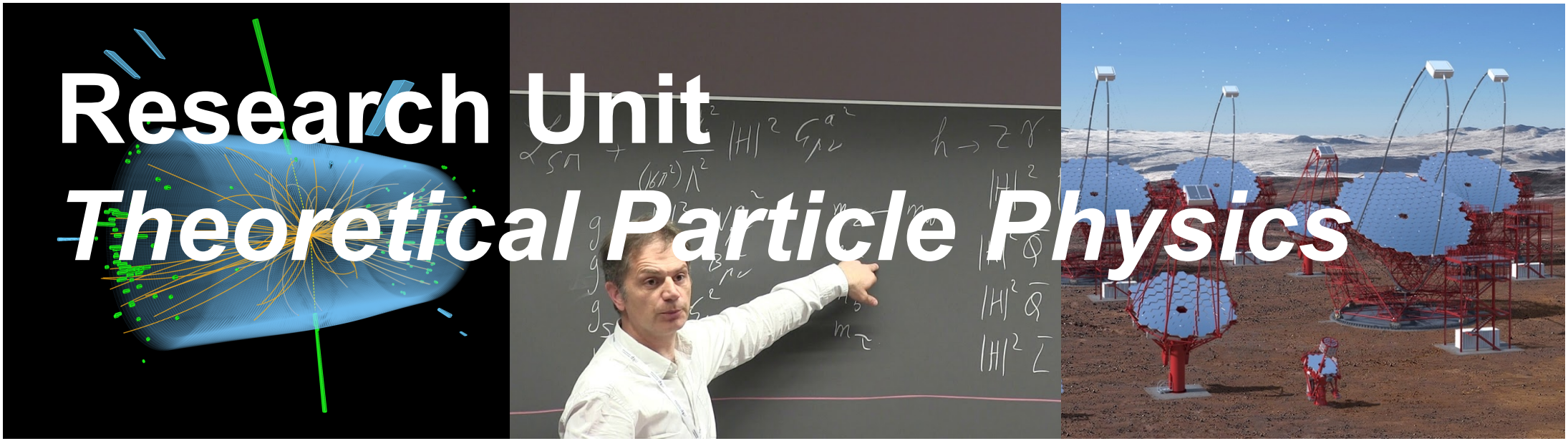


Research Unit *Theoretical Particle Physics*

Helmholtz Programme: Matter and the Universe (MU)

PoF III Topic: Fundamental Particles and Forces

DESY Research Unit: Theoretical Particle Physics

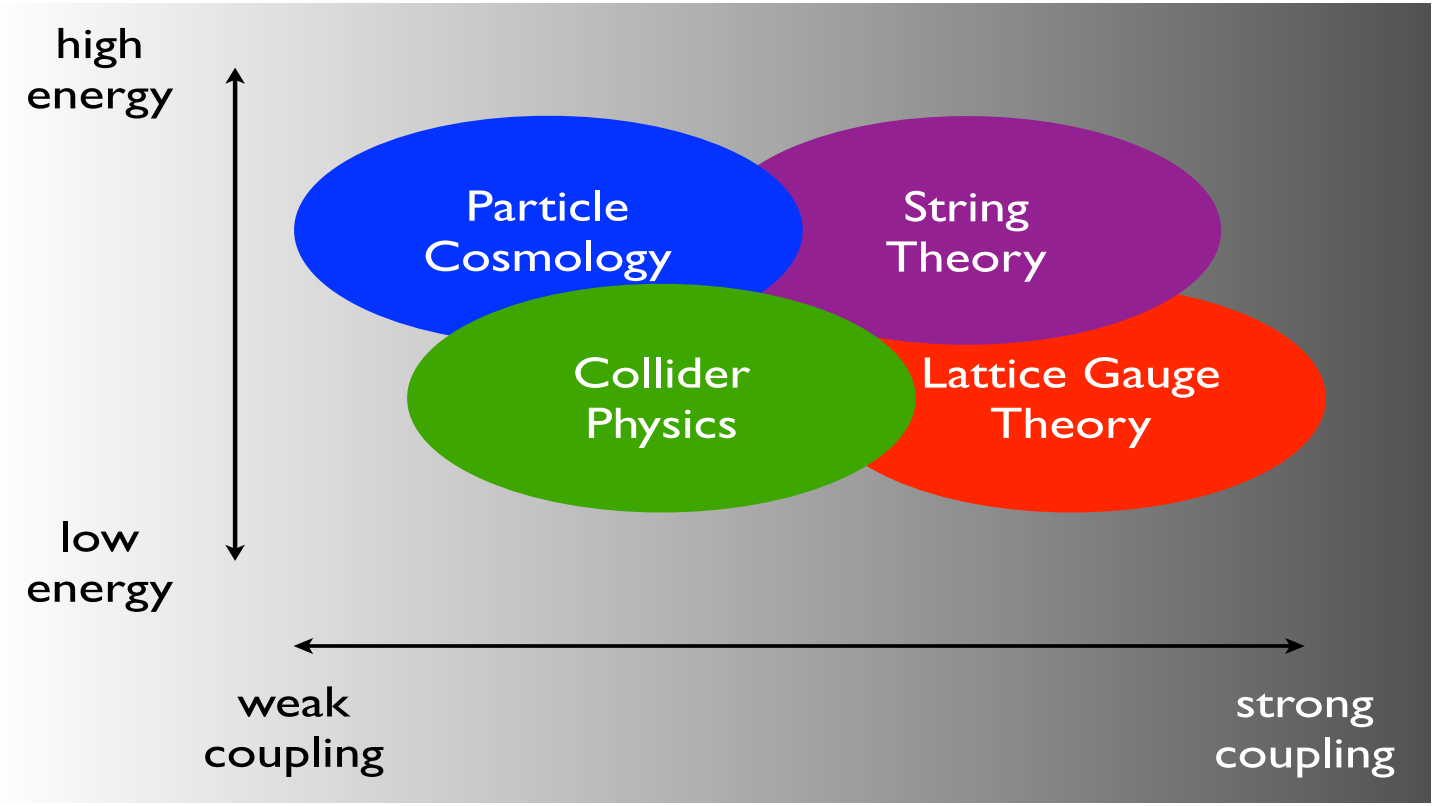
Georg Weiglein
Centre Evaluation DESY, 5 – 9 February 2018

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

DESY

Theoretical Particle Physics (Hamburg & Zeuthen)

Research topics

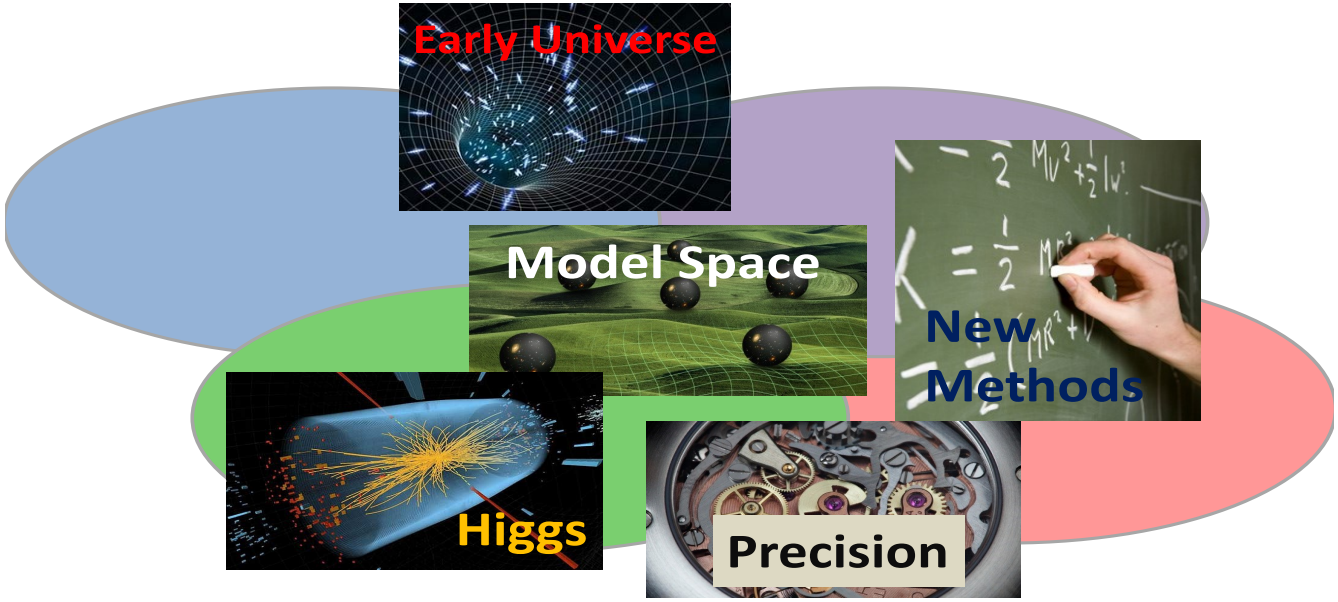


Close interaction with experiment: predictions, interpretation, tools
Development of new methods, algorithms and concepts

Research topics and methods

Mission:

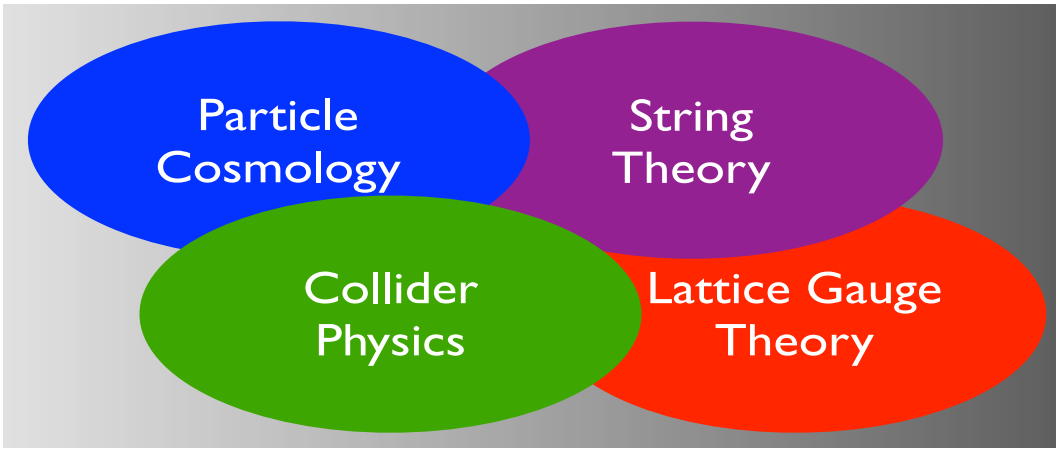
- Identify fundamental particles
- Determine fundamental laws of nature
- Understand development of the Universe



Key challenges of hep-th are addressed by combining approaches from different research areas.

