Attraktive Physik
Dezember 2007

Arbeitsgruppe Quark Matter

Prof. Peter Braun-Munzinger
PD Dr. Helmut Oeschler

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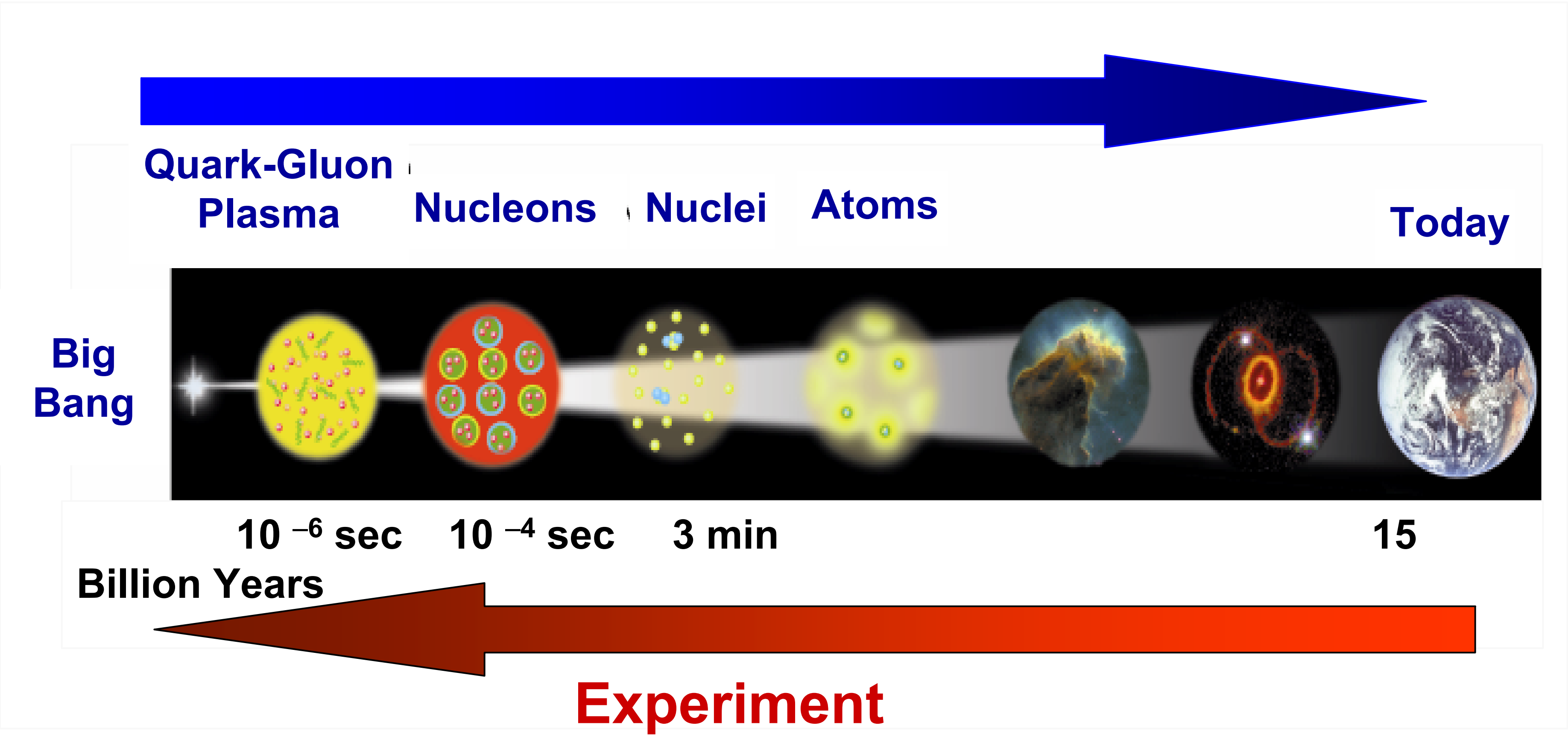
this talk given by:
Dariusz Miśkowiec, GSI

From the big bang to hadrons and nuclei



Phase Transitions in the Early Universe

---- inflation (GUT) phase transition T = 10^{16} GeV

---- electro-weak phase transition T = 10^{2} GeV

---- QCD phase transition T = 175 MeV

note: 10^{10} K ~ 1 MeV

QGP first mentioned...

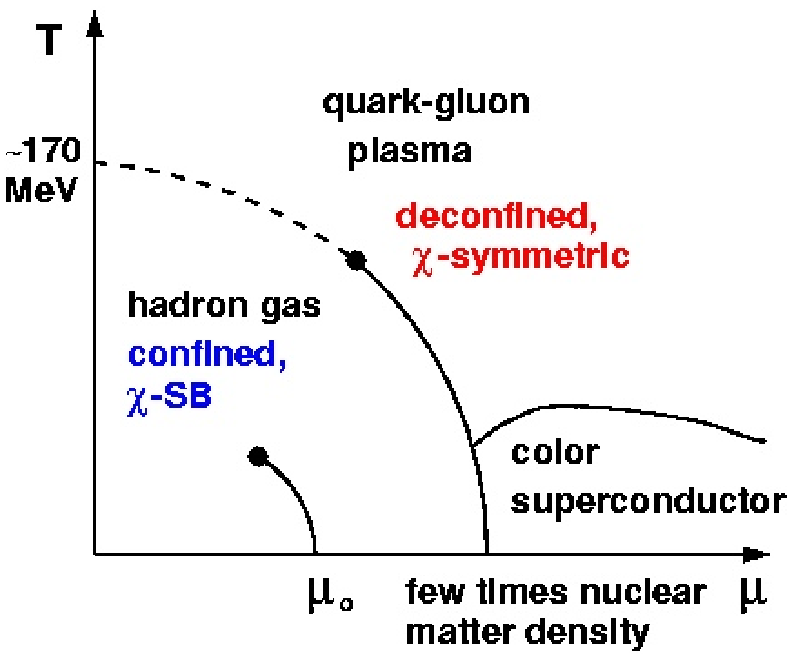
Superdense Matter: Neutrons or Asymptotically Free Quarks?

J. C. Collins and M. J. Perry
Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge CB3 9EW, England
(Received 6 January 1975)

We note the following: The quark model implies that superdense matter (found in neutron-star cores, exploding black holes, and the early big-bang universe) consists of quarks rather than of hadrons. Bjorken scaling implies that the quarks interact weakly. An asymptotically free gauge theory allows realistic calculations taking full account of strong interactions.

A neutron has a radius[10] of about 0.5–1 fm, and so has a density of about 8×10^{14} g cm^{-3}, whereas the central density of a neutron star[1,2] can be as much as 10^{16}–10^{17} g cm^{-3}. In this case, one must expect the hadrons to overlap, and their individuality to be confused. Therefore, we suggest that matter at such high densities is a quark soup. In such a system, long-range interactions are screened because of many-body effects,[11] and hence no problems will arise for any peculiar infrared behavior of quark binding forces. At short

QCD Phase Diagram, modern schematic version



rich structure:

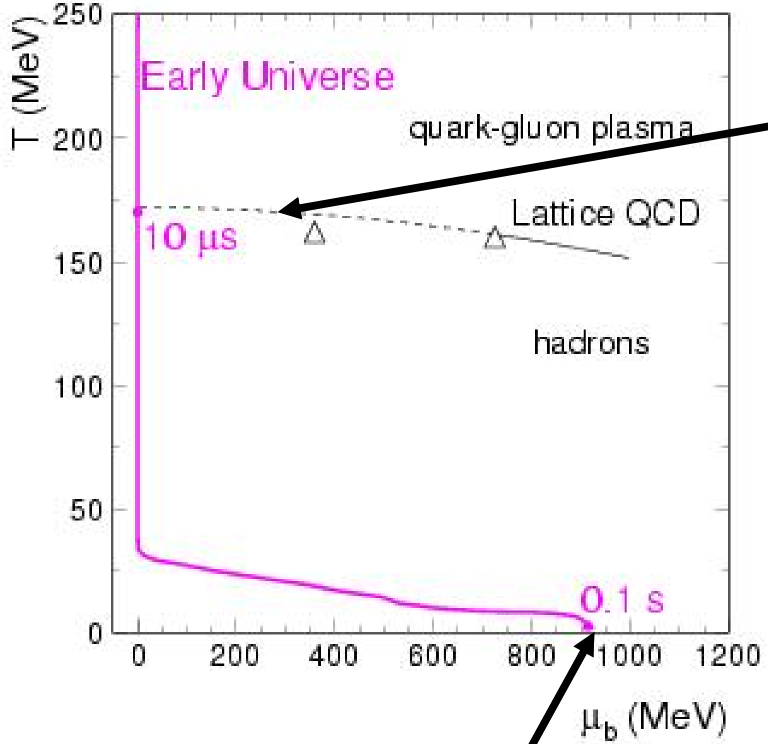
restoration of chiral symmetry coincides (?) with deconfinement;

color superconductivity at low T and high chemical potential;

existence of tri-critical point.

