Quantum Chromodynamics and Strong Interactions at the IPhT

IPhT external review, 21-22 November, 2011

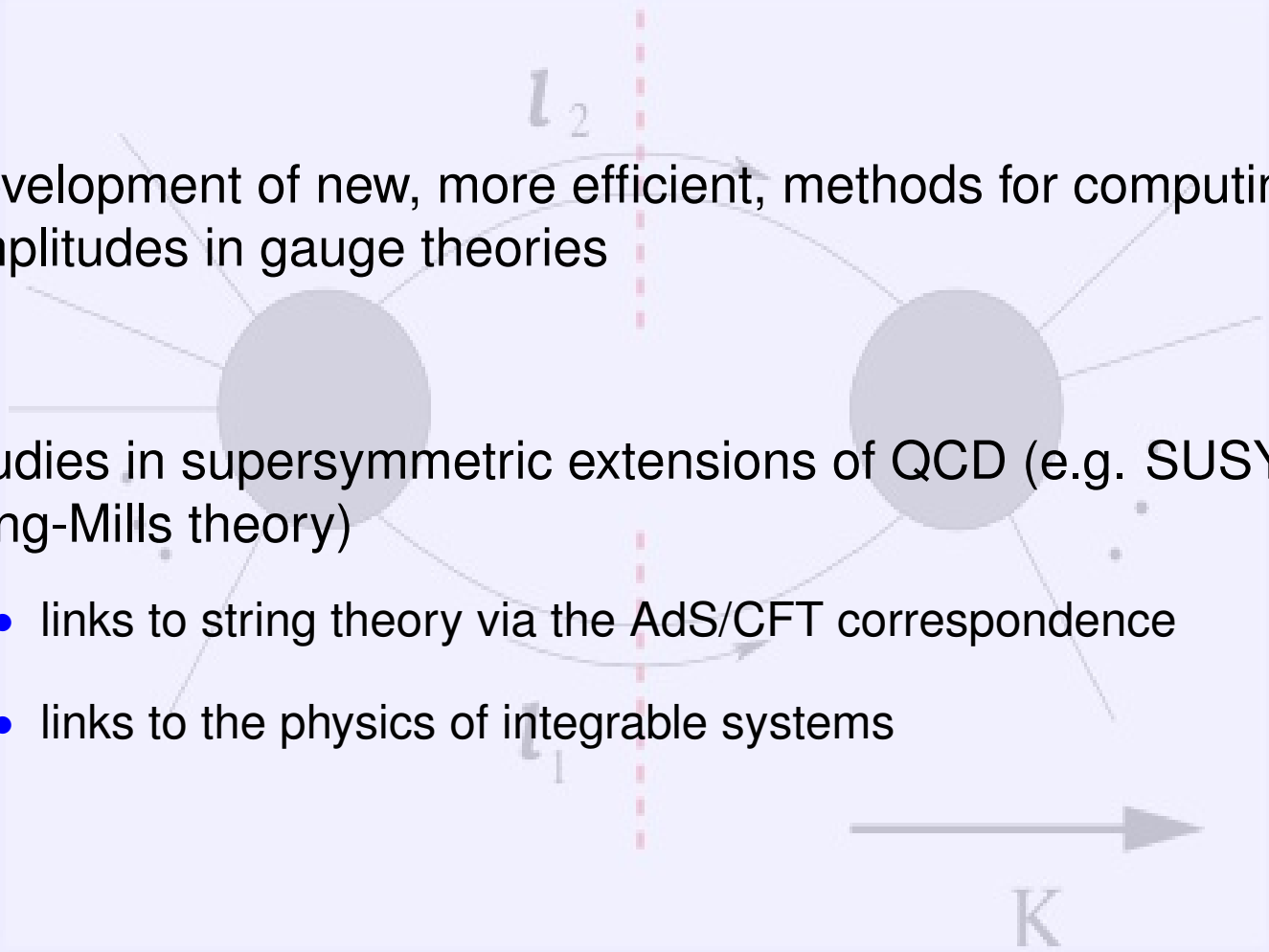
QCD at the Large Hadron Collider

- 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

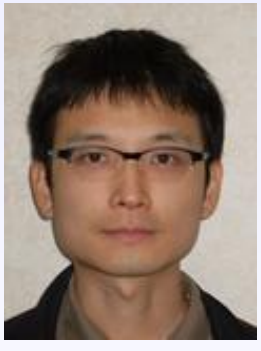
J. Albacete

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

E. Avsar	$\longrightarrow$	PennState U.		
S. Badger	$\longrightarrow$	DESY	$\longrightarrow$	NBI
Y. Hatta	$\longrightarrow$	U. Tsukuba		
T. Lappi	$\longrightarrow$	U. Jyväskylä		
C. Marquet	$\longrightarrow$	CERN		
E. Mirabella	$\longrightarrow$	MPI Munich		
J. Zhang	$\longrightarrow$	Beijing U.		

Former students

B. Basso	$\longrightarrow$	Princeton U.		
G. Beuf	$\longrightarrow$	BNL	$\longrightarrow$	U. Santiago
G. Giecold	$\longrightarrow$	Stony Brook U.		
C. Gombeaud	$\longrightarrow$	U. Bielefeld		
C. Vergu	$\longrightarrow$	Brown U.	$\longrightarrow$	ETH Zurich

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)

Publications: june 2007 - june 2011

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[t07/172] B.G. Giraud. *Density functionals in the laboratory frame*. *Phys. Rev. C*, 77, 014311, (2008), arXiv:0707.3901.

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[t07/219] H. Fujii, F. Gelis, A.M. Stasto, and R. Venugopalan. *Melting the Color Glass Condensate at the LHC*. (2007), arXiv:0707.1870.

[t08/001] M. Boonekamp, J. Cammin, R. Peschanski, and C. Royon. *Threshold scans in diffractive W pair production via QED processes at the LHC*. *Phys. Lett. B*, 654, 104–109, (2007), arXiv:0709.2742.

[t08/010] B.-Y. Park, M. Rho, and V. Vento. *The Role of the Dilaton in Dense Skyrmion Matter*. *Nucl. Phys. A*, 807, 28–37, (2008), arXiv:0801.1374.

