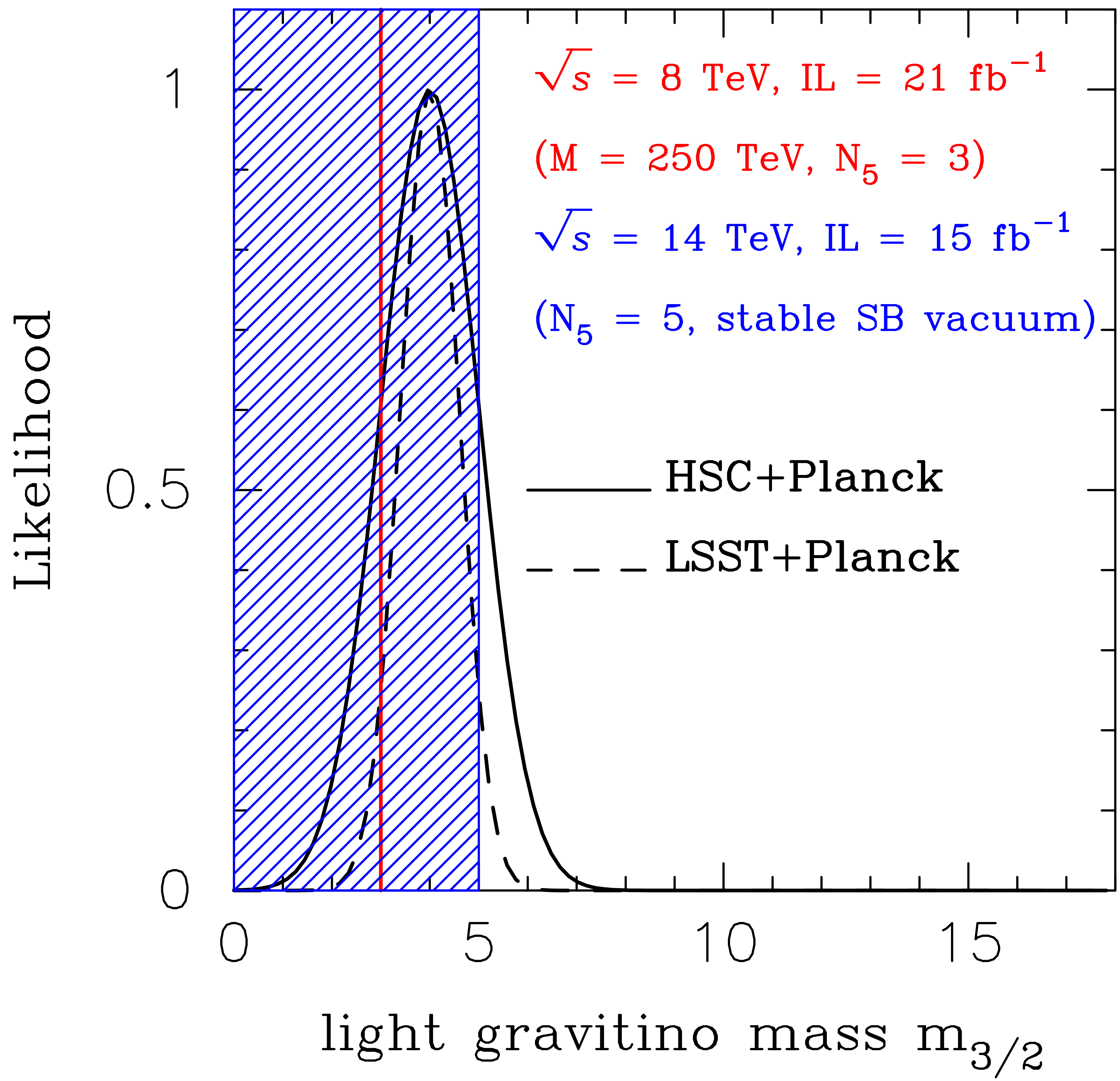
Cosmological constraint on light gravitino mass from cosmic shear

Ayuki Kamada (Kavli IPMU)

in preparation
with Masato Shirasaki (The University of Tokyo)
and Naoki Yoshida (Kavli IPMU, The University of Tokyo)

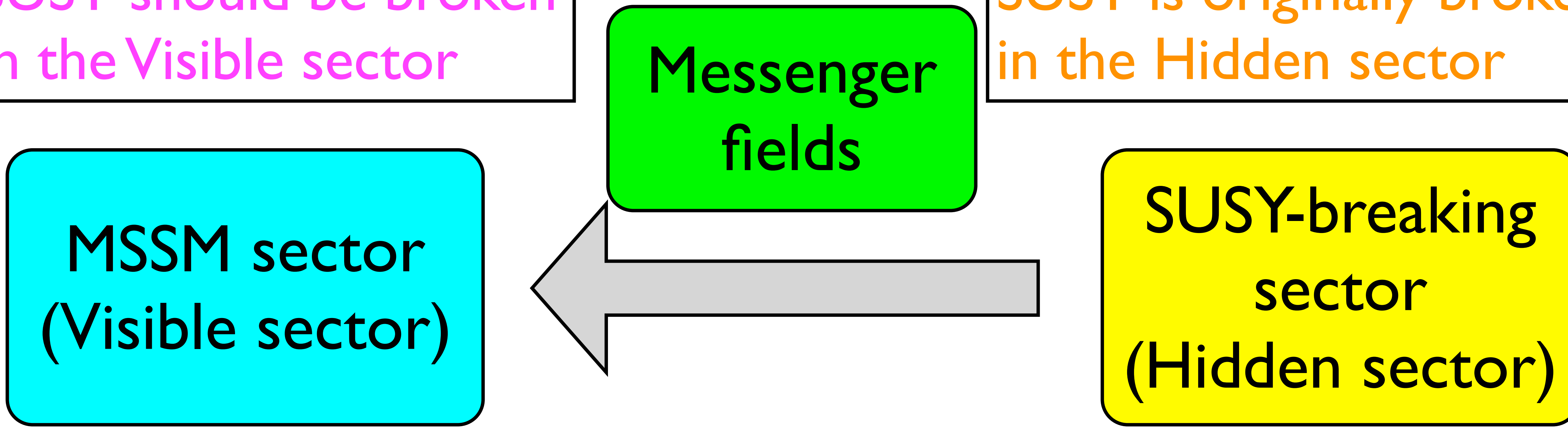
GMSB (LHC + weak lensing)



SUSY models

SUSY should be broken in the Visible sector

SUSY is originally broken in the Hidden sector



Three SUSY models w/ different mediation mechanisms

Gauge mediation (GMSB)

Gravity mediation

Anomaly mediation

SUSY models

SUSY should be broken in the Visible sector

SUSY is originally broken in the Hidden sector

MSSM sector (Visible sector) ← Messenger fields ← SUSY-breaking sector (Hidden sector)

We focus on

models w/ different mediation mechanisms

Gauge mediation (GMSB)

naturally evade
the flavor-problems
the CP-problems

Gravity mediation

Anomaly

GMSB mass spectrum

superpotential of minimal model

$$W = (\lambda S + M) \sum_{n=1}^{N_5} \Phi_n \bar{\Phi}_n$$

sfermion mass squared

$$m_{\phi_i}^2 = 2\Lambda^2 N_5 \sum_{a=1}^{3} C_a(i) \left(\frac{g_a^2}{16\pi^2}\right)^2 f(x)$$

gaugino mass

$$M_a = \frac{g_a^2}{16\pi^2} \Lambda N_5 g(x)$$

gravitino mass

$$m_{3/2} = \frac{F}{\sqrt{3} M_{\rm pl}}$$

SM ⇔ SUSY

graviton ⇔ gravitino

the lightest supersymmetric particle (LSP)

Φ_n : messenger superfields

N_5 : # of messengers

M : messenger mass

$S \; (\langle S \rangle = \theta^2 F)$

: SUSY-breaking (goldstino) field

$\Lambda \; (= \lambda F/M)$

: SUSY-breaking mass in the Visible sector

$x = \Lambda/M$

$$f(x) = \frac{1+x}{x^2}\left[\ln(1+x) - 2\mathrm{Li}_2\left(\frac{x}{1+x}\right) + \frac{1}{2}\mathrm{Li}_2\left(\frac{2x}{1+x}\right)\right] + (x \to -x)$$

$$g(x) = \frac{1}{x^2}(1+x)\ln(1+x) + (x \to -x)$$

GMSB mass spectrum

superpotential of minimal model

$$W = (\lambda S + M) \sum_{n=1}^{N_5} \Phi_n \bar{\Phi}_n$$

Φ_n : messenger superfields

N_5 : # of messengers

M : messenger mass

Sfermion m

$m_{\phi_i}^2 = 2\Lambda^2 N$

gaugino ma

$M_a = \frac{g_a^2}{16\pi^2}$

mass

ctor

$x = \Lambda/M$

Distinctive feature of GMSB

Light gravitino LSP

$$m_{3/2} = \mathcal{O}(\mathrm{eV} - \mathrm{keV})$$

gravitino mass

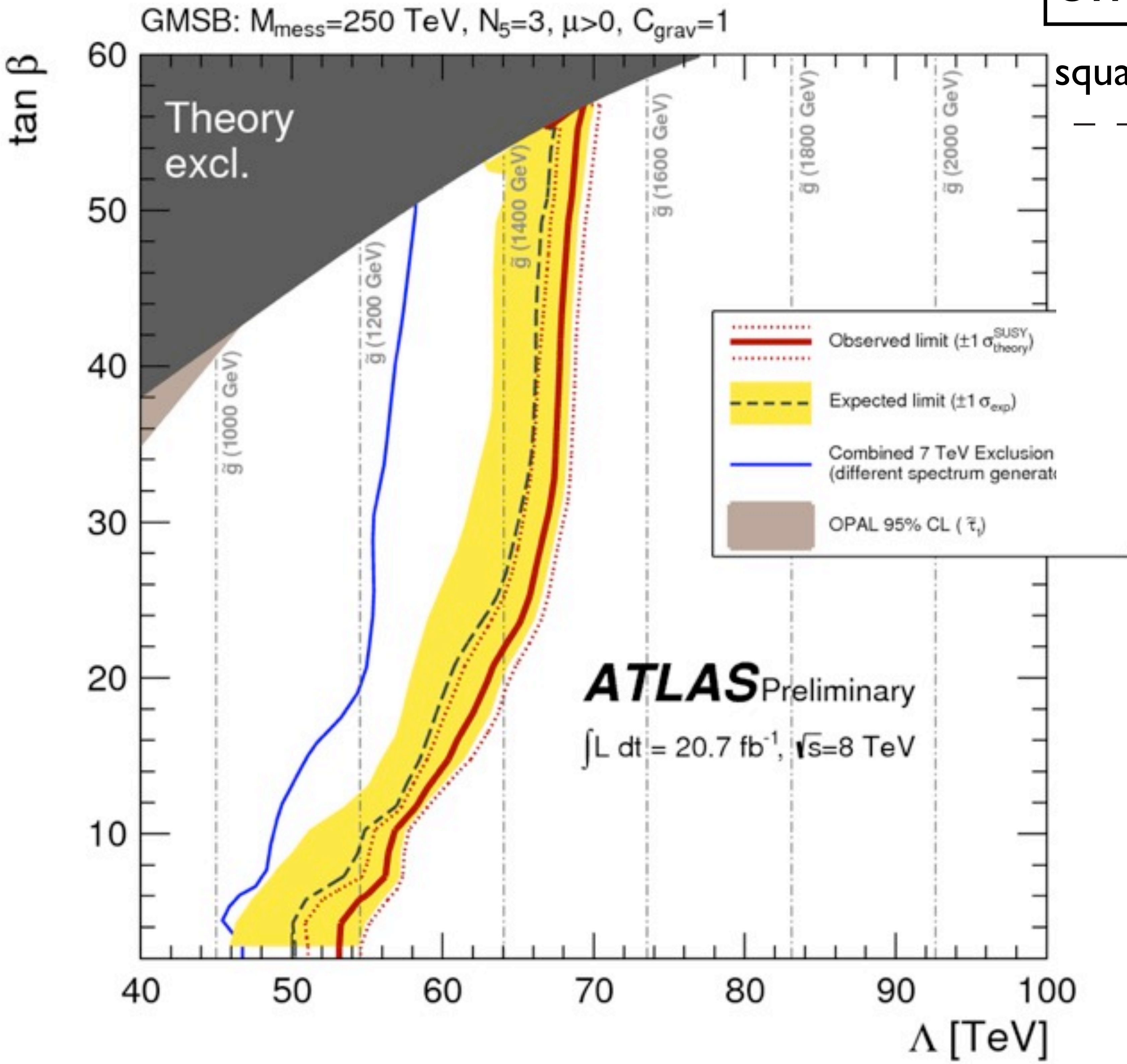
$$m_{3/2} = \frac{F}{\sqrt{3} M_{\rm pl}}$$

supersymmetric particle (LSP)

