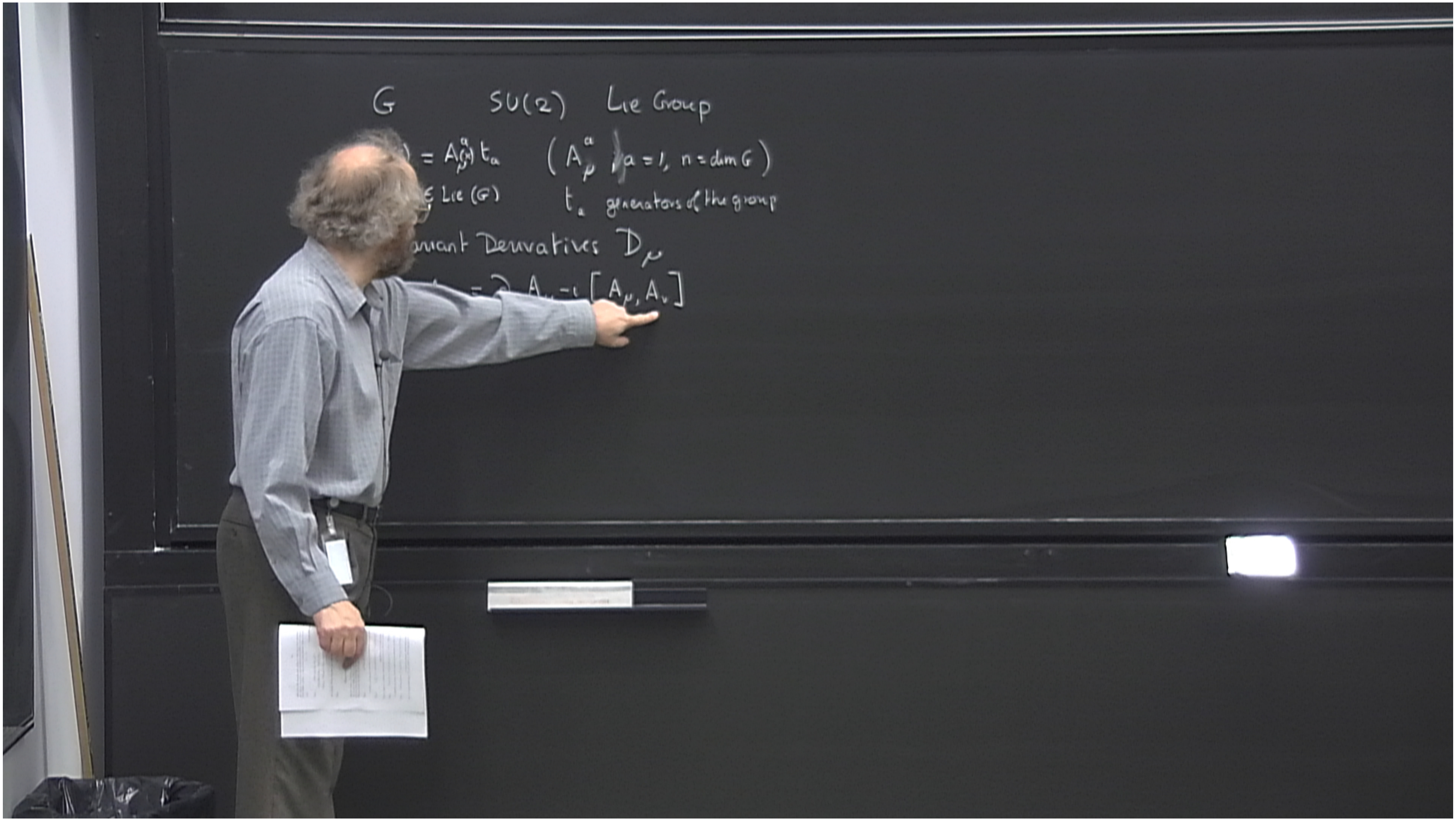
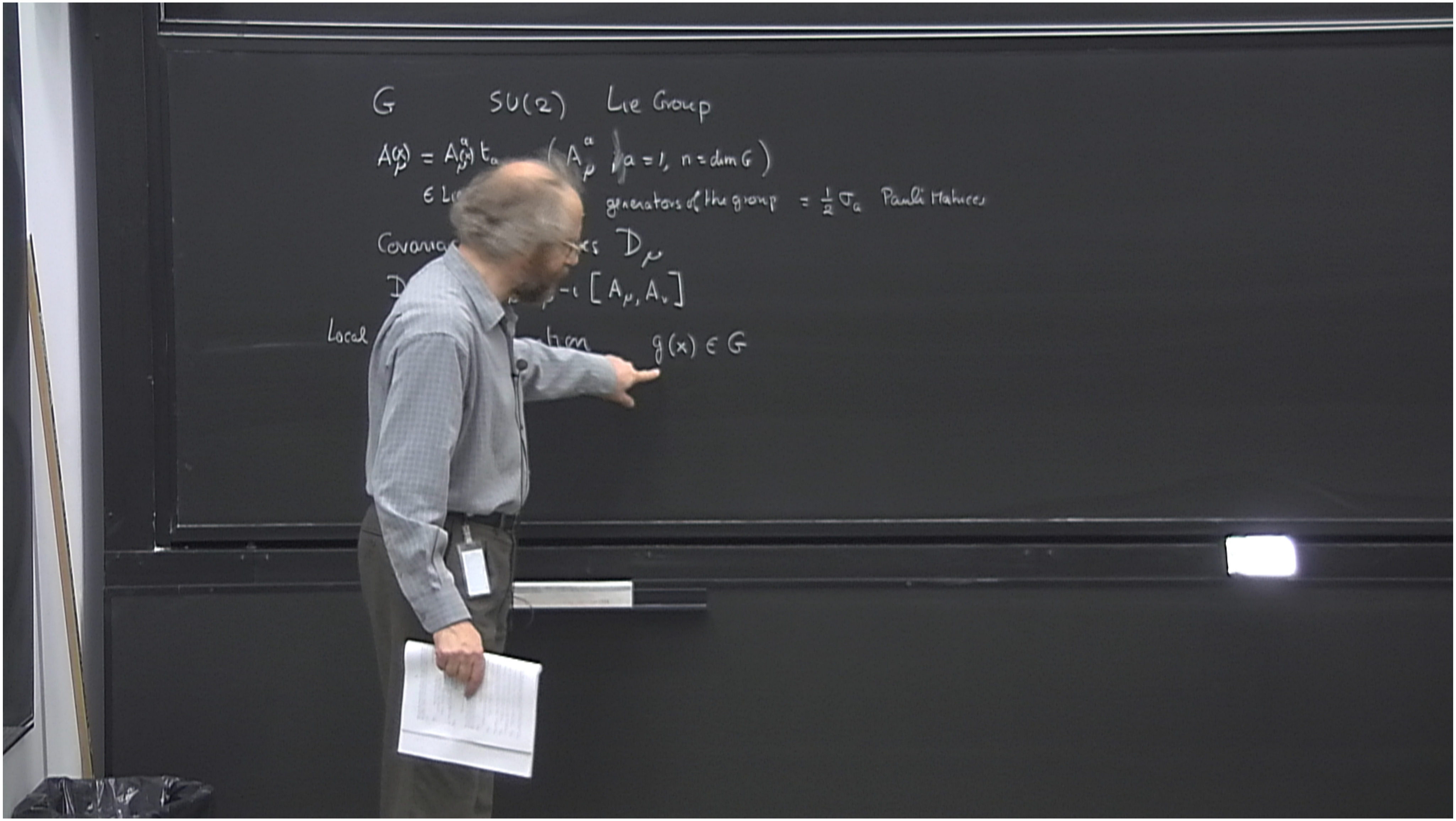
Title: Quantum Field Theory II - Lecture 13

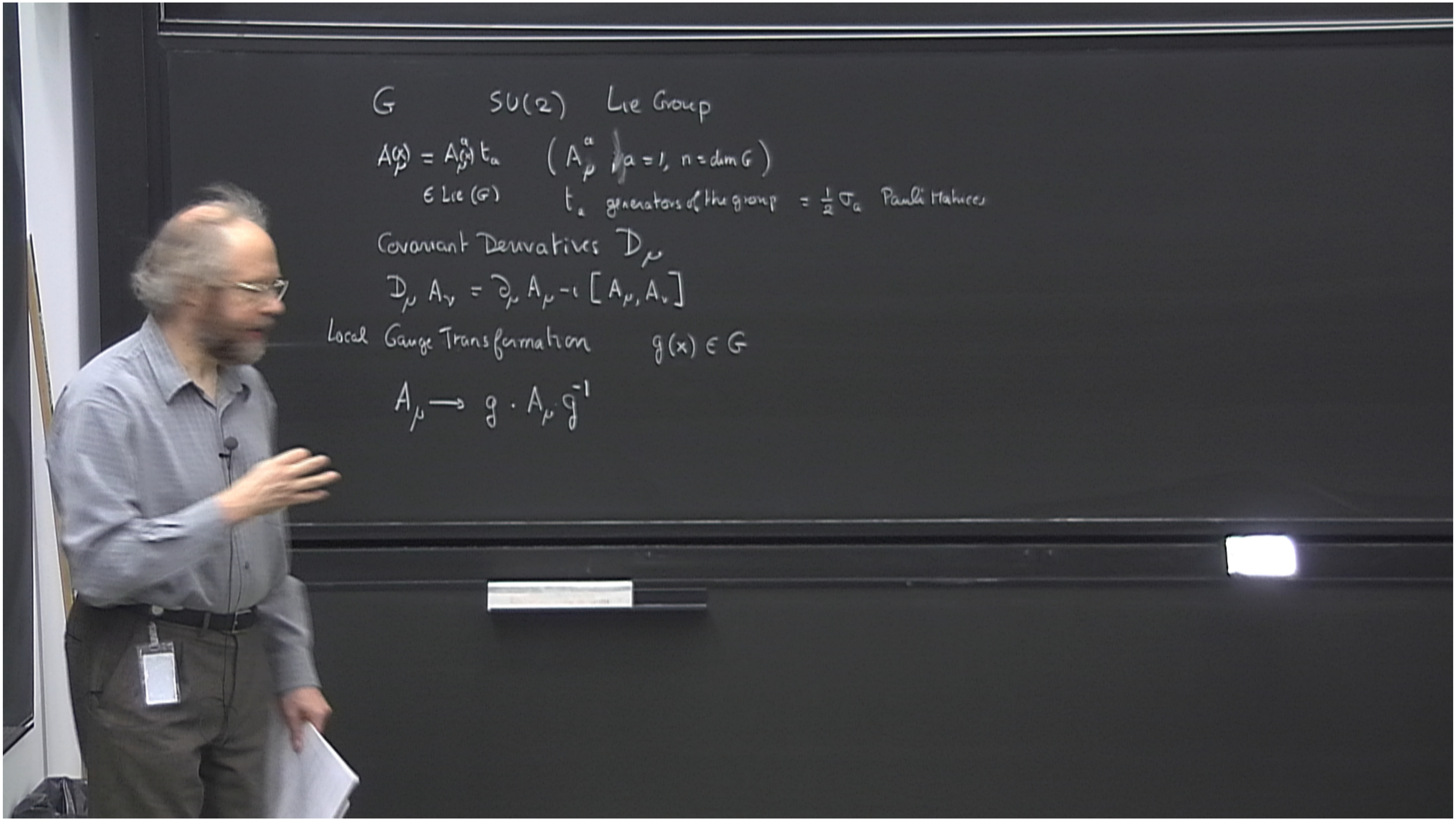
Date: Nov 16, 2011 09:00 AM

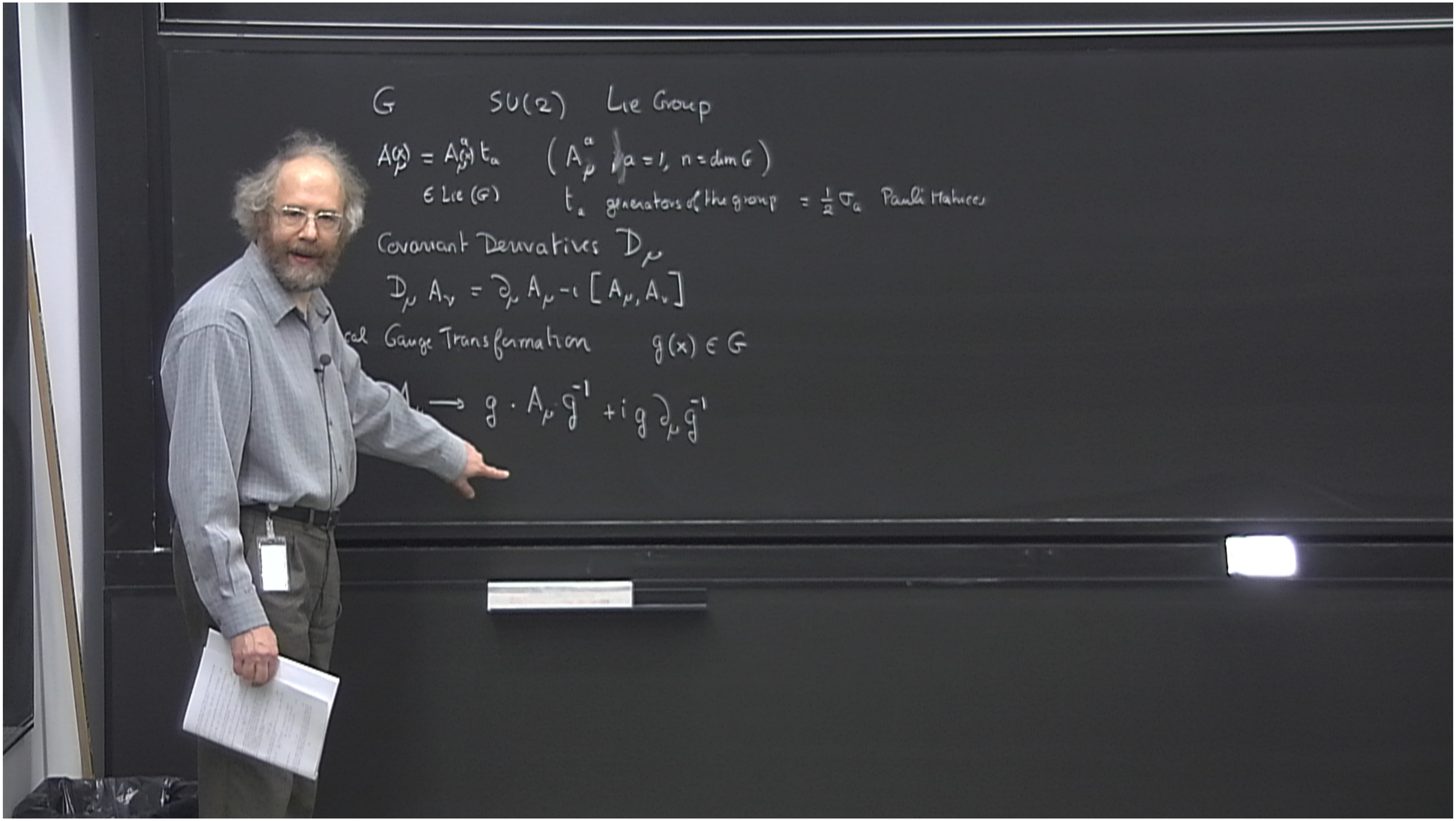
URL: http://pirsa.org/11110019

Abstract:


G SU(2) Lie Group
= A t
a = 1, n = dim G
Lie (G)
generators of the group
Derivatives D
[A, A]


G SU(2) Lie Group
A(x) = A^a(x) t_a (A^a_μ a = 1, n = dim G)
generators of the group = 1/2 σ_a Pauli Matrices
D_μ
[A_μ, A_ν]
Local
g(x) ∈ G


G SU(2) Lie Group
$A_\mu(x) = A^a_\mu(x)\, t_a$ (A^a_μ , a = 1, n = dim G)
∈ Lie (G) t_a generators of the group = $\frac{1}{2}\sigma_a$ Pauli Matrices
Covariant Derivatives D_μ
$D_\mu A_\nu = \partial_\mu A_\mu - i\,[A_\mu, A_\nu]$
Local Gauge Transformation $g(x) \in G$
$A_\mu \longrightarrow g \cdot A_\mu \cdot g^{-1}$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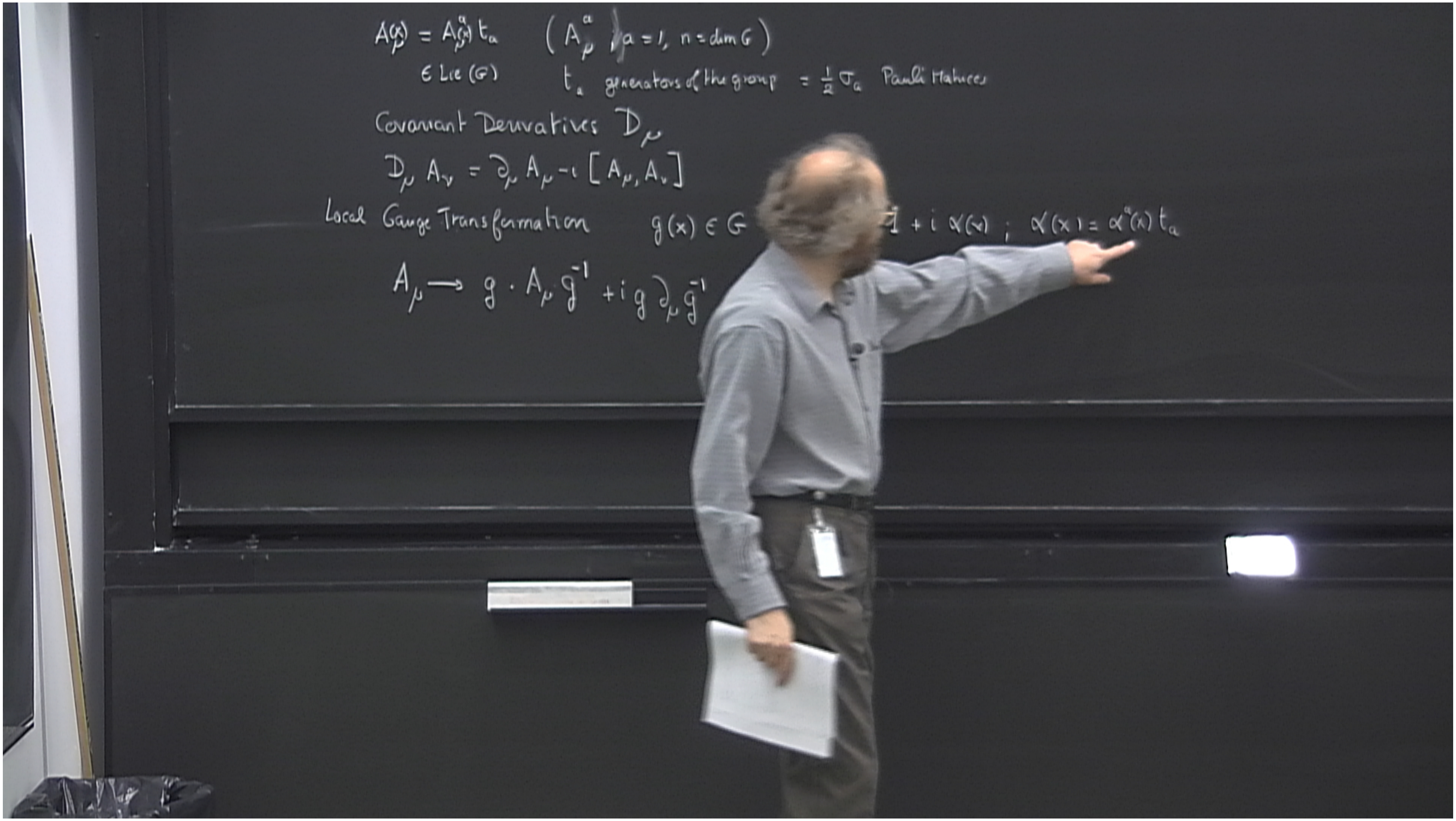
$A_\mu \longrightarrow g \cdot A_\mu \cdot g^{-1} + i\, g\, \partial_\mu g^{-1}$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D_μ A_ν = ∂_μ A_ν − i [A_μ, A_ν]
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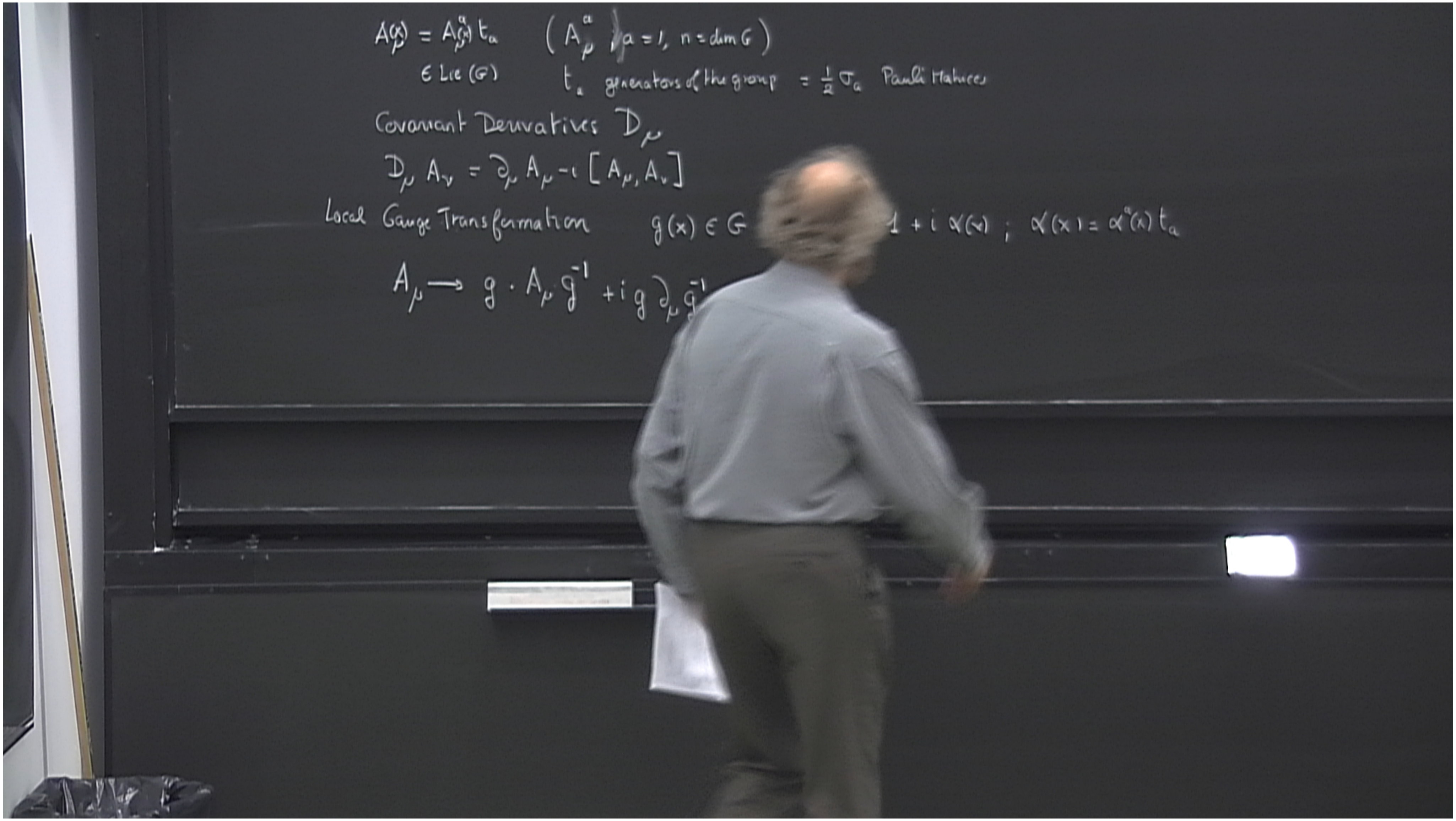
+ i α(x) ; α(x) = α^a(x) t_a
A_μ ⟶ g · A_μ g^-1 + i g ∂_μ g^-1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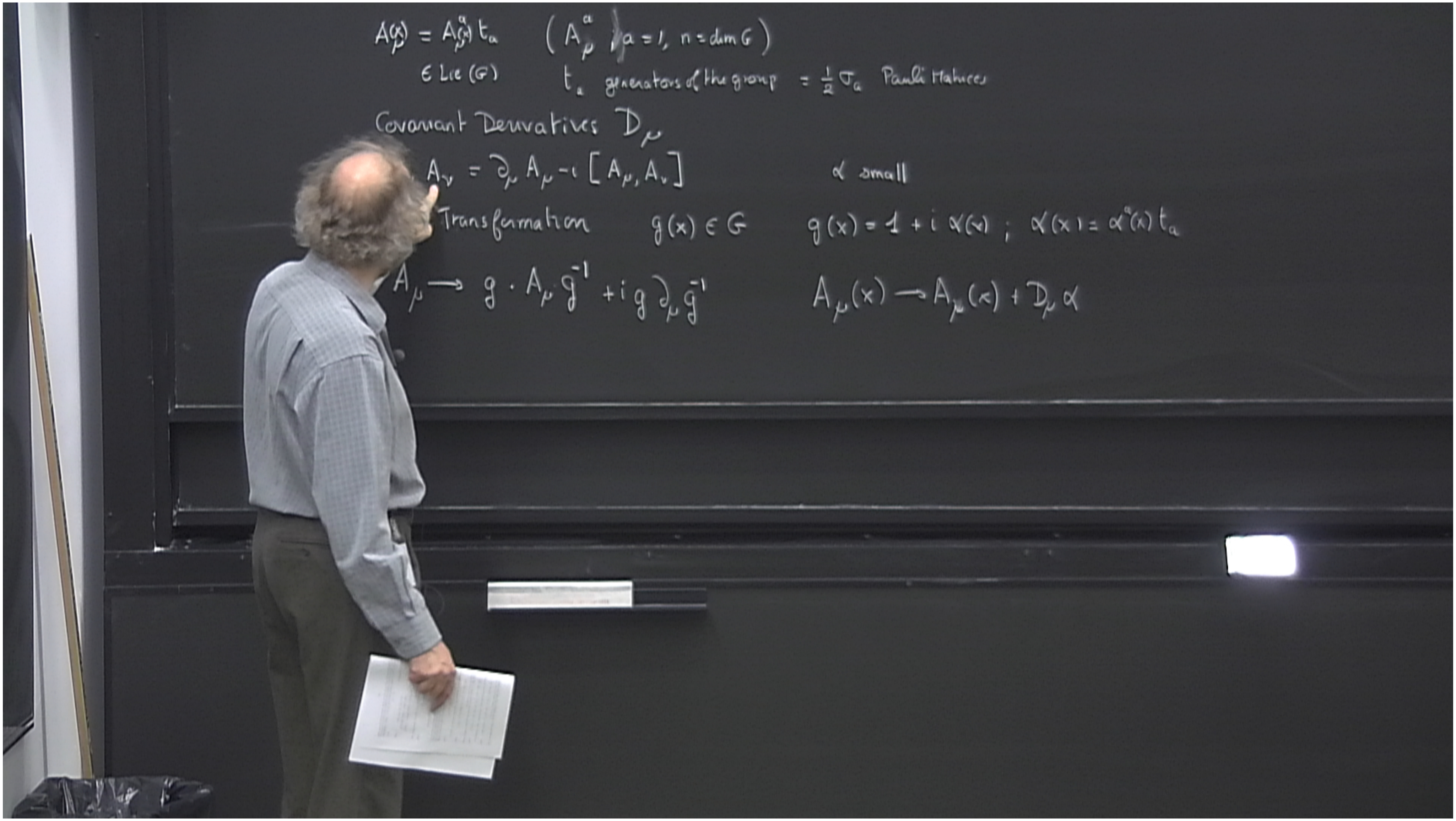
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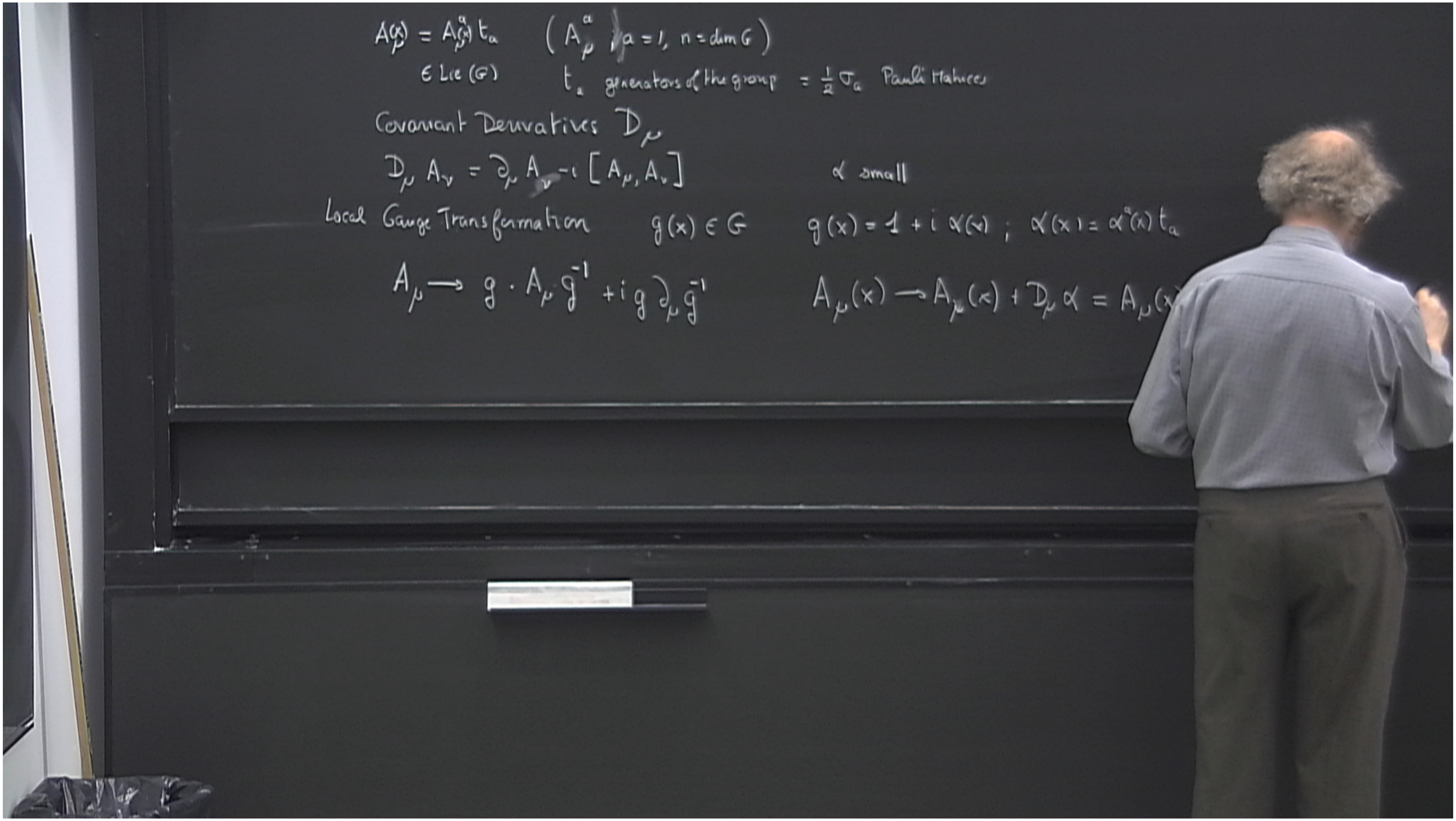
Covariant Derivatives D_μ
A_ν = ∂_μ A_ν − i [A_μ, A_ν]
α small
Transformation g(x) ∈ G
g(x) = 1 + i α(x) ; α(x) = α^a(x) t_a
A_μ → g · A_μ g^-1 + i g ∂_μ g^-1
A_μ(x) → A_μ(x) + D_μ α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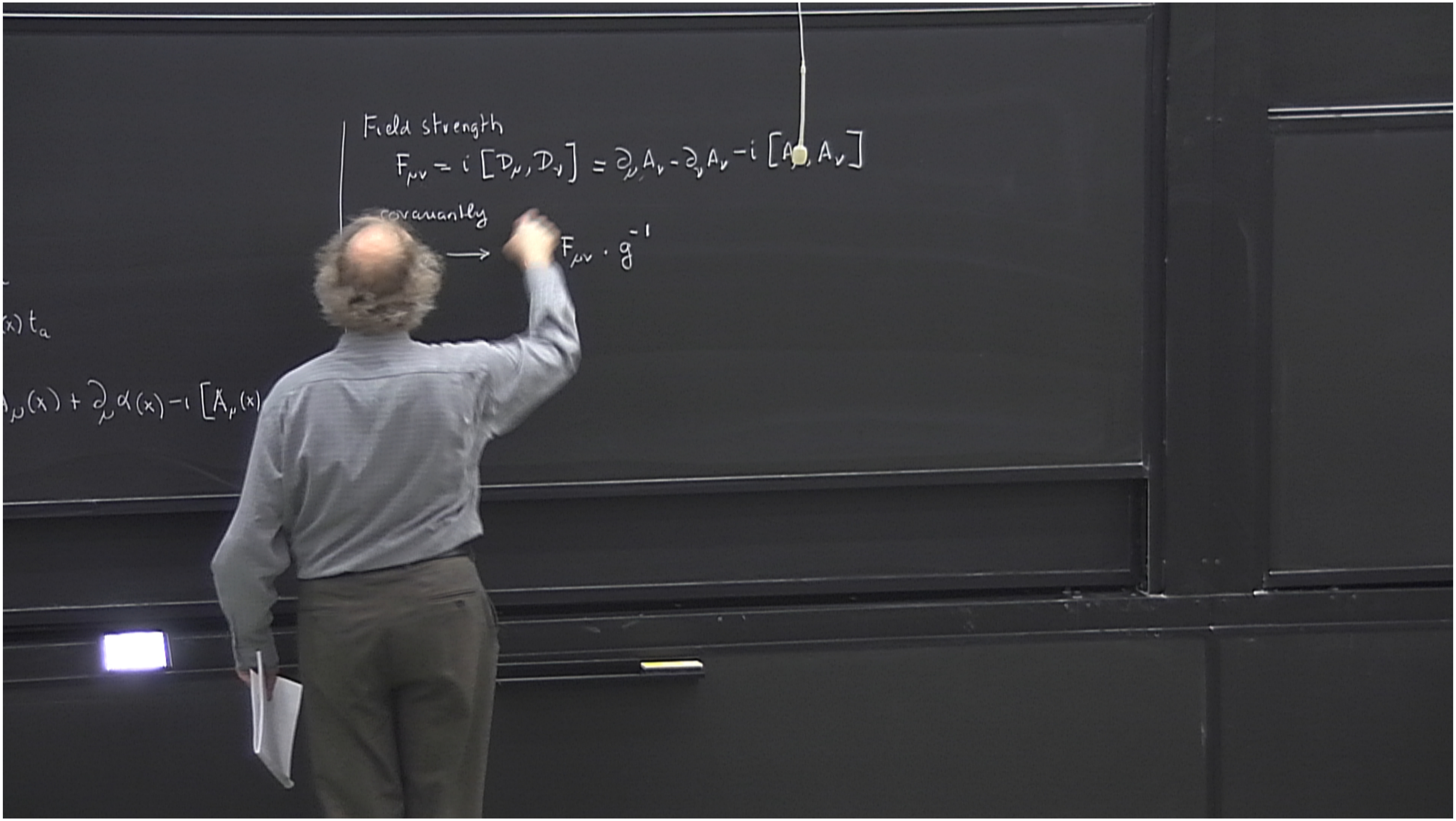
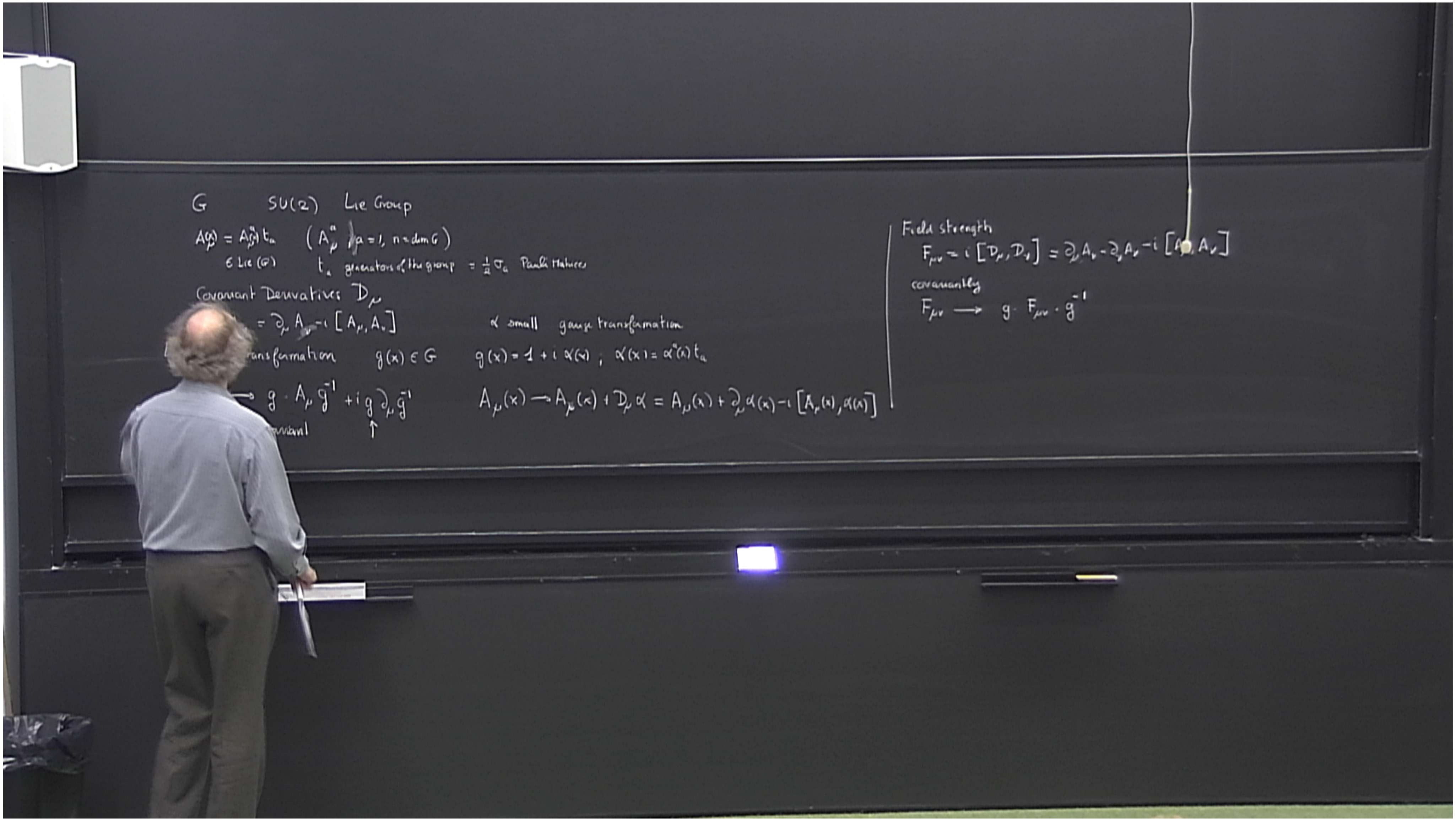
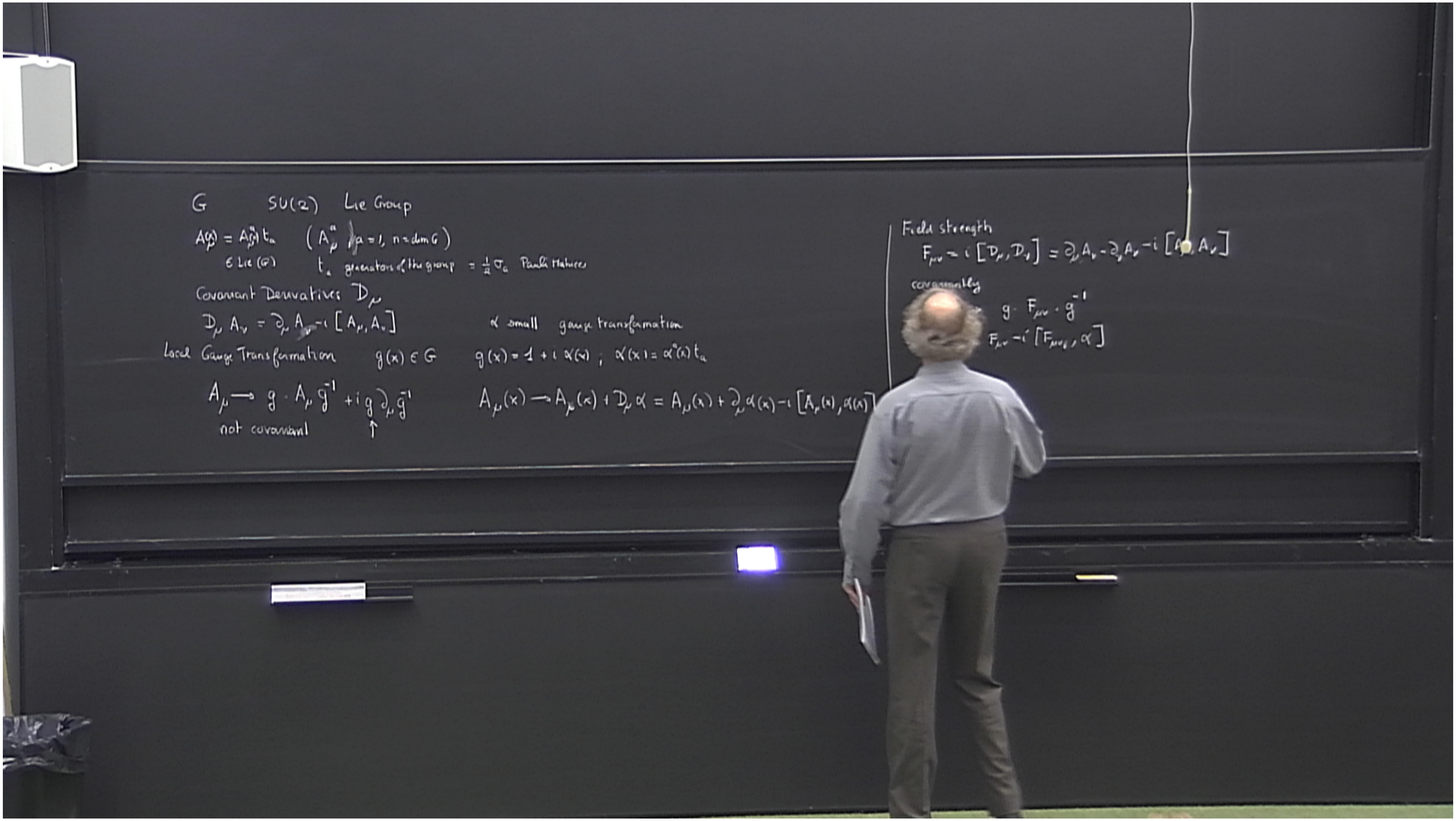
α small
Local Gauge Transformation $g(x) \in G$ $g(x) = 1 + i\,\alpha(x)$; $\alpha(x) = \alpha^a(x)\, t_a$
$A_\mu \longrightarrow g \cdot A_\mu\, g^{-1} + i\, g\, \partial_\mu g^{-1}$
$A_\mu(x) \longrightarrow A_\mu(x) + D_\mu \alpha = A_\mu(x$


Field strength
F_{μν} = i [D_μ, D_ν] = ∂_μ A_ν - ∂_ν A_μ - i [A_μ, A_ν]
covariantly
F_{μν} · g^{-1}
(x) t_a
A_μ(x) + ∂_μ α(x) - i [A_μ(x)


G SU(2) Lie Group
∈ Lie (G)
generators of the group
Pauli Matrices
Covariant Derivatives
α small gauge transformation
g(x) ∈ G
Field strength
covariantly


G SU(2) Lie Group
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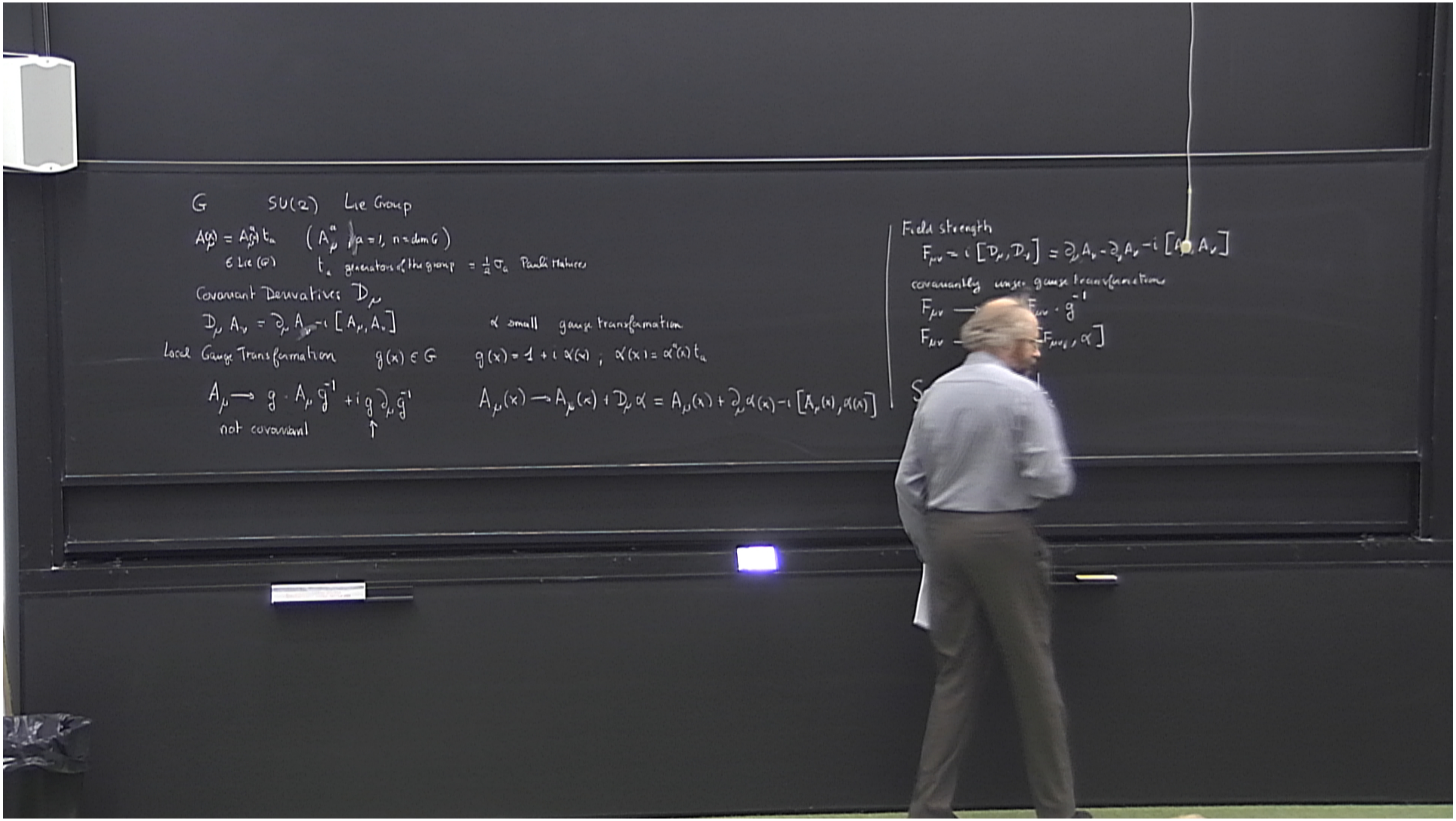
Pauli Matrices
Covariant Derivative: D_μ
α small gauge transformation
Local Gauge Transformation g(x) ∈ G
g(x) = 1 + i α(x) ; α(x) = α^a(x) t_a
not covariant
Field strength
covariantly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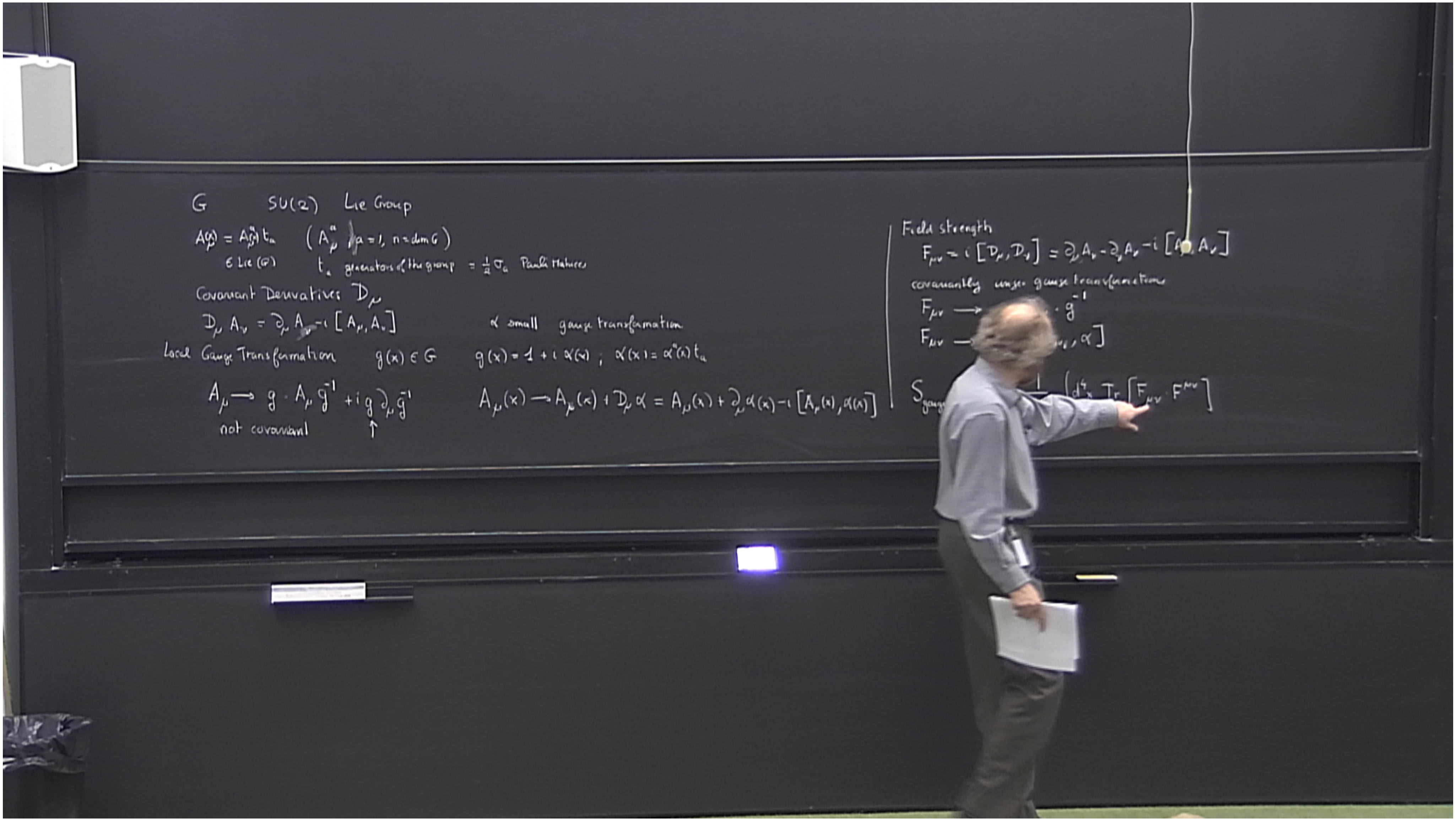
not covariant
Field strength
covariantly under gauge transformations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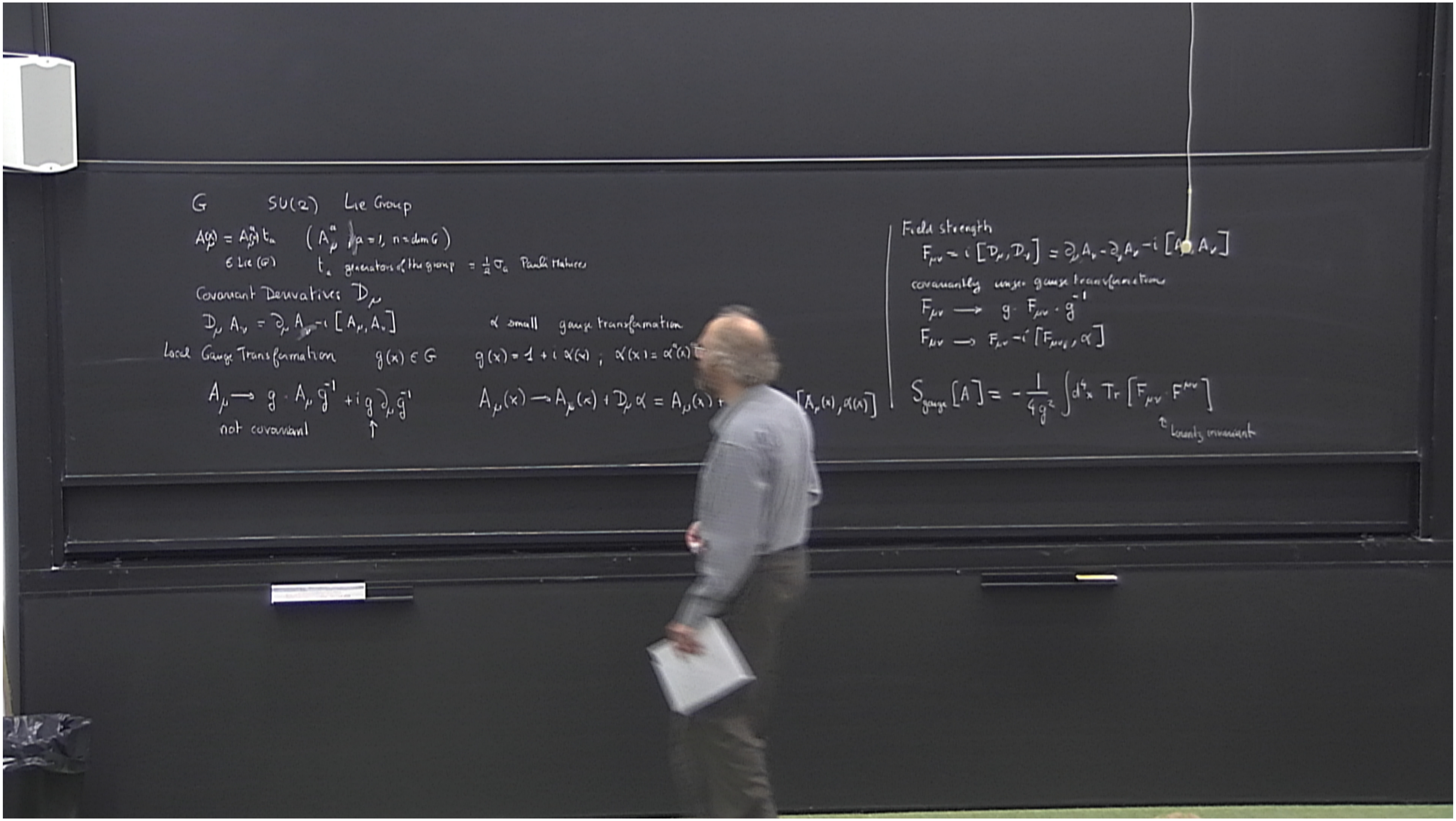
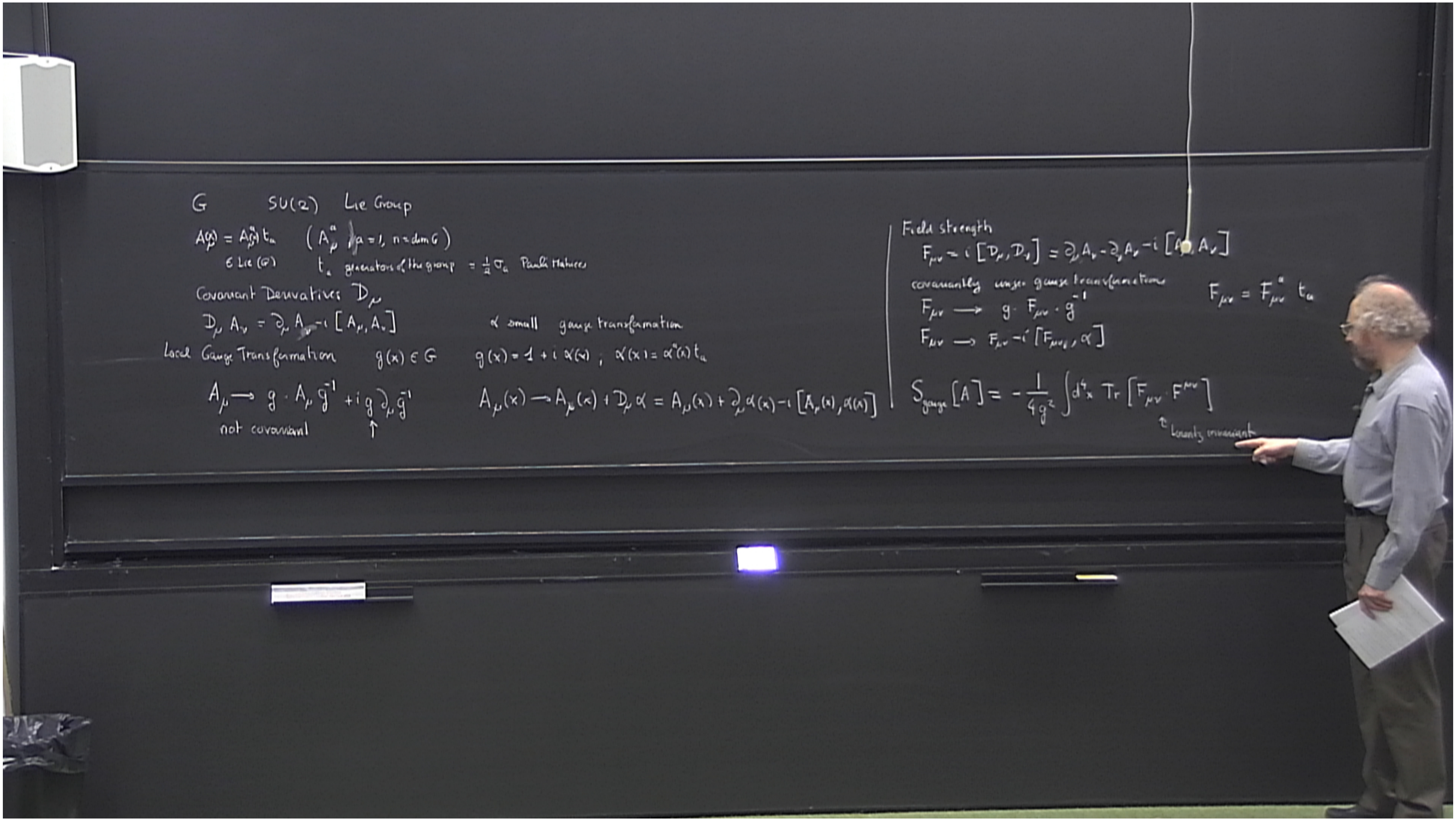
not covariant
A_μ(x) ⟶ A_μ(x) + D_μ α = A_μ(x) + ∂_μ α(x) − i [A_μ(x), α(x)]
Field strength
F_μν = i [D_μ, D_ν] = ∂_μ A_ν − ∂_ν A_μ − i [A_μ, A_ν]
covariantly under gauge transformations
F_μν ⟶
F_μν ⟶
S
d^4x Tr [F_μν · F^μν]


