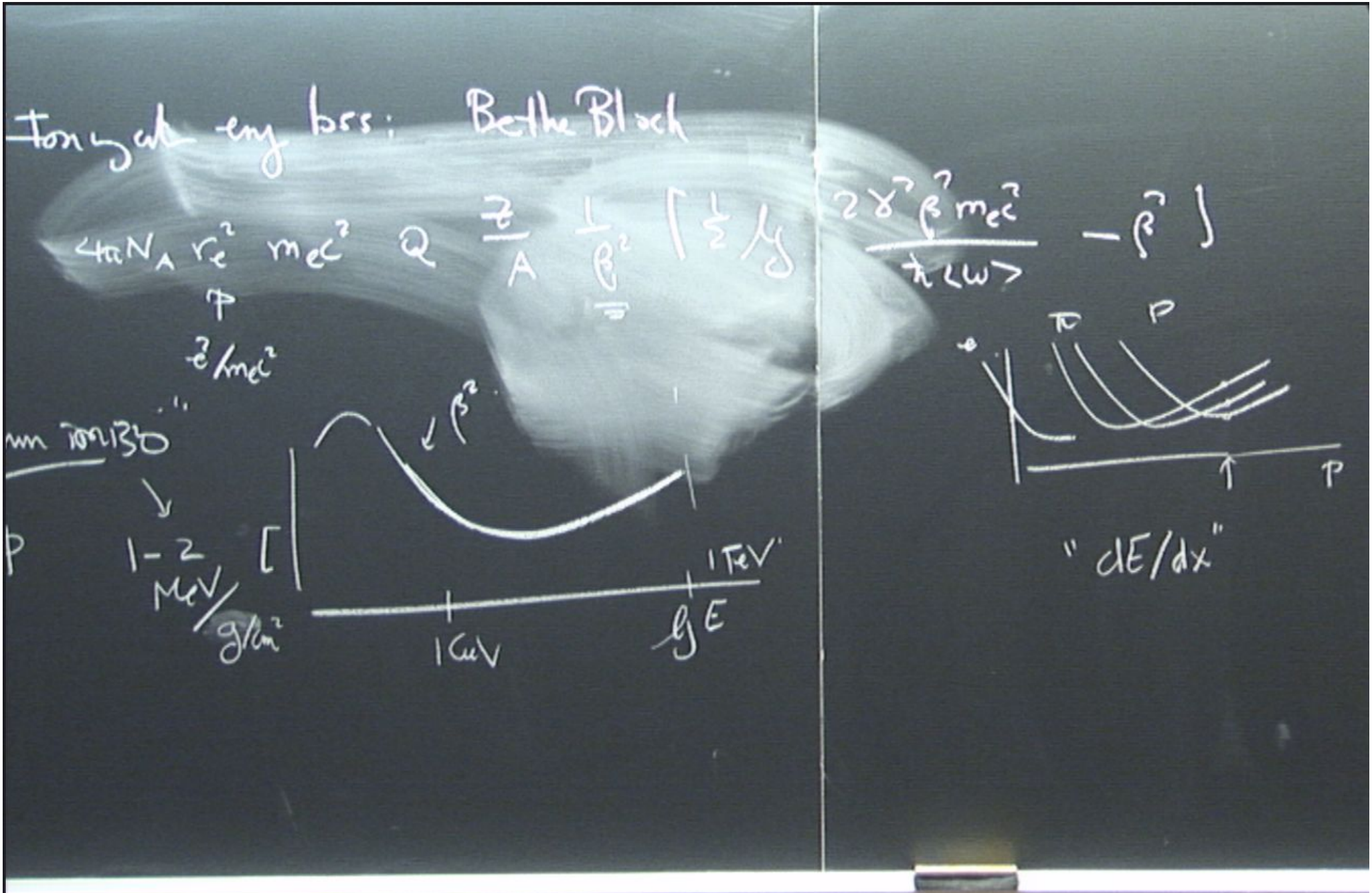
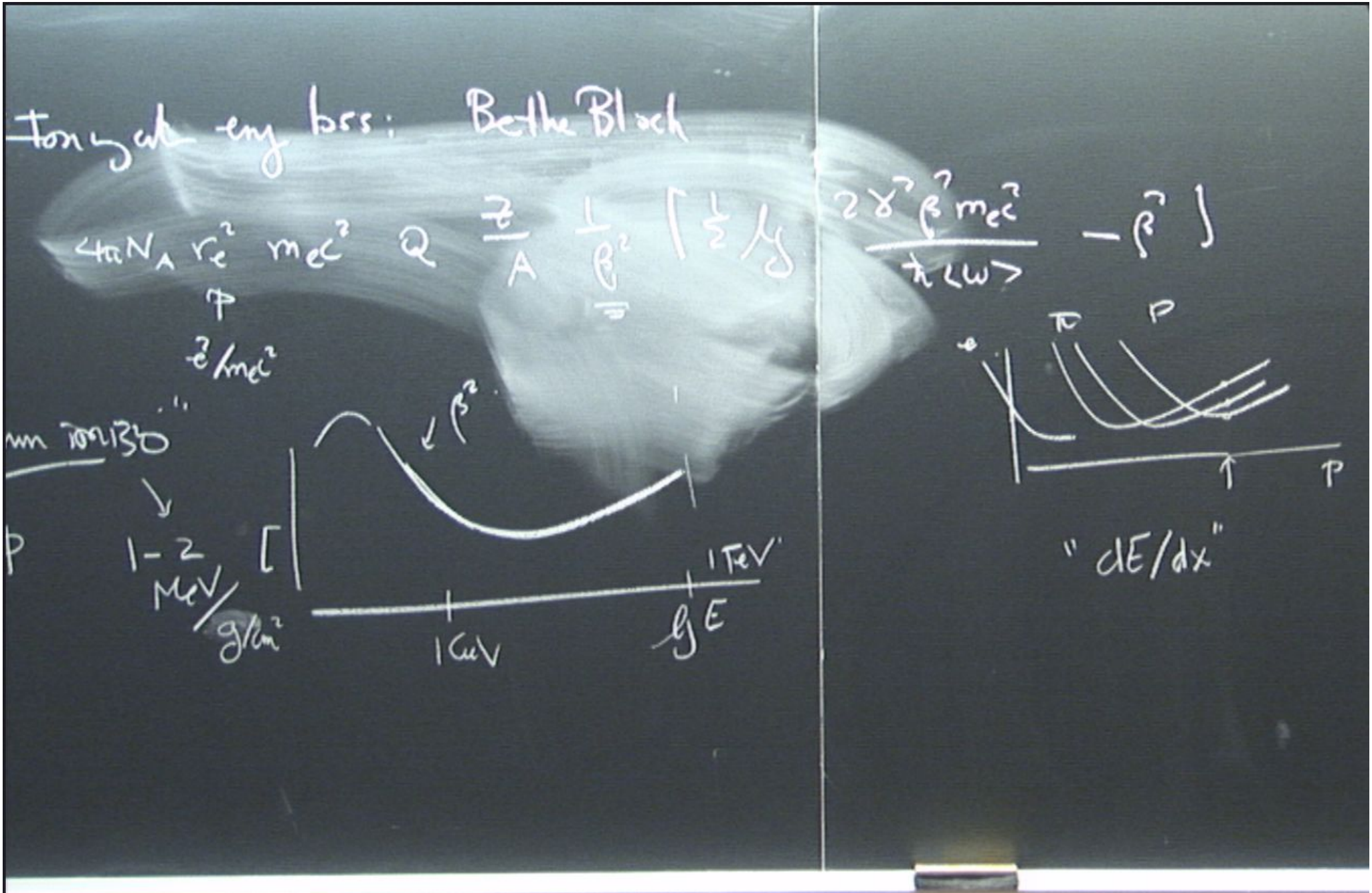
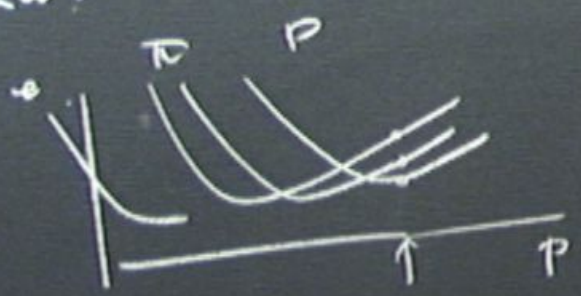
$\hbar^2/m_e c^2$
$1/\beta^2$
1-2 MeV/g/cm²
1 GeV
1 TeV
lg E
π
p
p

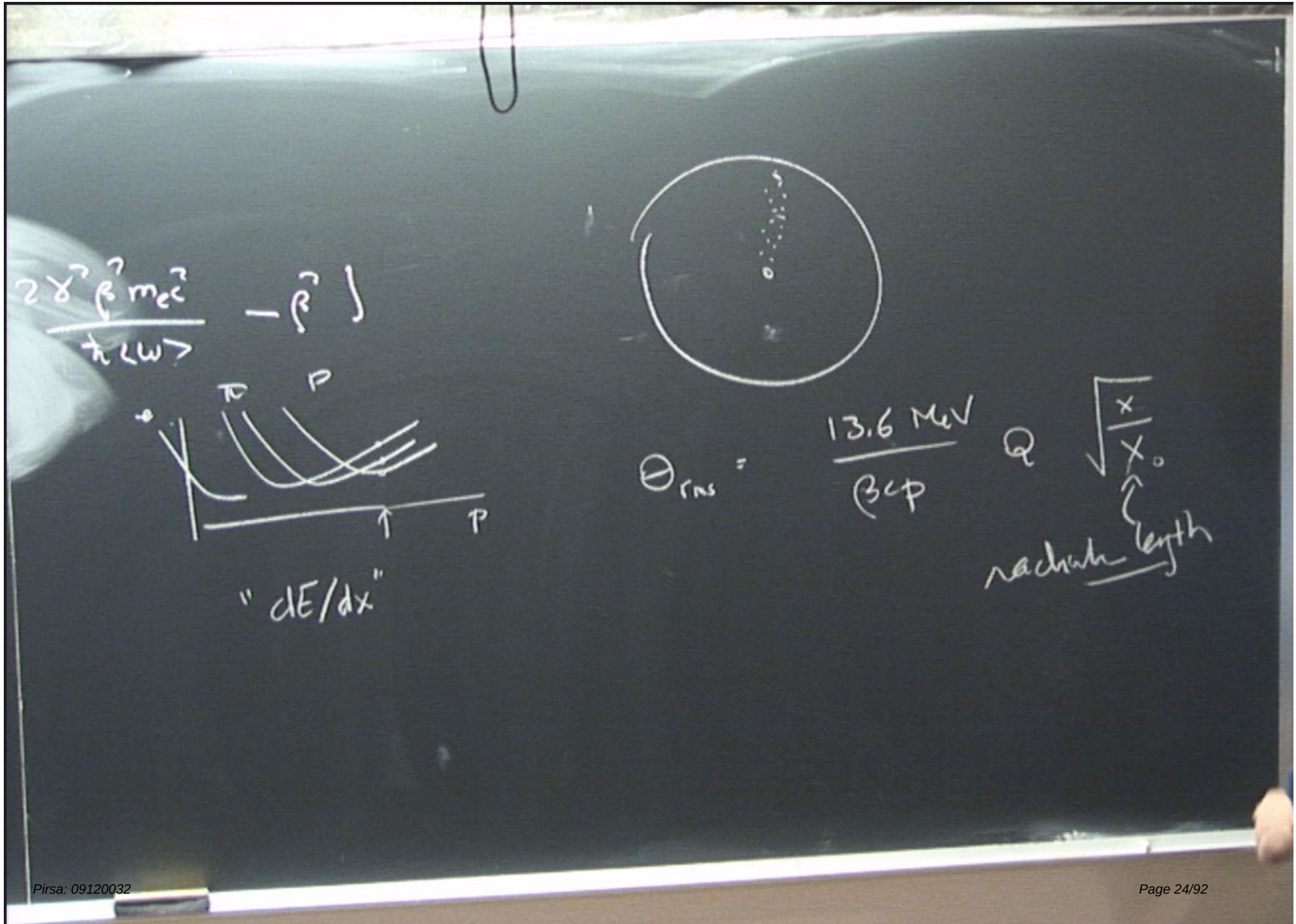

Energy loss: Bethe Bloch
$4\pi N_A r_e^2 m_e c^2 Q \frac{z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2\right]$
$z^2/4\pi\epsilon_0 c^2$
β^2
1-2 MeV/g/cm²
1 GeV
1 TeV
$\ln E$
π
p
p
"dE/dx"


Ionization energy loss: Bethe Bloch
$\langle -\frac{dE}{dx} \rangle = 4\pi N_A r_e^2 m_e c^2 \, Q \, \frac{Z}{A} \, \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \beta^2 \right]$
$\propto z^2/mc^2$
min ionizing
β^2
$\beta\gamma$
1-2 MeV/g/cm²
1 GeV
1 TeV
log E
π
p
p
"dE/dx"

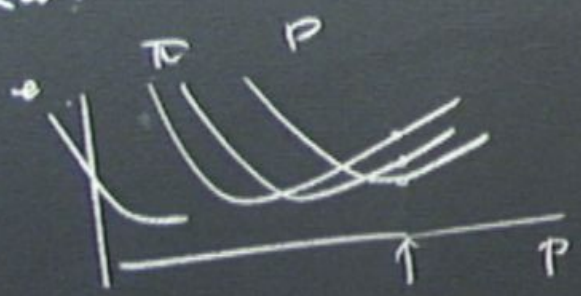
$$\frac{2\gamma\vec{\beta}m_e c^2}{\hbar\langle\omega\rangle} - \vec{\beta}\,]$$



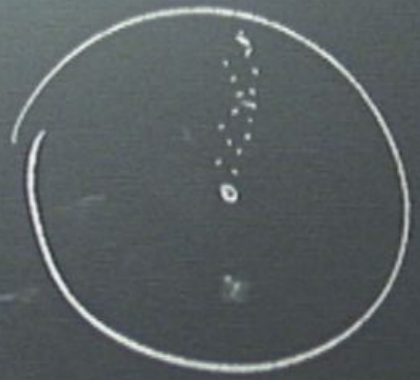
"dE/dx"


$\frac{2\gamma\vec{\beta}m_e c^2}{\hbar\langle\omega\rangle} - \vec{\beta}$
π
p
p
"dE/dx"
$\theta_{rms} = \frac{13.6\ MeV}{\beta cp} Q \sqrt{\frac{x}{X_0}}$
radiation length

$$\frac{2\gamma\vec{\beta}m_e c^2}{\hbar\langle\omega\rangle} - \vec{\beta}\,]$$



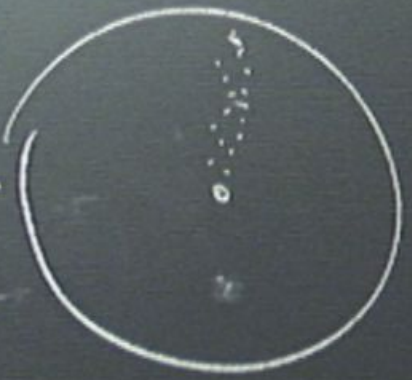
"dE/dx"



$$\theta_{rms} = \frac{13.6\ \text{MeV}}{\beta c p} Q \sqrt{\frac{x}{X_0}}$$

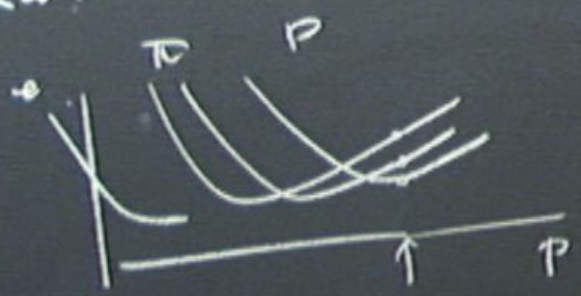
radiation length

Cloud Ch.
Bubble Chamber
Spark Chamber



drift- chambers
Time Projection Chamber

$$\frac{2\gamma \vec{\beta} m_e c^2}{\hbar \langle \omega \rangle} - \vec{\beta} \Big]$$



"dE/dx"

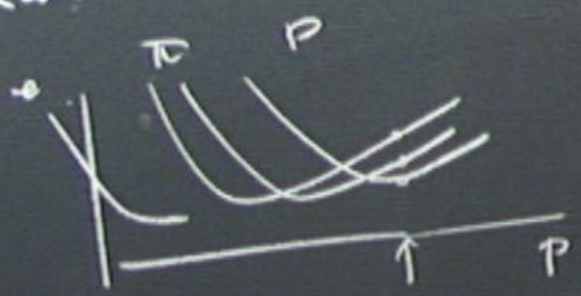
$$\theta_{rms} = \frac{13.6\ \text{MeV}}{\beta c p} Q \sqrt{\frac{x}{X_0}}$$

radiation length

Cloud Ch.
Bubble Chamber
Spark Chamber

drift- chambers
Time Projection Chamber

$$\frac{2\gamma\vec{\beta}\,m_e c^2}{\hbar\langle\omega\rangle} - \vec{\beta}\,]$$



"dE/dx"

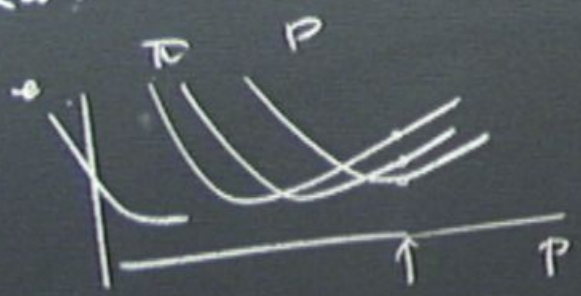
$$\theta_{rms} = \frac{13.6\ \text{MeV}}{\beta c p}\, Q \sqrt{\frac{x}{X_0}}$$

X_0 { radiation length

Cloud Ch.
Bubble Chamber
Spark Chamber

drift - chambers
Time Projection Chamber

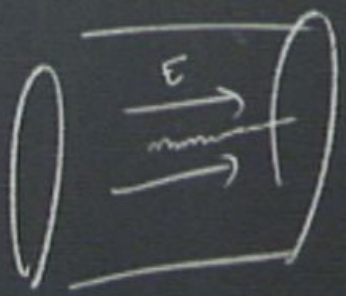
$$\frac{2\gamma \vec{\beta} m_e c^2}{\hbar \langle w \rangle} - \vec{\beta} \Big]$$



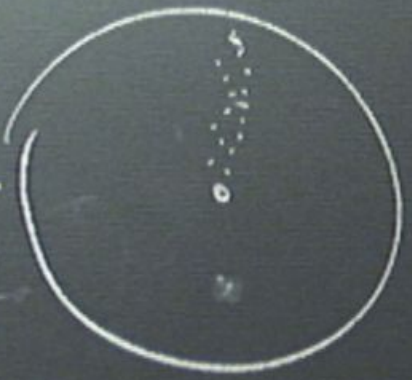
"dE/dx"

$$\theta_{rms} = \frac{13.6\ \text{MeV}}{\beta c p} Q \sqrt{\frac{x}{X_0}}$$

radiation length

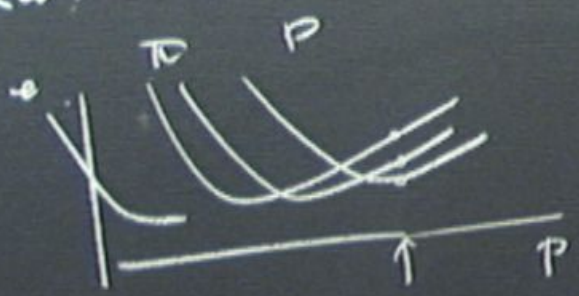


Cloud Ch.
Bubble Chamber
Spark Chamber



drift- chambers
Time Projection Chamber

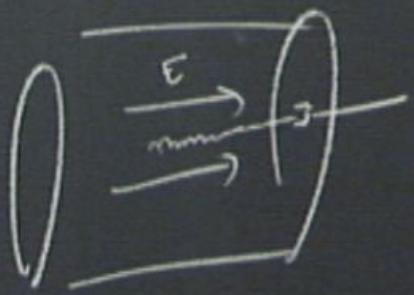
$$\frac{2\gamma \vec{\beta} m_e c}{\hbar \langle w \rangle} - \vec{\beta}$$

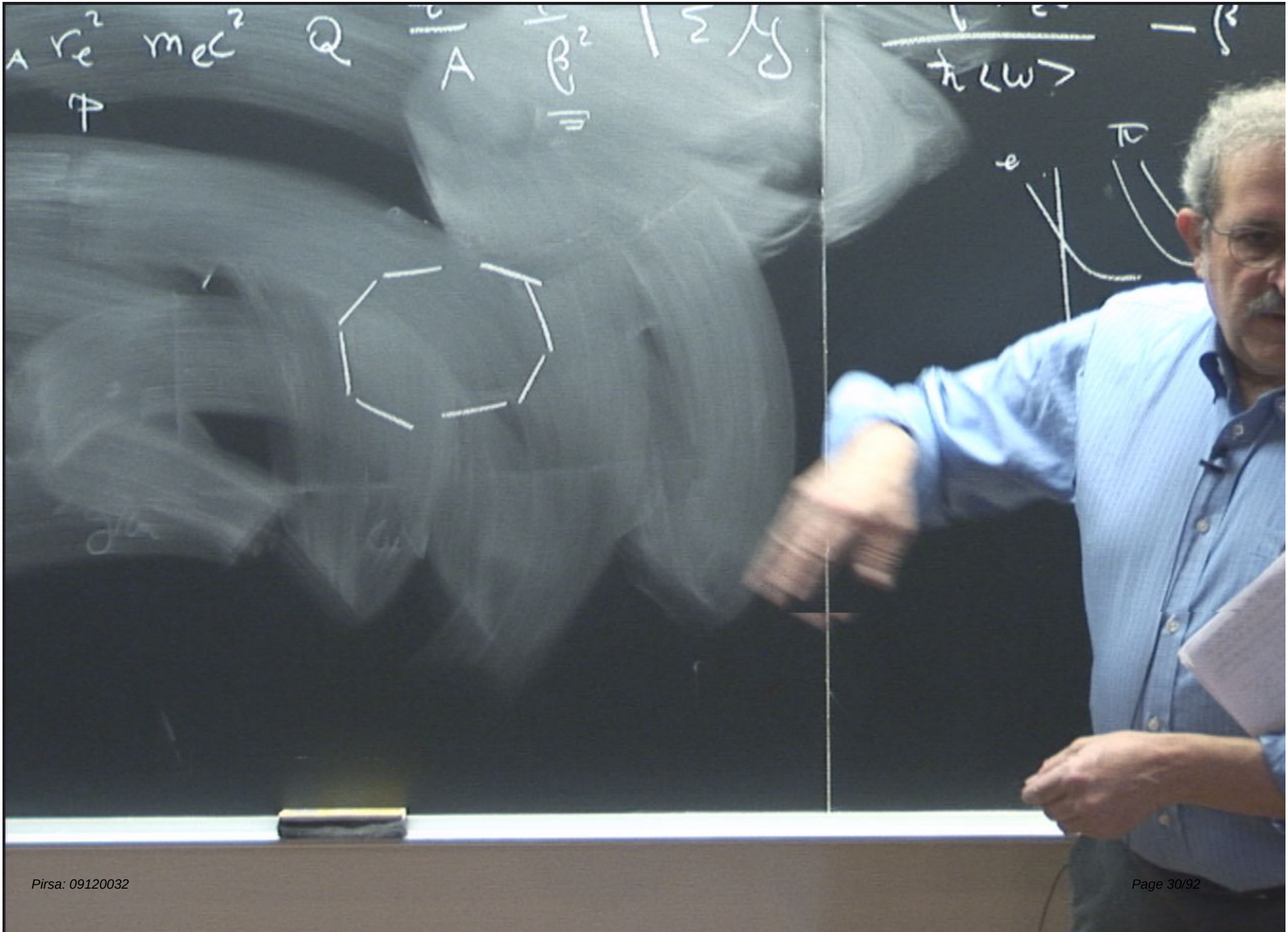


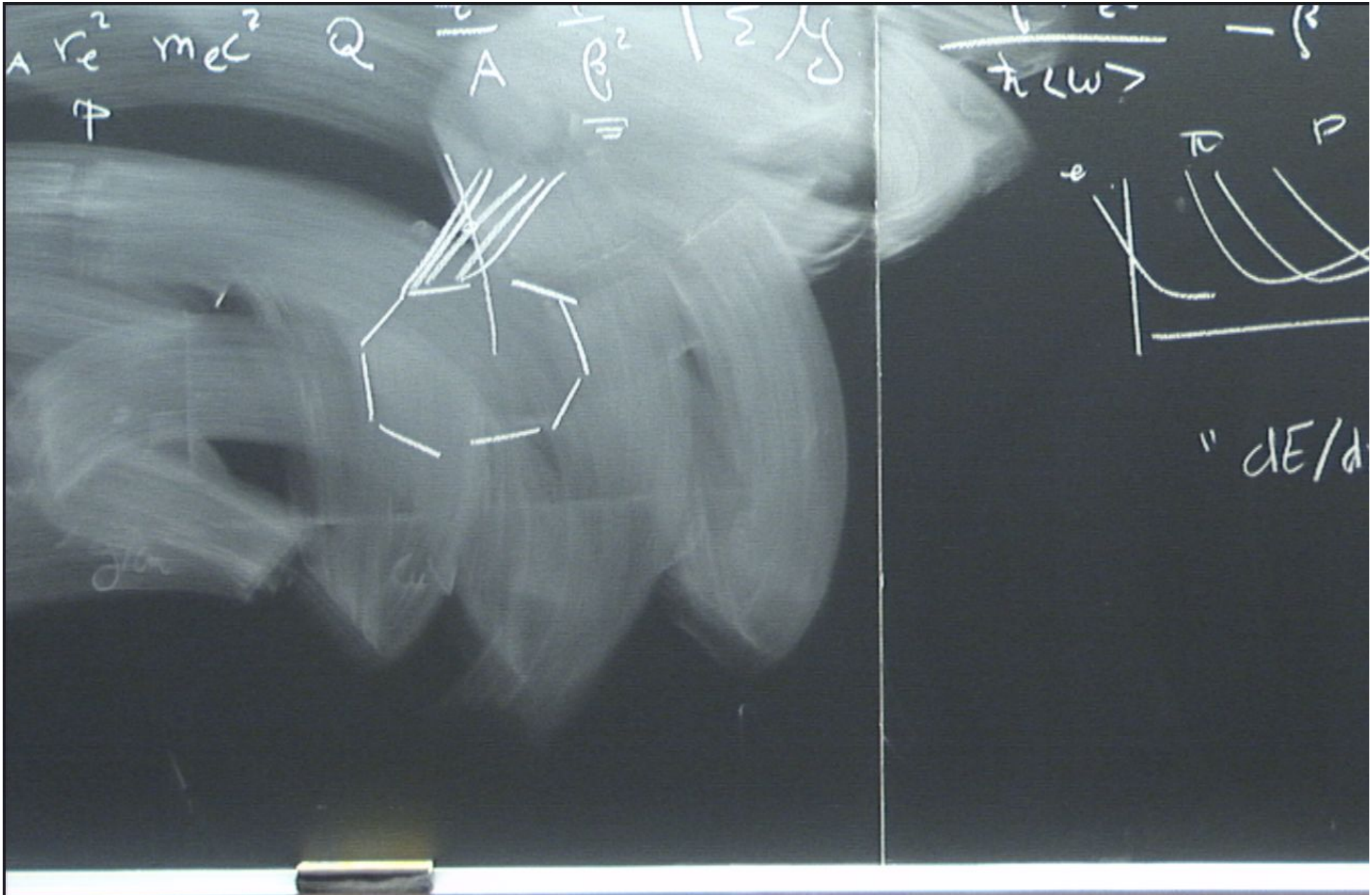
"dE/dx"

