# String Theory and Mathematical Physics

Volker Schomerus, PRC 91, May 4, 2021, Hamburg





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# **DESY String Theory Group**

### **Members**

**Staff:** Elli Pomoni (tenured in 07/18) Volker Schomerus (head of group) Joerg Teschner (with UHH math)

Pedro Liendo (EN since 10/18) Georgios Papathanasiou (5y J-staff)

Craig Lawrie (5y J-staff) from 10/21



Joerg Teschner



**Pedro Liendo** 



G. Papathanasiou

Elli Pomoni



Craig Lawrie

**Postdocs:** Apratim Kaviraj, Gleb Kotousov<sub>QU</sub>, Fabrizio Nieri<sub>AvH</sub>, Chengwen Liu, Junchen Rong<sub>EN</sub>,

**PhDs**: Ilija Buric, Aleix Giminez<sub>EN</sub>, Niklas Henke<sub>StuSti</sub>, Jeremy Mann<sub>QU</sub>, Lorenzo Quintavalle<sub>SAGEX</sub>, Felix Tellander, Philip Tontsch, Philine van Vliet<sub>EN</sub>.



Preproposal for SFB: Moduli Spaces, Higher Structures and Integrability to be submitted (Q2 2021)

# **Funding and Networking II**

Beyond the SFB 676/RTG 1670/QU EC...

Two DFG funded Emmy Noether young investigator groups – Pomoni (15-21), Liendo (18-23)

Two running EN Applications: Till Bargheer, invited for interview; Fabrizio Nieri (applied w. UHH)

GiF Regular Program: From 6d (1,0) SCFTs to 4d N=1 SCFTS: classification and exact results with Technion, Haifa (E. Pomoni)



MoU signed in 16/17 by 15 leading European Institutions www: gatisplus.desy.de



**DESY String Theory & Zeuthen particle physics** 

# **Organization of Events**

- Higgs Bundles in Mathematics and Physics
- WPC Theoretical Physics Symposium 2018
- Tensor Networks from Simulation to Holography 03/19
- First SAGEX school/String Steilkurs II
- QFT meets gravity, DTW 2019
- WPC Theoretical Physics Symposium 2019
- Young Researchers Integrability School
- Anti-differentiation and the Calculation of Feynman
  Amplitudes
  joint WPC/Perimeter
- Tensor Networks from Simulation to Holography 11/20
- WPC Theoretical Physics Symposium 2021 11/21

#### joint event of 2 excellence clusters



**DESY.** String Theory and Mathematical Physics| Volker Schomerus

# **Science: Scale Invariant Systems**

In Quantum Field Theory, String Theory and Statistical Physics



# **Scale Invariant Quantum Systems**

In Statistical Physics, Quantum Field and String Theory

First example: critical point in phase diagram of water

correlation length diverges CPs tend to be strongly correlated and hence difficult to approach

Today many examples kown in Ferromagnets, Superfluids & Superconductors ... conformal window of QCD.

Modern Motivation comes from Gauge/Gravity duality

``AdS / CFT correspondence"

Many examples of supersymmetric CFTs in D > = 3

i.p. maximally supersymmetric Yang-Mills Theory in 4D





# (Super-)Conformal Symmetry

"Conformal Fourier Analysis" of correlation functions through decomposition into **conformal partial waves** 

New `chapter' in group theory, unknown to Wigner ...

We initiated a systematic theory of partial waves for

• superconformal symmetry



Boundaries & Defects





# (Non-)perturbative Dynamics of QFT

From N=4 SYM Theory to QCD

In the context of N=4 SYM theory we explored and advanced

conformal bootstrap, amplitudes and integrability techniques.



We studied the rich landscape of N=2 superconformal gauge

theories with continuous couplings & vacuum manifolds.



Eg.: `Cluster algebras' control the singularities of Feynman integrals much beyond N=4 SYM:



the heavy-top mass limit of QCD



Eine Partnerschaft der Universität Hamburg und DESY

# **The Wolfgang Pauli Centre**

Status November 3, 2020

WPC Task Group: Christophe Grojean, Carmen Herrmann, Karl Jansen, Robin Santra, Volker Schomerus, Günter Sigl, Michael Thorwart; Kelly Beernaert, Moritz Habermehl.

WPC Evaluators: Gian Guidice, Robert Myers, Shaul Mukhamel, Hitoshi Murayama, Peter Zoller.





It is the mission of the Wolfgang Pauli Centre to be a leading centre for theoretical physics that pursues and promotes interdisciplinary research to address the fundamental challenges in our understanding of matter, materials and the universe under one organisational roof.

Profiting from its unique embedding in a large-scale research center, the Wolfgang Pauli Centre fosters international cooperation as well as a vivid dialogue between theory and experiment. With its novel setup it serves as a hub for scientific exchange between all partners and for educating and training the next generation.

