Title: Lecture - Beautiful Papers

Speakers: Pedro Vieira

Collection/Series: Beautiful Papers - October 7, 2024 - January 31, 2025

Subject: Other

Date: November 15, 2024 - 9:15 AM

URL: https://pirsa.org/24110034

Nuclear From Ch. Lagr.

- Can you bound states and binding Energ

$$(H_0 + V)\psi = i\hbar \partial_t \psi$$

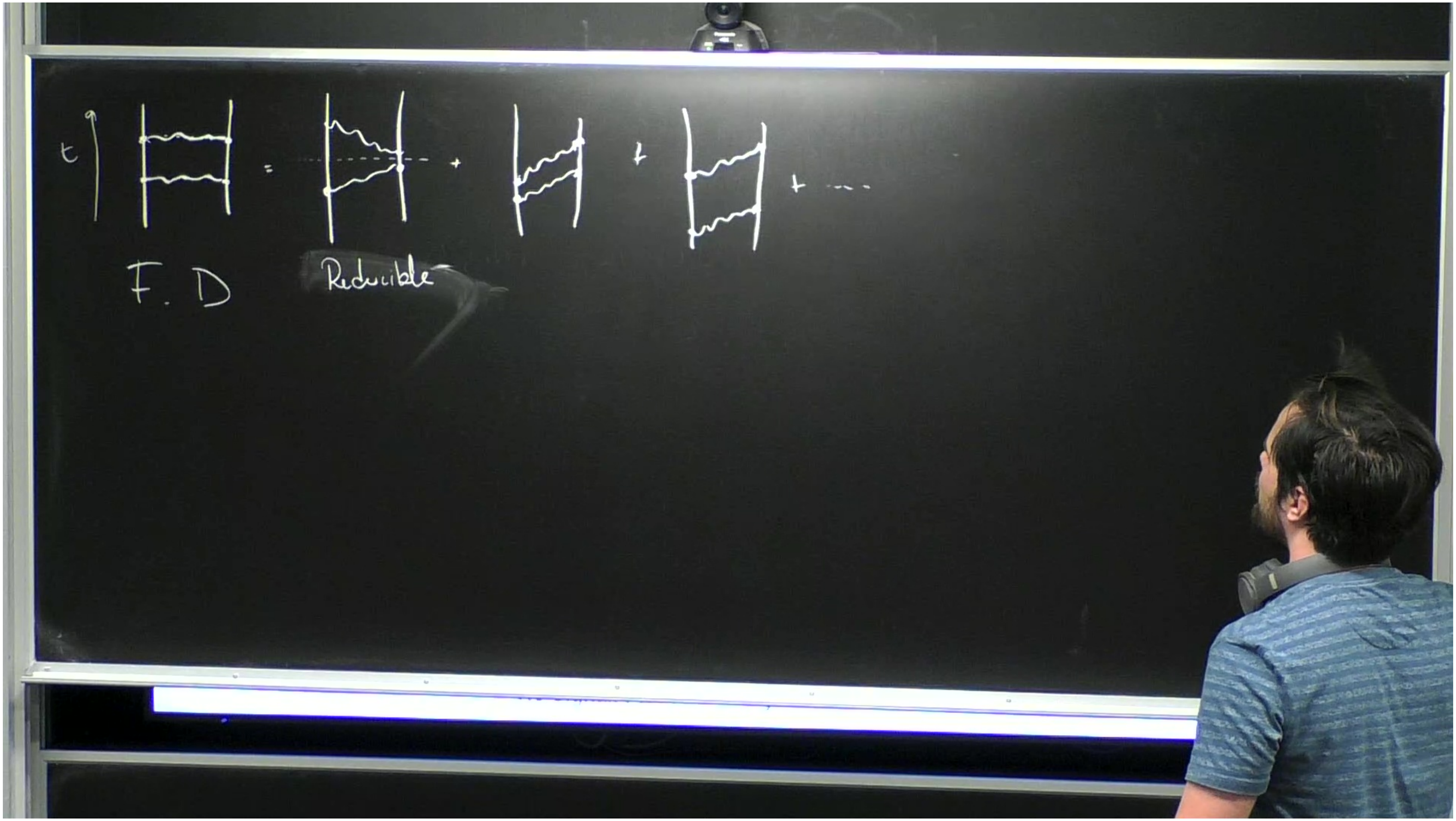
- Use chiral Lag. to constrain V.

$$\mathcal{L} = D_\mu \vec{\pi} \cdot D^\mu \vec{\pi} + D^4 + D^6 + \cdots \quad ; \quad N = \begin{bmatrix} p \\ n \end{bmatrix}$$

$$+ \bar{N}(\not{D} + m + g \not{D}\vec{\pi} \cdot \vec{\tau} \gamma_5) N + \cdots$$

$$\delta N = (\epsilon \times \frac{\vec{\pi}}{F}) \cdot \vec{\tau} N$$

$$\delta D N = (\epsilon \times \frac{\vec{\pi}}{F}) \cdot t D_\mu N$$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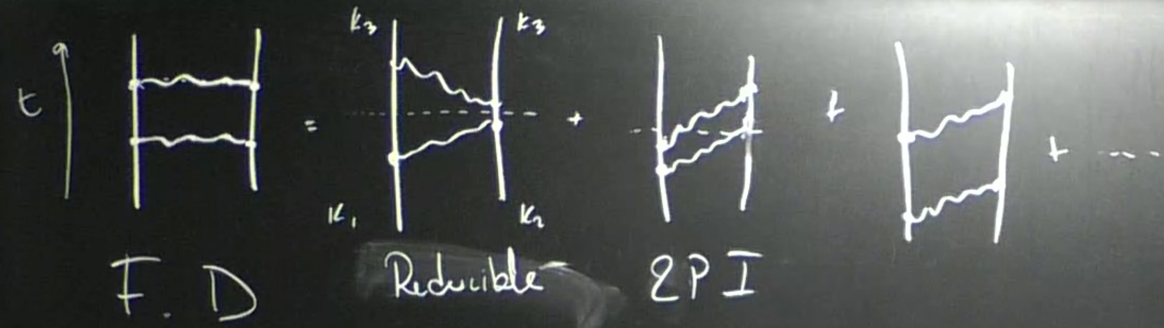

$$(2PI) = f(k_1 \cdots k_4) = \langle k_4\, k_3 |\, V^{(2)} \,| k_1\, k_2 \rangle$$

– Use chiral Lag. to constrain V.

$$D_\mu \pi = \frac{\partial_\mu \pi}{1+\pi^2} = \partial_\mu \pi + \cdots$$

$$\mathcal{L} = D_\mu \vec{\pi} \cdot D^\mu \vec{\pi} + D^4 + D^6 + \cdots \quad ; \quad N = \begin{bmatrix} p \\ n \end{bmatrix}$$

$$+ \bar{N}(\not{D} + m + g \not{D}\vec{\pi} \cdot \vec{\tau}\, \gamma_5) N + \cdots$$

