Title: AdS/CFT

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Collection: AdS/CFT 2021/2022

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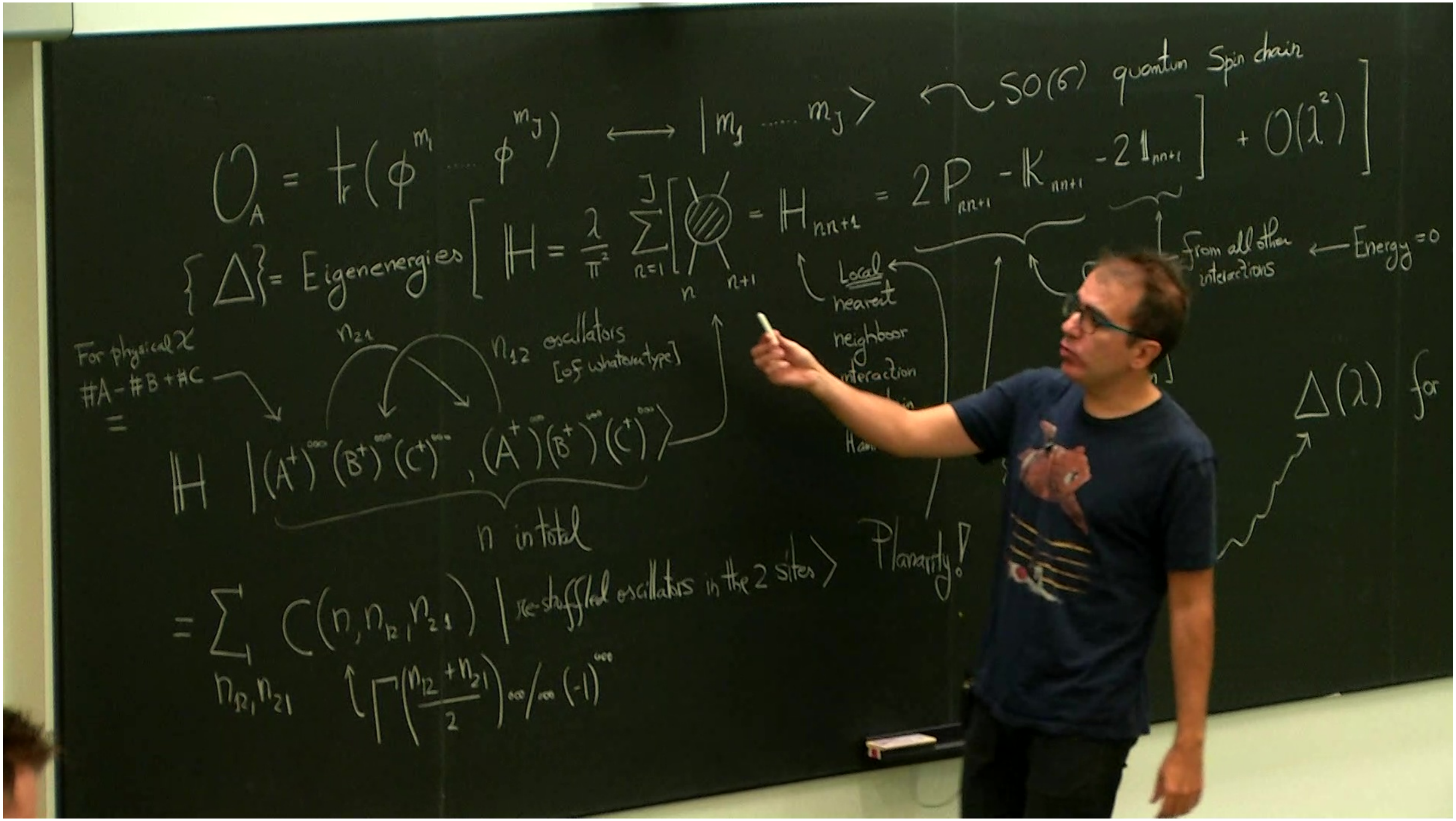
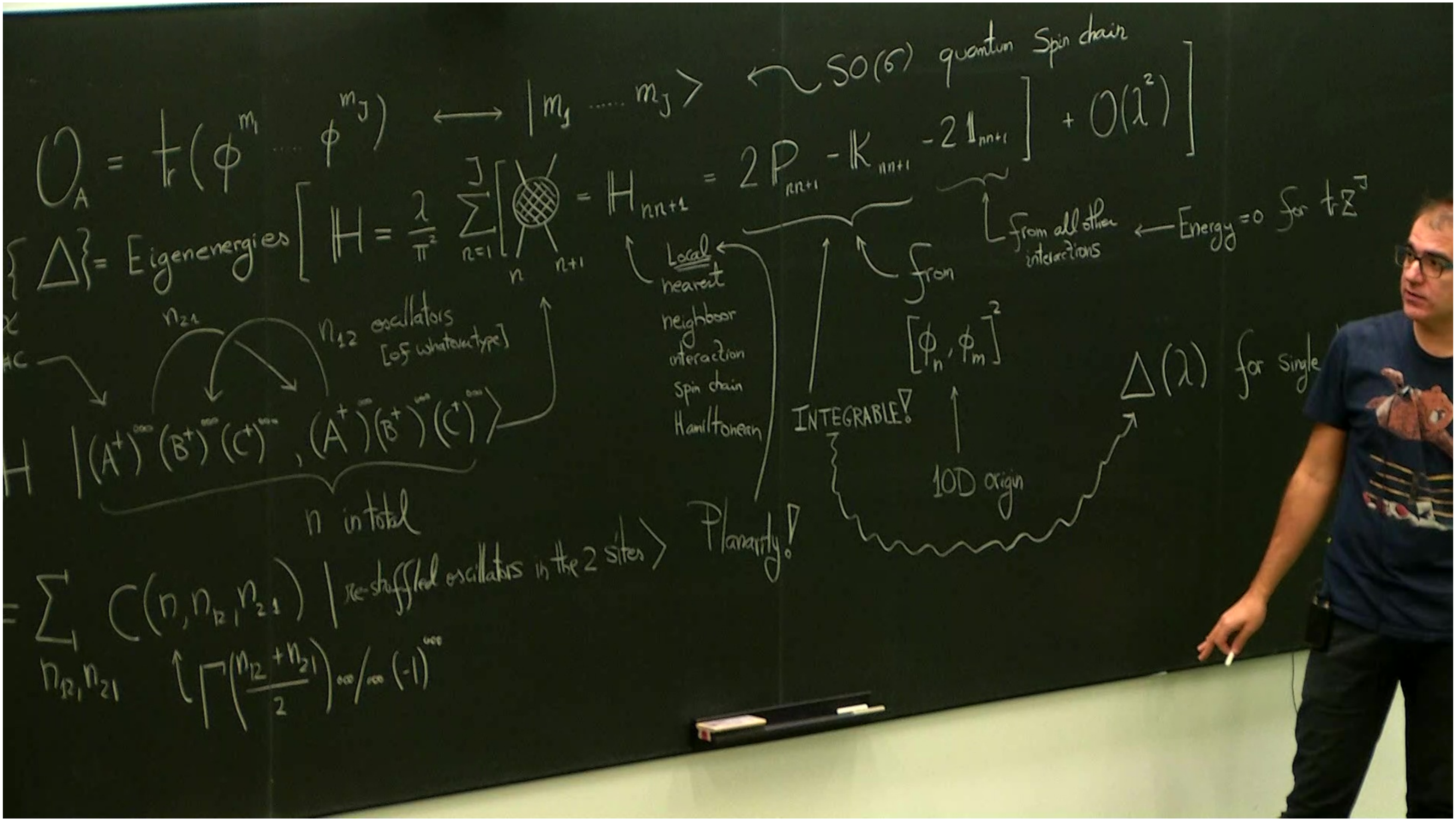
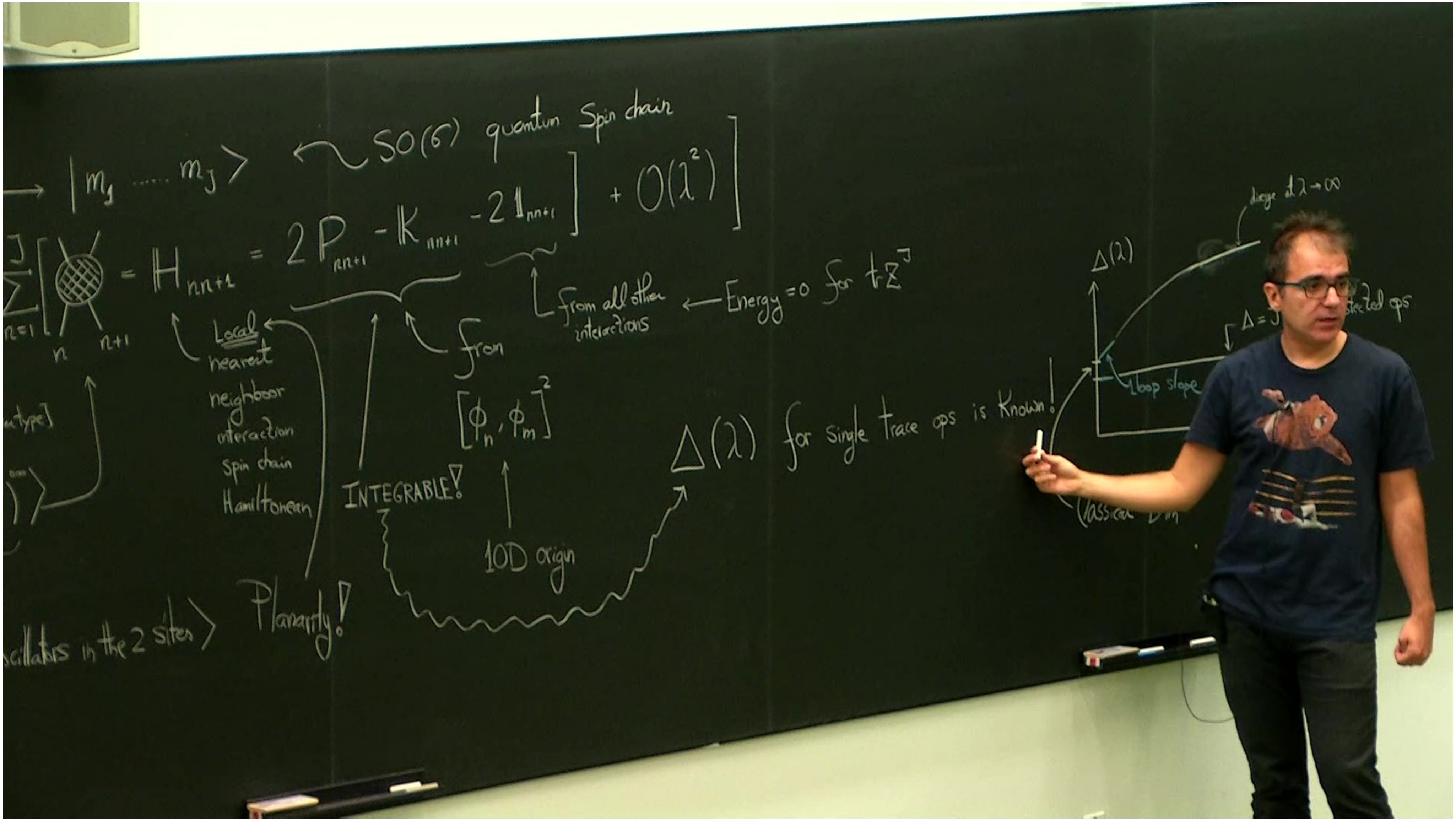
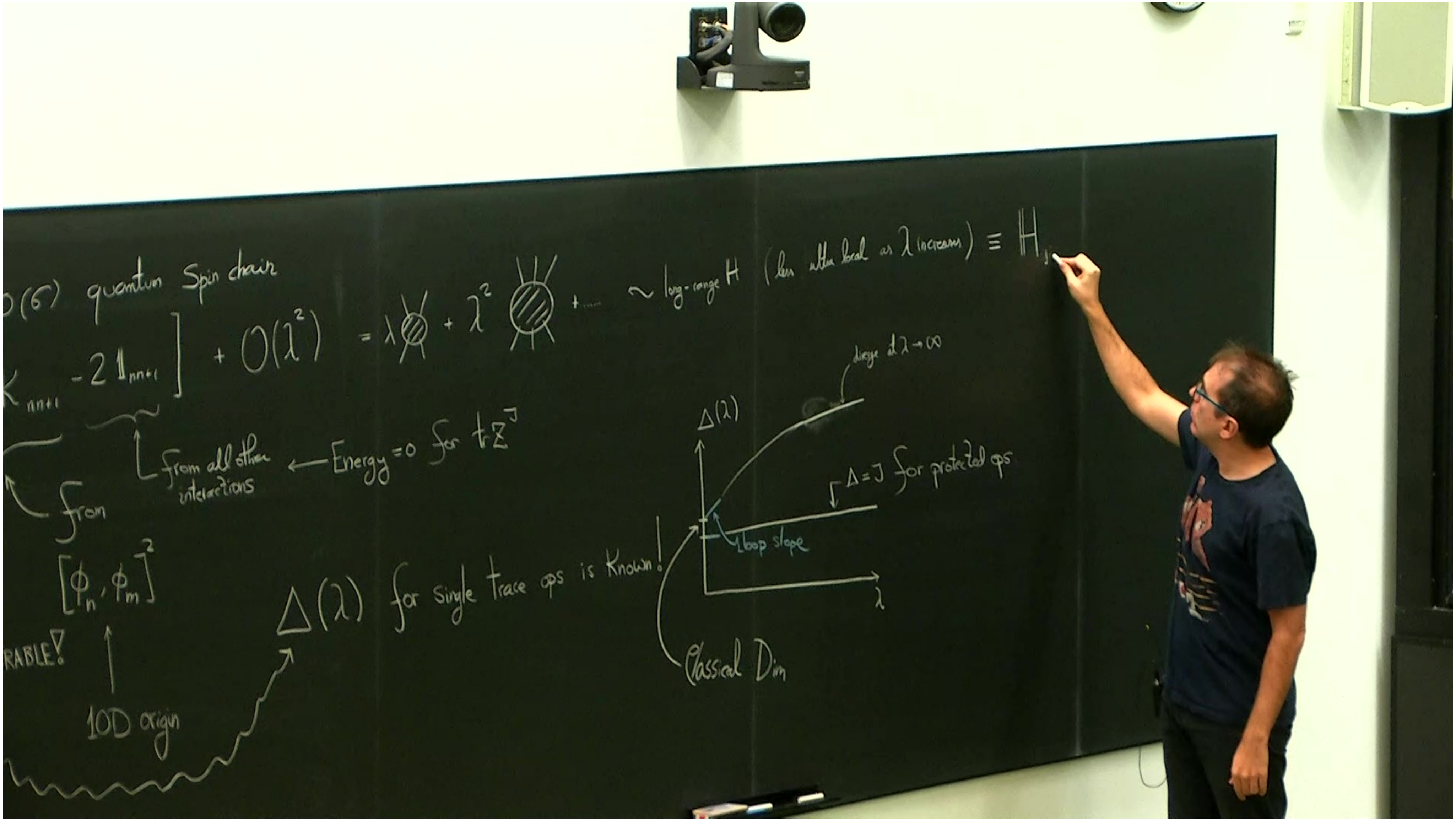
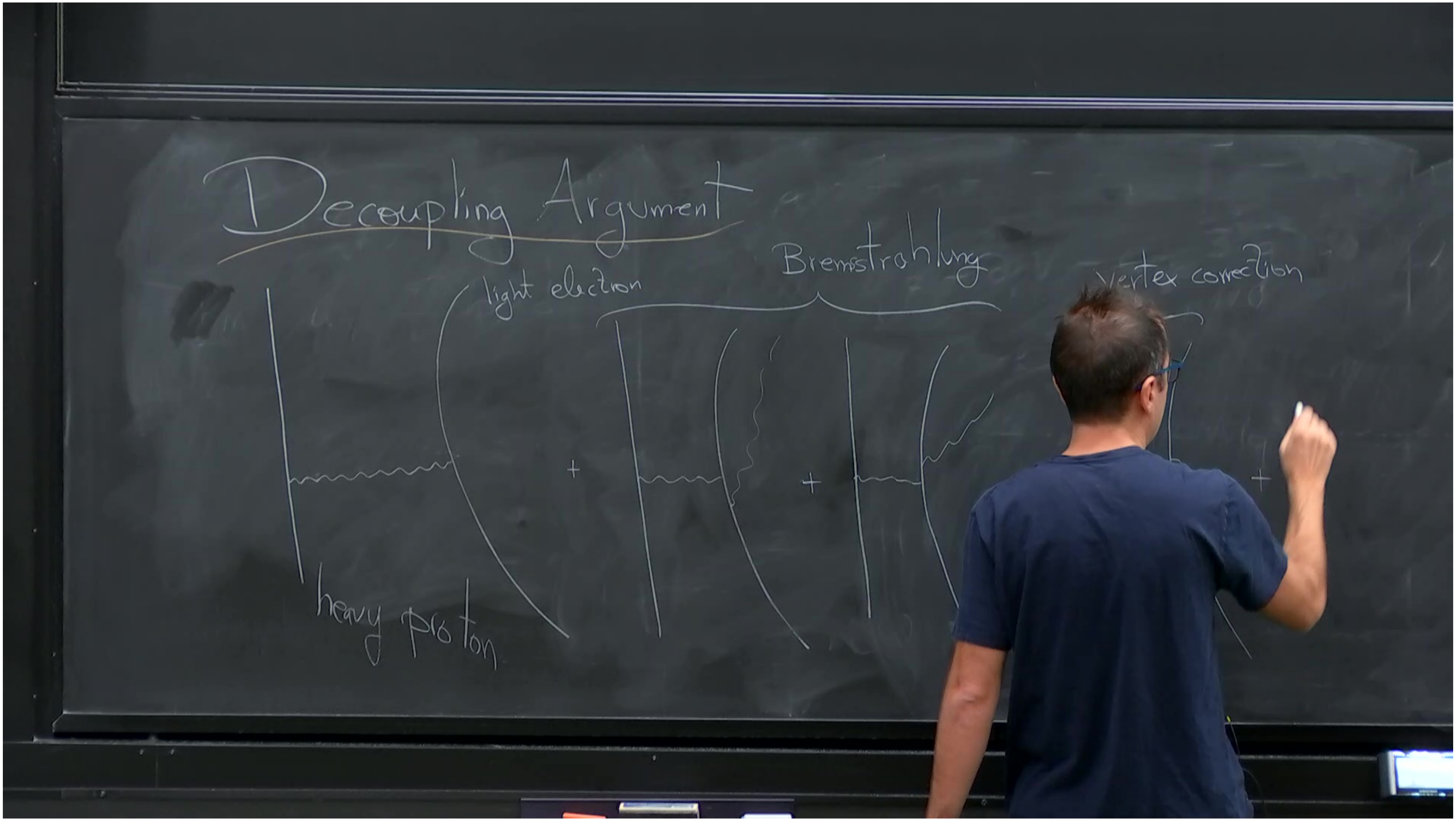

SO(6) quantum Spin chain
{Δ} = Eigenenergies
Local
nearest
neighbour
interaction
from all other interactions
Energy = 0
For physical X
#A - #B + #C
=
oscillators
[of whatever type]
n in total
re-shuffled oscillators in the 2 sites
Planarity!

