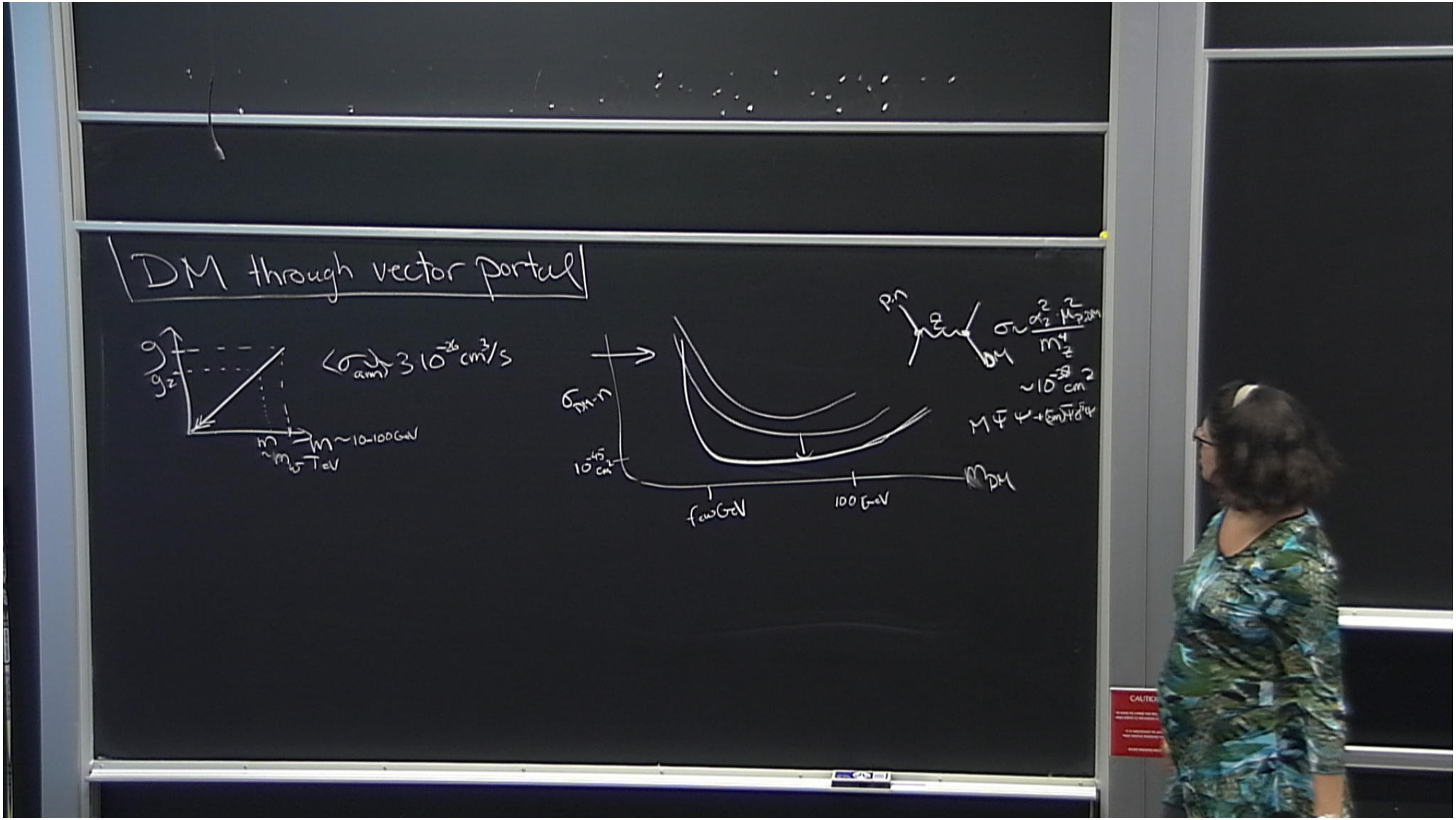
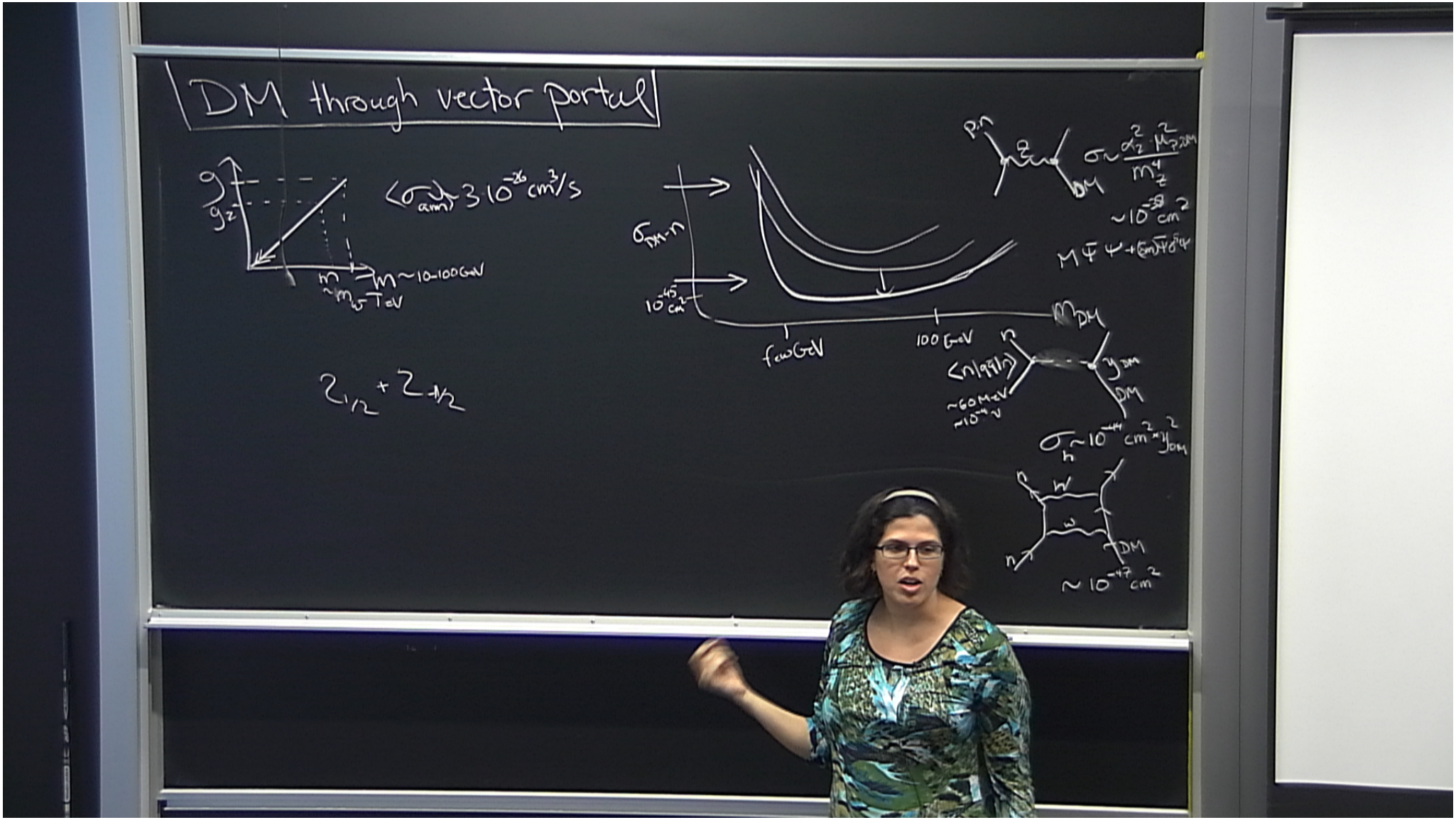
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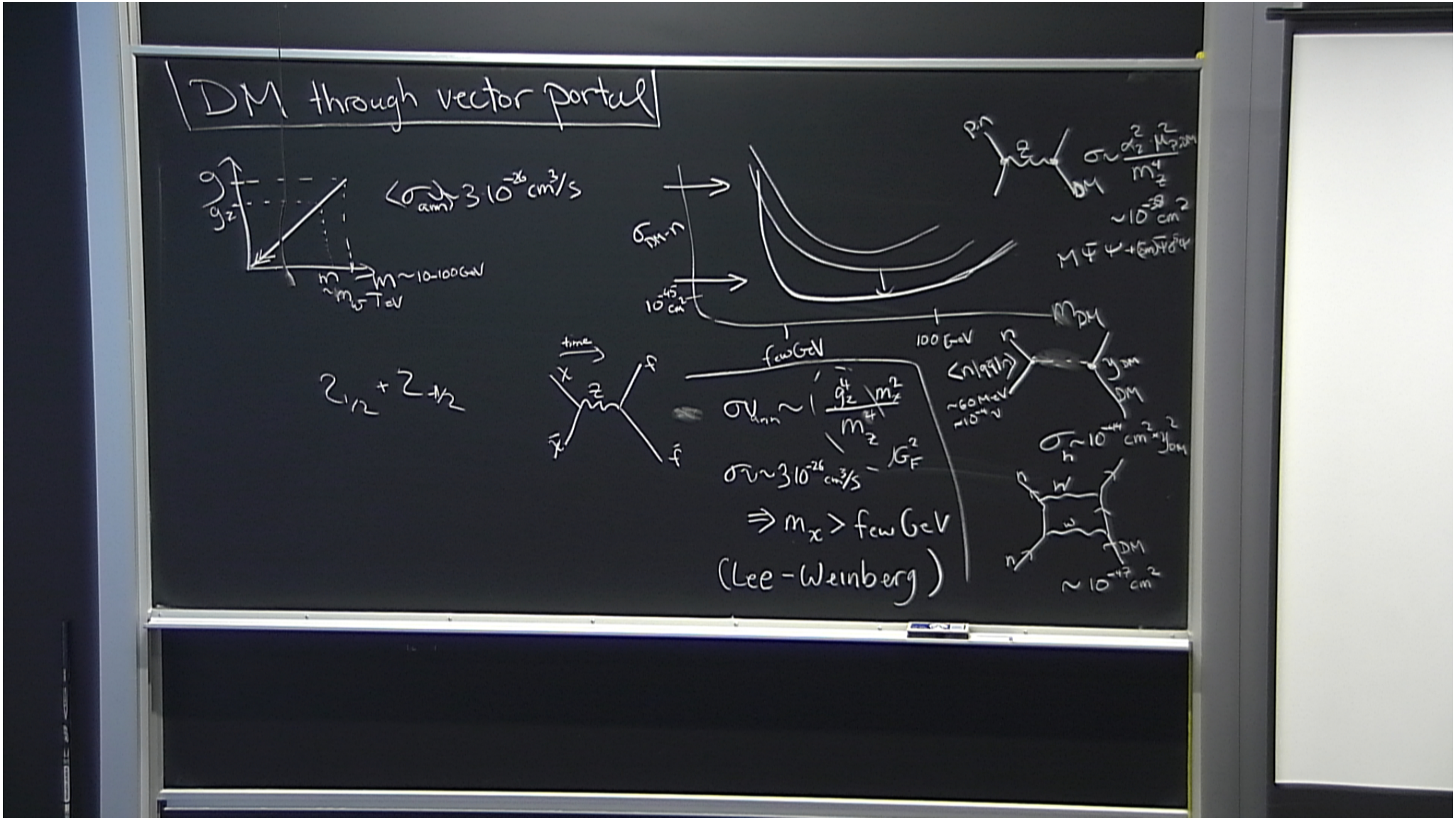
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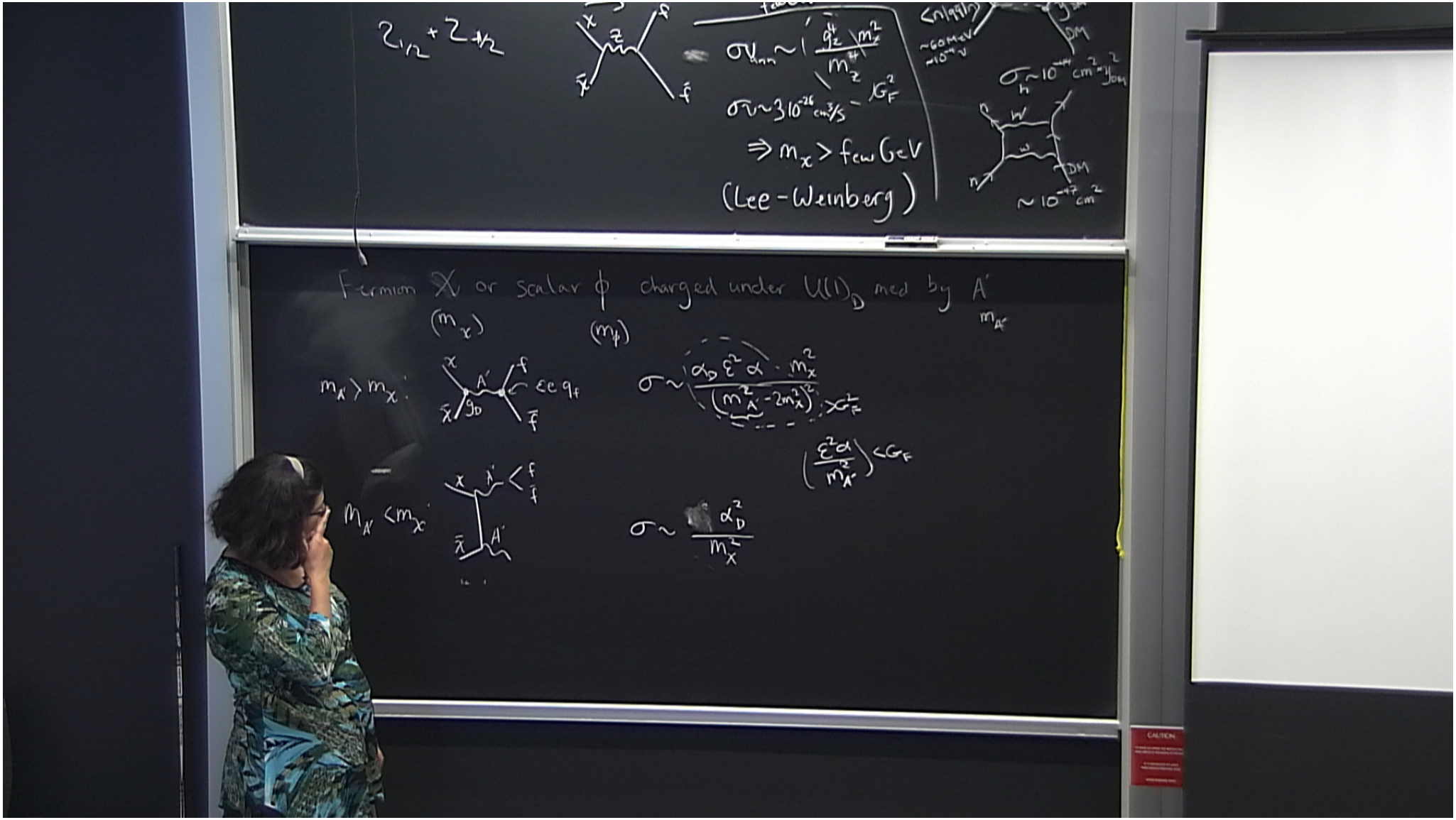
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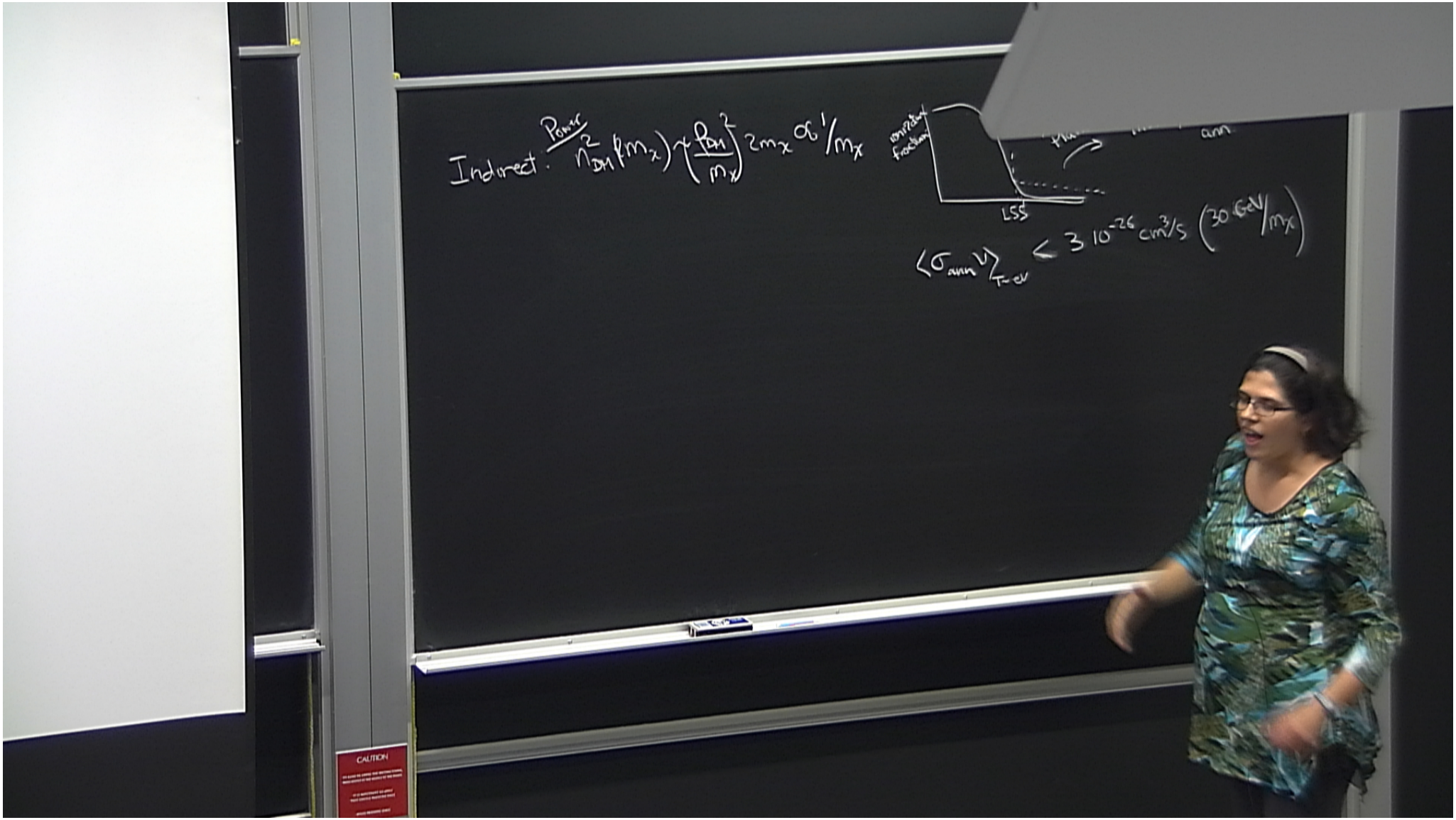
Abstract:

