Non-perturbative effect of EWIMP on indirect probe at collider

Taisuke Katayose (Kavli IPMU)
Collaborate with Shigeki Matsumoto and Satoshi Shirai

Contents

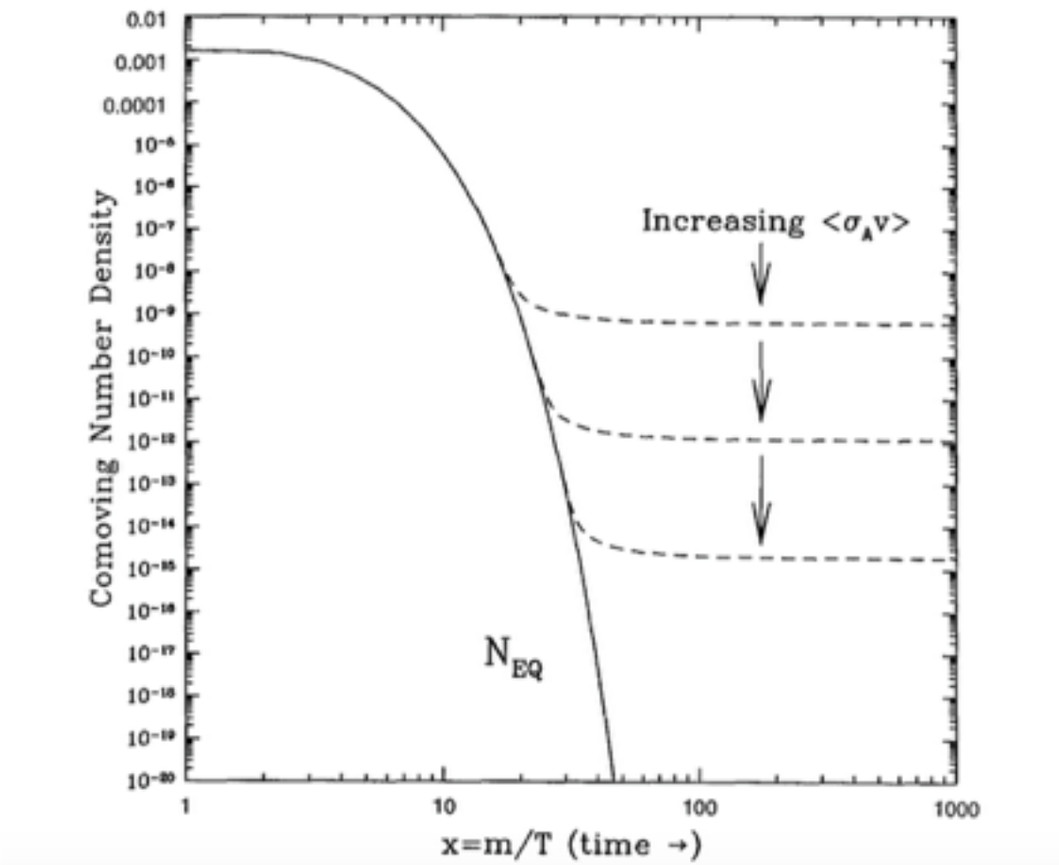
- About EWIMP
- Indirect probe
- Previous calculation and issue
- Non-perturbative effect
- Summary

Contents

- About EWIMP
- Indirect probe
- Previous calculation and issue
- Non-perturbative effect
- Summary

EWIMP

- ElectroWeakly Interacting Massive Particle
- (E)WIMP is good candidate of dark matter
- e.g. Wino or Higgsino in SUSY



We can estimate relic density through Boltzmann equation.

$$\frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle (n^2 - n_{eq}^2)$$

Our model

- Consider Majorana fermonic EWIMP
- SU(2) 3-plet, U(1) hypercharge is 0 (wino-like EWIMP)
- Parameter is only m_χ (Majorana mass)

$$\mathcal{L} = \mathcal{L}_{\rm sm} + \frac{i}{2}\bar{\chi}\gamma^\mu D_\mu \chi + \frac{1}{2} m_\chi \bar{\chi}\chi$$

$$\chi \equiv \begin{pmatrix} \begin{pmatrix} \xi_+ \\ \eta_+ \end{pmatrix} \\ \begin{pmatrix} \eta_0^c \\ \eta_0 \end{pmatrix} \\ \begin{pmatrix} \xi_- \\ \eta_- \end{pmatrix} \end{pmatrix}$$

Majorana condition

$$\xi_+ = -\eta_-^c$$
$$\xi_- = -\eta_+^c$$

$$\eta^c \equiv (-i\sigma_2)\eta^*$$

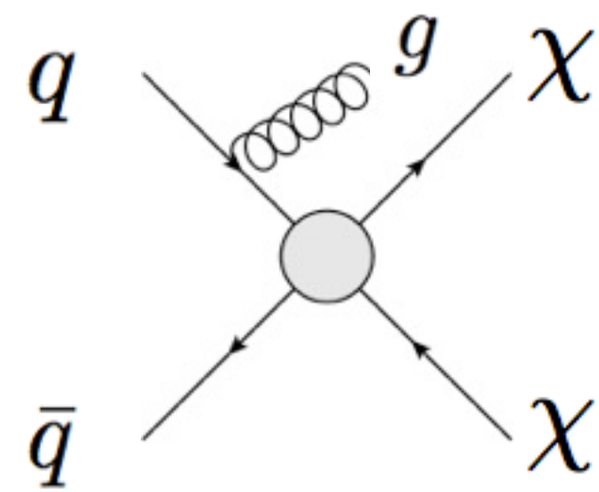
Contents

- About EWIMP
- Indirect probe
- Previous calculation and issue
- Non-perturbative effect
- Summary

