Title: Lecture

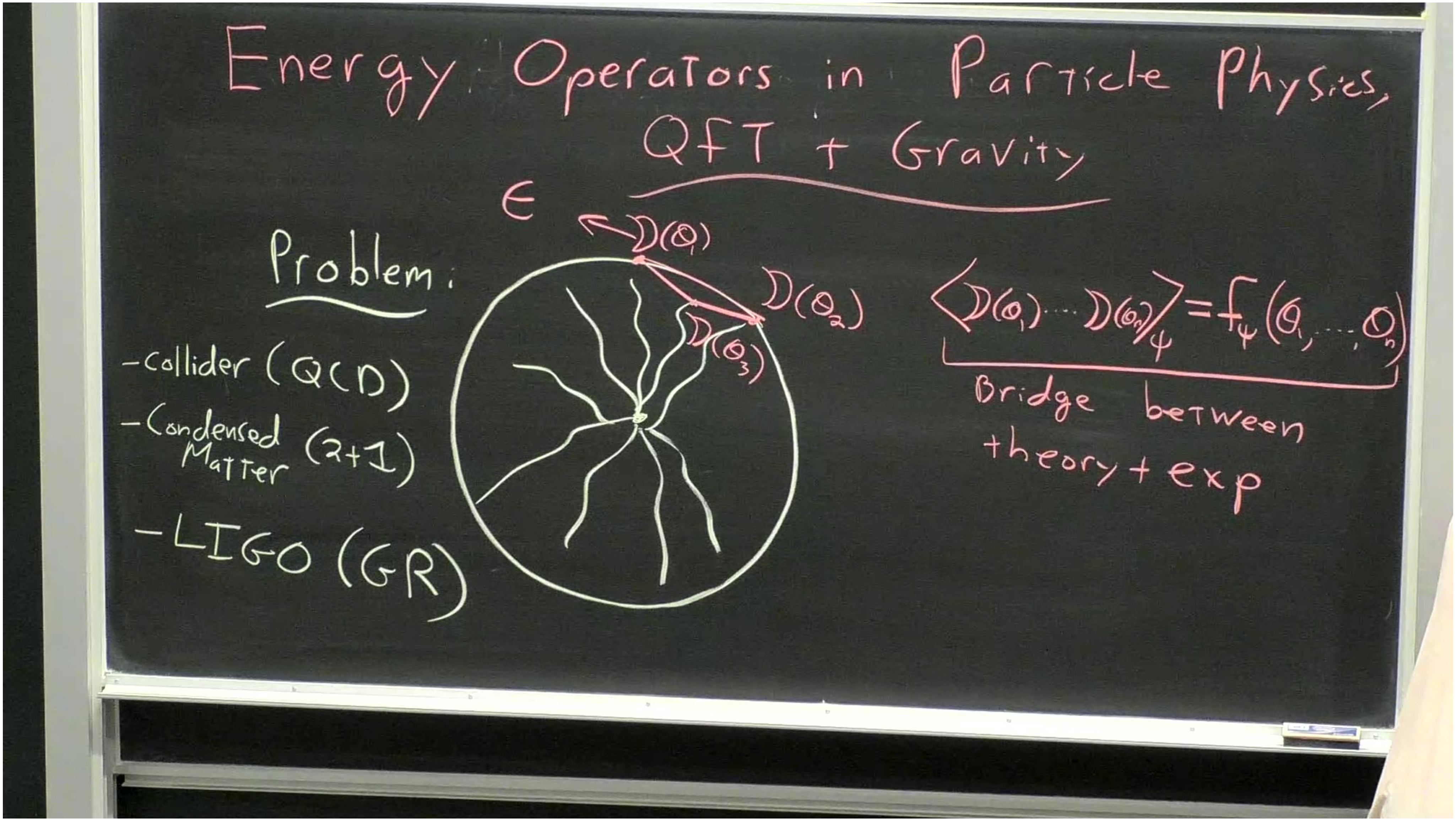
Speakers: Ian Moult

Collection/Series: Energy Operators in Particle Physics, QFT, and Gravity - June 6, 9, 11, 2025