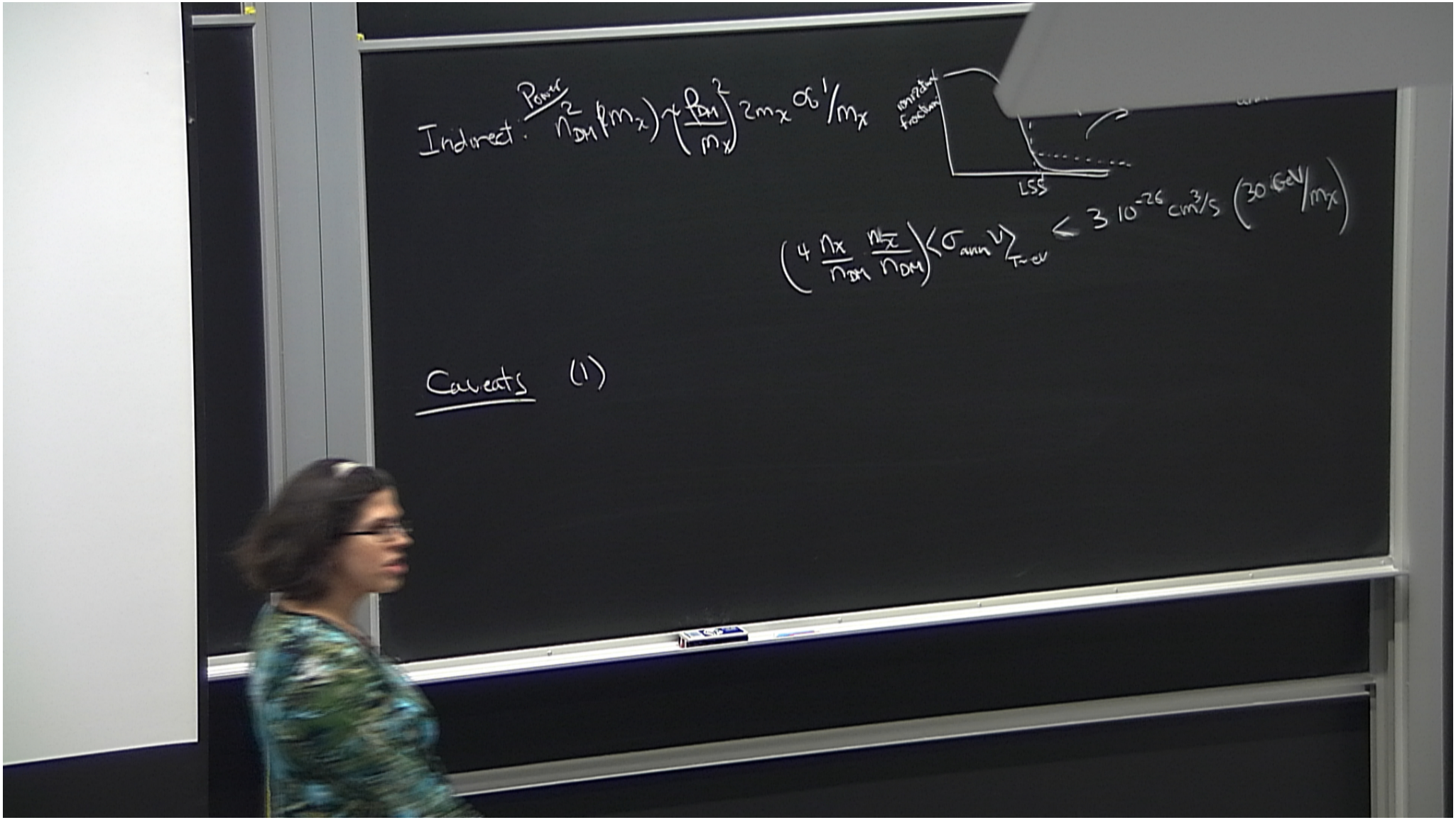

DM through vector portal
$g_z$
$\langle \sigma v \rangle_{ann} \sim 3\times10^{-26}\,cm^3/s$
$m \sim m_{g_z} \sim$ TeV
$m \sim$ 10-100 GeV
$\sigma_{DM-n}$
$10^{-45}\,cm^2$
few GeV
100 GeV
$m_{DM}$
n
DM
$\sigma \sim \frac{\alpha_z^2 \cdot \mu^2_{n,DM}}{m_z^4}$
$\sim 10^{-38}\,cm^2$

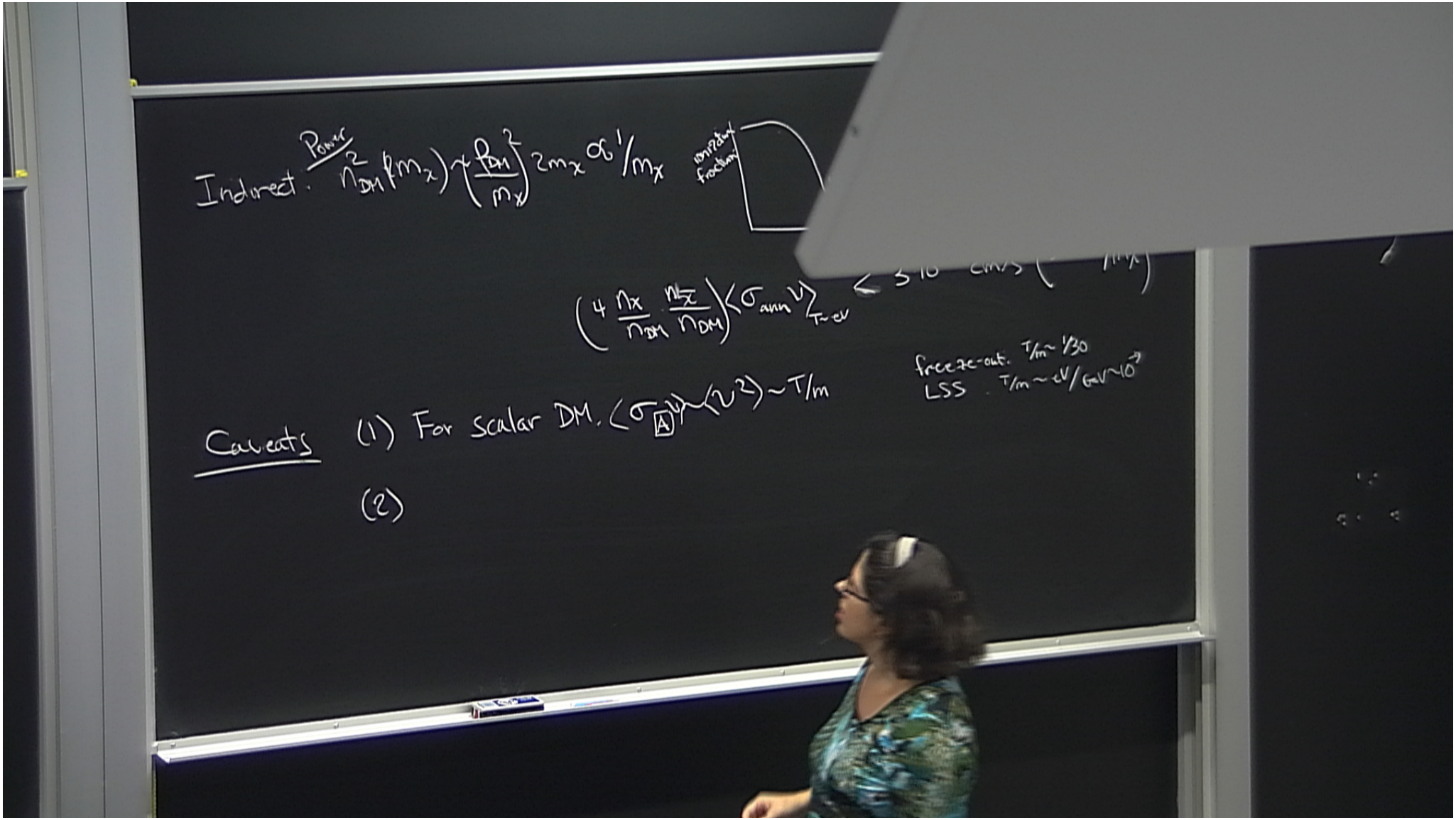

DM through vector portal
~10-100 GeV
~m_W ~TeV
100 GeV
few GeV
~60 MeV
~10^-4 v
DM
DM
DM

