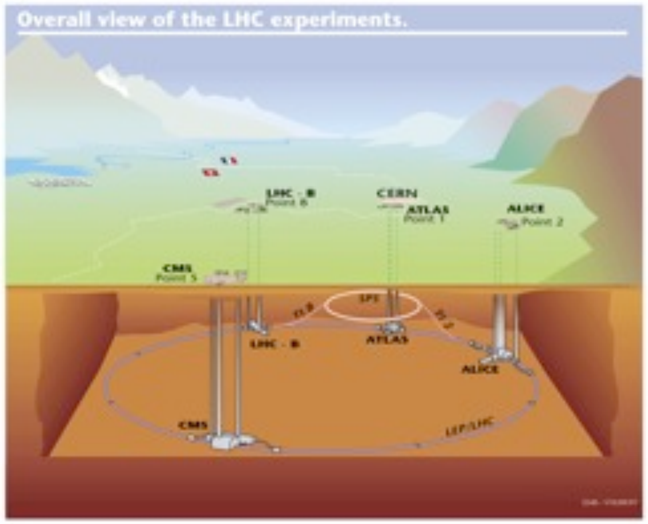
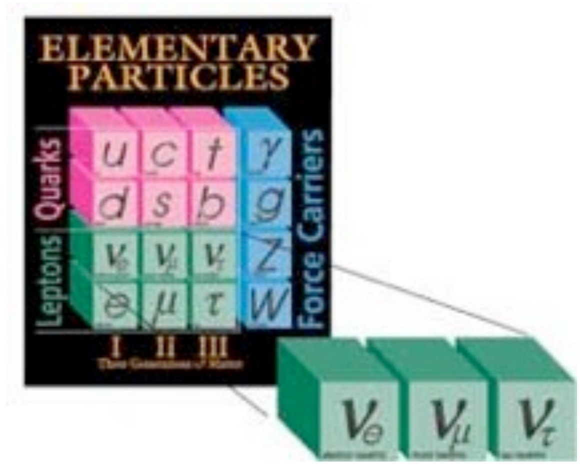
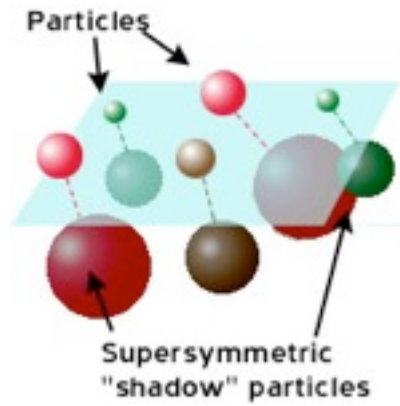
THE UNIVERSITY of WISCONSIN MADISON

Task G: Phenomenology Institute







http://www.pheno.info/

Presentation to the U.S. Department of Energy
August 27, 2010

FY2011 Pheno Institute Faculty

Vernon Barger

colliders, neutrino physics, Higgs physics, unified theories, supersymmetry, astrophysics, cosmology

Lisa Everett

supersymmetry, neutrino physics, string-motivated phenomenology

Tao Han

colliders, extra dimensions, supersymmetry, neutrino physics, Higgs physics, unified models, QCD

Francis Halzen

neutrino astrophysics, collider physics, QCD

FY2011 Pheno Institute Fellows/Postdocs

Neil Christensen

(NSF LHC-TI Fellowship)
collider physics

Pavel Fileviez Perez

(Dirac Fellow)
grand unified theories,
neutrinos, supersymmetry

Sogee Spinner

supersymmetry,
grand unified theories

Maike Trenkel

collider physics,
QCD

Graduate Students of FY2011 Institute Faculty

Barger:

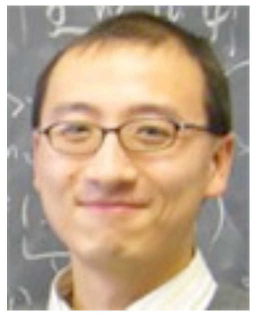
P. Huang

C. Yu

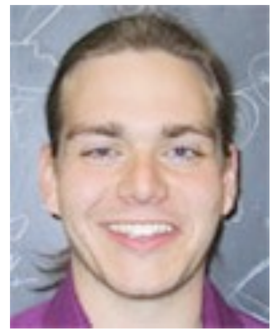
B. Yencho

Everett:

V. Plaus



Y. Rao



A. Stuart

Han:

C. Garcia

I. Lewis (DOE fellow)

Z. Liu

J. Schmitthenner

Z. Dong

Long-Term/Sabbatical Visitors

FY2011

Cheng-Wei Chiang

National Central U., Taiwan

Danny Marfatia

U. Kansas

Gui-Jun Ding

U. of Science & Tech, China

FY2010

Xerxes Tata

U. Hawaii

Marc Sher

William & Mary

Jeonghyeon Song

Konkuk U., S. Korea

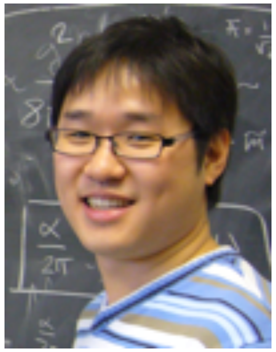
Recent Pheno Institute Fellows/Postdocs

Kathryn Zurek: FY2007-2008

David Schramm Fellow, Fermilab, 2008-2009
Faculty, U. Michigan 2009-present

Thomas McElmurry: FY2007-FY2009

Postdoctoral fellow, BNL 2009-present



Ian-Woo Kim: FY2008-2010

Winner, American Korean Physicist Organization
Outstanding Young Researcher Award (2010)
Postdoctoral Fellow, U. Michigan 2010-present

History/Mission of Pheno Institute

Pheno group formed in 1960's, Institute established in 1984
(after the discovery of the electroweak gauge bosons at CERN)

Mission: HEP research at the theory/experiment interface

Probes of Standard Model and New Physics from
current experiments, physics potential of future facilities

Broad scope: any area where particle physics
may explain experimental observations

collider physics, neutrino physics, astrophysics, cosmology

Impact of Pheno Institute

Research Impact: many important/highly cited contributions

Seminal advances: Collider search strategies for Higgs

SUSY models/RGE/search strategies

Feynman rules/signatures of large extra dimensions

Matter effects/CPV in neutrino oscillations

Ongoing support of experimental programs:

Tevatron, LHC, Neutrino and Muon Programs, IceCube

Stay tuned for recent research highlights!

Impact of Pheno Institute

Training of Students and Postdocs

More grad students and postdocs trained in phenomenology at UW-Madison Pheno than at any other U.S. university

50% of grad students and 74% of postdocs now hold academic or lab positions in physics

Conferences and Summer Schools

Annual Pheno Symposia (32nd held in 2010):

largest student attendance among any U.S. HEP conference/ school, now regarded as first-level international meeting

CTEQ Summer Schools: held every other year at UW-Madison

Local organizers: B. Mellado (CTEQ), Y. Pan, T. Han, A. Lefkow

Order of Presentation

Tao Han

Maike Trenkel

Neil Christensen

Lisa Everett

Sogee Spinner

Pavel Fileviez Perez

Vernon Barger

Presentation for DOE Review

Tao Han (August 27, 2010)

Tevatron and LHC Phenomenology

(since Jan. 2007)

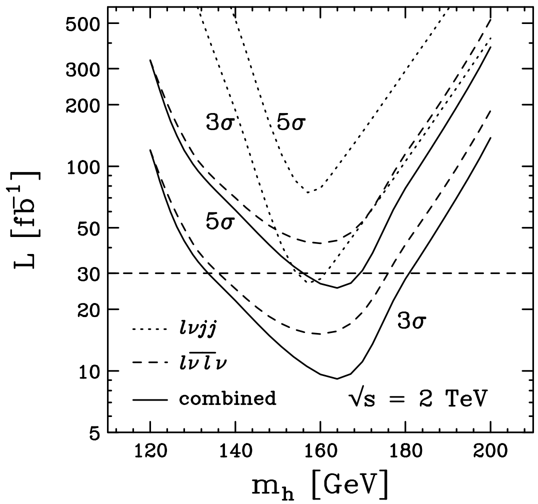
Research Directions:

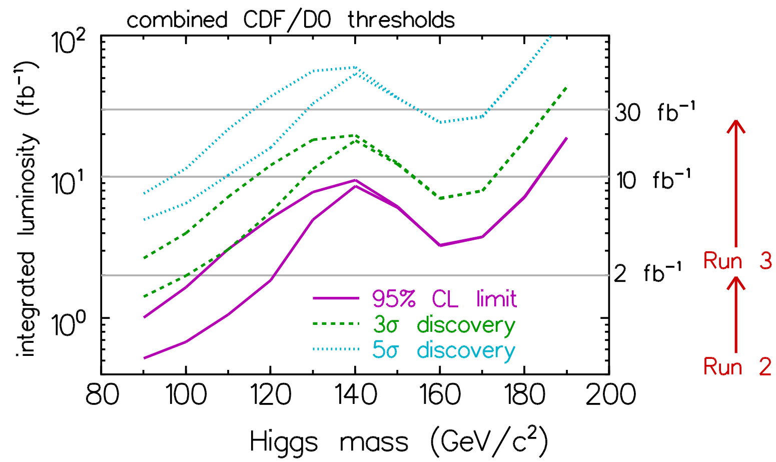
- Collider phenomenology of electroweak symmetry breaking.
- Top quark as a window to new physics.
- Determining missing particle mass (dark matter connection).
- Majorana neutrinos and lepton-number violation.
- Construction of genuine CP odd variables at the LHC.
- Strategies of searching for new gauge bosons and fermions.

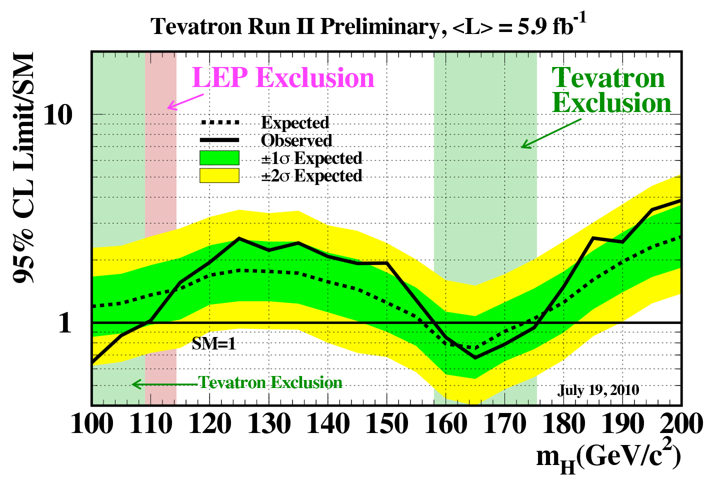
I. A Few Highlights:

(1). $H \to WW^*,\ \tau^+\tau^-,\ 4b's$ at the Tevatron

The first proposal $H \to WW^*$ and Run-II workshop: *



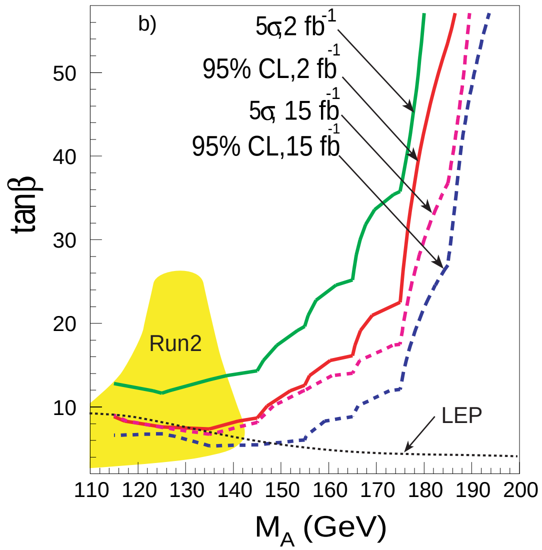


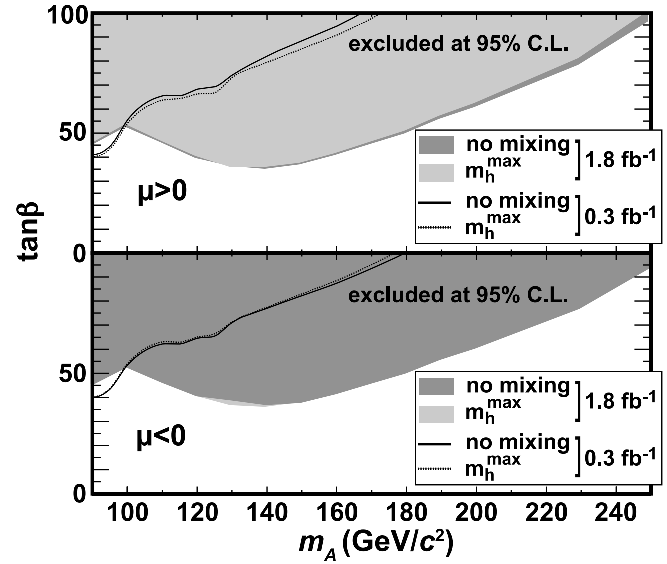


(led by Matt Herndon)

*T. Han and R.-J. Zhang, PRL, **82**, 25(1999),
T. Han, A. Turcot and R.-J. Zhang, Phys.Rev.D59:093001 (1999).

- Search for $h, H, A \to \tau^+\tau^-$ very important! †





CDF/D0 carried out the studies ‡

- Search for $h, H, A \to aa \to \tau^+\tau^-\ 2b,\ 4b$ also important! §

CDF/D0 carried out the studies ¶.
The sensitivity is similar to the above.

†T. Han, A. Belyaev, R. Rosenfeld, JHEP 0307:021 (2003).

‡CDF/D0 τ mode: arXiv:0906.1014.

§M. Carena, T. Han, G. Huang, C. Wagner, JHEP 0804:092 (2008).

¶CDF/D0 $b\bar{b}$'s: arXiv:0811.0024.

• Strong $W_L W_L$ scattering at the LHC ‖

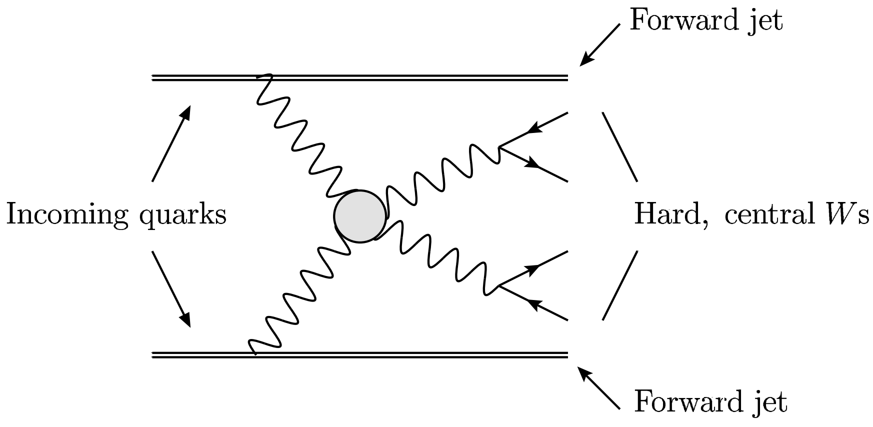
With or without a light Higgs, the study is needed.

