Probing a minimal $U(1)_X$ model at future e^-e^+ collider via the fermion pair production channels

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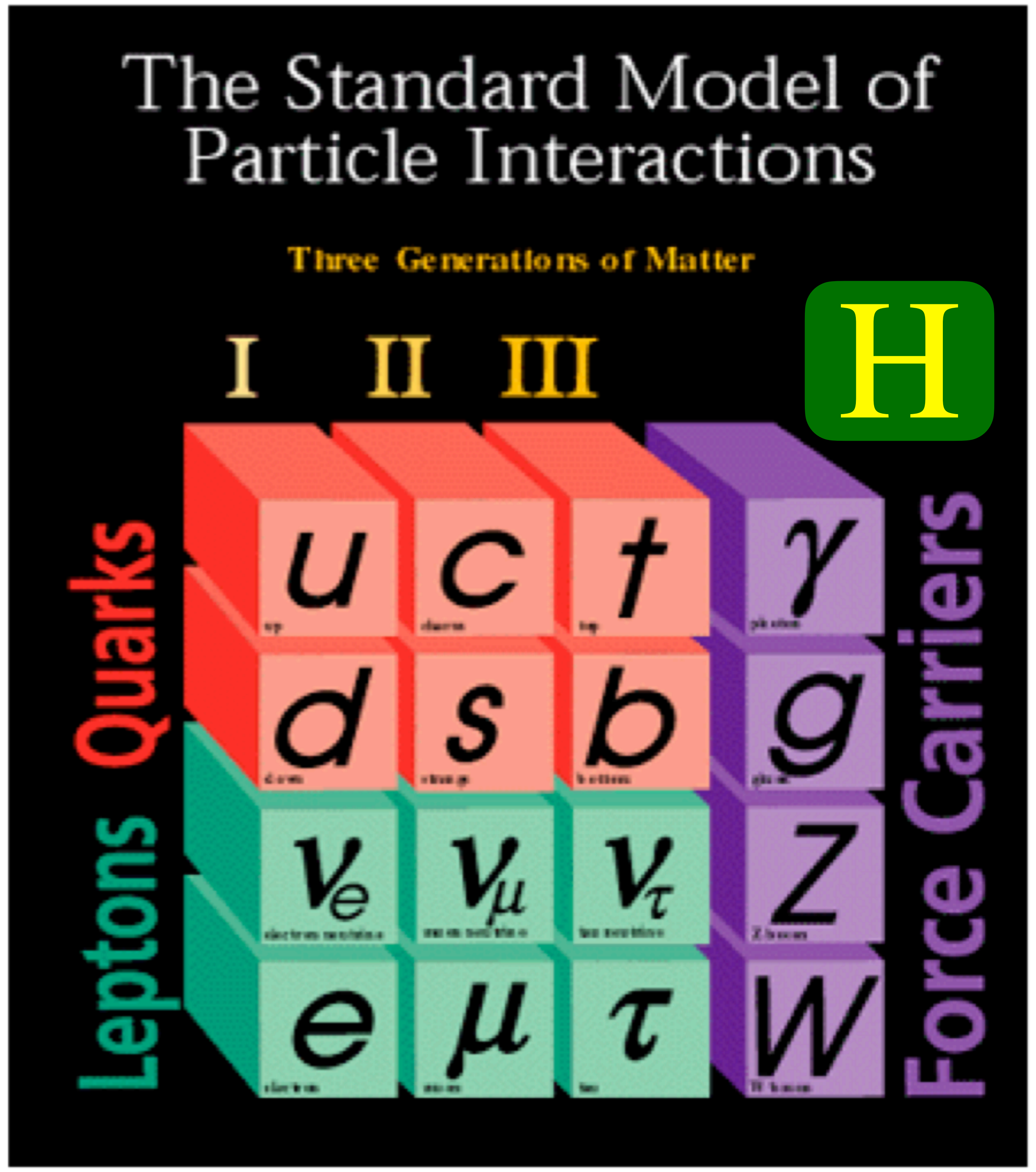
Standard model and missing link/s



Over the decades experiments have found each and every missing pieces

Verified the facts that they belong to this family

Finally at the Large Hadron collider Higgs has been observed

→ Its properties must be verified

Strongly established with interesting shortcomings

Few of the very interesting anomalies :

Tiny neutrino mass and flavor mixings → Neutrino oscillation experiment : SNO, Super − K, etc .

Relic abundance of dark matter . . .

- Nature : Majorana/ Dirac
- Ordering : Normal/Inverted
- Nature of the mixing between the mass and the flavor eigenstates

Unkown ←

SM can not explain them

Different physics frontiers

Energy frontier : Scientists build partcile acclerators to explore high energy scale to explore new phenomena after the subatomic collisions .

Intensity frontier : Highly intense beams from accelerators are used to to investigate the ultra rare processes of nature .

Cosmic frontier : Astrophysicists use the cosmos as the laboratory to investigate the fundamental laws of physics from a complementary point of view of particle accelerator .

ENERGY FRONTIER
INTENSITY FRONTIER
COSMIC FRONTIER
Future Circular Collider – hh/ee/eP
ILC
Origin of mass
Matter/ Antimatter Asymmetry
Dark Matter
Origin and evolution of the universe
Inflation
Unification of the forces
Neutrino Physics
Dark Energy
New physics Beyond the Standard Model
Proton Decay
Cosmic Particles
CMS
ATLAS
LHC
ALICE
SPS
LHCb
PS
FASER
MATHUSLA
DUNE
SHiP
NA62
IecCube/PINGU
Hyper – K
LFV(MEG, BaBaR)
Ground based telescopes
Interferometers
LIGO/ DECIGO
CMB/WMAP
Space Telescopes (FermiLAT)

Proposal of a scenario

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$	
q_L^i	**3**	**2**	$\frac{1}{6}$	x'_q =	$\frac{1}{6}x_H + \frac{1}{3}x_\Phi$
u_R^i	**3**	**1**	$\frac{2}{3}$	x'_u =	$\frac{2}{3}x_H + \frac{1}{3}x_\Phi$
d_R^i	**3**	**1**	$-\frac{1}{3}$	x'_d =	$-\frac{1}{3}x_H + \frac{1}{3}x_\Phi$
ℓ_L^i	**1**	**2**	$-\frac{1}{2}$	x'_ℓ =	$-\frac{1}{2}x_H - x_\Phi$
e_R^i	**1**	**1**	-1	x'_e =	$-x_H - x_\Phi$
N_R^i	**1**	**1**	0	x'_ν =	$-x_\Phi$
H	**1**	**2**	$-\frac{1}{2}$	$-\frac{x_H}{2}$ =	$-\frac{x_H}{2}$
Φ	**1**	**1**	0	$2x_\Phi$ =	$2x_\Phi$

Before anomaly cancellation

After anomaly cancellation

Relevant part of the Yukawa sector

$$\mathcal{L}^{\rm Yukawa} = -Y_u^{\alpha\beta}\overline{q_L^\alpha}Hu_R^\beta - Y_d^{\alpha\beta}\overline{q_L^\alpha}\tilde{H}d_R^\beta - Y_e^{\alpha\beta}\overline{\ell_L^\alpha}\tilde{H}e_R^\beta - Y_\nu^{\alpha\beta}\overline{\ell_L^\alpha}HN_R^\beta - Y_N^\alpha\Phi\overline{N_R^{\alpha c}}N_R^\alpha + \text{h.c.}$$

Anomaly cancellation conditions

$$\begin{aligned}
U(1)_X \otimes [SU(3)_c]^2 &: & 2x'_q - x'_u - x'_d &= 0,\\
U(1)_X \otimes [SU(2)_L]^2 &: & 3x'_q + x'_\ell &= 0,\\
U(1)_X \otimes [U(1)_Y]^2 &: & x'_q - 8x'_u - 2x'_d + 3x'_\ell - 6x'_e &= 0,\\
[U(1)_X]^2 \otimes U(1)_Y &: & {x'_q}^2 - 2{x'_u}^2 + {x'_d}^2 - {x'_\ell}^2 + {x'_e}^2 &= 0,\\
[U(1)_X]^3 &: & 6{x'_q}^3 - 3{x'_u}^3 - 3{x'_d}^3 + 2{x'_\ell}^3 - {x'_\nu}^3 - {x'_e}^3 &= 0,\\
U(1)_X \otimes [\text{grav.}]^2 &: & 6x'_q - 3x'_u - 3x'_d + 2x'_\ell - x'_\nu - x'_e &= 0.
\end{aligned}$$

Linear combination of $U(1)_Y$ and $U(1)_{B-L}$

Higgs potential

$$V = m_h^2(H^\dagger H) + \lambda(H^\dagger H)^2 + m_\Phi^2(\Phi^\dagger\Phi) + \lambda_\Phi(\Phi^\dagger\Phi)^2 + \lambda'(H^\dagger H)(\Phi^\dagger\Phi)$$

$U(1)_X$ breaking Electroweak breaking

$$\langle\Phi\rangle = \frac{v_\Phi + \phi}{\sqrt{2}} \qquad \langle H\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} v+h \\ 0 \end{pmatrix} \qquad v \simeq 246\,\mathrm{GeV}, v_\Phi >> v_h$$

Mass of the neutral gauge boson Z'

$$M_{Z'} = g'\sqrt{4v_\Phi^2 + \frac{1}{4}x_H^2 v_h^2} \simeq 2g' v_\Phi.$$

Neutrino masss

$$\mathscr{L}^{\mathrm{mass}} = -Y_\nu^{\alpha\beta}\overline{\ell_L^\alpha}HN_R^\beta - Y_N^\alpha\Phi\overline{N_R^{\alpha c}}N_R^\alpha + \mathrm{h.c.}$$

$U(1)_X$ breaking

$$m_{N_\alpha} = \frac{Y_N^\alpha}{\sqrt{2}}v_\Phi, \quad m_D^{\alpha\beta} = \frac{Y_\nu^{\alpha\beta}}{\sqrt{2}}v. \quad m_\nu^{\mathrm{mass}} = \begin{pmatrix} 0 & m_D \\ m_D^T & m_N \end{pmatrix}$$

$$m_\nu \simeq -m_D m_N^{-1} m_D^T$$

Seesaw mechnism

can explain the origin of the light neutrino mass and can be tested at the experiments

Z' interactions

Interaction between the quarks and Z' $$\mathcal{L}^q = -g'(\overline{q}\gamma_\mu q^q_{x_L} P_L q + \overline{q}\gamma_\mu q^q_{x_R} P_R q)Z'_\mu$$

Interaction between the leptons and Z' $$\mathcal{L}^\ell = -g'(\overline{\ell}\gamma_\mu q^\ell_{x_L} P_L \ell + \overline{e}\gamma_\mu q^\ell_{x_R} P_R e)Z'_\mu$$

$q^f_{x_L} \neq q^f_{x_R}$ affects the phenomenology

Partial decay width

Charged fermions $$\Gamma(Z' \to 2f) = N_c \frac{M_{Z'}}{24\pi} \left(g^f_L\Big[g', x_H, x_\Phi\Big]^2 + g^f_R\Big[g', x_H, x_\Phi\Big]^2 \right)$$

light neutrinos $$\Gamma(Z' \to 2\nu) = \frac{M_{Z'}}{24\pi} \, g^\nu_L\Big[g', x_H, x_\Phi\Big]^2$$

heavy neutrinos $$\Gamma(Z' \to 2N) = \frac{M_{Z'}}{24\pi} \, g^N_R\Big[g', x_\Phi\Big]^2 \left(1 - 4\frac{m_N^2}{M_{Z'}^2}\right)^{\frac{3}{2}}$$

Implications of the choices of x_H keeping $x_\Phi = 1$

No interaction with e_R

No interaction with d_R

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$		-2 $U(1)_R$	-1	-0.5	0 B−L	0.5	1	2
q_L^i	**3**	**2**	$\frac{1}{6}$	$x'_q =$	$\frac{1}{6}x_H + \frac{1}{3}x_\Phi$	0	$\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{1}{3}$
u_R^i	**3**	**1**	$\frac{2}{3}$	$x'_u =$	$\frac{2}{3}x_H + \frac{1}{3}x_\Phi$	-1	$-\frac{1}{3}$	0	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{5}{3}$
d_R^i	**3**	**1**	$-\frac{1}{3}$	$x'_d =$	$-\frac{1}{3}x_H + \frac{1}{3}x_\Phi$	1	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{6}$	0	$-\frac{1}{3}$
ℓ_L^i	**1**	**2**	$-\frac{1}{2}$	$x'_\ell =$	$-\frac{1}{2}x_H - x_\Phi$	0	$-\frac{1}{2}$	$-\frac{3}{4}$	-1	$\frac{5}{4}$	$-\frac{3}{2}$	-2
e_R^i	**1**	**1**	-1	$x'_e =$	$-x_H - x_\Phi$	1	0	$-\frac{1}{2}$	-1	$-\frac{3}{2}$	-2	-3
N_R^i	**1**	**1**	0	$x'_\nu =$	$-x_\Phi$	-1	-1	-1	-1	-1	-1	-1
H	**1**	**2**	$-\frac{1}{2}$	$-\frac{x_H}{2} =$	$-\frac{x_H}{2}$	1	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{4}$	1
Φ	**1**	**1**	0	$2x_\Phi =$	$2x_\Phi$	2	2	2	2	2	2	2

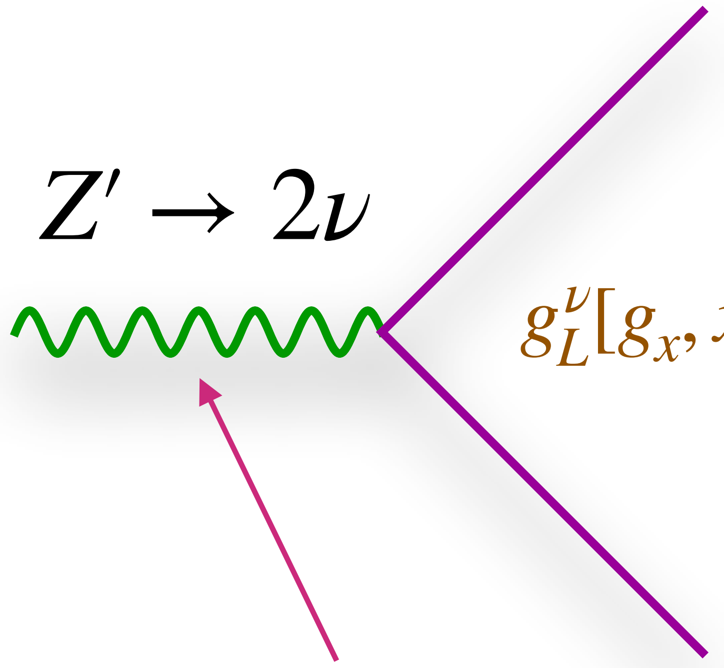
No interaction with left handed fermions

No interaction with u_R

Partial decay widths of Z'

$x_\Phi = 1$

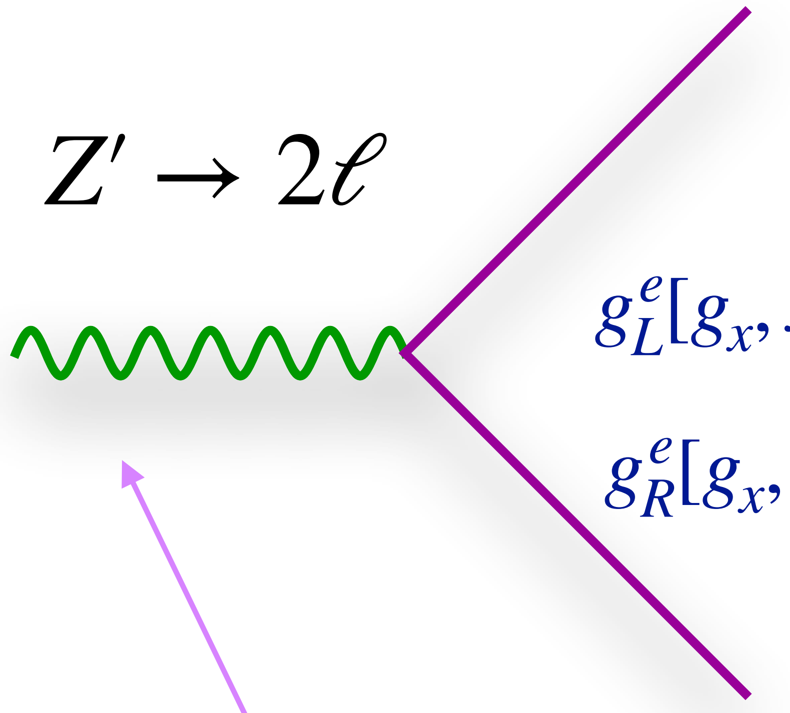
$Z' \to 2\nu$



$$g_L^\nu[g_x, x_H] = \left((-\frac{1}{2})x_H + (-1)\right)g_x$$

$$\Gamma[Z' \to 2\nu] = \frac{M_{Z'}}{24\pi} g_L^\nu[g_x, x_H]^2$$

$Z' \to 2\ell$

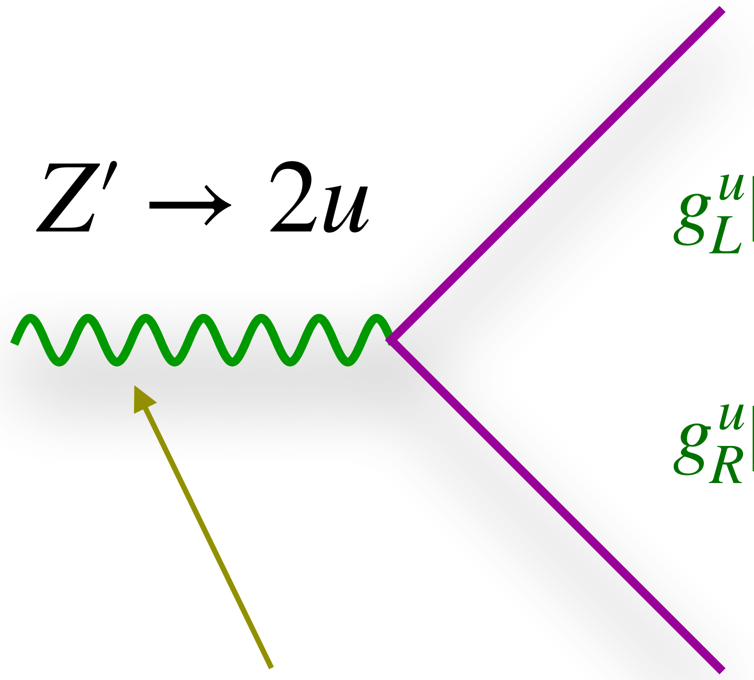


$$g_L^e[g_x, x_H] = \left((-\frac{1}{2})x_H + (-1)\right)g_x$$

$$g_R^e[g_x, x_H] = \left((-1)x_H + (-1)\right)g_x$$

$$\Gamma[Z' \to 2\ell] = \frac{M_{Z'}}{24\pi}(g_L^e[g_x, x_H]^2 + g_R^e[g_x, x_H]^2)$$

$Z' \to 2u$

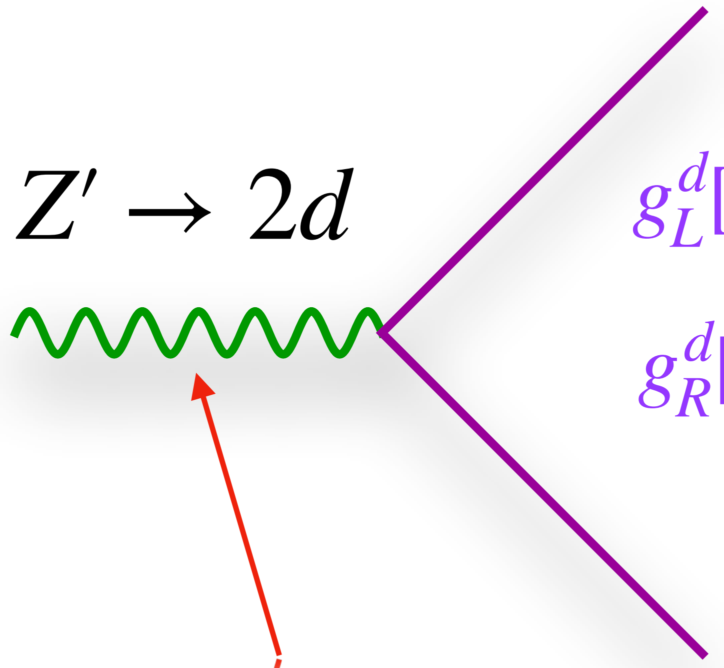


$$g_L^u[g_x, x_H] = \left((\frac{1}{6})x_H + (\frac{1}{3})\right)g_x$$

$$g_R^u[g_x, x_H] = \left((\frac{2}{3})x_H + (\frac{1}{3})\right)g_x$$

$$\Gamma[Z' \to 2u] = \frac{M_{Z'}}{24\pi}(g_L^u[g_x, x_H]^2 + g_R^u[g_x, x_H]^2)$$

$Z' \to 2d$



$$g_L^d[g_x, x_H] = \left((\frac{1}{6})x_H + (\frac{1}{3})\right)g_x$$

$$g_R^d[g_x, x_H] = \left((-\frac{1}{3})x_H + (\frac{1}{3})\right)g_x$$

$$\Gamma[Z' \to 2d] = \frac{M_{Z'}}{24\pi}(g_L^d[g_x, x_H]^2 + g_R^d[g_x, x_H]^2)$$

Properties of the model and phenomenology

New particles

Z' boson

Heavy Majorana Neutrino

$U(1)_X$ Higgs boson

Phenomenology

Z' boson production and decay

Z' boson mediated processes

Jurina Nakajima's talk ← Heavy neutrino production

$U(1)_X$Higgs phenoemenology : Vacuum Stability

collider

Dark Matter

Leptogenesis and many more

Fermionic pair production form the Z'

Fermionic pair production form the Z'

