

Collider Phenomenology

Research highlights of
the Hamburg and Zeuthen groups



Helmholtz Programme: Matter and the Universe (MU)

PoF III Topic: Fundamental Particles and Forces

DESY Research Unit: Theoretical Particle Physics

Christophe Grojean

Centre Evaluation DESY, 5 – 9 February 2018

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES



Collider Phenomenology @ DESY

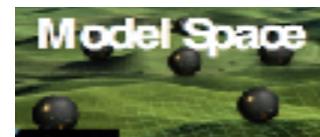
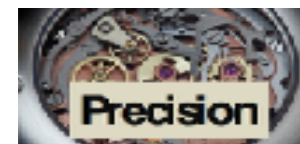
Who are we? What are we doing? Whom are we talking to?

- **Structure and composition of the HH and Z groups**

- **HH:** M. Diehl, C. Grojean, Z. Nagy, J. Reuter, K. Schmidt-Hoberg, F. Tackmann, G. Weiglein + 1x5-yr staff (NN)
- **Z:** J. Blümlein, P. Marquard + 1 vacant position

- **Main topics of interest:**

- (i) Precision predictions in QCD, EW, BSM: Drell-Yan, top, jets.
- (ii) Precision Higgs physics and EW symmetry breaking.
- (iii) Massive calculations: algebraic and numeric.
- (iv) BSM predictions and model building.



- Connections with other DESY **theory** activities (Particle cosmology, String theory, Lattice QCD).

- Close interactions with **experimental** groups ATLAS, CMS, ILC, Belle2: ➤ **Support and guidance**

LHC physics discussions (monthly),
pizza seminars (soon, weekly).

SFB B9 Higgs meetings (monthly),
ILC project meetings (monthly), one-
to-one meetings.

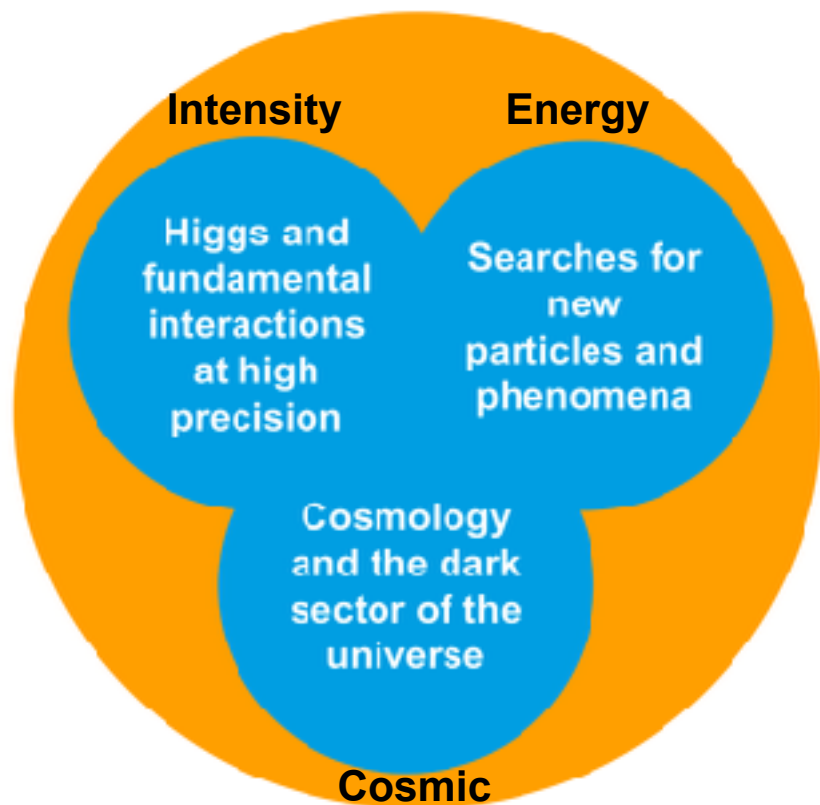
Common projects and joint
publications (e.g. PROSA), joint
PhD supervisions etc...

- Strong involvement in different **Working Groups** (Particle Data Group, Terascale Alliance, LHC Higgs cross section WG, EW WG, B2TiP=Belle 2 Theory interface platform, ILC TDR, European Strategy Update, Snowmass)

- Strong engagement in **teaching** and **mentoring** (PhD students + Postdocs)

Collider Phenomenology: State of the Art

EXP Frontiers



the 3 frontiers are dynamical and might be more intertwined than originally thought

TH Frontiers

SM precision



BSM model building

synergy fuels progress



no BSM major discovery without a thorough understanding of SM background

Activities of the Group: an Incomplete Overview

Construct and test models

- SUSY scenarios, Composite/Little Higgs models, GUT, string inspired models
- Test against constraints from colliders, cosmology, high-precision measurements...
 - i. fit/constrain parameter space
 - ii. phenomenology of simplified models
- Flavour physics

