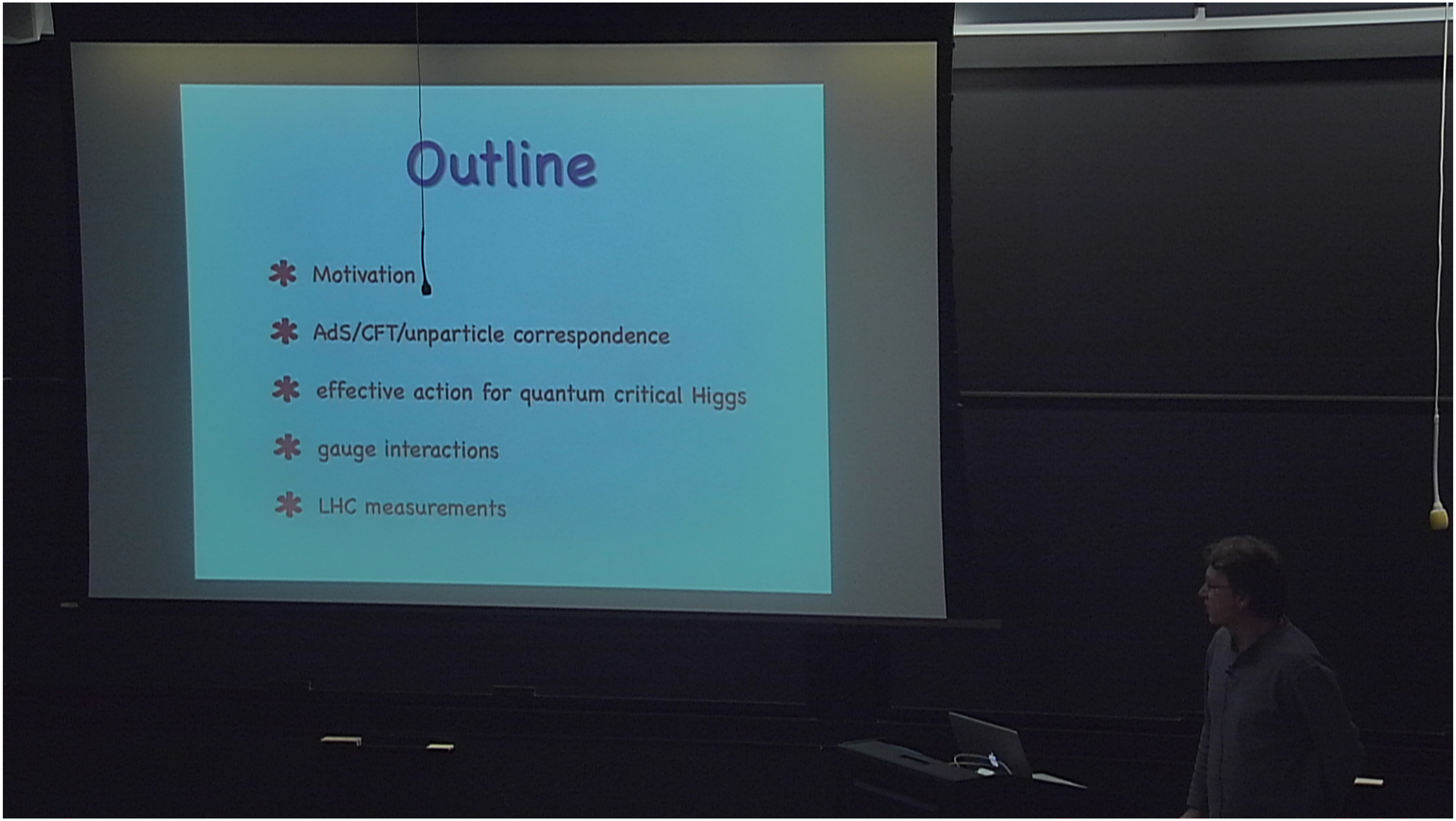
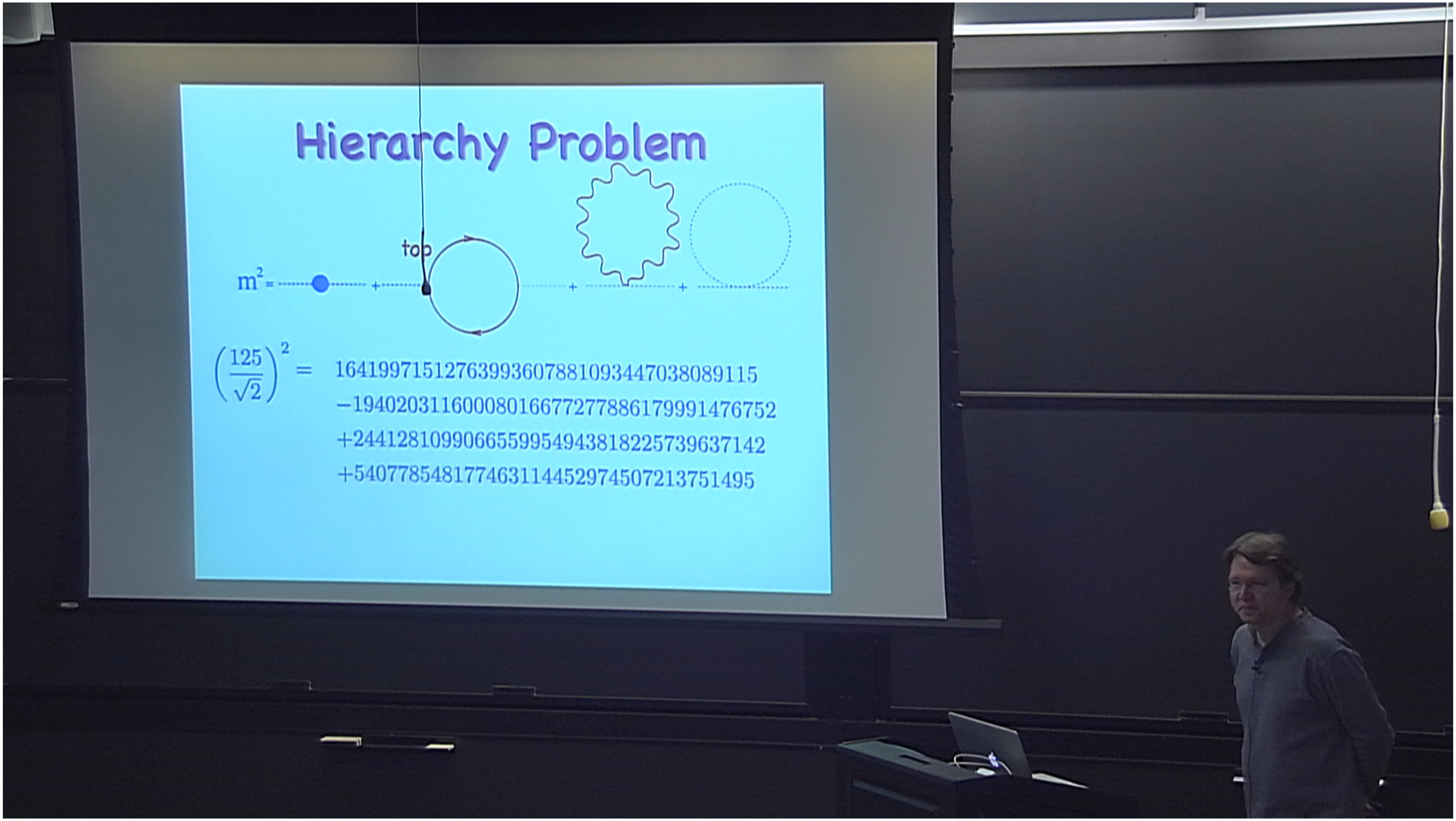
Title: TBA - John Terning

Date: Nov 14, 2014 01:00 PM

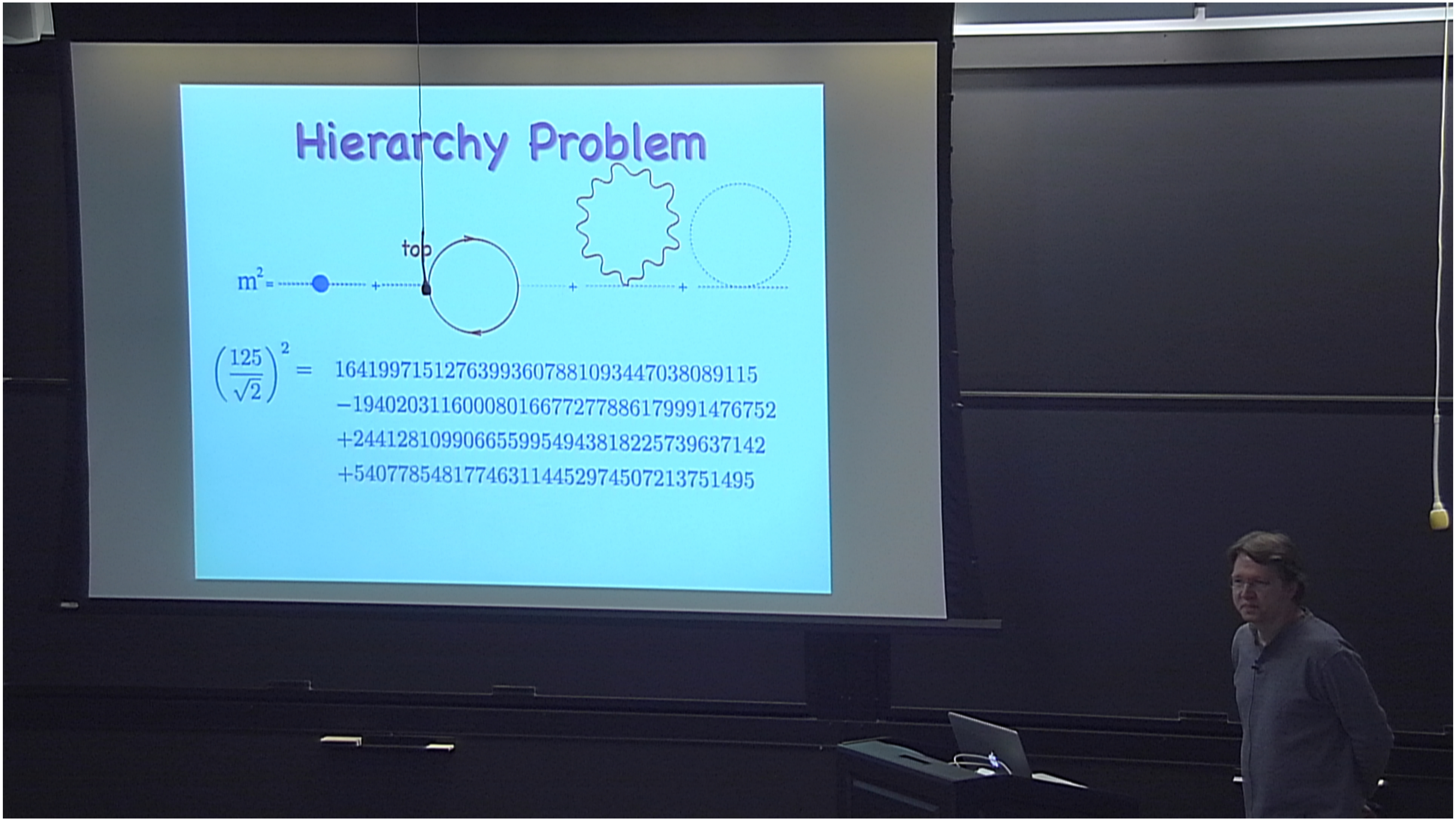
URL: http://pirsa.org/14110004

Abstract:


Outline
Motivation
AdS/CFT/unparticle correspondence
effective action for quantum critical Higgs
gauge interactions
LHC measurements



Hierarchy Problem
top
m² =
(125/√2)² = 16419971512763993607881093447038089115
−19402031160008016677277886179991476752
+24412810990665599549438182257396371142
+5407785481774631144529745072137514 95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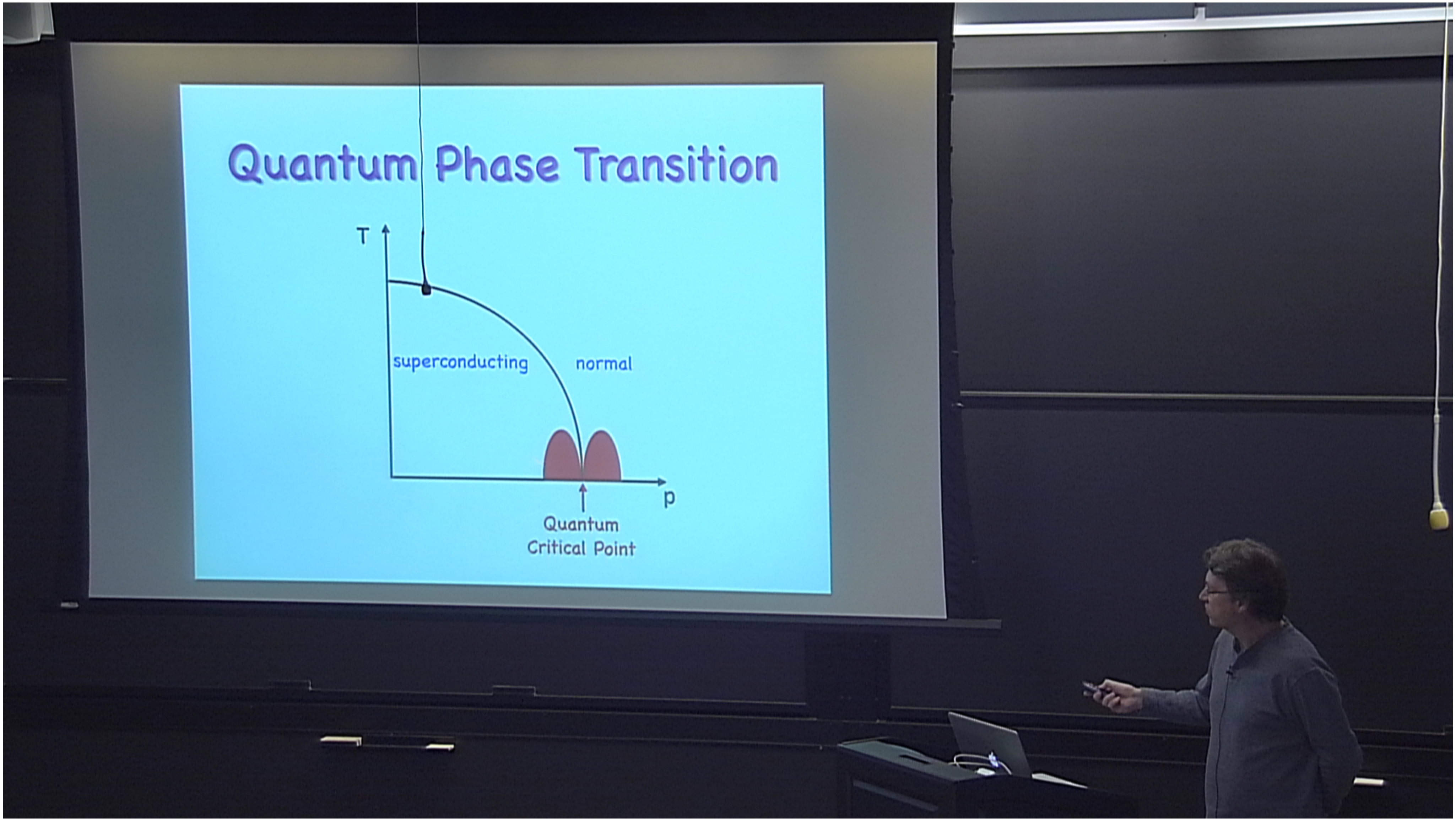
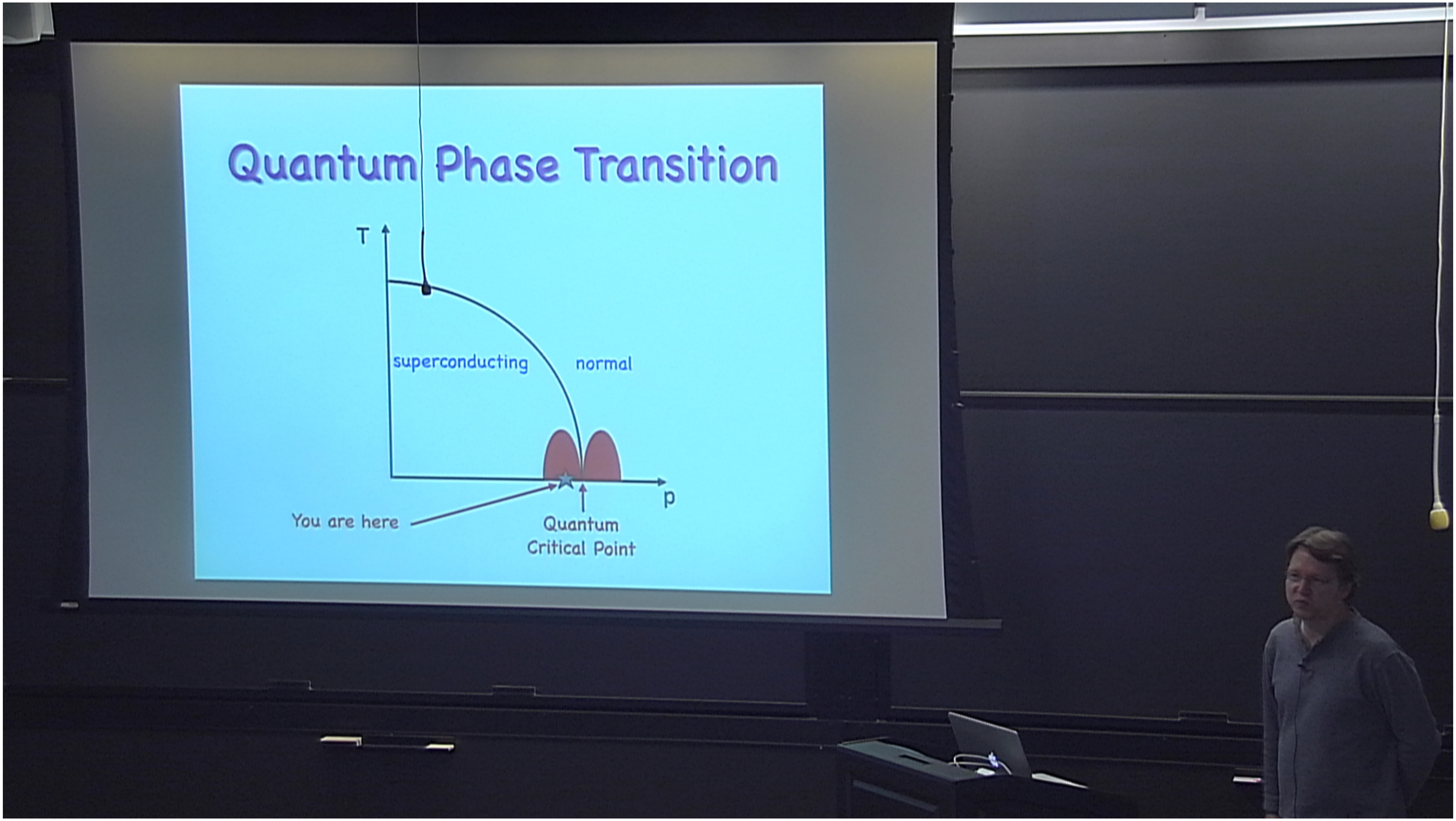

