Theory
focus: collider phenomenology

Markus Diehl
Deutsches Elektronen-Synchroton DESY

76th PRC, Hamburg, 24 October 2013

Theory group: structure and staff

Collider phenomenology

M.D., J. Reuter,
F. Tackmann, A. Weiler,
G. Weiglein;
J. Blümlein, P. Marquard,
T. Riemann

Particle Cosmology

W. Buchmüller, T. Konstandin,
A. Ringwald, A. Westphal,
NN

String theory

I. Kirsch, V. Schomerus,
J. Teschner

Lattice QCD (NIC)

K. Jansen, H. Simma,
S. Schaefer, R. Sommer

Staff news

Collider phenomenology

A. Weiler: leave of absence from Sept 2013 to Aug 2015
for a fixed-term staff position at CERN

P. Marquard: tenure track position in Zeuthen since June 2013
four-loop calculations, inclusion of masses, development of methods, high-performance computer algebra

Particle Cosmology

NN: O. Lebedev (5 yr postdoc) → professor in Helsinki
position in process of being filled

Lattice QCD (NIC)

S. Schaefer will reinforce lattice group starting November
algorithms for dynamical fermions, small lattice spacings

Funding

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

GRADUIERTEN KOLLEG
Masse-Spektrum-Symmetrie

Lattice QCD (NIC)

Computational Theoretical Particle Physics
KA AC B
SFB TR9

Collider phenomenology

Particles, Strings, and the Early Universe
Collaborative Research Center SFB 676

DESY

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Application for 3rd funding period 2014-18 submitted to DFG

String theory

Particle Cosmology

Research Training Group 1670
MATHEMATICS INSPIRED BY STRING THEORY AND QUANTUM FIELD THEORY

Funding

Collider phenomenology

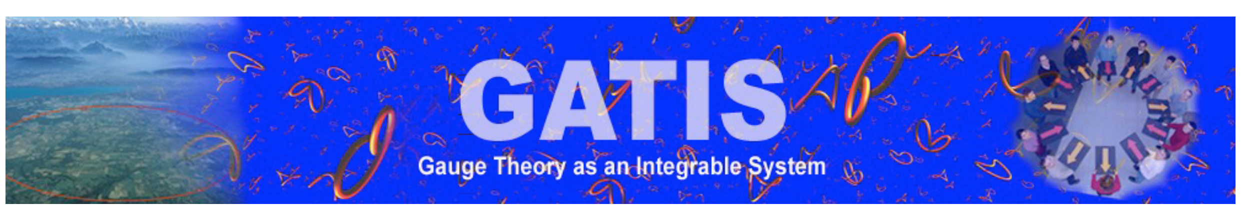
LHCphenOnet

New EU Network:
The Higgs quest - exploring symmetry breaking at the LHC
HIGGSTOOLS
Jan. 2014 - Dec 2017

Lattice QCD (NIC)

major EU computing time awards with strong NIC participation

String theory

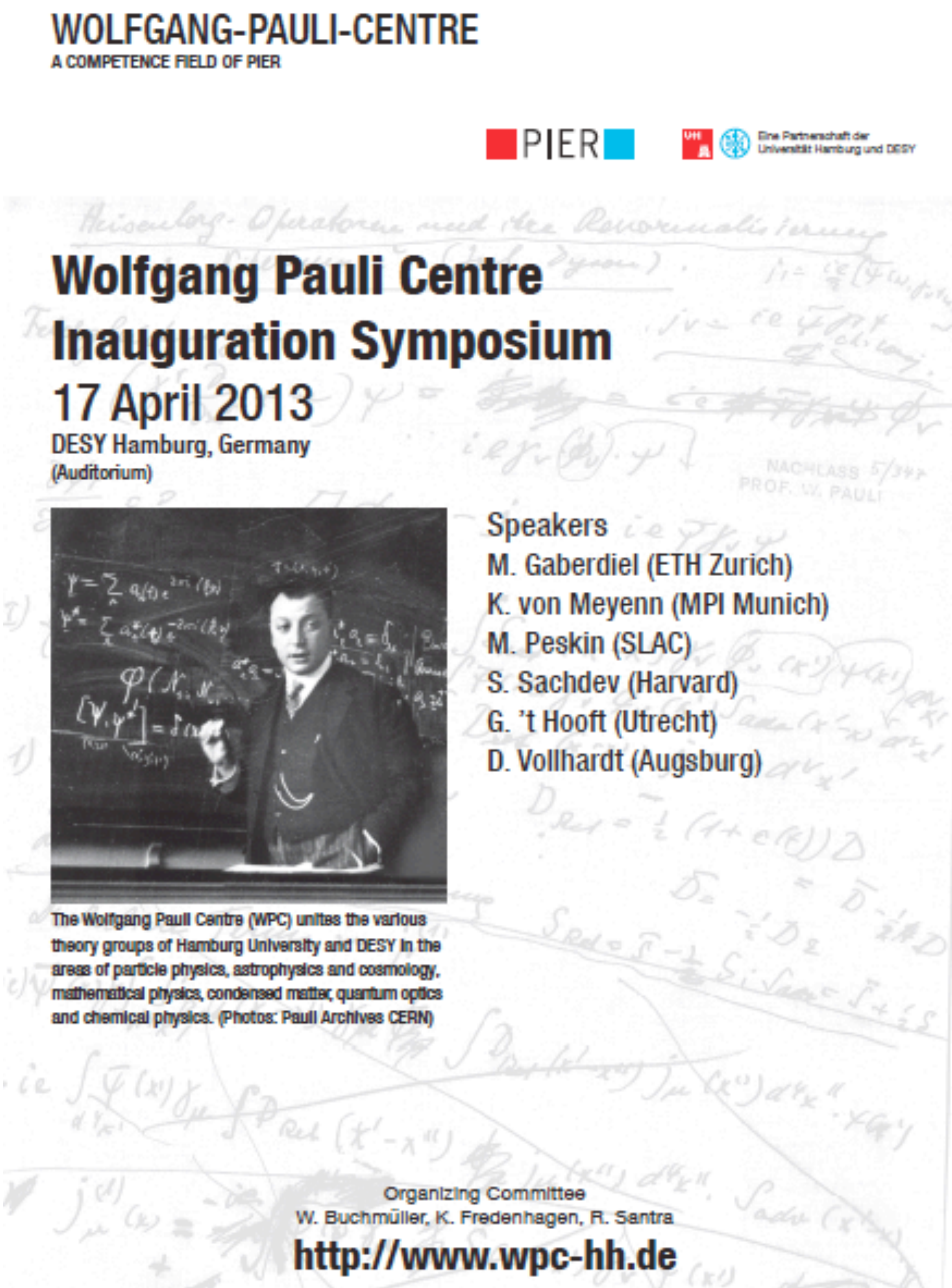


coordinated by DESY
one postdoc position filled here

Individual grants

Humboldt Foundation
JSPS (Japan)
Studienstiftung
Joachim Herz Foundation

Wolfgang Pauli Centre



- 11-13 Sept: Workshop on Nonequilibrium Techniques in Cosmology and Condensed Matter

coming up:

- 7 Nov: Pauli Lecture:
  Johannes Henn (IAS Princeton)
  From the harmonic oscillator to elementary particle physics
- planned for winter term 2013/14
  - ★ Mini-Workshop on AdS/CFT and Condensed Matter Systems
  - ★ Lecture Series on Topological Defects in Phase Transitions

Conferences and workshops

Hosted or (co)organized

HELMHOLTZ GEMEINSCHAFT

DESY THEORY WORKSHOP
SEPT. 24 - 27, 2013
DESY, Hamburg, Germany

DESY

NONPERTURBATIVE QFT:
METHODS AND APPLICATIONS

PLENARY SESSIONS — **Sept. 24 - 27, 2013**

S. Catterall (Syracuse University)
N. Drukker (King's College London)
G. Dunne (Connecticut University)
D. Gaiotto (PI Waterloo)
A. Gonzales-Arroyo (UA Madrid)
J. Jäckel (Heidelberg University)
D. Jafferis (Harvard University)
Z. Komargodsky (WI Rehovot)
G. Korchemsky (IPhT Saclay)
M. Luty (UC Davis)
M. Marino (Geneva University)
R. Myers (PI Waterloo)
A. Ramos (DESY)
R. Rattazzi (EPFL Lausanne)
S. Razamat (Princeton University)
K. Rummukainen (Helsinki Univ.)
M. Shifman (UM Minneapolis)
H. Wittig (Mainz University)

DESY Heinrich-Hertz Lecture on Physics — **Sept. 25, 2013**
C. Vafa (Harvard University)

- 1st GATIS Fellow meeting, London, Feb.
- Monte Carlo Tools for Physics beyond the SM, Hamburg, Apr.
- ECFA Linear Collider Workshop, Hamburg, May
- String Pheno 2013, Hamburg, July
- QCD@LHC, Hamburg, Sept.
- Anomalous Quartic Gauge Couplings, Dresden, Sept
- Semi-inclusive QCD Processes at the LHC, Liebenberg, Oct.

