Probing the origin of 750 GeV diphoton excess with the precision measurements at the ILC

K. J. Bae, K. Hamaguchi, T. Moroi, K. Y, PLB 759 (2016) 575 [arXiv:1604.08307]

Keisuke Yanagi
(Univ. of Tokyo)

Probing the diphoton

New Physics

excess

with the precision measurements at the ILC

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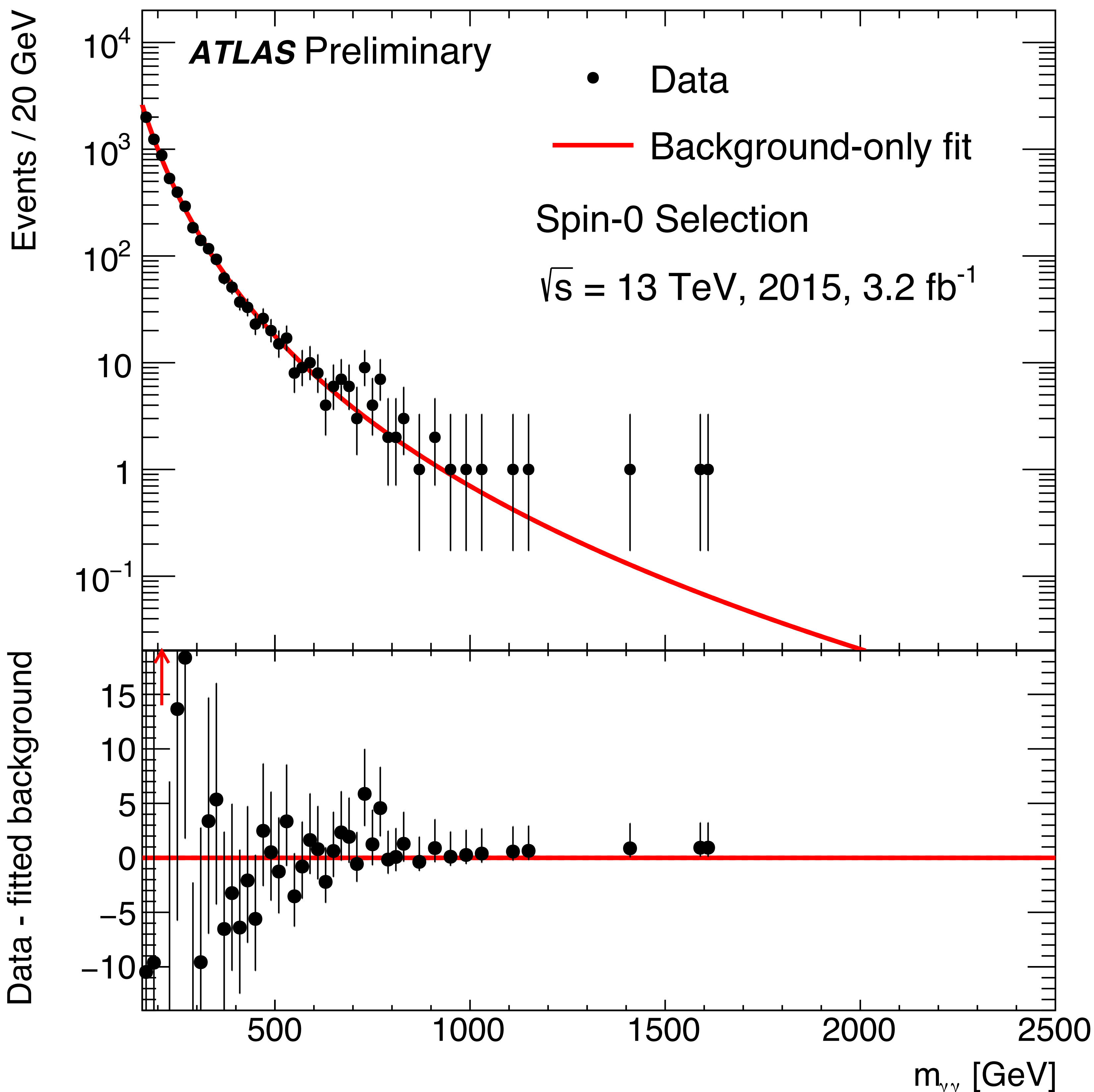

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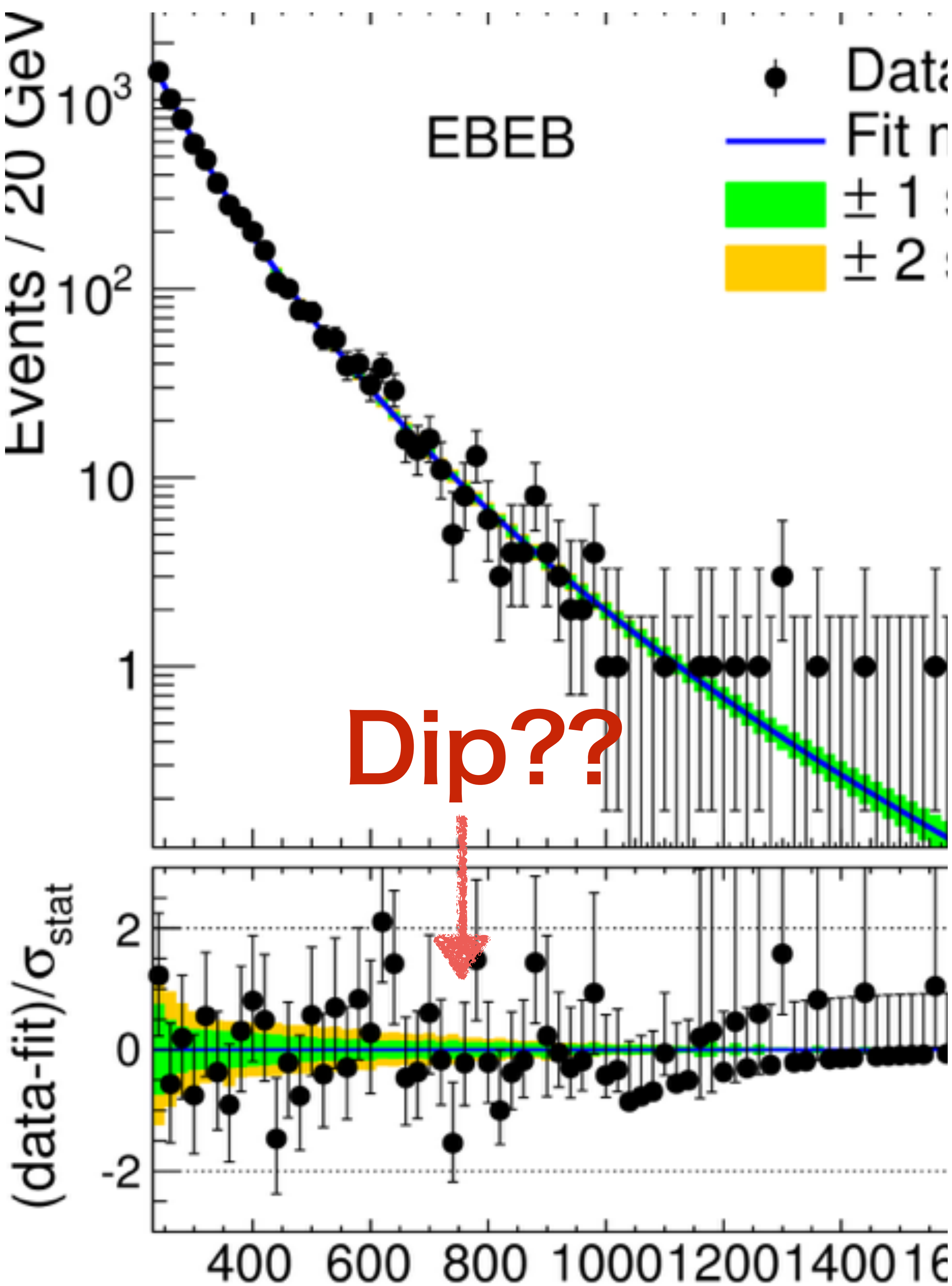