Group structure and staff

T. Konstandin
A. Ringwald (also ALPS)
G. Servant (joint with Univ. Hamburg)
A. Westphal
V. Domcke and F. Sala (5yr fellows)



V. Schomerus
J. Teschner (joint with Univ. Hamburg, Math. Dept.)
E. Pomoni and G. Papathanasiou (5yr fellows)

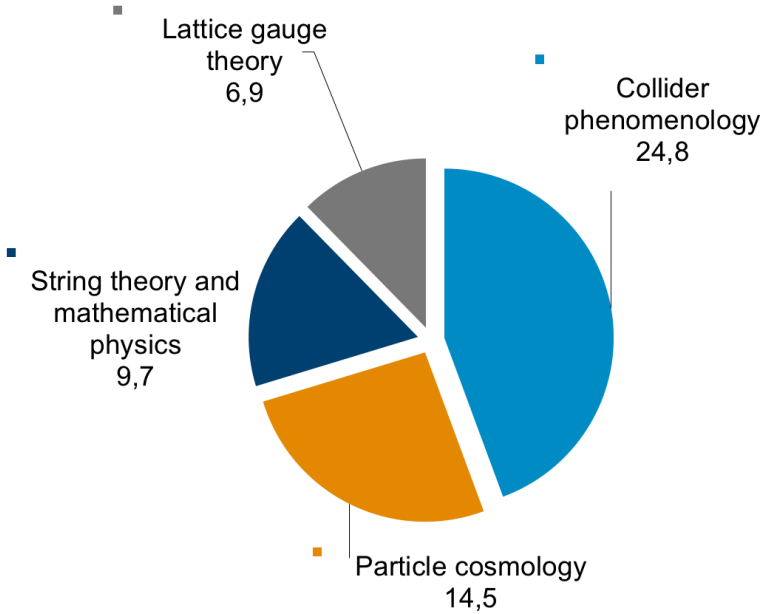
Hamburg:
M. Diehl
C. Grojean (joint with HU Berlin)
Z. Nagy
J. Reuter
K. Schmidt-Hoberg
F. Tackmann
G. Weiglein
5yr fellow position advertised

Zeuthen:
J. Blümlein
P. Marquard
1 position vacant

K. Jansen
S. Schäfer
H. Simma
R. Sommer
Joint W2 position at HU Berlin, hiring in progress (start: 04/2018)

Group structure

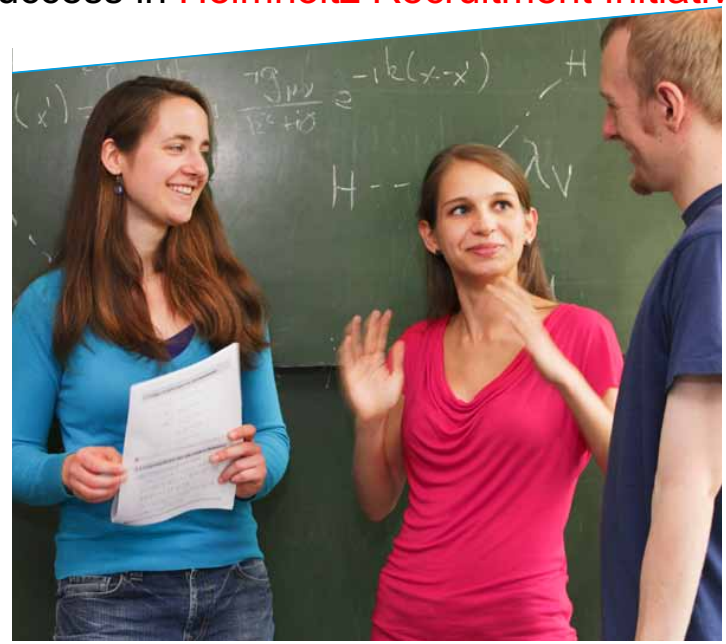
Core-funded plus third-party-funded scientists (FTE) without Ph.D. students



55.9 FTE in total without Ph.D. students
Ph.D. students (2016): 23; 28 theses completed in 2013-16

Core-financed costs (2016): 6.015 MEUR
Third-party funding (2016): 1.389 MEUR

Double success in Helmholtz Recruitment Initiative

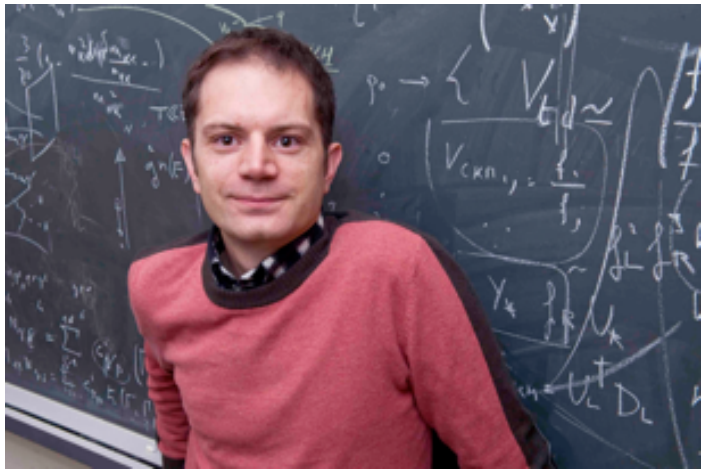


High-impact Fellowship programme:

- About 500 applications every year
- Very high success rate in hiring first-choice candidates in world-wide competition
- Among the 56 Fellows who have been at DESY 2013-2016, 16 (29%) already have tenure (track)

Double success in Recruitment Initiative of the Helmholtz Association

Geraldine Servant:
electroweak phase transition, dark matter
baryon asymmetry, gravitational waves
collider phenomenology
Joint appointment with Hamburg University

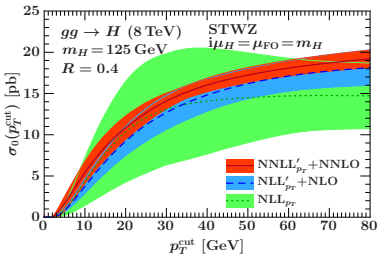


Christophe Grojean:
collider phenomenology
electroweak symmetry breaking
Joint appointment with HU Berlin

Higgs physics

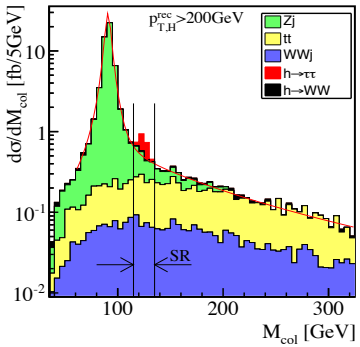
Probing the underlying physics at the origin of mass of elementary particles

Precision predictions

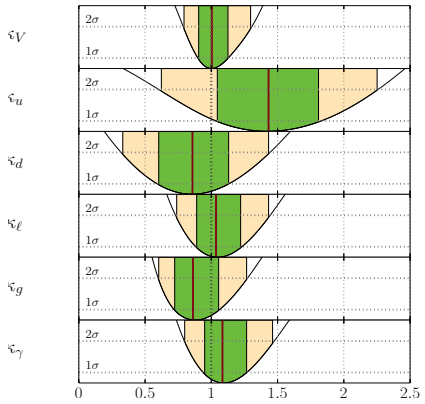


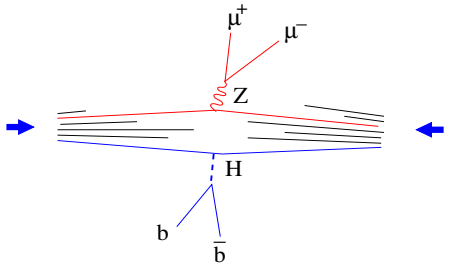
Backgrounds

New strategies

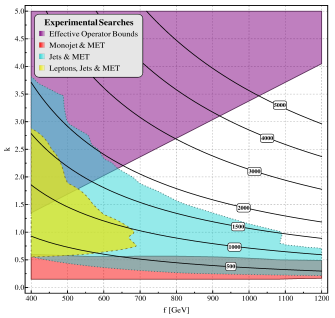


Properties & Interpretation





BSM constraints



+ related SM and BSM studies

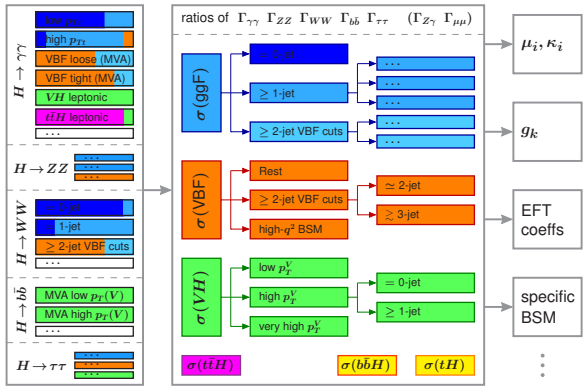
+ close interaction with experiments

Higgs physics

Discrimination between different realizations of the symmetry-breaking mechanism giving rise to the origin of mass

