

# Activity and Plans: Theoretical Particle Physics

CPPS Retreat  
Th. 15.2.2024  
Alexander Lenz

- 1. Setting the scene**
- 2. TP1 at a glance**
- 3. Third Party Funding**
- 4. TP1 in more details**
- 5. International visibility/outreach**
- 6. Outlook**

“Dass ich erkenne, was die Welt im Innersten zusammenhält”

Standardmodell (SM) of particle physics:

Matter: (Fermions, Spin 1/2)

Quarks

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$$

Leptons

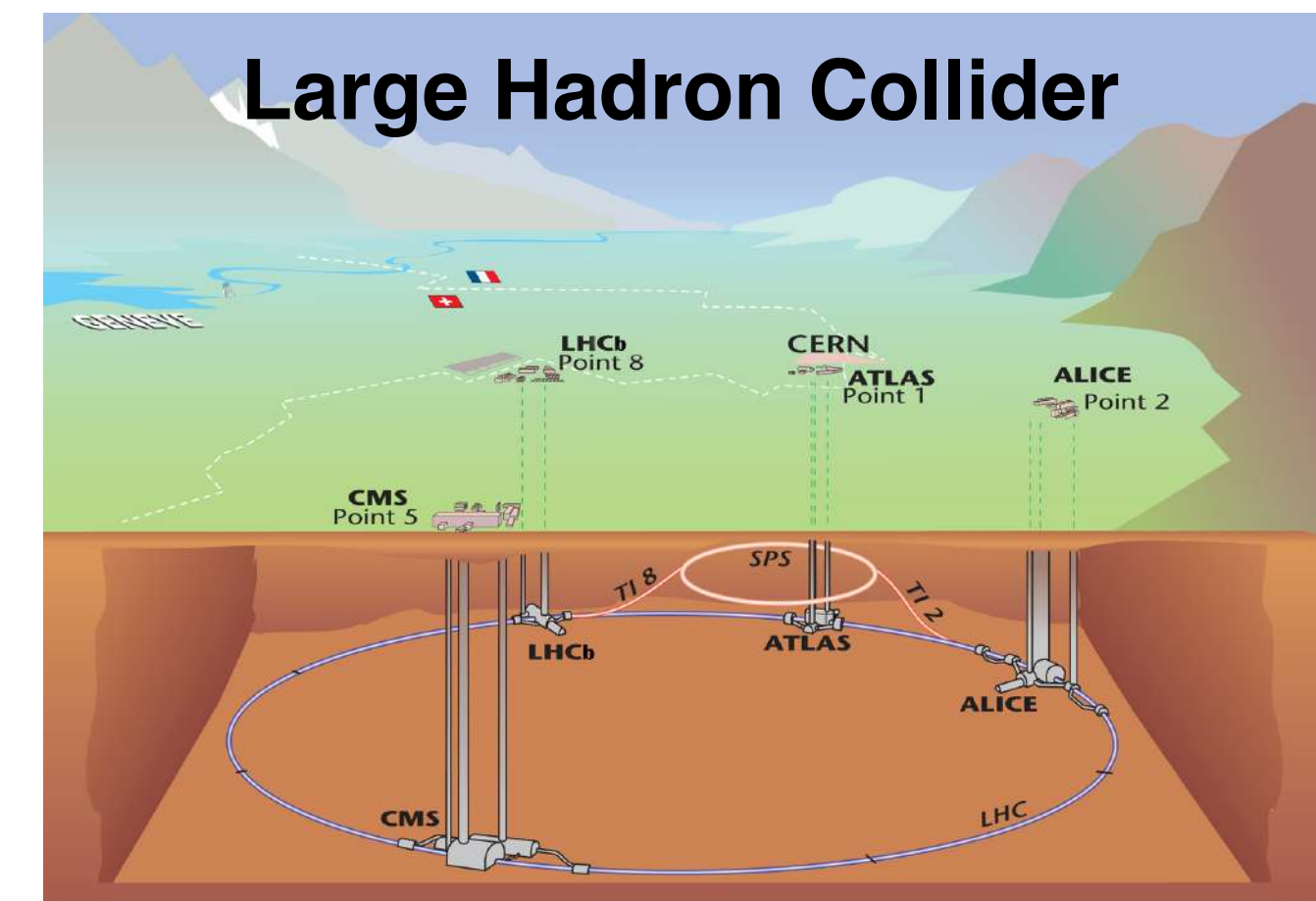
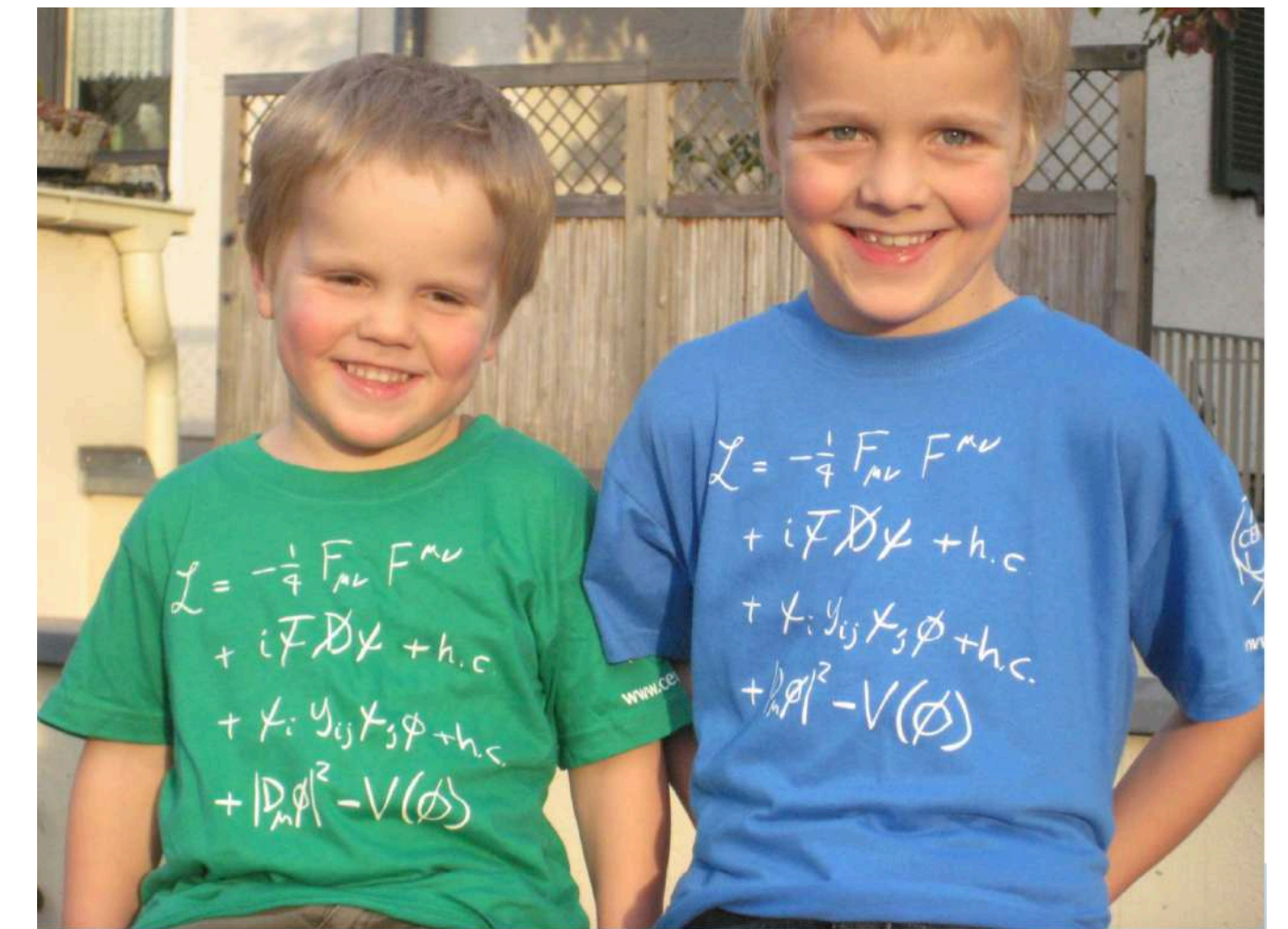
$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

Force carriers: (Bosons, Spin 1 = Gauge bosons)

Photon  
Weak gauge bosons  
Gluons

Mass creation: (Boson, Spin 0)

Higgs particle H



## Current research:

**SM explains thousands of observables, many with a high precision,  
but it leaves many questions unanswered, like the **existence of matter in the Universe**  
=> **SM is low energy limit of a more **fundamental theory (BSM)******

### Direct search for BSM:

Create new particles directly  
In a collider, like the **Higgs-  
Boson** in 2012

### Indirect search for BSM:

Compare precision measurements  
with precision calculations

$$f^{\text{Exp}} \pm \delta^{\text{Exp}} = f^{\text{SM}} \pm \delta^{\text{SM}} + f^{\text{BSM}} \pm \delta^{\text{BSM}}$$

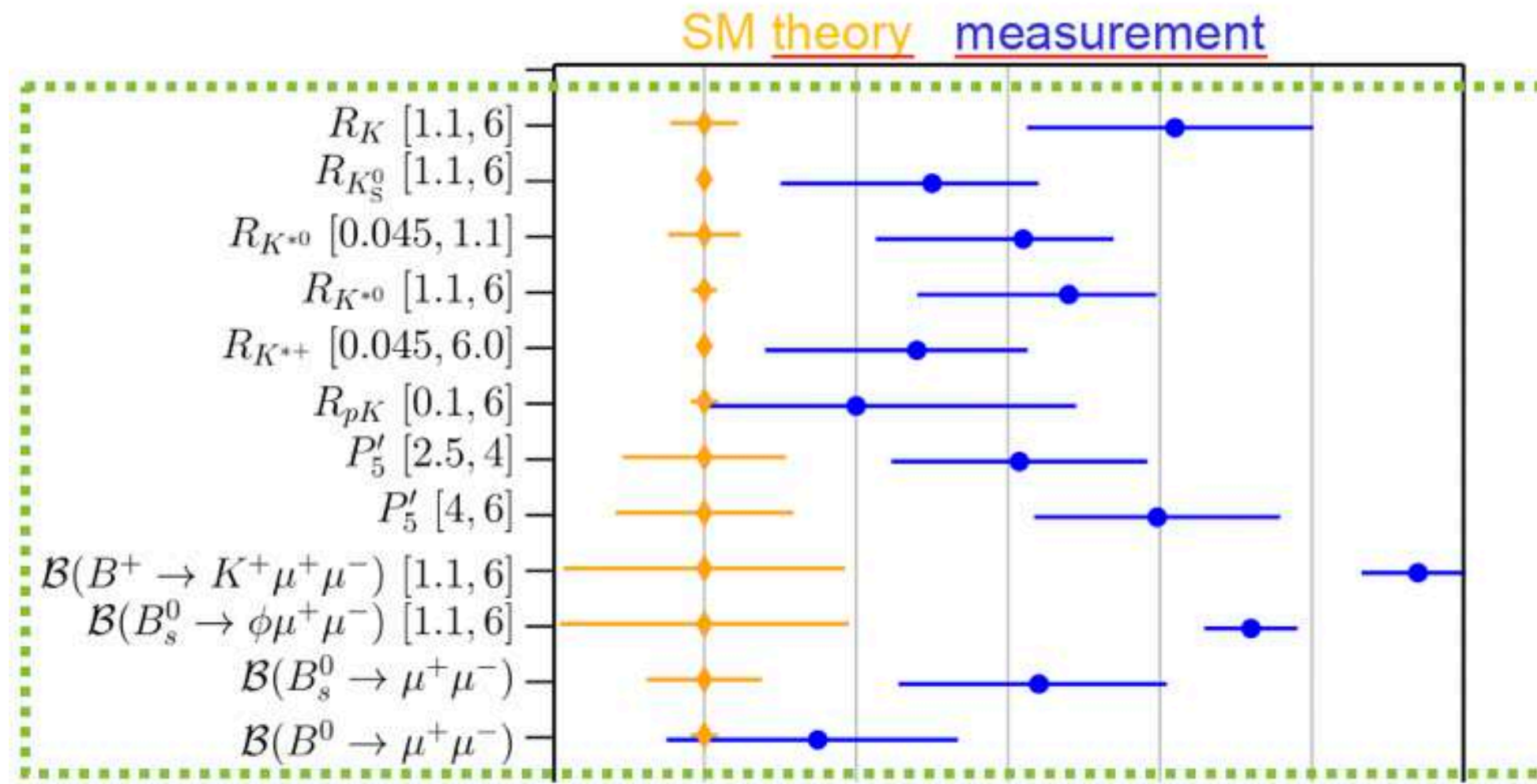
Statistical significant deviations  
could give hints for BSM

- **Flavour anomalies**

### Theory hints for BSM:

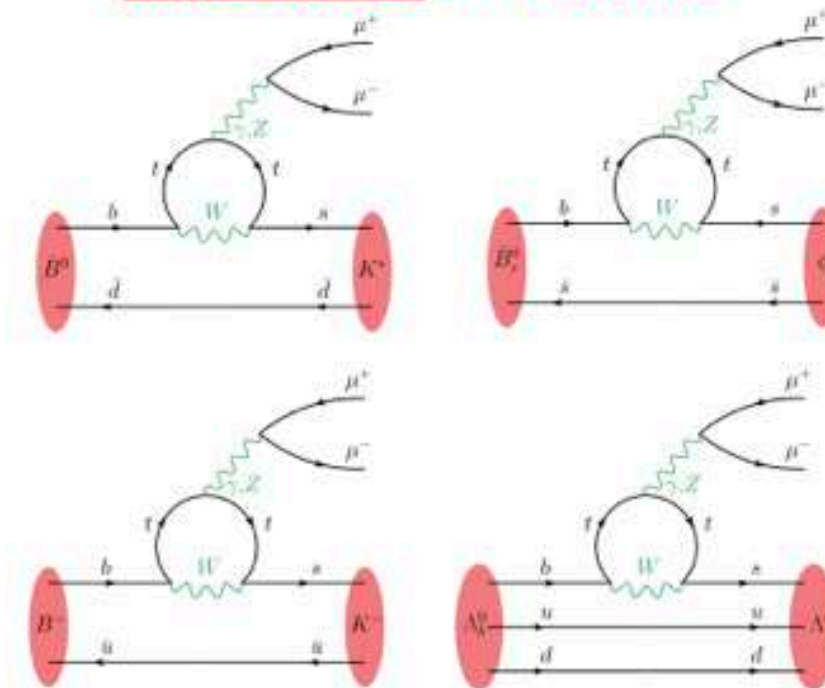
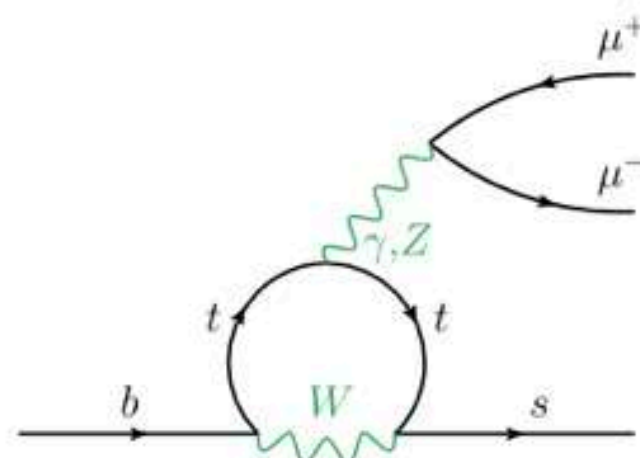
e.g. existence of matter requires

- CP violation
- 1st order phase transition. e.g. 2HDM

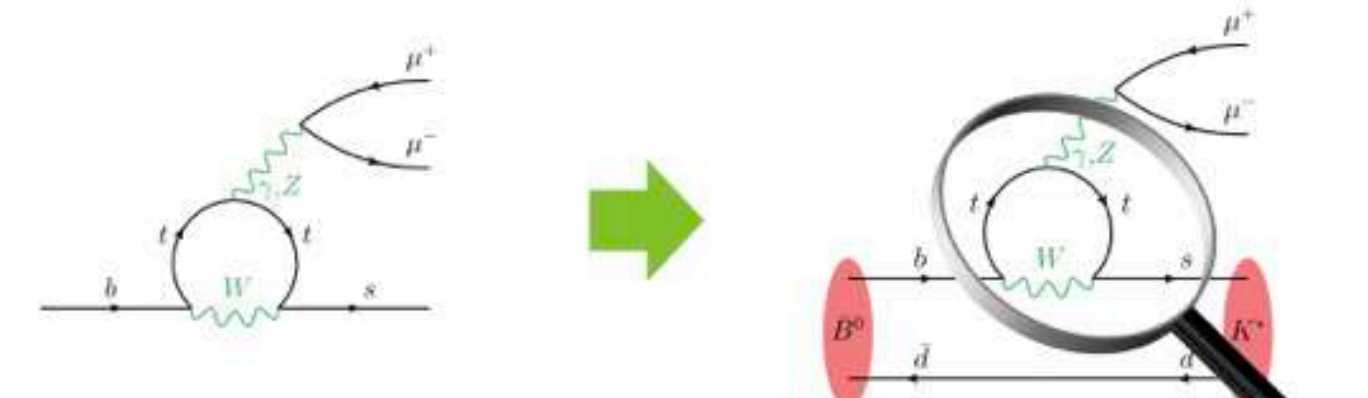


$b \rightarrow s$   $|\uparrow\downarrow$  **weak decay**

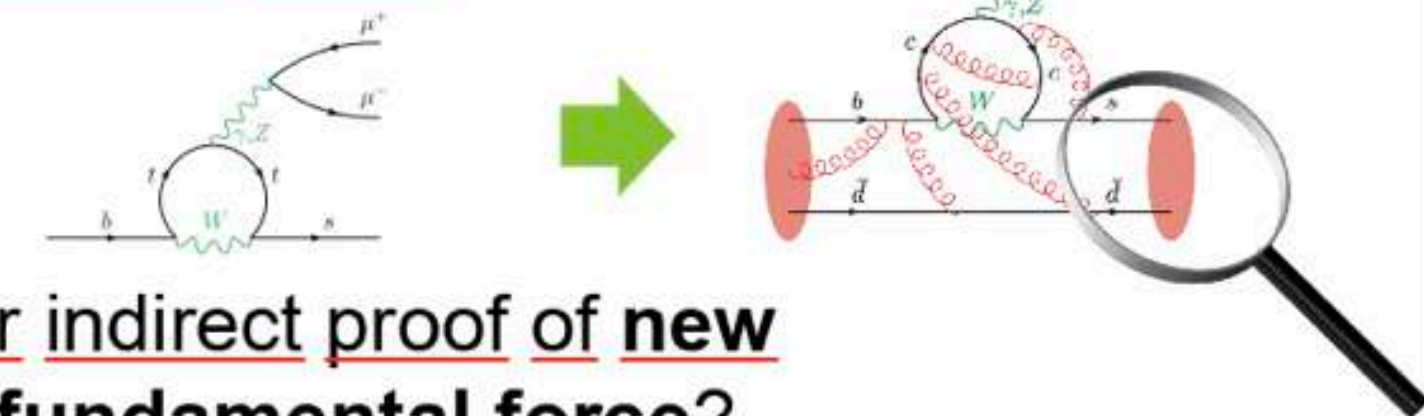
**Hadronic structure**



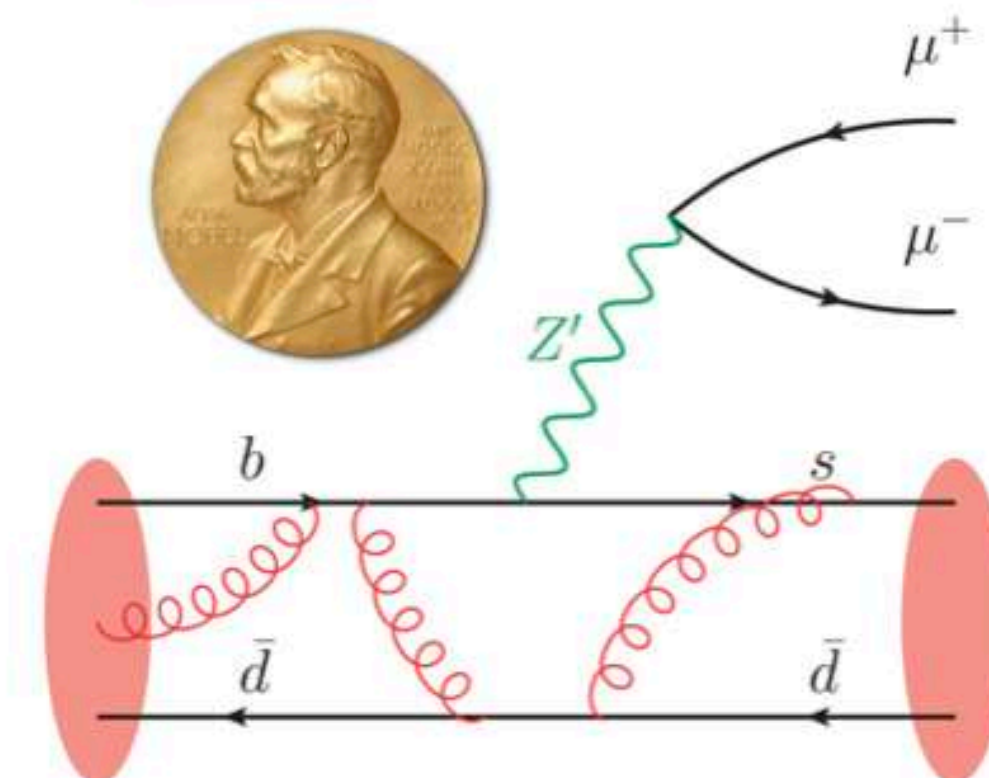
- **Decisive question:**
  - **Common theoretical issue?**



