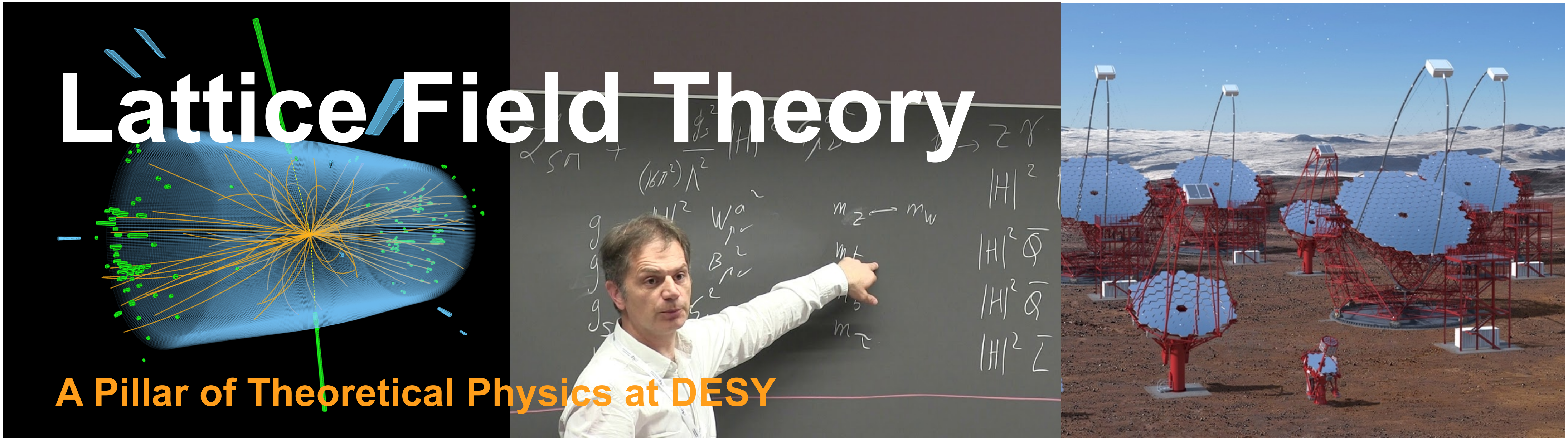
Lattice Field Theory

A Pillar of Theoretical Physics at DESY



Helmholtz Program: Matter and the Universe (MU)

PoF III Topic: Fundamental Particles and Forces

DESY Research Unit: Theoretical Particle Physics

Karl Jansen

Center Evaluation DESY, 5 – 9 February 2018

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

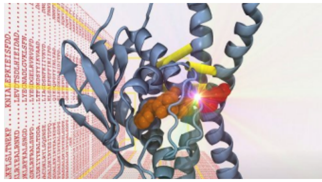
DESY

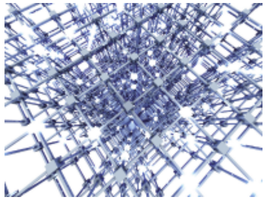
NIC: John von Neumann Institute for Computing

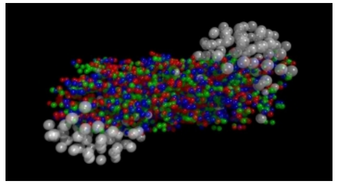
Research group “ Elementary Particle Physics”

What is NIC?

- Cooperation between
  Helmholtz Centres Forschungszentrum Jülich,
  Deutsches Eletronensynchroton DESY
  GSI Helmholtzzentrum für Schwerionenforschung
- NIC maintains five research groups:
  Computational Biophysical Chemistry (JSC)
  Computational Structural Biology (JSC)
  Elementary Particle Physics (DESY)
  Lattice Quantum Chromodynamics (GSI)
  Nuclear Matter (GSI)







- NIC provides supercomputer time at Jülich
  supercomputer centre through a peer review process
- Group “Elementary Particle Physics”:
  staff : Karl Jansen, Stefan Schaefer, Hubert Simma, Rainer Sommer
  Connection to HU Berlin, joint professorship in progress
  3 Postdoc position plus 1 PhD
  Third party grants

