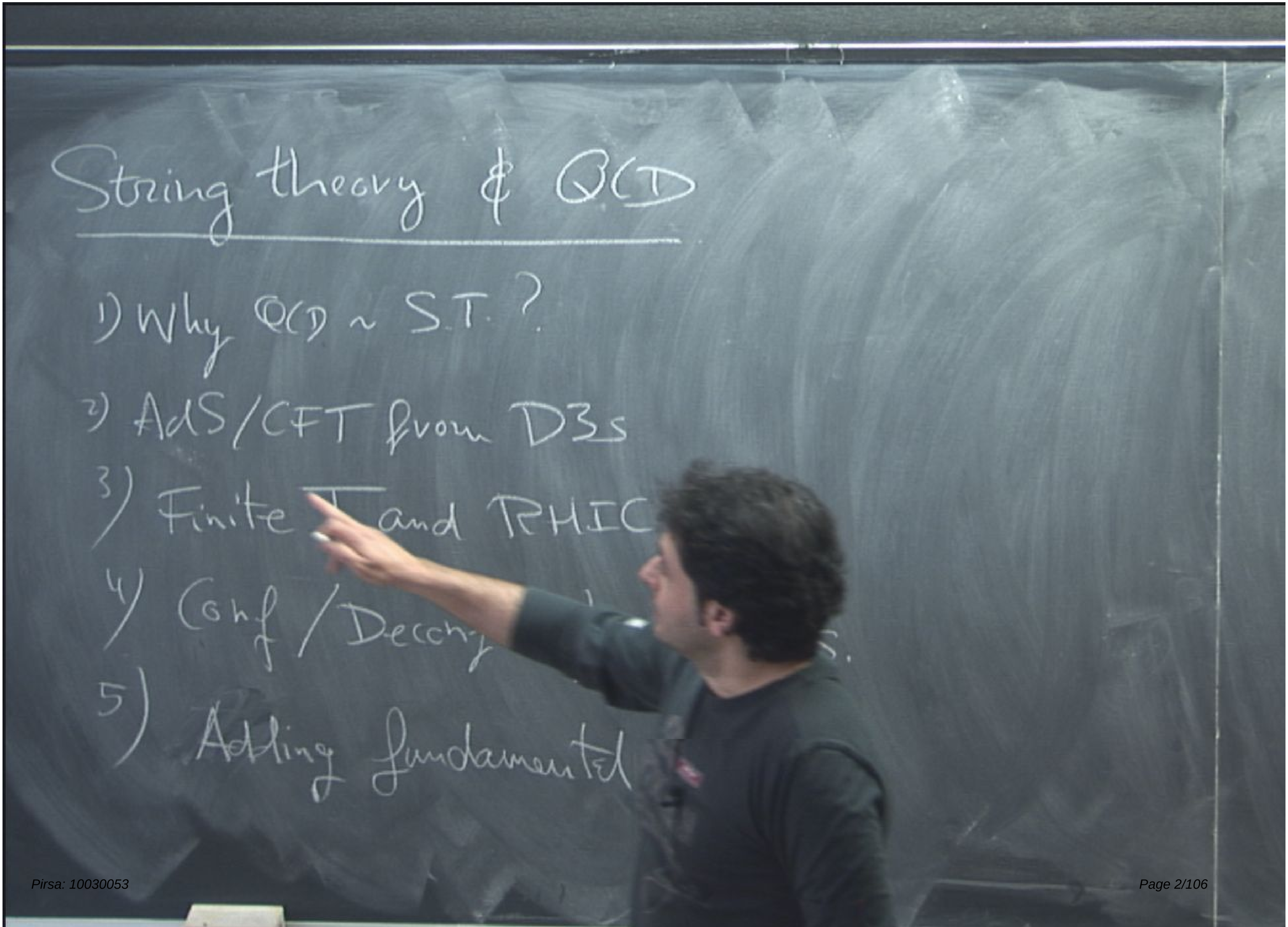
Title: Explorations in String Theory (PHYS 647) - Lecture 11

Date: Mar 01, 2010 04:00 PM

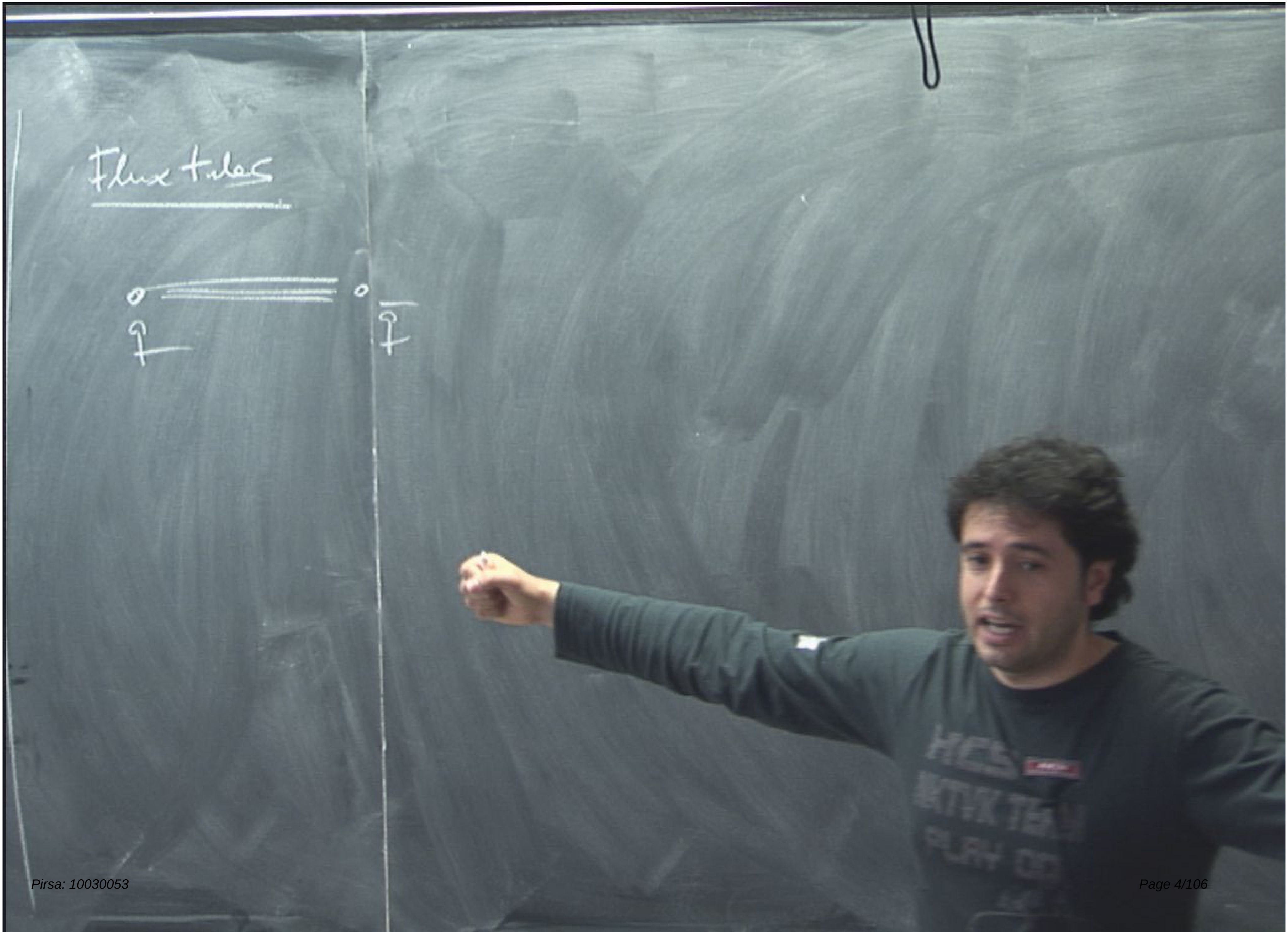
URL: http://pirsa.org/10030053

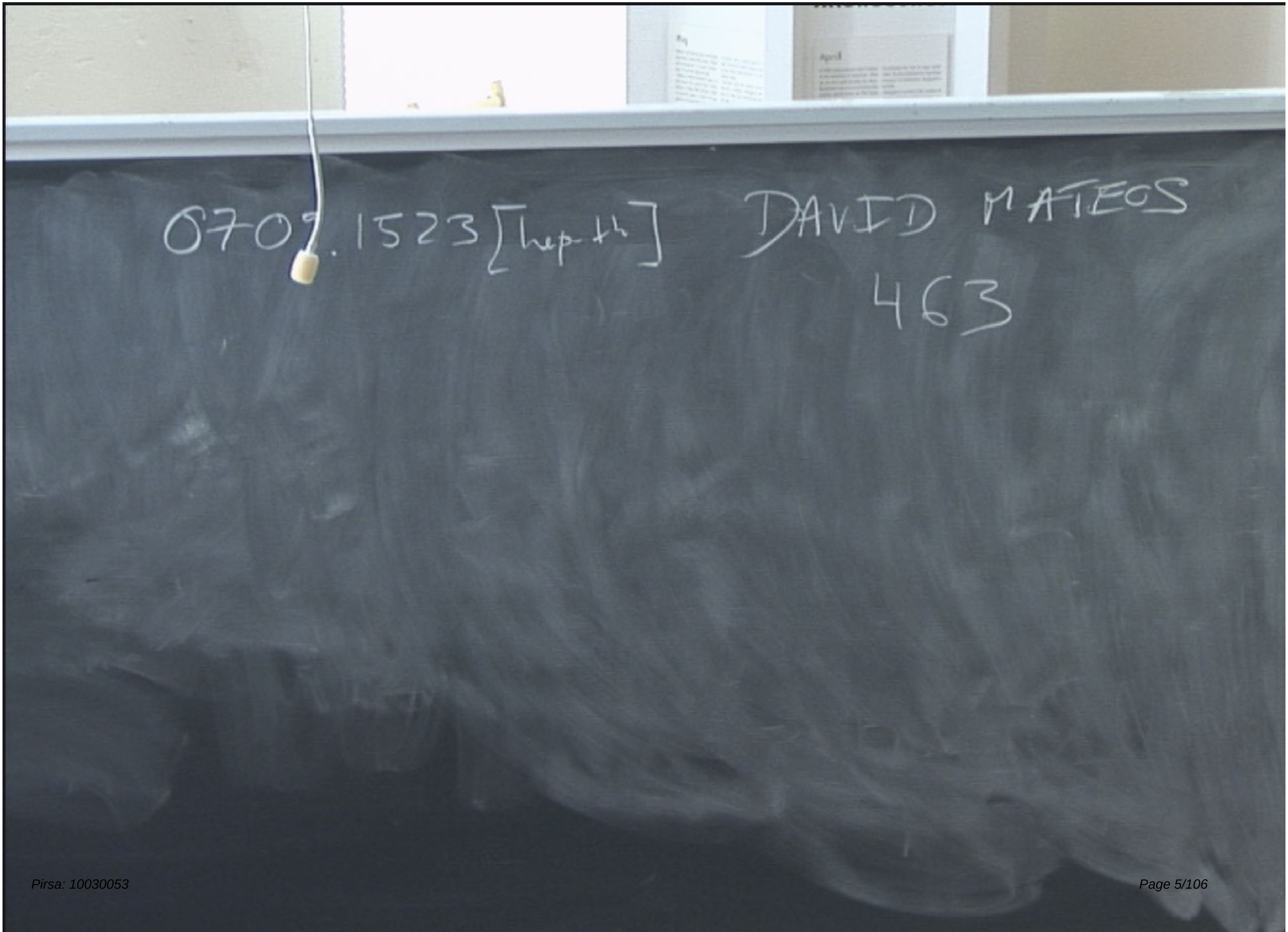
Abstract:


String theory & QCD
1) Why QCD ~ S.T. ?
2) AdS/CFT from D3s
3) Finite T and RHIC
4) Conf / Decon
5) Adding fundamental

String theory & QCD

1) Why QCD ~ S.T.?
2) AdS/CFT from D3s
3) Finite T and RHIC
4) Conf/Deconf. phase trans.
5) Adding fundamental matter


Flux tubes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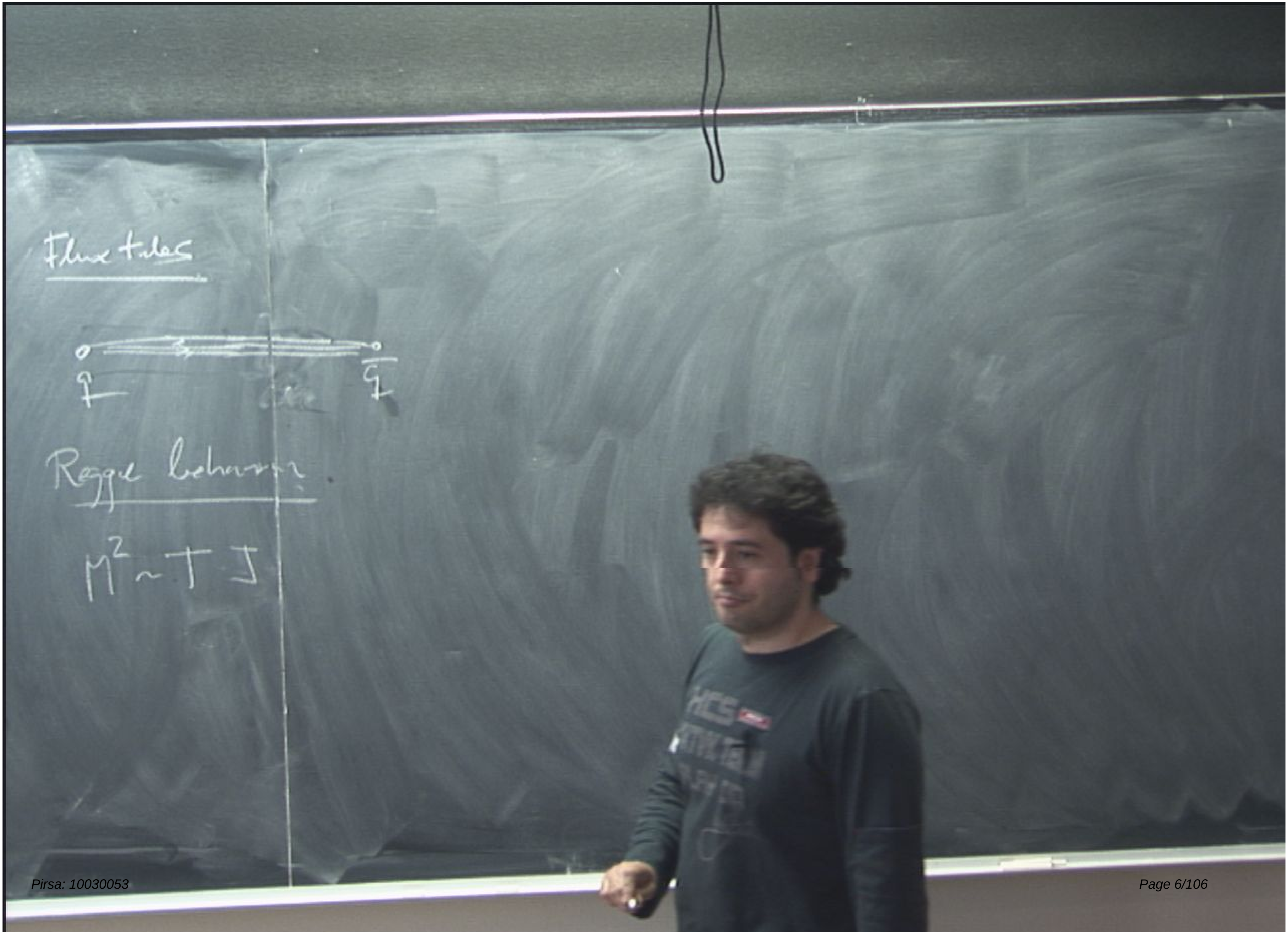
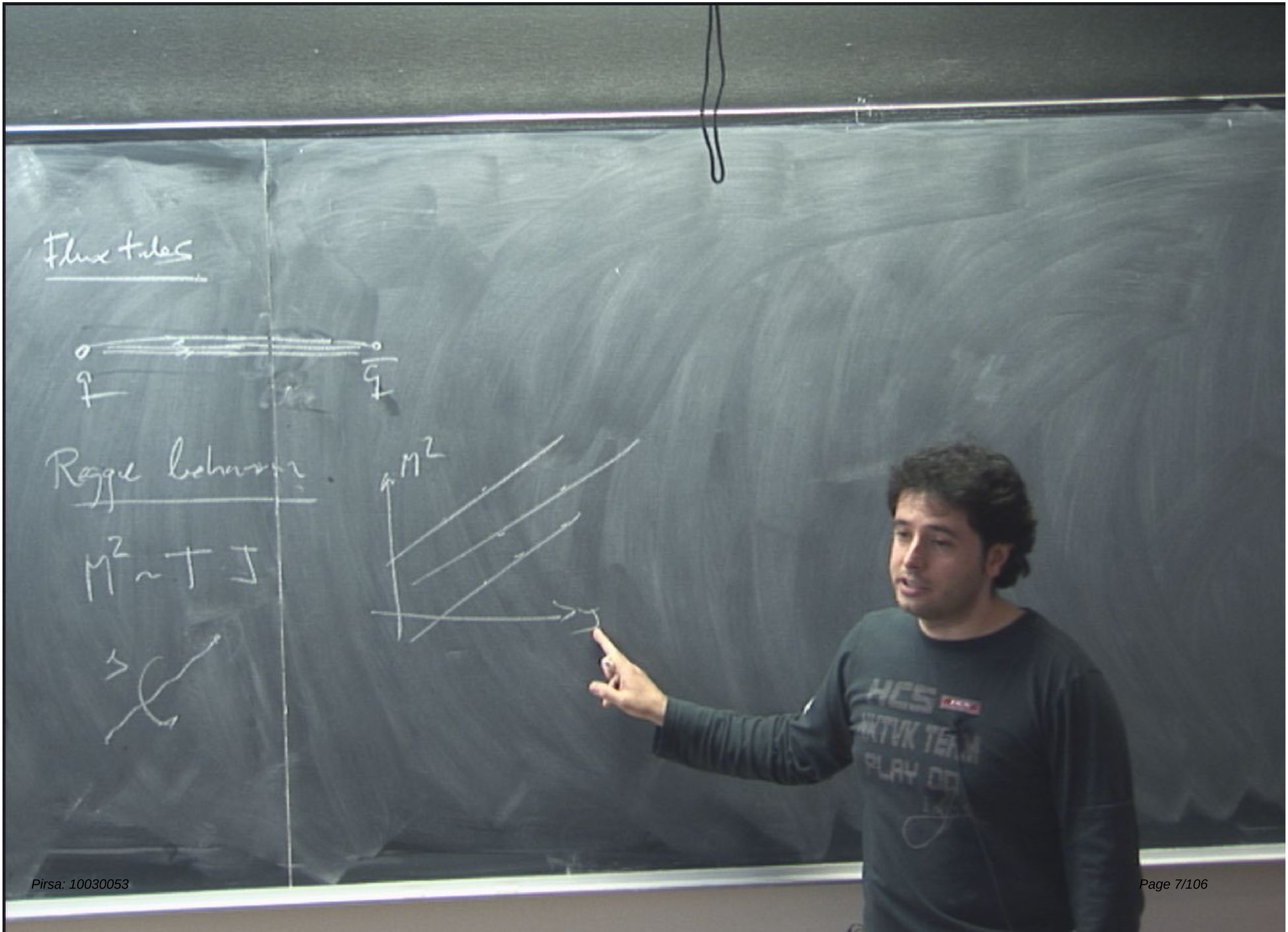
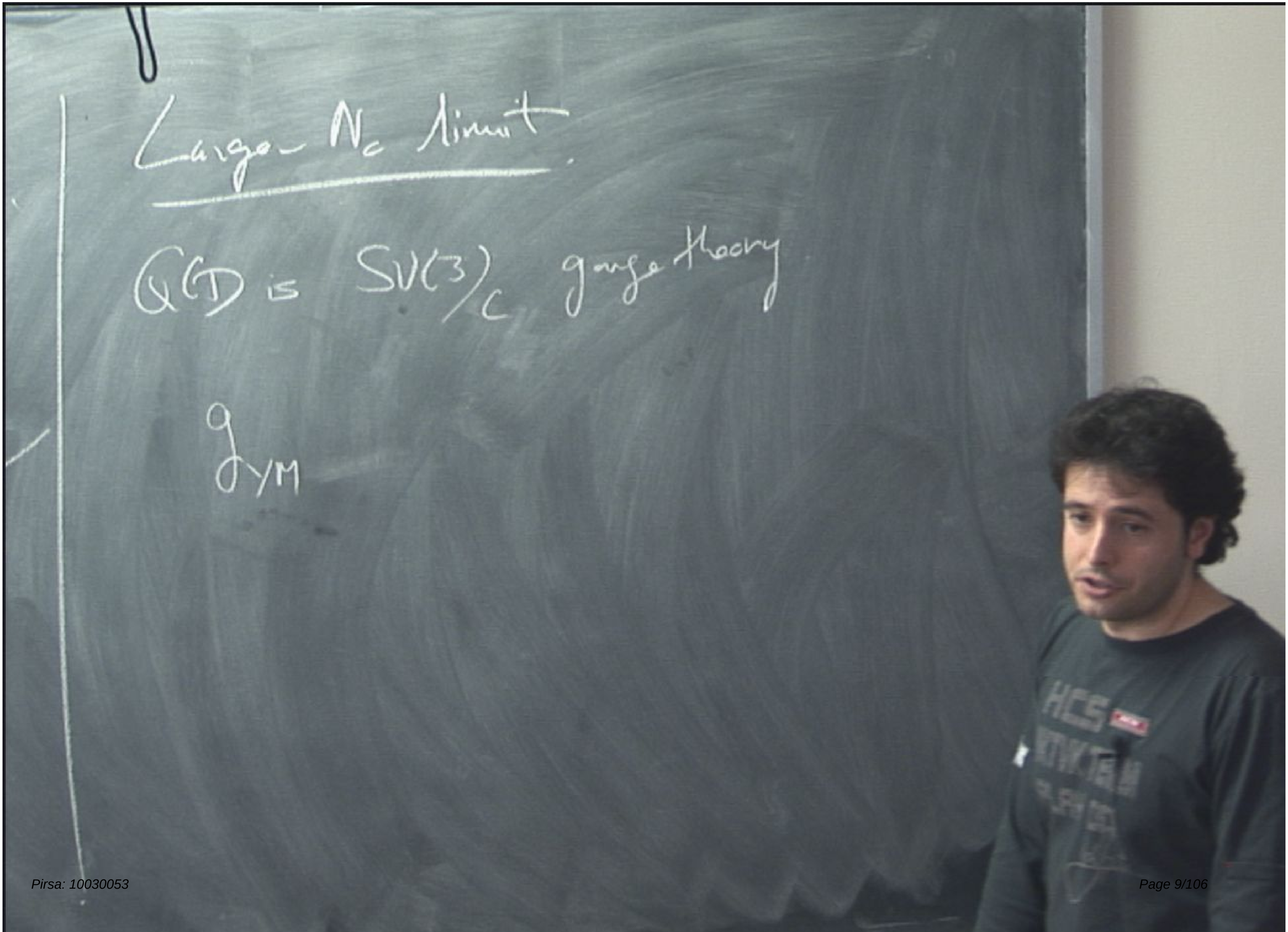
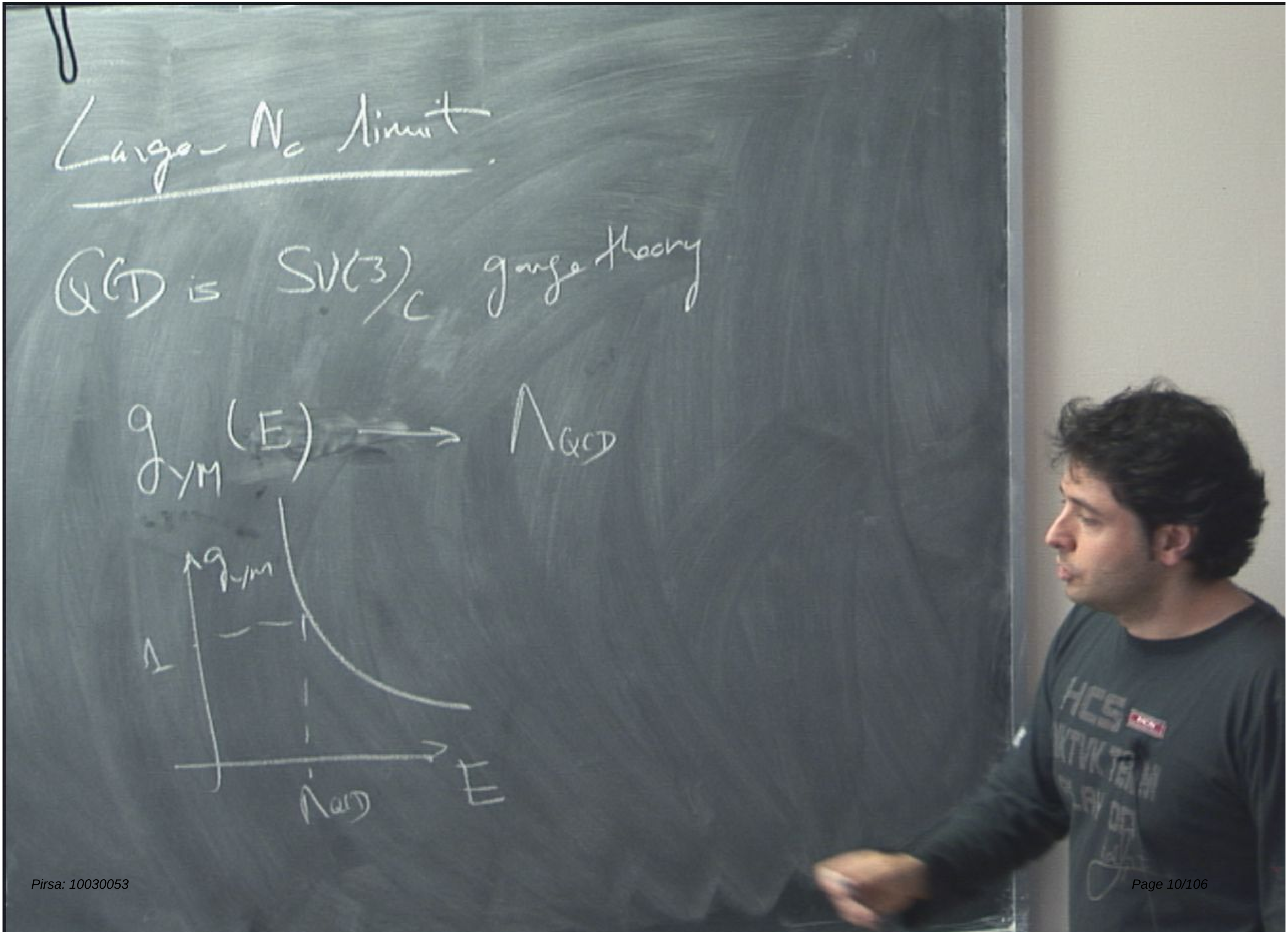

Flux tubes
q
q̄
Regge behavior
M² ~ T J

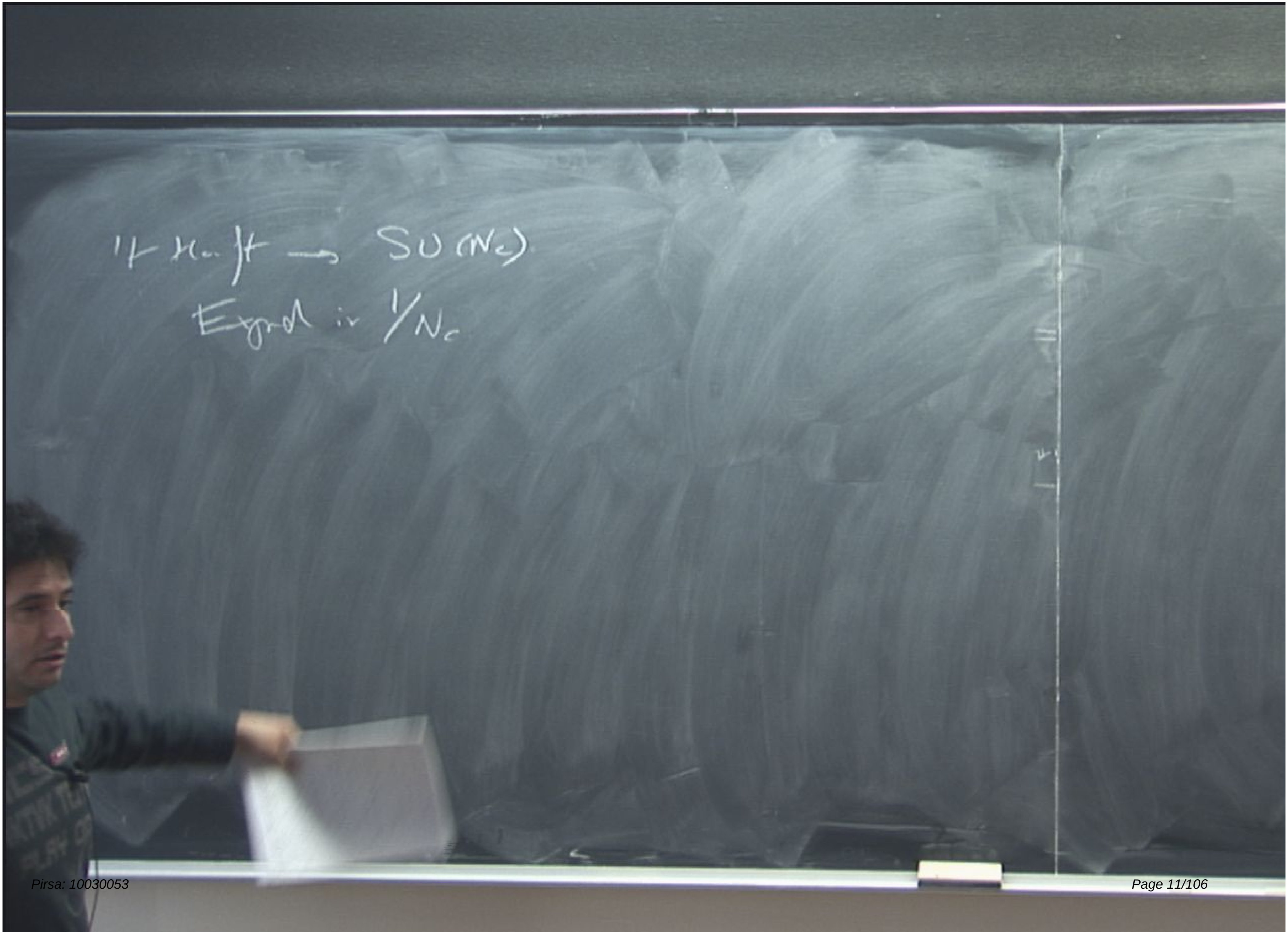

Flux tubes
q
q̄
Regge behavior
M^2
M^2 ~ T J

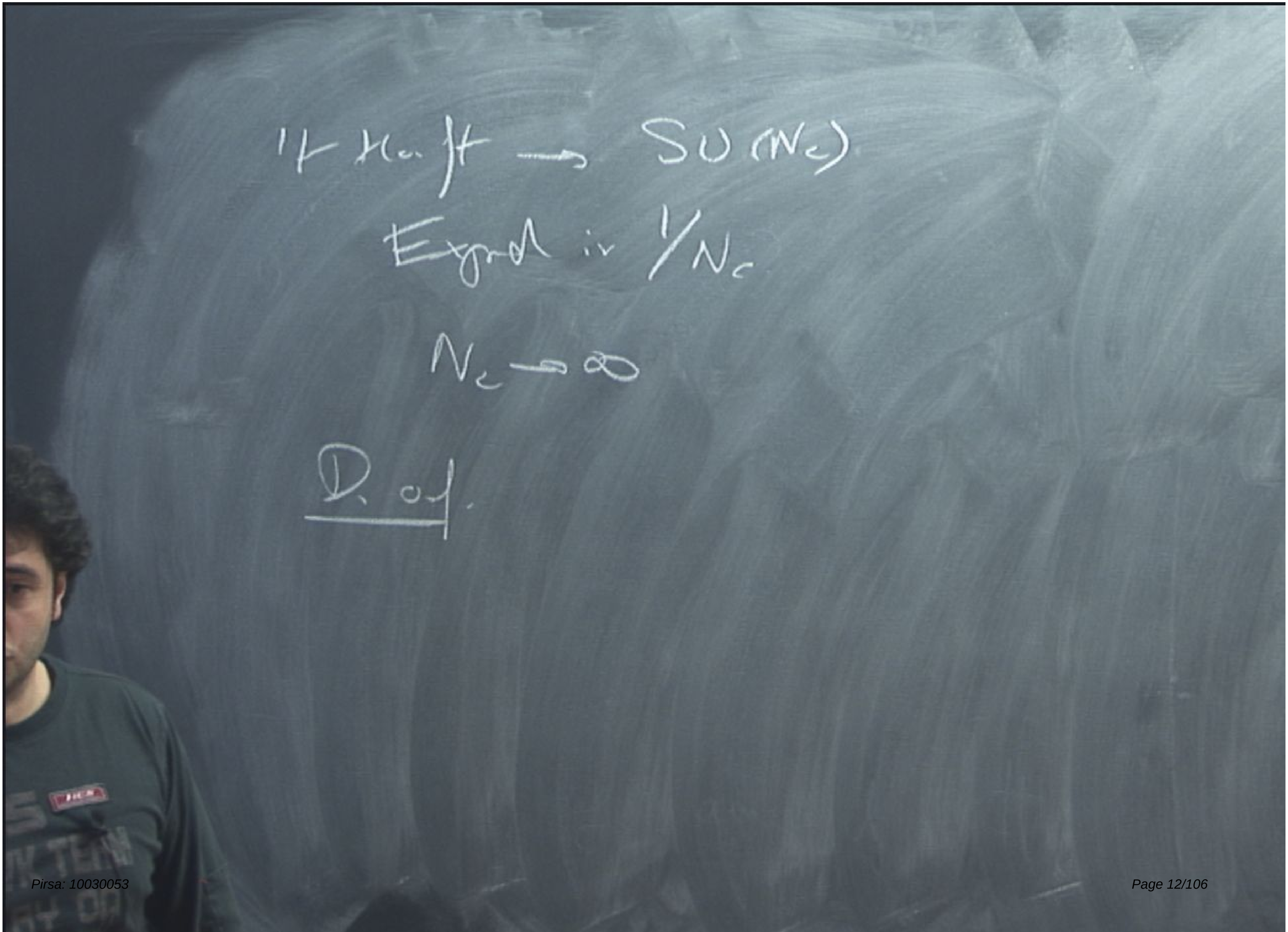
Large N_c limit

QCD is $SU(3)_c$ gauge theory


Large N_c limit
QCD is $SU(3)_C$ gauge theory
g_{YM}


Large N_c limit
QCD is $SU(3)_c$ gauge theory
$g_{YM}(E) \longrightarrow \Lambda_{QCD}$
g_{YM}
1
E
Λ_{QCD}


't Hooft → SU(N_c)
Expand in 1/N_c


't Hooft → SU(N_c)
Expand in 1/N_c
N_c → ∞
Def.