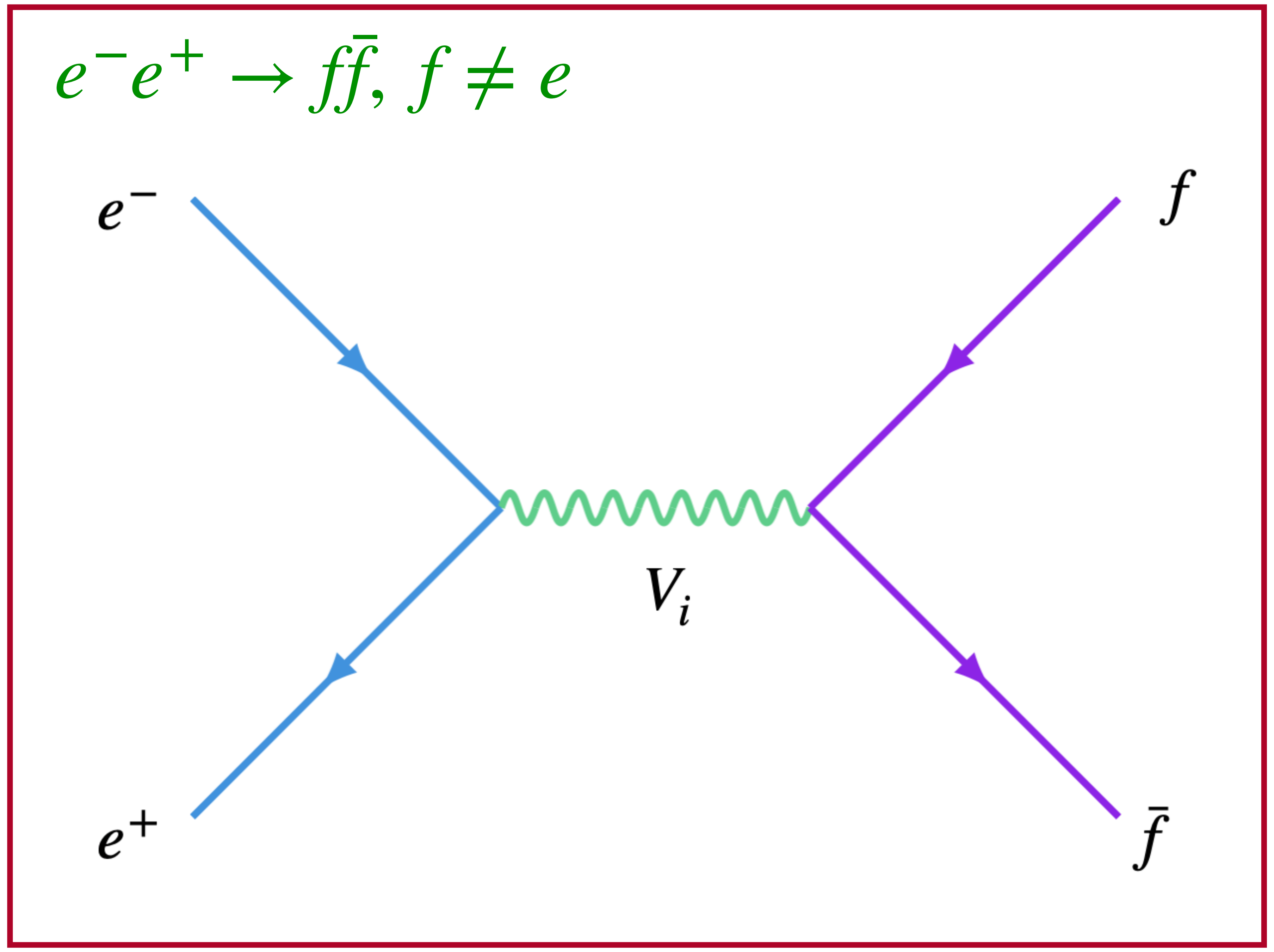
New particles Z' boson Heavy Majorana Neutrino $U(1)_X$ Higgs boson

Phenomenology Z' boson production and decay Heavy neutrino production

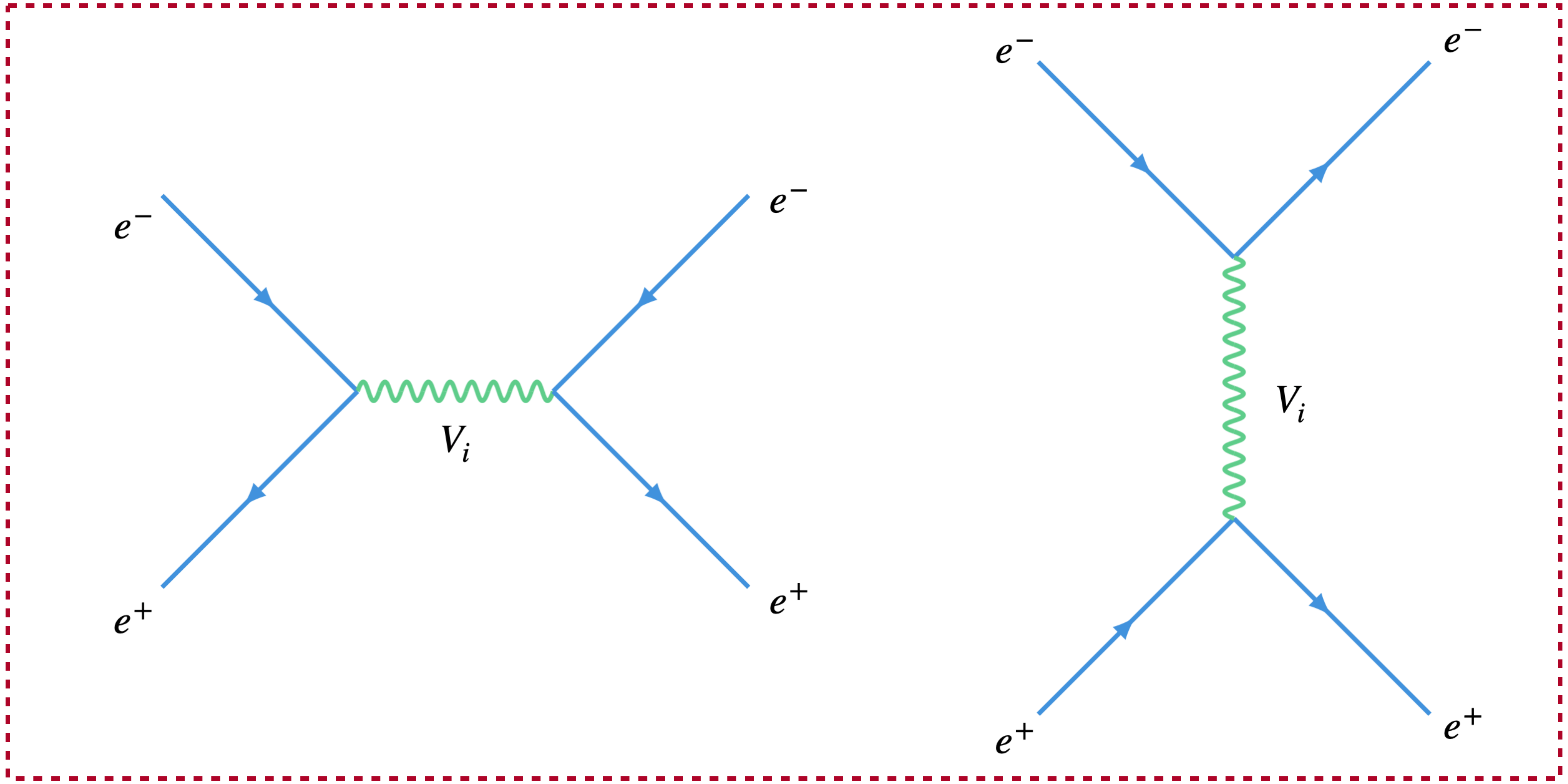
Dark Matter collider $U(1)_X$Higgs phenoemenology : Vacuum Stability

Leptogenesis and many more

Bhabha scattering

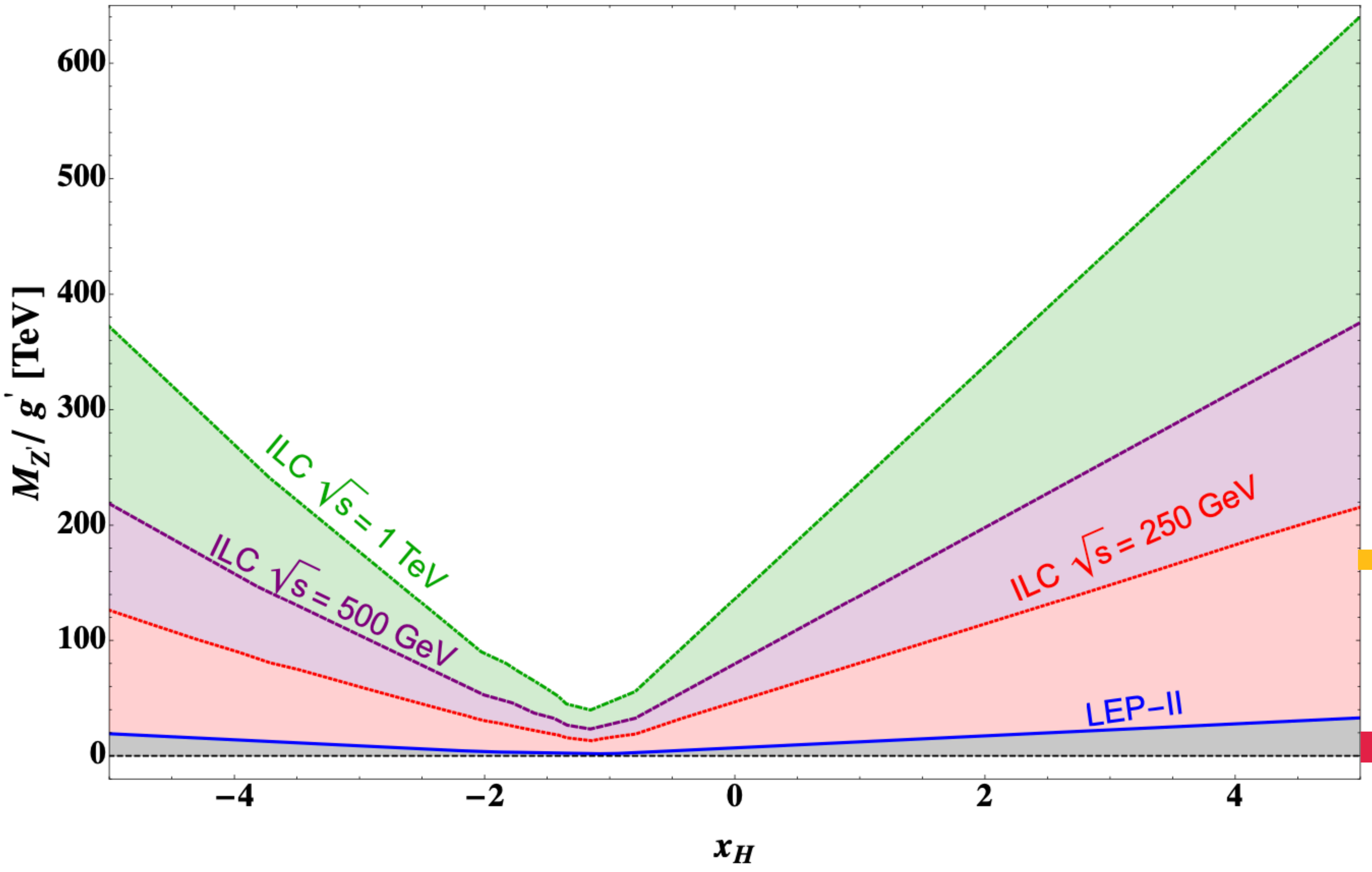


$V_i = \{\gamma, Z, Z'\}$



Limits on the model parameters

Considering the limit $M_{Z'} >> \sqrt{s}$ and appling effective theory we find the limits on $\frac{M_{Z'}}{g'}$ using LEP – II (1302.3415) and (prospective) ILC (1908.11299) :



$$\frac{\pm 4\pi}{(1+\delta_{ef})(\Lambda^{f\pm}_{AB})^2}(\bar{e}\gamma_\mu P_A e)(\bar{f}\gamma_\mu P_B f)$$

Z' exchange matrix element for our process

$$\frac{(g')^2}{{M_{Z'}}^2 - s}[\bar{e}\gamma_\mu(x_\ell' P_L + x_e' P_R)e][\bar{f}\gamma_\mu(x_{f_L} P_L + x_{f_R} P_R)f]$$

Matching the above equations we obtain

$$M^2_{Z'} - s \geq \frac{g'^2}{4\pi}|x_{e_A} x_{f_B}|(\Lambda^{f\pm}_{AB})^2$$

Indicates a large VEV scale can be probed from LEP – II to ILC1000 via ILC250 and ILC500

Shows limits on $M_{Z'}$ vs g' for LEP – II, ILC250, ILC500 and ILC1000

Limits on $M_{Z'}$ and g' can also be obtained from dilepton and dijet searches at the LHC

$$g' = \sqrt{g^2_{\text{Model}}\left(\frac{\sigma^{\text{Obs.}}_{\text{ATLAS}}}{\sigma_{\text{Model}}}\right)}$$

Interaction between fermions and Z′

U(1)′ coupling

$$-L_{int} \supset f_L \gamma^\mu g' Q_x Z'_\mu f_L + f_R \gamma^\mu g' Q'_x Z'_\mu f_R .$$

U(1)′ charge of left handed fermions

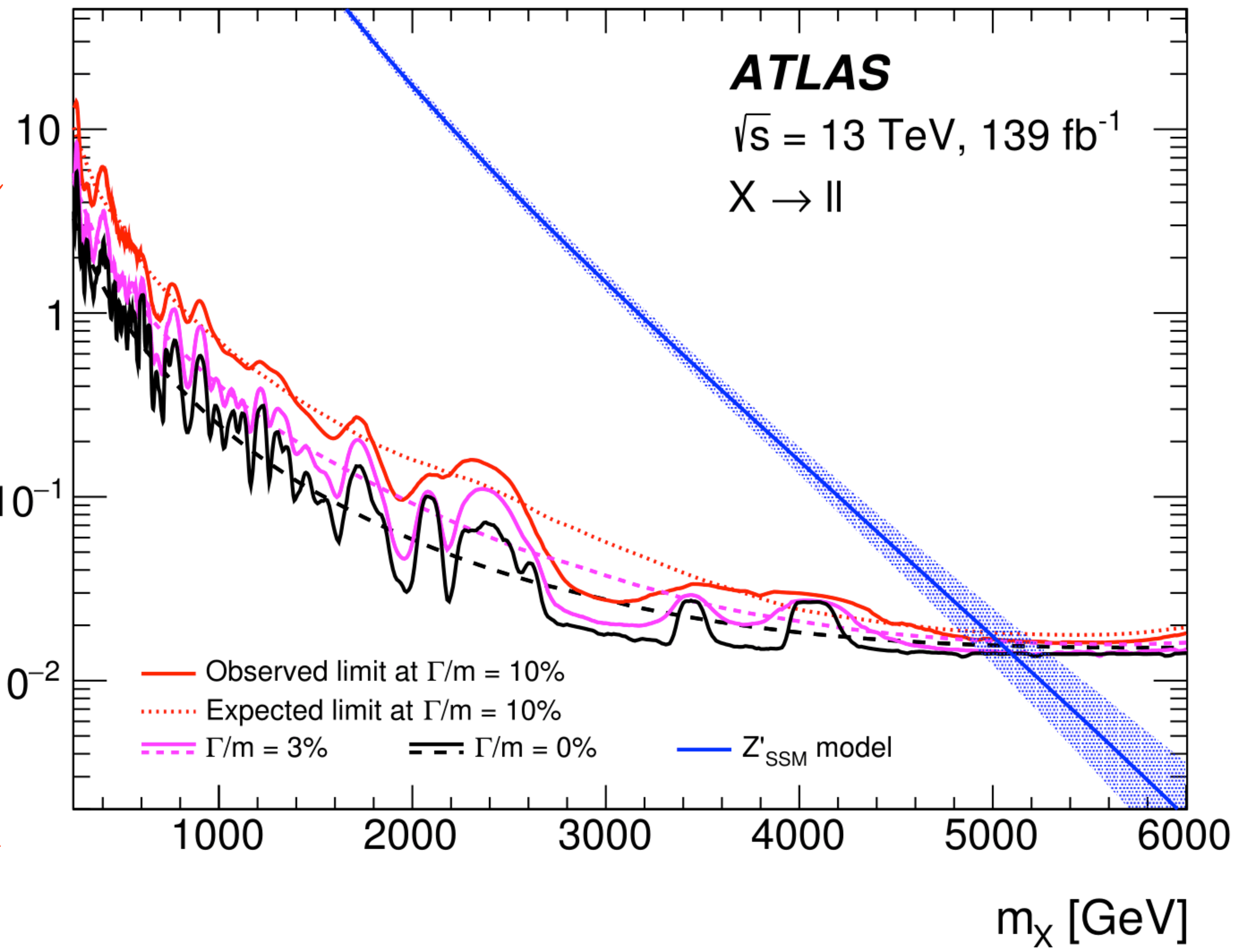
U(1)′ charge of right handed fermions

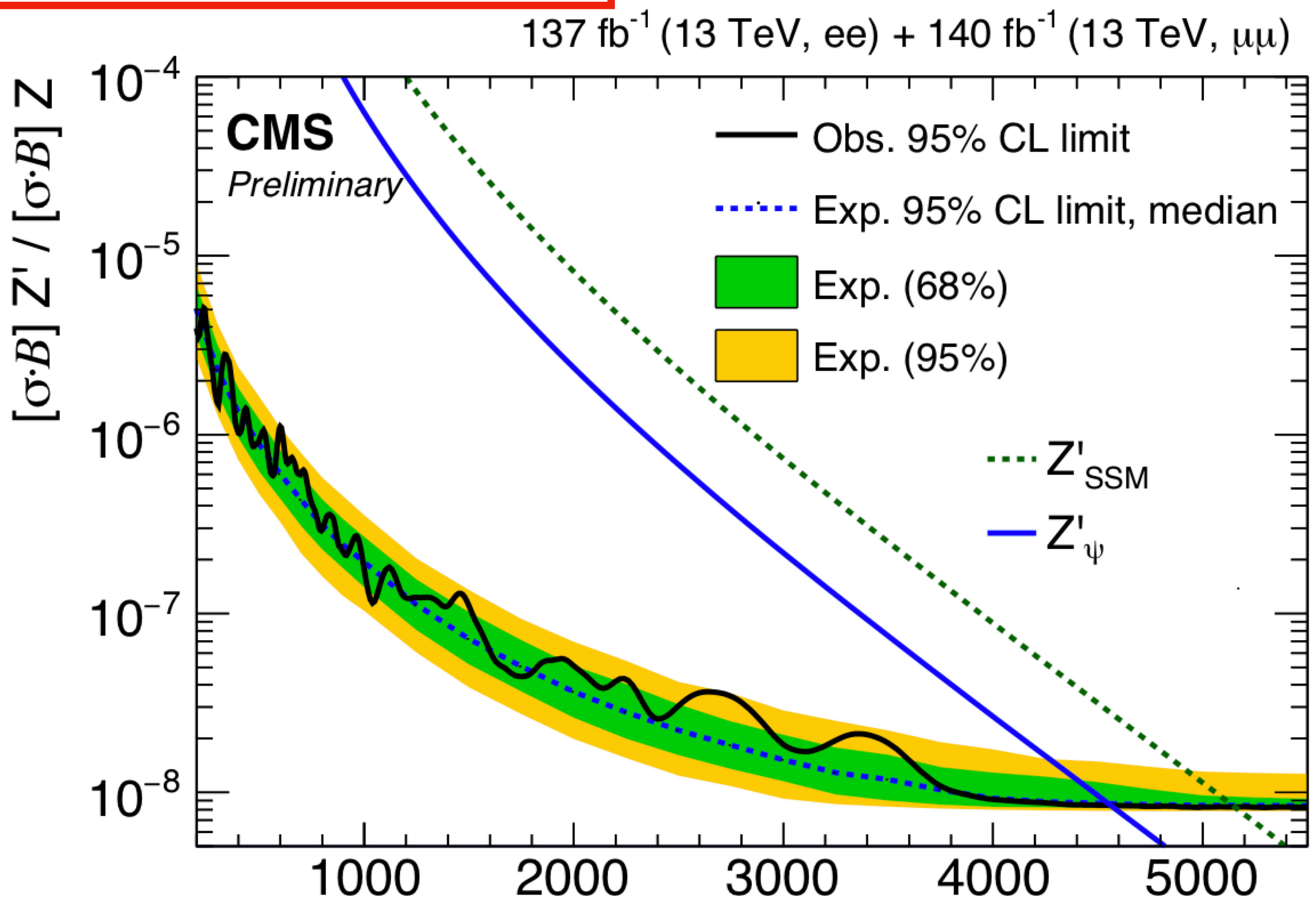
We compare dilepton production cross section with the dilepton production at the ATLAS

$$g' = \sqrt{\frac{\sigma^{\text{Observed}}_{\text{ATLAS}}}{\left(\frac{\sigma_{\text{Model}}}{g^2_{\text{Model}}}\right)}}$$

