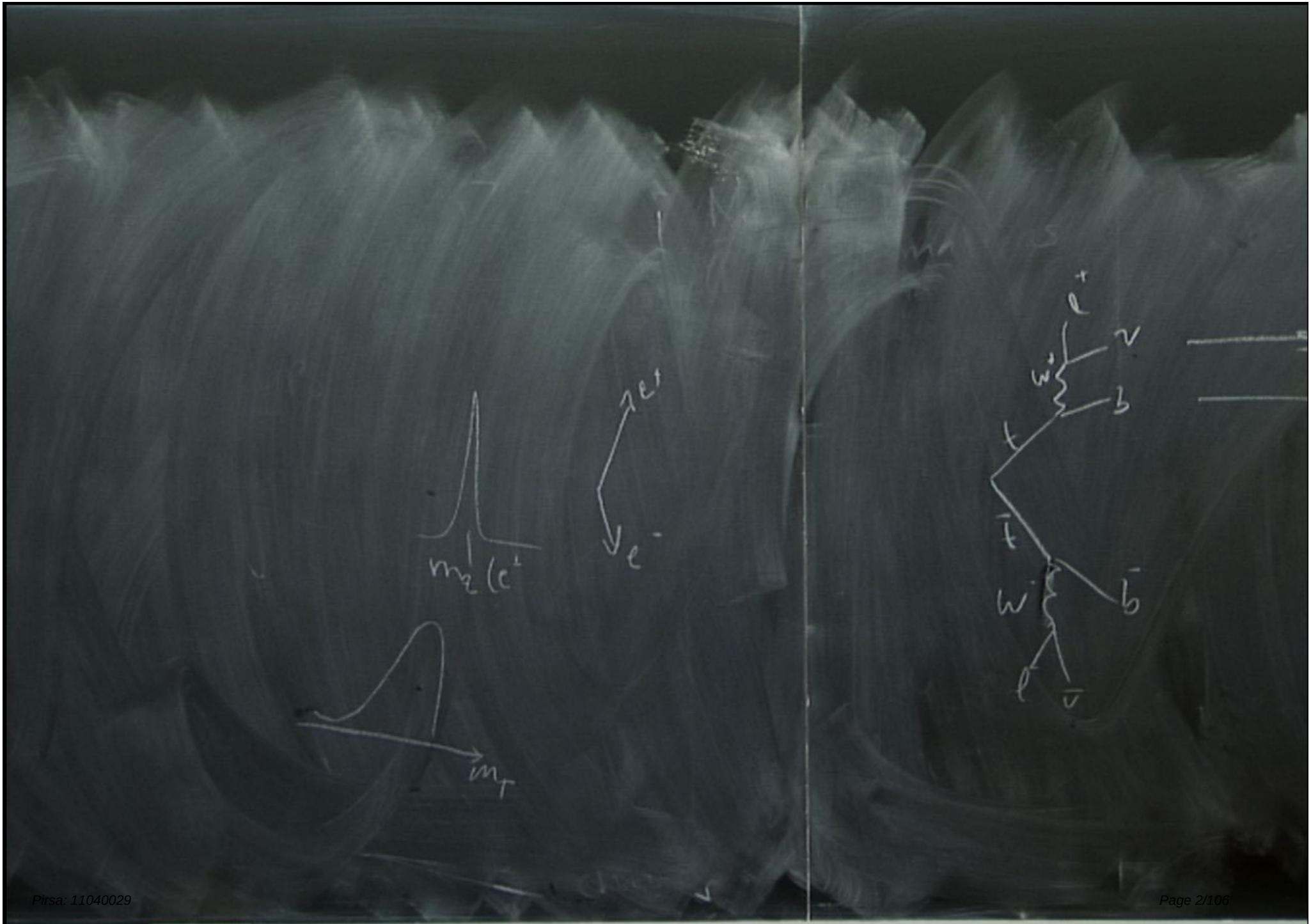
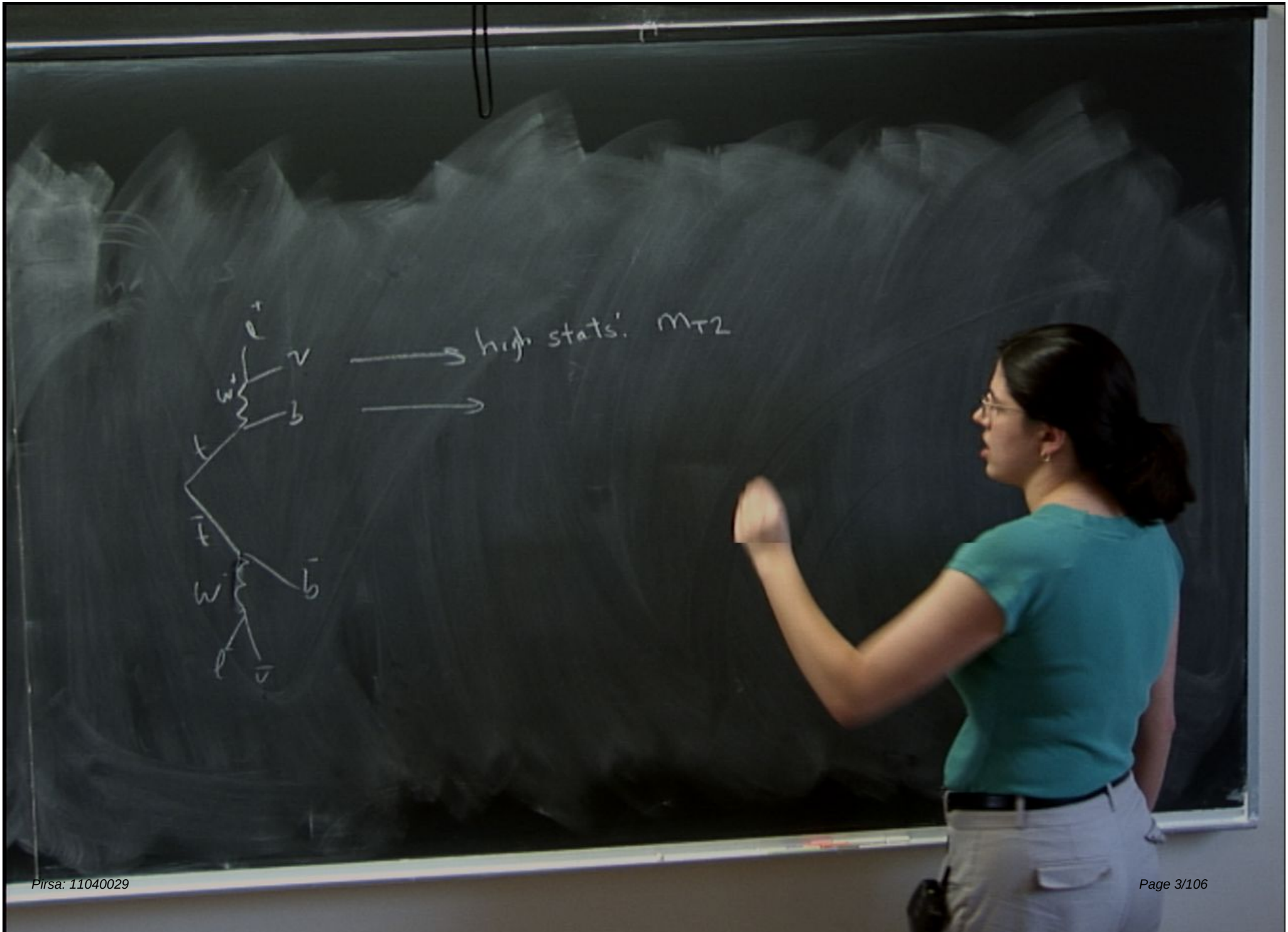
Title: Explorations in Particle Theory - Lecture 7

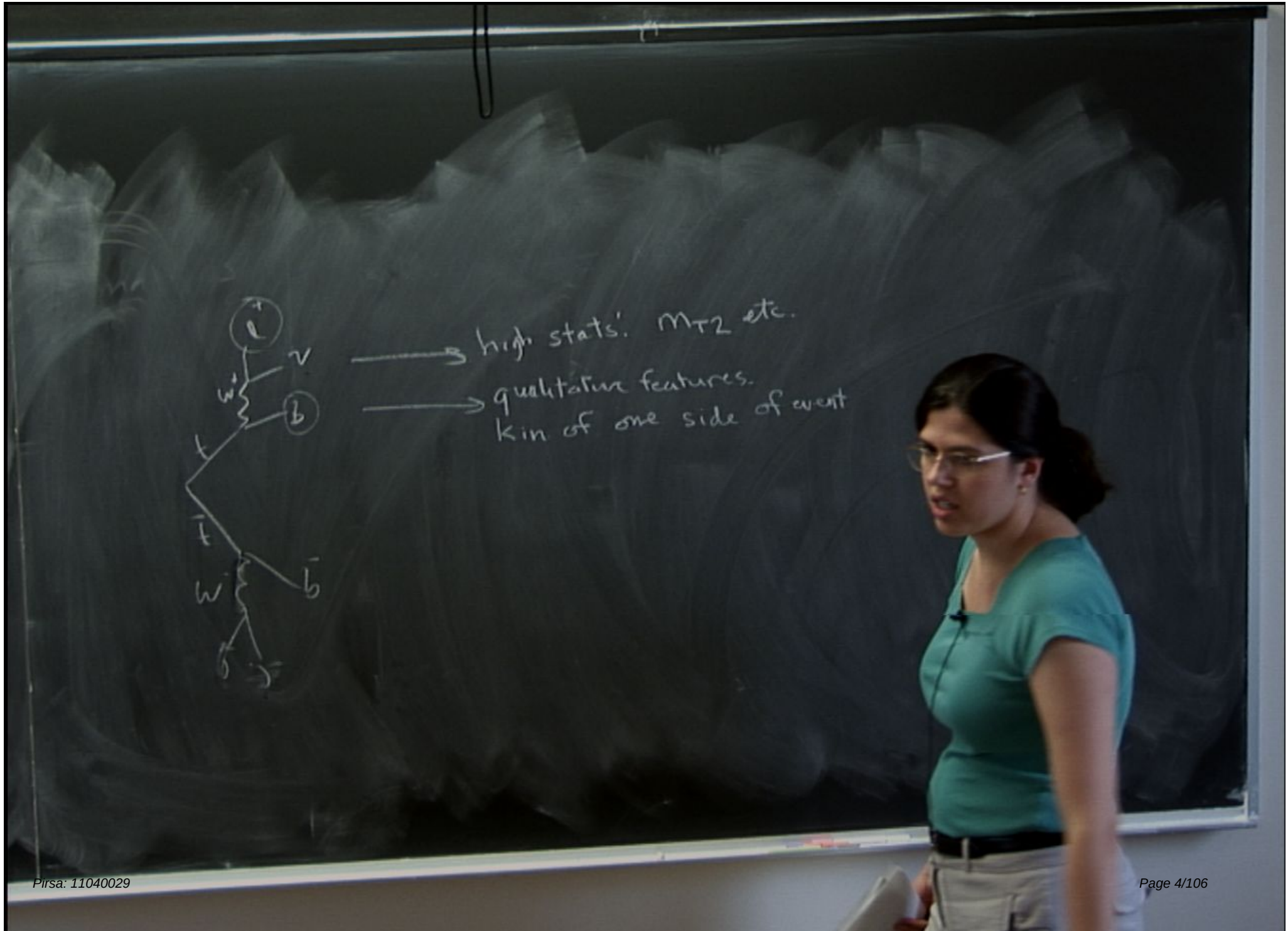
Date: Apr 18, 2011 10:15 AM

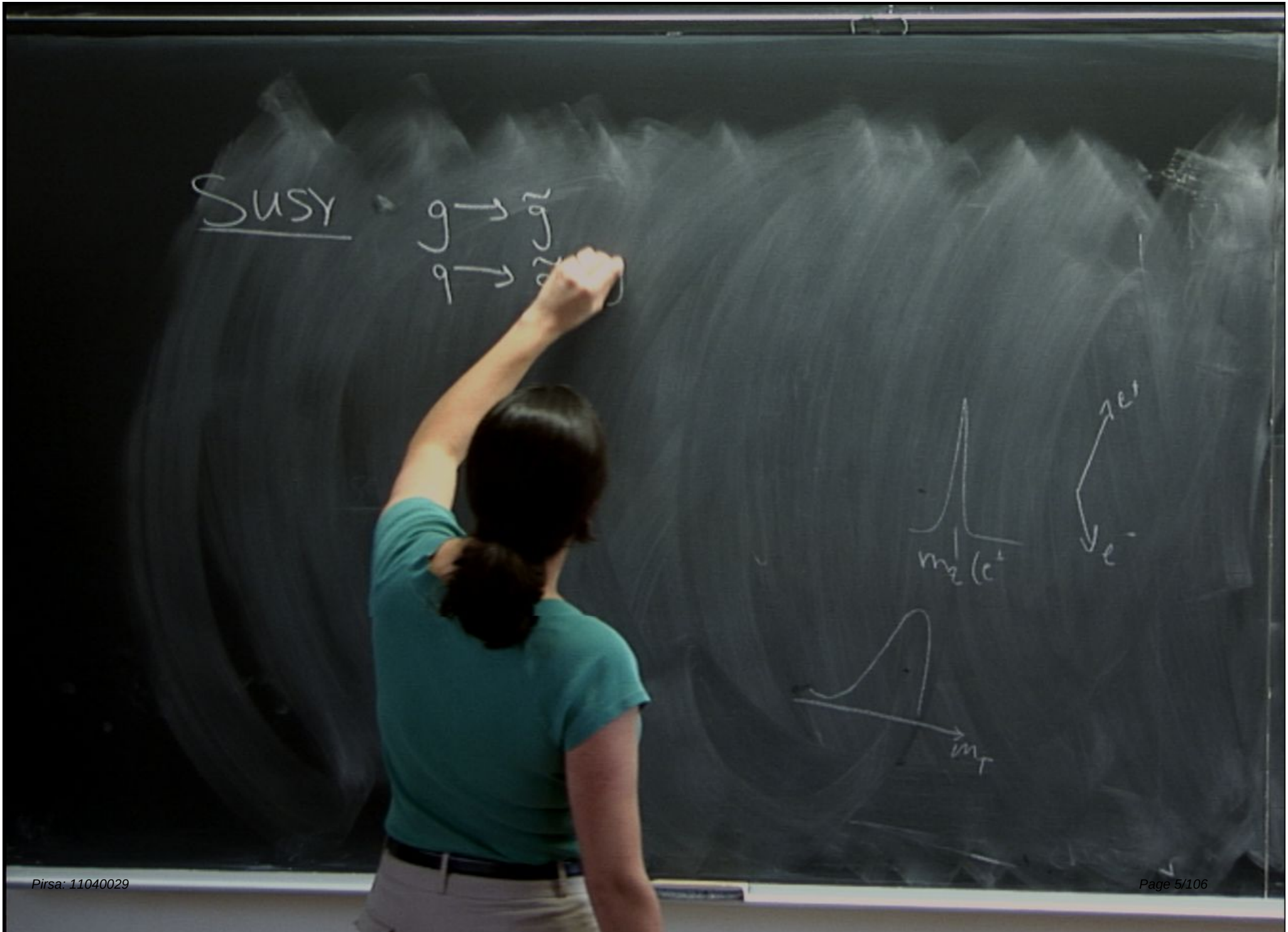
URL: http://pirsa.org/11040029

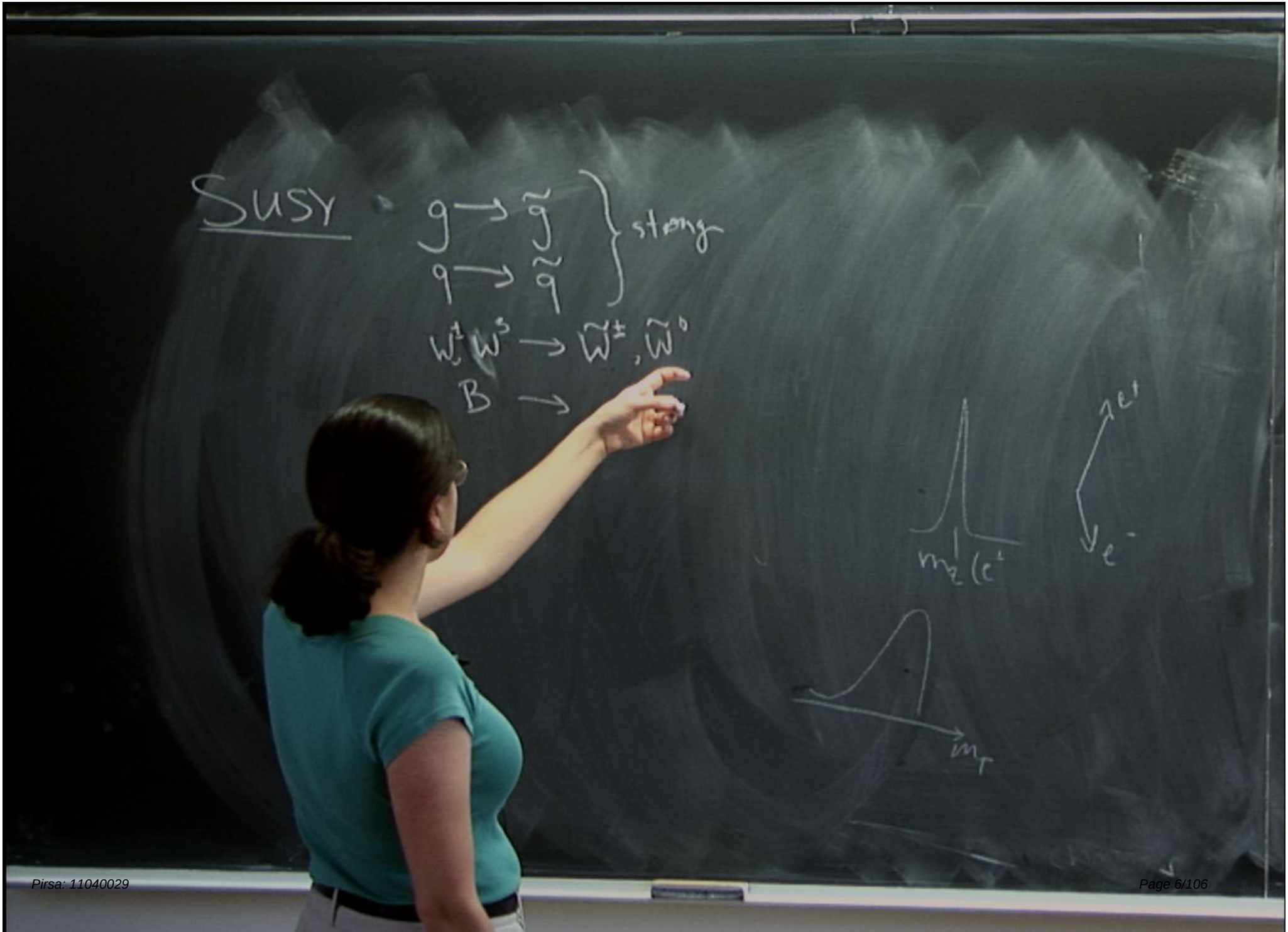
Abstract:

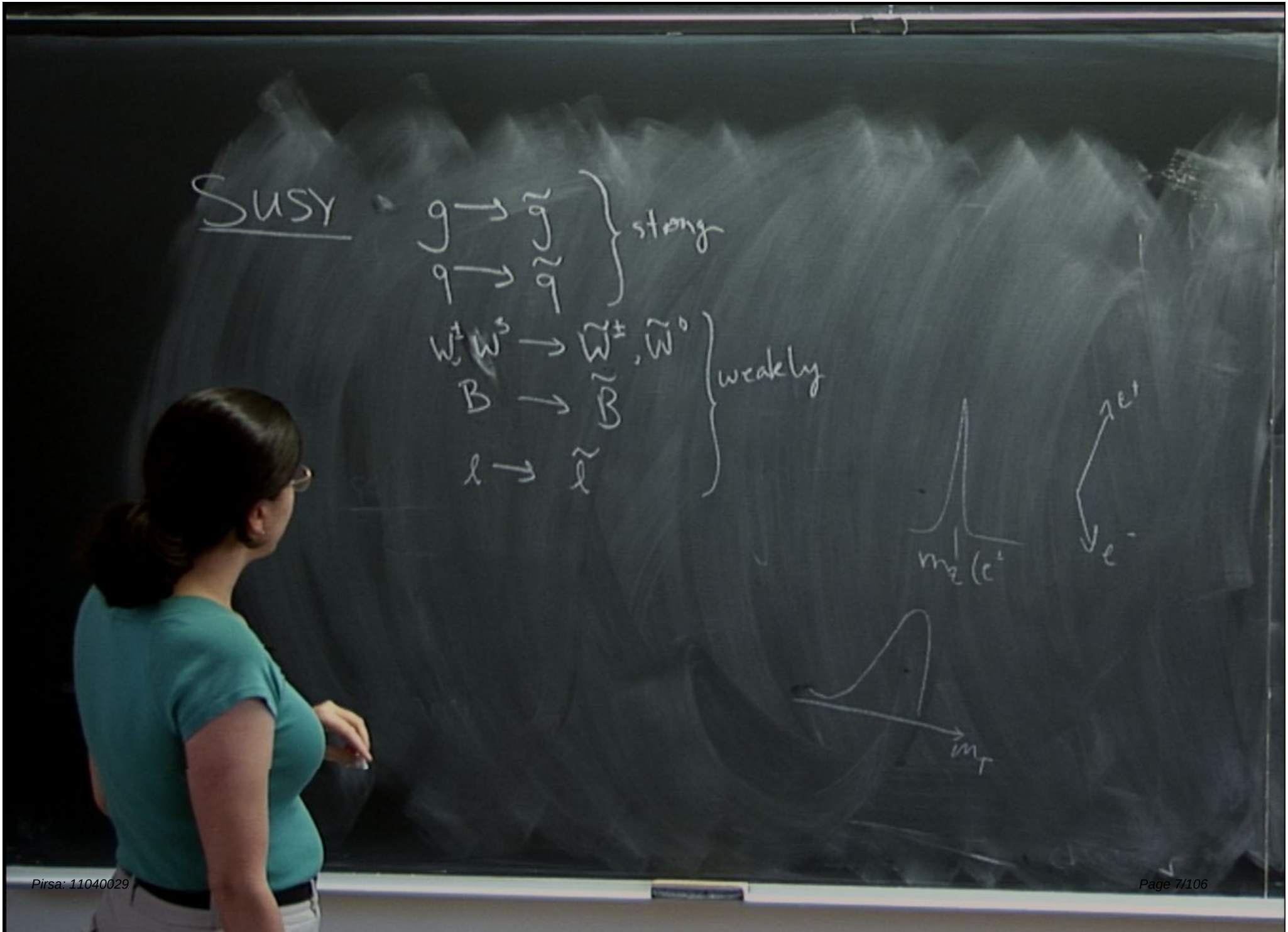

$m_{\ell\ell}(e^+e^-)$
e^+
e^-
m_t
e^+
ν
W^+
b
t
$\bar{t}$
W^-
$\bar{b}$
ℓ^-
$\bar{\nu}$

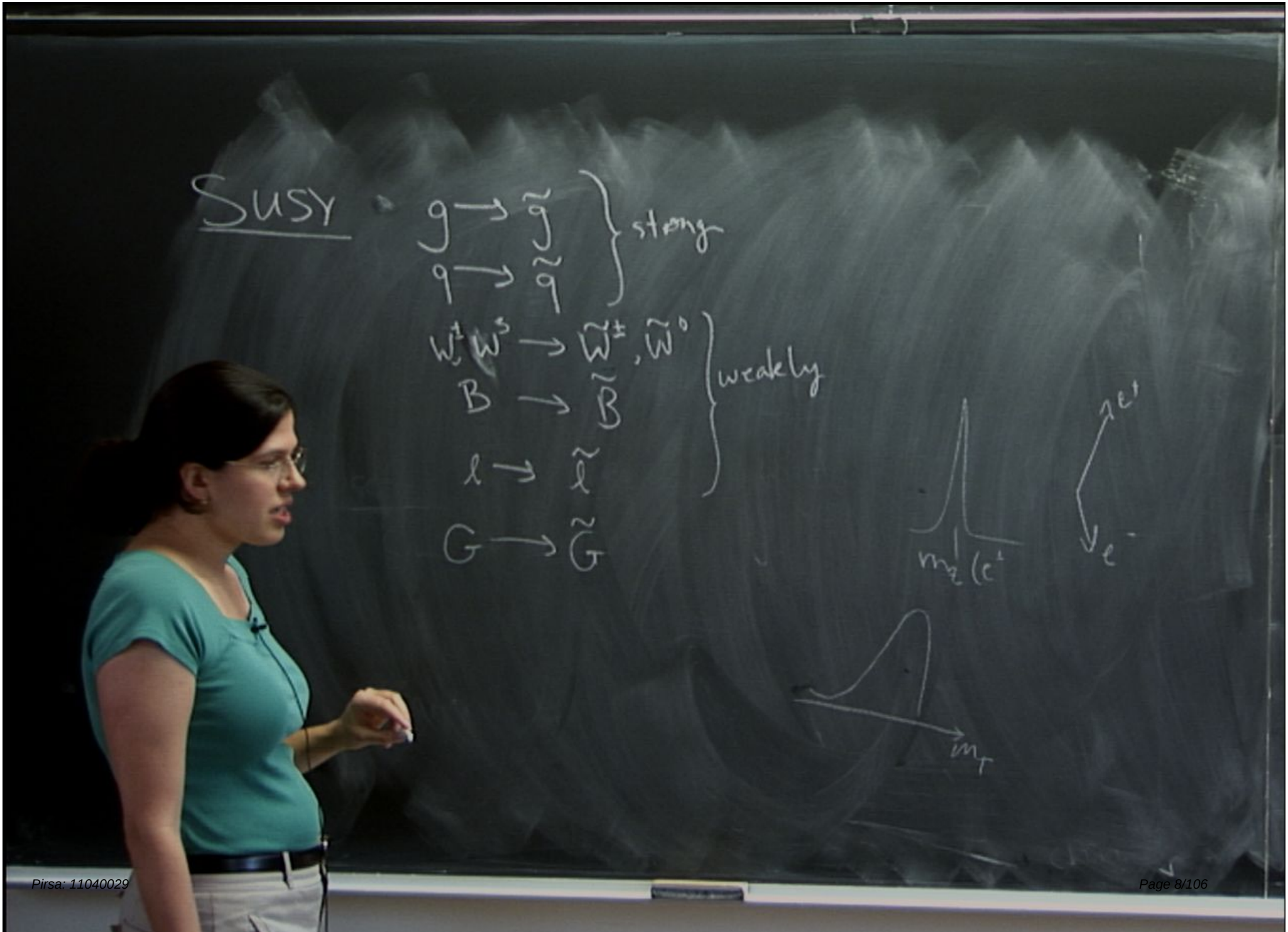

high stats. m_{T2}

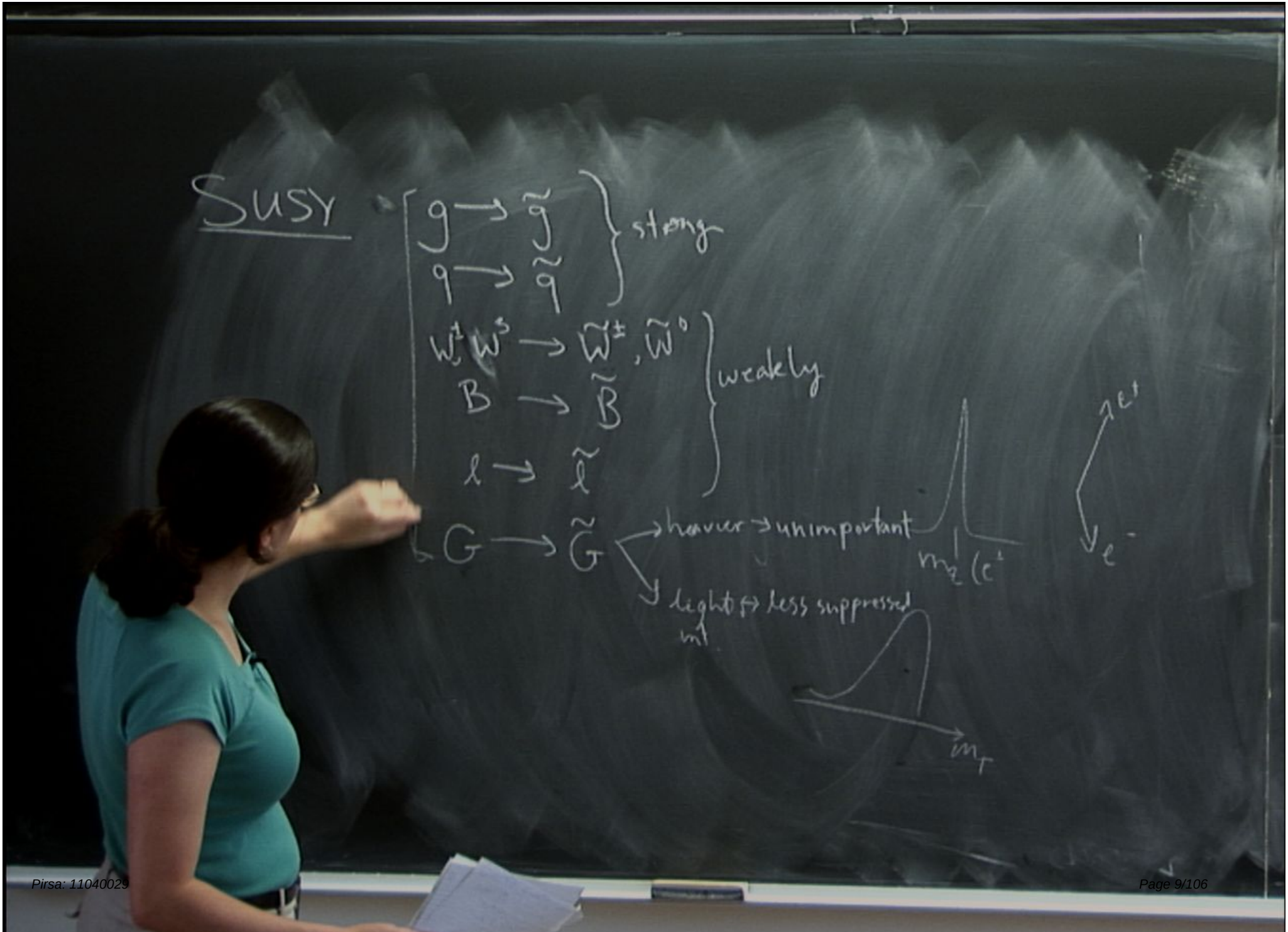

l
ν
W
b
t
t̄
W
b̄
high stats. m_{T2} etc.
qualitative features.
kin of one side of event

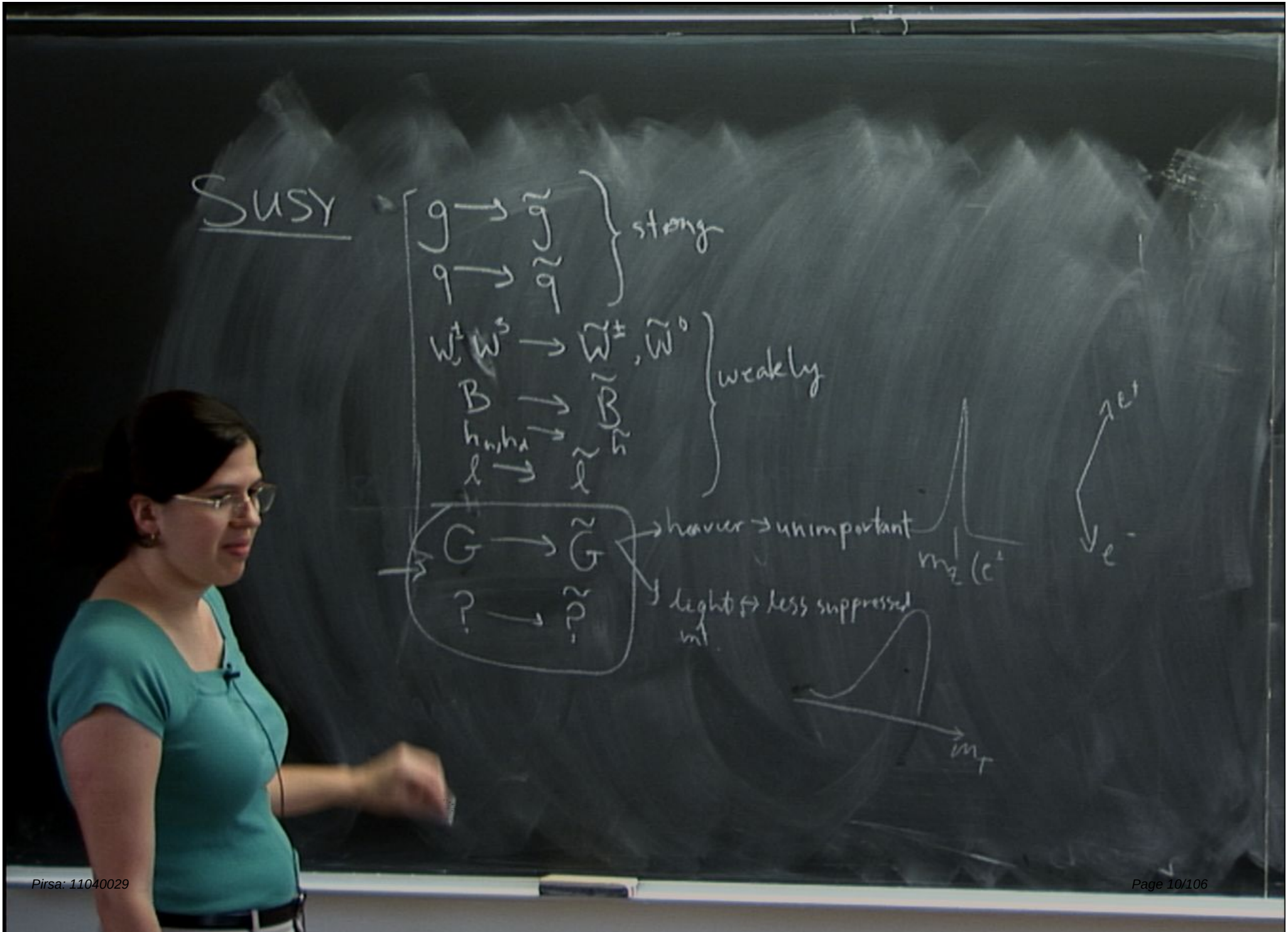

SUSY
g → g̃
q → q̃
m_χ̃ (e⁺
e⁺
e⁻
m_T

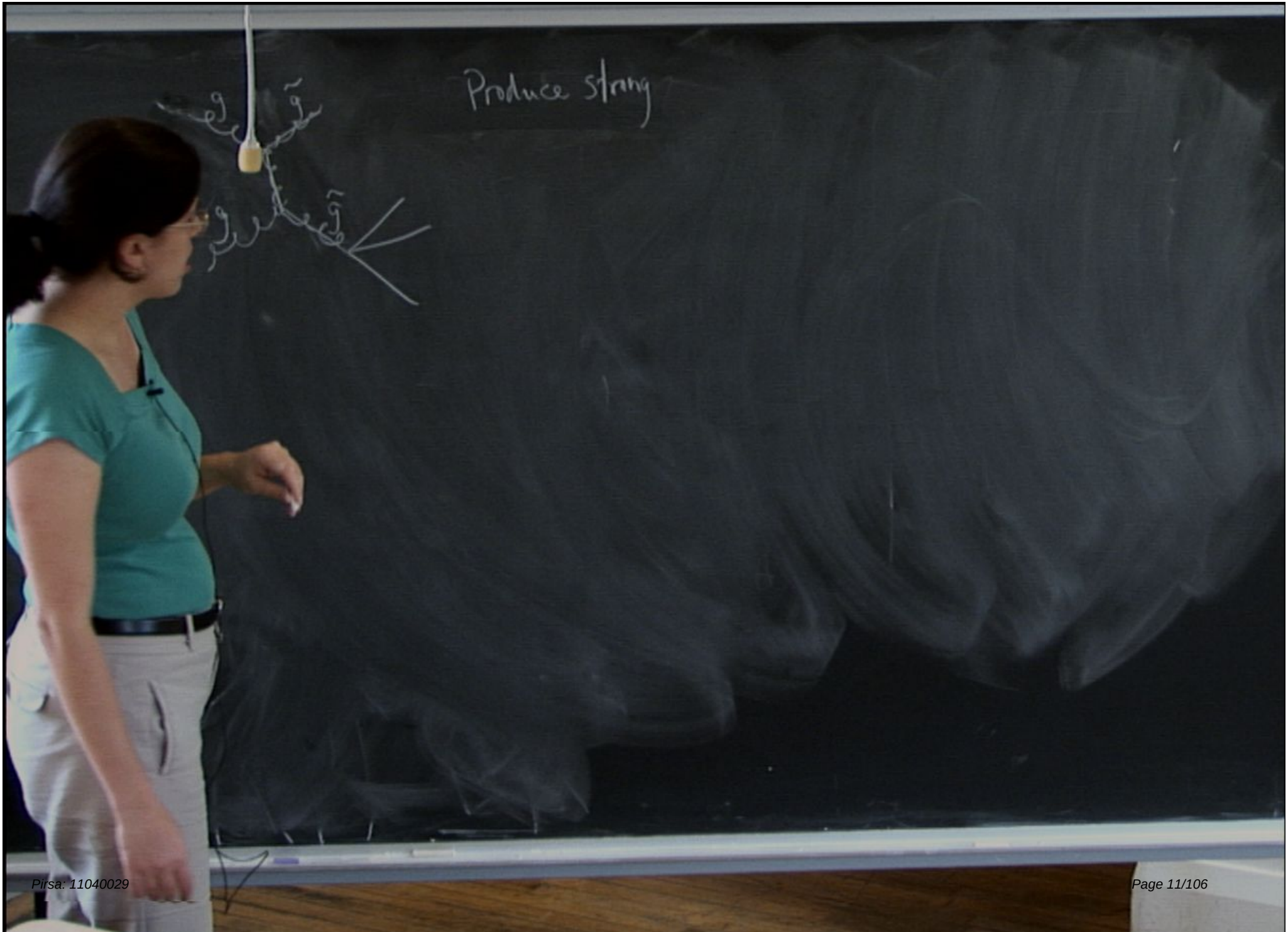

SUSY
g → g̃
q → q̃
strong
W₃ W³ → W̃± , W̃⁰
B →
e⁺
e⁻

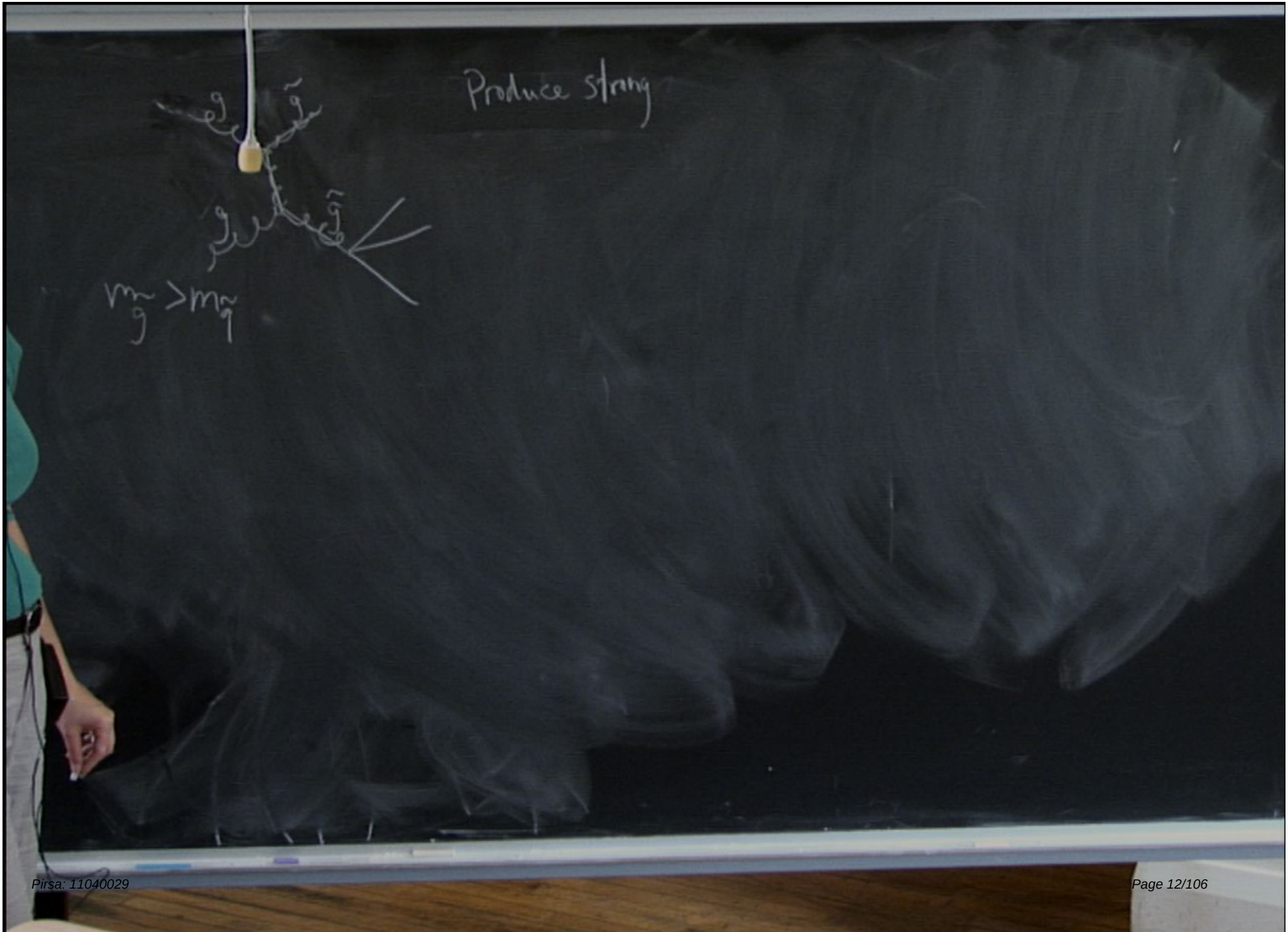

SUSY
g → g̃
q → q̃
q → q̃
strong
W±, W³ → W̃±, W̃⁰
B → B̃
ℓ → ℓ̃
weakly
e⁺
e⁻
m_ℓ⁺ℓ⁻
m_ℓ⁺ℓ⁻