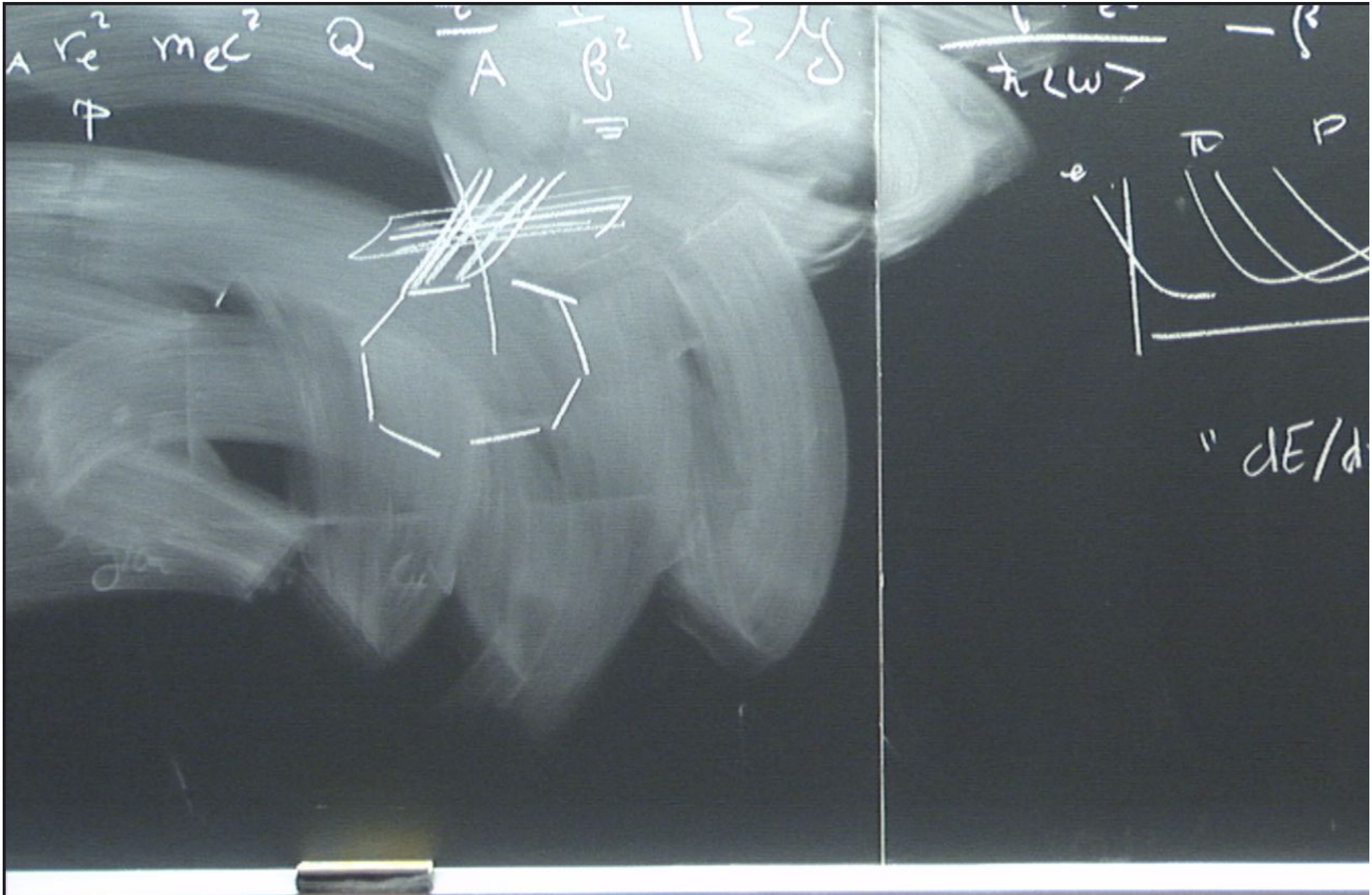
$$\theta_{rms} = \frac{13.6\ \text{MeV}}{\beta c p} Q \sqrt{\frac{x}{X_0}}$$

radiation length



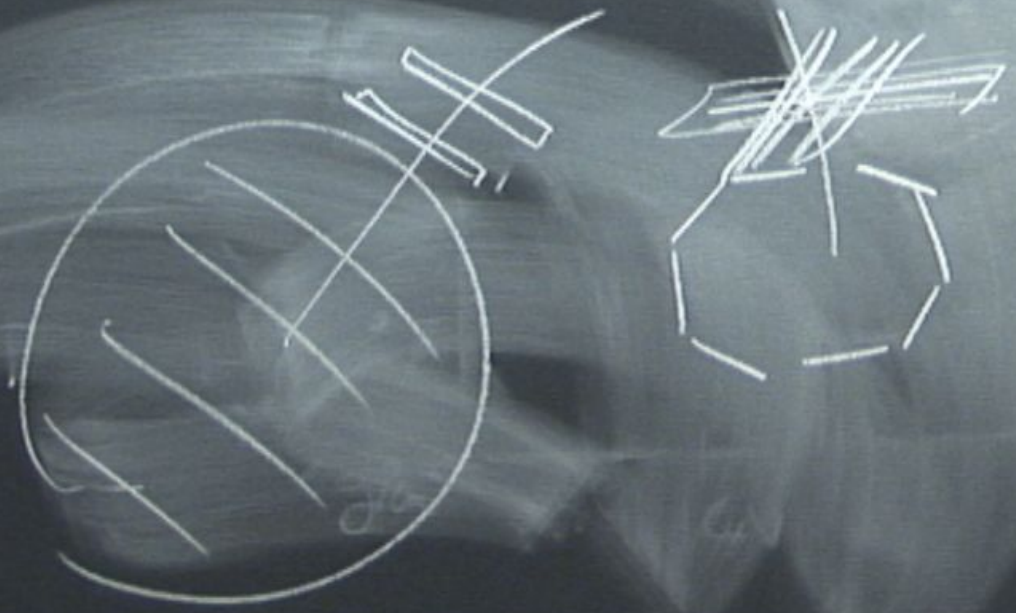

A r_e^2 $m_e c^2$ Q
A β^2
$\hbar\langle\omega\rangle$
e


$A\ r_e^2\ m_e c^2\ Q$
$\frac{}{A}\ \beta^2$
$\hbar\langle\omega\rangle$
$-\beta$
D
P
e
" dE/d


$\frac{1}{4\pi\varepsilon_0}$ r_e^2 $m_e c^2$ Q $\frac{Z}{A}$ β^2 $\frac{1}{2}\ln$
$\hbar\langle\omega\rangle$ $-\beta^2$
π p
e
" dE/dx

Ionization energy loss: Bethe Bloch

$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 \; Q \; \frac{Z}{A} \; \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \left(\right.}{I} \right.$$



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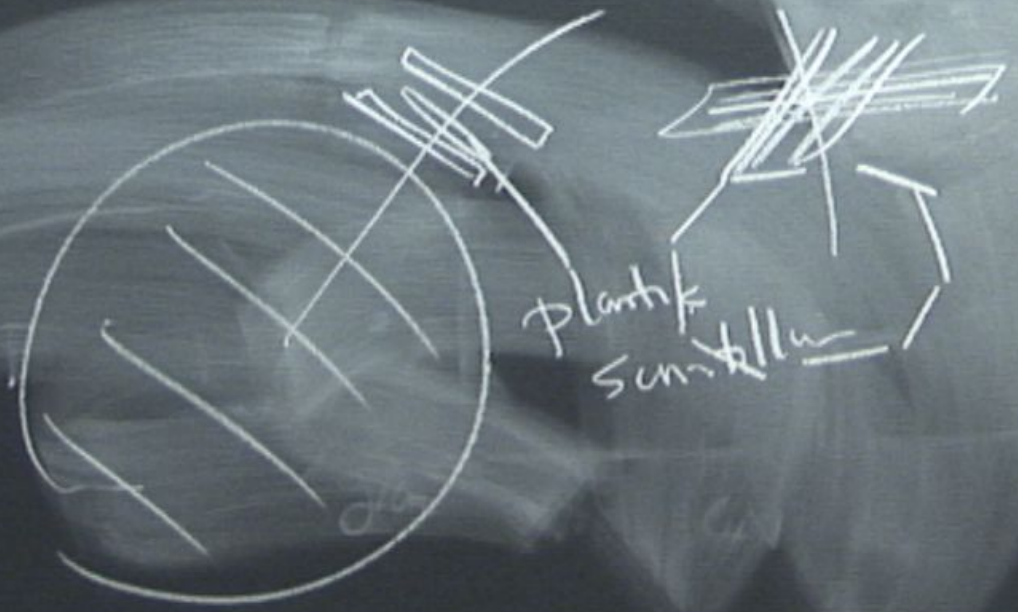

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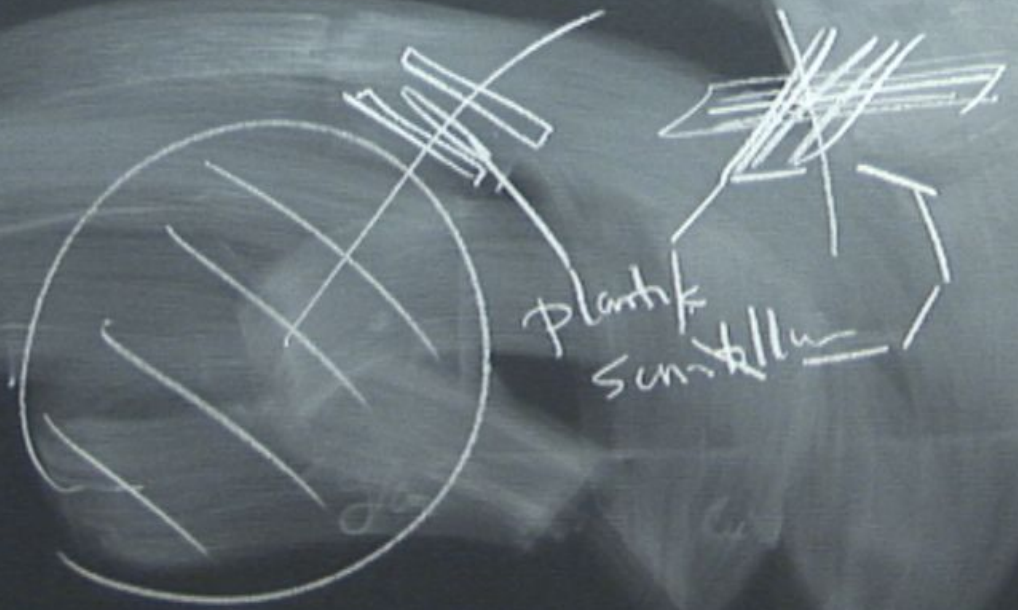
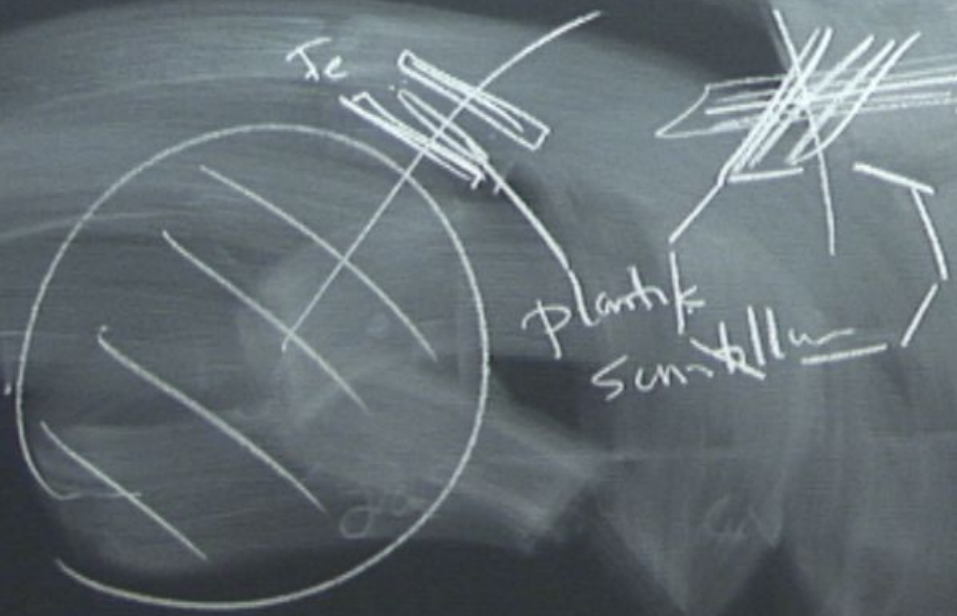
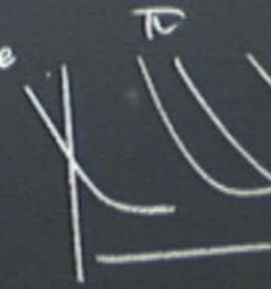


Ionization energy loss: Bethe Bloch

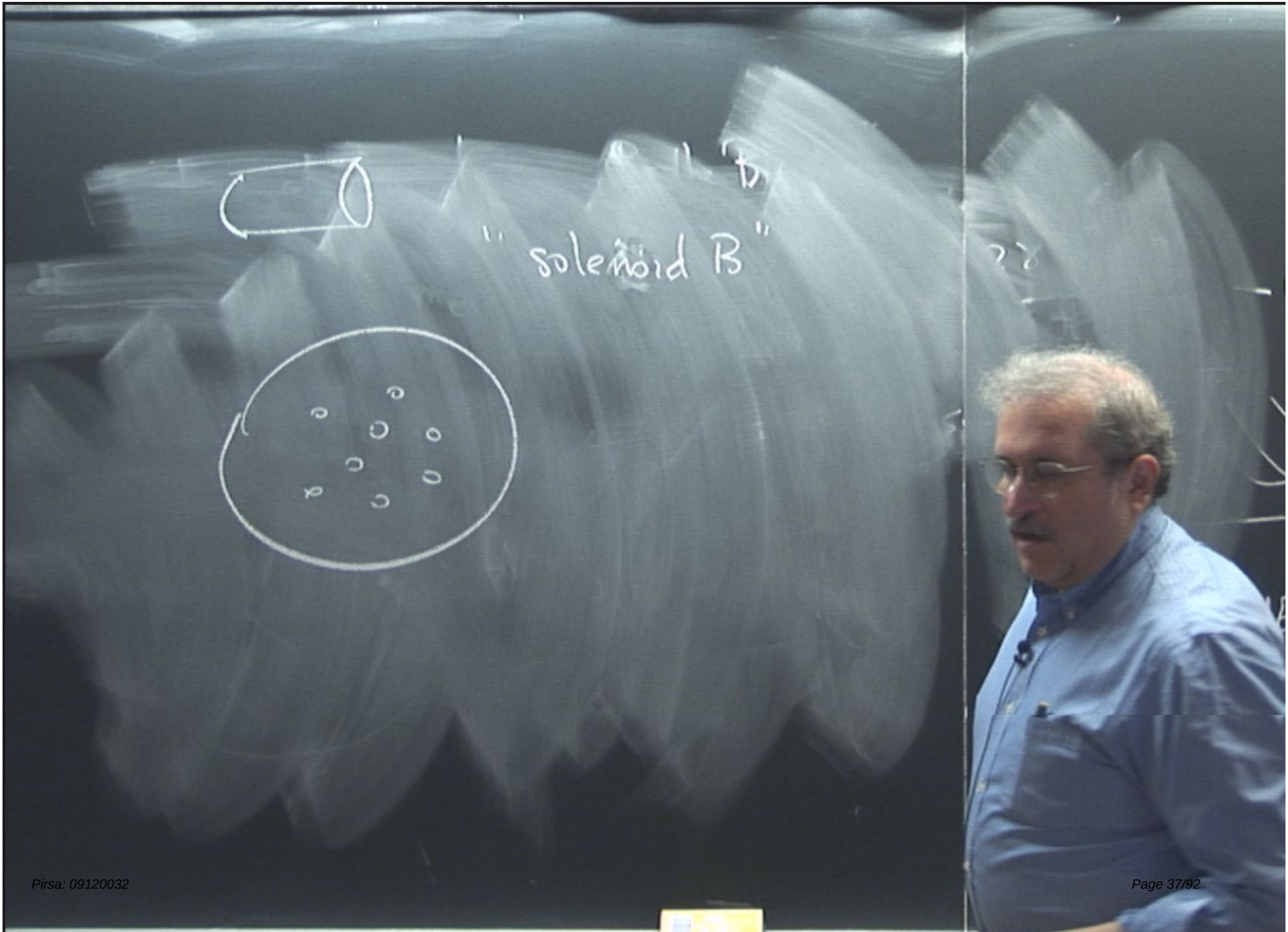
$$\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 Q \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2\gamma^2 \beta^2 m_e c^2}{\hbar \langle \omega \rangle} - \right]$$

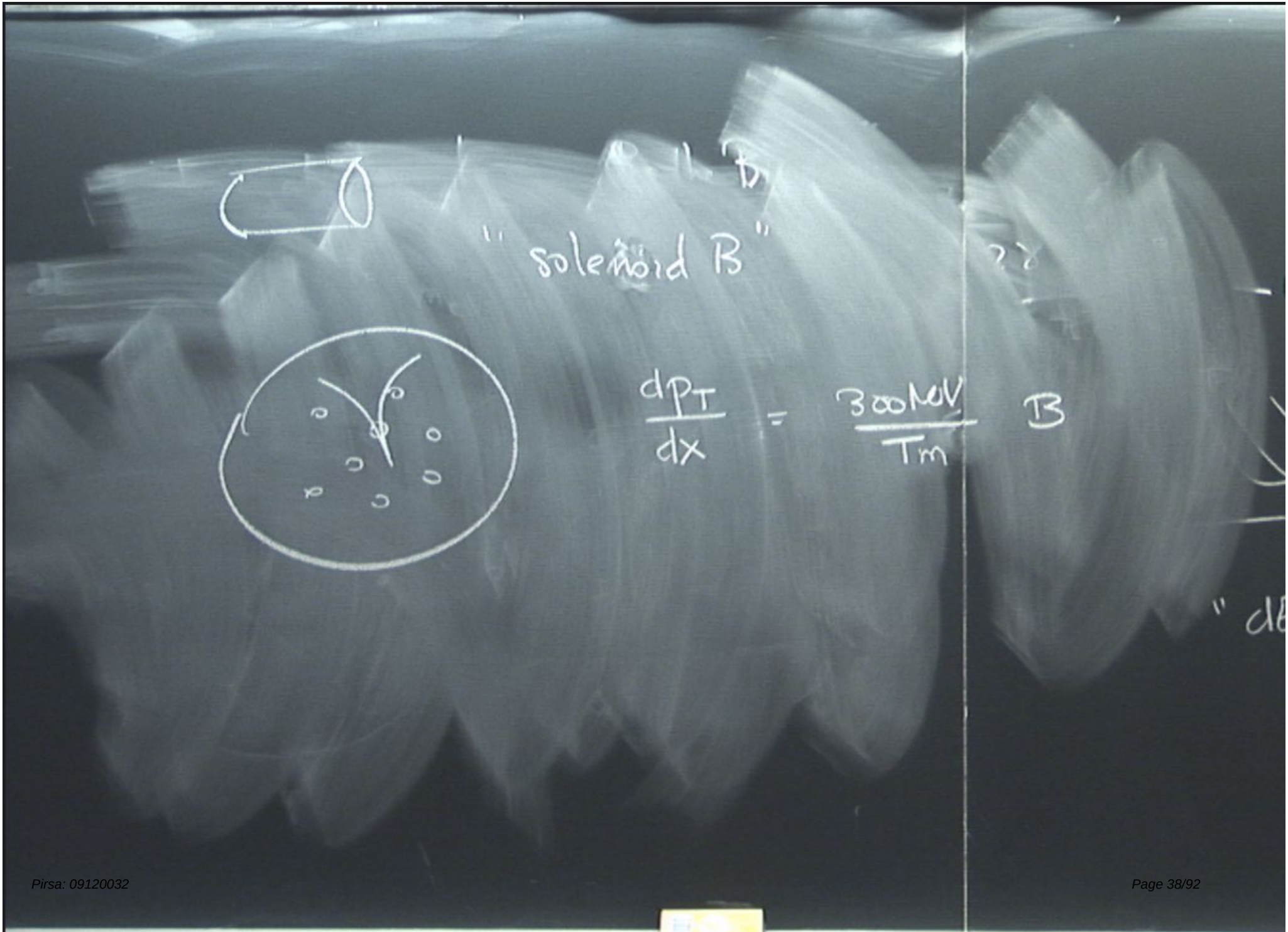


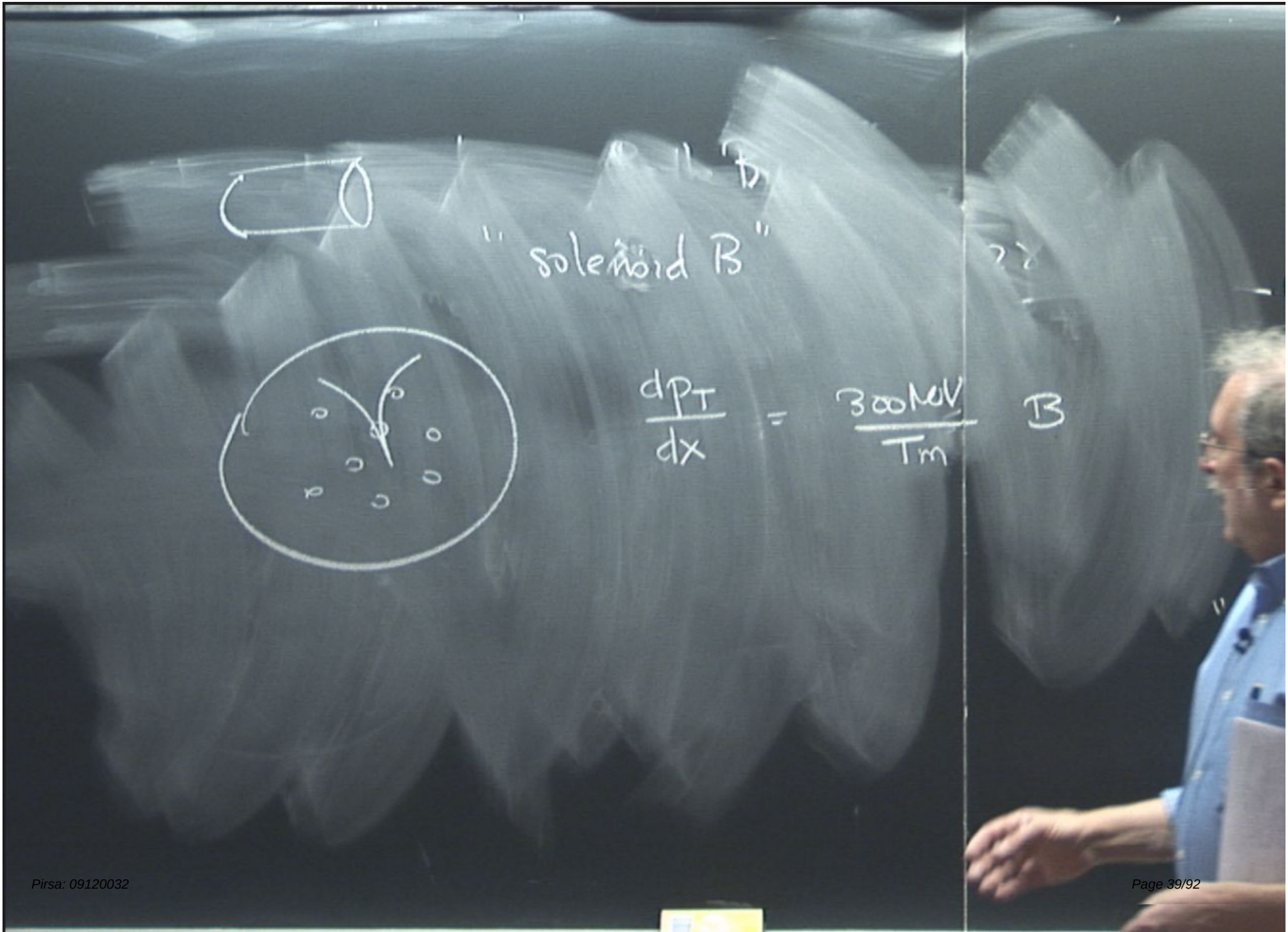
"kaleidoscope"