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[t08/071] A. Bialas, A. Bzdak, and R. Peschanski. *Limiting fragmentation from scale-invariant merging of fast partons*. *Phys. Lett. B*, 665, 35–38, (2008), arXiv:0804.2364.

[t08/084] E. Iancu, M.S. Kugeratski, and D.N. Triantafyllopoulos. *Geometric Scaling in Mueller-Navelet Jets*. *Nucl Phys. A*, 808, 95–116, (2008), arXiv:0802.0343.

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[t08/226] F. Dominguez, C. Marquet, and B. Wu. *On multiple scatterings of mesons in hot and cold QCD matter*. *Nucl. Phys. A*, 823, 99–119, (2009), arXiv:0812.3878.

[t08/232] F. Gelis, T. Lappi, and R. Venugopalan. *High energy factorization in nucleus-nucleus collisions. 3. Long range rapidity correlations*. *Phys. Rev. D*, 79, 094017, (2009), arXiv:0810.4829v2.

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[t08/261] J.-P. Blaizot and Y. Mehtar-Tani. *The classical field created in early stages of high energy nucleus-nucleus collisions*. *Nucl. Phys. A*, 818, 97–119, (2009), arXiv:0806.1422.

[t08/278] R. Peschanski, M. Rangel, and C. Royon. *Hybrid Pomeron Model of exclusive central diffractive production*. *Acta Phys. Pol. B*, 40, 2323–2344, (2009), arXiv:0808.1691.

[t09/018] C. Gombeaud, T. Lappi, and J.-Y. Ollitrault. *Does interferometry probe thermalization?* *Phys. Rev. C*, 79, 054914, (2009), arXiv:0901.4908.

[t09/019] C.F. Berger, Z. Bern, L.J. Dixon, F. Febres Cordero, D. Forde, T. Gleisberg, H. Ita, D.A. Kosower, and D. Maitre. *Precise Predictions for $W + 3$ Jet Production at Hadron Colliders*. *Phys. Rev. Lett.*, 102, 222001, (2009), arXiv:0902.2760.

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[t09/056] G. Giecold, E. Iancu, and A.H. Mueller. *Stochastic trailing string and Langevin dynamics from AdS/CFT*. *JHEP*, 0907, 033, (2009), arXiv:0903.1840.