't Hooft $\longrightarrow$ $SU(N_c)$

Expand in $1/N_c$

$N_c \to \infty$

color

$i, j = 1 \ldots$

D. of f.

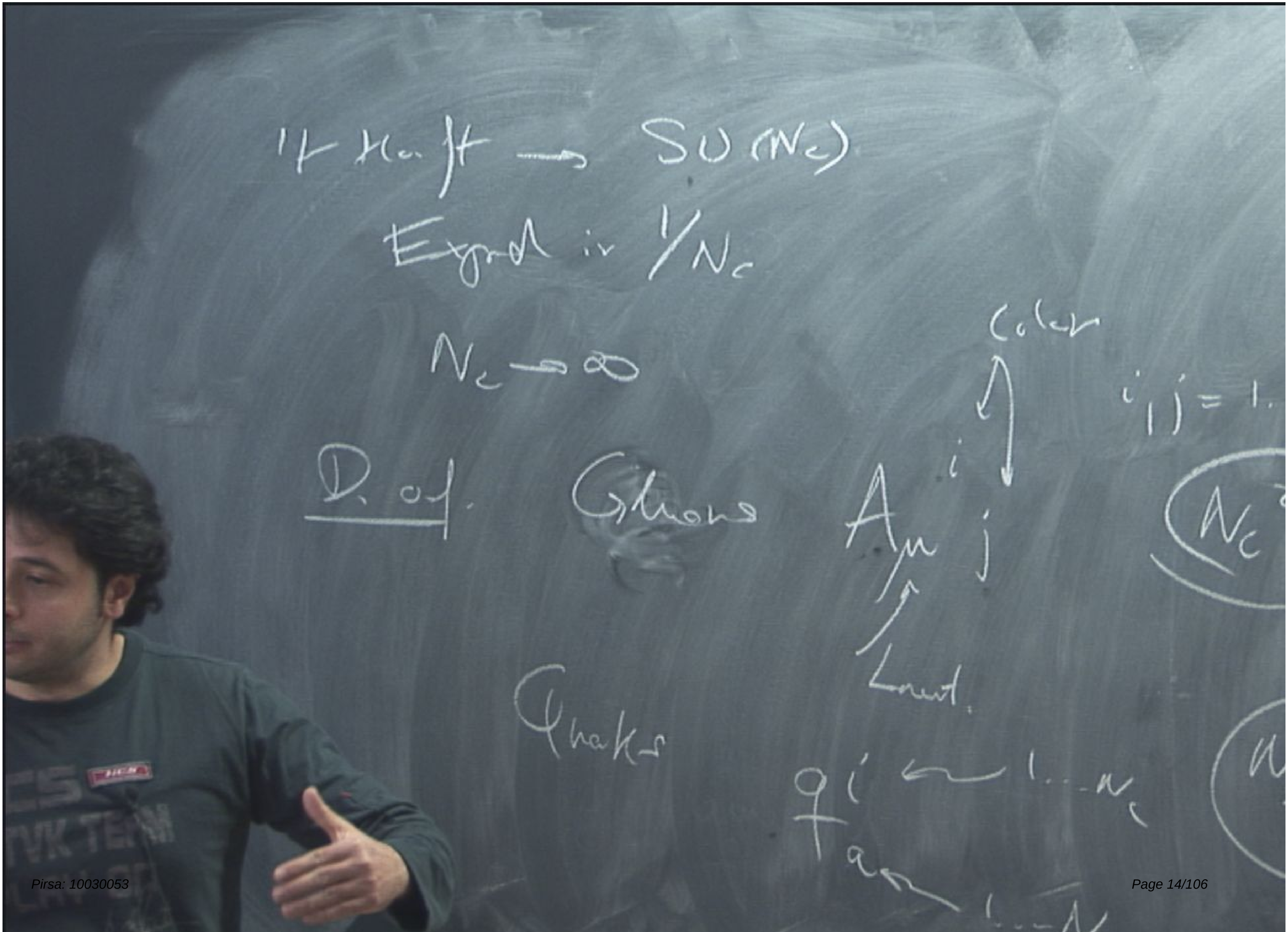
Gluons $A_{\mu}{}^{i}{}_{j}$

Lorentz

Quarks

q^{i}_{a}

$1 \ldots N$



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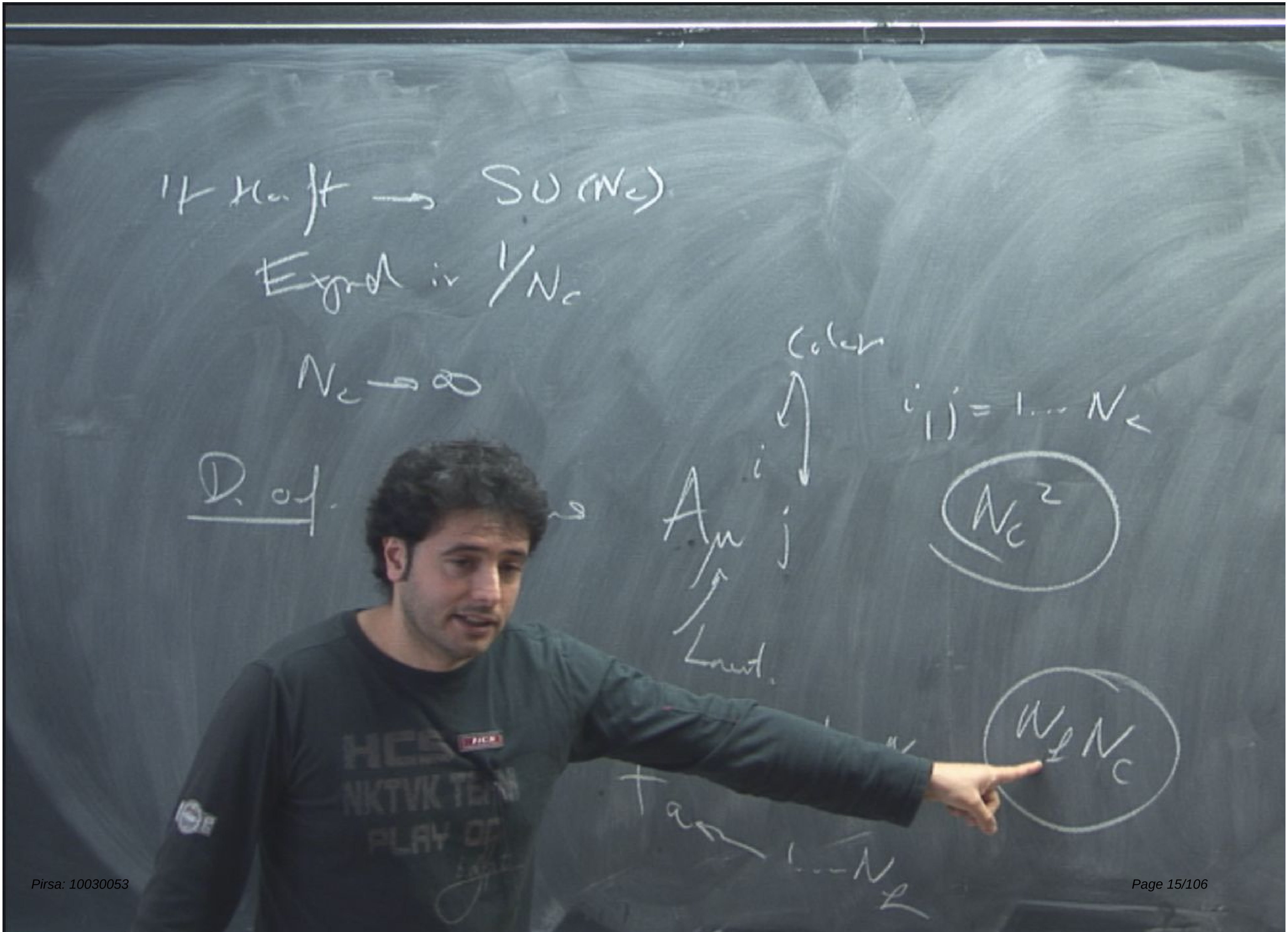


't Hooft → $SU(N_c)$
Expand in $1/N_c$
$N_c \to \infty$
color
D. of.
$A_\mu{}^i{}_j$
$i, j = 1 \ldots N_c$
N_c^2
$N_f N_c$
$1 \ldots N_f$

't Hooft $\rightarrow$ $SU(N_c)$

Expand in $1/N_c$

$N_c \rightarrow \infty$

Color

$i, j = 1 \ldots N_c$

D. of f.

Gluons $A_\mu{}^i{}_j$

N_c^2

Lorentz

Quarks

$q^i \rightarrow 1 \ldots N_c$

$q_a \rightarrow 1 \ldots N_f$

$N_f N_c$

't Hooft → $SU(N_c)$

Expand in $1/N_c$

$N_c \to \infty$

D. of f.

Gluons

color

$A_\mu{}^i{}_j$ $\quad i, j = 1 \dots N_c$ $\quad N_c^2$

Lorentz

Quarks

$q^i \quad 1 \dots N_c$

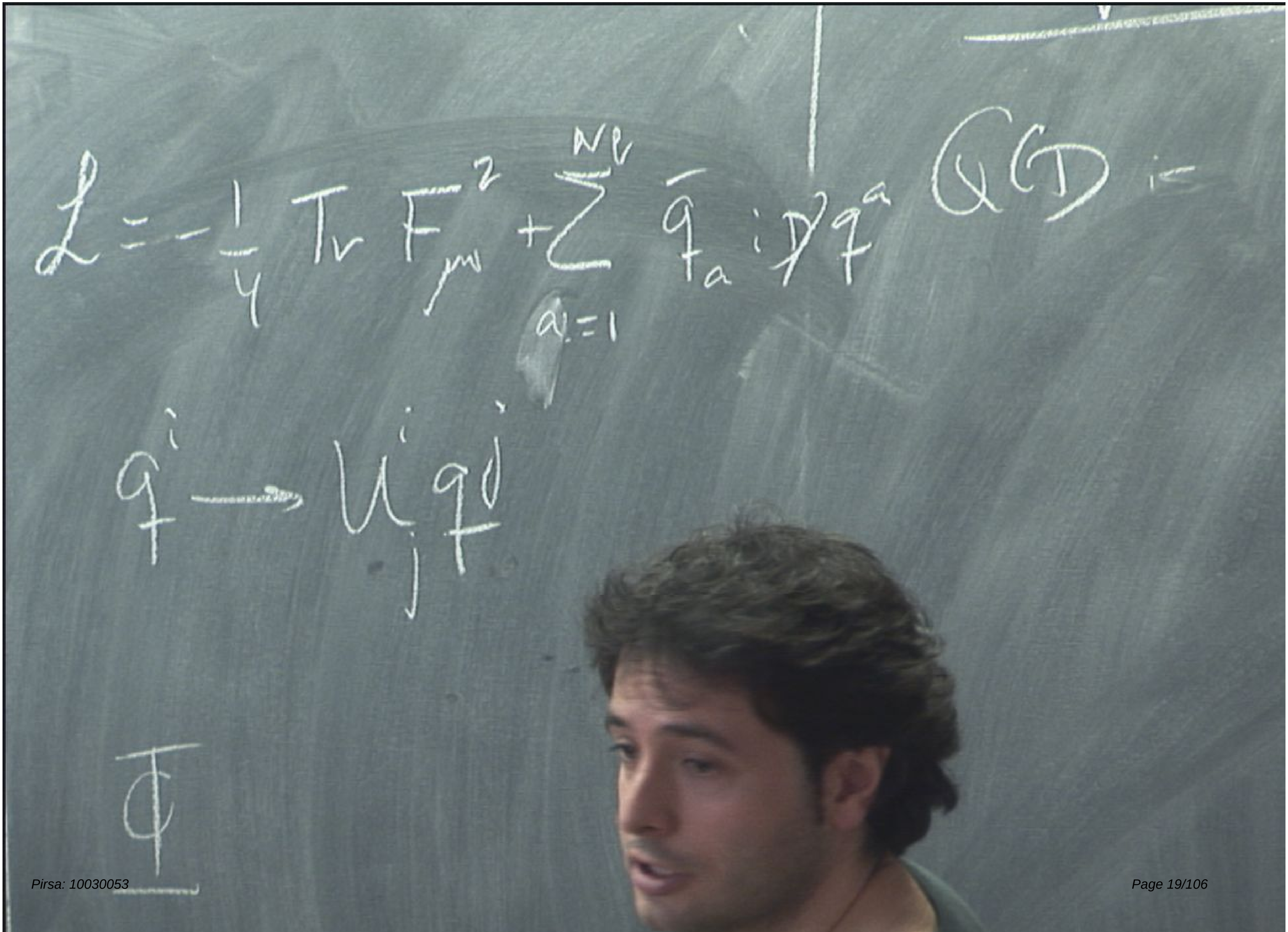
$a \quad 1 \dots N_f$ $\quad N_f N_c$

$$\mathcal{L} = -\frac{1}{4}\,\mathrm{Tr}\,F_{\mu\nu}^2 + \sum_{a=1}^{N_f} \bar{q}_a\, i \not{D}\, q^a$$

QCD

g

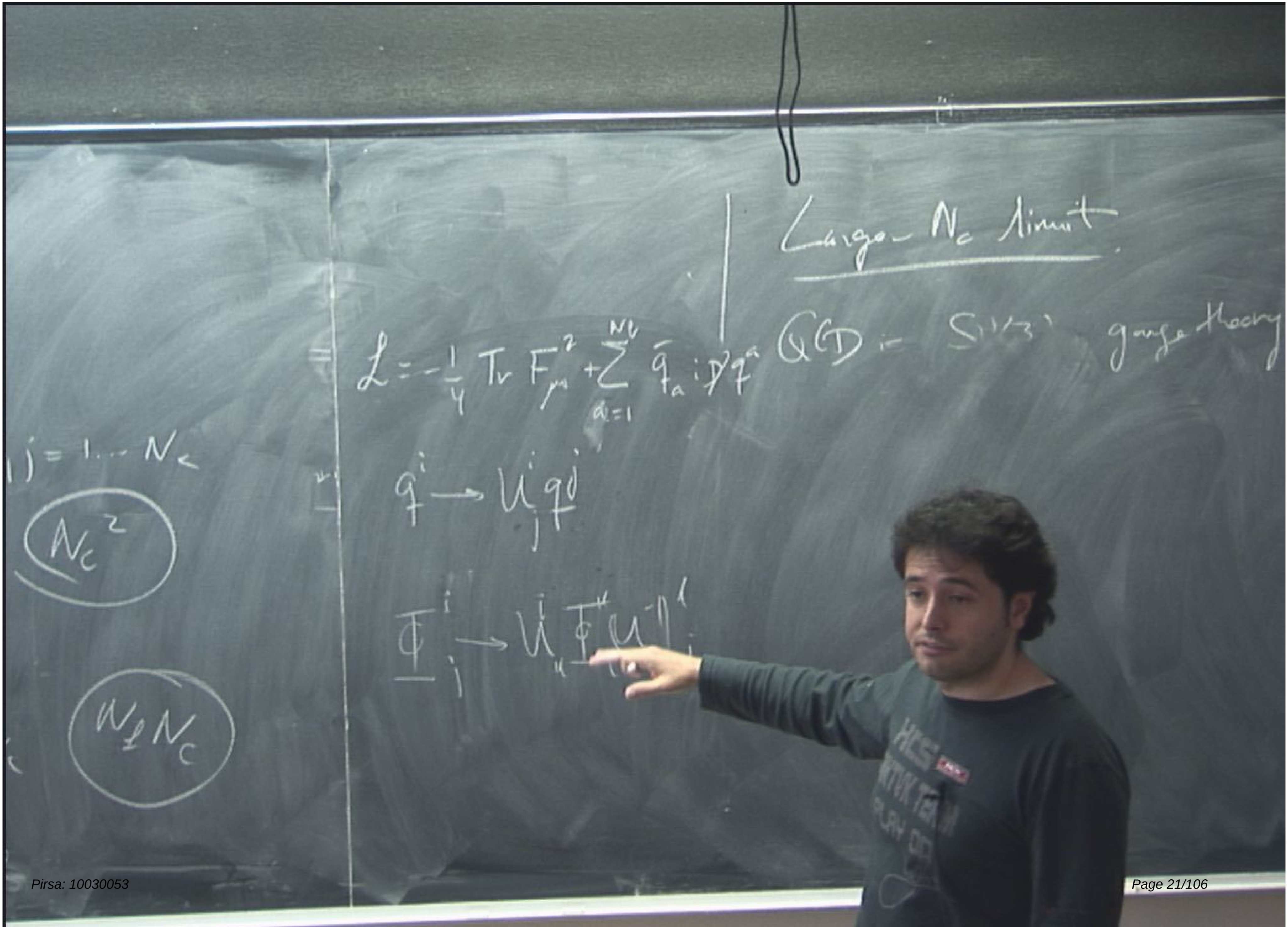
1


$\mathcal{L} = -\frac{1}{4} \mathrm{Tr}\, F_{\mu\nu}^2 + \sum_{a=1}^{N_f} \bar{q}_a\, i \not{D}\, q^a$
QCD is
$q^i \longrightarrow U^i_j\, q^j$

$$\mathcal{L} = -\frac{1}{4}\,\mathrm{Tr}\, F_{\mu\nu}^2 + \sum_{a=1}^{N_f} \bar{q}_a\, i \not{D}\, q^a \qquad \text{QCD}$$

$$q^i \longrightarrow U^i_{\ j}\, q^j$$

$$\Phi \longrightarrow U \Phi U^{-1}$$


Large-N_c limit
QCD in SU(3) gauge theory
$\mathcal{L} = -\frac{1}{4} \mathrm{Tr}\, F_{\mu\nu}^2 + \sum_{a=1}^{N_f} \bar{q}_a \, i \not{D} q^a$
$i,j = 1 \ldots N_c$
$q^i \to U^i_j q^j$
$\Phi^i_j \to U^i_k \Phi^k_l (U^{-1})^l_j$
N_c^2
$N_f N_c$

Large N_c limit

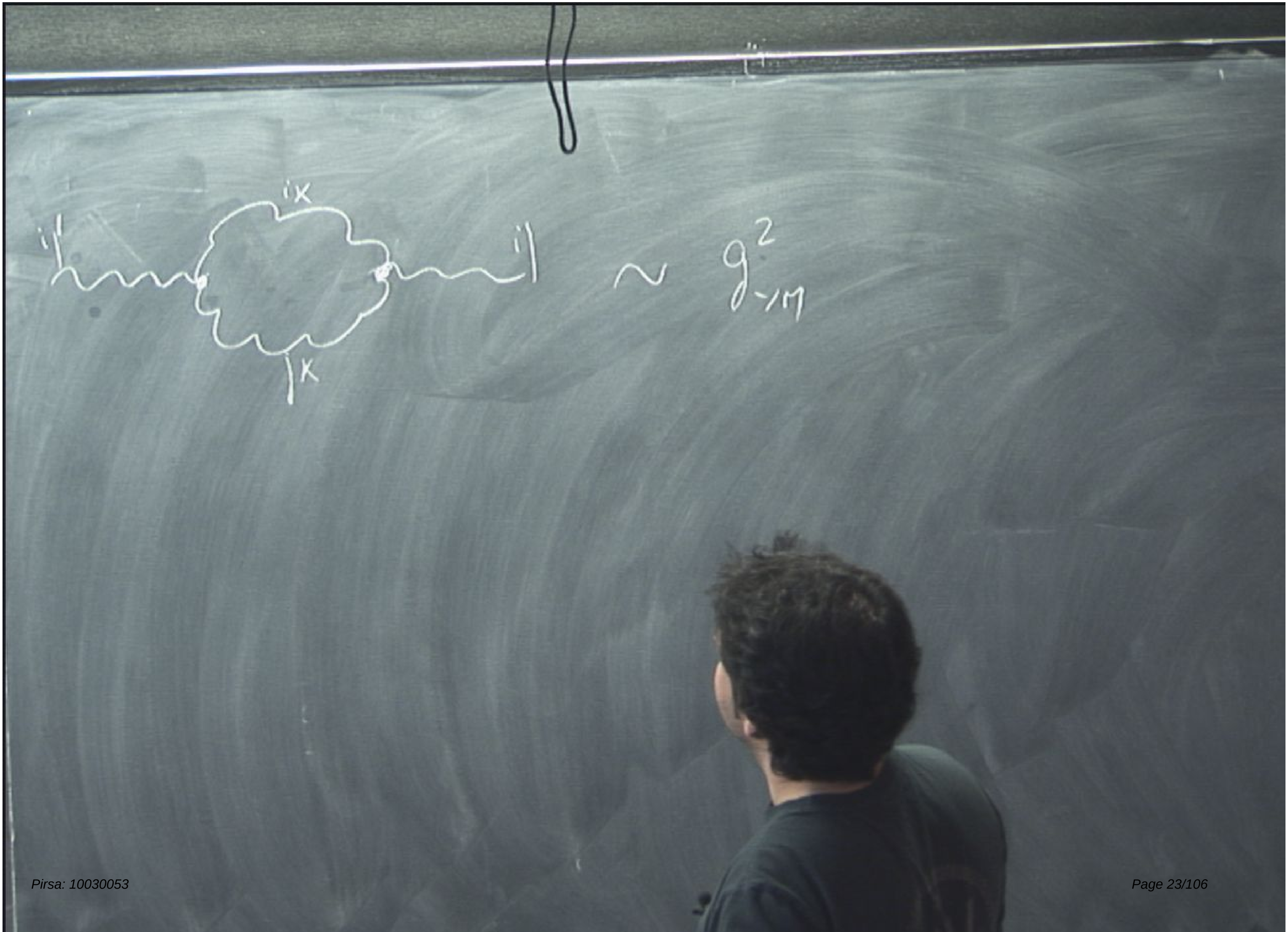
QCD is SU(3) gauge theory

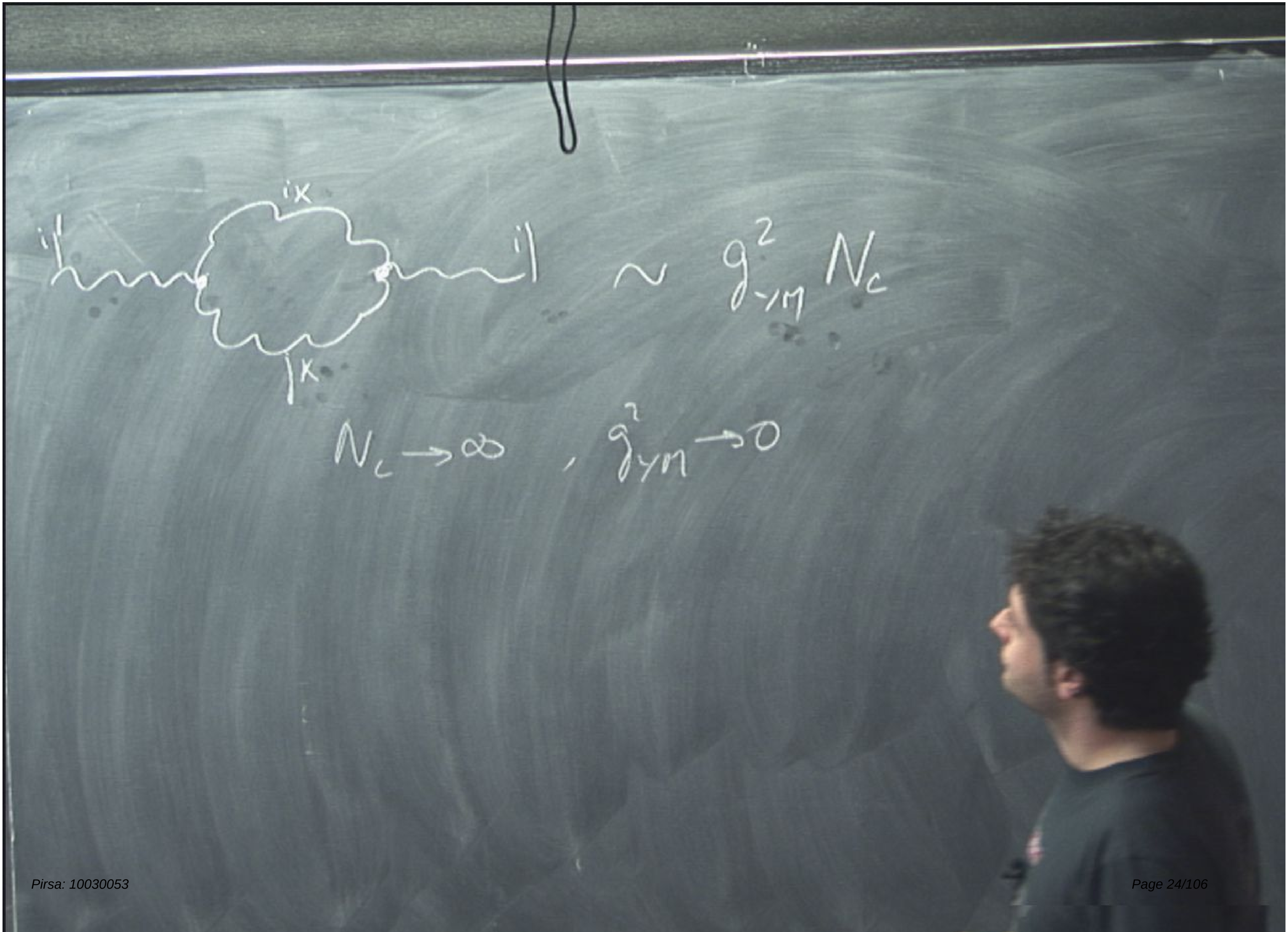
$$-\frac{1}{4}\,\mathrm{Tr}\,F_{\mu\nu}^2 + \sum_{a=1}^{N_f} \bar{q}_a\, i \not{D}\, q^a$$

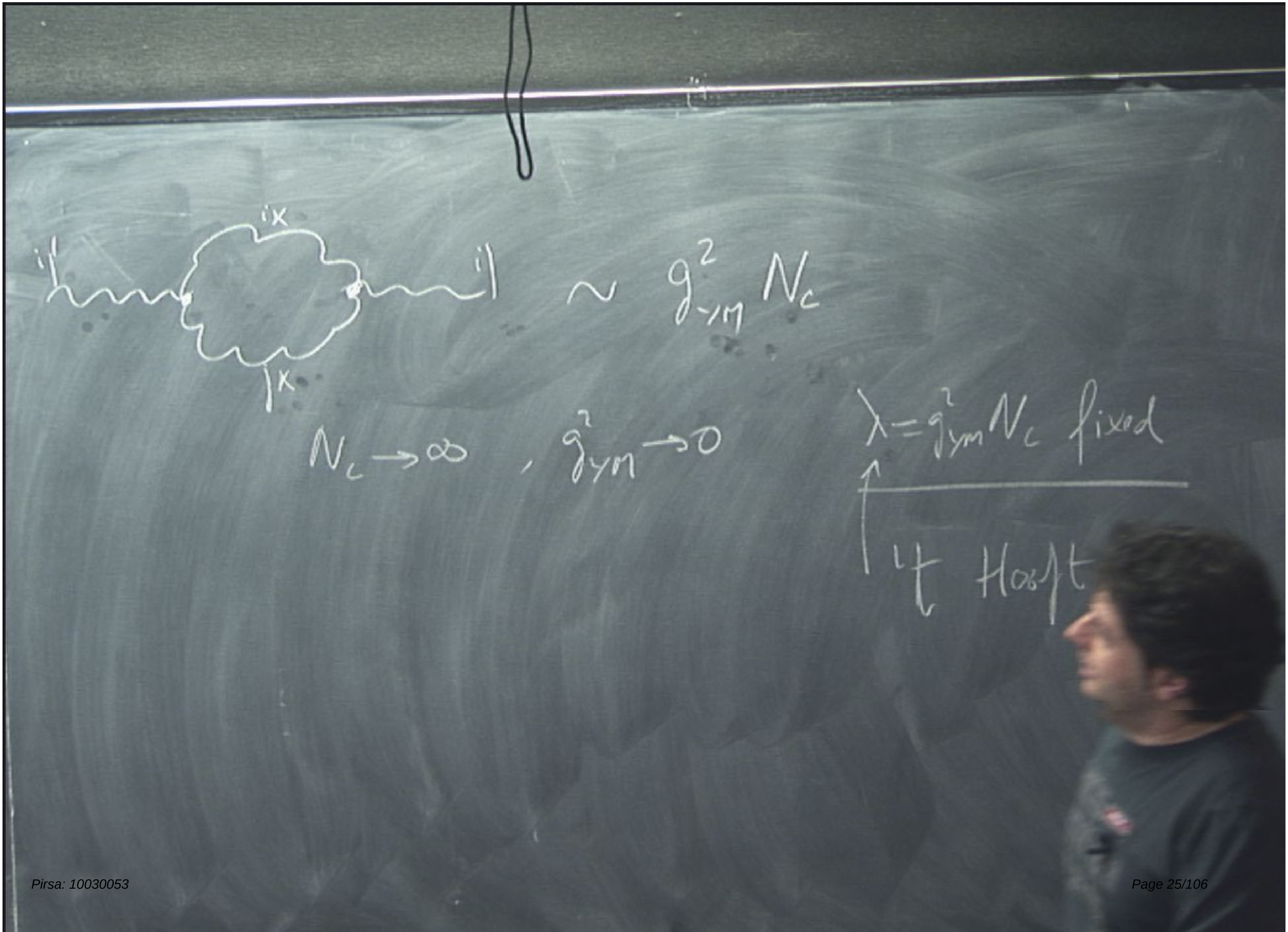
$$q^i \to U^i_j\, q^j$$

$$\Phi^i_j \to U^i_k\, \Phi^k_l\, (U^{-1})^l_j$$

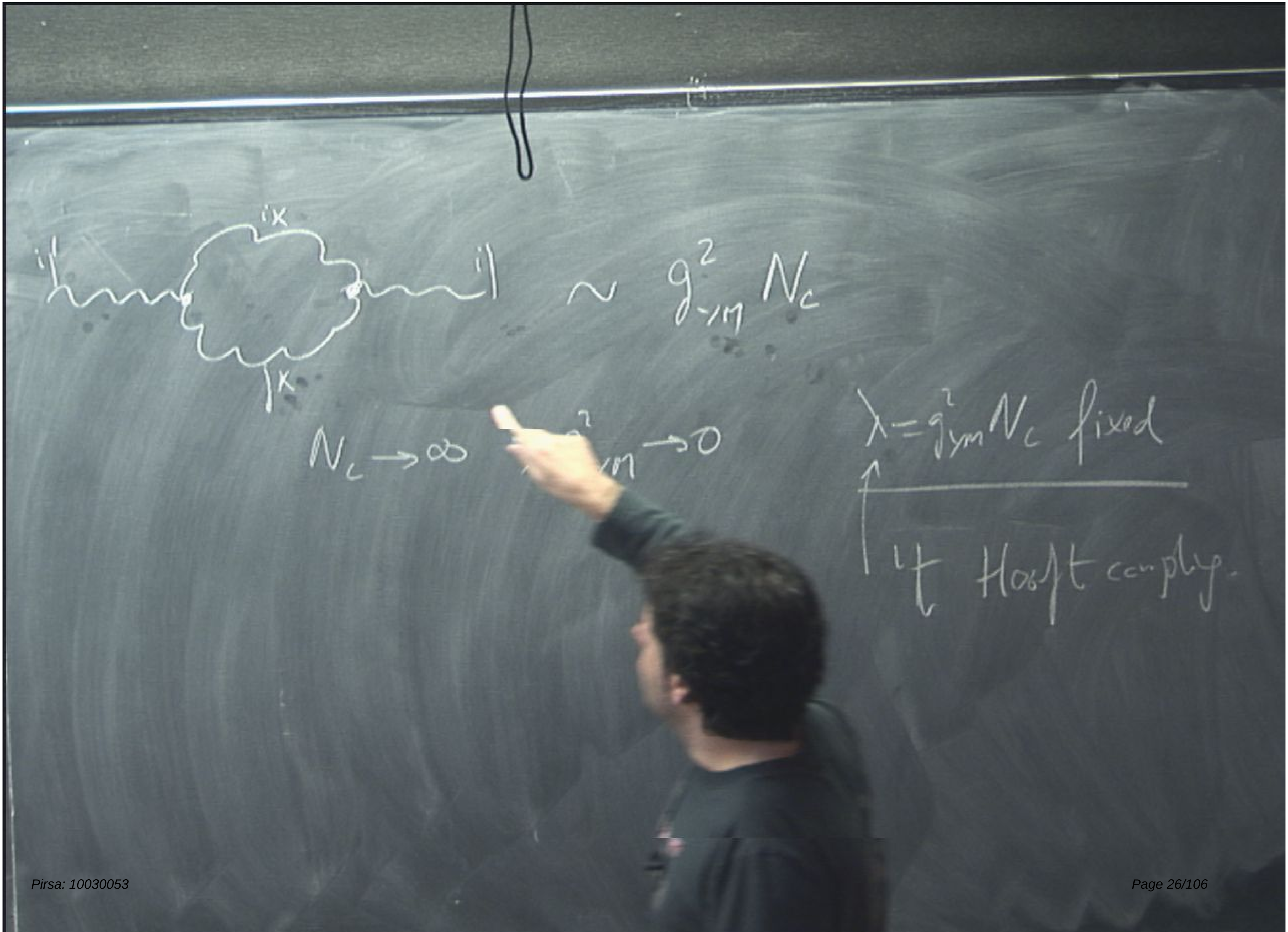
$$A^i_j = \sum_\alpha A_\alpha (T^\alpha)^i_j$$