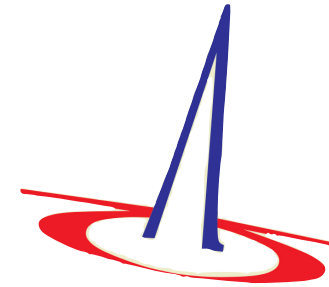
Precision calculations

- Multiloop and multileg calculations:
 - i. Development of new methods $\leftrightarrow$ mathematics and computer algebra, informatics and numerical methods
 - ii. Application to strong and EW sectors
- Standard candle processes: PDFs, α_s , quark masses
- Factorisation, resummation, effective field theories: jet physics, ...
- Multiparton interactions
- SUSY at one-loop accuracy and beyond

Activities of the Group: a Concrete Output Beyond Papers

Tools for the HEP community

- Monte Carlo generators
 - **WHIZARD** (J. Reuter),
 - **GENEVA** (F. Tackmann),
 - **DEDUCTOR** (Z. Nagy)
- Fitting codes:
 - **MasterCode** (G. Weiglein)
 - **HiggsBounds** and **HiggsSignals**, **FeynHiggs** (G. Weiglein)
- **ATOM**: Automated Tester of Models (A. Weiler - now at TUM)
- **FASTLIM**: limit setting and coverage checks of BSM theories using the LHC results (A. Weiler, L. Zeune)
- **SCETLIB**: general and flexible framework for precision resummed predictions based on SCET (F. Tackmann)
- **PDF evolution** code and parametrisation (J. Blümlein et al.)



Two Examples of Research Highlights

P. Marquard et al. JHEP1703(2017)020

5-loop $\overline{\text{MS}}$ renormalisation of QCD

- Renormalisation constants @ five loops for a general gauge group
- Running coupling and anomalous dimensions gauge independent
- What it is useful for?
 - Assessing the convergence of perturbation series
 - Allowing an evolution over large scales

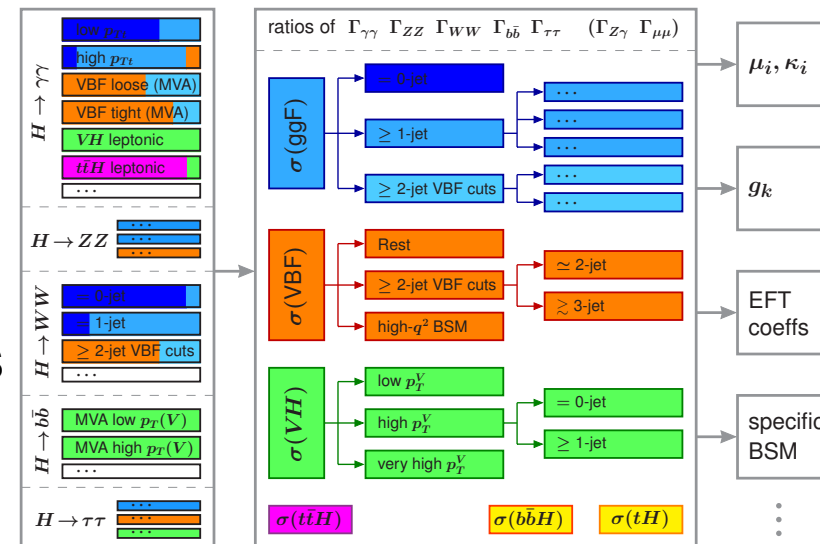
F. Tackmann et al., CERN-2017-002-M, YR4

Higgs simplified template cross section framework

- Developed in close collaboration with experiments
- Going to be used for Higgs measurements and combination by ATLAS & CMS
- Reduce theory dependence folded into measurements
- Allow flexible reinterpretation in different scenarios (SM, BSM, EFT,...)

$$\partial_{\ln \mu^2} a = -a \left[\varepsilon - \beta \right] = -a \left[\varepsilon + b_0 a + b_1 a^2 + b_2 a^3 + b_3 a^4 + b_4 a^5 + \dots \right]$$

$$\begin{aligned} 3^5 b_4 &= b_{44} n_f^4 + b_{43} n_f^3 + b_{42} n_f^2 + b_{41} n_f + b_{40}, \\ b_{44} &= \{c_f, 1\} \cdot \left\{ -8(107 + 144\zeta_3), 4(229 - 480\zeta_3) \right\}, \\ b_{43} &= \{c_f^2, c_f d_1, 1\} \cdot \left\{ -6(4961 - 11424\zeta_3 + 4752\zeta_4), -48(46 + 1065\zeta_3 - 378\zeta_4), \right. \\ &\quad \left. 1728(55 - 123\zeta_3 + 36\zeta_4 + 60\zeta_5), -3(6231 + 9736\zeta_3 - 3024\zeta_4 - 2880\zeta_5) \right\}, \\ b_{42} &= \{c_f^3, c_f^2 d_1, c_f d_2, d_1, 1\} \cdot \left\{ -54(2509 + 3216\zeta_3 - 6960\zeta_5), \right. \\ &\quad 9(94749/2 - 28628\zeta_3 + 10296\zeta_4 - 39600\zeta_5), 25920(13 + 16\zeta_3 - 40\zeta_5), \\ &\quad 3(5701/2 + 79356\zeta_3 - 25488\zeta_4 + 43200\zeta_5), -864(115 - 1255\zeta_3 + 234\zeta_4 + 40\zeta_5), \\ &\quad \left. -432(1347 - 2521\zeta_3 + 396\zeta_4 - 140\zeta_5), 843067/2 + 166014\zeta_3 - 8424\zeta_4 - 178200\zeta_5 \right\} \end{aligned}$$