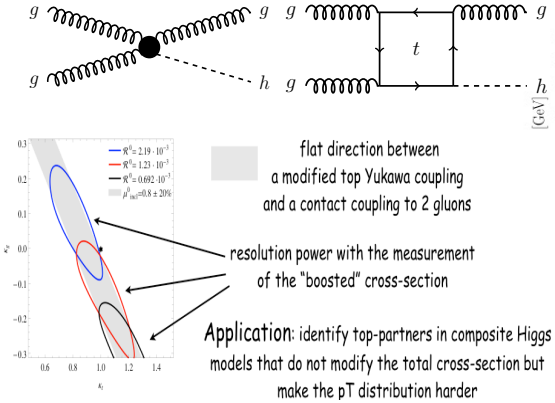
Interface between experiment and theory: Simplified Template Cross Sections

F. Tackmann, K. Tackmann et al.



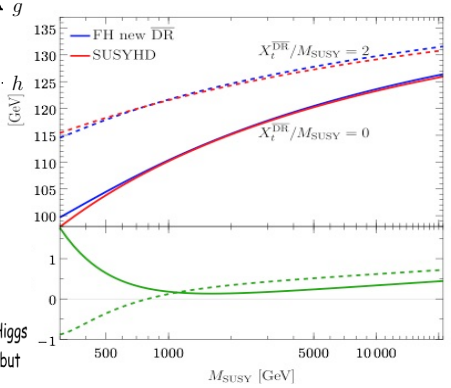
Exploitation of experimental signatures: boosted Higgs

M. Schlaffer et al., PhD 2015



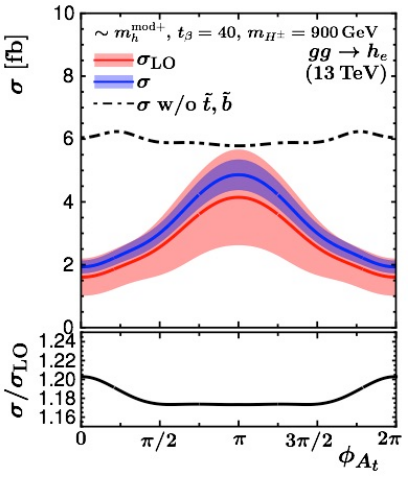
Higgs-mass predictions In SUSY theories

G. Weiglein et al.



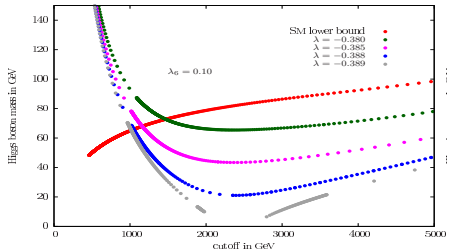
Higgs production: Higher-order predictions

S. Patel et al., PhD 2017



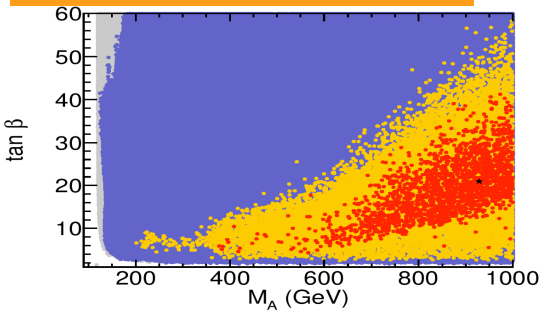
Higgs Yukawa model on the lattice:

K. Jansen et al.



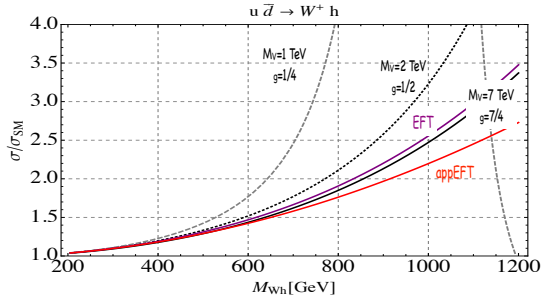
Model interpretation:

L. Zeune et al., PhD 2014



EFT interpretation:

C. Grojean et al.



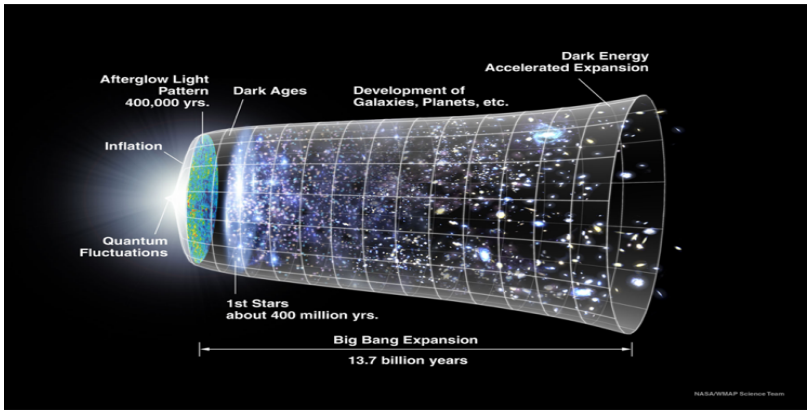
EFT validity

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_i c_i^{(6)} \mathcal{O}_i^{(6)} + \sum_j c_j^{(8)} \mathcal{O}_j^{(8)} + \cdots$$

Included Ignored

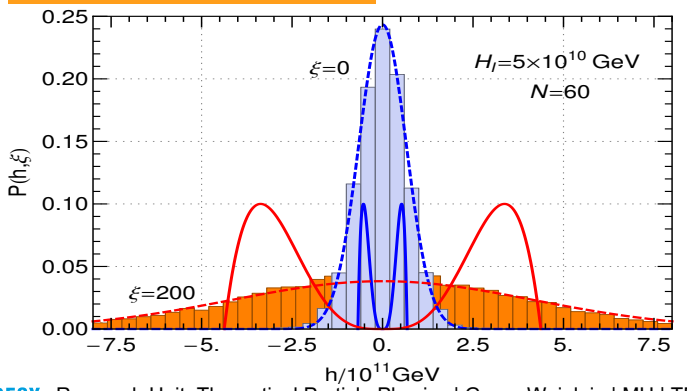
Interplay of Higgs physics and cosmology

Inflation and the electroweak phase transition



Effects of quantum fluctuations during inflation on the Higgs field: stabilization through inflation?

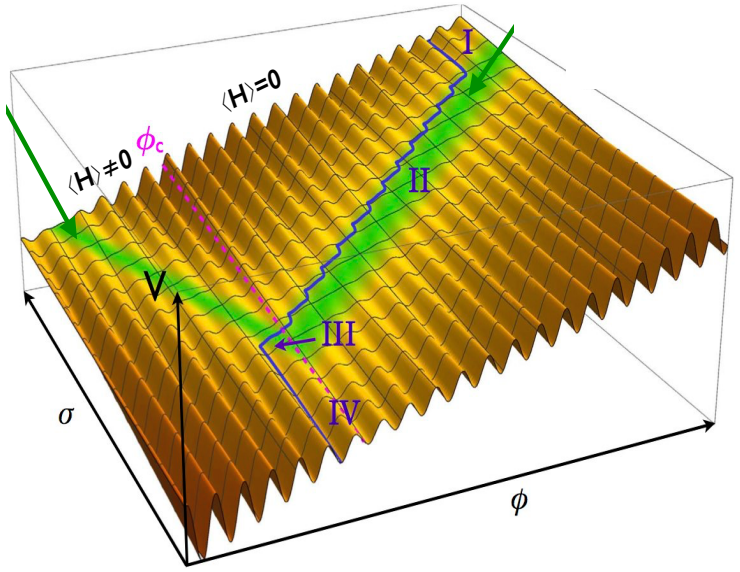
T. Konstandin et al.



C. Grojean, G. Servant et al.

Cosmological Higgs-Axion Interplay for a Naturally Small Electroweak Scale

existence proof of a model that generates a large mass gap between the Higgs mass and the new physics threshold, with no new physics @ the weak scale. Only ultra-light scalars.



