Title: Explorations in Particle Theory-8

Date: Apr 15, 2015 09:00 AM

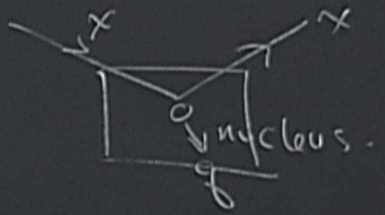
URL: http://pirsa.org/15040015

Abstract:

Tutorial today
on
direct & indirect
detection

3:45 - 5:15

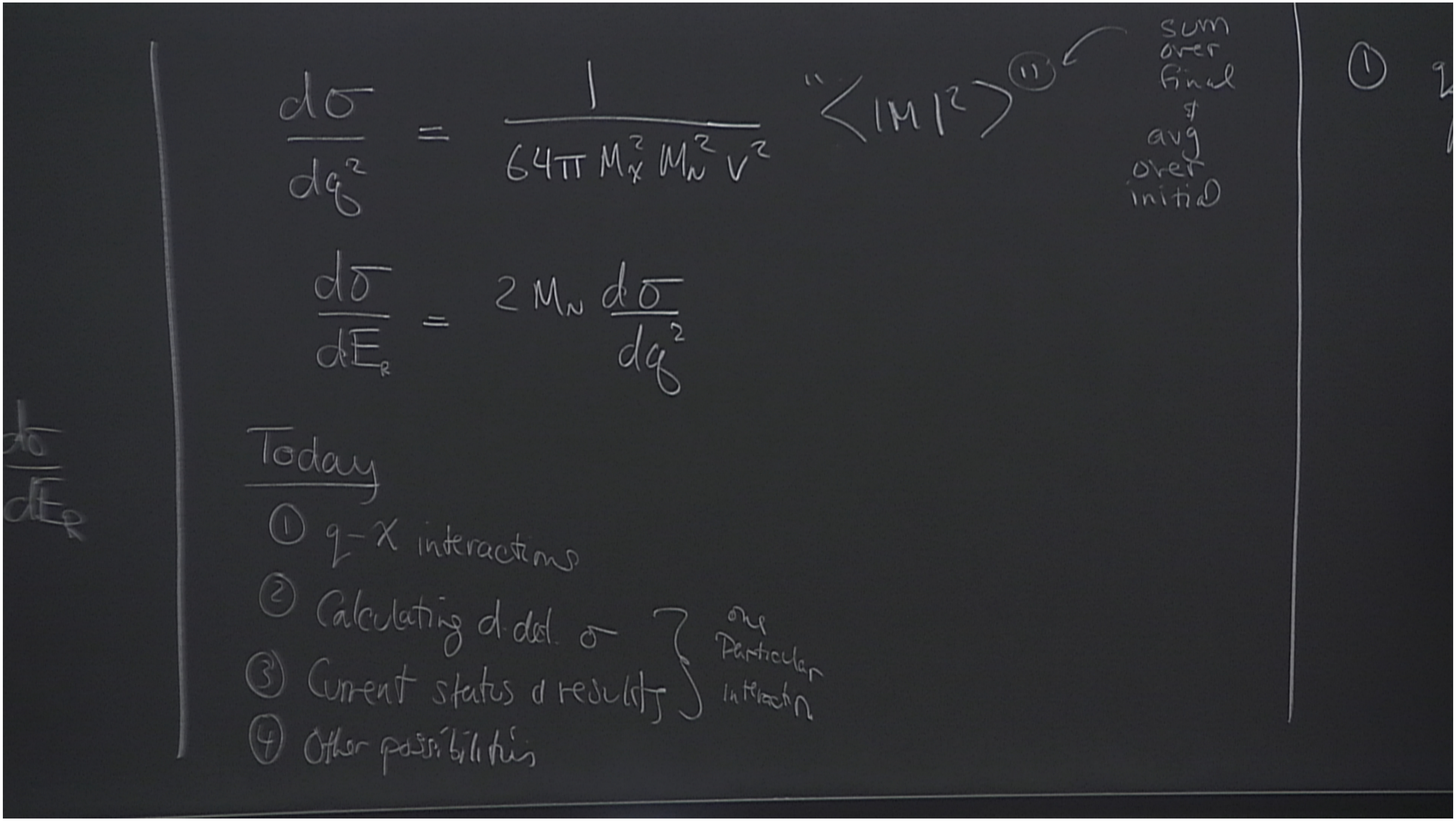
Direct Detection



$$\frac{dR}{dE_R} = n_T \frac{\rho_\chi}{m_\chi} \int d^3v \, f_E(\vec{v}) \, |\vec{v}| \frac{d\sigma}{dE_R}$$

$$q = \mu v \cos\theta \sim 100 \text{ MeV}$$

$$E_R = \frac{q^2}{2M_N} \sim 100 \text{ keV}$$



$$\frac{d\sigma}{dq^2} = \frac{1}{64\pi M_\chi^2 M_N^2 v^2} \text{ ``}\langle |M|^2 \rangle\text{''}$$

sum
over
final
&
avg
over
initial

$$\frac{d\sigma}{dE_R} = 2 M_N \frac{d\sigma}{dq^2}$$

$\frac{d\sigma}{dE_R}$

① q

Today

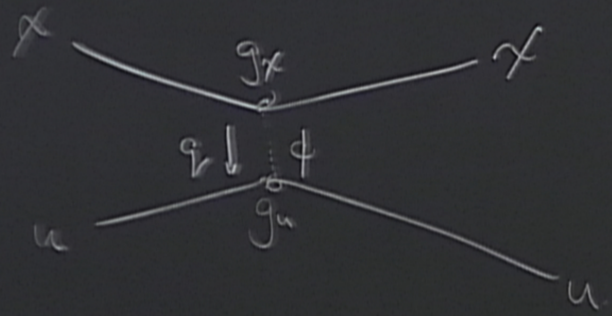
① q-χ interactions
② Calculating d.d. σ
③ Current status of results
④ Other possibilities

one
particular
interaction

sum over final & avg over initial

① q-χ interactions

Assume only χ-q interactions (neglect e-χ, ..)