Recent bounds on the heavy Z' from dilepton channel

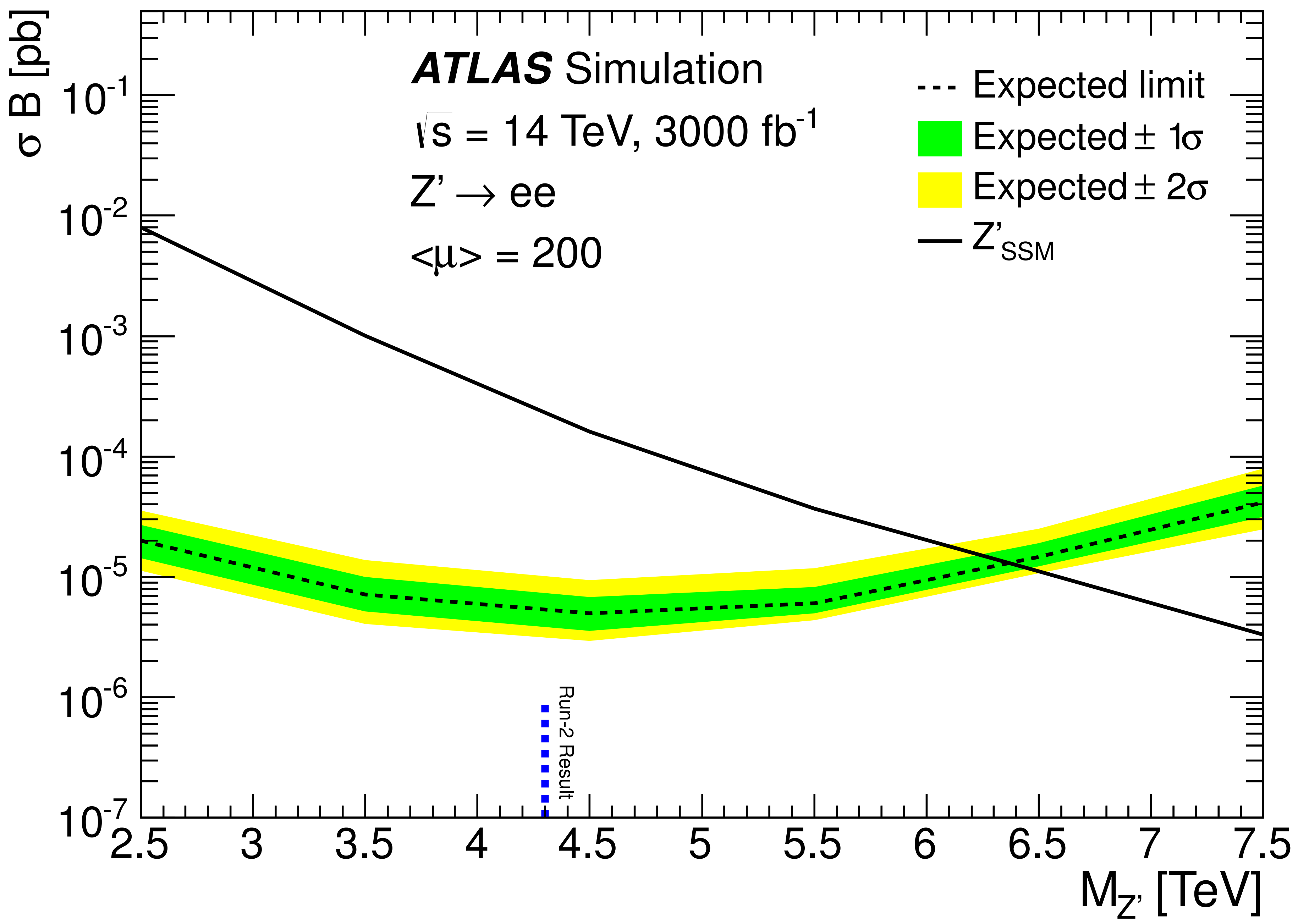
2ℓ, ATLAS : 1903.06248 (139 fb^{-1})



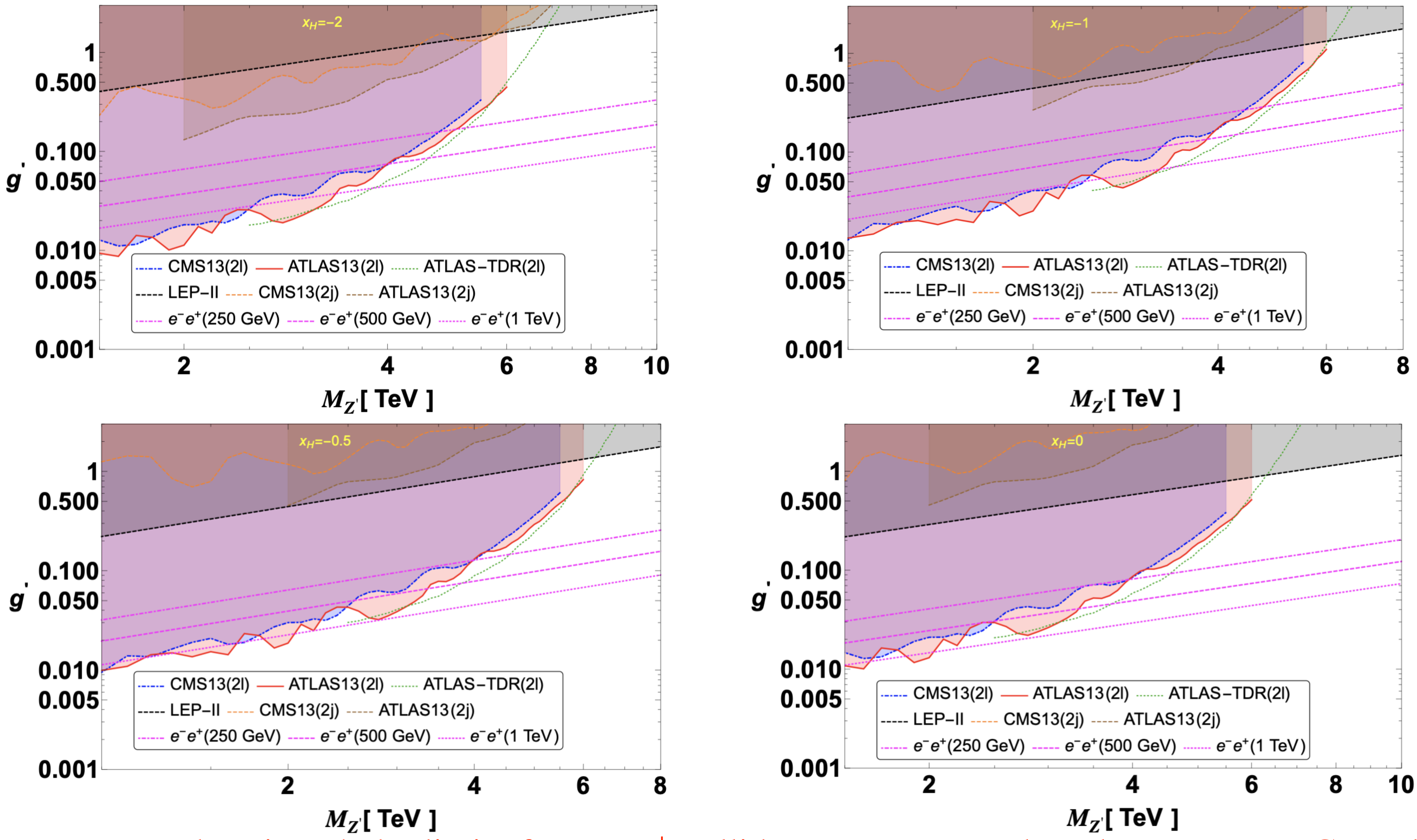


CMS PAS EXO − 19 − 019
ee(137 fb^{-1}) + $\mu\mu$(140 fb^{-1})

ATLAS − TDR − 027
ee (Prospective)

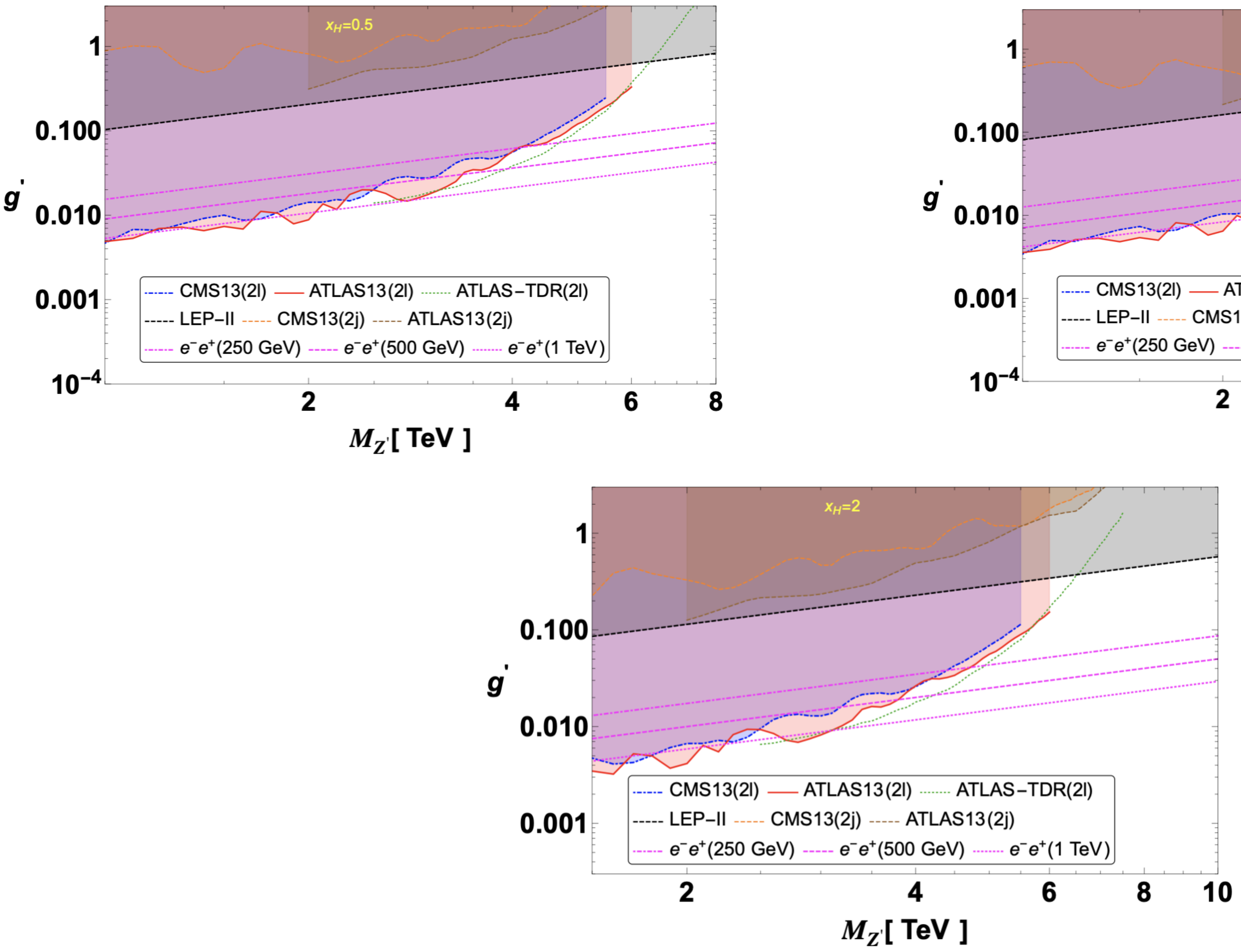


$x_H \leq 0$



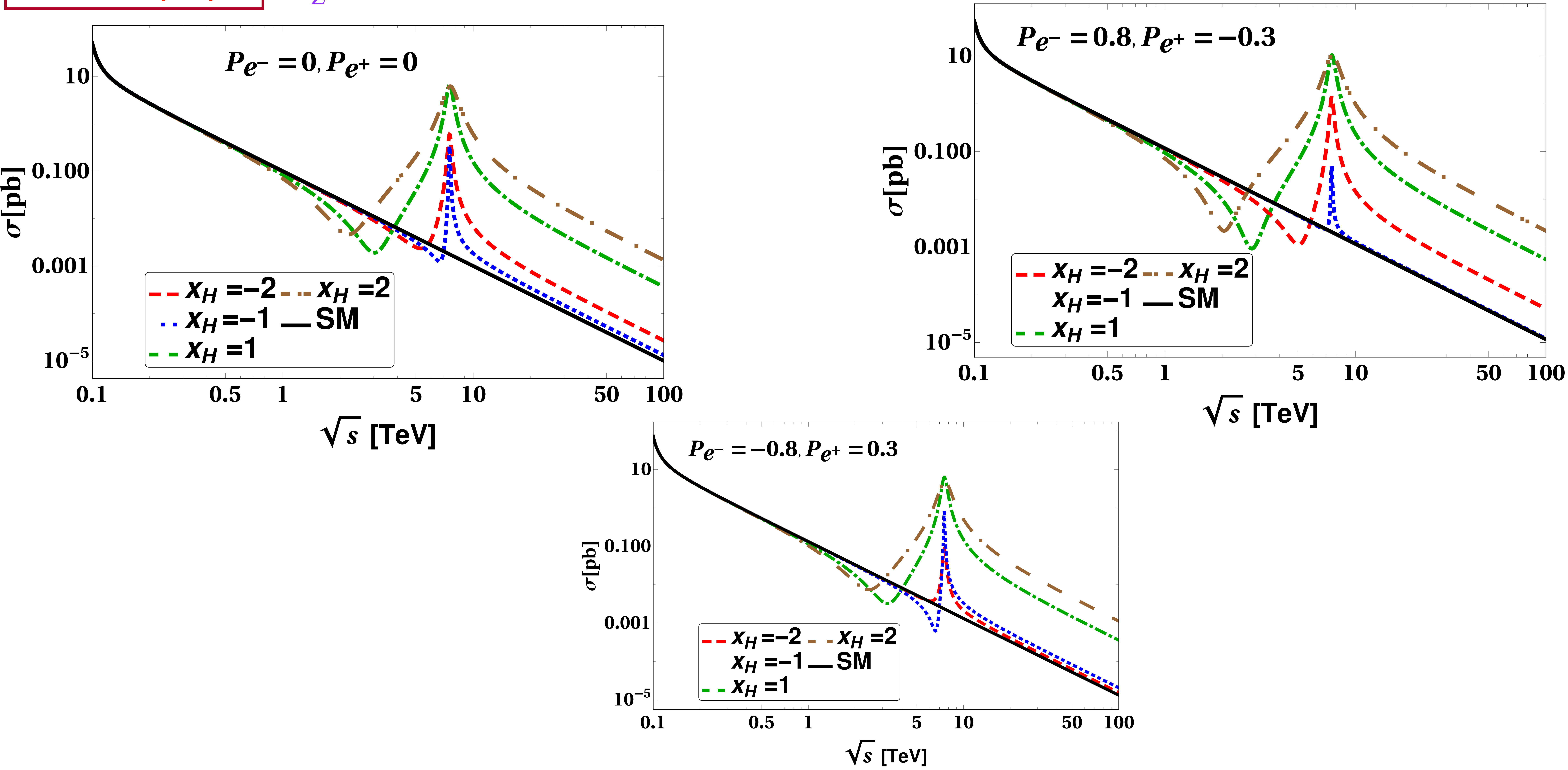
For heavier Z', the limits from e^-e^+ colliders are stronger than the current LHC results

$x_H > 0$



For heavier Z', the limits from e^-e^+ colliders are stronger than the current LHC results

$e^-e^+ \to \mu^+\mu^-$ $M_{Z'} = 7.5$ TeV



Deviations in total cross sections from SM is more than 100 % for $x_H \geq 1$ for $\sqrt{s} = 3$ TeV . For $\sqrt{s} < 3$TeV the deviation is also sizable .

$e^- e^+ \to f\, f$

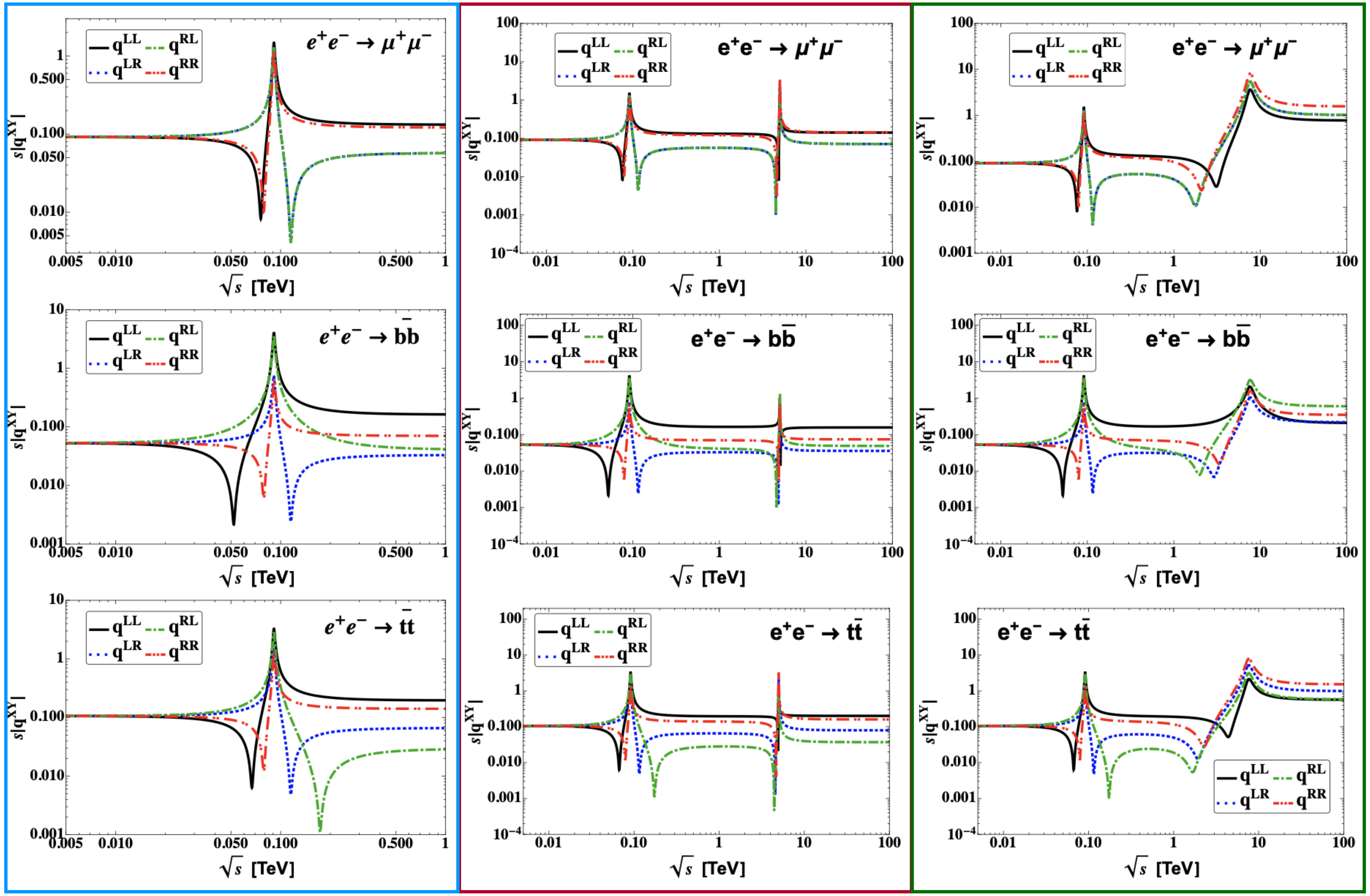
We define

$$q^{e_L f_L} = \sum_i \frac{g_L^{V_i e} g_L^{V_i f}}{s - m_{V_i}^2 + i\, m_{V_i}\Gamma_{V_i}}, \quad q^{e_L f_R} = \sum_i \frac{g_L^{V_i e} g_R^{V_i f}}{s - m_{V_i}^2 + i\, m_{V_i}\Gamma_{V_i}}$$

$$q^{e_R f_L} = \sum_i \frac{g_R^{V_i e} g_L^{V_i f}}{s - m_{V_i}^2 + i\, m_{V_i}\Gamma_{V_i}}, \quad q^{e_R f_R} = \sum_i \frac{g_R^{V_i e} g_R^{V_i f}}{s - m_{V_i}^2 + i\, m_{V_i}\Gamma_{V_i}}$$