Exploration of the Phases of QCD:
a key theme of modern nuclear physics

Evolution of the Early Universe



QCD Phase Boundary

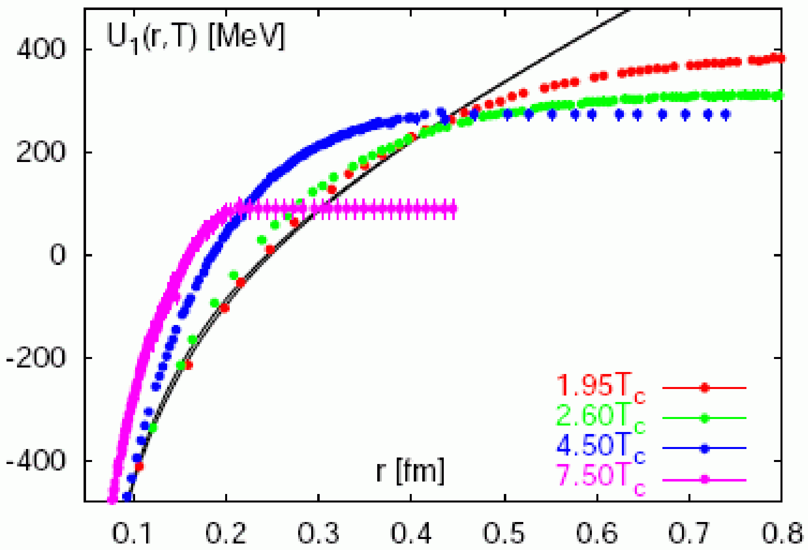
Homogeneous Universe in Equilibrium

- Charge neutrality
- Net lepton number = net baryon number
- Constant entropy/baryon

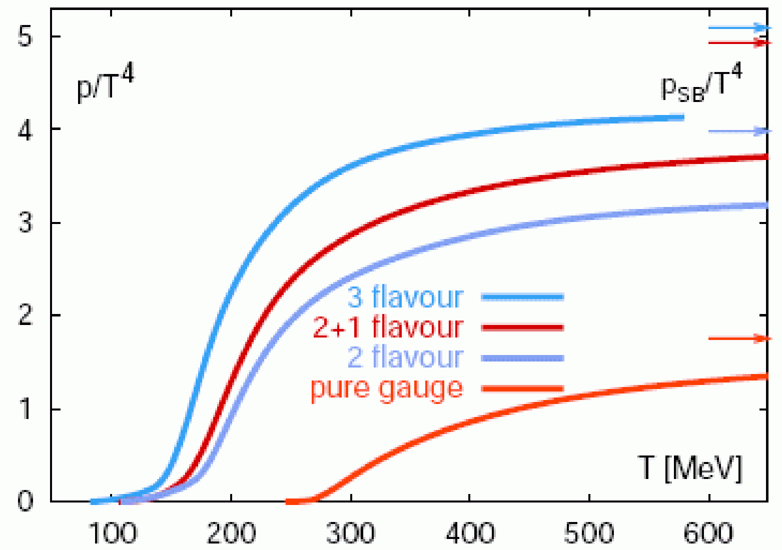
neutrinos decouple and light nuclei begin to be formed

Lattice theory support for the QCD phase transition

qq potential flattens



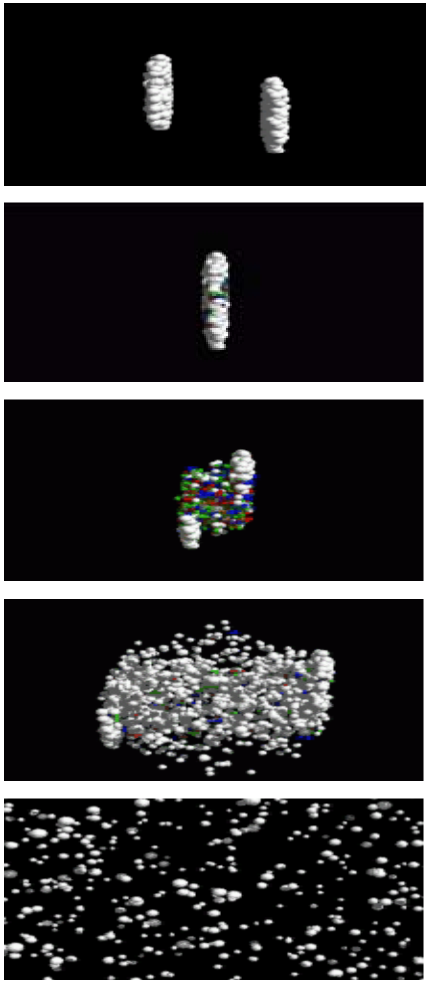
number of degrees of freedom (particle species) increases



F. Karsch, arXiv:0711.0656, arXiv:0711.0661

Heavy ion collision

UrQMD 160 GeV Au+Au



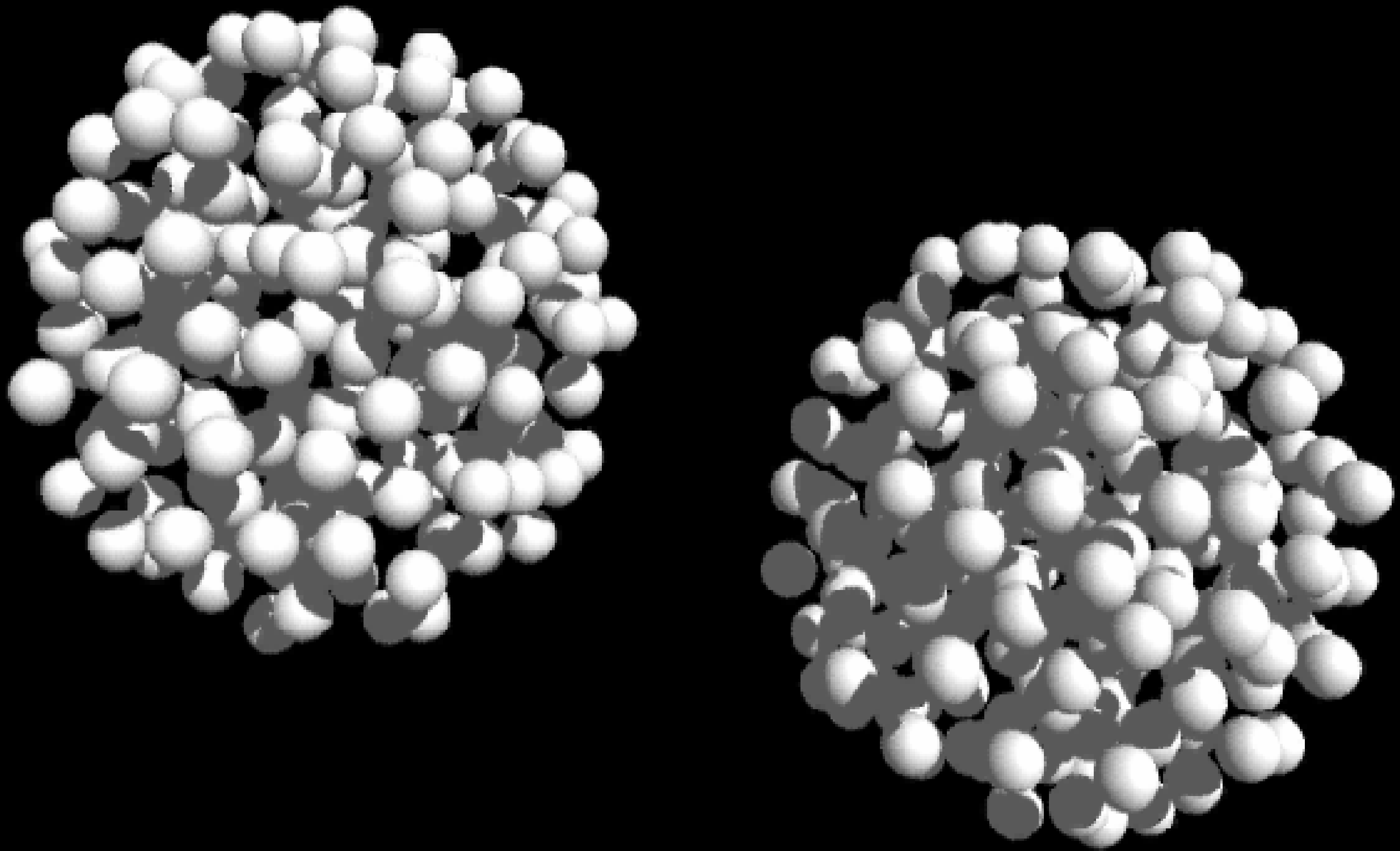
- before collision
- compression and heating
- thermalization
- expansion
- chemical freezeout (number of particles frozen)
- kinetic freezeout (particle momenta frozen)

