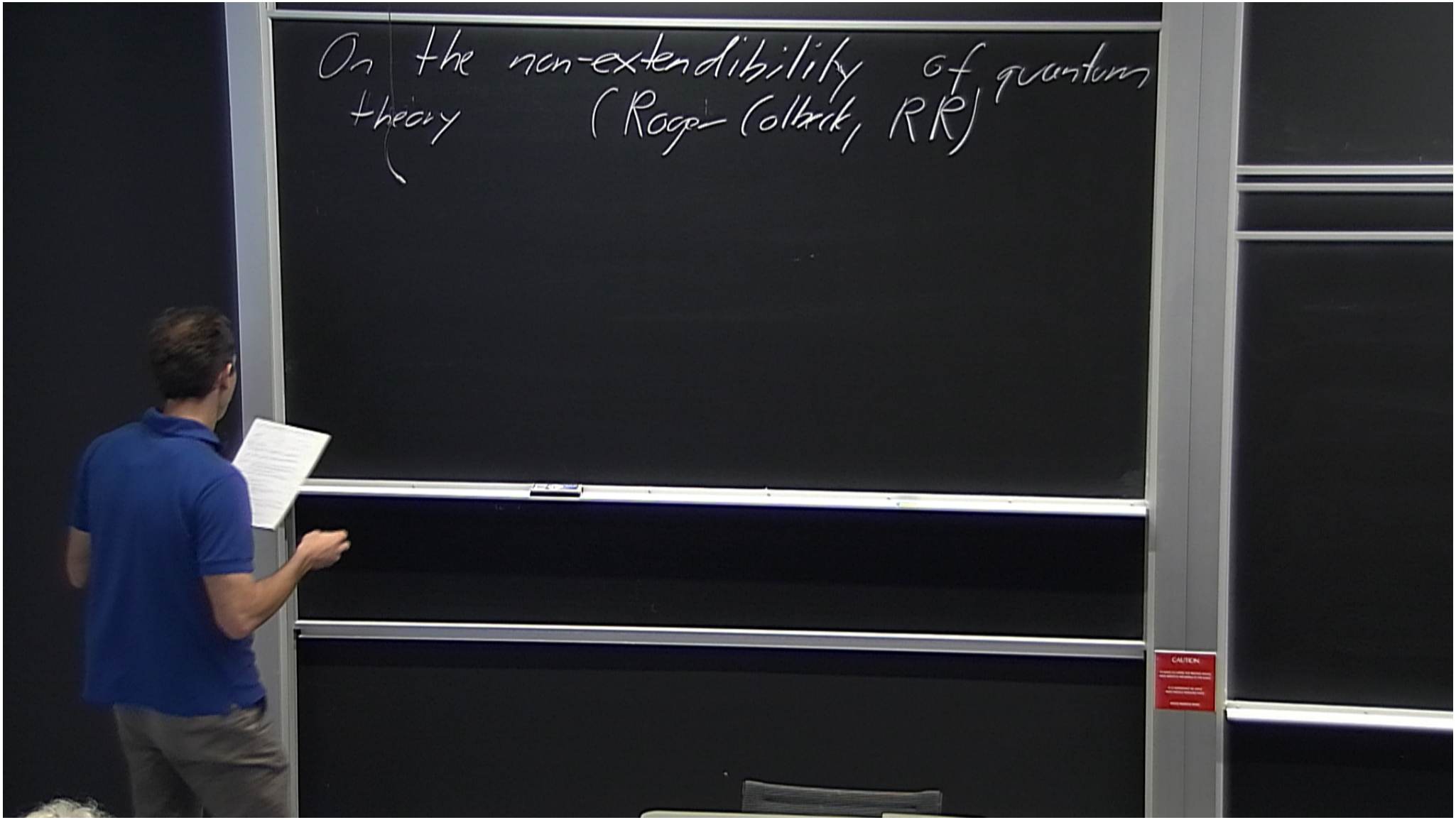
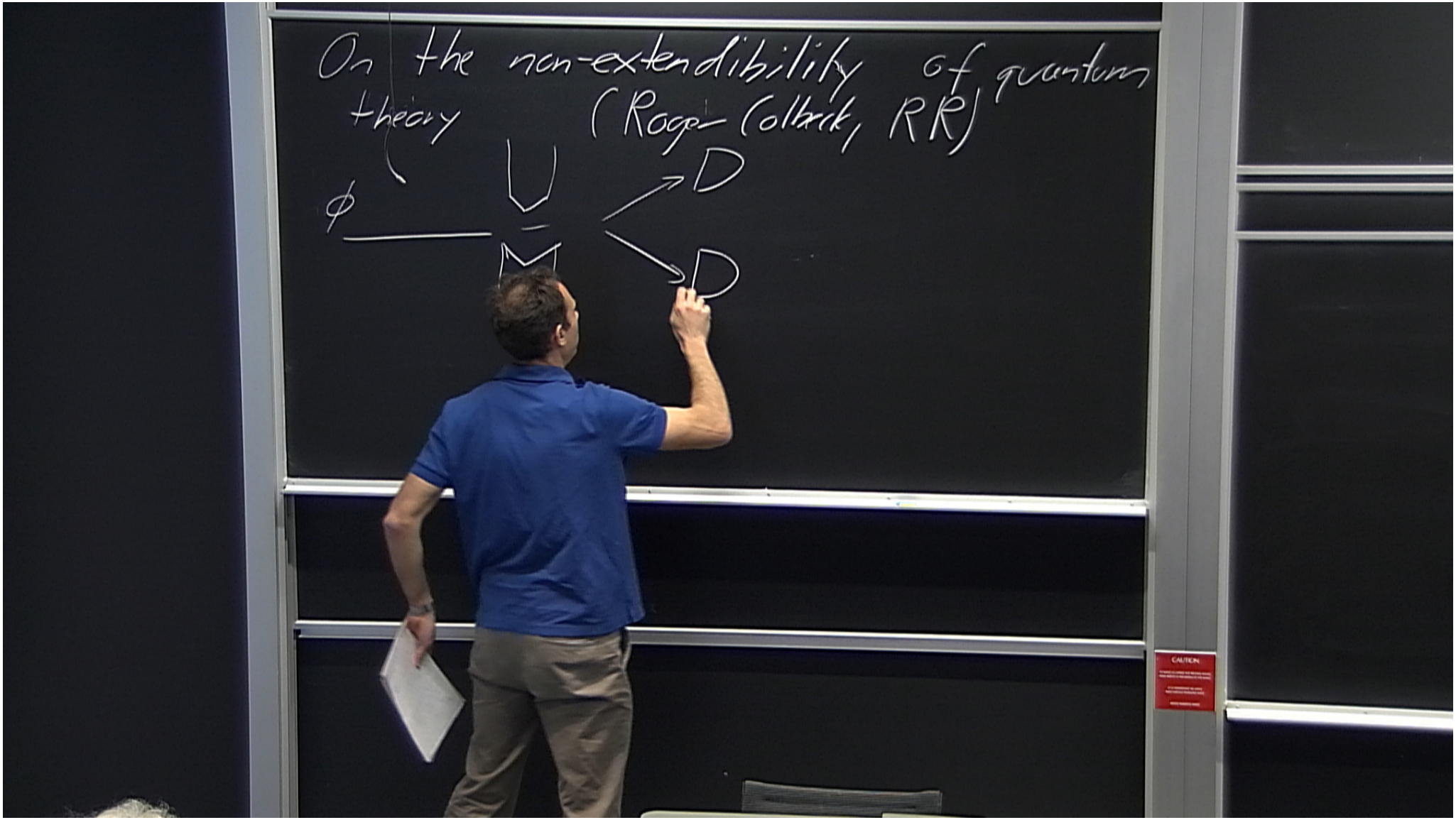
Title: On the non-extendibility of quantum theory

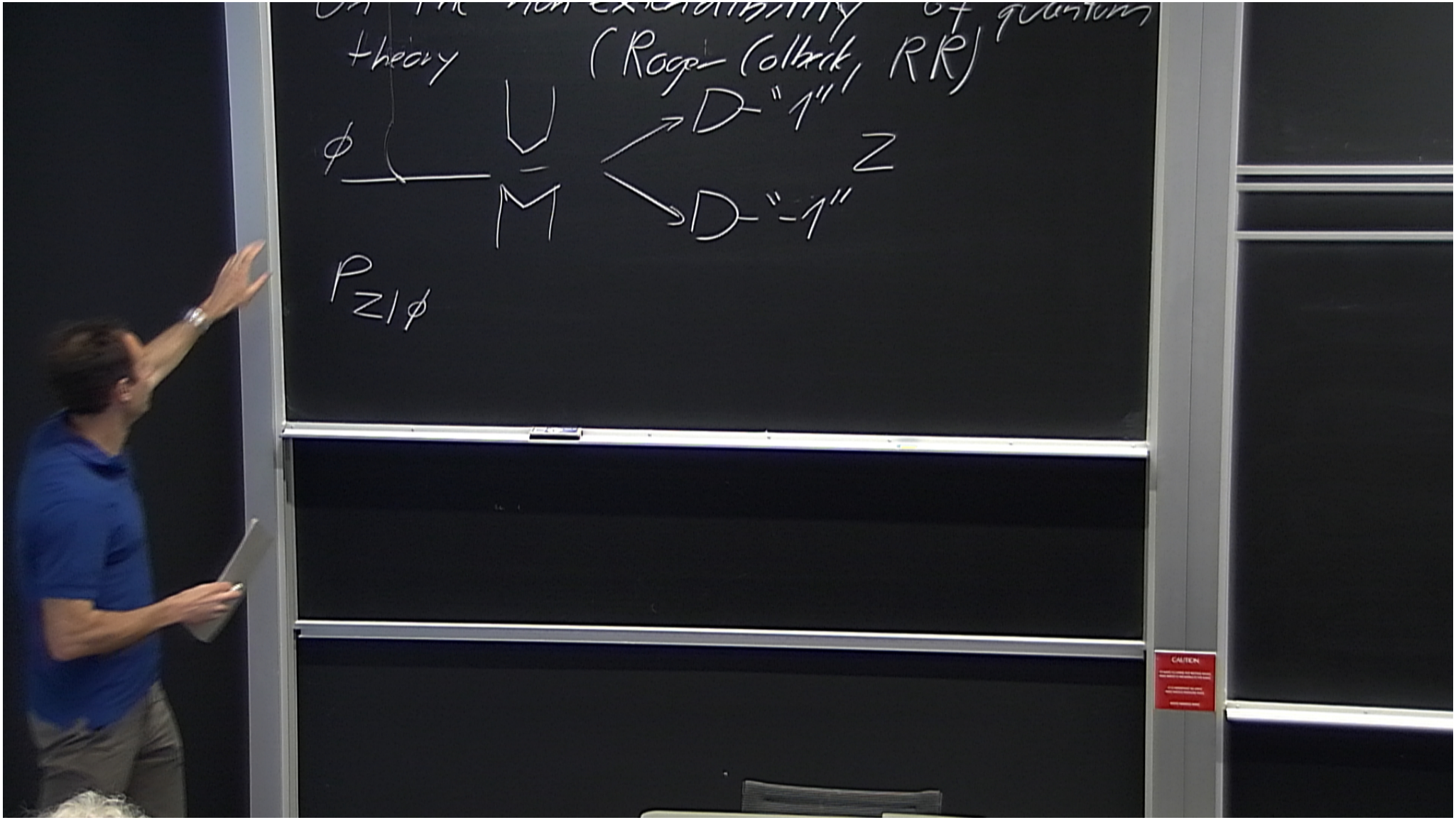
Date: May 27, 2013 10:05 AM

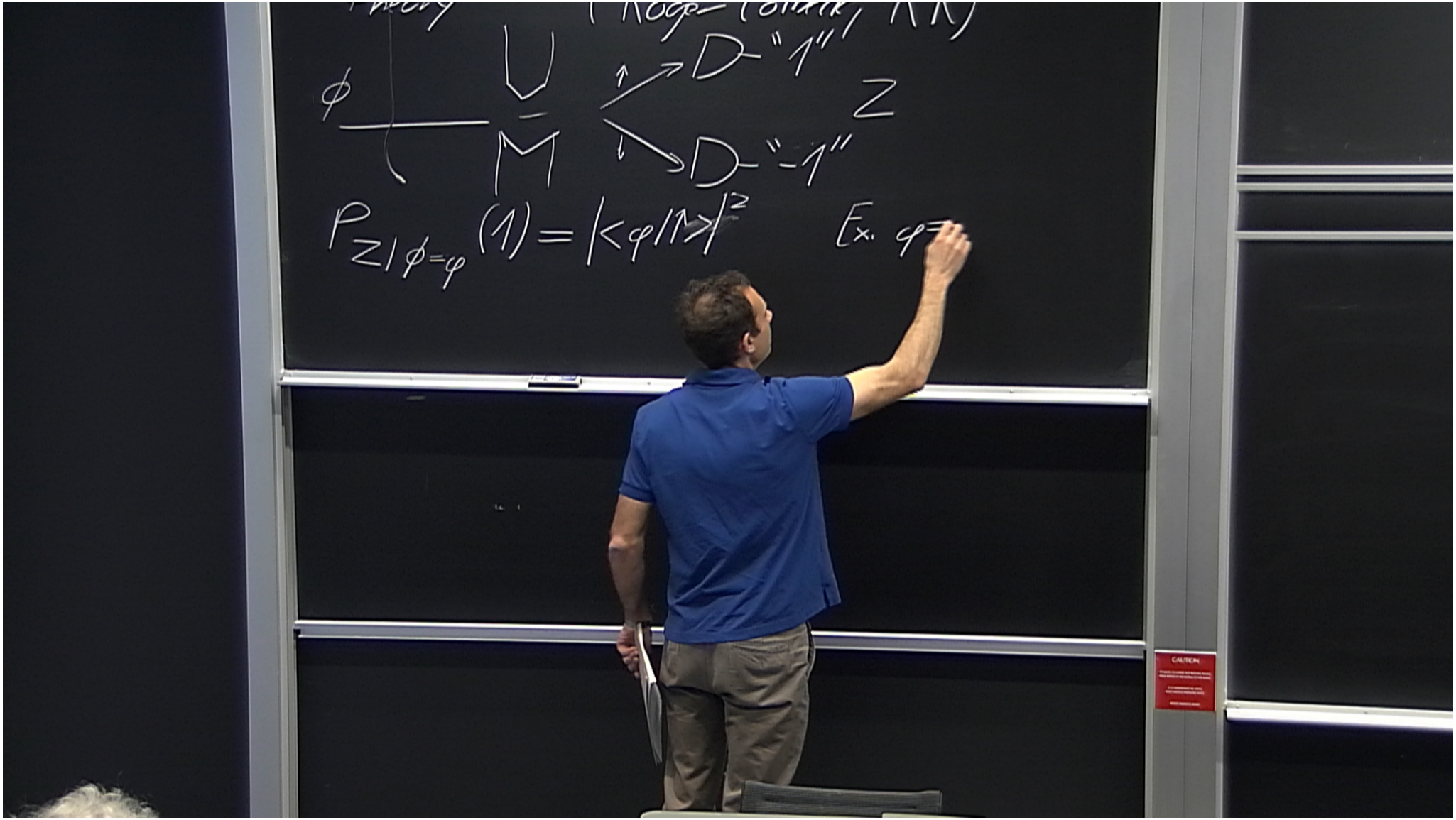
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Abstract: I will present a recent theorem that asserts that there cannot exist an "extension of quantum theory" that allows us to make more informative predictions about future measurable events (e.g., whether a horizontally polarized photon passes a polarization filter with a given orientation) than standard quantum theory. The theorem is based on two assumptions about the extended theory: (i) the theory should be compatible with quantum theory (this means, in practice, that the theory is not falsified by current experimental data); (ii) the theory should not preclude experimenters from freely choosing the measurement settings. More precisely, the latter assumption corresponds to the requirement that measurement settings can be chosen at random such that they are independent of any other events, except of course those that lie in the causal future of the choice (i.e., in its future light cone). In addition, I will discuss a corollary of the non-extendibility theorem which leads to the same conclusions as a recent theorem by Pusey, Barrett, and Rudolph on the "reality of the quantum state", based only on the above assumptions.