$g_{L/R}^{V_i}$ → information of charges x_H, x_Φ

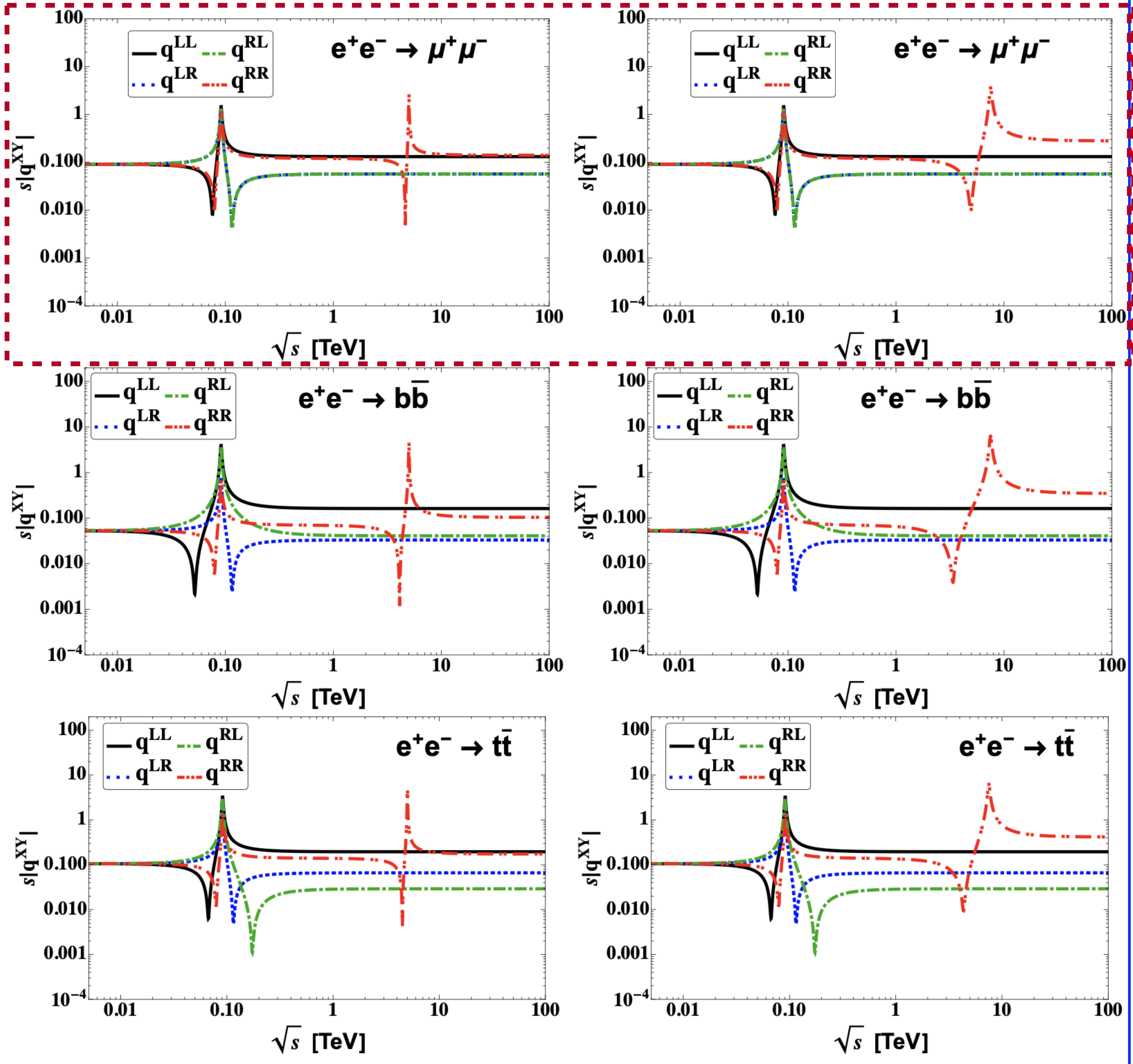
SM | $M'_Z = 5$ TeV | $M'_Z = 7.5$ TeV



$x_H = 2,\ x_\Phi = 1$

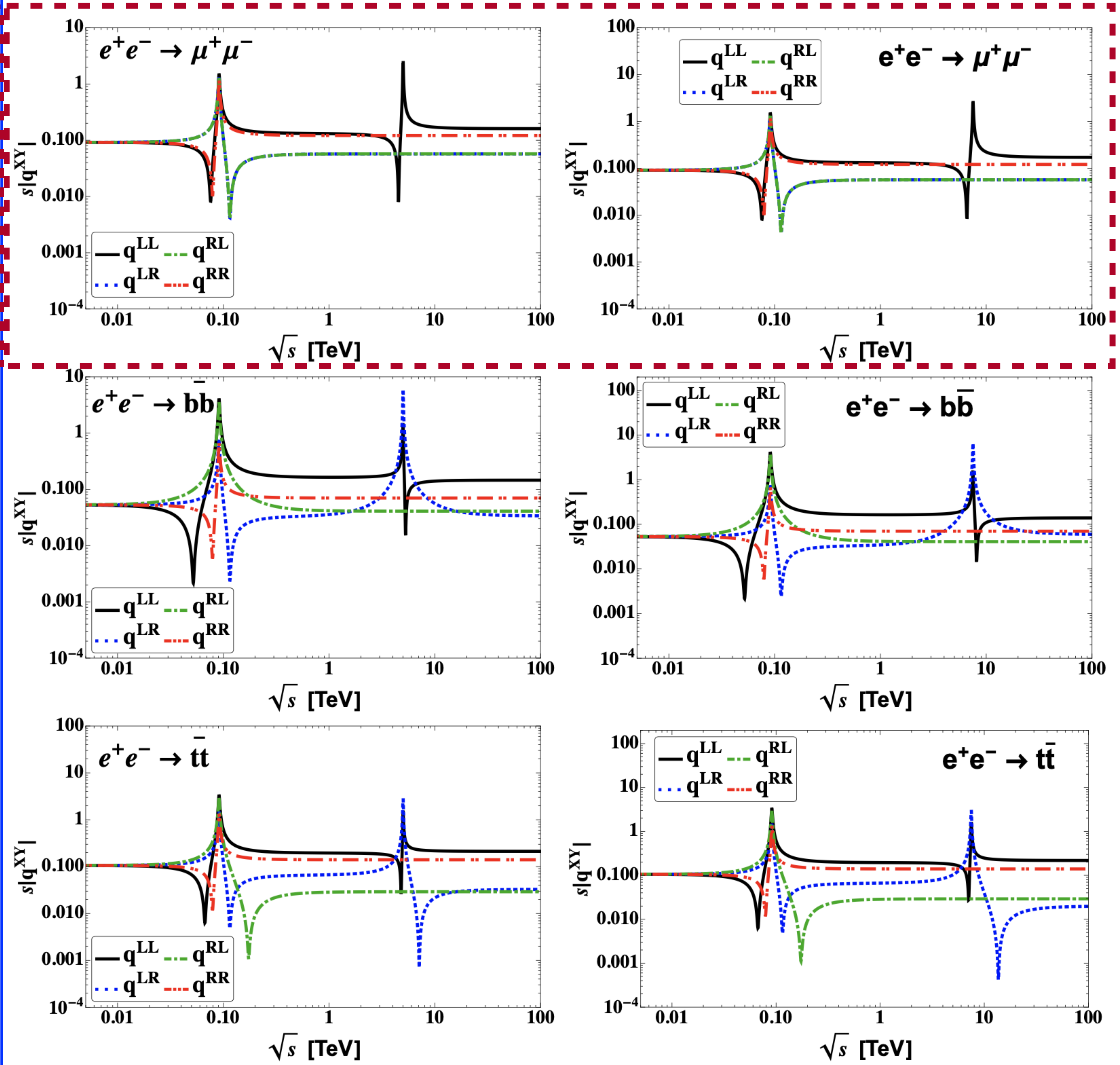
$x_H = -2$ No interaction with left handed fermions

No contribution q_{LL}, q_{LR}, q_{RL} in $\mu^+\mu^-$



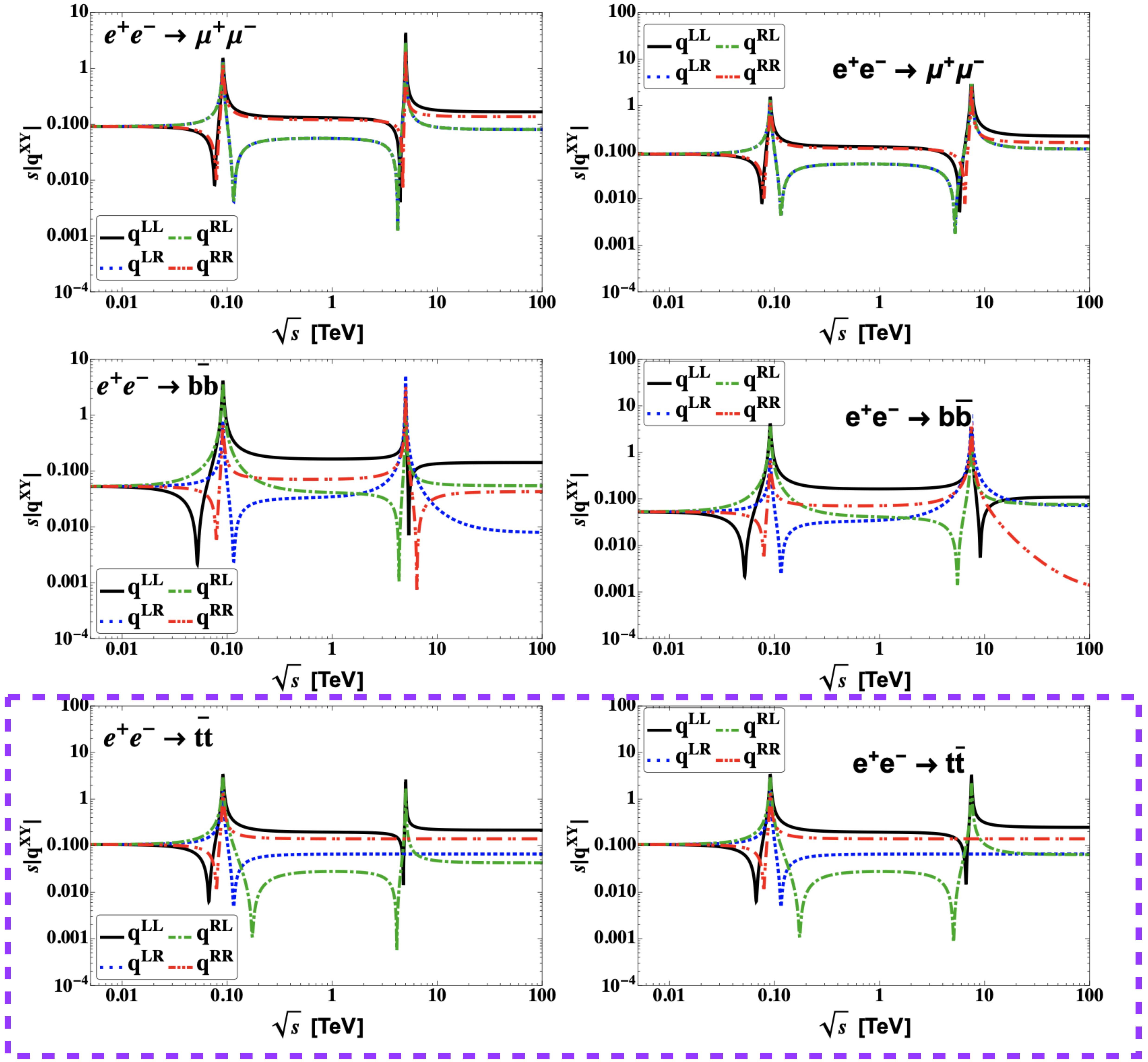
$x_H = -1$ No interaction with e_R

No contribution q_{RR}, q_{LR}, q_{RL} in $\mu^+\mu^-$



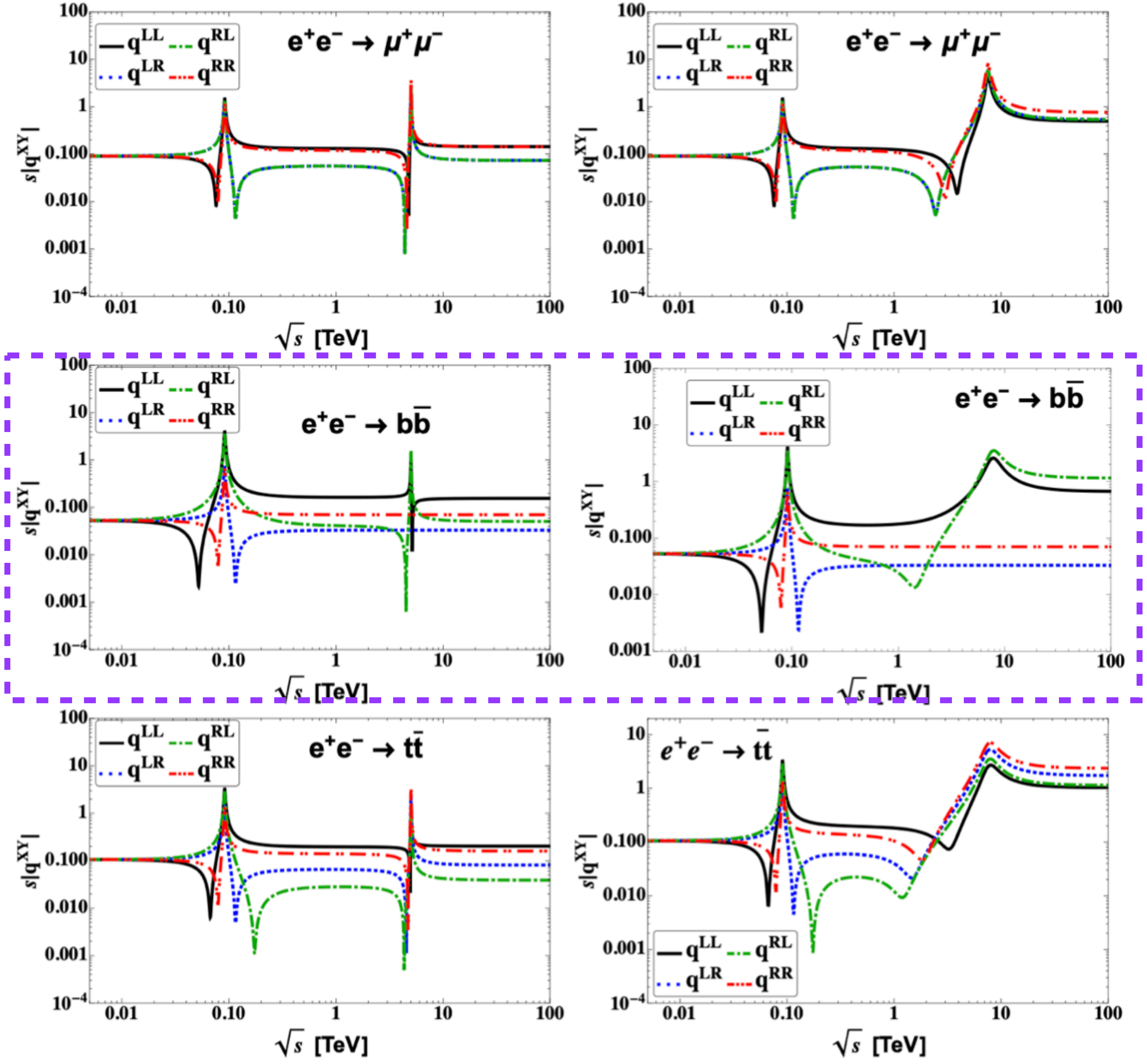
$x_H = 0.5$ No interaction with u_R

No contribution q_{RR}, q_{LR} in $t\bar{t}$



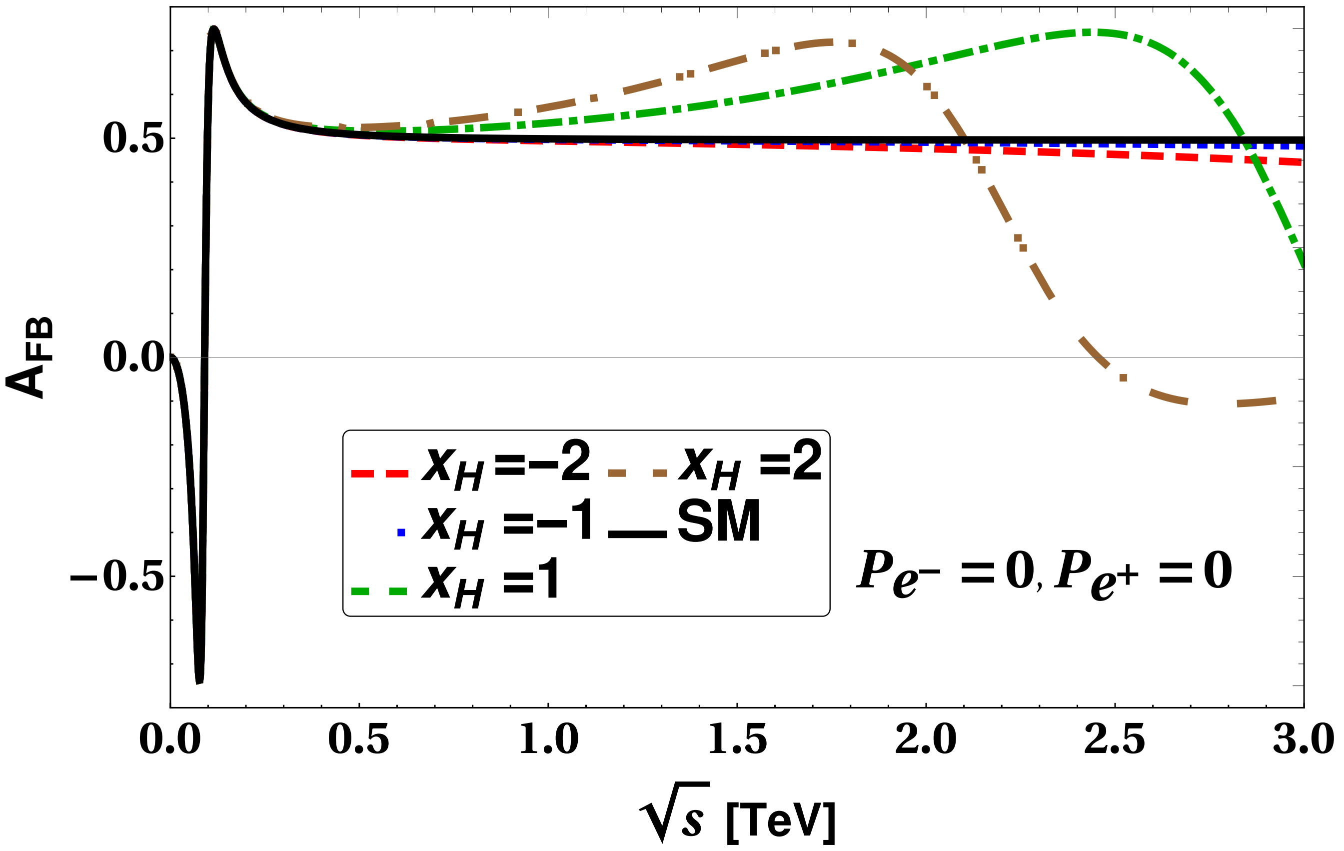
$x_H = 1$ No interaction with d_R

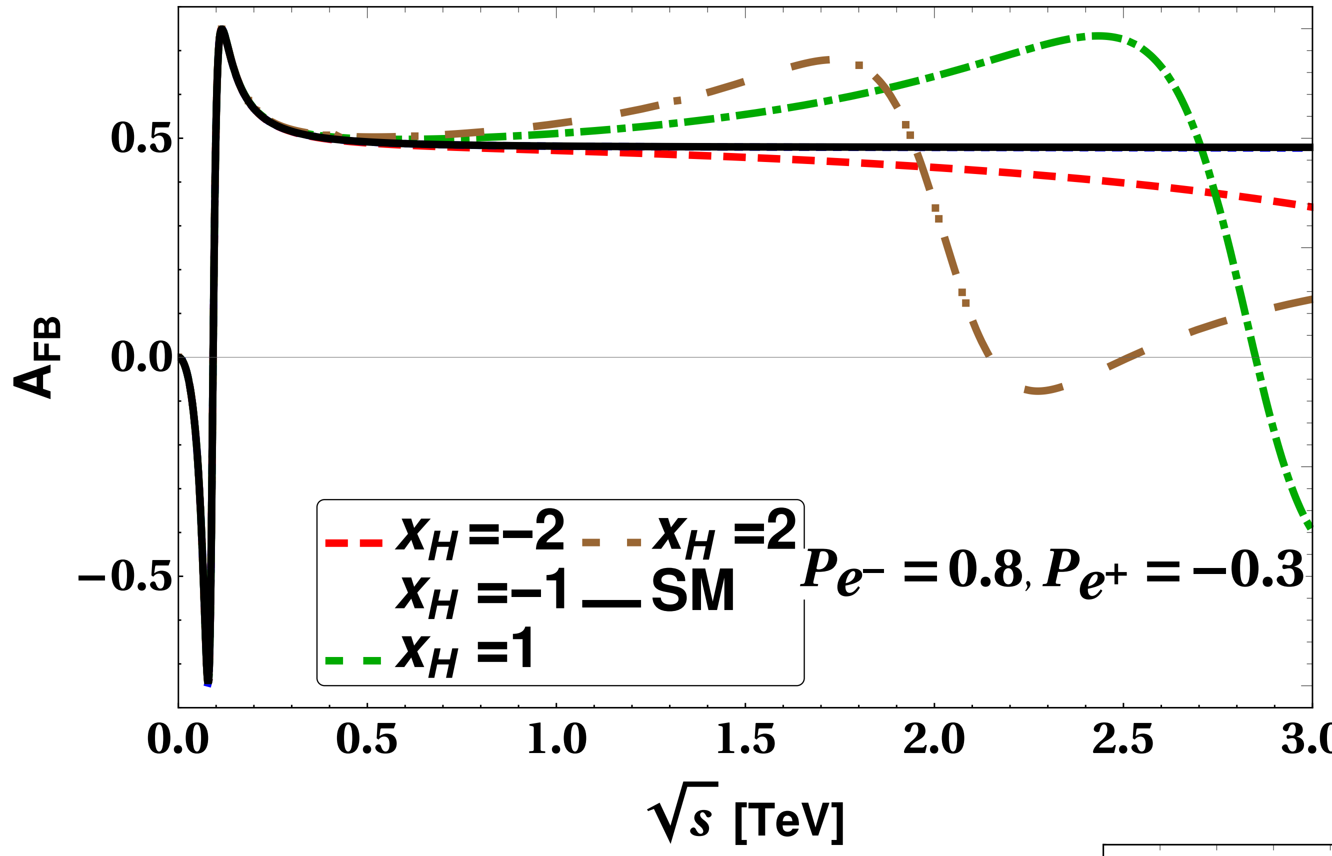
No contribution q_{RR}, q_{LR} in $b\bar{b}$