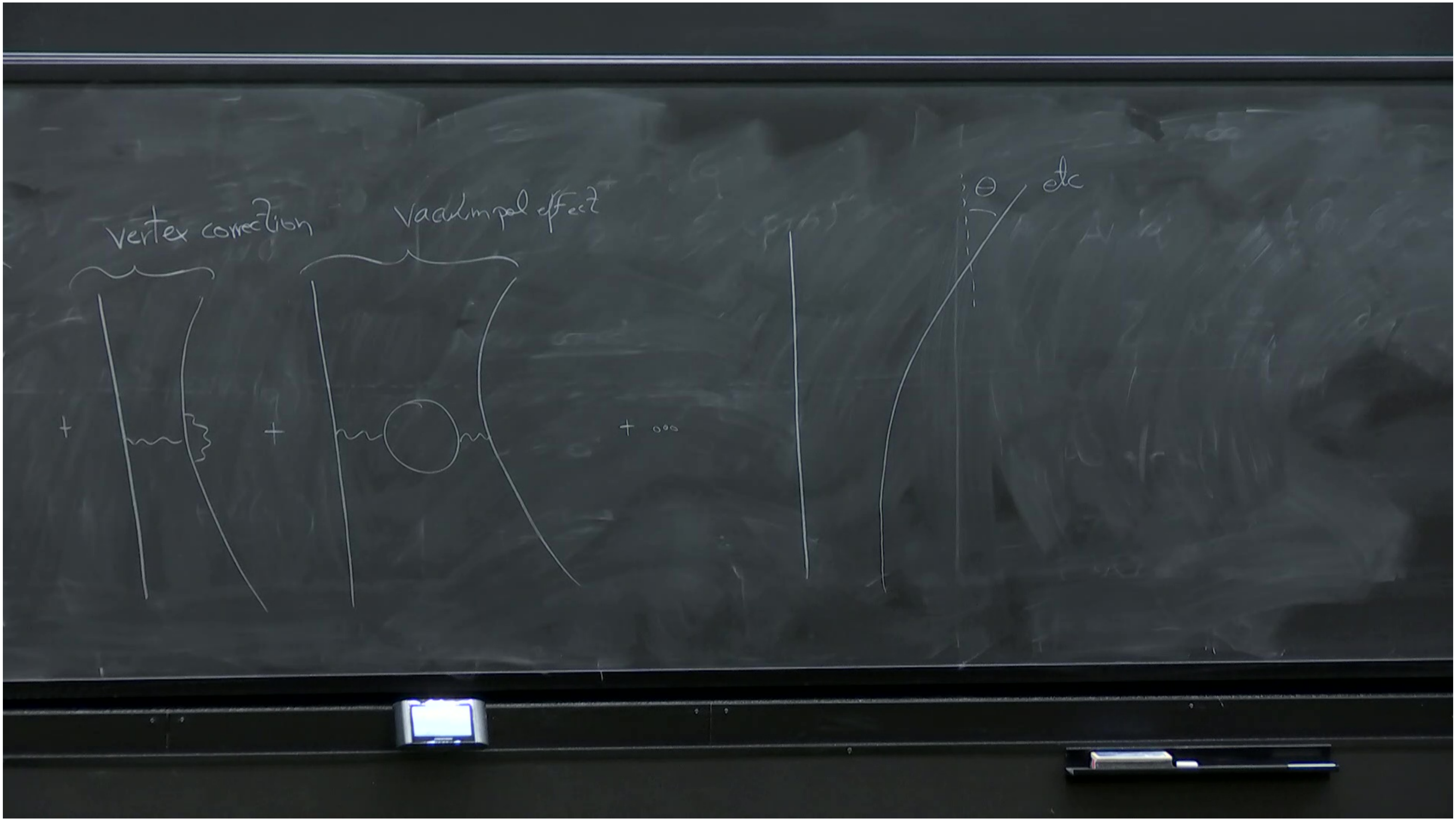

SO(6) quantum Spin chain
Eigenenergies
Local nearest neighbour interaction spin chain Hamiltonian
from
from all other interactions
Energy = 0 for tr Z^J
n12 oscillators [of whatever type]
n in total
re-shuffled oscillators in the 2 sites
Planarity!
INTEGRABLE!
10D origin
for single

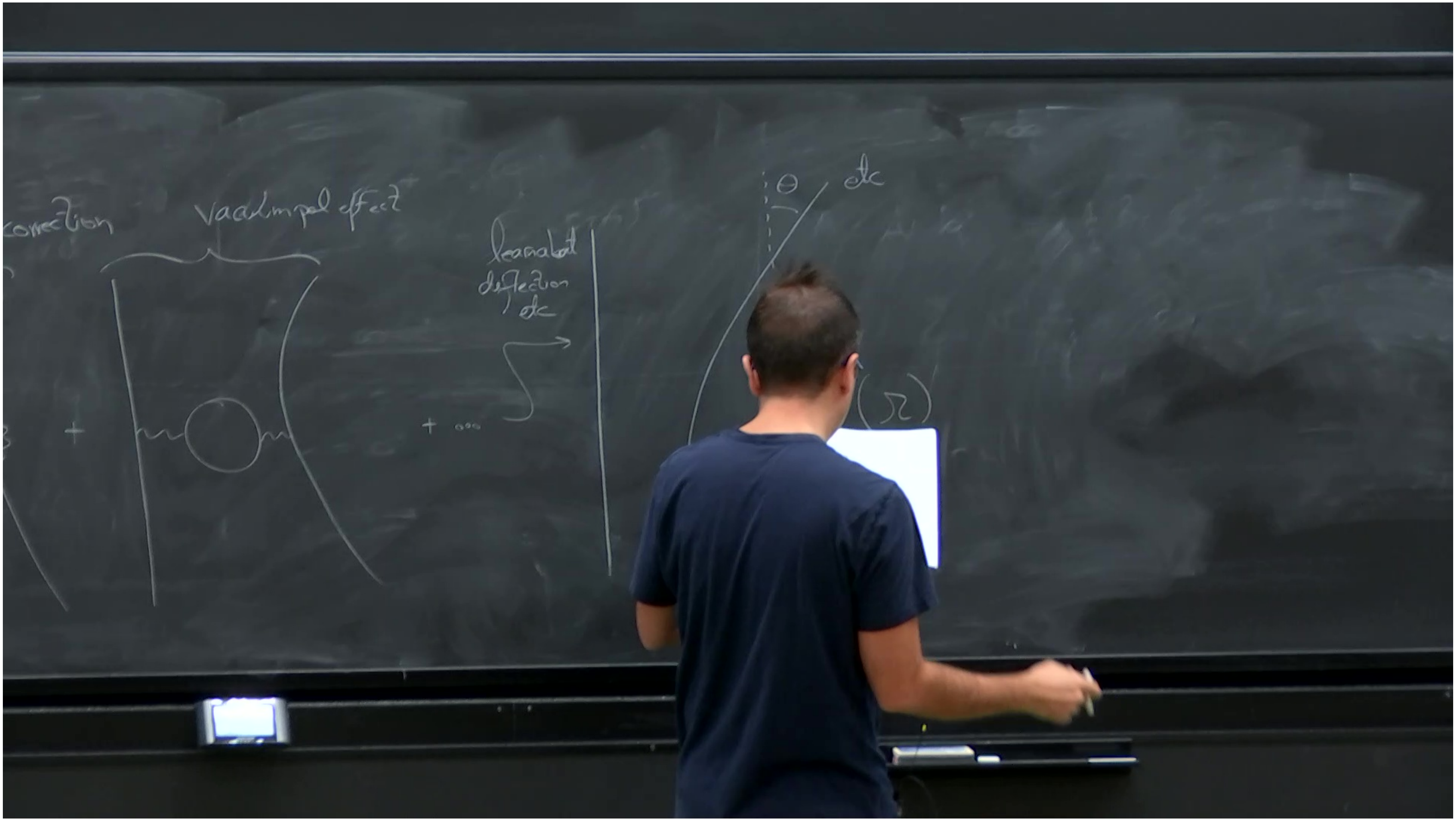

SO(6) quantum Spin chain
$\rightarrow |m_1 \ldots\ldots m_J\rangle$
$\sum_{n=1}^{J} = \mathbb{H}_{n\,n+1} = 2P_{n\,n+1} - K_{n\,n+1} - 2\,\mathbb{1}_{n\,n+1}] + O(\lambda^2)]$
n n+1
Local nearest neighbour interaction spin chain Hamiltonian
from $[\phi_n, \phi_m]^2$
from all other interactions
Energy = 0 for $\mathrm{tr}\, Z^J$
INTEGRABLE!
10D origin
Planarity!
$\Delta(\lambda)$ for single trace ops is known!
scillators in the 2 sites⟩
$\Delta(\lambda)$
diverge at $\lambda \to \infty$
$\Delta = J$
1 loop slope
Classical Dim

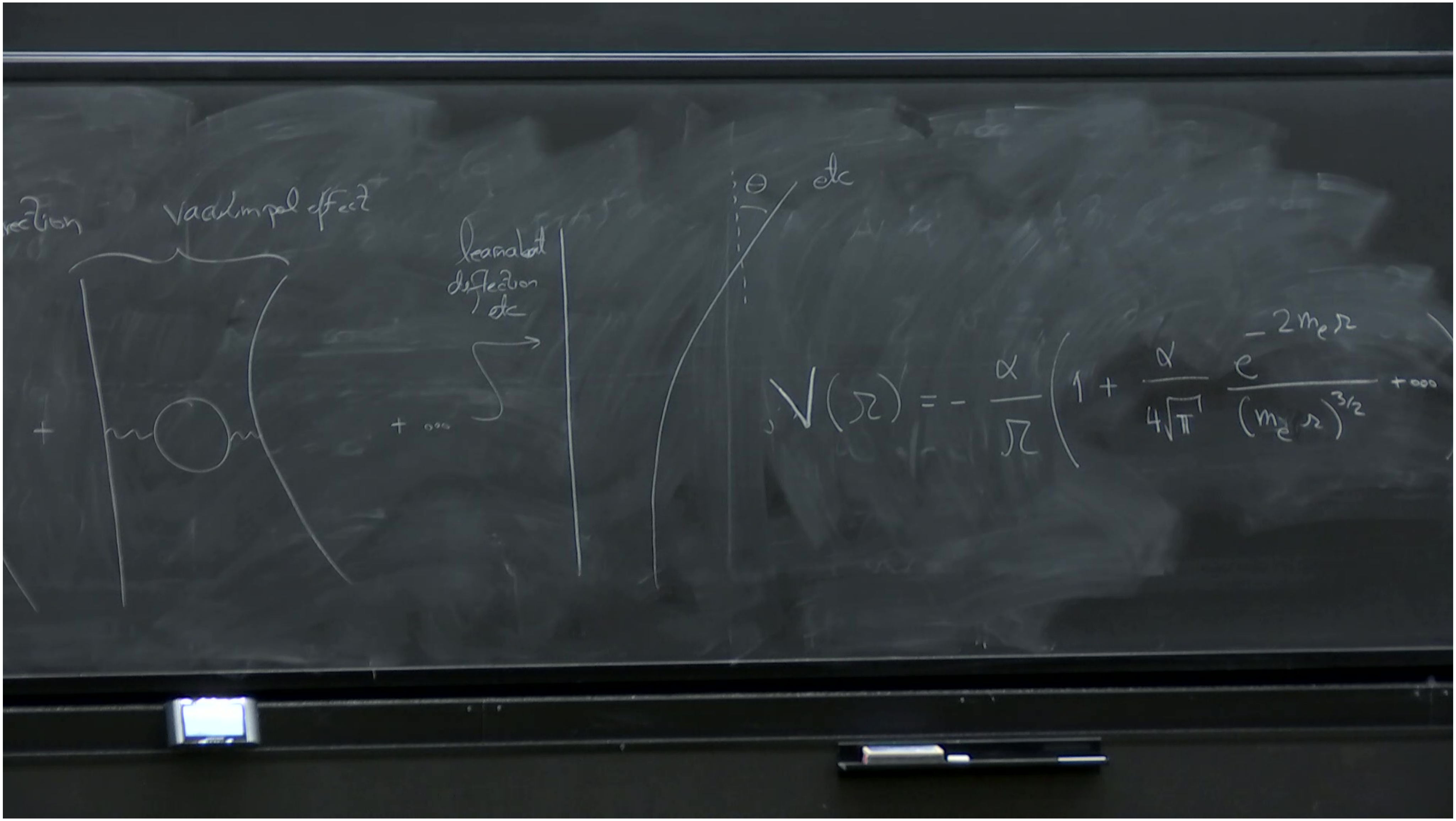


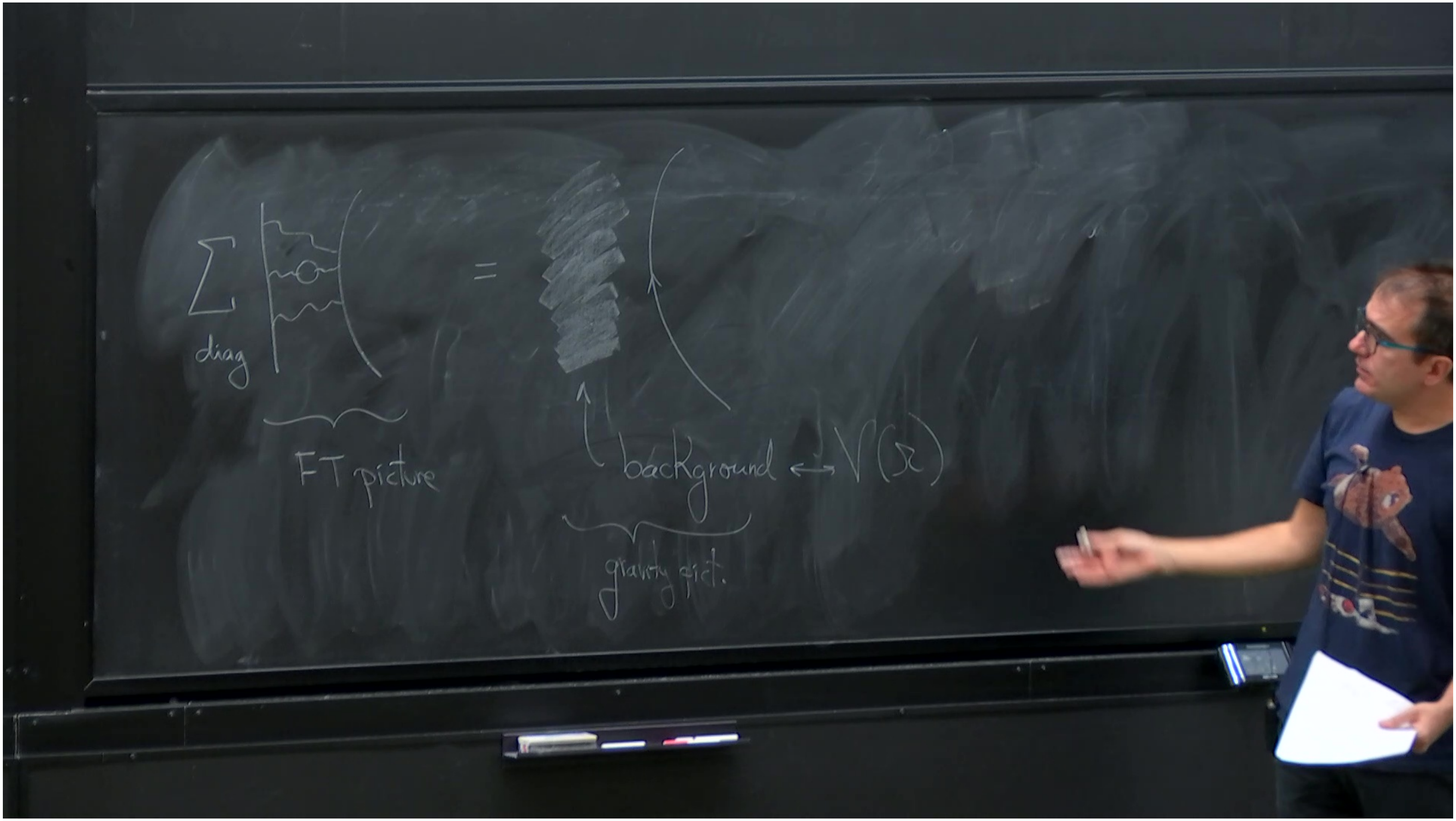
quantum Spin chain
+ O(λ²) = λ + λ² + ... ~ long-range H (less and less local as λ increases) ≡ H
from all other interactions
← Energy = 0 for tr Z^J
from
[φn, φm]²
RABLE!
10D origin
Δ(λ) for single trace ops is Known!
Δ(λ)
diverge at λ → ∞
Δ = J for protected ops
1 loop slope
λ
Classical Dim