- .. **or effect of strong interaction (hadronic effect?)**



- .. **or indirect proof of new fundamental force?**



1. **Setting the scene**
2. **TP1 at a glance**
3. **Third Party Funding**
4. **TP1 in more details**
5. **International visibility/outreach**
6. **Outlook**

## History of TP1

- Founded 2003: Mannel & Khodjamirian
- 2006: Kilian
- 2012: Feldmann
- 2 permanent: Huber, Lange
- 2 Long-term: Pivovarov, Uraltsev
- 2015: Bell
- 2020: Lenz

- Structural idea for the physics department:
  - Two Professors in particle theory
  - Two professors in solid state theory
- **We did not succeed to hire solid state theory ...**
- Structural re-adjustment:
  - One Professorship in theoretical Quantum Optics
- **One (more) professorship in theoretical particle physics: 2012**


DFG FOR 1873 "Quark Flavour  
Physics and Effective Field Theories"



- QFET FP1 went very well
- Official retirement of Alex Khodjamirian after FP1
- ... Replacement by a new hire of a professorship
- Alex K. continued as a "senior professor"

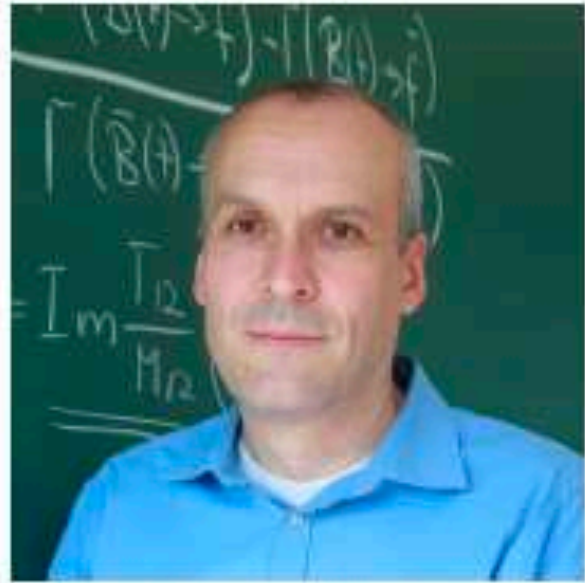
- 2018: Funding Proposal for a TRR with Karlsruhe and Aachen
- "Particle Physics Phenomenology after the Higgs Discovery"

Collaborative Research Center TRR 257

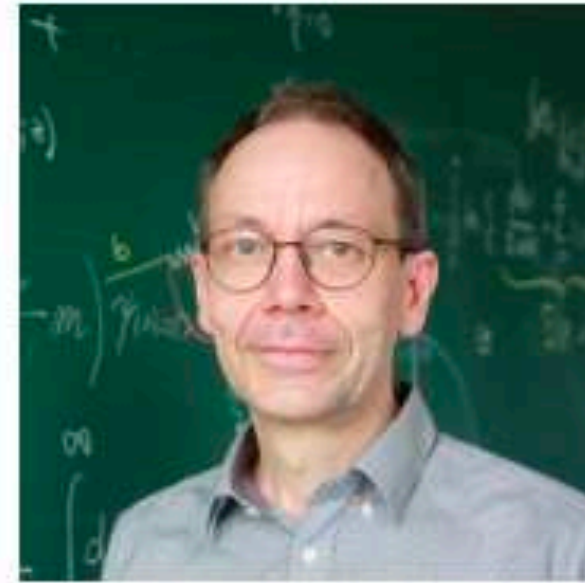
PPPH = P<sup>3</sup>H =  H

Particle Physics Phenomenology after the Higgs Discovery

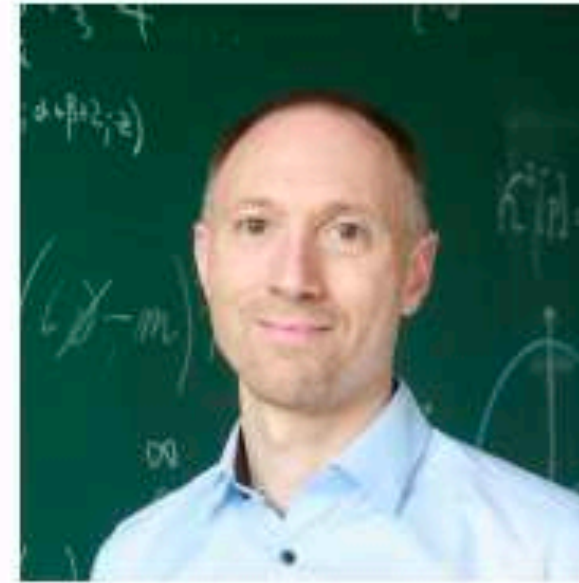
- 2018: NRW started a program to enhance the capacities for Master Curricula
- ... so early replacements could be hired!
- Theoretical Particle Physics was granted the early replacement of ThM,  
**provided that the CRC will be funded!**