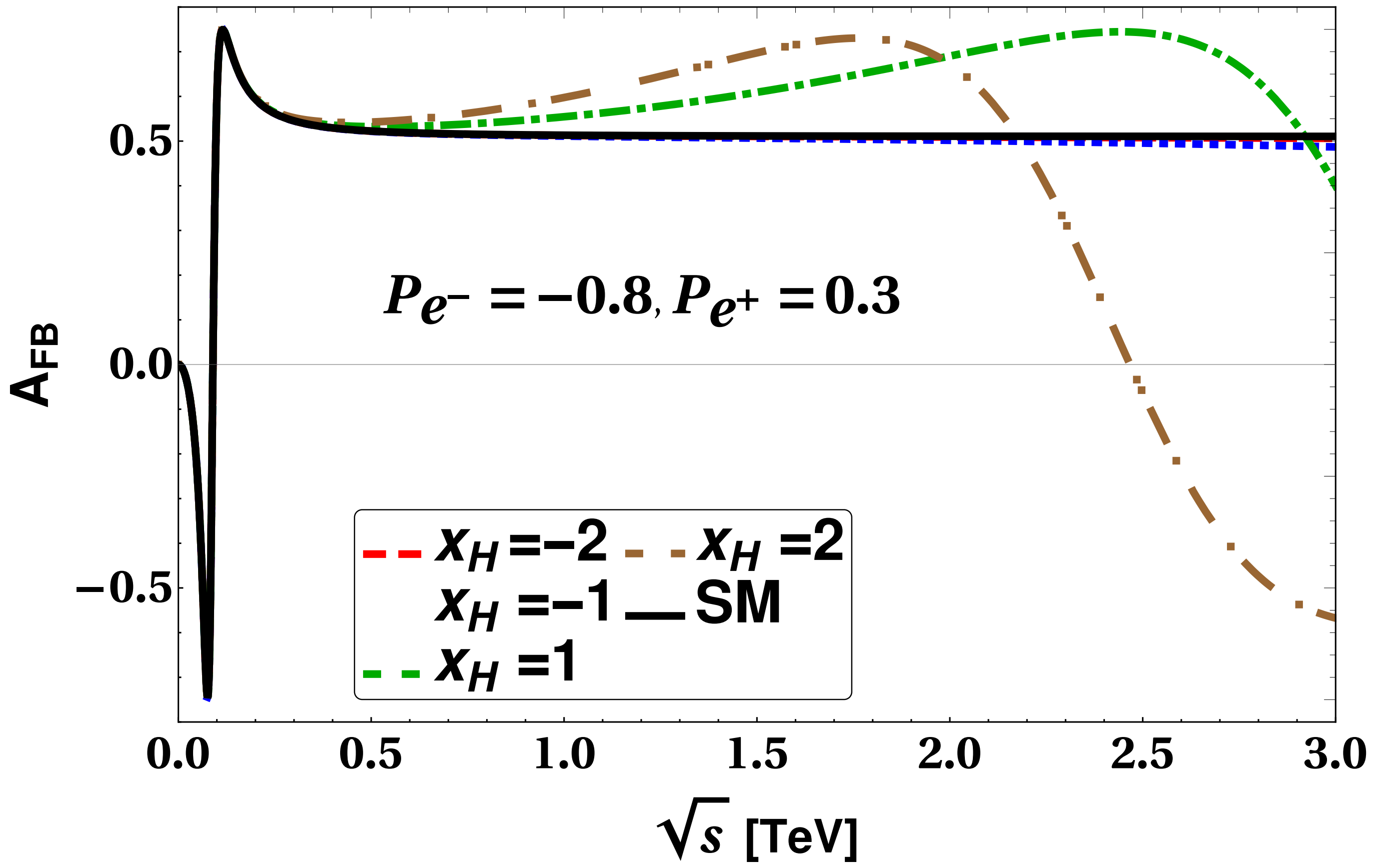


Integrated Forward – Backward Asymmetry ($e^-e^+ \to \mu^-\mu^+$) : $\mathscr{A}_{\rm FB}$

$M_{Z'} = 7.5$ TeV







Integrated

$$\mathcal{A}_{FB}(P_{e^-},P_{e^+}) = \frac{\sigma_F(P_{e^-},P_{e^+})-\sigma_B(P_{e^-},P_{e^+})}{\sigma_F(P_{e^-},P_{e^+})+\sigma_B(P_{e^-},P_{e^+})}$$

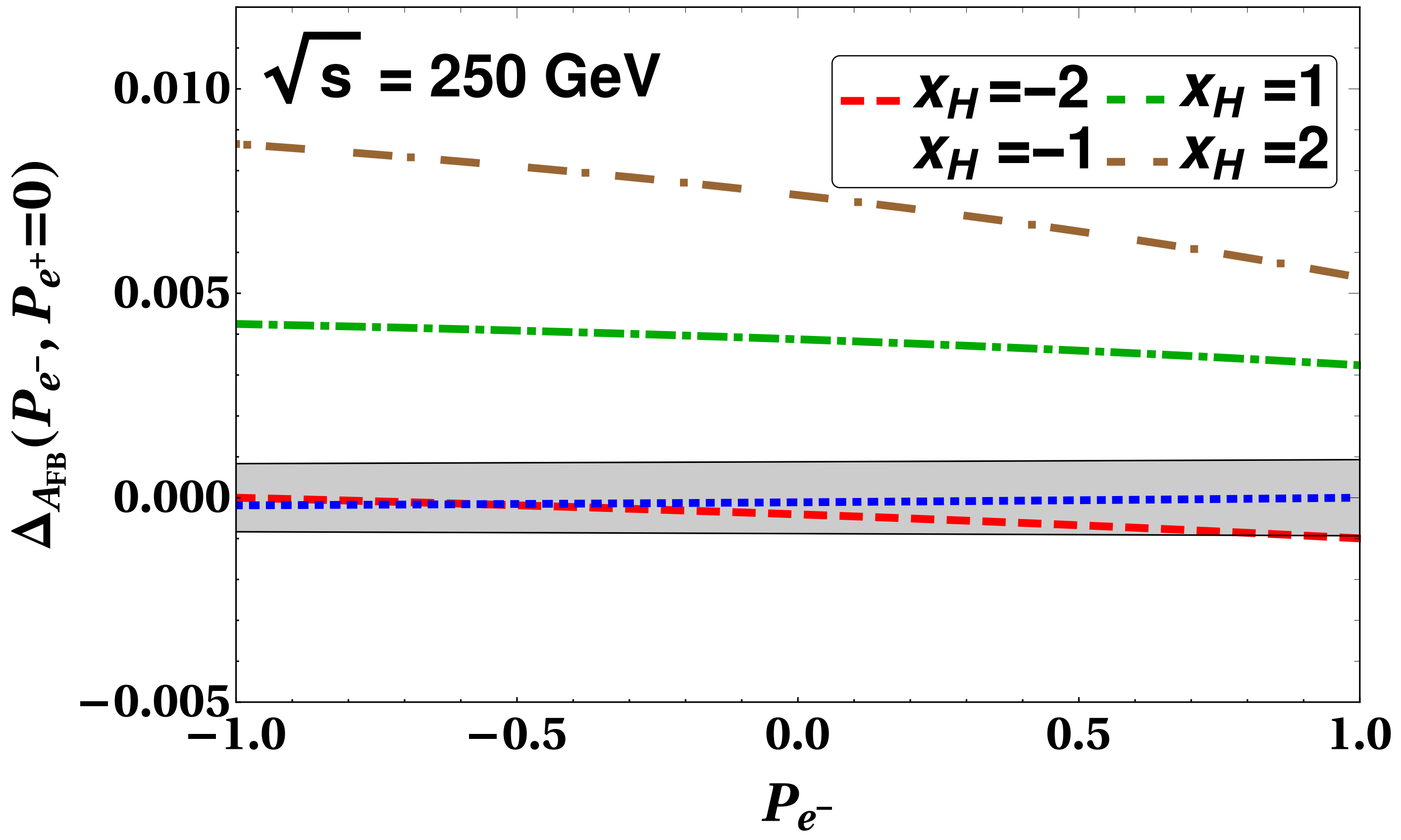
Deviation from the SM

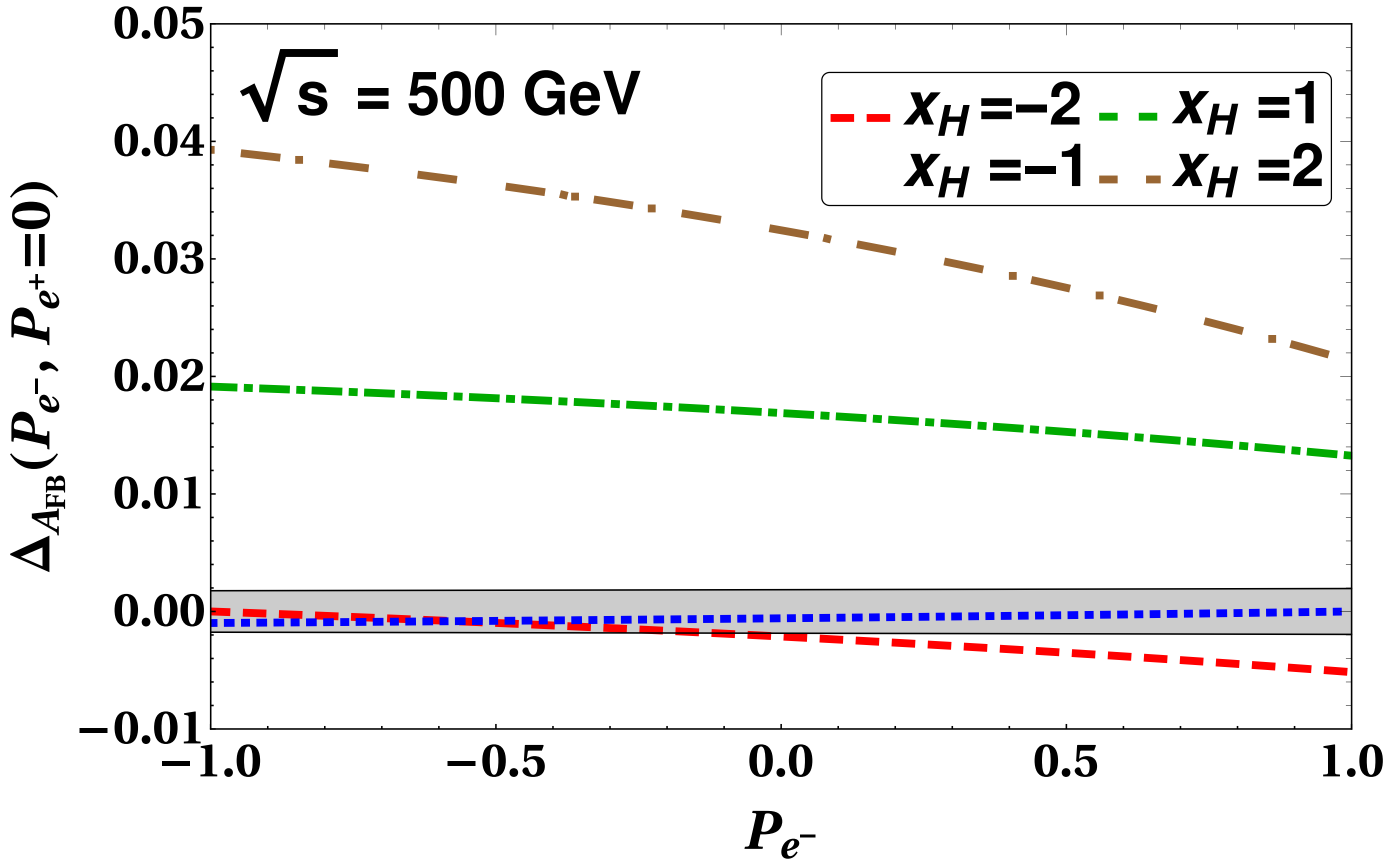
$$\Delta_{\mathcal{A}_{FB}} = \frac{\mathcal{A}_{\rm FB}^{U(1)_X}}{\mathcal{A}_{\rm FB}^{SM}} - 1.$$

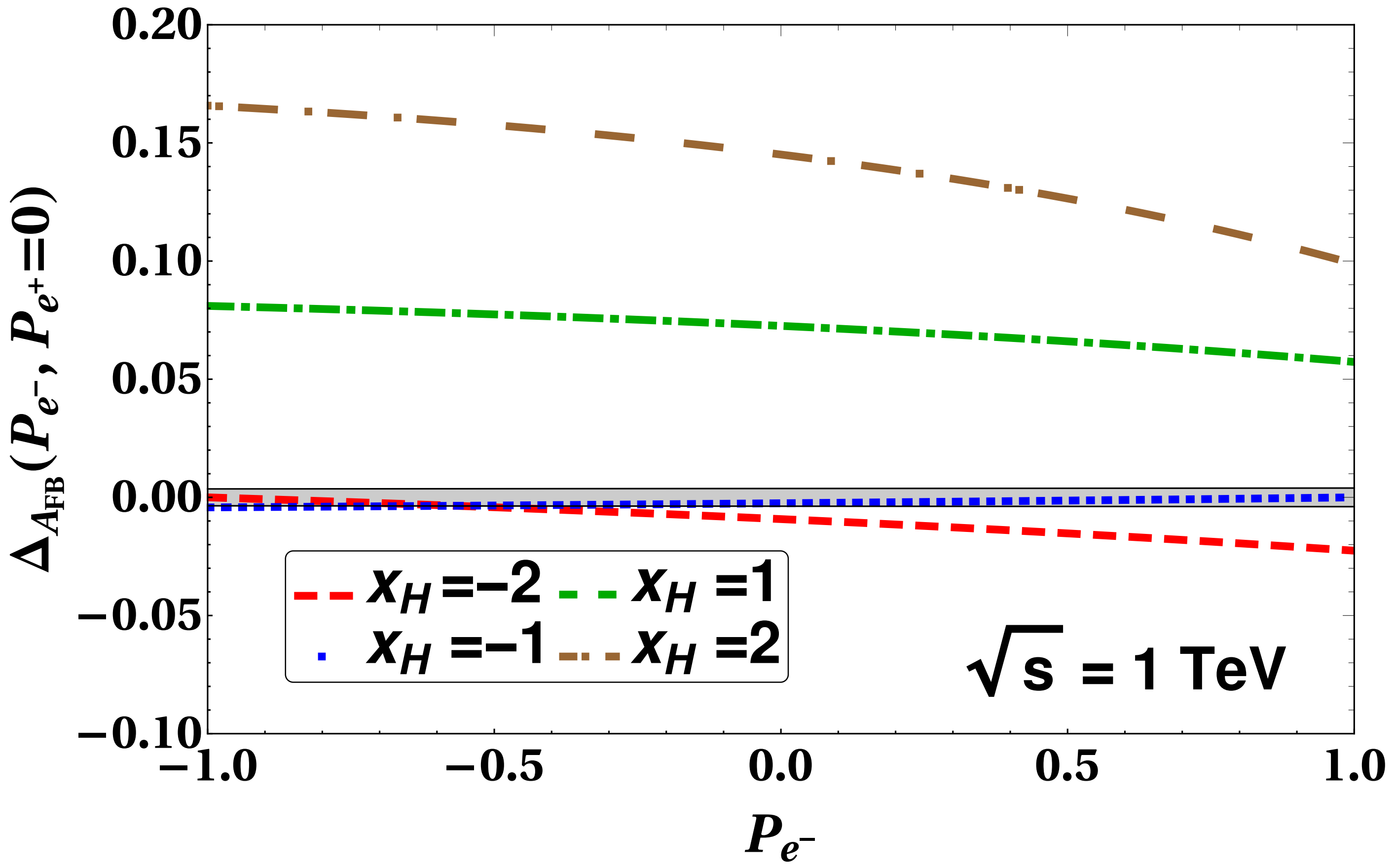
$x_H = 2$: 3.8 % for $P_{e^-} = -0.8$ at 500 GeV

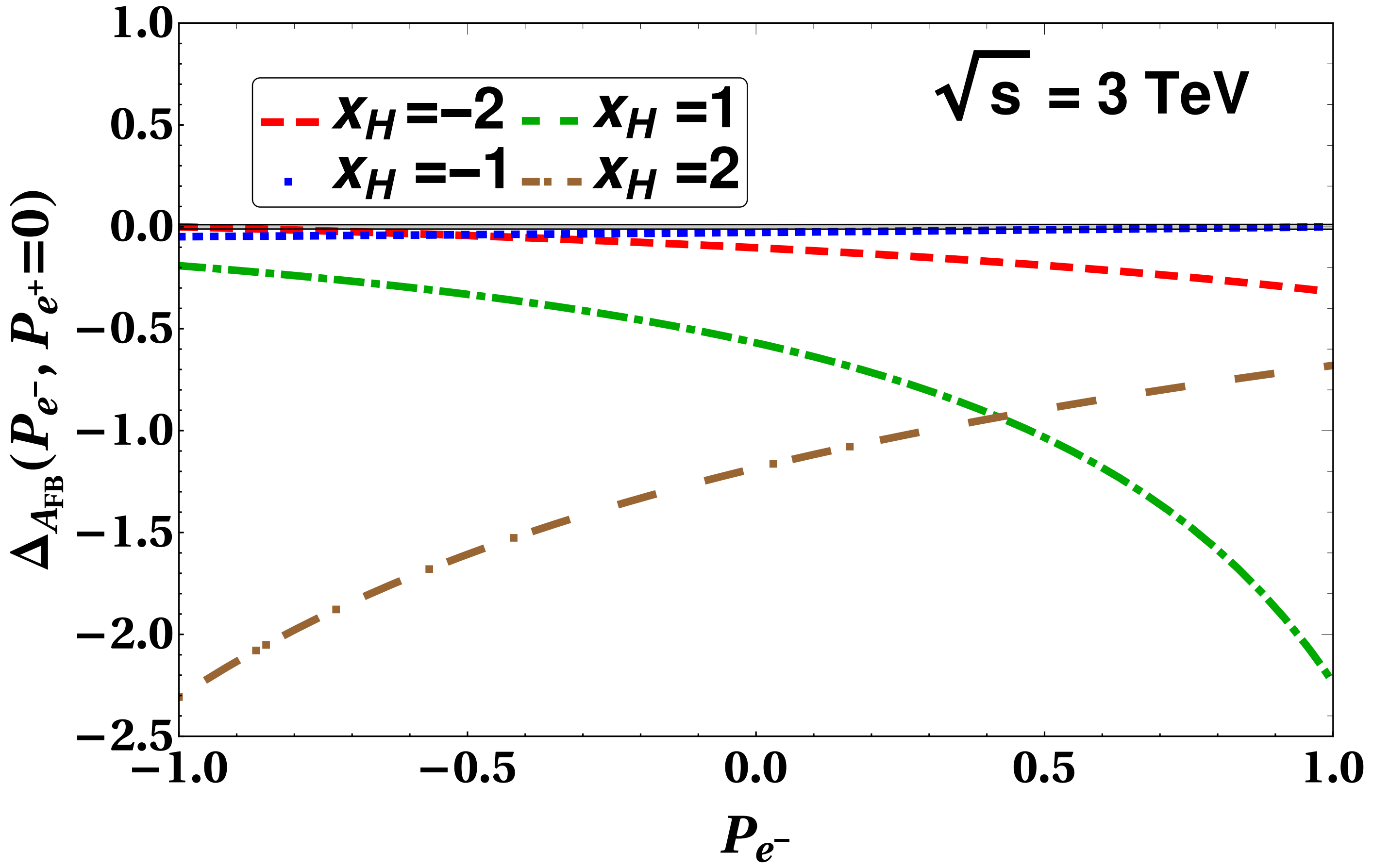
$x_H = 1$: 79 % for $P_{e^-} = -0.8$ at 1 TeV