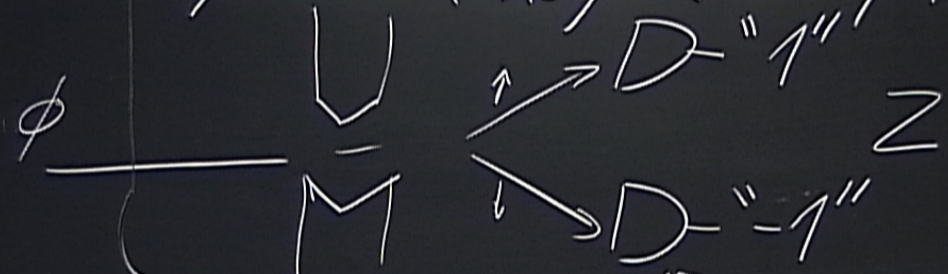

On the non-extendibility of quantum
theory (Roga-Colbeck, RR)


On the non-extendibility of quantum
theory (Roga-Colbeck, RR)
U
D
D


theory
(Rogo-Colbeck, RR)
U
M
D "1"
D "-1"
Z
$P_{Z|\phi}$

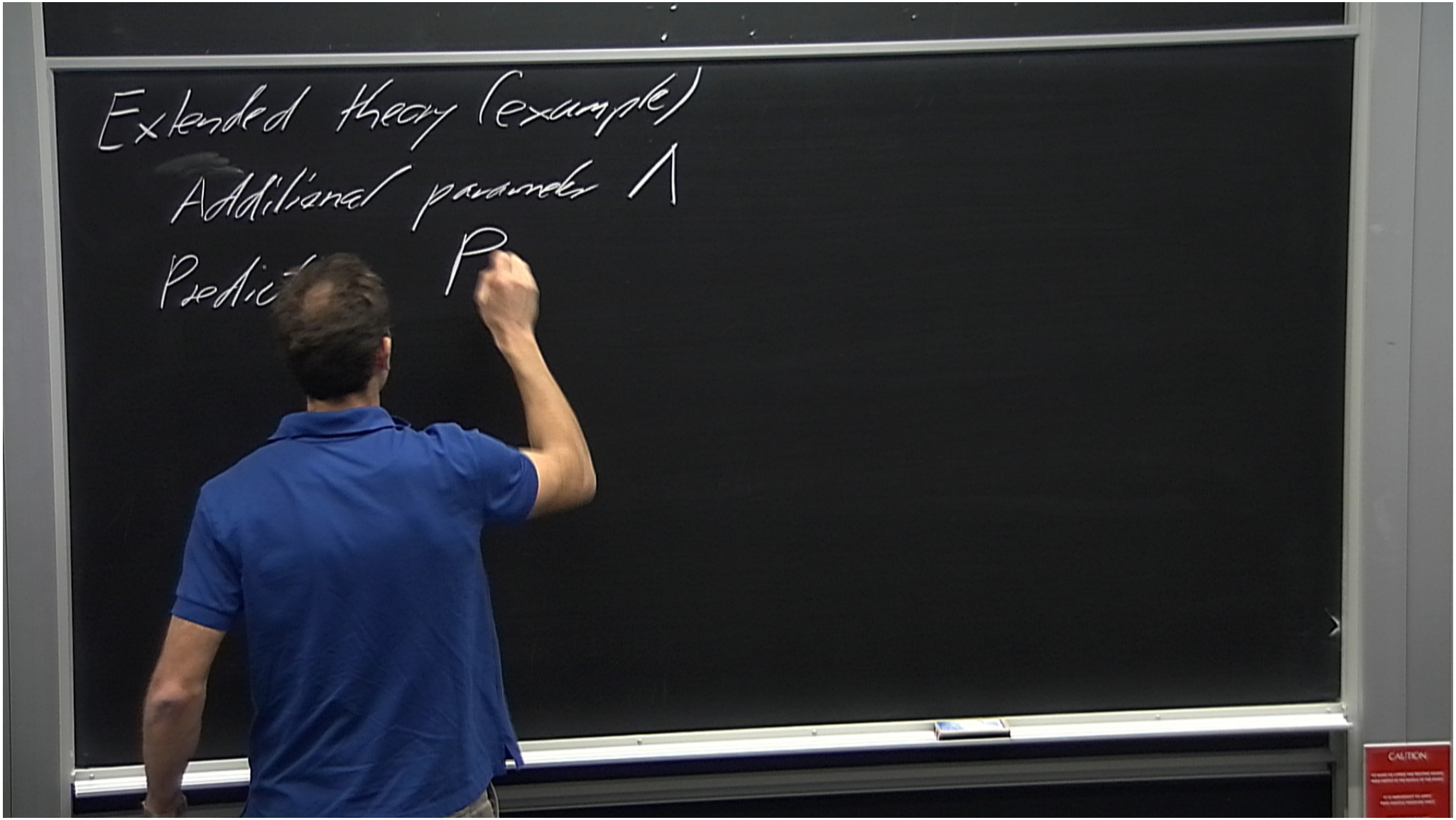

U
M
D "1"
D "-1"
Z
$P_{Z|\phi=\varphi}(1) = |\langle\varphi|M\rangle|^2$
Ex. $\varphi =$

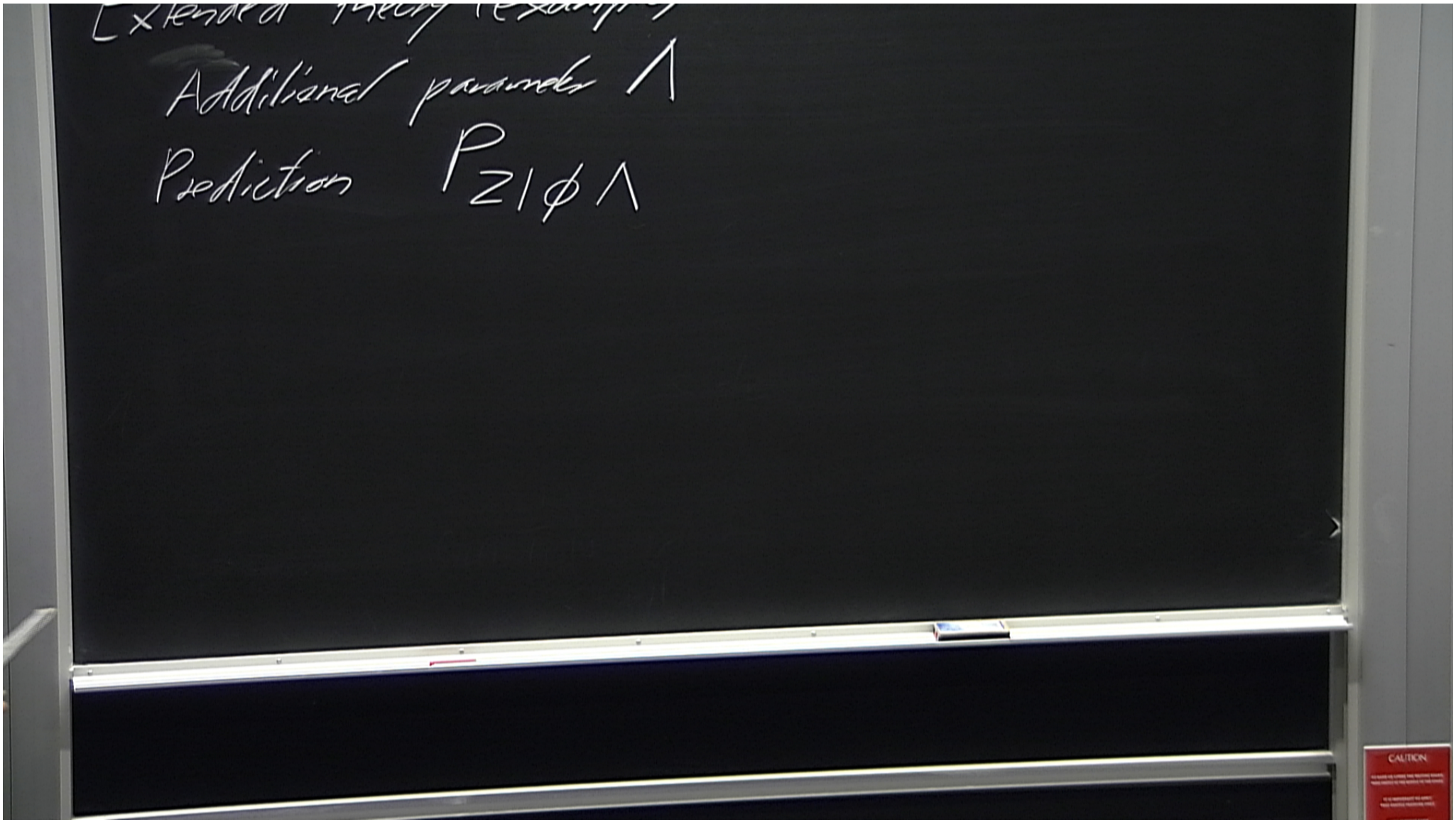
On the non-extendibility of quantum theory (Roger Colbeck, RR)

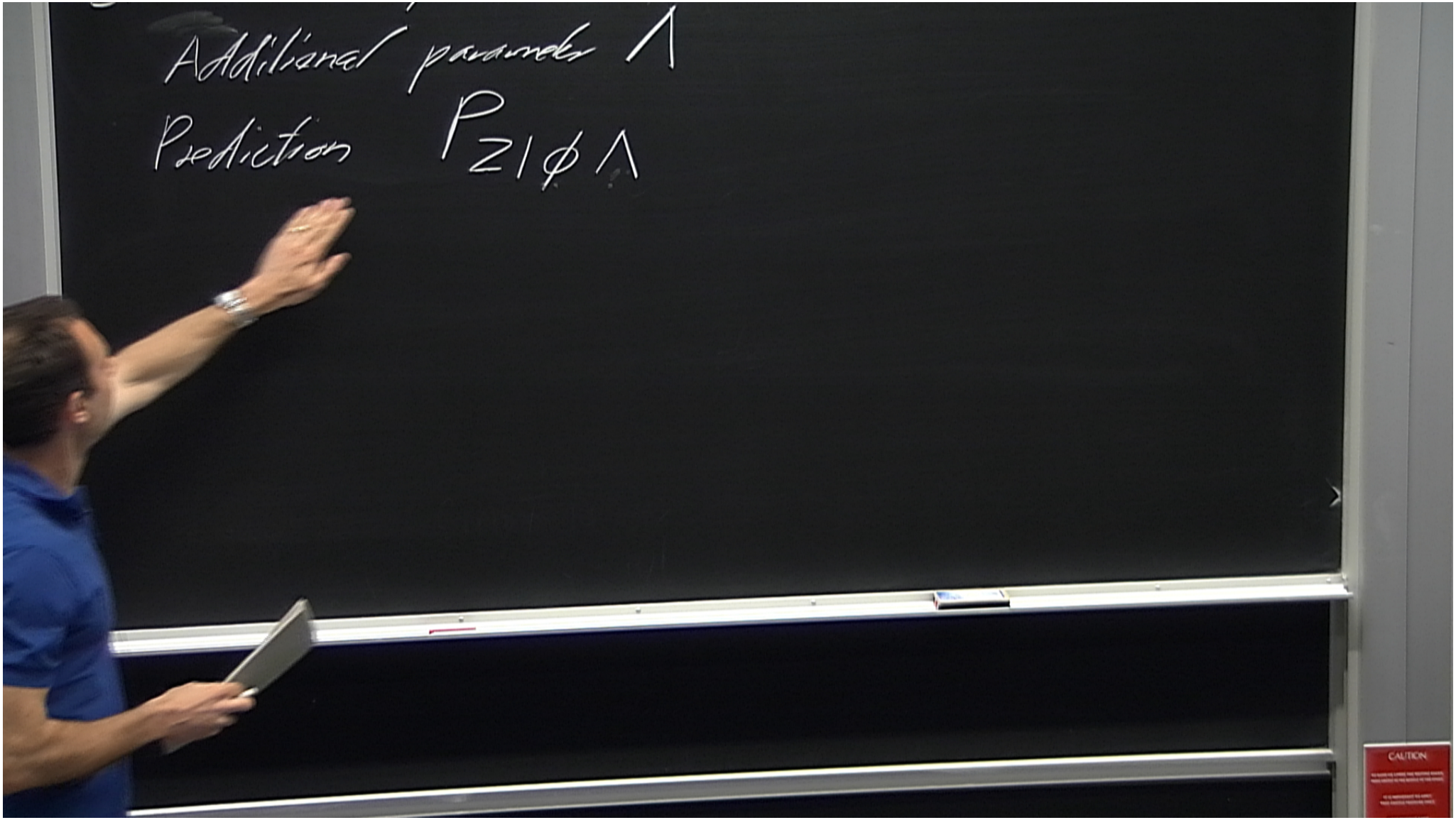


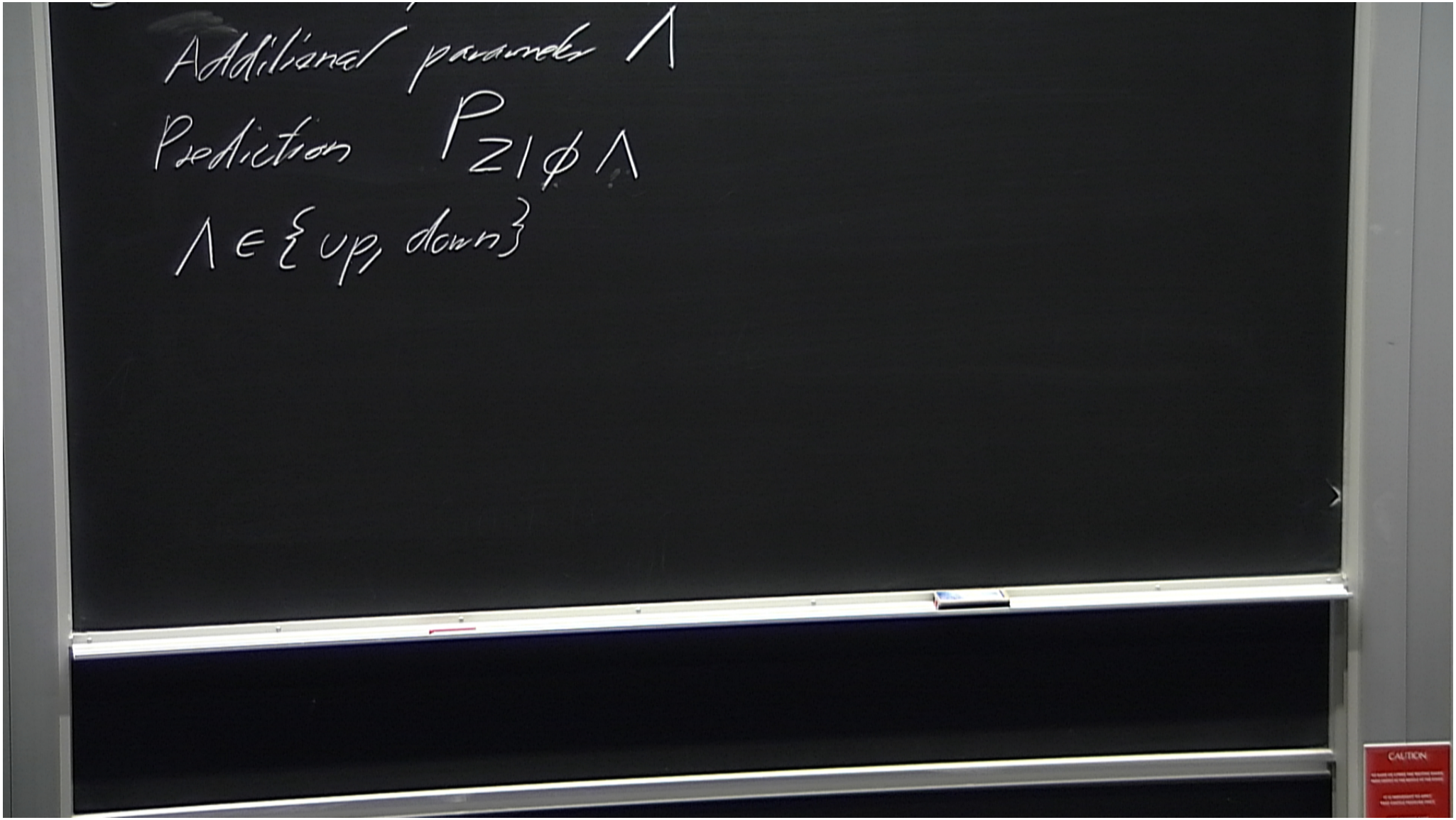
$P_{Z|\phi=\varphi}(1) = |\langle\varphi|\Pi\rangle|^2$ Ex. $\varphi=\bar{\varphi}=\frac{1}{\sqrt{2}}(|1\rangle+|0\rangle)$

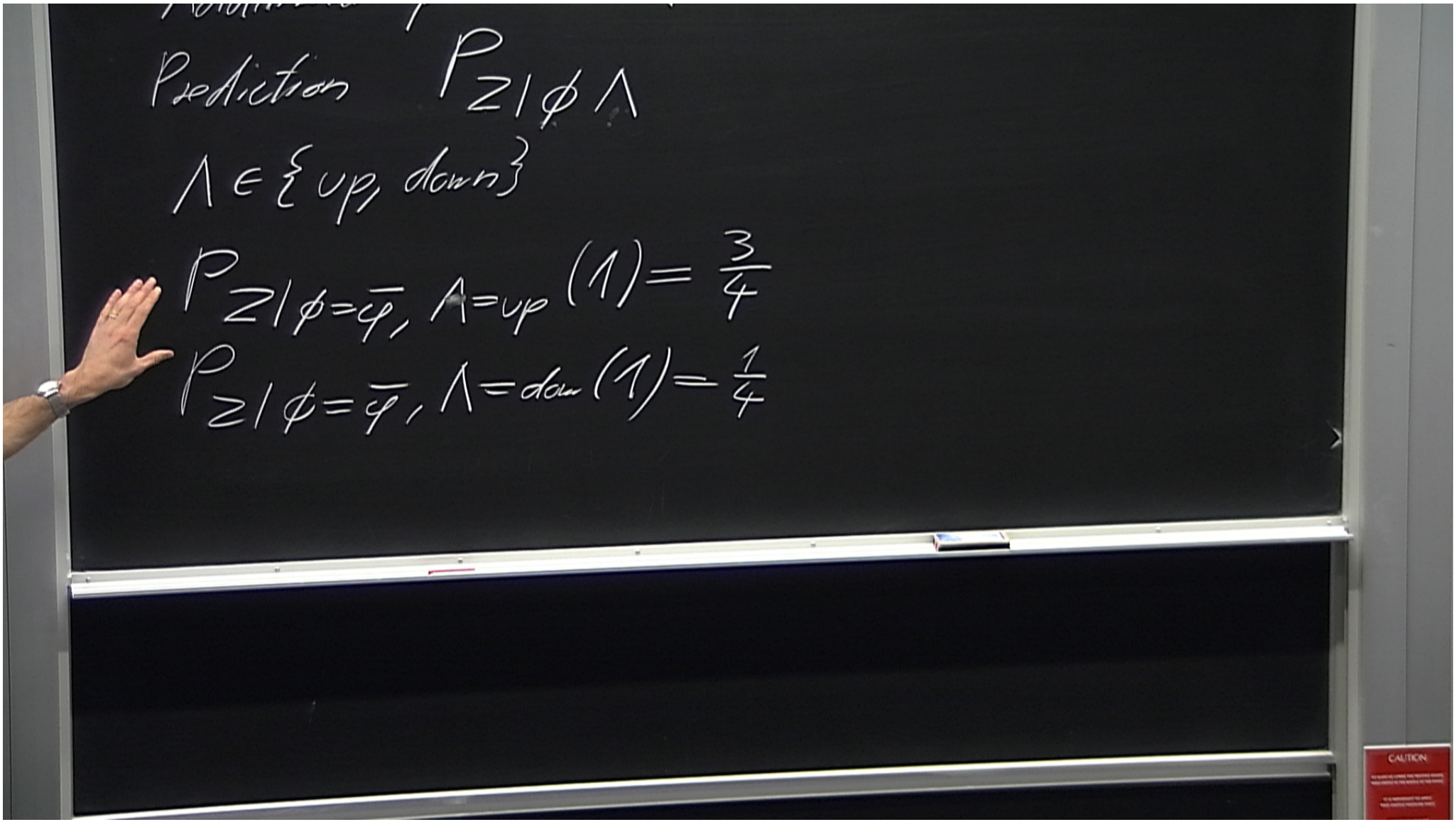
$P_{Z|\phi=\bar{\varphi}}(1) = \frac{1}{2}$