[t09/063] F. Gelis, T. Lappi, and L. McLerran. *Glittering Glasmas*. *Nucl. Phys. A*, 828, 149–160, (2009), arXiv:0905.3234.

[t09/076] G. Korchemsky and E. Sokatchev. *Symmetries and analytic properties of scattering amplitudes in N=4 SYM theory*. *Nucl. Phys. B*, 882, 1–51, (2010), arXiv:0906.1737.

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[t09/099] C. Gombeaud, T. Lappi, and J.-Y. Ollitrault. *Effects of partial thermalization on HBT interferometry*. volume 830 of *Nucl. Phys. A*, 817c–820c, (2009), arXiv:0907.1392. The 21st International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions (Quark Matter 2009), Knoxville, TN, 2009-03-30/2009-04-04.

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Highlights

Unitarity methods for one-loop amplitudes

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Solving for tadpole coefficients in one-loop amplitudes.
Phys. Lett. B 681, 376 (2009).

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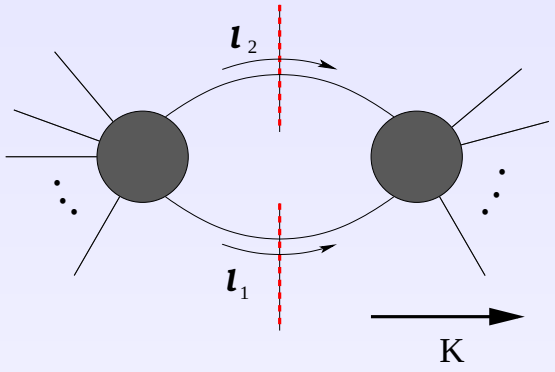
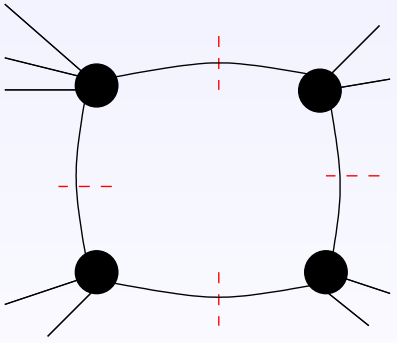
Single Cut Integration.
JHEP 1101, 135 (2011).

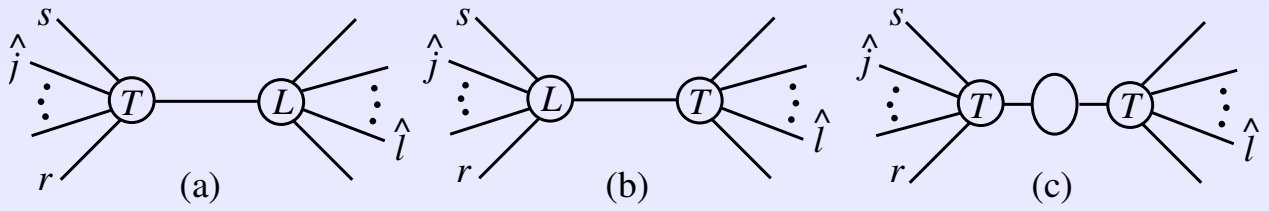


Prospects

- Complete treatment of massive particles in the unitarity method
- Full analysis of multiloop integrals and their cuts



Automated tools for 1-loop amplitudes (BlackHat)



