Planck 2009 Padova, 28th May 2009

GRAVITINO DARK MATTER & THE LHC

Laura Covi

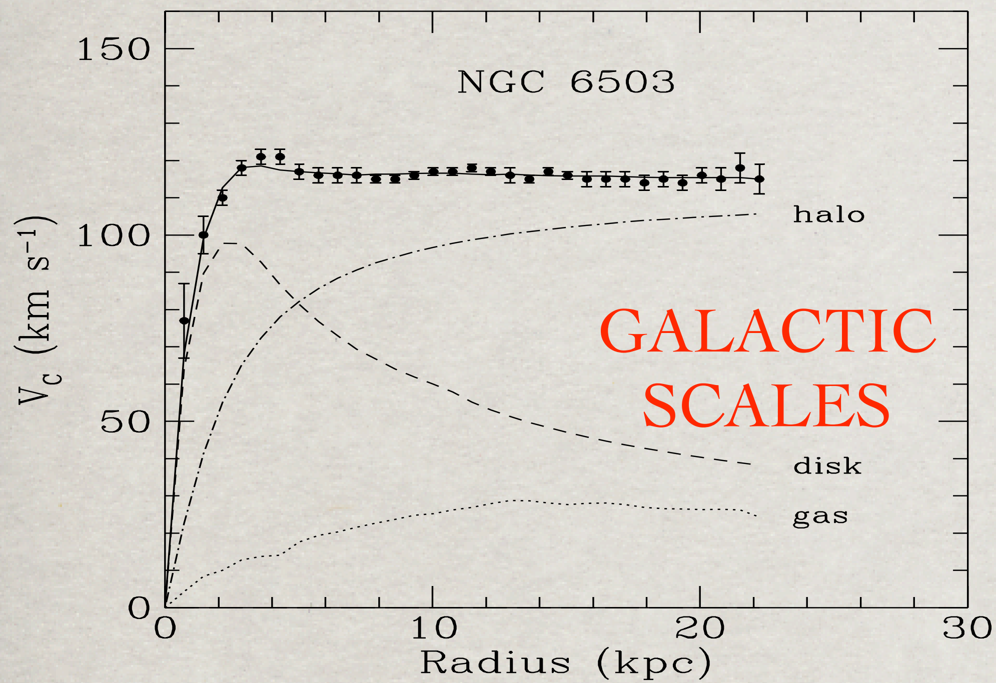
DESY HELMHOLTZ ASSOCIATION

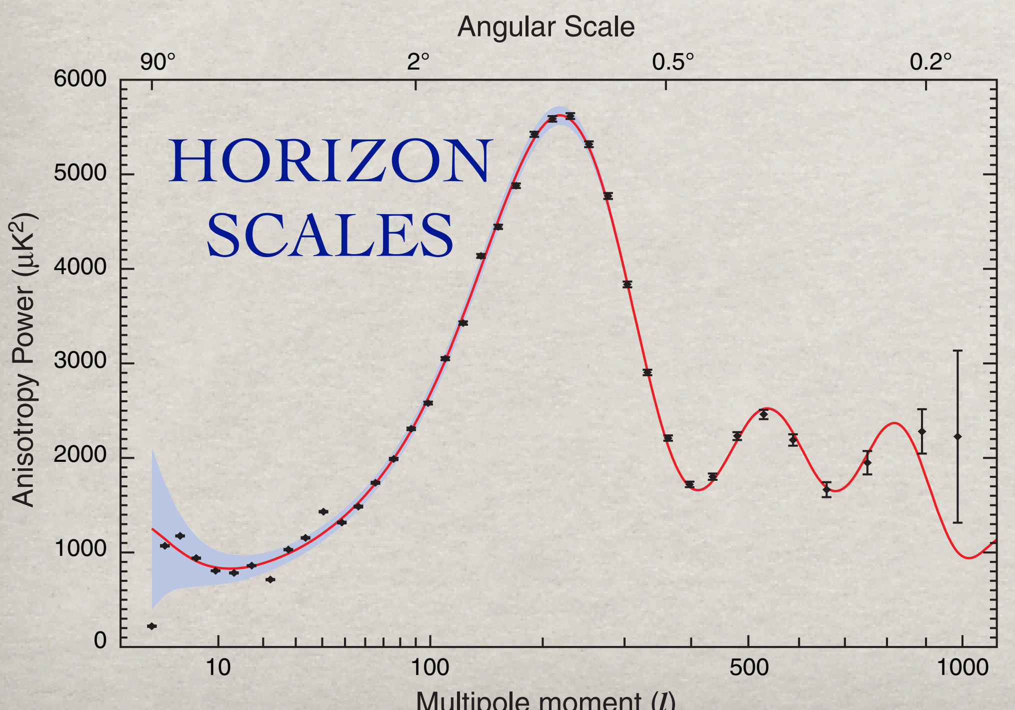
In collaboration with:
C. Berger, S. Kraml and F. Palorini,
J. Hasenkamp, J. Roberts and S. Pokorski

OUTLINE

- Introduction: Dark Matter properties
  Why gravitino DM ?
- Cosmological constraints on gravitino DM
- Charged NLSPs: stop NLSP
- Revisiting neutralino NLSP:
  Wino and Higgsino @ LHC ?
- Outlook

DARK MATTER EVIDENCE





Particles	Ωh^2	Type
Baryons	0.0224	Cold
Neutrinos	< 0.01	Hot
Dark Matter	0.1-0.13	Cold

DARK MATTER PROPERTIES

- Interacts very weakly, but surely gravitationally (electrically neutral, non-baryonic and decoupled from the primordial plasma !!!)
- It must have the right density profile to “fill in” the galaxy rotation curves.
- No pressure and negligible free-streaming velocity, it must cluster & cause structure formation.

⬇

COLD DARK MATTER

WHY GRAVITINO DM?

- Solves the DM problem within gravity and with sufficiently high reheat temperature.
- Based on supersymmetric extension, i.e. very theoretically attractive: gives gauge unification, solves hierarchy problem, etc...
- Opens a WINDOW ON SUSY BREAKING !
- Allows for coherent framework, with a small number of parameters in the minimal setting apart from the SM ones...
- R-parity conservation is not strictly necessary...

CAN THE GRAVITINO BE COLD DARK MATTER ?

YES, if the Universe was never hot enough
for gravitinos to be in thermal equilibrium...

Very weakly interacting particles as the gravitino
are produced even in this case, at least by two mechanisms

PLASMA SCATTERINGS

$$\Omega_{3/2}h^2 \propto \frac{m_{1/2}^2}{m_{3/2}} T_R$$

NLSP DECAY OUT OF EQUILIBRIUM

$$\Omega_{3/2}h^2 \propto \frac{m_{3/2}}{m_{\mathrm{NLSP}}} \Omega_{\mathrm{NLSP}} h^2$$

CAN THE GRAVITINO BE COLD DARK MATTER ?

YES, if the Universe was never hot enough
for gravitinos to be in thermal equilibrium...