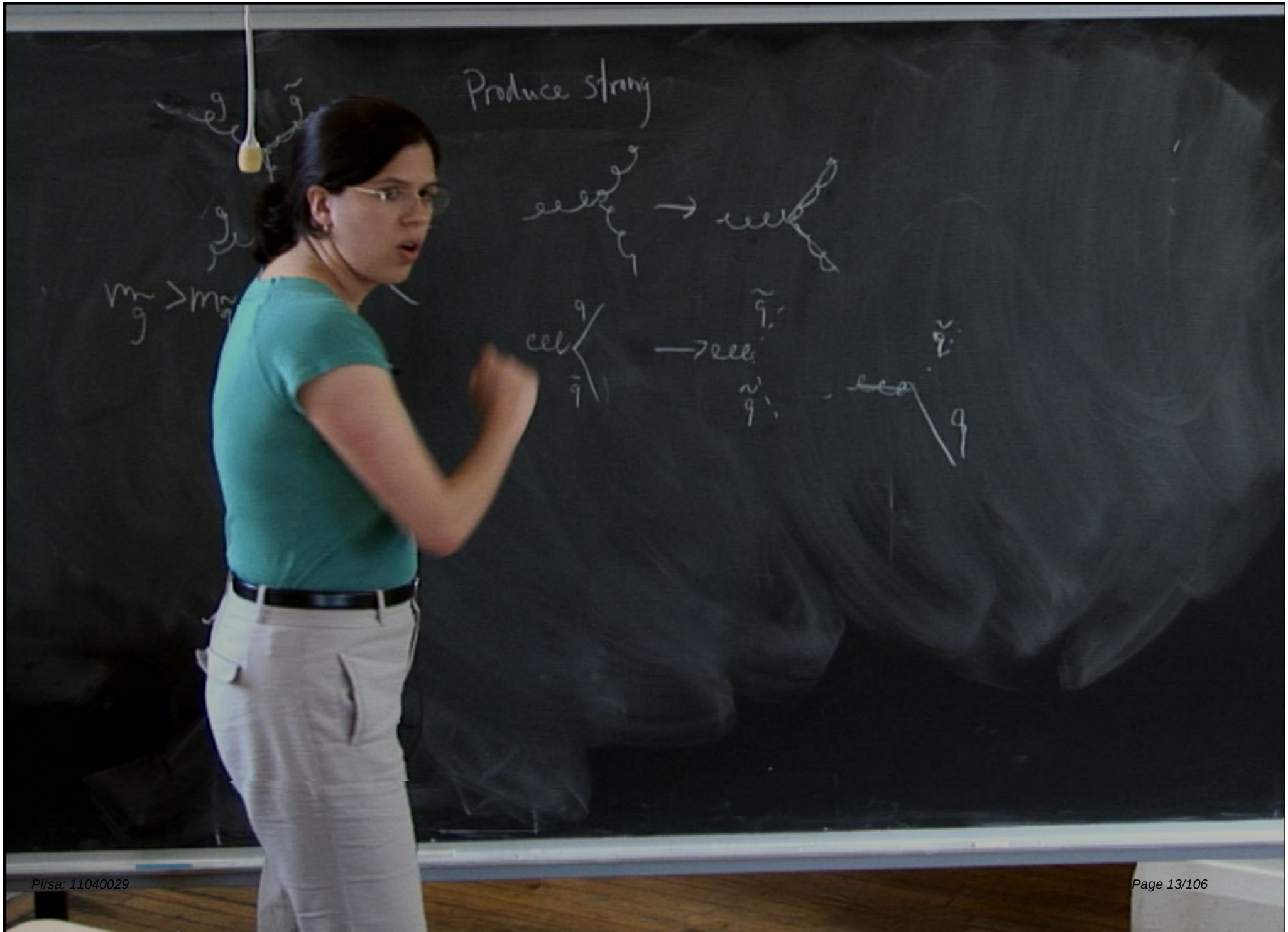

SUSY
g → g̃
q → q̃
strong
W±, W³ → W̃±, W̃⁰
B → B̃
weakly
ℓ → ℓ̃
G → G̃
e⁺
e⁻
m_ℓ(e⁺e⁻)
m_T

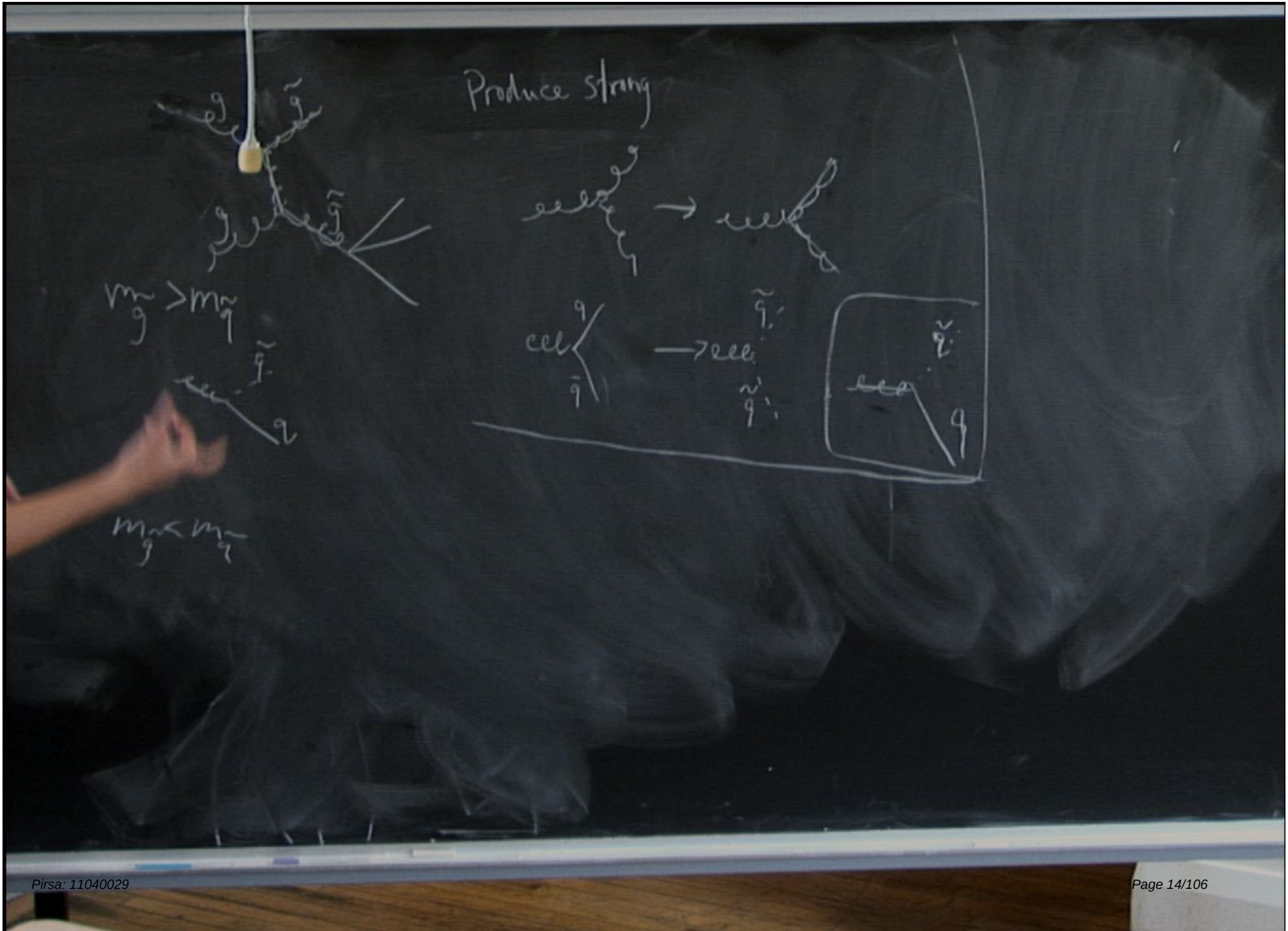

SUSY
g → g̃
g → g̃
strong
W±, W³ → W̃±, W̃⁰
B → B̃
weakly
ℓ → ℓ̃
G → G̃
heavier → unimportant
lighter → less suppressed
e⁺
e⁻