G SU(2) Lie Group
Covariant Derivative: D
Local Gauge Transformation
not covariant
α small gauge transformation
Field strength
covariantly under gauge transformations
Lorentz invariant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A_μ → g · A_μ g^-1 + i g ∂_μ g^-1
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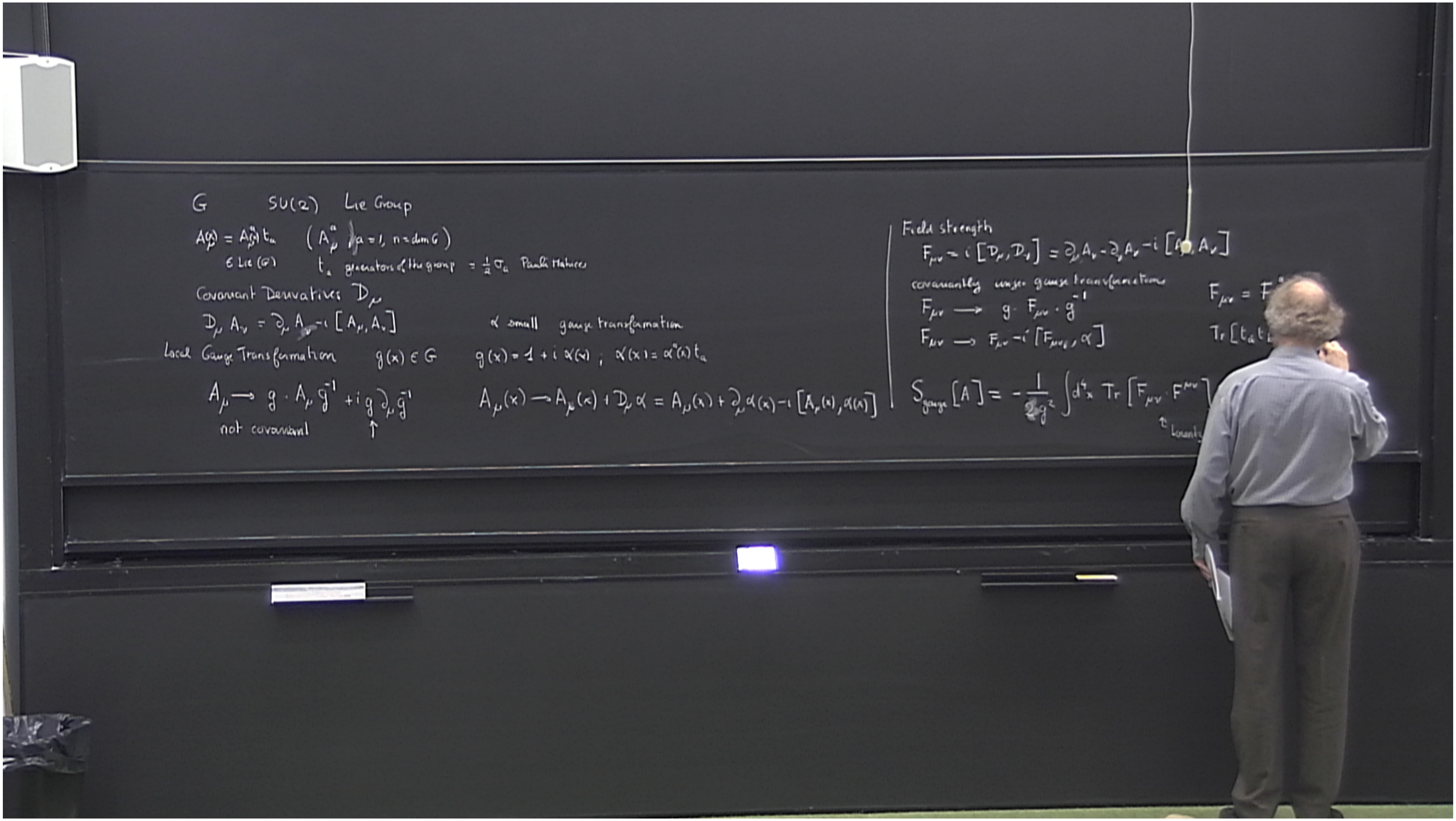
A_μ(x) → A_μ(x) + D_μ α = A_μ(x) + ∂_μ α(x) − i [A_μ(x), α(x)]
Field strength
F_μν = i [D_μ, D_ν] = ∂_μ A_ν − ∂_ν A_μ − i [A_μ, A_ν]
covariantly under gauge transformations
F_μν = F^a_μν t_a
F_μν → g · F_μν · g^-1
F_μν → F_μν − i [F_μν, α]
S_gauge [A] = − 1/(4g²) ∫ d⁴x Tr [F_μν F^μν]
Lorentz invariant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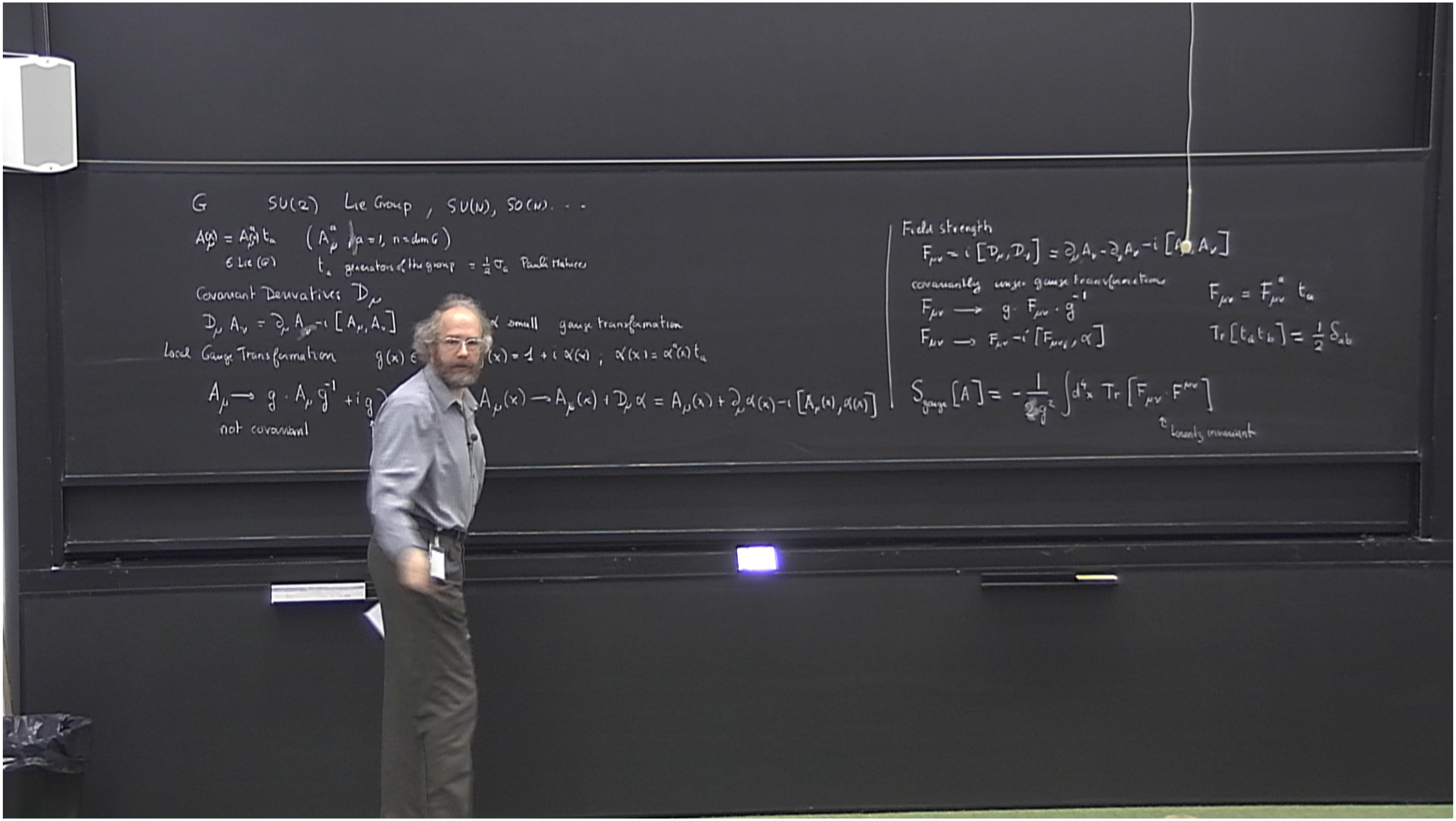
Field strength
F_μν = i [D_μ, D_ν] = ∂_μ A_ν − ∂_ν A_μ − i [A_μ, A_ν]
covariantly under gauge transformations
F_μν → g · F_μν · g^{-1}
F_μν → F_μν − i [F_μν, α]
S_gauge [A] = − 1/(2g²) ∫ d⁴x Tr [F_μν · F^μν]
Lorentz
F_μν = F
Tr [t_a t


G SU(2) Lie Group , SU(N), SO(N) . . .
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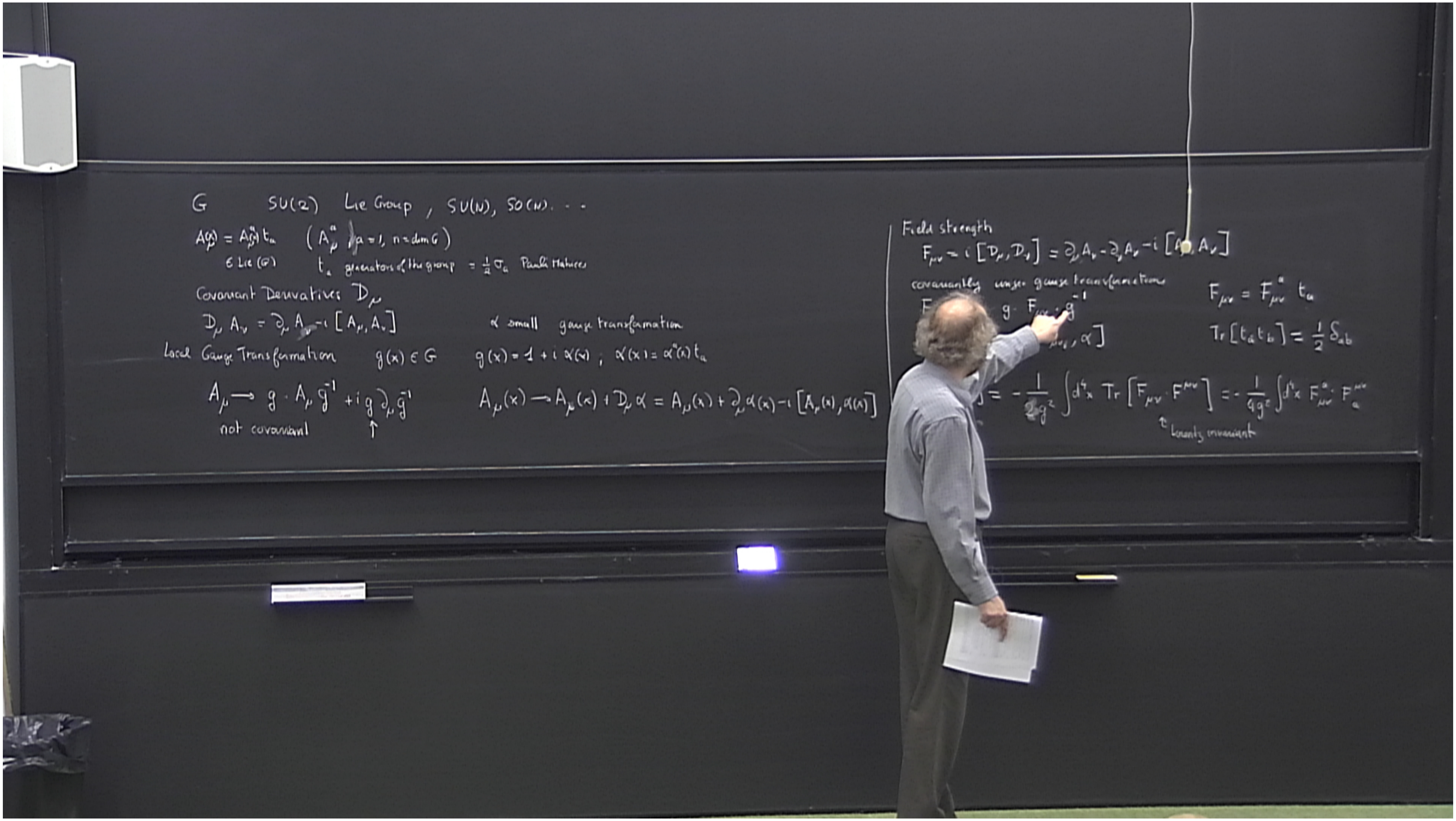
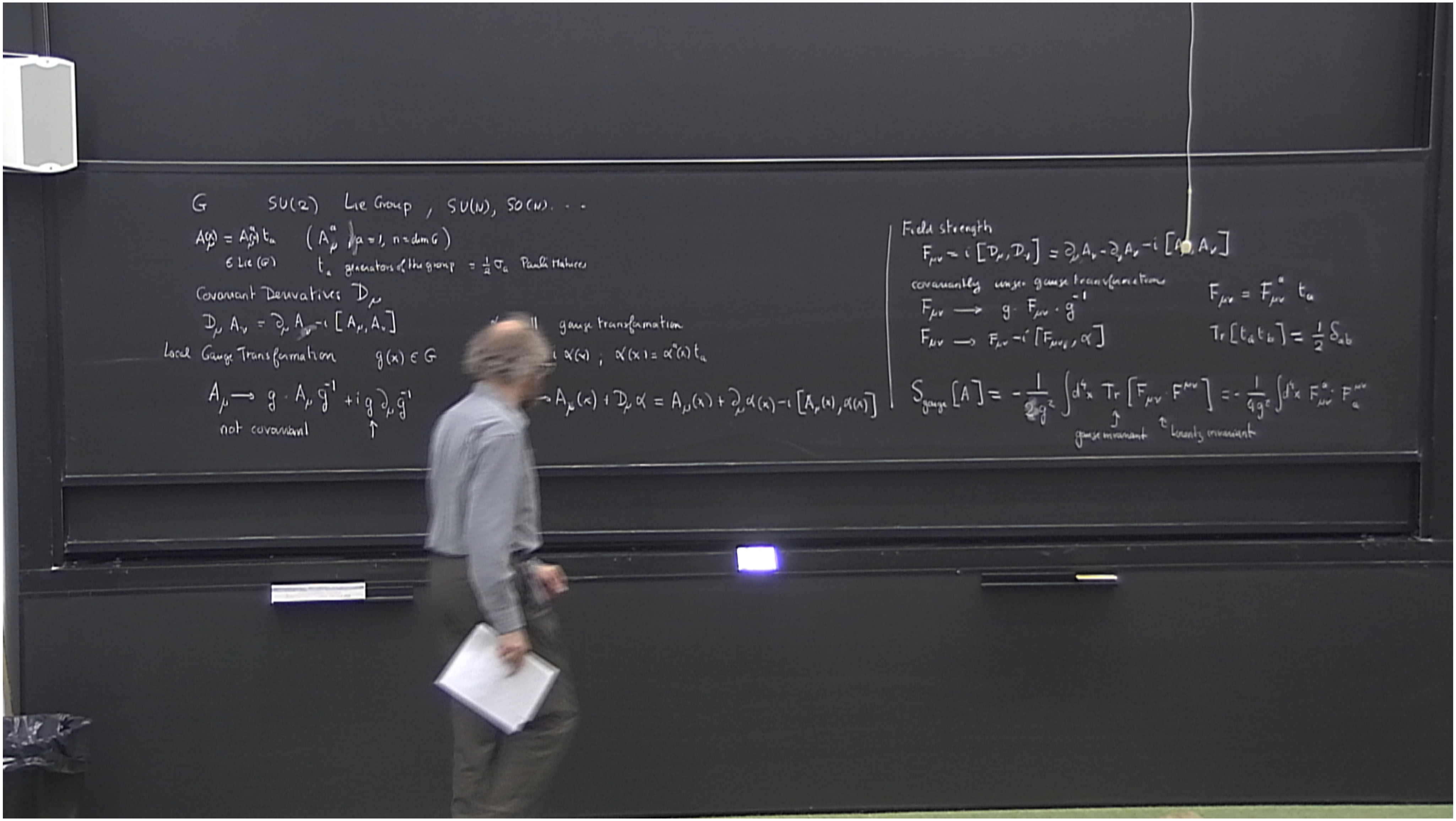
F_μν ⟶ g · F_μν · g^{-1}
F_μν ⟶ F_μν − i [F_μν, α]
F_μν = F^a_μν t_a
Tr [t_a t_b] = 1/2 δ_ab
S_gauge [A] = − 1/(2g²) ∫ d⁴x Tr [F_μν · F^μν]
Lorentz invariant


G SU(2) Lie Group , SU(N), SO(N). . .
Covariant Derivative: D_μ
α small gauge transformation
Local Gauge Transformation g(x) ∈ G
not covariant
Field strength
covariantly under gauge transformations
Lorentz invariant



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covariantly under gauge transformations
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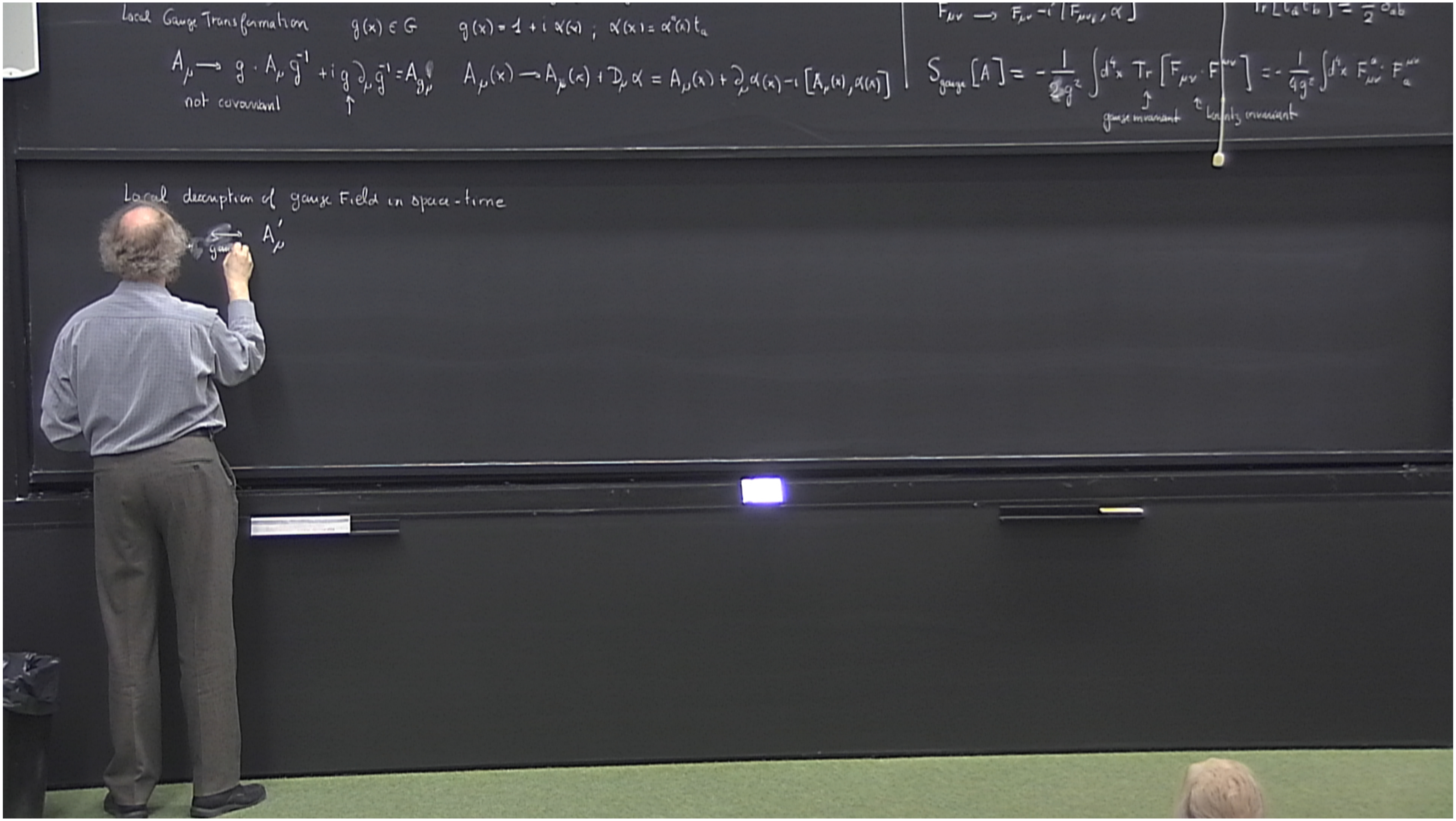
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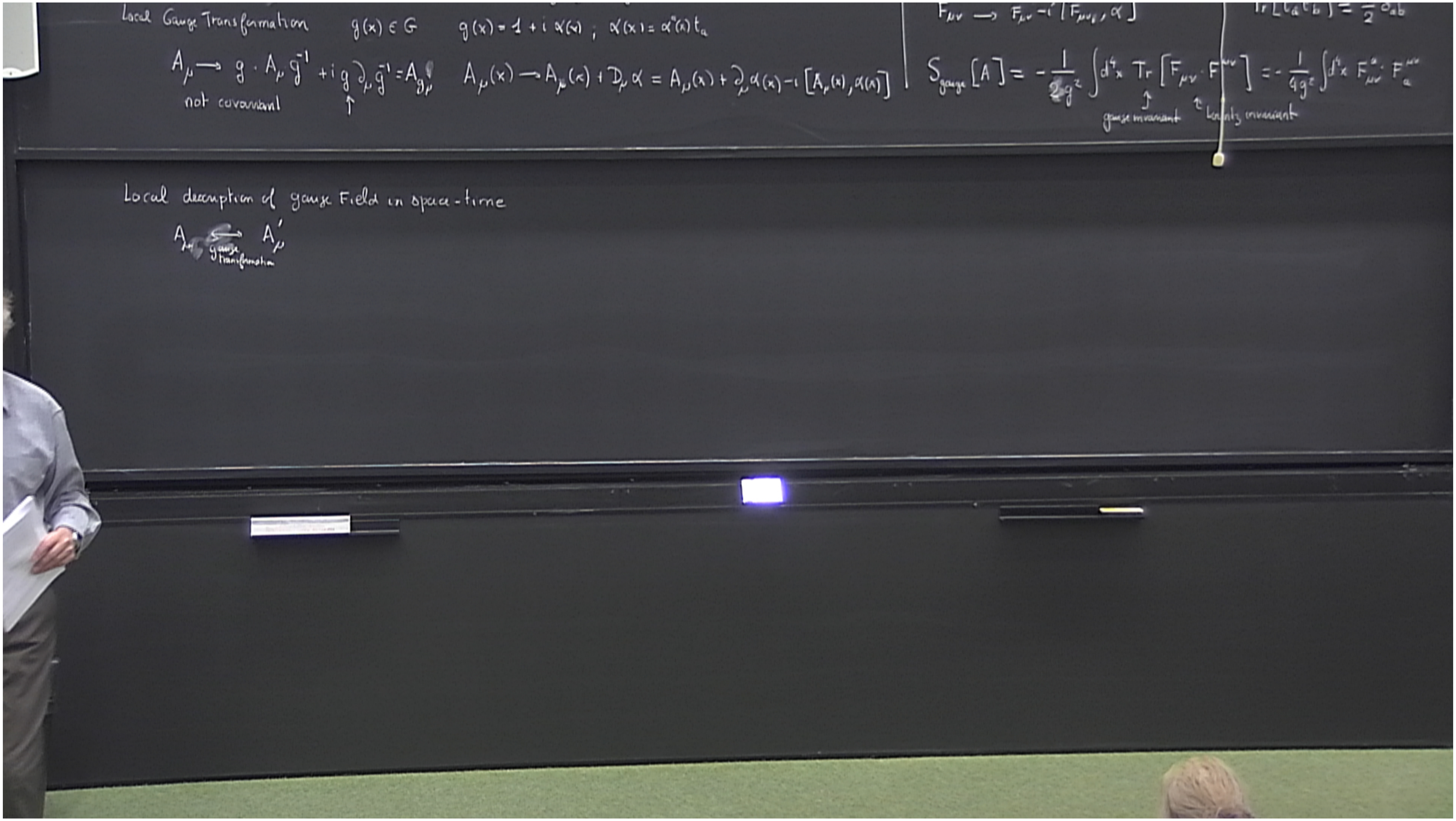
A_μ(x) → A_μ(x) + D_μ α = A_μ(x) + ∂_μ α(x) − i [A_μ(x), α(x)]
not covariant
F_μν → F_μν − i [F_μν, α]
Tr [t_a t_b] = 1/2 δ_ab
S_gauge [A] = − 1/2g² ∫ d^4x Tr [F_μν · F^μν] = − 1/4g² ∫ d^4x F^a_μν · F_a^μν
gauge invariant
Lorentz invariant
Local description of gauge Field in space-time
A'_μ


Local Gauge Transformation
g(x) ∈ G
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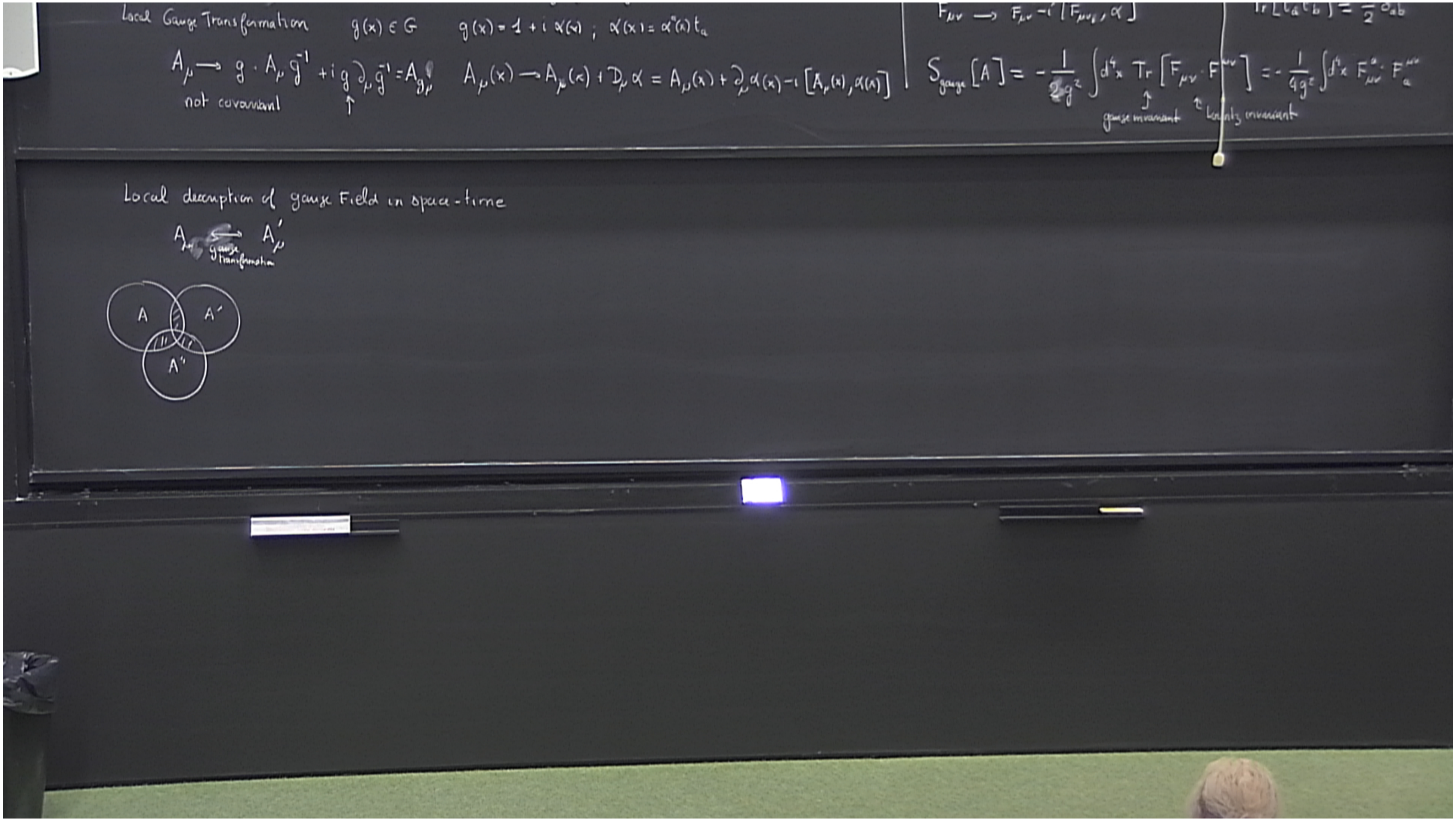
not covariant
gauge invariant
Lorentz invariant
Local description of gauge Field in space-time
gauge transformation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g(x) ∈ G
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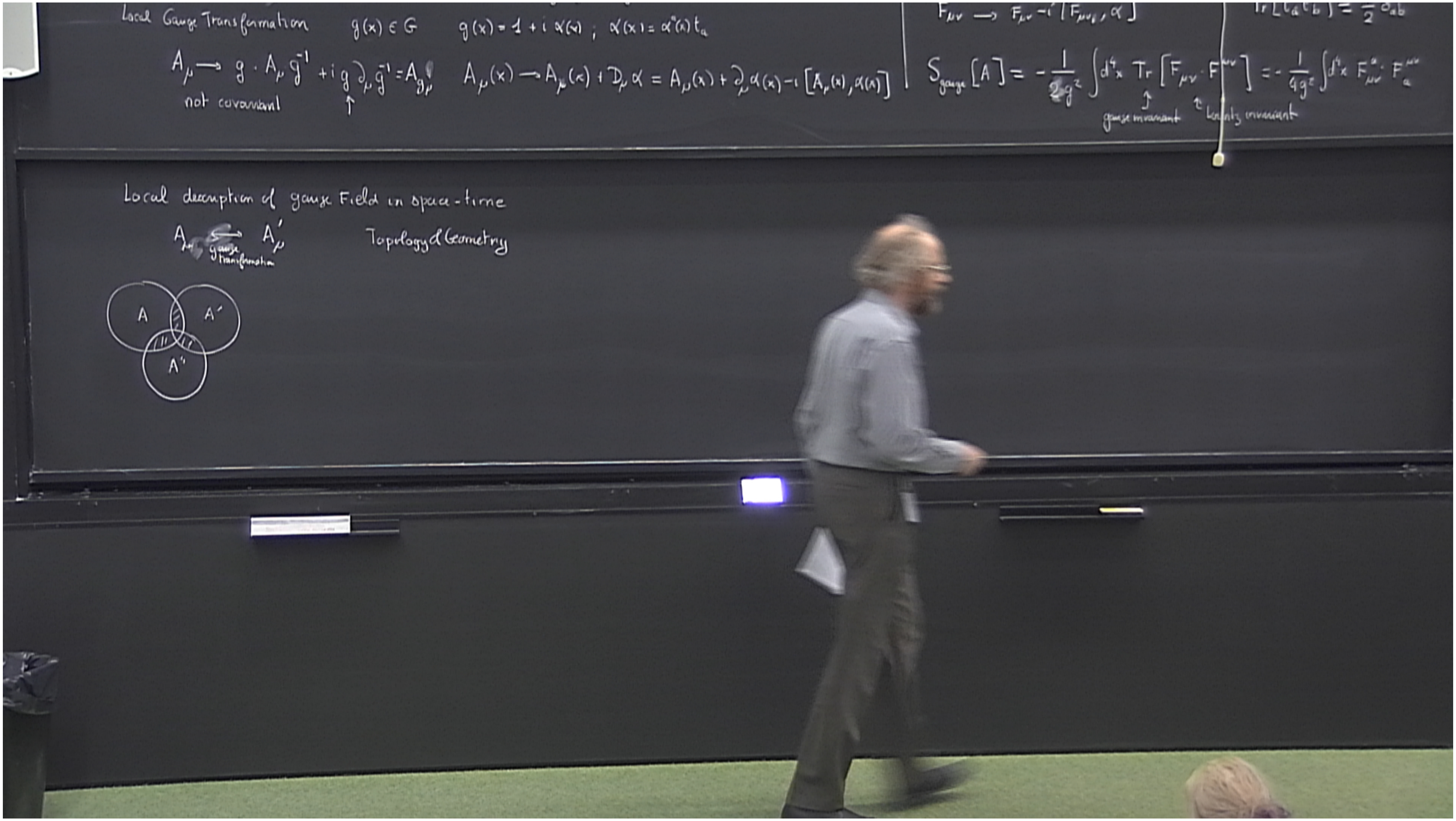
A_μ → g · A_μ g^-1 + i g ∂_μ g^-1 = A_μ^g
not covariant
A_μ(x) → A_μ(x) + D_μ α = A_μ(x) + ∂_μ α(x) − i [A_μ(x), α(x)]
F_μν → F_μν − i [F_μν, α]
Tr [t_a t_b] = 1/2 δ_ab
S_gauge [A] = − 1/(2g²) ∫d⁴x Tr [F_μν · F^μν] = − 1/(4g²) ∫d⁴x F^a_μν F_a^μν
gauge invariant
Lorentz invariant
Local description of gauge Field in space-time
A_μ → A'_μ
gauge transformation
A
A'
A''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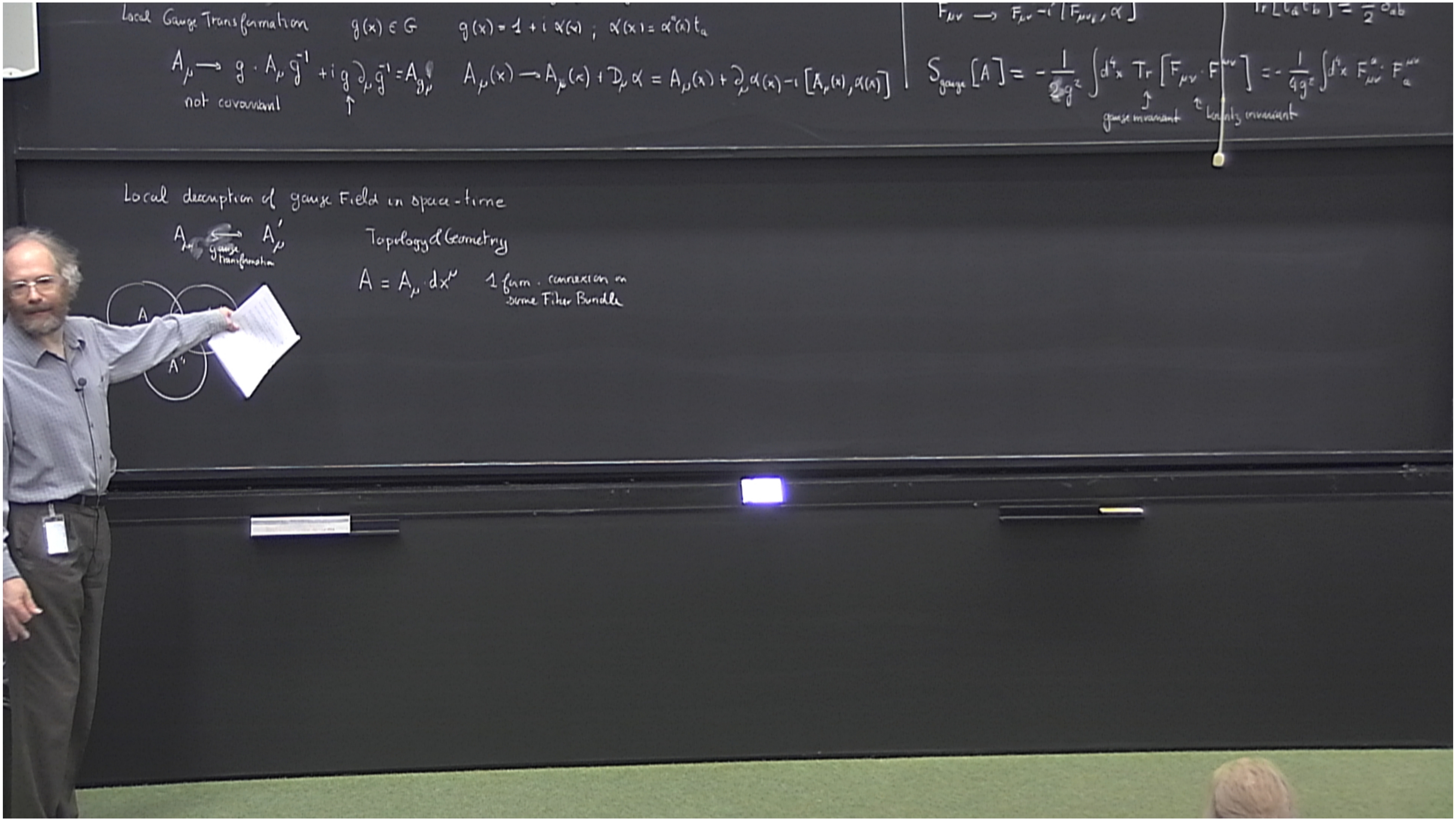
g(x) = 1 + i α(x) ; α(x) = α^a(x) t_a
not covariant
gauge invariant
Lorentz invariant
Local description of gauge Field in space-time
gauge transformation
Topology of Geometry
A
A'
A''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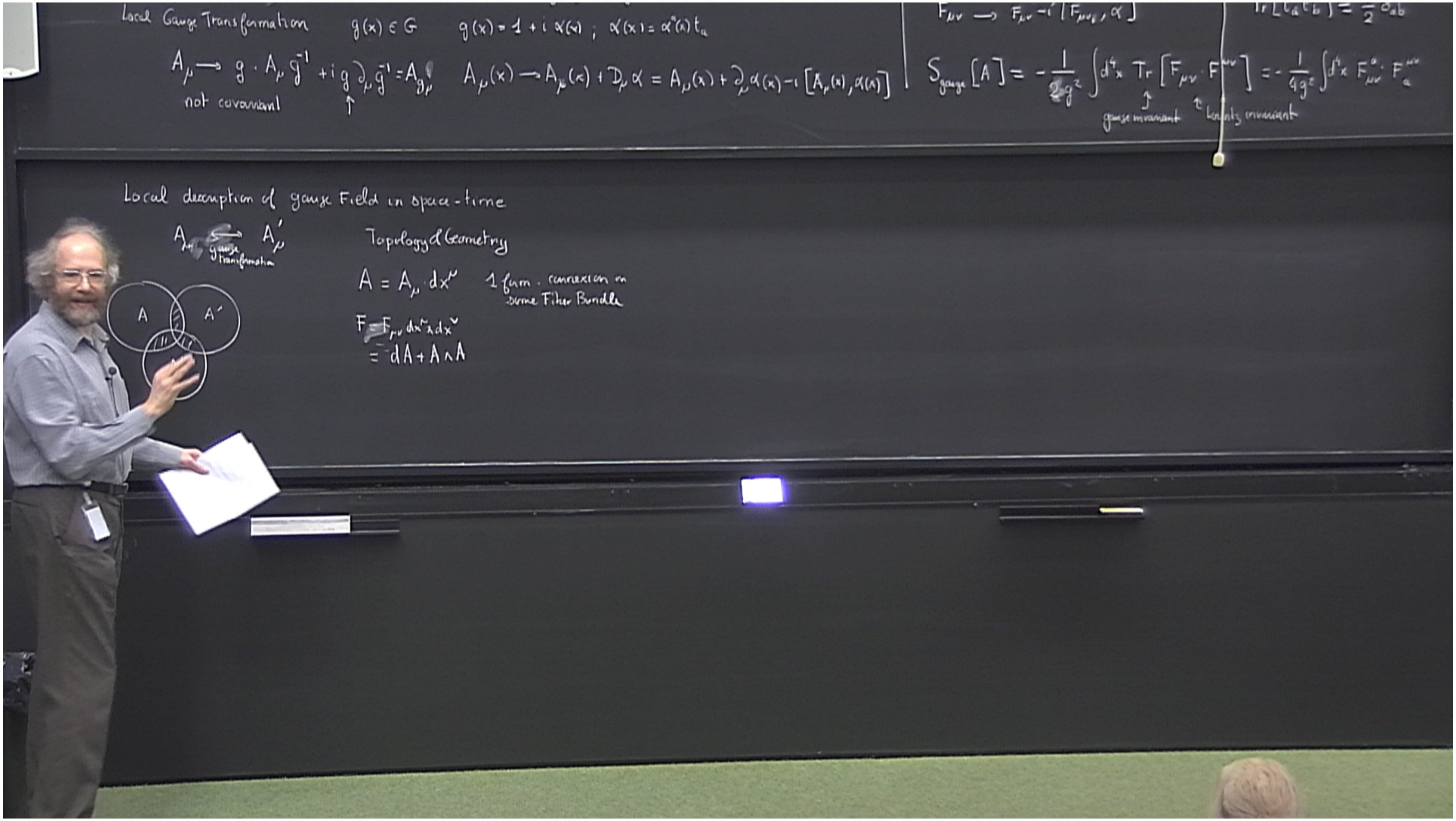
not covariant
$A_\mu(x) \to A_\mu(x) + D_\mu \alpha = A_\mu(x) + \partial_\mu \alpha(x) - i\,[A_\mu(x), \alpha(x)]$
$F_{\mu\nu} \to F_{\mu\nu} - i\,[F_{\mu\nu}, \alpha]$
$S_{gauge}[A] = -\frac{1}{2g^2}\int d^4x\, Tr\,[F_{\mu\nu} \cdot F^{\mu\nu}] = -\frac{1}{4g^2}\int d^4x\, F^a_{\mu\nu} F_a^{\mu\nu}$
gauge invariant
Lorentz invariant
Local description of gauge Field in space-time
$A_\mu \to A'_\mu$
gauge transformation
Topology & Geometry
$A = A_\mu\, dx^\mu$ 1 form · connexion on some Fiber Bundle
A
A'



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not covariant
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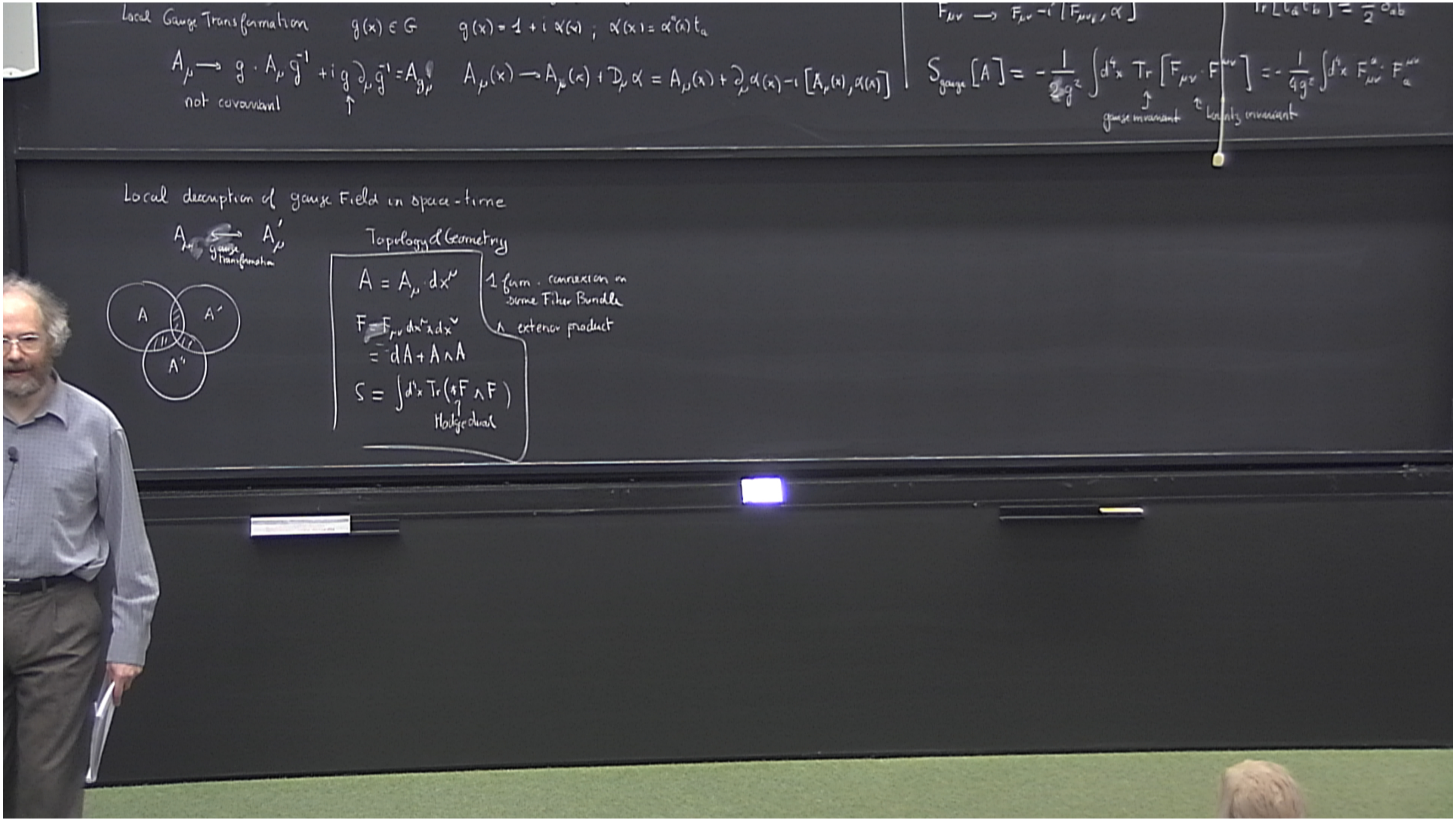
Local description of gauge Field in space-time
gauge transformation
Topology & Geometry
A = A_μ dx^μ
1 form . connexion on some Fiber Bundle
F = F_μν dx^μ ∧ dx^ν
= dA + A ∧ A
A
A'



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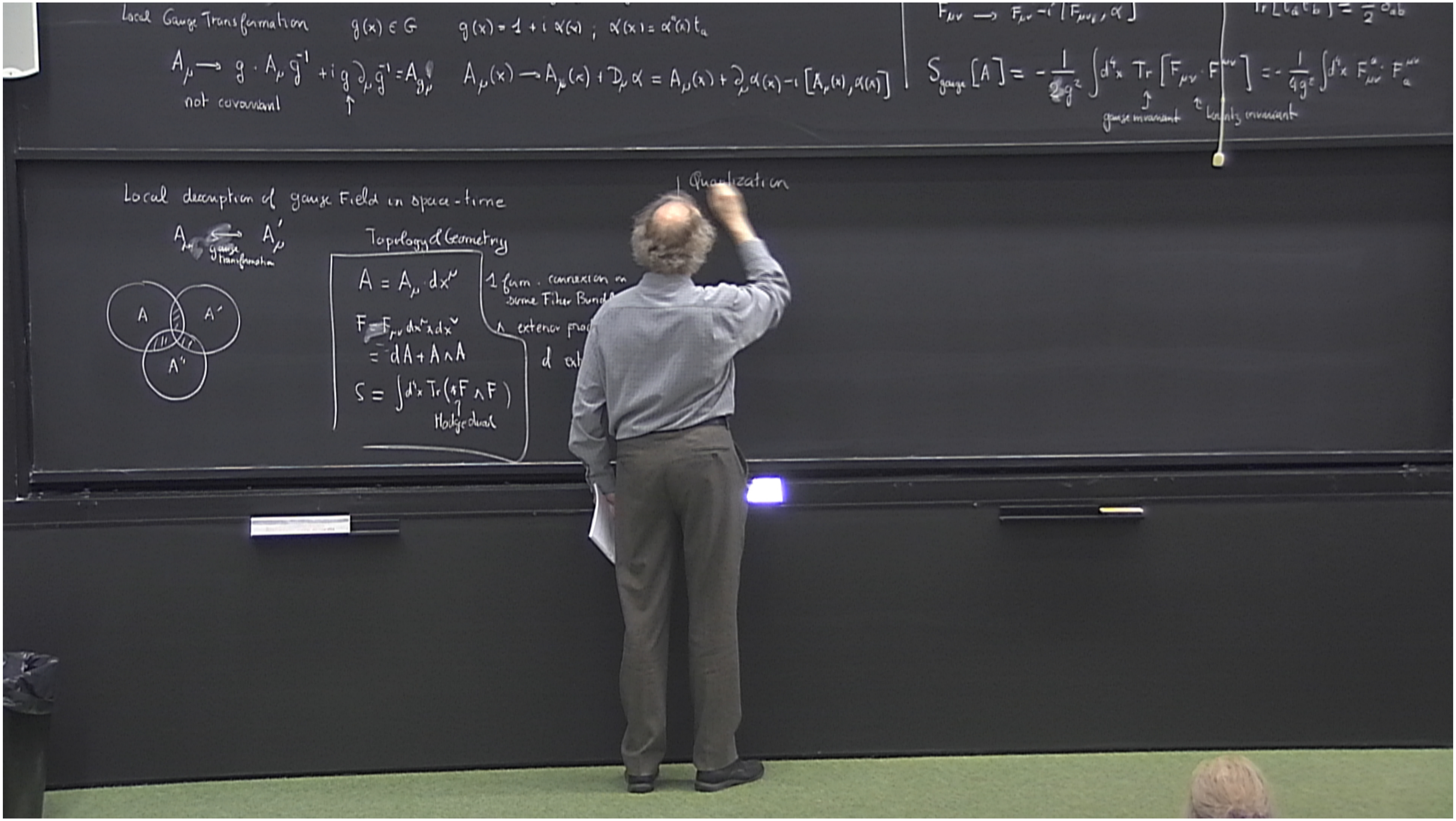
Topology & Geometry
A = A_μ dx^μ
1 form . connexion on some Fiber Bundle
F = F_μν dx^μ ∧ dx^ν
= dA + A ∧ A
∧ exterior product
S = ∫d⁴x Tr (*F ∧ F)
Hodge dual