Interplay of Higgs physics and cosmology

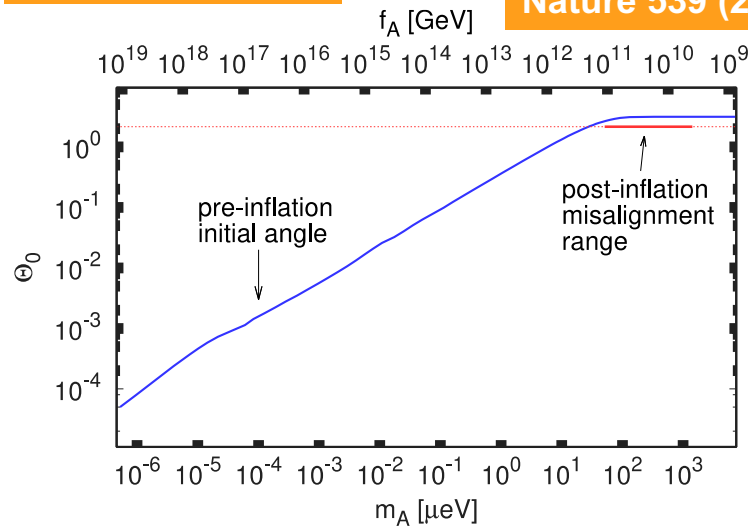
Extensions of the SM addressing inflation, dark matter, strong CP problem, neutrino masses, baryogenesis

Axion dark matter: ``SMASH" model
Unifies inflation and dark matter,
solves ``strong CP problem", …

A. Ringwald et al.

From lattice input for temperature dependence of axion mass:

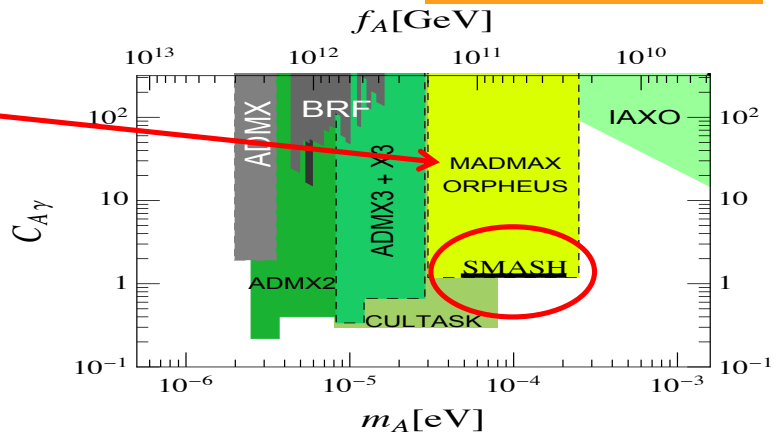
Nature 539 (2016)



Prediction for axion mass range:
m_A = 50 – 1500 μeV

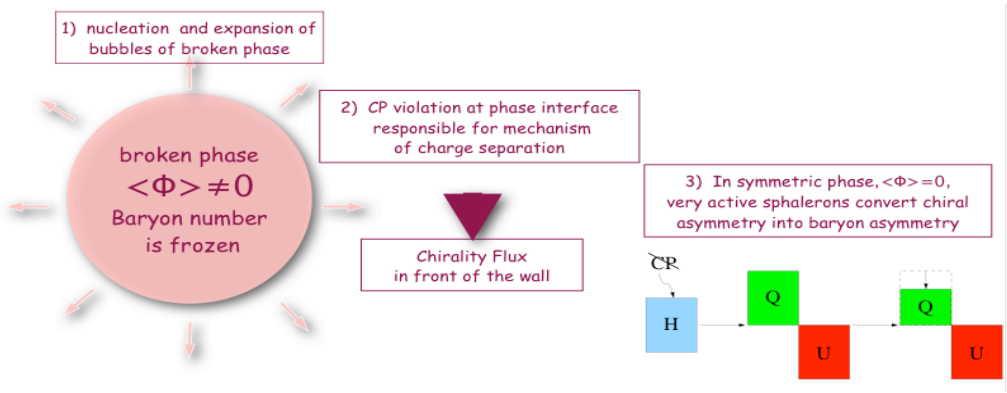
Can ne probed with the proposed MADMAX experiment

A. Ringwald et al.



Mechanisms for creating the matter—anti-matter asymmetry in the universe (baryogenesis): dynamical Yukawa couplings, axion interactions

G. Servant et al.



Precise predictions and new concepts

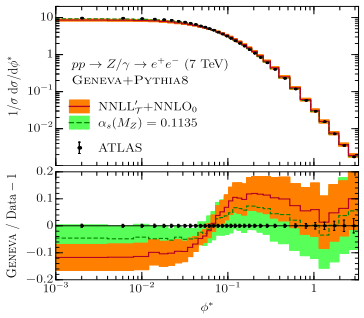
Development of new methods for accurate theoretical predictions

Perturbative higher-order results and Monte Carlo tools:

F. Tackmann et al.

First combination of NNLO+NNLL′ with parton shower, hadronization and MPI from PYTHIA8

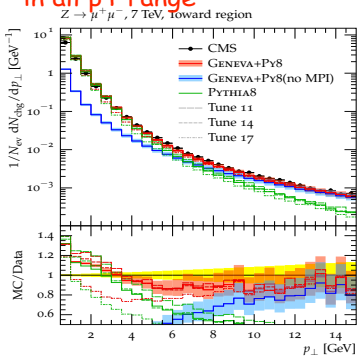
- N-jettiness NNLL′ resummation and NNLO subtractions are key ingredients



→ With higher pert. precision included, data prefers lower $\alpha_s(m_Z)$ (as in e^+e^-)

GENEVA

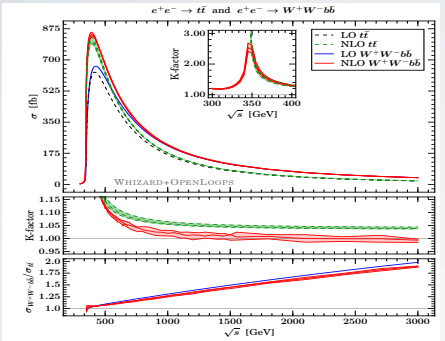
needed to describe data in all pT range

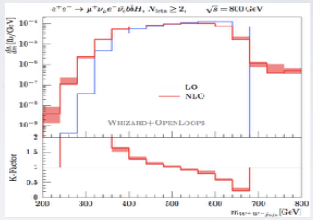


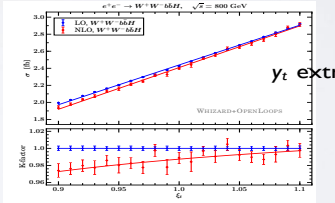
→ Combining GENEVA+PYTHIA8 also improves UE-sensitive measurements

J. Reuter et al.

- First NLO QCD result for 2 → 7 processes in lepton collisions (fully differential)
- Polarized NLO cross sections







WHIZARD v2.4.0 (28.11.2016)

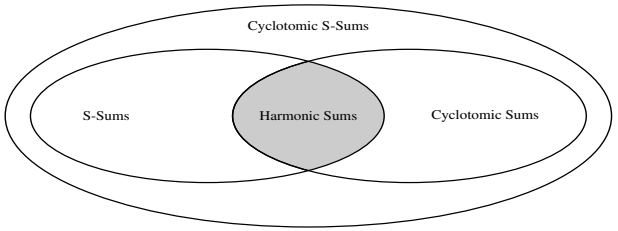
NLO QCD automation; FKS subtraction (also resonance-aware)

String description of gauge theories: large simplifications possible compared to perturbative expansions in field theories

V. Schomerus, M. Sprenger et al., PhD 2014

Mathematics of perturbative expansions:

J. Bluemlein, G. Papathanasiou, V. Schomerus et al.



Precise predictions and new concepts

Development of new methods for accurate theoretical predictions

Running coupling of QCD and anomalous magnetic moment of the muon: perturbative and lattice results

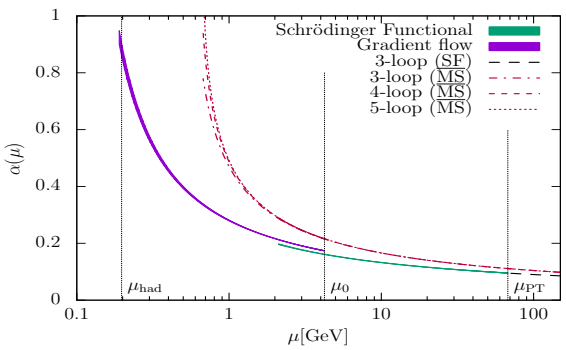
P. Marquard et al.

$$\partial_{\ln \mu^2} a = -a\left[\varepsilon + b_0 a + b_1 a^2 + b_2 a^3 + b_3 a^4 + b_4 a^5 + \dots\right], \quad a \equiv \frac{C_A g^2(\mu)}{16\pi^2},$$

$$\begin{aligned} 3^5 b_4 &= \left[-8(107 + 144\zeta_3) c_f + 4(229 - 480\zeta_3)\right] n_f^4 \\ &\quad + \left[c_1 c_f^2 + c_2 c_f + c_3 + c_4 d_1\right] n_f^3 + \dots, \\ c_1 &= -6(4961 - 11424\zeta_3 + 4752\zeta_4), \quad c_2 = -48(46 + 1065\zeta_3 - 378\zeta_4), \\ c_3 &= -3(6231 + 9736\zeta_3 - 3024\zeta_4 - 2880\zeta_5), \\ c_4 &= 1728(55 - 123\zeta_3 + 36\zeta_4 + 60\zeta_5), \end{aligned}$$

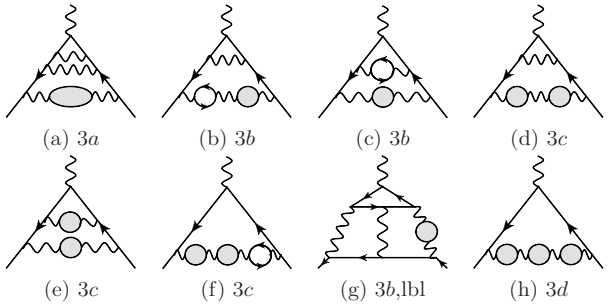
$$n_f = \frac{N_f}{2N}, \quad c_f = \frac{N^2 - 1}{2N^2}, \quad d_1 = \frac{N^4 - 6N^2 + 18}{24N^4}$$