normal nuclear matter
ρ_0 = 0.17 /fm^3
ε_0 = 0.16 GeV/fm^3

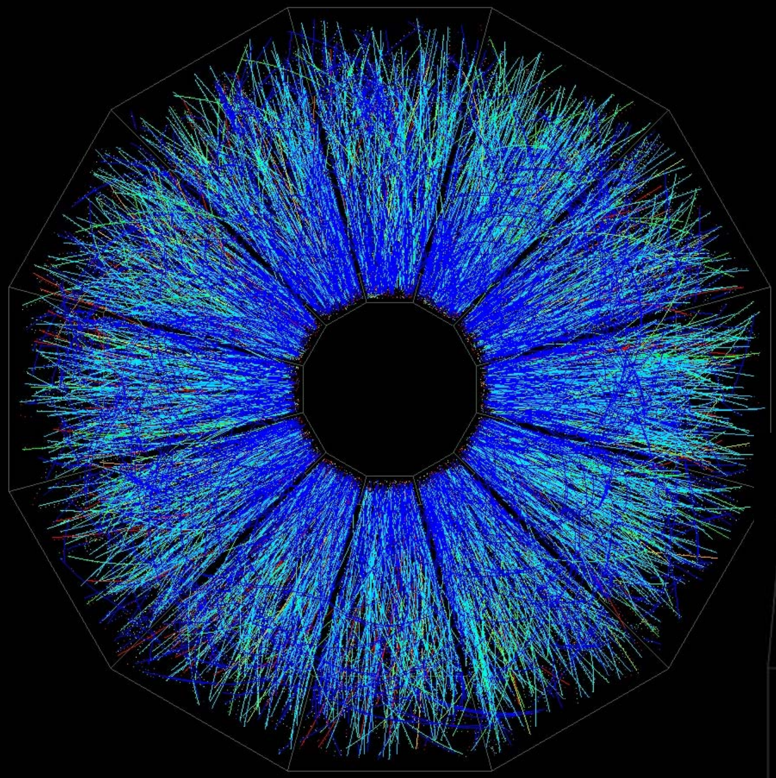
Quark-Gluon Plasma
ρ > 1.2 /fm^3
ε > 3 GeV/fm^3

Heavy ion collision in UrQMD

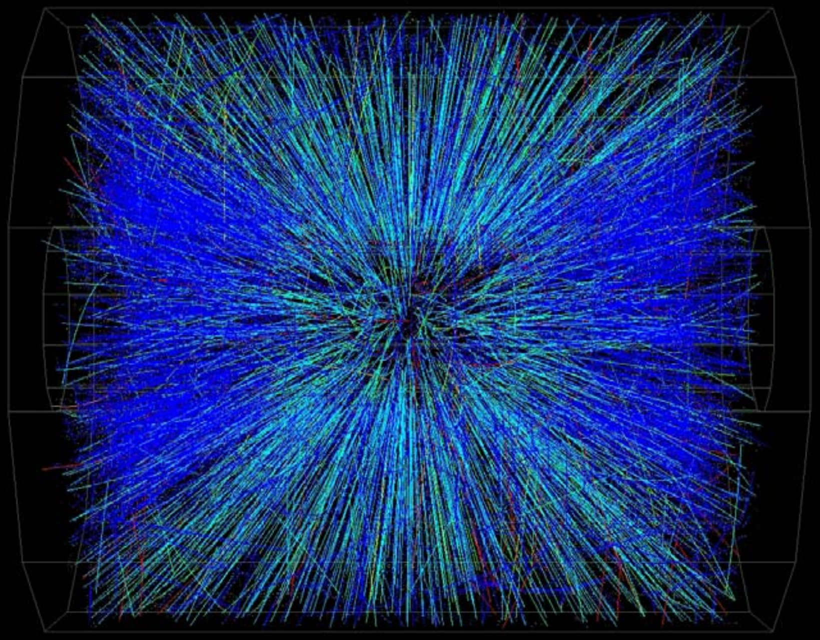
Ultrarelativistic Quantum Molecular Dynamics (UrQMD) --
one of the most commonly used theoretical models, Frankfurt University



Au on Au Event at cm Energy ~ 130 A-GeV

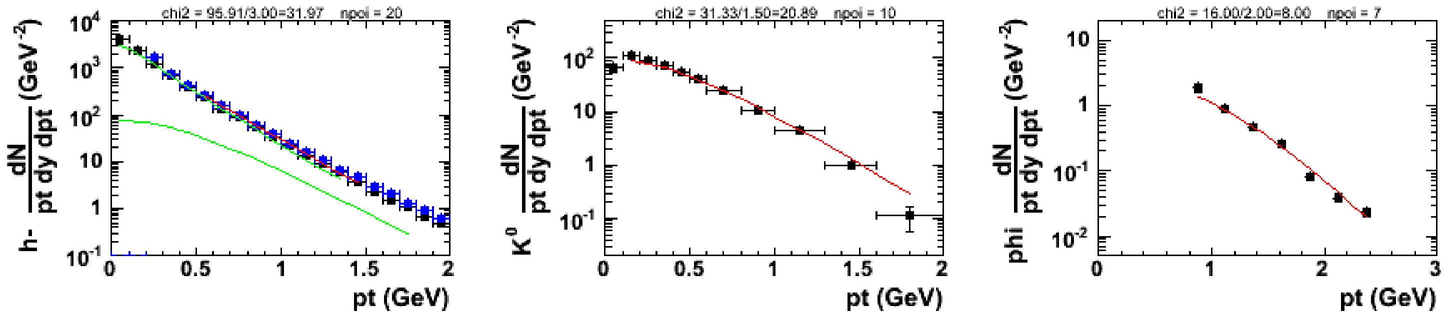


Central Event

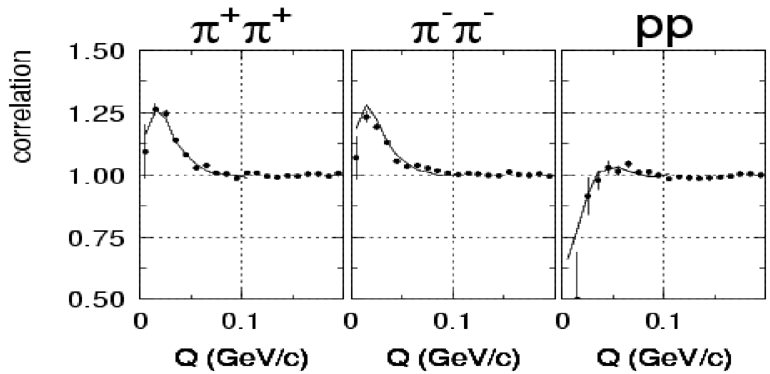


observables in heavy ion collisions

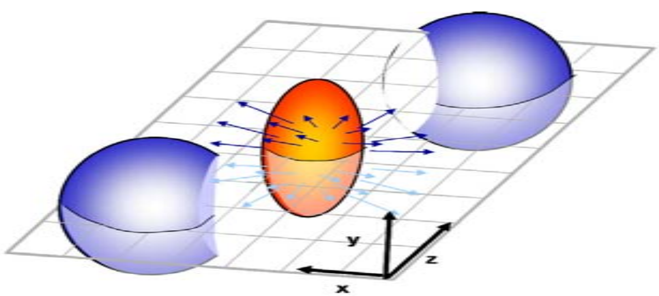
single particle spectra and yields

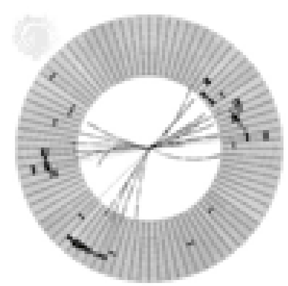


two-particle correlation functions



many-particle correlations (flow, jets)





