The W' Search in $SU(2) \times SU(2) \times U(1)$ Models at the Tevatron and LHC

Jiang-Hao Yu

Michigan State University

Based on the work with Ken Hsieh, Zhao Li, Kai Schmitz, and C.–P. Yuan, in preparation

and Ken Hsieh, Kai Schmitz, JY and C.–P. Yuan, arXiv:1003.3482 [hep-ph]

Outline

MICHIGAN STATE UNIVERSITY

Outline

MICHIGAN STATE UNIVERSITY

Motivation

MICHIGAN STATE UNIVERSITY

- Many new physics models contain extended gauge structure, with heavy Z' or W' gauge bosons.
- Phenomenology of the Z' has been studied in many papers. However, researches on the W' are not so popular.
- The minimal gauge structure extension including the W' is $SU(2) \times SU(2) \times U(1)$ ("G221") models.

Outline

MICHIGAN STATE UNIVERSITY

Model Classification

Step One

MICHIGAN STATE UNIVERSITY

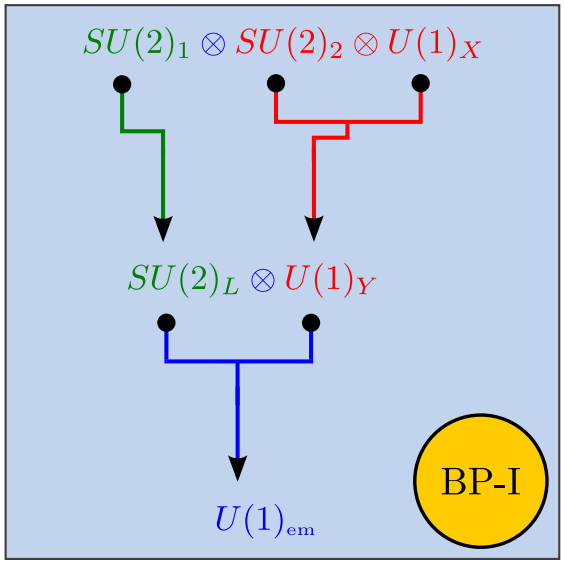
G221 gauge symmetry can be broken in the following ways:

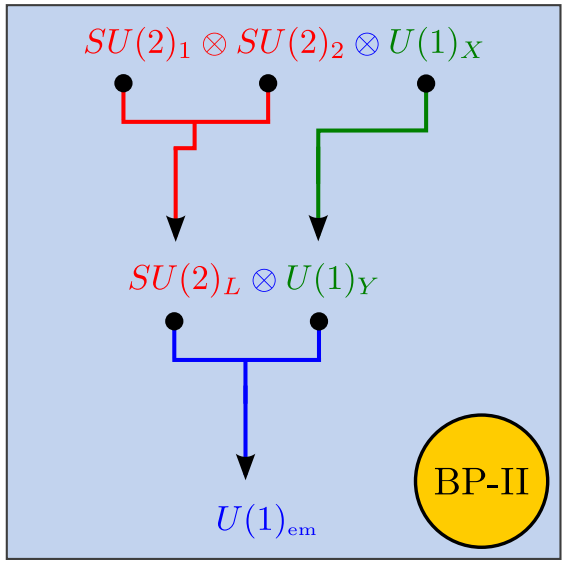
1^{st} stage:

$$\Phi \;\to\; \langle \Phi \rangle \sim \tilde{u} \gtrsim 1\,\text{TeV}$$

2^{nd} stage:

$$H \;\to\; \langle H \rangle \sim \tilde{v} \approx 250\,\text{GeV}$$



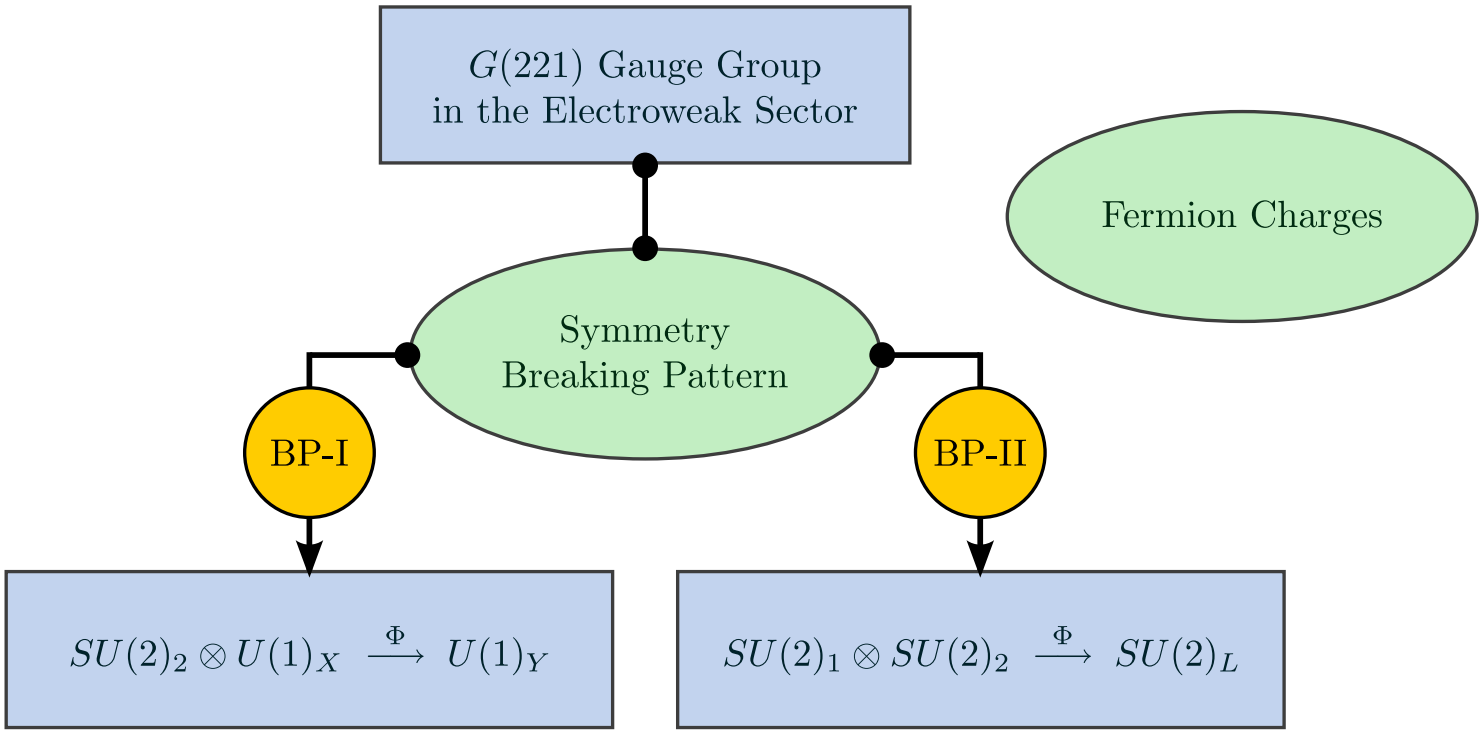


Model Classification

Step Two

MICHIGAN STATE UNIVERSITY

There are different fermion assignments:



Model Classification

Step Two

MICHIGAN STATE UNIVERSITY

There are different fermion assignments:

Model	$SU(2)_1$	$SU(2)_2$	
Left-right	Q_L L_L	Q_R L_R	BP-I
Lepto-phobic	Q_L L_L	Q_R	BP-I
Hadro-phobic	Q_L L_L	L_R	BP-I
Fermio-phobic	Q_L L_L		BP-I
Un-unified	Q_L	L_L	BP-II
Non-universal	Q_L^1 L_L^1 Q_L^2 L_L^2	Q_L^3 L_L^3	BP-II

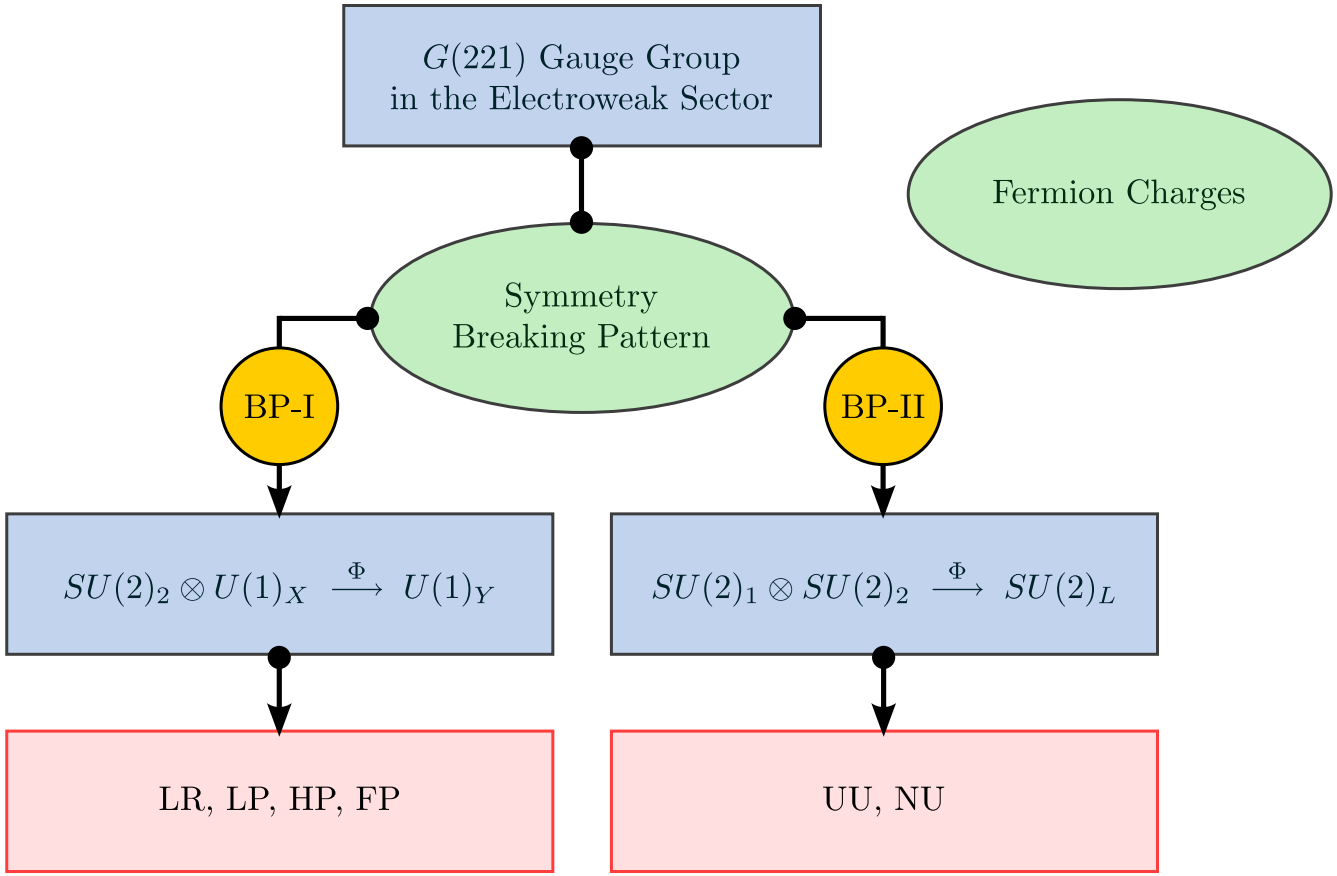
$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$ $L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$ $Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix}$ $L_R = \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$