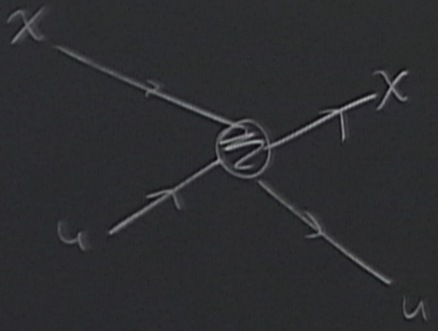
$$M \sim g_\chi g_u \frac{i}{q^2 - m_\phi^2} \left[\text{spin stuff}\right]$$

$q \approx 100$ MeV

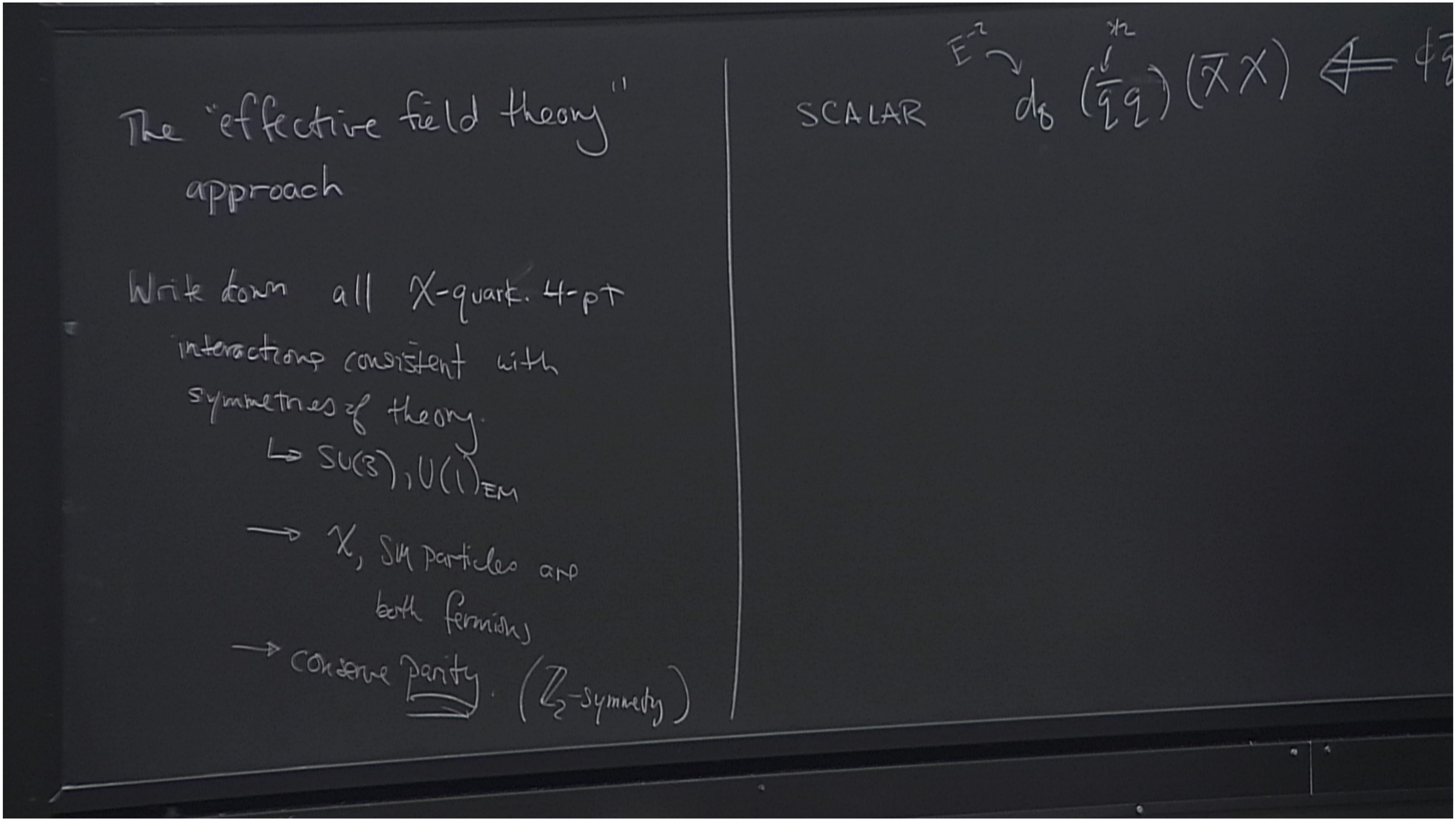
$m_Z \sim 90$ GeV

m_ϕ probably big

$q \ll m_\phi$



$$\Rightarrow \frac{1}{m_\phi^2}(\bar{\chi}\Gamma\chi)(\bar{u}\Gamma u)$$



The "effective field theory" approach

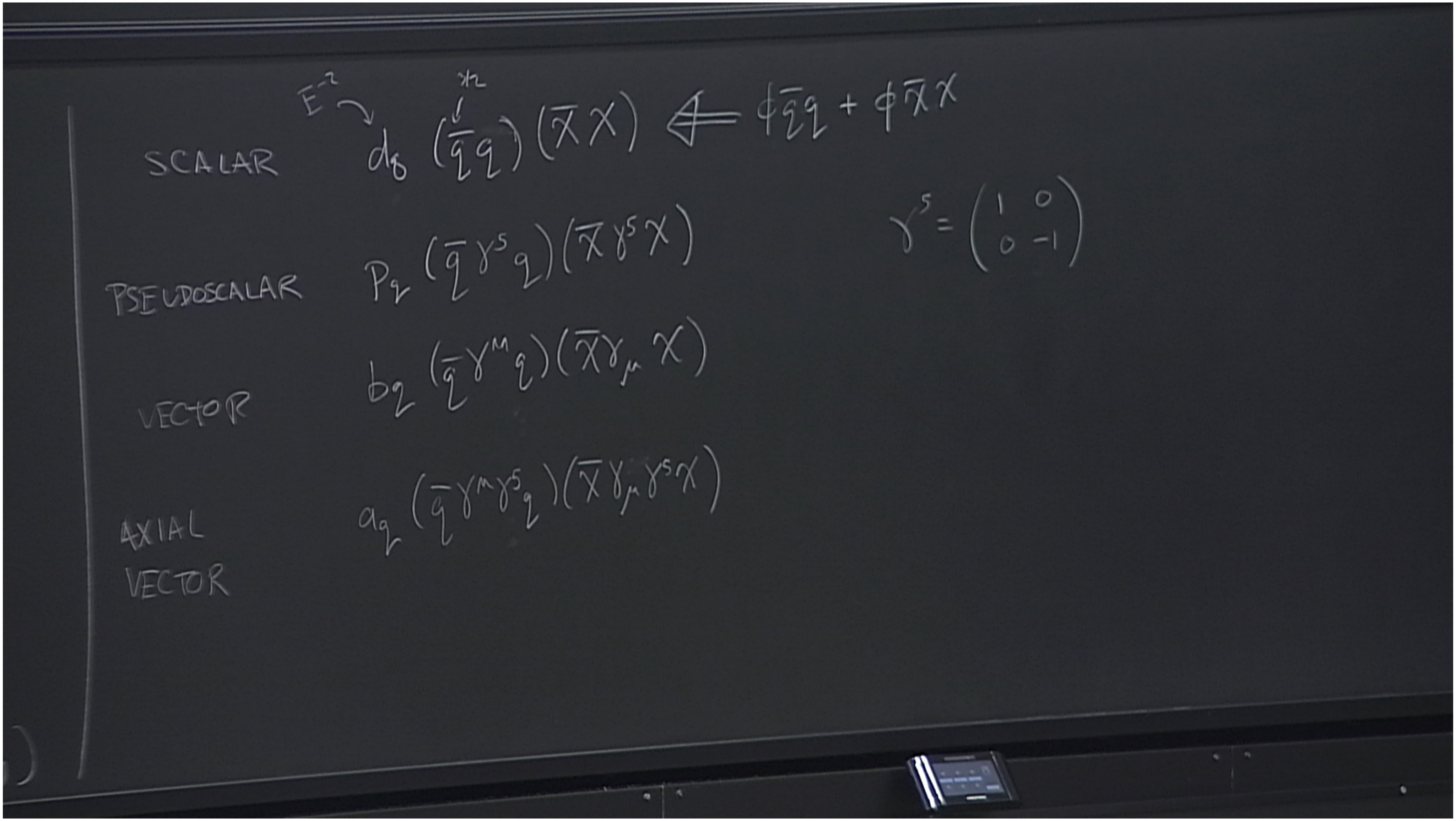
Write down all χ-quark. 4-pt interactions consistent with symmetries of theory.