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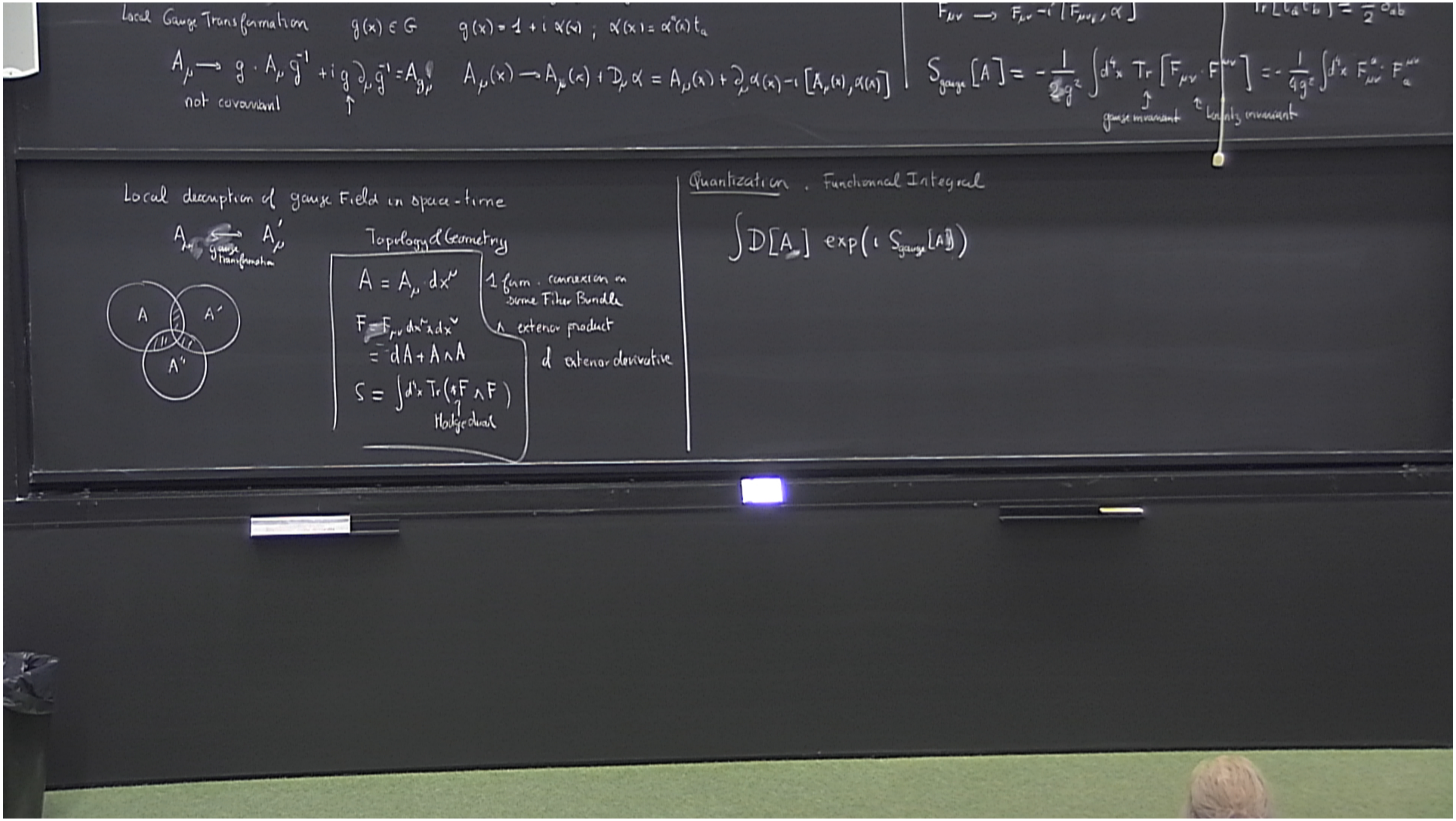
S = ∫ d^4x Tr(*F ∧ F)
Hodge dual
Quantization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Local description of gauge Field in space-time
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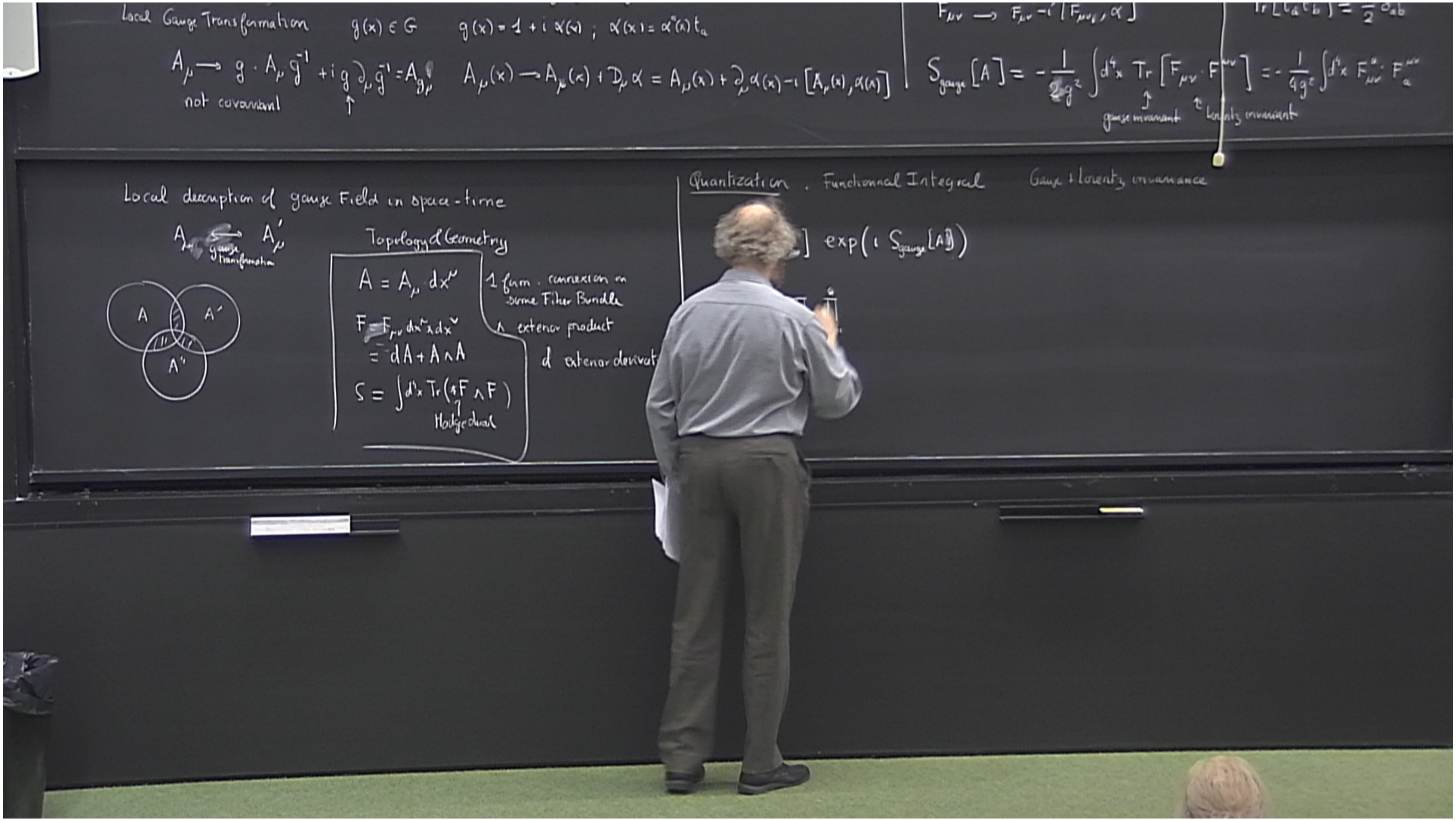
Topology & Geometry
1 form . connexion on some Fiber Bundle
∧ exterior product
d exterior derivative
Hodge dual
Quantization . Functional Integral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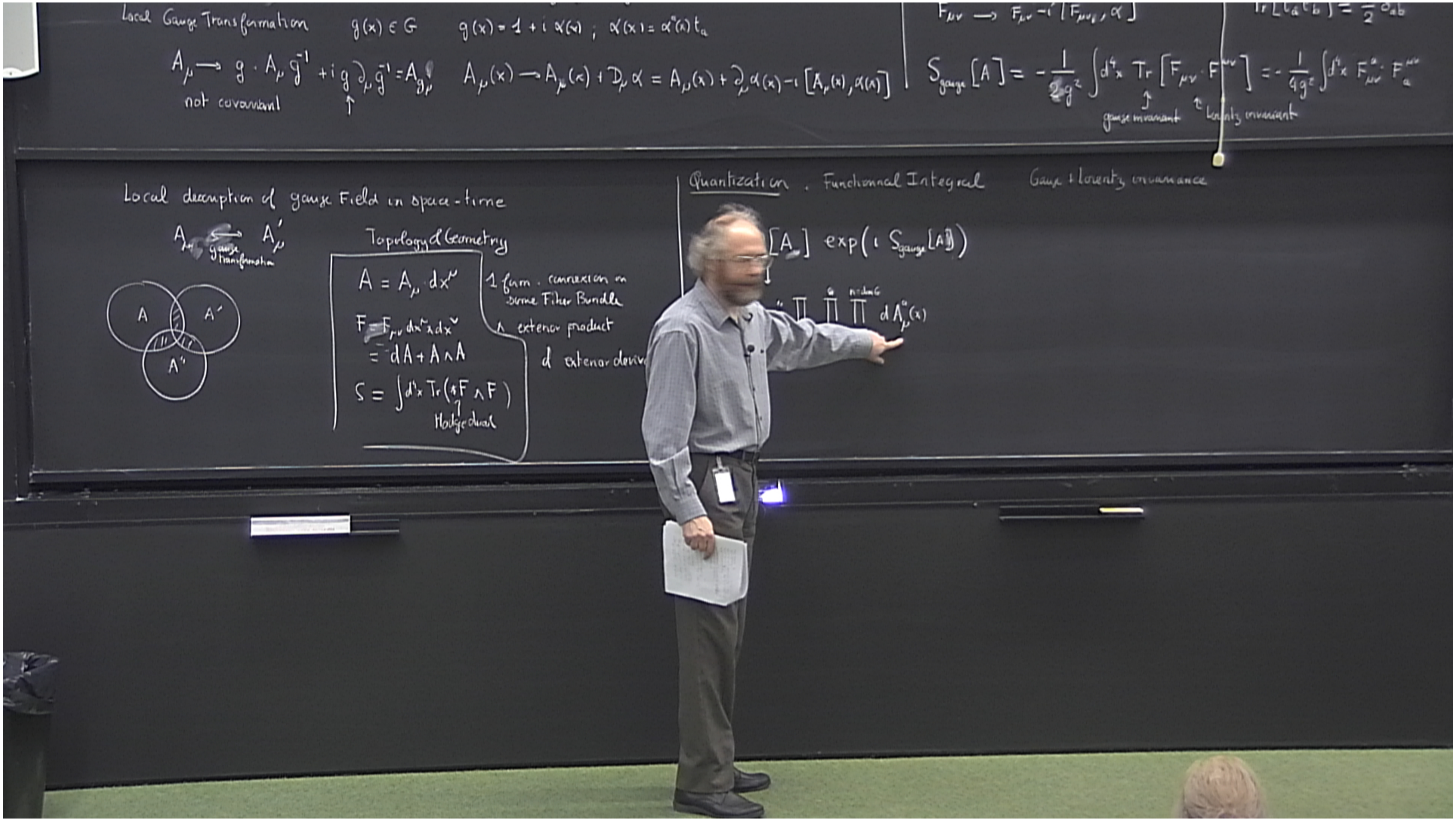
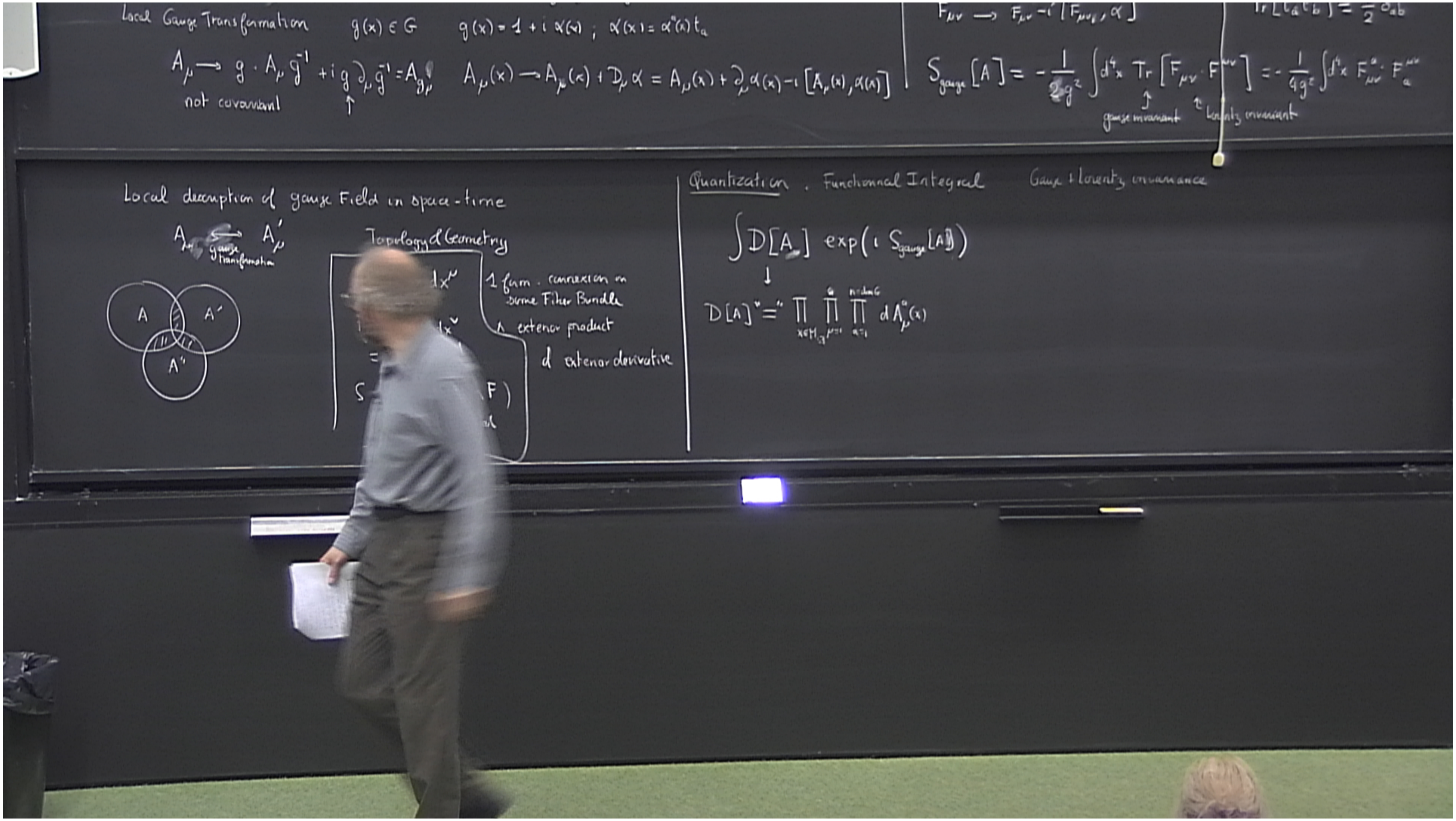
Local description of gauge Field in space-time
gauge transformation
Topology & Geometry
A = A_μ dx^μ
1 form . connexion on some Fiber Bundle
F = F_μν dx^μ ∧ dx^ν
∧ exterior product
= dA + A ∧ A
d exterior derivat
S = ∫d⁴x Tr(*F ∧ F)
Hodge dual
A
A′
A″
Quantization . Functional Integral
Gauge + Lorentz invariance
exp(i S_gauge[A])


Local Gauge Transformation
not covariant
Local description of gauge Field in space-time
gauge transformation
Topology & Geometry
1 form . connexion on some Fiber Bundle
∧ exterior product
d exterior deriv
Hodge dual
Quantization . Functional Integral
Gauge + Lorentz invariance
gauge invariant
Lorentz invariant


Local Gauge Transformation
g(x) ∈ G
not covariant
gauge invariant
Lorentz invariant
Local description of gauge Field in space-time
gauge transformation
Topology & Geometry
1 form . connexion on some Fiber Bundle
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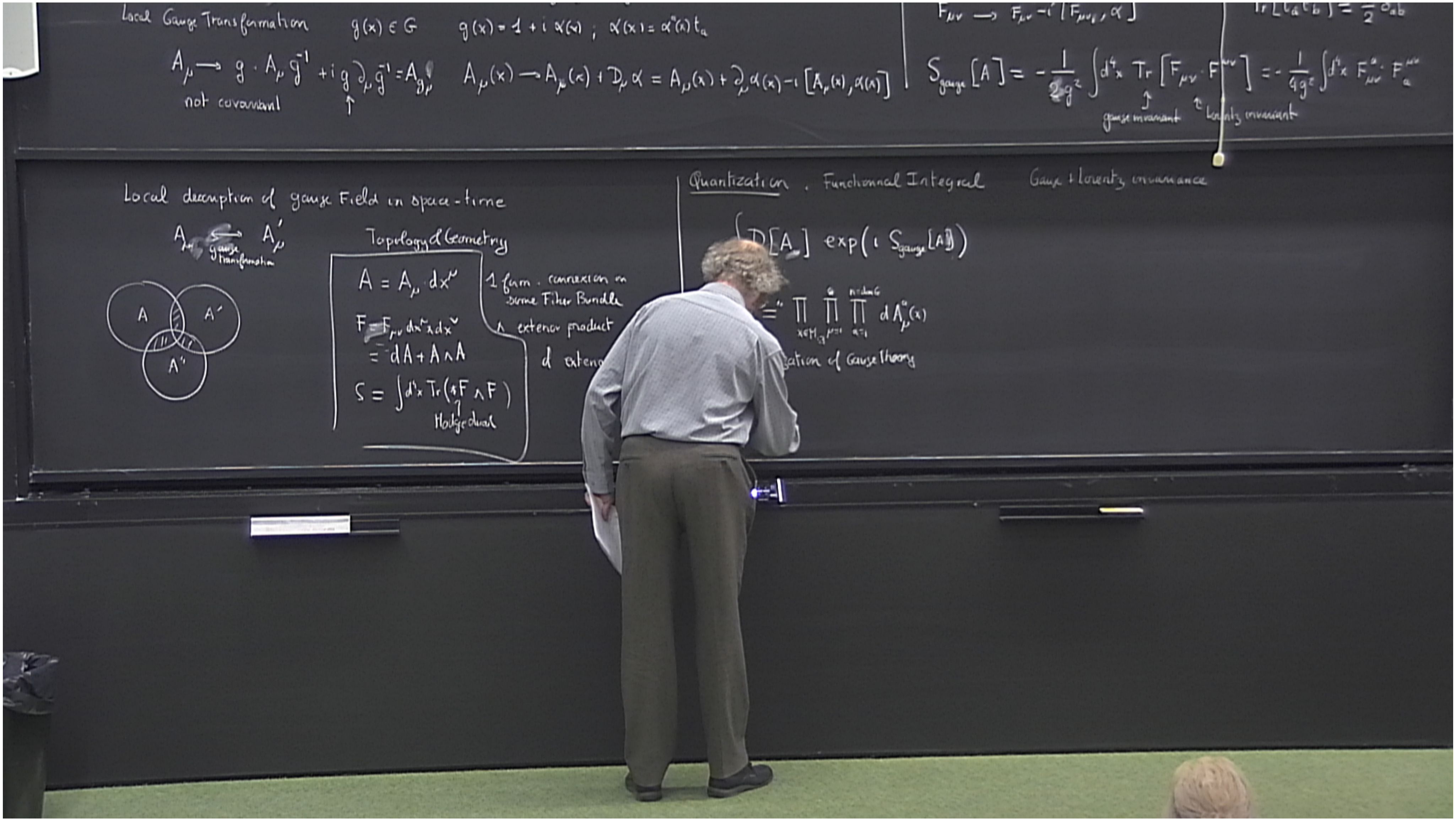
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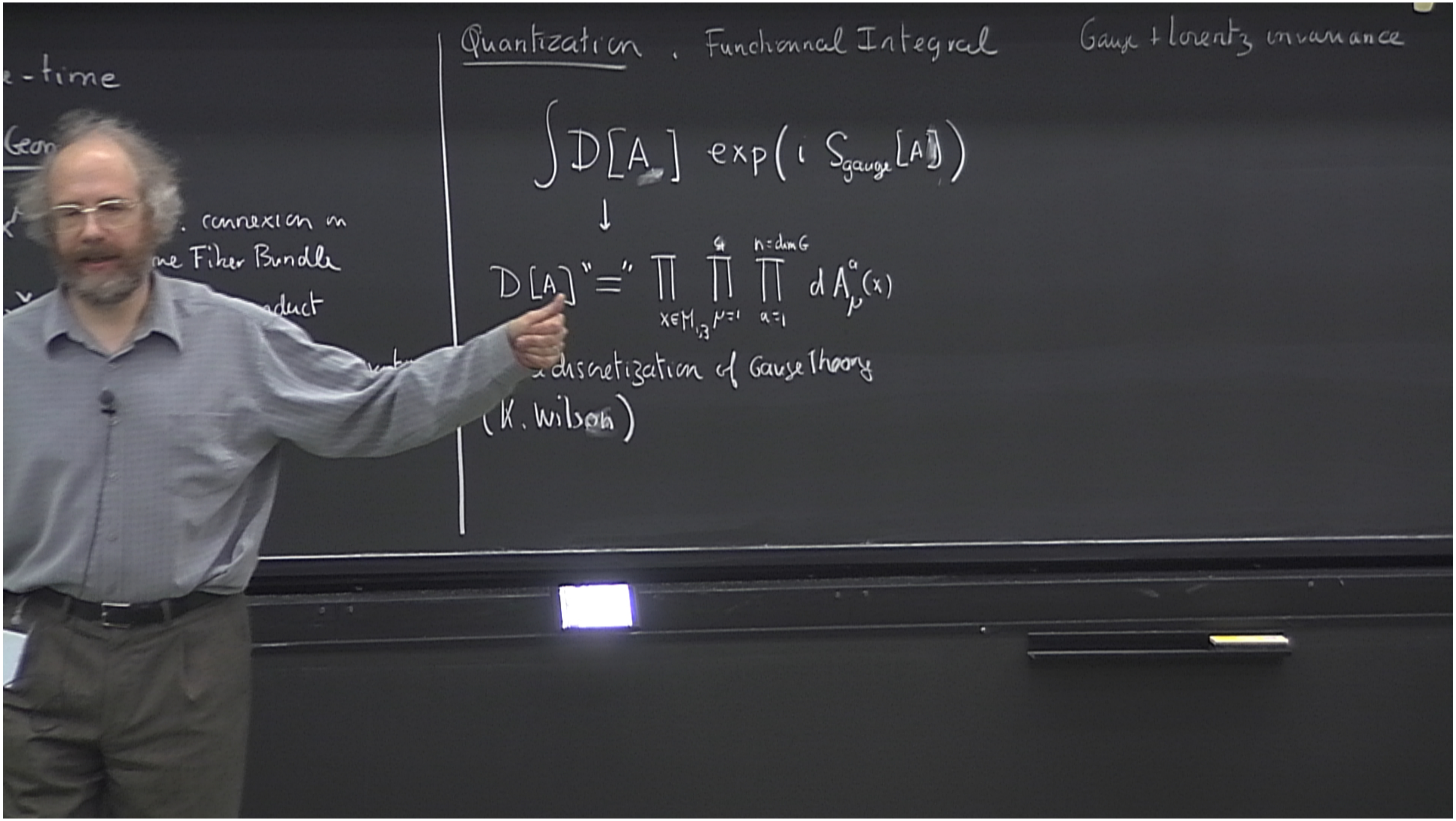
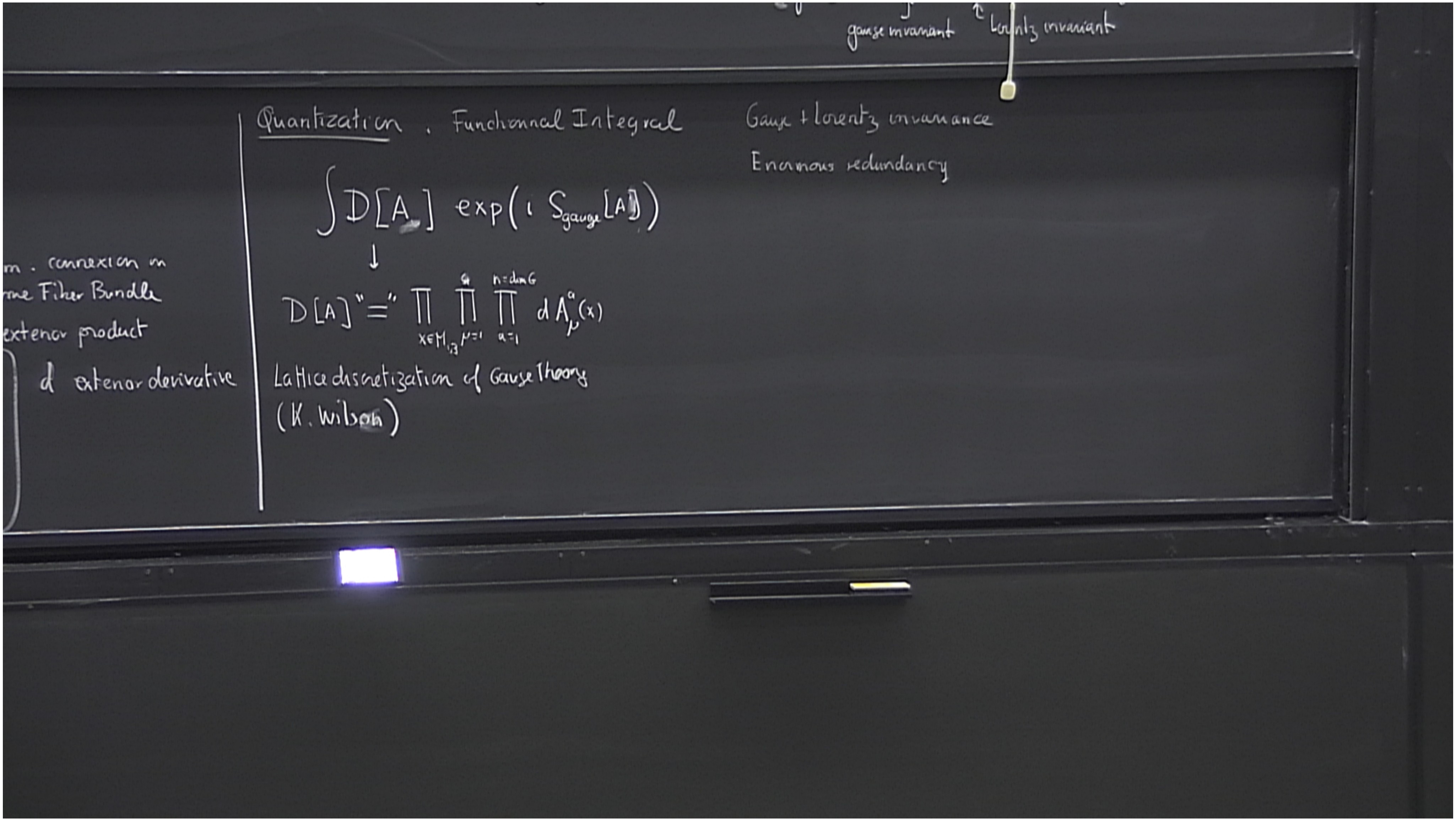
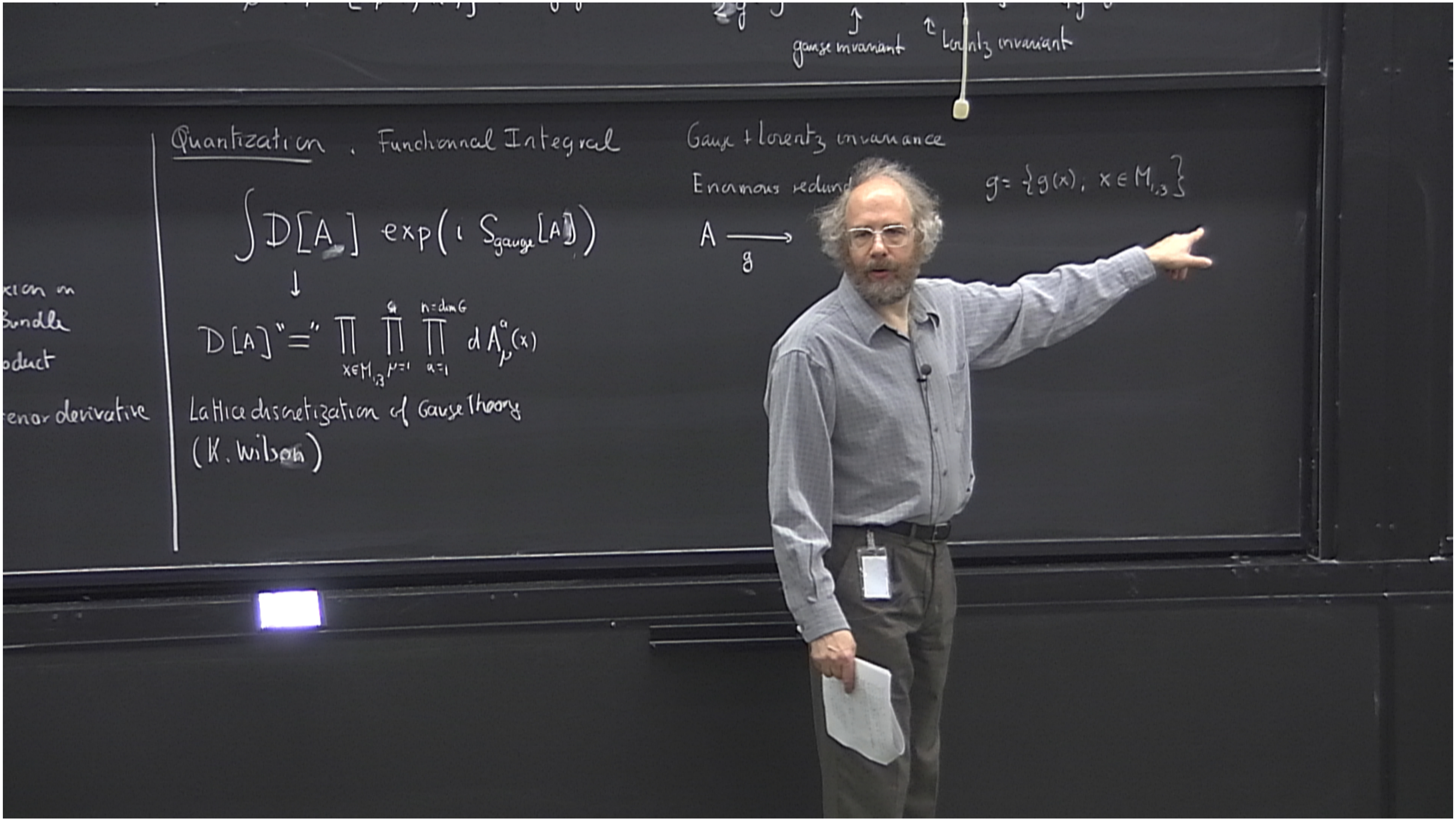

Quantization . Functionnal Integral
Gauge + Lorentz invariance
-time
connexion in
Fiber Bundle
product
∫D[A] exp(i S_gauge[A])
D[A] "=" ∏ ∏ ∏ dA^a_μ(x)
n=dim G
discretization of Gauge Theory
(K. Wilson)


gauge invariant
Lorentz invariant
Quantization . Functional Integral
Gauge + Lorentz invariance
Enormous redundancy
$\int D[A] \exp(i S_{gauge}[A])$
$D[A]$ "=" $\prod_{x \in M_{1,3}} \prod_{\mu=1}^{4} \prod_{a=1}^{n=\dim G} dA_\mu^a(x)$
Lattice discretization of Gauge Theory
(K. Wilson)
m . connexion on
me Fiber Bundle
exterior product
d exterior derivative


gauge invariant
Lorentz invariant
Quantization . Functional Integral
Gauge + Lorentz invariance
Enormous redund
g = {g(x); x ∈ M1,3}
∫D[A] exp(i Sgauge[A])
A → g
D[A] "=" ∏ ∏ ∏ dAaμ(x)
x∈M1,3 μ=1 a=1
n=dim G
Lattice discretization of Gauge Theory
(K. Wilson)
Bundle
oduct
enor derivative

gauge invariant — Lorentz invariant

Quantization. Functional Integral

$$\int D[A] \exp\left(i\, S_{gauge}[A]\right)$$

$$D[A] \text{ "=" } \prod_{x \in M_{1,3}} \prod_{\mu=1}^{4} \prod_{a=1}^{n=\dim G} d A_\mu^a(x)$$

Lattice discretization of Gauge Theory (K. Wilson)

Gauge + Lorentz invariance

Enormous redundancy

$$A \xrightarrow[g]{} $$

$$g = \{ g(x) ;\ x \in M_{1,3} \}$$

$$g \in \mathcal{G} = \bigotimes_{x \in M_{1,3}} G$$

gauge invariant ↑ ↑ Lorentz invariant

xion on
Bundle
oduct
enor derivative

Quantization . Functional Integral

$$\int D[A] \exp\left(i\, S_{gauge}[A]\right)$$

↓

$$D[A] \text{"="} \prod_{x\in M_{1,3}} \prod_{\mu=1}^{4} \prod_{a=1}^{n=\dim G} dA_\mu^a(x)$$

Lattice discretization of Gauge Theory (K. Wilson)

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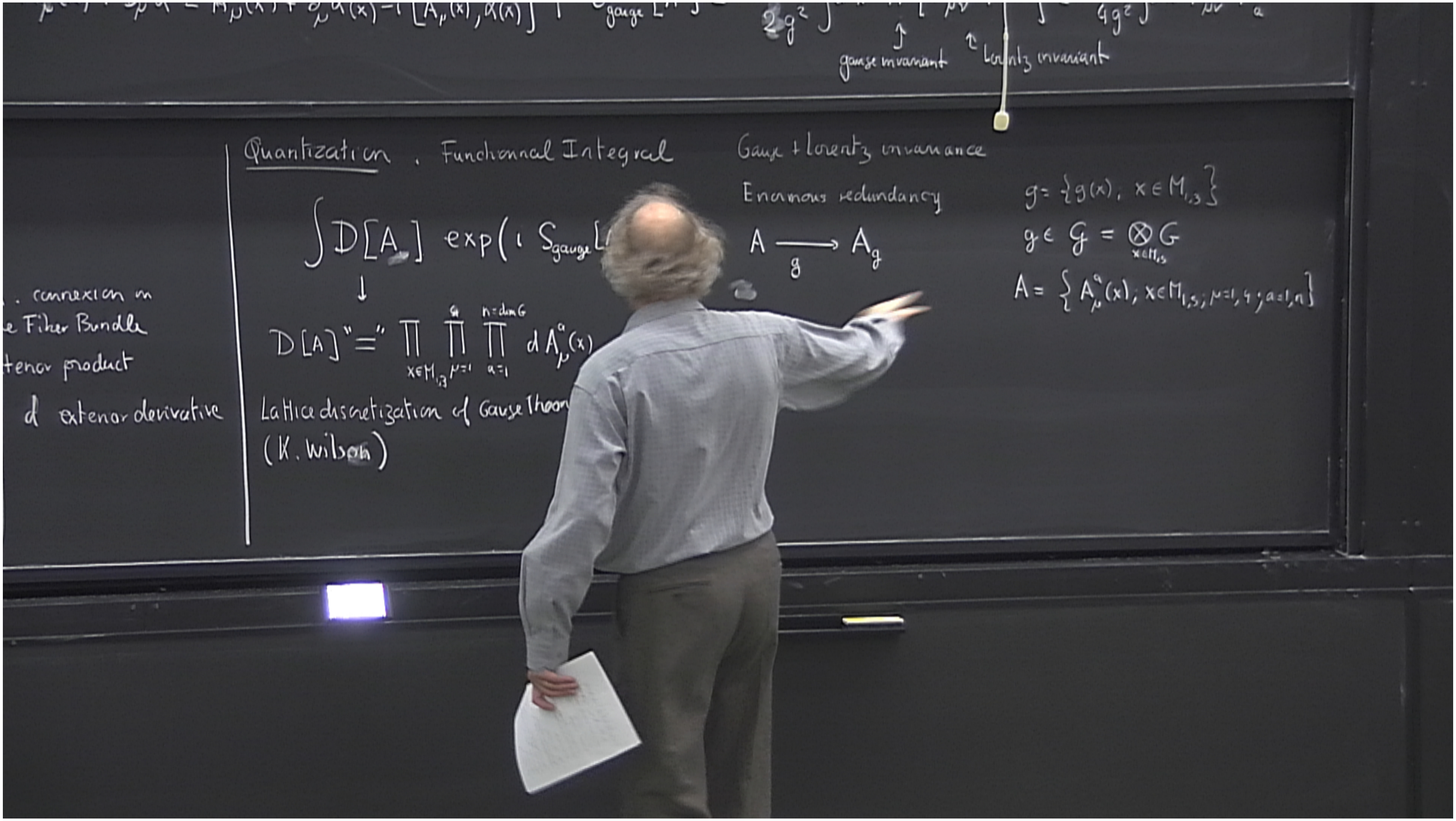
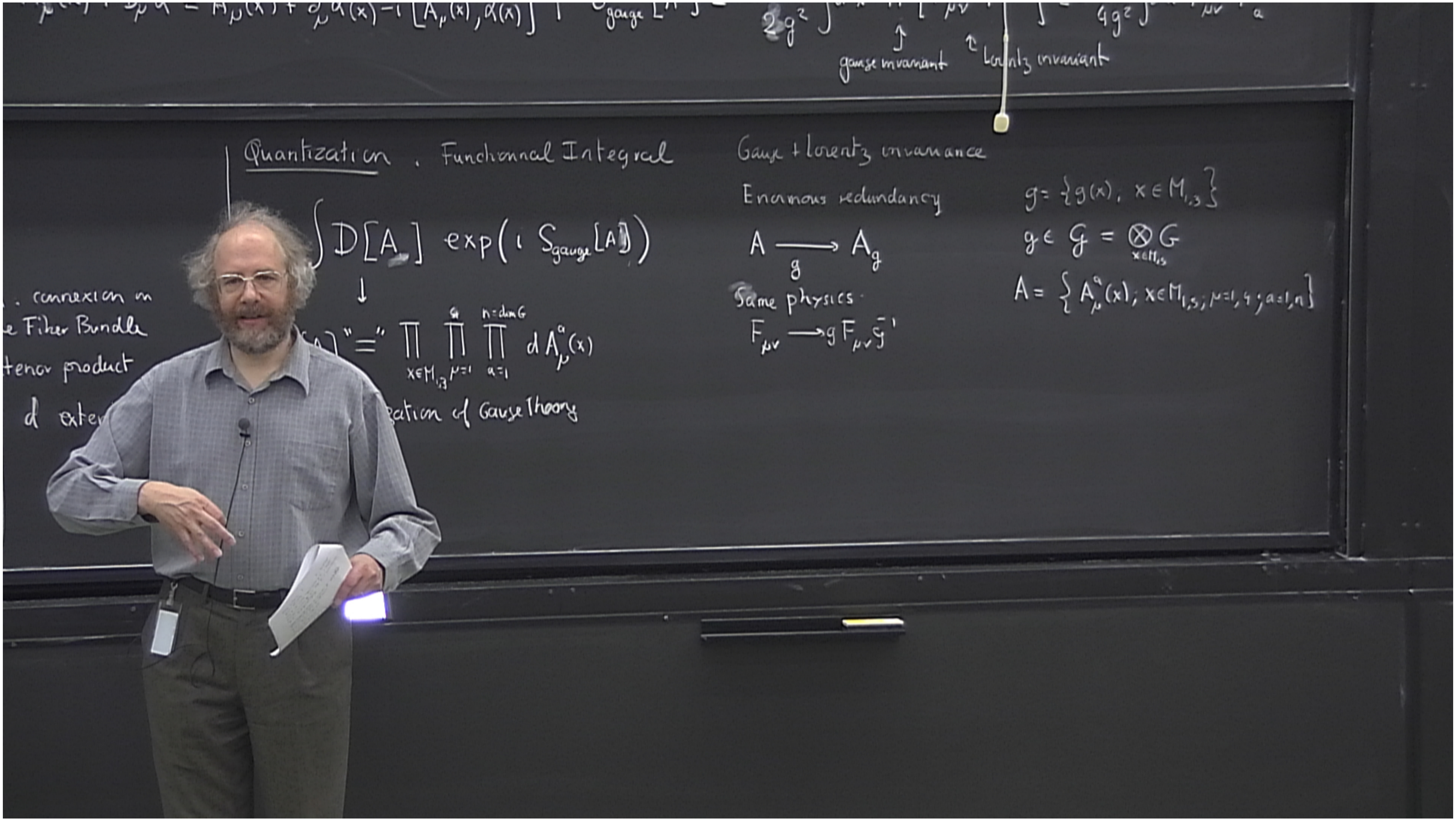
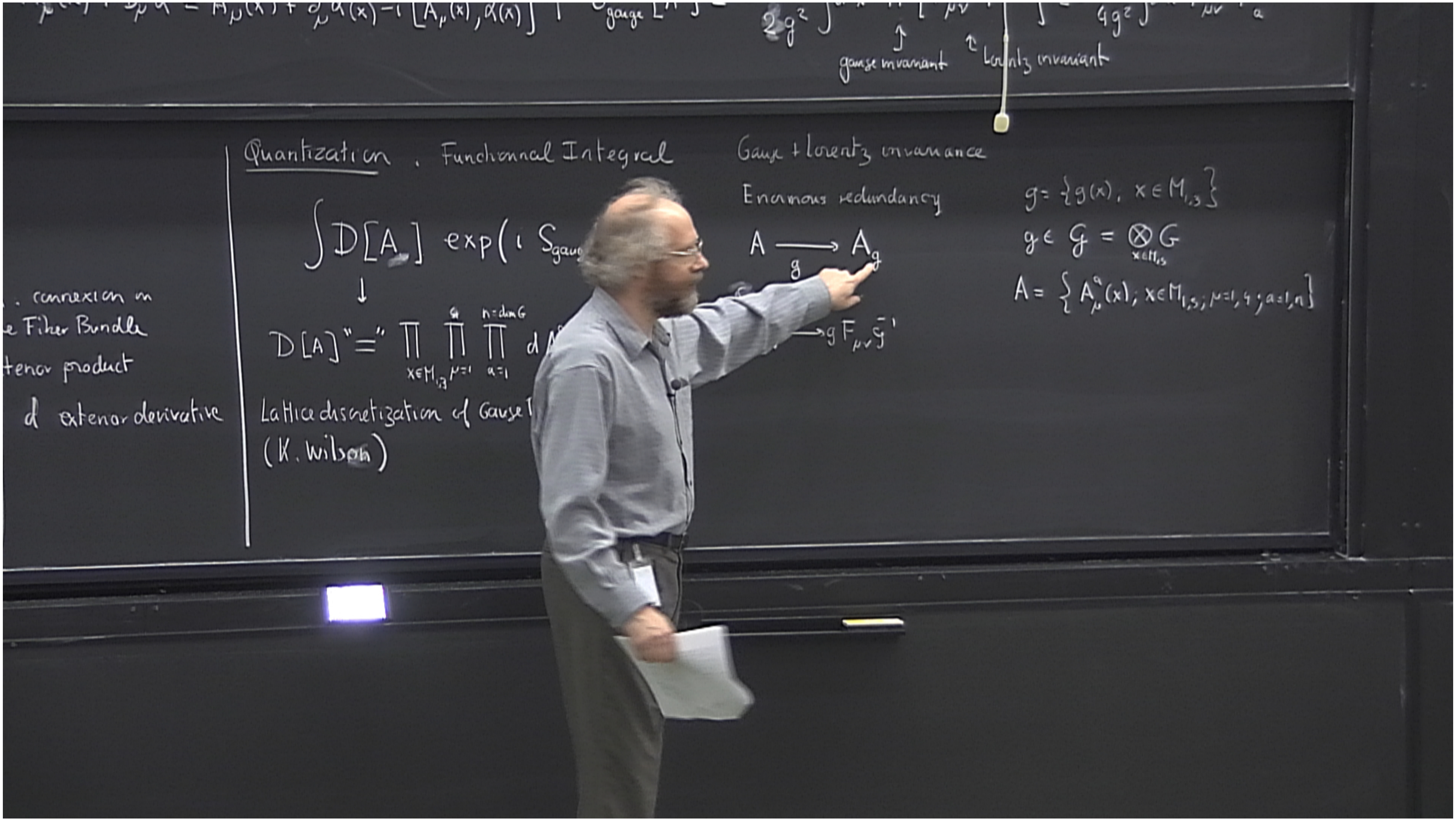


gauge invariant
Lorentz invariant
Quantization . Functional Integral
Gauge + Lorentz invariance
Enormous redundancy
A → A_g
g = {g(x), x ∈ M_{1,3}}
connexion on
Fiber Bundle
tensor product
d exterior derivative
Lattice discretization of Gauge Theory
(K. Wilson)


gauge invariant
Lorentz invariant
Quantization . Functional Integral
Gauge + Lorentz invariance
Enormous redundancy
Same physics
connexion on
Fiber Bundle
tensor product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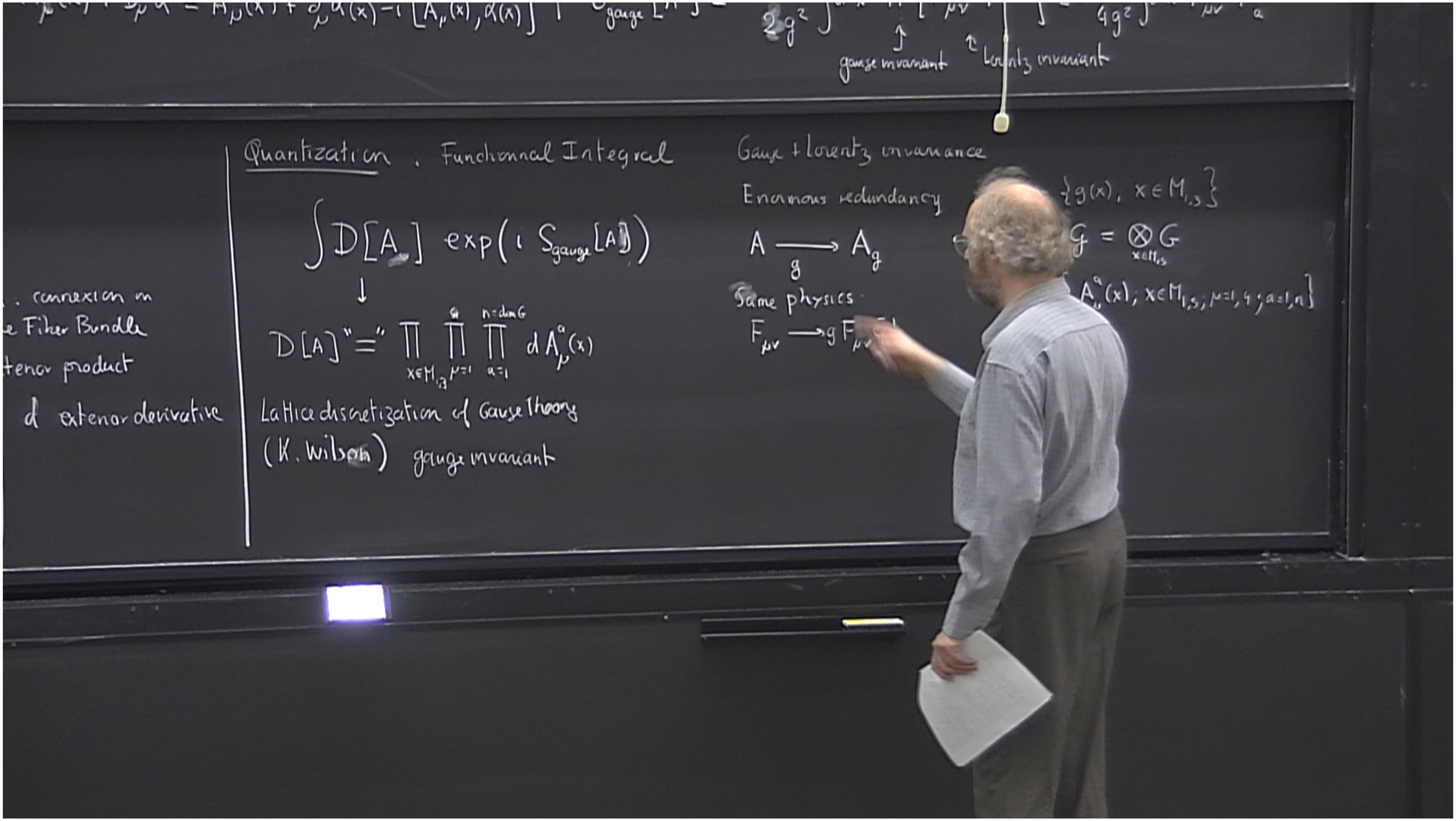
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Lattice discretization of Gauge Theory
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Fiber Bundle
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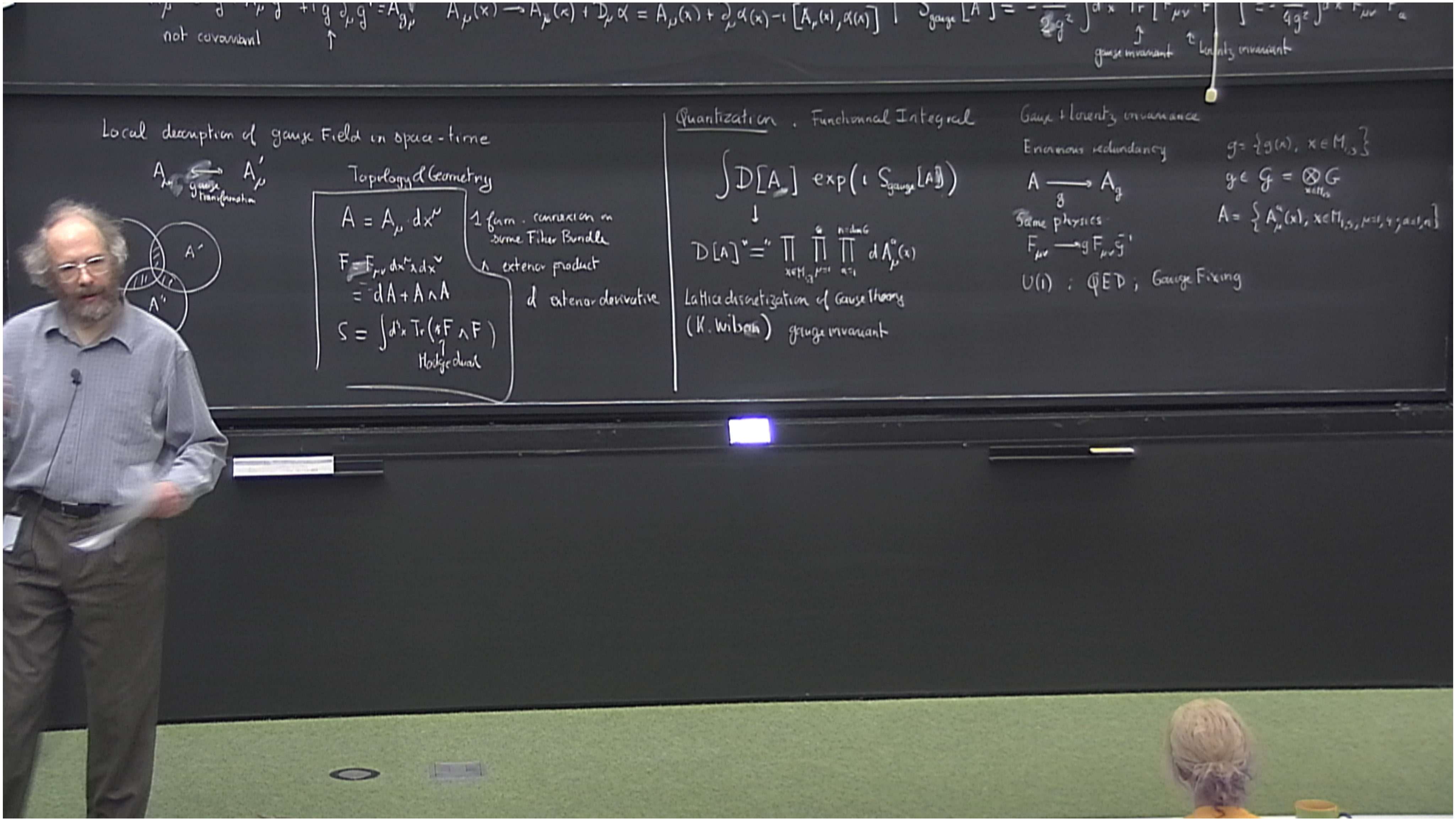
Gauge + Lorentz invariance
Enormous redundancy
$A \xrightarrow{g} A_g$
Same physics
$\{g(x), x \in M_{1,3}\}$
$\mathcal{G} = \bigotimes_{x \in M_{1,3}} G$
$A^a_\mu(x); x \in M_{1,3}; \mu=1,4; a=1,n\}$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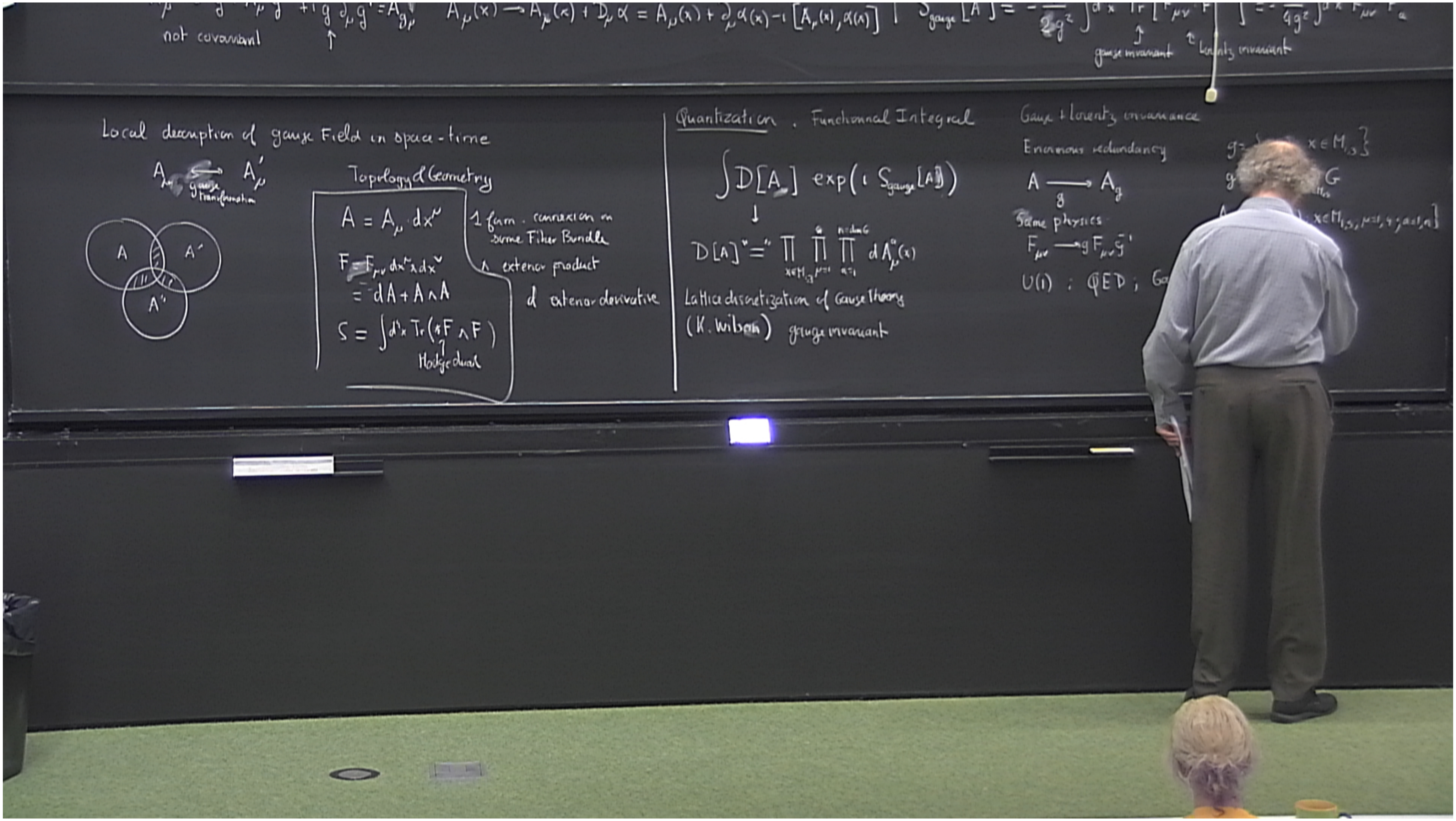
Same physics
U(1) ; QED ; Gauge Fixing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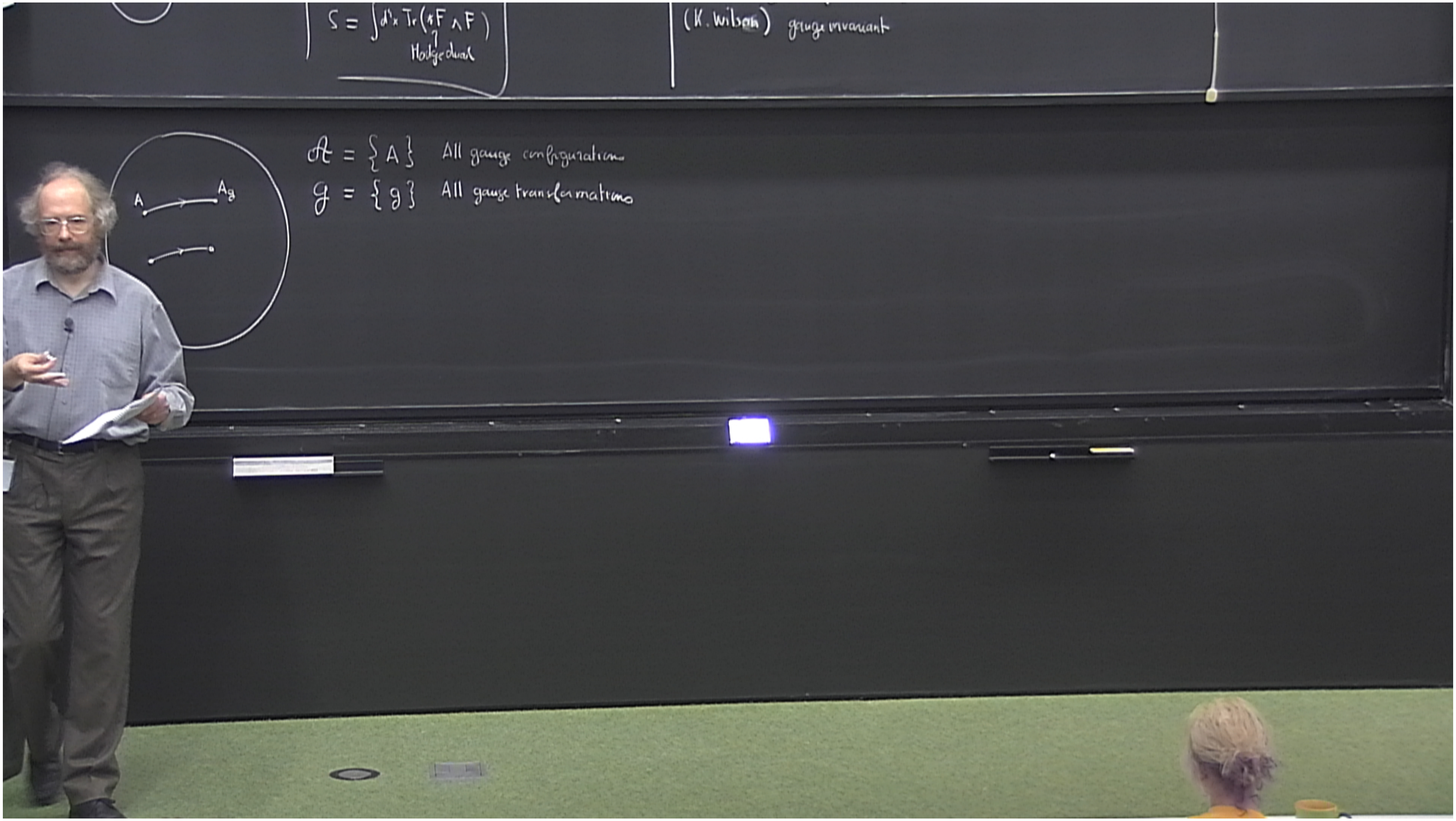
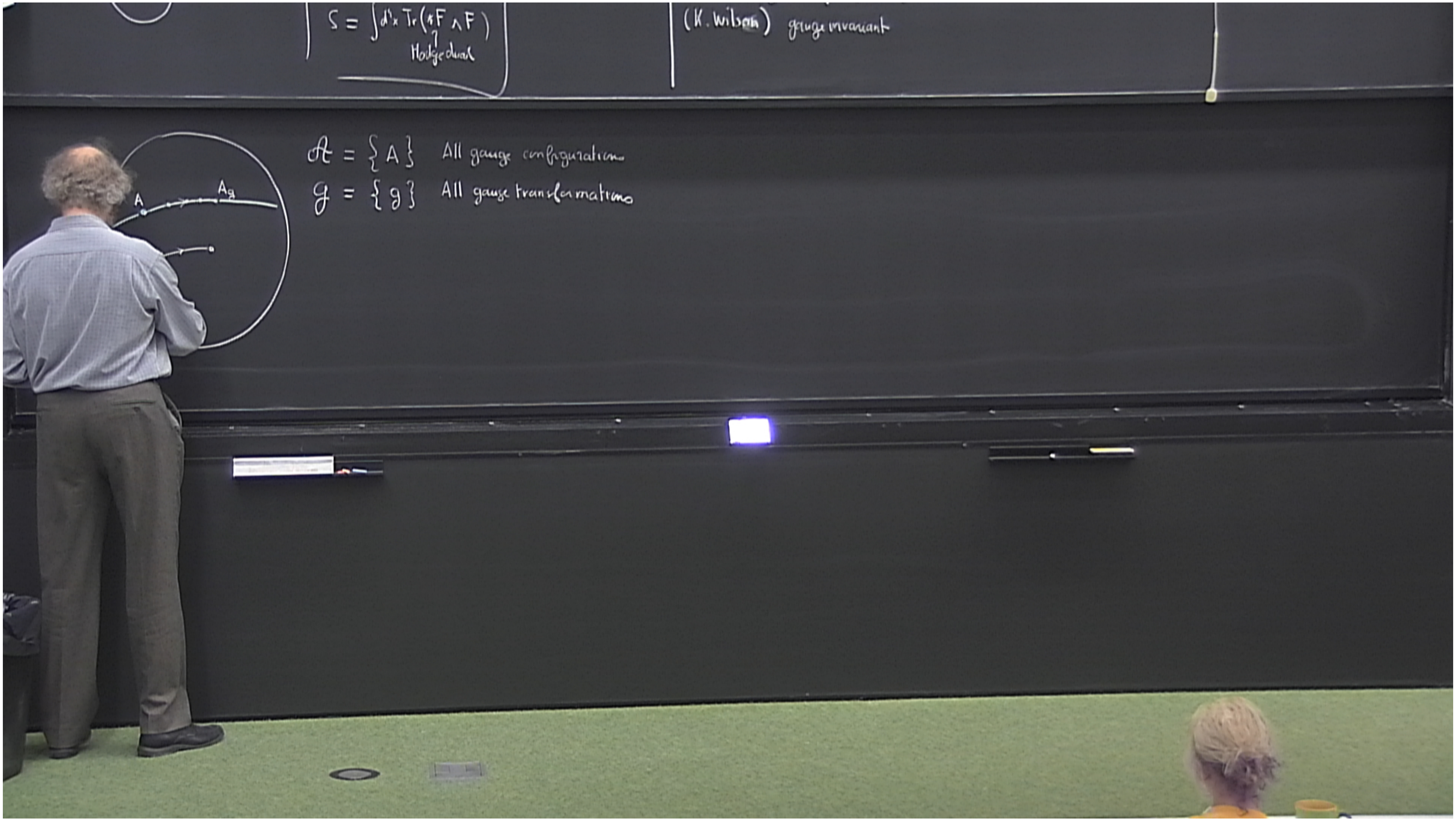
Lattice discretization of Gauge Theory
(K. Wilson) gauge invariant
Gauge + Lorentz invariance
Enormous redundancy
A ⟶ A_g
Same physics
U(1) : QED ;