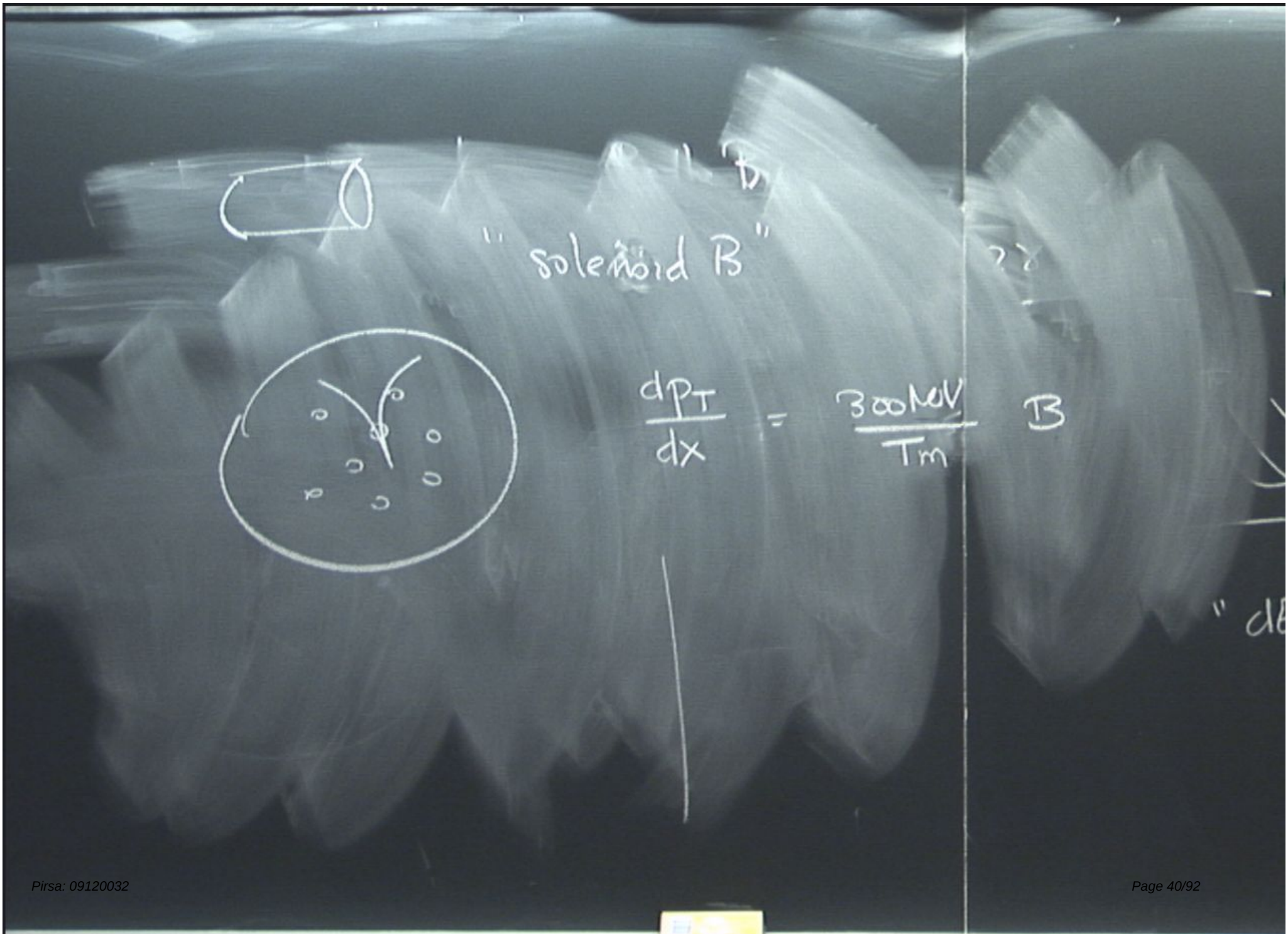


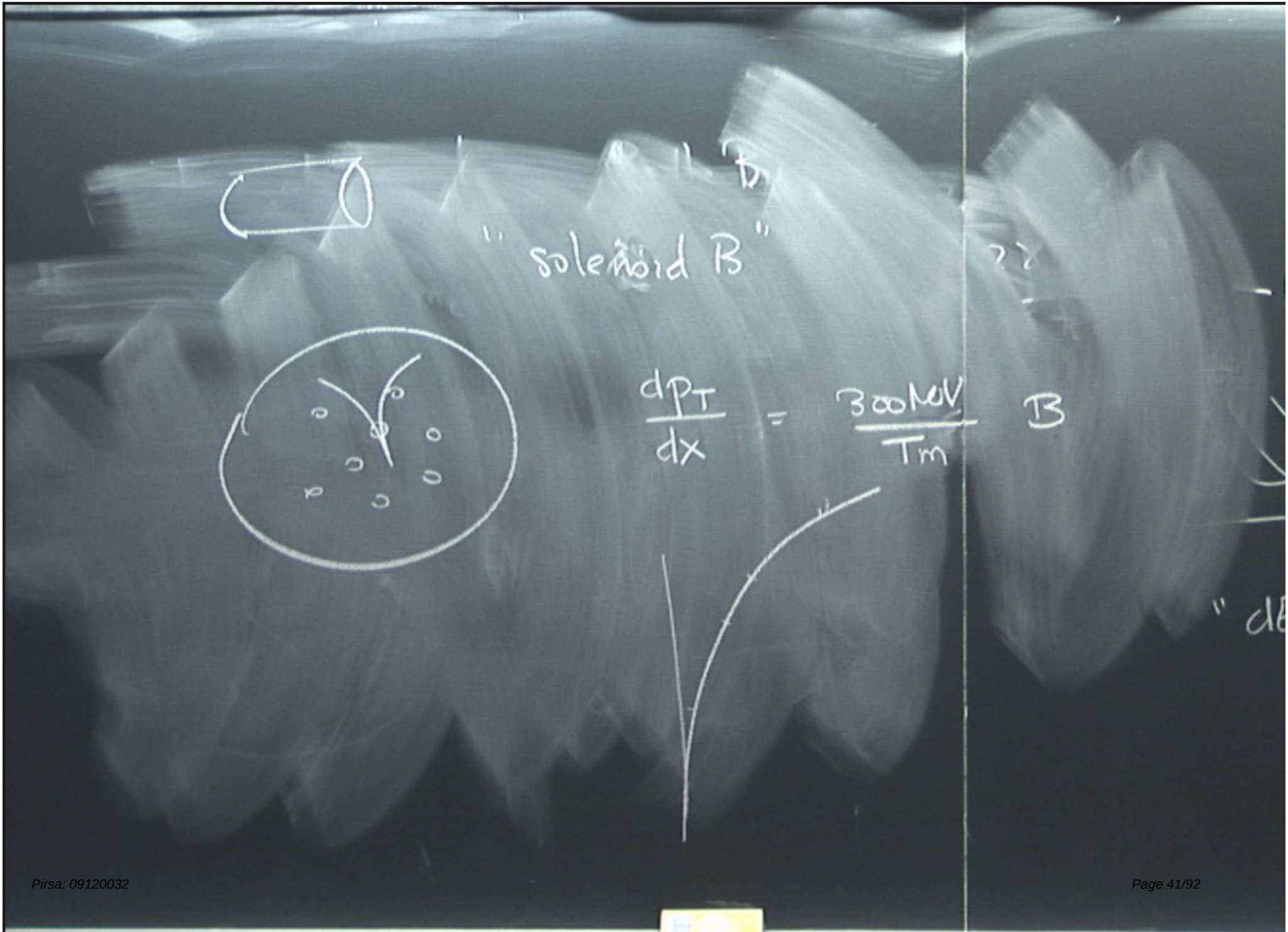
"dE

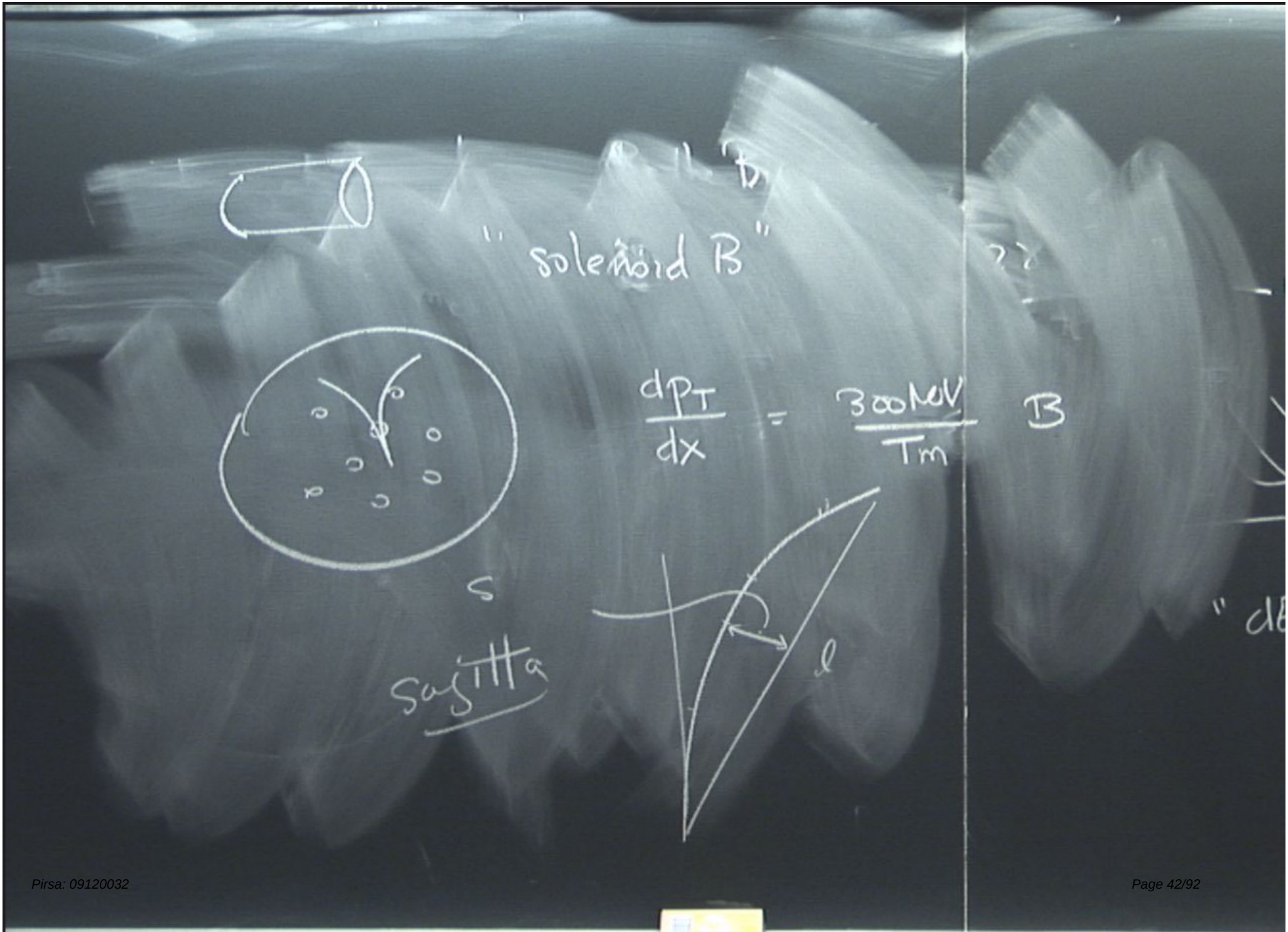

"solenoid B"


"solenoid B"
$\frac{dp_T}{dx} = \frac{300 MeV}{Tm} B$


"solenoid B"
$\frac{dp_T}{dx} = \frac{300 MeV}{Tm} B$


"solenoid B"
$\frac{dp_T}{dx} = \frac{300 MeV}{Tm} B$


"solenoid B"
$\frac{dp_T}{dx} = \frac{300\,MeV}{Tm} B$


"solenoid B"
$\frac{dp_T}{dx} = \frac{300 MeV}{Tm} B$
s
Sagitta
l

drift- chambers

Time Projection Chamber

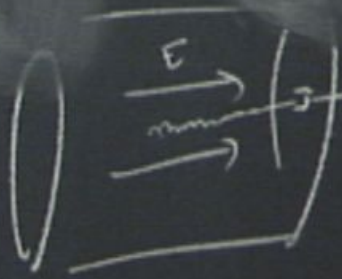
$$s = \frac{1}{2} R\theta^2$$

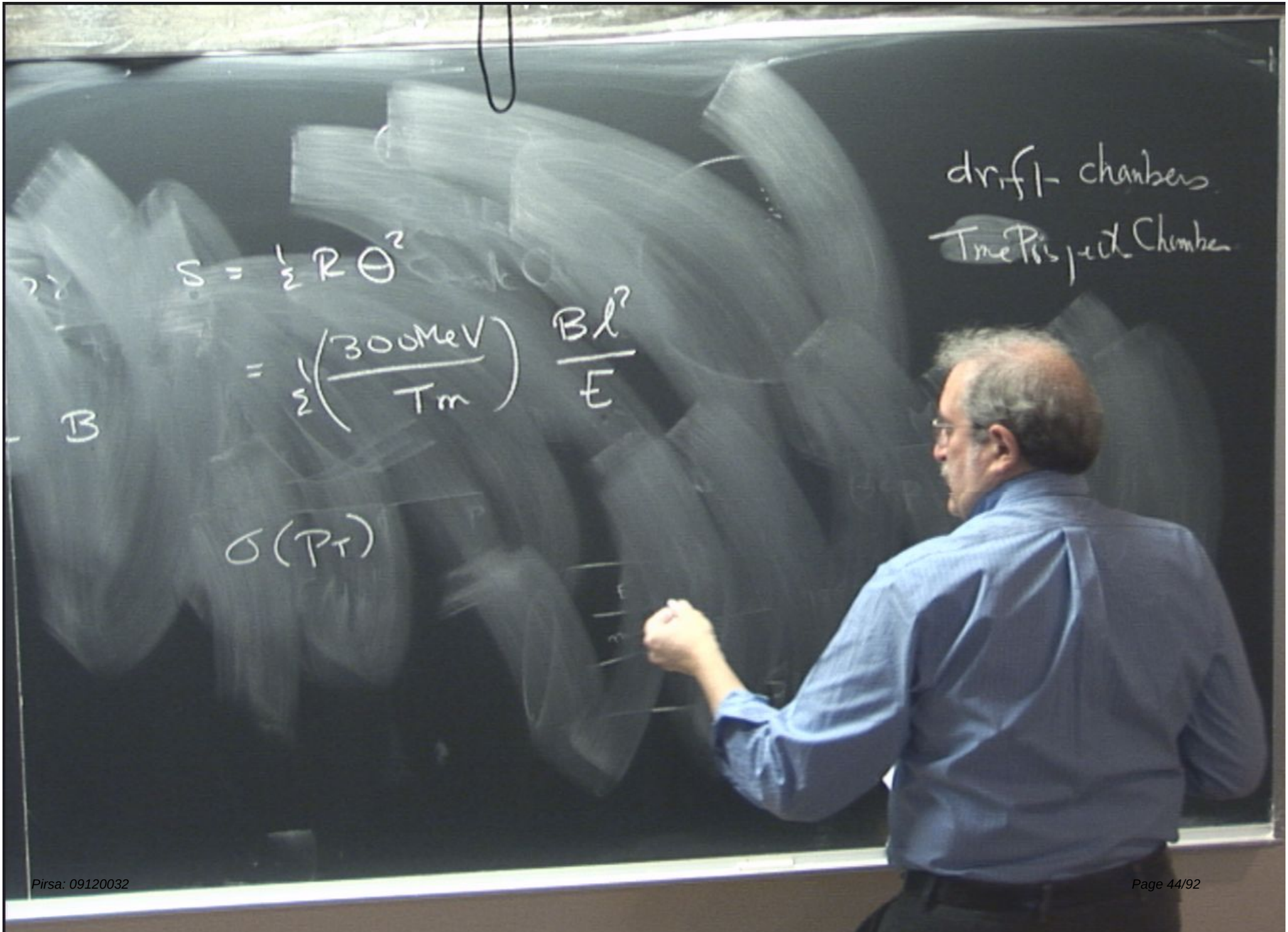
$$= \frac{1}{2}\left(\frac{300\,\mathrm{MeV}}{Tm}\right)\frac{BL^2}{E}$$

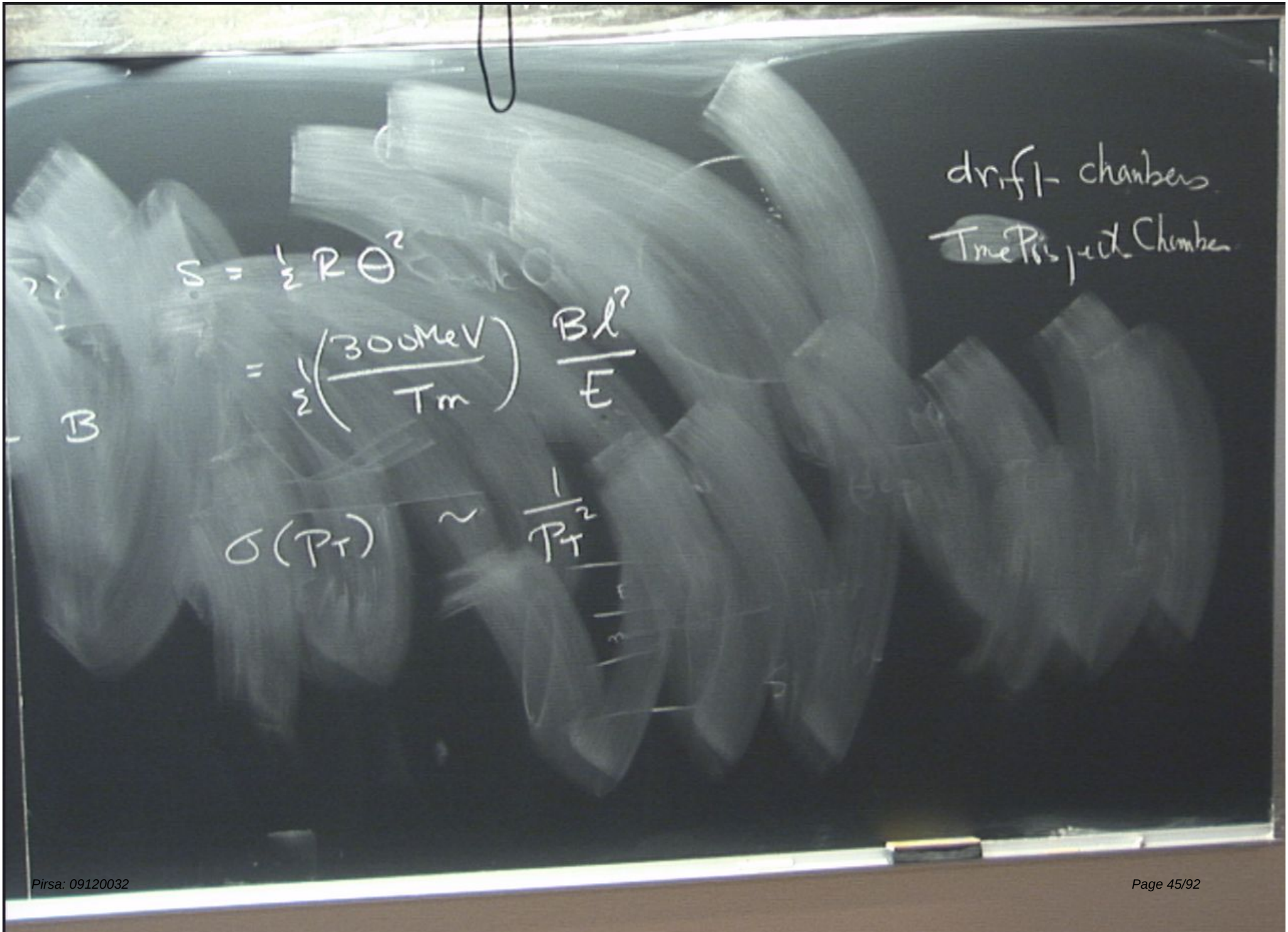
B

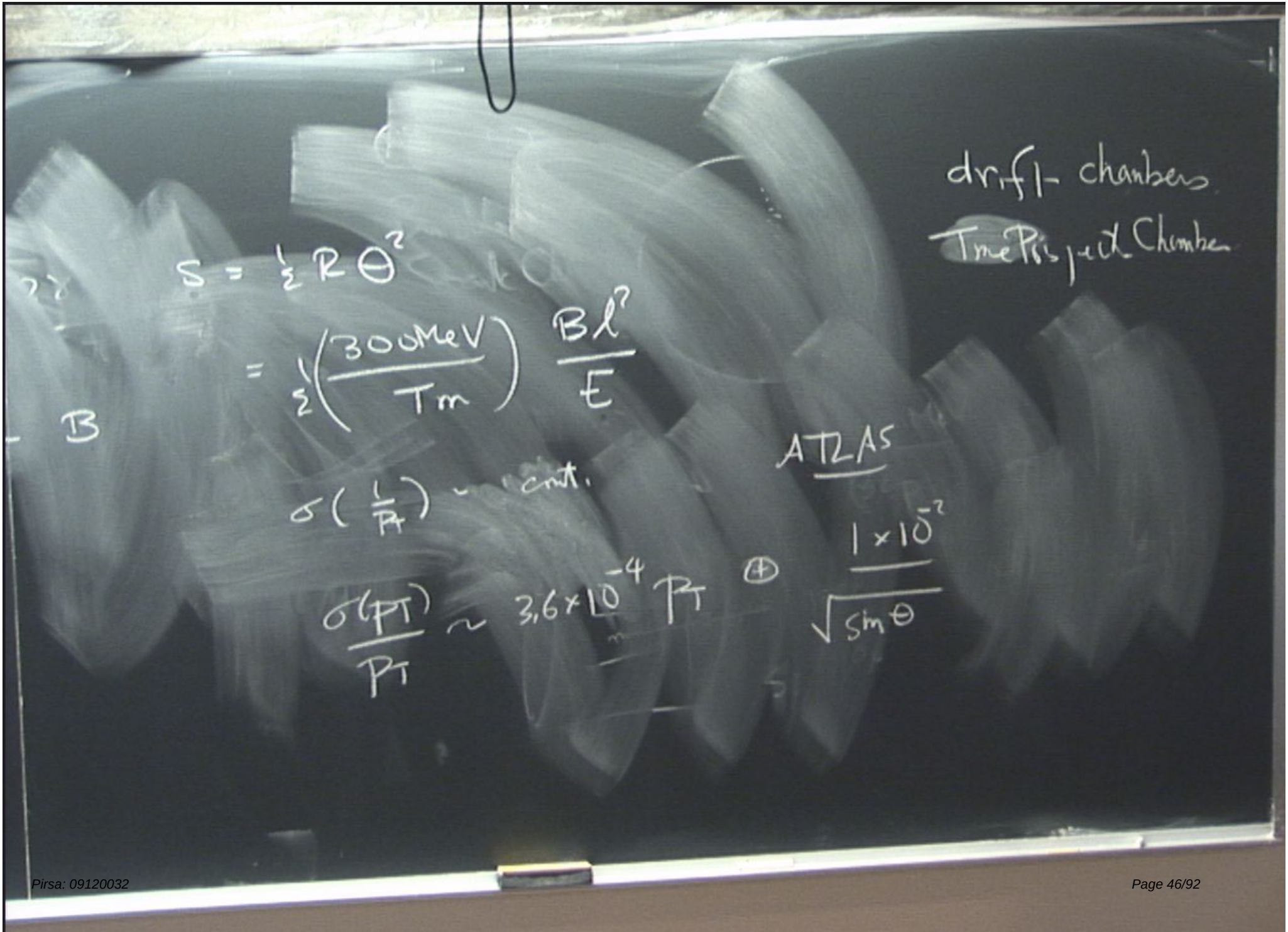
$$\frac{\mathrm{MeV}}{\beta c p} \; Q \sqrt{\frac{x}{X_0}}$$