Quantum Phase Transition
T
superconducting
normal
p
Quantum
Critical Point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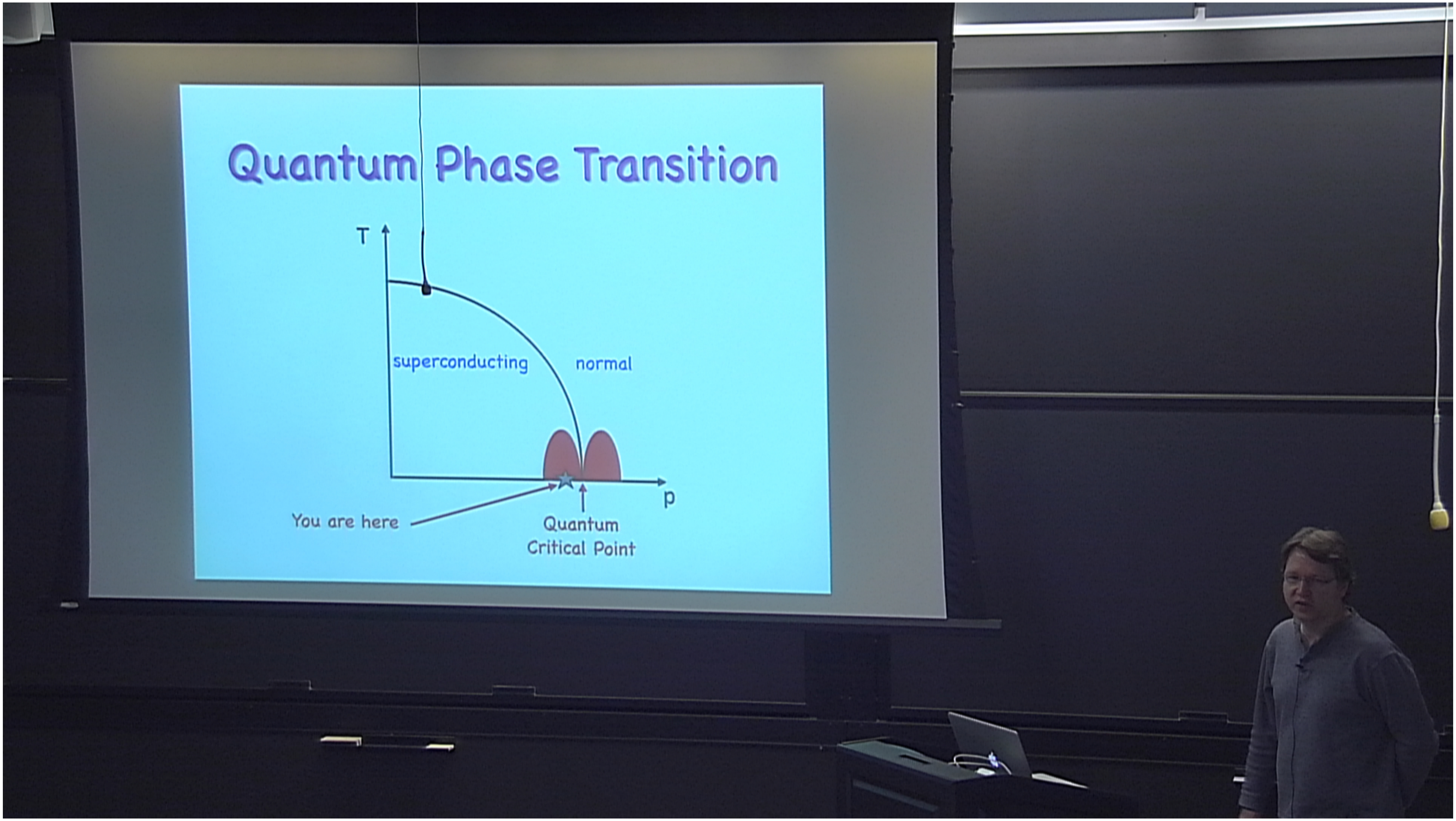
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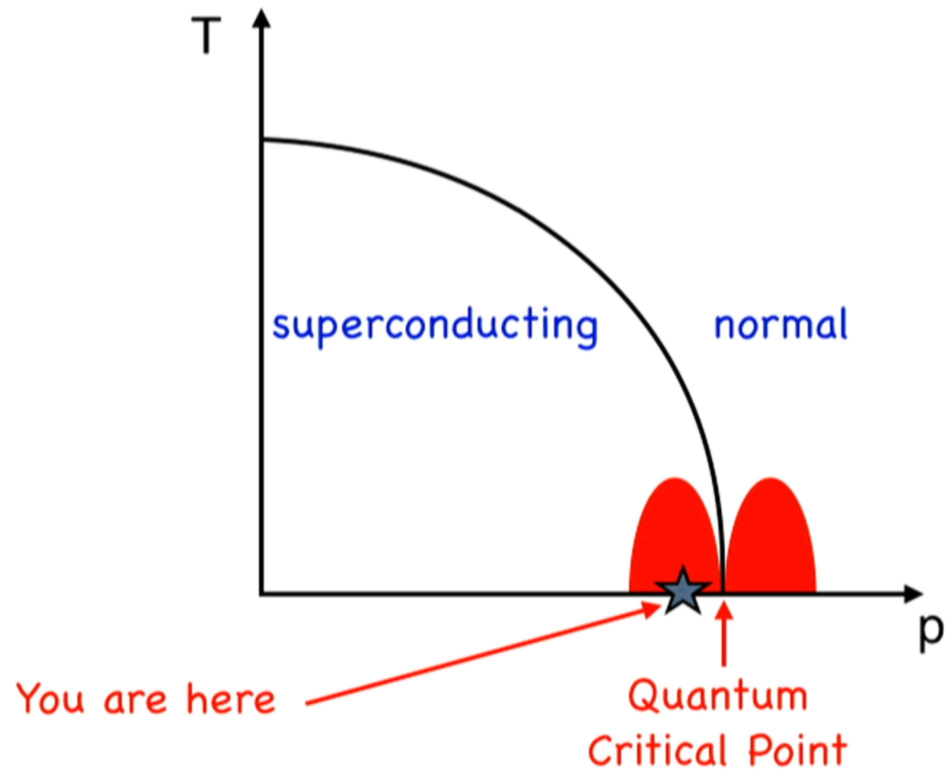
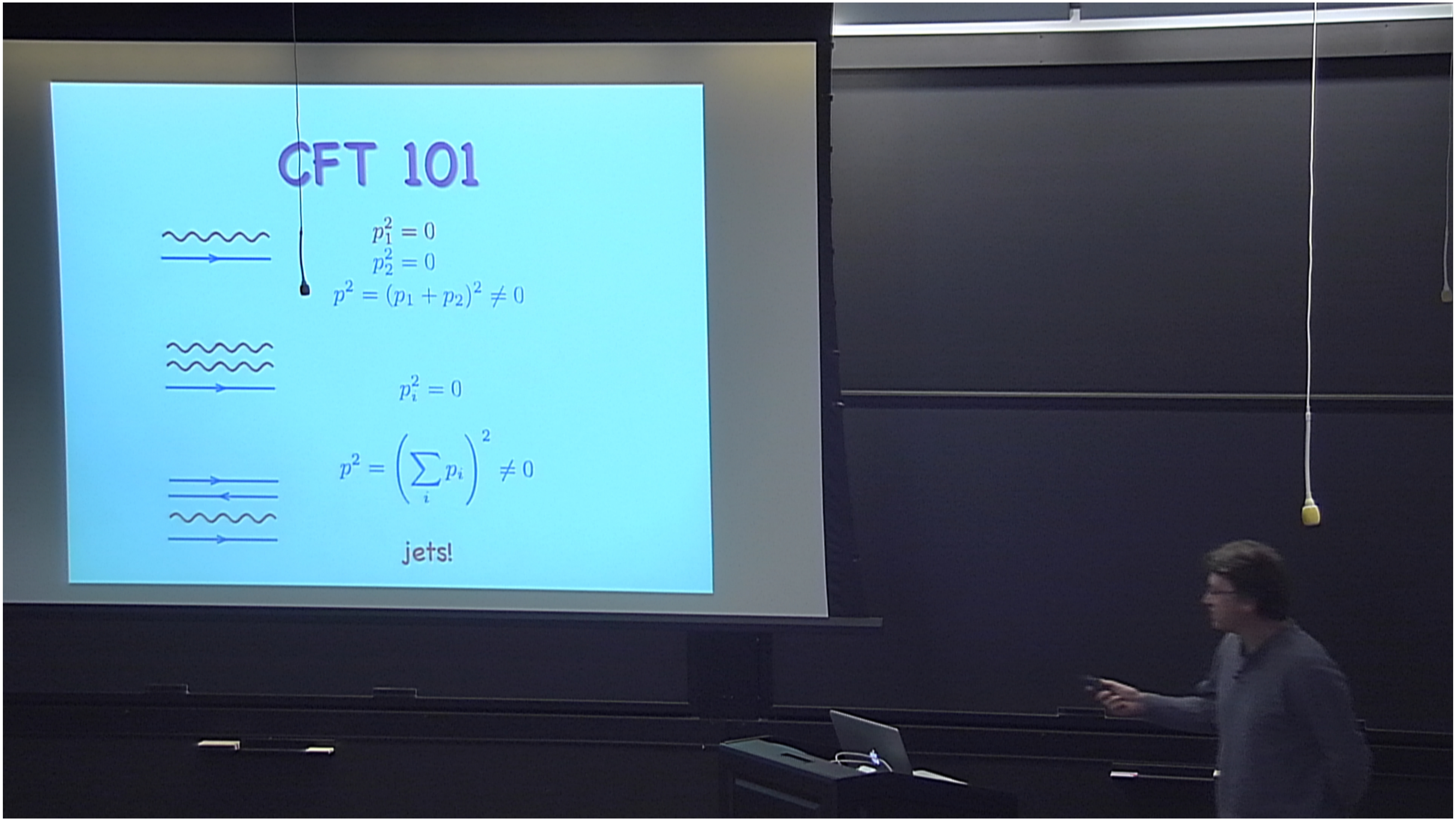
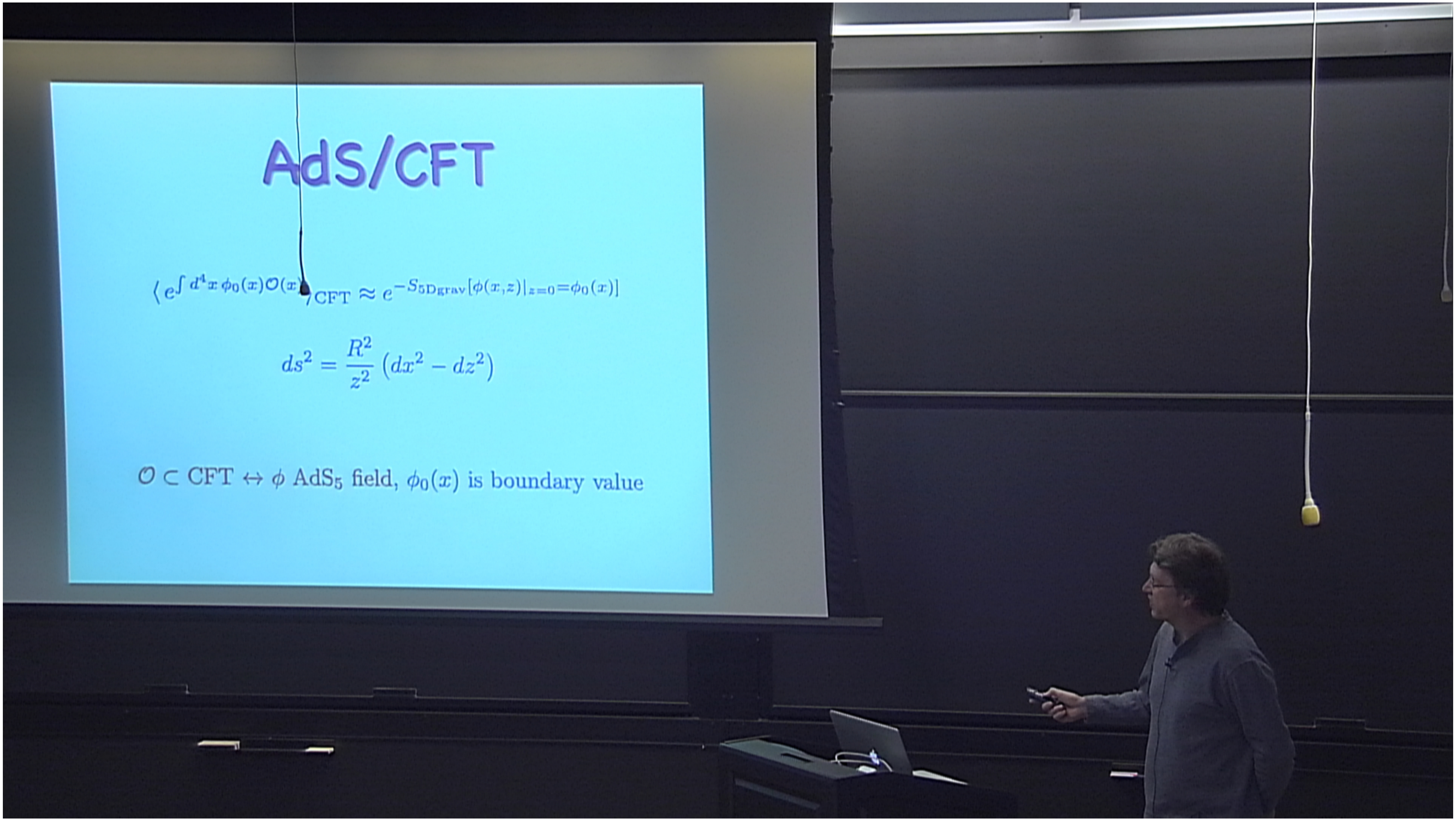
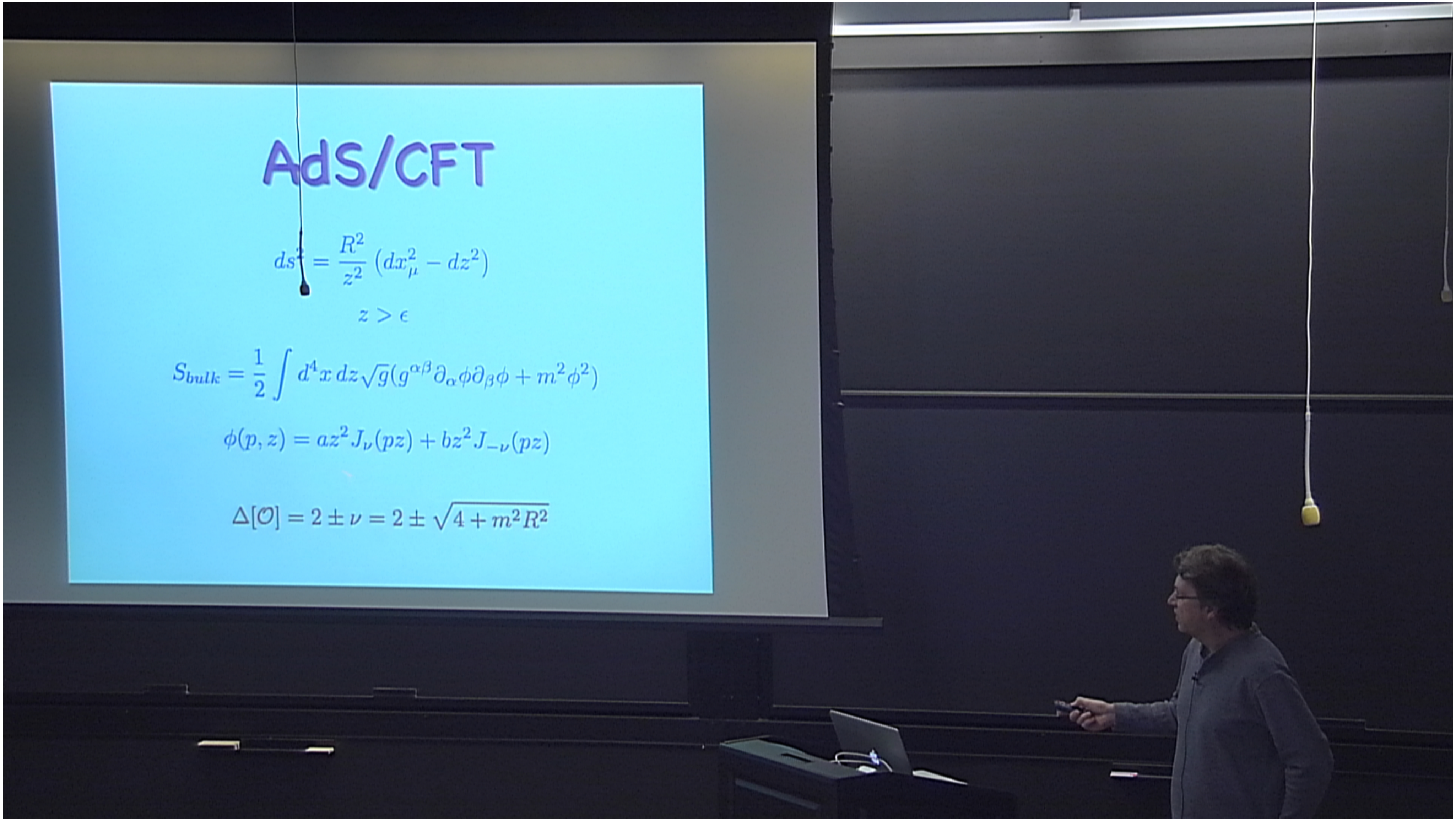
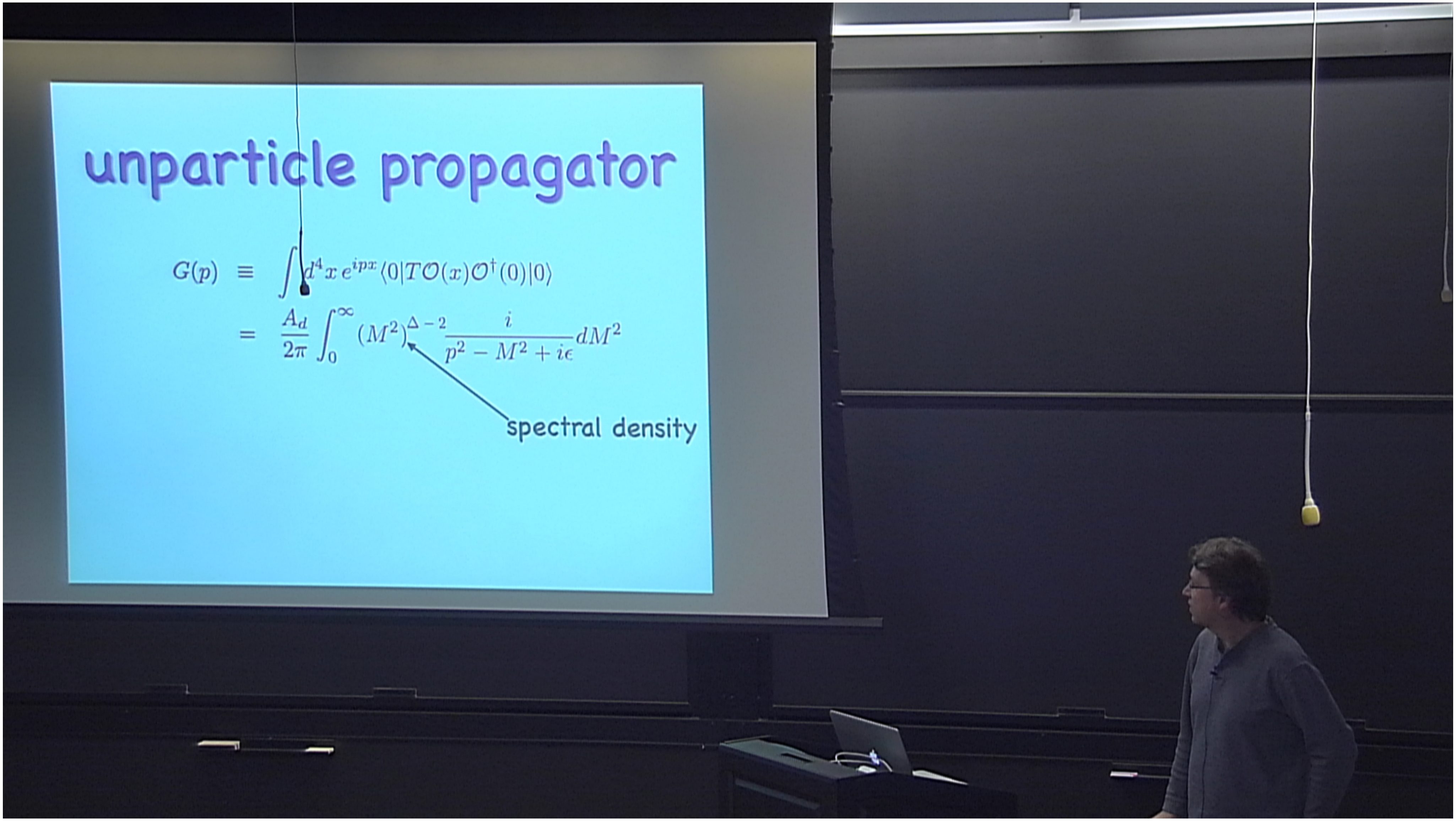
Quantum Phase Transition