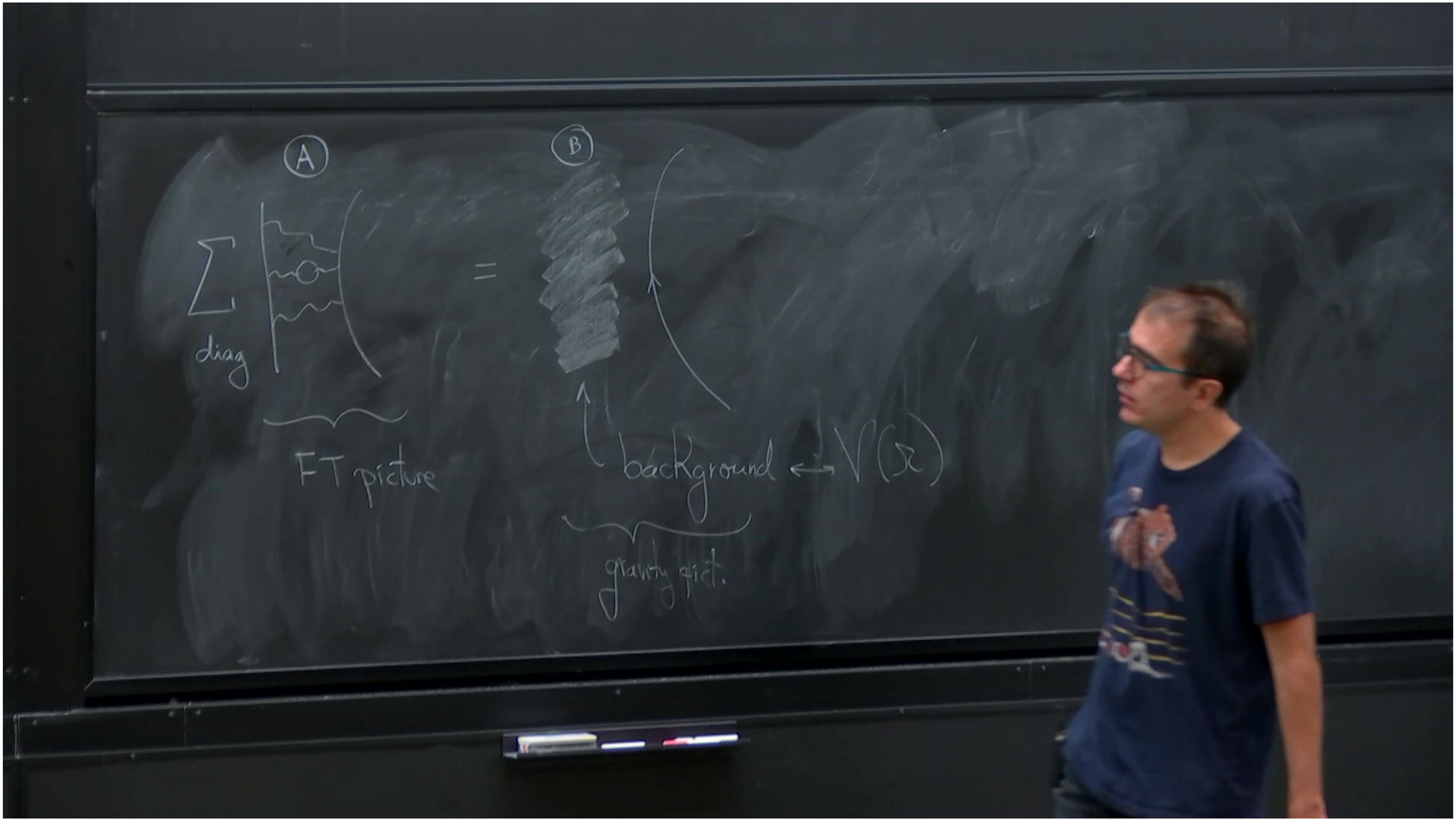

Decoupling Argument
light electron
Bremsstrahlung
vertex correction
heavy proton
+
+
+

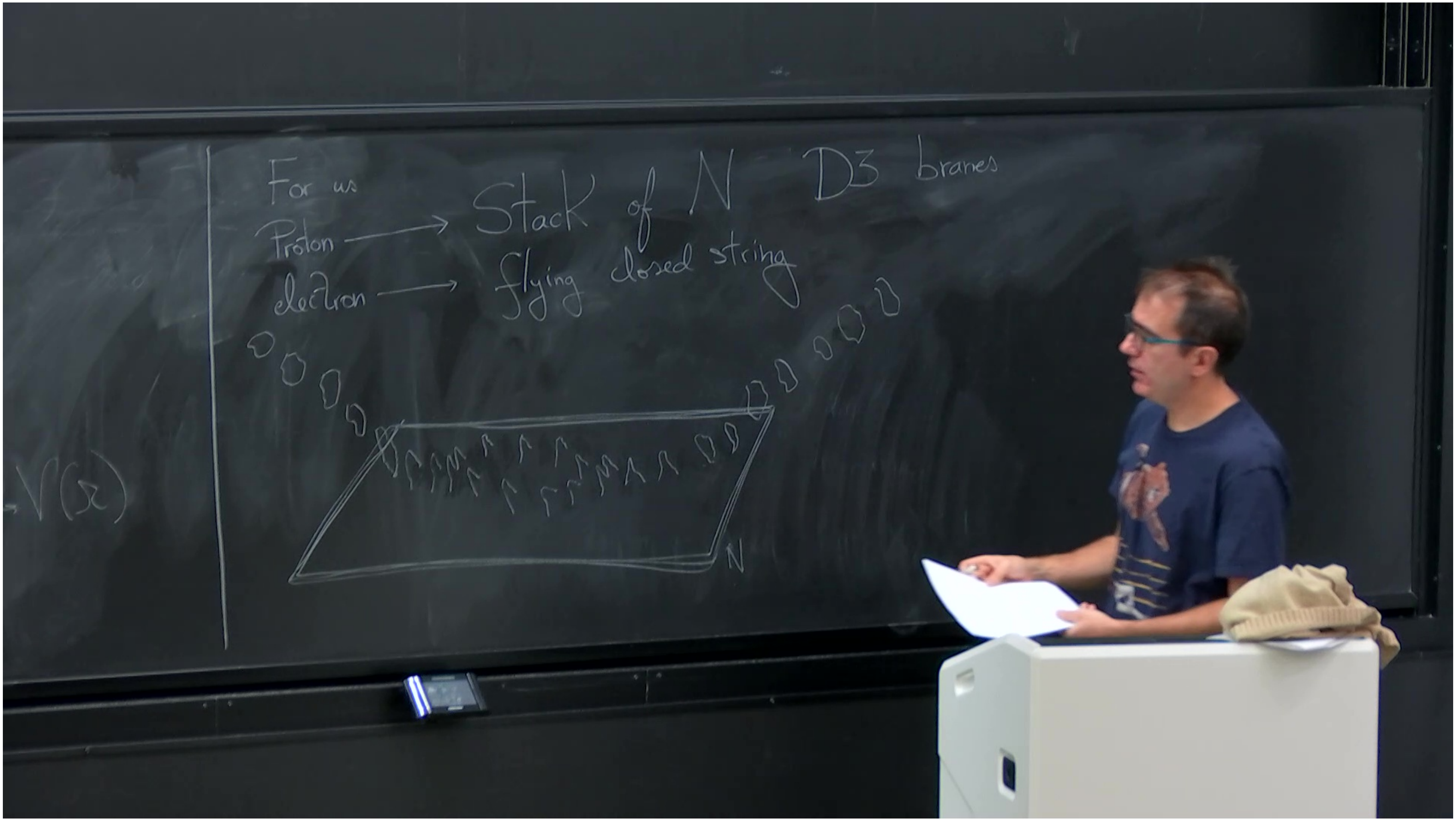

vertex correction
Vacuum pol effect
+
+
+ ...
θ
etc

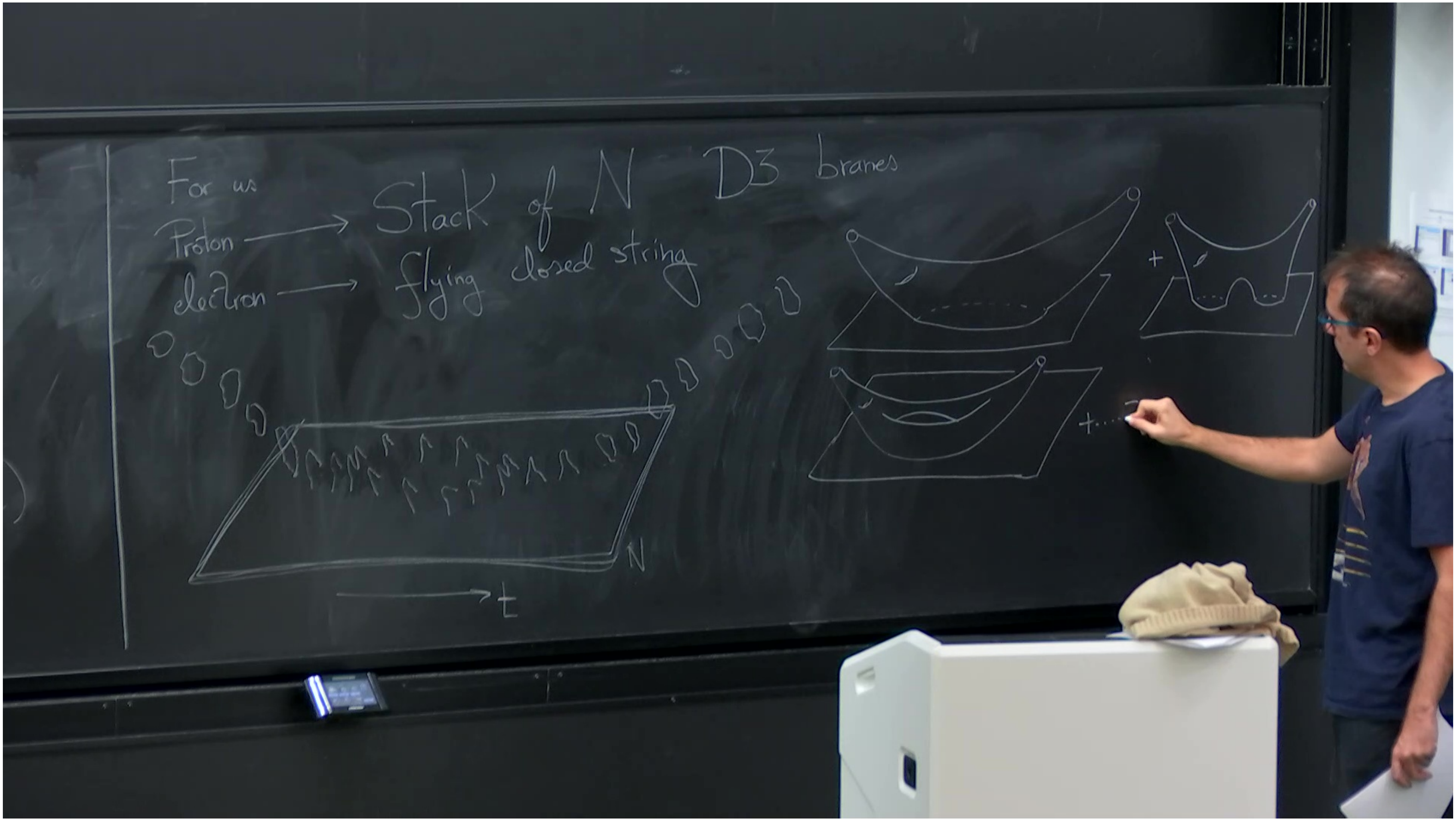

correction
deflection
etc
etc

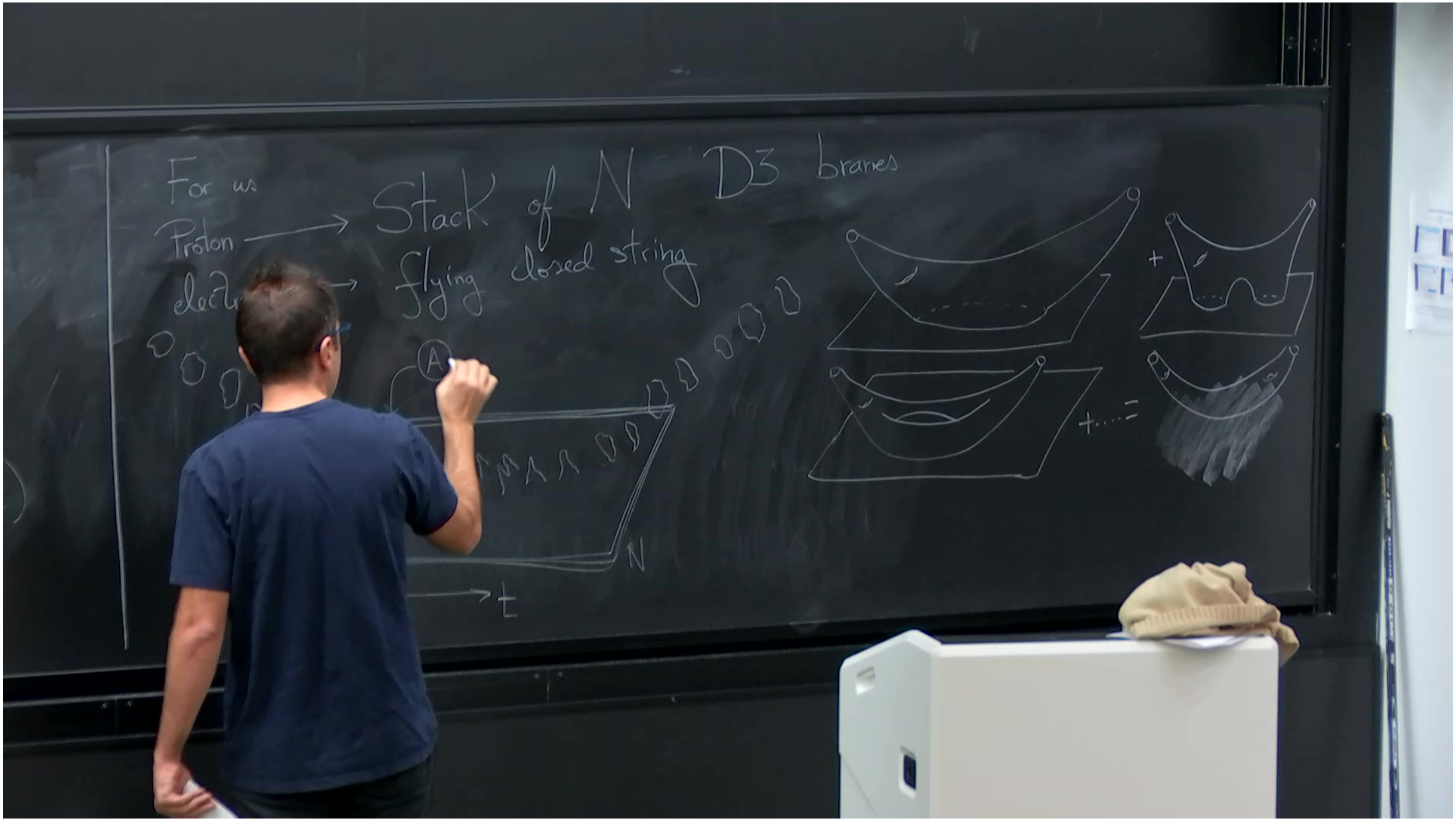

Vacuum pol effect
deflection
etc
θ
etc
$V(r) = -\frac{\alpha}{r}\left(1 + \frac{\alpha}{4\sqrt{\pi}}\frac{e^{-2m_e r}}{(m_e r)^{3/2}} + \dots\right)$

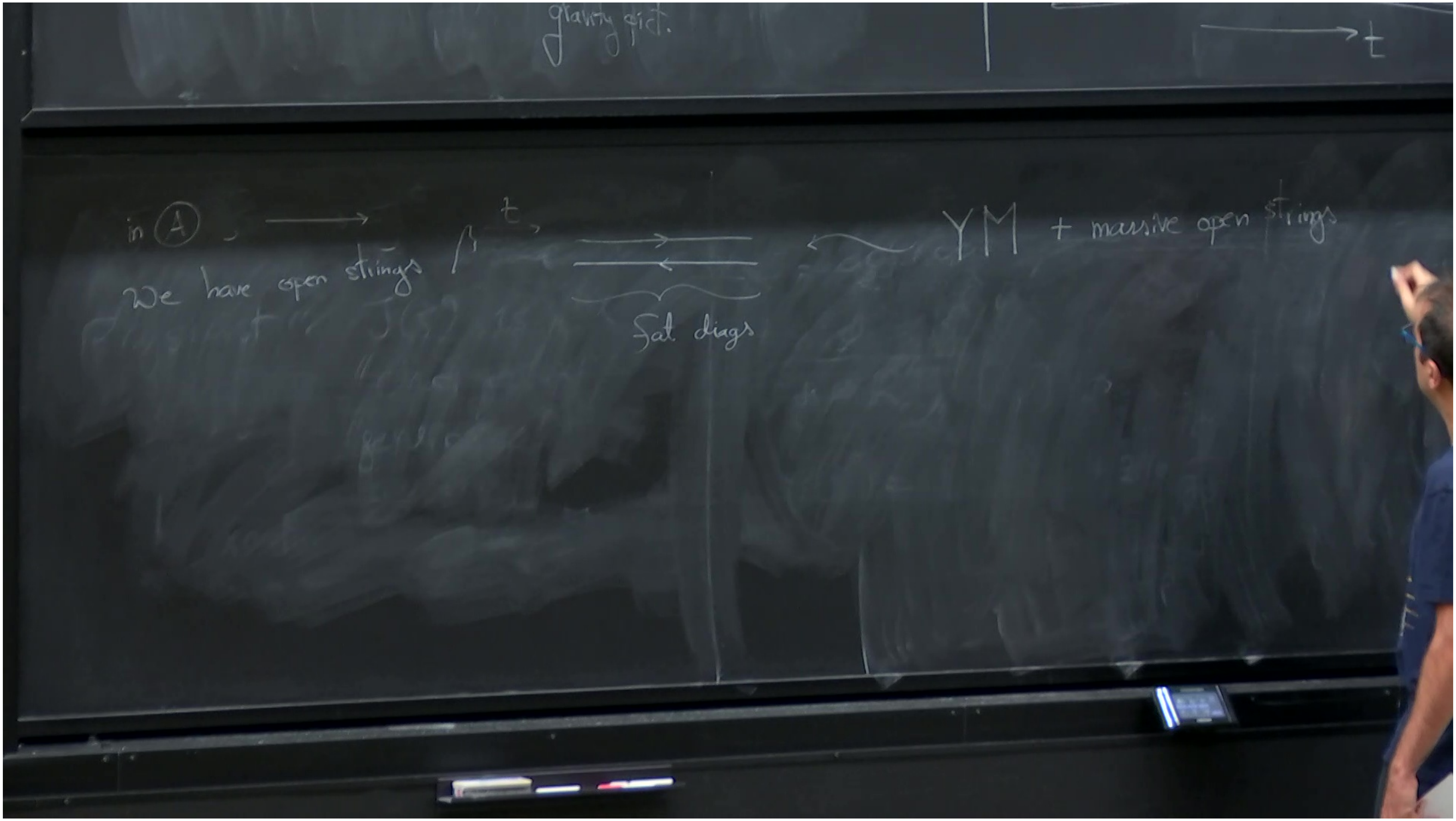

diag
FT picture
background ↔ V(x)
gravity pict.