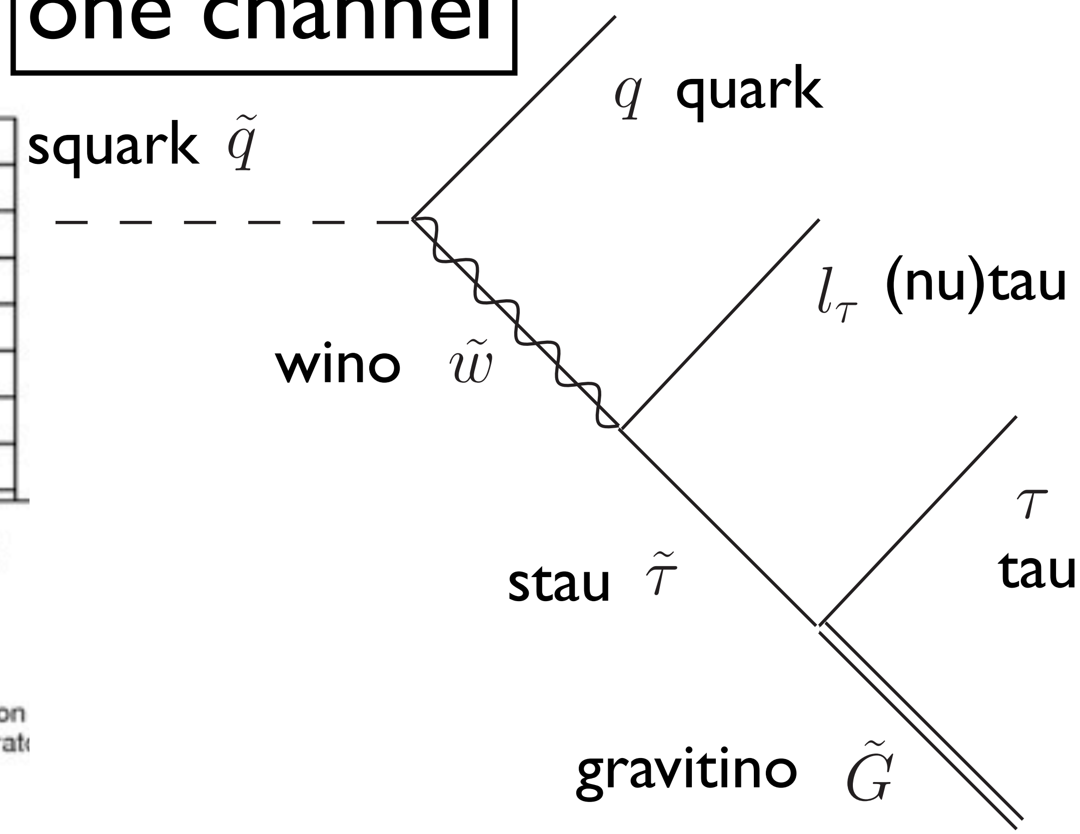
$$f(x) = \frac{1+x}{x^2}\left[\ln(1+x) - 2\mathrm{Li}_2\left(\frac{x}{1+x}\right) + \frac{1}{2}\mathrm{Li}_2\left(\frac{2x}{1+x}\right)\right] + (x \to -x)$$

$$g(x) = \frac{1}{x^2}(1+x)\ln(1+x) + (x \to -x)$$

GMSB in the 8TeV LHC



one channel



Fixing:

$N_5 = 3$

$M = 250\,\mathrm{TeV}$

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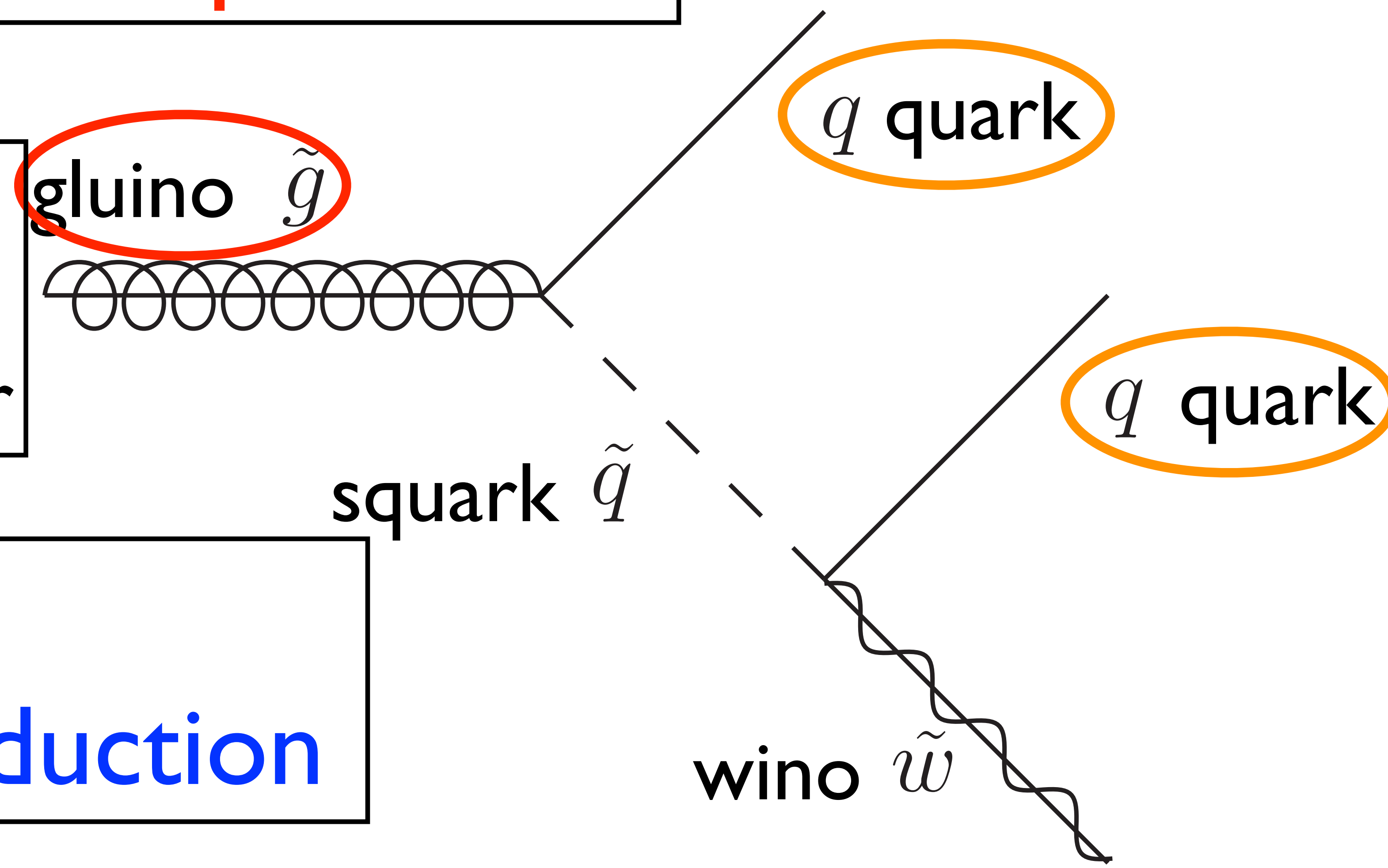
Basics of SUSY searches in the LHC

SUSY particles should be produced

Colored Particles (gluino, squarks) are important in the p-p collider



High-energy collision
⇔Heavy particle production

Decay products should be distinguishable

In the p-p collider, there are so many background high-energy colored particles (gluons, quarks)

GMSB mass spectrum

superpotential of minimal model

$$W = (\lambda S + M) \sum_{n=1}^{N_5} \Phi_n \bar{\Phi}_n$$

Φ_n : messenger superfields

N_5 : # of messengers

M : messenger mass

sfermion mass s

$$m_{\phi_i}^2 = 2\Lambda^2 N_5 \sum_{a=1}^{3} C$$

king

ield

gaugino mass

$$M_a = \frac{g_a^2}{16\pi^2} \Lambda N_5 g$$

king mass

e sector

the lightest supersymmetric particle (LSP)

$x = \Lambda / M$

gravitino mass

$$m_{3/2} = \frac{F}{\sqrt{3} M_{\rm pl}}$$

$$f(x) = \frac{1+x}{x^2}\left[\ln(1+x) - 2\mathrm{Li}_2\left(\frac{x}{1+x}\right) + \frac{1}{2}\mathrm{Li}_2\left(\frac{2x}{1+x}\right)\right] + (x \to -x)$$

