宇宙の進化と素粒子模型

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(2) Precise estimate of charged Wino decay rate
By Masahiro Ibe, Masataka Mishima, Yuhei Nakayama, Satoshi Shirai
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DOI: 10.1103/PhysRevD.105.103518 (publication)

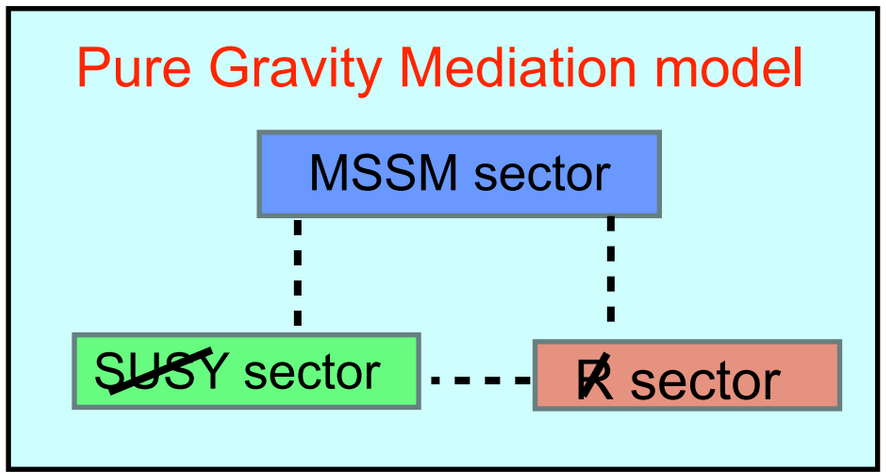
Precise estimate of charged Wino decay rate