DM search at collider

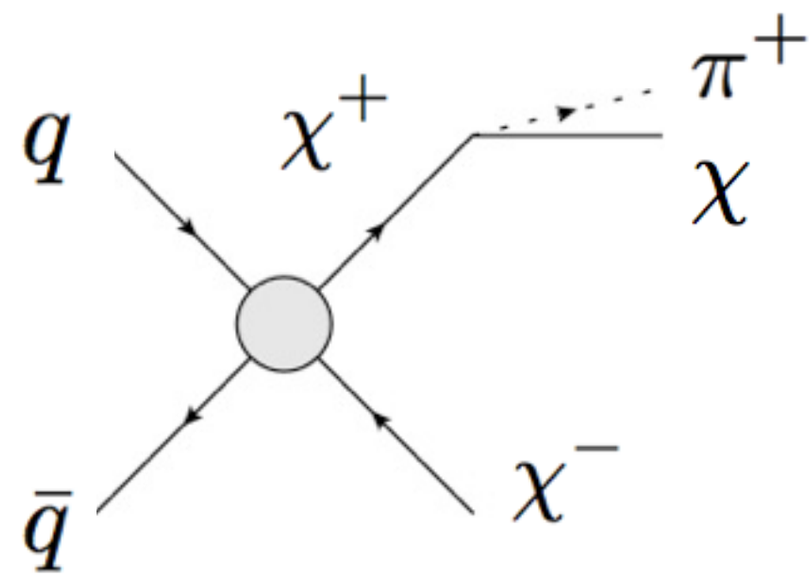
- Mono-jet search

Mono-jet (gluon) is detected.

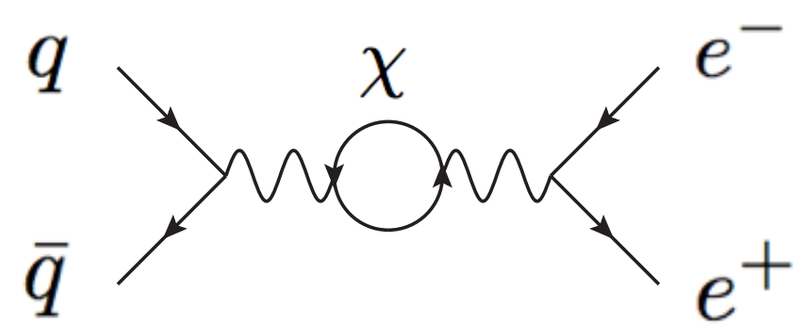


- Long lived particle search

χ^+ can fly long distance.

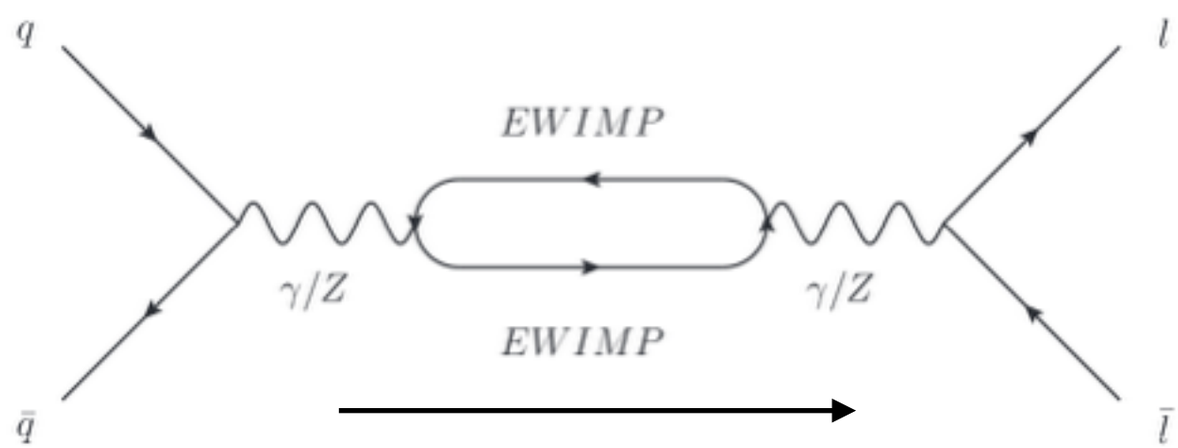


- Indirect probe



Indirect probe

- Look at the radiative correction by EWIMP



energy flow: √s

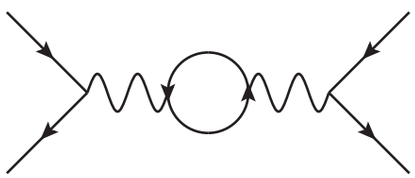
- Cross section changes from SM-only depending on √s
- √s is equal to invariant mass of final particles

Contents

- About EWIMP
- Indirect probe
- Previous calculation and issue
- Non-perturbative effect
- Summary

Radiative correction

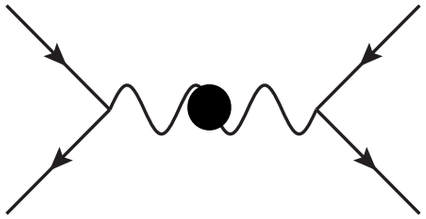
$$\mathcal{L} = \mathcal{L}_{\rm sm} + \frac{i}{2}\bar{\chi}\gamma^\mu D_\mu \chi + \frac{1}{2} m_\chi \bar{\chi}\chi$$



DM

Integrating out DM field

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{g^2 C_{WW}}{2} W^a_{\mu\nu} \Pi(-D^2/m_\chi^2) W^{a\mu\nu}$$