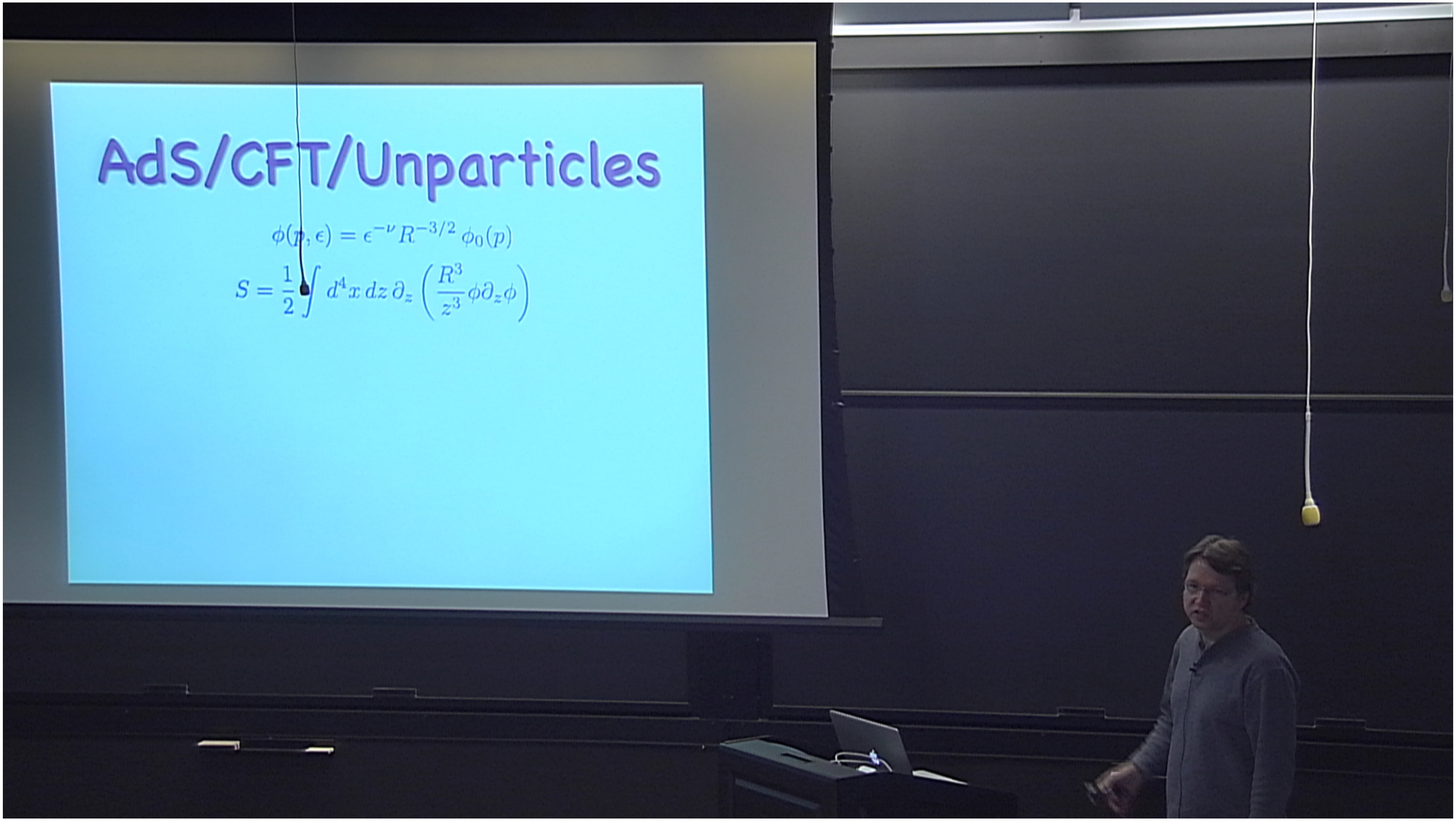


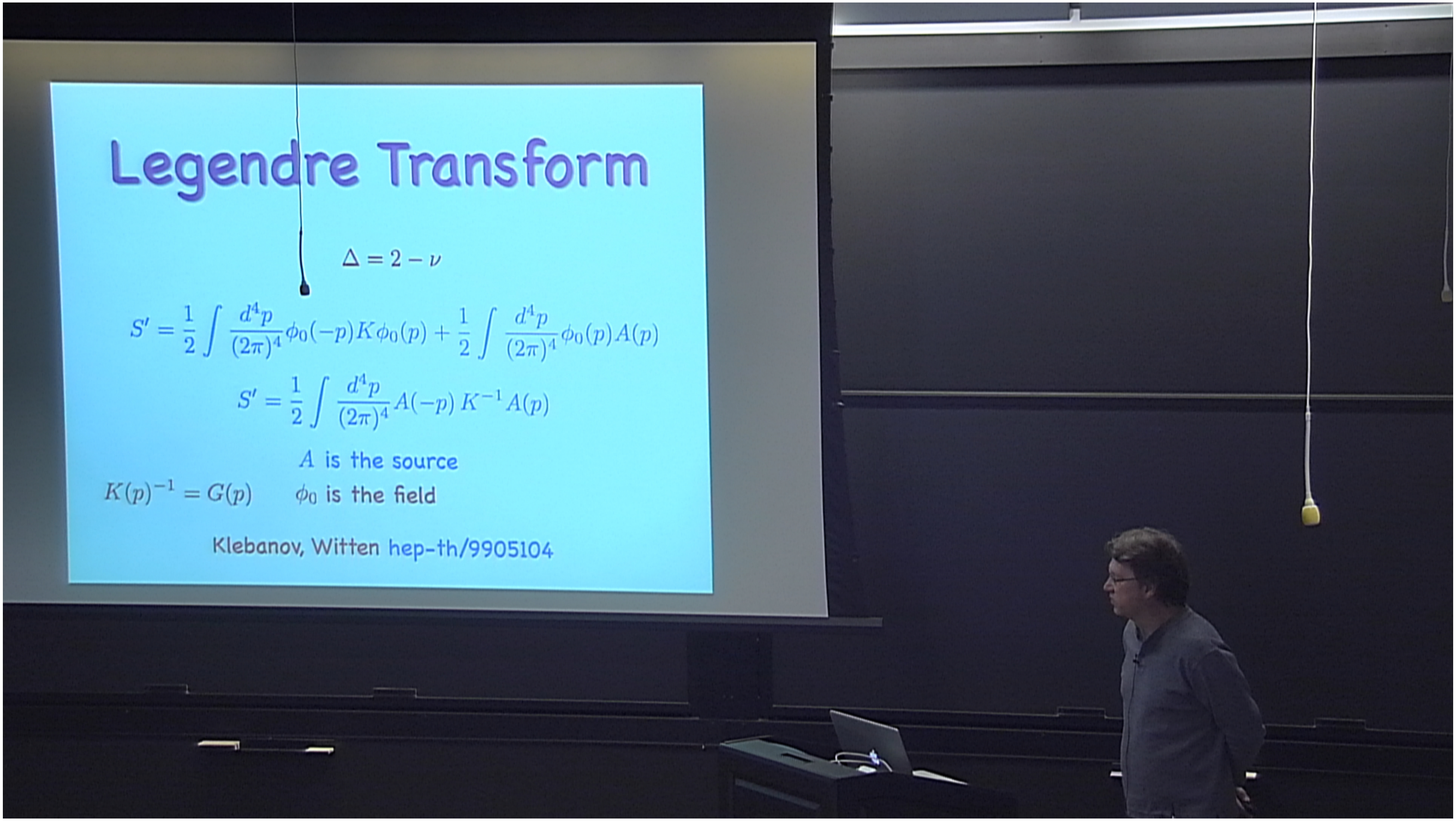

CFT 101
$p_1^2 = 0$
$p_2^2 = 0$
$p^2 = (p_1 + p_2)^2 \neq 0$
$p_i^2 = 0$
$p^2 = \left(\sum_i p_i\right)^2 \neq 0$
jets!


AdS/CFT
$\langle e^{\int d^4x\, \phi_0(x)\mathcal{O}(x)} \rangle_{\mathrm{CFT}} \approx e^{-S_{5\mathrm{Dgrav}}[\phi(x,z)|_{z=0}=\phi_0(x)]}$
$ds^2 = \frac{R^2}{z^2}\left(dx^2 - dz^2\right)$
$\mathcal{O} \subset$ CFT $\leftrightarrow \phi$ AdS$_5$ field, $\phi_0(x)$ is boundary value


AdS/CFT
$ds^2 = \frac{R^2}{z^2}\left(dx_\mu^2 - dz^2\right)$
$z > \epsilon$
$S_{bulk} = \frac{1}{2}\int d^4x\, dz \sqrt{g}(g^{\alpha\beta}\partial_\alpha\phi\partial_\beta\phi + m^2\phi^2)$
$\phi(p,z) = az^2 J_\nu(pz) + bz^2 J_{-\nu}(pz)$
$\Delta[\mathcal{O}] = 2 \pm \nu = 2 \pm \sqrt{4 + m^2R^2}$


unparticle propagator
$G(p) \equiv \int d^4x\, e^{ipx} \langle 0|T\mathcal{O}(x)\mathcal{O}^\dagger(0)|0\rangle$
$= \frac{A_d}{2\pi} \int_0^\infty (M^2)^{\Delta-2} \frac{i}{p^2 - M^2 + i\epsilon} dM^2$
spectral density


AdS/CFT/Unparticles
$\phi(p,\epsilon) = \epsilon^{-\nu} R^{-3/2}\, \phi_0(p)$
$S = \frac{1}{2}\int d^4x\, dz\, \partial_z \left(\frac{R^3}{z^3} \phi \partial_z \phi \right)$


Legendre Transform
$\Delta = 2 - \nu$
$S' = \frac{1}{2}\int \frac{d^4p}{(2\pi)^4}\phi_0(-p)K\phi_0(p) + \frac{1}{2}\int \frac{d^4p}{(2\pi)^4}\phi_0(p)A(p)$
$S' = \frac{1}{2}\int \frac{d^4p}{(2\pi)^4}A(-p)\,K^{-1}A(p)$
A is the source
$K(p)^{-1} = G(p)$
ϕ_0 is the field
Klebanov, Witten hep-th/9905104

Legendre Transform

$$\Delta = 2 - \nu$$

$$S' = \frac{1}{2}\int \frac{d^4p}{(2\pi)^4}\phi_0(-p)K\phi_0(p) + \frac{1}{2}\int \frac{d^4p}{(2\pi)^4}\phi_0(p)A(p)$$

$$S' = \frac{1}{2}\int \frac{d^4p}{(2\pi)^4}A(-p)\,K^{-1}A(p)$$

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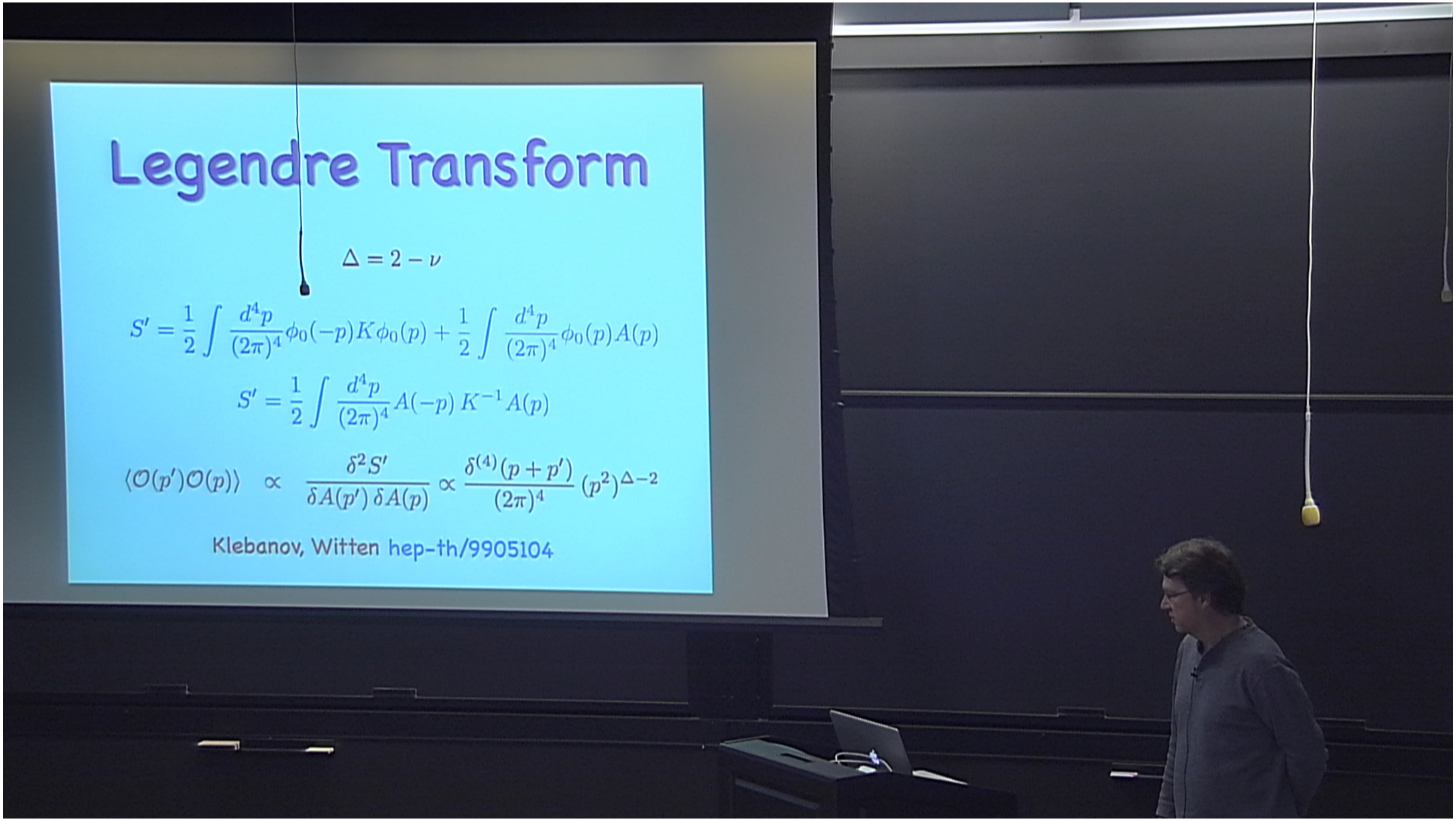
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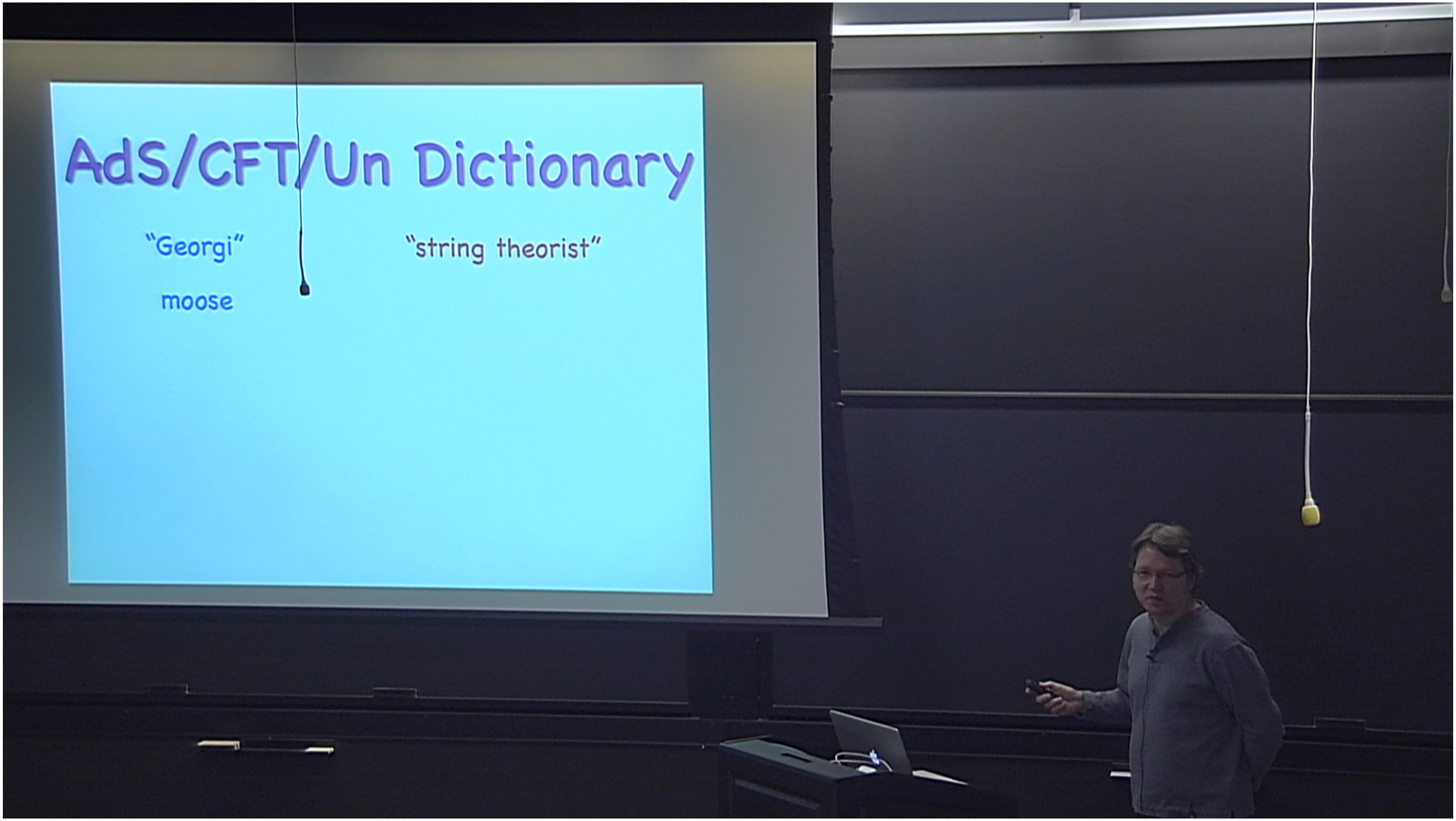
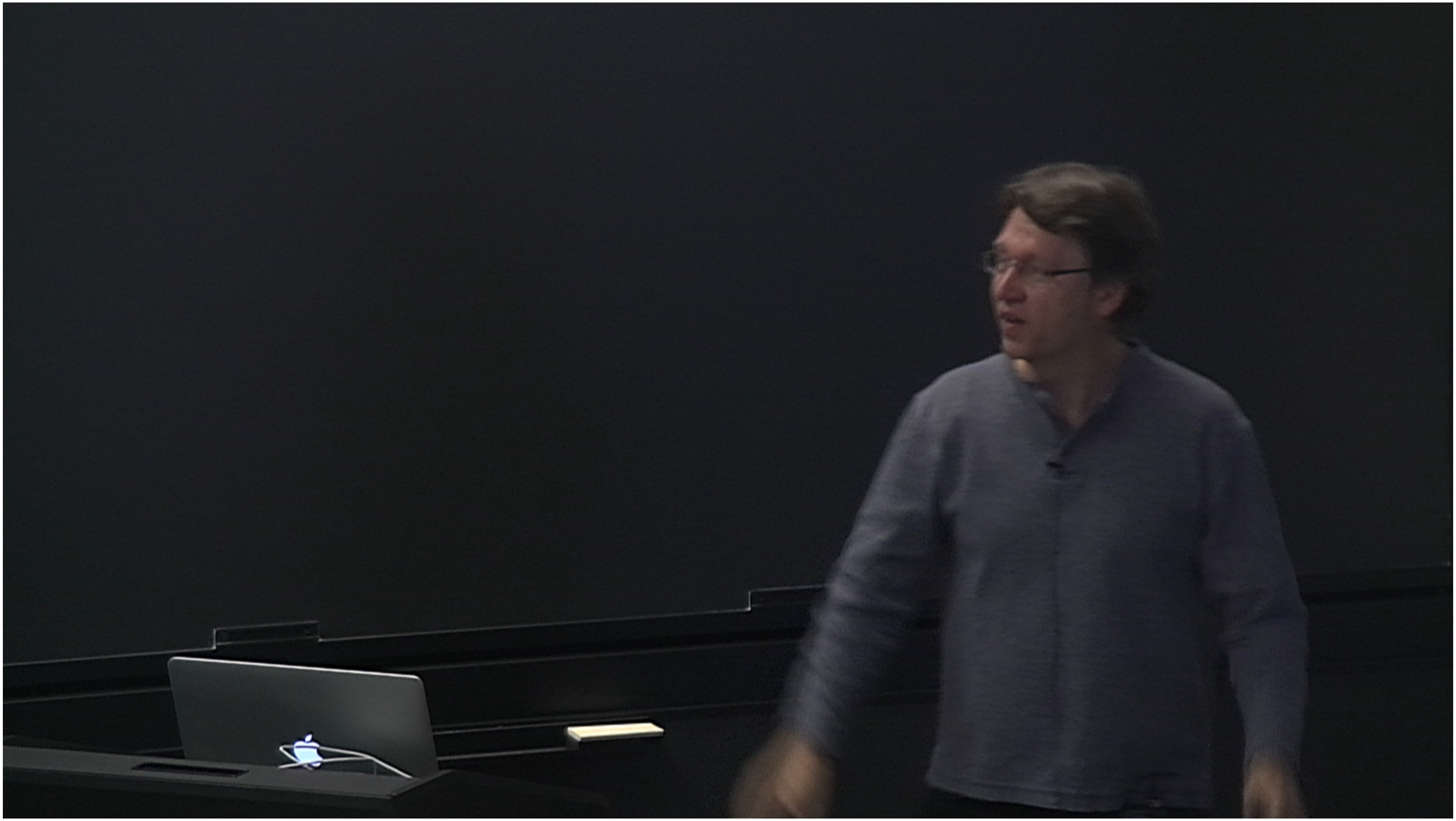
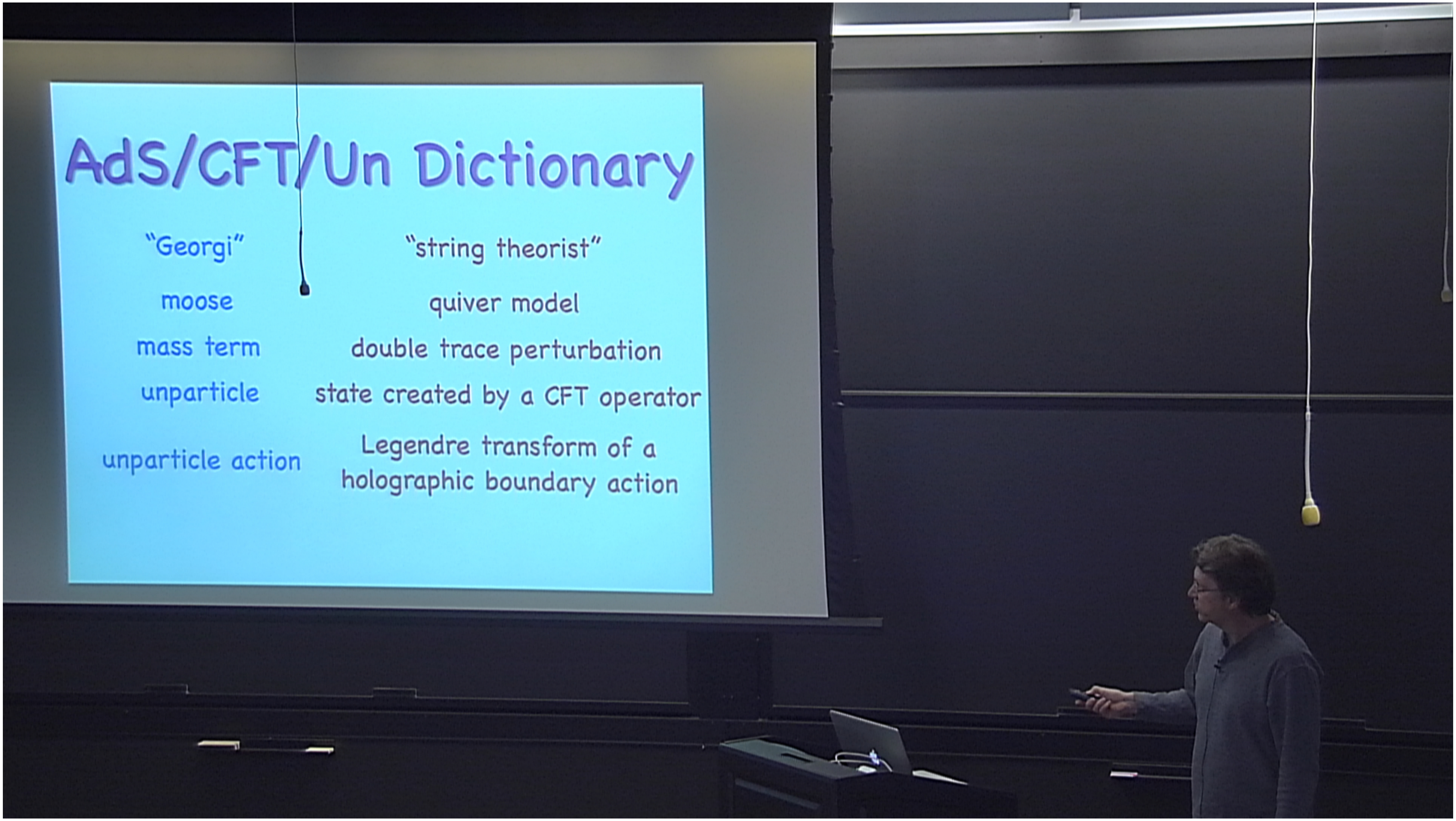
$S' = \frac{1}{2}\int \frac{d^4p}{(2\pi)^4}A(-p)\,K^{-1}A(p)$
$\langle \mathcal{O}(p')\mathcal{O}(p)\rangle \propto \frac{\delta^2 S'}{\delta A(p')\,\delta A(p)} \propto \frac{\delta^{(4)}(p+p')}{(2\pi)^4}(p^2)^{\Delta-2}$
Klebanov, Witten hep-th/9905104