Teaching

- lectures and seminars (Berlin, Dortmund, Dresden, Hamburg, Hannover, Postdam)
  - ★ summer 2013
    Einführung in die Teilchenphysik
    Theoretical Astroparticle Physics and Cosmology
    Introduction to String Theory
    Seminar on Mathematical Aspects/Methods of Theoretical Physics
  - ★ winter 2013/14
    Higgs Physics
    Standard Model
    Quantum Field Theory and Introduction to Elementary Particle Theory
    Theoretical Cosmology
    Introduction to Integrable Models
    Group Theory and Lie Algebras
    Theoretische Physik B für Studierende des Lehramts
    Workshop Seminar onSupergravity and Inflation
- schools: lecturing and/or (co)organization
  School on Computer Algebra and Partcle Physics (Zeuthen, Mar.)
  Non-perturbative Renormalisation (Natal, Brazil, Mar.)
  String Steilkurs (Hamburg, Apr.)
  DESY Summer Student Programme (Hamburg+Zeuthen, July/Aug.)
  Summer School on Moduli Spaces in Algebraic Geometry and Physics (HH, Aug.)
  Fermilab/CERN hadron collider physics school (CERN, Aug.)
  LHCPHENOnet School (Cracow, Sept.)
  Linear Collider Physics School (Hamburg, Oct.)
  Autumn School on Particle Cosmology (Göttingen, Oct.)

LHC physics discussions: ATLAS, CMS, Theory

LHC Physics Discussions

Go to parent category | iCal export | View | Create

ATLAS/CMS + Theory

Managers: Borras, K.; Meyer, A.; Moenig, K.; Schoerner-Sadenius, T.; Weiglein, G.; Ehrenfeld, W.; Weiler, A.; Melzer-Pellmann, I.; South, D.

November 2013

- 11 Nov LHC Physics Discussion: QCD

October 2013

- 28 Oct LHC Physics Discussion: High-lumi LHC physics case

September 2013

- 09 Sep LHC Physics Discussion: Top

July 2013

- 08 Jul LHC Physics Discussion: SUSY

June 2013

- 10 Jun LHC Physics Discussion: Higgs

February 2013

- 04 Feb LHC Physics Discussions: Beyond the 14 TeV LHC

Particle phenomenology

after the first LHC runs and the discovery of a Higgs boson

which with present precision looks fairly standard-model like

- investigate nature of electroweak symmetry breaking
  - ★ properties of the new particle (couplings, spin, CP)
  - ★ what is the Higgs potential, which dynamics is at its origin?
- search for new physics, construct and test models
  - ★ dark matter
  - ★ baryon asymmetry of the universe → CP violation
  - ★ neutrino sector
  - ★ unification of forces
- precision calculations in the Standard Model and its extensions
  - ★ especially (but not only) in the strong sector
  - ★ precision determination of SM parameters

Particle Cosmology

String Theory

Lattice

Activities of the group: an incomplete overview

Construct and test models

- SUSY scenarios
  Composite/Little Higgs models
  GUTs, string inspired models
- test against constraints from colliders, cosmology, high-precision measurements, ...
  - ★ fit/constrain parameter space
  - ★ phenomenology of simplified models
- flavor physics

Precision calculations

- multiloop and multileg calculations
  - ★ development of new methods ↔ mathematics and computer algebra
  - ★ apply to strong and e.w. sector
- standard candle processes
  → PDFs, α_S, quark masses
- factorization, resummation, effective field theories → jet physics, ...
- multiparton interactions
- SUSY at one-loop accuracy and beyond

Tools for the HEP community

- Monte Carlo generators
  - ★ WHIZARD (J. Reuter): emphasis on new physics; major upgrade for LHC run II and for ILC
  - ★ GENEVA (F. Tackmann): combine higher-order resummation with fully exclusive Monte Carlo
- HiggsBounds and HiggsSignals; FeynHiggs (G. Weiglein)
- ATOM: Automated Tester of Models (A. Weiler)
- PDF evolution code and parameterizations (J. Blümlein)

following slides:
some selected highlights

HiggsBounds and *HiggsSignals*

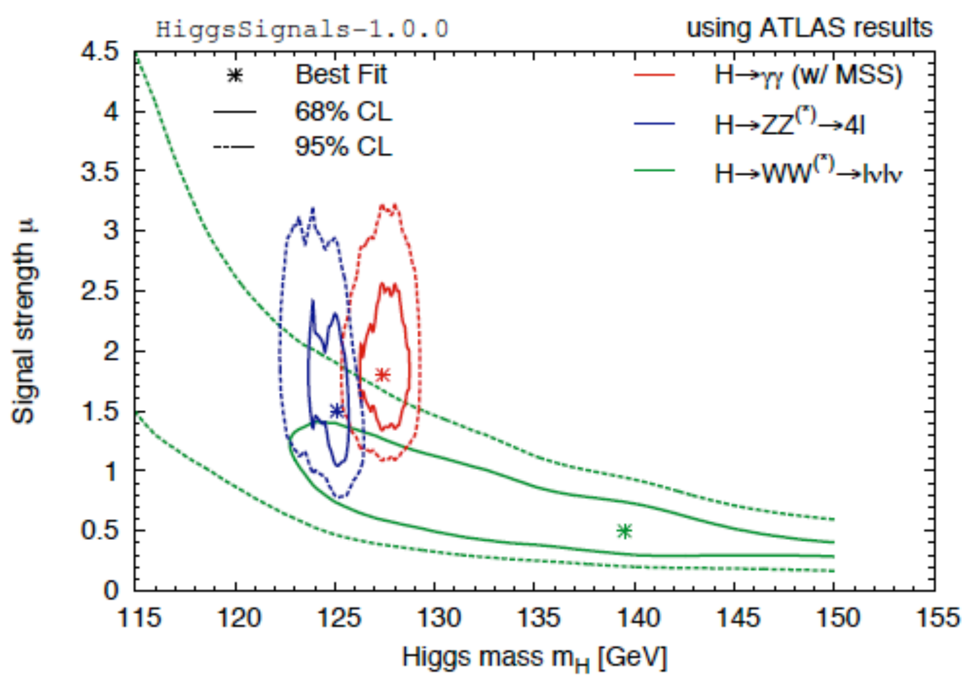
P. Bechtle, ..., G. Weiglein, ..., 2008, '12, '13

Programs that use the experimental information on cross section limits (*HiggsBounds*) and observed signal strengths (*HiggsSignals*) for testing theory predictions

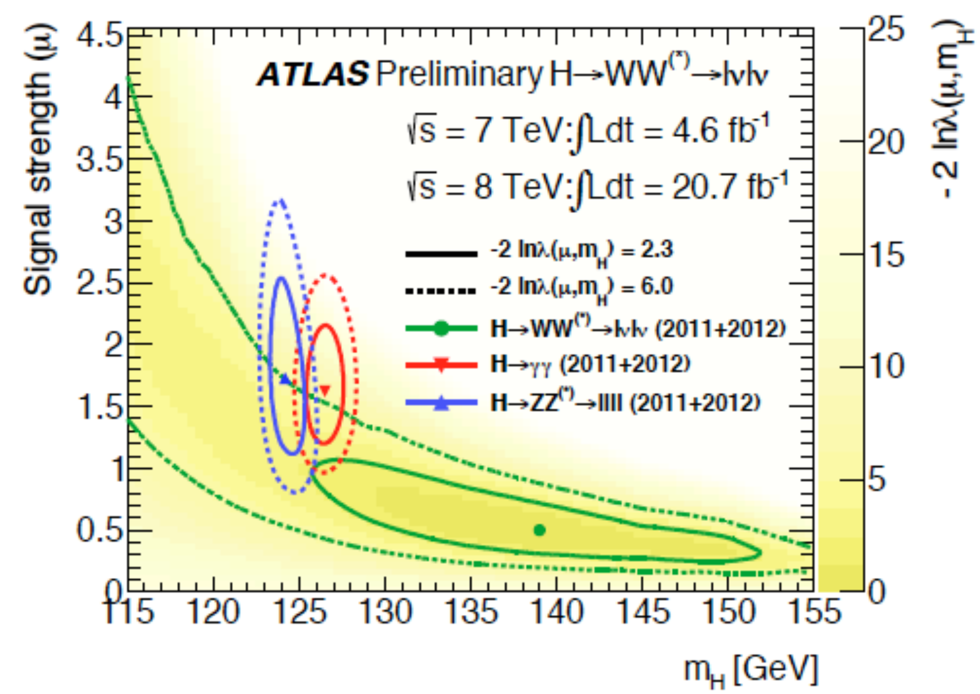
HiggsSignals: Test of Higgs sector predictions in arbitrary models against measured signal rates and masses

Systematic uncertainties and correlations of signal rates, luminosity and Higgs mass predictions taken into account

validation against official ATLAS result:



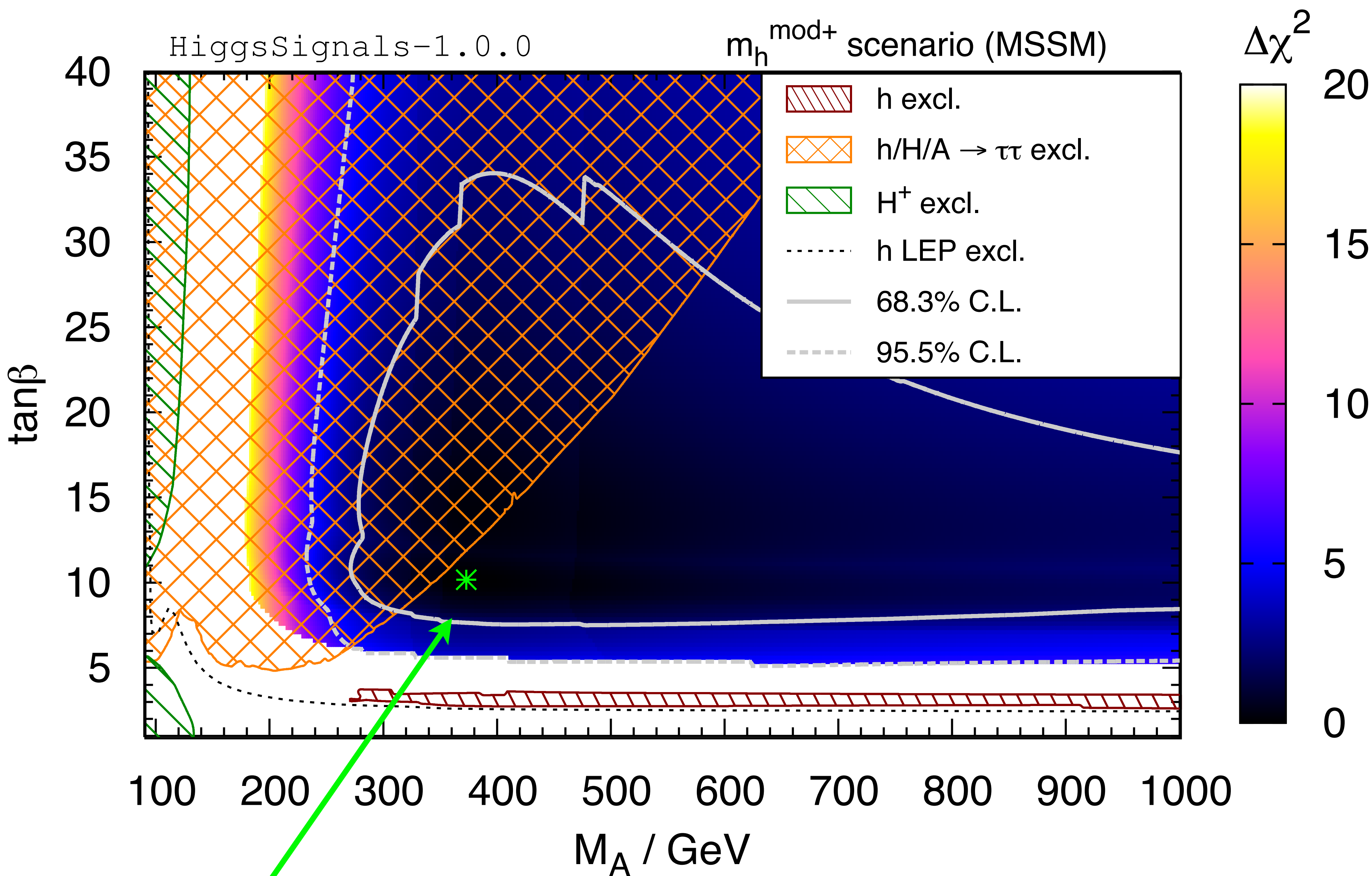
(a) **HiggsSignals** result on the best-fit regions obtained using the mass-centered χ^2 method. The data on $H \to WW^{(*)}$ is only available for $m_H \leq 150$ GeV.



(b) Official ATLAS result from [44].

Example for combined use of both programs

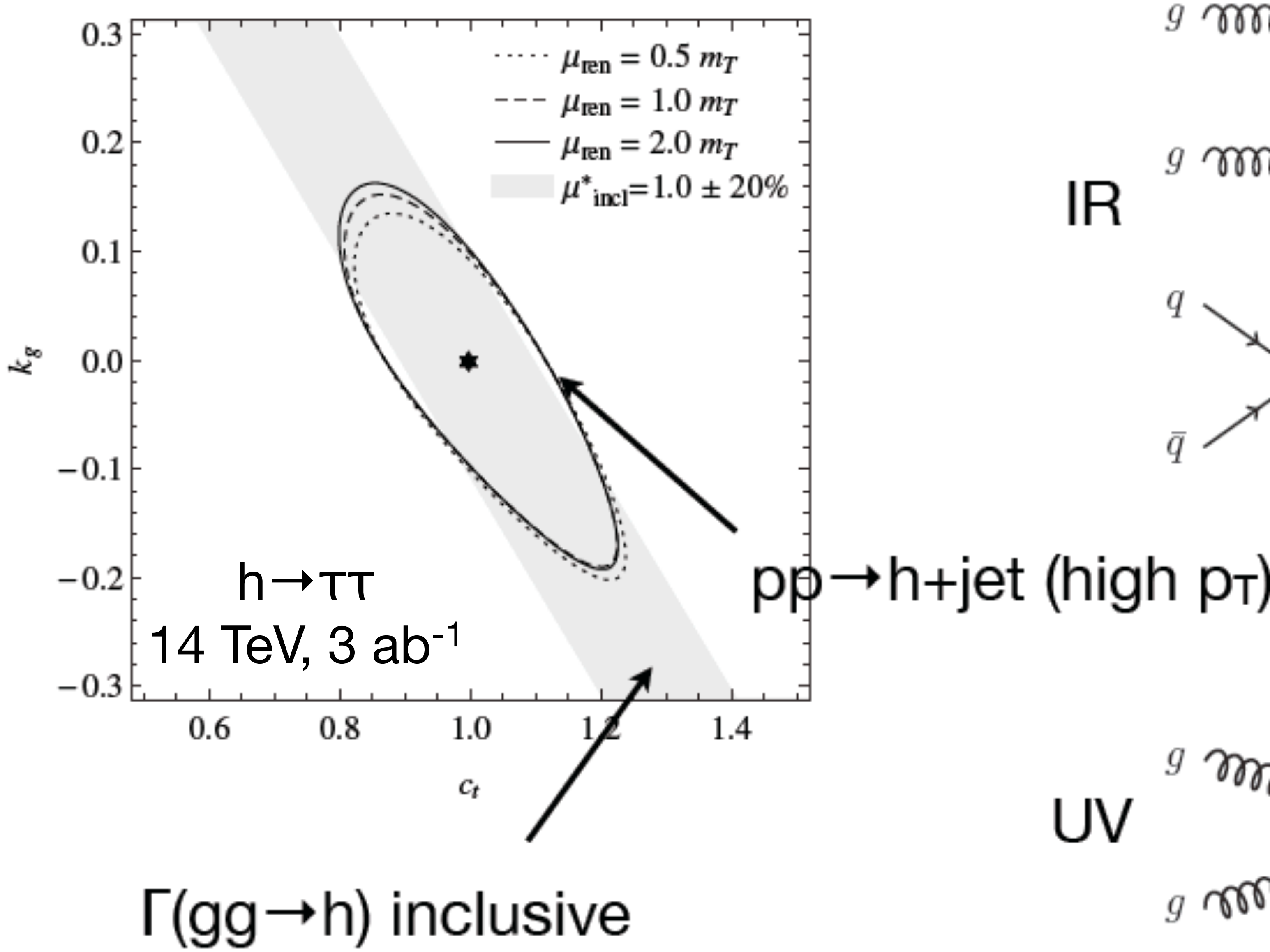
Best fit point and $\Delta\chi^2$ distribution from *HiggsSignals* and LEP exclusion limits in the MSSM (m_h^{mod} scenario) vs. LHC exclusion limits

