Title: Positivity, negativity, entanglement, and holography

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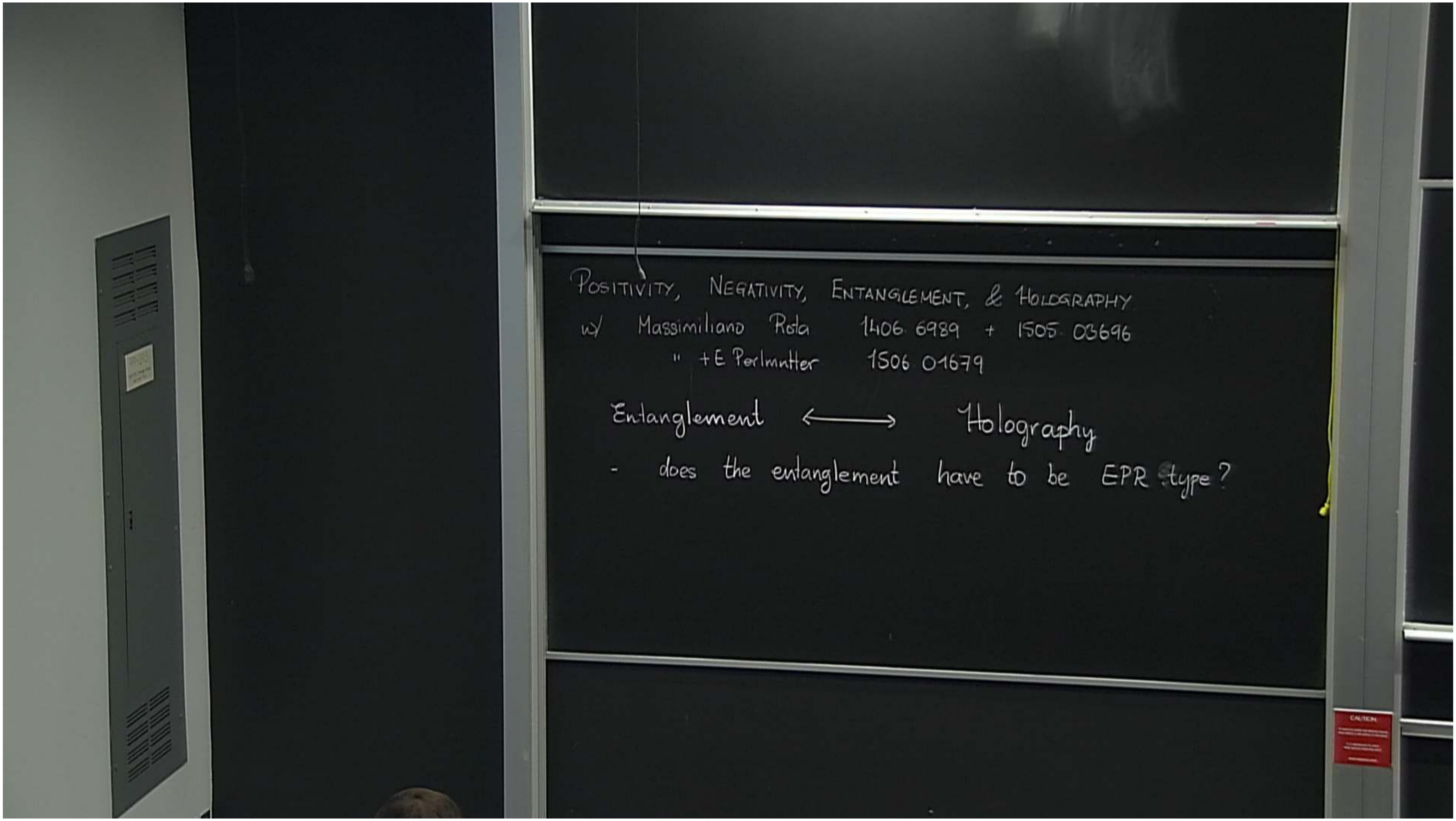
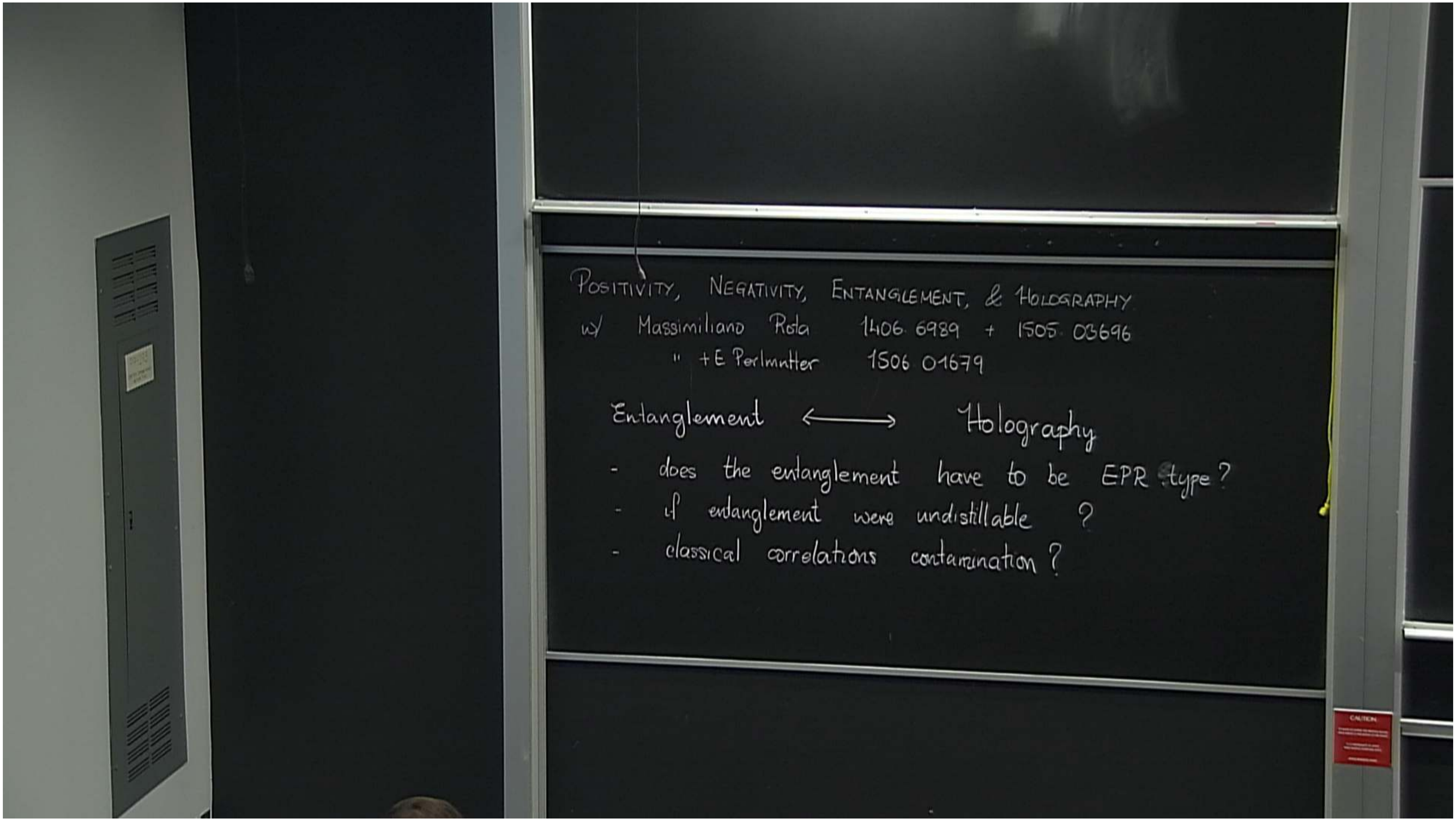
Abstract: TBA