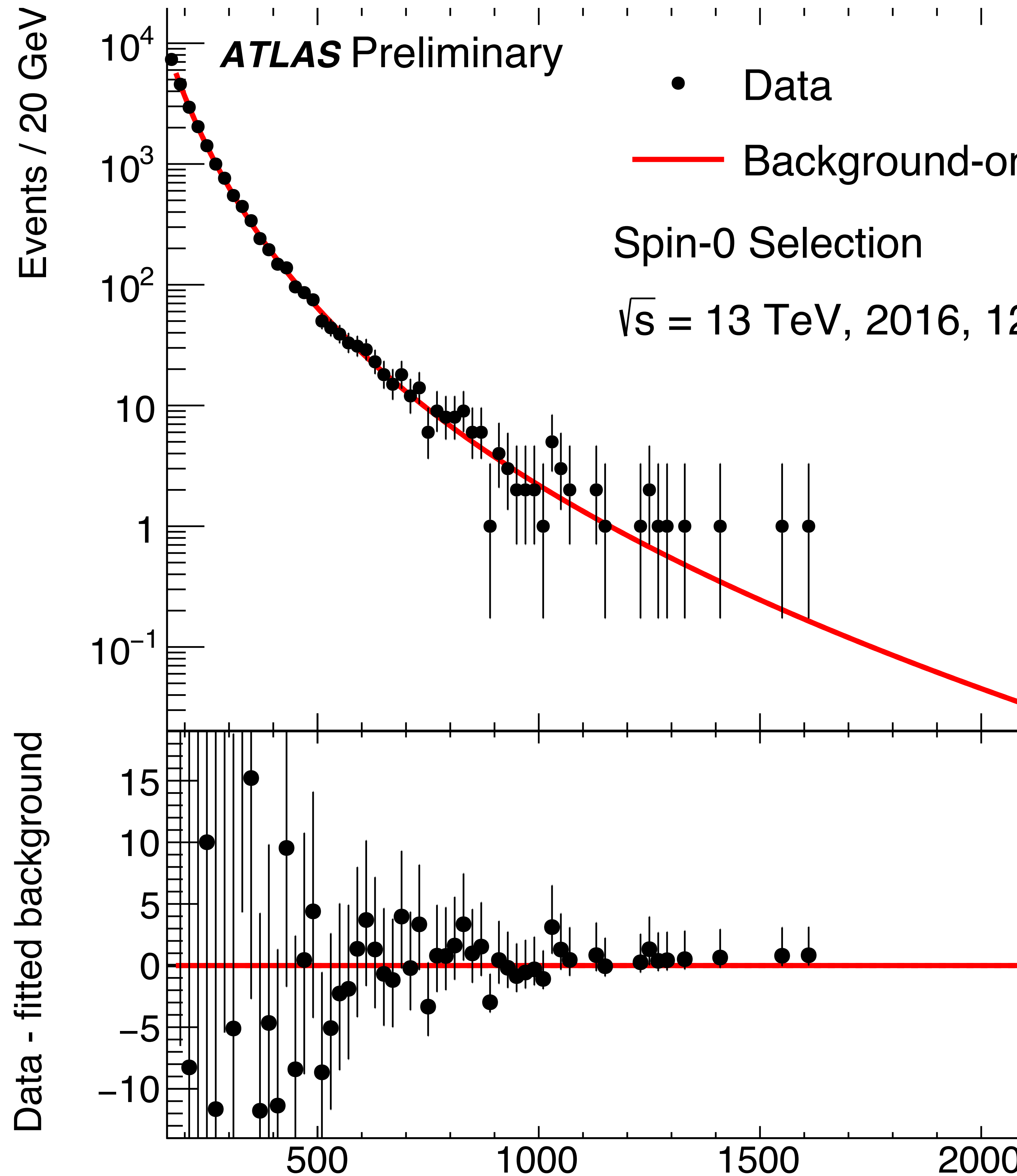

Precision measurement at the ILC

- The ILC is future electron-positron collider
- Center of Mass energy: $\sqrt{s} =$ **250GeV - 1TeV (3TeV??)**
- Clean environment compared with the LHC
- Even if $m > \sqrt{s}/2$, **new particle affects SM process** via loop correction

We focus on **the differential cross section** of $e^+e^- \to f\bar{f}$

Motivations for indirect probe

Powerful method to search new heavy (non-colored) particles with **large EW quantum number** and/or **large multiplicity**

Examples

- Several models for the diphoton excess:
  SM + **singlet** scalar (750GeV) + **charged** scalars/fermions
- WIMP DM models [K. Harigaya et al., arXiv: 1504.03402]
  (Wino/Higgsino DM, Minimal DM…)
- Other BSM particles …

Indirect method is widely applicable!

(even though the 750 GeV diphoton excess is dead)

Motivations for in… e

Powerful method to search new heav…
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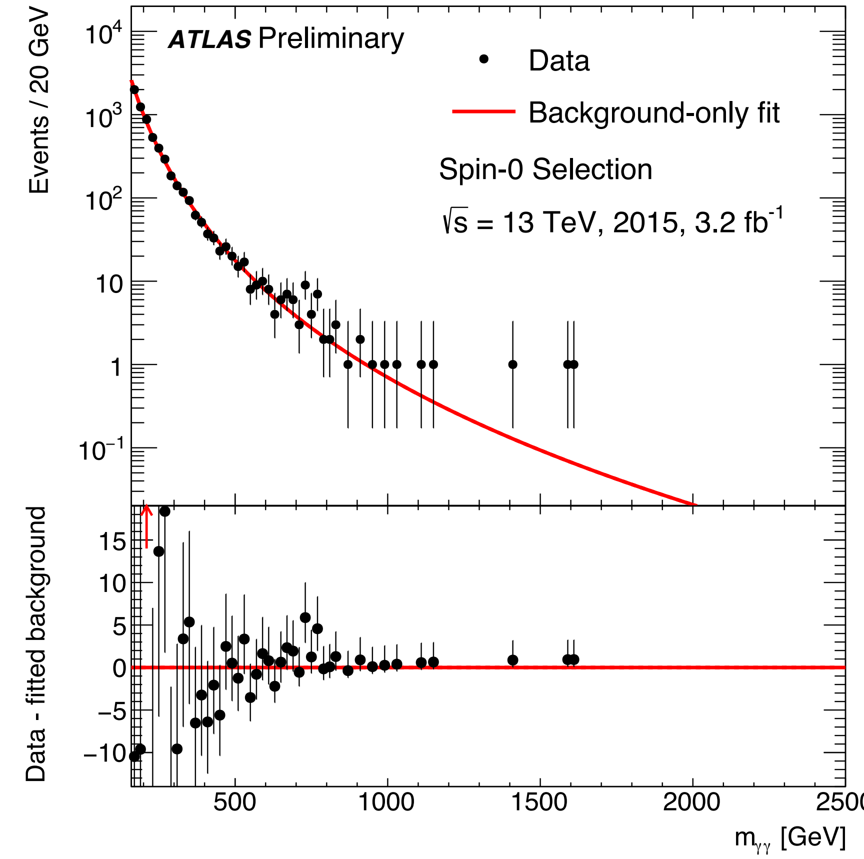

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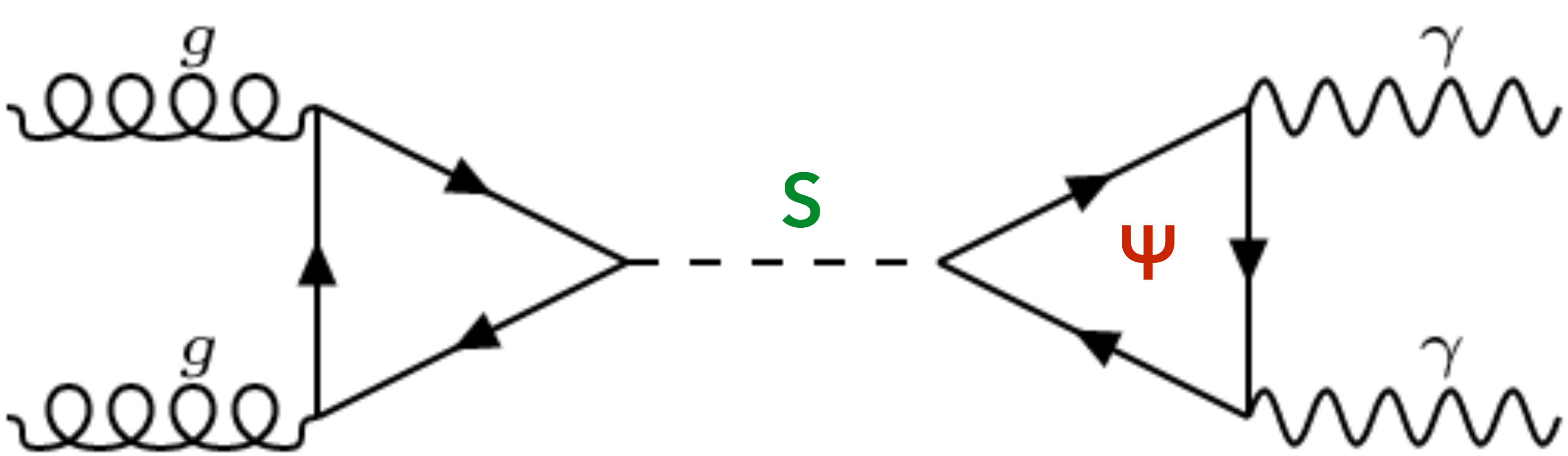
- V…
  (…



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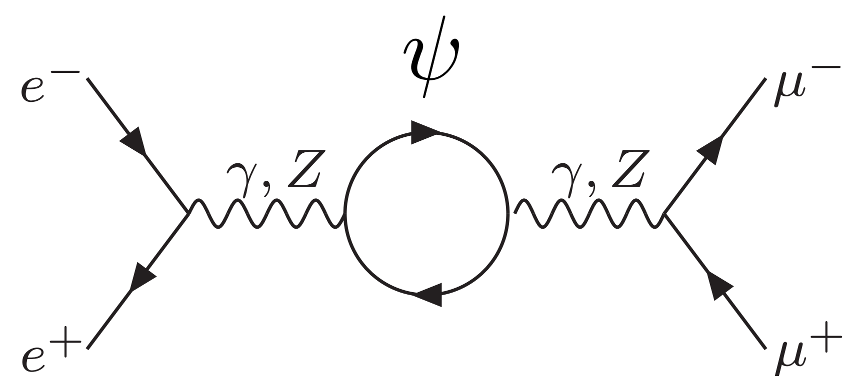
Setup

$SU(3) \times SU(2)_L \times U(1)_Y$

- SM + **N** vector-like fermions ψ of mass **m**, and rep. (**1**, **n**, **Y**)
- $e^+e^- \to \mu^+\mu^-$ process



- Define

$$\Delta\chi^2 = \sum_{i:\,\mathrm{bins}} \frac{(N_i^{\mathrm{SM}+\psi} - N_i^{\mathrm{SM}})^2}{N_i^{\mathrm{SM}} + (\epsilon N_i^{\mathrm{SM}})^2}$$