JHEP 01 (2023) 017

Masahiro Ibe, Masataka Mishima, Yuhei Nakayama, Satoshi Shirai

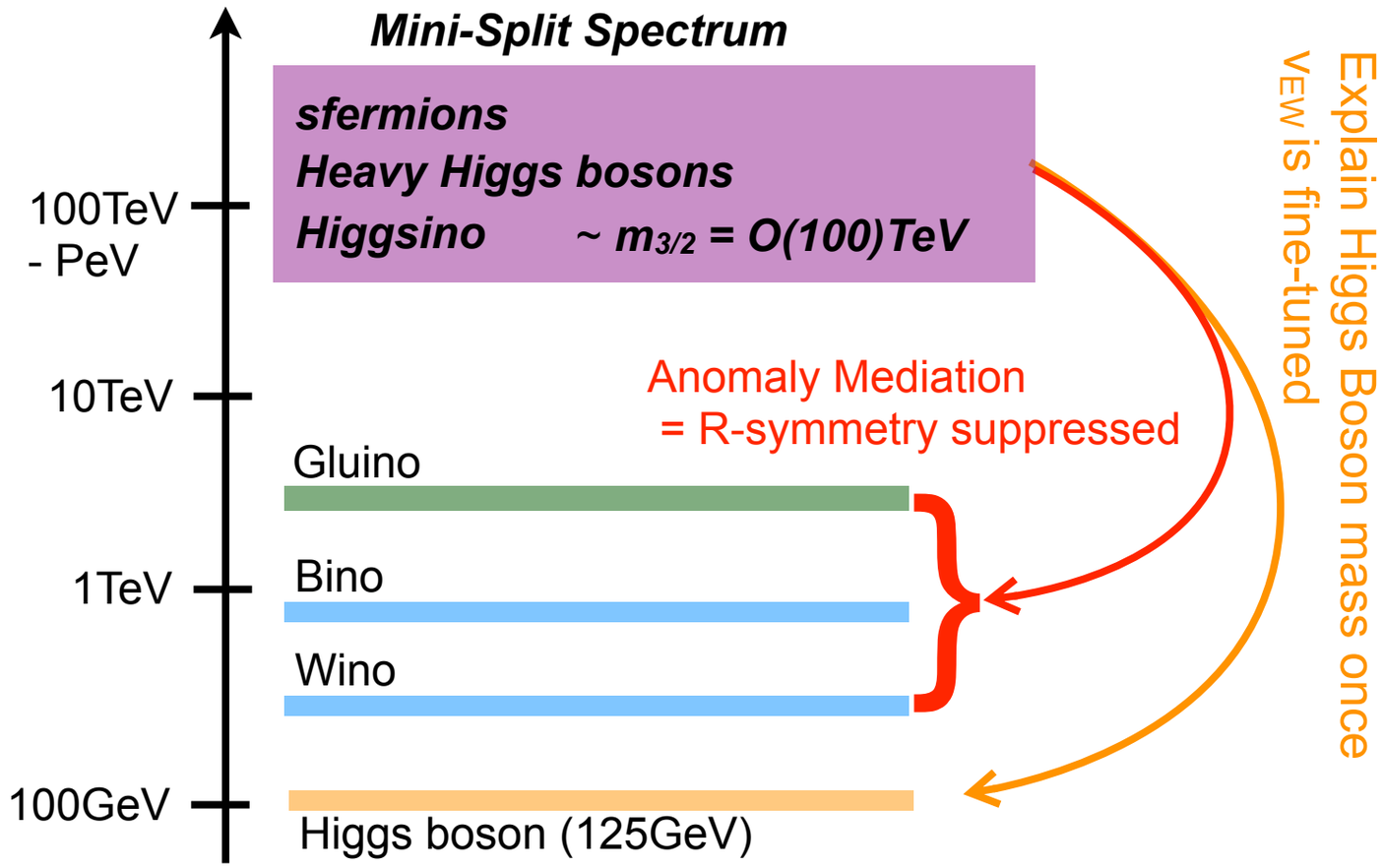
High Scale SUSY at 100TeV - PeV

- ✓ Consistent with cosmology (good DM candidate, no Gravitino/Polonyi problem)
- ✓ Model building is very simple and consistent with 125GeV Higgs !
- ✓ Fine-tuning problem between ***O(10-1000)TeV*** and ***v_{EW} = 174 GeV…***



They are connected by generic
Planck suppressed operators
with each other.

['04 Wells, 06'MI,Moroi,Yanagida,12 MI,Yanagida, '12 Arkani-hamed, Gupta, Kaplan, Weiner, Zorawski…]



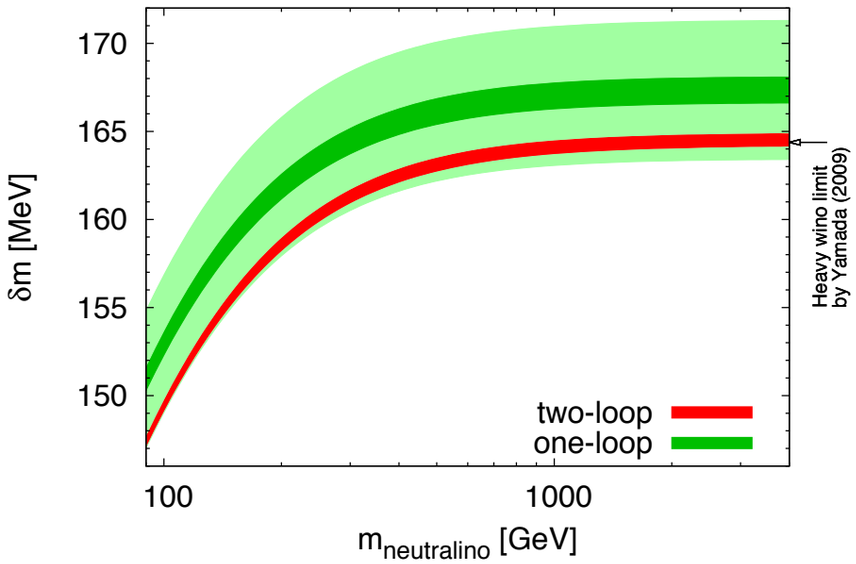
Gaugino Masses are One-Loop Suppressed !

Gaugino Masses = Anomaly Mediation + Higgsino Mediation

['99 Giudice, Luty, Murayama, Rattazzi, '99 Gherghetta, Giudice, Wells]

Neutral Wino (superpartner of W/Z boson) is the candidate for dark matter !