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS


POSITIVITY, NEGATIVITY, ENTANGLEMENT, & HOLOGRAPHY
w/ Massimiliano Rota 1406.6989 + 1505.03696
" + E Perlmutter 1506.01679
Entanglement ⟷ Holography
- does the entanglement have to be EPR type?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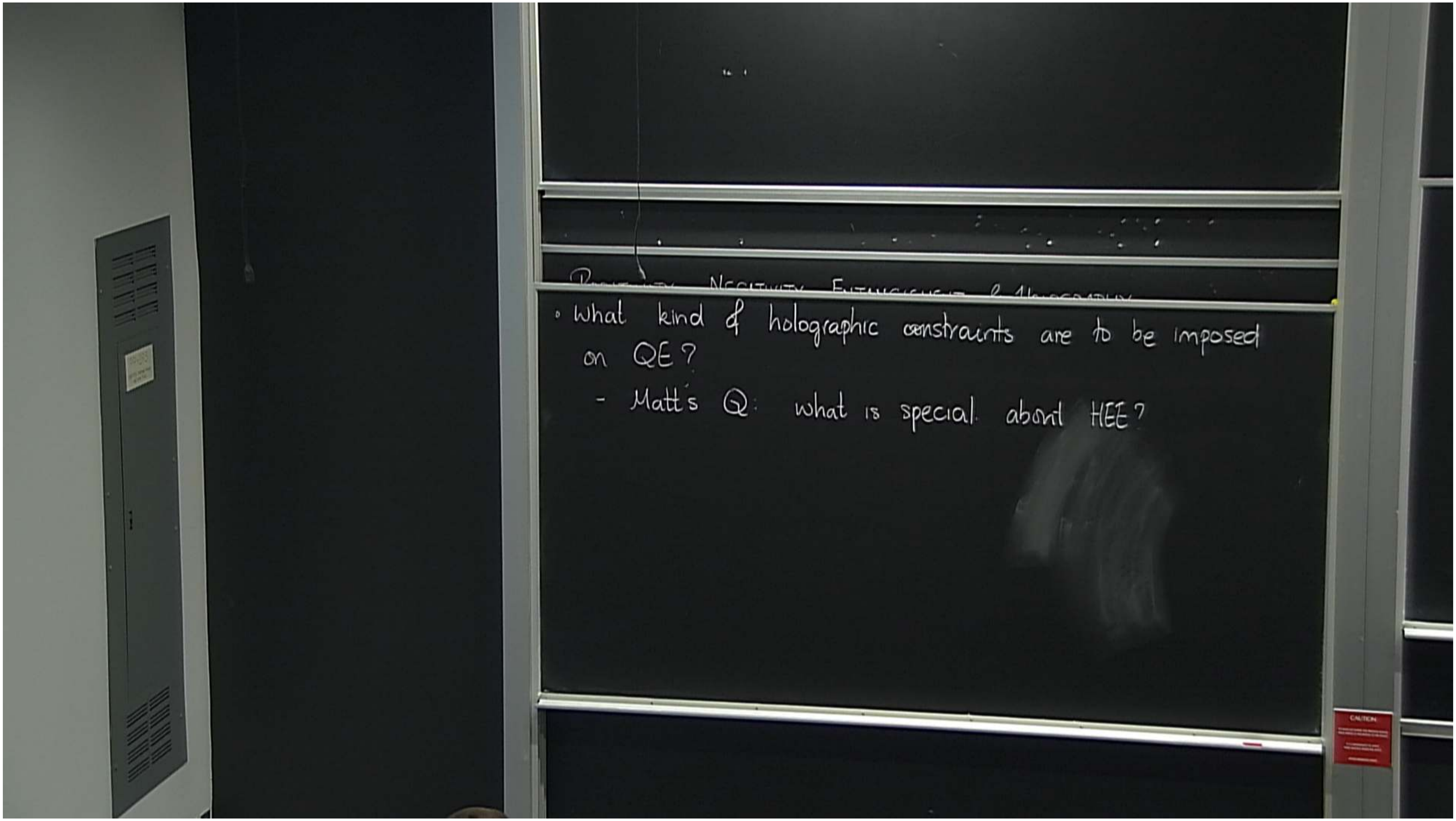
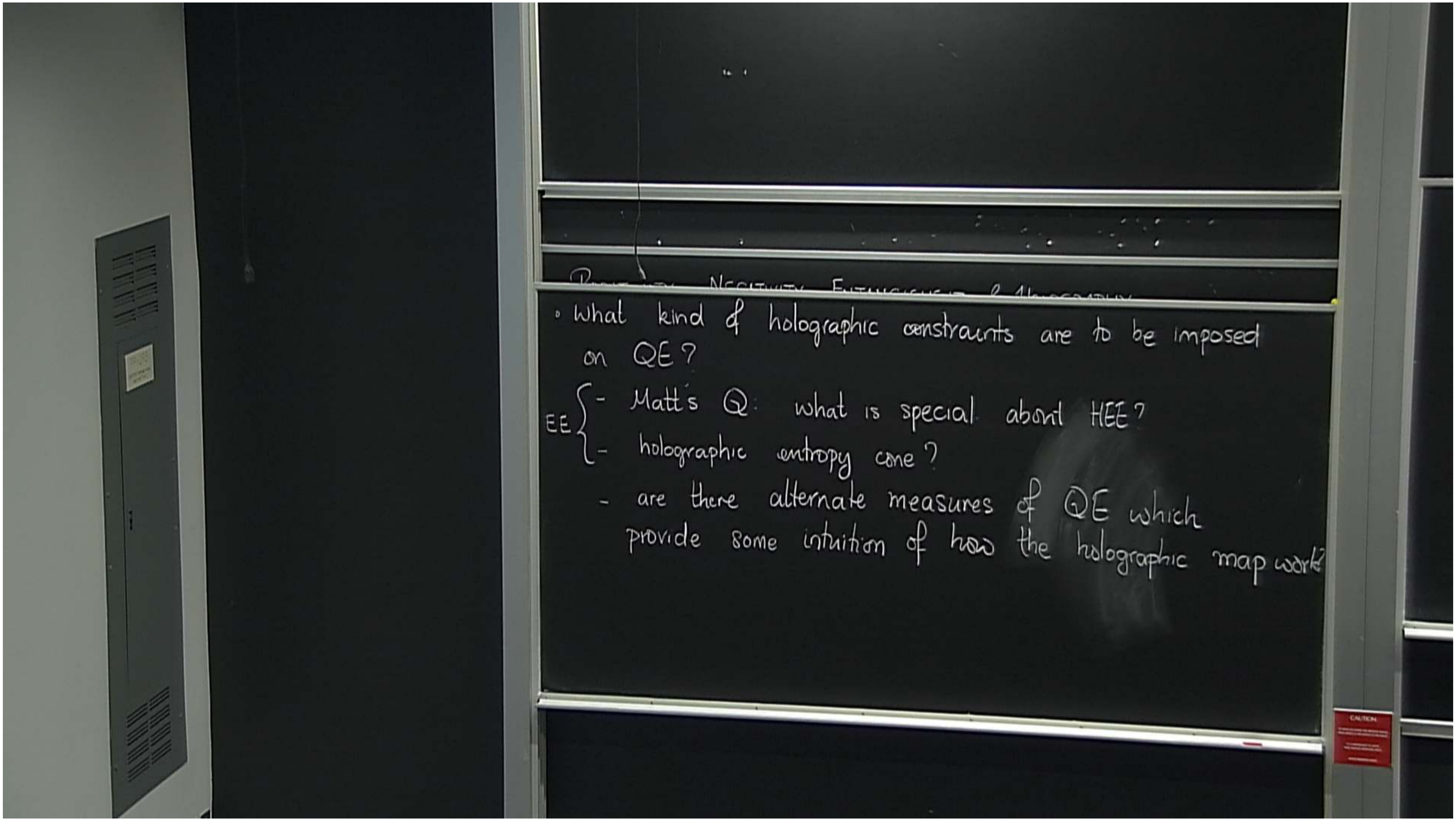
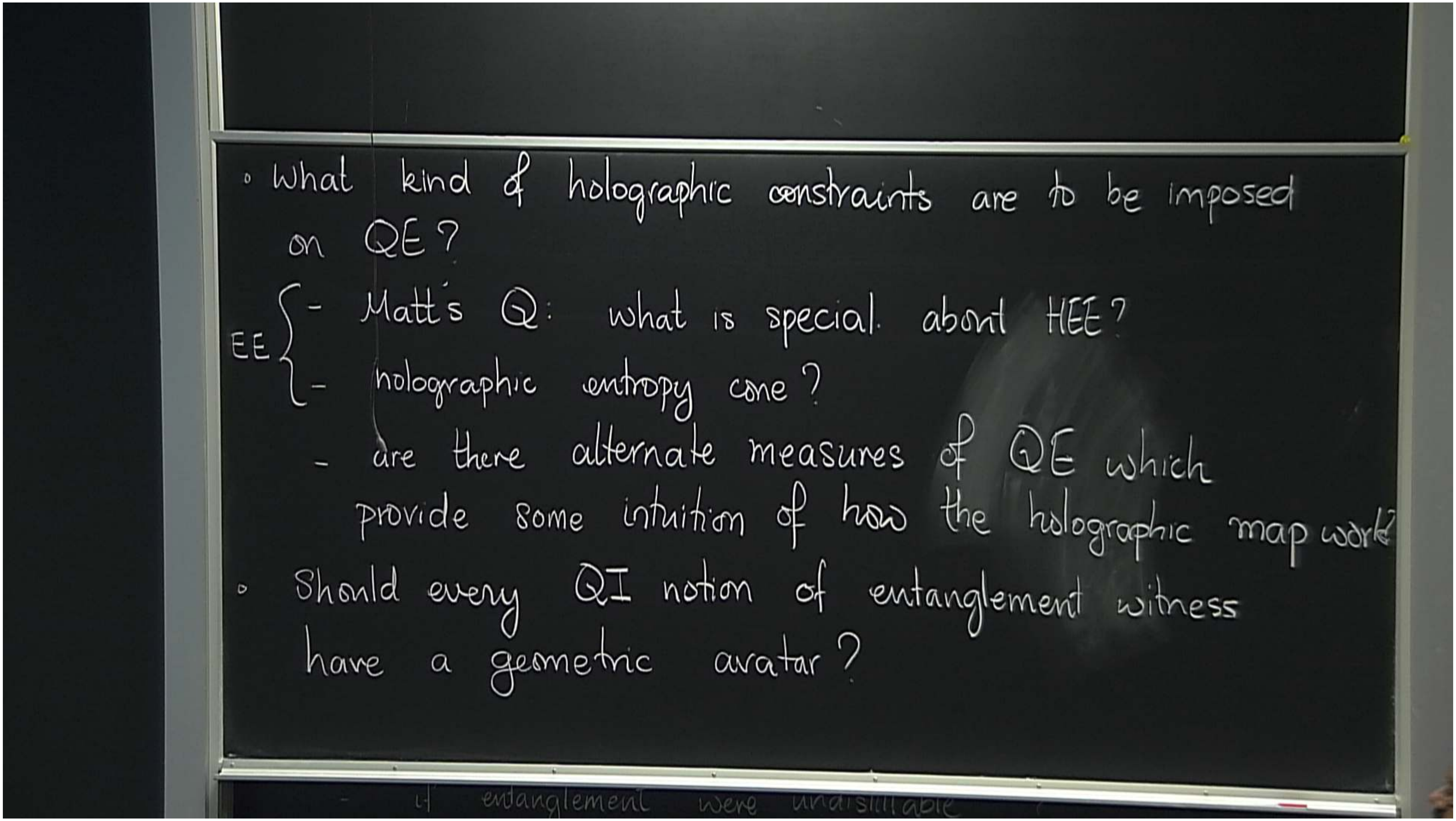
Entanglement ⟷ Holography
- does the entanglement have to be EPR type?
- if entanglement were undistillable ?
- classical correlations contamination ?


What kind of holographic constraints are to be imposed on QE?
- Matt's Q: what is special about HEE?



• What kind of holographic constraints are to be imposed on QE?
EE { - Matt's Q: what is special about HEE?
- holographic entropy cone?
- are there alternate measures of QE which provide some intuition of how the holographic map works?