Very weakly interacting particles as the gravitino
are produced even in this case, at least by two mechanisms

PLASMA SCATTERINGS

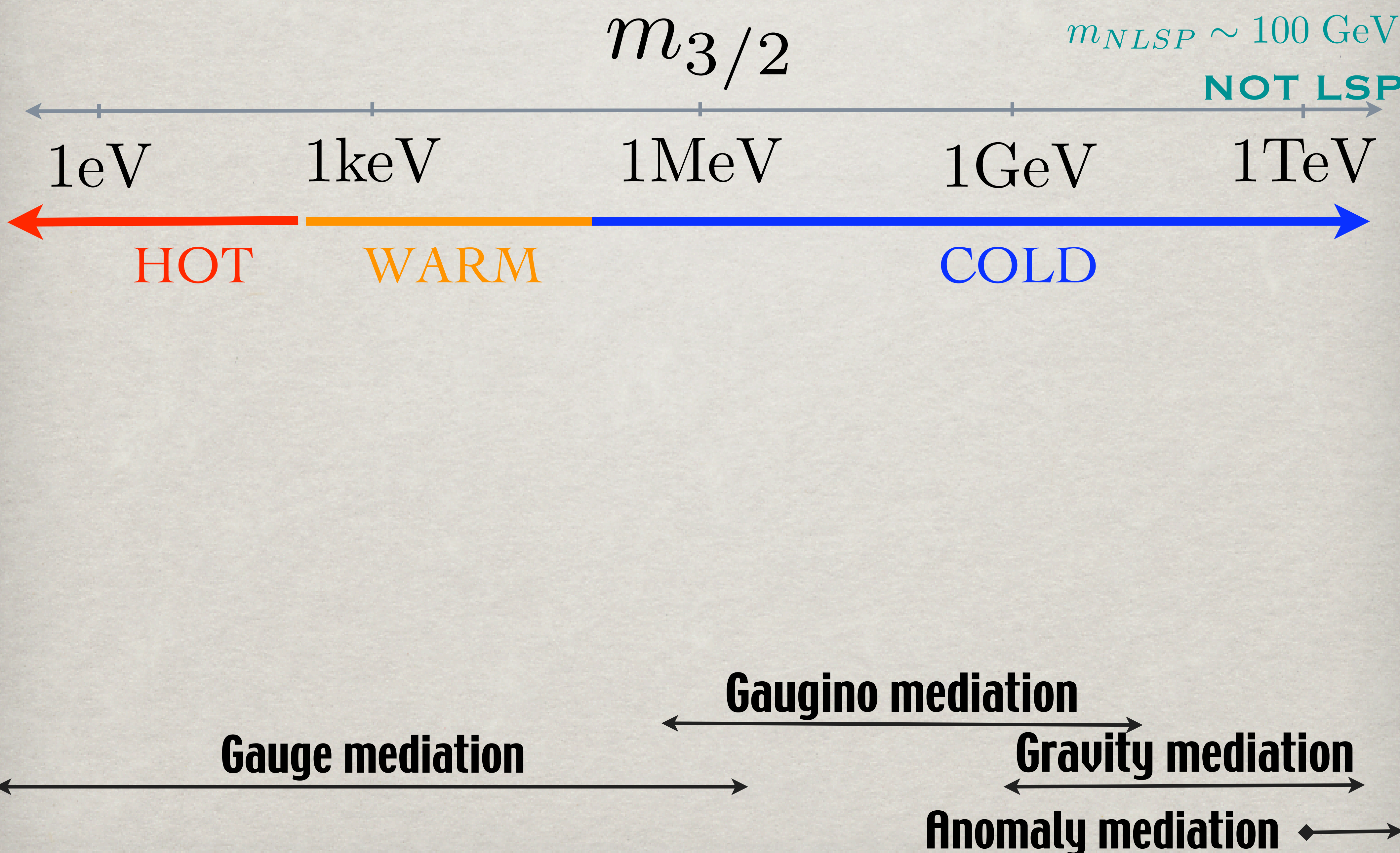
$$\Omega_{3/2}h^2 \propto \frac{m_{1/2}^2}{m_{3/2}} T_R$$

NLSP DECAY OUT OF EQUILIBRIUM

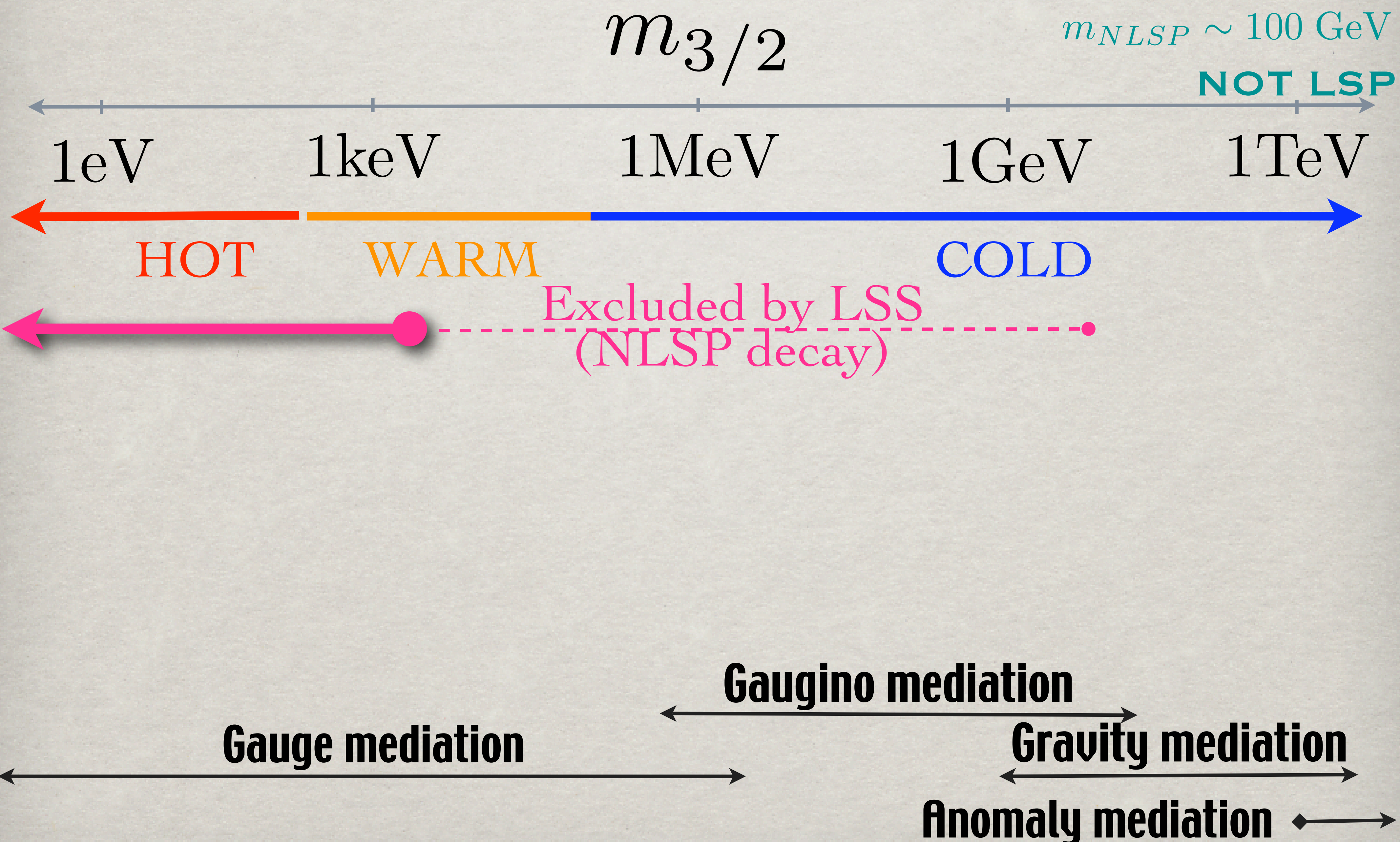
$$\Omega \ldots {}^2 \propto \ldots h^2$$

DANGER !!!
BBN at risk !