Guido  
Bell



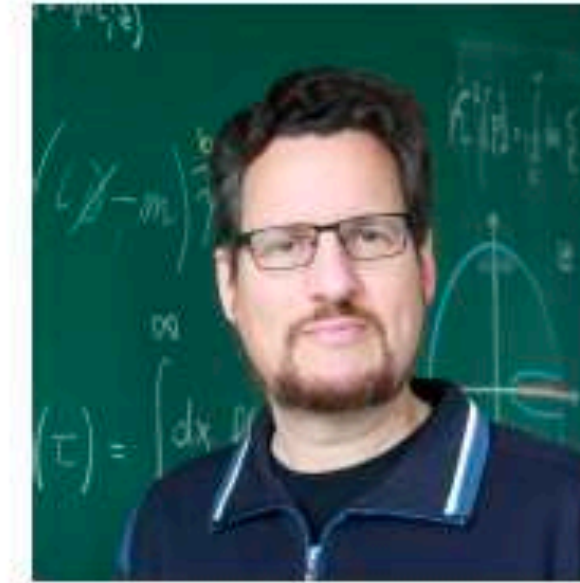
Thorsten  
Feldmann



Tobias  
Huber



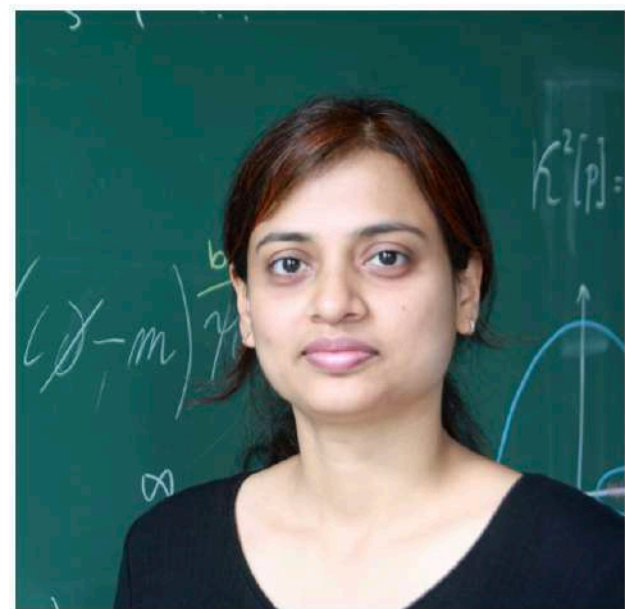
Alexander  
Khodjamirian



Wolfgang  
Kilian



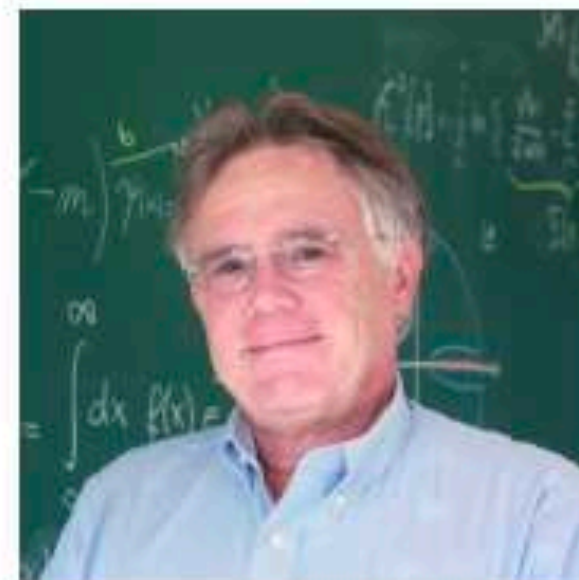
Björn  
Lange



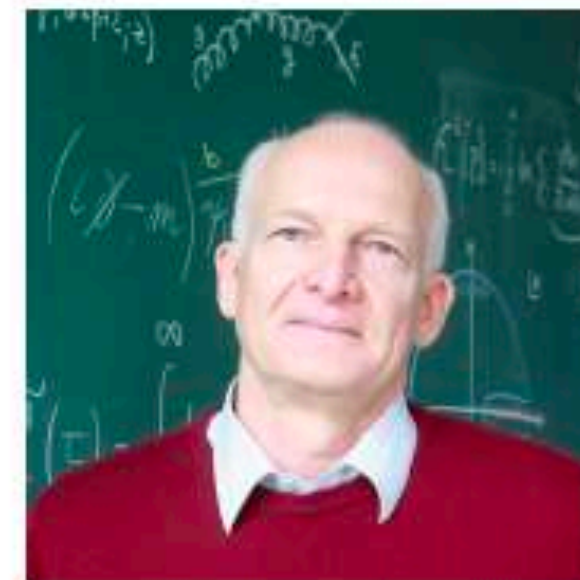
Rusa Mandal



Alexander  
Lenz



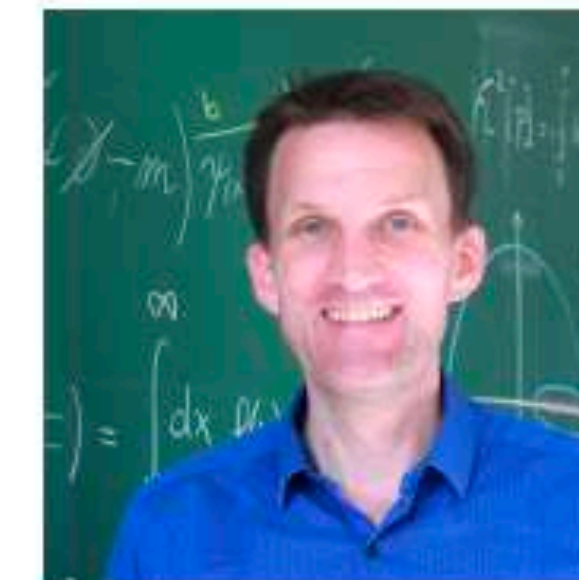
Thomas  
Mannel



Alexei  
Pivovarov



Vladislav  
Shtabovenko



Oliver  
Witzel



# TP1- post-docs



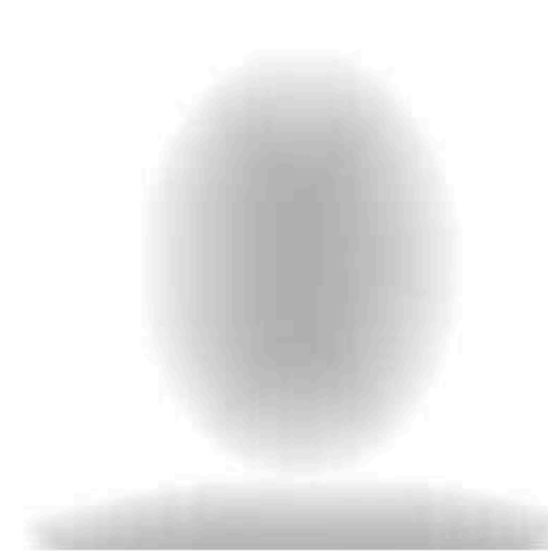
Anshika  
Bansal



Pia  
Bredt



Kevin  
Brune



Jack  
Jenkins



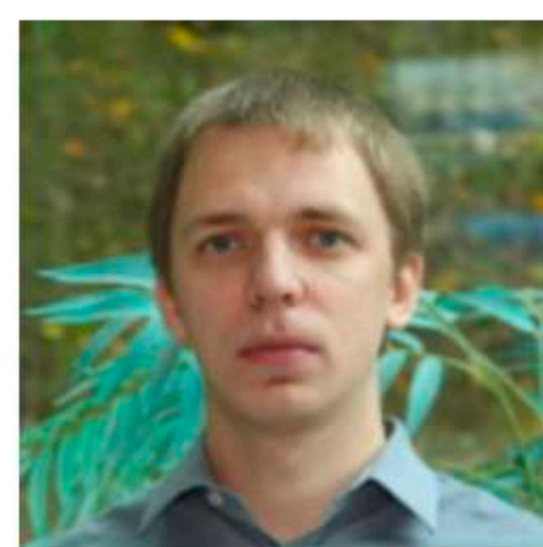
Martin  
Lang



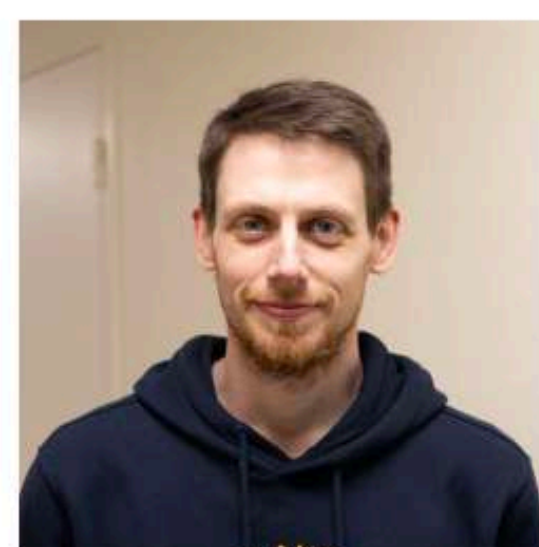
Eleftheria  
Malami



Maria Laura  
Piscopo



Aleksey  
Rusov



Meril  
Reboud



Gilberto  
Tetlalmatzi-  
Xolocotzi



Tom  
Tong



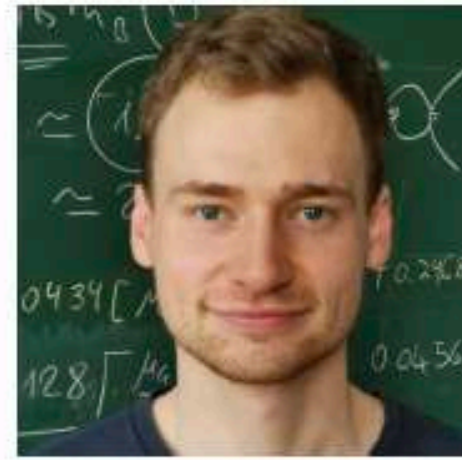
Matthew  
Black



Anastasia  
Boushmelev



Sebastian  
Edelmann



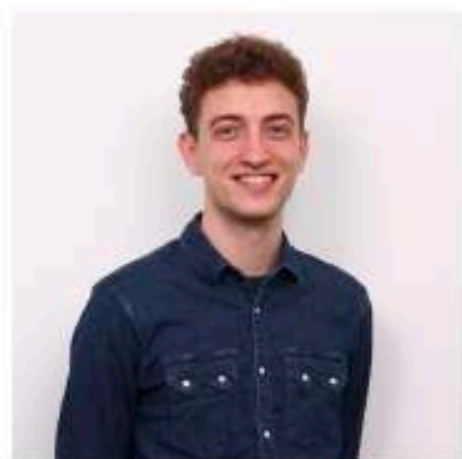
Dennis  
Horstmann



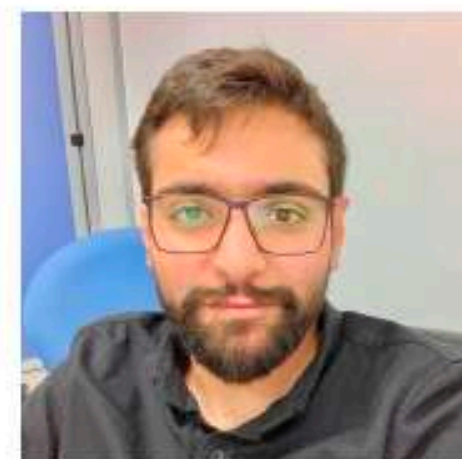
Nils  
Kreher



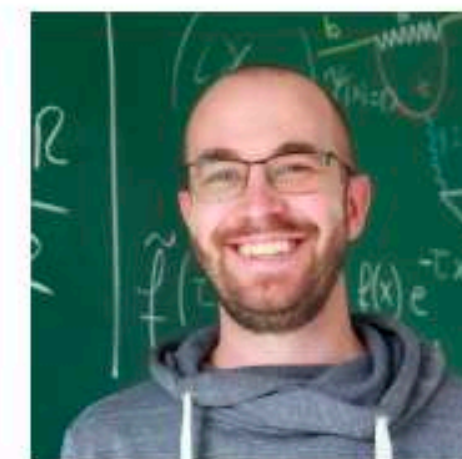
Philip  
Lüghausen



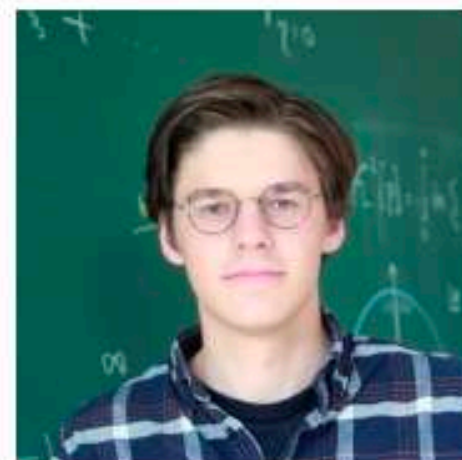
Ilija  
Milutin



Ali  
Mohamed



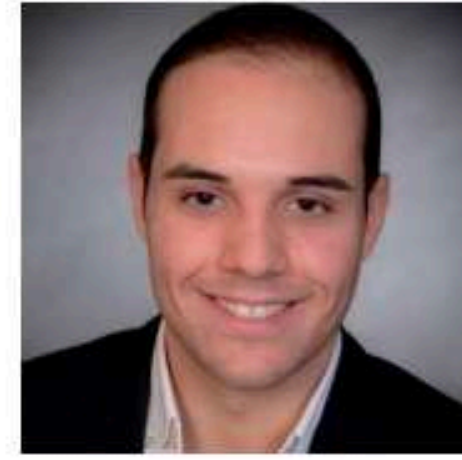
Lars-Thorben  
Moos



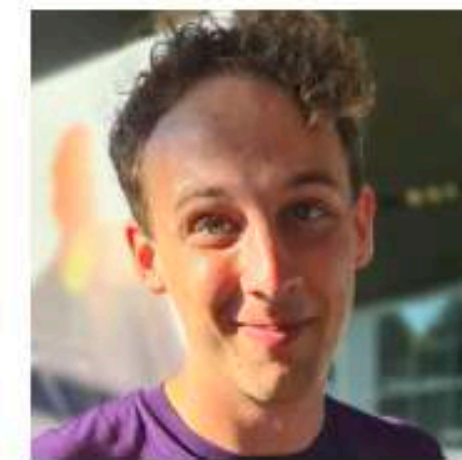
Jakob  
Müller



Nicolas  
Seitz

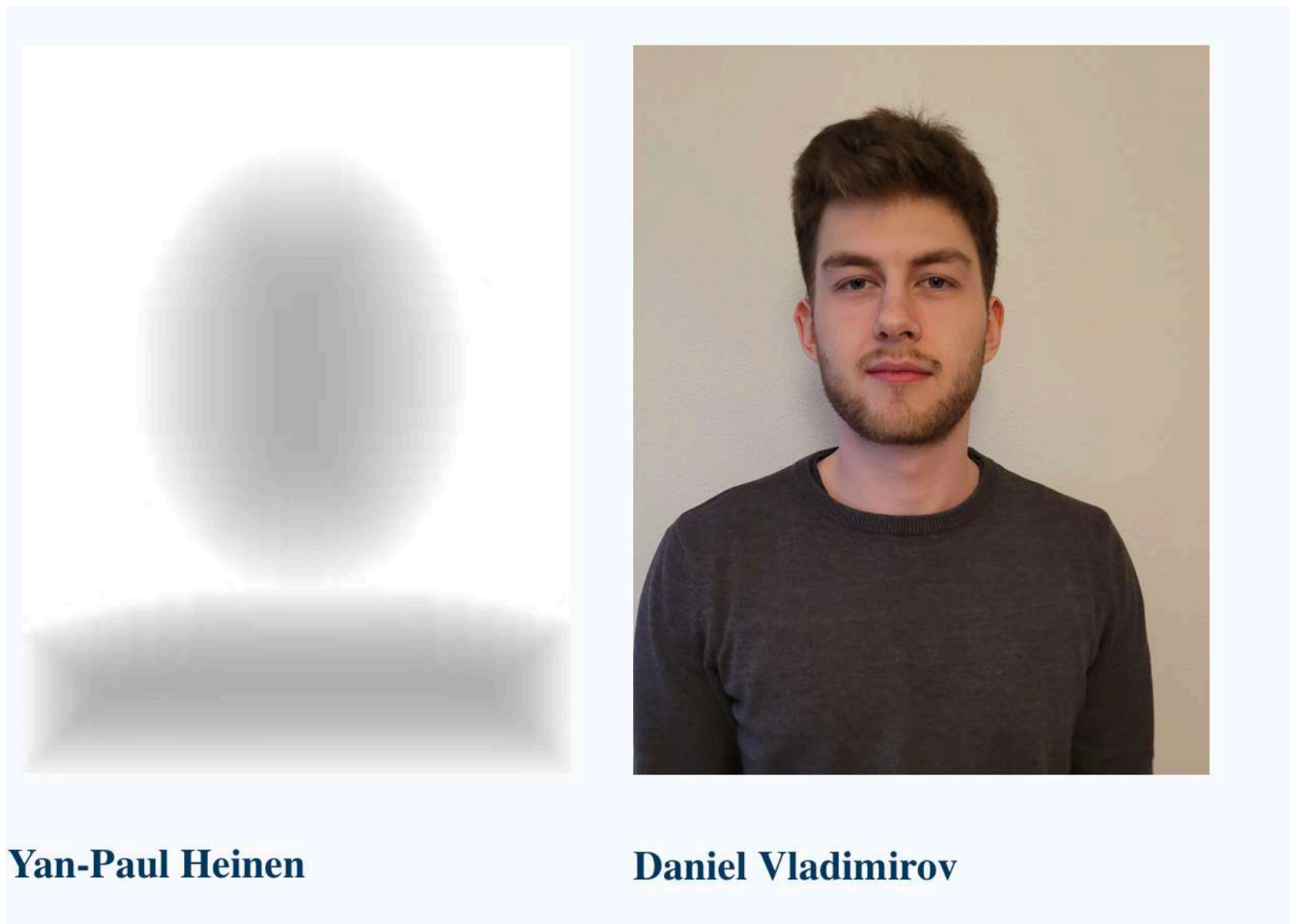


Tobias  
Striegl

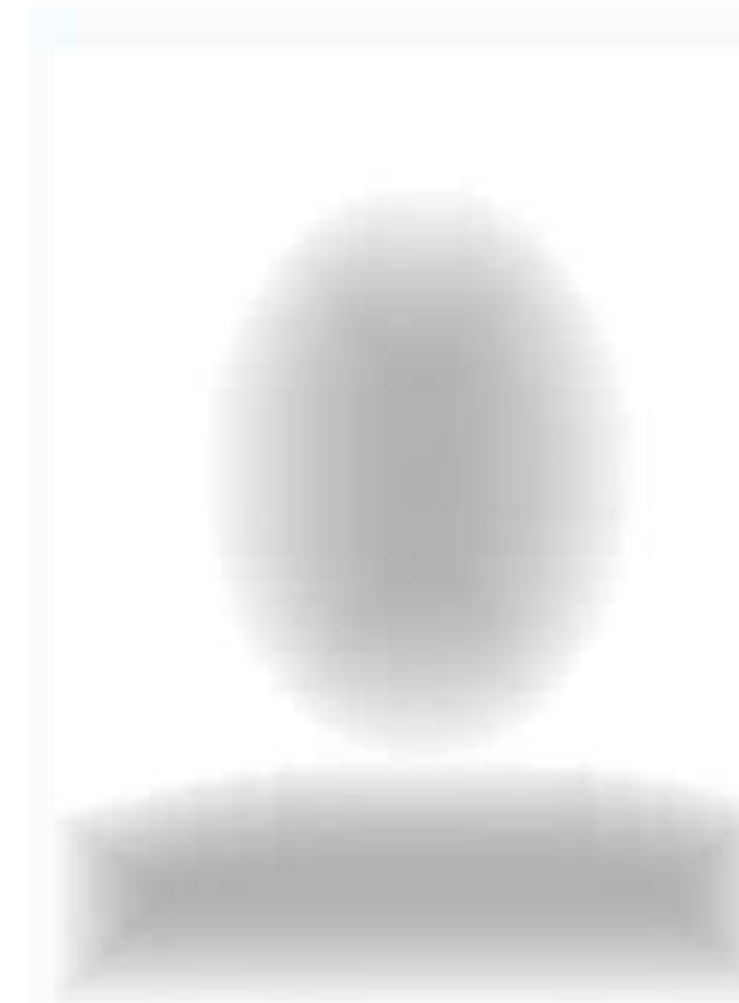


Zachary  
Wüthrich

## Master



## Bachelor



**Tobias Boer**



**Alexander Breitenbach**

**?**

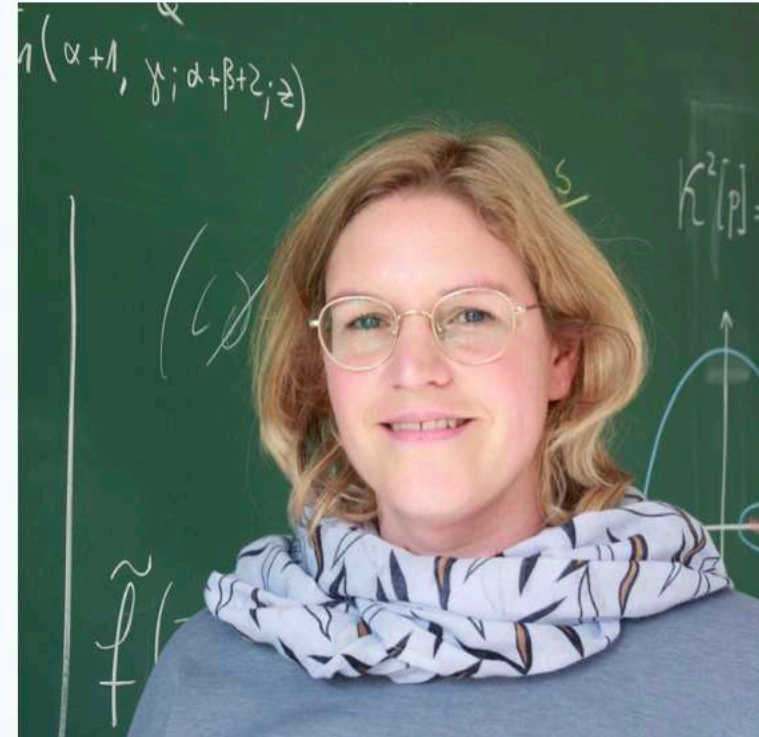
XXX

**?**

XXX



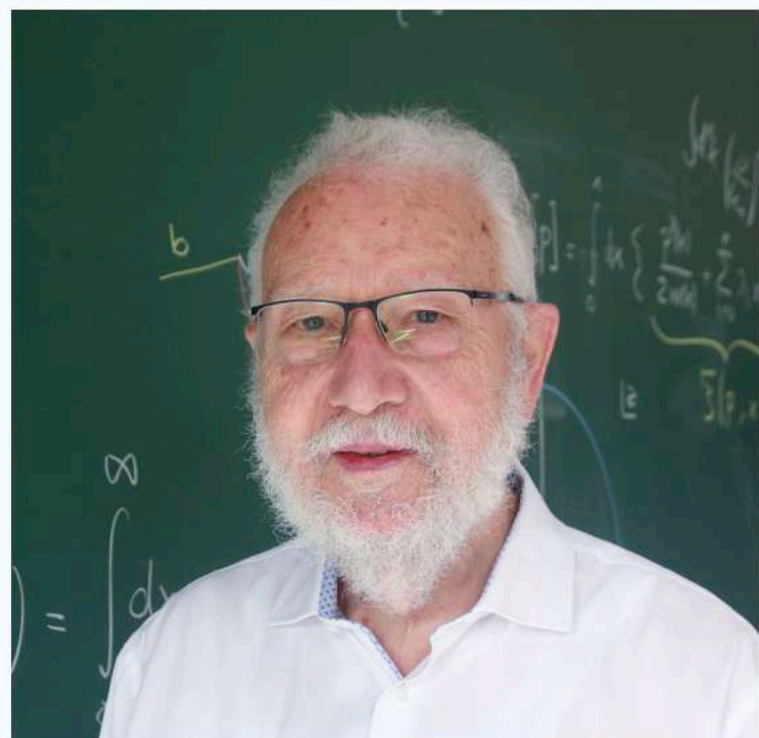
Arzu Ergüzel



Sharon Harvey



Daniela Lehmann



Claus Grupen

42 Members

- 12 staff members
- 11 post-docs
- 13 PhD students
- 2 Master students
- 2 Bachelor students
- 1+2 secretaries

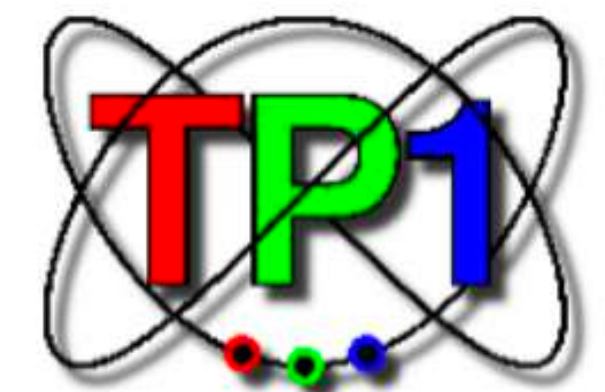
+1 honorary emeritus

◇ Theoretical Particle Physics Group  
at University of Siegen founded in 2003

⇒ 20th anniversary celebration on 19 October 2023

# 42

The answer to  
life, the universe  
and everything.



## Topics

- ★ Tree-level decays  $B \rightarrow D^{*,**} \dots$
- ★ Rare FCNC decays  $b \rightarrow (d, s)\ell^+\ell^-$
- ★ Non-leptonic  $B$ -meson decays
- ★ Exclusive and inclusive  $V_{cb}, V_{ub}$
- ★ Heavy hadron lifetimes and mixing
- ★ CP violation
- ★ Electroweak physics
- ★ LHC phenomenology
- ★ Beyond SM (2HDMs, DM, ...)
- \* QCD and jets" oder "Event shapes and jets

## Tools

- ★ Effective field theories (HQET, SCET, SMEFT)
- ★ Heavy quark expansion
- ★ QCD factorisation
- ★ Light-cone distribution functions
- ★ Multi-loop techniques
- ★ QCD sum rules, LCSR
- ★ Lattice Field Theory
- ★ MC-based event generators (WHIZARD, SHERPA)
- \* Light cone distribution amplitudes

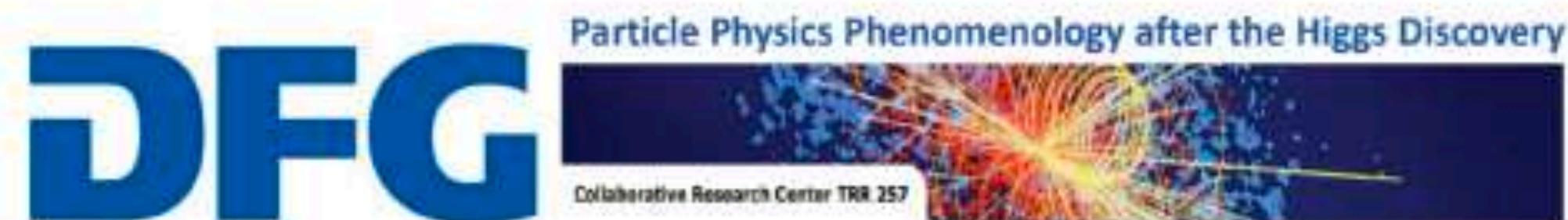
1. **Setting the scene**
2. **TP1 at a glance**
3. **Third Party Funding**
4. **TP1 in more details**
5. **International visibility/outreach**
6. **Outlook**

# Projects

- ◇ Collaboration with experimental flavour Physics
  - ★ BMBF Projects with Heidelberg and Dortmund  
"Theoretical Methods for LHCb and Belle II"
  - ★ Common lecture courses with Bonn and Dortmund
  - ★ Common conferences with Bonn and Dortmund
  - ★ Common schools with Bonn and Dortmund



- ◇ SFB with Aachen, Karlsruhe and Heidelberg



**Funding period I 1/2019 - 12/2022**  
**Funding period II 1/2023 - 12/2026**  
**Funding period III 1/2027 - 12/2030**



## Color meets Flavor



RA 1

RA 2

RA 3

RA 4



	UP, DOWN STRANGE	CHARM BOTTOM	TOP HIGGS	AXION
Experiments	ELSA (Bonn) AMBER (CERN)	LHCb (CERN) Belle II (KEK)	ATLAS (CERN)	IAXO (DESY)
Experimental Groups	Bonn, Dortmund, Siegen	Bonn, Dortmund	Bonn, Dortmund, Siegen Bonn, Siegen, Dortmund	Bonn, Siegen
Theoretical Groups	Bonn, Jülich	Siegen, Dortmund, Bonn, Jülich	Bonn, Dortmund, Siegen Bonn, Siegen	Bonn, Dortmund

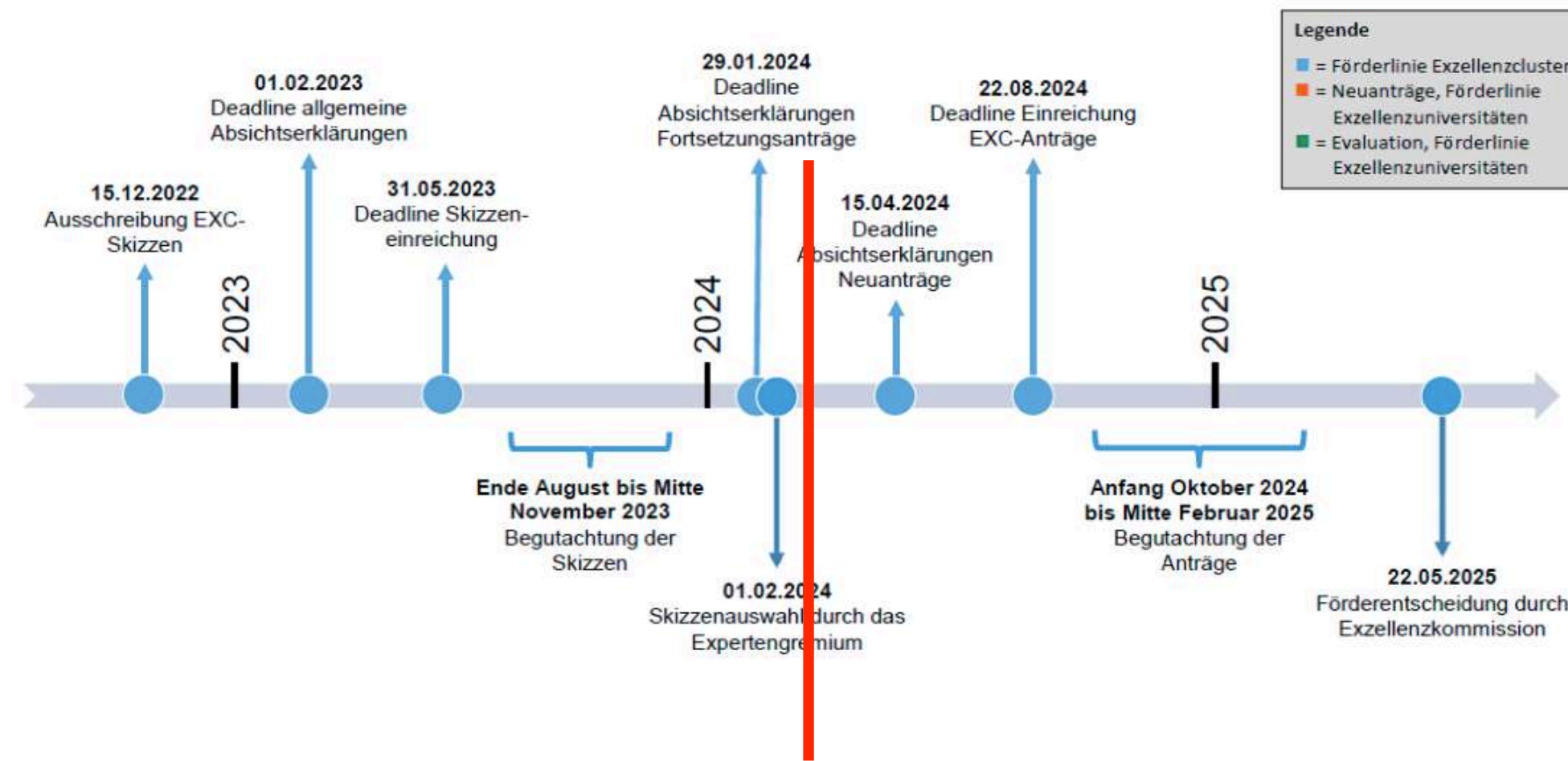


## History:

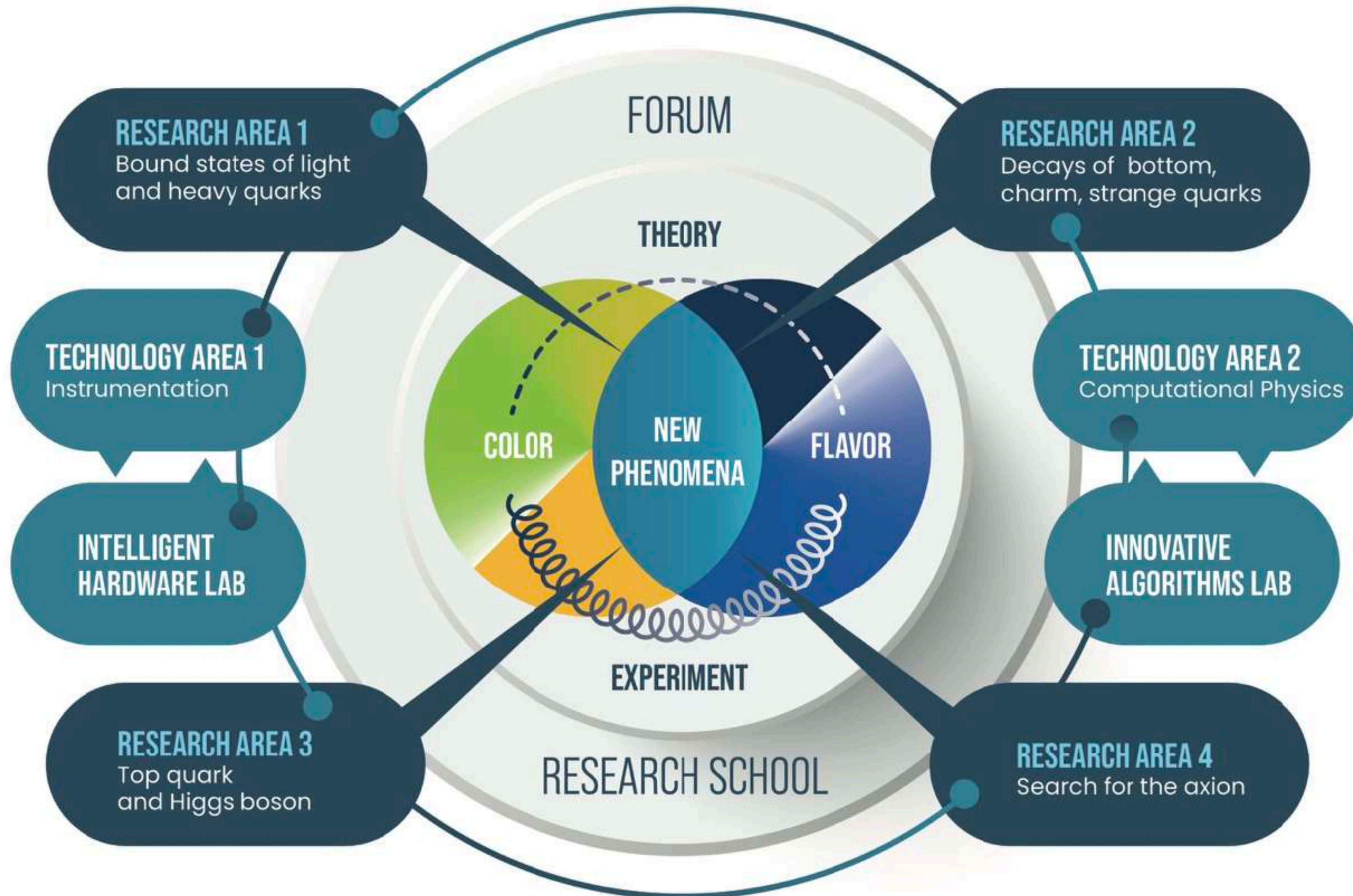
- Color meets Flavor: Name 2011 Symposium Alex K. @60
- Siegen - Dortmund Theorie: QFET 2013- 2019
- Siegen - Dortmund Experiment: Lehre Flavorphysik in Experiment seit 2018
- Siegen - Bonn: 2016 semi-leptonische Zerfälle  
Leptonic and semileptonic decays of B mesons  
Jochen Dingfelder (Bonn U.), Thomas Mannel (Siegen U.) (Sep 21, 2016)  
Published in: *Rev.Mod.Phys.* 88 (2016) 3, 035008
- Netzwerk NRW-Antrag 2019: Albrecht, Dingfelder, Mannel
- 29.1.2021 Email: Th. Mannel to Albrecht, Dingfelder, Lenz, Spaan

