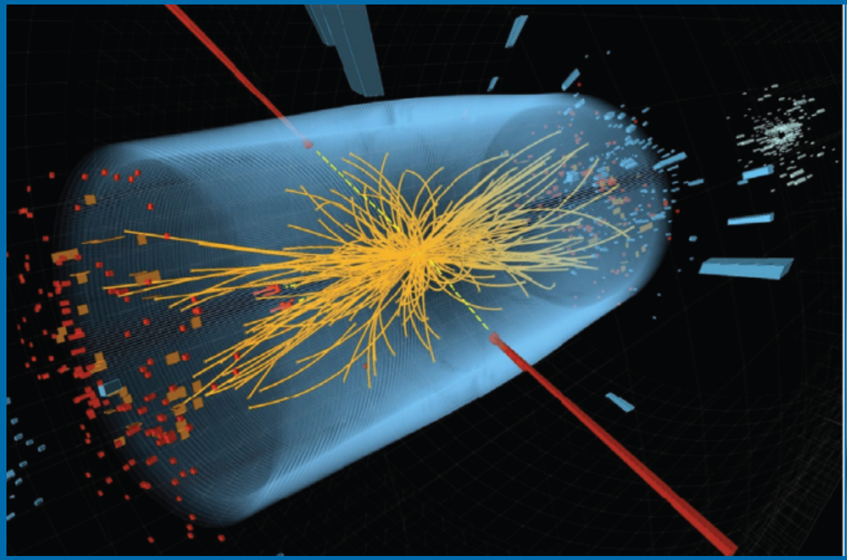
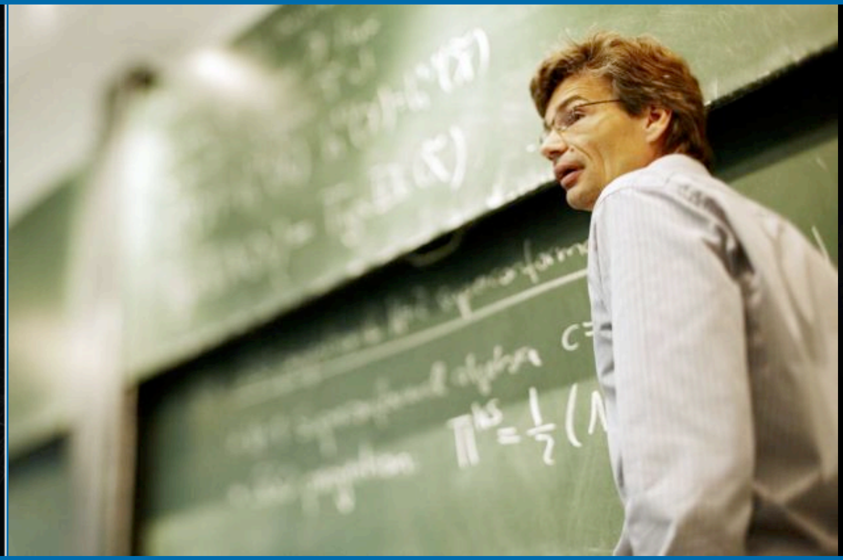
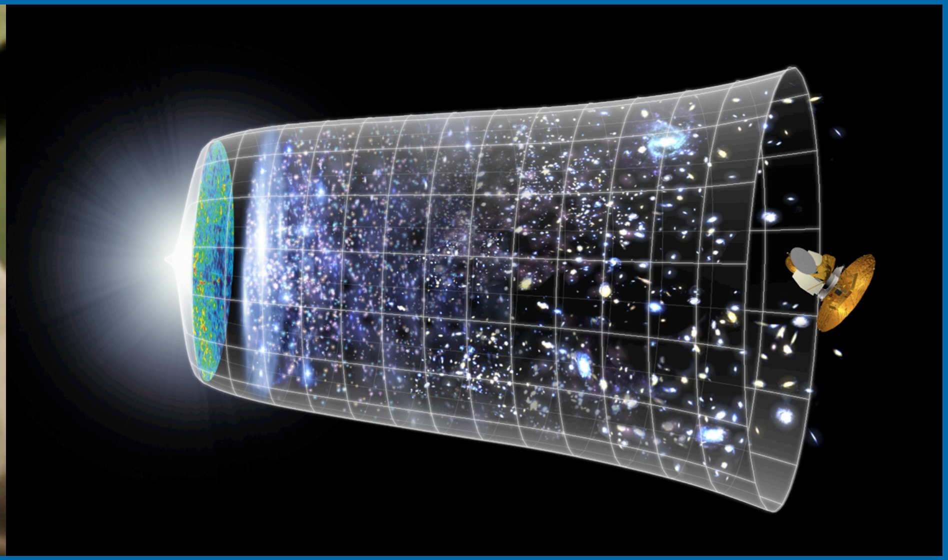
Matter and the Universe

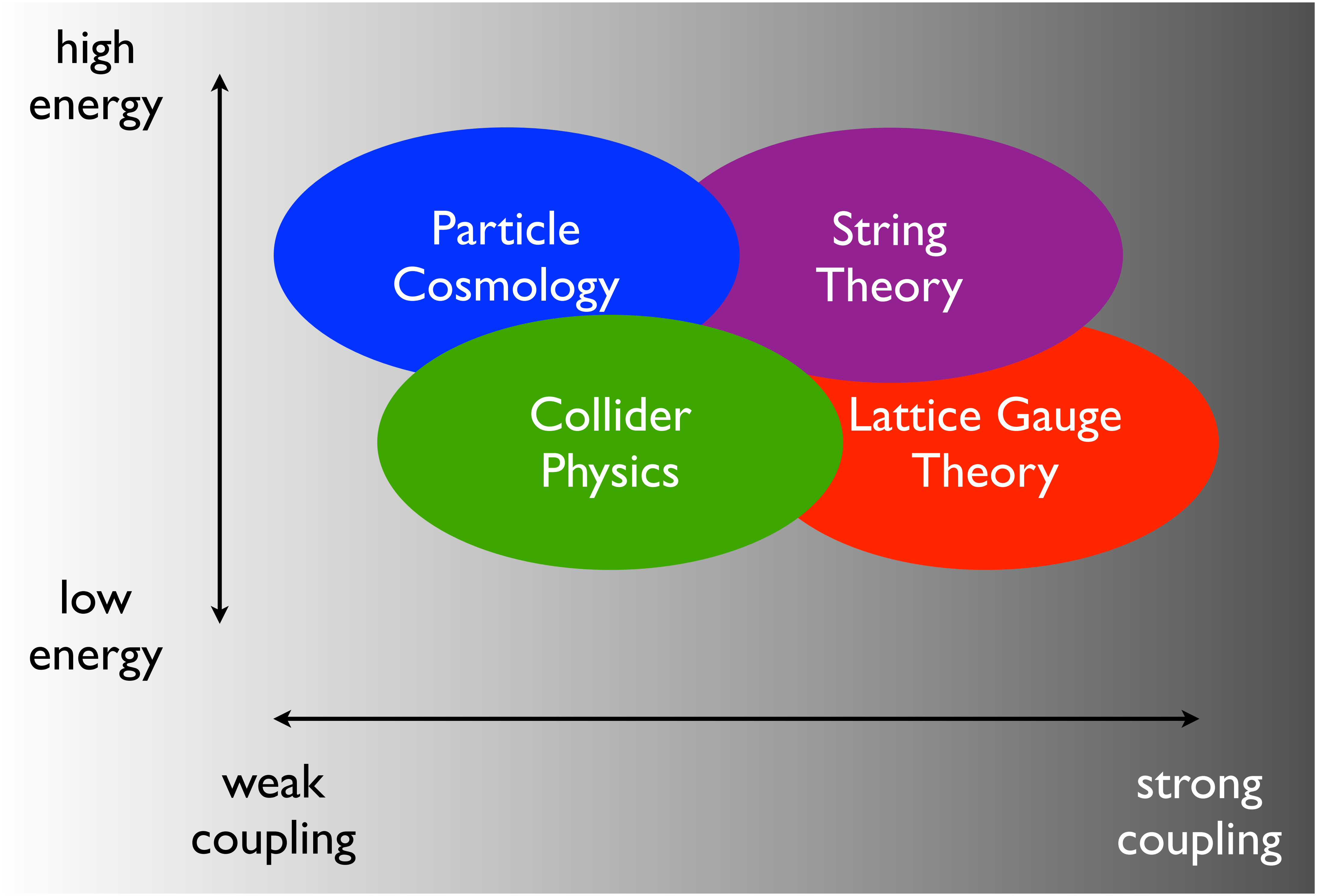
Particle Physics Theory

Georg Weiglein – DESY

HELMHOLTZ ASSOCIATION

Particle physics theory



⇒ Close interaction with experiment: predictions, interpretation, tools

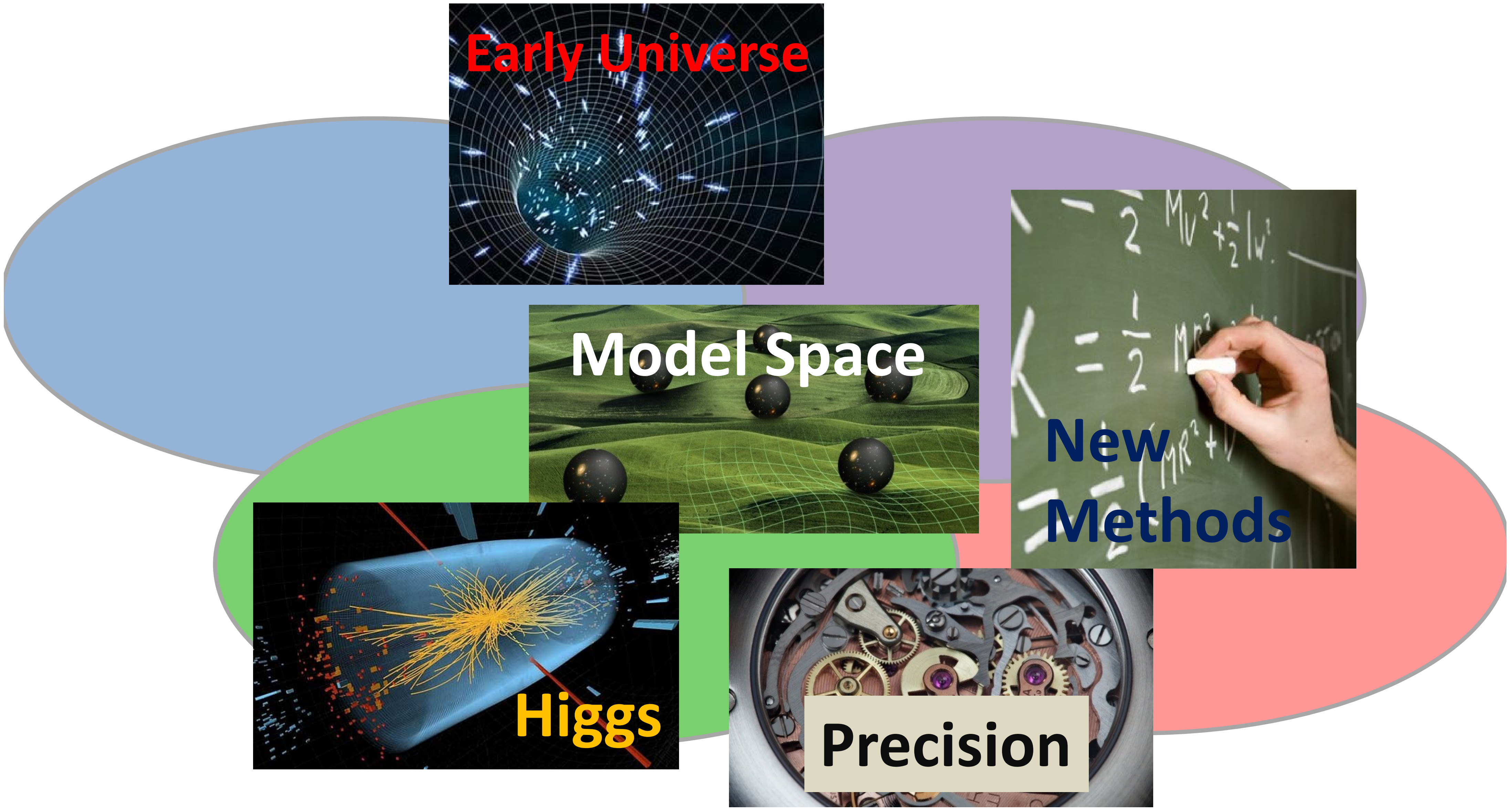
Development of new methods, algorithms and concepts

Crucial for LHC physics!

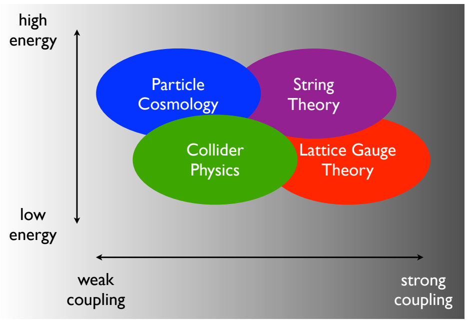
Particle physics theory

DESY (Collider phenomenology, Particle cosmology, Lattice field theory, String theory) + KIT (Collider phenomenology)

Challenges:



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

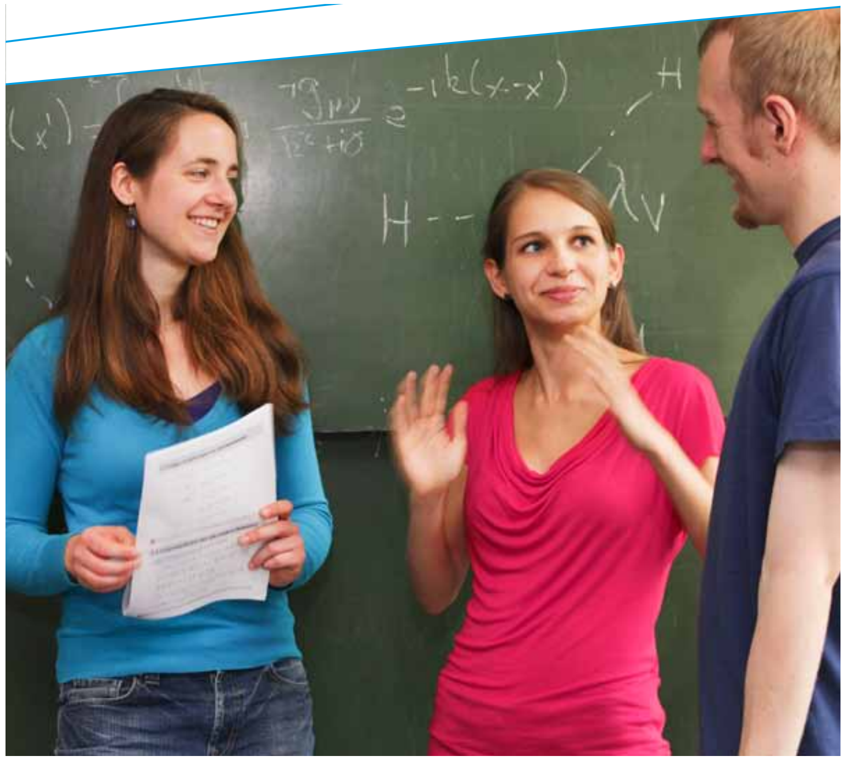


Theory group at DESY (Hamburg, Zeuthen)

Staff: 17 permanent / tenure-track, increase in collider phenomenology by 3 (renewal of activities in this field was prime goal of PoF 2 period)

Fellows: 17 DESY-funded, 19 third-party-funded

PhD Students: 28 theses completed during PoF 2, currently 25 ongoing (15 DESY-funded, 10 third-party-funded)



Success in Helmholtz recruitment initiative: two ongoing appointment procedures

Fellowship programme: 479 applications in current round (HH), very high success rate in hiring first-choice candidates in world-wide competition

Theory group at KIT

KIT theory staff participating in PoF 3 (topic 1):

- 5 professors, 2 staff, 4.5 FTE postdocs from state funding

PhD Students: 21 theses completed since 2010, currently 21 ongoing

Research topics for PoF 3:

- collider physics (Higgs, SUSY, QCD, Monte Carlo),
- precision calculations (for SM parameters and ILC physics)
- flavour physics (FCNC amplitudes in SM and SUSY)

Proposed Helmholtz funding for PoF 3:

- 7 FTE

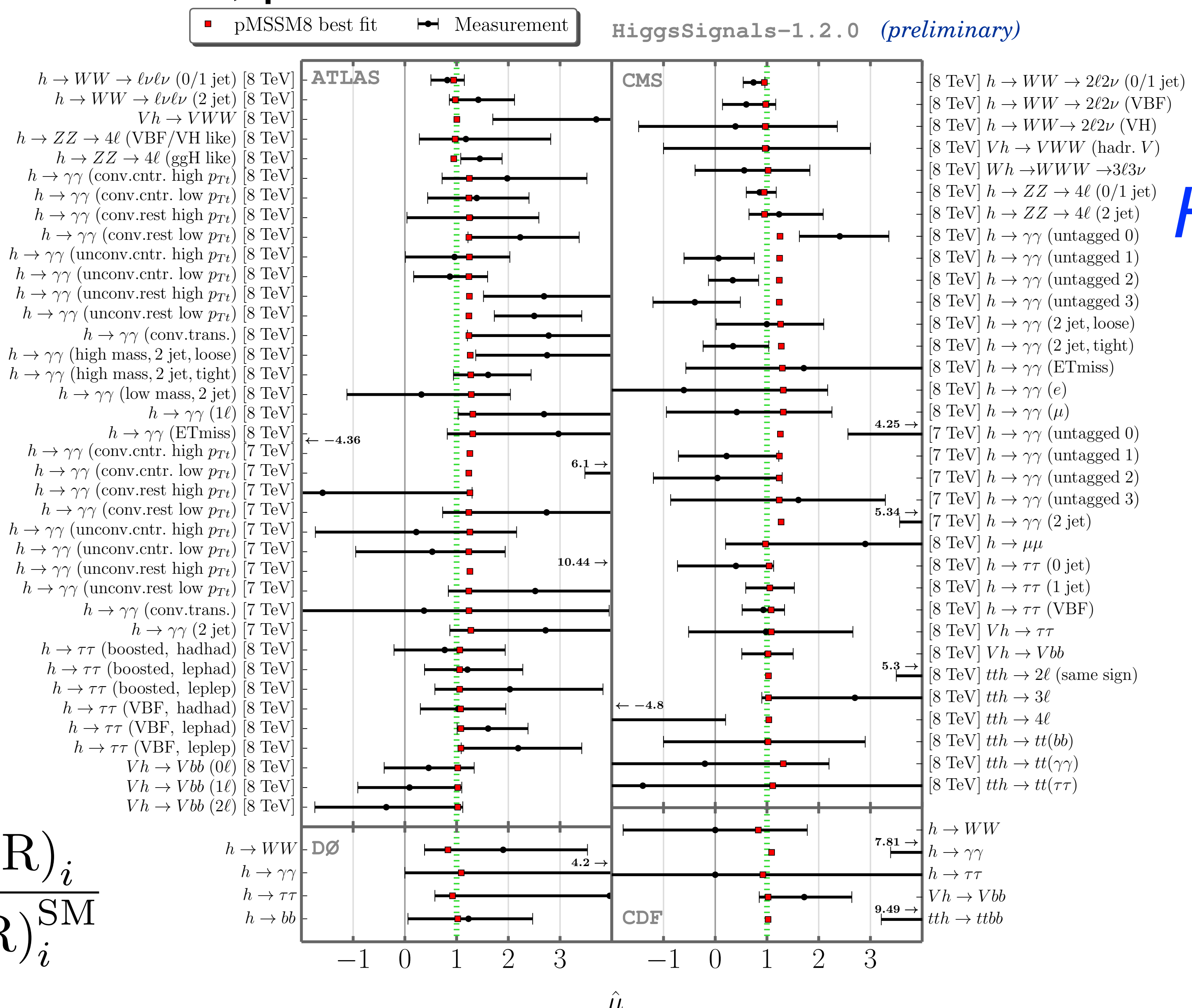
⇒ Synergies from collaboration between different Helmholtz Centres

Collider phenomenology (DESY + KIT)

SUSY interpretation of the observed Higgs signal: light Higgs h?