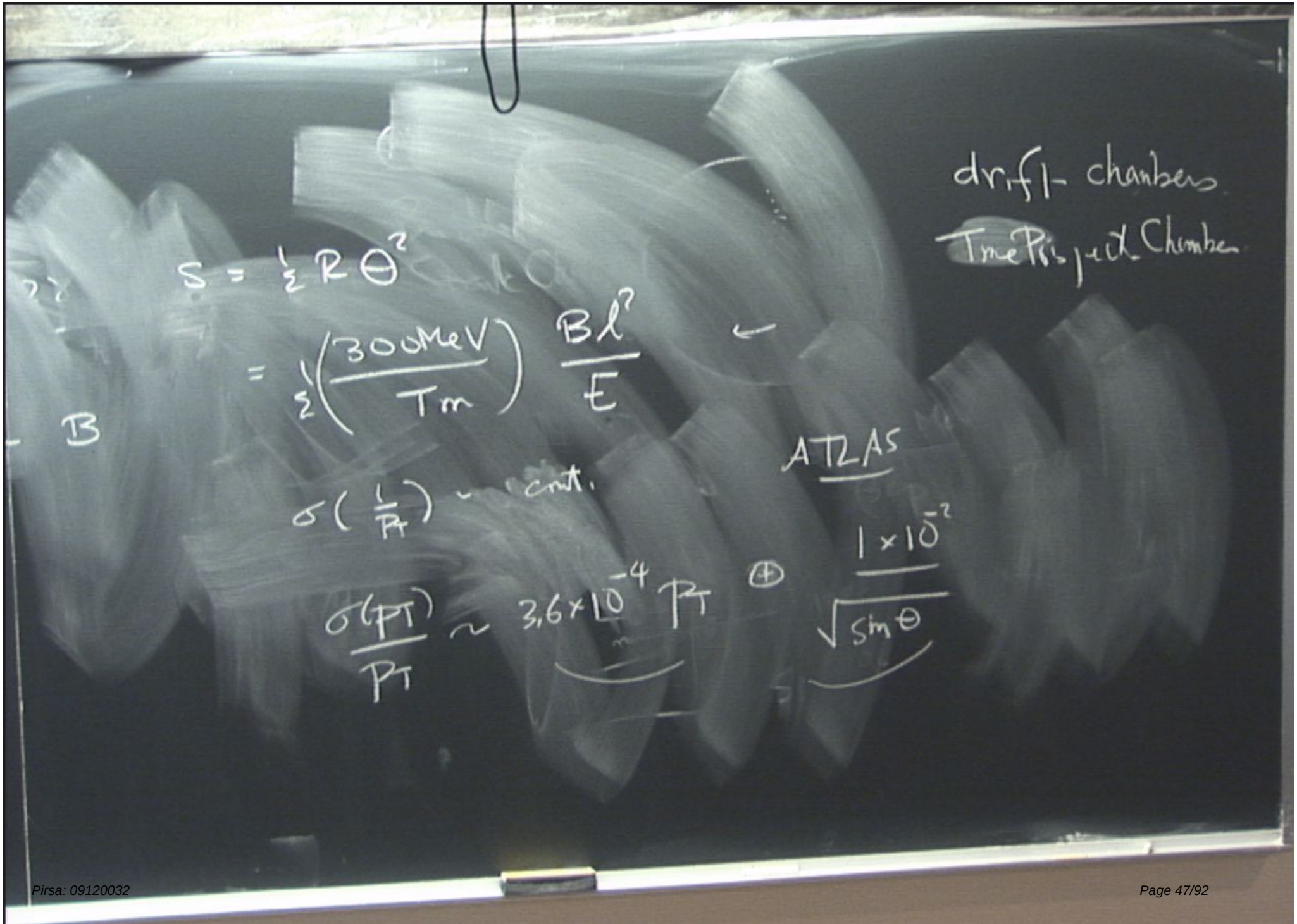
radiation length

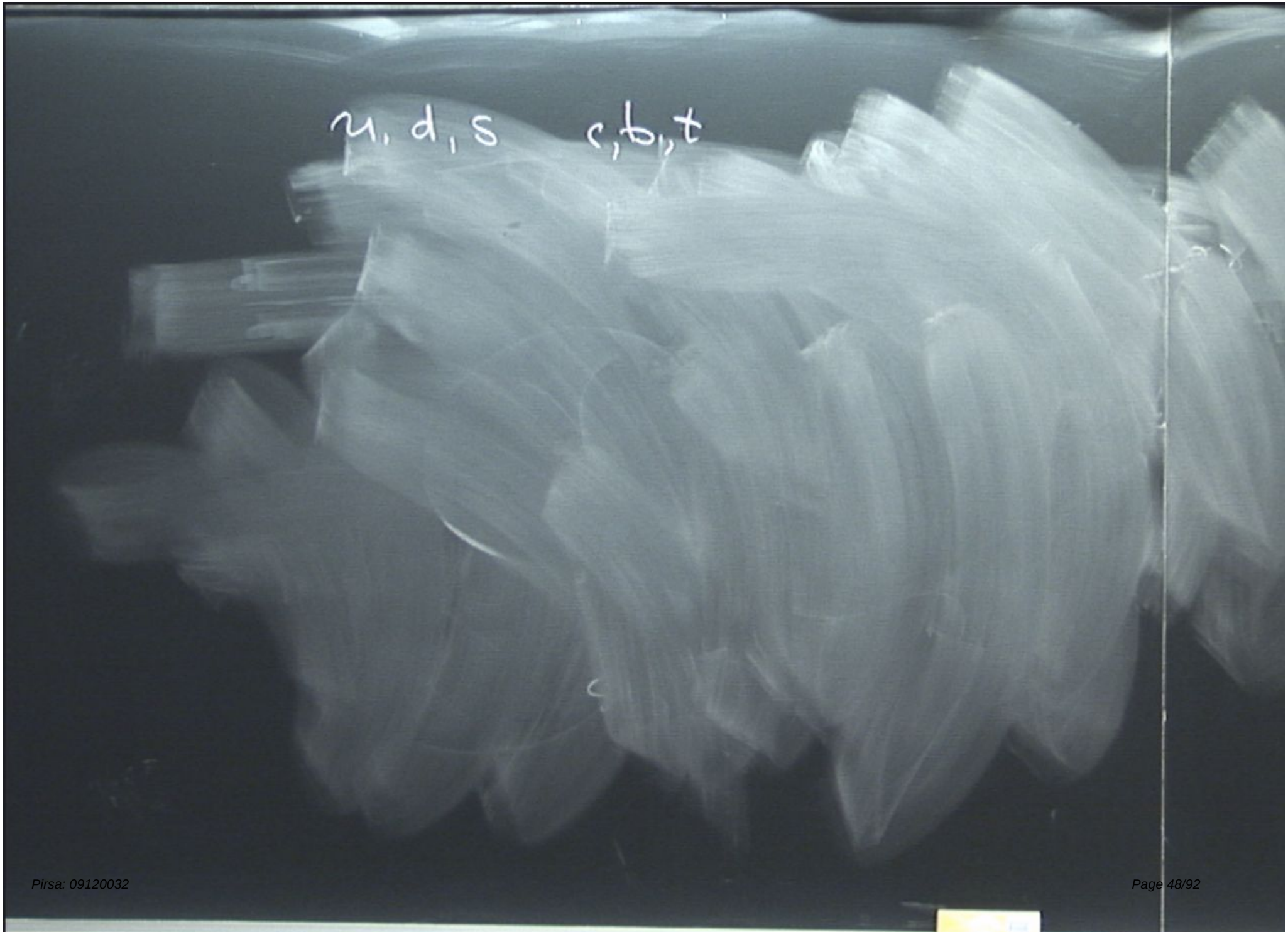



drift- chambers
Time Projection Chamber
$s = \frac{1}{2} R\theta^2$
$= \frac{1}{2}\left(\frac{300\,\mathrm{MeV}}{Tm}\right)\frac{Bl^2}{E}$
B
$\sigma(p_T)$


drift- chambers
Time Projection Chamber
$s = \frac{1}{2} R\theta^2$
$= \frac{1}{2}\left(\frac{300\,\mathrm{MeV}}{Tm}\right)\frac{Bl^2}{E}$
B
$\sigma(P_T) \sim \frac{1}{P_T^2}$


drift- chambers
Time Projection Chambers
$s = \frac{1}{2} R\theta^2$
$= \frac{1}{2}\left(\frac{300\,\mathrm{MeV}}{Tm}\right)\frac{BL^2}{E}$
B
$\sigma\left(\frac{1}{P_T}\right)$ ~ const.
ATLAS
$\frac{\sigma(P_T)}{P_T} \sim 3.6\times10^{-4} P_T \oplus \frac{1\times10^{-2}}{\sqrt{\sin\theta}}$


drift- chambers
Time Projection Chambers
$s = \frac{1}{2} R \theta^2$
$= \frac{1}{2}\left(\frac{300\,\mathrm{MeV}}{Tm}\right) \frac{BL^2}{E}$
B
ATLAS
$\sigma\left(\frac{1}{p_T}\right)$ ~ const.
$\frac{\sigma(p_T)}{p_T} \sim 3{,}6\times10^{-4}\, p_T \oplus \frac{1\times10^{-2}}{\sqrt{\sin\theta}}$

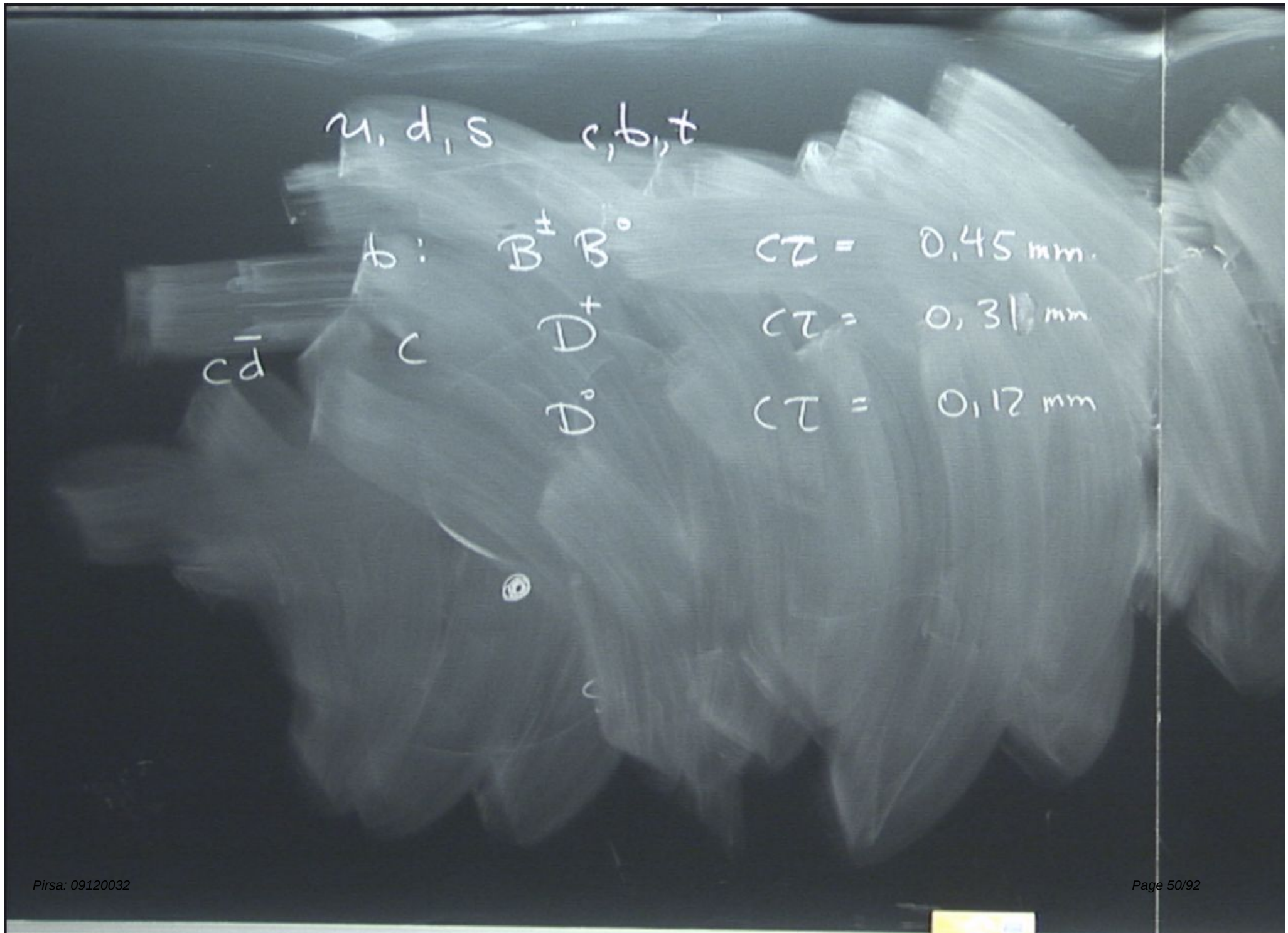

u, d, s
c, b, t

u, d, s c, b, t

b: $B^{\pm}$ B^{0} $c\tau$ = 0,45 mm.

$c\bar{d}$ c D^{+} $c\tau$ = 0,31 mm

D^{0} $c\tau$ = 0,12 mm


u, d, s c, b, t
b: $B^{\pm}$ B^{0} $c\tau$ = 0,45 mm.
$c\bar{d}$ c D^{+} $c\tau$ = 0,31 mm
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u, d, s c, b, t

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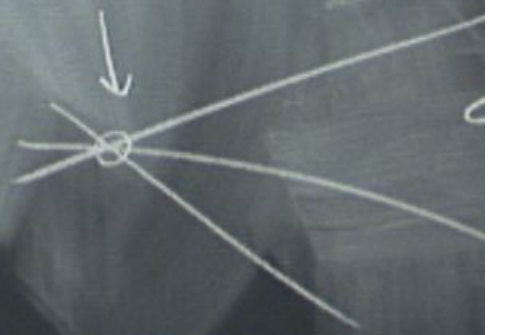
u, d, s c, b, t

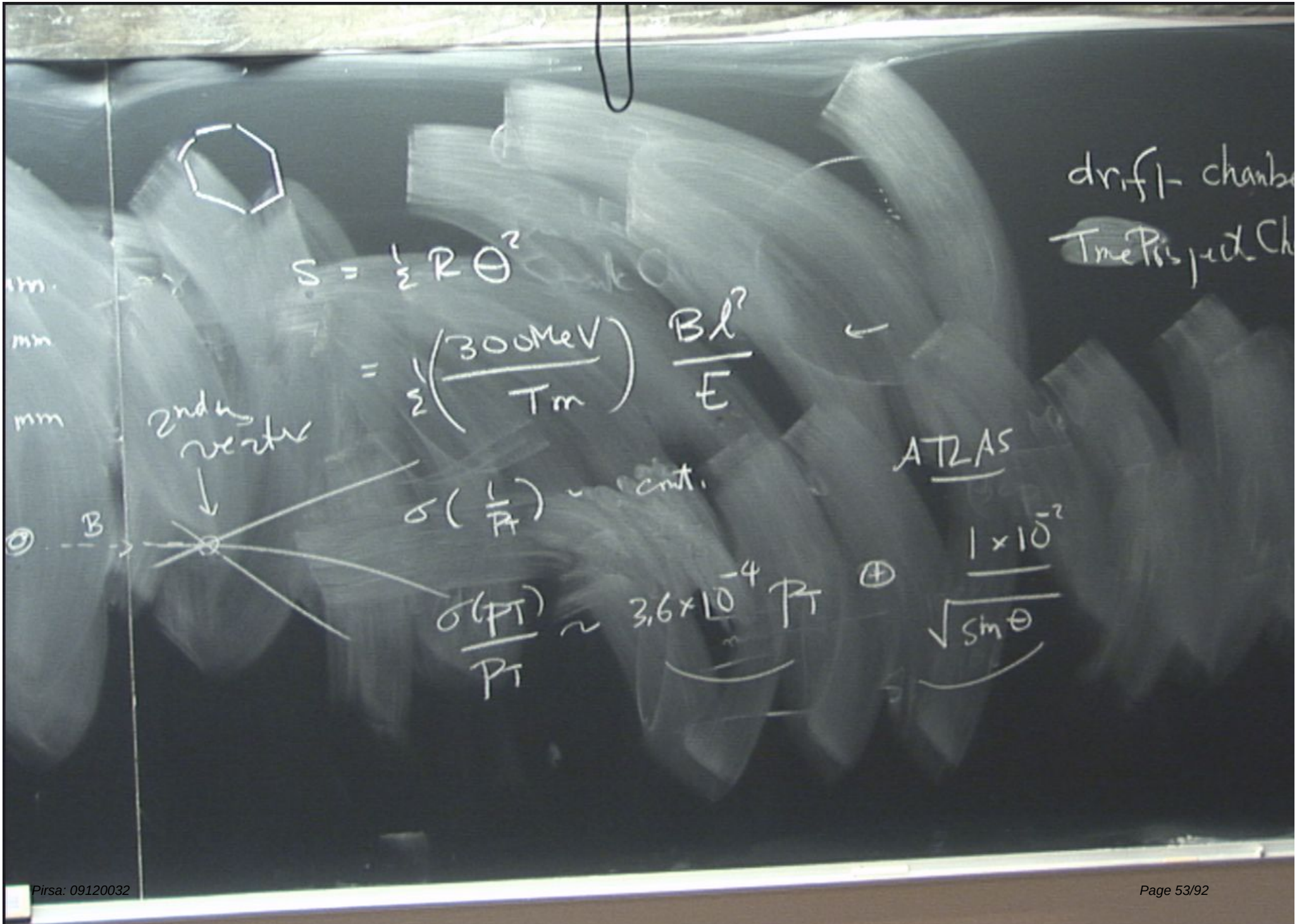
b: $B^{\pm}$ B^{0} $c\tau$ = 0,45 mm.

$c\bar{d}$ c D^{+} $c\tau$ = 0,31 mm.

D^{0} $c\tau$ = 0,12 mm

impact parameter



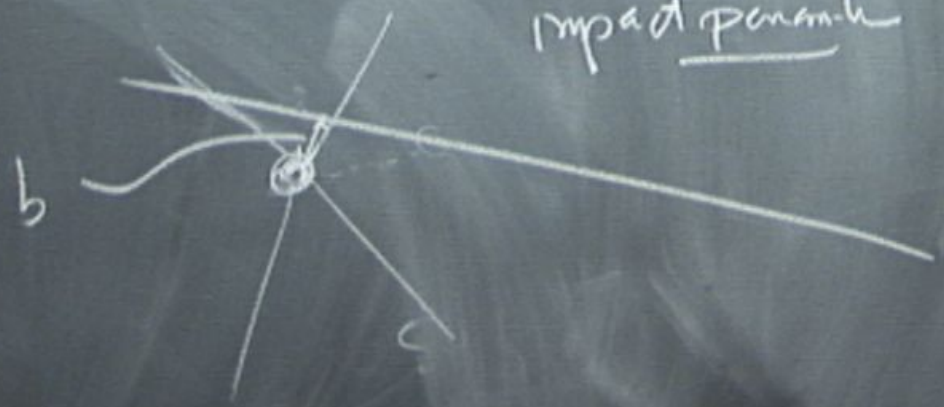

drift- chamb
Time Projd. Ch
$s = \frac{1}{2} R\theta^2$
$= \frac{1}{2}\left(\frac{300\,MeV}{Tm}\right)\frac{Bl^2}{E}$
2nd vertex
B
ATLAS
$\sigma\left(\frac{1}{P_T}\right)$ = const.
$\frac{\sigma(P_T)}{P_T} \sim 3{,}6\times10^{-4} P_T \oplus \frac{1\times10^{-2}}{\sqrt{\sin\theta}}$

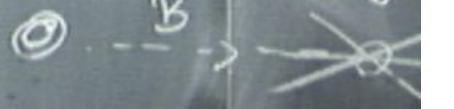
u, d, s c, b, t

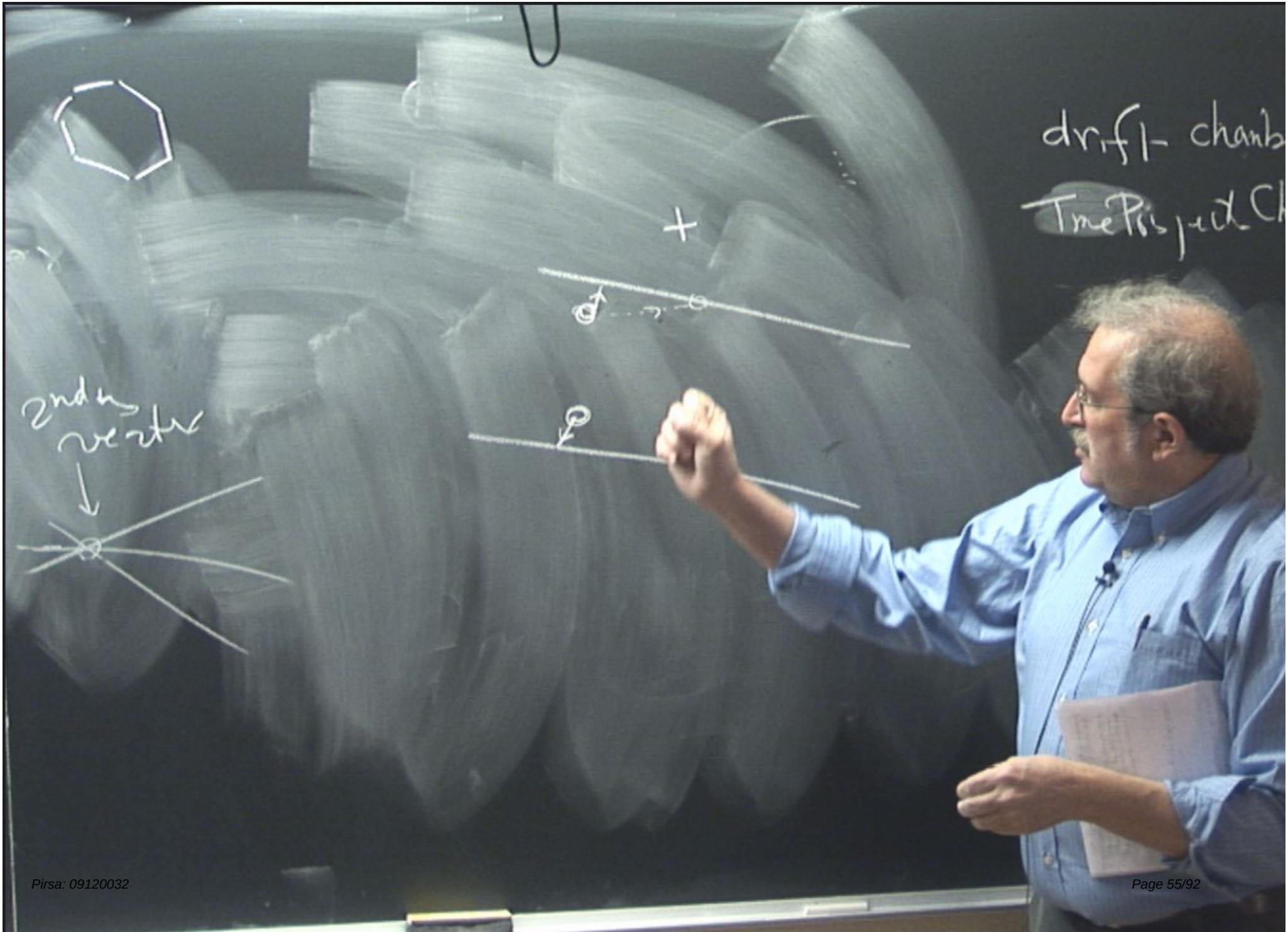
b : $B^{\pm}$ B^{0} $c\tau$ = 0,45 mm.