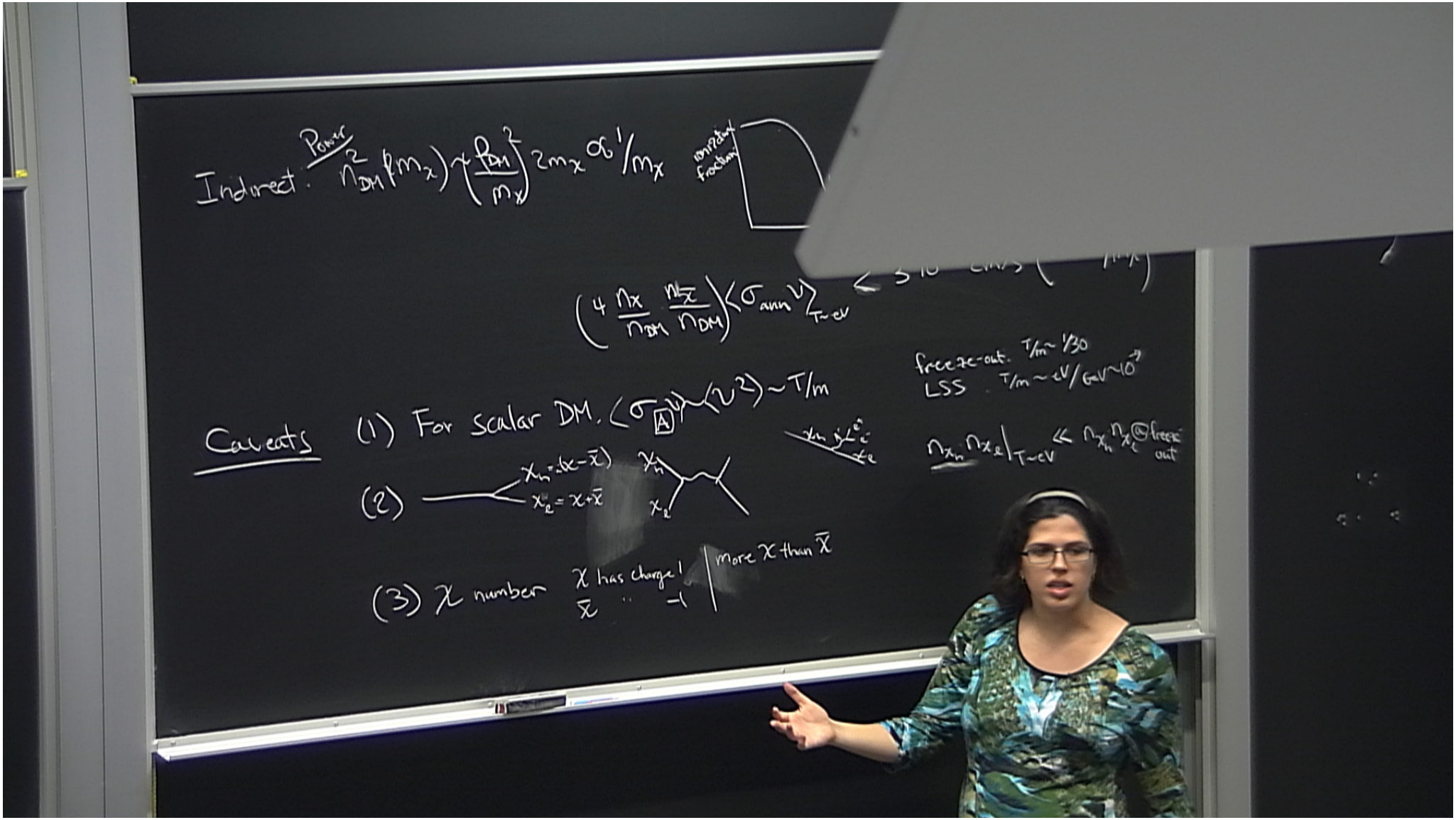

DM through vector portal
$g_z$
$m \sim m_W$ TeV
$m \sim$ 10-100 GeV
$\langle \sigma v \rangle_{ann} \sim 3 \cdot 10^{-26}$ cm$^3$/s
$\sigma_{DM-n}$
$10^{-45}$ cm$^2$
few GeV
100 GeV
$m_{DM}$
$\sigma \sim \frac{\alpha_z^2 \mu_{n,DM}^2}{m_z^4}$
$\sim 10^{-38}$ cm$^2$
$2_{1/2} + 2_{-1/2}$
time
$\sigma v_{ann} \sim 1 \frac{g_z^4}{m_z^4} \frac{m^2}{m_z^2}$
$\sigma v \sim 3 \cdot 10^{-26}$ cm$^3$/s $\sim G_F^2$
$\Rightarrow m_x >$ few GeV
(Lee-Weinberg)
~60 MeV
$\sim 10^{-4} \nu$
$\sigma_n \sim 10^{-44}$ cm$^2 \times y_{DM}^2$
$\sim 10^{-47}$ cm$^2$

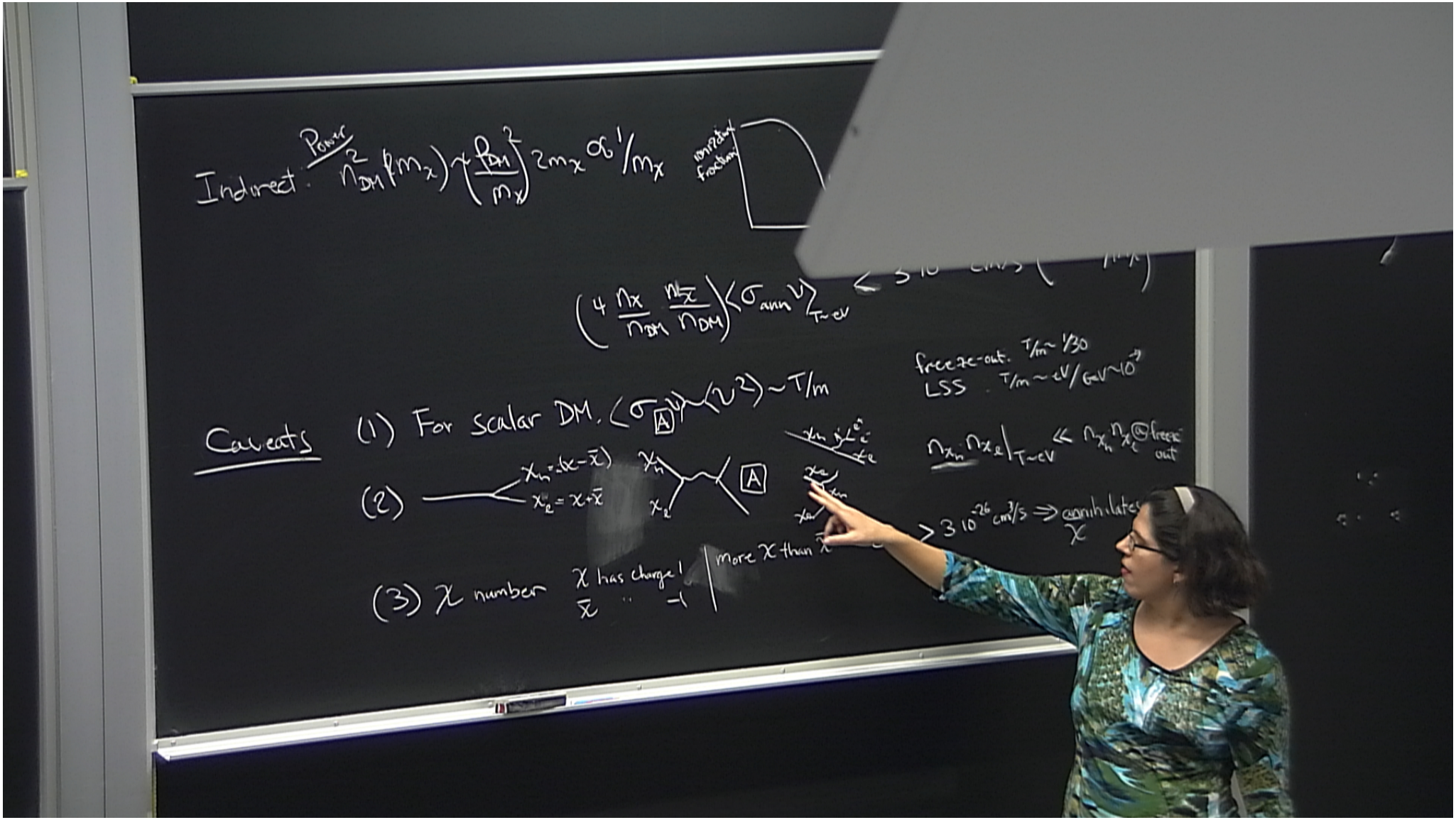

Fermion χ (m_χ) or scalar φ (m_φ) charged under U(1)_D med by A' m_A'
(Lee-Weinberg)
m_A' > m_χ
m_A' < m_χ
CALTECH

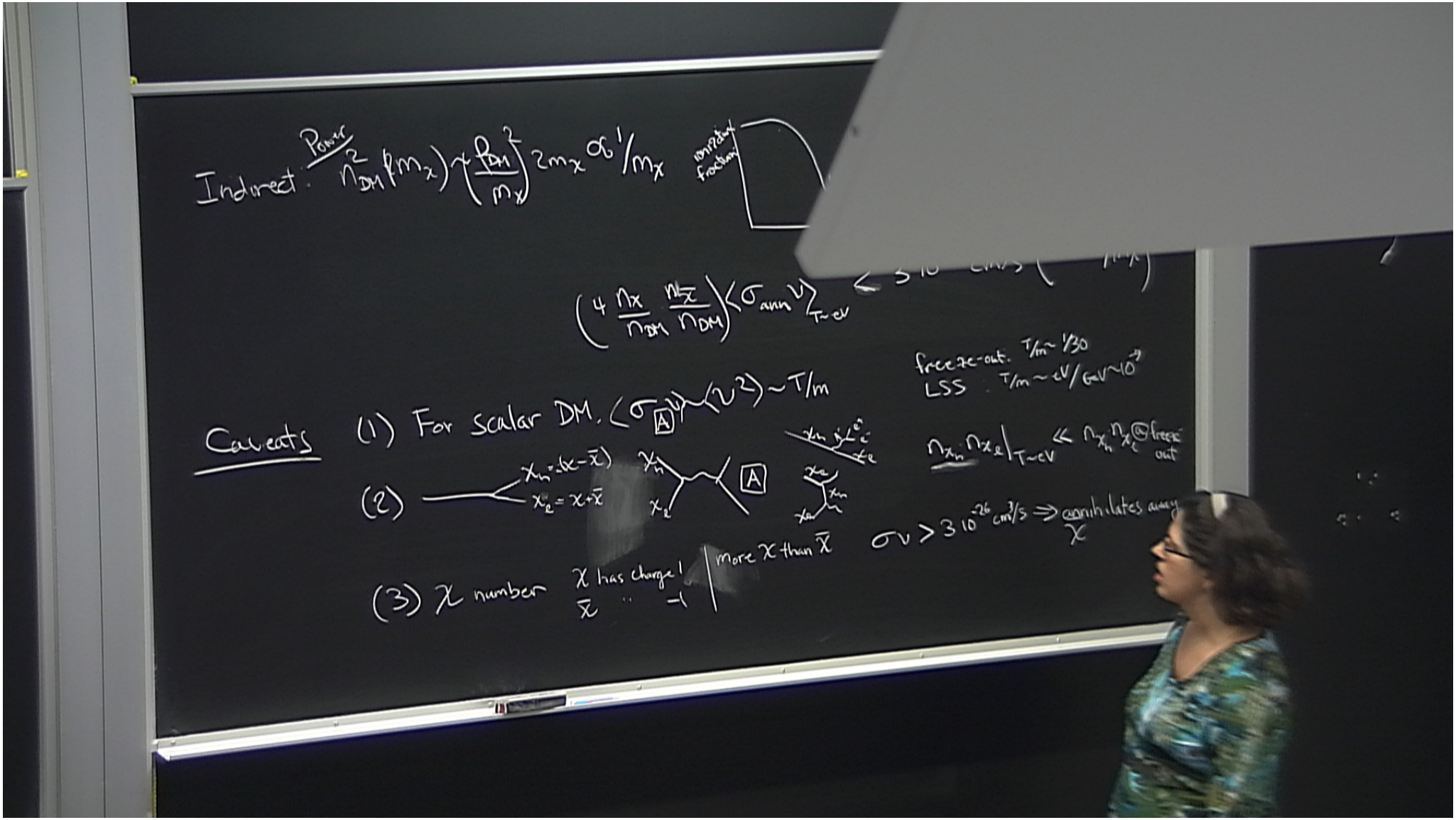

Indirect
Power
$n^2_{DM}(m_x) \propto \left(\frac{\rho_{DM}}{m_x}\right)^2 \langle\sigma v\rangle m_x^{-2} \propto 1/m_x$
$\langle\sigma_{ann} v\rangle_{T\sim 0} < 3\times 10^{-26}\ cm^3/s \left(\frac{30\ GeV}{m_x}\right)$
CAUTION