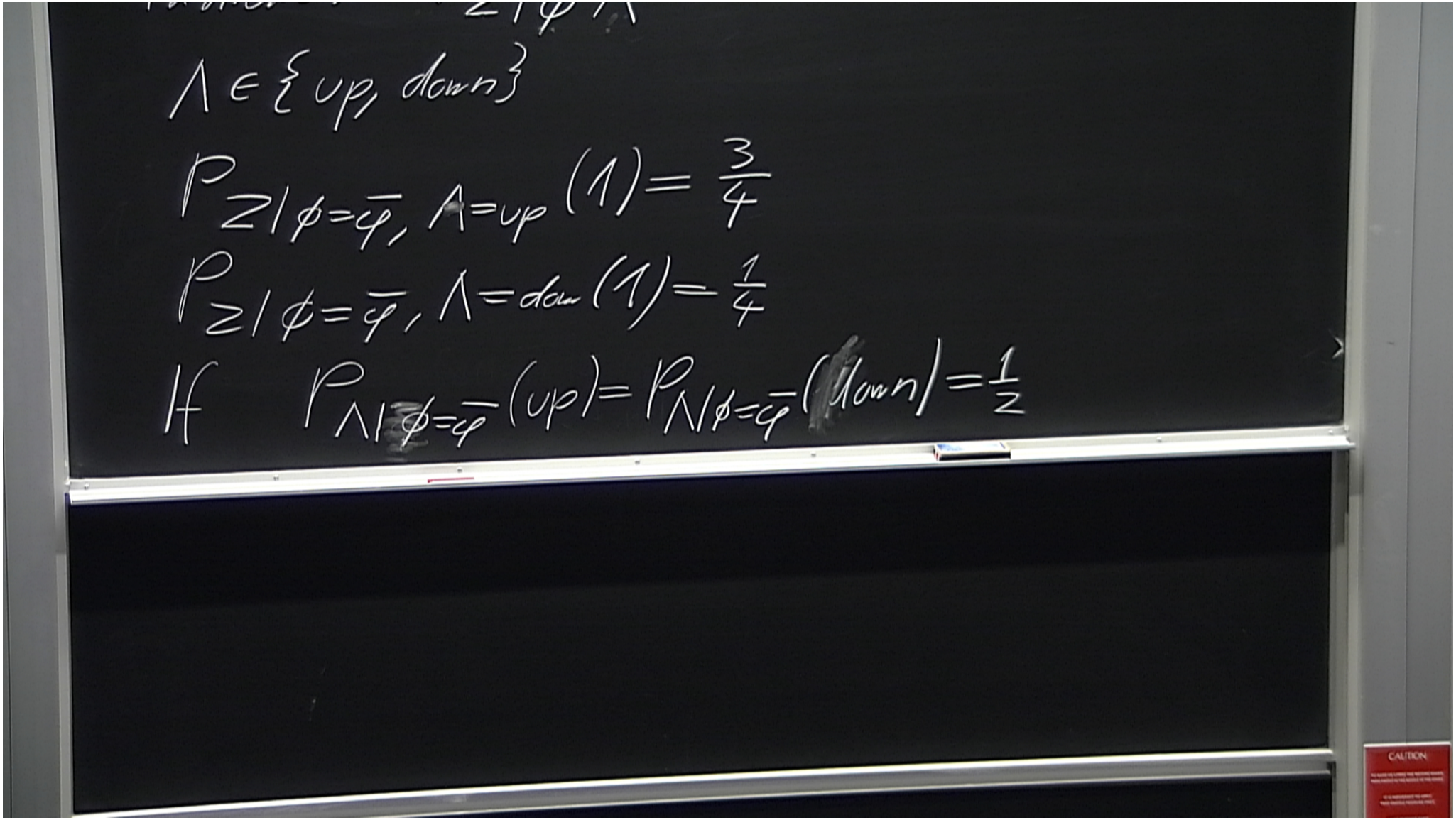

Extended theory (example)
Additional parameter Λ
Predic
P
CAUTION

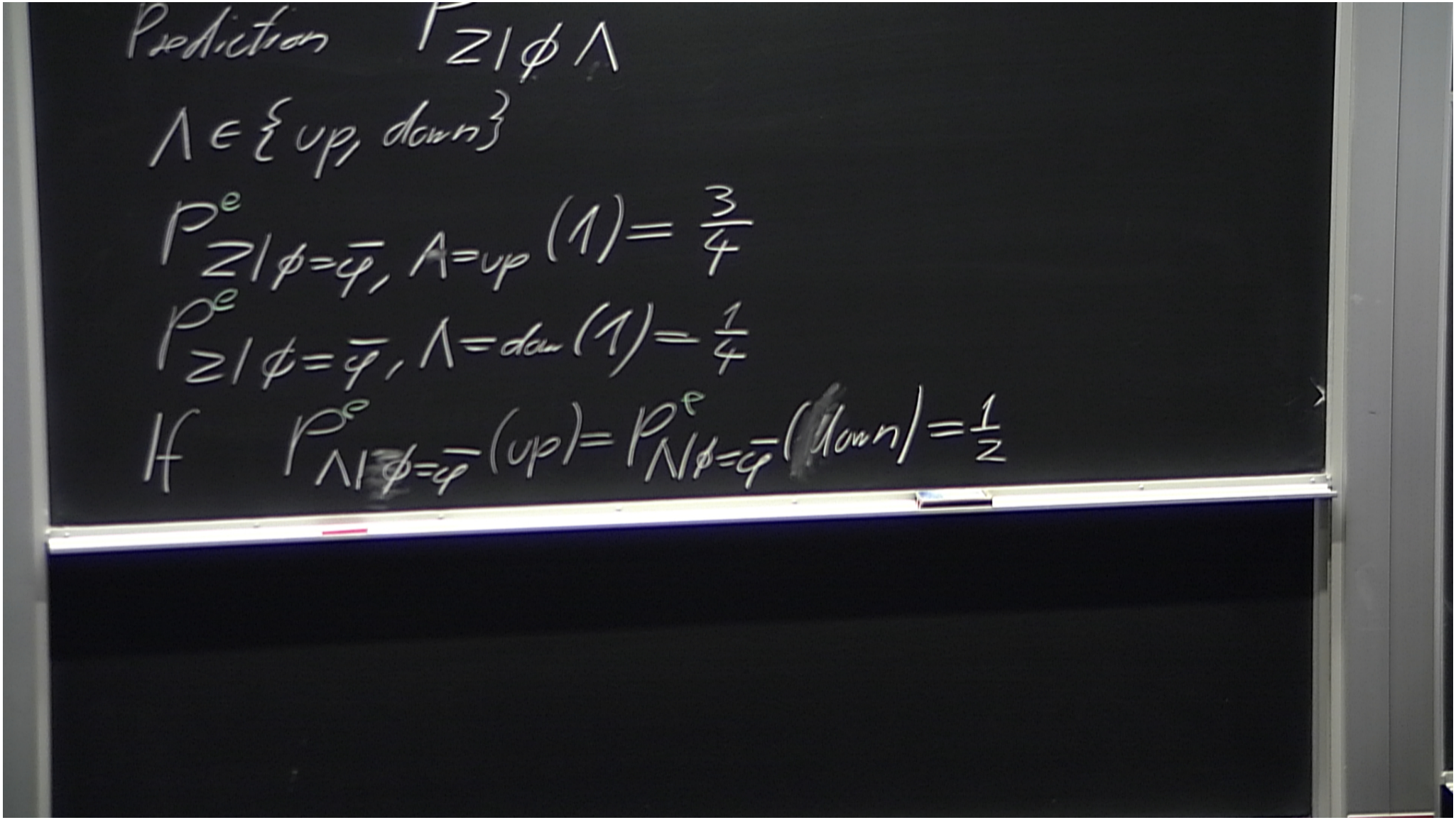

Extended
Additional parameter Λ
Prediction
$P_{Z|\phi\Lambda}$
CAUTION

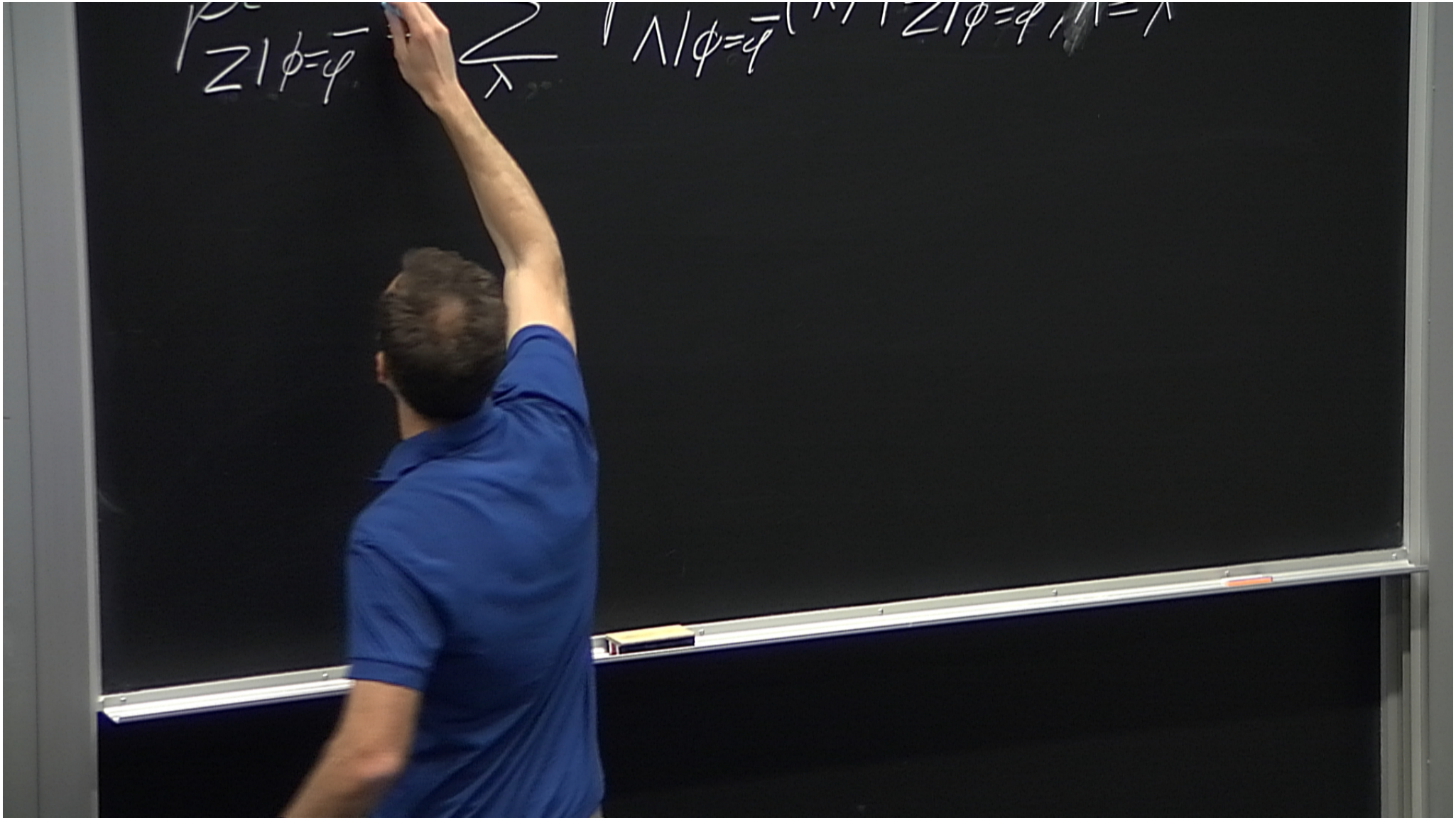

Additional parameter Λ
Prediction P_{Z|φΛ}
CAUTION

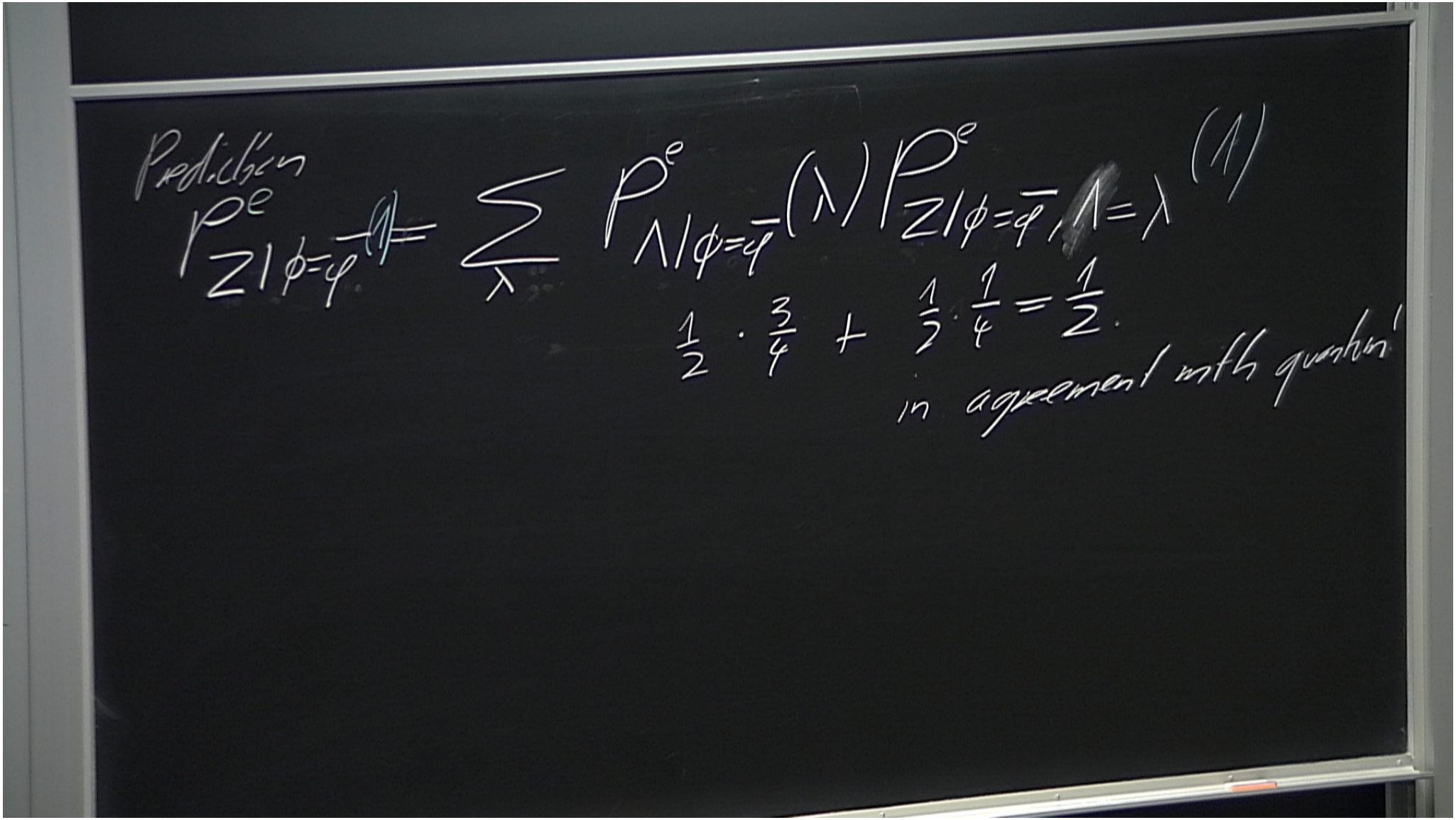

Additional parameter Λ
Prediction $P_{Z|\phi\Lambda}$
$\Lambda \in \{up, down\}$
CAUTION