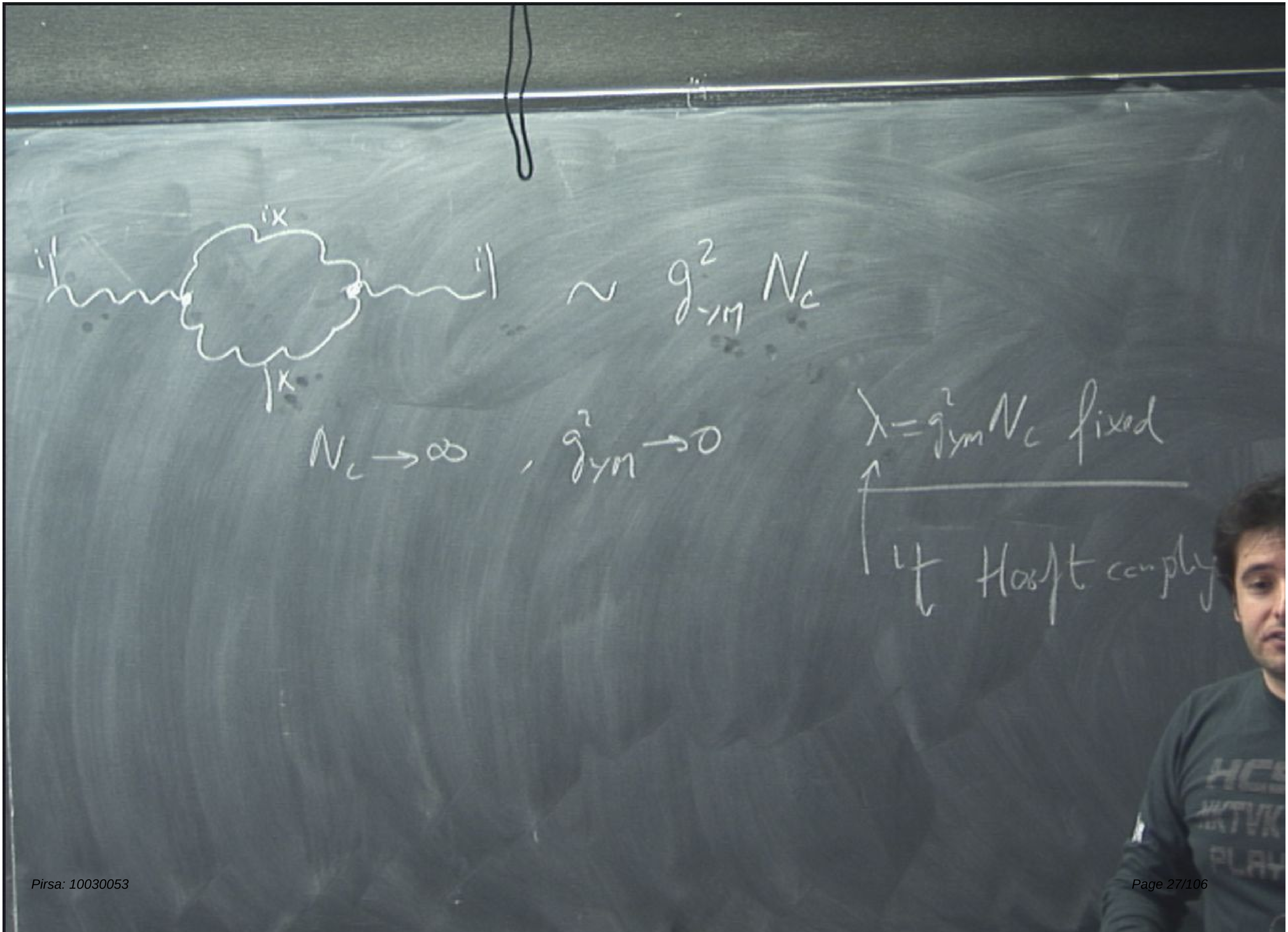



$\sim g^2_{YM} N_c$
$N_c \to \infty \,,\; g^2_{YM} \to 0$

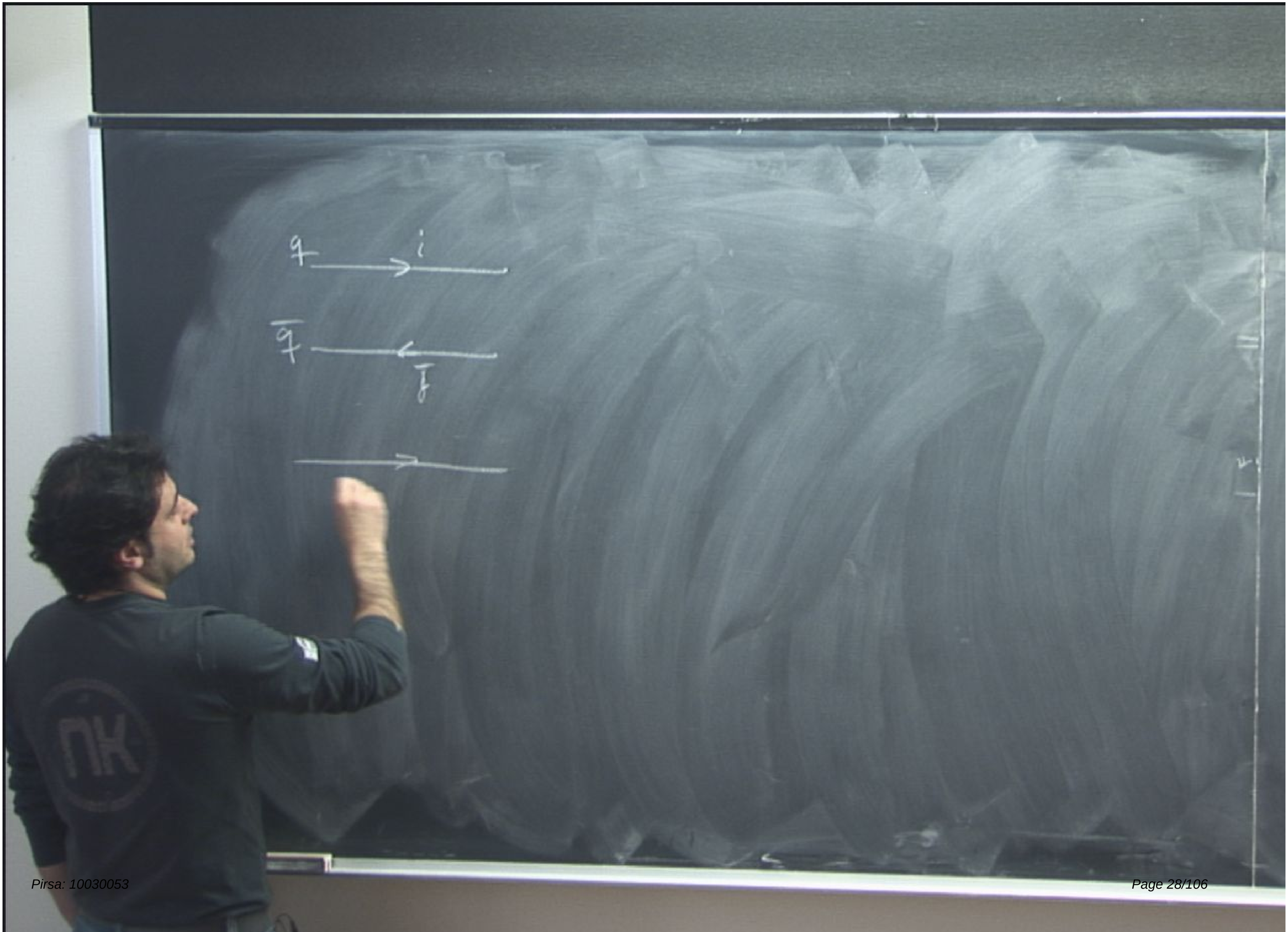


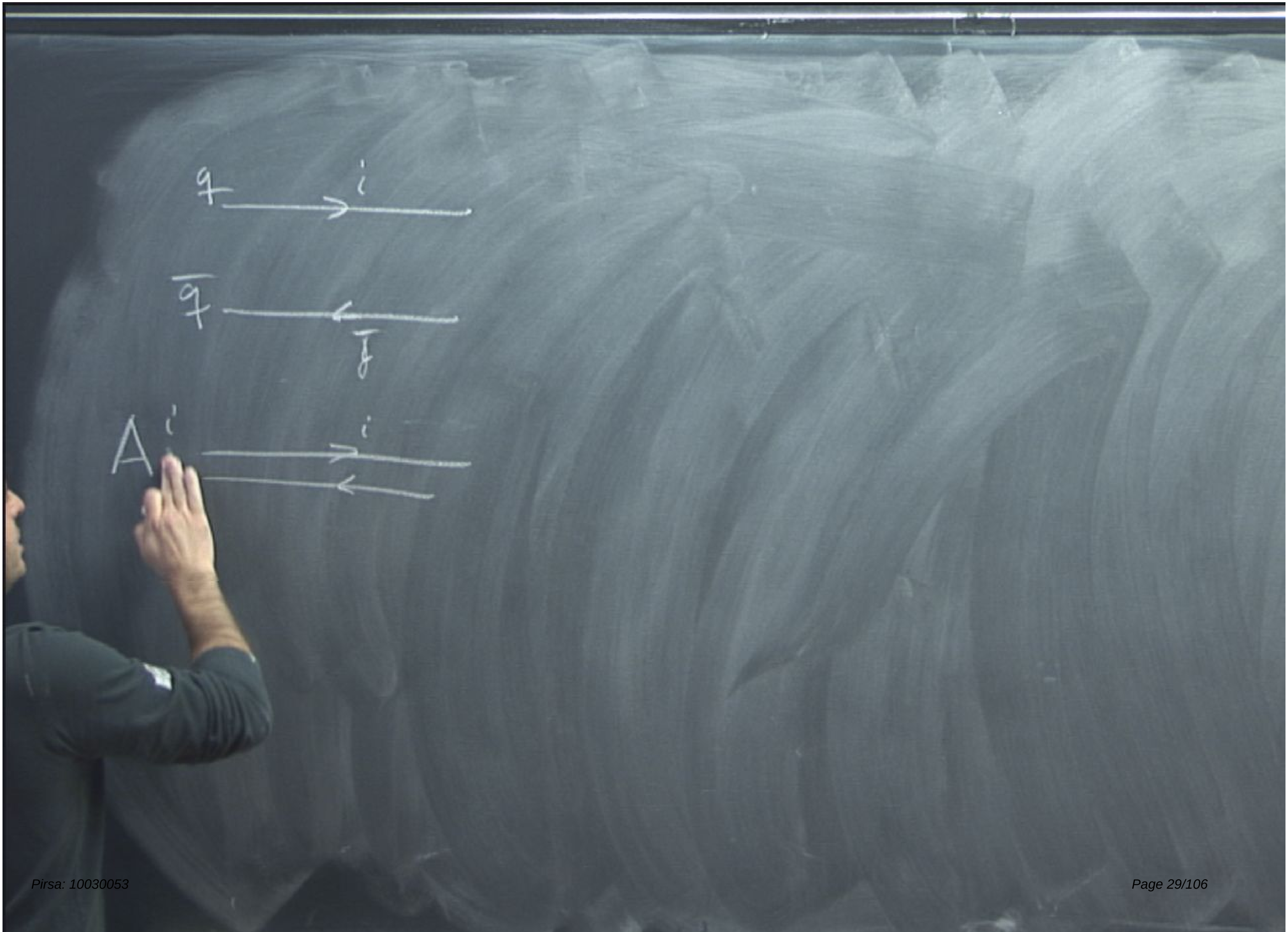
ik
il
il
jk
$\sim g^2_{YM} N_c$
$N_c \to \infty \ , \ g^2_{YM} \to 0$
$\lambda = g^2_{YM} N_c$ fixed
't Hooft

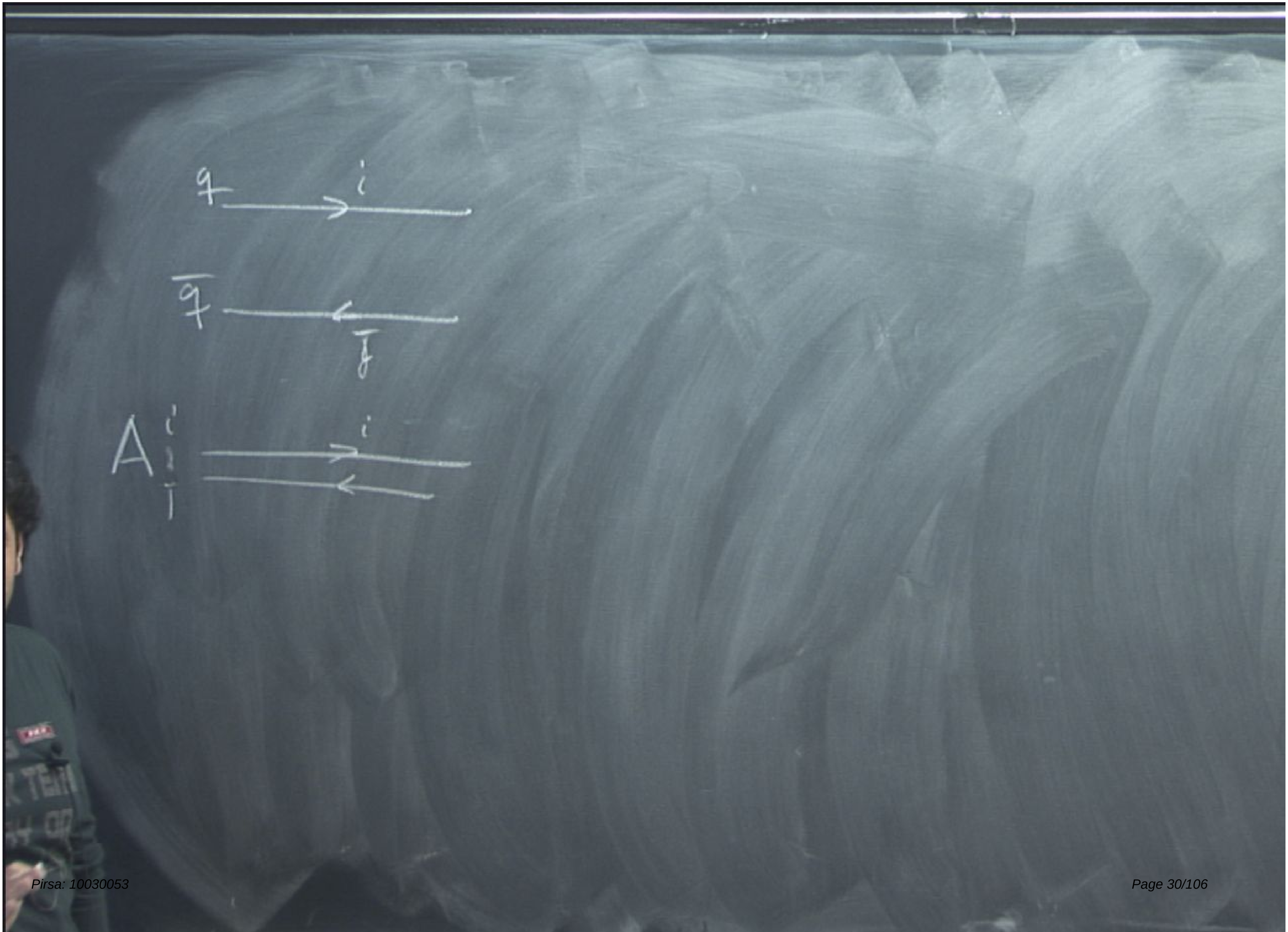

i l
i x
i l
j k
~ $g^2_{YM} N_c$
$N_c \to \infty$
$\lambda = g^2_{YM} N_c$ fixed
't Hooft coupling

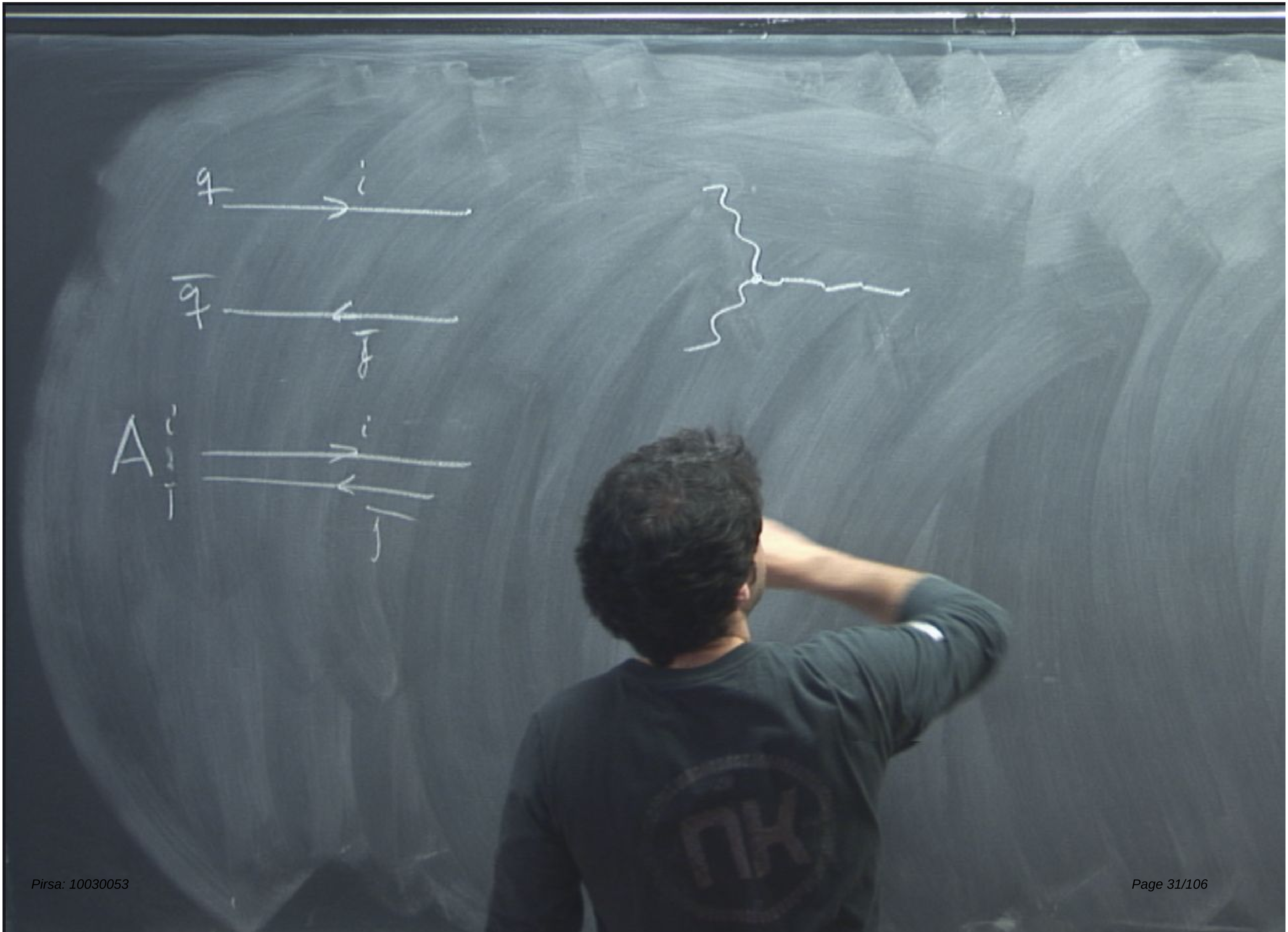


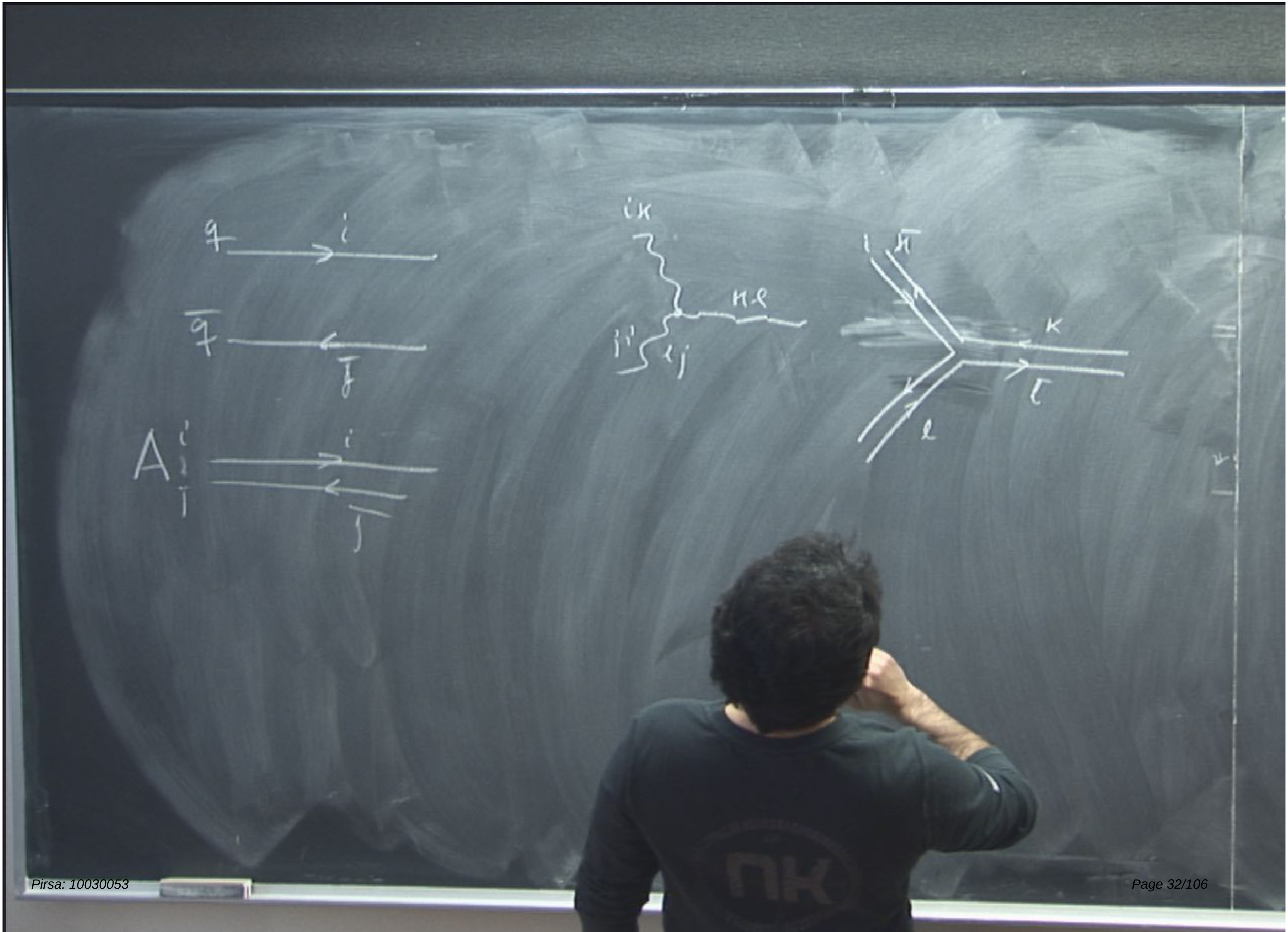
~ g²_YM N_c
N_c → ∞ , g²_YM → 0
λ = g²_YM N_c fixed
't Hooft coupling