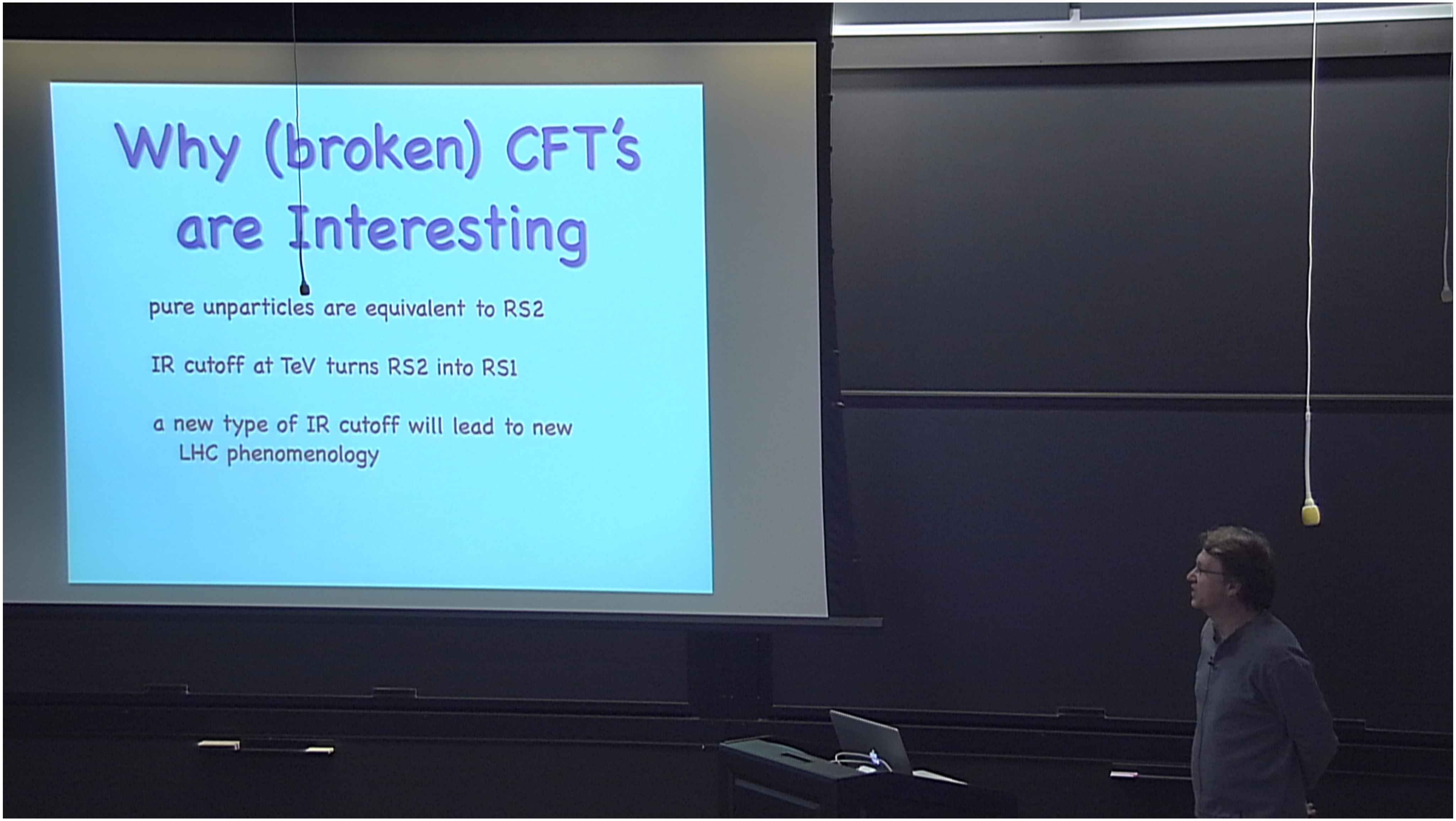

AdS/CFT/Un Dictionary
"Georgi"
"string theorist"
moose

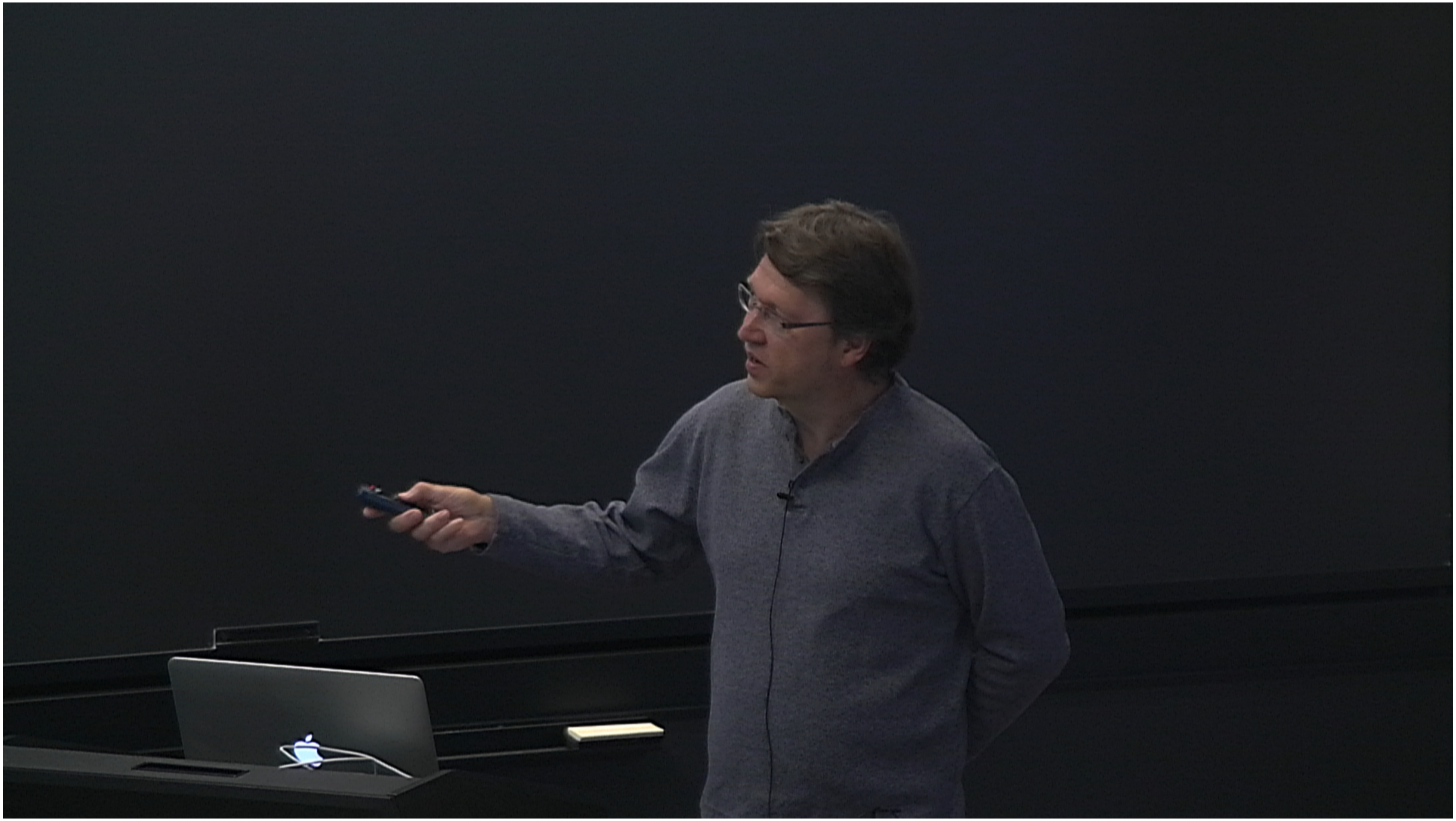
AdS/CFT/Un Dictionary

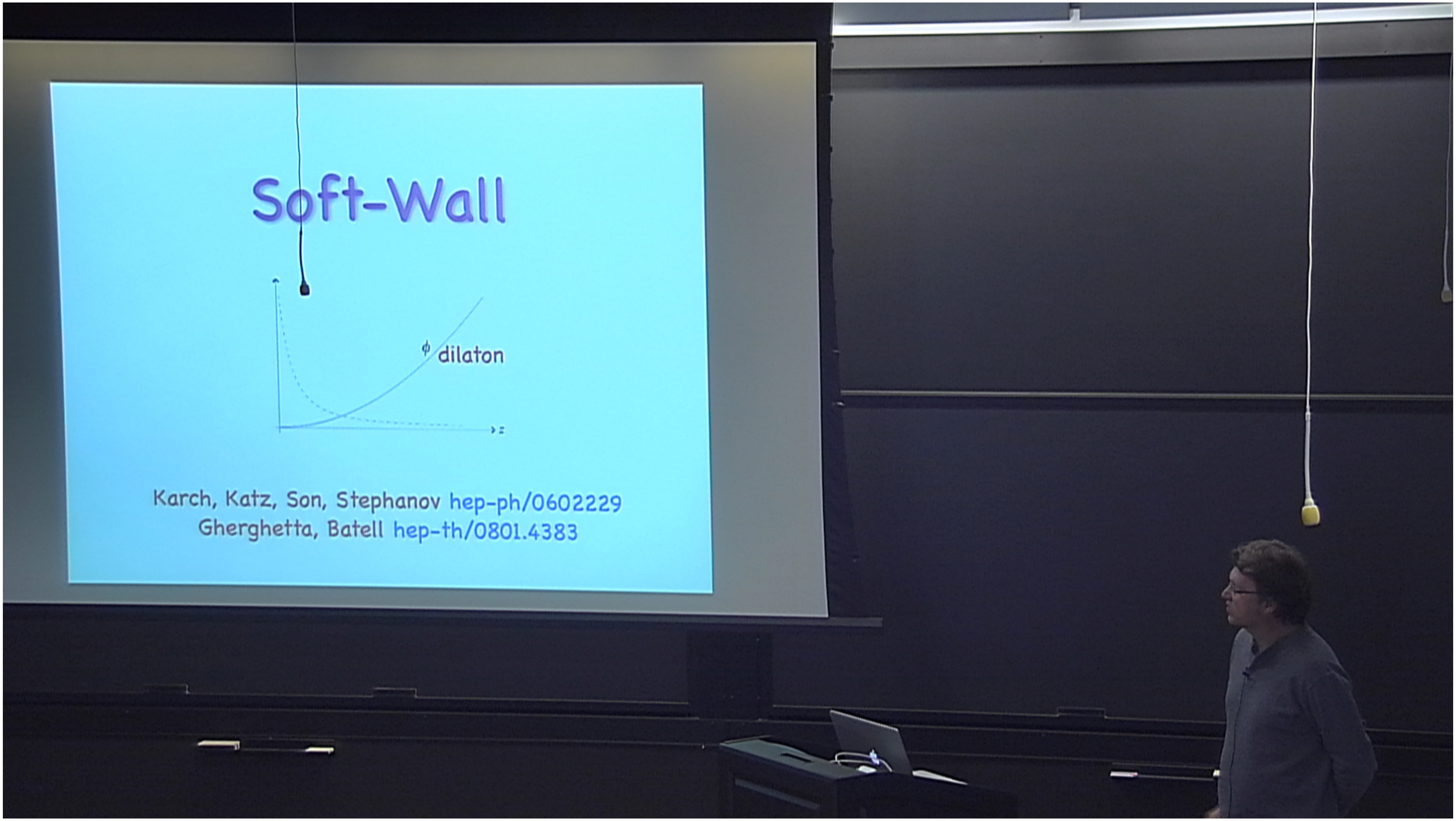
"Georgi"	"string theorist"
moose	

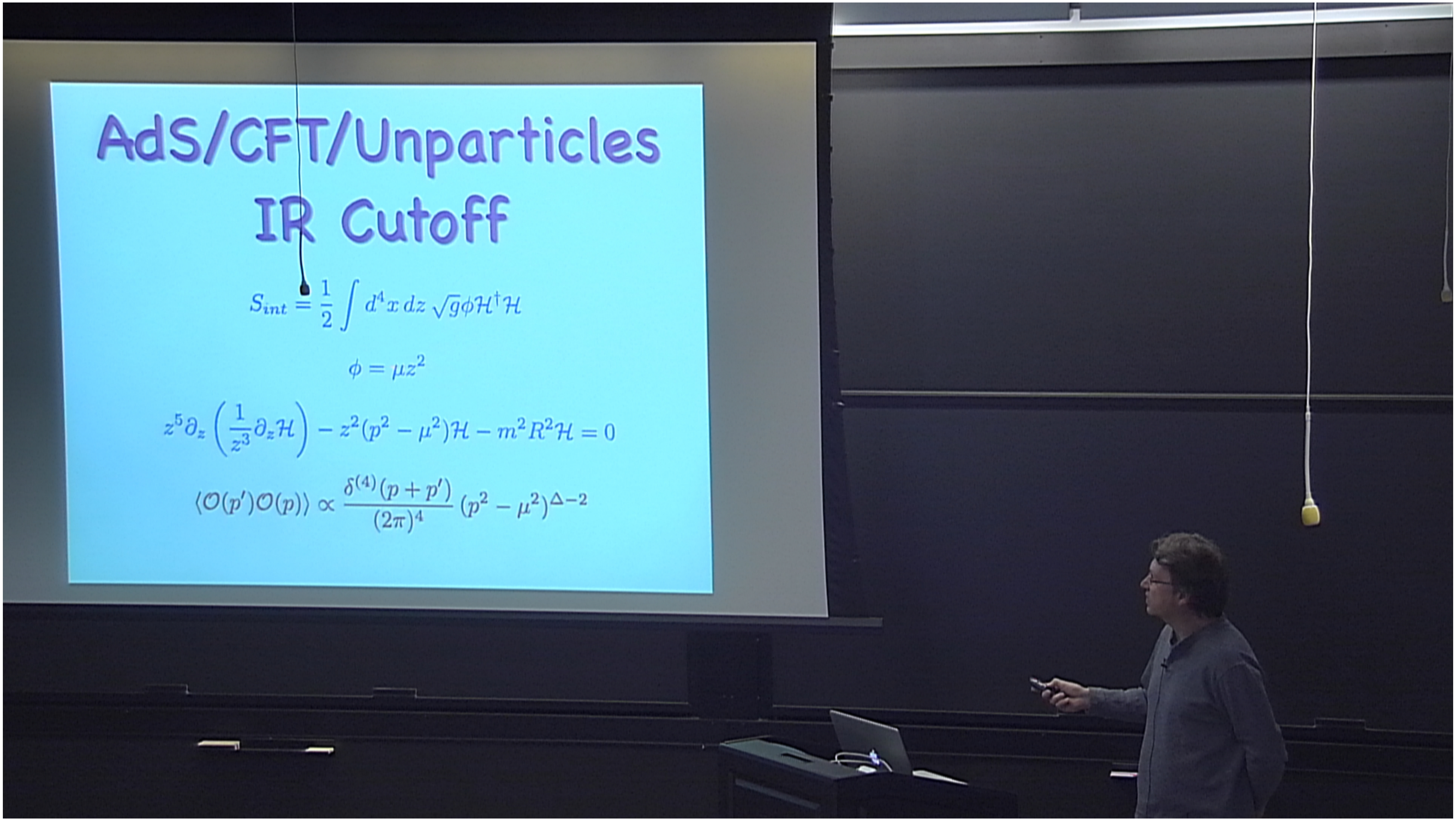


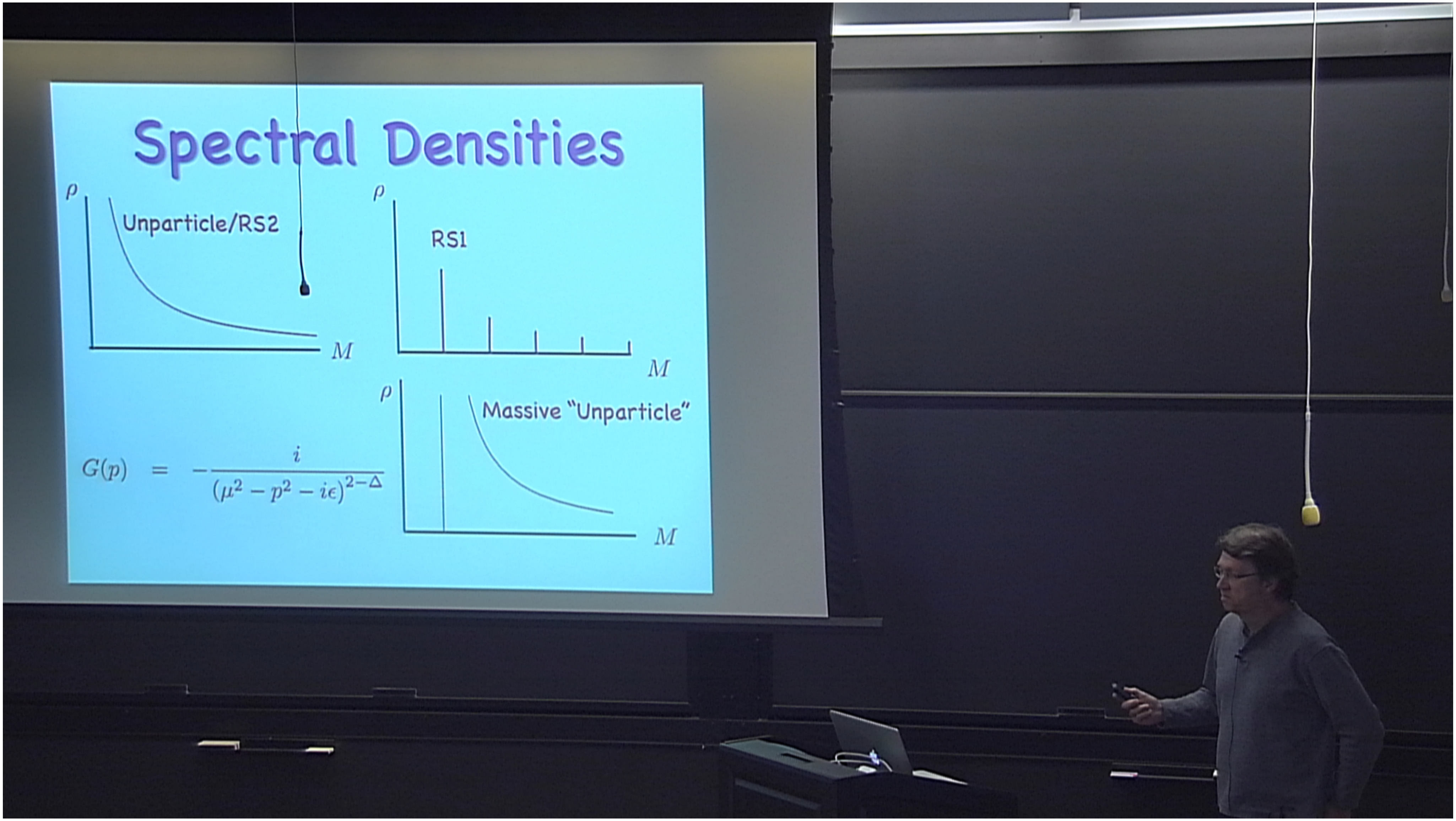

AdS/CFT/Un Dictionary
"Georgi"
"string theorist"
moose
quiver model
mass term
double trace perturbation
unparticle
state created by a CFT operator
unparticle action
Legendre transform of a holographic boundary action