∘ What kind of holographic constraints are to be imposed on QE?
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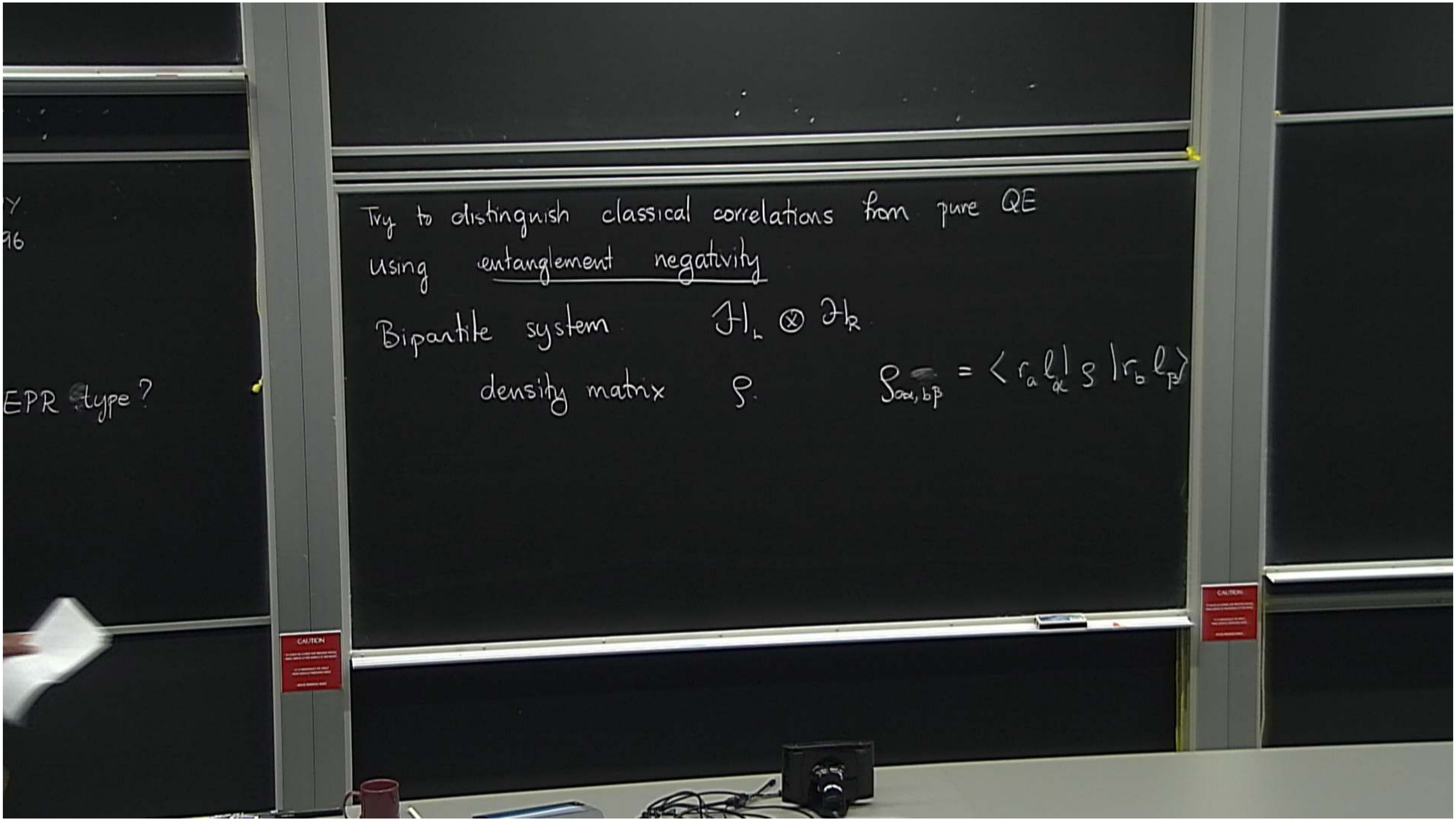
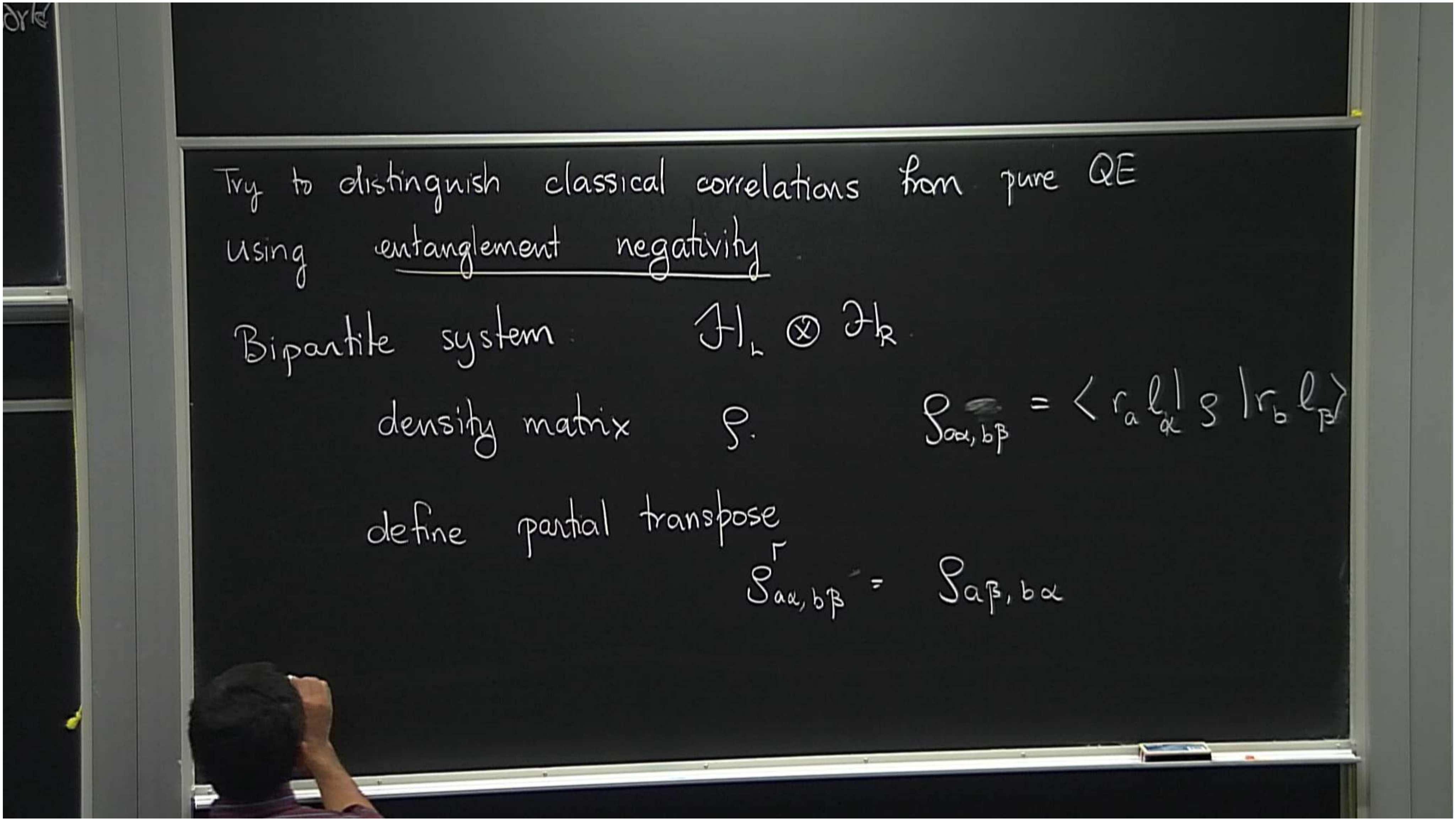
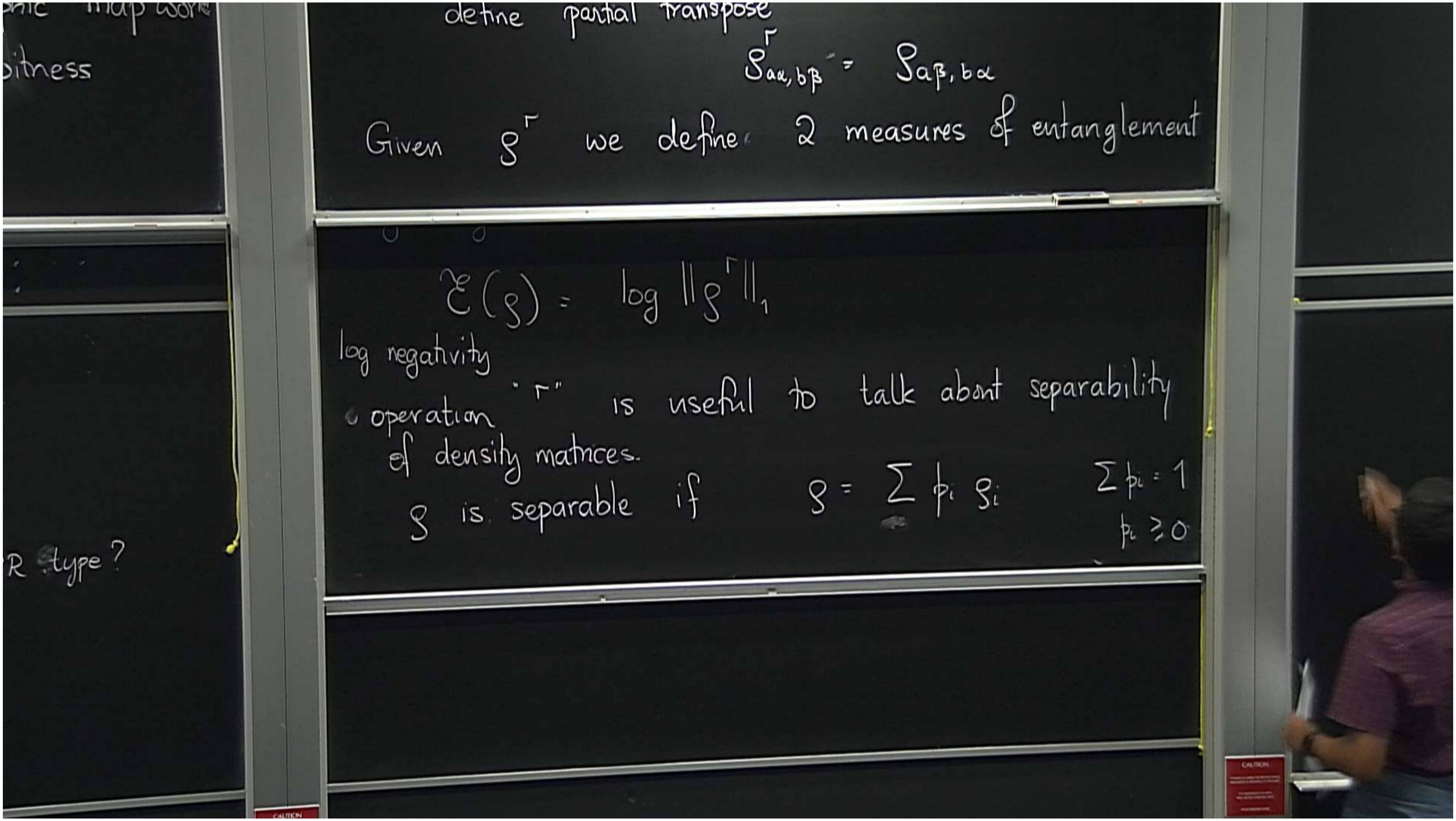
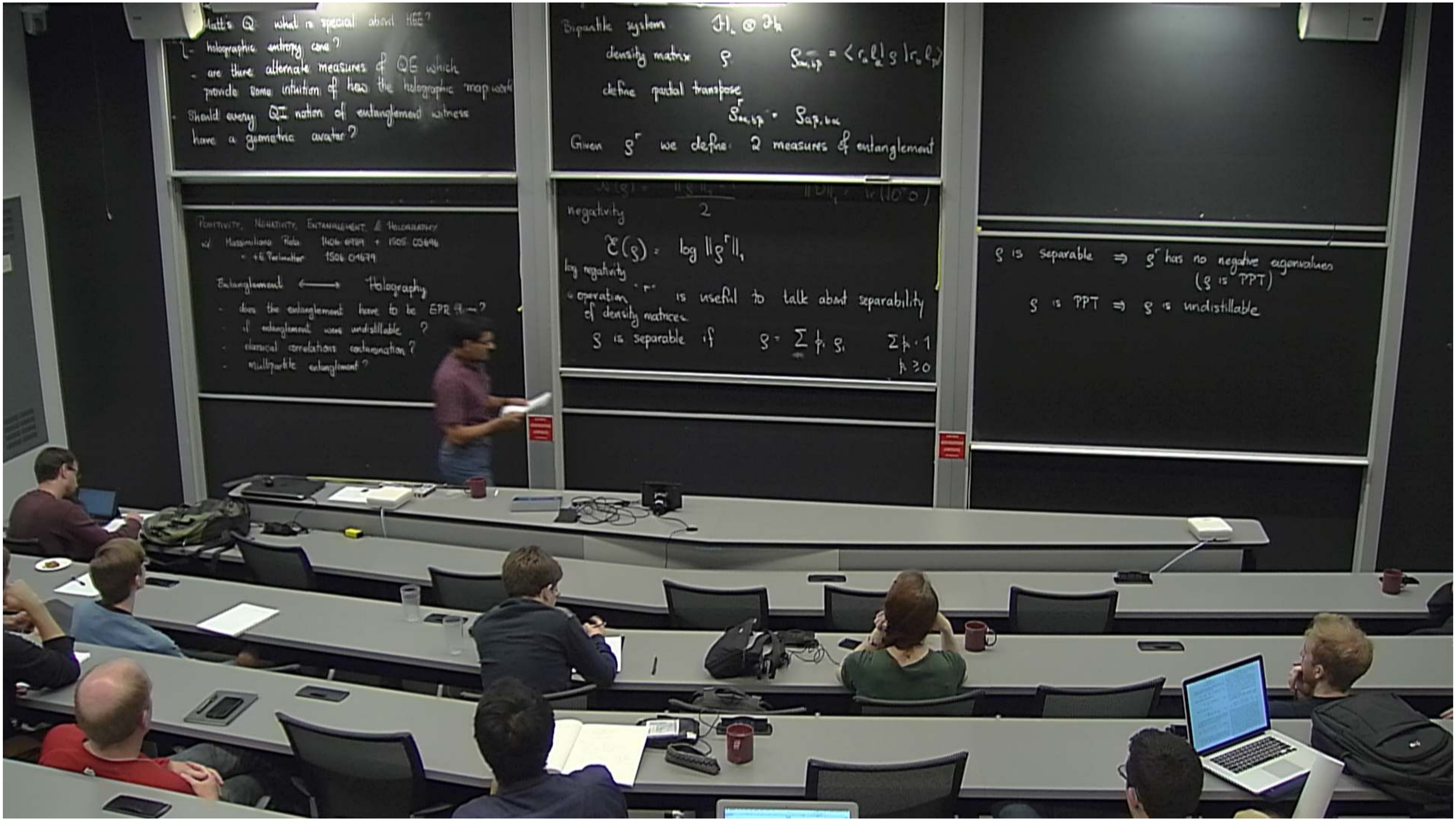
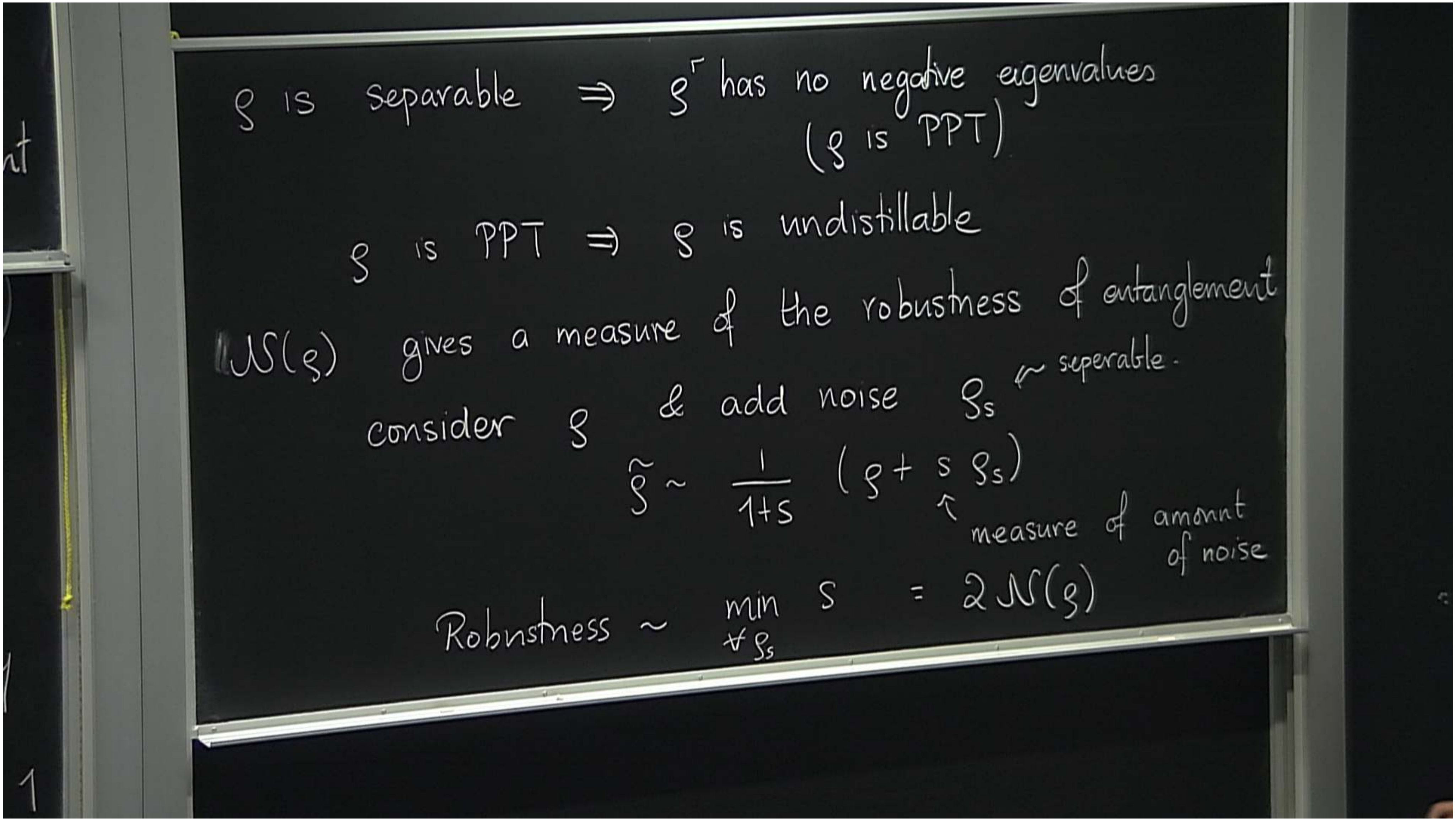
∘ Should every QI notion of entanglement witness have a geometric avatar?