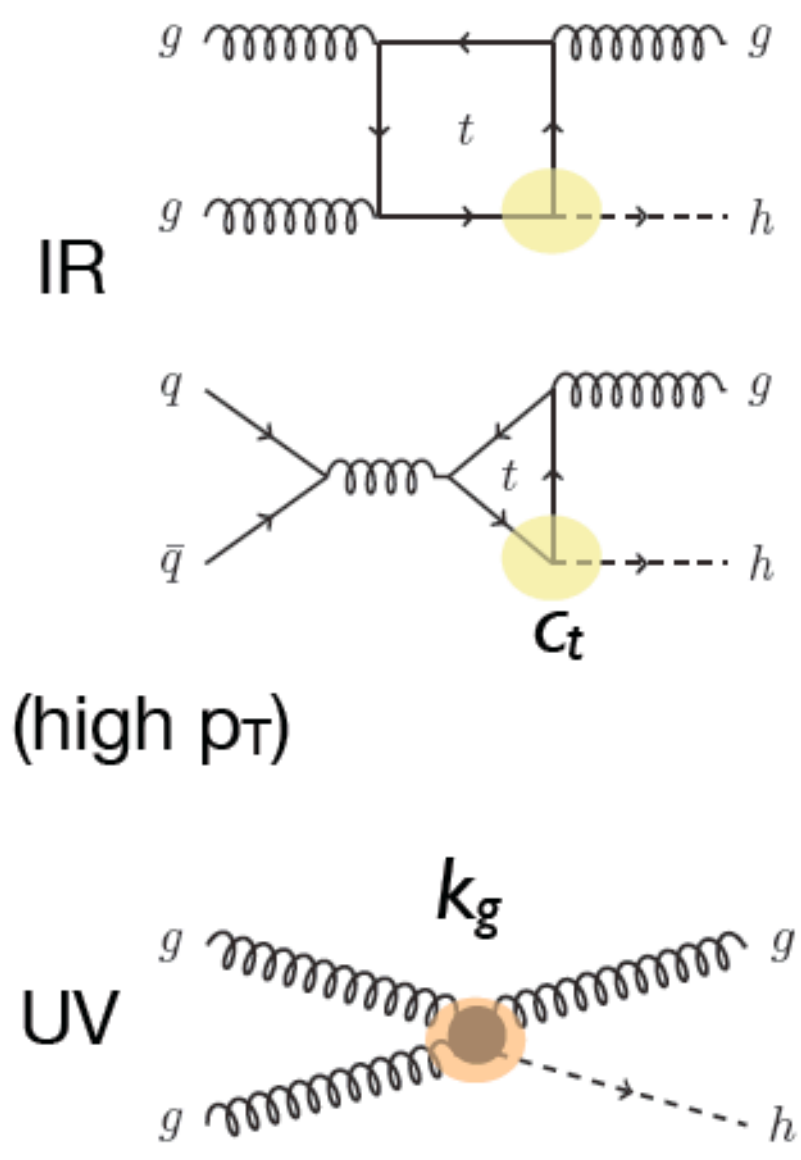


best fit point of *HiggsSignals*

Higgs production: probing top partners and the UV stabilization mechanism

Degeneracy in gluon fusion, break by boosting the Higgs





c_t $\qquad$ k_g

$$\mathcal{O}_t = \frac{y_t}{v^2}|H|^2\bar{Q}_L\tilde{H}t_R\,, \qquad \mathcal{O}_g = \frac{\alpha_s}{12\pi v^2}|H|^2 G^a_{\mu\nu}G^{a\,\mu\nu}$$

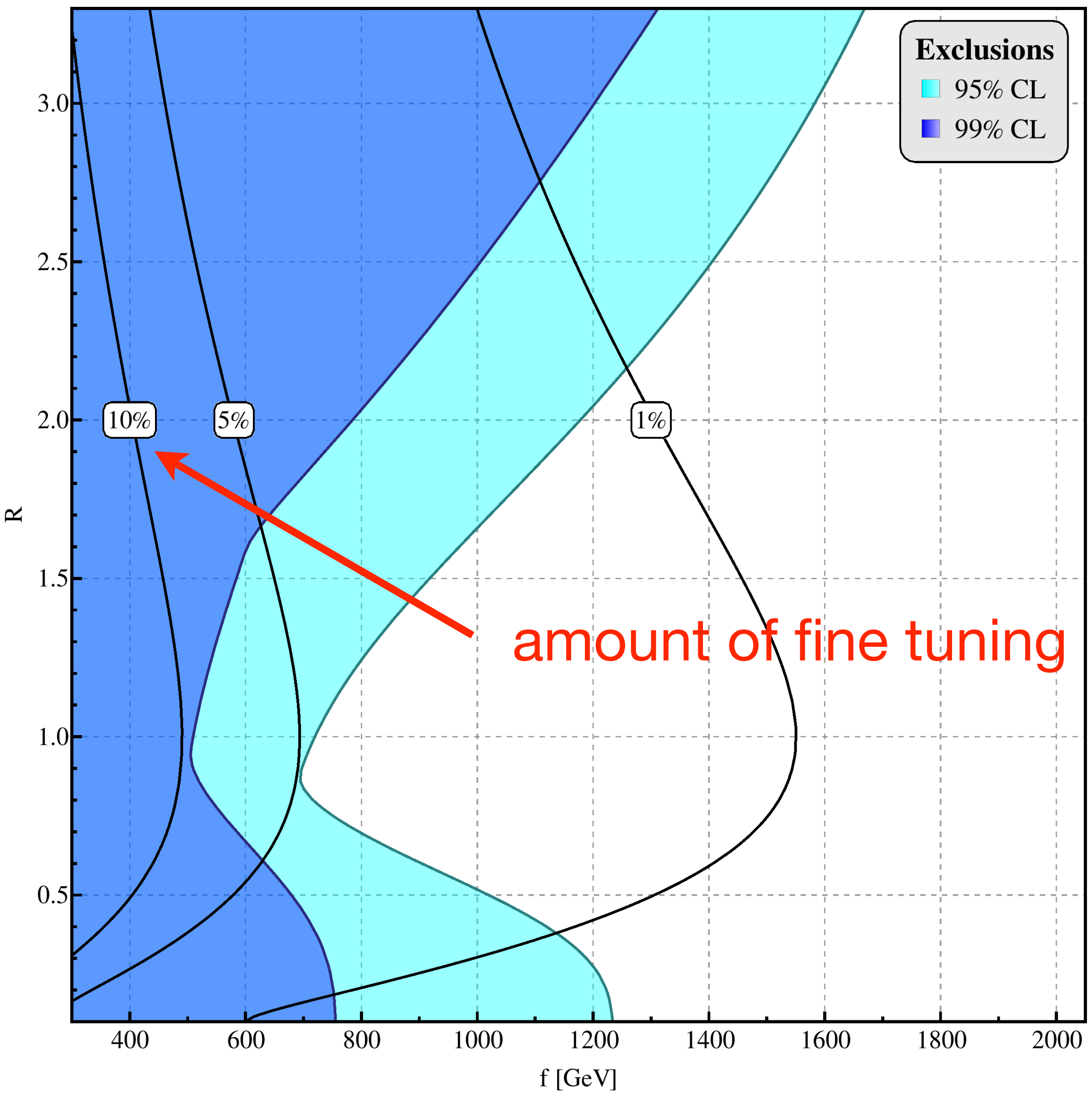
C. Grojean, E. Salvioni, M. Schlaffer, A. Weiler
arXiv:1310.xxxx