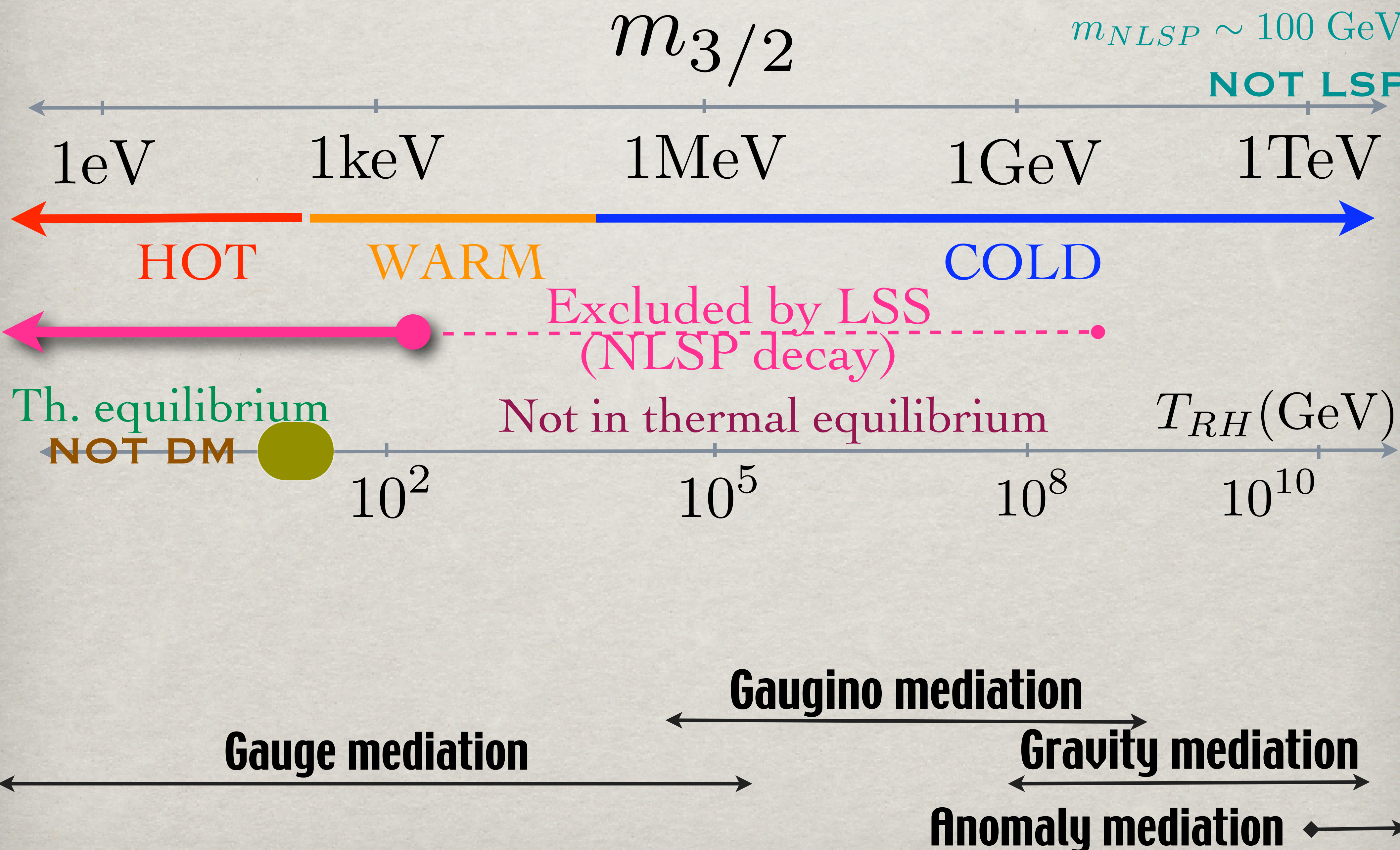
Gravitino DM summary



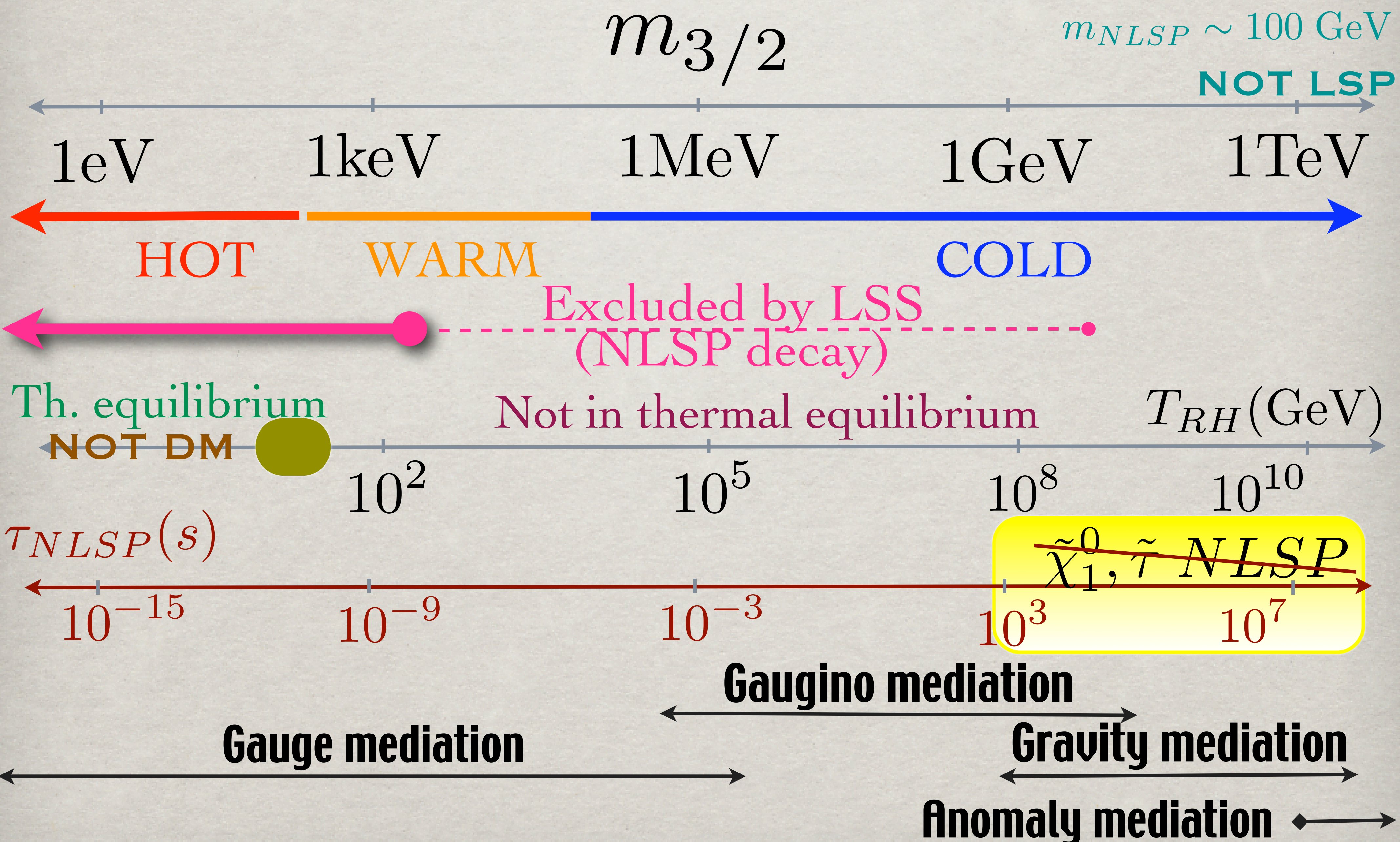
Gravitino DM summary II



Gravitino DM summary II

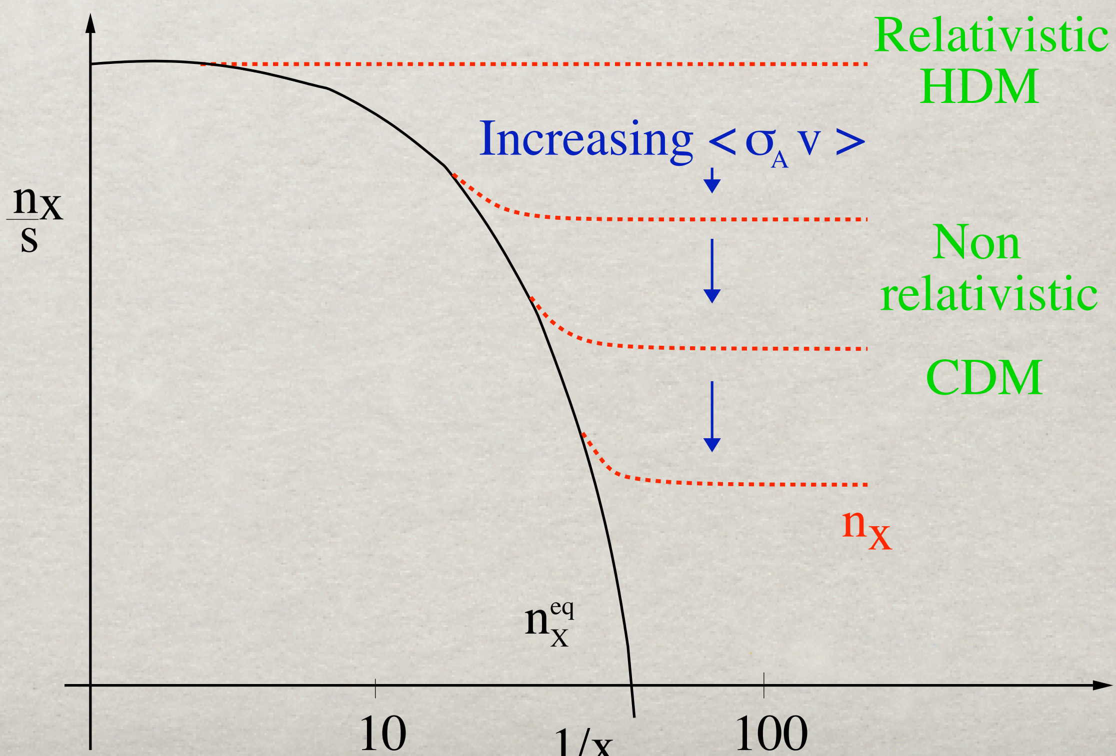


Gravitino DM summary II

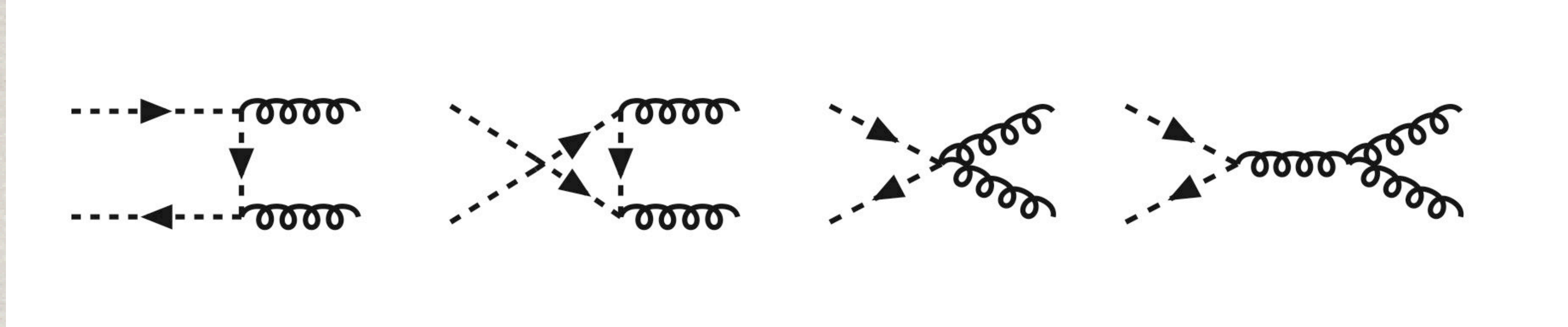


CHARGED RELIC'S DENSITY

- Consider a scalar particle charged under a gauge interaction
- How strong can the annihilation cross-section be ??? Sufficient to reduce the number density to negligible numbers ?
- Classical examples in the MSSM: stau, stop...
- And what about the maximal cross section, the unitary bound ?



Annihilation into gauge bosons



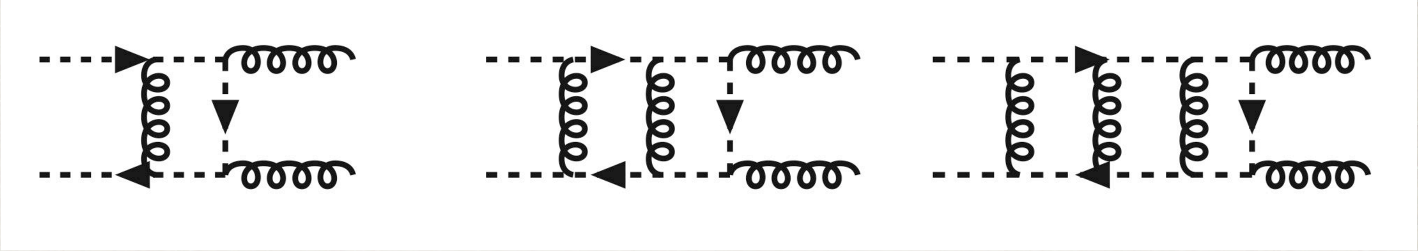
- Take two scalars in the (anti)fundamental representation and just the annihilation into gauge bosons: dominant channel for strong coupling and depending only on the gauge coupling and mass of the relic;
- 4 diagrams contribute for a non-abelian interaction; the result has a symmetric and antisymmetric part in group indices

$$\tilde{\sigma}_{sym}(\beta) = \pi\alpha_N^2 \frac{(N^2-1)(N^2-2)}{N^3}\beta\left[1 - \frac{\beta^2}{2} + \frac{1-\beta^4}{4\beta}\log\left(\frac{1-\beta}{1+\beta}\right)\right] \mathcal{O}(\beta)$$

$$\tilde{\sigma}_{as}(\beta) = \pi\alpha_N^2 \frac{(N^2-1)}{N}\beta\left[\frac{3}{2} - \frac{4}{3}\beta^2 + \frac{(1-\beta^2)(3+\beta^2)}{4\beta}\log\left(\frac{1-\beta}{1+\beta}\right)\right] \mathcal{O}(\beta^3)$$