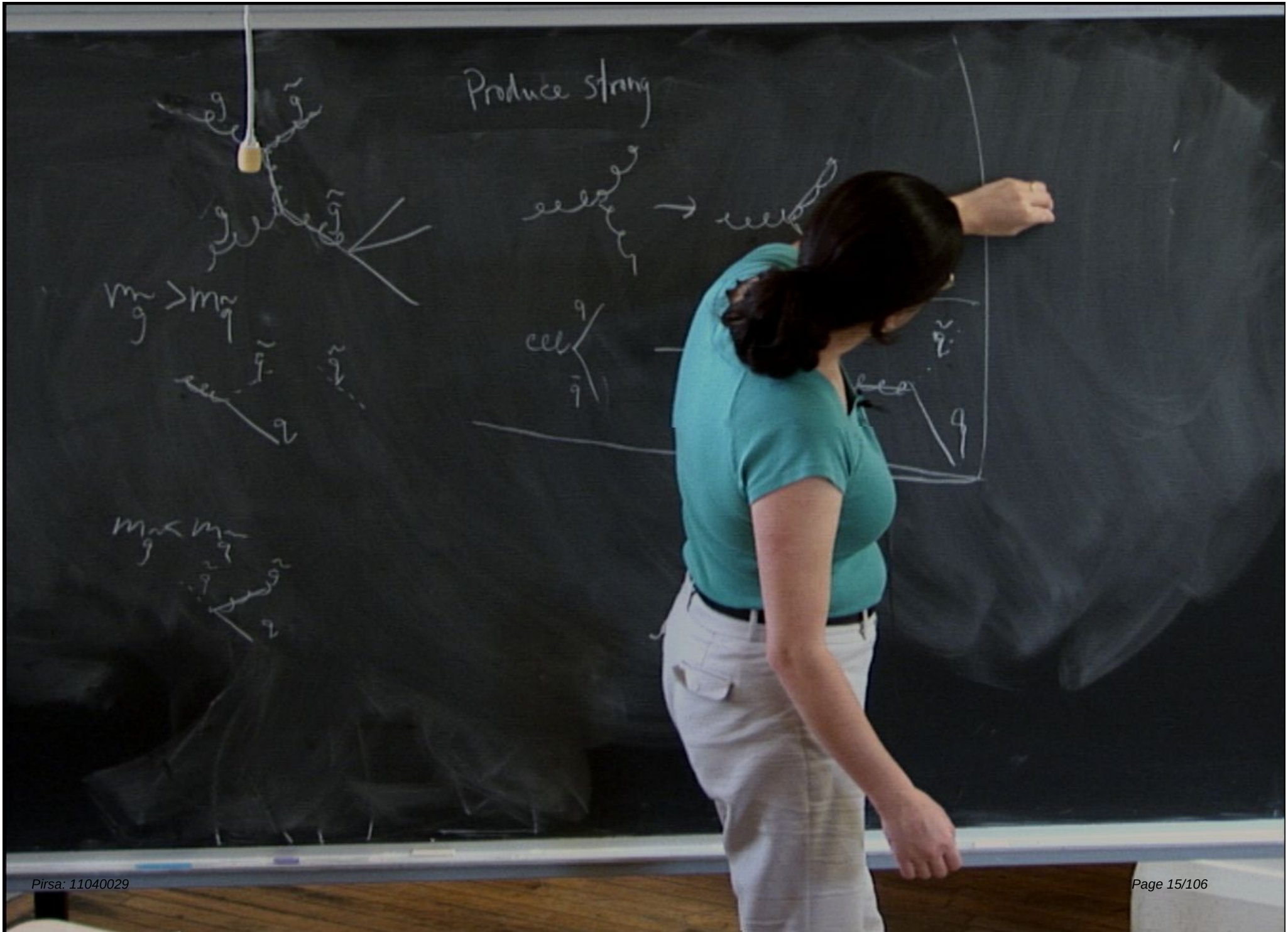

SUSY
strong
weakly
heavier → unimportant
lighter ↔ less suppressed

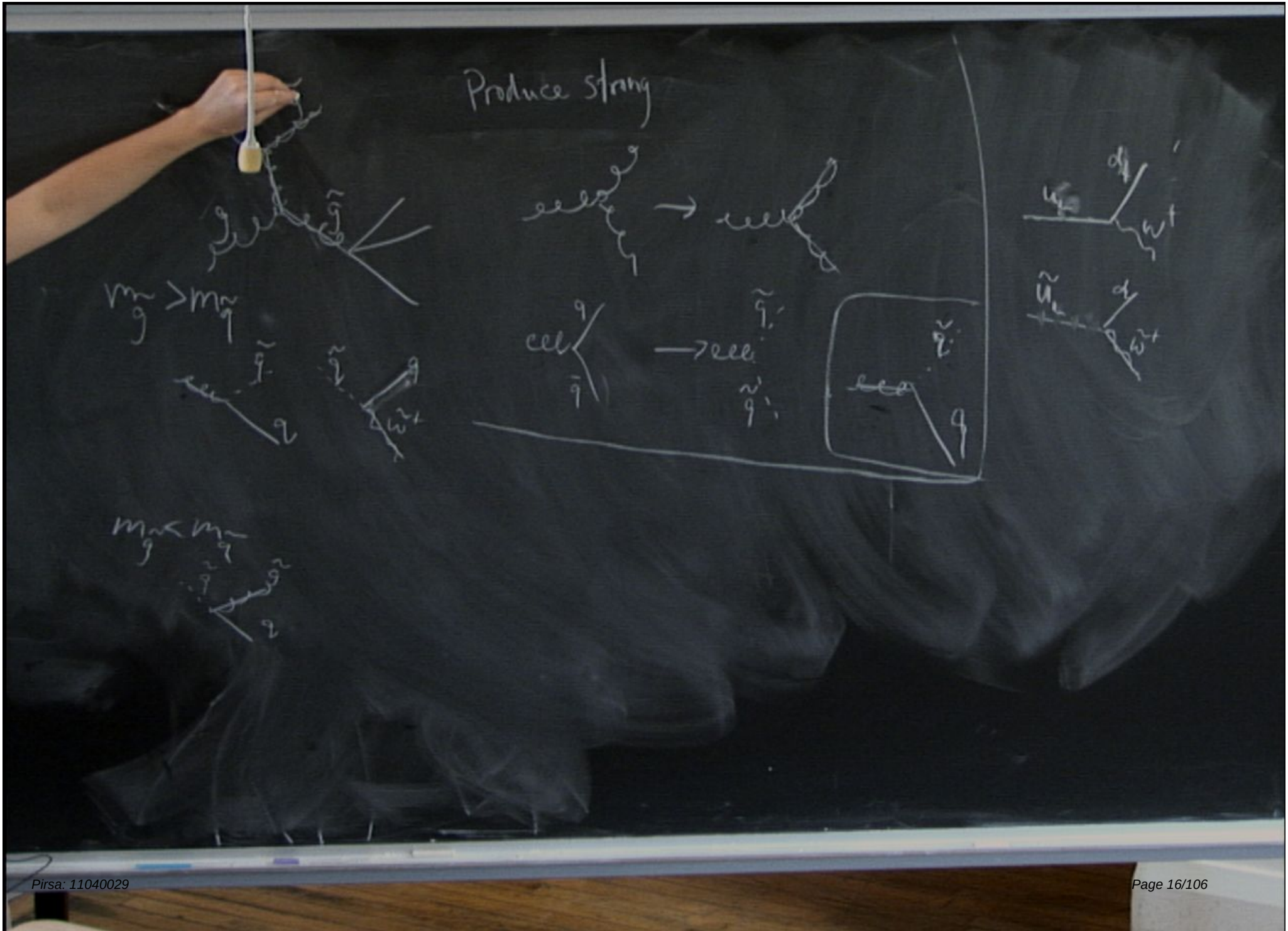

Produce string

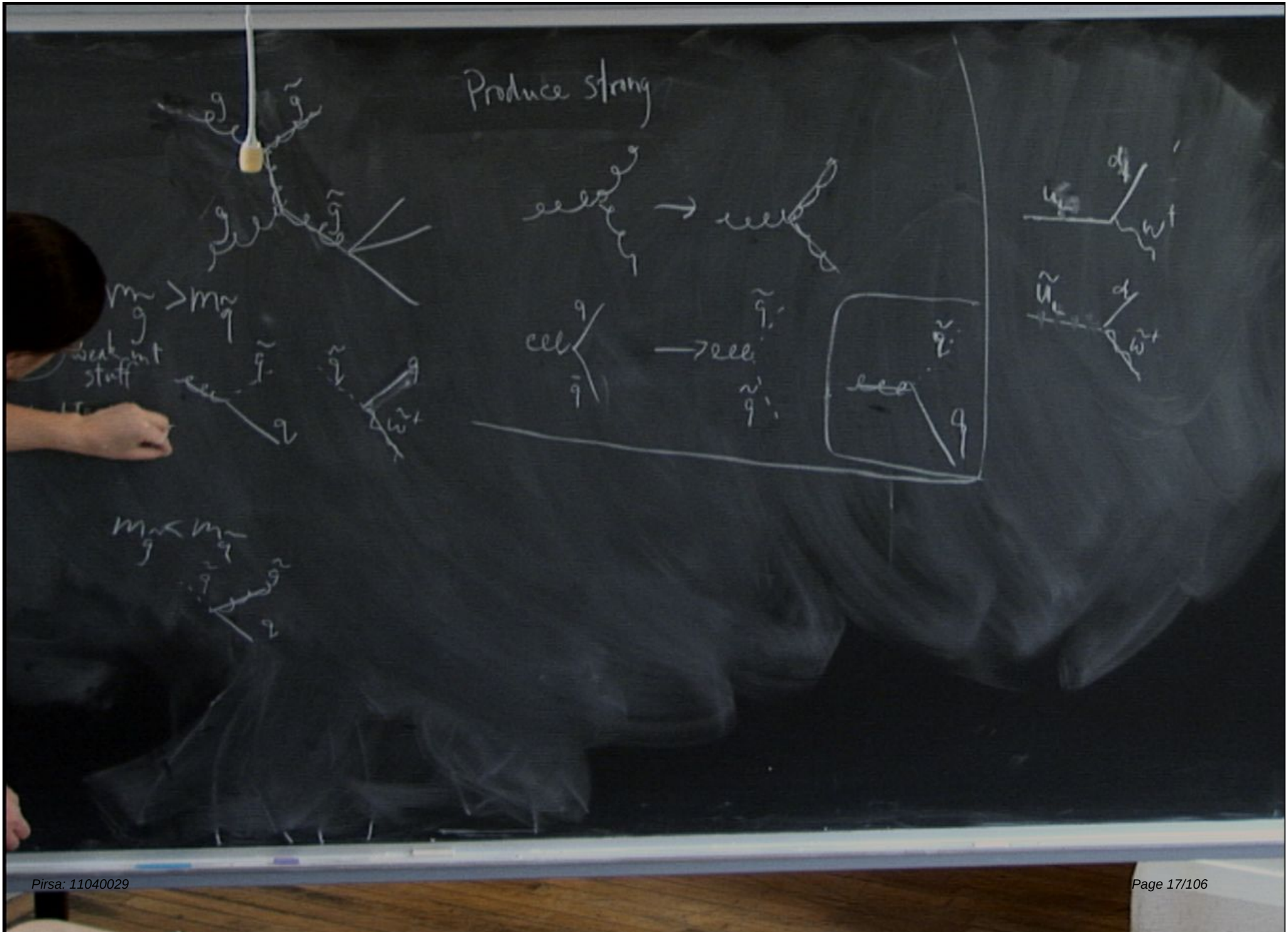

Produce string
$m_{\tilde{g}} > m_{\tilde{q}}$

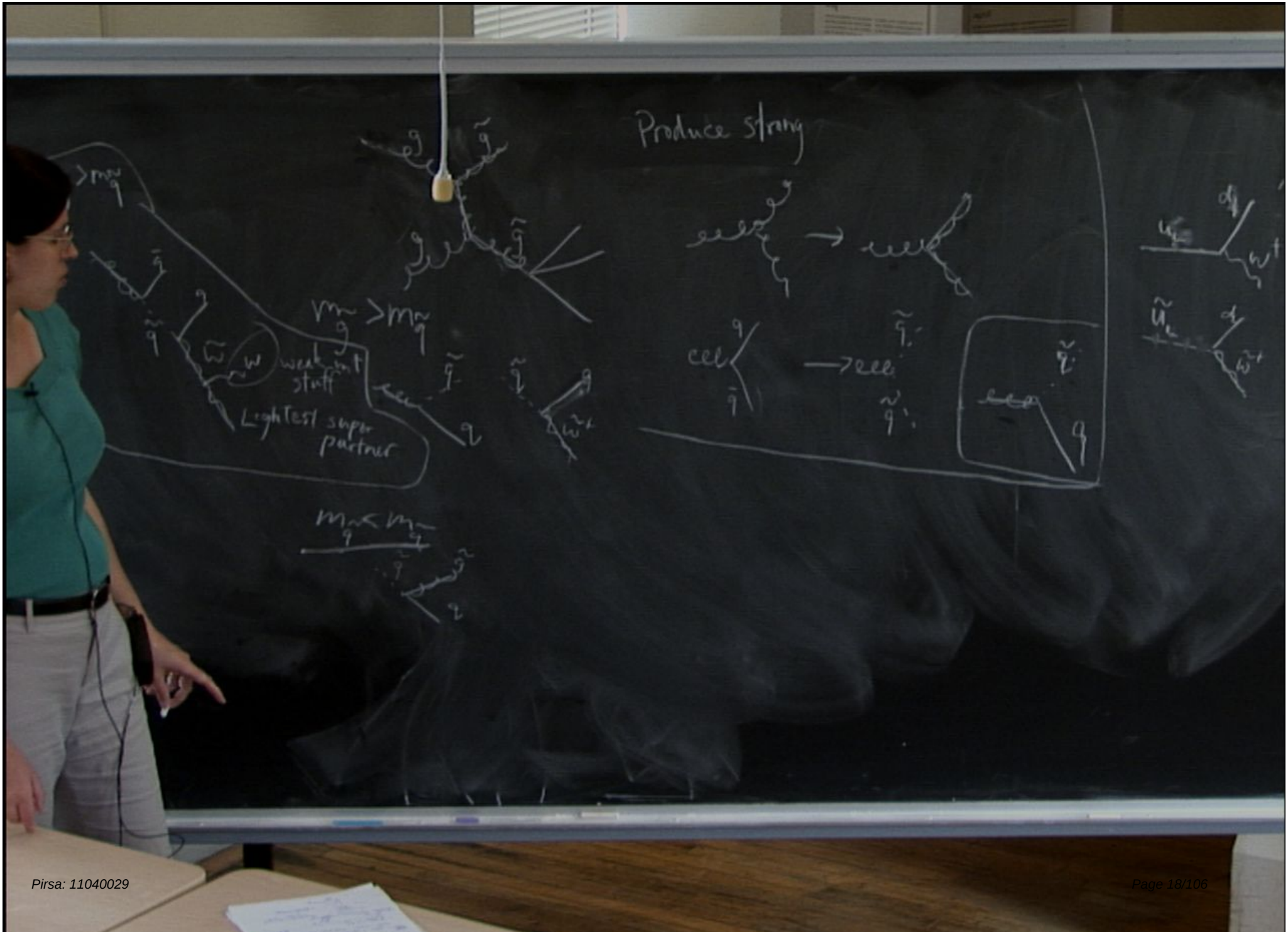

Produce string

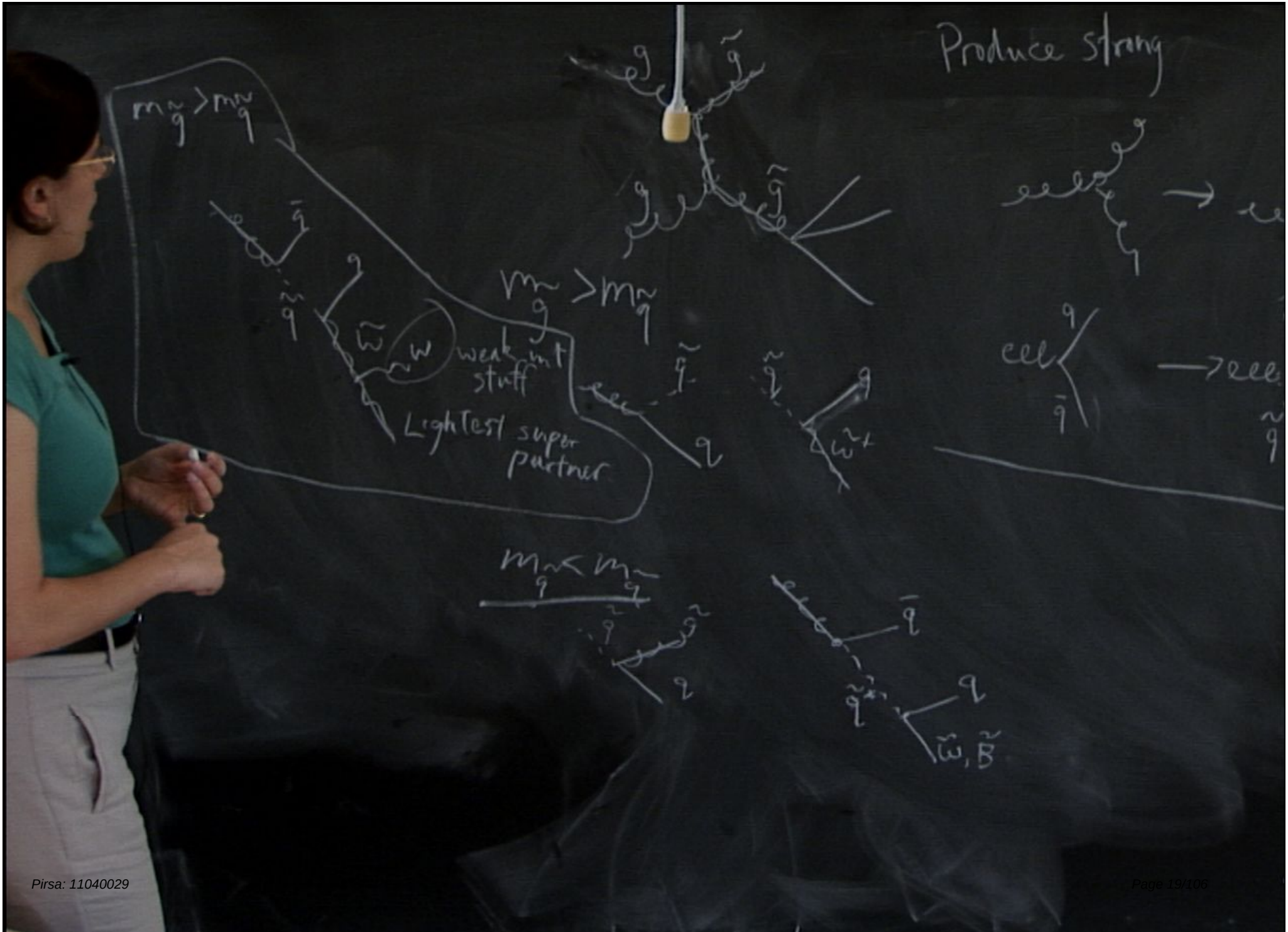

Produce string
$m_{\tilde{g}} > m_{\tilde{q}}$
$m_{\tilde{g}} < m_{\tilde{q}}$

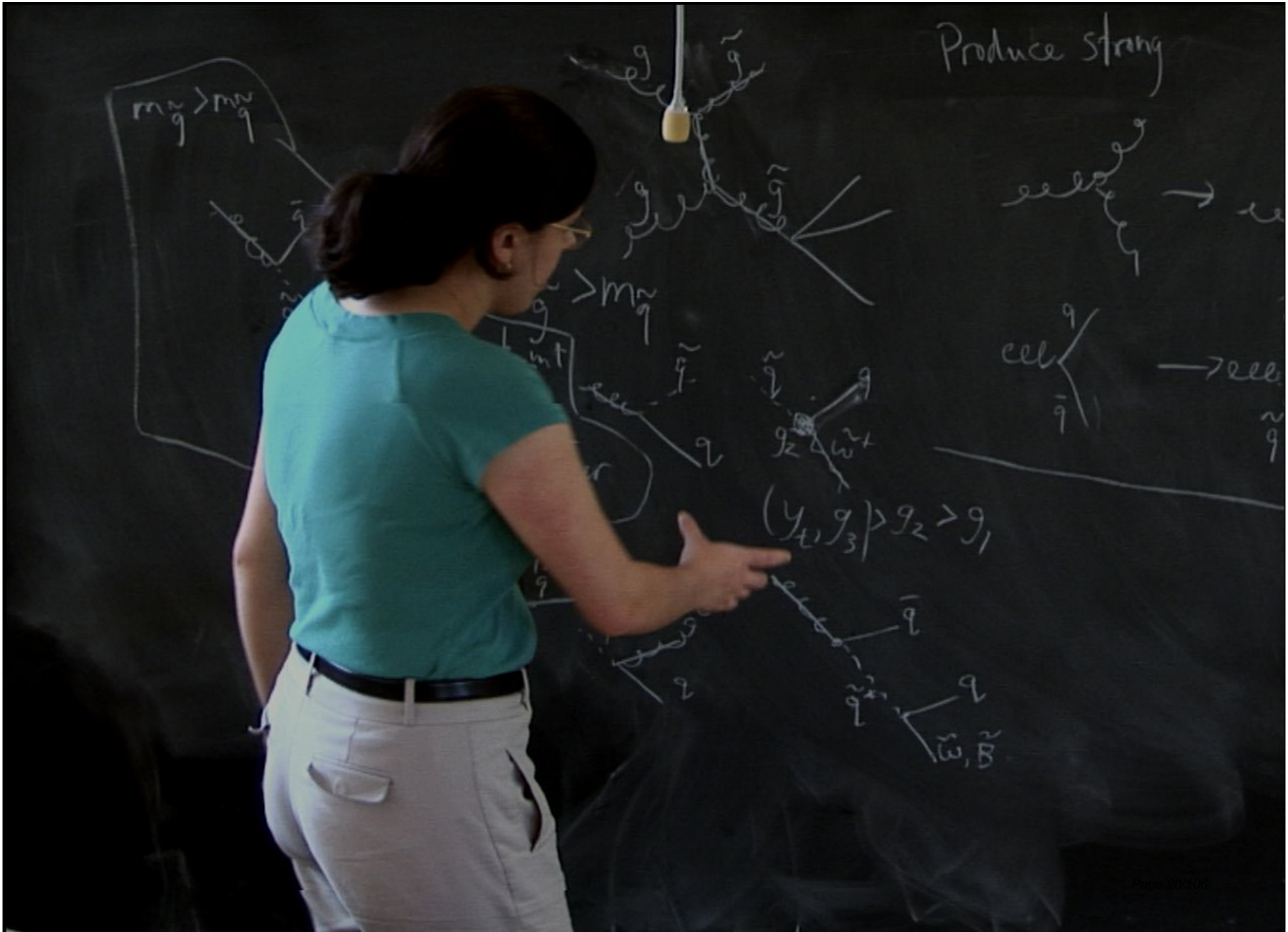

Produce string

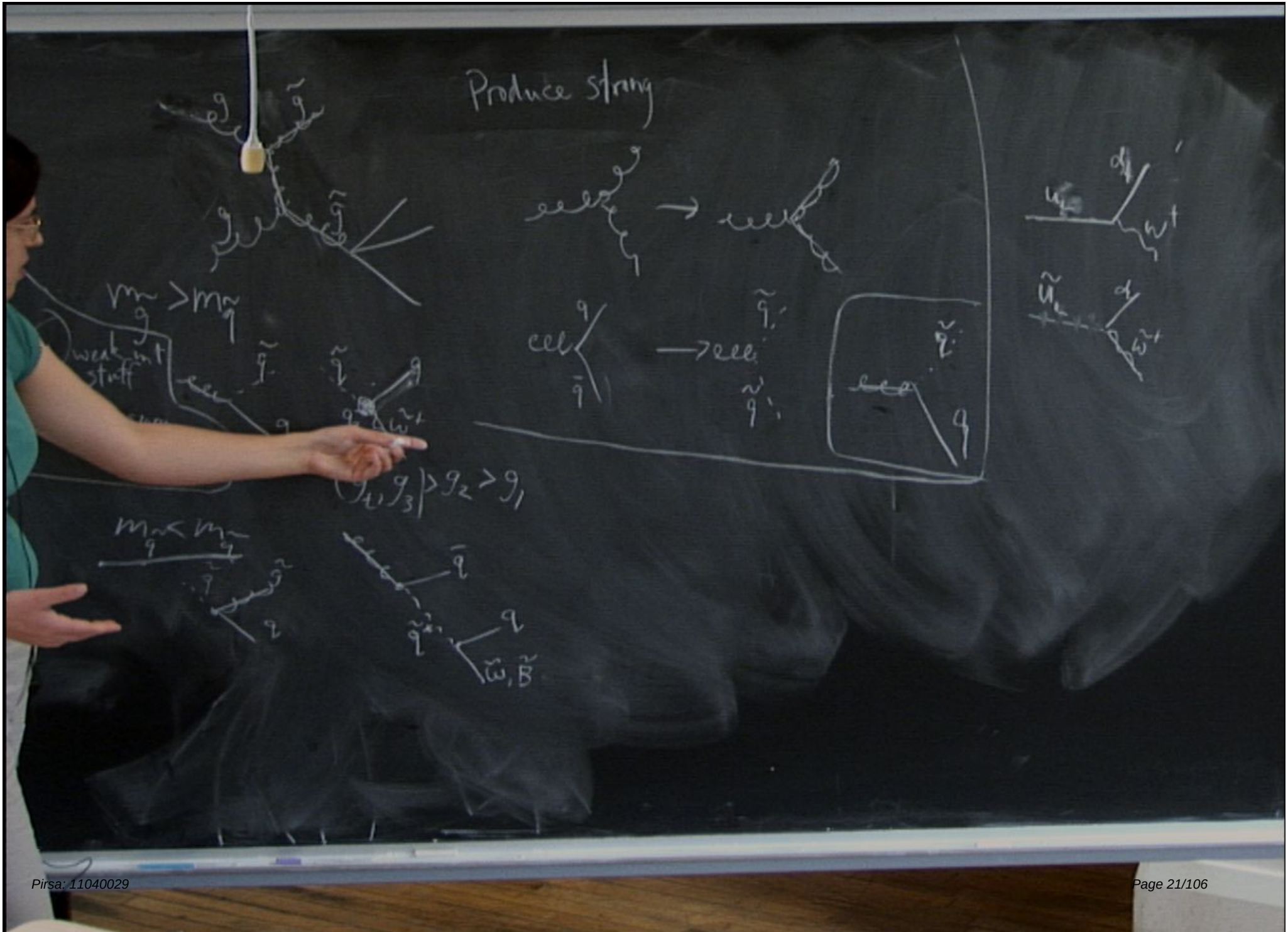

Produce string

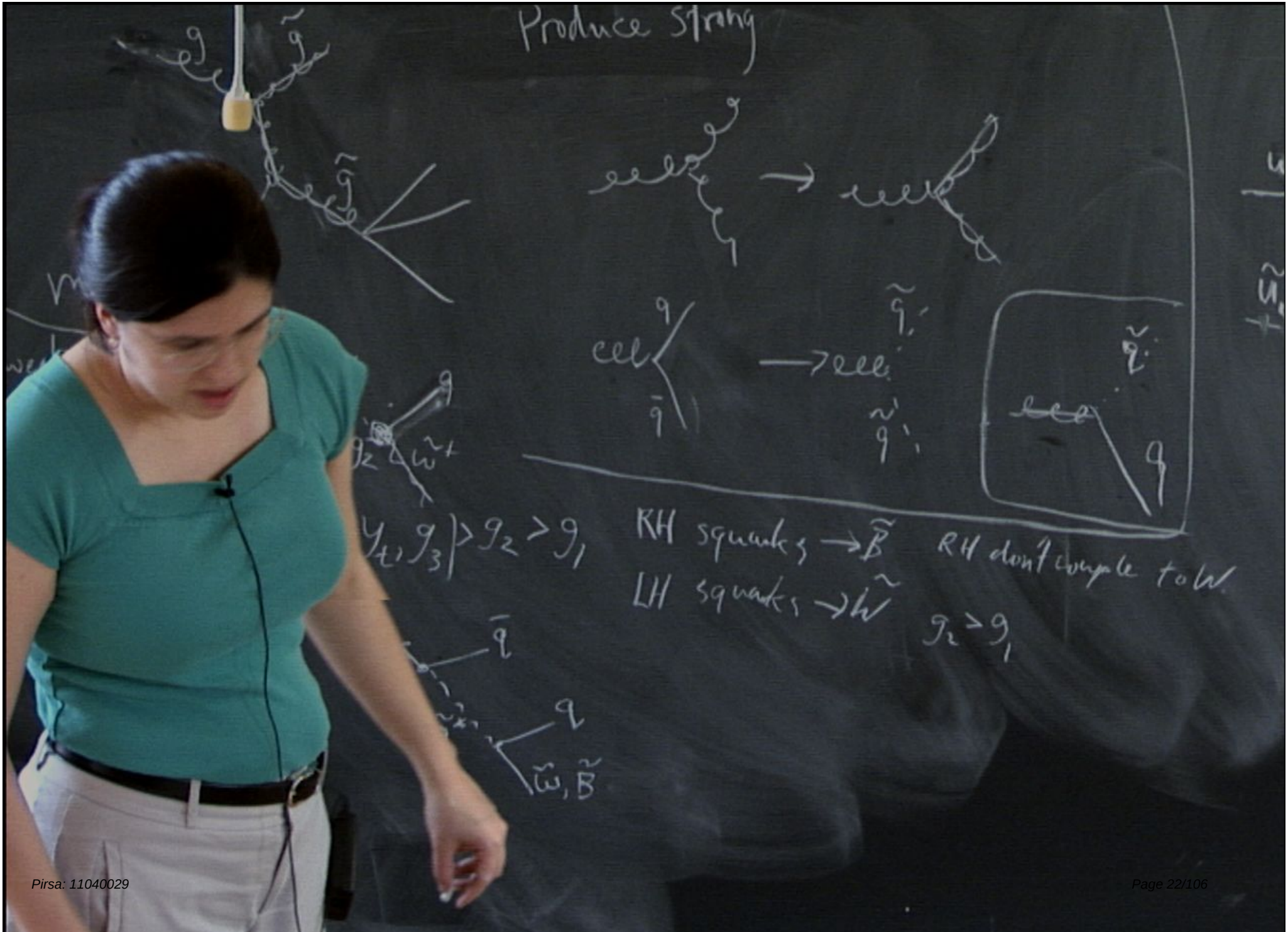

Produce string
weak stuff

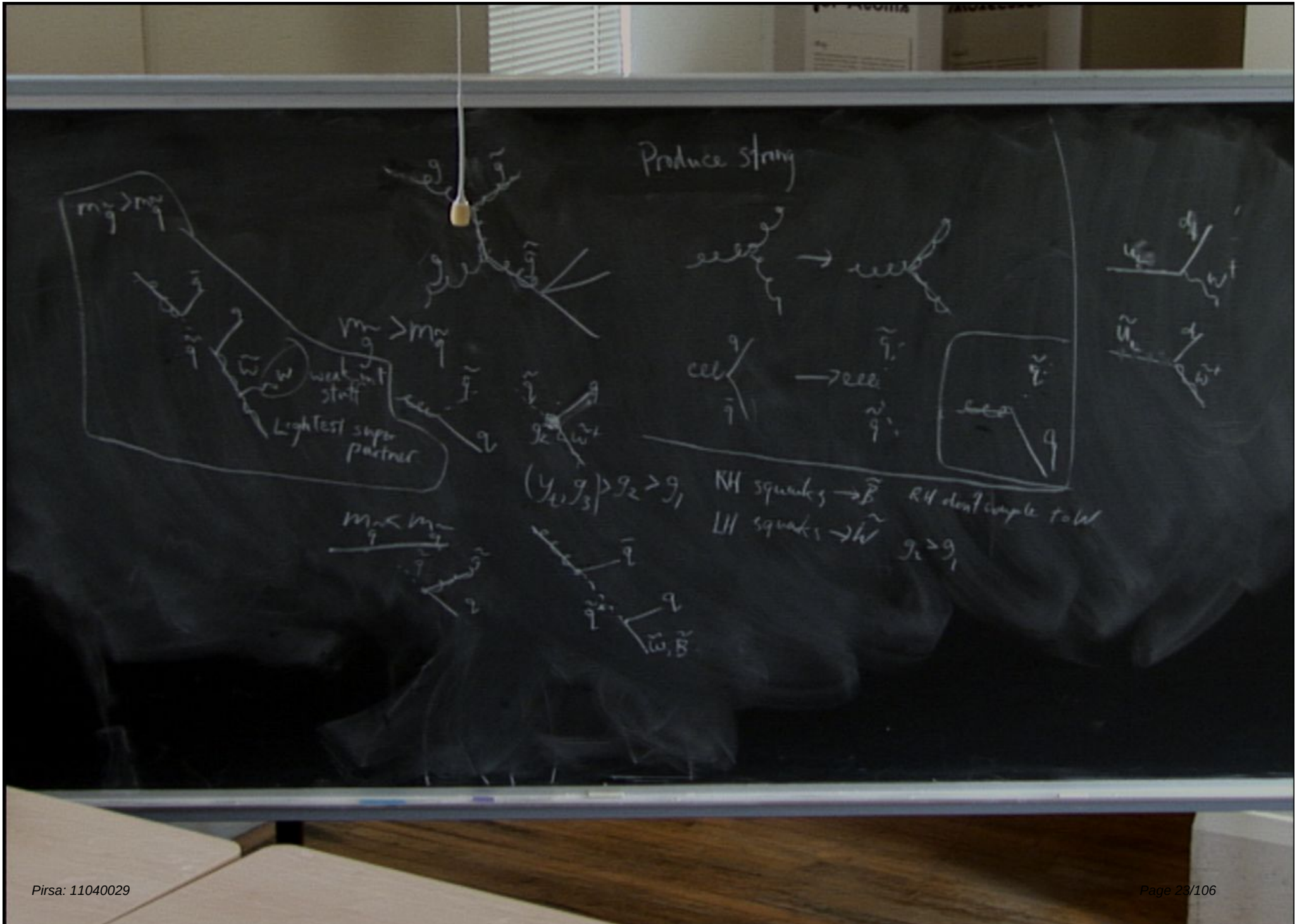

Produce strong
weak stuff
Lightest super partner

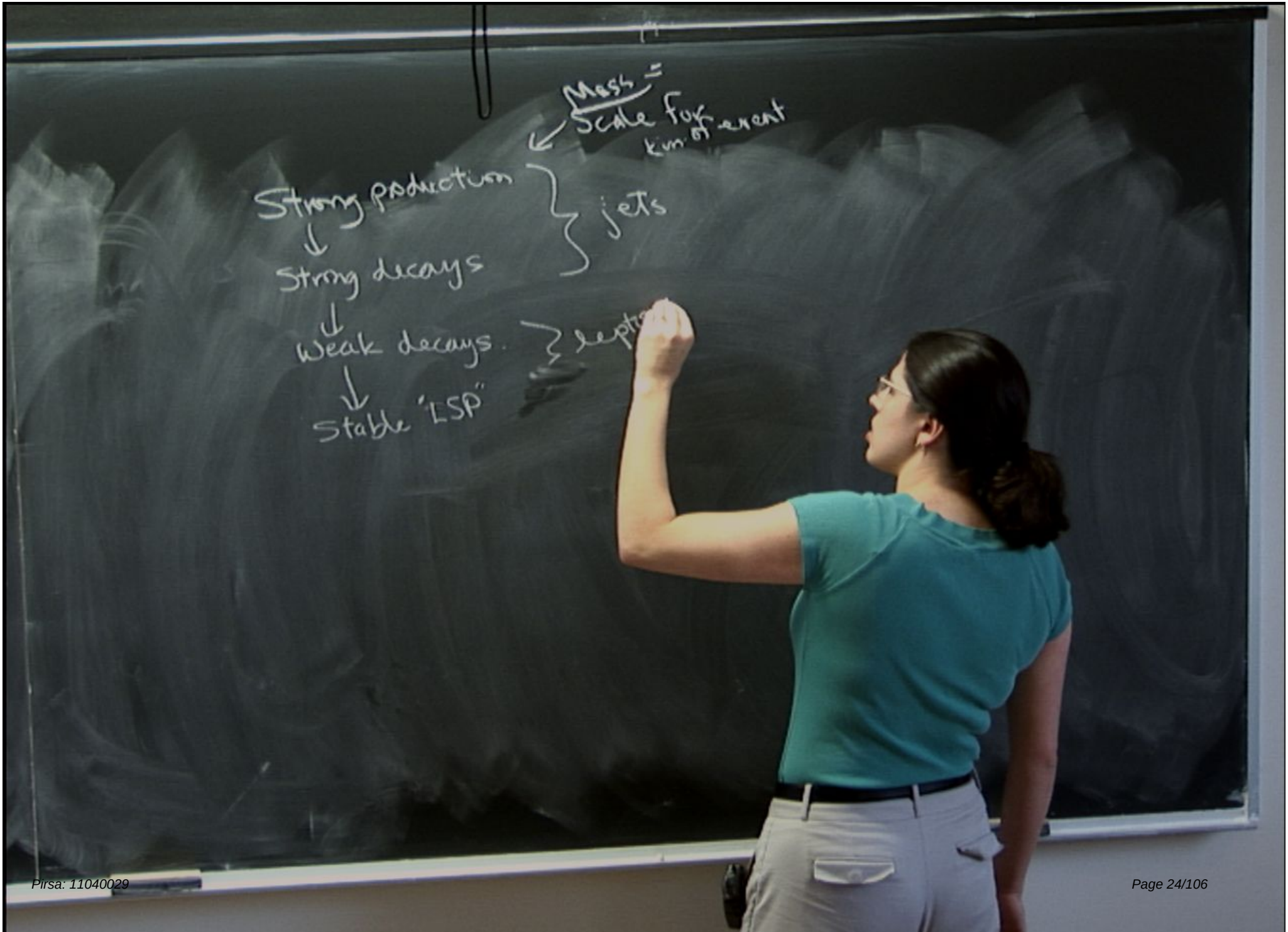

Produce strong
weak int stuff
Lightest super partner

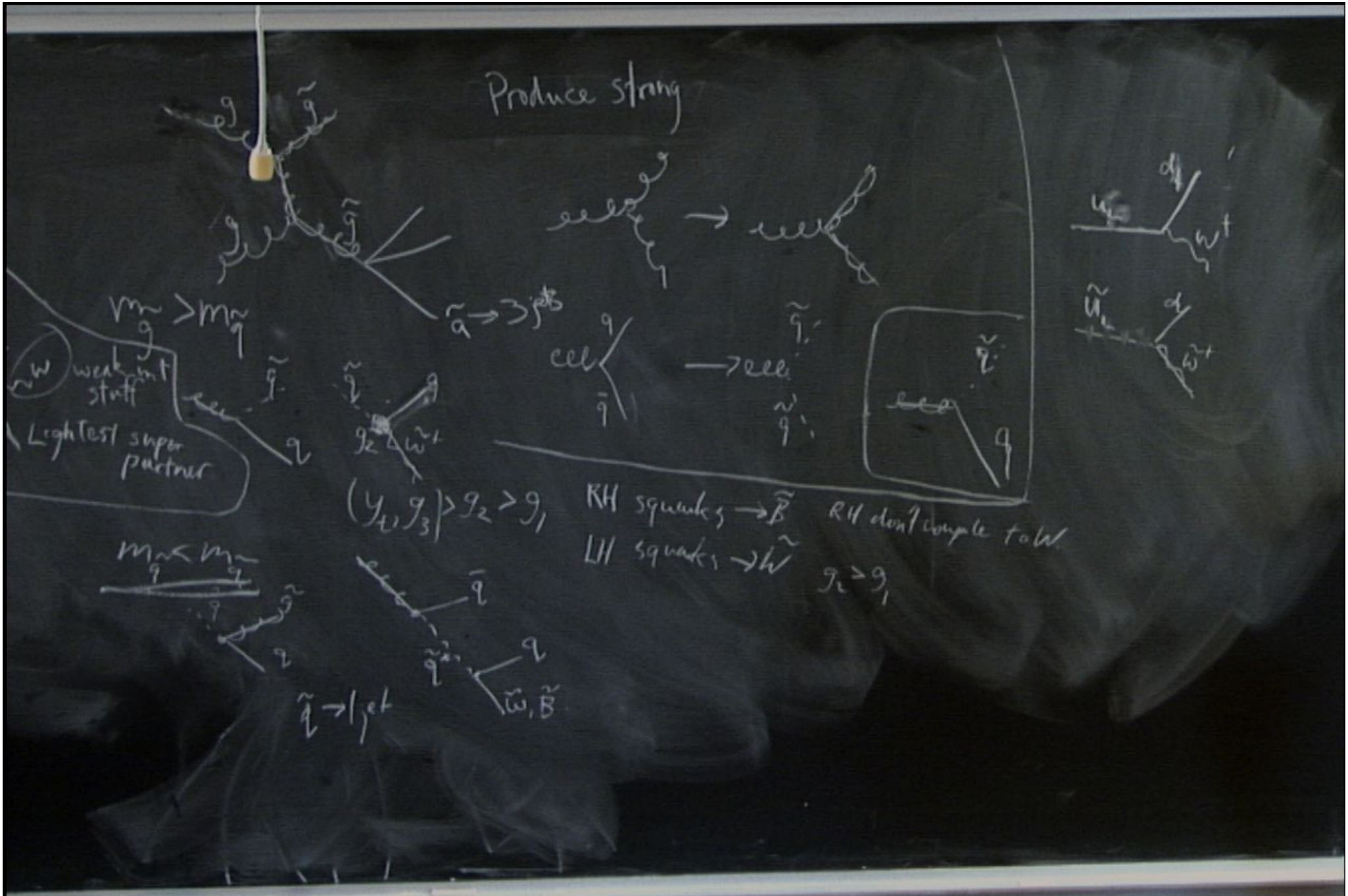

Produce strong

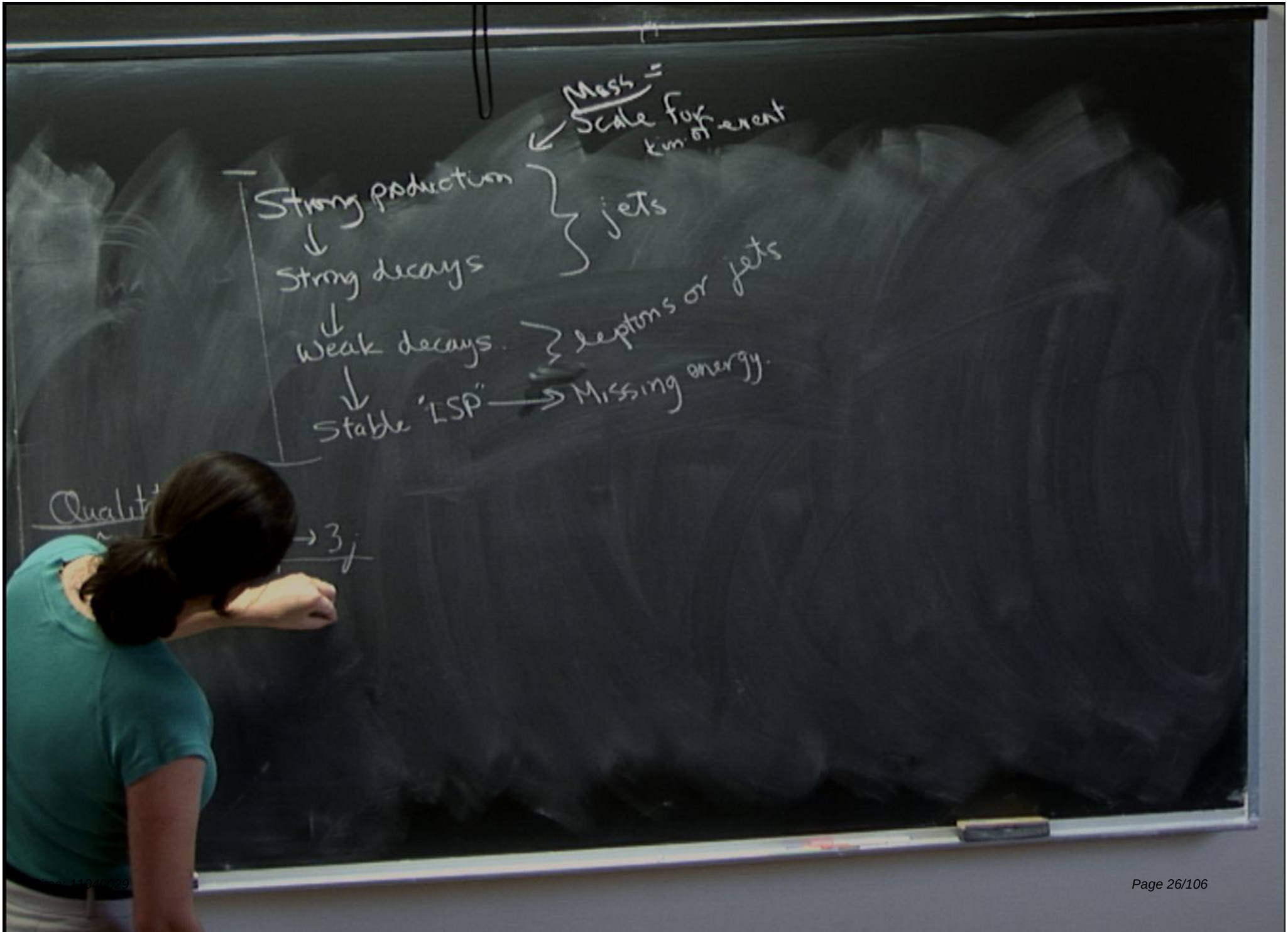

Produce strong
weak stuff


Produce String
RH squarks → $\tilde{B}$
RH don't couple to W
LH squarks → $\tilde{W}$
$q_2 > q_1$
$\tilde{\omega}, \tilde{B}$


Produce strong
Lightest super partner
RH squarks → $\tilde{B}$
LH squarks → $\tilde{W}$


Mass
Scale for
kin. of event
Strong production
Strong decays
Weak decays
Stable "LSP"
jets


Produce string
$\tilde{q} \to 3$ jets
weak stuff
Lightest super partner
RH squarks $\to \tilde{B}$
RH don't couple to W
LH squarks $\to \tilde{W}$
$\tilde{q} \to$ jet
$\tilde{W}, \tilde{B}$

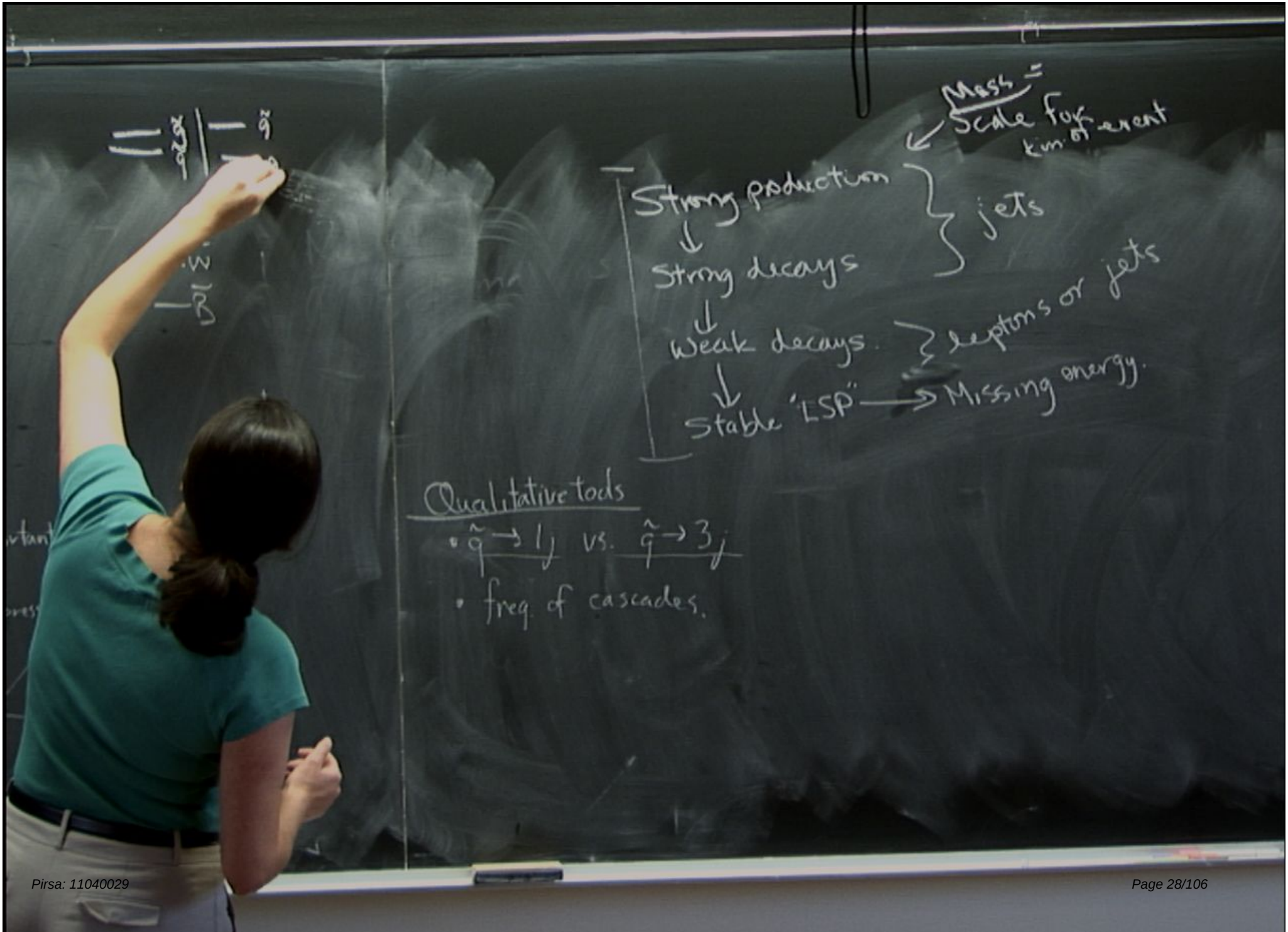

Mass ≈ Scale for kin. of event
Strong production
Strong decays
jets
Weak decays
leptons or jets
Stable 'LSP'
Missing energy.
Qualit
→ 3 j

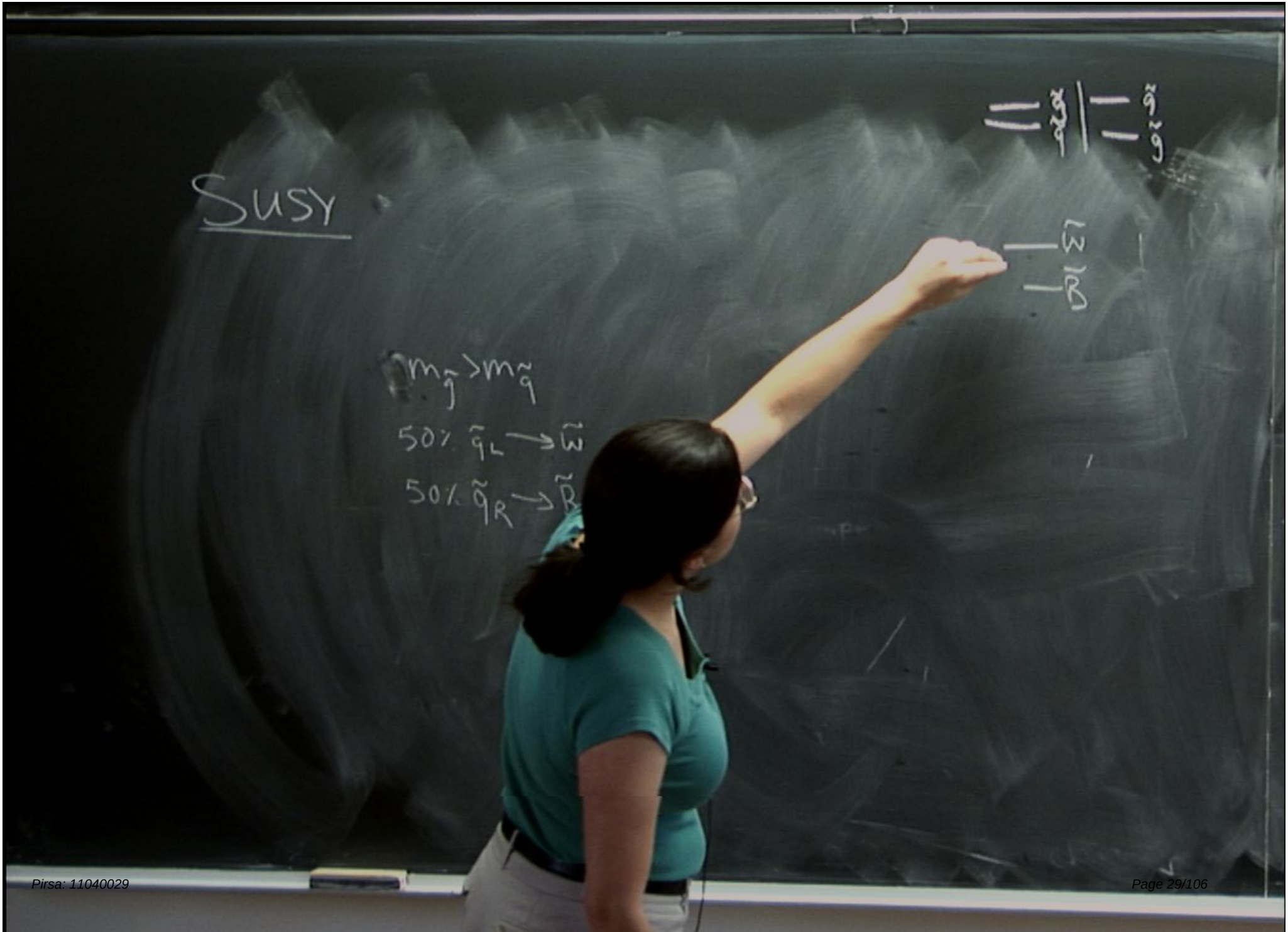
Mass = Scale for kin. of event

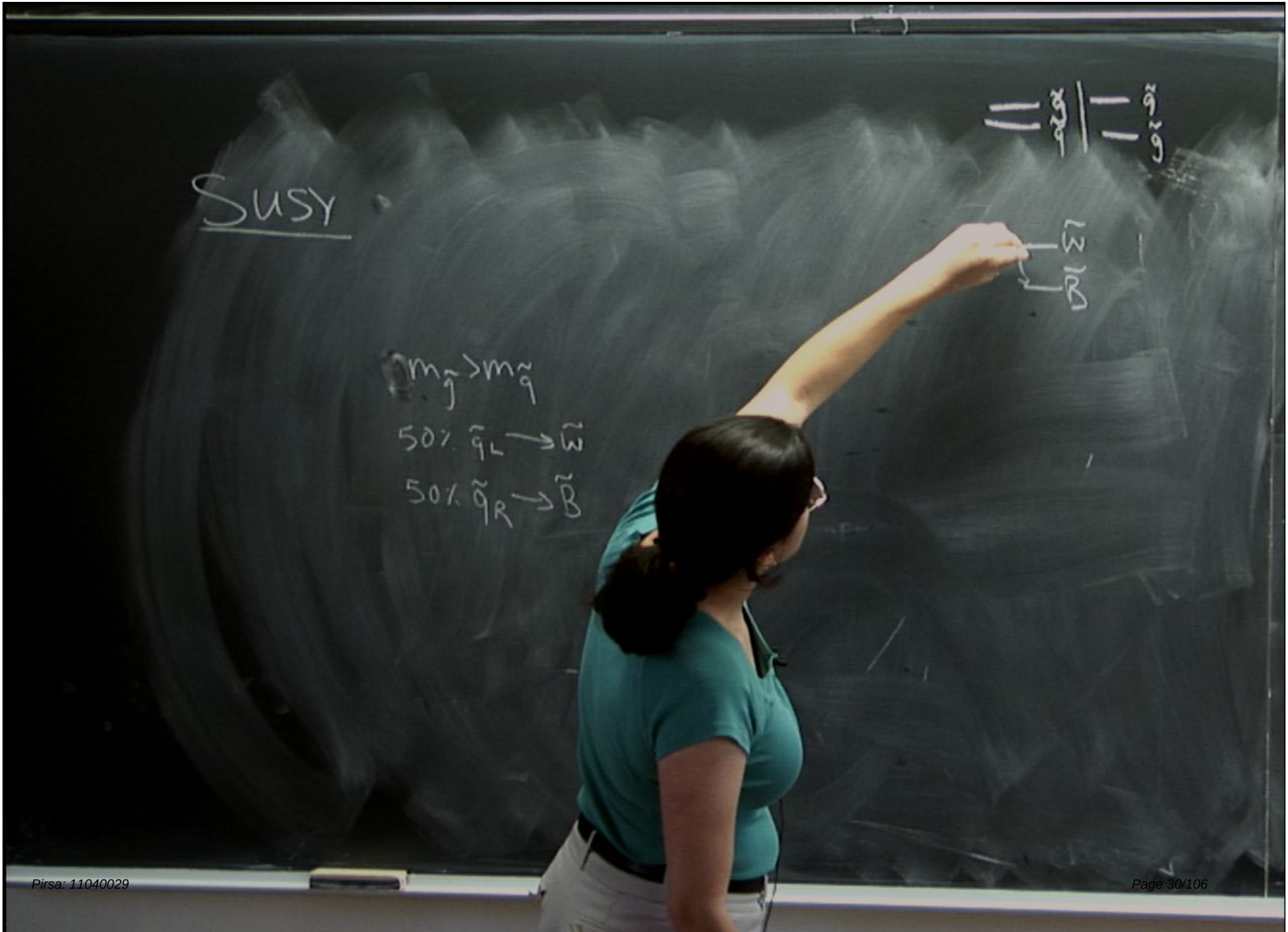
Strong production
↓
Strong decays } jets
↓
Weak decays } leptons or jets
↓
Stable 'LSP' → Missing energy.

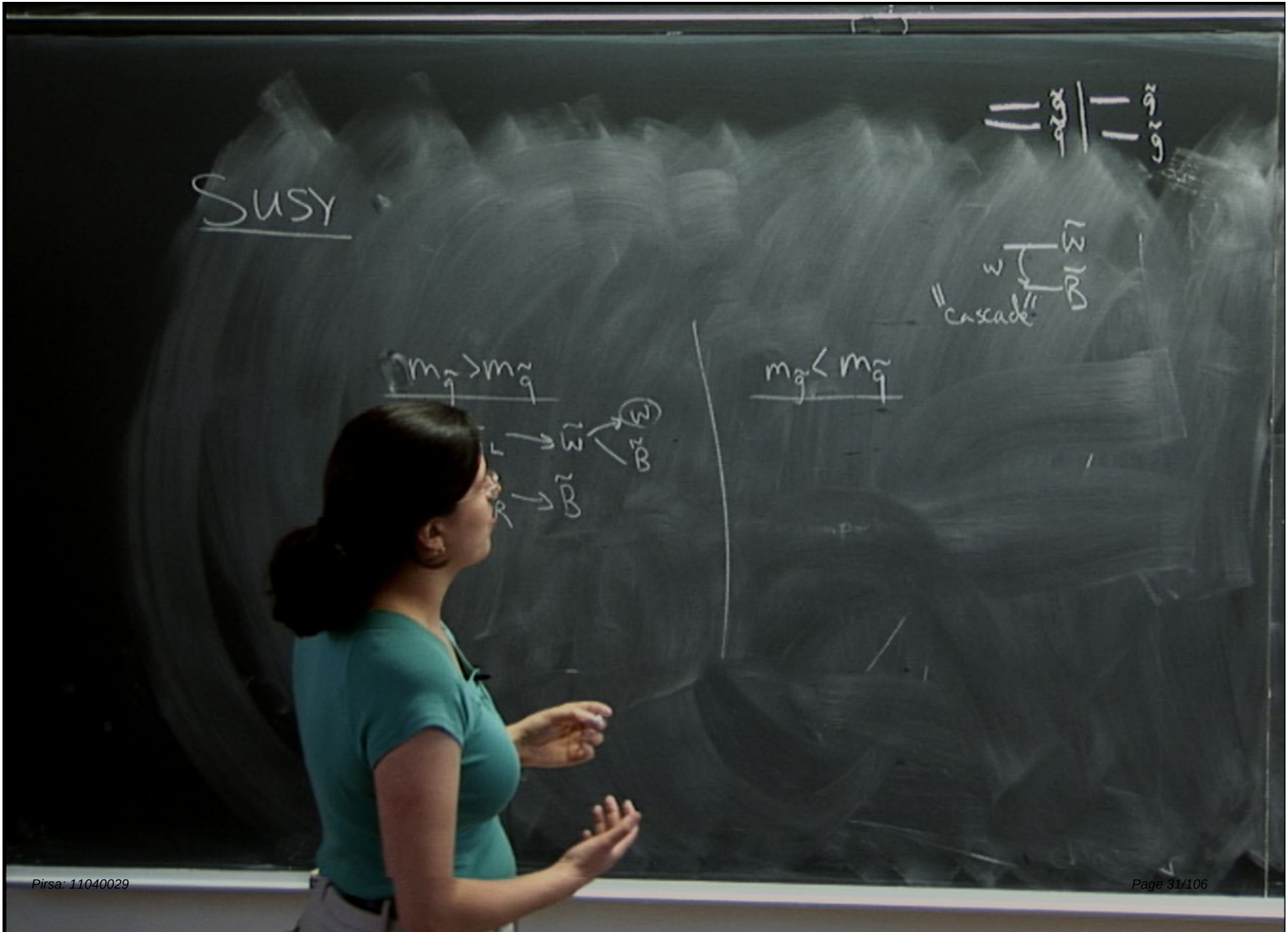
Qualitative tools

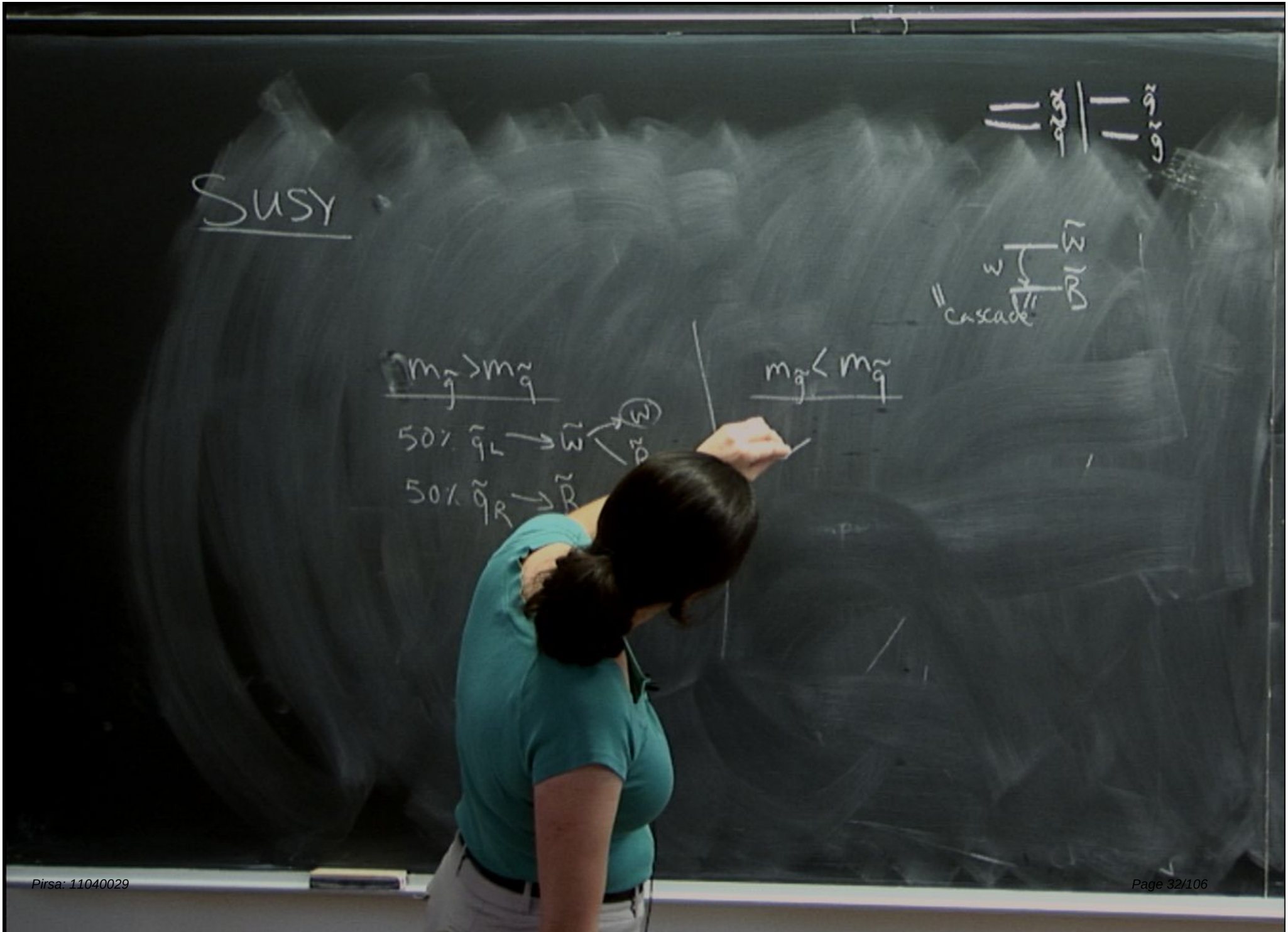
- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq of cascades.

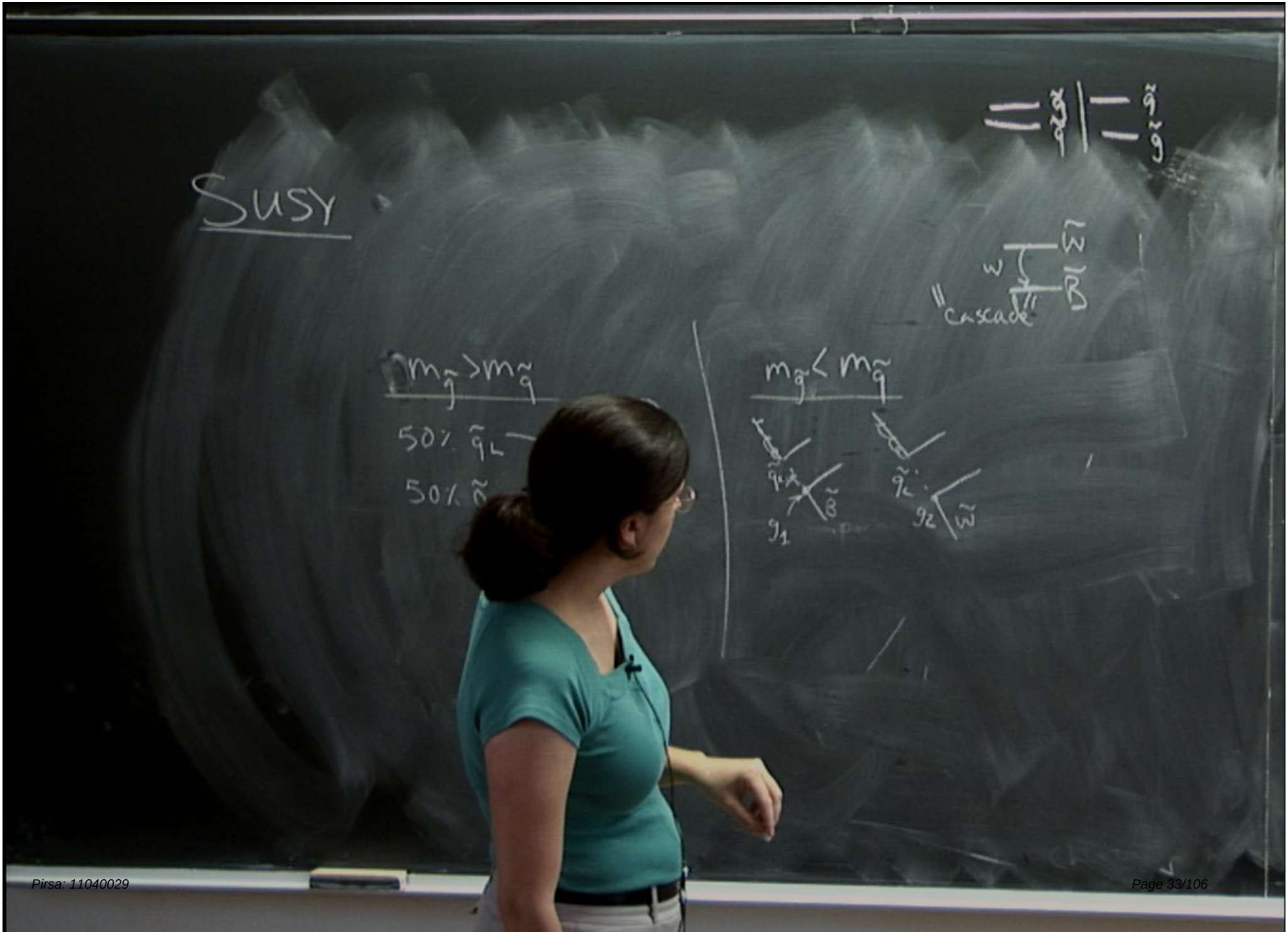

Mass scale for different kinds of event
Strong production
Strong decays
Weak decays
Stable "LSP"
jets
leptons or jets
Missing energy.
Qualitative tools
• $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
• freq. of cascades.

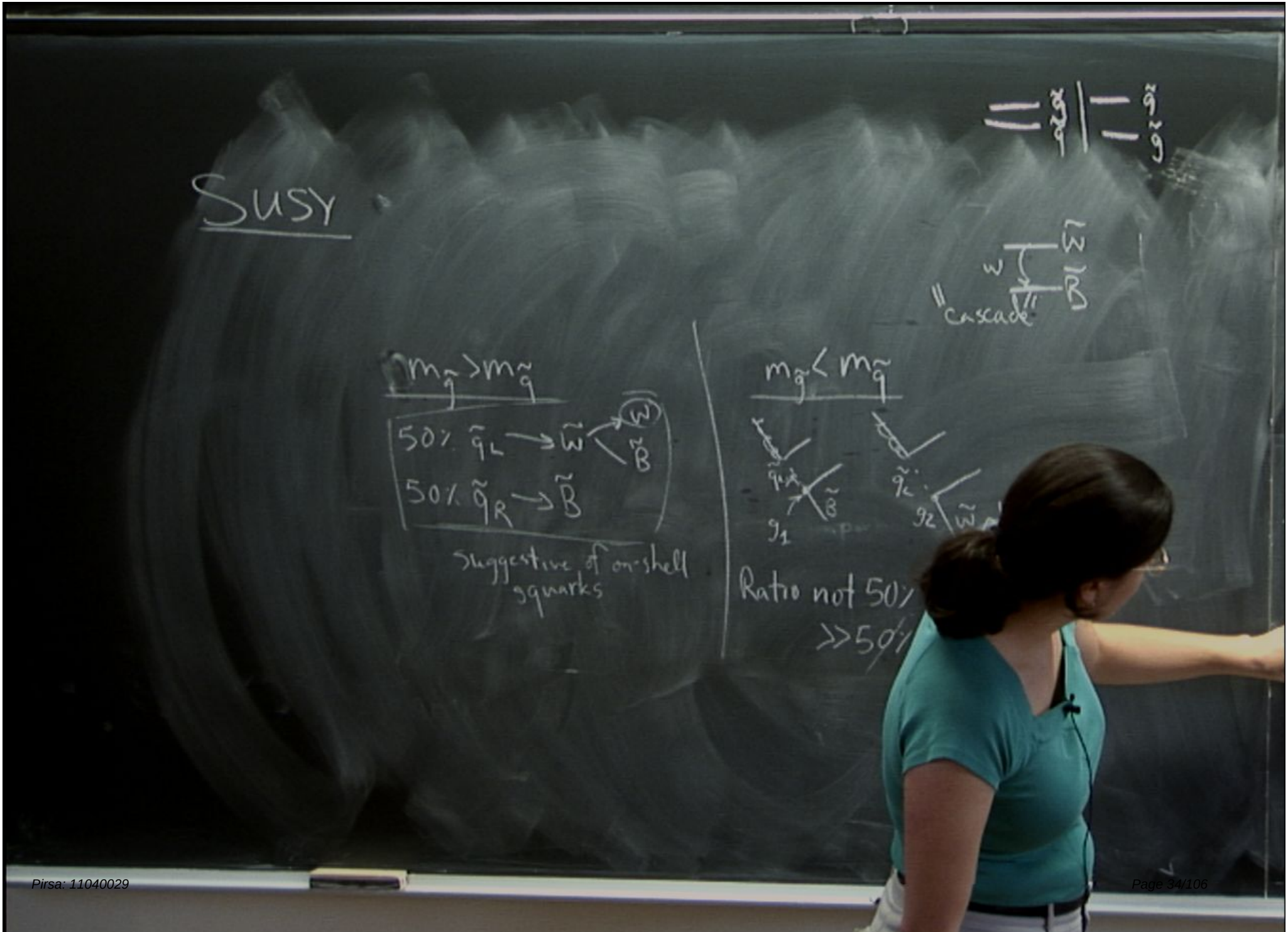

SUSY
$m_{\tilde{g}} > m_{\tilde{q}}$
50% $\tilde{q}_L \to \tilde{W}$
50% $\tilde{q}_R \to \tilde{B}$

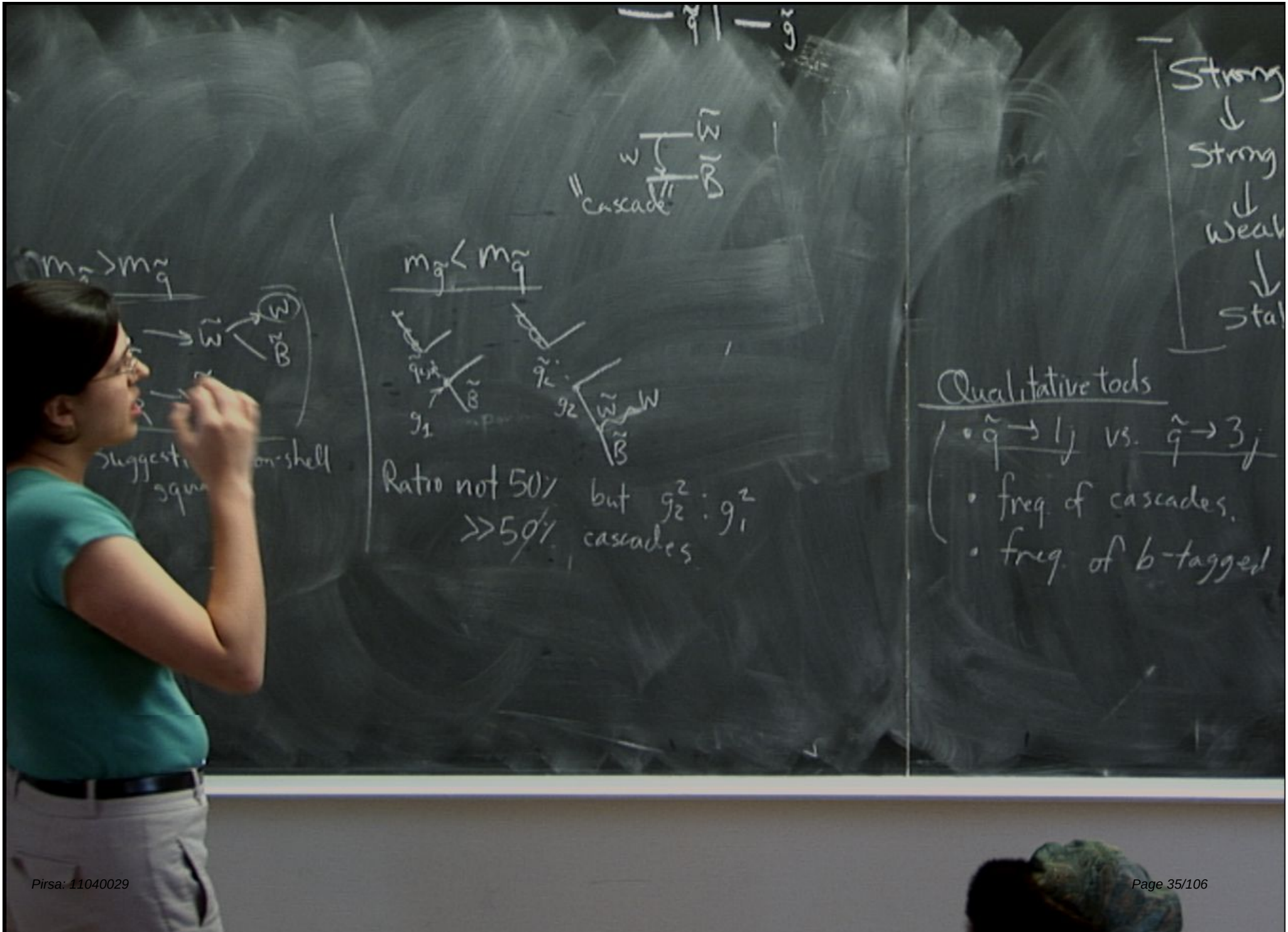

SUSY
$m_{\tilde{g}} > m_{\tilde{q}}$
50% $\tilde{q}_L \to \tilde{W}$
50% $\tilde{q}_R \to \tilde{B}$