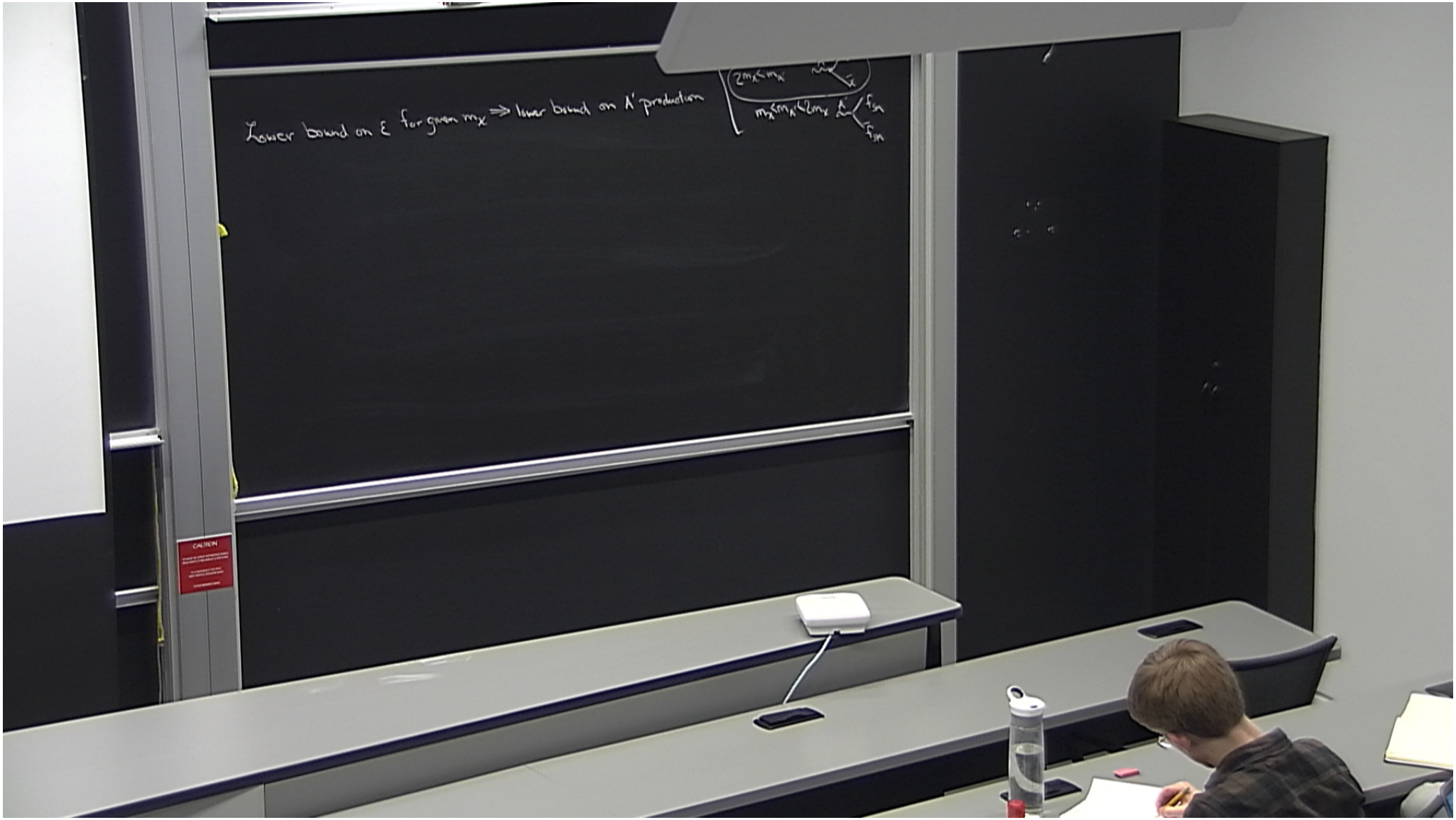

Indirect: Power
$n_{DM}^2(m_x) \propto \left(\frac{\rho_{DM}}{m_x}\right)^2 \langle m_x \propto 1/m_x$
LSS
$\left(4 \frac{n_x}{n_{DM}} \frac{n_{\bar{x}}}{n_{DM}}\right) \langle \sigma_{ann} v \rangle_{T\sim eV} < 3\,10^{-26}\,cm^3/s \left(30\,GeV/m_x\right)$
Caveats (1)

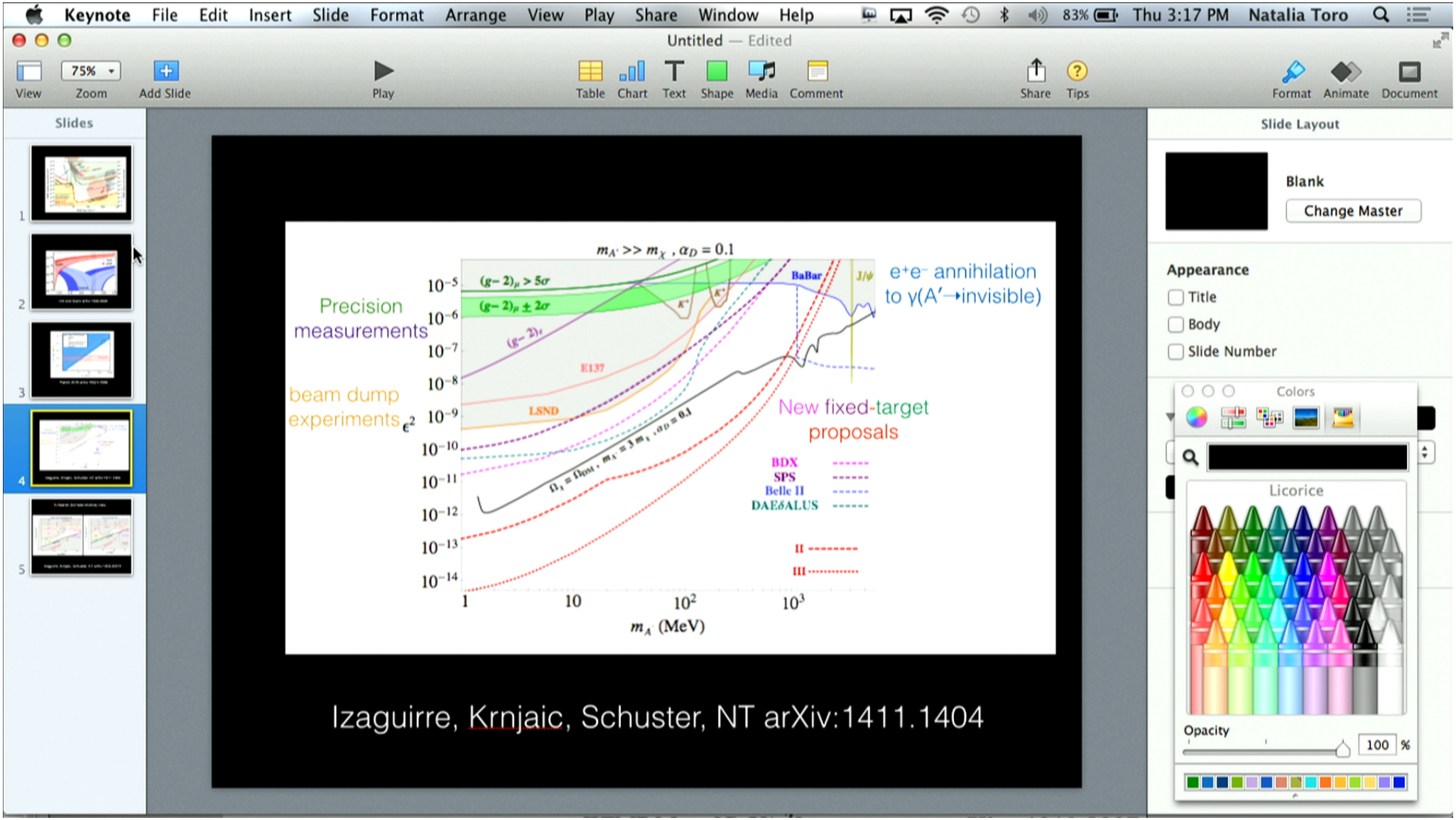

Indirect
Power
$n_{DM}^2 \langle \sigma_{ann} v \rangle (m_x) \propto \left(\frac{\rho_{DM}}{m_x}\right)^2 2m_x \propto 1/m_x$
ionization fraction
$\left(4 \frac{n_x}{n_{DM}} \frac{n_{\bar{x}}}{n_{DM}}\right) \langle \sigma_{ann} v \rangle_{T \sim eV}$
freeze-out. $T/m \sim 1/30$
LSS $T/m \sim eV/GeV \sim 10^{-9}$
Caveats (1) For scalar DM. $\langle \sigma_{[A]} v \rangle (2 \to 3) \sim T/m$
(2)

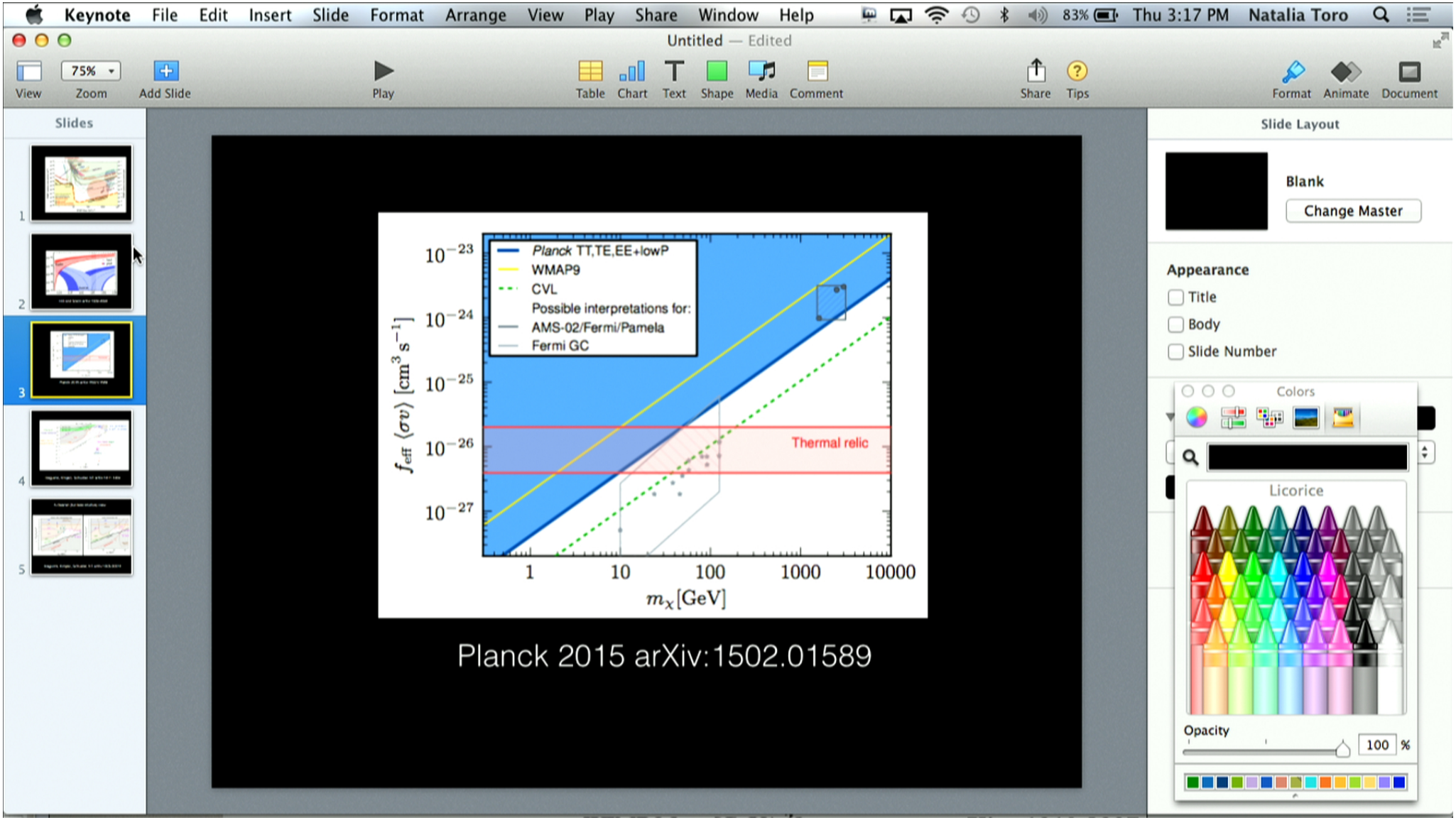

Indirect
Caveats
(1) For scalar DM,
(2)
(3) χ number
χ has charge 1
more χ than χ̄
free χ-out
LSS