$$g(x) = \frac{1}{x^2}(1+x)\ln(1+x) + (x \to -x)$$

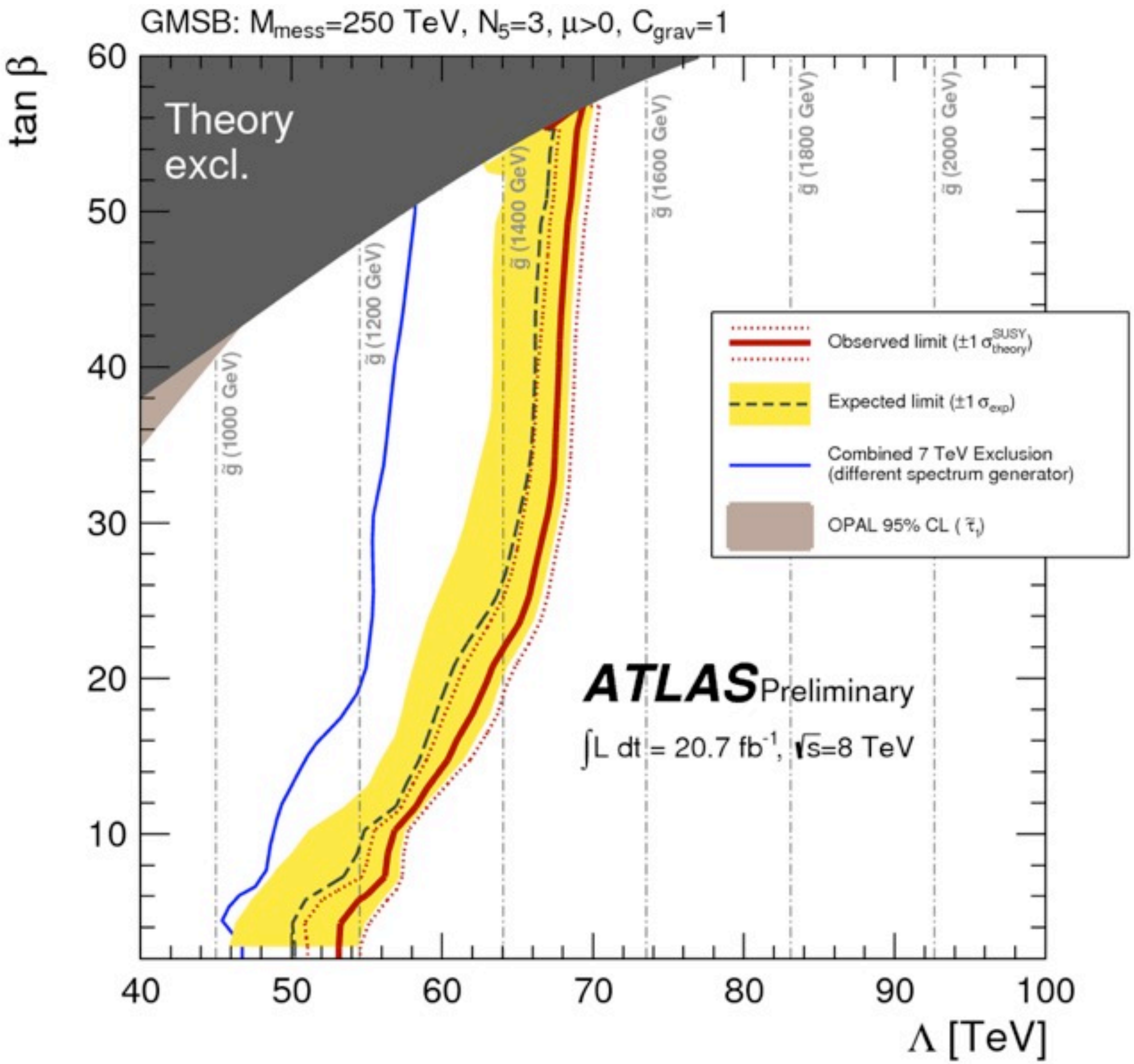
squark mass

$$m_{\tilde{q}} \propto \Lambda \sqrt{N_5}$$

gluino mass

$$m_{\tilde{g}} \propto \Lambda N_5$$

GMSB in the 8TeV LHC



Lower bound on
$\Lambda > 51\,\mathrm{TeV}$

Fixing:
$N_5 = 3$
$M = 250\,\mathrm{TeV}$

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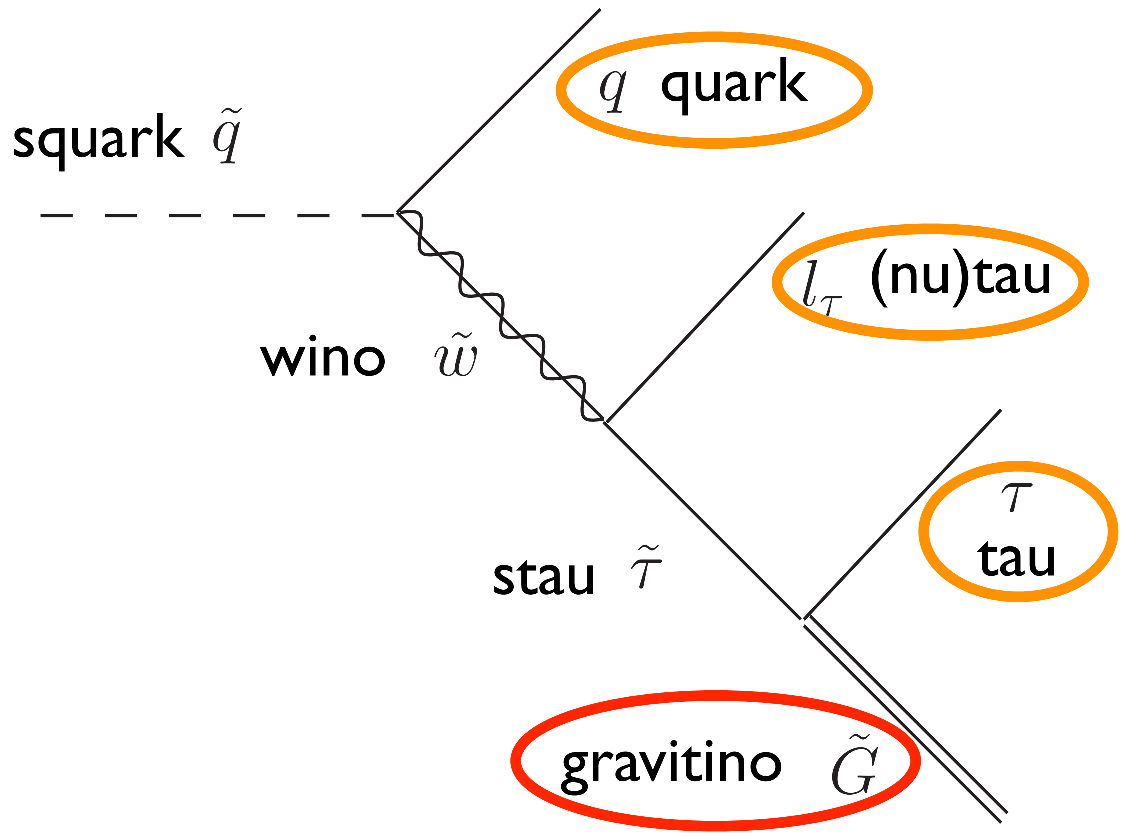
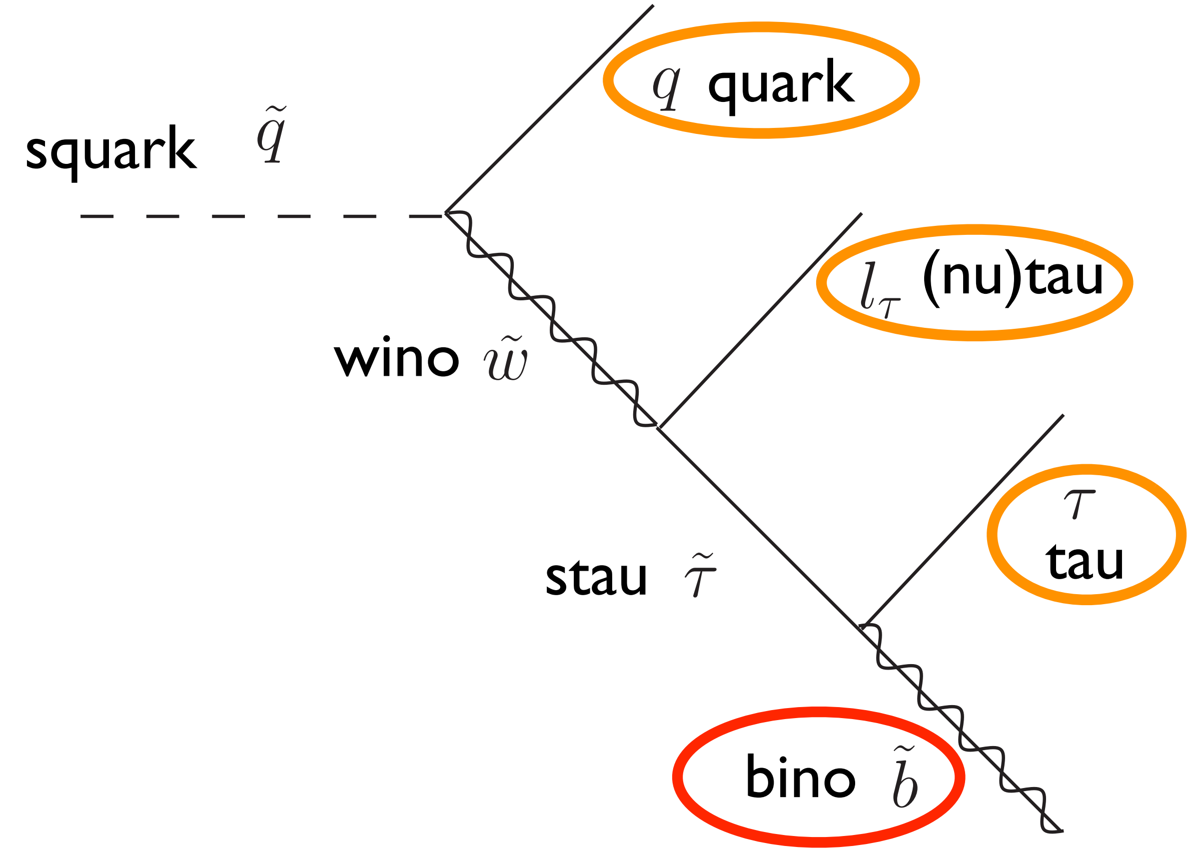
Difficult to distinguish...

mSUGRA (Minimal Supergravity)
: a model of Gravity mediation

channel in GMSB



channel in mSUGRA



○ : we can detect

○ : we can not detect

⇒ Light gravitino is one of missing energies

⇒ Light gravitino mass can not be probed in a direct manner

GMSB mass spectrum

superpotential of minimal model

$$W = (\lambda S + M) \sum_{n=1}^{N_5} \Phi_n \bar{\Phi}_n$$

Φ_n : messenger superfields

N_5 : # of messengers

M : messenger mass

sfermi

$m^2_{\phi_i} =$

gaugin

$M_a =$

Indirect probe of light gravitino mass through the SUSY-breaking mass Λ

gravitino mass

$$m_{3/2} = \frac{\Lambda M}{\sqrt{3}\lambda M_{\rm pl}}$$

gravitino mass

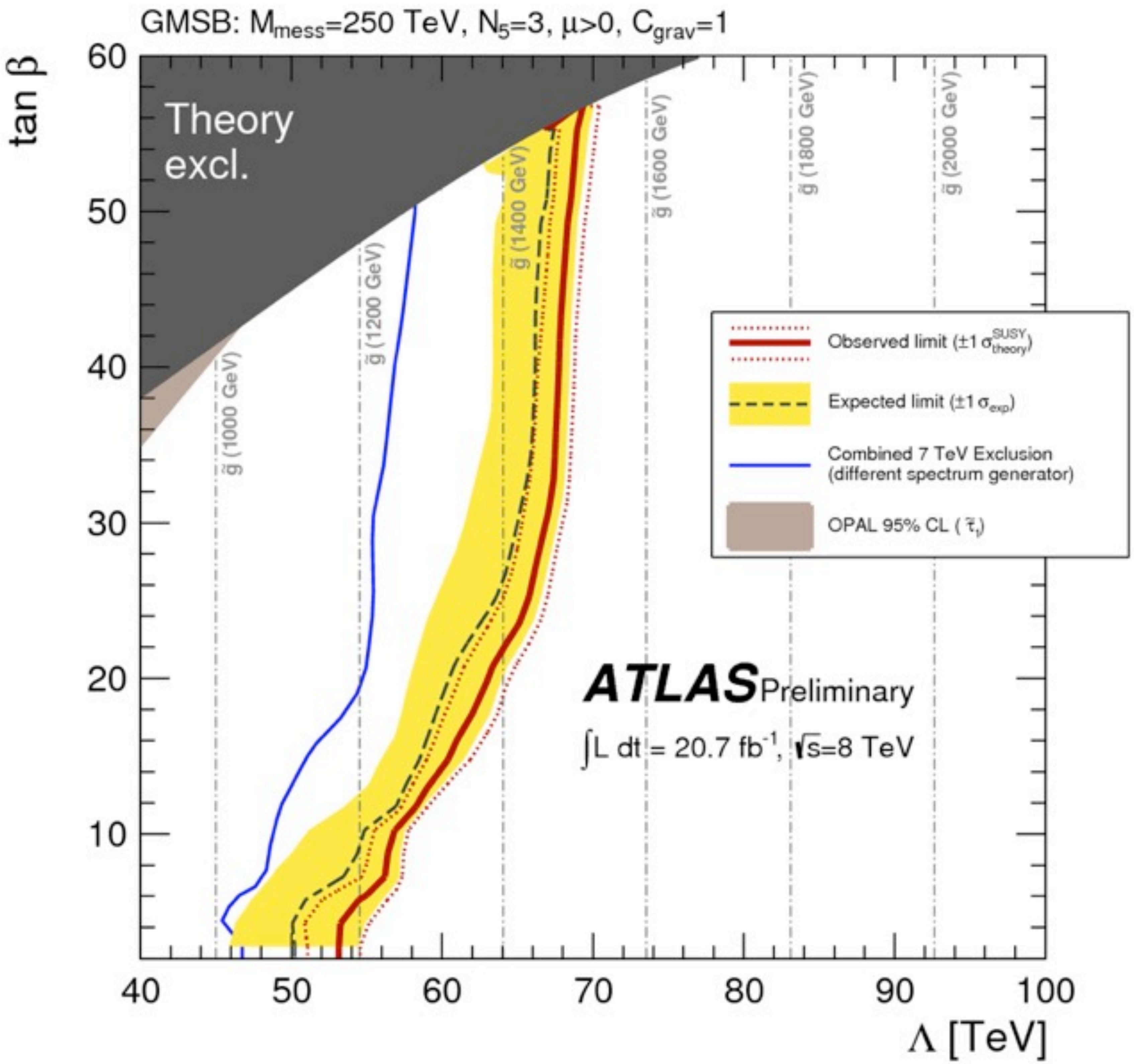
$$m_{3/2} = \frac{F}{\sqrt{3} M_{\rm pl}}$$

particle (LSP)

$$f(x) = \frac{1+x}{x^2}\left[\ln(1+x) - 2\mathrm{Li}_2\left(\frac{x}{1+x}\right) + \frac{1}{2}\mathrm{Li}_2\left(\frac{2x}{1+x}\right)\right] + (x \to -x)$$

$$g(x) = \frac{1}{x^2}(1+x)\ln(1+x) + (x \to -x)$$

Light gravitino mass in the 8 TeV LHC



$\Lambda > 51\,\mathrm{TeV}$

$m_{3/2} > 3\,\mathrm{eV} \times \lambda^{-1}$

$\lambda \lesssim 1$: perturbative coupling

fixing:

$N_5 = 3$

$M = 250\,\mathrm{TeV}$

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Short Summary

Free parameters in GMSB: $N_5 \ \Lambda \ \lambda \ \ x$

squark mass

$$m_{\tilde{q}} \propto \Lambda \sqrt{N_5}$$

gluino mass

$$m_{\tilde{g}} \propto \Lambda N_5$$

gravitino mass

$$m_{3/2} = \frac{\Lambda^2}{\sqrt{3}\lambda x M_{\rm pl}}$$

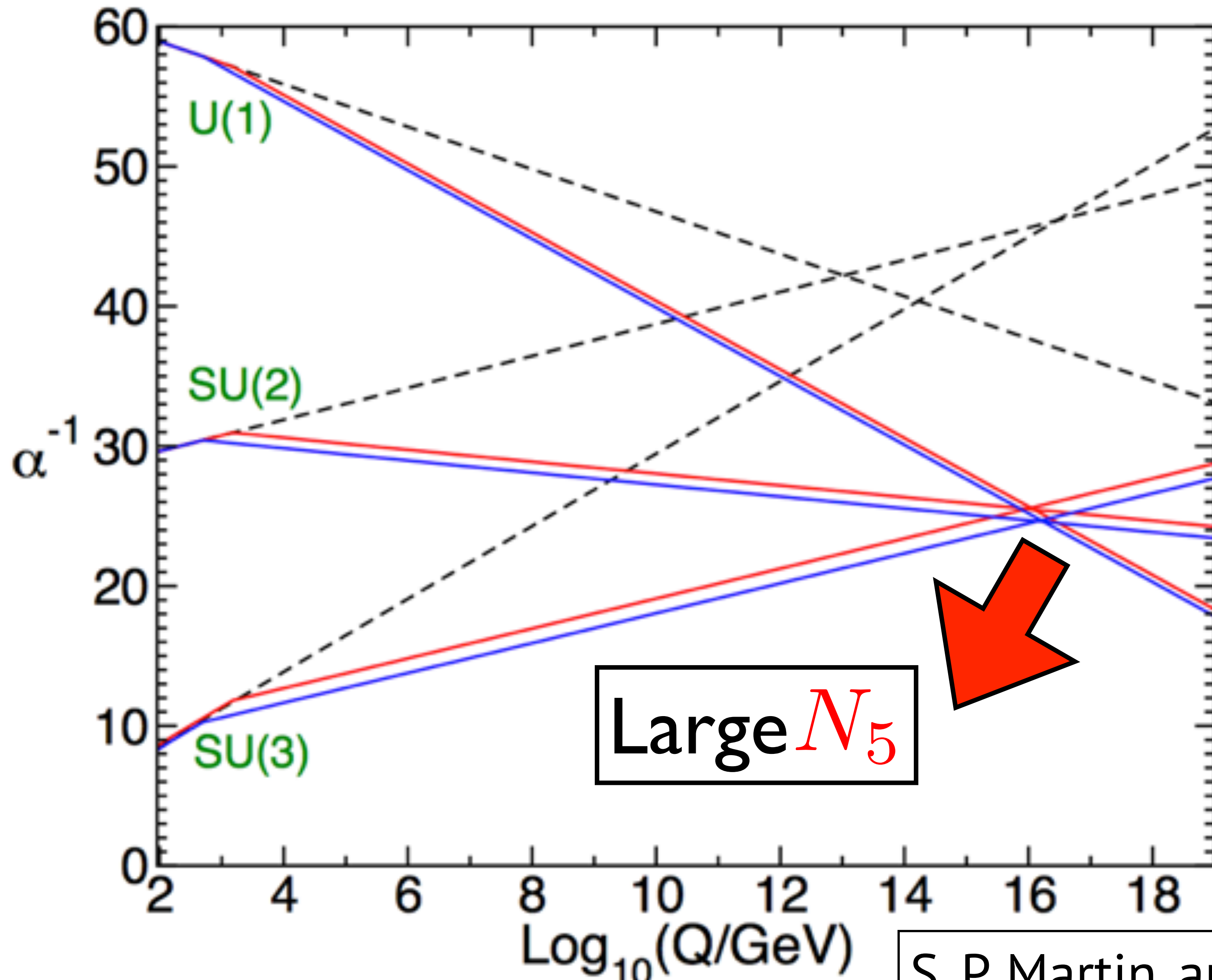
↓

To derive conservative lower bound on gravitino mass

Maximize N_5 and λx

N_5 and λx

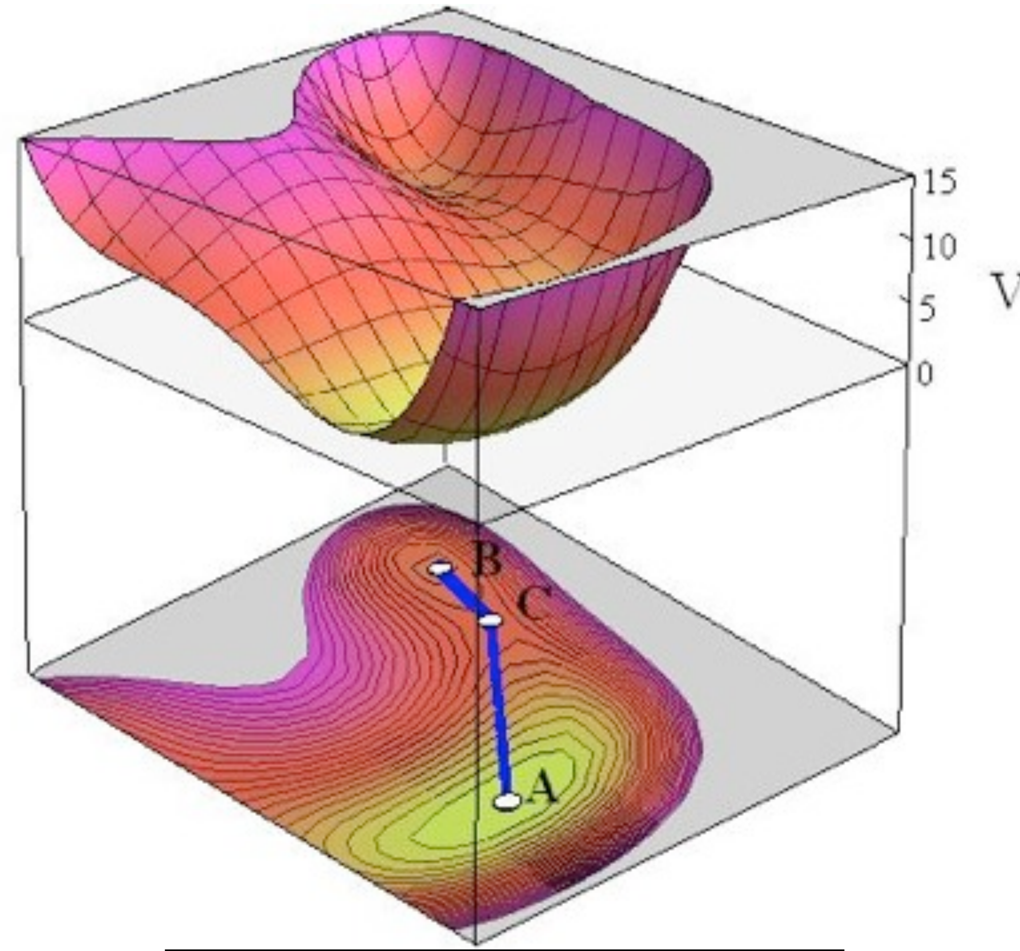
N_5 changes the running of gauge couplings



S. P. Martin, arXiv:hep-ph/9709356

For $N_5 > 5$, the gauge couplings diverge until the unification

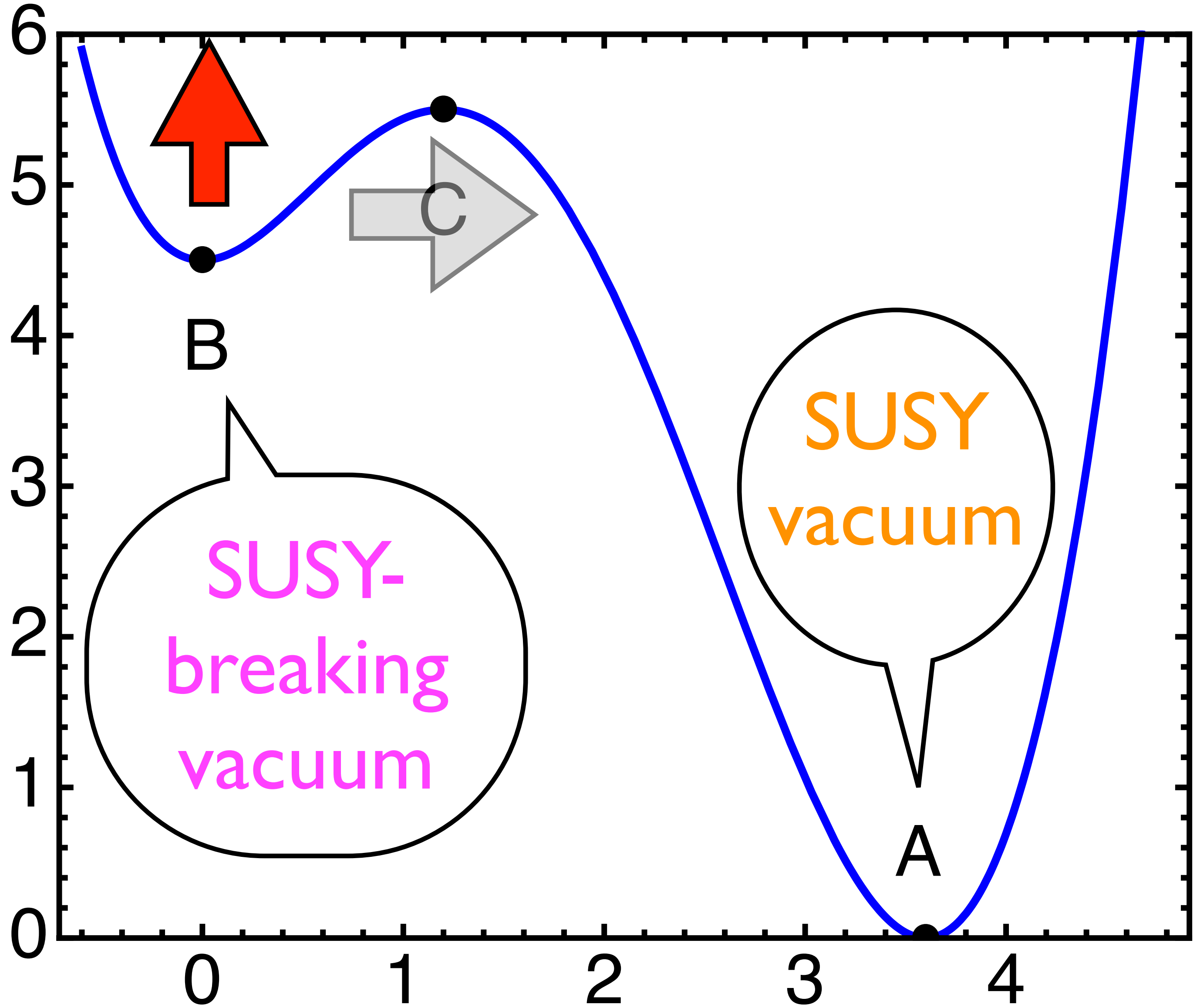
N_5 and λx



K. R. Dienes, PRD (2008)

λx affects the stability of the SUSY-breaking vacuum

Large λx



For $\lambda x > 1.4$, SUSY-breaking vacuum decays within the age of the Universe