Coordination and Compute Time Awards

Role of NIC group at DESY for international collaborations

Coordination of large collaborations

- Alpha collaboration
  (Dublin, Madrid, Münster, Rome, Wuppertal, Zeuthen)
- Coordinated Lattice Simulations (CLS)
  (CERN, Madrid, Mailand, Mainz, Münster, Odense, Regensburg, Rome,Wuppertal, Zeuthen)
- European Twisted Mass Collaboration (ETMC)
  (Bern, Bonn, Cyprus, Grenoble, Rome, Zeuthen)

Leading role in generation of gauge field configurations

Supercomputer time through successful applications at
Gauss, NIC, PRACE

Compute Time

Table of awarded supercomputer time

(Alpha, CLS, ETMC + smaller projects)

period	programme	site	machine	core hours (ch)
2013–16	Tier-1	HLRN		0.3 Mch
2013–16	Tier-1	LRZ	SuperMUC	41 Mch
2015/16	PRACE	CINECA	FERMI	74 Mch
2015/16	Gauss	JSC	JUQUEEN	78 Mch
2016/17	Gauss	JSC	JUQUEEN/JURECA	70 Mch
2017/18	Gauss	HLRS	Cray XC40	70 Mch
2017/18	Gauss	LRZ	SuperMUC	35 Mch
2017/18	Tier-1	HLRN		12 Mch
2015	Gauss	HLRS	Cray XC40	50 Mch
2015	Gauss	JSC	JUQUEEN	40 Mch
2015	Gauss	JSC	JURECA	1.2 Mch
2016	CSCS-Call	CSCS	PizDaint	2 Mch
2016	Gauss	JSC	JUQUEEN	40 Mch
2016	Gauss	JSC	JURECA	2.7 Mch
2016	Gauss	LRZ	SuperMUC	90 Mch
2016	PRACE	CINECA	FERMI	48 Mch
2017	Gauss	JSC	JUQUEEN	45 Mch
2017	Gauss	JSC	JURECA	3 Mch
Total				702 Mch
1 year		DESY	Cluster	15 Mch

N.B.: 1 kch $\approx$ 13 . . . 26 €

Local HPC infrastructure in Zeuthen

- Parallel Linux cluster with 1762 cores
- Delivering 63TFlops
- Shared with astroparticle theory group

European Projects

Networking in Europe

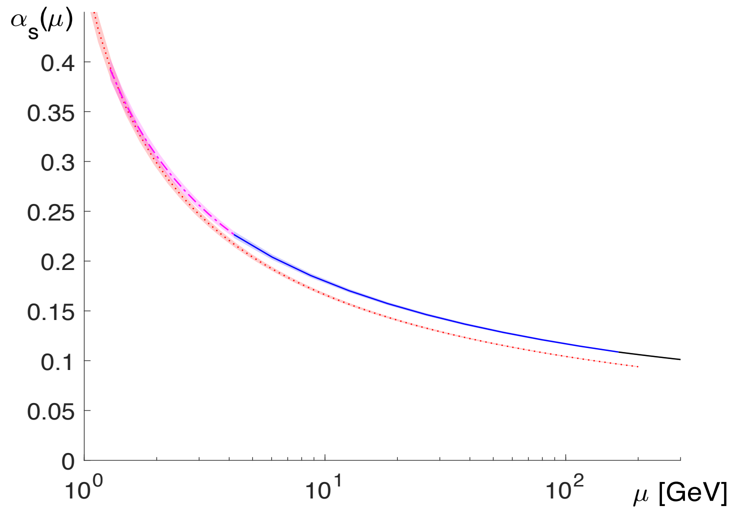
- **HPC-LEAP**
  High Performance Computing in Life sciences, Engineering and Physics
  runs until end 2018