Sommerfeld Factor

[Sommerfeld 39, Sakharov 48]



- Consider one particle moving in the Coulomb field produced by the other... In Feynman diagrams it correspond to resumming over all ladder diagrams with soft gluons.
- The cross-section factorizes; for a massless gauge boson:

$$\sigma_S = \sigma_0 \times E_S(\beta) \qquad E_S(\beta) = \frac{z}{1 - e^{-z}} \quad \text{with} \quad z = \frac{C\pi\alpha_N}{\beta}$$

- Large correction for small velocity !!!
  RELEVANT AT FREEZE-OUT !   [Hisano et al 04, 06]

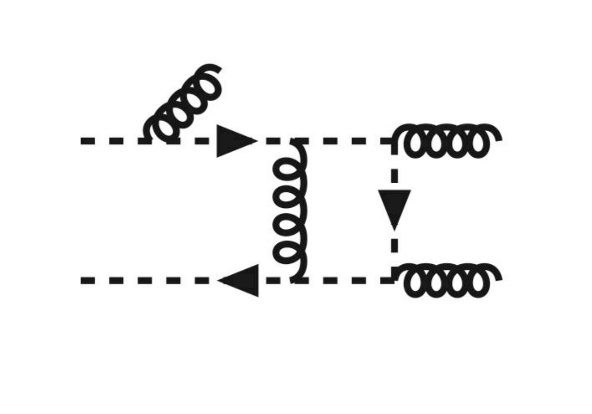
Plasma effects ?

- Plasma screening/Debye thermal mass for the gluon:
negligible since $m_g \sim gT \ll m\beta \sim \sqrt{mT}$

- Mixing between initial state configurations:
the Sommerfeld factor at T=0 depends on the channel, e.g. it is attractive (C>0) for the singlet case, but repulsive (C<0) for the adjoint configuration. In a thermal plasma there is no definite color configuration....

$$N \times \bar{N} = S + A$$

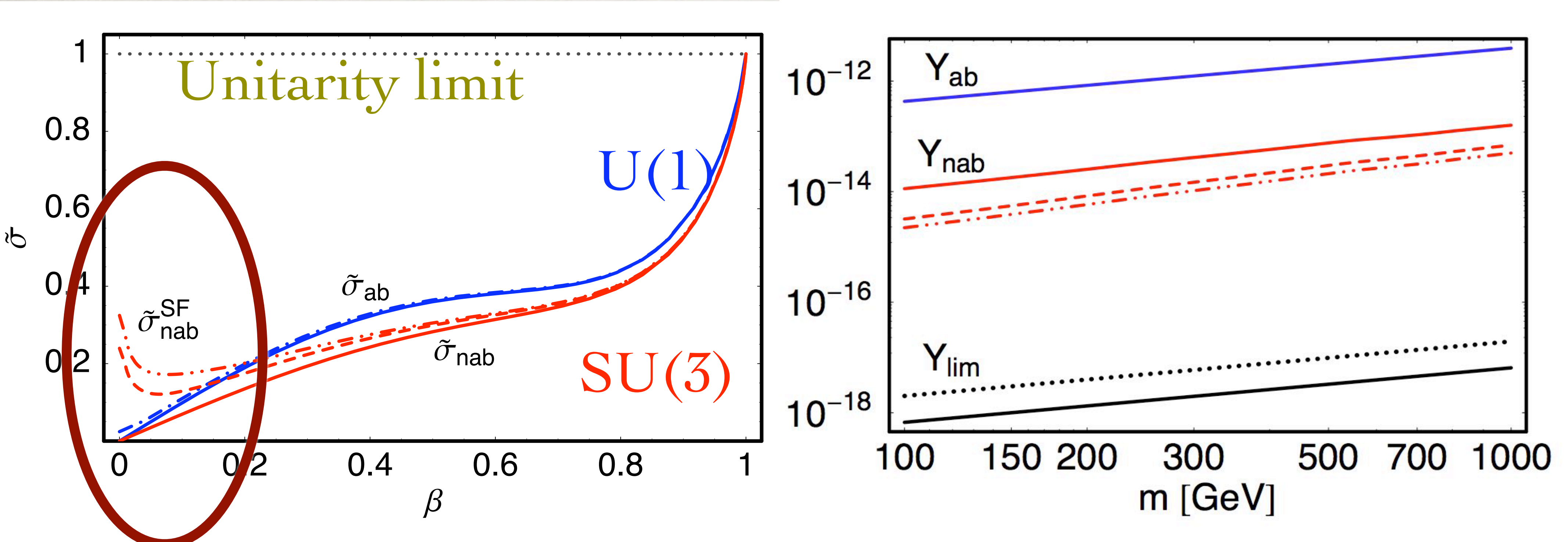
$$S \leftrightarrow A + g$$



We consider both T=0 and average case (equal at one loop)

Enhanced cross-section

[Berger, LC, Kraml, Palorini 08]



The Sommerfeld enhancement is very small for a U(1), but strong for non-abelian SU(3): note both sum and average SF give a larger cross-section at small beta !

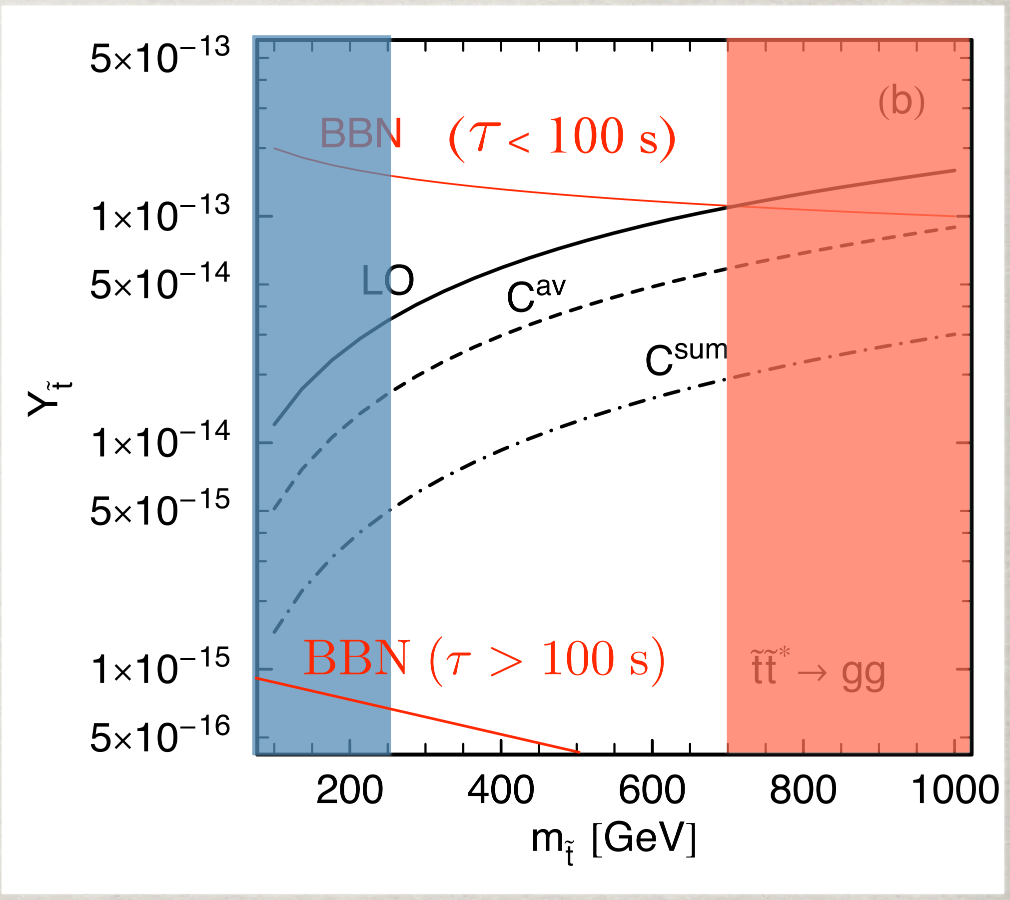
This gives a factor 2/3 reduction in the relic abundance, after being convoluted with Maxwell-Boltzmann !