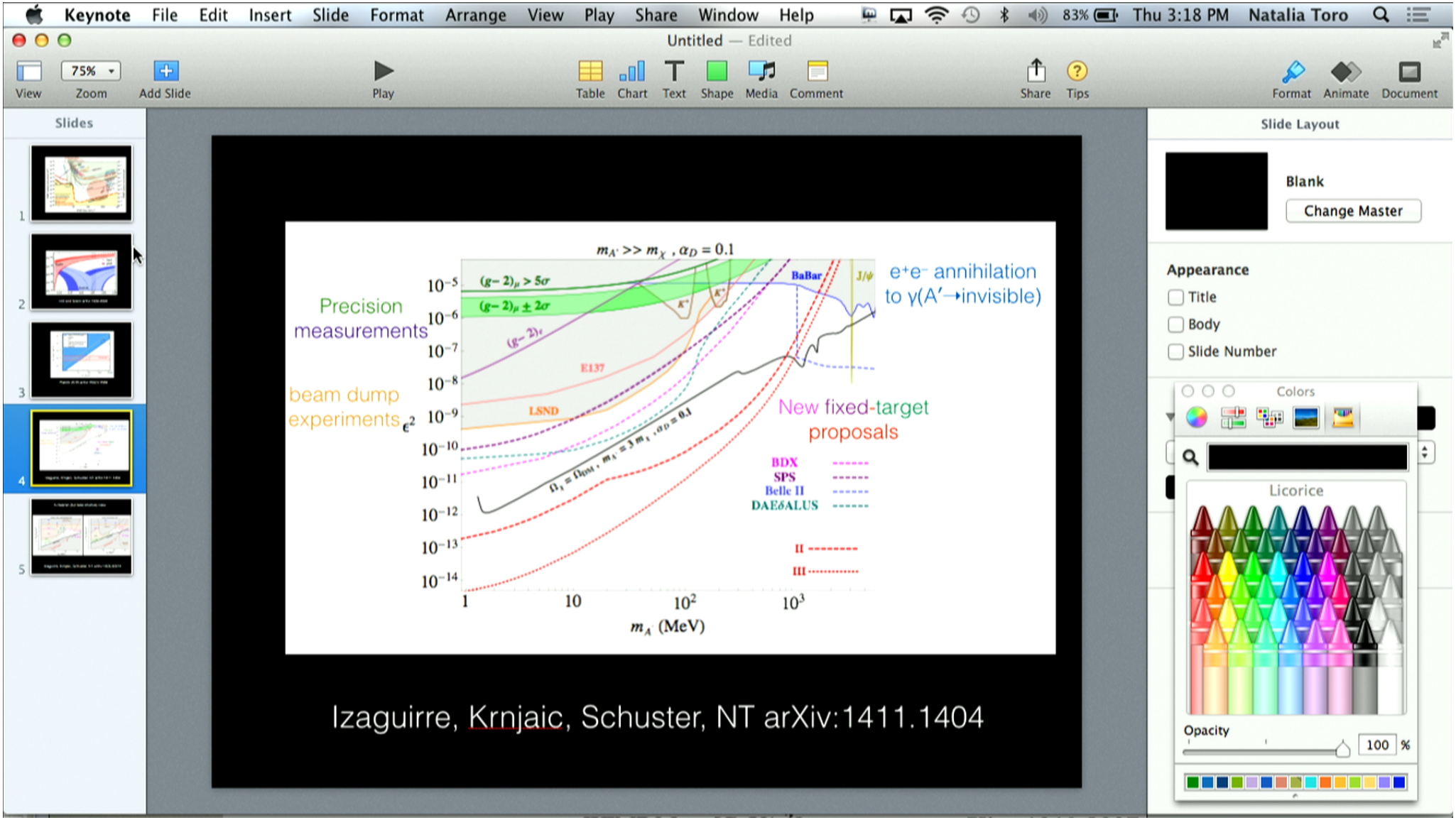

Indirect
Power
$n_{DM}^2(m_\chi)\propto\left(\frac{\rho_{DM}}{m_\chi}\right)^2 2m_\chi\,\sigma\,1/m_\chi$
annihilation fraction
$\left(4\frac{n_\chi}{n_{DM}}\frac{n_{\bar\chi}}{n_{DM}}\right)\langle\sigma_{ann}v\rangle_{T\sim eV}$
freeze-out. $T/m\sim 1/30$
LSS $T/m\sim eV/GeV\sim 10^{-9}$
Caveats
(1) For scalar DM, $\langle\sigma_A v\rangle(2\to 3)\sim T/m$
$n_{\chi_1}n_{\chi_2}|_{T\sim eV} \ll n_{\chi_1}n_{\chi_2}$ @freeze out
(2)
$\chi_{1,2}=(\chi-\bar\chi)$
$\chi_2=\chi+\bar\chi$
A
$>3\,10^{-26}\,cm^3/s \Rightarrow$ annihilates
(3) $\chi$ number
$\chi$ has charge 1
$\bar\chi$ " $-1$
more $\chi$ than $\bar\chi$

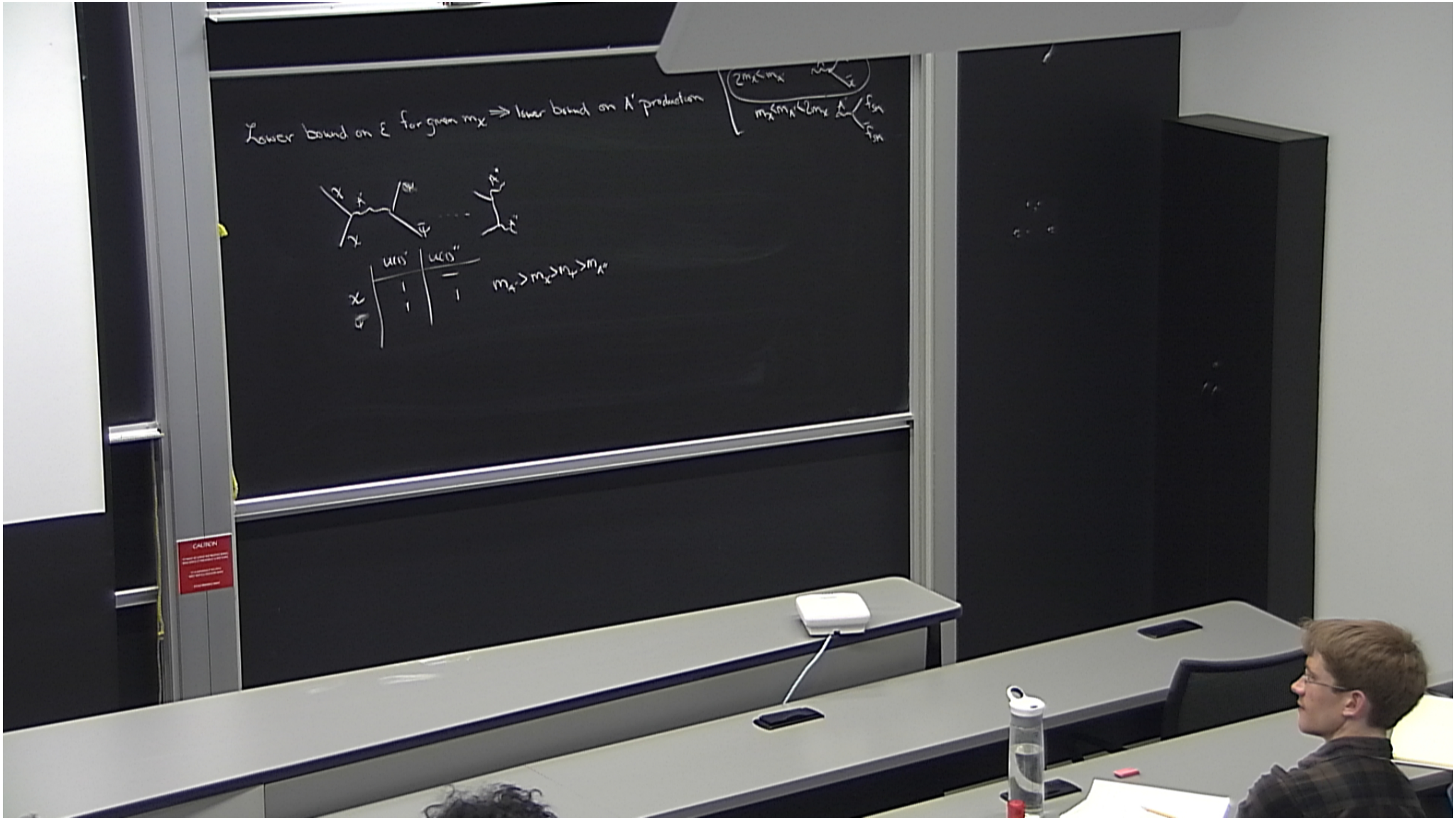

Indirect
Power
$n_{DM}^2 f(m_\chi) \propto \left(\frac{\rho_{DM}}{m_\chi}\right)^2 \langle\sigma v\rangle \propto 1/m_\chi$
annihilation fraction
$\left(4 \frac{n_\chi}{n_{DM}} \frac{n_{\bar\chi}}{n_{DM}}\right) \langle\sigma_{ann} v\rangle_{T\sim eV} < 3\,10^{-26}$ cm$^3$/s
freeze-out. $T/m \sim 1/30$
LSS $T/m \sim eV/GeV \sim 10^{-9}$
Caveats
(1) For scalar DM. $\langle\sigma_A v\rangle \propto \langle v^3\rangle \sim T/m$
(2)
$\chi_m = \frac{1}{\sqrt{2}}(\chi - \bar\chi)$
$\chi_2 = \chi + \bar\chi$
A
$n_{\chi_m} n_{\chi_2}|_{T\sim eV} \ll n_{\chi_m} n_{\chi_2}$ @ freeze out
(3) $\chi$ number
$\chi$ has charge 1
$\bar\chi$ " $-1$
more $\chi$ than $\bar\chi$
$\sigma v > 3\,10^{-26}$ cm$^3$/s $\Rightarrow$ annihilates away $\chi$