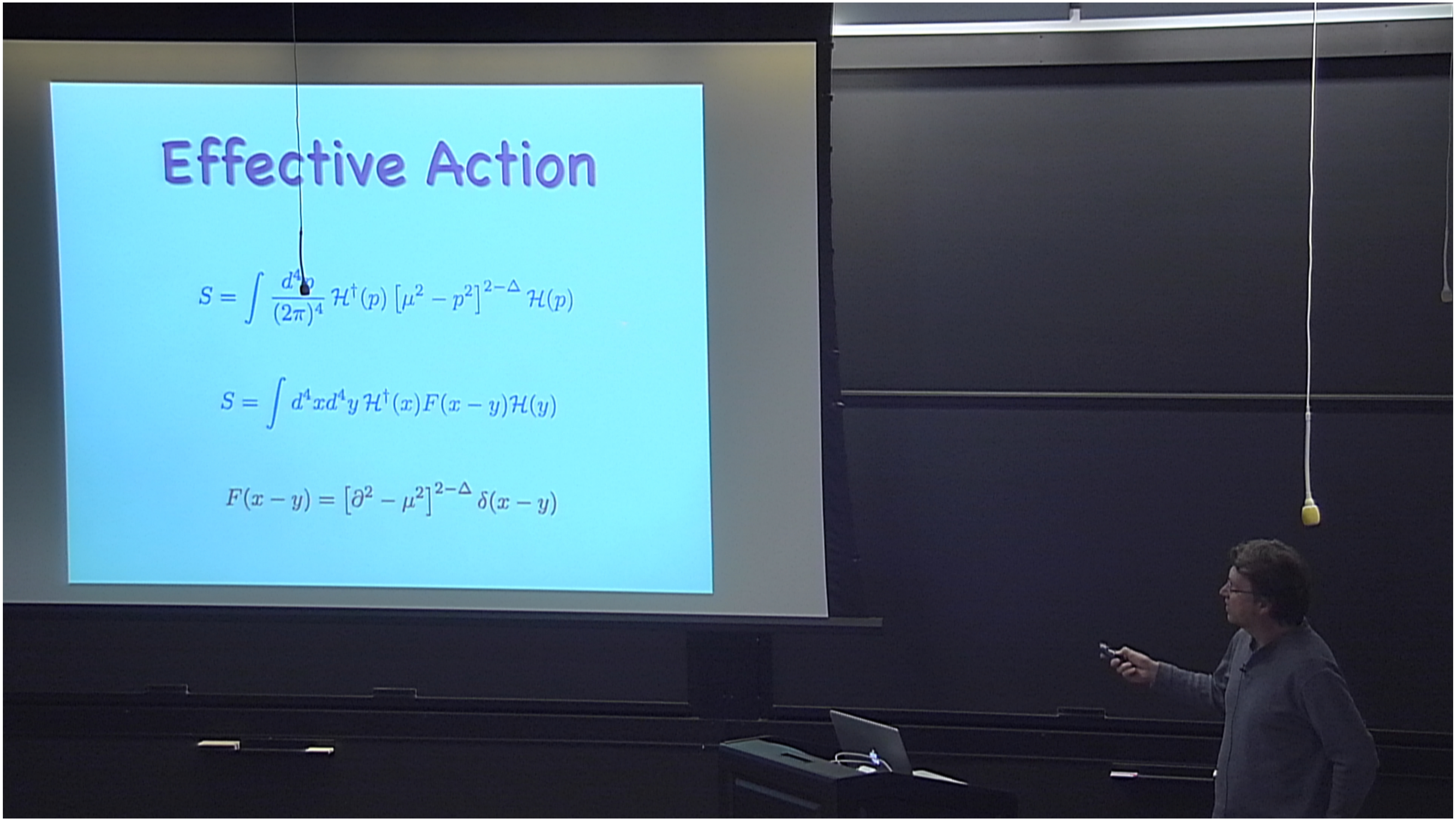

Why (broken) CFT's are Interesting
pure unparticles are equivalent to RS2
IR cutoff at TeV turns RS2 into RS1
a new type of IR cutoff will lead to new LHC phenomenology

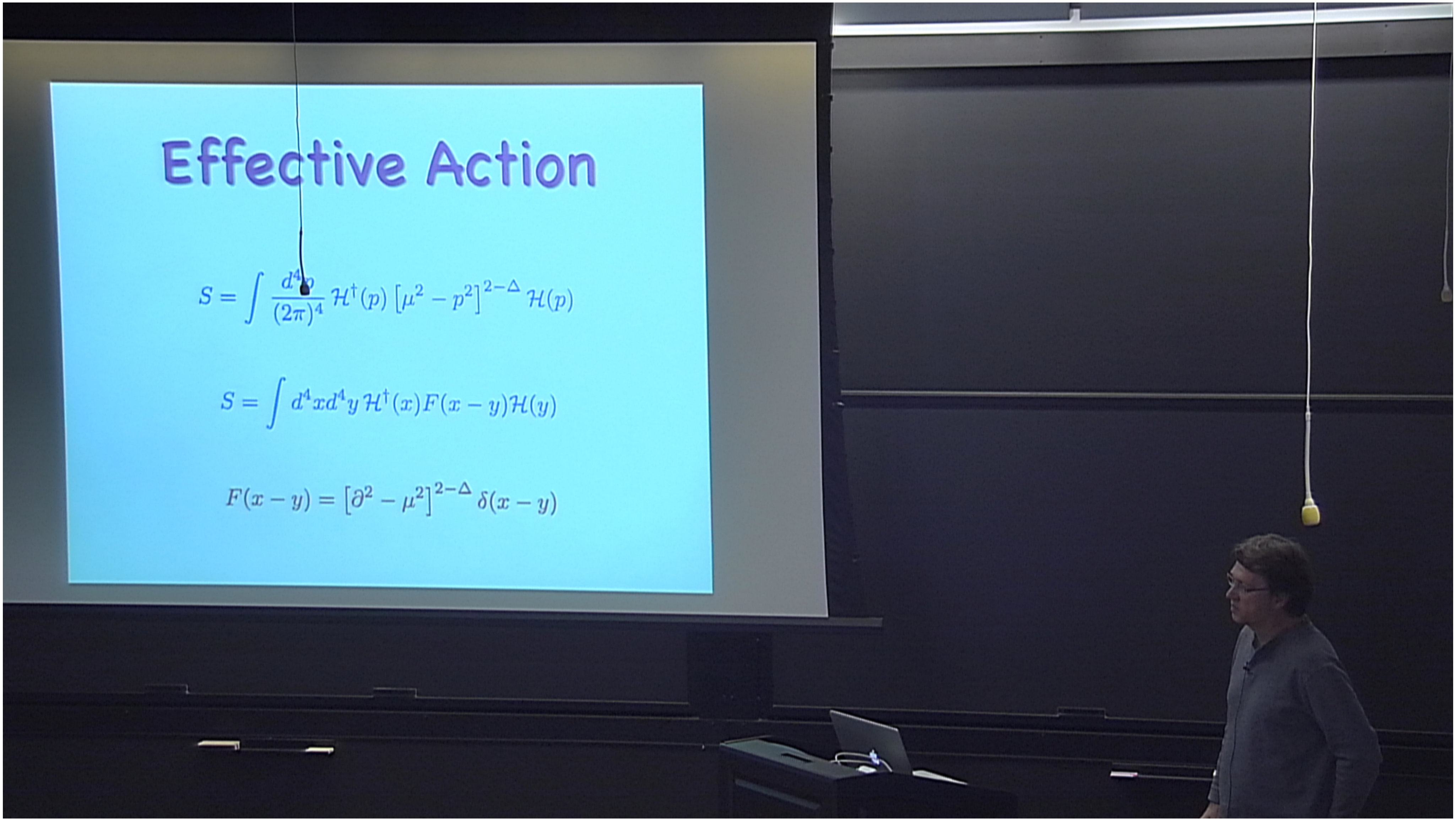


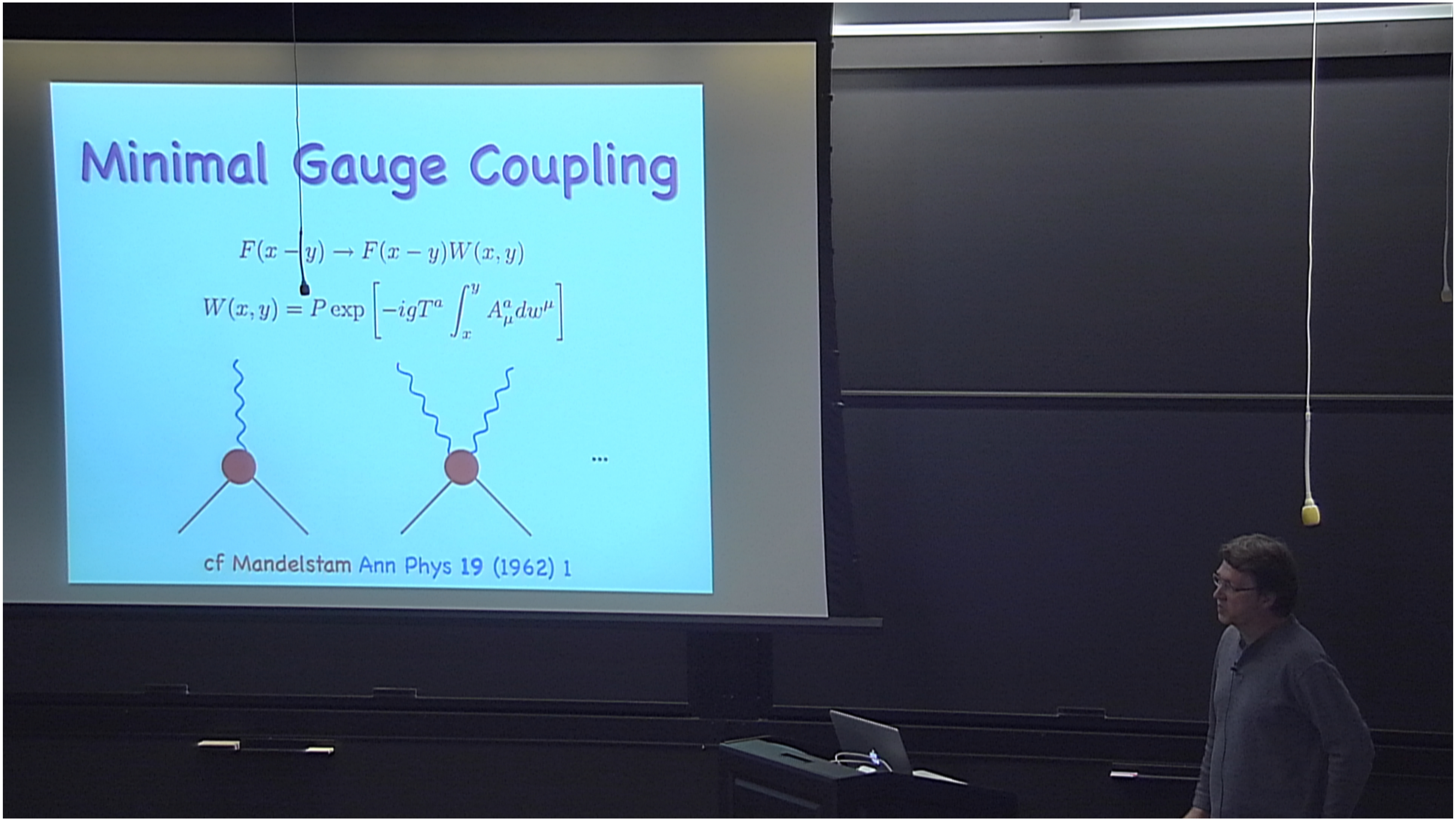

Soft-Wall
ϕ dilaton
z
Karch, Katz, Son, Stephanov hep-ph/0602229
Gherghetta, Batell hep-th/0801.4383

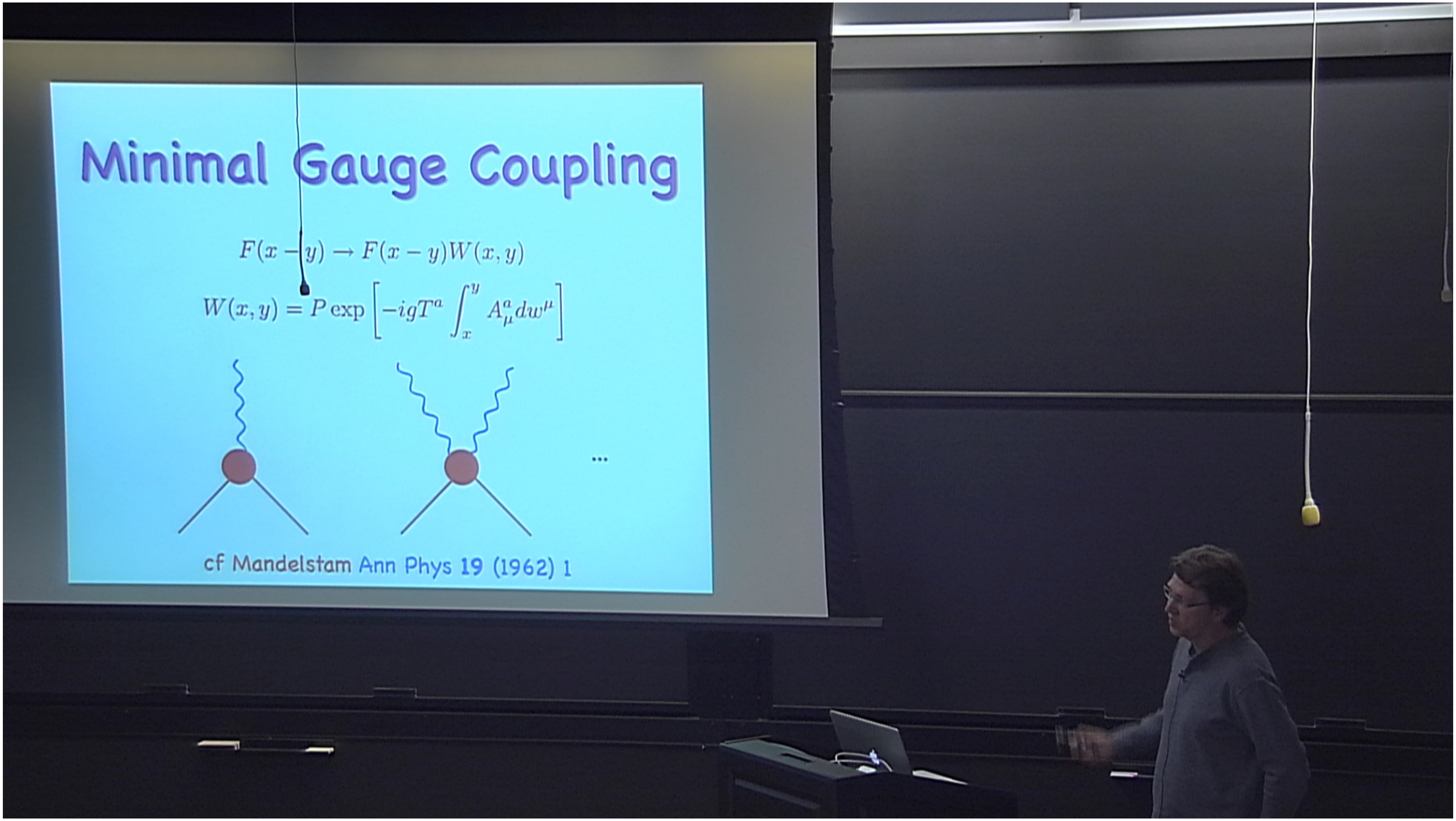

AdS/CFT/Unparticles
IR Cutoff
$S_{int} = \frac{1}{2}\int d^4x\, dz\, \sqrt{g}\phi\mathcal{H}^\dagger\mathcal{H}$
$\phi = \mu z^2$
$z^5\partial_z\left(\frac{1}{z^3}\partial_z\mathcal{H}\right) - z^2(p^2-\mu^2)\mathcal{H} - m^2R^2\mathcal{H} = 0$
$\langle\mathcal{O}(p')\mathcal{O}(p)\rangle \propto \frac{\delta^{(4)}(p+p')}{(2\pi)^4}(p^2-\mu^2)^{\Delta-2}$


Spectral Densities
ρ
Unparticle/RS2
M
ρ
RS1
M
ρ
Massive "Unparticle"
M
$G(p) = -\frac{i}{(\mu^2 - p^2 - i\epsilon)^{2-\Delta}}$


Effective Action
$S = \int \frac{d^4p}{(2\pi)^4} \mathcal{H}^\dagger(p) \left[\mu^2 - p^2\right]^{2-\Delta} \mathcal{H}(p)$
$S = \int d^4x d^4y \, \mathcal{H}^\dagger(x) F(x-y) \mathcal{H}(y)$
$F(x-y) = \left[\partial^2 - \mu^2\right]^{2-\Delta} \delta(x-y)$


Effective Action
$S = \int \frac{d^4p}{(2\pi)^4}\, \mathcal{H}^\dagger(p)\, \left[\mu^2 - p^2\right]^{2-\Delta} \mathcal{H}(p)$
$S = \int d^4x d^4y\, \mathcal{H}^\dagger(x) F(x-y) \mathcal{H}(y)$
$F(x-y) = \left[\partial^2 - \mu^2\right]^{2-\Delta} \delta(x-y)$


Minimal Gauge Coupling
$F(x-y) \rightarrow F(x-y)W(x,y)$
$W(x,y) = P\exp\left[-igT^a\int_x^y A_\mu^a dw^\mu\right]$
...
cf Mandelstam Ann Phys 19 (1962) 1