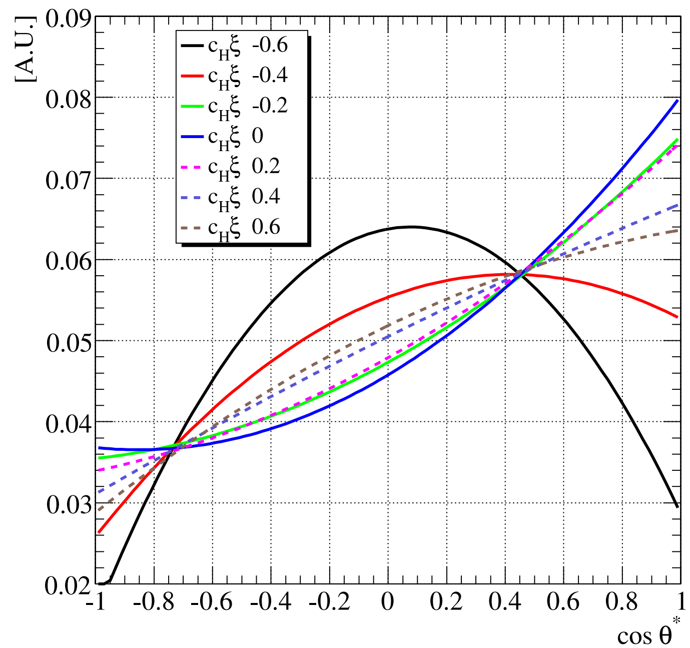
– Making use of the gauge boson polarization

– Fit the distributions to get the ratio $W_L W_L / W_T W_T$

– This probes E^2-growth of longitudinal vector boson scattering

– The technique is stable against the QCD effects.



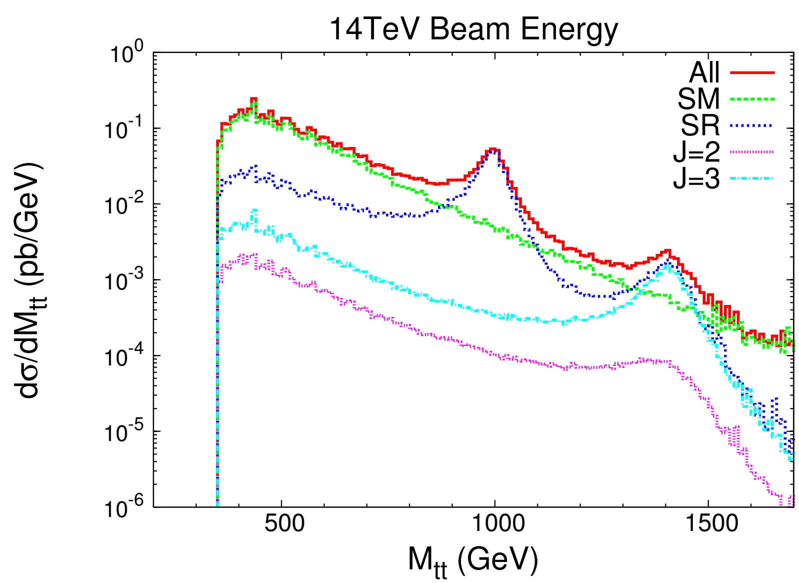


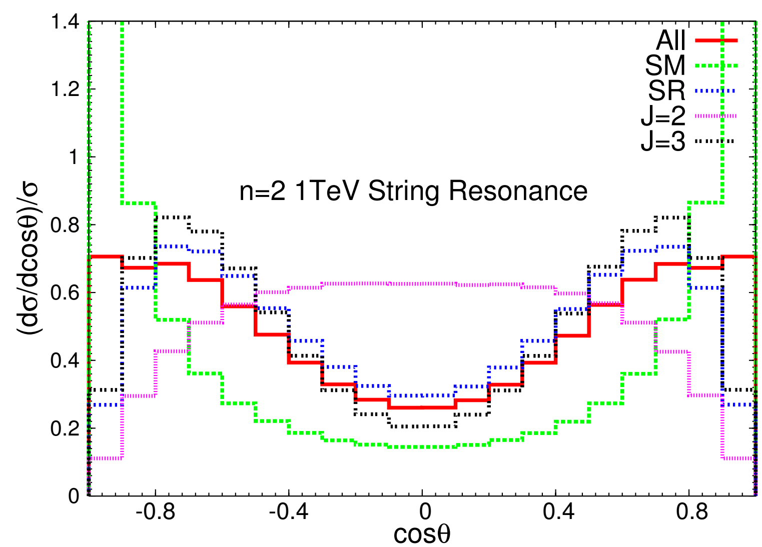
‖T. Han, D. Krohn, L.-T. Wang, W.-H. Zhu, JHEP, JHEP 1003:082 (2010).

(2). Top quark as a window for new physics
(Top-2010 conference summary: "Vision from the Top")

• Search for TeV-scale string resonances:

Following our early work to reconstruct a $t\bar{t}$ resonance, **
– Possible to observe string resonances up to about 4 TeV. ††
– If so, likely to observe more than one states.
– Their mass ratio and distinctive angular distributions can be characteristic.

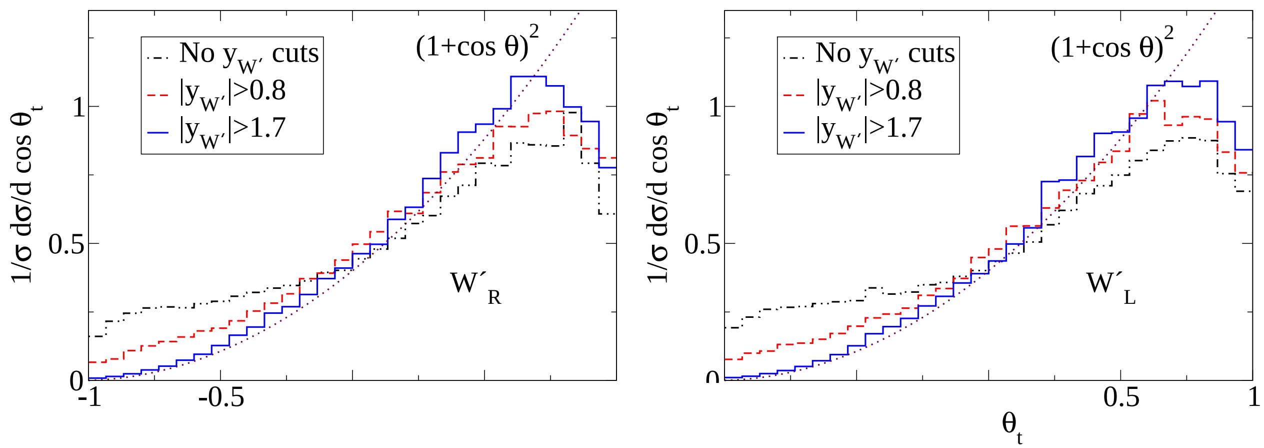


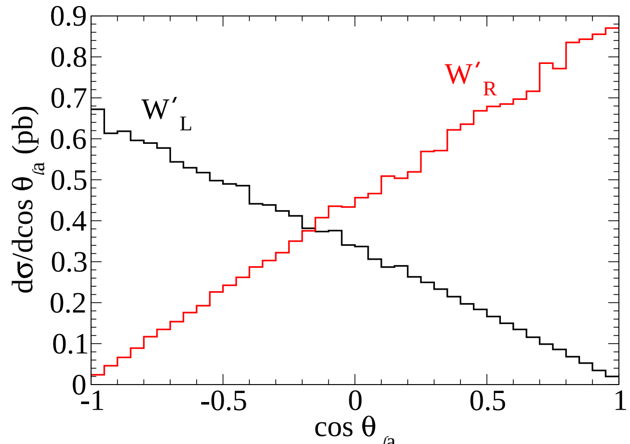


**V. Barger, T. Han, D. Walker, PRL 100:031801 (2008).
††Z. Dong, T. Han, M.X. Huang, G. Shiu, arXiv:1004.5441.

- Top polarization as a diagnostic tool: ‡‡

In $W' \to t\bar{b} \to \ell\nu, b$, the top-quark decay products carry information on the W' chirality, not available for light quarks nor leptons.



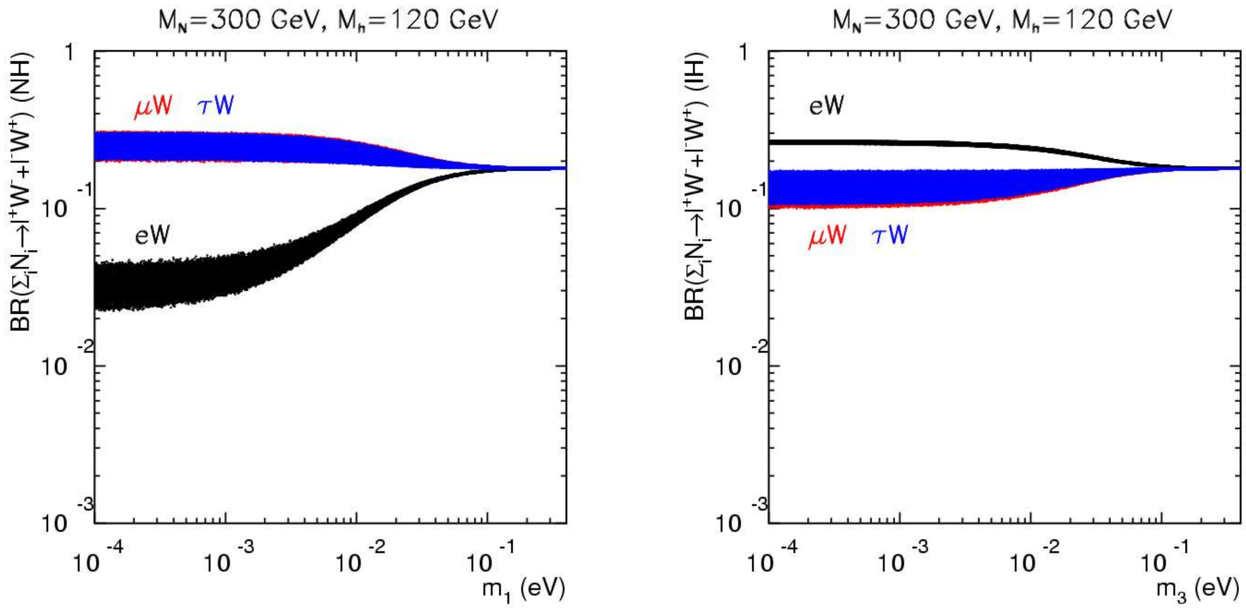


(Lepton & top-spin angle)

‡‡Shri Gopalakrishna, Tao Han, Ian Lewis, Zong-guo Si, Yu-Feng Zhou, arXiv:1008.3508.

(3). Neutrino mass and the LHC *

Neutrino mass pattern (NH or IH) may be tested at the LHC!
If the neutrino mass generation is due to a "seesaw" mechanism, then the related heavy particle N, $H^{\pm}$, $H^{\pm\pm}$, $T^{\pm}$... decays would be correlated with the mass pattern.
e.g. in Type I seesaw, the heavy Majorana neutrinos may decay like:

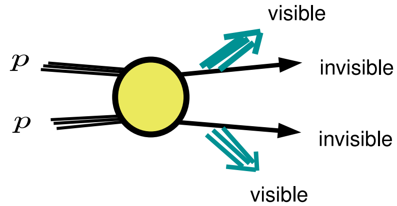


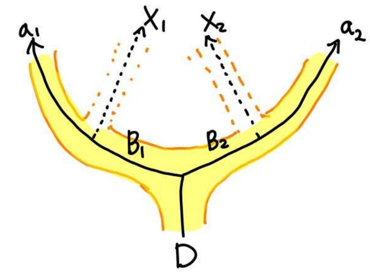
Similar study for Type II seesaw see Pavel's talk.

*Pavel Fileviez Perez, Tao Han, Gui-yu Huang, Tong Li, Kai Wang, Phys.Rev.D78:015018 (2008);
Pavel Fileviez Perez, Tao Han, Tong Li, Phys.Rev.D80:073015 (2009).

(4). Determining the missing particle mass *

It is extremely challenging to reconstruct the mass of the *two* missing particles. We examined a different kind of kinematics, an "antler decay":

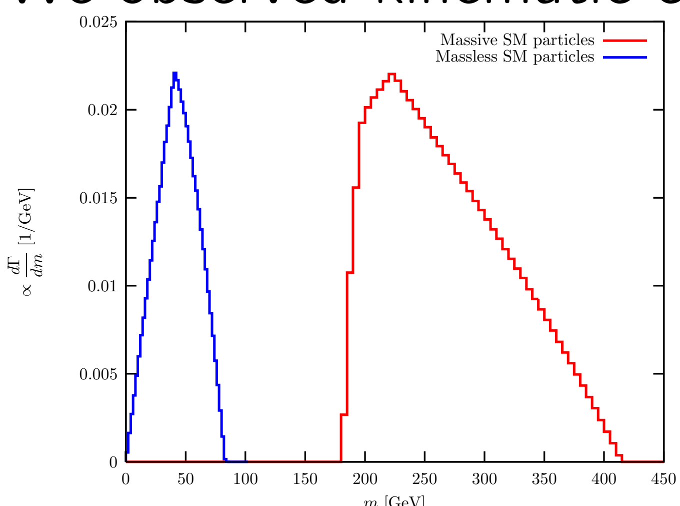




$$D \to A_1 A_2 \to (a_1 X_1)\ (a_2 X_2)$$

where a_1 and a_2 are observable SM particles and X_1 and X_2 are missing particles (the DM candidates).

We observed kinematic cusp structures:



$$M_{aa}^{\text{max}} = m_B \left(1 - \frac{m_X^2}{m_B^2}\right) e^{\eta},$$

$$M_{aa}^{\text{cusp}} = m_B \left(1 - \frac{m_X^2}{m_B^2}\right) e^{-\eta}.$$

*Tao Han, Ian-Woo Kim, Jeonghyeon Song, e-Print: arXiv:0906.5009.

II. Publications since Jan. 2007:

In close collaboration with students (currently 5),

postdocs and researchers world-wide (both theorists & expts),

28 in journals; 8 in proceedings; 1 book edited.

Selected papers:

(Magenta names are students, Greens are postdocs.)

1. Higgs Signal for $h \to aa$ at Hadron Colliders
M. Carena, T. Han, G.-Y. Huang, C.E.M. Wagner, JHEP **0804**, 092 (2008).

2. New Physics Signals in Longitudinal Gauge Boson Scattering at the LHC
T. Han, David Krohn, Lian-Tao Wang, Wenhan Zhu, JHEP 1003:082, (2010).