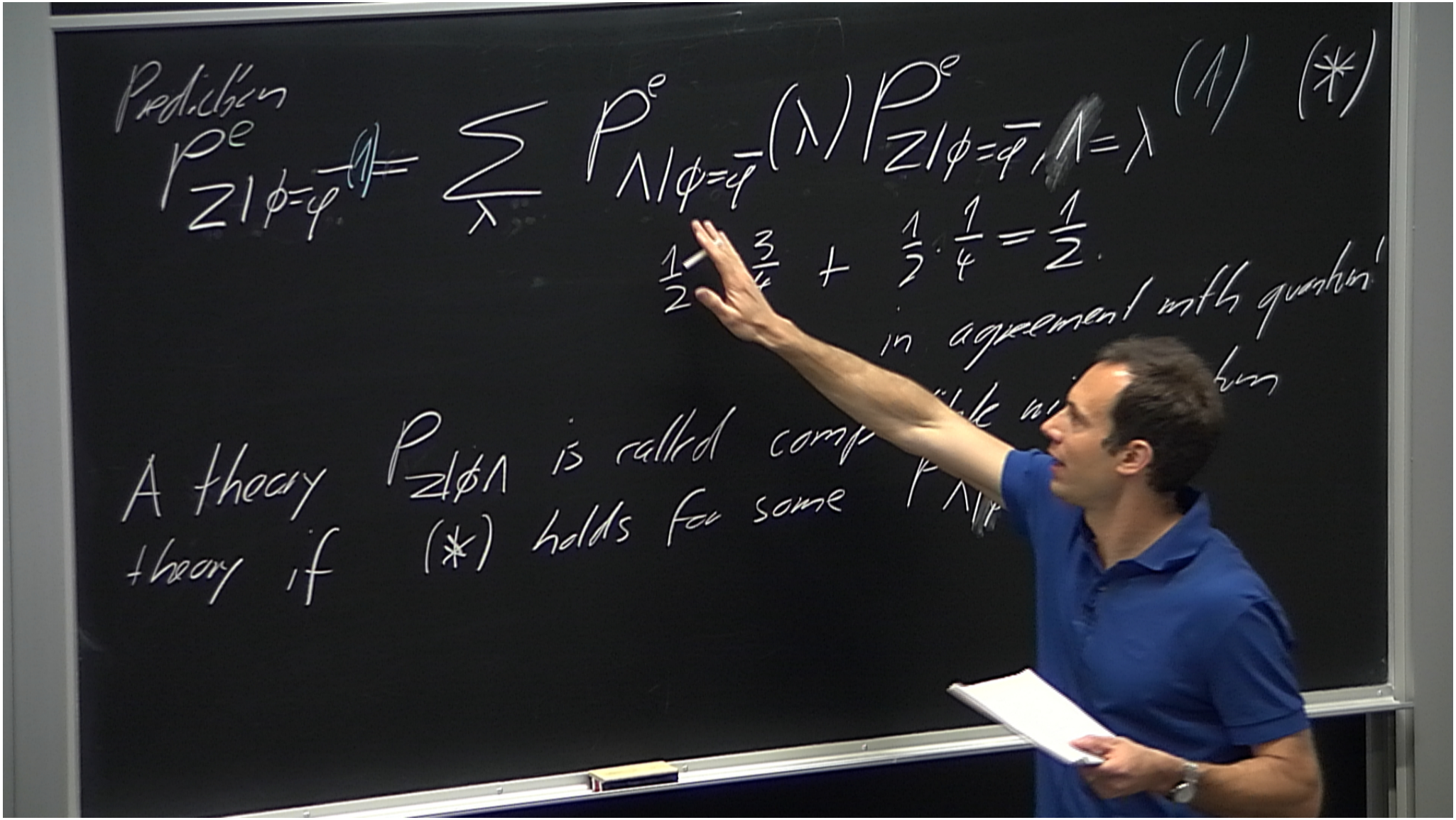

Prediction $P_{Z|\phi\Lambda}$
$\Lambda \in \{up, down\}$
$P_{Z|\phi=\bar{\varphi}, \Lambda=up}(1) = \frac{3}{4}$
$P_{Z|\phi=\bar{\varphi}, \Lambda=down}(1) = \frac{1}{4}$
CAUTION

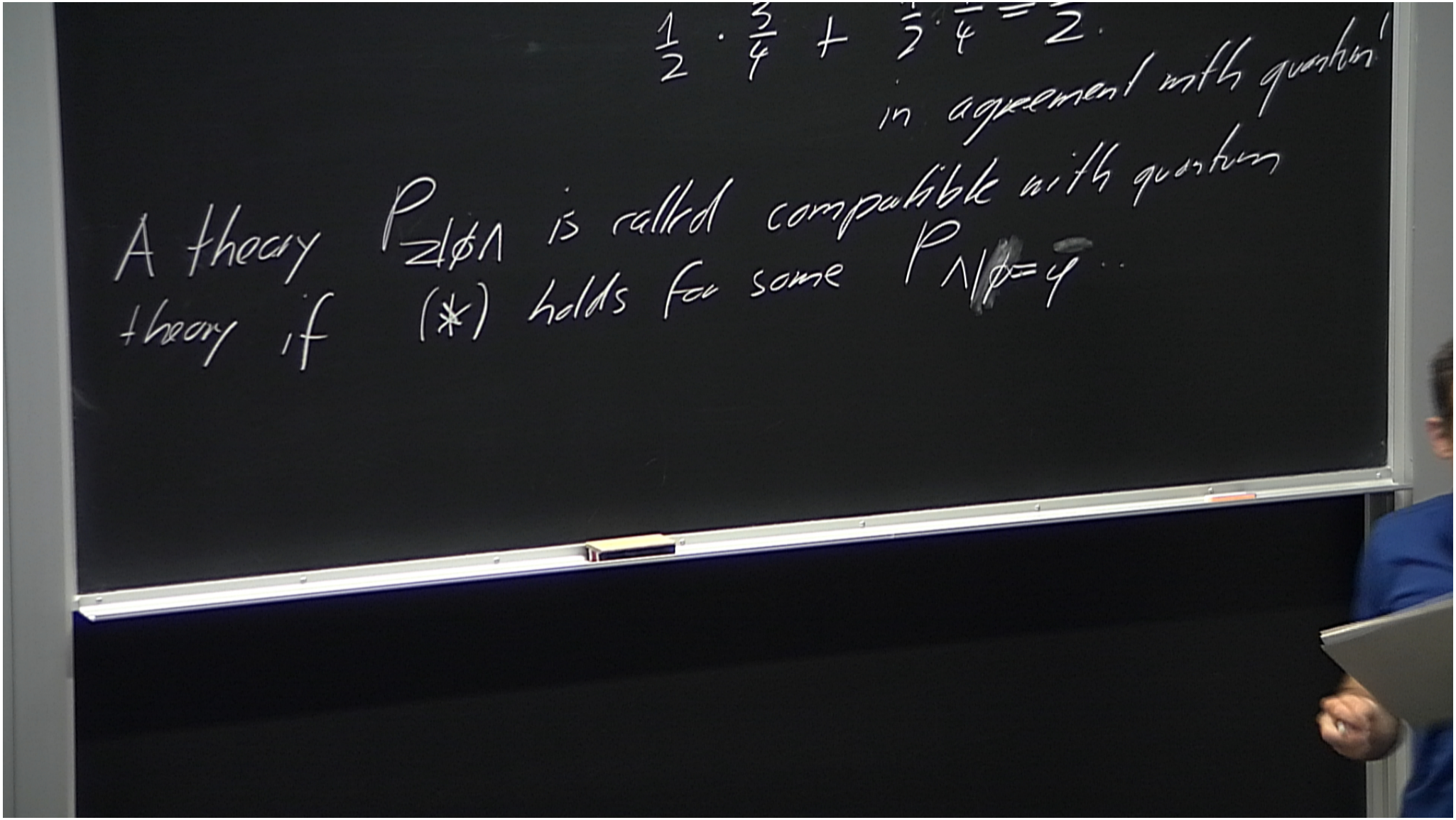

$\Lambda \in \{up, down\}$
$P_{Z|\phi=\bar{\varphi}, \Lambda=up}(1) = \frac{3}{4}$
$P_{Z|\phi=\bar{\varphi}, \Lambda=down}(1) = \frac{1}{4}$
If $P_{\Lambda|\phi=\bar{\varphi}}(up) = P_{\Lambda|\phi=\bar{\varphi}}(down) = \frac{1}{2}$
CAUTION

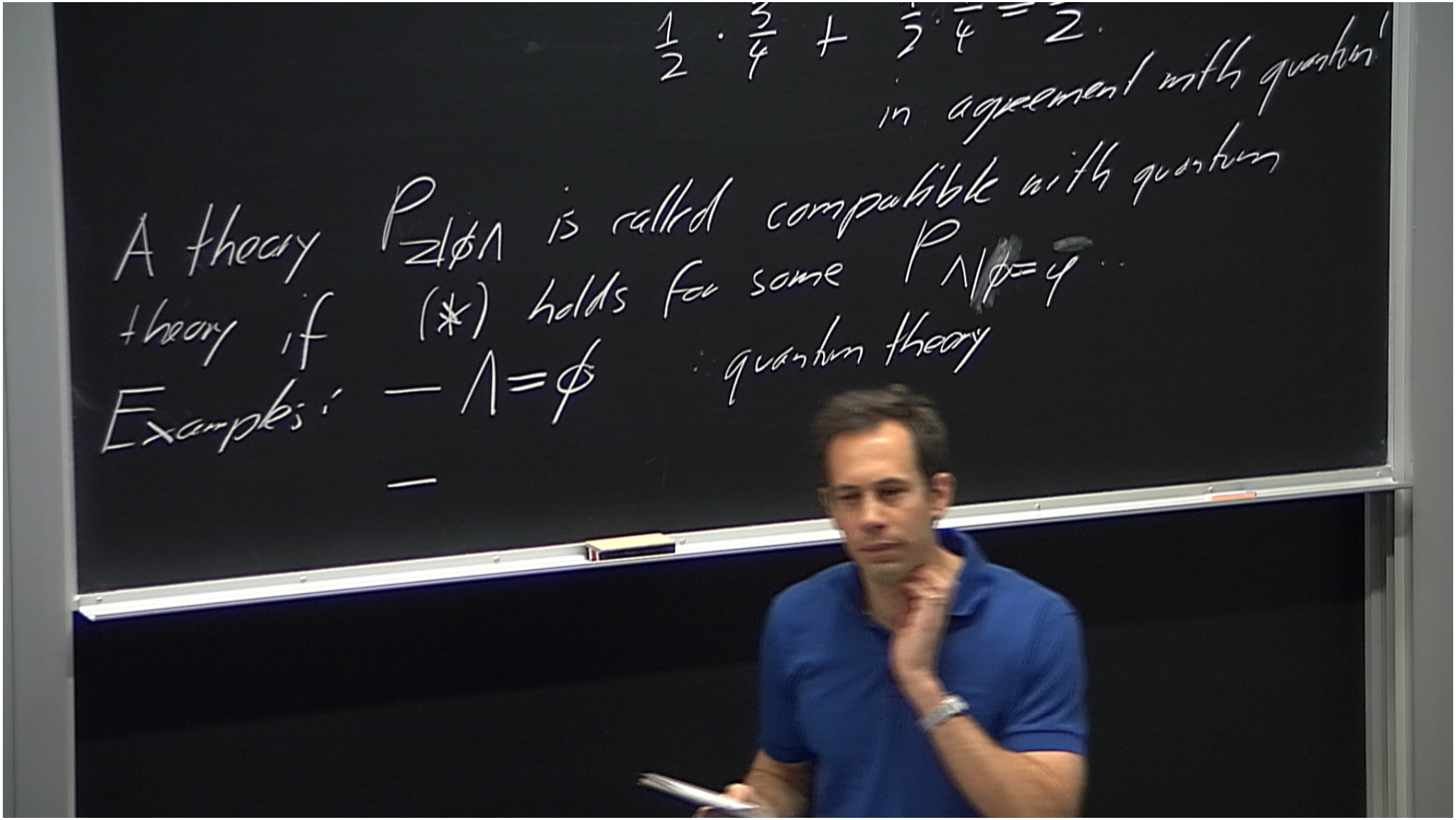

Prediction $P_{Z|\phi\Lambda}$
$\Lambda \in \{up, down\}$
$P^e_{Z|\phi=\bar{\varphi}, \Lambda=up}(1) = \frac{3}{4}$
$P^e_{Z|\phi=\bar{\varphi}, \Lambda=down}(1) = \frac{1}{4}$
If $P^e_{\Lambda|\phi=\bar{\varphi}}(up) = P^e_{\Lambda|\phi=\bar{\varphi}}(down) = \frac{1}{2}$




Prediction
$P^e_{Z|\phi=\varphi}(1) = \sum_\lambda P^e_{\Lambda|\phi=\varphi}(\lambda) P^e_{Z|\phi=\varphi,\Lambda=\lambda}(1)$
$\frac{1}{2} \cdot \frac{3}{4} + \frac{1}{2} \cdot \frac{1}{4} = \frac{1}{2}$.
in agreement with quantum!


Prediction
(1)
(*)
in agreement with quantum
A theory
is called
theory if
(*) holds for some


$\frac{1}{2} \cdot \frac{3}{4} + \frac{1}{2} \cdot \frac{1}{4} = 2$
in agreement with quantum
A theory $P_{Z|\phi\Lambda}$ is called compatible with quantum
theory if (*) holds for some $P_{\Lambda|\phi=\psi}$


$\frac{1}{2} \cdot \frac{3}{4} + \frac{1}{2} \cdot \frac{1}{4} = 2$
in agreement with quantum
A theory $P_{\mathbb{Z}[\phi,\Lambda]}$ is called compatible with quantum
theory if (*) holds for some $P_{\Lambda/\phi=4}$
Examples: $-\Lambda=\phi$: quantum theory
—

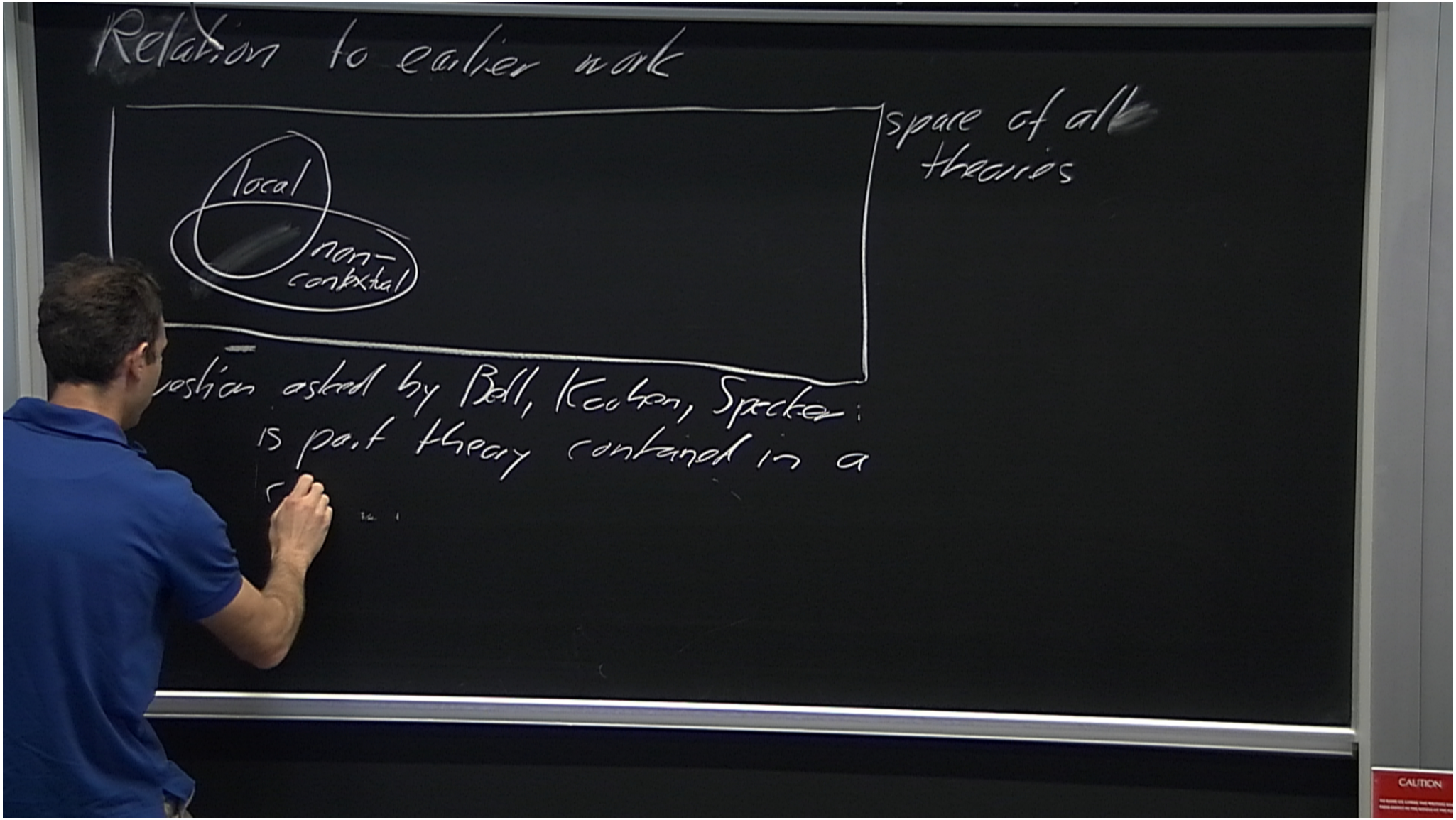
$\frac{1}{2} \cdot \frac{3}{4} + \frac{1}{2} \cdot \frac{1}{4} = 2.$