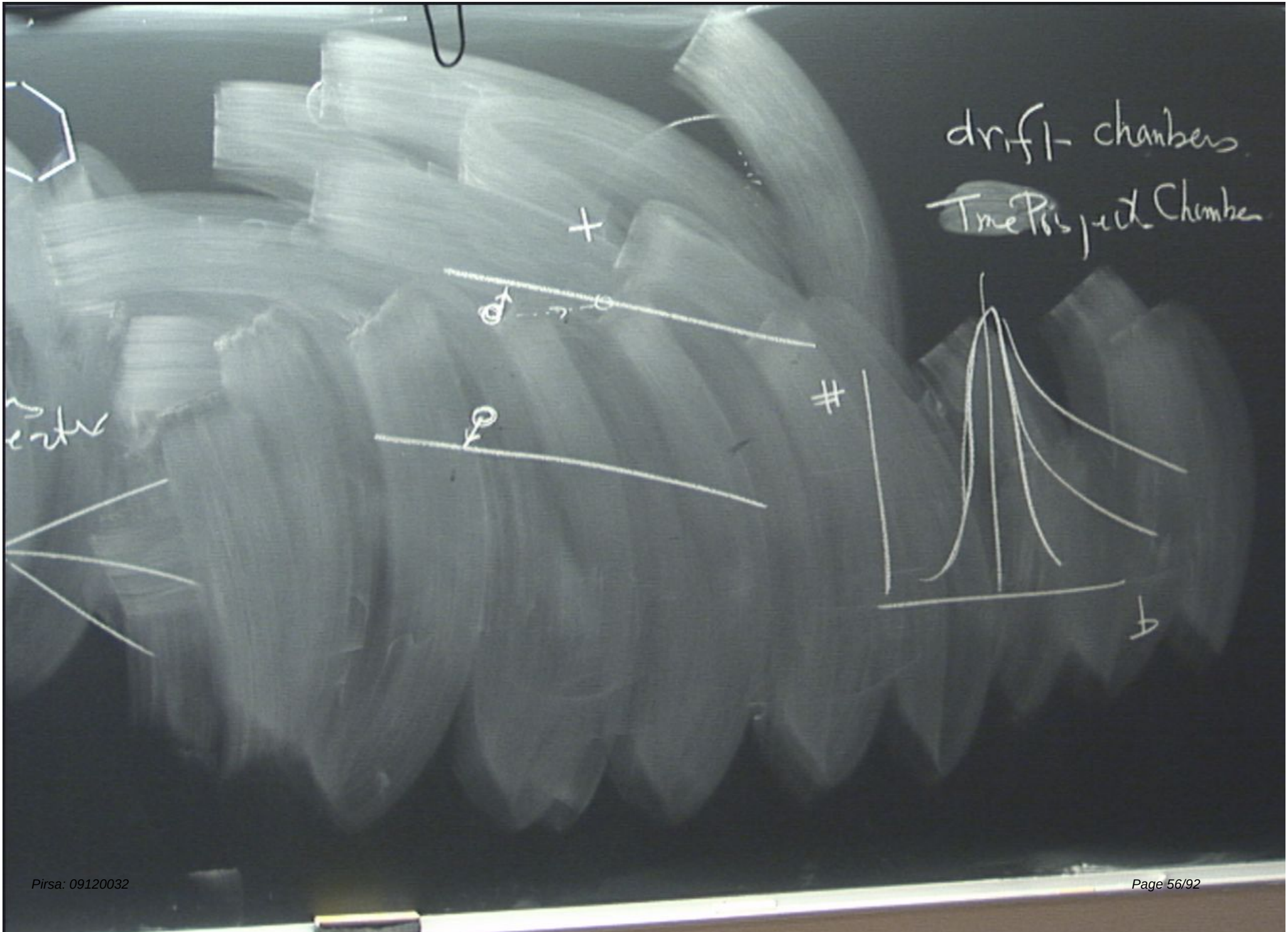
$c\bar{d}$ c D^{+} $c\tau$ = 0,31 mm

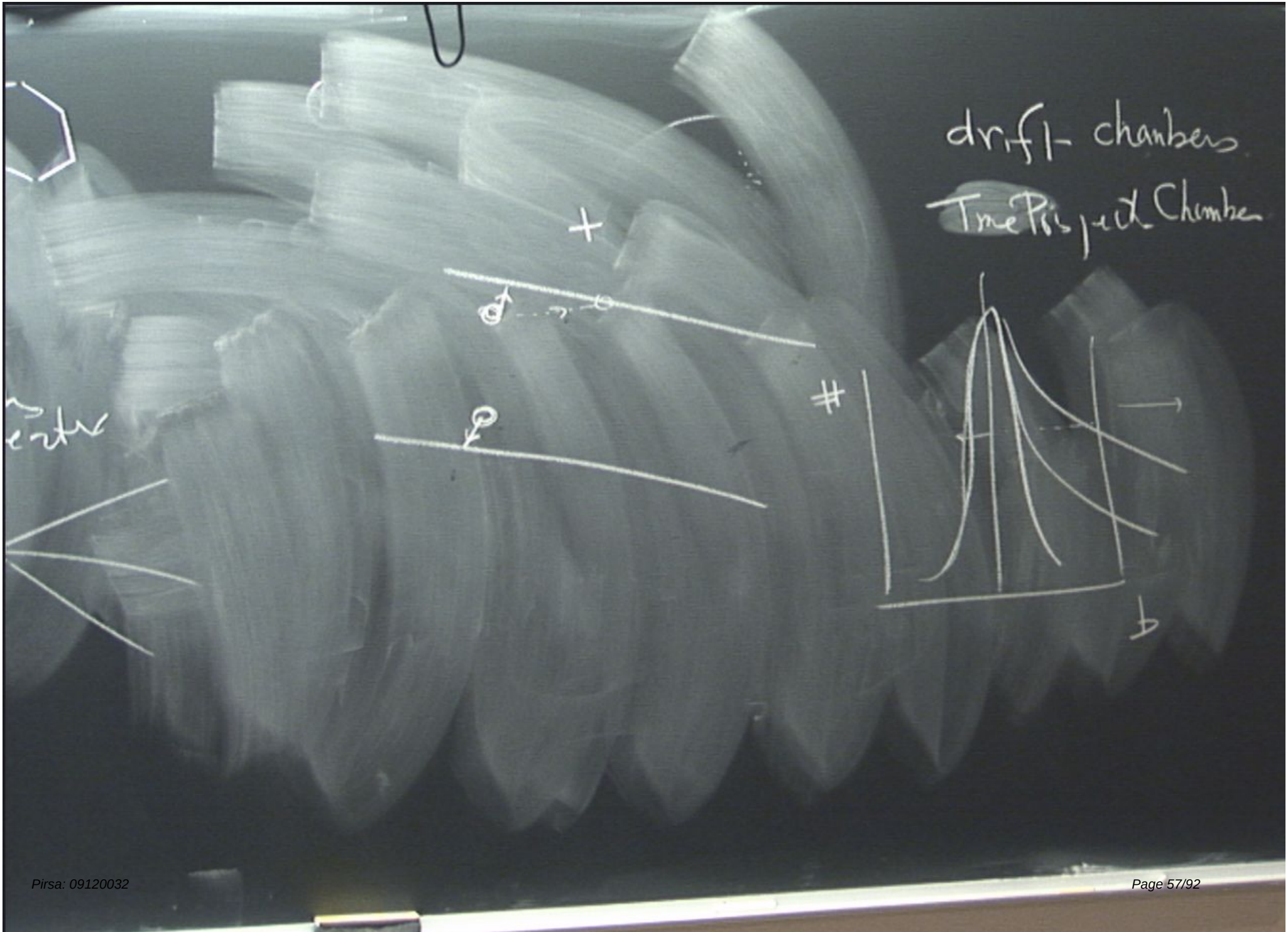
D^{0} $c\tau$ = 0,17 mm

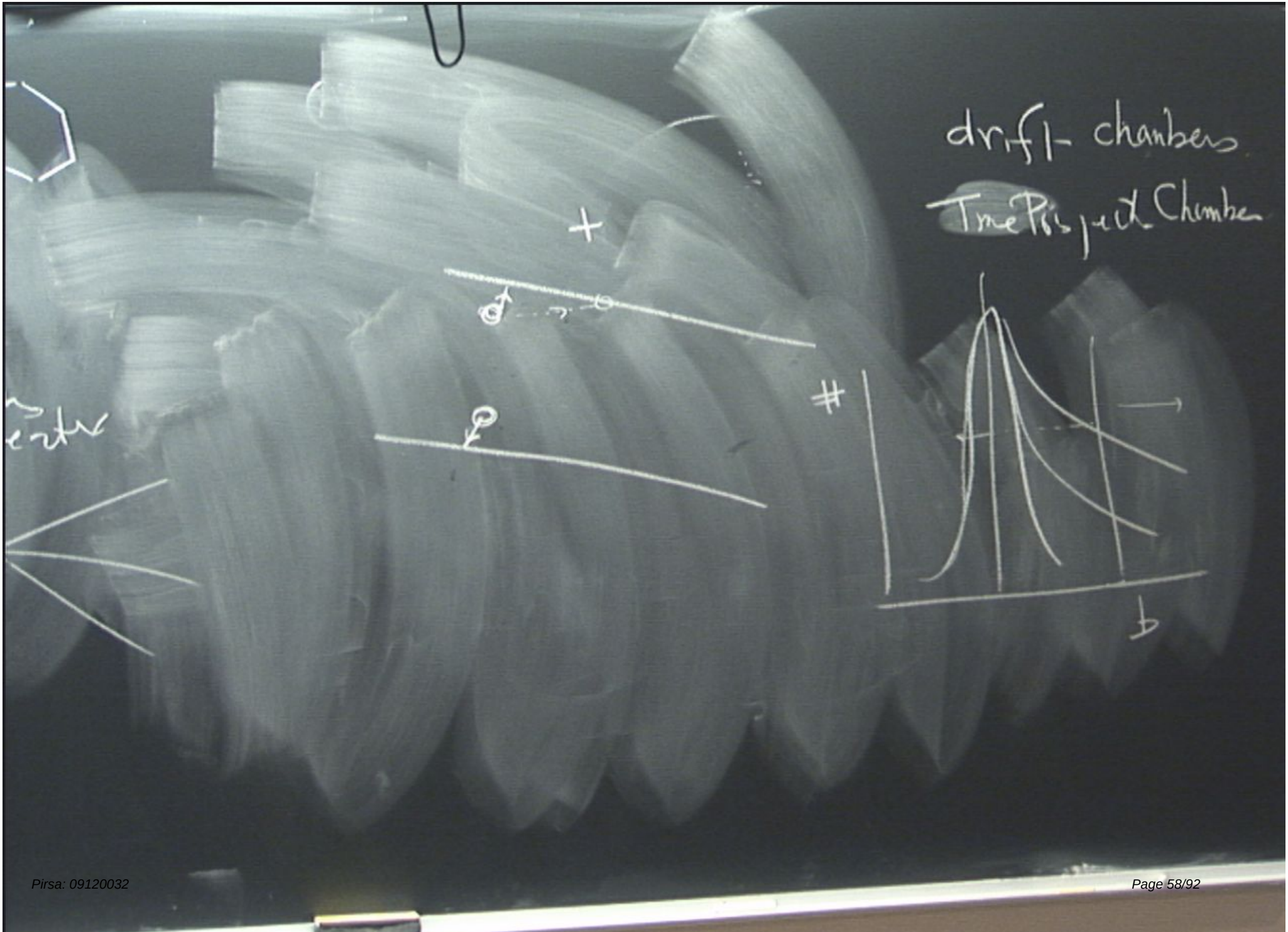


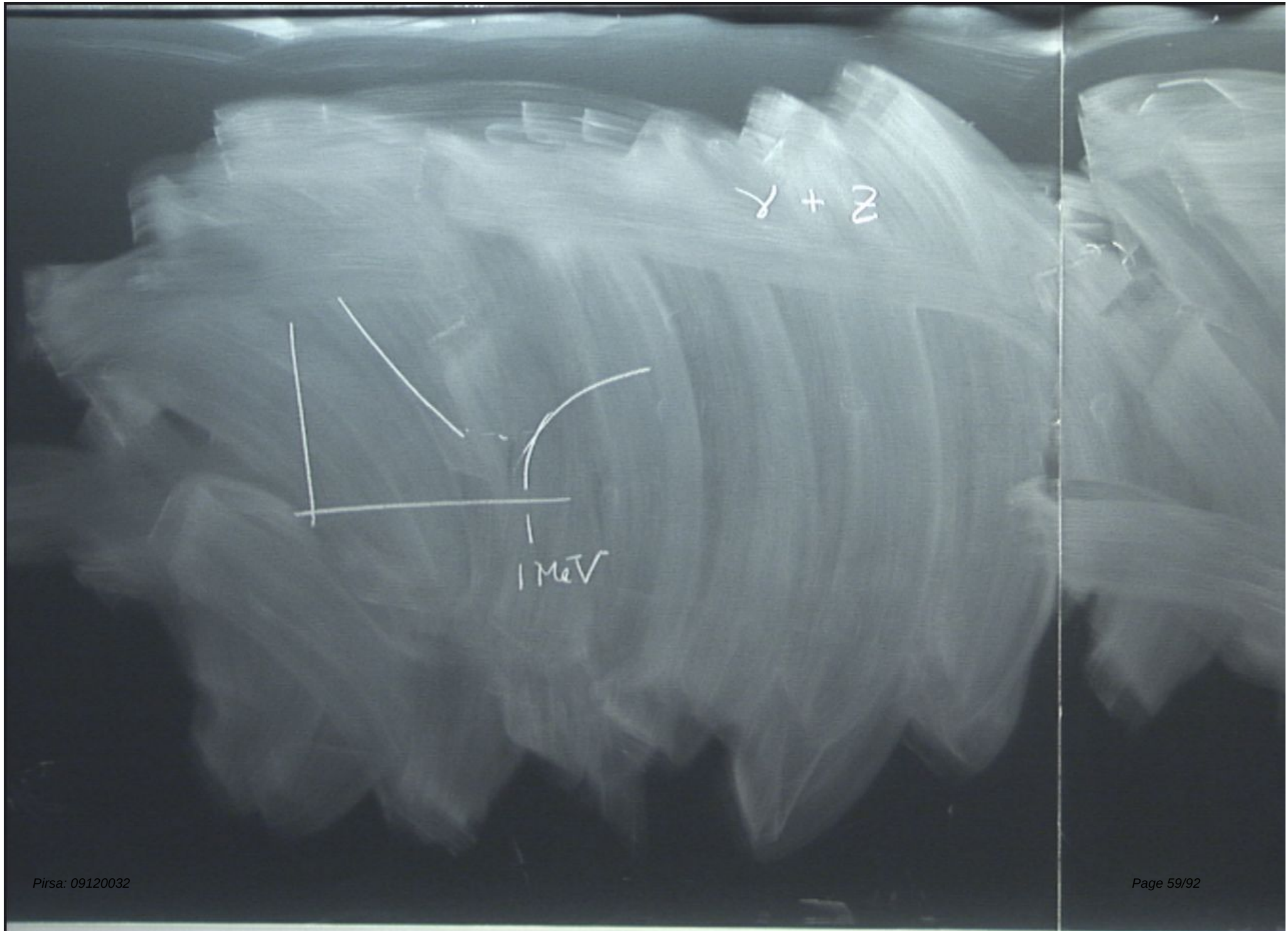


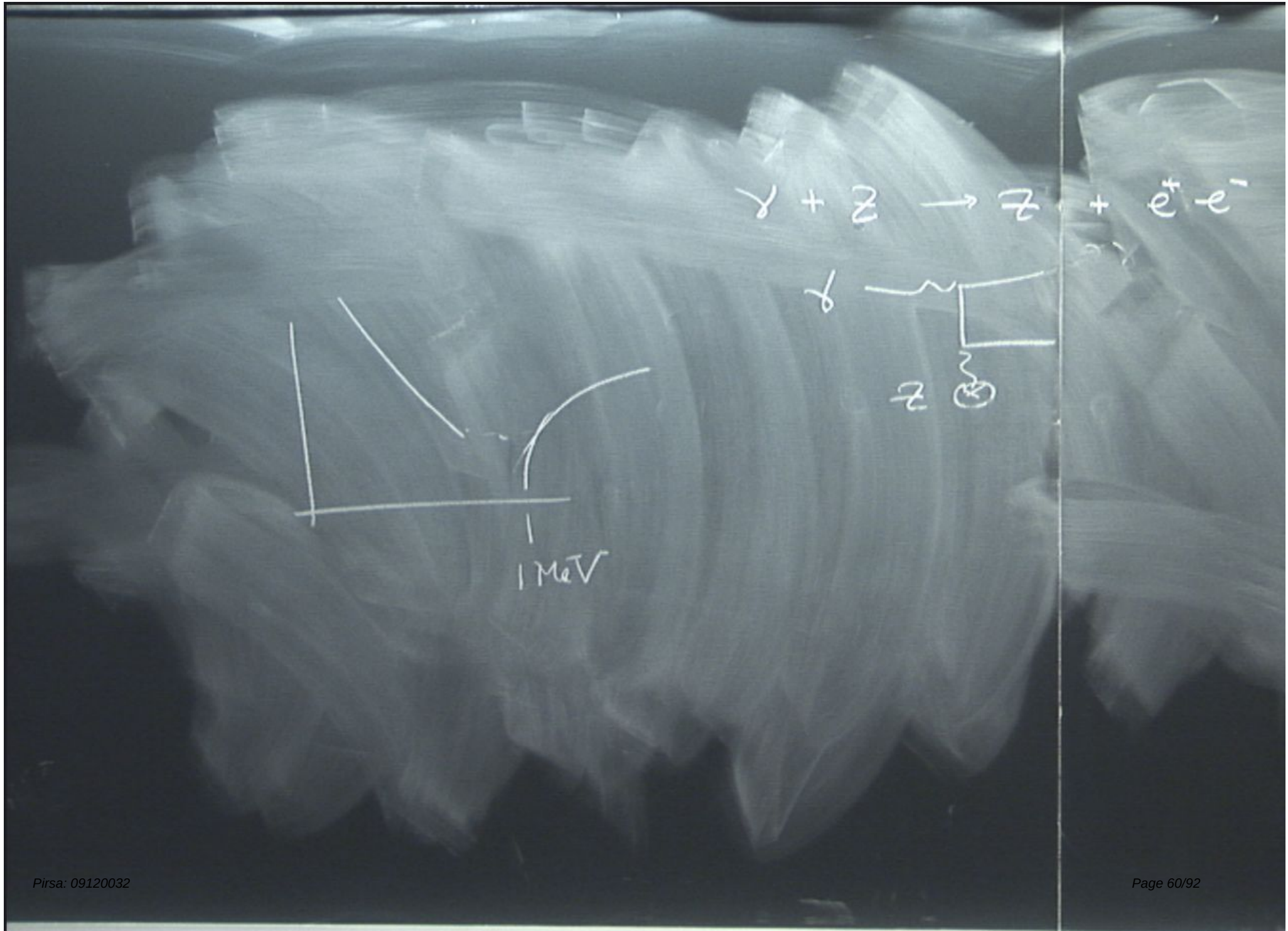

drift- chamb
2nd vertex

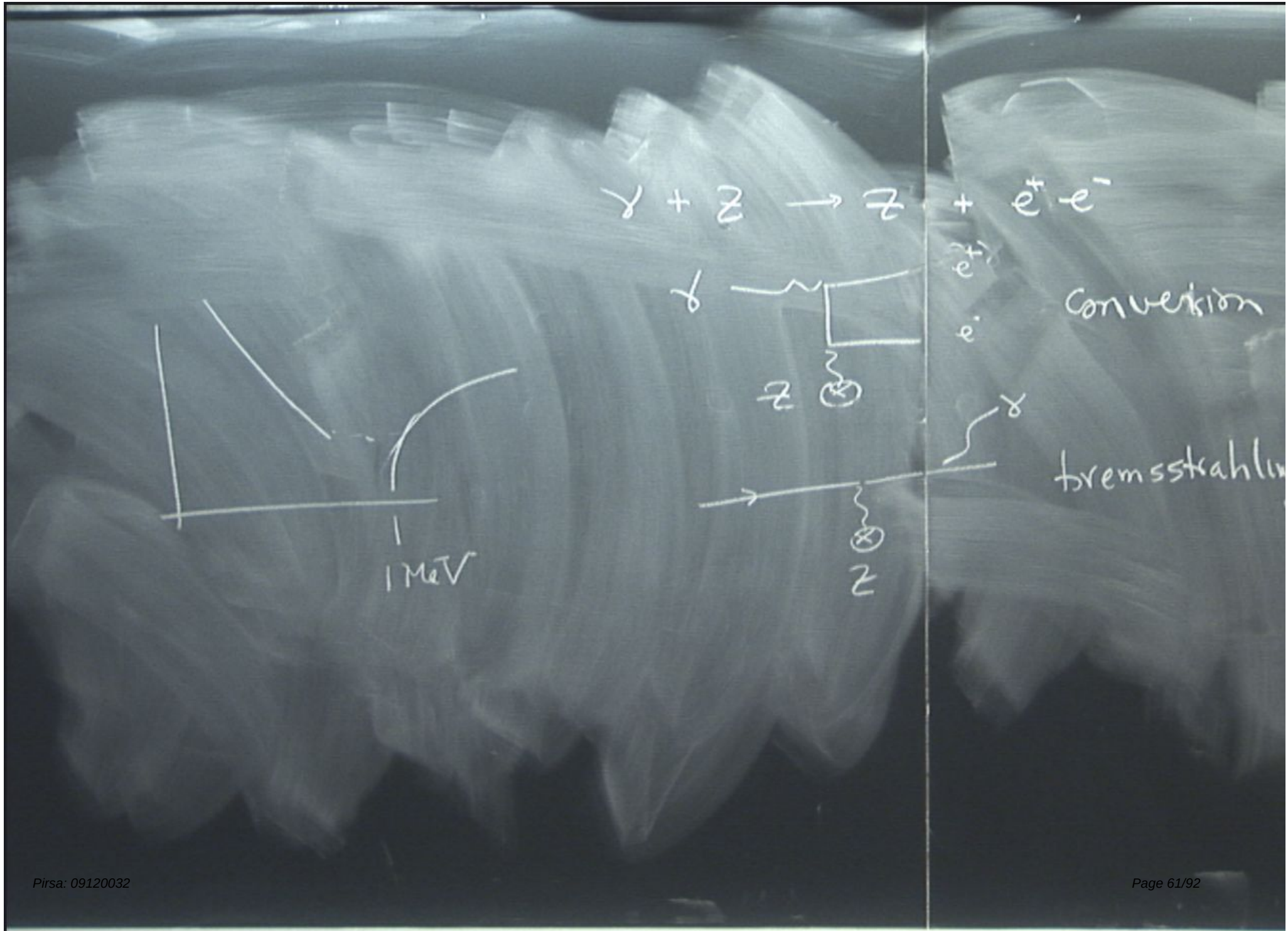

drift chambers
Time Projection Chamber
+
#
t

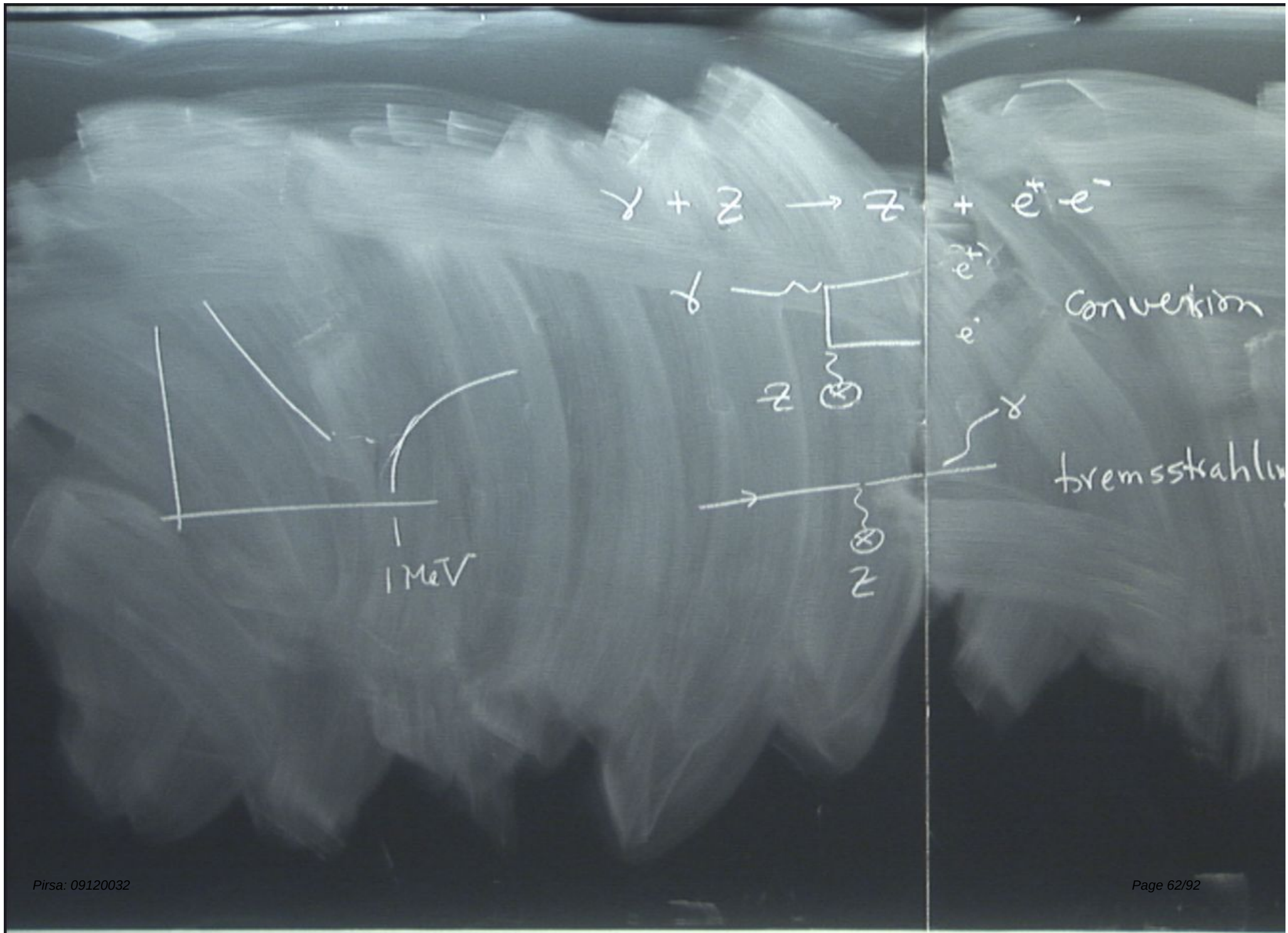

drift- chambers
Time Projection Chamber
+
#
b

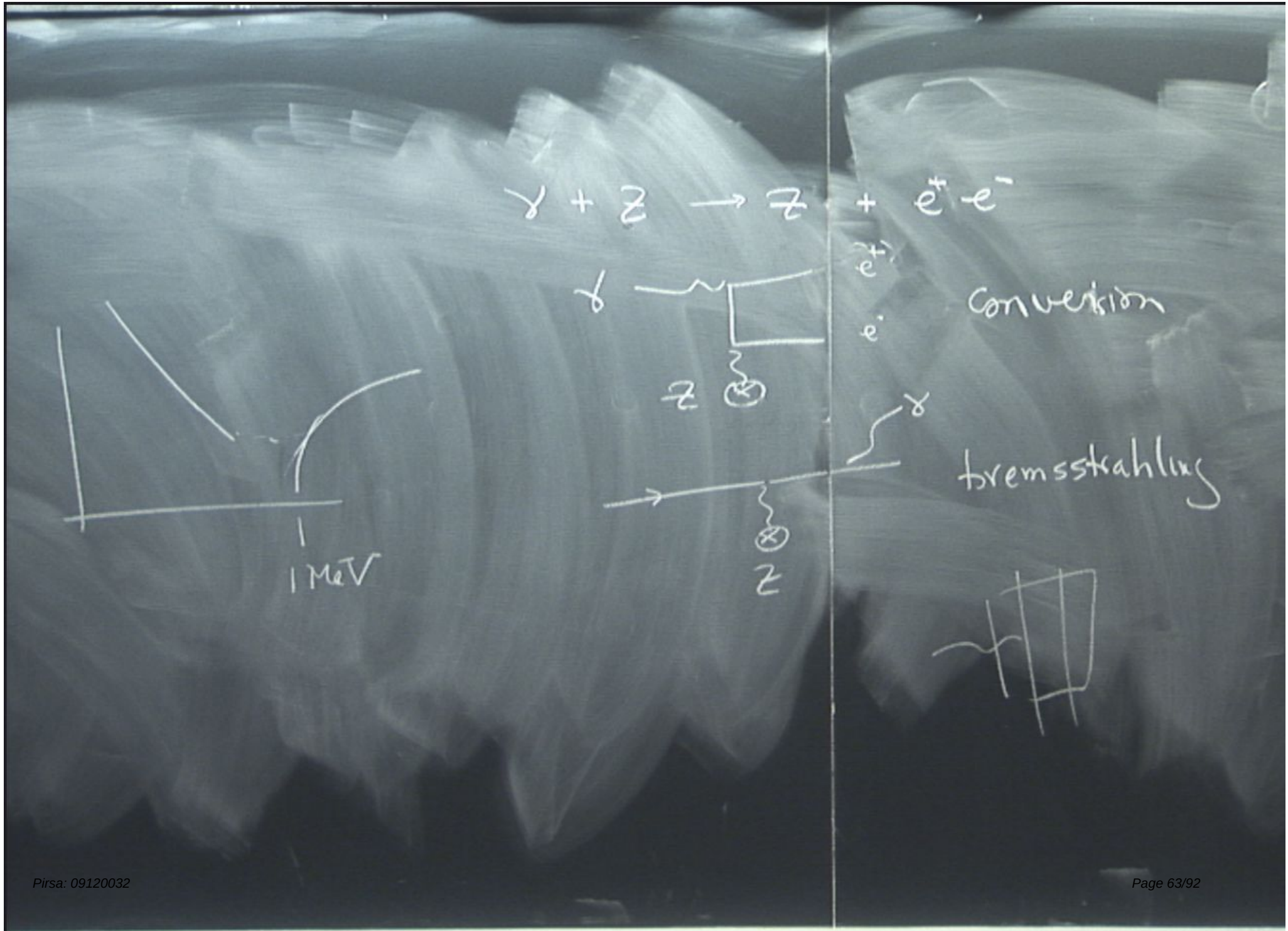

drift chambers
Time Projection Chamber
+
#
t

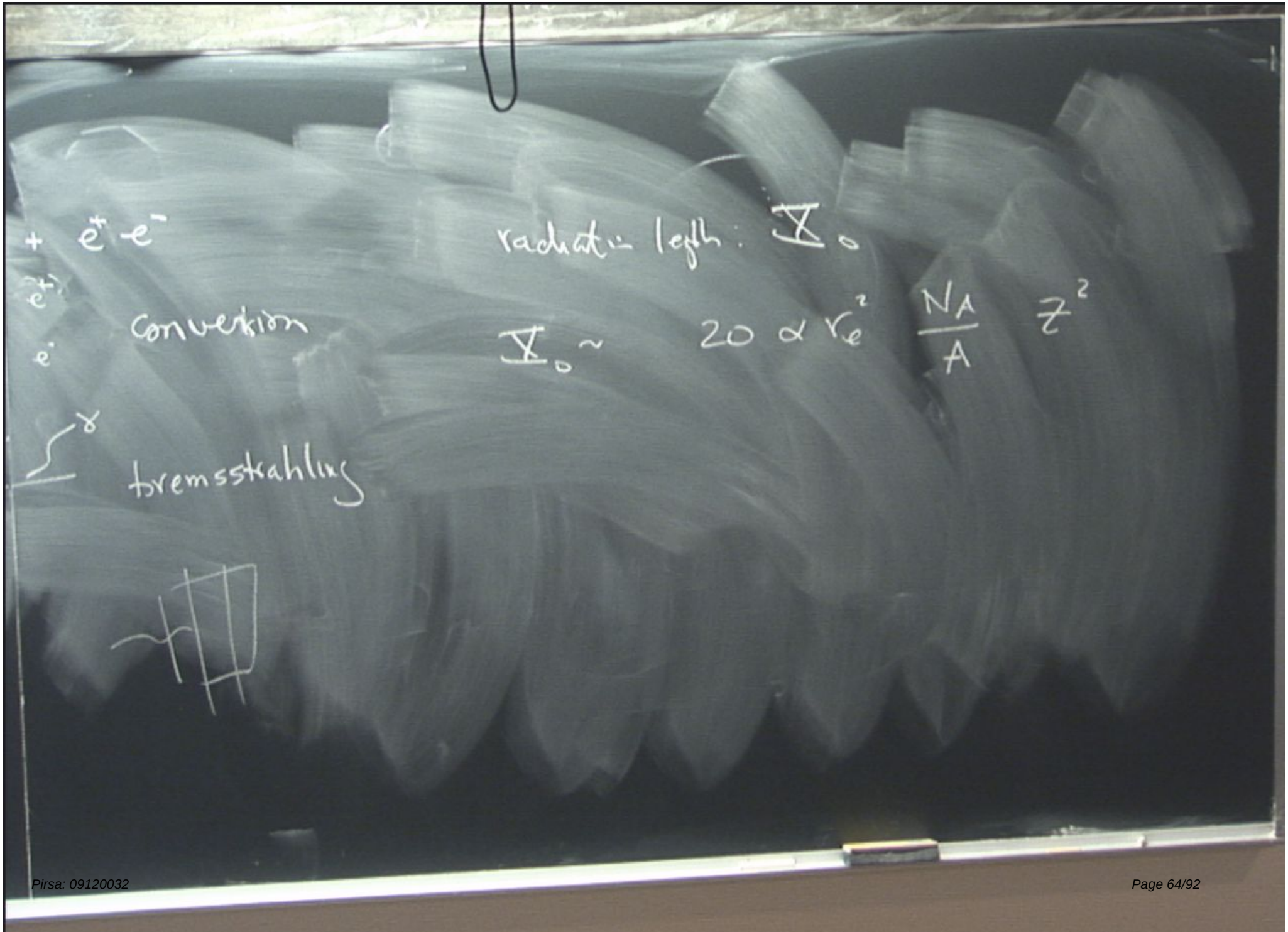

γ + Z
1 MeV

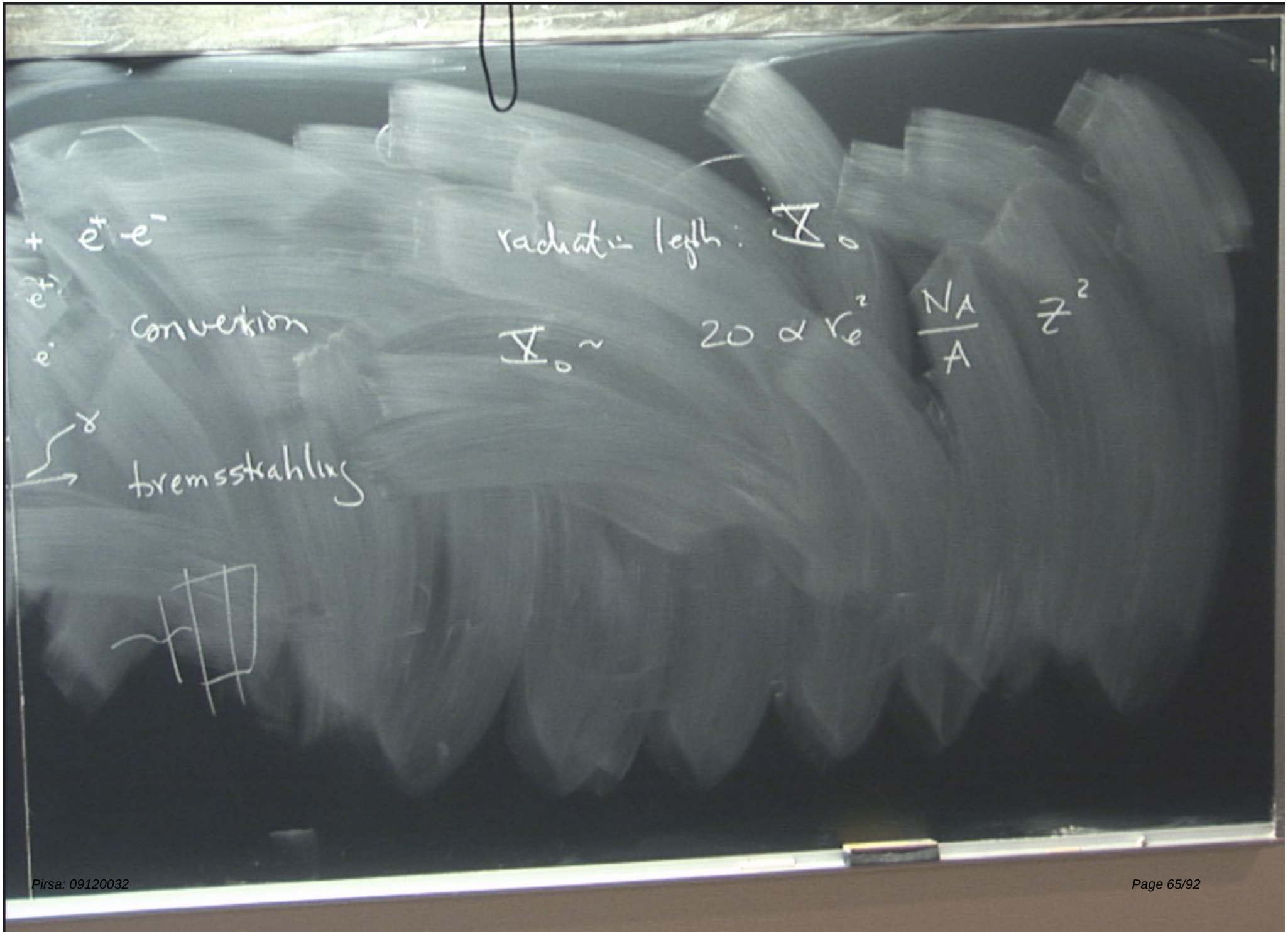

γ + Z → Z + e⁺ e⁻
γ
Z
1 MeV


γ + Z → Z + e⁺ e⁻
γ
e⁺
e⁻
Conversion
Z
γ
bremsstrahlu
Z
1 MeV


γ + Z → Z + e⁺ e⁻
γ
e⁺
e⁻
Z
Conversion
1 MeV
γ
Z
bremsstrahlu


γ + Z → Z + e⁺ e⁻
γ
e⁺
e⁻
Z
Conversion
1 MeV
γ
Z
bremsstrahlung