experimental data on the QCD phase diagram

HELMHOLTZ GEMEINSCHAFT

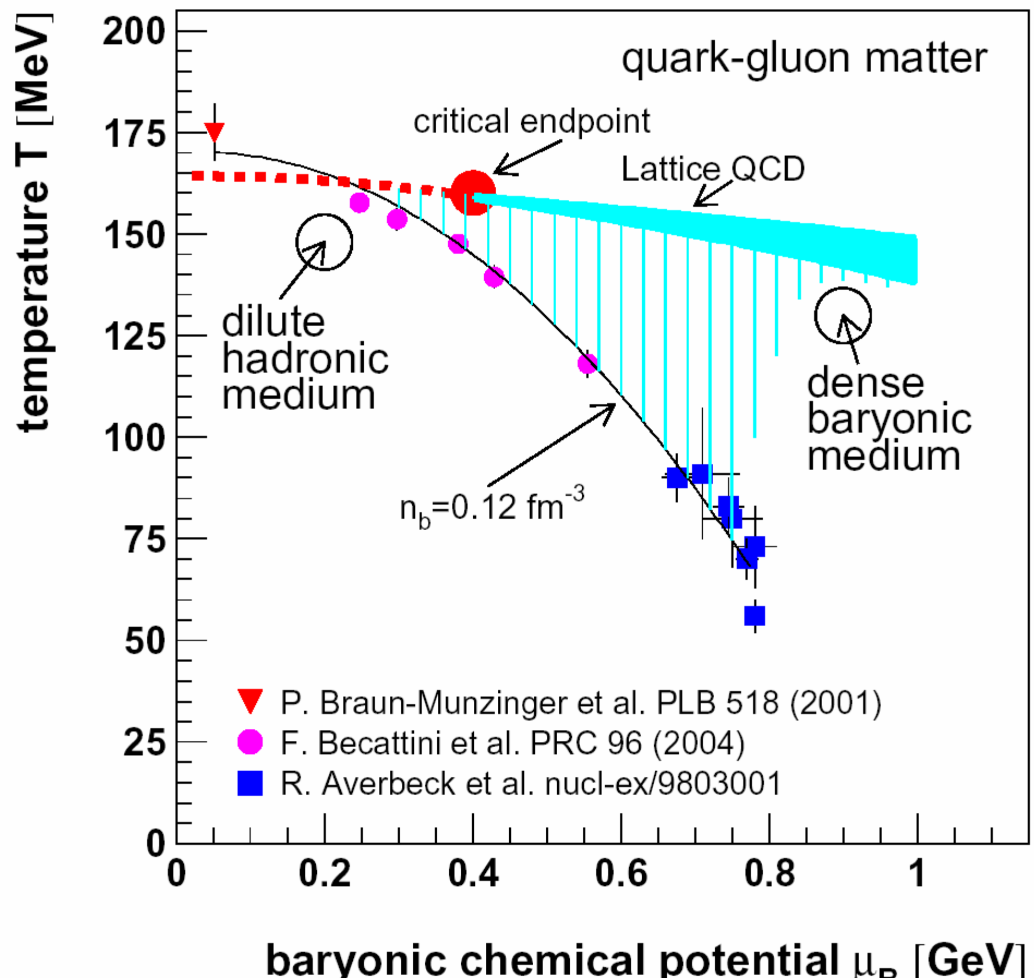
The **Thermal Model** assumes that all particles stem from a thermalized fireball, where all inelastic collisions stop at the same temperature.

By adjusting only two parameters, the **baryon chemical potential** and the **temperature**, relative particle yields can be explained.

$$\rho_i = \frac{g_i}{2\pi^2}\int \frac{p^2 dp}{\exp\left\{\frac{1}{T}\left(E_i - \mu_B B_i - \mu_S S_i\right) \pm 1\right\}}$$

data taken at:

RHIC SPS AGS SIS



GSI TECHNISCHE UNIVERSITÄT DARMSTADT

CERN press statement 1.2.2000

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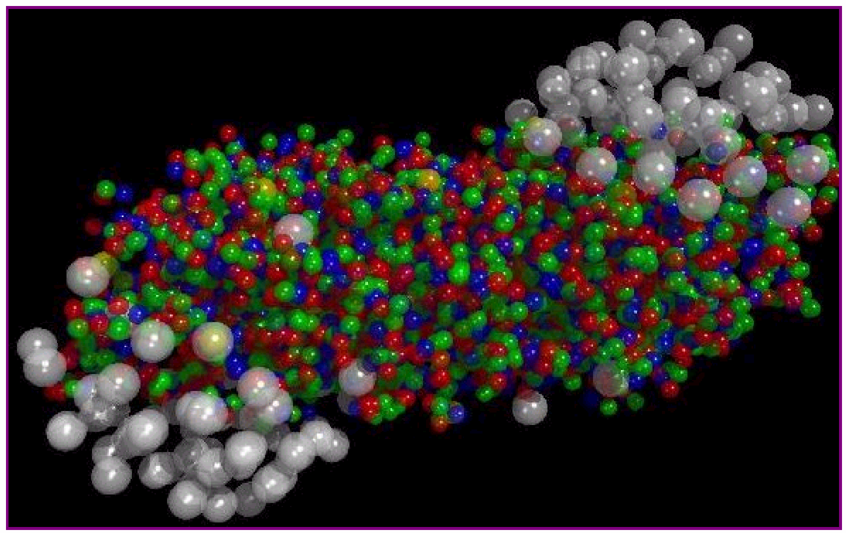
CERN

PRESS RELEASE

Organisation Européenne pour la Recherche Nucléaire
European Organization for Nuclear Research

New State of Matter created at CERN



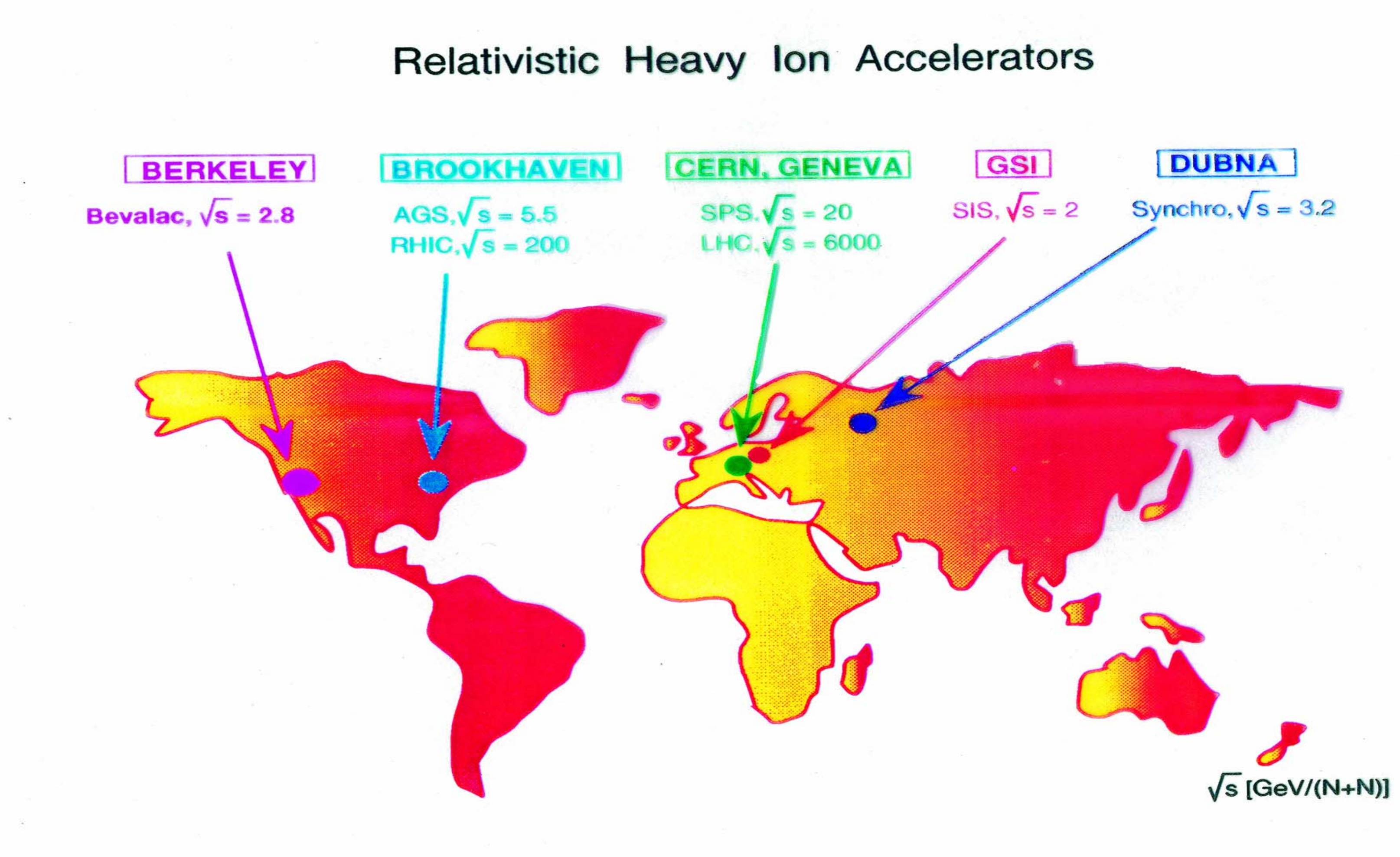
At a special seminar on 10 February, spokespersons from the experiments on CERN* 's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.