J. Hisano et al, JHEP (2007, 2008)

Short Summary

Free parameters in GMSB: N_5 Λ λ x

squark mass

$$m_{\tilde{q}} \propto \Lambda\sqrt{N_5}$$

gluino mass

$$m_{\tilde{g}} \propto \Lambda N_5$$

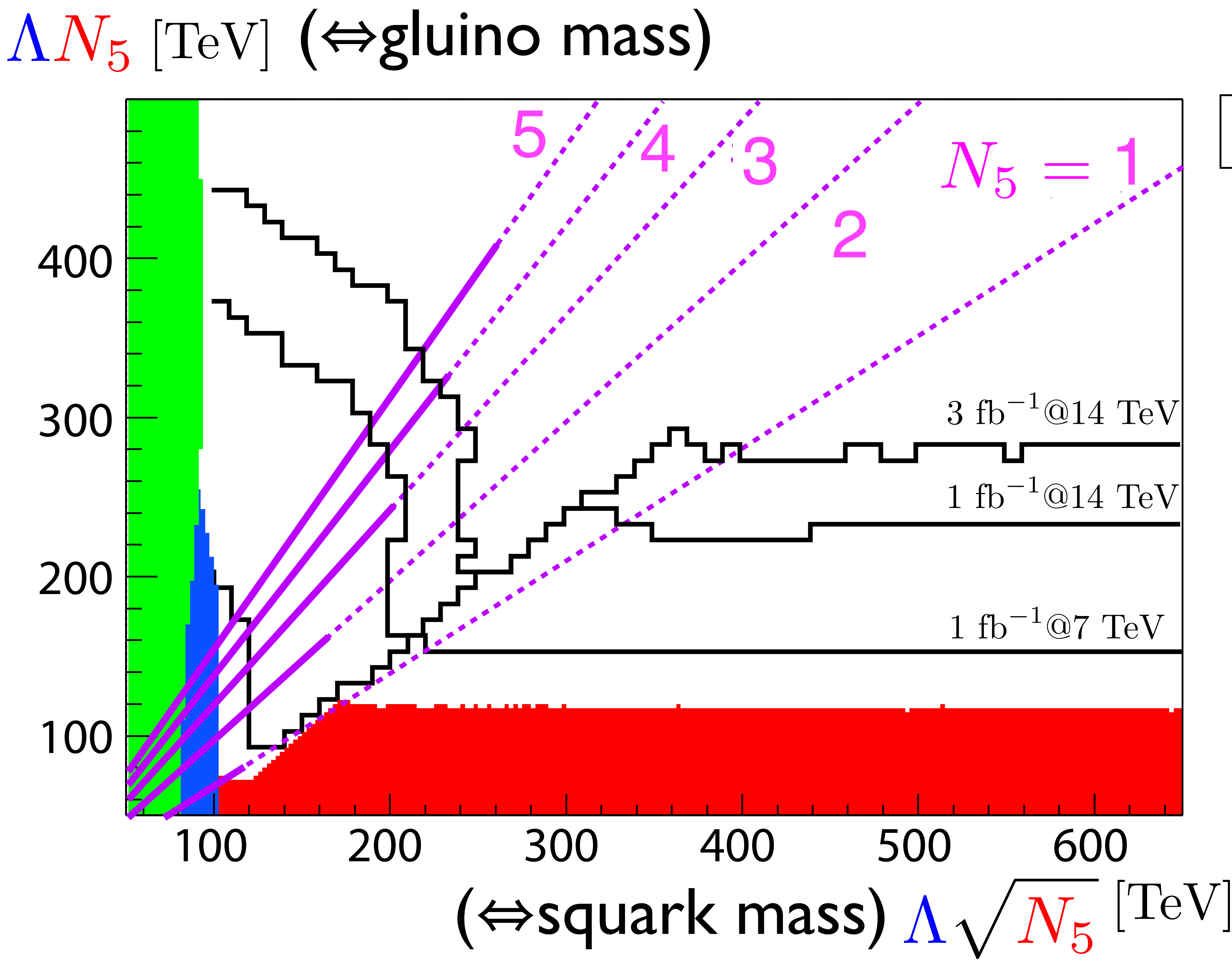
gravitino mass

$$m_{3/2} = \frac{\Lambda^2}{\sqrt{3}\lambda x M_{\rm pl}}$$

To derive conservative lower bound on gravitino mass

$N_5 = 5$ and $\lambda x = 1.4$

Light gravitino mass in the 14 TeV LHC



E. Nakamura et al, JHEP (2011)

$15\,\mathrm{fb}^{-1}$ (~1yr) of the 14TeV LHC will reach $\Lambda = 80\,\mathrm{TeV}$ even in the case of $N_5 = 5$

Virtually all GMSB models with $m_{3/2} < 5\,\mathrm{eV}$ can be probed

fixing:
$N_5 = 5$
$\lambda x = 1.4$

Thursday, November 14, 13

Short Summary

focus point	fixed GMSB parameters
current	$M = 250\,\text{TeV}, N_5 = 3, \lvert\lambda\rvert = 1$
future	$\lvert\lambda\rvert x = 1.4, N_5 = 5$

LHC	Λ	$m_{3/2}$
$21\,\text{fb}^{-1}$ at $\sqrt{s} = 8\,\text{TeV}$	$\Lambda = 51\,\text{TeV}$	$m_{3/2} = 3\,\text{eV}$
$15\,\text{fb}^{-1}$ at $\sqrt{s} = 14\,\text{TeV}$	$\Lambda = 80\,\text{TeV}$	$m_{3/2} = 5\,\text{eV}$

In the LHC, we can obtain only the lower bound on the light gravitino mass through the gluino/sfermion mass

In order to confirm GMSB, the light gravitino mass should be directly detected

Light gravitino in cosmology

Thermal history

Produced and thermalized
just after the reheating of the Universe

$T = \mathcal{O}(10 - 100)\,\mathrm{GeV}$ ⟺ at the freeze-out of the other SUSY particles

Decoupled from the thermal background and
begins to **stream freely with speed of light**

$(1+z) \simeq 6 \times 10^3 \times (m_{3/2}/1\,\mathrm{eV})(10.75/g_{*s})^{-1/3}$

Contribute to the mass density of the Universe

Light gravitino is "hot" component

Relic gravitino

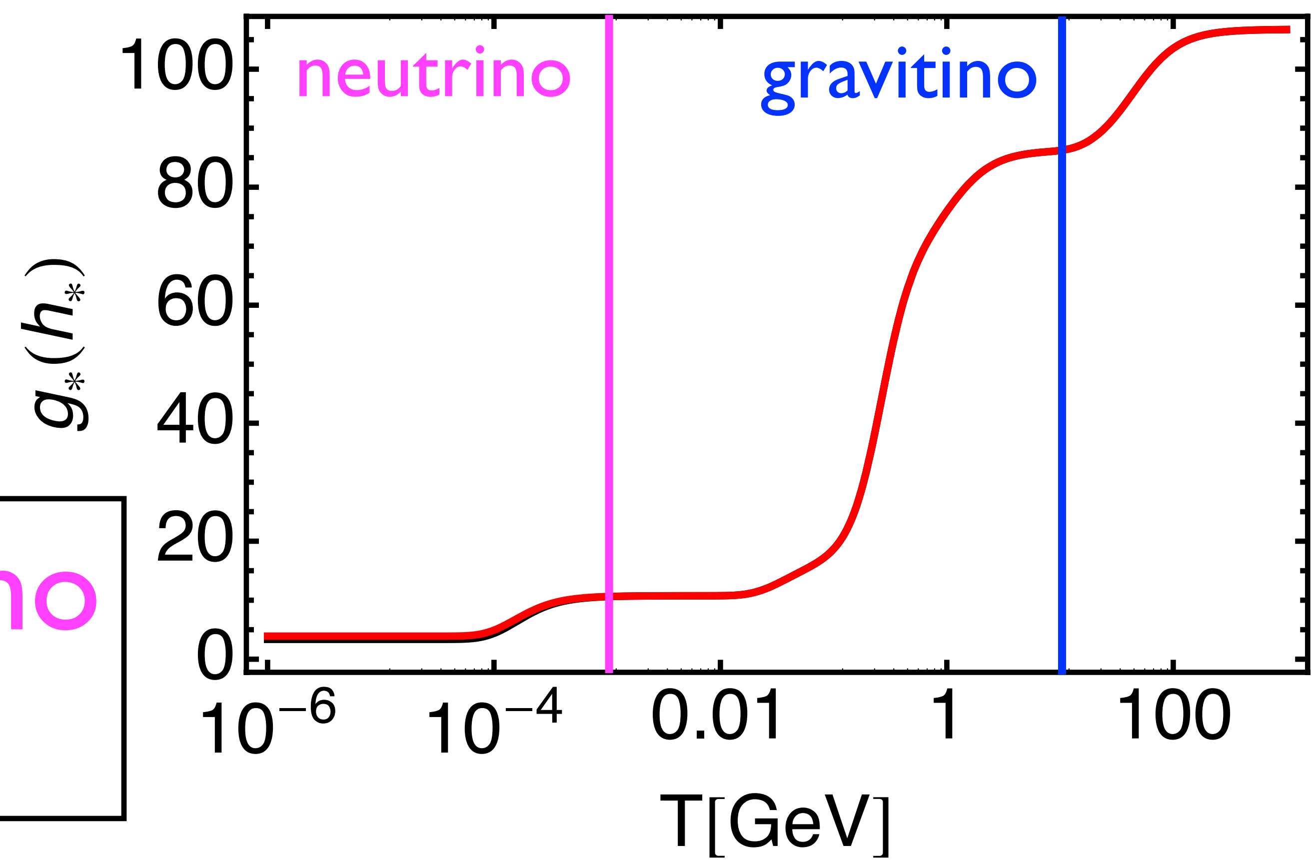
Present mass density of the gravitino

$$\Omega_{3/2}h^2 = 0.13\left(\frac{g_{3/2}}{2}\right)\left(\frac{m_{3/2}}{100\,\mathrm{eV}}\right)\left(\frac{g_{*s3/2}}{90}\right)^{-1}$$

$g_{*s3/2}$:Effective degrees of freedom for the entropy density at the decoupling of the gravitino

$g_{*s3/2} \simeq 90$
for $m_{3/2} = \mathcal{O}(1-10)\,\mathrm{eV}$

E. Pierpaoli et al, PRD (1998)



Different from the neutrino

$g_{*s\nu} \simeq 43/4$ ⟺ $g_{*s3/2} \simeq 90$

Mixed Dark Matter (MDM)

Present mass density of the gravitino

$$\Omega_{3/2}h^2 = 0.13\left(\frac{g_{3/2}}{2}\right)\left(\frac{m_{3/2}}{100\,\mathrm{eV}}\right)\left(\frac{g_{*s3/2}}{90}\right)^{-1}$$