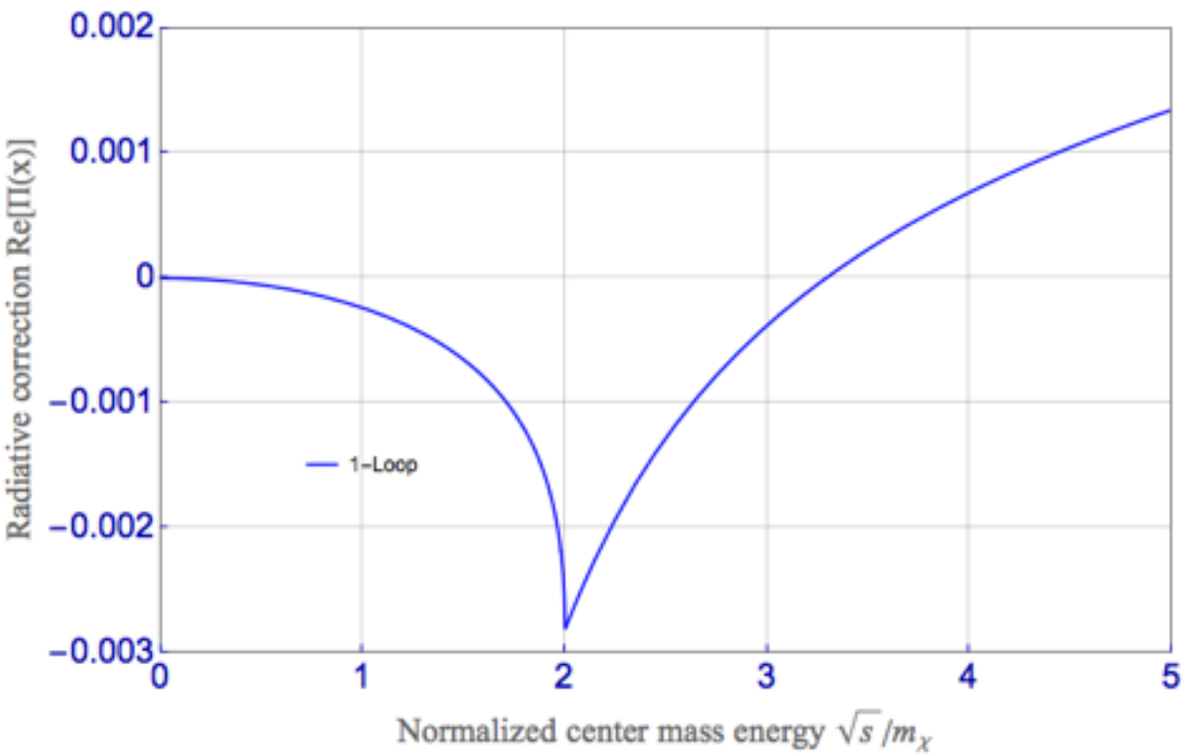
$$C_{WW} \equiv (n^3 - n)/6$$

$-D^2$ in $\Pi(-D^2/m_\chi^2)$ can be considered as "$\hat{s}$"