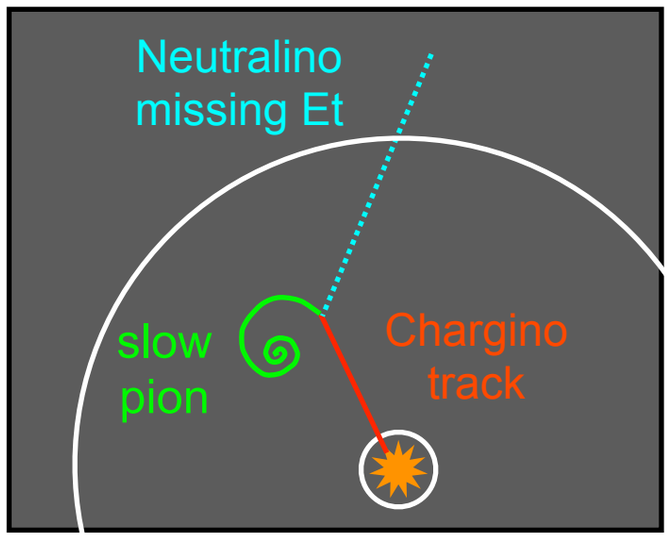
High Scale SUSY at 100TeV - PeV



- A unique feature : degenerate mass spectrum of charged Wino and neutral Wino

$$\Delta m = m_{\chi^\pm} - m_{\chi^0} \simeq 164\,\text{MeV}$$

@ 2-loop [12' MI, Matsumoto,Sato]



- The charged Wino has a rather long lifetime

Main decay mode : $\chi^\pm \to \chi^0 + \pi^\pm$

$$\Gamma_{\text{tree}}(\chi^- \to \pi^- + \chi^0) = \frac{4}{\pi} F_\pi^2 (G_\pi^0)^2 \Delta m^3 \left(1 - \frac{m_\pi^2}{\Delta m^2}\right)^{1/2}$$

$$\leftrightarrow \quad \tau_{\text{Wino}} = \mathcal{O}(10^{-10})\,\text{s}$$

Leptonic modes : $\chi^\pm \to \chi^0 + e^\pm + \nu_e$ (2%)

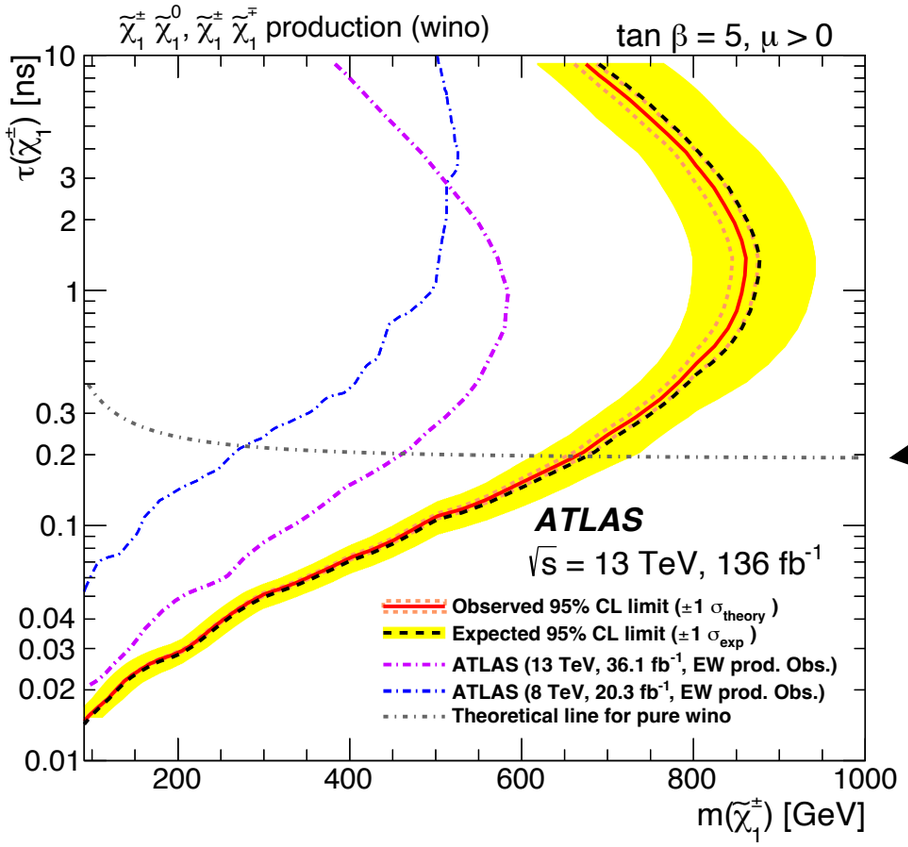
$\chi^\pm \to \chi^0 + \mu^\pm + \nu_\mu$ (0.5%)