STOP NLSP

- The stop number density is highly reduced thanks to the strong coupling and to non-perturbative effects, like the Sommerfeld enhancement !

- Late annihilations after the QCD phase transition can reduce the yield further and evade the BBN bounds for $\tau < 10^7 s$ up to m< 700 GeV, if the annihilation approches the unitarity limit, no need to invoke $\sigma \propto 1/\Lambda^2_{QCD}$ from bound state effects as in [Kang, Luty & Nasri 06]

[Berger, LC, Kraml, Palorini 08]



Excluded by Tevatron

STOP HADRONIZATION

[Gates & Lebedev 00]

- At the QCD phase transition, stops hadronize with the quarks and produce mesinos and shadrons:

$$T^{0,+} = (\tilde{t}\bar{u}), (\tilde{t}\bar{d})$$

$$S^{+} = \frac{1}{\sqrt{2}}(\tilde{t}(ud - du))$$

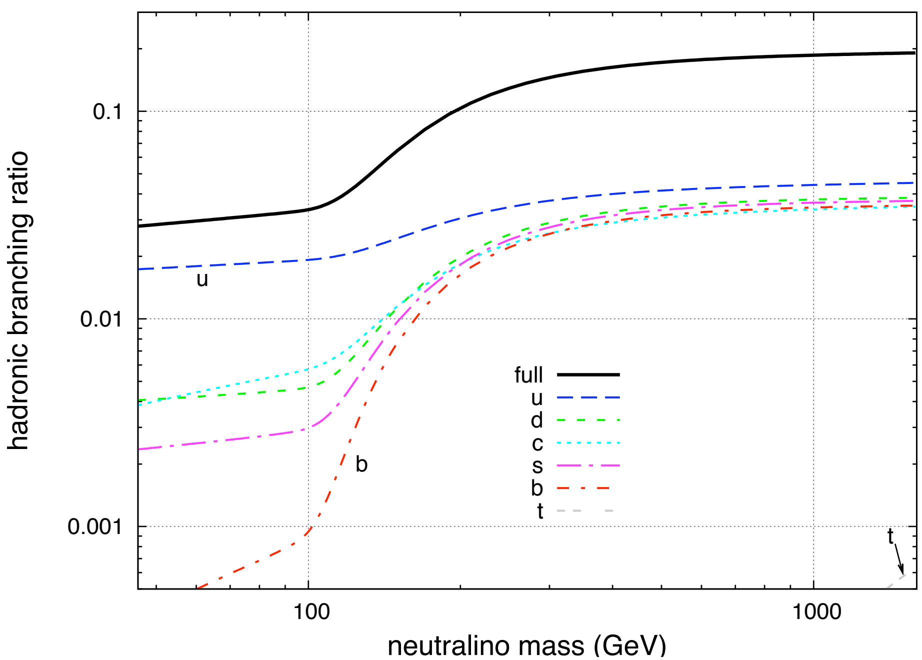
$$V^{++,+,0} = (\tilde{t}uu), (\tilde{t}ud), (\tilde{t}dd)$$

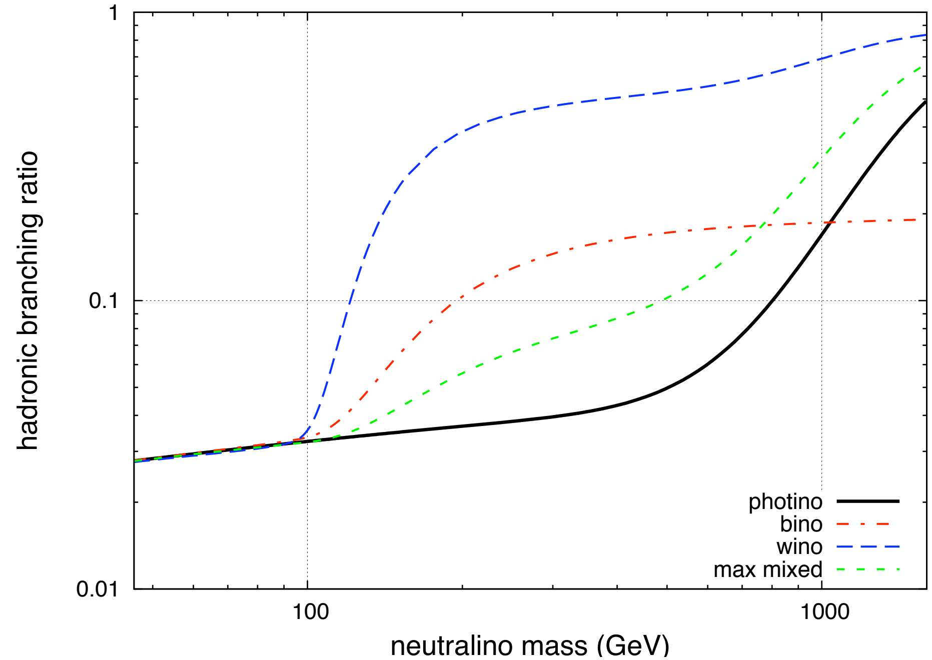
- $T^0, \bar{T}^0$ mixing a la $B^0, \bar{B}^0$ gives the lightest mesino mass eigenstate as the neutral T^1
- The lightest shadrons should be S^+ with a mass difference of 300-400 MeV to V's. It carries baryon number and cannot decay, but could get interconverted with p/n.
- But note: the density of stops for unitary cross-section is ~ three orders of magnitude below the BBN bounds

LHC should see a long-lived stop mesino/shadron !

General neutralino NLSP

[LC, Hasenkamp, Roberts & Pokorski 09]