↳ $SU(3), U(1)_{EM}$

→ χ, SM particles are both fermions

→ conserve $\underline{\text{parity}}$. ($\mathbb{Z}_2$-symmetry)

SCALAR $\quad \overset{E^{-2}}{d_8}\,(\overset{3/2}{\bar{q}}q)(\bar{\chi}\chi) \Longleftarrow \phi\bar{q}$



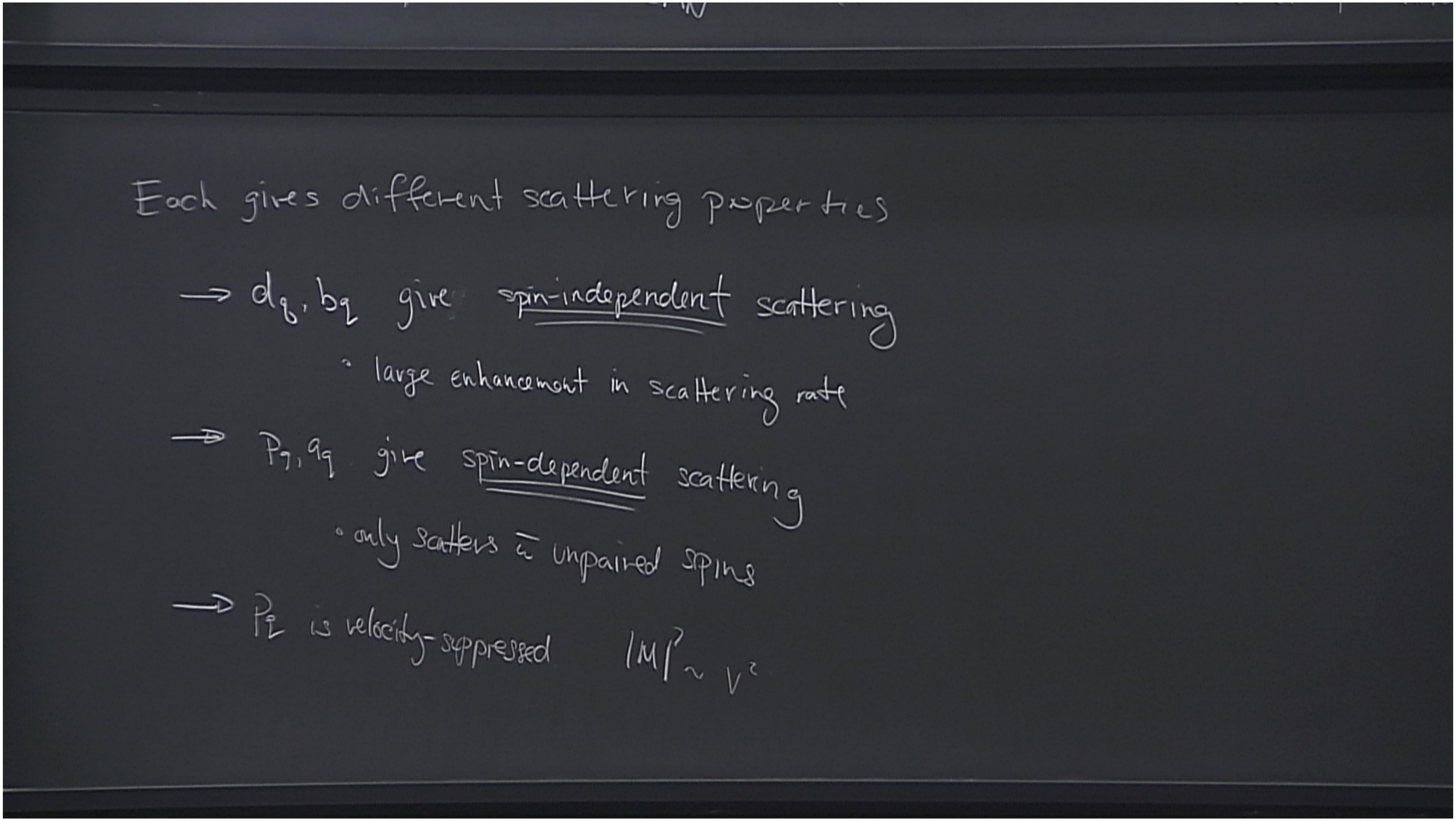
SCALAR $\overset{E^{-2}}{\curvearrowright} d_q \, (\overset{\times 2}{\bar{q}} q)(\bar{\chi}\chi) \Leftarrow \phi\bar{q}q + \phi\bar{\chi}\chi$