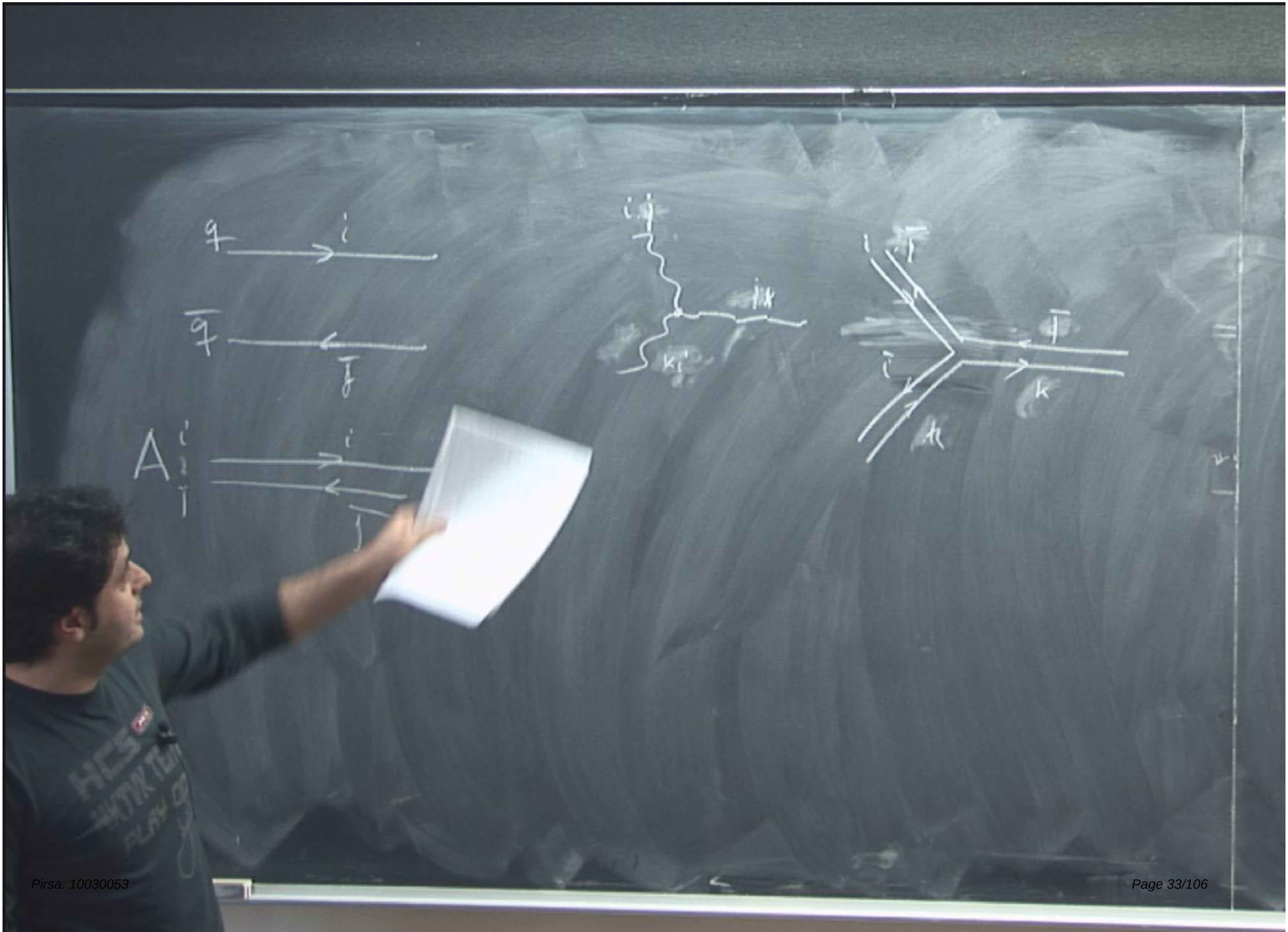

q
i
q̄
j̄

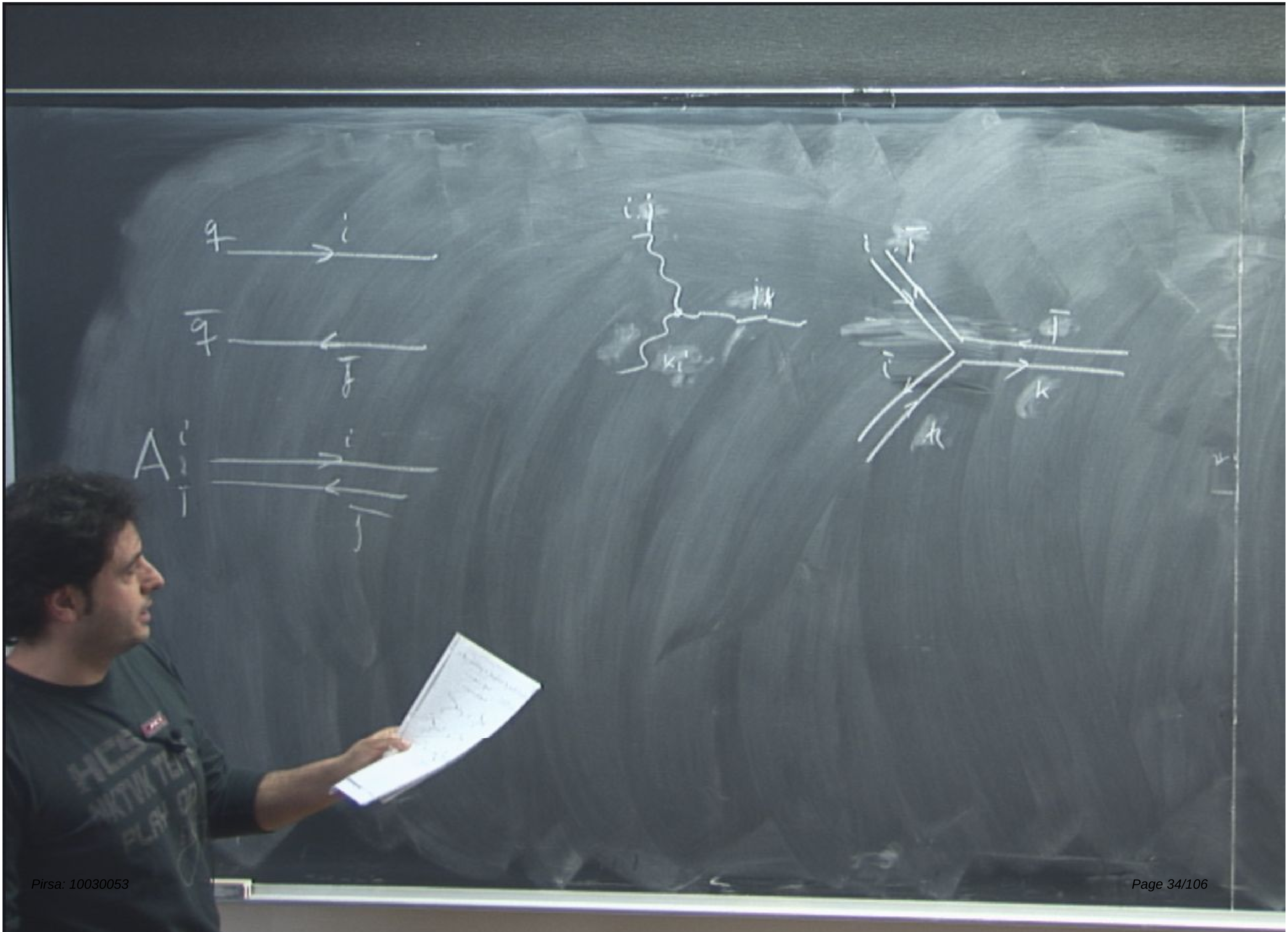

q
i
q̄
j̄
A
i
i

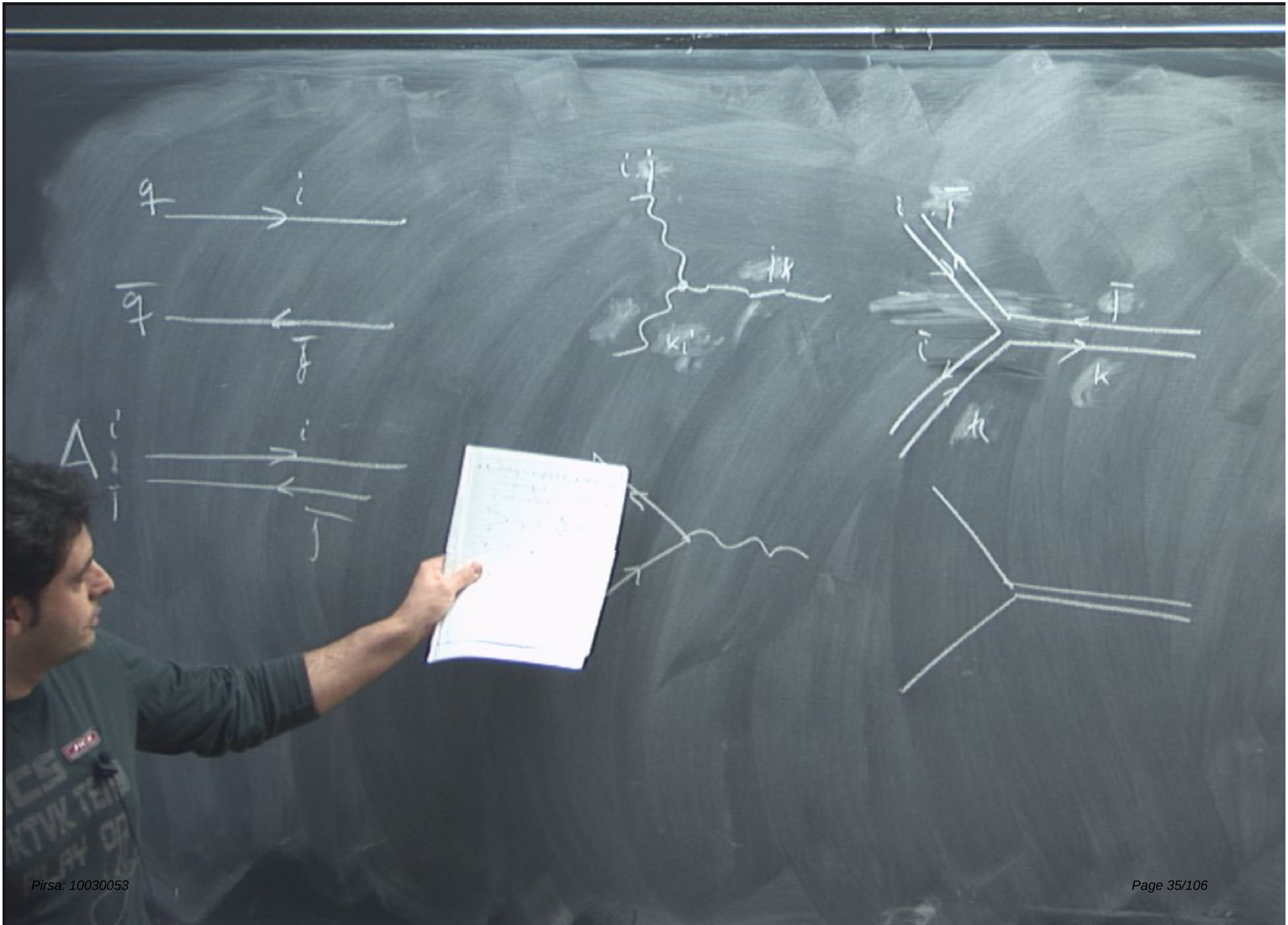

q
i
$\bar{q}$
$\bar{j}$
$A^{i}_{\bar{j}}$
i

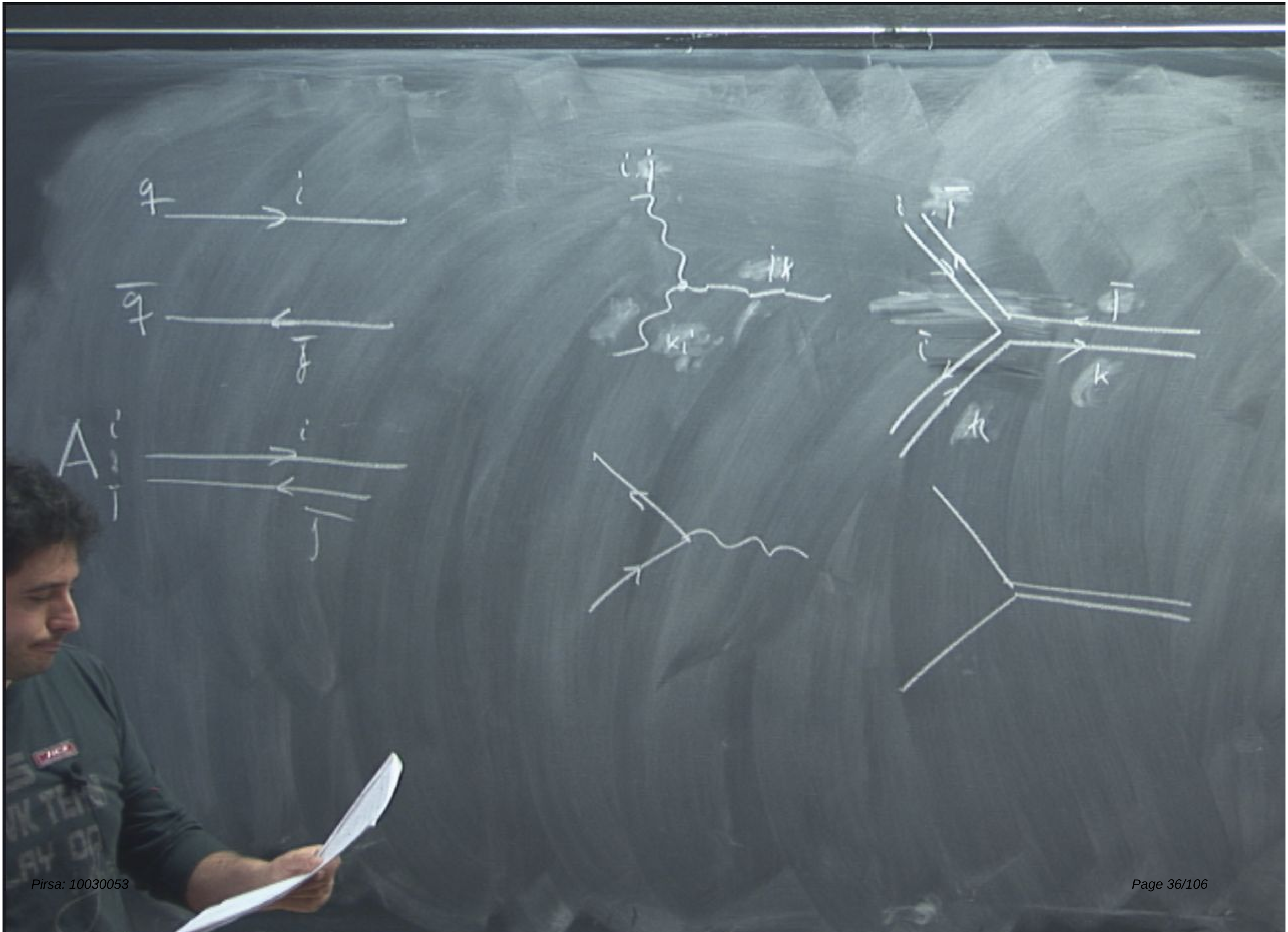


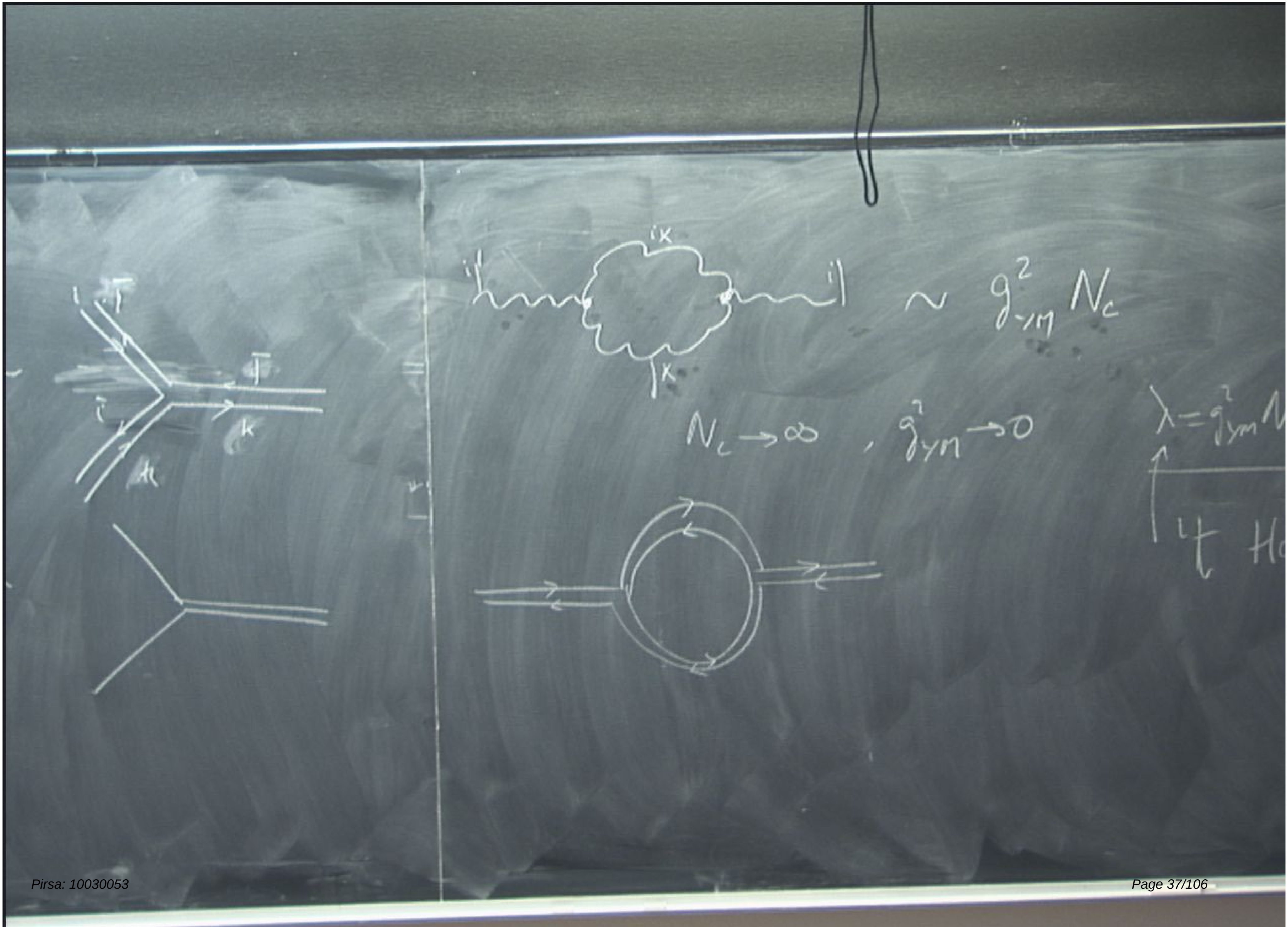


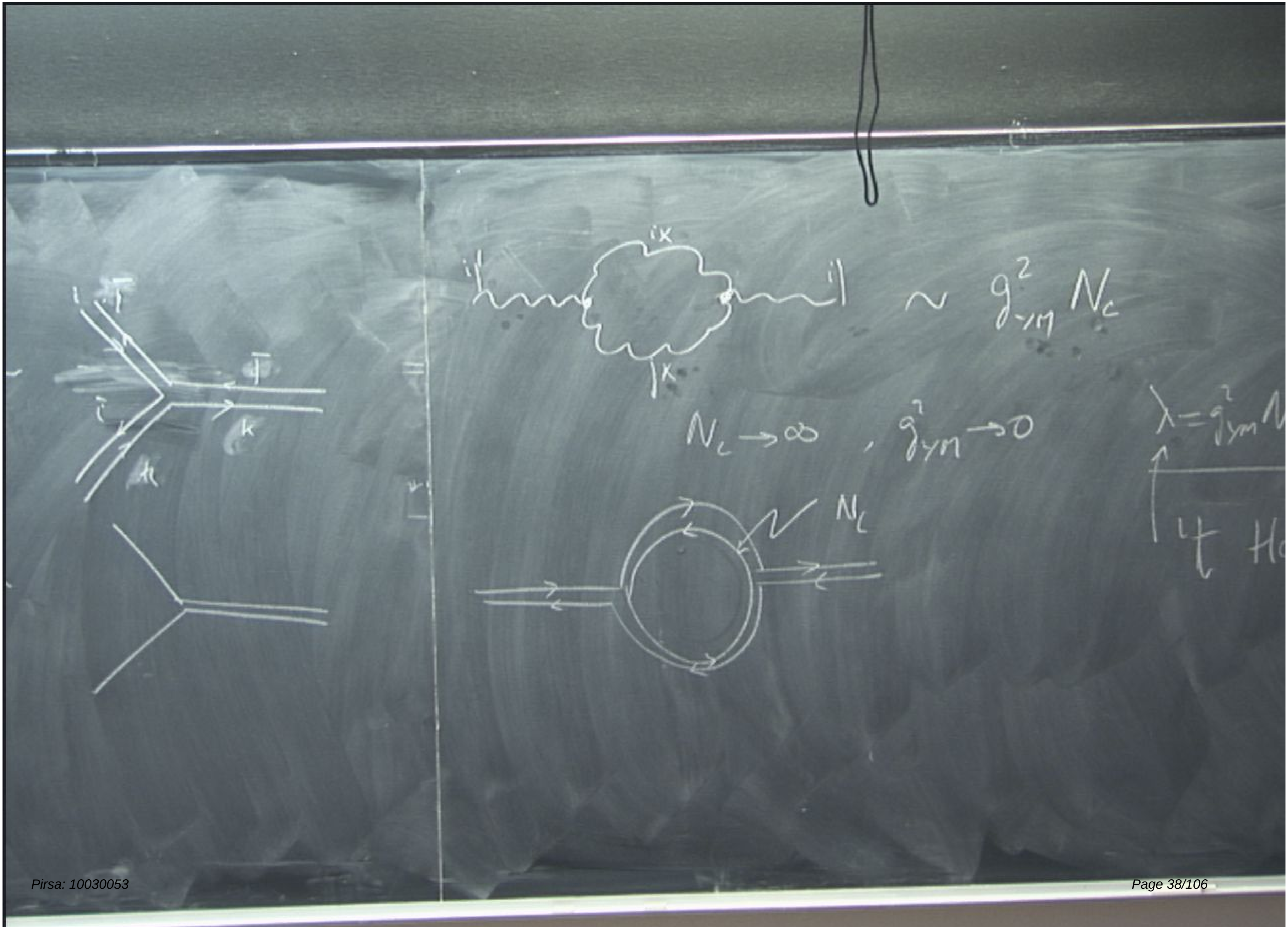


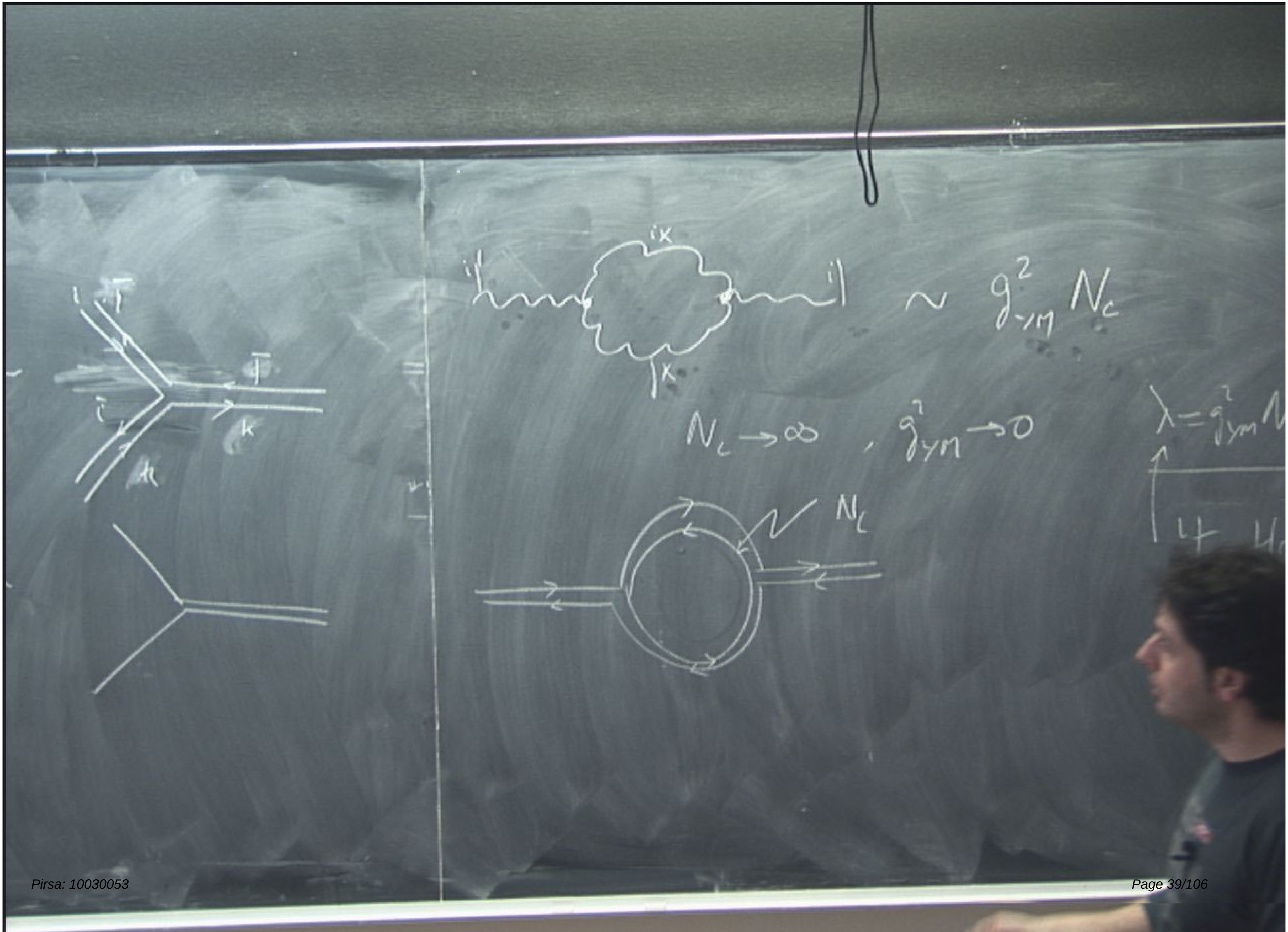


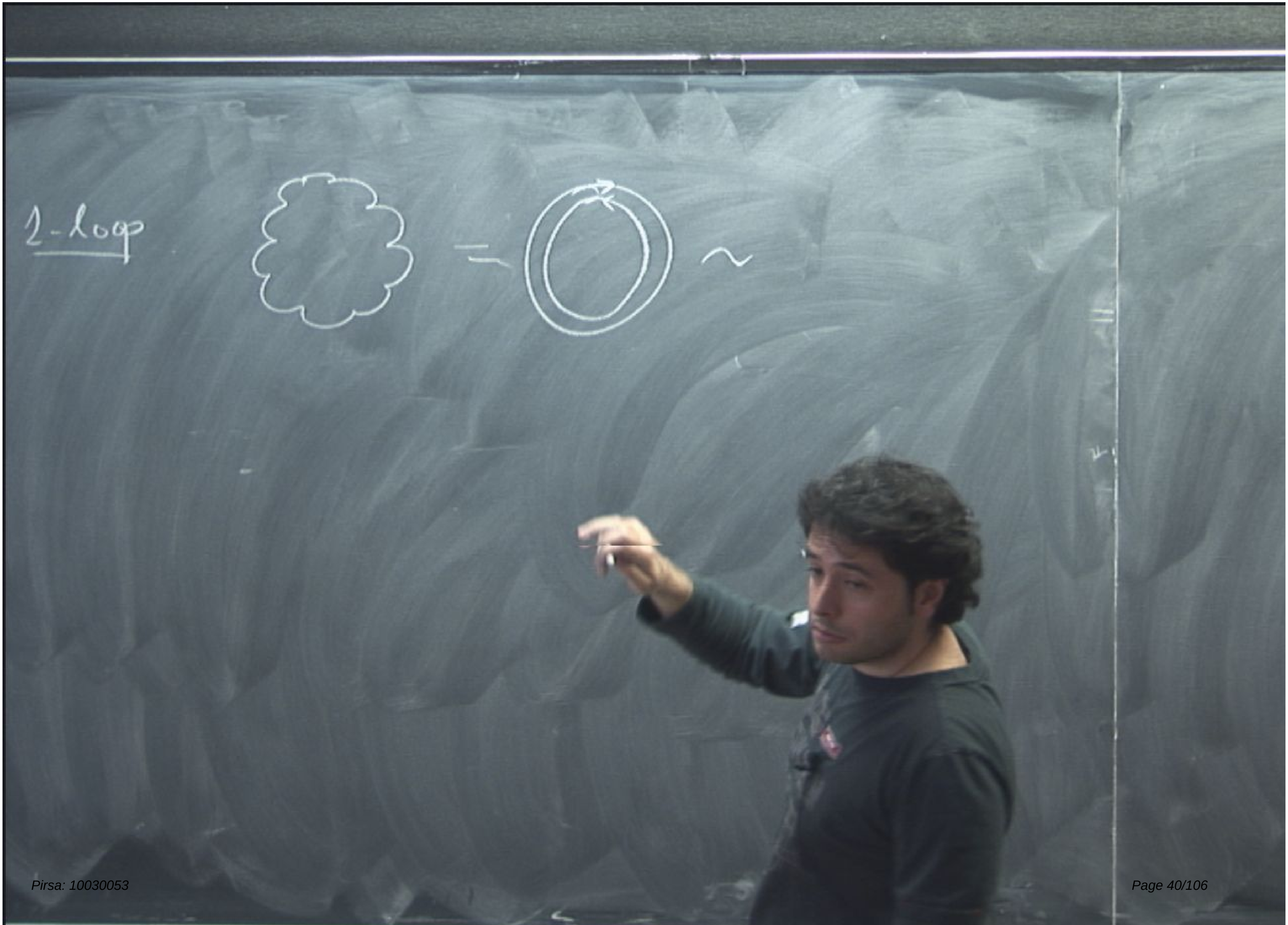




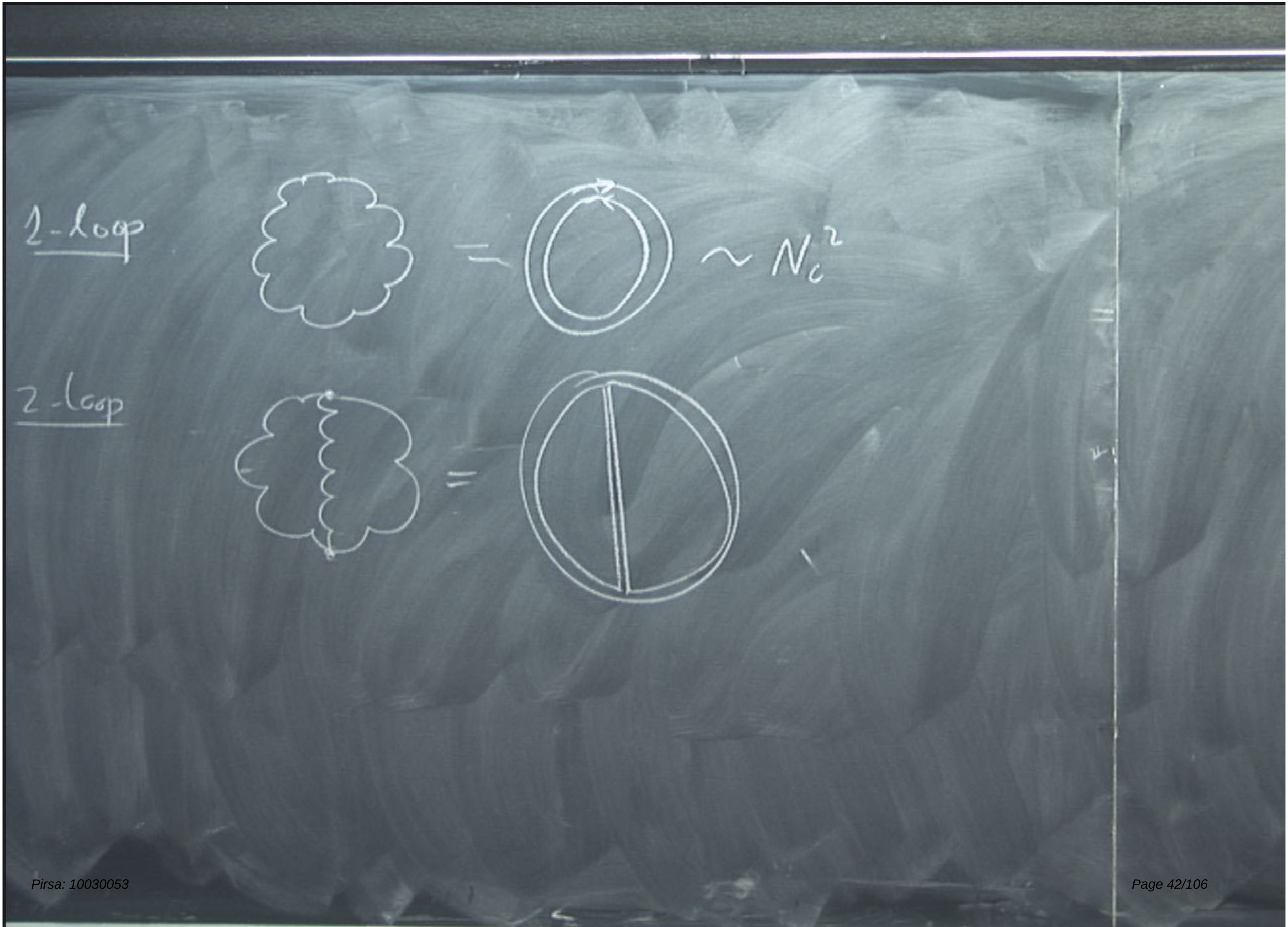

~ g²_YM N_c
N_c → ∞ , g²_YM → 0
λ = g²_YM N

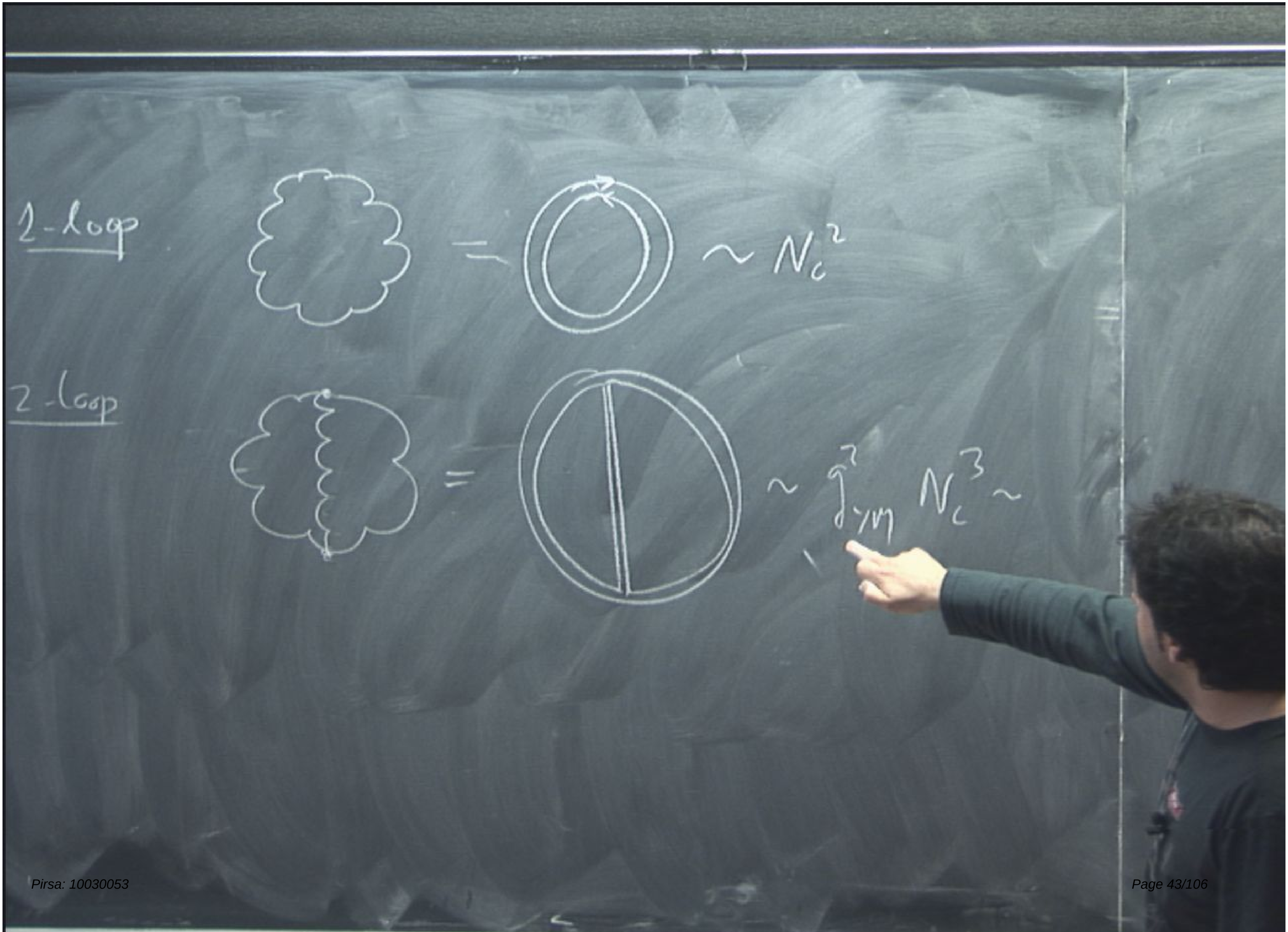

~ g²_YM N_c
N_c → ∞ , g²_YM → 0
N_c
λ = g²_YM N


~ g²_YM N_c
N_c → ∞ , g²_YM → 0
N_c
λ = g²_ym N


1-loop


1-loop
$= \sim N_c^2$
2-lo

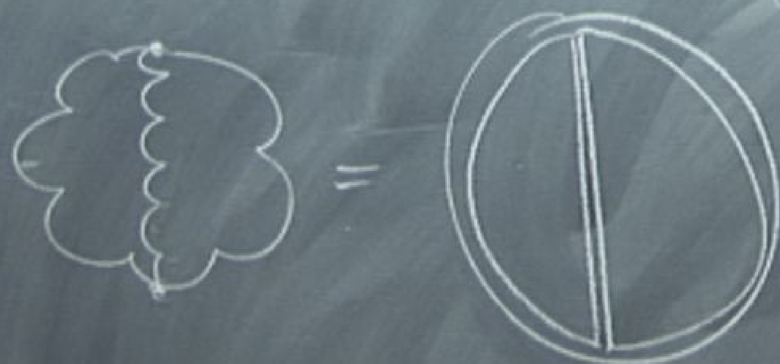

1-loop
= ~ N_c^2
2-loop
=


1-loop
= ~ N_c^2
2-loop
= ~ $g_{YM}^2 N_c^3$ ~

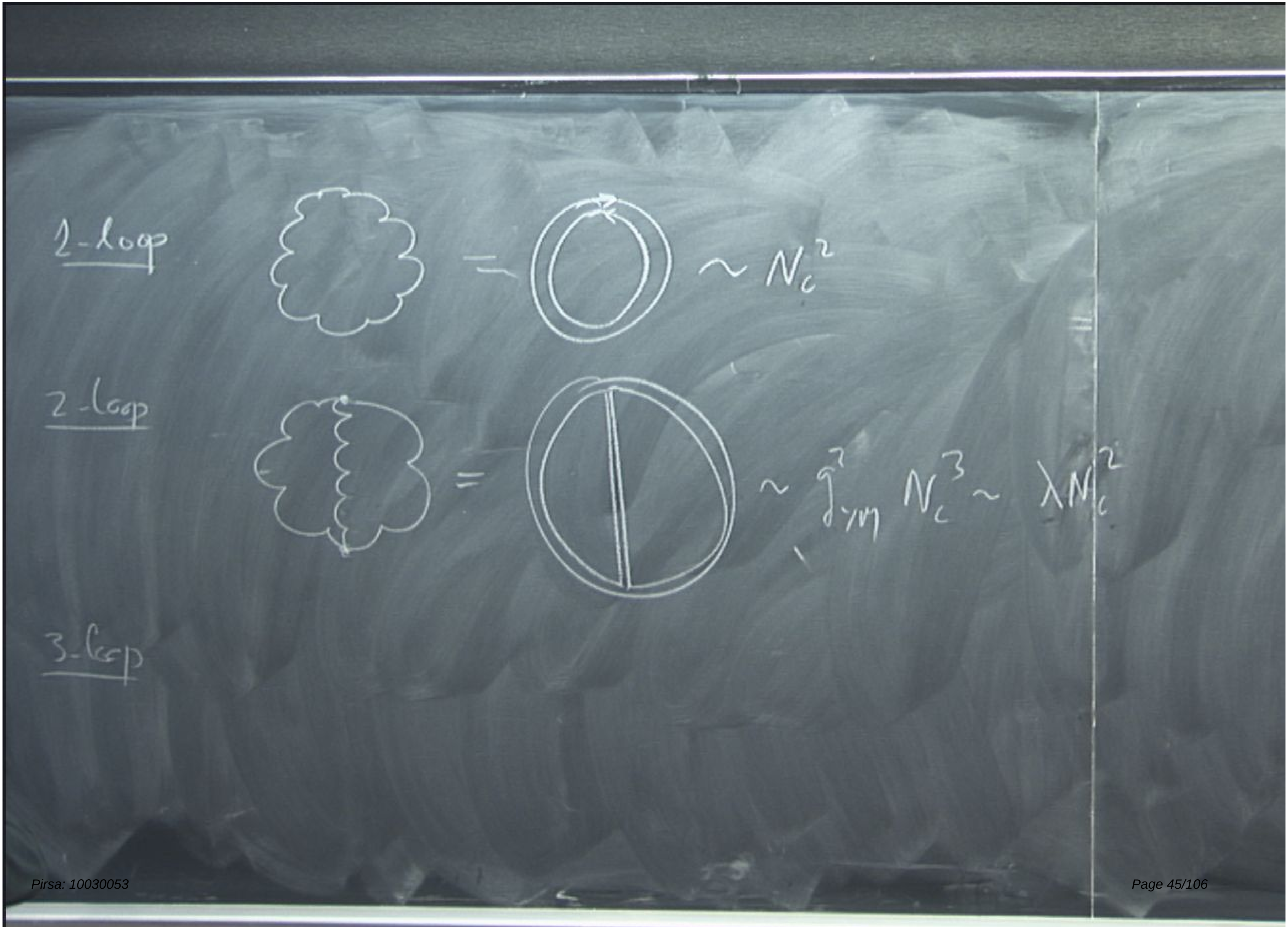
1-loop

$\sim N_c^2$

2-loop



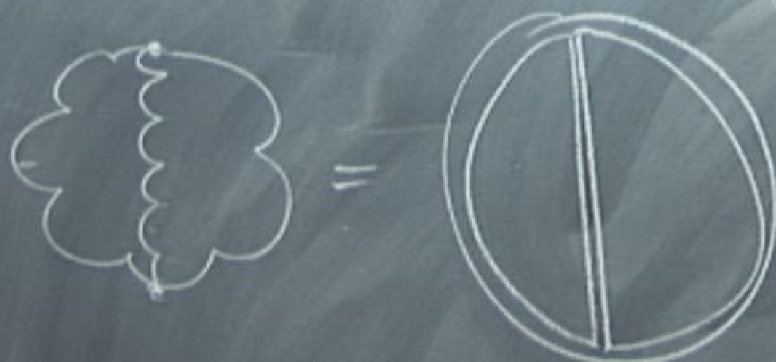
$\sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$


1-loop
$\sim N_c^2$
2-loop
$\sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$
3-loop

1-loop

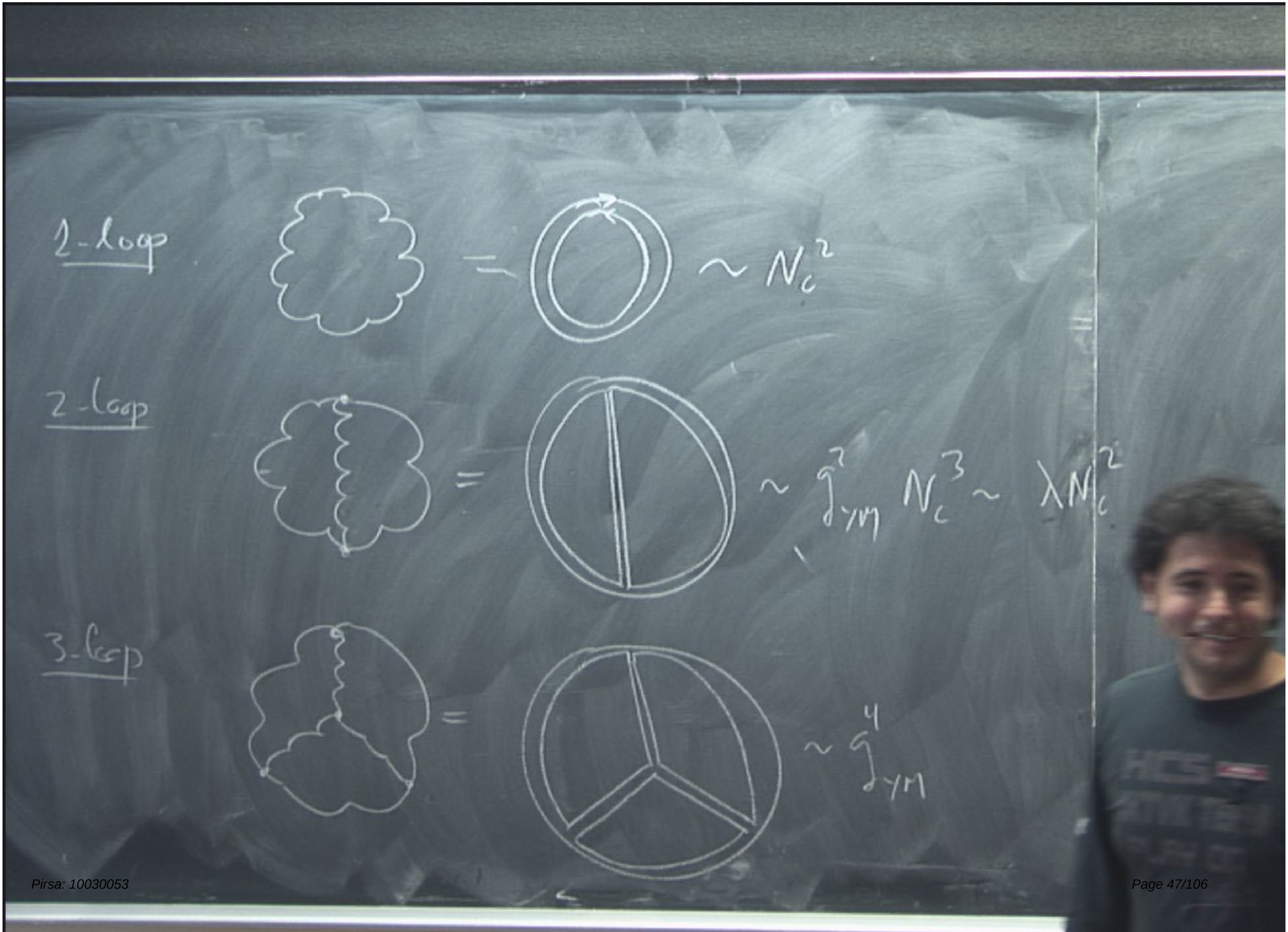
$\sim N_c^2$

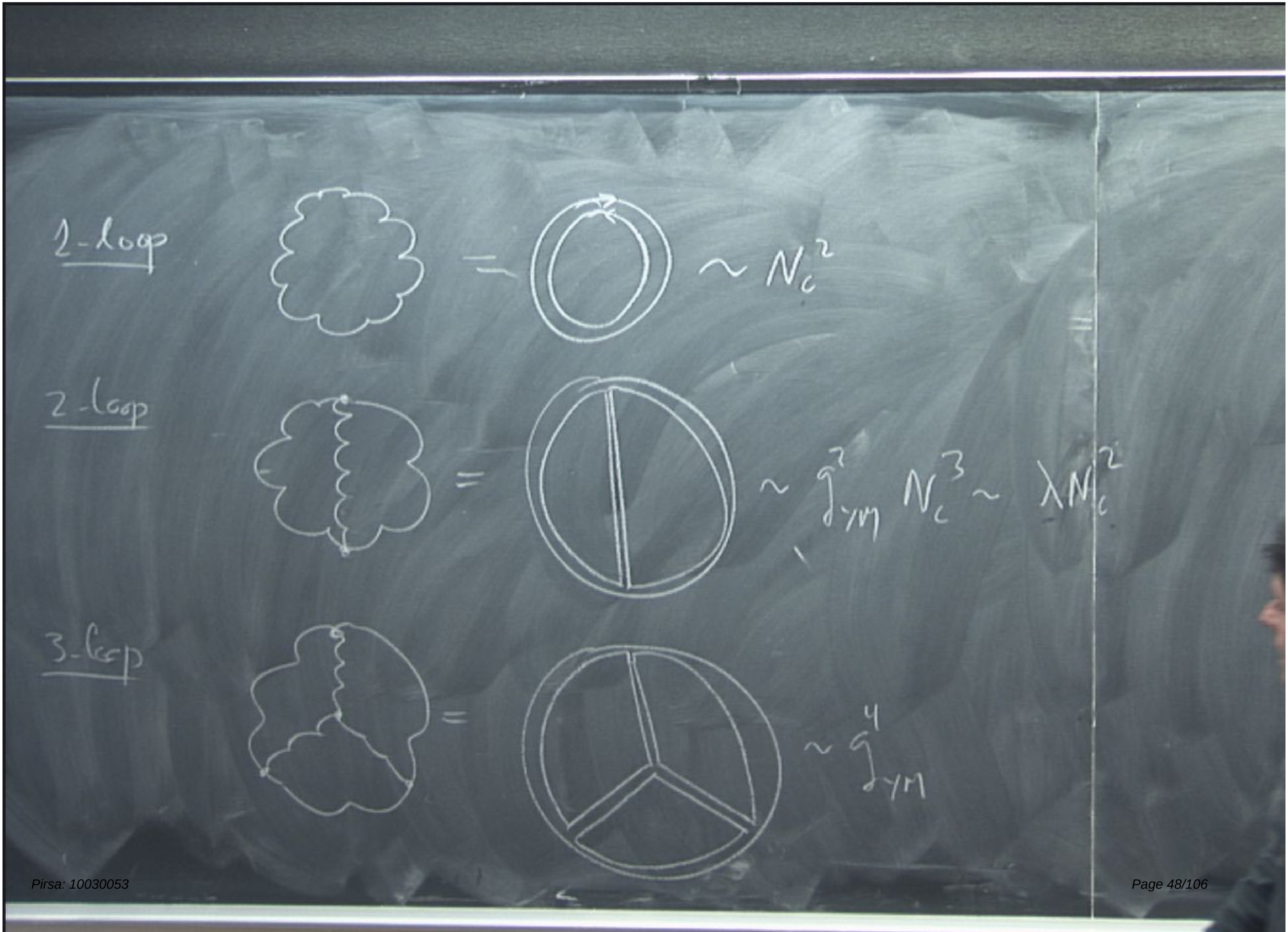
2-loop



$\sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$

3-loop

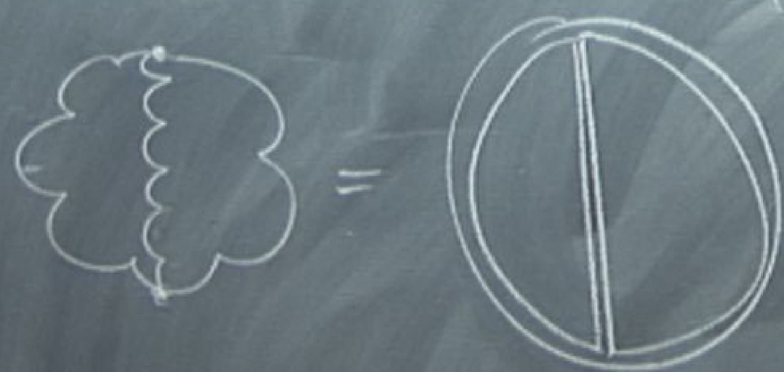

1-loop
= ~ N_c^2
2-loop
= ~ $g_{YM}^2 N_c^3 \sim \lambda N_c^2$
3-loop
= ~ g_{YM}^4