Theory predicts that this state must have existed at about 10 microseconds after the Big Bang, before the formation of matter as we know it today, but until now it had not been confirmed experimentally. Our understanding of how the universe was created, which was previously unverified theory for any point in time before the formation of ordinary atomic nuclei, about three minutes after the Big Bang, has with these results now been experimentally tested back to a point only a few microseconds after the Big Bang.

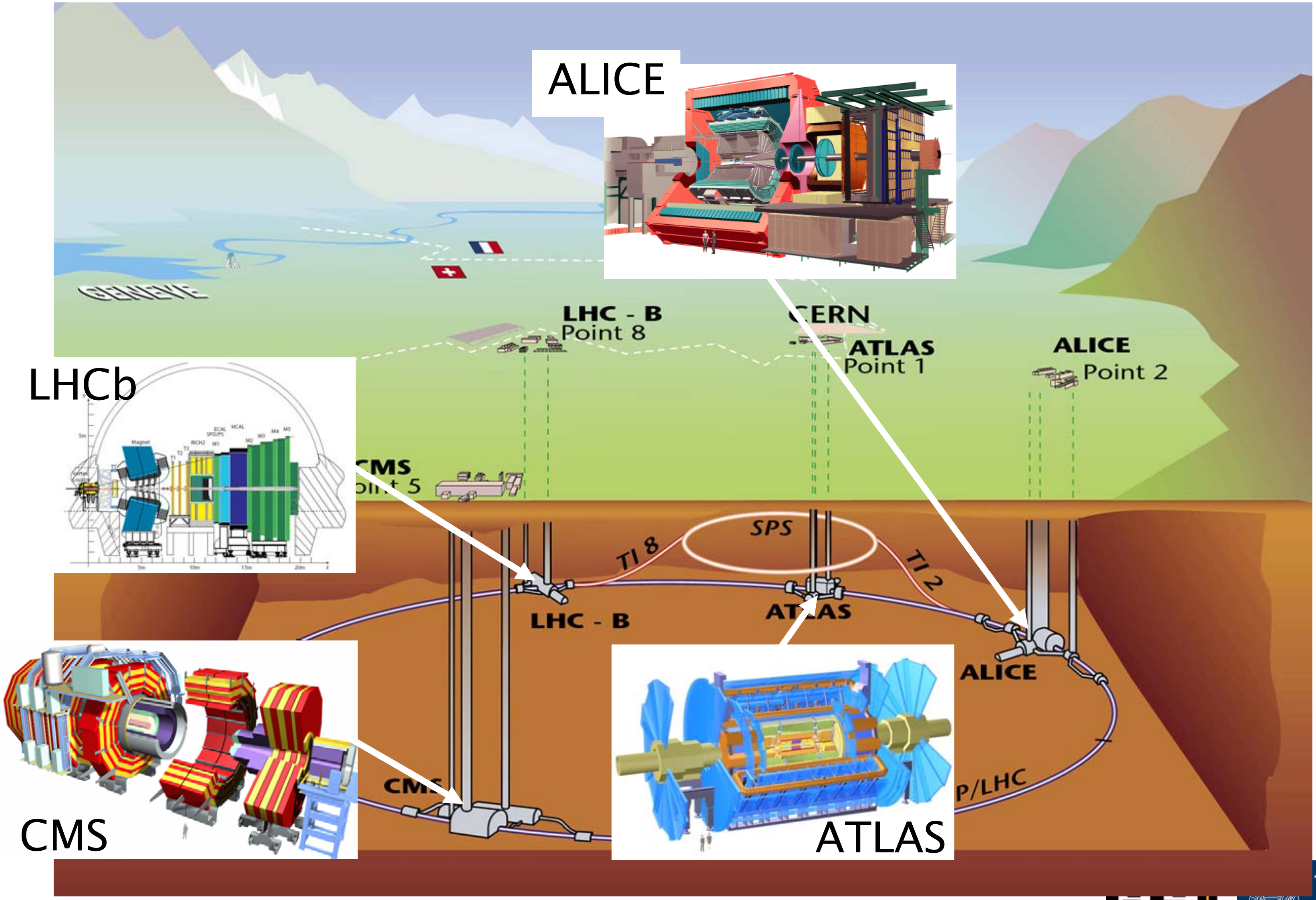
BNL press release on July 18, 2003

…In comparing these very different types of collisions, scientists have seen distinctions that clearly show that head-on gold-gold collisions are producing a nuclear environment quite different from that of deuteron-gold collisions. Although RHIC scientists are not ready to claim success, they are confident that RHIC collisions of gold ions have created unusual conditions and that they are on the right path to the discovery of quark-gluon plasma…

World-wide heavy ion community



LHC experiments



ALICE experiment at the LHC

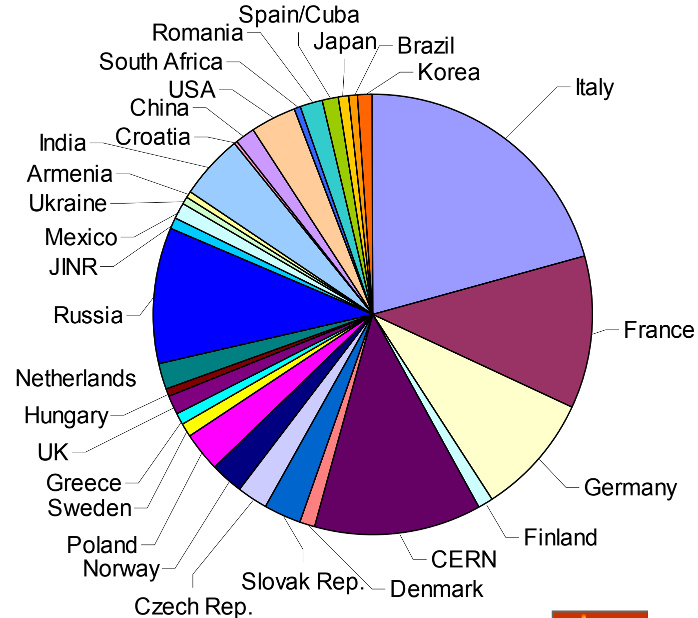
1• L3 MAGNET
2• HMPID
3• TOF
4• DIPOLE MAGNET
5• MUON FILTER
6• TRACKING CHAMBERS
6'• TRIGGER CHAMBERS
7• ABSORBER
8• TPC
9• PHOS
10• ITS

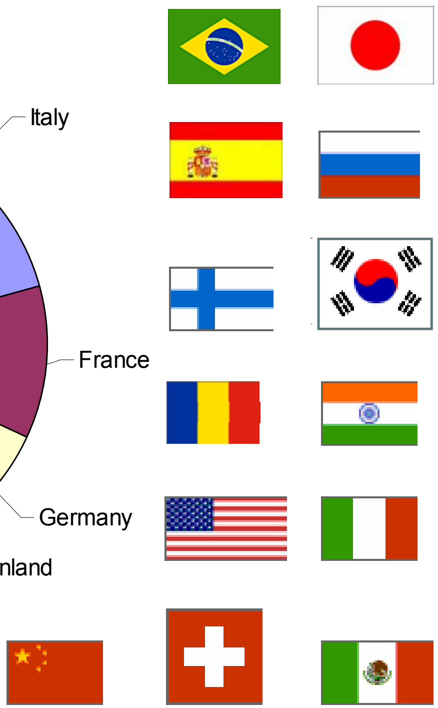
The Alice Collaboration

Some numbers:

Members: ca. 1000

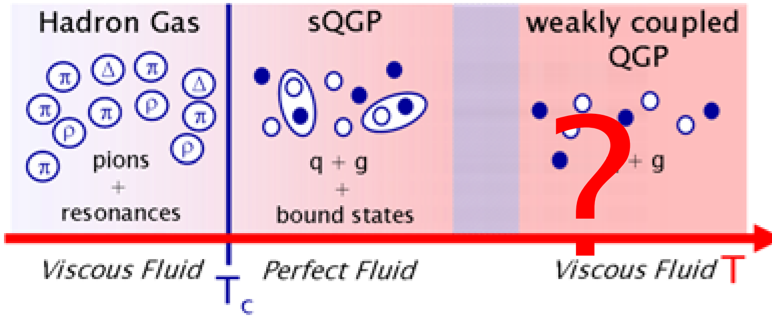
Universität Heidelberg
FZK Karlsruhe
FH Köln
Universität Münster
FH Worms





