Quantum Chromodynamics and Strong Interactions at the IPhT

IPhT external review, 21-22 November, 2011
QCD at the Large Hadron Collider

- The LHC collides protons and nuclei, i.e. quarks and gluons. QCD is therefore at the heart of LHC physics.
- QCD processes are backgrounds to searches for new physics (Higgs, SUSY,...) and must be computed accurately.
- The LHC also provides opportunities for studying the strong interactions themselves:
  - Heavy ion collisions probe the properties of quark-gluon matter in extreme conditions.
QCD as a playground for more formal developments

- Development of new, more efficient, methods for computing amplitudes in gauge theories

- Studies in supersymmetric extensions of QCD (e.g. SUSY N=4 Yang-Mills theory)
  - links to string theory via the AdS/CFT correspondence
  - links to the physics of integrable systems
Group members: staff and emeritus

J.-P. Blaizot
R. Britto
F. Gelis
E. Iancu
G. Korchemsky
D. Kosower
J.-Y. Ollitrault
G. Soyez
R. Peschanski
M. Rho
Group members: 3 new members since 2007

J.-P. Blaizot

R. Britto

F. Gelis

E. Iancu

G. Korchemsky

D. Kosower

J.-Y. Ollitrault

G. Soyez

R. Peschanski

M. Rho
Group members: current postdocs

J. Albacete  
L. Almeida  
G. Diana  
F. Dominguez  
H. Johansson  
J. Kim  
M. Luzum  
M. Ritzmann
Group members: current PhD students

T. Epelbaum  J. Laidet  K. Larsen  A. Ochirov
Z. Peng  E. Retinskaya  P. Warchol
## Former postdocs and students

### Former postdocs

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<thead>
<tr>
<th>Name</th>
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<tr>
<td>E. Avsar</td>
<td>→</td>
<td>PennState U.</td>
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<td>S. Badger</td>
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<td>DESY</td>
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<td>Y. Hatta</td>
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<td>U. Tsukuba</td>
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<td>T. Lappi</td>
<td>→</td>
<td>U. Jyväskylä</td>
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<td>C. Marquet</td>
<td>→</td>
<td>CERN</td>
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<td>E. Mirabella</td>
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<td>MPI Munich</td>
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<td>J. Zhang</td>
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<td>Beijing U.</td>
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### Former students

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<tr>
<td>B. Basso</td>
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<td>Princeton U.</td>
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<td>G. Beuf</td>
<td>→</td>
<td>BNL</td>
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<td>G. Giecold</td>
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<td>Stony Brook U.</td>
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<td>C. Gombeaud</td>
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<td>U. Bielefeld</td>
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<td>C. Vergu</td>
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<td>Brown U.</td>
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<td>ETH Zurich</td>
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Collaborators

- approx. 130 collaborators
- from 80 institutes, in 25 countries
External funding

- 2 senior grants from the European Research Council
- 7 grants from the Agence Nationale de la Recherche
- 1 Initial Training Network (European network)
- Other international programs
  - Austria
  - Brazil
  - CERN
  - India
  - Japan
  - Poland
  - Russia
  - UK
  - USA
22 Lectures in summer schools

- J.-P. Blaizot: Heavy-quarks in a quark-gluon plasma (Dubna, Russia)
- J.-P. Blaizot: Quantum fields at finite temperature, from nano to tera kelvin (Nanjing, China)
- R. Britto: Scattering amplitudes in gauge theories (Driebergen, Netherlands)
- R. Britto: Multi-leg amplitudes (Orsay, France)
- R. Britto: Recursive construction of amplitudes (Les Houches, France)
- F. Gelis: Gluon saturation from DIS to nucleus-nucleus collisions (Copanello, Italy)
- F. Gelis: Pre-equilibrium dynamics in heavy ion collisions (Mumbai, India)
- F. Gelis: Quantum chromo-dynamics at finite temperature (Rio de Janeiro, Brazil)
- F. Gelis: Gluon saturation from DIS to AA collisions (Les Houches, France)
- F. Gelis: Color glass condensate and initial stages of heavy-ion collisions (Dubna, Russia)
- F. Gelis: Initial conditions in AA collisions (Goa, India)
- E. Iancu: Non-linear evolution in QCD at high energies (Copanello, Italy)
- E. Iancu: High-energy QCD: the color glass condensate (Rio de Janeiro, Brazil)
- E. Iancu: Gluon saturation and the color glass condensate (Les Houches, France)
- E. Iancu: Partons and jets in a strongly-coupled plasma from AdS/CFT (Zakopane, Poland)
- E. Iancu: High energy scattering: from weak to strong coupling (Magurele, Romania)
- D. Kosower: On-shell methods in gauge field theory (Weizmann Institute, Israel)
- D. Kosower: On-shell methods in gauge theory (Chi-Tou, Taiwan)
- J.-Y. Ollitrault: Relativistic hydrodynamics (Mumbai, India)
- J.-Y. Ollitrault: Relativistic hydrodynamics (Les Houches, France)
- G. Soyez: Phenomenology of hadronic colliders (Ostend, Belgium)
Organization of 16 conferences/workshops/schools