S. Schaefer, H. Simma, R. Sommer et al.

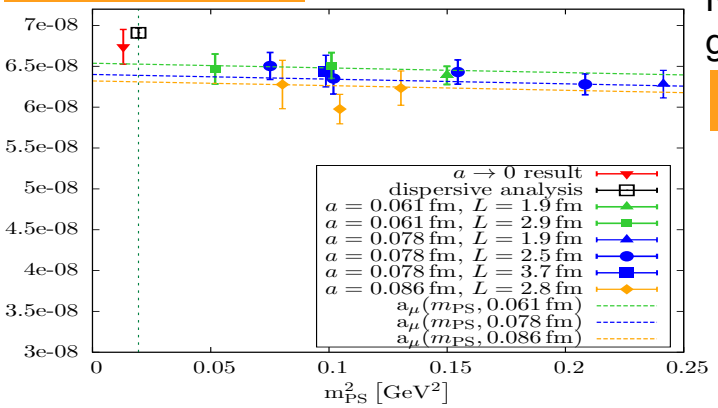


ALPHA Collaboration

P. Marquard et al.

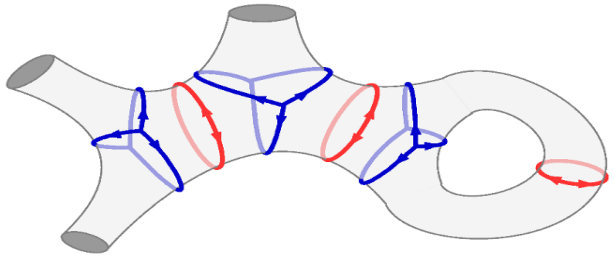


K. Jansen et al.



Non-perturbative effects in supersymmetric gauge theories:

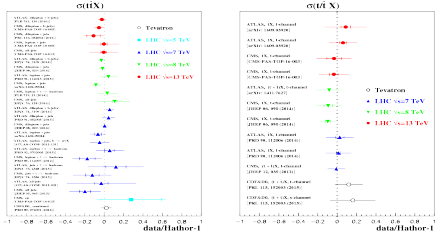
I. Coman, V. Mitev, E. Pomoni, J. Teschner



Determination of SM parameters from global fits to DIS and LHC data:

J. Bluemlein et al.

$m_c(m_c) = 1.25 \pm 0.018(exp)$ GeV
$m_t(m_t) = 160.9 \pm 1.1(exp)$ GeV
$m_b(m_b) = 3.83 \pm 0.12(exp)$ GeV
$\alpha_s(M_Z) = 0.1147 \pm 0.0008(exp)$

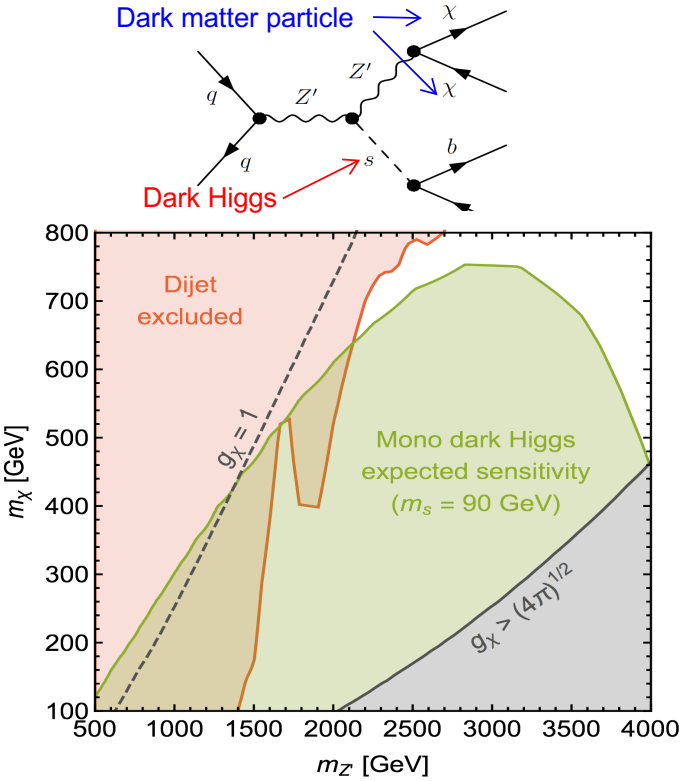


Dark matter, gravitational waves and cosmology

Confrontation of dark matter models with data, gravitational waves as a window to cosmological phase transitions

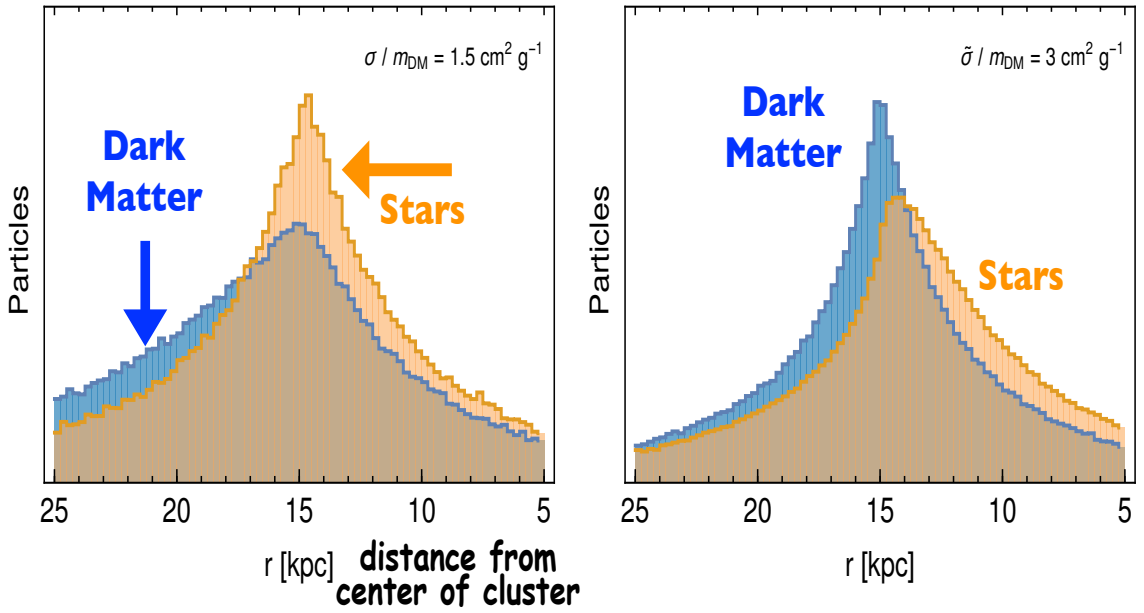
Hunting the Dark Higgs:

M. Duerr, A. Grohsjean, F. Kahlhoefer, K. Schmidt-Hoberg, C. Schwanenberger et al



Dark matter self-interactions:
Possible interpretation of the separation between dark matter and stars in the galaxy cluster Abell 3827 in terms of dark matter self-interactions

J. Kummer et al, PhD 2014

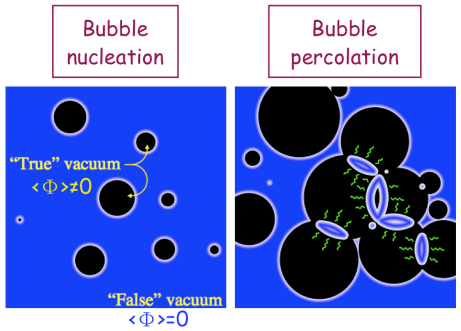


Dark matter, gravitational waves and cosmology

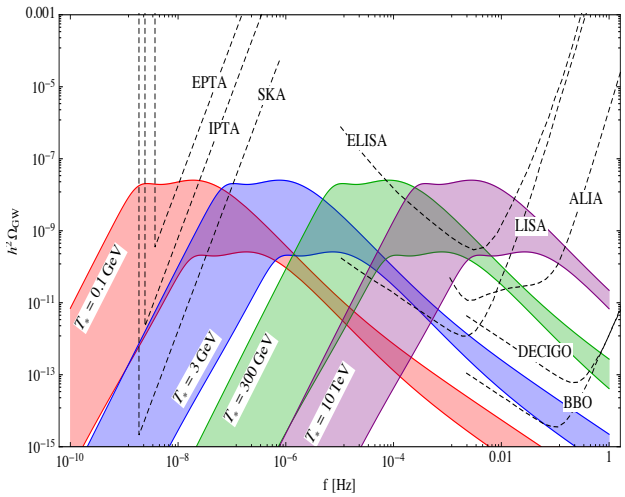
Confrontation of dark matter models with data, gravitational waves as a window to cosmological phase transitions

Gravitational wave signals from first order cosmological phase transitions:

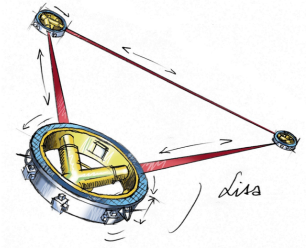
T. Konstandin, P. Schwaller, G. Servant et al.