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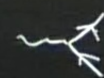

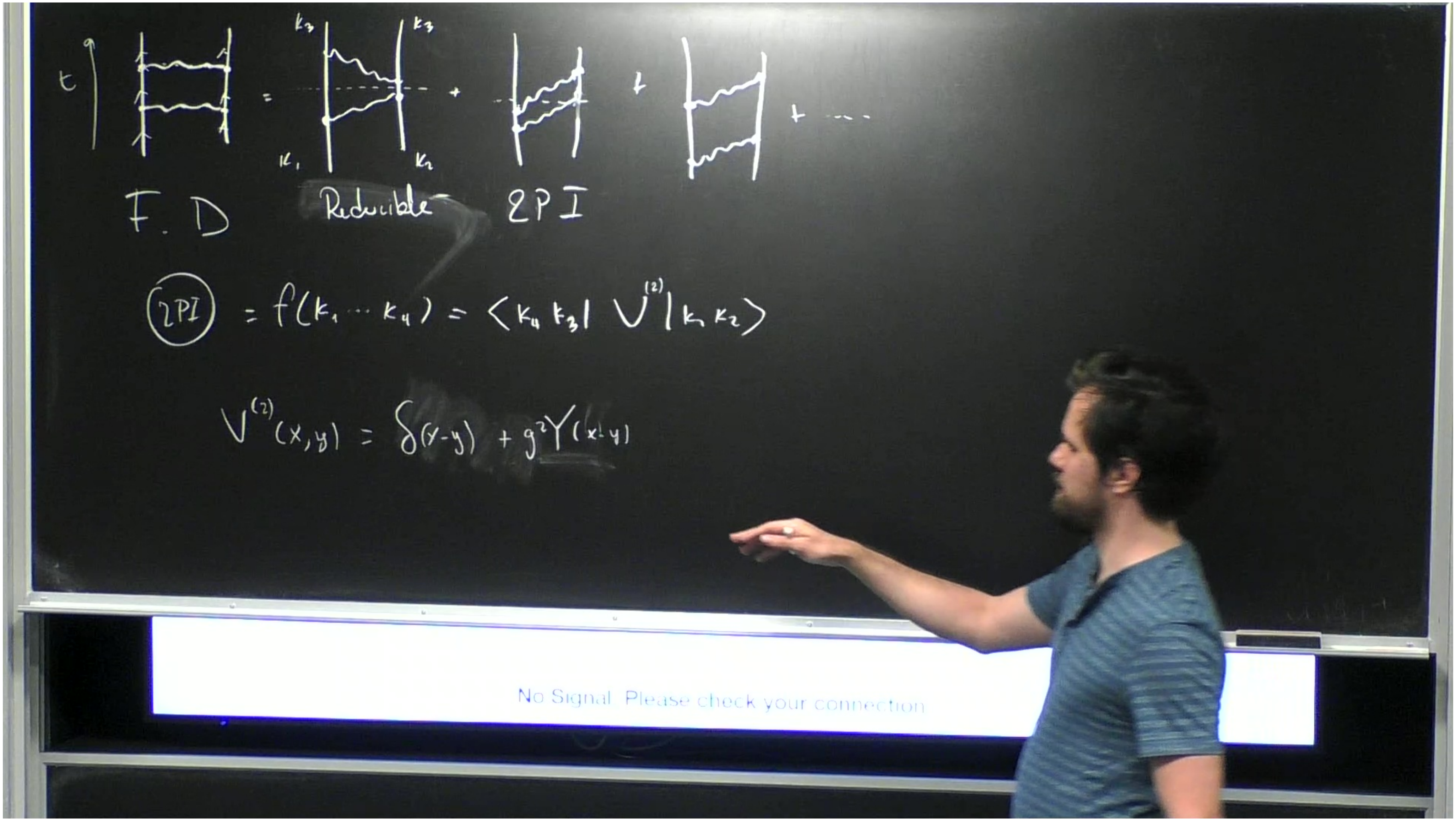
t
k_3
k_3
k_1
k_2
F. D
Reducible
2PI
2PI $= f(k_1 \cdots k_4) = \langle k_4\, k_3 | V^{(2)} | k_1\, k_2 \rangle$
$V^{(2)}(x,y) = \delta(x-y) + g^2 Y(x-y)$
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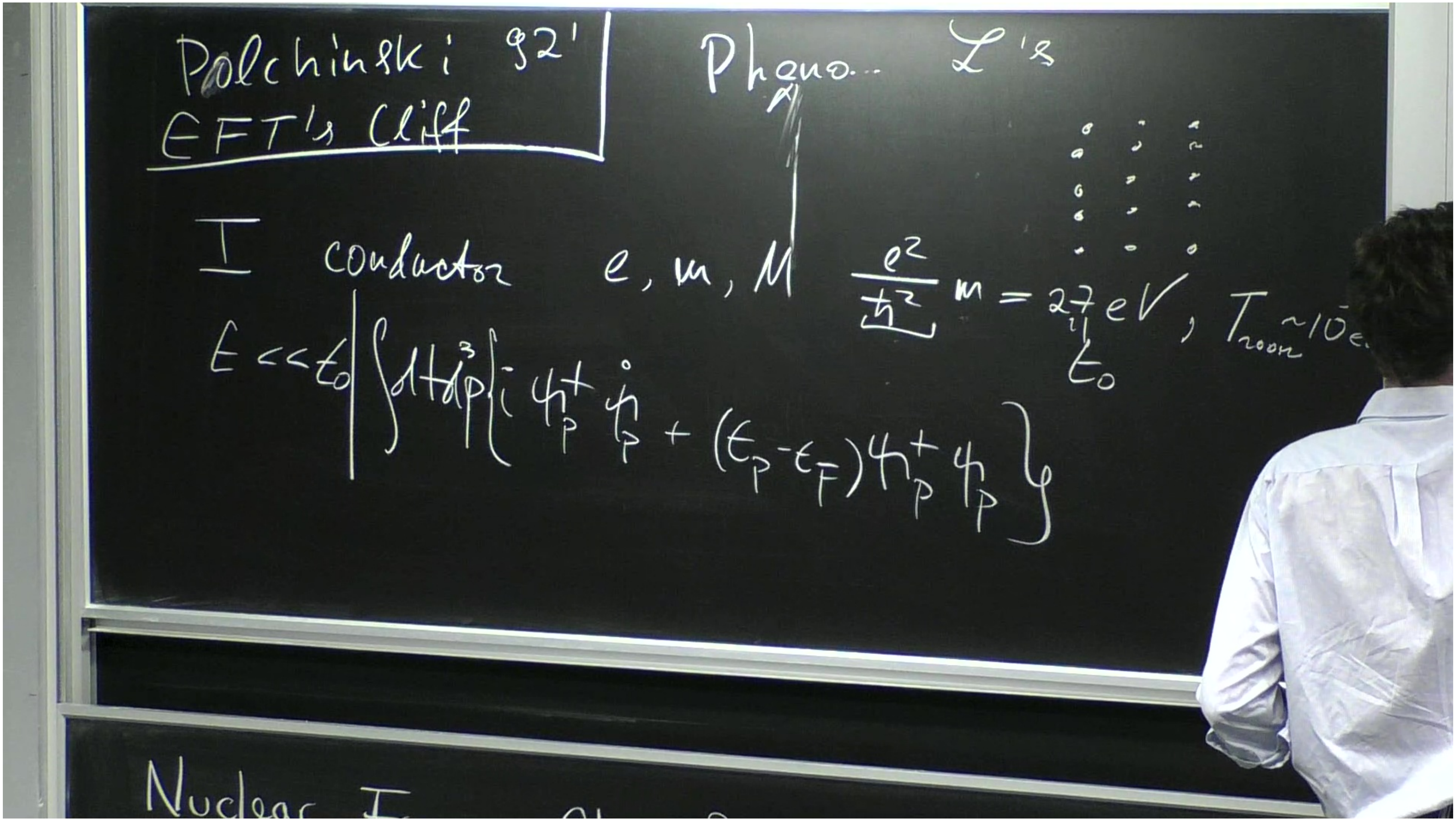