Subject: Particle Physics, Quantum Fields and Strings

Date: June 06, 2025 - 2:00 PM

URL: https://pirsa.org/25060090


Energy Operators in Particle Physics,
QFT + Gravity
ϵ
$\mathcal{D}(\theta_1)$
$\mathcal{D}(\theta_2)$
$\mathcal{D}(\theta_3)$
Problem:
-collider (QCD)
-Condensed Matter (2+1)
-LIGO (GR)
$\langle \mathcal{D}(\theta_1) \cdots \mathcal{D}(\theta_n) \rangle_\psi = f_\psi(\theta_1, \ldots, \theta_n)$
Bridge between theory + exp

Questions:

① How to write "$\mathcal{D}$" in QFT?
What is the space of "$\mathcal{D}$"?

② How to compute?

perturbative: – Scattering amplitudes
– Space of functions

CFT: – relate to OPE data

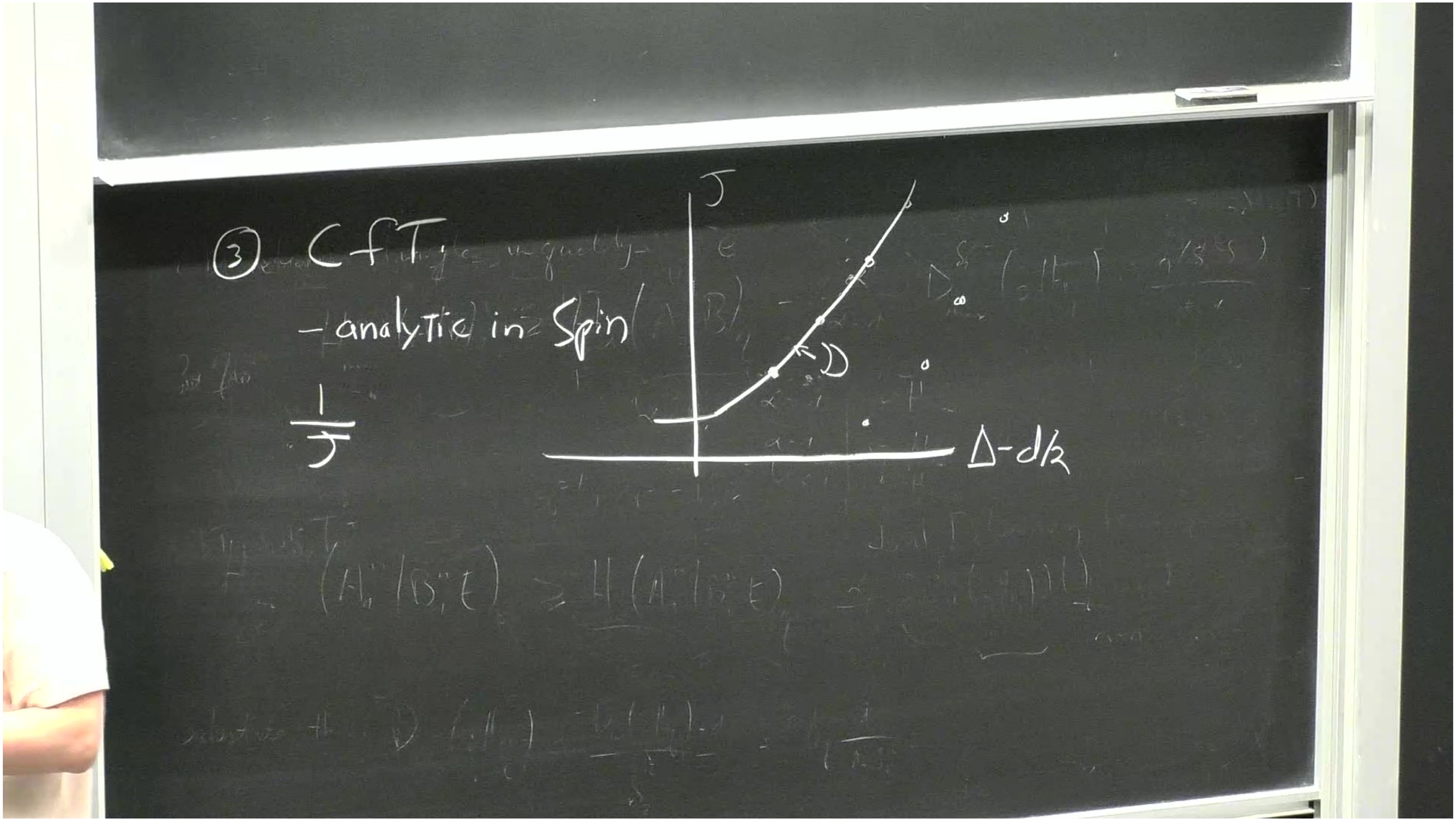
Motivation:

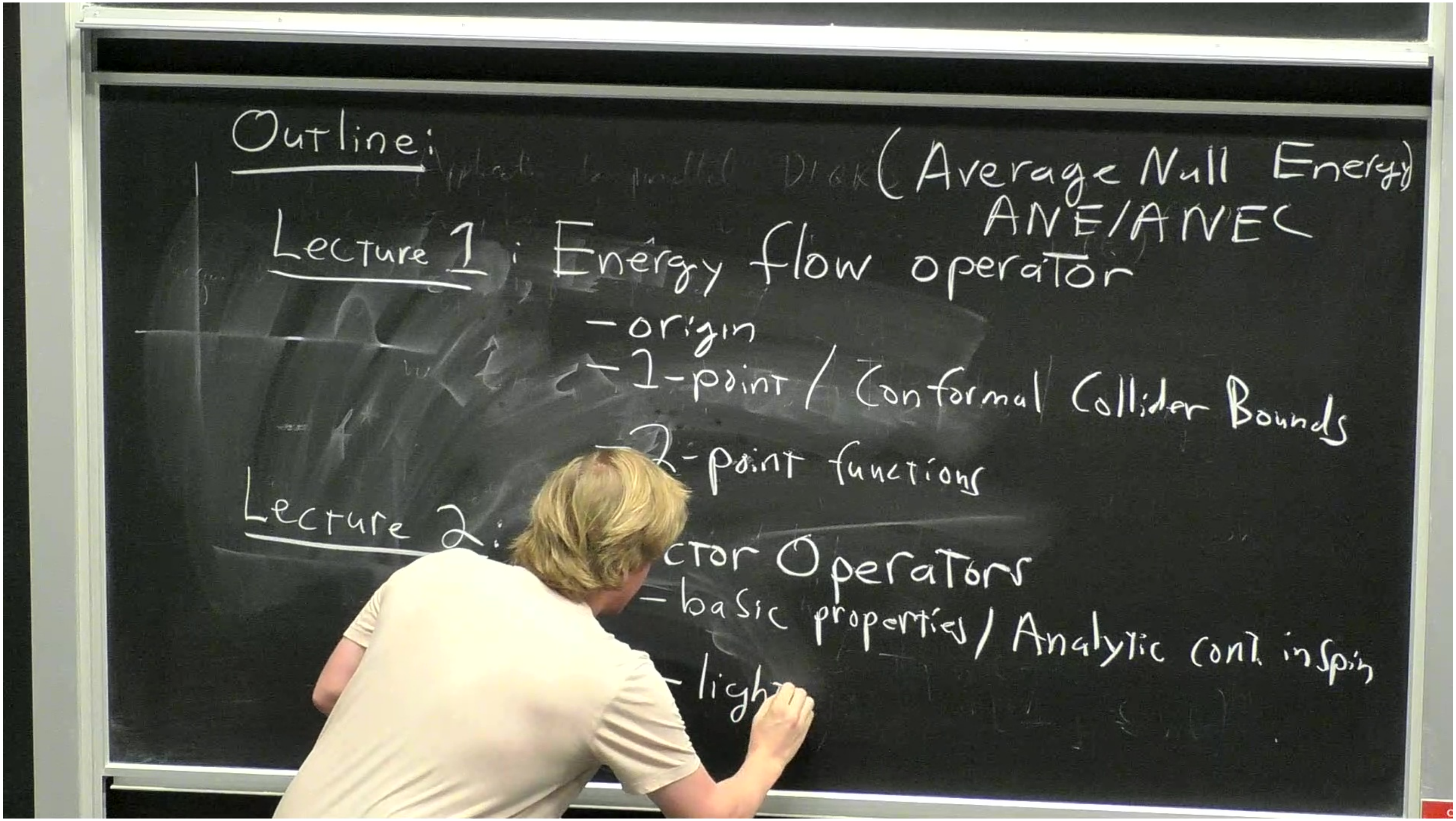
① Phenomenology: $J^\mu = \bar{\Psi}\gamma^\mu \psi$