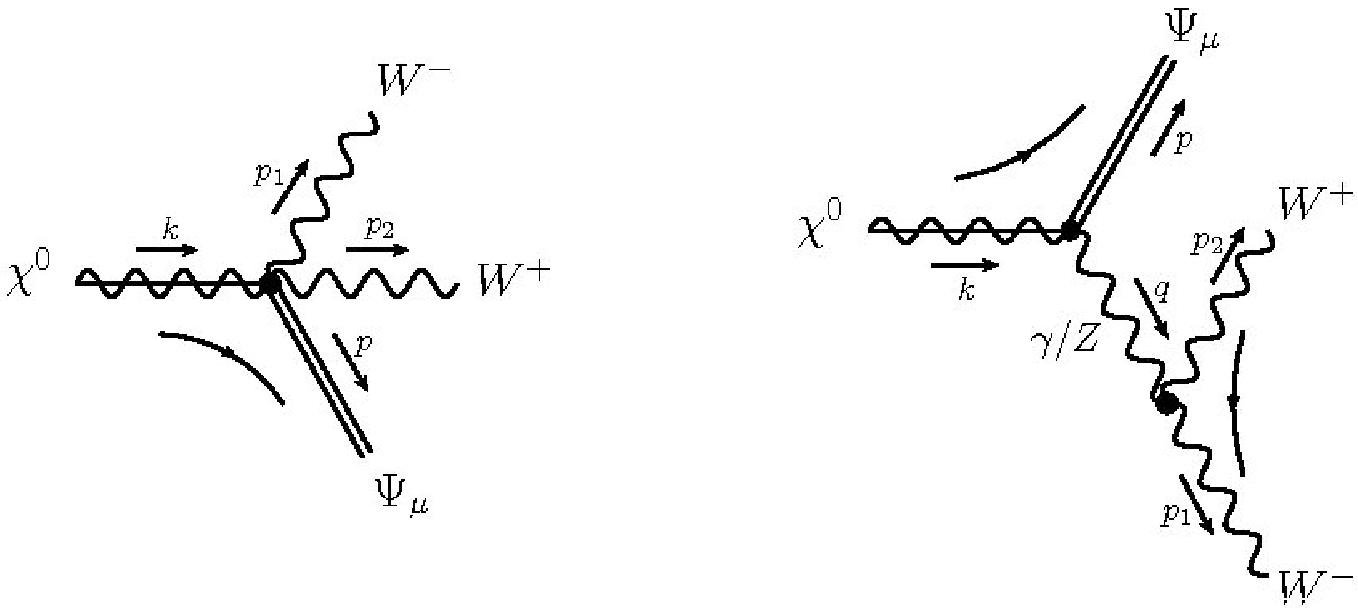




Reconsider the neutralino case in the most general terms: Compute the hadronic branching ratio exactly, including the contribution of intermediate photon, Z, Higgs and squarks.... The hadronic BR is always larger than 0.03, but for large masses it can be suppressed by interference effects...

General neutralino NLSP

[LC, Hasenkamp, Roberts & Pokorski 09]



Important role at masse ~ 1 TeV is played by the non-abelian vertices for the Wino component, which lower the lifetime since they are enhanced by a factor $(m_\chi/M_W)^4$. Charginos play a less important role...

Funny interplay between the SUSY and EW symmetry breaking as observed also in WW scattering [A. Ferrantelli 07]

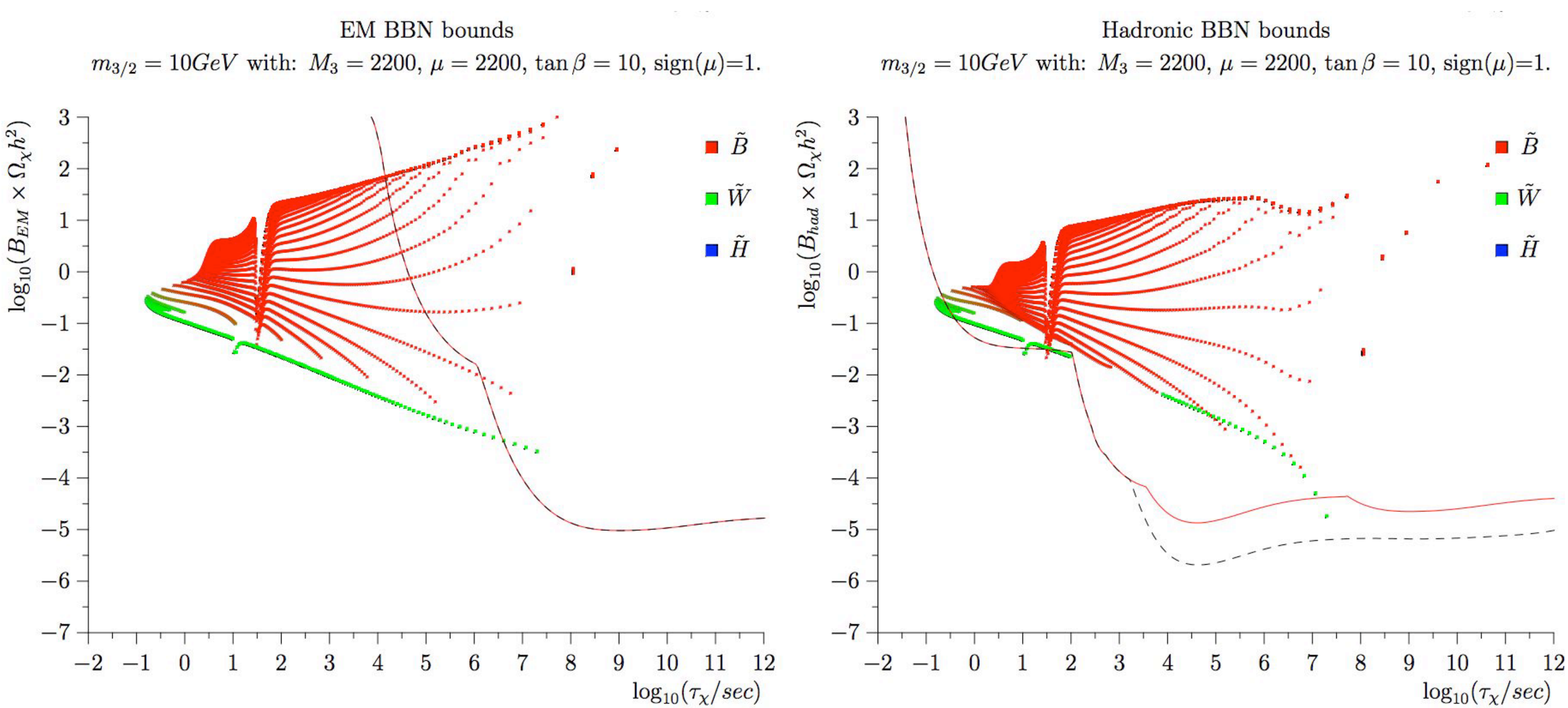
General neutralino NLSP

[LC, Hasenkamp, Roberts & Pokorski 09]

- The other important parameter for BBN constraints is the number density: We compute it with Micromegas 2.0 by [Belanger et al. 06] in the general mixed case.
- We do not include the Sommerfeld enhancement in this case, since it becomes effective only at very large (Wino) masses above 2 TeV [Hisano et al 04, 06]
- We compare our results with the BBN bounds for neutral relics given for the pure electromagnetic decays and also for different values of the hadronic branching ratios by [K. Jedamzik 06]