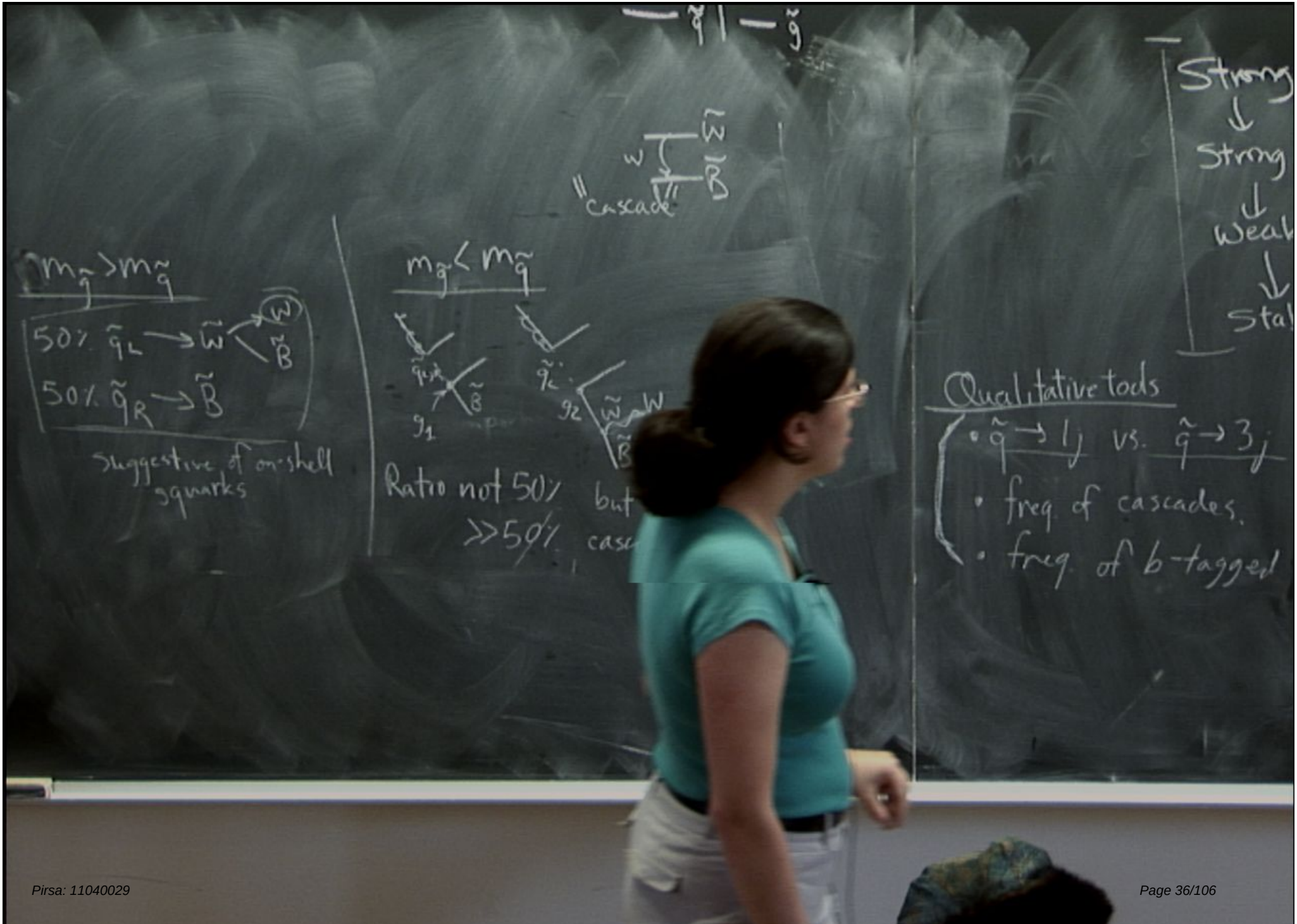

SUSY
"cascade"
$m_{\tilde{q}} > m_{\tilde{g}}$
$m_{\tilde{g}} < m_{\tilde{q}}$

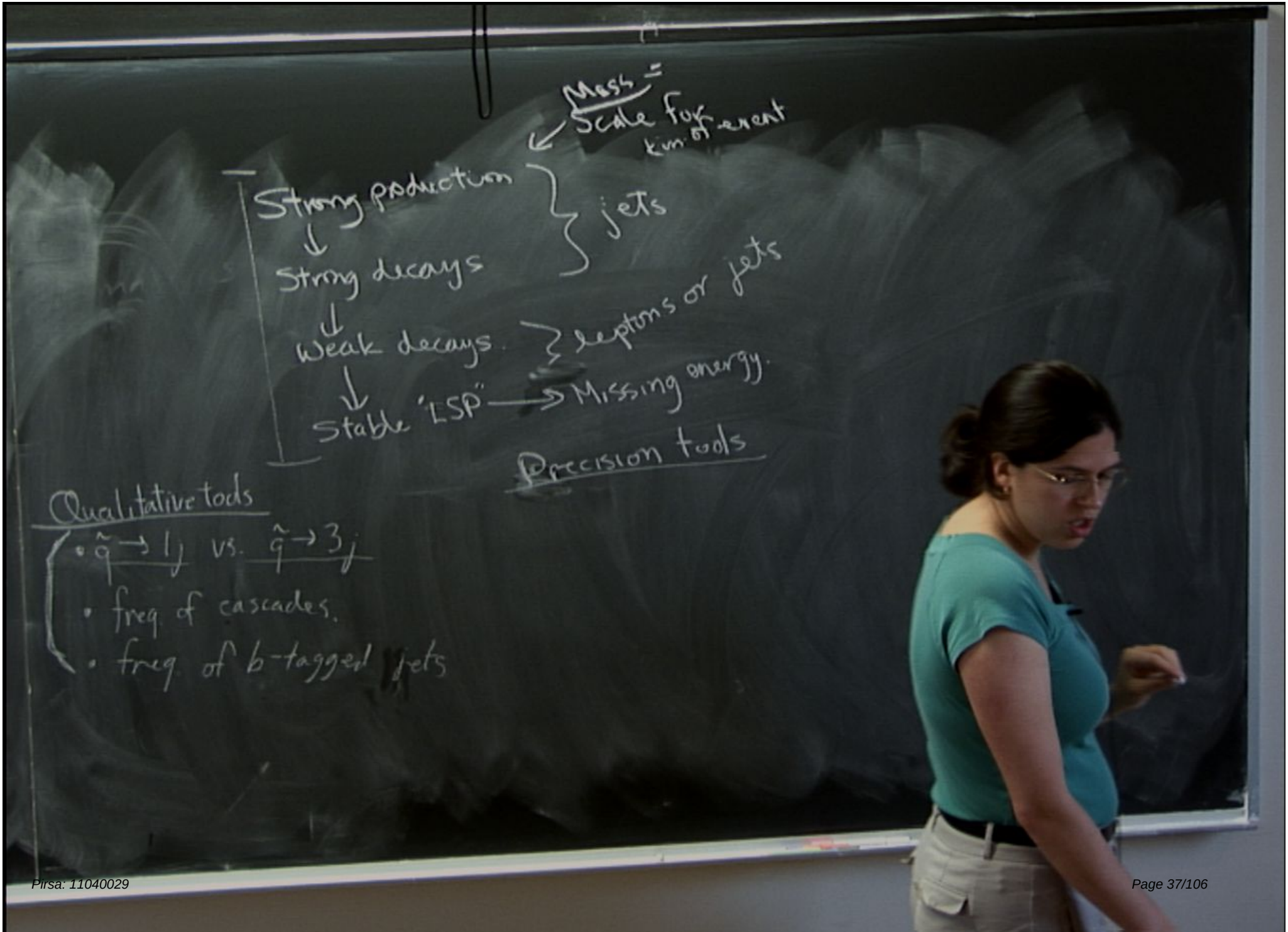

SUSY
"cascade"
50%
50%

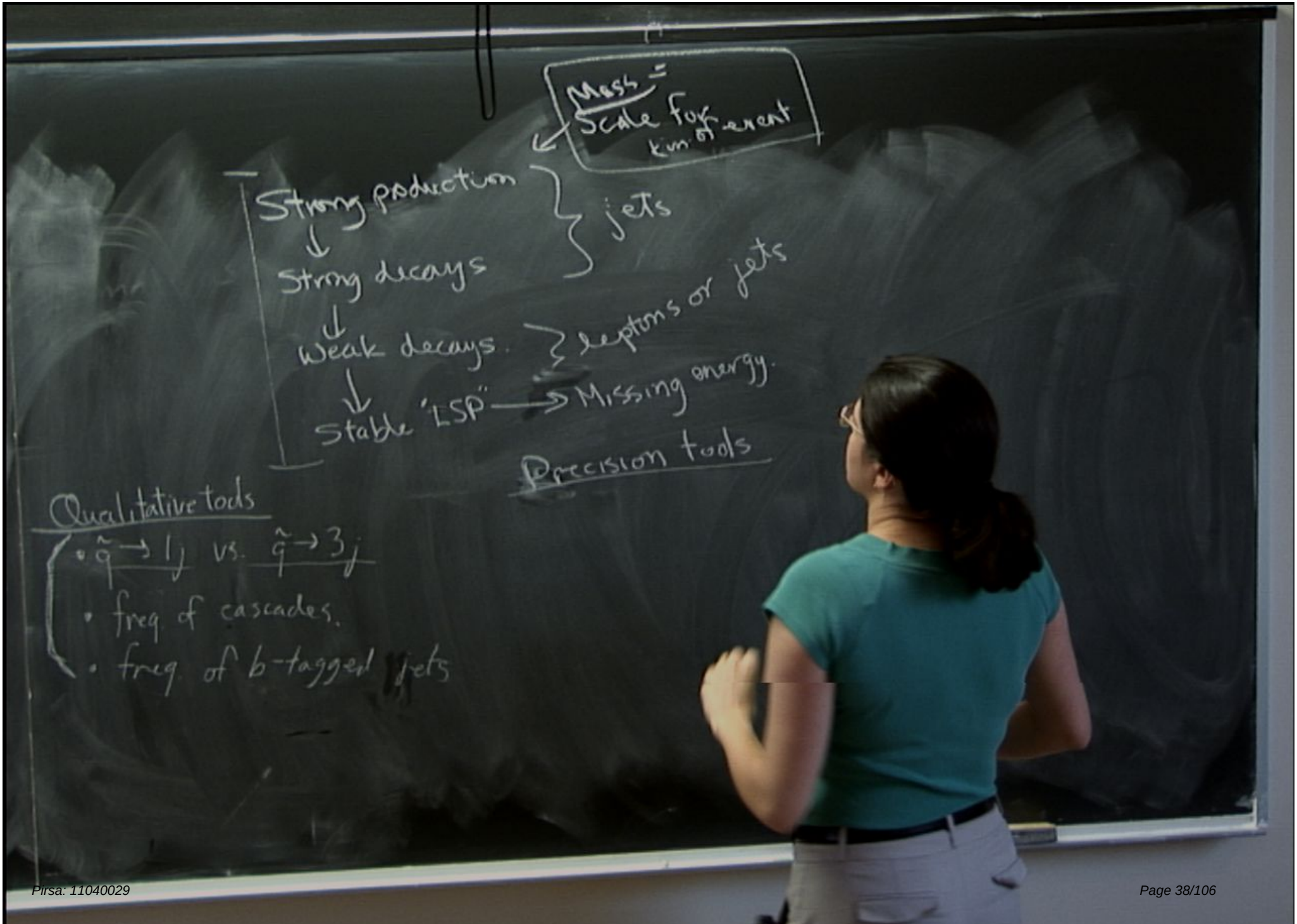

SUSY
"cascade"
$m_{\tilde{g}} > m_{\tilde{q}}$
50%
50%
$m_{\tilde{g}} < m_{\tilde{q}}$


SUSY
"cascade"
$m_{\tilde{q}} > m_{\tilde{g}}$
50% $\tilde{q}_L \to \tilde{W}$
50% $\tilde{q}_R \to \tilde{B}$
Suggestive of on-shell squarks
$m_{\tilde{q}} < m_{\tilde{g}}$
Ratio not 50%
>>50%


"cascade"
Strong
Strong
Weak
Stable
Qualitative tools
• $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
• freq. of cascades.
• freq. of b-tagged
Ratio not 50% but $g_2^2 : g_1^2$
>>50% cascades


$m_{\tilde{g}} > m_{\tilde{q}}$
50% $\tilde{q}_L \to \tilde{W}$
50% $\tilde{q}_R \to \tilde{B}$
Suggestive of on-shell squarks
$m_{\tilde{g}} < m_{\tilde{q}}$
Ratio not 50%
>>50%
but
cascade
Strong
Strong
Weak
Qualitative tools
$\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
• freq. of cascades
• freq. of b-tagged


Mass ≈ Scale for different kinds of event
Strong production
Strong decays
jets
Weak decays
leptons or jets
Stable "LSP" → Missing energy.
Precision tools
Qualitative tools
• $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
• freq of cascades.
• freq of b-tagged jets


Mass = Scale for kin. of event
Strong production
Strong decays
Weak decays
Stable "LSP"
jets
leptons or jets
Missing energy
Precision tools
Qualitative tools
• $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
• freq of cascades.
• freq of b-tagged jets

Mass = Scale for kinematic event

Strong production → Strong decays → jets

Weak decays → leptons or jets

Stable 'LSP' → Missing energy

Precision tools

Qualitative tools

- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq. of cascades.
- freq. of b-tagged jets

Mass = Scale for kin. of event

Strong production → jets
↓
Strong decays → jets
↓
Weak decays → leptons or jets
↓
Stable "LSP" → Missing energy

$\sum p_{T,i}$

Precision tools

Parton lum

Qualitative tools

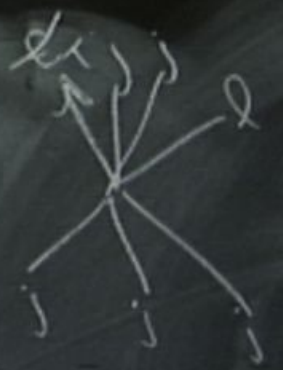
- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq. of cascades.
- freq. of b-tagged jets

Mass ≈ Scale for kin. of event

Strong production → Strong decays → Weak decays → Stable 'LSP' → Missing energy.

Strong production, Strong decays: jets

Weak decays: } leptons or jets



$\sum p_{T,i}$

Precision tools

Parton lumi

Qualitative tools

- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq of cascades.
- freq of b-tagged jets

Mass = Scale for kin. of event

Strong production → Strong decays → Weak decays → Stable "LSP"

Strong production, Strong decays → jets

Weak decays → leptons or jets

Stable "LSP" → Missing energy

$\sum p_{T,i}$

Precision tools

Qualitative tools

- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq. of cascades.
- freq. of b-tagged jets

Parton lumi

$\sqrt{s} > 2m_{\tilde{g}}$

$\sqrt{\hat{s}}$

Mass = Scale for kin. of event

Strong production → Strong decays → jets

Weak decays → leptons or jets

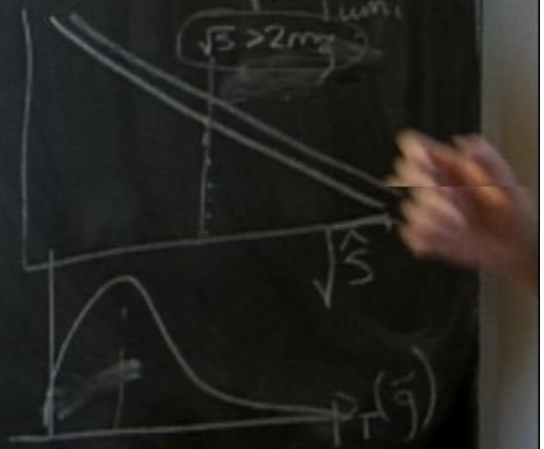
Stable 'LSP' → Missing energy

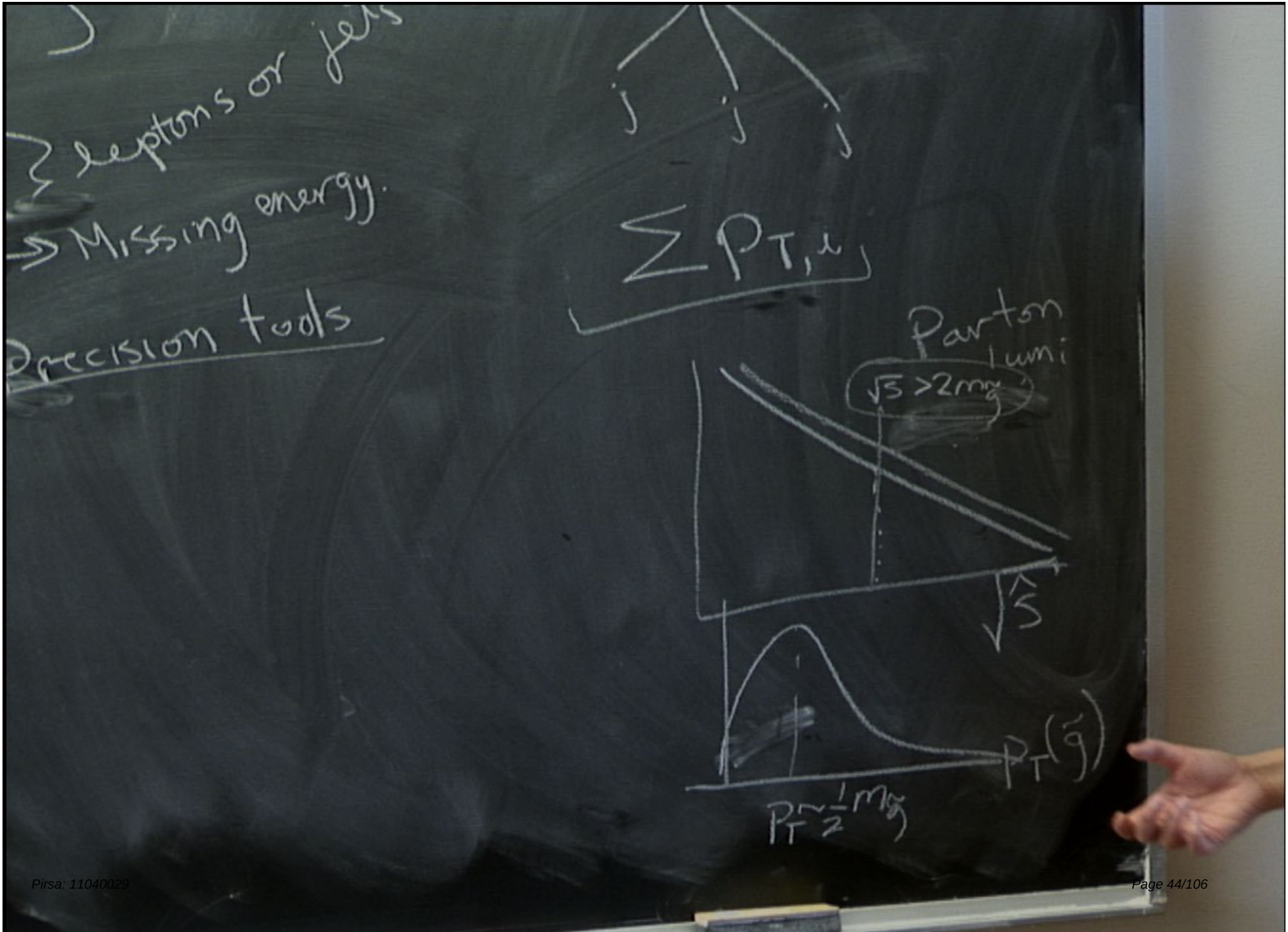
$\sum p_{T,i}$

Precision tools

Qualitative tools

- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq. of cascades.
- freq. of b-tagged jets




leptons or jets
Missing energy.
Precision tools
$\sum p_{T,i}$
Parton lumi
$\sqrt{s} > 2m_{\tilde{g}}$
$\sqrt{s}$
$p_T(\tilde{g})$
$p_T \sim \frac{1}{2} m_{\tilde{g}}$

Mass = Scale for kin. of event

Strong production → jets
↓
String decays → jets
↓
Weak decays → leptons or jets
↓
Stable "LSP" → Missing energy.

Precision tools

$\sum p_{T,i} \sim m_{Prod}^{\times(1-2)}$

Parton lumi

$\sqrt{s} > 2m_{\tilde{g}}$

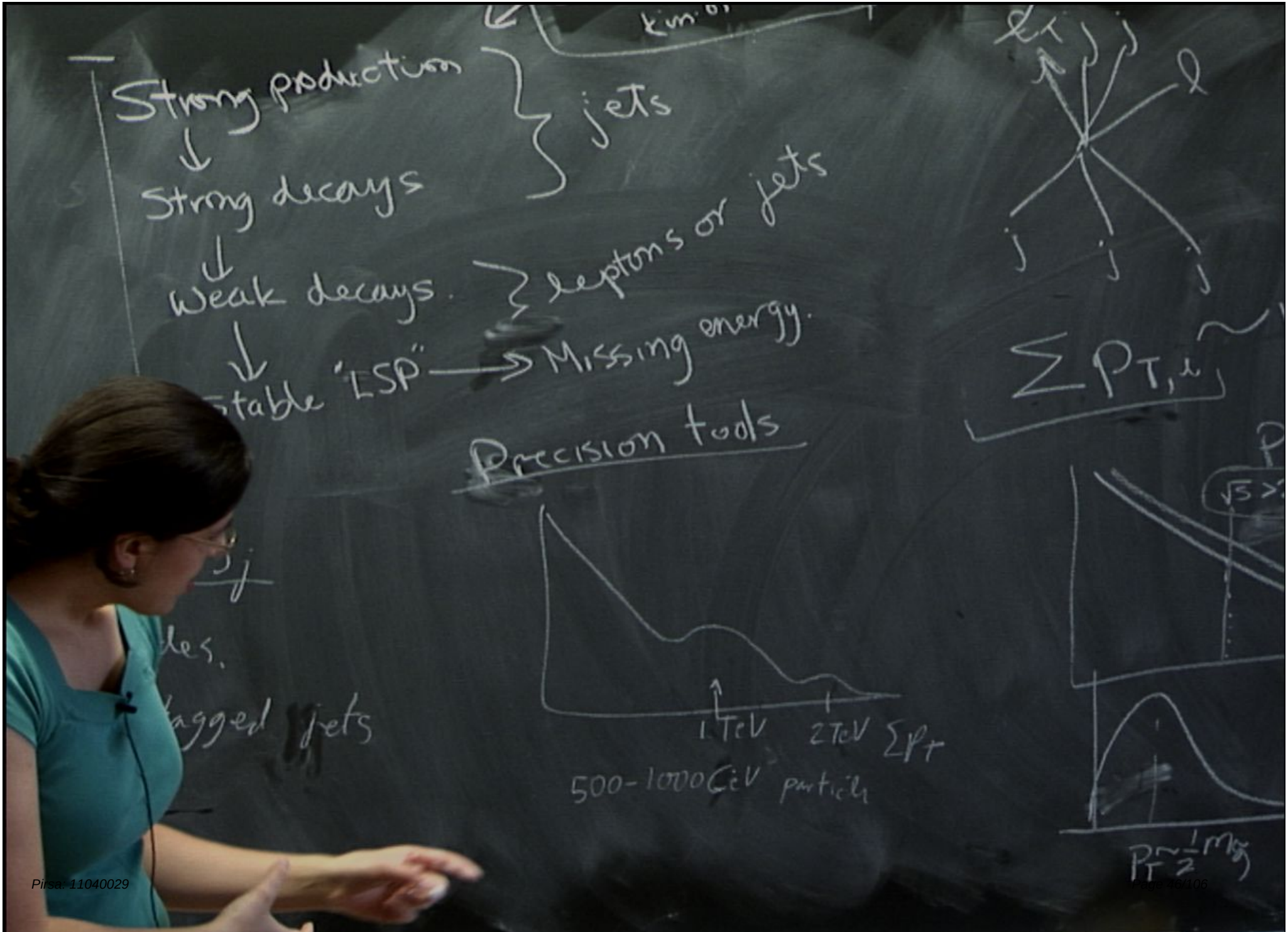
$\sqrt{\hat{s}}$

$p_T(\tilde{g})$

$p_T \sim \frac{1}{2} m_{\tilde{g}}$

Qualitative tools

- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq. of cascades.
- freq. of b-tagged jets


Strong production
Strong decays
Weak decays
jets
leptons or jets
Missing energy
stable "LSP"
Precision tools
1 TeV
2 TeV
500-1000 GeV

Mass = Scale for kin. of event

Strong production → jets
↓
String decays → jets
↓
Weak decays → leptons or jets
↓
Stable "LSP" → Missing energy.

$\sum |\vec{p}_{T,i}| \sim (m_{Prod} \times (1-2) - m_{LSP})$

Qualitative tools
- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq. of cascades.
- freq. of b-tagged jets

Precision tools

1 TeV 2 TeV $\sum p_T$

500-1000 GeV particle

Parton lumi

$\sqrt{s} > 2m_{\tilde{g}}$

$\sqrt{\hat{s}}$

$p_T(\tilde{g})$

$p_T \sim \frac{1}{2} m_{\tilde{g}}$

Mass = Scale for kin. of event

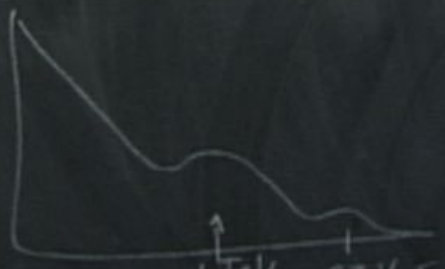
Strong production → jets
↓
Strong decays → jets
↓
Weak decays → leptons or jets
↓
Stable "LSP" → Missing energy.

$\sum |\vec{p}_{T,i}| \sim (m_{Prod} \times (1-2) - m_{LSP})$

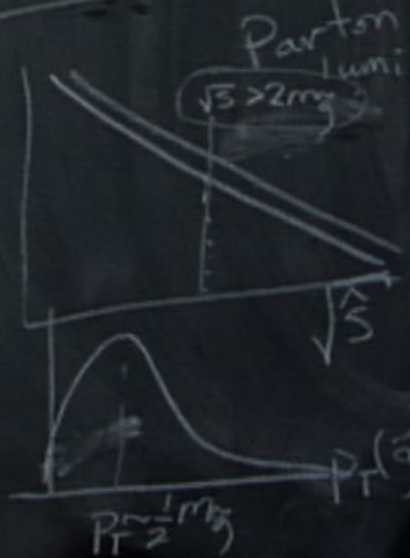
Qualitative tools

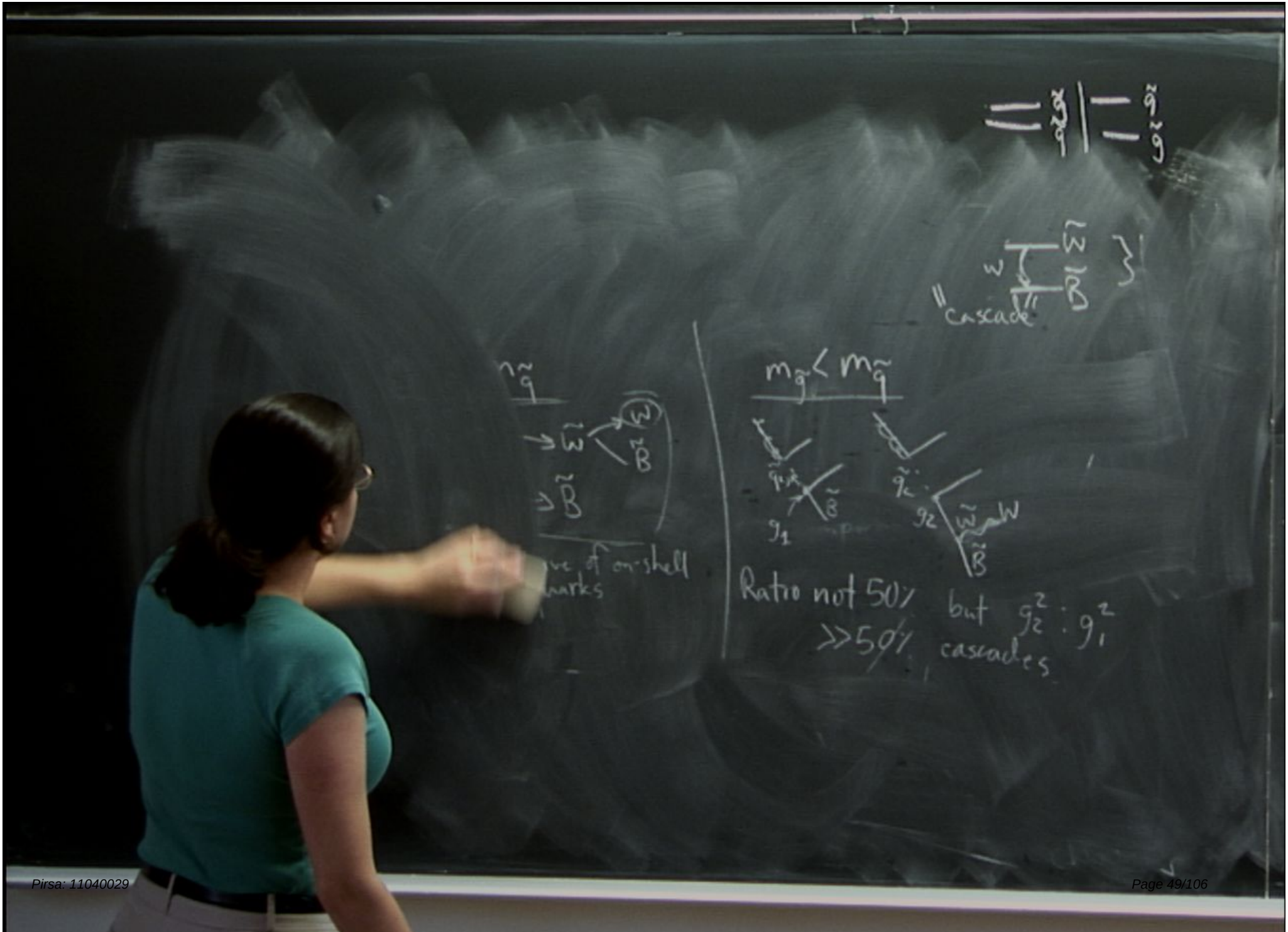
- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq. of cascades.
- freq. of b-tagged jets
- Mass scale from $\sum p_T$ jets

Precision tools



500-1000 GeV particle




"cascade"
Ratio not 50%
but
>>50%
cascades

Mass = Scale for kin. of event

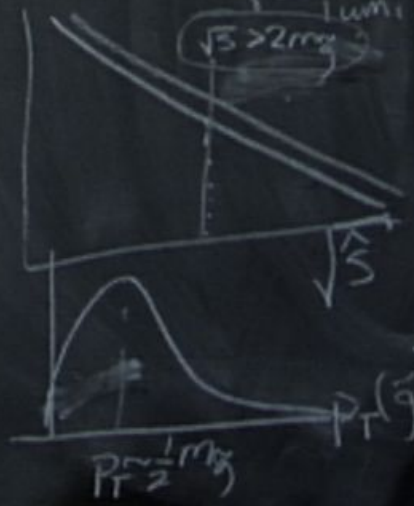
Strong production → jets
↓
Strong decays → jets
↓
Weak decays → leptons or jets
↓
Stable 'LSP' → Missing energy

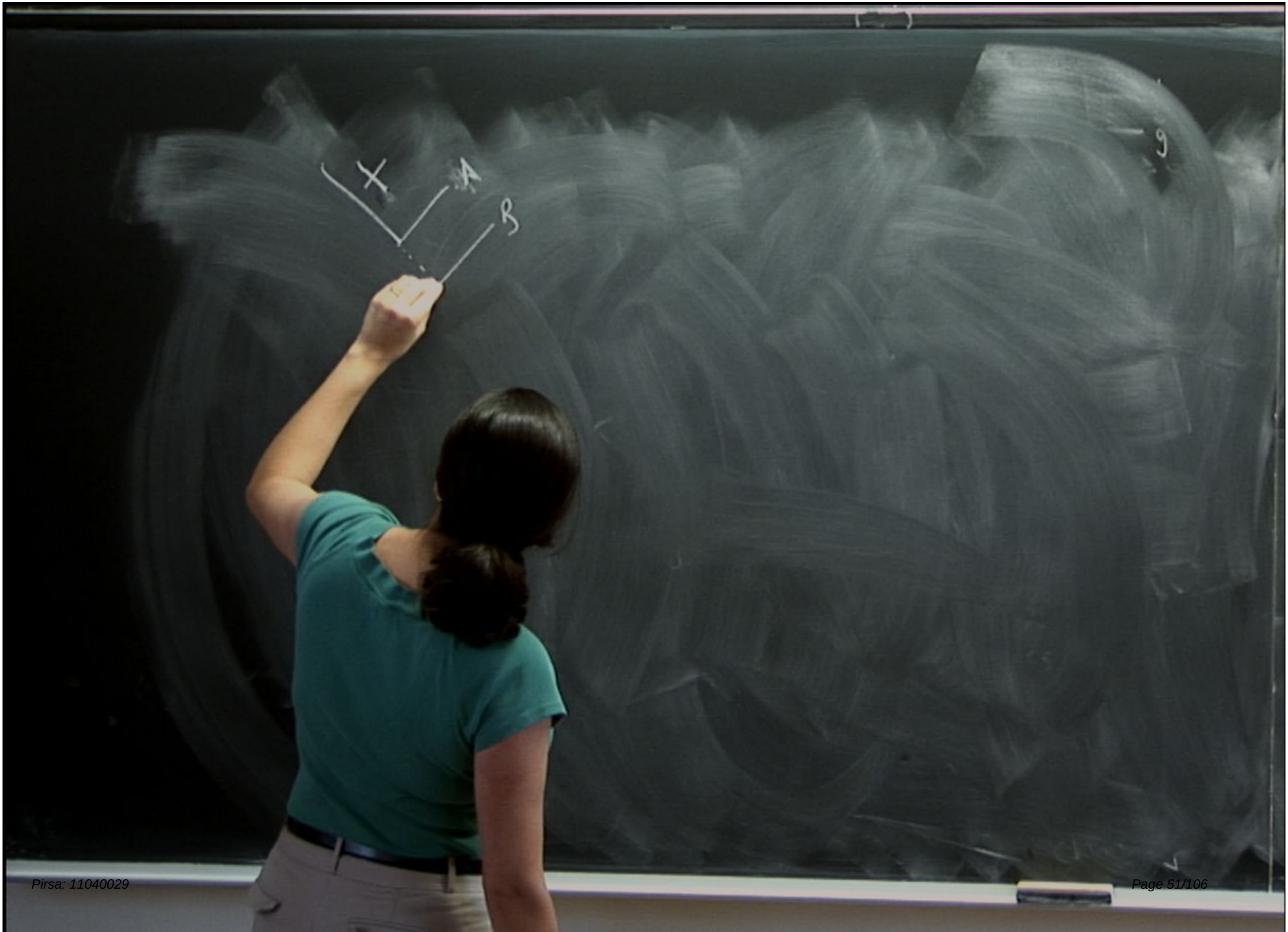
$\sum |\vec{p}_{T,i}| \sim (m_{Prod} \times (1-2) - m_{LSP})$

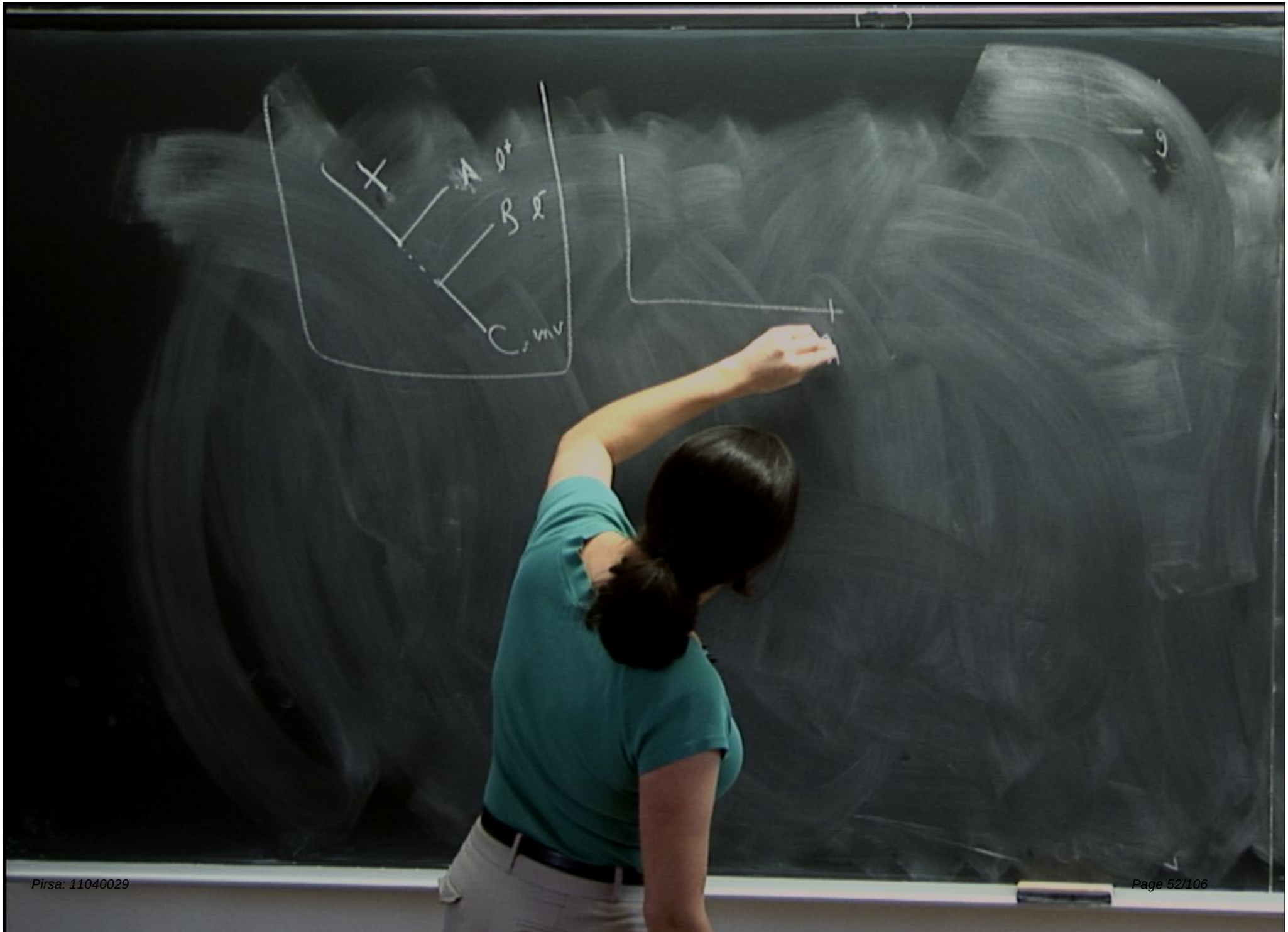
Qualitative tools
- $\tilde{q} \to 1j$ vs. $\tilde{q} \to 3j$
- freq. of cascades.
- freq. of b-tagged jets
- Mass scale from $\sum p_T$, $|\vec{p}_T|$ of l's