- Bins: 10 uniform intervals for the scattering angle $\cos\theta \in [-1, 1]$

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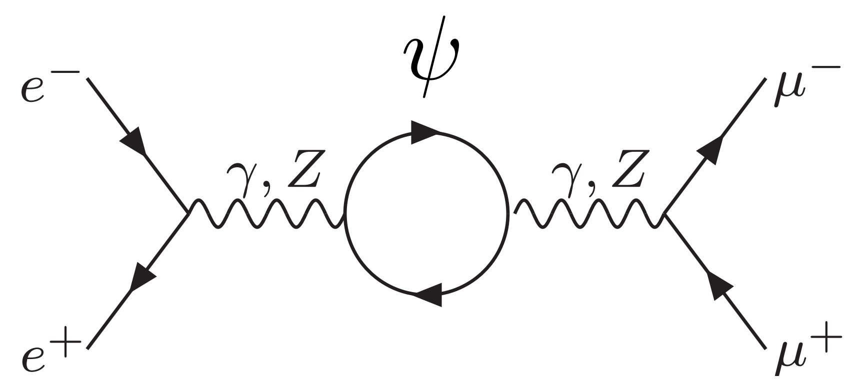

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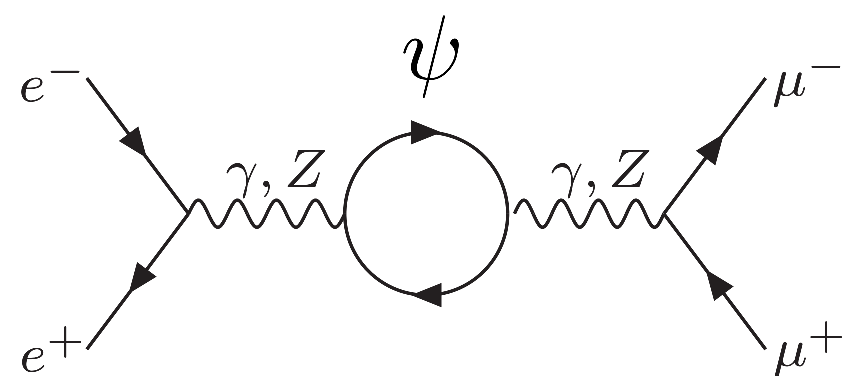

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Systematic uncertainty

- Bins: 10 uniform intervals for the scattering angle cosθ ∈ [-1, 1]

Mass reach

- Expected mass reach (95% C.L.)
- New particle: SU(2) triplet (**n=3**), **Y=0**
- $\sqrt{s} = 1\ \mathrm{TeV}$
- $m > \sqrt{s}/2$ can be probed!
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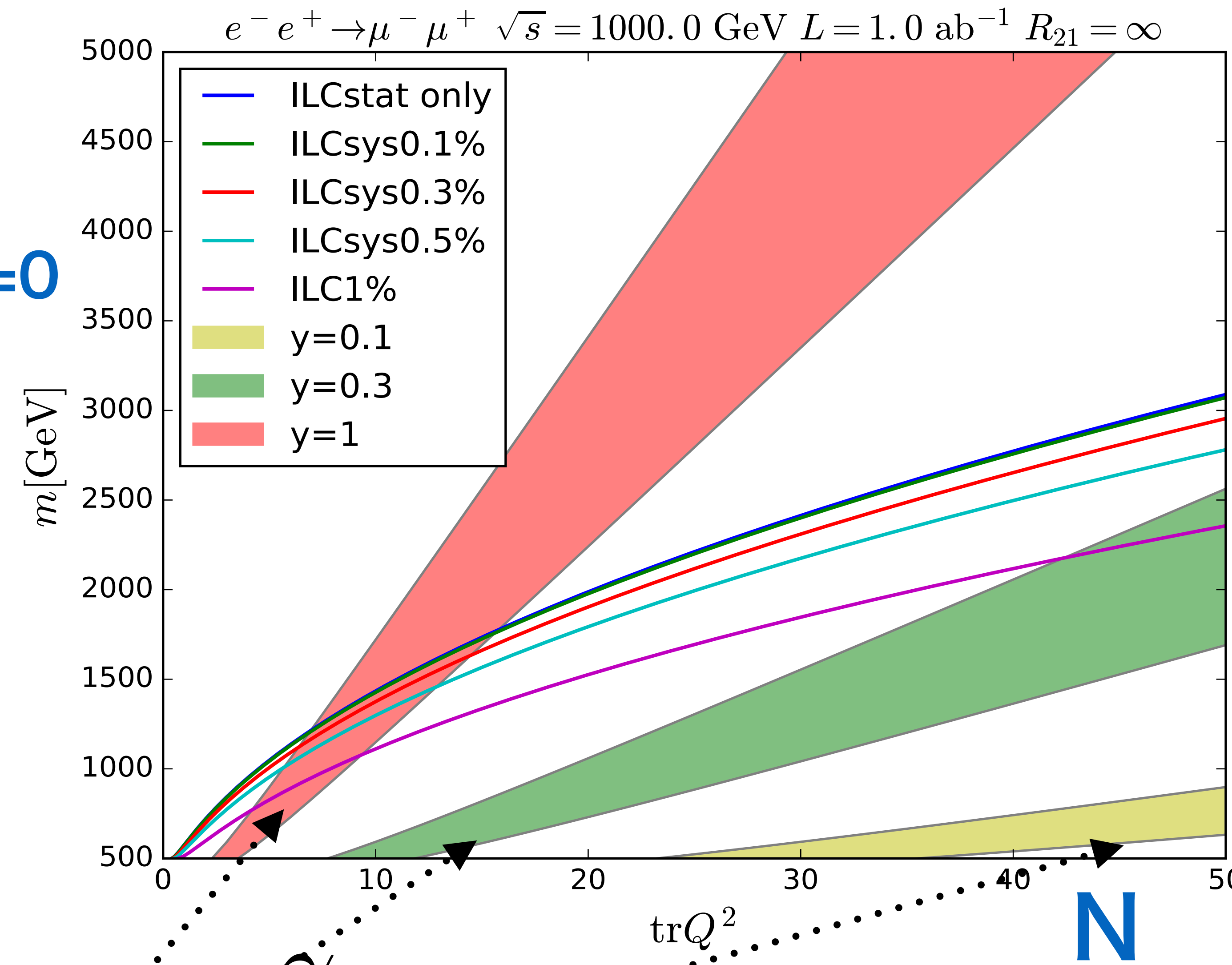

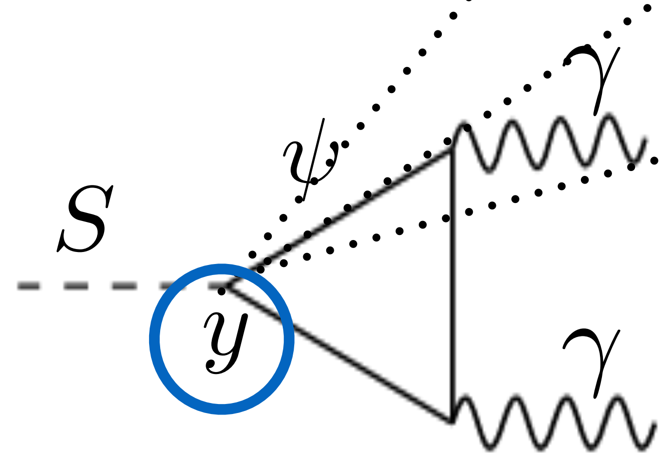

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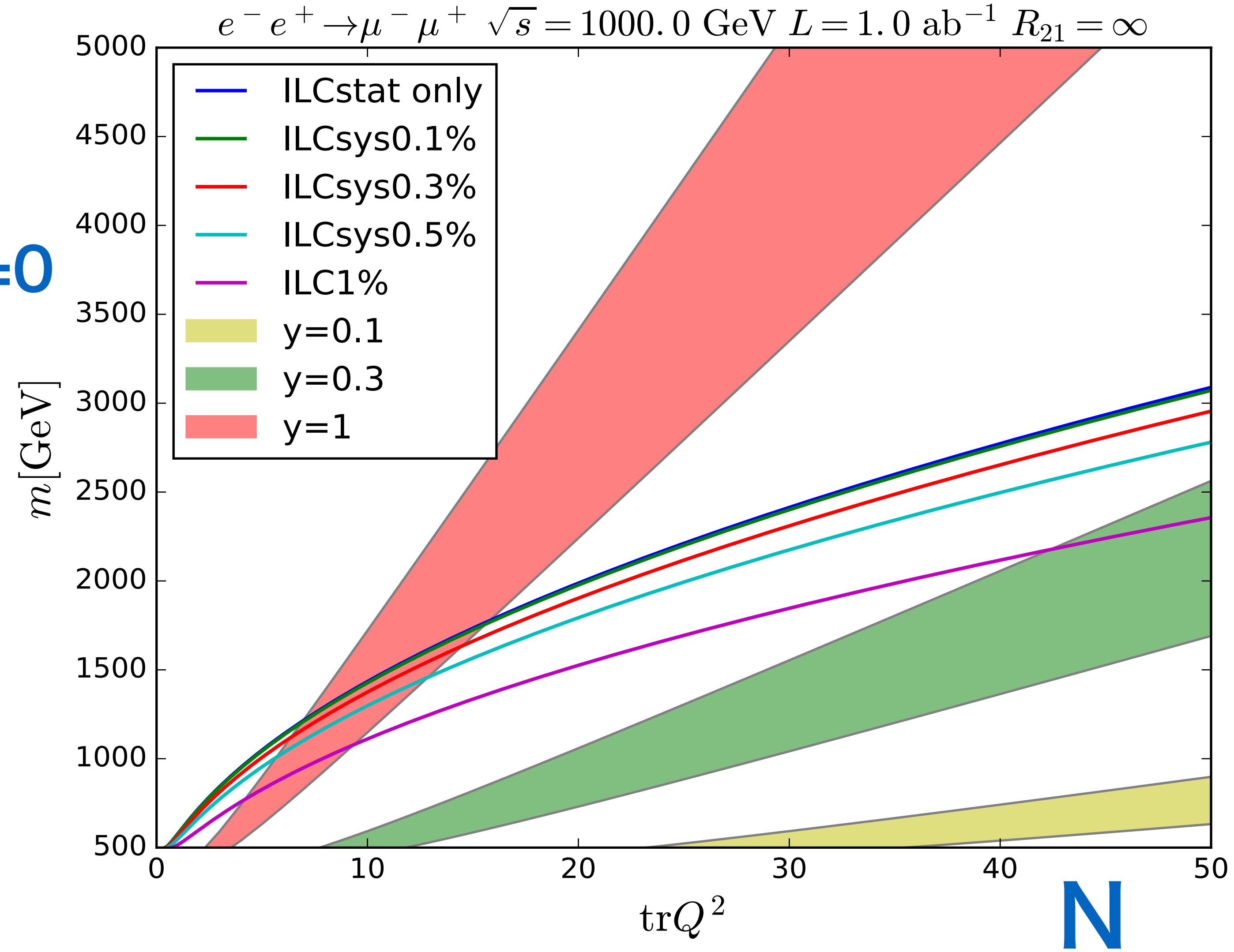