Model Classification

Step Two

MICHIGAN STATE UNIVERSITY

There are different fermion assignments:

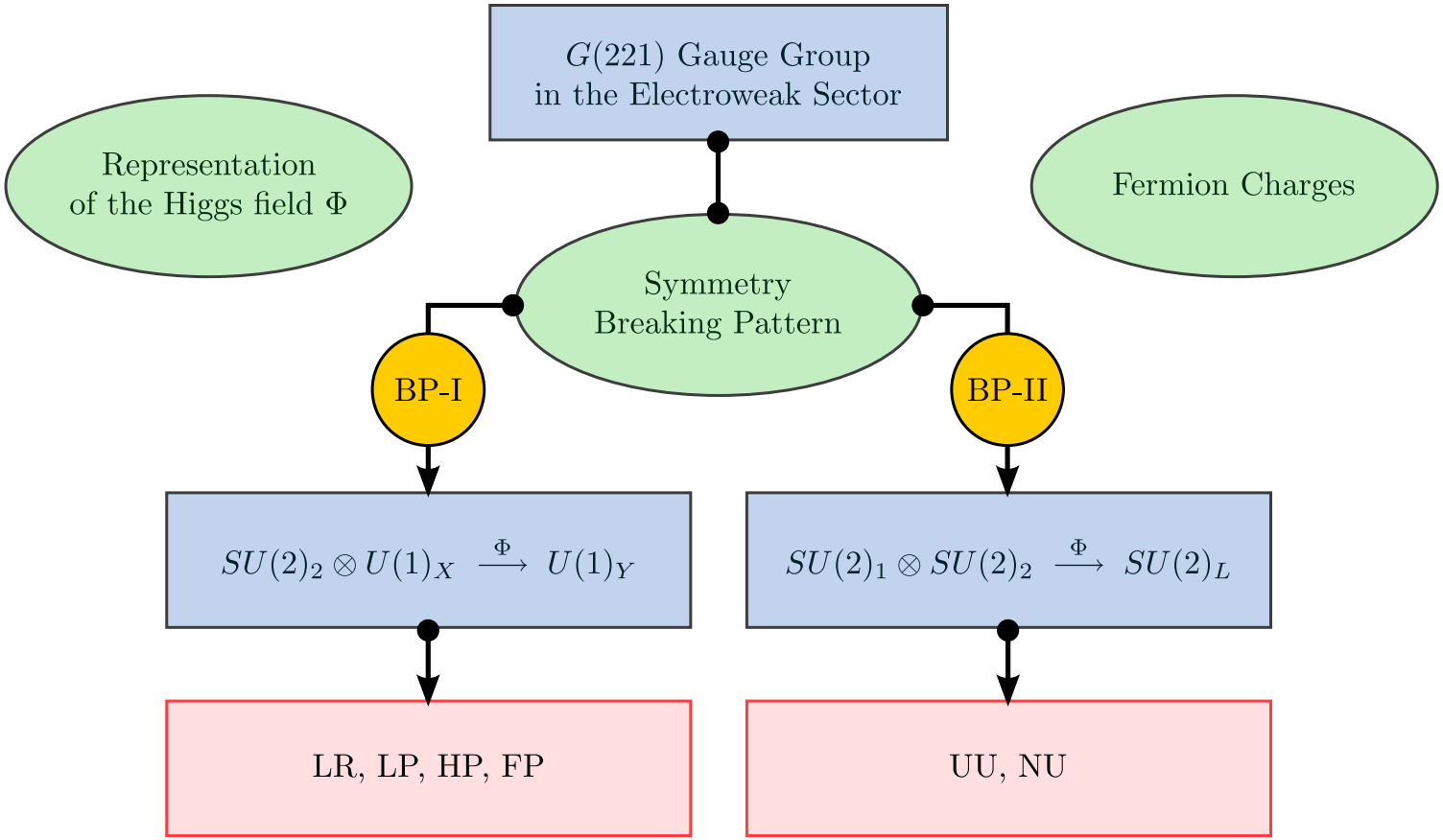


Model Classification

Step Three

MICHIGAN STATE UNIVERSITY

Representation of Higgs fields will further classify:

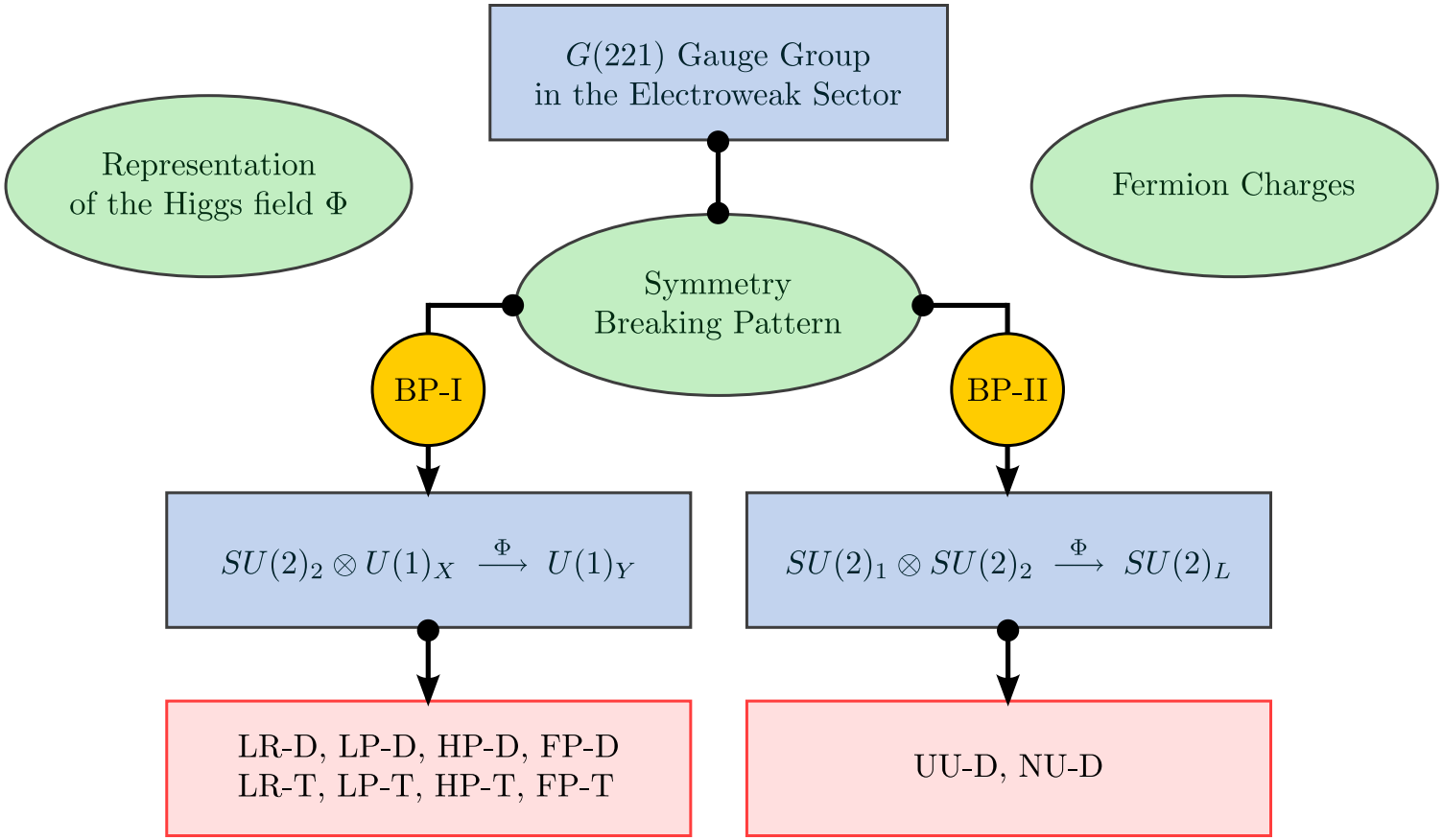


Model Classification

Step Three

MICHIGAN STATE UNIVERSITY

Representation of Higgs fields will further classify:



Model Classification

Step Four

MICHIGAN STATE UNIVERSITY

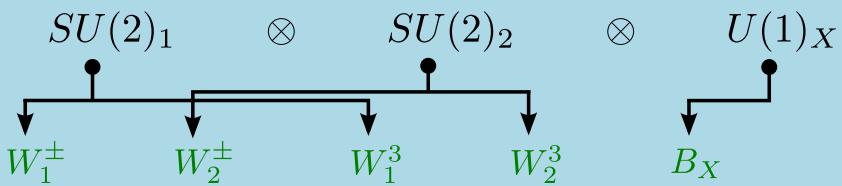
Lists of references:

- R. N. Mohapatra and J. C. Pati, Phys. Rev. D **11**, 2558 (1975); Phys. Rev. D **11**, 566 (1975).
- V. D. Barger, W. Y. Keung and E. Ma, Phys. Rev. D **22**, 727 (1980); Phys. Rev. Lett. **44**, 1169 (1980).
- R. N. Mohapatra and G. Senjanovic, Phys. Rev. D **23**, 165 (1981).
- X. Li and E. Ma, Phys. Rev. Lett. **47**, 1788 (1981).
- H. Georgi, E. E. Jenkins and E. H. Simmons, Phys. Rev. Lett. **62**, 2789 (1989) [Erratum-ibid. **63**, 1540 (1989)]; Nucl. Phys. B **331**, 541 (1990).
- J. Polak and M. Zralek, Phys. Lett. B **276**, 492 (1992).
- E. Malkawi, T. M. P. Tait and C.–P. Yuan, Phys. Lett. B **385**, 304 (1996) [arXiv:hep-ph/9603349].
- D. J. Muller and S. Nandi, Phys. Lett. B **383**, 345 (1996) [arXiv:hep-ph/9602390].
- A. Donini, F. Feruglio, J. Matias and F. Zwirner, Nucl. Phys. B **507**, 51 (1997) [arXiv:hep-ph/9705450].
- J. Chay, K. Y. Lee and S. h. Nam, Phys. Rev. D **61**, 035002 (2000) [arXiv:hep-ph/9809298].
- X. G. He and G. Valencia, Phys. Rev. D **66**, 013004 (2002) [Erratum-ibid. D **66**, 079901 (2002)] [arXiv:hep-ph/0203036].
- R. S. Chivukula, B. Coleppa, S. Di Chiara, E. H. Simmons, H. J. He, M. Kurachi and M. Tanabashi, Phys. Rev. D **74**, 075011 (2006) [arXiv:hep-ph/0607124].

Templete: LR-D model

To be specific, pick up one popular model

MICHIGAN STATE UNIVERSITY



First stage

$SU(2)_2$ doublet: $\Phi \sim (1, 2, \frac{1}{2})$ and $\langle \Phi \rangle \sim \tilde{u}$

Second stage

Bi-doublet: $H \sim (2, \bar{2}, 0)$ and

$$\langle H \rangle \sim \tilde{v} \cdot \begin{pmatrix} \tilde{c}_\beta & 0 \\ 0 & \tilde{s}_\beta \end{pmatrix}$$

Mass Eigenstates

$$x = \frac{\tilde{u}^2}{\tilde{v}^2}, \qquad \text{or} \quad M_{W'} = \frac{e\tilde{v}}{2c_{\tilde{\theta}} s_{\tilde{\phi}}} \sqrt{x}.$$

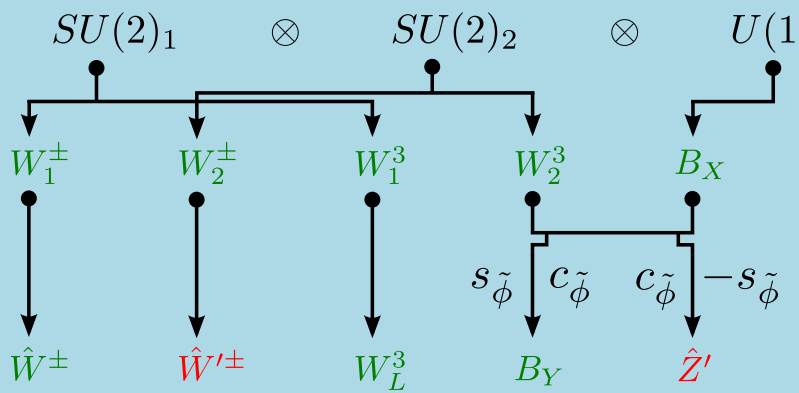
Model parameters (8 in BP-1, 7 in BP-2)

$$(e, \tilde{v}, s_{\tilde{\theta}}, m_t, m_H, c_{\tilde{\phi}}, s_{2\tilde{\beta}}, M_{W'})$$

Templete: LR-D model

To be specific, pick up one popular model

MICHIGAN STATE UNIVERSITY



First stage

$SU(2)_2$ doublet: $\Phi \sim (1, 2, \frac{1}{2})$ and $\langle \Phi \rangle \sim \tilde{u}$

Second stage

Bi-doublet: $H \sim (2, \bar{2}, 0)$ and

$$\langle H \rangle \sim \tilde{v} \cdot \begin{pmatrix} \tilde{c}_\beta & 0 \\ 0 & \tilde{s}_\beta \end{pmatrix}$$

Mass Eigenstates

$$x = \frac{\tilde{u}^2}{\tilde{v}^2}, \qquad \text{or} \quad M_{W'} = \frac{e\tilde{v}}{2c_{\tilde\theta}s_{\tilde\phi}}\sqrt{x}.$$

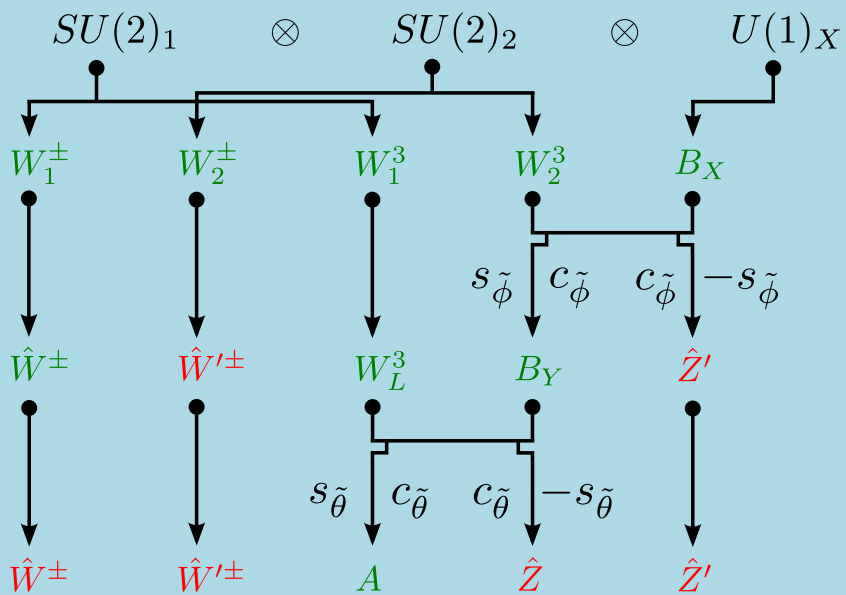
Model parameters (8 in BP-1, 7 in BP-2)

$$(e, \tilde{v}, s_{\tilde\theta}, m_t, m_H, c_{\tilde\phi}, s_{2\tilde\beta}, M_{W'})$$

Templete: LR-D model

To be specific, pick up one popular model

MICHIGAN STATE UNIVERSITY



First stage

$SU(2)_2$ doublet: $\Phi \sim (1, 2, \frac{1}{2})$ and $\langle \Phi \rangle \sim \tilde{u}$

Second stage

Bi-doublet: $H \sim (2, \bar{2}, 0)$ and

$$\langle H \rangle \sim \tilde{v} \cdot \begin{pmatrix} \tilde{c}_\beta & 0 \\ 0 & \tilde{s}_\beta \end{pmatrix}$$

Mass Eigenstates

$$x = \frac{\tilde{u}^2}{\tilde{v}^2}, \qquad \text{or} \quad M_{W'} = \frac{e\tilde{v}}{2c_{\tilde\theta}s_{\tilde\phi}}\sqrt{x}.$$