As a lighthouse for theoretical physics in Science City Bahrenfeld it also seeks dialogue with society in the region and beyond.







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Better exploit synergies in TP while maintaining links to experiments









# Scientific Structure of the Wolfgang Pauli Centre

The six existing research areas of the WPC

### Will be restructured into:

five interdisciplinary scientific pillars

Non-equilibrium Physics

CLUSTER OF EXCELLENCE CUI: ADVANCED IMAGING OF MATTER

- Fabric of the Universe
- Analytic Methods



CLUSTER OF EXCELLENCE

QUANTUM UNIVERSE

#### **Overarching pillars:**

- New Phases and Phase Transitions
- Simulation and Numerical Methods







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CLUSTER OF EXCELLENCE

Fully aligned with existing structures, i.p. with clusters of excellence



#### **Overarching pillars:**

- New Phases and Phase Transitions
- Simulation and Numerical Methods

WPC implementation of future strategic goals

AIM  $\leftrightarrow$  QU; CDCS, DASHH; HH  $\leftrightarrow$  Zeuthen, HGF



DESY.

# **The WPC Building**

**Offices** for DESY/UHH theoretical particle physics.

### Central facilities will host (ca 1000 m2)

- *Discussion areas & co-working spaces* for members
- *Thematic Institutes* to address key challenges of five scientific pillars.
- *Research hotel* hosting long term guests (sabbaticals, Humboldt etc.) and young investigator groups.
- Cross-disciplinary training (Masters, PhD, Postdocs) through lectures, schools; open student area
- WPC-Koordinator Bürofläche [20m<sup>2</sup>]
- Wissenschaftlicher Konferenzraum für 150-200 Personen [200m<sup>2</sup>]
- Internationaler Besucherbereich Büroflächen [280m<sup>2</sup>]
- Forschungshotel Sabbaticals Büroflächen [100m<sup>2</sup>]
- Foyer/Atrium [400m<sup>2</sup>]

UHH  $\rightarrow$  HH (as of 30.10.2019)









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## **Status and Timeline**

# Construction costs of **20 Mio Euros** split 60/40 between DESY and UHH

#### Secured (cut by 1,5 Mio from DESY)



Cooperation contract (Rahmenvertrag) Coordination office Management board Planning for building Construction of building Implementation of governance workgroups First WPC YIGs are installed Research hostel

Scientific evaluation (completed)

Completion of building Ramp up of guest program

Thematic Institutes



#### Wolfgang Pauli Centre - V Summary of the Review of WPC White Pa

Gian Giudice, Head of the Theoretical Physics Department, CEN
 Shaui Mukhamel, University of California, Irvine, USA
 Robert Myers, Director, Perimeter Institute, Waterioo, Canada
 Peter Zoller, Research Director, University of Instruck, Austria
 o Hitoshi Murayama, University of California, Berkeley, USA

#### Evaluation of the WPC Strategy

The WPC offers a unique opportunity for Germany to create an international center that will act as a beacon for scientific innovation and as a pole of attraction for the international community. It will build on experience with centers for theoretical physics around the world (such as KITP Santa Berbara, Perimeter Institute, IPMU Tolyo, CERN, Golf Florence and others) but add something new. Its conception embodies a new vision of research in which theoretical physics plays a catalyzing role advancing science. Today, the scene of theoretical physics plays a task were and it is difficult to predict how the present situation will evolve and which research functions will trum out to be most successful. The WPC goals and spirit are well adapted to this dynamical situation and are likely to become the keys to its future access.

#### The Initial Conditions

Is Hamburg a good location for the WPC?

Creating a successful center with the WPC proposal's ambitions requires pre-usibiling fertile ground, rich in research diversity and scientific excellence. There are only a handhi of places around the world where this is possible, and Hamburg is certainly one of them. Hamburg has long been the home of a diverse and outstanding community of researchers in the physical sciences. As the strategy paper outlines, there are remarkable opportunities to exploit intersections between the diverse areas of physics there, e.g., one can envisage interactions between cosmology and condensed matter on nonequilibrium phenomena, or synergies between praving and particle physics not bot analytic and numerical computations. In addition, many important connections between fundamental theory and application are arising today. Therefore, giving a permanent home to WPC and amplifying its activities is also very likely to give rise to unexpected connections that could well be an important stimulus to neve technologies.

To give a concrete example we can consider the field of quantum optics, in which quantum information and quantum science come together with quantum mamp-hough physics in condense matter and high-energy physics, with strong connections to experiment. Hamburg, together with theory groups at DESY Zeuthen, provides indeed the unique environment where, within on attractive science location, all these elements are present, offering opportunities for interdisciplinar research based on local strength. In the US the DOE has a strong efforts to connect quantum computing and quantum simulation with high-energy physics, and with existing expertise at Hamburg University and DESY, one might as well envision and establish a new research direction as e.g.