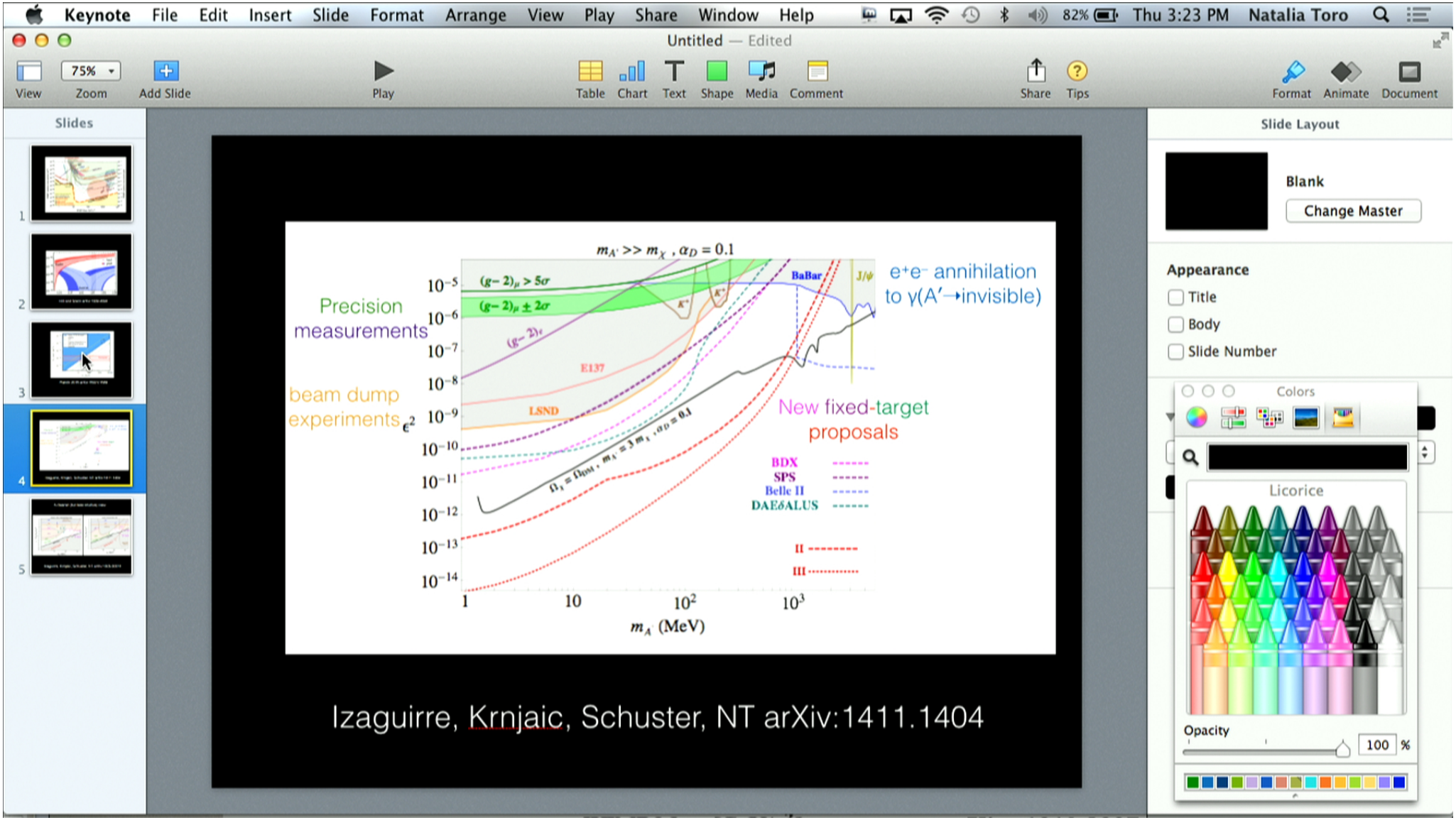

Lower bound on ε for given $m_{\chi}$ ⇒ lower bound on $\Lambda'$ production
$2m_{\chi} < m_{\chi'}$
$m_{\chi} < m_{\chi'} < 2m_{\chi}$
$f_{SM}$
$f_{SM}$

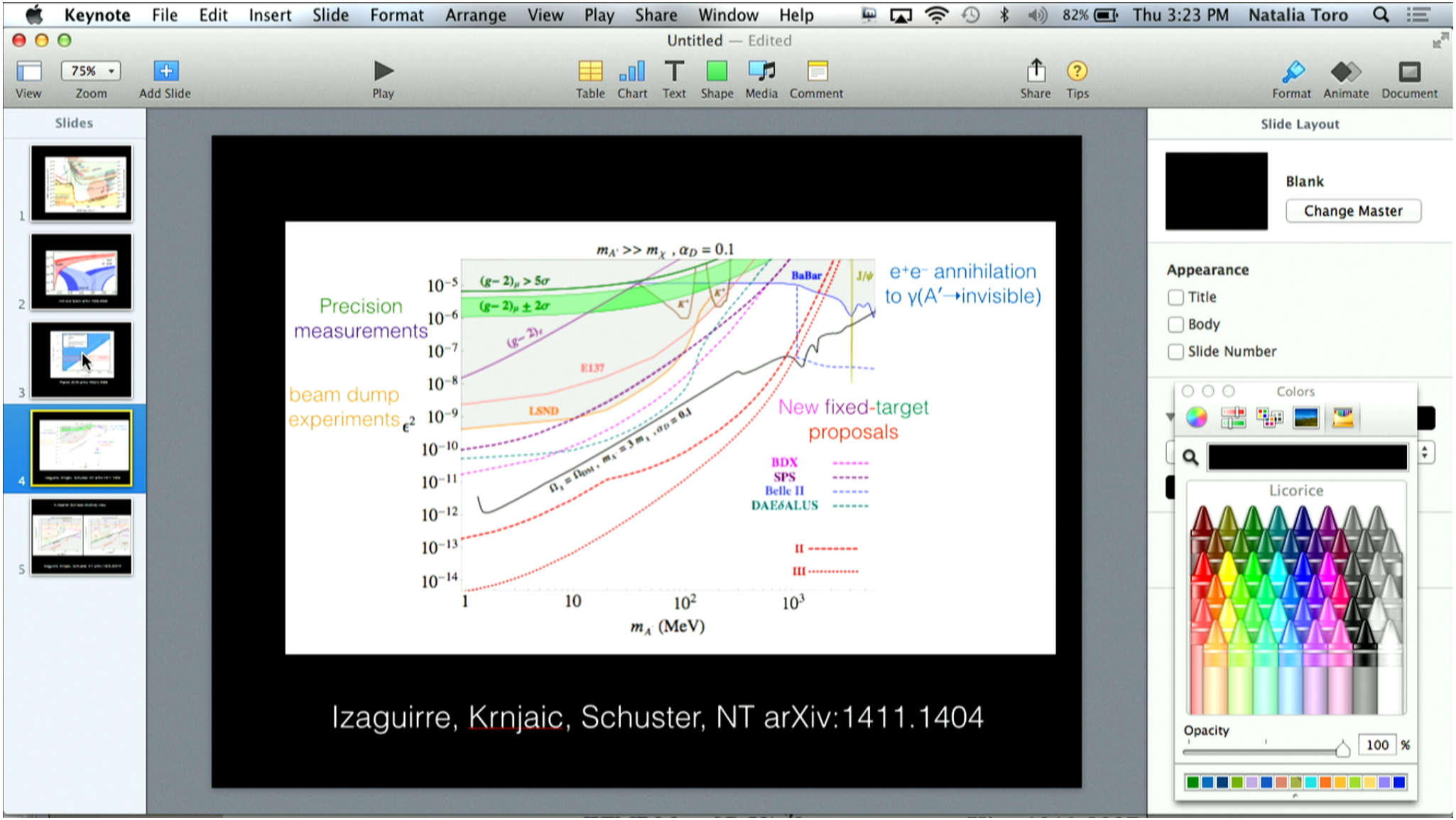

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100 %
$m_{A'} >> m_\chi$ , $\alpha_D = 0.1$
Precision measurements
beam dump experiments
$(g-2)_\mu > 5\sigma$
$(g-2)_\mu \pm 2\sigma$
$(g-2)_e$
E137
LSND
BaBar
J/ψ
e⁺e⁻ annihilation to γ(A′→invisible)
New fixed-target proposals
BDX
SPS
Belle II
DAEδALUS
II
III
$\epsilon^2$
$m_{A'}$ (MeV)
Izaguirre, Krnjaic, Schuster, NT arXiv:1411.1404


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Planck TT,TE,EE+lowP
WMAP9
CVL
Possible interpretations for:
AMS-02/Fermi/Pamela
Fermi GC
Thermal relic
$f_{\rm eff}\,\langle\sigma v\rangle\,[{\rm cm}^3\,{\rm s}^{-1}]$
$m_\chi\,[{\rm GeV}]$
Planck 2015 arXiv:1502.01589


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$m_{A'} >> m_\chi$ , $\alpha_D = 0.1$
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$(g-2)_\mu > 5\sigma$
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$K^+$
$K^+$
e⁺e⁻ annihilation to γ(A′→invisible)
New fixed-target proposals
BDX
SPS
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DAEδALUS
II
III
$\Omega_\chi = \Omega_{DM}$ , $m_\chi = 3\, m_\chi$ , $\alpha_D = 0.1$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
1
10
$10^2$
$10^3$
$m_A$ (MeV)
Izaguirre, Krnjaic, Schuster, NT arXiv:1411.1404


Lower bound on ε for given $m_{\chi}$ ⇒ lower bound on $\Lambda'$ production
$m_{\chi} > m_{\chi'} > m_{\chi''} > m_{\chi'''}$

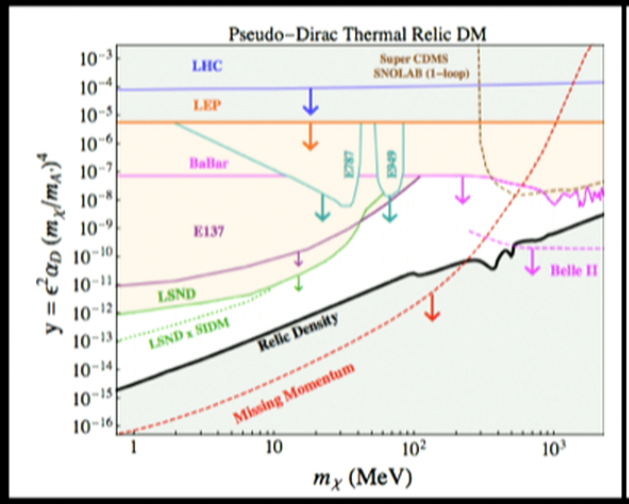

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$m_{A'}$ (MeV)
Izaguirre, Krnjaic, Schuster, NT arXiv:1411.1404

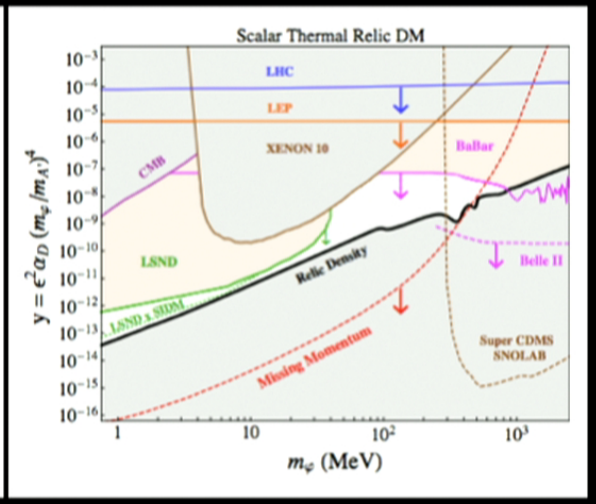

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$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
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1
10
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$m_A$ (MeV)
e⁺e⁻ annihilation to γ(A′→invisible)
New fixed-target proposals
BDX
SPS
Belle II
DAEδALUS
II
III
Izaguirre, Krnjaic, Schuster, NT arXiv:1411.1404

Slides

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# A cleaner (but less intuitive) view…