S = ∫d⁴x Tr(*F ∧ F)
Hodge dual
(K. Wilson) gauge invariant
A
Ag
𝒜 = { A } All gauge configurations
𝒢 = { g } All gauge transformations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Hodge dual
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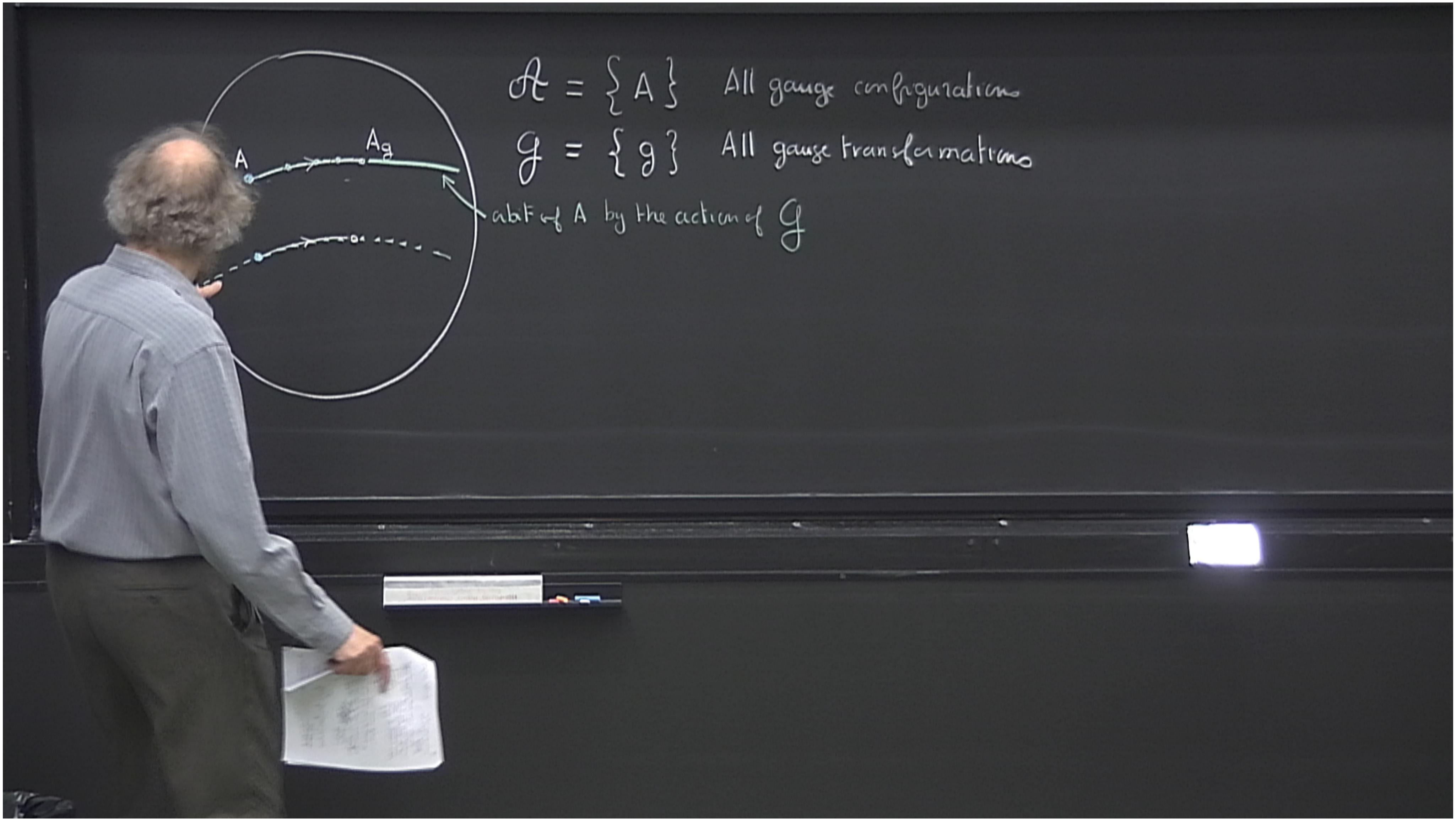
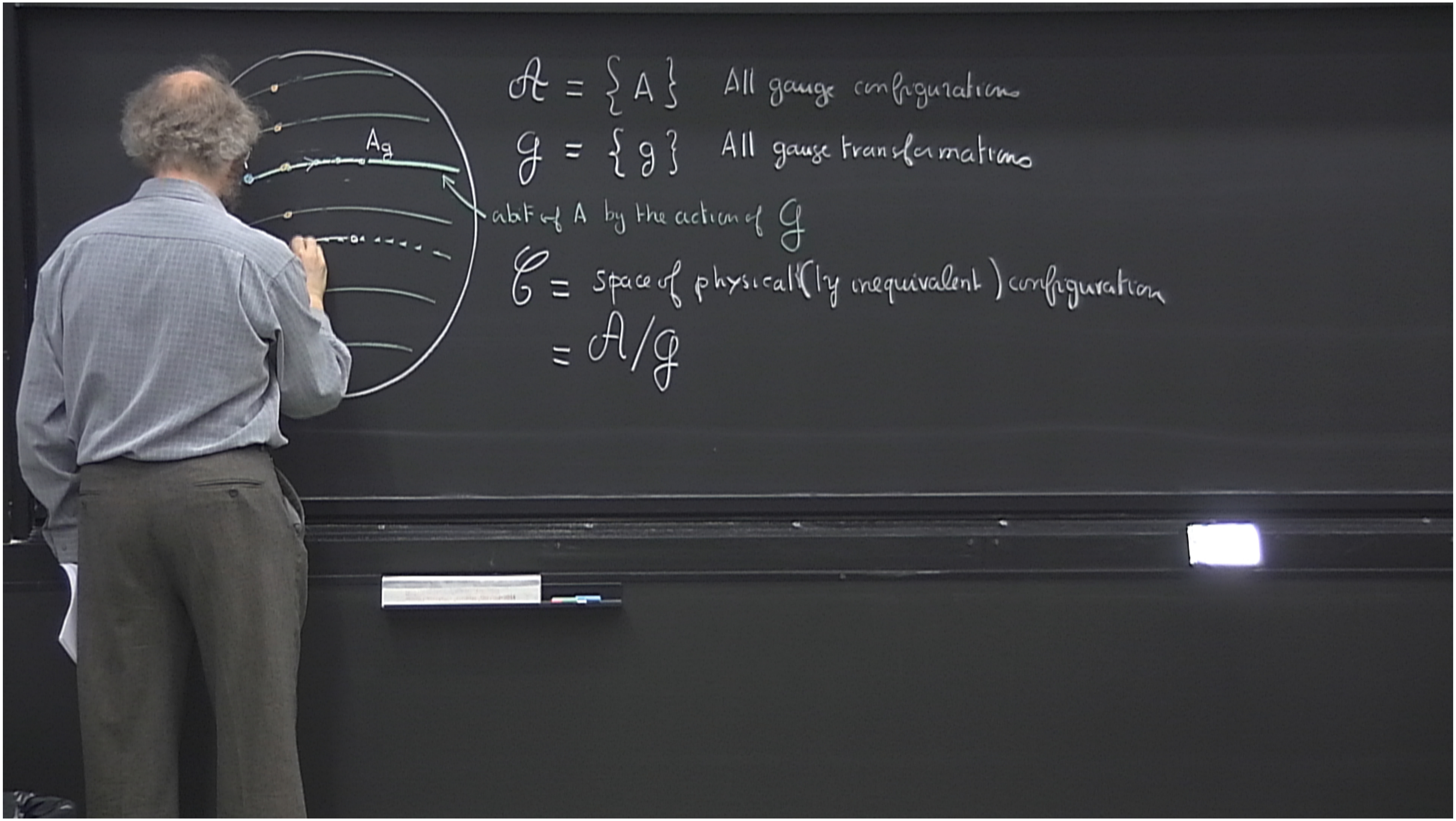
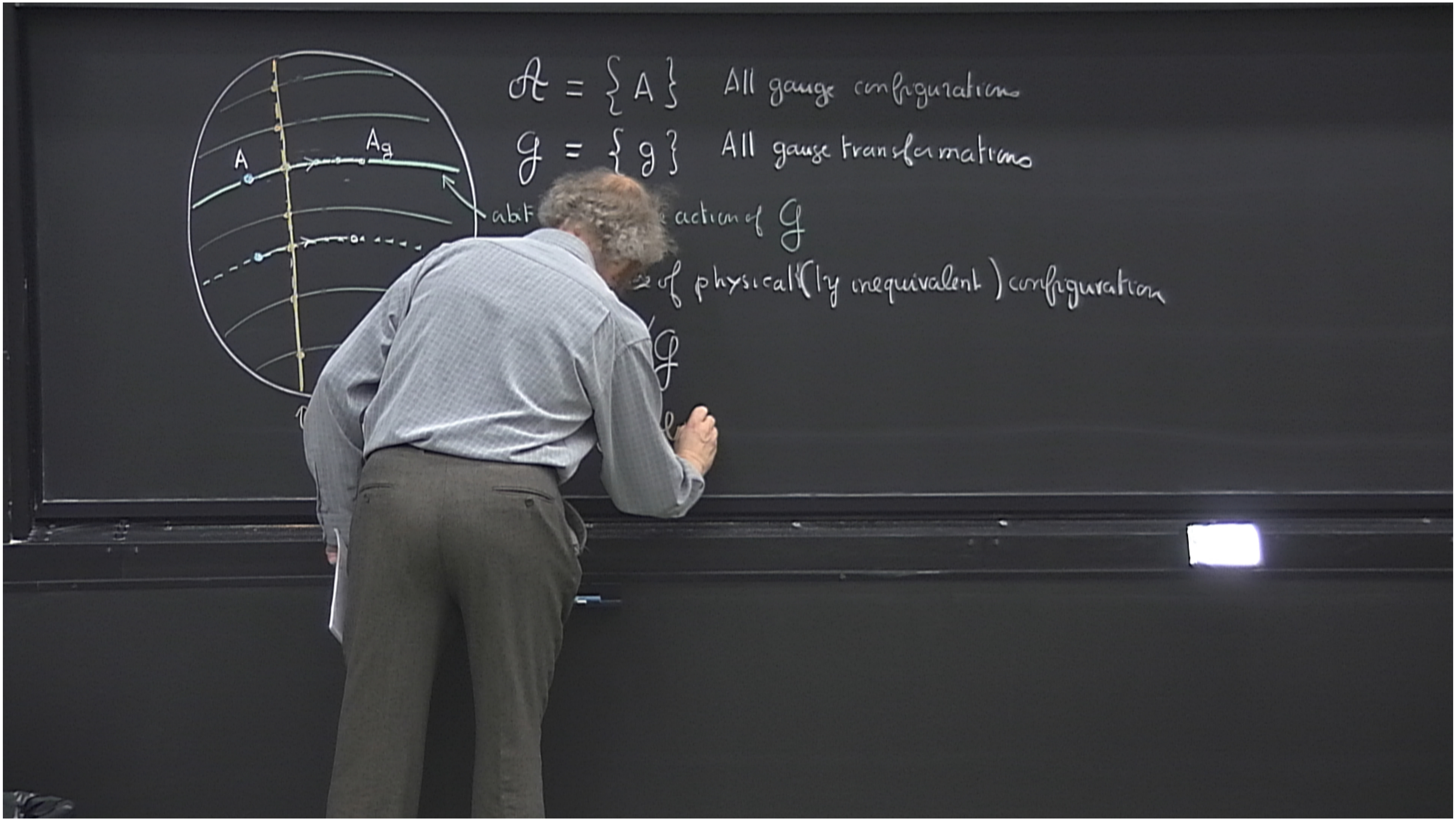
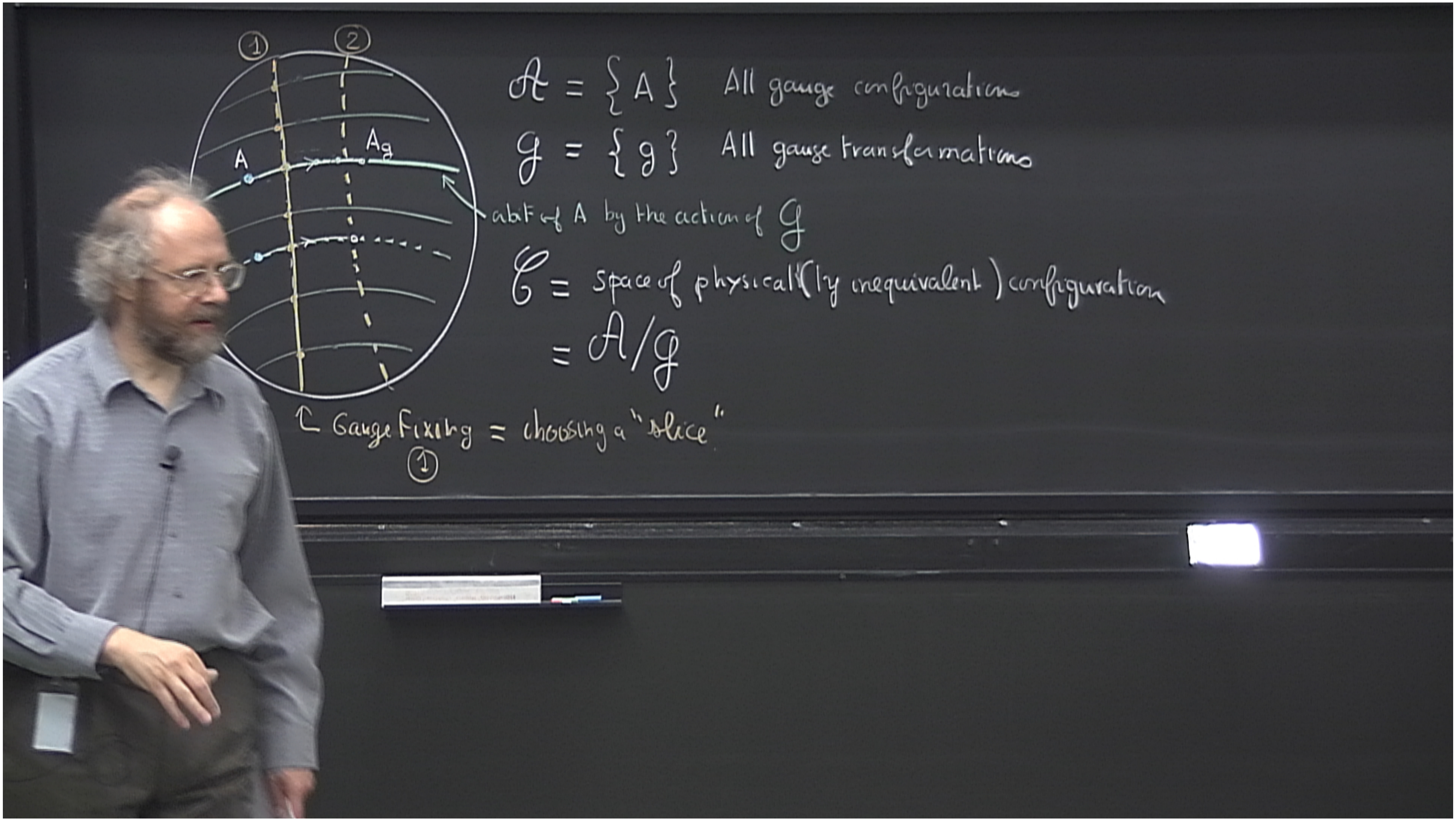
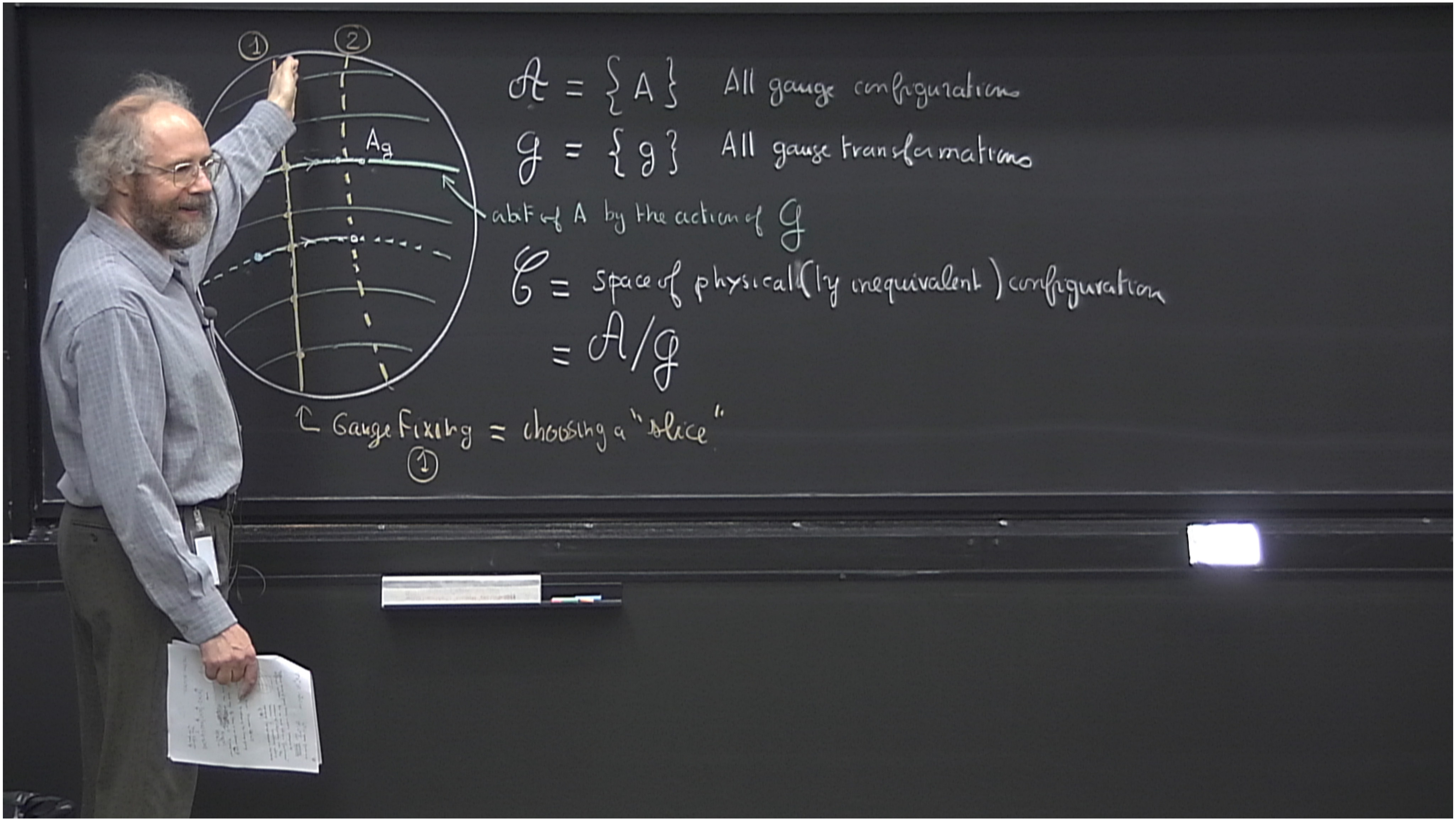

A
A_g
$\mathcal{A} = \{ A \}$ All gauge configurations
$\mathcal{G} = \{ g \}$ All gauge transformations
orbit of A by the action of $\mathcal{G}$

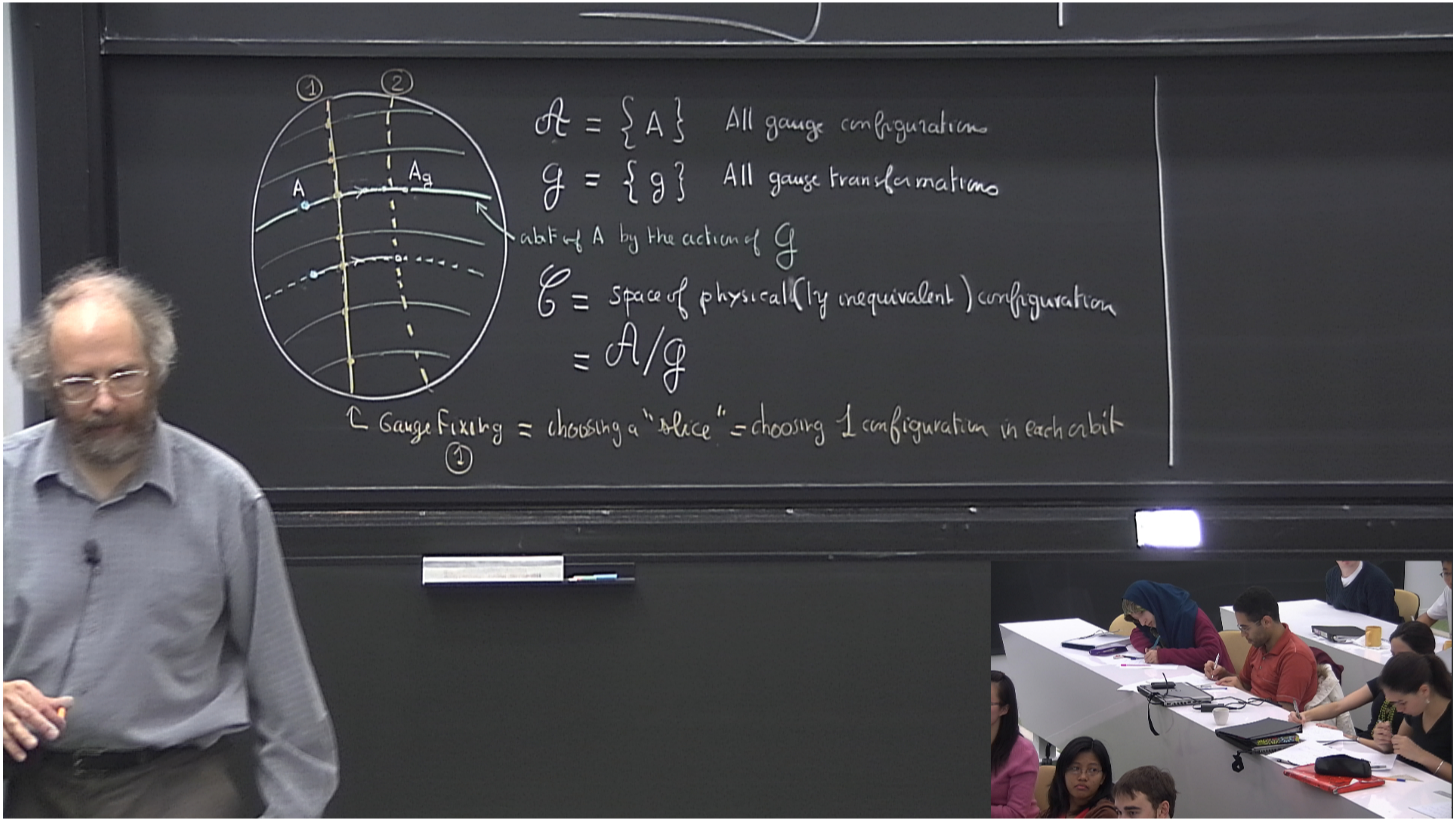

A = { A } All gauge configurations
G = { g } All gauge transformations
Ag
orbit of A by the action of G
C = space of physical(ly inequivalent) configuration
= A/G


A
Ag
𝒜 = { A } All gauge configurations
𝒢 = { g } All gauge transformations
action of 𝒢
of physical(ly inequivalent) configuration



1
2
A
A_g
𝒜 = { A } All gauge configurations
𝒢 = { g } All gauge transformations
orbit of A by the action of 𝒢
𝒞 = space of physical(ly inequivalent) configuration
= 𝒜/𝒢
Gauge fixing = choosing a "slice"
1


① ②
A_g
𝒜 = { A } All gauge configurations
𝒢 = { g } All gauge transformations
orbit of A by the action of 𝒢
𝒞 = space of physical(ly inequivalent) configuration
= 𝒜/𝒢
Gauge Fixing = choosing a "slice"
①



①
②
A
A_g
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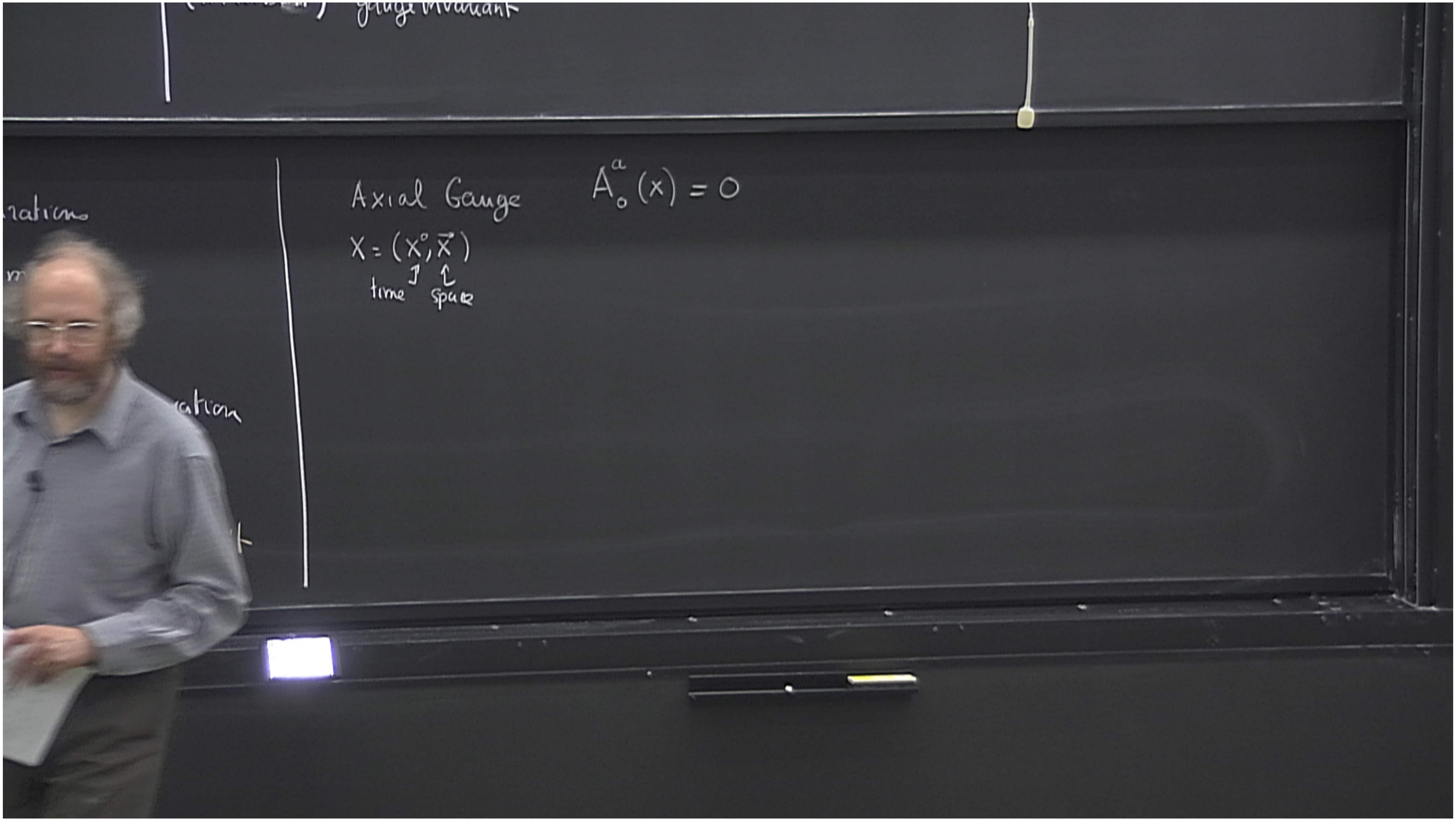
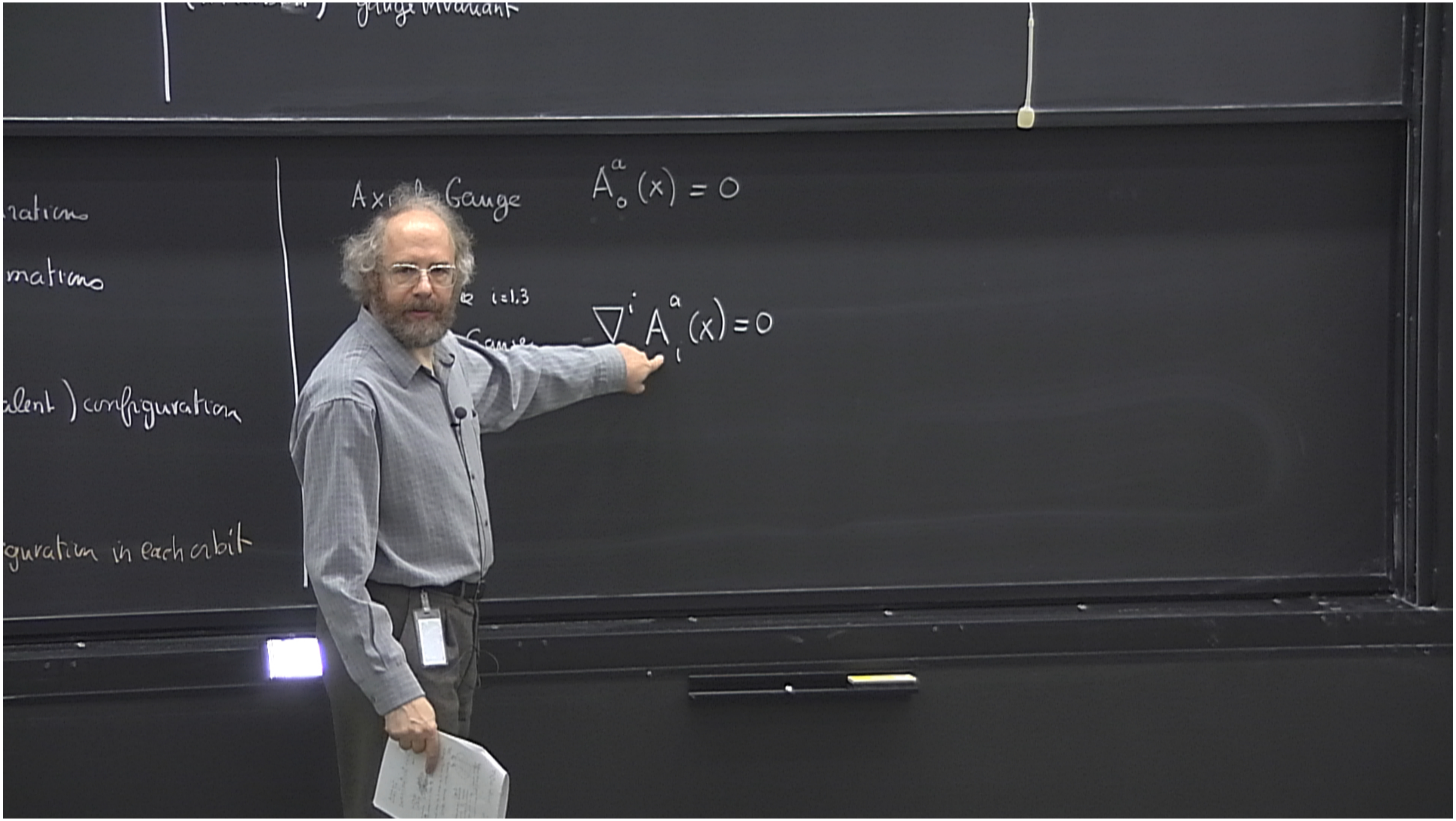
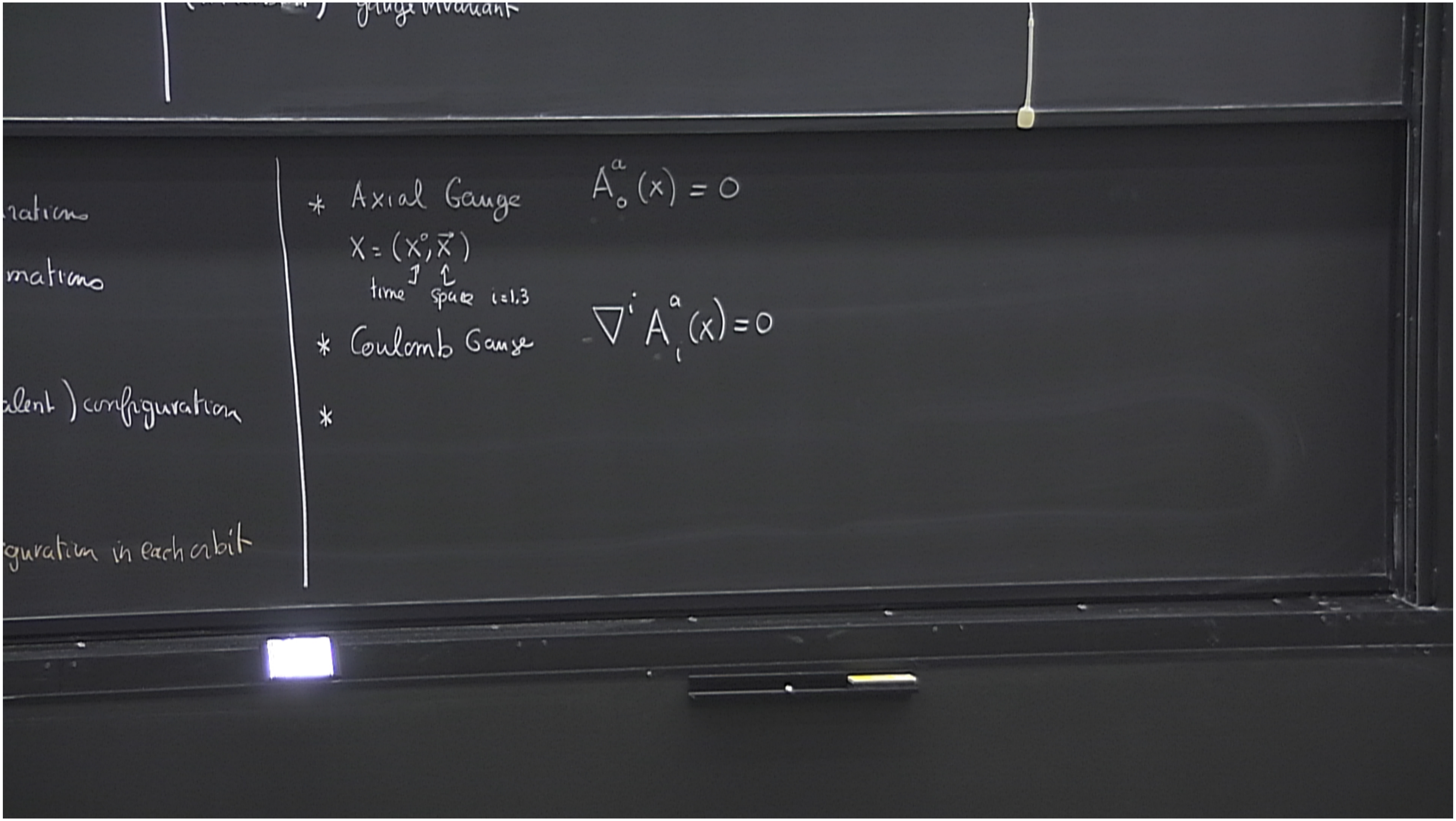
𝒢 = { g } All gauge transformations
orbit of A by the action of 𝒢
𝒞 = space of physical(ly inequivalent) configuration
= 𝒜/𝒢
Gauge fixing = choosing a "slice" = choosing 1 configuration in each orbit
①

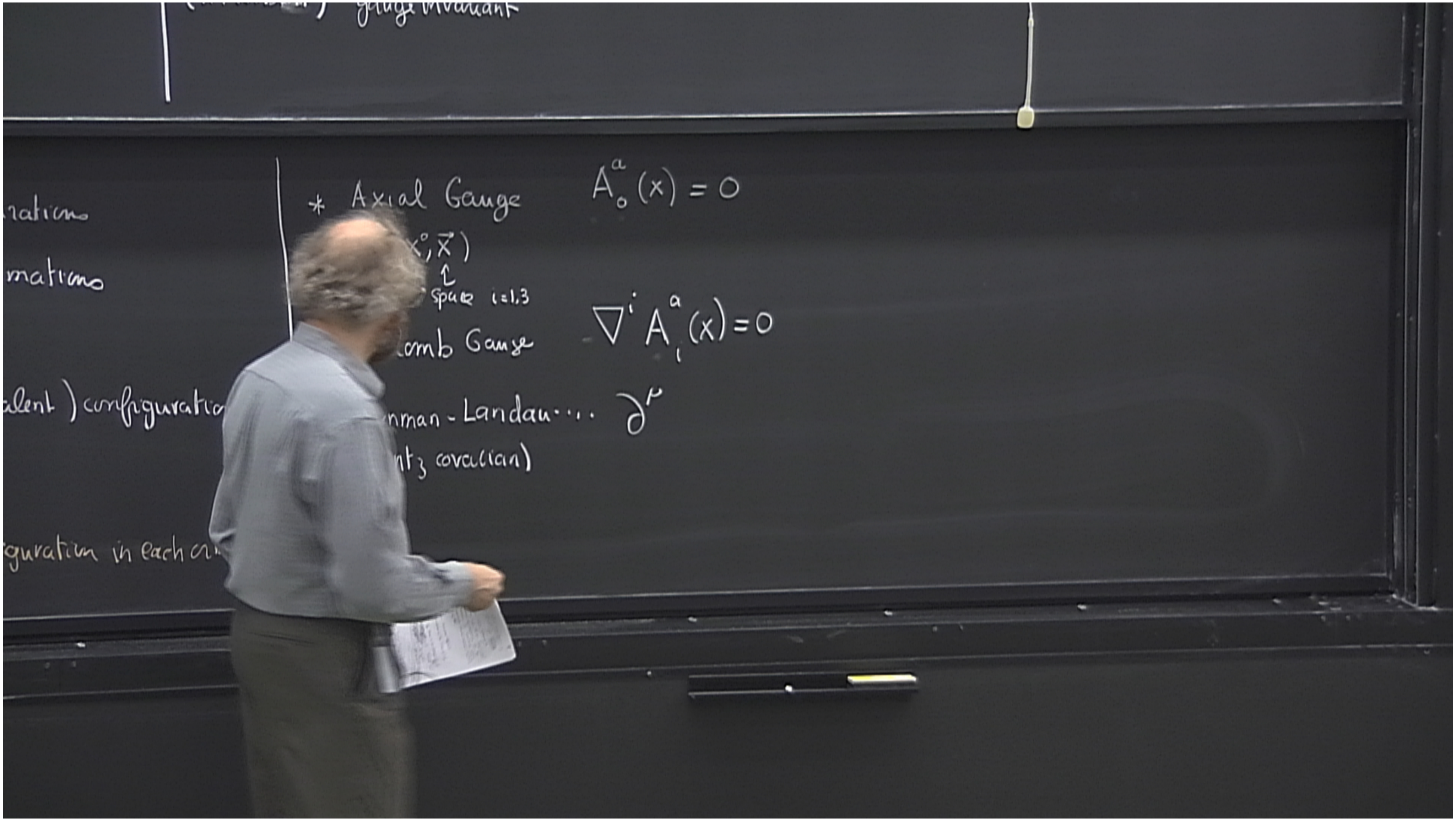

Axial Gauge
$A^a_0(x) = 0$
$x = (x^0, \vec{x})$
time
space

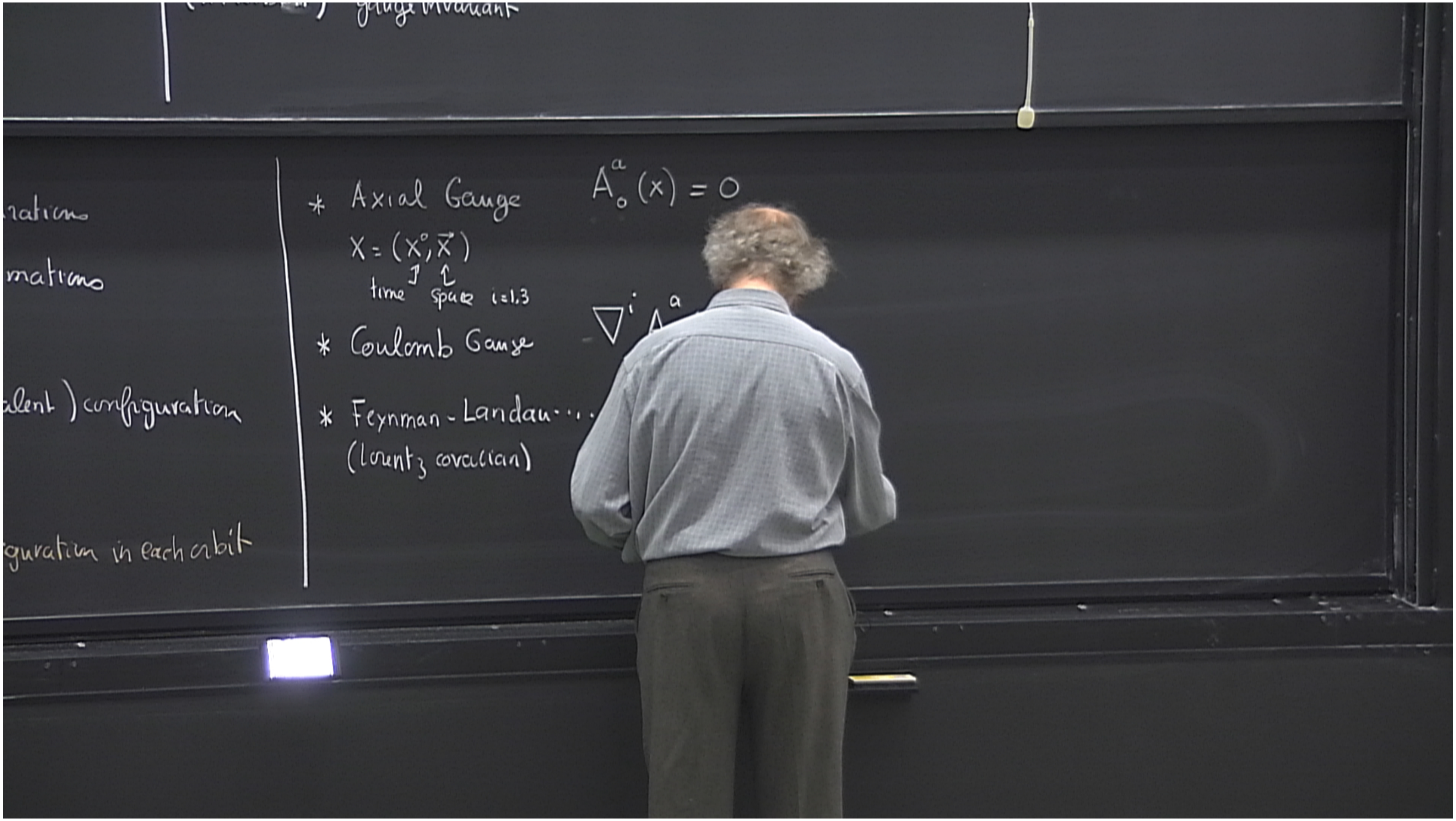


A_0^a (x) = 0
i=1,3
∇^i A_i^a (x) = 0
configuration
in each orbit



gauge invariant
* Axial Gauge
A^a_0(x) = 0
X = (x^0, \vec{x})
time
space
i=1,3
* Coulomb Gauge
∇^i A^a_i(x)=0
*
alent) configuration
guration in each orbit