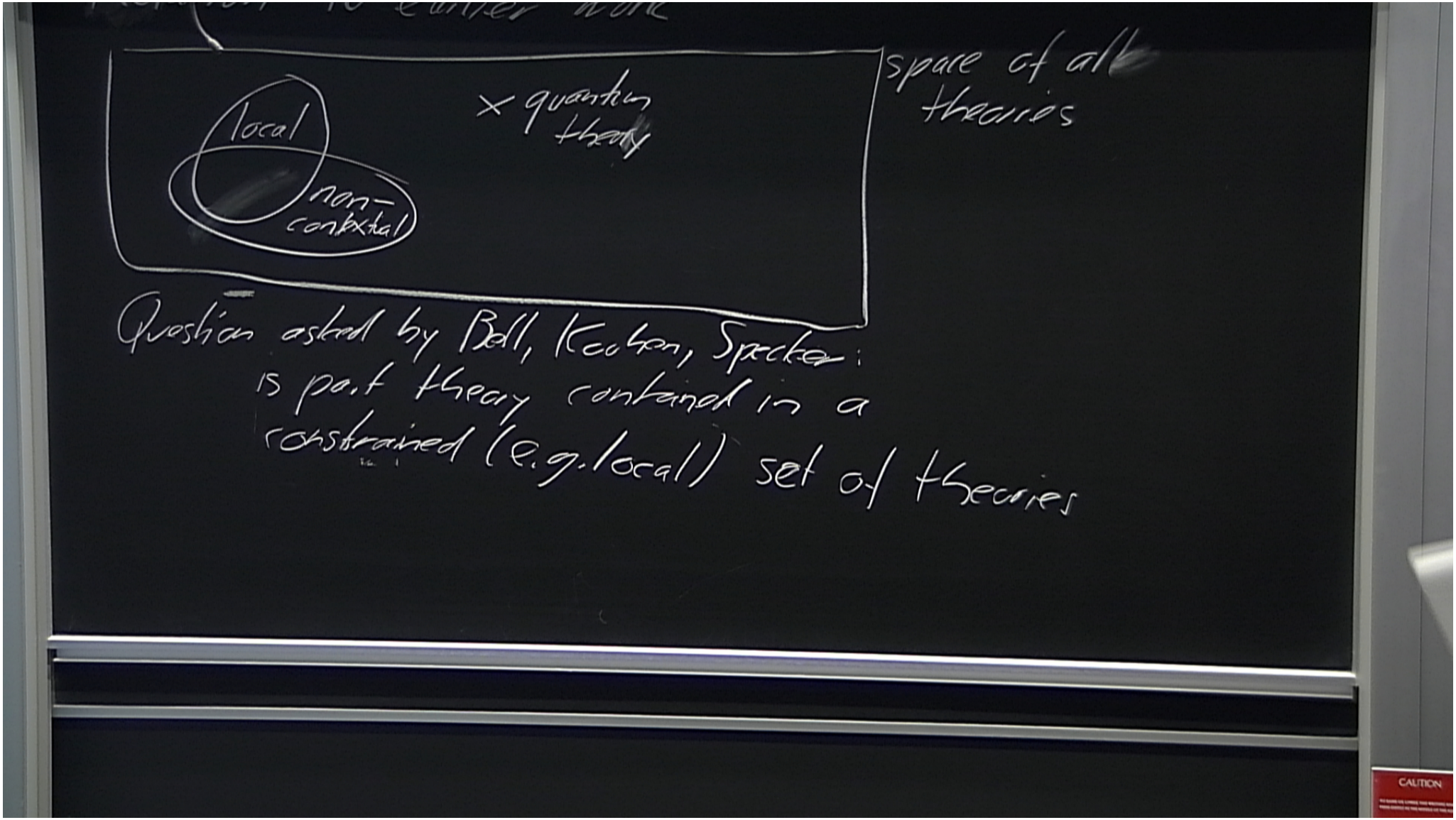
in agreement with quantum

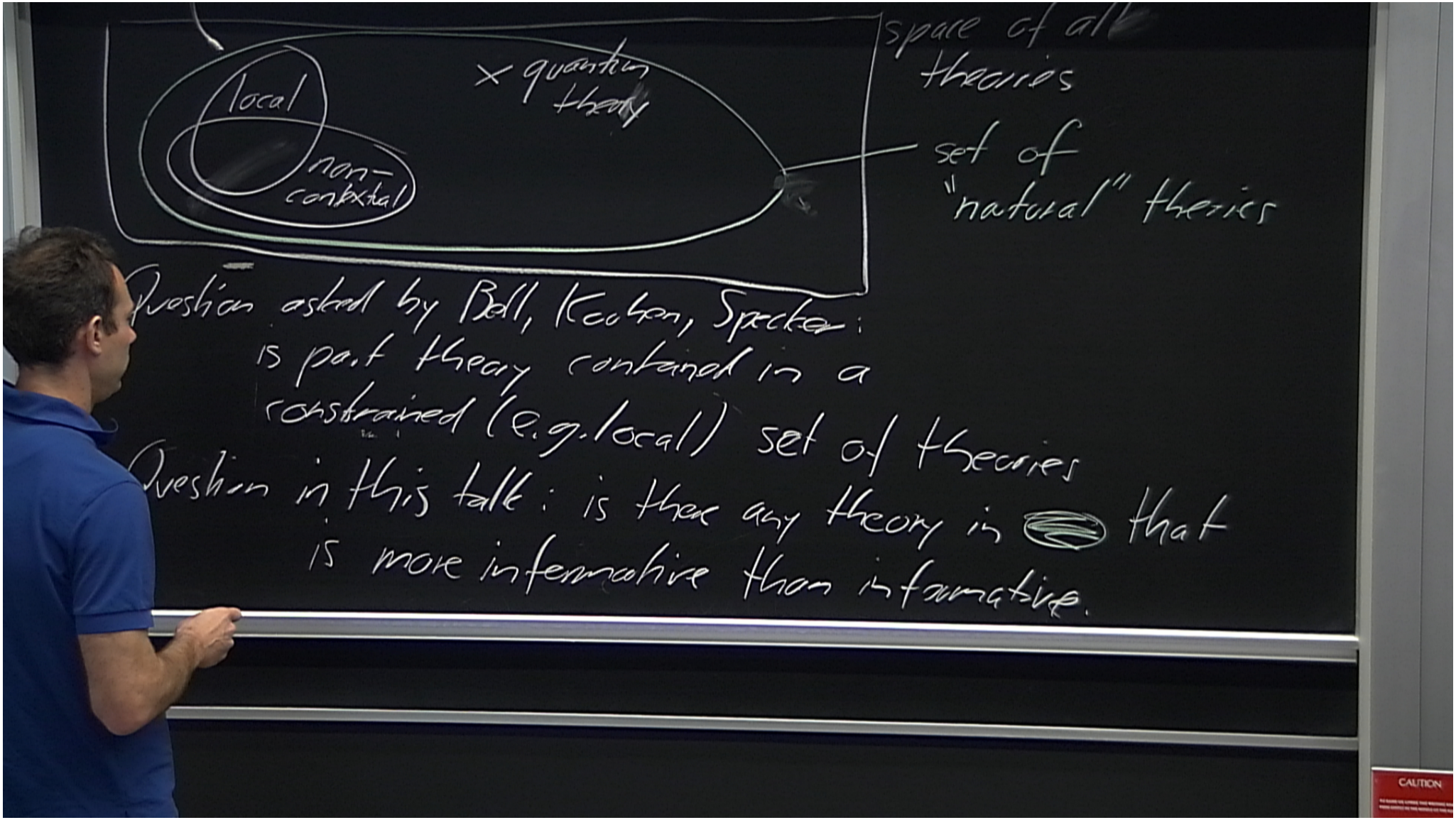
A theory $P_{\Sigma|\phi\Lambda}$ is called compatible with quantum theory if (*) holds for some $P_{\Lambda|\phi=\psi}$.

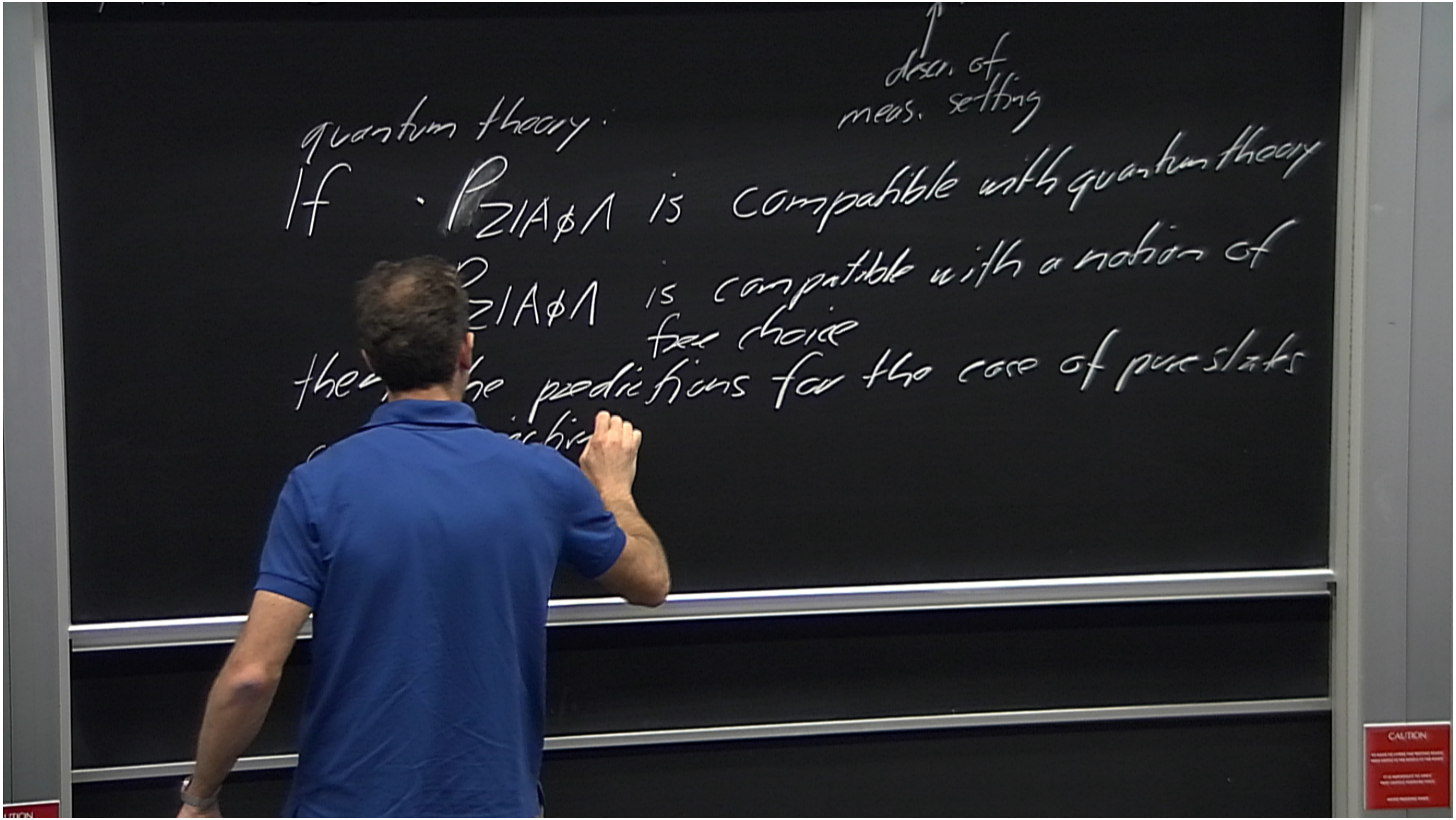
Examples: $-\Lambda = \phi$: quantum theory

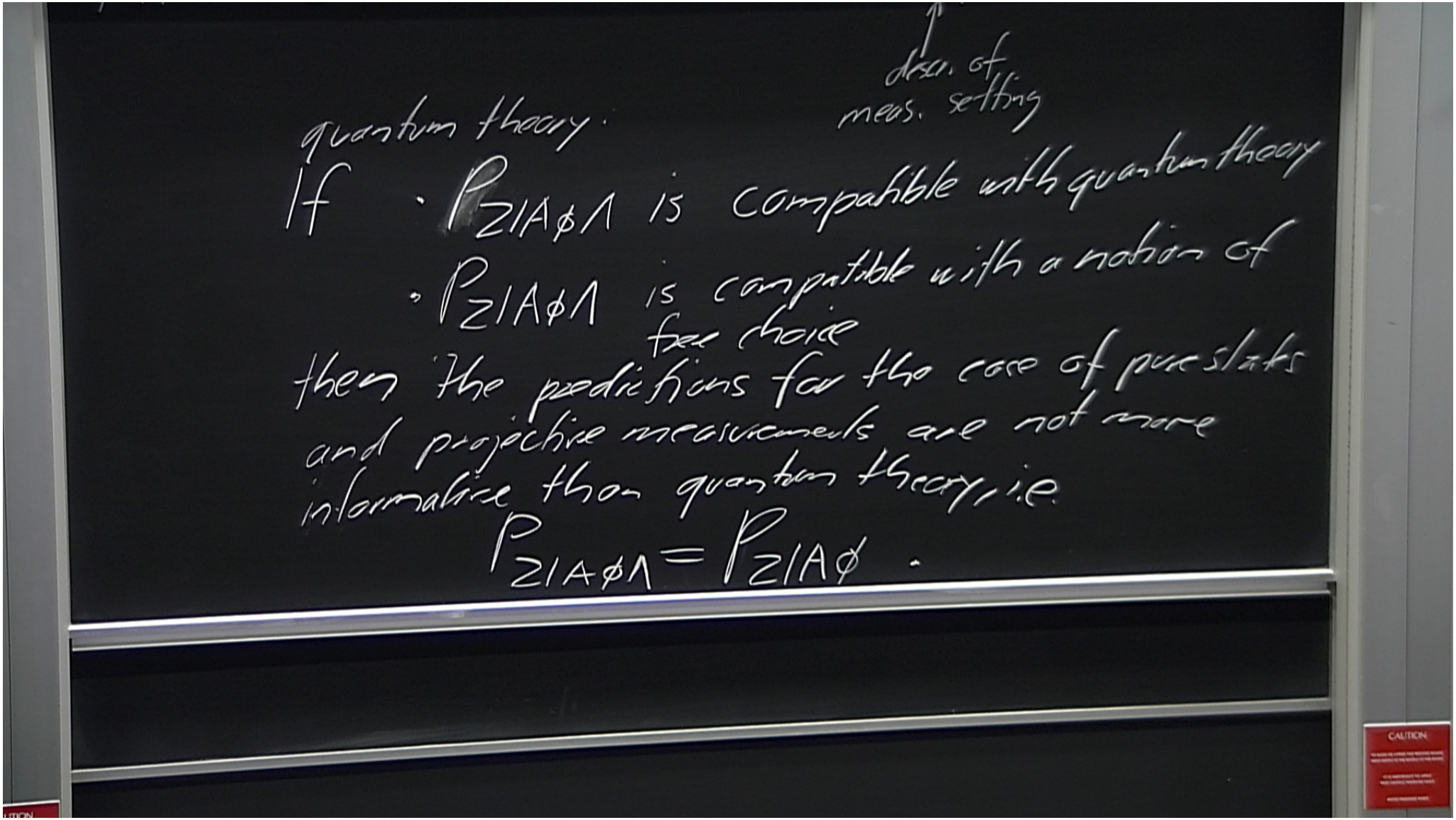
– hidden variable models by Bell, Kochen, Specker, Legett

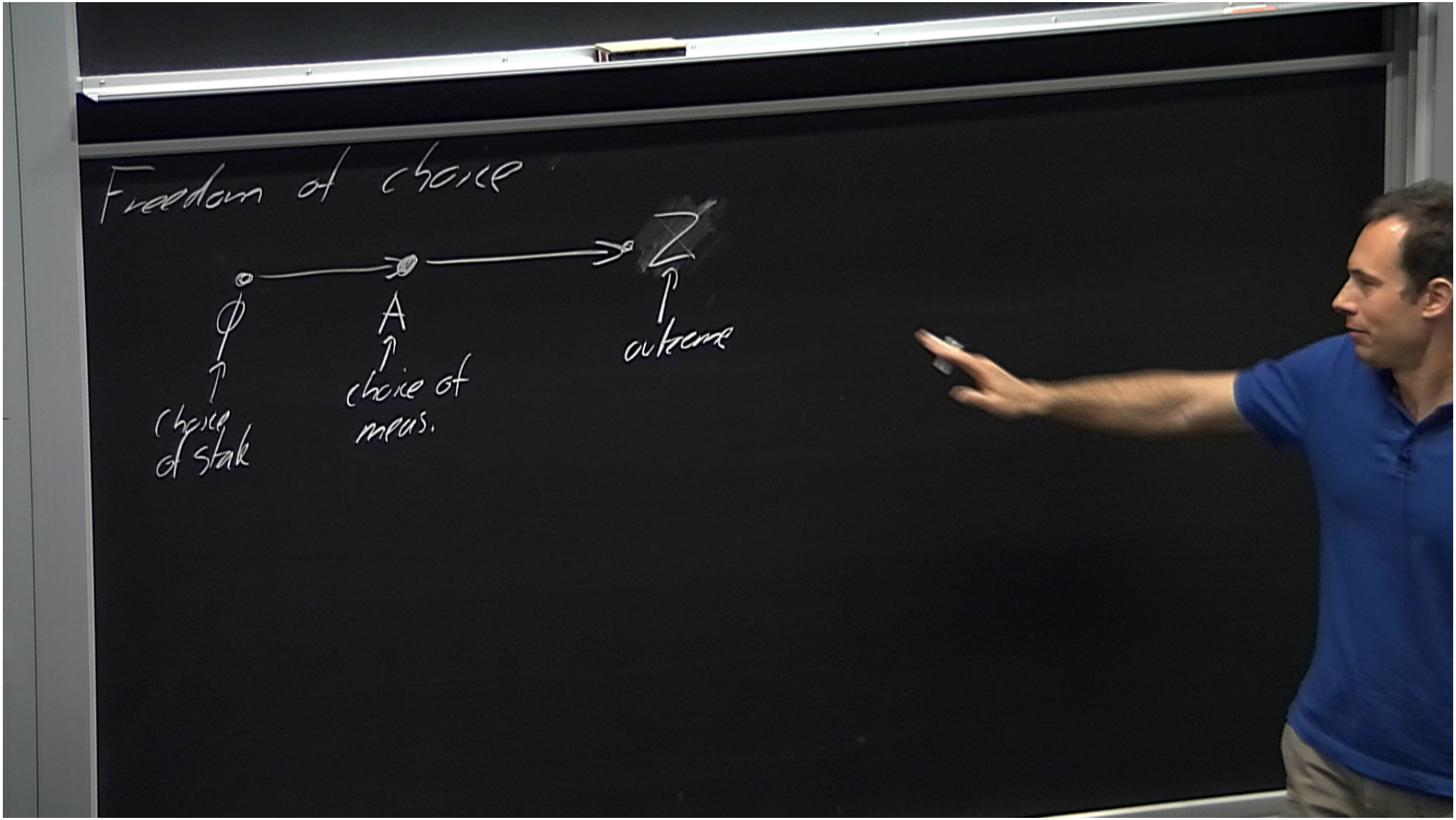

Relation to earlier work
local
non-contextual
space of all theories
question asked by Bell, Kochen, Specker:
is part theory contained in a


local
non-
contextual
× quantum
theory
space of all
theories
Question asked by Bell, Kochen, Specker:
is part theory contained in a
constrained (e.g. local) set of theories


local
non-contextual
× quantum theory
space of all theories
set of "natural" theories
Question asked by Bell, Kochen, Specker:
is part theory contained in a
constrained (e.g. local) set of theories
Question in this talk: is there any theory in that
is more informative than informative.