Fit to LHC data, Tevatron, precision observables: SM vs. MSSM

Observables:



HiggsSignals

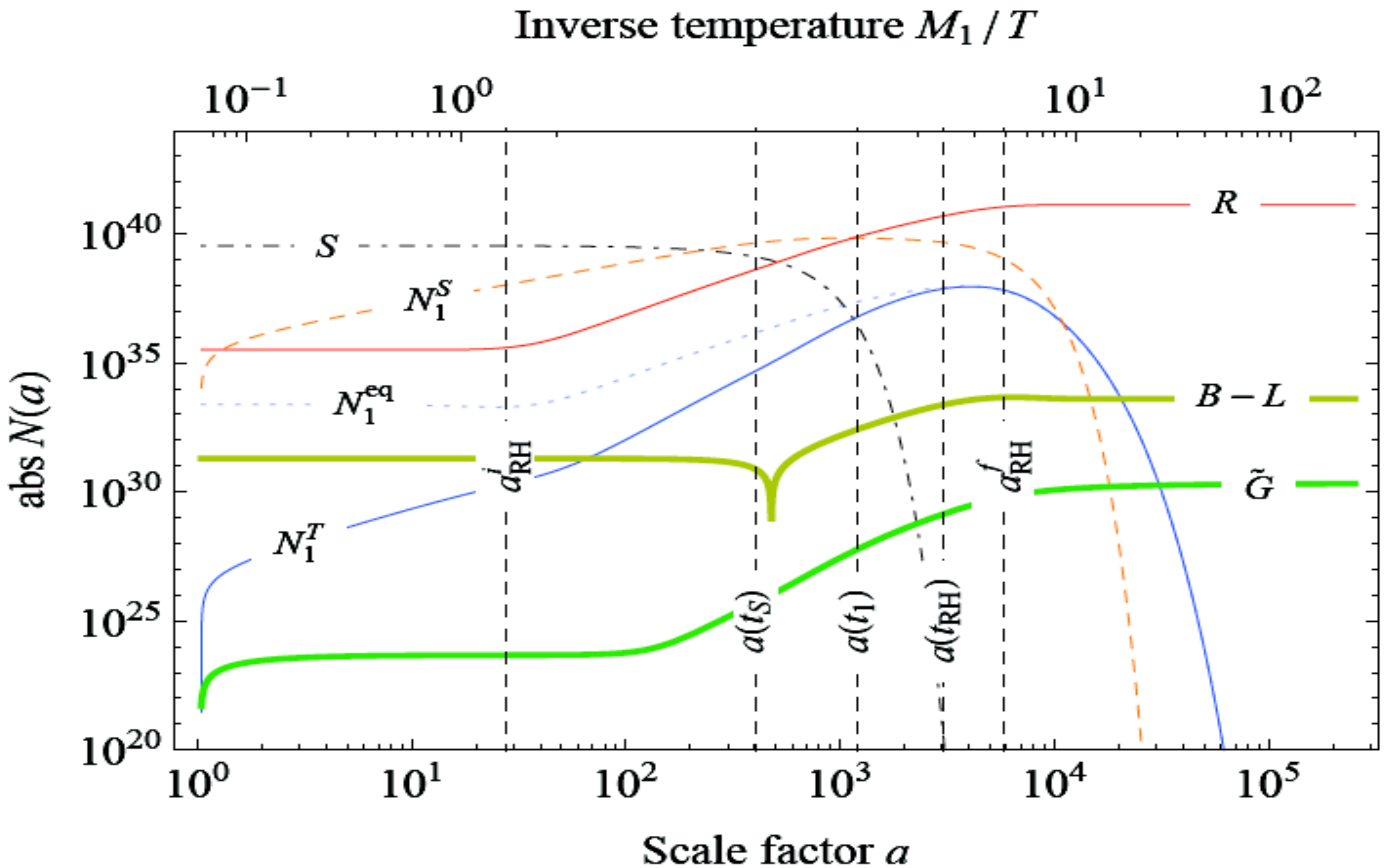
$$\mu_i = \frac{(\sigma \times \mathrm{BR})_i}{(\sigma \times \mathrm{BR})_i^{\mathrm{SM}}}$$

⇒ χ^2 reduced compared to the SM, (slightly) improved fit quality

Higgs as a portal to physics beyond the Standard Model, dark matter, ...?

Particle cosmology

Explanation of the initial conditions of the hot early universe from a phase transition at the end of inflation:



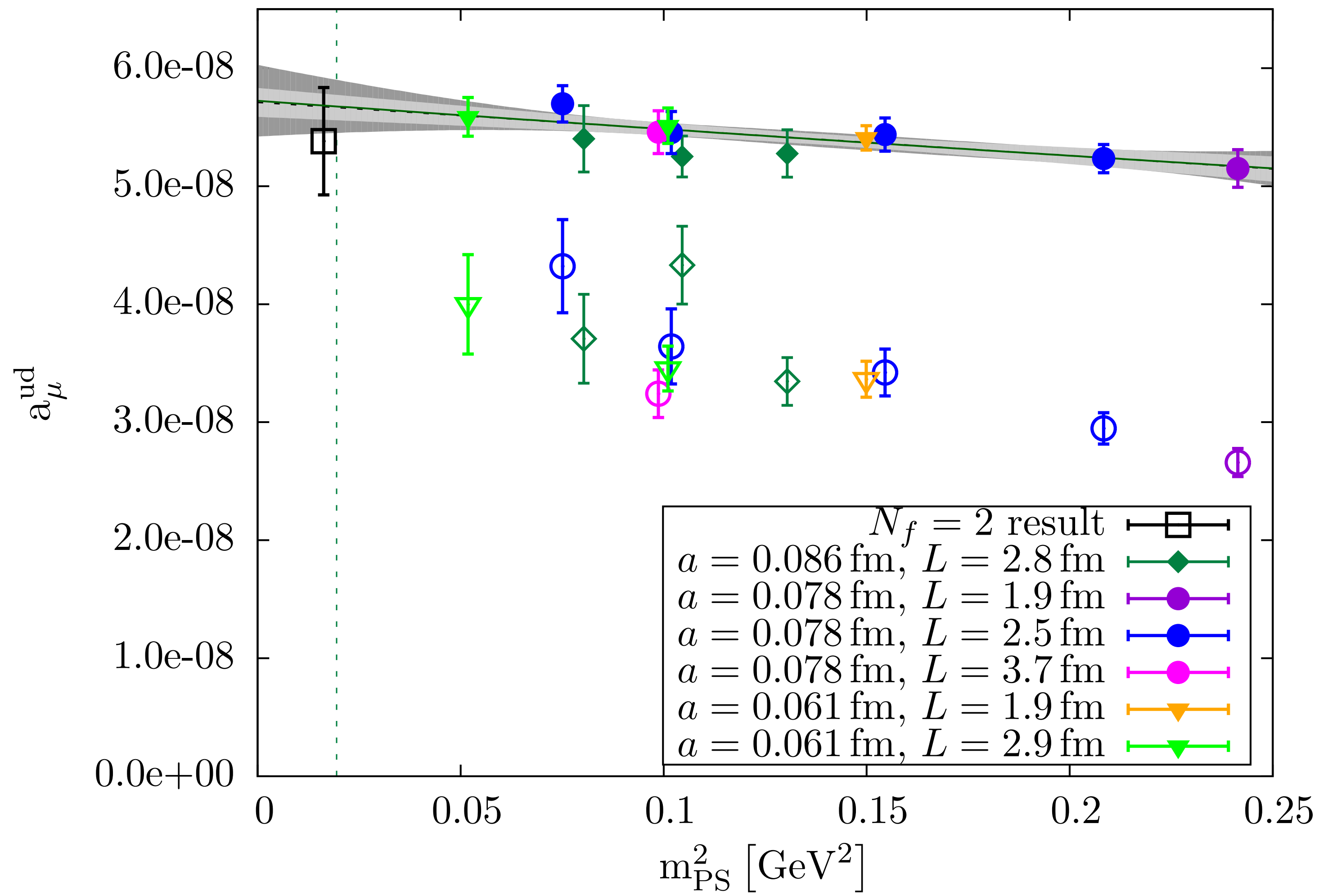
[Generation of entropy (R), matter-antimatter asymmetry (B-L) and dark matter (G) after inflation]

Inflation models in light of Planck results? Dark matter candidates that are consistent with all cosmological, astrophysical collider constraints?

Lattice field theory

Hadronic contributions for precision physics
$\rightarrow$ e.g. $g-2$ of the muon

- PoF 2:
  - chiral extrapolation

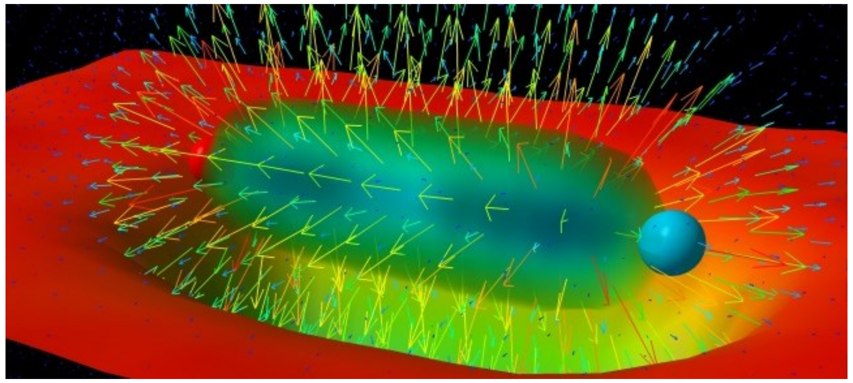


- PoF 3:
  - direct computation at physical m_π
  - continuum limit
  - community support by simulation laboratory

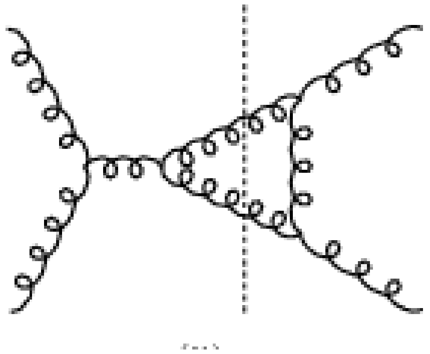
String Theory

Development of novel string theory methods to compute gauge theory quantities

- to high or all loops
- non-perturbatively

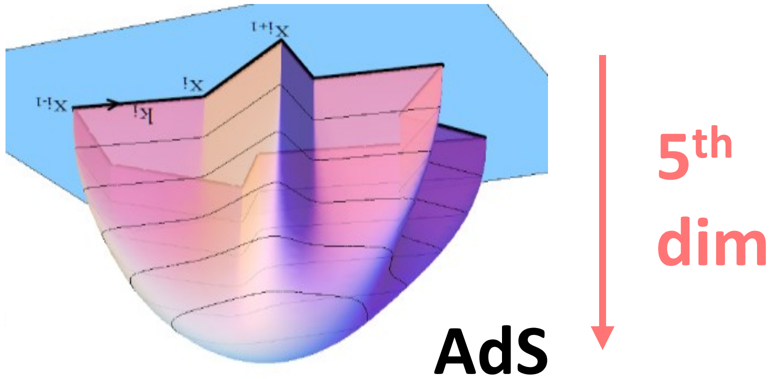


e.g. gluon scattering amplitudes in high energy limit



Feynman graph

interpolation



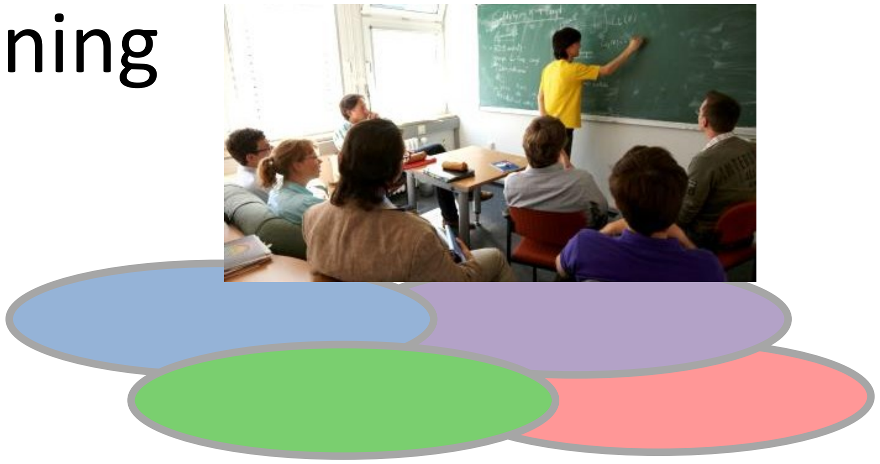
minimal area

Applications of string theory methods to strongly coupled quantum systems [Quark-Gluon plasma, condensed mat]

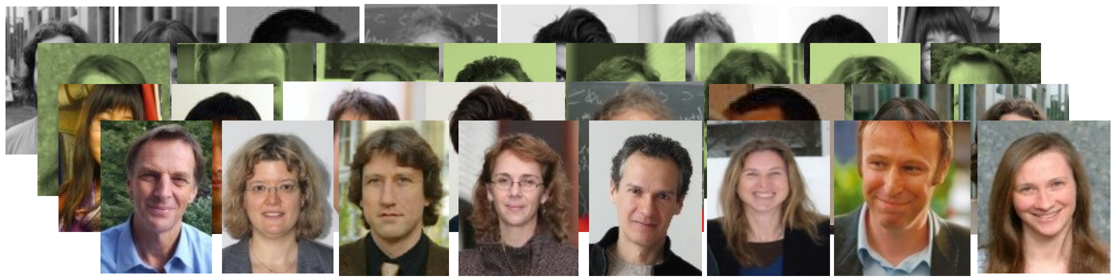
Theory activities: wider impact

- Training and research partnership with local universities

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



- High impact fellowship programme; **e.g. out of the 46 fellows (HH) who left between 01/2010 - 12/2012, 14 (30%) have tenure (track).**
- Important role as national laboratory; **e.g. large fraction of German hep-th Univ faculty have been DESY PhDs, fellows or staff.**



Workshops, schools, coordinating tasks

Wider impact and networking

Collaboration of the various theory groups in Hamburg

- Wolfgang-Pauli-Centre:

WOLFGANG-PAULI-CENTRE
A COMPETENCE FIELD OF PIER

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

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

- LHC Physics Discussions:

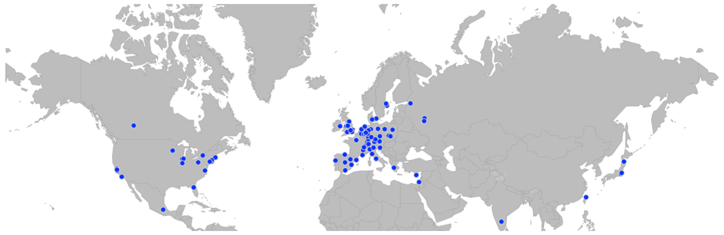
ATLAS EXPERIMENT ⟺ THEORY ⟺ CMS

+ ILC, Belle, ...

Theory forms link in communication across the experiments

- Terascale alliance: Monte Carlo generators, pdfs, SUSY / BSM fit working group, ...

- Many collaborations with institutes world-wide



- Key contributions to working groups for LHC and e^+e^- physics, European Strategy update, ``Snowmass process'', ...