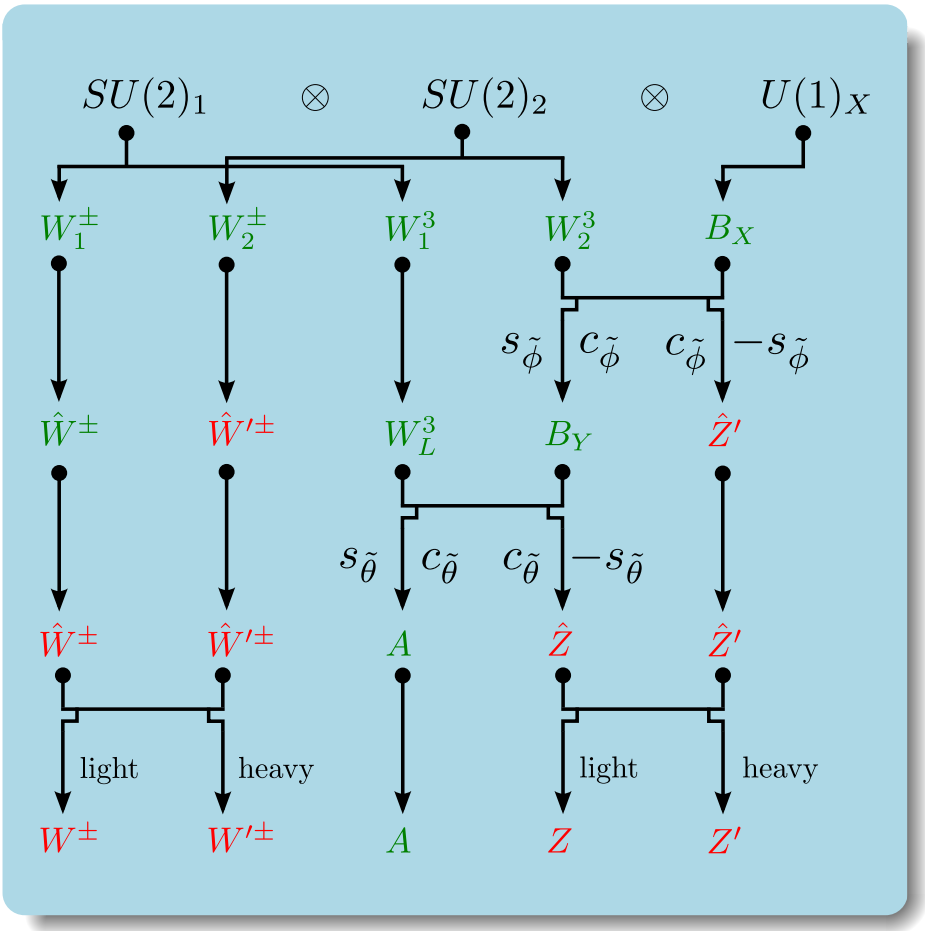
Model parameters (8 in BP-1, 7 in BP-2)

$$(e, \tilde{v}, s_{\tilde\theta}, m_t, m_H, c_{\tilde\phi}, s_{2\tilde\beta}, M_{W'})$$

Templete: LR-D model

To be specific, pick up one popular model

MICHIGAN STATE UNIVERSITY



First stage

$SU(2)_2$ doublet: $\Phi \sim (1, 2, \frac{1}{2})$ and $\langle \Phi \rangle \sim \tilde u$

Second stage

Bi-doublet: $H \sim (2, \bar 2, 0)$ and

$$\langle H \rangle \sim \tilde v \cdot \begin{pmatrix} \tilde c_\beta & 0 \\ 0 & \tilde s_\beta \end{pmatrix}$$

Mass Eigenstates

$$x = \frac{\tilde u^2}{\tilde v^2}, \qquad \text{or} \quad M_{W'} = \frac{e\tilde v}{2 c_{\tilde\theta} s_{\tilde\phi}} \sqrt{x}.$$

Model parameters (8 in BP-1, 7 in BP-2)

$(e, \tilde v, s_{\tilde\theta}, m_t, m_H, c_{\tilde\phi}, s_{2\tilde\beta}, M_{W'})$

Outline

MICHIGAN STATE UNIVERSITY

Indirect Constraints on $M_{W'}$

Global fitting of the low-energy and LEP data (LR-D)

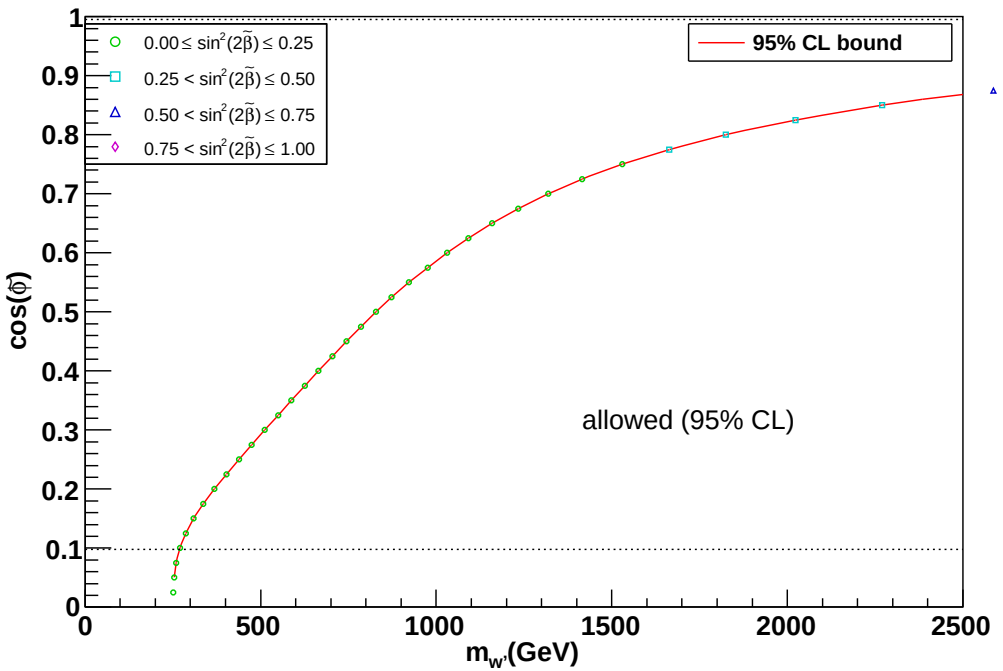
MICHIGAN STATE UNIVERSITY

37 observables included (using GAPP code by J. Erler):

- Z pole data (21): Total width Γ_Z, cross section $\sigma_{\text{had.}}$, ratios $R(f)$, LR, FB, and charge asymmetries $A_{LR}(f)$, $A_{FB}(f)$, and Q_{FB};
- $W^{\pm}$ and top data (3): Mass M_W and total width Γ_W, m_t pole mass;
- νN-scattering (5): NC couplings $\left(g_L^{\nu N}\right)^2$ and $\left(g_R^{\nu N}\right)^2$, NC-CC ratios R_ν and $R_{\bar{\nu}}$;
- νe^--scattering (2): NC couplings $g_V^{\nu e}$ and $g_A^{\nu e}$;
- PV interactions (5): $Q_W\left(^{133}\text{Cs}\right)$ $Q_W\left(^{205}\text{Tl}\right)$, $Q_W(e)$, NC couplings C_1, C_2;
- τ lifetime (1).

Focus on LR-D model in the rest of my talk. For other models, please refer to Ken Hsieh, Kai Schmitz, JY and C.–P. Yuan, arXiv:1003.3482 [hep-ph]

$$\chi^2 \equiv \sum_i \mathcal{P}_i^2 \equiv \sum_i \frac{1}{\sigma_i^2}\left(\bar{\mathcal{O}}_i^{\text{exp.}} - \mathcal{O}_i^{\text{theo.}}\right)^2 \; ; \chi^2_{\text{min.}} = 43.22$$



Indirect Constraints on $M_{W'}$

Global fitting of the low-energy and LEP data (LR-D)

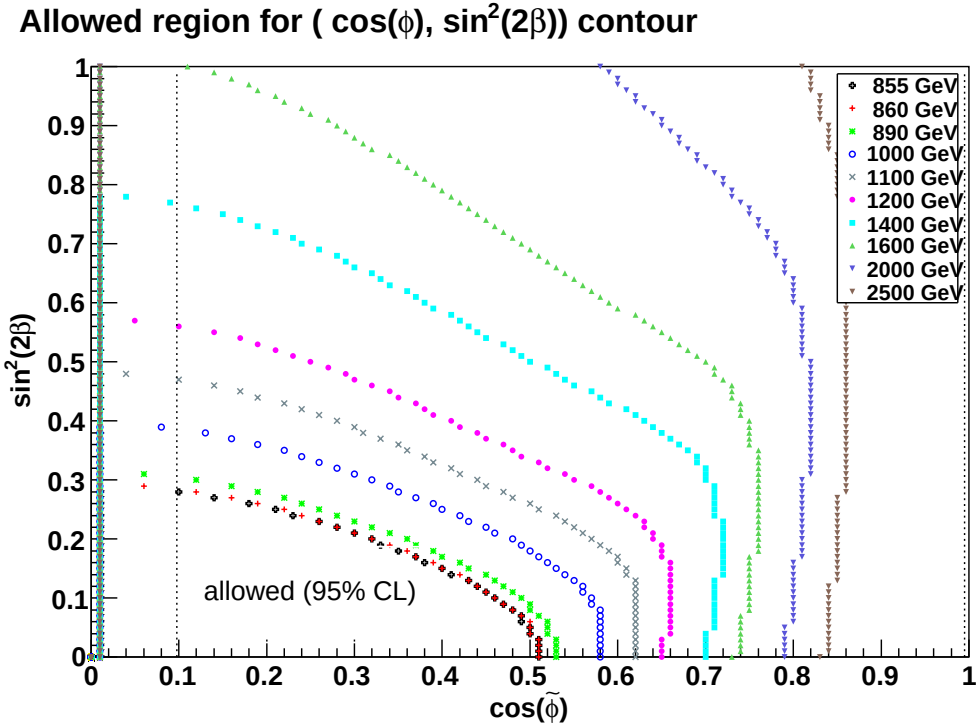
MICHIGAN STATE UNIVERSITY

37 observables included (using GAPP code by J. Erler):

- Z pole data (21): Total width Γ_Z, cross section $\sigma_{\text{had.}}$, ratios $R(f)$, LR, FB, and charge asymmetries $A_{LR}(f)$, $A_{FB}(f)$, and Q_{FB};
- $W^{\pm}$ and top data (3): Mass M_W and total width Γ_W, m_t pole mass;
- νN-scattering (5): NC couplings $\left(g_L^{\nu N}\right)^2$ and $\left(g_R^{\nu N}\right)^2$, NC-CC ratios R_ν and $R_{\bar{\nu}}$;
- νe^--scattering (2): NC couplings $g_V^{\nu e}$ and $g_A^{\nu e}$;
- PV interactions (5): $Q_W\left(^{133}\text{Cs}\right)$ $Q_W\left(^{205}\text{Tl}\right)$, $Q_W(e)$, NC couplings C_1, C_2;
- τ lifetime (1).