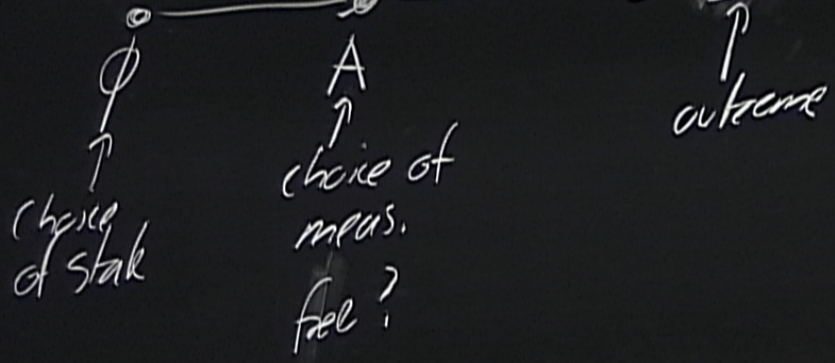

quantum theory:
If · $P_{Z|A\phi\Lambda}$ is compatible with quantum theory
$P_{Z|A\phi\Lambda}$ is compatible with a notion of
free choice
meas. setting
CAUTION

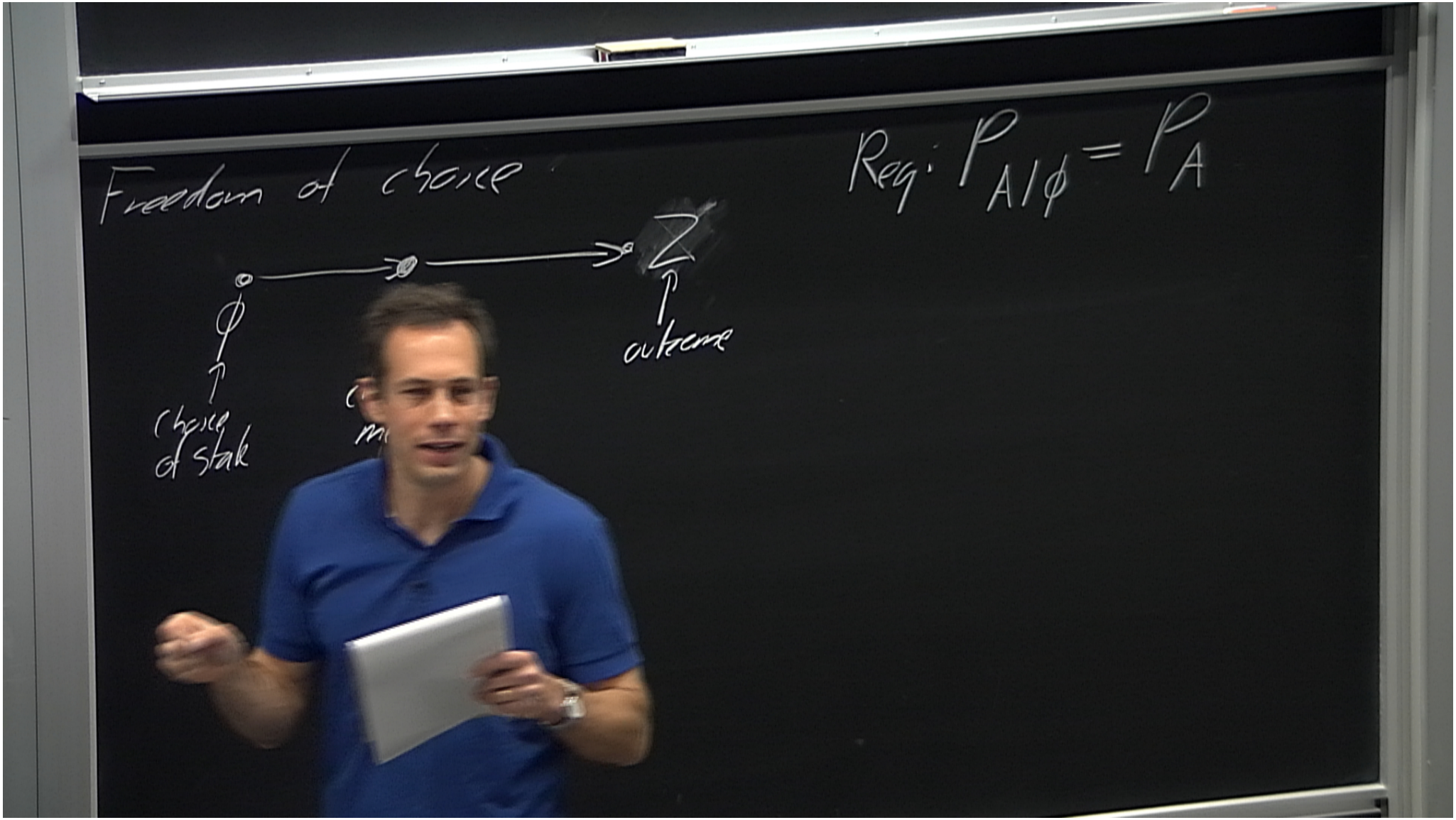

quantum theory.
If · $P_{Z|A\phi\Lambda}$ is compatible with quantum theory
· $P_{Z|A\phi\Lambda}$ is compatible with a notion of free choice
then the predictions for the case of pure states and projective measurements are not more informative than quantum theory, i.e.
$P_{Z|A\phi\Lambda} = P_{Z|A\phi}$.
distr. of meas. setting
CAUTION