- The charged Wino leaves a disappearing charged track ! *[06'MI,Moroi,Yanagida]*

One of the most important channel to test the Wino scenario !

NLO calculation of the main Wino decay

✔ Current Constraint from disappearing track search



95%CL limit on the Wino mass by ATLAS

$$m_\chi > 660\,\mathrm{GeV}$$

[Eur. Phys. J. C 82 (2022) 606]

$$\Gamma_{\mathrm{tree}}(\chi^- \to \pi^- + \chi^0) = \frac{4}{\pi} F_\pi^2 (G_\pi^0)^2 \underline{\Delta m}^3 \left(1 - \frac{m_\pi^2}{\Delta m^2}\right)^{1/2}$$

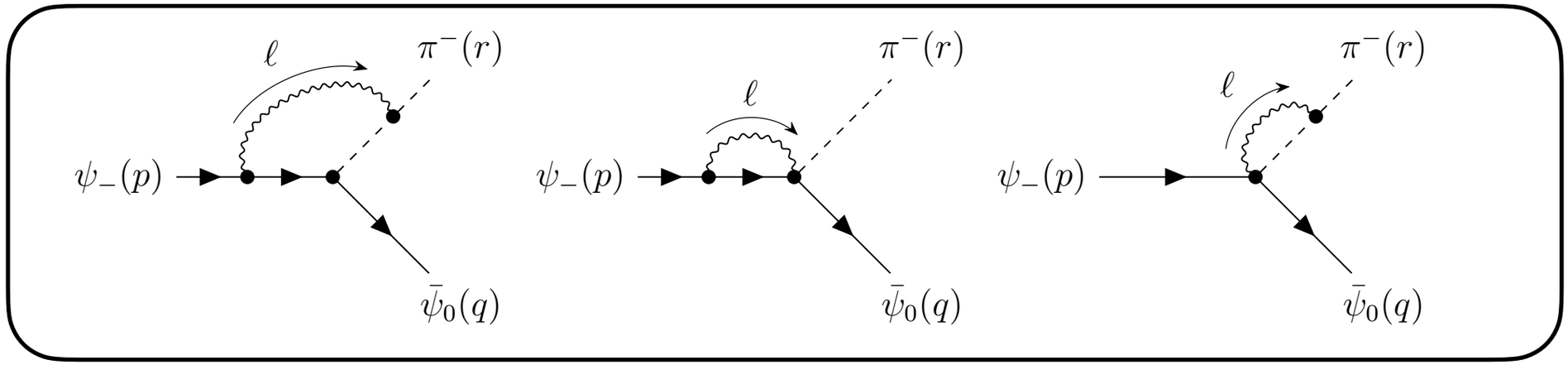
2-loop

✔ So far main decay mode is calculated only up to the leading order, although the mass difference @NLO(= 2-loop) is used.

QED NLO analysis of the decay width is important to know the uncertainty!

