How Higgs is the Higgs?

- A study of Vector Boson Scattering at μTRISTAN
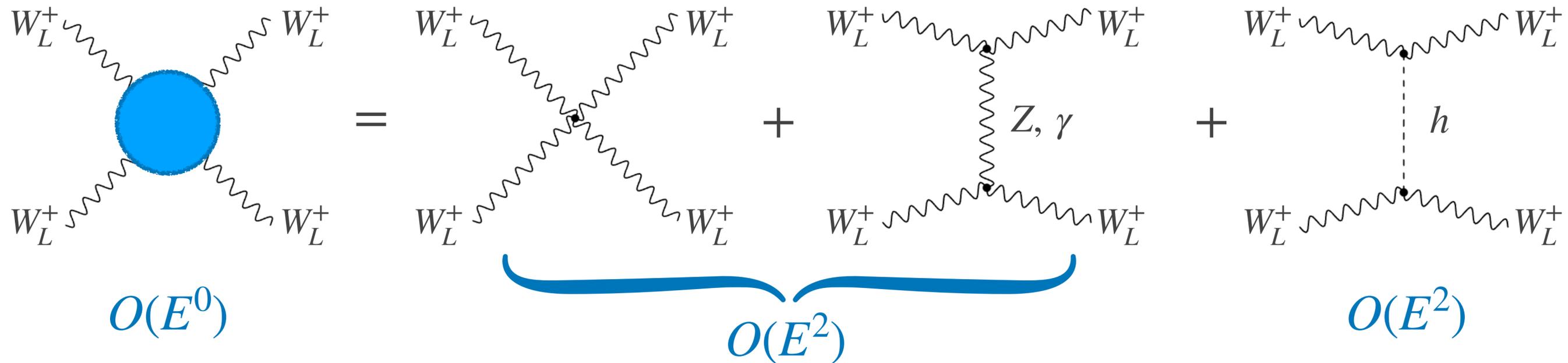
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Work in progress

with **Ryuichiro Kitano** (YITP) and **Satoshi Shirai** (IPMU)

2nd Hokkaido Workshop on Particle Physics at Crossroads @ Hokkaido U. (3 Mar. 2026)

Motivation - How Higgs is the Higgs?

An important role of Higgs: **unitarization of WW scatterings**

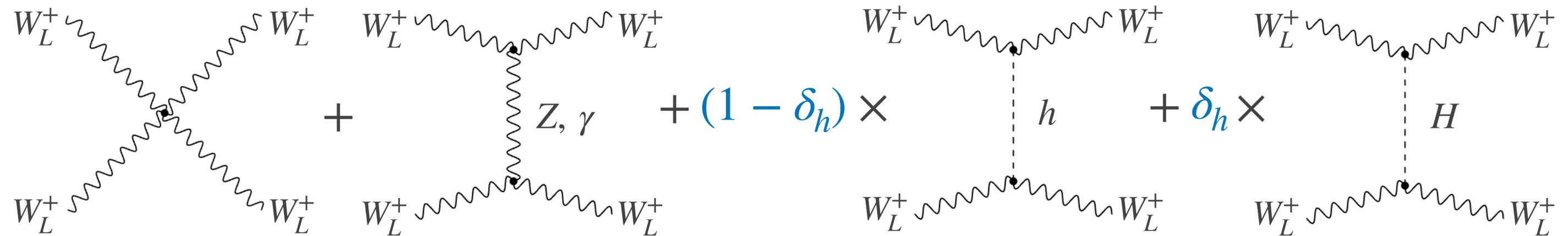$O(E^0) \qquad \underbrace{\qquad\qquad\qquad}_{O(E^2)} \qquad O(E^2)$

Deviation of Higgs coupling **enhances** WW scatterings with $O(E^2)$

▸ How much does the 125 GeV Higgs unitarize the scatterings?