3. Higgs Boson Searches and the $Hb\bar{b}$ Coupling at the LHC
Tao Han and Bruce Mellado, Phys.Rev.D82:016009 (2010).

4. The "Top Priority" at the LHC
Tao Han, Int. J. Mod. Phys. **A23** 4107 (2008).

5. Top Quark Pairs at High Invariant Mass – A Model-Independent Discriminator of New Physics at the LHC
V. Barger, T. Han, D.G.E. Walker, Phys. Rev. Lett. **100**, 031801 (2008).

6. Heavy Quarks Above the Top at the Tevatron
A. Atre, M. Carena, T. Han, J. Santiago, Phys. Rev. **D79**, 054018 (2009).

7. Pair production of doubly-charged scalars: Neutrino mass constraints and signals at the LHC
T. Han, B. Mukhopadhyaya, Z. Si, and K. Wang, Phys. Rev. **D76**, 075013 (2007).

8. Neutrino Masses and the CERN LHC: Testing Type II Seesaw
P. Fileviez Perez, T. Han, G.-Y. Huang, T. Li, and K. Wang, Phys. Rev. **D78**, 015018 (2008).

9. The Search for Heavy Majorana Neutrinos
Anupama Atre, Tao Han, Silvia Pascoli, and Bin Zhang, JHEP 0905:030, (2009).

10. Kinematic Cusps: Determining the Missing Particle Mass at the LHC
Tao Han, Ian-Woo Kim, Jeonghyeon Song, arXiv:0906.5009 [hep-ph].

11. Genuine CP-odd Observables at the LHC
Tao Han and Yingchuan Li, Phys. Lett. B683:278, 2010.

12. Phenomenology of hidden valleys at hadron colliders
T. Han, Z.-G. Si, K. M. Zurek and M. J. Strassler, JHEP **0807**, 008 (2008).

13. Chiral couplings of W' and top quark polarization at the LHC
S. Gokrishna, T. Han, I. Lewis, Z.G. Si, and Y.F. Zhou, arXiv:1008.3508 [hep-ph].

III. Other Activities since Jan. 2007:

- 16 invited talks in conferences; 13 seminars; 13 colloquia.

- 8 lecture series in summer/winter schools on LHC pheno.

- Organizer, convener, scientific director:
for 15 international conferences/workshops/schools;
edited TASI 08 Proceedings: "The dawn of the LHC Era".

- Board member:
Physical Review D; Chinese Physics C; KITP-China;
Oversea Chinese Physics Association.

- Panelist, reviewer, consultant:
for DOE, NSF, STFC (UK),
PRD, PRL, PLB, JHEP ...

At the exciting time of the LHC era, I fully expect more productive research and professional activities.

Maike Trenkel

LHC phenomenology of physics beyond the Standard Model and precision calculations

- Production of **squarks and gluinos** at the LHC within the MSSM: tree-level and NLO **electroweak contributions**
  [with J. Germer, W. Hollik, E. Mirabella]

- New physics contributions to **Drell-Yan + jet** at NLO QCD
  [with R. Gavin, F. Petriello]

- Neutrino mass generation via a **colored see-saw** mechanism: **collider phenomenology**
  [with P. Fileviez Pérez, S. Spinner]

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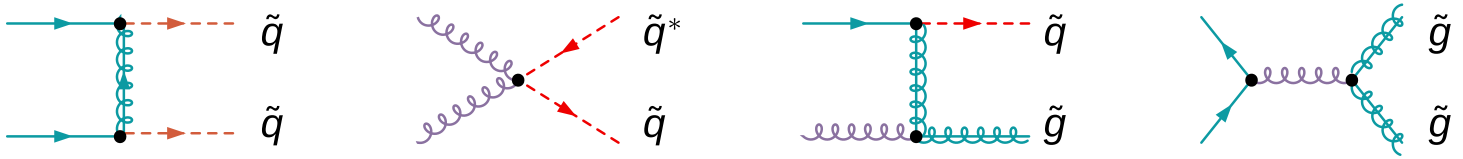
Squark and gluino production at the LHC

- **MSSM**: pair production of **squarks ($\tilde{q}$)** and **gluinos ($\tilde{g}$)** at $\mathcal{O}(\alpha_s^2)$

  ➡ **high rate** at LHC!

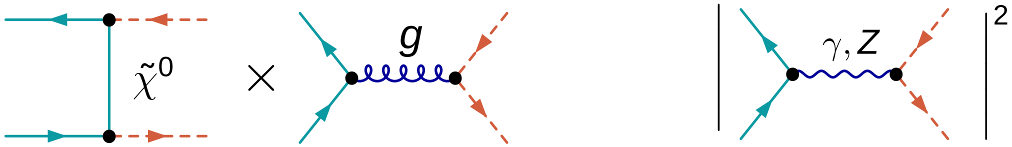


- $\mathcal{O}(\alpha_s^3)$ NLO QCD corrections well known, large and positive
  NLL results now available, further stabilization

  [Beenakker etal. '95+] $\longrightarrow$ Prospino,
  [Kulesza etal. '08],. . .

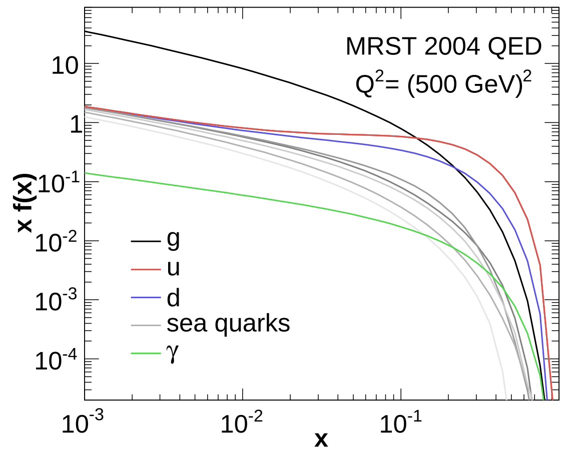
- $\mathcal{O}(\alpha_s\alpha + \alpha^2)$ tree-level EW contributions

  [Bornhauser etal. '07]
  [Bozzi etal. '07]



- $\mathcal{O}(\alpha_s\alpha)$ photon-induced processes

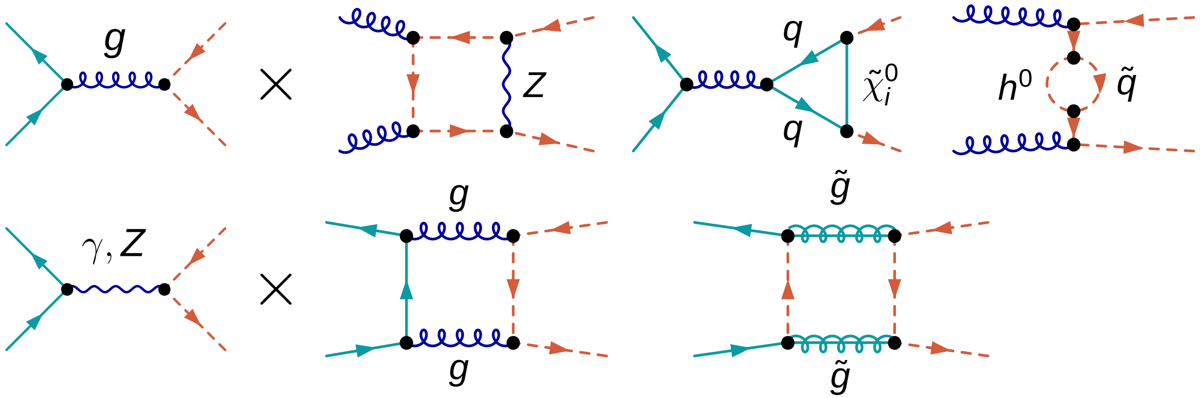
[Hollik, Kollar, Mirabella, MT '07+]



Squark and gluino production at the LHC (II)

[Germer, Hollik, Mirabella, MT '10]

- $\mathcal{O}(\alpha_s^2\alpha)$ NLO EW contributions



- **UV singularities**
  ➡ **renormalization** required
  -quarks, squarks at $\mathcal{O}(\alpha)$ & $\mathcal{O}(\alpha_s)$
  -gluino and $\hat{g}_s$ at $\mathcal{O}(\alpha_s)$

- **soft** & **collinear singularities** from **massless particles**
  ➡ need **γ & g bremsstrahlung**
  ➡ factorization and **redefinition of PDFs**

- hadronic results for $\tilde{q}\tilde{q}$ **@ 7 TeV**:

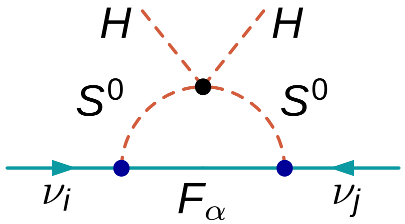
SPS1a'	σ_{Born}	$\sigma_{tree\ EW}$	$\sigma_{NLO\ EW}$	δ_{EW}
$\tilde{q}_L\tilde{q}'_L$	342	90	-6.1	25%
$\tilde{q}_R\tilde{q}'_R$	409	9.8	0.4	2.5%
$\tilde{q}_L\tilde{q}'_R$	278	0.5	-9.7	-3.3%
$\tilde{q}\tilde{q}$	**1023**	**100**	**-15.3**	**8.3%**

[in fb; $\mu_{F,R} = m(\tilde{q})$, MRST 2004 QED; $m(\tilde{q}) \approx 550$ GeV, $m(\tilde{g}) = 609$ GeV]

LHC phenomenology of a colored see-saw model

- **neutrino masses** could be **generated at one-loop** by adding two types of **color-octet “see-saw”** fields

[Fileviez Perez & Wise ’09]



fermions $F_\alpha \sim (8,1,0)$

scalar $S \sim (8,2,1/2)$, $S = \begin{pmatrix} S^+ \\ S^0 \end{pmatrix}$

- new scalars and fermions can be **produced at the LHC**

$$gg \to S^0 S^0,\ S^+ S^-$$
$$gg \to S^0$$
$$bg \to tS^-; \quad b\bar{b} \to S^0$$

cf. [Manohar & Wise ’06]; [Gerbush etal. ’07], [Greisham etal.’07], [Fileviez Perez etal.’08],..

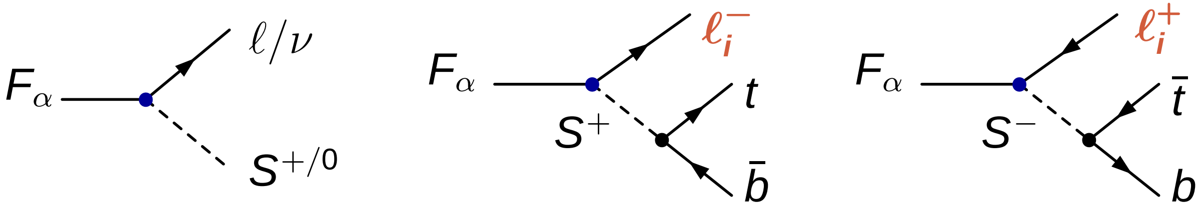
$$gg \to F_\alpha F_\alpha$$

➡ violates lepton number by 2

➡ promising signal of **LNV at LHC**!

$$gg \to F_\alpha F_\alpha \to (e^- t\bar{b})\,(e^- t\bar{b}),$$
$$gg \to F_\alpha F_\alpha \to (\mu^+ \bar{t} b)\,(e^+ \bar{t} b),\ \ldots$$

- decay properties of F_α depend on m_S, m_F, and couplings Y_ν



Outlook

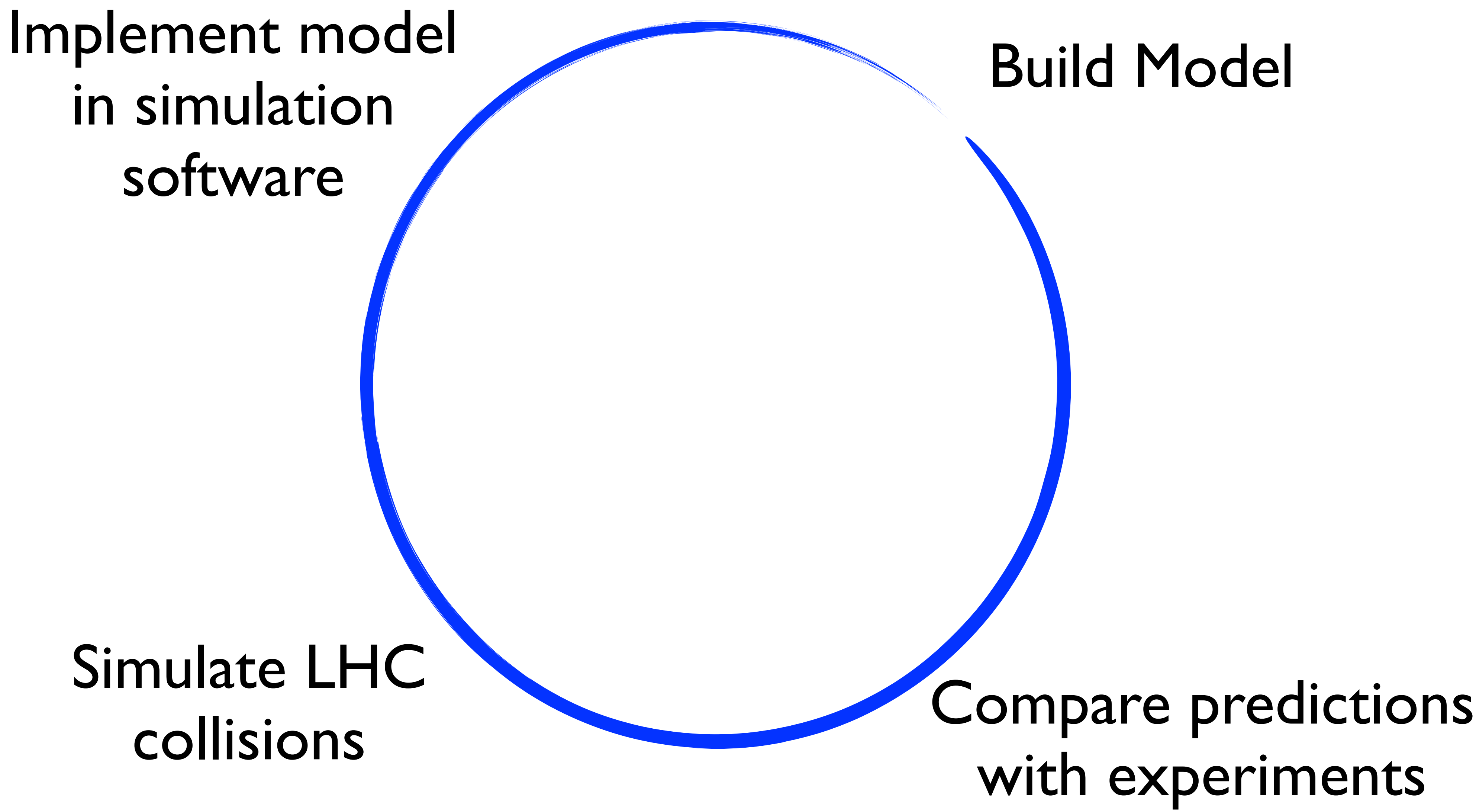
- **precision calculations**
  - NLO EW for SUSY: missing $\tilde{b}\tilde{b}^*$, include real W, Z **radiation**?
  - **new physics** virtual corrections to **SM processes**:

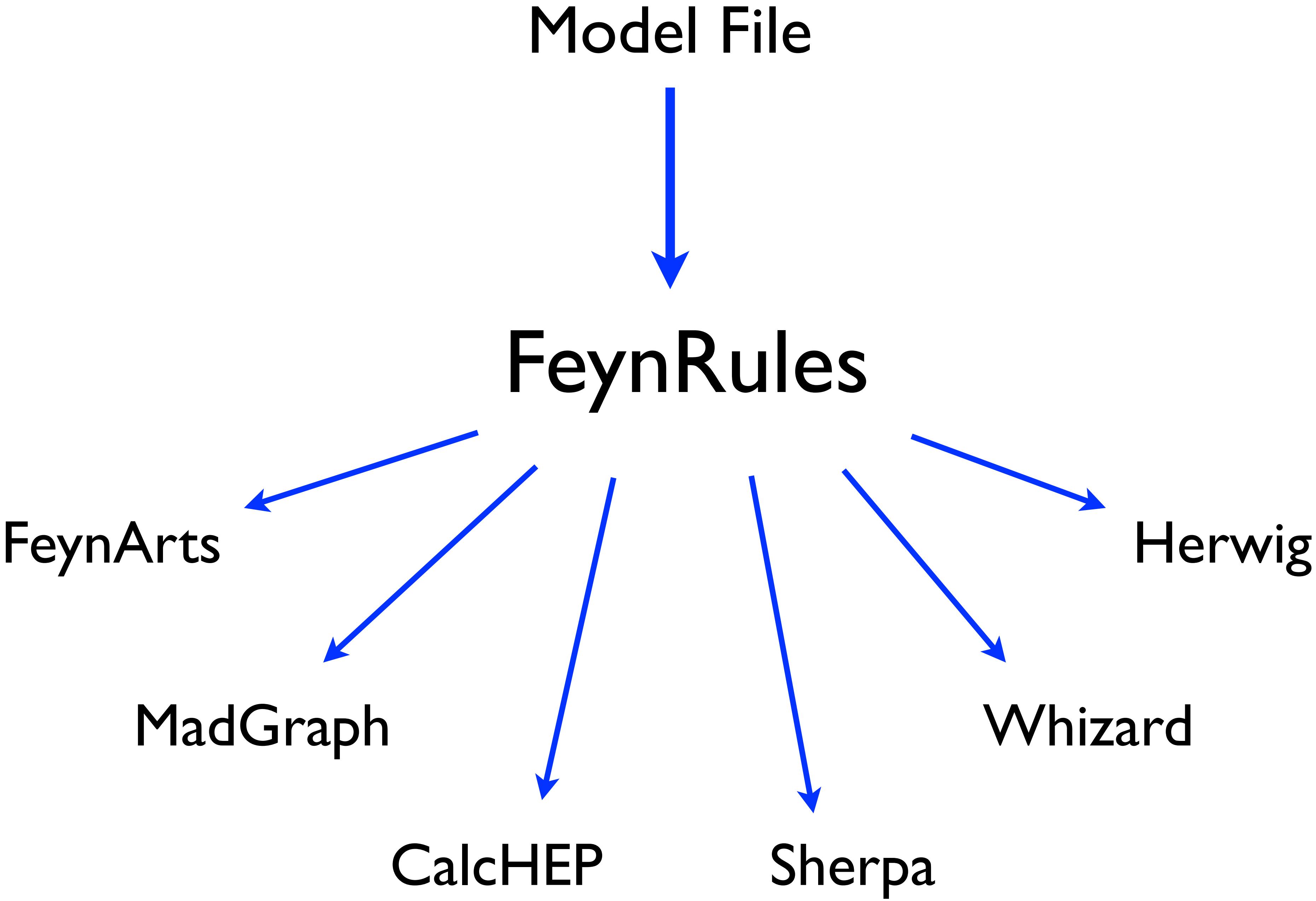
    Drell-Yan + jet at NLO QCD with new scalars (fermions, SUSY), Color-octets and **Higgs** production at NNLO ?
- **collider phenomenology**
  - connection of neutrino and collider physics, observability of **LNV at colliders**?
  - mass **measurements** and spin determination, **promising signals** for SUSY discovery?
  - **. . .**

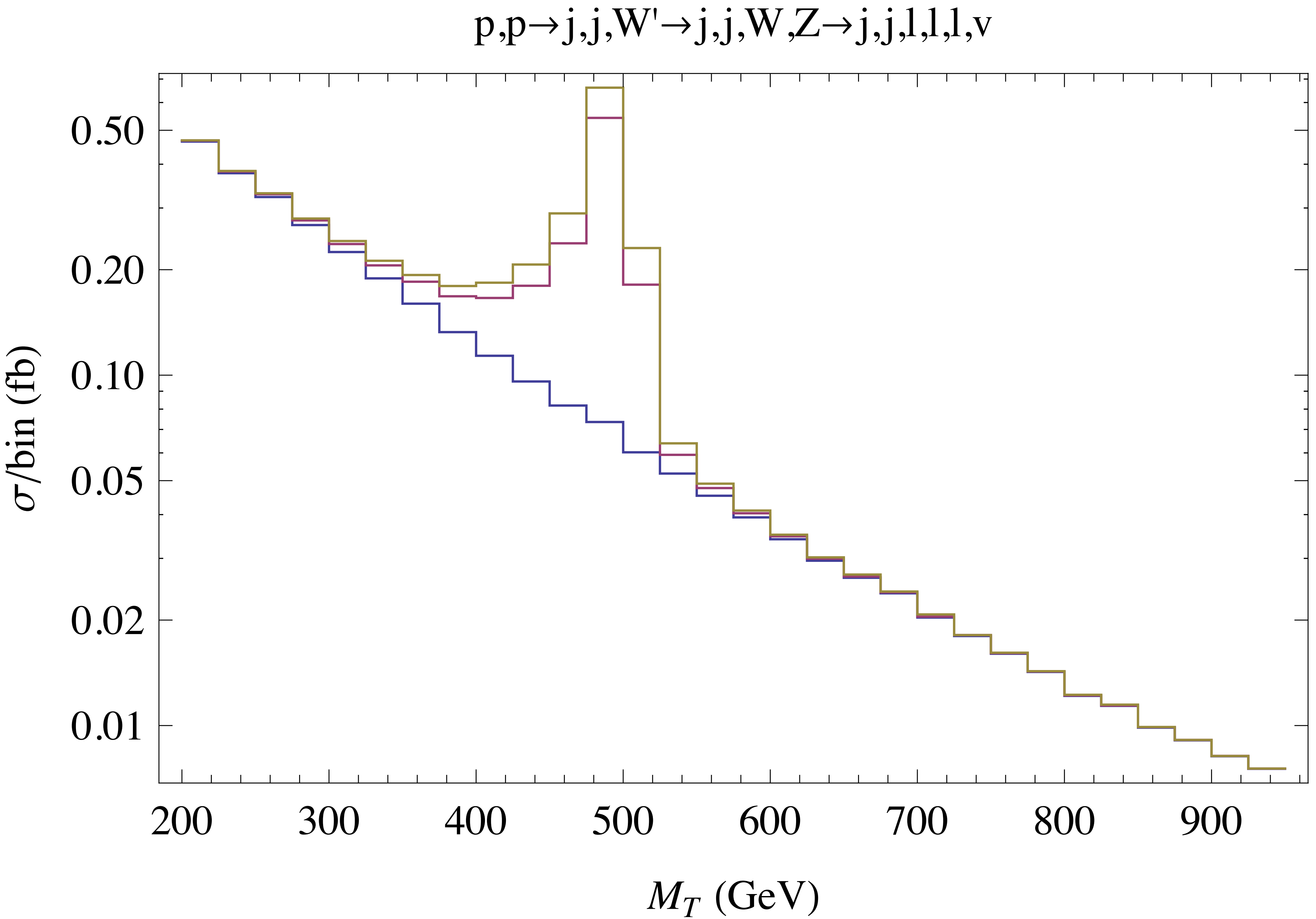
Thank You!

Neil D. Christensen

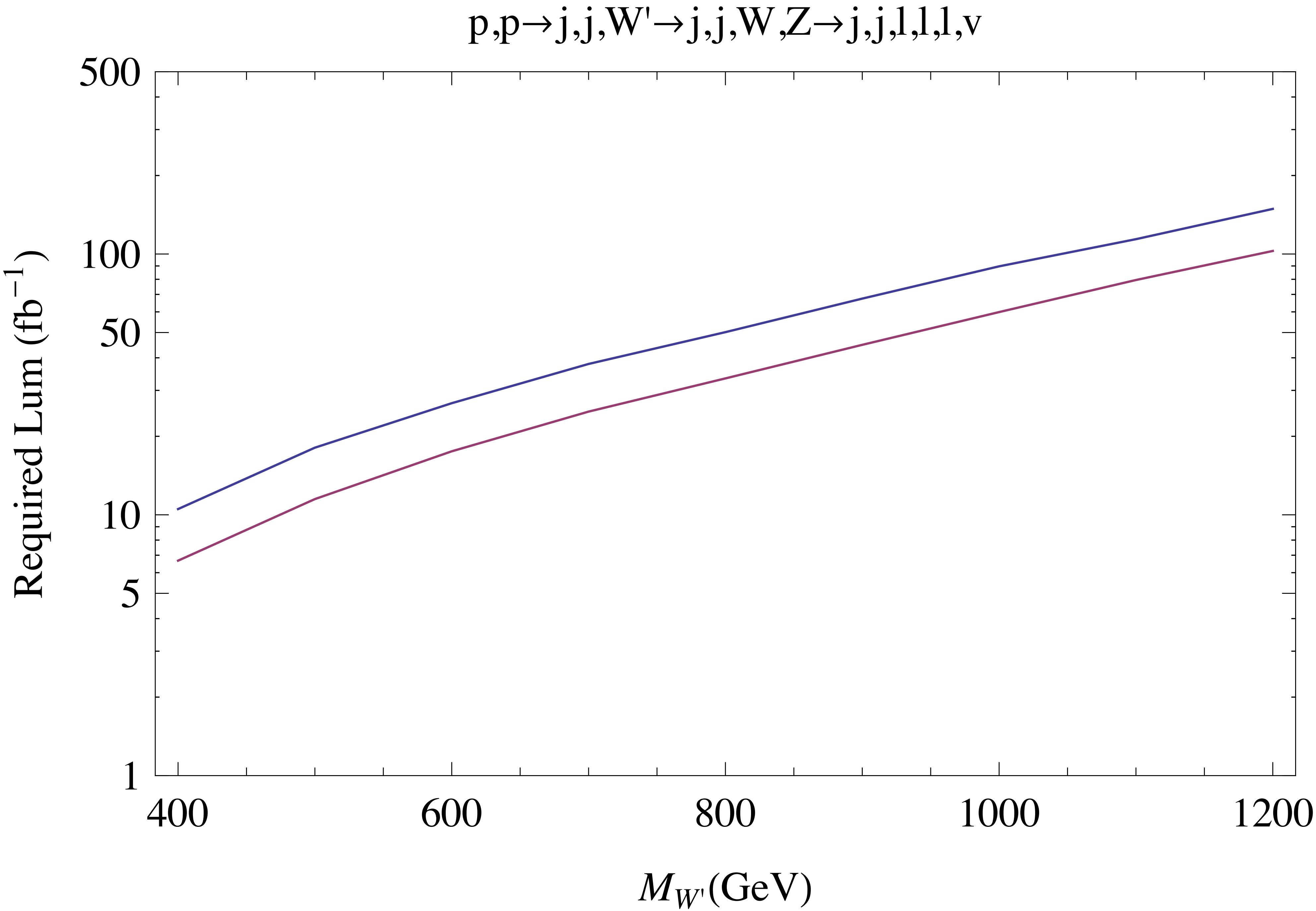
LHC-TI Fellow
University of Wisconsin - Madison


Implement model in simulation software
Build Model
Simulate LHC collisions
Compare predictions with experiments