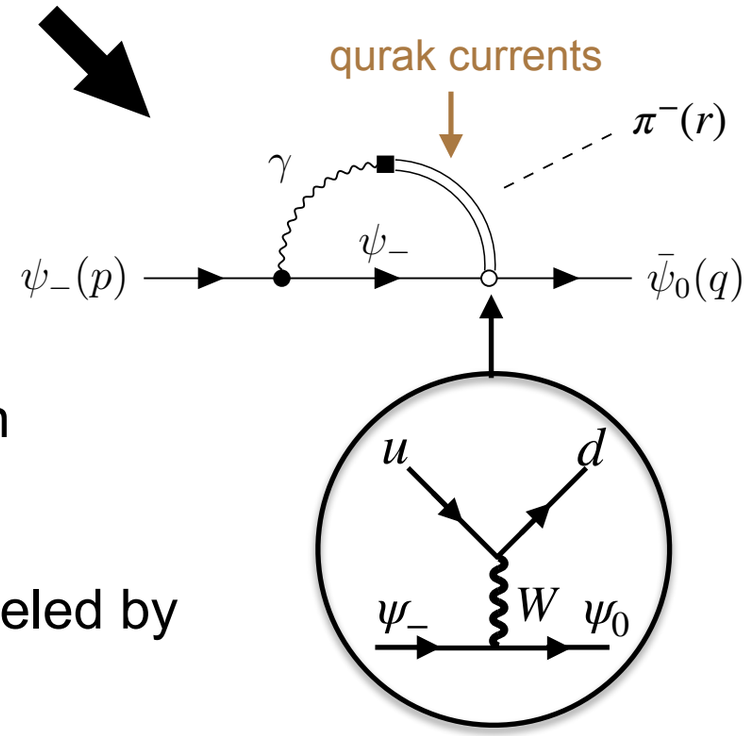
NLO calculation of the main Wino decay

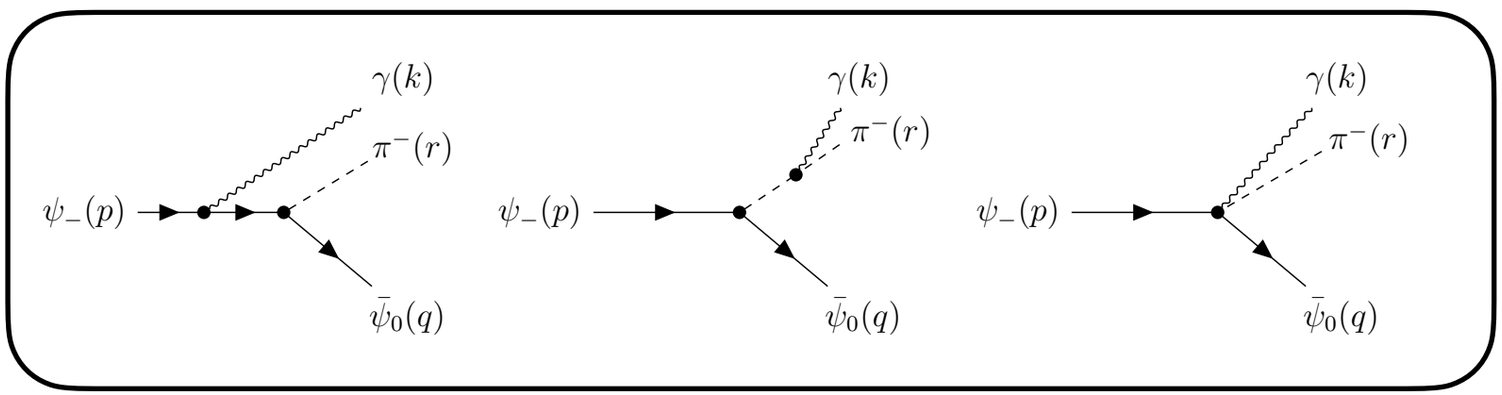
Simple Photon Loops … Look easy ?



Not really…

- ✔ Pion theory is NOT renormalizable
- ✔ Non-perturbative effects exist…
- ✔ Weak interaction via the four-fermi interaction is non-renormalizable
- ✔ IR divergence of QED (which should be canceled by the IR divergences of real emissions).