# Color meets Flavor

## Förderlinie Exzellenzcluster

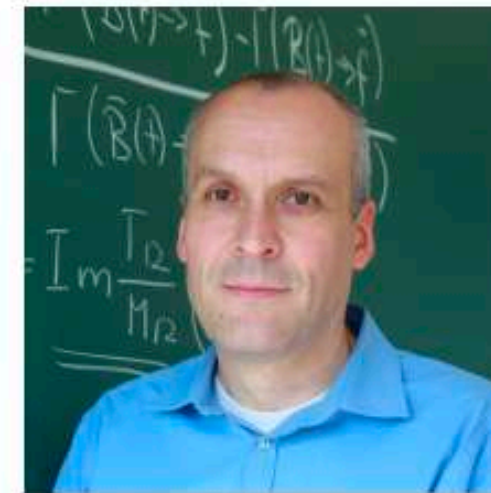


# Projects

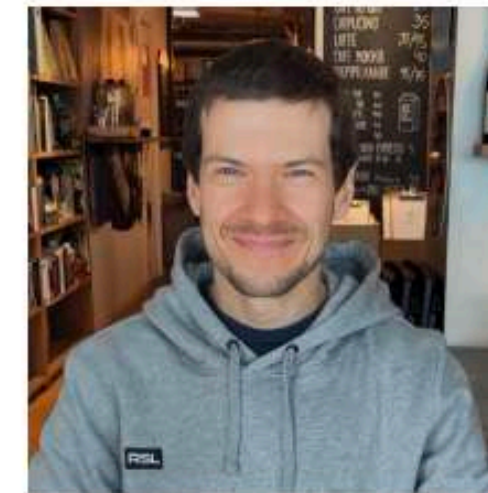


1. **Setting the scene**
2. **TP1 at a glance**
3. **Third Party Funding**
4. **TP1 in more details**
5. **International visibility/outreach**
6. **Outlook**

- ▶ Applications of Soft-Collinear Effective Theory (SCET) in flavour and collider physics
- ▶ Automation of NNLO calculations
- ▶ Factorisation of soft and collinear dynamics at next-to-leading power
- ▶ Study of event shapes at  $e^+e^-$  and hadron colliders
- ▶ Non-leptonic  $B$  decays



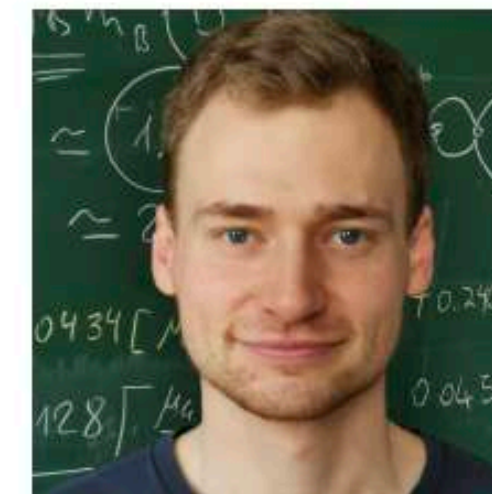
Prof. Guido Bell



Dr. Vladislav Stabovenko



Dr. Kevin Brune



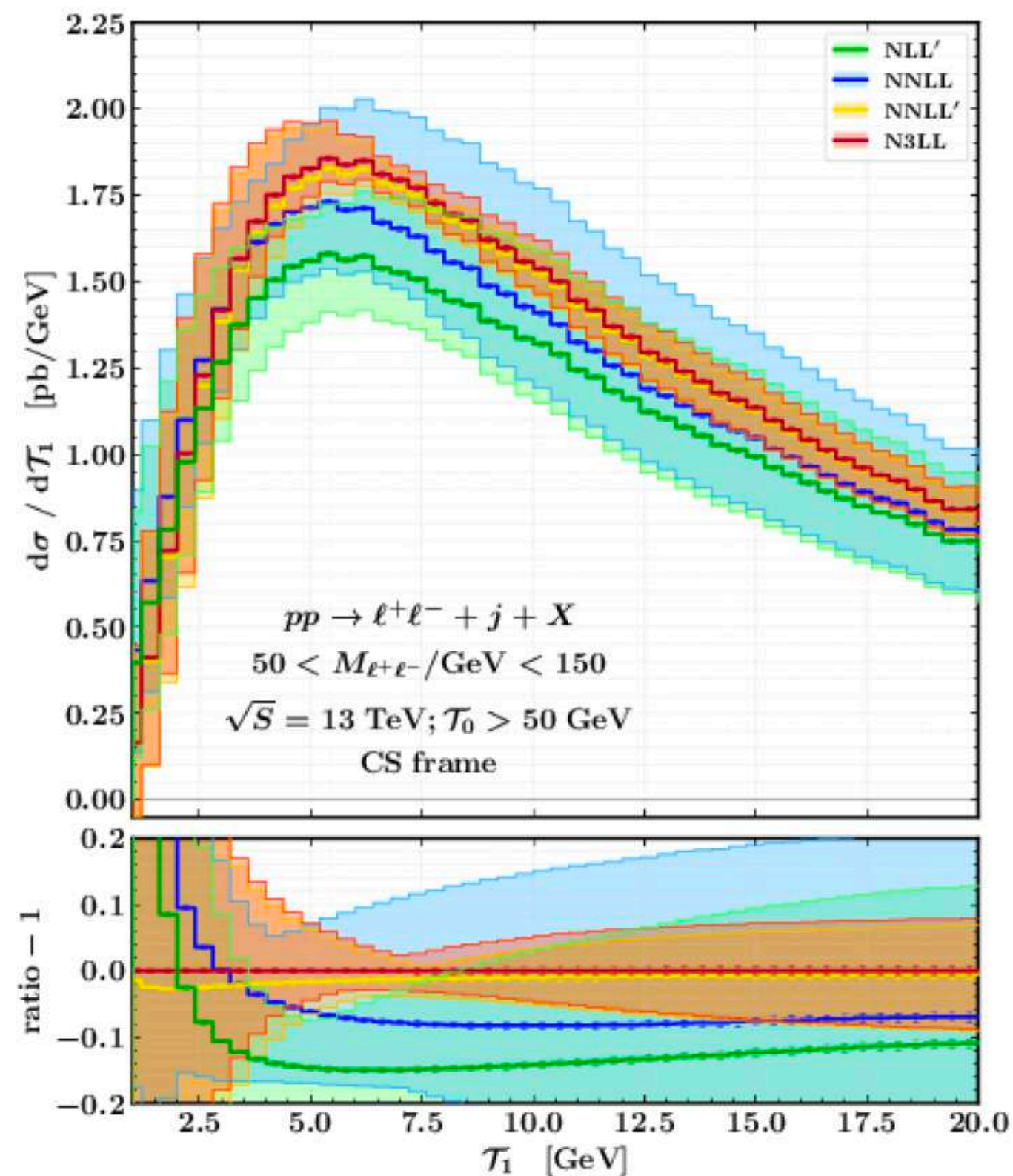
Dennis Horstmann



Sebastian Edelmann

Resummation of soft+collinear logarithms beyond the parton-shower accuracy (LL)

1-jettiness in  $Z$ +jet production



$$\frac{d\sigma}{d\mathcal{T}_1} \simeq H_{ij \rightarrow k} \cdot B_i \otimes B_j \otimes J_k \otimes S_{ij \rightarrow k} + \mathcal{O}(\mathcal{T}_1)$$

- ▶ Automated calculation of NNLO soft functions



[Bell, Rahn, Talbert 18,20;  
[Bell, Dehnadi, Mohrmann, Rahn 23]

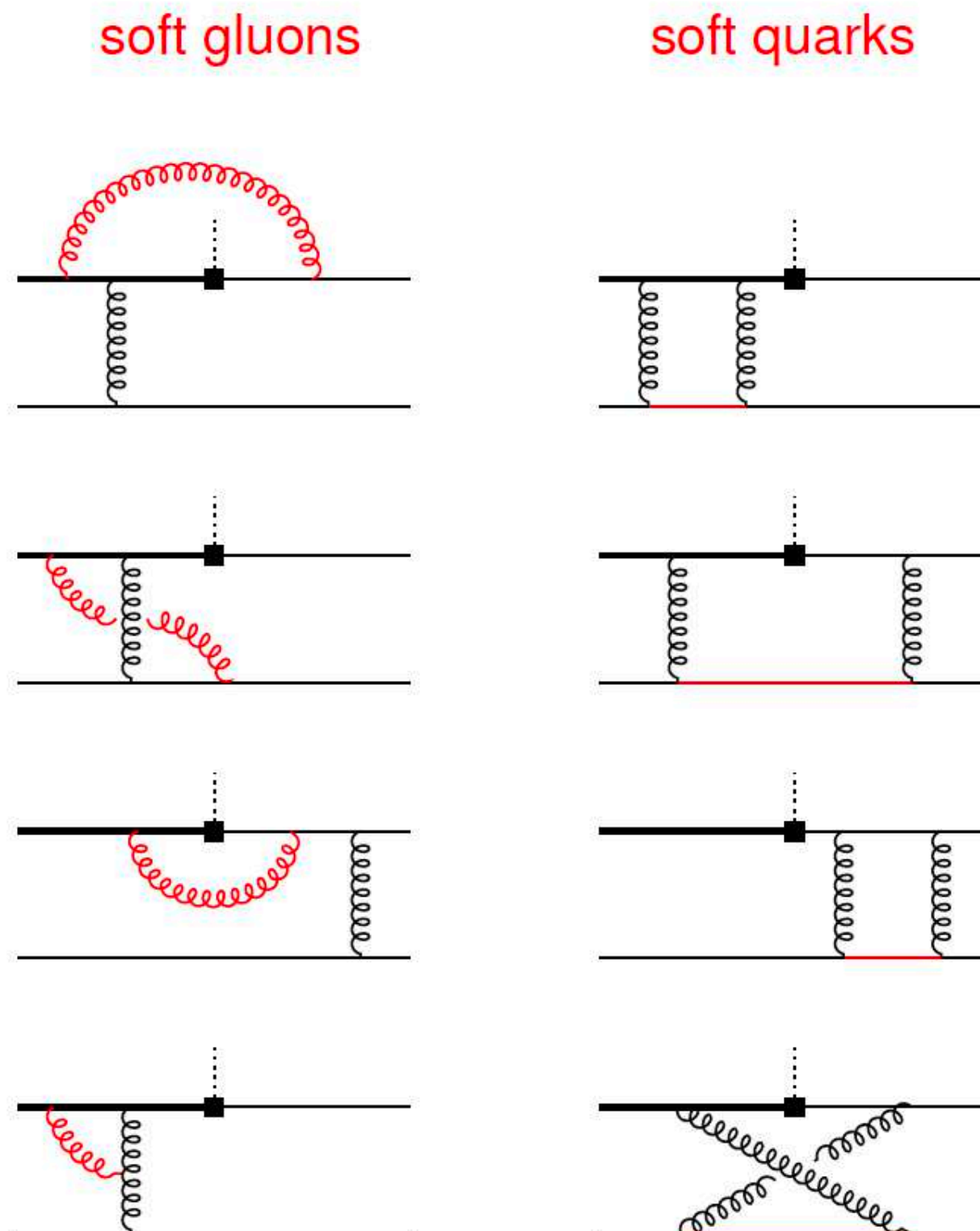
extension to  $pp \rightarrow t\bar{t}X$  (→ poster by Sebastian)

- ▶ Similar setup for NNLO jet and beam functions

[Bell, Brune, Das, Wald 22+wip]

Parton shower resums the leading logarithms (LL) via soft-gluon exponentiation

⇒ resummation more complicated at next-to-leading power due to **soft-quark** configurations



- ▶ Factorisation currently not understood

$$F_{B_c \rightarrow \eta_c}(q^2 \approx 0) \neq H \cdot \phi_{\eta_c} \otimes J \otimes \phi_{B_c}$$

- ▶ Resummation of LL with diagrammatic techniques

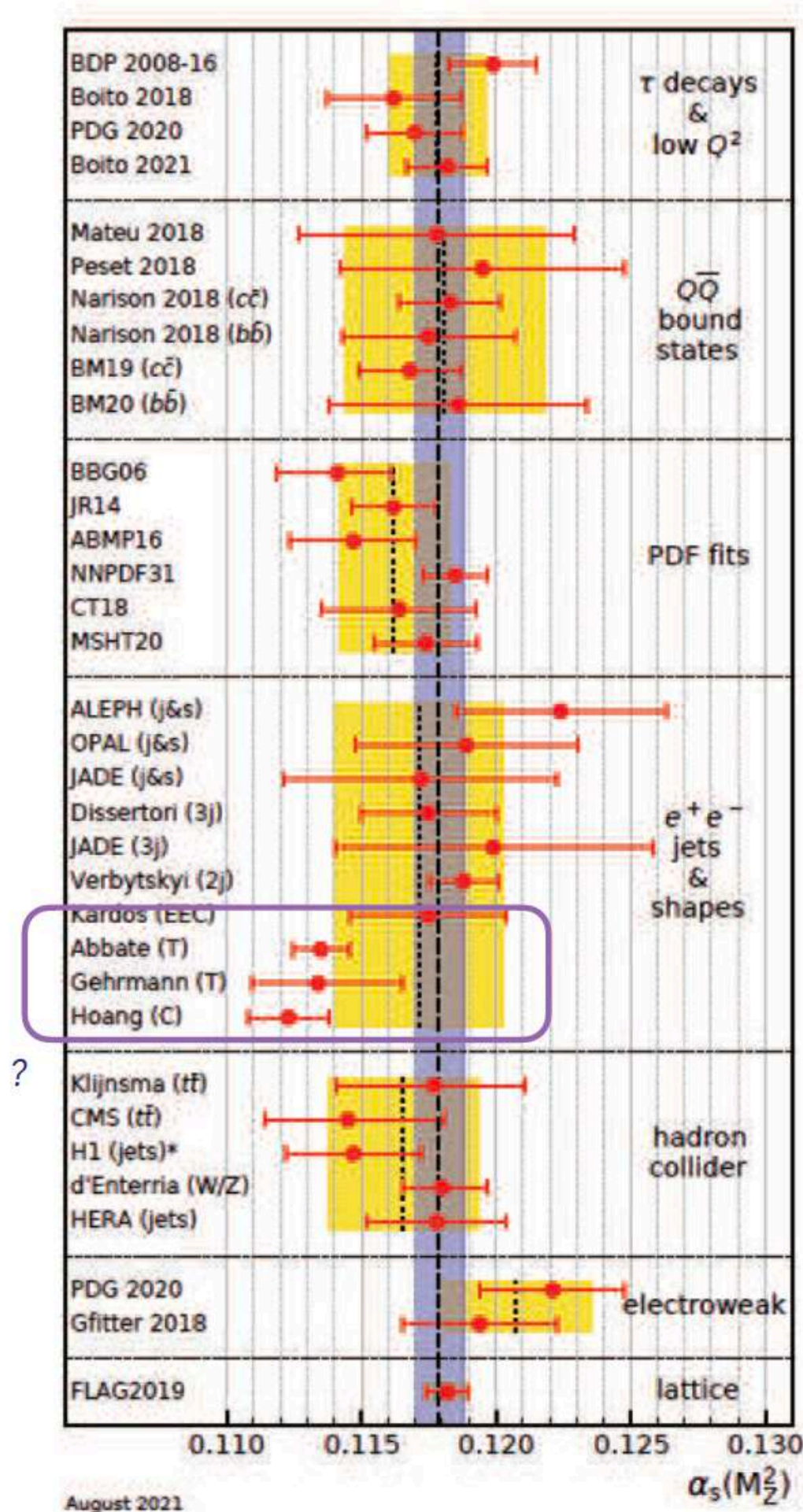
[Bell, Böer, Feldmann, Horstmann, Shtabovenko 23+wip]

$$F_m(\eta) = 1 + \hat{\alpha} C_F \int_0^\eta d\eta' \eta' e^{-S(\eta-\eta', \eta')} F_m(\eta')$$

(→ poster by Dennis)

- ▶ relevant for exclusive  $B$  decays

## Precision determinations of $\alpha_s$ from $e^+e^-$ event shapes

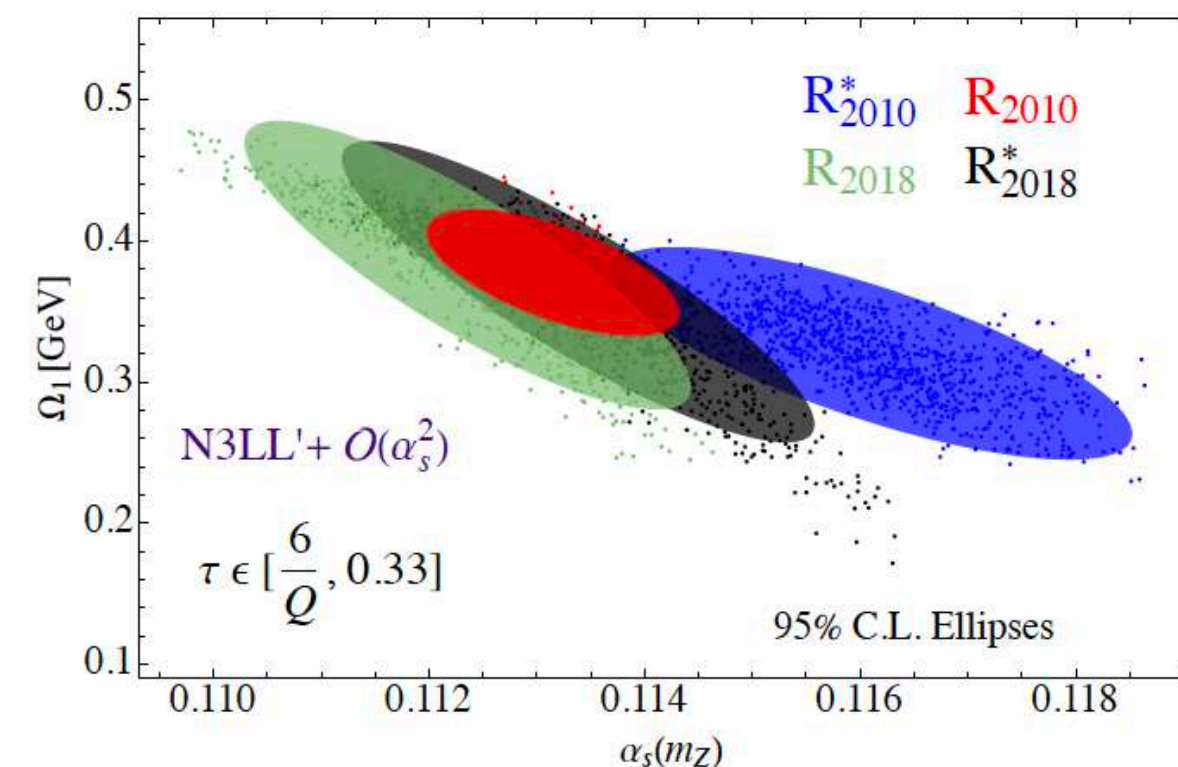


$3\sigma$  tension with other  $\alpha_s$  determinations

$$\alpha_s(M_Z) = \begin{cases} 0.1135 \pm 0.0011 & \text{Thrust} \\ 0.1179 \pm 0.0009 & \text{PDG world average} \end{cases}$$

Careful reanalysis of scale and scheme dependence

[Bell, Lee, Makris, Talbert, Yan 23]



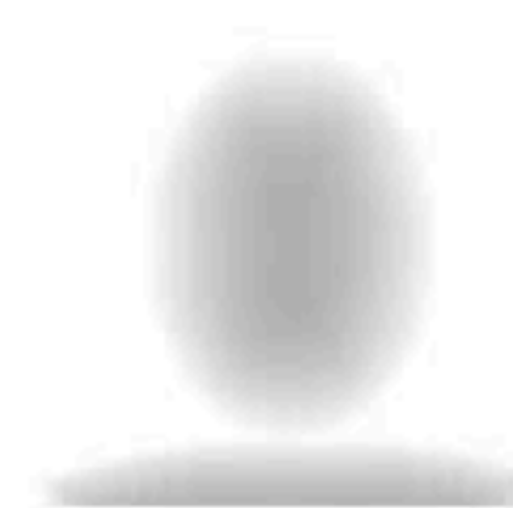
sign of underestimated theory uncertainties?