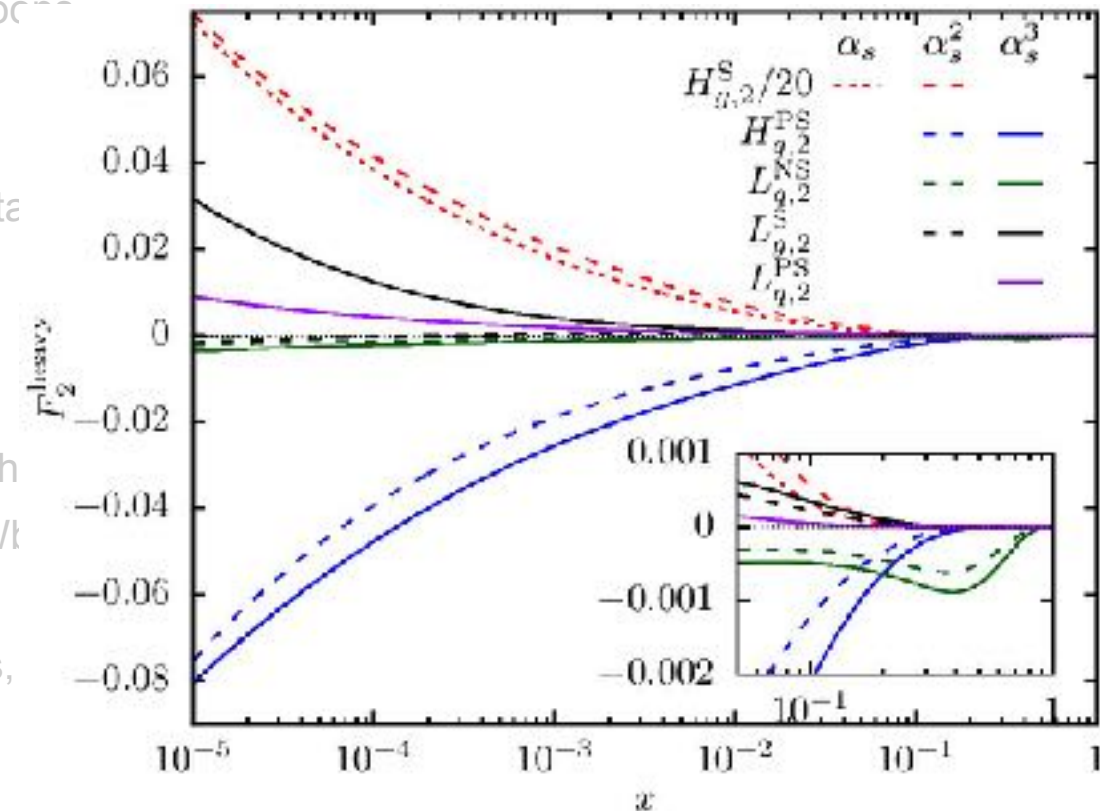


Other Major Achievements: a Sample Selection

- Precision determination of PDFs, α_s and m_c (using combined H1+ZEUS data on charm production in DIS)
- Multileg calculations at one loop at LHC, ILC and meson factories ($2 \rightarrow \dots 5, 6, 7 \dots$ production)
- Analytic computation of muon anomalous magnetic moment at four loops
- Systematic theory for multiparton interactions at the LHC
- Resummed predictions for Higgs+0 jet production ($p_T^{\text{jet}} < p_T^{\text{cut}}$)