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WPC White Paper Review 2020

- WPC	nd the present concept of WPC as	ely topics. The WPC proposal be primarily driven by local d GGI. Further, distinct from tivities of the local members. probably fair to say that the esearch areas than either of	hat the WPC will become an rce of inspiration for the physics
eferees: nt, CERN ine, USA Canada , Austria ley, USA	erm vision/mission of the WPC? and how to organize Hamburg's diverse cts. We praise the vision of the WPC's disciplinary exchanges and interaction. lovative and is likely to be conducive in ture is designed well, with the board ary initiatives.	IAP) and the Mainz Institute ms each year, on topics in I in high energy and nuclear hg drive from local scientists ensed matter theory) with a grided as competitors but as	pretical Physics Department, CERN d broad vision. [] Hamburg is an j in multiple institutions in all five DESY and the European XFEL" University of California, Irvine, USA d enhance the WPCL.1   can well
act as a y. It will P Santa ng new. cing role goal of difficult ut to be re likely	rities for reaching the goals of the WPC for creating a common identity, for ensuring the engagement of visiting tific enrichment and for promoting the by young scientists is an excellent and re training of young scientists. There is ion and the informal interactions and ading such a rich and diverse scientific ill provide an ample boost for graduate a straticture draw for the recruitment of	timulating cooperation and Advanced Imaging of Matter niversity. Let us add that by ony community, one should the university and DESY, will also spill over to further consideration the WPC also rganizational entities in the jes in organizing e.g. a joint esin organizing e.g. a joint from its main international hat can be is used to employ rouse and supports visitor	y's leading institute for theoretical inneter Institute, Waterloo, Canado ential for a unique interdisciplinary strengths in Hamburg." or, University of Innsbruck, Austria sites. New WEC brings not only the bring in international leaders. In proposal makes perfect sense, and around the world."
ground, und the een the strategy diverse d matter analytic il theory fying its sportant uantum idensed her with	feature is a positive aspect that should it, however, not to penalize opecialized advancements. We believe that finding strategical issue which is critical to the it and successful lines of research in the bout introducing mechanisms that will secting new research areas which may scientific pillars.	ucing the scientists involved ut the future of the center, ent institutions deprives the to external decisions not sider providing some seed as theve assisted the ongoing draw together the diverse ing from esiting groups and the WPC it would clearly be y- but this is a strategic, and The real success of the WPC ms of (qualitative)) new in the various disciplines in	
iplinary uantum lamburg as e.g.	ting centers with a focus on theoretical ta Barbara), the Galileo Galilei Institute oo), or the Institute for the Physics and (KITP and GGI) focus on running visitor		









# **Backup Material**

## **The Governance Model**









## **National and International Partners**

National Partners complement the scientific spectrum:

- Contribution to working groups
- Organisation of scientific programs
- Scientific collaborations

#### **International Partners**

- Share the multidisciplinary approach
- Have a history of collaboration with WPC groups
- Conduct exchange programs for young scientists (PhD and Postdocs)

*First joint WPC postdoc With Weizmann Instritute hired in 2020* 

Additional partners can join in the future (e.g. Universities or experimental collaborations)





"I fully endorse the WPC's visionary proposal and I am convinced that the WPC will become an internationally-recognized center of scientific excellence and a source of inspiration for the physics community and the public alike."

#### Gian Giudice, Head of the Theoretical Physics Department, CERN

"The WPC is well conceived and is truly impressive in its scope and broad vision. [....] Hamburg is an ideal place for this center thanks to the well-established activity in multiple institutions in all five pillars, and to the proximity of unique experimental capabilities at DESY and the European XFEL." Shaul Mukhamel, University of California, Irvine, USA

"I wholeheartedly endorse this exciting proposal to expand and enhance the WPC.[...] I can well imagine that this initiative will raise the WPC to become Germany's leading institute for theoretical physics and a recognized leader on the world stage." *Robert Myers, Director, Perimeter Institute, Waterloo, Canada* 

"I express my strong support for the WPC effort, and I see potential for a unique interdisciplinary environment for theoretical physics to develop, based on existing strengths in Hamburg."

#### Peter Zoller, Research Director, University of Innsbruck, Austria

"Hamburg has a long tradition as a power house in theoretical physics. Now WPC brings not only the local talents together but also conducts thematic programs that bring in international leaders. In addition, it maintains proximity to experimental activities. The proposal makes perfect sense, and WPC is poised to become a formidable foe of all the other centers around the world."