- ★ Phenomenology of rare  $B$ -meson and  $\Lambda_b$ -baryon decays
- ★ NP interpretation of flavor anomalies
- ★ Light-cone distribution amplitudes and form factors of  $B$  mesons
- ★ QCD factorisation and SCET



Prof. Thorsten Feldmann



Dr. Jack Jenkins



Philip Lüghausen



Nikolas Seitz



Daniel Vladimirov

## Phenomenological applications

Rare decays of  $\Lambda_b$  baryons:

- angular analysis of  $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$   
[Böer, Feldmann, van Dyk, JHEP **01** (2015)]  
\* standard reference
- contributions of 4-quark operators  
[Feldmann, Gubernari, arXiv:2312.14146 [hep-ph].]
- properties of  $\Lambda_b$  soft functions  
[Feldmann, Gubernari, planned]

Rare decays of  $B$ -mesons

- QCD factorization for exclusive  $b \rightarrow s(d) \ell^+ \ell^-$  transitions  
[Beneke, Feldmann, Seidel, Nucl. Phys. B **612** (2001)]  
[Beneke, Feldmann, Seidel, Eur. Phys. J. C **41** (2005)]  
\* standard references
- $B \rightarrow K^{(*)} \ell^+ \ell^-$  decays at high  $q^2$   
[Beylich, Buchalla, Feldmann, EPJ-C **71** (2011)]  
\* standard reference
- QED corrections to  $B_s \rightarrow \mu^+ \mu^-$   
[Feldmann, Gubernari, Huber, Seitz, PRD **107** (2023)]

→ poster

## Hadronic Input functions

## Light-cone distribution amplitudes

- LCDAs for non-relativistic bound states  
[Bell, Feldmann, JHEP **04** (2008)]
- RG evolution of heavy-hadron LCDAs  
[Bell, Feldmann, Wang, Yip, JHEP **11** (2013)]  
\* standard reference
- generic parametrization for  $B$ -meson  
[Feldmann, Lüghausen, van Dyk, JHEP **10** (2022)]  
→ poster
- strange-quark mass effects for  $B_s$   
[Feldmann, Lüghausen, Seitz, JHEP **08** (2023)]  
→ poster
- phenomenological fit, using  $B \rightarrow \gamma \ell \bar{\nu}$   
[Feldmann, Lüghausen, van Dyk, work in progress]
- radiative tail of  $\Lambda_b$  LCDAs  
[Feldmann, Vladimirov, planned]

## Heavy-to-light form factors

- $B \rightarrow P, V$  form factors at large recoil  
[Beneke, Feldmann, Nucl. Phys. B **592** (2001)]  
\* standard reference
- $B \rightarrow P, V$  FFs from SCET sum rules  
[De Fazio, Feldmann, Hurth, Nucl. Phys. B **733** (2006)]  
[De Fazio, Feldmann, Hurth, JHEP **02** (2008)]
- $\Lambda_b \rightarrow \Lambda$  form factors from sum rules  
[Feldmann, Yip, Phys. Rev. D **85** (2012)]
- soft-overlap for  $B_c \rightarrow \eta_c$  FFs  
[Böer et al, arXiv:2309.08410 [hep-ph].

→ poster

## Effective Field Theory approaches

### Interpretation of flavour anomalies

- minimal flavour violation and beyond  
[Feldmann, Mannel, JHEP **02** (2007)]
- sequential flavour symmetry breaking  
[Feldmann, Mannel, Phys. Rev. Lett. **100** (2008)]  
[Feldmann, Jung, Mannel, Phys. Rev. D **80** (2009)]
- lepto-quarks in SMEFT  
[Bordone, Catà, Feldmann, JHEP **01** (2020)]  
[Bordone, et al., JHEP **03** (2021)]

→ parallel talk by TF

### SCET and QCD factorization

- SCET and heavy-to-light currents  
[Beneke et al., Nucl. Phys. B **643**]  
Beneke, Feldmann, Phys. Lett. B **553** (2003)  
\* standard references
- factorization of  $B \rightarrow \pi$  form factor  
Beneke, Feldmann, Nucl. Phys. B **685** (2004)  
\* standard reference
- endpoint logs in  $\mu^- e^-$  scattering  
[Bell, Böer, Feldmann, JHEP **09** (2022)]

- ★ Non-leptonic  $B$ -meson decays
- ★ FCNCs decays  $B \rightarrow X_{s,d} \{ \gamma, l^+ l^- \}$
- ★ Effective field theories
- ★ Multi-loop computations



Prof. Tobias Huber



Dr. Gilberto  
Tetlalmatzi-Xolocotzi



Eleftheria Malami



Lars-Thorben Moos



Jakob Müller

Ongoing and recently completed projects (see also poster session)

- Non-leptonic B decays

- charmless two-body decays

- Flavour symmetries vs. QCD factorization  
[Gilberto, Eleftheria, TH et al.]
    - Power corrections in QCD factorization  
[Guido, TH et al.]

- Two-body B decays with open charm

- Higher-order corrections, phenomenology, and power corrections in QCD factorization  
[N. Gubernari, TH et al.]

- Three-body B decays

- CP violation, flavour symmetries, topological amplitudes and QCD factorization  
[Eleftheria, Thomas, TH et al.]
    - $B \rightarrow D\pi\pi$  decays in QCD factorization  
[TH et al.]

- Rare and radiative B decays

- Inclusive  $\bar{B} \rightarrow X_s \gamma$

- Multibody contributions at NLO [Kevin, Lars, TH]
    - Exact charm-mass dependence at NNLO  
[TH et al.]

- Inclusive  $\bar{B} \rightarrow X_{s,d} \ell^+ \ell^-$

- SM prediction (higher orders,  $c\bar{c}$  resonances, hadronic mass cut), model-independent NP analysis [Jack, TH et al.]

- QED corrections to  $\bar{B}_s \rightarrow \mu\mu$

- Factorization and resummation of log-enhanced QED corrections at subleading power [Thorsten, Nicolas, N. Gubernari, TH]

- Multi-loop computations

- Massless form factors at higher loops

- $\mathcal{N} = 4$  super Yang-Mills theory

- $\gamma^* \rightarrow q\bar{q}, gg \rightarrow H, H \rightarrow b\bar{b}$

[TH et al.]

- Heavy-to-light currents at three loops in QCD

- $b \rightarrow ul\nu, b \rightarrow s\gamma, b \rightarrow sll$

[Jakob,TH et al.]

- Development of new algorithms for (parametric) loop-integral reduction

- Methods from algebraic geometry

- Syzygies, Gröbner bases

[Barakat,TH et al.]

- Collider physics

- Extended Higgs sectors

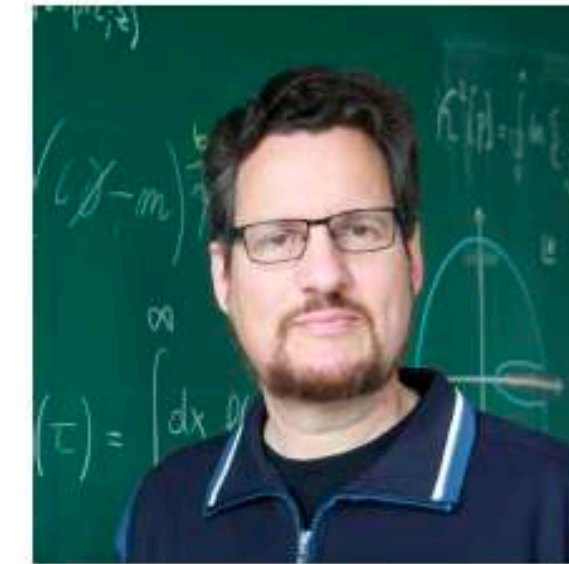
- Flavour - high- $p_T$  interplay

[Gilberto et al.]

- ★ Monte Carlo based event generators  
WHIZARD and SHERPA for  $e^+e^-$   
colliders

- ★ Standard Model effective field theory  
(SMEFT)

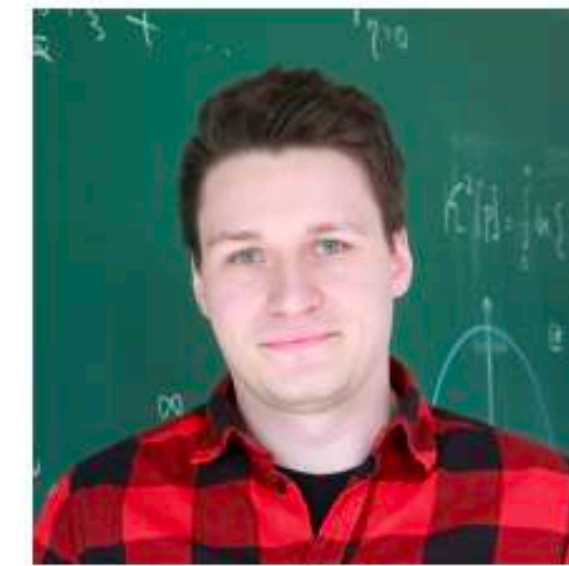
- ★ Electroweak physics



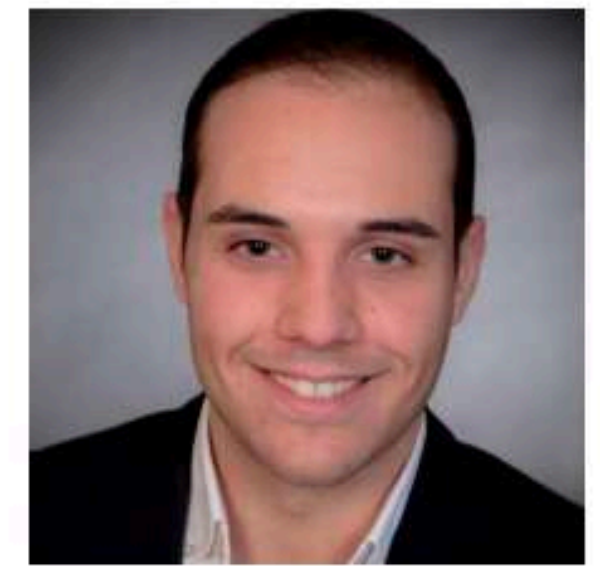
Prof. Wolfgang Kilian



Dr. Pia Bredt



Nils Kreher



Tobias Striegl



**Pia Bredt** + the Whizard team: Multi-particle production and event generation at one loop in the complete SM: (LHC,  $e^+e^-$ ,  $\mu^+\mu^-$ )

JHEP 12 (2022) 138 (arXiv:2208.09438)

Current projects:

- ▶ SMEFT @ one loop (with G. Heinrich, M. Höfer / KA)
- ▶ Validation: fully matched exclusive events (Pythia8)  
⇒ collab. with experiment welcome

Example:  $t\bar{t}Z$  @ LHC

$pp \rightarrow t\bar{t}Z$	$\alpha_s^n \alpha^m$	$\sigma^{\text{tot}}$ [fb]		$\sigma^{\text{sig}} / \text{dev}$
		MUNICH <sub>(CS)</sub>	WHIZARD	MUNICH <sub>(CS)</sub> -WHIZARD
LO <sub>21</sub>	$\alpha_s^2 \alpha$	$5.04648(2) \cdot 10^2$	$5.0463(2) \cdot 10^2$	0.82 / 0.003%
LO <sub>12</sub>	$\alpha_s \alpha^2$	$-3.48777(7) \cdot 10^0$	$-3.4876(2) \cdot 10^0$	0.71 / 0.004%
LO <sub>03</sub>	$\alpha^3$	$1.141785(6) \cdot 10^1$	$1.14179(4) \cdot 10^1$	0.008 / 0.000%
$\delta\text{NLO}_{31}$	$\alpha_s^3 \alpha$	$2.26389(6) \cdot 10^2$	$2.264(1) \cdot 10^2$	0.26 / 0.017%
$\delta\text{NLO}_{22}$	$\alpha_s^2 \alpha^2$	$-4.231(2) \cdot 10^0$	$-4.228(3) \cdot 10^0$	1.02 / 0.084%
$\delta\text{NLO}_{13}$	$\alpha_s \alpha^3$	$4.2428(7) \cdot 10^0$	$4.245(3) \cdot 10^0$	0.76 / 0.062%
$\delta\text{NLO}_{04}$	$\alpha^4$	$-4.111(1) \cdot 10^{-1}$	$-4.111(2) \cdot 10^{-1}$	0.21 / 0.012%

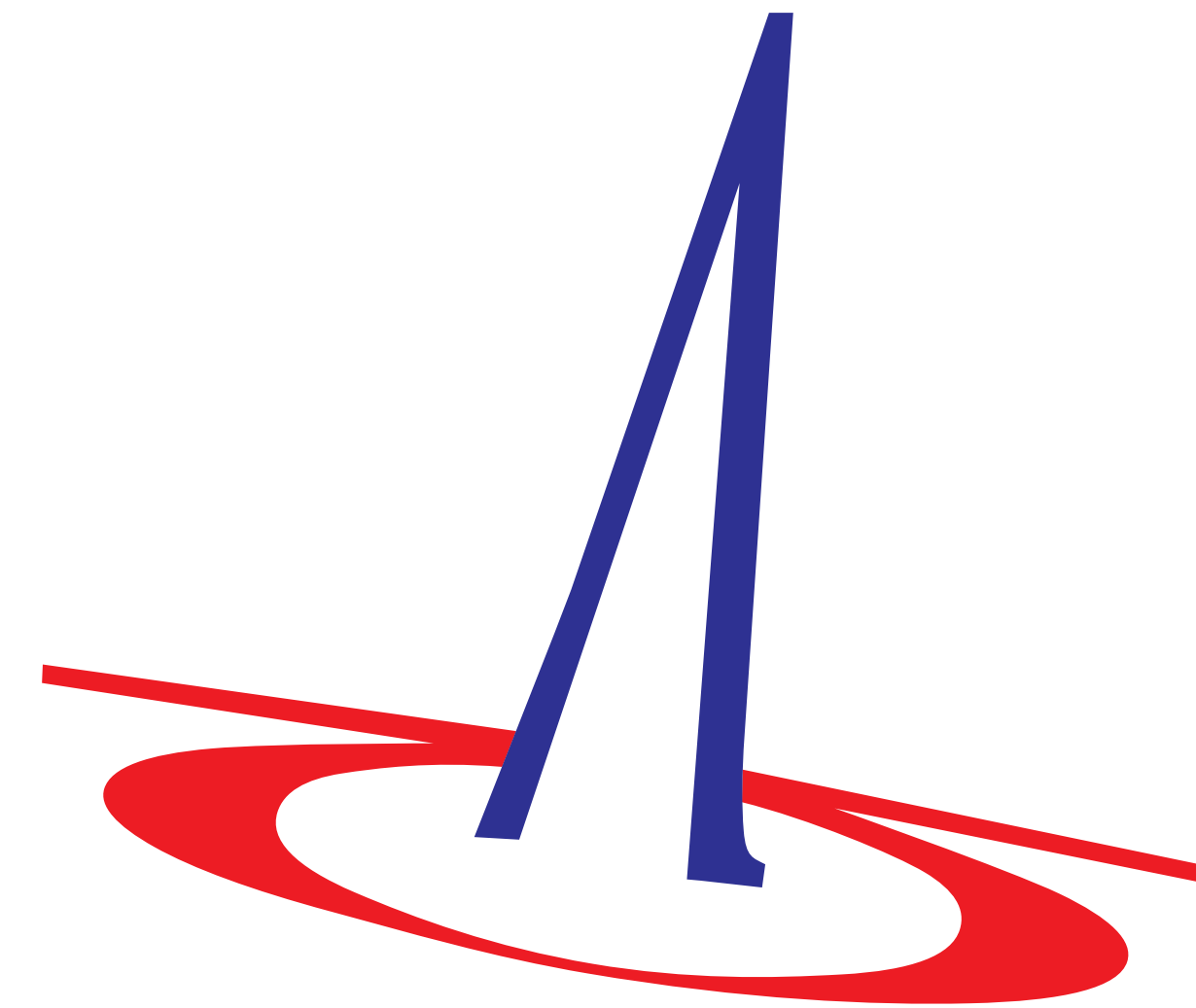


**Nils Kreher, Tobias Striegl** + T. Han, F. Maltoni, et.al.:  
Multi-boson production and new physics at a **multi-TeV Muon Collider**  
JHEP 12 (2021) 162 (2108.05362); 2312.13082

- ▶ SMEFT / HEFT / simplified models
- ▶ Probing the muon Yukawa sector
- ▶ **Plan:** Matching to effective electroweak shower / jets

**Pia Bredt, Tobias Striegl** + the Whizard team:

- ▶ **Current project:** (**ILC/CLIC/FCC-ee**) Effective electron structure function + exclusive photon radiation at NLO



## Nils Kreher:

- ▶ **Current project:** Pheno of parity-odd electroweak amplitudes at one loop / with SMEFT (“gauge anomaly”)

## Whizard (Bredt, Kreher, Striegl) with

J. Reuter, K. Mekala (DESY) + T. Ohl (WÜ) + F. Zarnecki (Warsaw)

- ▶ Universal **Monte Carlo for HEP colliders**, now with NLO-SM (v3)
- ▶ Beamstrahlung, ISR, PDF, polarization, shower/matching  
⇒ event-sample production in ILC/CLIC/FCC/CEPC studies
- ▶ MPI (parallel) evaluation + generation
- ▶ **Current project:** ML improvements for NLO phase space (with A. Butter, T. Plehn / HD)



- ★ Lifetimes of bottom and charm hadrons
- ★ Mixing in bottom and charm sectors
- ★ Lattice QCD for semileptonic form factors and Bag parameters
- ★ FCNC  $b \rightarrow (s, d)l^+l^-$  processes
- ★ Non-leptonic  $B$ -meson decays from LCSR
- ★ Beyond SM (incl. 2HDMs and DM)



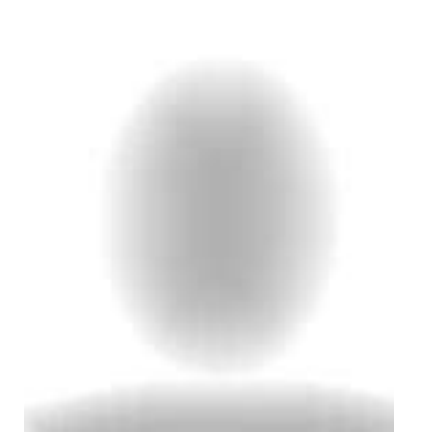
Prof. Alexander Lenz



Dr. Oliver Witzel



Dr. Aleksey Rusov



Jan Paul Heinen



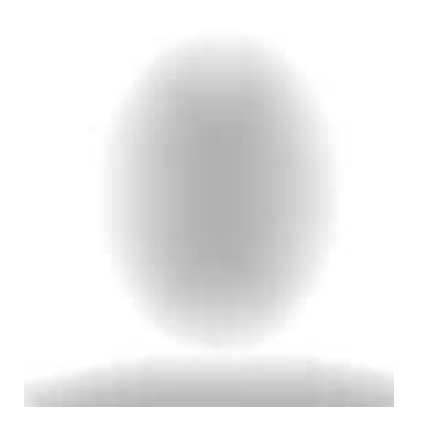
Dr. Maria Laura Piscopo



Dr. Meril Reboud



Martin Lang



Tobias Boer



Matthew Black



Zachary Wüthrich



Ali Mohamed

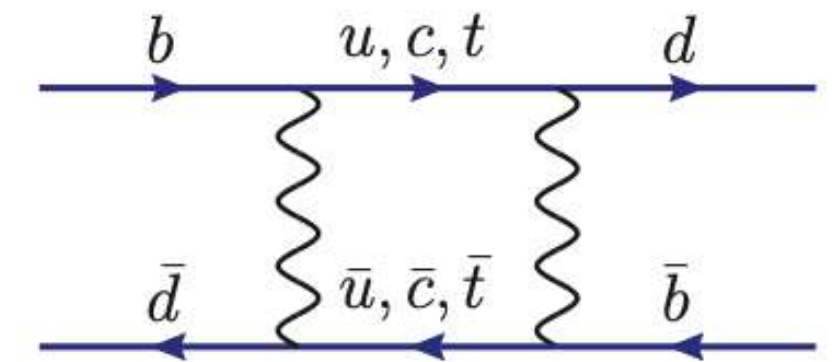


Alexander Breitenbach

Lifetime  
 $\tau = 1/\Gamma$

$$\Gamma(B_q) = \Gamma_3 + \Gamma_5 \frac{\langle \mathcal{O}_5 \rangle}{m_b^2} + \Gamma_6 \frac{\langle \mathcal{O}_6 \rangle}{m_b^3} + \dots + 16\pi^2 \left( \tilde{\Gamma}_6 \frac{\langle \tilde{\mathcal{O}}_6 \rangle}{m_b^3} + \tilde{\Gamma}_7 \frac{\langle \tilde{\mathcal{O}}_7 \rangle}{m_b^4} + \dots \right)$$