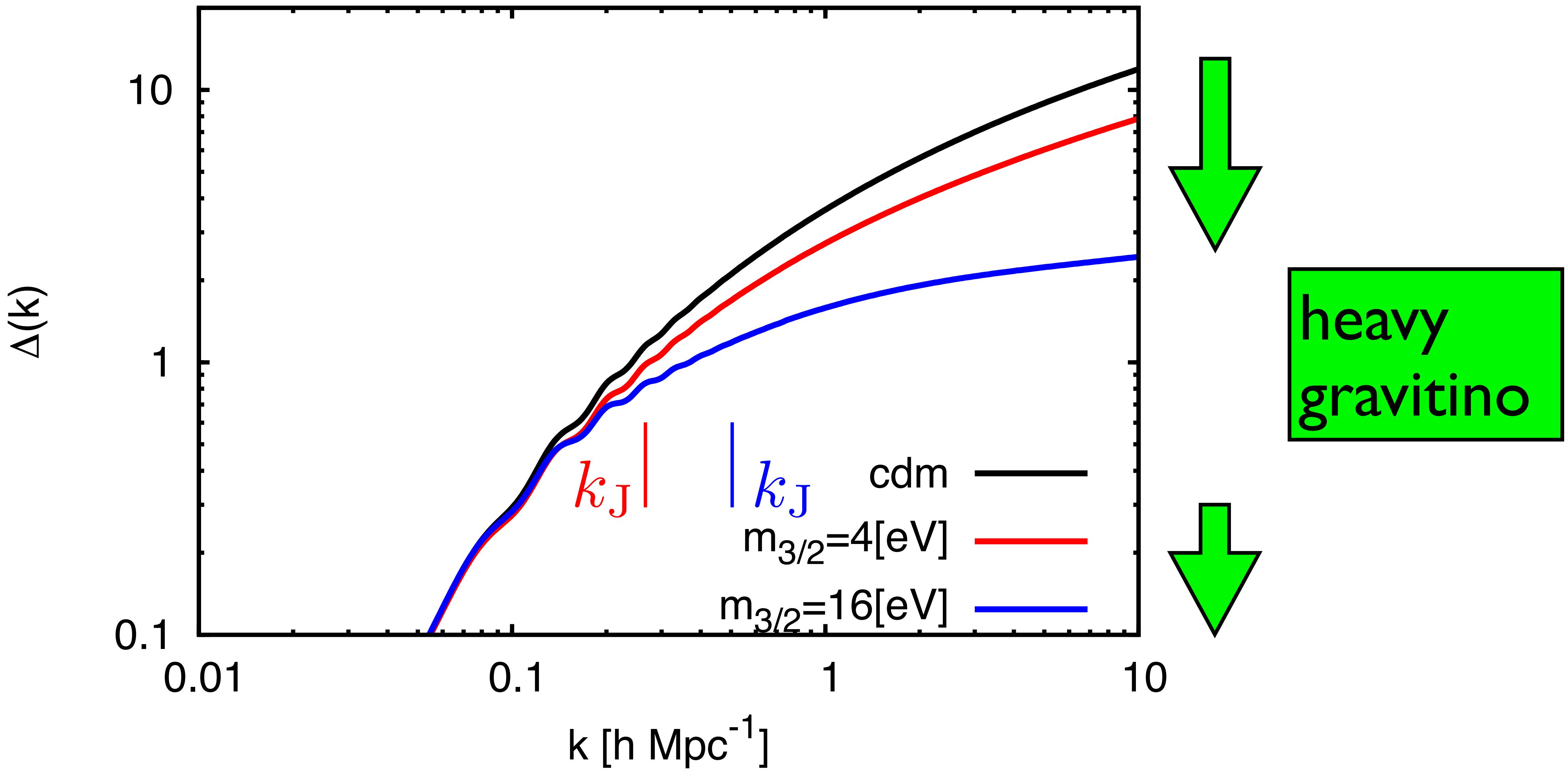
⇩

$m_{3/2} = \mathcal{O}(1-10)\,\mathrm{eV}$ ⇨ $\Omega_{3/2}h^2 = \mathcal{O}(0.001-0.01)$

⇩ To be consistent with CMB

Assume another cold and stable particle with $\Omega_{cs}h^2$ ⇨ $\Omega_{dm} = \Omega_{cs} + \Omega_{3/2}$

Linear matter power spectra for MDM

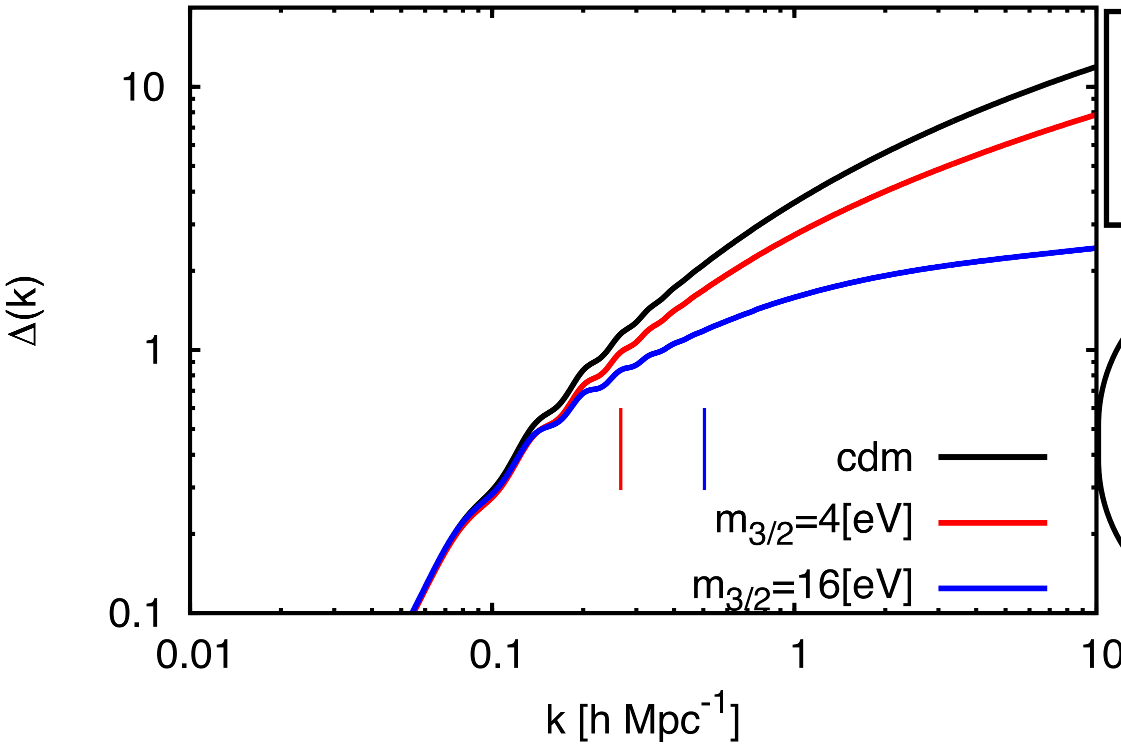


cut-off scale: $k_J = a\sqrt{\frac{4\pi G\rho_M}{\langle v^2\rangle}}\Big|_{a=a_{eq}} \simeq 0.86\,\mathrm{Mpc}^{-1}\left(\frac{g_{3/2}}{2}\right)^{-1/2}\left(\frac{m_{3/2}}{100\,\mathrm{eV}}\right)^{1/2}\left(\frac{g_{*s3/2}}{90}\right)^{5/6}$

Upper bound on the gravitino mass in cosmology

⇔ Lower bound in the LHC

Weak lensing is suitable probe

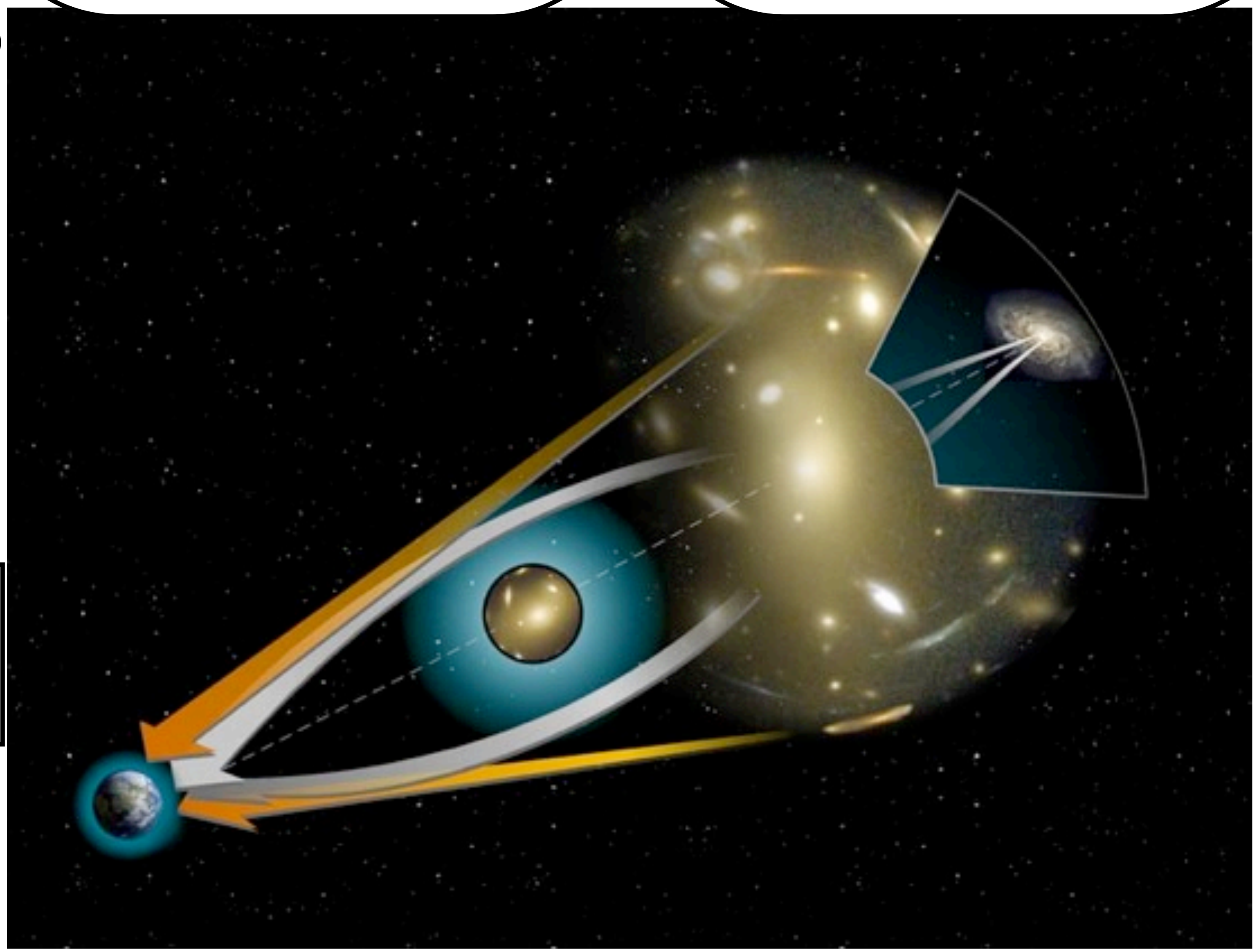


$$P_\kappa(\ell) = \int_0^{\chi_s} \mathrm{d}\chi \frac{W(\chi)^2}{r(\chi)^2} P_\delta\left(k = \frac{\ell}{r(\chi)}, z(\chi)\right)$$

convergence power spectrum

matter power spectrum

weak lensing



distortion of image of a source object

$$A_{ij} = \frac{\partial \beta^i}{\partial \theta^j} \equiv \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

convergence: κ

Analysis - standard procedure

N-body simulation: make 5 realizations for each model $(m_{3/2} = 0,\ 4,\ 16\,\mathrm{eV})$ as mock matter distributions

