

# Argonne National Laboratory HEP Theory Group

## Overview of the Group Activities

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Argonne National Laboratory

KICP and EFI, University of Chicago

DOE HEP Division Review, Argonne, May 24, 2011

# Group Members

## Staff Members:

Ed Berger

Geoff Bodwin

Radja Boughezal

Ian Low (joint with Northwestern University)

Frank Petriello (joint with Northwestern University)

Carlos Wagner (joint with University of Chicago)

Cosmas Zachos

## Postdoctoral Fellows :

Qing-Hong Cao ( Joint Theory Institute, departing this year )

Jamie Gainer ( joint with Northwestern University )

Seth Quackenbush

Gabe Shaughnessy ( joint with Northwestern University, departing this year )

Pedro Schwaller ( joint with Univ. of Illinois at Chicago )

## New Arrivals (fall 2011) :

Chuan-Ren Chen

Xiaohui Liu (Joint with NW)

Sonny Mantry (LHC Fellow )

Markus Schulze (Director Postdoc position)

Hao Zhang (Joint with IIT)

Only 3 postdoc positions will be supported by long term base funding.  
(2.5 positions in FY11)

## Students :

Patrick Draper (Univ. of Chicago, student of C. Wagner)

Wei-Chi Huang (Northwestern Univ., student of I. Low)

Ran Huo (Univ. of Chicago, student of C. Wagner)

Ye Li (Northwestern Univ., student of F. Petriello)

# New Staff Appointments

## 1. Frank Petriello

Physicist at ANL and Associate Professor at NW

Frank has substantially strengthened QCD and hadron collider physics theory activity.

## 2. Radja Boughezal

Assistant Physicist, with impressive credentials in perturbative QCD, Higgs boson physics and collider physics.

# New HEP Theory Effort

- **Salman Habib and Katrin Heitmann** have been appointed at ANL to lead a theory effort in computational cosmology, based in the HEP division.
- Initial funding for three years comes from LDRD Director's funds, which includes four postdoctoral positions.
- These appointments complement the **Astroparticle Physics** work in the HEP Division.
- The Theory Group is strongly interested in a strong connection to these new Division members, in the areas of **Dark Matter, Dark Energy and Structure Formation**, an interest that is reciprocal.
- This presents a new opportunity to strengthen our efforts in the area of Astrophysics and Cosmology.

# Postdocs

- The HEP Theory Group has been very successful in the supervision of postdocs.
- Most of the recent Argonne postdocs have found excellent positions and carried on successful careers after their stay at Argonne.
- Notable recent cases in last four years are Csaba Balazs, Ayres Freitas, Xavier Garcia i Tormo, Jay Hubisz, Chris Jackson, Pavel Nadolsky and Alexander Velytsky.
- Current postdocs, Q.H. Cao and G. Shaughnessy, departing this year, have already secured faculty and postdoc positions to continue their high quality research activities.

# Organization of Workshops and Conferences

The group has organized local international workshops at the Argonne HEP Division in the last few years. Subjects included

**Symmetry Breaking Dynamics, 2009** (jointly with Chicago, C. Zachos)

**Collider Physics, 2009** (jointly with IIT, E. Berger, I. Low and C. Wagner)

**ATLAS Physics Jamborees, 2009, 2010, 2011** (planned) (E. Berger and R. Yoshida)

Apart from these local workshops, members of the group have helped in the organization of numerous international workshops and conferences worldwide and have participated in several national DOE and NSF committees. Recent international conferences hosted locally by group members include

**LoopFest, 2011** (R. Boughezal and F. Petriello, Organized by Argonne and NW)

**Quarkonia, 2010** (G. Bodwin, Organized by Argonne and FNAL)

All these activities have greatly enhanced the visibility of the Theory group and of the HEP Division at Argonne.