* Axial Gauge
$A^a_0(x) = 0$
space i=1,3
$\nabla^i A^a_i(x) = 0$
Landau....
∂^μ
covarian)
configuration in each


gauge invariant
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A_0^a(x) = 0
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time space i=1,3
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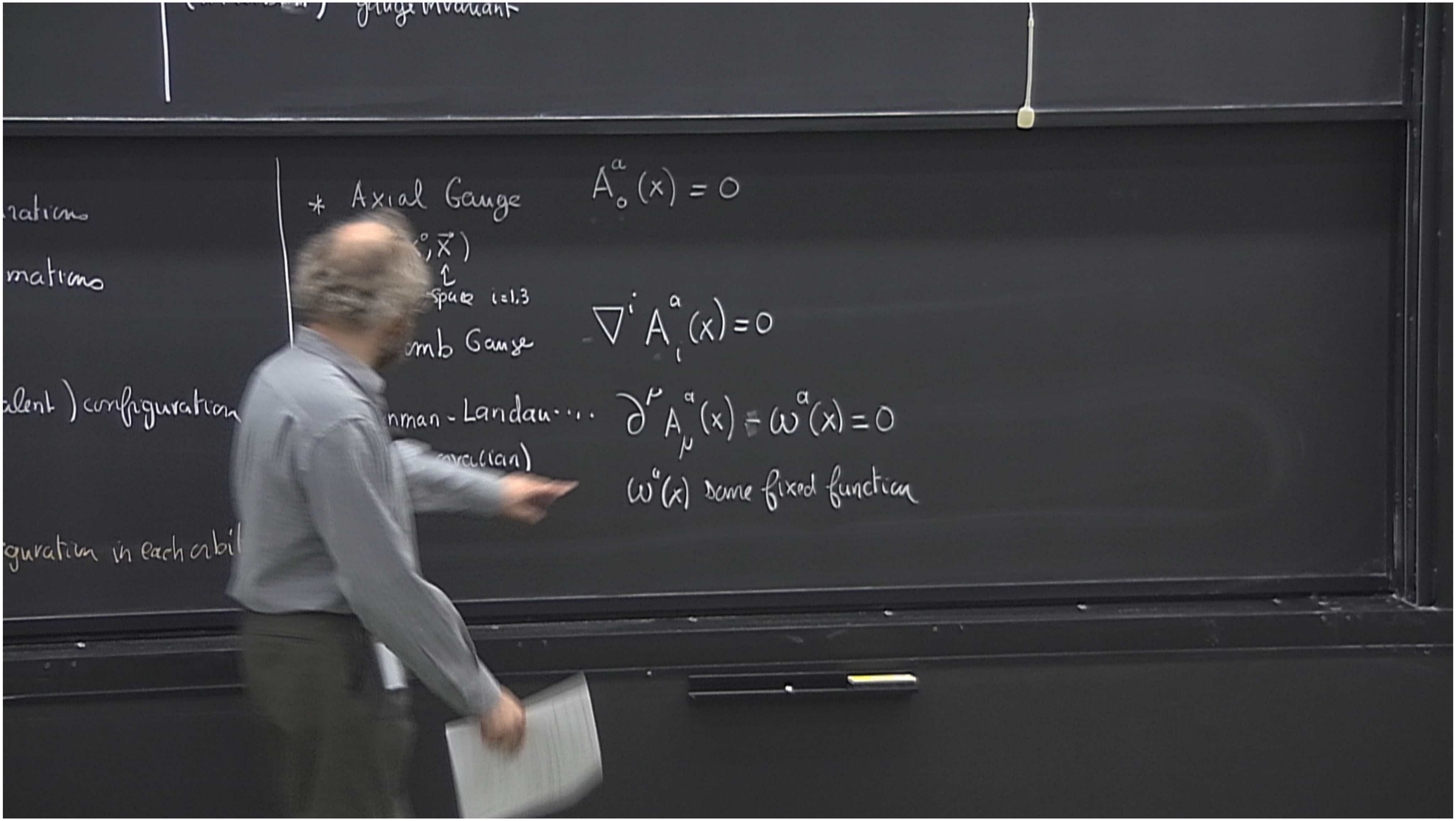
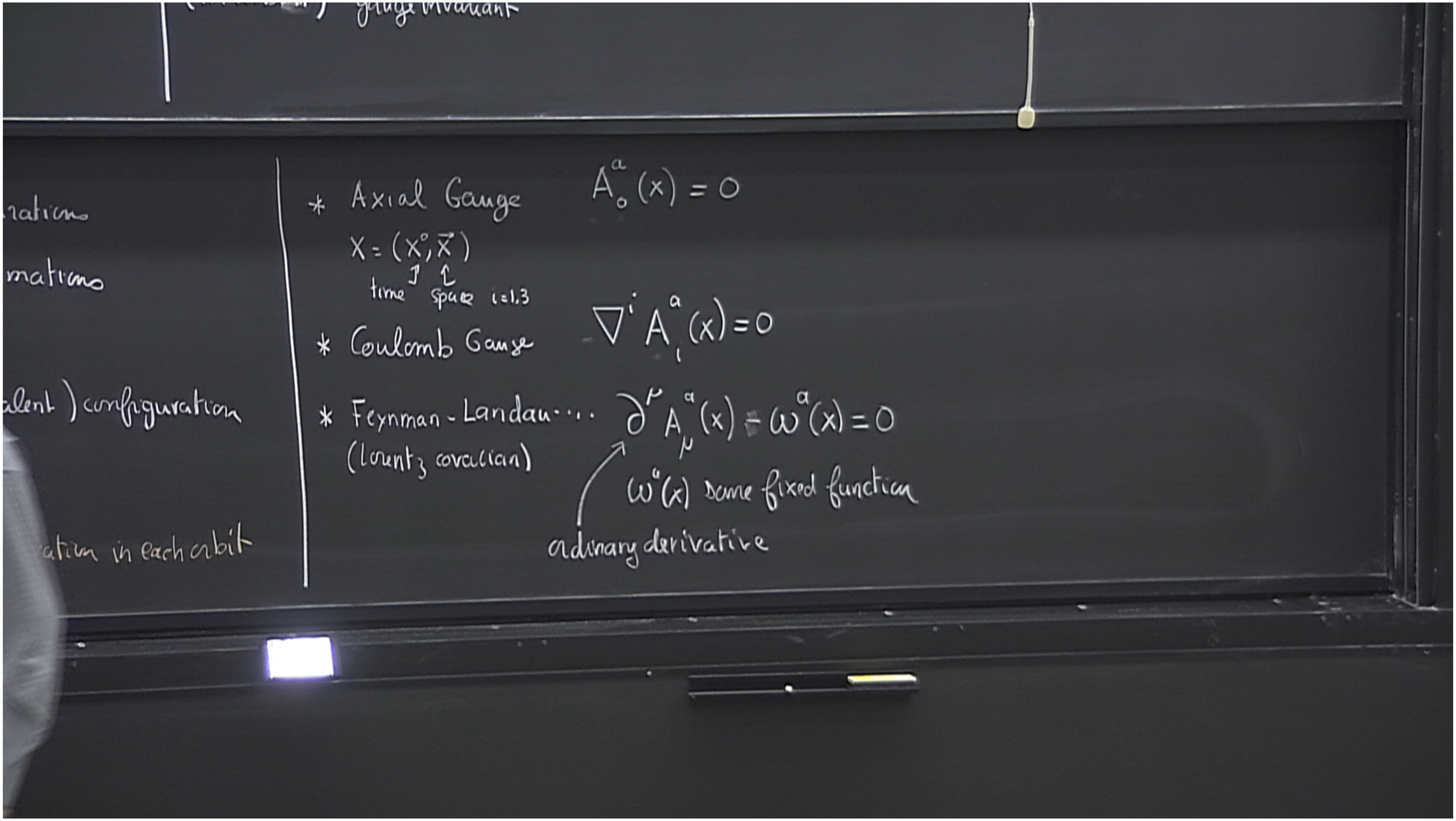
* Feynman - Landau ...
(Lorentz covariant)
configuration
guration in each orbit


* Axial Gauge
$A^a_0(x) = 0$
$\nabla^i A^a_i(x) = 0$
mb Gauge
nman - Landau . . .
$\partial^\mu A^a_\mu(x) - \omega^a(x) = 0$
$\omega^a(x)$ some fixed function
ations
mations
alent) configuration
guration in each orbi


gauge invariant
rations
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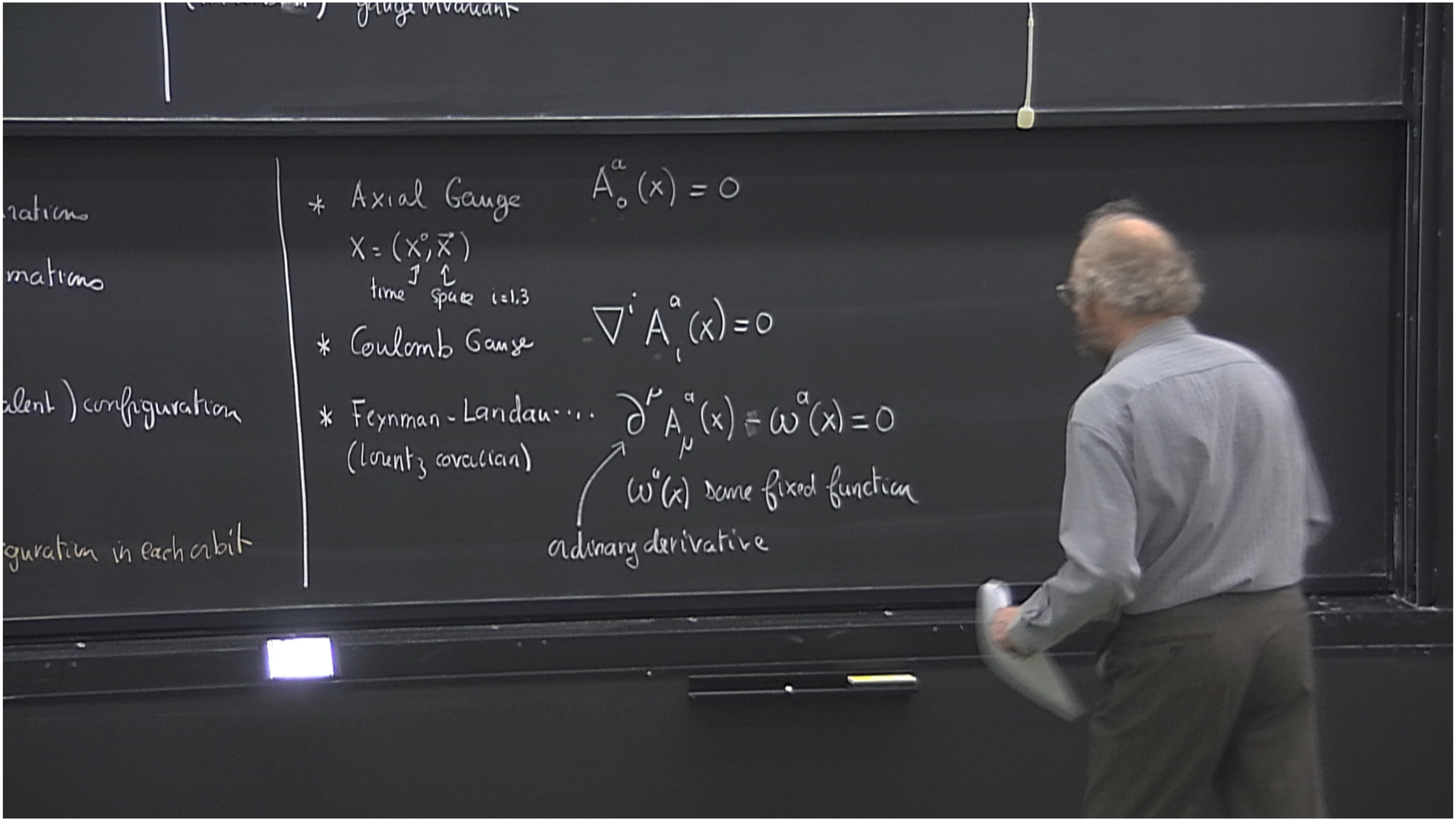
(Lorentz covariant)
$\omega^a(x)$ some fixed function
ordinary derivative



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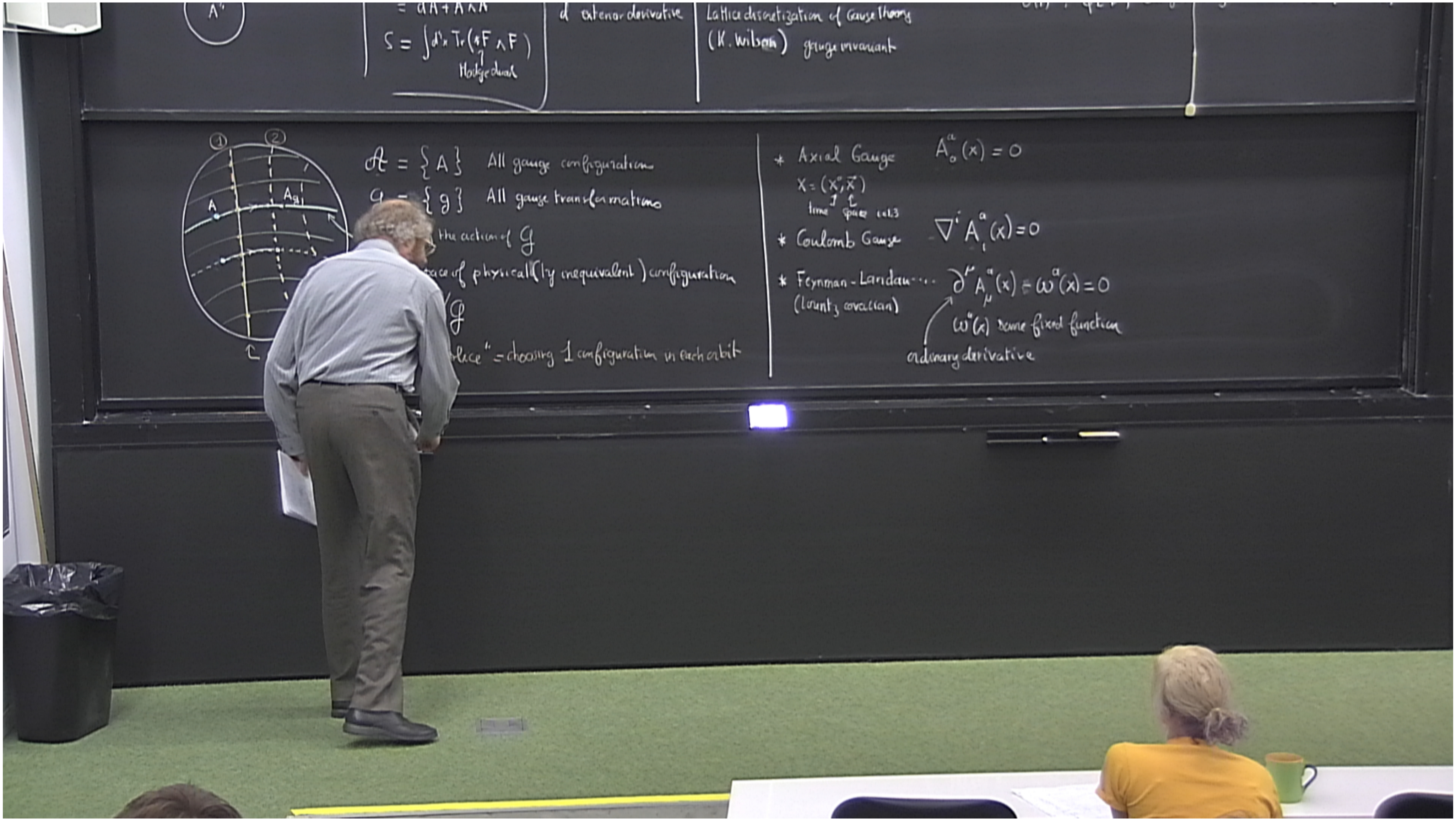
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Lattice discretization of Gauge Theory
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$\mathcal{A} = \{A\}$ All gauge configurations
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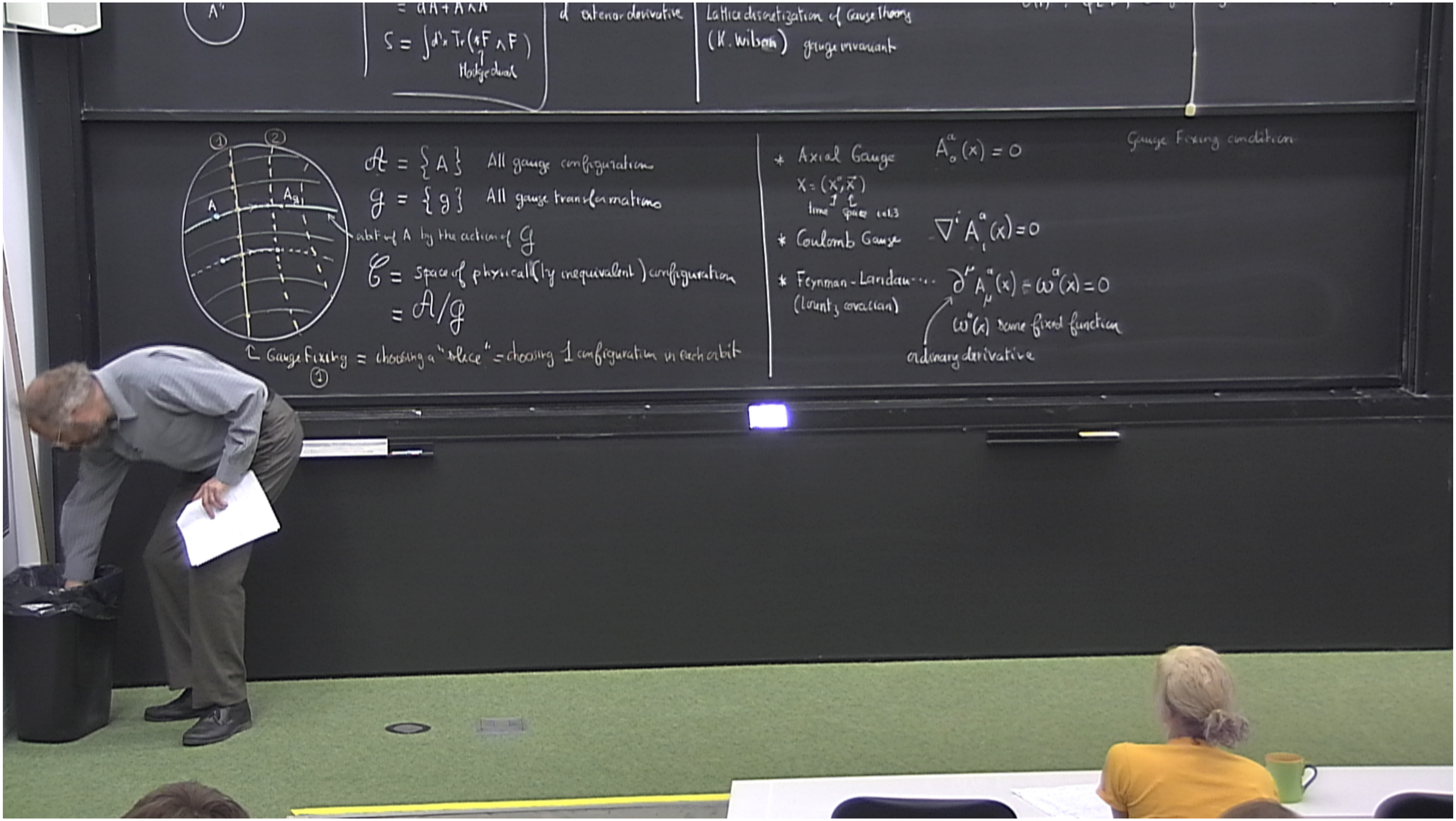
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Gauge Fixing = choosing a "slice" = choosing 1 configuration in each orbit
Axial Gauge
Coulomb Gauge
Feynman-Landau
(Lorentz covariant)
Gauge Fixing condition
some fixed function
ordinary derivative

$$A_0^a(x) = 0$$

Gauge Fixing condition

$$F^a[A](x) = 0$$ all a and x

↑ Function involving A and its derivatives

$$\nabla^i A_i^a(x) = 0$$

$$\partial^\mu A_\mu^a(x) - \omega^a(x) = 0$$

$\omega^a(x)$ some fixed function

ordinary derivative

* Axial Gauge $A_0^a(x) = 0$

$x = (x^0, \vec{x})$

time ↑ ↑ space $i = 1, 3$

* Coulomb Gauge $\nabla^i A_i^a(x) = 0$

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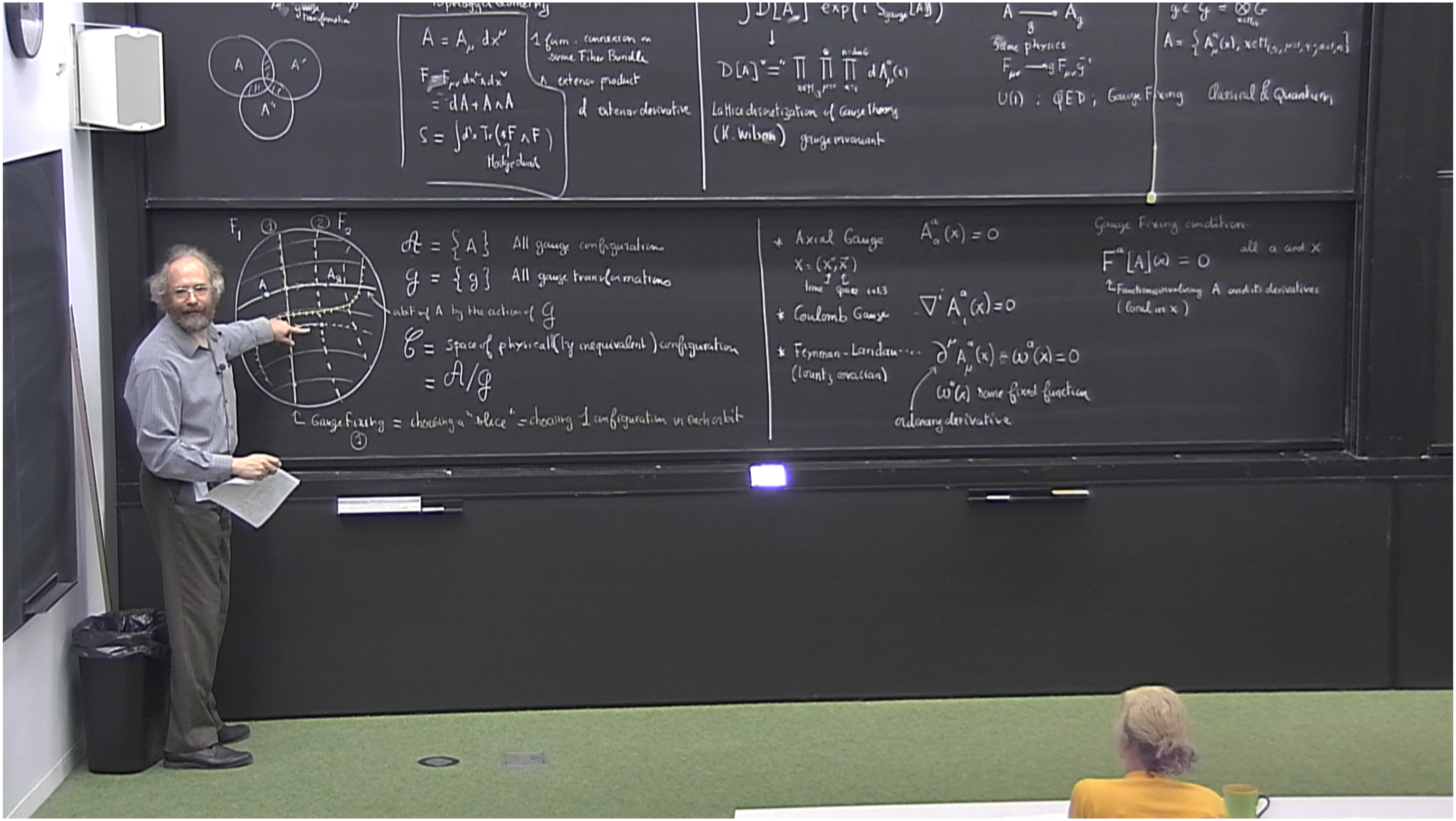
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U(1) : QED ; Gauge Fixing   Classical & Quantum
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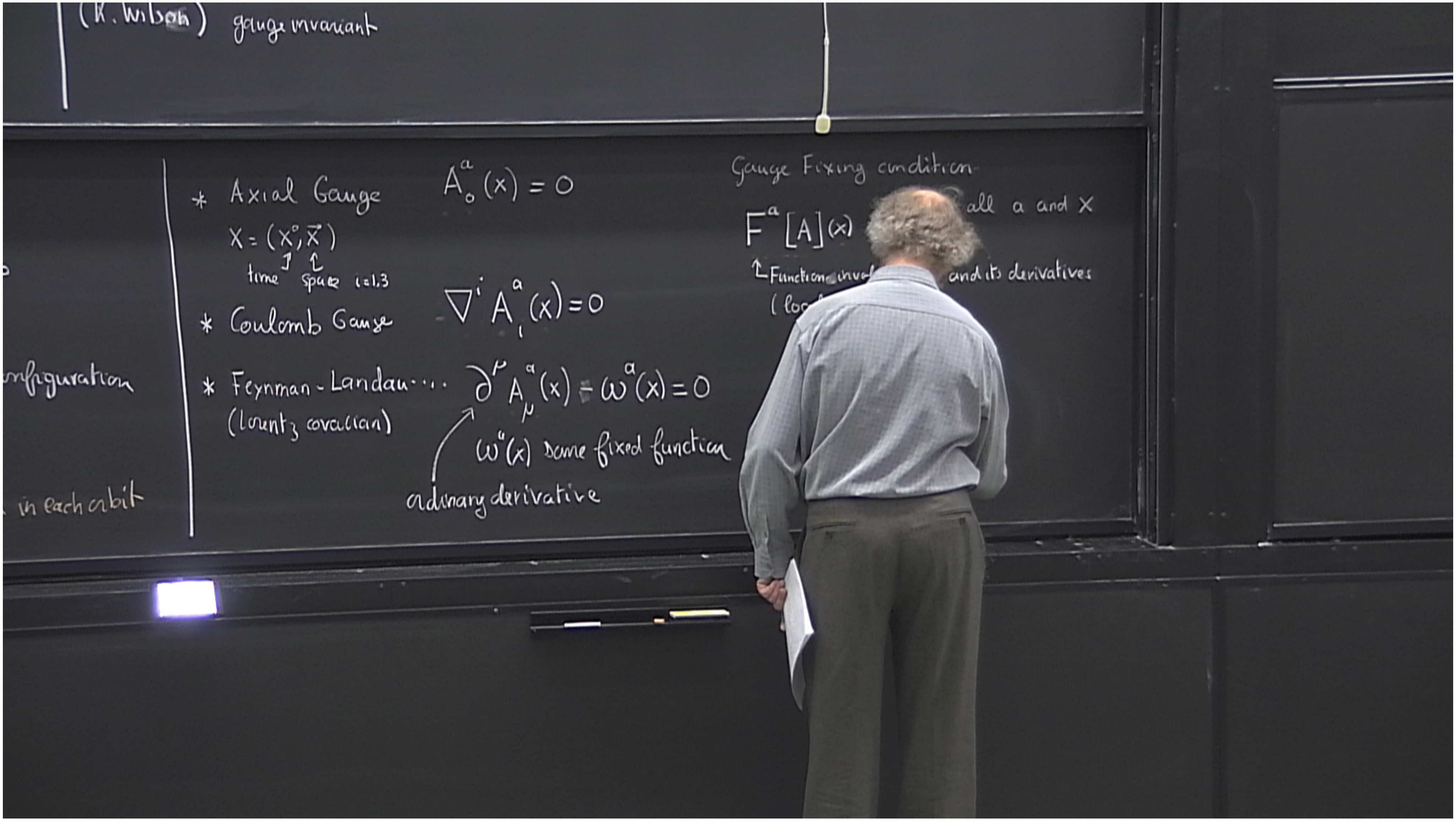
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$F^a[A](x)$
Function
and its derivatives
nfiguration
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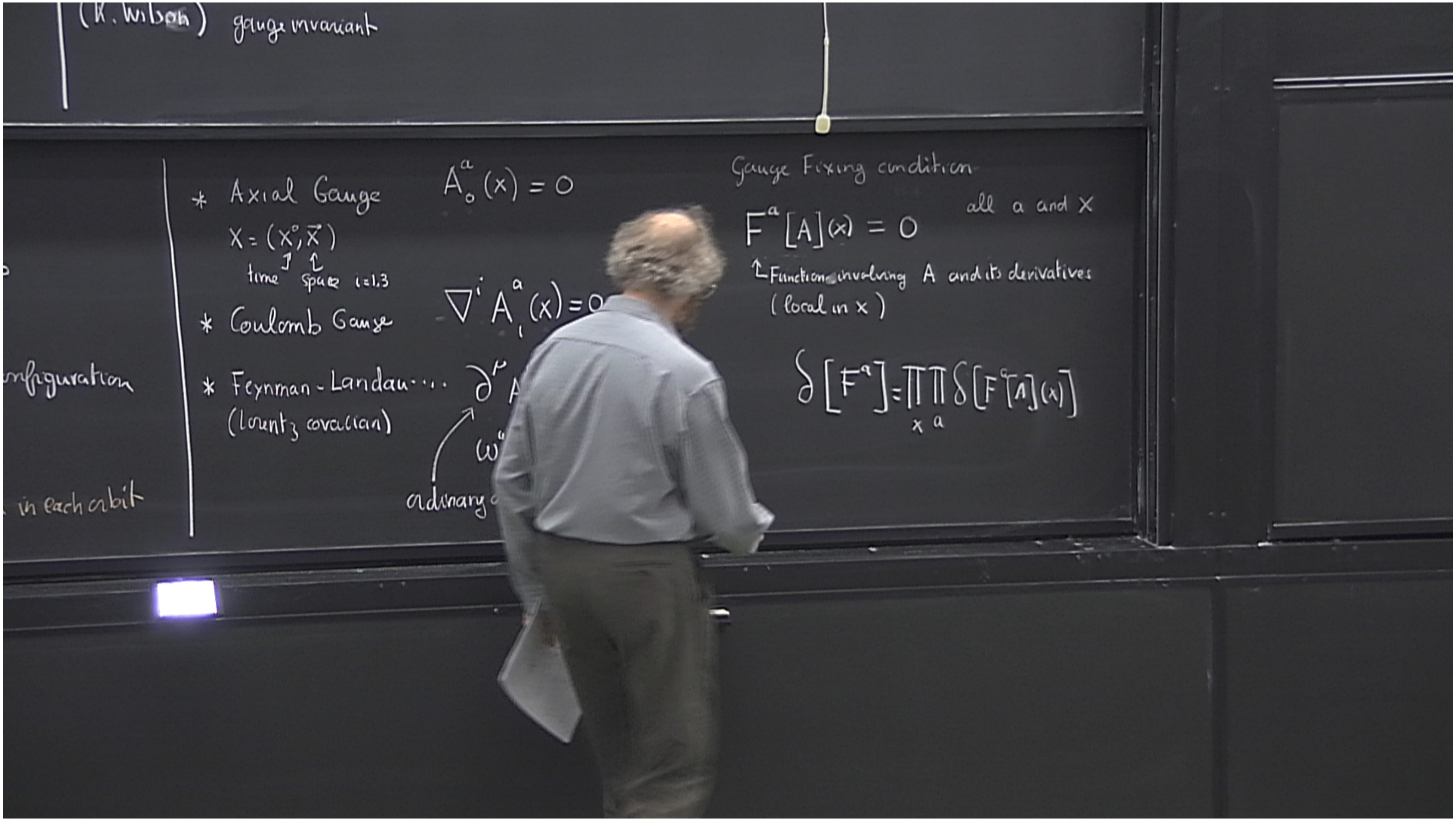

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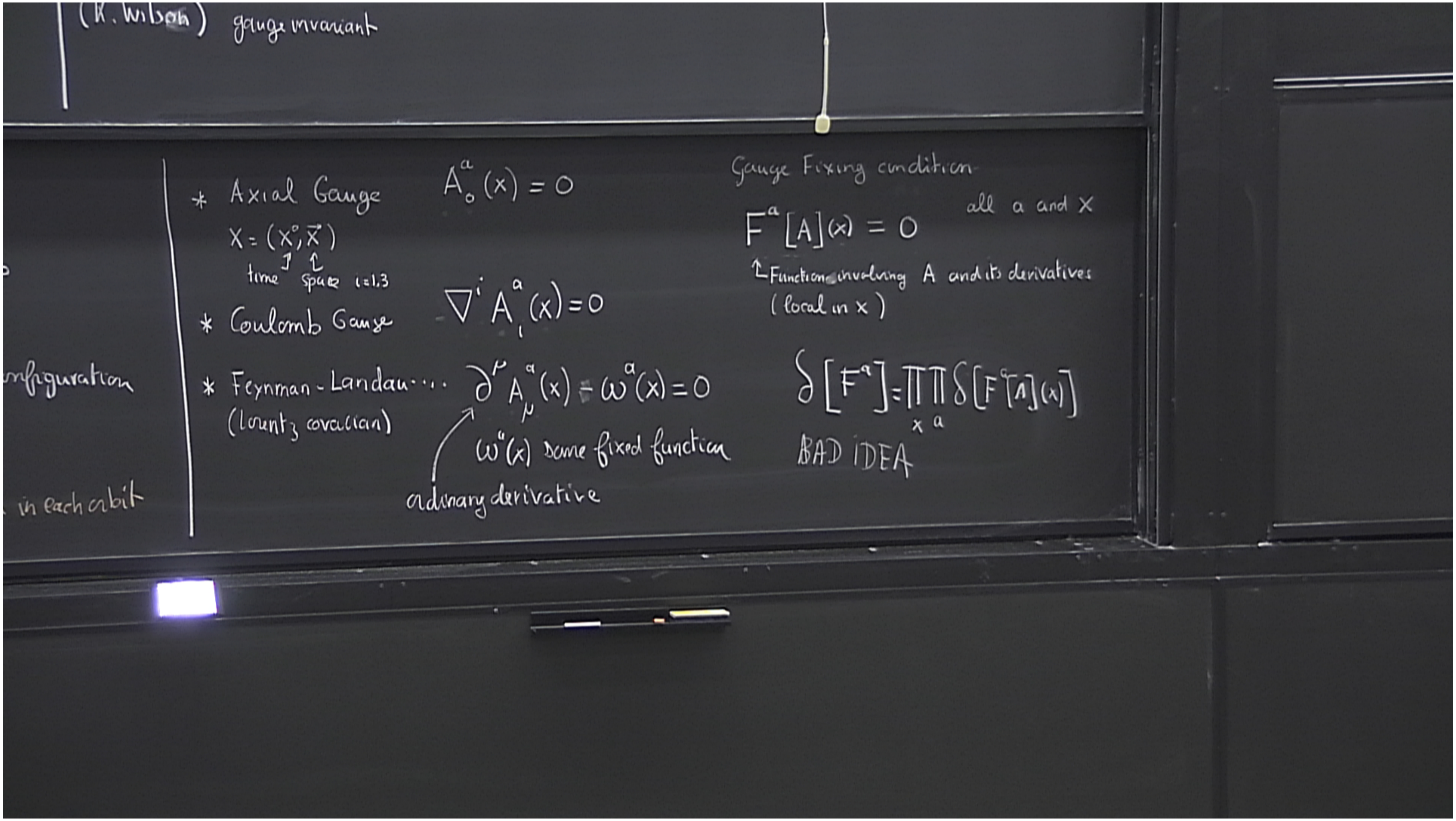
ordinary
Gauge Fixing condition
$F^a[A](x) = 0$
all a and x
Function involving A and its derivatives
(local in x)
$\delta[F^a] = \prod_x \prod_a \delta[F^a[A](x)]$
in each orbit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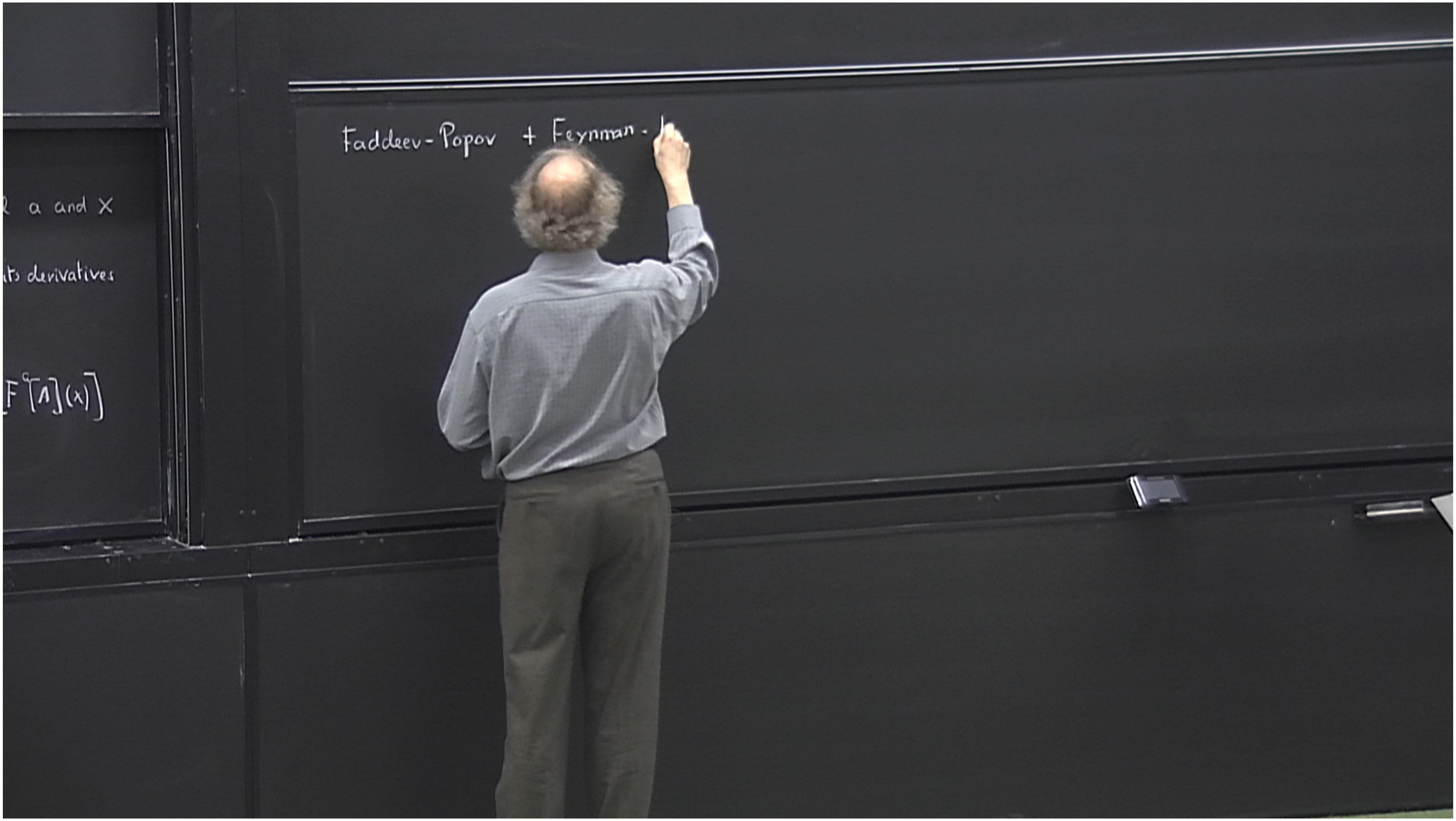
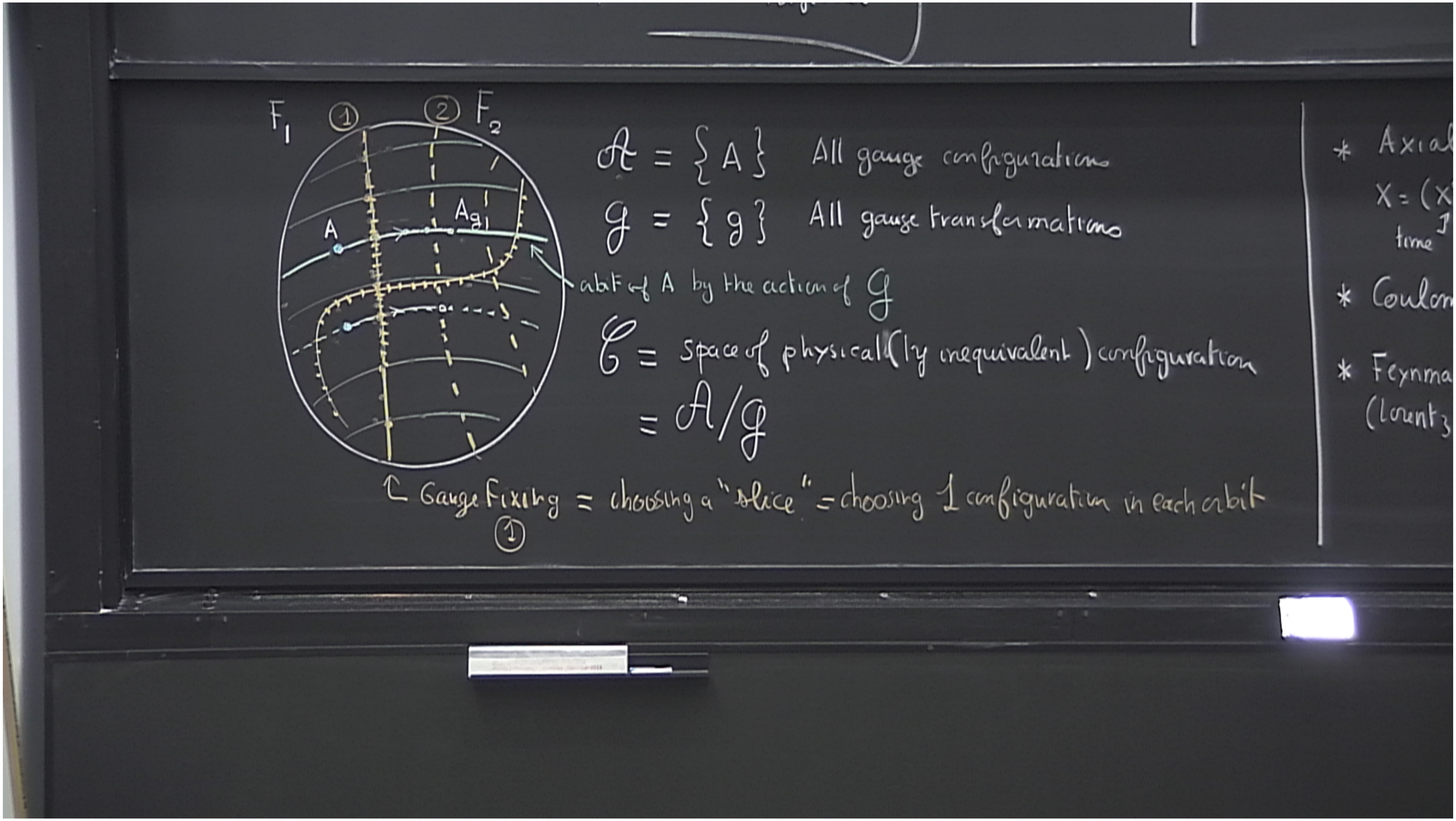
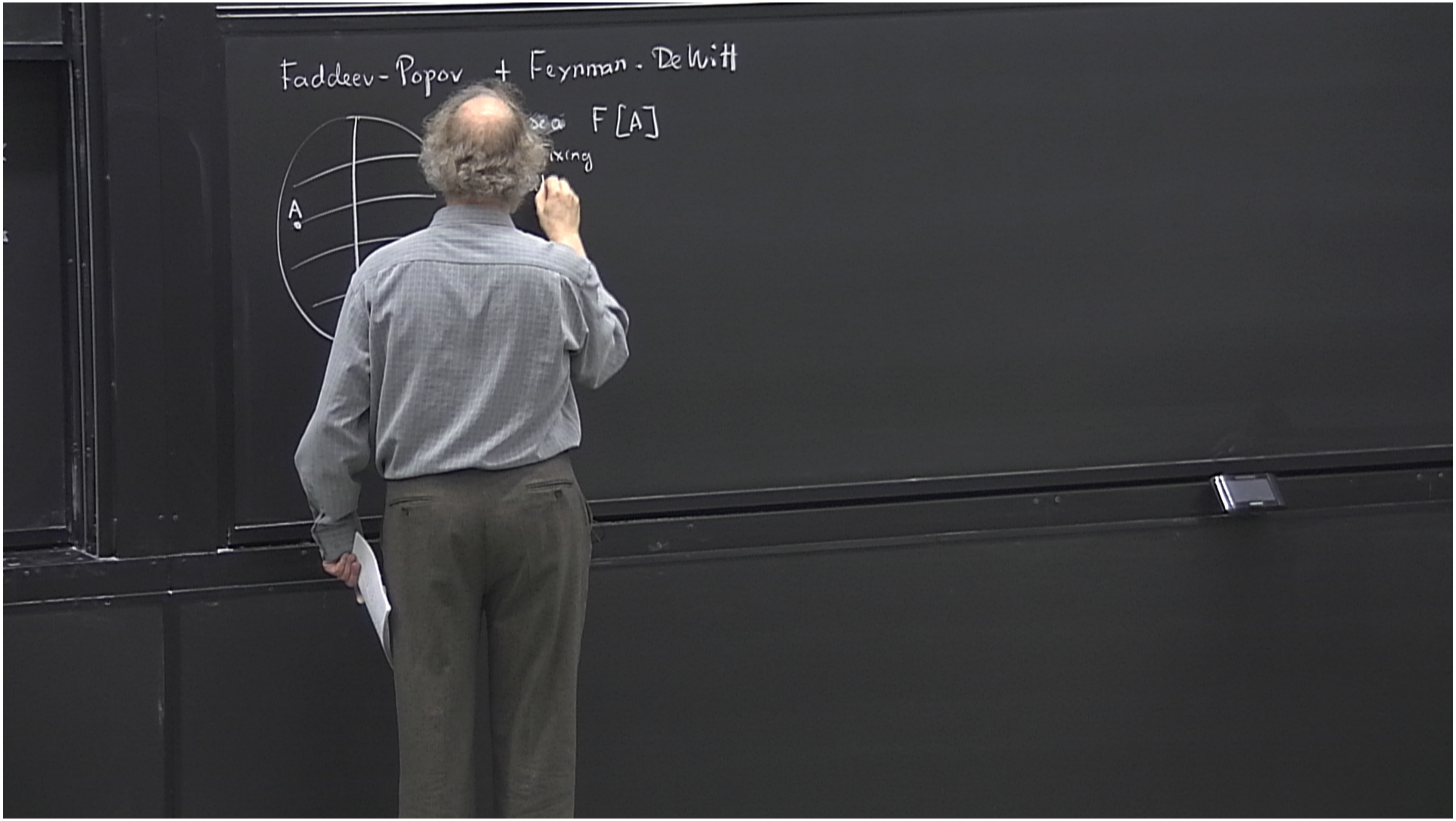
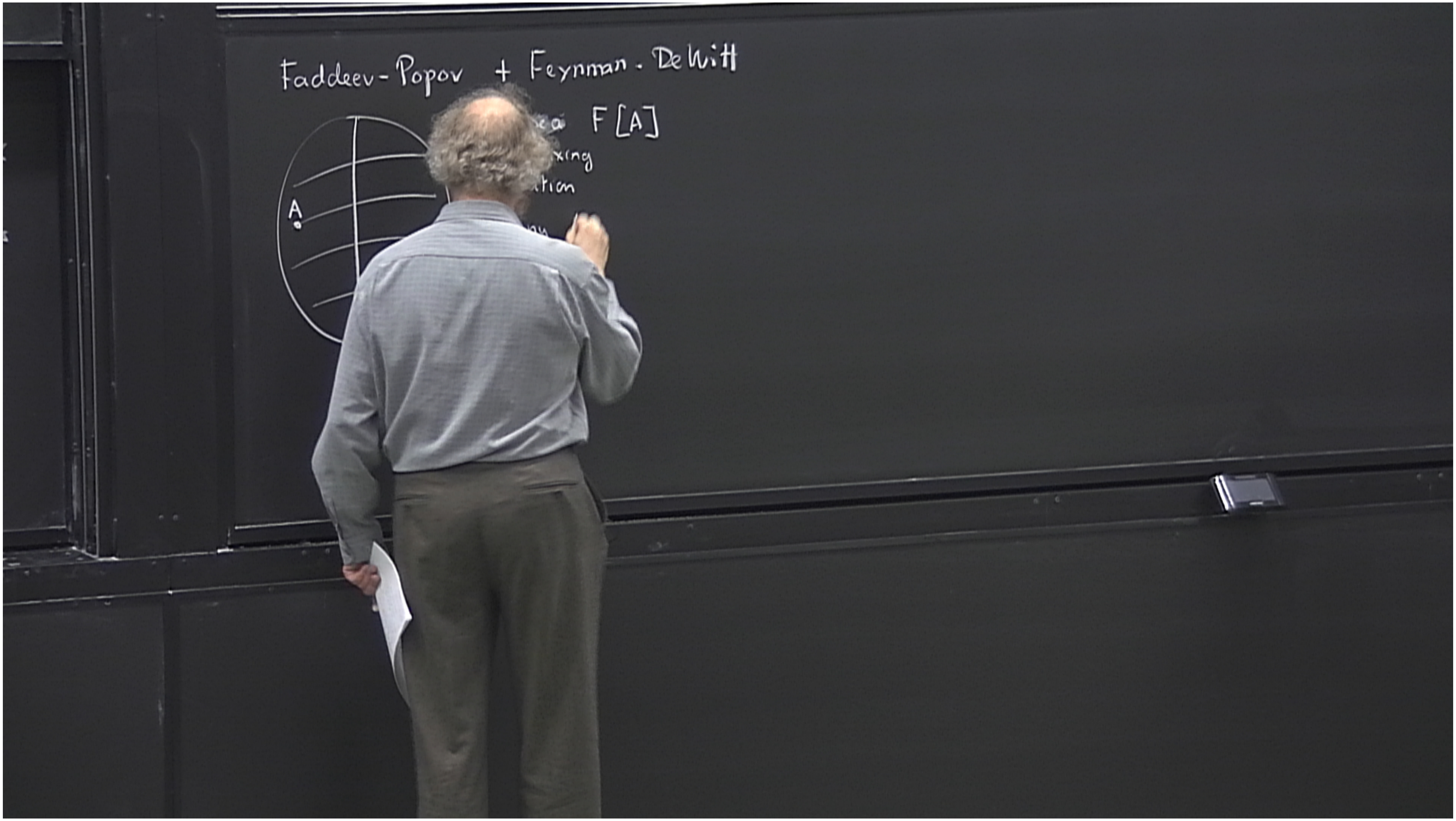
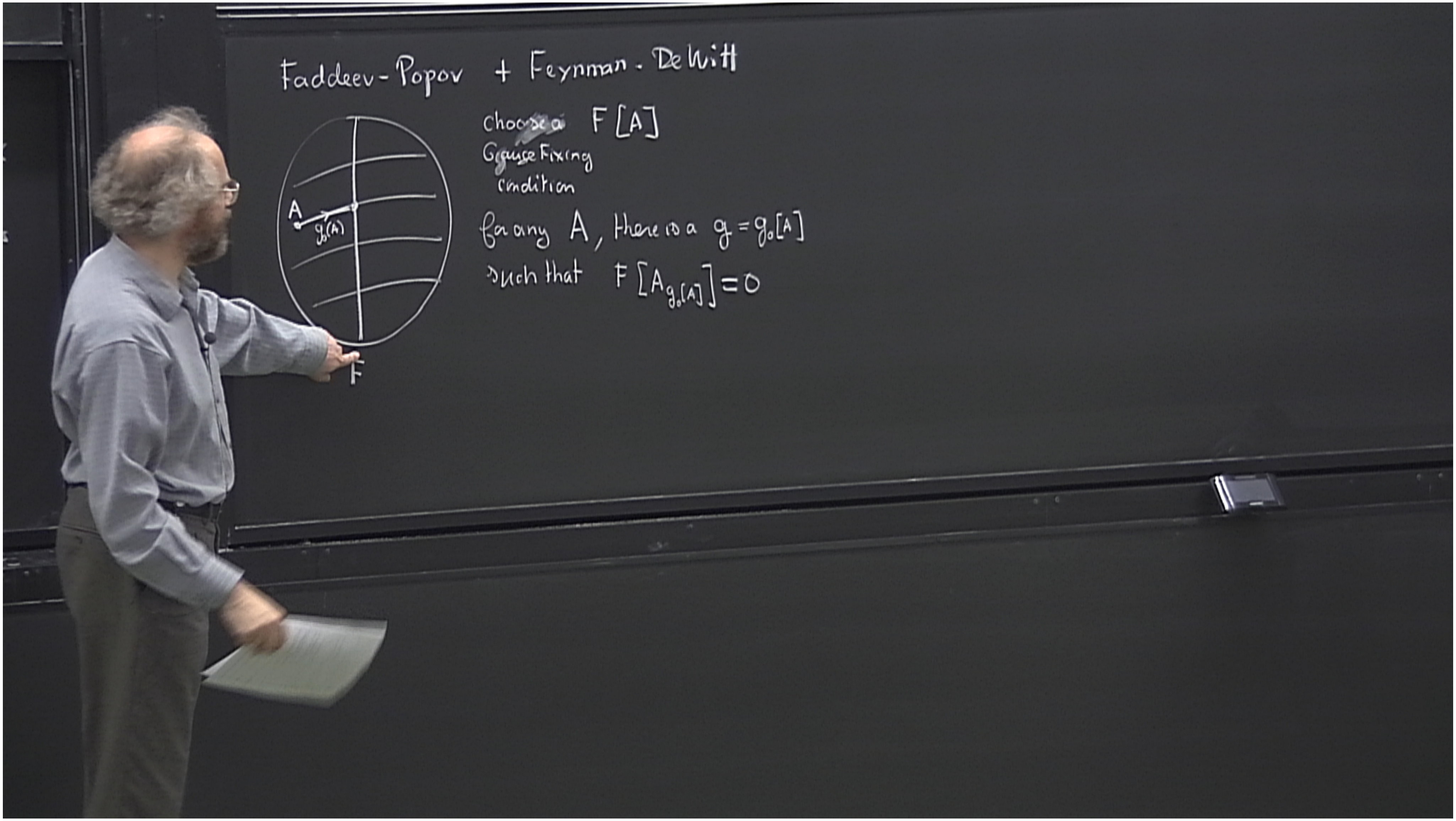
BAD IDEA
nfiguration
in each orbit