Stochastic background of gravitational radiation



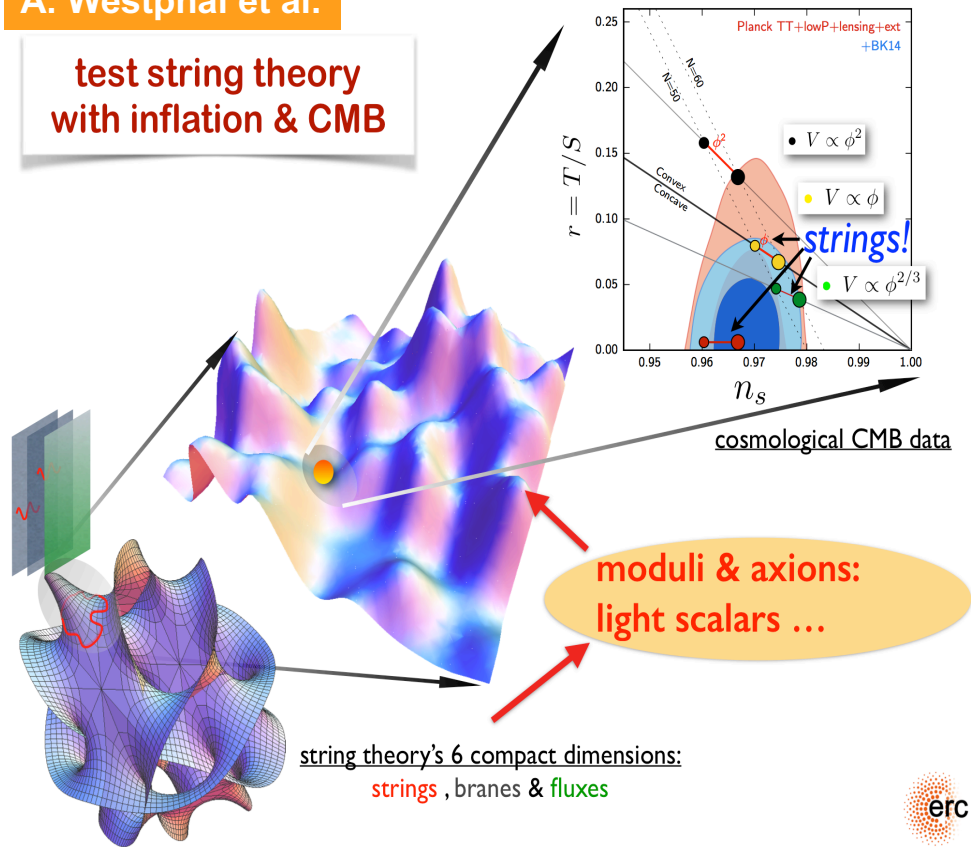
EW phase transition
-> mHz -> eLISA!



String cosmology:

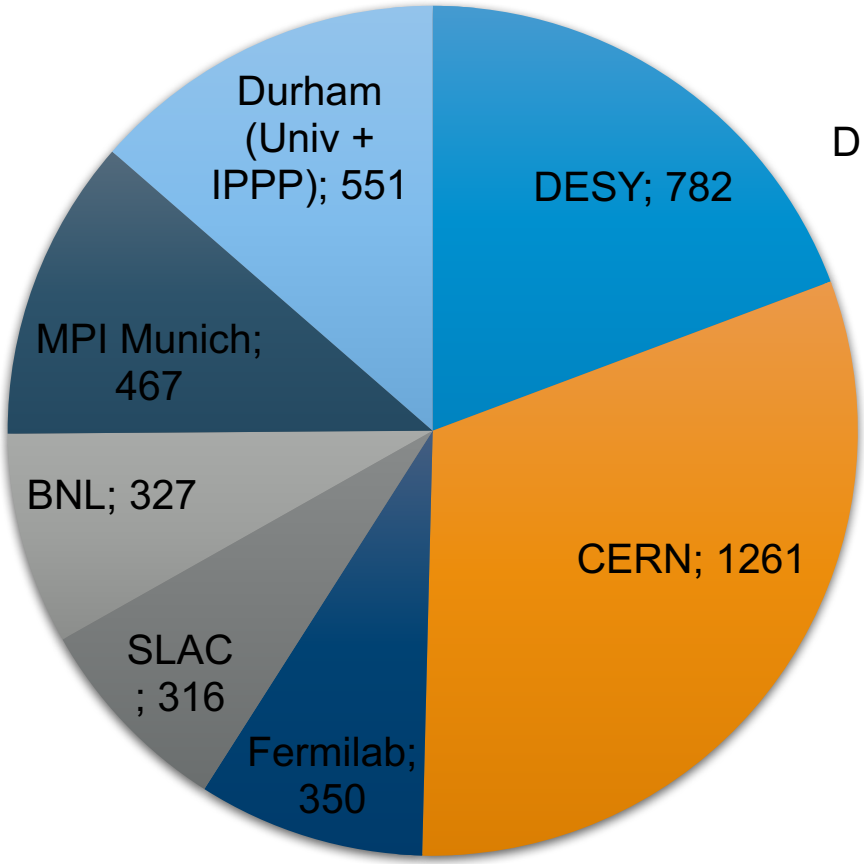
A. Westphal et al.

test string theory with inflation & CMB



Scientific output: international comparison

Papers 2013-2016 in hep-ph, hep-th, hep-lat by affiliation (INSPIRE)



DESY: HH and Zeuthen

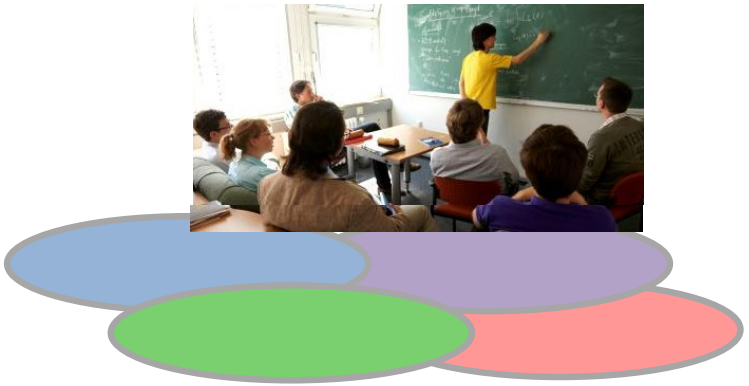
find primarch hep-ph or primarch hep-th or primarch hep-lat and aff desy and date after 2012 and date before 2017 (January 11, 2018)

Theory activities: wider impact

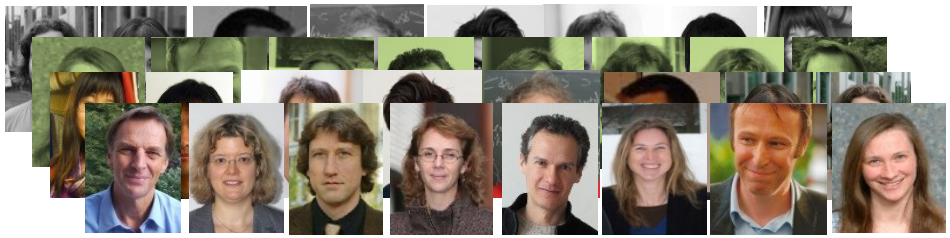
- Training and research partnership with local universities

- Interdisciplinary research & training is highly attractive for international fellows and students

- High-impact Fellowship programme



- Important role as national laboratory:
  About 40% of the particle theory faculty in Germany have been DESY PhDs, Fellows or staff



+ Workshops, schools, coordinating tasks

The Wolfgang-Pauli Centre

A Competence Centre in Theoretical Physics at Hamburg

Collaboration of the various theory groups in Hamburg

I.+II. Institute for Theoretical Physics
Sternwarte Hamburg
DESY Theory group
Center for Free-Electron Laser Science
The Institute of Laser Physics

PIER

Eine Partnerschaft der Universität Hamburg und DESY

RESEARCH | PROGRAMMES OF STUDY | INTERNAL

50 faculty members in 12 institutions

particle physics	condensed matter
astrophysics and cosmology	quantum optics
mathematical physics	chemical physics

Spokesperson: Volker Schomerus

<u>Mission</u>: Forge leading centre for TP from existing research teams & institutions

Organizes blackboard seminars, Wolfgang-Pauli lecture, workshops **with support from DSF**

Hamburg Prize for Theoretical Physics

100.000 € given annually to a distinguished theoretical physicist

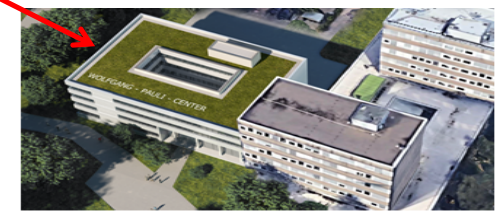
funded by Joachim Herz foundation

nominated and selected by WPC & award jury with international experts

JOACHIM HERZ STIFTUNG

The WPC Building

Plans for a dedicated building



Funding and Networking

Collider physics

Lattice Gauge Theory

Dresden – Berlin – Zeuthen

QTFLAG

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

String Theory

Research Training Group 1670
Mathematics inspired by String Theory and Quantum Field Theory