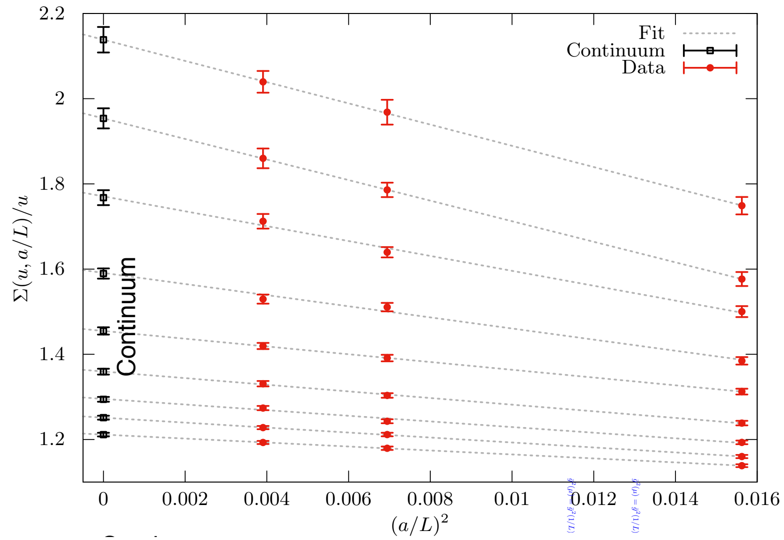
- **STIMULATE**
  Simula**TI**on in **MU**ltisca**L**e physic**A**l and biological sys**TE**ms
  starts fall of 2018

- **QTFLAG**
  Quantum Technologies For LAttice Gauge theories
  starts in April 2018

Highlight: Computation of Running Strong Coupling

Phys. Rev. Lett. 119 (2017) no. 10, 1020





- Scale μ dependence of α_s
- Fundamental parameter in QCD
  - → Important for analysis of collider data
  - → lattice has significant impact
- link to perturbation theory
- Challenge for lattice: connect very high energies with low-energy physics

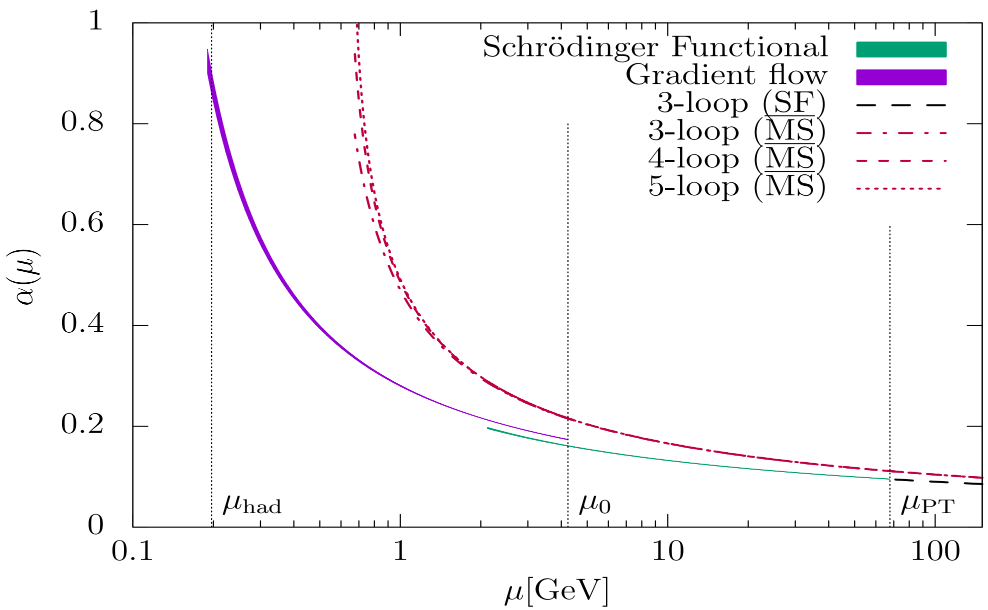
- Strategy developed at DESY in 90's: finite volume definition scale $\mu = 1/L$
- Allows to reach small α_s:
  - → check of perturbation theory
  - → scale dependence of α_s at very high energy
- Beta-function → step scaling function