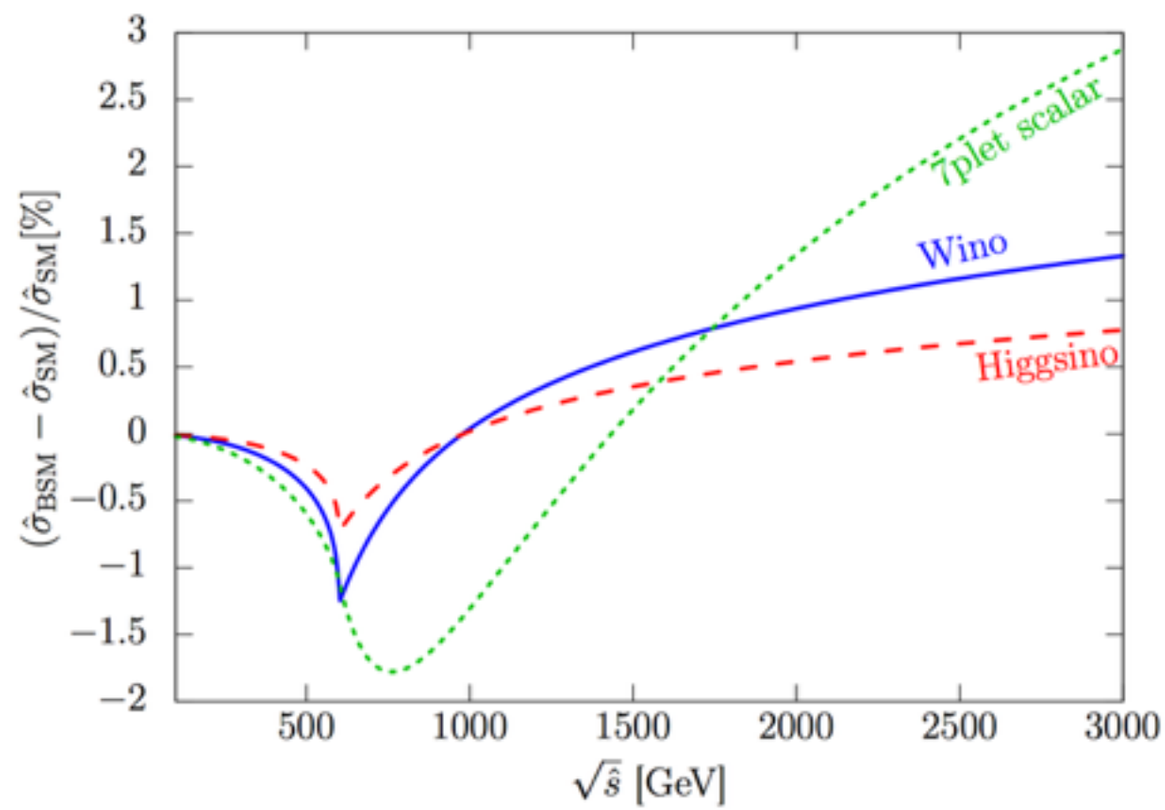
Let's look at the function $\Pi(x)$

1-loop calculation

$$\Pi(x) = \frac{1}{16\pi^2}\int_0^1 dy\, y(1-y)\ln[1-y(1-y)x - i0^+]$$

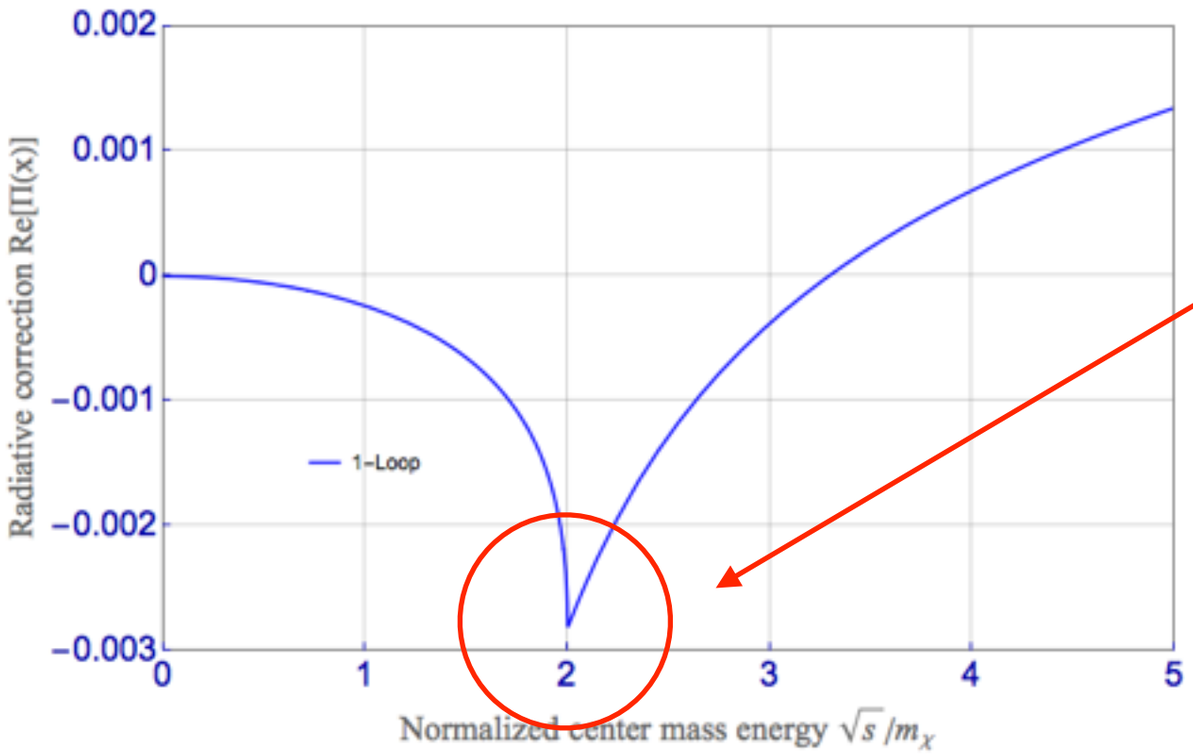


$\sqrt{x}$



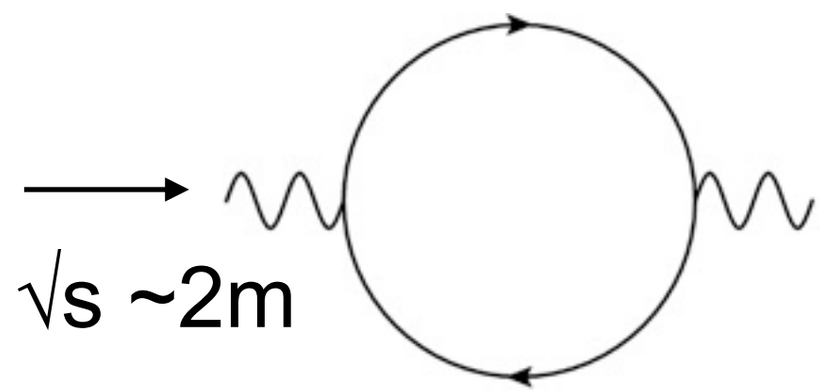
[2017, Shigeki Matsumoto, Satoshi Shirai and Michihisa Takeuchi]

Issue on 1-loop



$\sqrt{x}$

EWIMPs are non relativistic here



√s ~2m

Non relativistic

There may be another enhancement by non-perturbative effect at already extremum region!

Contents

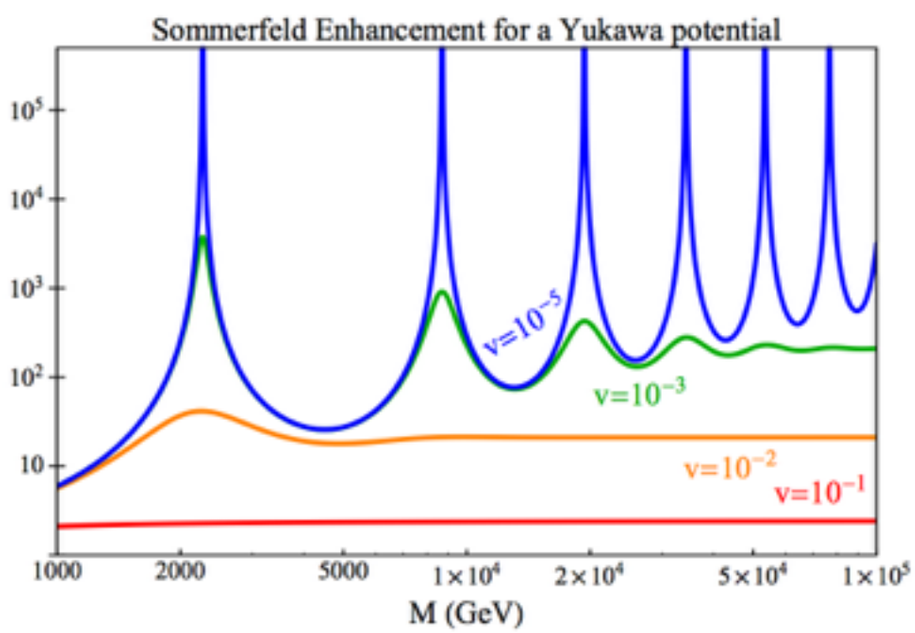
- About EWIMP
- Indirect probe
- Previous calculation and issue
- Non-perturbative effect
- Summary