$x_H = -1$: 20 % for $P_{e^-} = 0.3$ at 3 TeV







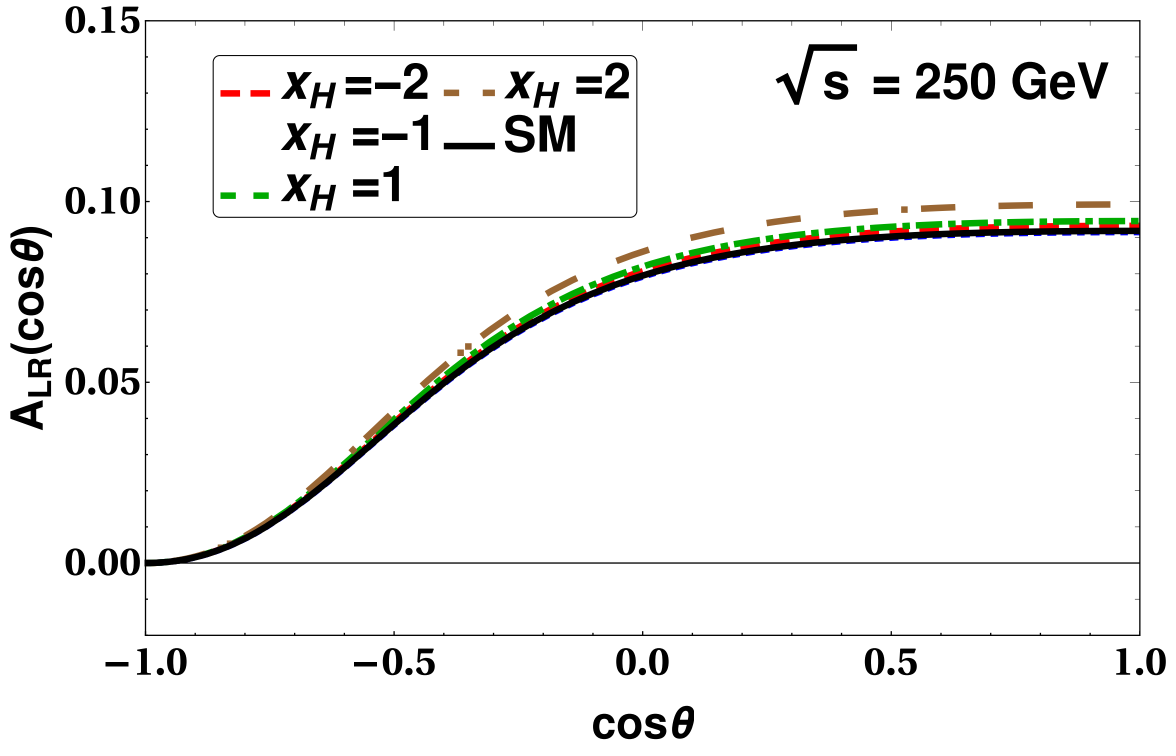


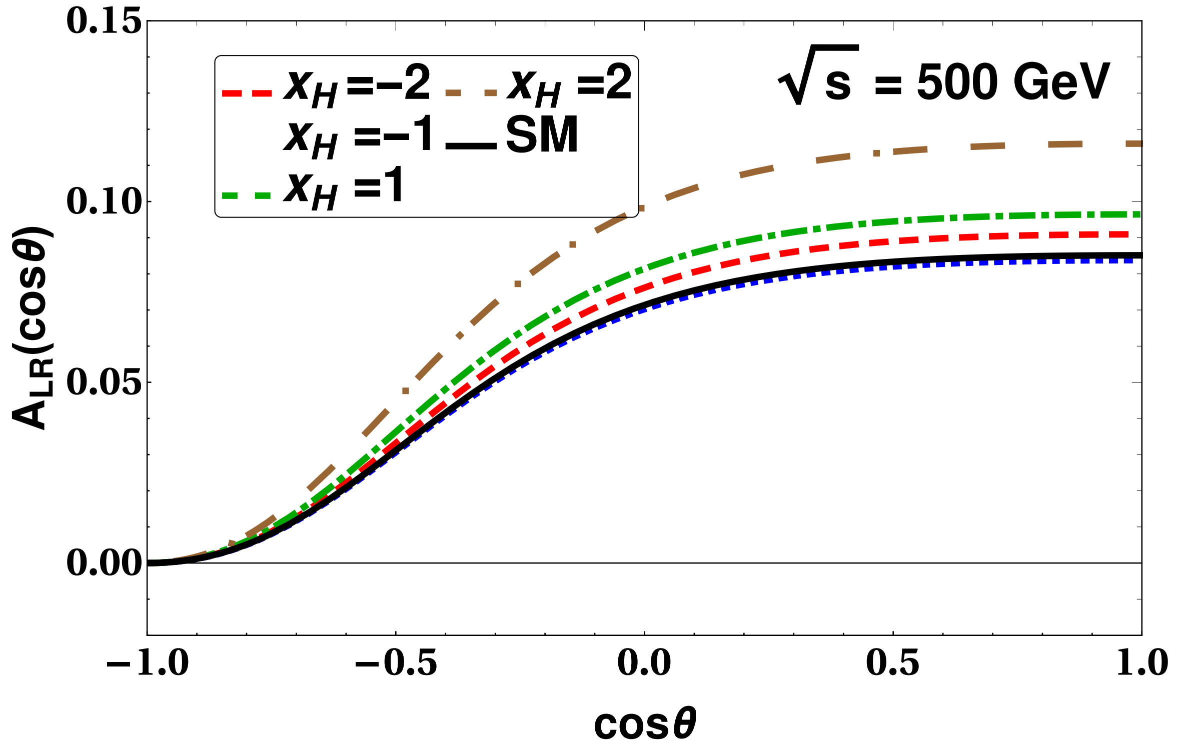
Statistical error

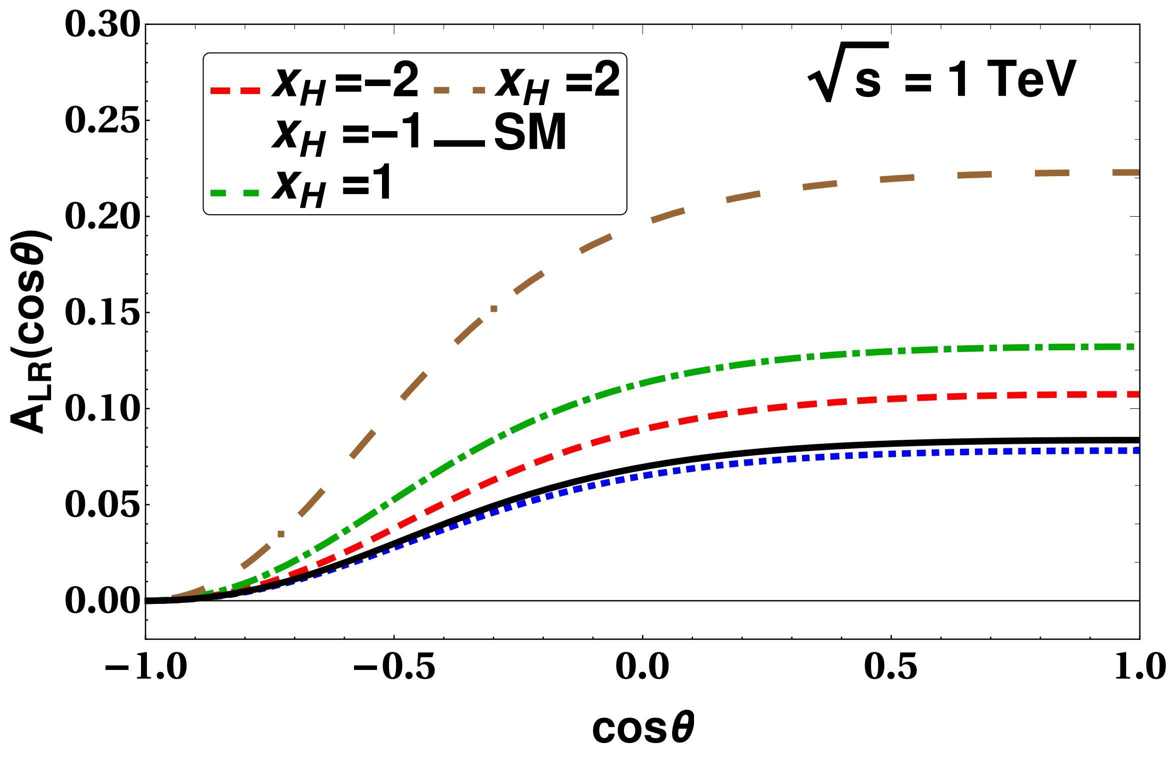
$$\Delta\mathcal{A}_{\rm FB} = 2\frac{\sqrt{n_1 n_2}\left(\sqrt{n_1}+\sqrt{n_2}\right)}{(n_1+n_2)^2} = \frac{2\sqrt{n_1 n_2}}{(n_1+n_2)\left(\sqrt{n_1}-\sqrt{n_2}\right)}\mathcal{A}_{FB}$$

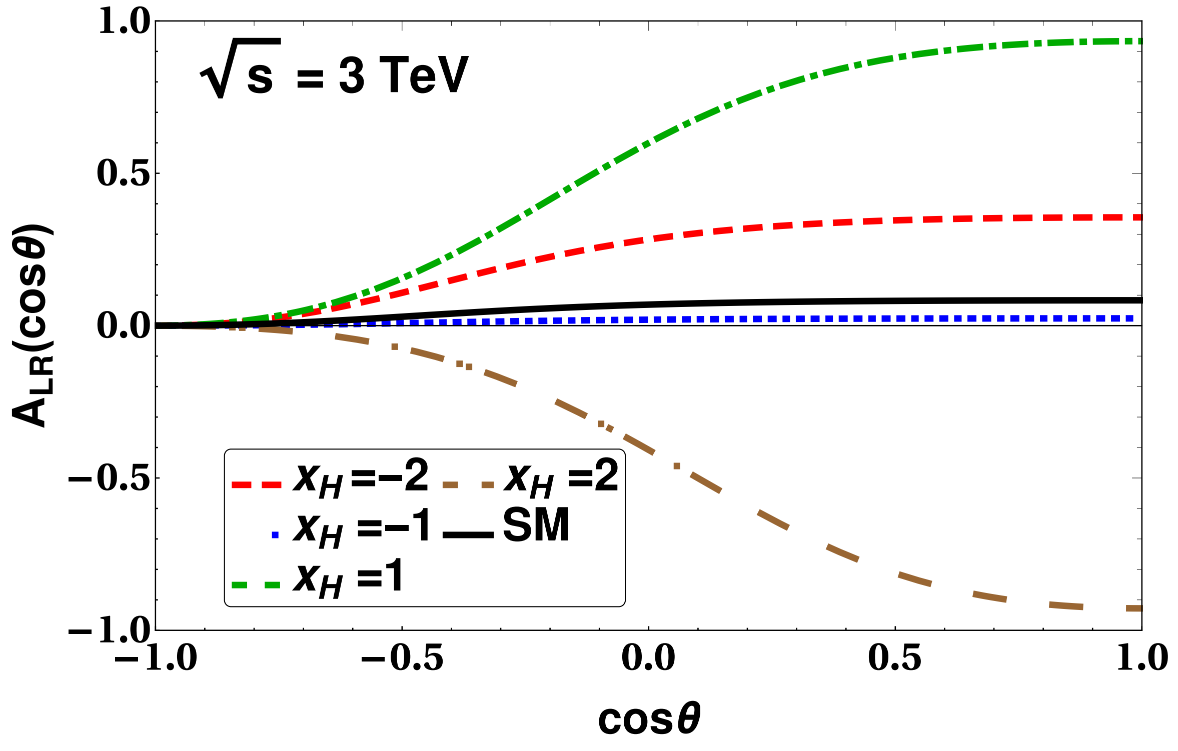
$$(n_1,n_2) = (N_F,N_B) \qquad N_{F(B)} = L_{\rm int}\sigma_{F(B)}(P_{e^-},P_{e^+})$$

Differenial and integarted Left – Right Asymmetry ($e^-e^+ \to \mu^-\mu^+$) : $\mathscr{A}_{\rm LR}$ $M_{Z'} = 7.5$ TeV









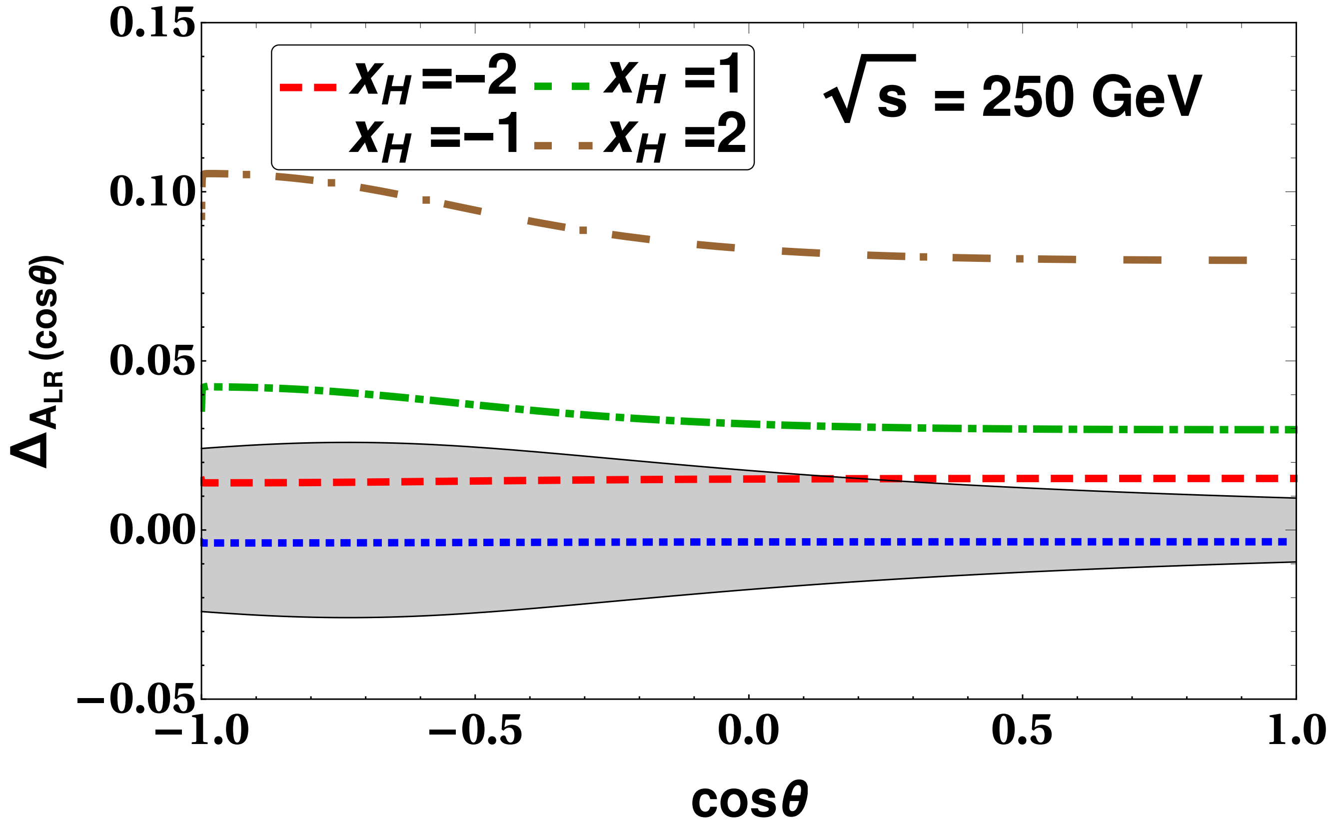
Differential

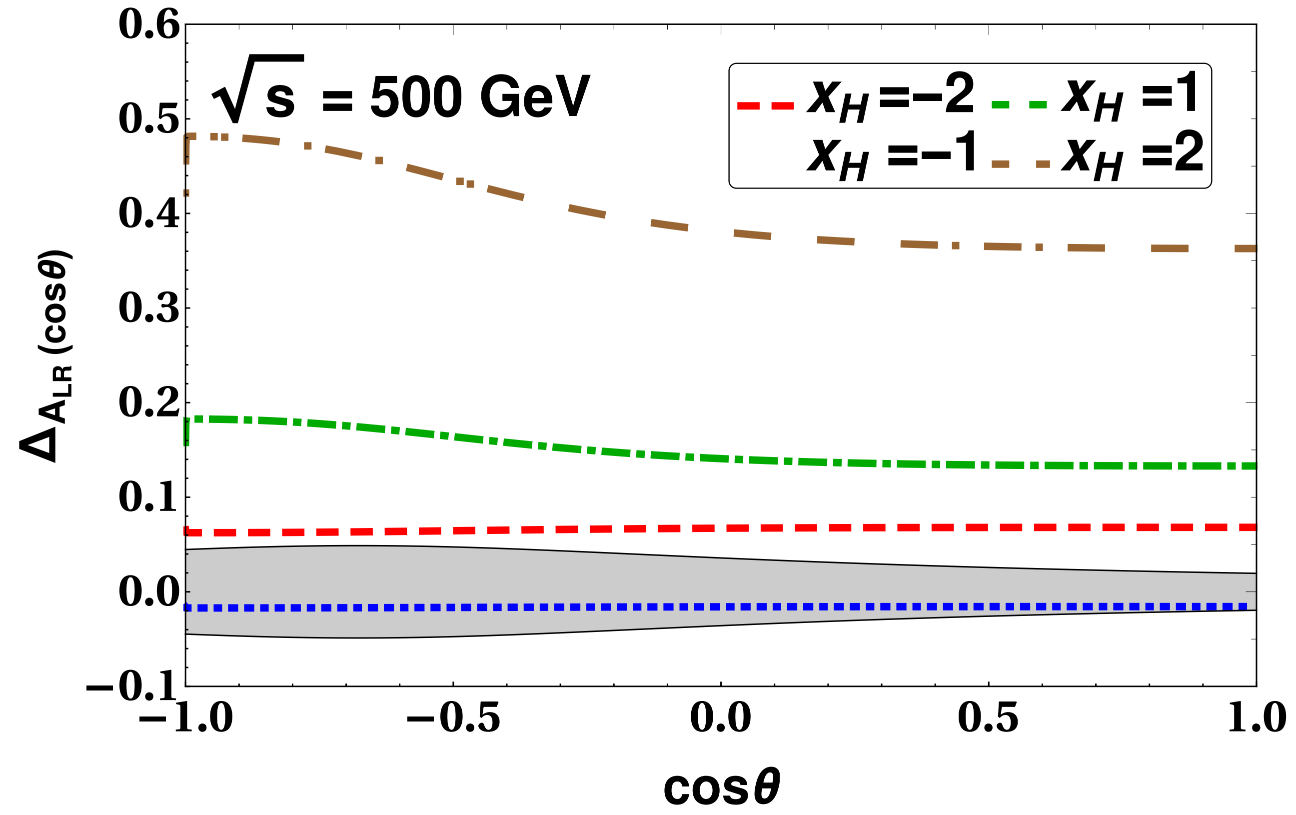
$$\mathcal{A}_{\rm LR}(\cos\theta) = \frac{\frac{d\sigma_{\rm LR}}{d\cos\theta}(\cos\theta) - \frac{d\sigma_{\rm RL}}{d\cos\theta}(\cos\theta)}{\frac{d\sigma_{\rm LR}}{d\cos\theta}(\cos\theta) + \frac{d\sigma_{\rm RL}}{d\cos\theta}(\cos\theta)}$$

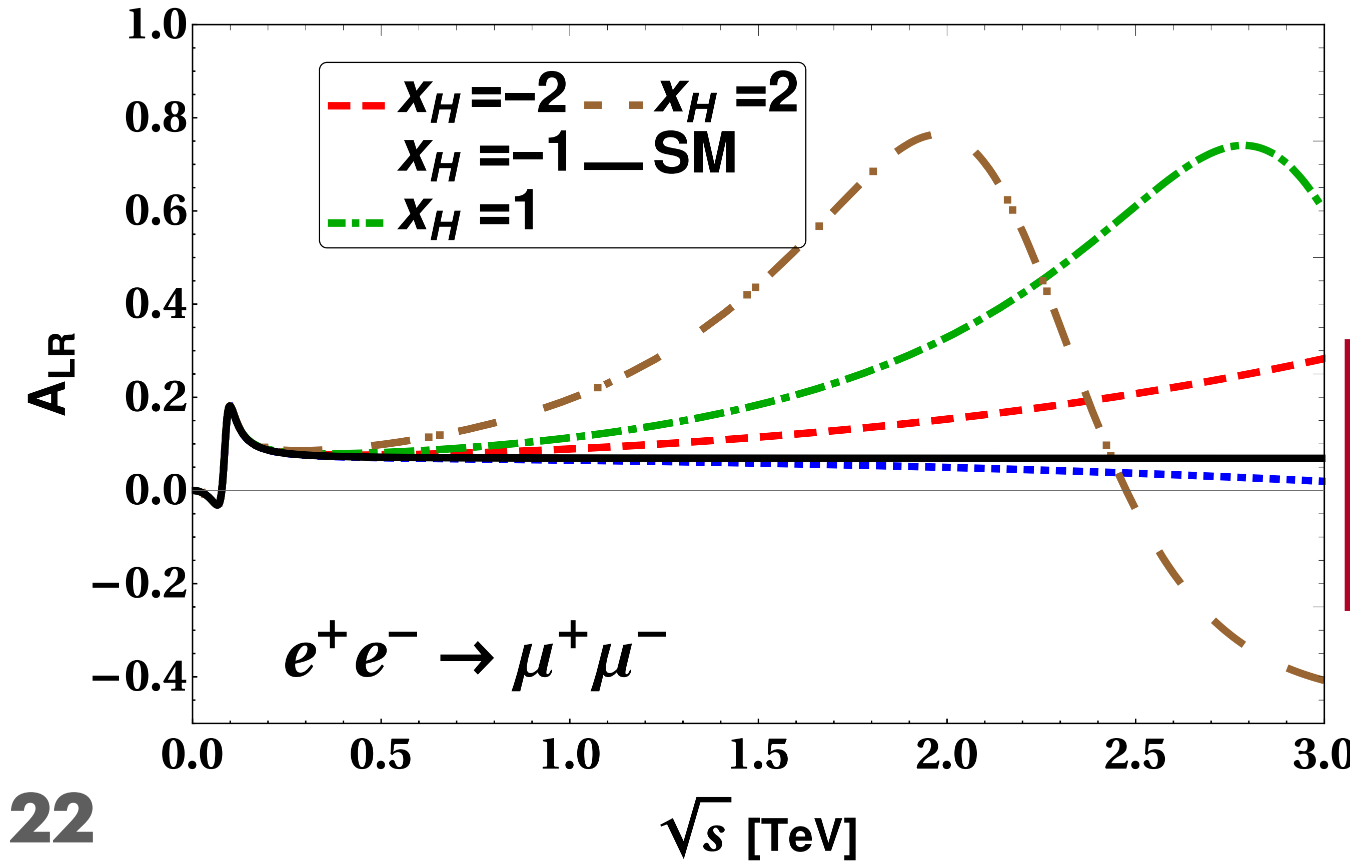
Deviation from the SM

$x_H = 2$: 10 % for at 250 GeV
$x_H = 1$: 20 % for at 500 GeV
$x_H = -2$: 8 % for at 500 GeV

$$\Delta_{\mathcal{A}_{LR}}(\cos\theta) = \frac{\mathcal{A}_{LR}^{U(1)_X}(\cos\theta)}{\mathcal{A}_{LR}^{\rm SM}(\cos\theta)} - 1$$

