Groupe de travail 2
Compte rendu

Carlos Munoz Camacho,
Cyrille Marquet,
Michael Winn
for GT4

18/12/2024

Disclaimer

Presentation from GTS meeting yesterday not the real draft of January

- **The final presentation will have more time and more time for preparation :)**

Indispensable:

- **Add time-scale slides of EIC and LHC Run 5 and FCC:**
  Do you have an up-to-date version of timing of EIC, LHC Run 5 and FCC?

  Either once or either at every step of the recommendation for experimental projects

Idea of additions

Develop physics ideas more

- **Examples for run 5 physics ideas from Workshop**
  If you have specific examples that you would like to put forward, please tell.
  I would be in favour of having 3 cases for LHCb and ALICE of things that you can't do with ATLAS/CMS
  LHCb: preequilibrium dileptons (my bias), quarkonium/heavy-flavour forward and fixed-target (variation energy density and 'doping'), speed-of-sound via <pt> in collider and fixed-target
  ALICE: net-baryon fluctuations (needs large acceptance/PID), Charm-charm correlations with comparison with CMS, Third thing ?

- **Take 2 examples of theory, where we are leading/important**
  - **I would take saturation since there is a dedicated contribution and connect it to EIC and UPC**
  - **I would take LQCD since it is very important for our field and France is not much above critical mass, is there a case from the contribution that is ok to highlight? What about GPD physics interplay lattice vs. experiment ?**

One example where theory community 'needed' for ee…. Difficult to do since we have not really a contribution to rely on… ideas ?

Idea of additions

EIC: try to find an example for physics and for technology synergy
Physics can be UPC and EIC for saturation (to be seen if repeated from theory)
Detector: is there a good choice where France is synergistic within itself (ideal) ? If not, I think that it would be ok to take two examples where the synergy is between HL-LHC France and EIC international partners (I am thinking about CMOS since it is also a key competence for FCCee) and vice-versa

- **wondering whether the workshop screen shot can go to back-up. Feed-back ?**
- **Put supportive cartoons and links to documents publication: will try to make appear all submissions as a link as well**

Disclaimer

Presentation from GTS meeting yesterday not the real draft of January

- **The final presentation will have more time and more time for preparation :)**
- **Idea:**
  - **Develop physics ideas more**
    - **Examples for run 5 physics ideas from Workshop**
      If you have specific examples that you would like to put forward, please tell.
      I would be in favour of having 3 cases for LHCb and ALICE of things that you can't do with ATLAS/CMS
      LHCb: preequilibrium dileptons (my bias), quarkonium/heavy-flavour forward and fixed-target (variation energy density and 'doping'), speed-of-sound via <pt> in collider and fixed-target
      ALICE: net-baryon fluctuations (needs large acceptance/PID), Charm-charm correlations with comparison with CMS, Third thing ?
    - **Take 2 examples of theory, where we are leading/important**
      - **I would take saturation since there is a dedicated contribution and connect it to EIC and UPC**
      - **I would take LQCD since it is very important for our field and France is not much above critical mass, is there a case from the contribution that is ok to highlight? What about GPD physics interplay lattice vs. experiment ?**

    One example where theory community 'needed' for ee…. Difficult to do since we have not really a contribution to rely on… ideas ?

    EIC: try to find an example for physics and for technology synergy
    Physics can be UPC and EIC for saturation (to be seen if repeated from theory)
    Detector: is there a good choice where France is synergistic within itself (ideal) ? If not, I think that it would be ok to take two examples where the synergy is between HL-LHC France and EIC international partners (I am thinking about CMOS since it is also a key competence for FCCee) and vice-versa

  - **wondering whether the workshop screen shot can go to back-up. Feed-back ?**
  - **Put supportive cartoons and links to documents publication: will try to make appear all submissions as a link as well**

GT4 - QCD - community

LHC heavy-ion programme
ALICE, LHCb collider & fixed-target, CMS

Theory community
large, diverse & leading/strong contributor in a number of areas

Hadron structure programme
Jefferson Lab & future Electron-Ion Collider

In contrast to other countries

Small lower beam energy hadron/heavy-ion collision community
not addressed here

Hadron spectroscopy not a main topic for any group
not addressed here

GT4 workshop

Large participation by QCD/heavy-ion community

Interesting and lively discussions

Document focused on heavy-ions submitted to arxiv & to French site

Starting point of our synthesis (work in progress)

8 GT4 contributions to national strategy of various type

Expect additional submissions from the community to ESPPU directly

No contradictions in view of scenarios among submitted documents

Link to workshop: https://indico.in2p3.fr/event/33460/

GT4 workshop

09:30 → 10:15 **Welcome coffee** 45m

10:15 → 10:40 **Introduction**

Conveners: Carlos MUNOZ CAMACHO (IJCLab), Michael Winn (DPhN/IRFU/DRF/CEA Paris-Saclay)

10:15 **Welcome from working group GT4: QCD and heavy-ion collisions** 10m

Speakers: Carlos MUNOZ CAMACHO (IJCLab), Cyrille Marquet (CPHT - Ecole Polytechnique), Michael Winn (DPhN/IRFU/DRF/CEA Paris-Saclay)

Welcome from GT4-...