$\gamma^5 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

PSEUDOSCALAR $p_q \, (\bar{q}\gamma^5 q)(\bar{\chi}\gamma^5\chi)$

VECTOR $b_q \, (\bar{q}\gamma^\mu q)(\bar{\chi}\gamma_\mu \chi)$

AXIAL VECTOR $a_q \, (\bar{q}\gamma^\mu\gamma^5 q)(\bar{\chi}\gamma_\mu\gamma^5\chi)$



Each gives different scattering properties

- → d_q, b_q give spin-independent scattering
  - ∘ large enhancement in scattering rate
- → p_q, q_q give spin-dependent scattering
  - ∘ only scatters $\bar{c}$ unpaired spins
- → p_ℓ is velocity-suppressed $|M|^2 \sim v^2$

① Other possibilities

② Calculating σ

quarks $\Rightarrow$ nucleons $\Rightarrow$ nuclei

χ-u, χ-d χ-p, χ-n χ-Xe, ..

At energies $\sim \Lambda_{QCD} \sim 200$ MeV

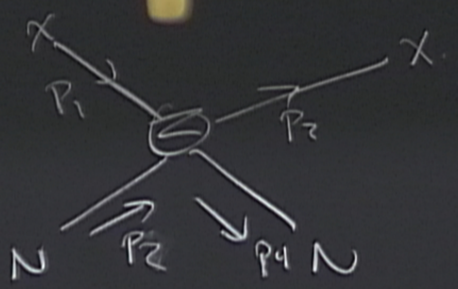
$\rightarrow$ don't have free quarks

$\bar{u}(p_4)$ $u(p_1)$

$$\mathcal{M} = \langle \chi(p_3) q(p_4) | \bar{\chi}\Gamma\chi \bar{q}\Gamma q | \chi(p_1) q(p_2) \rangle = \bar{u}_\chi(p_3)\Gamma u_\chi(p_1)\, \bar{u}_q(p_4)\Gamma u_q(p_2)$$

$\bar{u}(p_3)$ $u(p_2)$

$$\sum_s \bar{u}_s u_s = \not{p} + m \ldots$$



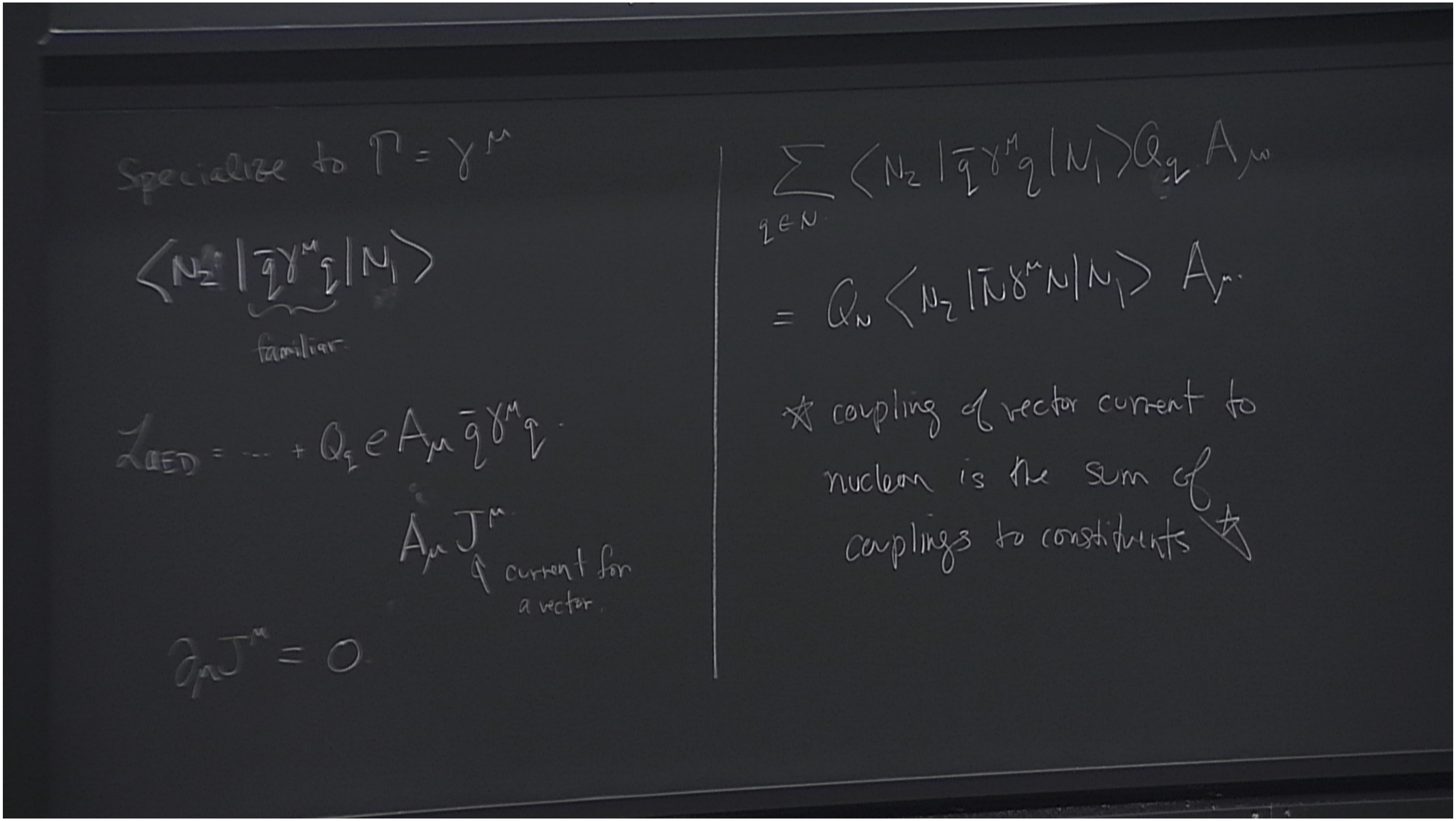
$$M = \langle \chi(p_3) N(p_4) | \bar{\chi} \Gamma \chi \, \bar{q} \Gamma q | \chi(p_1) N(p_2) \rangle$$