Izaguirre, Krnjaic, Schuster, NT arXiv:1505.00011

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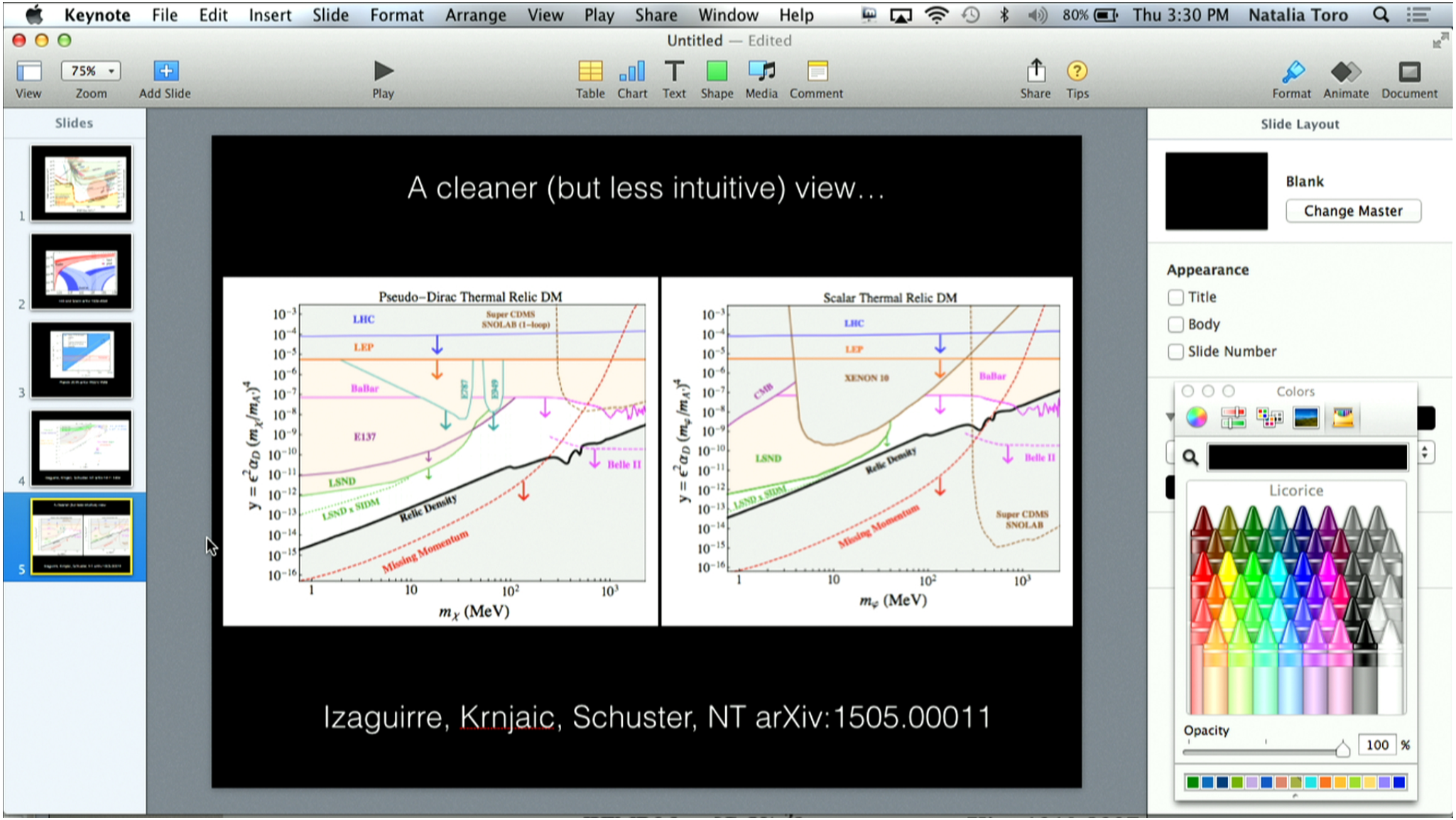
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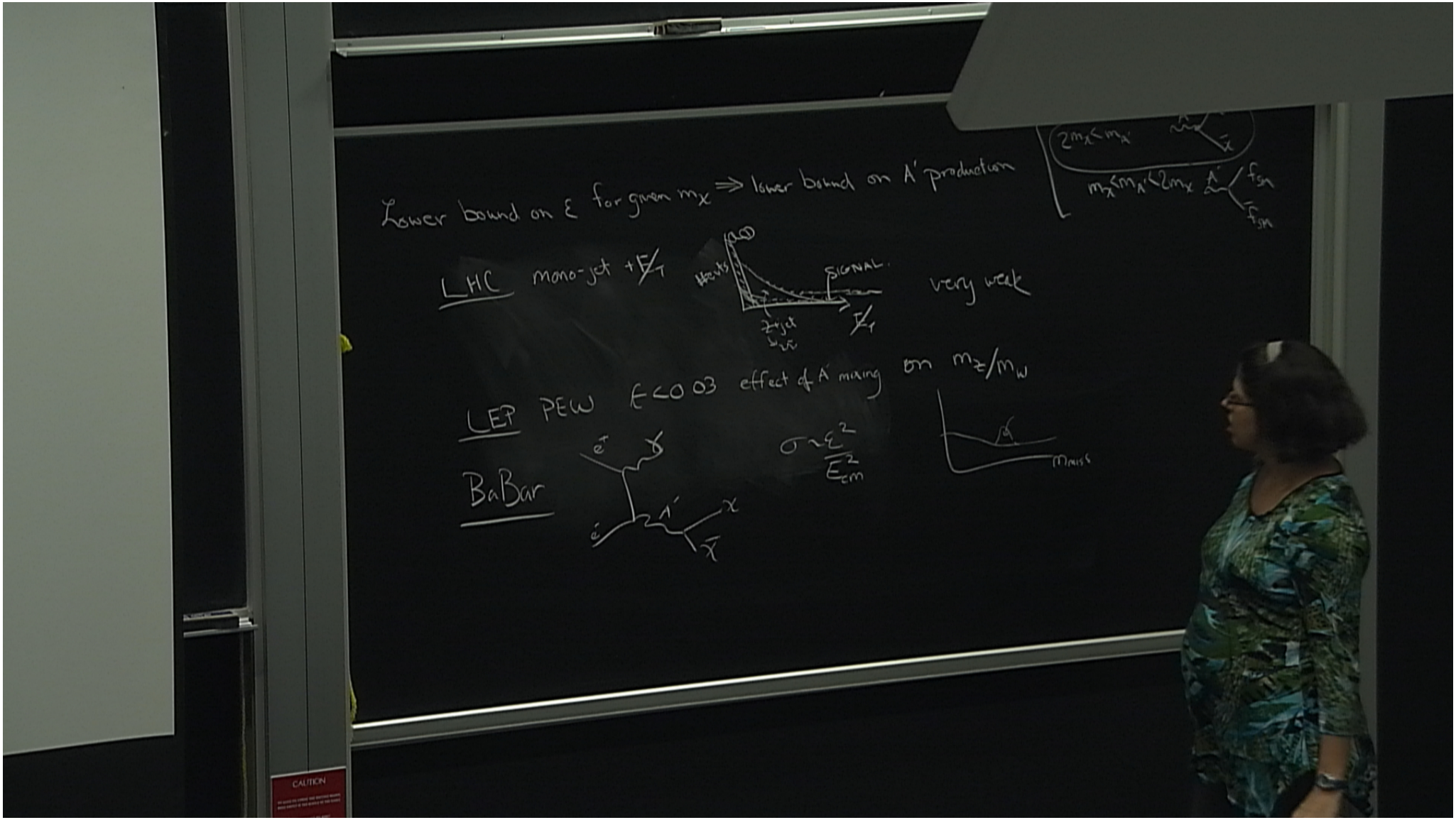
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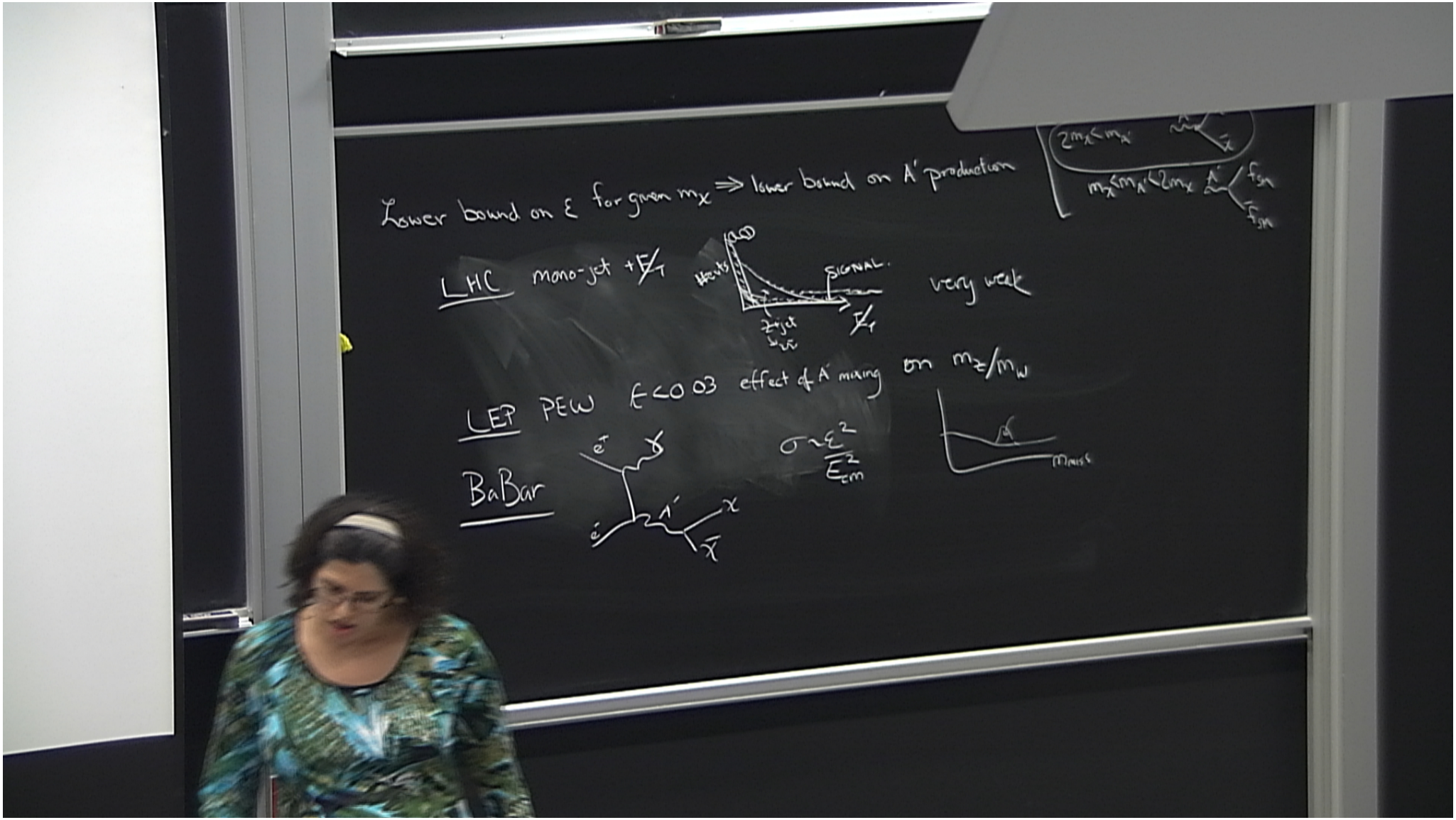
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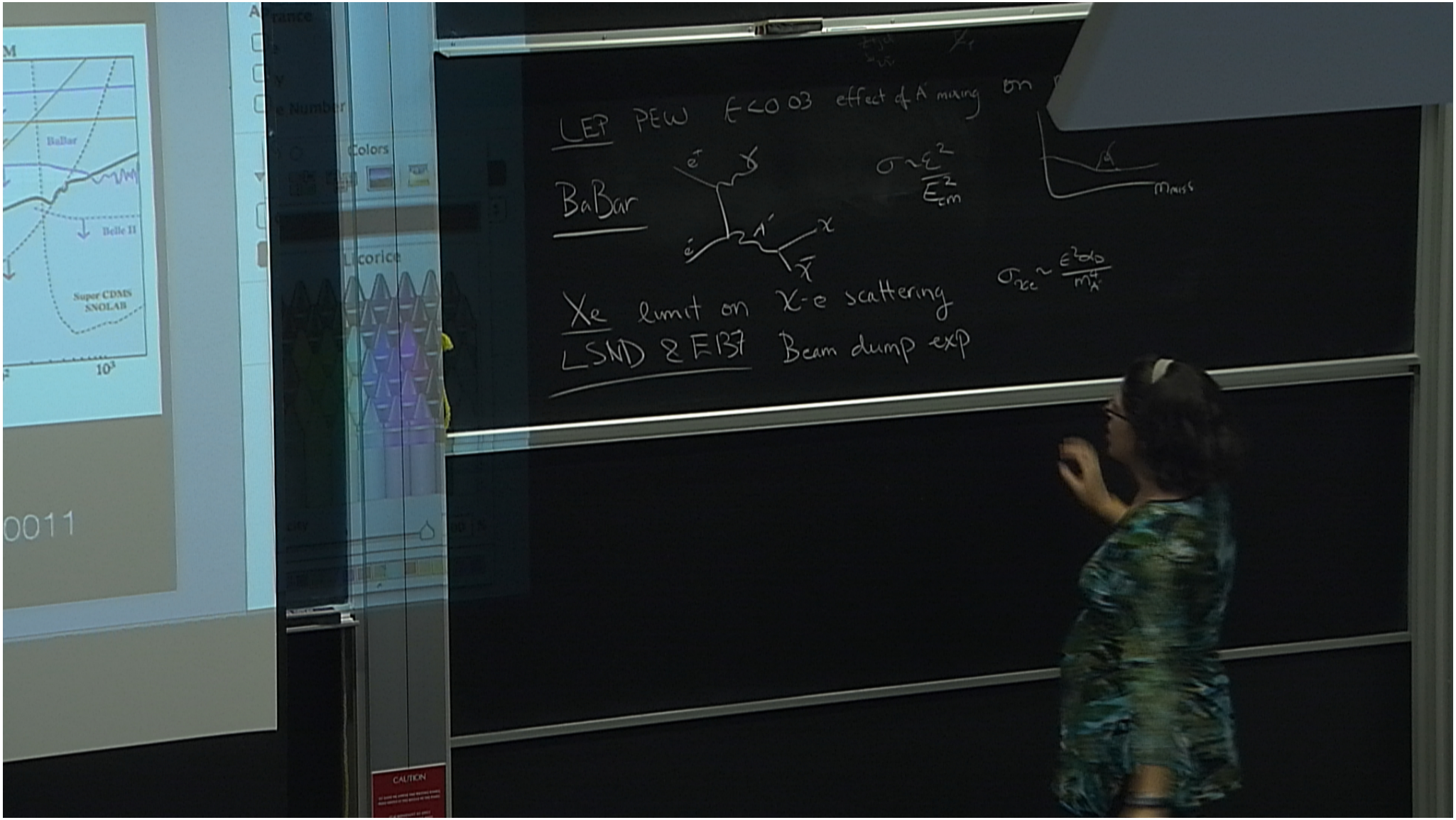
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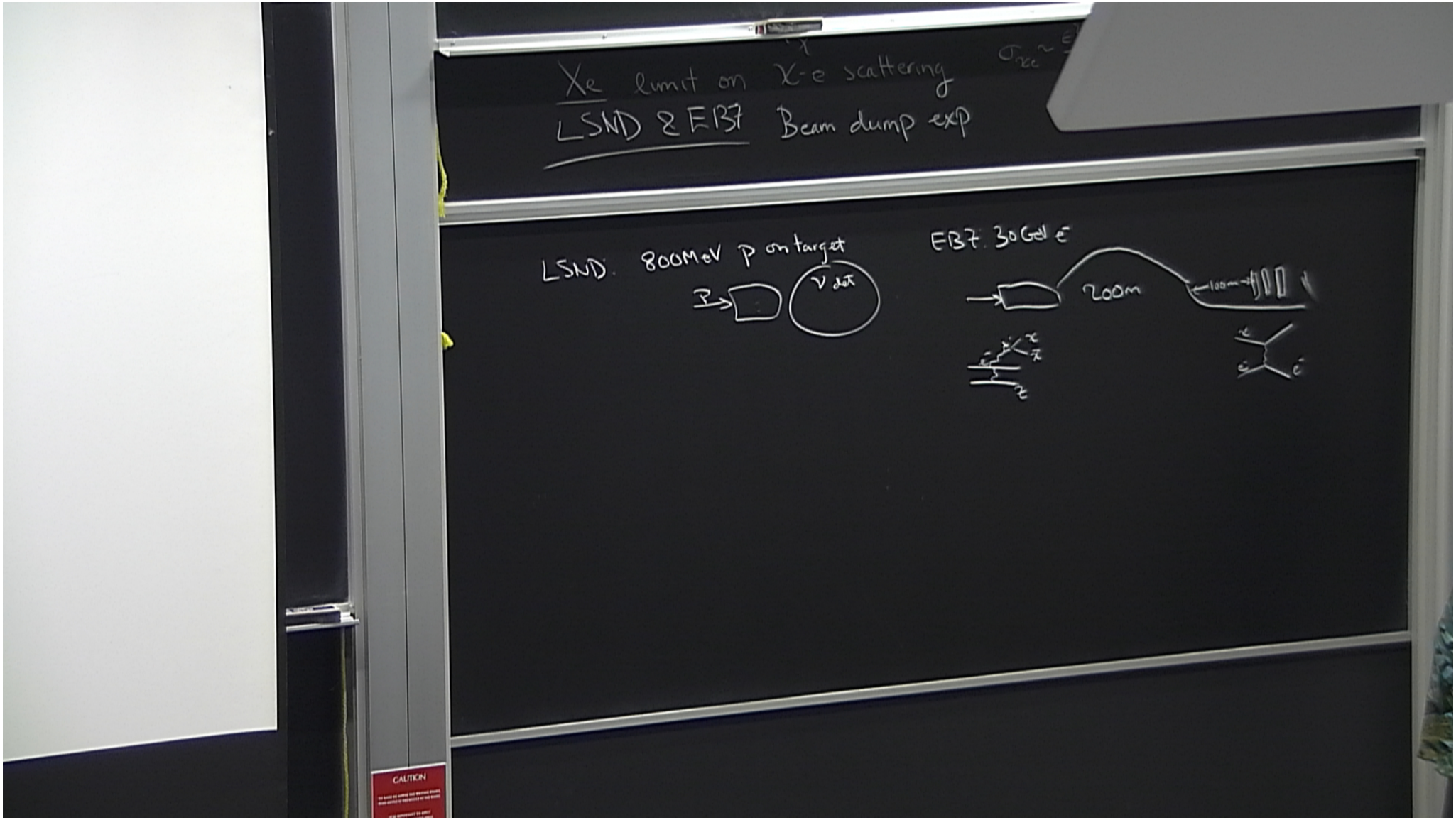
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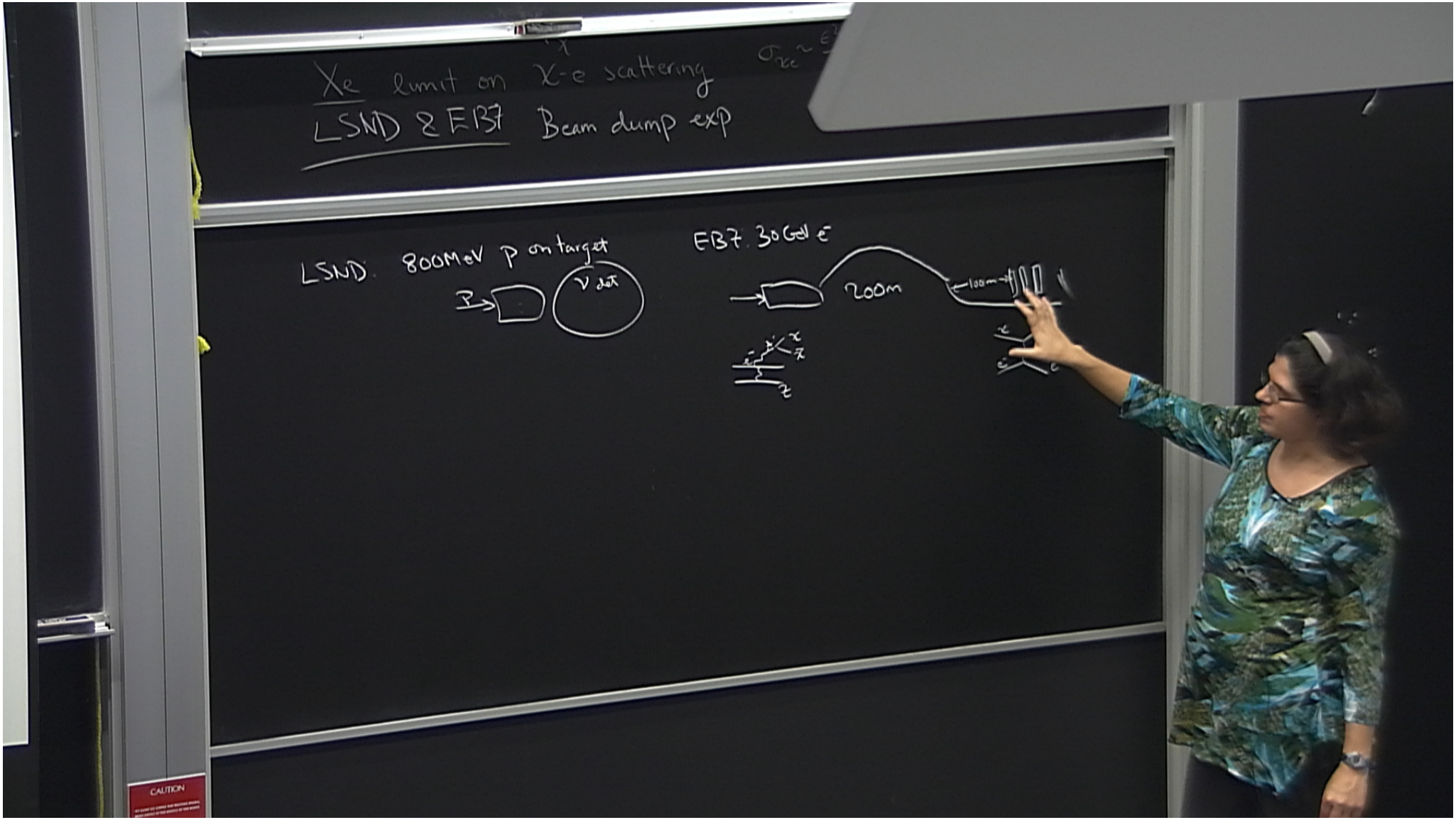