NLO calculation of the main Wino decay

Flow Chart of Matching

Electroweak

$$\mathcal{L}^{\mathrm{EW}} = \mathcal{L}^{\mathrm{EW}}_{(\mathrm{Wino})} + \mathcal{L}^{\mathrm{EW}}_{(\mathrm{SM})} + \mathcal{L}^{\mathrm{EW}}_{\mathrm{CT}}$$

Matching of decay into free quarks

Four-Fermi

$$\mathcal{L}^{\mathrm{FF}} = \mathcal{L}^{\mathrm{FF}}_{(\mathrm{Wino})} + \mathcal{L}^{\mathrm{FF}}_{(\mathrm{SM})} + \mathcal{L}^{\mathrm{FF}}_{\mathrm{CT}}$$

Matching of current correlators (We rely on the hadron model)

ChPT

$$\mathcal{L}^{\mathrm{ChPT+QED}} = \mathcal{L}^{\mathrm{QED}}_{(\mathrm{Wino}+\pi)} + \mathcal{L}^{\mathrm{ChPT}}_{(\mathrm{Wino}+\pi)} + \mathcal{L}^{\mathrm{ChPT+QED}}_{\mathrm{CT}}$$

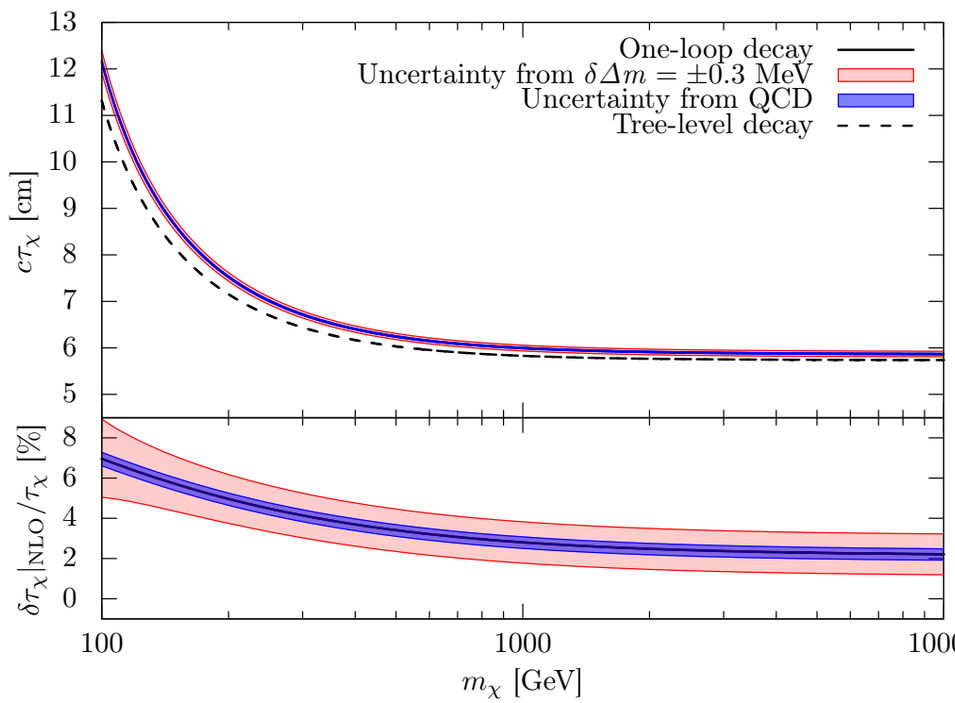
(Theory of pion)