$$= \bar{u}_\chi(p_3) \Gamma u_\chi(p_1)$$

$$\times \langle N(p_4) | \bar{q} \Gamma q | N(p_2) \rangle$$

$$= \bar{u}_\chi(p_3) \Gamma u_\chi(p_1) \, \bar{u}_q(p_4) \Gamma u_q(p_2)$$

$$\sum_s \bar{u}_s u_s = \not{p} + m \ldots$$



Specialize to $\Gamma = \gamma^\mu$

$$\langle N_2 | \underbrace{\bar{q}\gamma^\mu q}_{\text{familiar}} | N_1 \rangle$$

$$\mathcal{L}_{QED} = \cdots + Q_q e A_\mu \bar{q}\gamma^\mu q$$

$$A_\mu J^\mu$$

$\uparrow$ current for a vector.

$$\partial_\mu J^\mu = 0$$

$$\sum_{q \in N} \langle N_2 | \bar{q}\gamma^\mu q | N_1 \rangle Q_q A_\mu$$

$$= Q_N \langle N_2 | \bar{N}\gamma^\mu N | N_1 \rangle A_\mu$$

☆ coupling of vector current to nucleon is the sum of couplings to constituents ☆

$$b_q (\bar{\chi} \gamma^\mu \chi)(\bar{q} \gamma_\mu q) \rightarrow b_N (\bar{\chi} \gamma^\mu \chi)(\bar{N} \gamma_\mu N)$$

$b_p = 2 b_u + b_d$ $\qquad$ $b_n = b_u + 2 b_d$

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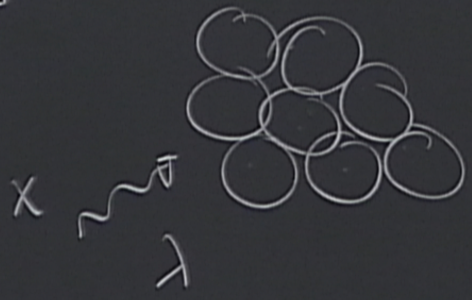
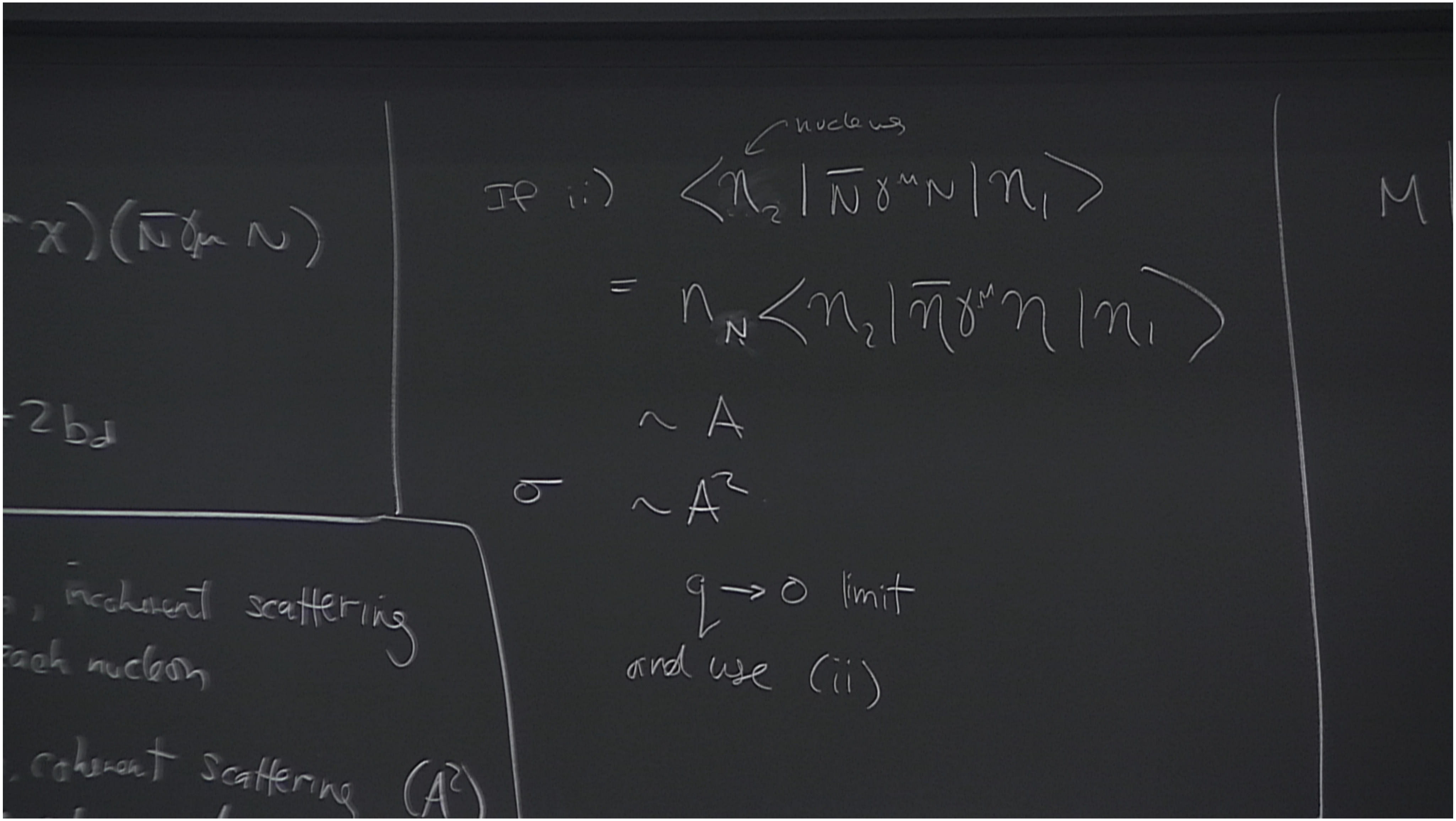
nucleus