↓

Ray-tracing simulation: measure the convergence power spectra

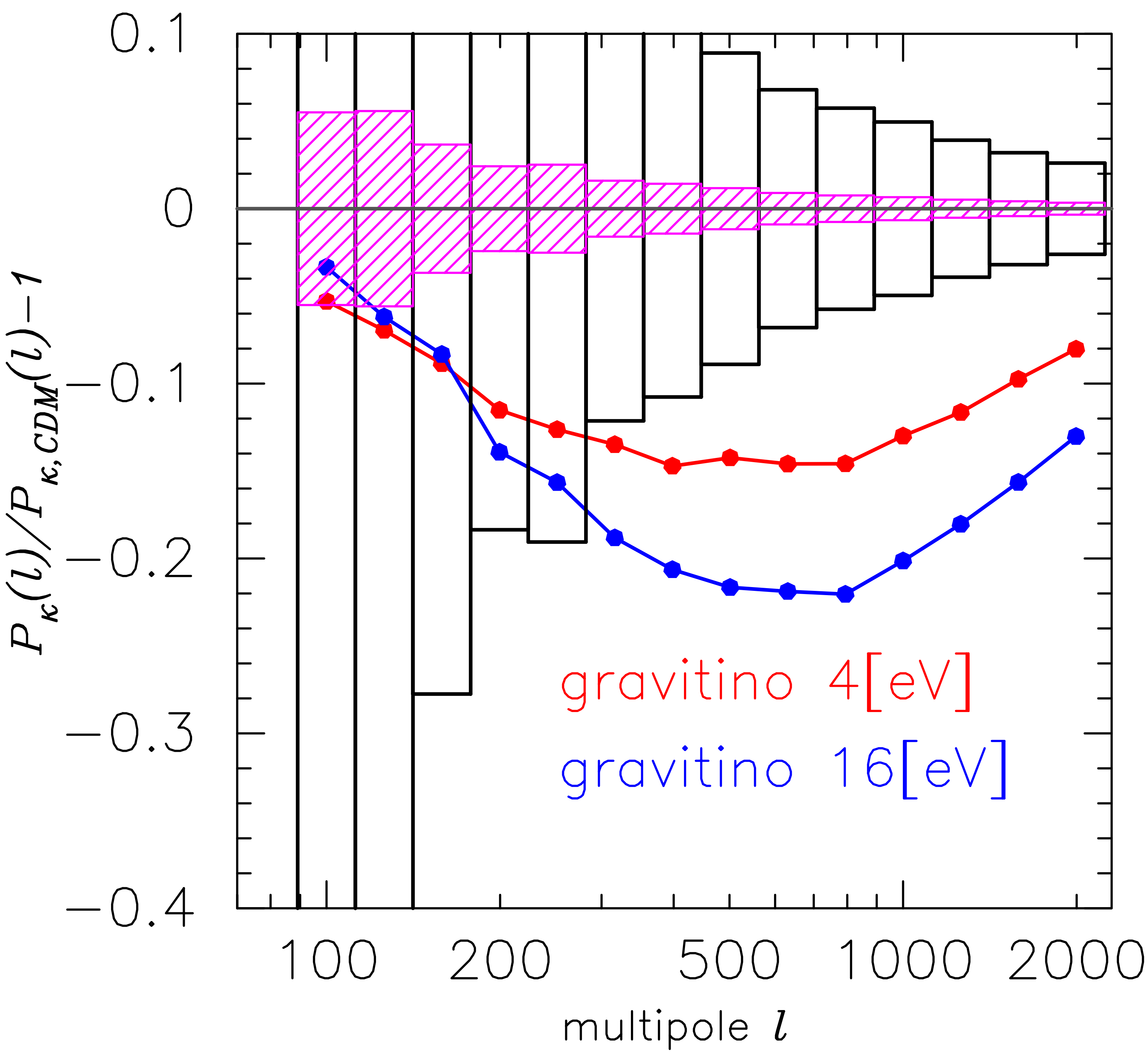
↓

Fisher analysis w/ cosmic variance + noise:
cosmic variance - from 1000 lensing maps

M. Sato et al, ApJ (2009)

noise - the same way as in M. Takada et al, ApJ (2004)

Lensing power spectrum



Blocks: statistical errors assuming

$1500\ \mathrm{deg}^2$

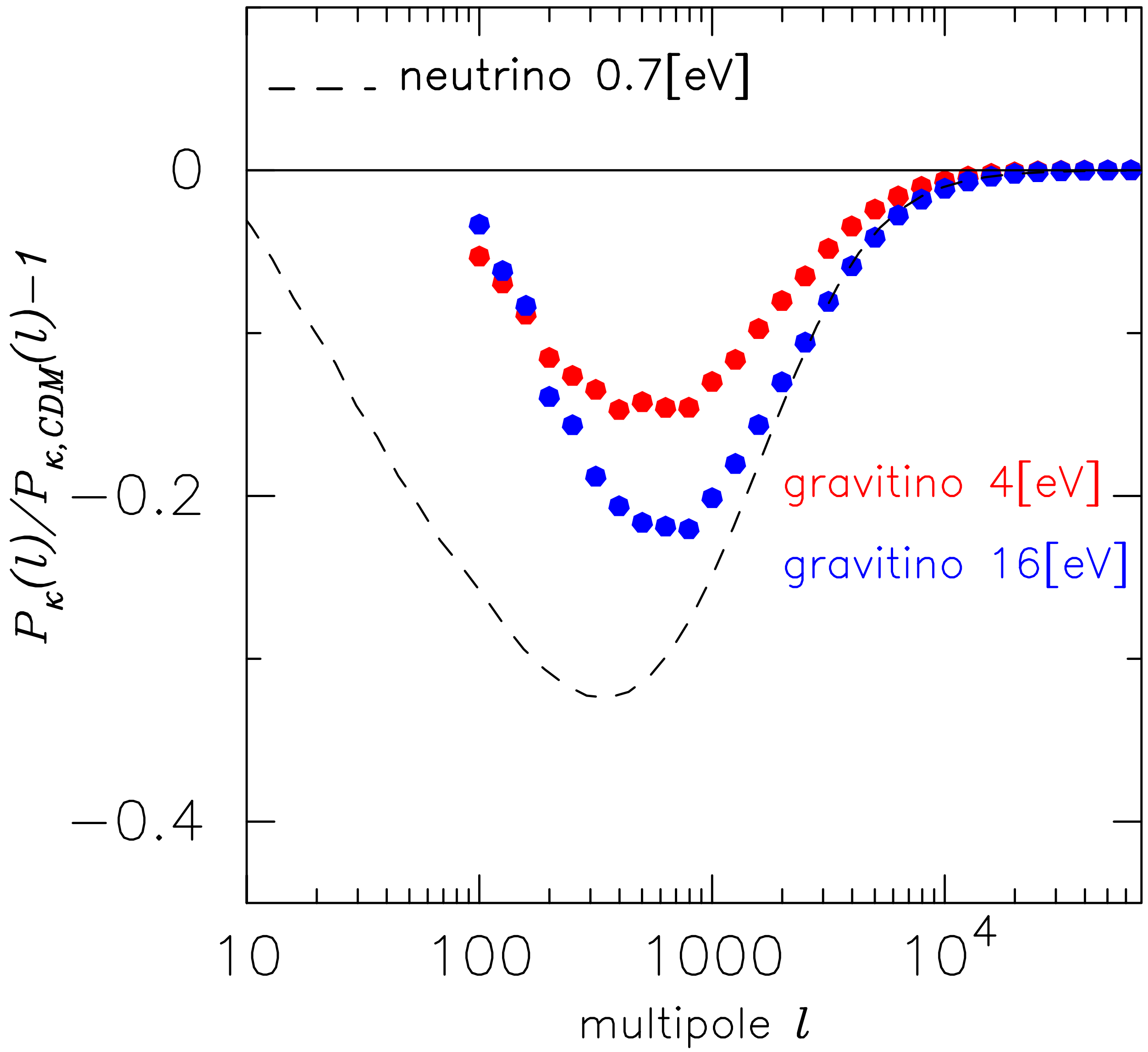
$n_{\mathrm{gal}} = 10\ [\mathrm{arcmin}^{-2}]$

$25\ \mathrm{deg}^2$

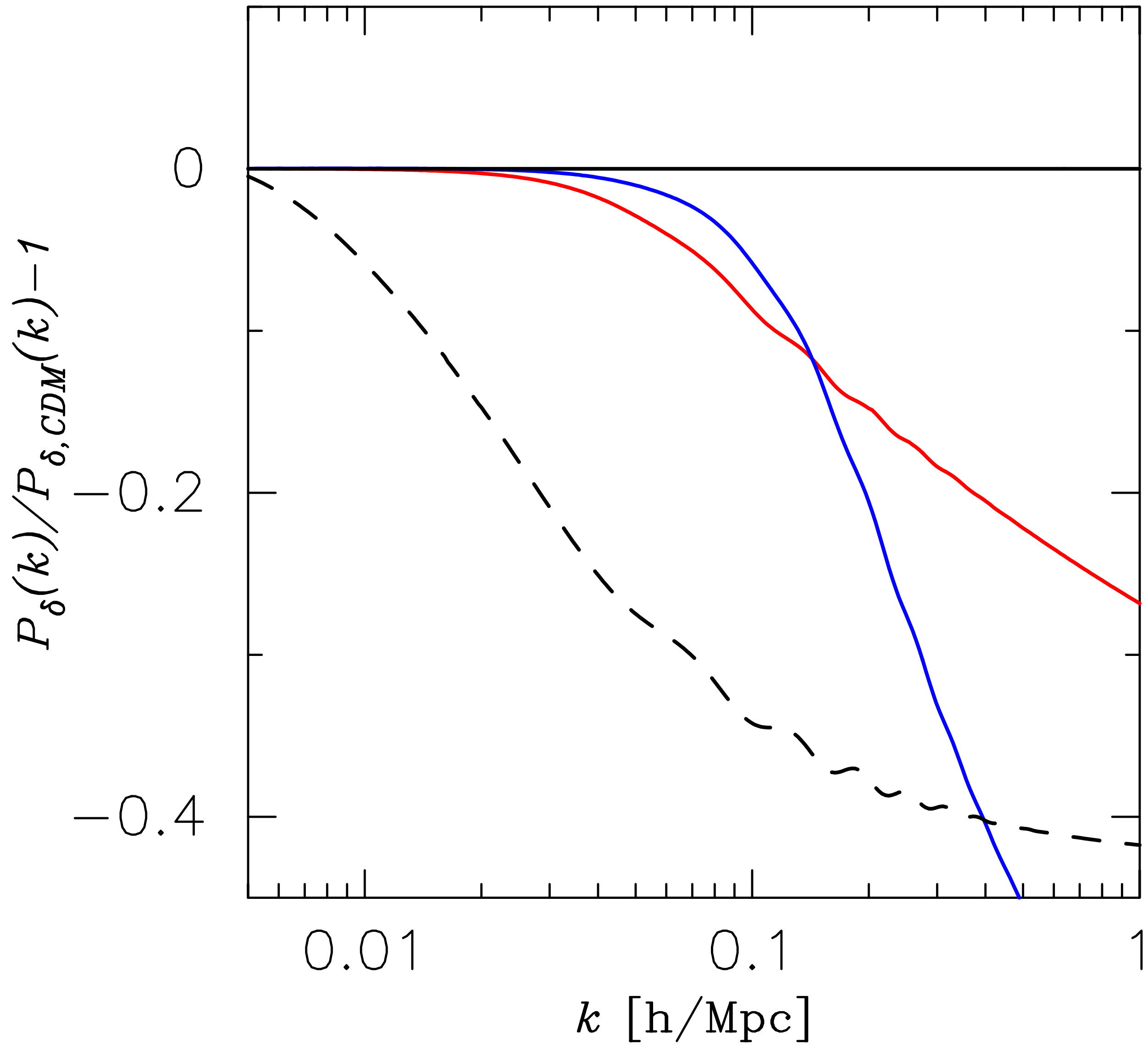
$n_{\mathrm{gal}} = 10\ [\mathrm{arcmin}^{-2}]$