Preliminary results

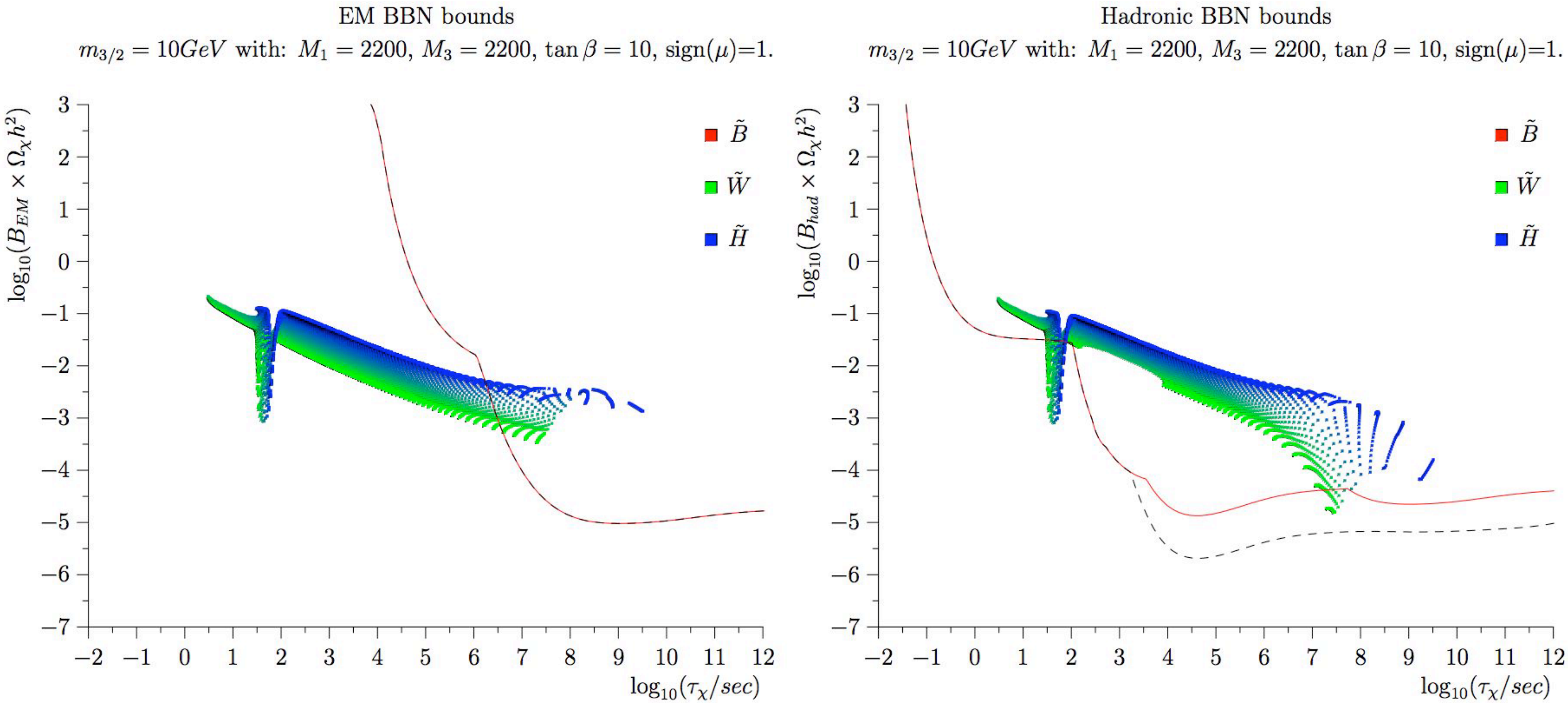
[LC, Hasenkamp, Roberts & Pokorski 09]



Not much room for Bino-Wino neutralino, even when the branching ratio is reduced by interference...
Still for low Wino masses the EM constraints are stronger !

Preliminary results

[LC, Hasenkamp, Roberts & Pokorski 09]



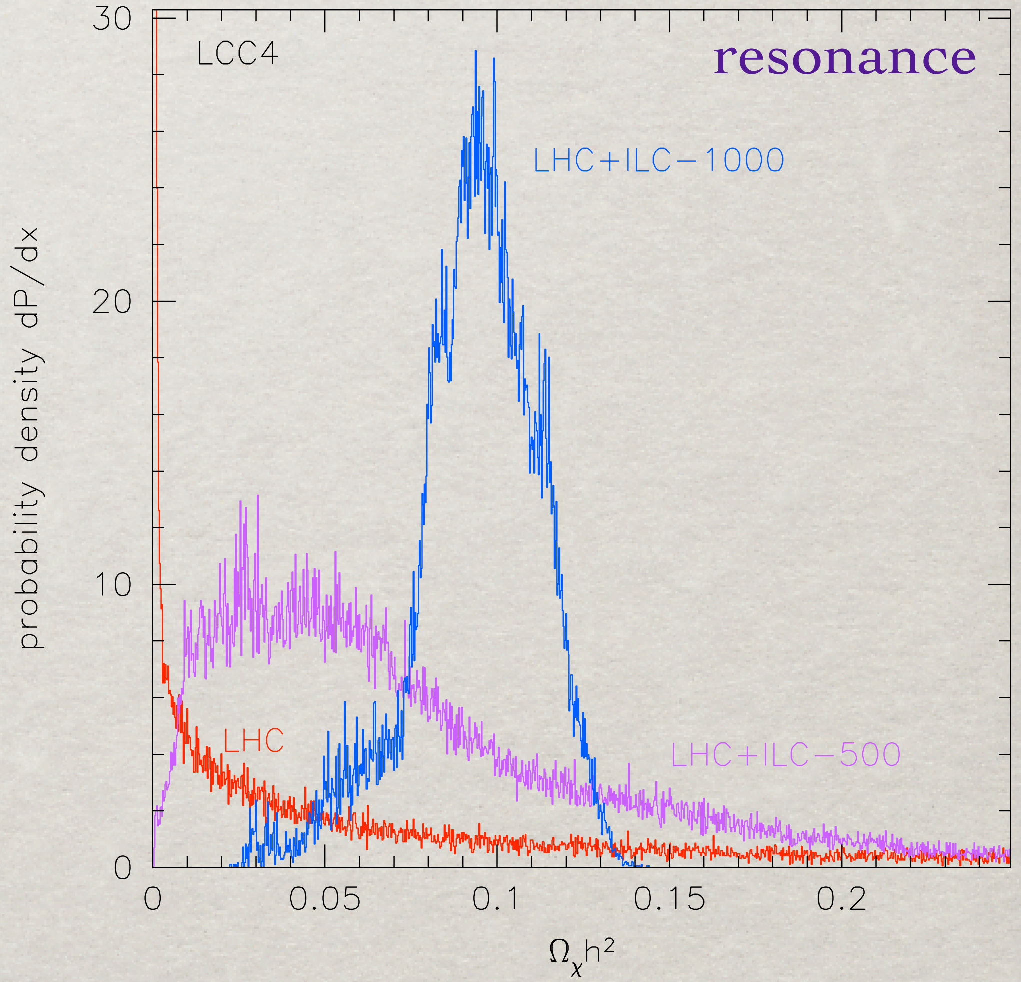
The number density is reduced for the Wino and Higgsino case, in particular at the A/H resonance: 10-20 GeV gravitino masses are still allowed if $2\, m_\chi \sim M_{A/H}$

LHC: MISMATCH IN $\Omega_{DM}h^2$?

Unfortunately it will be difficult to reconstruct precisely the relic density in the resonance case by LHC measurements alone;
still possible perhaps to improve when data are coming...

Another possibility is a Wino NLSP in the TeV region..., but that is also difficult to produce, apart if the SUSY spectrum is compressed.

[Baltz, Battaglia, Peskin & Wizanski '06]



Outlook

- Gravitino DM is pretty natural if such particle is the LSP; substantial thermal production is needed to obtain DM abundance & avoid BBN bounds for the gravitino, i.e. $T_R \sim 10^{10}\mathrm{GeV}$
A coloured NLSP can ease some of the constraints.
- If the gravitino is Dark Matter, clear signals are expected at colliders, different than for neutralino Dark Matter: e.g. a metastable neutral mesino or a charged shadron for stop NLSP or even a neutral Wino/Higgsino with large annihilation cross-section !
- There is a good chance that we will know soon:
Watch out for LHC data !