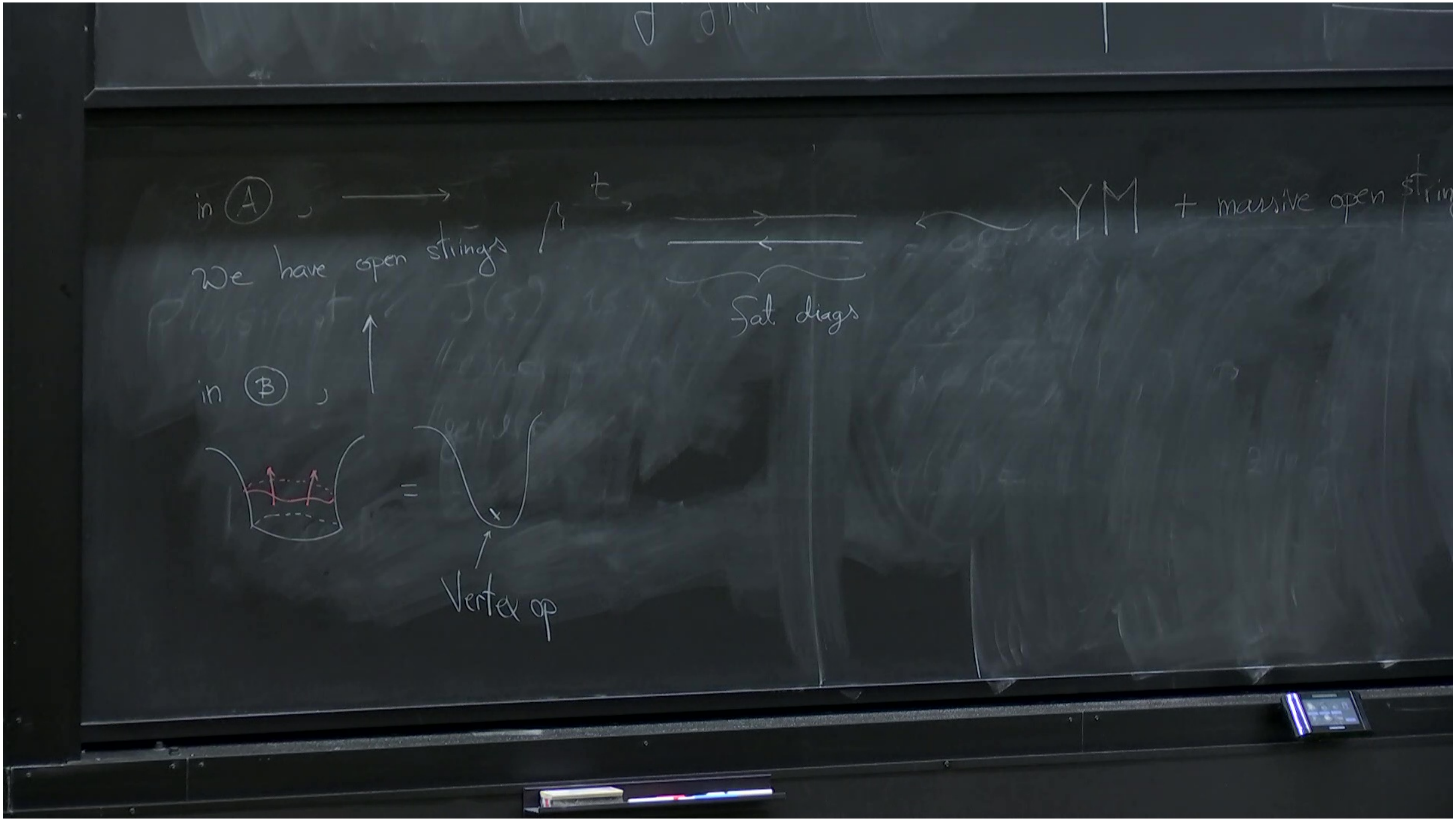

A
B
diag
=
FT picture
background ⟷ V(x)
gravity pict.

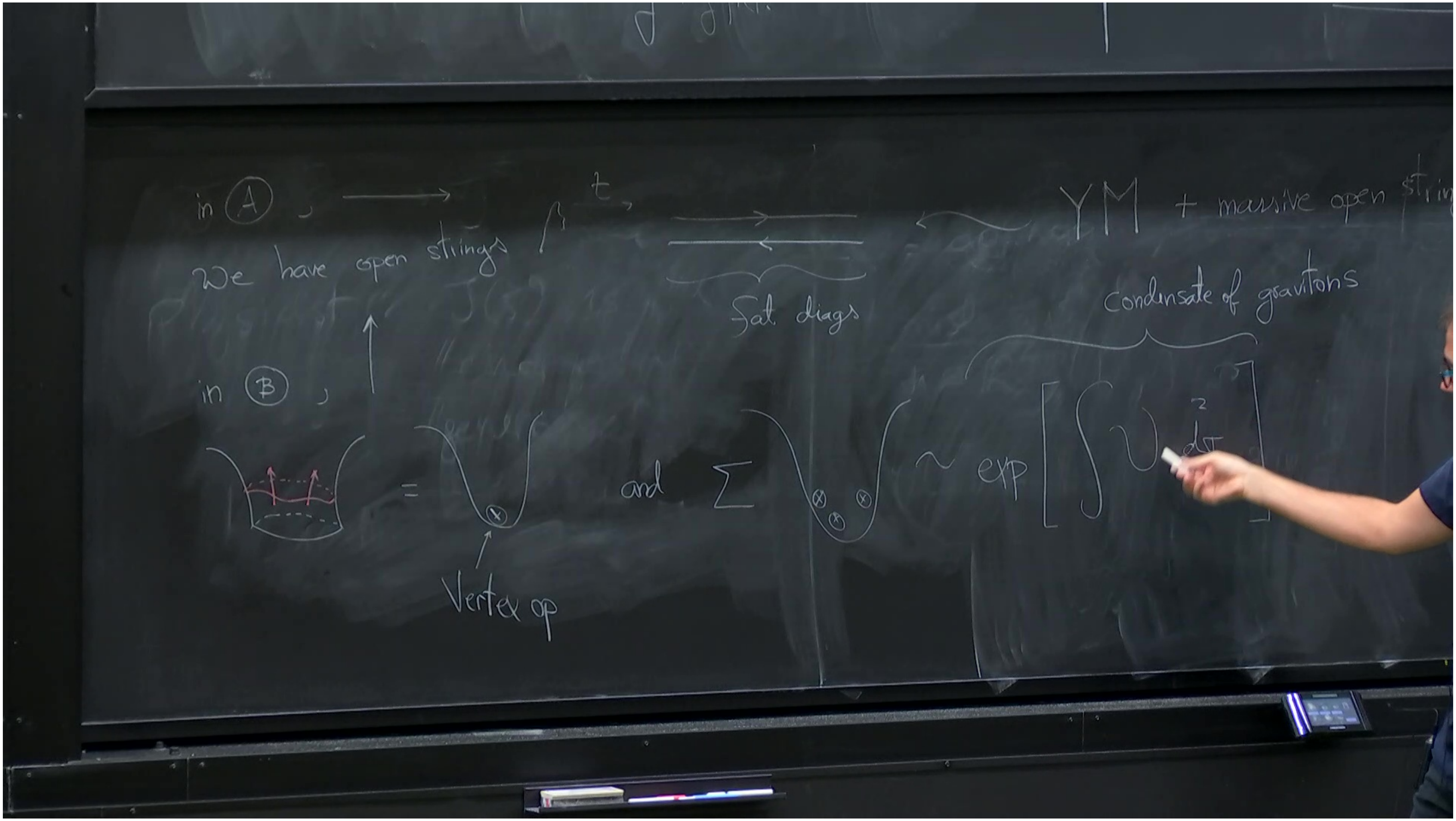

For us
Proton → Stack of N D3 branes
electron → flying closed string
N
V(Ω)