1-loop
$= \sim N_c^2$
2-loop
$= \sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$
3-loop
$= \sim g_{YM}^4$

1-loop

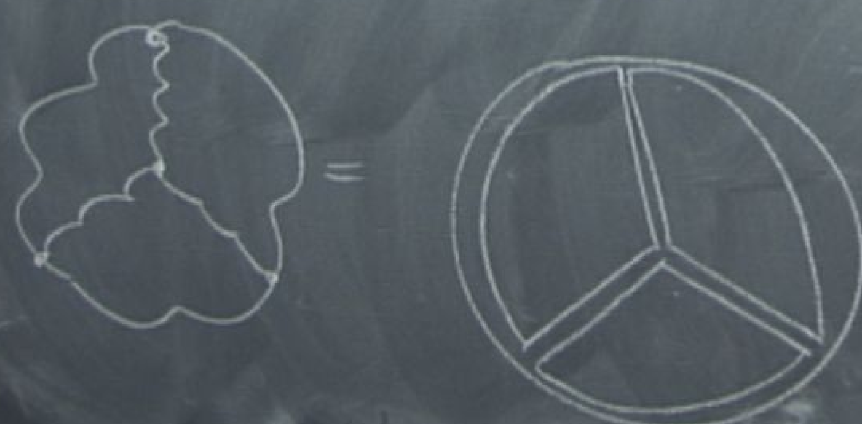
$\sim N_c^2$

2-loop



$\sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$

3-loop

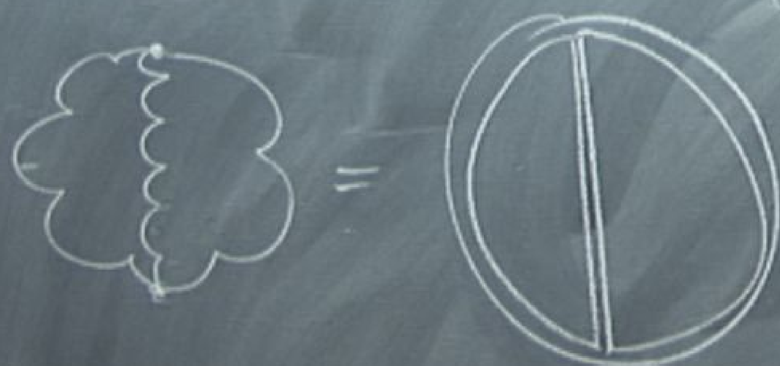


$\sim g_{YM}^4 N_c^4 \sim$

1-loop

$\sim N_c^2$

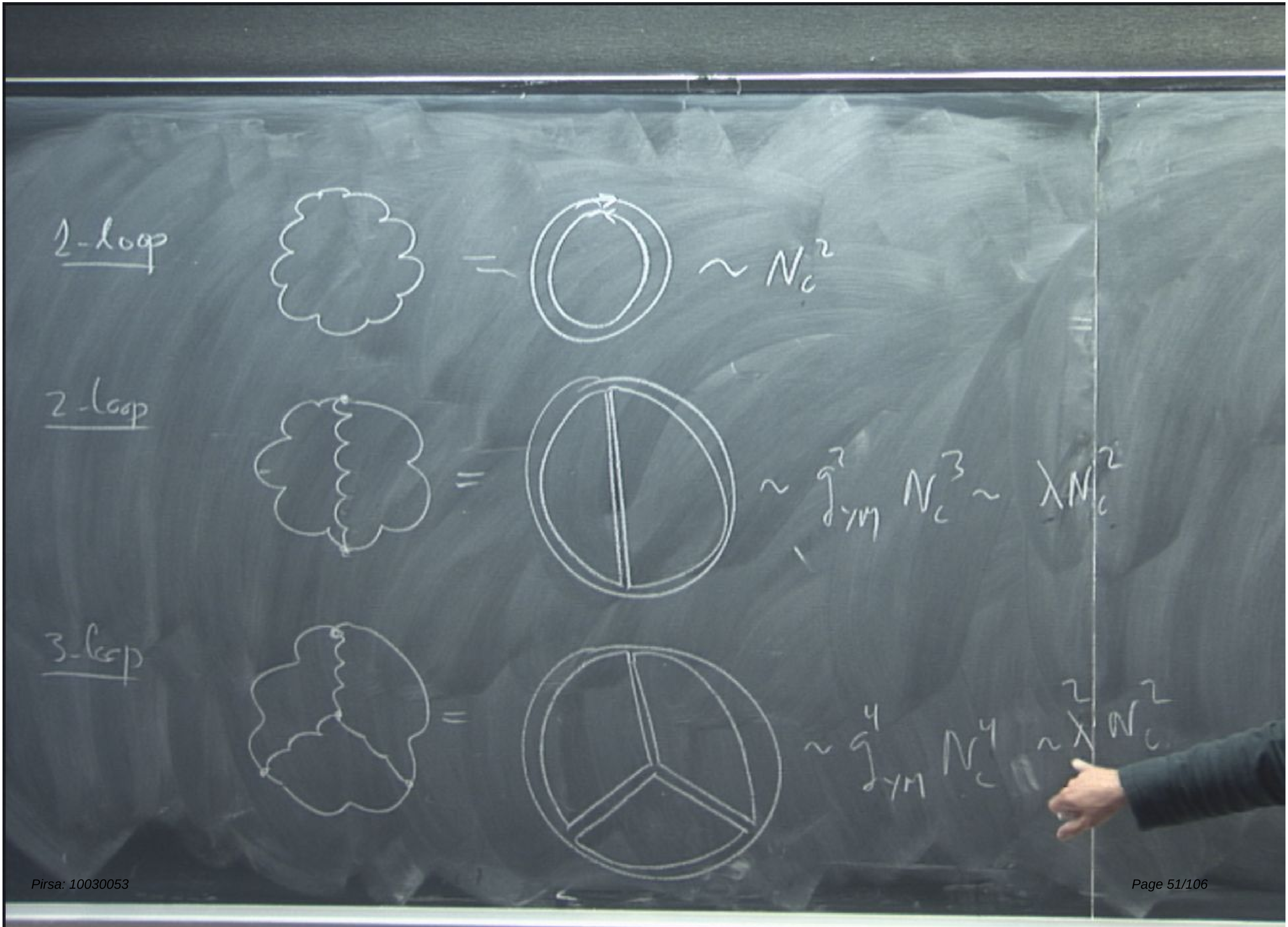
2-loop

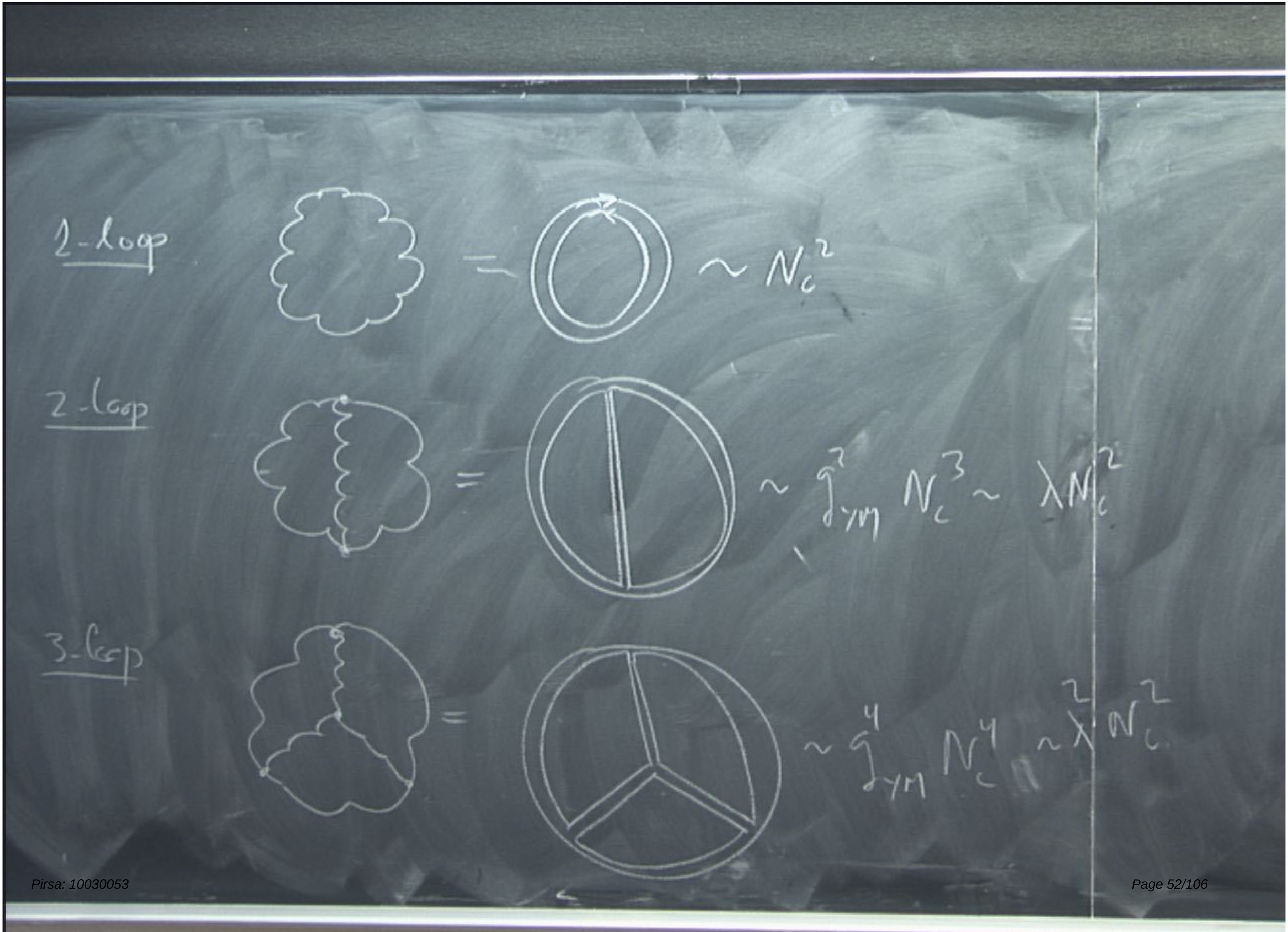


$\sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$

3-loop

$\sim g_{YM}^4 N_c^4 \sim \lambda^2 N_c^2$


1-loop
$\sim N_c^2$
2-loop
$\sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$
3-loop
$\sim g_{YM}^4 N_c^4 \sim \lambda^2 N_c^2$

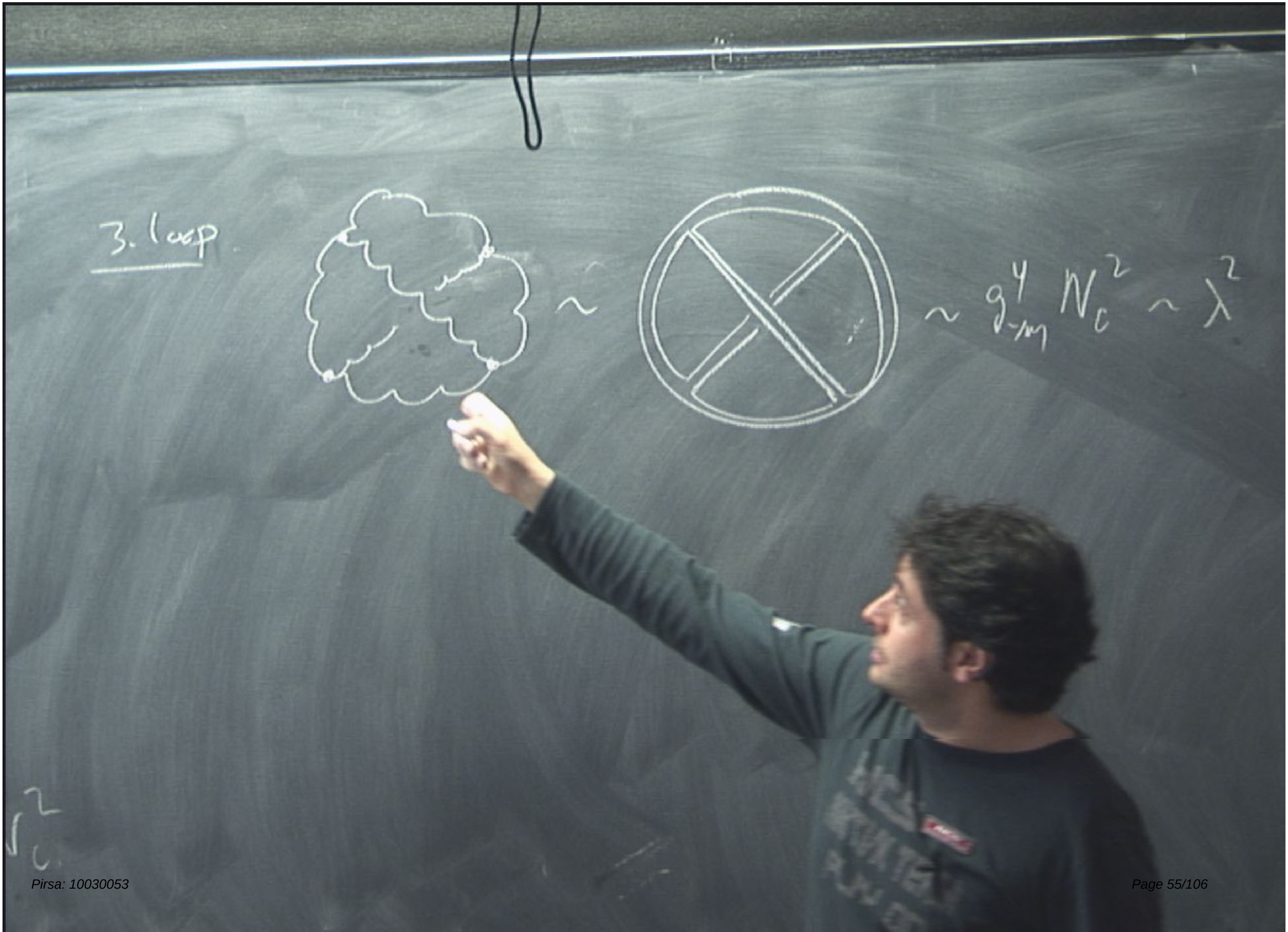

1-loop
$= \sim N_c^2$
2-loop
$= \sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$
3-loop
$= \sim g_{YM}^4 N_c^4 \sim \lambda^2 N_c^2$


3. loop

3. loop

$\sim$

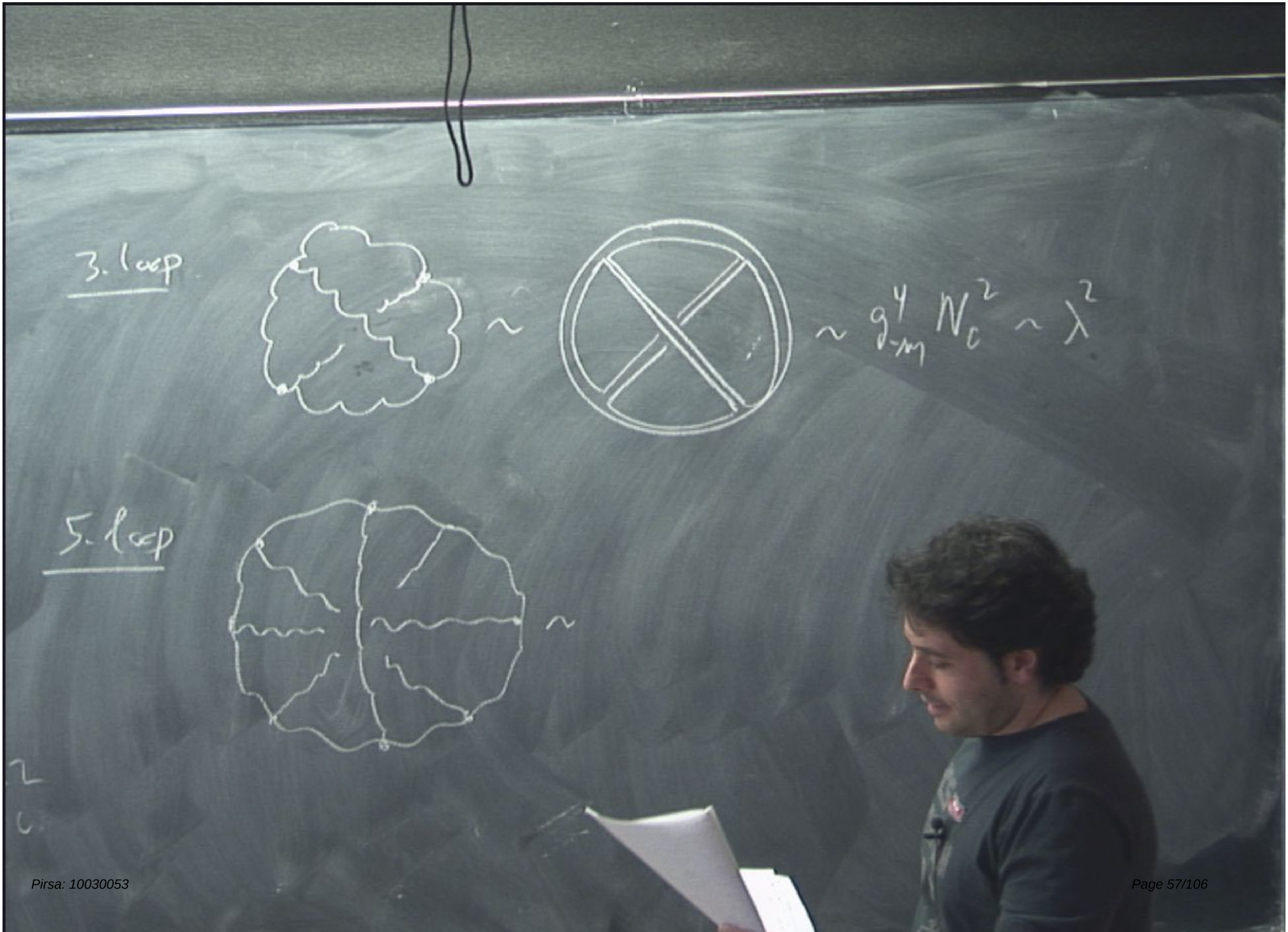
$\sim g^4_{YM}$


3. loop
$\sim$
$\sim g^4_{ym} N_c^2 \sim \lambda^2$

3. loop

 $\sim$  $\sim g_{YM}^4 N_c^2 \sim \lambda^2$

$$g^2_{YM}(\mu) N_c = \lambda(\mu)$$


3. loop
$\sim g_{YM}^4 N_c^2 \sim \lambda^2$
5. loop
$\sim$

3. loop

 $\sim$  $\sim g_{YM}^4 N_c^2 \sim \lambda^2$

5. loop

 $\sim$  $\sim$

3. loop

 $\sim$  $\sim g_{ym}^4 N_c^2 \sim \lambda^2$

5. loop

 $\sim$  $\sim g_{ym}^8 N_c^2 \sim \dfrac{\lambda^4}{N_c^2}$

N_c^2

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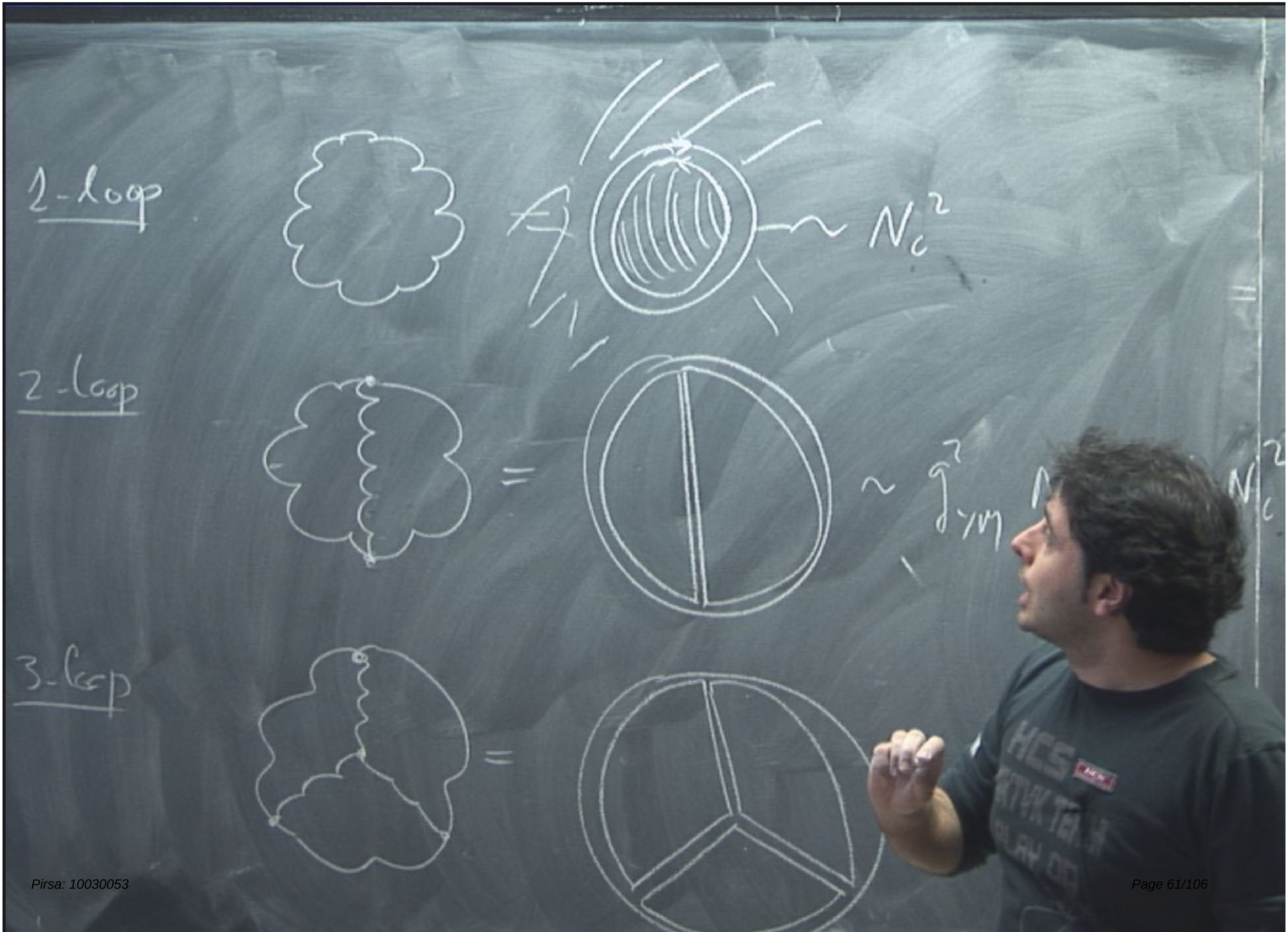
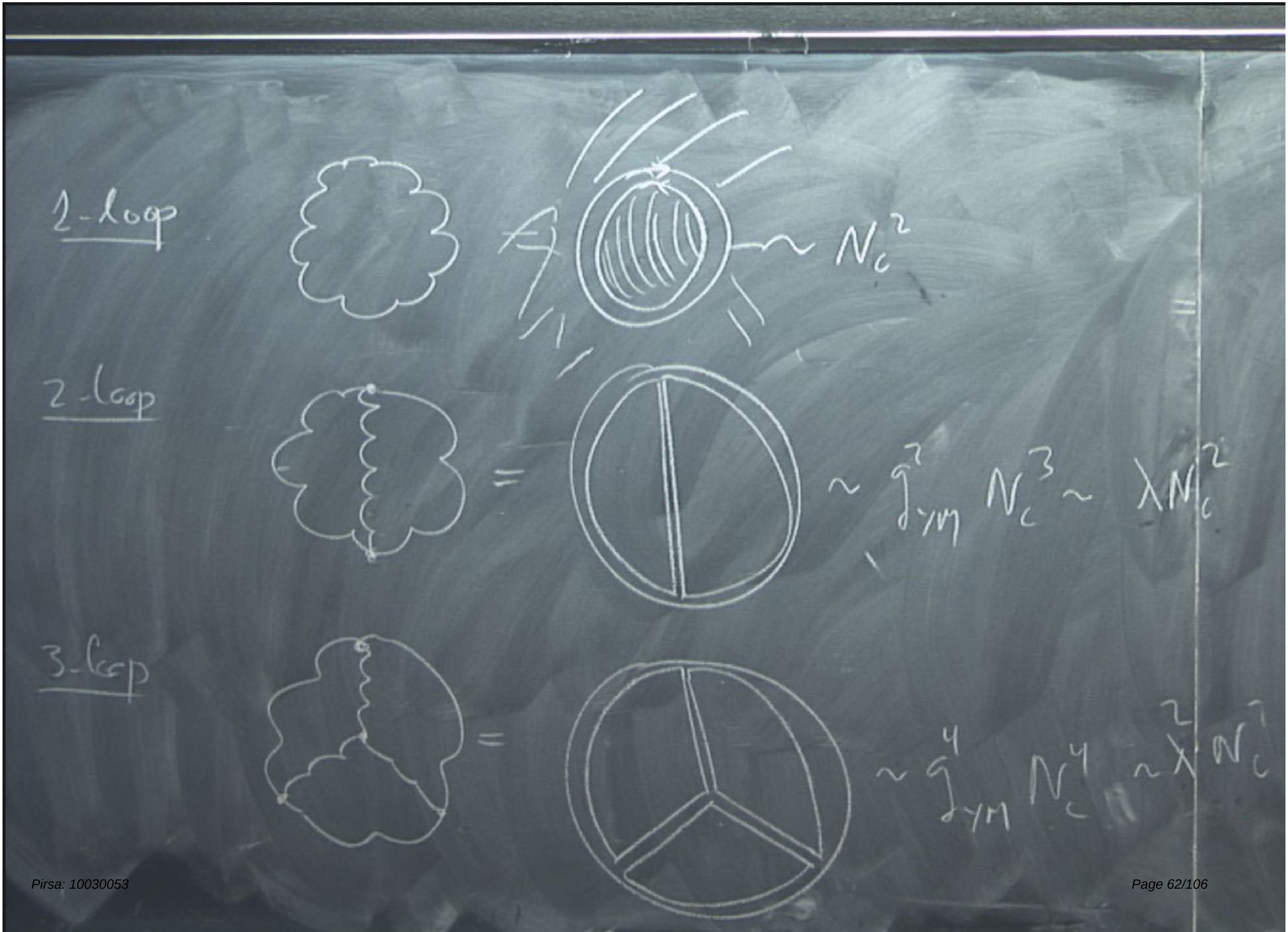
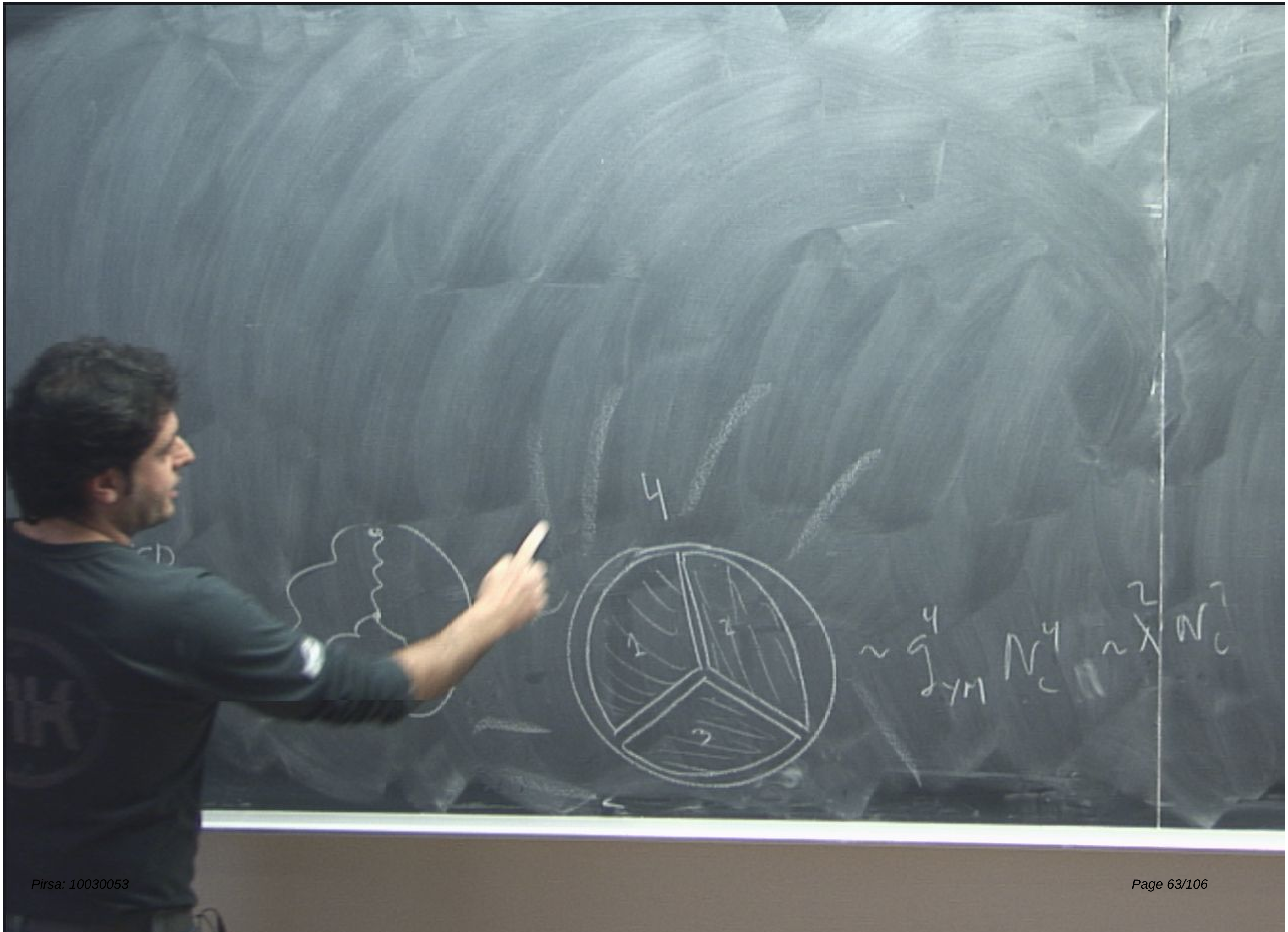
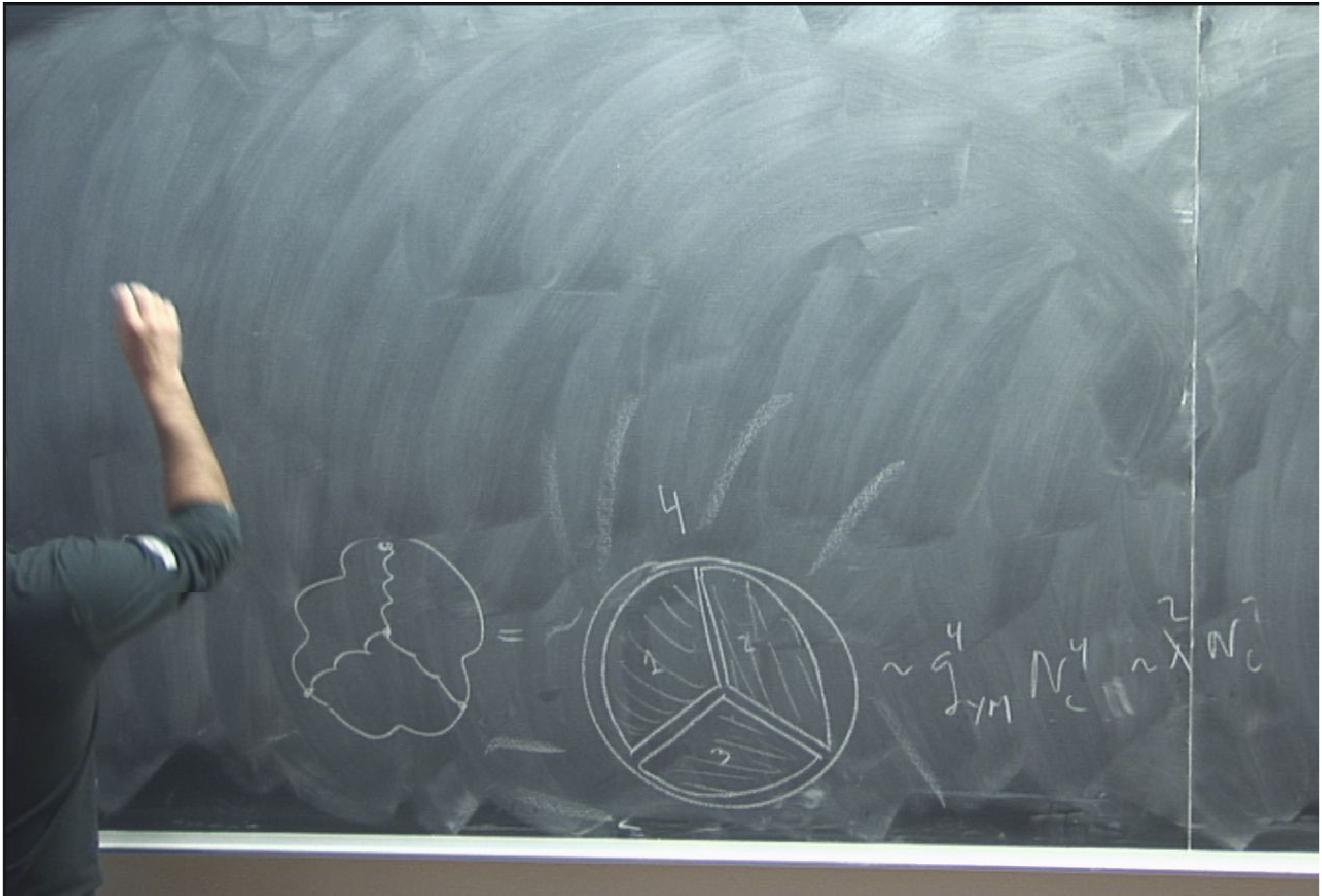
$\boxed{\text{Diagrams classif. by topology}}$