Highlight: Computation of Running Strong Coupling

Phys. Rev. Lett. 119 (2017) no. 10, 1020

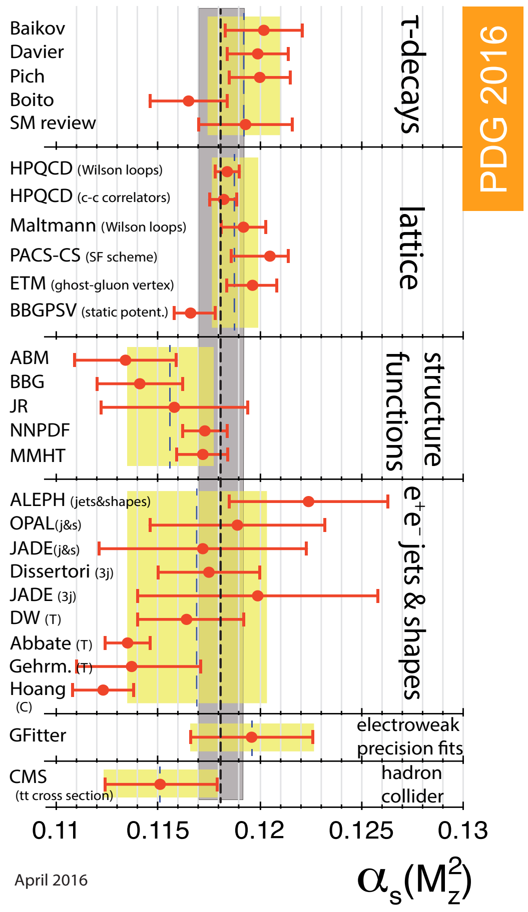
- Cover large energy range
- Contact to perturbation theory for $\mu \approx 70\ GeV$
- Contact to low energy physics at $\mu \approx 0.5\ GeV$

  → Demanding and time consuming



Highlight: Computation of Running Strong Coupling

Comparison of $\alpha_s(M_Z^2)$

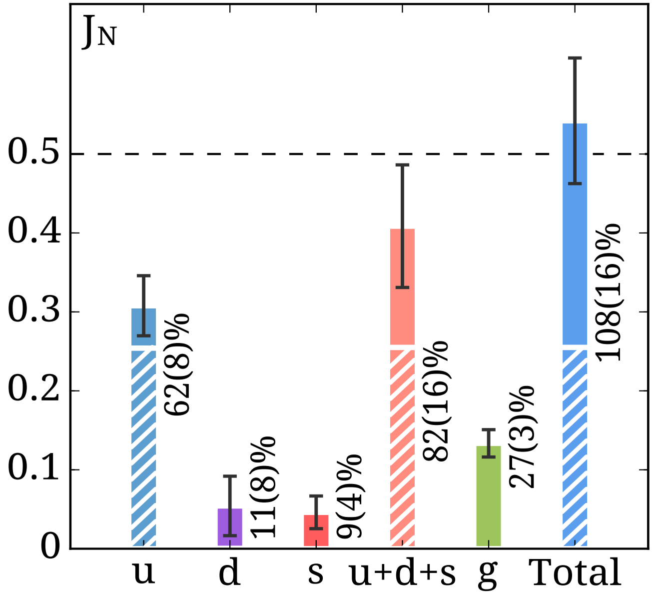


	$\alpha_s(M_Z^2)$
ALPHA	0.1185(8)
PDG (w/o lattice)	0.1175(17)
FLAG	0.1182(12)

"the recent ALPHA lattice result is potentially a breakthrough"
G. Salam in arXiv:1712.05165