Interpreting the LHC data: Littlest Higgs with T parity

J. Reuter, M. Tonini, M. de Vries 2013

Higgs and e.w. precision data

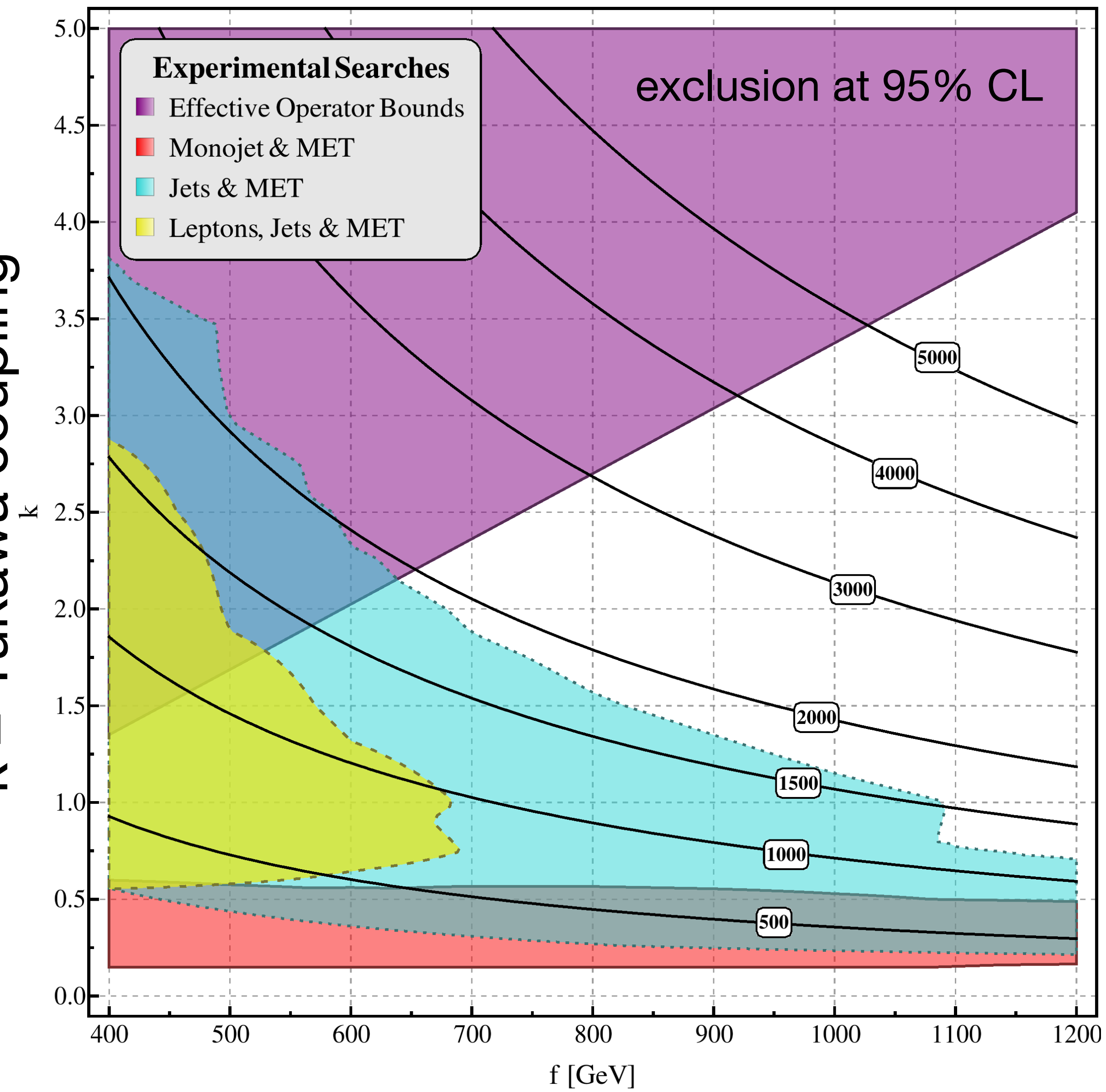
R = ratio of Yukawa couplings



f = collective symmetry breaking scale

Direct LHC searches for new particles

k = Yukawa coupling

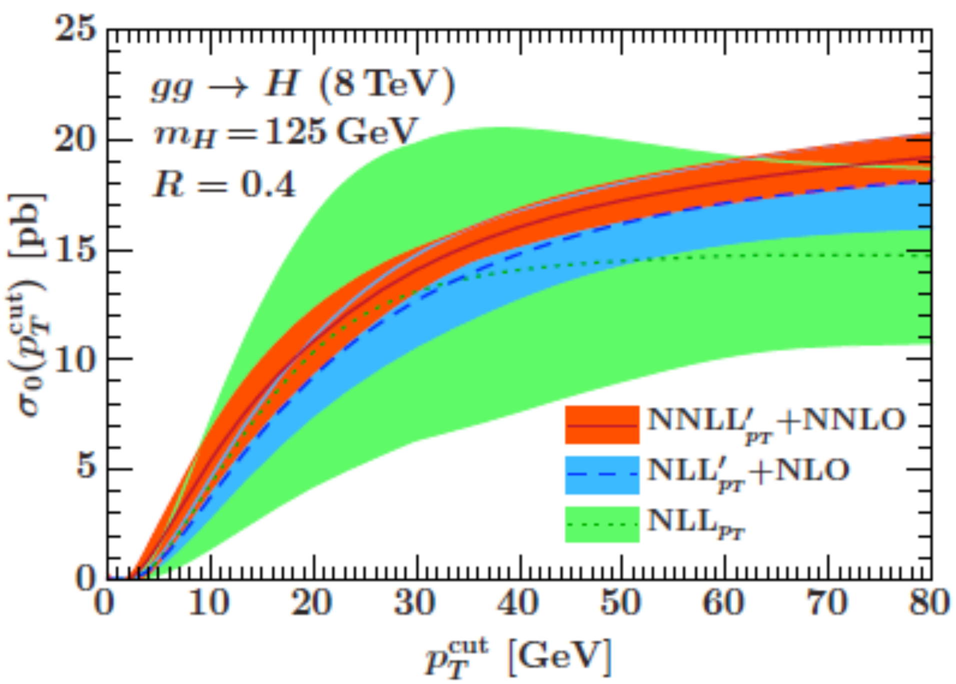


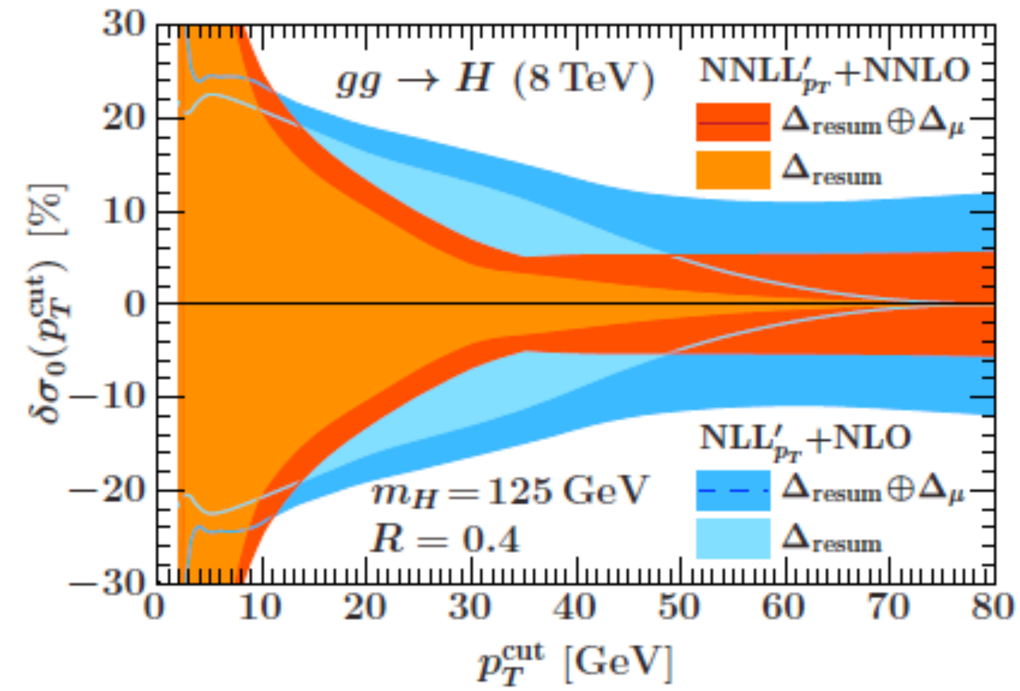
Resummed predictions for Higgs + 0 jet production

Higgs measurements divide data into exclusive categories
based on number of jets, decay kinematics, etc.

- $H + 0$ jets cross section $\sigma_0(p_T^{\rm jet} < p_T^{\rm cut})$ important in $H \to WW$ and $H \to \tau\tau$ analyses
- resum $\log(p_T^{\rm cut}/m_H)$ terms using SCET

[Stewart, Tackmann, Walsh, Zuberi; arXiv:1307.1808]





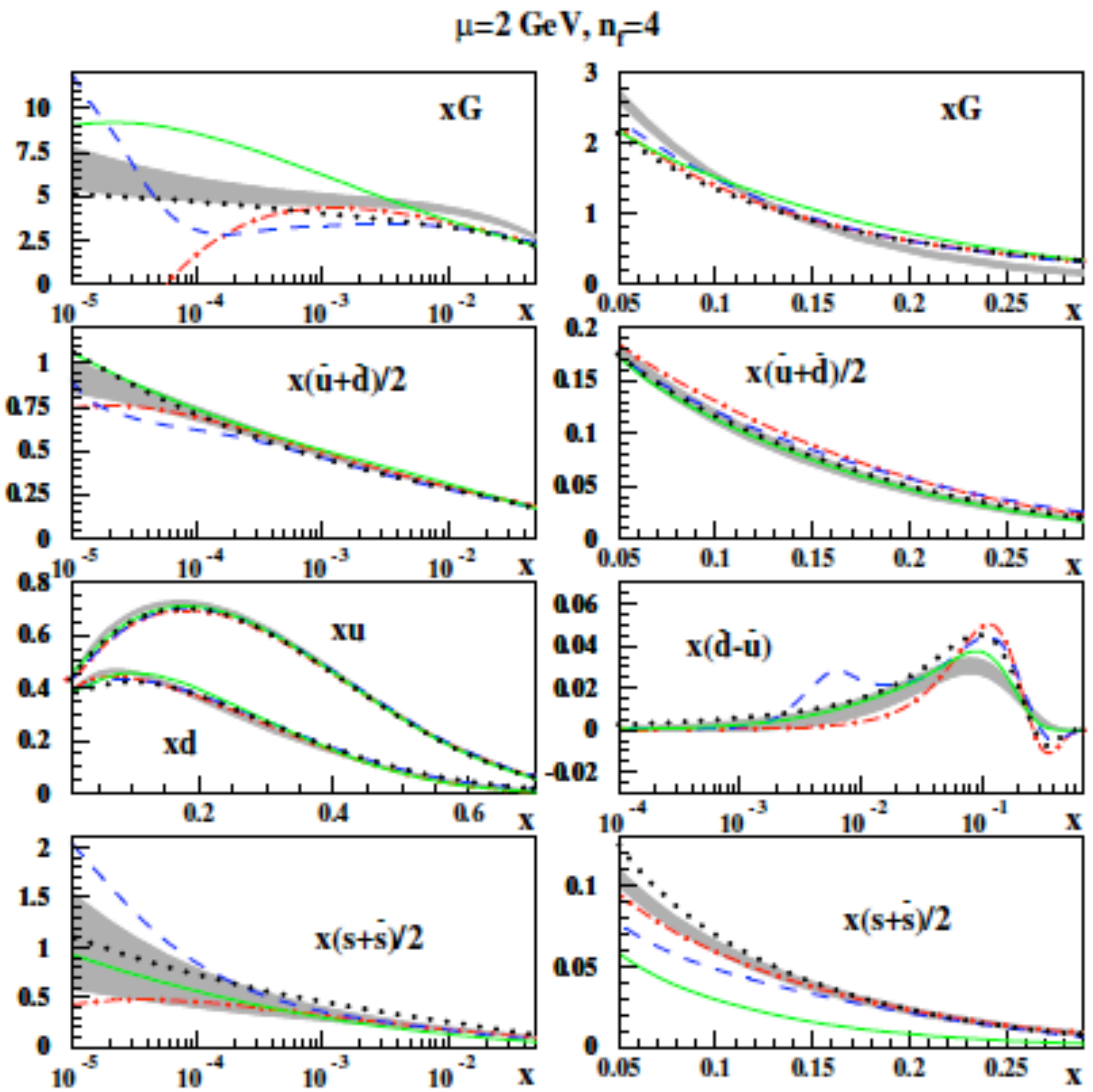
Systematic and careful uncertainty analysis required for reliable predictions