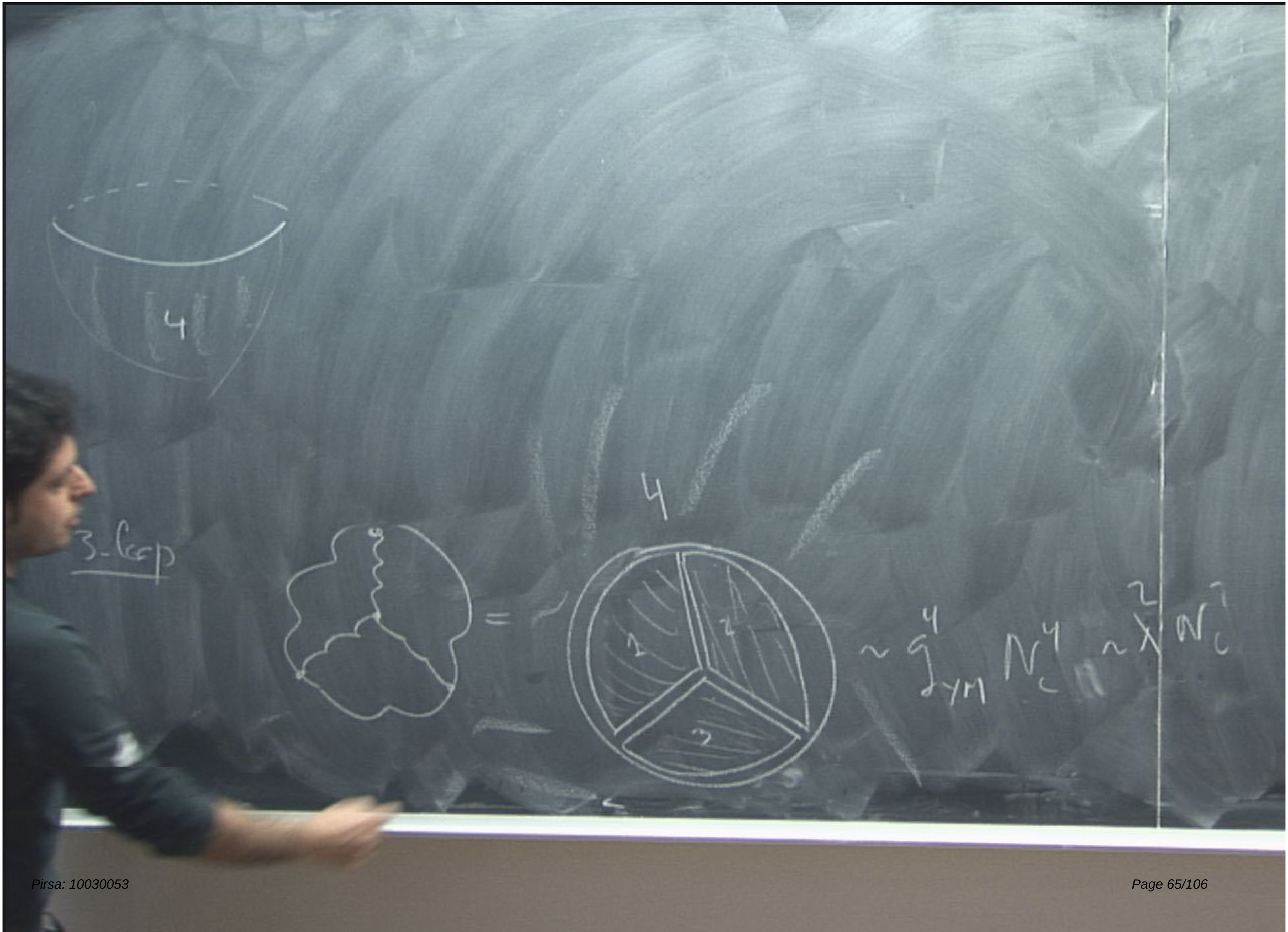
$\boxed{\text{Non-planar diag. are } \frac{1}{N_c^2}\text{-suppressed}}$

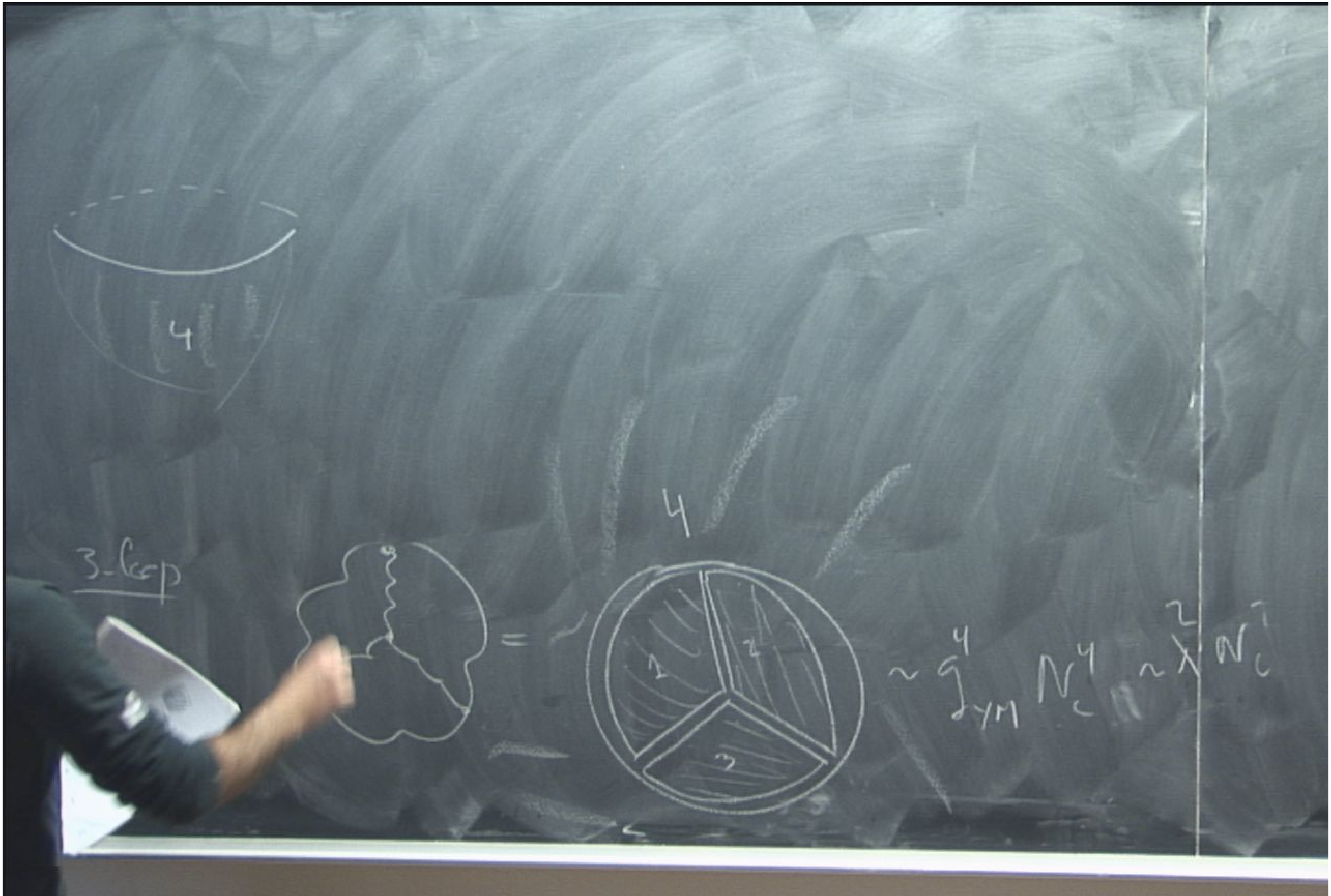

1-loop
~ N_c^2
2-loop
=
~ g^2_YM
3-loop
=

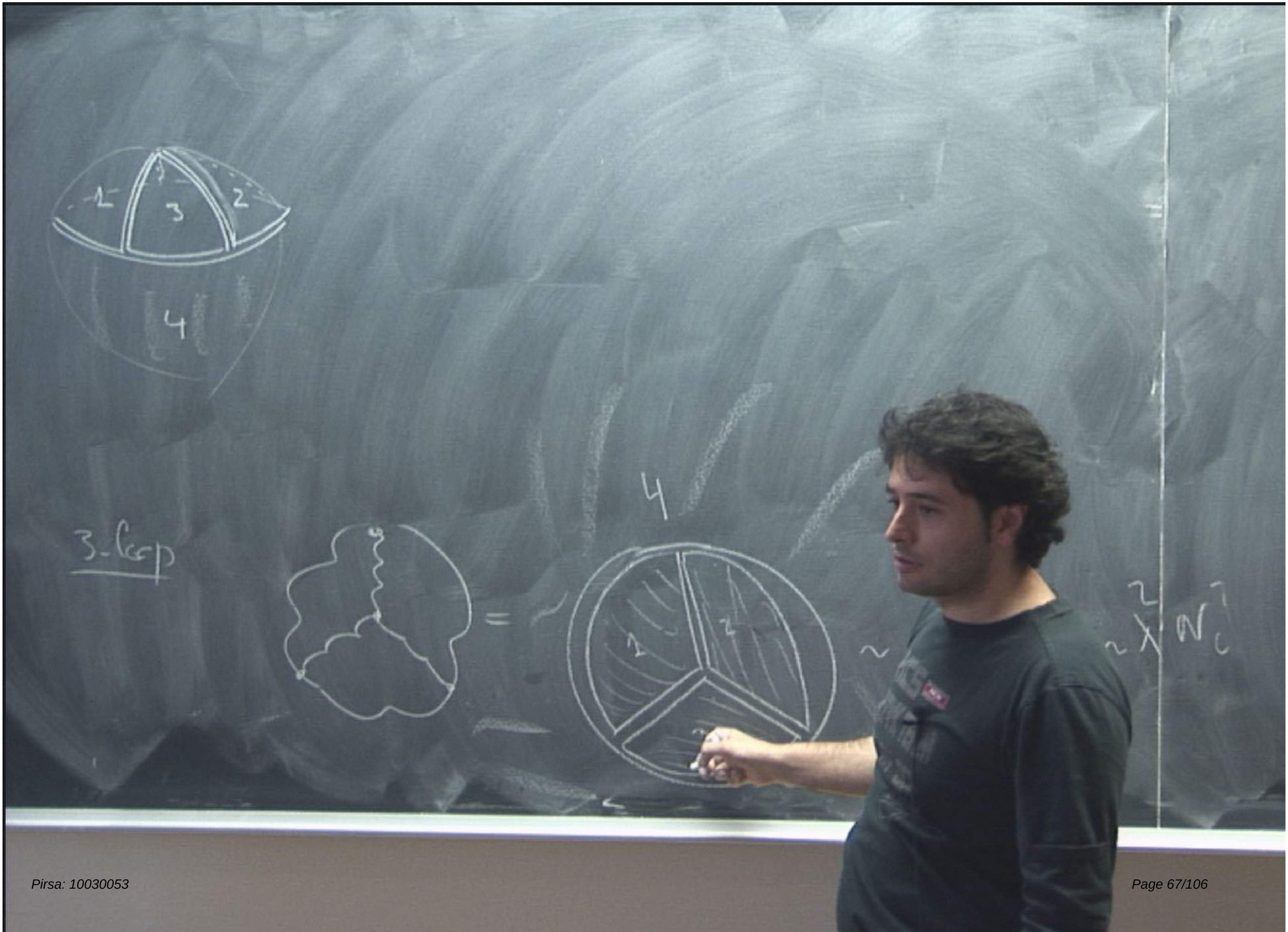

1-loop
$= \sim N_c^2$
2-loop
$= \sim g_{YM}^2 N_c^3 \sim \lambda N_c^2$
3-loop
$= \sim g_{YM}^4 N_c^4 \sim \lambda^2 N_c^2$