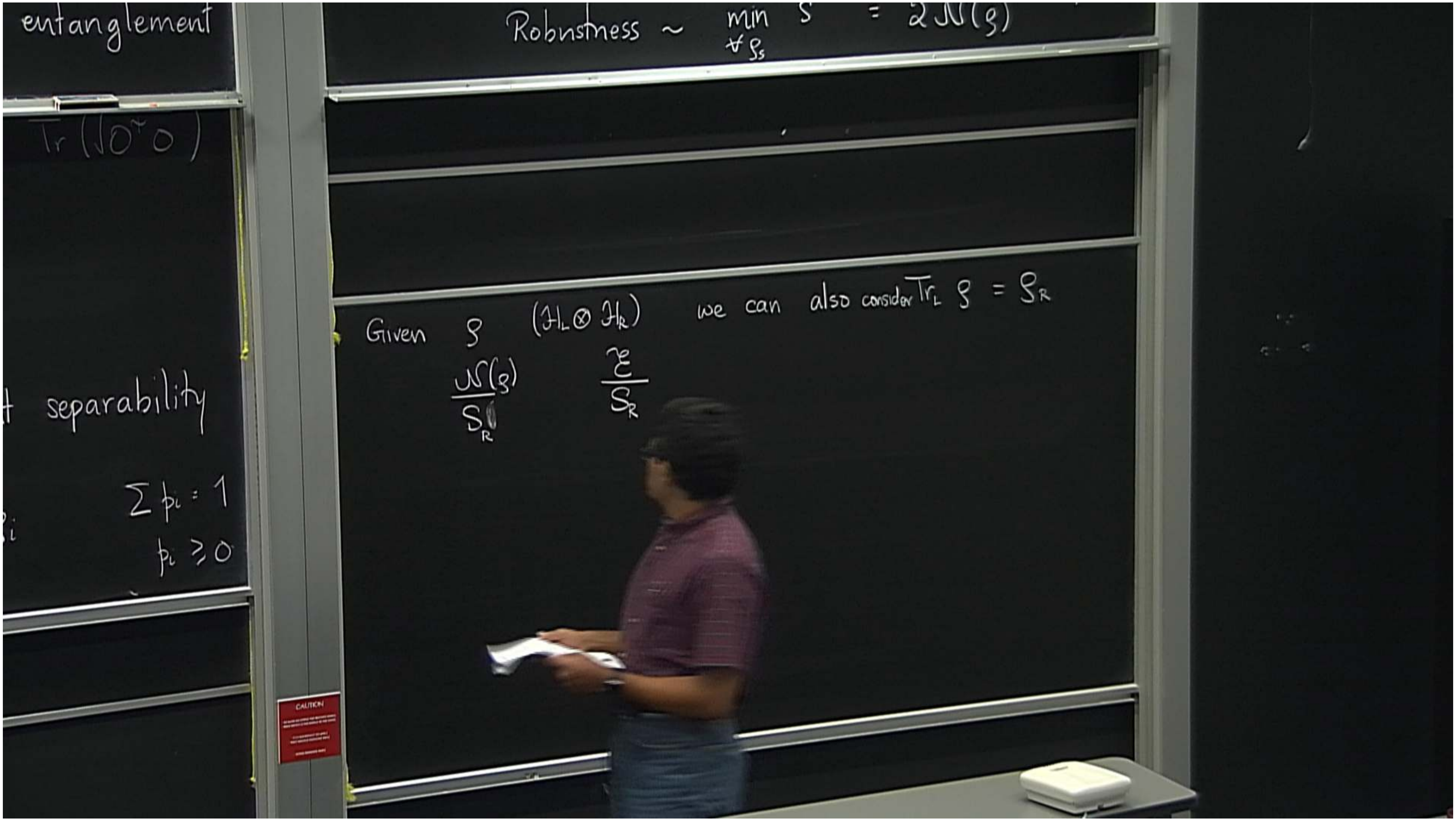

Try to distinguish classical correlations from pure QE
using entanglement negativity
Bipartite system
density matrix ρ
EPR type?