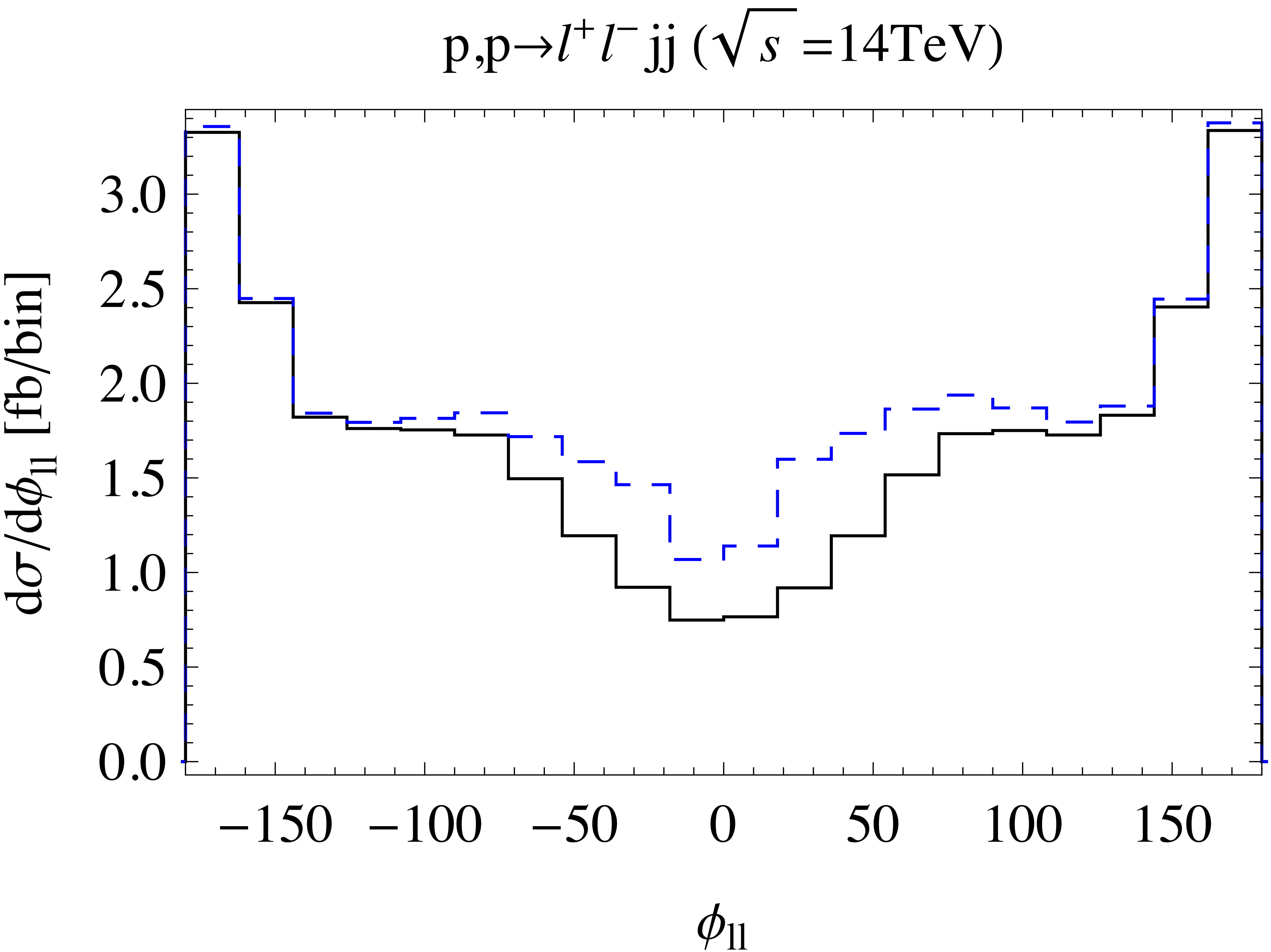

Model File
FeynRules
FeynArts
MadGraph
CalcHEP
Sherpa
Whizard
Herwig



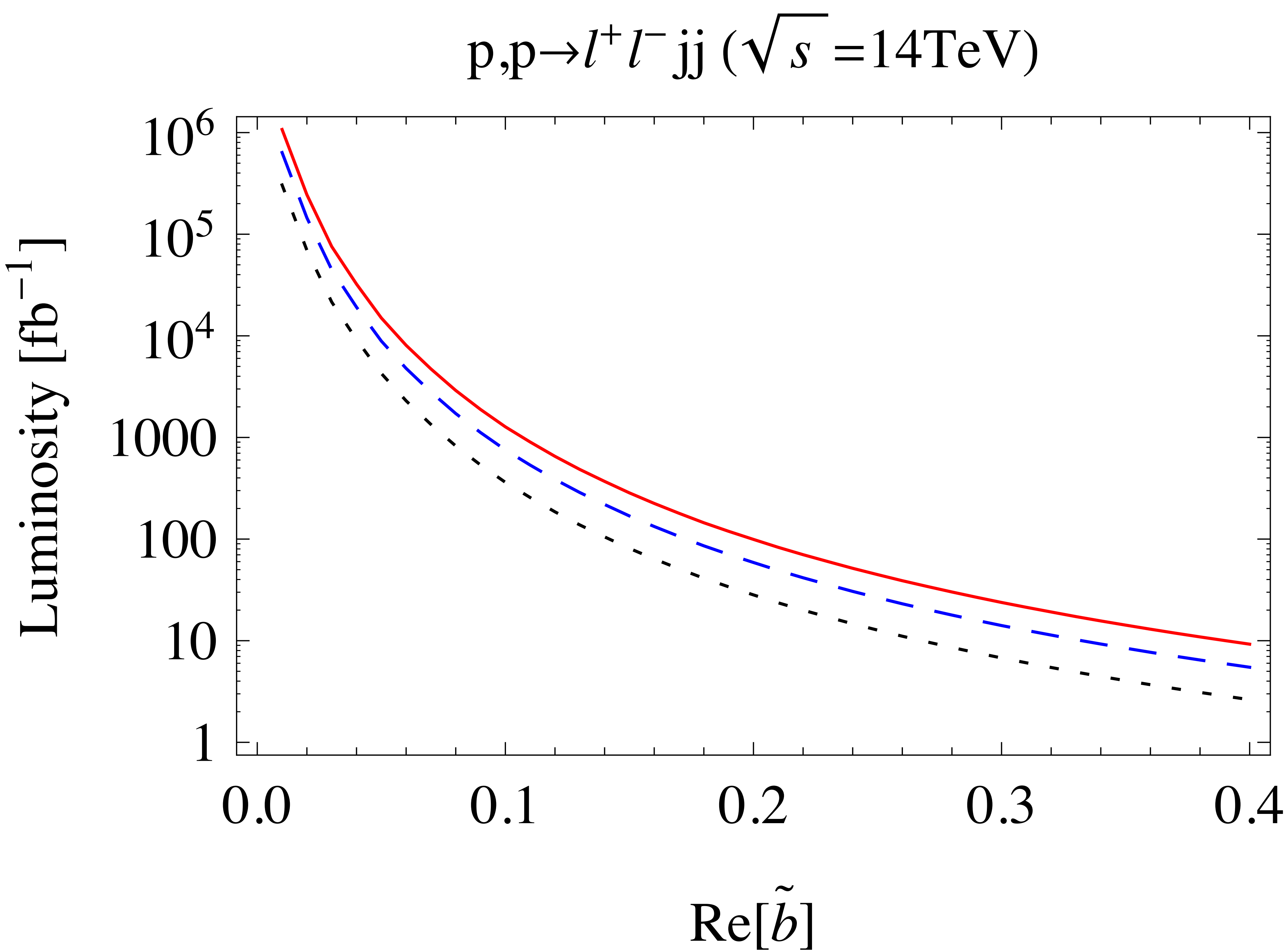
p,p→j,j,W'→j,j,W,Z→j,j,l,l,l,v
0.50
0.20
0.10
0.05
0.02
0.01
σ/bin (fb)
200
300
400
500
600
700
800
900
M_T (GeV)



p,p→j,j,W'→j,j,W,Z→j,j,l,l,l,v
Required Lum (fb^{-1})
500
100
50
10
5
1
400
600
800
1000
1200
$M_{W'}$(GeV)

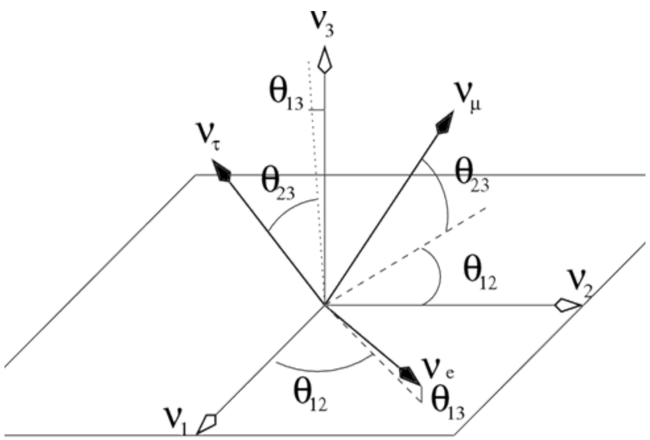


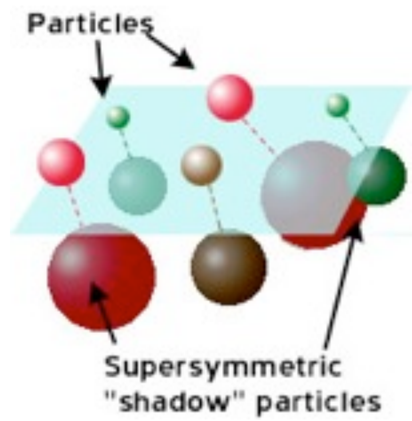
p,p→l^+l^-jj ($\sqrt{s}$ =14TeV)
dσ/dϕ_{ll} [fb/bin]
ϕ_{ll}
0.0
0.5
1.0
1.5
2.0
2.5
3.0
−150
−100
−50
0
50
100
150

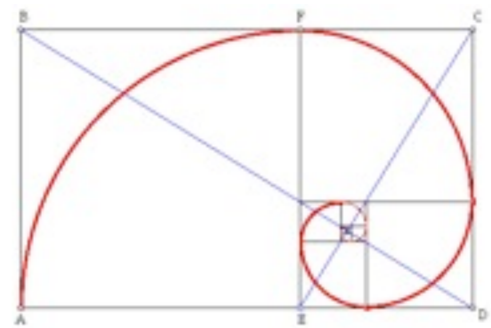


p,p→$l^+ l^-$ jj ($\sqrt{s}$ =14TeV)
Luminosity [fb^{-1}]
10^6
10^5
10^4
1000
100
10
1
0.0
0.1
0.2
0.3
0.4
Re[$\tilde{b}$]

Research 2007-10: L. Everett et al.







Presentation for the U.S. Department of Energy
August 27, 2010

Overview of Research Program

Theme: Physics Beyond the Standard Model

seek connections b/w observable physics and fundamental theory

Research Directions

TeV-scale supersymmetry (SUSY):

supersymmetry breaking models

extended gauge/Higgs sectors

Neutrino physics and the Standard Model flavor puzzle:

origin of fermion masses and mixing angles

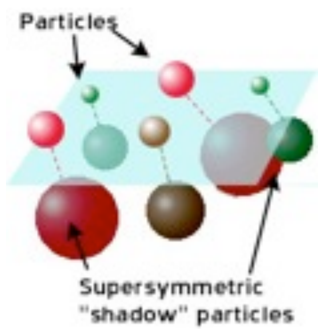
focus on scenarios motivated by string and/or unified theories

TeV-scale Supersymmetry

TeV-scale Supersymmetry:

after several decades, remains the best-motivated new physics scenario

should face definitive tests at LHC!



Models of supersymmetry breaking

Extended gauge sectors: MSSM+ new TeV-scale *U(1)'*

TeV-scale Supersymmetry: SUSY breaking

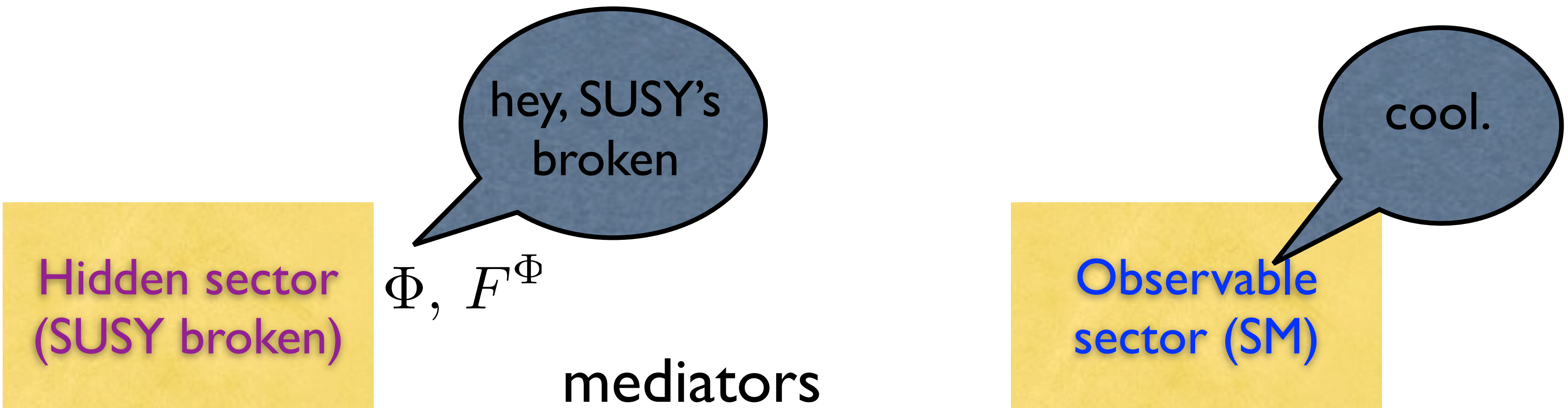
General MSSM: 105 parameters, ~20 relevant for collider pheno

gaugino masses $M_{1,2,3}$ scalar masses: $m^2_{f_{ij}}$

Higgs bilinear $b \equiv B\mu$ trilinears: $A_{u,d,e_{ij}}$

Coping with impractically vast parameter space: SUSY models

Hidden sector paradigm:



(gravity, gauge, anomaly,...)

TeV-scale Supersymmetry: SUSY breaking

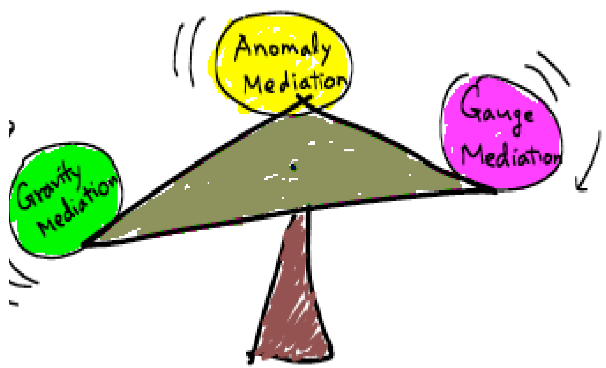
Standard approach: single mediation mechanism dominates

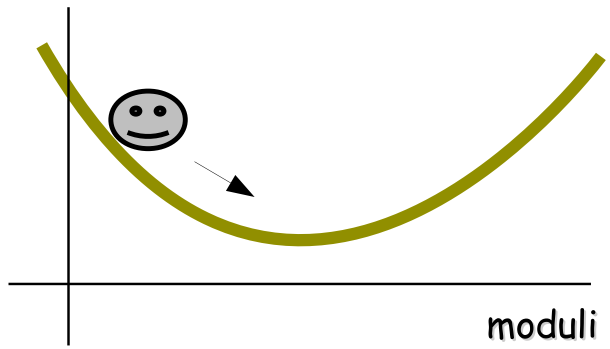
prototype: minimal supergravity (mSUGRA/CMSSM)

5 parameters: (4 + 1 sign) $m_0, m_{1/2}, A_0, \tan\beta, \text{sign}(\mu)$

New approach: theory-motivated "mixed" scenarios

all 3 mediation mechanisms can have comparable contributions!