N

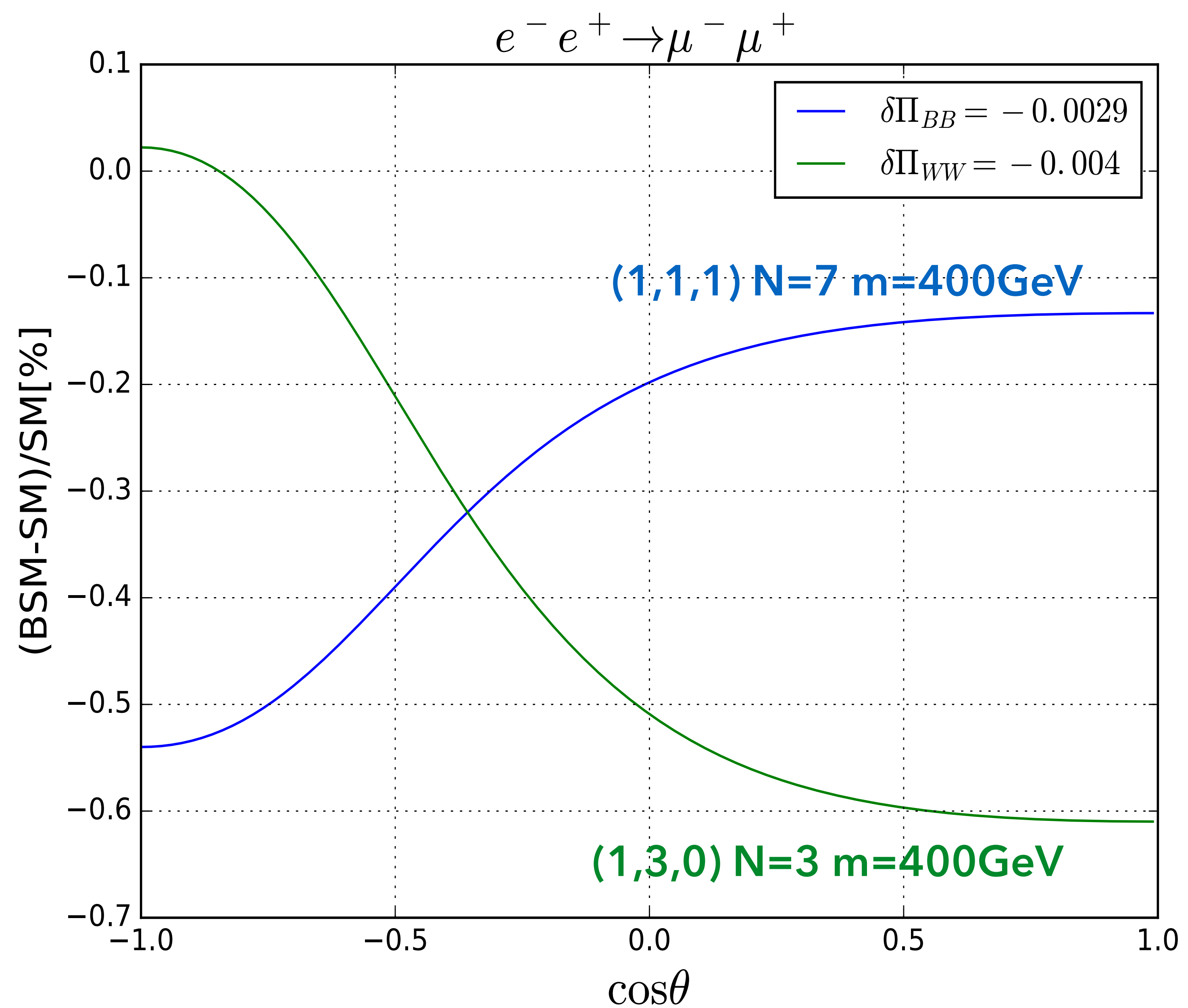
How about quantum number of $SU(2)_L \times U(1)_Y$?

Is it possible to **discriminate different BSM particles?**

Angular distribution

- The deviation of the differential cross section from SM
- $e^+e^- \to \mu^+\mu^-$ process
- **Angular distribution is different** for different quantum number

$$\Delta\chi^2 = \sum_{i:\,\text{bins}} \frac{(N_i^{\text{SM}+\psi} - N_i^{\text{SM}})^2}{N_i^{\text{SM}} + (\epsilon N_i^{\text{SM}})^2}$$



$P_+ = +30\ \%\quad P_- = -80\ \%$ (Beam polarization)

$\sqrt{s} = 500\ \text{GeV}$ (Beam energy)

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SM+ψ'

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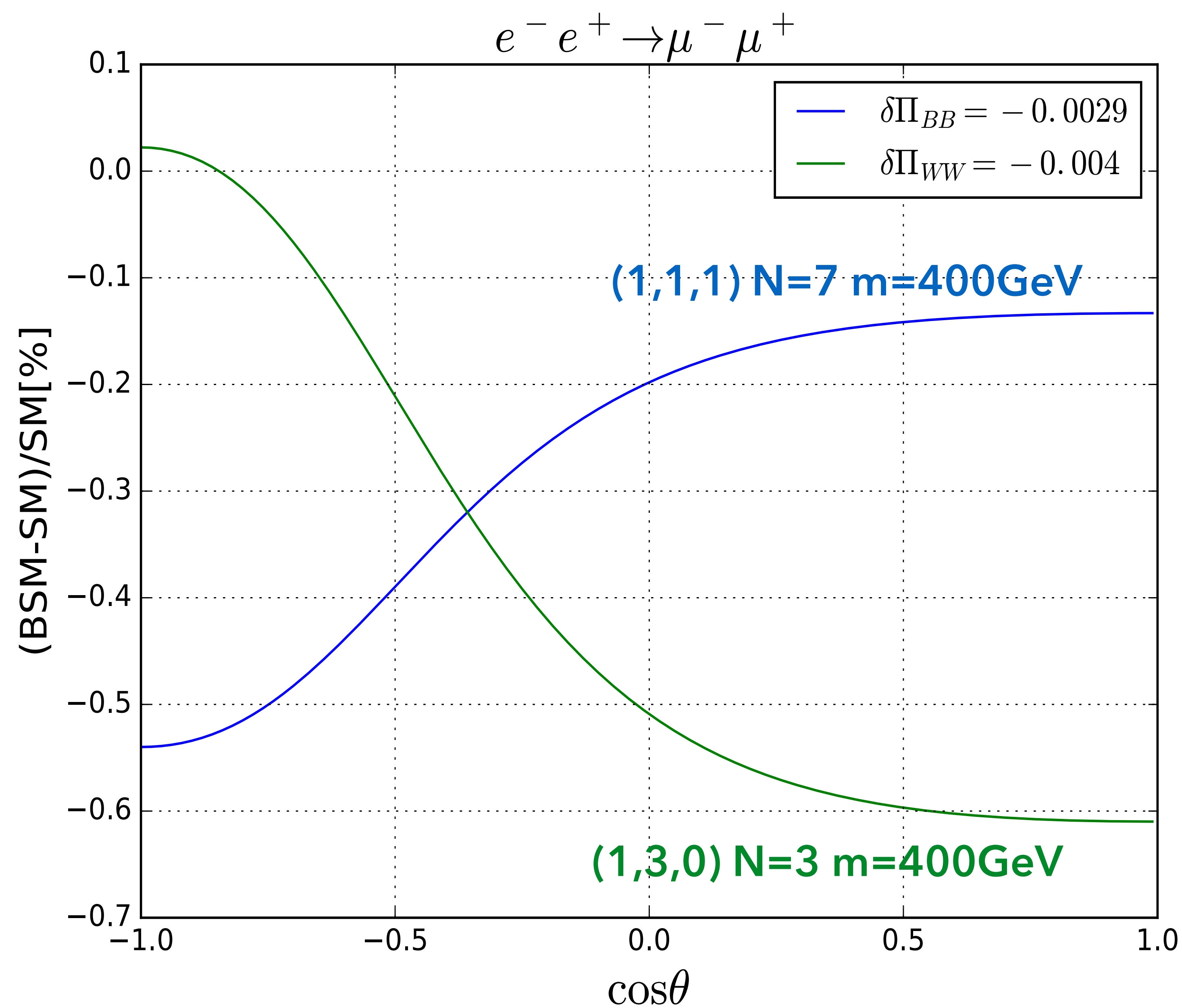