ALICE programme

***mission*:**
create quark-gluon matter
study its properties quantitatively
be prepared for unexpected = be versatile



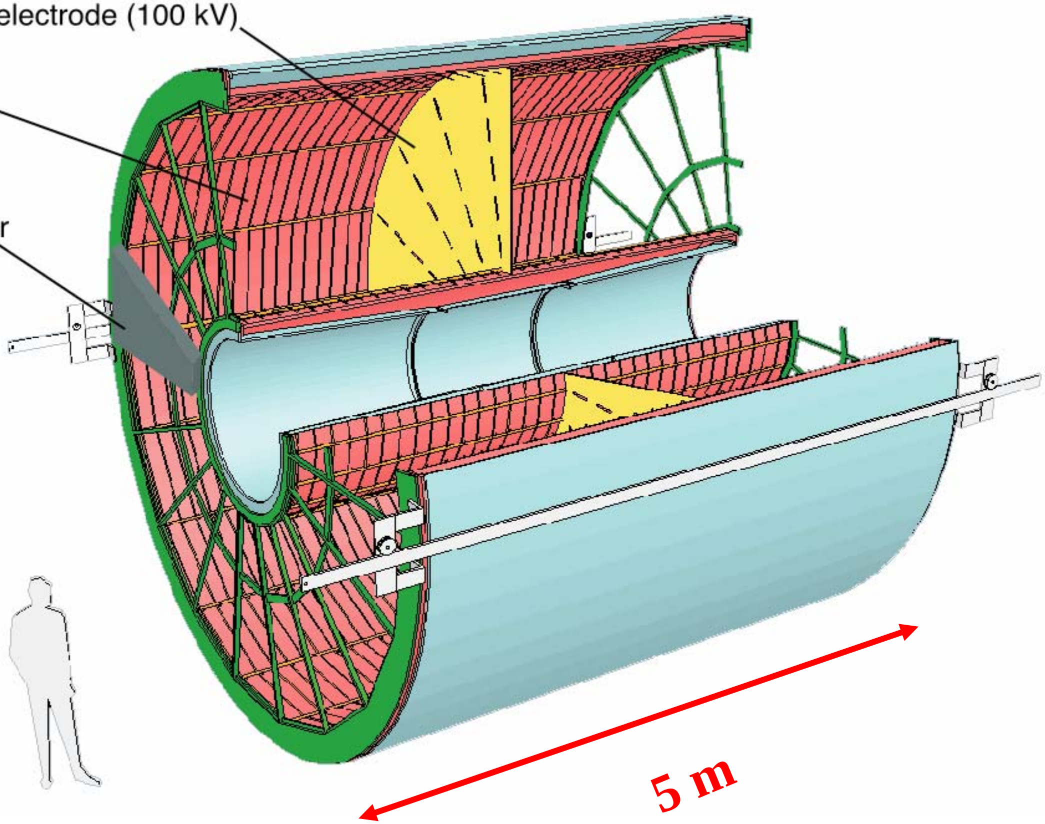
***methods*:**
spectra and correlations of various particles

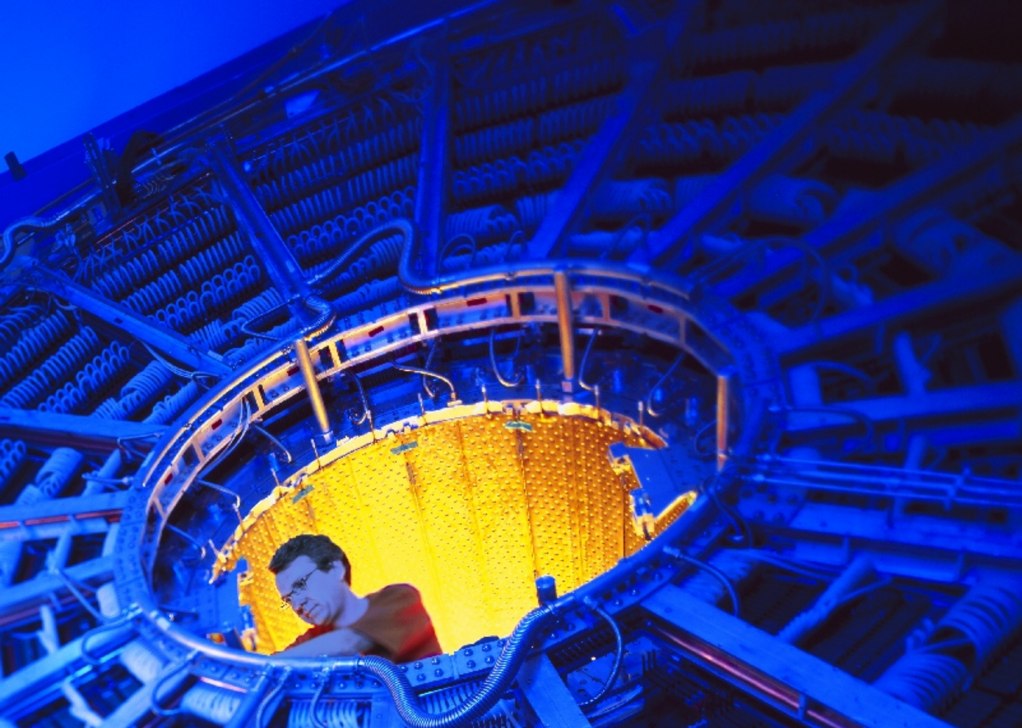
e.g. heavy quarks (open beauty, J/ψ and upsilon-states)
jets in heavy ion environment
weakly interacting probes (Z^0, $W^{\pm}$)

***special at LHC*:**
higher energy density
larger system
more heavy quarks and jets
weak probes W/Z available
access to lower x

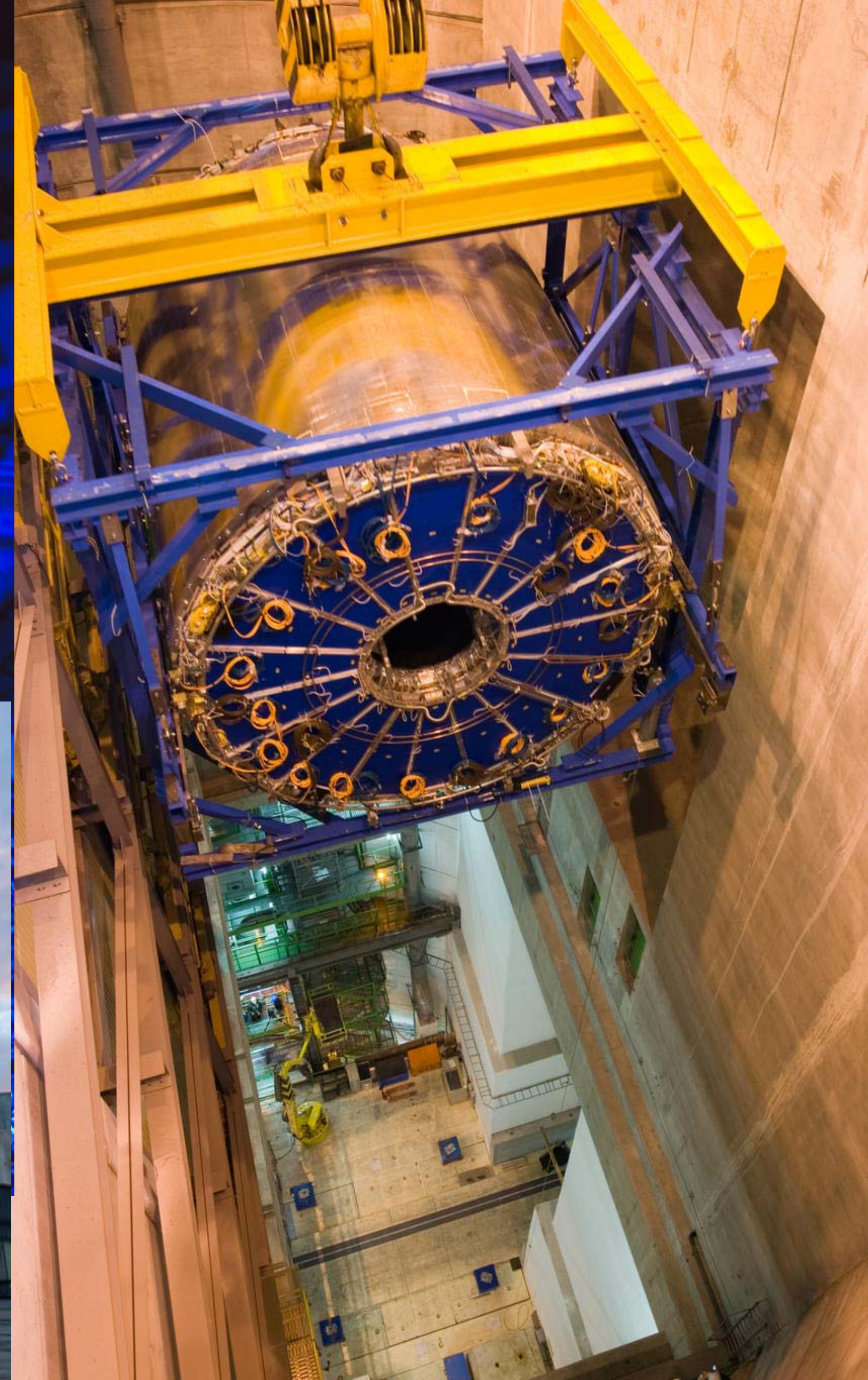
	SPS	RHIC	LHC
$\sqrt{s_{NN}}$ (GeV)	17	200	5500
dN_{ch}/dy	~450	~850	1500-4000
ε(GeV/fm³)	3	5	15-60
τ_{QGP} (fm/c)	≤ 2	2-4	≥ 10