10:25 **French input to EPPSU: procedure and calendar** 10m

Speakers: Herve Moutarde (CEA-IRFU-SPHN), Laurent Vacavant (IN2P3), Marcella Grasso (IN2P3)

10:40 → 11:55 **HL-LHC programme in Run 5 and 6**

10:40 **LHCb upgrade II physics programme** 25m

Speaker: Frédéric FLEURET (LLR-Ecole polytechnique, CNRS/IN2P3)

ESPPU2025.pdf

11:05 **ALICE 3 physics programme** 25m

Speaker: Antonin Maire (IPHC Strasbourg - CNRS)

Conf-2024-09-Prosp...

11:30 **Proton-nucleus collisions: future opportunities** 25m

Speakers: Jean-Philippe Lansberg (IJCLab - Université Paris-Saclay - CNRS (FR)), Jean-Philippe Lansberg (Paris-Saclay U. - IJCLab - CNRS)

pA-LHC-180924.pdf

GT4 workshop

13:00 → 13:45 **Future colliders at CERN**

13:00 **FCCee with emphasis on QCD** 25m

Speaker: David d'Enterria (CERN)

dde_FCC_qcd_ions_...

13:25 **Accelerator technologies with potential for QCD beyond the LHC** 20m

Technology status

- High-field magnet: high-energy hadron beams fixed-target/collider with smaller synchrotrons than LHC and in view of FCC-hh
- Energy Recovery LINAC: high-energy, high-intensity electron beam for fixed-target or collider
- Plasma-wave acceleration: very high-energy, low-intensity electron beam for fixed-target or collider (TBC)

Speaker: Dr Maria De Los Angeles FAUS-GOLFE (IJClab)

QCD_heavy_ions_E...

13:45 → 14:45 **Discussions on HL-LHC and future colliders**

13:45 **Guided discussion on community inputs w.r.t. Run 5 and 6 programme, time-parallel activities and w.r.t. future colliders at CERN** 1h

Goal:
find factual statement w.r.t. community repartitions and consensus (or close-to) statements w.r.t. accelerator schedule and requirements in terms of human resources and investment already to be taken into account when writing inputs

Speakers: Alberto Baldisseri (IRFU/SPhN, CEA Saclay), Antonio Uras (IPNL Lyon), Mr Gines MARTINEZ (Subatech CNRS/IN2P3 - IMT Atlantique - Nantes Universite)

QCDRun5-6.pptx

GT4 workshop

15:15 → 16:15 **Theory**

15:15 **Round table on: theory perspectives for QCD in heavy-ion collisions at the HL-LHC, hadron structure at HL-LHC and EIC, precision physics at lepton colliders** 1h

Goal:
- requirements
- open questions in this field

Speakers: Cyrille Marquet (CPHT - Ecole Polytechnique), Pol Gossiaux (Subatech)

16:15 → 16:55 **Synergy and interdependence between CERN-based projects and other projects**

16:15 **Synergy between CERN projects and EIC: physics and technology** 20m

Speaker: Francesco Bossu (CEA-Saclay)

synergy_eic_lhc.pdf

16:35 **Discussion on synergy and interdependence between different accelerator-based activities** 20m

Goal:
find factual statement w.r.t. R&D interdependence and requirements in terms of human resources and investment already to be taken into account when writing inputs

Speakers: Carlos MUNOZ CAMACHO (IJCLab), Michael Winn (DPhN/IRFU/DRF/CEA Paris-Saclay)

Submission summary

4 contributions with GT4 as primary group

Precision predictions for hard processes in multi-TeV ion collisions
perturbative QCD theorists, nuclear PDFs from hard processes

Prospective report of the French QCD community to the ESPPU 2025 with respect to the program of the LHC Run 5 and beyond and future colliders at CERN
experimentalists report focused on LHCb U2, ALICE 3, a long-term perspective FCC, synergy EIC

The Electron-Ion Collider
experimentalists dominated document in support of EIC; **synergy in physics and instrumentation to CERN**

QCD à haute énergie au HL-LHC et au futur collisionneur EIC
saturation theory group in support of related theory and EIC and HL-LHC

Submission summary

4 contributions with GT4 as secondary group

Intérêt de la communauté française pour une participation au programme de physique et aux améliorations du détecteur LHCb pour la période 2035 – 2041 (LHCb Upgrade II)
experimentalists interested in LHCb: flavour + QCD/heavy-ion