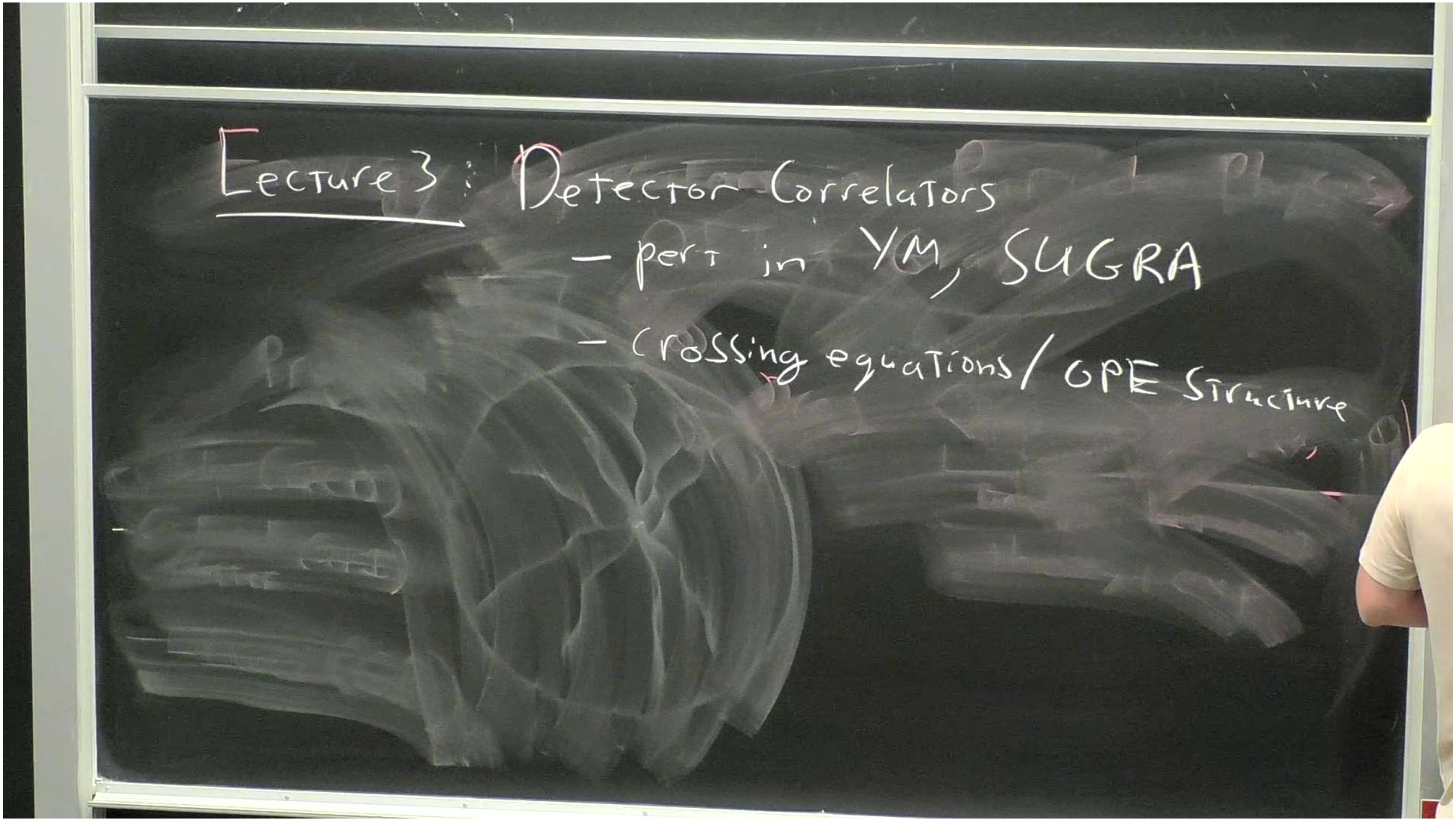
$$\langle J \mathcal{E} \mathcal{E} J \rangle$$

② Exploring Space of QFT/QG:

- well defined observables in general theories.
- Conformal Collider bounds.