Supporting material

Particle accelerators: viewing the early Universe

Today's universe is cold and empty: only the stable relics and leftovers of the big bang remain

The unstable particles have decayed away with time, and the symmetries that shaped the early Universe have been broken as it has cooled

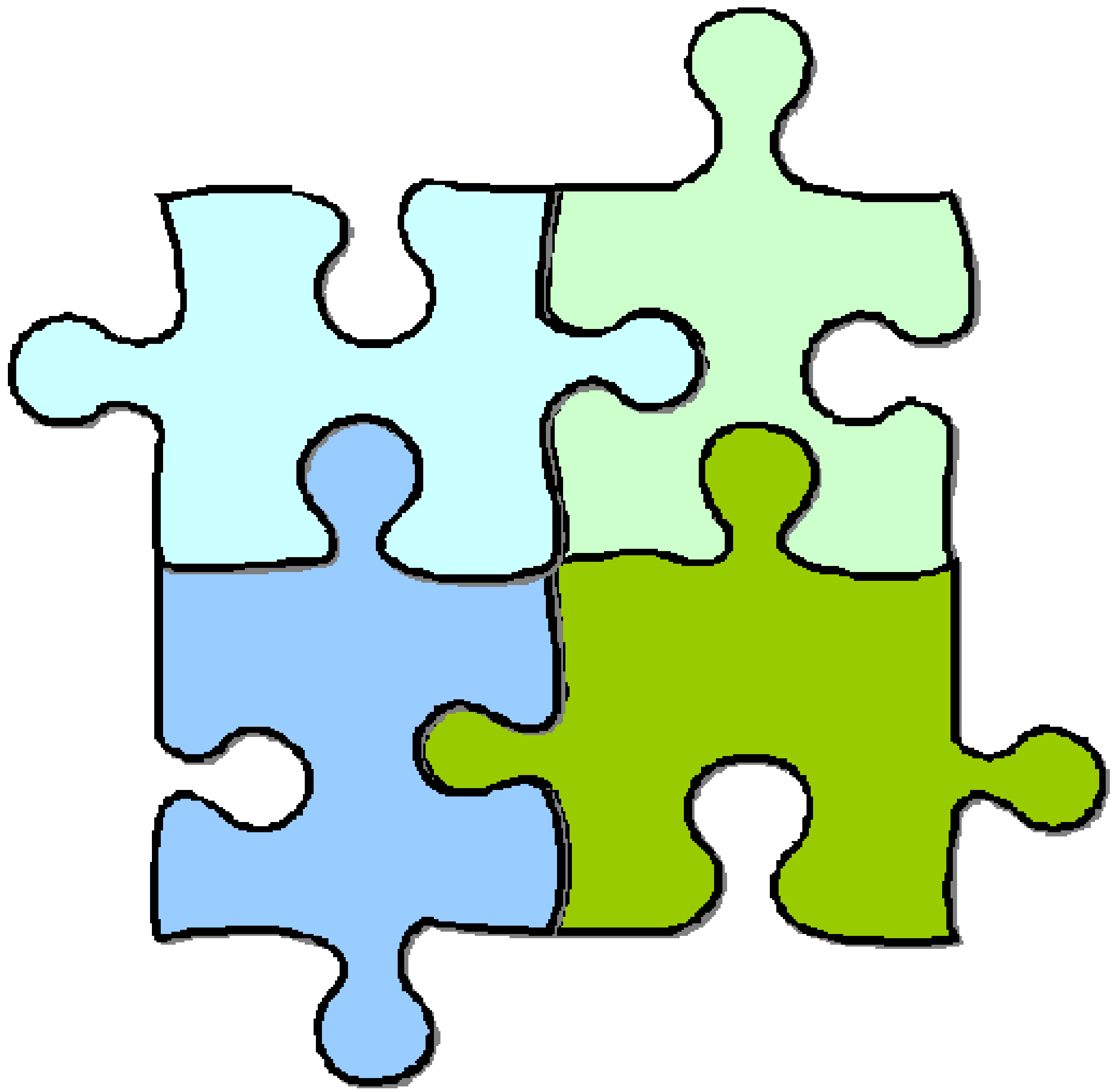
$\Rightarrow$ Use particle accelerators to pump sufficient energy into a point in space to re-create the short-lived particles and uncover the forces and symmetries that existed in the earliest Universe

$\Rightarrow$ Accelerators probe not only the structure of matter but also the structure of space-time, i.e. the fabric of the Universe itself

The Quantum Universe

Particle
Physics
Experiments
Accelerators
Underground

Quantum
Field
Theory
(Standard
Model)



Astronomy
Experiments
Telescopes
Satellites

Standard
Cosmology
Model

10^{-18} m

10^{26} m

What can we learn from exploring the Terascale?

- How do elementary particles obtain the property of mass: what is the mechanism of electroweak symmetry breaking? What is the role of the discovered particle at $\sim 126\ \mathrm{GeV}$ in this context?
- Do all the forces of nature arise from a single fundamental interaction?
- Are there more than three dimensions of space?
- Are space and time embedded into a "superspace"?
- What is dark matter? Can it be produced in the laboratory?
- Are there new sources of $\mathcal{CP}$-violation?
  Can they explain the asymmetry between matter and anti-matter in the Universe?

Roles of particle theory

collider phenomenology

experiments
LHC, ILC, ALPS, ...

interpret data
precision predictions
plan future experiments

string theory
mathematical physics

construct and test
new theories

particle
cosmology

study structure of
quantum field theory

mathematics

lattice field
theory

NIC

John von Neumann
Institute for Computing

- Collaboration between different HGF centres: DESY, Jülich, GSI, KIT (new)
- Closely integrated with local Universities (Hamburg, Berlin, Karlsruhe; theory & experimental groups)

PoF 2 proposal and HGF Senate recommendations

Key initiatives for this funding period:

- Strengthen collider phenomenology with a leading role in the Analysis Centre of the Helmholtz-Alliance in Hamburg and Zeuthen.
- Install new Junior Research Groups at the interface of main current research activities.
- Maintain activities in particle cosmology at current level after VIPAC phase-out.
- Continue to develop the Center for Mathematical Physics (Hamburg) as a leading interdisciplinary centre for mathematical physics and string theory.
- Maintain the position of Zeuthen as a leading centre for research and training in lattice field theory (NIC and theory group) and precision collider phenomenology.
- Develop a centre for Theoretical Physics with Hamburg University as one component of a new particle physics cluster in Hamburg.

Milestones:

- Confront theory predictions with early LHC data in pursuit of the physics responsible for electroweak symmetry breaking and for stabilising the gauge hierarchy
- Study implications of satellite experiments and LHC for supersymmetry breaking and dark matter
- Provide realistic lattice QCD simulations for a large set of observables with two generations of quarks close to their physical masses
- Study string theory in Anti-deSitter space and its implications for perturbative and non-perturbative gauge physics

Recommendations of the HGF Senate

- Complete the renewal of the collider phenomenology effort, turn more toward the LHC programme, rebuild the postdoctoral fellow population in this area
- Pursue additional avenues for cooperation with new institutes, strengthen links with the Astroparticle Physics Programme, monitor and use the novel opportunities for cooperation with condensed-matter theory that will grow up around the photon physics programme

PoF 2 Midterm Evaluation by the Scientific Council Review Report, Nov. 2012

Theoretical Particle Physics

Technical and scientific achievements

Research in Theoretical Particle Physics at DESY is very wide and performed along different key directions. The DESY theory group continues to produce influential results and actively participates in training young researchers and providing a service to the community through the organization of well-known schools and workshops. It has strong ties with experimental groups at LHC. The Theory group activities are therefore very satisfactory.

Future plans and recommendations

Continue strong support of the ongoing activities in Theoretical Particle Physics.

Collider phenomenology

- 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

Collider phenomenology: some activities at DESY

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 + HERWIG, PYTHIA, parton shower development
  - ★ 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)

Synergies DESY - KIT

KIT brings synergies

- with the theory groups at DESY-H and DESY-Z in collider physics
  - HERWIG++ Monte-Carlo simulations
  - QCD corrections to LHC collider processes
  - probing new physics with collider data
- with the theory group at DESY-Z in precision calculations
  - precise determination of fundamental parameters of the Standard Model (α_s, m_c, m_b)
  - N^3LO corrections to top-quark threshold production at ILC
- with the Belle II group at DESY-H in flavour physics
  - NLO and NNLO corrections to flavour-changing processes
  - probing new physics with B and D meson decays

Theory group at KIT

KIT theory staff participating in PoF 3 (topic 1):

- Professors: K.Melnikov, M.Mühlleitner, U.Nierste, M.Steinhauser, D.Zeppenfeld
- Other scientists: M.Blanke, S.Gieseke, 4.5 FTE postdocs from State funding

All KIT theory staff: 6 professors, 18 postdocs, 25 PhD students

PhD theses:
- 21 completed PhD theses since 2010, 21 on-going PhD theses
- Gender balance: percentage of female PhD students:
  14% for completed PhD theses
  24% for ongoing PhD theses

Theory Group at KIT: research on precision physics

- NNLO corrections to $B_s \rightarrow \mu^-\mu^+$
- NNLO corrections to $B \rightarrow X_s\gamma$ (SM and 2HDM)
- NNNLO corrections to top quark threshold production at ILC and to Upsilon(1S) $\rightarrow l^+l^-$
- NLO corrections to double Higgs boson production at LHC including finite top quark mass effects
- Building blocks for NNNLO corrections to gg $\rightarrow$ H at LHC
- SUSY-QCD NNLO corrections to gg $\rightarrow$ H
- Leptonic (g-2) to 4 loops
- SM beta function to 3 loops

Theory Group at KIT: research on flavour physics

- Calculations for the Belle-II and LHCb experiments: semi-leptonic CP asymmetry in B decays, $B \to D\tau\nu$, penguin contributions to mixing-induced CP asymmetries; in the SM and beyond

- Analyses of models of new physics with flavour observables: supersymmetry, extended Higgs sectors, grand unification

- Flavour model building: radiative breaking of flavour symmetries, Yukawa textures from flavour symmetries

- Phenomenology for the Belle-II and LHCb experiments: new observables and correlations, model-independent analyses

Theory Group at KIT: research on LHC physics

- Techniques for NNLO QCD computations for collider physics
- NNLO QCD corrections to Higgs + jet production at the LHC
- NNLO QCD corrections to top quark decay rate and kinematic distributions
- NNLO QCD corrections to t-channel single top quark production and decay at the LHC
- Bounding the Higgs boson width using events $gg \to H \to ZZ$ with high ZZ invariant mass at the LHC
- Constraining Higgs boson anomalous couplings with vector bosons at the LHC

Theory Group at KIT: research on model building for the LHC

- Phenomenology of new flavour-violating interactions at the LHC: flavour-violating stop decays in SUSY, impact on gluino searches; flavour-violating top partner decays etc.

- Identification and analysis of best-suited observables for discovery of new CP-violating interactions at the LHC

- Study of the implications of LHC direct search results on the predictions for precision flavour observables: extra-dimension models, Little Higgs, SUSY

- Correlations between LHC and precision flavour data in the identification of the correct new physics scenario

Theory Group at KIT: start into PoF 3

The KIT theory activity within the Helmholtz programme is new. As a first commitment a junior-staff tenure-track position (E14) has been created from the budget of the IKP

- 70 applicants from 3 continents
- Monika Blanke (CERN) will join KIT in autumn 2014

Collider phenomenology: some highlights from the PoF 2 period

Significant strengthening of collider phenomenology at DESY: new appointments, three additional staff members compared to previous funding period (2 permanent + 1 Emmy Noether group leader (tenure track))

Important input for Higgs searches and the determination of the properties of the observed signal, strong involvement in LHC Higgs Cross Section WG

Interpretation of observed signal, exclusion of different scenarios (SM with a fourth fermion generation, etc.)

Interpretation of limits from new physics searches at the LHC

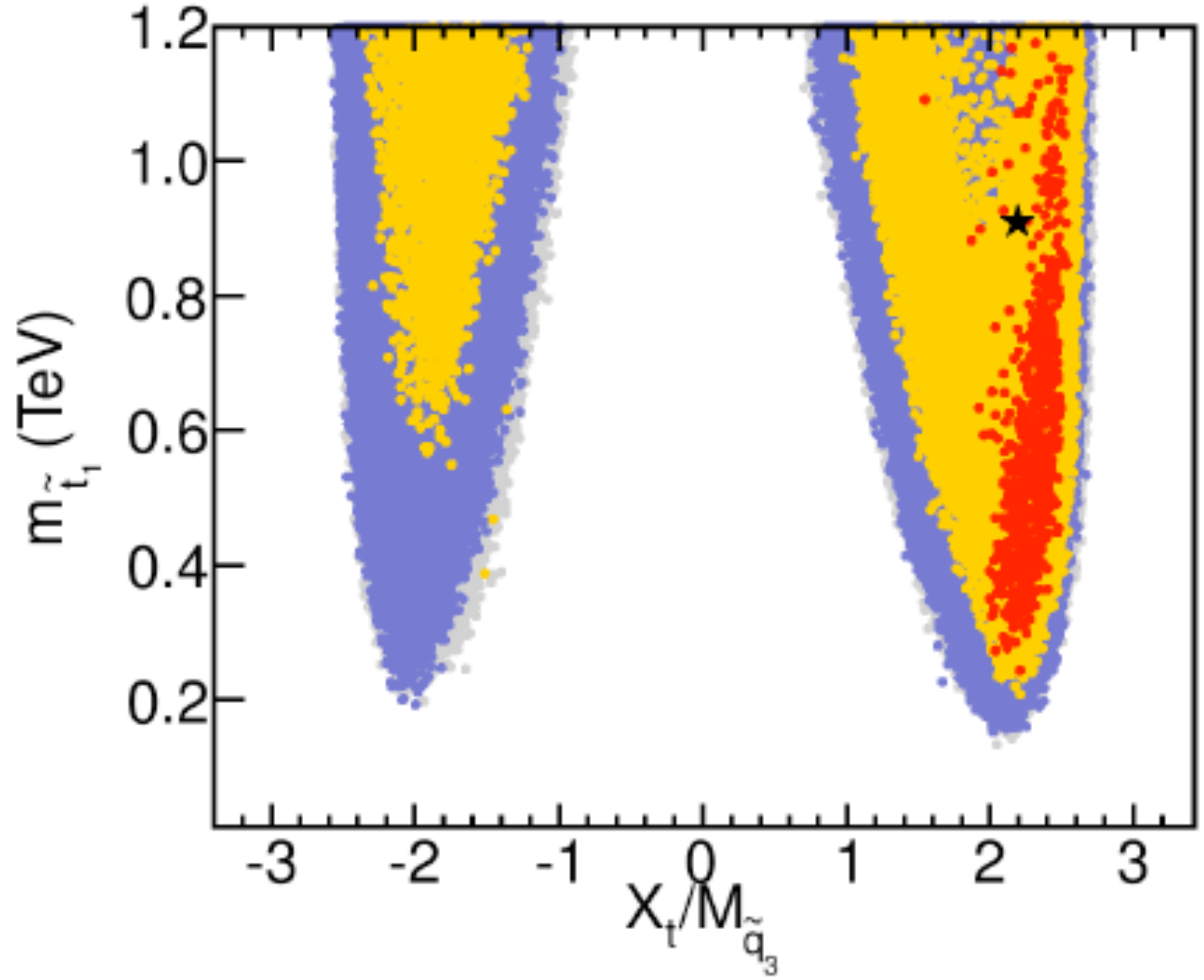
Precise predictions for signal and background processes at the LHC, provision of tools that are used by experimentalists for the data analysis (parton shower for Monte Carlo event generators, etc.)

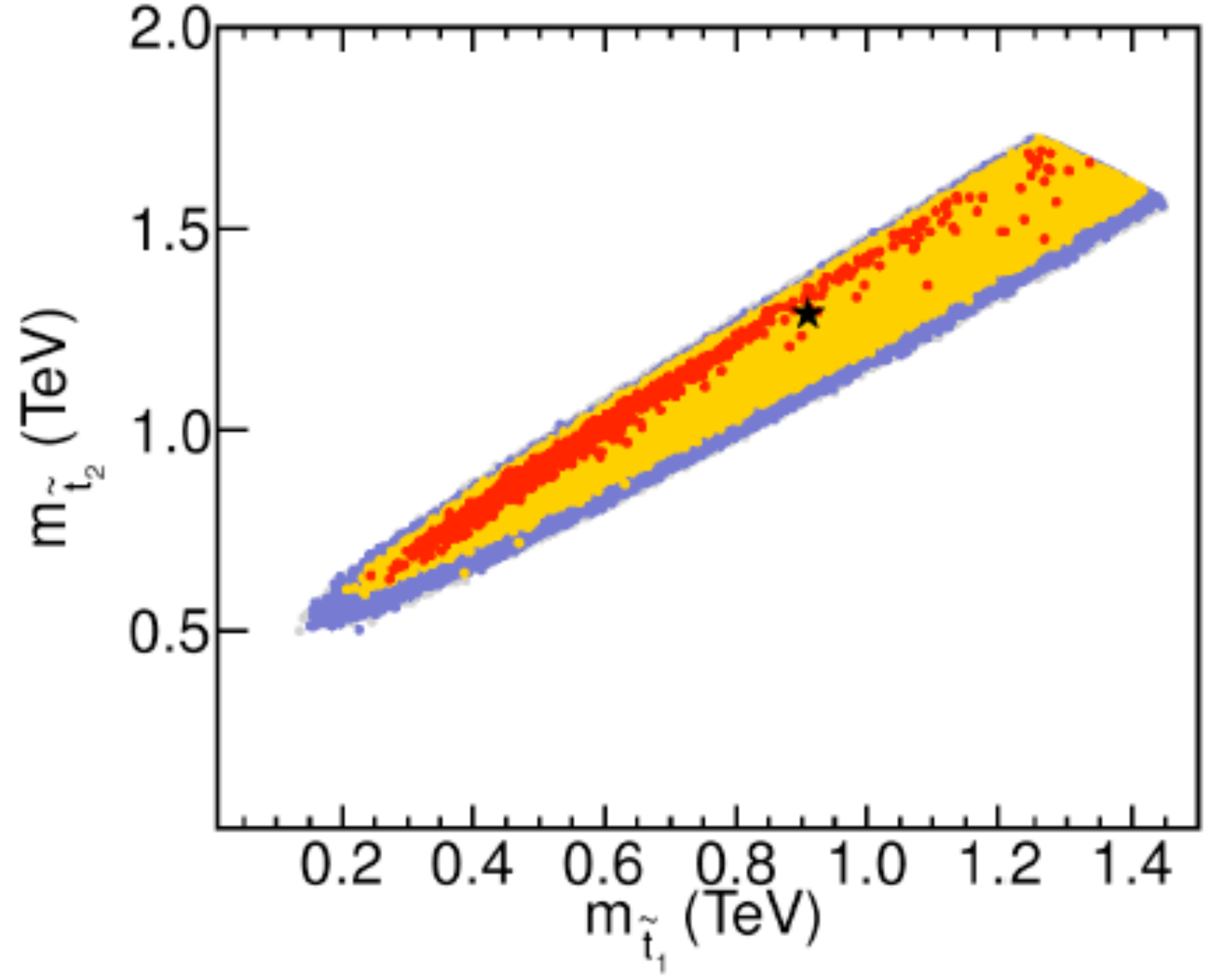
Precise determination of parton distributions, α_s, charm and bottom masses

MSSM interpretation of the signal at 126 GeV in terms of the light Higgs h of the MSSM

MSSM fit, preferred values for the stop masses:

[P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak, G. W., L. Zeune '12]





$\Rightarrow M_h \sim 126$ GeV requires large stop mixing, but stop masses can still be light

Test of different models with the experimental information about the Higgs sector

HiggsBounds and *HiggsSignals*

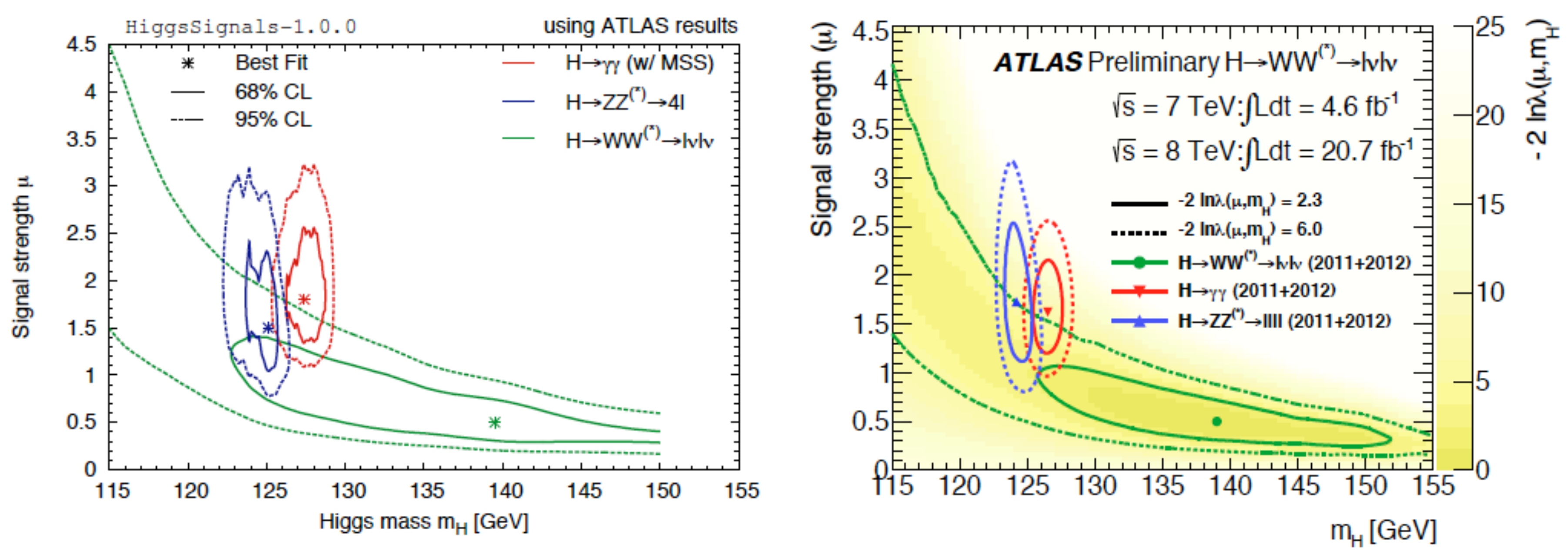
P. Bechtle, ..., G. Weiglein, ..., 2008, ‘12, ‘13

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.