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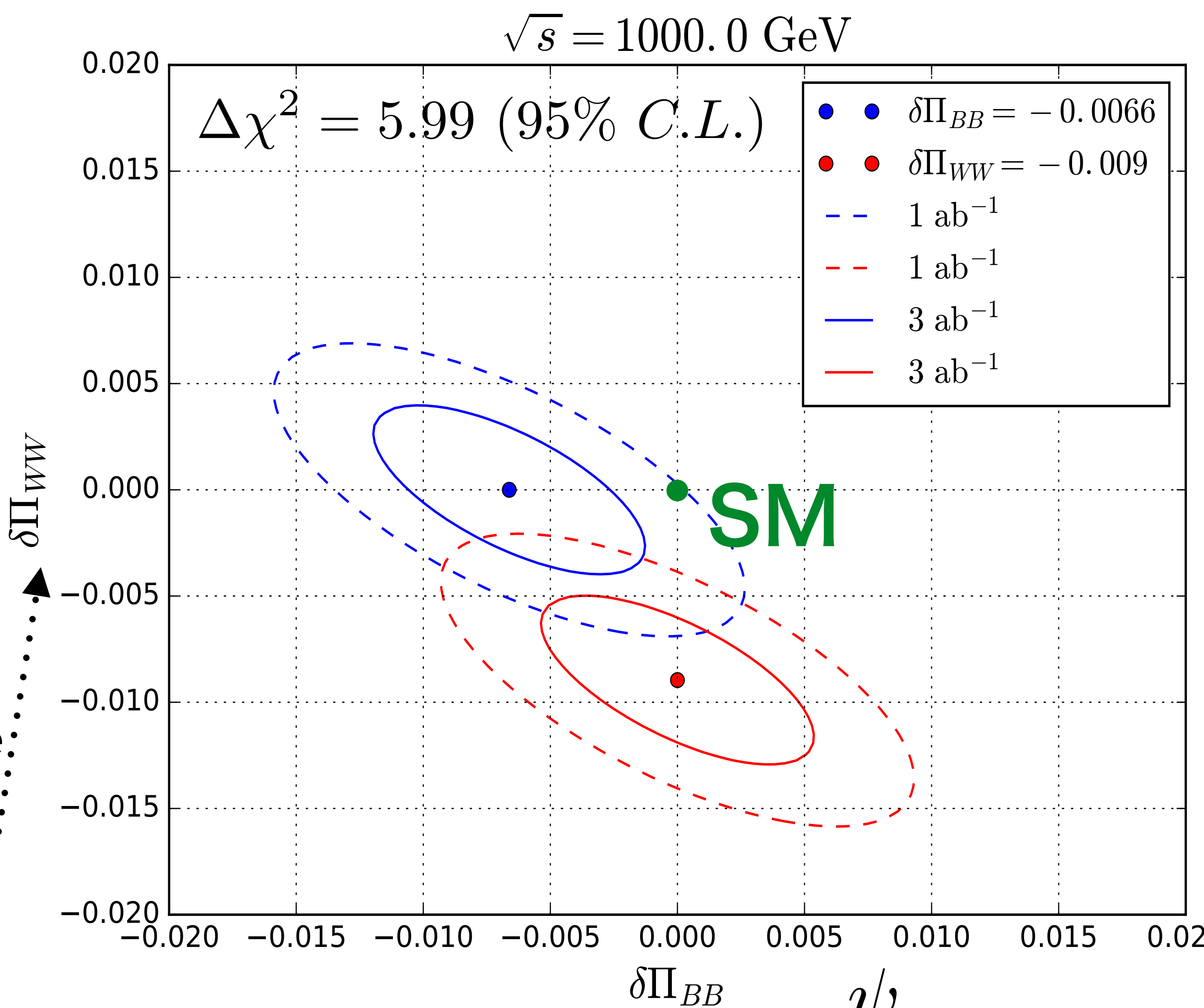
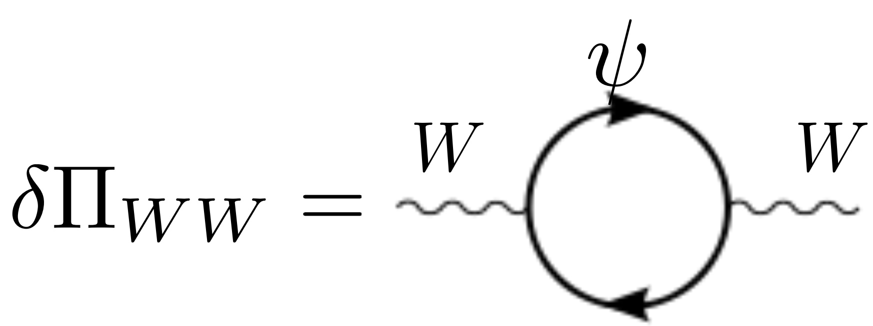
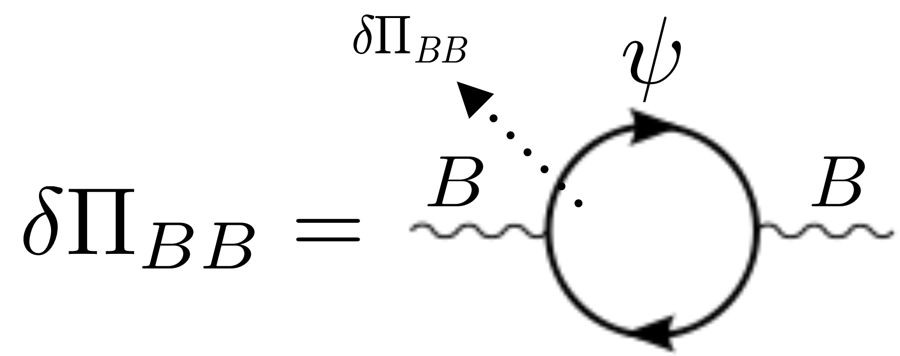
SU(2)$_L$ vs. U(1)$_Y$

- $\delta\Pi_{WW}$,$\delta\Pi_{BB}$ are the vacuum polarizations of new particles
- Each point corresponds to a new physics model
- Integrated luminosity **1 ab^{-1}** and **3 ab^{-1}** are considered
- SM+U(1)$_Y$ or SM+SU(2)$_L$ can be distinguished from **models outside the contour** at 95 % C.L.







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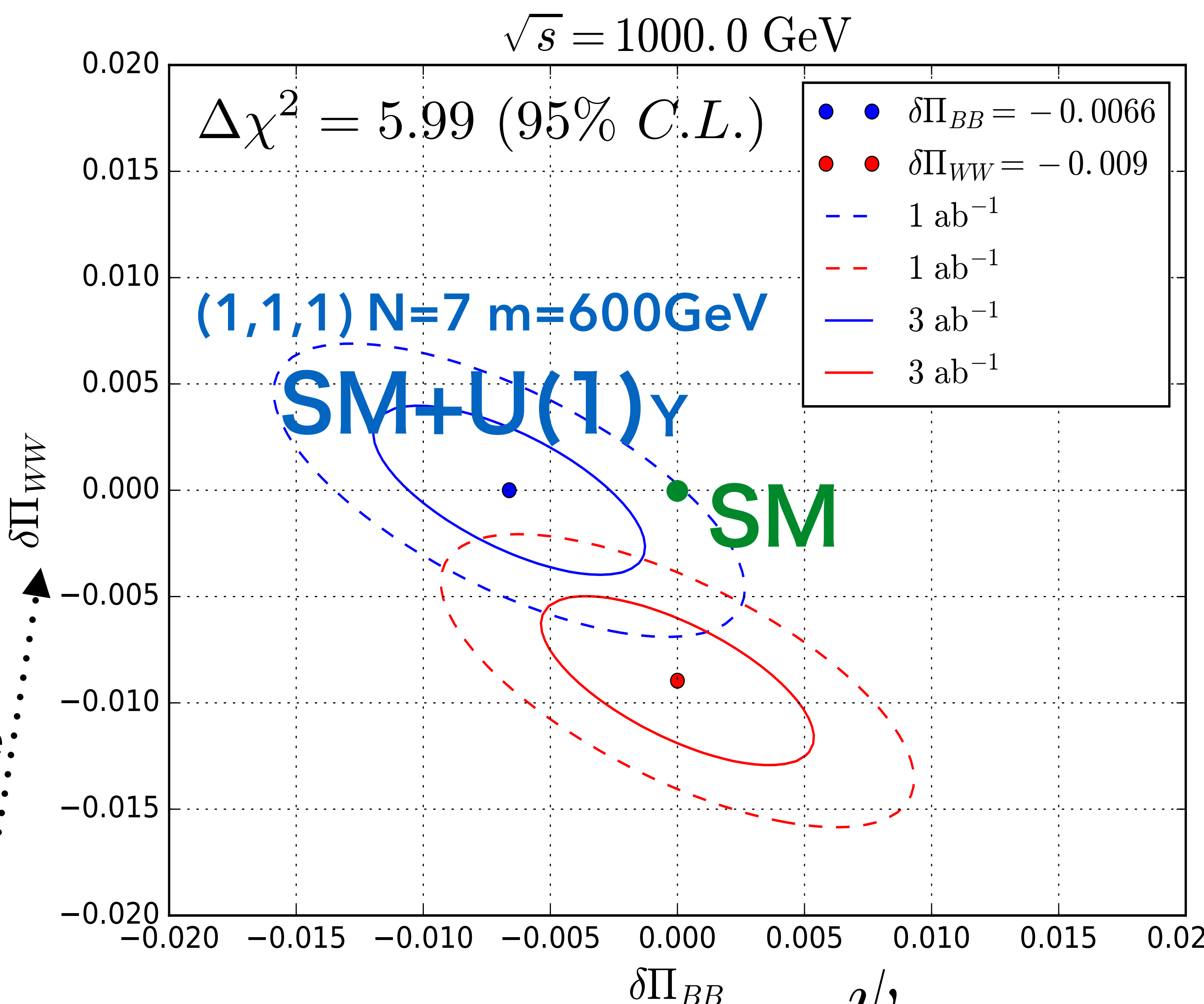
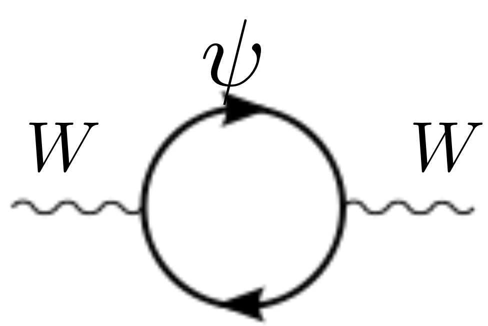
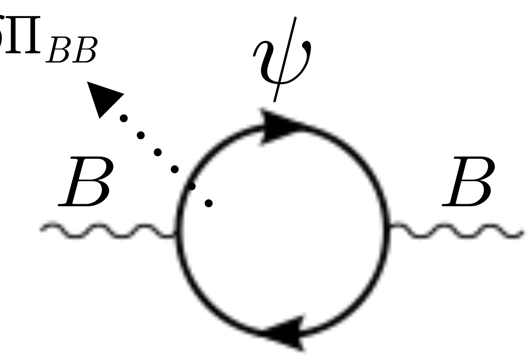