Polchinski 92'
EFT's Cliff
Phono... $\mathcal{L}$'s
I conductor e, m, M
$\frac{e^2}{\hbar^2} m = 27\,eV$, $T_{room} \sim 10^{-}$
ϵ_0
$E \ll \epsilon_0$
$\int dt\, d^3p \{ i\, \psi_p^\dagger \dot{\psi}_p + (\epsilon_p - \epsilon_F) \psi_p^\dagger \psi_p \}$
Nuclear

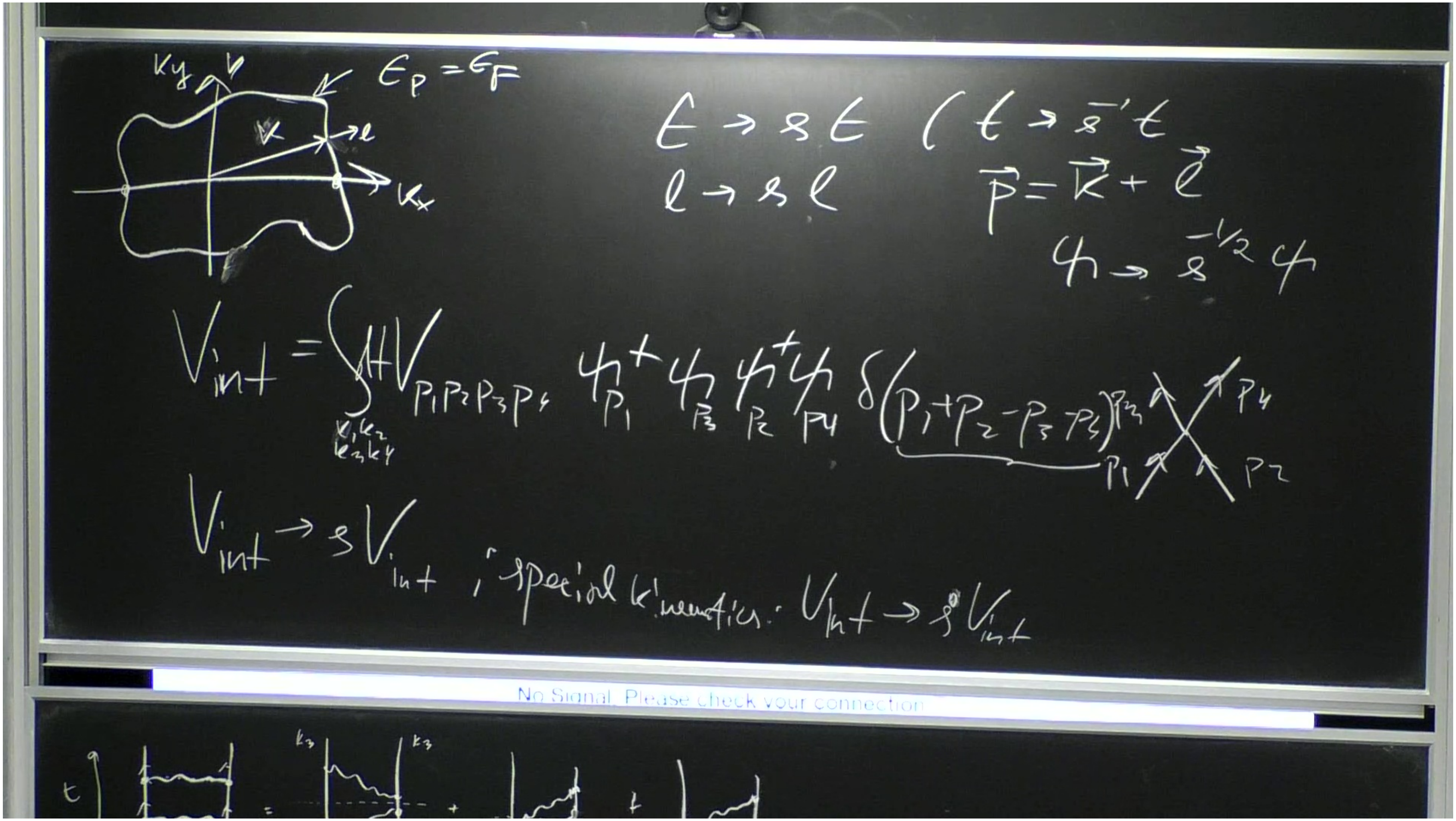
Polchinski 92'
EFT's Cliff

Pheno... $\mathcal{L}$'s

I conductor e, m, M $\quad \frac{e^2}{\hbar^2} m = \underset{\epsilon_0}{27}\, eV$, $T_{room} \sim 10^{-2} eV$

$E \ll \epsilon_0$ $\quad \int dt\, d^3p \left\{ i \psi_p^\dagger \dot{\psi}_p + (\epsilon_p - \epsilon_F) \psi_p^\dagger \psi_p \right\}$