i) $\lambda < r_{\text{nucleus}}$, incoherent scattering over each nucleon

ii) $\lambda > r_{\text{nucleus}}$, coherent scattering (A

↳ huge enhancement



$x)(\bar{N}\gamma_\mu N)$

$2bd$

, incoherent scattering

each nucleon

, coherent scattering (A^2)

$$\text{If ii)} \quad \langle \overset{\text{nucleus}}{n_2} | \bar{N}\gamma^\mu N | n_1 \rangle$$

$$= n_N \langle n_2 | \bar{\eta}\gamma^\mu \eta | n_1 \rangle$$

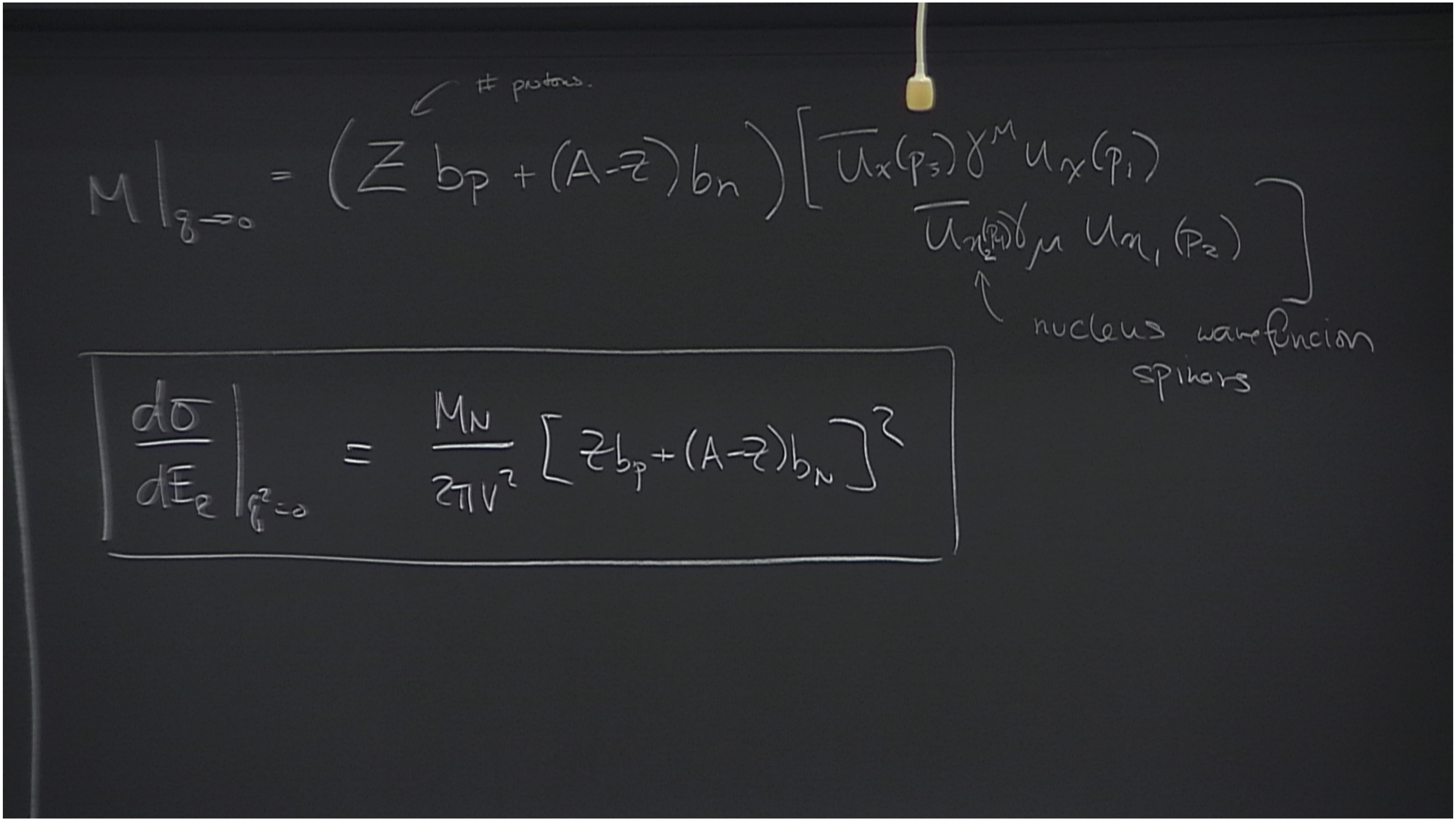
$$\sim A$$

$$\sigma \sim A^2$$

$q \to 0$ limit

and use (ii)