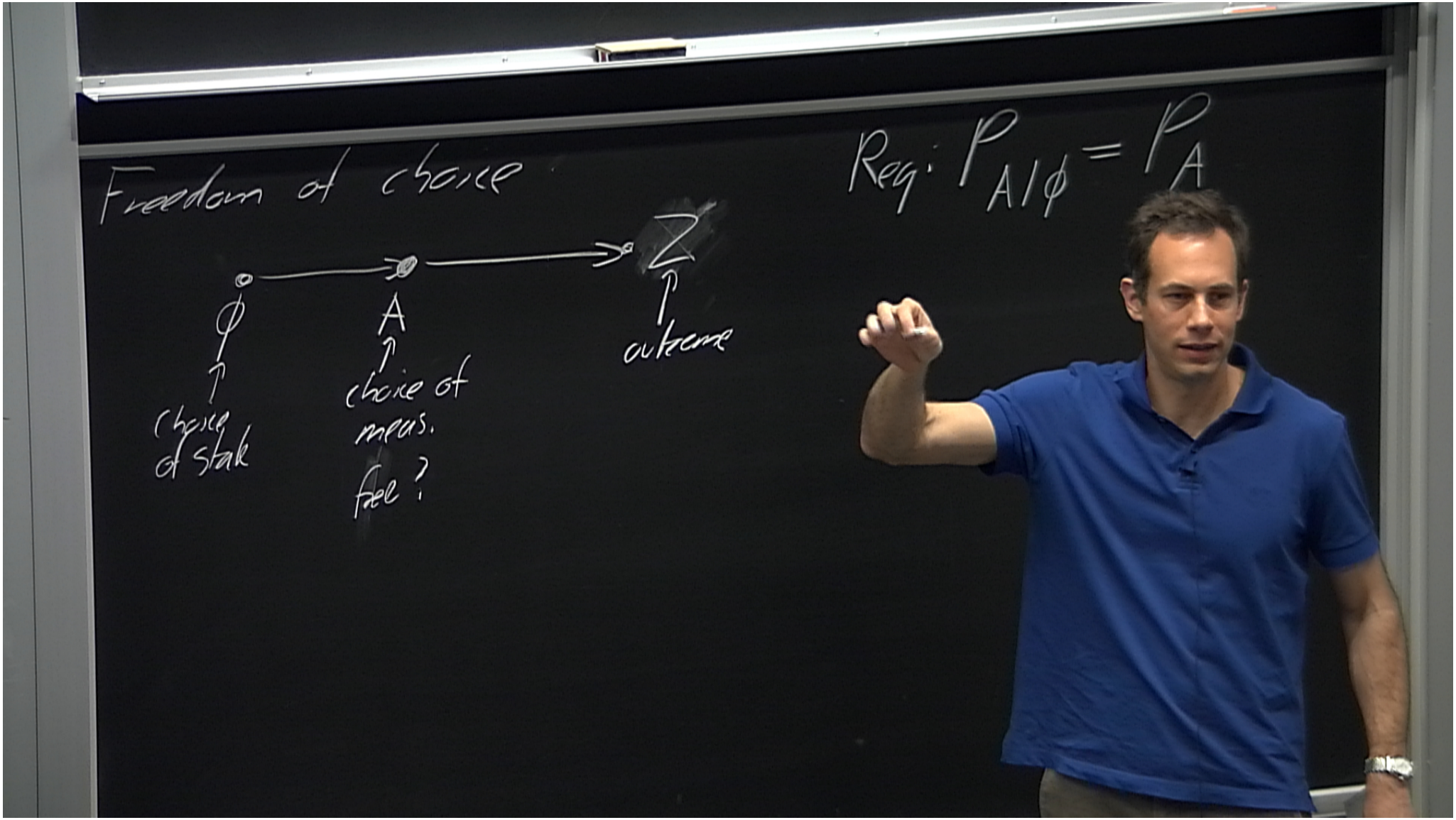

Freedom of choice
φ
A
Z
choice of stak
choice of meas.
outcome

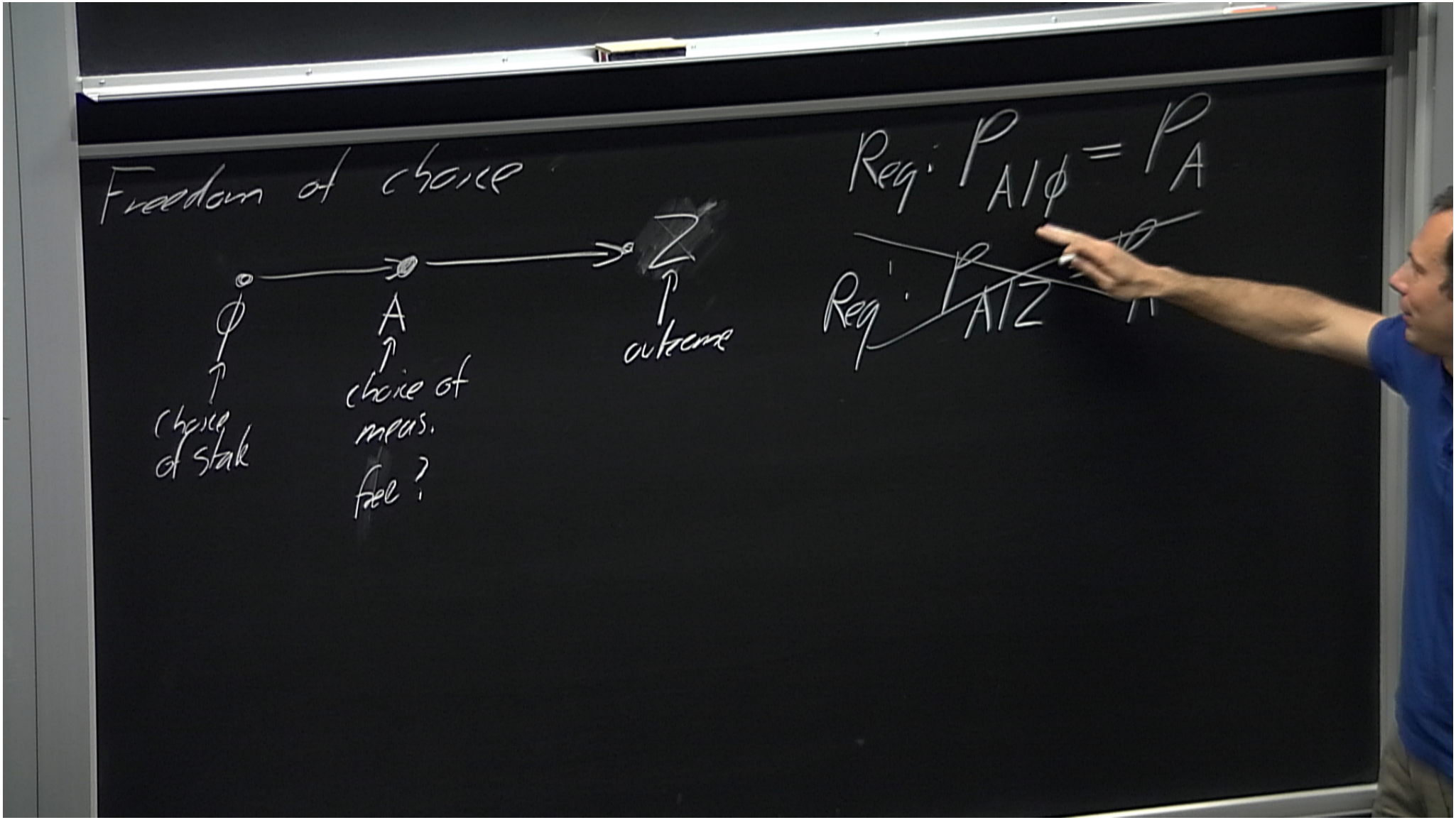
Freedom of choice

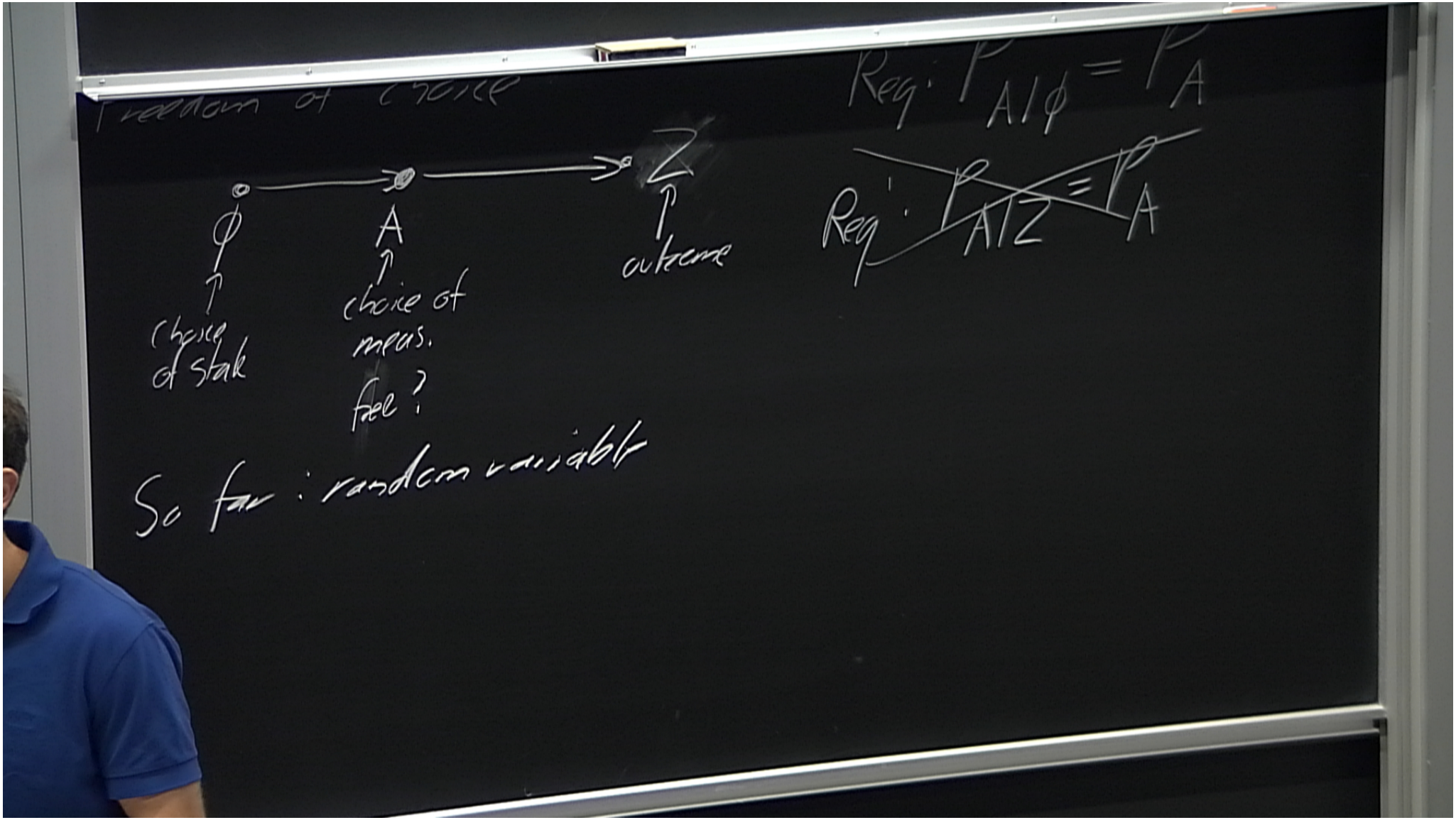
Req: $P_{A|\phi} = P_A$

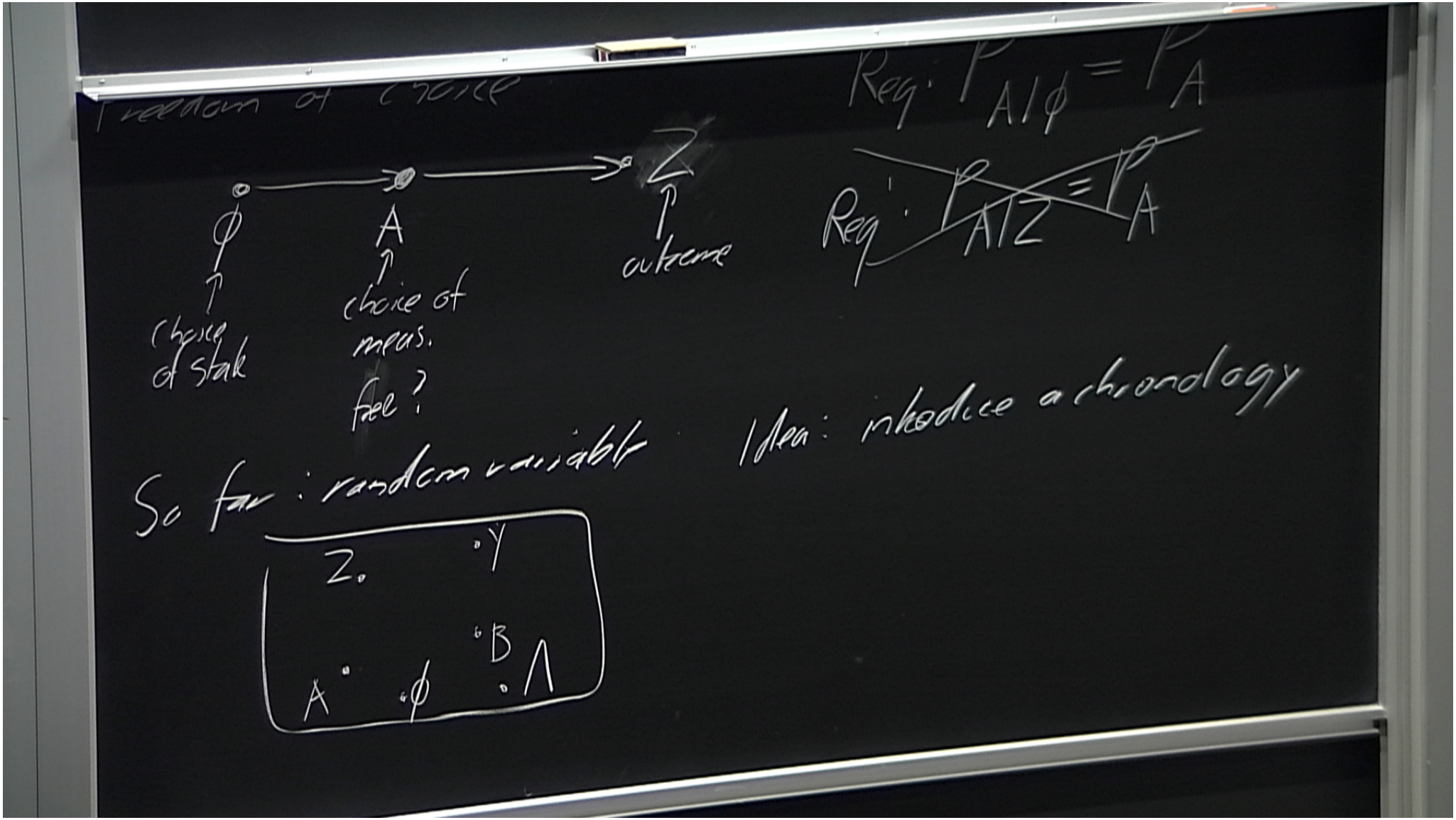


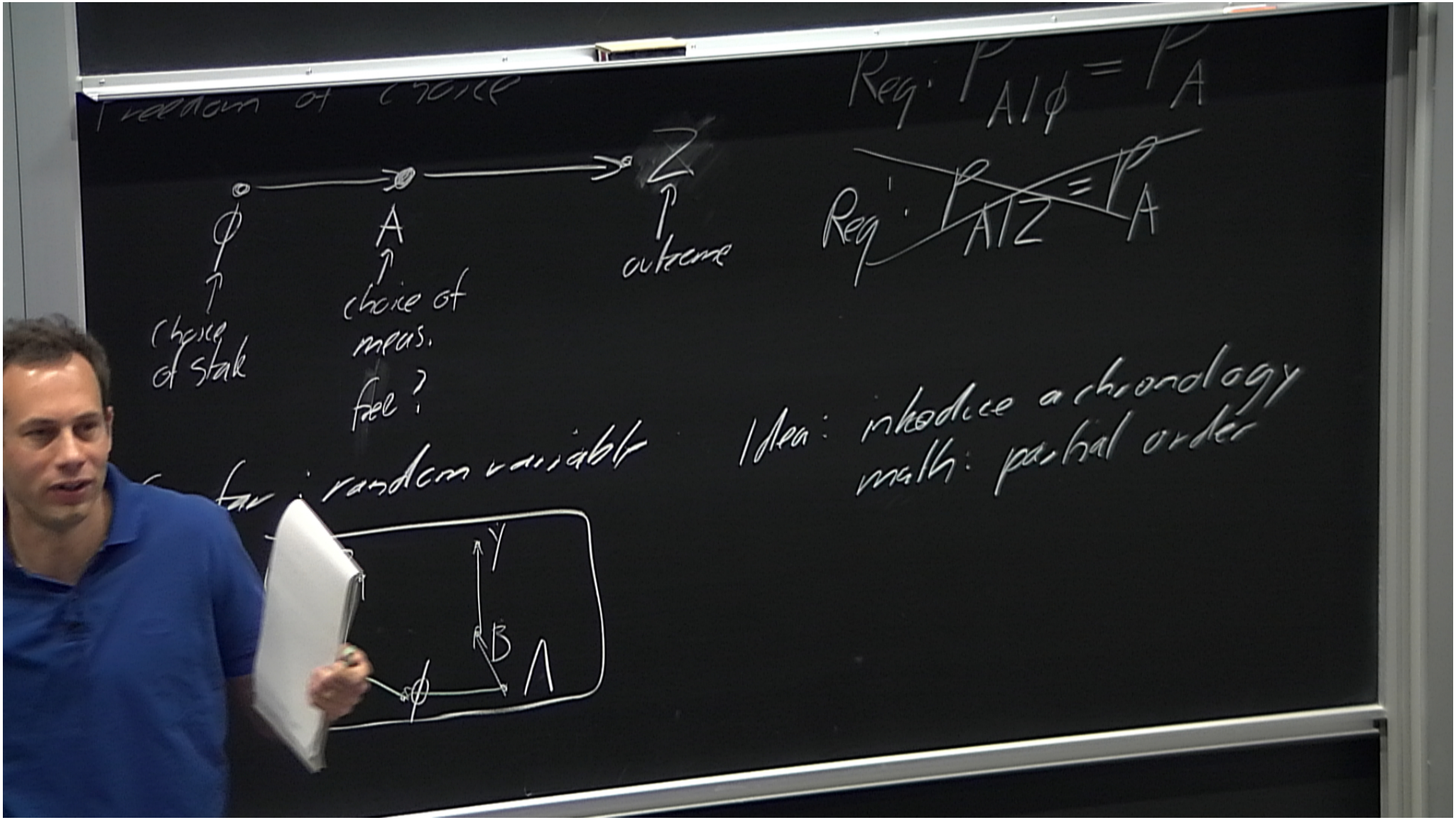

Freedom of choice
Req: $P_{A|\phi} = P_A$
ϕ
choice of state
outcome

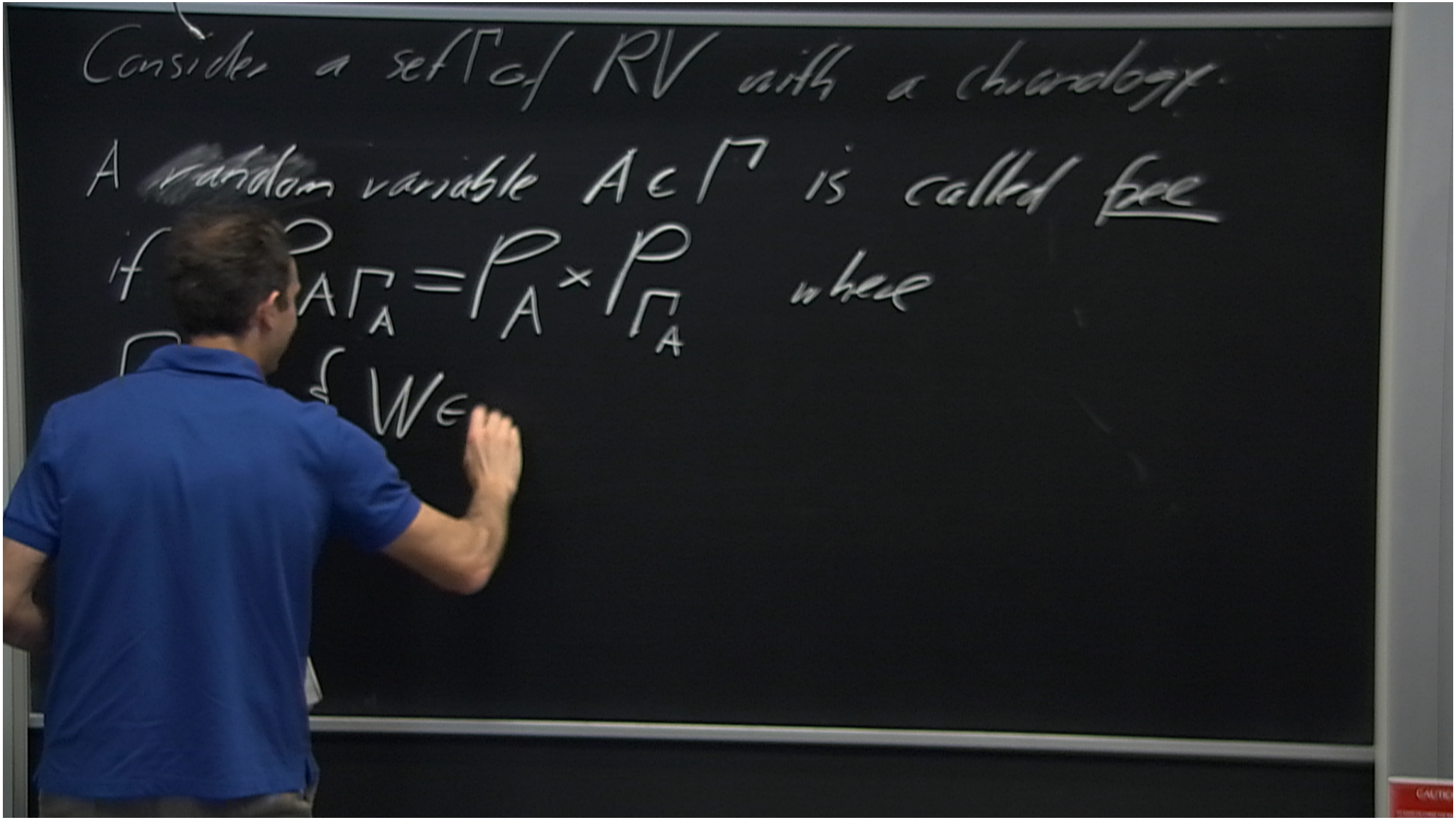

Freedom of choice
Req: $P_{A|\phi} = P_A$
ϕ
choice of stak
A
choice of meas. fac?
Z
outcome

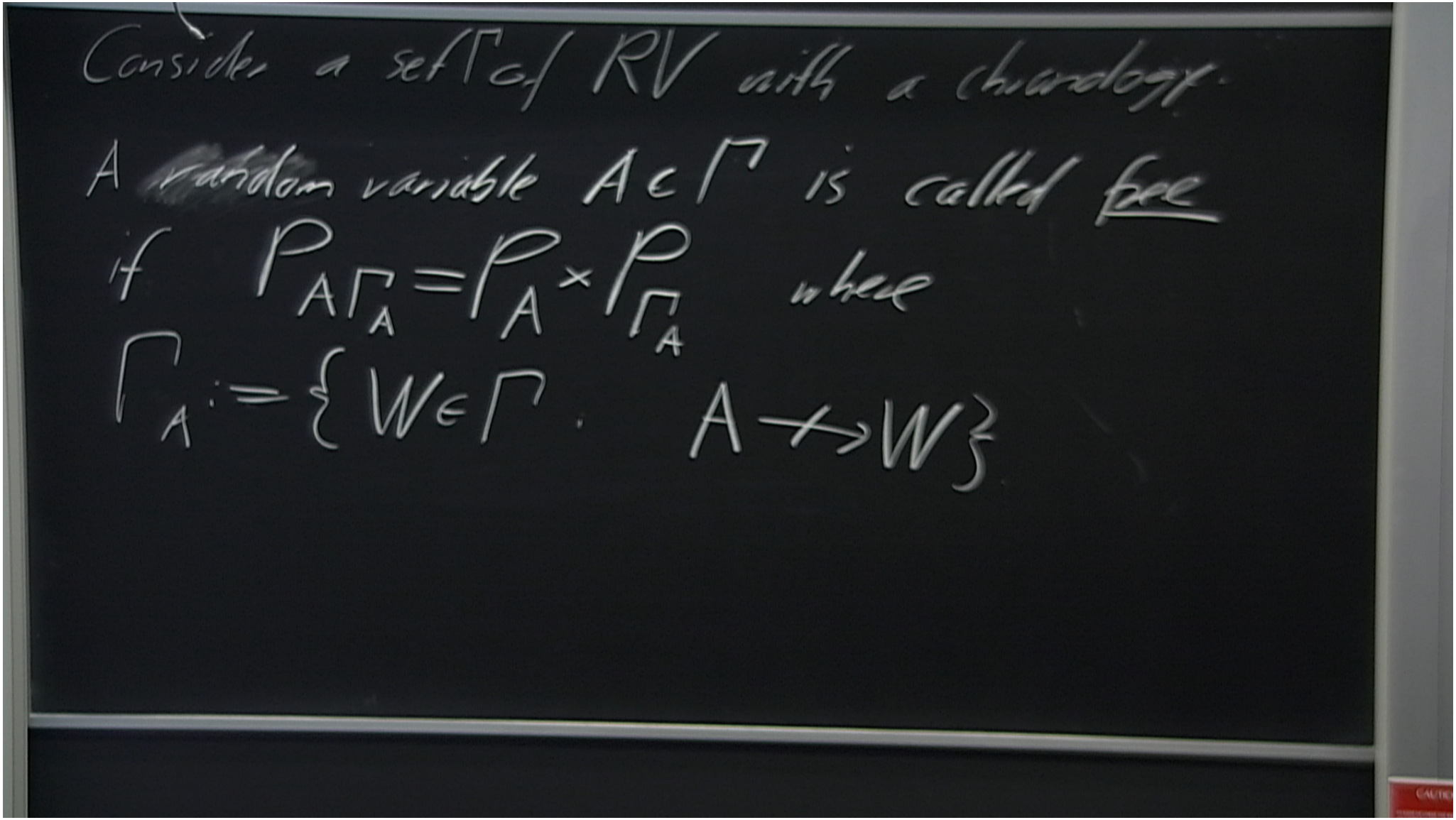

Freedom of choice
Req: $P_{A|\phi} = P_A$
ϕ
choice of state
A
choice of meas. to be?
Z
outcome
Req: $P_{A|Z}$