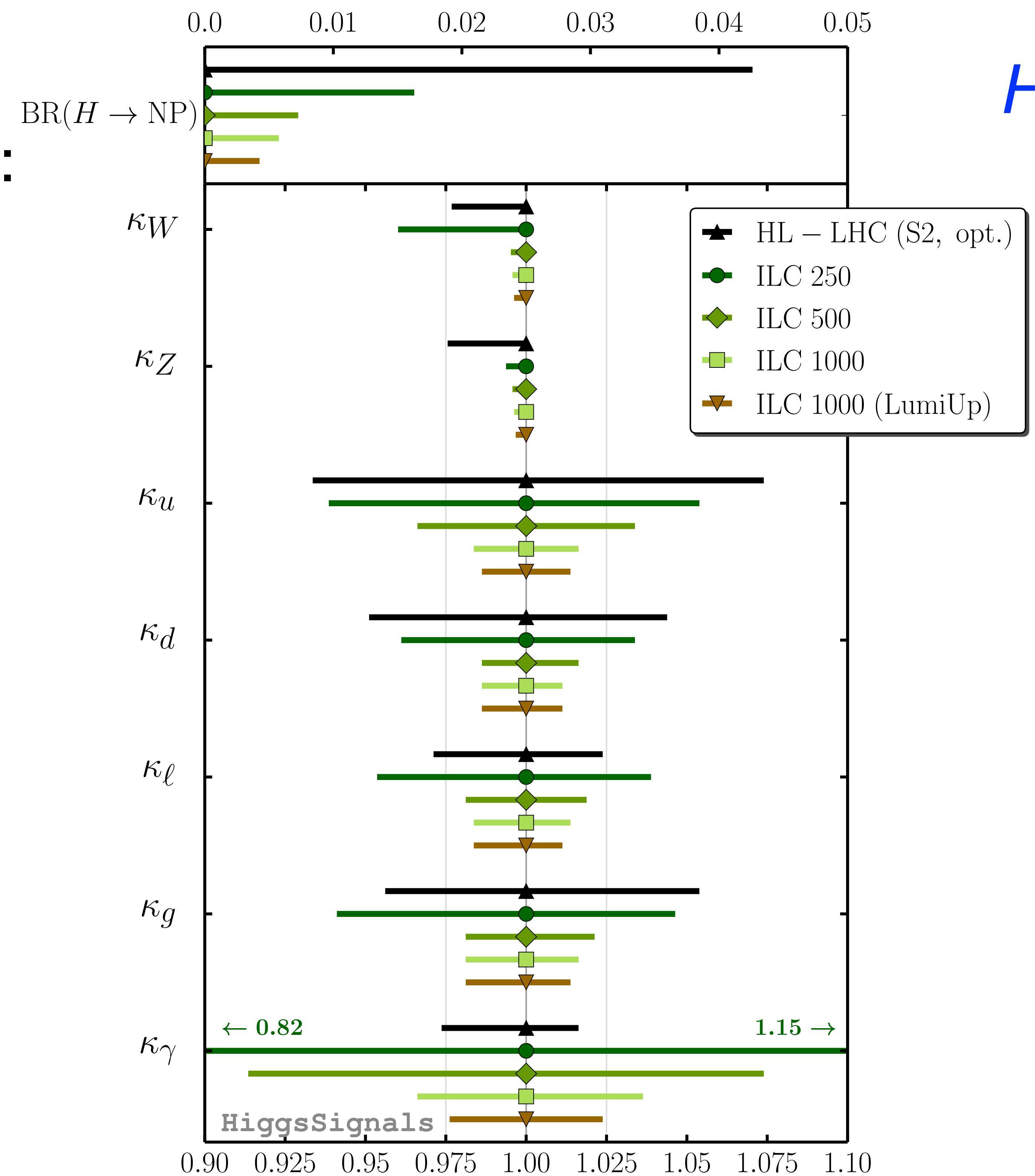
(b) Official ATLAS result from [44].

Prospects for Higgs-coupling determinations at HL-LHC and ILC

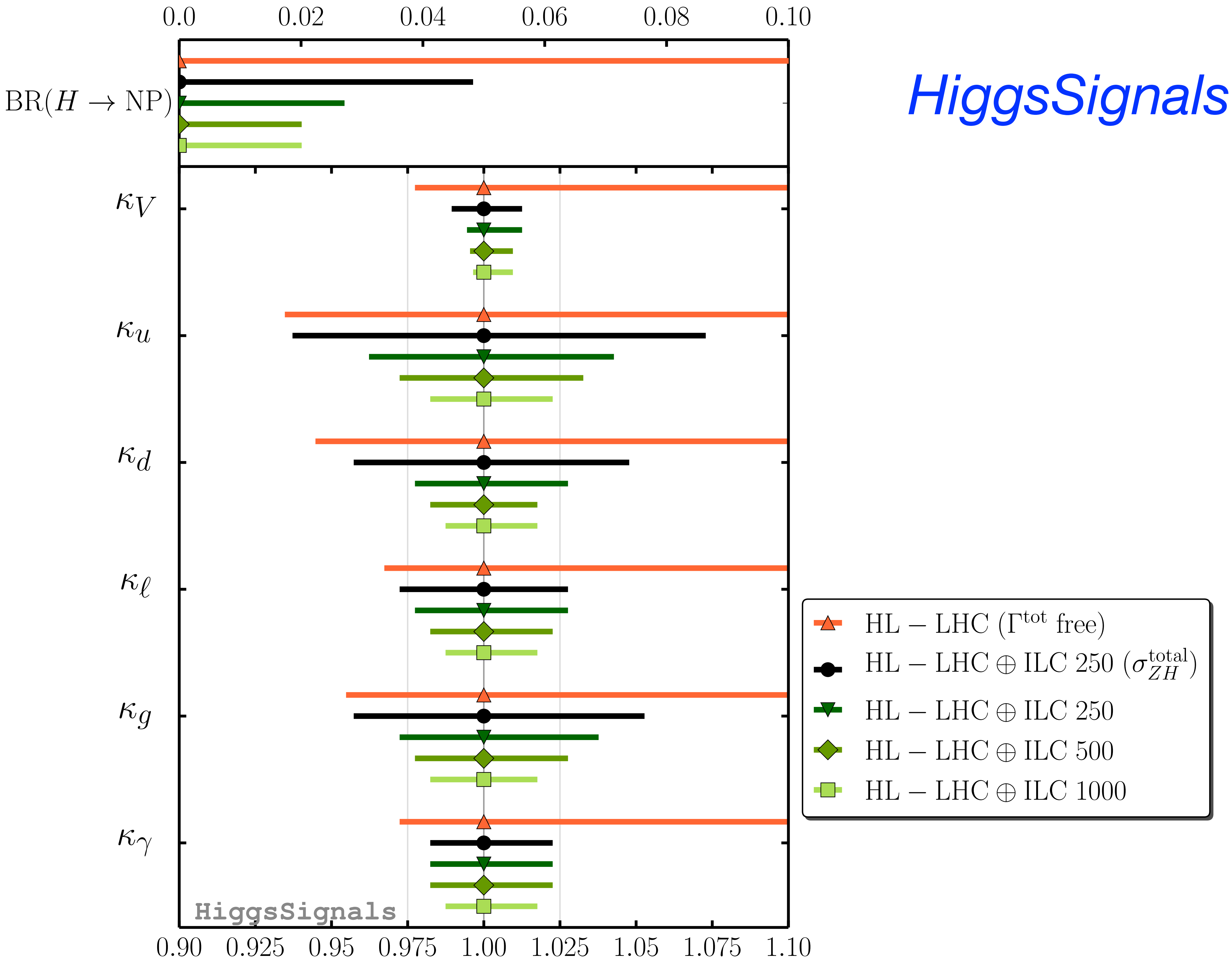
HiggsSignals

Assumed:

$\kappa_V \leq 1$



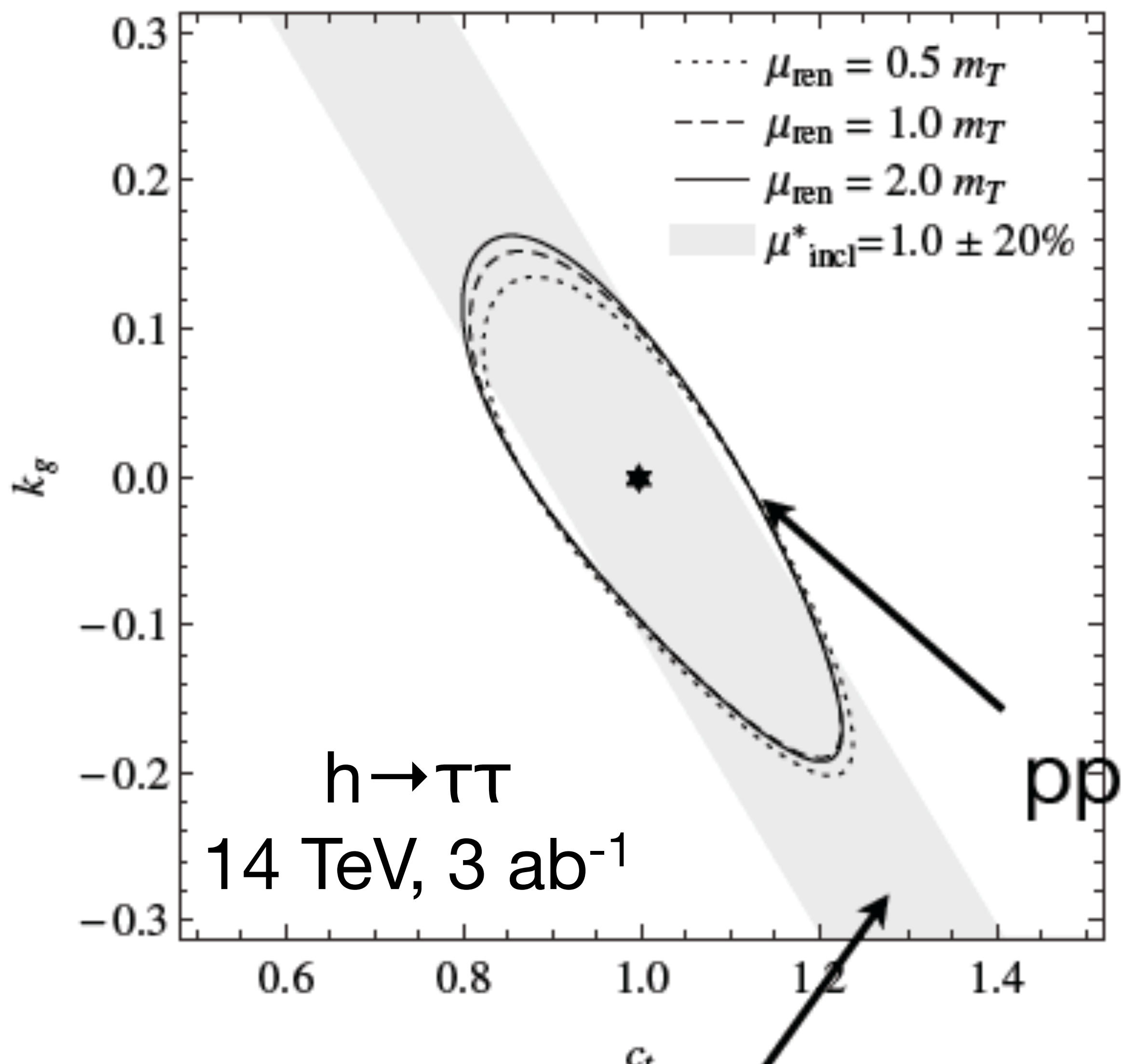
Prospects for Higgs-coupling determinations at HL-LHC and ILC



HiggsSignals

Higgs production: probing top partners and the UV stabilisation mechanism

Degeneracy in gluon fusion, break by boosting the Higgs

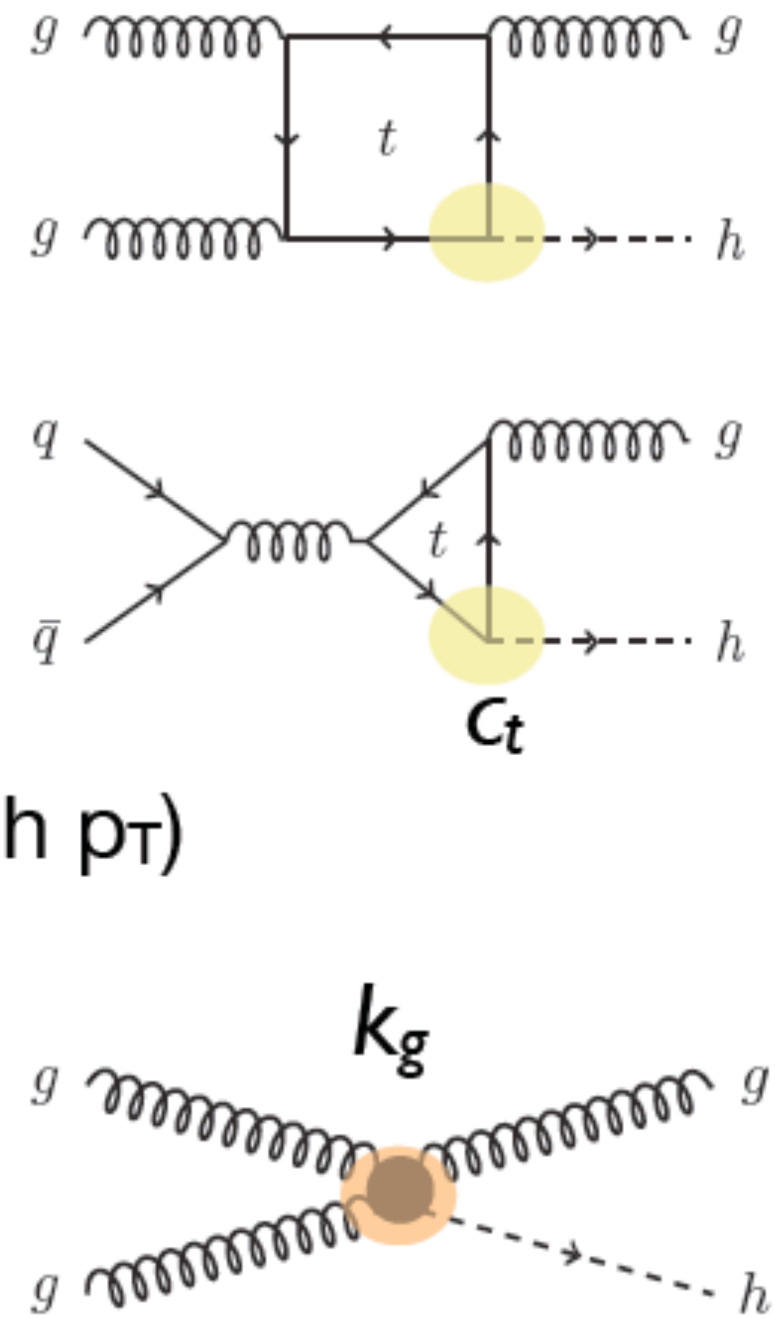


pp→h+jet (high p_T)