Minimal Gauge Coupling
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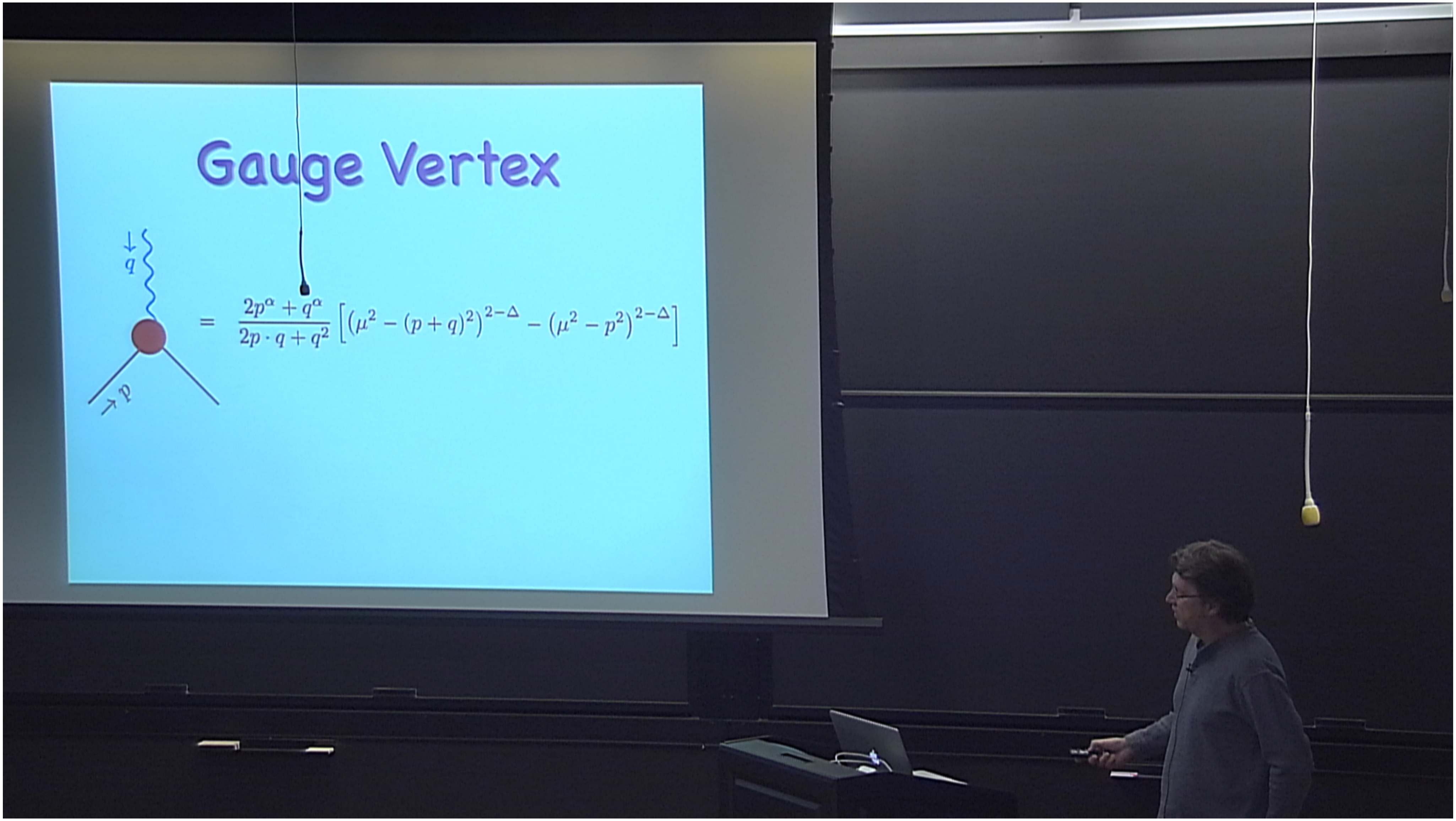
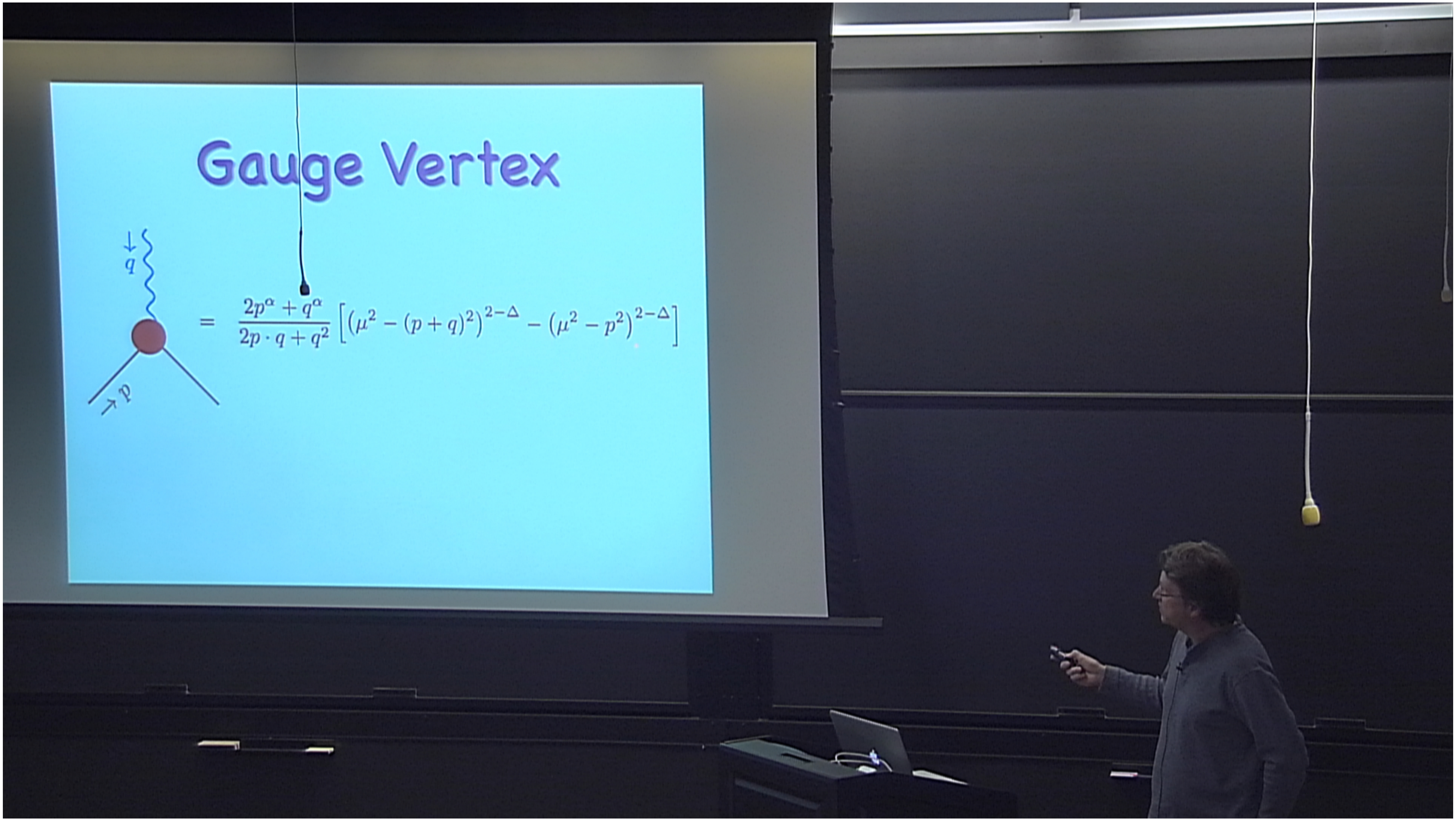
cf Mandelstam Ann Phys 19 (1962) 1


Gauge Vertex
q
p
$= \frac{2p^\alpha + q^\alpha}{2p \cdot q + q^2} \left[\left(\mu^2 - (p+q)^2\right)^{2-\Delta} - \left(\mu^2 - p^2\right)^{2-\Delta} \right]$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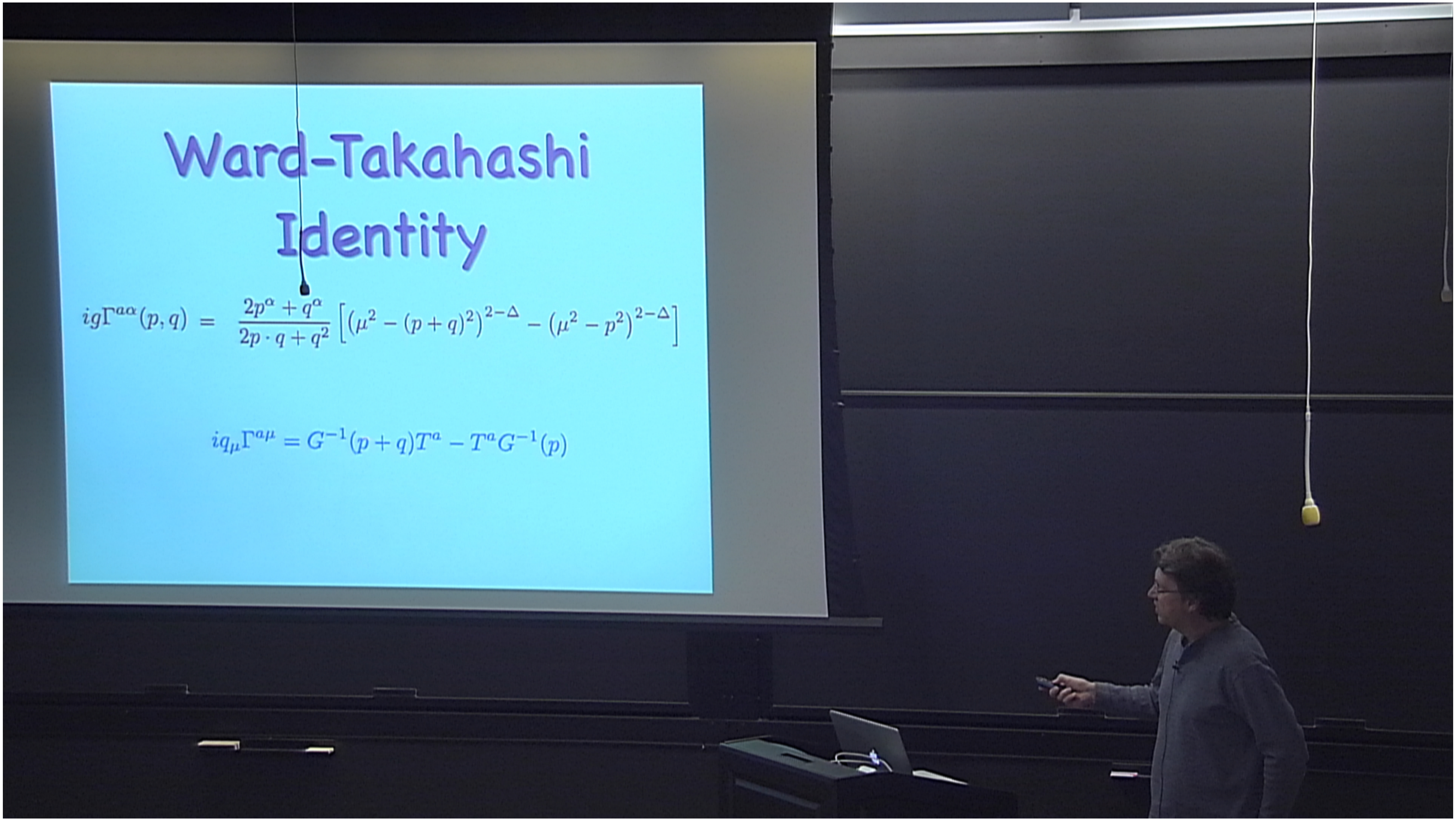
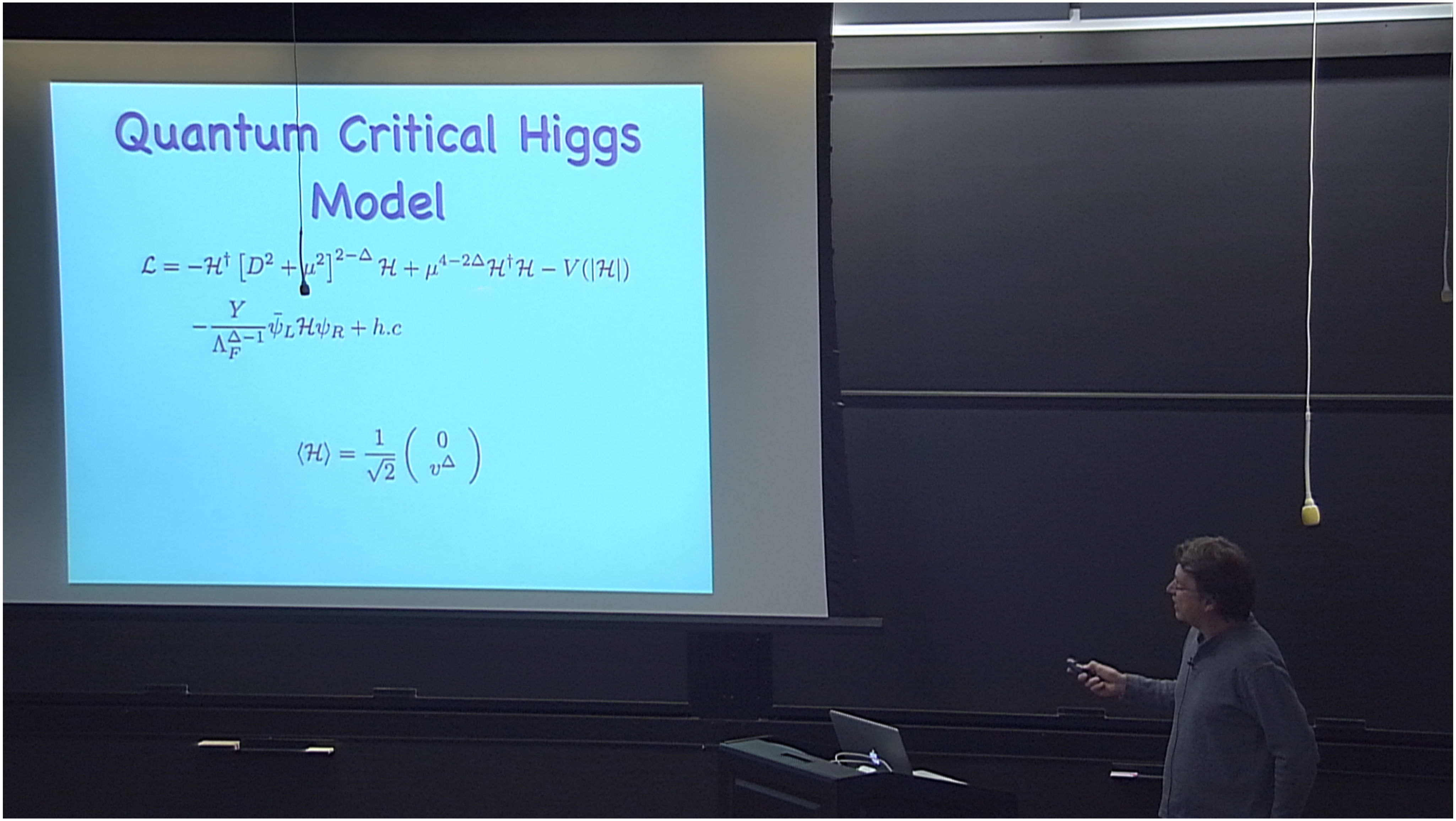
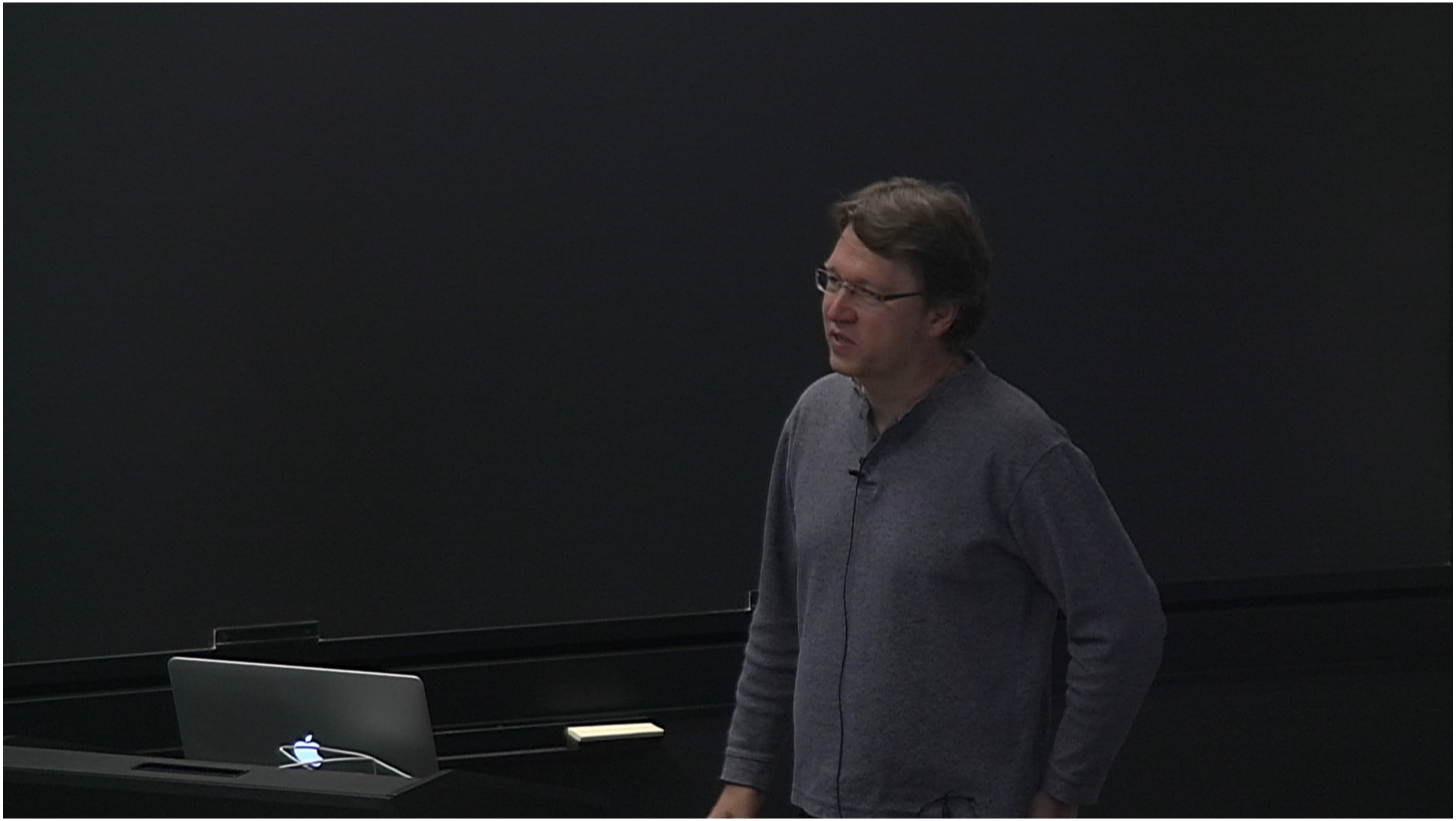
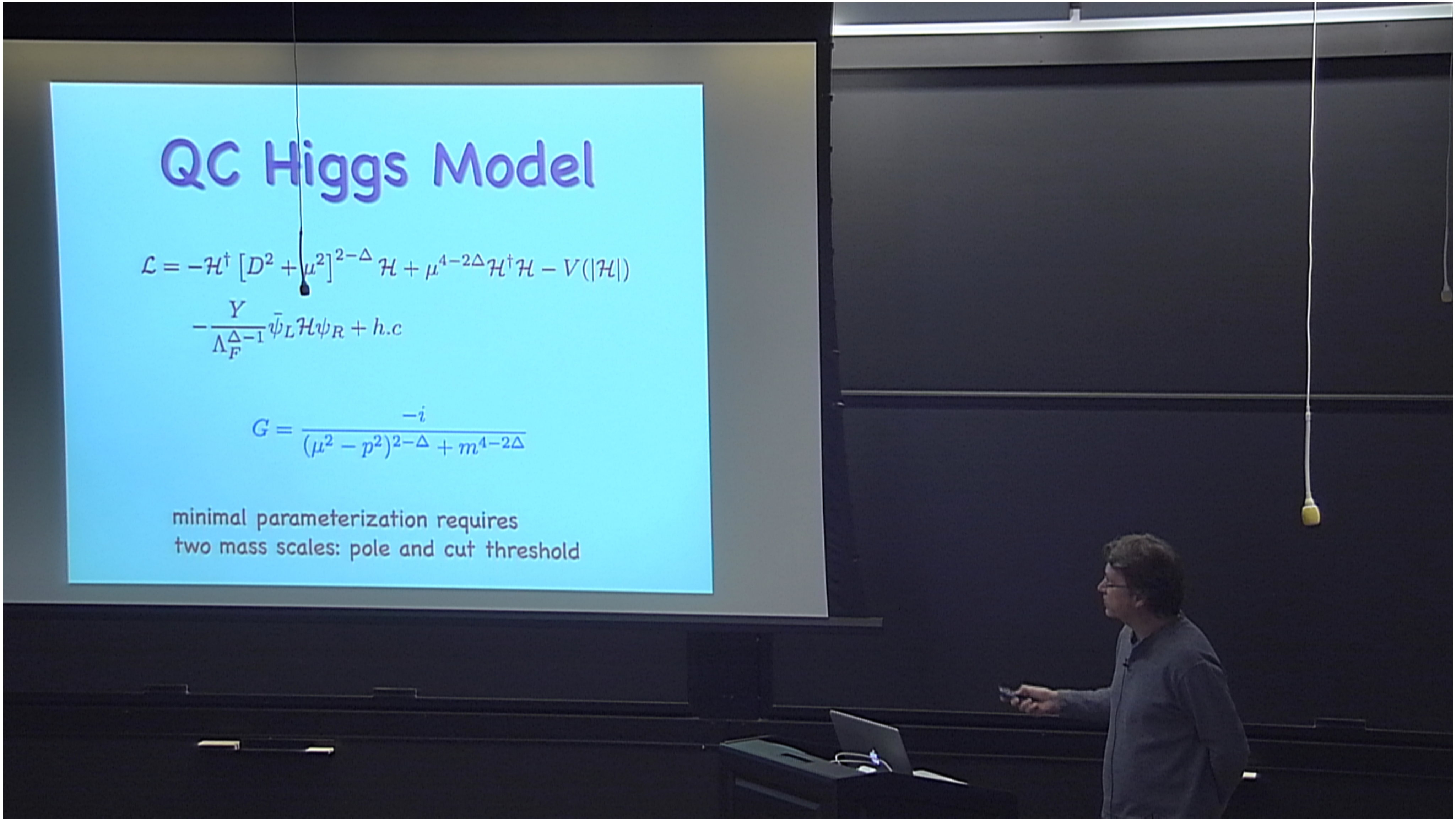
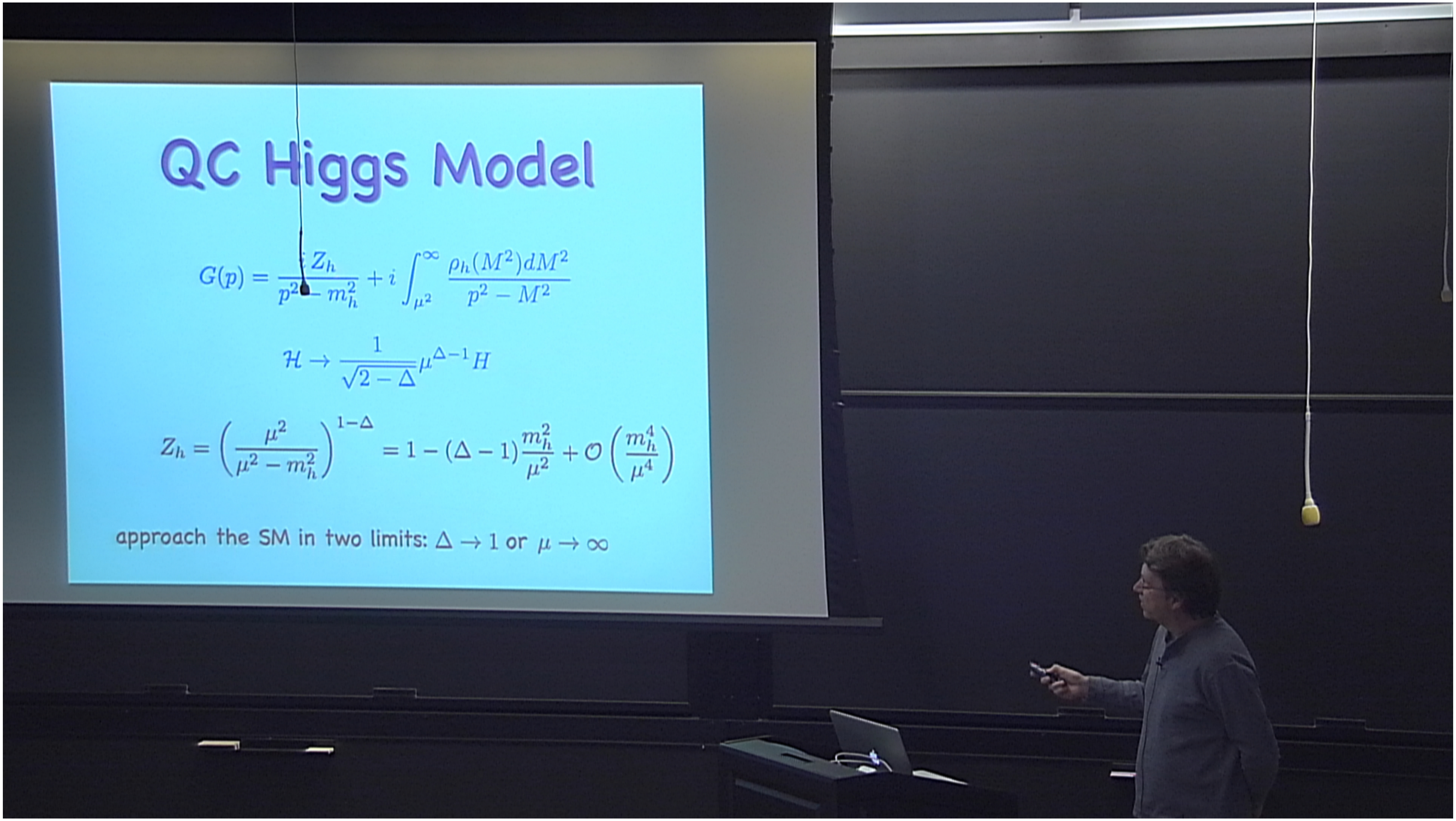
$$= \frac{2p^\alpha + q^\alpha}{2p \cdot q + q^2}\left[\left(\mu^2 - (p+q)^2\right)^{2-\Delta} - \left(\mu^2 - p^2\right)^{2-\Delta}\right]$$