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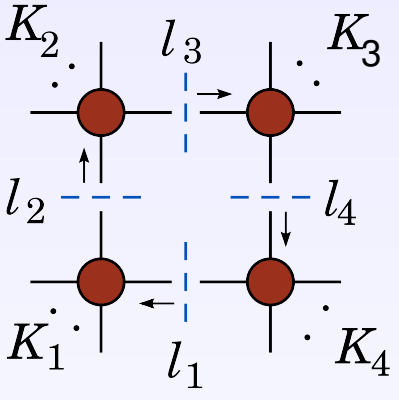
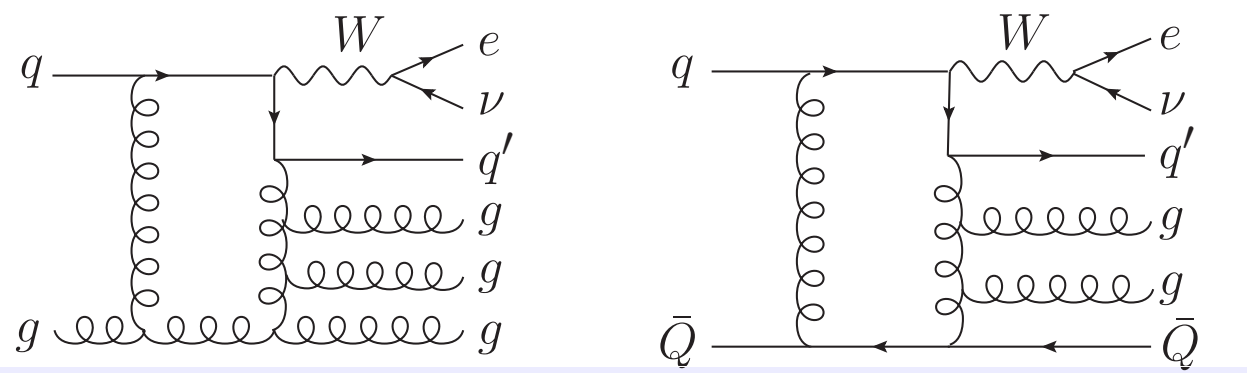


Ongoing work

- Development of BlackHat 1-loop software library

First computation of p+p $\to$ W+4 jets at NLO (using BlackHat w/ Sherpa)



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F. Febres Cordero, D. Forde, T. Gleisberg,
H. Ita, **D.A. Kosower**, and D. Maitre.
Precise Predictions for W + 4 Jet Production at the Large Hadron Collider.
Phys. Rev. Lett. 106, 092001 (2011).

Recent work and prospects

- Z+4 jets at NLO; other complex processes
- $t\bar{t}$+ multi-jets at NLO

Anti-Kt jet clustering algorithm

- M. Cacciari, J. Rojo, G.P. Salam, and **G. Soyez**.
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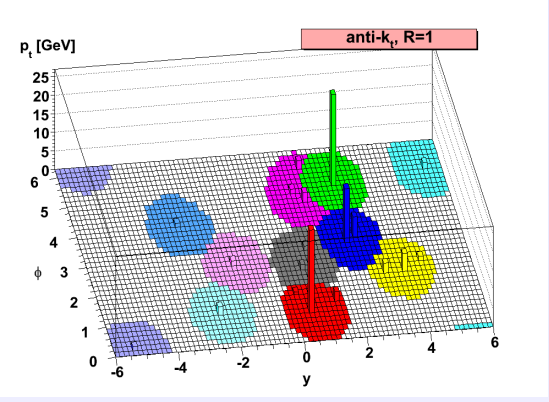
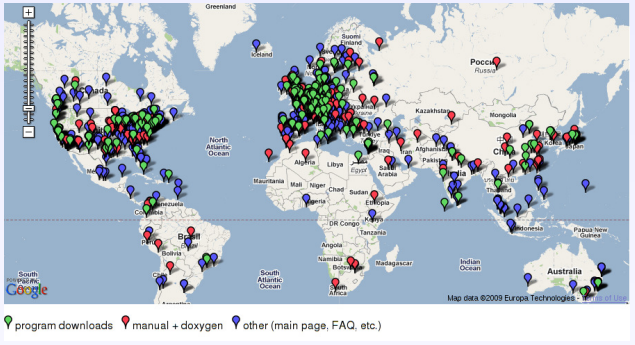


- M. Cacciari, G.P. Salam, and **G. Soyez**.
  FastJet package
  http://www.fastjet.fr