Nuclear


k_y
k_x
$\epsilon_p = \epsilon_F$
$\epsilon \to s\,\epsilon \quad (t \to s^{-1} t$
$\ell \to s\,\ell$
$\vec{p} = \vec{k} + \vec{\ell}$
$\psi \to s^{-1/2}\,\psi$
$V_{int} = \int_{k_1 k_2 k_3 k_4} dt\, V_{p_1 p_2 p_3 p_4}\, \psi^{+}_{p_1} \psi_{p_3} \psi^{+}_{p_2} \psi_{p_4}\, \delta(p_1 + p_2 - p_3 - p_4)$
p_1 p_2 p_3 p_4
$V_{int} \to s\, V_{int}$; special kinematics: $V_{int} \to s^0\, V_{int}$
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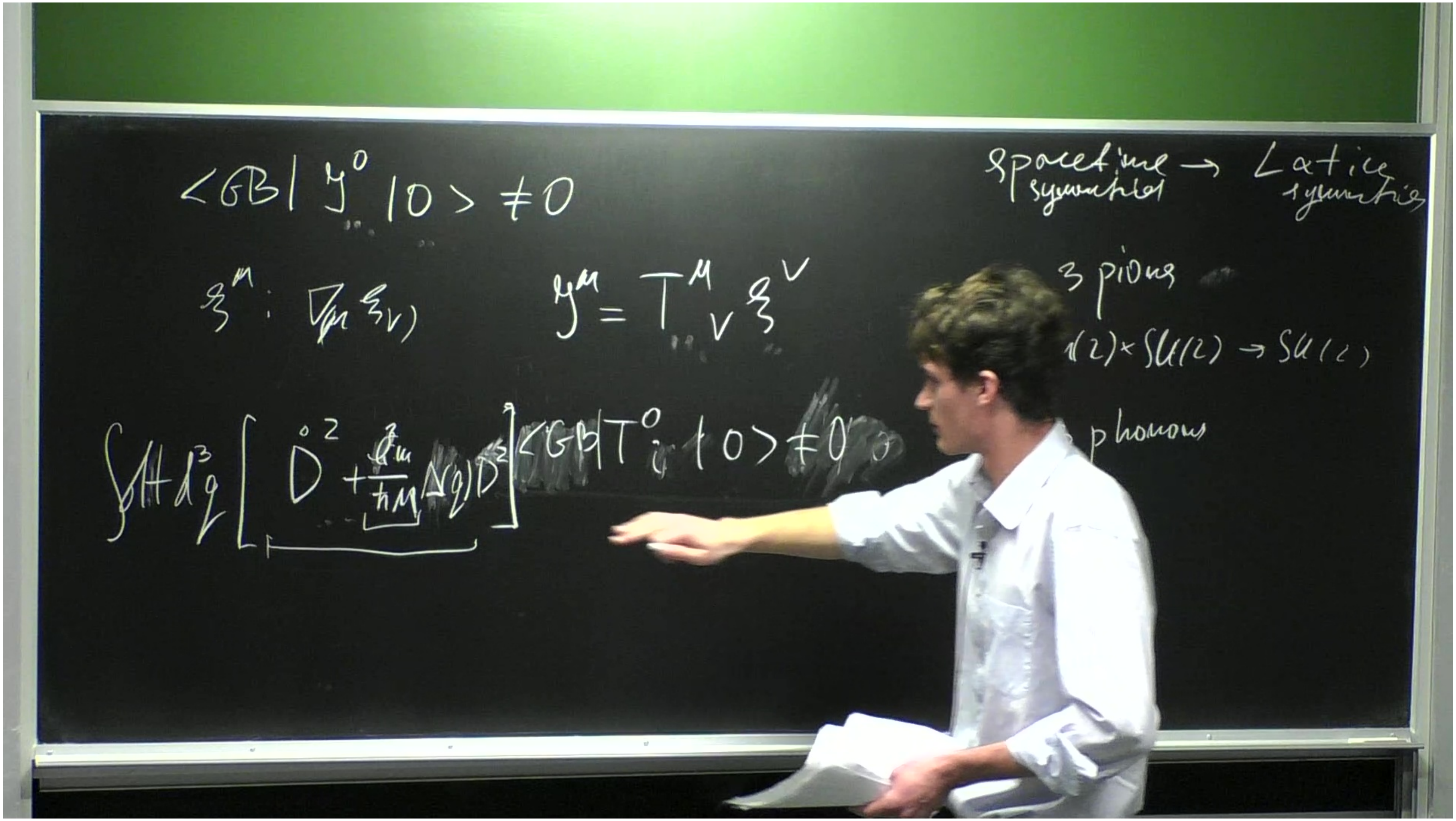
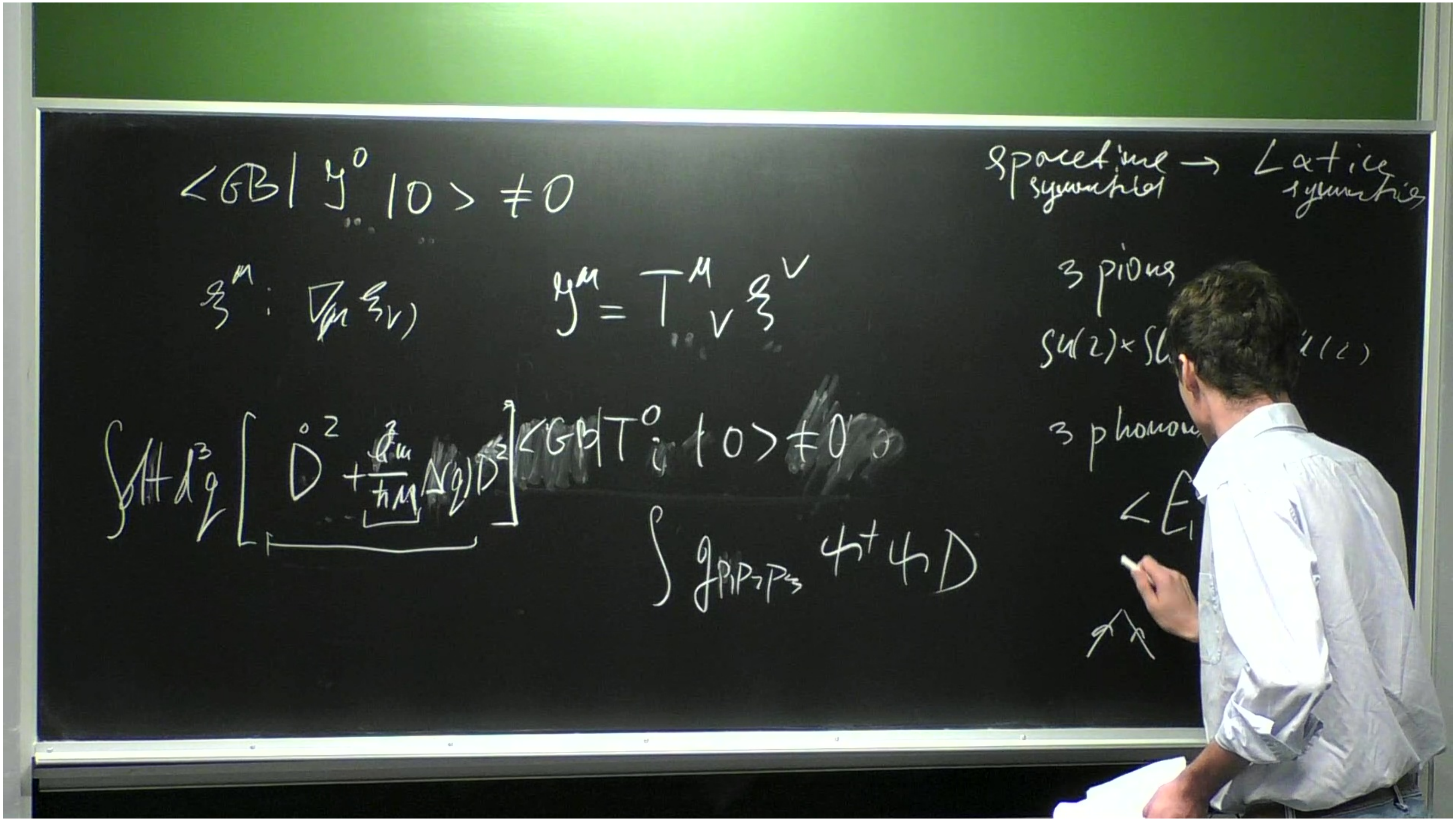