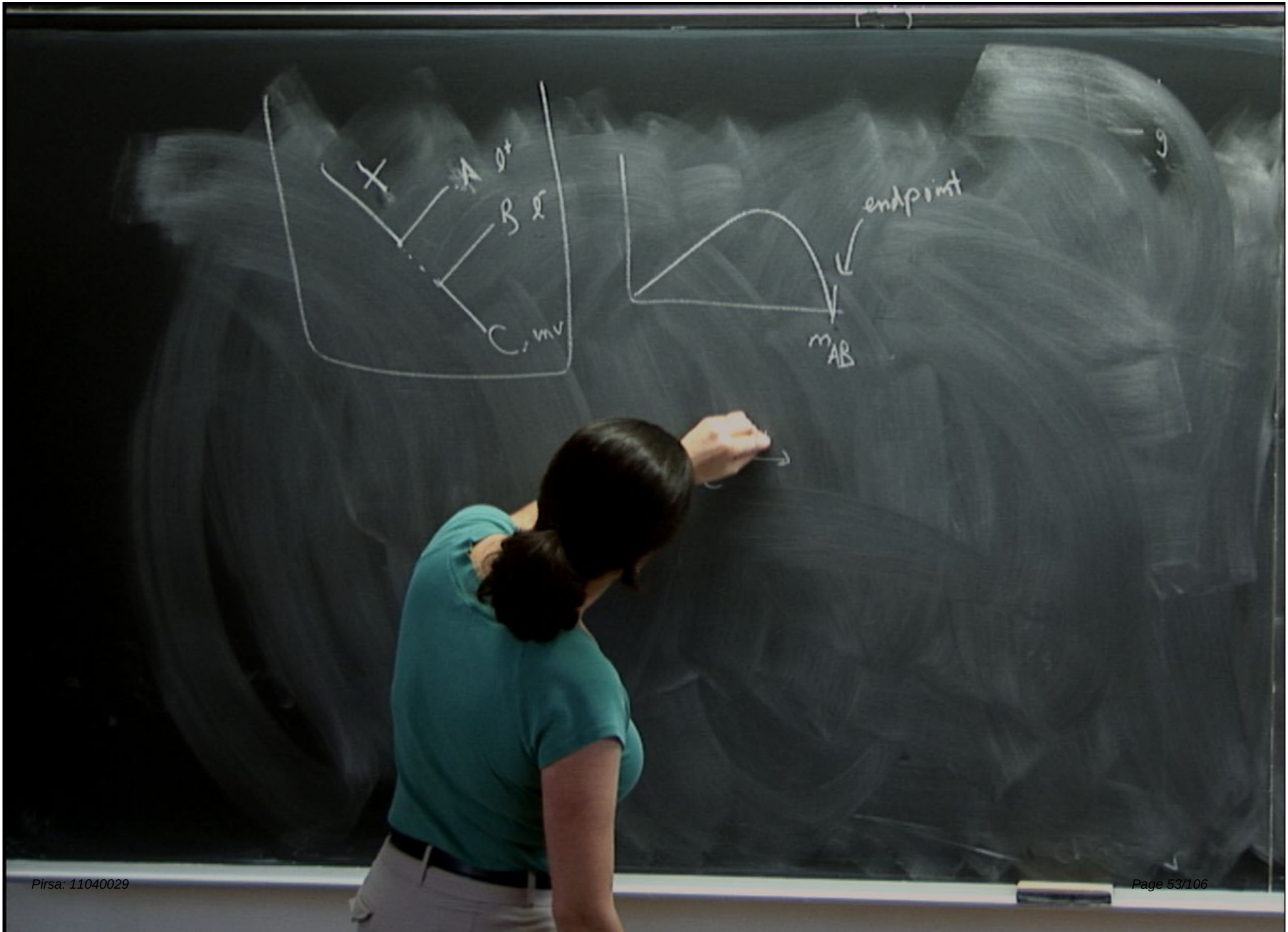
Precision tools

500-1000 GeV particles

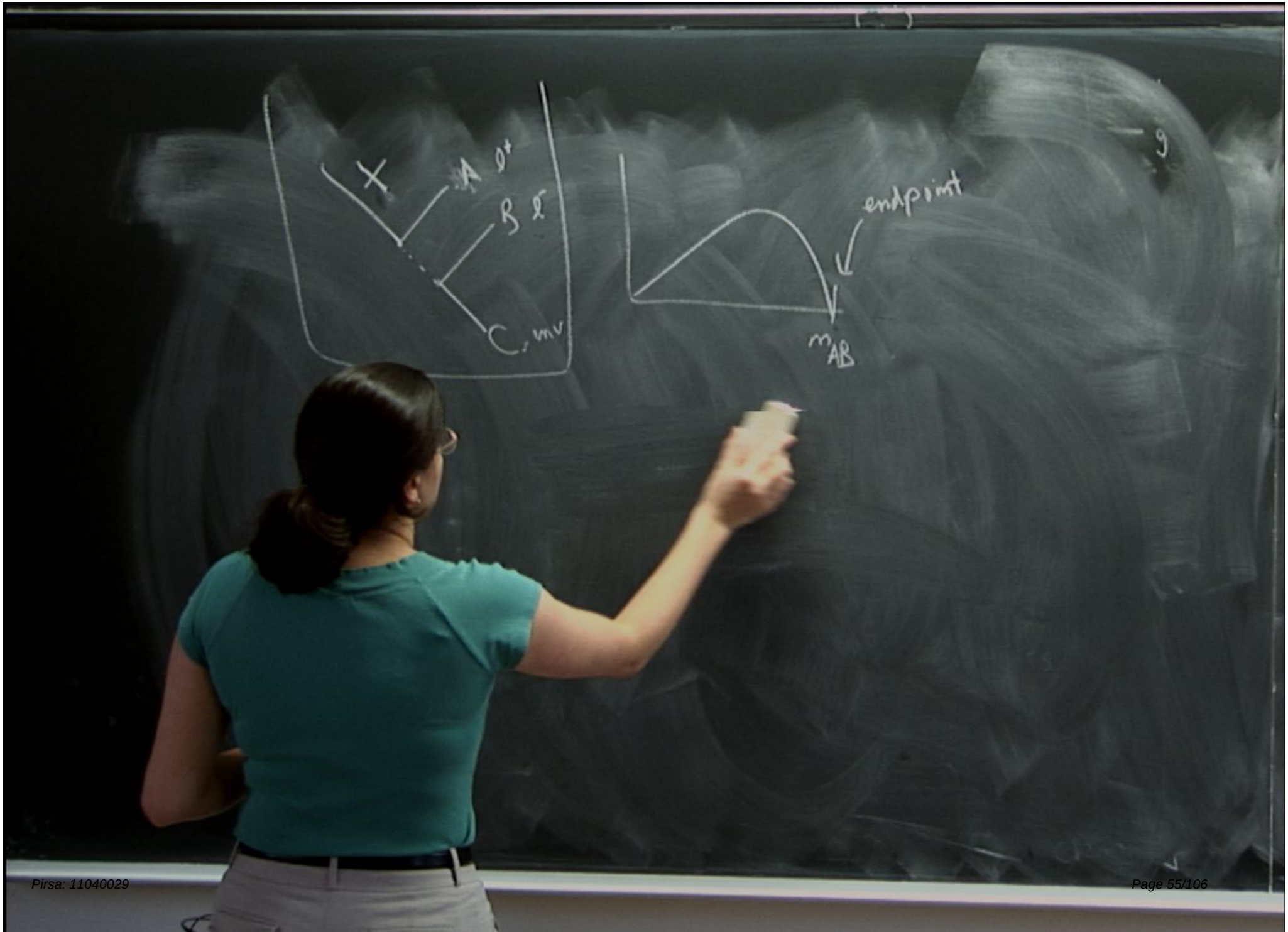



X
A
B

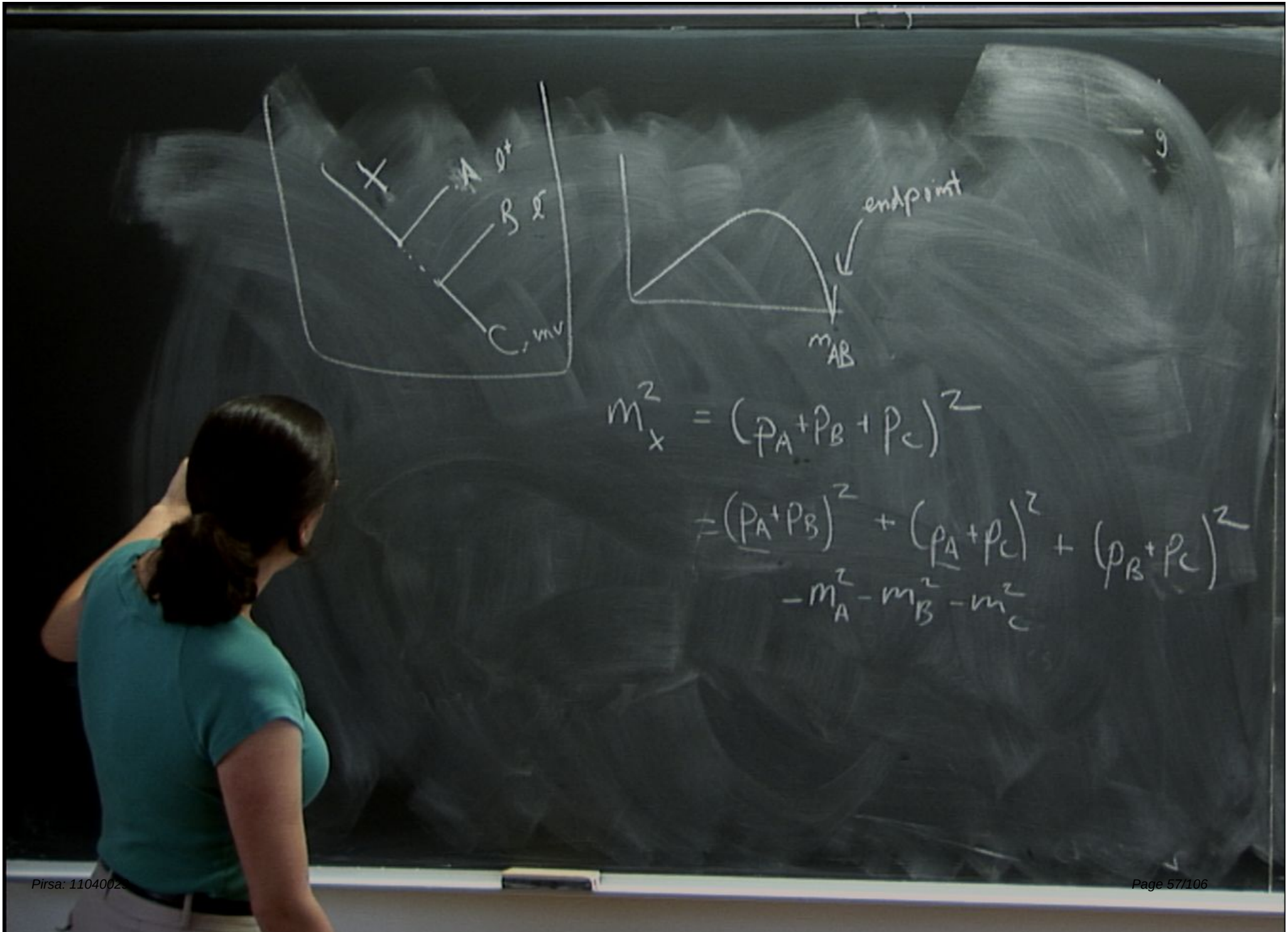

X
A α
B β
C, mv

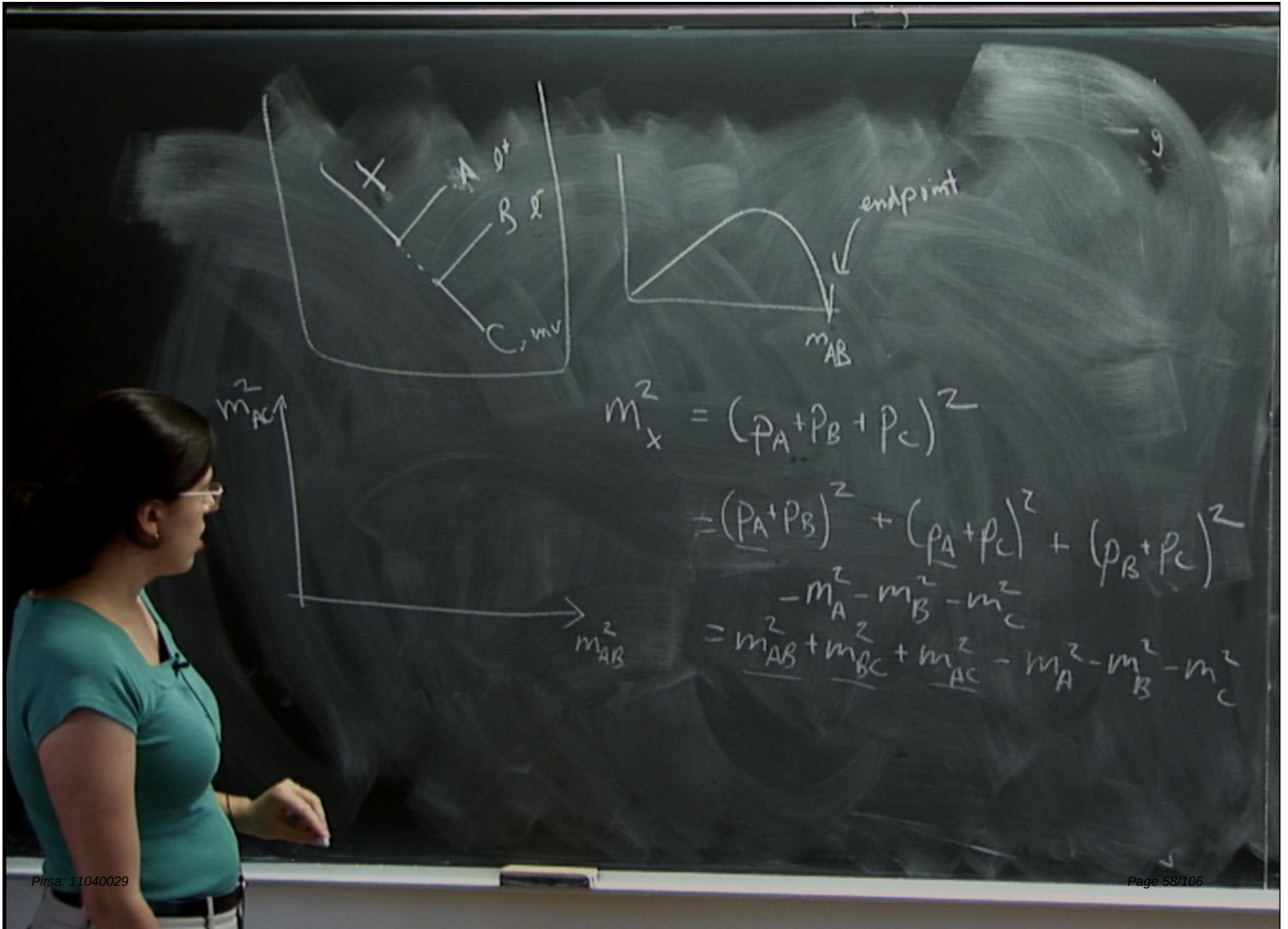

X
A
B
C, mν
endpoint
m_{AB}

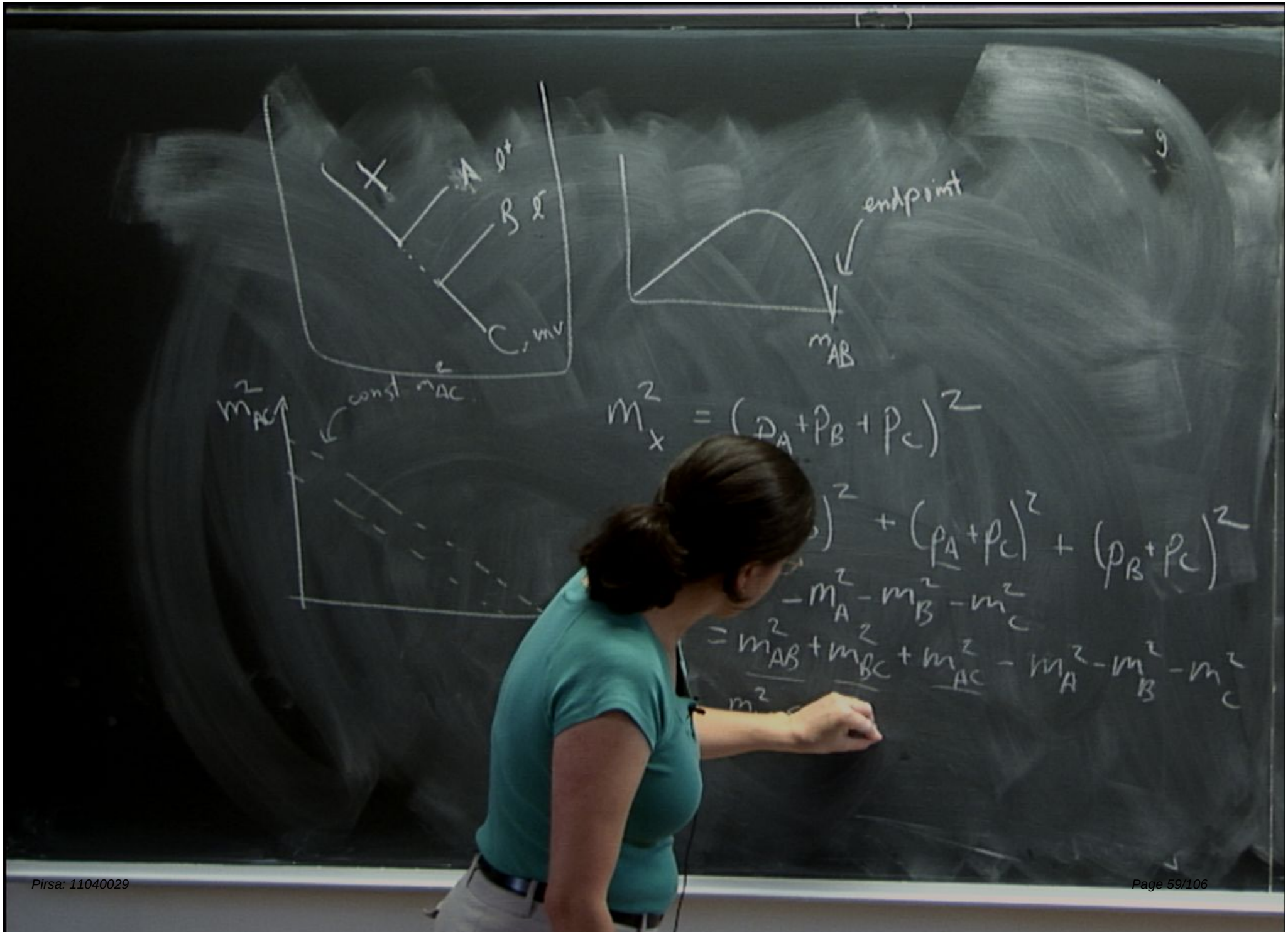

endpoint
A
B
C

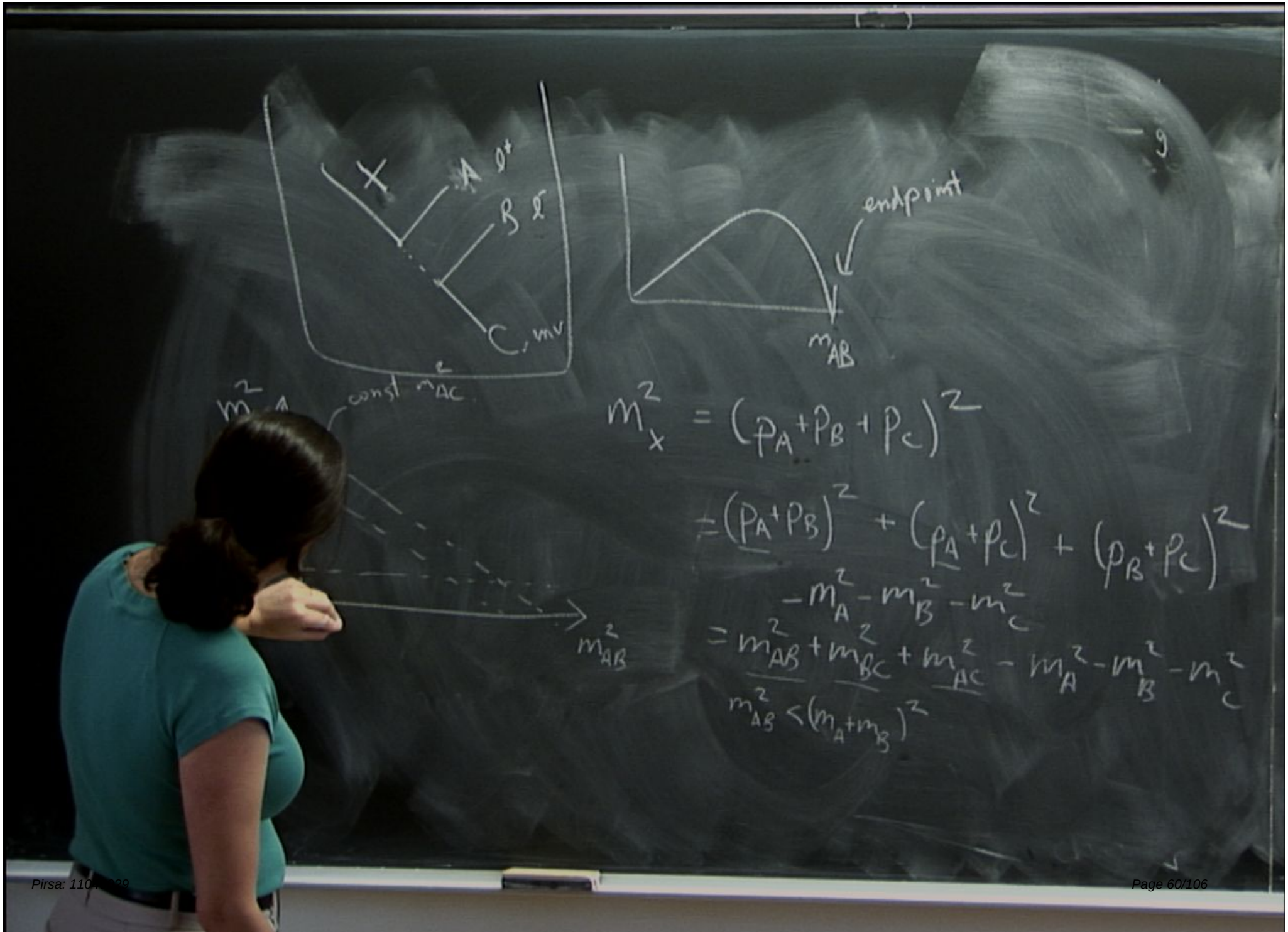

endpoint
m_{AB}

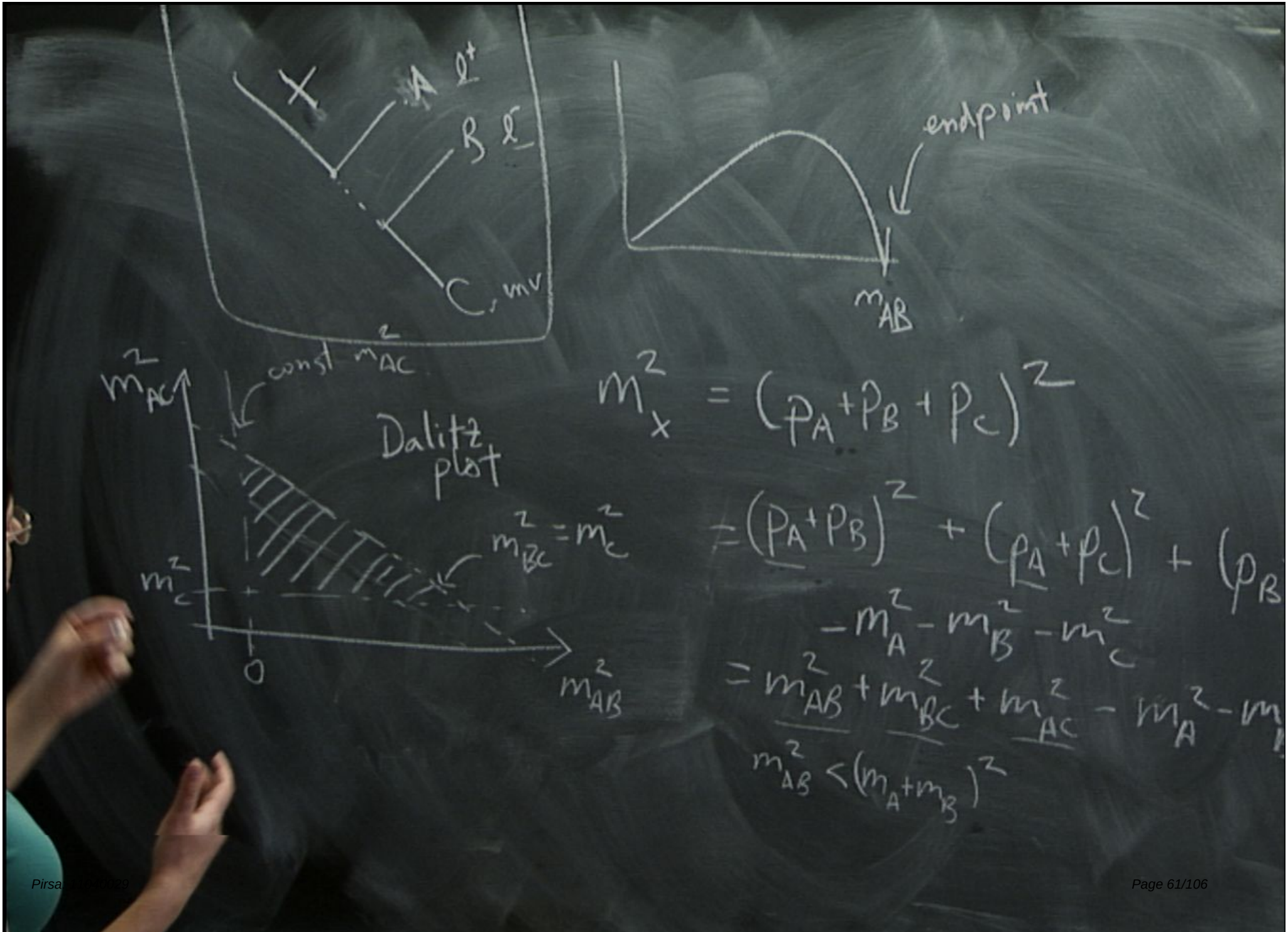

X
A
B
C, inv
endpoint
m_{AB}
$m_X^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$

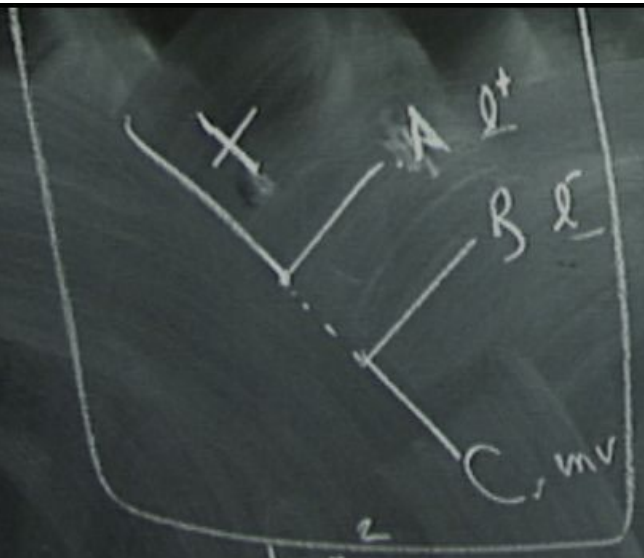

X
A
B
C, mv
endpoint
m_{AB}
$m_X^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$


X
A
B
C, inv
endpoint
m_{AB}
m^2_{AC}
m^2_{AB}
$m_x^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m_B^2 - m_C^2$


endpoint
const m^2_{AC}
m^2_{AC}
m^2_{AB}
$m^2_x = (p_A + p_B + p_C)^2$
$+ (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m^2_{AB} + m^2_{BC} + m^2_{AC} - m_A^2 - m_B^2 - m_C^2$


X
A 0+
B ℓ
C, mν
endpoint
m_{AB}
m^2_{AC}
const
m^2_{AB}
$m_x^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m_B^2 - m_C^2$
$m_{AB}^2 < (m_A + m_B)^2$


X
A ℓ+
B ℓ−
C, mν
endpoint
m_{AB}
m^2_{AC}
const m^2_{AC}
Dalitz plot
$m^2_{BC} = m^2_c$
m^2_c
0
m^2_{AB}
$m_x^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m$
$m_{AB}^2 < (m_A + m_B)^2$



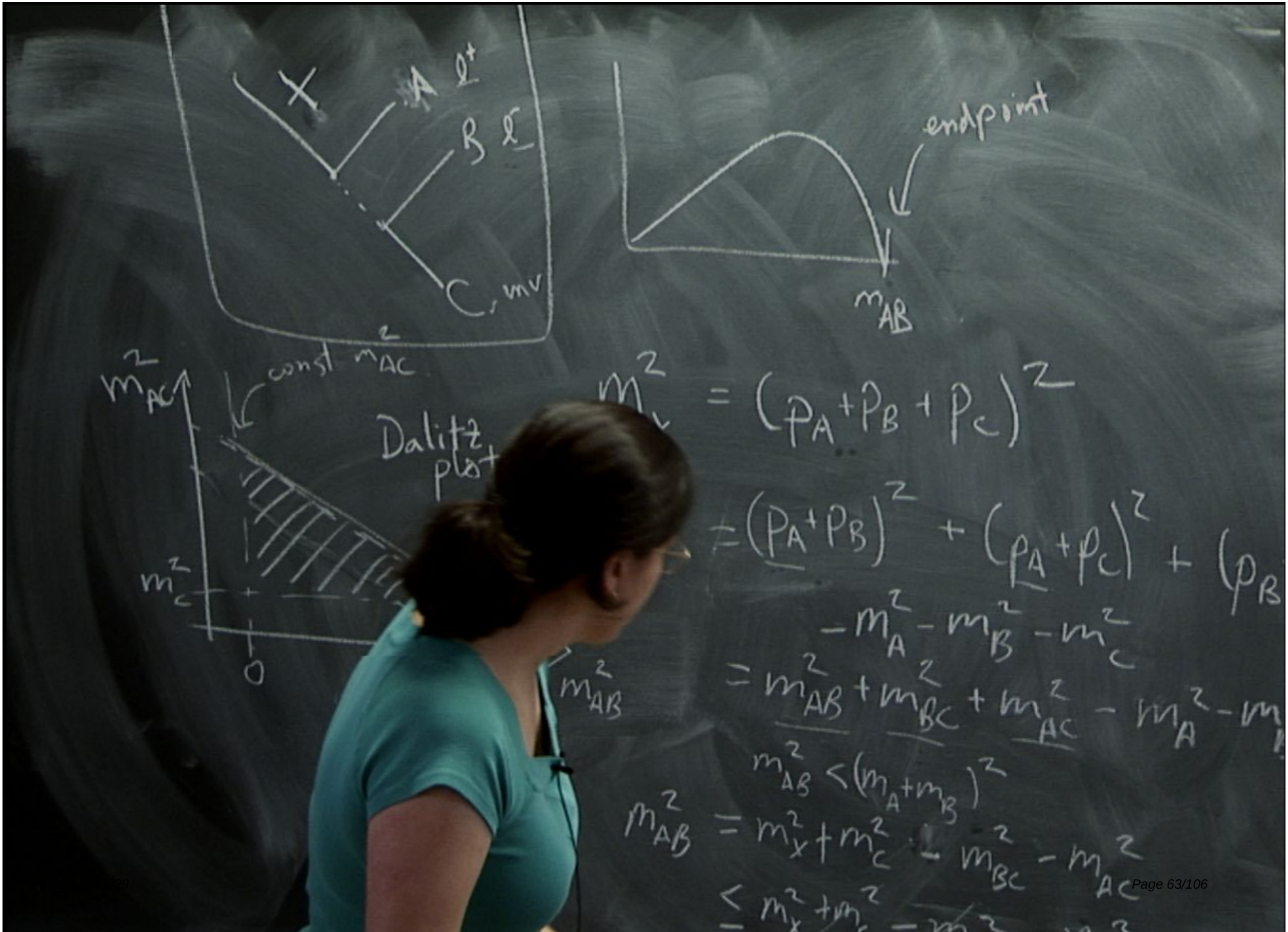
$$m_X^2 = (p_A + p_B + p_C)^2$$

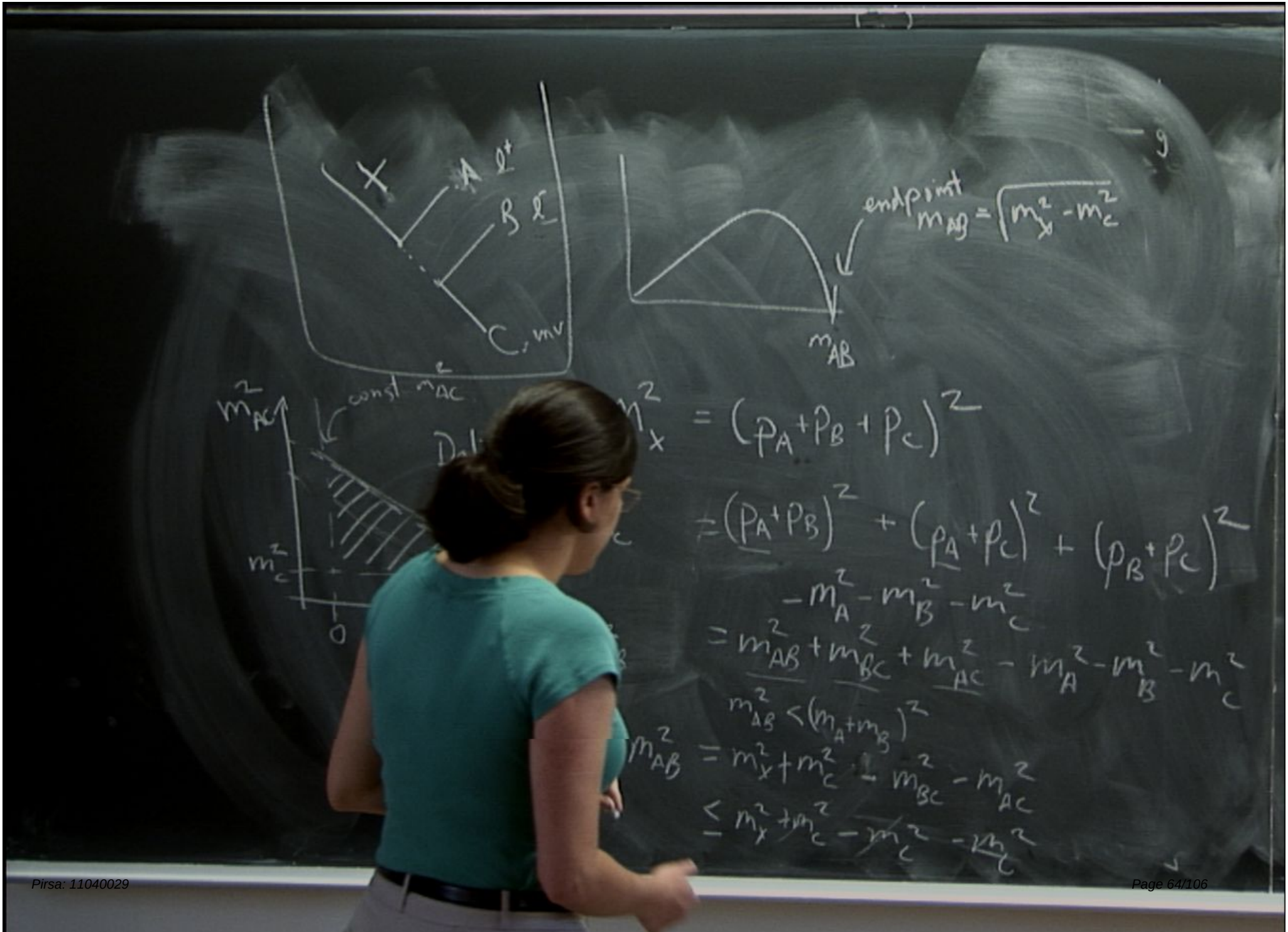
$$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B$$

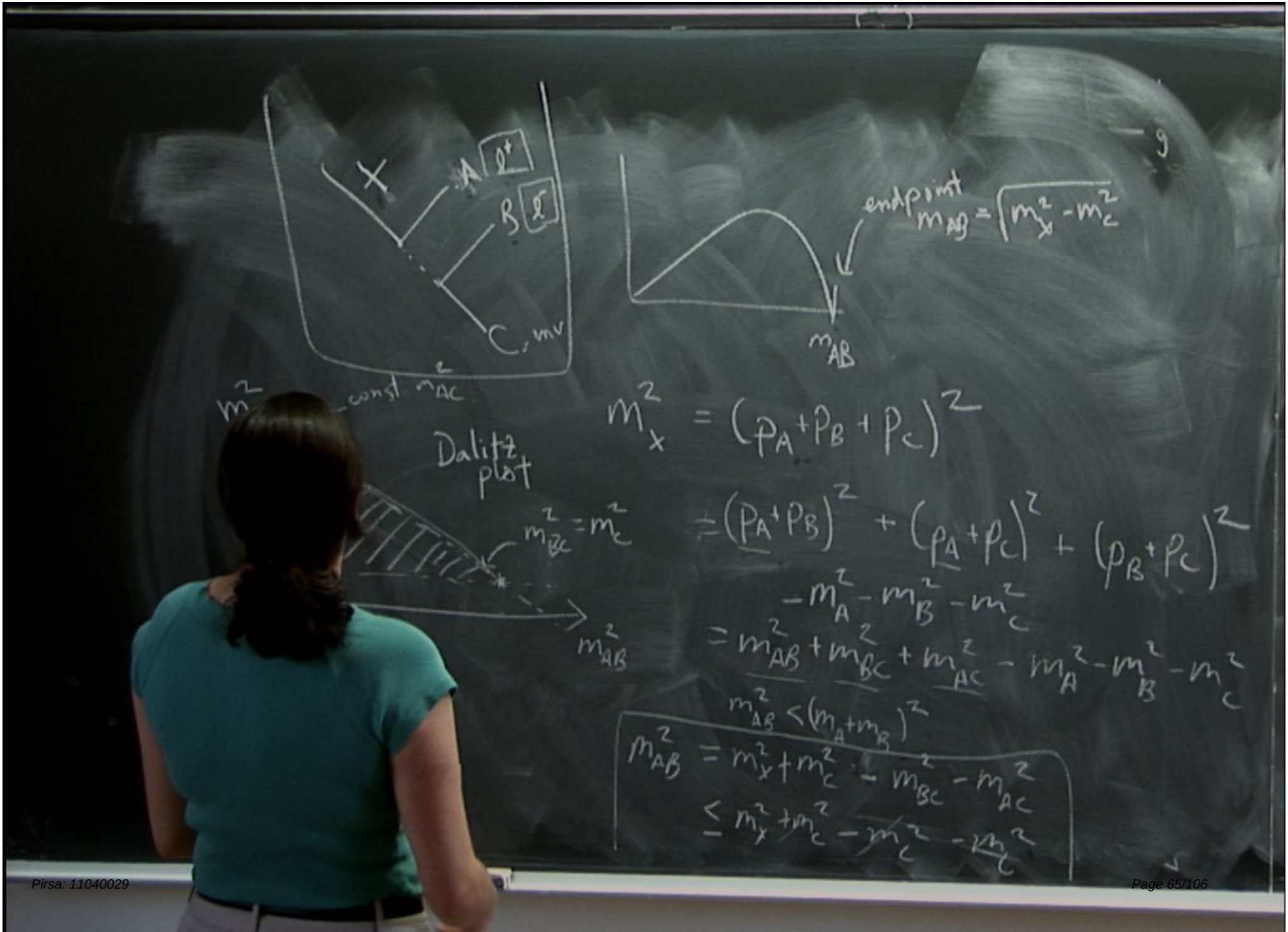
$$- m_A^2 - m_B^2 - m_C^2$$

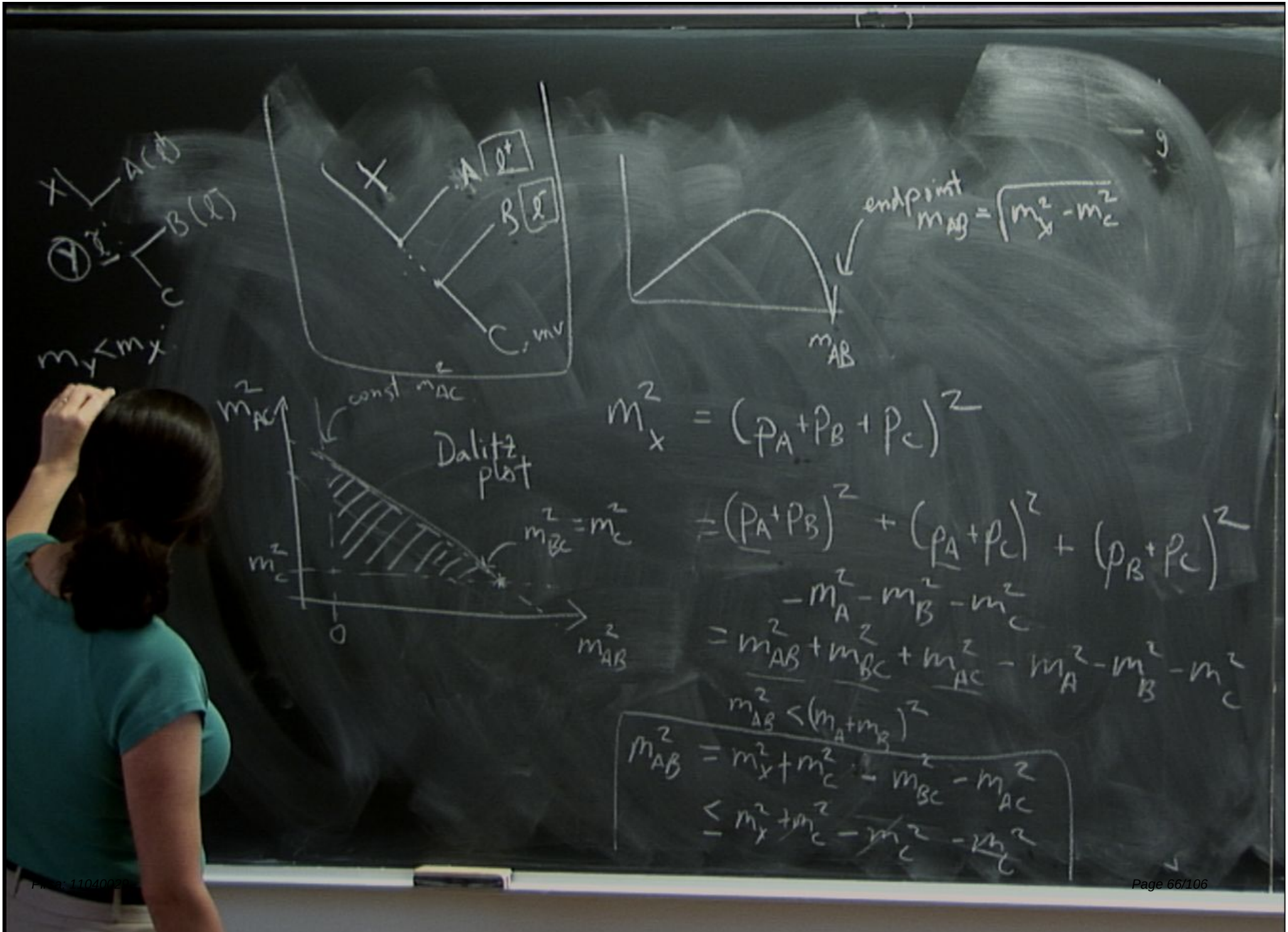
$$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m$$

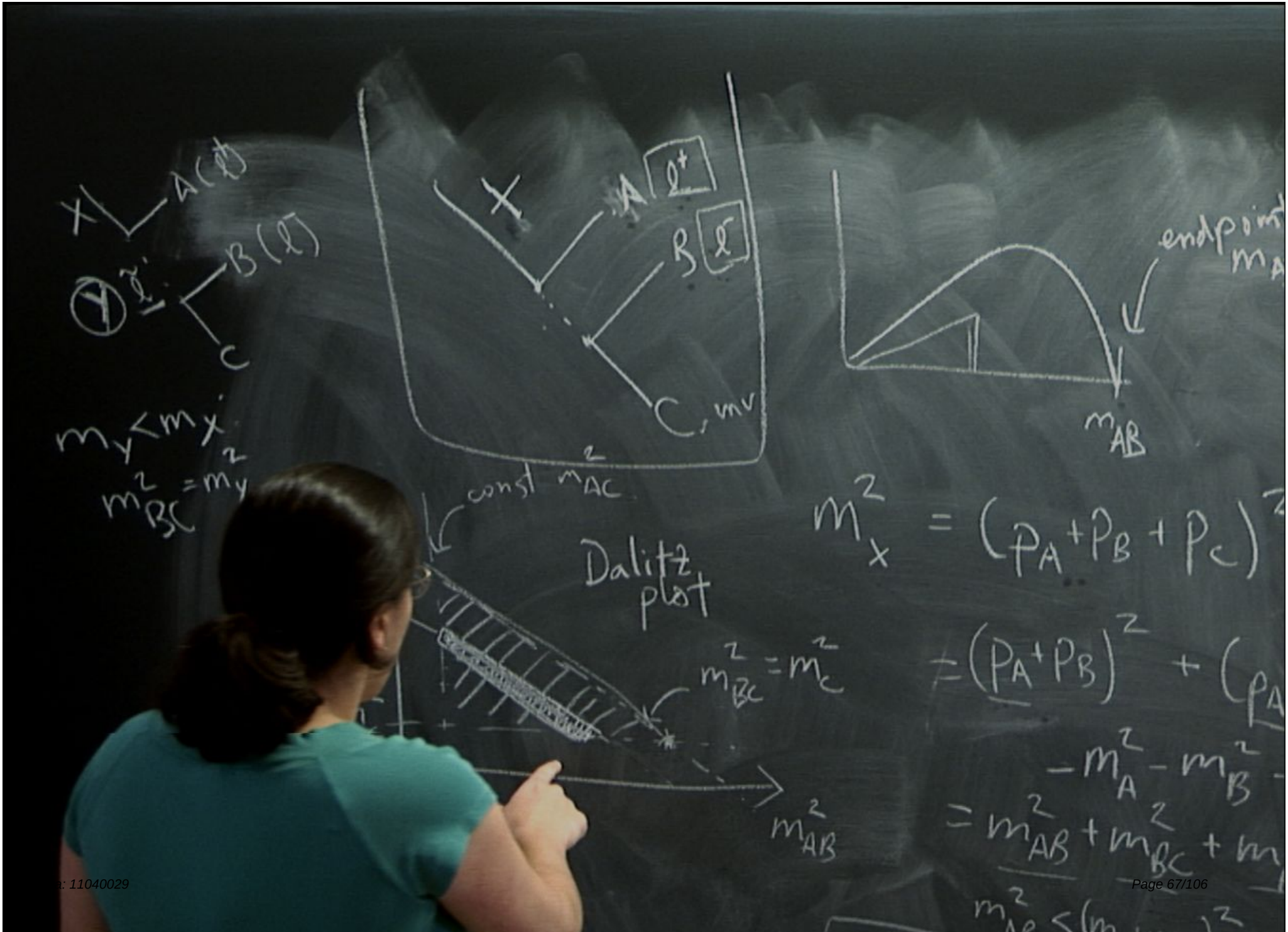
$$m_{AB}^2 < (m_A + m_B)^2$$

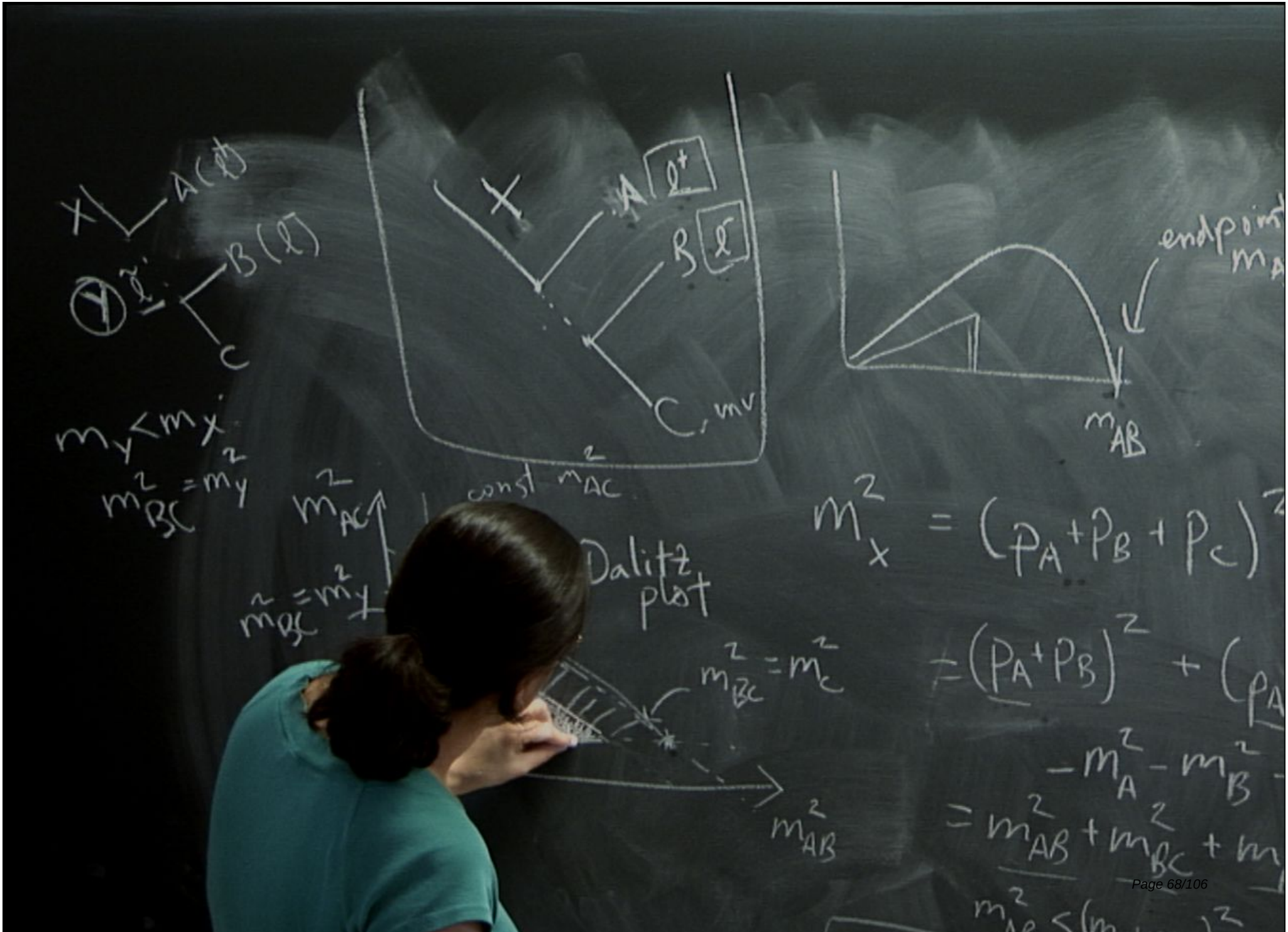

X
A ℓ+
B ℓ-
C, νν
endpoint
m_{AB}
m^2_{AC}
const
m^2_{AC}
Dalitz plot
m^2_C
0
m^2_{AB}
$m^2_{AB} = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B$
$- m_A^2 - m_B^2 - m_C^2$
$= m^2_{AB} + m^2_{BC} + m^2_{AC} - m_A^2 - m$
$m^2_{AB} < (m_A + m_B)^2$
$m^2_{AB} = m_X^2 + m_C^2 - m^2_{BC} - m^2_{AC}$
$\leq m_X^2 + m_C^2$

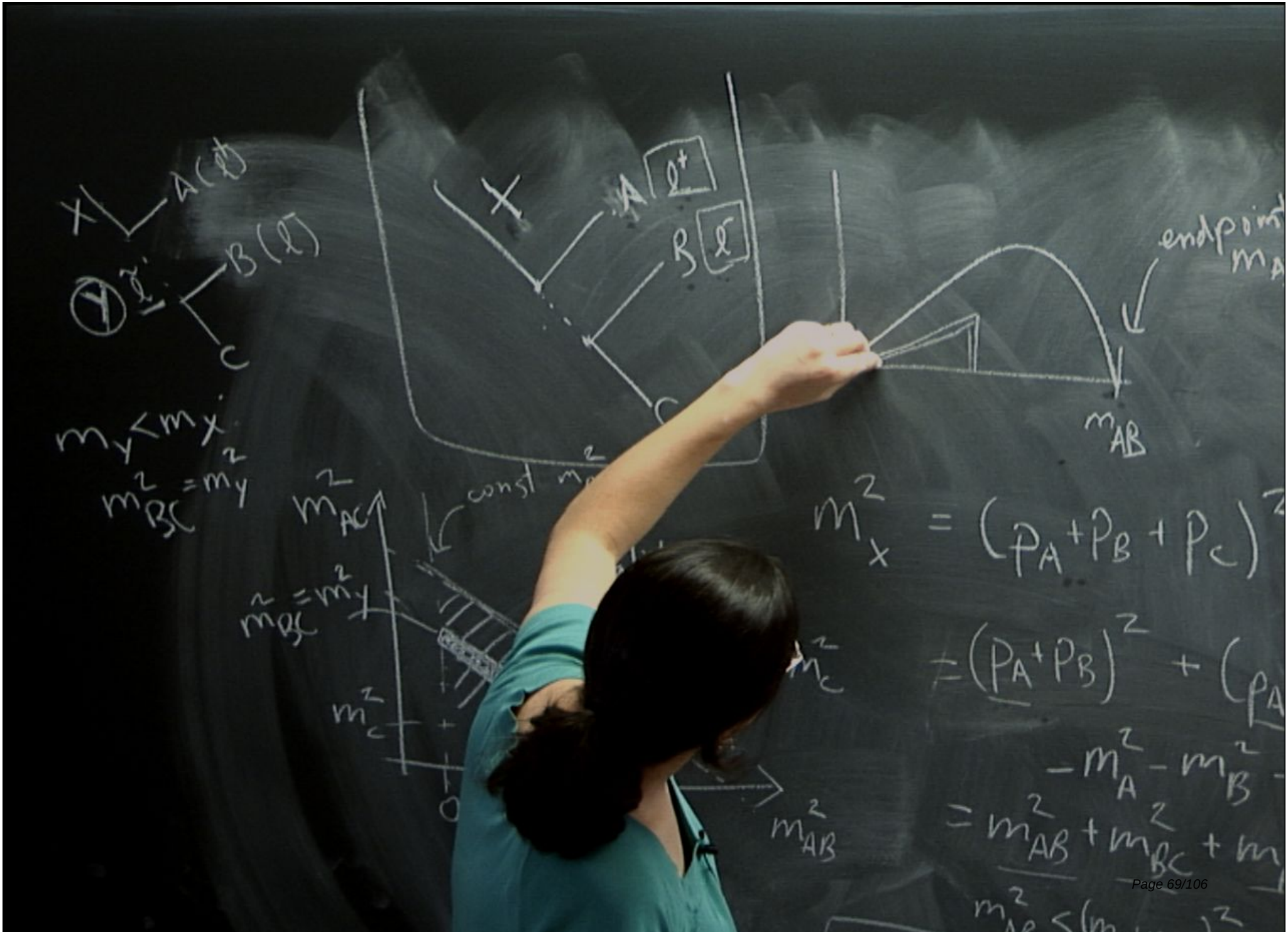

X
A ℓ+
B ℓ−
C, ν
endpoint
$m_{AB} = \sqrt{m_X^2 - m_C^2}$
m_{AB}
m_{AC}^2
const m_{AC}
m_C^2
0
$m_X^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m_B^2 - m_C^2$
$m_{AB}^2 < (m_A + m_B)^2$
$m_{AB}^2 = m_X^2 + m_C^2 - m_{BC}^2 - m_{AC}^2$
$\leq m_X^2 + m_C^2 - m_C^2 - m_C^2$