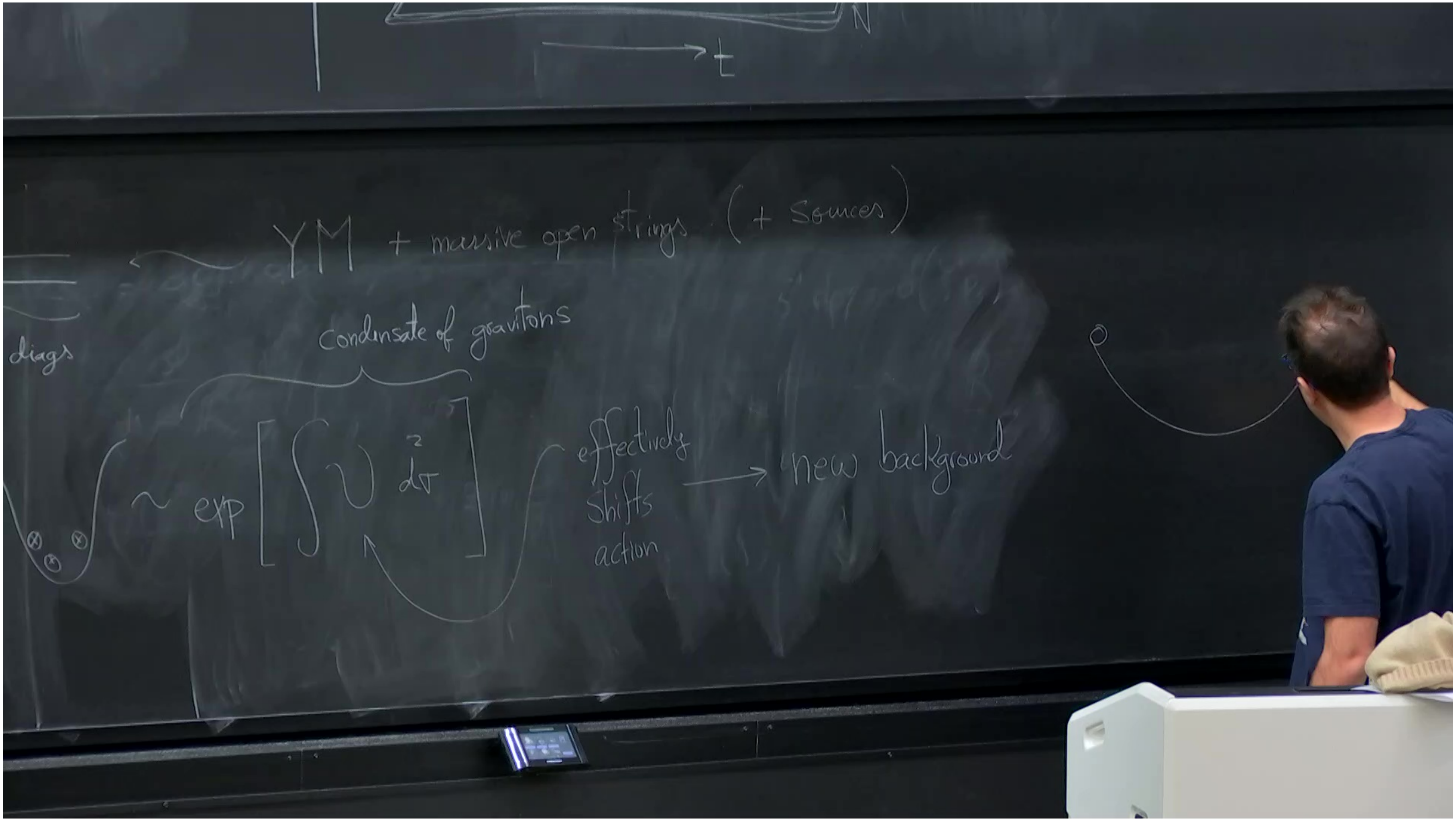

For us
Proton → Stack of N D3 branes
electron → flying closed string
N
t

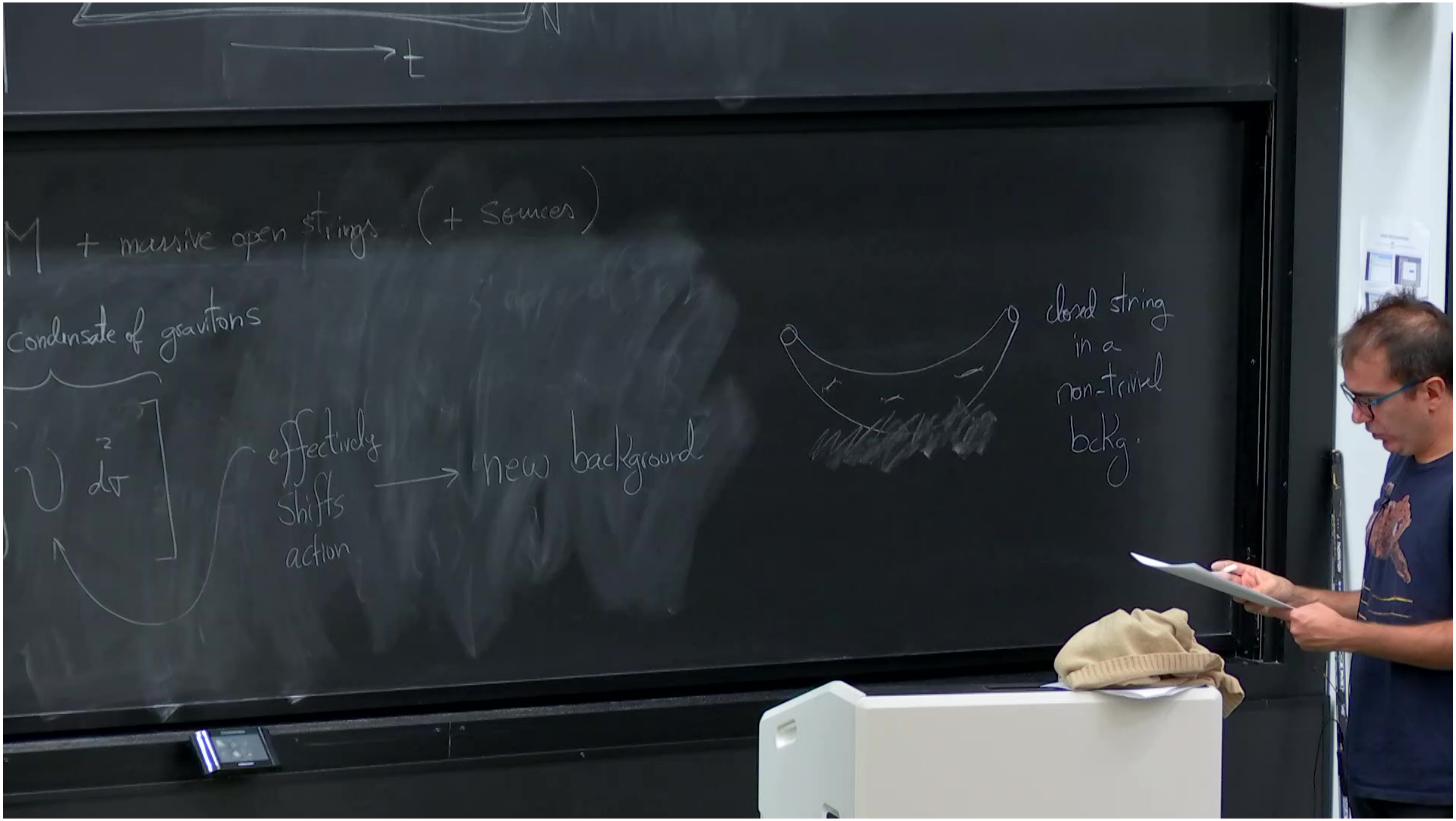

For us
Proton → Stack of N D3 branes
flying closed string
N
t

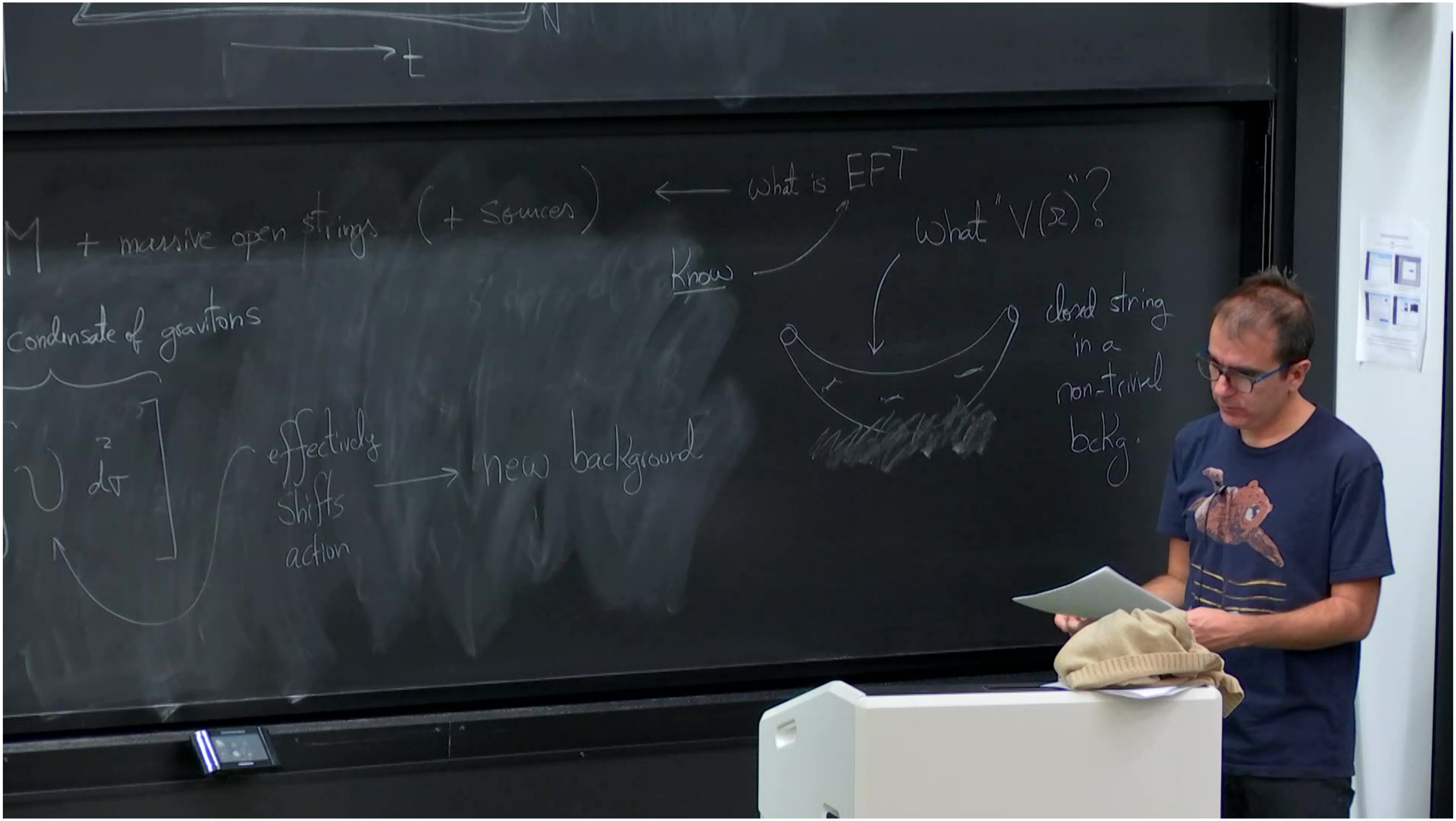

gravity pict.
t
in A
t
We have open strings
fat diags
YM + massive open strings

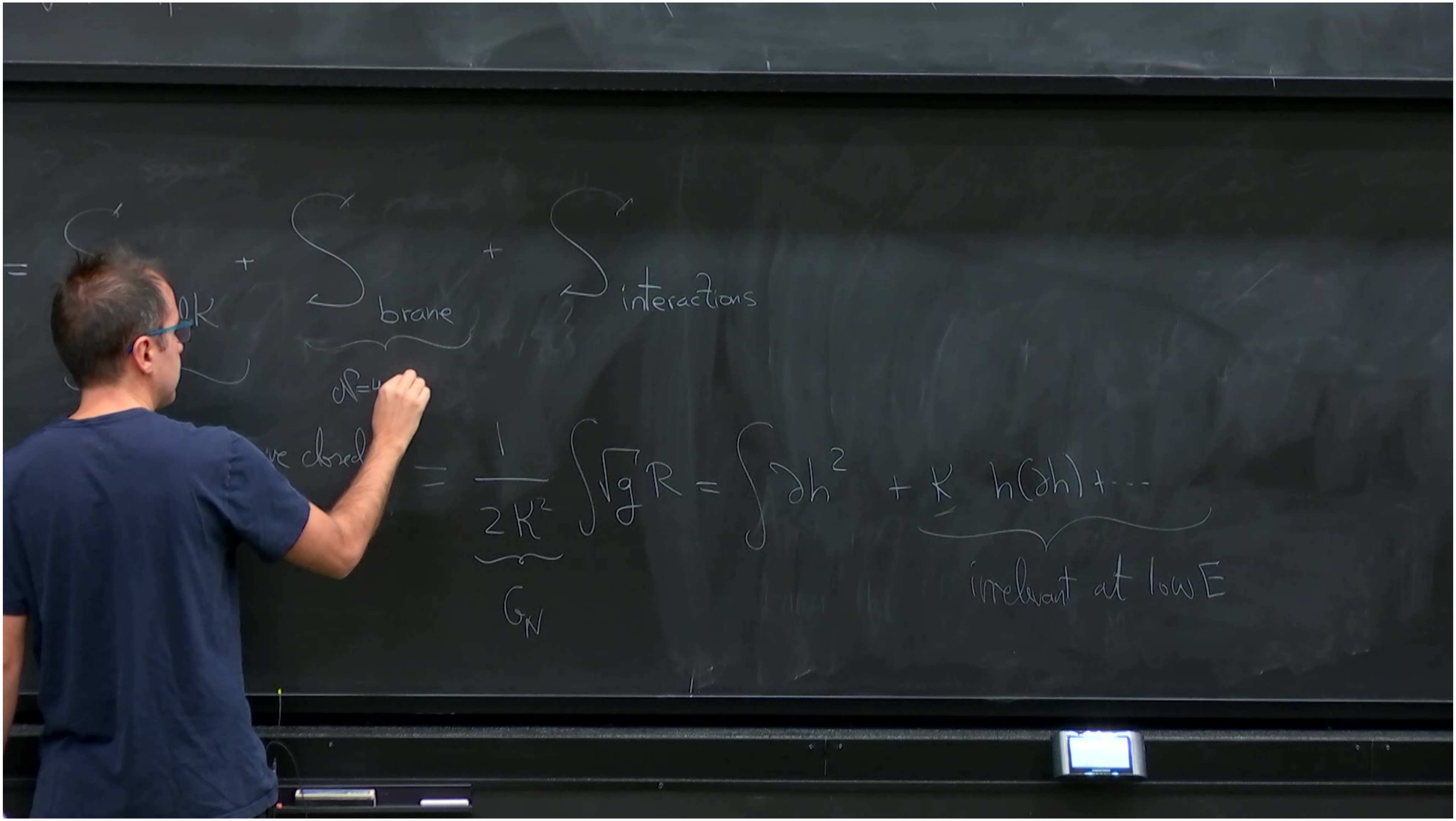

in A ,
t
YM + massive open strin
We have open strings
fat diags
in B ,
=
Vertex op

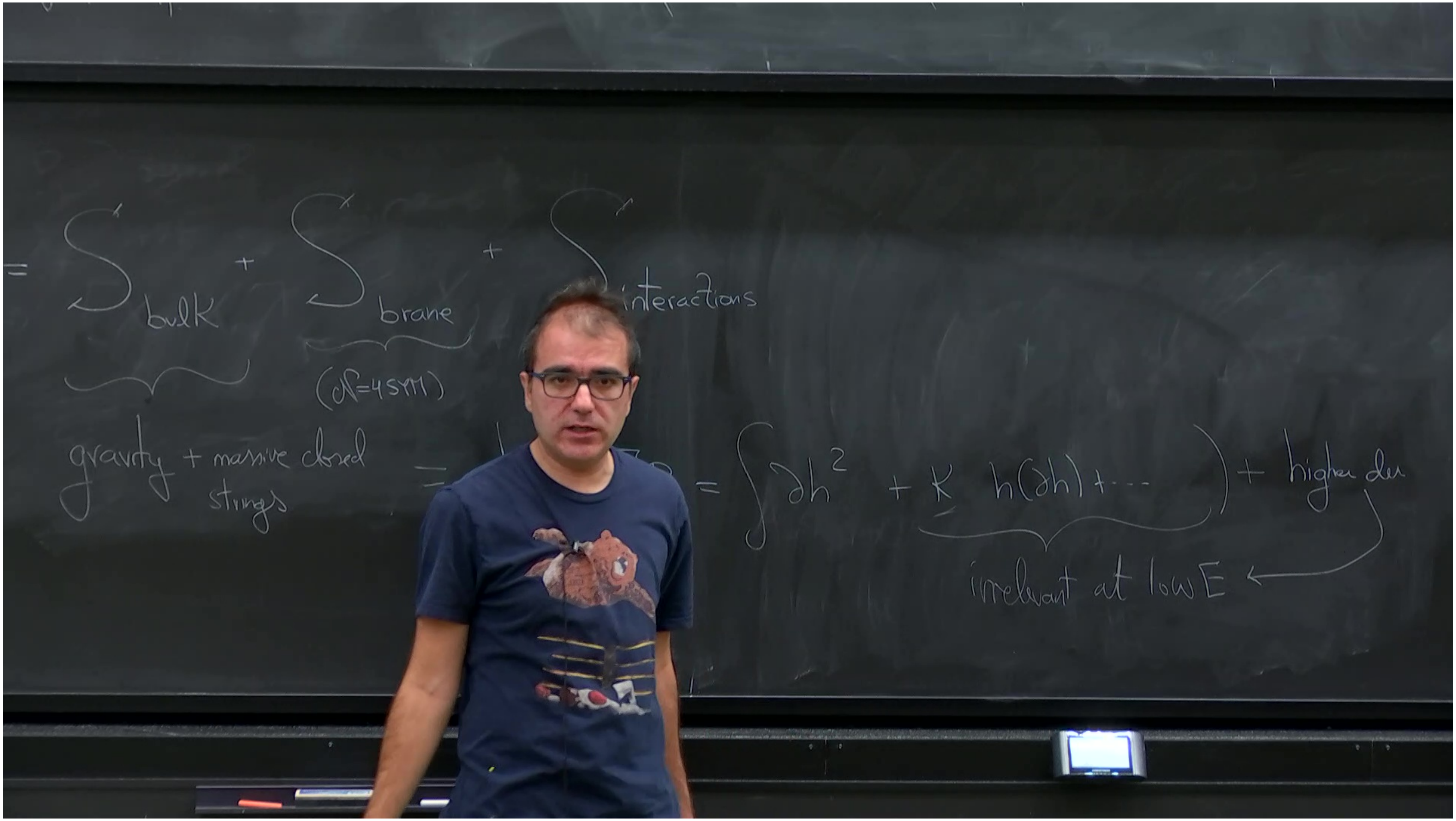

in A ,
t,
YM + massive open
We have open strings
fat diags
Condensate of gravitons
in B ,
=
and Σ
~ exp
Vertex op

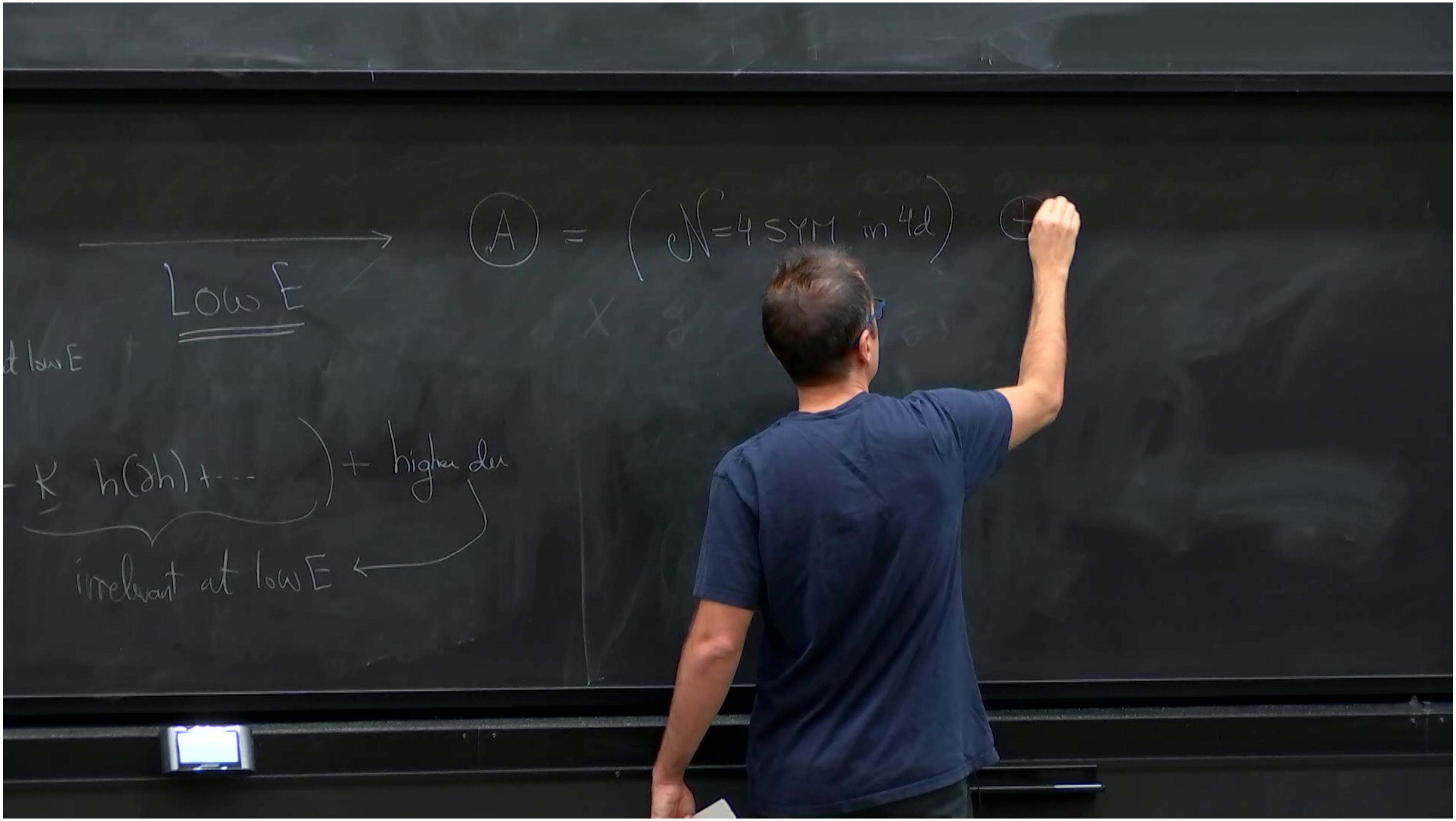

N
t
YM + massive open strings (+ sources)
diags
condensate of gravitons
~ exp
dτ
effectively shifts action
new background

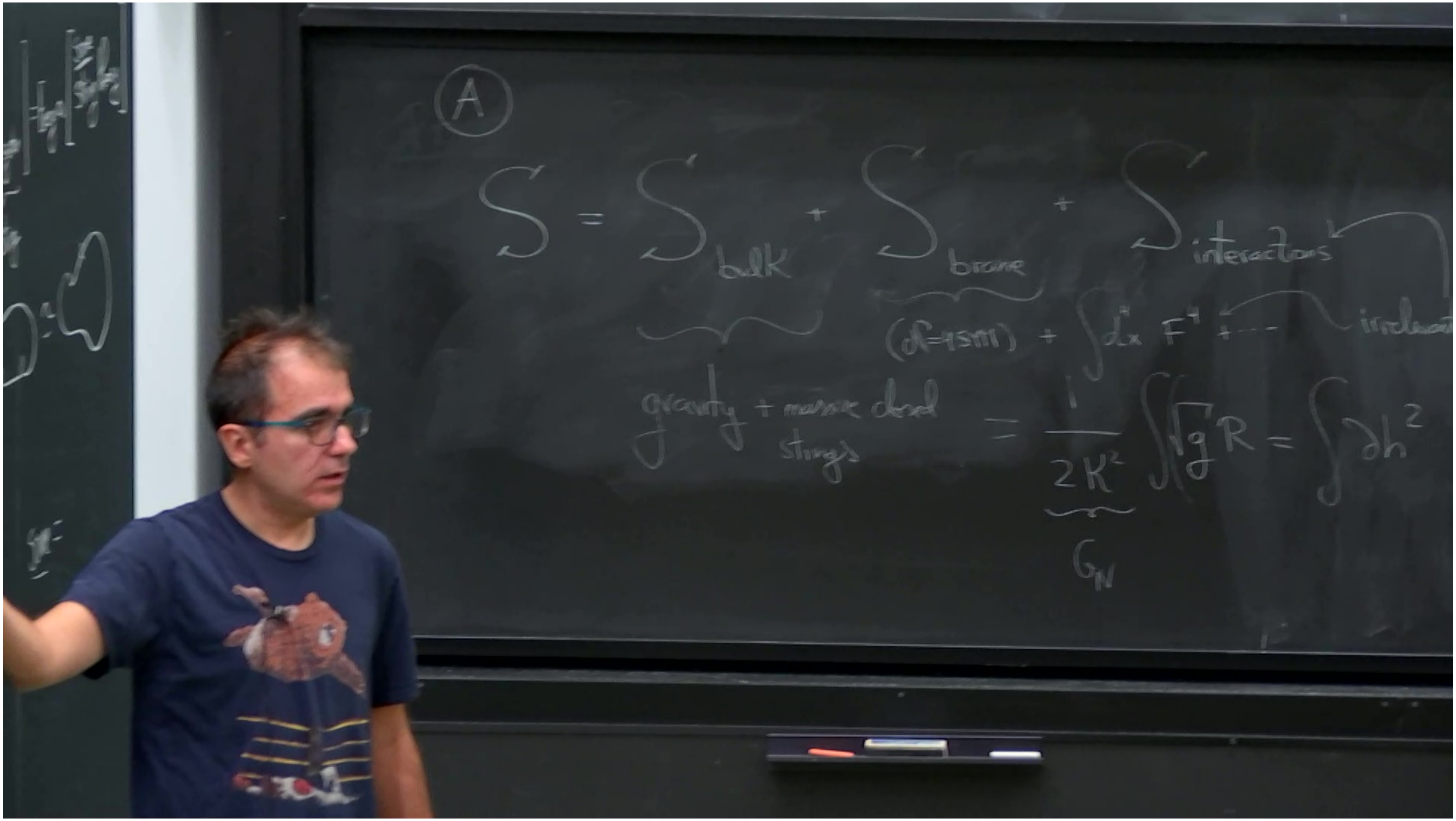

t
+ massive open strings (+ sources)
condensate of gravitons
effectively shifts action
new background
closed string in a non-trivial bckg.


t
M + massive open strings (+ sources)
← what is EFT
Know
What "V(Ω)"?
condensate of gravitons
closed string
in a
non-trivial
bckg.
effectively
shifts
action
→ new background


$= S + S_{brane} + S_{interactions}$
$\mathcal{N}=4$
ve closed
$= \frac{1}{2\kappa^2}\int\sqrt{g}R = \int \partial h^2 + \kappa\, h(\partial h) + \cdots$
G_N
irrelevant at low E