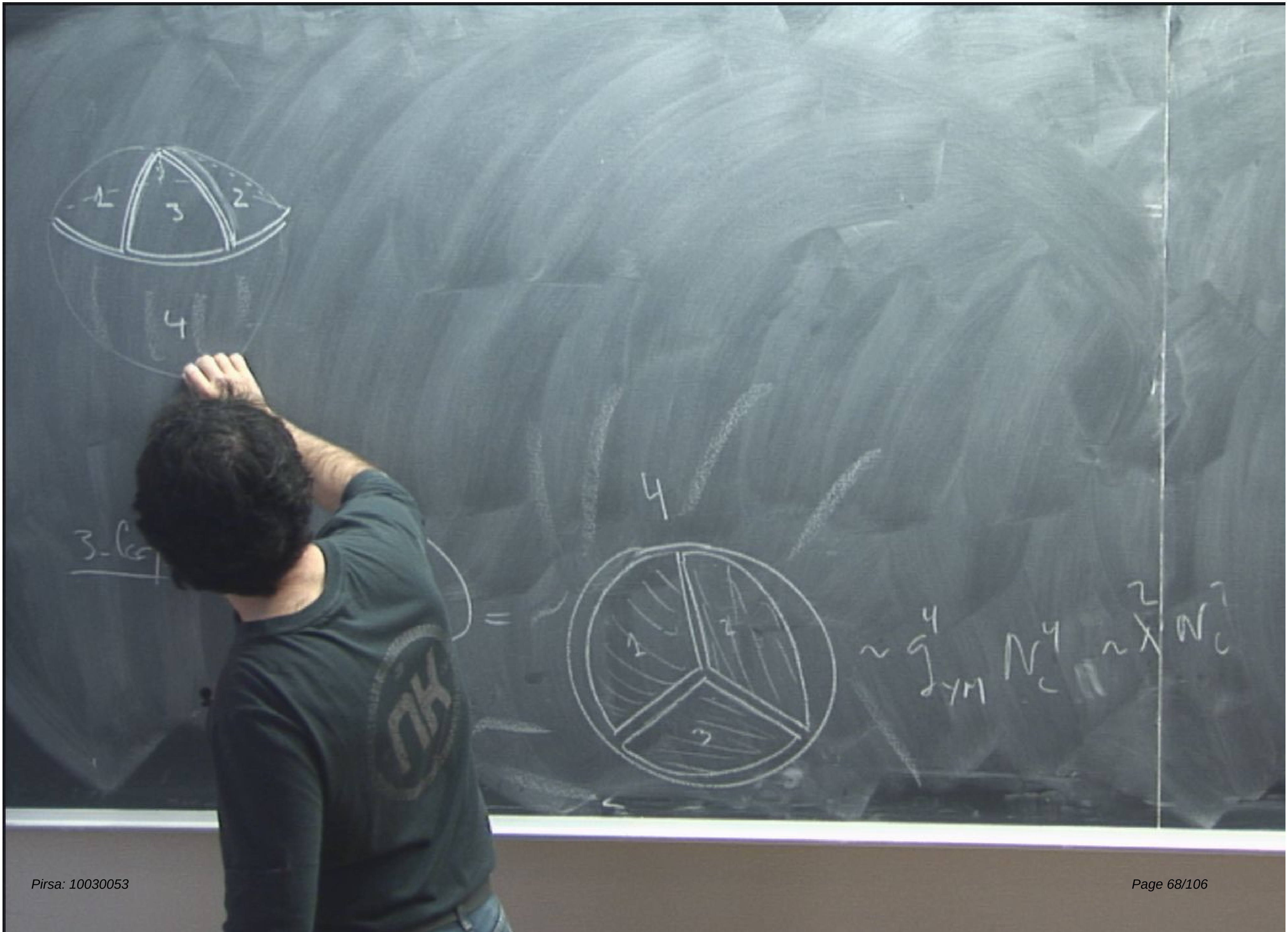

4
$\sim g_{YM}^4 N_c^4 \sim \lambda^2 N_c^2$

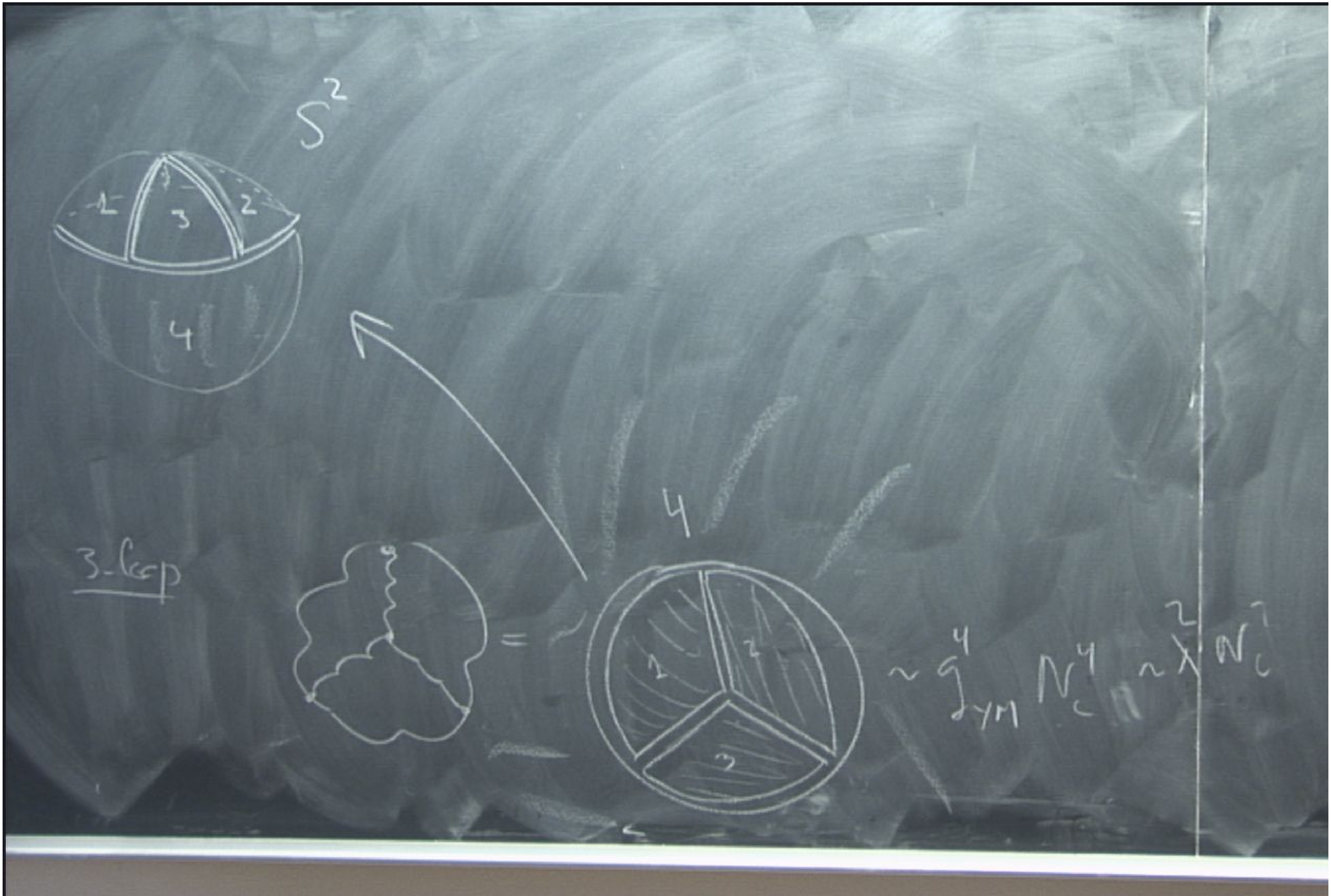

$= \sim \; \sim g_{YM}^4 N_c^4 \sim \lambda^2 N_c^2$

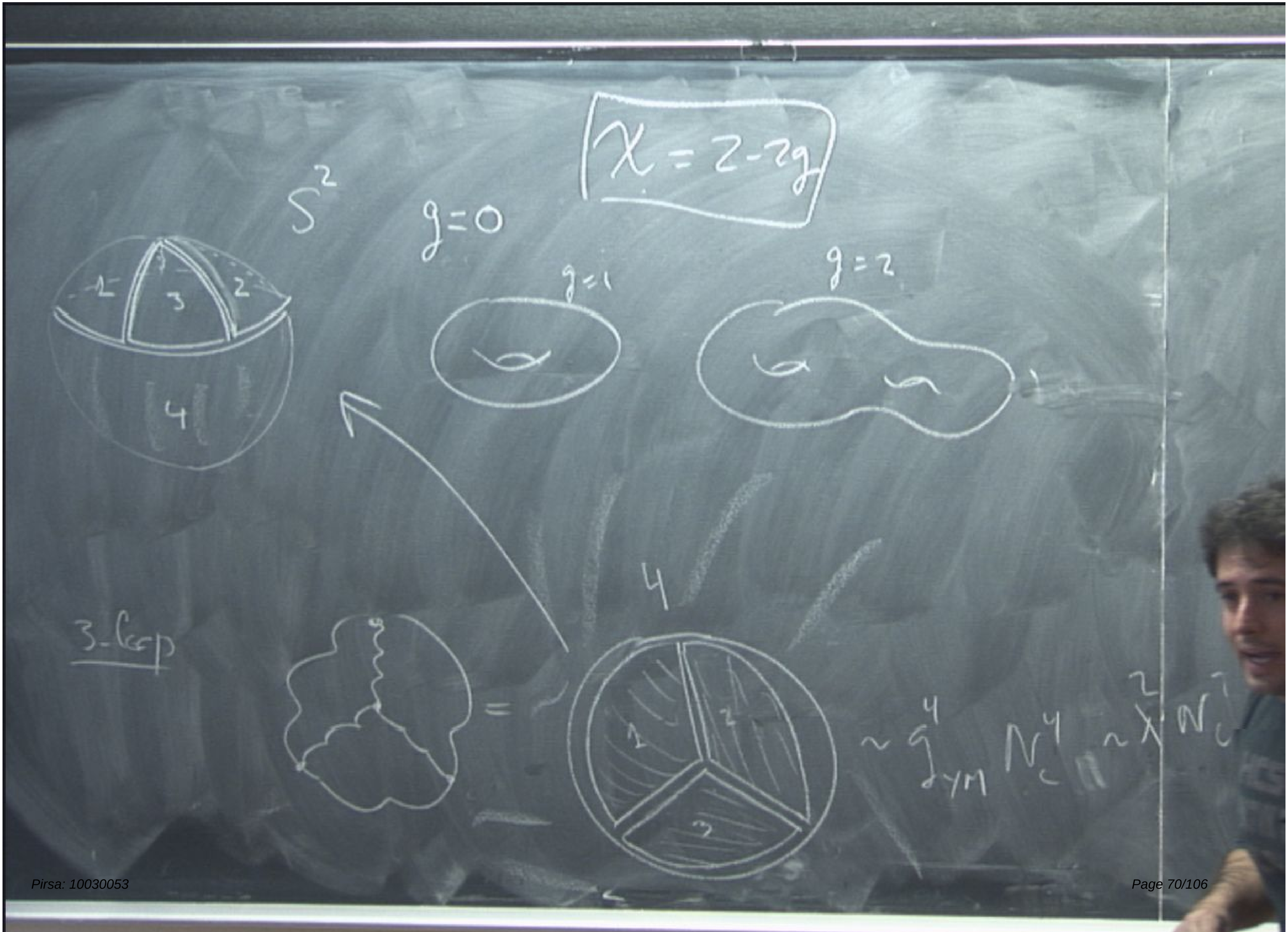

4
3-loop
4
1
2
3
$\sim g_{YM}^4 N_c^4 \sim \lambda^2 N_c^2$


4
3-loop
=
~
4
~ g4 YM N4 c ~ λ2 Nc

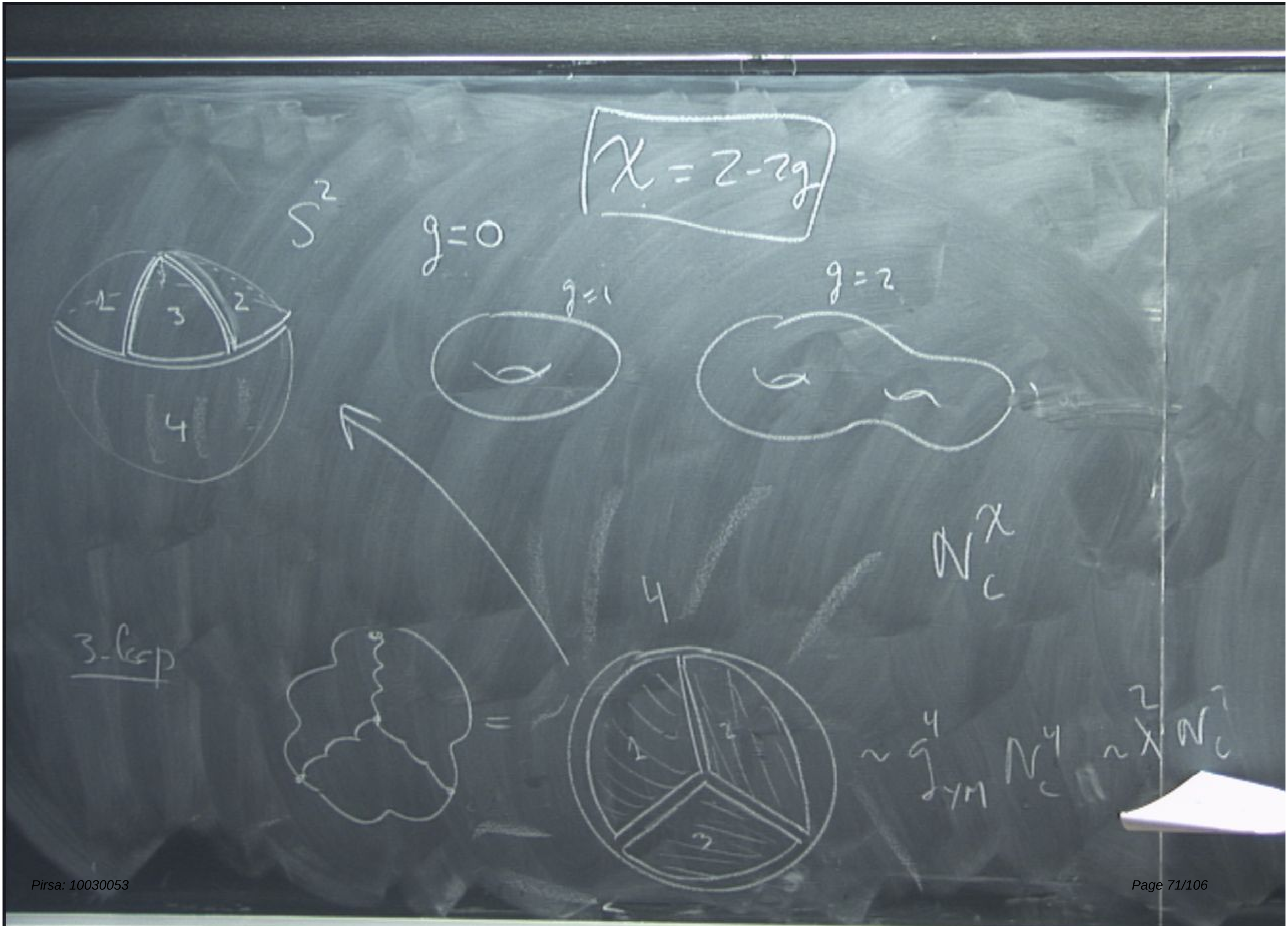

1
2
3
4


$\sim g_{YM}^4 N_c^4$

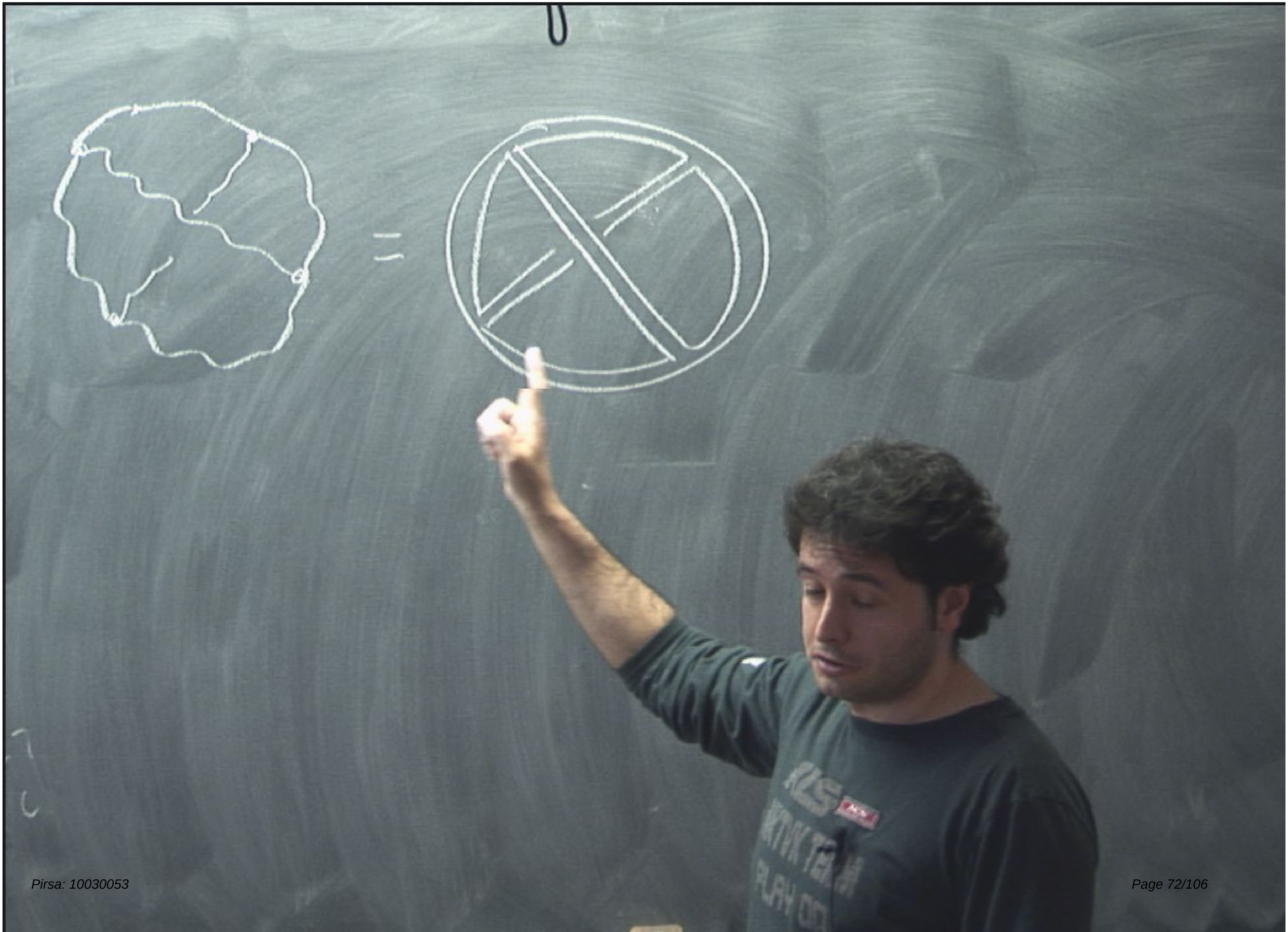

S^2
3-loop
$\sim g^4_{YM} N_c^4$

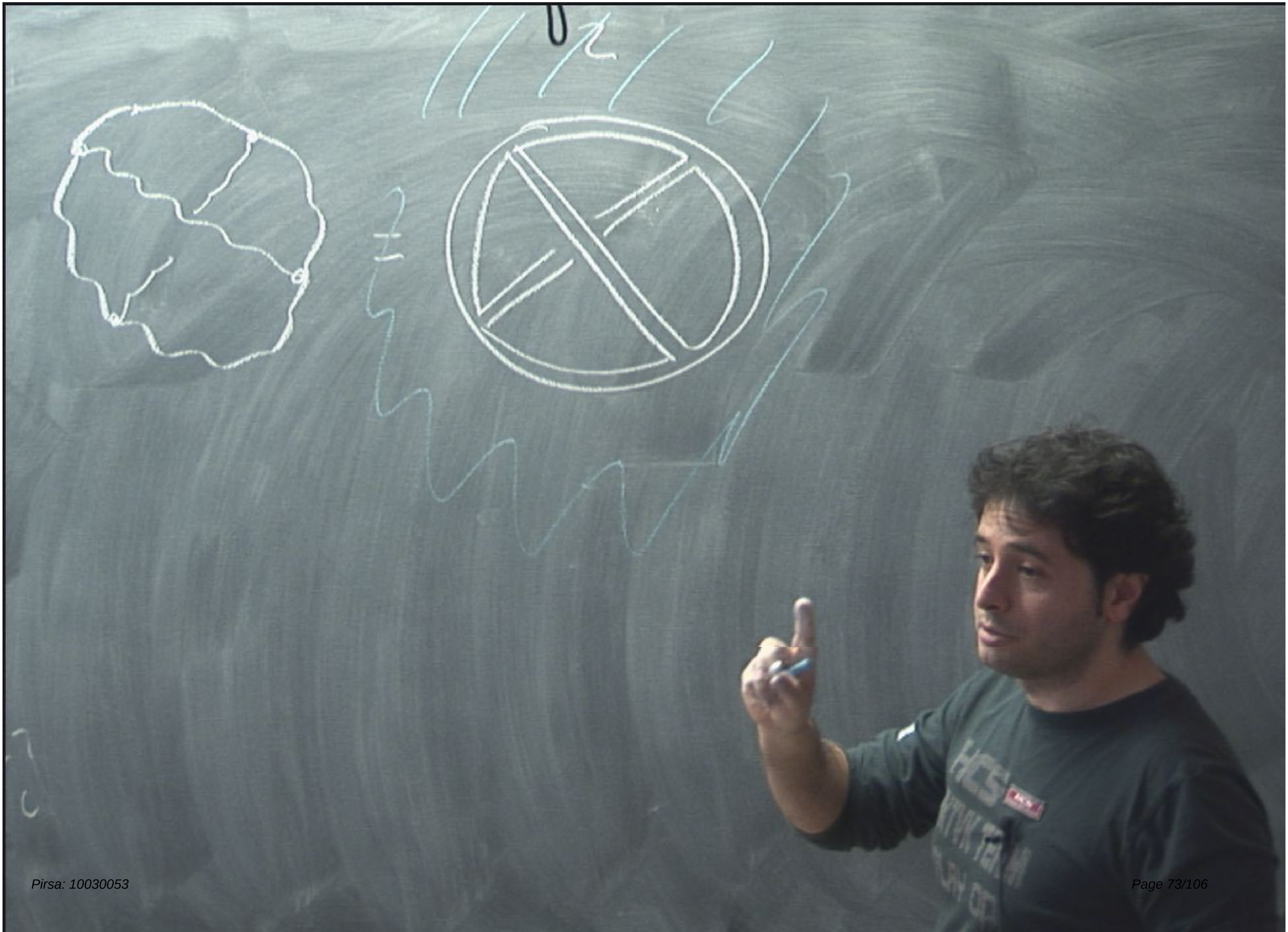


χ = 2-2g
S2
g=0
g=1
g=2
3-Loop

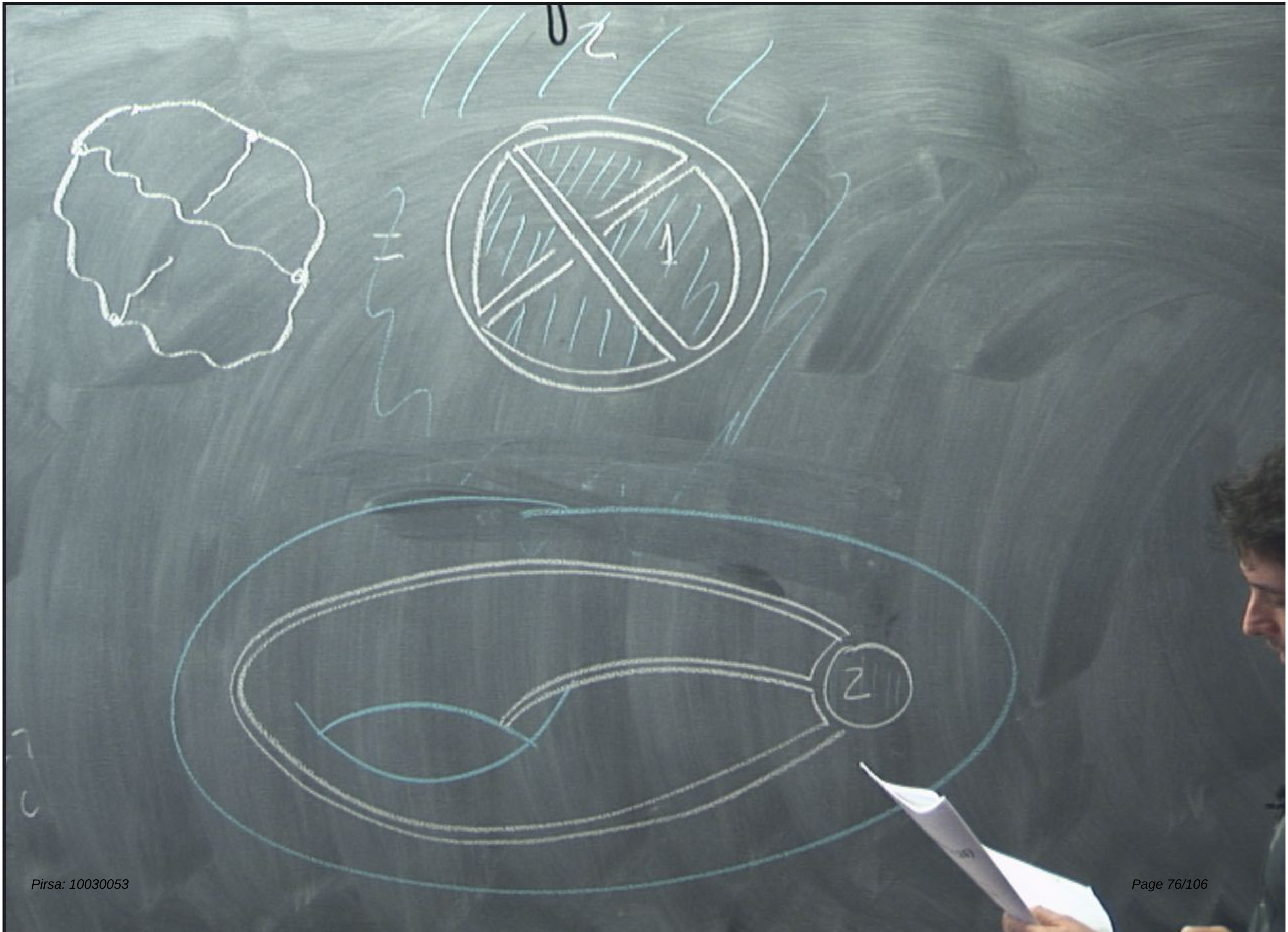


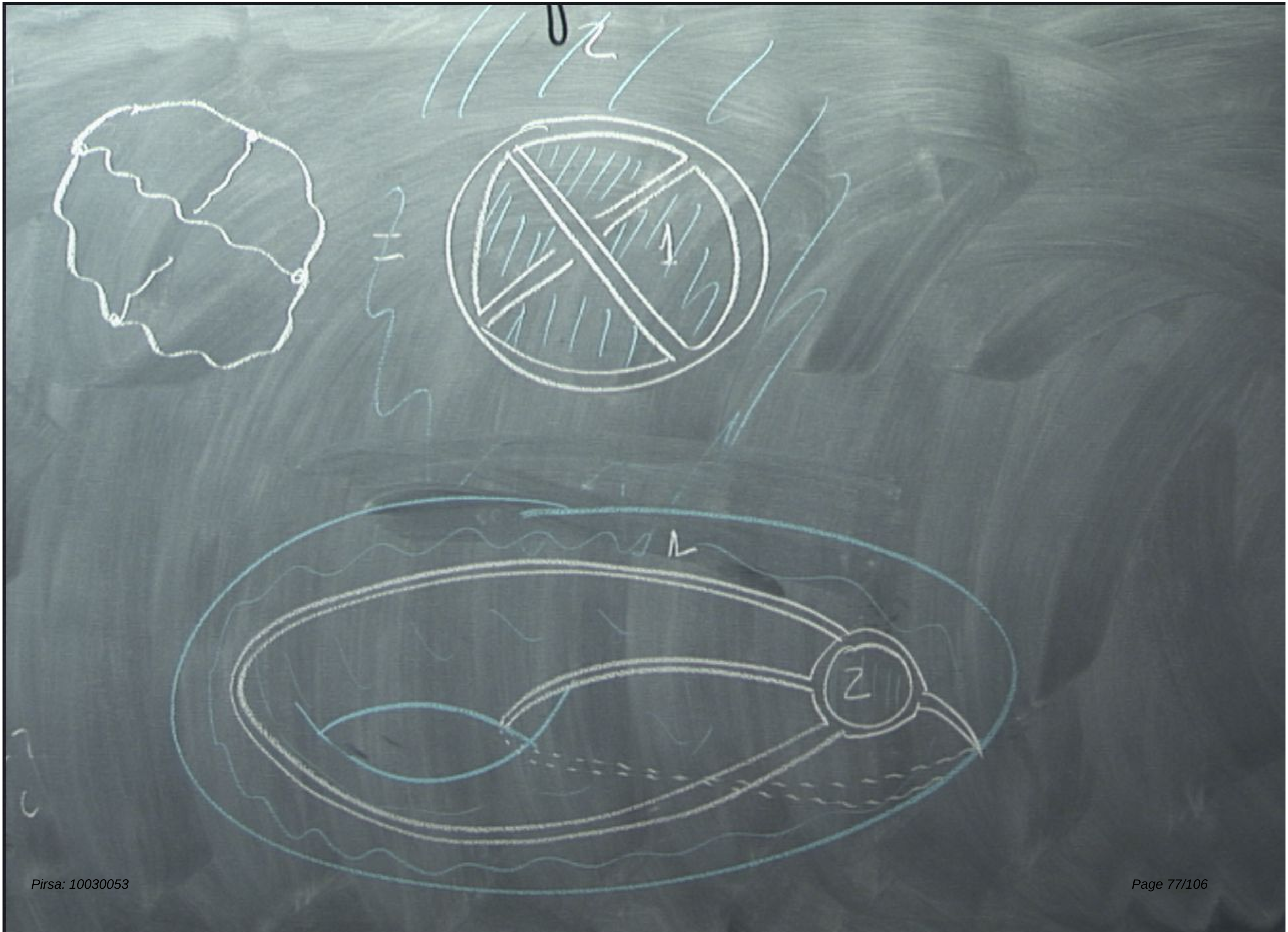
χ = 2-2g
S²
g=0
g=1
g=2
1
2
3
4
3-loop
4
N_c^χ
~ g_YM^4 N_c^4 ~ χ² N_c²






1
2
2

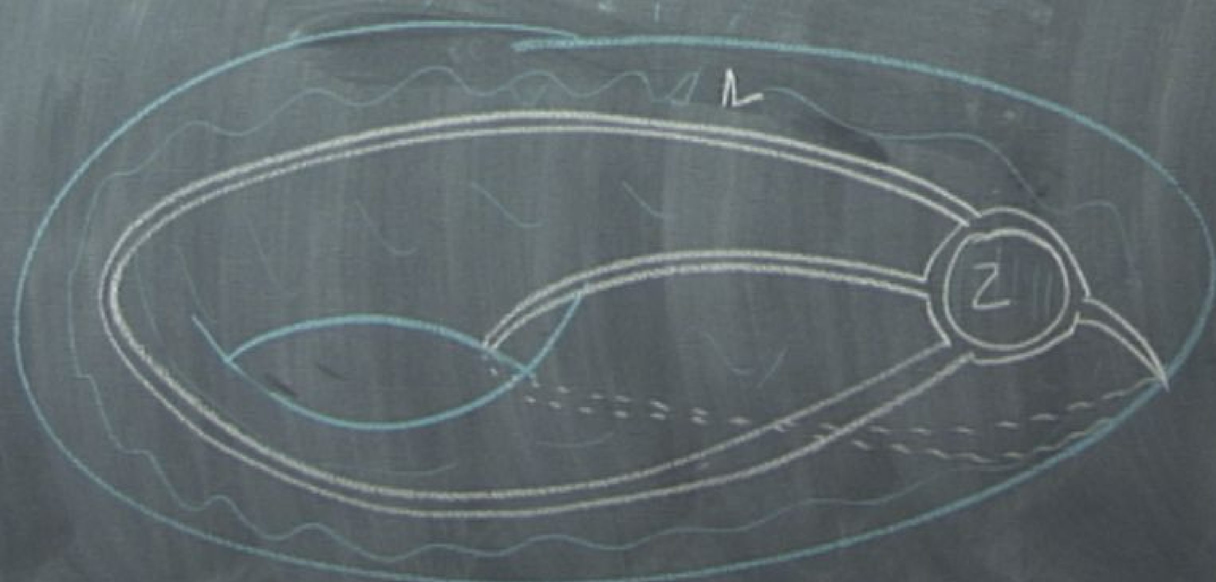




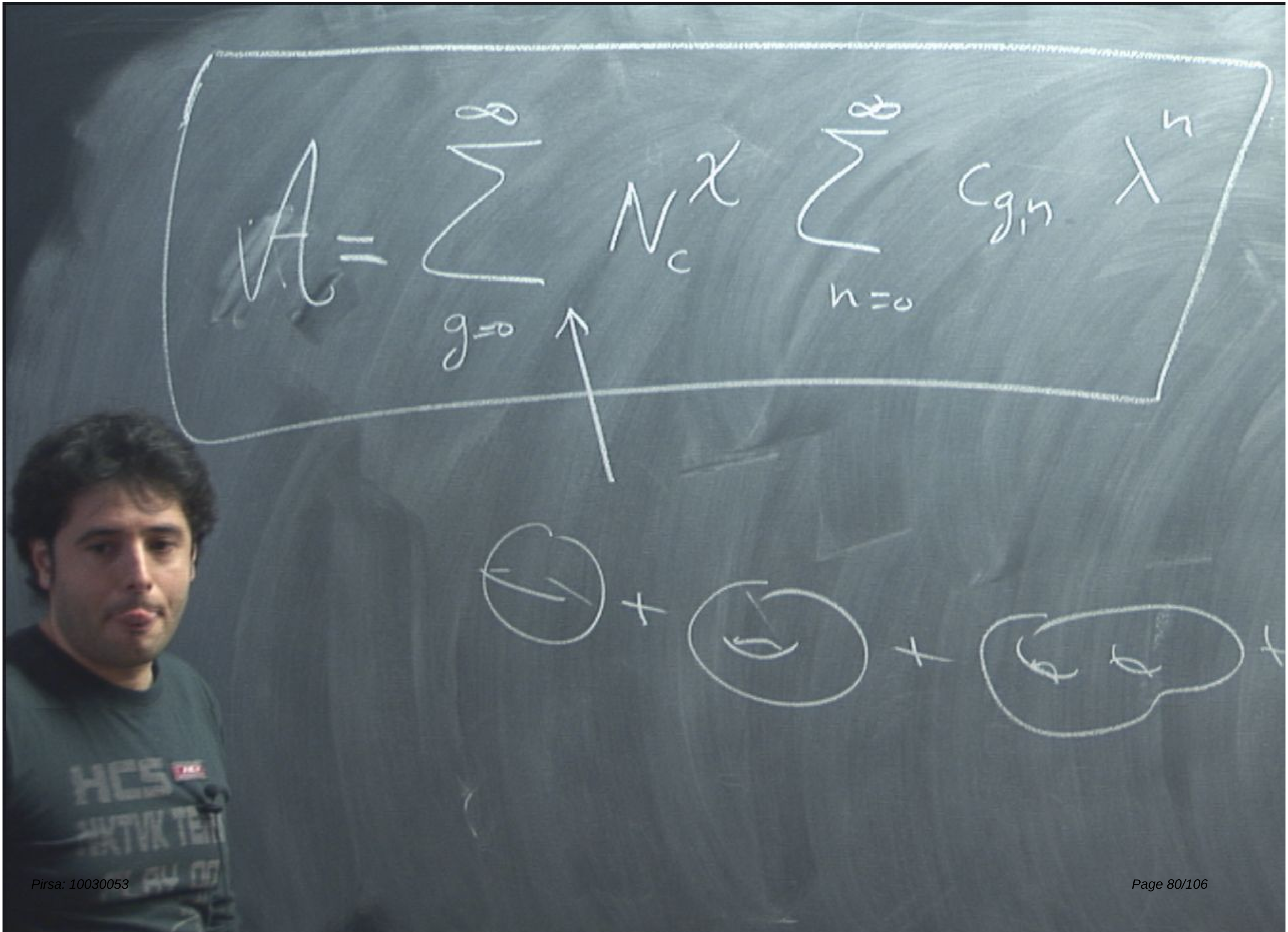
$$\sim \lambda^2$$

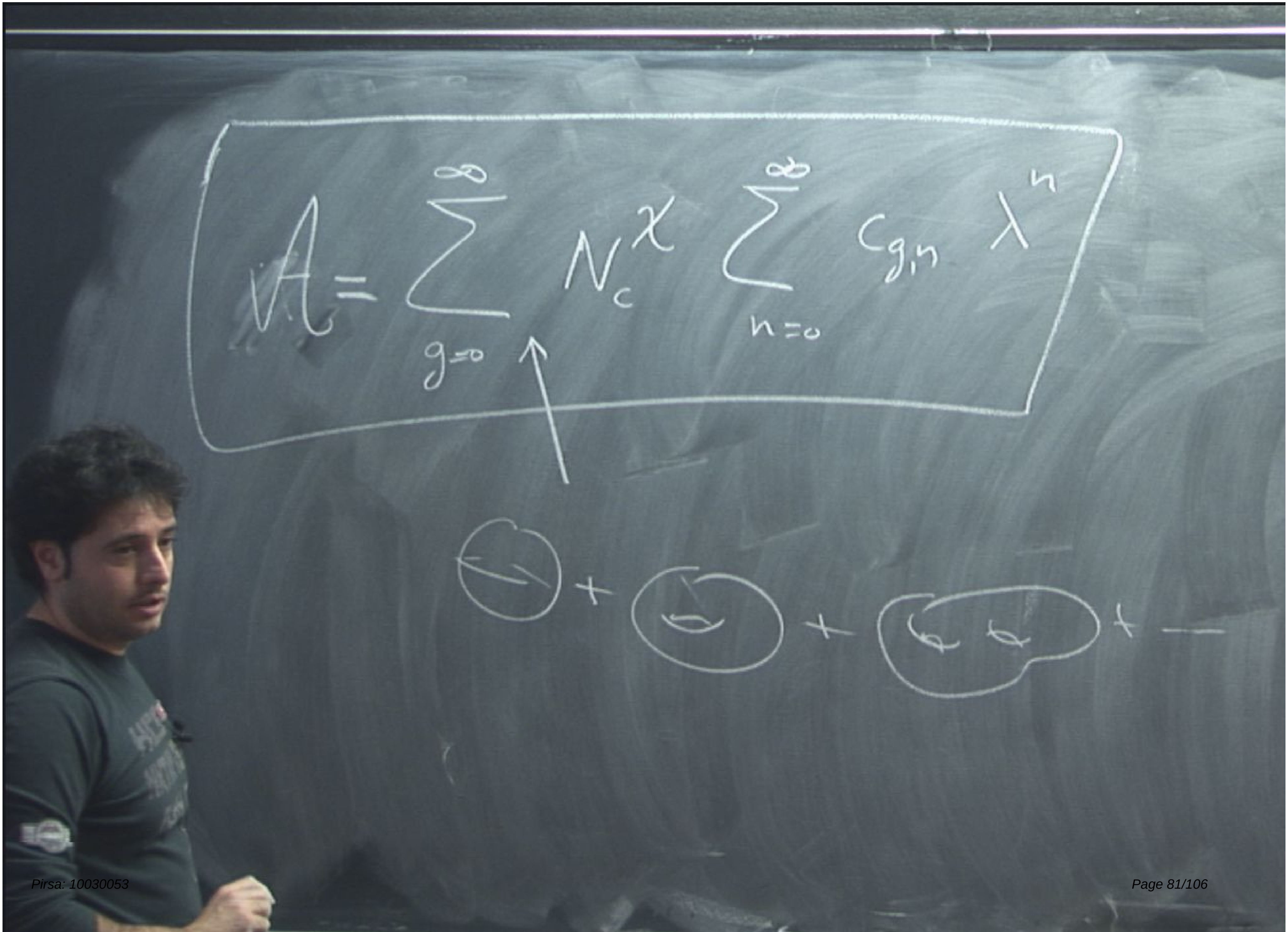
$$\chi = 2-2g = 2-2 = 0$$

$$N_c^{\chi} = N_c^0$$

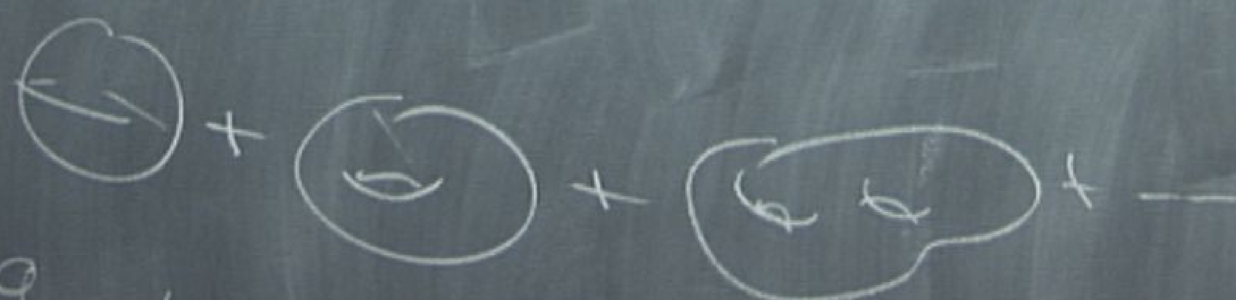


$$\mathcal{A} = \sum_{g=0}^{\infty} N_c^{\chi} \sum$$

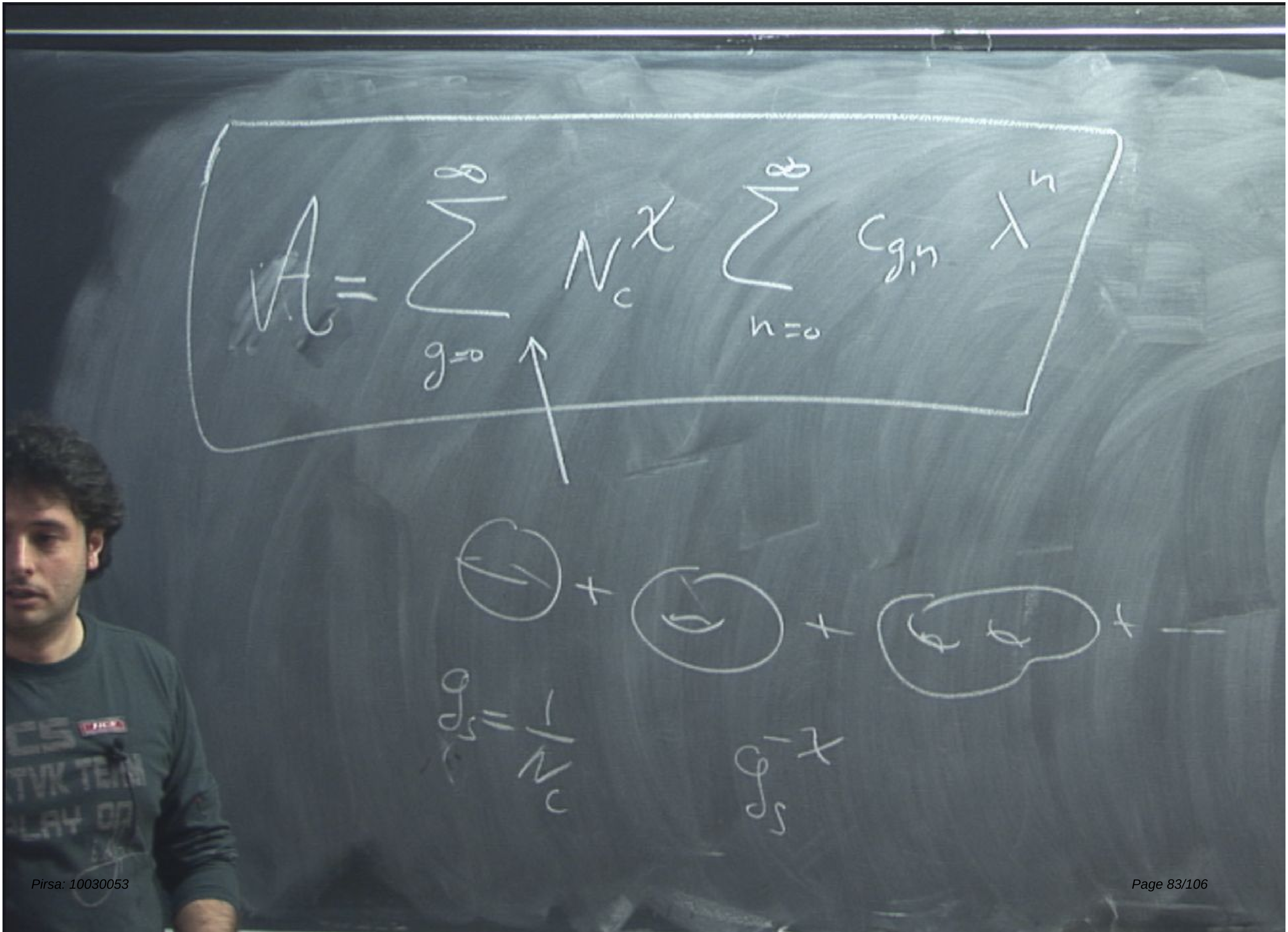

$A = \sum_{g=0}^{\infty} N_c^{\chi} \sum_{n=0}^{\infty} c_{g,n} \lambda^n$


$A = \sum_{g=0}^{\infty} N_c^{\chi} \sum_{n=0}^{\infty} c_{g,n} \lambda^n$

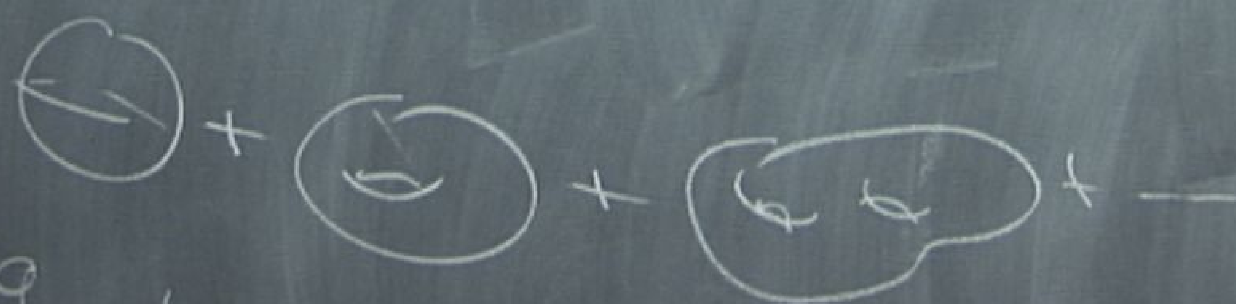
$$\boxed{\mathcal{A} = \sum_{g=0}^{\infty} N_c^{\chi} \sum_{n=0}^{\infty} c_{g,n} \lambda^n}$$



$$g_s = \frac{1}{N_c}$$


$A = \sum_{g=0}^{\infty} N_c^{\chi} \sum_{n=0}^{\infty} c_{g,n} \lambda^n$
$+$ $+$ $+ \cdots$
$g_s = \frac{1}{N_c}$
$g_s^{-\chi}$

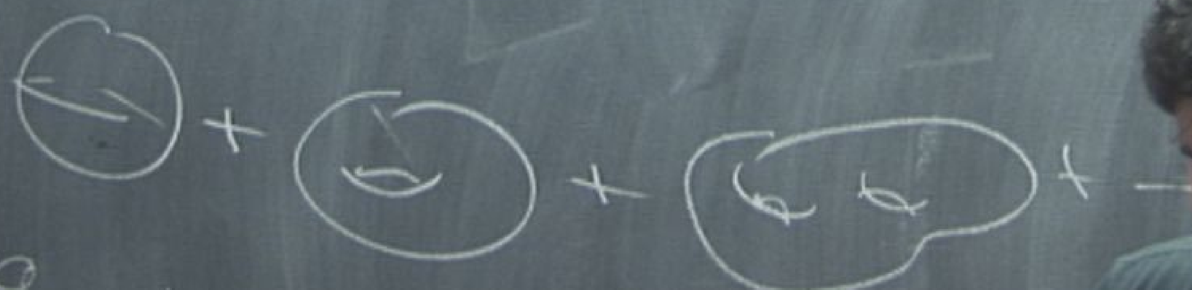
$$\boxed{A = \sum_{g=0}^{\infty} N_c^{\chi} \sum_{n=0}^{\infty} c_{g,n} \lambda^n}$$



$$g_s = \frac{1}{N_c} \qquad g_s^{-\chi}$$

$$\boxed{A = \sum_{g=0}^{\infty} N_c^{\chi} \sum_{n=0}^{\infty} c_{g,n} \lambda^n}$$