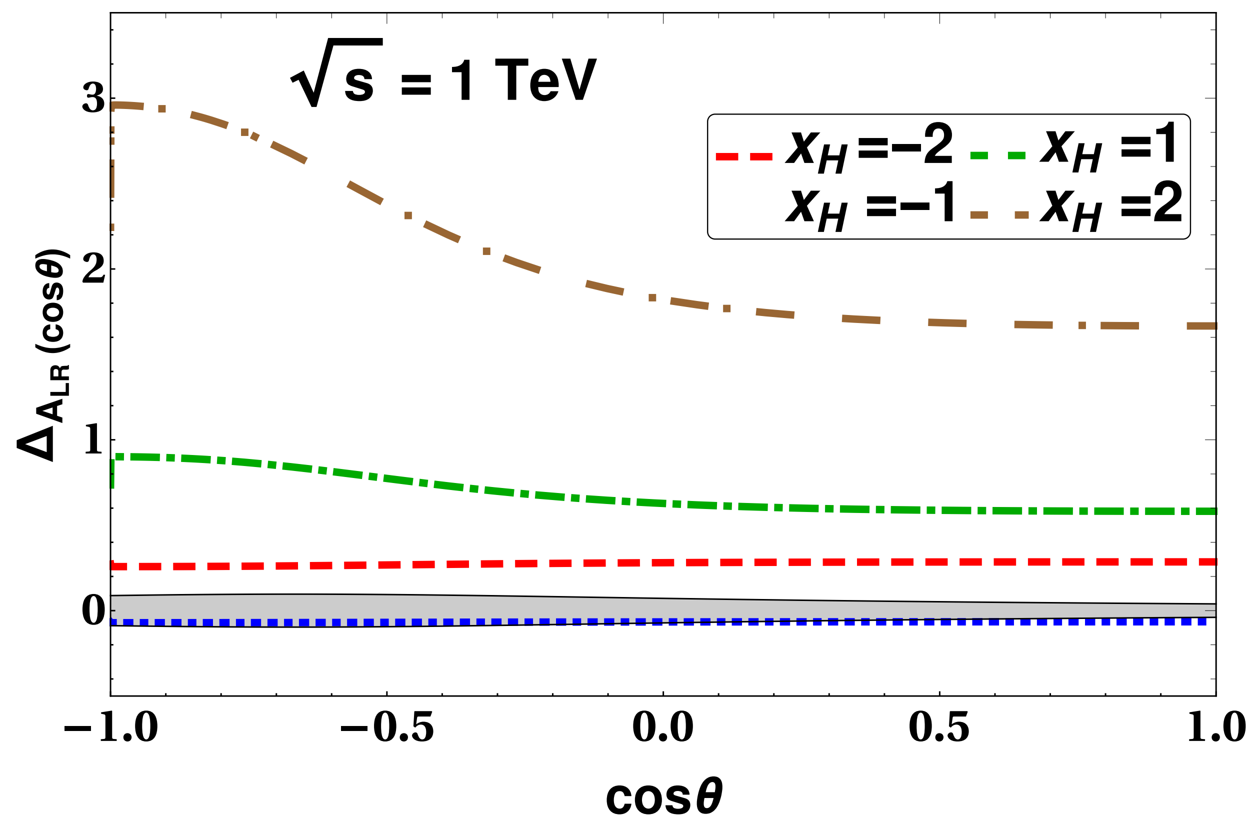


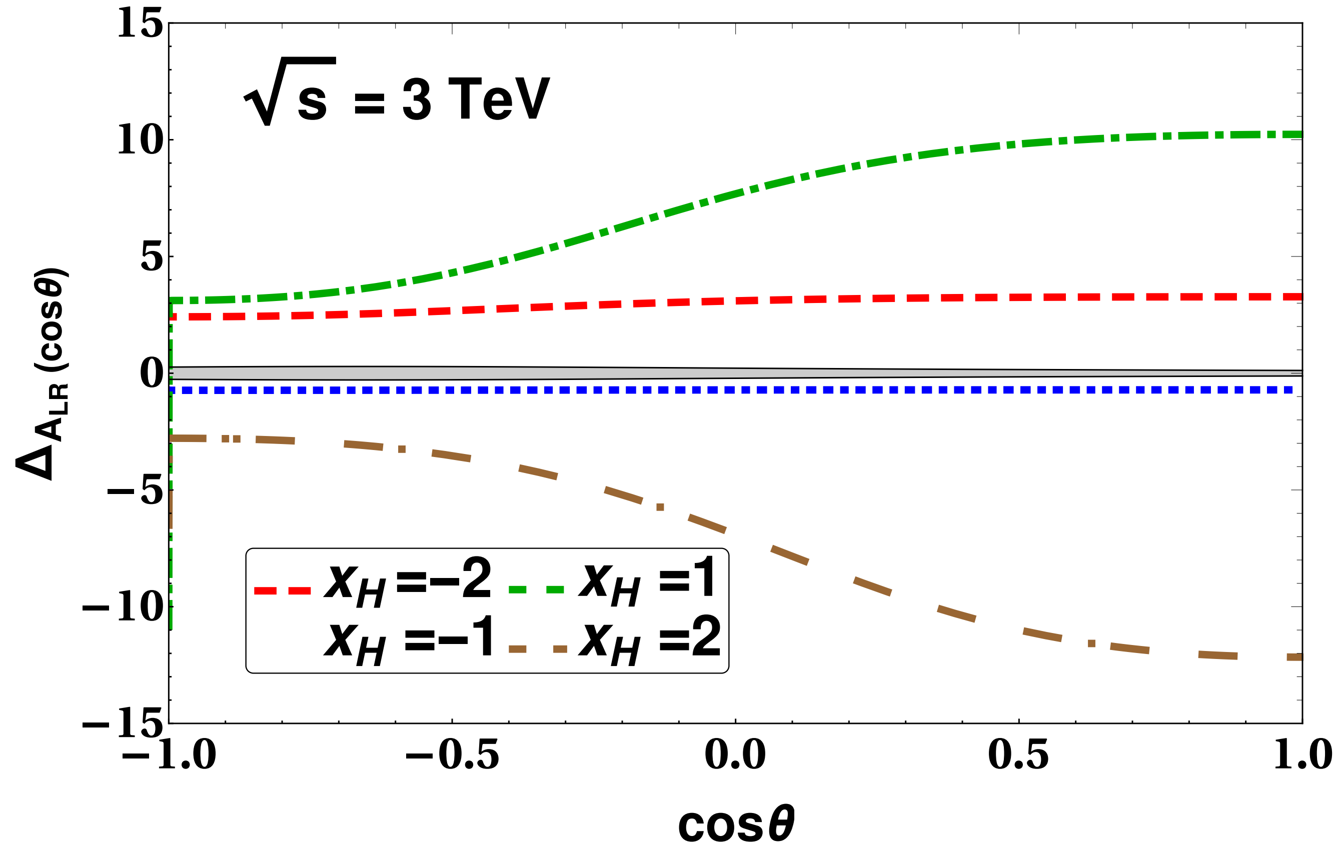




Integral

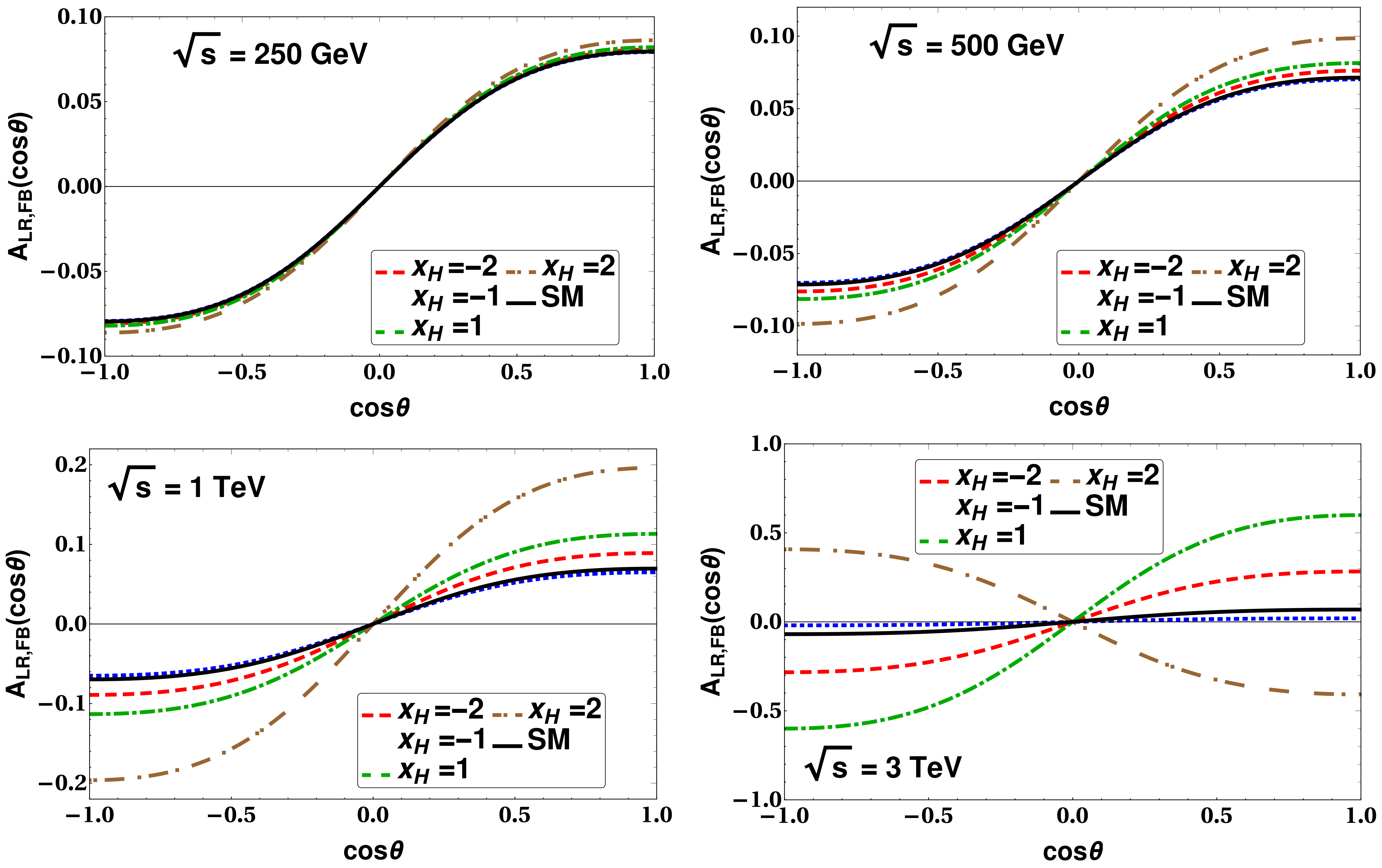
$$\mathcal{A}_{LR} = \frac{\sigma^{LR} - \sigma^{RL}}{\sigma^{LR} + \sigma^{RL}}.$$





Differential Left – Right, Forward – Backward Asymmetry ($e^-e^+ \to \mu^-\mu^+$) : $\mathscr{A}_{\mathrm{LR,\,FB}}$

$M_{Z'} = 7.5$ TeV



Differential

$$\mathcal{A}_{LR,FB}(\cos\theta) = \frac{[\sigma_{\mathrm{LR}}(\cos\theta) - \sigma_{\mathrm{RL}}(\cos\theta)] - [\sigma_{\mathrm{LR}}(-\cos\theta) - \sigma_{\mathrm{RL}}(-\cos\theta)]}{[\sigma_{\mathrm{LR}}(\cos\theta) + \sigma_{\mathrm{RL}}(\cos\theta)] + [\sigma_{\mathrm{LR}}(-\cos\theta) + \sigma_{\mathrm{RL}}(-\cos\theta)]}$$

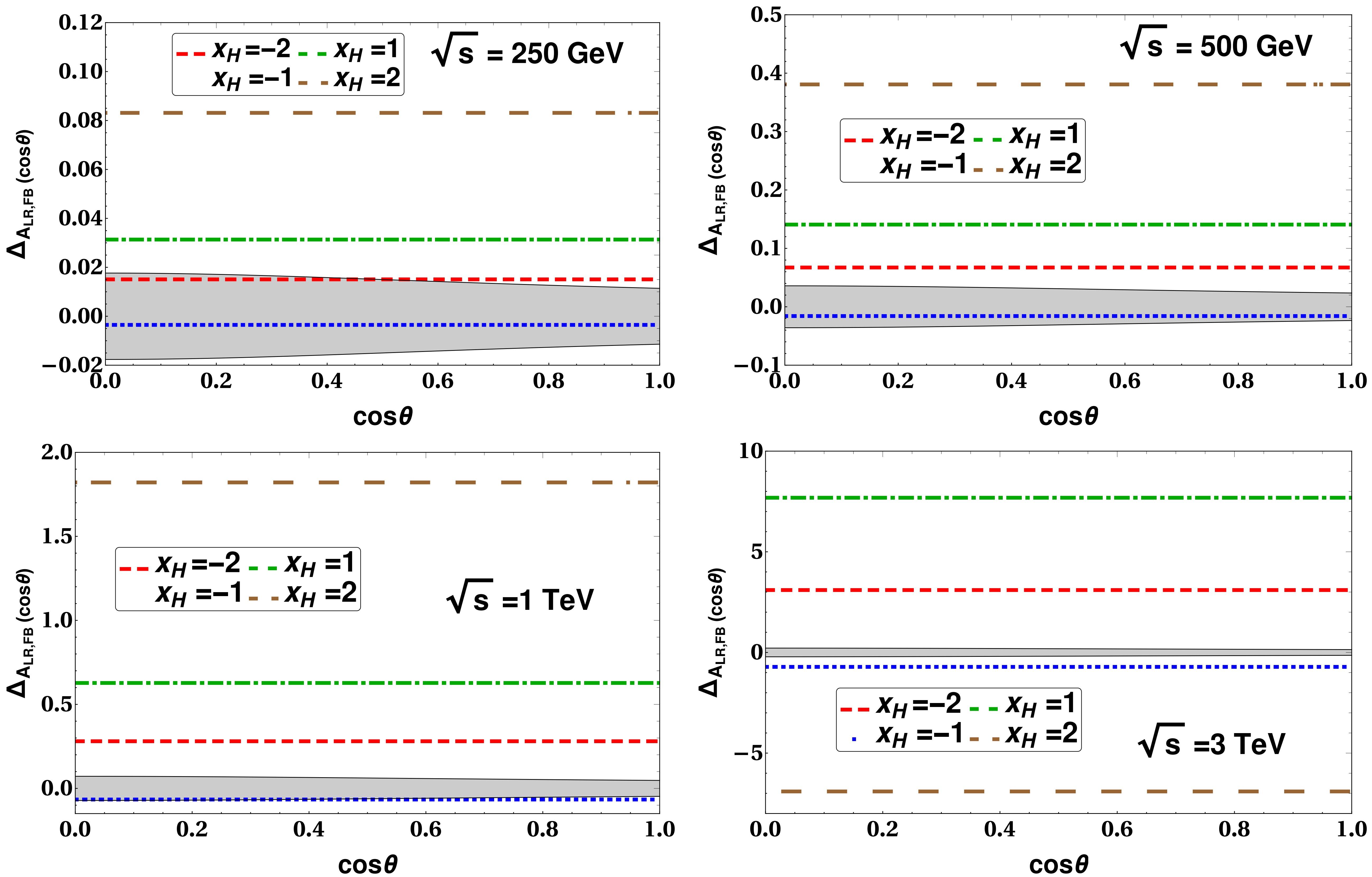
Deviation from the SM

$$\Delta_{\mathcal{A}_{LR,FB}}(\cos\theta) = \frac{\mathcal{A}_{LR,FB}{}^{\mathrm{U(1)_X}}(\cos\theta)}{\mathcal{A}_{LR,FB}{}^{\mathrm{SM}}(\cos\theta)} - 1$$

$x_H = 2 : 8.2\,\%$ for at 250 GeV

$x_H = 1 : 15\,\%$ for at 500 GeV

$x_H = -2 : 7.5\,\%$ for at 500 GeV

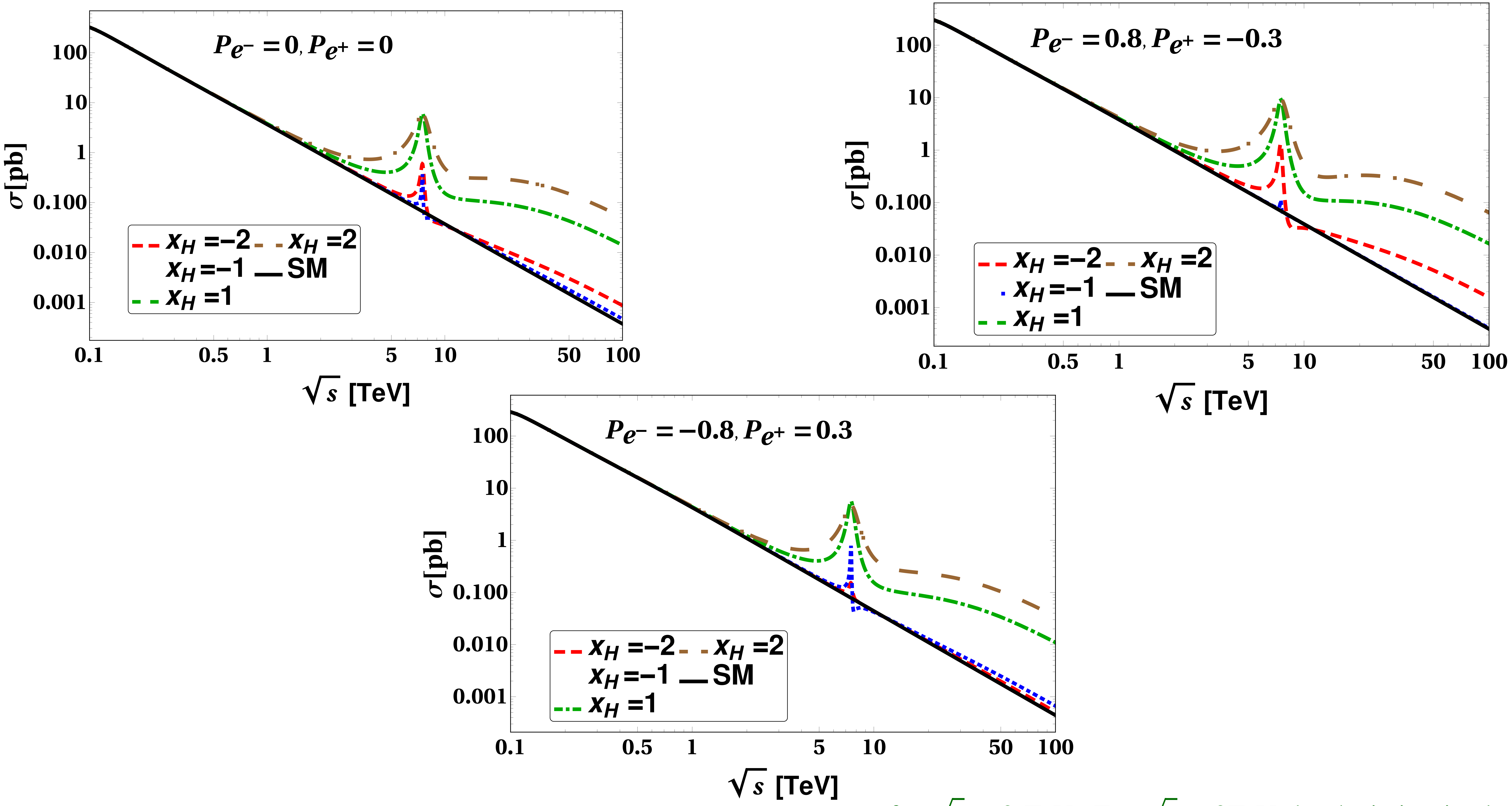


Statistical error

$$\Delta\mathcal{A}_{LR,FB} = 2\frac{(n_3+n_2)\left(\sqrt{n_1}+\sqrt{n_4}\right) + (n_1+n_4)\left(\sqrt{n_3}+\sqrt{n_2}\right)}{(n_1+n_4)^2 - (n_3+n_2)^2} A_{LR,FB}$$

Bhabha scattering

$e^-e^+ \to e^+e^-$



 Deviations in total cross sections from SM is more than 100 % for $x_H \geq 1$ for $\sqrt{s} = 3$ TeV . For $\sqrt{s} < 3$TeV the deviation is also sizable .

Bhabha scattering

$$q_s(s)^{\rm LL} = \frac{e^2}{s} + \frac{g_L^2}{s - M_Z^2 + iM_Z\Gamma_Z} + \frac{g_L'^2}{s - M_{Z'}^2 + iM_{Z'}\Gamma_{Z'}}$$

$$q_s(s)^{\rm RR} = \frac{e^2}{s} + \frac{g_R^2}{s - M_Z^2 + iM_Z\Gamma_Z} + \frac{g_R'^2}{s - M_{Z'}^2 + iM_{Z'}\Gamma_{Z'}}$$

$$q_s(s)^{\rm LR} = q_s(s)^{\rm RL} = \frac{e^2}{s} + \frac{g_L g_R}{s - M_Z^2 + iM_Z\Gamma_Z} + \frac{g_L' g_R'}{s - M_{Z'}^2 + iM_{Z'}\Gamma_{Z'}}$$

$s -$ channel

$$q_t(s,\theta)^{\rm LL} = \frac{e^2}{t} + \frac{g_L^2}{t - M_Z^2 + iM_Z\Gamma_Z} + \frac{g_L'^2}{t - M_{Z'}^2 + iM_{Z'}\Gamma_{Z'}}$$

$$q_t(s,\theta)^{\rm RR} = \frac{e^2}{t} + \frac{g_R^2}{t - M_Z^2 + iM_Z\Gamma_Z} + \frac{g_R'^2}{t - M_{Z'}^2 + iM_{Z'}\Gamma_{Z'}}$$

$$q_t(s,\theta)^{\rm LR} = q_t(s,\theta)^{\rm RL} = \frac{e^2}{t} + \frac{g_L g_R}{t - M_Z^2 + iM_Z\Gamma_Z} + \frac{g_L' g_R'}{t - M_{Z'}^2 + iM_{Z'}\Gamma_{Z'}}$$