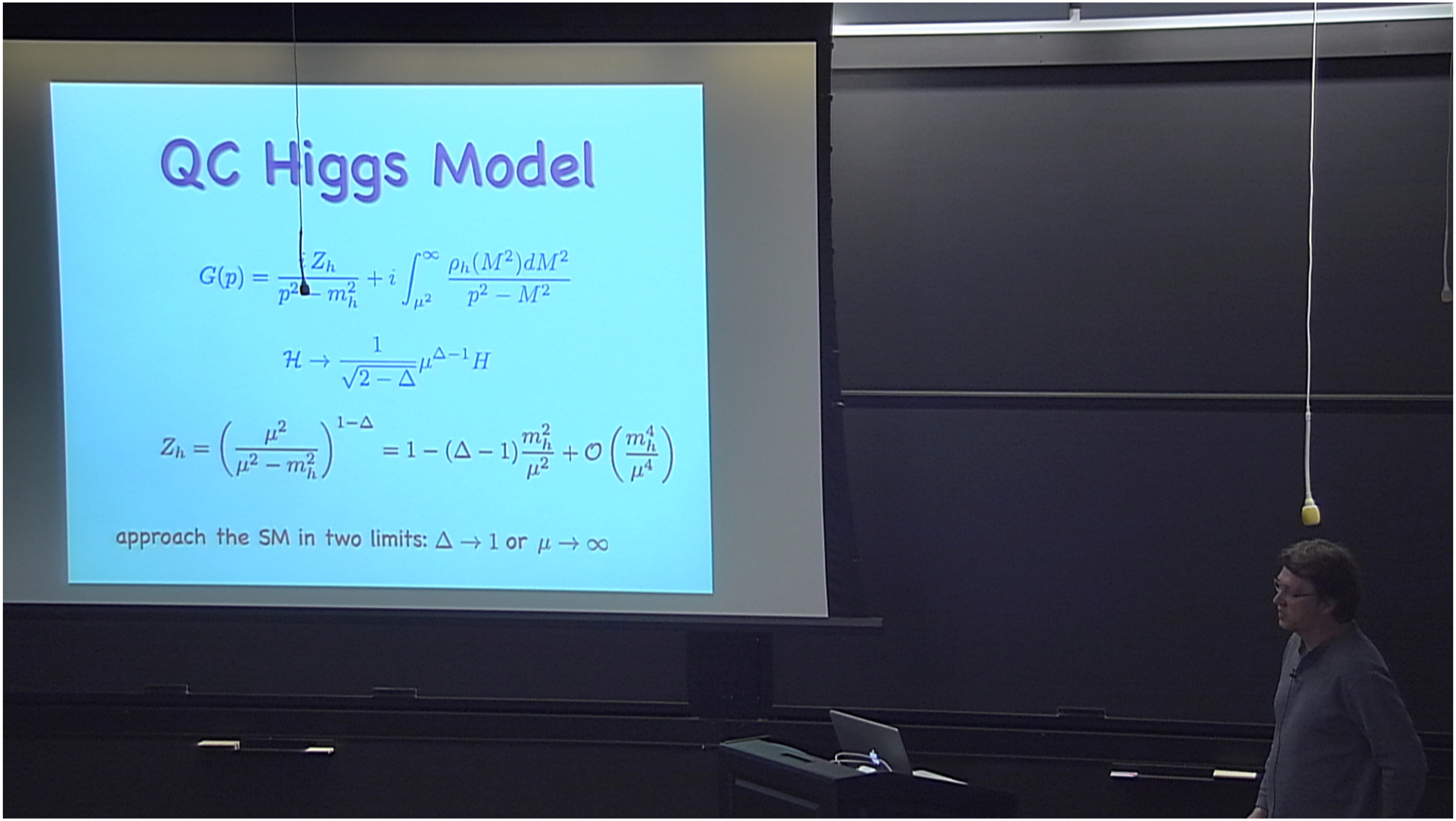

Ward-Takahashi Identity
$ig\Gamma^{a\alpha}(p,q) = \frac{2p^\alpha + q^\alpha}{2p\cdot q + q^2}\left[\left(\mu^2-(p+q)^2\right)^{2-\Delta} - \left(\mu^2-p^2\right)^{2-\Delta}\right]$
$iq_\mu\Gamma^{a\mu} = G^{-1}(p+q)T^a - T^a G^{-1}(p)$


Quantum Critical Higgs Model
$\mathcal{L} = -\mathcal{H}^\dagger \left[D^2 + \mu^2\right]^{2-\Delta} \mathcal{H} + \mu^{4-2\Delta}\mathcal{H}^\dagger\mathcal{H} - V(|\mathcal{H}|)$
$-\frac{Y}{\Lambda_F^{\Delta-1}}\bar{\psi}_L \mathcal{H} \psi_R + h.c$
$\langle \mathcal{H} \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v^\Delta \end{pmatrix}$




QC Higgs Model
$\mathcal{L} = -\mathcal{H}^\dagger \left[D^2 + \mu^2\right]^{2-\Delta} \mathcal{H} + \mu^{4-2\Delta}\mathcal{H}^\dagger\mathcal{H} - V(|\mathcal{H}|)$
$-\frac{Y}{\Lambda_F^{\Delta-1}}\bar{\psi}_L \mathcal{H} \psi_R + h.c$
$G = \frac{-i}{(\mu^2 - p^2)^{2-\Delta} + m^{4-2\Delta}}$
minimal parameterization requires
two mass scales: pole and cut threshold


QC Higgs Model
$G(p) = \frac{i Z_h}{p^2 - m_h^2} + i \int_{\mu^2}^{\infty} \frac{\rho_h(M^2) dM^2}{p^2 - M^2}$
$\mathcal{H} \to \frac{1}{\sqrt{2-\Delta}} \mu^{\Delta - 1} H$
$Z_h = \left(\frac{\mu^2}{\mu^2 - m_h^2} \right)^{1-\Delta} = 1 - (\Delta - 1) \frac{m_h^2}{\mu^2} + \mathcal{O}\left(\frac{m_h^4}{\mu^4} \right)$
approach the SM in two limits: $\Delta \to 1$ or $\mu \to \infty$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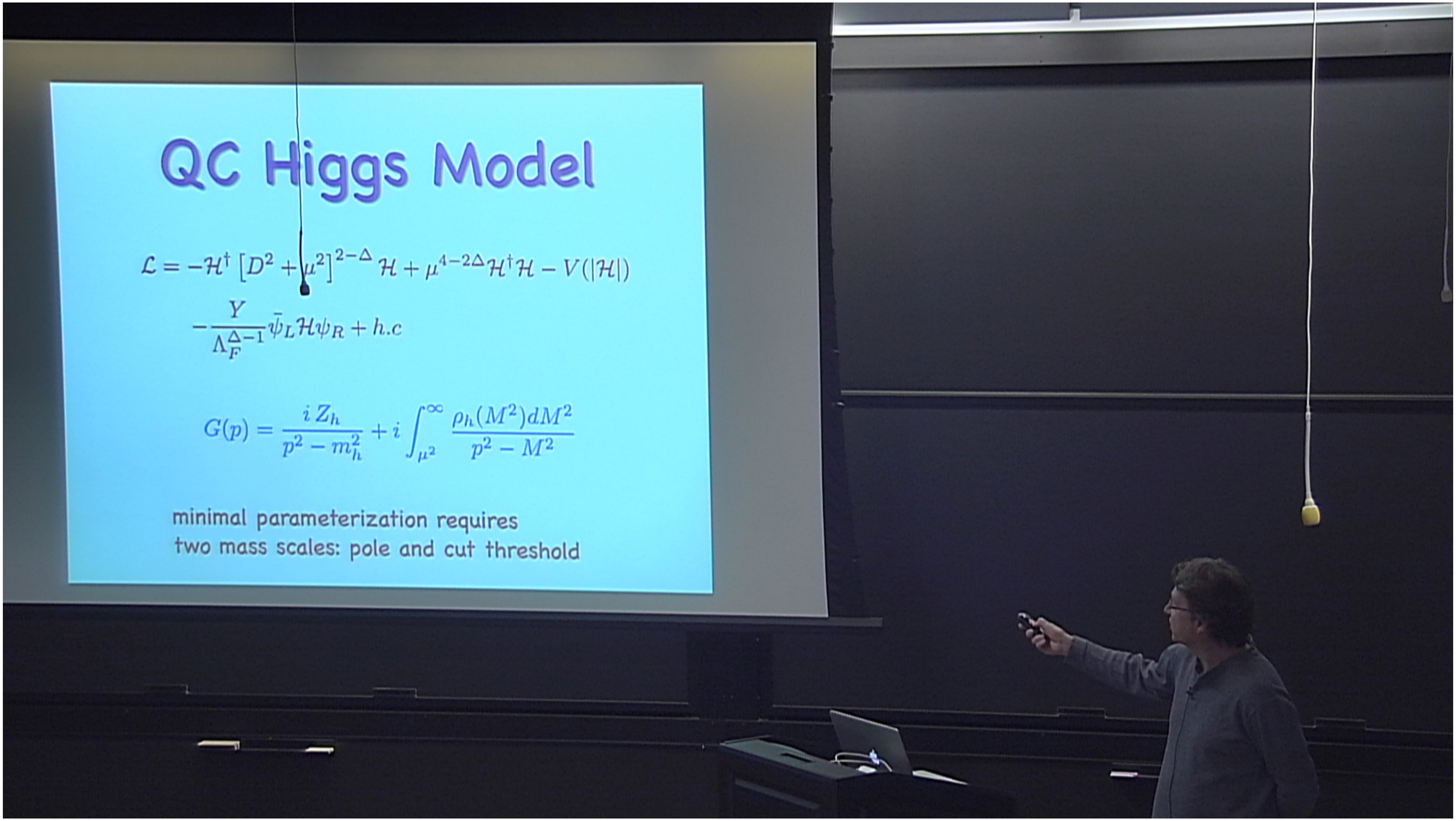
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minimal parameterization requires
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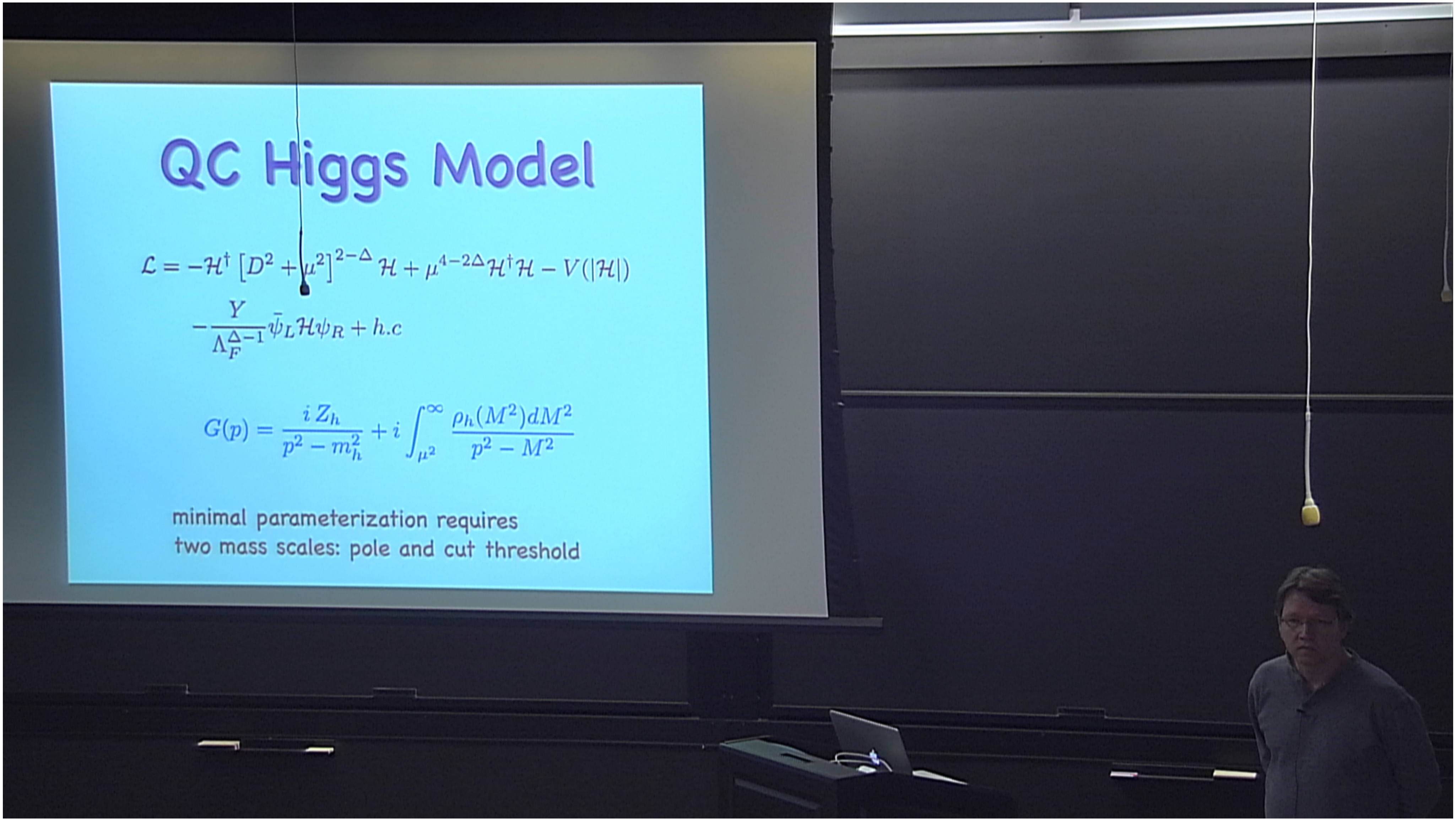
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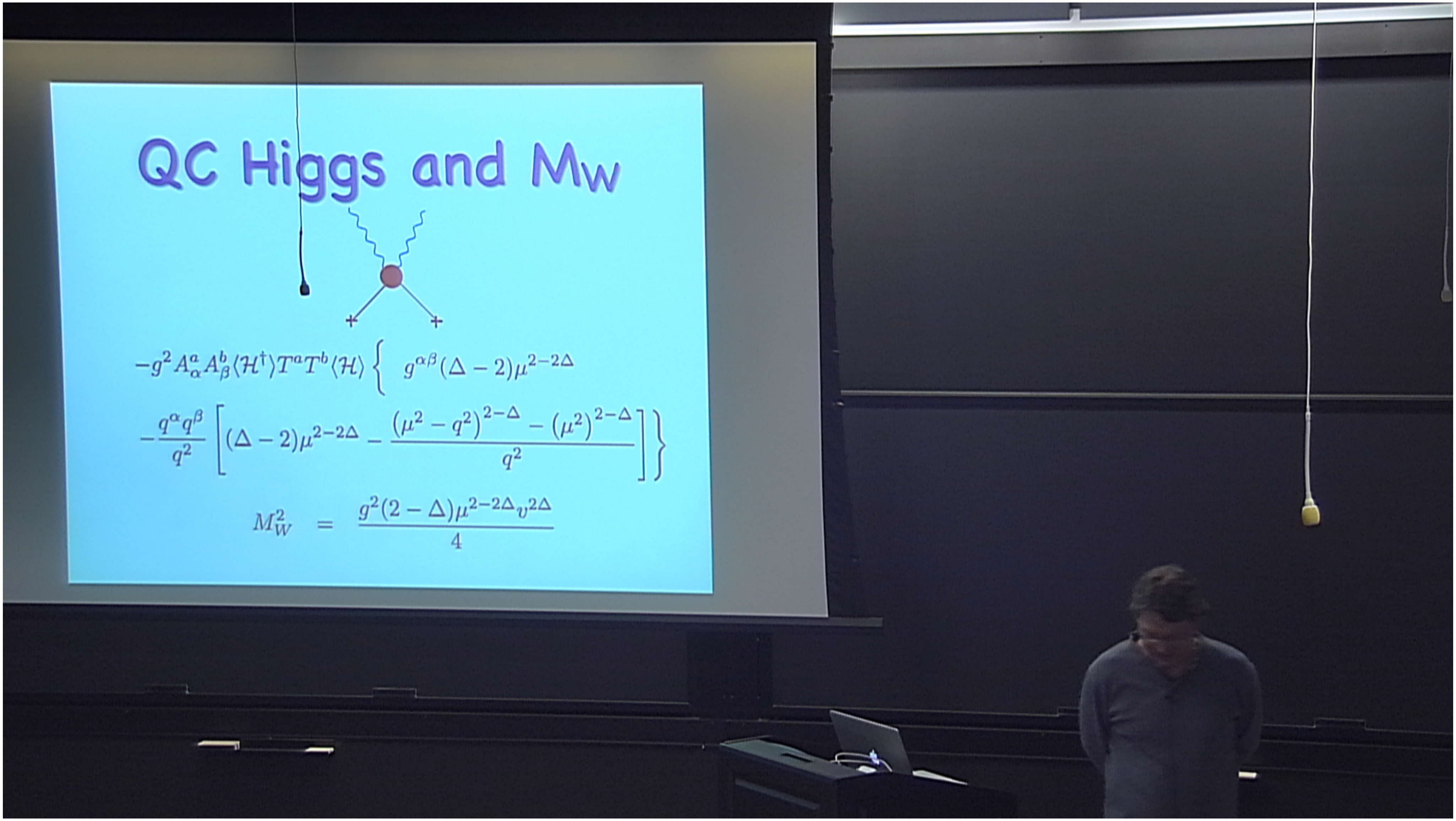
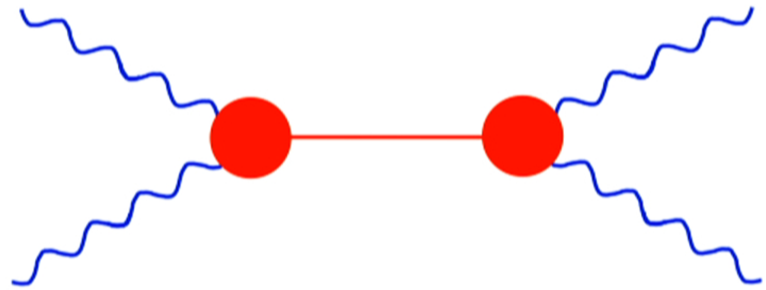