$\delta\Pi_{WW} =$ 

$\delta\Pi_{BB} =$ 

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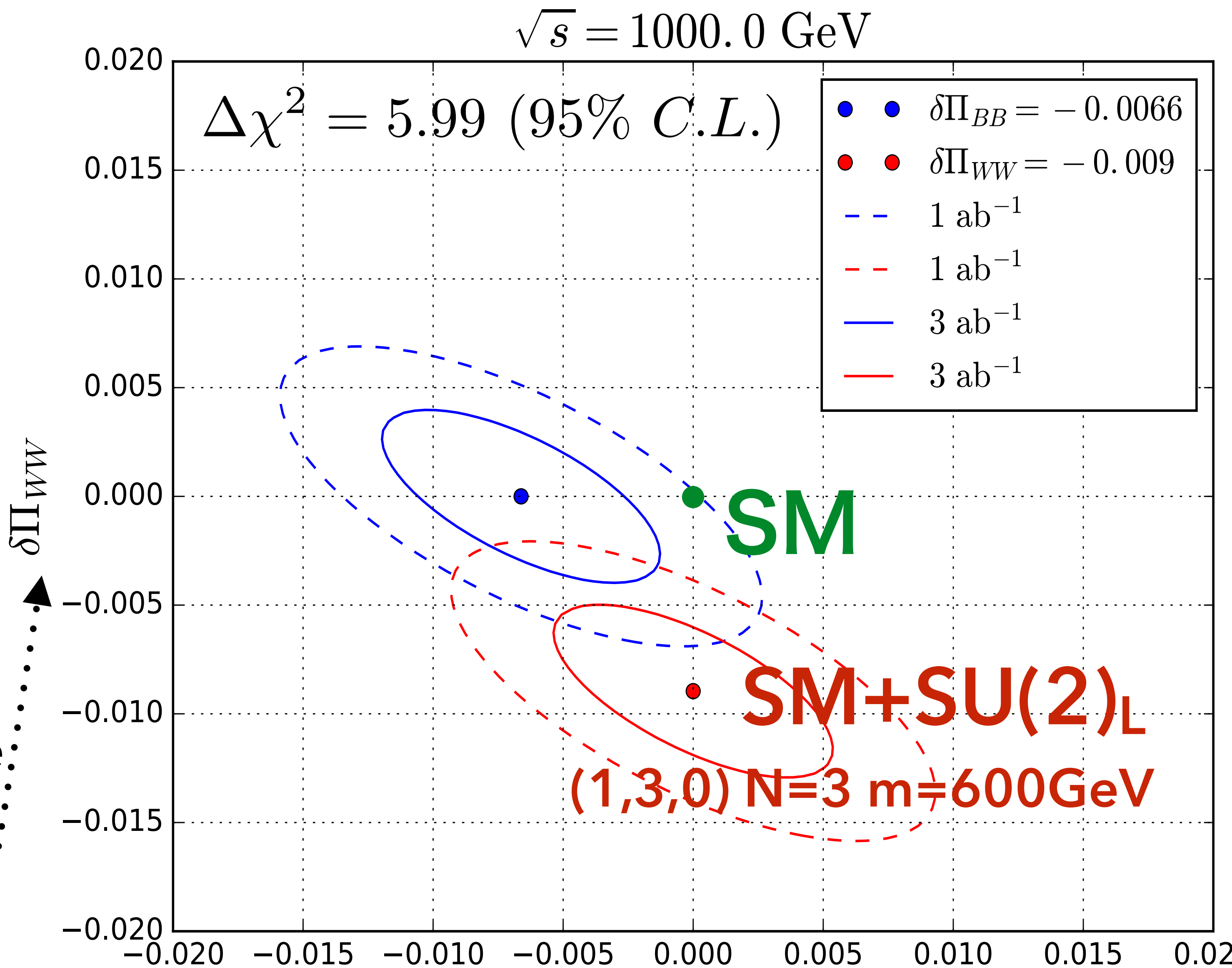

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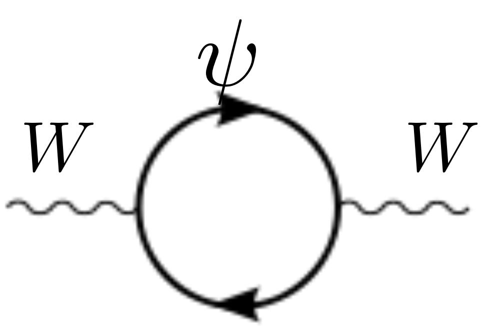

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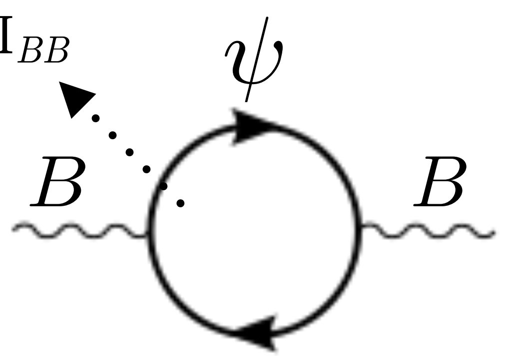

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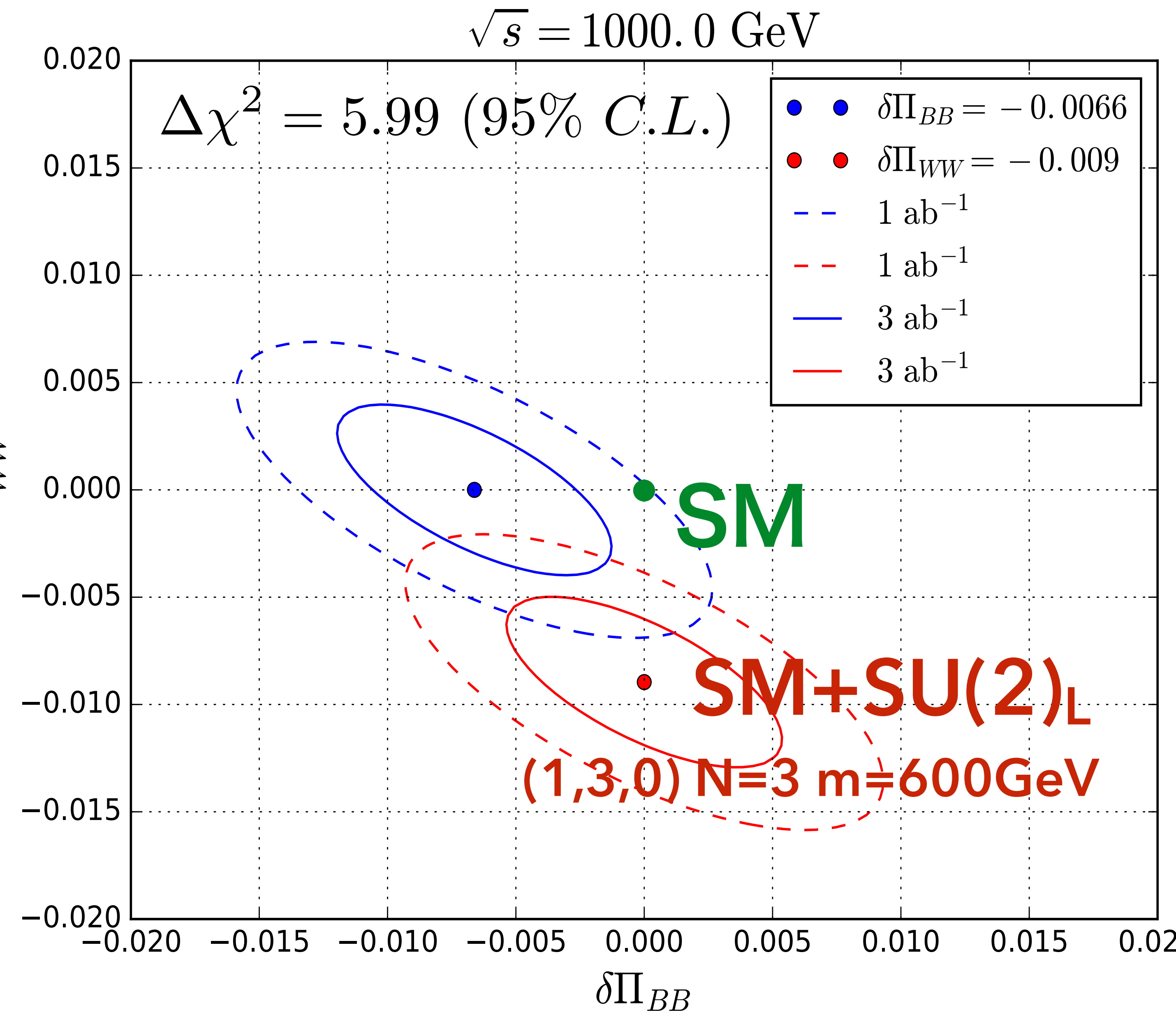

It is possible to **discriminate SU(2)$_L$×U(1)$_Y$ quantum number!**

Summary

Precision measurement of the process $e^+e^- \to f\bar{f}$ provides a clue for the beyond standard physics.