③ CFT
- analytic in Spin
$\frac{1}{J}$
J
D
Δ-d/2


Outline:
(Average Null Energy)
ANE/ANEC
Lecture 1: Energy flow operator
- origin
- 1-point / Conformal Collider Bounds
- 2-point functions
Lecture 2:
ctor Operators
- basic properties / Analytic cont. in spin
- ligh


Lecture 3: Detector Correlators
– pert in YM, SUGRA
– Crossing equations / OPE Structure

Energy Operators

CFT/QFT:

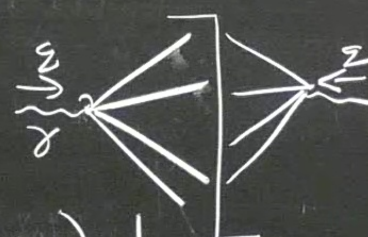
2-point: $\langle 0 | \mathcal{O}^\dagger(x)\, \mathcal{O}(0) | 0 \rangle$

asymptotic states

$\sum |X\rangle\langle X|$

"Inclusive cross section":

$$\sigma(q) = \int d^4x\, e^{iq\cdot x} \langle 0 | \mathcal{O}^\dagger(x) \, \mathcal{O}(0) | 0 \rangle$$



$$= \sum_X \int d\Pi_{LIPS}\, (2\pi)^4 \delta^{(4)}(q - k_X)\, |\langle X | \mathcal{O}(0) | 0 \rangle|^2$$

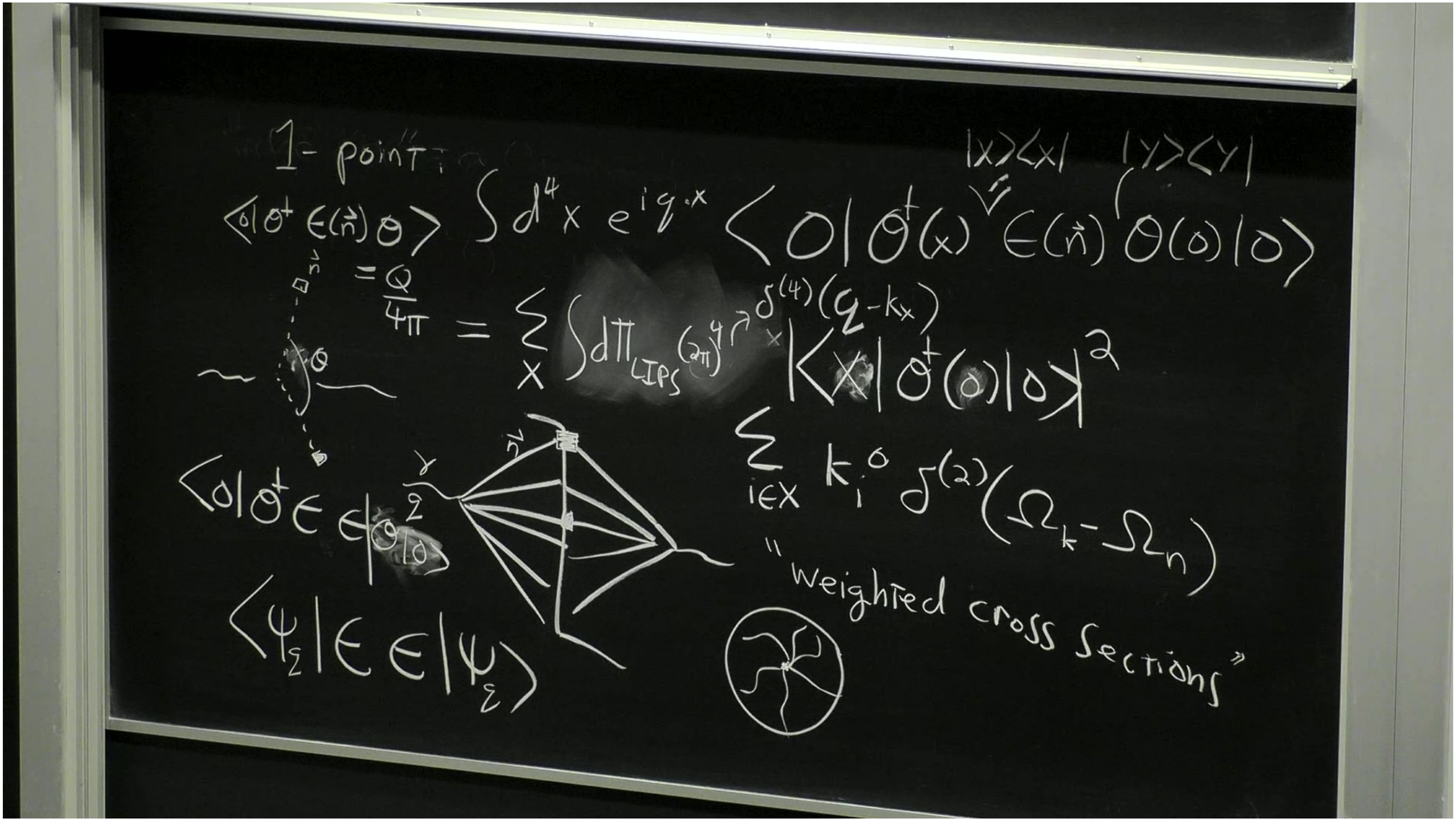
$$\to \langle 0 | \mathcal{O}^\dagger(x)\; T(y)\; \mathcal{O}(0) | 0 \rangle$$