<GB| j^0 |0> ≠ 0
ξ^μ : ∇_(μ ξ_ν)
j^μ = T^μ_ν ξ^ν
<GB| T^0_i |0> ≠ 0
spacetime symmetries → Lattice symmetries
3 pions
phonons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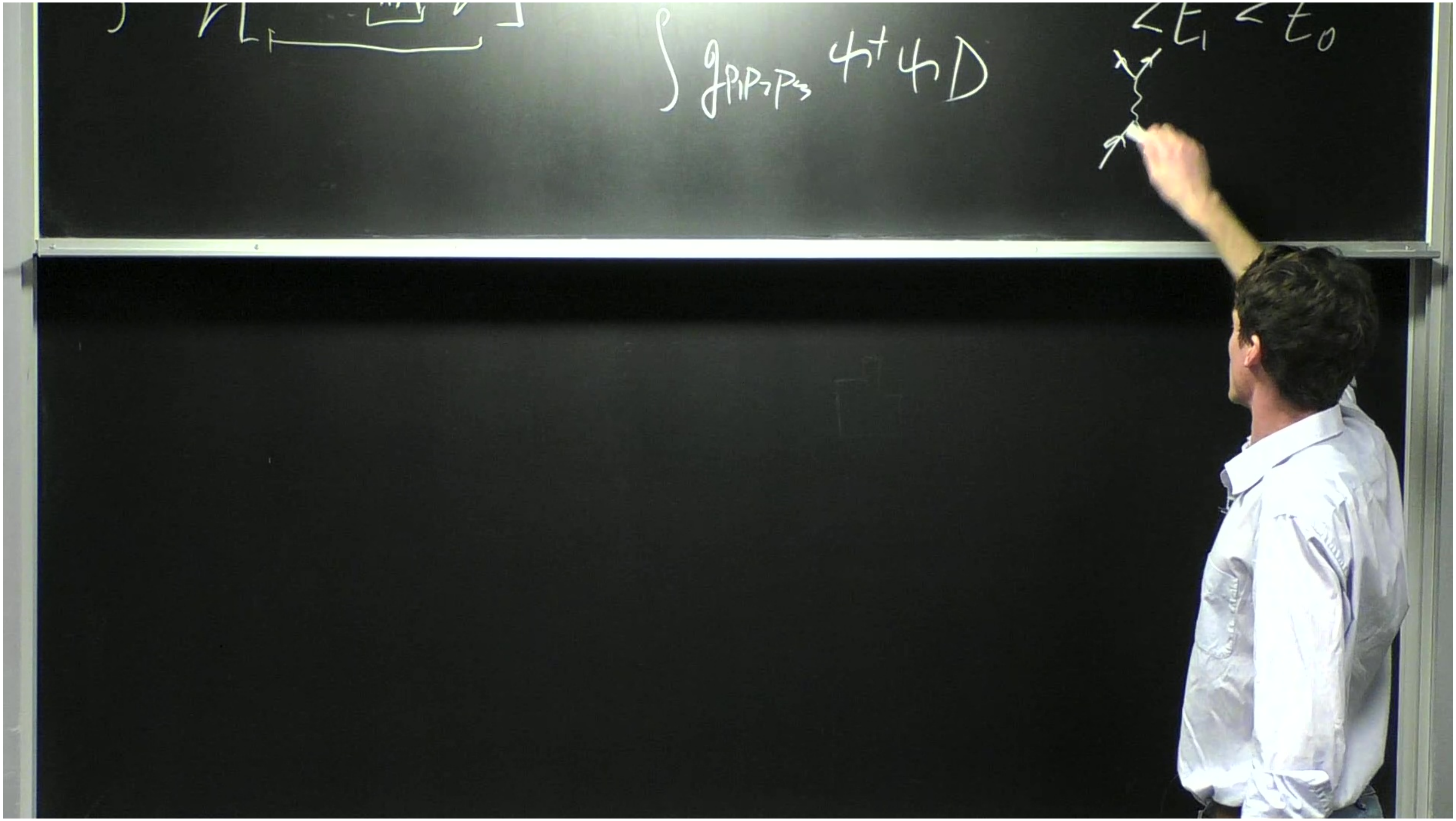

$\int g_{p_1 p_2 p_3} \psi^\dagger \psi D$
$< E_1 < E_0$

EFT's Cliff

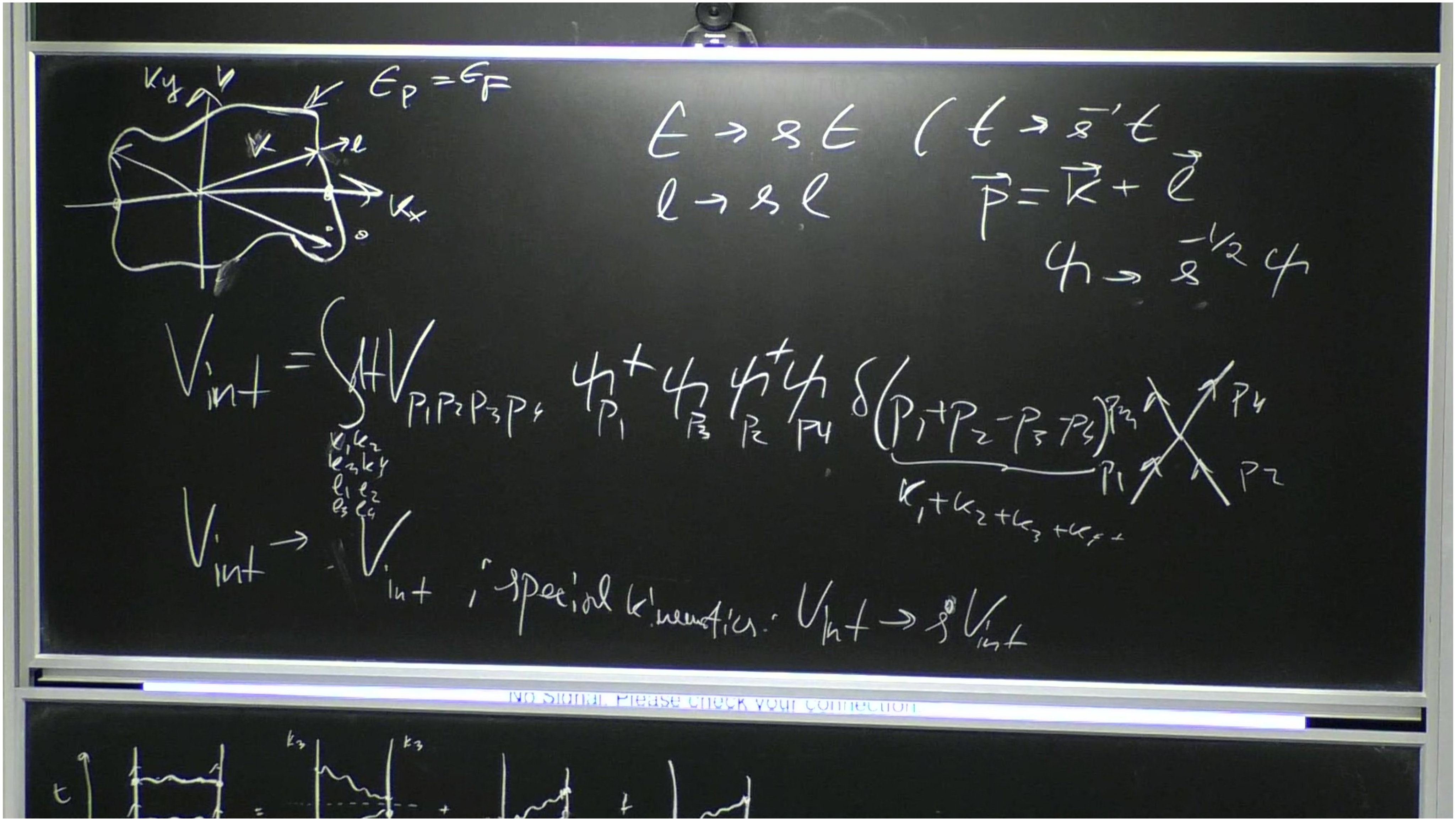
I conductor e, m, M $\quad \underbrace{\frac{e^2}{\hbar^2} m = 27\, eV}_{\epsilon_0}, \; T_{room} \sim 10^{-2} eV$