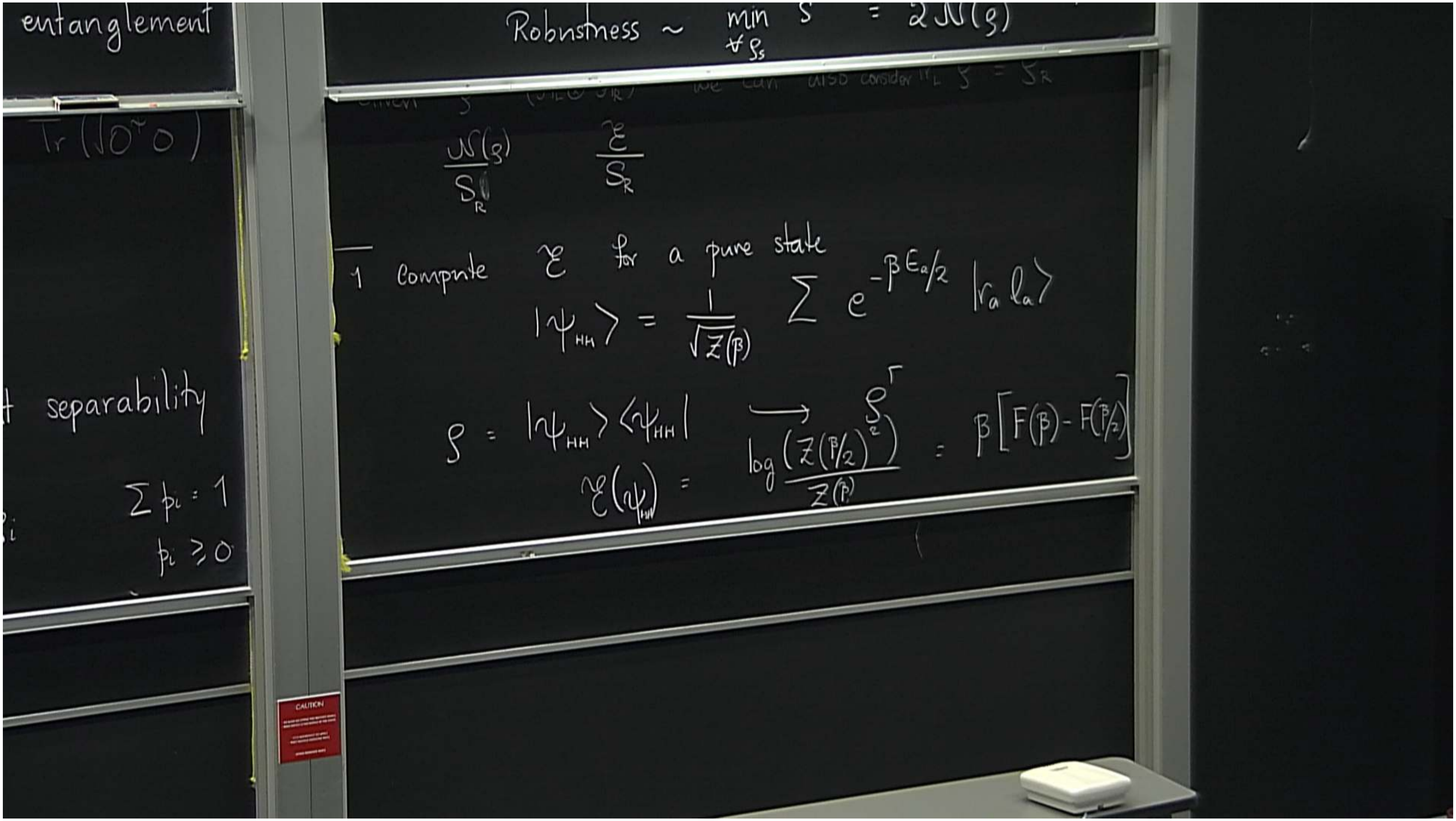

Try to distinguish classical correlations from pure QE
using entanglement negativity
Bipartite system $\mathcal{H}_L \otimes \mathcal{H}_R$
density matrix ρ. $\rho_{a\alpha, b\beta} = \langle r_a \ell_\alpha | \rho | r_b \ell_\beta \rangle$
define partial transpose
$\rho^{\Gamma}_{a\alpha, b\beta} = \rho_{a\beta, b\alpha}$

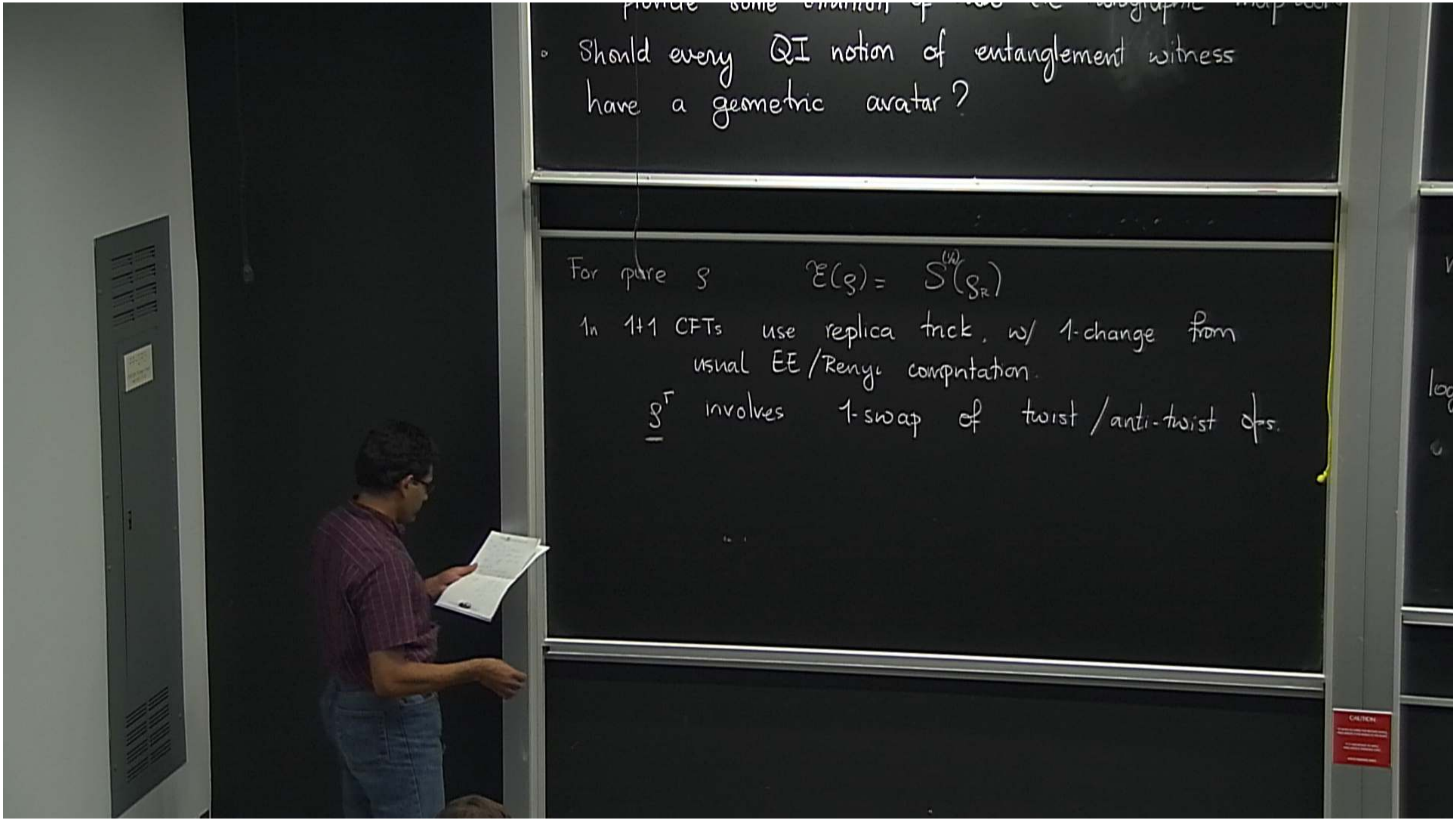

define partial transpose
$\varrho^{\Gamma}_{a\alpha, b\beta} = \varrho_{a\beta, b\alpha}$
Given ϱ^{Γ} we define 2 measures of entanglement
$\mathcal{E}(\varrho) = \log \|\varrho^{\Gamma}\|_1$
log negativity
operation "Γ" is useful to talk about separability
of density matrices.
ϱ is separable if $\varrho = \sum p_i \varrho_i$
$\sum p_i = 1$
$p_i \geq 0$
itness
R type?
CAUTION

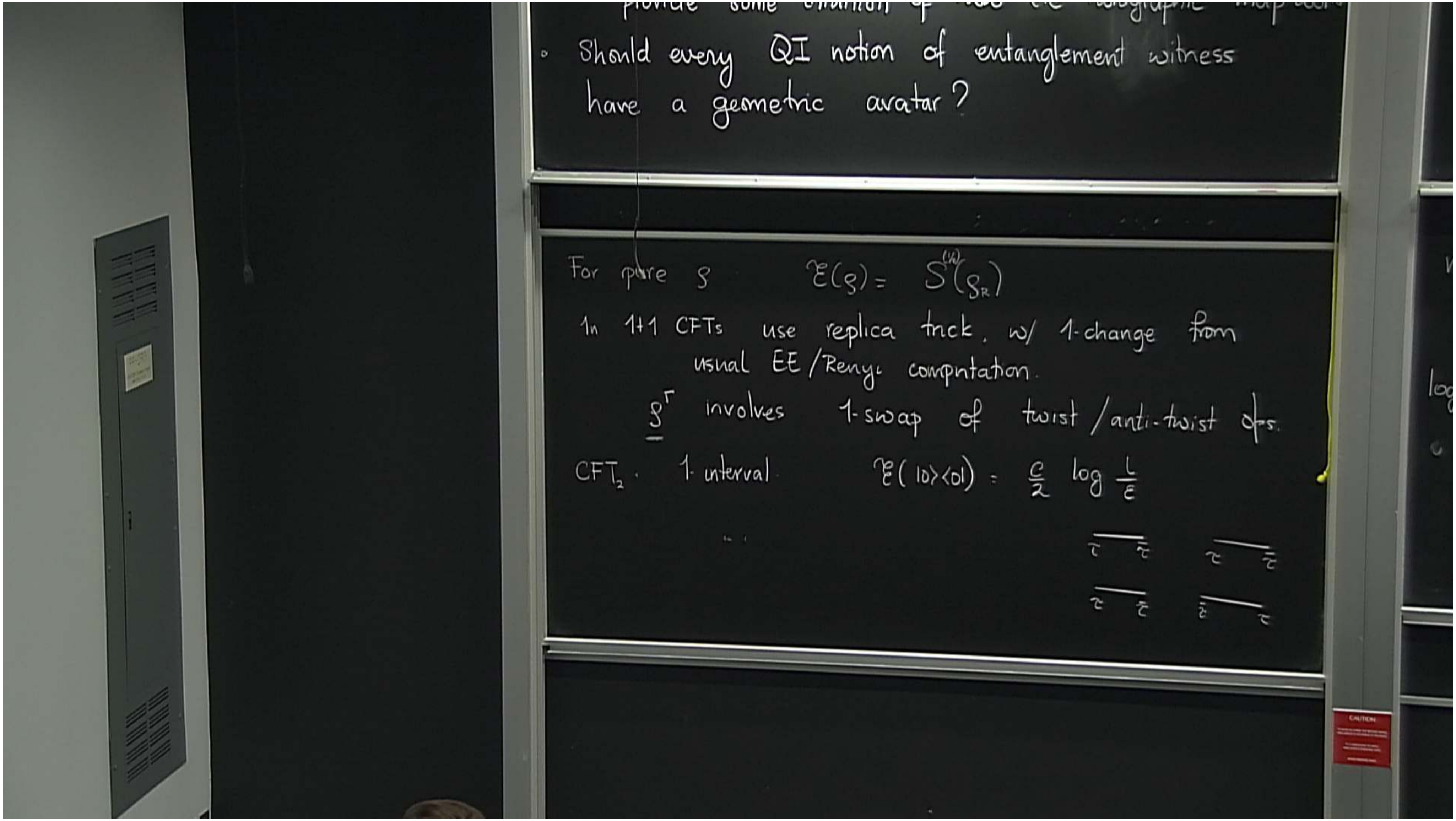

Matt's Q: what is special about HEE?
- holographic entropy cone?
- are there alternate measures of QE which provide some intuition of how the holographic map works
- Should every QI notion of entanglement witness have a geometric avatar?
Bipartite system
density matrix
define partial transpose
Given ρ^Γ we define 2 measures of entanglement
negativity
log negativity
operation is useful to talk about separability of density matrices
ρ is separable if
ρ is separable ⇒ ρ^Γ has no negative eigenvalues
(ρ is PPT)
ρ is PPT ⇒ ρ is undistillable
Positivity, Negativity, Entanglement, & Holography
w/ Massimiliano Rota 1406.6989 + 1505.05696
+ G. Penington 1506.04679
Entanglement ⟷ Holography
- does the entanglement have to be EPR?
- if entanglement were undistillable?
- classical correlations contamination?
- multipartite entanglement?


