

ヨーロッパの科学技術における国際協力 — LHC 実験とヘルムホルツ協会 (EMMI) を中心に 日本語解説

長崎総合科学大学

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長崎総合科学大学 新技術創生研究所国際セミナー

「世界で活躍する技術者育成を目指して」
～ドイツに学ぶマイスター&研究者育成法～

ピーター・ブラウン＝ミュンツィンガー教授
(Prof. Dr. Peter Braun-Munzinger)

原子核物理学者。主な研究対象はクォーク・グルーオン・プラズマ (QGP)。これまで米ブルックヘブン国立研究所 (BNL)、独ヘルツホルム協会¹重イオン研究所 (GSI)、欧州原子核研究機構 (CERN) ALICE 実験等に在籍。

ホルムヘルツ協会極限物質機関 (EMMI) 科学理事 (2008-)、ALICE 共同研究委員会議長 (2011-)、学術雑誌『Nuclear Physics A』監督編集者 (2012-)、ハイデルベルク大学名誉教授 (2014-) 等。

¹正式名称：ドイツ研究センターヘルムホルツ協会

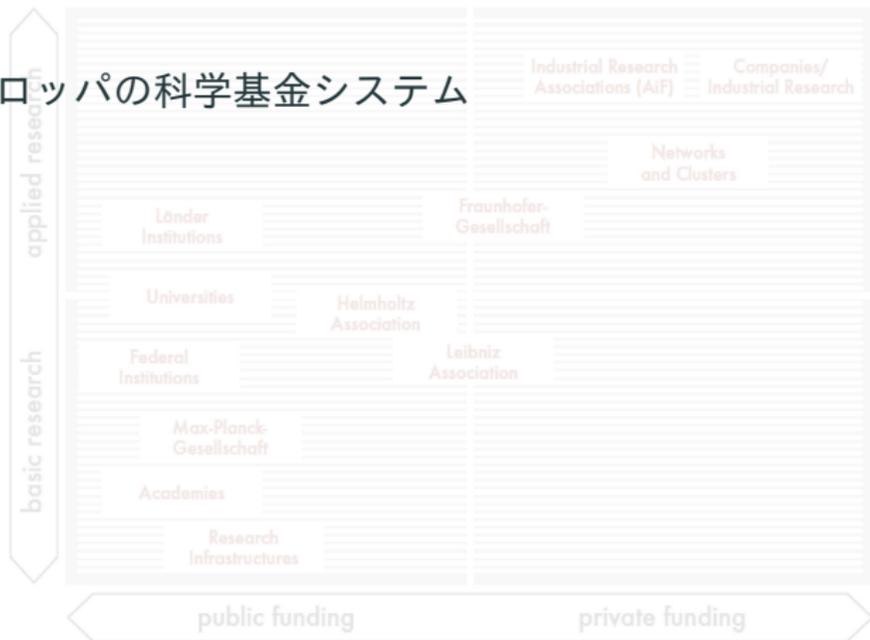
First a few remarks about German/European Science funding

最初に、ドイツ/ヨーロッパの科学基金についていくつかの注釈

German and European Science Funding System

Overview of Research Performing Organisations in Germany
Research institutions differ in terms of their type of research (basic/applied) and financing (public/private).

ドイツとヨーロッパの科学基金システム



Research Performing Organisations

Science and research in Germany are characterised by an excellent infrastructure, a wide variety of disciplines, well-equipped research facilities and competent staff. Germany offers various forms of research

locations: universities, non-university institutes, companies and institutions run by federal or state authorities. All in all, there are nearly 1,000 public and private research and development (R&D) in Germany. Companies also have a high number of R&D centres

In selected fields or regions, these industrial and academic institutions pool their research and development activities in networks and clusters to

work more efficiently and to benefit from a higher level of knowledge. Furthermore, cooperation at European as well as international level has become an essential dimension of science and research in Germany.

turn on research and development funding spent by industry. Higher education institutions, state and federal governments and publicly funded non-university research institutions, for example the Helmholtz Centres or the institutes of the Fraunhofer-Gesellschaft, invest 15% of the R&D total.