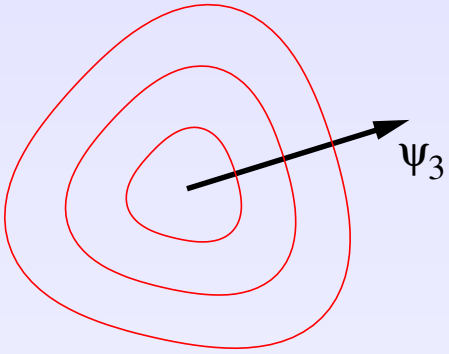


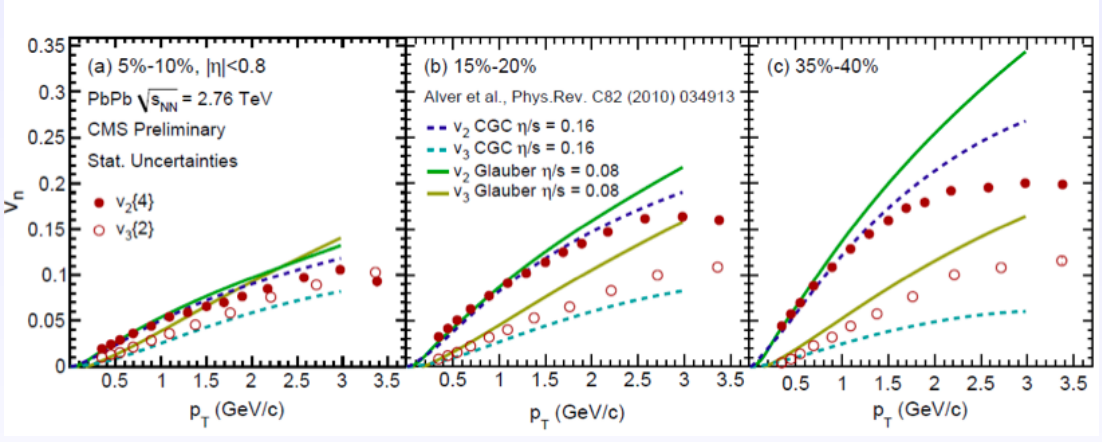
Prospects

- Jet response to soft backgrounds (e.g. pile-up)
- Jet substructure

Flow fluctuations and transport properties

B.H Alver, **C. Gombeaud**, **M. Luzum**, and **J.-Y. Ollitrault**.
Triangular flow in hydrodynamics and transport theory.
Phys. Rev. C 82, 034913 (2010).





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.
  High energy factorization in nucleus-nucleus collisions. *Phys. Rev. D* 78, 054019 (2008).
- A. Dumitru, **F. Gelis**, L. McLerran, and R. Venugopalan.
  Glasma flux tubes and the near side ridge phenomenon at RHIC.
  Nucl. Phys. A 810, 91 (2008).
- **L. Albacete** and **C. Marquet**.
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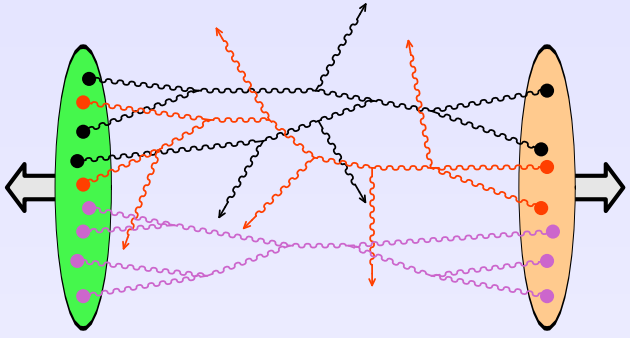

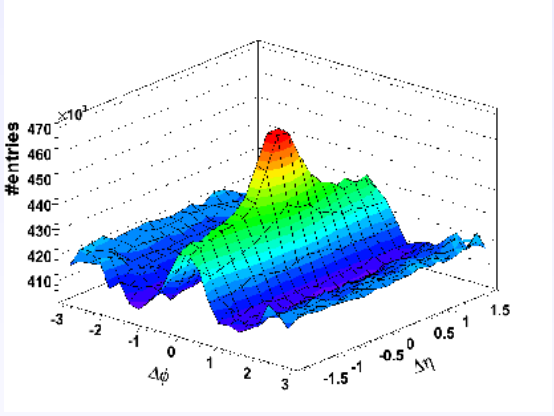

Prospects

- Factorization for less inclusive observables
- Final state evolution and thermalization