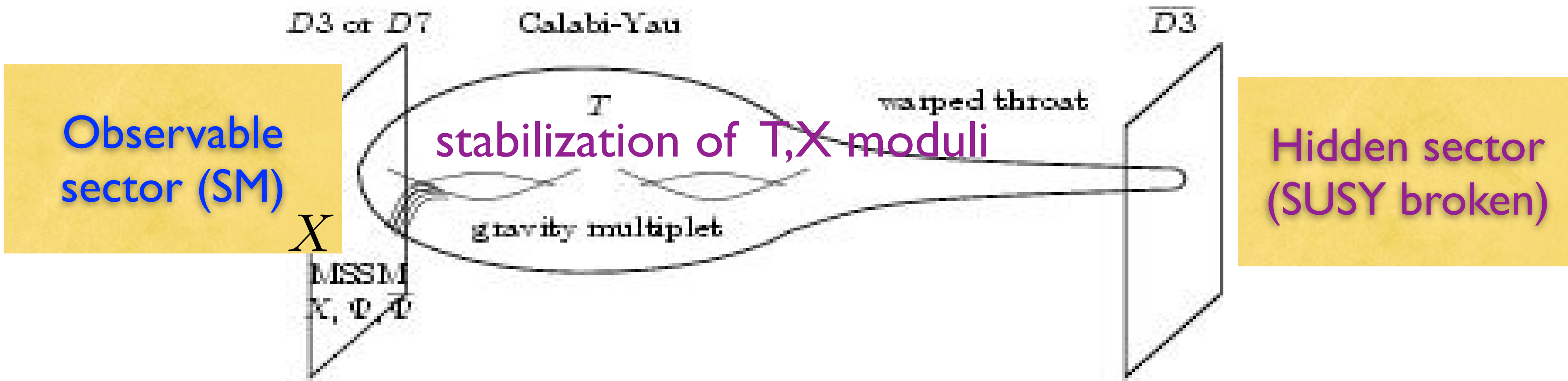
deflected mirage mediation (DMM)

L.E., I.-W. Kim, P. Ouyang, K. Zurek, 0804.0592, 0806.2330

Deflected Mirage Mediation Models

generalizes KKLT string-motivated mirage (grav/anomaly) mediation

to include gauge mediation effects



mirage unification in gaugino sector: "deflected" from KKLT prediction

⟶ non-standard spectra (gaugino mass ratios)

Allows for minimal 7 (6+1sign)-parameter models

motivation for specific non-universal parameters: benchmark models

Deflected Mirage Mediation Models

Progress and Current/Future Directions:

Theory and Model Setup

L.E., I.-W. Kim, P. Ouyang, K. Zurek, 0804.0592, 0806.2330

Phenomenology: comparison with mirage mediation

B. Altunkaynak, L.E., I.-W. Kim, B. Nelson, Y. Rao, 1001.5261

Phenomenology: landscape of light state hierarchies

B. Altunkaynak, L.E., I.-W. Kim, B. Nelson, Y. Rao, to appear soon

Dark matter constraints, gauge-gravity limit

L.E., I.-W. Kim, B. Nelson, Y. Rao,... work in progress

Extended Gauge Sectors: MSSM+$U(1)'$

Progress and Current/Future Directions:

$U(1)'$ and Neutrino Mass Models

Dirac ν masses from SUSY ✓ — D. Demir, L.E., P. Langacker, 0712.1341

sneutrino dark matter — D. Demir, L.E.,M. Frank, L. Selbuz, I. Turan, 0906.3540

$U(1)'$ (B-L) and R-parity violation

L.E., P. Fileviez Perez, S. Spinner, 0906.4095

Family non-universal $U(1)'$: FCNC constraints

V. Barger, L.E.,J. Jiang, P. Langacker, T. Liu, C. Wagner, 0902.4507, 0906.3745

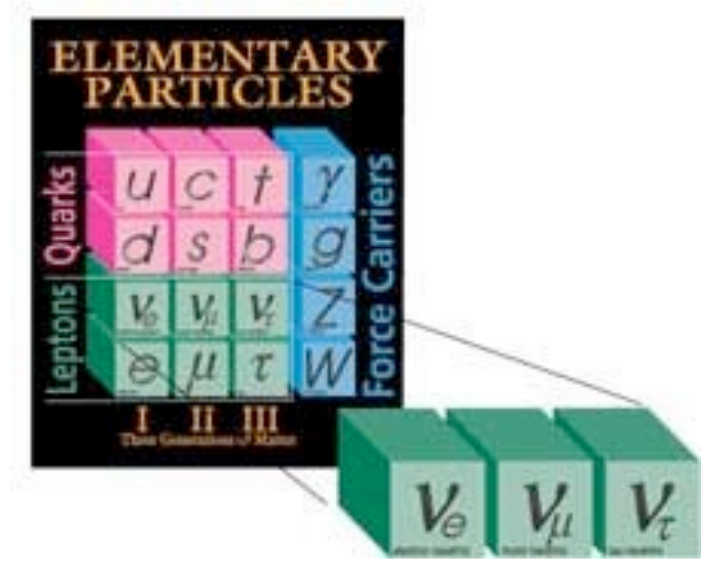
L.E.,J. Jiang, P. Langacker, T. Liu, 0911.3549

V. Barger, L.E.,P. Langacker, T. Liu, C. Wagner, work in progress

$U(1)'$ and Multi-Higgs Doublet Models

V. Barger, L.E., M. McCaskey, V. Plaus, work in progress

Neutrino Physics



Neutrino Oscillation data:

$$\mathcal{P}_{\nu_\alpha \to \nu_\beta}(L) = \sum_{ij} \mathcal{U}_{i\alpha} \mathcal{U}^*_{i\beta} \mathcal{U}^*_{j\alpha} \mathcal{U}_{j\beta} e^{-\frac{i\Delta m^2_{ij} L}{2E}}$$

neutrinos are massive, lepton mixing is observable

Revolutionized SM flavor puzzle!

origin of ultralight neutrino mass scale, mild family mass hierarchies

lepton mixing angle pattern: 2 large angles, 1 small angle

most challenging pattern for model-building (3 families)

implications for quark-lepton unification paradigm?

THE UNIVERSITY of WISCONSIN MADISON

Lepton Mixing Angles

The data: $\theta_{\odot} = \theta_{12} = 33.4^\circ \pm 1.4^\circ \quad \theta_{\oplus} = \theta_{23} = 45.0^\circ\,{}^{+4.0}_{-3.4}$

$\epsilon = \sin\theta_{13}, \quad \theta_{13} = 5.7^\circ\,{}^{+3.5}_{-5.7}$ (best fit $\pm 1\sigma$)

compare quarks (Cabibbo angle parametrization): $\lambda \equiv \sin\theta_c = 0.22$

$$\theta_{12}^{(q)} \sim \lambda \qquad \theta_{23}^{(q)} \sim \lambda^2 \qquad \theta_{13}^{(q)} \sim \lambda^3$$

CKM matrix: $\mathcal{U}_{\rm CKM} = \mathcal{U}_u \mathcal{U}_d^\dagger \sim 1 + \mathcal{O}(\lambda)$

Hypothesis for Leptons: "Cabibbo Haze"

MNSP matrix: $\mathcal{U}_{\rm MNSP} = \mathcal{U}_e \mathcal{U}_\nu^\dagger \sim \mathcal{W} + \mathcal{O}(\lambda)$

"bare" mixing angles $(\theta_{12}^0, \theta_{13}^0, \theta_{23}^0)$ → $\mathcal{W}$

Cabibbo-sized effects → $\mathcal{O}(\lambda)$

L.E., Ramond, Datta '05

THE UNIVERSITY of WISCONSIN MADISON

Family Symmetries: Icosahedral Group

bare mixing angles: starting point for flavor theory

$\theta_{23}^0 \sim 45^\circ$ $\theta_{13}^0 \sim 0$ $\theta_{12}^0 \sim ?$ (many options)

New paradigm for flavor theory:

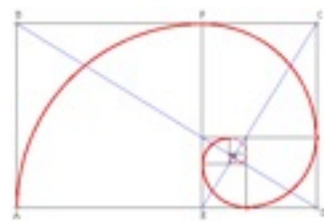
family symmetry = discrete non-Abelian symmetry

Our work: use icosahedral symmetry

rich and virtually unexplored framework!

first project: golden ratio hypothesis

$$\tan\theta_{12}^0 = \phi^{-1} \qquad \phi = (1+\sqrt{5})/2$$



L.E., A. Stuart, 0812.1057

Family Symmetries: Icosahedral Group

Rotational Icosahedral group, *I* ~ A5

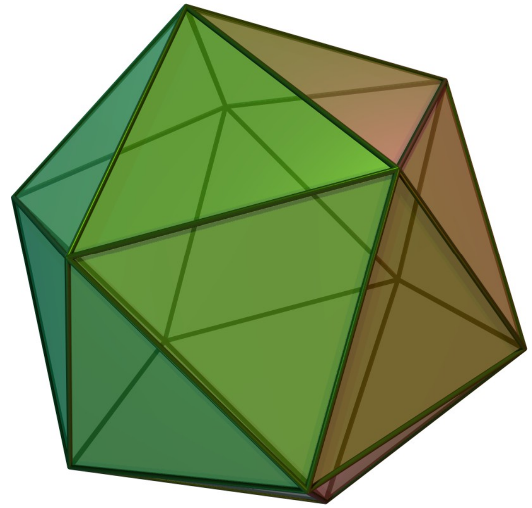
representations

C_n^k = $\dfrac{2\pi k}{n}$

rotations

$\mathcal{I}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{3'}$	$\mathbf{4}$	$\mathbf{5}$
e	1	3	3	4	5
$12C_5$	1	ϕ	$1-\phi$	-1	0
$12C_5^2$	1	$1-\phi$	ϕ	-1	0
$20C_3$	1	0	0	1	-1
$15C_2$	1	-1	-1	0	1

Character Table



$$0,\ \frac{2\pi}{5},\ \frac{4\pi}{5},\ \frac{2\pi}{3},\ \pi$$

Two triplets! $L \longrightarrow 3, \quad \bar{e} \longrightarrow 3'$

$$LL : 3 \otimes 3 = 1 \oplus \not{3} \oplus 5, \qquad L\bar{e} : 3 \otimes 3' = 4 \oplus 5$$

break *I* to discrete subgroup: $\mathcal{Z}_2 \times \mathcal{Z}_2$ (golden ratio hypothesis)

using flavons (Higgs fields for family symmetry)

Family Symmetries: Icosahedral Group

Progress and Current/Future Directions:

"Physics-ready" group theory of *I*

explicit representations, Clebsch-Gordon coefficients

I not a crystallographic point group, so work needed to be done...

L.E., A. Stuart, 0812.1057 and work in progress

Viable lepton model with golden ratio hypothesis

L.E., A. Stuart, 0812.1057

Explore more general lepton models (e.g. HPS tri-bimaximal)

L.E., A. Stuart, work in progress

Quark sector: extend to double cover group *I'*, *U(2)* textures

L.E., A. Stuart, work in progress

Future directions

TeV-scale Supersymmetry

DMM: "dialing" b/w SUSY models, FCNC, CPV,...

Z' models: implications of new B system results

many other possibilities....

Neutrino physics and flavor models

continue to explore icosahedral symmetry (and others)

connections to string/unified models

new MINOS/MiniBooNE data: $\nu, \bar{\nu}$ discrepancy?

hopefully data will lead the way!

Research Results

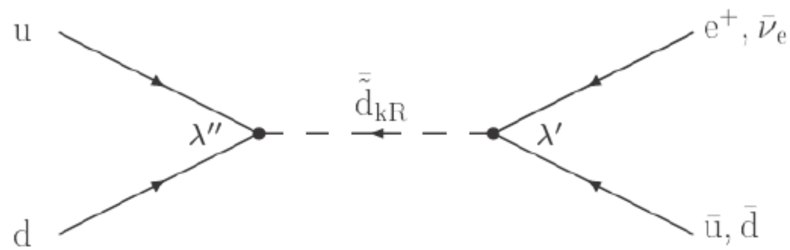
Sogee Spinner
University of Wisconsin-Madison

DOE Review, 27-Aug-10

Based on work with: V. Barger L. Everett and P. Fileviez Perez

B-L Violation in the MSSM

- MSSM: trilinear *B-L* breaking terms: $W \supset \lambda'' \hat{U}^C \hat{D}^c \hat{D}^C + \lambda' \hat{Q}\hat{L}\hat{D}^C$



- These yield rapid proton decay; $\tau_p > 10^{32}$ years
  - Severally constrains these couplings: $|\lambda' \lambda''| < 10^{-26}$
- Impose a discrete symmetry, R-parity: $R = (-1)^{3(B-L)+2S}$
  - Forbids B-L violation; only proton decay is dangerous; motivation?
  - R-parity is a subgroup of *B – L;* exploit this connection.
- SUSY Pheno/Cosmo hinges on the presence of these terms!
  - RPC: missing energy/WIMP Dark Matter (lightest neutralino).
  - RPV: no missing energy/non-WIMP Dark Matter (gravitino).

V. Barger, L. Everett, P. Fileviez Perez, S.S.

Minimal Local B-L:

- Charges: Quarks $\pm\frac{1}{3}$; Leptons ± 1
- For anomaly cancelation, 3 copies of right-handed neutrinos: $\hat{N}^c \sim (1,1,0,1)$;(neutrino masses)
- New Higgs sector? Scalar component of $\hat{N}^C$

$$m^2_{\tilde{N}^C} < 0 \rightarrow \left\langle \tilde{N}^C \right\rangle \neq 0: \ \mathrm{SM} \otimes U(1)_{B-L} \rightarrow \mathrm{SM}$$

  - Only bilinear B-L violating terms: no rapid proton decay:

$$W_{B-L} = W_{\mathrm{MSSM}} + Y_\nu \left\langle \hat{N}^C \right\rangle \hat{L}\hat{H}_u$$

- Two questions:
  - Why is the right-handed sneutrino tachyonic?
  - Why not an even B-L field? can preserve R-parity.

P. Fileviez Perez, S.S.

Two for the Price of One

- Introduce even charged Higgs sector: $\hat{X}, \hat{\bar{X}} \sim -2, 2$

$$W \supset f\hat{N}^C\hat{N}^C\hat{X} + \mu_X \hat{X}\hat{\bar{X}}$$

- Large (seesaw) Yukawa couplings are now possible
  - Therefore so is Radiative Symmetry Breaking.
  - X is tachyonic RPC; If N^C RPV: What is the Fate of R-parity

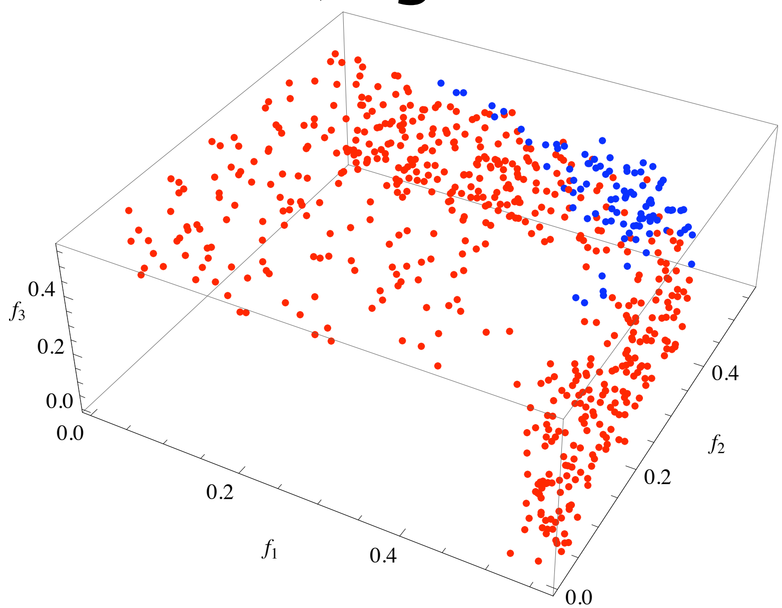
- Assume all soft scalar masses are degenerate at the GUT scale, evolve to low scale using RGEs
  - Larger charges tends to drive masses positive.
  - Larger Yukawa symmetry factors drive masses negative.

$$\frac{m_{\tilde{N}^C}}{dt} \sim 8f^2M^2 - 3g_{BL}^2M_{BL}^2 \quad \frac{m_X}{dt} \sim 4f^2M^2 - 12g_{BL}^2M_{BL}^2$$

Still Favors R-parity Violation!