・研究開発予算全体：年間 800 億ユーロ（～9.6 兆円）

・高等教育機関：年間 140 億ユーロ（～1.7 兆円）

・国立研究所：年間 120 億ユーロ（～1.4 兆円）

14 Bill. Euro/yr
12 Bill. Euro/yr

Facts and Figures



Almost 1,000 publicly funded research institutions (2013)



605,000 staff in R&D including 361,000 R&D researchers (2013)



Approx. 500 innovation clusters and networks (2015)



Gross domestic expenditure on R&D (GERD): 80 billion euros (2013)

Germany offers various forms of research locations: universities, non-university institutes, companies and institutions run by federal or state [Länder] authorities. For an overview, visit the Research in Germany website: www.research-in-germany.org/research-landscape

The research directory "Research Explorer" contains over 23,000 institutes of German universities and non-university research institutions, searchable by geographic location subject and other structural criteria www.research-explorer.de

2つの例：ケーススタディとして

- The ALICE Experiment at the CERN
Large Hadron Collider

- 欧州原子核研究機構（CERN）の LHC（Large Hadron Collider; 大型ハドロン衝突型加速器）で行われている ALICE 実験
- EMMI（ExtreMe Matter Institute; 極限物質機関）
ヘルムホルツ協会の例

相対論的（光速に近い速度で動く）重い原子核の衝突による、
ビッグバンのマイクロ秒後に存在した物質の生成
実験室での「リトルバン」を通してビッグバンにおける物質の性質を研究する

ALICE: 42ヶ国から集まった174もの科学研究機関による協力
協力している科学者の総数は1800人を超える

ALICE: a collaboration of more than xx scientific institutes from yy different countries. Total number of collaborating scientists is > 1600.

特別な焦点：いかにして ALICE 実験の大型副検出器を構築するか： ALICE TPC

For such a major sub-detector project one needs:

このような大型の副検出器プロジェクトのために、次のようなものが必要だった：

- A clear idea concerning the physics and technical requirements
 - ・ 物理学的・技術的要求についての明確なアイデア
- A scientifically and technically strong (international) collaboration
 - ・ 科学的かつ技術的な優れた（国際）協力
- A good estimate of the funds and manpower required
 - ・ 必要な資金と労働力の適切な推定
 - ・ 必要な資金を調達する上での計画
- A plan how to raise the necessary funds

このような科学者の国際協力はいかにして行われているのか？

collaboration of scientists work?

1. loose and horizontal management structure

1. ゆるやかで横並びの管理構造

2. govern by consensus

2. 合意による運営

3. ホスト機関 (CERN) による資金的・技術的監修 (CERN)

4. 自発的なスタッフ

4. self-motivated staff

5. 成功も失敗も共有する

5. share successes but also failures

6. 科学と予定表に焦点を置き続ける

6. keep focus on science and time lines

Next: an overview of the project

次：プロジェクトの概要

LHC : 世界最高水準の高エネルギー粒子加速器

20 髪の毛ほどの大きさ (長さ 10 cm、直径 25 μm) の 10^{11} 個の陽子 (10 の束が円周 27 km の輪を周回し、25 ns 毎に衝突する collide every 25 ns

- もし、この陽子と光が LHC を回って競争したら、光が 0.2 mm だけ先を行くが、問題はエネルギーであり、速度ではない
 - 衝突するそれぞれの陽子ビームは 150 km/h の新幹線に比類するエネルギーを帯びている — しかしビームは交差の度にその 10^{-11} ほどのエネルギーを失うのみである
 - 鉛原子核の各衝突で莫大なエネルギーが解放され 10000 を越える粒子 (ハドロン) が生成される
- in each collision of 2 Pb atomic nuclei a macroscopic amount of energy is released and more than 10000 particles (hadrons) are created

LHC — 世界最高の技術的挑戦

1232 superconducting dipole magnets – magnetic field 8 Tesla
700.000 l He at 1.9 K - 27 km circumference