GATIS
Gauge Theory as an Integrable System

Nordic network on dark matter

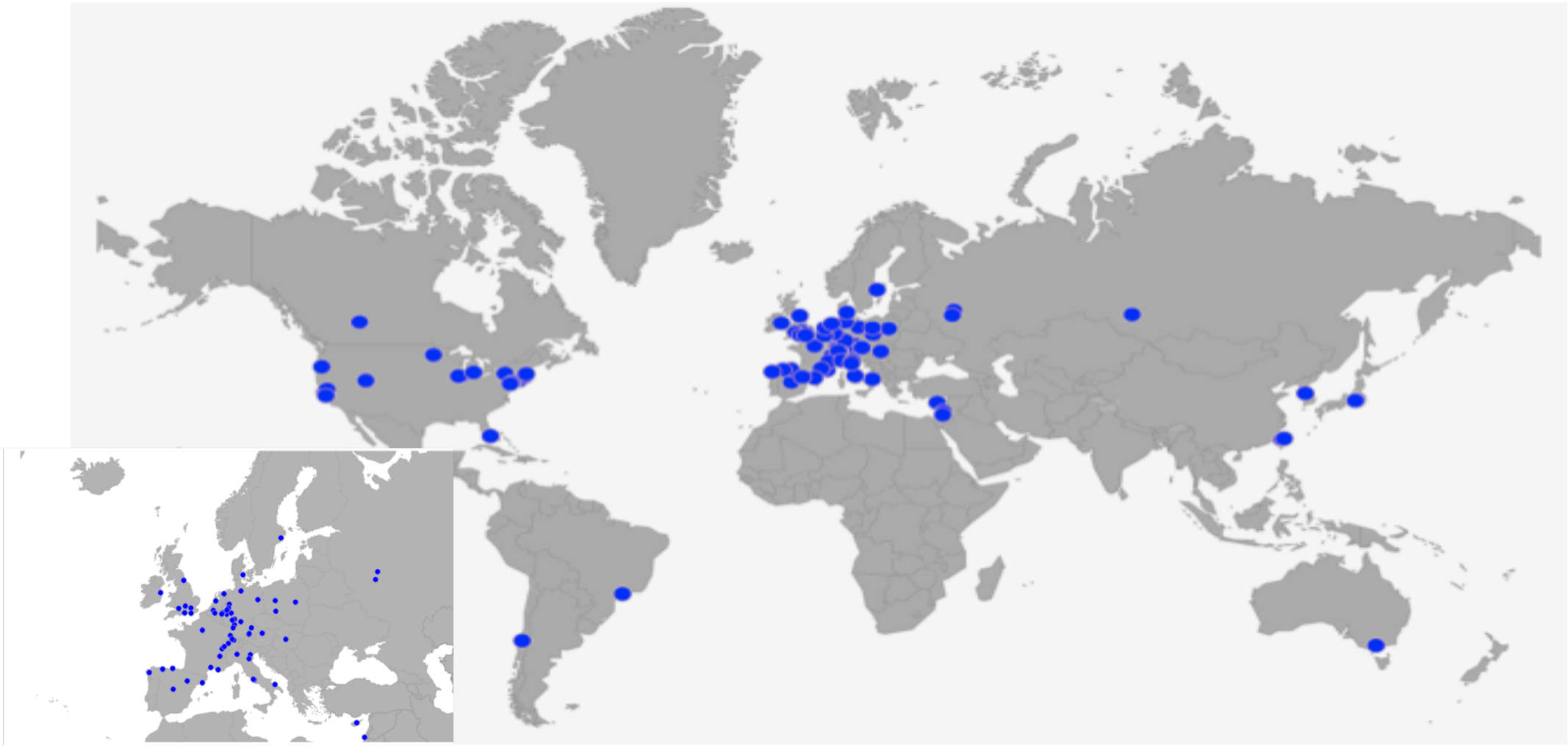
Particle Cosmology

Young Investigator Group

Starting grant (Schmidt-Hoberg)
Consolidator grant (Westphal)

German federal excellence initiative Proposal "Quantum Universe" has passed pre-selection stage.
Working now on full proposal, strong involvement of theory group

Networking: world-wide collaborations



Some examples of recent outreach activities

WISSEN vom FASS

Hamburg Kreativ Gesellschaft

EUROPÄISCHE UNION
Europäischer Fonds für regionale Entwicklung

Public lectures in bars

Latest: April 2017

Theory group members active in all 3 editions

Art meets Science, 13.10. – 9.11.2017

~2500 visitors, ~ 2/3 of which were on the DESY campus for the 1st time

Einstein exhibition in Hamburg (HAW)

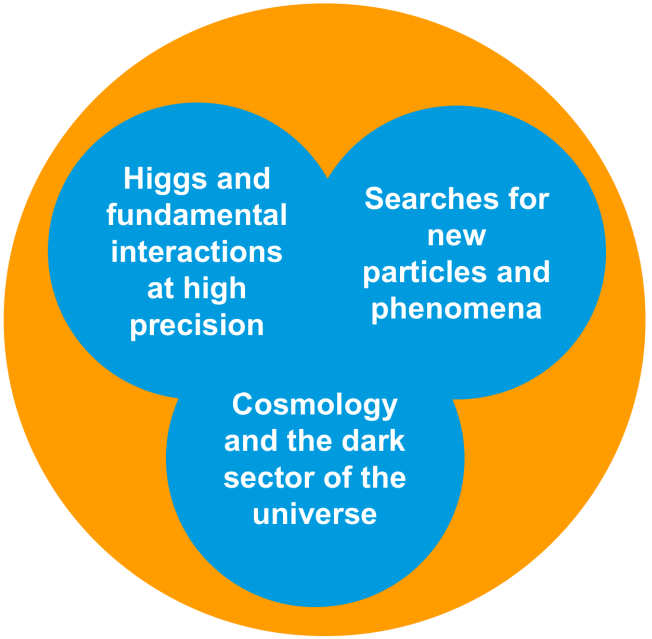
Public outreach theory talks

Night of Science / DESY Day, 4 Nov.

Lectures from DESY theorists

Strategy

Theoretical Particle Physics at DESY



- Address origin of **mass**, structure of the **vacuum**, nature of **dark matter** and **dark energy**, asymmetry between matter and **anti-matter** in the Universe, ...
  making use of the synergies between the different research areas

- Provide **input** (predictions, tools) and **guidance** for the **experimental programme** on- and off-site, in particular LHC physics, Belle, axion and neutrino physics, **interpret** the experimental results in terms of the underlying physics and **assess** the capabilities of possible **future facilities**

- **Foster links** to other research areas: experimental particle physics, astroparticle physics, mathematics, condensed matter physics, accelerator physics, ...
  Wolfgang-Pauli-Centre, Centre for Mathematical Physics HH, Kolleg Mathematik und Physik Berlin

Strategy

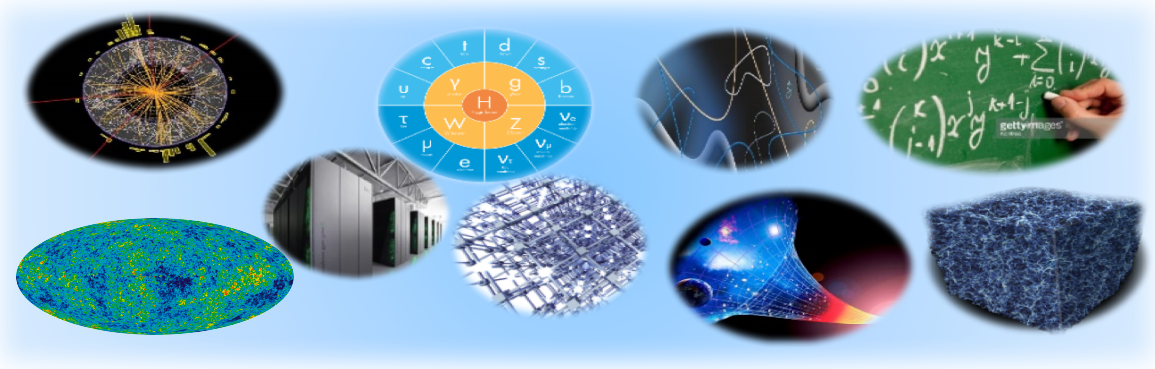
Theoretical Particle Physics at DESY

- Extend position as international competence centre for the **theory of the fundamental interactions of nature, matter and space-time**, addressing all aspects in the theory of matter and gravity through research and training, from observation to mathematics

Matter

Dark Sector

Cosmology



Observation **Theoretical Physics** **Mathematics**

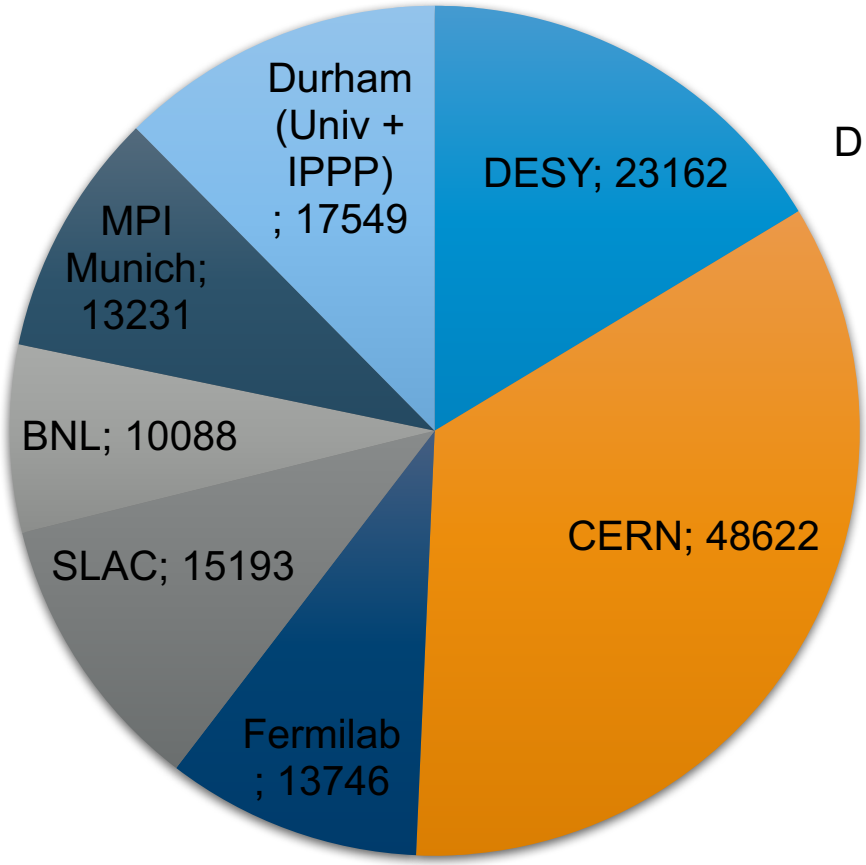
offers unique cross-disciplinary training opportunities for young researchers