Mixing



$\Gamma_3^{(1)}$	1983	Ho-Kim, Pham [180]
	1991	Altarelli, Petrarca [211]
	1994	Voloshin [212]
	1994/95	Bagan, Ball, Braun/Fiol, Goszinsky [213, 214]
	1997/98	Lenz, Nierste, Ostermaier [215, 216]
$\Gamma_3^{(2)}$	2005	Czarnecki, Slusarczyk, Tkachov [220] (partly)
	2008	Greub, Liniger [217, 218]
$\Gamma_5^{(0)}$	1992	Bigi, Uraltsev, Vainshtein [195]
	1992	Bigi, Blok, Shifman, Uraltsev, Vainshtein [196]
	1992	Blok, Shifman [197, 198]
$\Gamma_5^{(1)}$	2023	Mannel, Moreno, Pivovarov [221]
$\Gamma_6^{(0)}$	2020	Lenz, Piscopo, Rusov [179]
	2020	Mannel, Moreno, Pivovarov [222, 223]
$\tilde{\Gamma}_6^{(0)}$	1979	Guberina, Nussinov, Peccei, Ruckl [225]
	1986	Shifman, Voloshin [22]
	1996	Uraltsev [226]
	1996	Neubert, Sachrajda [227]
$\tilde{\Gamma}_6^{(1)}$	2002	Beneke, Buchalla, Greub, Lenz, Nierste [228]
	2002	Franco, Lubicz, Mescia, Tarantino [229]
	2013	Lenz, Rauh [230]
$\tilde{\Gamma}_7^{(0)}$	2003/04	Gabbiani, Onishchenko, Petrov [231, 232]

**Table 3** Summary of the theory status of the short-distance coefficients in the *non-leptonic* decay widths.

$$\Gamma_i = \Gamma_i^{(0)} + \frac{\alpha_s}{4\pi} \Gamma_i^{(1)} + \left(\frac{\alpha_s}{4\pi}\right)^2 \Gamma_i^{(2)} + \dots$$

$\langle Q_5 \rangle_{B_d}$	1993/96 2013-2023 2017/18	QCD sum rule [234, 235] Fit of inclusive data [236–241] Lattice QCD [242, 243]
$\langle Q_5 \rangle_{B_s}$	2011	Spectroscopy relations [244]
$\langle Q_5 \rangle_{\mathcal{B}}$	2023	Spectroscopy relations [34]
$\langle Q_6 \rangle_{B_d}$	1994/2022 2013-2023	EOM relation [31, 245] Fit of inclusive data [236–241]
$\langle Q_6 \rangle_{B_s}$	1994/2022 2011	EOM relation [31, 245] Sum rule [244]
$\langle Q_6 \rangle_{\mathcal{B}}$	2023	EOM relation [34]
$\langle \tilde{Q}_6 \rangle_{B_d}$	2017	HQET sum rule [246]
$\langle \tilde{Q}_6 \rangle_{B_s}$	2022	HQET sum rule [247]
$\langle \tilde{Q}_6 \rangle_{\Lambda_b}$	1996	QCD sum rule [248]
$\langle \tilde{Q}_6 \rangle_{\mathcal{B}}$	2023	NRCQM [34]
$\langle \tilde{Q}_7 \rangle$		VIA

**Table 4** Status of determinations of the non-perturbative parameters for the *b*-hadron lifetimes. Here,  $\mathcal{B}$  denotes the set of *b*-baryons  $\{\Lambda_b, \Xi_b^0, \Xi_b^-, \Omega_b\}$ .

$\tilde{\Gamma}_6^{(1)}$	1998	Beneke, Buchalla, Greub, Lenz, Nierste [280]
	2003	Beneke, Buchalla, Lenz, Nierste [281]
	2003	Franco, Lubicz, Mescia, Tarantino [282]
	2006	Lenz, Nierste [283]
$\tilde{\Gamma}_6^{(2)}$	2017	Asatrian, Hovhannisyan, Nierste, Yeghiazaryan [284]
	2020	Asatrian, Asatryan, Hovhannisyan, Nierste, Tumasyan, Yeghiazaryan [285]
	2021	Gerlach, Nierste, Shtabovenko, Steinhauser [286–288]
$\tilde{\Gamma}_7^{(0)}$	1996	Beneke, Buchalla [278]
$\tilde{\Gamma}_8^{(0)}$	2007	Badin, Gabbiani, Petrov [289]

**Table 6** Summary of theory status of short-distance contributions in  $\Gamma_{12}^q$ .

Lattice QCD		
$\langle \tilde{Q}_{6,1-5} \rangle_{B_{d,s}}$	2016	FNAL-MILC [270]
$\langle \tilde{Q}_{6,1-5} \rangle_{B_{d,s}}$	2019	HPQCD [271]
HQET sum rule		
$\langle \tilde{Q}_{6,1} \rangle_{B_d}$	2017	Grozin, Klein, Mannel, Pivovarov [272]
$\langle \tilde{Q}_{6,1-5} \rangle_{B_d}$	2017	Kirk, Lenz, Rauh [246]
$\langle \tilde{Q}_{6,1-5} \rangle_{B_s}$	2019	King, Lenz, Rauh [273]

**Table 5** Status of determinations of the non-perturbative parameters for *B<sub>q</sub>*-mixing.

Lifetimes of *b*-hadrons and mixing of neutral *B*-mesons: theoretical and experimental status

Johannes Albrecht, Florian Bernlochner, Alexander Lenz, Aleksey Rusov (Feb 6, 2024)

e-Print: 2402.04224 [hep-ph]

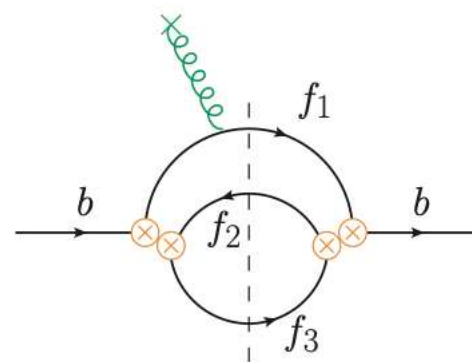
**Our SM predictions are the standard reference for HFLAG**

## CRC work in progress:

C1b:  $\Gamma_6^{(0),BSM}$ : Lang, Piscopo, Mohamed

$\Gamma_7^{(0),SM}$ : Reboud, Rusov

$\Gamma_5^{(1),SM}$ : Pivovarov, Wüthrich

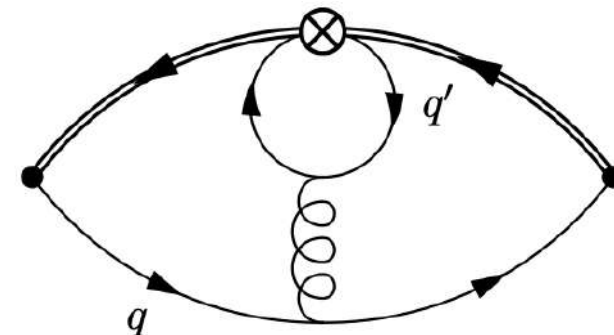
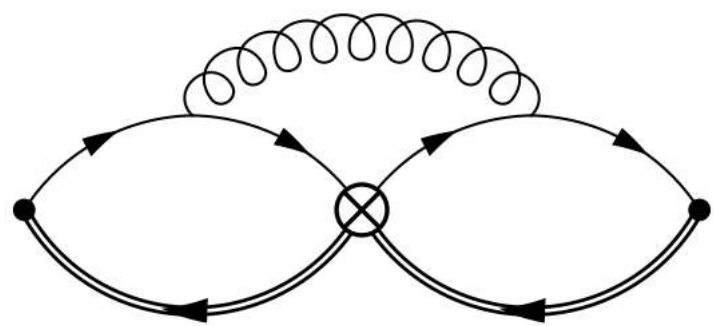


C1c:  $\langle \tilde{\mathcal{O}}_6 \rangle^{BSM}$  with HQET sum rules

Black, Lang, **Wüthrich**

$\langle \tilde{\mathcal{O}}_6 \rangle^{SM}$  with Gradient-Flow/Lattice

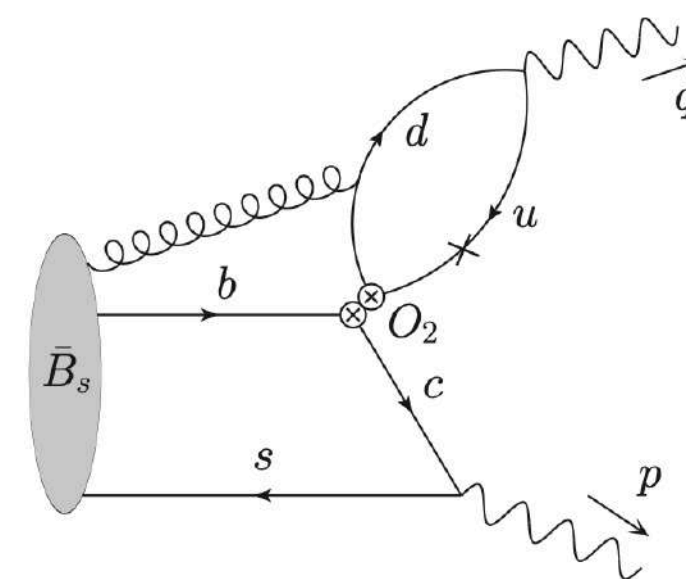
**Black**, Witzel



## Phenomenological Implications:

- Constraints on Baryogenesis models: **Mohamed**, Wüthrich
- Constraints on BSM in  $b \rightarrow c\bar{c}s$
- Constraints on BSM in  $b \rightarrow c\bar{u}d$ : Müller, Piscopo, Rusov
- Constraints on BSM in non-leptonic decays: Tetlalmatzi-Xolocotzi

## Non-leptonic decays with LCSR:



Two body non-leptonic  $D^0$  decays from LCSR and implications for  $\Delta a_{CP}^{dir}$

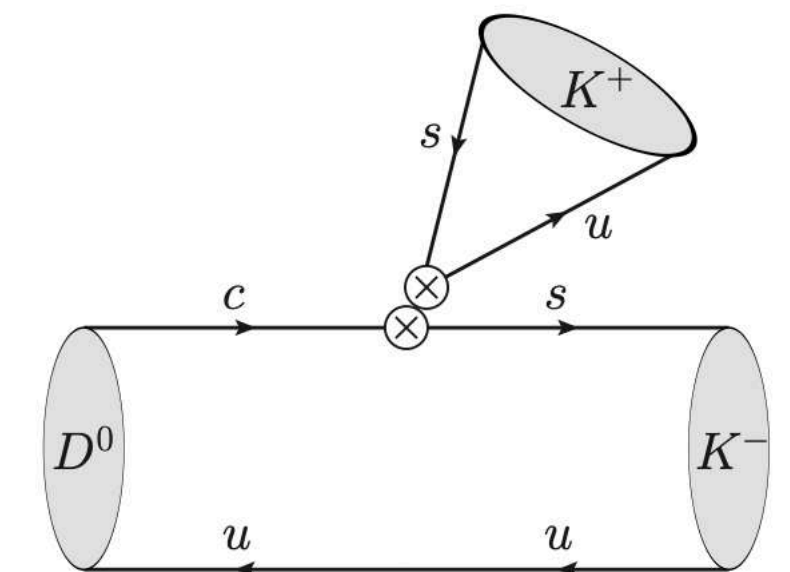
Alexander Lenz, Maria Laura Piscopo, Aleksey V. Rusov (Dec 20, 2023)

e-Print: 2312.13245 [hep-ph]

Non-factorisable effects in the decays  $\bar{B}_s^0 \rightarrow D_s^+ \pi^-$  and  $\bar{B}^0 \rightarrow D^+ K^-$  from LCSR

Maria Laura Piscopo (Siegen U.), Aleksey V. Rusov (Siegen U.) (Jul 14, 2023)

Published in: *JHEP* 10 (2023) 180 • e-Print: 2307.07594 [hep-ph]



**CPV in up-sector**



## Lattice:

### B and D physics phenomenology [RBC-UKQCD]

- Semileptonic decays with pseudoscalar final states  
e.g.  $B_s \rightarrow Kl\nu$ ,  $B \rightarrow \pi l\nu$ ,  $B_s \rightarrow D_s l\nu$ ,  $B \rightarrow Dl\nu$ ,
- Semileptonic decays with vector final states (narrow width approx.)  
e.g.  $B_s \rightarrow D_s^* l\nu$ ,  $B \rightarrow D^* l\nu$  Boushmelev
- Heavy neutral meson mixing and lifetimes **Black**

### Gradient flow based renormalization [Aachen, Odense, Boulder]

- Short flow time expansion (application to mixing and lifetimes) **Black**
- Relation of Gradient flow to RG flow
- New concept to determine  $\alpha_s$ ,  $\Lambda_{\text{QCD}}$

### Strongly coupled Quantum Field Theories [Boulder, LSD]

- Onset of the conformal window
- Testing hypothesis of asymptotic safe theories or phases of symmetric mass generation

### Models for physics beyond the standard model [LSD]

- Composite Higgs scenarios
- Composite stealth dark matter

## Rare b decays

Form factors for  $b \rightarrow s, dl$  transitions  
Khodjamirian, Rusov

## 2HDM:

- Fits of flavour and collider data...: Black, **Rusov**
- Multi-loop to 2HDM: **Lang**

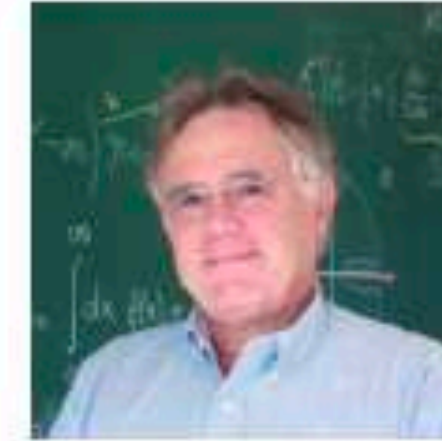
★ Inclusive  $B \rightarrow X_{(c)} l \bar{\nu}_l$  decays  
within heavy quark expansion

★ Inclusive and exclusive extraction  
of  $V_{ub}$  and  $V_{cb}$

★  $B \rightarrow D^{**}$  form factors from  
light-cone sum rules

★ Exclusive  $B_c$  and  $\Lambda_b$  decays

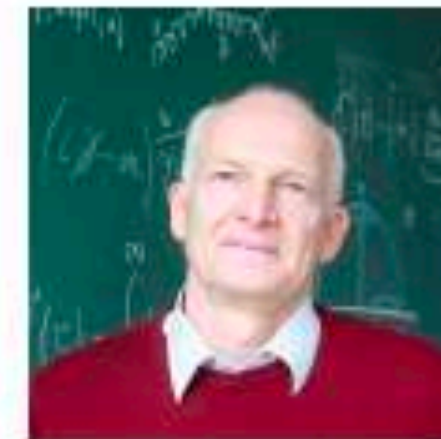
★ CP violation in  $B^+ \rightarrow \pi^+ \pi^- \pi^+$



Prof. Thomas Mannel



Prof. Alexander Khodjamirian



Dr. Alexei Pivovarov



Dr. Björn Lange



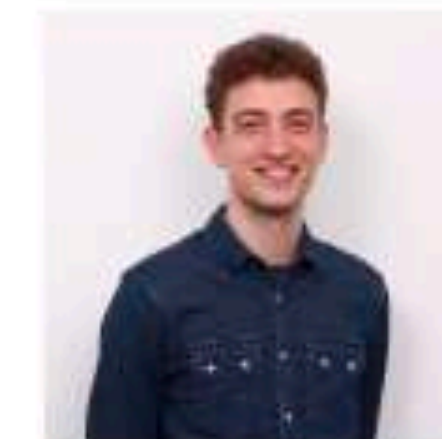
Dr. Anshika Bansal



Dr. Tom Tong



Anastasia Boushemelev



Ilija Milutin



## Inclusive Semileptonics

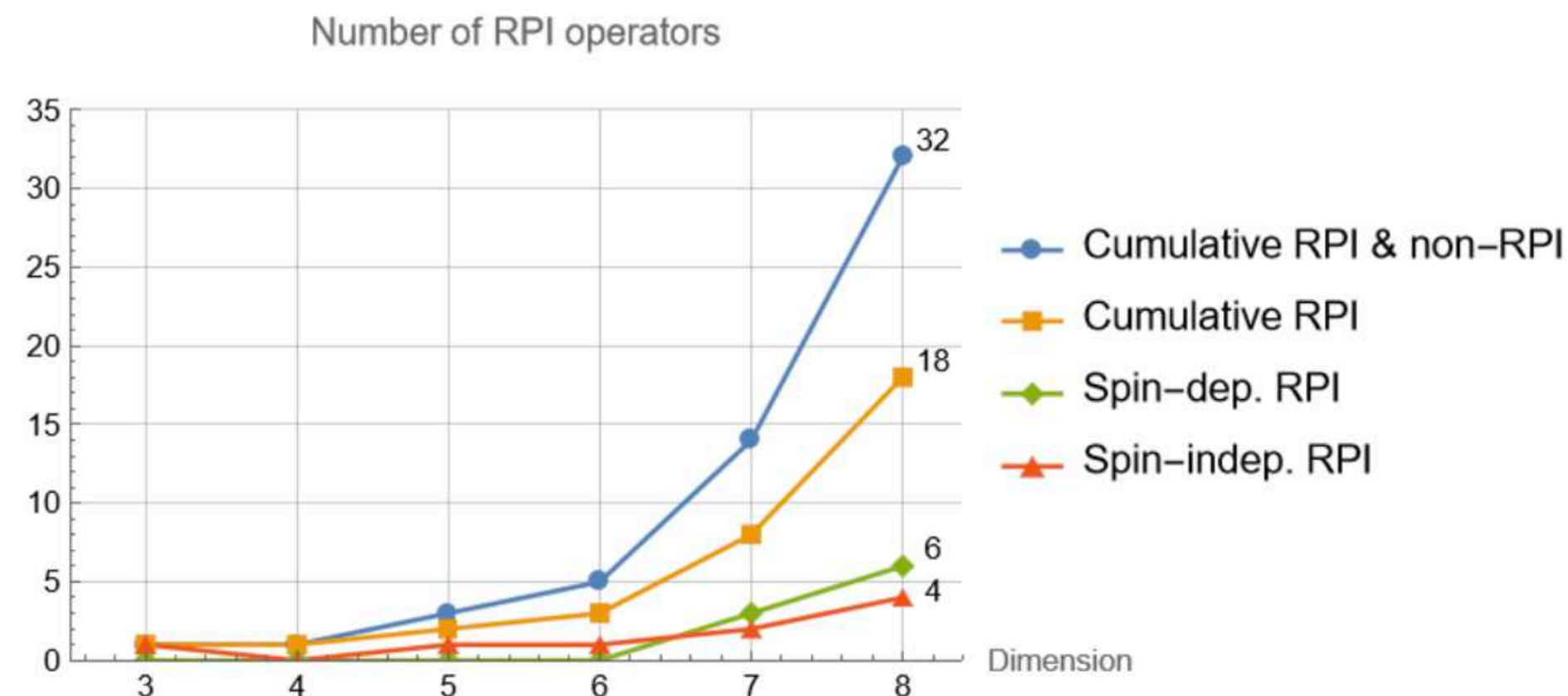
$$\Gamma(B_q) = \Gamma_3 + \Gamma_5 \frac{\langle \mathcal{O}_5 \rangle}{m_b^2} + \Gamma_6 \frac{\langle \mathcal{O}_6 \rangle}{m_b^3} + \dots + 16\pi^2 \left( \tilde{\Gamma}_6 \frac{\langle \tilde{\mathcal{O}}_6 \rangle}{m_b^3} + \tilde{\Gamma}_7 \frac{\langle \tilde{\mathcal{O}}_7 \rangle}{m_b^4} + \dots \right)$$

$$\Gamma_i = \Gamma_i^{(0)} + \frac{\alpha_s}{4\pi} \Gamma_i^{(1)} + \left( \frac{\alpha_s}{4\pi} \right)^2 \Gamma_i^{(2)} + \dots$$

- Use Heavy Quark Expansion for the total rate and for kinematic moments

$$Q_n \equiv \frac{1}{\Gamma_0} \int_{\hat{q}^2=0}^{\infty} d\hat{q}^2 (\hat{q}^2)^n \frac{d\Gamma}{d\hat{q}^2}$$