1232 個の超伝導ダイポール磁石

8 テスラの磁場

1.9 ケルビン、700,000 リットルのヘリウム

円周 27 km

Large Hadron Collider

CMS

訳者による補足

LHC 内部には、山手線のように時計回りと反時計回りにビームが周回する経路が用意されており、交差点でビームが衝突する。

ALICE・ATLAS・LHCb・CMS はいずれも LHC で行われている主要実験プロジェクト。

LHC の直径（約 9 km）はこの会場と稲佐山の直線距離に近い。

ATLAS

LHC 実験計画の始まり

the start of the LHC experimental program

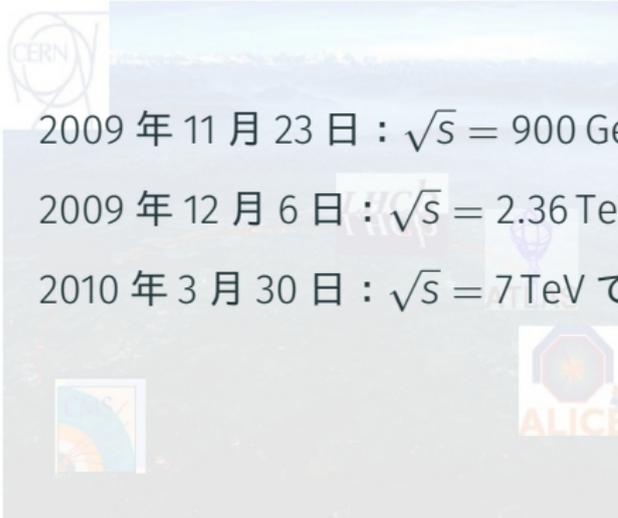
November 23, 2009

First proton-proton collisions

2009年11月23日： $\sqrt{s} = 900 \text{ GeV}^2$ での最初の陽子-陽子衝突

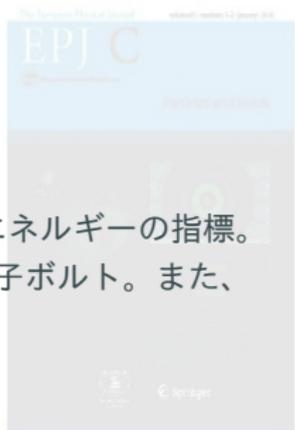
2009年12月6日： $\sqrt{s} = 2.36 \text{ TeV}$ での陽子-陽子衝突

2010年3月30日： $\sqrt{s} = 7 \text{ TeV}$ での陽子-陽子衝突



mid-rapidity pseudorapidity density

(Nov 28)



Eur. J. Phys. C65 (2010) 111

² 記者注： \sqrt{s} は LHC のような粒子加速器で使われる衝突エネルギーの指標。

電子ボルト (eV) はエネルギーの単位で、1 GeV は 10 億電子ボルト。また、1 TeV は 1 兆電子ボルト。

Dec 6, 2009 pp at $\sqrt{s}=2.36 \text{ TeV}$
Mar 30, 2010 pp at $\sqrt{s}=7 \text{ TeV}$

the ALICE experiment: Schematic Setup



ALICE 実験：セットアップの概略

プロジェクトの対象

ALICE Time Projection Chamber (TPC)

総投資額：1500 万ユーロ（～18 兆円）

総人的資産：200 人以上 15 MEuro

ベルゲン大学、ブラチスラヴァ大学、CERN、コペンハーゲン大学、ダルムシュタット大学、ハイデルベルク大学、フランクフルト大学、GSI、クラクフ大学、ルンド大学

8ヶ国からの投資機関

50人の科学者の共同作業、ライン管理なし

プロジェクトは建造と稼動に7年を要した

TRD

電子同定のための大面積 TRD (Transition Radiation Detector; 遷移放射検出器)

TPC

Time Projection Chamber

大容量・高解像度・高頻度な飛跡追跡装置

ITS

6層のシリコンセンサーによって構成されるバーテックス検出器

TRD

large area Transition Radiation Detector for

TPC

Time Projection Chamber
large volume, high resolution and high rate tracking device

ITS

A vertex detector built from 6 layers of Si sensors

ALICE TPC — LHC における 2 つの鉛原子衝突によって生成される 5000 を越える荷電粒子の飛跡を記録する高速画像化装置

created in a collision of 2 Pb nuclei at LHC

with 95 m³ the largest TPC ever

ALICE

95 m³ : 史上最大の TPC

5.6 億画素 !