- QCD renormalisation: 4 loops on-shell and 5-loop MS (running couplingss)
- Precision jet physics (N-jettiness)
- Drell-Yan at NNLO+NNLL+PS+MPI
- Threshold resummation in parton shower
- Precision top physics at lepton colliders: $t\bar{t}$ @ NNNLO @ ILC at threshold
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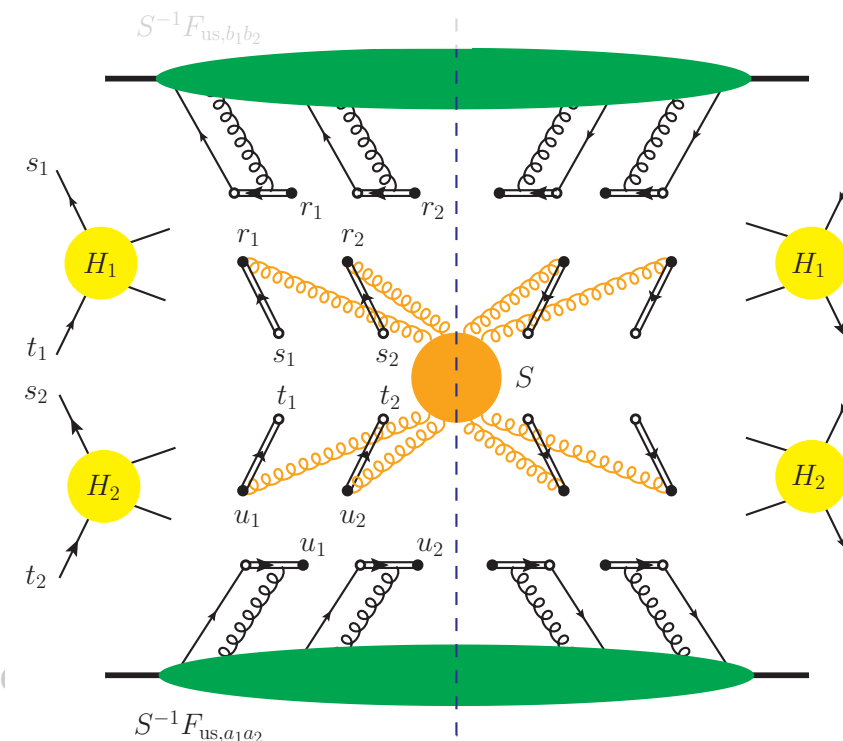
J. Ablinger, A. Berhing, J. Blümlein et al.
PoS(QCDEV2016)052

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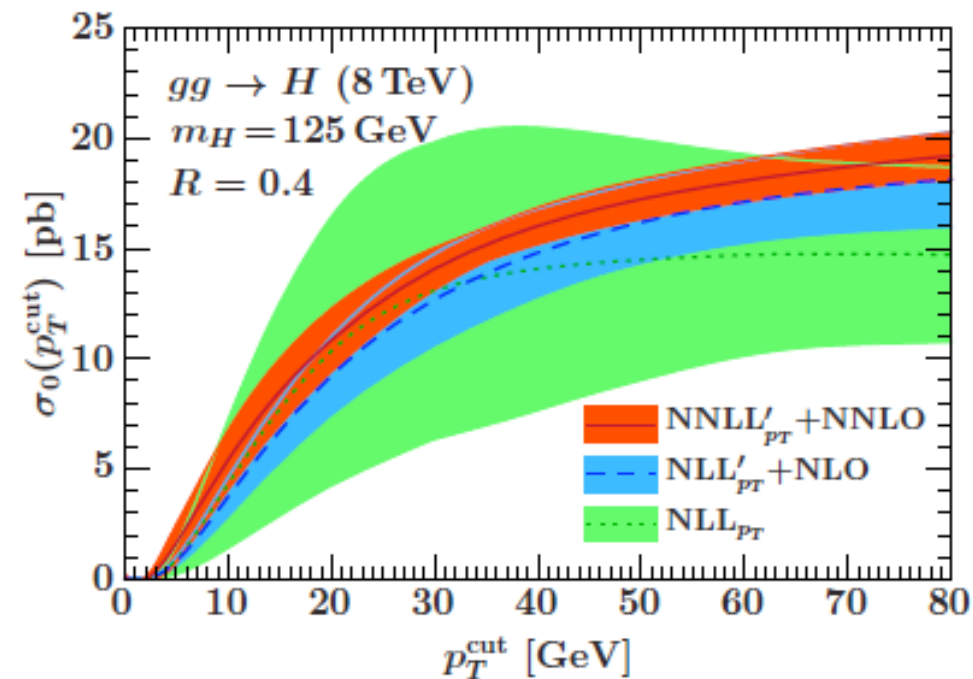