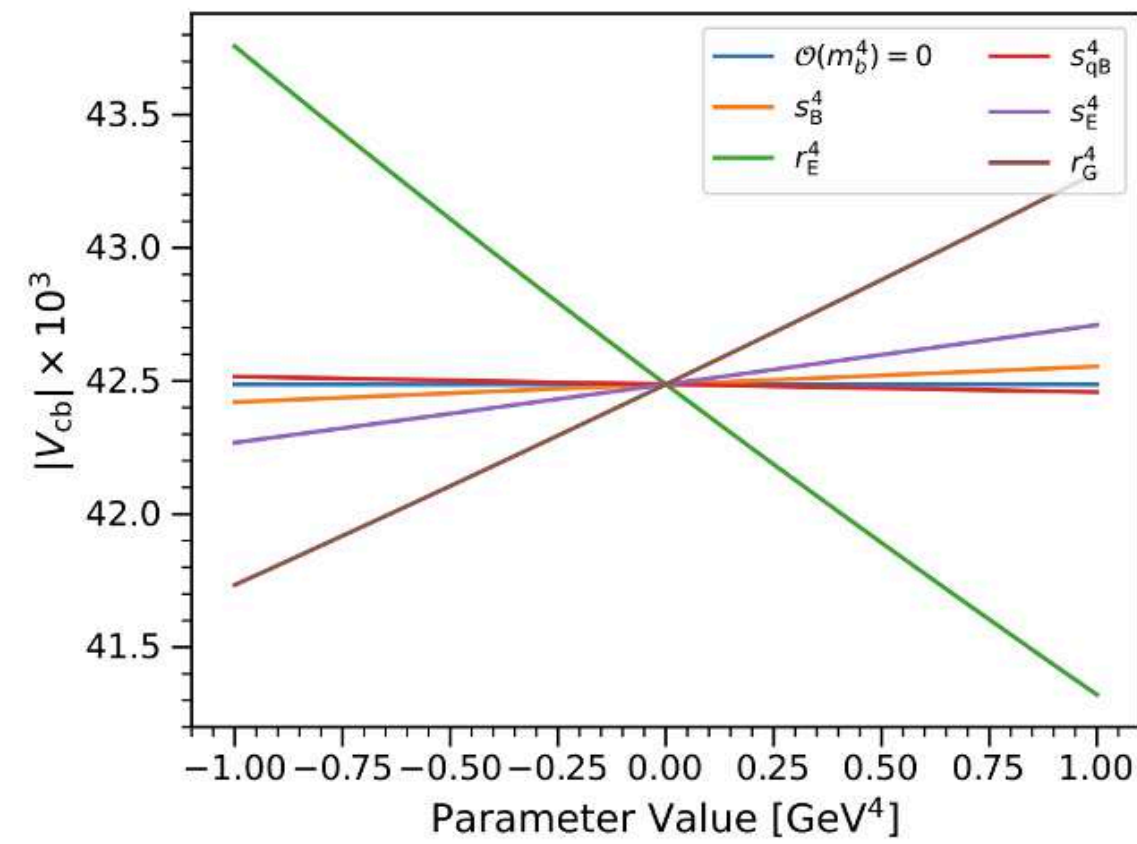
- Employ **Reparametrization Invariance** (= remnant of Lorentz Invariance in HQET) to reduce number of HQE parameters



$\Gamma_3^{(1)}$	1983	Ho-Kim, Pham [180]
$\Gamma_3^{(2)}$	1997/98 1999 2008 2008 2008 2008 2009 2013 2023	Czarnecki, Melnikov [181, 182] van Ritbergen [183] Melnikov [184] Pak, Czarnecki [185, 186] Dowling, Pak, Czarnecki [187] Bonciani, Ferroglia [188] Biswas, Melnikov [189] Brucherseifer, Caola, Melnikov [190] Egner, Fael, Schönwald Steinhauser [191]
$\Gamma_3^{(3)}$	2020 2021 2023	Fael, Schönwald, Steinhauser [192] Czakon, Czarnecki, Dowling [193] Fael, Usovitsch [194]
$\Gamma_5^{(0)}$	1992 1992 1992	Bigi, Uraltsev, Vainshtein [195] Bigi, Blok, Shifman, Uraltsev, Vainshtein [196] Blok, Shifman [197, 198]
$\Gamma_5^{(1)}$	2013 2014/15	Alberti, Gambino, Nandi [199] Mannel, Pivovarov, Rosenthal [200, 201]
$\Gamma_6^{(0)}$	1996 2017 2022	Gremm, Kapustin [202] Mannel, Rusov, Shahriaran [203] Rahimi, Vos [204]
$\Gamma_6^{(1)}$	2019 2021 2022	Mannel, Pivovarov [205] Mannel, Moreno, Pivovarov [206] Moreno [207]
$\Gamma_7^{(0)}$	2006	Dassinger, Mannel, Turczyk [208]
$\Gamma_8^{(0)}$	2010 2023	Mannel, Turczyk, Uraltsev [209] Mannel, Milutin, Vos [210]

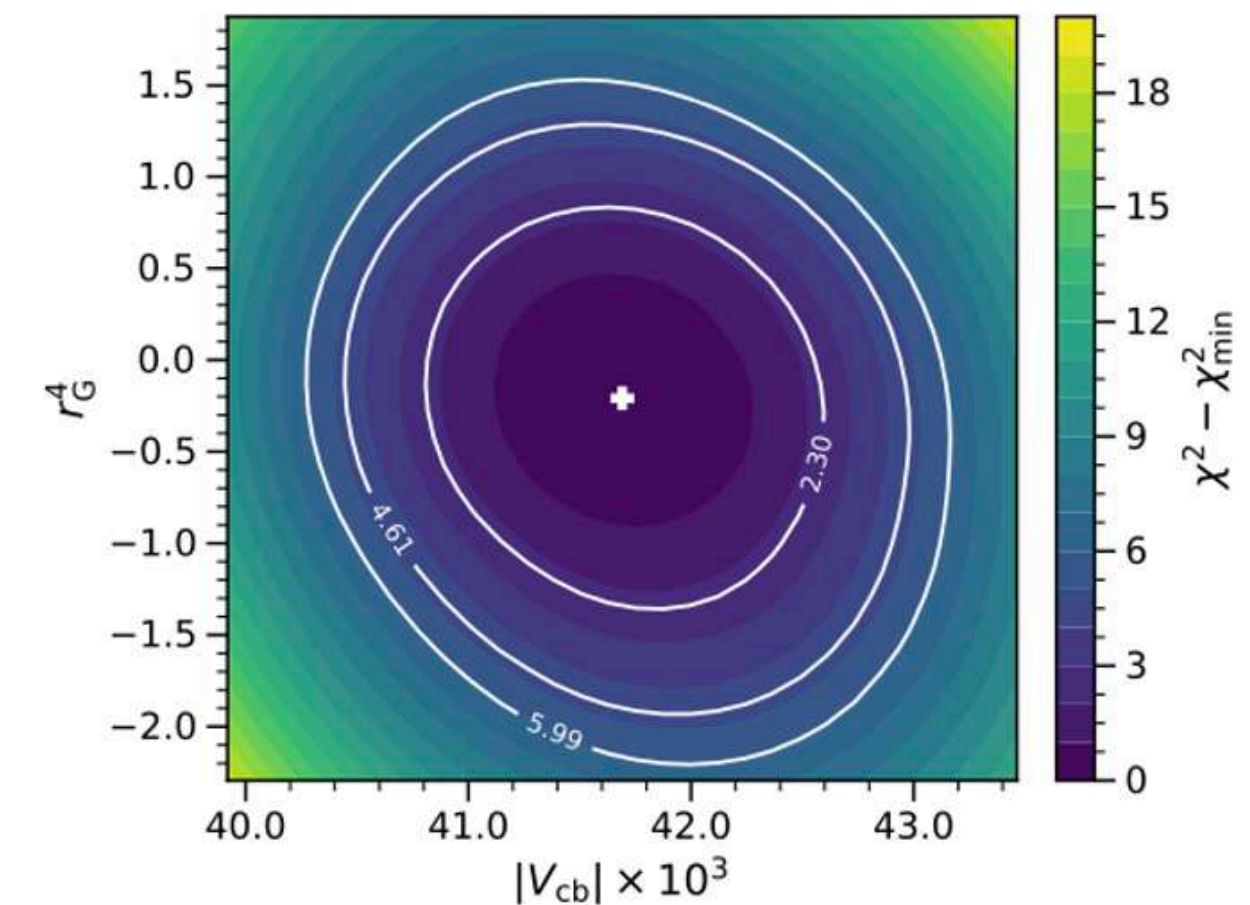
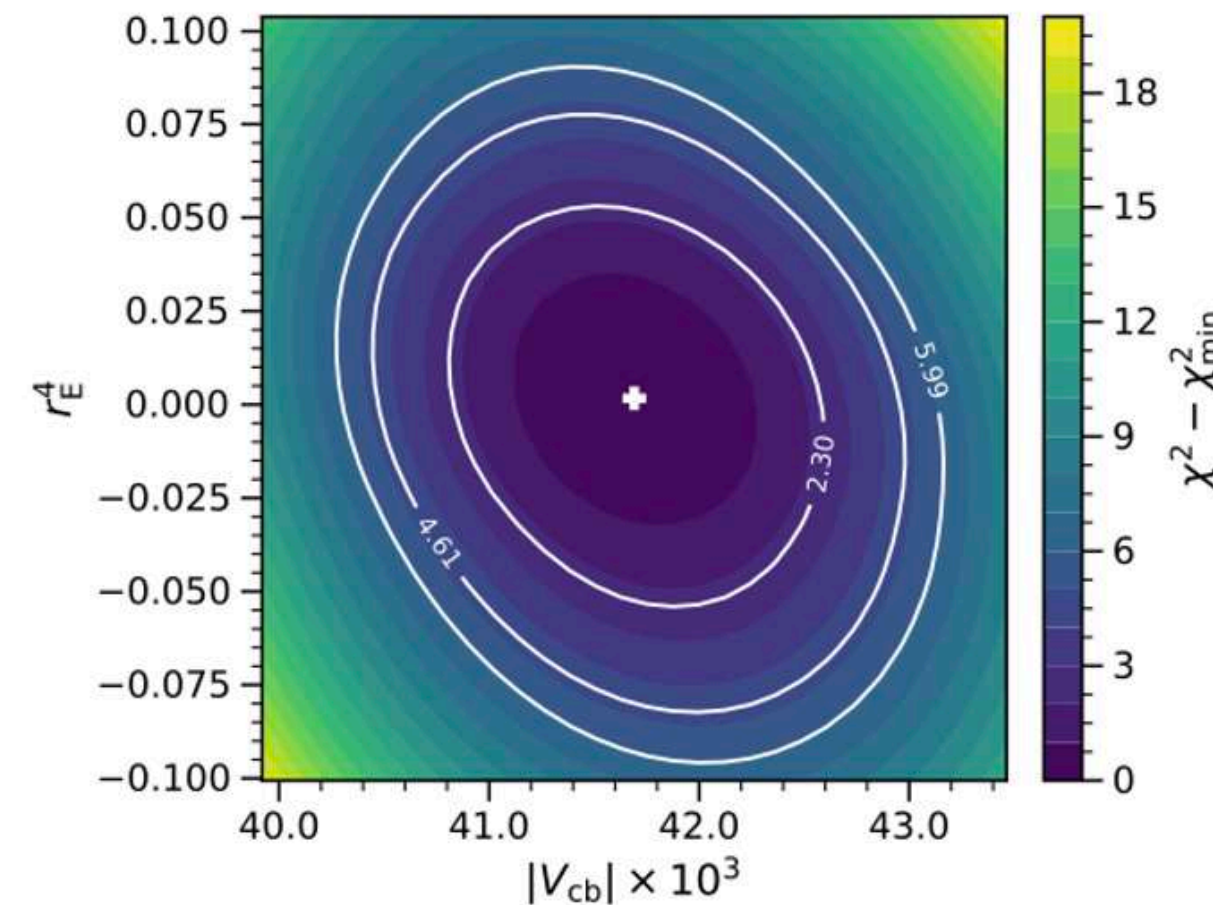
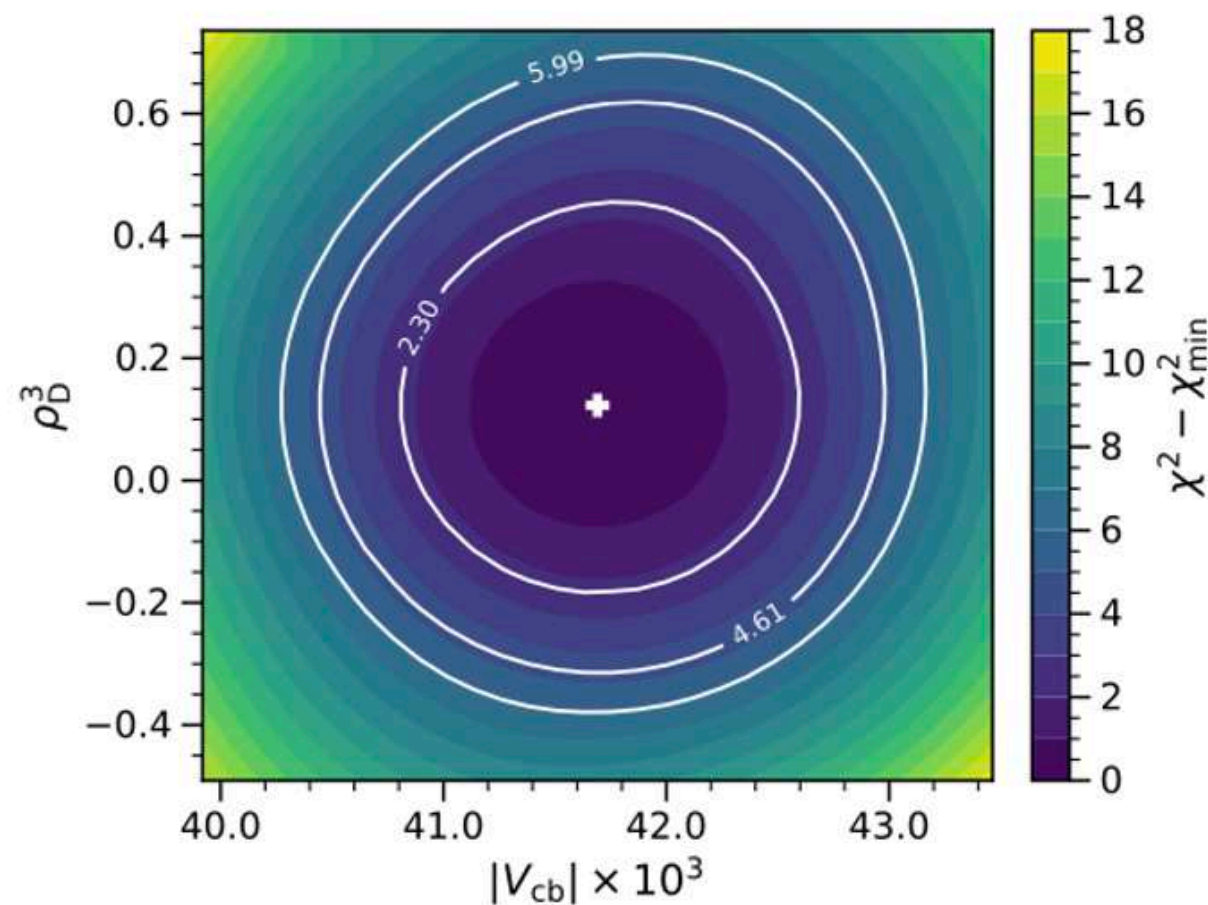
**Table 2** Summary of the theory status of the short-distance coefficients in the *semi-leptonic* decay widths.

- Data driven analysis up to  $1/m^4$  (Bernlochner, ... Vos, Olschewsky et al.)



	$ V_{cb}  \times 10^3$	$m_b^{\text{kin}}$	$\bar{m}_c$	$\mu_G^2$	$\mu_\pi^2$	$\rho_D^3$	$r_G^4$	$r_E^4 \times 10$	$s_E^4$	$s_{qB}^4$	$s_B^4$	$\rho_{\text{cut}}$	$\rho_{\text{mom}}$
Value	41.69	4.56	1.09	0.37	0.43	0.10	-0.12	0.04	-0.04	-0.02	0.04	0.05	0.10
Uncertainty	0.59	0.02	0.01	0.07	0.24	0.18	0.68	0.31	0.95	0.99	0.95	$+0.03$ $-0.01$	$+0.10$ $-0.10$

Table 5: Fit result including all  $1/m_b^4$  parameters with a standard normal Gaussian constraint. All parameters are expressed in GeV at the appropriate power.



1. **Setting the scene**
2. **TP1 at a glance**
3. **Third Party Funding**
4. **TP1 in more details**
5. **International visibility/outreach**
6. **Outlook**

## International co-authorships

Glasgow (UK), Oxford (UK), Durham (UK), Warwick (UK), Manchester (UK), Hawaii (US), Oregon (US), Chennai (India), Turin (It), Amsterdam (NL), Maastricht (NL), Beijing (CHN), Jefferson Lab (US), Nanjing (CHN), Bern (CH), Trieste (It), Lanzhou (CHN), Rome (It), Louvain (Be), Zürich (CHN), Edinburgh (UK), Zagreb (Kr),...

## Opening/closing talks:

LHCb Implications 22, FPCP 2020, Charm 2016,..

55. Herbstschule für  
Hochenergiephysik 2024



03. – 13. September 2024

### Allgemeine Information

Diese Veranstaltung wendet sich vornehmlich an Doktorandinnen und Doktoranden der theoretischen und experimentellen Hochenergiephysik. Eine Teilnahme ist nur auf Antrag und vom Bundesministerium für Bildung und Forschung unterstützt.

Prof. Dr. A. Lenz  
Universität Siegen

Freiburg

**Maria Laach**



Überblicksbild der Teilnehmerinnen und Teilnehmer des Workshops. Foto: Alexander Lenz

The 5th edition of the workshop  
"Beyond the Flavour Anomalies"

Siegen, Germany, 9 – 11 April 2024



### Topics

- Anomalies in rare semileptonic decays
- Anomalies in tree-level semileptonic decays
- Anomalies in lepton universality ratios
- Anomalies in tree-level non-leptonic decays
- Anomalies in charm sector
- Hadronic effects
- Experimental overviews and prospects
- Beyond Standard Model

### Organising Committee

- Alexander Lenz (Siegen University)
- Mitesh Patel (Imperial College London)
- Konstantinos Petridis (Bristol University)
- Aleksey Rusov (Siegen University)
- Danny van Dyk (Durham University)

### Secretariat

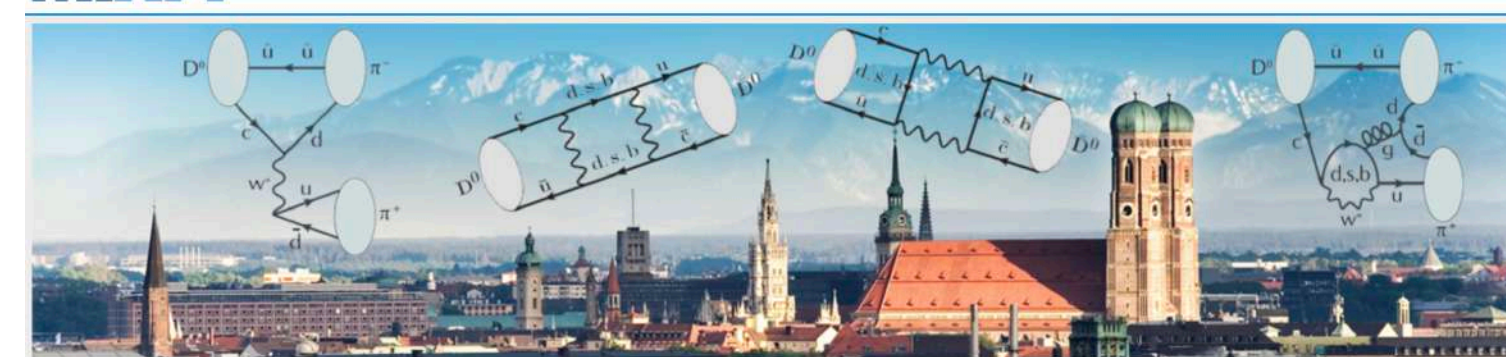
- Arzu Ergüzel (Siegen University)



Rund 50 Wissenschaftlerinnen und Wissenschaftler aus aller Welt nahmen Mitte Februar in Siegen am Workshop „Mathematical Structures in Feynman Integrals“ teil.