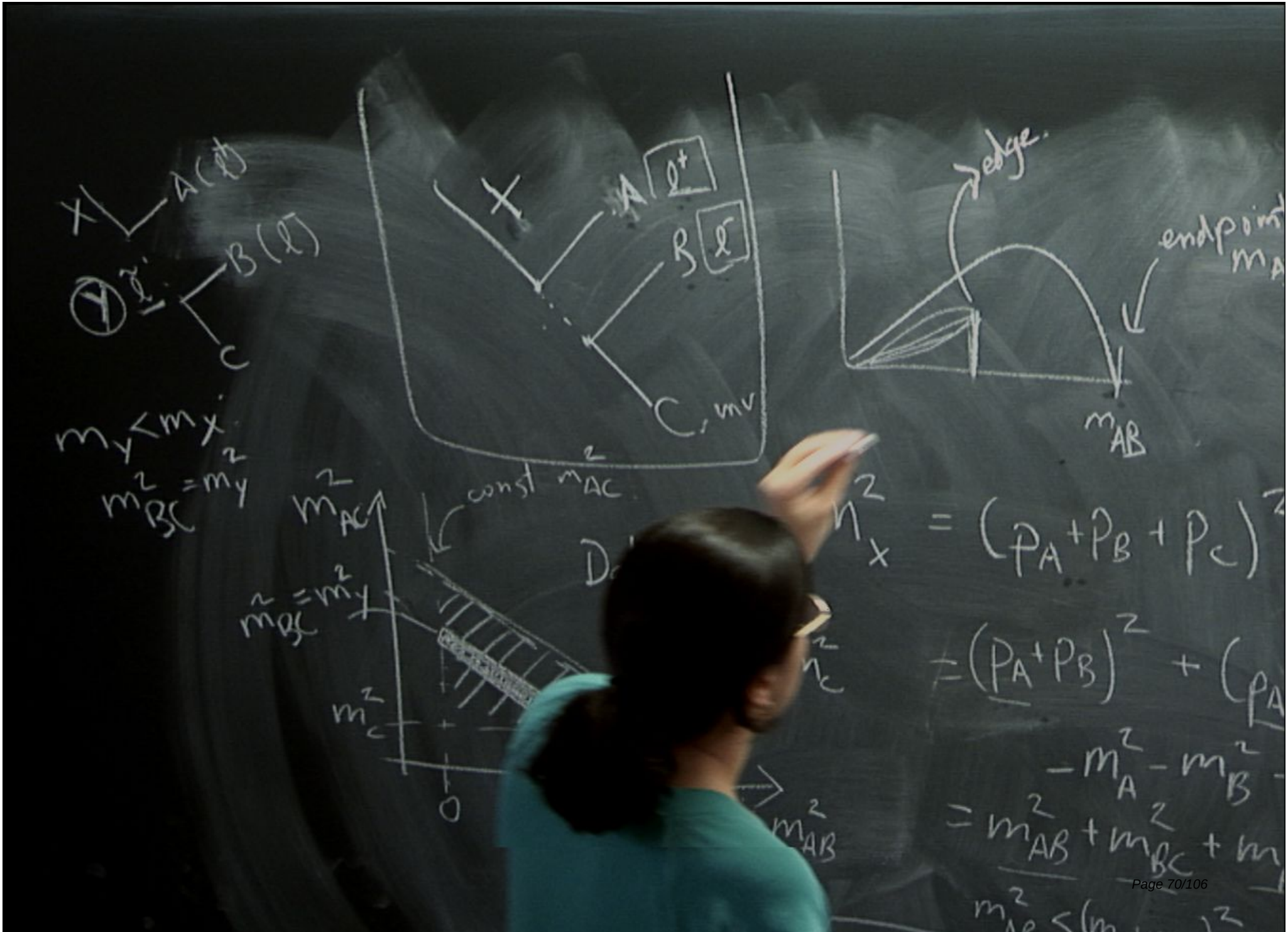

X
A
B
C, mν
endpoint
$m_{AB} = \sqrt{m_X^2 - m_C^2}$
m_{AB}
const m_{AC}^2
Dalitz plot
$m_{BC}^2 = m_C^2$
m_{AB}^2
$m_X^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m_B^2 - m_C^2$
$m_{AB}^2 \leq (m_A + m_B)^2$
$m_{AB}^2 = m_X^2 + m_C^2 - m_{BC}^2 - m_{AC}^2$
$\leq m_X^2 + m_C^2 - m_C^2 - m_C^2$

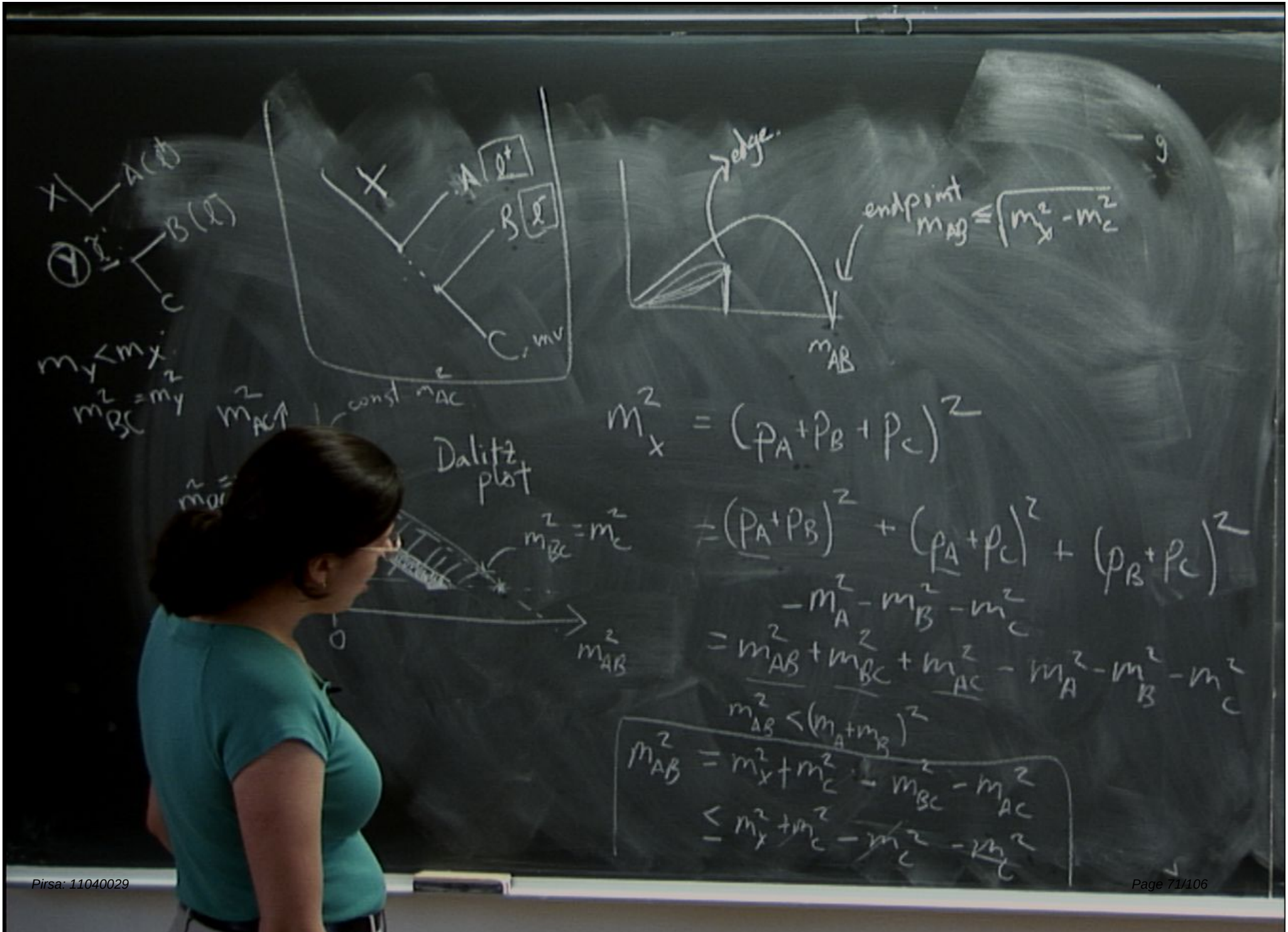

endpoint
$m_{AB} = \sqrt{m_X^2 - m_C^2}$
m_{AB}
$m_Y < m_X$
const m_{AC}^2
Dalitz plot
m_{AC}^2
$m_{BC}^2 = m_C^2$
m_C^2
0
m_{AB}^2
$m_X^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m_B^2 - m_C^2$
$m_{AB}^2 \le (m_A + m_B)^2$
$m_{AB}^2 = m_X^2 + m_C^2 - m_{BC}^2 - m_{AC}^2$
$\le m_X^2 + m_C^2 - m_C^2 - m_C^2$

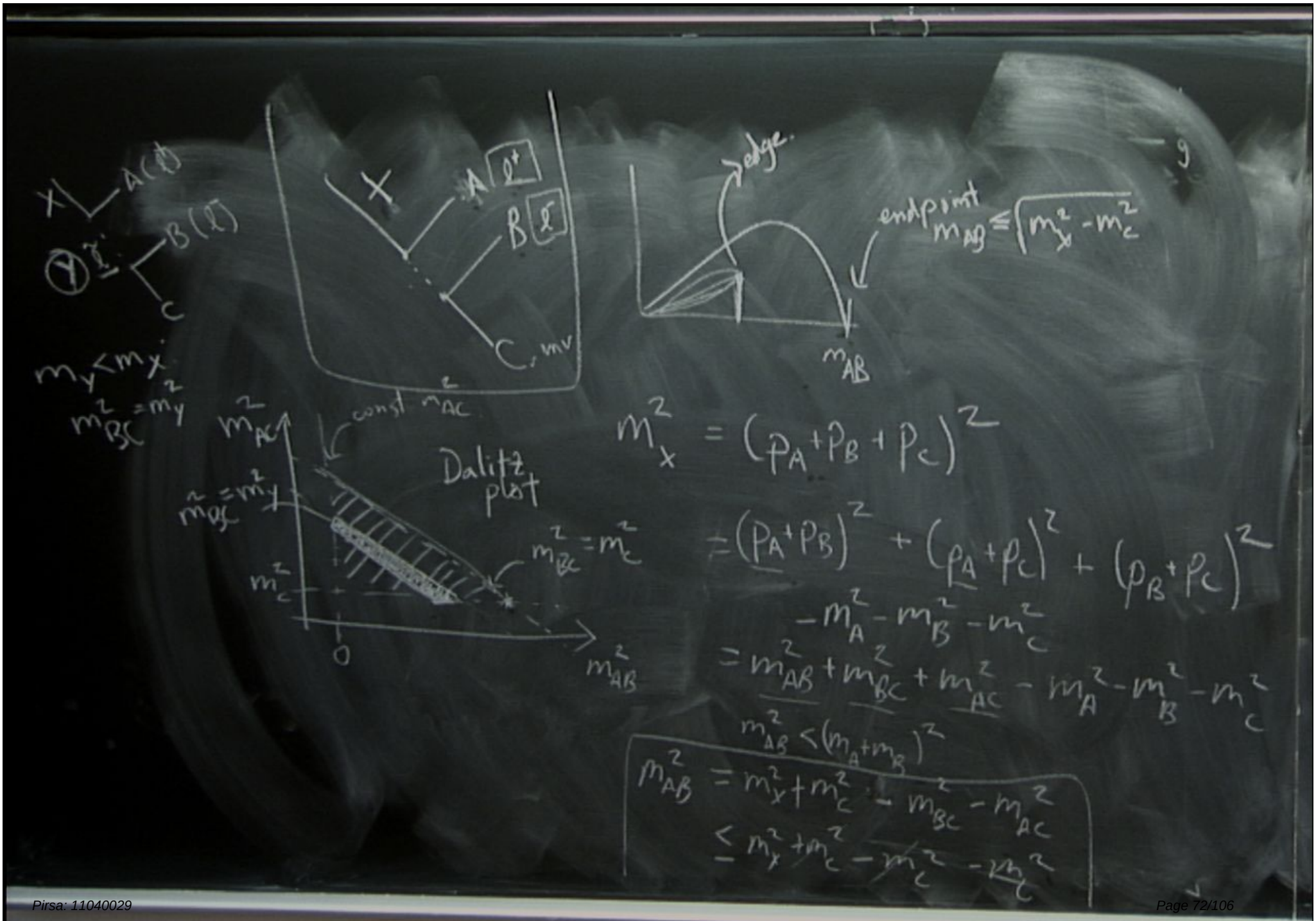

endpoint
Dalitz plot
const
m_{AB}
m_{BC}
$m_X^2 = (p_A + p_B + p_C)$
$= (p_A + p_B)^2 + (p_A$
$= m_{AB}^2 + m_{BC}^2 + m$

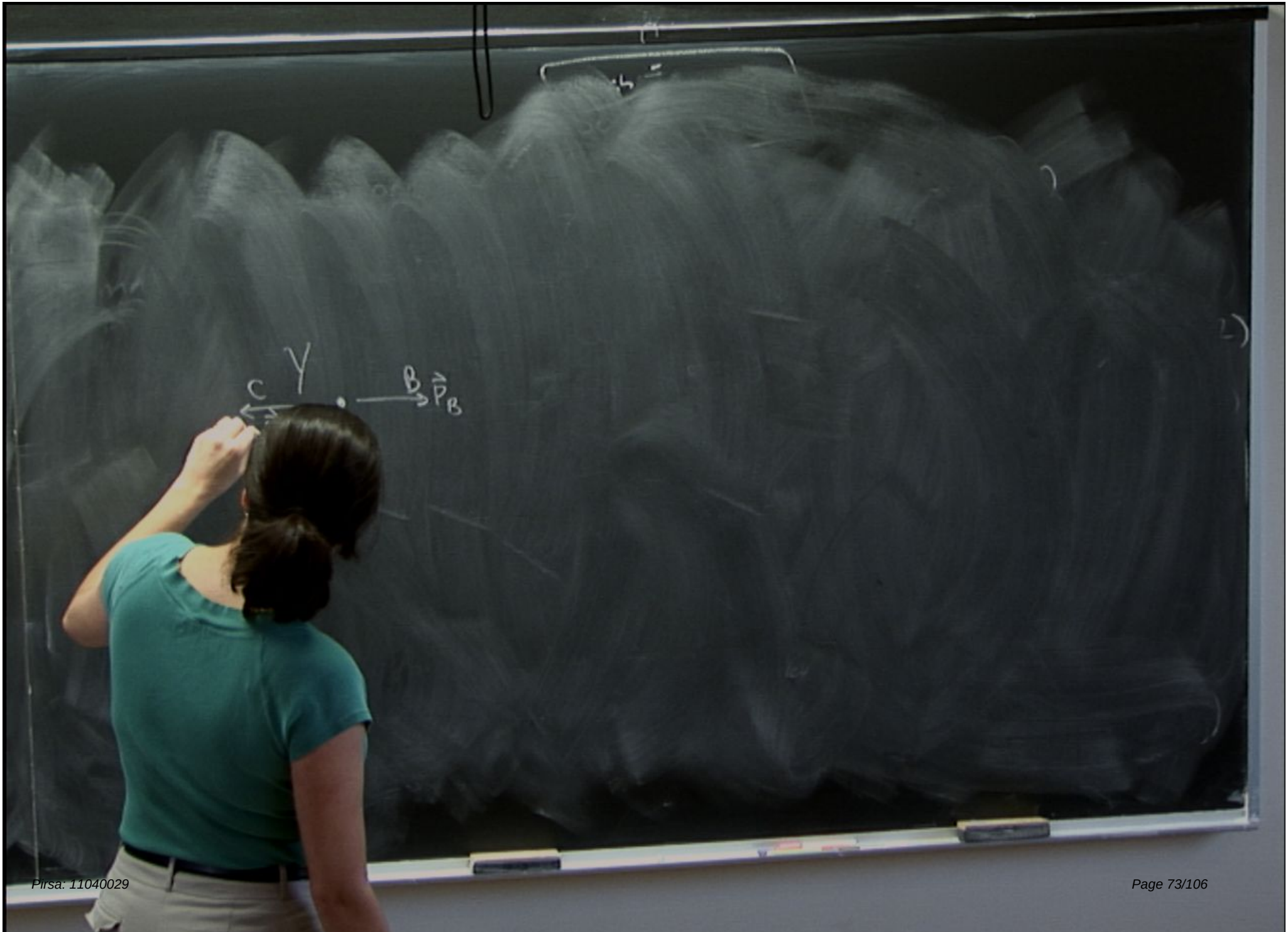

X
A(ℓ)
B(ℓ)
C
$m_Y < m_X$
$m^2_{BC} = m^2_Y$
X
A
ℓ⁺
B
ℓ⁻
C, mν
m^2_{AC}
const
endpoint
m_A
m_{AB}
m^2_{AC}
$m^2_{BC} = m^2_Y$
Dalitz plot
$m^2_{BC} = m^2_C$
m^2_{AB}
$m^2_X = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A$
$- m^2_A - m^2_B$
$= m^2_{AB} + m^2_{BC} + m$

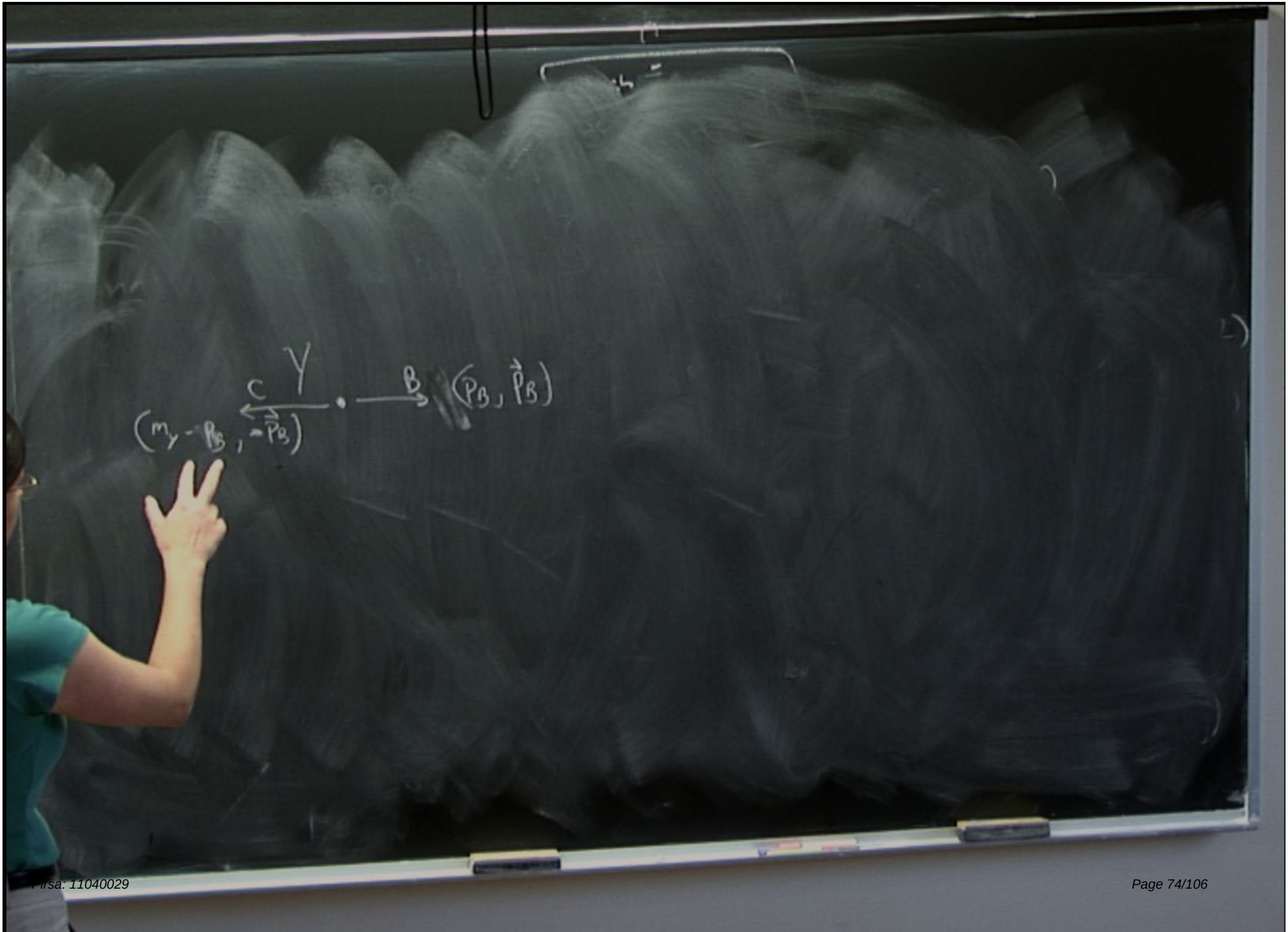

endpoint
m_{AB}
$m_{BC}^2 = m_Y^2$
$m_Y < m_X$
m_{AC}^2
m_{AB}^2
$m_X^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A$
$= m_{AB}^2 + m_{BC}^2 + m$

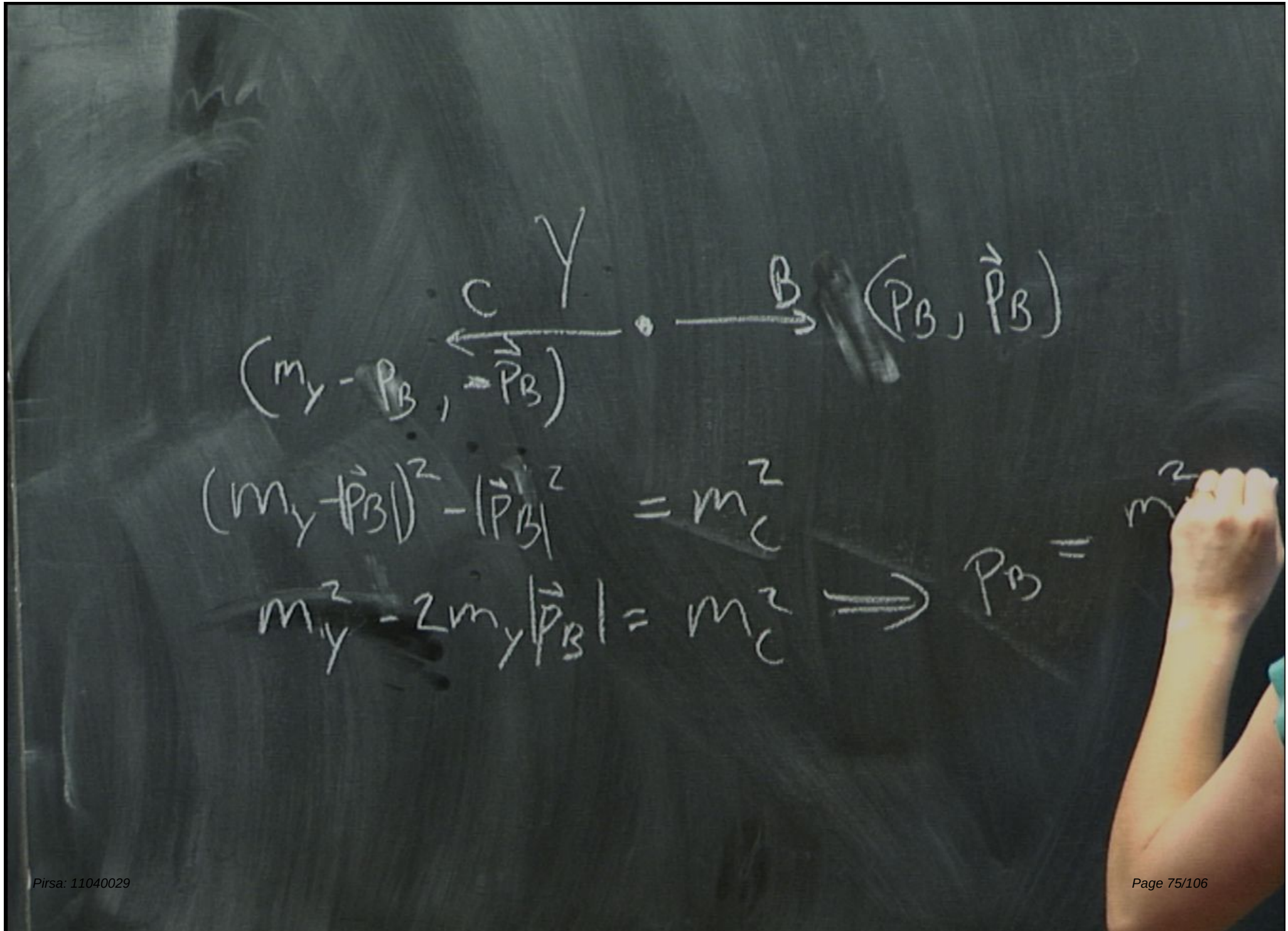

A(ℓ)
B(ℓ)
C
X
A ℓ
B ℓ
C, mv
edge
endpoint
m_{AB}
$m_Y < m_X$
$m^2_{BC} = m^2_Y$
m^2_{AC}
const
m^2_{AC}
$m^2_{BC} = m^2_Y$
m^2_C
0
m^2_{AB}
$m^2_X = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A$
$- m^2_A - m^2_B$
$= m^2_{AB} + m^2_{BC} + m$

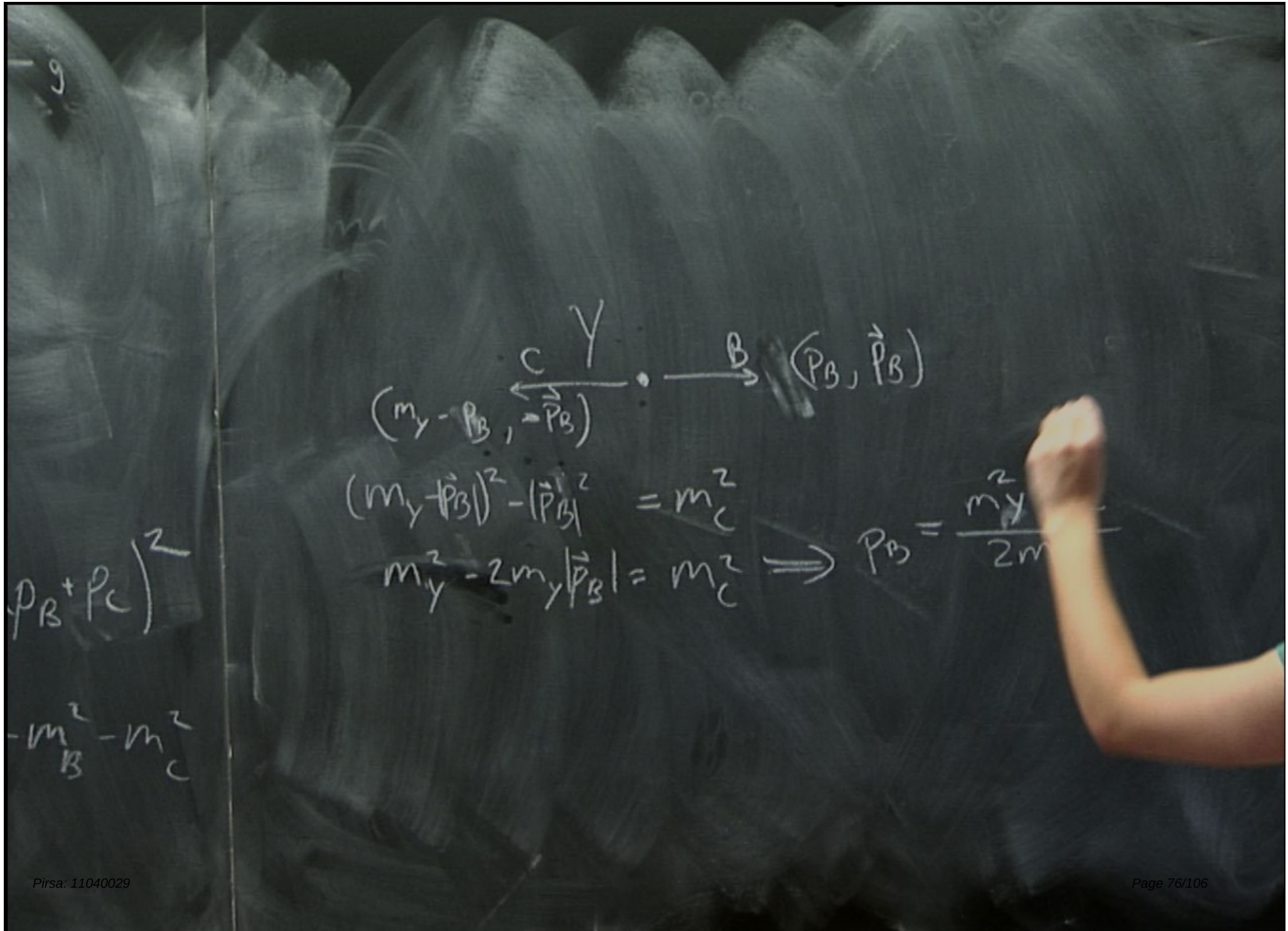

edge
endpoint
$m_{AB} \leq \sqrt{m_X^2 - m_C^2}$
m_{AB}
Dalitz plot
$m_{BC}^2 = m_C^2$
m_{AB}^2
$m_X^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m_B^2 - m_C^2$
$m_{AB}^2 \leq (m_A + m_B)^2$
$m_{AB}^2 = m_X^2 + m_C^2 - m_{BC}^2 - m_{AC}^2$
$\leq m_X^2 + m_C^2 - m_C^2 - m_C^2$

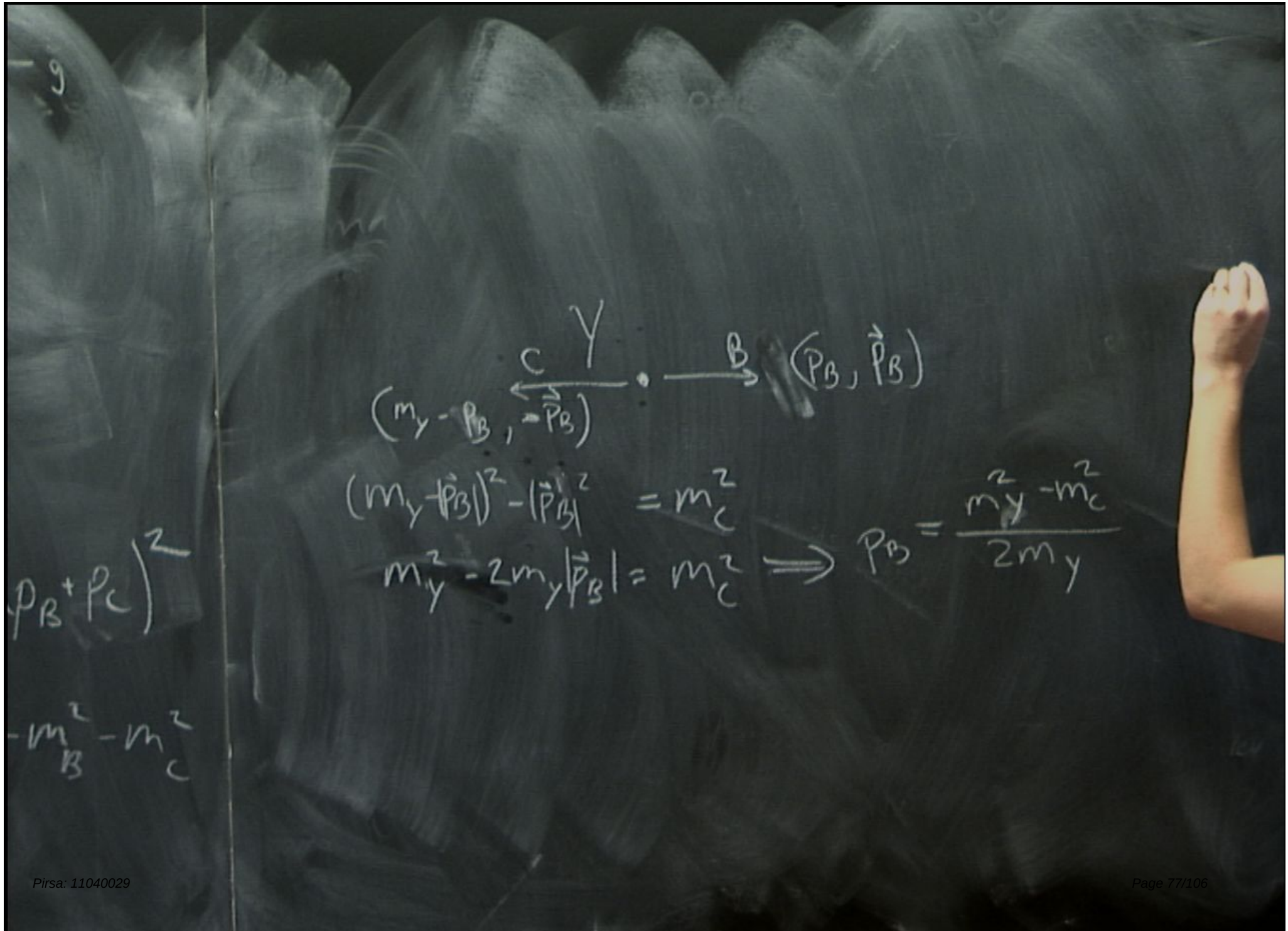

X
A(l)
B(l)
C
$m_Y < m_X$
$m^2_{BC} = m^2_Y$
X
A l^+
B l^-
C, ν_{MU}
m^2_{AC}
edge
endpoint
$m_{AB} \leq \sqrt{m_X^2 - m_C^2}$
m_{AB}
const m^2_{AC}
Dalitz plot
$m^2_{BC} = m^2_Y$
$m^2_{BC} = m^2_C$
m^2_C
0
m^2_{AB}
$m_X^2 = (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m_B^2 - m_C^2$
$m_{AB}^2 < (m_A + m_B)^2$
$m_{AB}^2 = m_X^2 + m_C^2 - m_{BC}^2 - m_{AC}^2$
$\leq m_X^2 + m_C^2 - m_C^2 - m_C^2$

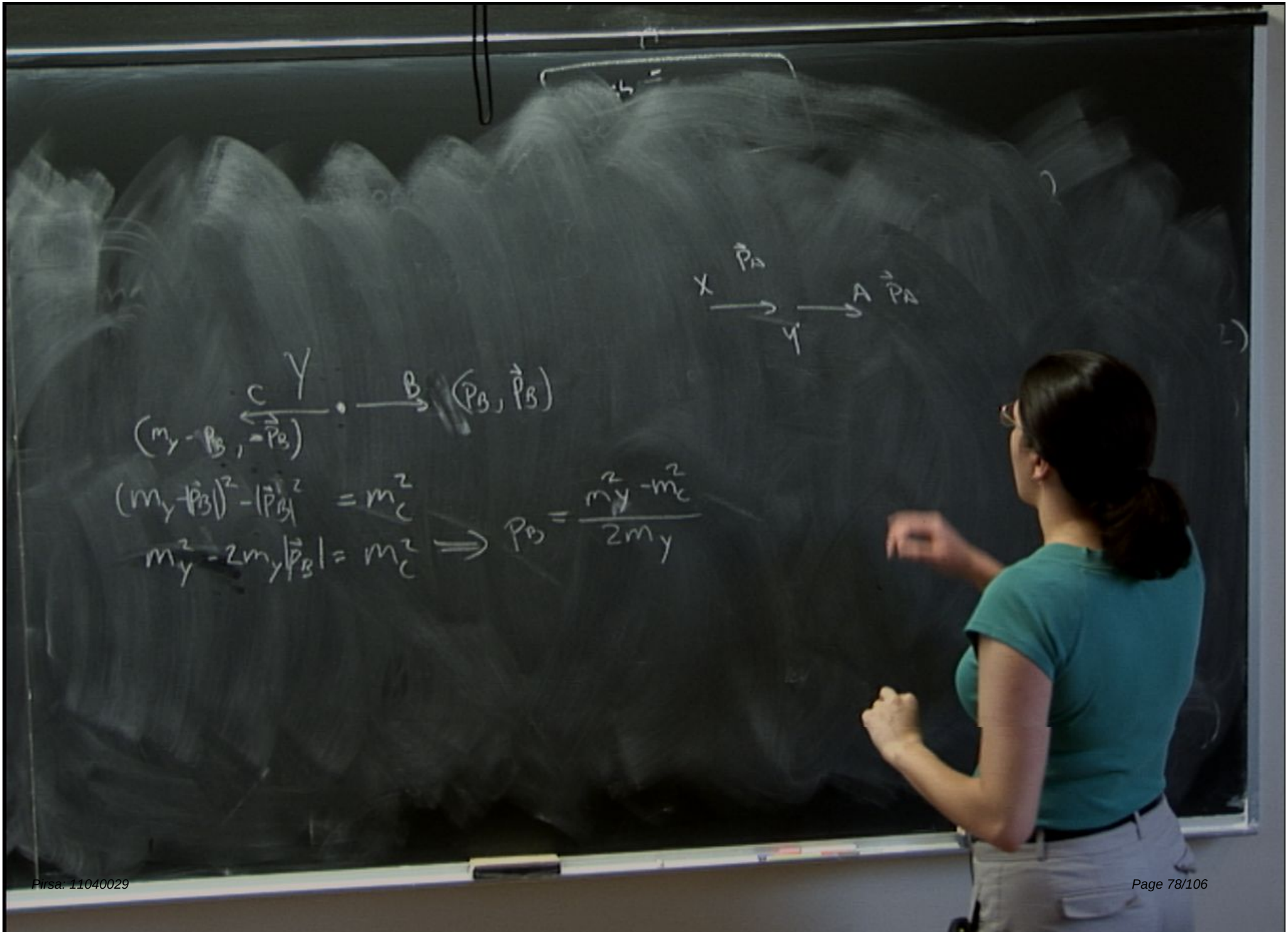

γ
B
$\vec{p}_B$

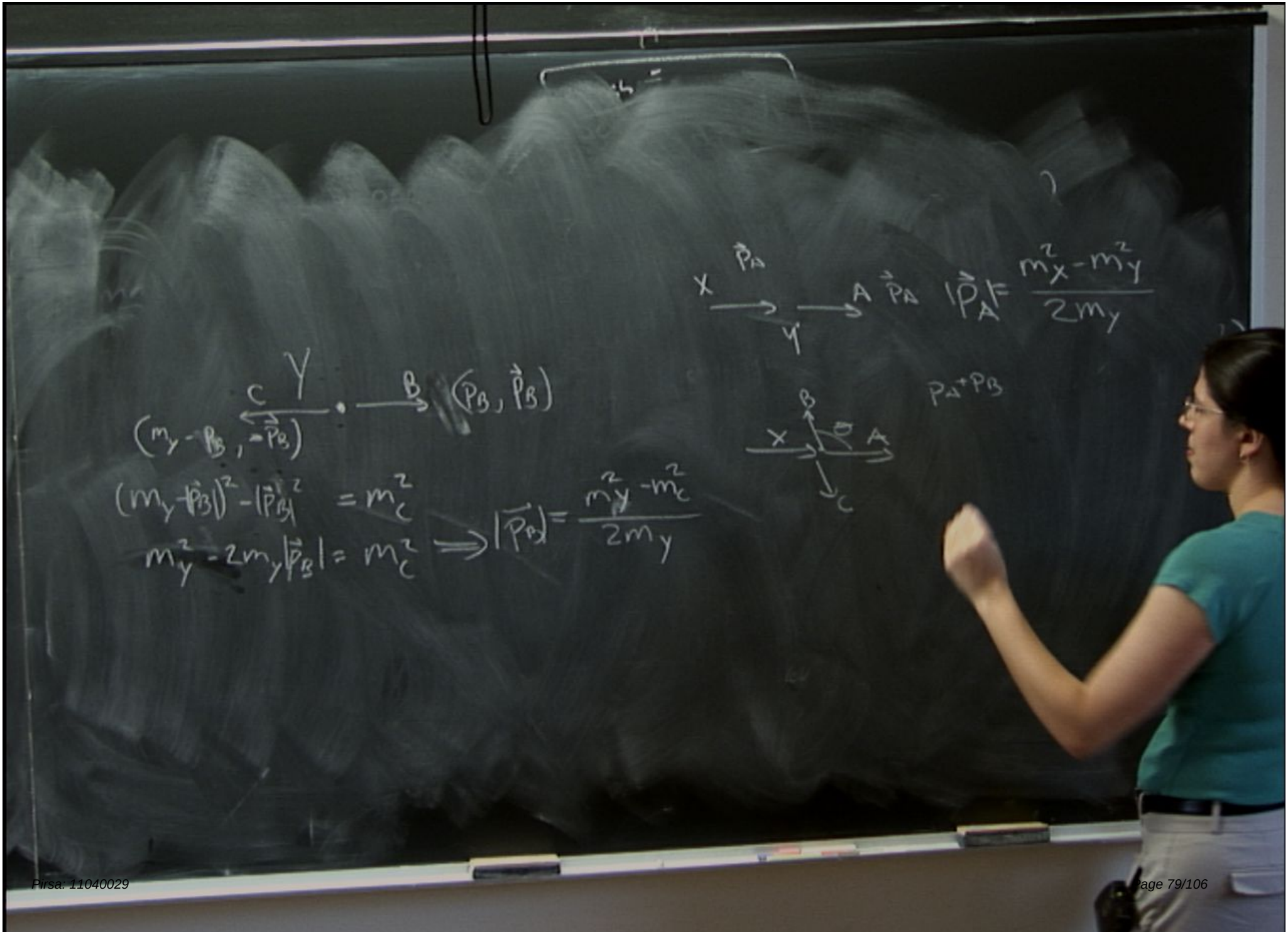

C
Y
B
$(E_B, \vec{P}_B)$
$(m_Y - E_B, -\vec{P}_B)$

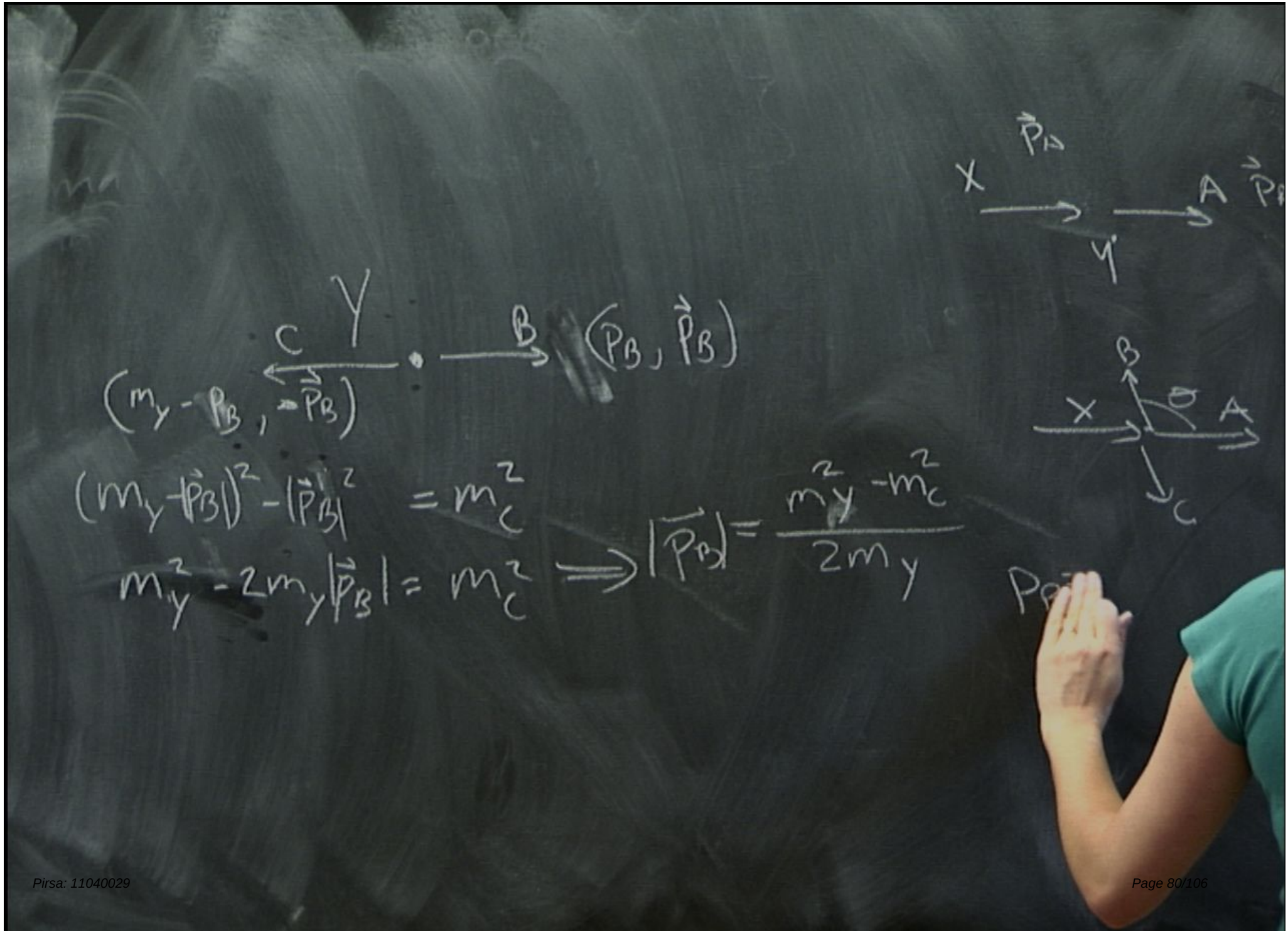

C
γ
B
$(P_B, \vec{P}_B)$
$(m_Y - P_B, -\vec{P}_B)$
$(m_Y - |\vec{P}_B|)^2 - |\vec{P}_B|^2 = m_C^2$
$m_Y^2 - 2m_Y|\vec{P}_B| = m_C^2 \Rightarrow P_B =$