Sterman 1975 $\quad \langle \mathcal{O} | \mathcal{E}(n) | \mathcal{O} \rangle = \frac{Q}{4\pi}$

$|X\rangle = |k_1, \dots k_n\rangle$

Energy flow operator $\mathcal{E}(\vec{n})$

$$``\mathcal{E}(\vec{n})" \, |X\rangle = \sum_{i \in X} k_i^0 \, \delta^{(2)}(\Omega_{\vec{k}_i} - \Omega_{\vec{n}}) \, |X\rangle$$


1- point
$|x\rangle\langle x|$ $|y\rangle\langle y|$
$\langle 0|\mathcal{O}^\dagger \mathcal{E}(\vec{n})\mathcal{O}\rangle$ $\int d^4x\, e^{iq\cdot x} \langle 0|\mathcal{O}^\dagger(x)\, \mathcal{E}(\vec{n})\, \mathcal{O}(0)|0\rangle$
$= \frac{Q}{4\pi} = \sum_X \int d\Pi_{LIPS} (2\pi)^4 \delta^{(4)}(q - k_X) \, |\langle X|\mathcal{O}^\dagger(0)|0\rangle|^2$
$\sum_{i\in X} k_i^0 \, \delta^{(2)}(\Omega_k - \Omega_n)$
"weighted cross sections"
$\langle 0|\mathcal{O}^\dagger \mathcal{E}\,\mathcal{E}|\mathcal{O}|0\rangle$
$\langle \psi_\Sigma|\mathcal{E}\,\mathcal{E}|\psi_\Sigma\rangle$