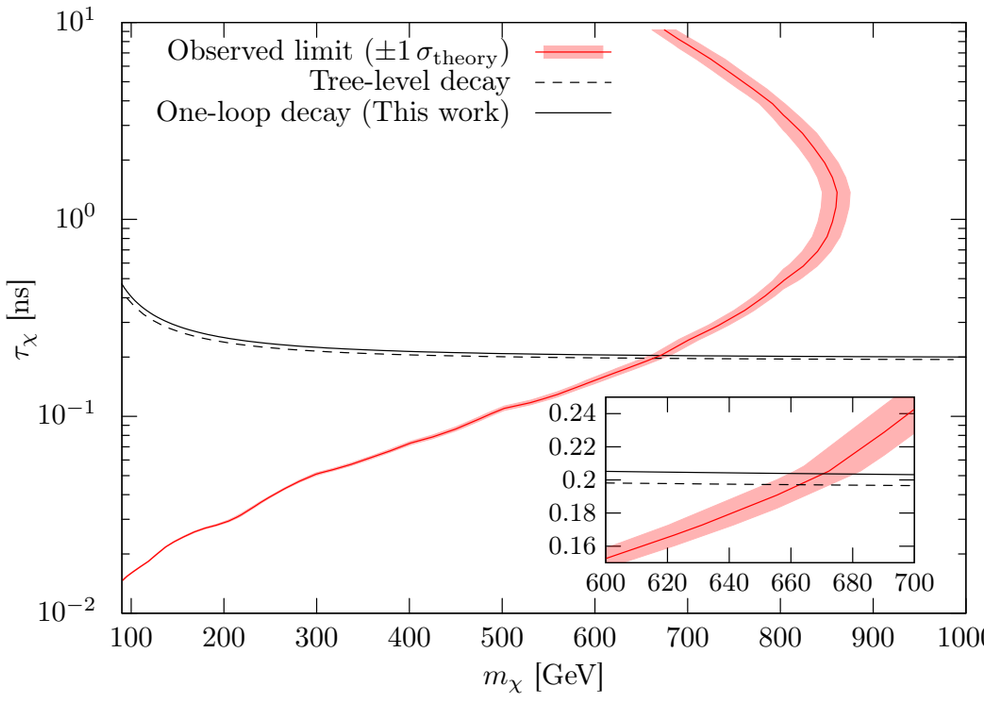
e.g. QED NLO analysis of $\pi^- \to \mu + \nu_\mu + (\gamma)$

1959 Kinoshita, 1986 Marciano&Sirline (No hadronic effects),
→ 2006 Descotes-Genon&Moussallam (hadron effects)

NLO calculation of the main Wino decay

Results



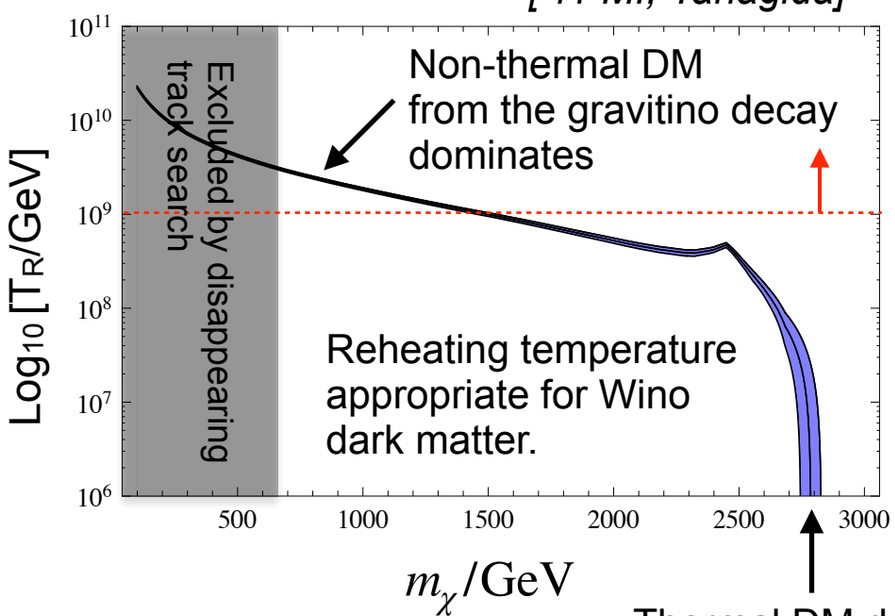


- ✔ Now, we can make prediction of the wino lifetime at the O(1)% precision.
- ✔ The NLO effect is around 2-6 % depending on the Wino mass
  [much larger than naive expectation $\mathcal{O}(\alpha/4\pi)$]
- ✔ The lower limit on the wino mass gets slightly tightened.
  [The uncertainty are dominated by the 3-loop Δm and production cross section]

Wino DM vs Thermal Leptogenesis (work in progress)