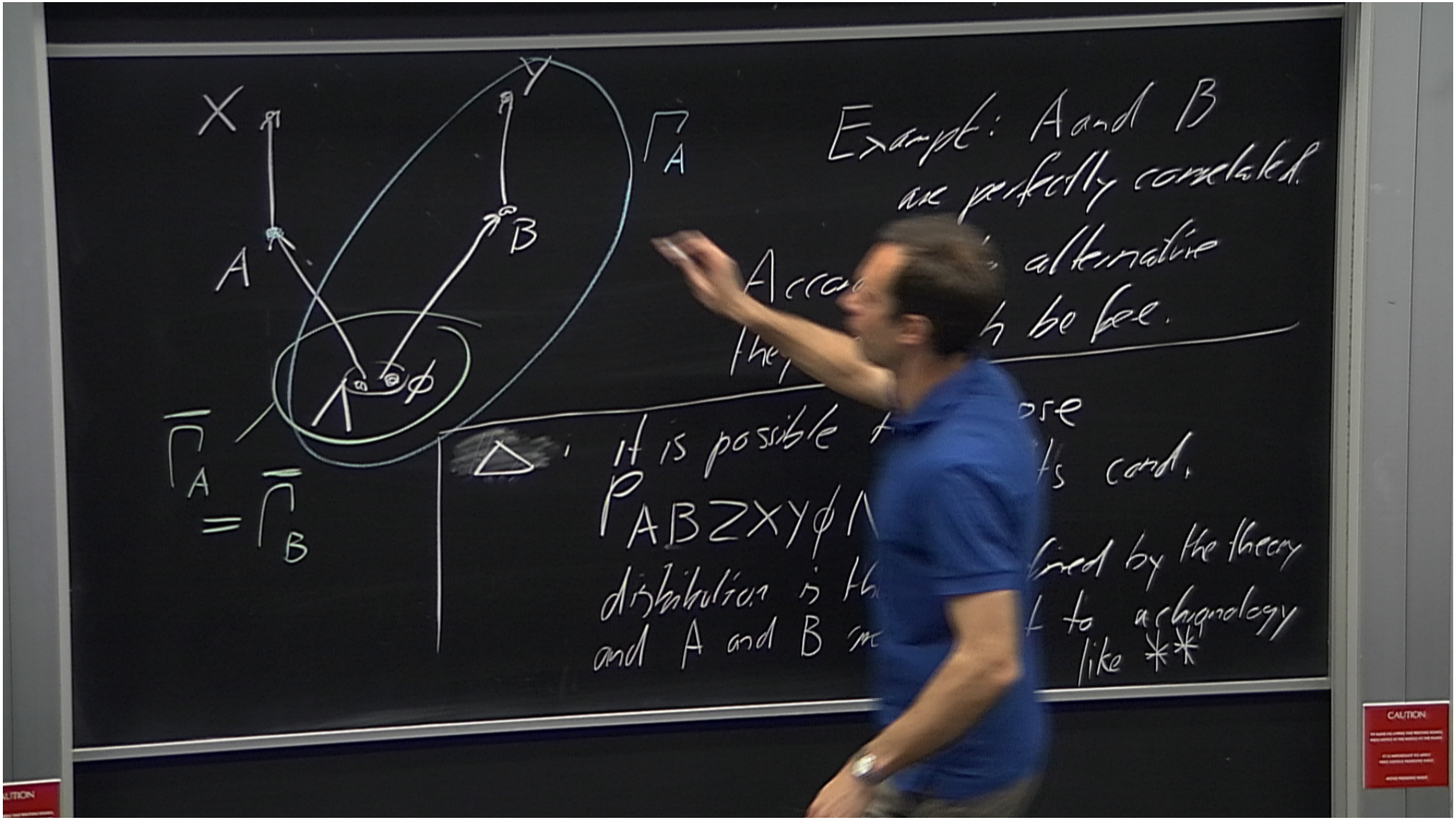

Freedom of choice
φ
A
Z
choice of stak
choice of meas.
feel?
outcome
So far: random variable
Req: $P_{A|\phi} = P_A$
Req: $P_{A|Z} = P_A$

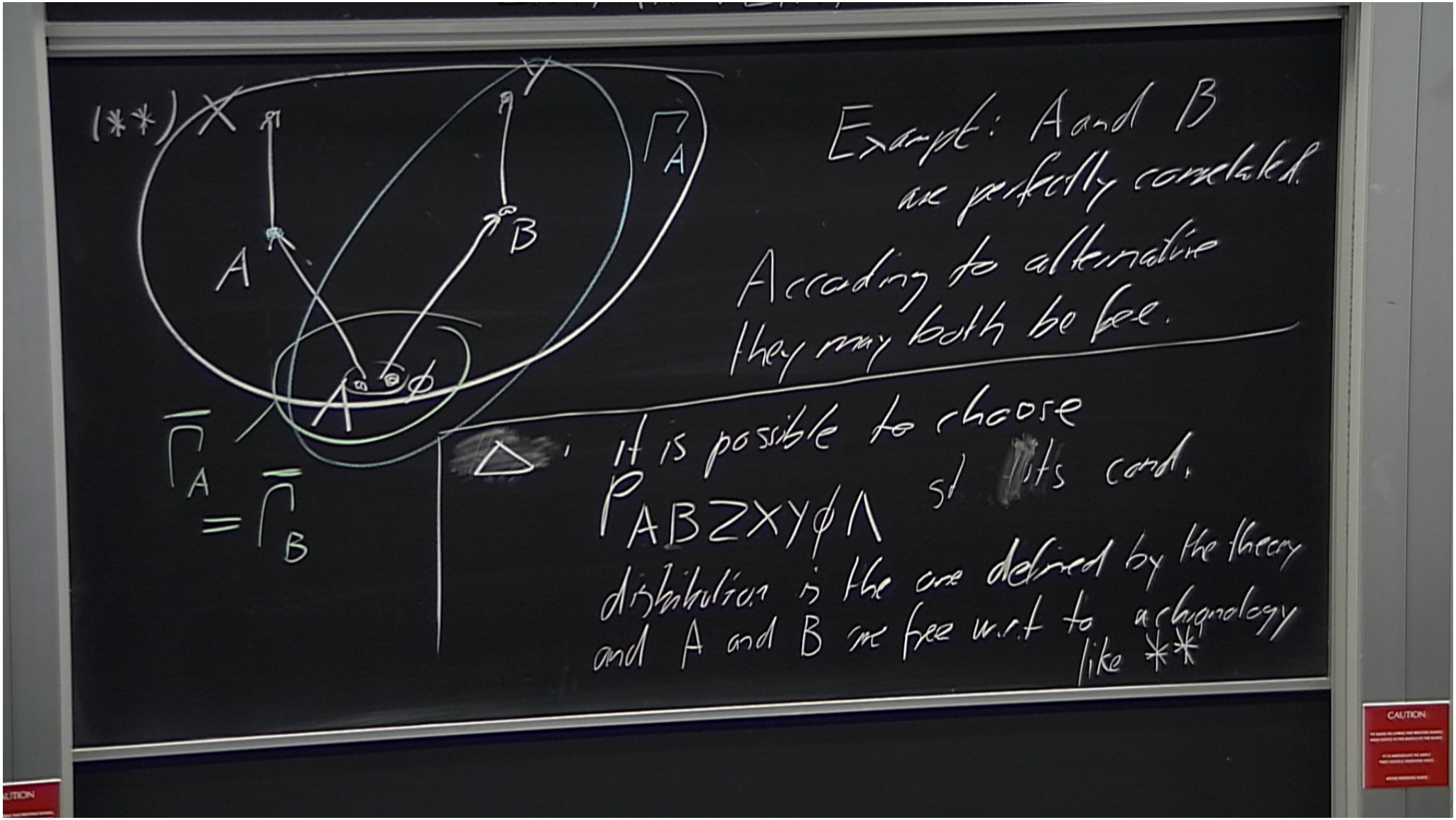

Freedom of choice
Req: $P_{A|\phi} = P_A$
Req: $P_{A|Z} = P_A$
ϕ
A
Z
choice of stak
choice of meas.
outcome
feel?
So far: random variable
Idea: introduce a chronology
Z
Y
B
A
ϕ
Λ

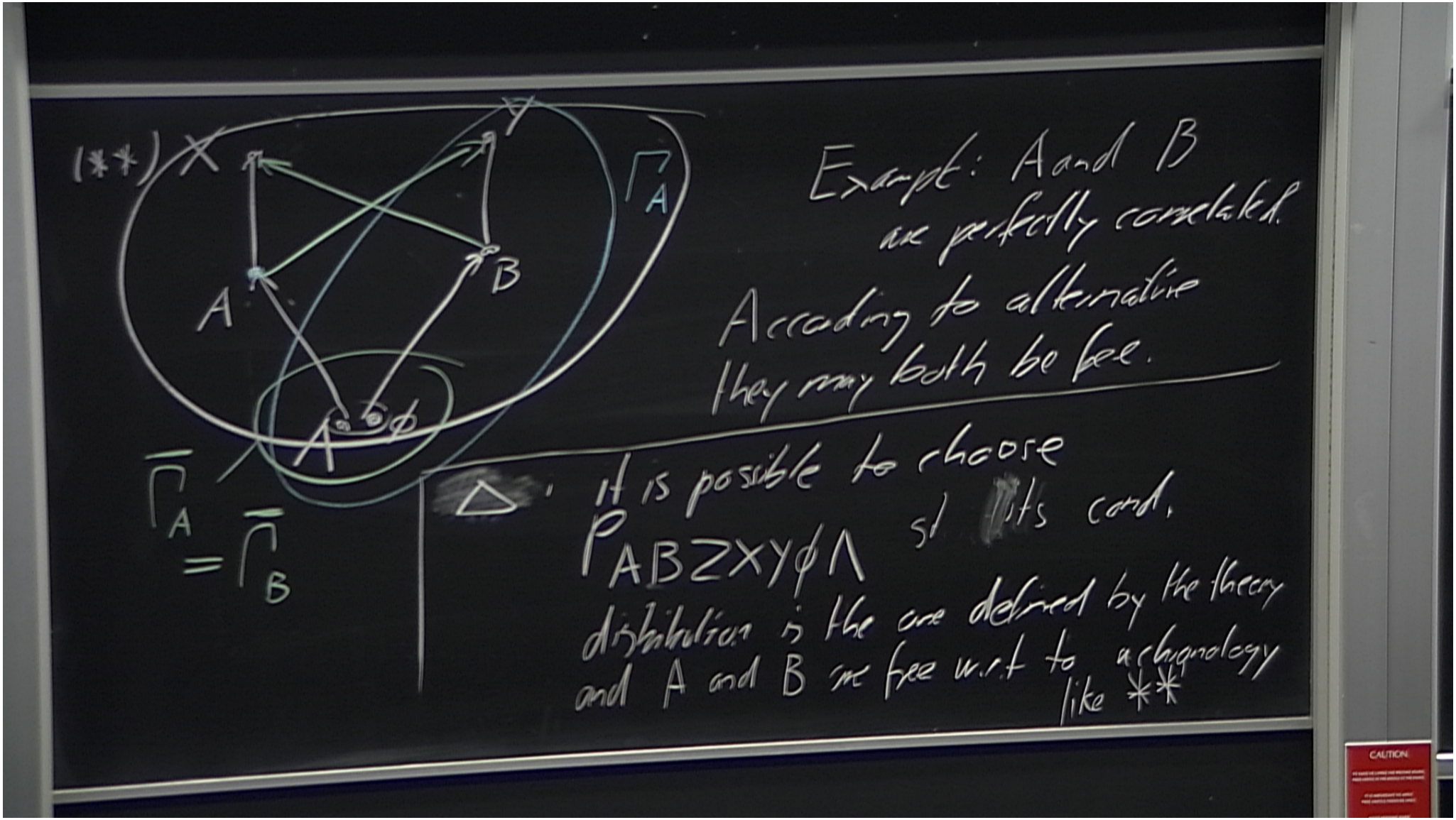

choice of stat
choice of meas.
feel?
outcome
Req: $P_{A|\phi} = P_A$
Req: $P_{A|Z} = P_A$
Idea: introduce a chronology
math: partial order
Y
B
A
ϕ


Consider a set Γ of RV with a chirality.
A random variable A ∈ Γ is called free
if P_{AΓ_A} = P_A × P_{Γ_A} where

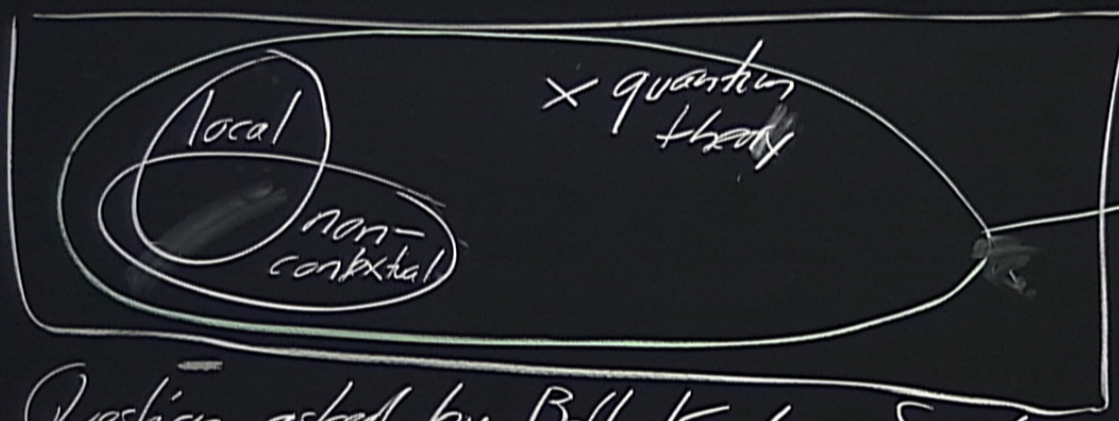

Consider a set $\Gamma \subset$ RV with a chirality χ.
A random variable $A \in \Gamma$ is called free
if $P_{A\Gamma_A} = P_A \times P_{\Gamma_A}$ where
$\Gamma_A := \{W \in \Gamma : A \not\leftrightarrow W\}$


X
Y
A
B
Γ_A
$\bar{\Gamma}_A = \bar{\Gamma}_B$
Example: A and B
are perfectly correlated.
alternative
be fee.
Δ:
It is possible
$P_{ABZXY\phi\Lambda}$
distribution is
and A and B
fixed by the theory
to a cryptology
like **
CAUTION


(**)
X
A
B
A
B
Γ_A
$\bar{\Gamma}_A = \bar{\Gamma}_B$
Example: A and B are perfectly correlated.
According to alternative they may both be free.
Δ: It is possible to choose $P_{ABZXY\phi\Lambda}$ s.t. its cond. distribution is the one defined by the theory and A and B are free w.r.t to a change like **

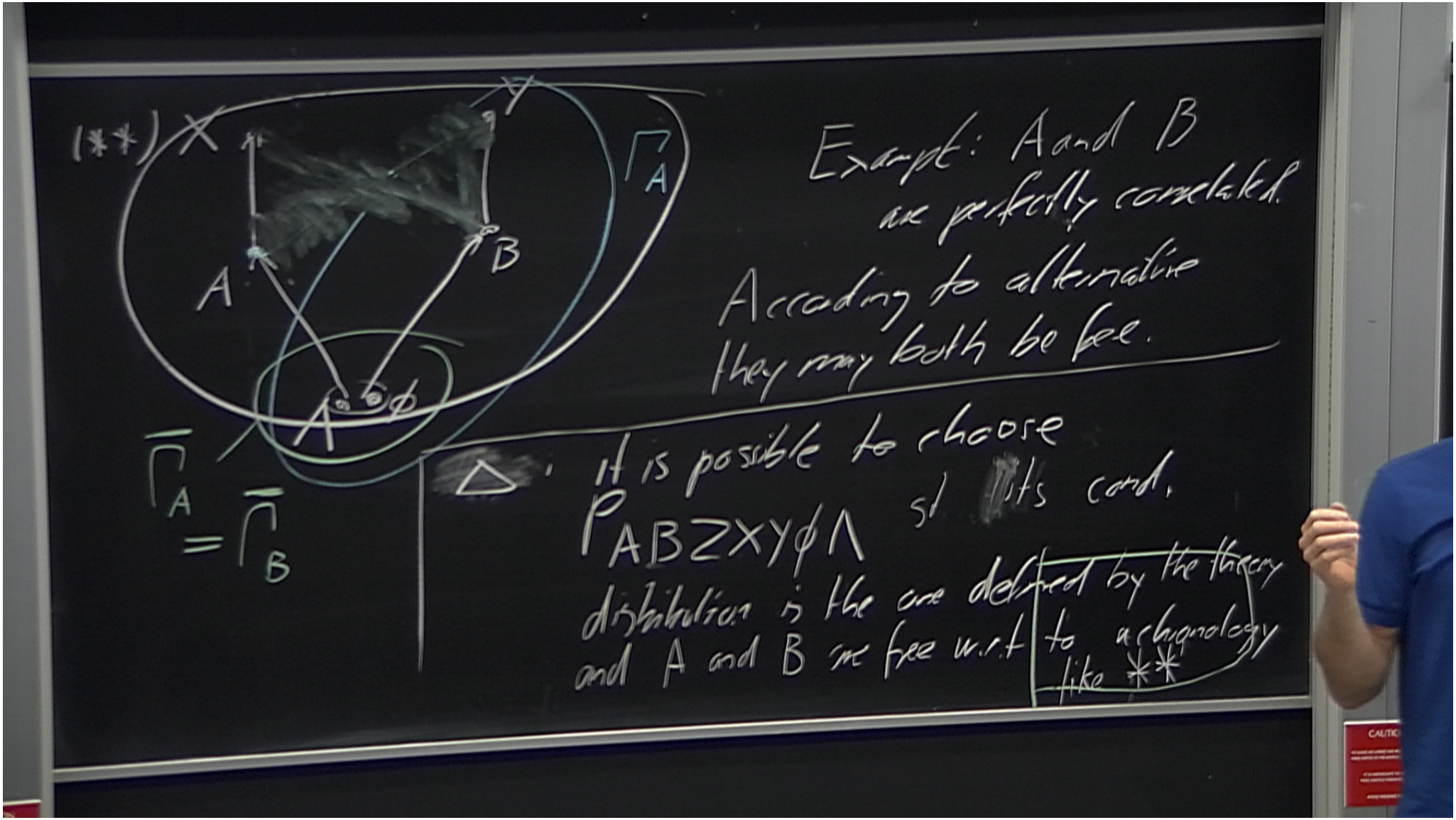

(**)
X
Y
A
B
A
Γ_A
$\bar{\Gamma}_A = \bar{\Gamma}_B$
Exampl: A and B are perfectly correlated.
According to alternative they may both be bee.
Δ: It is possible to choose $P_{ABZXY\phi\Lambda}$ s.t. its cond. distribution is the one defined by the theory and A and B are free w.r.t to ψ ontology like **

Relation to earlier work



Question asked by Bell, Kochen, Specker:
is quant theory contained in a constrained (e.g. local) set of theories?

Question in this talk: is there any theory in ⬭ that is more informative than quantum theory?


(**)
X
Y
Γ_A
A
B
ϕ
$\bar{\Gamma}_A = \bar{\Gamma}_B$
Example: A and B are perfectly correlated.
According to alternative they may both be bee.
Δ: It is possible to choose $P_{ABZXY\phi\Lambda}$ s.t. its cond. distribution is the one defined by the theory and A and B are free w.r.t to a ch[illegible]ology like **