1. We can probe new charged fermions **even when they are out of kinematical reach** at the ILC.

2. We can **discriminate $SU(2)_L \times U(1)_Y$** quantum numbers of the new particles by **studying the angular distribution** at the ILC.

Backup

Mass reach

- Expected mass reach (95% C.L.)
- New particle: SU(2) triplet (**n=3**), **Y=0**
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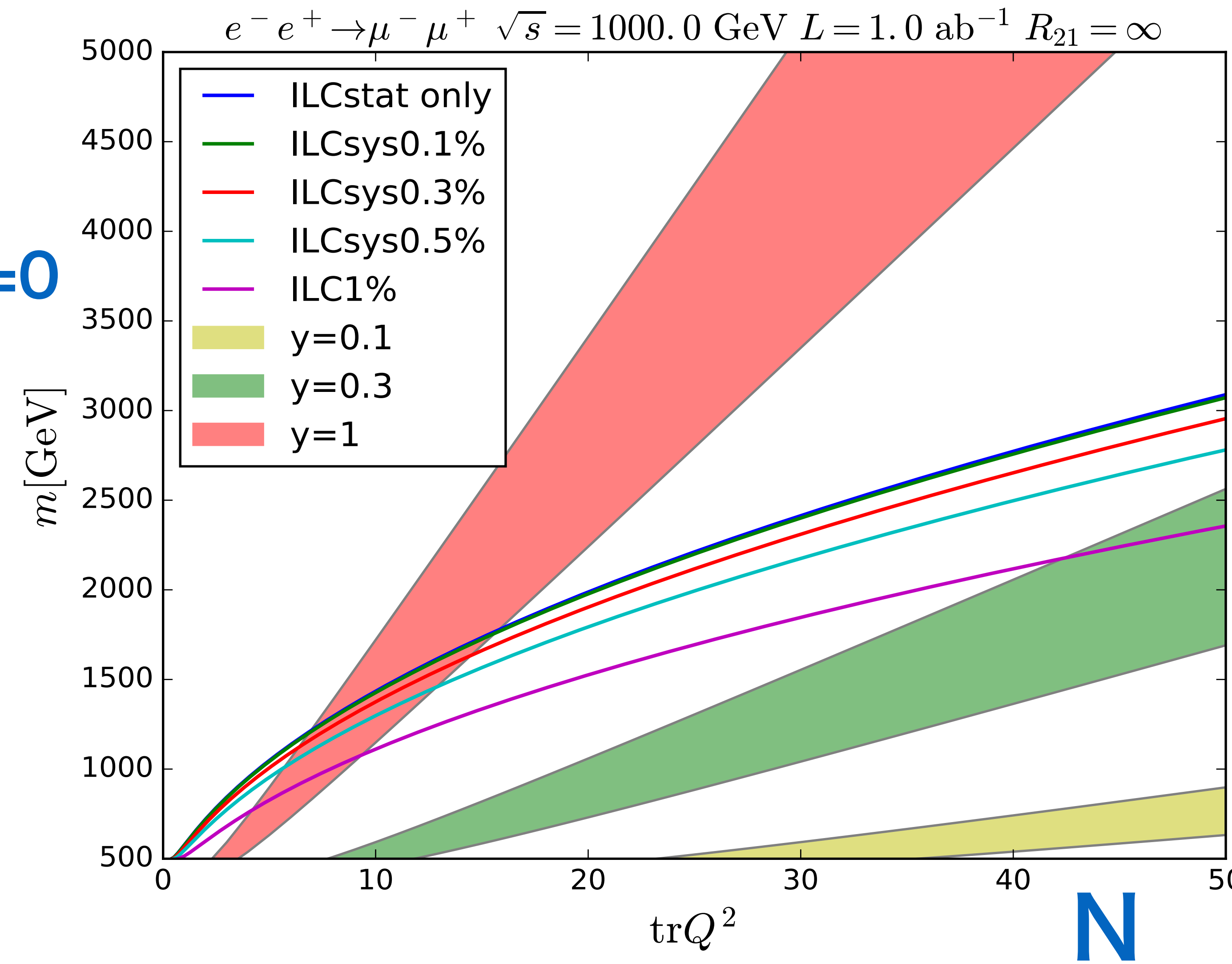

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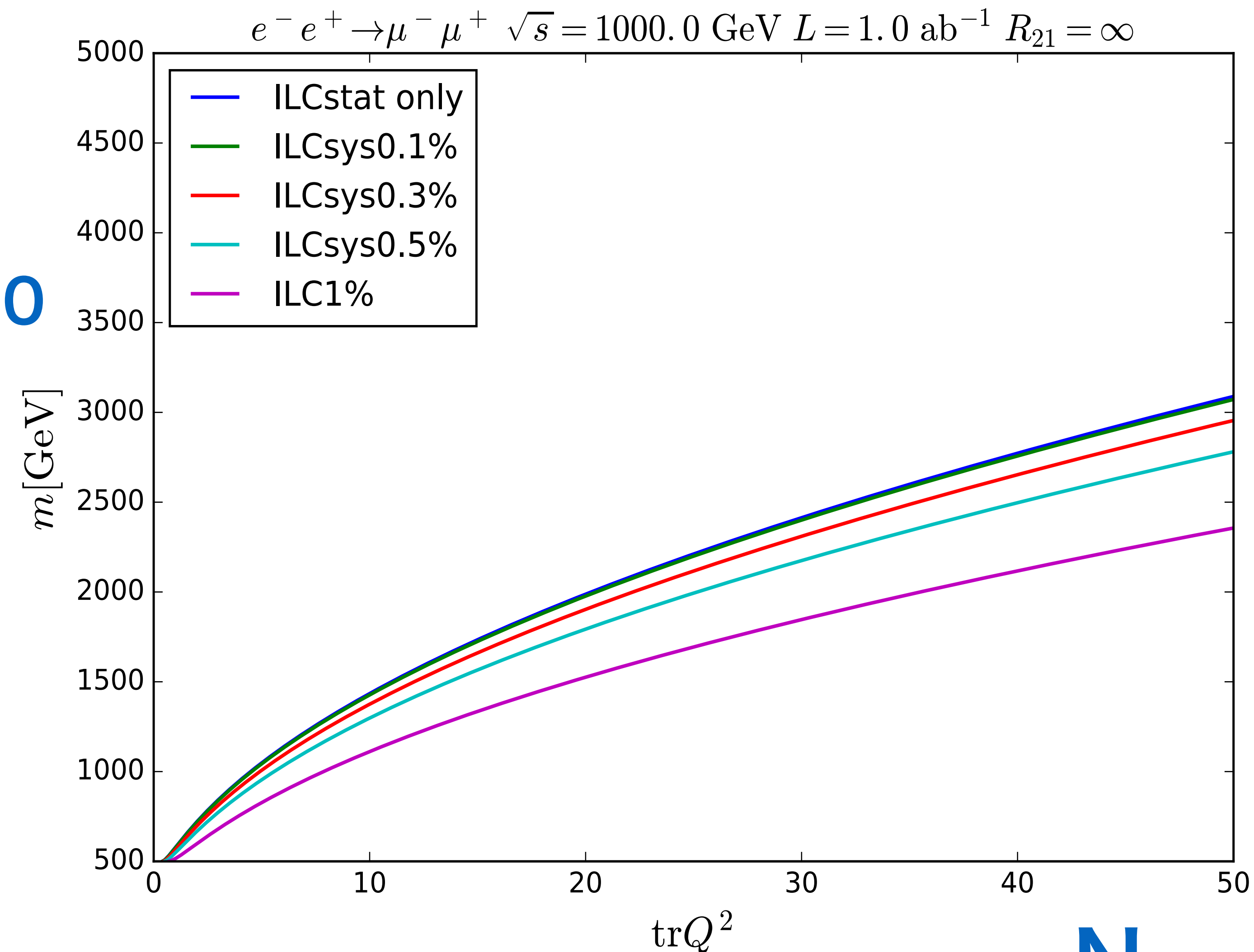