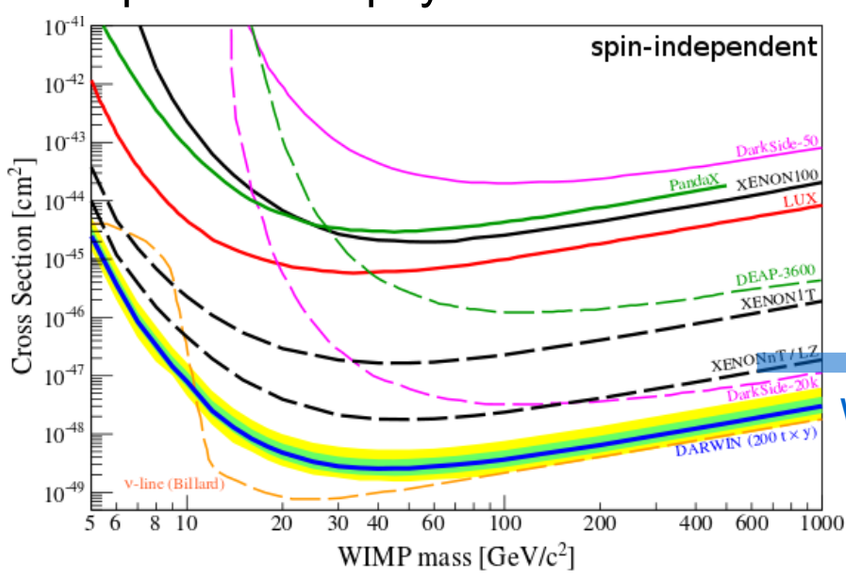
✔ Wino dark matter and thermal Leptogenesis is consistent only for

['11 MI, Yanagida]



['07 Hisano, Matsumoto, Nagai, Saito, Senarmi]

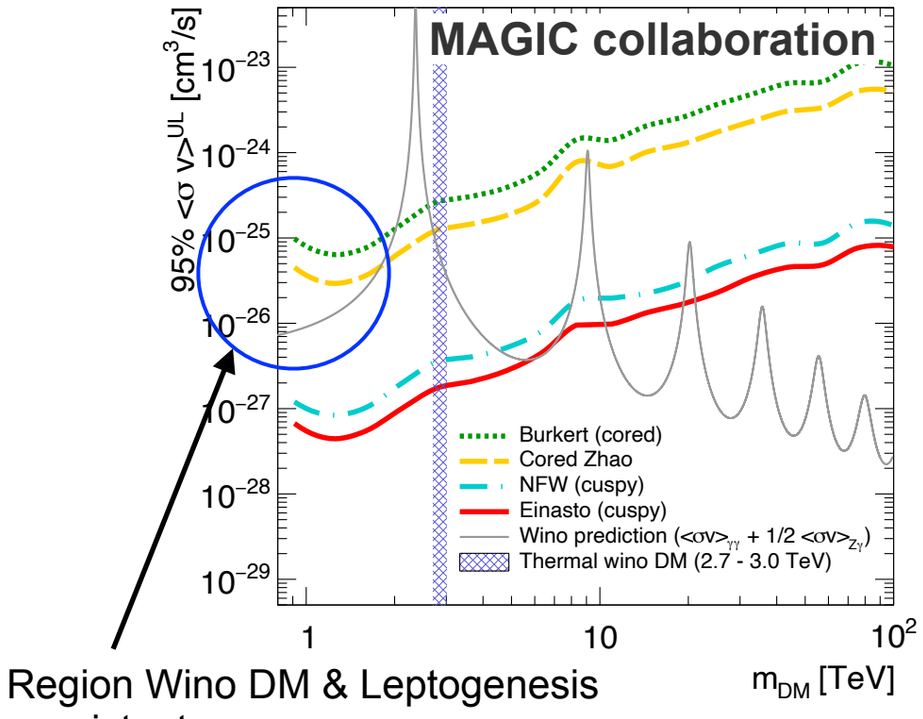
https://darwin.physik.uzh.ch/darwin.html



Wino Prediction

['10, Hisano Ishiwata Nagata]

Line γ-ray from Galaxy center
[*Phys.Rev.Lett.* 130 (2023) 6, 061002]



Region Wino DM & Leptogenesis consistent

The Wino with thermal leptogenesis

$$660\,\mathrm{GeV} < m_\chi \lesssim 1.5\,\mathrm{TeV}$$

is under siege.

(We are going to revisit the uncertainties of the theoretical prediction of m_χ from leptogenesis)