Quark-Antiquark correlators at finite temperature

- A. Beraudo, **J.-P. Blaizot**, and C. Ratti.
  Real and imaginary-time $\mathrm{Q}\bar{\mathrm{Q}}$ *correlators in a thermal medium*,
  Nucl. Phys. A 806, 312 (2008).
- A. Beraudo, **J.-P. Blaizot**, P. Faccioli, and G. Garberoglio.
  A path integral for heavy quarks in a hot plasma.
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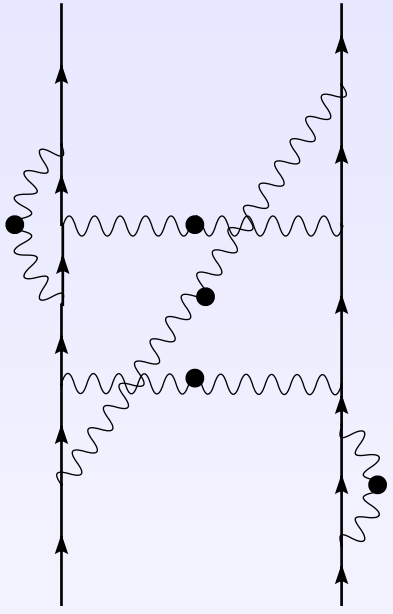
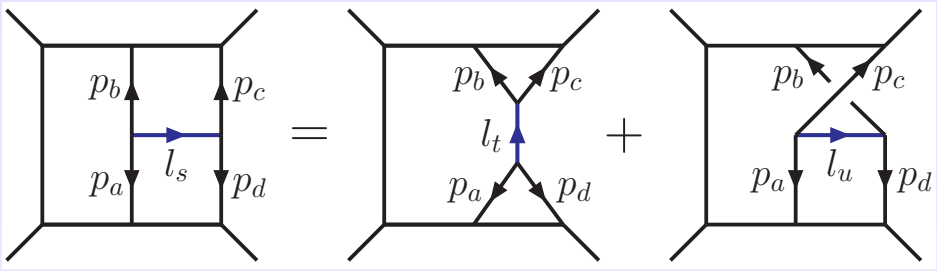


Prospects

- Ultimate goal: full dynamics of heavy quarks and heavy quark pairs in a quark-gluon plasma.

Amplitudes in SUSY N=4 Yang-Mills theory



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The Two-Loop Six-Gluon MHV Amplitude in Maximally Supersymmetric Yang-Mills Theory.
Phys. Rev. D 78, 045007 (2008).

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Perturbative Quantum Gravity as a Double Copy of Gauge Theory.
Phys. Rev. Lett. 105, 061602 (2010).

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.
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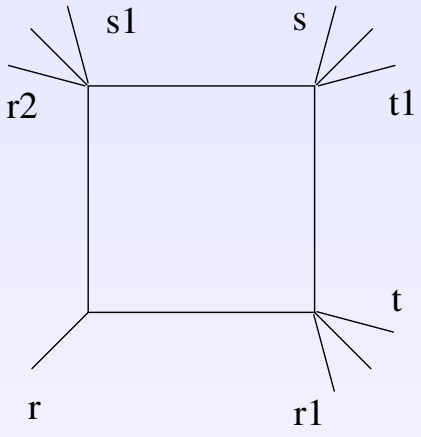
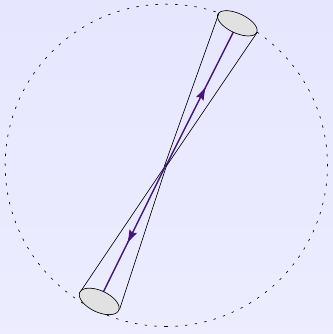


Prospects

- 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

- **Y. Hatta**, **E. Iancu**, and A.H. Mueller.
  Deep inelastic scattering at strong coupling from gauge/string duality : the saturation line.
  JHEP 0801, 026, (2008).



- **Y. Hatta**, **E. Iancu**, and A.H. Mueller.
  Jet evolution in the N=4 SYM plasma at strong coupling.
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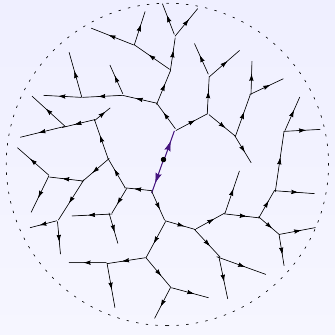

- **G. Beuf**, M.P. Heller, R.A. Janik, and **R. Peschanski**.
  Boost-invariant early time dynamics from AdS/CFT.
  JHEP 0910, 043, (2009).

Prospects

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