UV complete amplitudes with an additional scalar

Higgs coupling deviation can be complemented by an additional scalar
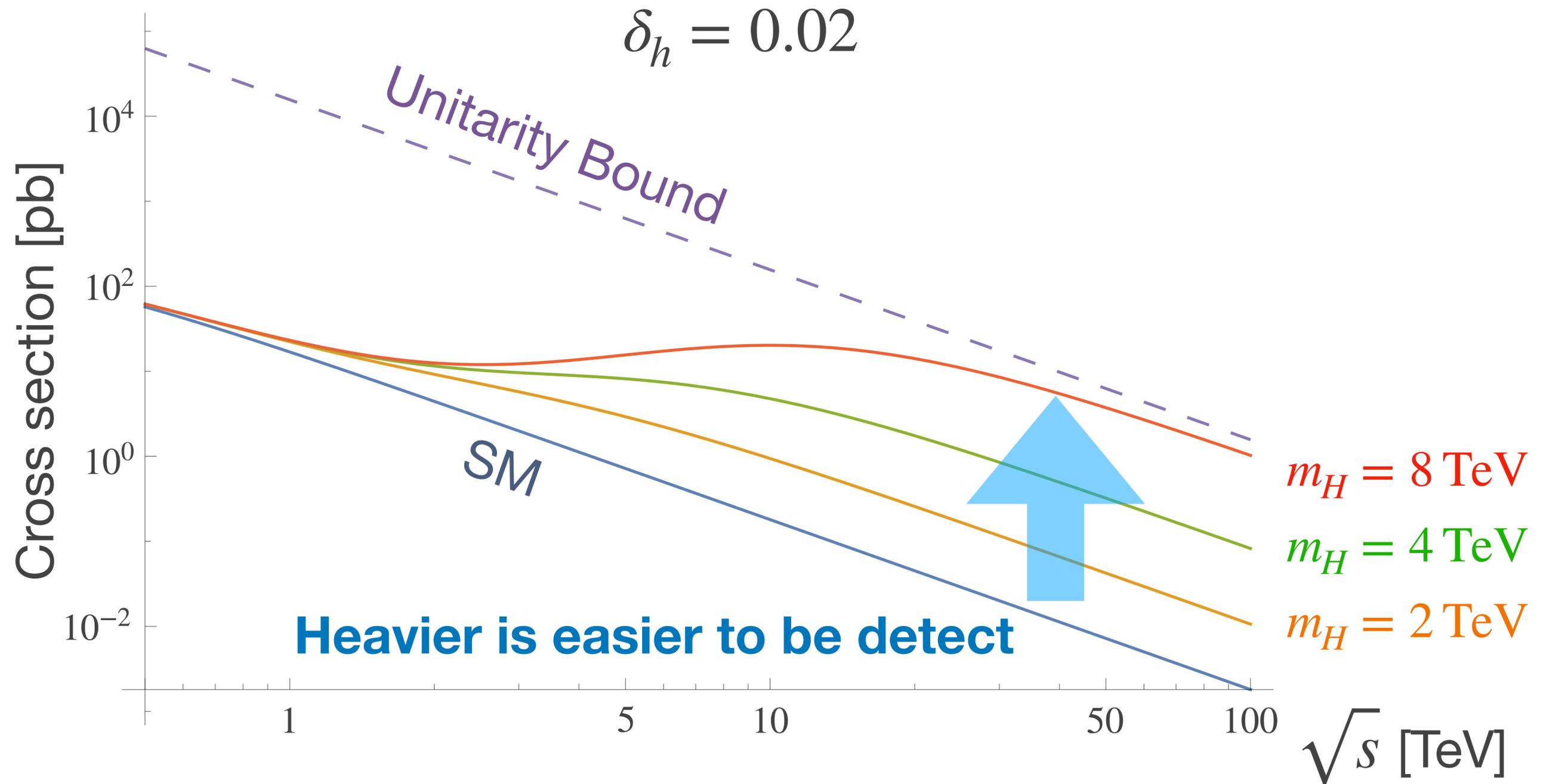
$$\mathcal{M}(W_L^+ W_L^+ \to W_L^+ W_L^+) =$$

$$+ \quad Z, \gamma \quad + (1 - \delta_h) \times \quad h \quad + \delta_h \times \quad H$$