ρ is separable $\Rightarrow$ ρ^{Γ} has no negative eigenvalues
(ρ is PPT)
ρ is PPT $\Rightarrow$ ρ is undistillable
$\mathcal{N}(\rho)$ gives a measure of the robustness of entanglement
consider ρ & add noise ρ_s ← seperable.
$\tilde{\rho} \sim \frac{1}{1+s} (\rho + s\,\rho_s)$
↑ measure of amount of noise
Robustness $\sim \min_{\forall \rho_s} s = 2\mathcal{N}(\rho)$


entanglement
Robustness ~ min s = 2N(ρ)
∀ρs
separability
Σ pi = 1
pi ≥ 0
Given ρ (HL ⊗ HR) we can also consider TrL ρ = ρR
CAUTION


entanglement
Robustness ~ min S = 2 N(ρ)
∀ ρ_s
Tr(√O†O)
N(ρ) / S_R
ℰ / S_R
1 Compute ℰ for a pure state
|ψ_HH⟩ = 1/√Z(β) Σ e^{-βE_a/2} |r_a l_a⟩
separability
ρ = |ψ_HH⟩⟨ψ_HH|
ℰ(ψ_HH) = log (Z(β/2)²)/Z(β) = β[F(β) - F(β/2)]
Σ p_i = 1
p_i ≥ 0
CAUTION


Should every QI notion of entanglement witness have a geometric avatar?
For pure ρ $\mathcal{E}(\rho) = S^{(1/2)}(\rho_R)$
In 1+1 CFTs use replica trick, w/ 1-change from usual EE/Renyi computation.
ρ^{Γ} involves 1-swap of twist/anti-twist ops.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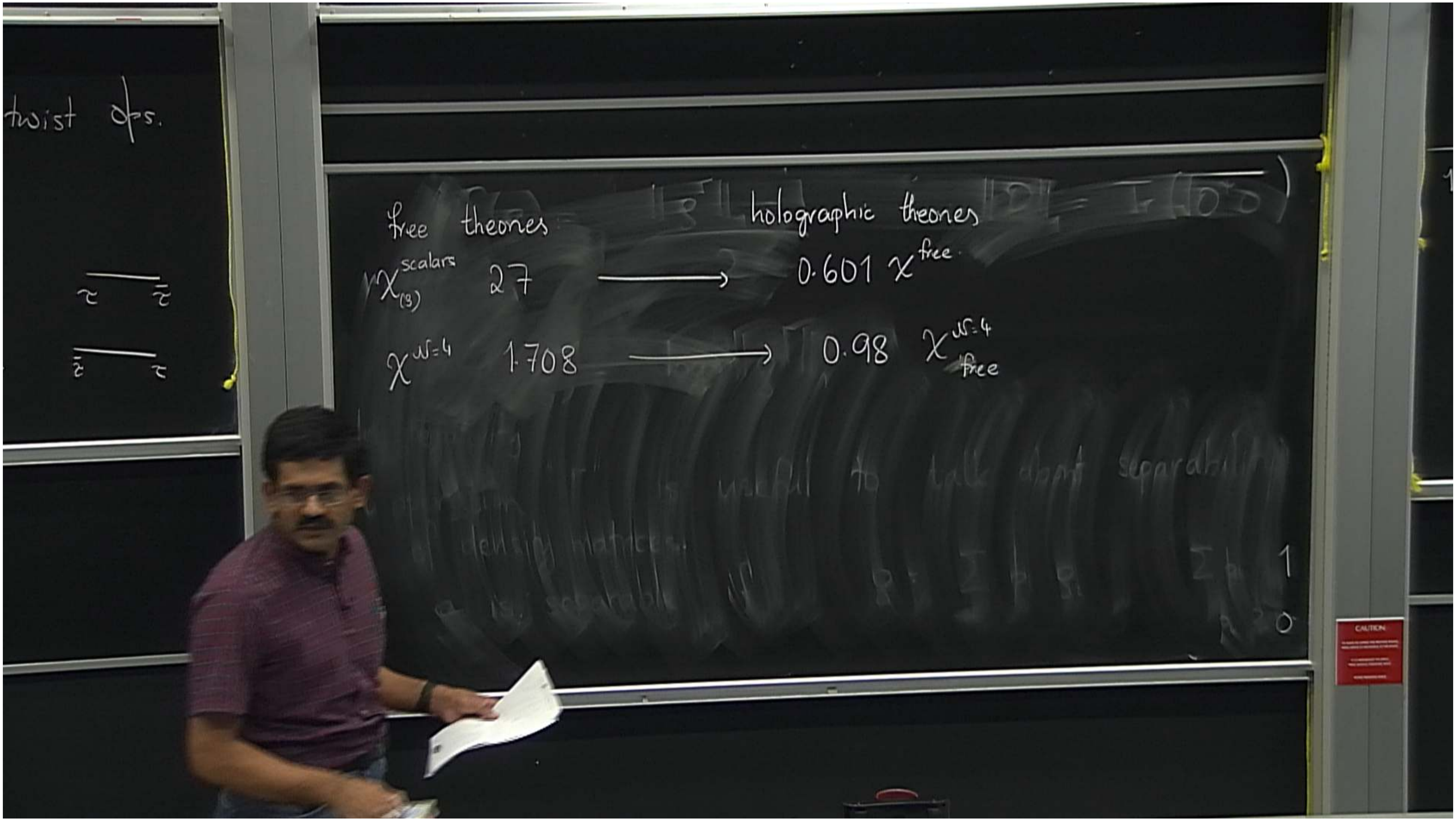
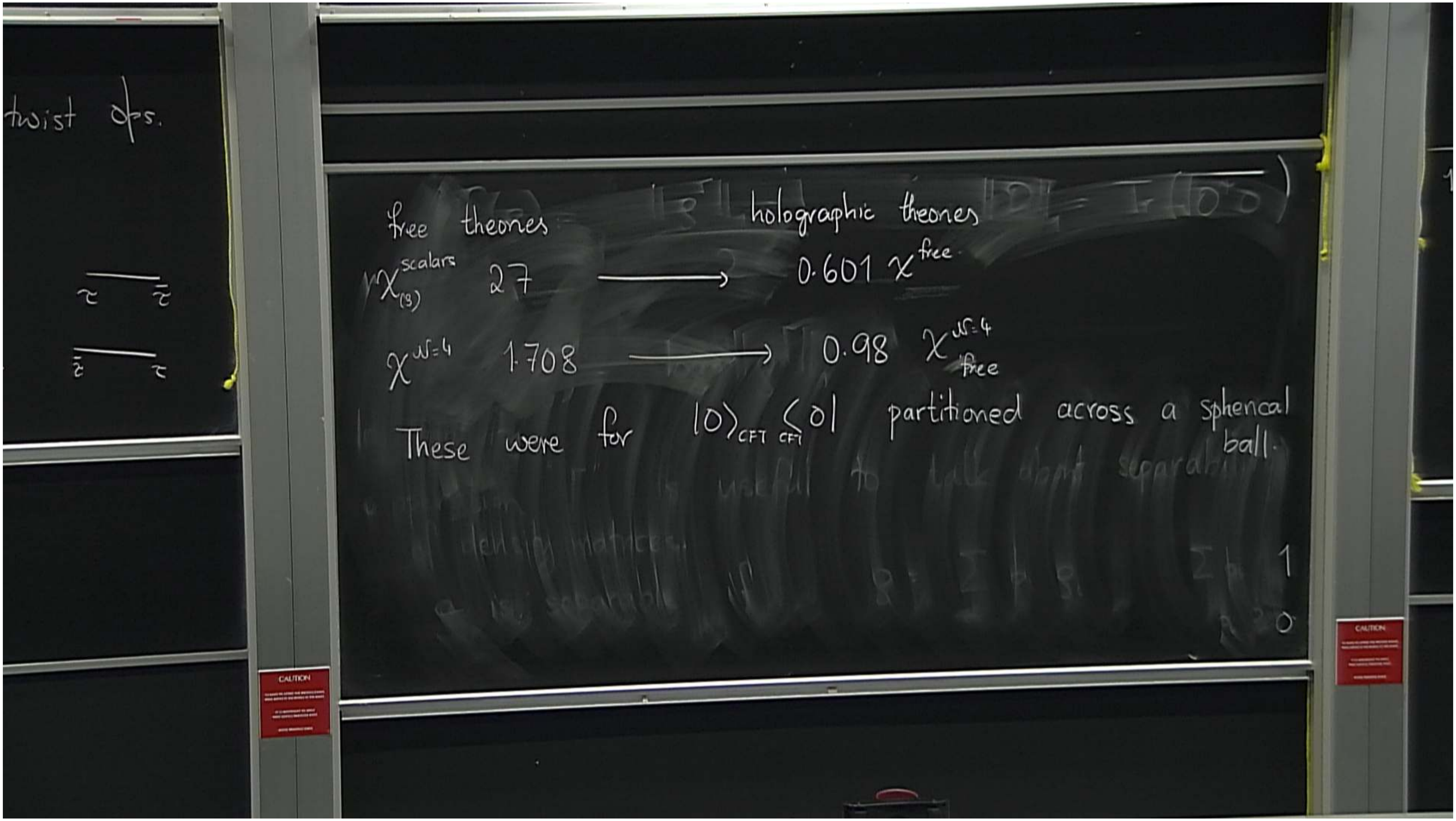
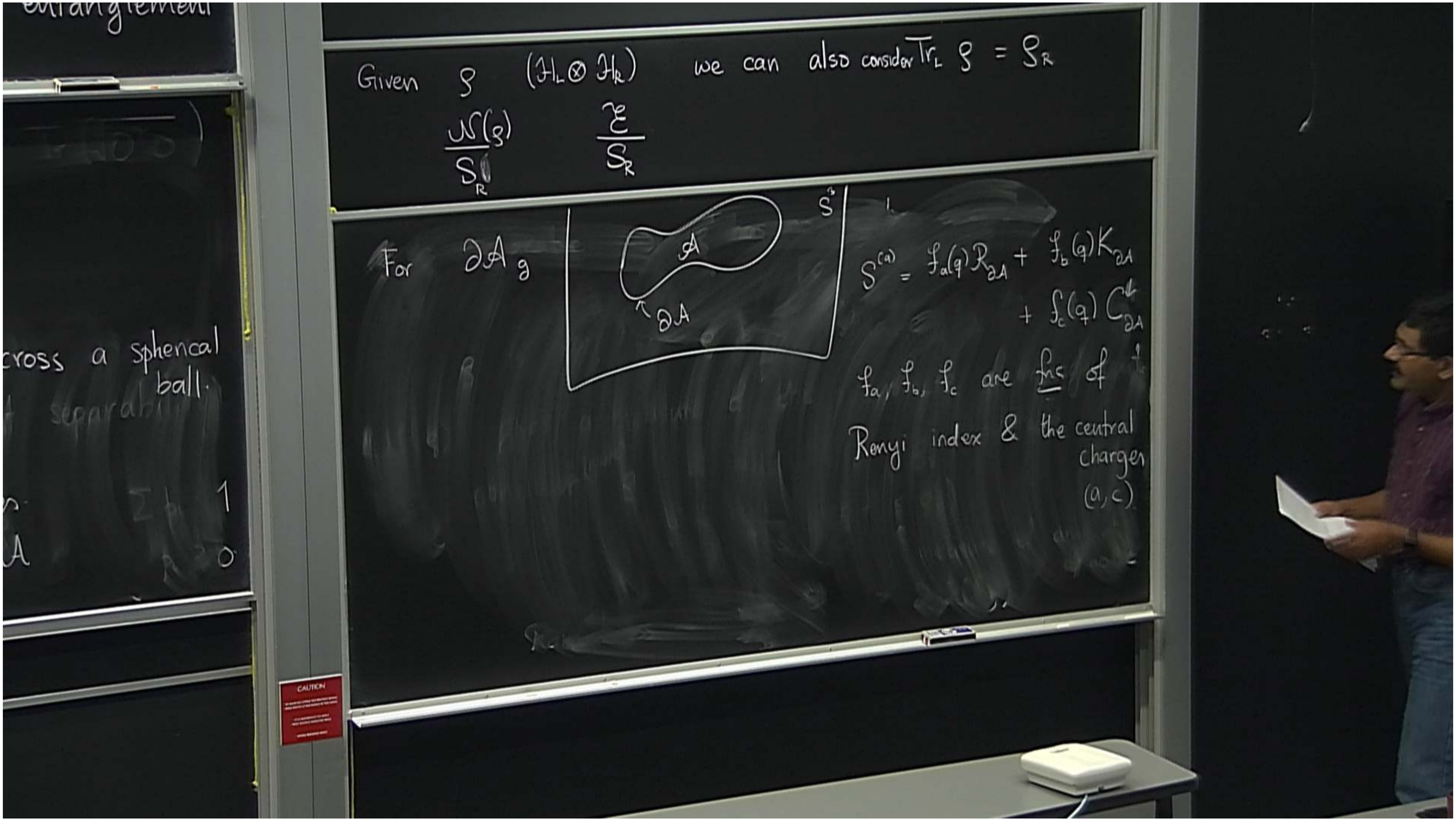
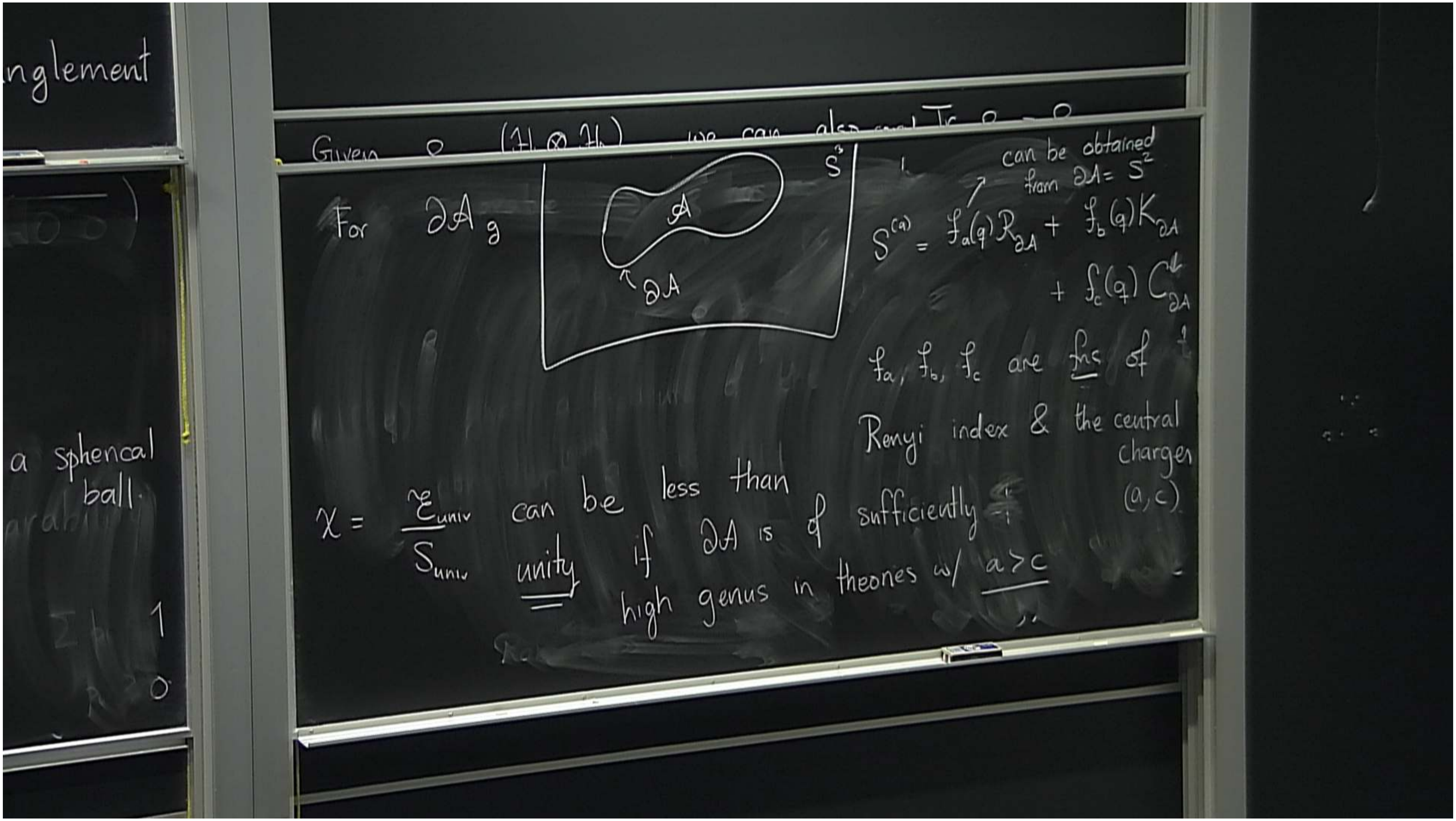
CFT_2. 1-interval   ℰ(|0⟩⟨0|) = $\frac{c}{2} \log \frac{L}{\epsilon}$