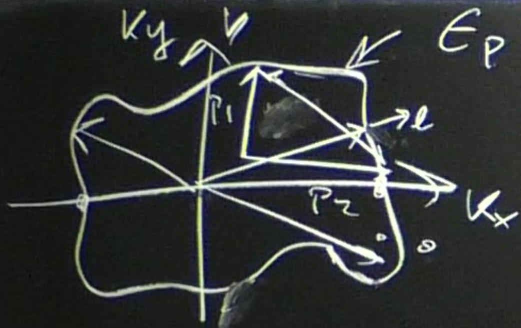
$E \ll \epsilon_0 \; \Big| \; \int dt\, d^2k\, d\ell \left\{ i \psi_p^\dagger \dot{\psi}_p + (\underbrace{\epsilon_p - \epsilon_F}_{v_F \ell}) \psi_p^\dagger \psi_p \right\} + V_{int}$

$\omega = v_F \ell$ $\qquad \epsilon_p = \epsilon_k + \underbrace{\partial_p \epsilon_p}_{v_F} \ell$

Nuclear From Ch. Lagr.

- Can you bound states


k_y
k
ℓ
k_x
$\epsilon_p = \epsilon_F$
$E \to s E$ ($t \to s^{-1} t$
$\ell \to s \ell$
$\vec{p} = \vec{k} + \vec{\ell}$
$\psi \to s^{-1/2} \psi$
$V_{int} = \int dt V_{p_1 p_2 p_3 p_4} \psi^+_{p_1} \psi_{p_3} \psi^+_{p_2} \psi_{p_4} \delta(p_1 + p_2 - p_3 - p_3)$
$k_1 k_2 k_3 k_4 \ell_1 \ell_2 \ell_3 \ell_4$
$k_1 + k_2 + k_3 + k_4 +$
p_3 p_4 p_1 p_2
$V_{int} \to V_{int}$; special kinematics: $V_{int} \to s^0 V_{int}$
No Signal. Please check your connection
k_3
t



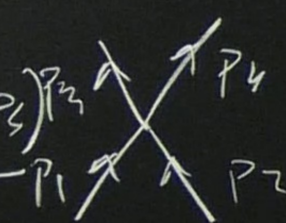
$\epsilon_p = \epsilon_F$

$\epsilon \to s\,\epsilon \quad (t \to s^{-1} t$

$\ell \to s\,\ell \qquad \vec{p} = \vec{k} + \vec{\ell}$

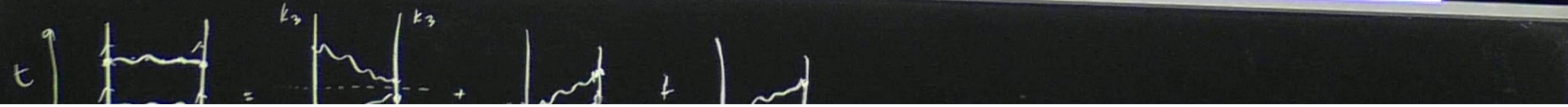
$\psi \to s^{-1/2}\,\psi$

$$V_{int} = \int_{\substack{k_1 k_2 \\ k_3 k_4 \\ \ell_1 \ell_2 \\ \ell_3 \ell_4}} dV_{p_1 p_2 p_3 p_4}\, \psi^+_{p_1} \psi_{p_3} \psi^+_{p_2} \psi_{p_4}\, \delta\big(\underbrace{p_1 + p_2 - p_3 - p_3}_{k_1 + k_2 + k_3 + k_4 + \ldots}\big)$$



$d^d p = d^{d-1}k\, d\ell$

$V_{int} \to V_{int}$; special kinematics: $V_{int} \to s^0 V_{int}$



The (classical) EFT

Guiding principles:

1. $\{g_{\mu\nu}, \psi\}$ are the correct degrees of freedom to describe low-energy physics
2. diffeo. invariance
3. curvatures are small

The (classical) EFT

Guiding principles:

$g\,,\ \partial g\,,\ \partial\partial g\,,\ \sqrt{g}\,\partial\psi\,,\ \dots$

① $\{g_{\mu\nu}, \psi\}$ are the correct degrees of freedom to describe low-energy physics

② diffeo. invariance

$$D_\mu A^\nu = \partial_\mu A^\nu + \Gamma^\nu_{\mu\lambda} A^\lambda$$

③ curvatures are small

$\Downarrow$ derivative expansion!

and $\mathcal{L}_{\text{matter}}$!