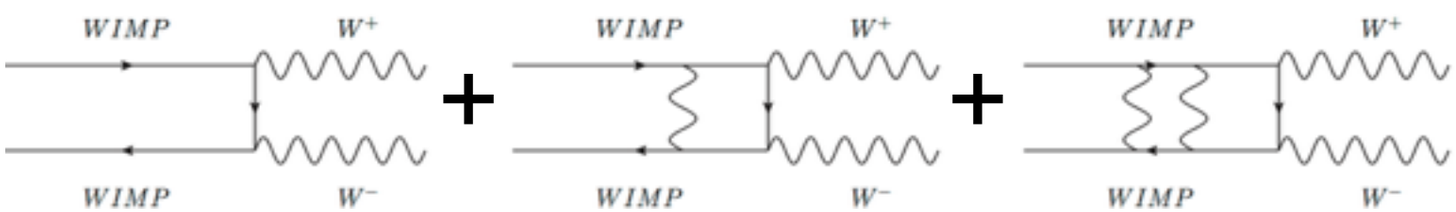
Sommerfeld enhancement

- For non relativistic EWIMP, there might be enhancement
- cf. Sommerfeld enhancement of annihilation cross section for non relativistic WIMP

(2004, Junji Hisano, Shigeki Matsumoto and Mihoko Nojiri)

- We need sum up all orders of diagrams!

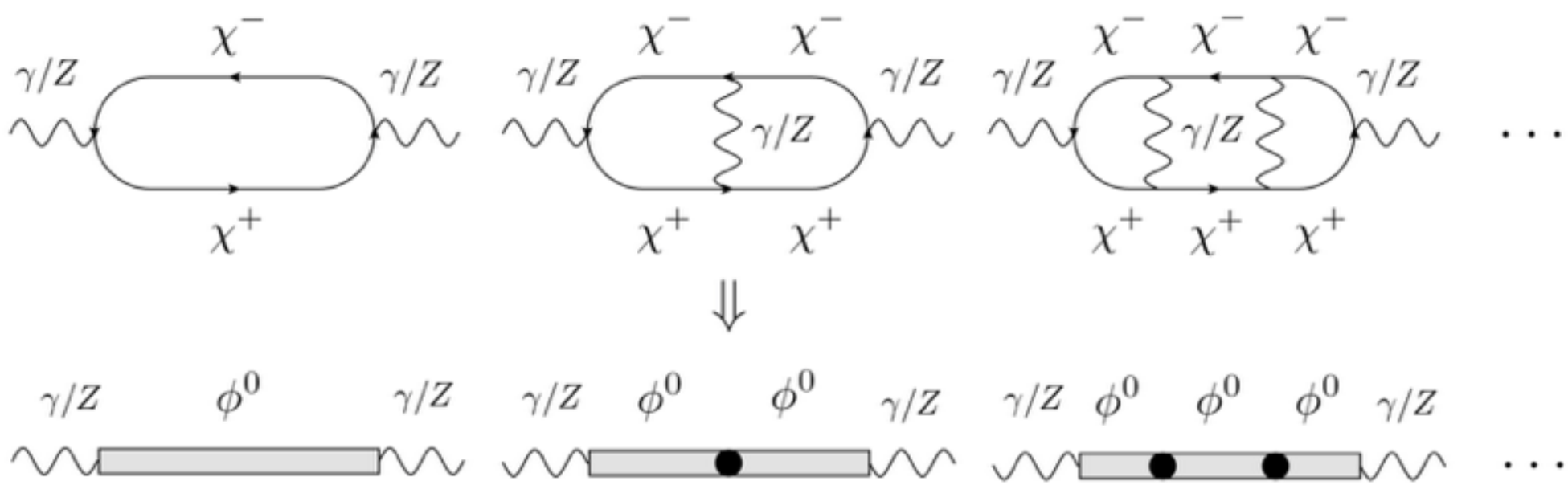




(Picuture from Phys.Rev.D88 (2013) 083506 Brando Bellazzini et al.)