# Activities

- Large productivity in areas related to phenomenology of particle physics, which has been our main research priority : **Collider physics, QCD, Higgs physics, heavy quarkonia and beyond the standard model phenomenology.**
- The group has also produced relevant articles in the areas of cosmology and astroparticle physics, in particular on the questions of **dark-matter and baryogenesis.**
- The group has also contributed to **fundamental physics** and to **non-perturbative field theory.**

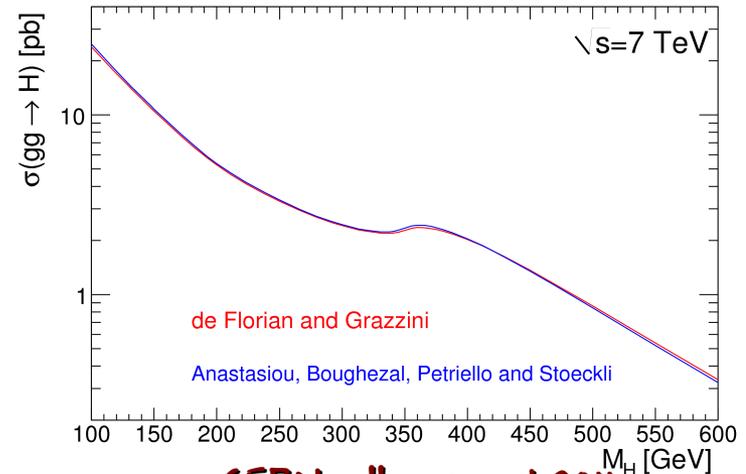
# Some Recent Research Activities

# Radja Boughezal's research highlights

- Provided Higgs production cross sections for  $gg \rightarrow H$ .

These are the official predictions used by the Tevatron and the LHC experiments

(Anastasiou, Boughezal, Petriello 2010)

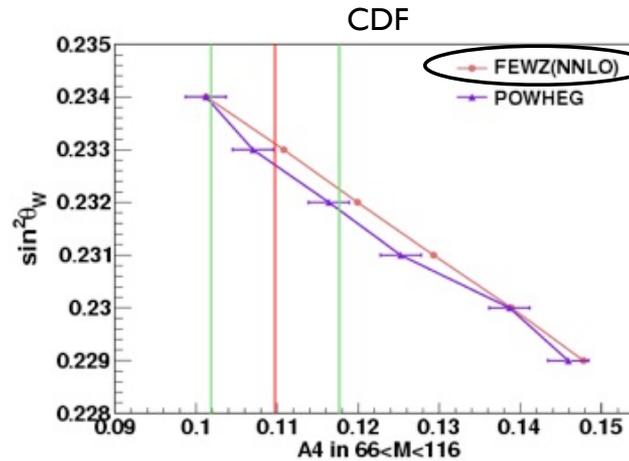
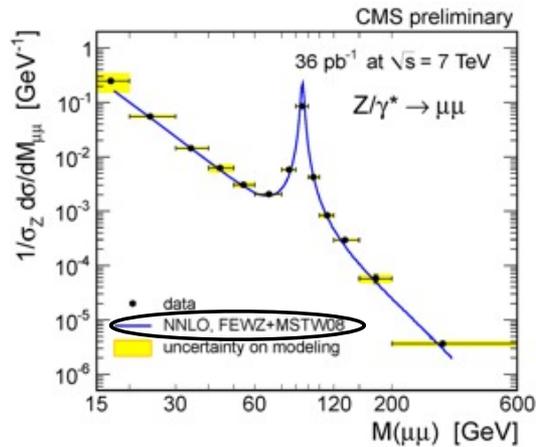


CERN yellow report 2011

- Quantified the effect of a fourth generation of heavy quarks on the Higgs production cross section. Result used by the Tevatron collaborations in setting exclusion limits (Anastasiou, Boughezal, Furlan 2010)
- Studied the effect of colored scalar particles on the Higgs production cross section in  $gg \rightarrow H$  and used the Tevatron bounds to constrain their parameter space (Boughezal 2011)
- Studied the hadronic-light-by-light contribution to the muon anomalous magnetic moment ( $g-2$ ). Our results strengthen the  $\approx 3$  sigma discrepancy between theory and experiment (Boughezal, Melnikov 2011)
- Extended a subtraction scheme to deal with the infrared problem from double real radiation matrix elements needed for higher multiplicity LHC processes such as Z/W+jets through NNLO (Boughezal, Gehrmann, Ritzmann 2010)

# Petriello research highlights

- Research goal: Develop novel approaches for higher-order QCD calculations, and apply to analysis of collider data



- Significant upgrade of FEWZ for EW gauge boson production at NNLO  
Now powerful enough for full NNLO analysis of differential spectra  
Gavin, Li, Petriello, Quackenbush  
arXiv:1011.3540

- Responsible for convening LHC Higgs cross section working group, editing gluon-fusion chapter for CERN Yellow Report on Higgs cross sections arXiv:1101.0593
- New ideas for the application of EFT techniques to hadron collider predictions  
Mantry, Petriello PRD 81:093007 (2010); PRD 83:053007 (2011); arXiv:1011.0757; ANL-HEP-PR-11-35 (with Y. Li)