Buffing, Diehl, Kasemets
JHEP1801(2018)044

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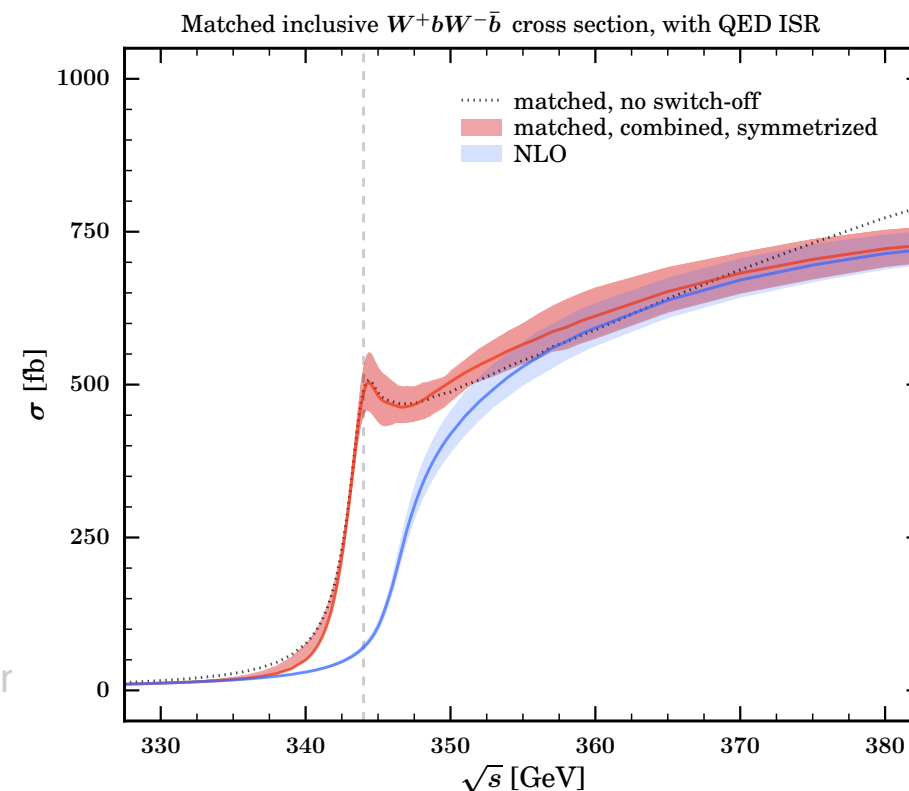
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Stewart, Tackmann, Walsh, Zuberi
PRD89(2014)054001

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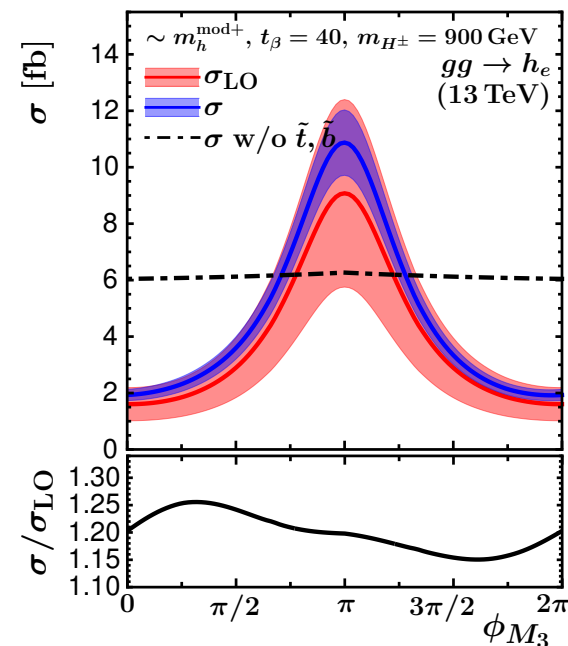
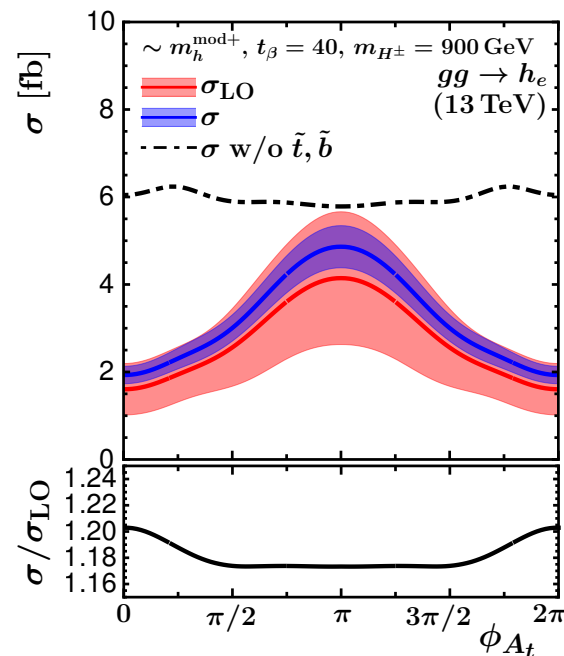
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**Bach, Chokouf  Nejad, Hoang, Kilian,
Reuter, Stahlhofen, Teubner, Weiss
DESY-17-158**