- Jet binning analyses require full theory correlation matrix for $\{\sigma_0, \sigma_{\geq 1}\}$

$$C = \begin{pmatrix} \Delta_{\mu 0}^2 & \Delta_{\mu 0}\,\Delta_{\mu \geq 1} \\ \Delta_{\mu 0}\,\Delta_{\mu \geq 1} & \Delta_{\mu \geq 1}^2 \end{pmatrix} + \begin{pmatrix} \Delta_{\rm resum}^2 & -\Delta_{\rm resum}^2 \\ -\Delta_{\rm resum}^2 & \Delta_{\rm resum}^2 \end{pmatrix}$$

- Uncertainties due to unresummed higher-order jet clustering logarithms

Precision determination of PDFs, α_S and m_c

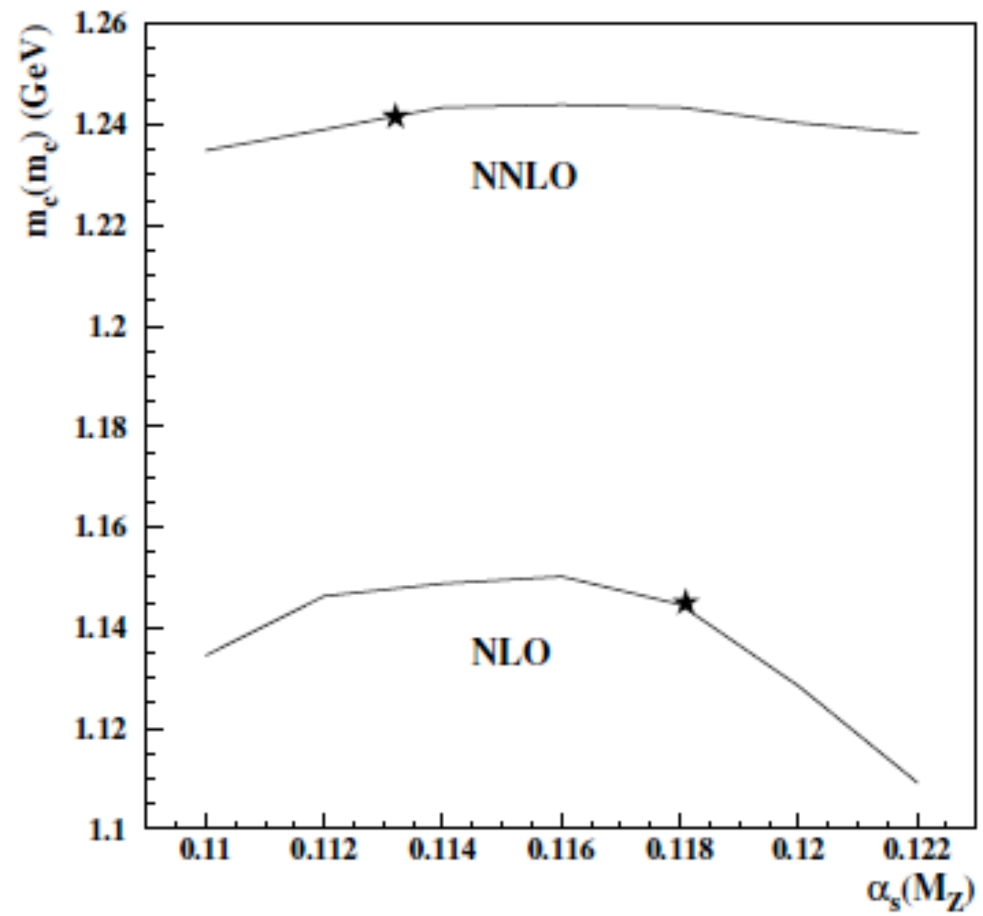


Alekhin, Blümlein, Moch

new NNLO PDF analysis

DIS + LHC DY & $t\bar{t}$ data

using combined H1 + ZEUS data on charm production in DIS:



NLO and NNLO $m_c(m_c)$ vs $\alpha_s(M_Z)$

Alekhin, Blümlein, Daum, Lipka, Moch

collaboration theory ↔ HERA experimentalists

On the way of completion: 3 Loop Massive Wilson Coefficients

5 of 8 coefficients have been calculated by now.

$$a_{gq}^{(3)} = C_F^2 T_F \Biggl\{ \frac{(N^2+N+2)}{(N-1)N(N+1)} \left(\frac{64}{3}B_4 - 96\zeta_4\right) - 2\Biggl[-\frac{29(N^2+N+2)}{27(N-1)N(N+1)}S_1^4$$

$$+\frac{2(275N^4+472N^3+951N^2+598N+96)}{81(N-1)N^2(N+1)^2}S_1^3 + \Biggl[\frac{14(N^2+N+2))}{9(N-1)N(N+1)}S_2$$

$$-\frac{2P_0}{81(N-1)N^3(N+1)^3}\Biggr]S_1^2 + \Biggl[-\frac{4P_1}{243(N-1)N^4(N+1)^4}$$

$$-\frac{2(209N^3+376N^2+669N+418)}{27(N-1)N(N+1)^2}S_2 + \frac{104(N^2+N+2)}{27(N-1)N(N+1)}S_3 - \frac{16(N^2+N+2)}{9(N-1)N(N+1)}S_{2,1}\Biggr]S_1$$

$$+\frac{(N^2+N+2)}{3(N-1)N(N+1)}S_2^2 + \frac{2P_2}{243(N-2)(N-1)^2N^5(N+1)^5(N+2)^4}$$

$$+\frac{2P_3}{81(N-2)(N-1)^2N^4(N+1)^4(N+2)^2}S_2 - \frac{64(N^2+N+2)}{(N-1)^2N^2(N+1)^2(N+2)}S_{-1}S_2$$

$$-\frac{4P_4}{81(N-1)^2N^3(N+1)^3(N+2)}S_3 + \frac{110(N^2+N+2)}{9(N-1)N(N+1)}S_4$$

$$+\Biggl[\frac{16P_5}{3(N-2)(N-1)^2N^3(N+1)^3(N+2)^2} + \frac{64(N^2+N+2)S_{-1}(N)}{(N-1)^2N^2(N+1)^2(N+2)}S_{-1}\Biggr]S_{-2}$$

$$-\frac{64(N^2+N+2)}{3(N-1)^2N^2(N+1)^2(N+2)}\left[S_{-3} - S_{2,1} + S_{-2,-1}\right] + \frac{8(35N^3+64N^2+111N+70)}{27(N-1)N(N+1)^2}S_{2,1}$$

$$-\frac{16(N^2+N+2)}{3(N-1)N(N+1)}\left[S_{3,1} - S_{2,1,1}\right]\Biggr] - 2\Biggl[-\frac{(N^2+N+2)}{3(N-1)N(N+1)}\left(10S_1^2 - 14S_2\right)$$

$$+\frac{2(17N^4+28N^3+69N^2+46N+24)}{9(N-1)N^2(N+1)^2}S_1 + \frac{P_6}{9(N-1)^2N^3(N+1)^3(N+2)^2}\Biggr]\zeta_2$$

$$+2\Biggl[\frac{2P_7}{9(N-1)^2N^3(N+1)^3(N+2)} + \frac{152(N^2+N+2)}{9(N-1)N(N+1)}S_1\Biggr]\zeta_3\Biggr\}$$

$$+C_F T_F^2 \Biggl\{-2N_F\Biggl[\frac{8(N^2+N+2)}{27(N-1)N(N+1)}S_1^3 - \frac{8(8N^3+13N^2+27N+16)}{27(N-1)N(N+1)^2}\left[S_1^2 + S_2\right]$$

$$+\Biggl[\frac{16(35N^4+97N^3+178N^2+180N+70)}{27(N-1)N(N+1)^3} + \frac{8(N^2+N+2)}{9(N-1)N(N+1)}S_2\Biggr]S_1(N)$$

$$-\frac{16(1138N^5+4237N^4+8861N^3+11668N^2+8236N+2276)}{243(N-1)N(N+1)^4}$$

$$+\frac{16(N^2+N+2)}{27(N-1)N(N+1)}S_3\Biggr] - 2\Biggl[\frac{16(N^2+N+2)}{27(N-1)N(N+1)}S_1^3 - \frac{16(8N^3+13N^2+27N+16)}{27(N-1)N(N+1)^2}S_1^2$$

$$+3\Biggl[\frac{16(39N^4+101N^3+201N^2+205N+78)}{81(N-1)N(N+1)^3} + \frac{16(N^2+N+2)S_2(N)}{27(N-1)N(N+1)}\Biggr]S_1$$

$$-\frac{8(1129N^5+3814N^4+8618N^3+11884N^2+8425N+2258)}{243(N-1)N(N+1)^4}$$

$$-\frac{16(8N^3+13N^2+27N+16)}{27(N-1)N(N+1)^2}S_2 + \frac{32(N^2+N+2)}{27(N-1)N(N+1)}S_3\Biggr]$$