R-parity: Violation or Conservation?

- m_X^2 can be enhanced by summing over all 3 values of f (3 generations)–RPC still possible:



$$\begin{aligned} m_0 &= 2000 \text{ GeV}, \\ M_{1/2} &= 200 \text{ GeV}, \\ A_0 &= 0 \end{aligned}$$

Blue – RPC; Red – RPV --- RPV 5 times more likely:

Even B-L Higgses --- RPV is still probable.

Conclusion

- *R*–parity is closely linked to *B*–*L.*

- Minimal *B*–*L* models: R–parity violation.

- Add B–L even Higgs: radiative symmetry breaking but R–parity violation still very likely.

- In both cases R–parity violation is viable:
  - No tree–level proton decay.
  - TeV scale theories great for LHC.
  - Dark matter still possible.

Research Topics

Pavel Fileviez Perez

Assistant Scientist and Dirac Fellow

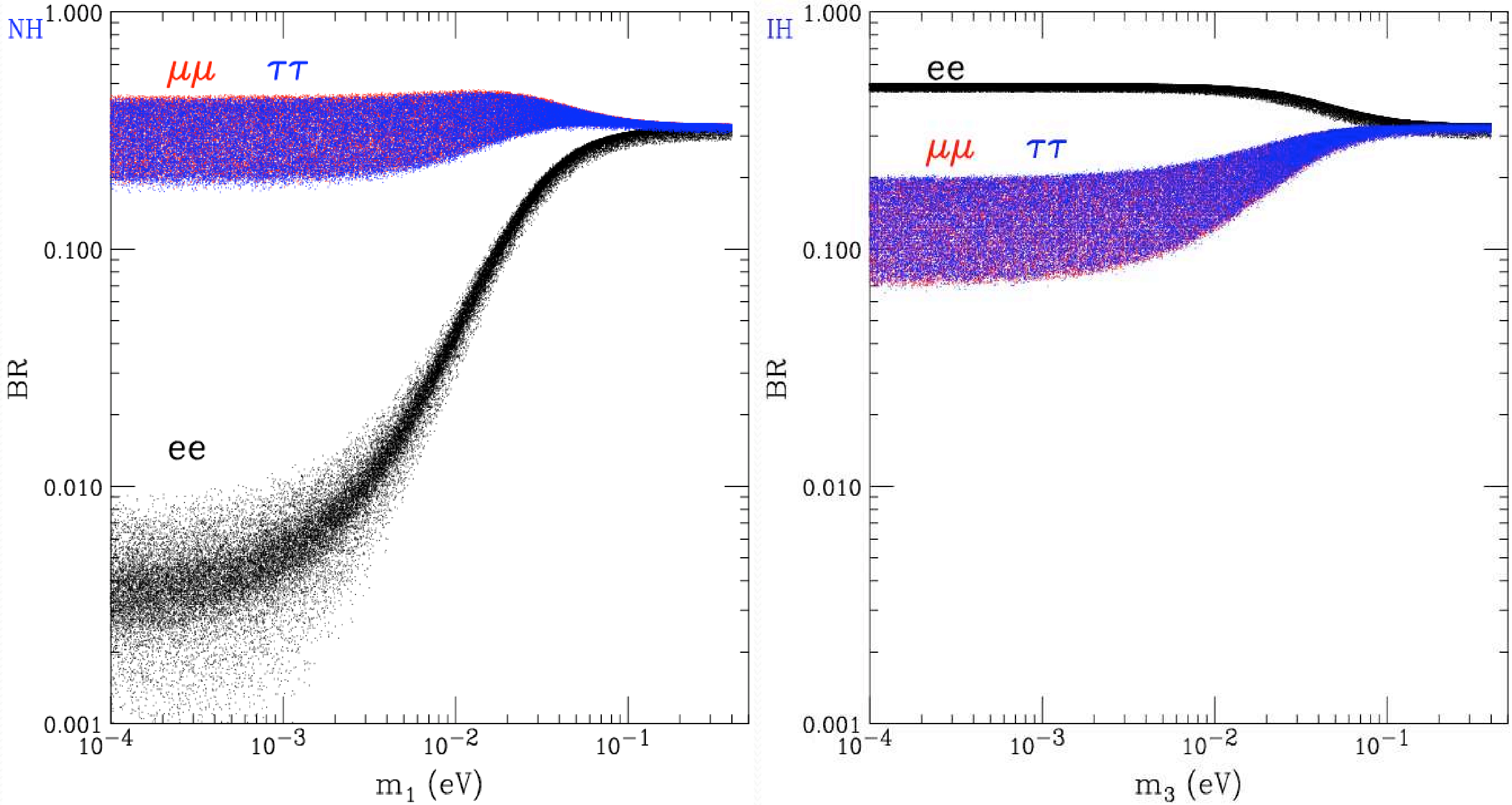
-Supersymmetric Theories
-Neutrino Physics
-Collider Phenomenology
-Grand Unified Theories
-Proton Stability
-Dark Matter
-Baryogenesis via Leptogenesis

DOE Review, August 27, 2010

(P.F.P., T. Han, G. Huang, T. Li, K. Wang, 2008)

Can we learn about the Neutrino Spectrum at the LHC ?

(Type II Seesaw) $H^{++} \longrightarrow e_i^+ e_j^+$



P.F.P., S. Spinner 2009,2010; V. Barger, L. Everett, P.F.P., S. Spinner, *2009.*

What is the Origin of R-Parity Violation?

$$SU(2)_L \bigotimes U(1)_Y \bigotimes U(1)_{B-L}$$

Extra Matter: $\hat{N}^C \sim (1,0,1)$

- **In the Minimal Model we must have R-Parity Violation.**
- **Massive Neutrinos and NO Proton Decay.**
- **We can use the radiative symmetry breaking mechanism to explain dynamically these results.**

Can we break B and L at the Low Scale ?

$$SU(2)_L \bigotimes U(1)_Y \bigotimes U(1)_B \bigotimes U(1)_L$$

- New Family of Fermions with B(quarks)=1 and L(leptons)=3.
- New Dark Matter Candidate (Automatic Stability).
- NO Flavour Violation at Tree Level.
- Interesting Mechanism for Neutrino Masses.
- Peculiar Signals at the LHC.
- Correlation between Baryon Asymmetry and DM Density.

Future Goals:

- Which are the predictions for the LHC and cosmology in the context of different extensions of the SM where B and/or L are broken at the low scale ?
- How to test at the LHC the predictions from the mechanisms for RpC or SRpV ?
- Always Looking for New Ideas !!

Research 2007-10: Barger et. al.

Newly minted PhDs

Yu Gao → U. Oregon postdoc

Mat McCaskey → Kansas U. postdoc

Research 2007-10: Barger et. al.

Neutrinos:

Research monograph (with Marfatia & Whisnant)

The Physics of Neutrinos (Princeton University Press)

Long Baseline oscillations comparative study---beams (narrow band, wide band), detectors (H2O, LqAr), distance, exposure: found that WWB from Fermilab to DUSEL wins .

Research 2007-10: Barger et. al.

Tevatron / LHC Physics

SM / MSSM extensions with singlet fields

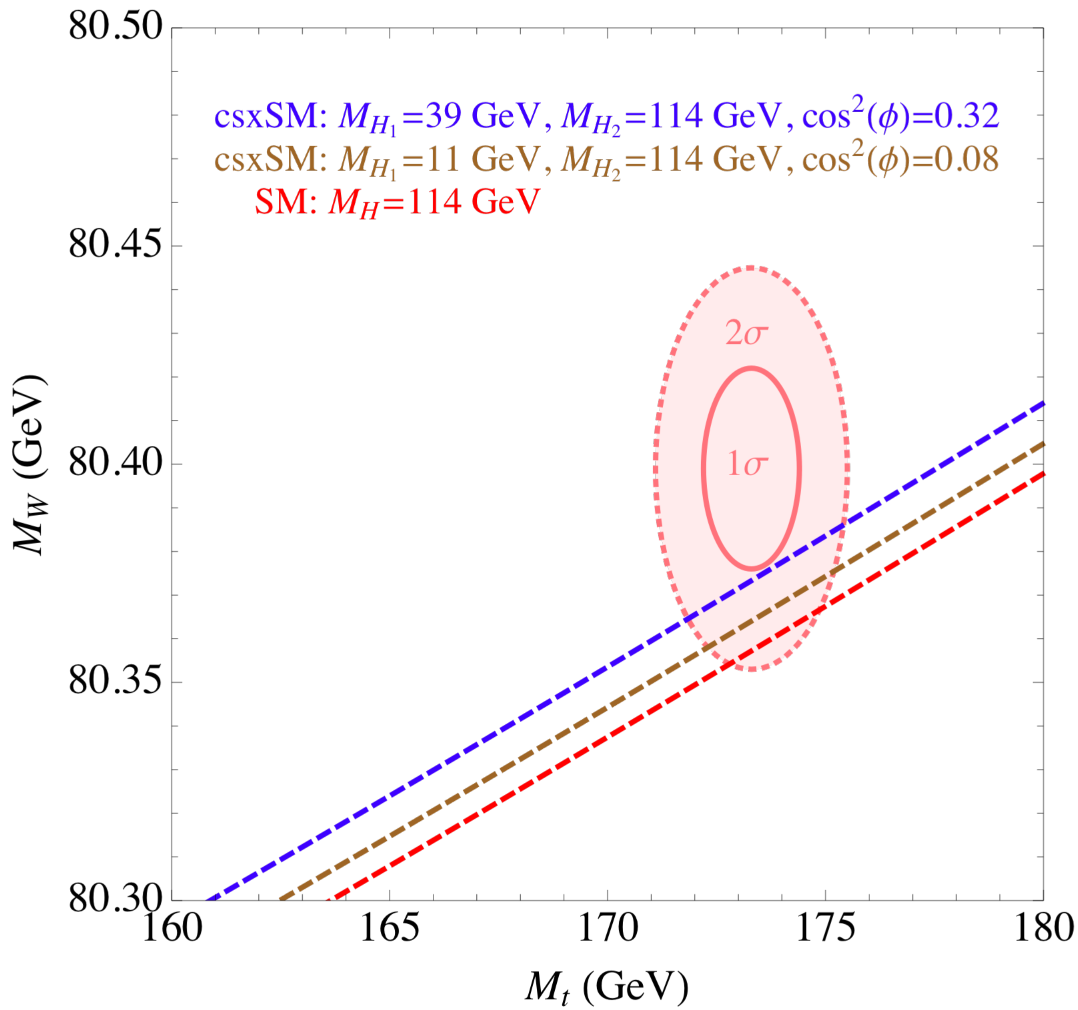
Higgs and neutralino properties changed

New Higgs decays (invisible, cascade)

Lightest Higgs mainly singlet.

Research 2007-10: Barger et. al.

Tevatron / LHC Physics



Research 2007-10: Barger et. al.

Tevatron Physics

Top pair F/B asymmetry is 2 sigma from SM

Proposed model: W’, Z’ with RH (t,b) interaction

Accounts for all data with 175 GeV W’, 900 GeV Z’

Research 2007-10: Barger et. al.

LHC Physics

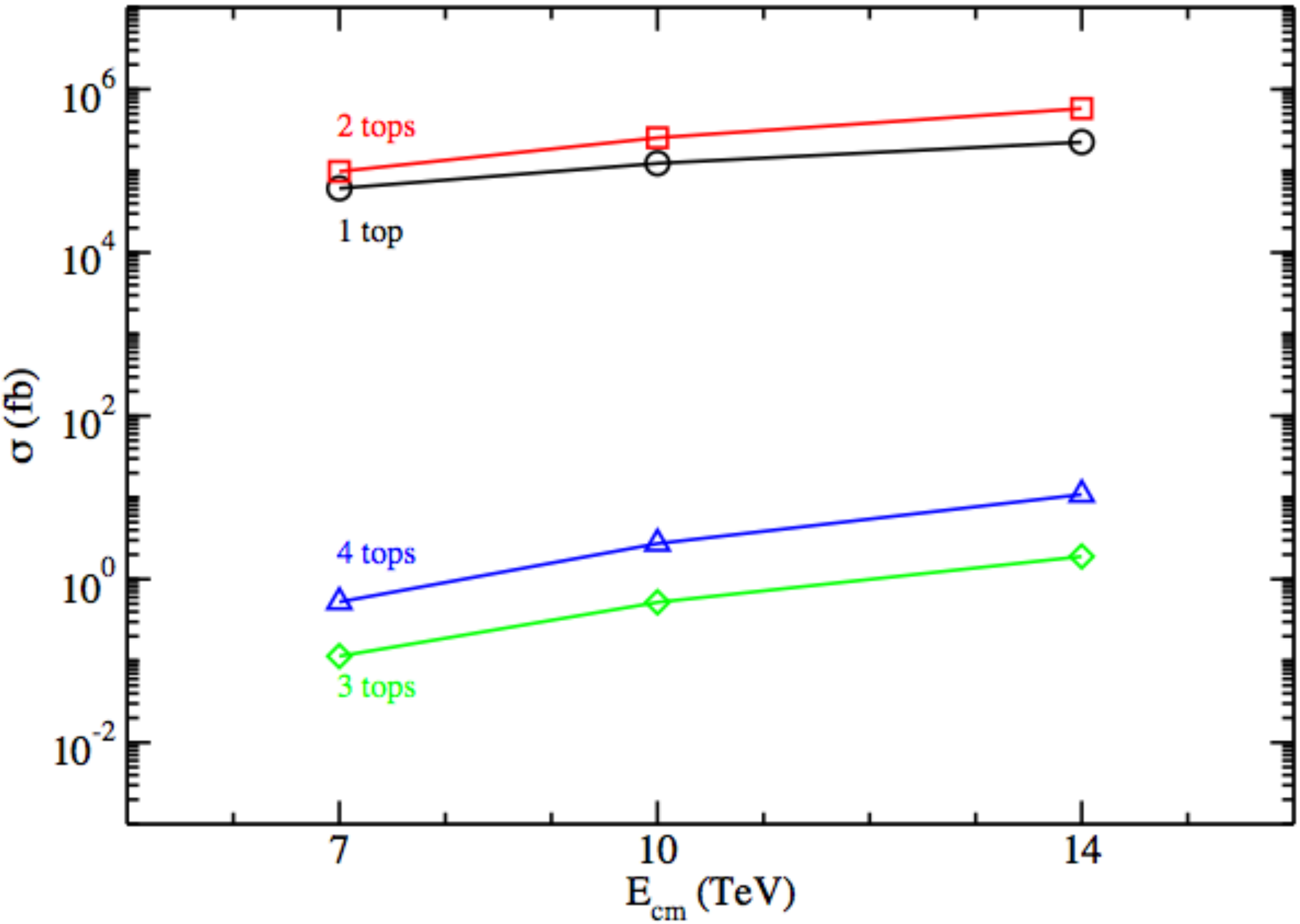
Single top + Higgs—first study of H→WW signal

→ probe of top Yukawa coupling

Triple Top—first SM calculation

New physics models can give
large enhancements: gluino, Z'

Research 2007-10: Barger et. al.