Focus on LR-D model in the rest of my talk. For other models, please refer to Ken Hsieh, Kai Schmitz, JY and C.–P. Yuan, arXiv:1003.3482 [hep-ph]

$$\chi^2 \equiv \sum_i \mathcal{P}_i^2 \equiv \sum_i \frac{1}{\sigma_i^2}\left(\bar{\mathcal{O}}_i^{\text{exp.}} - \mathcal{O}_i^{\text{theo.}}\right)^2 \; ; \chi^2_{\text{min.}} = 43.22$$



Direct Constraints on $M_{W'}$

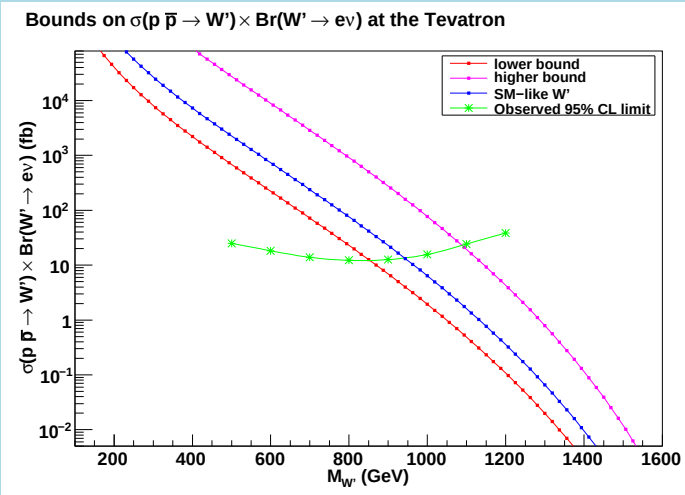
Direct searches at the Tevatron (LR-D)

MICHIGAN STATE UNIVERSITY

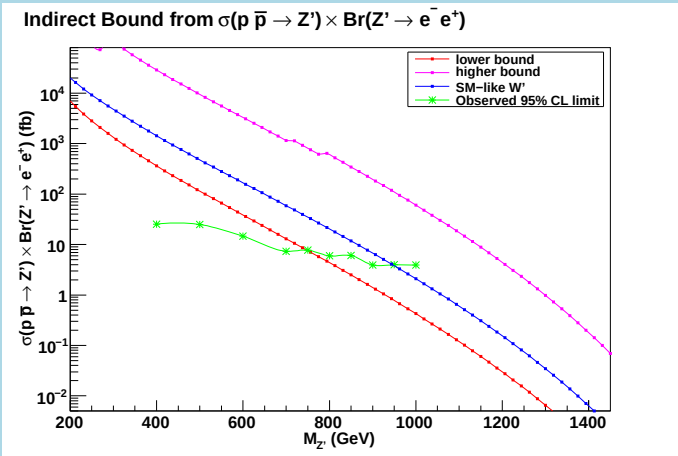
Tevatron Data included:

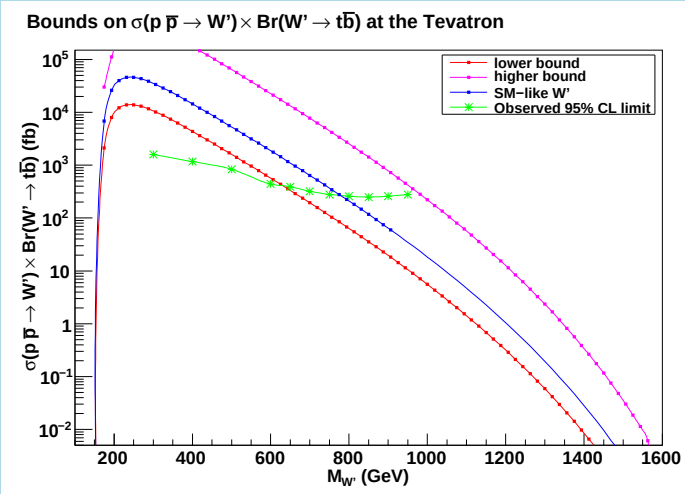
- $p\bar{p} \to W'^{\pm} \to e\nu$ with $\int \mathcal{L}dt = 1.0\text{fb}^{-1}$;
- $p\bar{p} \to W'^{\pm} \to t\bar{b}$ with $\int \mathcal{L}dt = 1.9\text{fb}^{-1}$;
- $p\bar{p} \to Z' \to ee$ with $\int \mathcal{L}dt = 3.6\text{fb}^{-1}$.

Drell-Yan production and decay at NLO are used. The lower bound on $m_{W'}$ is lower than one in the SM-like W' model.



Indirect constraints from Z' search data





Direct Constraints on $M_{W'}$

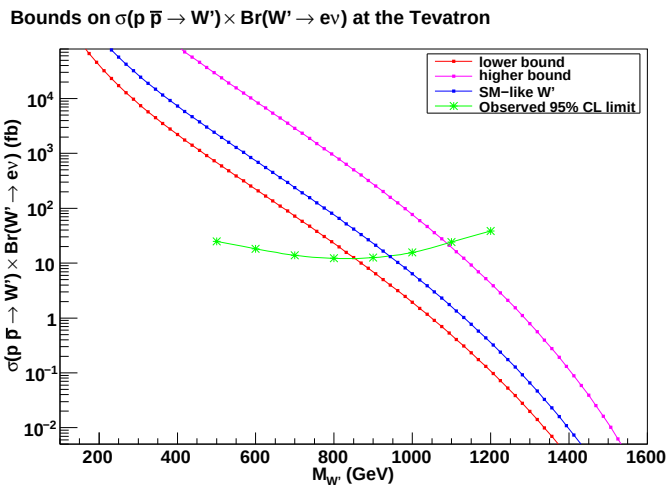
Direct searches at the Tevatron (LR-D)

MICHIGAN STATE UNIVERSITY

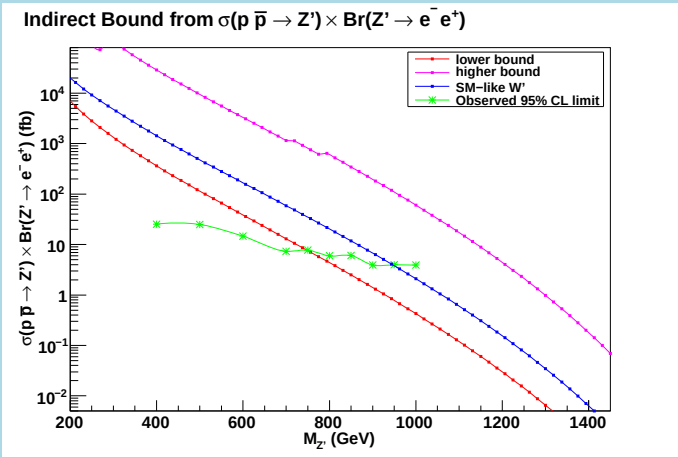
Tevatron Data included:

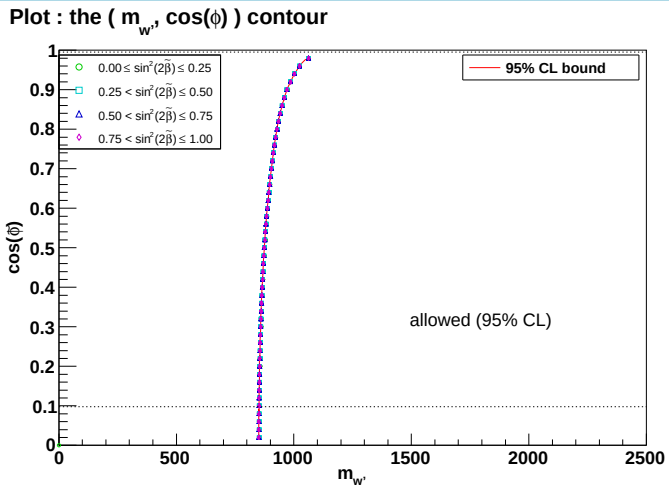
- $p\bar{p} \to W'^{\pm} \to e\nu$ with $\int \mathcal{L}dt = 1.0\text{fb}^{-1}$;
- $p\bar{p} \to W'^{\pm} \to t\bar{b}$ with $\int \mathcal{L}dt = 1.9\text{fb}^{-1}$;
- $p\bar{p} \to Z' \to ee$ with $\int \mathcal{L}dt = 3.6\text{fb}^{-1}$.

Drell-Yan production and decay at NLO are used. The lower bound on $m_{W'}$ is lower than one in the SM-like W' model.