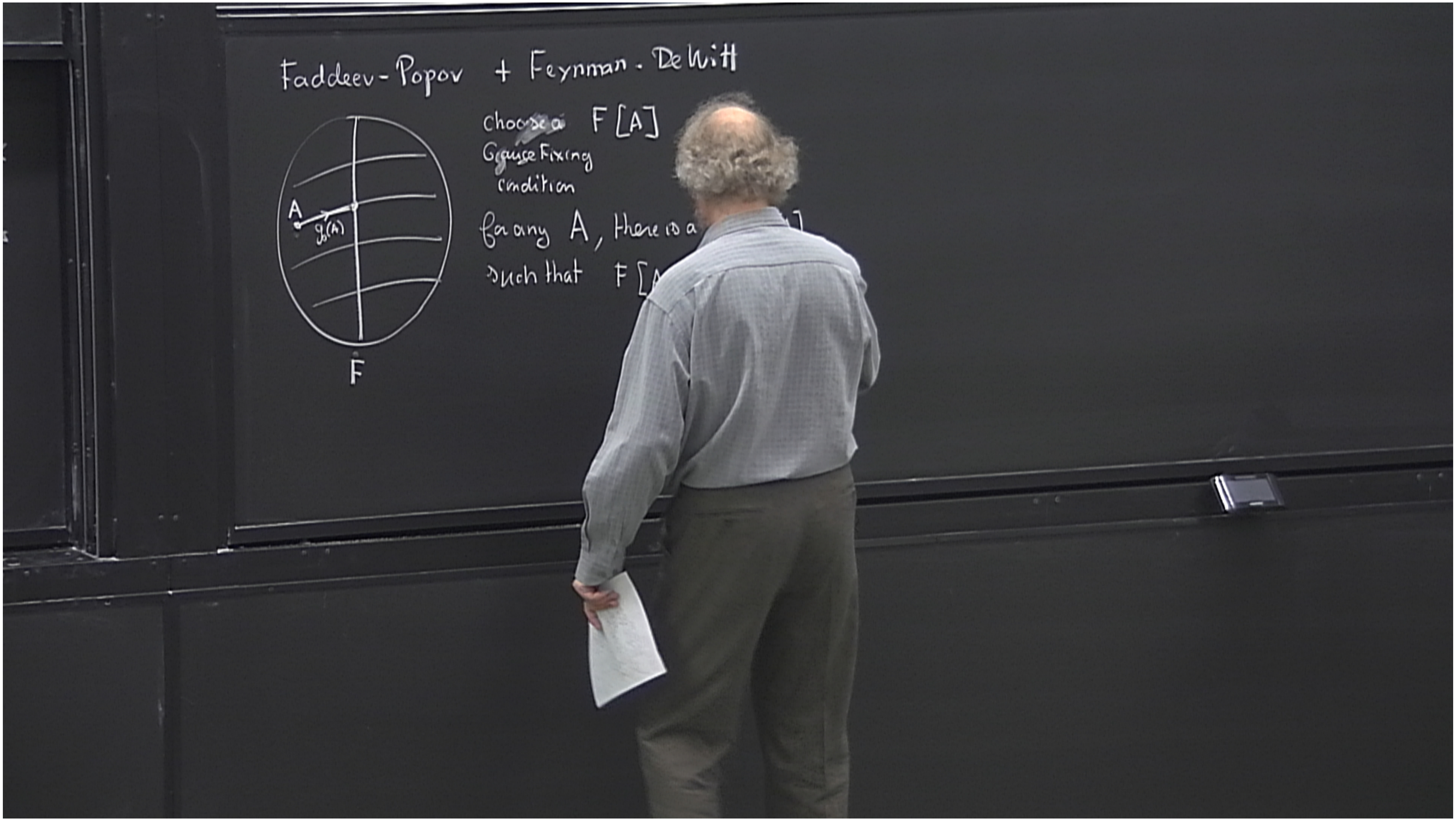

Faddeev-Popov + Feynman -
a and X
derivatives

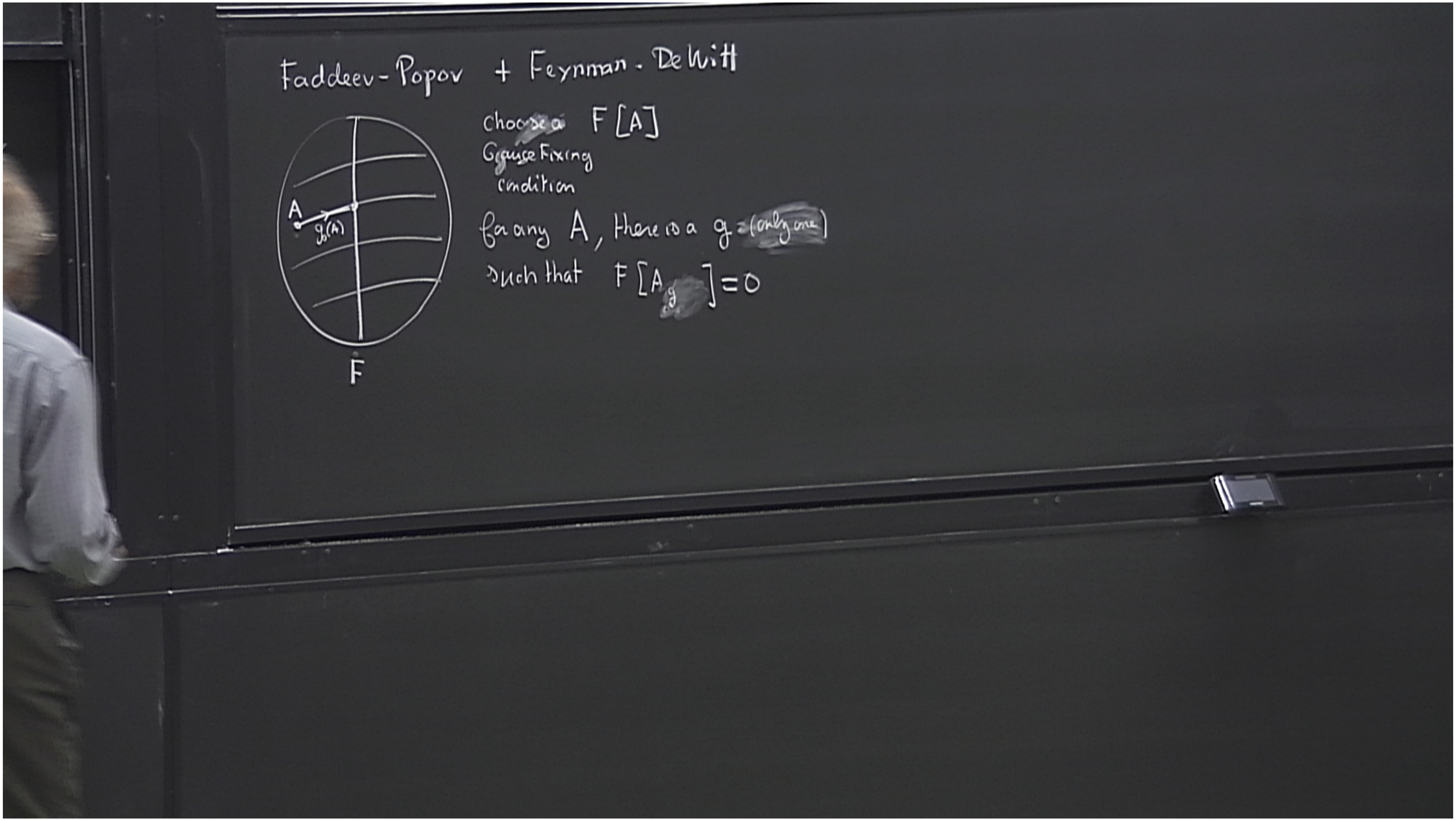

F1 ① ② F2
A
Ag1
𝒜 = { A } All gauge configurations
𝒢 = { g } All gauge transformations
orbit of A by the action of 𝒢
𝒞 = space of physical(ly inequivalent) configuration
= 𝒜/𝒢
Gauge fixing = choosing a "slice" = choosing 1 configuration in each orbit
①
* Axia
time
* Coulom
* Feynma

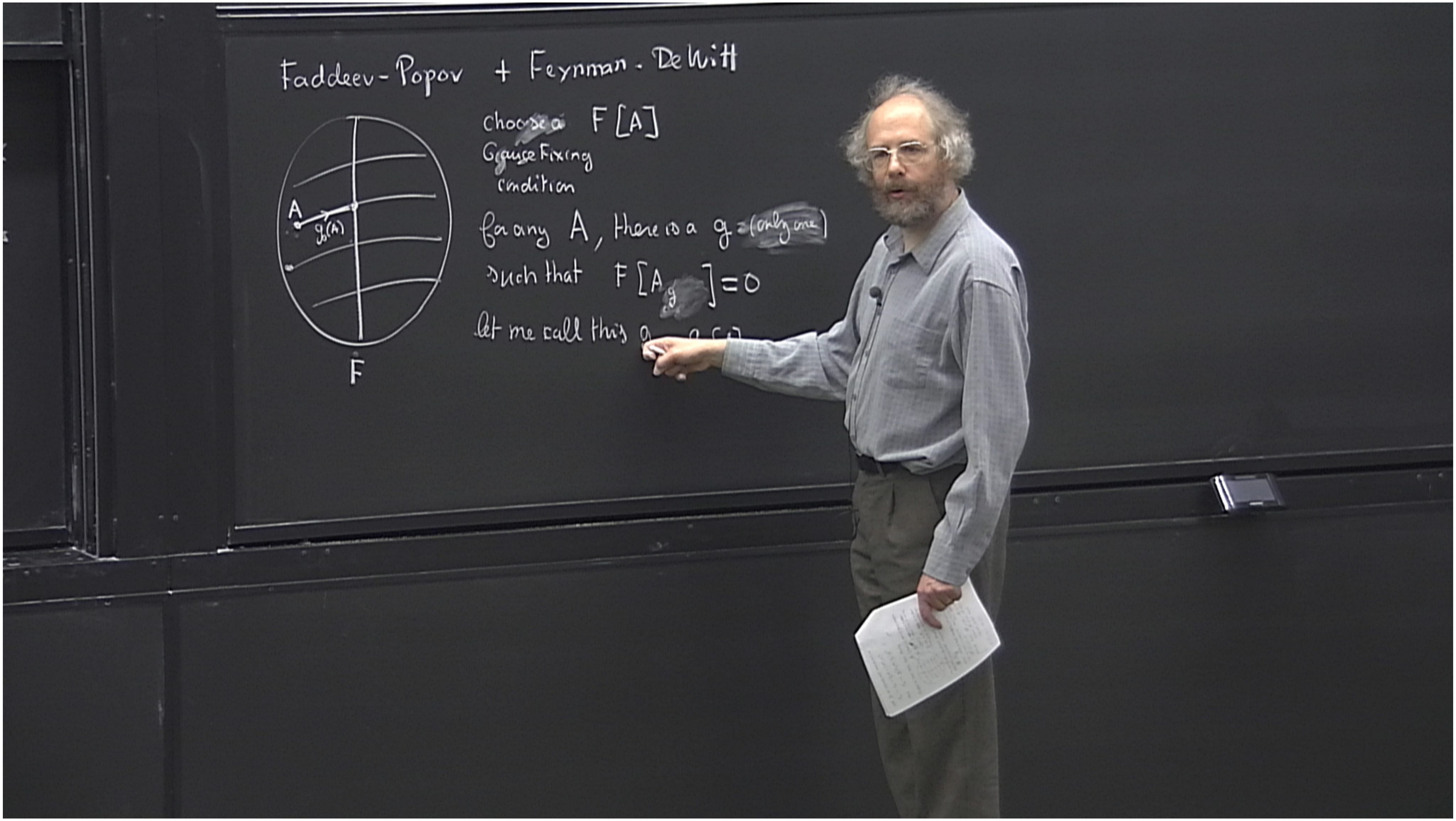

Faddeev - Popov + Feynman - DeWitt
F [A]
ixing
A

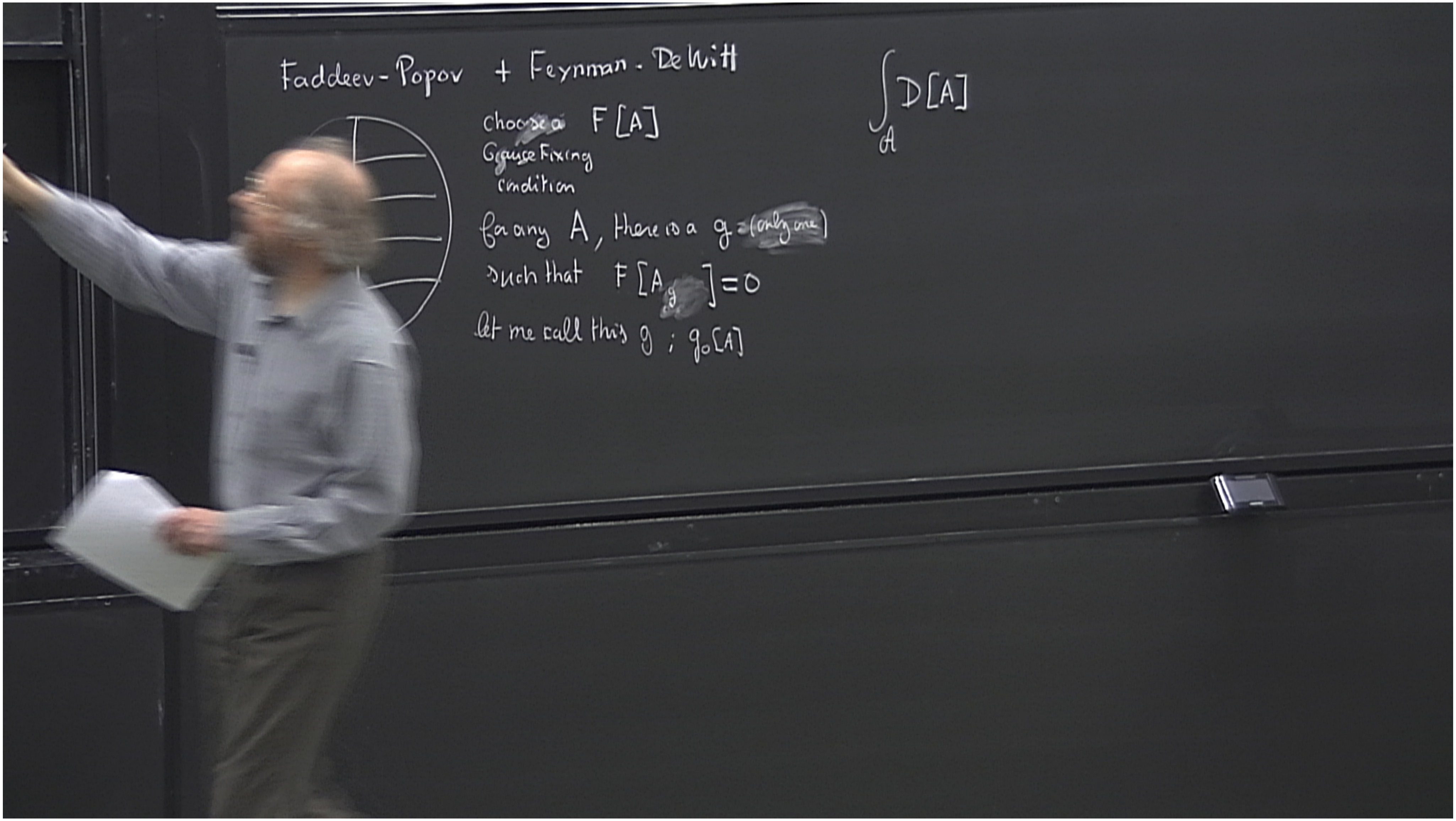

Faddeev-Popov + Feynman-DeWitt
F[A]
A

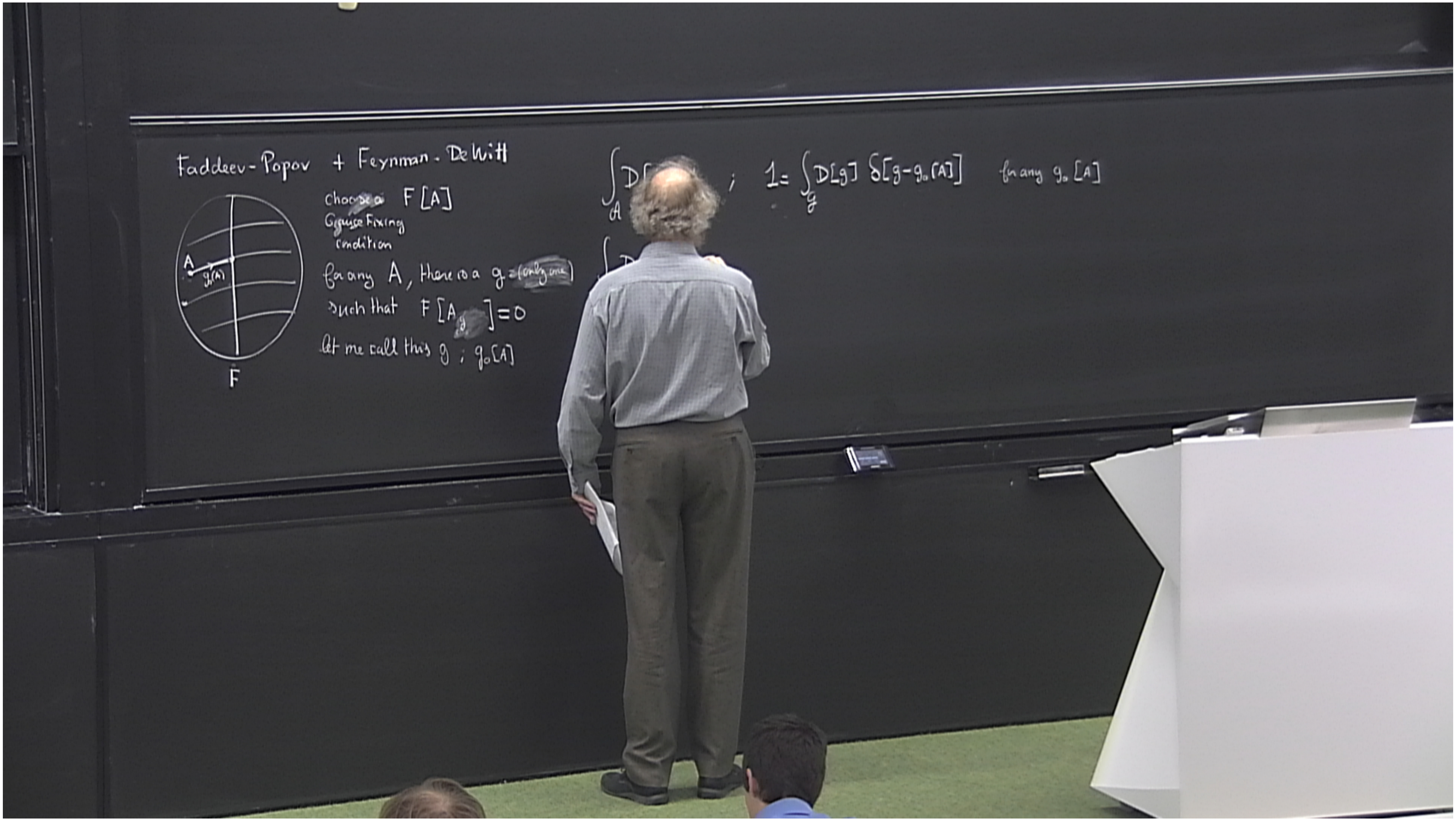

Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g = g0[A]
such that F[Ag0[A]] = 0
A
g0(A)
F

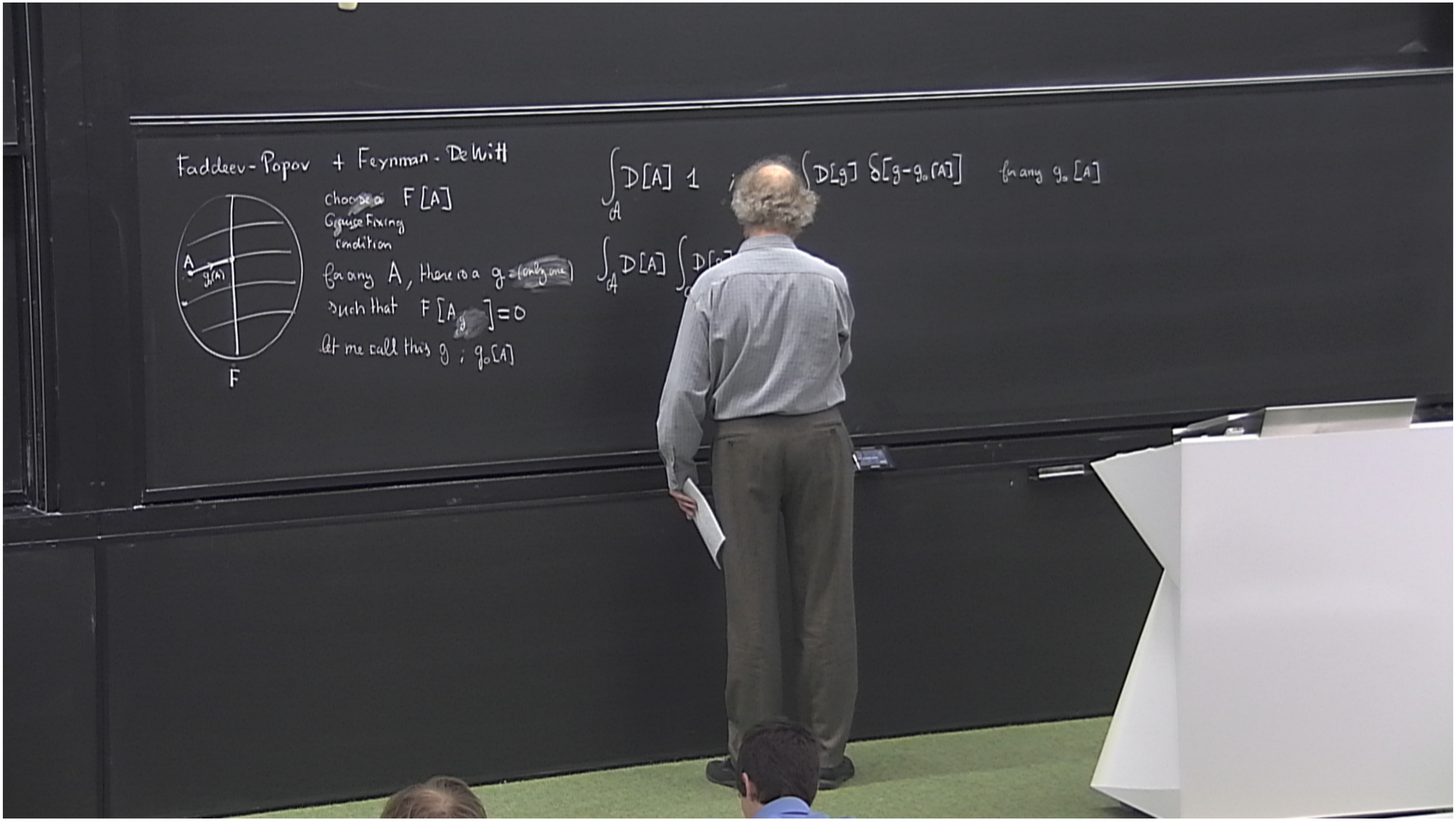

Faddeev-Popov + Feynman - DeWitt
Choose a F [A]
Gauge Fixing
condition
for any A, there is a
such that F [A
A
F

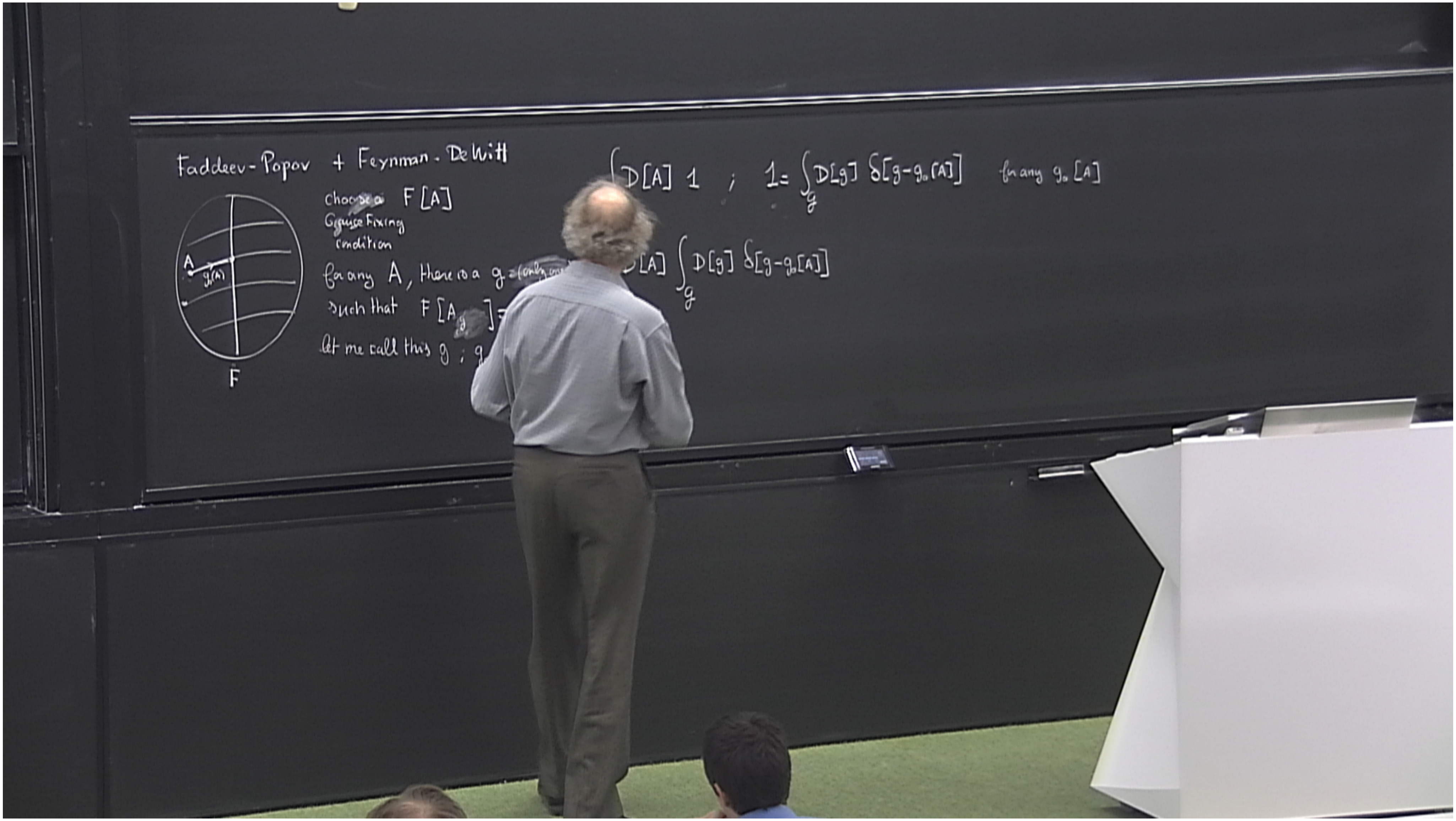

Faddeev - Popov + Feynman - DeWitt
Choose a F [A]
Gauge Fixing
condition
for any A, there is a g (only one)
such that F [A g] = 0
A
F

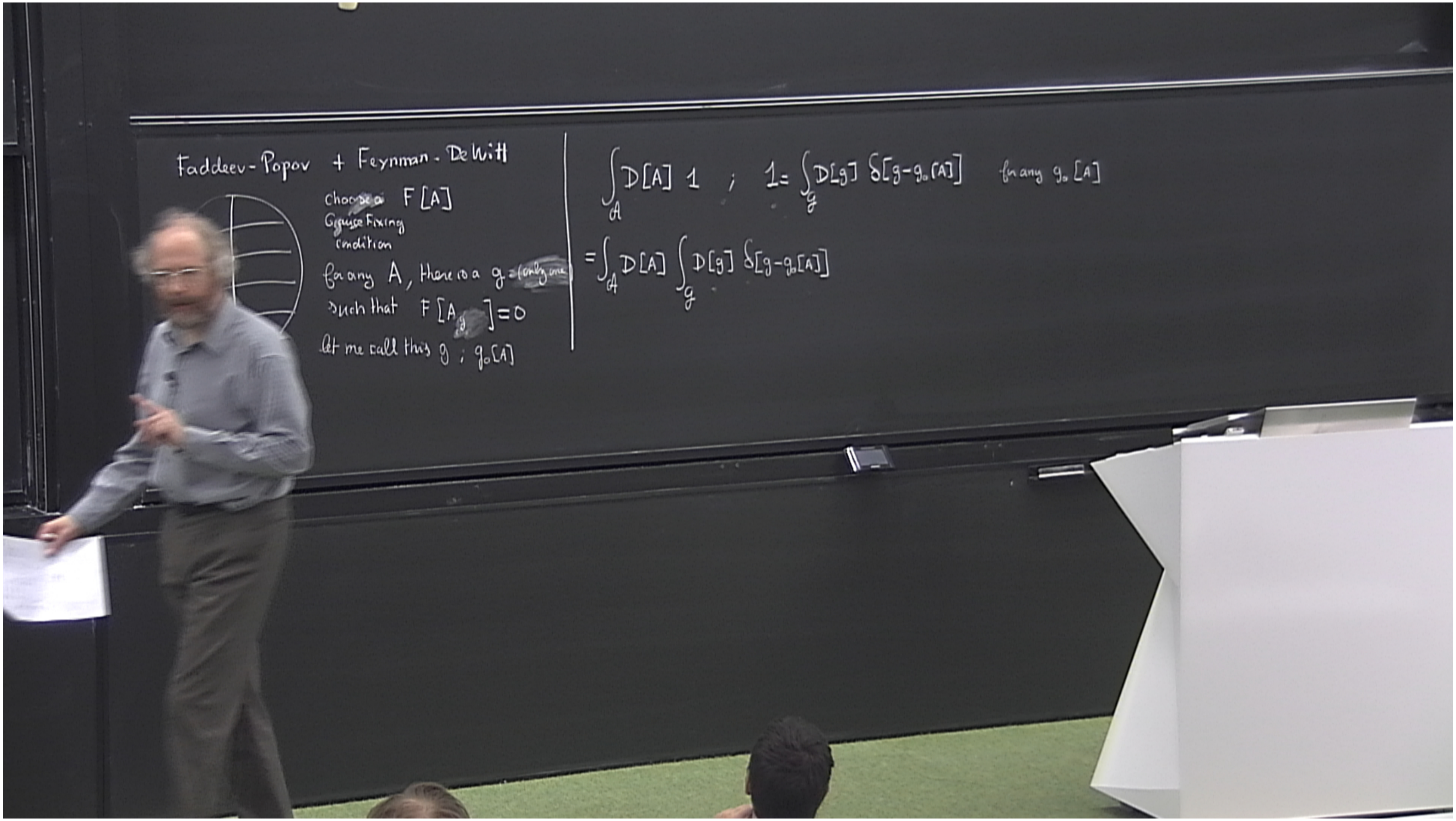

Faddeev-Popov + Feynman-DeWitt
choose a F[A]
Gauge Fixing condition
for any A, there is a g = (only one)
such that F[A g] = 0
let me call this
A
F


Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g (only one)
such that F[A g] = 0
let me call this g ; g0[A]
∫ D[A]
A

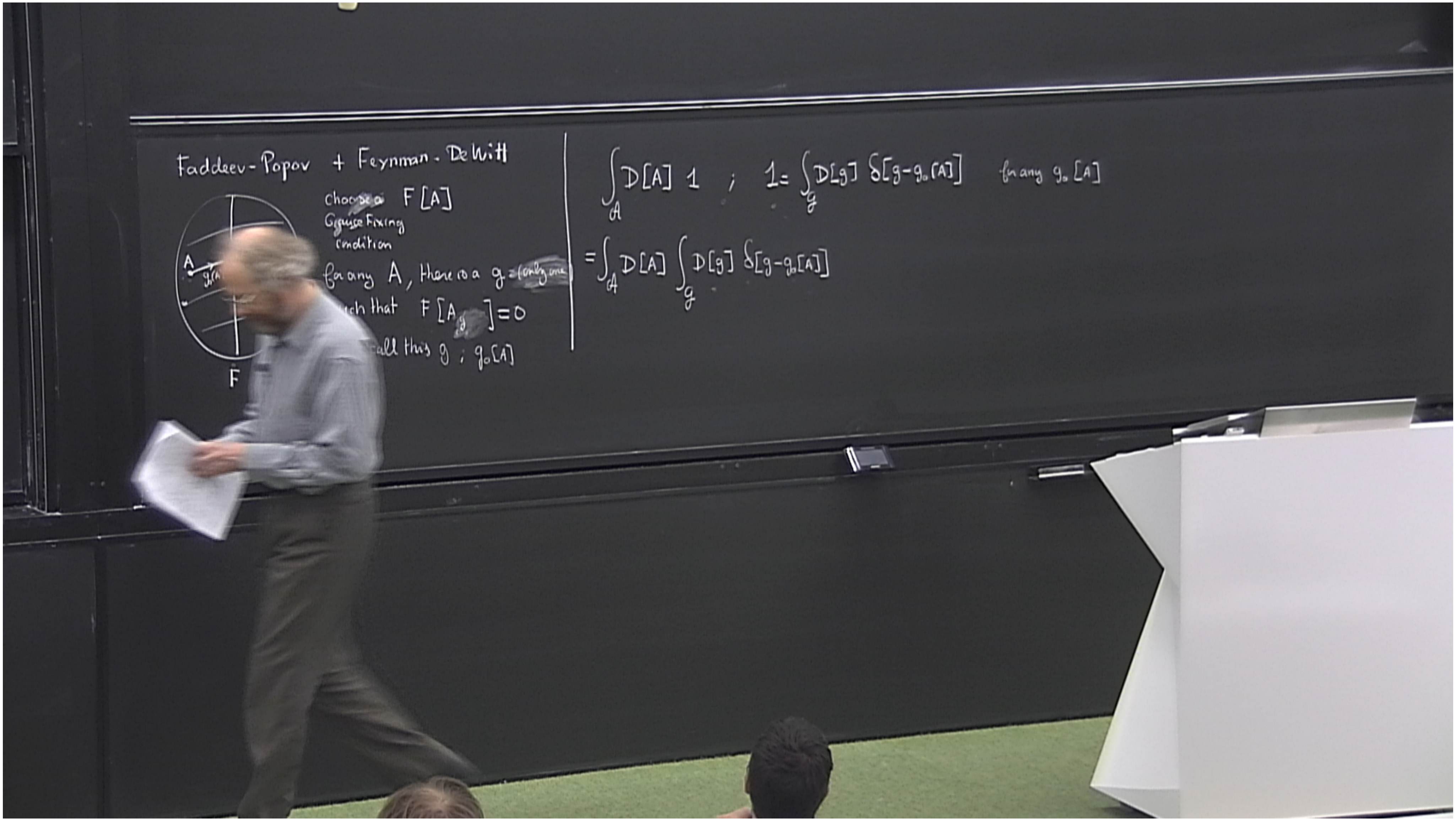

Faddeev - Popov + Feynman - DeWitt
Choose a F[A]
Gauge Fixing condition
A
F
for any A, there is a g (only one)
such that F[A_g] = 0
let me call this g ; g₀[A]
1 = ∫_g D[g] δ[g - g₀[A]]
for any g₀[A]

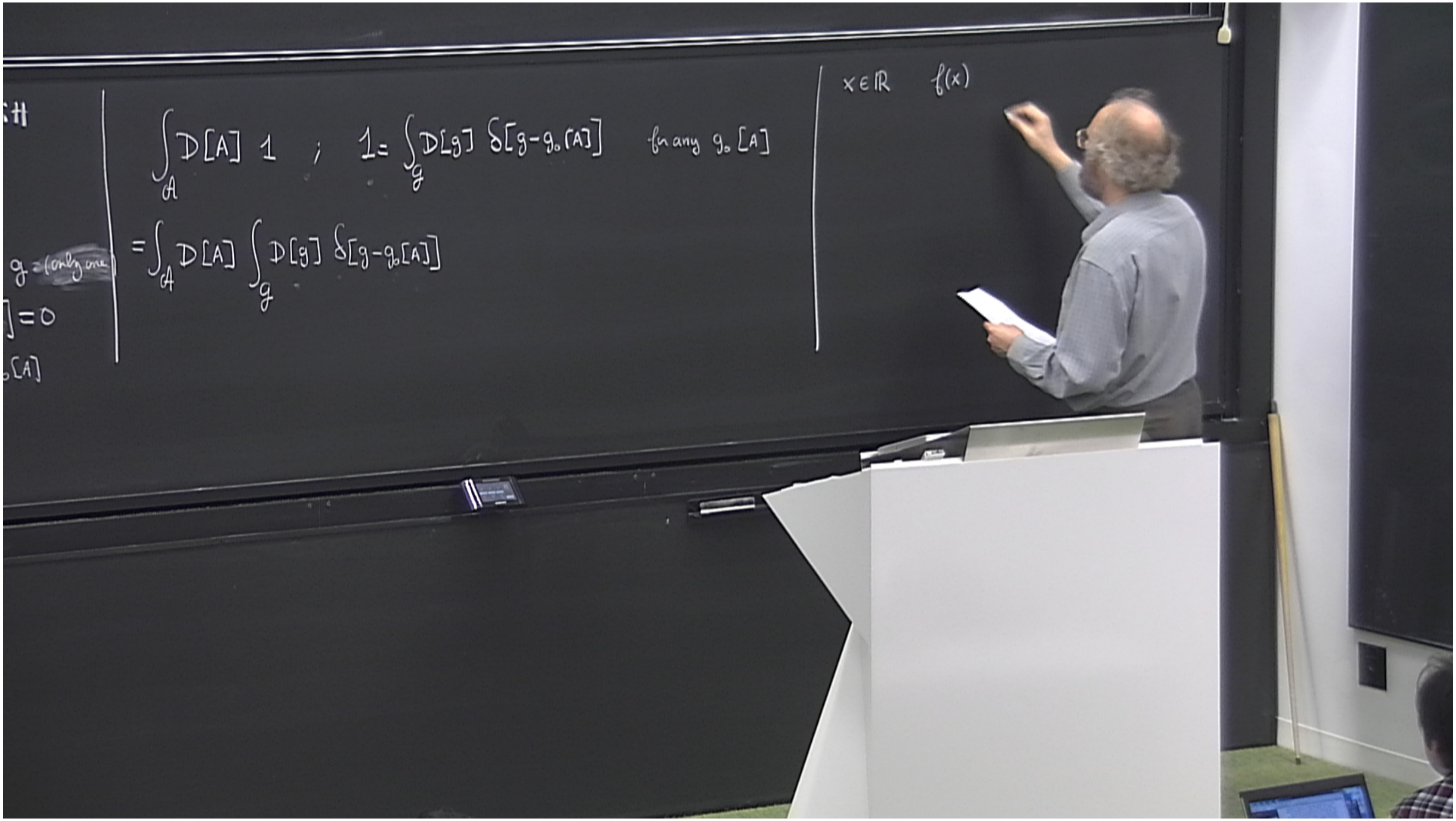

Faddeev - Popov + Feynman - DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g (only one)
such that F[A_g]=0
Let me call this g ; g_0[A]
A
F
for any g_0[A]

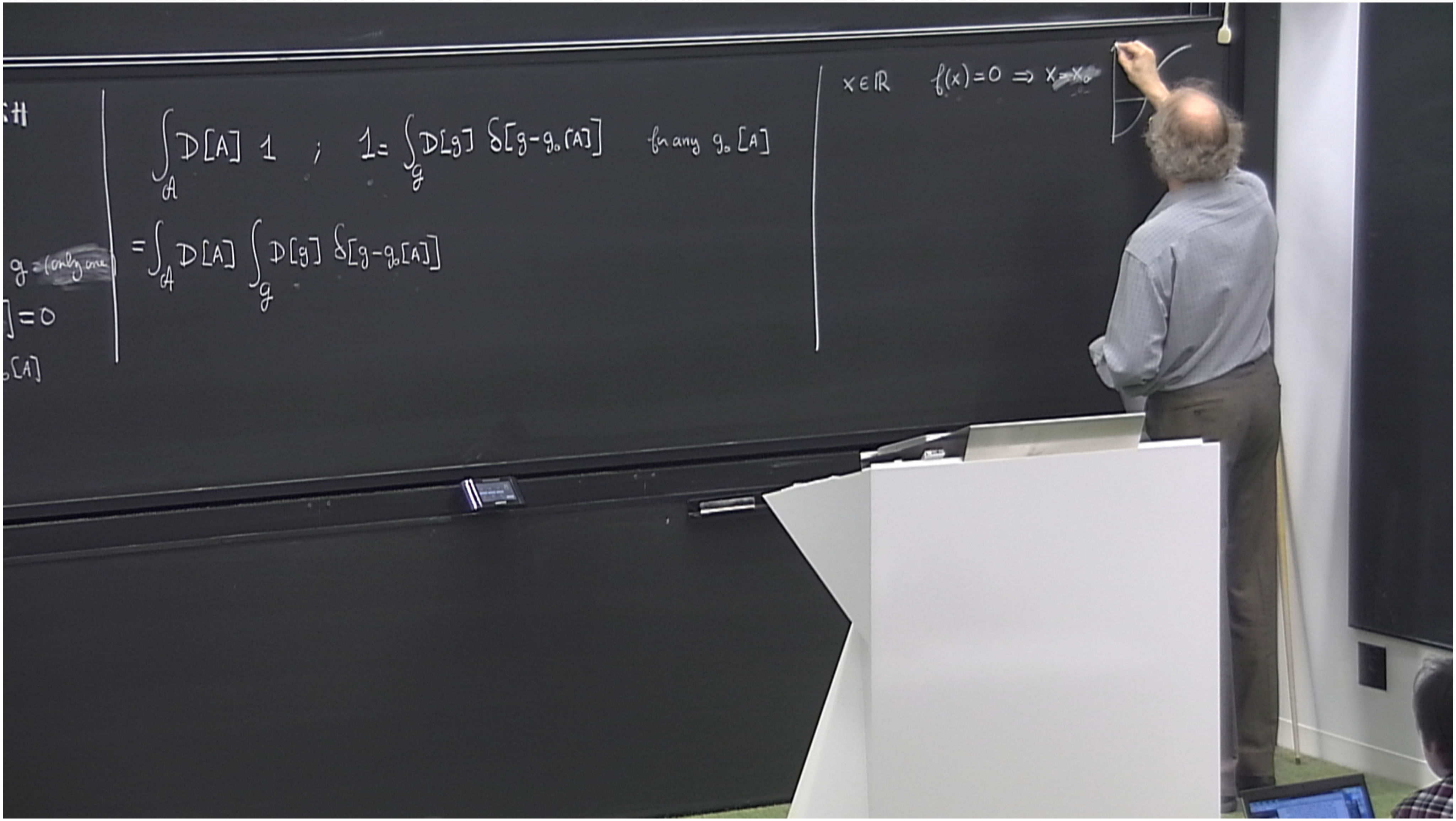

Faddeev - Popov + Feynman - DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g
such that F[A
let me call this g ; g
A
F
∫D[A] 1 ; 1 = ∫g D[g] δ[g - g0[A]] for any g0[A]
D[A] ∫g D[g] δ[g - g0[A]]

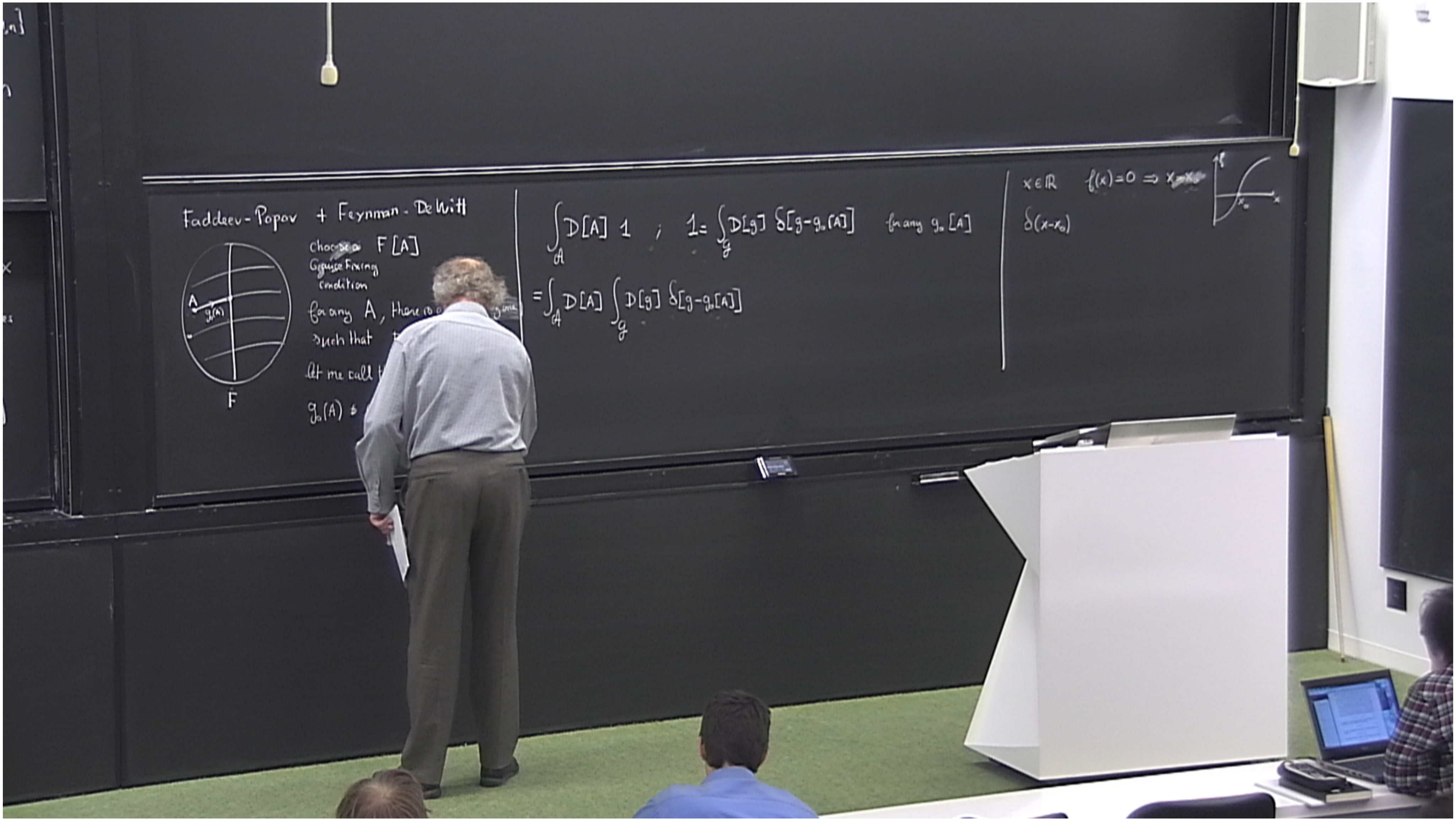


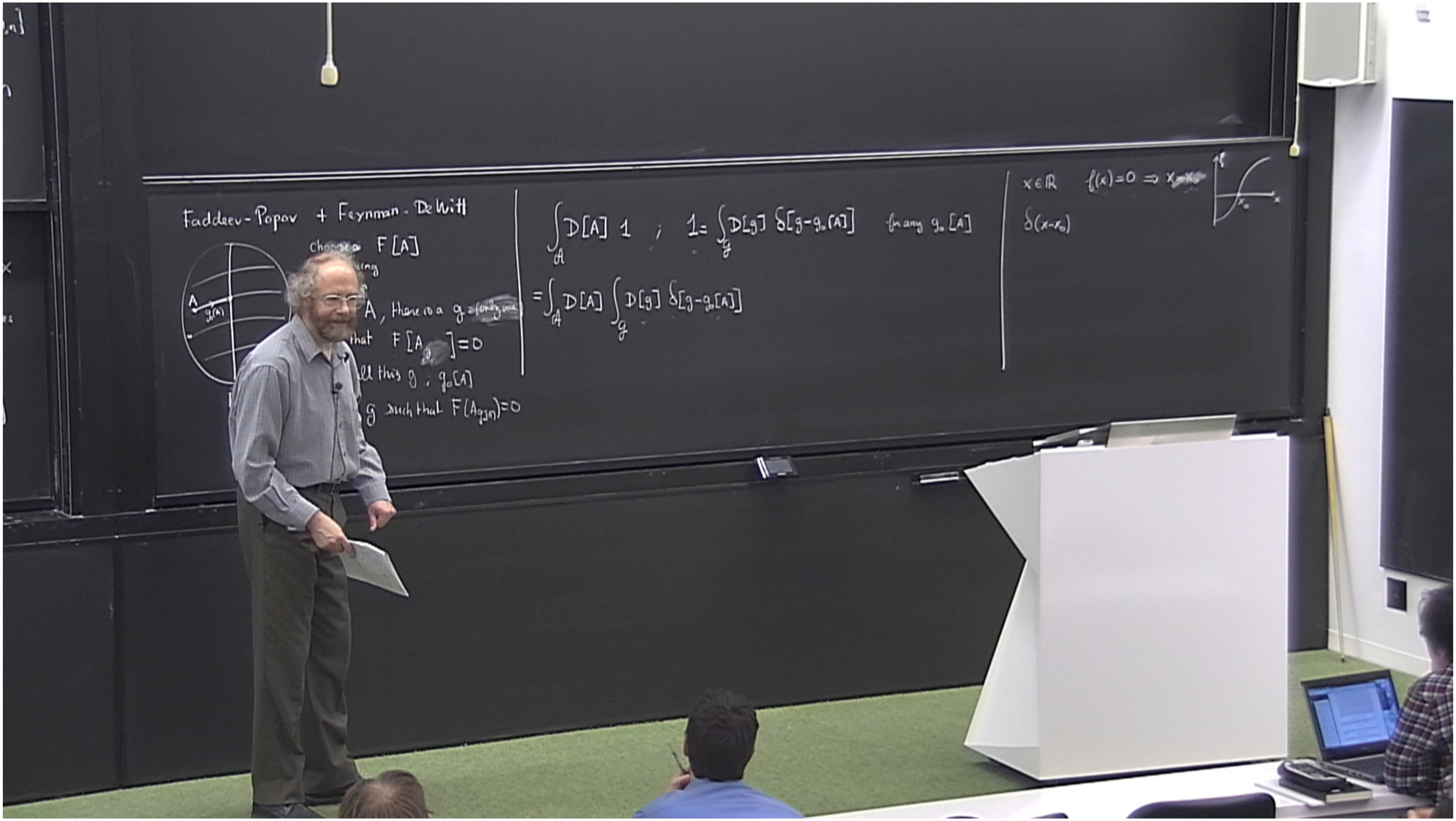
Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g (only one)
such that F[A_g]=0
let me call this g ; g_0[A]
$\int_A D[A]\, 1$; $1 = \int_g D[g]\, \delta[g-g_0[A]]$ for any $g_0[A]$
$= \int_A D[A] \int_g D[g]\, \delta[g-g_0[A]]$


Faddeev - Popov + Feynman - DeWitt
F [A]
Gauge Fixing
condition
for any A, there is a g
such that F [A_g] = 0
call this g ; g₀[A]
F
$\int_A D[A]\ 1 \quad ; \quad 1 = \int_g D[g]\ \delta[g - g_0[A]]$ for any $g_0[A]$
$= \int_A D[A] \int_g D[g]\ \delta[g - g_0[A]]$

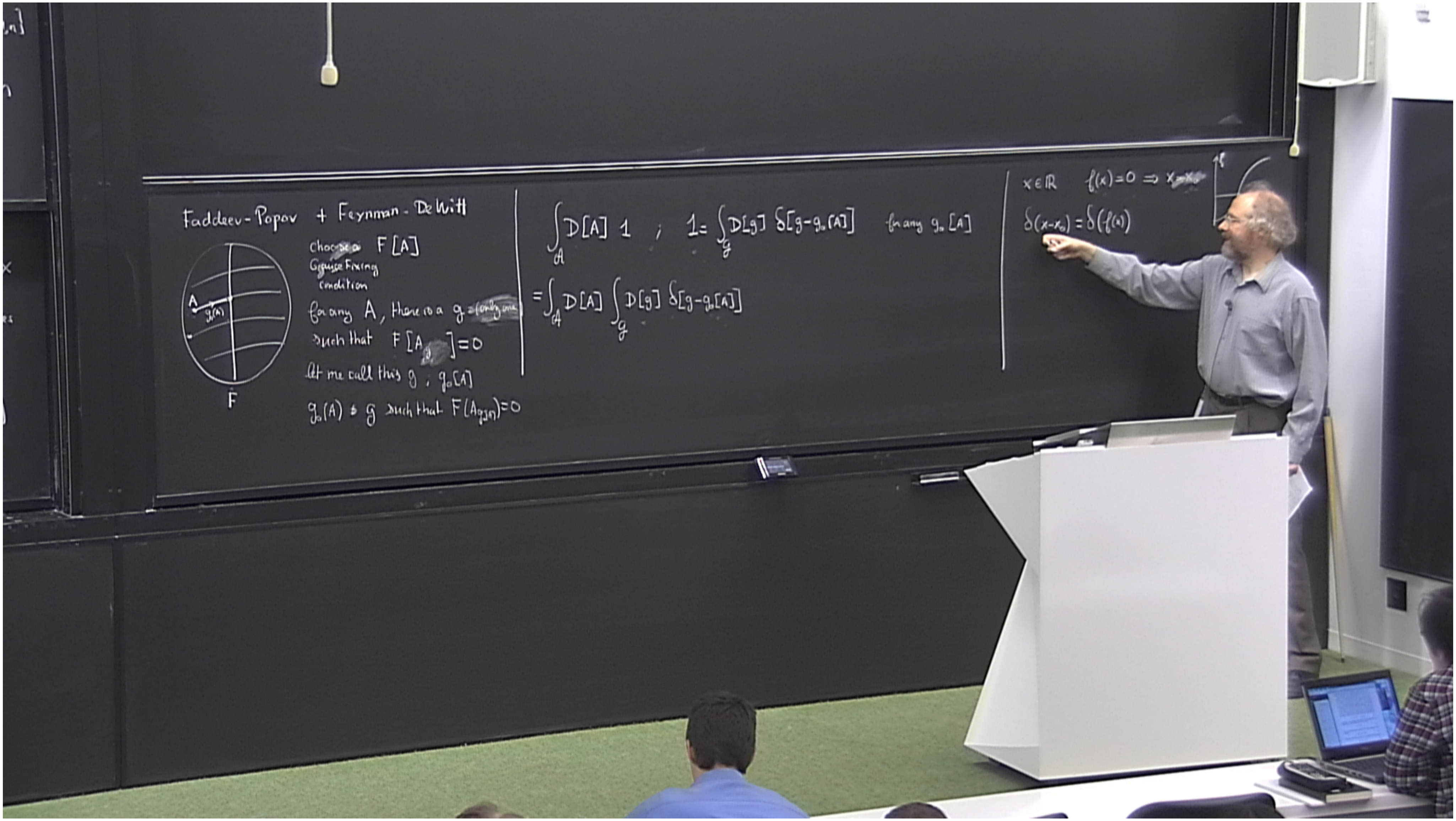

∫_A D[A] 1 ; 1 = ∫_g D[g] δ[g − g₀[A]] for any g₀[A]
= ∫_A D[A] ∫_g D[g] δ[g − g₀[A]]
g = (only one)
]=0
x ∈ ℝ f(x)