QC Higgs and M_W
$-g^2 A^a_\alpha A^b_\beta \langle \mathcal{H}^\dagger \rangle T^a T^b \langle \mathcal{H} \rangle \Big\{ \; g^{\alpha\beta}(\Delta - 2)\mu^{2-2\Delta}$
$-\frac{q^\alpha q^\beta}{q^2}\left[(\Delta-2)\mu^{2-2\Delta} - \frac{(\mu^2-q^2)^{2-\Delta} - (\mu^2)^{2-\Delta}}{q^2}\right]\Big\}$
$M_W^2 \;=\; \frac{g^2(2-\Delta)\mu^{2-2\Delta}v^{2\Delta}}{4}$

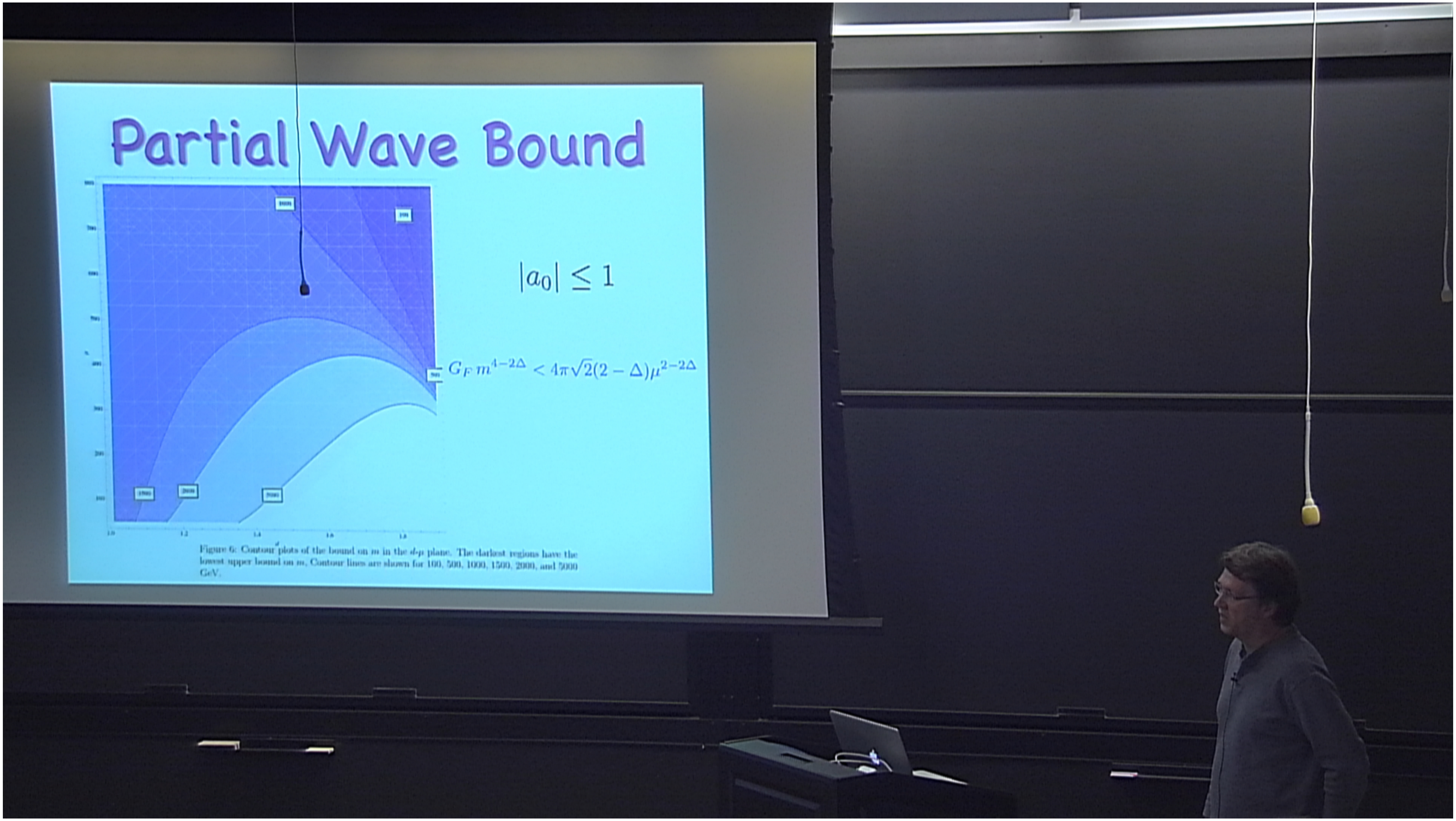
WW Scattering



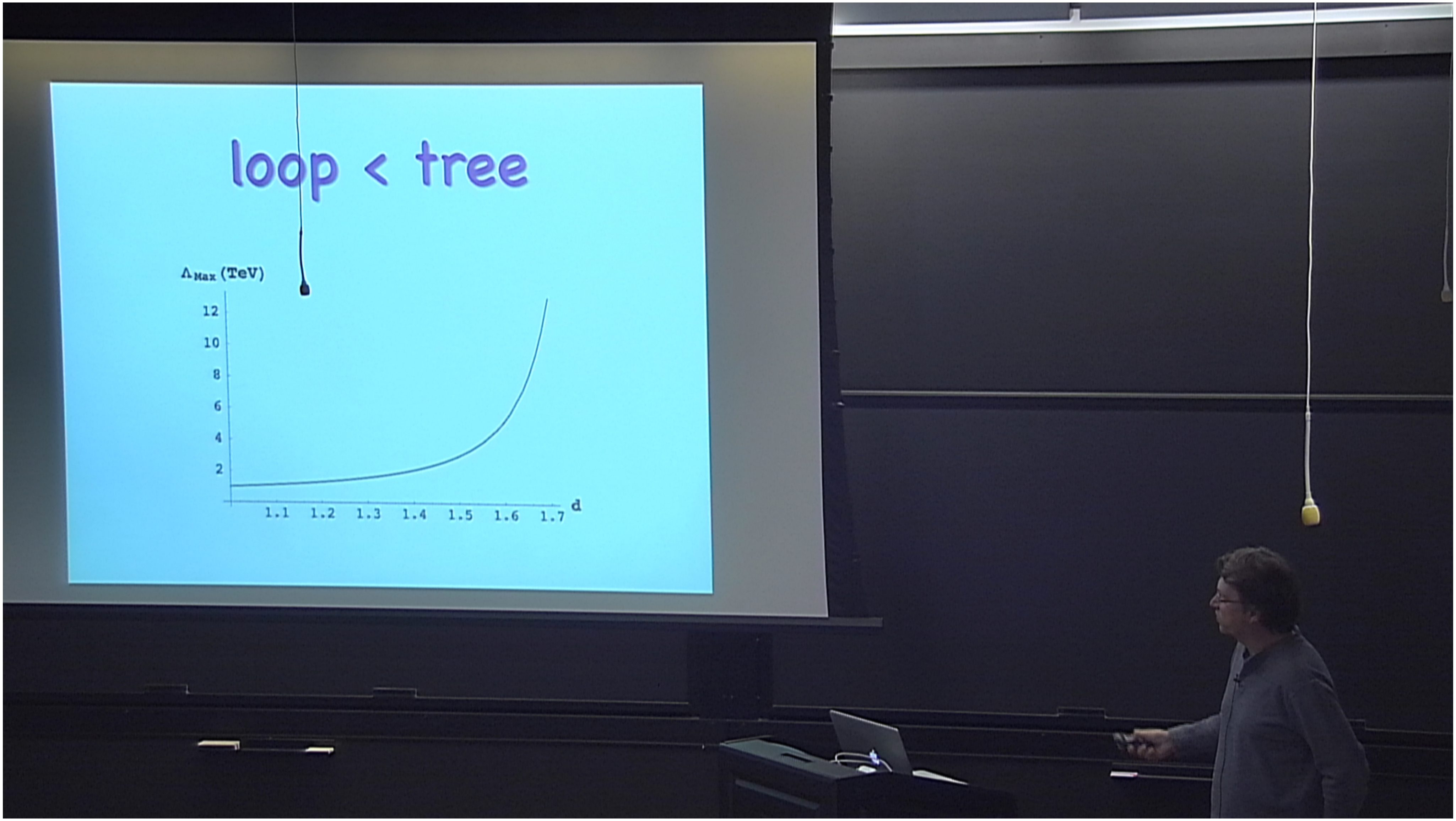
at large s

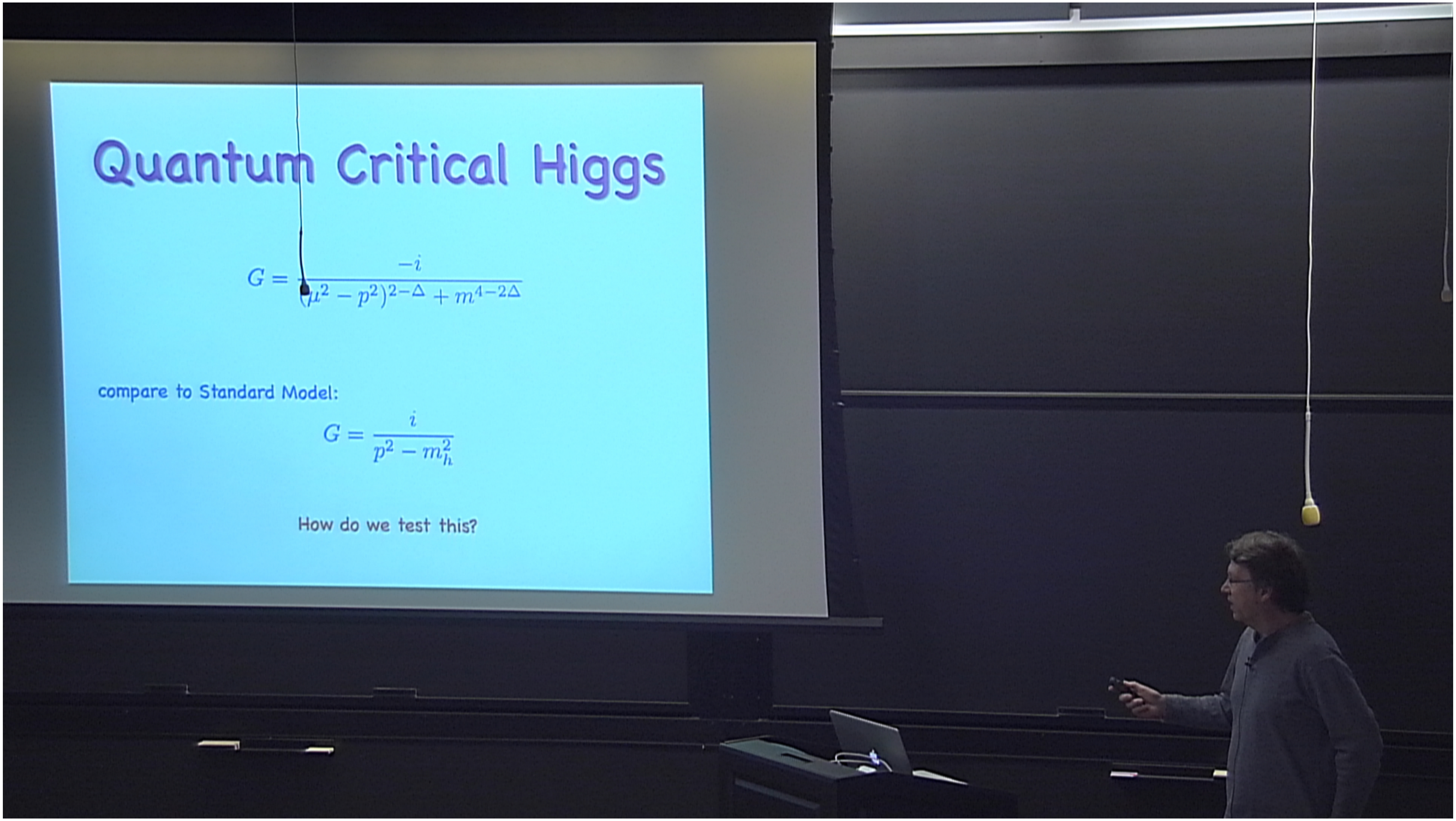
$$\mathcal{M}_h = -i\frac{g^4}{4M_W^2(2-\Delta)\mu^{2-2\Delta}}(-s)^{2-\Delta}$$

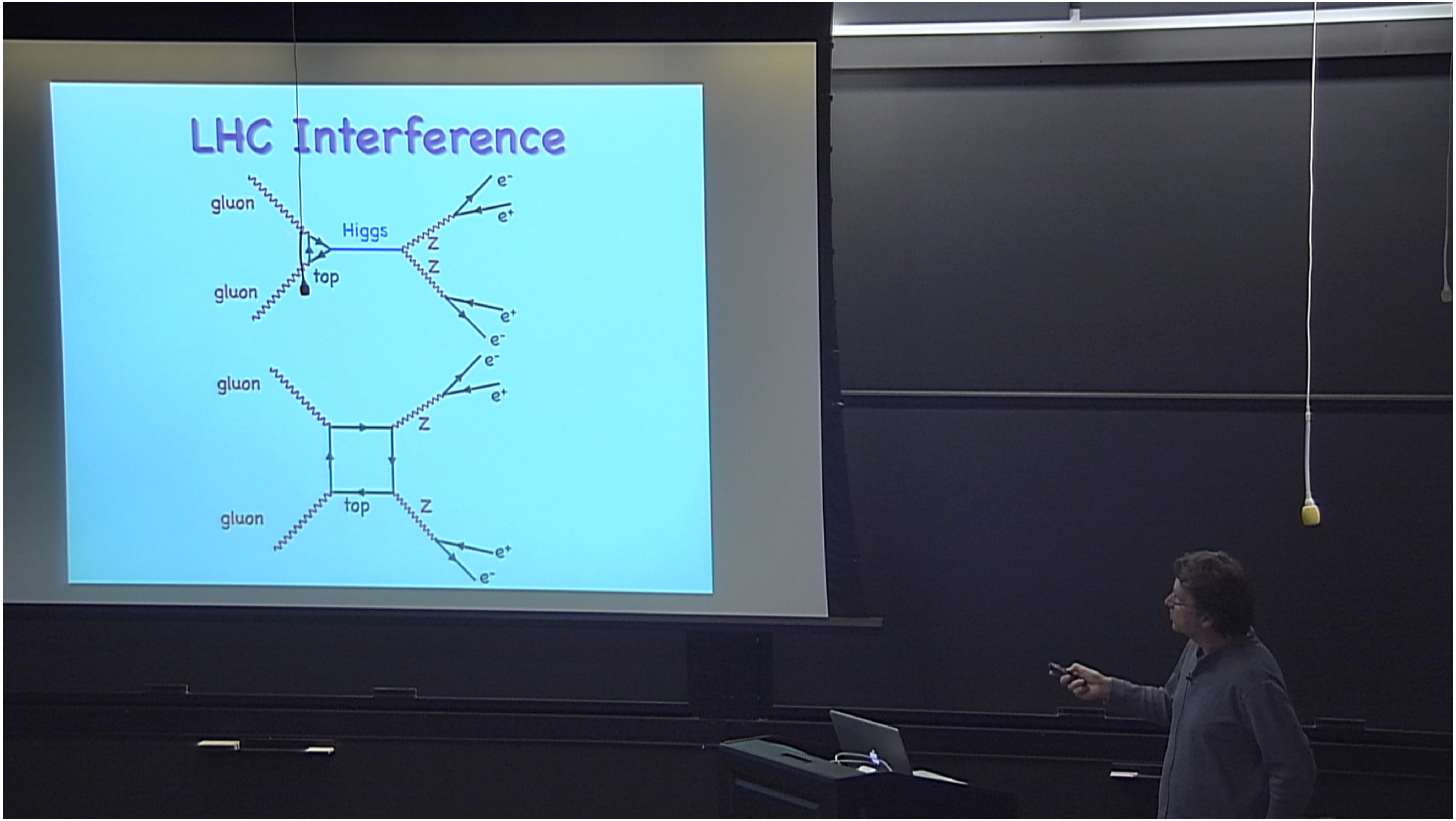
QC Higgs exchange is insufficient
to unitarize WW scattering



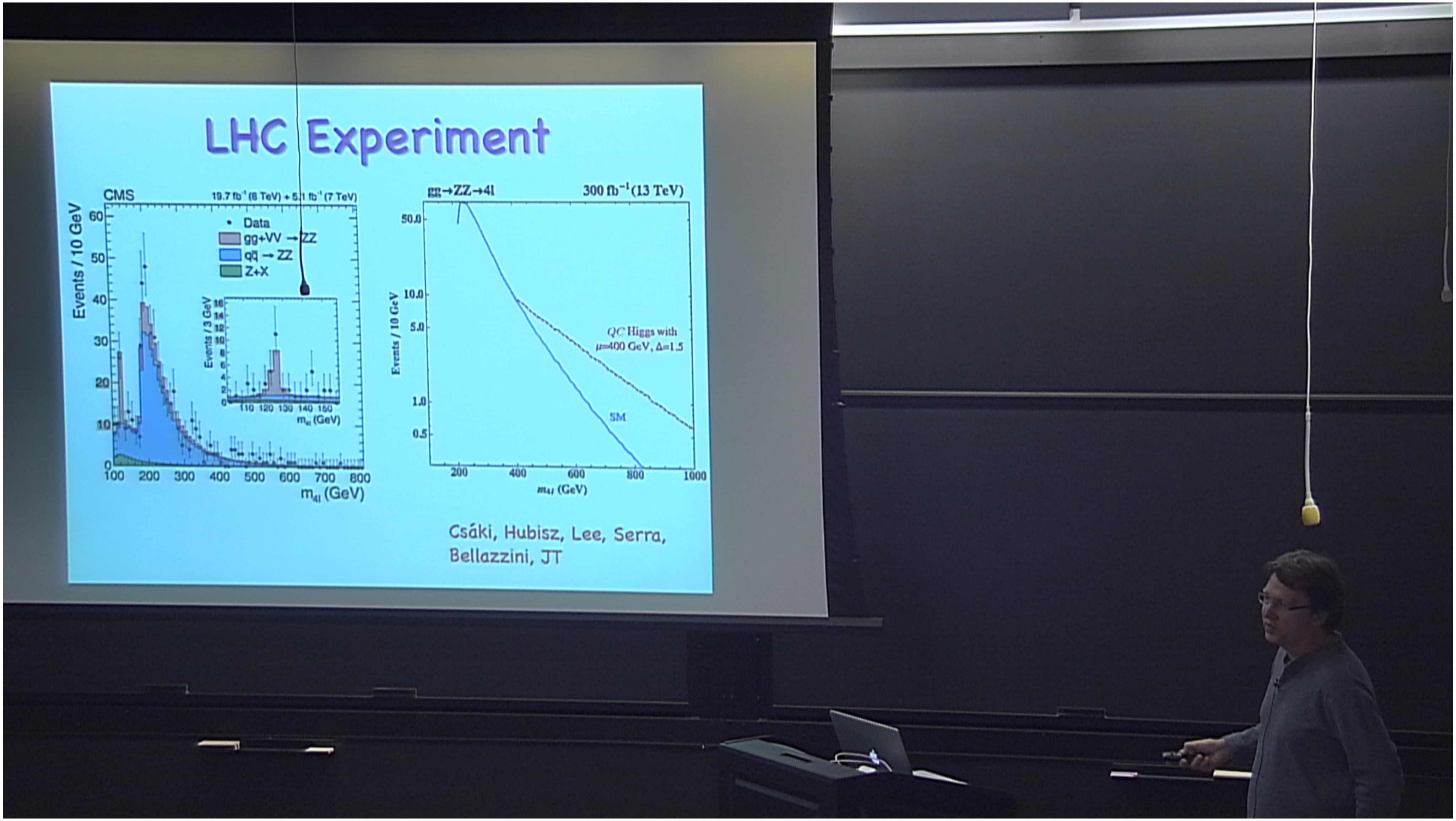
Partial Wave Bound
$|a_0| \leq 1$
$G_F\, m^{4-2\Delta} < 4\pi\sqrt{2}(2-\Delta)\mu^{2-2\Delta}$
Figure 6: Contour plots of the bound on m in the d-μ plane. The darkest regions have the lowest upper bound on m. Contour lines are shown for 100, 500, 1000, 1500, 2000, and 5000 GeV.


loop < tree
Λ Max (TeV)
12
10
8
6
4
2
1.1 1.2 1.3 1.4 1.5 1.6 1.7
d


Quantum Critical Higgs
$G = \frac{-i}{(\mu^2 - p^2)^{2-\Delta} + m^{4-2\Delta}}$
compare to Standard Model:
$G = \frac{i}{p^2 - m_h^2}$
How do we test this?



LHC Interference
gluon
gluon
Higgs
top
Z
Z
e⁻
e⁺
e⁺
e⁻
gluon
gluon
top
Z
Z
e⁻
e⁺
e⁺
e⁻


LHC Experiment
CMS
19.7 fb⁻¹ (8 TeV) + 5.1 fb⁻¹ (7 TeV)
Data
gg+VV → ZZ
qq̄ → ZZ
Z+X
Events / 10 GeV
Events / 3 GeV
m4l (GeV)
gg→ZZ→4l
300 fb⁻¹(13 TeV)
Events / 10 GeV
QC Higgs with
μ=400 GeV, Δ=1.5
SM
m4l (GeV)
Csáki, Hubisz, Lee, Serra,
Bellazzini, JT