Indirect constraints from Z' search data





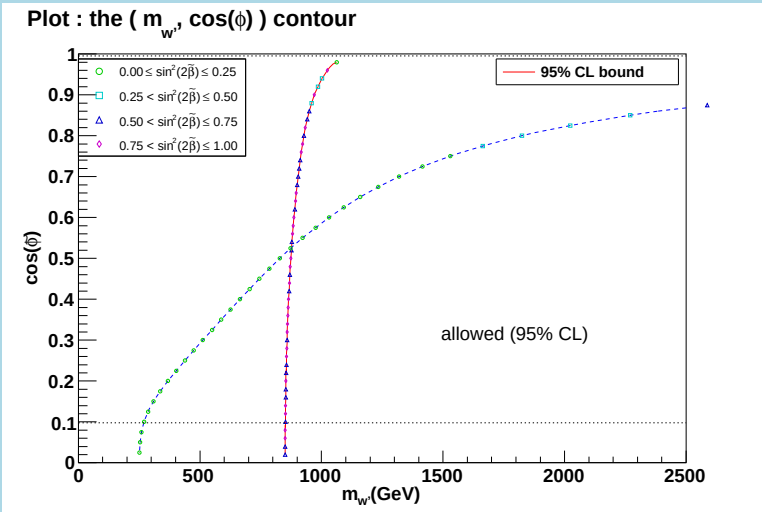
Allowed Parameter Space

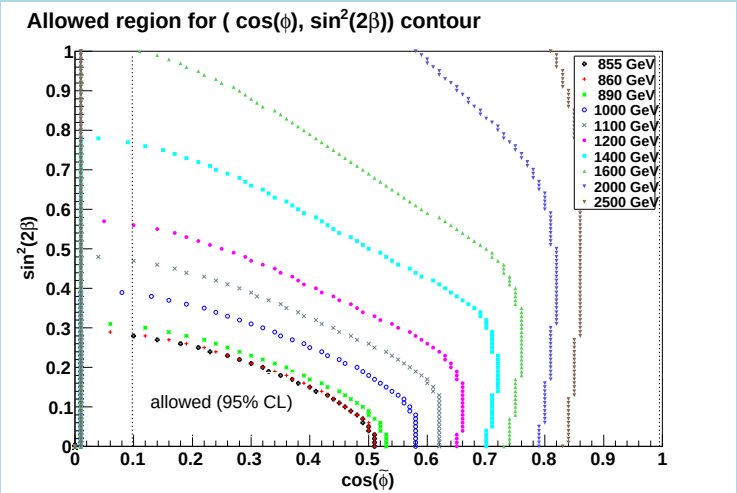
MICHIGAN STATE UNIVERSITY

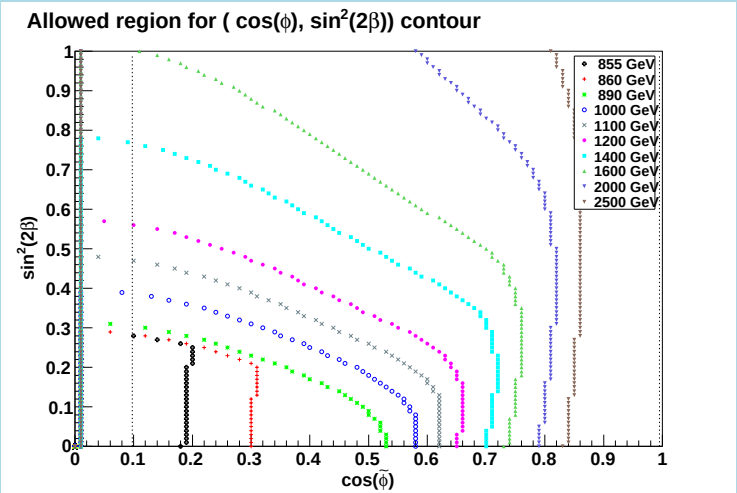
Combine the constraints from the low-energy, LEP, and Tevatron data

Combined constraints:

- Theoretical bounds on the perturbativity of the gauge couplings is included;
- Tevatron data puts strong constraints on $M_{W'}$;
- Drell-Yan production of fermions is not sensitive to parameter $\sin^2(2\tilde{\beta})$;
- Indirect constraints exclude some parameter region that Tevatron data favor.