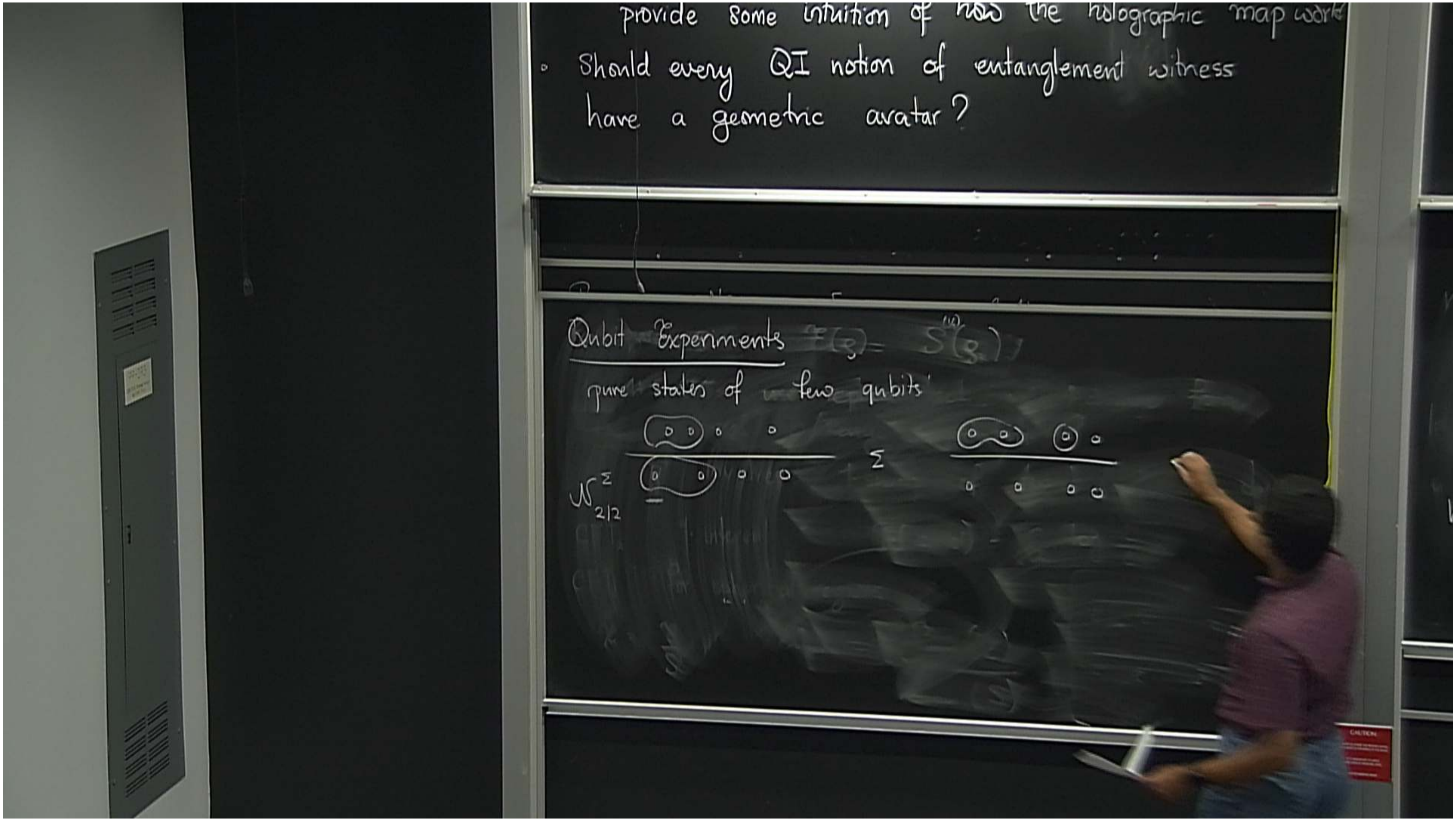

twist ops.
free theories
holographic theories
χ scalars (3) 27 → 0.601 χ free
χ N=4 1.708 → 0.98 χ N=4 free