ALICE Time Projection Chamber (TPC)






Friderici



ALICE Transition Radiation Detector (TRD)

HELMHOLTZ GEMEINSCHAFT

Purpose:

Electron-ID

Quarkonia → e^+e^-
Heavy flavour

Some numbers:

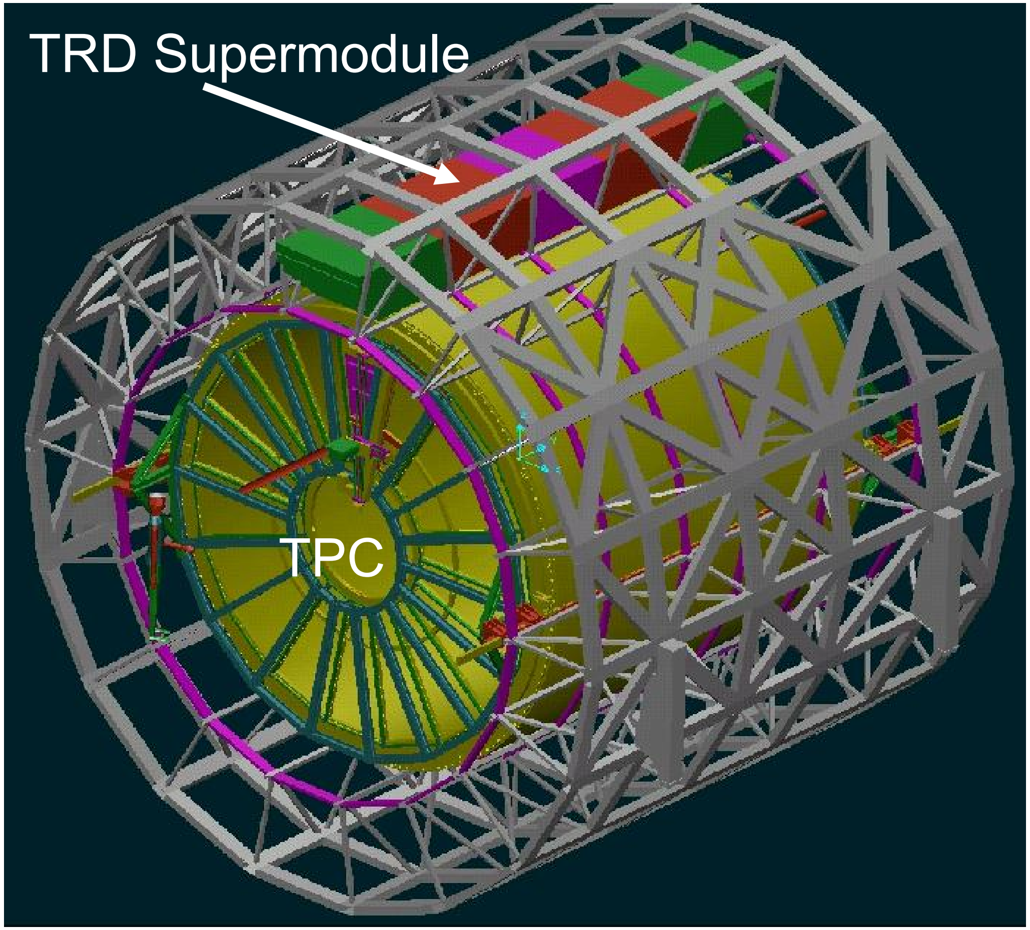
540 chambers

Total area: 736 m^2
(3 tennis courts)

Gas volume: 27.2 m^3

Resolution
($r\varphi$) 400 μm

Number of read out channels: 1.2×10^6



GSI

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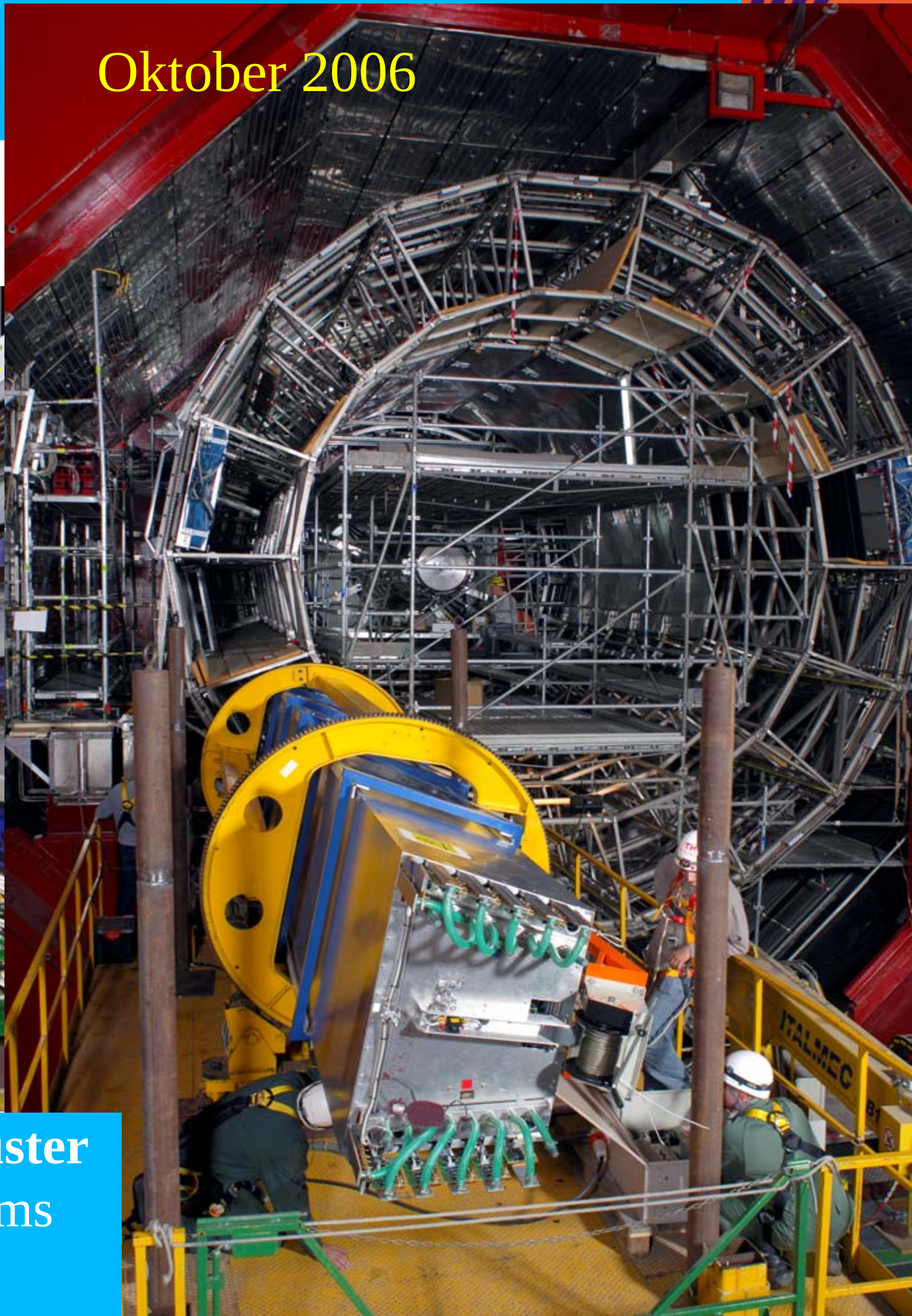
Aufbau u. Einbau des
ersten TRD Supermoduls

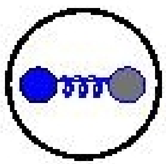


Kontrolle des Detektors: **540 CPU Linux Cluster**
PI und KIP U. Heidelberg, FH Köln, FH Worms
U. Münster, GSI