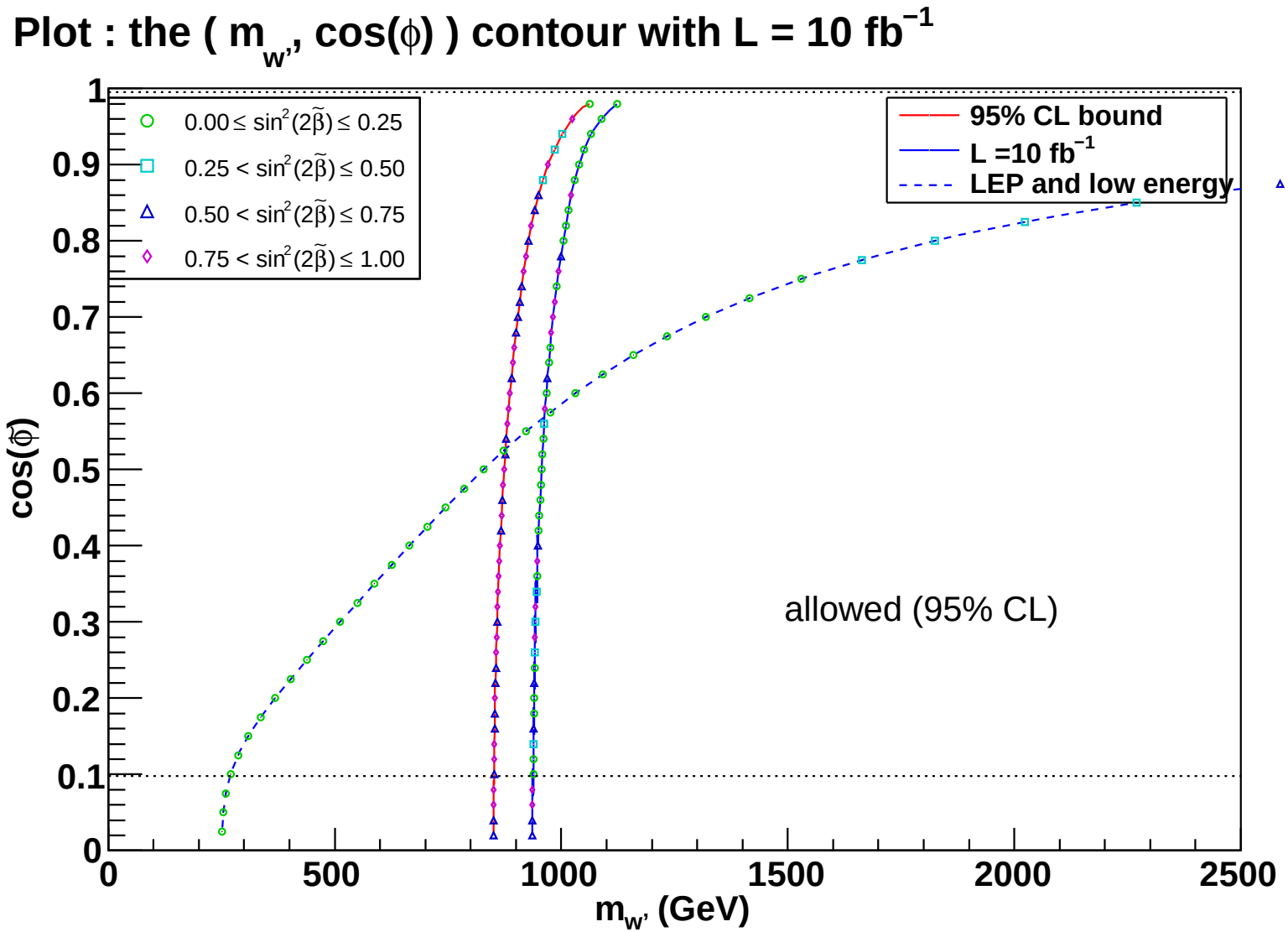




Discovery Potential

Signature space at the Tevatron with $\mathcal{L} = 10\ \mathrm{fb}^{-1}$

MICHIGAN STATE UNIVERSITY



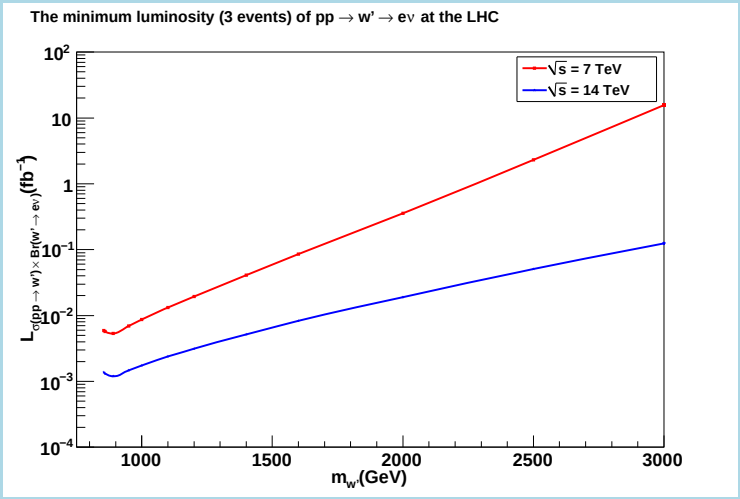
Outline

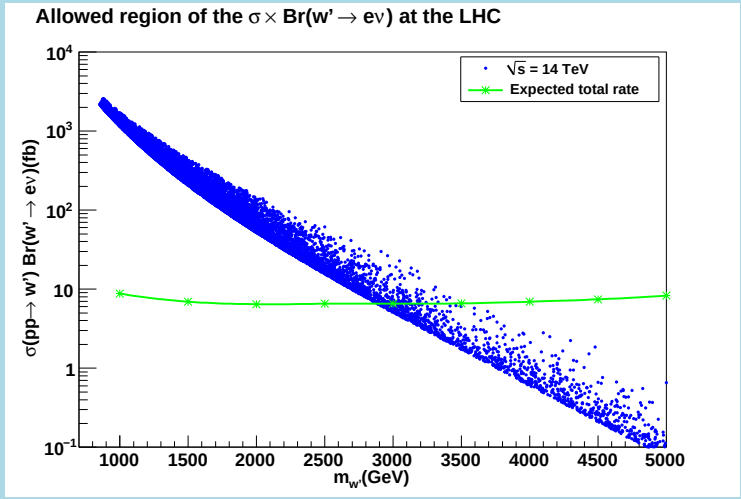
MICHIGAN STATE UNIVERSITY

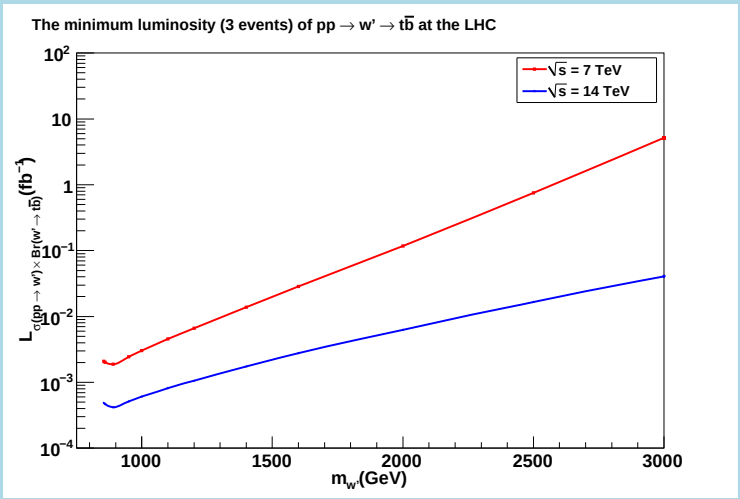
Discovery Potential at the LHC

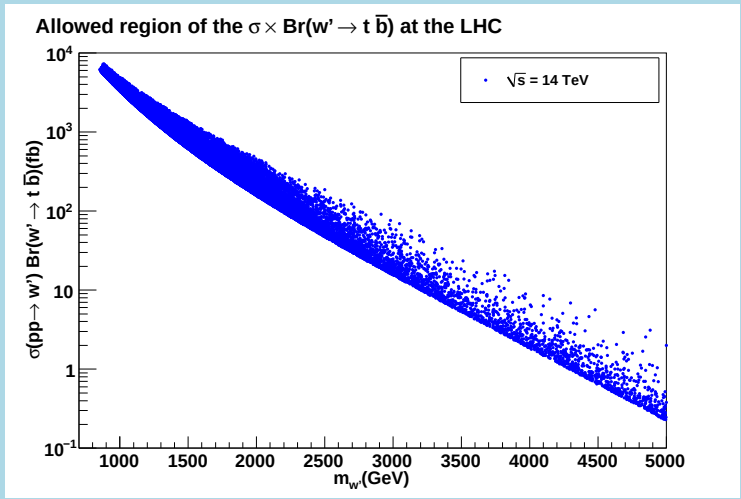
Mininmal luminosity for 3 events (scanning allowed space in LR-D)

MICHIGAN STATE UNIVERSITY







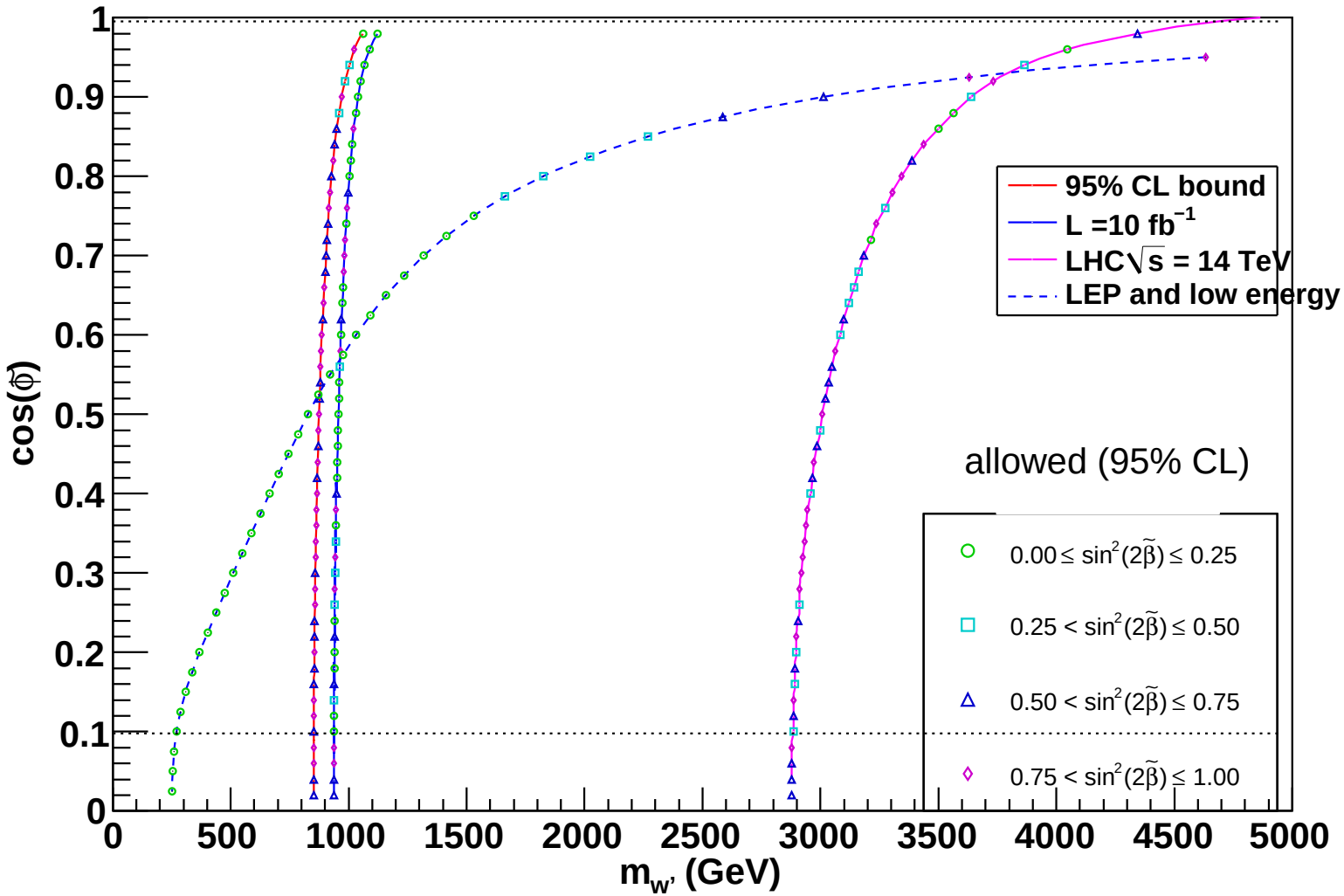


Signature Space at the LHC

Predicted limits from LHC TDR (LR-D)

MICHIGAN STATE UNIVERSITY

Plot : Discovery potential at the LHC



Outline

MICHIGAN STATE UNIVERSITY

Conclusion

MICHIGAN STATE UNIVERSITY

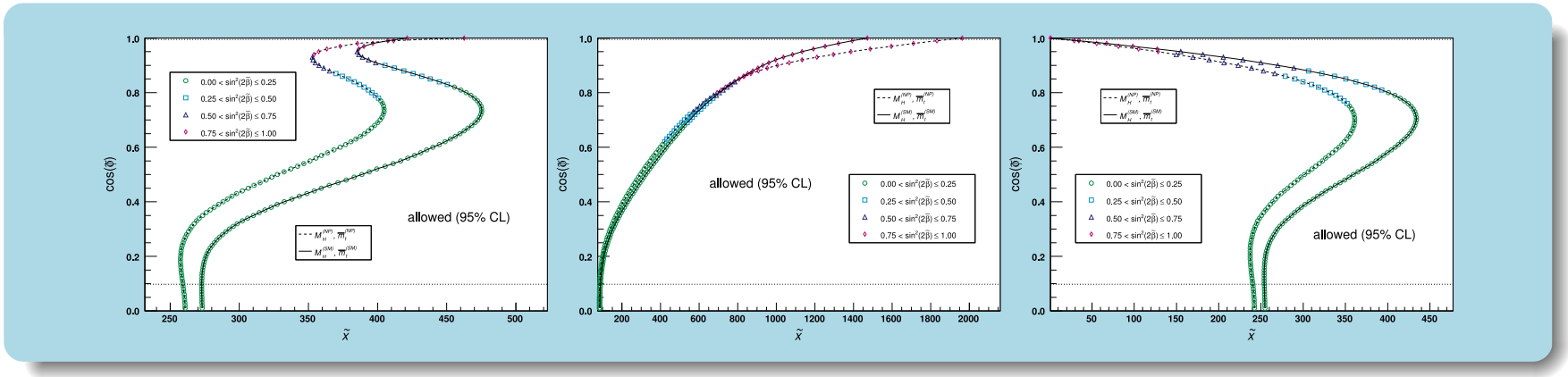
- G221 models (can be viewed as an effective theory description) can be classified based on breaking patterns, fermion assignments, and Higgs representation.
- Tevatron direct searches put the strong bounds on $M_{W'}$, which is lower than one in SM-like W' model. It is important to include indrect data, which are sensitive to model parameters.
- We explore the discovery potential of the W' and signature space at the Tevatron and LHC. At the LHC, the needed luminosity in the single top channel is lower than one in the leptonic channel.
- Although $W' \to WZ$ channel is suppressed, $W' \to WH$ channel has leading-order contribution, and can be served as a golden channel to distinguish the BP-I from BP-II.