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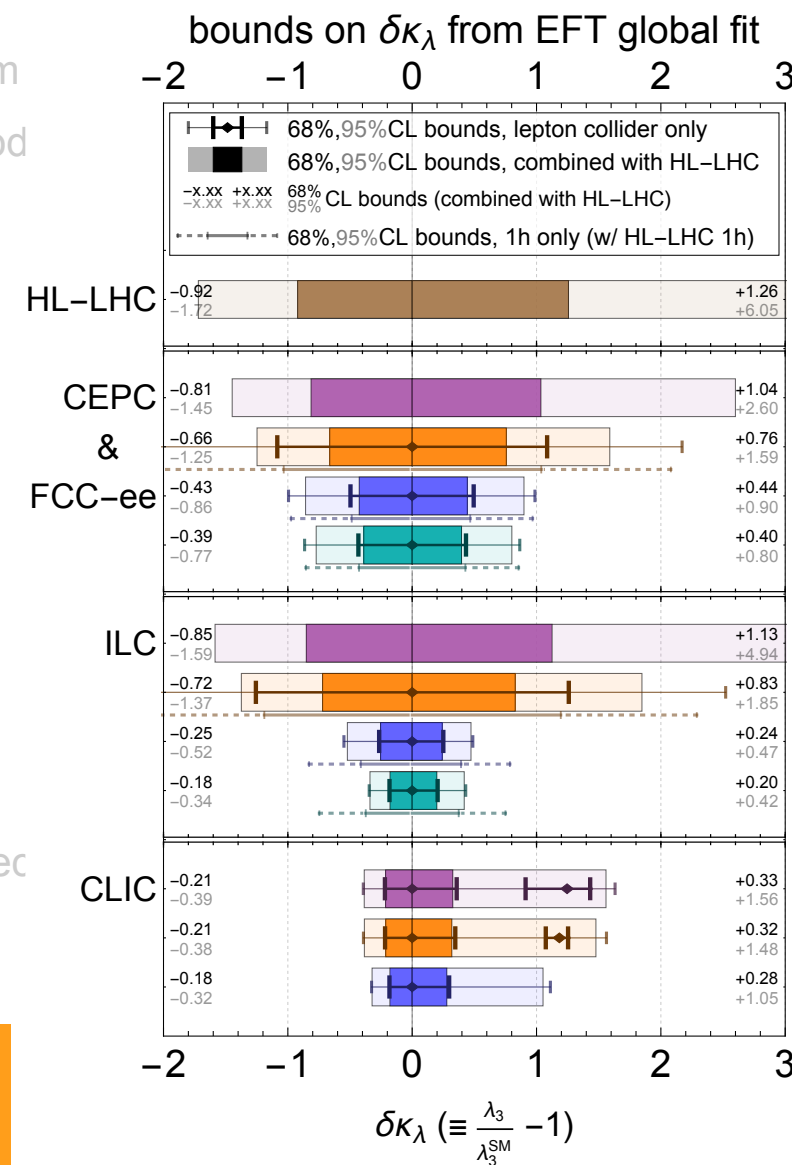
Liebler, Patel, Weiglein
 EPJC77(2017)305

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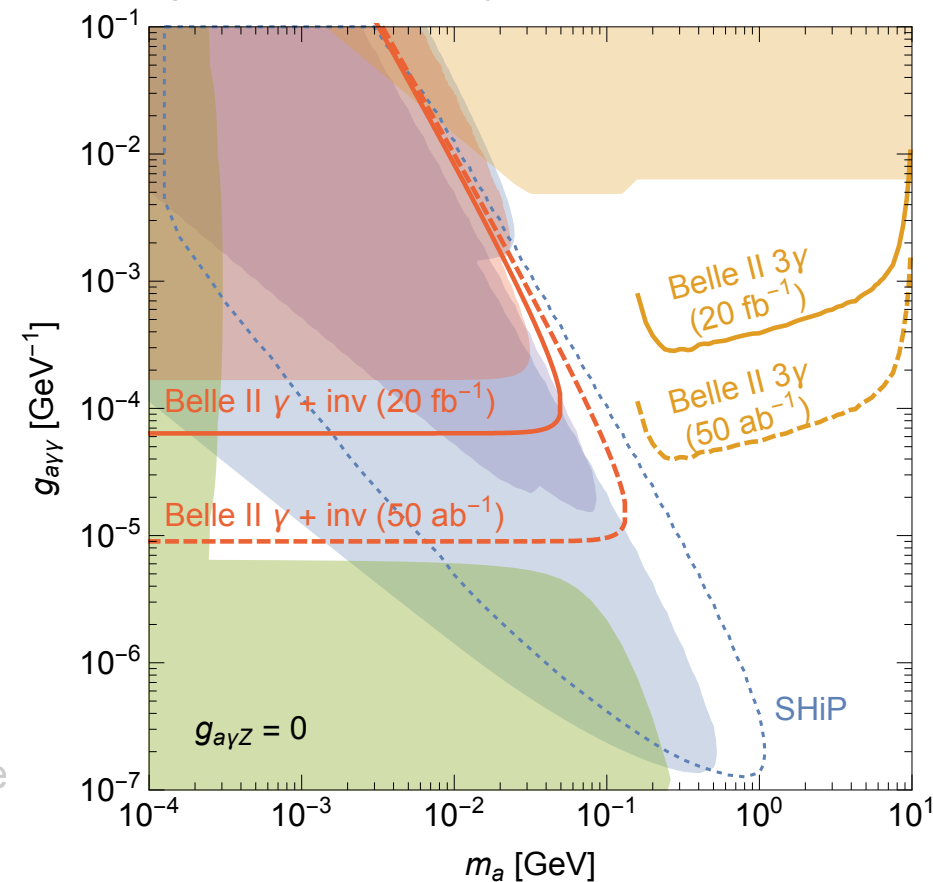
Di Vita, Durieux, Grojean, Gu, Liu,
Panico, Riembau, Vantalon