3次元全ての軸で 500 μm より細かい精度
軌跡毎に 180 の空間と電荷点

560 million read-out pixels!
precision better than 500 μm in all 3 dim.
180 space and charge points per track

Working inside before completion of the TPC

完成前の TPC 内部での作業



complete and calibrated!

完成、そして調整完了！



ITS russian dolls - sliding the SSD/SDD over the SPD



TPC

ITS のマトリョーシカ : SSD と SDD を SPD に覆い被せる

SPD

SSD/SDD



Installation of 1rst TRD module
into space frame

空間フレーム内部に最初の TRD モジュールを設置

$\sqrt{s} = 2.76$ A TeV での LHC 初の鉛-鉛衝突

setup for ion collisions: November 4
first collisions with stable beams:
November 8 until Dec 6

already in Dec 2010
5 publications in PRL and PLB

イオン衝突のセットアップ：11月4日

安定ビームでの初衝突：11月8日から12月6日まで

12月10日には5報が PRL と PLB に



Pb+Pb @ \sqrt{s} = 2.76 ATeV
2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x0000000003BBE693

このようなプロジェクトを組織するのに何が必要か？ (1)

1. the general idea and a dedicated and scientifically outstanding collaboration

1. 一般的なアイデアと科学的に傑出し、専心した協力

2. project structure and coordination

2. プロジェクトの構造と調整

3. milestones and technical follow-up within project

3. プロジェクトの技術的フォローアップとマイルストーン

4. monthly review by technical board and management board of experiment into which the project is embedded

4. プロジェクトを内包する実験の技術委員会と管理委員会による月例レビュー

What is needed to organize such a project? (II)

1. an organizational structure from the host laboratory (CERN)

このようなプロジェクトを組織するのに何が必要か？ (2)

a) for technical oversight, on a monthly basis

b) for budgetary oversight on a bi-yearly basis

2. after approval of scientific part at CERN parallel application for funds by all partners

CERN scientific committees

Scientific Policy Advice to CERN Council

SPC - Scientific Policy Committee

Approval of Experiments at CERN

CERNの科学委員会

- General Conditions applicable to all Experiments at CERN (updated Feb. 2008)

Experimental Committees

INTC - ISOLDE-Neutron Time of flight experiments Committee (formerly ISC)

LHCC - The Large Hadron Collider experiments Committee

SPSC - The SPS and PS experiments Committee

CERN Resources Committees

Resources Review

CERN の資源委員会

LHC RRB - LHC Resources Review Boards

Convened by CERN Director of Research

Members: for each major project:

1 representative plus 1 physicist of each funding agency

Lesson from project TPC

a complex project requiring cooperation of 8 different funding agencies and 10 institutions was realized in time and on budget

1/TPCプロジェクトからの教訓 funding agencies and CERN

loose and horizontal management structure

technical follow-up by CERN

largely self-motivated staff – share successes **AND** problems/failures

groups deliver in-kind and cash contributions

minimal number of written reports – keep groups focused on delivering the final product

2nd case – the ExtreMe Matter Institute EMMI

An alliance in the framework of the Helmholtz Association (HGF)

第二の例 : EMMI (ExtreMe Matter Institute; 極限物質機関)

ExtreMe Matter Institute EMMI



www.gsi.de/emmi



EMMI

- founded in 2008 in framework of Helmholtz Alliance (2008 - 2015)
Cosmic Matter in the Laboratory



Alliance on Cosmic Matter
in the Laboratory

- now continued as part of GSI:
taking the momentum of the alliance into the future



... and its Partners

EMMI の協力機関



Organisation

13 Partner Institutions

Management:

組織

Scientific Director: Peter Braun-Munzinger

Scientific Coordinator: Carlo Ewerz

+ administrative support

32 further experts as **Associated Partners**

Steering Committee (representatives of Partners)
as main steering body

Scientific Advisory Committee (8 external experts)