- **Develop the Wolfgang-Pauli-Centre** as centre for theoretical physics
- **Theory building**, importance of communication space
- Explore scientific opportunities in the **Hamburg-Berlin metropolitan area** (particle/astro: theory/exp/computing)

Back-up

Scientific output: international comparison

Citations of papers 2013-2016 in hep-ph, hep-th, hep-lat by affiliation (INSPIRE)



DESY: HH and Zeuthen

find primarch hep-ph or primarch hep-th or primarch hep-lat and aff desy and date after 2012 and date before 2017 (January 11, 2018)

Networking and cooperation, use of infrastructures, talent management

• Research centre with international reputation, hub of **scientific excellence**
• On-site expertise on wide range of topics, multi-disciplinary environment: full spectrum of topics in high-energy theory with close connections to experiments; interplay and mutual enrichment of theoretical physics, mathematics, computing
• National laboratory, well-established cooperation with local universities and prominent role in education
• Cooperation with the local **experimental activities** (LHC, Belle, ALPS, ILC), strong collaboration with experiments (globally)
• Third-party funding and networking
• Links to (inter)national partners: Very international field, many international cooperations already exist, e.g. CERN, Durham (UK), IPMU (Japan), MIT(USA), Nikhef (Netherlands), ...
• High potential in all fields for leading and coordinating **international collaborations**

Use of excellent **local infrastructure**:
• DESY computing centres, HPC, J von Neumann institute for computing: hub for lattice computing
• Logistics and facilities to organise workshops, schools and scientific exchanges

Talent management:
• Rich **Fellowship, PhD programmes**
• Interaction with highly qualified students

Common activities of experiment & theory at DESY

Meetings, schools

LHC Physics Discussions (monthly)

Theory forms link in communication across the experiments

Higgs @ DESY meetings in the context of the SFB Higgs project (monthly)

ILC Project Meeting (bi-weekly)

Annual FH Fellows Meeting

Many common seminars and colloquia

+ many informal meetings in small groups

Joint organisation of schools, e.g. annual Monte Carlo School of Terascale Alliance (organizers: H. Jung, J. Katzy, I. Melzer-Pellmann, Z. Nagy, J. Reuter)

Common activities of experiment & theory at DESY

Direct experimental involvement, working groups, tools for experimental analyses

ALPS experiment: driven by A. Ringwald from inception to experimental realization and analysis

Experiment & theory at DESY have provided key contributions to working groups for LHC and physics at future facilities, European Strategy update, ``Snowmass process'', …

Tools for the HEP community

- Monte Carlo generators: **WHIZARD** (J. Reuter), **GENEVA** (F. Tackmann), **DEDUCTOR** (Z. Nagy)
- **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)

+ global fits:

MasterCode, Gambit, …

Close interaction with **GFitter**

PDF fits

Common activities of experiment & theory at DESY

Common projects, joint supervision

Common projects with experimental groups at DESY and UHH:

Common **SFB projects**: Higgs, BSM searches, dark matter searches

ATLAS/theory: H ➔ γγ, use of jet vetoes, Higgs template cross sections
Several theory papers triggered by regular contacts as well as important part of work in Ph.D. or master theses (Theory: S. Gangal; ATLAS: M. Filipuzzi, F. Braren, M. Bessener)

CMS/theory: dark matter searches (C. Schwanenberger, K. Schmidt-Hoberg)
DESY theory paper (O. Stal, G. Weiglein) triggered analysis in DESY CMS group: PhD thesis G. Mittag (2015) and CMS publication

Examples of **joint supervisions of PhD students**:

T: J. Wittbrodt (C. Grojean, G. Weiglein, P. Schleper)
CMS: N. Stefanov (C. Schwanenberger, J. Haller, K. Schmidt-Hoberg)

Common activities of experiment & theory at DESY

Examples of joint publications

PHYSICAL REVIEW D **94,** 051901(R) (2016)

Exploiting jet binning to identify the initial state of high-mass resonances

Markus A. Ebert,[1] Stefan Liebler,[1] Ian Moult,[2] Iain W. Stewart,[2] Frank J. Tackmann,[1] Kerstin Tackmann,[1] and Lisa Zeune[3]

[1]*Deutsches Elektronen-Synchrotron (DESY), D-22607 Hamburg, Germany*
[2]*Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
[3]*Nikhef, Theory Group, Science Park 105, 1098 XG Amsterdam, The Netherlands*

(Received 7 June 2016; published 28 September 2016)

Hunting the dark Higgs

Michael Duerr,[a] **Alexander Grohsjean,**[a] **Felix Kahlhoefer,**[a] **Bjoern Penning,**[b] **Kai Schmidt-Hoberg**[a] **and Christian Schwanenberger**[a]

[a]*DESY, Notkestraße 85, D-22607 Hamburg, Germany*
[b]*University of Bristol, HH Wills Physics Laboratory, Tyndall Avenue, Bristol BS8 1TL, U.K.*

Eur. Phys. J. C (2015) 75:396
DOI 10.1140/epjc/s10052-015-3618-z

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

JHEP04(2

Impact of heavy-flavour production cross sections measured by the LHCb experiment on parton distribution functions at low x

PROSA Collaboration

O. Zenaiev[1,a], A. Geiser[1], K. Lipka[1], J. Blümlein[1], A. Cooper-Sarkar[2], M.-V. Garzelli[3], M. Guzzi[4], O. Kuprash[1], S.-O. Moch[3], P. Nadolsky[5], R. Placakyte[1], K. Rabbertz[6], I. Schienbein[7], P. Starovoitov[1]

[1] DESY Hamburg and Zeuthen, Hamburg, Germany
[2] University of Oxford, Oxford, UK
[3] Universität Hamburg, Hamburg, Germany
[4] School of Physics and Astronomy, The University of Manchester, Manchester, UK
[5] Southern Methodist University, Dallas, TX, USA
[6] Karlsruher Institut für Technologie, Karlsruhe, Germany
[7] LPSC Grenoble, Grenoble, France

Extracting gluino endpoints with event topology patterns

Niklas Pietsch,[a] **Jürgen Reuter,**[b] **Kazuki Sakurai**[b] **and Daniel Wiesler**[b]

[a]*University of Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany*
[b]*DESY Theory Group, Notkestr. 85, D-22603 Hamburg, Germany*

Eur. Phys. J. C (2016) 76:471
DOI 10.1140/epjc/s10052-016-4285-4

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

JHEP07(2C

A critical appraisal and evaluation of modern PDFs

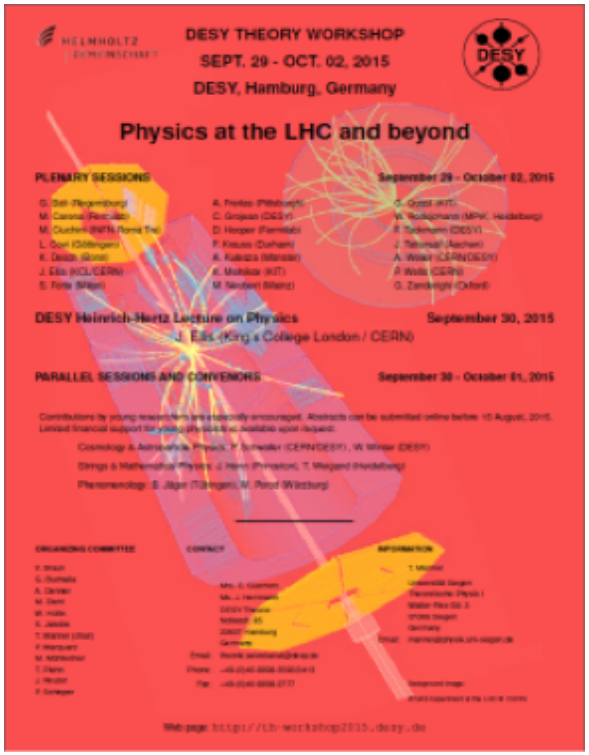
A. Accardi[1,2], S. Alekhin[3,4], J. Blümlein[5], M. V. Garzelli[3], K. Lipka[6], W. Melnitchouk[2], S. Moch[3,a], J. F. Owens[7], R. Plačakytė[6], E. Reya[8], N. Sato[2], A. Vogt[9], O. Zenaiev[6]

[1] Hampton University, Hampton, VA 23668, USA
[2] Jefferson Lab, Newport News, VA 23606, USA
[3] II. Institut für Theoretische Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
[4] Institute for High Energy Physics, 142281 Protvino, Moscow region, Russia
[5] Deutsches Elektronensynchrotron DESY, Platanenallee 6, 15738 Zeuthen, Germany
[6] Deutsches Elektronensynchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany
[7] Florida State University, Tallahassee, FL 32306, USA
[8] Institut für Physik, Technische Universität Dortmund, 44221 Dortmund, Germany
[9] Department of Mathematical Sciences, University of Liverpool, Liverpool L69 3BX, UK

DESY Theory Workshop

Annual Meeting of the German Theory Community

Many more conferences and workshops hosted or (co)organised



Main topic rotates between the areas Cosmology & Astroparticle Physics / Strings & Mathematical Physics / Particle Phenomenology each year; parallel sessions cover all areas at each workshop; forum for young researchers from German particle physics institutions; > 200 participants each year

Tensor Networks – WPC workshop in 2017

An example of cross-disciplinary interaction in the WPC