DESY-17-131



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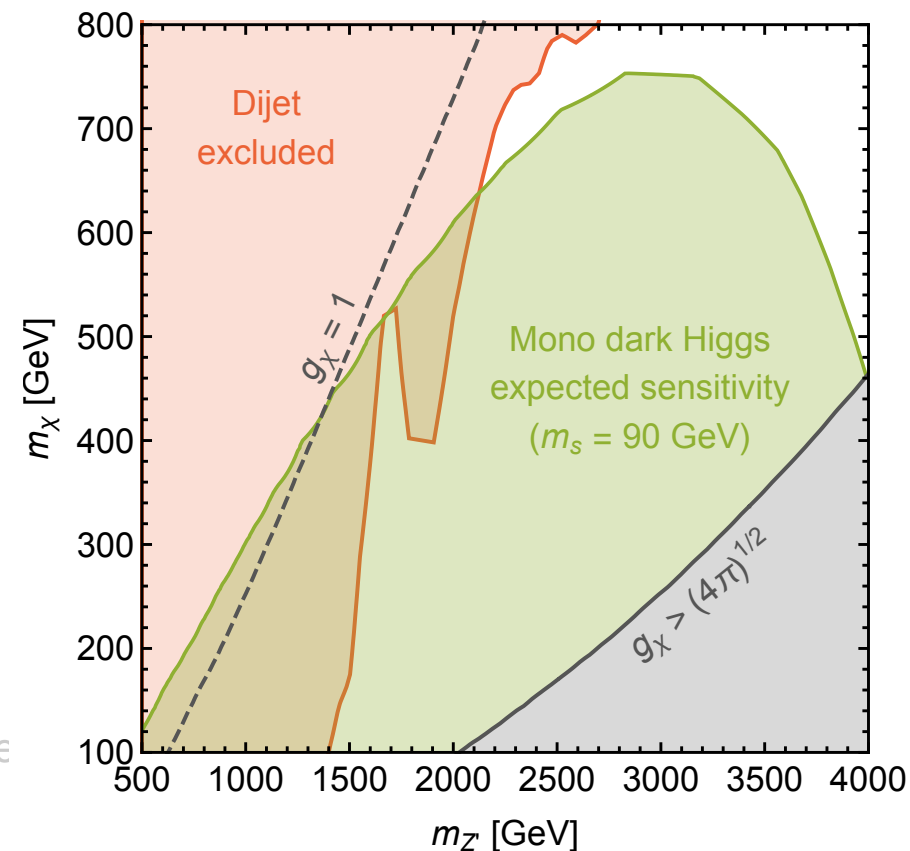
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Dolan, Ferber, Hearty,
Kahlhoefer, Schmidt-Hoberg
JHEP1712(2017)094

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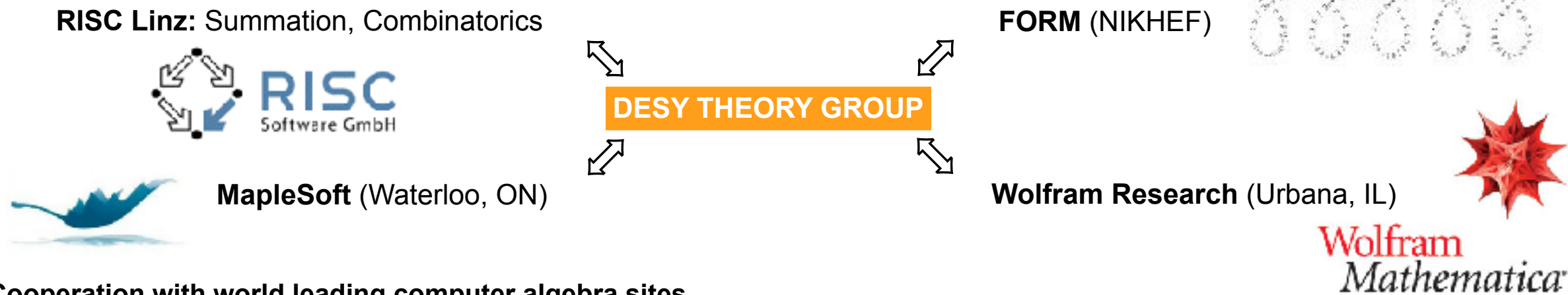
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Duerr, Grohsjean, Kahlhoefer
Penning, Schmidt-Hoberg, Schwanenberger
JHEP1704(2017)143