QCD sur réseau,
theorist group importance of lattice QCD

Prospects of QCD and Lund Jet Plane studies at FCC-ee
HEP group in view of precision QCD studies in view of jet and alpha-s

Prospects of future vacuum polarisation studies and applications
diverse group in view of mostly low-energy precision tests of the SM partially limited by QCD knowledge

Addendum to 'Contribution of the members of IRFU to the update of the European Strategy for Particle Physics' on strong interaction
IRFU DPhN statement in view of future colliders

Driving physics questions

QCD-Lagrangian known

not able to derive the emergent properties of strongly interacting matter

Motivation not dependent on beyond-standard-model physics at accessible scales

QCD research is complementary to classical High-energy physics !

QCD as an important piece

dominating ordinary matter in the universe

high-temperature strongly interacting matter in the big bang

High-baryon density strongly interacting matter in astrophysical objects as neutron stars

Lattice QCD & gravitational waves will provide information as well on part of the questions

Executive summary

1) **Keep heavy-ions beam time until the end of the HL-LHC lifetime**

2) **Engage on LHCb U2 & ALICE 3**

3) **FCCee + FCC-hh as choice number one for future colliders in Europe**

   If no FCCee: prolongate LHC and lever potential with LHeC: saturation precision programme

4) **Support French (and European) teams on Electron-Ion collider**

   physics & instrumentation synergy/interdependence with HL-LHC

5) **Support French theory groups: keep our leadership in key areas**

Keep heavy-ions beam time until the end of the HL-LHC lifetime

Observables & data type

'Run 5:

understanding the onset of collectivity in small systems *….and its evolution with the size of the system.*

Classic QGP physics: convincing paradigm

Picture to a certain extent qualitative

Understand inner workings of the emergence of QGP

Properties

- *Deconfinement*
- *chiral restoration*

Transition to hadrons (Hadronisation)

microscopic picture the initial state

thermalisation

Light ion running & other related to thermalisation

saturation and nuclear PDF, UPC programme & precision hard probes in pPb

'Quarkonia'

dilepton, lineshapes

heavy quarks & different acceptances available as new tool

Light ions & preequilibrium

(photon/dilepton)

Engage on LHCb U2 & ALICE 3

Program

- **not feasible without new instrumentation provided by LHCb U2 and ALICE 3**

FCCee + FCC-hh choice for future colliders in Europe

FCC-hh: QGP in a different regime and with different probes

500 charm quark pairs in central Pb-Pb collisions

charm as active degrees of freedom

QGP state up to τ ≈ 15 fm/c.

Larger temporal and spatial extent

collision energies & integrated luminosities

About 10 x higher than the LHC each

top quark, Higgs and other heavy objects also boosted in large numbers

hard and heavy particles for “Tomograpy”

BSM in gamma-gamma

Saturation physics in gamma-hadron: Bjorken-x 10^{-7}

FCCee + FCC-hh as choice number one for future colliders in Europe

FCC-ee: High-precision QCD

crucial for indirect searches of physics beyond the SM at FCC-ee

***determinations of the strong coupling constant** with permille uncertainties*

*ultrapure samples of **flavour-tagged jets,***

***accurate energy-angle analyses of hadrons inside jets to constrain high-orde**r (fixed and logarithmic) perturbative corrections of parton showers via **Lund Jet plane techniques**, multidifferential studies of final hadrons for very precise determinations of fragmentation functions,*

pristine experimental conditions to investigate non-perturbative phenomena (colour reconnection, hadronization, final-state interactions,...),

*production of particularly **exotic QCD bound states***

from ultrarare hadronic decays of 8 · 10^12 Z bosons

rich QCD programme, different w.r.t. hadron machine QCD programme

Freehand explanatory remarks on lepton colliders

Different QCD programme w.r.t. to hadron-hadron or hadron-lepton

large fraction of key physics areas of strong interaction physics not addressable

Addressable:

Progress on hadronisation, parton shower, precision alphas determination and spectroscopy at lepton colliders require large statistics sample of jet samples.

FCCee can provide this

The QCD community is open for creative proposals to make new type, comparatively cost effective particle accelerators during a potential lepton collider epoch at CERN

Not enough time to come up with mature ideas

LHeC + FCC-hh as alternative and fixed-target comment

"If FCC-ee+FCC-hh after HL-LHC:

***large temporal gap** between HL-LHC and FCC-hh without hadron-hadron or DIS colliders*

Exception: electron-ion collider program in the USA for hadron structure

***Having a FCC-hh first,** the gap needed to finalizing the necessary R&D (magnets)*

- *Covered by **LHeC machine**.*
  - *parton distribution measurements needed for FCC-hh data.*
  - *Saturation physics*

Explore the high-baryon density region of the QCD phase diagram at fixed-target energies with dedicated experiments complementary to FAIR with the CERN accelerator complex.