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A cleaner (but less intuitive) view…
Pseudo−Dirac Thermal Relic DM
Scalar Thermal Relic DM
LHC
LEP
BaBar
E137
LSND
LSND x SIDM
Relic Density
Missing Momentum
Belle II
Super CDMS SNOLAB (1−loop)
XENON 10
CMB
$m_\chi$ (MeV)
$m_\varphi$ (MeV)
Izaguirre, Krnjaic, Schuster, NT arXiv:1505.00011
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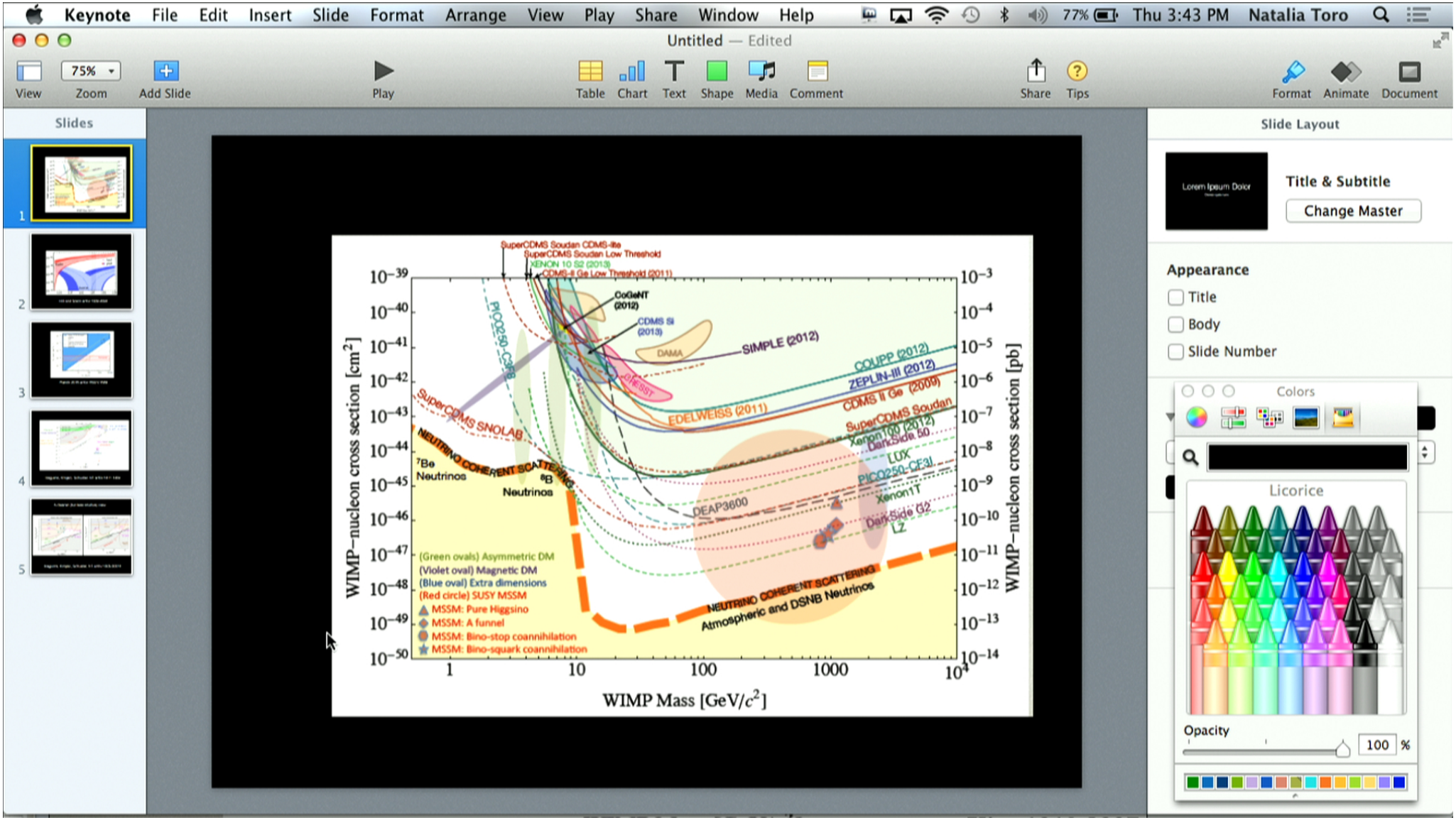

Lower bound on ε for given $m_\chi$ ⇒ lower bound on A′ production
LHC mono-jet $+\not{E}_T$
SIGNAL
very weak
LEP PEW ε<0.03 effect of A′ mixing on $m_Z/m_W$
Mass
BaBar
$\sigma \sim \frac{\varepsilon^2}{E_{cm}^2}$
$2m_\chi < m_{A'}$
$m_\chi < m_{A'} < 2m_\chi$
CAUTION


Lower bound on ε for given $m_\chi$ ⇒ lower bound on A′ production
LHC mono-jet $+\not{E}_T$
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$\sigma \sim \frac{\varepsilon^2}{E_{cm}^2}$
$2m_\chi < m_{A'}$
$m_\chi < m_{A'} < 2m_\chi$


LEP PEW ε<0.03 effect of A' mixing on
BaBar
Xe limit on χ-e scattering
LSND & E137 Beam dump exp
Mass
Belle II
Super CDMS SNOLAB
Colors
Licorice
CAUTION


Xe limit on χ-e scattering
LSND & E137 Beam dump exp
LSND: 800MeV p on target
ν dar
E137: 30GeV e⁻
200m
100m
CAUTION


Xe limit on χ-e scattering
LSND & E137 Beam dump exp
LSND 800MeV p on target
ν det
E137 30GeV e⁻
200m
100m
CAUTION


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SuperCDMS Soudan CDMS-lite
SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
DAMA
CRESST
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
Xenon1T
DarkSide G2
LZ
DEAP3600
PICO250-CF3I
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
NEUTRINO COHERENT SCATTERING
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm²]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c²]