Current LHC constraints by indirect Higgs coupling measurements

$$|\delta_h| < 0.084 \ \text{(95\% CL)} \qquad \textbf{[Lane, Lewis, Sullivan (2024)]}$$
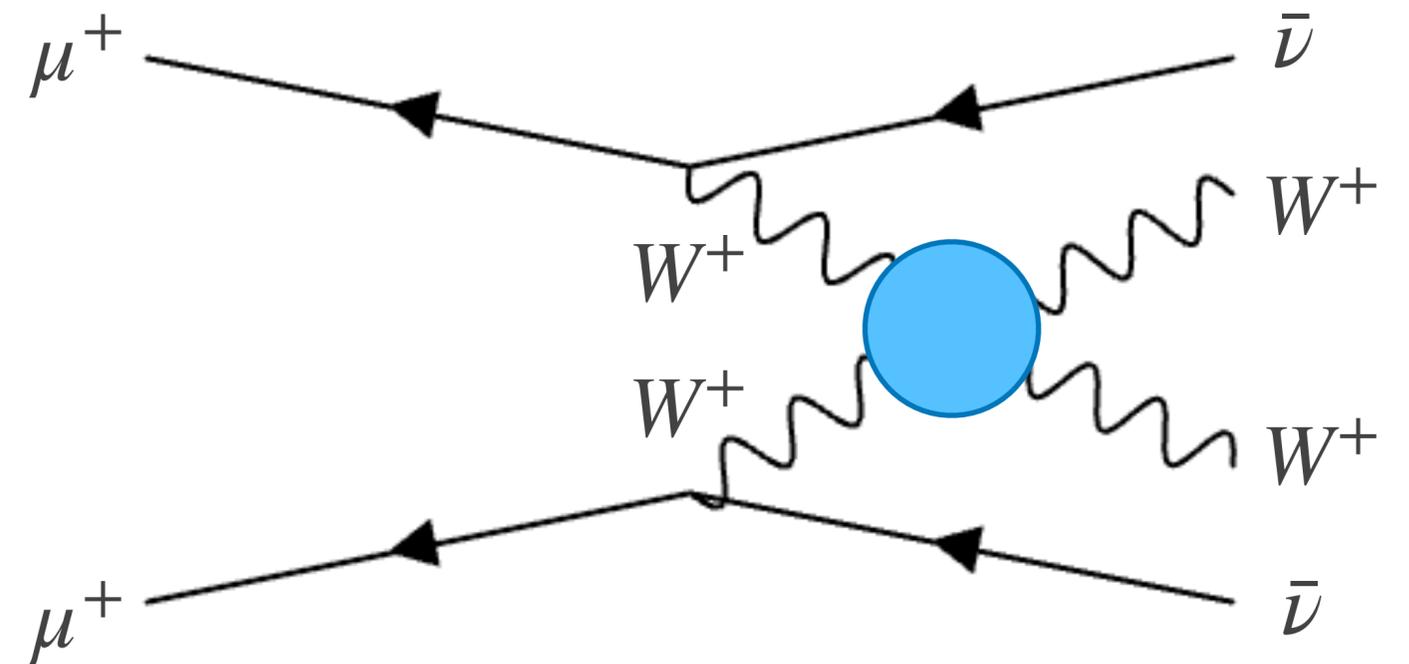
Enhancements of $\sigma(W_L^+ W_L^+ \to W_L^+ W_L^+)$

$\delta_h = 0.02$

Unitarity Bound

Cross section [pb]