Main Research Areas of EMMI

Matter under extreme conditions of temperature, density and pressure, in particular

EMMI の主要研究分野

- quark-gluon plasma and phase diagram of QCD & new hadronic states
- neutron matter
- plasma physics
- atomic physics and ultracold gases

... and related topics

Aim:

bringing together the best minds from these communities

Emergence of common concepts

Common structures and underlying theoretical concepts for these strongly coupled systems, for example

共通するコンセプトの出現

- from BEC to BCS
- from QGP to ultracold Fermi gases
- from conformal field theory to QCD via black holes (AdS/CFT)
- from neutron star matter to strongly coupled electromagnetic plasmas
- hydrodynamics, turbulence, ...
- ...

Goals

central goal of EMMI:

目標

act as think tank & provide intellectual environment
for extreme matter research (at GSI and beyond)

aiming at:

- interdisciplinary scientific events of highest quality
- strong promotion of early-career researchers
- network among two Helmholtz centres and eleven top national and international laboratories and universities

EMMI Scientists

- more than 100 senior researchers participating in EMMI, more than 400 scientists in total

EMMI の科学者

- 14 new positions (professorships / tenured) created by partners:
 - 10 at TUD, F, MPI-K, MS, HD, LBNL
 - 4 EMMI Fellow positions at GSI
- EMMI supported PhD students associated with surrounding graduate schools (H-QM, HGS-HIRe, HGSFP)

EMMI Programs

EMMI の計画

- EMMI Workshops
- EMMI Programs
- EMMI Rapid Reaction Task Force meetings (RRTFs)
- joint workshops with ECT* Trento



- Visiting Professor program
- Visiting Researcher program

Interdisciplinary Events: examples

学際領域のイベント：例

Workshop on
Relaxation, Turbulence, and Non-Equilibrium Dynamics of Matter Fields
From Quark-Gluon Plasma to High Energy Physics

ExtreMe Matter Institute EMMI

Relaxation, Turbulence, and Non-Equilibrium Dynamics of Matter Fields
From Quark-Gluon Plasma to High Energy Physics

Workshop on Relaxation, Turbulence, and Non-Equilibrium Dynamics of Matter Fields
From Quark-Gluon Plasma to High Energy Physics
Hirschfeld, 45-000
August 27-31, 2012

Workshop
This workshop is part of the EMMI program, which is a joint effort of the Helmholtz Association and the Deutsche Forschungsgemeinschaft (DFG) to establish a research center for the study of matter under extreme conditions. The workshop is organized by the EMMI program and the Helmholtz Association.

Workshop Objectives
The workshop aims to bring together experts in the field of matter under extreme conditions to discuss the latest developments in the field and to identify key research areas for future studies.

Workshop Topics
The workshop covers a wide range of topics, including the dynamics of matter fields, relaxation processes, turbulence, and non-equilibrium dynamics. The topics are discussed in the context of high energy physics and the quark-gluon plasma.

Workshop Organizers
The workshop is organized by the EMMI program and the Helmholtz Association. The organizers are Prof. Dr. J. Schuch and Prof. Dr. M. Bleicher.

Workshop Location
The workshop is held at the Helmholtz Institute for Radiation Physics (HIRP) at the Helmholtz Center for Heavy Ion Research (HZDR) in Dresden, Germany.

Workshop Dates
The workshop is held from August 27 to 31, 2012.

Workshop Website
The workshop website is www.emmi.de.

Workshop Contact
The workshop contact information is emmi@emmi.de.



Workshop on
Quark-Gluon Plasma meets Cold Atoms - Episode III

ExtreMe Matter Institute EMMI

Quark-Gluon Plasma meets Cold Atoms - Episode III

Workshop on Quark-Gluon Plasma meets Cold Atoms - Episode III
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Workshop Objectives
The workshop aims to bring together experts in the field of quark-gluon plasma and cold atoms to discuss the latest developments in the field and to identify key research areas for future studies.

Workshop Topics
The workshop covers a wide range of topics, including the dynamics of quark-gluon plasma, cold atoms, and the interaction between the two.