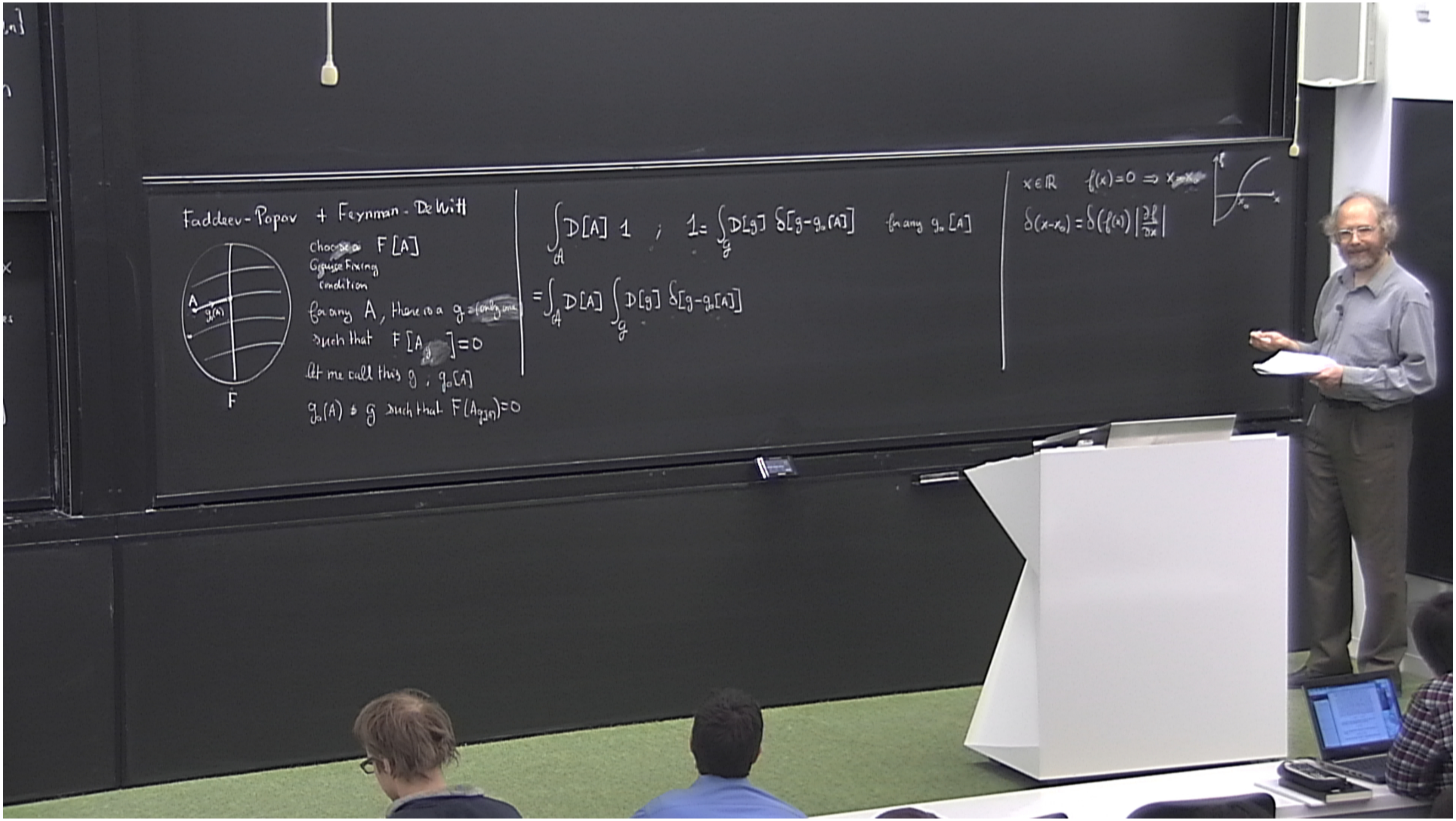

$\int_{\mathcal{A}} D[A]\ 1 \quad ; \quad 1 = \int_{g} D[g]\ \delta[g - g_0[A]]$ for any $g_0[A]$
$= \int_{\mathcal{A}} D[A] \int_{g} D[g]\ \delta[g - g_0[A]]$
$x \in \mathbb{R} \quad f(x) = 0 \Rightarrow x = x_0$
g = (only one)
$] = 0$

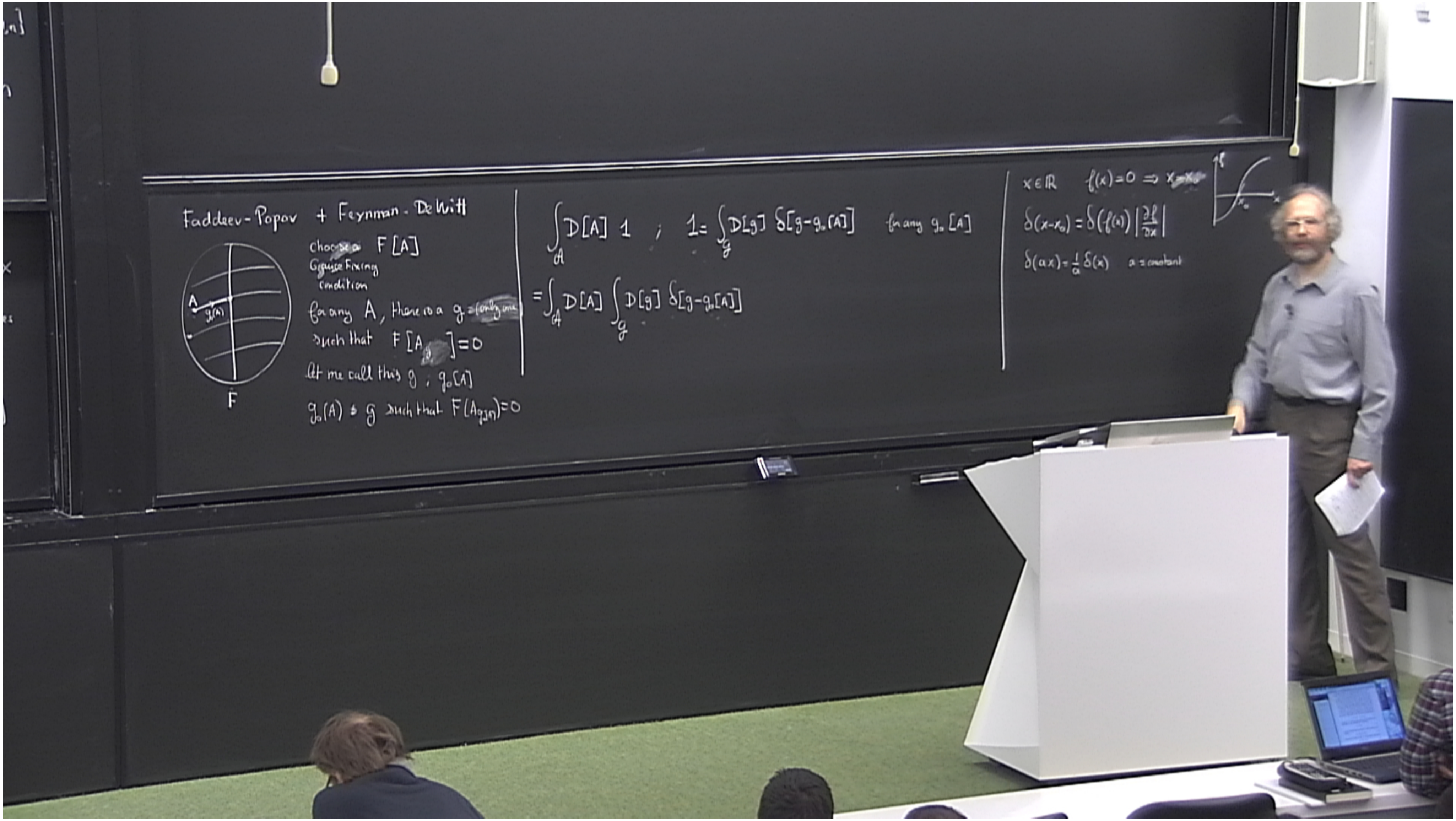

Faddeev-Popov + Feynman - DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a
such that
let me call
$g_0(A)$
F
A
$\int_A D[A]\, 1$; $1 = \int_g D[g]\, \delta[g - g_0[A]]$ for any $g_0[A]$
$= \int_A D[A] \int_g D[g]\, \delta[g - g_0[A]]$
$x \in \mathbb{R}$ $f(x) = 0 \Rightarrow x$
$\delta(x - x_0)$



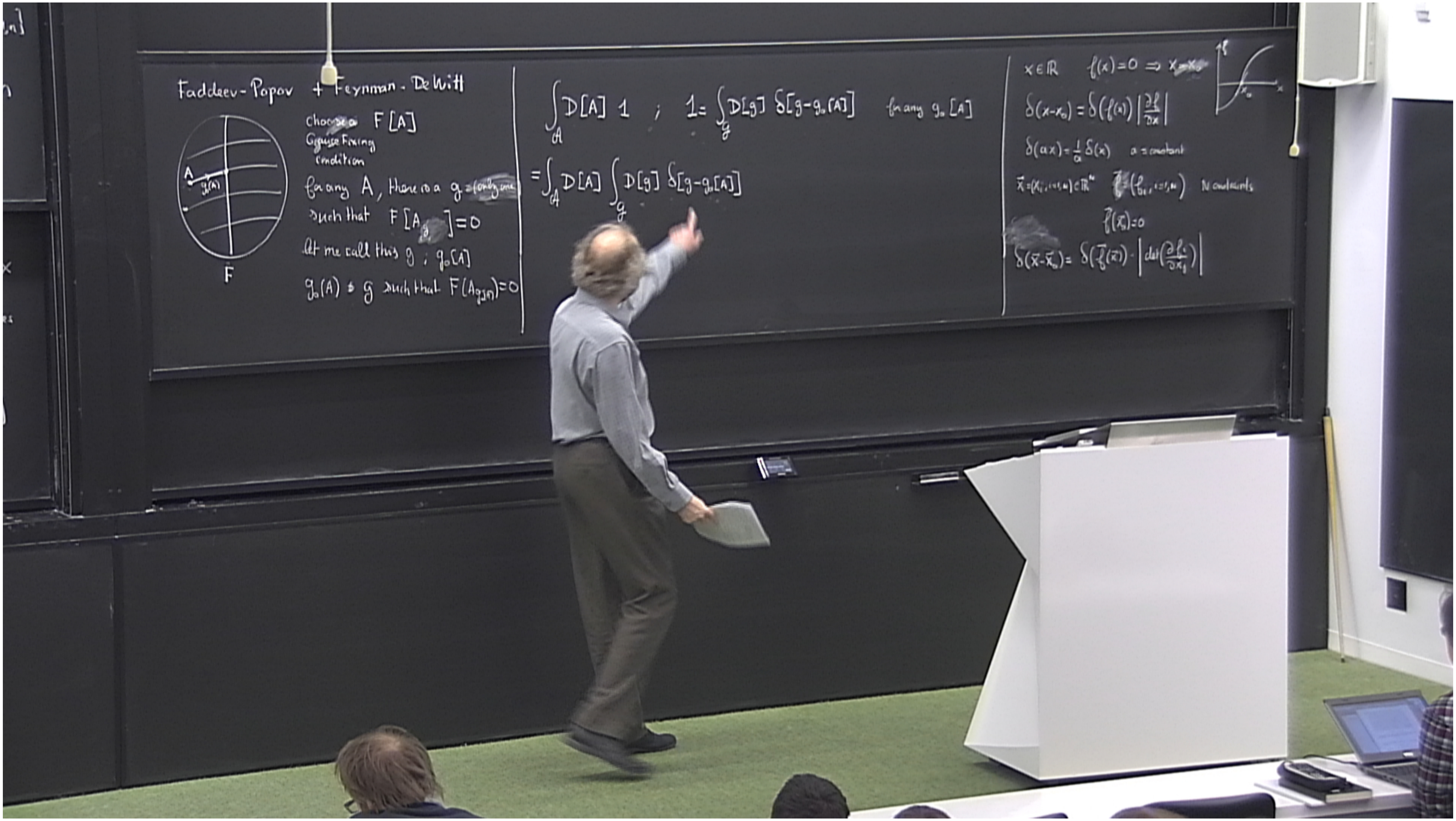
Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
A, there is a g
that F[A_g]=0
call this g ; g_0[A]
g such that F(A_{g_0[A]})=0
∫_A D[A] 1 ; 1 = ∫_g D[g] δ[g-g_0[A]] for any g_0[A]
= ∫_A D[A] ∫_g D[g] δ[g-g_0[A]]
x ∈ ℝ f(x)=0 ⇒ x
δ(x-x_0)

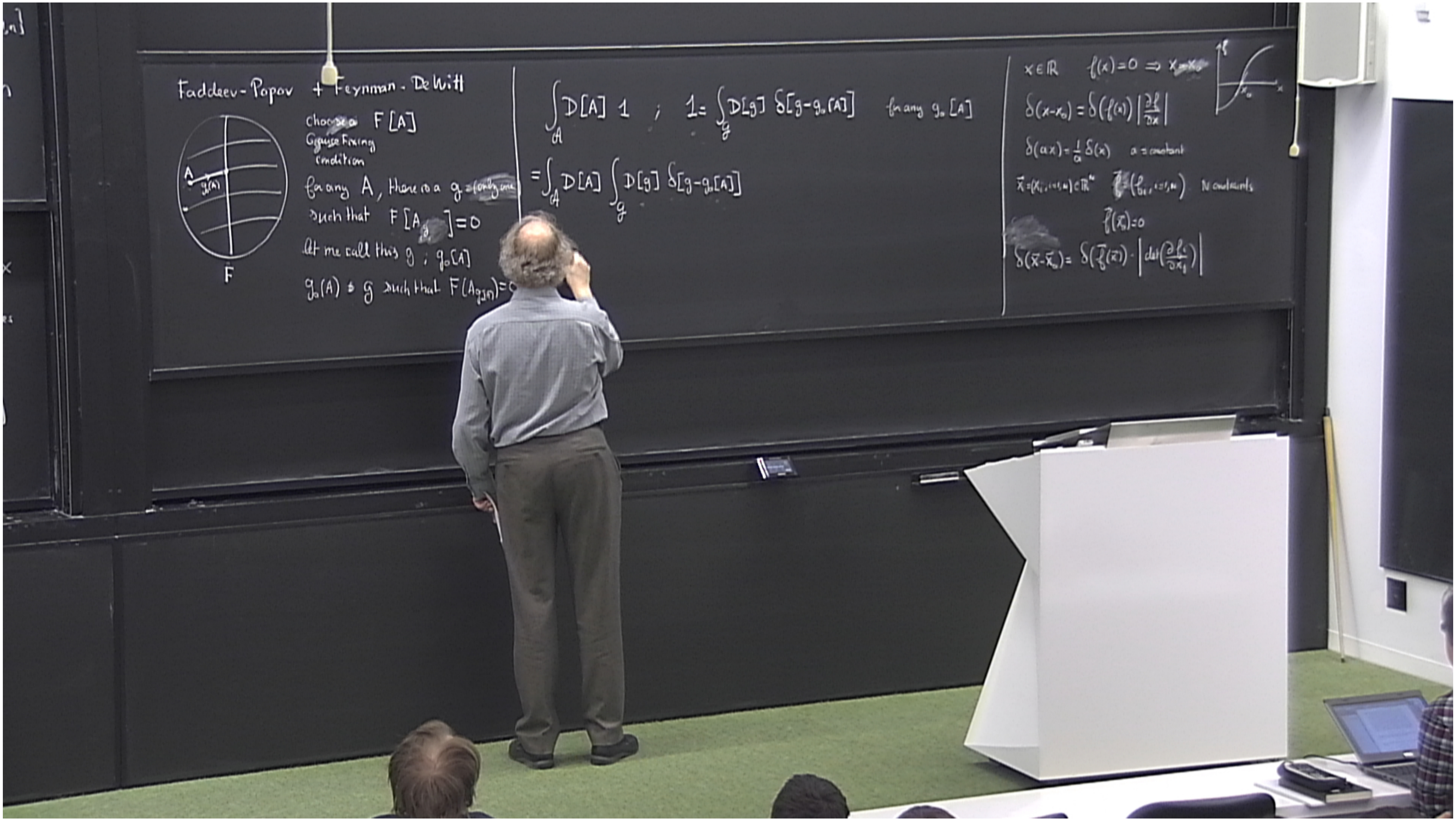

Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g
such that F[A_g]=0
let me call this g ; g_0[A]
F
∫_A D[A] 1 ; 1 = ∫_g D[g] δ[g−g_0[A]] for any g_0[A]
= ∫_A D[A] ∫_g D[g] δ[g−g_0[A]]
x ∈ ℝ f(x)=0 ⇒
δ(x−x_0) = δ(f(x))

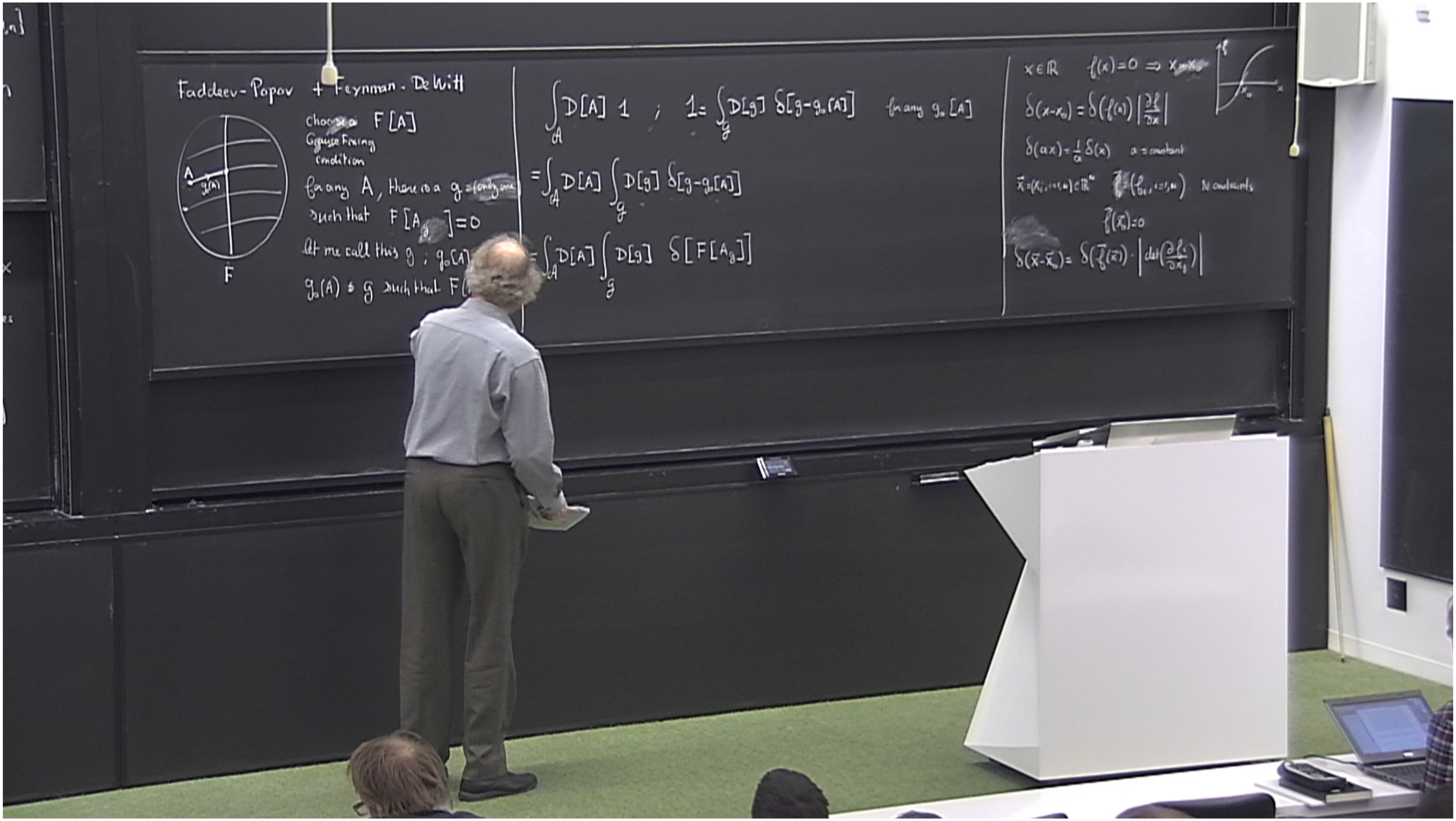

Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g
such that F[A_g]=0
let me call this g, g_0[A]
g_0(A) = g such that F(A_{g_0(A)})=0
A
g_0(A)
F
∫_A D[A] 1 ; 1= ∫_g D[g] δ[g-g_0[A]] for any g_0[A]
= ∫_A D[A] ∫_g D[g] δ[g-g_0[A]]
x ∈ ℝ f(x)=0 ⇒ x
δ(x-x_0) = δ(f(x)) |∂f/∂x|

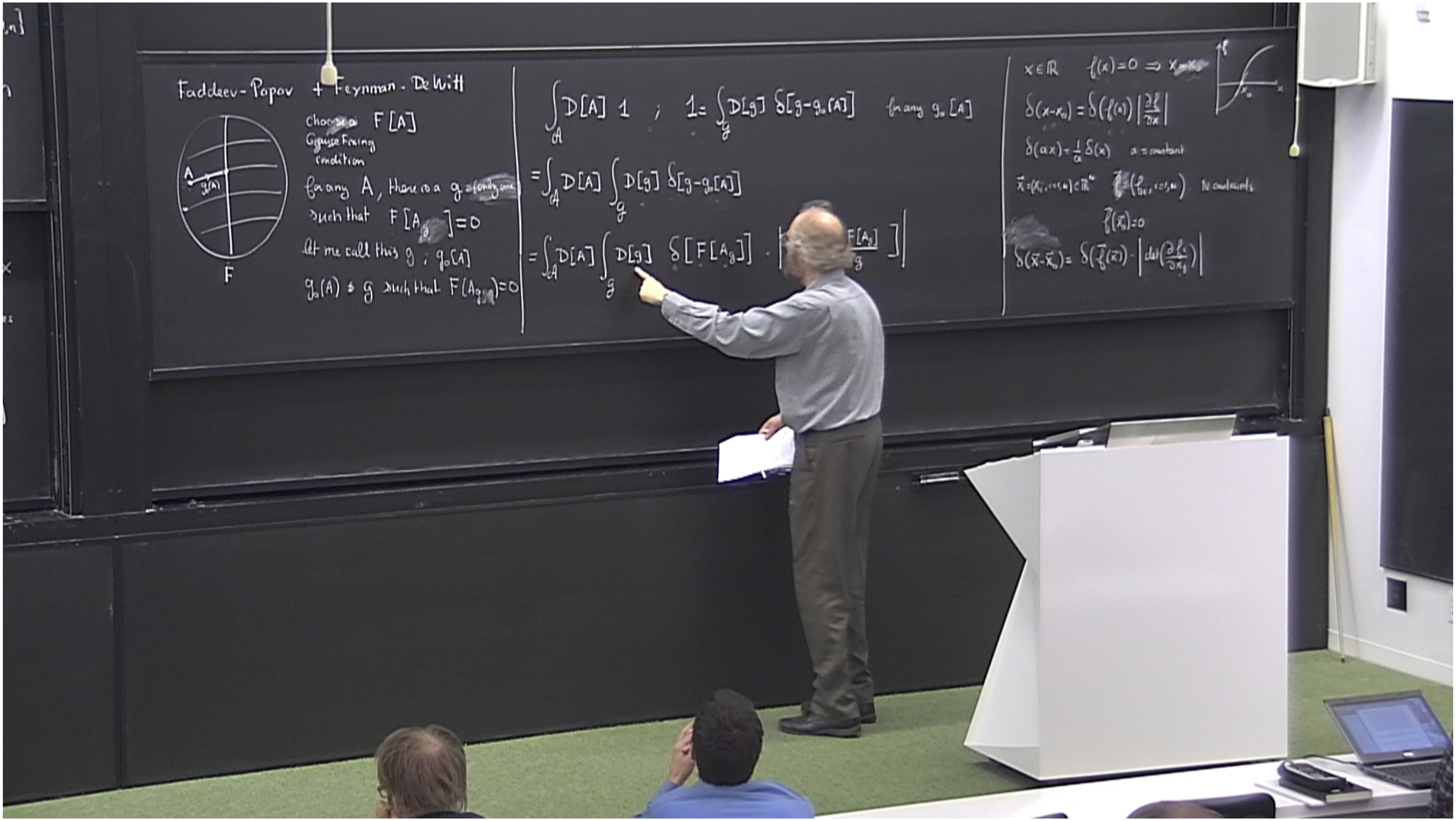


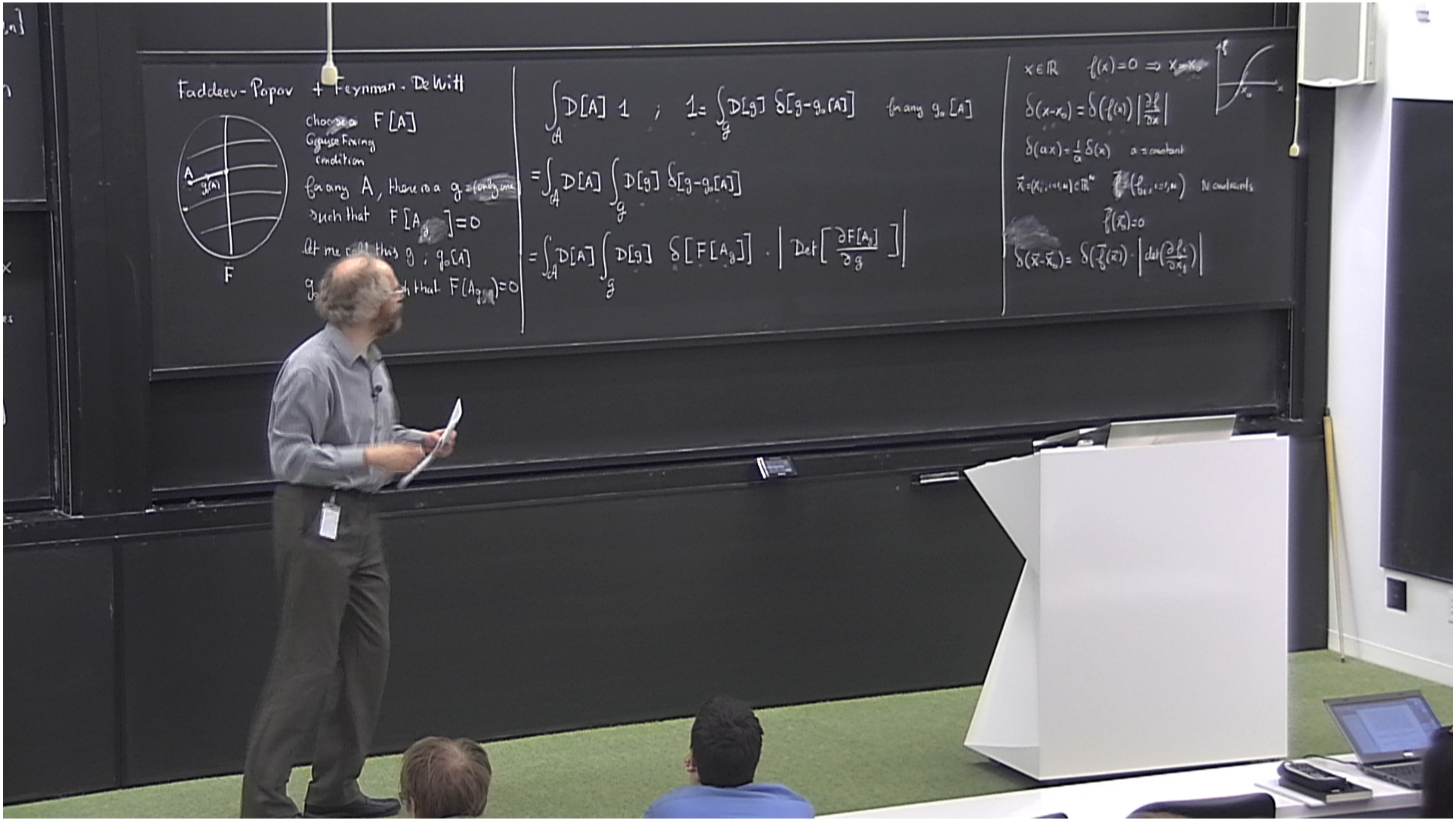
Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g = (only one)
such that F[A_g] = 0
let me call this g ; g₀[A]
g₀(A) ≡ g such that F(A_{g₀(A)}) = 0
F
∫_A D[A] 1 ; 1 = ∫_g D[g] δ[g − g₀[A]] for any g₀[A]
= ∫_A D[A] ∫_g D[g] δ[g − g₀[A]]
x ∈ ℝ f(x) = 0 ⇒ x = x₀
δ(x − x₀) = δ(f(x)) |∂f/∂x|
δ(ax) = 1/a δ(x) a = constant

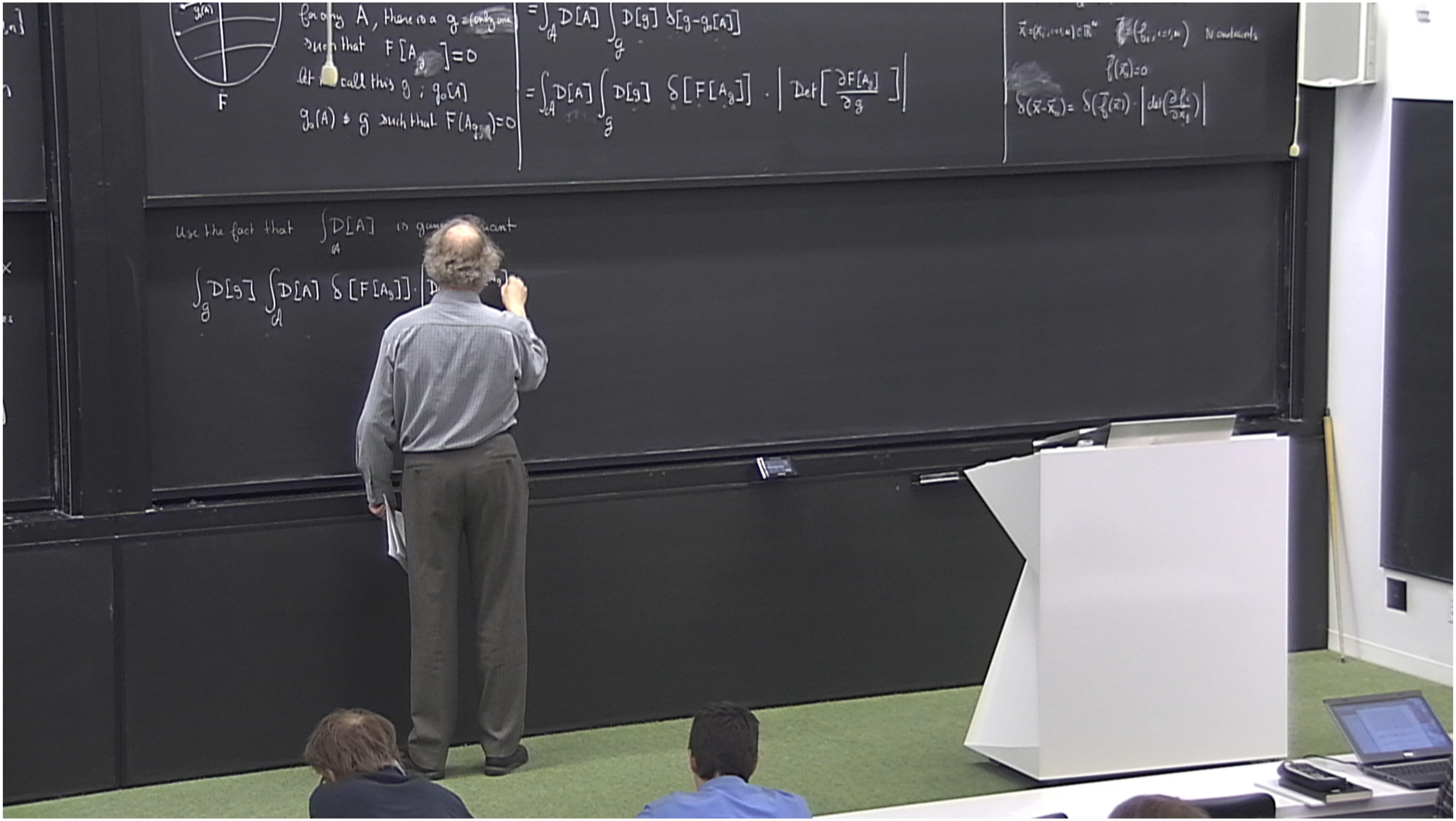

Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g
such that F[A_g]=0
let me call this g ; g_0[A]
for any g_0[A]
N constraints
a = constant

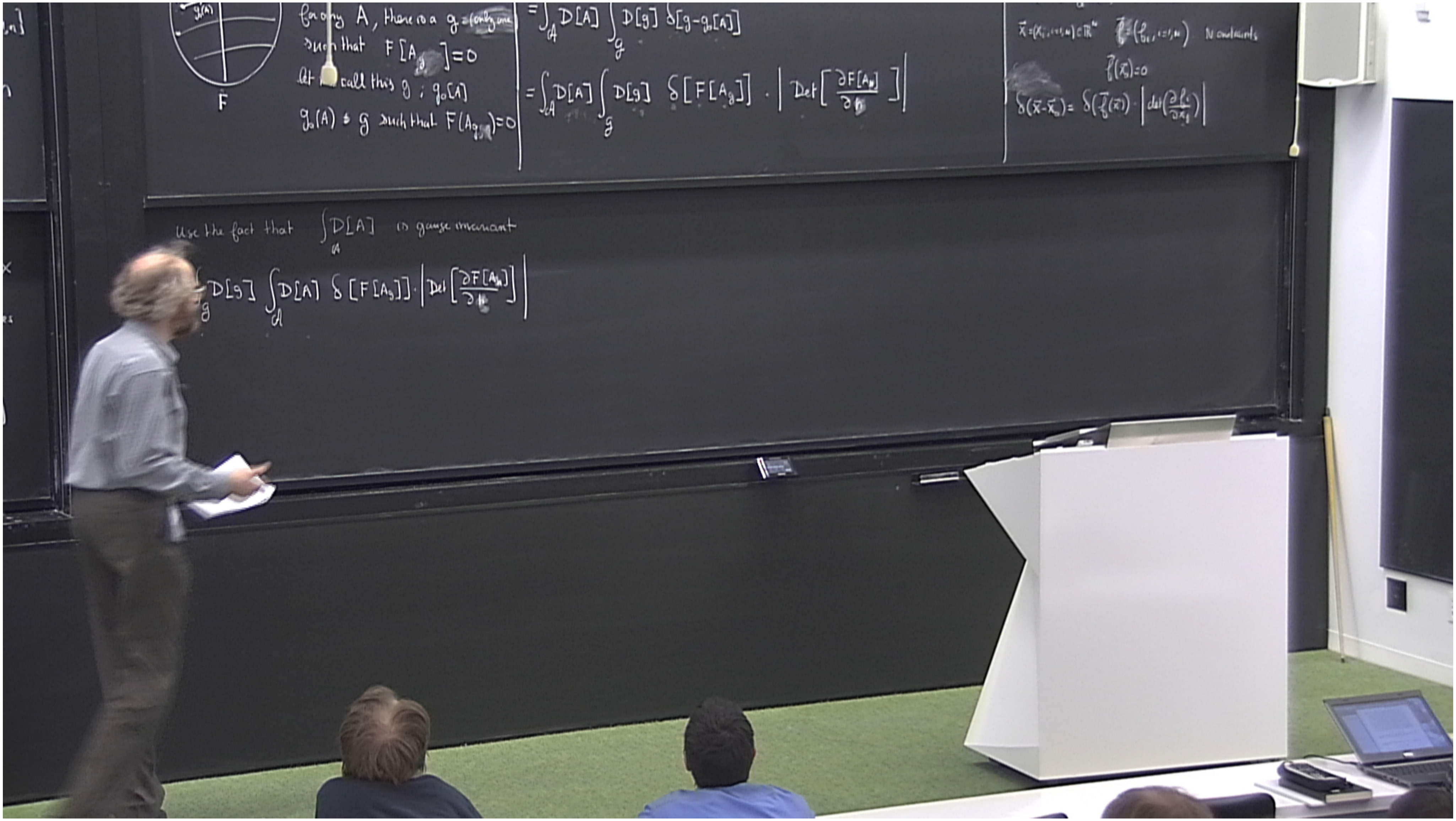

Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g = (only one)
such that F[A_g]=0
let me call this g ; g₀[A]
g₀(A) ≡ g such that F(A_g(A))=0
F
∫_A D[A] 1 ; 1= ∫_g D[g] δ[g-g₀[A]] for any g₀[A]
= ∫_A D[A] ∫_g D[g] δ[g-g₀[A]]
x ∈ ℝ f(x)=0 ⇒ x=x₀
δ(x-x₀) = δ(f(x)) |∂f/∂x|
δ(ax) = 1/a δ(x) a = constant
N constraints
f(x₀)=0
δ(x-x₀) = δ(f(x)) · |det(∂f/∂x)|

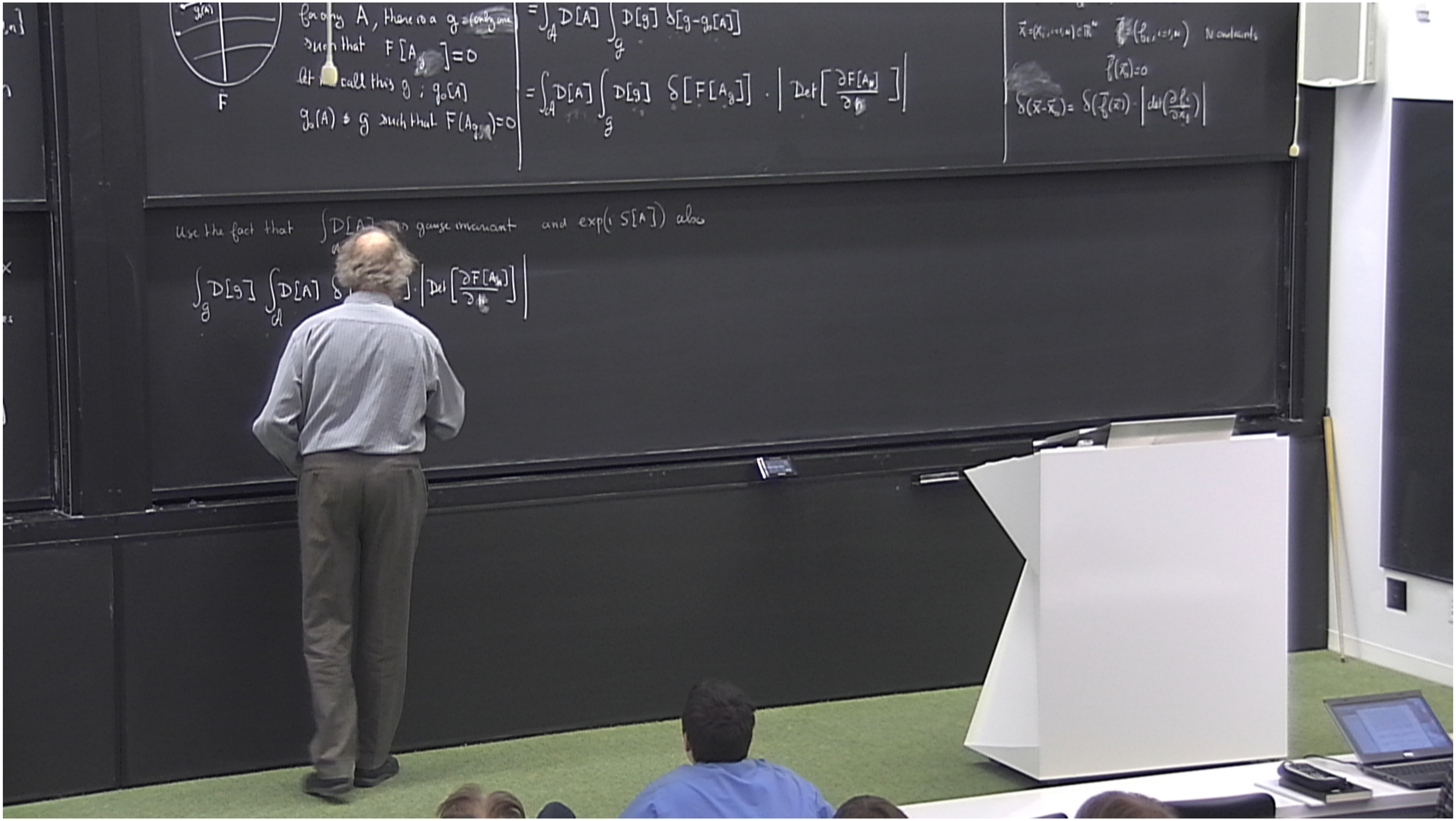

Faddeev-Popov + Feynman-DeWitt
F[A]
condition
for any A, there is a g
such that F[A] = 0
let me call this g ; g₀[A]
g₀(A) = g such that F
D[A] 1 ; 1 = ∫ D[g] δ[g-g₀[A]]
for any g₀[A]
= ∫ D[A] ∫ D[g] δ[g-g₀[A]]
= ∫ D[A] ∫ D[g] δ[F[A_g]]
x ∈ ℝ f(x)=0 ⇒ x
δ(x-x₀) = δ(f(x)) |∂f/∂x|
δ(ax) = 1/a δ(x) a = constant
N constraints
δ(x̄-x̄₀) = δ(f̄(x̄)) · |det(∂fᵢ/∂xⱼ)|


Faddeev-Popov + Feynman-DeWitt
Choose a F[A] Gauge Fixing condition
for any A, there is a g (only one) such that F[A_g]=0
Let me call this g ; g₀[A]
g₀(A) ≠ g such that F(A_g)=0
F
∫_A D[A] 1 ; 1 = ∫_g D[g] δ[g−g₀[A]] for any g₀[A]
= ∫_A D[A] ∫_g D[g] δ[g−g₀[A]]
= ∫_A D[A] ∫_g D[g] δ[F[A_g]]
x ∈ ℝ f(x)=0 ⇒ x=x₀
δ(x−x₀) = δ(f(x)) |∂f/∂x|
δ(ax) = 1/a δ(x) a = constant
N constraints
f(x₀)=0

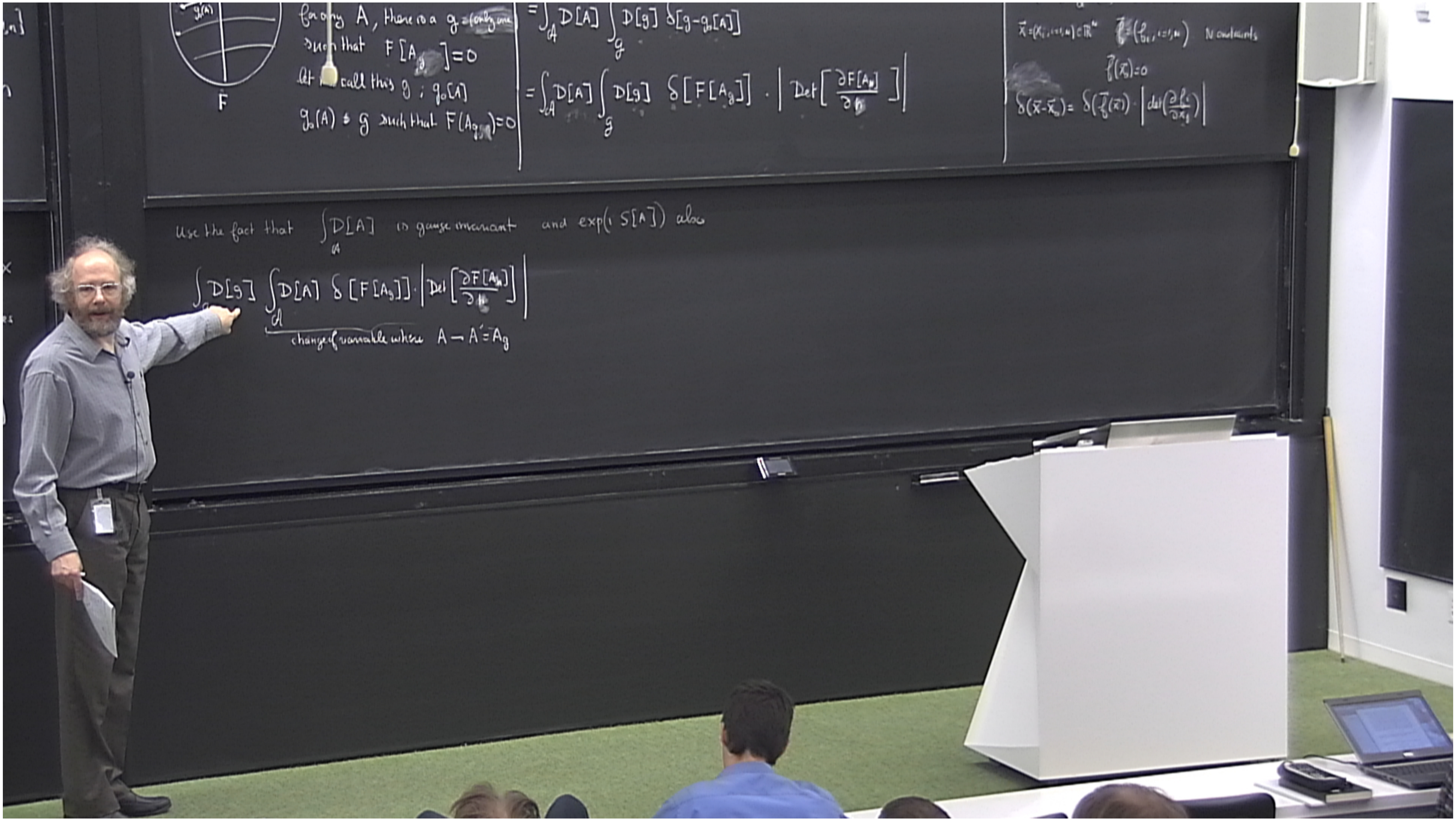

Faddeev-Popov + Feynman-DeWitt
Choose a F[A]
Gauge Fixing condition
for any A, there is a g
such that F[A_g]=0
F
for any g_0[A]
x ∈ ℝ
N constraints
a = constant

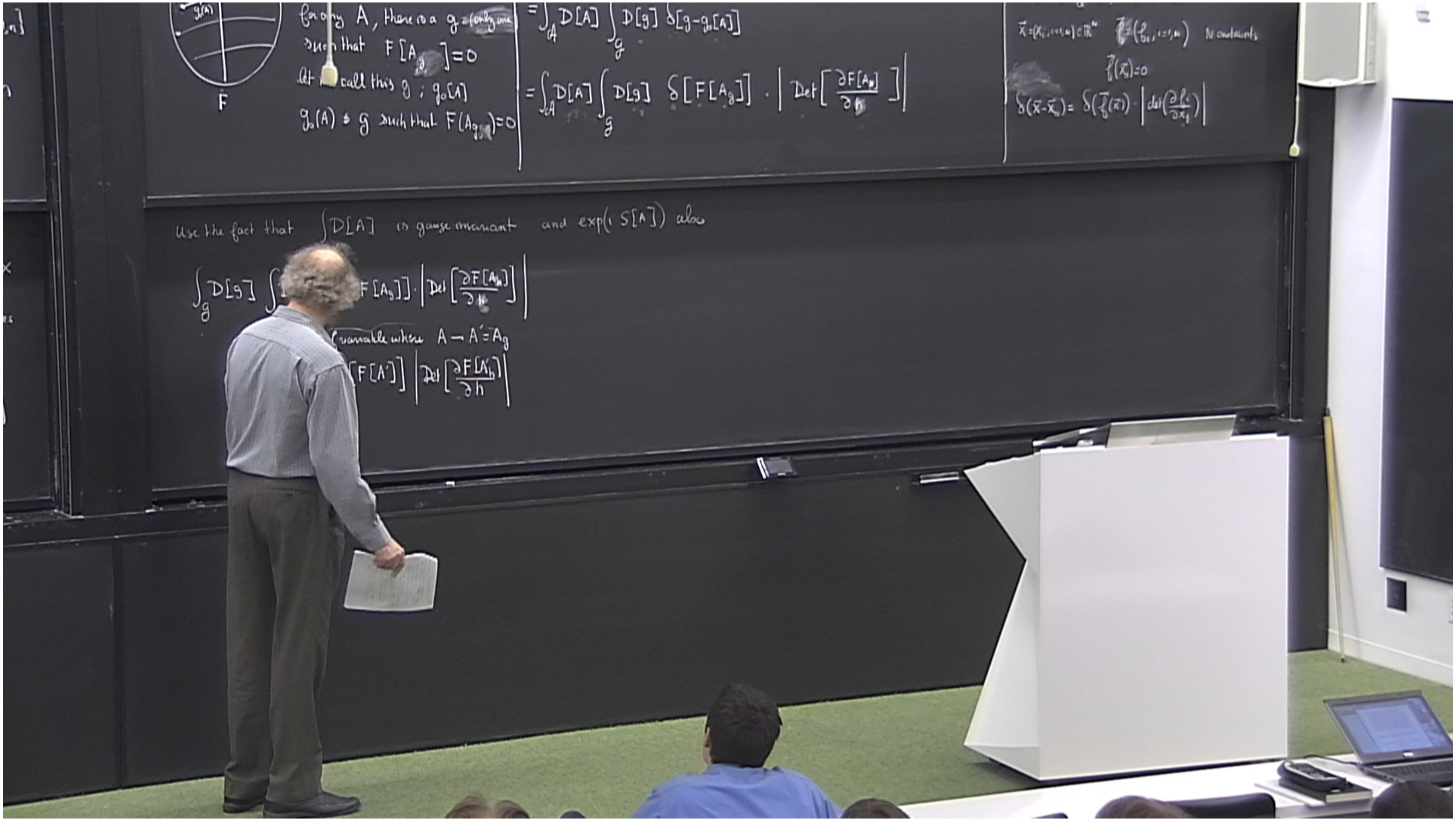

F
for any A, there is a g = (only one)
such that F[A_g]=0
call this g ; g_0[A]
g_0(A) = g such that F(A_g)=0
= ∫_A D[A] ∫_g D[g] δ[g-g_0[A]]
= ∫_A D[A] ∫_g D[g] δ[F[A_g]] . | Det[∂F[A_g]/∂g] |
N constraints
f(x_0)=0
δ(x-x_0) = δ(f(x)) · |det(∂f_i/∂x_j)|
Use the fact that ∫_A D[A]
∫_g D[g] ∫_A D[A] δ[F[A_g]] ·

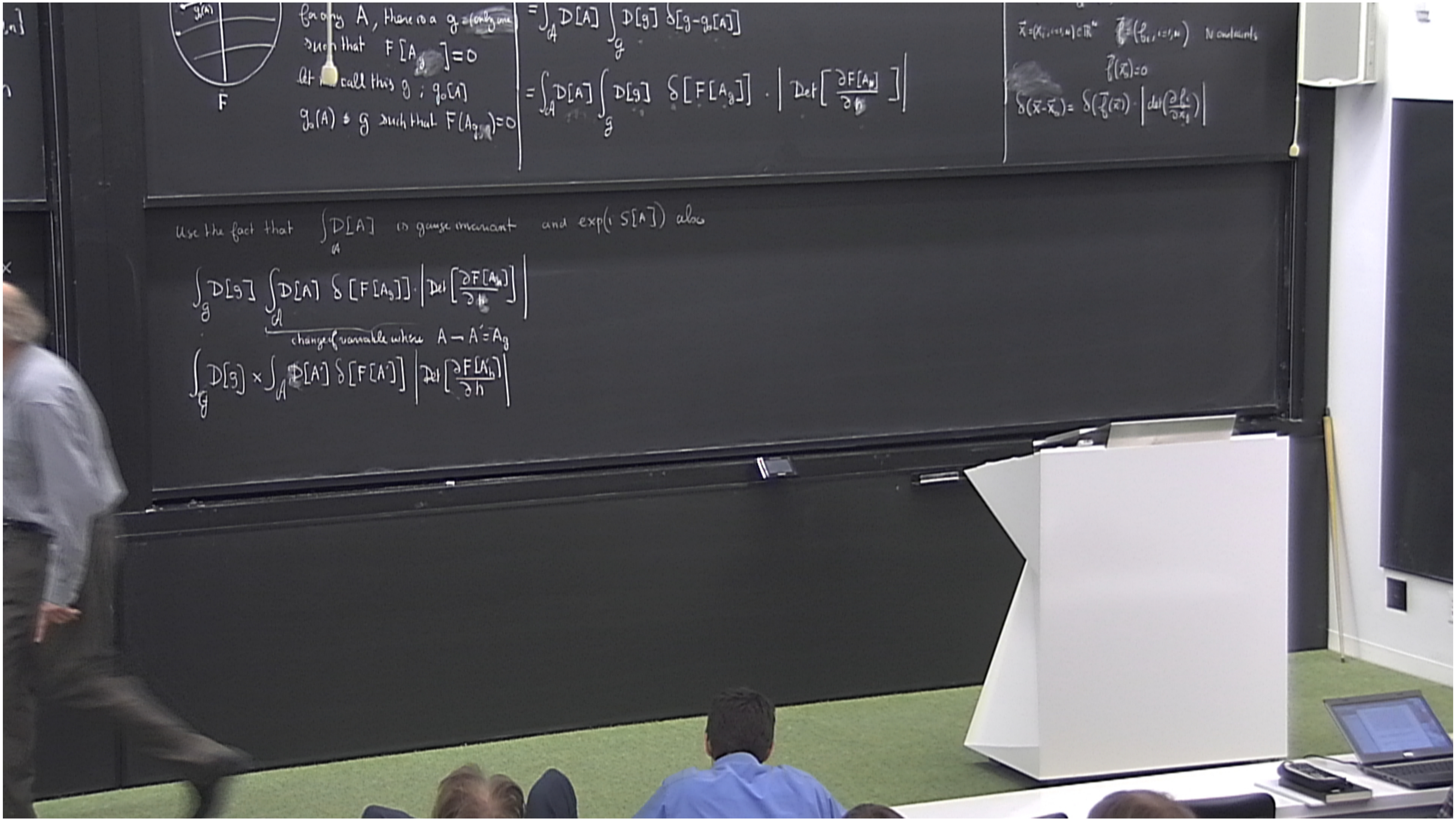

for any A, there is a g
such that F[A_g] = 0
let call this g ; g_0[A]
g_0(A) = g such that F(A_g) = 0
F
= ∫_A D[A] ∫_g D[g] δ[g − g_0[A]]
= ∫_A D[A] ∫_g D[g] δ[F[A_g]] · |Det[∂F[A_g]/∂g]|
f(x_0) = 0
N constraints
Use the fact that ∫_A D[A] is gauge invariant
∫_g D[g] ∫_A D[A] δ[F[A_g]] · |Det[∂F[A_g]/∂g]|