Calculation

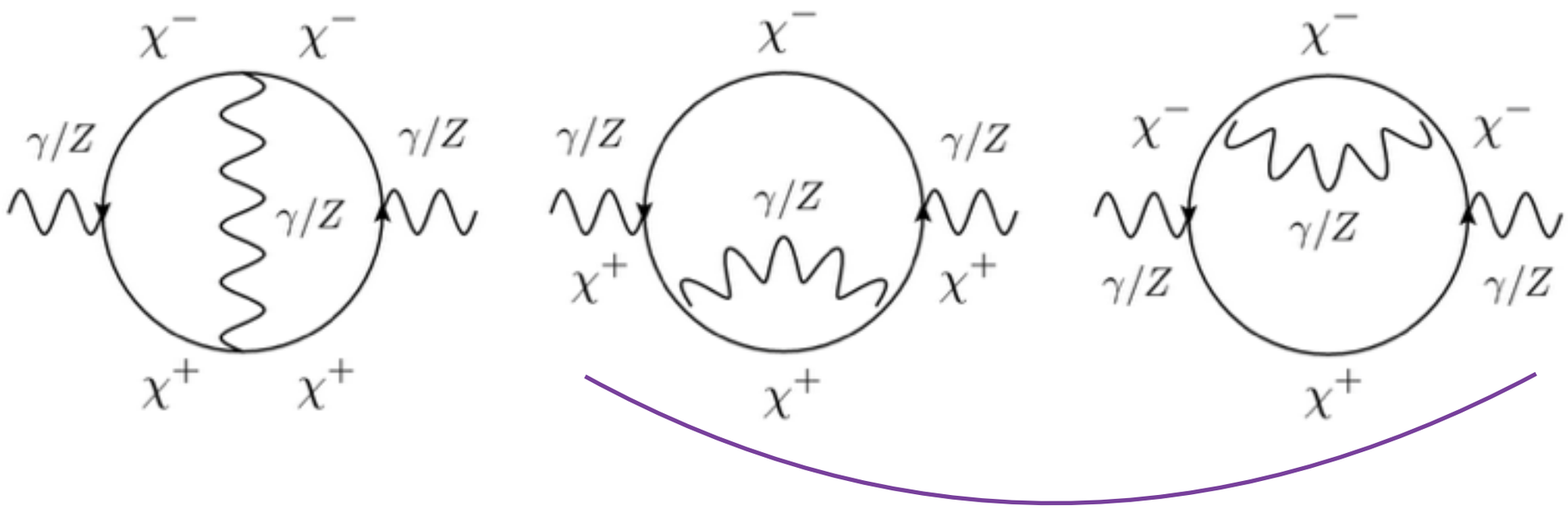
Let's calculate such diagrams at non relativistic region



Solve non relativistic Schrodinger equation for two body state of EWIMPs

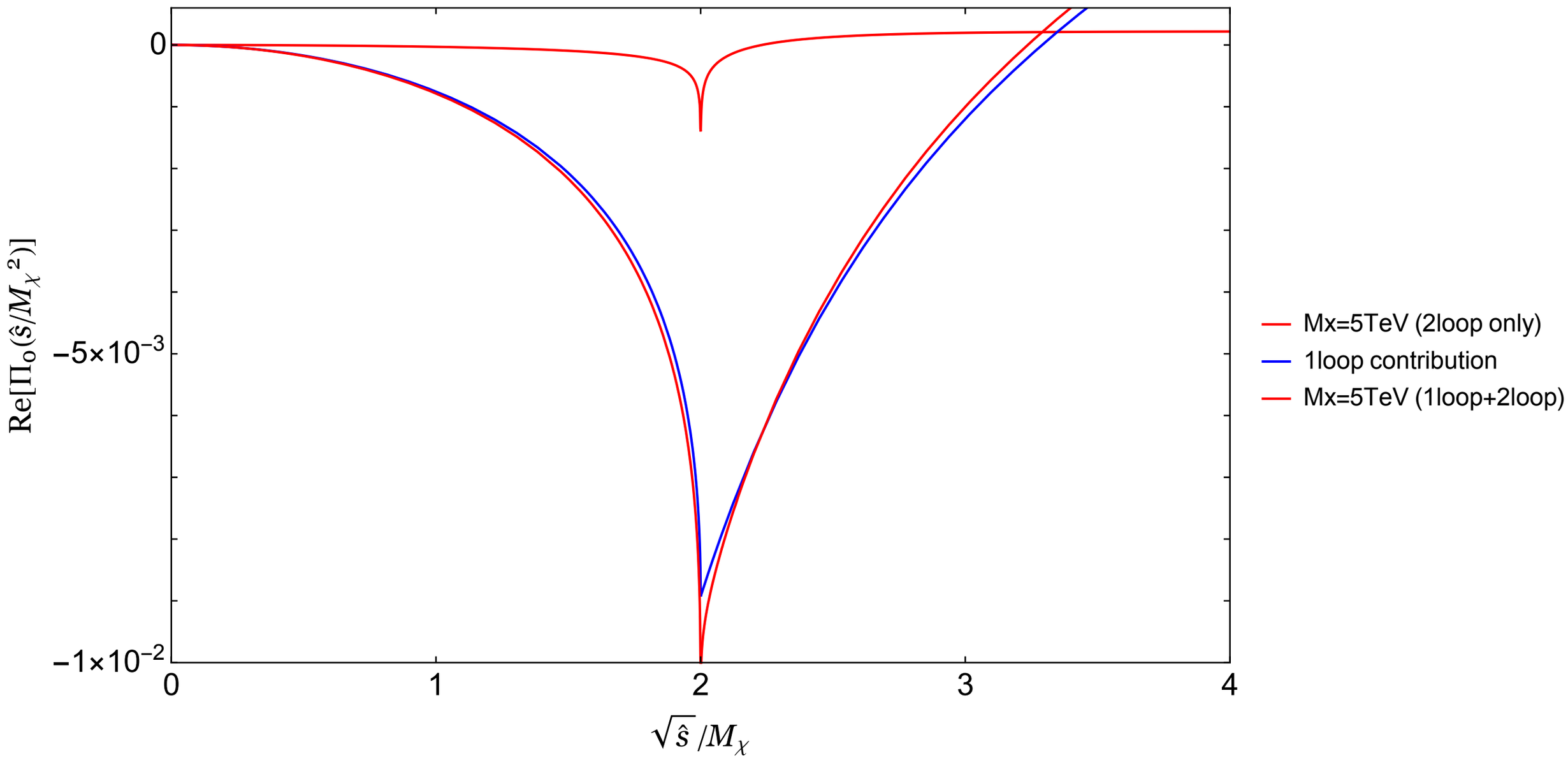
Matching with 2-loop

- NR calculation have uncertainty of constant coming from renormalization constant
- We need matching of NR calculation and perturbative calculation
- Use 2-loop for matching