SM

Heavier is easier to be detect

$m_H = 8\,\mathrm{TeV}$

$m_H = 4\,\mathrm{TeV}$

$m_H = 2\,\mathrm{TeV}$

$\sqrt{s}\,\mathrm{[TeV]}$
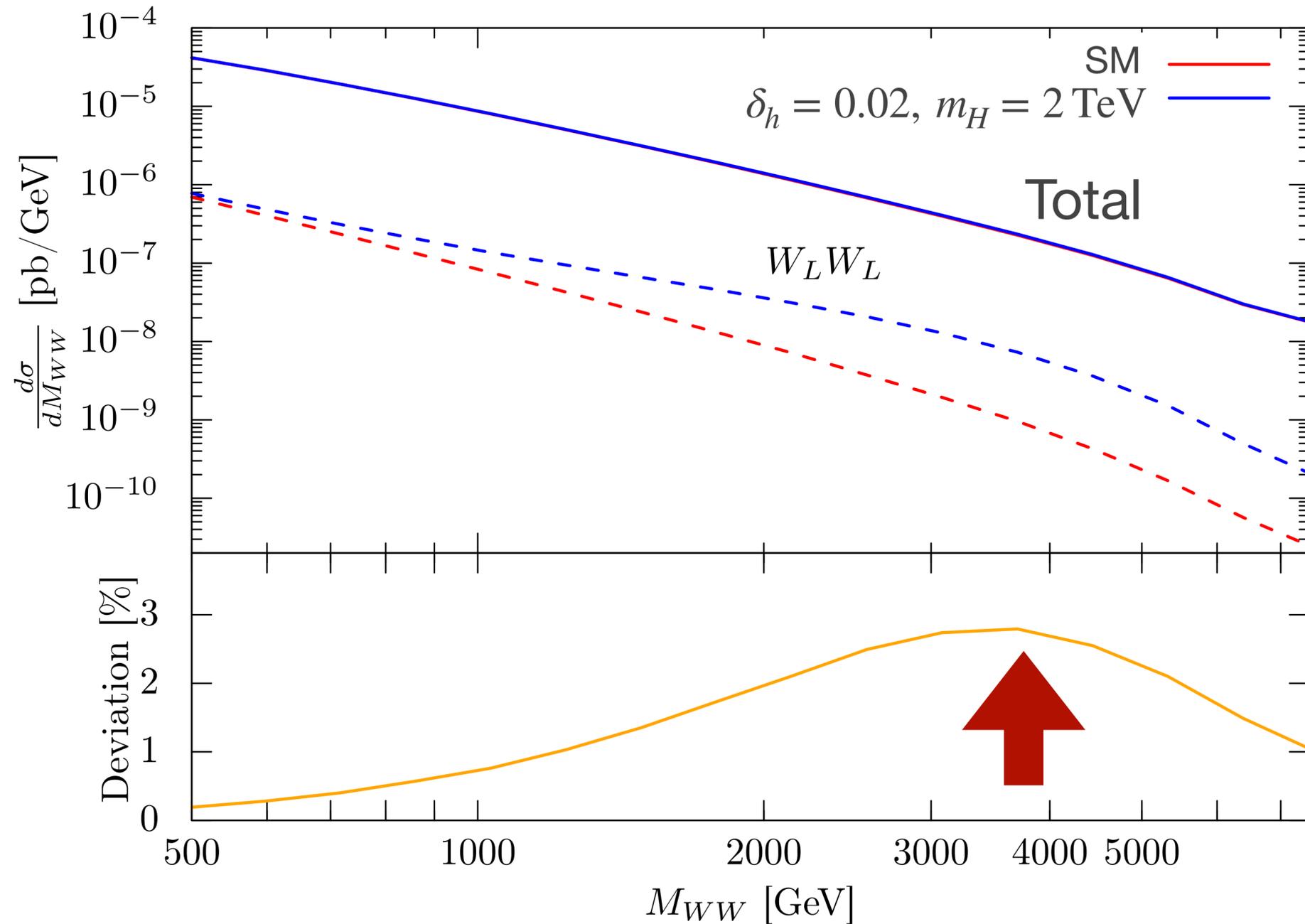
μTRISTAN: $\mu^+\mu^+$ collider

[Hamada, Kitano, Matsudo, Takaura, Yoshida (2022)]

- **Lepton collider**

  ‣ Clean environment

- **High center-of-mass energy**

  ‣ Probe high-energy growth

- **Cooling techniques of μ^+ beam**

  ‣ High luminosity

Ideal for precise measurement of "Higgsness"