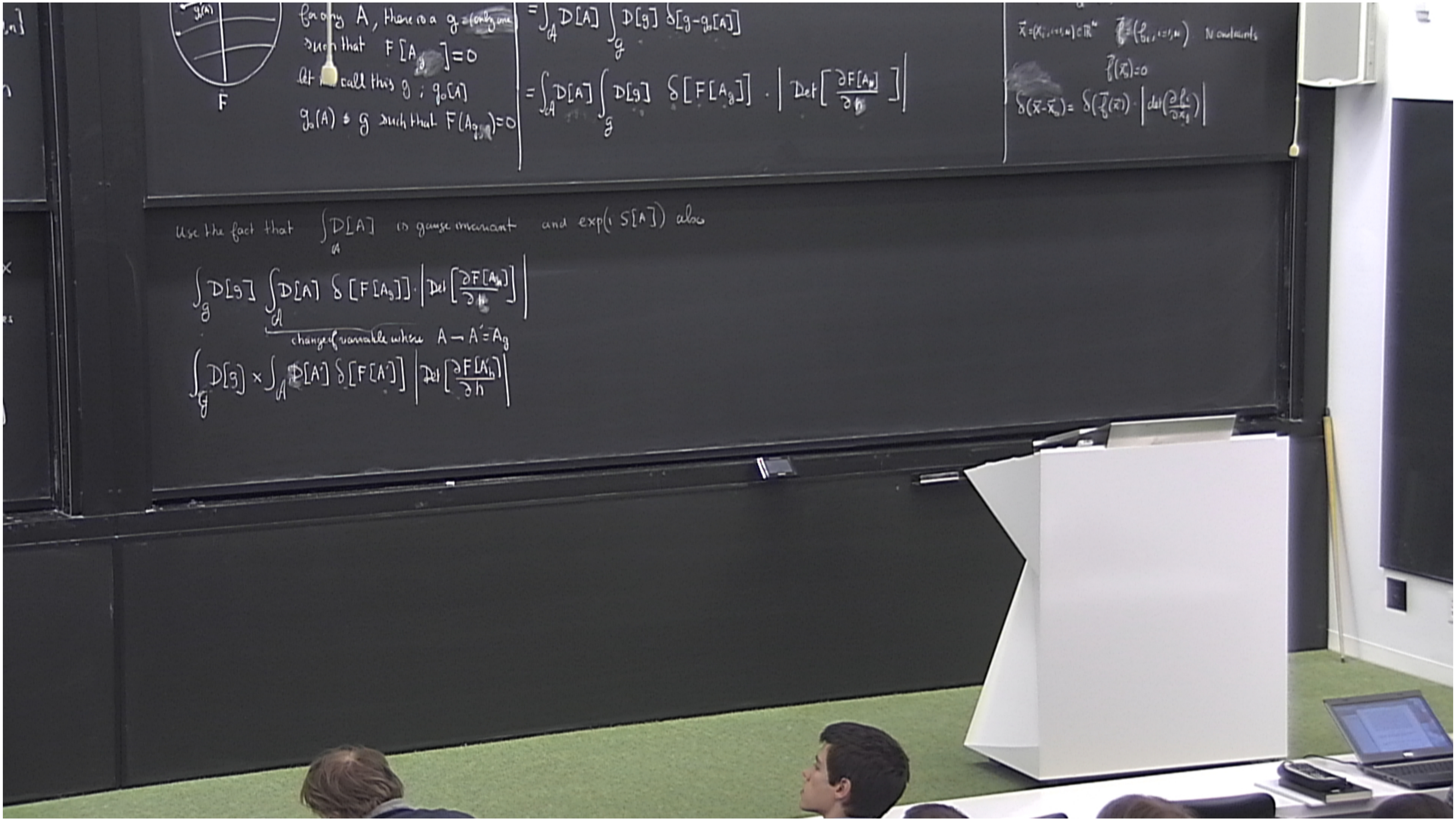


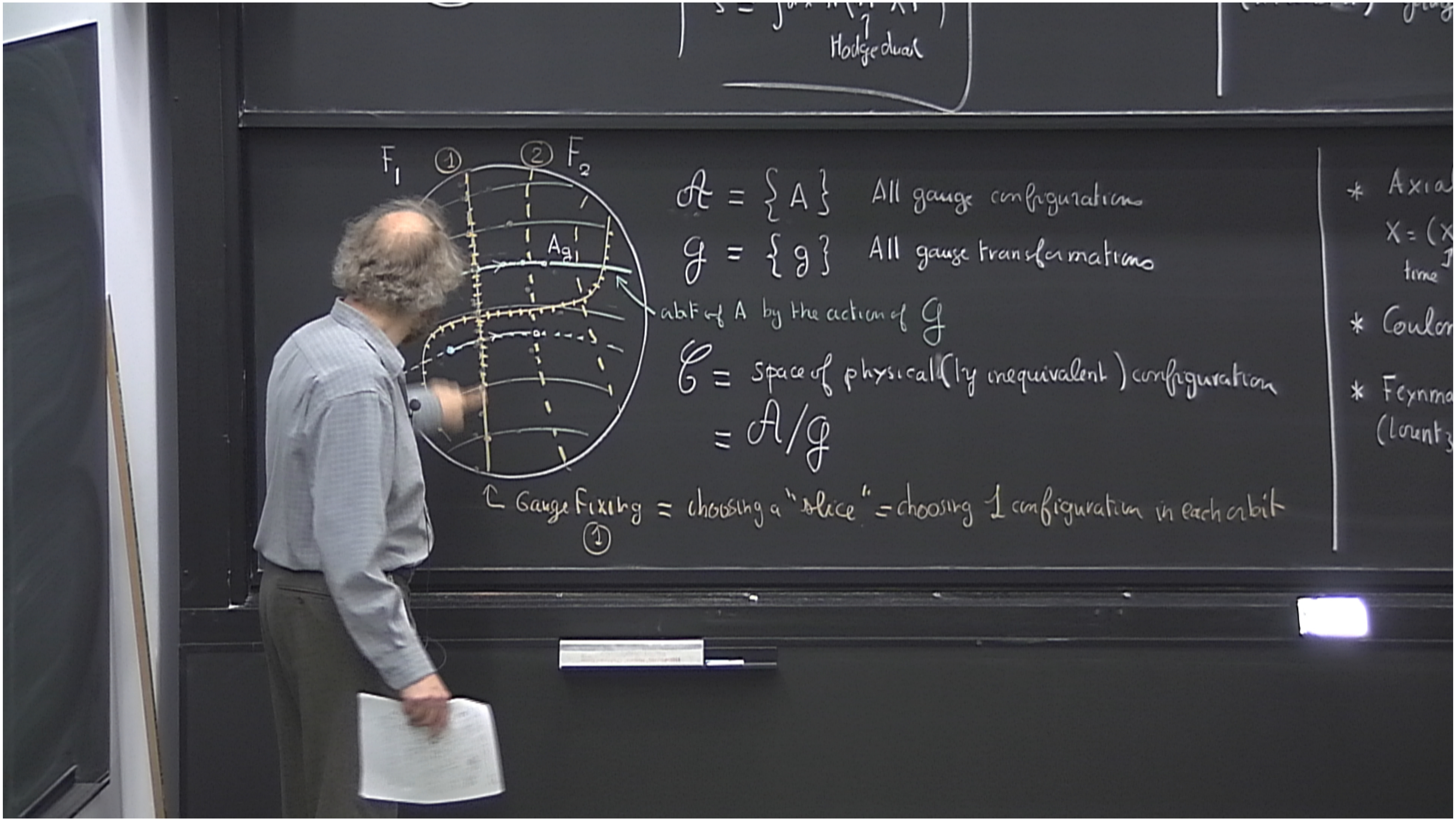
such that F[A
let call this g ; g0[A]
g0(A) = g such that F(A
N constraints
Use the fact that
gauge invariant
and exp(i S[A]) also

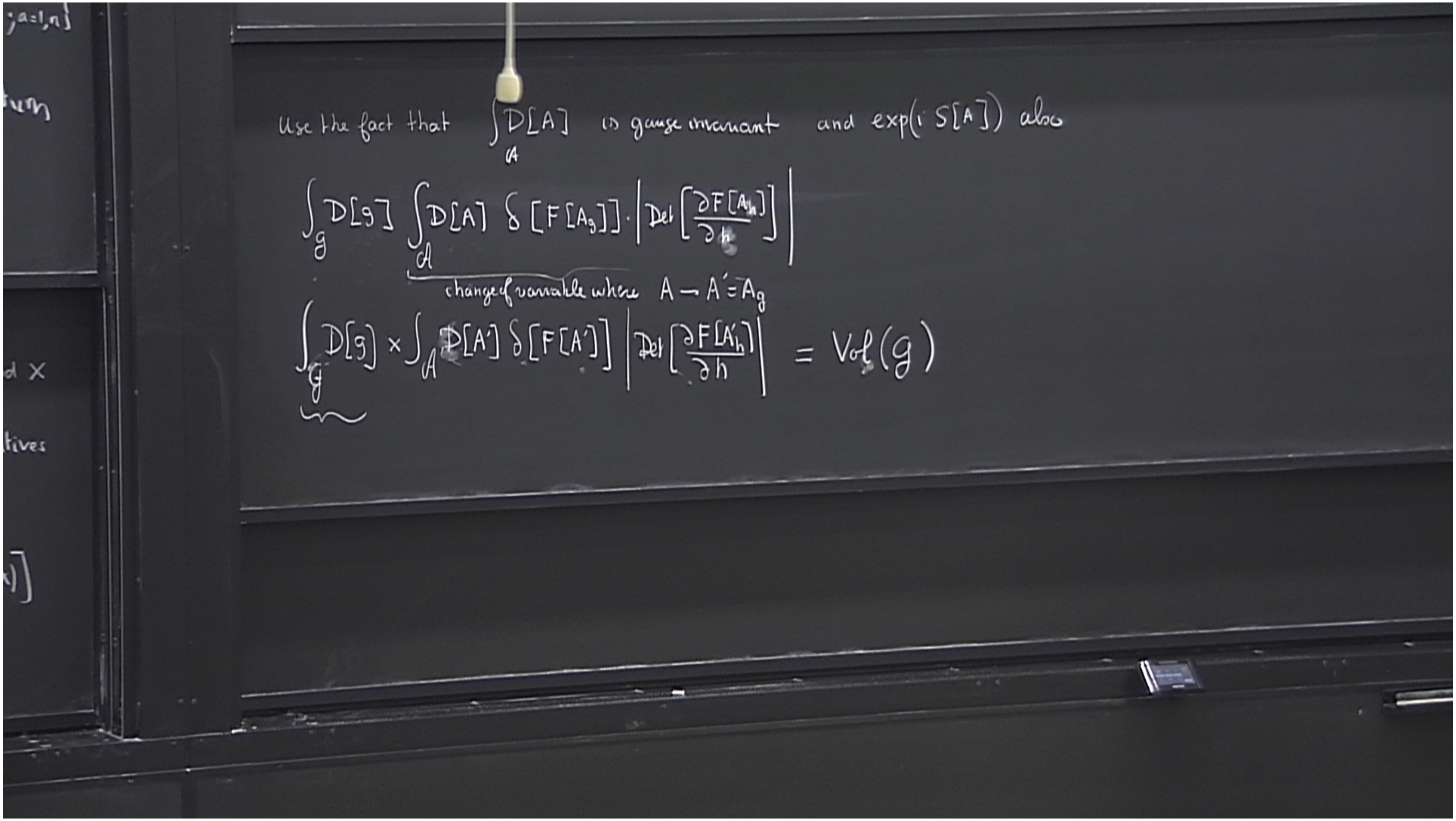

Use the fact that $\int_A D[A]$ is gauge invariant and exp(i S[A]) also
$\int D[g] \int_A D[A]\ \delta[F[A_g]] \cdot \left| \mathrm{Det}\left[\frac{\partial F[A_g]}{\partial g}\right]\right|$
change of variable where $A \to A' = A_g$

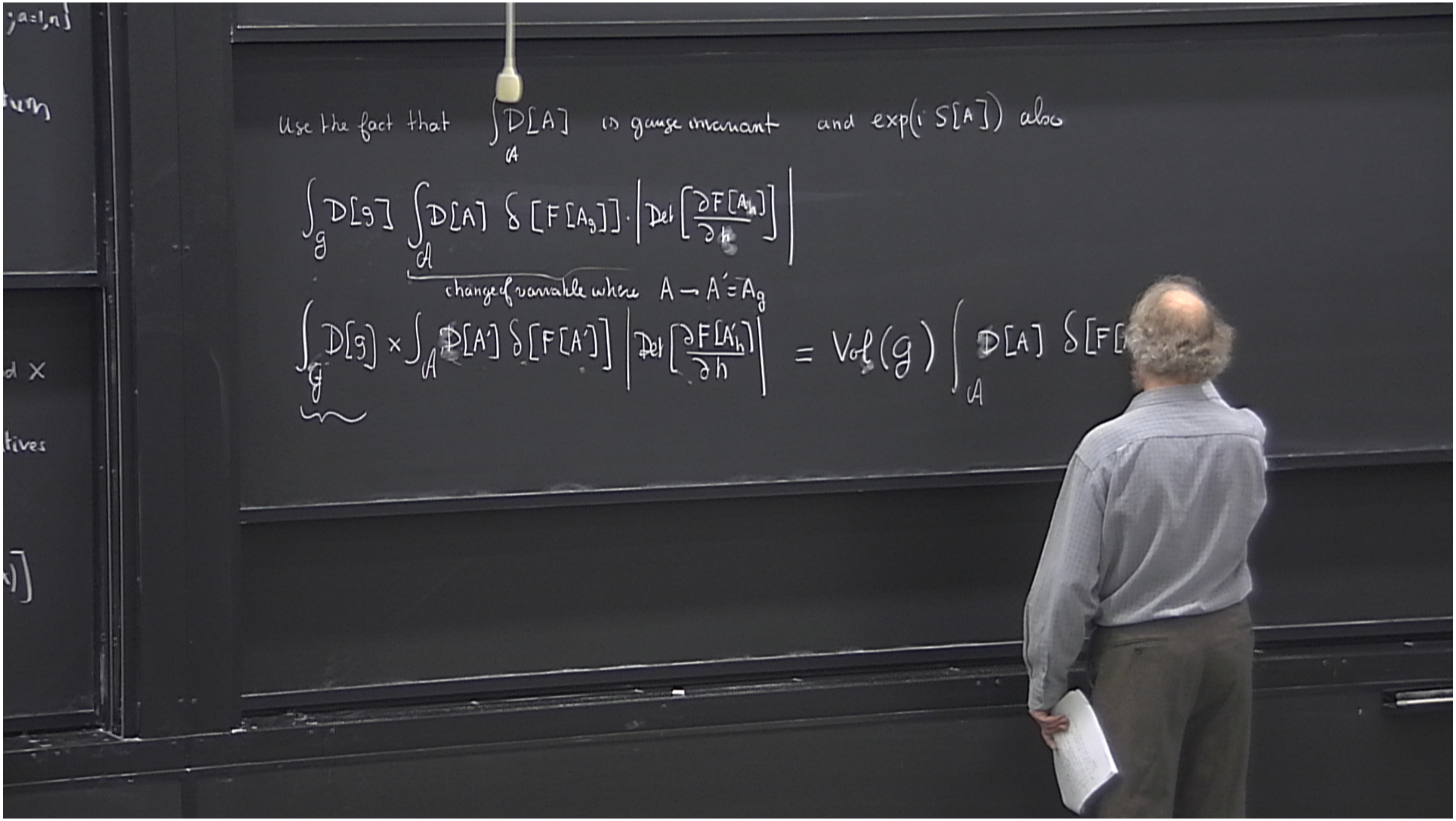

Use the fact that ∫D[A] is gauge invariant and exp(i S[A]) also
F[A_g] = 0
N constraints
f(x_0) = 0

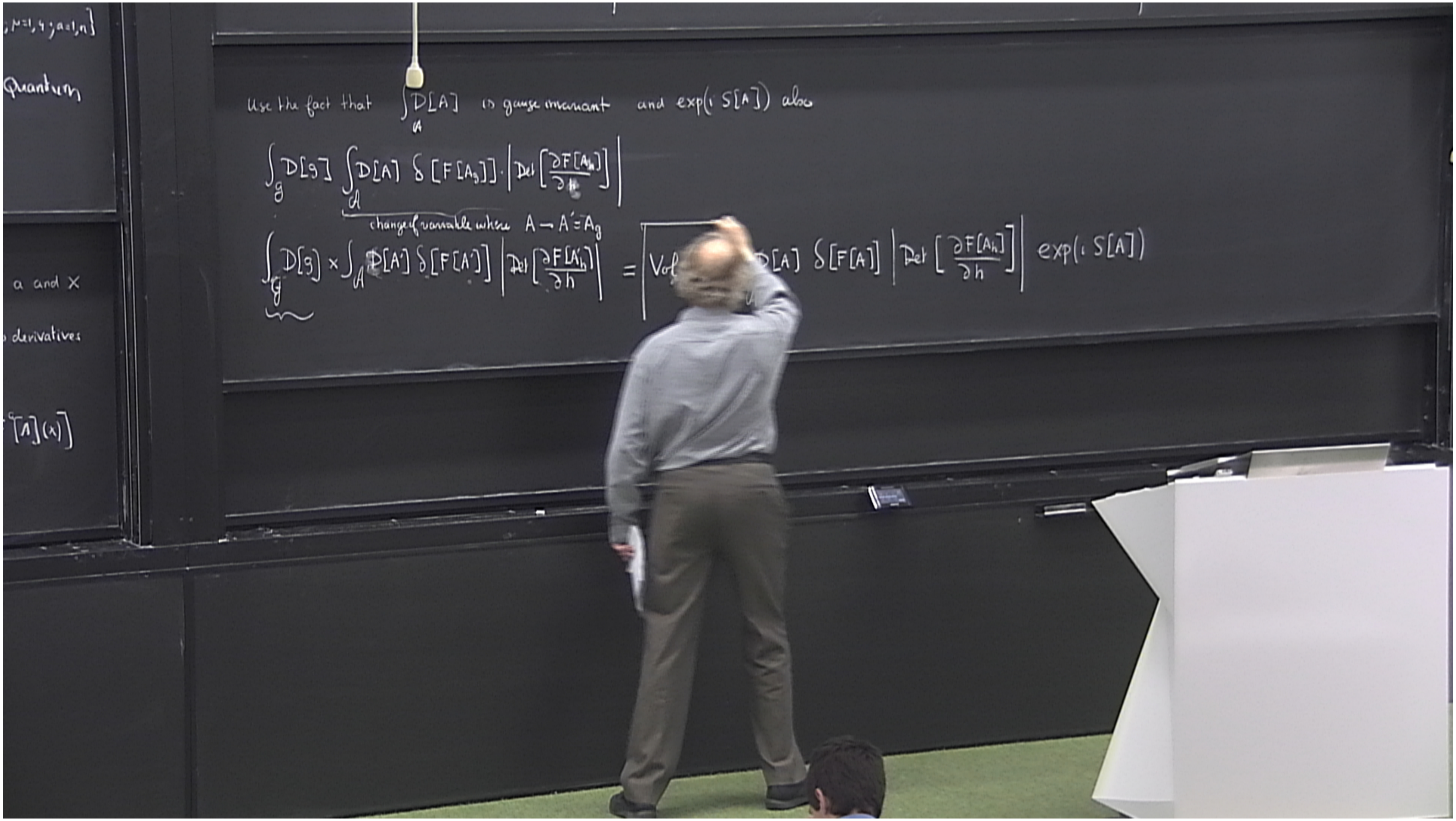

for any A, there is a g
such that F[A_g] = 0
call this g ; g_0[A]
g_0(A) = g such that F(A_g) = 0
= ∫_A D[A] ∫_g D[g] δ[g - g_0[A]]
= ∫_A D[A] ∫_g D[g] δ[F[A_g]] · |Det[∂F[A_g]/∂h]|
N constraints
δ(x - x_0) = δ(f(x)) · |det(∂f_i/∂x_j)|
Use the fact that ∫_A D[A] is gauge invariant and exp(i S[A]) also
∫_g D[g] ∫_A D[A] δ[F[A_g]] · |Det[∂F[A_g]/∂h]|
change of variable where A → A' = A_g
∫_g D[g] × ∫_A D[A'] δ[F[A']] |Det[∂F[A'_h]/∂h]|

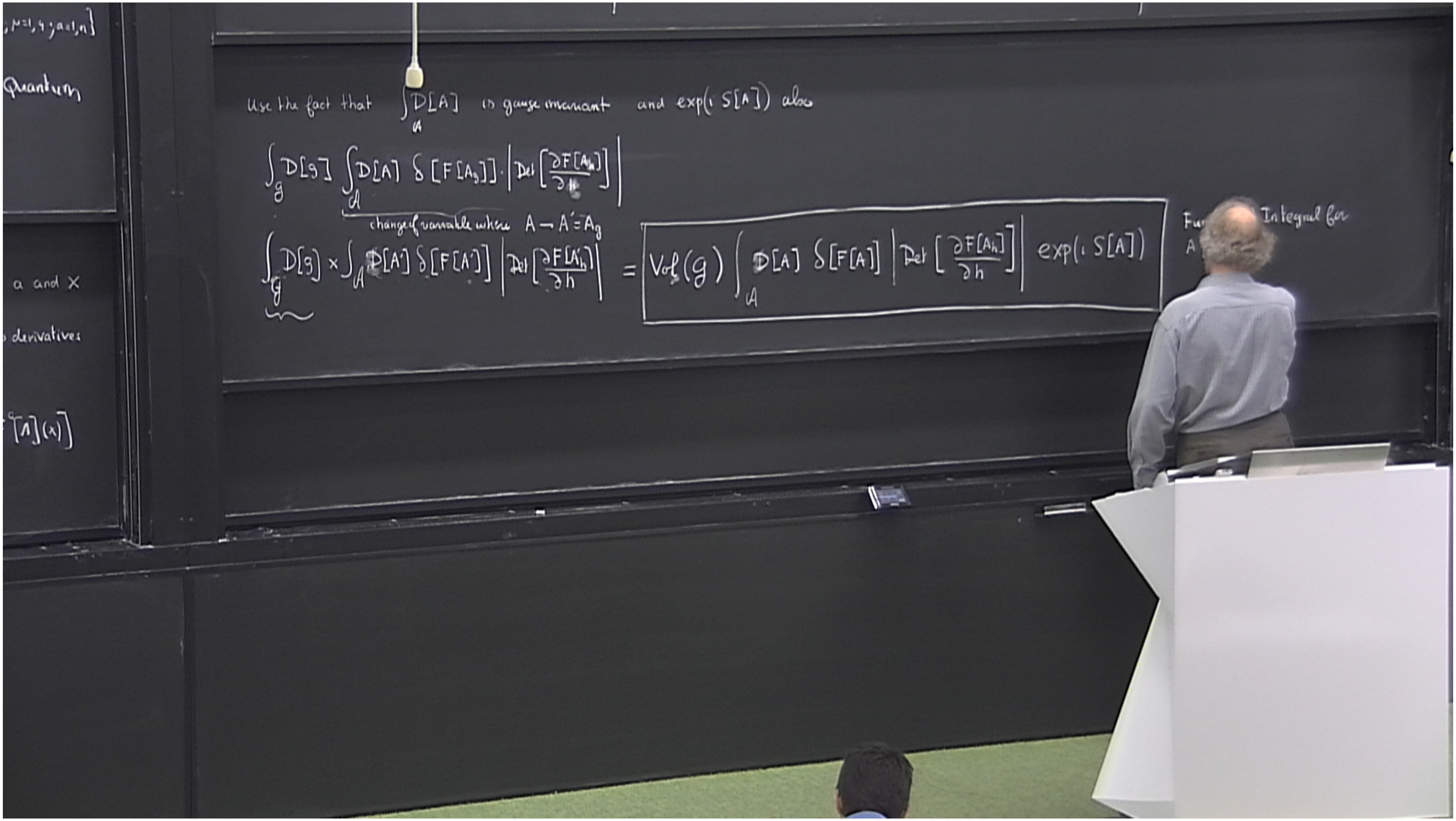

for any A, there is a g = (only one)
such that F[A_g] = 0
let us call this g ; g_0[A]
g_0(A) = g such that F(A_g) = 0
= ∫_A D[A] ∫_g D[g] δ[g - g_0[A]]
= ∫_A D[A] ∫_g D[g] δ[F[A_g]] . | Det [∂F[A_h] / ∂h] |
δ(x - x_0) = δ(f(x)) · | det(∂f_i / ∂x_j) |
N constraints
f(x_0) = 0
Use the fact that ∫_A D[A] is gauge invariant and exp(i S[A]) also
∫_g D[g] ∫_A D[A] δ[F[A_g]] · | Det [∂F[A_h] / ∂h] |
change of variable where A → A' = A_g
∫_g D[g] × ∫_A D[A'] δ[F[A']] | Det [∂F[A'_h] / ∂h] |

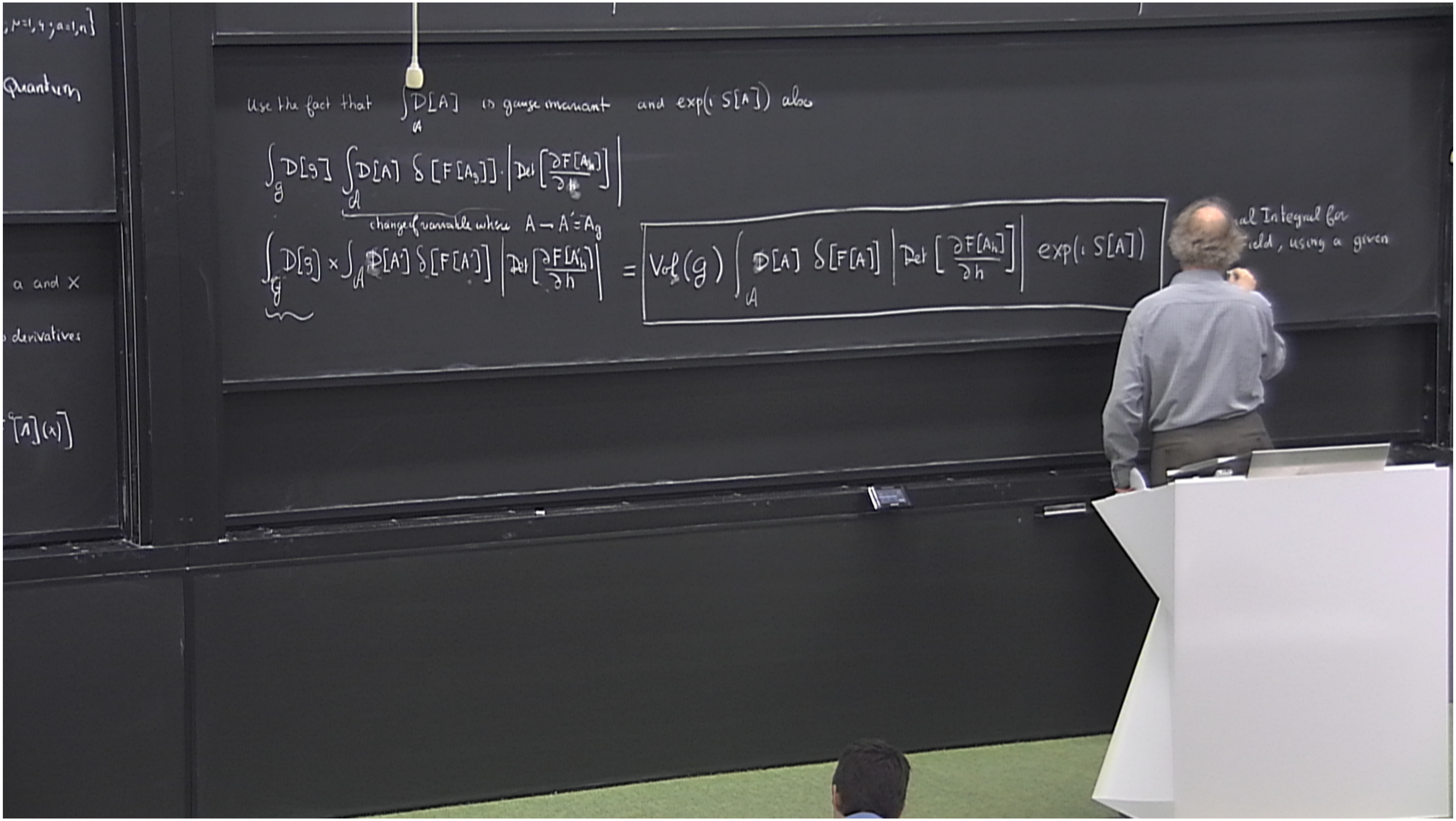

Hodge dual
F1
①
②
F2
Ag1
𝒜 = { A } All gauge configurations
𝒢 = { g } All gauge transformations
orbit of A by the action of 𝒢
𝒞 = space of physical(ly inequivalent) configuration
= 𝒜/𝒢
Gauge Fixing = choosing a "slice" = choosing 1 configuration in each orbit
①

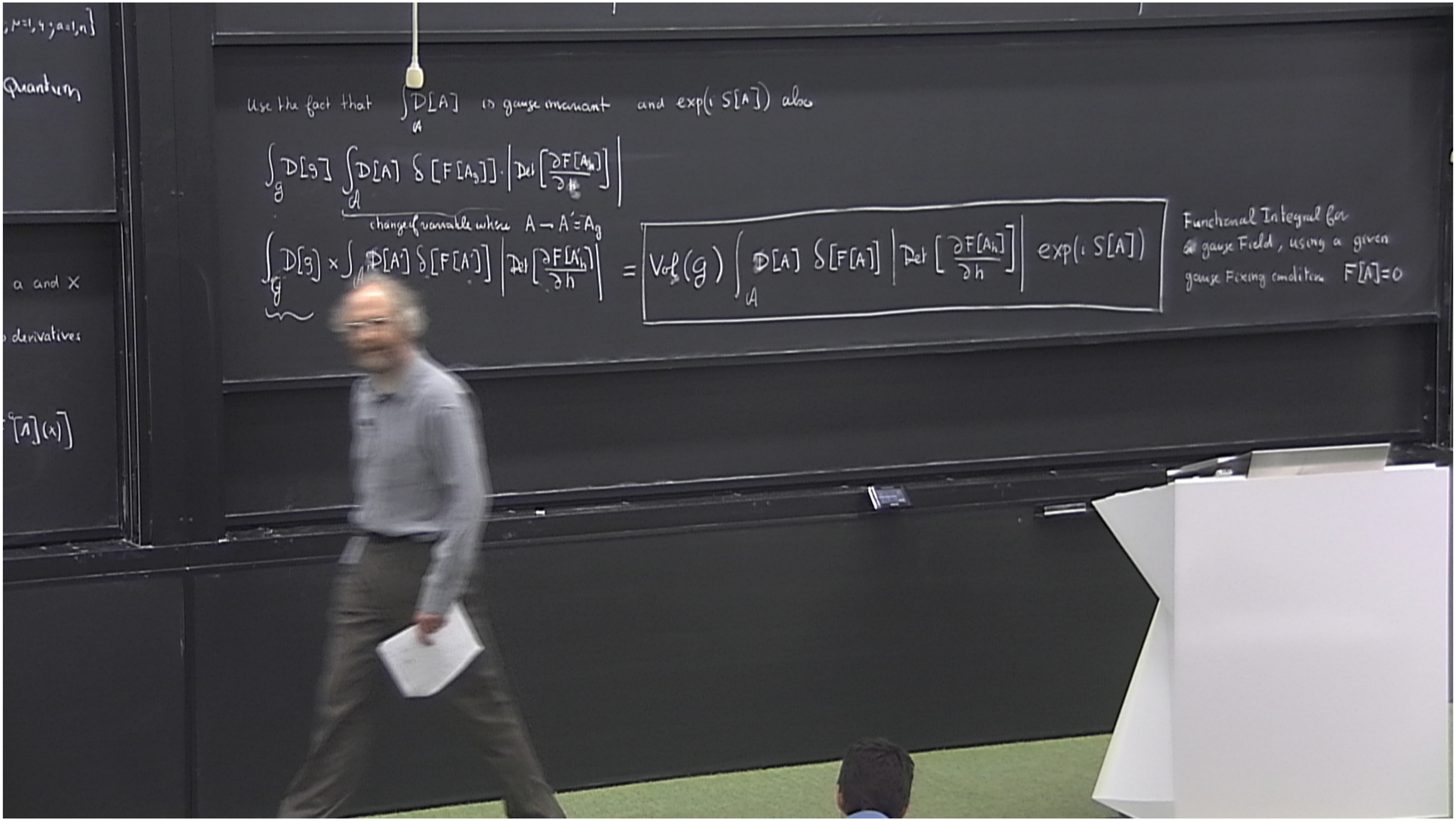

Use the fact that $\int_{\mathcal{A}} D[A]$ is gauge invariant and $\exp(i\, S[A])$ also
$\int_{g} D[g] \int_{\mathcal{A}} D[A]\, \delta[F[A_g]] \cdot \left| \mathrm{Det}\left[\frac{\partial F[A_h]}{\partial h}\right] \right|$
change of variable where $A \to A' = A_g$
$\int_{g} D[g] \times \int_{\mathcal{A}} D[A']\, \delta[F[A']] \left| \mathrm{Det}\left[\frac{\partial F[A'_h]}{\partial h}\right] \right| = Vol(g)$


Use the fact that $\int_{\mathcal{A}} D[A]$ is gauge invariant and $\exp(i\, S[A])$ also
$\int_{\mathcal{G}} D[g] \int_{\mathcal{A}} D[A]\, \delta[F[A_g]] \cdot \left| \mathrm{Det}\left[\frac{\partial F[A_h]}{\partial h}\right] \right|$
change of variable where $A \to A' = A_g$
$\int_{\mathcal{G}} D[g] \times \int_{\mathcal{A}} D[A']\, \delta[F[A']] \left| \mathrm{Det}\left[\frac{\partial F[A'_h]}{\partial h}\right] \right| = \mathrm{Vol}(\mathcal{G}) \int_{\mathcal{A}} D[A]\, \delta[F[$


Quantum
Use the fact that ∫D[A] is gauge invariant and exp(i S[A]) also
change of variable where A → A' = A_g
a and X
derivatives


Quantum
a and X
derivatives
Use the fact that ∫_A D[A] is gauge invariant and exp(i S[A]) also
∫_g D[g] ∫_A D[A] δ[F[A_g]] · |Det[∂F[A_h]/∂h]|
change of variable where A → A' = A_g
∫_g D[g] × ∫_A D[A'] δ[F[A']] |Det[∂F[A'_h]/∂h]| = Vol(g) ∫_A D[A] δ[F[A]] |Det[∂F[A_h]/∂h]| exp(i S[A])
Integral for


Use the fact that $\int_A D[A]$ is gauge invariant and exp(i S[A]) also
$\int_g D[g] \int_A D[A]\, \delta[F[A_g]] \cdot \left|Det\left[\frac{\partial F[A_h]}{\partial h}\right]\right|$
change of variable where $A \to A' = A_g$
$\int_g D[g] \times \int_A D[A]\, \delta[F[A']] \left|Det\left[\frac{\partial F[A'_h]}{\partial h}\right]\right| = Vol(g) \int_A D[A]\, \delta[F[A]] \left|Det\left[\frac{\partial F[A_h]}{\partial h}\right]\right| exp(i\, S[A])$
Quantum
a and X
derivatives


Use the fact that ∫_A D[A] is gauge invariant and exp(i S[A]) also
∫_g D[g] ∫_A D[A] δ[F[A_g]] · |Det[∂F[A_h]/∂h]|
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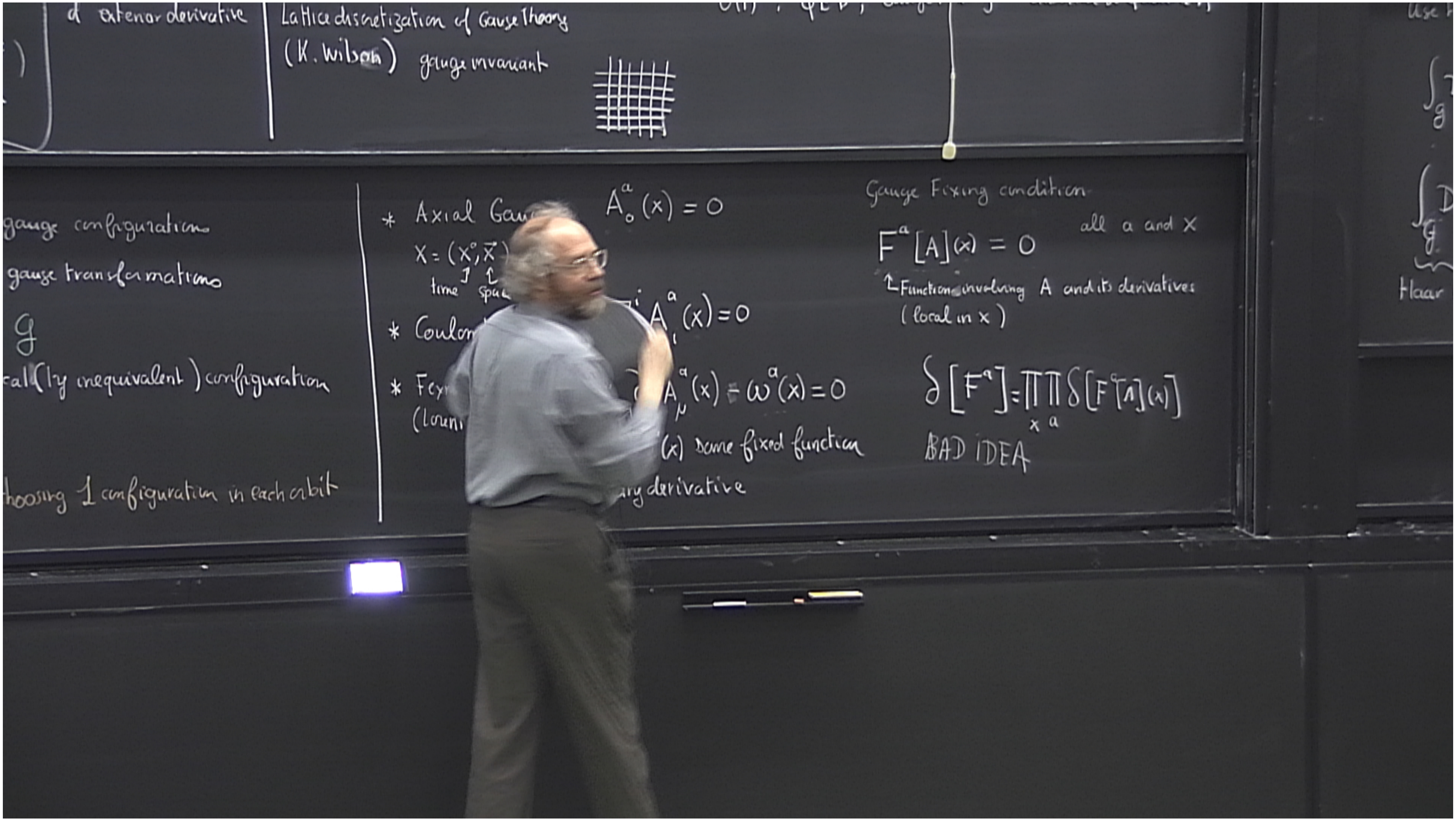
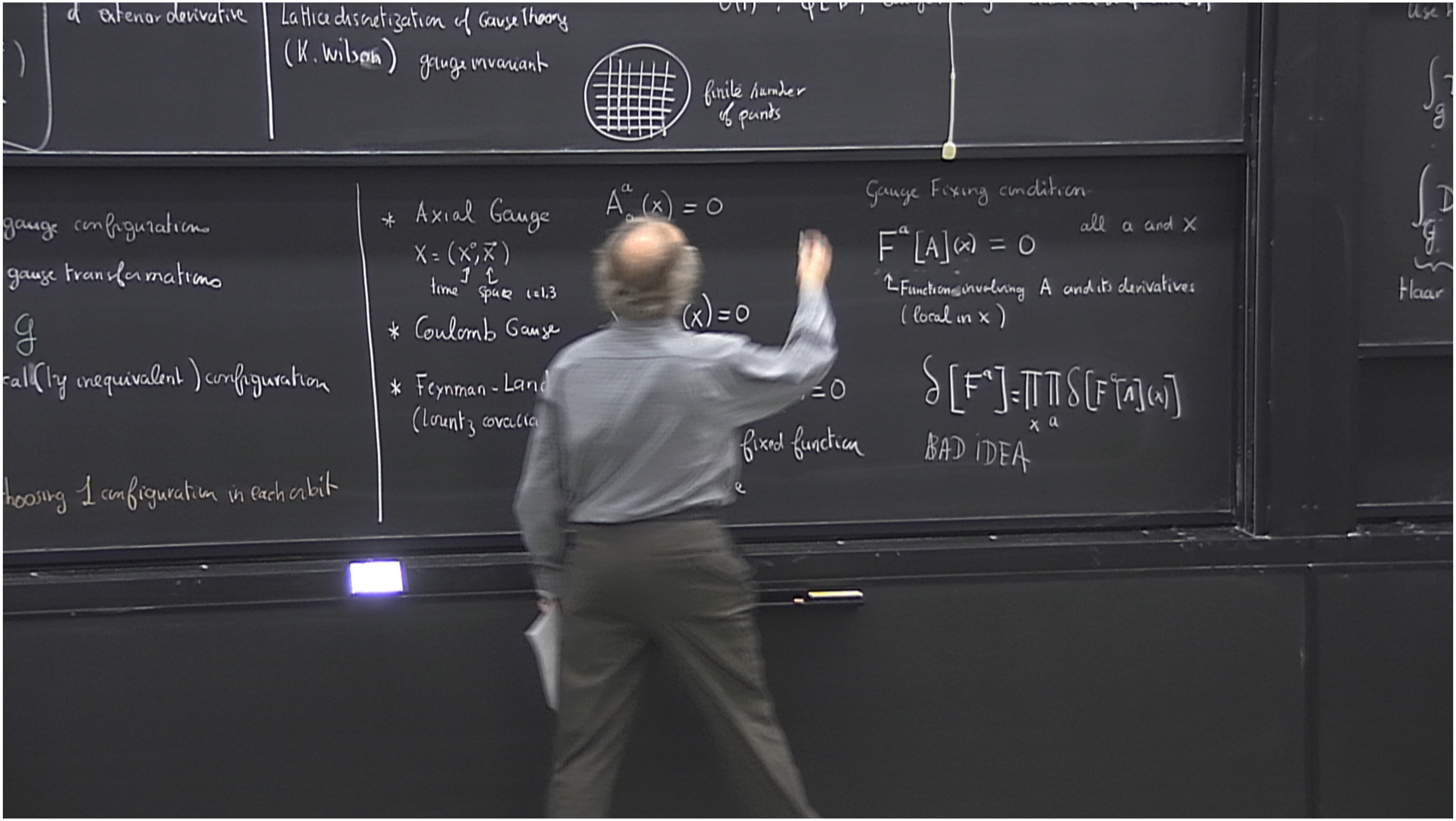
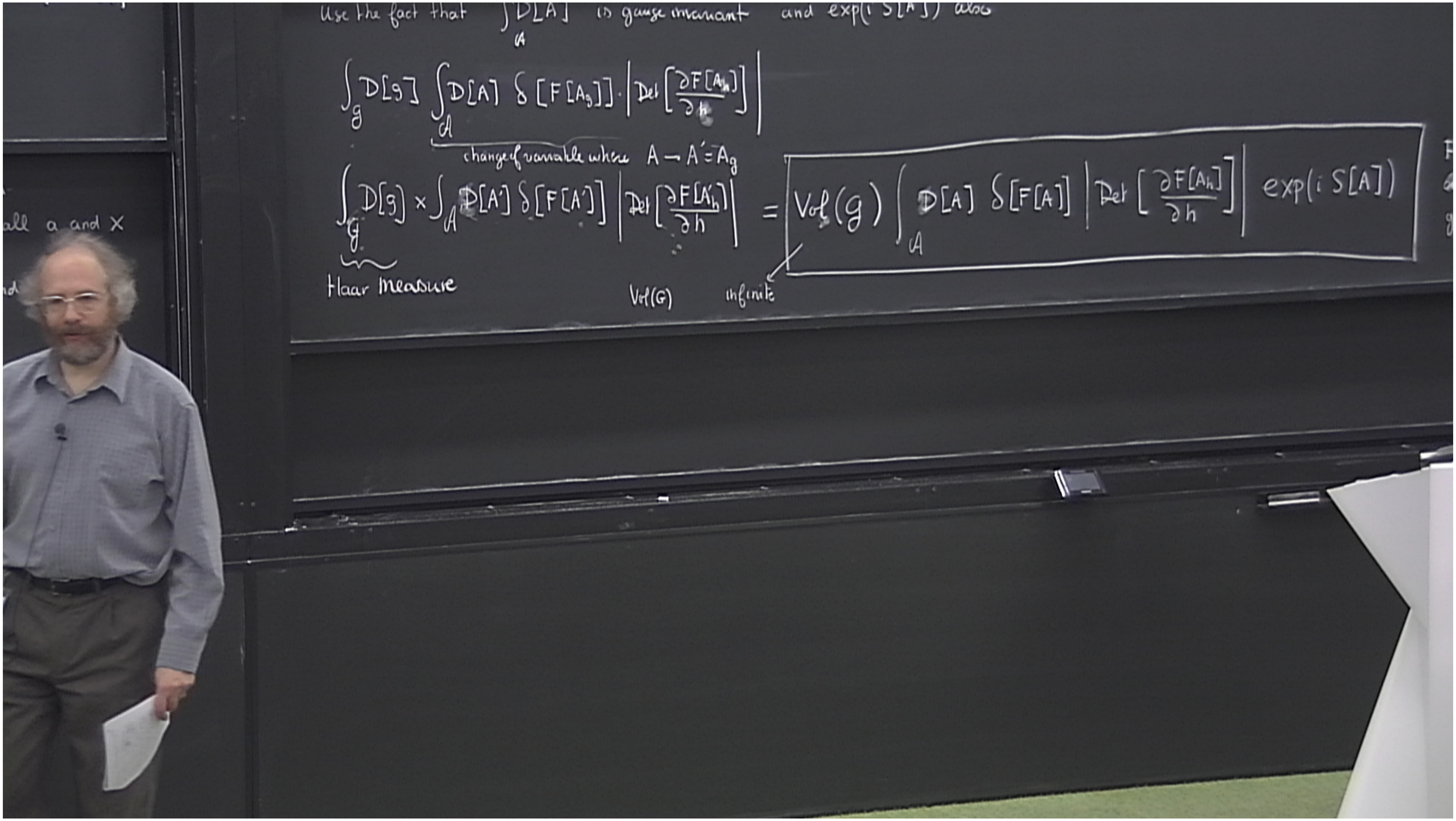
∫_g D[g] × ∫_A D[A'] δ[F[A']] |Det[∂F[A'_h]/∂h]| = Vol(g) ∫_A D[A] δ[F[A]] |Det[∂F[A_h]/∂h]| exp(i S[A])
Functional Integral for gauge Field, using a given gauge Fixing condition F[A]=0
, μ=1,4 ; a=1,n}
Quantum
a and X
derivatives
[A](x)]


extenor derivative
Lattice discretization of Gauge Theory
(K. Wilson) gauge invariant
gauge configurations
gauge transformations
all(ly inequivalent) configuration
choosing 1 configuration in each orbit
* Axial Gau
$A_0^a(x) = 0$
$x = (x^0, \vec{x})$
time
* Coulom
$A_i^a(x) = 0$
* Fey
(Loren
$A_\mu^a(x) = \omega^a(x) = 0$
(x) some fixed function
derivative
Gauge Fixing condition
$F^a[A](x) = 0$
all a and x
Function involving A and its derivatives
(local in x)
$\delta[F^a] = \prod_x \prod_a \delta[F^a[A](x)]$
BAD IDEA
Haar



Lattice discretization of Gauge Theory
(K. Wilson) gauge invariant
finite number of points
gauge configurations
gauge transformations
Axial Gauge
Coulomb Gauge
Feynman - Land
Gauge Fixing condition
all a and x
Functions involving A and its derivatives
(local in x)
BAD IDEA
fixed function
choosing 1 configuration in each orbit
Haar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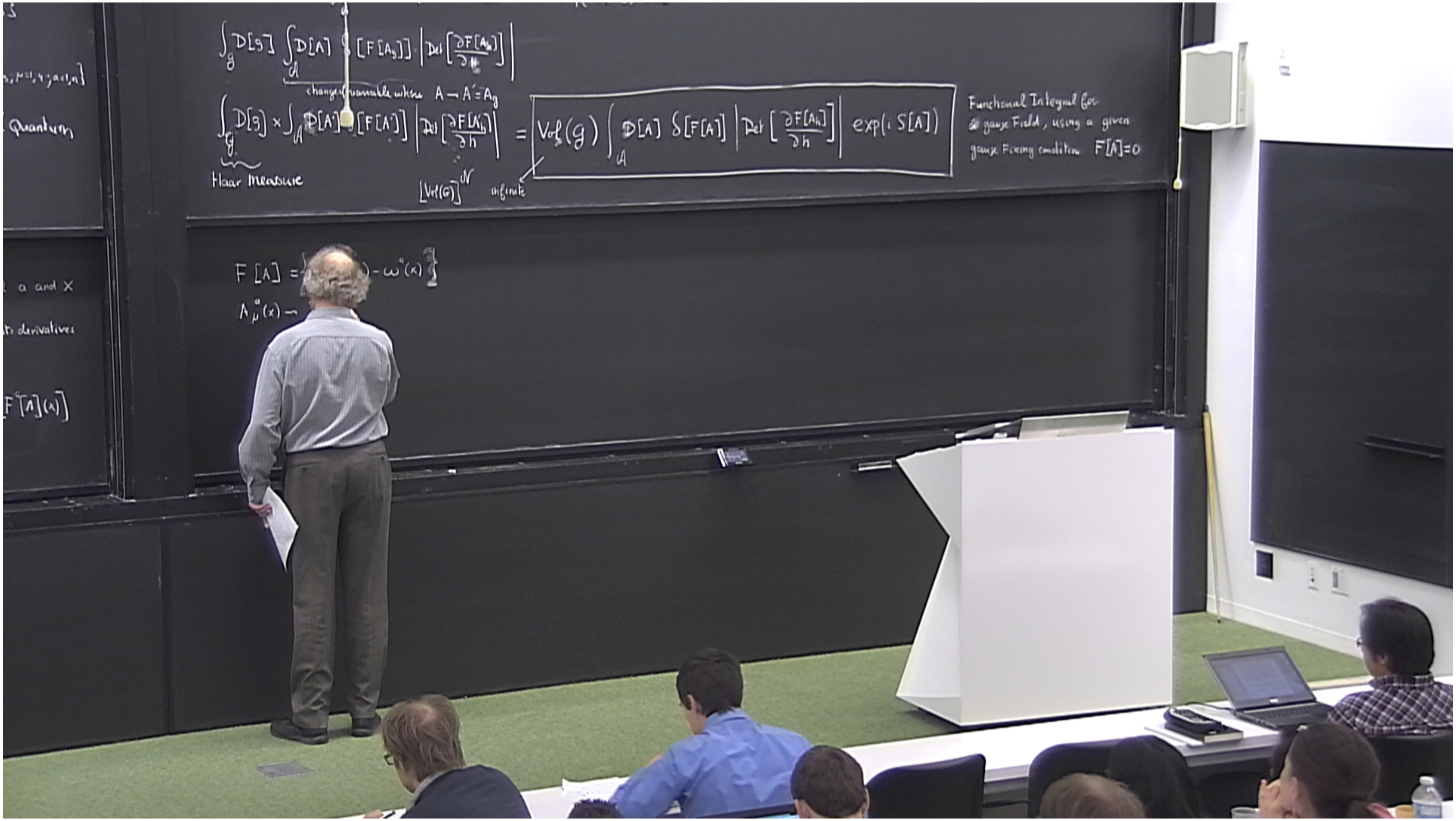
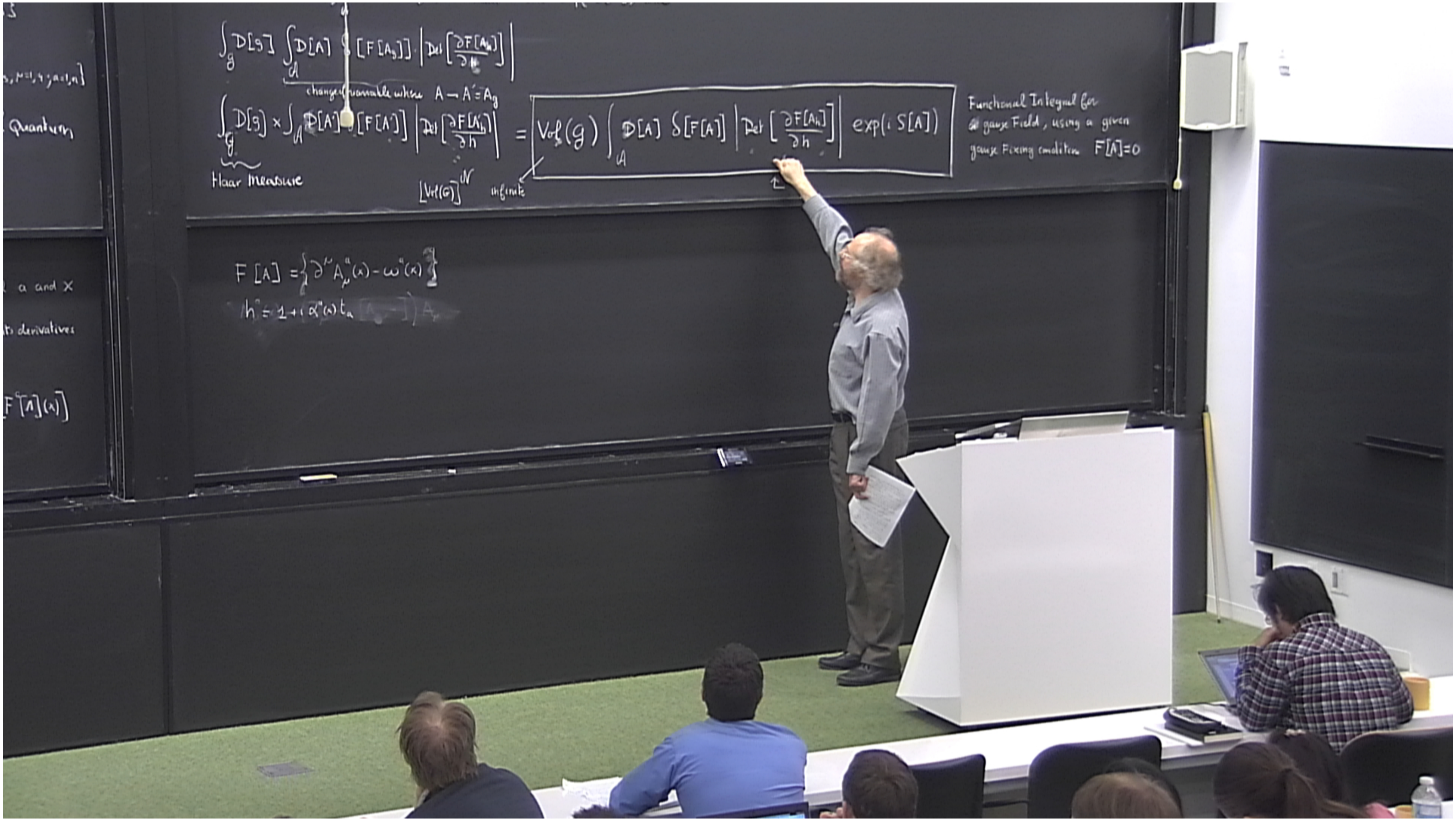
change of variable where $A \to A' = A_g$
$\int_g D[g] \times \int_A D[A']\, \delta[F[A']] \left| \mathrm{Det}\left[\frac{\partial F[A'_h]}{\partial h}\right] \right| = \mathrm{Vol}(g) \int_A D[A]\, \delta[F[A]] \left| \mathrm{Det}\left[\frac{\partial F[A_h]}{\partial h}\right] \right| \exp(i S[A])$
Haar measure
Vol(G)
infinite
all a and X


change of variable where A → A' = A_g
Haar measure
infinite
Functional Integral for
gauge Field, using a given
gauge Fixing condition F[A]=0
Quantum
a and X
derivatives


Functional Integral for
gauge Field, using a given
gauge Fixing condition F[A]=0
Haar Measure
infinite
and X
derivatives
Quantum