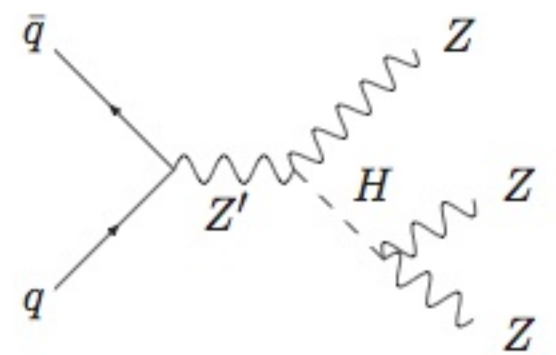


Research 2007-10: Barger et. al.

LHC Physics

New Z’ signal:

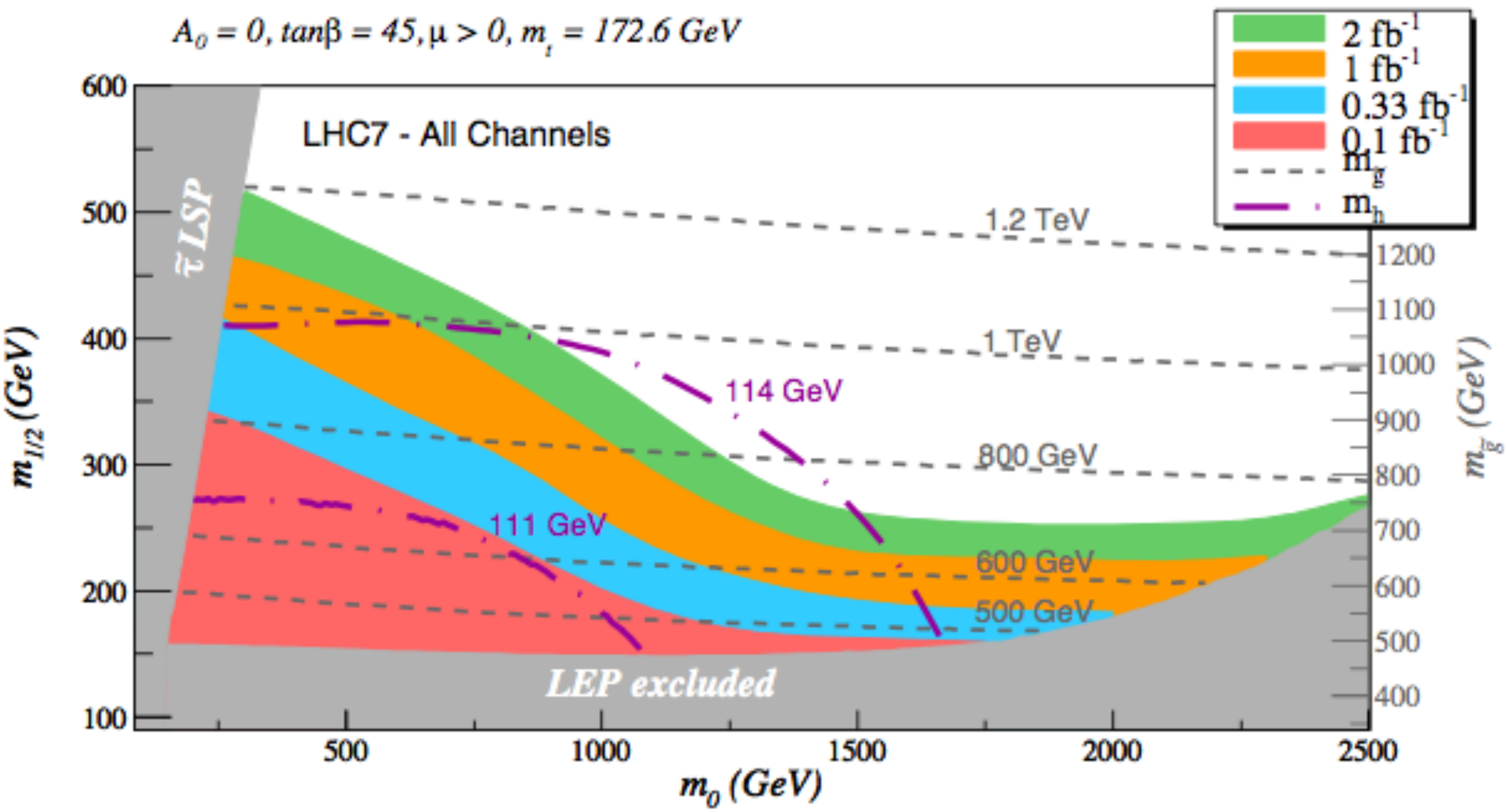
Z→ZH→ZZZ→ 6 leptons



SUSY:

discovery potential at 7 TeV as luminosity grows:
-----surprisingly robust!

Research 2007-10: Barger et. al.



Barger research (2007-2010)

Dark Matter

Particle physics origin—many possibilities—which one ?

Intertwined with LHC physics—missing energy signals of WIMPS.

Unexplained events in directs searches—DAMA/LIBRA, CoGeNT, CRESST--if real, DM mass is ~10 GeV.

Unexplained excess of cosmic positrons by PAMELA—if real, DM mass is ~ TeV.

Fermi may be seeing gamma ray excesses.

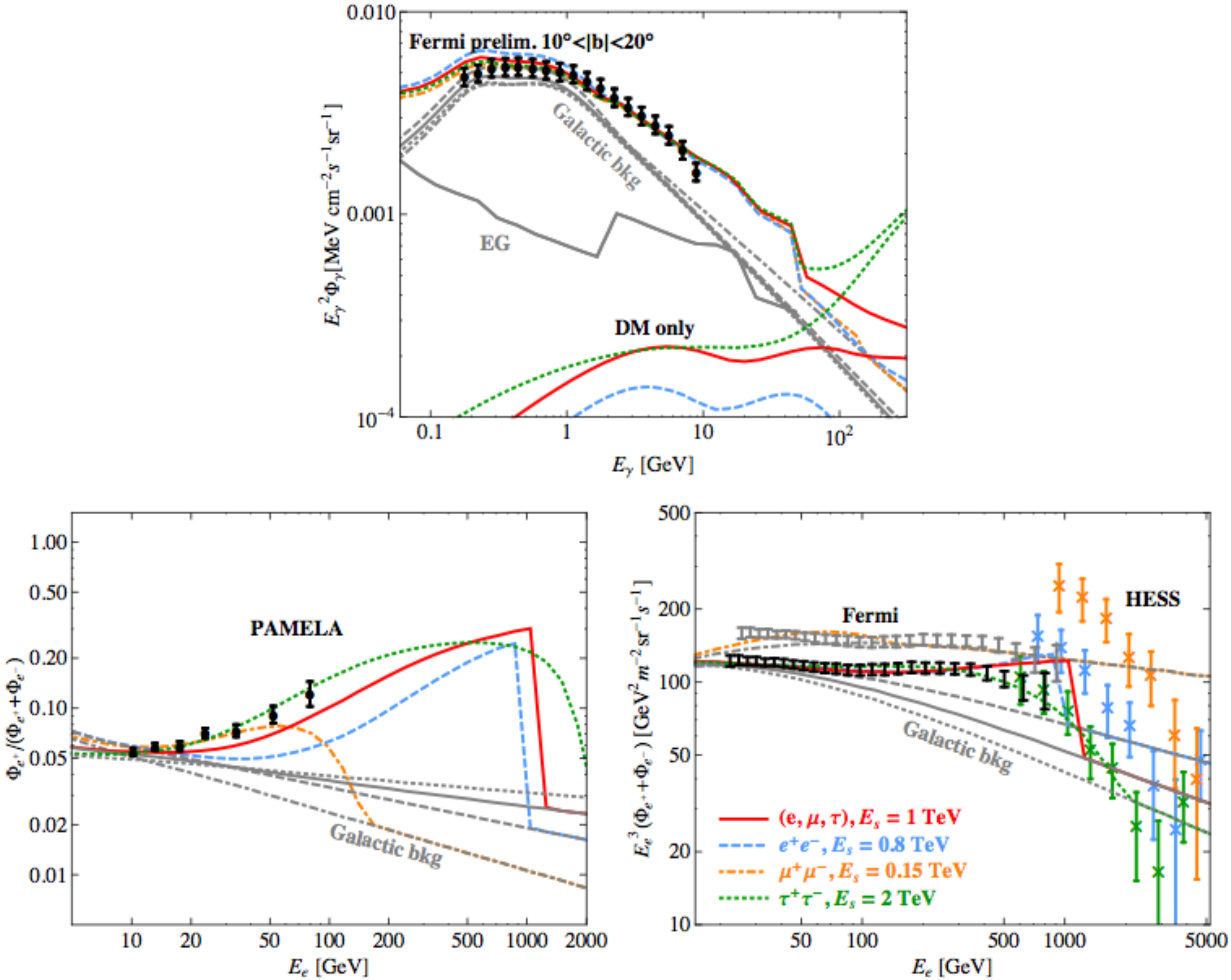
Barger research (2007-2010)

Dark Matter

We studied SUSY, extended MSSM, singlet, and general models for the DM relic density, direct and indirect signals, and collider signals.

TeV DM needs a ‘boost’ in local annihilation of order 100.
Muon pair final states are preferred.
Pulsars are an alternative to the PAMELA signal.

Light DM would naturally explain a 1 pb annihilation x-section
---compatible with XENON exprs.
Light DM & Light Higgs can be related in models.



Fermi prelim. 10°<|b|<20°
Galactic bkg
EG
DM only
$E_\gamma^2 \Phi_\gamma$ [MeV cm^{-2} s^{-1} sr^{-1}]
E_γ [GeV]
PAMELA
Galactic bkg
$\Phi_{e^+}/(\Phi_{e^+}+\Phi_{e^-})$
E_e [GeV]
Fermi
HESS
Galactic bkg
$E_e^3(\Phi_{e^+}+\Phi_{e^-})$ [GeV^2 m^{-2} sr^{-1} s^{-1}]
$(e, \mu, \tau), E_s = 1$ TeV
$e^+e^-, E_s = 0.8$ TeV
$\mu^+\mu^-, E_s = 0.15$ TeV
$\tau^+\tau^-, E_s = 2$ TeV
E_e [GeV]

Barger research (2007-2010)

Dark Matter

A WILD CARD:

the neutral DM could have a electric dipole moment or a magnetic dipole moment—explain the CoGeNT recoil spectrum (with 7 GeV DM mass)

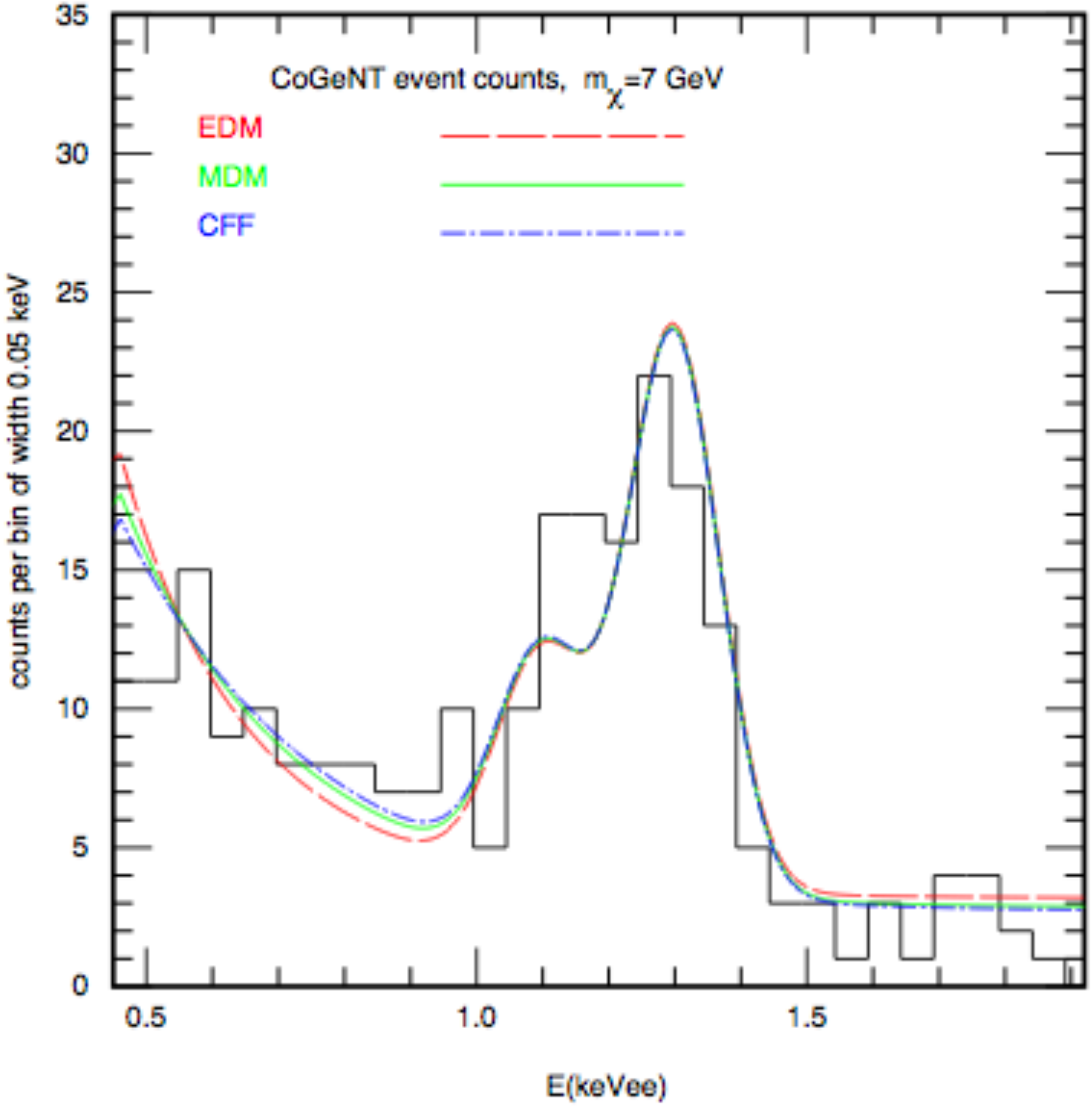
EDM: d_χ = 10–20 e·cm =e/(1.97 PeV)

MDM: mu_X = e/(3.34 TeV)

CFF: (q/187 GeV) ^2 corresponds to Λ_SI ≈ 6.6 Λ_CFF)

Barger research (2007-2010)

Dark Matter



FY2011-2014 PHENO RESEARCH

Exciting times just around the corner:

LHC discoveries…..

TeVatron neutrinos…..

Dark matter……

It's the perfect time for pheno research…..