Effects on $\sigma_{\text{tot}}(\mu^+\mu^+ \to \bar{\nu}\,\bar{\nu}\,W^+W^+)$

SM
$\delta_h = 0.02,\ m_H = 2\,\text{TeV}$

Total

$W_L W_L$

$W_L W_L$ contribution
suppressed by
small parton luminosity
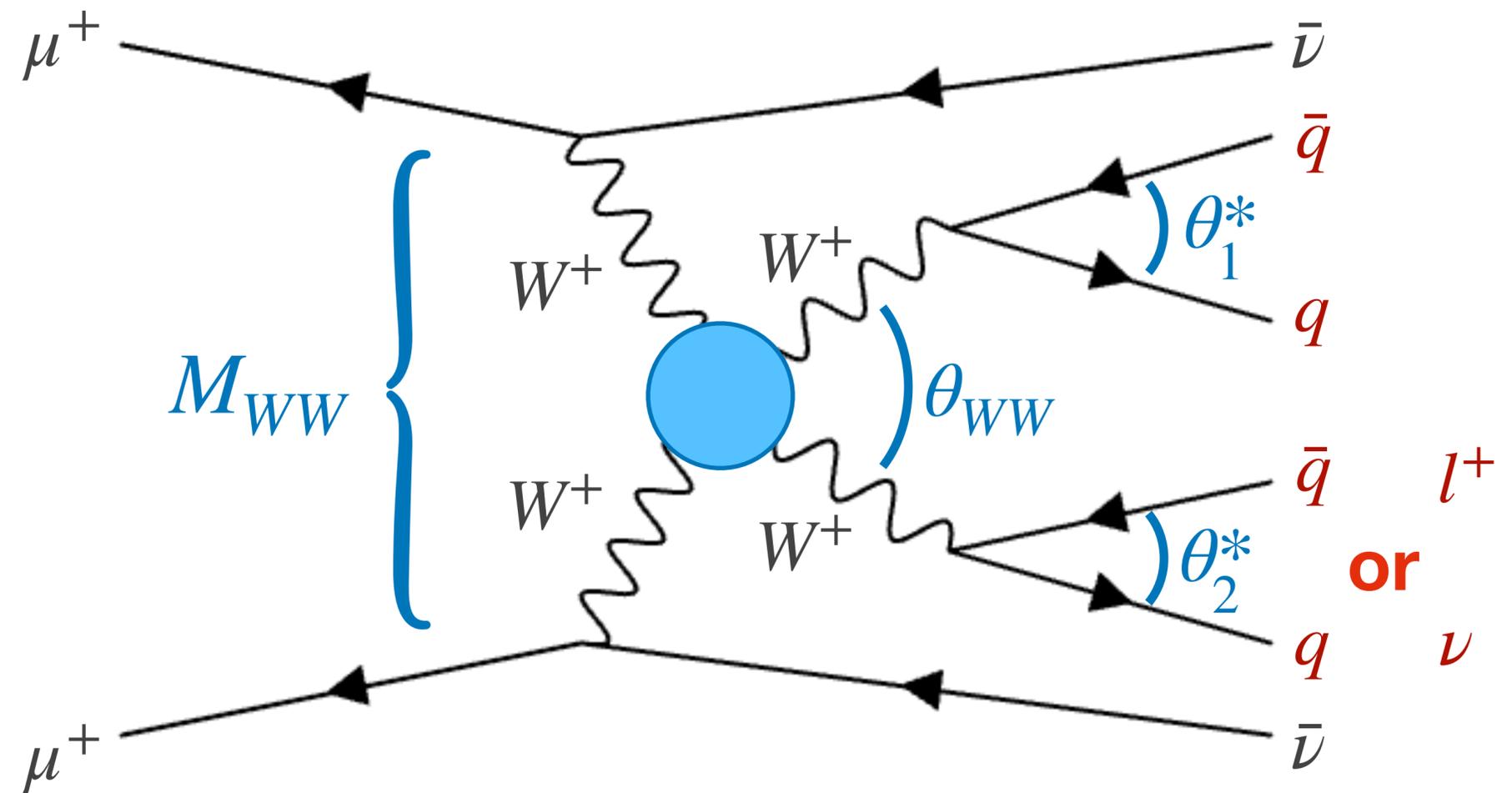
But BSM effect can be $O(1)\,\%$