J/ψ Unterdrückung als QGP Signatur

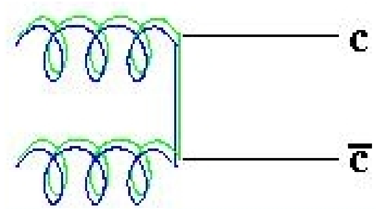
HELMHOLTZ GEMEINSCHAFT

Johanna Stachel

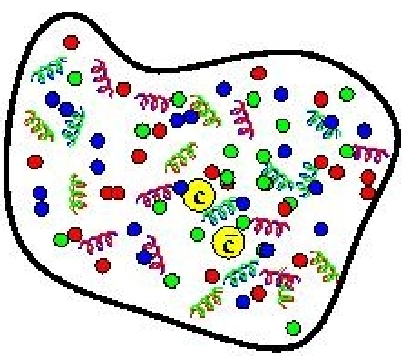


J/ψ : gebundener Zustand aus charm- und anticharm-quark
wasserstoffähnlich Radius: 0.45 fm Masse: 3.097 GeV >> T

charm- und anticharm-Quarks in der Anfangsphase der Kollision durch Fusion von Gluonen der beiden Kerne gebildet



etwa 1 aus 100 $c\bar{c}$-Paaren entwickelt sich in ein J/ψ

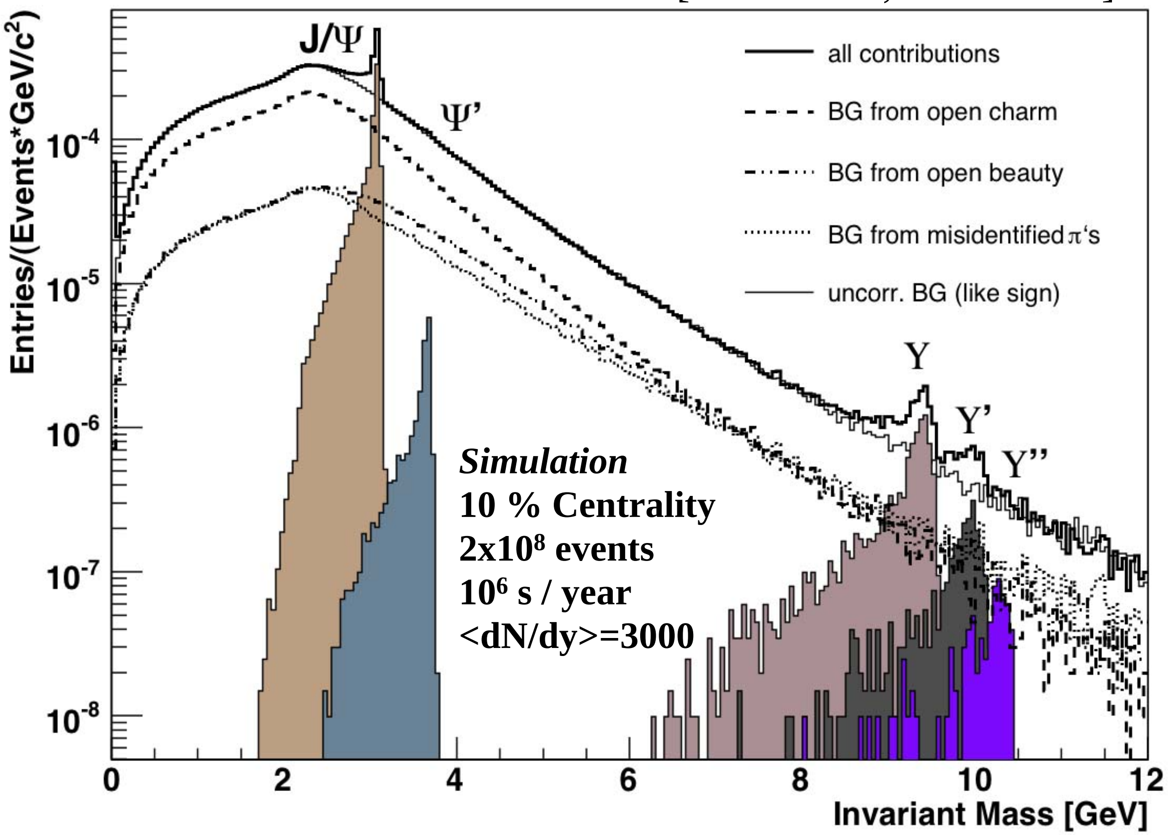


im QGP: attraktive Wechselwirkung zwischen charm and anticharm-Quark durch Präsenz vieler anderer Quarks und Gluonen abgeschirmt
Konsequenz: erwarte signifikant weniger J/ψ wenn QGP präsent

Nachweis von J/ψ: 7% zerfallen in e+e- Paar

Messung von Charmonia und Bottomonia im ALICE zentralen Barrel

[W. Sommer, ALICE PPR]

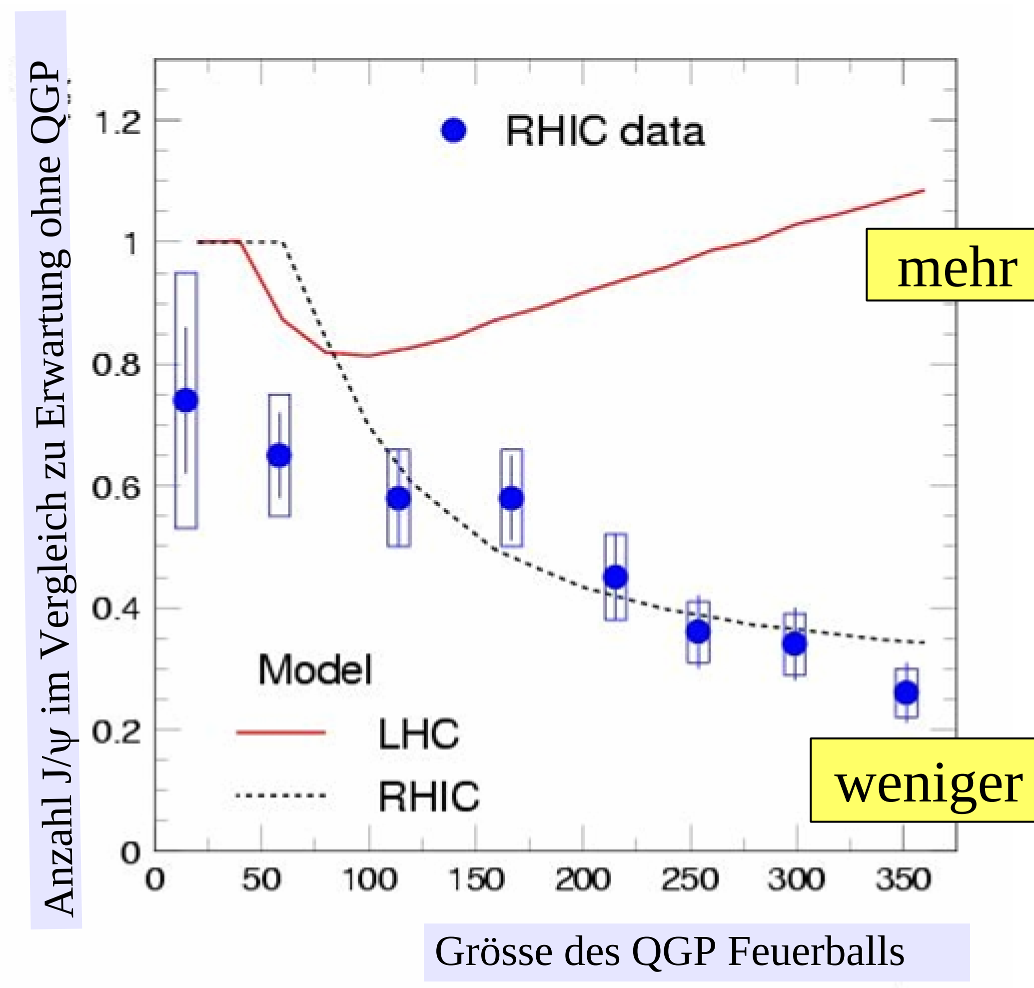


Statistik: 1 Monat Blei-Blei Kollisionen bei LHC Design-Luminosität

Umkehr der J/ψ Unterdrückung in Erhöhung bei LHC
Beweis für Deconfinement im QGP

A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel

wenn Anzahl der produzierten cc-Paare gross (LHC) → zwei c-Quarks aus ursprünglich verschiedenen Paaren können sich beim Ausfrieren in die hadronische Phase 'finden' und ein Charmonium (J/ψ) bilden
mehr J/ψ als ohne QGP



thesis opportunities in the ALICE/GSI group

ALICE first collisions .... summer 2008
ALICE first data-taking run .... 10-21 Dec 2007

currently 5 students from TU working at GSI and at CERN:

- **detector calibration**
- **development of data analysis algorithms**
- **participation in data-taking**
  (December run: out of 16 TPC shift crew members 6 are our students)

enough work for many more students...