The (classical) EFT

$$S = \int d^4x \sqrt{g}\left(\overset{\partial^0}{\underset{\approx 0}{\Lambda}} + \underset{\substack{\| \\ 32\pi G \sim 1/M_p^2}}{\frac{2}{\kappa^2}} \overset{\partial^2}{R} + \underbrace{\underset{O(1)}{c_1} R^2 + \underset{O(1)}{c_2} R_{\mu\nu} R^{\mu\nu}}_{\partial^4} + \overset{\partial^6}{\ldots} \right)$$

Sketchy notation:

$$\boxed{\mathcal{L} = \frac{2}{\kappa^2} R + c R^2 + \mathcal{L}_{\text{matter}}} \, .$$

$$\boxed{\mathcal{L} = \frac{2}{\kappa^2} R + c R^2 + \mathcal{L}_{matter}}$$

Newtonian potential, take 1

$$g_{\mu\nu} = \eta_{\mu\nu} + \kappa h_{\mu\nu} \quad + \quad G_\alpha(h) = 0 \quad \text{gauge fixing}$$

$$\Downarrow$$

EOM $$\boxed{\underbrace{\Box}_{q^2} h_{\mu\nu} + \kappa^2 c \, \underbrace{\Box\Box}_{q^4} h_{\mu\nu} = 8\pi G T_{\mu\nu}}$$

Green's function: $$\int d^4q \, \frac{e^{iq\cdot x}}{q^2 + \kappa^2 c \, q^4} = \int d^4q \, e^{iq\cdot x} \left[\frac{1}{q^2} - \frac{1}{q^2 + (1/\kappa^2 c)} \right]$$

$$\mathcal{L} = \frac{2}{\kappa^2} R + c R^2 + \mathcal{L}_{\text{matter}}$$

Newtonian potential, take 1

But no need to worry!

$$\int d^4q \, e^{iq\cdot x} \frac{1}{q^2} \xrightarrow{\text{FOURIER}} -\frac{G m_1 m_2}{r}$$

$$\int d^4q \, e^{iq\cdot x} \left[-\frac{1}{q^2 + (1/\kappa^2 c)} \right] \longrightarrow \frac{G m_1 m_2}{r} e^{-\frac{r}{\kappa\sqrt{c}}}$$

$$\boxed{\mathcal{L} = \frac{2}{\kappa^2} R + c R^2 + \mathcal{L}_{matter}}$$

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$$\int d^4q \, e^{iq\cdot x} \frac{1}{q^2} \xrightarrow{\text{FOURIER}} -\frac{G m_1 m_2}{r}$$

$$\frac{1}{q^2 + \kappa^2 c q^4} = \frac{1}{q^2} - \kappa^2 c + \ldots$$

$$\int d^4q \, e^{iq\cdot x} \left[-\frac{1}{q^2 + (1/\kappa^2 c)} \right] \longrightarrow \frac{G m_1 m_2}{r} e^{-\frac{r}{\kappa\sqrt{c}}} \sim c \kappa^4 \delta^3(r)$$

Ghosts are heavily suppressed, only playing a role at the scale of new physics.

$$\boxed{\mathcal{L} = \frac{2}{\kappa^2} R + c R^2 + \mathcal{L}_{matter}}$$

Newtonian potential, take 1

Remark: in modern treatments, replace

$$\mathcal{L} = \frac{2}{\kappa^2} R + \underset{\substack{\uparrow \\ O(1)}}{c} R^2 \quad \text{with} \quad \mathcal{L} = \frac{2}{\kappa^2}\left(R + \underset{\substack{\uparrow \\ O\left(\frac{1}{M_s^2}\right)}}{c} R^2\right).$$

Allows for possibility that new physics appears <u>below</u> M_{planck}.

Analogy:

	Naïve SONP	Actual SONP
Gravity	M_{planck}	"M_{string}"
Weak interaxns	100 GeV	$M_{Z\text{-boson}} \sim 70\text{ GeV}$

http://www.hartmanhep.net/topics2015/gravity-lectures.pdf

Newtonian potential, take 2 : "quantum" EFT @ tree level

$$g_{\mu\nu} = \bar{g}_{\mu\nu} + \kappa h_{\mu\nu}$$

$$\Downarrow$$

$\bar{g}$ solves EE

$$\sqrt{g}\,\mathcal{L}_{grav.} = \sqrt{g}\,\frac{2}{\kappa^2} R \stackrel{\downarrow}{=} \sqrt{\bar{g}}\left(\frac{2}{\kappa^2}\bar{R} + \bar{D}h\bar{D}h + \bar{R}h^2\right)$$

$$Z \neq \int \mathcal{D}h_{\mu\nu}\, e^{iS} \rightsquigarrow Z = \int \mathcal{D}h_{\mu\nu}\, \underbrace{\delta(G_\alpha(h))}_{\text{More } \bar{D}h\bar{D}h}\, \underbrace{\det\left|\frac{\delta G_\alpha}{\delta \epsilon_\beta}\right|}_{\eta^*[\bar{D}^2\bar{g} - \bar{R}]\eta}\, e^{iS}.$$

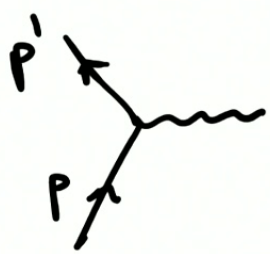
Newtonian potential, take 2 : "quantum" EFT @ tree level

A nice quadratic theory!

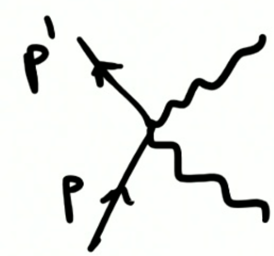
$g^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi$

$$\boxed{\mathcal{L} = -\frac{1}{2} h_{\alpha\beta} D^{\alpha\beta,\gamma\delta} h_{\gamma\delta} + \text{ghost} + (\bar{g}, \bar{R}) + \mathcal{L}_{\text{matter}}}$$

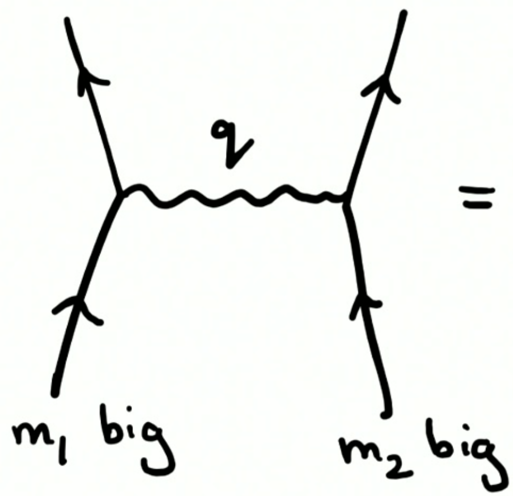
$$= \frac{i}{q^2 + i\epsilon} (\eta\eta)$$



$$= -\frac{i\kappa}{2} \left(p p' - \bar{g}_{\mu\nu} (p \cdot p' - m^2) \right)$$