Kinematic observables

Four observables

- WW invariant mass M_{WW}

- Scattering angle of WW θ_{WW}

- Decay angles of two W's $\theta^*_{1,2}$
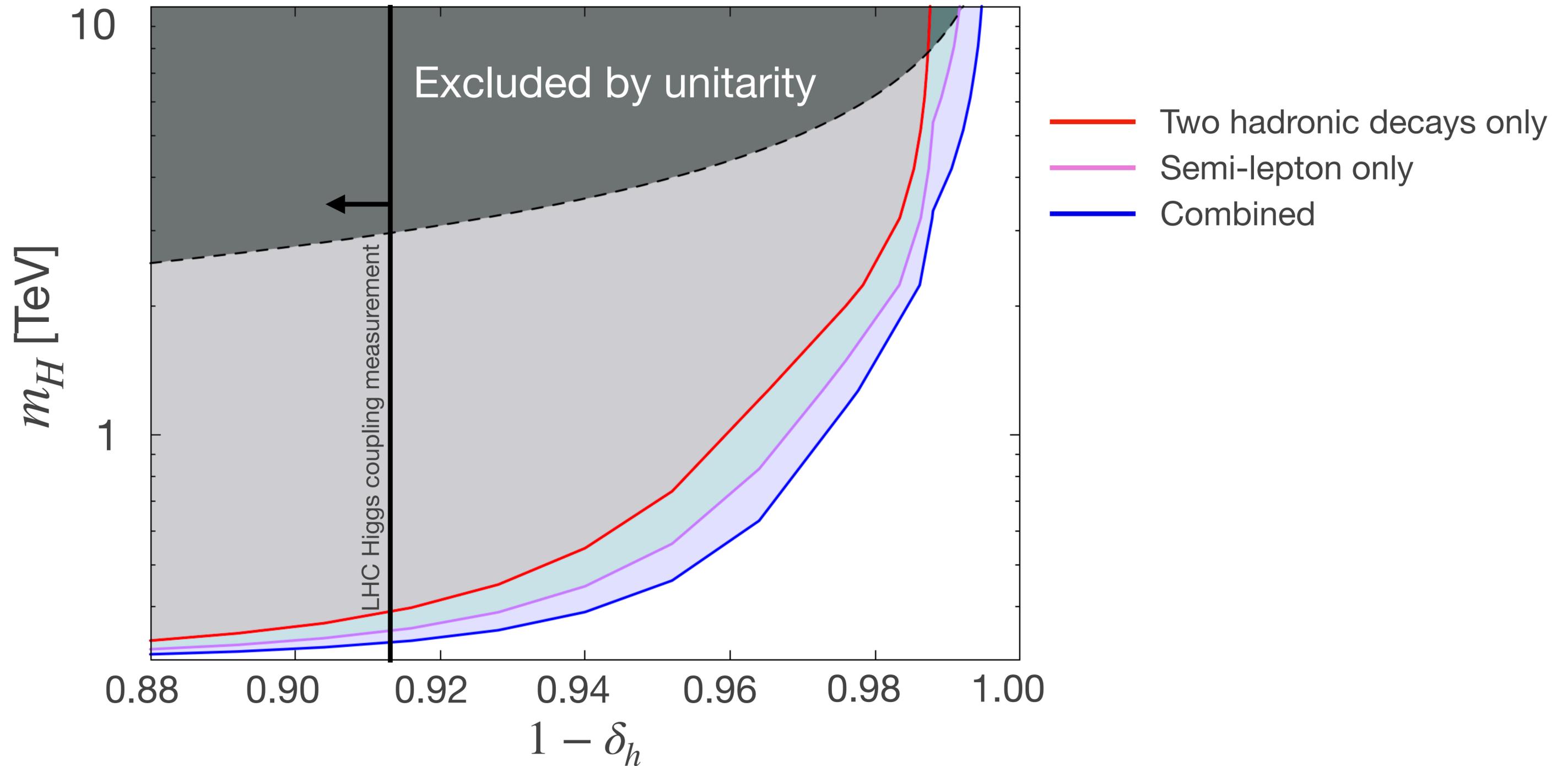
Final States

- Two hadronic decays

- Semi-leptonic (hadronic decay + lepton decay)

Setup for analysis

- Center-of-mass energy: $\sqrt{s} = 10\,\mathrm{TeV}$

- Integrated luminosity: $L = 10\,\mathrm{ab}^{-1}$

- Cuts

  ‣ Invariant mass: $M_{WW} > 800\,\mathrm{GeV}$

  ‣ Pseudo-rapidity: $|\eta| < 1.5$

- Binned χ^2 analysis: 6 bins for M_{WW}, 3 bins for θ_{WW}, 3 bins for $\theta^*_{1,2}$

Results - Sensitivity reach (95% CL)

Summary

- **Higgs is the key to unitarization of Vector Boson Scattering (VBS)**

  - Deviation of hWW coupling can be detected through VBS

- **Same-sign lepton collider $\rightarrow t, u$-channels**

  - Not affected by resonance peaks

  - Complementary probe to s-channel resonance searches

- **µTRISTAN is great test site for Higgs measurements!**

Next steps

- **Other unitarization mechanisms**

  ▸ Heavy vector boson Z' ? Discrimination from scalar case?

- **Estimation of backgrounds**

  ▸ ZW, ZZ, $q\bar{q}$ channels

- **Effective vector approximation vs Full tree-level calculation**

  ▸ Particle distribution function may be less precise in high energies

  ▸ Compare with MadGraph simulation