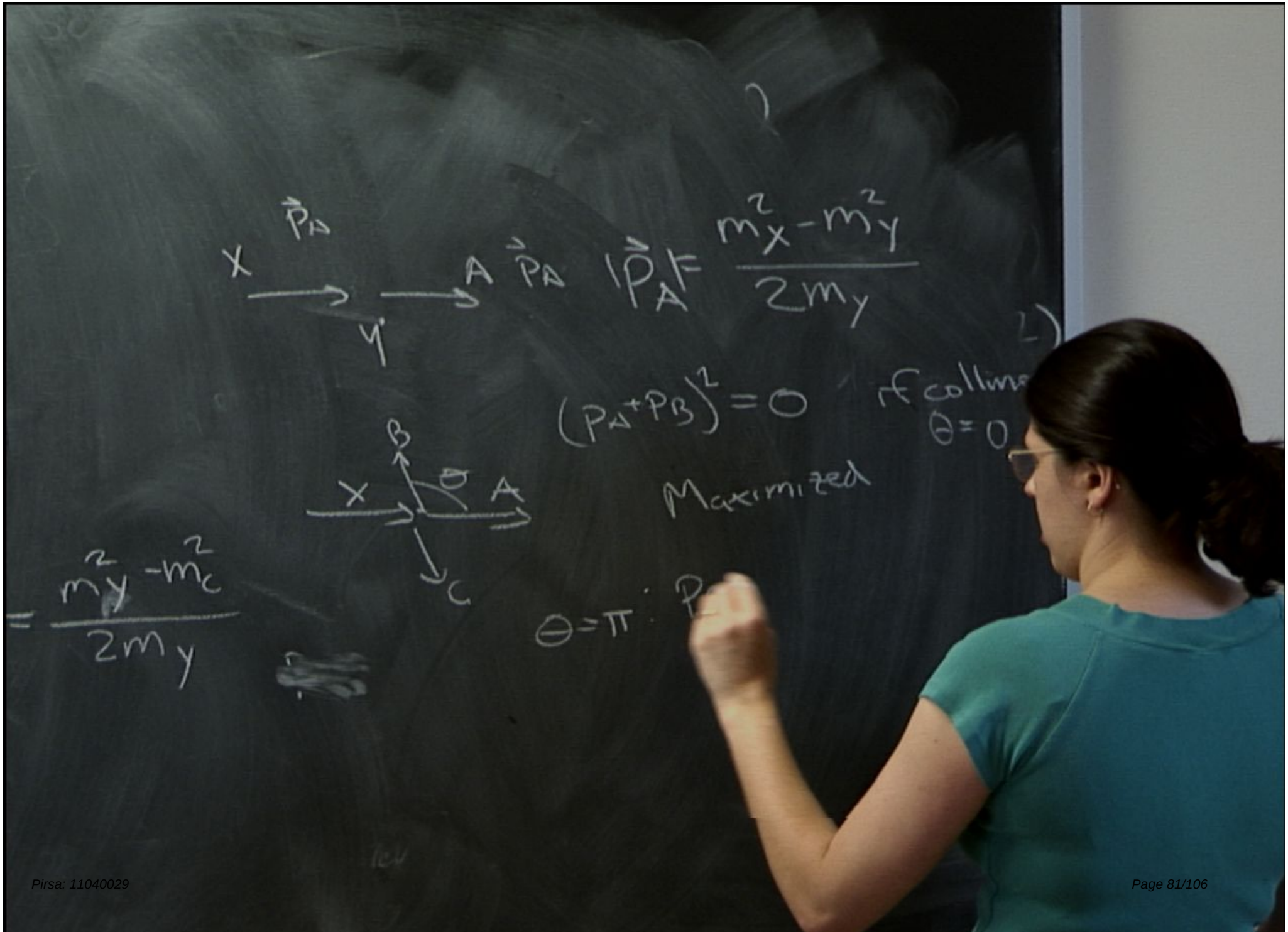

9
C
Y
B
$(\vec{p}_B, \vec{p}_B)$
$(m_Y - p_B, -\vec{p}_B)$
$(m_Y - |\vec{p}_B|)^2 - |\vec{p}_B|^2 = m_C^2$
$m_Y^2 - 2m_Y|\vec{p}_B| = m_C^2 \Rightarrow p_B =$
$p_B + p_C)^2$
$- m_B^2 - m_C^2$

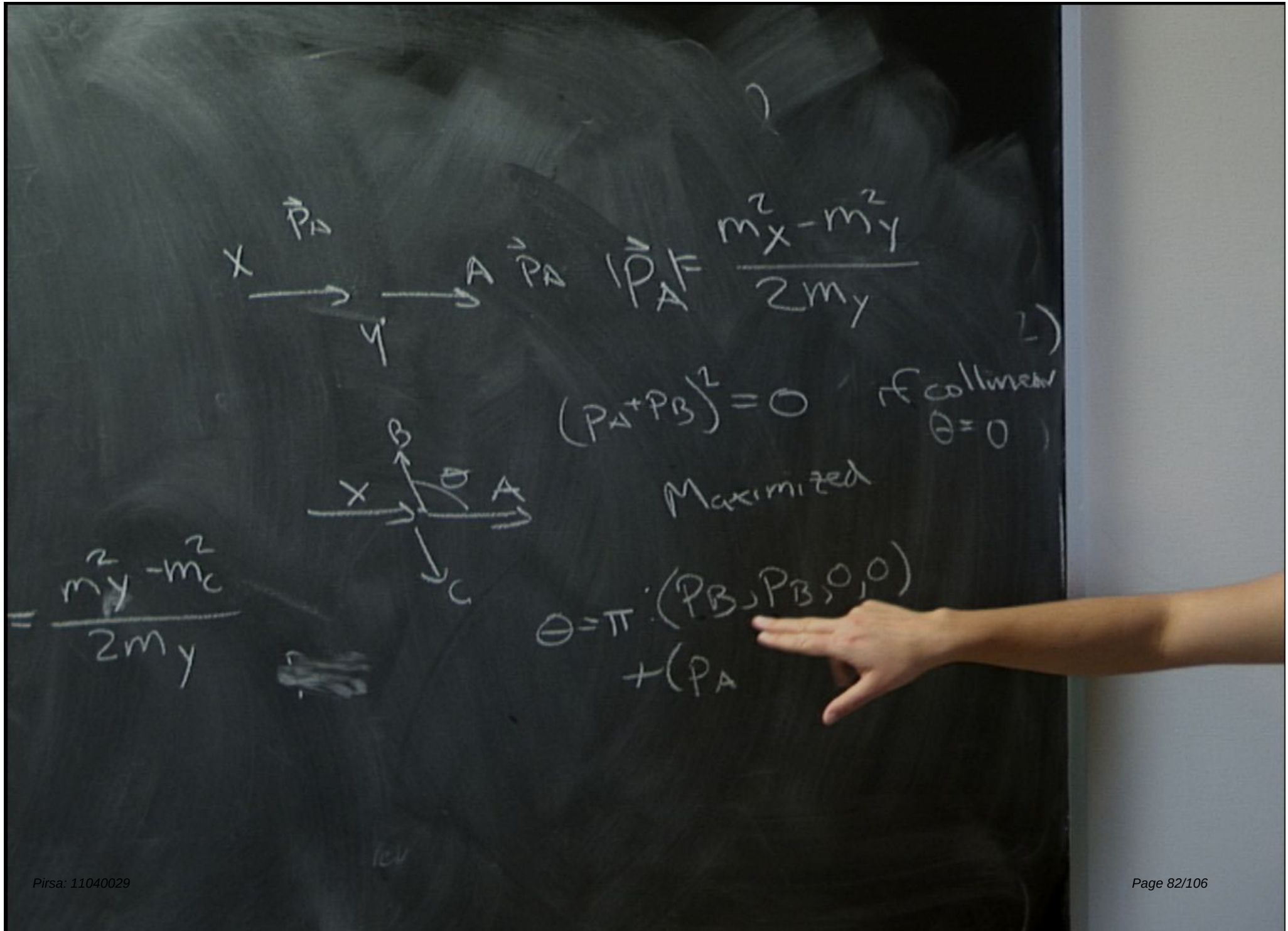

C
Y
B
$(E_B, \vec{p}_B)$
$(m_Y - E_B, -\vec{p}_B)$
$(m_Y - |\vec{p}_B|)^2 - |\vec{p}_B|^2 = m_C^2$
$m_Y^2 - 2m_Y|\vec{p}_B| = m_C^2 \Rightarrow p_B = \frac{m_Y^2 - m_C^2}{2m_Y}$
$(p_B + p_C)^2$
$m_B^2 - m_C^2$

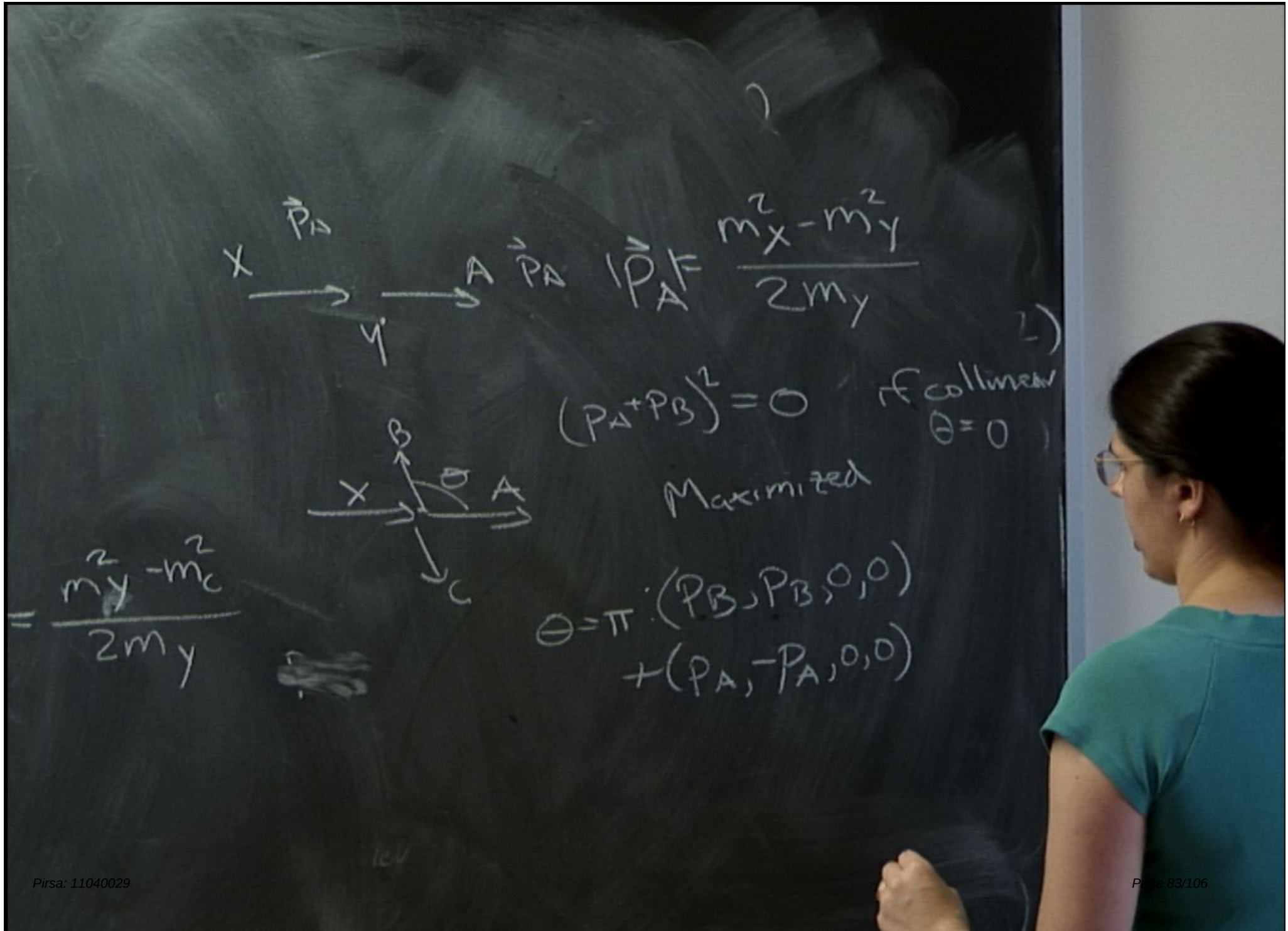

X
$\vec{p}_A$
A
$\vec{p}_A$
Y
C
B
$(p_B, \vec{p}_B)$
$(m_y - p_B, -\vec{p}_B)$
$(m_y + |\vec{p}_B|)^2 - |\vec{p}_B|^2 = m_c^2$
$m_y^2 + 2m_y|\vec{p}_B| = m_c^2 \Rightarrow p_B = \frac{m_y^2 - m_c^2}{2m_y}$

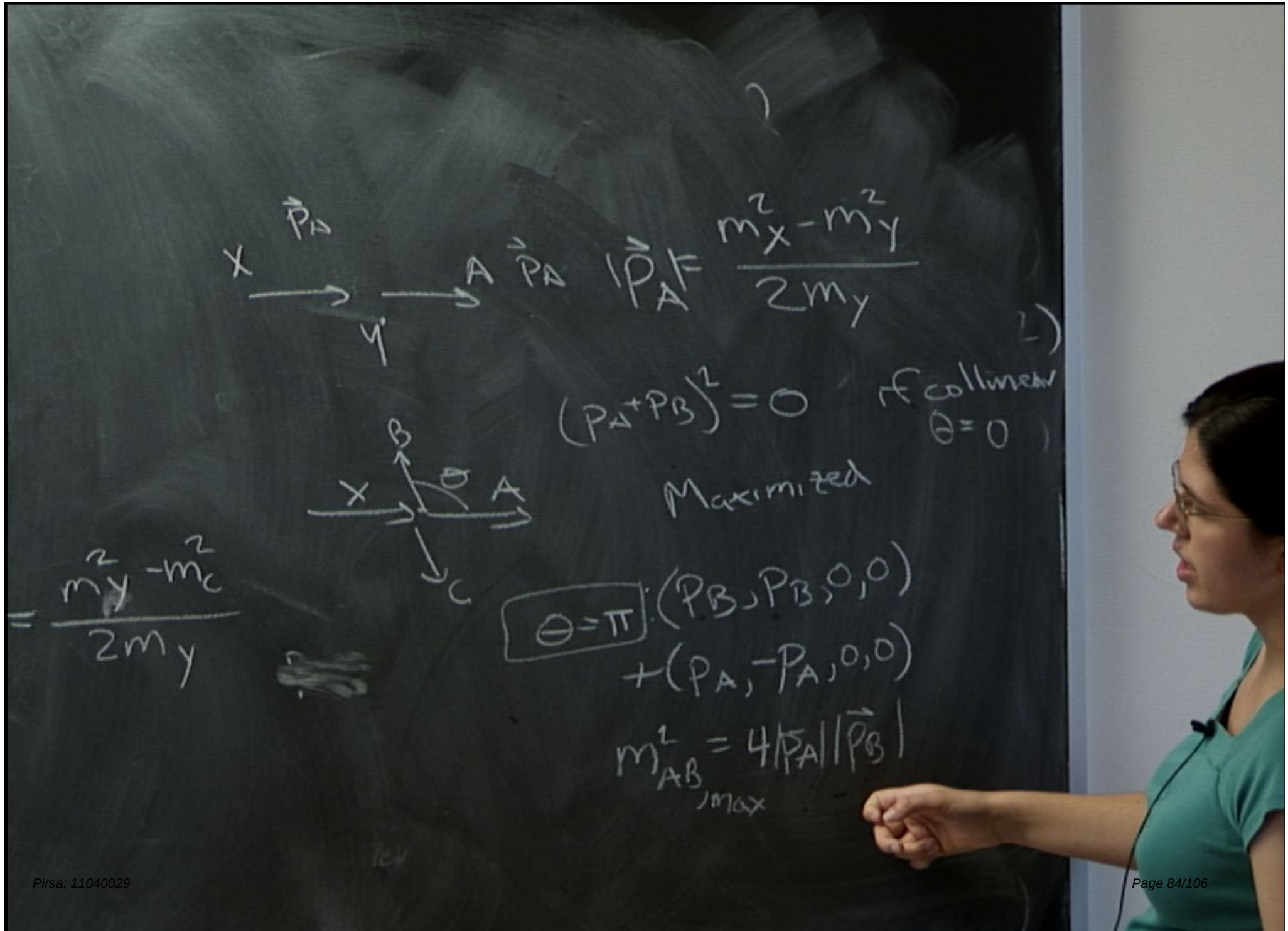

X
A
Y
B
C
$|\vec{p}_A| = \frac{m_X^2 - m_Y^2}{2m_Y}$
$(m_Y - |\vec{p}_B|, -\vec{p}_B)$
$(p_B, \vec{p}_B)$
$p_A + p_B$
$(m_Y - |\vec{p}_B|)^2 - |\vec{p}_B|^2 = m_C^2$
$m_Y^2 - 2m_Y|\vec{p}_B| = m_C^2 \Rightarrow |\vec{p}_B| = \frac{m_Y^2 - m_C^2}{2m_Y}$

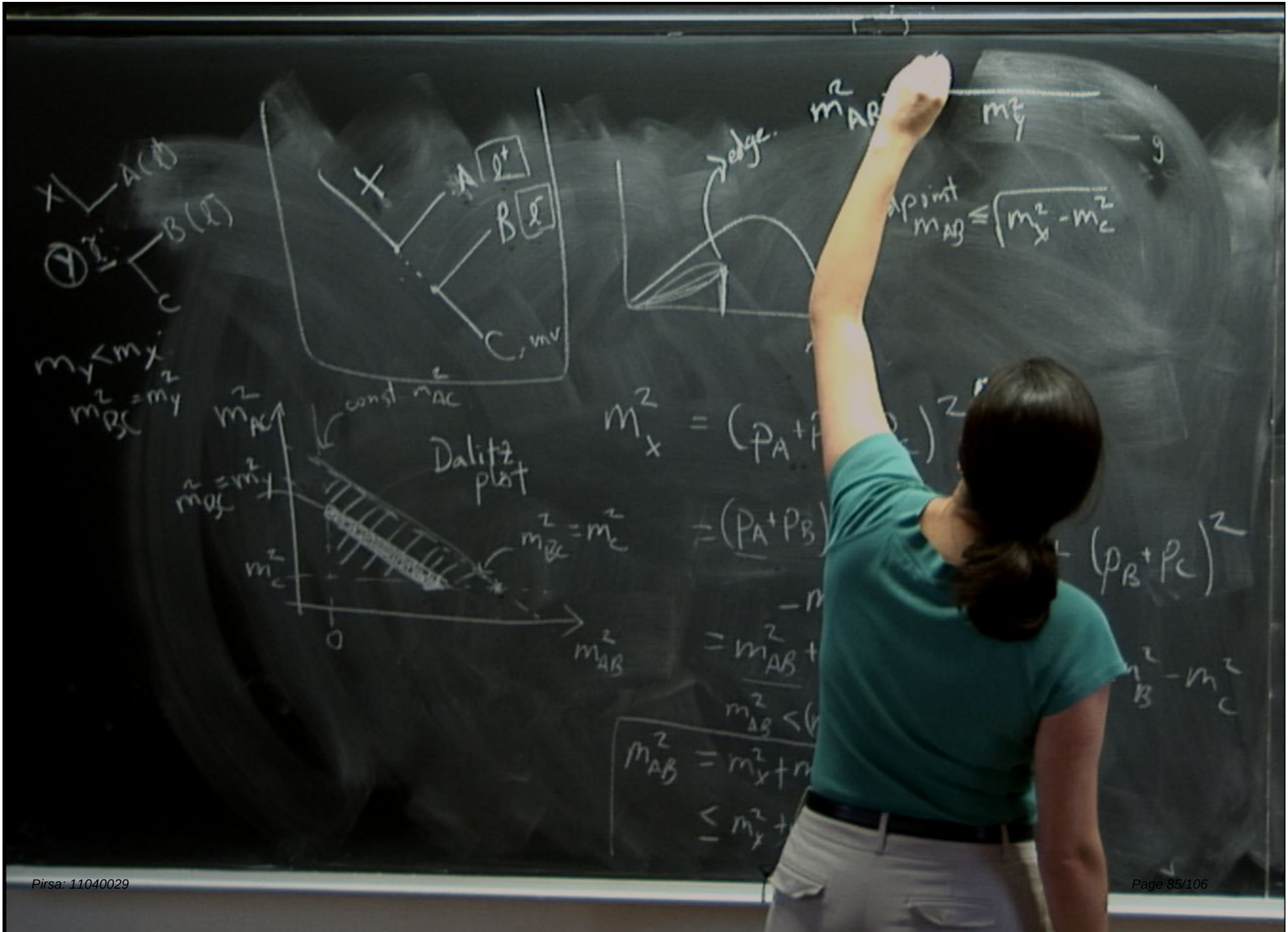

X
$\vec{P}_A$
A
$\vec{P}$
Y
C
Y
B
$(P_B, \vec{P}_B)$
$(m_Y - P_B, -\vec{P}_B)$
$(m_Y - |\vec{P}_B|)^2 - |\vec{P}_B|^2 = m_C^2$
$m_Y^2 - 2m_Y|\vec{P}_B| = m_C^2 \Rightarrow |\vec{P}_B| = \frac{m_Y^2 - m_C^2}{2m_Y}$
B
X
θ
A
C

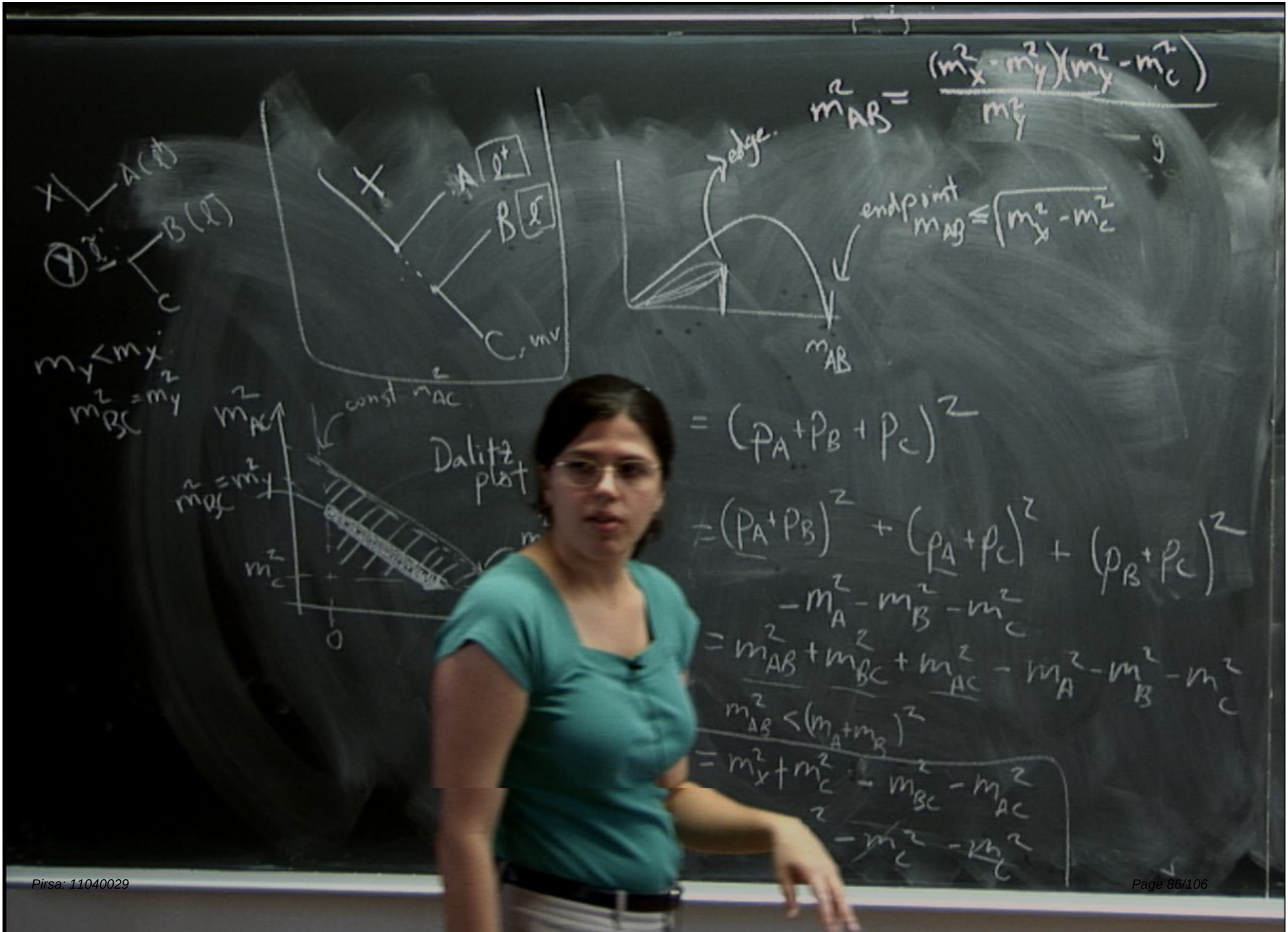

X
$\vec{p}_A$
A
$\vec{p}_A$
y
$|\vec{p}_A| = \frac{m_X^2 - m_y^2}{2m_y}$
$(p_A + p_B)^2 = 0$
B
X
θ
A
C
Maximized
$= \frac{m_y^2 - m_c^2}{2m_y}$
$\theta = \pi$

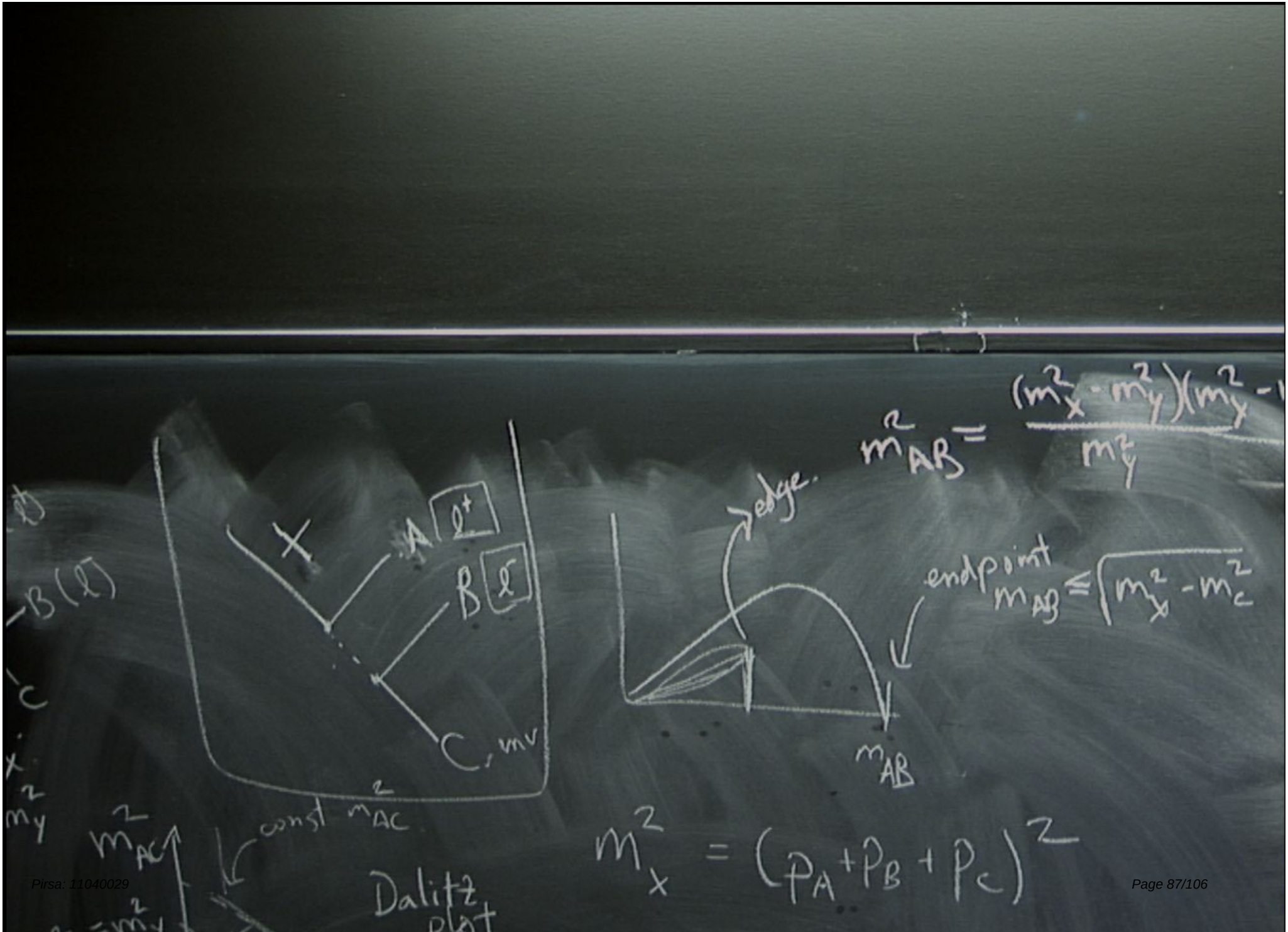

X
$\vec{p}_A$
A
$\vec{p}_A$
Y
$|\vec{p}_A| = \frac{m_X^2 - m_Y^2}{2m_Y}$
$(p_A + p_B)^2 = 0$
if collinear
$\theta = 0$
Maximized
B
X
θ
A
C
$= \frac{m_Y^2 - m_C^2}{2m_Y}$
$\theta = \pi$ · $(p_B, p_B, 0, 0)$
$+ (p_A$

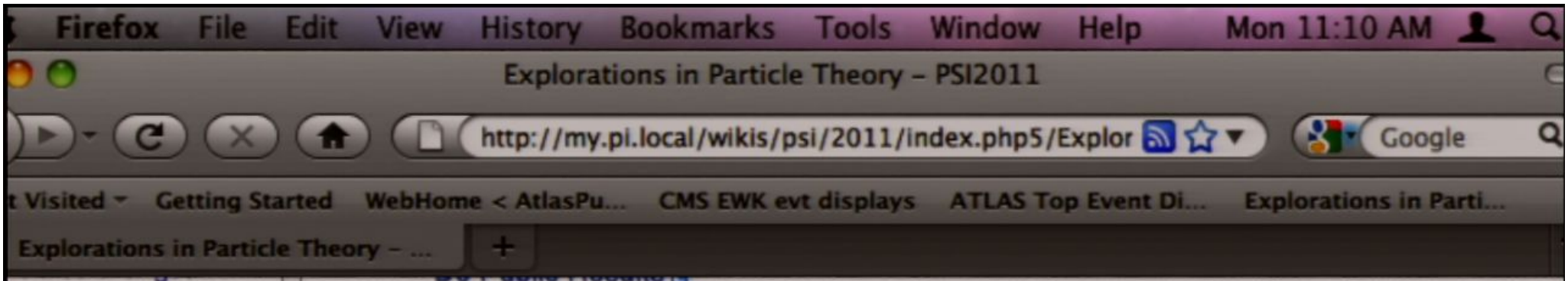

X
$\vec{P}_A$
A
$\vec{P}_A$
Y
$|\vec{P}_A| = \frac{m_X^2 - m_Y^2}{2m_Y}$
$(P_A + P_B)^2 = 0$
if collinear
$\theta = 0$
B
X
θ
A
C
Maximized
$\theta = \pi$
$(P_B, P_B, 0, 0)$
$+(P_A, -P_A, 0, 0)$
$= \frac{m_Y^2 - m_C^2}{2m_Y}$


X
$\vec{p}_A$
A
$\vec{p}_A$
Y
$|\vec{p}_A| = \frac{m_X^2 - m_Y^2}{2m_Y}$
$(p_A + p_B)^2 = 0$
collinear
$\theta = 0$
Maximized
B
X
θ
A
C
$= \frac{m_Y^2 - m_C^2}{2m_Y}$
$\theta = \pi$
$(p_B, p_B, 0, 0)$
$+ (p_A, -p_A, 0, 0)$
$m_{AB,max}^2 = 4|\vec{p}_A||\vec{p}_B|$


Dalitz plot
edge
const
0


edge
endpoint
Dalitz plot
const
$m_{AB}^2 = \frac{(m_X^2 - m_Y^2)(m_Y^2 - m_C^2)}{m_Y^2}$
$m_{AB} \leq \sqrt{m_X^2 - m_C^2}$
$m_Y < m_X$
$m_{BC}^2 = m_Y^2$
$m_{BC}^2 = m_Y^2$
$= (p_A + p_B + p_C)^2$
$= (p_A + p_B)^2 + (p_A + p_C)^2 + (p_B + p_C)^2$
$- m_A^2 - m_B^2 - m_C^2$
$= m_{AB}^2 + m_{BC}^2 + m_{AC}^2 - m_A^2 - m_B^2 - m_C^2$
$m_{AB}^2 < (m_A + m_B)^2$
$= m_X^2 + m_C^2 - m_{BC}^2 - m_{AC}^2$
$- m_C^2 - m_C^2$


X
A
ℓ^+
B
ℓ^-
C, $\nu\nu$
const m^2_{AC}
m^2_{AC}
Dalitz plot
m^2_{AB} =
edge
endpoint
$m_{AB} \leq \sqrt{m_X^2 - m_C^2}$
m_{AB}
$m_X^2 = (p_A + p_B + p_C)^2$



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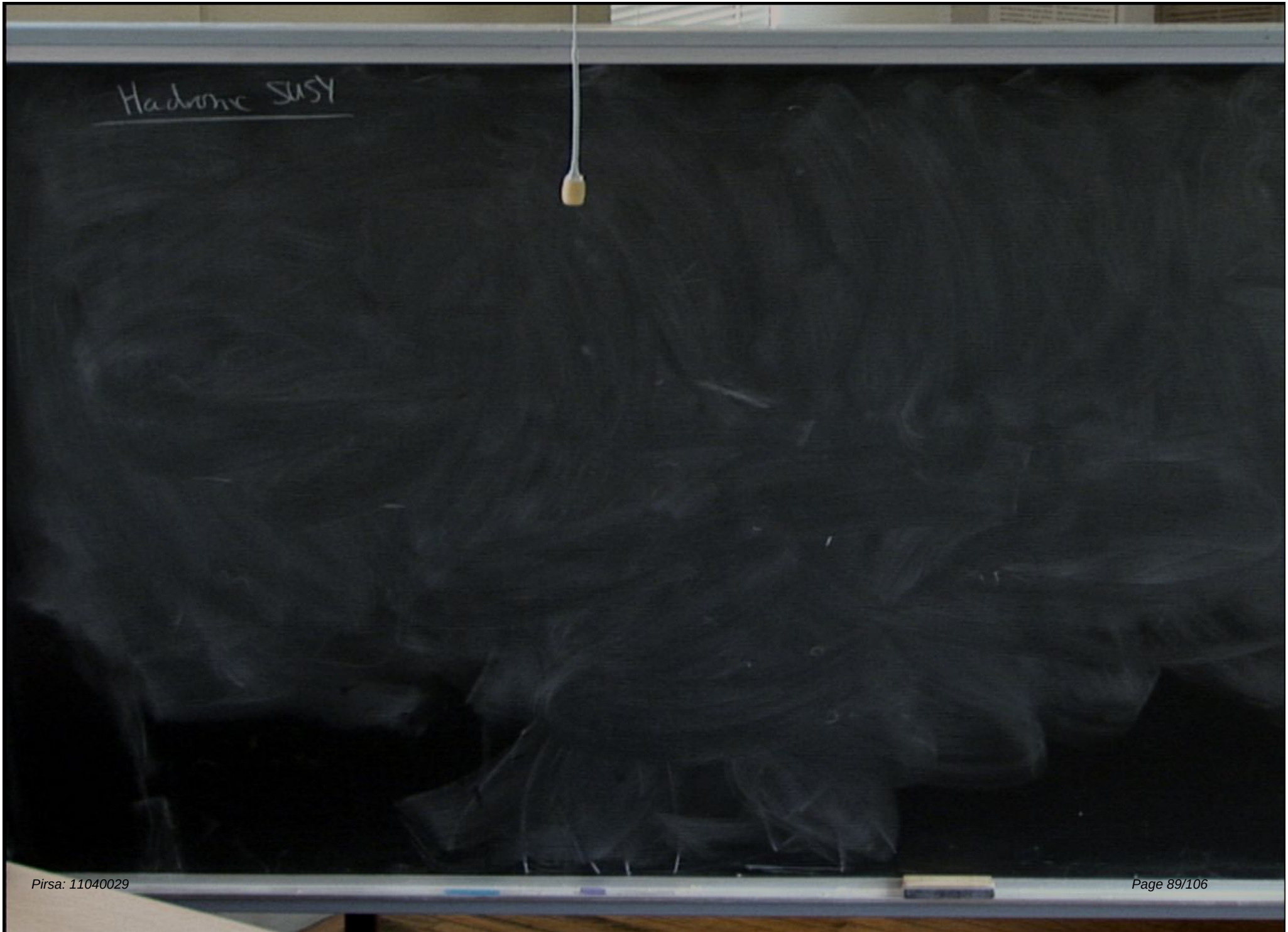
- LHC Results
  - ATLAS Public Results
  - CMS Public Results
- Interesting Tevatron Results that we'll look at in lectures:
  - Invariant Mass Distribution of Jet Pairs Produced in Association with a W boson in ppbar Collisions at sqrt(s) = 1.96 TeV
    - The web site for the analysis is here
  - Measurement of trilinear gauge boson couplings from WW + WZ to lnu jj events in pp-bar collisions at sqrt{s}=1.96 TeV
- LHC results that we'll look at in lectures:
  - [1] ATLAS hadronic SUSY searches
  - [2] One of three CMS hadronic SUSY searches
- We will probably use Prospino at some point. The homepage for this is here.

Suggested Reading [edit]

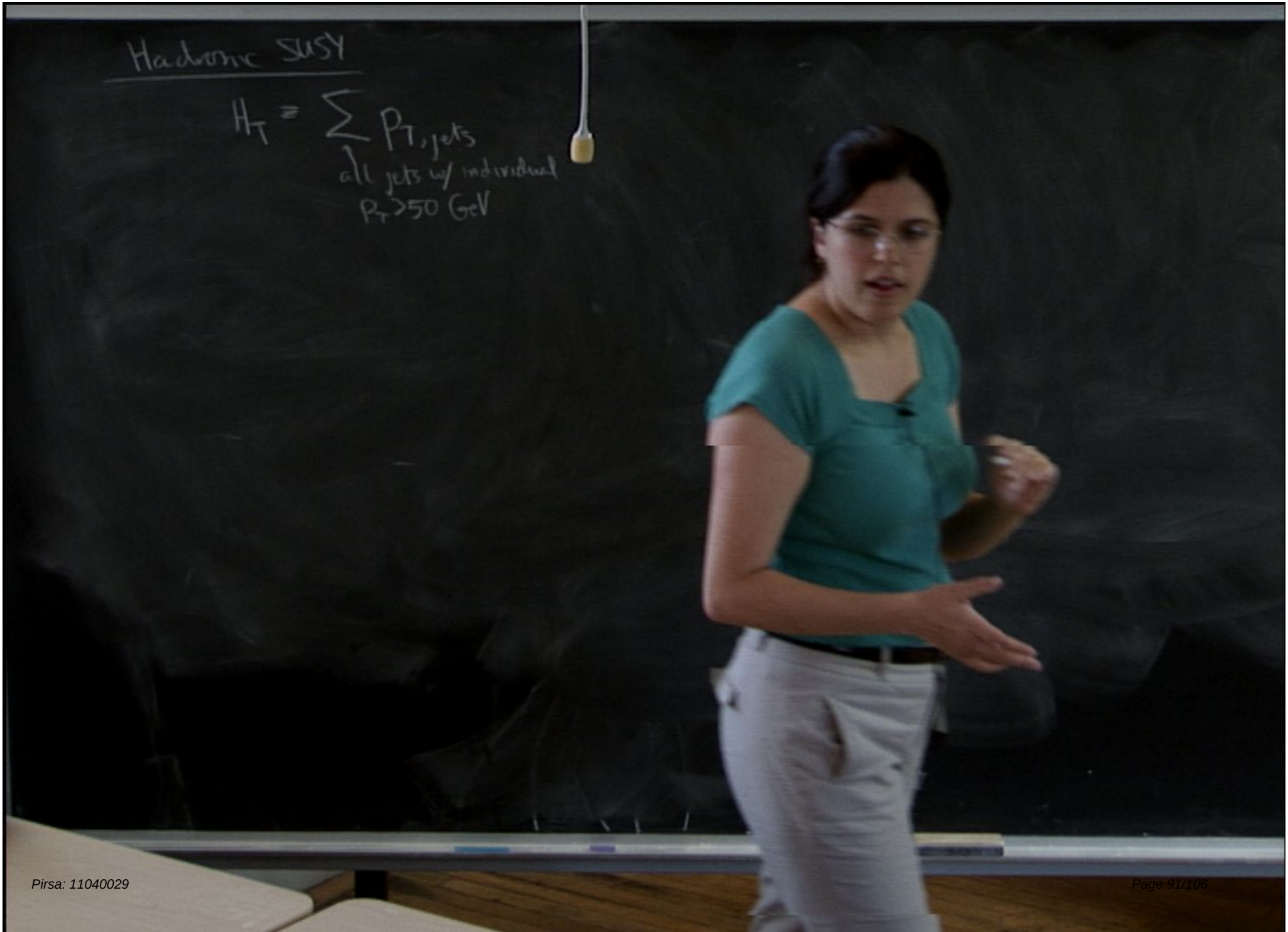
- PDG Review of Particle Physics
- Collider Physics

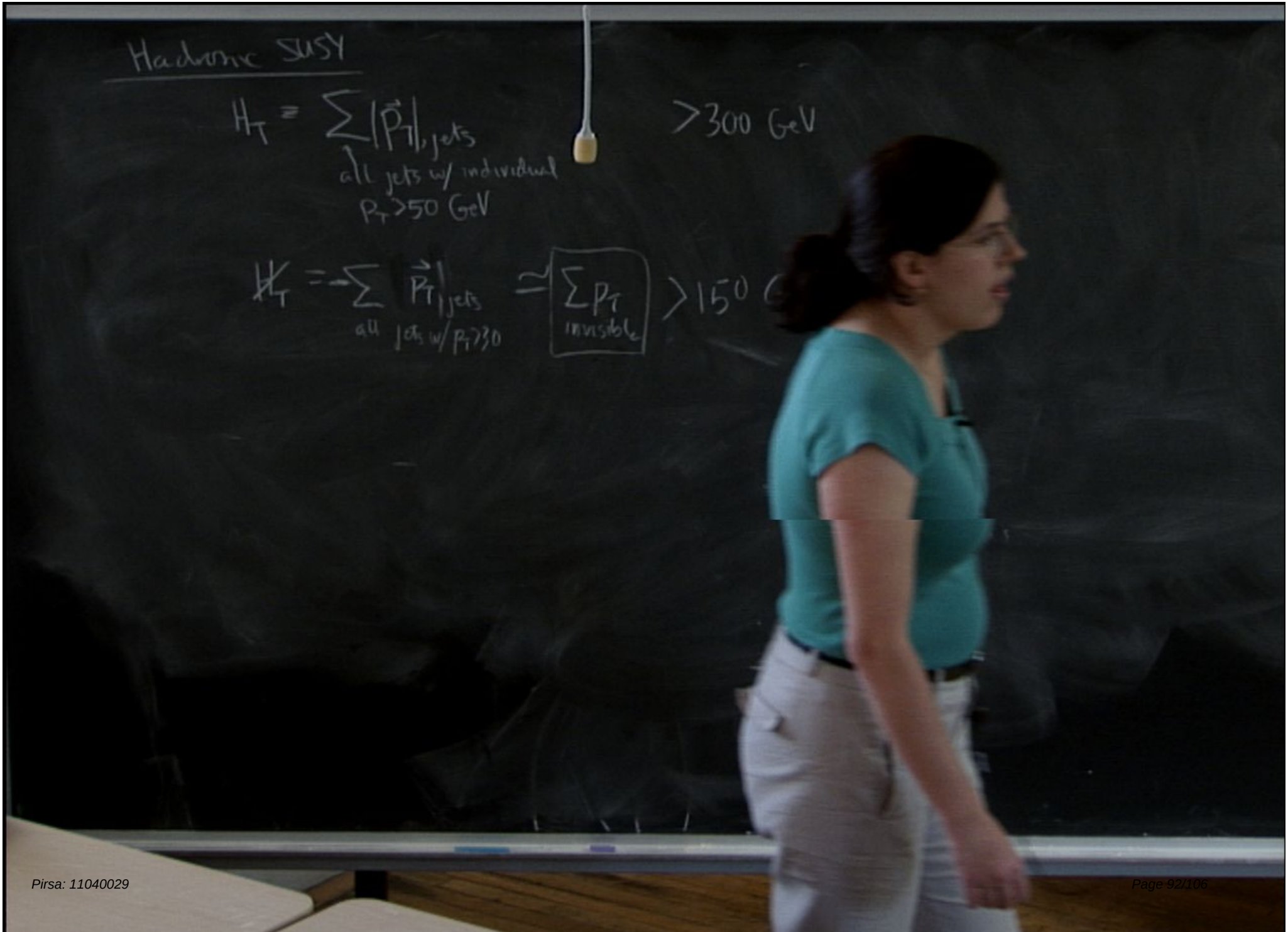

Hadronic SUSY

selection criteria are applied to define the search selections. The baseline selection requirements after trigger are:

- At least three jets with $p_T > 50\,\text{GeV}/c$ and $|\eta| < 2.5$.
- $H_T > 300\,\text{GeV}$, with H_T defined as the scalar sum of the p_Ts of all the jets having $p_T > 50\,\text{GeV}/c$ and $|\eta| < 2.5$.