M

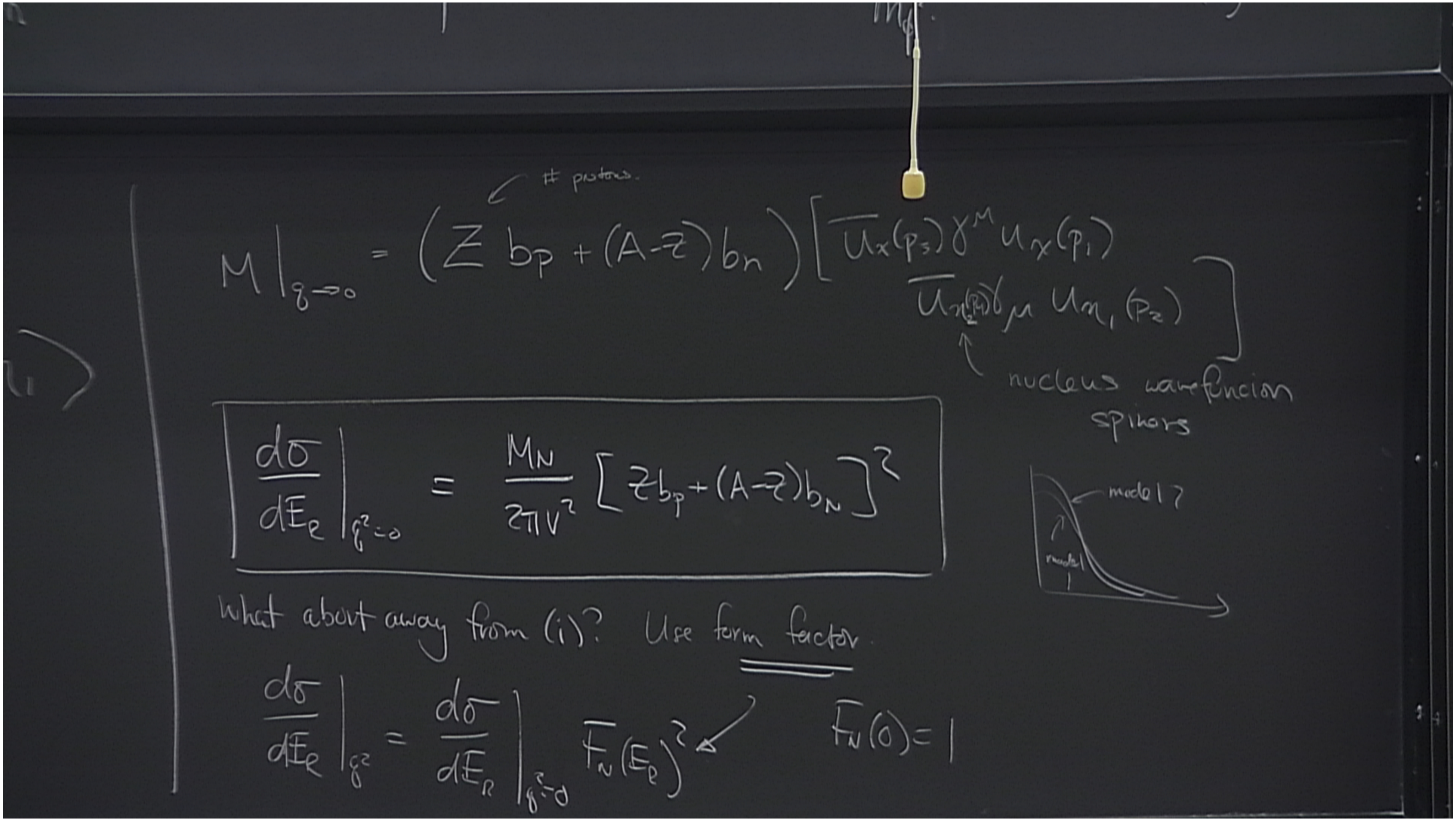


\# protons.

$$M\Big|_{q\to 0} = \left(Z\, b_p + (A-Z)\, b_n\right)\Big[\bar{u}_\chi(p_3)\gamma^\mu u_\chi(p_1)\;\bar{u}_{n_2}(p_4)\gamma_\mu u_{n_1}(p_2)\Big]$$

nucleus wavefuncion spinors

$$\boxed{\frac{d\sigma}{dE_R}\Big|_{q^2=0} = \frac{M_N}{2\pi v^2}\left[Z b_p + (A-Z) b_N\right]^2}$$



\# protons

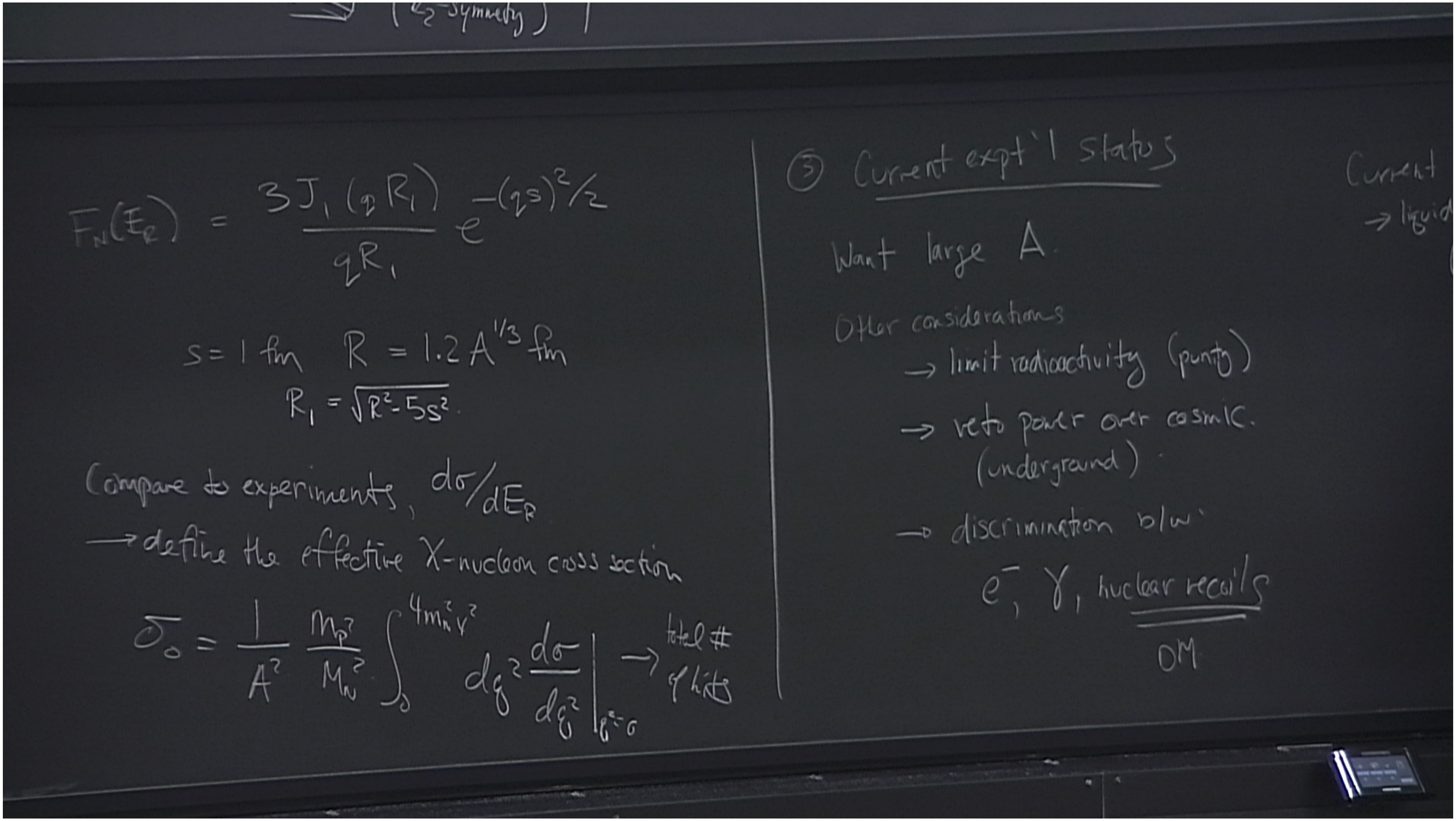
$$M\Big|_{q\to 0} = \left(Z\, b_p + (A-Z)\, b_n\right)\Big[\overline{u}_\chi(p_3)\gamma^\mu u_\chi(p_1)\ \overline{u}_{n_2}(p_4)\gamma_\mu u_{n_1}(p_2)\Big]$$