= S bulk + S brane + S interactions
(N=4 SYM)
gravity + massive closed strings
= ∫ ∂h² + κ h(∂h) + ...) + higher der
irrelevant at low E


Low E
t low E
A = (N=4 SYM in 4d) +
K h(∂h) + ...) + higher der
irrelevant at low E


A
S = S bulk + S brane + S interactions
gravity + massive closed strings
(d=4 SM) + ∫d^4x F^4 + ...
= 1/2K^2 ∫√g R = ∫∂h^2
G_N

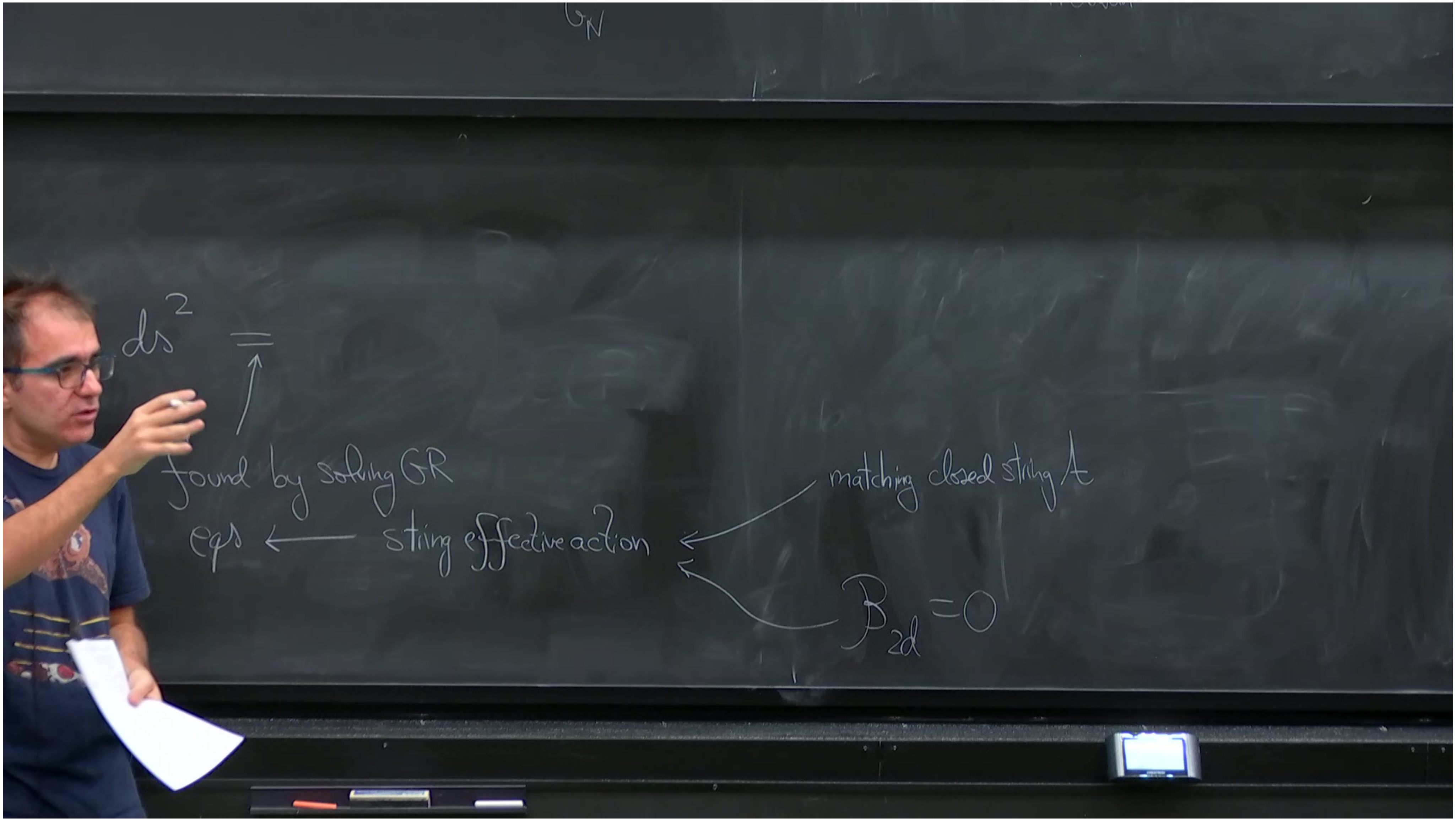
$$A = \left(\mathcal{N}=4 \text{ SYM in 4d}\right) \oplus \left(10\,d \text{ SUGRA}\right)$$

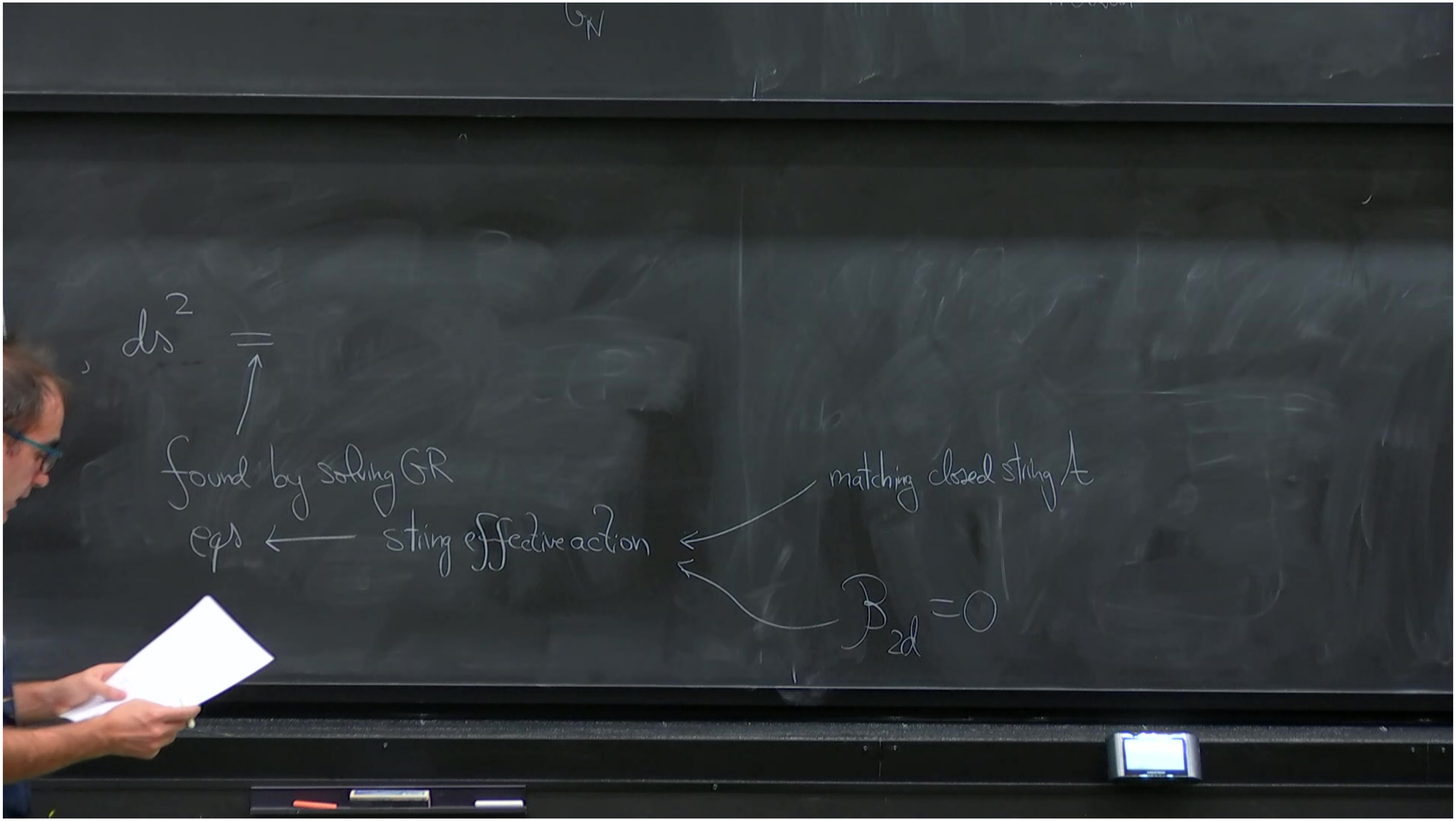
easiest for $\lambda \ll 1$

LOW E

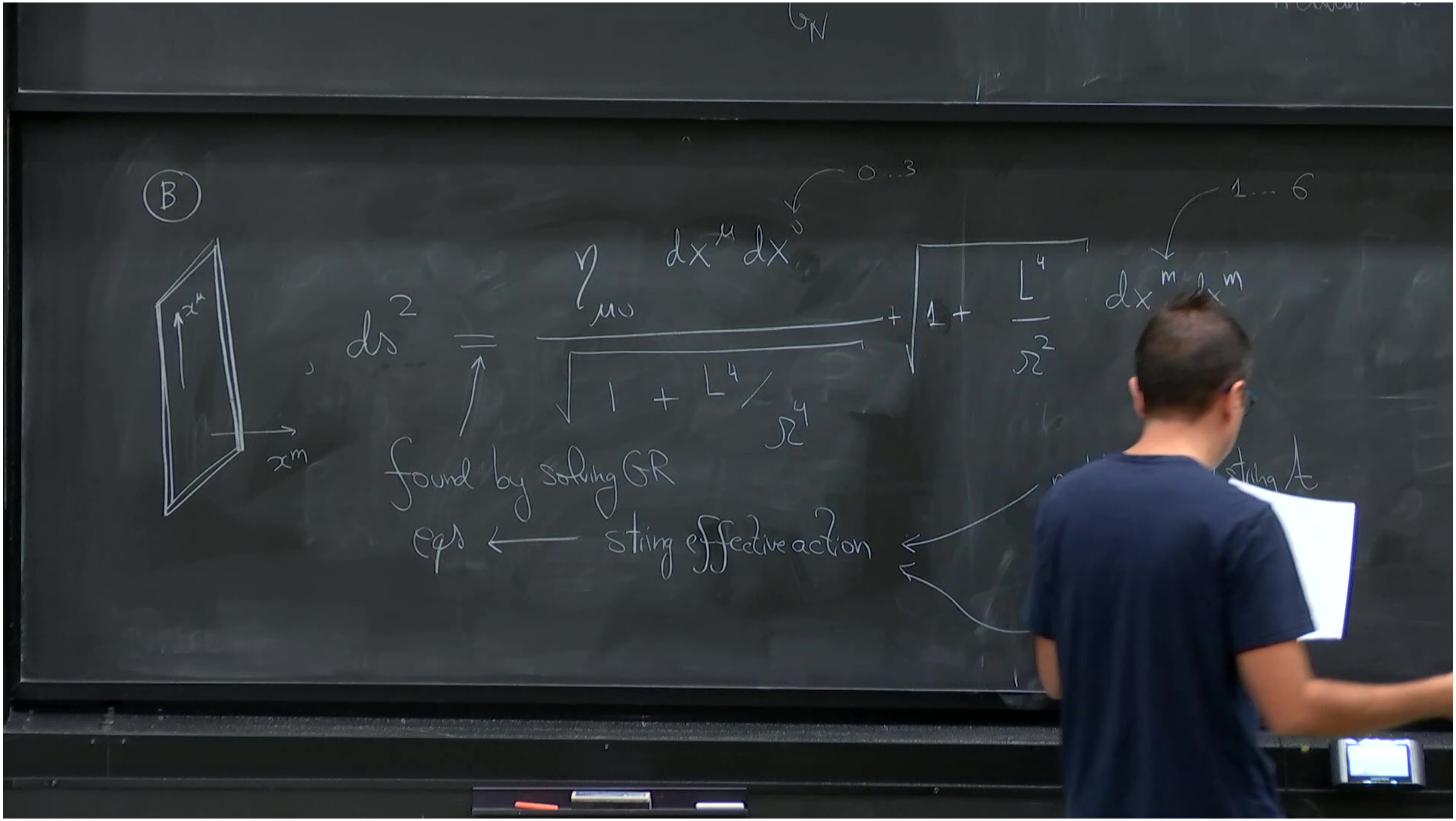
$) + \cdots \quad) +$ higher der

at low E


G_N
$ds^2 =$
found by solving GR
eqs ← string effective action
matching closed string A
$\beta_{2d} = 0$



G_N
$ds^2 =$
found by solving GR
eqs ← string effective action
matching closed string A
$\beta_{2d} = 0$


B
0 ... 3
1 ... 6
x^μ
x^m
$ds^2 = \frac{\eta_{\mu\nu}\, dx^\mu dx^\nu}{\sqrt{1 + L^4/r^4}} + \sqrt{1 + \frac{L^4}{r^2}}\, dx^m dx^m$
found by solving GR
eqs ← string effective action

Where $\Omega = \sqrt{X^m X^m}$

and

$$L^4 = g_s \overset{\to \infty}{N} \, 4\pi\alpha'^2 \quad \leftarrow \quad \text{easiest for } \underbrace{\lambda \gg 1}_{L \text{ is large}}$$