 All ATLAS, CMS, and many CDF/D0/LHCb results on Higgs, W, Z physics use ANL theory group results and codes

## Factorization Theorems for Exclusive Quarkonium Production

G.T. Bodwin (ANL), J. Lee (Korea U.), X. Garcia i Tormo (ANL, U. of Alberta)

Phys. Rev. Lett. **101**, 102002 (2008)

Phys. Rev. D **81**, 114014 (2010)

- Bodwin and collaborators proved factorization theorems to all orders in perturbation theory for  $e^+e^- \rightarrow \text{charmonium} + \text{charmonium}$ ,  
 $B \rightarrow \text{light meson} + \text{charmonium}$ .
- These are the first factorization theorems to be proven for quarkonium production.

## Heavy Quarkonium: Progress, Puzzles and Opportunities

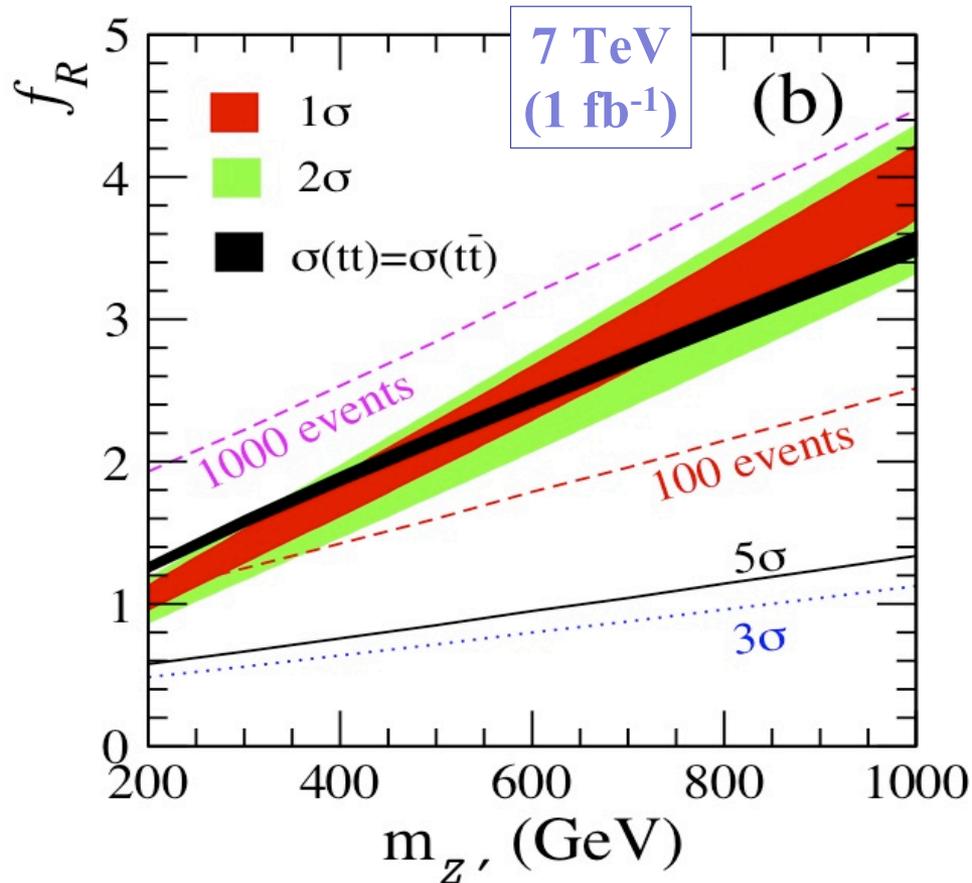
Nora Brambilla (TU München), G.T. Bodwin (ANL), *et al.*

Eur. Phys. J. C **71**, 1534 (2011)

- Members of the Quarkonium Working Group (QWG) have prepared a comprehensive (181 page) document that describes recent progress in quarkonium physics and the outstanding current issues in experiment and theory.
- The document also lists specific opportunities for quarkonium physics at collider facilities.
- Bodwin was a coordinator and principal author of the section on production.