- **E. Iancu** QCD, low X physics, saturation and diffraction (Copanello, Italy)
- **F. Gelis** QCD under extreme conditions (Rio de Janeiro, Brazil)
- **E. Iancu, R. Peschanski** Low X meeting (Helsinki, Finland)
- **F. Gelis, E. Iancu, J.-Y. Ollitrault** Hadronic collisions at the LHC and QCD at high density (Les Houches, France)
- **F. Gelis** Structure of hadrons and nuclei at an electron-ion collider (Trento, Italy)
- **D. Kosower** Wonders of gauge theory and supergravity (Paris, France)
- **J.-P. Blaizot** Phases of strongly interacting matter (Orsay, France)
- **J.-P. Blaizot** Renormalization group approach from ultra cold atoms to the hot QGP (Kyoto, Japan)
- **F. Gelis** Initial conditions in Heavy Ion Collisions (Goa, India)
- **F. Gelis, E. Iancu, J.-Y. Ollitrault** Quantum field theory in extreme environments (Saclay, France)
- **F. Gelis** Aspects of perturbative QCD (Orsay, France)
- **F. Gelis** Structure Functions, Geometric Scaling and Parton Saturation (Darmstadt, Germany)
- **E. Iancu, R. Peschanski** Low X meeting (Kavala, Greece)
- **F. Gelis** Winter Workshop on Recent QCD Advances at the LHC (Les Houches, France)
- **E. Iancu** Excited QCD 2011 (Les Houches, France)
- **F. Gelis, E. Iancu** Standard and novel QCD phenomena at hadron colliders (Trento, Italy)
Highlights
Unitarity methods for one-loop amplitudes

R. Britto and B. Feng.  
*Solving for tadpole coefficients in one-loop amplitudes.*  

R. Britto and E. Mirabella.  
*Single Cut Integration.*  

Prospects

- Complete treatment of massive particles in the unitarity method
- Full analysis of multiloop integrals and their cuts
Automated tools for 1-loop amplitudes (BlackHat)


**Ongoing work**

- Development of BlackHat 1-loop software library
First computation of $p+p \rightarrow W+4$ jets at NLO (using BlackHat w/ Sherpa)

\[ q \rightarrow \begin{array}{c} W \rightarrow e + \nu \rightarrow q' + g + g + g + g \\ q' \rightarrow \bar{Q} + Q \end{array} \]


*Precise Predictions for $W + 4$ Jet Production at the Large Hadron Collider.*


Recent work and prospects

- Z+4 jets at NLO; other complex processes
- $t\bar{t}+$ multi-jets at NLO
Anti-Kt jet clustering algorithm


Jet Reconstruction in Heavy Ion Collisions.

M. Cacciari, G.P. Salam, and G. Soyez.

FastJet package
http://www.fastjet.fr

Prospects

- Jet response to soft backgrounds (e.g. pile-up)
- Jet substructure
Flow fluctuations and transport properties


Triangular flow in hydrodynamics and transport theory.


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**Prospects**

- Quantitative understanding of heavy-ion data from LHC in the soft sector
Factorization in high-energy heavy ion collisions

F. Gelis, T. Lappi, and R. Venugopalan.


A. Dumitru, F. Gelis, L. McLerran, and R. Venugopalan.


L. Albacete and C. Marquet.


**Prospects**

- Factorization for less inclusive observables
- Final state evolution and thermalization
Quark-Antiquark correlators at finite temperature


Real and imaginary-time $Q\bar{Q}$ correlators in a thermal medium,


A path integral for heavy quarks in a hot plasma.


**Prospects**

- Ultimate goal: full dynamics of heavy quarks and heavy quark pairs in a quark-gluon plasma.
Amplitudes in SUSY N=4 Yang-Mills theory


*The Two-Loop Six-Gluon MHV Amplitude in Maximally Supersymmetric Yang-Mills Theory.*


Z. Bern, J.J.M. Carrasco, and **H. Johansson**.

*Perturbative Quantum Gravity as a Double Copy of Gauge Theory.*


**Prospects**
- Investigating finiteness of N=8 supergravity
- General unitarity formalism at 2 loops
Dual superconformal symmetry; Amplitudes ↔ Wilson loops duality

**G. Korchemsky** and E. Sokatchev.
*Symmetries and analytic properties of scattering amplitudes in N=4 SYM theory.*
*Nucl. Phys. B 882, 1 (2010).*

**F. Alday, B. Eden, G. Korchemsky, J Maldacena, and E. Sokatchev.**
*From correlation functions to Wilson loops.*
*JHEP 1109, 123 (2011).*

**Prospects**
- Clarify the dynamical origin of this symmetry
- Turn it into new techniques for computing amplitudes
- Investigating the integrability of N=4 SUSY Yang-Mills
AdS/CFT correspondence

Deep inelastic scattering at strong coupling from gauge/string duality: the saturation line.

Jet evolution in the N=4 SYM plasma at strong coupling.
JHEP 0805, 037 (2008).

Boost-invariant early time dynamics from AdS/CFT.

Prospects

• Clarify the process of measurement at strong coupling
• Understanding thermalization at strong coupling