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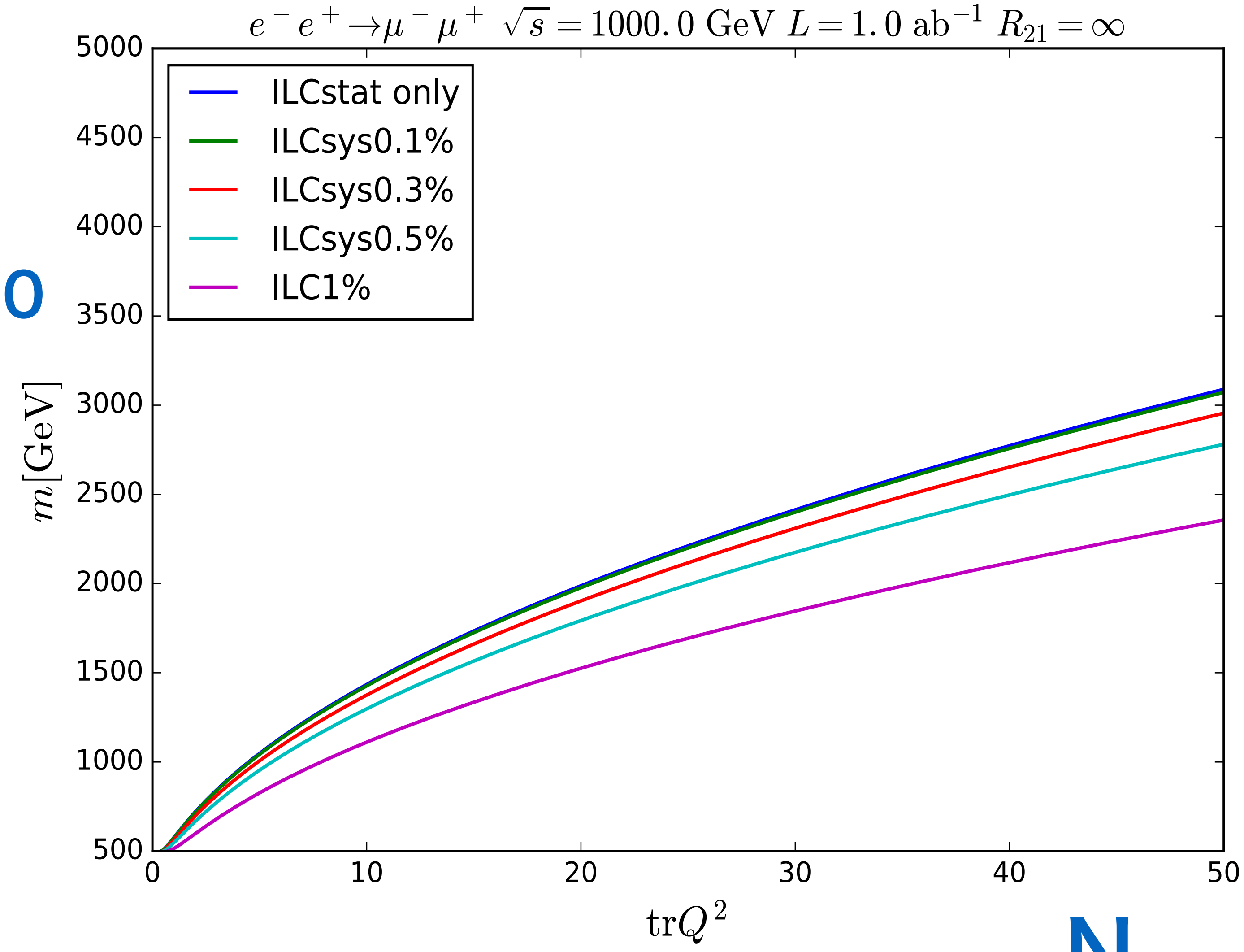

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How about quantum number of SU(2)×U(1)?

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750 GeV diphoton Excess (1)

SM + **singlet** pseudo-scalar (750GeV) + **charged** scalars/fermions

$$\mathcal{L}_\psi = \sum_i \bar{\psi}_i (i\not{D} - m)\psi_i - i\sum_i yS\bar{\psi}_i\gamma_5\psi_i$$

Narrow width approximation:

$$\sigma(pp \to S \to \gamma\gamma) \simeq \frac{C_{gg}}{s\, m_S}\Gamma(S \to \gamma\gamma)$$

Assuming

$\sqrt{s} = 13$ TeV $\quad \sigma = 3 - 10$ fb $\quad C_{gg} \simeq 2.1 \times 10^3 \quad m_S = 750$ GeV

Decay width

$$\Gamma(S \to \gamma\gamma) = 0.45 - 1.5 \text{ MeV}$$

is necessary.

750 GeV diphoton excess (2)

Functions

$$C_{gg} = (\pi^2/8)\int_0^1 dx_1 \int_0^1 dx_2 \delta(x_1 x_2 - m_S^2/s) g(x_1) g(x_2)$$

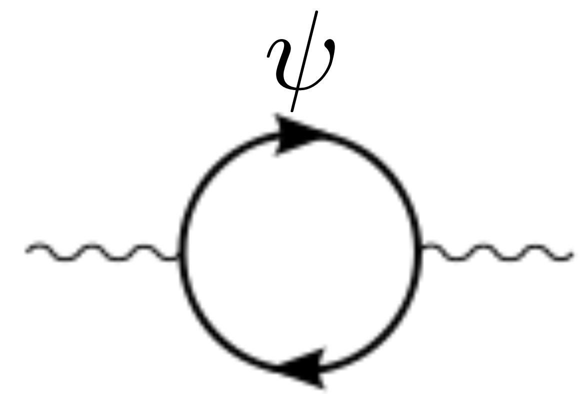
$$\Gamma(S \to \gamma\gamma) \simeq \frac{\alpha^2}{256\pi^3} m_S^3 \left[\frac{y}{m} \mathrm{tr} Q^2 L\left(\frac{m_S^2}{4m^2}\right)\right]^2$$

$$L(\tau) = \begin{cases} 2\tau^{-2}\left(\tau + (\tau - 1)\arcsin^2\sqrt{\tau}\right) & \text{for scalar } S\,, \\ 2\tau^{-1}\arcsin^2\sqrt{\tau} & \text{for pseudo-scalar } S\,, \end{cases}$$

$$\mathrm{tr} Q^2 = N\left[\frac{n(n-1)(n+1)}{12} + nY^2\right]$$

Vacuum polarization

$$\delta\Pi_{VV}(q^2, m^2) \equiv \frac{1}{2} g_V^2 C_{VV} I(q^2/m^2)$$



$$C_{WW} = \frac{4}{3} N n(n-1)(n+1)\,,$$

$$C_{BB} = 16 n N Y^2\,.$$

$$I(x) \equiv \frac{1}{16\pi^2}\int_0^1 dy\ y(1-y)\ln(1-y(1-y)x)$$ for fermion

$$I(x) \equiv \frac{1}{16\pi^2}\int_0^1 dy\ (1-2y)^2\ln(1-y(1-y)x)$$ for scalar

Particle representation

Electromagnetic charge can be written as follows,

$$\mathrm{tr}Q^2 = \frac{1}{16}\left(C_{WW} + C_{BB}\right)$$

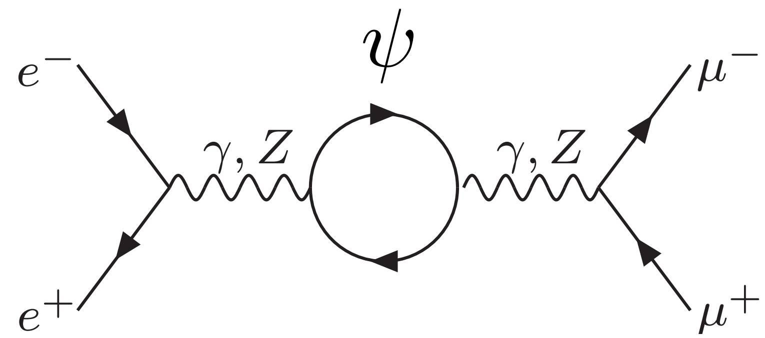
We parametrize the ratio of SU(2) and U(1) by

$$R_{21} \equiv C_{WW}/C_{BB} = \frac{n^2-1}{12Y^2}$$

Amplitudes (1)

$e^+e^- \to \mu^+\mu^-$ matrix element

$$\mathcal{M}^{\mathrm{SM},\psi}(e^-_h e^+_{\bar h} \to \mu^-_{h'}\mu^+_{\bar h'}) = \sum_{V,V'=\gamma,Z} C_{e_h V} C_{\mu_{h'} V'} D^{\mathrm{SM},\psi}_{VV'}(s)[\bar u_{h'}\gamma^\mu v_{\bar h'}][\bar v_{\bar h}\gamma_\mu u_h]$$



Coupling to gauge boson

$$C_{e_L Z} = C_{\mu_L Z} = g_Z(-1/2 + \sin^2\theta_W),$$
$$C_{e_R Z} = C_{\mu_R Z} = g_Z \sin^2\theta_W,$$
$$C_{e_L \gamma} = C_{e_R \gamma} = C_{\mu_L \gamma} = C_{\mu_R \gamma} = -e$$

$$g_Z = e/(\sin\theta_W \cos\theta_W)$$

Amplitude (2)

Photon and Z boson propagator

$$D^{\mathrm{SM}}_{VV'}(q^2) = \frac{\delta_{VV'}}{q^2 - m_V^2},$$

$$D^{\psi}_{VV'}(q^2) = \frac{q^2}{(q^2 - m_V^2)(q^2 - m_{V'}^2)}\delta\Pi_{VV'}(q^2, m)$$

where,

$$\delta\Pi_{\gamma\gamma}(q^2, m) = \delta\Pi_{WW}(q^2, m)\sin^2\theta_W + \delta\Pi_{BB}(q^2, m)\cos^2\theta_W,$$

$$\delta\Pi_{ZZ}(q^2, m) = \delta\Pi_{WW}(q^2, m)\cos^2\theta_W + \delta\Pi_{BB}(q^2, m)\sin^2\theta_W,$$

$$\delta\Pi_{\gamma Z}(q^2, m) = \left[\delta\Pi_{WW}(q^2, m) - \delta\Pi_{BB}(q^2, m)\right]\sin\theta_W\cos\theta_W$$