# Same-sign top pair production

Flavor Changing  $Z'$  Model -- LHC Predictions



Parameter region of right-handed coupling  $f_R$  and  $Z'$  mass to fit Tevatron  $A_{FB}$  is above the LHC  $5\sigma$  discovery curve.

*Bands show the  $1\sigma$  and  $2\sigma$  fits to the  $t\bar{t}$  inclusive cross section and  $A_{FB}$ .*

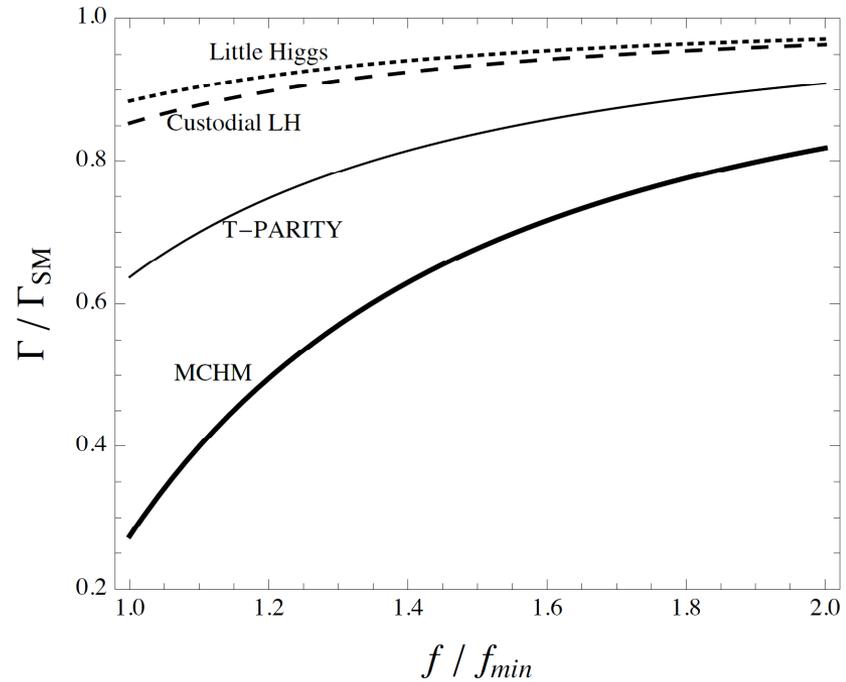
Z-prime exchange **alone** is an unlikely explanation of  $A_{FB}$

LHC 7 TeV measurements would impose hard constraints on  $f_R$ . Search for same-sign top quark pairs is interesting in other model contexts also.

## Ian Low's research highlights:

### The identity of the Higgs at the LHC :

- gluon-fusion production channel -- compositeness and naturalness  
[0901.0266](#), Low and Shalgar;  
[0907.5413](#), Rattazzi, Low, and Vichi;  
[1010.2753](#), Low and Vichi
- decay into ZZ final states - spin, CP, and origin of electroweak symmetry breaking  
[0806.2864](#), Keung, Low, and Shu  
[0911.3398](#), Cao, Jackson, Keung, Low, and Shu
- decay branching fractions  $V_1 V_2$ : electroweak quantum numbers  
[1005.0872](#), Low and Lykken



### The identity of the dark matter:

- relating direct detections to indirect detections -- [0912.4510](#), Cao, Low, and Shaughnessy; [1010.1774](#), Keung, Low, and Shaughnessy
- reconcile different indirect detection anomalies  
[1012.5300](#), Cheng, Huang, Low and Menon

# Carlos Wagner Research Highlights

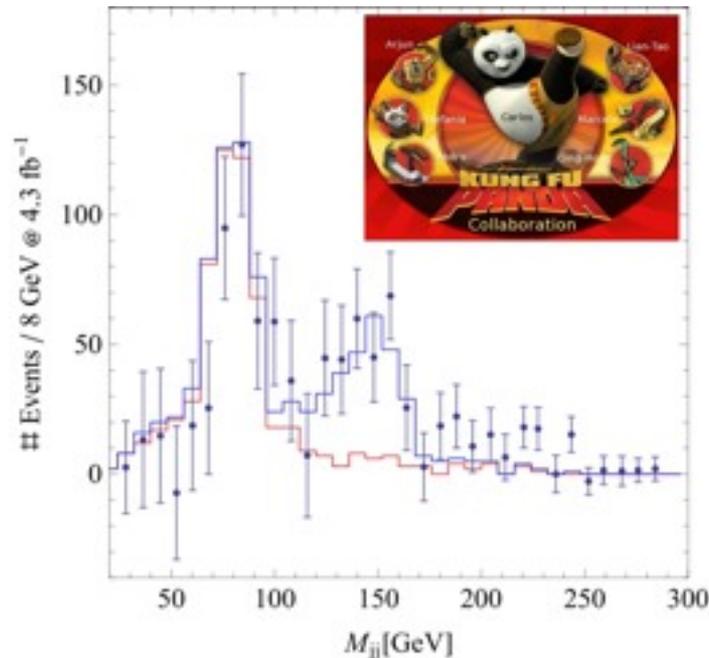
**Tevatron  $t\bar{t}$  asymmetry** : Analyzed different new physics scenarios. Axigluon and t-channel charged  $W'$ -boson preferred, Phys.Rev.D81:114004,2010 (**Cao, Mc Keen, Rosner, Shaughnessy**)