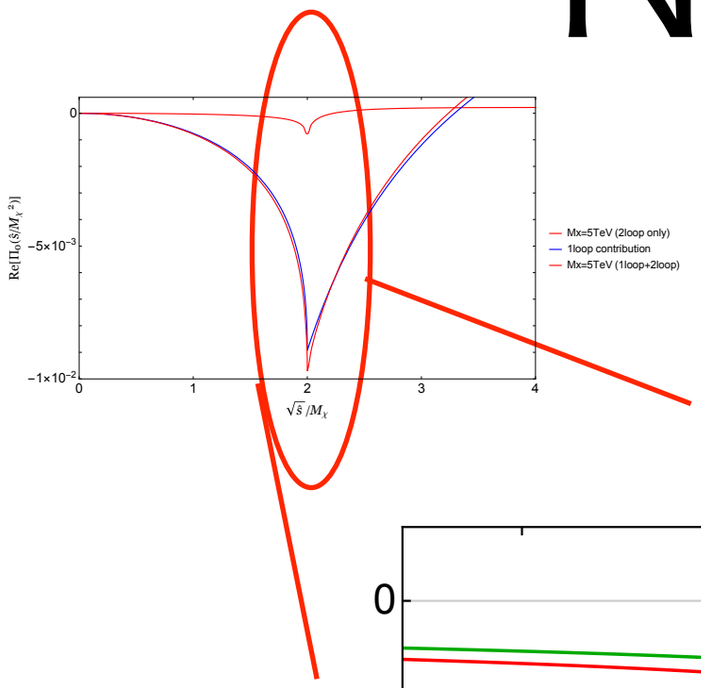


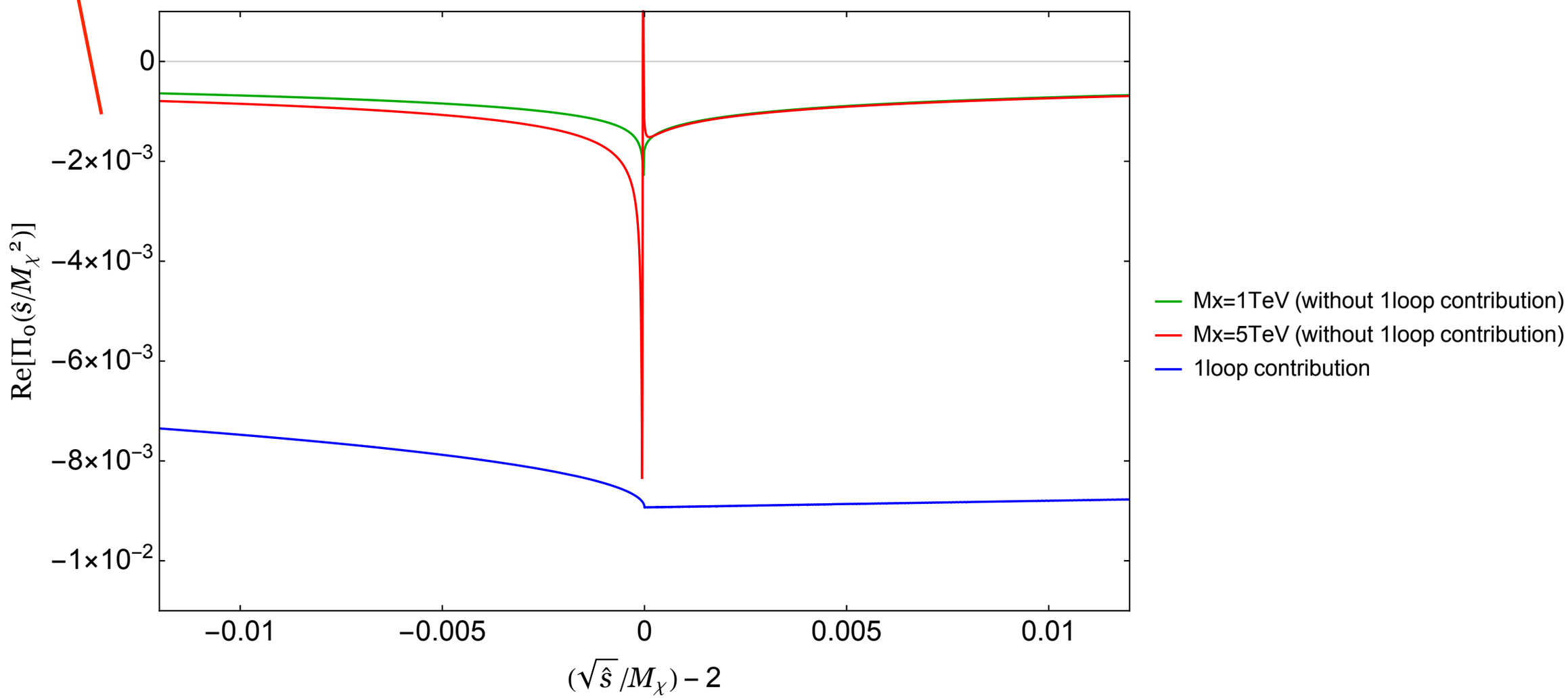
Needed for gauge invariance

2-loop calculation

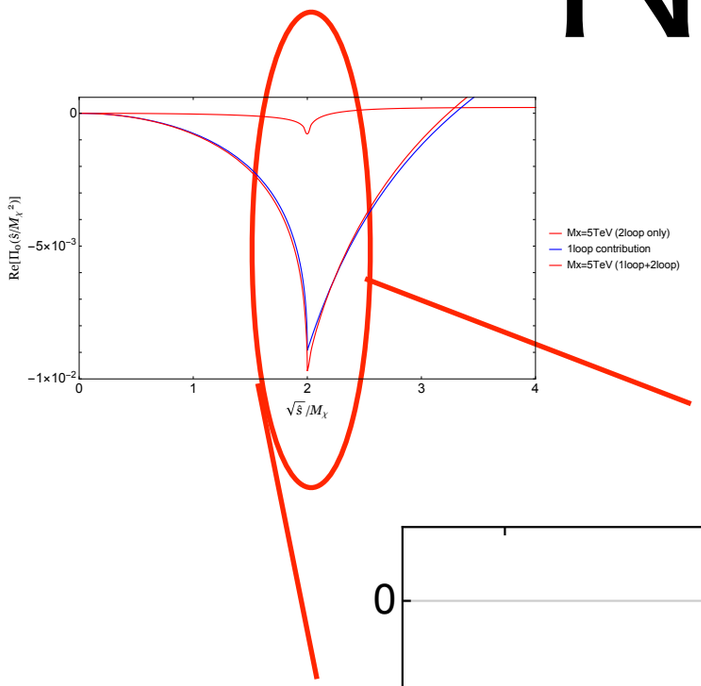


NR calculation

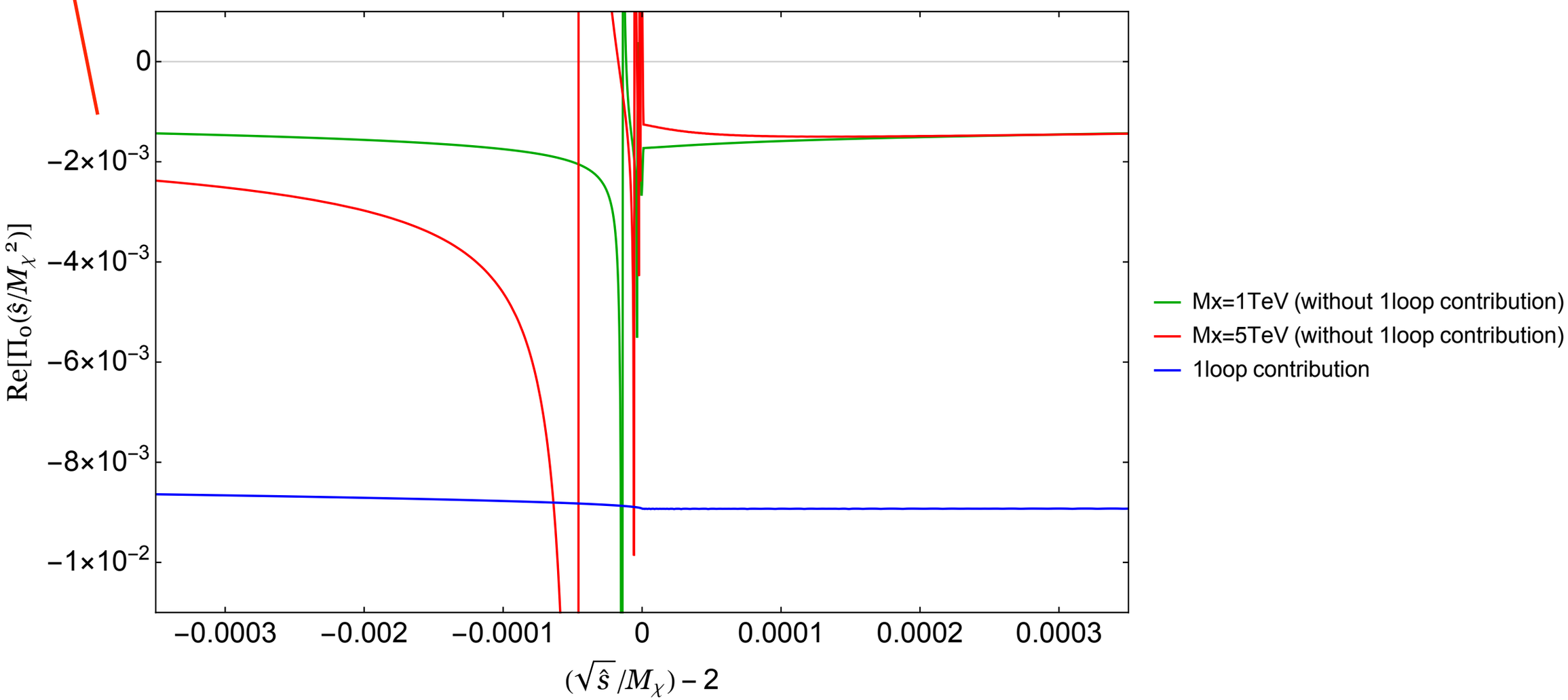




NR calculation



Zooming up more!!



Bound state

- Divergence from bound states

Radiative correction

$$\Pi(x) = \Pi(x)_{\rm reg} + \sum_n \frac{g_n^2}{x^2 - x_n^2 + 2i\Gamma_n/M_\chi}$$

regularized part

bound states part

- We can separate the effect of bound state

Contents

- About EWIMP
- Indirect probe
- Previous calculation and issue
- Non-perturbative effect
- Summary

Signal at collider (and summary)

- Bound states appear in very narrow region
- It is difficult to see at hadron collider because of its resolution
- For hadron collider, two loop calculation is good enough
- For lepton collider, these effects may be seen?
- For higher SU(2) multiplet, two loop and non perturbative effects are more drastic.

Back up

Easy view (of sommerfeld enhancement)

- Suppose EWIMP is much heavier than weak scale
- Exchange of massive gauge boson acts like long range force.
- For non relativistic EWIMP, loop expansion does not work well

  →It works as (α/v) expansion, (v is relative velocity) and if (α/v)>1, higher loop diagram diverge.