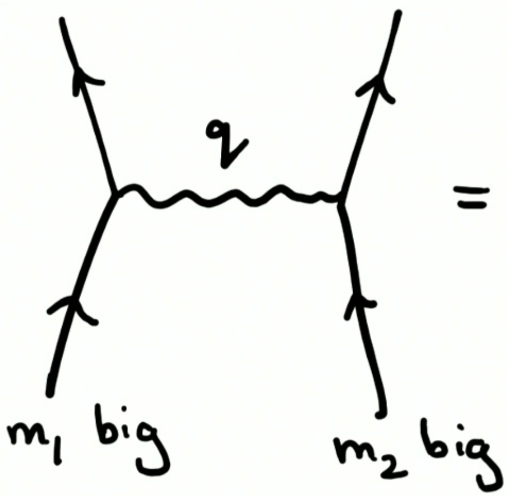


Newtonian potential, take 2 : "quantum" EFT @ tree level



$$= \# \, \frac{G m_1 m_2}{q^2} \xrightarrow{\text{FOURIER}} -\frac{G m_1 m_2}{r}$$

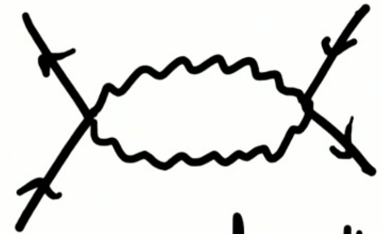
Newtonian potential, take 2 : "quantum" EFT @ tree level



$$= \# \, \frac{G m_1 m_2}{q^2} \xrightarrow{\text{FOURIER}} -\frac{G m_1 m_2}{r}$$

For all our hard work?!

Loops: a taste of non-reno.



$d = 4 - \epsilon$

$\frac{2}{\kappa^2} R$

$$\boxed{\mathcal{L} = -\frac{1}{2} h_{\alpha\beta} D^{\alpha\beta,\gamma\delta} h_{\gamma\delta} + \text{ghost} + (\bar{g}, \bar{R}) + \mathcal{L}_{matter}}$$

New !!

$$Z[\bar{g}] = \int \mathcal{D}h \, e^{i\int d^4x \, \mathcal{L}} \quad \text{needs} \quad \mathcal{L}_{ct}^{1\text{-loop}} = \frac{1}{8\pi^2 \epsilon}\left(c_1 \bar{R}^2 + c_2 \bar{R}_{\mu\nu} \bar{R}^{\mu\nu}\right).$$

$$c_1^{(r)} = c_1 + \frac{\#}{\epsilon}$$

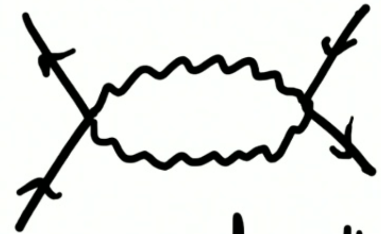
$$c_2^{(r)} = c_2 + \frac{\#}{\epsilon}$$

1 loop $\rightsquigarrow R^2 + (R_{\mu\nu})^2$

2 loops $\rightsquigarrow (R_{\mu\nu\rho\sigma})^3$

3 loops $\rightsquigarrow R_{\dots}^{\,4}$ ...

Loops: a taste of non-reno.



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$\frac{2}{\kappa^2} R$

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needs

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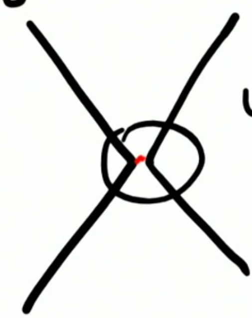
2 loops $\rightsquigarrow (R_{\mu\nu\rho\sigma})^3$

3 loops $\rightsquigarrow R_{\dots}{}^4$ . . .

The key point: one can renormalize the theory at any given order.

Predictions in EFT

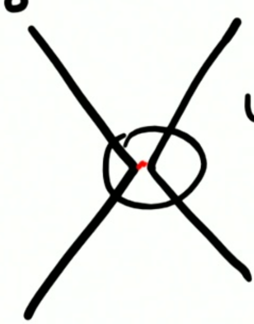
Key assumption: local terms in $\mathcal{L}$ account for the most general high-energy effects.



So if a loop gives a nonlocal divergence, we are seeing a genuinely low-energy effect.

Predictions in EFT

Key assumption: <u>local</u> terms in $\mathcal{L}$ account for the most general high-energy effects.



UV just corrects the vertex.

So if a loop gives a <u>nonlocal</u> divergence, we are seeing a genuinely low-energy effect.

Nonlocal = nonanalytic in $\vec{k}$ space.

Newtonian potential, take 3 : 1-loop

Final result:

$$V(q) = \frac{Gm_1m_2}{q}\Big(1 + \underbrace{\overset{\text{NONLINEAR CLASSICAL}}{a\,Gq^2\sqrt{\frac{m^2}{-q^2}}} + \overset{\text{QUANTUM LOOP}}{b\,Gq^2\ln(-q^2)}}_{\text{NON-ANALYTIC}} + \overset{???}{c\,Gq^2}\Big)$$

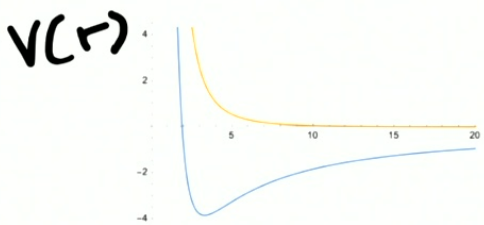
$$V(r) = -\frac{Gm_1m_2}{r}\Big(1 + \underbrace{a\frac{Gm}{rc^2} + b\frac{G\hbar}{r^2c^3}}_{\text{True low-energy prediction: } a,b \text{ indep. of } c_1^{(r)}, c_2^{(r)}, \text{etc.}} + \underbrace{c\,G^2\delta^3(r)}_{\text{Suppressed UV effect.}}\Big)$$

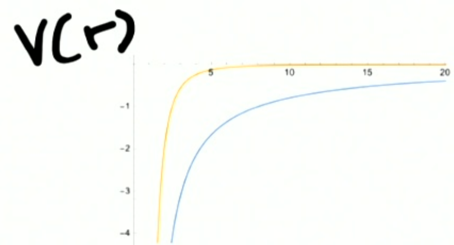
How big? $\quad b\,\dfrac{G\hbar}{r^2c^3} = b\left(\dfrac{\ell_{\text{Planck}}}{r}\right)^2.$

"unlikely to generate an active phenomenology"

What's b? A series of papers b/w '93 – '02 are consistently confused.

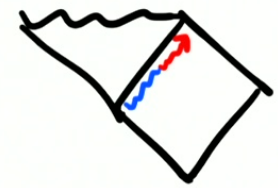
Even about the sign!





Exceptions to the game: theories w̄ UV/IR mixing

- String theory
- Noncommutative (quantum) geometry
- Holography
- Arguably, any theory of QG:
  - UV collisions/fluctuations can create BH!
  - Gravitational redshift means UV at horizon = IR far away!



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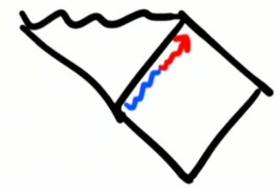

Then, why care? My favorite 2 reasons:

- Does Lambda run? (Cosmology)
- Does G run, such that generalized BH entropy is well-defined? (Susskind-Uglum conjecture)