+ e⁺ e⁻
e⁺
e⁻
conversion
γ
bremsstrahlung
radiation length: X_0
$X_0 \sim 20 \alpha r_e^2 \frac{N_A}{A} Z^2$


+ e⁺ e⁻
e⁺
e⁻
conversion
γ
bremsstrahlung
radiation length: X_0
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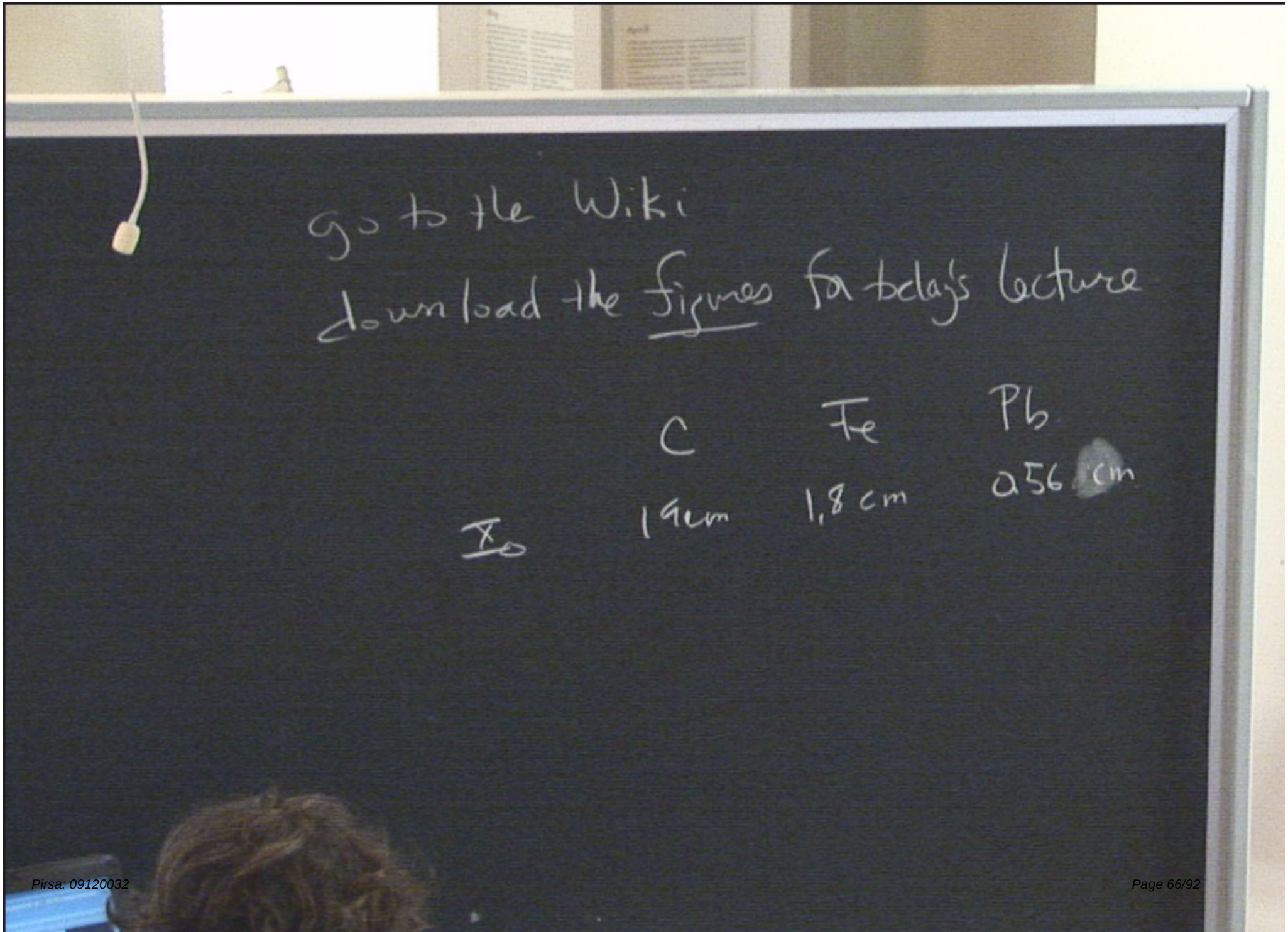
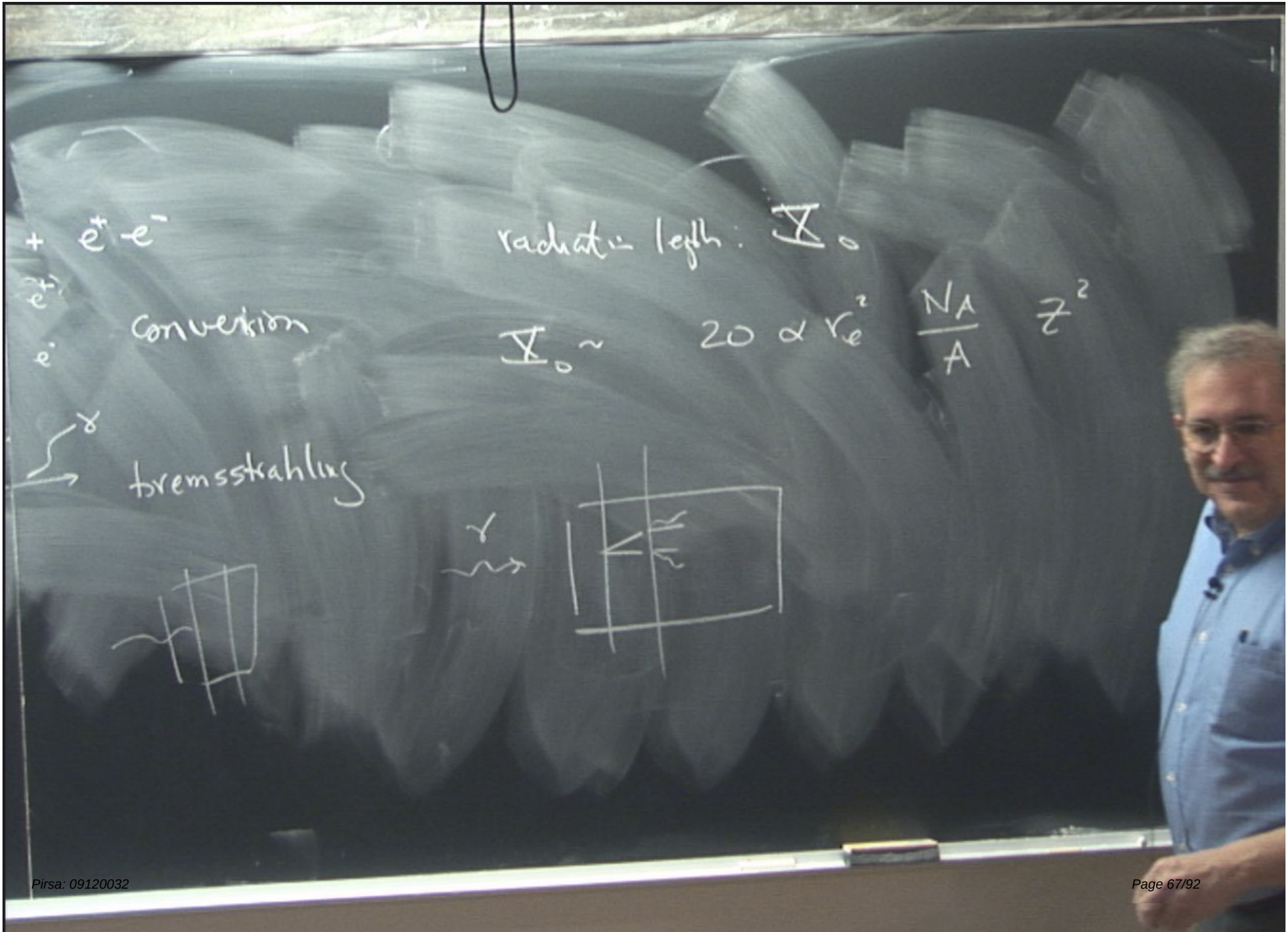
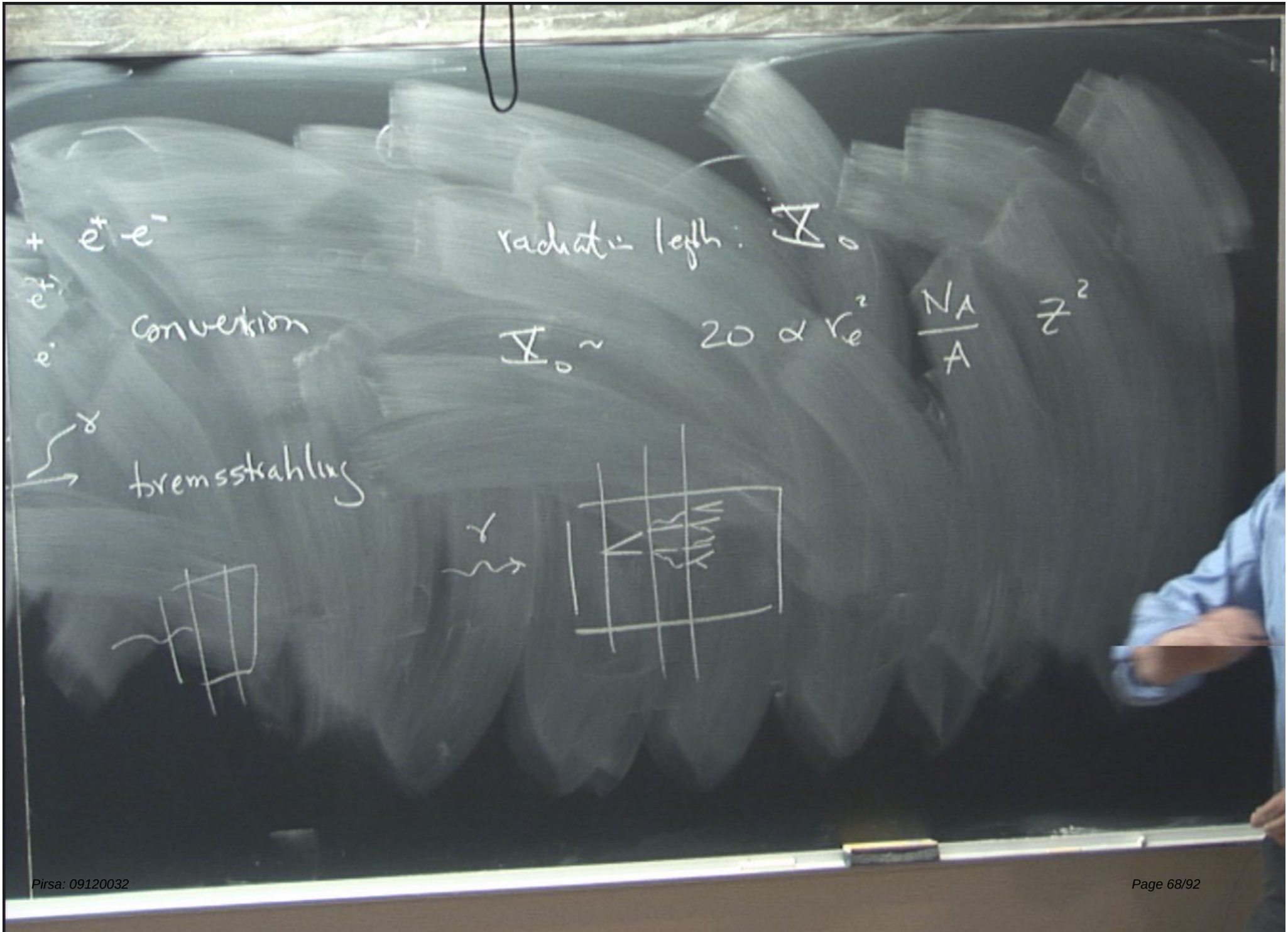
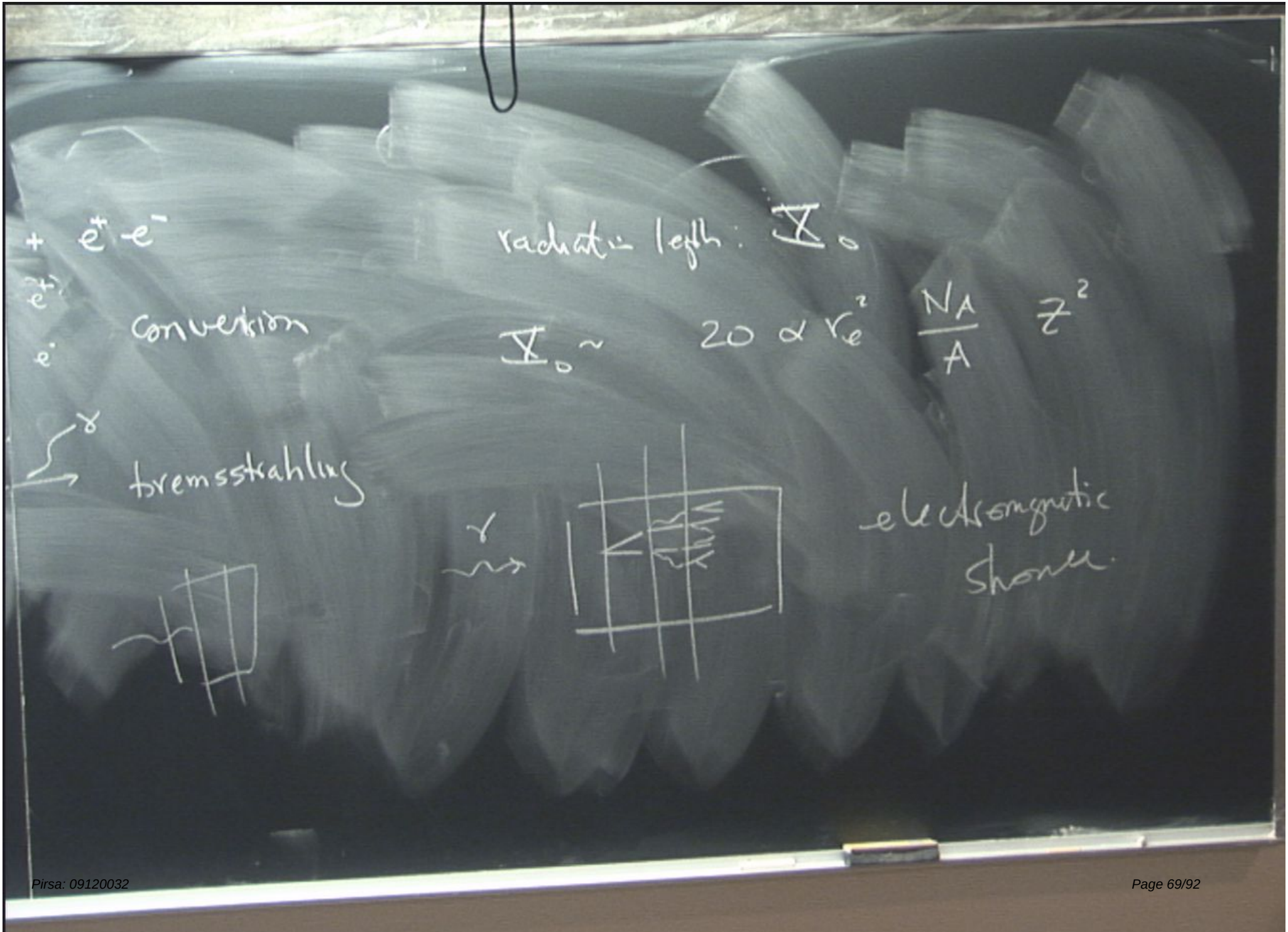

go to the Wiki
download the figures for today's lecture
C
Fe
Pb
I_0
19cm
1,8 cm
a56 cm


+ e⁺ e⁻
e⁺
e⁻
conversion
radiation length: X_0
$X_0 \sim 20 \alpha r_e^2 \frac{N_A}{A} Z^2$
γ
bremsstrahlung
γ


+ e⁺ e⁻
e⁺ e⁻
conversion
radiation length: X_0
$X_0 \sim 20 \alpha r_e^2 \frac{N_A}{A} Z^2$
γ
bremsstrahlung
γ

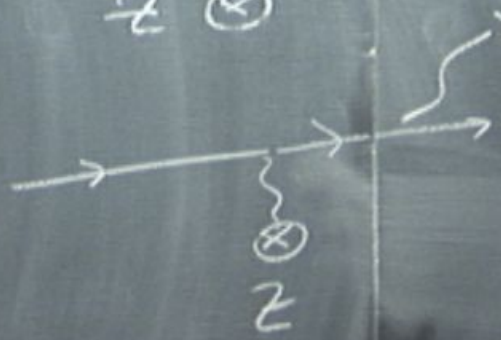

+ e⁺ e⁻
e⁺
e⁻
conversion
radiation length: X_0
$X_0 \sim 20 \alpha r_e^2 \frac{N_A}{A} Z^2$
γ
bremsstrahlung
γ
electromagnetic shower