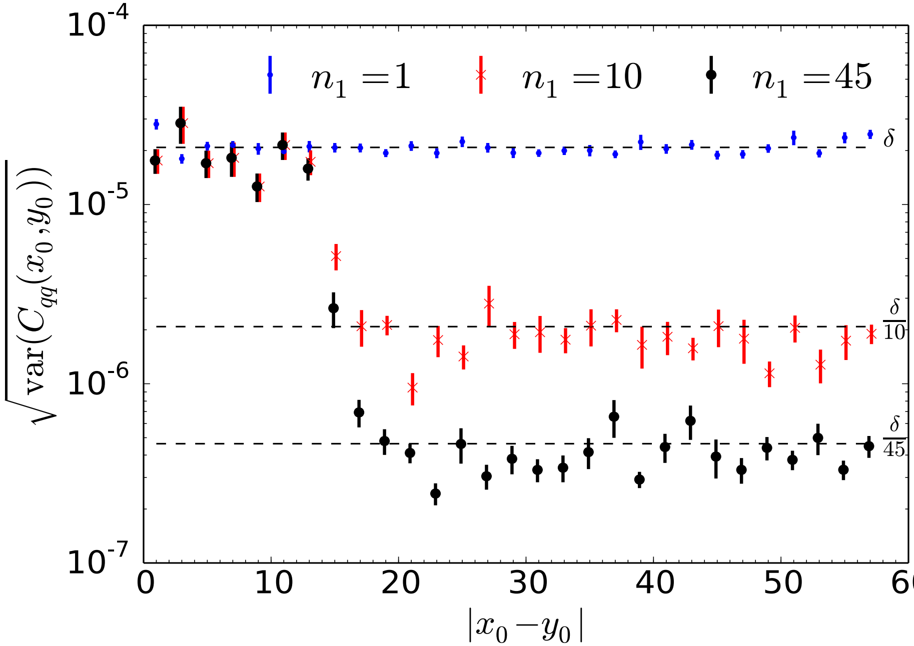
Further achievements

Nucleon structure and algorithm development



Nucleon spin and momentum decomposition using lattice QCD simulations

- Phys.Rev.Lett. 119 (2017) no.14, 142002
- complete determination of the proton's spin and momentum composition
- important step to solve the "spin puzzle"
  → connection to phenomenology



Development of multi-level algorithm

- Phys.Rev.D95 (2017) no.3, 034503
- great potential of breakthrough in lattice gauge theory computations
- Monte Carlo error $1/\sqrt{N} \to 1/N$

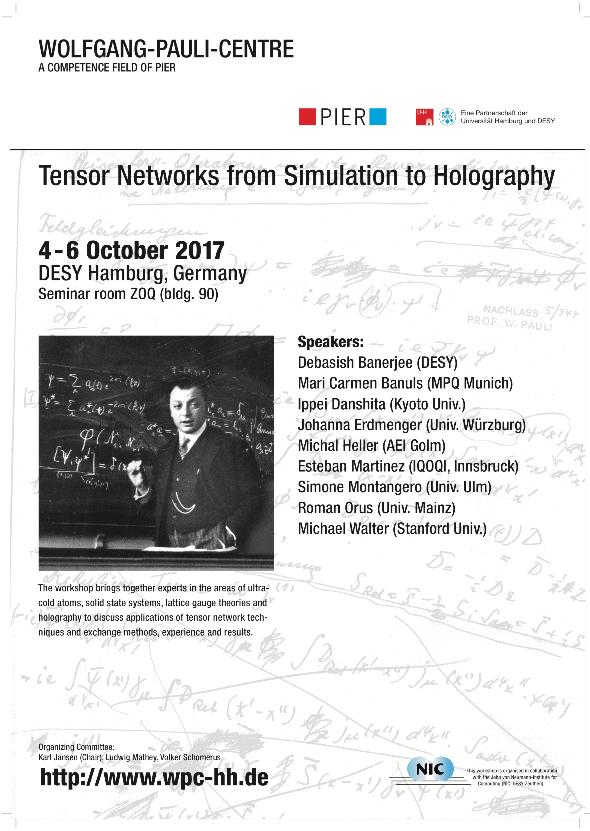
Further achievements

B-physics, muon anomalous magnetic moment and tensor networks

- **Development of lattice HQET for B-decays**
  New tool for non-perturbative precision computations
  in flavour physics (Belle)
  → important input for DESY theory and experiment groups
  → see poster by M. Koren