MIAPP

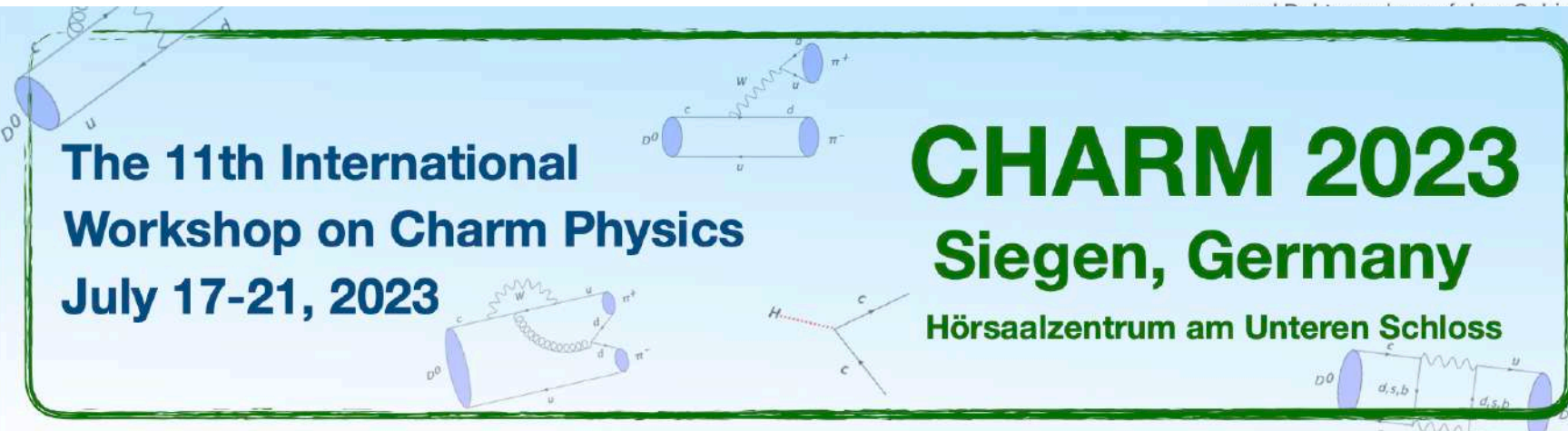
About MIAPP Activities Registration For Visitors Propose



CHARMING CLUES FOR EXISTENCE

7 March – 1 April 2022

Eva Gersabeck, Marco Gersabeck, Alexander Lenz, Stephan Paul, Danny van Dyk, Guy Wilkinson



The 11th International  
Workshop on Charm Physics  
July 17-21, 2023

**CHARM 2023**  
Siegen, Germany  
Hörsaalzentrum am Unteren Schloss



## Studierendenzahlen

Weltbestes Betreuungsverhältnis vs. Auslastung

### 1. Betreuung ist wirklich exzellent

TP1 AbsolventInnen finden attraktive Jobs in Industrie



TP1 AbsolventInnen finden attraktive Jobs in Academia



Matthew Black

- Edinburgh: Zentrum für Höchstleistungsrechnungen



Maria Laura Piscopo

- NIKHEF Amsterdam: Nationales Teilchenphysikinstitut



Aleksey Rusov

- TUM, bei Leibnizpresiträger



Meril Reboud

- Permanente Stelle in IJCLab, Orsay

TP1 erhält attraktive Bewerbungen aus der ganzen Welt

- Herbst 2023: 290 Bewerbungen auf 1 post-doc Stelle
- Post-docs



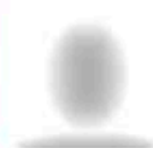
Anshika Bansal



Pia Bredt



Kevin Brune



Jack Jenkins



Martin Lang



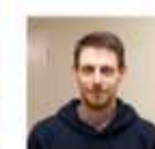
Eleftheria Malami



Maria Laura Piscopo



Aleksey Rusov



Meril Reboud



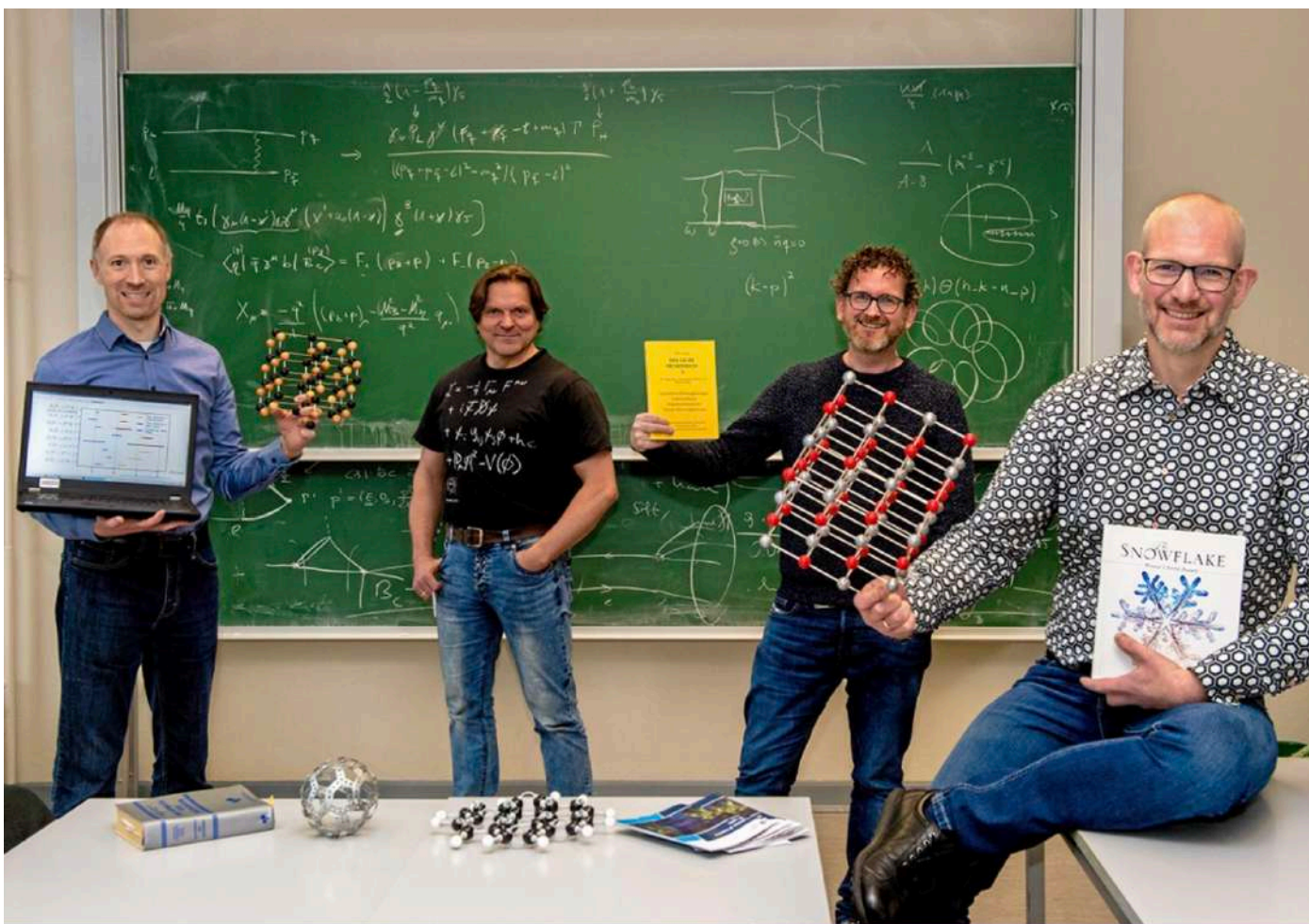
Gilberto Tetlalmatzi-Xolocotzi



Tom Tong

### 2. Öffentlichkeitsarbeit

# Outreach

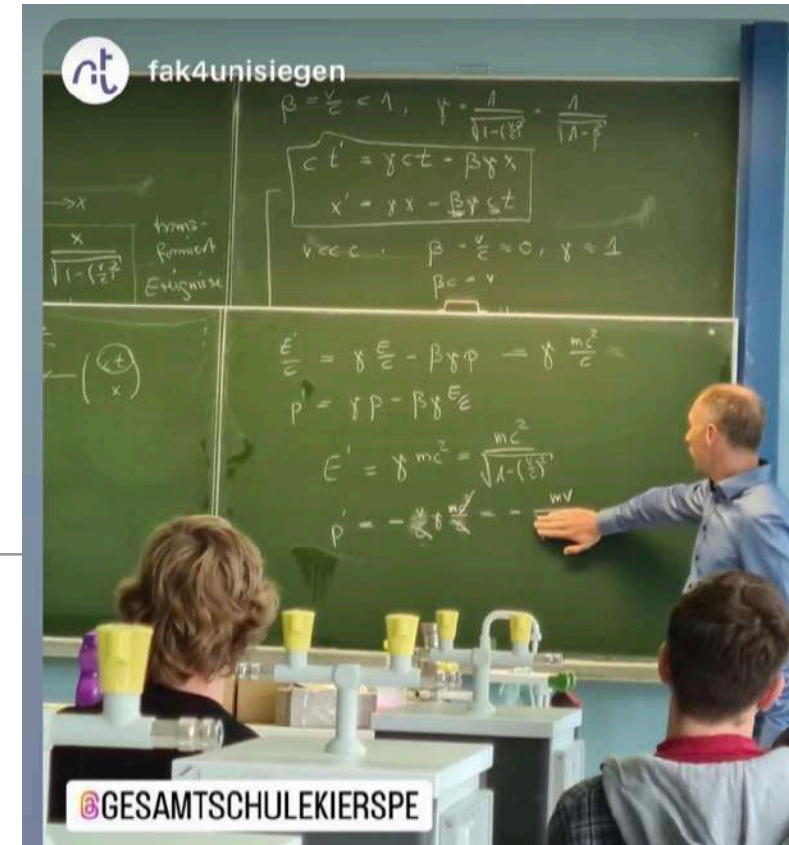


»Was machen Wissenschaftler:innen am liebsten? Forschen! Und am zweitliebsten? Über die Forschung berichten!«



**Rent a Prof**

Die Uni kommt ins Klassenzimmer



Im Rahmen von **Rent a Prof** erklärt Professor Tobias Huber an der Gesamtschule in Kierspe die spezielle Relativitätstheorie. Wie kann die Zeit unterschiedlich schnell laufen? Warum ist nichts schneller als das Licht?

SUBATOMIC HEROES

### 10 Jahre Higgs

Am 4.7.2012 wurde am CERN die Entdeckung des Higgsteilchens bekannt gegeben

Das Standardmodell der Teilchenphysik beinhaltet alle bekannte Materie in Form von Quarks und Leptonen, sowie alle Kräfte-übertragenden Teilchen (Photonen, Gluonen, elektroschwache Eichbosonen) und das Higgsteilchen, das allen Elementarteilchen Masse gibt.

### Woche der Teilchenwelt

6–12.11.2023

Center for Particle Physics Siegen



### Kampf der Wissenschaften Chemie vs. Physik

Begleite Henner und Frieda beim Studieninformationstag

Es wird blitzen

$$\begin{aligned} \nabla \cdot \vec{E} &= \rho_{ext} \\ \nabla \times \vec{E} &= -\dot{\vec{B}} \\ \nabla \cdot \vec{B} &= 0 \\ \nabla \times \vec{B} &= \mu_0 \vec{J} + \mu_0 \dot{\vec{D}} \end{aligned}$$

Es wird krachen

$$2 \text{C}_2\text{H}_2 + 5 \text{O}_2 \rightarrow 4 \text{CO}_2 + 2 \text{H}_2\text{O}$$

Es wird brennen

Und die Gravitation wird ausser Kraft gesetzt werden

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Das Standardmodell der Teilchenphysik beinhaltet alle bekannte Materie in Form von Quarks und Leptonen, sowie alle Kräfte-übertragenden Teilchen (Photonen, Gluonen, elektroschwache Eichbosonen) und das Higgsteilchen, das allen Elementarteilchen Masse gibt.

Das Standardmodell der Teilchenphysik beinhaltet alle bekannte Materie in Form von Quarks und Leptonen, sowie alle Kräfte-übertragenden Teilchen (Photonen, Gluonen, elektroschwache Eichbosonen) und das Higgsteilchen, das allen Elementarteilchen Masse gibt.

### PARTICLE FEVER

Uni Siegen

Woche des Higgsteilchens Siegerländer Spezialitäten

Teilchenphysik, Festkörperphysik Prof. Dr. Markus Cristinziani Alexander Lenz



Anmeldung via

UNIVERSITÄT SIEGEN

<https://indico.soc.kit.edu/event/2648>

Universität Siegen

<https://www.wocheteilchenwelt.de/#woche>

Samstag 14. Mai, Beginn 11:15 Uhr, Unteres Schloss, Siegen

UNIVERSITÄT SIEGEN 50 JAHRE 1972-2022 Offene Uni

9. Februar 2022, 09:00 Uhr • 33x gelesen

Universität Siegen

### Studientag Physik begeistert Oberstufen-Schüler

Autor: Dr. Andreas Goebel (Redakteur) aus Betzdorf



Prof. Dr. Carsten Busse (r.) übergibt seinem Kollegen Prof. Dr. Alexander Lenz eine schwere Kugel, die der nach vorn schleudern wird. Die Kraft überträgt sich auch auf das Skateboard, auf dem er sitzt. Foto: goeb hochgeladen von Dominik Jung

Rent a Prof

Die Uni kommt ins Klassenzimmer



PROFESSOR ALEXANDER LENZ ZU BESUCH IN DER 11

PIC-COLLAGES

# CmF meets arts

## Voller Saal bei Physik im Apollo

Das Publikum ließ sich bei der Premiere im Siegener Apollo-Theater von einem Vortrag über Dunkle Materie, Musik und Akrobatik faszinieren.

## Physik im Apollo



## Gravitation - Schwerkraft



SPIELPLAN KARTEN ABO WIR JOBS

### Beschreibung ↓

In der zweiten Edition von *Physik im Apollo* konnte Frau Dr. Heike Riel (Leiterin Quantencomputing Europe bei IBM) als Hauptrednerin für das Thema "Quantencomputing" gewonnen werden. Die Gesetze, die in der Quantenwelt herrschen, widersprechen oft unserer Alltagserfahrung und erscheinen daher sehr unverständlich. Auf der anderen Seite wurden sie durch unzählige Experimente im Mikrokosmos belegt. Lange Zeit waren diese Gesetze, die vor knapp 100 Jahren entdeckt wurden, reinste Grundlagenforschung, fernab von jeglicher praktischer Anwendung. In jüngeren Jahren zeichnet sich jedoch eine praktische Anwendung ab, die die Computerentwicklung revolutionieren könnte. Frau Dr. Riel wird in das Thema "Quantencomputing" einführen und auch den aktuellsten Stand hiervon vorstellen, welcher auch den Siegener Quantencomputer enthält.

»Physik muss nicht schwer verständlich sein. Anschaulich präsentiert und mit künstlerischen Einlagen, die ins jeweilige Themenfeld passen, garniert, verspricht dieser Abend aktuelle Grundlagenforschung, die alle verstehen.«

## Pilotprojekt: 18.7.2023

- 2 Stundenshow im Theater
- Musik, Akrobatik, Vortrag
- 500 Besucher

**Nächster Termin 12.4.2024**  
**Quantencomputing**



Startseite > Siegen > Physik im Apollo: Prof. Dr. Matthias Neubert spricht über Dunkle Materie

Wissenschaft im Apollo

**+ „Physik im Apollo“: Wissenschaftler sind der Dunklen Materie auf der Spur**



### Termine ↓

Fr • 12. Apr 24 • 19:00 Uhr • **Apollo-Theater** Eintritt frei  
(kostenlose Zählkarte erforderlich) • **VORVERKAUF AB 14.02.**

### Infos ↓

Vortrag & mehr 14+

Eine Veranstaltung der Universität Siegen

**Besetzung:** Dr. Heike Riel u.a.

**Leading Team:** Prof. Dr. Alexander Lenz

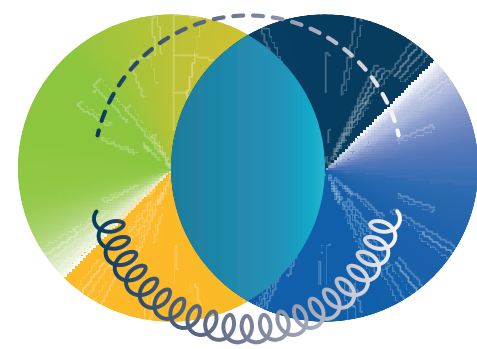
1. **Setting the scene**
2. **TP1 at a glance**
3. **Third Party Funding**
4. **TP1 in more details**
5. **International visibility/outreach**
6. **Outlook**



## Never change a winning team vs. acting on new developments



Computational physics: extend world center for sum rules with lattice + quantum computing



color meets flavor

**Start 1/26: deadline 22.8.2024**

3rd funding period of SFB/CRC 257 **Start 1/27**

Increase student numbers

**We have a new webpage  
advertise Master!**



**Lattice meets Continuum**

September 30, 2024 to October 4, 2024  
Europe/Berlin timezone

Overview

Privacy Information

Venue

Accommodation

Travel Information

Lunches and Coffee Breaks

Workshop Committee



Previous Editions

By fostering the exchange between the Lattice and the Continuum community, we intend to further the progress in flavor physics phenomenology.

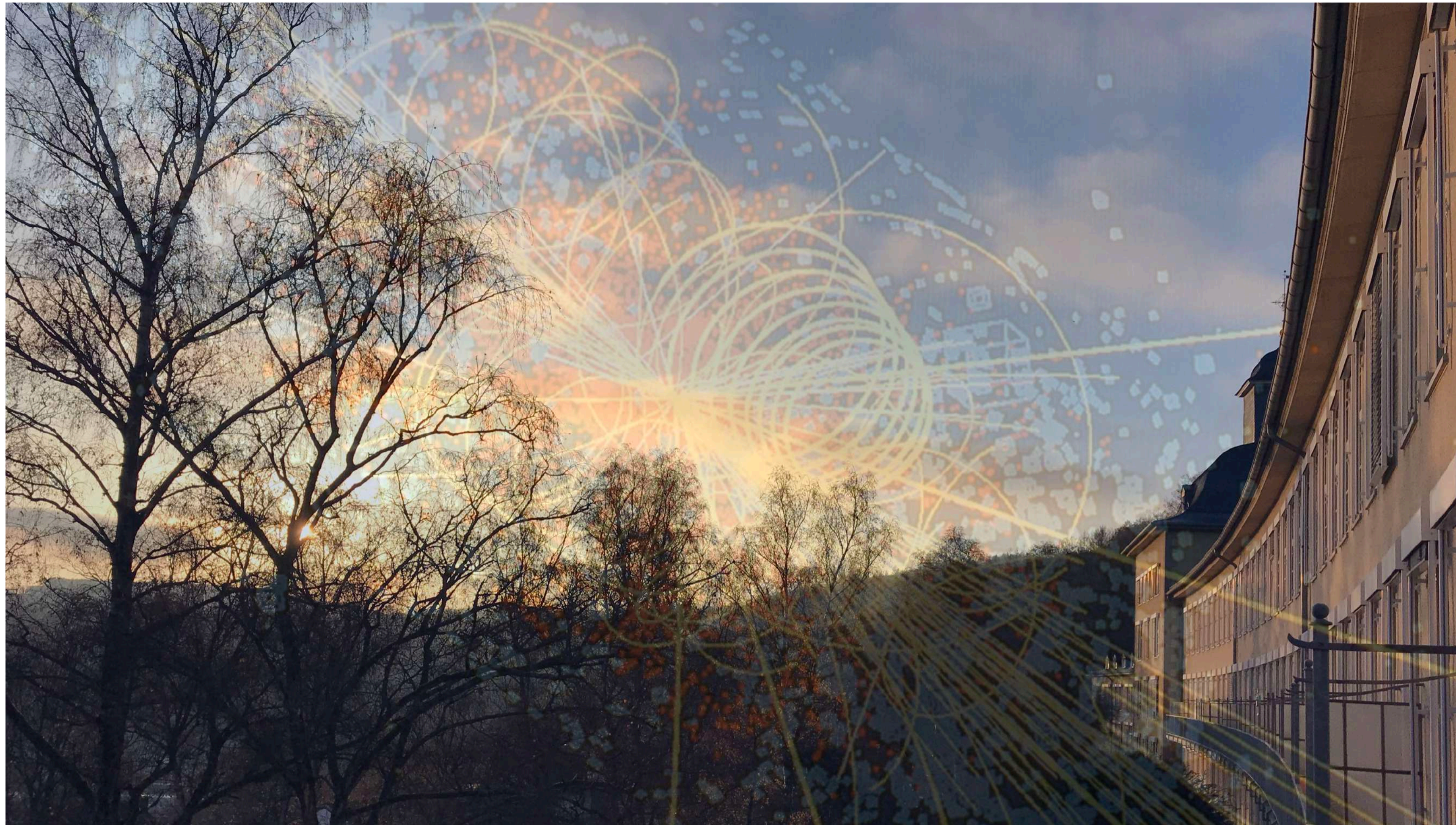
Topic for the 3rd. edition of this workshop will include:

- CKM matrix elements and global fits
- Semileptonic decays
- Rare decays
- Decays with two or more hadronic final states
- Meson mixing and lifetimes
- Gradient Flow
- Spectroscopy and exotic states

Siegen is located centrally in Germany, around 125 km northwest of Frankfurt and 90 km east of Cologne and can be reached well via train or car. Nearby international airports are in Frankfurt, Cologne and Düsseldorf.

# Outlook



**C**enter for **P**article **P**hysics **S**iegen