$$+\Biggl[-6\Biggl[\frac{16(N^2+N+2)}{9(N-1)N(N+1)}S_1 - \frac{16(8N^3+13N^2+27N+16)}{27(N-1)N(N+1)^2}\Biggr] - 2N_F\Biggl[\frac{8(N^2+N+2)}{3(N-1)N(N+1)}S_1$$

$$-\frac{8(8N^3+13N^2+27N+16)}{9(N-1)N(N+1)^2}\Biggr]\Biggr]\zeta_2 + \Biggl[\frac{512(N^2+N+2)}{9(N-1)N(N+1)} - \frac{224(N^2+N+2)}{9(N-1)N(N+1)}N_F\Biggr]\zeta_3\Biggr\}$$

$$+C_A C_F T_F \Biggl\{\frac{96(N^2+N+2)}{(N-1)N(N+1)}\left(96\zeta_4 - \frac{32}{3}B_4\right) - 2\Biggl[\frac{29(N^2+N+2)}{27(N-1)N(N+1)}S_1^4$$

$$-\frac{2P_8}{81(N-1)^2N^2(N+1)^2(N+2)}S_1^3 + \Biggl[\frac{2P_9}{81(N-1)^2N^3(N+1)^3(N+2)^2}$$

$$+\frac{58(N^2+N+2)}{9(N-1)N(N+1)}S_2\Biggr]S_1^2 + \Biggl[-\frac{4P_{10}}{243(N-1)^2N^4(N+1)^4(N+2)^3}$$

$$-\frac{2P_{11}}{27(N-1)^2N^2(N+1)^2(N+2)}S_2 + \frac{424(N^2+N+2)}{27(N-1)N(N+1)}S_3 + \frac{32(N^2+N+2)}{9(N-1)N(N+1)}S_{2,1}$$

$$-\frac{16(N^2+N+2)}{(N-1)N(N+1)}S_{-2,1}\Biggr]S_1 + \frac{61(N^2+N+2)}{9(N-1)N(N+1)}S_2^2 + \frac{16(N^2+N+2)}{9(N-1)N(N+1)}S_{-2}^2$$

$$+\frac{2P_{12}}{243(N-2)(N-1)^2N^5(N+1)^5(N+2)^4} + \Biggl[\frac{152(N^2+N+2)}{9(N-1)N(N+1)}S_1$$

$$-\frac{8P_{13}}{27(N-1)^2N^2(N+1)^2(N+2)}\Biggr]S_{-3} + \frac{2P_{14}}{27(N-2)(N-1)^2N^3(N+1)^3(N+2)^2}S_2$$

$$+\frac{32(N^2+N+2)}{(N-1)^2N^2(N+1)^2(N+2)}S_{-1}S_2 - \frac{8P_{15}}{81(N-1)^2N^2(N+1)^2(N+2)}S_3$$

$$+\frac{178(N^2+N+2)}{9(N-1)N(N+1)}S_4 + \Biggl[\frac{88(N^2+N+2)}{9(N-1)N(N+1)}S_1^2$$

$$-\frac{16(52N^4+95N^3+210N^2+137N+36)}{27(N-1)N^2(N+1)^2}\left[S_1 + S_2\right] + \frac{8P_{16}}{27(N-2)(N-1)^2N^3(N+1)^3(N+2)^2}$$

$$-\frac{32(N^2+N+2)}{(N-1)^2N^2(N+1)^2(N+2)}S_{-1}\Biggr]S_{-2} + \frac{160(N^2+N+2)}{9(N-1)N(N+1)}S_{-4}$$

$$-\frac{8(14N^5+15N^4+4N^3+81N^2-10N+88)}{9(N-1)^2N^2(N+1)^2(N+2)}S_{2,1} - \frac{32(N^2+N+2)}{(N-1)^2N^2(N+1)^2(N+2)}S_{2,-1}$$

$$-\frac{16(N^2+N+2)}{3(N-1)N(N+1)}S_{3,1} + \frac{16(26N^4+49N^3+126N^2+85N+36)}{27(N-1)N^2(N+1)^2}S_{-2,1}$$

$$-\frac{112(N^2+N+2)}{9(N-1)N(N+1)}S_{-2,2} + \frac{32(N^2+N+2)}{(N-1)^2N^2(N+1)^2(N+2)}S_{-2,-1} - \frac{136(N^2+N+2)}{9(N-1)N(N+1)}S_{-3,1}$$

$$-\frac{8(N^2+N+2)}{(N-1)N(N+1)}S_{2,1,1} + \frac{176(N^2+N+2)}{9(N-1)N(N+1)}S_{-2,1,1}\Biggr] - 2\Biggl[+\frac{2(N^2+N+2)}{(N-1)N(N+1)}$$

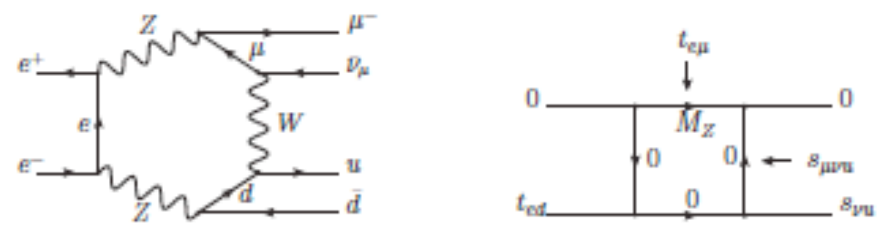
$$\times\left(\frac{10}{3}S_1^2 + S_2 + 4S_{-2}\right) - \frac{2(59N^5+94N^4+59N^3-84N^2-224N+168)}{9(N-1)^2N^2(N+1)(N+2)}S_1$$

$$+\frac{2P_{17}}{9(N-1)N^3(N+1)^3(N+2)^2}\Biggr]\zeta_2 - 2\Biggl[\frac{2P_{18}}{9(N-1)^2N^2(N+1)^2(N+2)} + \frac{56(N^2+N+2)}{9(N-1)N(N+1)}S_1\Biggr]\zeta_3\Biggr]\Biggr]\Biggr\}$$

Multileg calculations at one loop

NLO contributions to massive $2 \to \ldots 5, 6, 7 \ldots$ production at LHC, ILC, and meson factories

New algebraic approach, replacing tensor reduction by contractions with external momenta



A six-point topology (a) leading to four-point functions (b) with realistically vanishing Gram determinants.

A reduction of tensor $I_5^{\mu\nu}$ is replaced by analytic sums $\Sigma_b^{1,s}, \Sigma_a^{2,st}$

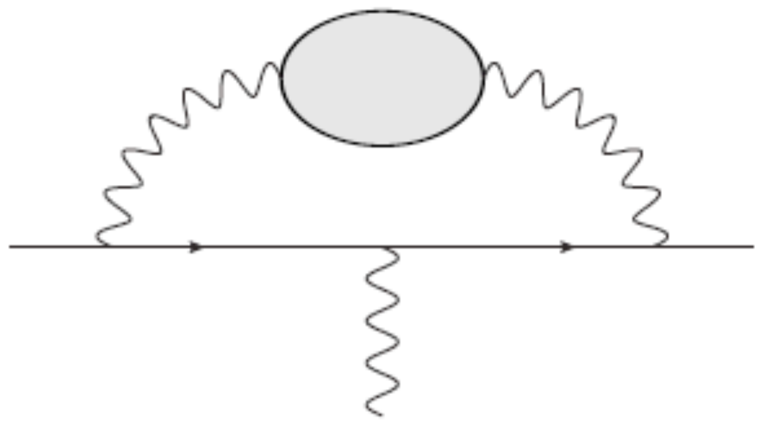
$$
\begin{aligned}
q_{a\mu} q_{b\nu} I_5^{\mu\,\nu} \quad = \quad & \frac{1}{4}\sum_{s=1}^{5}\left\{ \frac{\binom{s}{0}_5}{\binom{0s}{0s}_5}(\delta_{ab}\delta_{as}+\delta_{5s}) + \frac{\binom{s}{s}_5}{\binom{0s}{0s}_5}\Big[(\delta_{as}-\delta_{5s})(Y_{b5}-Y_{55}) \right. \\
& \left. + \; (\delta_{bs}-\delta_{5s})(Y_{a5}-Y_{55}) + \frac{\binom{s}{0}_5}{\binom{0}{0}_5}(Y_{a5}-Y_{55})(Y_{b5}-Y_{55})\Big] \right\} I_4^{[d+],s} \\
& + \frac{1}{\binom{0}{0}_5}\sum_{s=1}^{5}\frac{\Sigma_b^{1,s}}{\binom{0s}{0s}_5}\sum_{t=1}^{5}\Sigma_a^{2,st} I_3^{st},
\end{aligned}
$$