- **Hadronic contributions to electroweak observables**
  John von Neumann Excellence Project 2016
  prime candidate for finding BSM physics
  compute leading hadronic contribution a_μ^{had}=6.78(30
  → consistent wit dispersive analysis

- **Tensor networks for chemical potential and non-abelian gauge theories**
  Phys.Rev.Lett. 118 (2017) no.7, 071601;
  Phys.Rev. X7 (2017) no.4, 041046
  new approach to solve the "sign problem"
  preparation for quantum simulations (ultra cold atoms)
  → common DESY workshop with DESY string theory group
  and institute for laser physics



Outlook

Improving the already good

Adding charm to reach four active quarks in physical condition

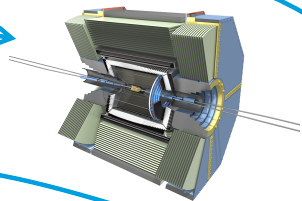
→ continuum computation of broad spectrum of physical observables

g-2, PDFs, hadronic form factors, scattering amplitudes, …

Jefferson Lab

Form factors for Belle II

→ input for and interpretation of experiment

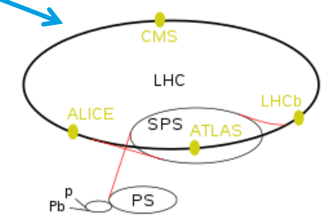


Half the error of $\alpha_s(M_Z^2)$

→ reach new level of precision of fundamental parameter

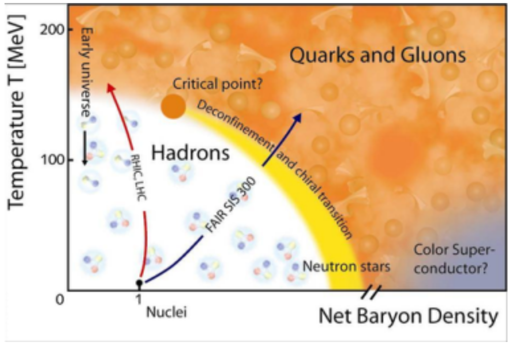
Investigate reliability of perturbation theory

→ compute several observables at intermediate to high energies



Outlook

Exploring news paths



Tensor networks in higher dimensions

→ ambitious goal to solve sign problem, real time simulation …

Development of algorithms for next generation of lattice simulations

→ exploit more, e.g. domain decomposition, tensor networks

Activities related to scientific computing/data (c.f. Heibrids, CDCS)

→ algorithm performance modelling on new architectures, quantum simulations

Be ready for the unkwown

Rounding up the picture

WIMPs, renormalization and Higgs-Yukawa model

Backup!

Computation of scalar quark content of nucleon

- Important input for WIMP cross-section for dark matter searches
  → connection to DESY cosmology group

Non-perturbative renormalization of lattice PDF

- Frontier article in Nucl. Phys. B923 (2017) 394
  → complementary to phenomenological extractions at DESY

Study of Higgs-Yukawa models on the lattice

- question of 1st-order phase transition, matter anti-matter asymmetry
  → connection to cosmology group

Gauss center and PRACE

National and European supercomputer resources BACKUP!

Gauss Center for Supercomputing (CGS)

- *The Gauss Centre for Supercomputing (GCS) provides the most powerful high-performance computing infrastructure in Europe to serve a broad range of research and industrial activities in various disciplines. GCS is the alliance of the three national supercomputing centres*
  High Performance Computing Center Stuttgart (HLRS),
  Jülich Supercomputing Centre (JSC), and
  Leibniz Supercomputing Centre, Garching near Munich (LRZ).

Partnership for Advanced Computing in Europe

- *The mission of PRACE is to enable high impact scientific discovery and engineering research and development across all disciplines.*
- *The computer systems and their operations accessible through PRACE are provided by 5 PRACE members (BSC representing Spain, CINECA representing Italy, CSCS representing Switzerland, GCS representing Germany and GENCI representing France). Computing time available via the PRACE Peer Review Process to researchers from academia and industry.*