α' expansion



$$g_s = \frac{1}{N_c} \qquad g_s^{-\chi}$$

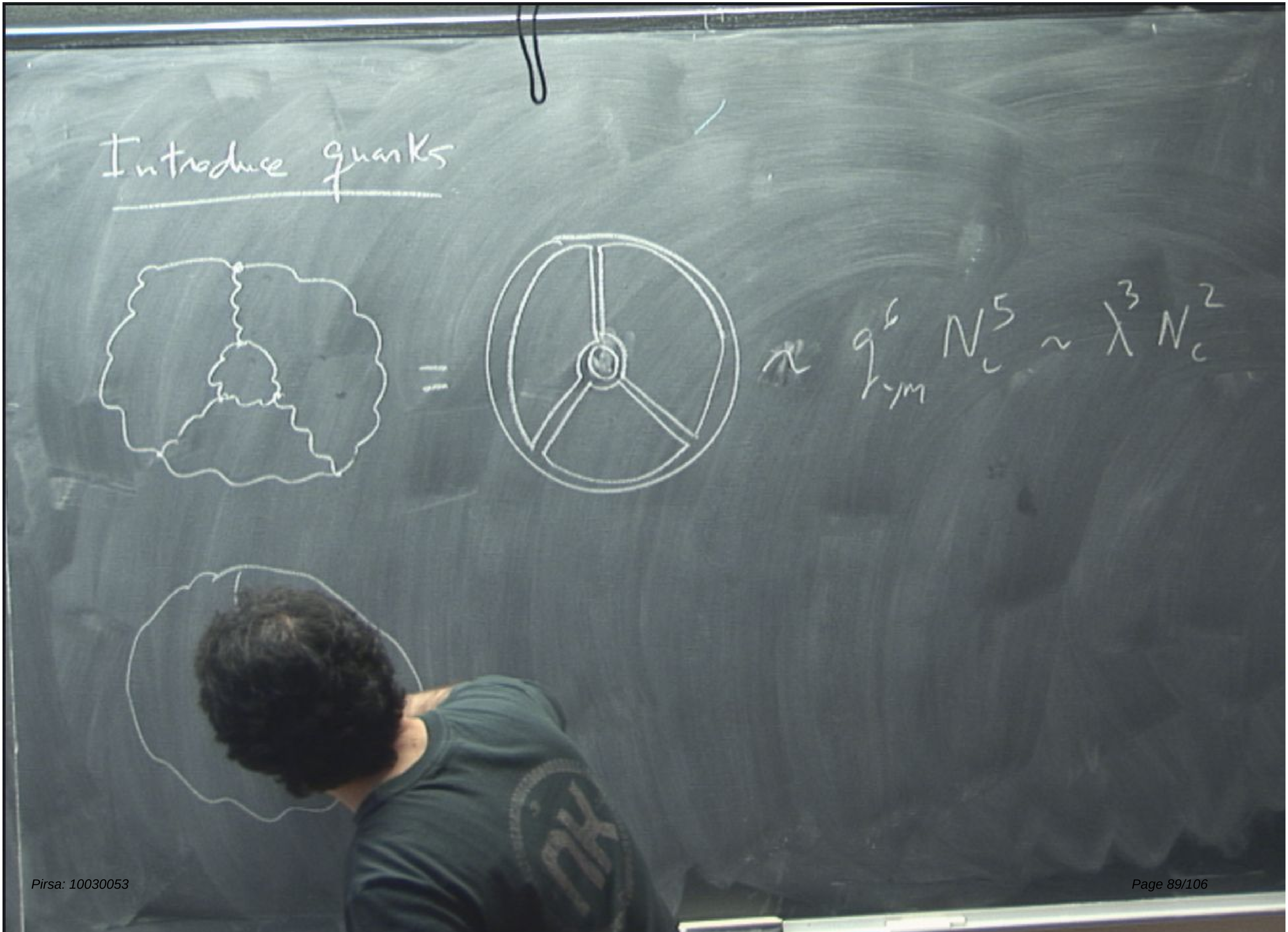
Introduce quarks

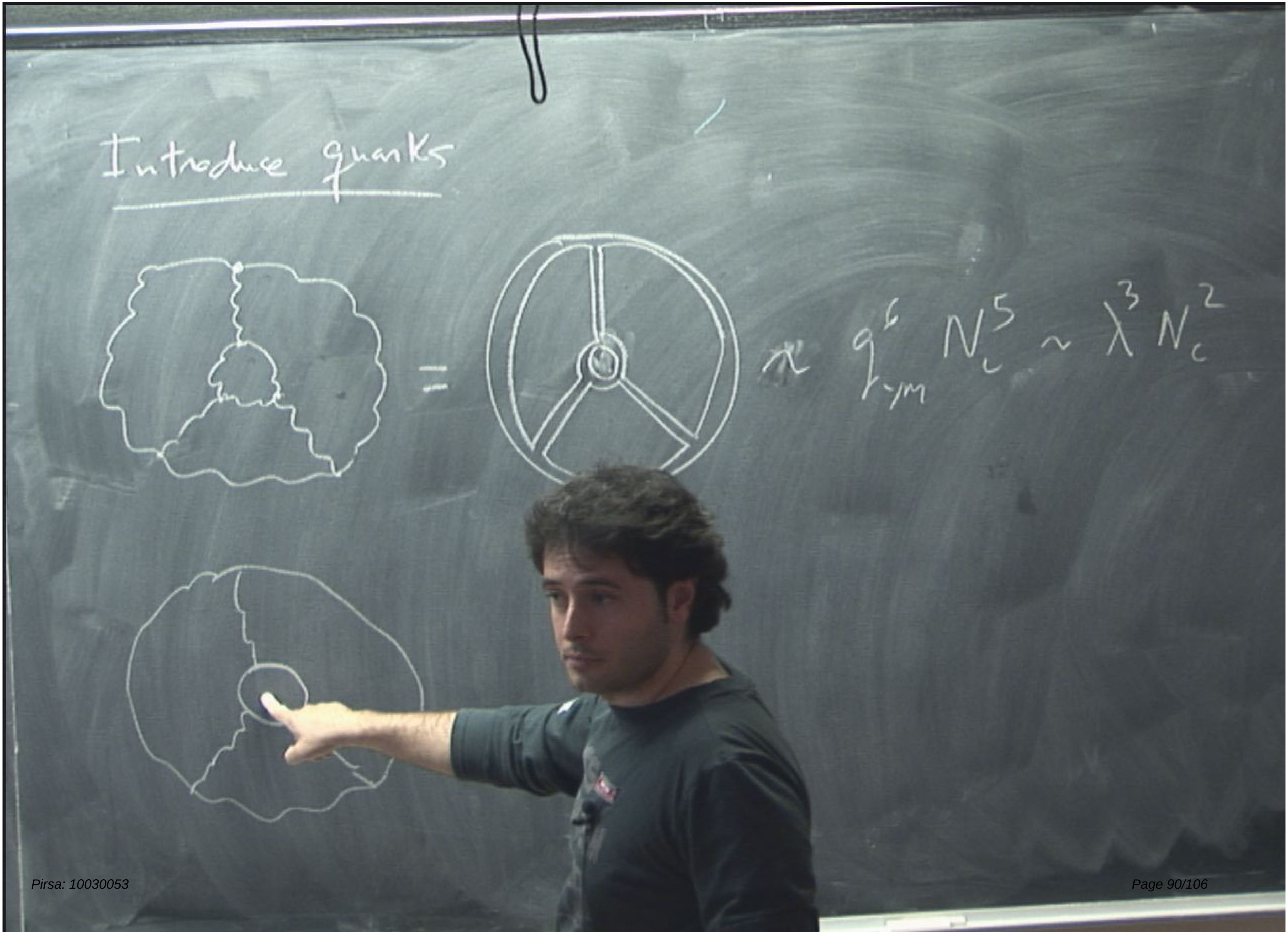
Introduce quarks

 $=$  $\sim g^6_{YM}$

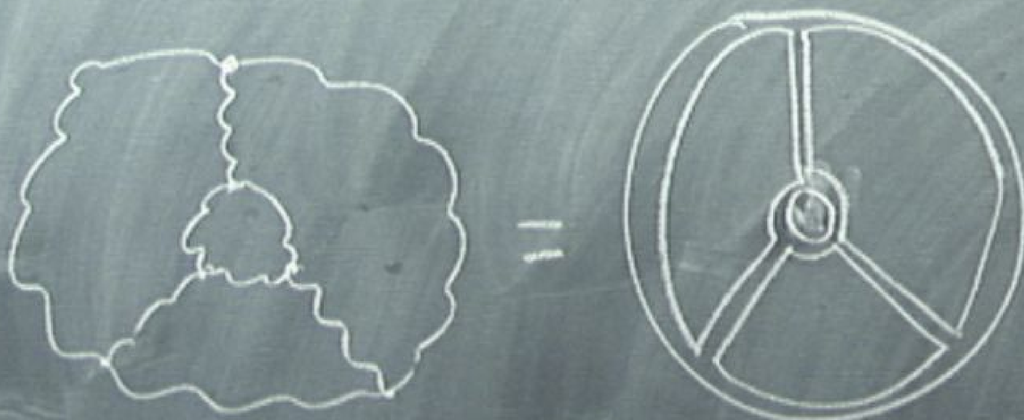
Introduce quarks

 =  $\propto g_{YM}^6 N_c^5 \sim$


Introduce quarks
=
g⁶YM N_c⁵ ~ λ³ N_c²

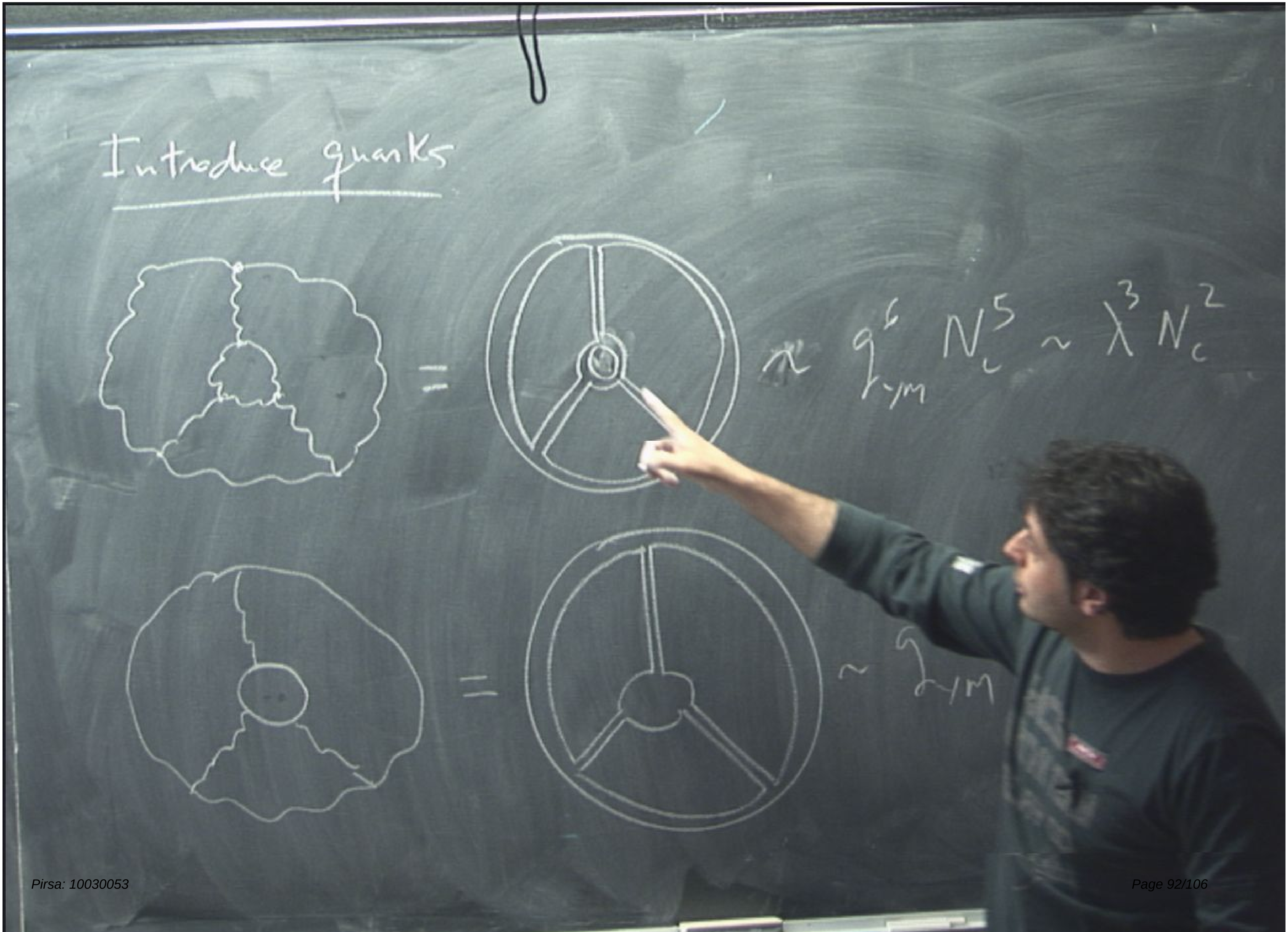

Introduce quarks
=
$g_{YM}^6 N_c^5 \sim \lambda^3 N_c^2$

Introduce quarks



$$\approx g_{YM}^6 N_c^5 \sim \lambda^3 N_c^2$$

$$\sim g \quad N$$


Introduce quarks
=
$\sim g_{YM}^6 N_c^5 \sim \lambda^3 N_c^2$
=
$\sim g_{YM}$

Introduce quarks

$=$

$$\sim g_{YM}^{6} N_c^{5} \sim \lambda^3 N_c^2$$

$=$

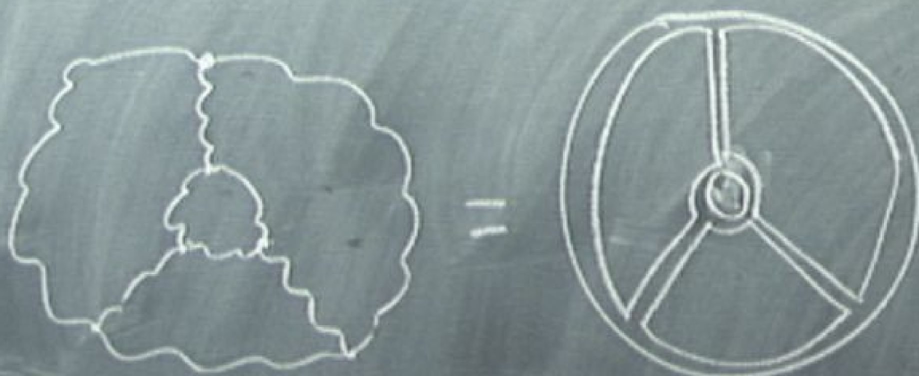
$$\sim g_{YM}^{6} N_c^{4}$$

Introduce quarks

 =  $\sim g_{YM}^6 N_c^5 \sim \lambda^3 N_c^2$

 =  $\sim g_{YM}^6 N_c^4 \sim \lambda^3 N_c$

Introduce quarks



$\sim g_{YM}^6 N_c^5 \sim \lambda^3 N_c^2$

$\sim g_{YM}^6 N_c^4 \sim \lambda^3 N_c N_f$

0709.1523 [hep-th] DAVID MATEOS

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Diagrams classif. by topology

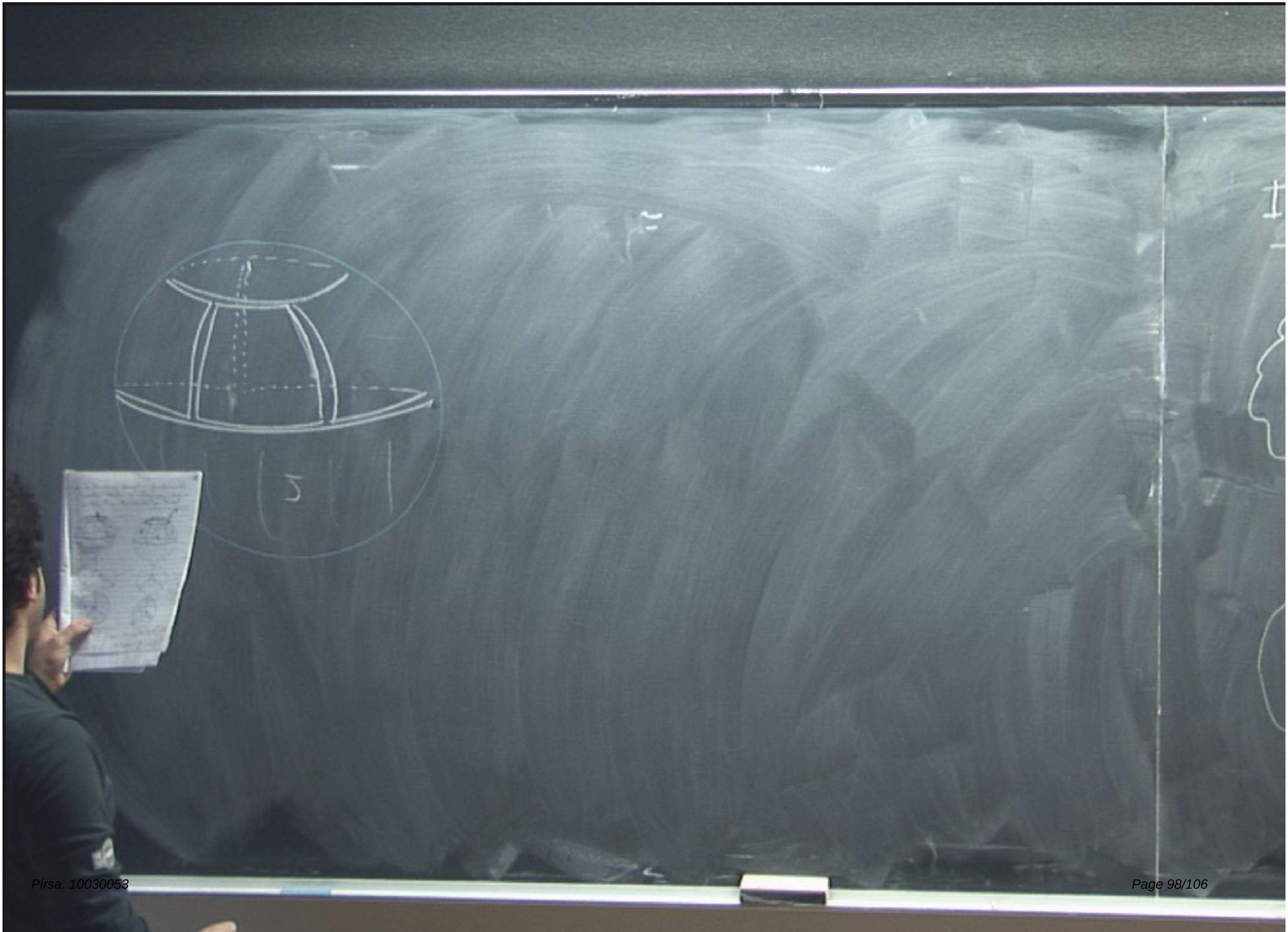
Non-planar diag. are $\frac{1}{N_c^2}$ - suppressed

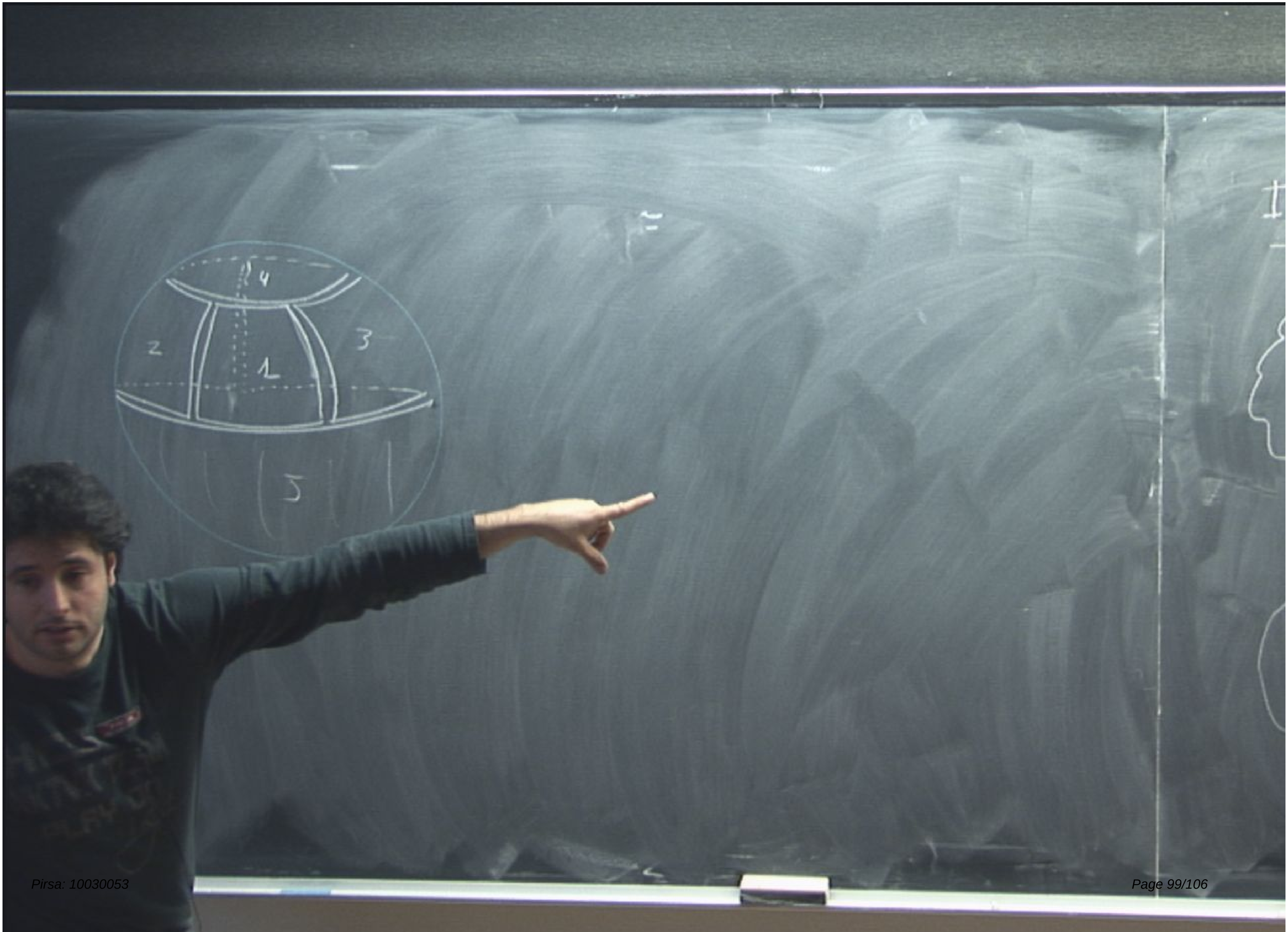
(Extra quark loops $\Longrightarrow$ $\frac{N_f}{N_c}$ suppress)

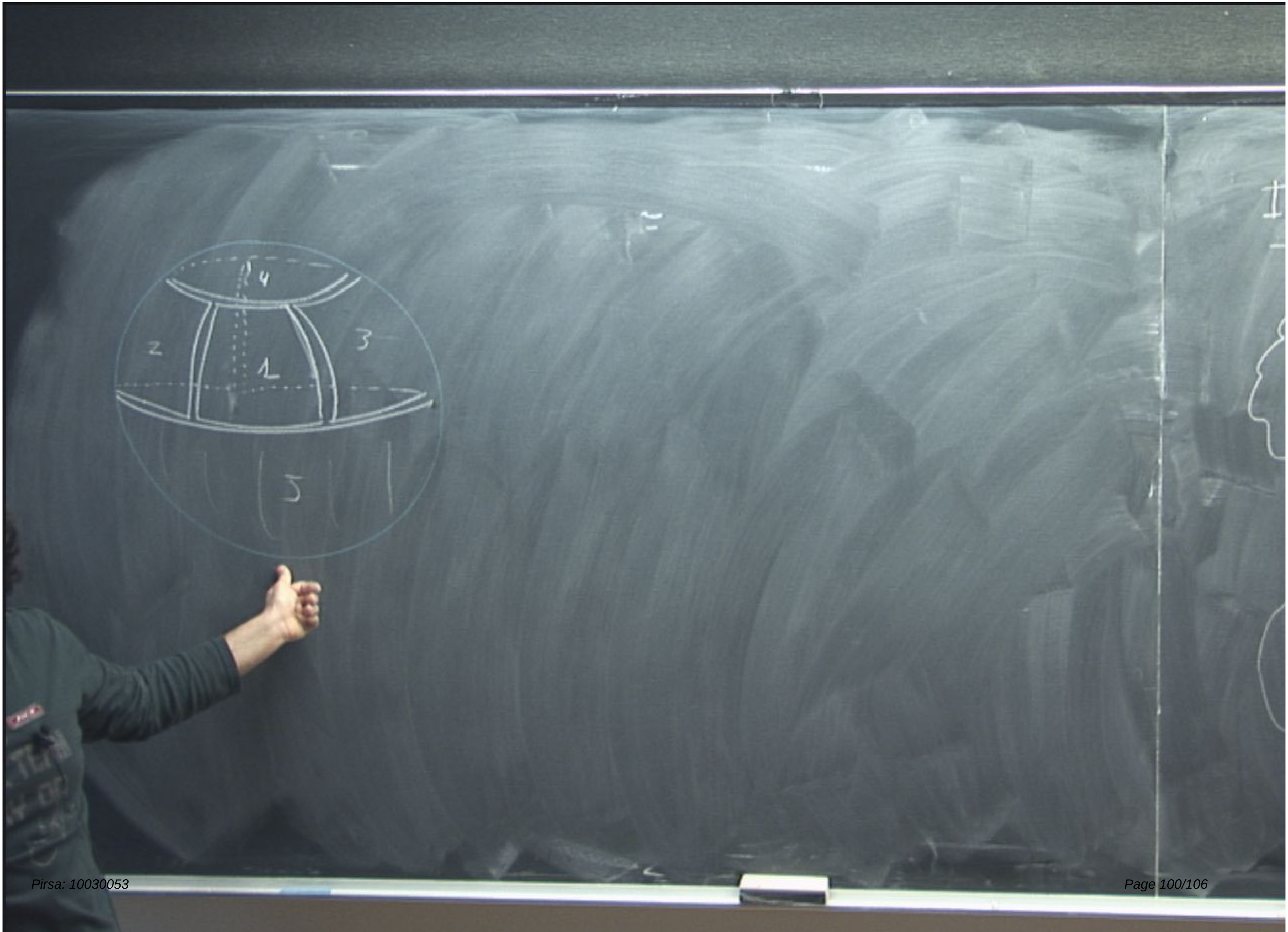
Introduce quarks

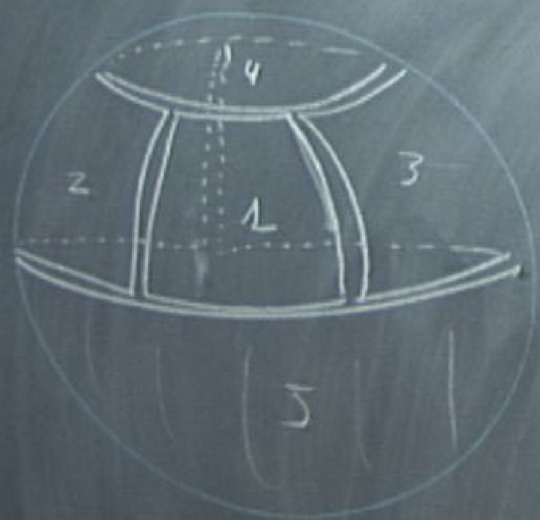
 =  $\sim g_{YM}^6 N_c^5 \sim \lambda^3 N_c^2$

 =  $\sim g_{YM}^6 N_c^4 \sim \lambda^3 N_c N_f$

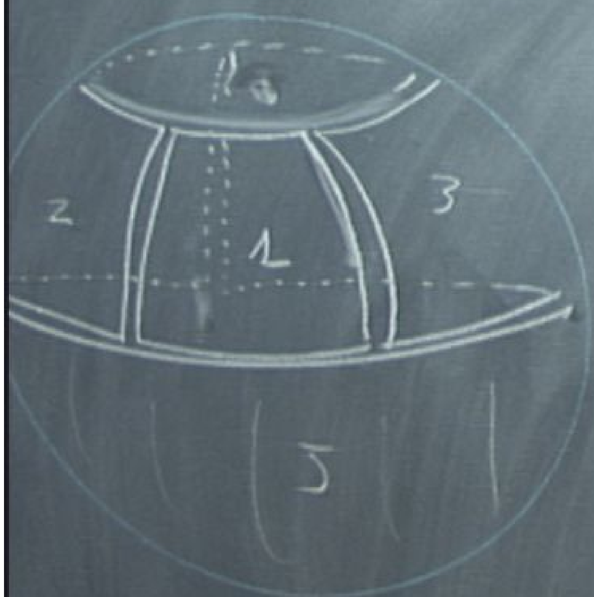



4
2
3
1
5


4
2
3
1
5



$S^2 \quad g=0 \quad \chi=2 \quad N_c^2$

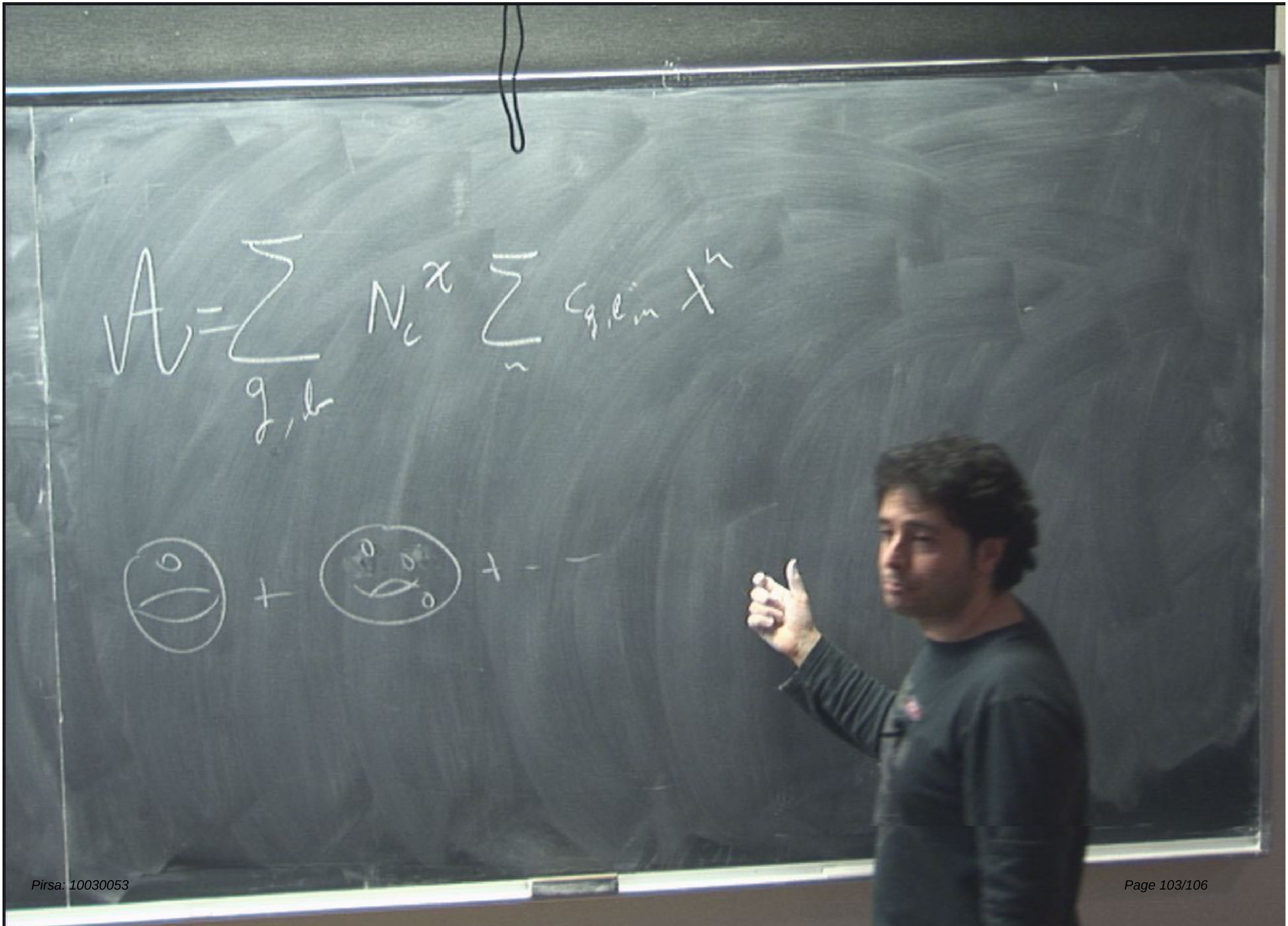


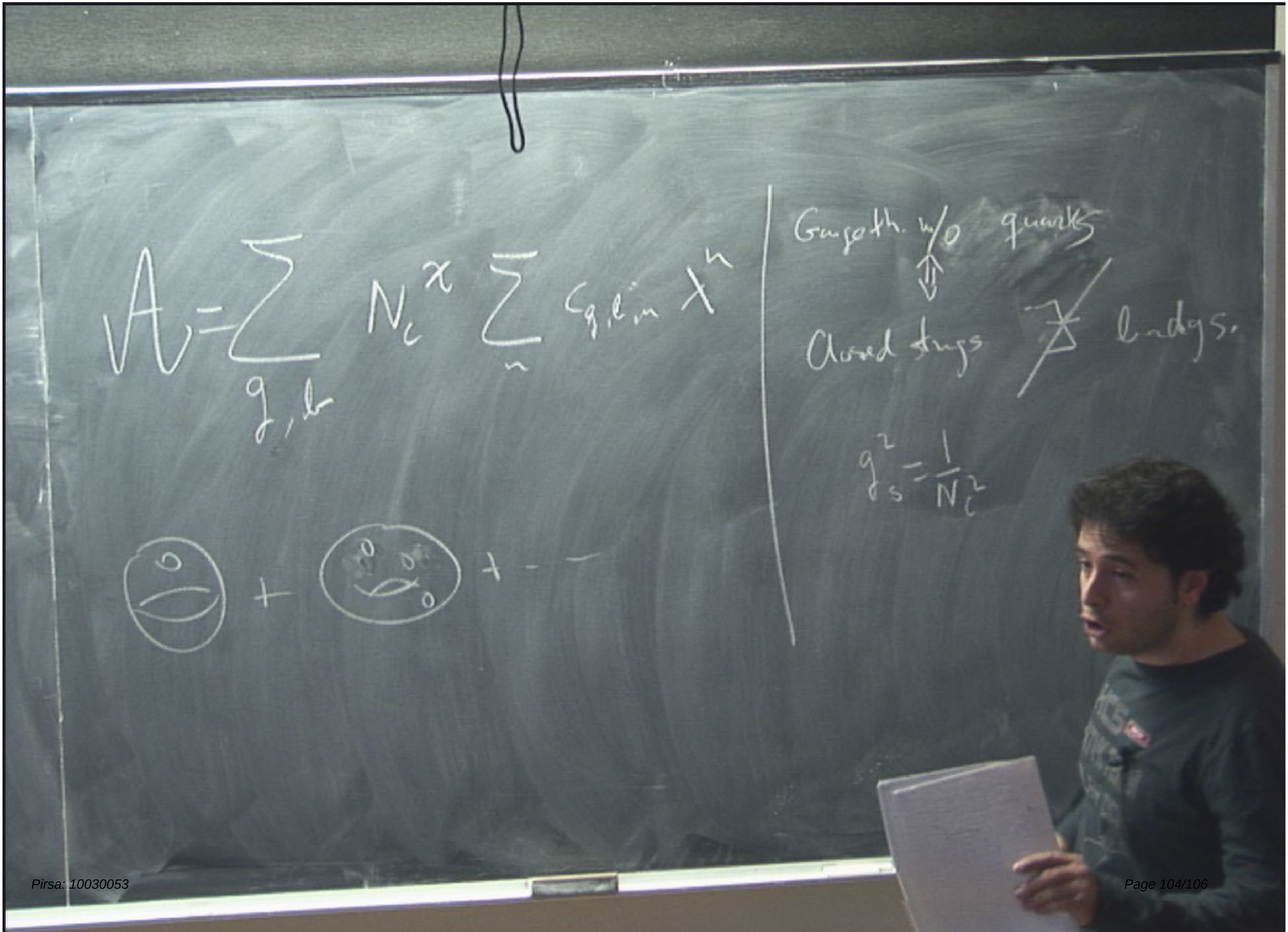
$$\chi = 2 - 2g - b$$

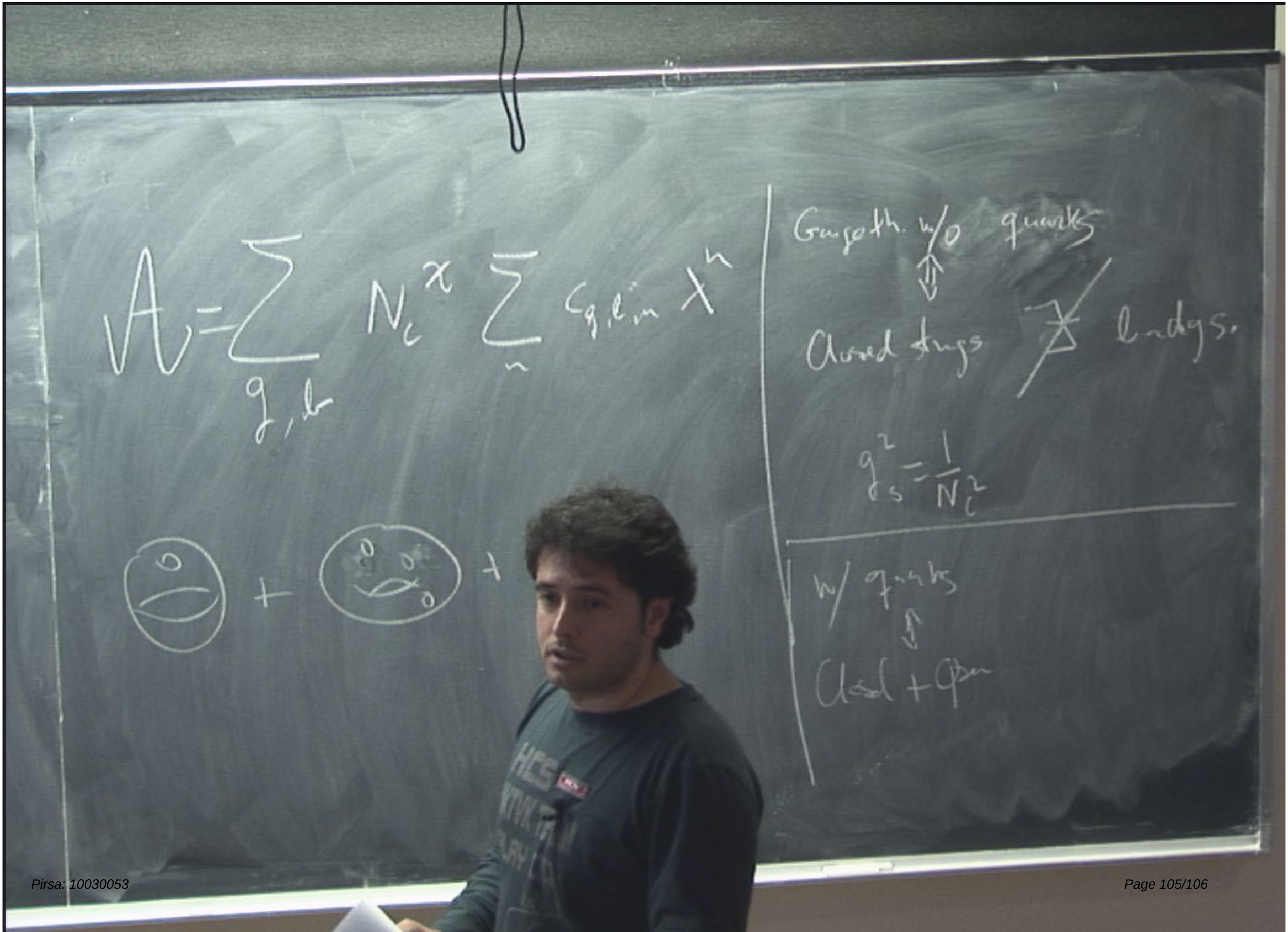
$$\chi = 2 - 2\cdot 0 - 1 = 1$$

$$N_c^{1}$$

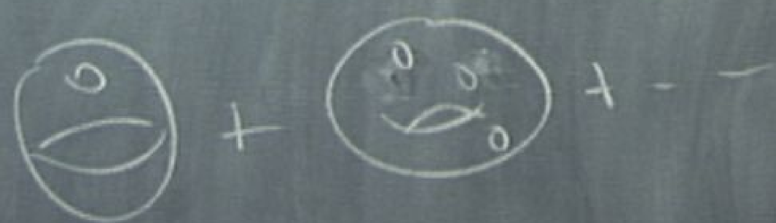
$$S^2 \quad g = 0 \quad \chi = 2 \quad N_c^{2}$$


$A = \sum_{g,b} N_c^{x} \sum_{n} c_{g,b,n} \lambda^{n}$
+
+ - -


$A = \sum_{g,b} N_c^{\chi} \sum_n c_{g,b,n} \lambda^n$
Gauge th. w/o quarks
Closed strings
$g_s^2 = \frac{1}{N_c^2}$


$A = \sum_{g,b} N_c^{\chi} \sum_n c_{g,b,n} \lambda^n$
Gauge th. w/o quarks
Closed strings
$g_s^2 = \frac{1}{N_c^2}$
w/ quarks
Closed + Open

$$A = \sum_{g,b} N_c^{\chi} \sum_n c_{g,b,n} \lambda^n$$



Gauge th. w/o quarks

$\Updownarrow$

Closed strings $\nexists$ bndys.

$$g_s^2 = \frac{1}{N_c^2}$$

w/ quarks

$\Updownarrow$

Closed + open $\quad 1/N_c$