Korchemsky, Sterman

Hofman, Maldacena

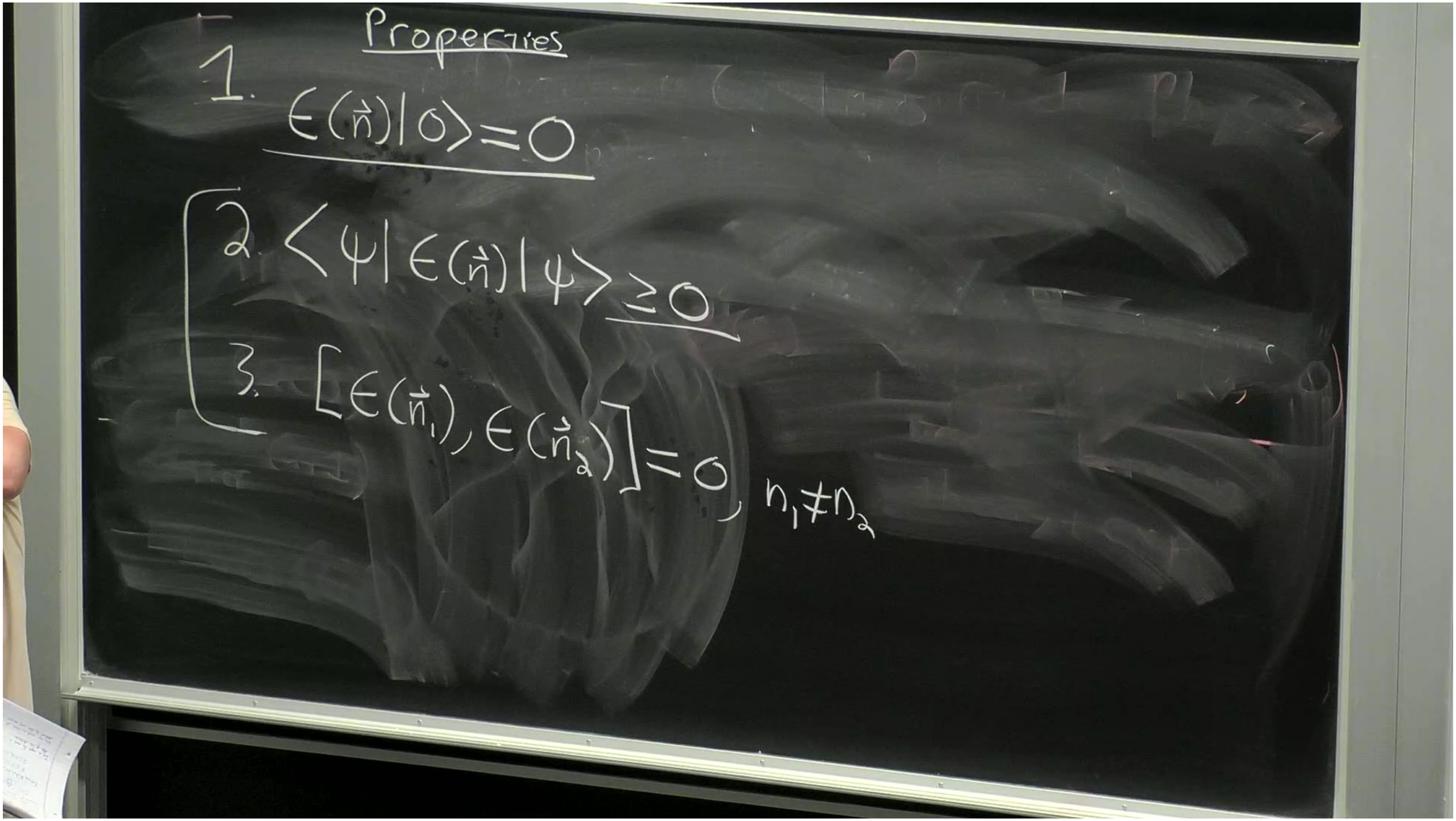
$$\langle 0| \underbrace{\mathcal{O}^\dagger T \cdots T \mathcal{O}}|0\rangle$$

$$\mathcal{E}(\vec{n}) = \underbrace{\int_{-\infty}^{\infty} d\tau \lim_{r\to\infty}} r^2 n^i T_{0i}(\tau, r\vec{n})$$

① Check action on states

② $\mathcal{E}(\vec{n})|0\rangle = 0$

③ $[\mathcal{E}(\vec{n}_1), \mathcal{E}(\vec{n}_2)] = 0$


Properties
1. $\epsilon(\vec{n})|0\rangle = 0$
2. $\langle\psi|\epsilon(\vec{n})|\psi\rangle \geq 0$
3. $[\epsilon(\vec{n}_1), \epsilon(\vec{n}_2)] = 0, \; n_1 \neq n_2$