Γ(gg→h) inclusive

IR

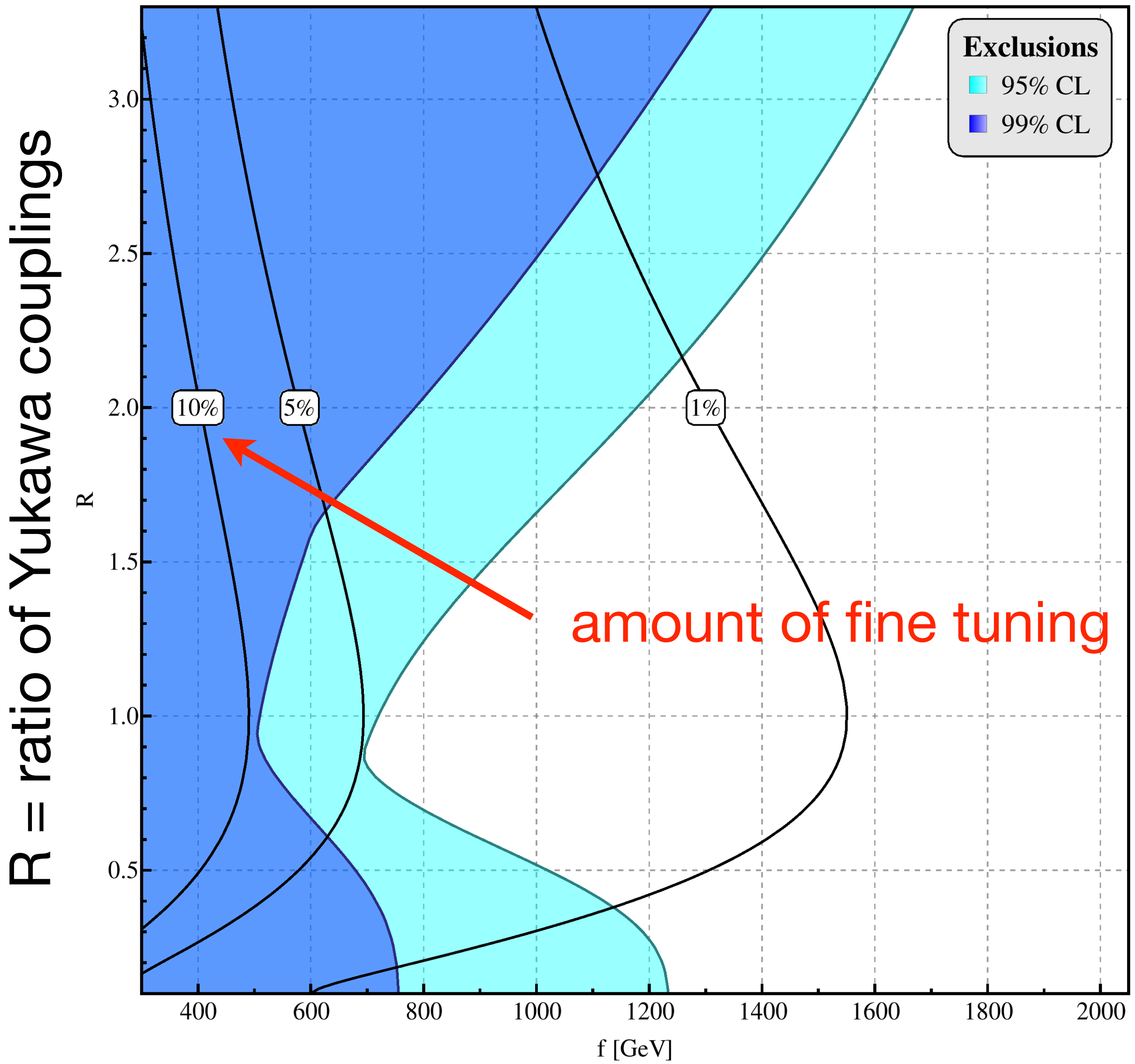
UV



Littlest Higgs with T parity vs. LHC results and electroweak precision data

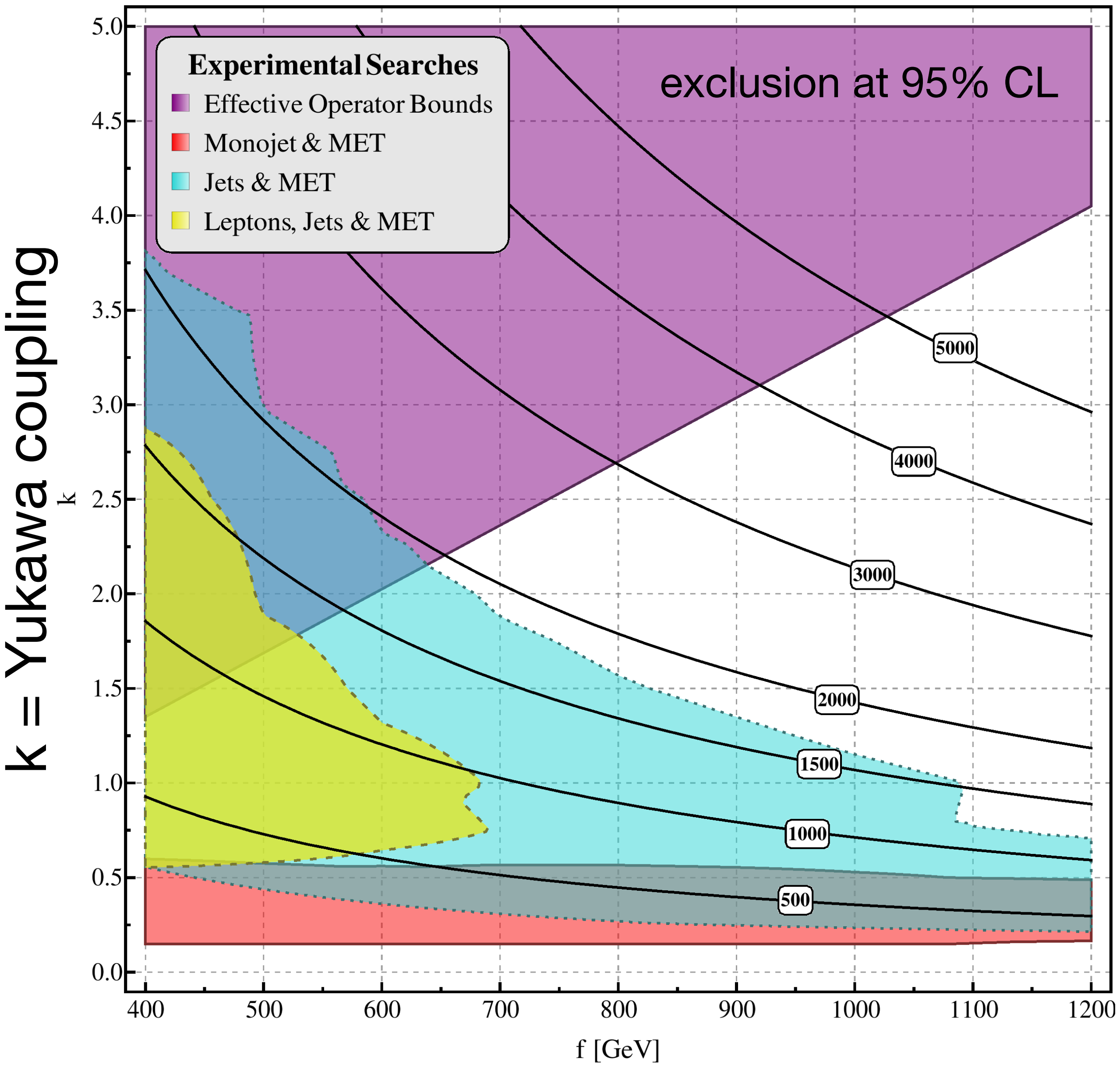
J. Reuter, M. Tonini, M. de Vries 2013

Higgs and e.w. precision data



f = collective symmetry breaking scale

Direct LHC searches for new particles

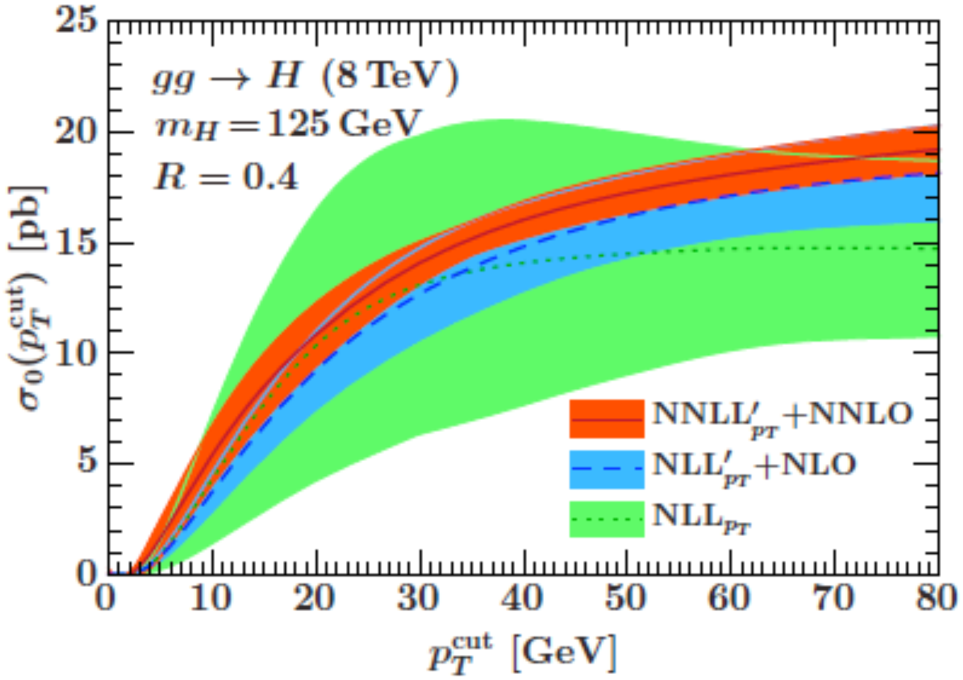


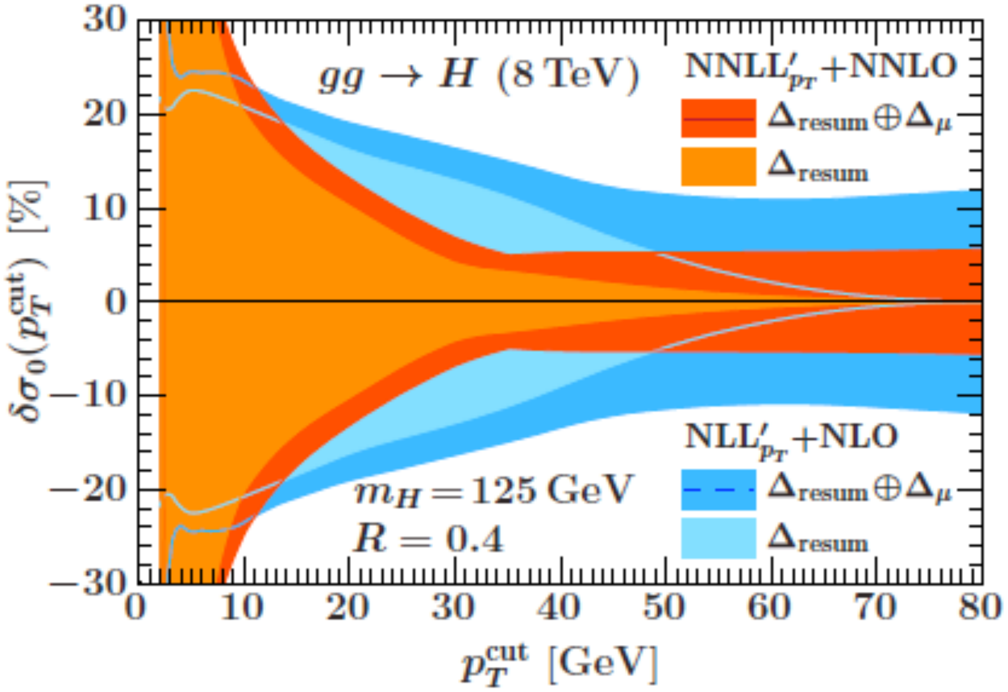
Predictions for Higgs + jet production

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

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

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





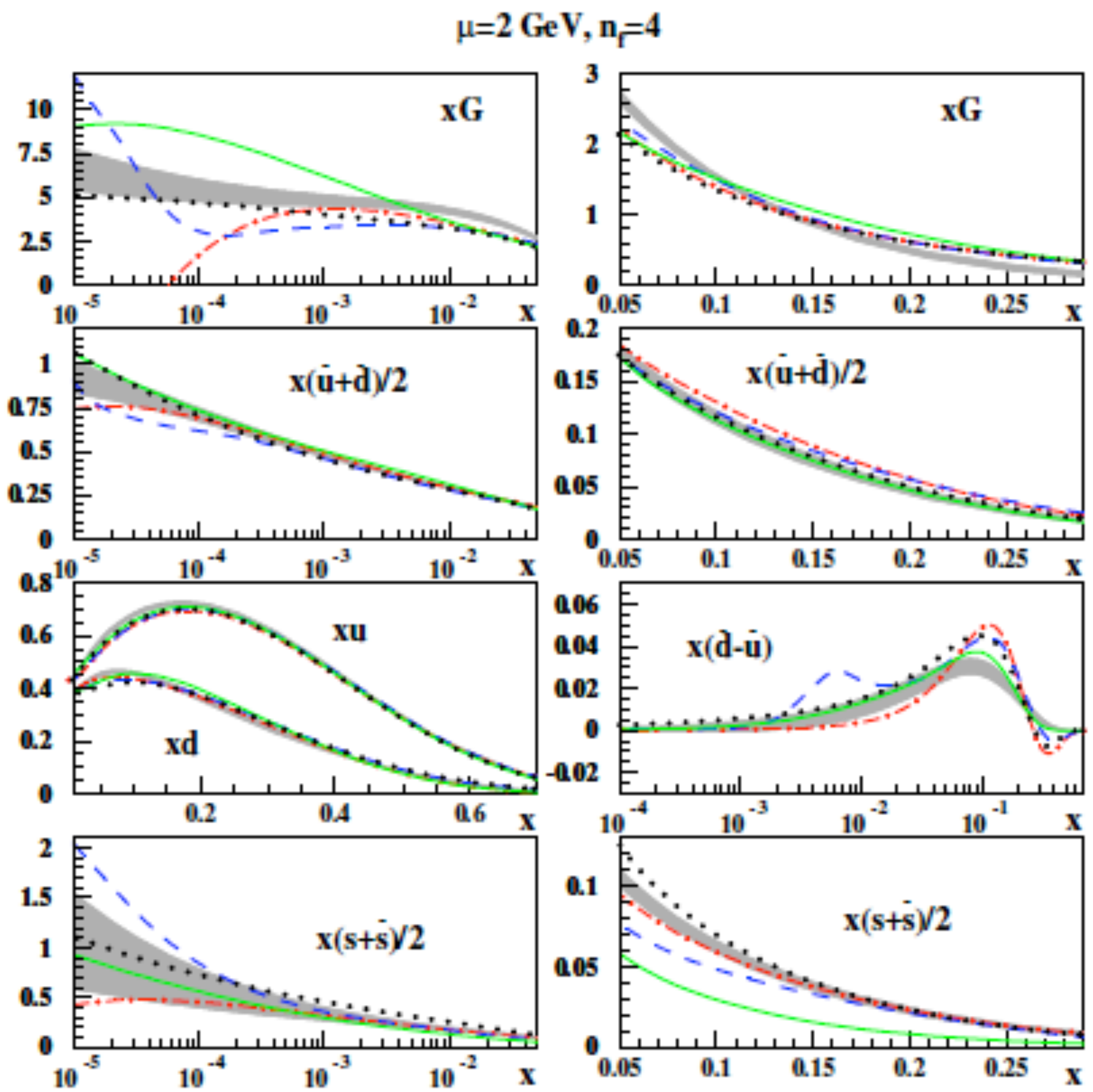
Systematic and careful uncertainty analysis required for reliable predictions

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

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

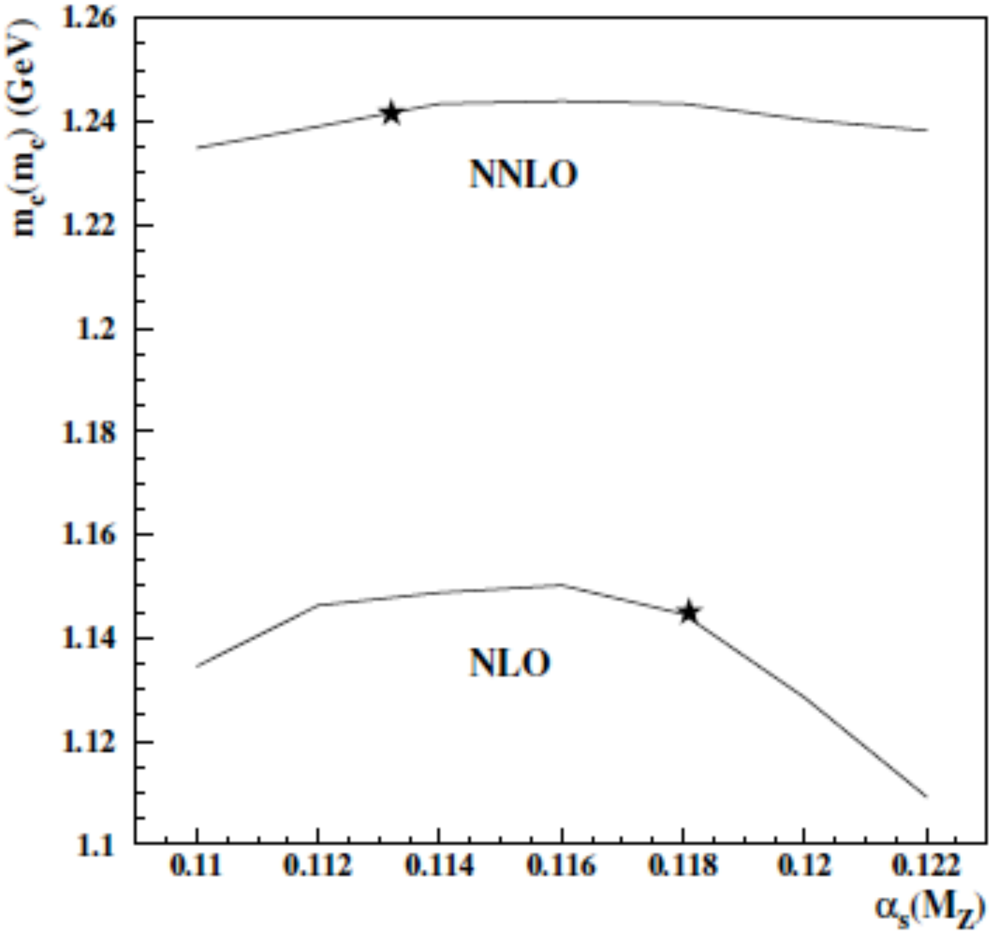
- Uncertainties due to unresummed higher-order jet clustering logarithms

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:

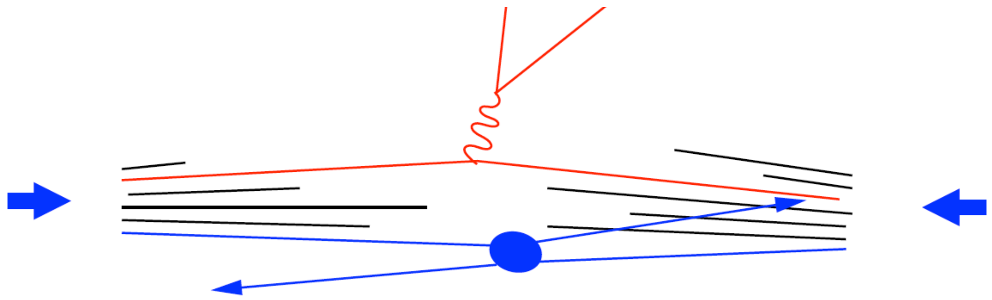


NLO and NNLO $m_c(m_c)$ vs $\alpha_s(M_Z)$
Alekhin, Blümlein, Daum, Lipka, Moch
collaboration theory ↔ HERA experimentalists

On the way of completion: 3 Loop Massive Wilson Coefficients
5 of 8 coefficients have been calculated by now.