Spin-offs & Spill-offs: Phenomenology Meets Mathematics and Computer Algebra

“HEP = the field where the web & grid computing were born”



Cooperation with world leading computer algebra sites

- Cooperation with *MapleSoft* and *Wolfram Research* within various EU networks (LHCPHENOnet, HiggsTools)
- Excellent PhD training sites: some students have already been hired by the companies
- *Wolfram Research* interested in continuous cooperation
- Invitations to plenary talks at *Mathematica* conference
- We operate **large scale computers** for computer algebra [170 TB fast disc, 5.5 TB RAM = world record]

Particle physics generates new mathematics

- Different special function spaces and algebras have been obtained (harmonic sums, iterated integrals, non-iterative structures) [Blümlein et al.]
- Monte Carlo algorithms, twistors, tensor networks were developed to respond to the needs of particle physicists
- Ricci flows [at least 2 Fields medals] emerge from ideas on renormalisation

Education - Dissemination - Networking

Teaching:

- UHH+DESY, HU Berlin, FU Berlin, Dortmund U., Hannover U., TU Dresden, U. Vienna
- DESY and CERN summer student programmes
- Many winter & summer schools (JLab, GGI, Cargèse, Mainz, CERN-Fermilab...)

Publications: over **250** publications with more than **12'000** citations (w/o PDG) in 2013-2016

Conferences and workshops organised on-site and elsewhere: **>40** in 2013-2016

Awards, prizes, visitors:

- 2 Alexander von Humboldt research awards (J. Wells, H. Murayama)
- 1 Humboldt research fellow (J. Unwin)
- KMPB research visit (van Hoesj)



Networking:

- EU training networks: Higgstools, LHCPHENOnet
- Terascale Alliance, Research Training Group "Masse, Spektrum, Symmetrie", SFB 676, SFB-TR-9
- iTHEPHY EU education network. Innovative team-teaching for physics Network Bologna, Clermont-Ferrand, Dortmund, DESY
- 2 EU Cost Actions: Connecting insights in fundamental physics & Vector Boson Scattering

Outreach



Public lectures in bars

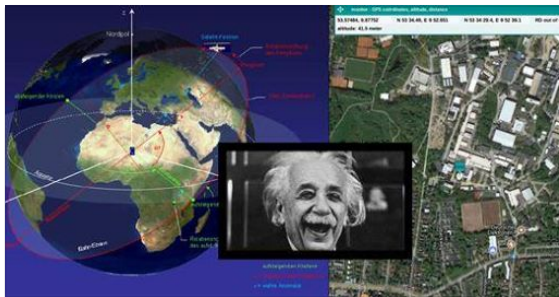
Latest: April 2017

Theory group members active
in all 3 editions



Einstein exhibition in Hamburg (HAW)

Public outreach theory talks



NOV 29 Why does not my smartphone find its way without Einstein?
Public · Host: [German Electron Synchrotron DESY](#)

Wednesday, November 29, 2017 19:00 - 21:00 UTC + 01
about 1 month ago

German electron synchrotron DESY
Notkestraße 85, 22607 Hamburg [Show map](#)

[info](#) [discussion](#)

2 participated · 23 are interested
[Share this event with your friends](#)

details

Why does not my smartphone find its way without Einstein?
Public evening lecture by Prof. Jürgen Reuter

November 29, 2017, 7 pm
DESY lecture hall, Hamburg
Admission free
<http://fortbildung.desy.de/e109/e130770> / [e231059](#) / [e256987](#) /

The Global Positioning System (GPS) is a satellite based method for exact positioning of mobile devices. In order to achieve an accuracy better than one meter, many details such as the satellite orbits and the rotation of the earth, as well as effects of Einstein's special and general relativity theory have to be considered. How this method works in detail will be explained in this lecture.

Outlook

Our dual mission: nailing down the knowns and hunting the unknowns

Make maximal use of current and coming collider data

- Being able to cover a broad and complementary range of topics is key to progress
- Strong connections with cosmology, string theory, lattice theory, pure mathematics and computer science
- Direct interactions with experimental groups at DESY are essential; continuous theory input for all the LHC experiments, Belle and others is provided

Assess the physics potential of possible future facilities

Tackle all fundamental questions about matter and the universe

Quantum field theory and string theory cross-fertilise each other through respective technical methods/algorithms
[iterative integrals, zeta-values, dualities, amplitudes...]

Meet the challenges and participate to the emergence of new paradigms ruling matter at the tiniest distances

HEP-PH/TH keeps providing vivid intellectual stimulation through idiosyncrasy and serendipity

Theory = melting pot of ideas. DESY theory jamborees and Wolfgang Pauli Center serve as incubators