T. Riemann

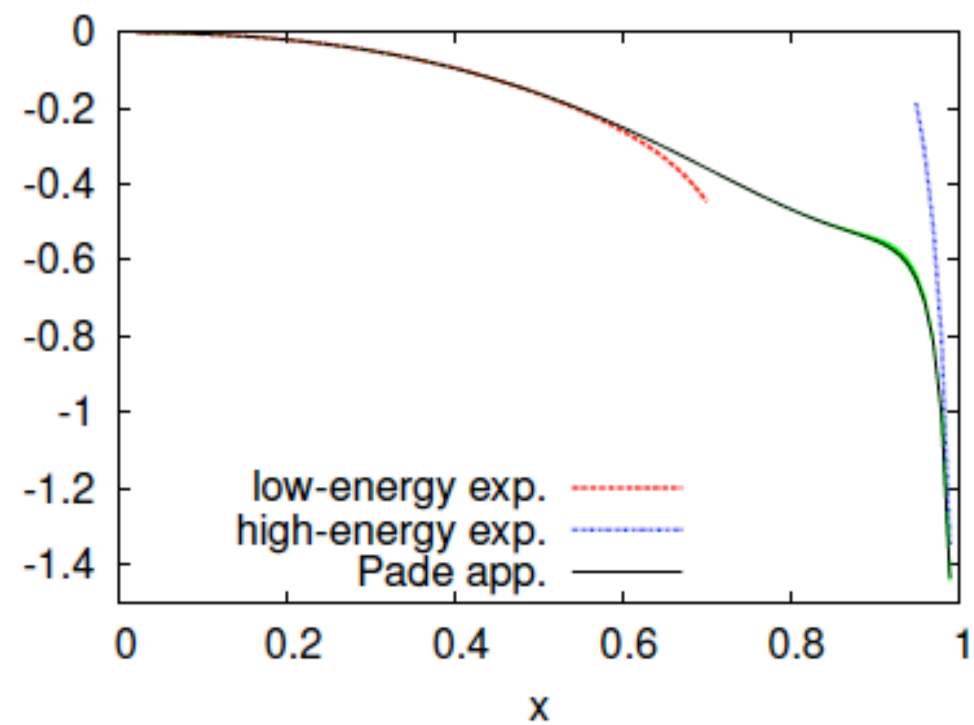
Muon anomalous magnetic moment at five loops: analytic computation

P.A. Baikov, A. Maier, P. Marquard, arXiv:1307.6105

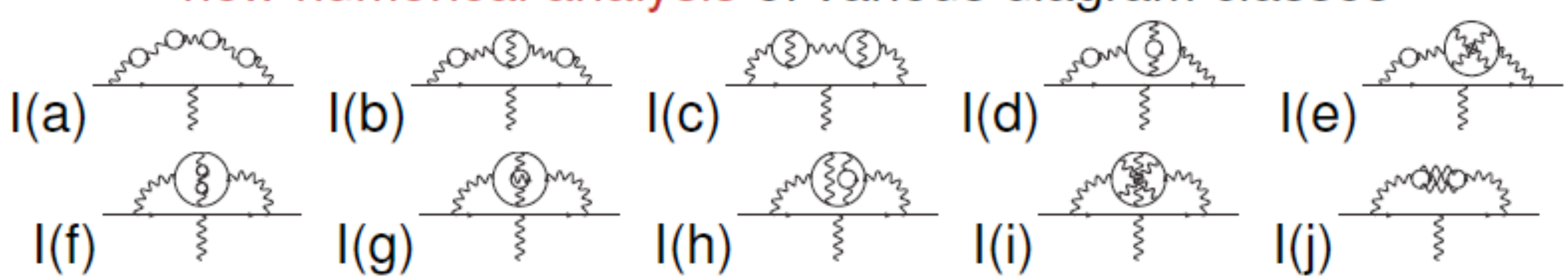
vacuum polarization function $\Pi(s_x)$ @ four loops in QED



$$a_\mu = \frac{\alpha}{\pi} \int_0^1 \mathrm{d}x(1-x)/(1+\Pi(s_x))$$
$$s_x = -m_\mu^2 x^2/(1-x)$$
$$x \in [0,1] \to s_x \in [0,-\infty]$$

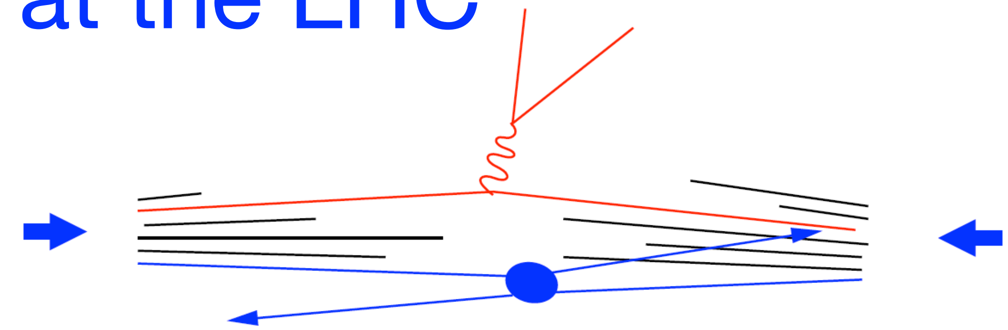


new numerical analysis of various diagram classes



full agreement with previous work

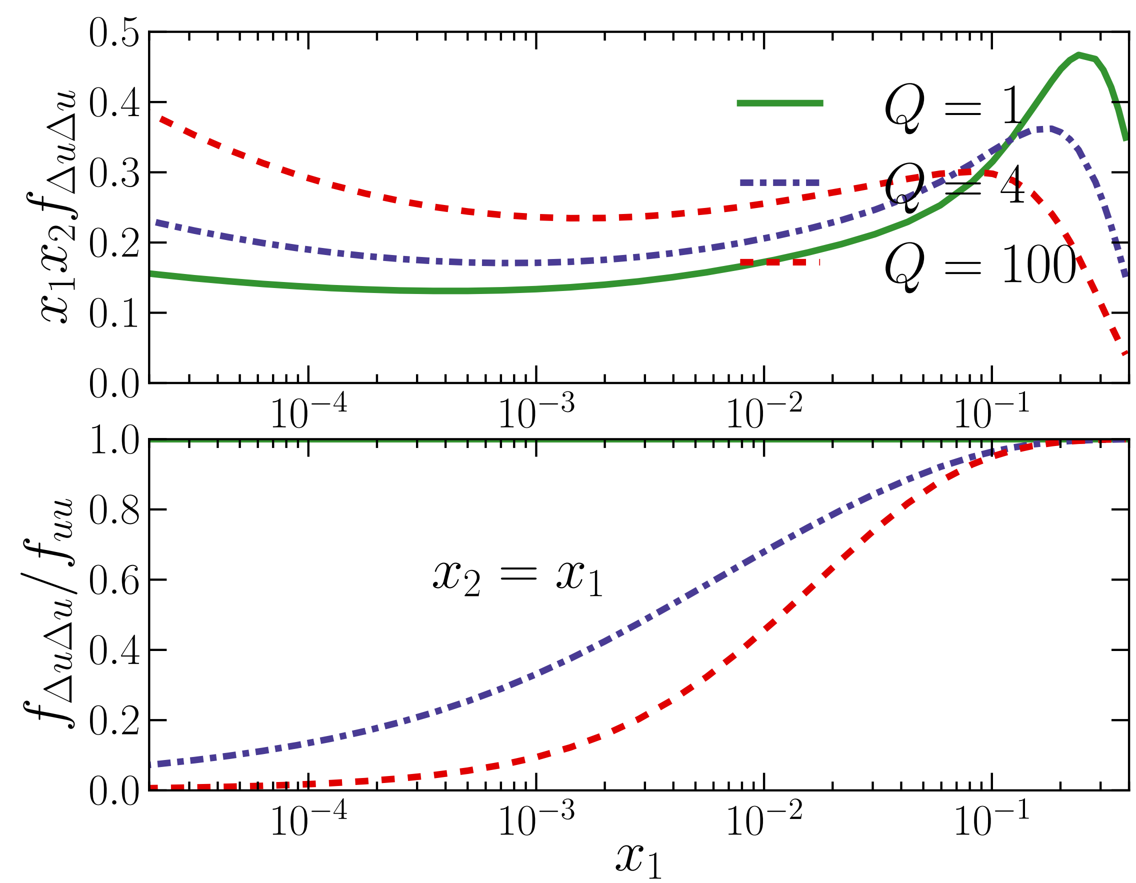
Multiparton interactions at the LHC



- several partons of each proton interact in same pp collision
- importance increases with energy
- complex QCD dynamics, esp. due to correlations between partons
- parton spin correlations
  - ★ affect rate and distributions in gauge boson pair prod'n (MD, T. Kasemets 2012)
  - ★ large spin correlations found in constituent quark models
    Q: washed out by evolution to high scales? (MD, S. Keane, T. Kasemets 2013)

assume maximal longitudinal spin correlation at Q = 1 GeV then evolve

degree of polarization



large spin correlations at low scale can persist up to high scales depending on parton and polarization type

Conclusions

- The theory group is very active and visible
- vacant staff positions filled or in process of being filled
- strong engagement in networking and teaching
- broad range of research in collider phenomenology
  - ★ Standard Model and beyond
  - ★ closely connected with experiment, esp. with LHC and ILC
    Terascale Alliance, LHC Higgs Cross Section Working Group, ILC TDR, European Strategy Update, Snowmass Process
  - ★ strong connections with cosmology, strings and lattice
  - ★ complementary activities in Hamburg and Zeuthen