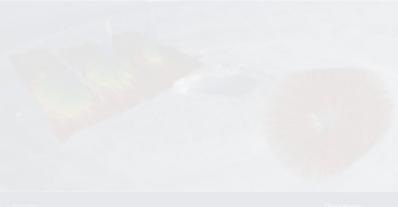
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EMMI RRTFs

- concentrates on focussed problem in intense discussion
- 15 - 25 expert participants
- aim: summary of results, optimally with publication on arXiv and/or in journal

defining the research environment -- extreme matter

研究環境の定義 — 極限物質

matter under extreme conditions of
temperature, pressure, density

involving many different fields of physics

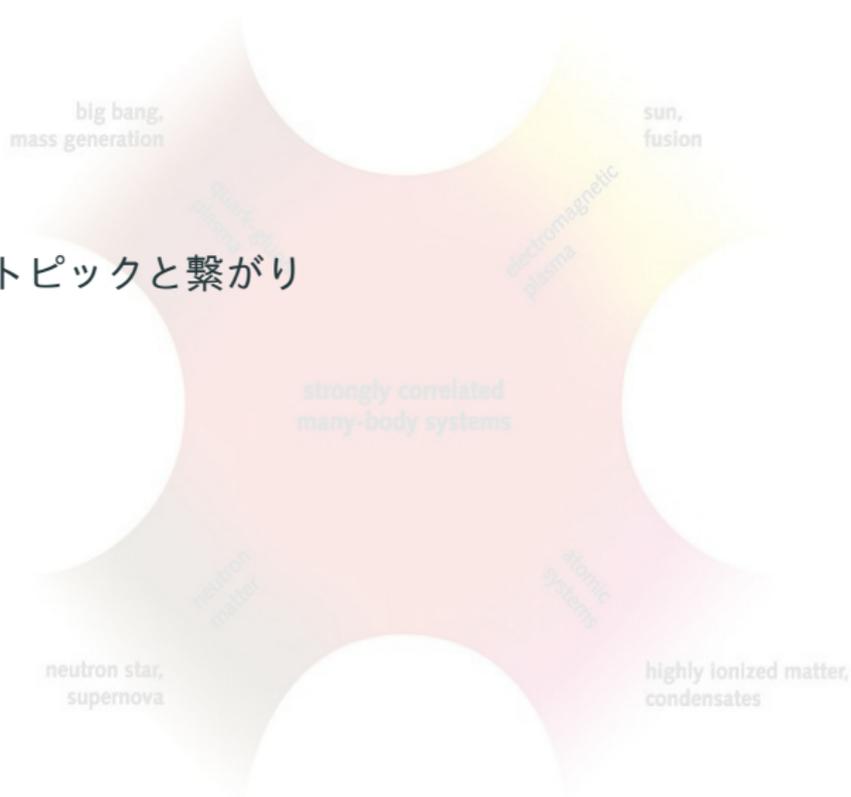
Physics Similarities and Synergies over a huge Temperature – Density Regime

超高温における物理学的な相似性と相乗効果 – 密度状態



Scientific Topics and Links

科学的なトピックと繋がり



EMMI Research

In EMMI are organized more than 400 scientists from the 13 partner institutions

About 15 EMMI Visiting Professors per year in the EMMI partner institutions

About 300 publications/year and 100 articles in conference proceedings per year

About 15 workshops of various formats per year

EMMIの研究

Summary EMMI

keep bureaucracy minimal

provide simple structures with efficient financial management

for interdisciplinary projects mix ideas not necessarily technical issues

EMMI の要約

EMMI as model for effective cooperation across borders



Other collaborations in physics

4 collaborations world-wide using special high performance computers to solve quantum field theories on a discrete lattice of space and time

物理学におけるその他の協力

organized very similarly as experimental projects

mixture of theoretical research and developing special tools for networking and computing

Overall summary

In physics there are many successful international collaborations

Collaborations may involve from 20 – 2500 members

All are organized along similar patterns.

全体の要約
1. a major scientific or scientific-technical goal

2. an organizational structure building on consensus
generally no line management

3. independent scientific and technical oversight on a regular basis

4. financial oversight via resources review boards

... but

Don't forget scientific and technical excellence !

しかし