**Direct DM Detection Anomalies** : Phys.Rev.Lett.106:121805,2011 (**Cao, Draper, Liu, Wang,Zhang**)

**RG Invariants in the MSSM** : Phys.Rev.D82:075005,2010; D83:035014,2011 (**Carena, Draper, Shah**)

**MSSM Higgs searches at hadron colliders** : Reach of Tevatron and early LHC; complementarity of search channels, Phys.Rev.D81:015014,2010; D83:055007,2011 (**Carena, Draper,Liu**)

**Higgs from SUSY cascade decays** : (Boosted) Higgs bosons abundantly produced in region of parameters consistent with neutralino DM; arXiv:1103.4138 (**Gori, Schwaller**)



## Higgs Doublet Explanation of Tevatron $W+2j$

Production of Charged Higgs, decaying into neutral Higgs and  $W$ . Consistent with precision measurements and flavor physics, as well as with photon/ $Z$  + 2jets constraints.

Q.H. Cao, M. Carena, A. Menon, P. Schwaller, L.T.Wang and C.W., Panda Collaboration, **arXiv:1104.4776**

T Curtright & C Zachos (ANL), [arXiv:1010.5174] PhysRevD83 (2011) 065019; & [arXiv:0909.2424] JPhysA42 (2009) 485208; [1002.0104] JPhysA43 (2010) 445101

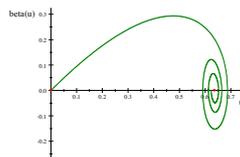
## THE GLOBAL STRUCTURE OF THE RENORMALIZATION GROUP

The Gell-Mann–Low finite renormalization group equation

$$\Psi(g(t)) = \lambda^t \Psi(g),$$

may be solved differently than the usual way of integrating a perturbative approximant to its algebra, the  $\beta$ -function. The **new methods** of calculation produce **an analytic interpolate without the benefit of a**

**local propagation relation.**



✓ Periodic  $\Psi^{-1}$ s yield **limit cycles** even for one real coupling, e.g.,  $\Psi^{-1} = \tan \log \quad \rightsquigarrow$  periodicity of the physics in  $t$ , the logarithm of the scale  $\mu$ . Solutions thus found have novel, exotic features, revealing intriguing **multivalued** behaviors including chaotic (spin-glass) RG flows.

# Independent work of Postdocs

**Q.H. Cao** studied NLO corrections to single top production at the LHC, arXiv:1012.5132, as well as the collider implication of discrete symmetries in the lepton sector, arXiv:1103.0008, Phys.Rev.Lett.106:131801,2011.

**J. Gainer** studied general SUSY models and their implications for searches at the LHC, arXiv:1009.2539, 1103.1697, as well as for indirect Dark Matter detection, JHEP 1101:064,2011.

**P. Schwaller** studied “long lived” four generation neutrino models arXiv:1103.3765, as well as other new Dark Matter ideas, JHEP 1103:048,2011.

**G. Shaughnessy** studied models leading to light Dark Matter and their direct and indirect Dark Matter detection and LHC signatures, Phys.Rev.D82:035019,2010, D82:095011,2010, as well as the possible appearance of multilepton signatures and its detection at the LHC, Phys.Rev.D83:055006,2011.

# Summary

- Theory Group carries a Broad Research Program.
- Emphasis on the connection of Theory with Experiment.
- Group develops programs which are being used by the Tevatron and LHC experimental collaborations.
- Successful supervision of postdocs and students.
- Active in National and International Committees and in the Organization of Workshops and Conferences.