Light gravitino v.s. Neutrino

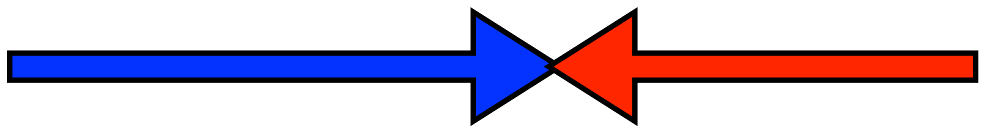
convergence power spectra



linear matter power spectra



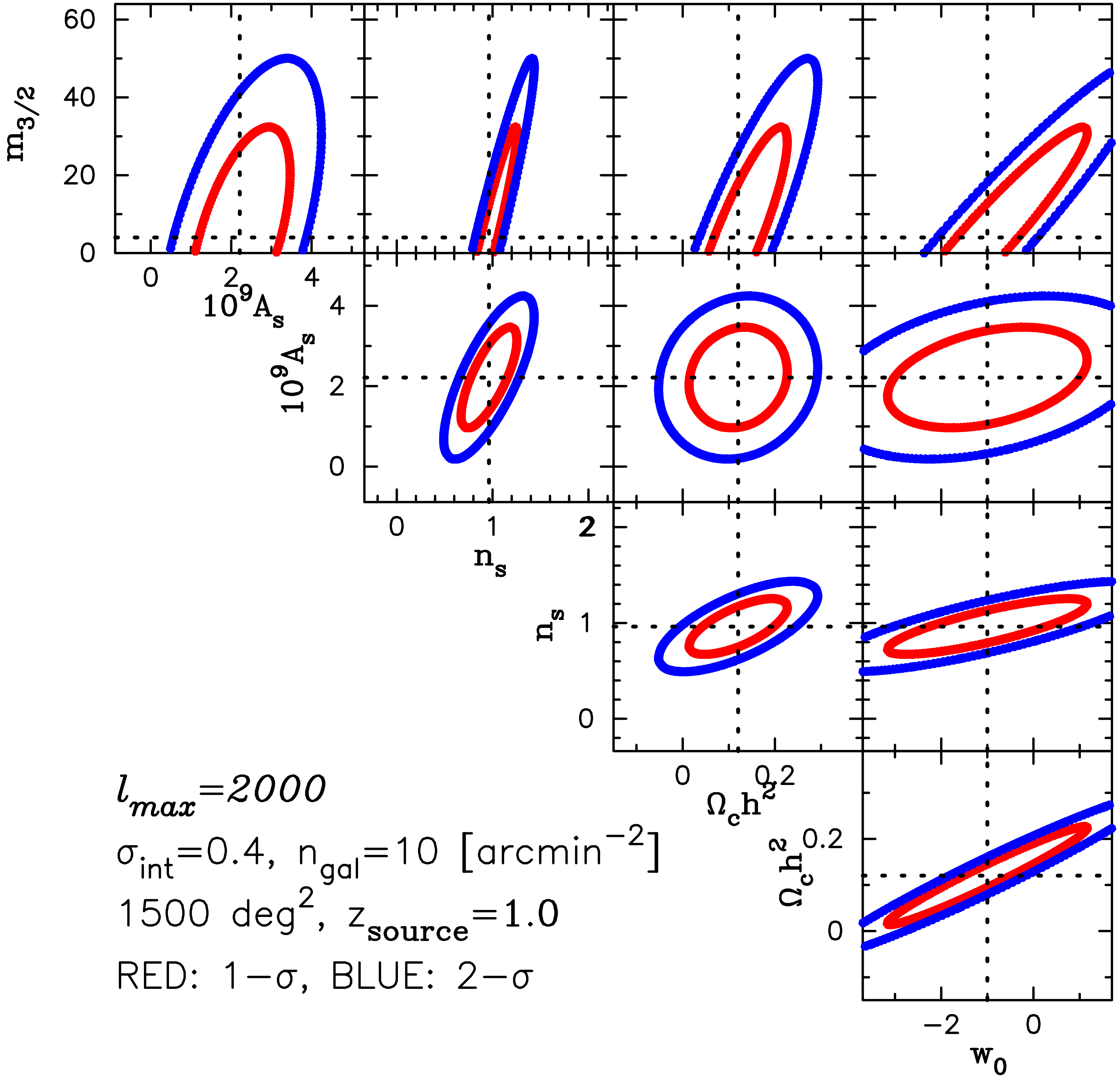
Combining observations at two different scales breaks the degeneracy



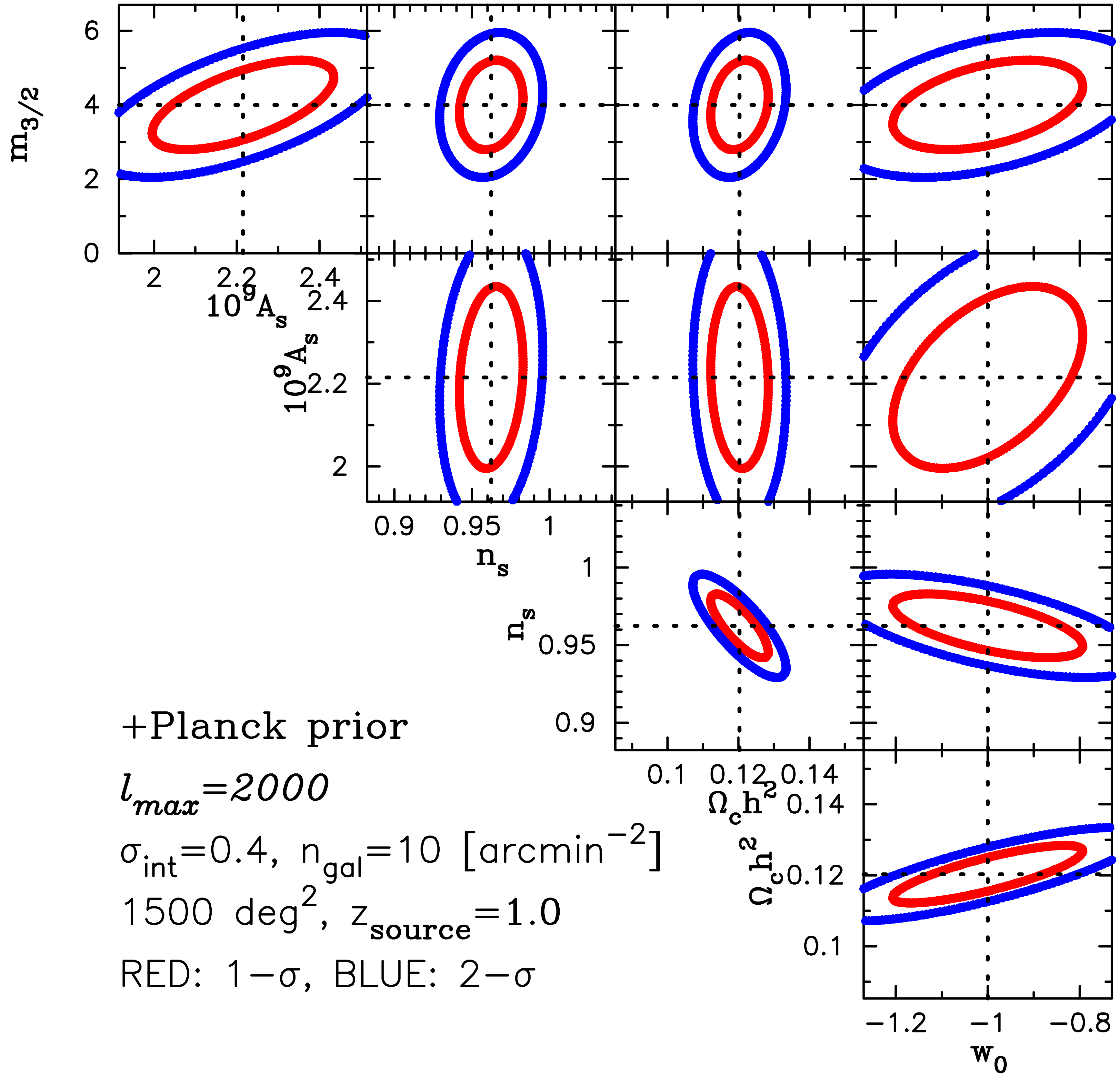
galaxy survey

weak lensing

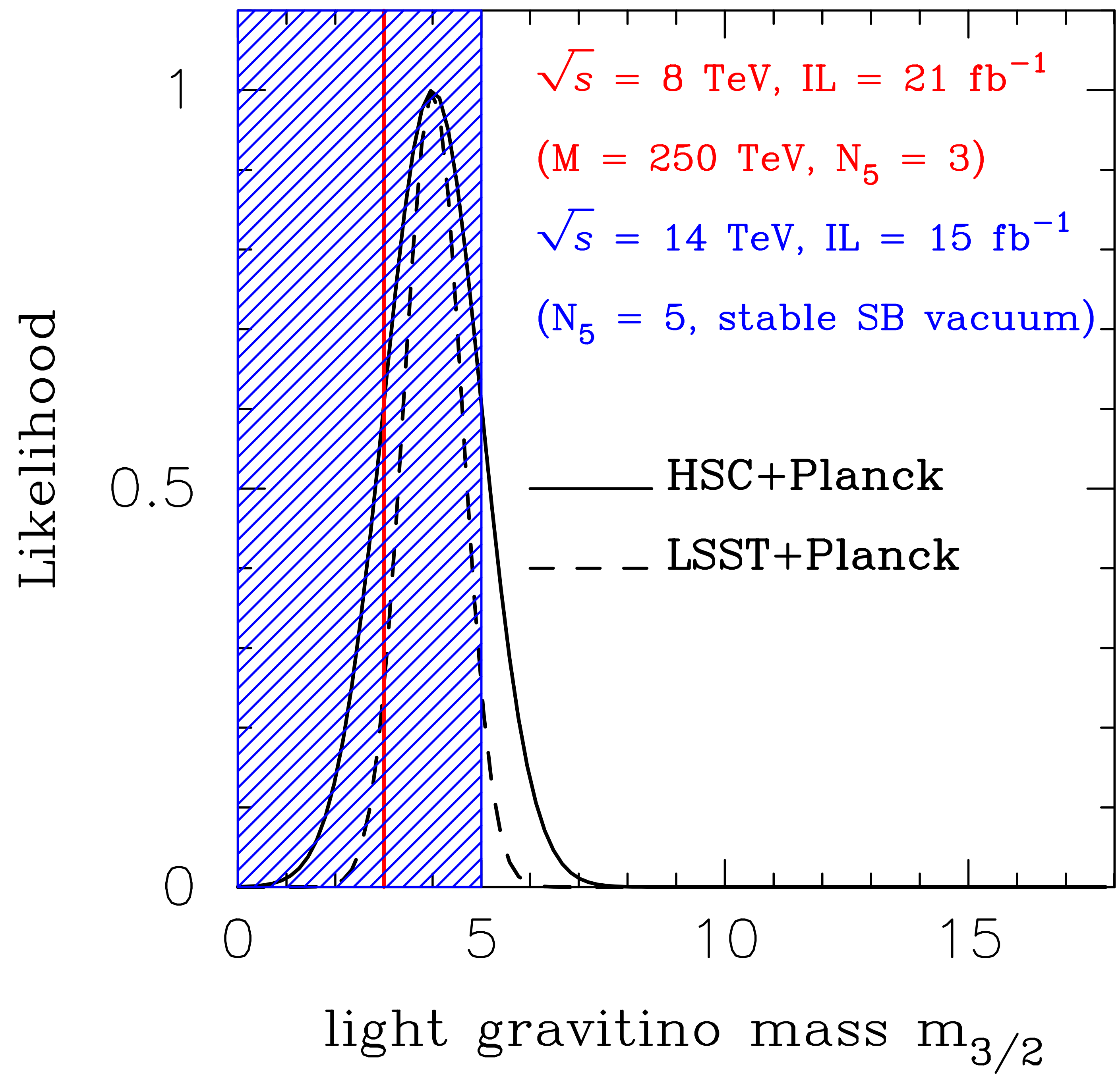
Forecast (weak lensing only)



Forecast (weak lensing + Planck)



GMSB (LHC + weak lensing)



We can reach the conclusion of GMSB in the near future