$$g_s = g_{YM}^2 \to 0$$

λ fixed

Where $\Omega = \sqrt{X^m X^m} \to \infty$

and

$L^4 = g_s N \, 4\pi \alpha'^2$

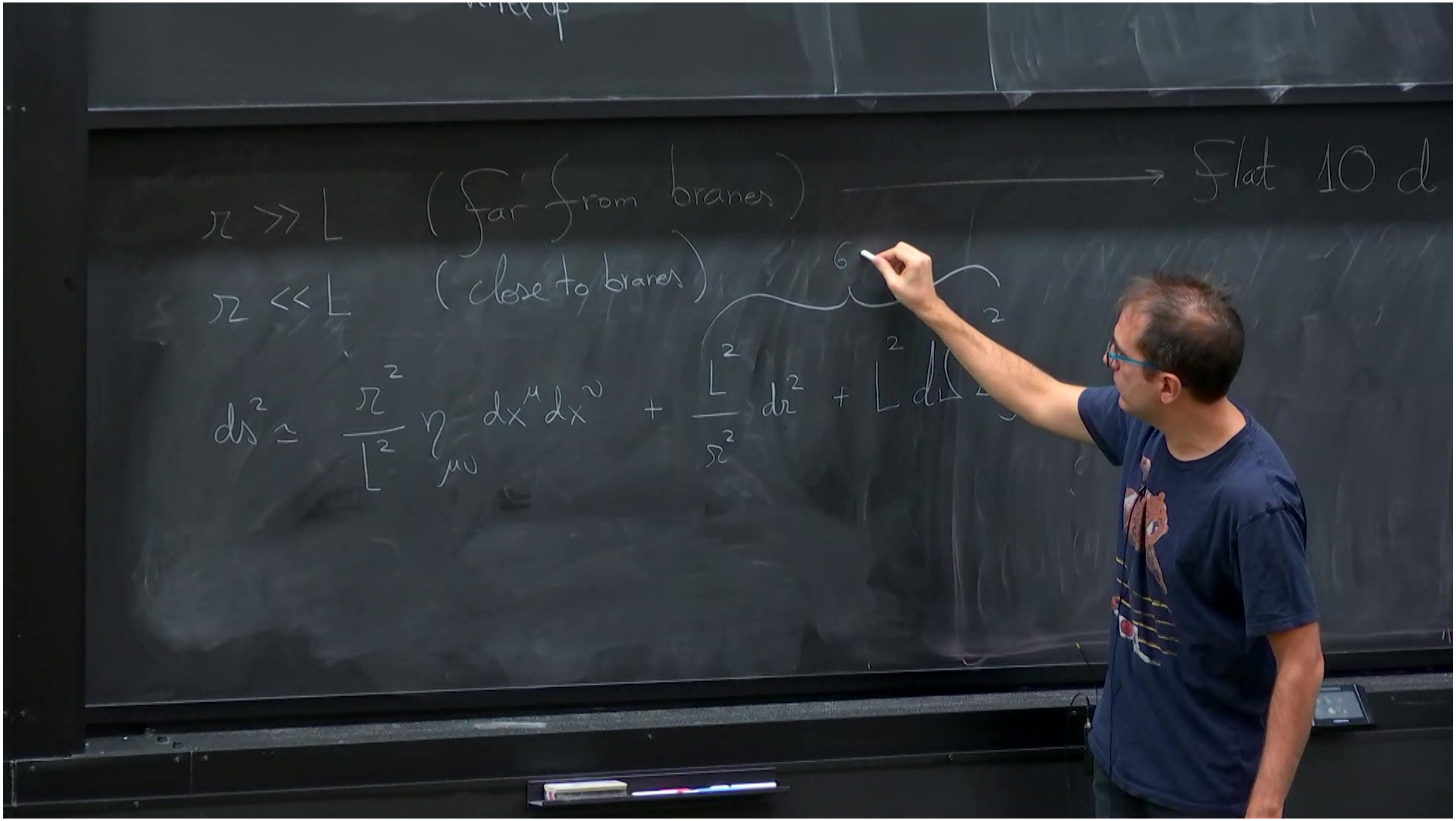
$g_s = g_{YM}^2 \to 0$

λ fixed

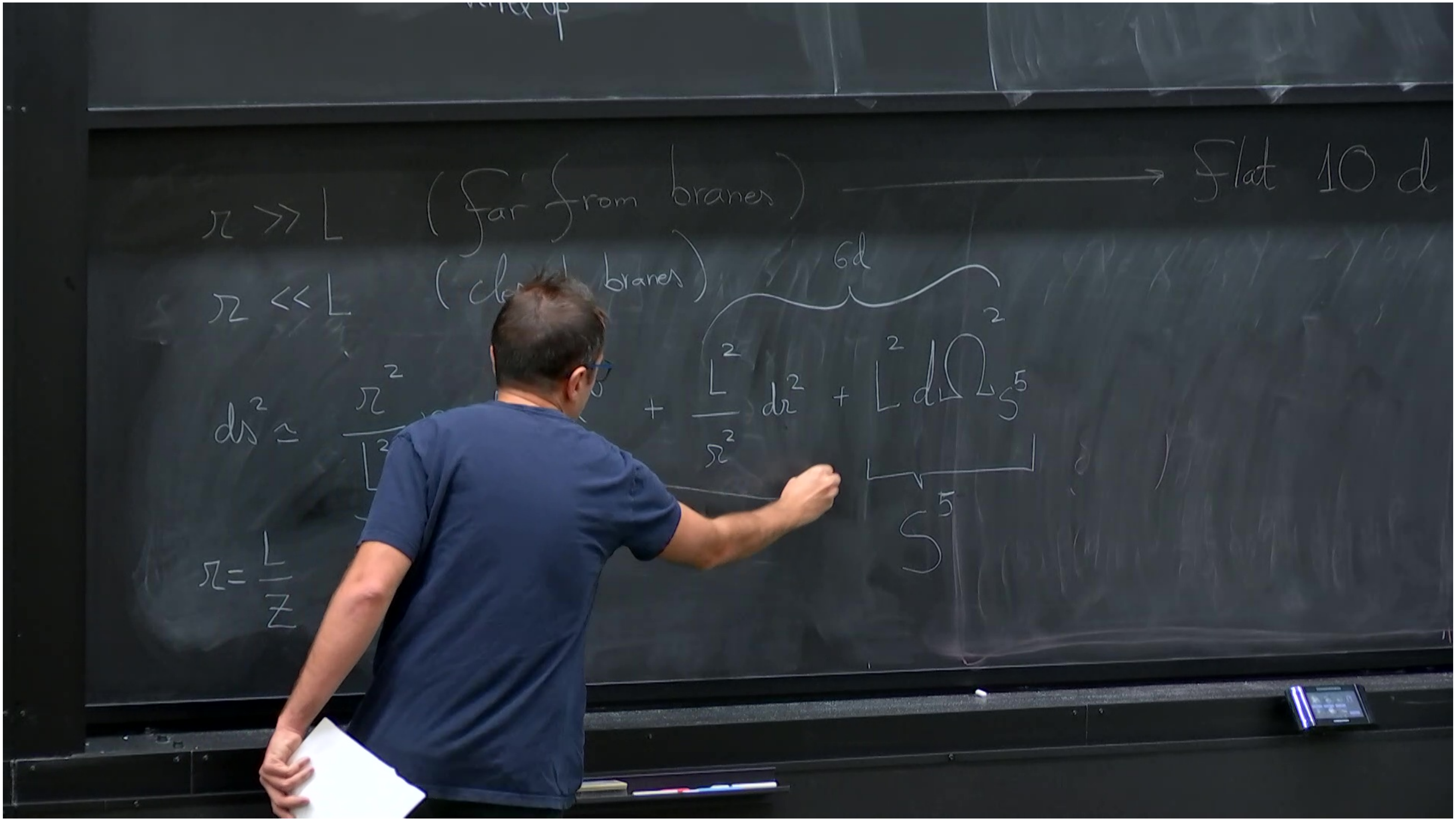
easiest for $\lambda \gg 1$

$\underbrace{\lambda \gg 1}_{L \text{ is large}}$

(L is many string lengths)



$r \gg L$ (far from branes) → flat 10 d
$r \ll L$ (close to branes)
$ds^2 \simeq \frac{r^2}{L^2} \eta_{\mu\nu} dx^\mu dx^\nu + \frac{L^2}{r^2} dr^2 + L^2 d\Omega^2$
6

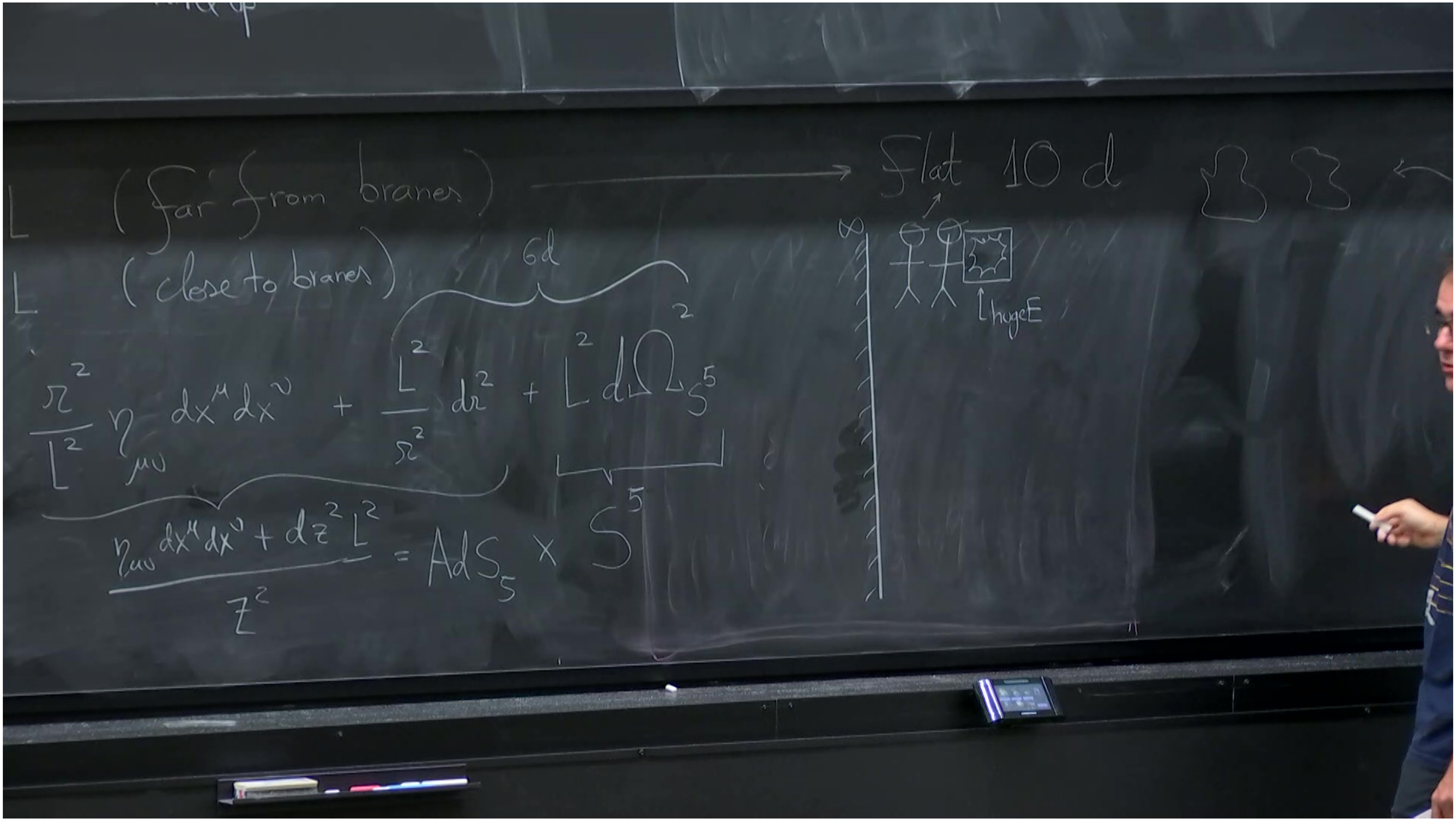

r >> L (far from branes) → flat 10 d
r << L
branes)
6d
ds^2 ≃ r^2/L^2
+ L^2/r^2 dr^2 + L^2 dΩ^2_{S^5}
S^5
r = L/Z

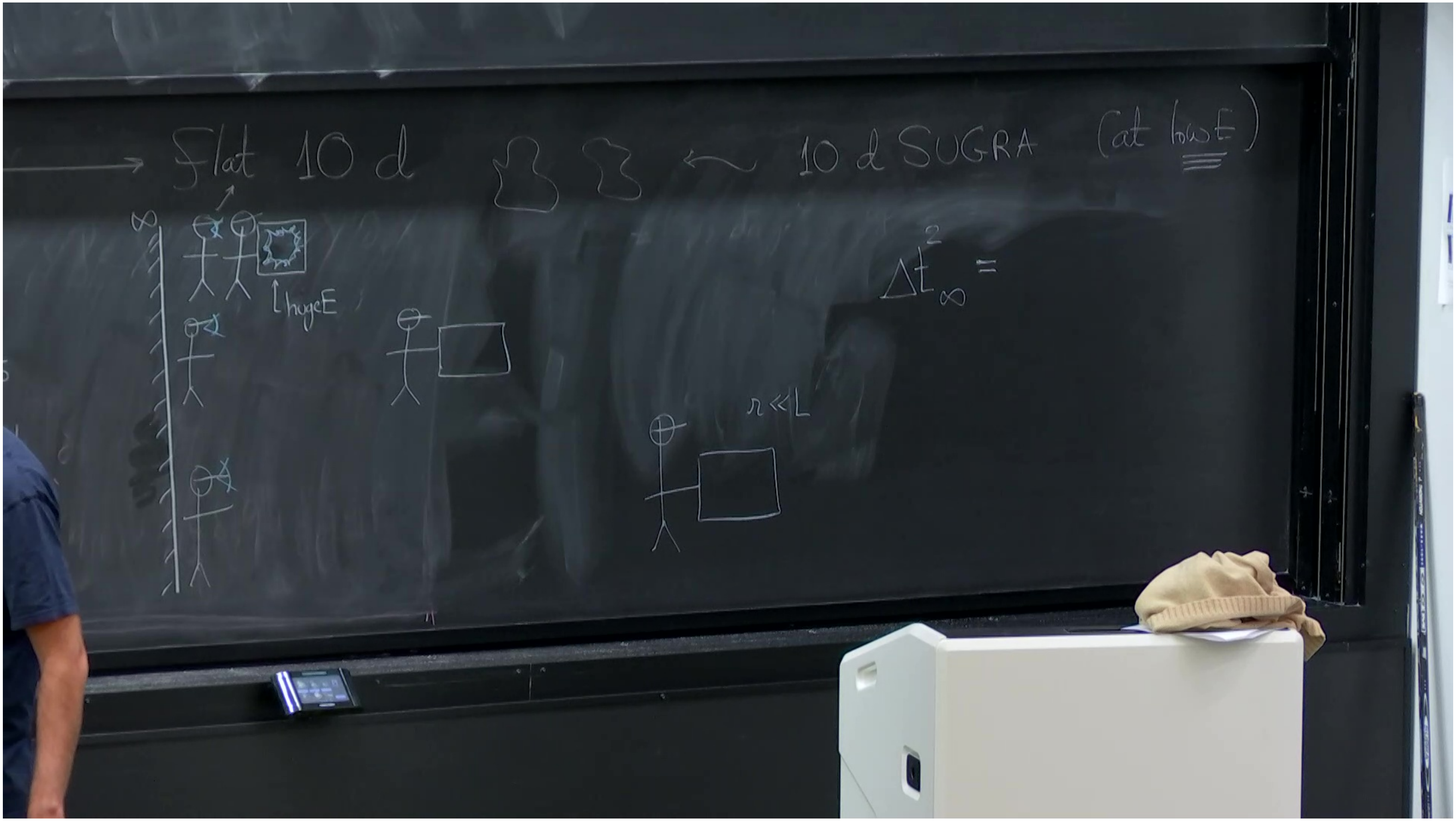
$r \gg L$ (far from branes) $\longrightarrow$ Flat 10 d

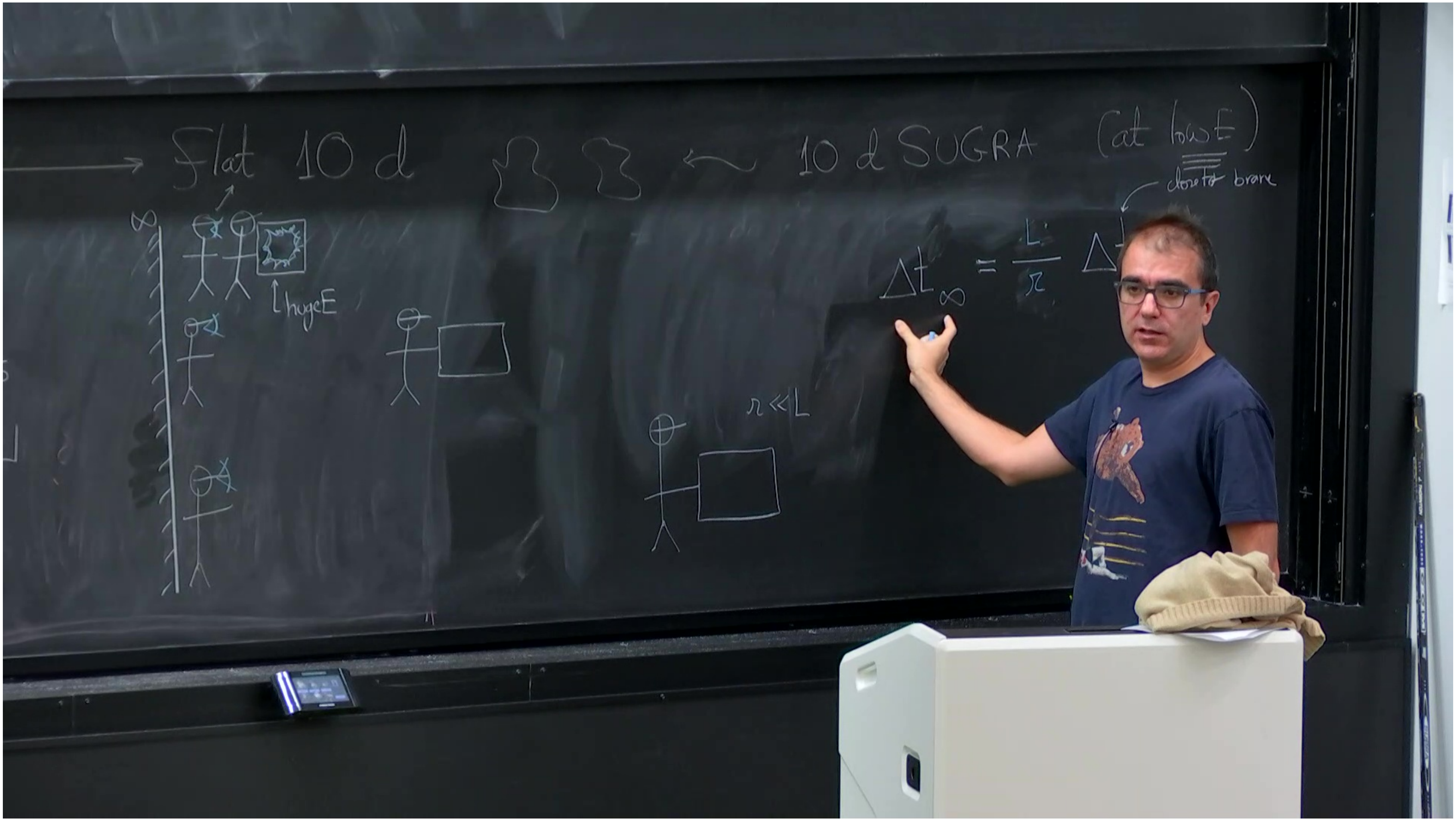
$r \ll L$ (close to branes)

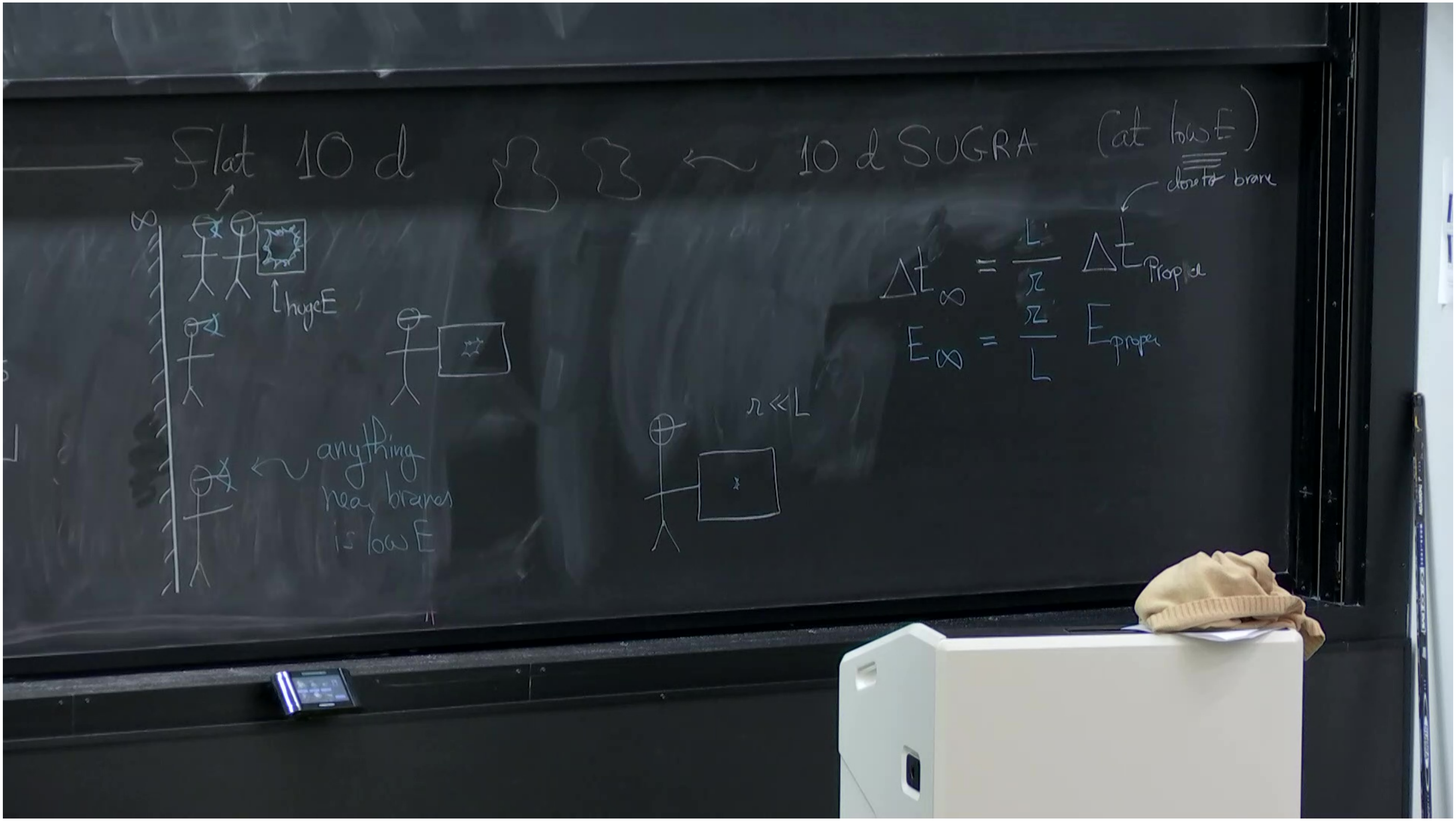
$$ds^2 \simeq \underbrace{\frac{r^2}{L^2}\eta_{\mu\nu}dx^\mu dx^\nu + \frac{L^2}{r^2}dr^2}\, + \overbrace{\phantom{\frac{L^2}{r^2}dr^2} + \underbrace{L^2 d\Omega^2_{S^5}}_{S^5}}^{6d}$$