Multi-parton interactions at the LHC

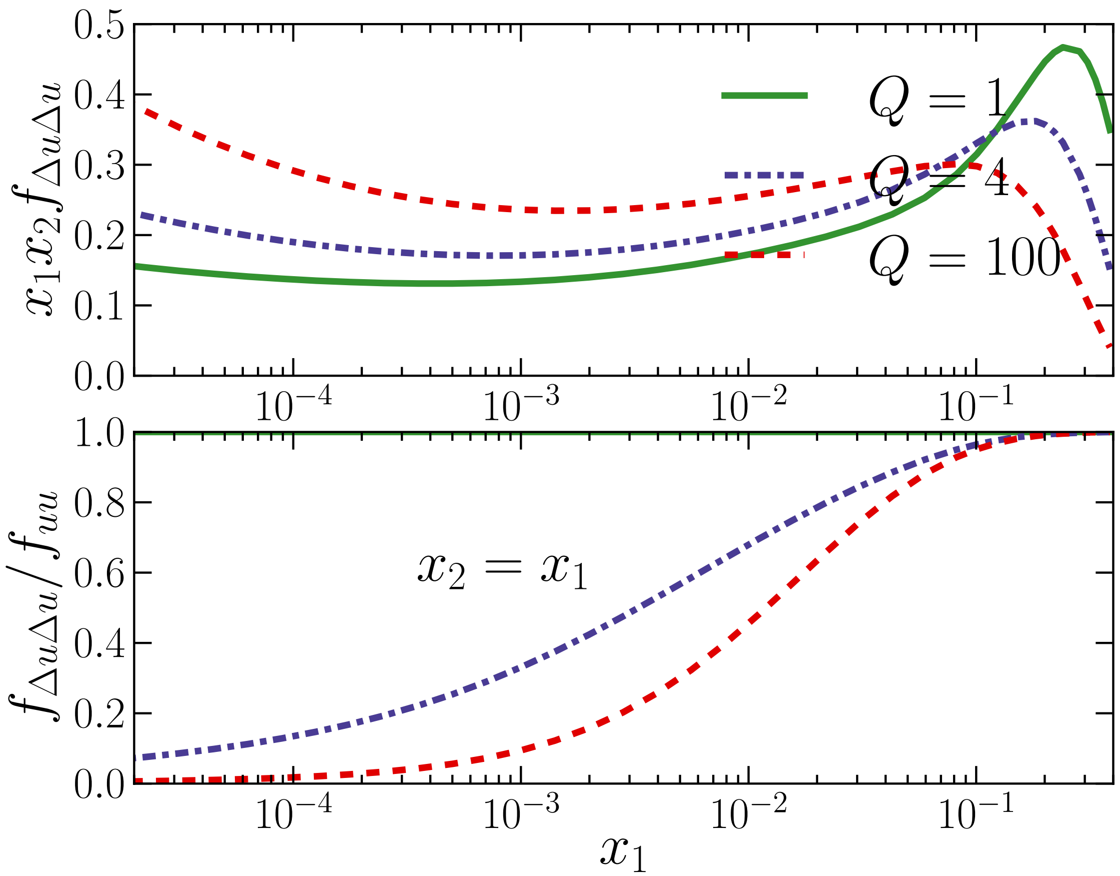
- several partons of each proton interact in same pp collision
- importance increases with energy
- complex QCD dynamics, esp. due to correlations between partons
- parton spin correlations
  - ★ affect rate and distributions in gauge boson pair prod'n (MD, T. Kasemets 2012)
  - ★ large spin correlations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



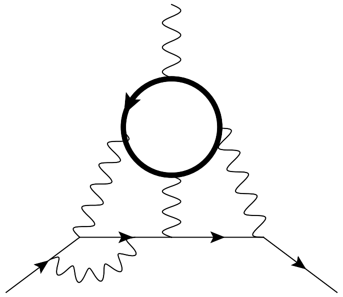
assume maximal longitudinal spin correlation at Q = 1 GeV then evolve

degree of polarization

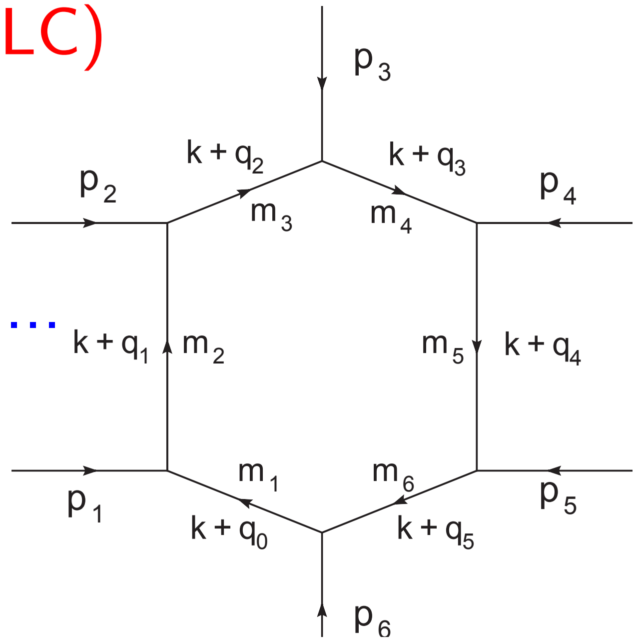
large spin correlations at low scale can persist up to high scales
depending on parton and polarization type

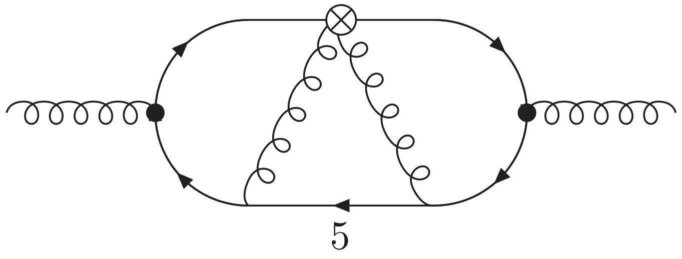


Multi-loop and multi-leg calculations



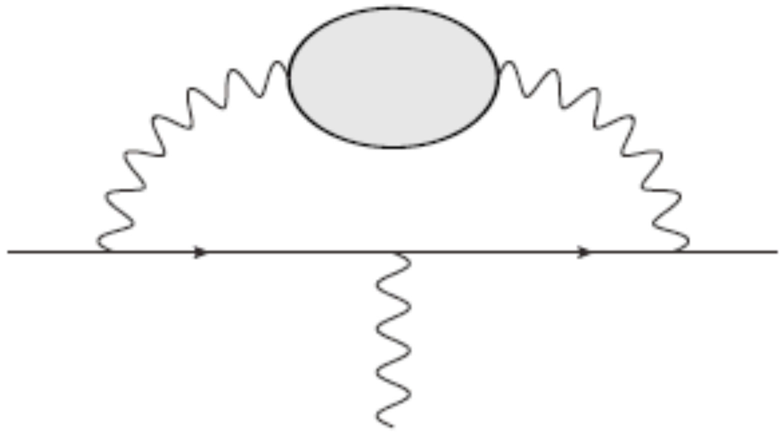
- 5...7 point 1- and 2-loop processes for HE colliders (LHC, ILC)
- 3-4 loop 2-3 leg processes for certain observables
- Heavy mass final states; High precision m_c & α_s, Wilson coefficients; $(g-2)$, B-decays at highest precision; ... Precision analysis codes for experiments
- Technology: Large scale computer algebra [Tbyte Ram, Multi-Tbyte fast disc]
- Systematic Approach to Feynman Integrals $\Longrightarrow$ Classes of New mathematical functions





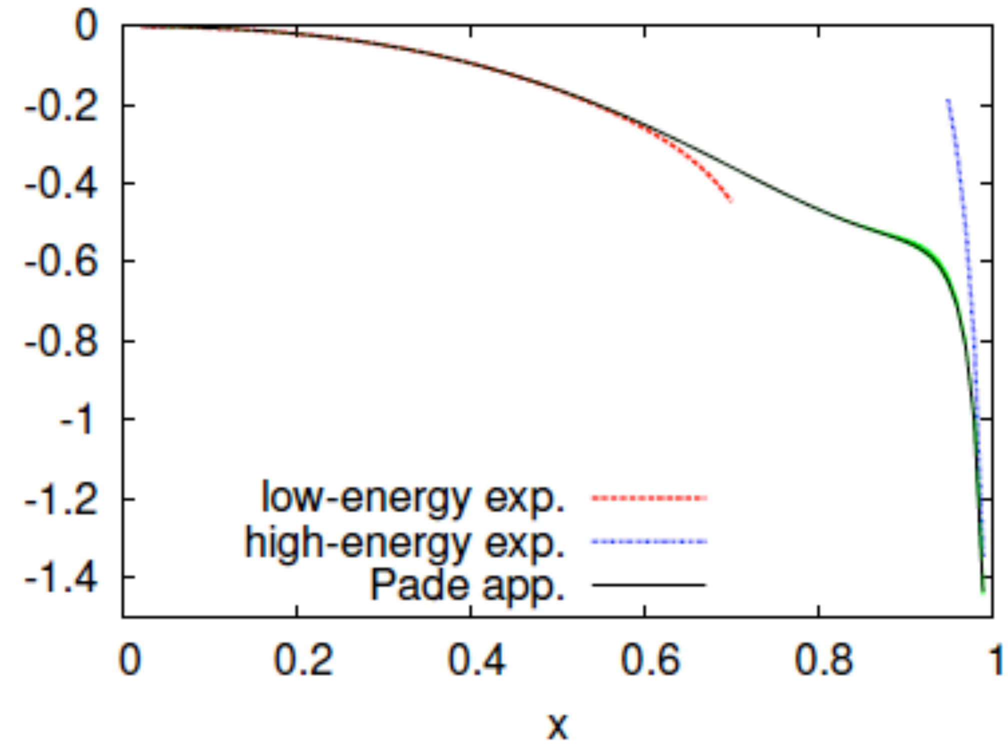
Muon anomalous magnetic moment at five loops: analytic computation

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

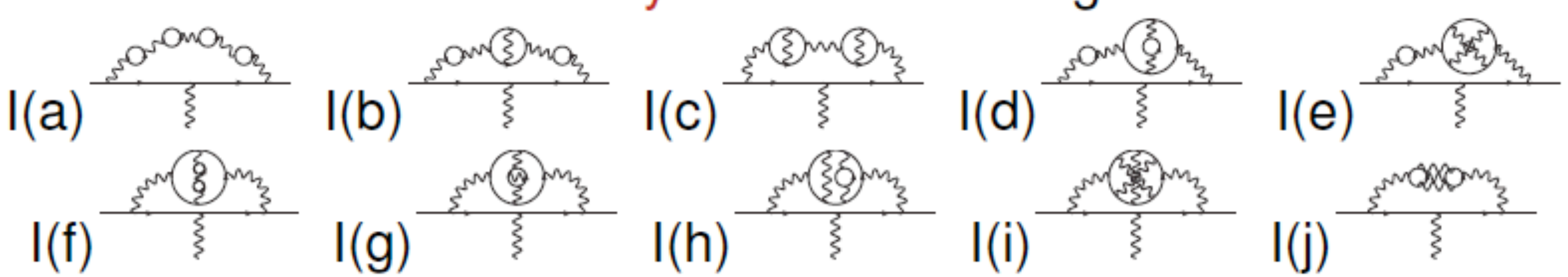


$$a_\mu = \frac{\alpha}{\pi}\int_0^1 \mathrm{d}x(1-x)/(1+\Pi(s_x))$$
$$s_x = -m_\mu^2 x^2/(1-x)$$
$$x \in [0,1] \to s_x \in [0,-\infty]$$

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



new numerical analysis of various diagram classes



full agreement with previous work

Cooperation with computer algebra sites

RISC Linz: Summation, Combinatorics

FORM (NIKHEF)

$\Updownarrow$ $\Updownarrow$

DESY, TH

$\Updownarrow$ $\Updownarrow$

MapleSoft (Waterloo,ON)

Wolfram Research (Urbana, IL)

- Development of new multi-loop technologies
- Creation of new Chapters in higher transcendental functions
- New results for multi-scale lower loop topologies

Collider phenomenology: plans for the PoF 3 period

Exploration of the physics of the signal at 126 GeV, discrimination between different theoretical interpretations

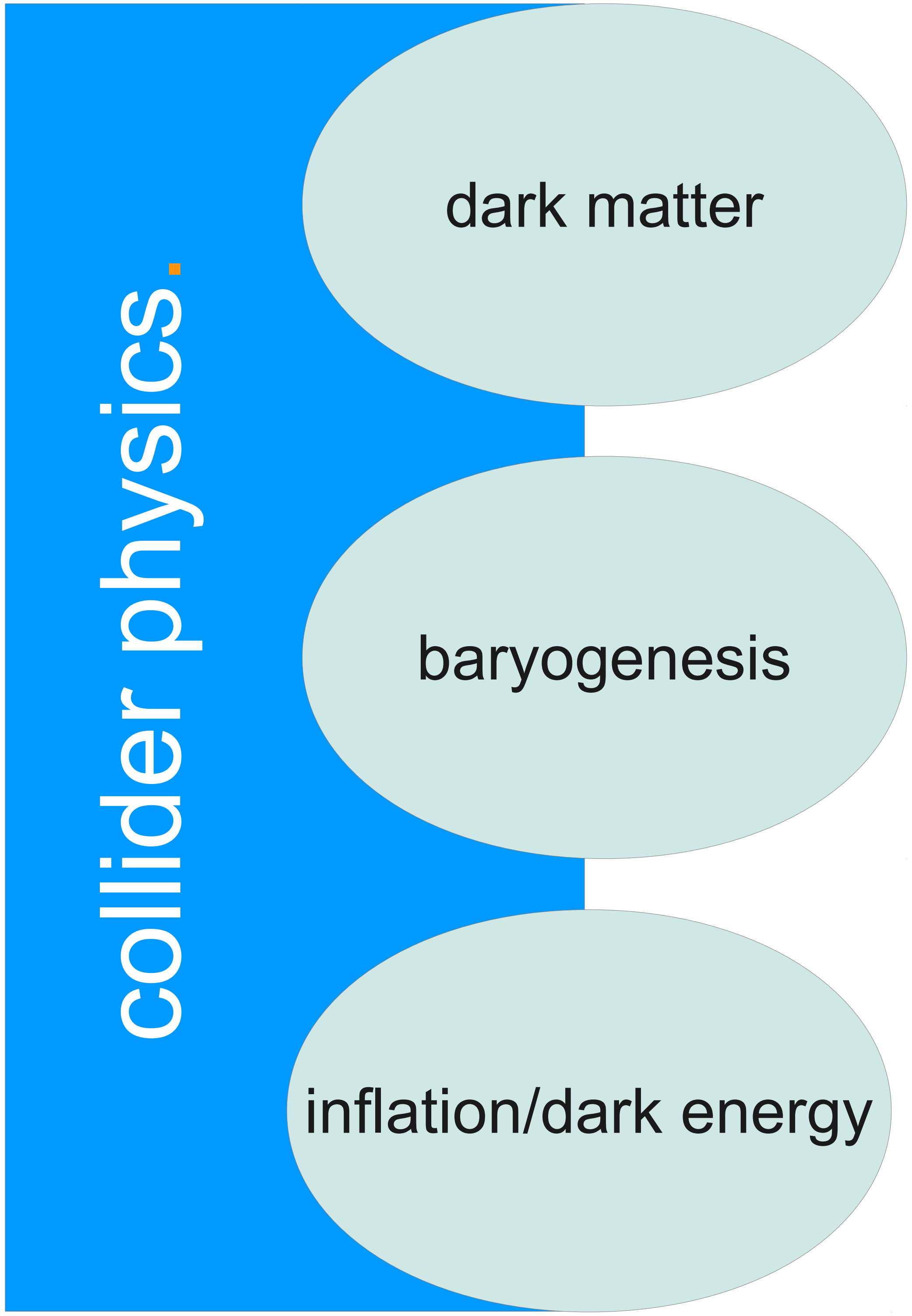
Global fits of different models (initiative of DESY theory group led to formation of dedicated SUSY/BSM Fit Working Group within Helmholtz Alliance during PoF 2 period)

Investigation how different scenarios can be probed in the future, exploration of ILC physics potential in view of the LHC results

High-precision predictions for LHC physics using improved perturbative methods (extension of classes of mathematical functions, etc.), computer algebra tools, all-order summations, generalised unitarity approach and new developments on non-perturbative methods

Development of more advanced event generators

Particle cosmology: research topics



Low energy cosmology

axions and other WISPs

Electroweak cosmology

electroweak baryogenesis
gravitational waves
„hidden Sector“ WIMP DM
Higgs inflation

GUT cosmology

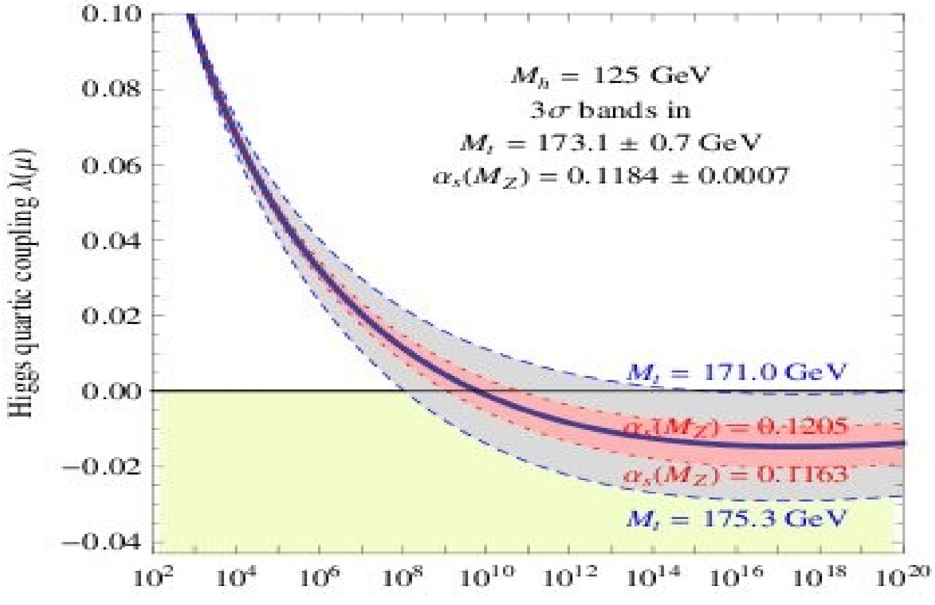
GUTs in extra dimensions
leptogenesis
gravitinos

Stringy cosmology

string inflation
heterotic/type IIB string theory

Electroweak vacuum

Assuming a Higgs mass of ~ 125 GeV, the running of the quartic coupling in the SM can be studied (NLO)



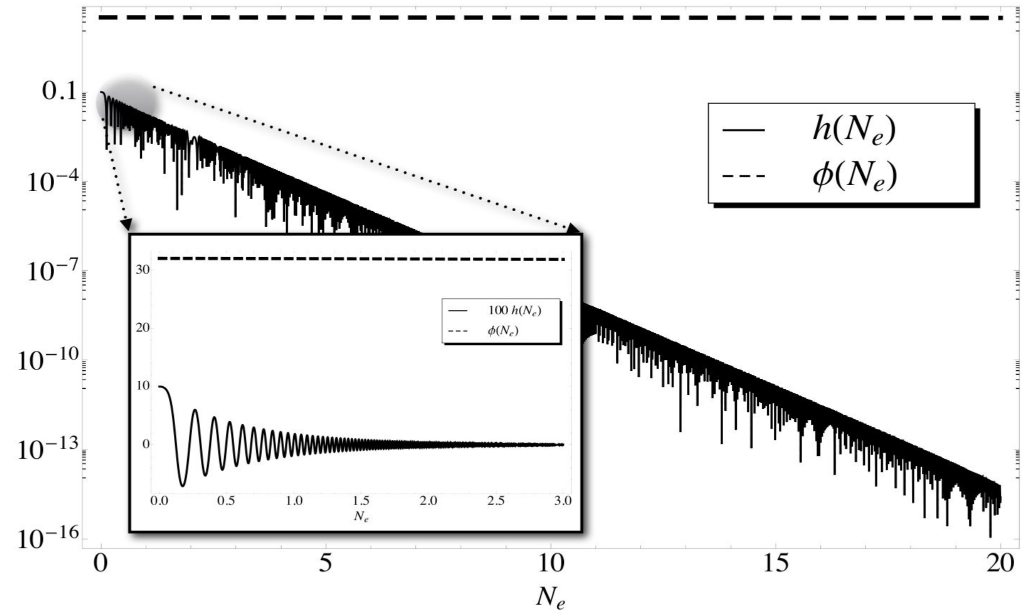
Even though the EW vacuum is meta-stable, this introduces a fine-tuning in the initial conditions.