$t -$ channel

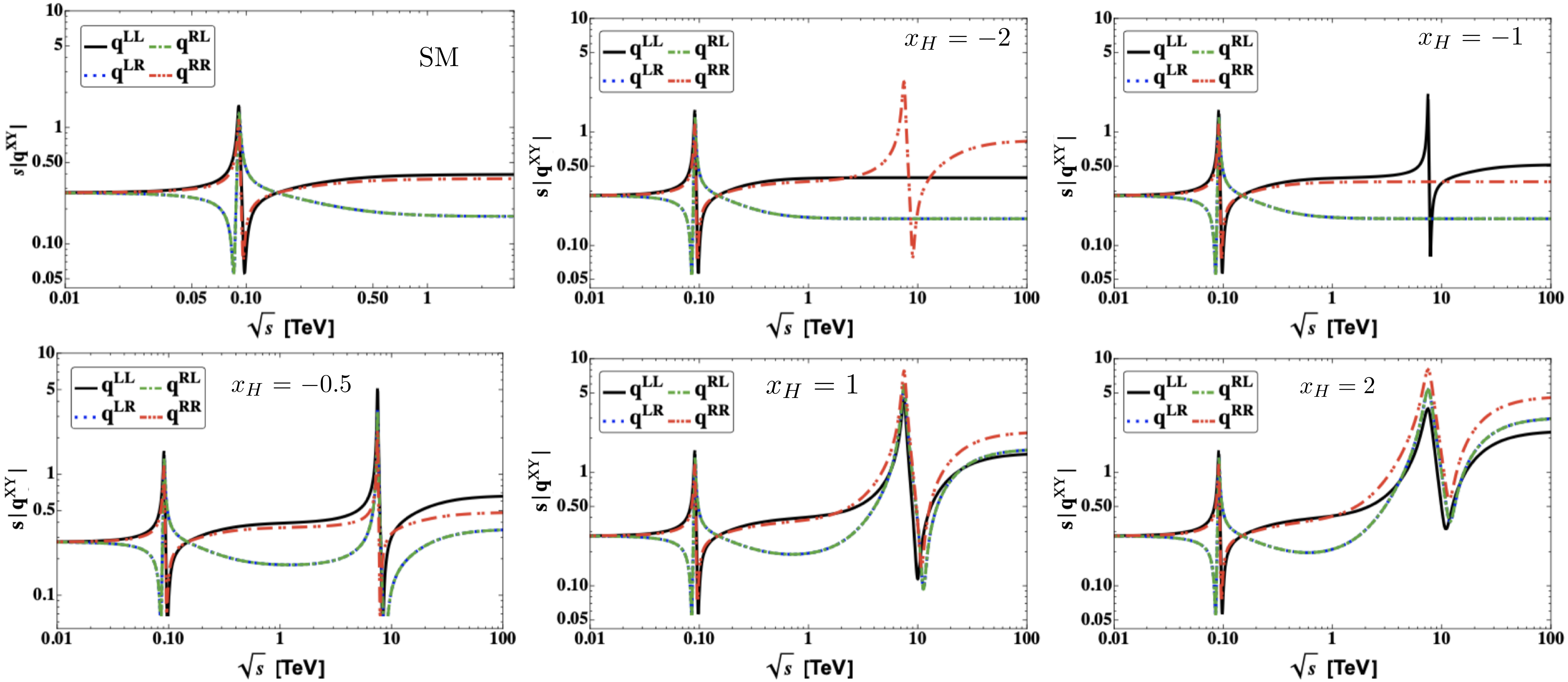
$$s|q^{\rm LL}| = s|q_s(s)^{\rm LL} + q_t(s,\theta)^{\rm LL}|$$

$$s|q^{\rm LR}| = s|q_s(s)^{\rm LR} + q_t(s,\theta)^{\rm LR}|$$

$$s|q^{\rm RL}| = s|q_s(s)^{\rm RL} + q_t(s,\theta)^{\rm RL}|$$

$$s|q^{\rm RR}| = s|q_s(s)^{\rm RR} + q_t(s,\theta)^{\rm RR}|$$

combined



Deviation in differential scattering cross section

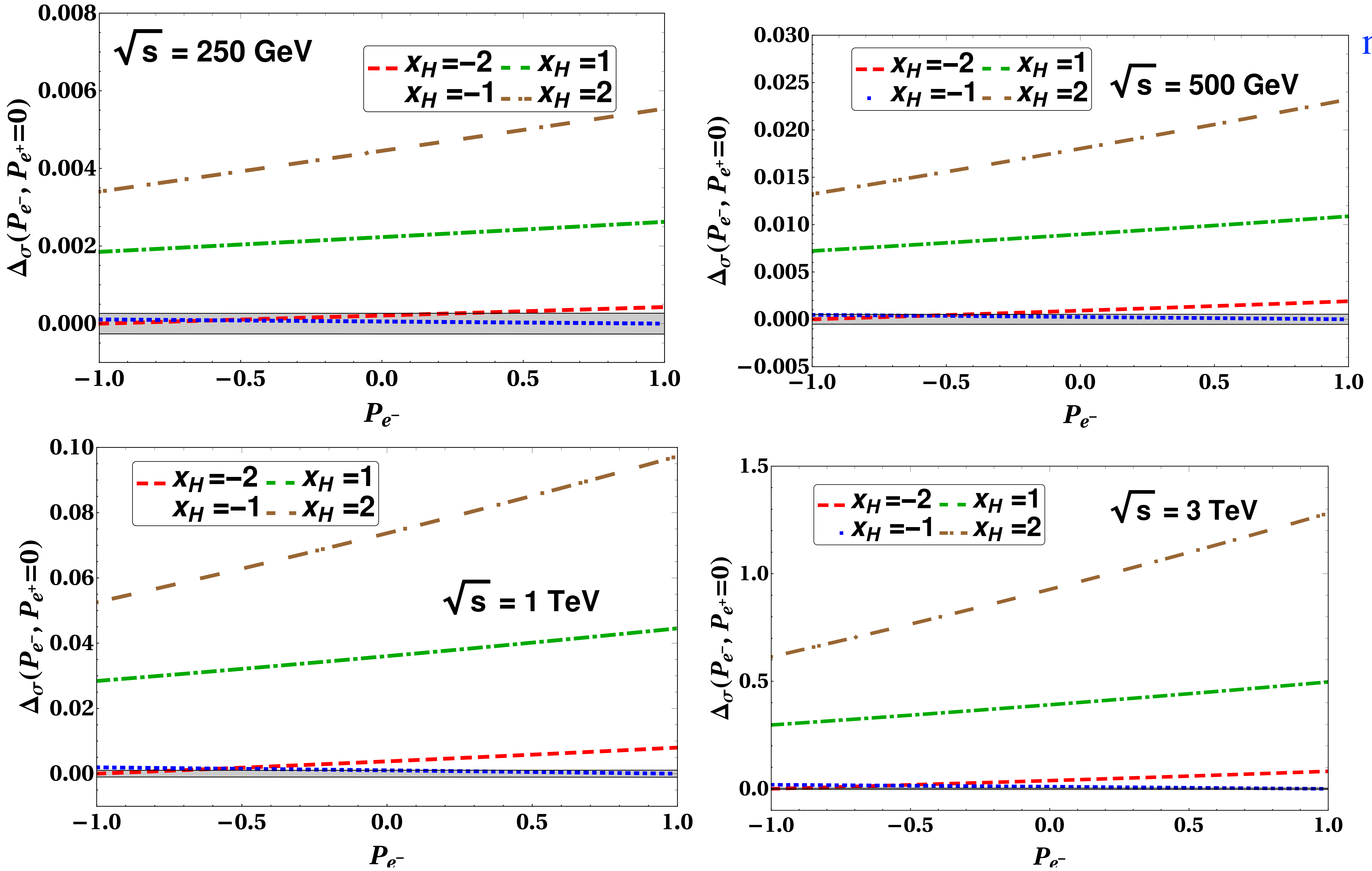
$M'_Z = 7.5$ TeV

maximum deviation 0.6 %

maximum deviation 2.3 %

maximum deviation 10 %

> 100 %



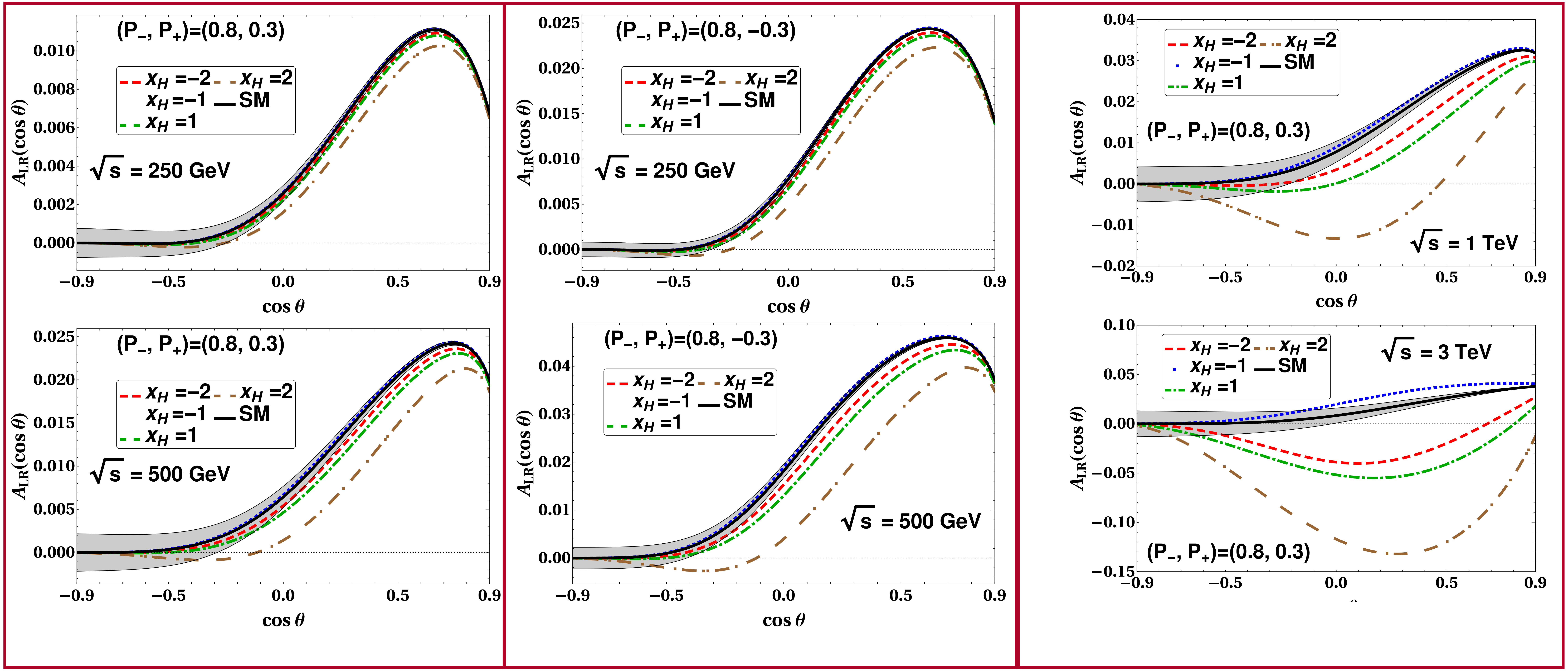
Differential LR asymmetry

$M'_Z = 7.5$ TeV

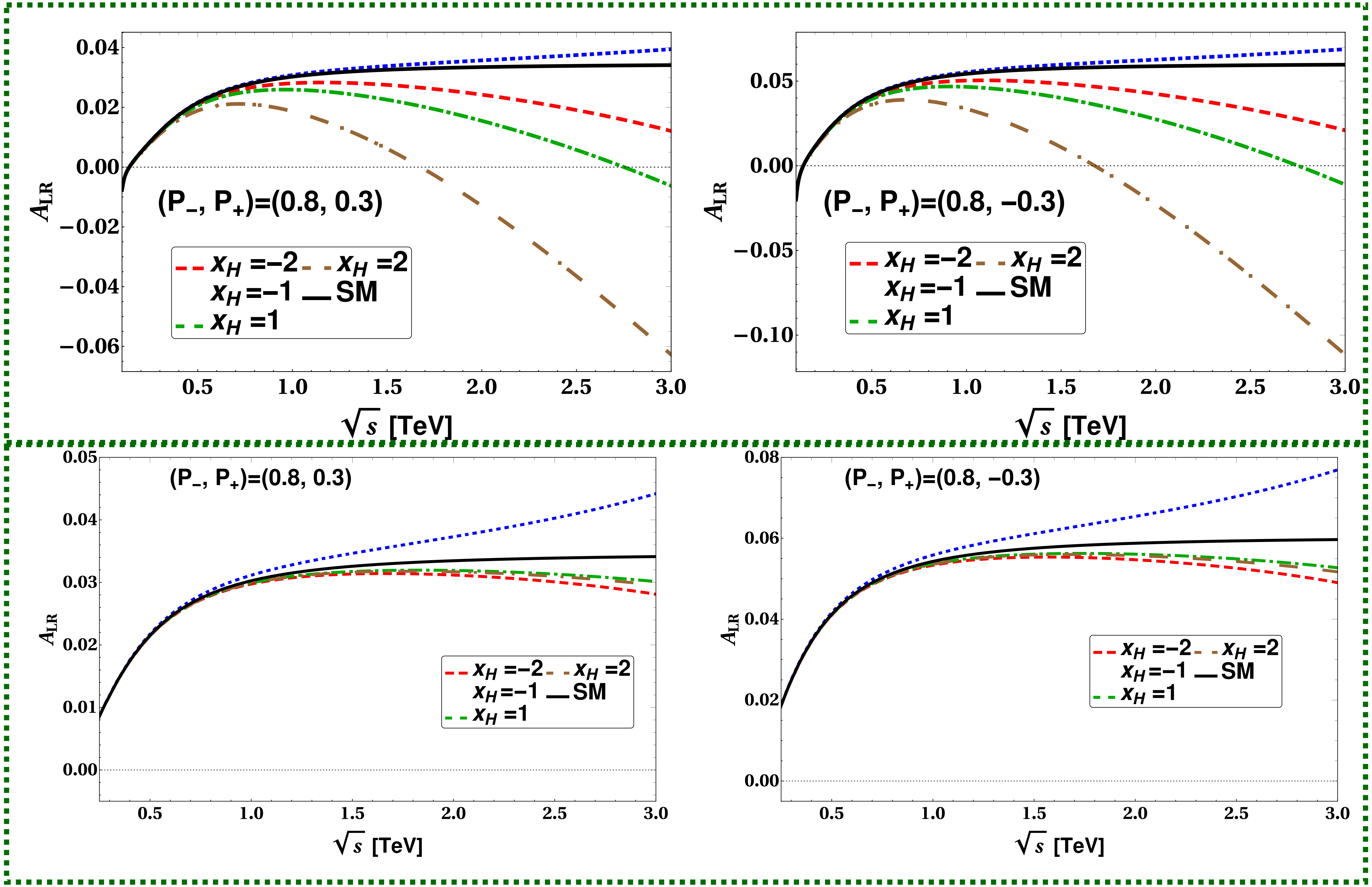
maximum deviation $1 - 2\,\%$ — $\sqrt{s} = 250$ GeV

maximum deviation $2.3 - 4.3\,\%$ — $\sqrt{s} = 500$ GeV

maximum deviation $12 - 13\,\%$ — $\sqrt{s} = 1$ TeV



Integrated LR asymmetry



$M_{Z'} = 7.5$ TeV

$M_{Z'} = 5$ TeV

The choices of x_H enhance the discovery potential

Conclusions :

We are looking for a scenario where which can explain a variety of beyond the SM sceanrios .

The proposal for the generation of the tiny neutrino mass, from the seesaw mechanism, under investigation at the energy frontier .

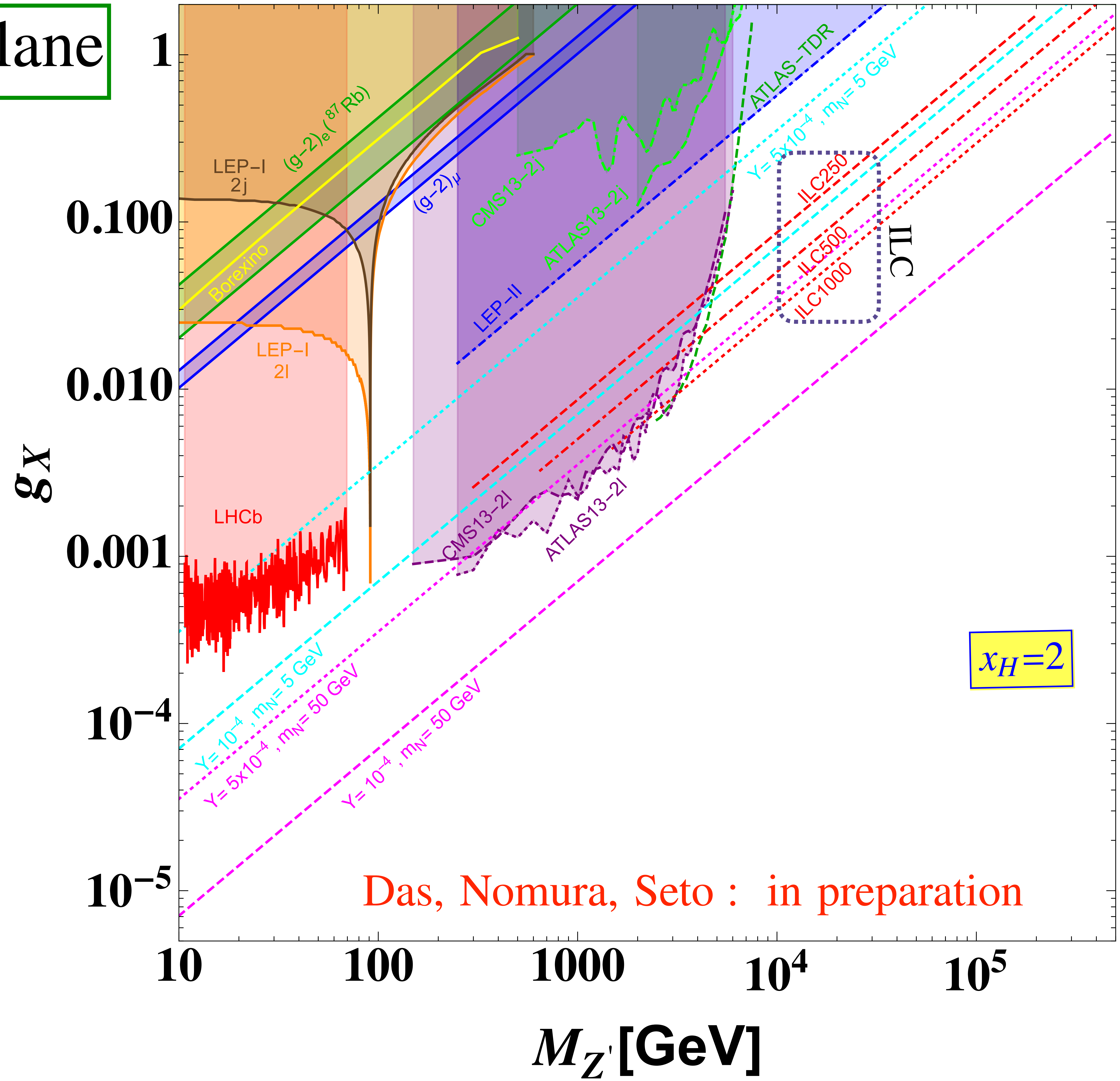
We study $\mathscr{A}_{\rm FB}$, $\mathscr{A}_{\rm LR}$, $\mathscr{A}_{\rm LR,\,FB}$. The asymmetries are sizable at the 250 GeV and 500 GeV e^-e^+ colliders or higher in the near future .

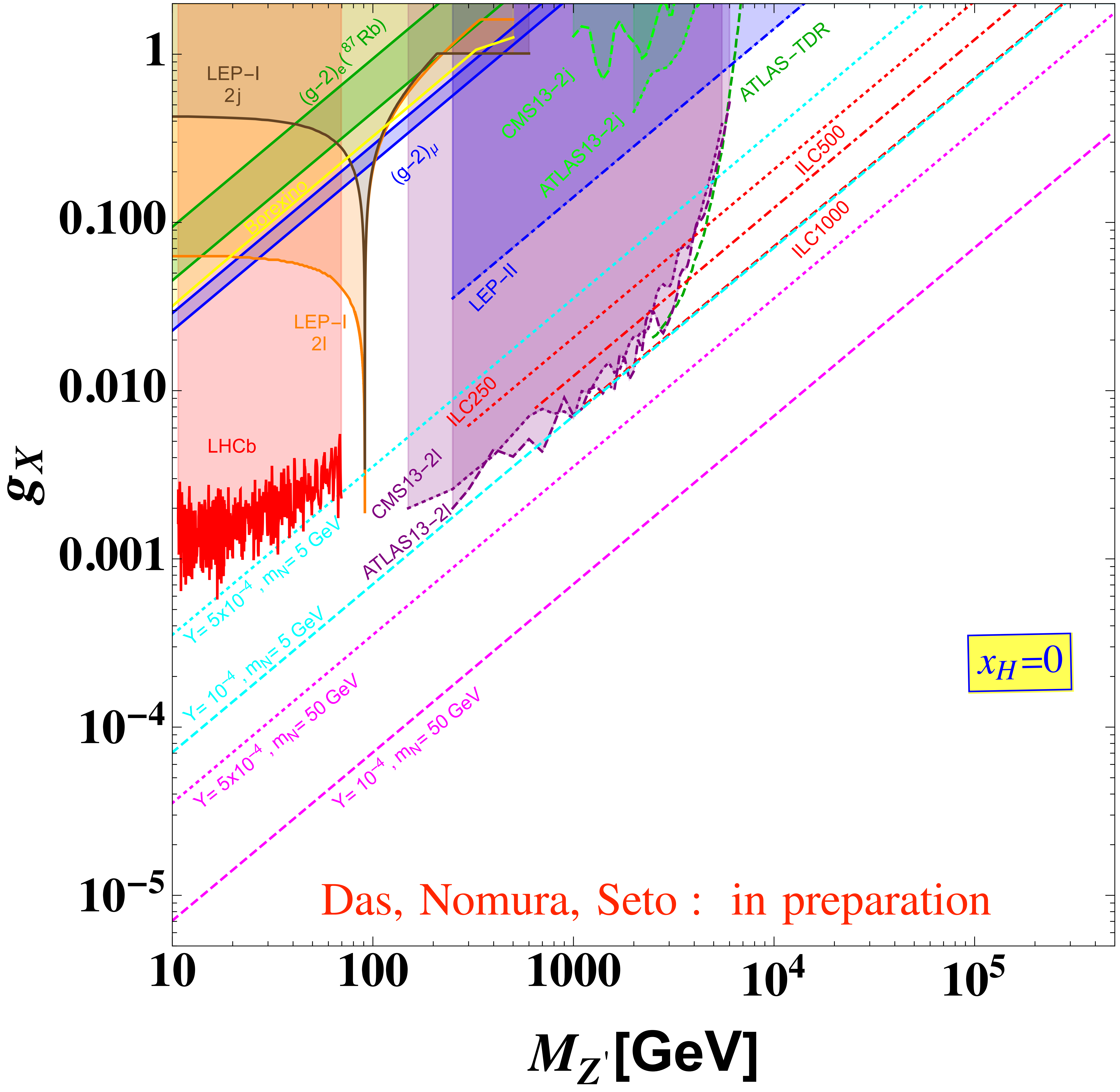
Such a model can be studied at muon colliders with high CM energy . This allows us to probe heavier Z' .

The motovation of this work is to find a new particle and/or a new force carrier as a part of the of the new physics searches including a variety of BSM aspects .

Back–up Slides

Limits on $g' - M_{Z'}$ plane





LEP-I 2j
$(g-2)_e(^{87}Rb)$
CMS13-2l
ATLAS13-2l
ATLAS-TDR
Borexino
$(g-2)_\mu$
LEP-II
LEP-I 2l
ILC500
ILC1000
ILC250
LHCb
CMS13-2l
ATLAS13-2l
Y= 5x10^{-4} , m$_N$= 5 GeV
Y= 10^{-4} , m$_N$=5 GeV
Y= 5x10^{-4} , m$_N$= 50 GeV
Y= 10^{-4} , m$_N$=50 GeV
x_H=0
Das, Nomura, Seto : in preparation
g_X
$M_{Z'}$[GeV]

Bounds on a sample B − L scenario with $x_H = 0$, $x_\Phi = 1$