nucleus wavefunction spinors

$$\boxed{\frac{d\sigma}{dE_R}\Big|_{q^2=0} = \frac{M_N}{2\pi v^2}\left[Z b_p + (A-Z) b_N\right]^2}$$

what about away from (i)? Use form factor.

$$\frac{d\sigma}{dE_R}\Big|_{q^2} = \frac{d\sigma}{dE_R}\Big|_{q^2=0} F_N(E_R)^2 \qquad F_N(0)=1$$



(Z_2-symmetry)

$$F_N(E_R) = \frac{3J_1(qR_1)}{qR_1}\, e^{-(qs)^2/2}$$

$s = 1$ fm $R = 1.2\,A^{1/3}$ fm

$R_1 = \sqrt{R^2 - 5s^2}$.

Compare to experiments, $d\sigma/dE_R$

→ define the effective X-nucleon cross section

$$\sigma_0 = \frac{1}{A^2}\,\frac{m_p^2}{M_N^2}\int_0^{4m_N^2v^2} dq^2\,\frac{d\sigma}{dq^2}\bigg|_{q^2=0} \rightarrow \text{total \# of hits}$$

③ Current expt'l status

Want large A.

Other considerations

→ limit radioactivity (purity)

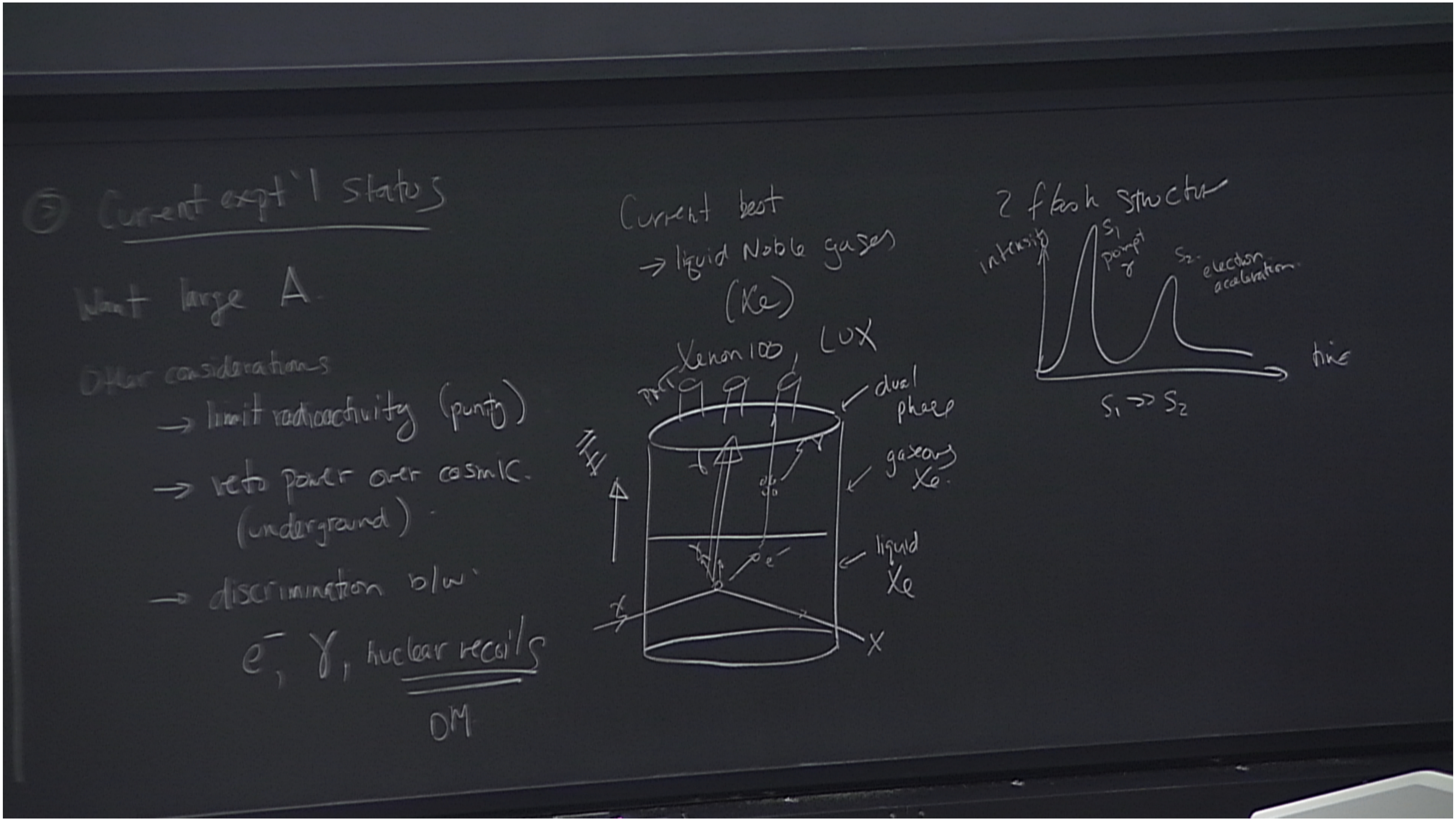
→ veto power over cosmic. (underground)

→ discrimination b/w: e^-, γ, nuclear recoils

DM

Current

→ liquid



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DM

Current best

→ liquid Noble gases (Xe)

Xenon100, LUX

2 flash structure

$S_1 >> S_2$