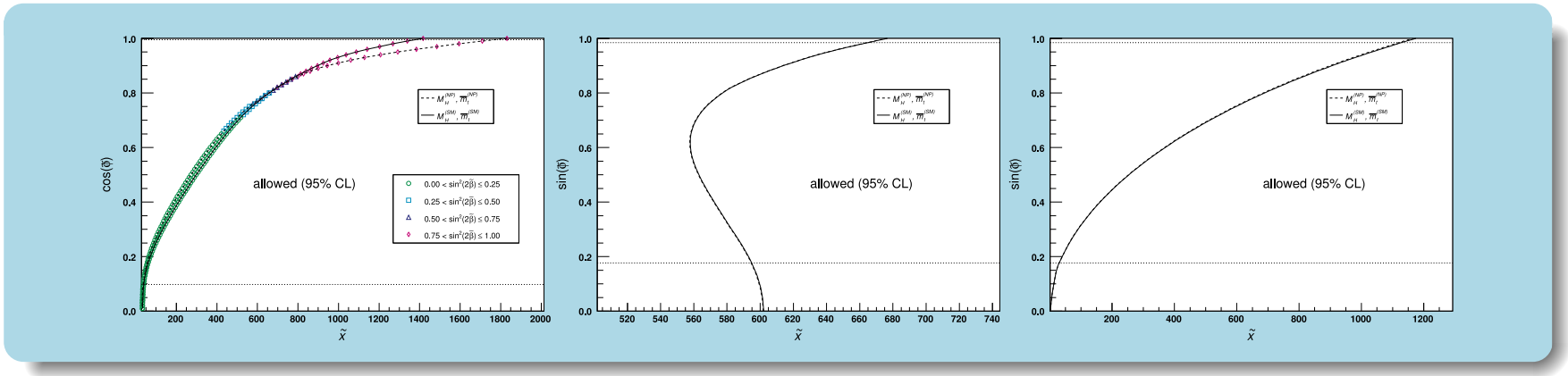
Thanks for your attention!

Backup Slides

Parameter Contour

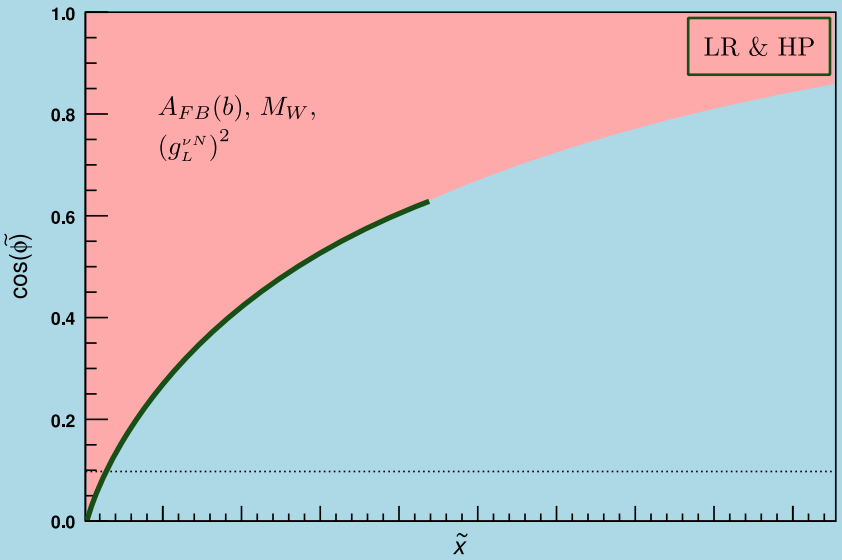
lp-d, hp-d, fp-d, lr-d, nu-d, uu-d models

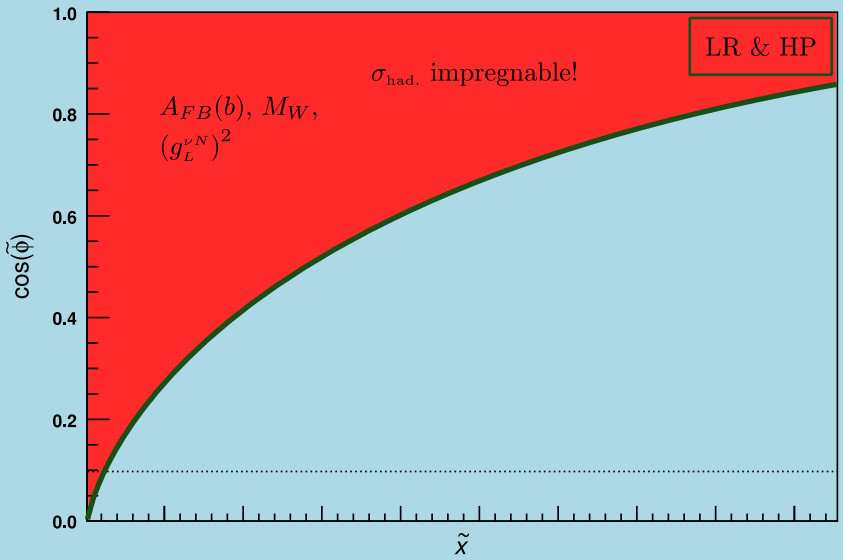




Data Drives the Parameter Contour

MICHIGAN STATE UNIVERSITY



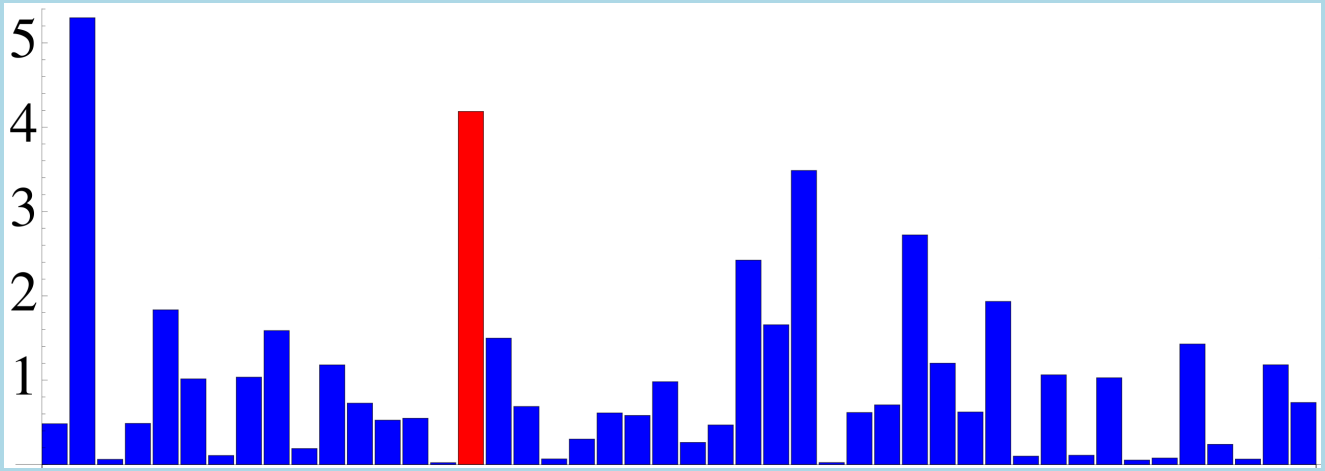


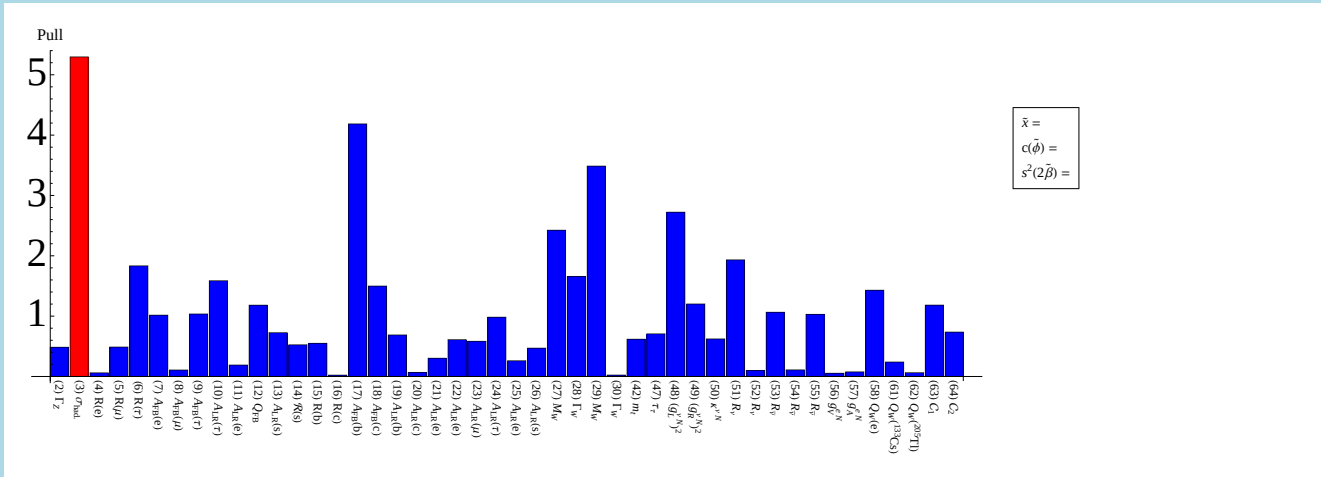
$$\tilde{x}\delta A_{\text{FB}} = -30.0 \cdot c^2_{\tilde{\phi}} + 67.6 \cdot c^4_{\tilde{\phi}} - 20.6 \cdot s^2_{2\tilde{\beta}}$$

$$\tilde{x}\delta \sigma_{\text{had}} = -1.1 \cdot c^2_{\tilde{\phi}} - 0.1 \cdot c^4_{\tilde{\phi}} + 0.04 \cdot s^2_{2\tilde{\beta}}$$

Pulls by Excluded Parameters

MICHIGAN STATE UNIVERSITY





Branch Ratio and total rates at the LHC

MICHIGAN STATE UNIVERSITY