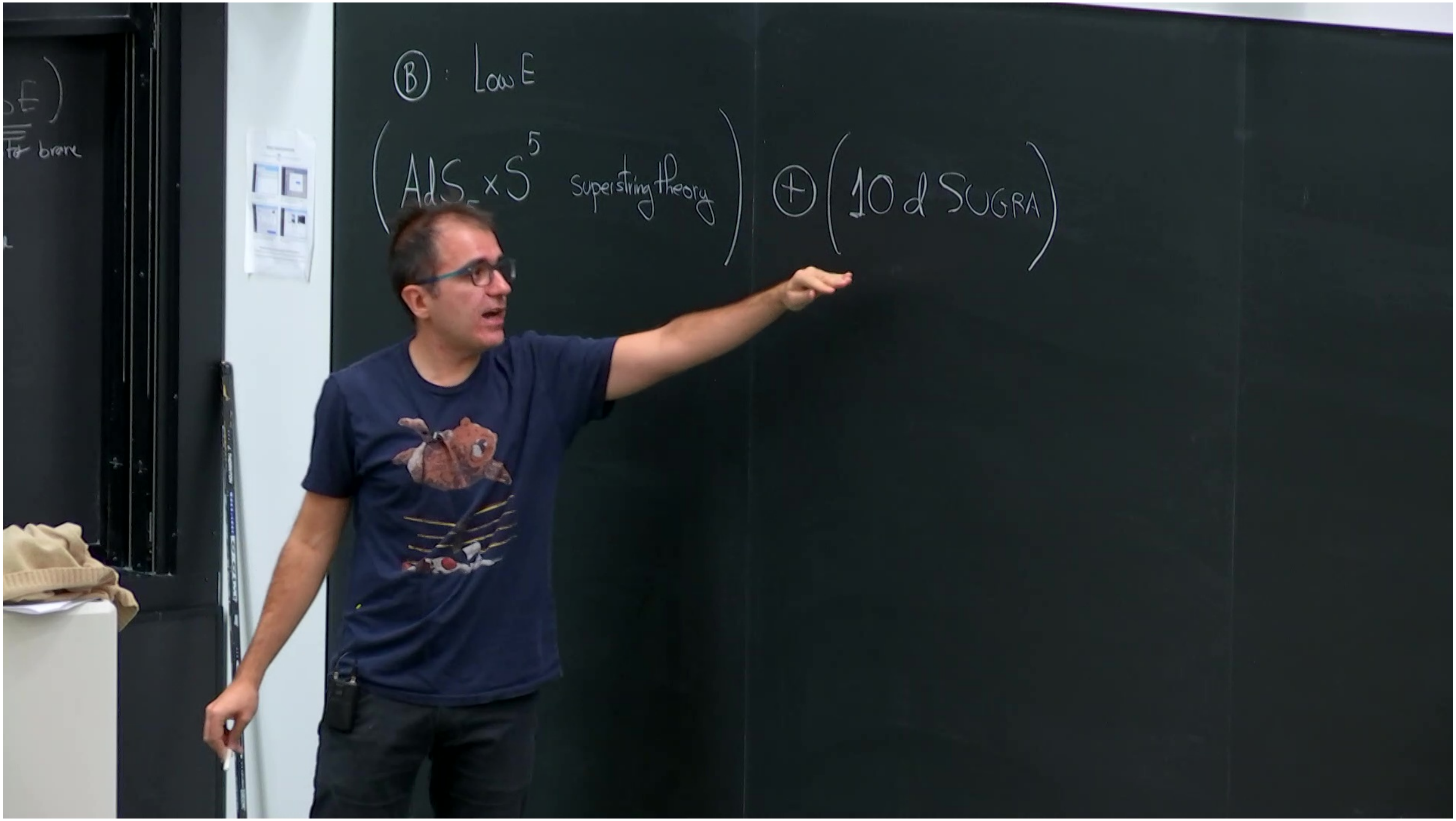
$$r = \frac{L}{z} \qquad \frac{\eta_{\mu\nu}dx^\mu dx^\nu + dz^2}{z^2}L^2 = AdS_5 \times S^5$$

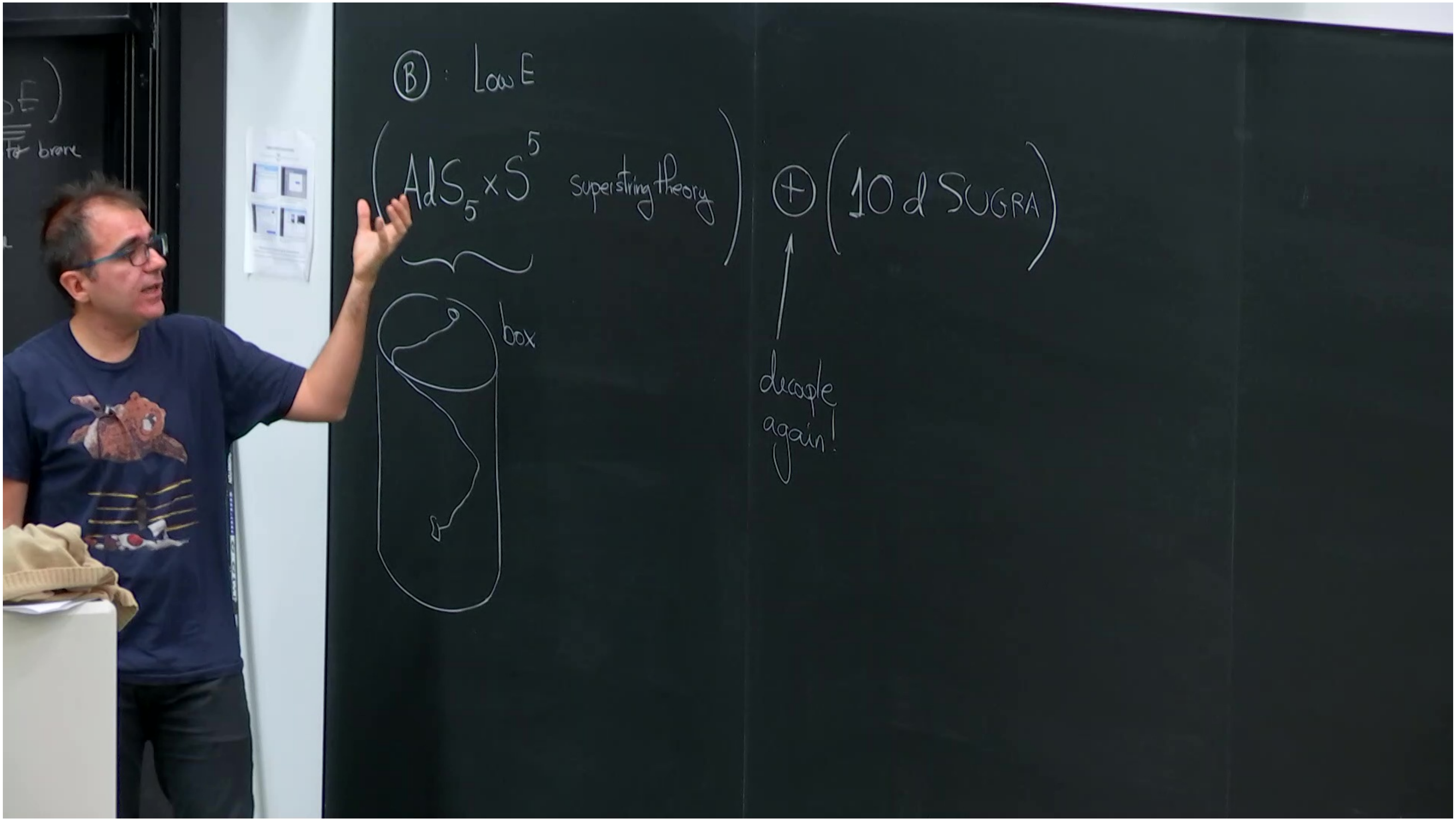

L (far from branes) → Flat 10 d
L (close to branes)
6d
$\frac{r^2}{L^2}\eta_{\mu\nu}dx^\mu dx^\nu + \frac{L^2}{r^2}dr^2 + L^2 d\Omega_{S^5}^2$
$\frac{\eta_{\mu\nu}dx^\mu dx^\nu + dz^2}{z^2}L^2 = AdS_5 \times S^5$
∞
huge E


Flat 10 d
10 d SUGRA (at low E)
huge E
r ≪ L
Δt²∞ =


Flat 10 d
10 d SUGRA (at low E)
close to brane
huge E
Δt∞ = L/r Δ
r ≪ L


Flat 10 d
10 d SUGRA (at low E)
close to brane
huge E
anything near branes is low E
r ≪ L
$\Delta t_\infty = \frac{L}{r} \Delta t_{proper}$
$E_\infty = \frac{r}{L} E_{proper}$


B : Low E
(AdS5 x S5 superstring theory) ⊕ (10 d SUGRA)


B : Low E
AdS5 x S5 superstring theory
⊕ (10 d SUGRA)
box
decouple again!
brane

Low E

$$\textcircled{A} = \left(\mathcal{N}=4 \text{ SYM in 4d}\right) \oplus \left(10d\ \cancel{\text{SUGRA}}\right)$$

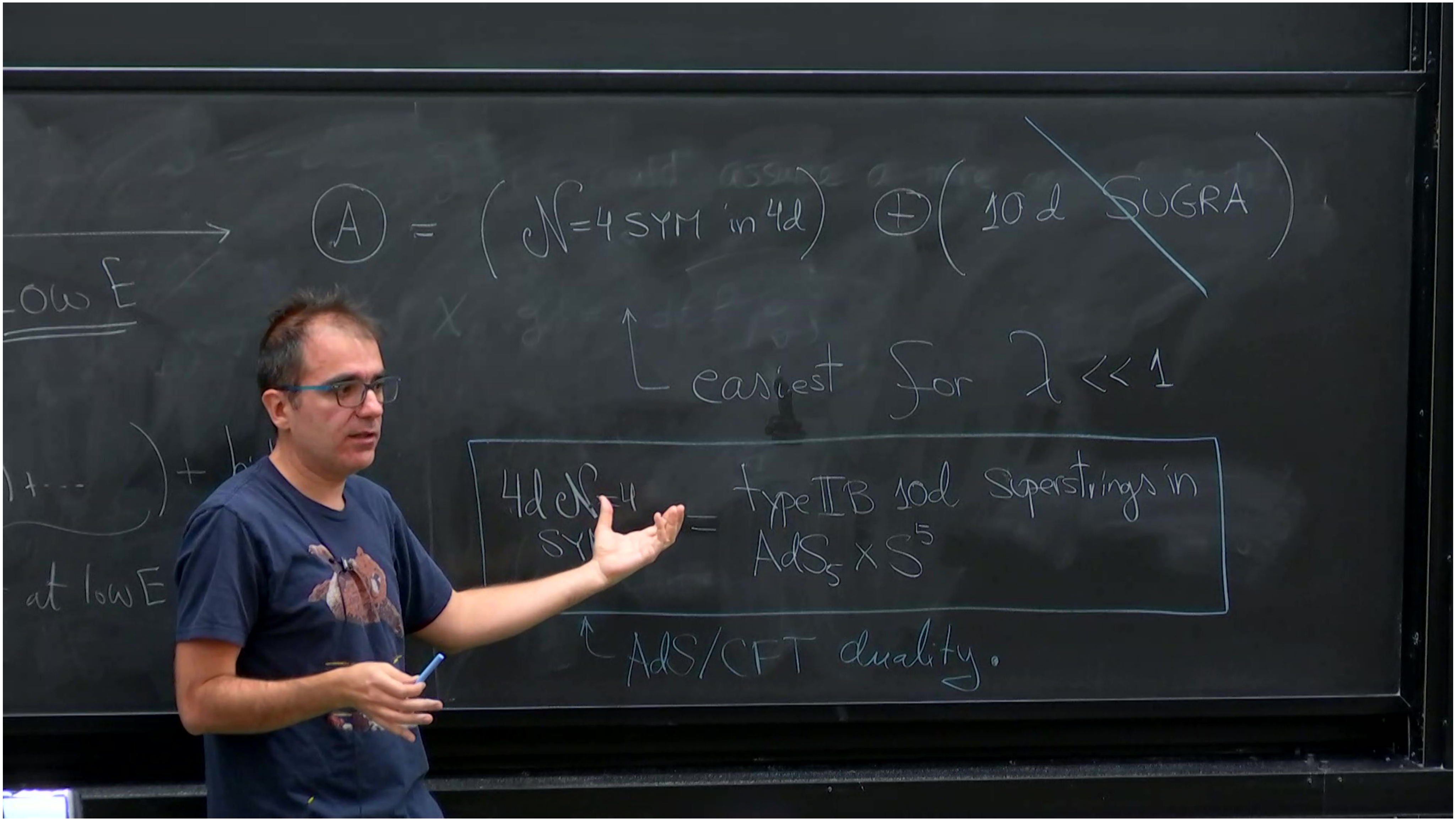
easiest for $\lambda \ll 1$

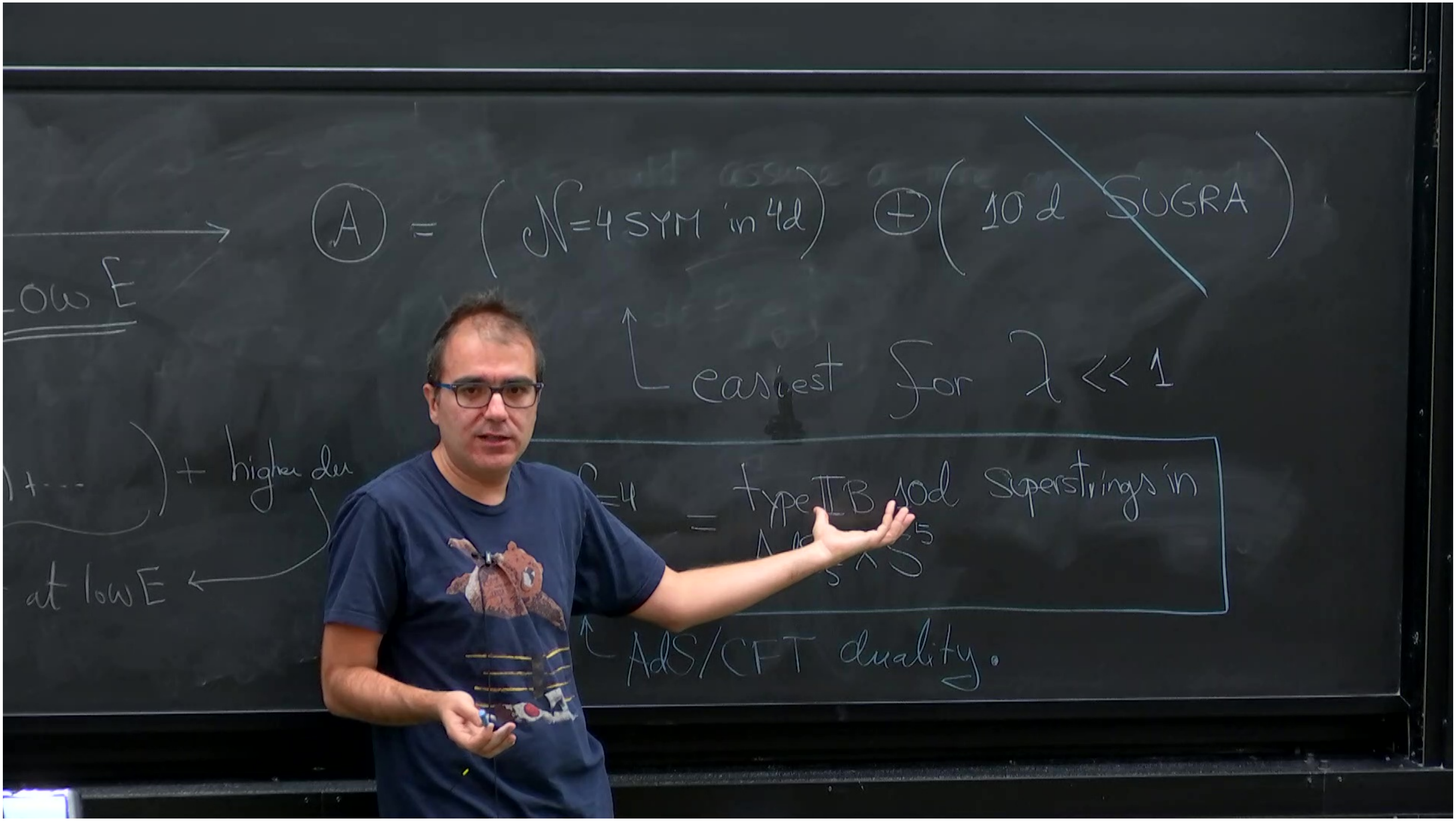
$$\boxed{\begin{matrix} \text{4d } \mathcal{N}=4 \\ \text{SYM} \end{matrix} = \begin{matrix} \text{type IIB 10d Superstrings in} \\ AdS_5 \times S^5 \end{matrix}}$$

AdS/CFT duality.

$) + \dots \quad) +$ higher der

t at low E


Low E
A = (N=4 SYM in 4d) ⊕ (10 d SUGRA)
easiest for λ << 1
4d N=4 SYM = type IIB 10d Superstrings in AdS5 × S5
AdS/CFT duality.
at low E


A = (N=4 SYM in 4d) ⊕ (10 d SUGRA)
easiest for λ << 1
+ higher der
at low E
= type IIB 10d superstrings in
AdS/CFT duality.