critical energy

E_c

$\gamma + Z \rightarrow Z + e^+ e^-$

Conversi



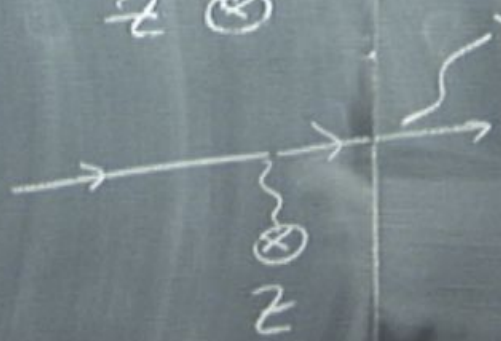
bremsstra

critical energy

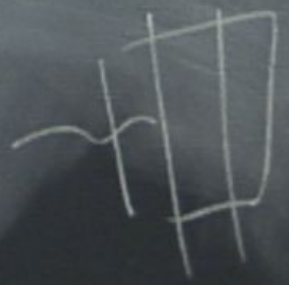
$E_c = 800\ \text{MeV}/Z$

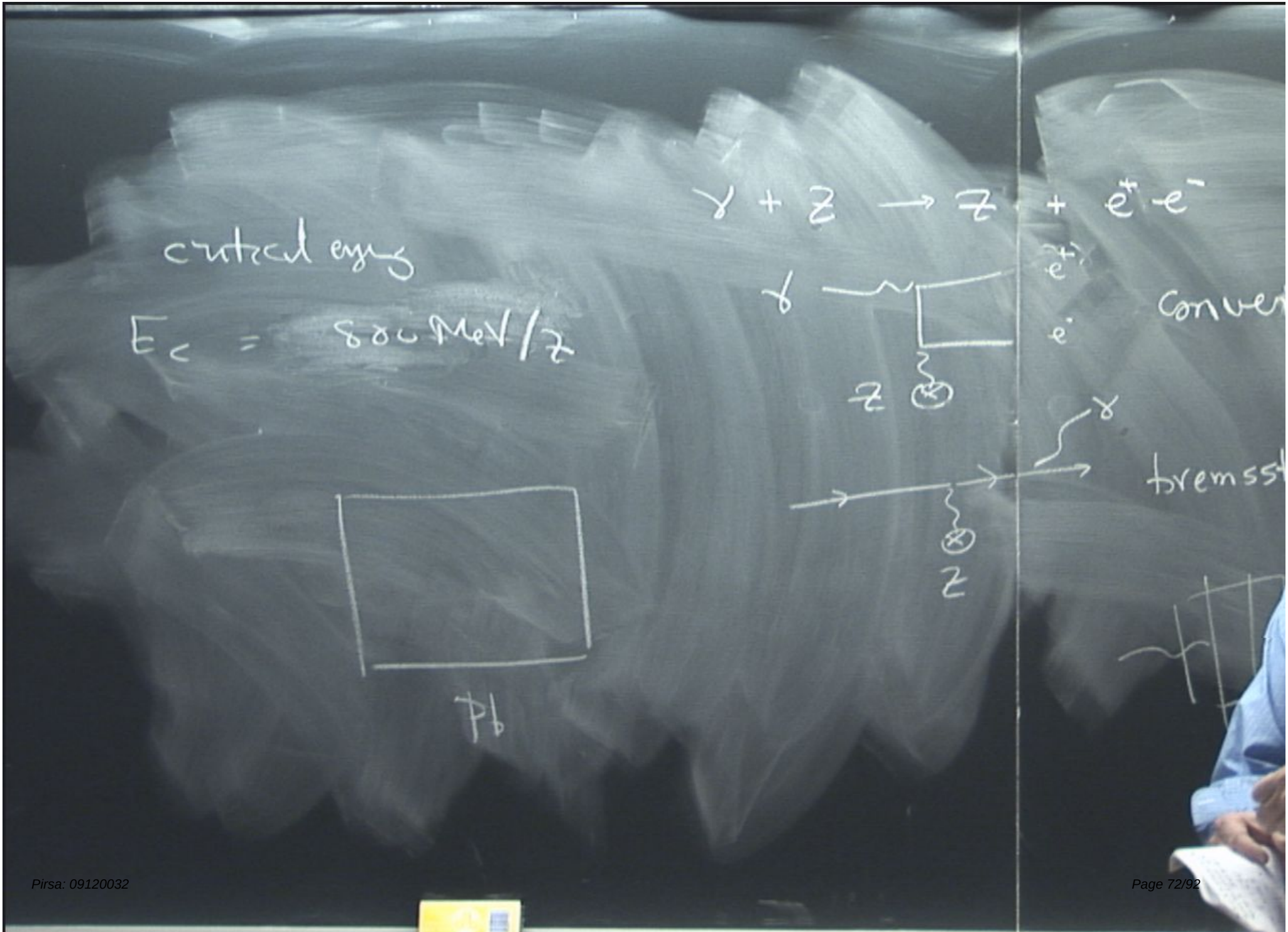
$\gamma + Z \rightarrow Z + e^+ e^-$

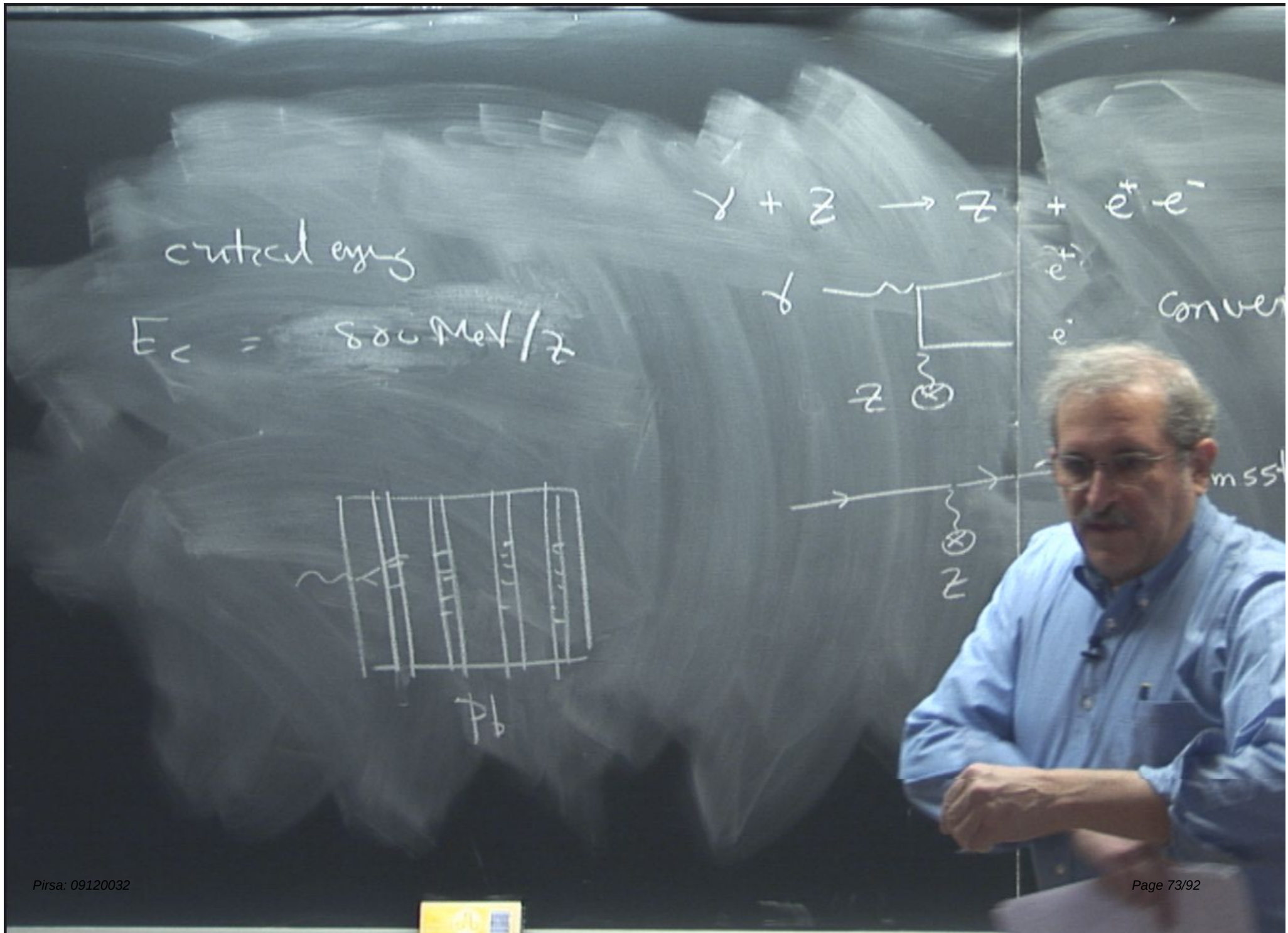
Conversion



bremsstra



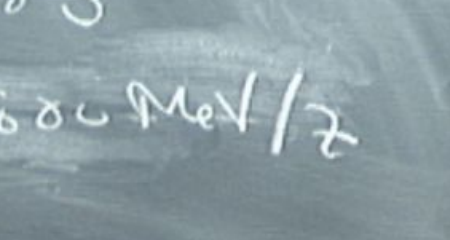

critical energy
$E_c = 800\ \mathrm{MeV}/Z$
$\gamma + Z \rightarrow Z + e^+ e^-$
γ
e^+
e^-
Z
Pb
brems
Pirsa: 09120032
Page 72/92


critical energy
$E_c = 800\,\mathrm{MeV}/Z$
$\gamma + Z \rightarrow Z + e^+ e^-$
γ
e^+
e^-
Z
Pb

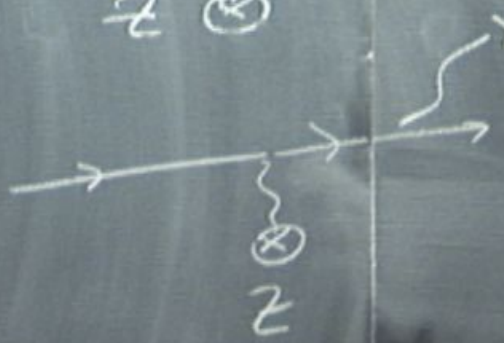
critical energy

$E_c = 800\ \text{MeV}/Z$

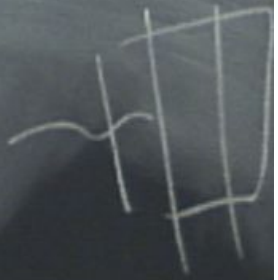
$\gamma + Z \rightarrow Z + e^+ e^-$

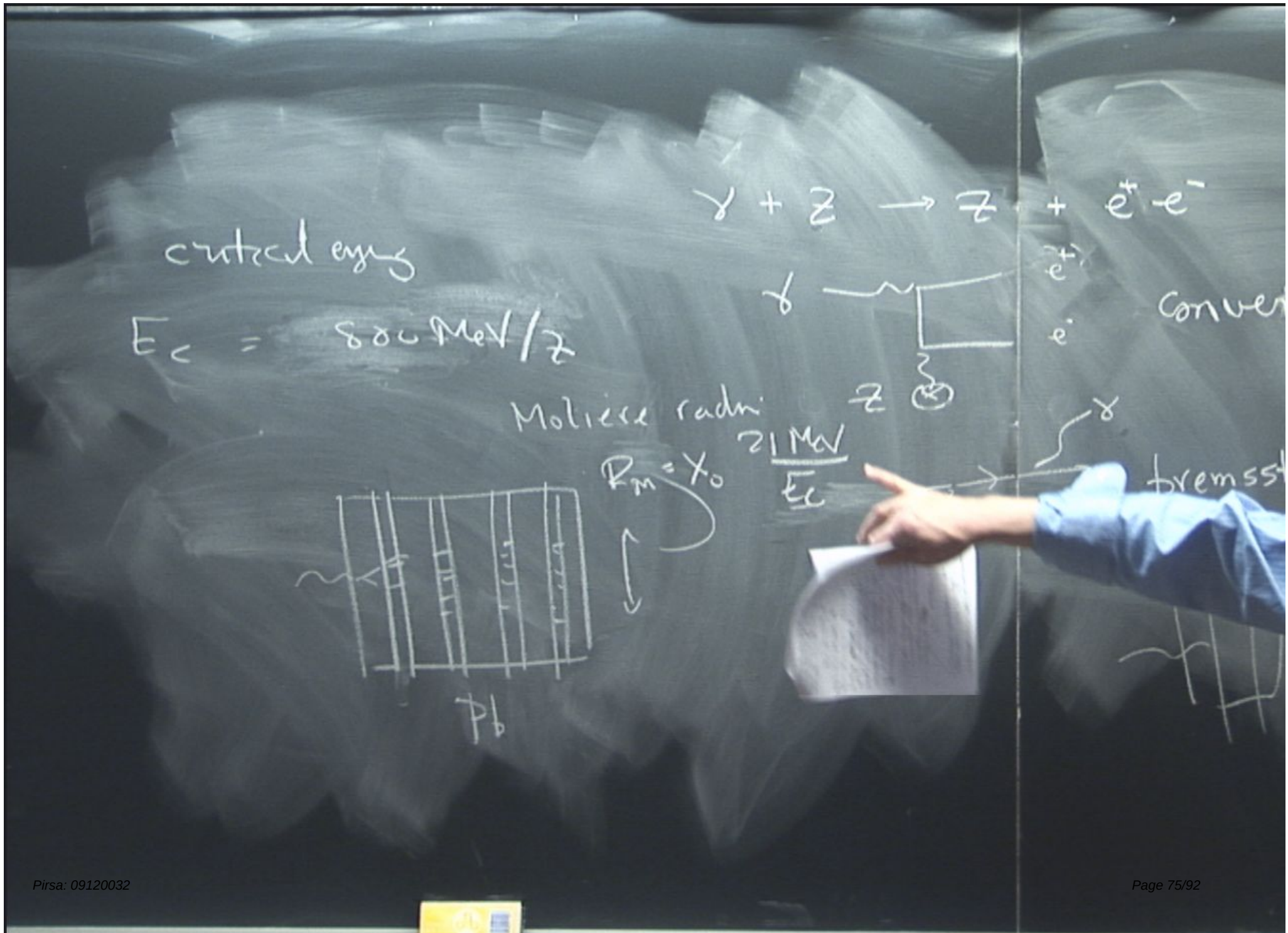


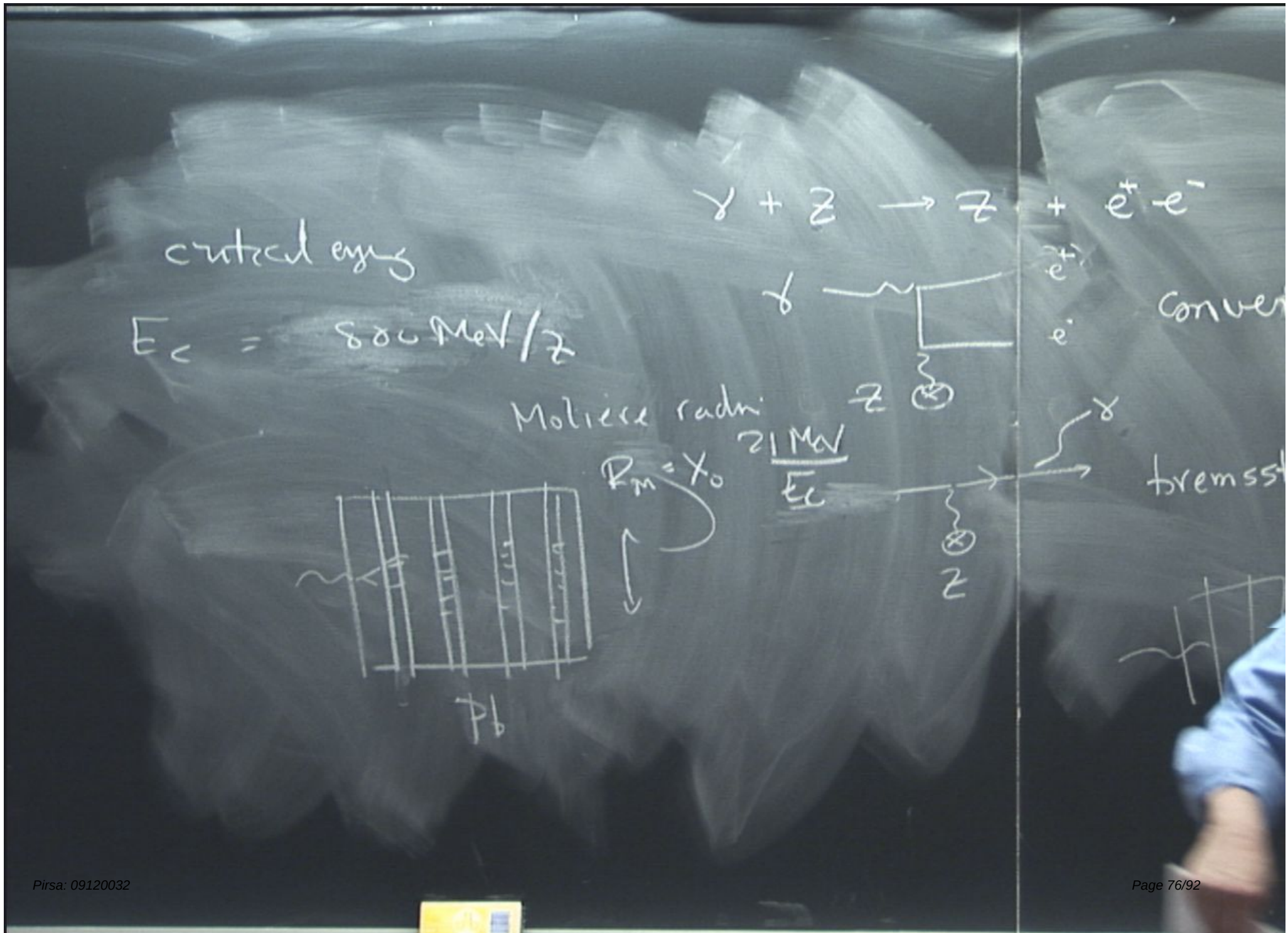
Conver

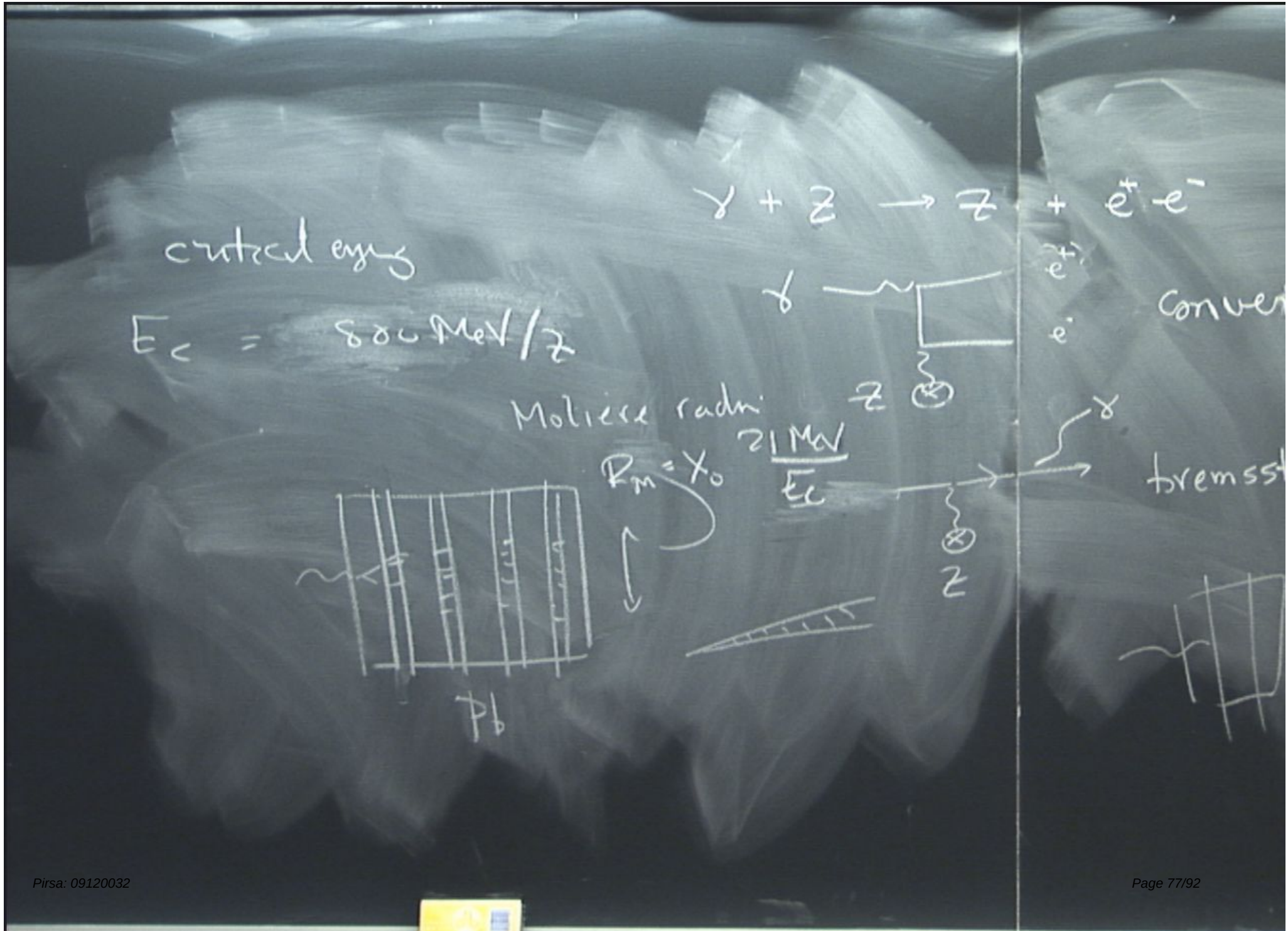


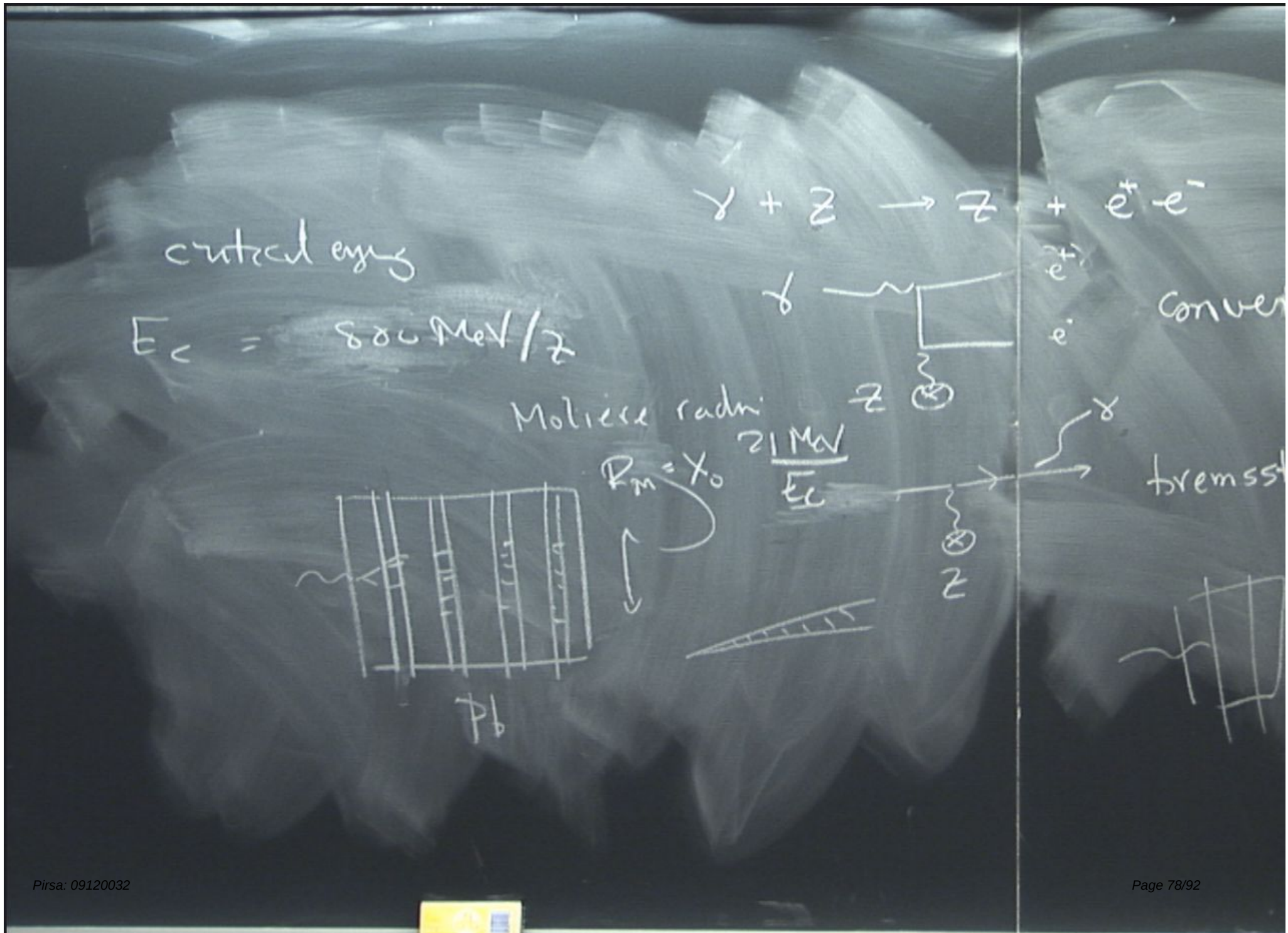
brems

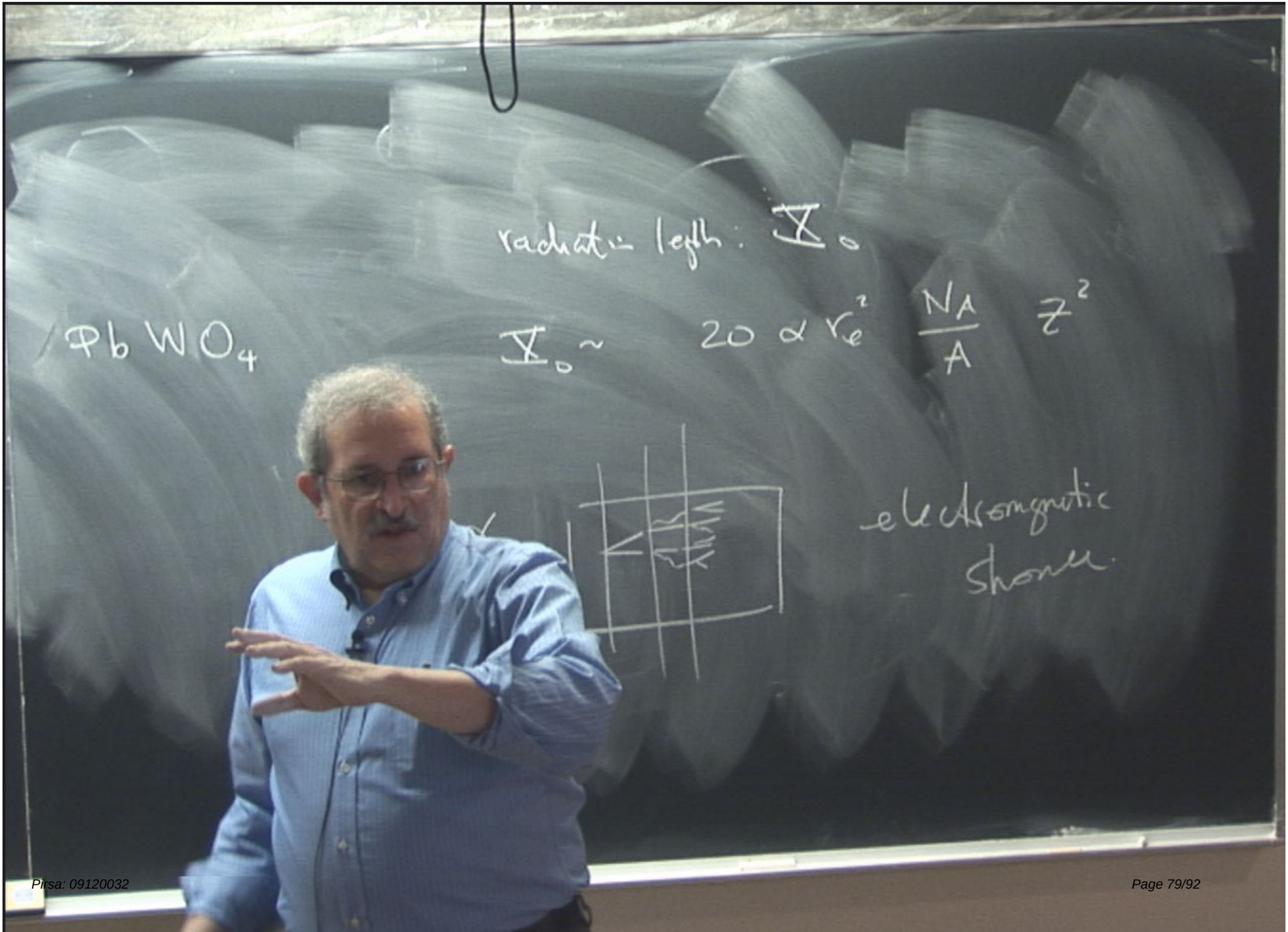


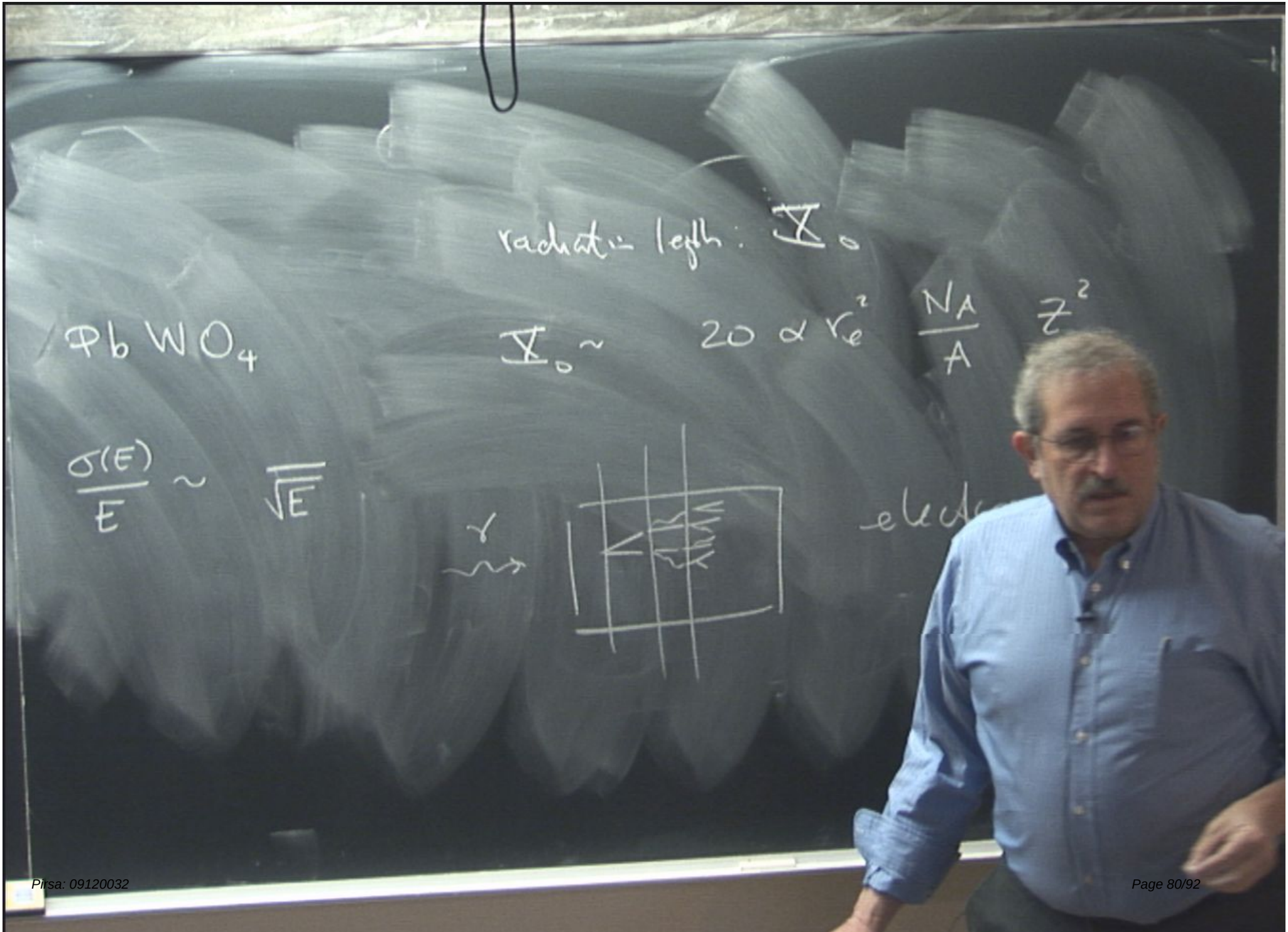

critical energy
$E_c = 800\,\mathrm{MeV}/Z$
$\gamma + Z \rightarrow Z + e^+ e^-$
γ
e^+
e^-
Z
Conver
Moliere radi
$R_M = X_0 \frac{21\,\mathrm{MeV}}{E_c}$
γ
brems
Pb