Higgs coupling to the inflaton

Metastable Electroweak Vacuum: Implications for Inflation
O. Lebedev, A. Westphal (1210.6987)

Already a small coupling between the Higgs and the inflaton

$$\mathcal{L} \ni m^2\phi^2 + \xi h^2\phi^2$$



introduces a effective Higgs mass that drives the Higgs field to small values during inflation.

WISPy dark matter

WISP = weakly interacting slim particle

Dark matter candidates with sub-MeV masses.

- axion like particles (ALPs): Scalars (ϕ) that are ubiquitous in string theory. Couple to SM gauge fields via

$$\mathcal{L} \ni g\,\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

- hidden photons: Massive U(1) gauge bosons (X^{μ}) that kinetically mix with EM photons.

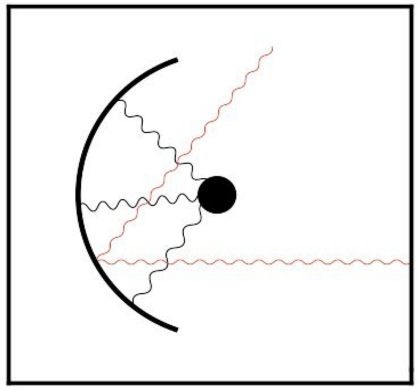
$$\mathcal{L} \ni -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{\chi}{2}X_{\mu\nu}F^{\mu\nu} + m_X^2 X^{\mu}X_{\mu}$$

WISP detection

Proposal of a dish antenna experiment for WISP detection

Searching for WISPy Cold Dark Matter with a Dish Antenna

D. Horns, J. Jaeckel, A. Lindner, A. Lobanov, J. Redondo, A. Ringwald (1212.2970)

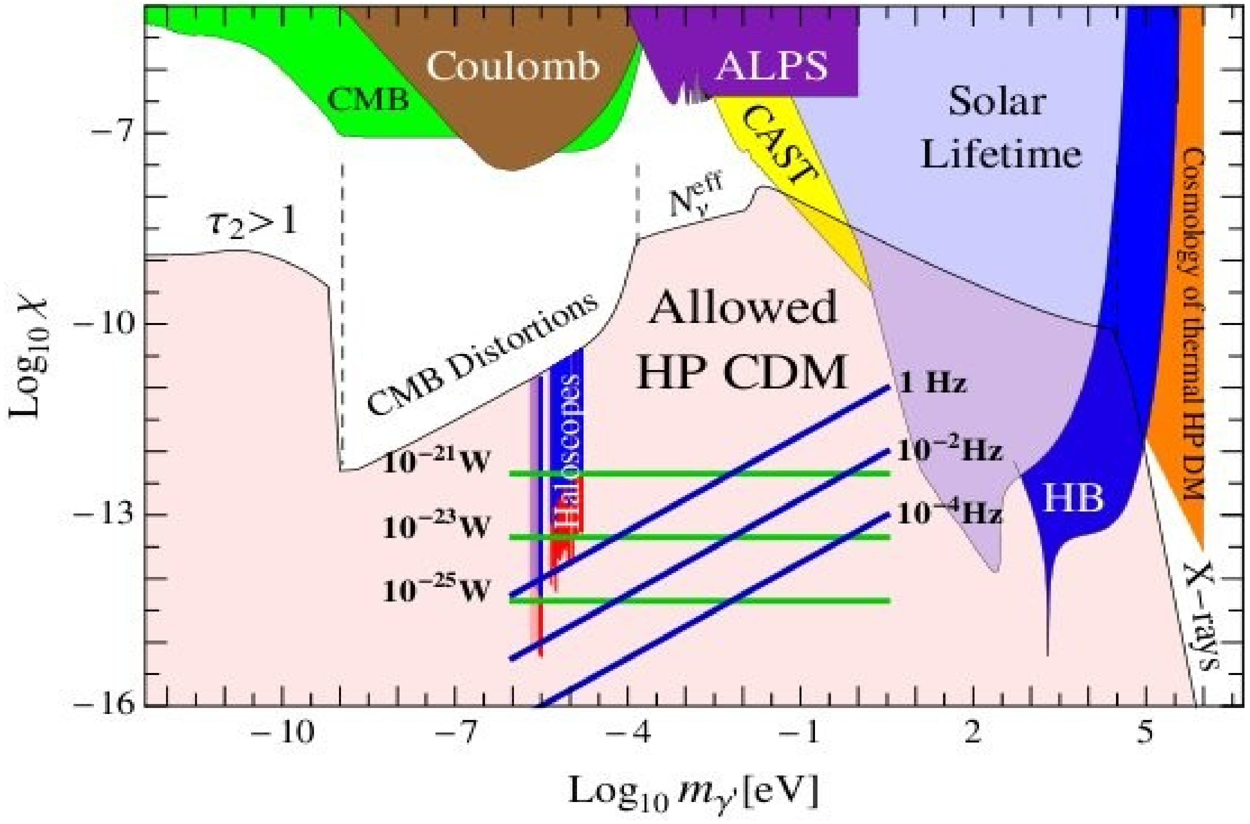


Hidden photon dark matter predicts a ambient hidden photon density

Close to conducting material, this induces EM photon densities that can be observed.

The experiment is rather insensitive to the mass.

This technique can also be used to observe ALPs if a magnetic field is applied.



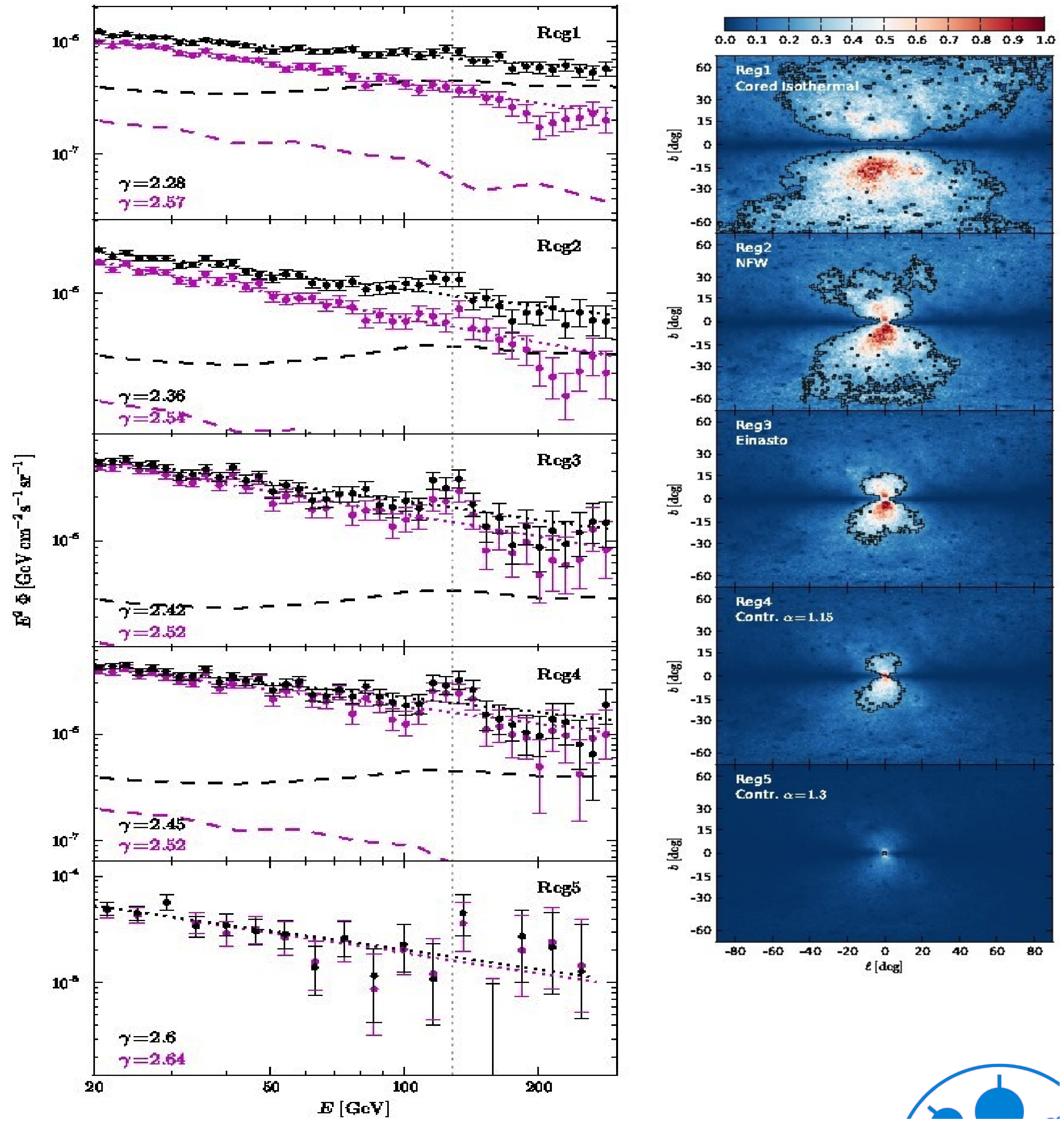
Dark matter vs. Fermi data

Weniger(-Bringmann-Huang-Ibarra-Vogl)-line.

Gamma-lines are a smoking gun signal for dark matter.

On the other hand, dark matter is dark and decays into gammas only at loop level.

If this signal is statistically confirmed, is it compatible with dark matter?



MSSM dark matter vs. Fermi data

Compatibility of continuum vs line

$$BR_\gamma > 0.5\%$$

- Annihilating dark matter:

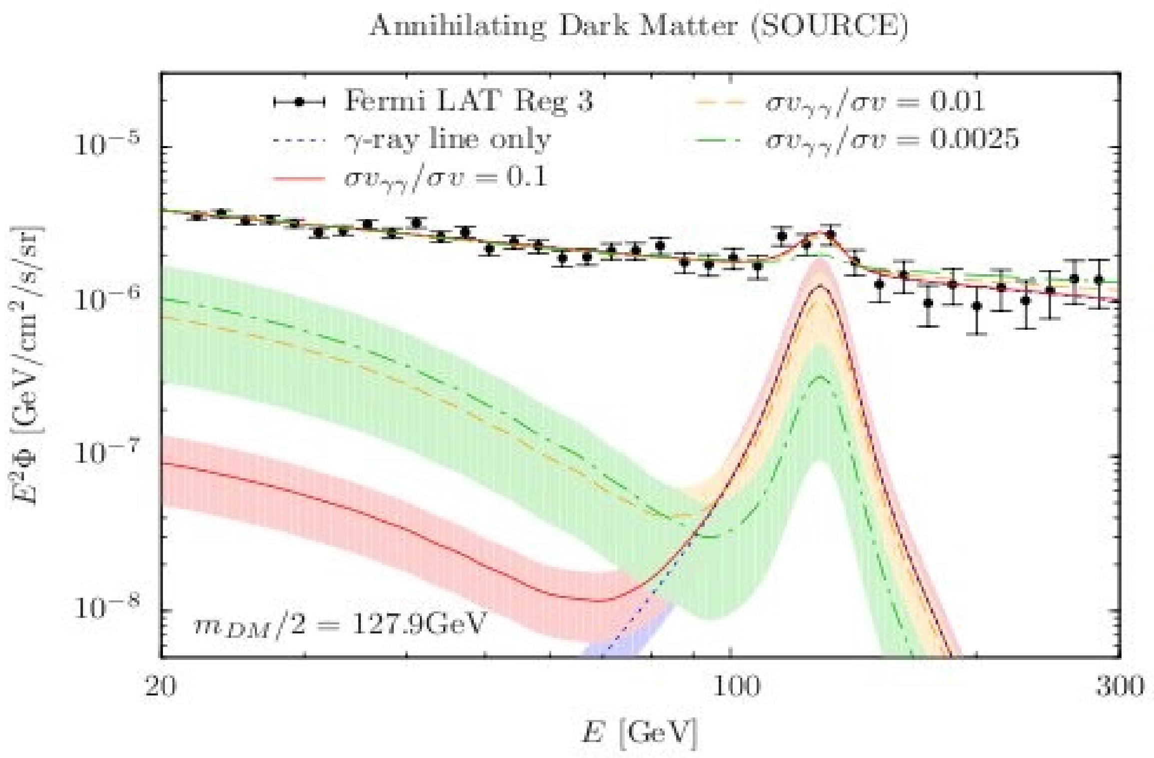
neutralino DM excluded

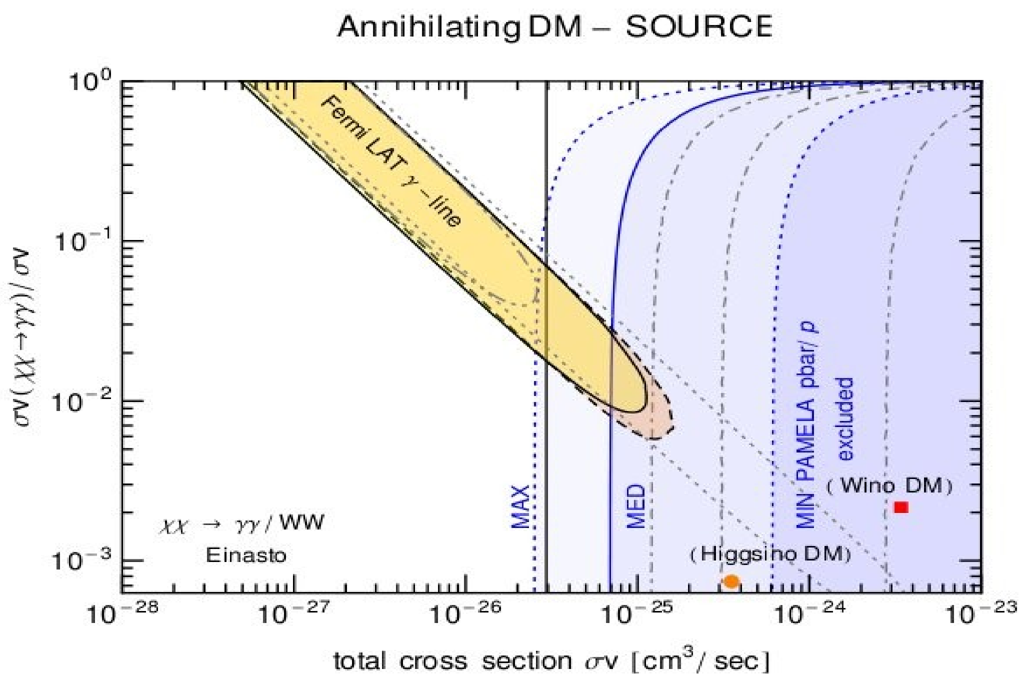
- Decaying dark matter:

possible in the MSSM with R-parity violation (gravitino DM).

excluded for standard DM halo profiles

Decaying vs Annihilating Dark Matter in Light of a Tentative Gamma-Ray Line
W. Buchmuller, M. Garny (1206.7056)





Particle cosmology: significant achievements in PoF 2

Central questions: cosmic microwave background and inflation, dark energy, matter-antimatter asymmetry, dark matter

Specific results:

- Axions and axion-like particles (alps) are interesting dark matter candidates, which can be searched for at DESY
- Signatures of WIMPs and gravitinos have been compared with a tentative gamma-ray line in the FERMI-LAT data.
- De Sitter vacua could be explicitly constructed in type IIB string theory
- The initial conditions of the hot early universe can be explained as result of a phase transition at the end of inflation