- $\not{H}_T > 150\,\text{GeV}$, with $\not{H}_T$ defined as the magnitude of the negative vectorial sum of the p_Ts of the jets having, in this case, $p_T > 30\,\text{GeV}/c$ and $|\eta| < 5$. This requirement suppresses high $\not{H}_T$ tails from QCD multi-jet events.
- $|\Delta\phi(J_n, \not{H}_T)| > 0.5$, $n = 1,2$ and $|\Delta\phi(J_3, \not{H}_T)| > 0.3$, vetoing events in which $\not{H}_T$ is aligned in the transverse plane along one of the three leading jets J. This requirement rejects most of the QCD multi-jet events in which a single mis-measured jet yields


Hadronic SUSY
$H_T = \sum_{\text{all jets w/ individual } P_T > 50\ GeV} P_{T,\text{jets}}$


Hadronic SUSY
$H_T \equiv \sum |\vec{p}_T|_{jets}$
all jets w/ individual $p_T > 50$ GeV
> 300 GeV
$\not{H}_T = -\sum \vec{p}_T|_{jets} \simeq \sum p_T$ invisible
all jets w/ $p_T > 30$
> 150

beam axis. They must also be isolated, with the relative isolation variable, defined as $\left[\sum_{\text{trk}}^{\Delta R=0.3} p_T^{\text{charged hadron}} + \sum_{\text{ecal}}^{\Delta R=0.3} p_T^{\text{neutral hadron}} + \sum_{\text{hcal}}^{\Delta R=0.3} p_T^{\text{photons}}\right] / p_T$, smaller than 20%. Muons are required to have $|\eta| < 2.4$, whereas electrons should have $|\eta| < 2.5$ excluding the transition region $1.444 < |\eta| < 1.566$.

Two search regions were chosen based on the observables central to this inclusive jets-plus-missing-momentum search. The first search selection, defining the *high-$\not\!\!H_T$ search region*, tightens the baseline cuts with an $\not\!\!H_T > 250\,\text{GeV}$ requirement, motivated by the search for a generic dark matter candidate with a selection that gives a high background rejection. The second selection adds a $H_T > 500\,\text{GeV}$ cut to the baseline selection, yielding the *high-H_T search region*, which is sensitive to the higher object multiplicities from cascade decays from high-mass new-physics particles. Such cascades lead to more energy being transferred to visible particles and less to the dark-matter candidate.

3.3 Data-simulation comparisons

Several Monte-Carlo (MC) simulated samples produced with a detailed Geant-based [27] CMS detector simulation were used. Samples for QCD multi-jet, $t\bar{t}$, W, Z, γ+jets, di-boson and single-top production were generated with the PYTHIA [28] and MADGRAPH [29] generators. While already excluded [12], the LM1 CMSSM point [30] is used as a benchmark of new physics in this search. It is defined to have universal scalar mass $m_0 = 60\,\text{GeV}/c^2$, universal gaugino mass $m_{1/2} = 250\,\text{GeV}/c^2$, universal trilinear soft SUSY breaking parameter $A_0 = 0$, the ratio of the vacuum expectation values of the two Higgs doublets $\tan\beta = 10$, and the sign of the Higgs mixing parameter $\text{sign}(\mu) > 0$. The squark and gluino mass for LM1 are respectively $559\,\text{GeV}/c^2$ and $611\,\text{GeV}/c^2$.

The event yield in data and MC simulated samples after trigger, cleaning and event selection is summarized in Table 1. For MC simulation, the cross sections used are normalized, when

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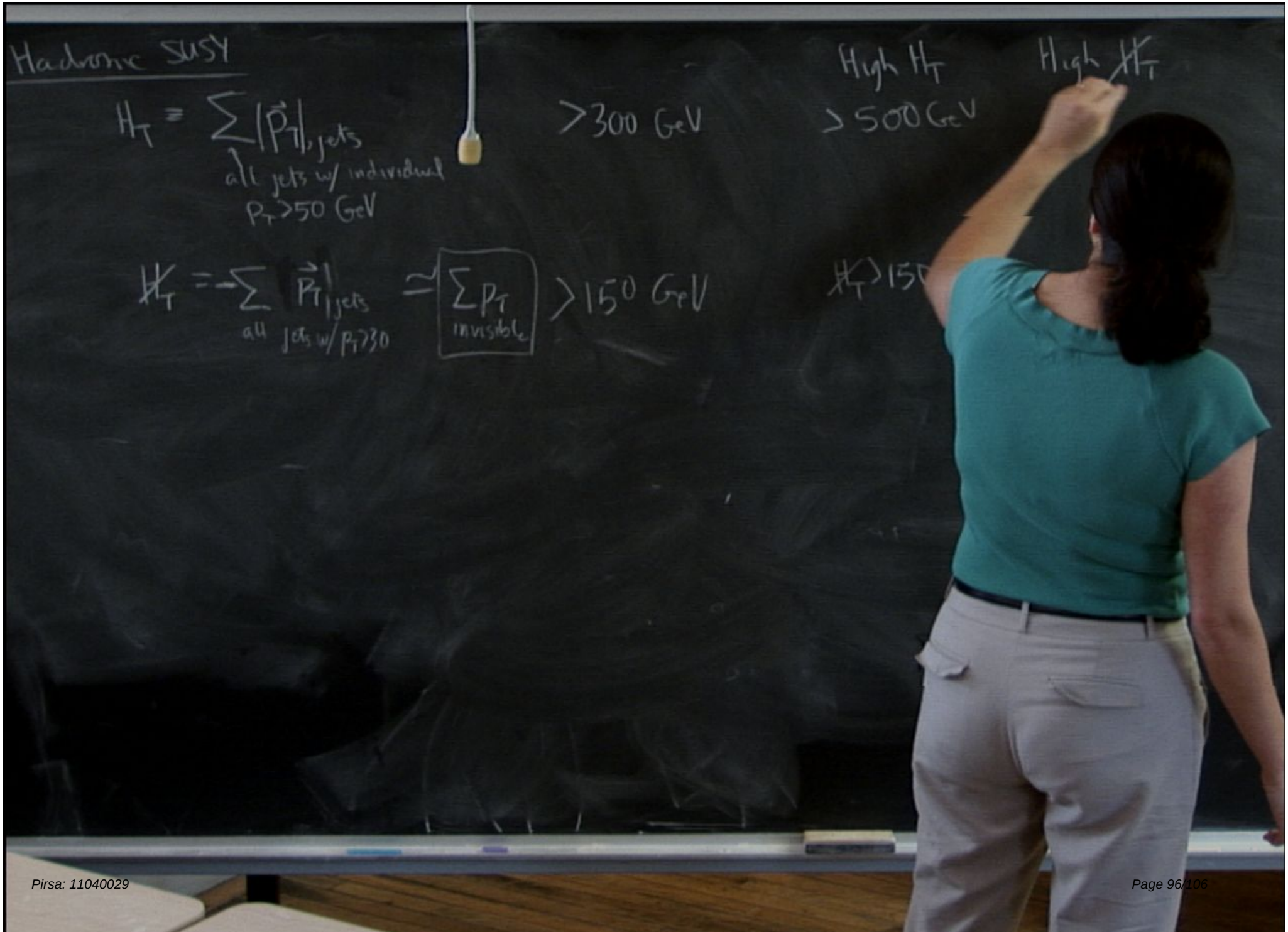
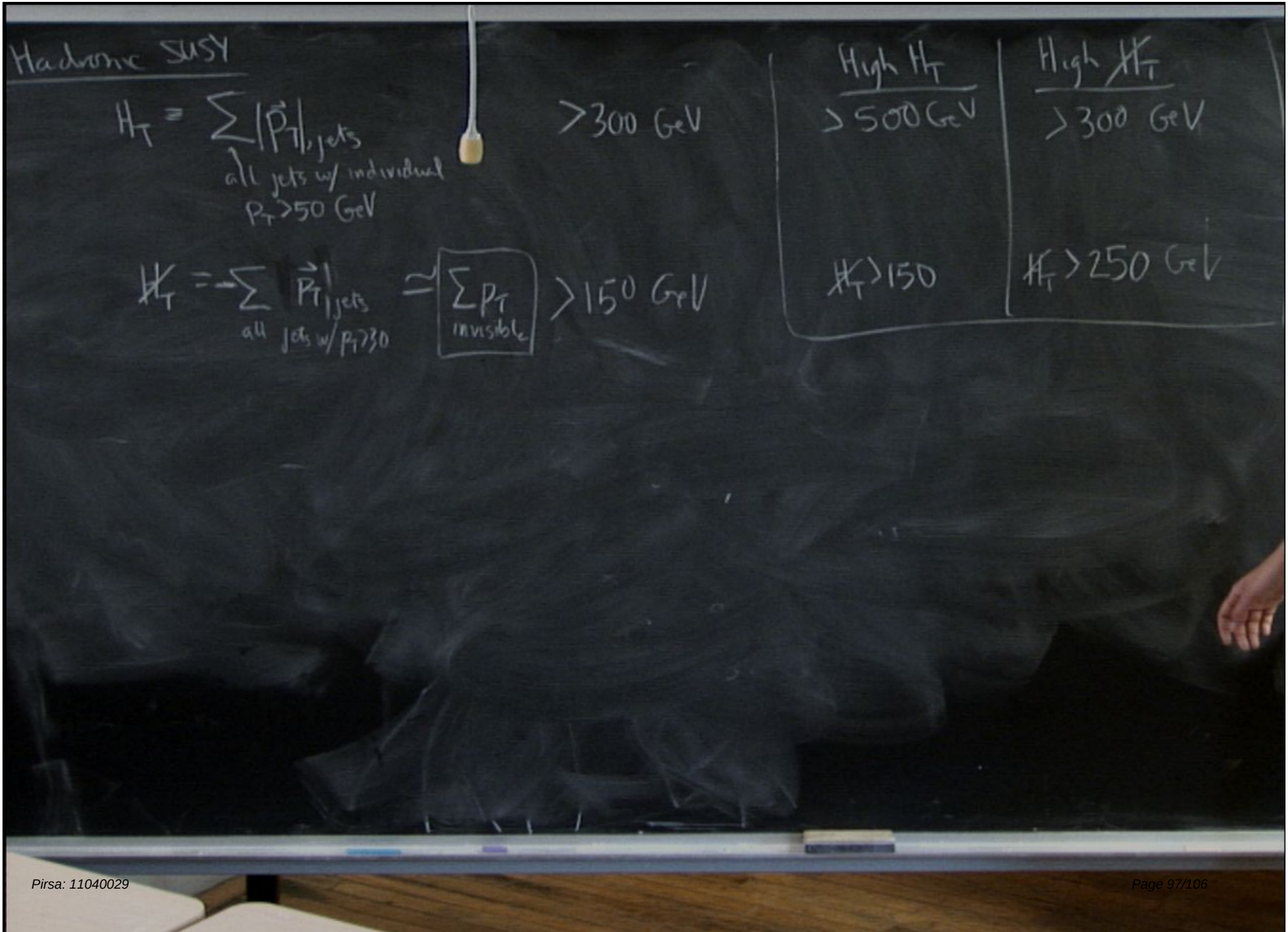

Hadronic SUSY
$H_T \equiv \sum |\vec{P}_T|_{,\text{jets}}$
all jets w/ individual $P_T > 50$ GeV
> 300 GeV
High H_T
> 500 GeV
High $\not{H}_T$
$\not{H}_T = -\sum \vec{P}_T|_{\text{jets}} \simeq \sum p_T$ invisible
all jets w/ $P_T > 30$
> 150 GeV
$\not{H}_T > 150$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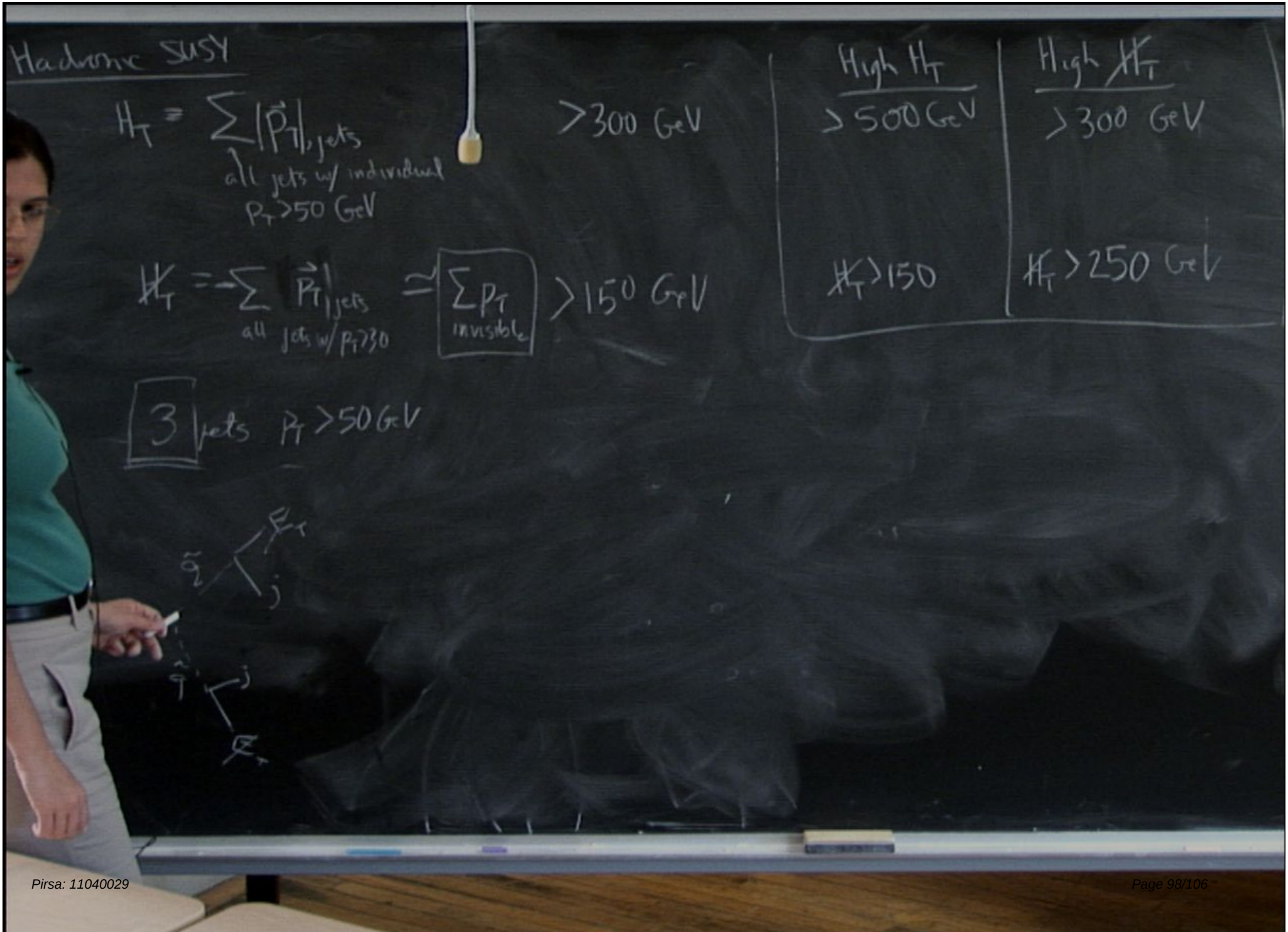
> 300 GeV
$\not{H}_T = -\sum_{\text{all jets w/ } P_T > 30} \vec{P}_{T\,\text{jets}} \simeq \sum_{\text{invisible}} P_T$
> 150 GeV
High H_T
> 500 GeV
$\not{H}_T > 150$
High $\not{H}_T$
> 300 GeV
$\not{H}_T > 250$ GeV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all jets w/ individual $P_T > 50$ GeV
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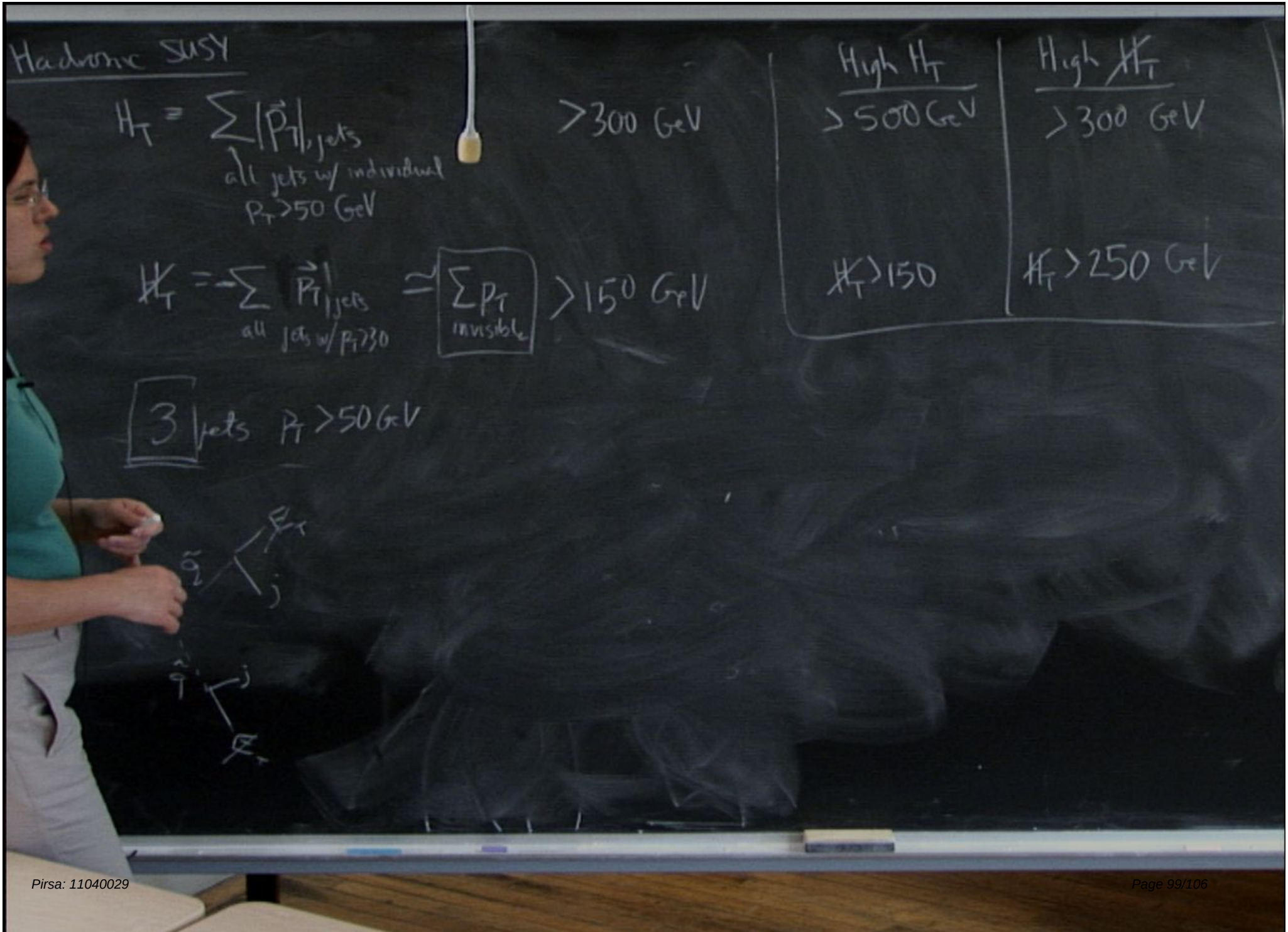
$\simeq \sum p_T$ invisible
> 150 GeV
3 jets $P_T > 50$ GeV
High H_T
> 500 GeV
$\not{H}_T > 150$
High $\not{H}_T$
> 300 GeV
$\not{H}_T > 250$ GeV
$\tilde{q}$
$\not{E}_T$
j
$\tilde{q}$
j
$\not{E}_T$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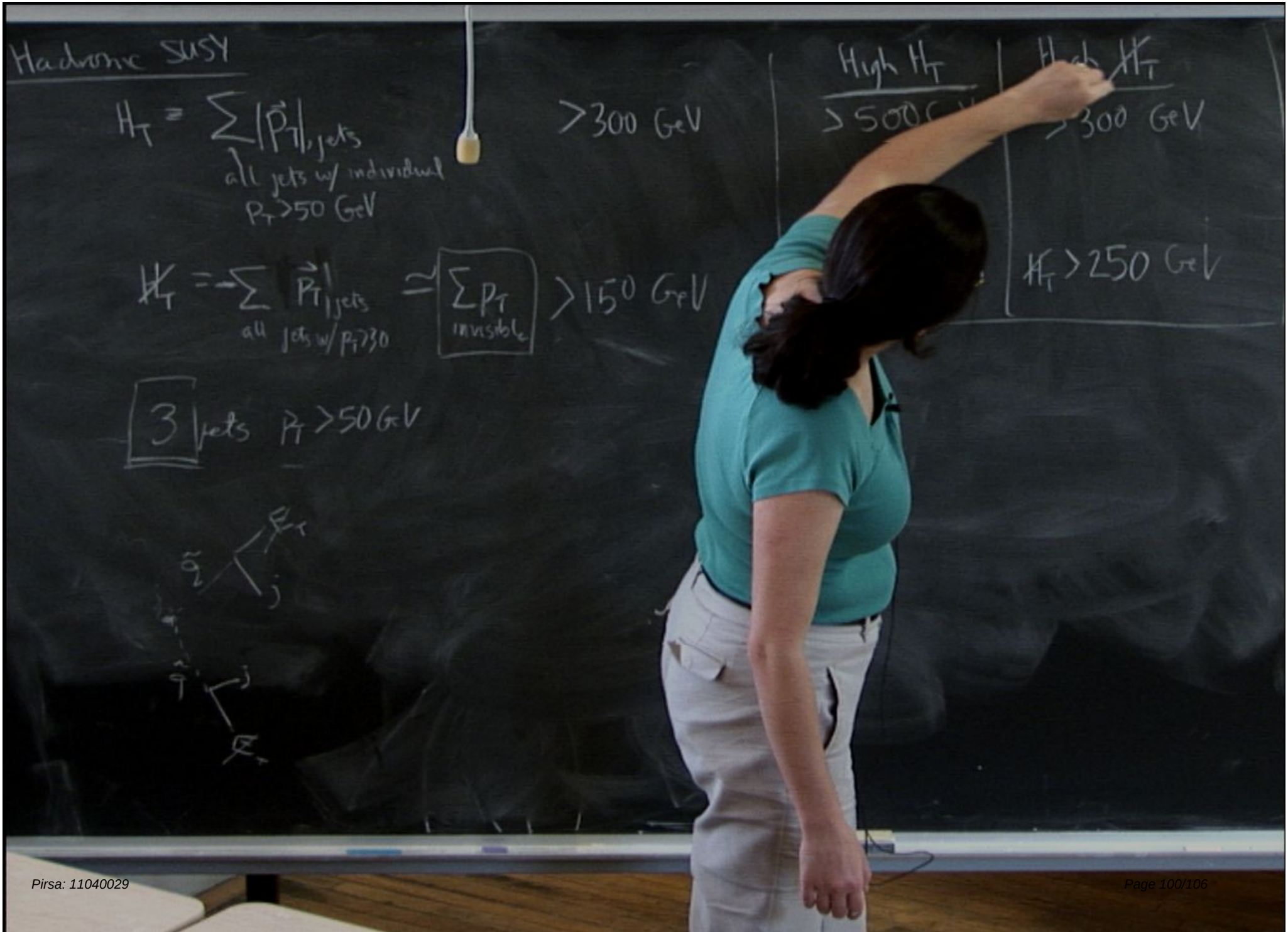
> 300 GeV
$\not{H}_T = -\sum |\vec{P}_T|$, jets
all jets w/ $P_T > 30$
$\simeq \sum p_T$ invisible
> 150 GeV
$\not{H}_T > 150$
$\not{H}_T > 250$ GeV
3 jets $P_T > 50$ GeV
$\tilde{q}$
$\not{E}_T$
j
$\tilde{q}$
j
$\not{E}_T$


Hadronic SUSY
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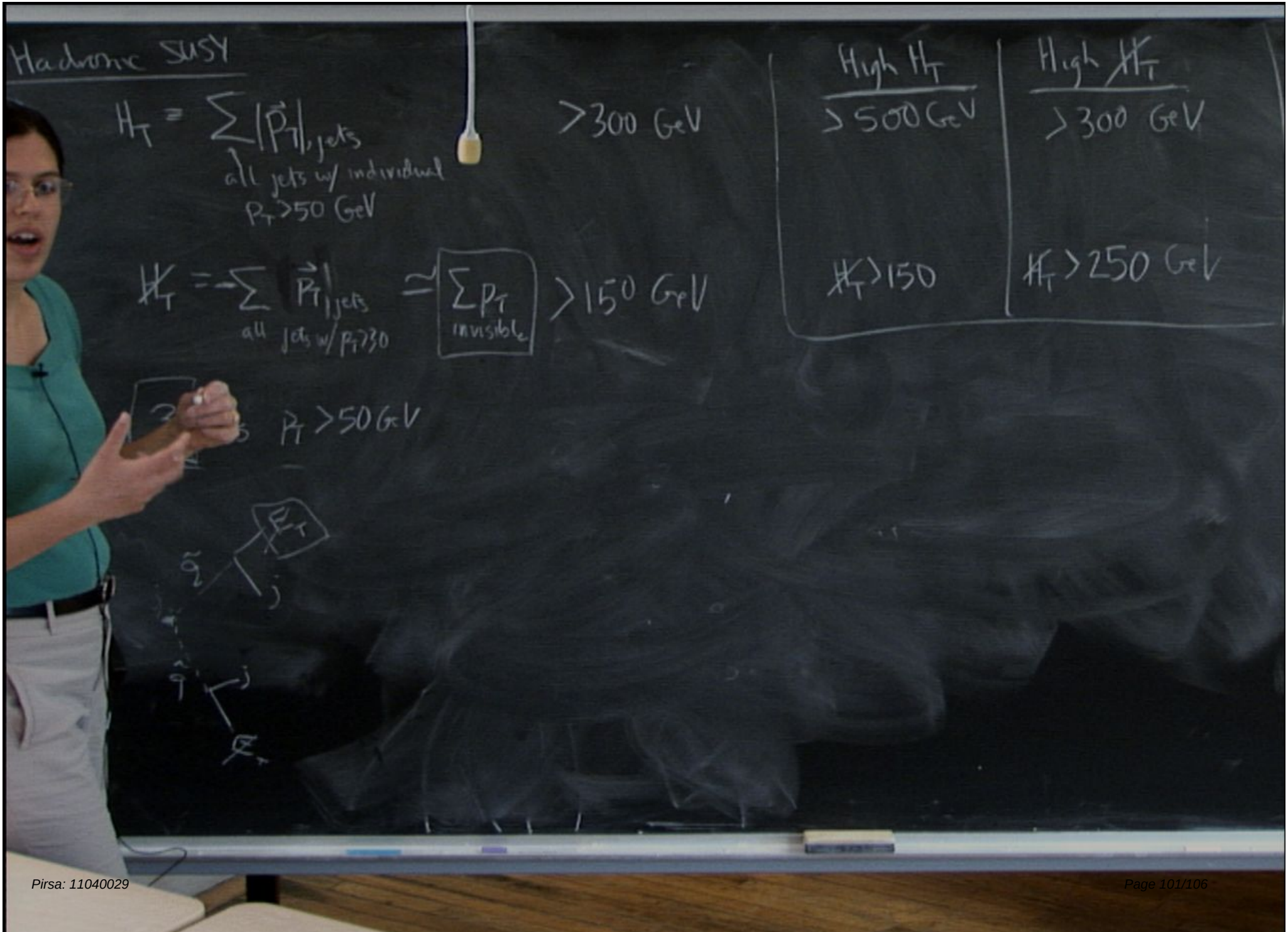
> 150 GeV
all jets w/ $P_T > 30$
$\not{H}_T > 250$ GeV
3 jets $P_T > 50$ GeV
$\tilde{q}$
$\not{E}_T$
j
$\tilde{g}$
j
$\not{E}_T$


Hadronic SUSY
$H_T = \sum |\vec{P}_T|$, jets
all jets w/ individual $P_T > 50$ GeV
> 300 GeV
High H_T
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High $\not{H}_T$
> 300 GeV
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all jets w/ $P_T > 30$
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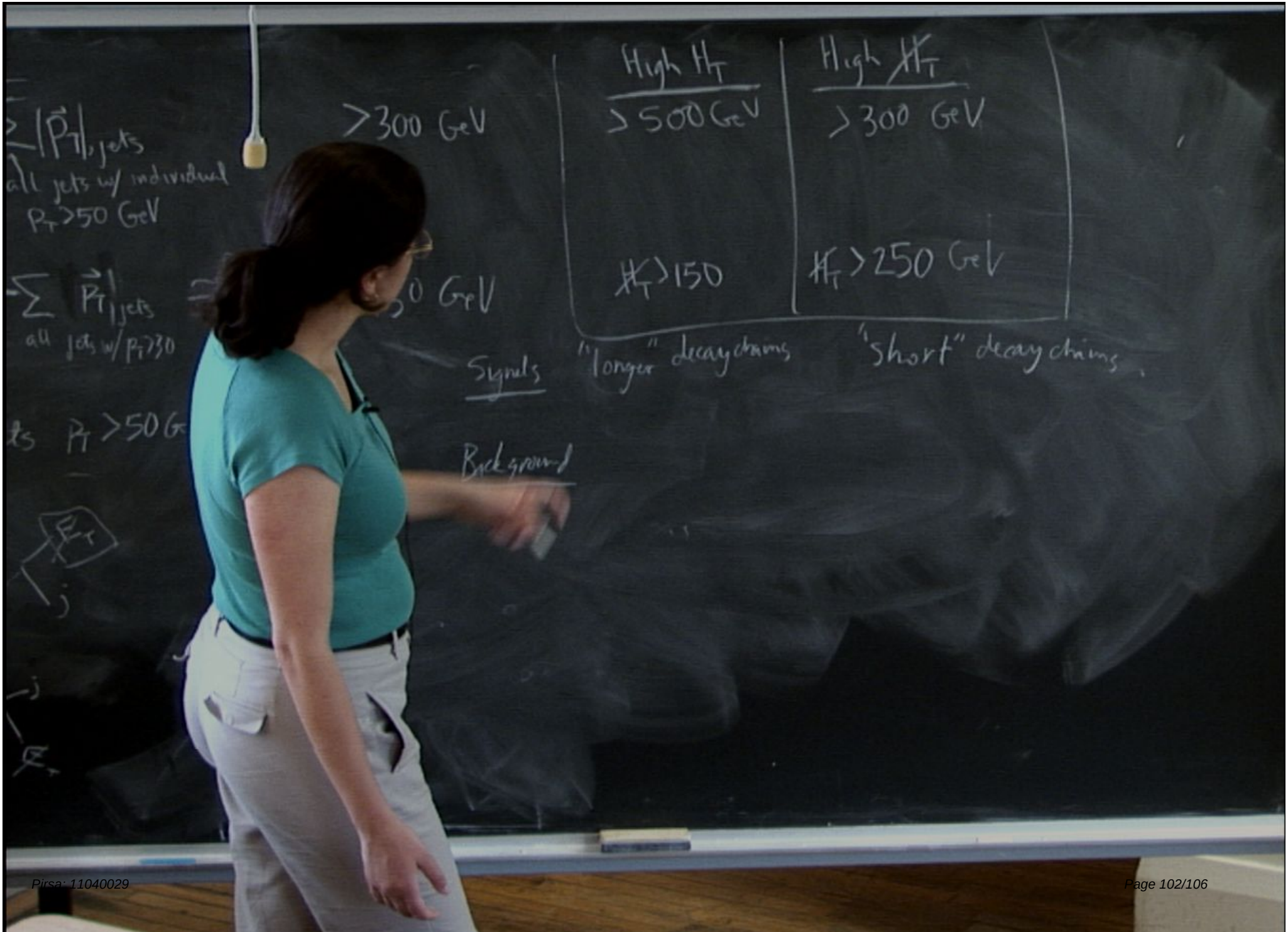
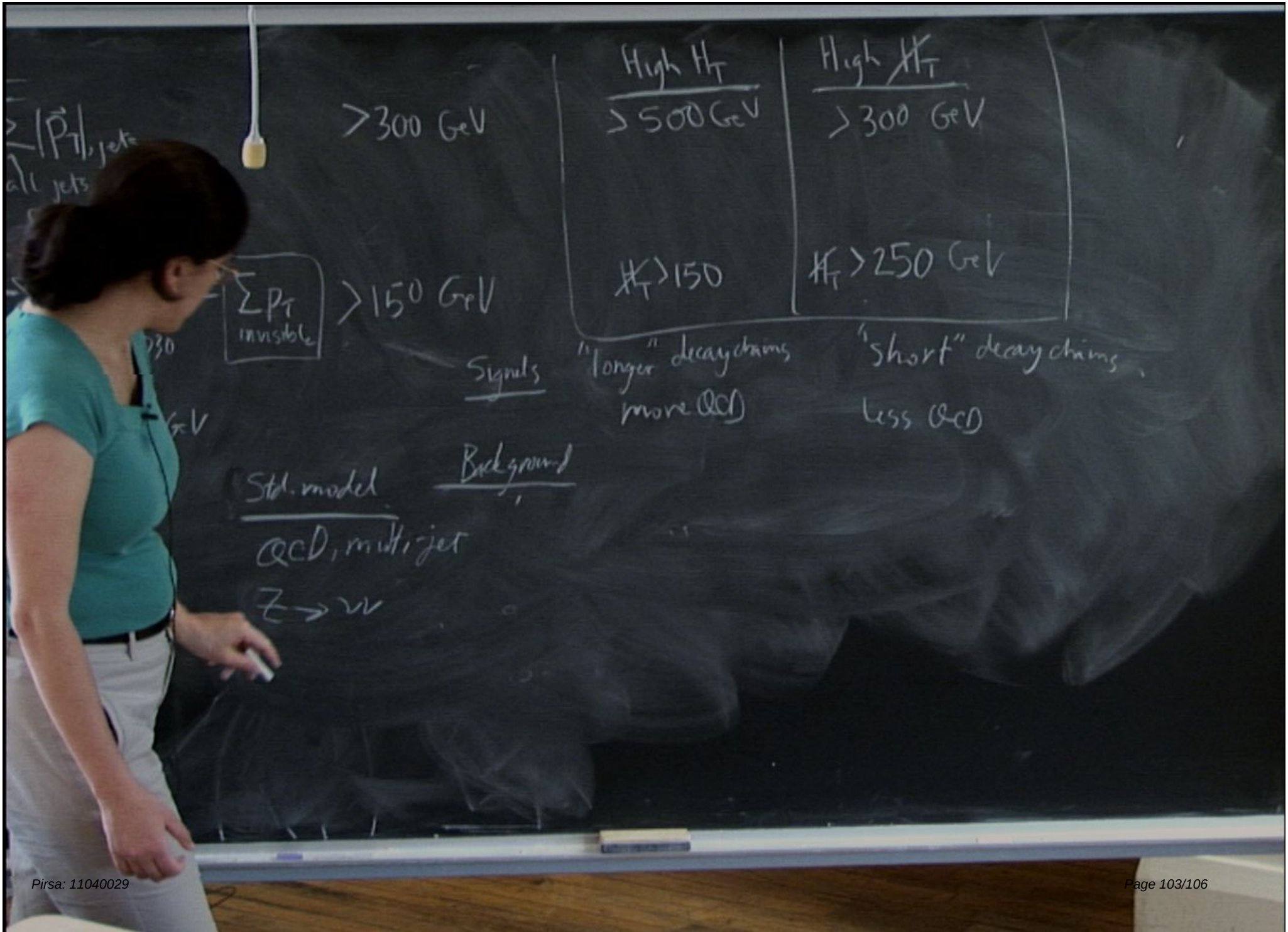
> 150 GeV
$\not{H}_T > 150$
$\not{H}_T > 250$ GeV
$P_T > 50$ GeV
$\not{E}_T$
$\tilde{q}$
j
$\tilde{g}$
j
$\not{E}_T$


High H_T
> 500 GeV
$\not{H}_T$ > 150
High $\not{H}_T$
> 300 GeV
$\not{H}_T$ > 250 GeV
> 300 GeV
all jets w/ individual P_T > 50 GeV
Signals
"longer" decay chains
"short" decay chains
Background


High H_T
> 500 GeV
$\not{H}_T$ > 150
High $\not{H}_T$
> 300 GeV
$\not{H}_T$ > 250 GeV
> 300 GeV
Σp_T invisible
> 150 GeV
Signals
"longer" decay chains
more QCD
"short" decay chains
less QCD
Background
Std. model
QCD, multijet
$Z \to \nu\nu$

Hadronic SUSY

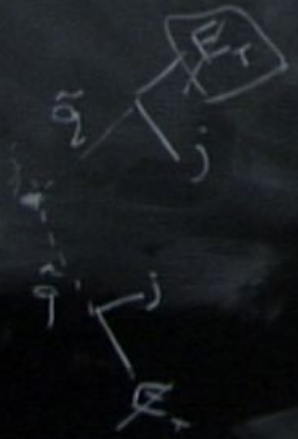
$H_T = \sum |\vec{P}_T|_{\text{jets}}$ > 300 GeV

all jets w/ individual $P_T > 50$ GeV

$\not{H}_T = -\sum |\vec{P}_T|_{\text{jets}} \simeq \sum p_T$ invisible > 150 GeV

all jets w/ $P_T > 30$

3 jets $P_T > 50$ GeV



High H_T	High $\not{H}_T$
> 500 GeV	> 300 GeV
$\not{H}_T > 150$	$\not{H}_T > 250$ GeV
"longer" decay chains	"short" decay c
more QCD	less QCD

Signals

Background

Std. model

- QCD, multi-jet
- $Z \to \nu\nu$
- $W \to e\nu$, e missed

Table 11: Predicted event yields from the different background estimation methods for the baseline selection and for the high-$\not\!\!H_T$ and high-H_T search selections. In the limit calculations the estimates of the QCD R+S are further used, along with the $Z \to \nu\bar{\nu}$ from photons, the $W/t\bar{t}$ lost-lepton and hadronic-tau estimates. The background combination is performed as explained in the text. The last line reports the 95% C.L. limit on the number of signal events given the predicted events of background and the observed ones.

Method	Baseline selection		High-$\not\!\!H_T$ selection		High-H_T selection	
$Z \to \nu\bar{\nu}$ from γ+jets	26.3	$\pm$4.8	7.1	$\pm$2.2	8.4	$\pm$2.3
$t\bar{t}/W \to e, \mu$+X lost-lepton method	33.0	$\pm$8.1	4.8	$\pm$1.9	10.9	$\pm$3.4
$t\bar{t}/W \to \tau_{had}$+X method	22.3	$\pm$4.6	6.7	$\pm$2.1	8.5	$\pm$2.5
QCD Rebalance+Smear method	29.7	$\pm$15.2	0.16	$\pm$0.10	16.0	$\pm$7.9
QCD factorization method	25.2	$\pm$13.4	0.4	$\pm$0.3	17.3	$\pm$9.4
Total data-driven background	111.3	$\pm$18.5	18.8	$\pm$3.5	43.8	$\pm$9.2
Observed in 36 pb^{-1} of data	111		15		40	
95% C.L. limit on signal events	40.4		9.6		19.6	

In order to derive limits on new physics, the expected number of signal events for the event selections are estimated using simulated signal samples, taking into account uncertainties corresponding to the event selection, theoretical uncertainties related to the event generation, and an overall luminosity uncertainty. Many of these uncertainties bring in a dependence on the event kinematics, and hence are model dependent.

The largest experimental contribution to the uncertainties arises from jet energy scale and resolution uncertainties. Smaller uncertainties are due to the lepton veto and the trigger. For the

7 Results and Interpretation

7.1 Results and limits

The predicted event yields from the different data-driven background estimation methods discussed in the previous sections and the number of events observed in 36 pb^{-1} of data are summarized in Table 11 for the three different selections. No excess of events is observed in either the high-$\not\!\!H_T$ or high-H_T search regions.

Table 11: Predicted event yields from the different background estimation methods for the baseline selection and for the high-$\not\!\!H_T$ and high-H_T search selections. In the limit calculations the estimates of the QCD R+S are further used, along with the $Z \to \nu\bar{\nu}$ from photons, the $W/t\bar{t}$ lost-lepton and hadronic-tau estimates. The background combination is performed as explained in the text. The last line reports the 95% C.L. limit on the number of signal events given the predicted events of background and the observed ones.

Method	Baseline selection		High-$\not\!\!H_T$ selection		High-H_T selection	
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Observed in 36 pb^{-1} of data	111		15		40	
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