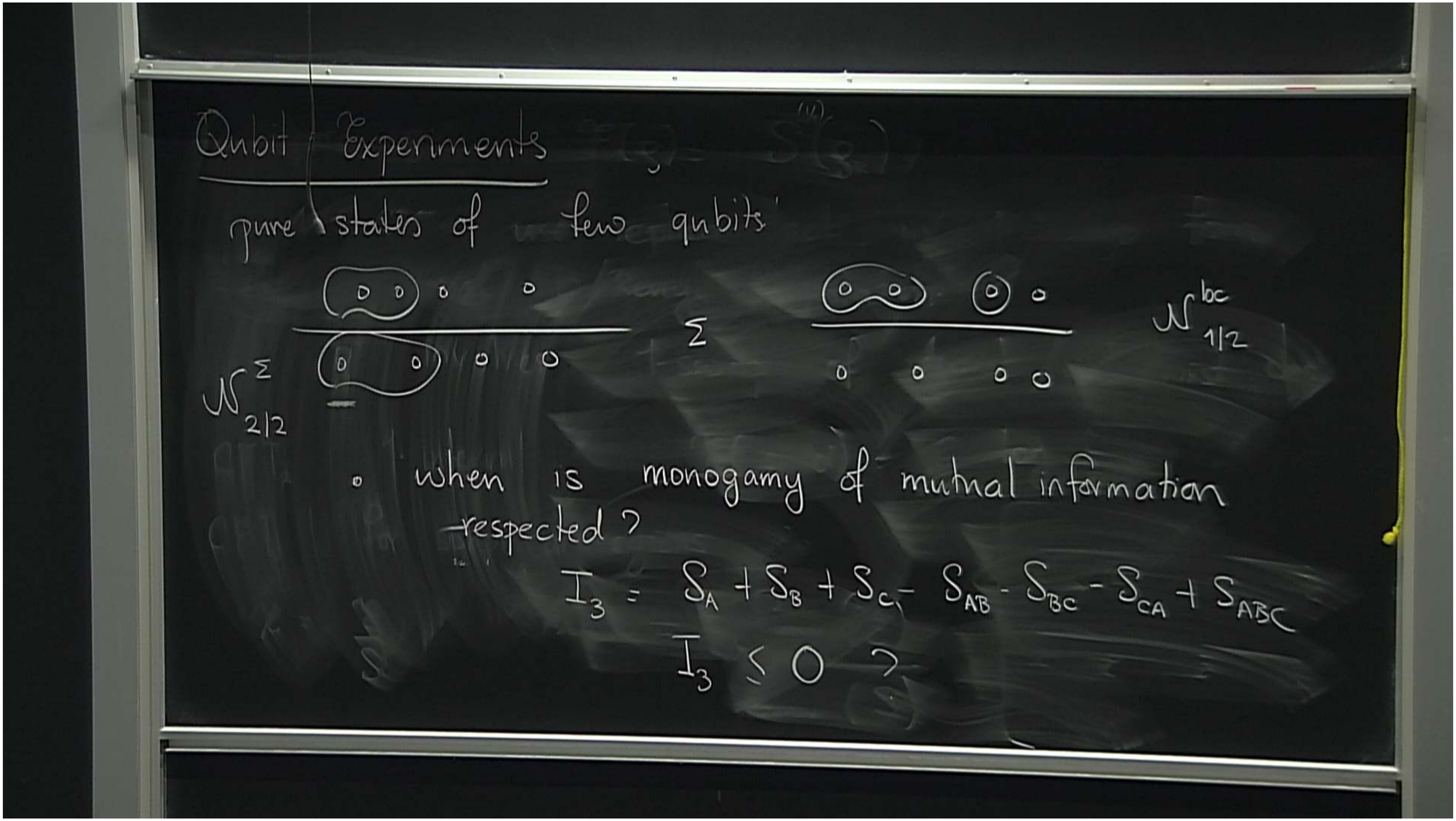

twist ops.
free theories
holographic theories
$\chi^{scalars}_{(3)}$ 27 → 0.601 χ^{free}
$\chi^{N=4}$ 1.708 → 0.98 $\chi^{N=4}_{free}$
These were for $|0\rangle_{CFT}\,{}_{CFT}\langle 0|$ partitioned across a spherical ball.


Given ϱ (ℋ_L ⊗ ℋ_R) we can also consider Tr_L ϱ = ϱ_R
For ∂A g
S^3
A
∂A
S^(q) = f_a(q) R_∂A + f_b(q) K_∂A + f_c(q) C_∂A
f_a, f_b, f_c are fns of Renyi index & the central charges (a, c)
across a spherical ball.



nglement
a sphencal ball.
For ∂A g
A
∂A
S³
can be obtained from ∂A = S²
S^(q) = f_a(q) R_∂A + f_b(q) K_∂A + f_c(q) C_∂A
f_a, f_b, f_c are fns of Renyi index & the central charges (a, c)
χ = ℰ_univ / S_univ can be less than unity if ∂A is of sufficiently high genus in theories w/ a > c


provide some intuition of how the holographic map works
Should every QI notion of entanglement witness have a geometric avatar?
Qubit Experiments
pure states of few qubits


Qubit Experiments
pure states of few qubits
Σ
N^Σ_{2|2}
N^{bc}_{1|2}
when is monogamy of mutual information respected?
I_3 = S_A + S_B + S_C - S_AB - S_BC - S_CA + S_ABC
I_3 ≤ 0 ?

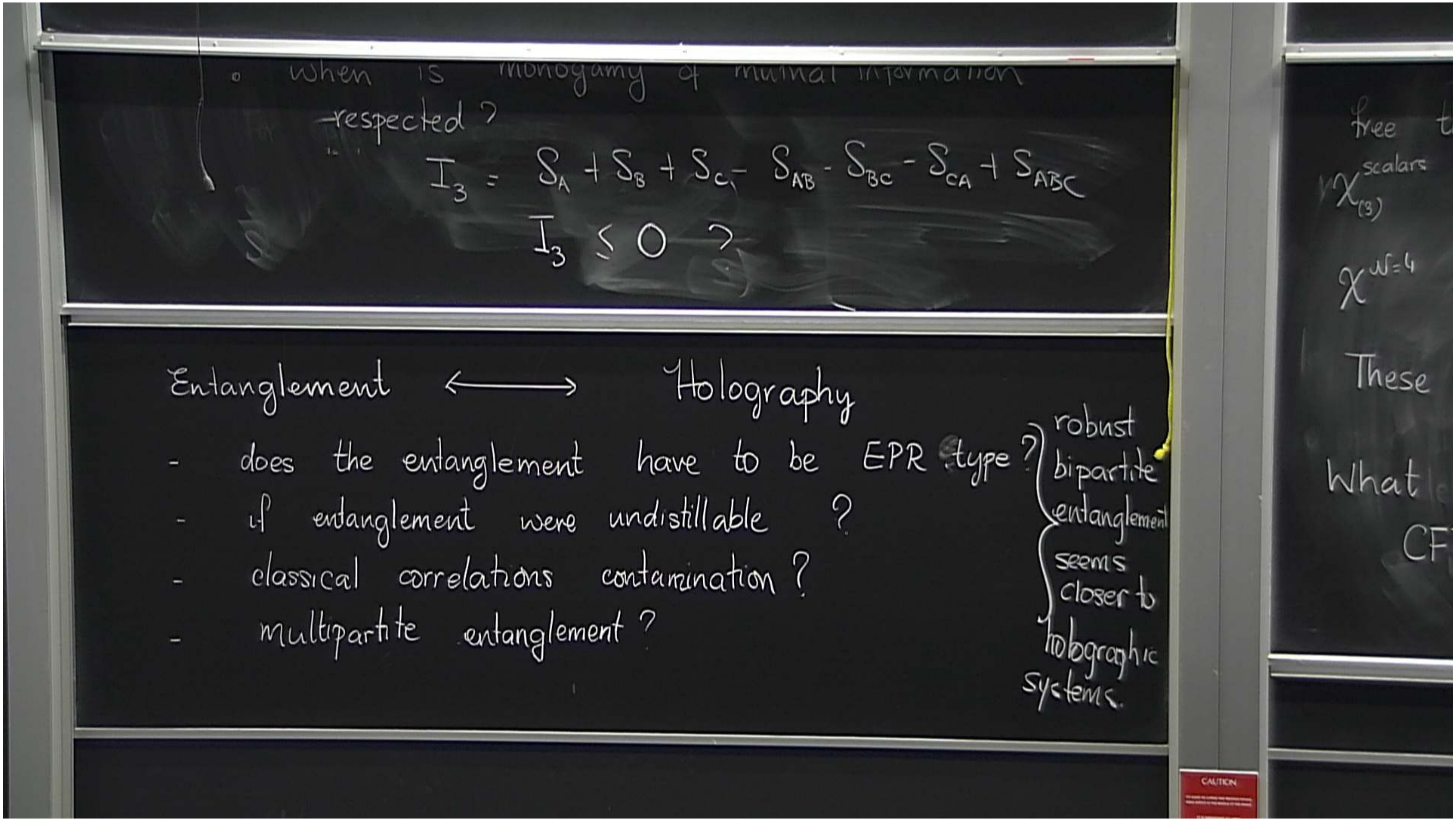
- under what conditions is monogamy of $\mathcal{N}^2$ respected?

$$\mathcal{N}^2_{A|C} + \mathcal{N}^2_{A|B} \le \mathcal{N}^2_{A|BC}$$

holographically one finds situations where Araki - Lieb is saturated

$$| S_A - S_{A^c} | \le S_{A \cup A^c}$$

→ MMI > 0 happens for states w/ low robustness and large multi-partite entanglement


when is monogamy of mutual information respected?
$I_3 = S_A + S_B + S_C - S_{AB} - S_{BC} - S_{CA} + S_{ABC}$
$I_3 \leq 0$?
Entanglement ⟷ Holography
- does the entanglement have to be EPR type?
- if entanglement were undistillable ?
- classical correlations contamination ?
- multipartite entanglement ?
robust bipartite entanglement seems closer to holographic systems.
free t
$\chi^{scalars}_{(3)}$
$\chi^{N=4}$
These
What
CF


holographic theories
0.601 χ^free
1.708 → 0.98 χ^N=4 free
were for |0⟩_CFT ⟨0| partitioned across a spherical ball.
about other domains?
for arbitrary entangling surfaces
2 surface ∂A
under what conditions is monogamy of 𝒮² respected?
𝒮²_A|C + 𝒮²_A|B ≤ 𝒮²_A|BC
holographically one finds situations where Araki-Lieb is saturated
|S_A - S_A^c| ≤ S_A∪A^c
MMI > 0 happens for states w/ low robustness and large multi-partite entanglement