Particle Cosmology: goals for PoF 3

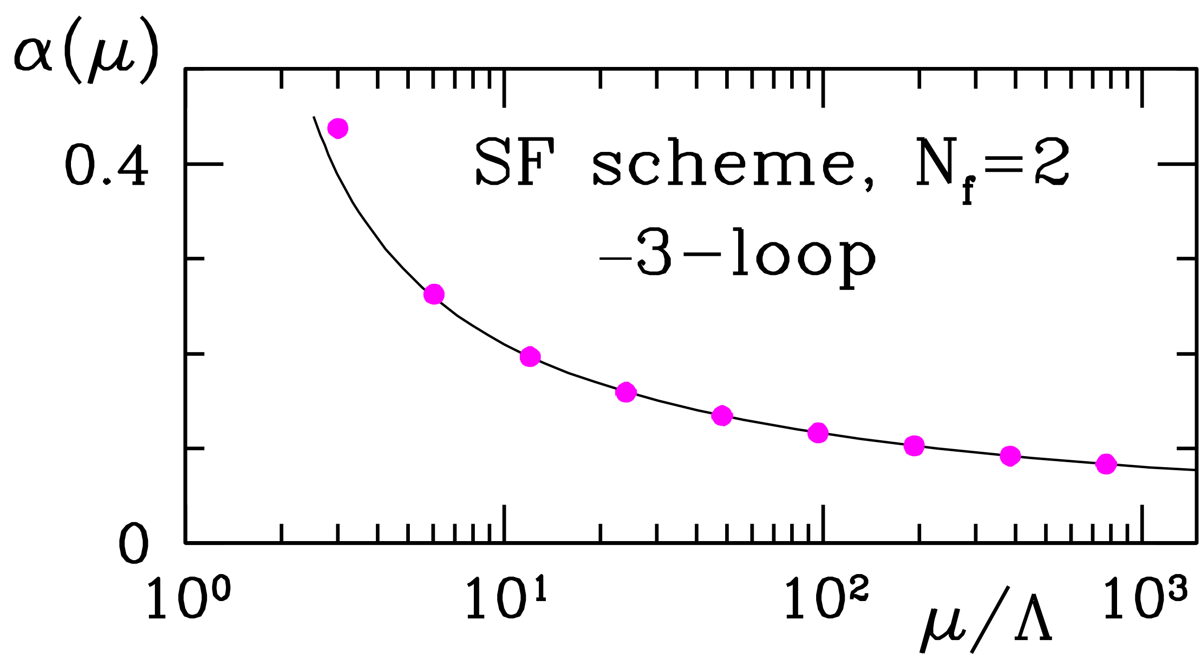
Recent results from Planck satellite and the discovery of the signal at 126 GeV will have major impact on theoretical activities

Specific goals:

- Construction of unified theory with extra dimensions and low-scale supersymmetry consistent with LHC results
- Identification of dark matter candidates consistent with all cosmological, astrophysical and collider constraints (e.g. axions, non-thermal WIMPs, gravitinos): cosmology, collider phenomenology, lattice field theory
- Detailed study of inflation models in light of Planck results
- Embedding of inflation models in extensions of Standard Model consistent with LHC results

Lattice field theory: highlights from the PoF 2 period

- Fundamental parameters of QCD $\rightarrow$ LHC, ILC, ...
  - α_s
  - quark masses



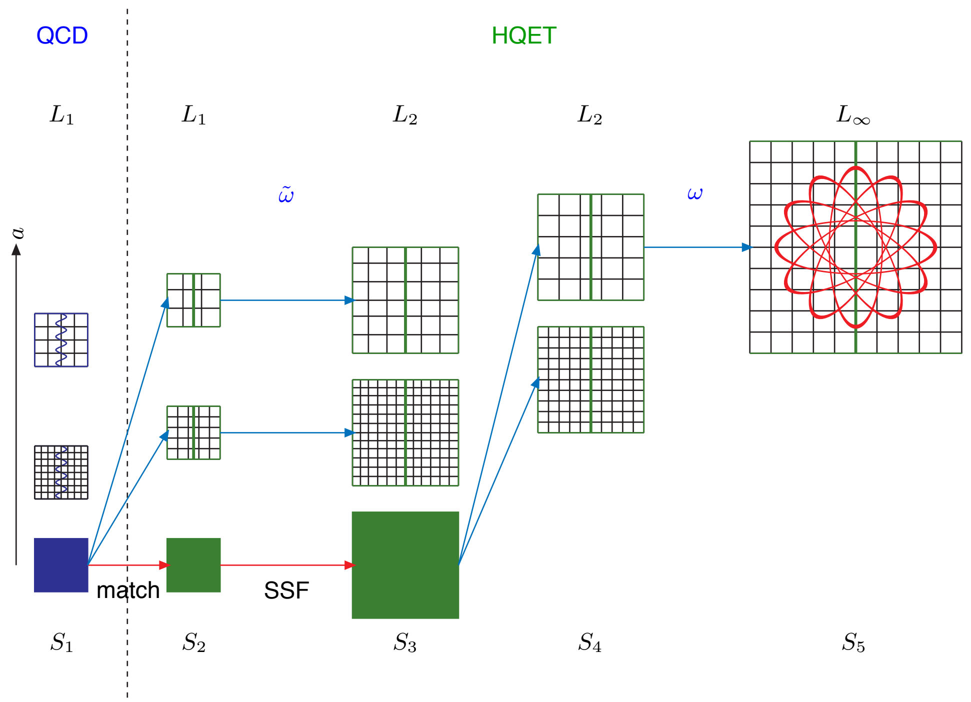
- Hadron structure $\rightarrow$ Astro Particle Physics
  - Moments of PDFs
  - Nucleon-WIMP cross-secton

Lattice field theory: highlights from the PoF 2 period

- **Flavour Physics** $\rightarrow$ Belle-II

  Theory and strategy for non-perturbative HQET

  - B-meson decay constants
  - b-quark mass



- **Higgs physics**
  - triviality
  - vacuum stability
- **Hadronic contributions to electroweak observables**
  - $g-2$ of muon

Lattice field theory: collaborations

Management of two European LGT Collaborations

ETMC

- Cyprus (Nicosia)
  C. Alexandrou, M. Constantinou
- France (Orsay, Grenoble, CEA)
  R. Baron, B. Blossier, Ph. Boucaud, M. Brinet, J. Carbonell, V. Drach, P. Guichon, P.A. Harraud, V. Morénas, M. Papinutto, O. Pène
- Germany (Berlin, Zeuthen, Hamburg, Münster, Bonn)
  C. McNeile, F. Farchioni, X. Feng, J. González López, G. Herdoiza, K. Jansen, T. Korsec, I. Montvay, G. Münster, D. Renner, T. Sudmann, C. Urbach, M. Wagner
- Italy (Roma I, II, III, Trento)
  P. Dimopoulos, R. Frezzotti, V. Lubicz, G. Martinelli, D. Palao, G.C. Rossi, L. Scorzato, S. Simula, C. Tarantino, A. Vladikas
- Netherlands (Groningen)
  A. Deuzeman, E. Pallante, S. Reker
- Poland (Poznan)
  K. Cichy
- + Spain + Switzerland + UK

ALPHA Collaboration

Teams (team leaders)

* Berlin (U. Wolff)
* DESY (H. Simma, R. Sommer, S. Schaefer)
* Dublin (J. Bulava, S. Sint)
* Madrid (C. Pena, G. Herdoiza)
* Münster (J. Heitger)
* Odense (M. Della Morte)
* Rome (A. Vladikas)
* Wuppertal (F. Knechtli)

Coordinated in **CLS**

Teams (team leaders)

* CERN (M. Lüscher)
* Mainz (H. Meyer, H. Wittig)
* Milano (L. Giusti)
* Regensburg (G. Bali, A. Schäfer)
* Valencia (P. Hernández)

Lattice field theory: goals for PoF 3 period

Simulations at physical quark masses, $N_{\mathrm{f}} = 2 + 1(+\dots)$

- Comprehensive investigation of B-meson system $\rightarrow$ Belle II

  $$B \to \pi\ell\nu, \quad B \to \ell\nu \longrightarrow V_{\mathrm{ub}}$$

- Strong coupling $\alpha_s(M_Z)$ $\rightarrow$ LHC, ILC

  with $\frac{\Delta\alpha_s}{\alpha_s} < 0.005$

- Precision computation of hadronic contributions to
  - $g_\mu - 2$, leading and NLO hadronic contributions
  - $\alpha_{\mathrm{em}}(\mu > M_Z)$ $\rightarrow$ ILC
  - Moments of PDFs, nucleon form factors, WIMP nucleon coupling $\rightarrow$ Astro particle physics

- Establishing a simulation laboratory

  with JSC Jülich and the Cyprus Institute

Simulation Laboratory (DESY with Cyprus and JSC)

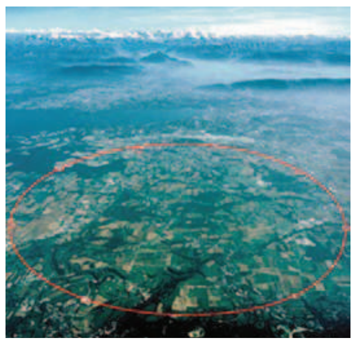
Advances in lattice simulations through progress in algorithms and machines
$\rightarrow$ require significant technical knowledge and expertise
$\rightarrow$ developed, maintained and disseminated by Simulation Lab

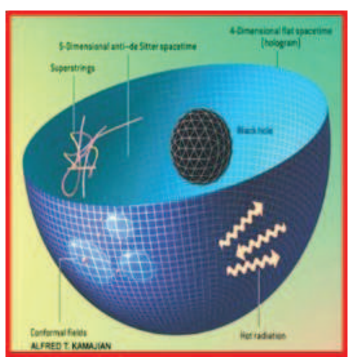
Objectives

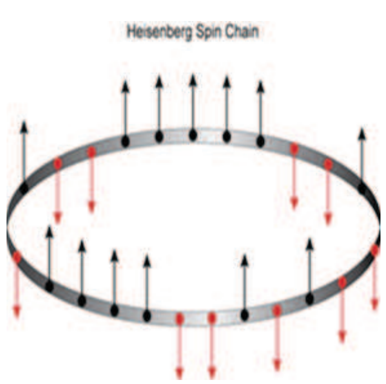
- Development of HPC eco-system for the LQCD community
  optimizing the use of available computing resources
- Large-scale simulations as part of the community
  Currently $N_f = 2 + 1$ simulations in CLS (Berlin, CERN, DESY, Madrid, Mainz, Milano, Münster, Regensburg, Rome, Wuppertal)
- Support of data sharing via lattice data grid (ILDG)
- Benchmarks and performance analysis of architectures
- Organization of workshops and training in LQCD
  Lattice Practices. . .

String theory: research topics

Various aspects of Gauge & String theory







AdS/CFT correspondence

Non-perturbative aspects of supersymmetric gauge theories, e.g. dualities [Teschner]

Geometric (gravitational) problems in weakly curved AdS $\leftrightarrow$ strongly coupled QFT, e.g.

- **Gluon scattering amplitudes [Schomerus]**
- **Thermalization in QG-Plasma… [Kirsch]**

1D (integrable) quantum systems relevant for strings in strongly curved backgrounds (AdS)

[Schomerus,Teschner]

Wider impact: String Theory

Local partnership

Center for
Mathematical Physics
Hamburg

Research Training Group 1670
MATHEMATICS INSPIRED BY STRING THEORY AND QUANTUM FIELD THEORY
DFG funded since 2010

International networking

GATIS
Gauge Theory as an Integrable System

11 academic & 5 private partners
Coordinated & managed by DESY

Tenured former members (15 PD in 2005-2013)


S.Ribault


Y. Okawa


N. Gromov

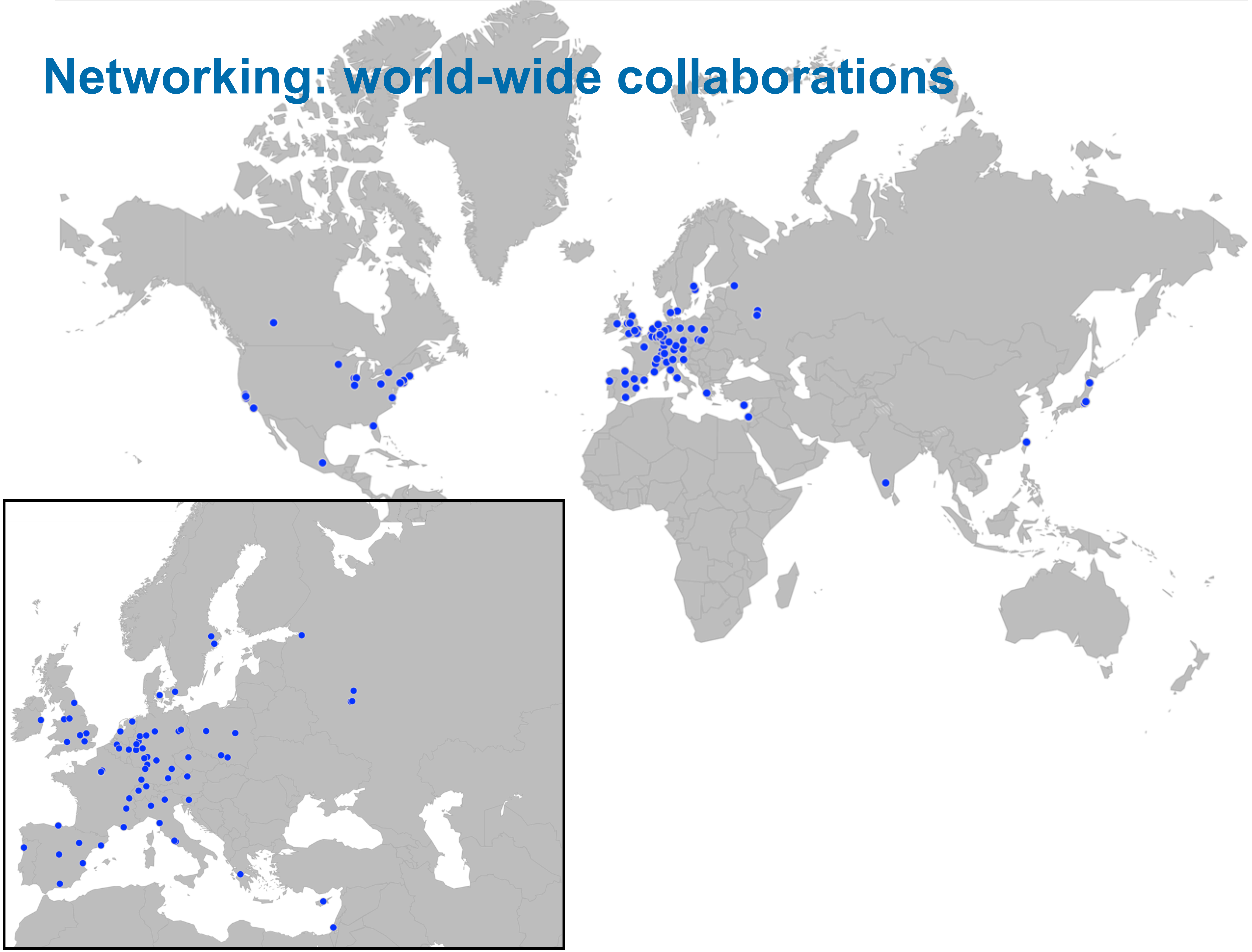

K. Koslovsky


B. Vicedo


T. Creutzig


G. Niccoli

Networking: world-wide collaborations



Funding

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

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

UHH 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

Collaboration with experiment: some examples

- Key contributions to working groups for LHC physics (LHC Higgs Cross Section WG, ...), e^+e^- physics (ILC TDR, ...), European Strategy update, ``Snowmass process'', ...

- Particle Data Group

- Terascale Alliance: Monte Carlo generators, pdf's, SUSY / BSM fit working group, ...

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

- Tools: *HERWIG, PYTHIA, WHIZARD, GENEVA, FeynHiggs, VBFNLO, HiggsBounds, HiggsSignals, ATOM, FastLim, ...*

- LHC Physics Discussions:

Theory forms link in communication across the experiments

ATLAS EXPERIMENT ⟺ THEORY ⟺ CMS

+ ILC, Belle, ...

Wolfgang Pauli Centre

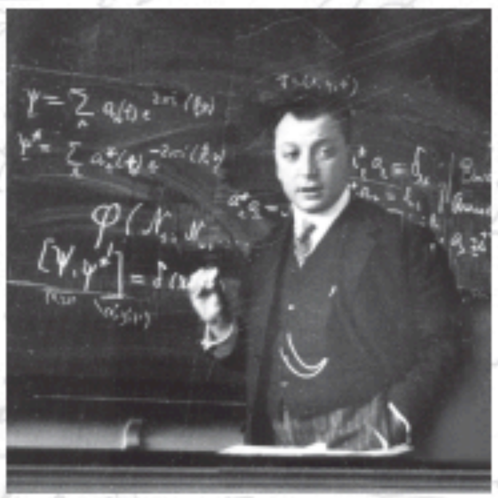
WOLFGANG-PAULI-CENTRE
A COMPETENCE FIELD OF PIER

PIER

Eine Partnerschaft der Universität Hamburg und DESY

Wolfgang Pauli Centre Inauguration Symposium

17 April 2013
DESY Hamburg, Germany
(Auditorium)



The Wolfgang Pauli Centre (WPC) unites the various theory groups of Hamburg University and DESY in the areas of particle physics, astrophysics and cosmology, mathematical physics, condensed matter, quantum optics and chemical physics. (Photos: Pauli Archives CERN)

Speakers
M. Gaberdiel (ETH Zurich)
K. von Meyenn (MPI Munich)
M. Peskin (SLAC)
S. Sachdev (Harvard)
G. 't Hooft (Utrecht)
D. Vollhardt (Augsburg)

Organizing Committee
W. Buchmüller, K. Fredenhagen, R. Santra
http://www.wpc-hh.de

Collaboration of the various theory groups in Hamburg

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

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

7 Nov: Pauli Lecture:
Johannes Henn (IAS Princeton)
From the harmonic oscillator to elementary particle physics

Workshop: Inflation after Planck

27 - 29 January 2014, DESY Hamburg

Pauli Center Blackboard Seminar

Christopher Mudry (Paul Scherrer Inst.) - " Fractional topological insulators: a progress report "

06 February 2014, 16:30

Quantum dynamics in systems with many coupled degrees of freedom: challenges for theory

24 - 26 March 2014

Topological Defect in Condensed Matter and Cosmology

Mark Hindmarsh (U. Sussex), 03rd and 10th April 2014, 02:00 - 06:00 pm

DESY Theory group: recent conferences, workshops

Hosted or (co)organized

- 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.

DESY Theory group: teaching activities

- 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.)

Outreach activities

HERTZ LECTURE.

The String Magic

Hertz Lecture 2013

Prof. Dr. Cumrun Vafa
Harvard University

String theory has emerged as the prime candidate for a fundamental theory of nature unifying quantum theory with gravity. New ideas in the context of string theory have revolutionized our understanding of quantum the nature of space and time. In his talk Prof. Dr. Cumrun Vafa reviews some aspects of lessons we have learned about the nature of fundamental laws of physics in the context of string theory. He especially concentrates on geometric aspects of the theory and the role the extra dimensions have played in the development of this field.

Science Café DESY

AKADEMIE DER WISSENSCHAFTEN IN HAMBURG

Teilchenzoo
AUF DEN SPUREN VON HIGGS, QUARKS UND PHOTONEN

+ Guided tours, etc.