γ + Z → Z + e⁺ e⁻
critical energy
$E_c = 800\,\mathrm{MeV}/Z$
γ
e⁺
e⁻
Z
Conver
Moliere radi
$R_M = X_0$
$\frac{21\,\mathrm{MeV}}{E_c}$
γ
brems
Z
Pb


γ + Z → Z + e⁺ e⁻
critical energy
$E_c = 800\ \mathrm{MeV}/Z$
γ
e⁺
e⁻
Z
Conver
Moliere radius
$R_M = X_0$
$\frac{21\ \mathrm{MeV}}{E_c}$
γ
brems
Z
Pb


γ + Z → Z + e⁺ e⁻
critical energy
$E_c = 800\ \mathrm{MeV}/Z$
γ
e⁺
e⁻
Z
Conver
Moliere radius
$R_M = X_0$
$21\ \mathrm{MeV}/E_c$
γ
brems
Z
Pb


radiation length: X_0
$PbWO_4$
$X_0 \sim 20 \alpha r_e^2 \frac{N_A}{A} Z^2$
electromagnetic
shower


radiation length: X_0
$PbWO_4$
$X_0 \sim 20 \alpha r_e^2 \frac{N_A}{A} Z^2$
$\frac{\sigma(E)}{E} \sim \frac{1}{\sqrt{E}}$
γ
elec

radiation length: X_0

$PbWO_4$ $\quad X_0 \sim 20\,\alpha\, r_e^2 \frac{N_A}{A} Z^2$

ATLAS

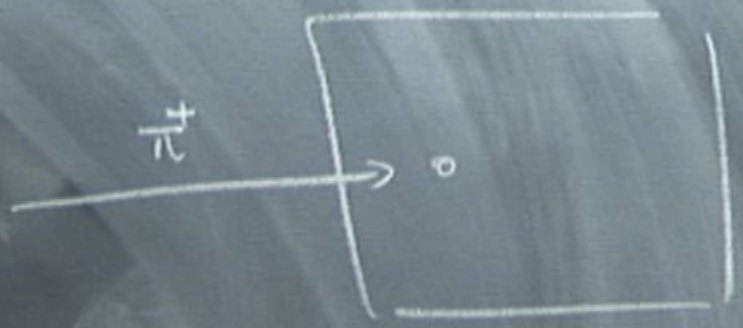
$\frac{\sigma(E)}{E} \sim \frac{10\%}{\sqrt{E}} \oplus 0.17\%$

electromagnetic shower

CMS

$\frac{\sigma(E)}{E} \sim \frac{4\%}{\sqrt{E}}$

hadron calorimeter



hadron calorimeter

$\pi^+ N \rightarrow N^* \pi^+ \pi^0 \pi^- K^+ K^- \pi^0$

$\pi^0 \rightarrow 2\gamma$

$\pi^0 \rightarrow 2\gamma$

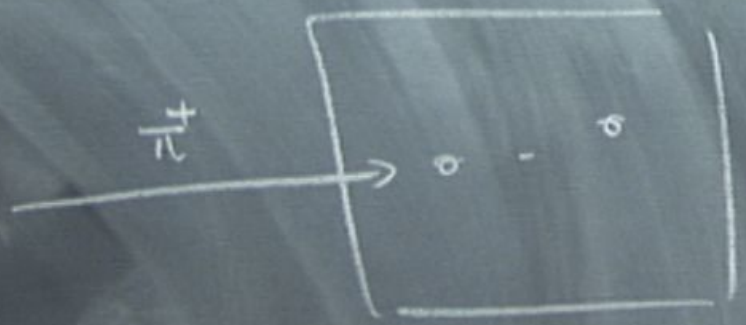
Pb W C

$\frac{\sigma(E)}{E} \sim$

CMS

$\frac{\sigma(E)}{E}$

hadron calorimeter



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PbWO

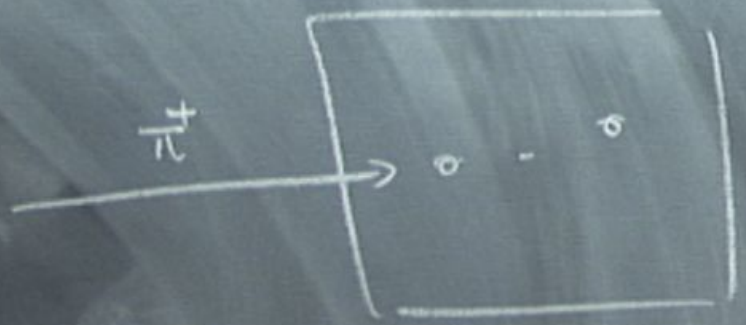
$\frac{\sigma(E)}{E} \sim$

CMS

$\frac{\sigma(E)}{E}$

hadron calorimeter

$\lambda_I^{-1} = n/\sigma_I$



$\pi^+ N \rightarrow N^* \pi^+ \pi^0 \pi^- K^+ K^- \pi^0$

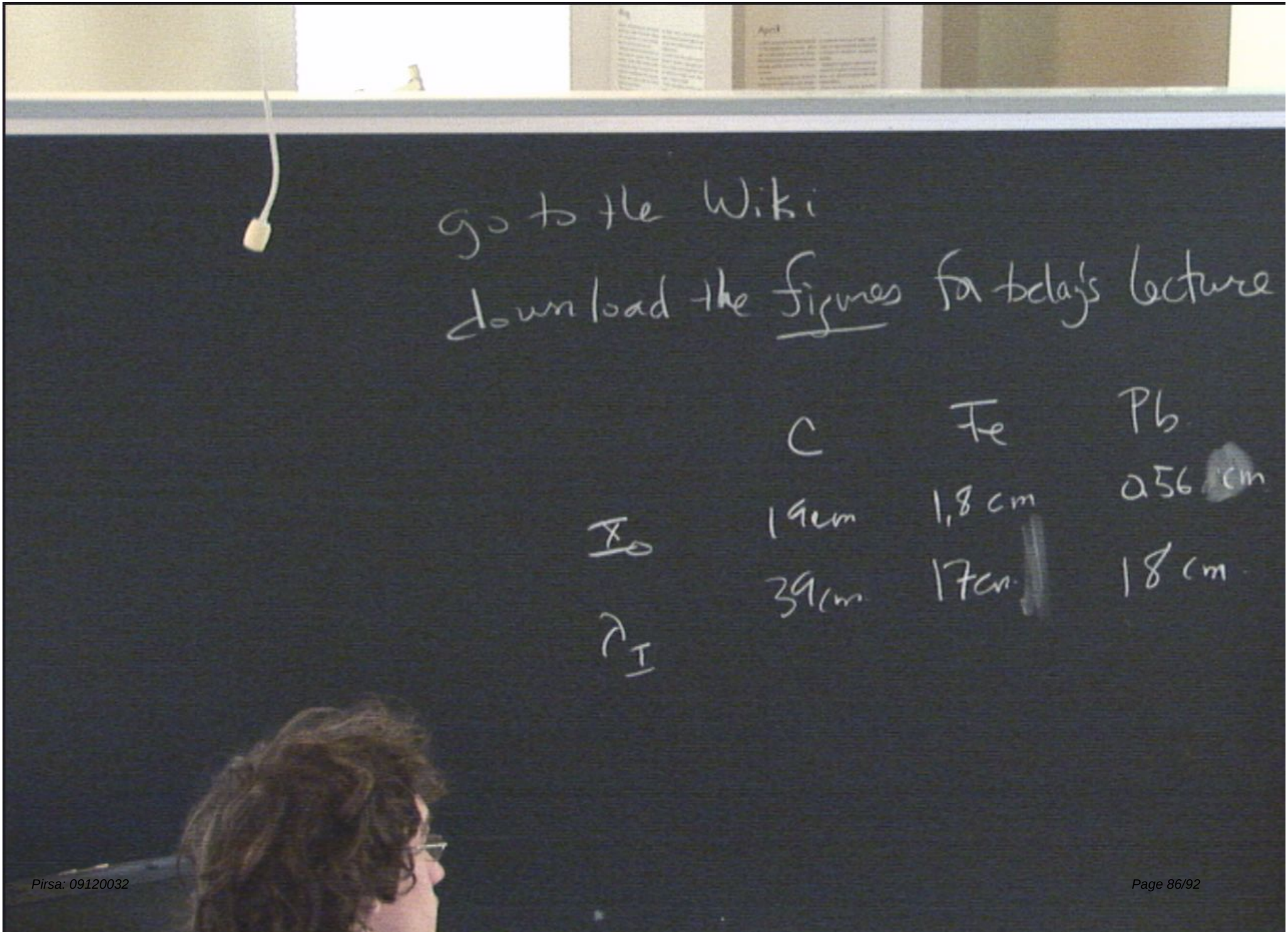
$\hookrightarrow 2\gamma$ $\hookrightarrow 2\gamma$

PbWO

$\frac{\sigma(E)}{E} \sim$

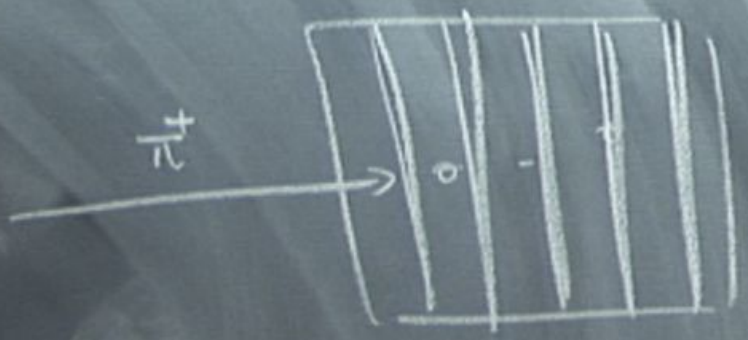
CMS

$\frac{\sigma(E)}{E}$


go to the Wiki
download the figures for today's lecture
C
Fe
Pb
X_0
19cm
1,8 cm
0,56 cm
λ_I
39cm
17cm
18 cm

hadron calorimeter

$\lambda_I^{-1} = n / \sigma_I$



$\pi^+ N \rightarrow N^* \pi^+ \pi^0 \pi^- K^+ K^- \pi^0$

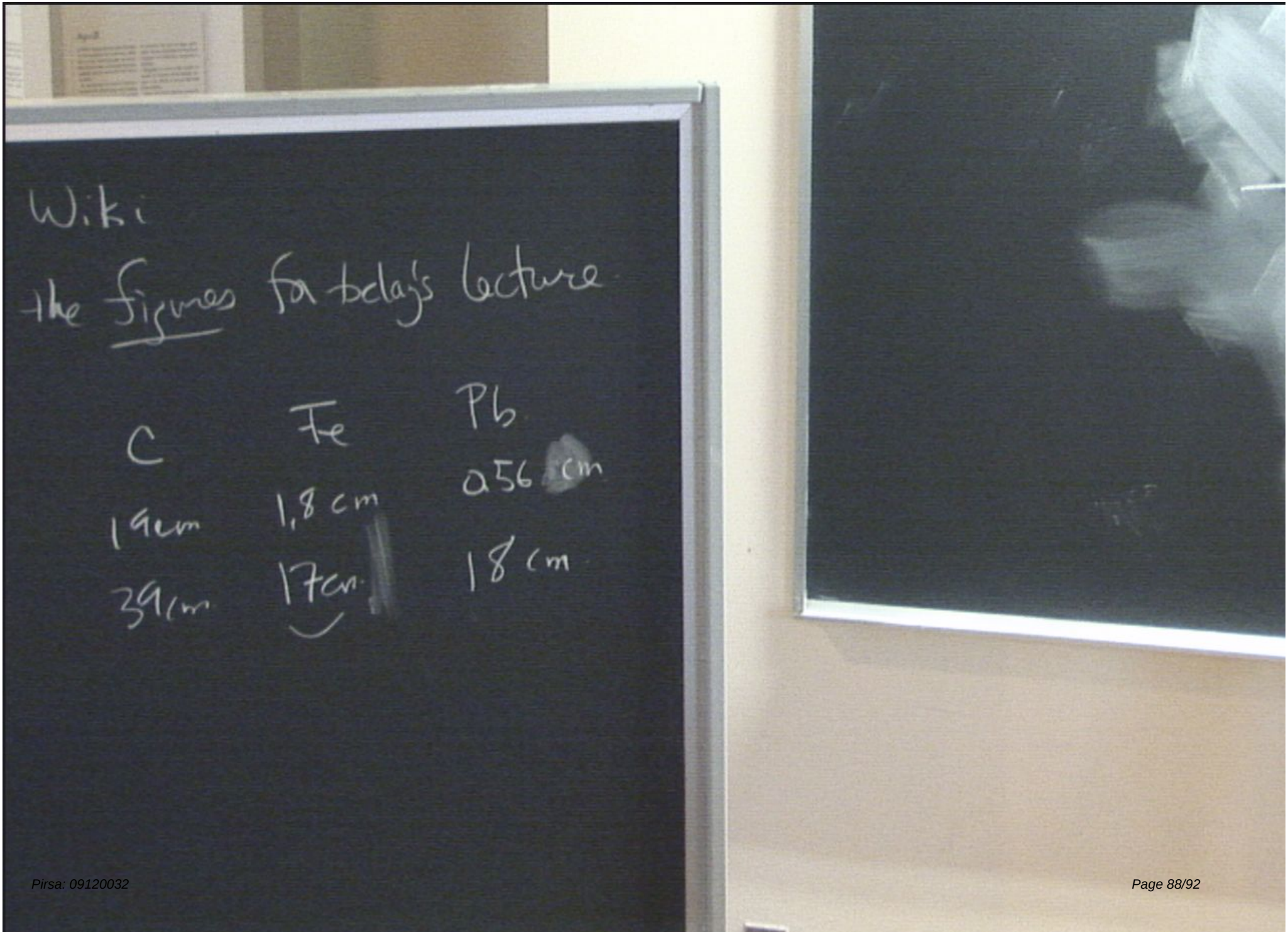
$\hookrightarrow 2\gamma$ $\qquad$ $\hookrightarrow 2\gamma$

$PbWO_4$

$\frac{\sigma(E)}{E} \sim \frac{1}{\sqrt{E}}$

CMS

$\frac{\sigma(E)}{E} \sim$


W.k.i
the figures for today's lecture
C
Fe
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19cm
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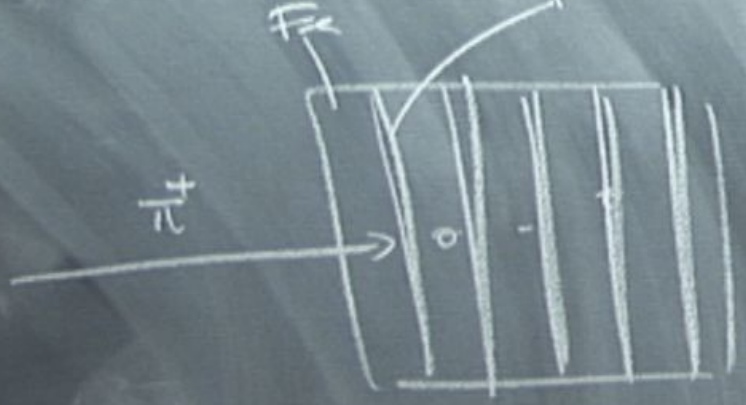
hadron calorimeter



$\lambda_I^{-1} = n/\sigma_I$

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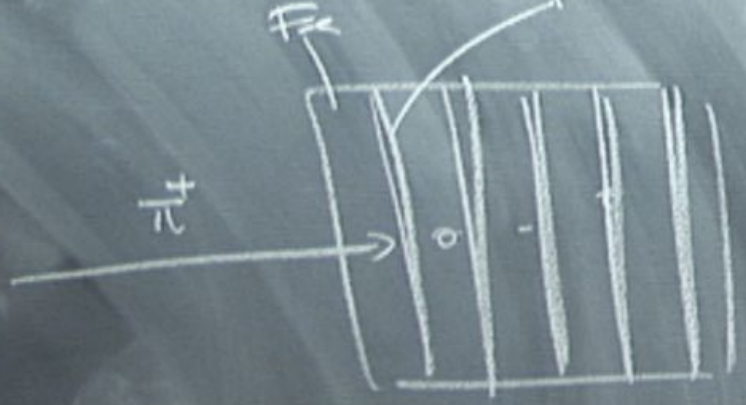
Pb W

$\frac{\sigma(E)}{E} \sim$

CMS

$\frac{\sigma(E)}{E}$

hadron calorimeter



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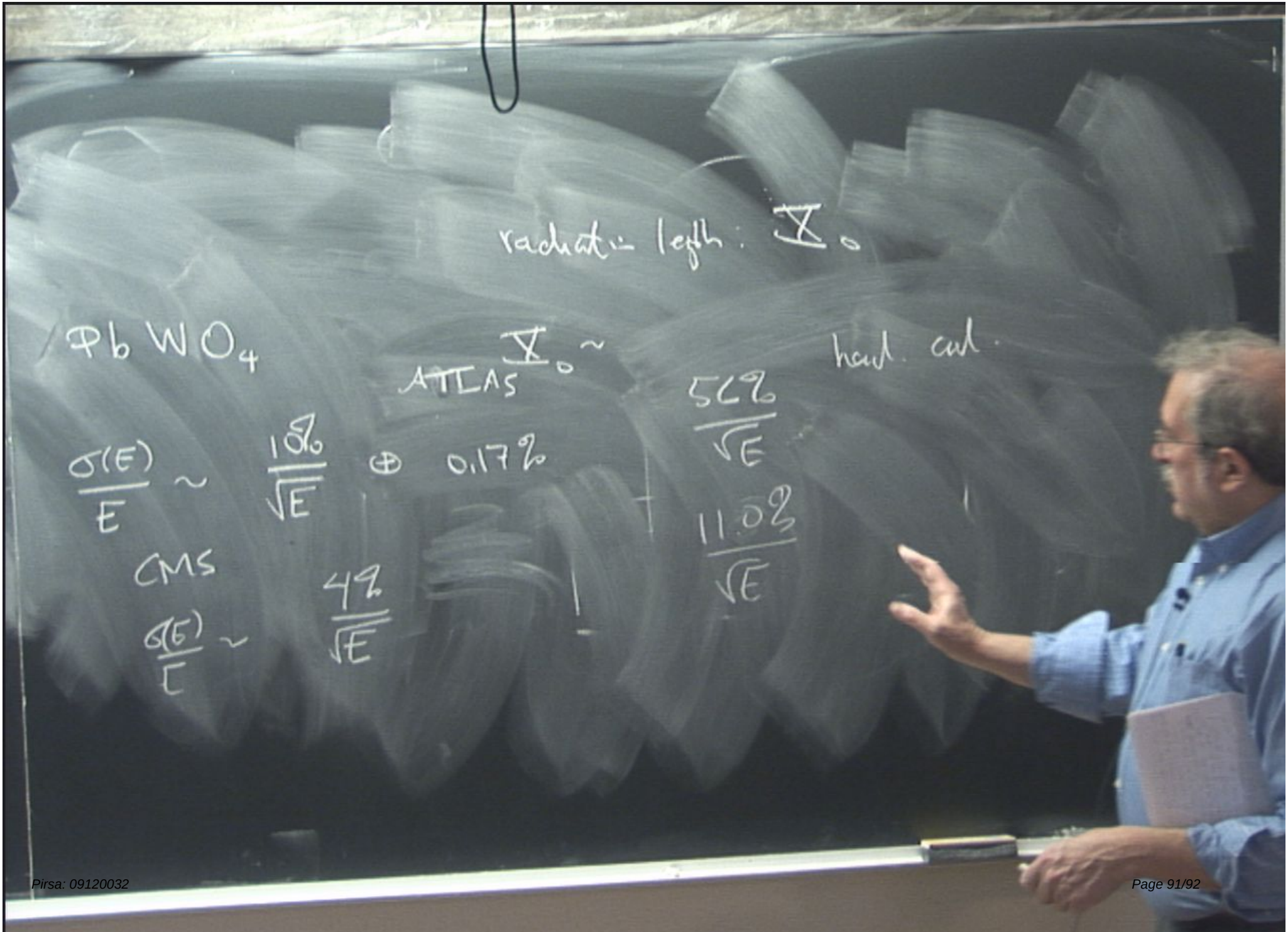
Pb W

$\frac{\sigma(E)}{E} \sim$

CMS

$\frac{\sigma(E)}{L}$


radiat. legth: X_0
$PbWO_4$
$X_0 \sim$
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CMS
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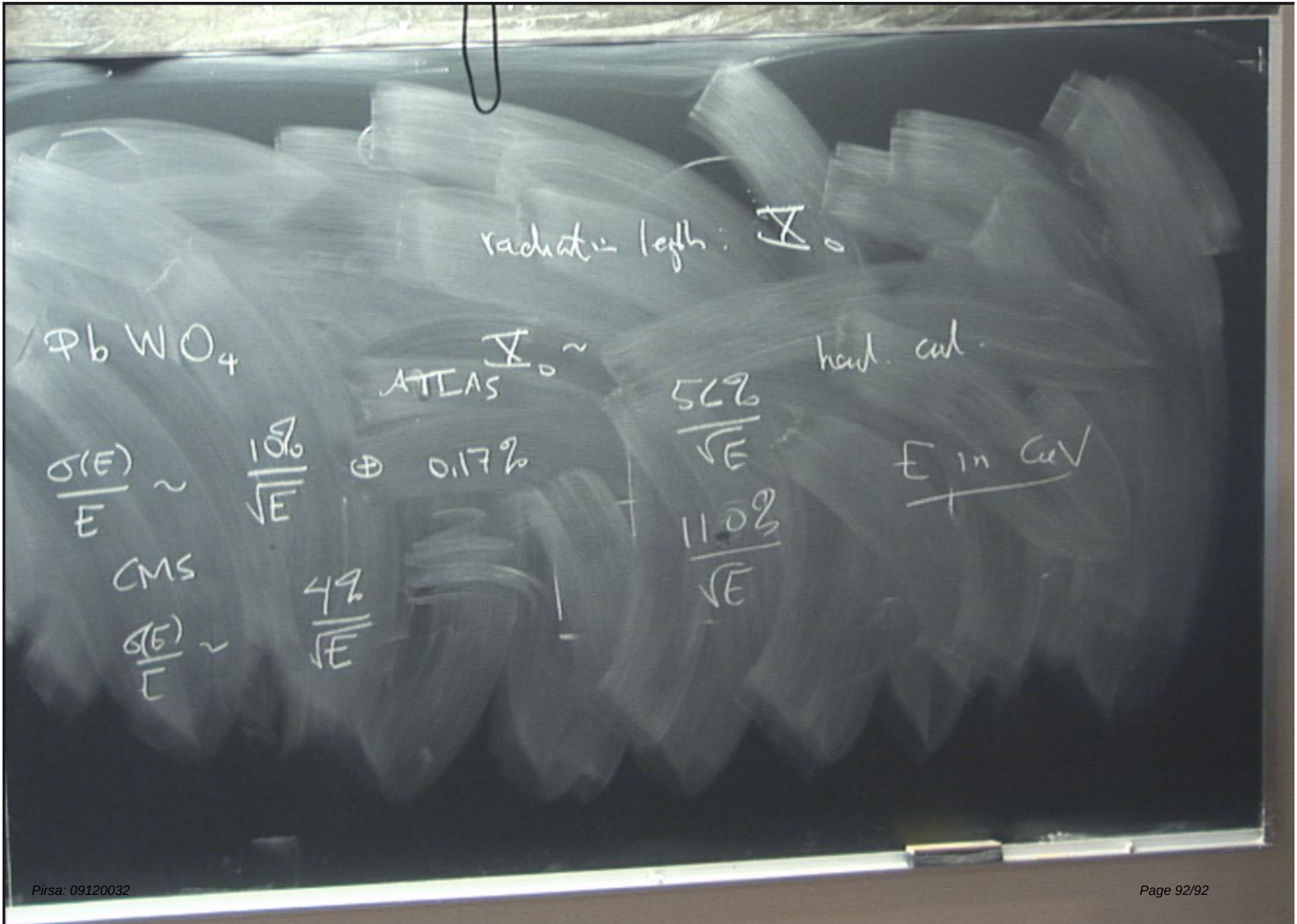
hadr. cal.
$\frac{50\%}{\sqrt{E}}$
$\frac{11.0\%}{\sqrt{E}}$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had. cal.
$\frac{50\%}{\sqrt{E}}$
$\frac{110\%}{\sqrt{E}}$
E in GeV