Support French (& European) teams on Electron-Ion collider

Highlights the strong complementarity of the LHC Run 5 and the ion program at the EIC.

Saturation physics

common/overlapping Detector R&D

Not only synergy, also interdependency in some cases

Support French theory groups: keep leadership in key areas

French QCD community leader/strong contributor in several domains

- Saturation physics
- Quarkonium physics
- Hydrodynamics
- Heavy-quark and hadron transport
- Event generators and community software tools
- GPD physics
- Nuclear PDFs
- Jet physics and parton showers
- Lattice QCD
- TMD physics and PDFs
- Higher order calculations

LHC data preservation

large temporal gap

limited available resources for data exploitation

Further data analysis to extent knowledge after end of LHC

Keep knowledge for future hadron colliders if built

Not formalised in a contribution, but strongly debated at workshop

Conclusion

QCD physics cases are a fundamental **complement of classical high-energy physics**

embrace that the world in its **complexity cannot only be understood in a reductionist** way of thought that reduces a given system to the understanding of its constituents and their fundamental interactions

Back-up

Driving physics questions: key areas

Momentum/spin/charge/mass decomposition of hadrons/nuclei in terms of partons

Thermalisation of strongly interacting matter

Properties of strongly interacting matter at finite temperature

The mass spectrum of strongly interacting particles

Gluon saturation at high-energy

Hadronisation in vacuum and at finite temperature/density

Hadron structure: open questions

Momentum, spin, charge and mass decomposition of hadrons/nuclei in terms of partons

So far only for 1-dimension with precision: HERA legacy

multi-dimensional approaches in their infancy in terms of precision

role of gluons approx. not accessed in multi-dimensions

Basically only for nucleons, not for nuclei

Hadron structure: future activities and relation to questions

EIC

Multi-dimensional structure (transverse space/momentum + longitudinal momentum) at a new level of precision: needed for spin/mass decomposition
Role of gluons so far largely unexplored

HL-LHC and EIC

Gluon saturation -> precision at HL-LHC limited, kinematic reach limited at EIC
Nuclear parton structure -> initial state of high-energy nuclear collisions at the LHC out of kinematic reach of EIC, HL-LHC limited precision in key areas

Lattice QCD

Highly complementary: other strengths and weaknesses
- a number of conceptual limitations: high-momentum reach, multi-scale problems rather in effective theory

Will be treated in various cases as ‘real data’

Strongly interacting matter at high collision energy: Observations

Hydrodynamics: ‘perfect fluid’ works

High energetic partons are breaked: ‘jet quenching’

Hadronisation: approach thermodynamic limit known from lattice QCD, ‘thermal matter’

Brownian motion of heavy-quarks: ‘heavy-quark diffusion’

modification of quarkonium production: ‘direct observation of deconfinement’

Signatures associated with QGP in pp/pPb/Pbpcollision: ‘collectivity in small systems’

Signatures of saturation: not accepted by full community as discovery

(Heavy)-ion ‘side’ topics

High-energy nuclear collision can be also used for

gamma-hadron/nucleus collisions:
LHC at about 10 times higher energy than EIC: saturation as main driving force

nuclear structure physics via correlation measurements

Hadron-hadron interaction studies via femtoscopy

Complementary conditions for gamma-gamma collider:
observation of light-by-light scattering, g-2 of tau measurements, strong field QED

Hadron structure measurements complementary to EIC:
polarised targets in LHCb-Spin

Strongly interacting matter: open questions

Very large effects visible, but precision required for quantitative understanding

Concepts applied that offer sometimes alternative explanations: difficult to discriminate

Conceptual advance: global multi-parameter fits for energy-momentum flow described by hydro

Quantitative questions

- Thermalisation of strongly interacting matter:
  Where/When and how fast? How can we understand the smooth onset of QGP signatures?
- Hadronisation:
  - Can we have a microscopic picture how the thermodynamic limit hadronisation arises from partons/strings ? What is the role of conserved quantum numbers as heavy-quarks?
- Condensed matter physics with only non-abelian theory system available in lab:
  - What are the thermodynamic equilibrium properties and transport properties of strongly interacting matter ? What are the phase transition characteristics ?
- Chiral restoration and deconfinement:
  Can we directly observe it?

Strongly interacting matter:
future activities and relation to questions, examples

Thermalisation:

- Run 3, 4: Oxygen-Oxygen run, electromagnetic programs in ALICE/LHCb, flow precision studies with all four experiments

  Run 5: new instrumentation for electromagnetic probes and for key charm/beauty observables, light-ions large luminosity, forward rapidity coverage in LHCb in central collisions and large acceptance with ALICE 3 (longitudinal dynamics and role of conserved charges)

Hadronisation:

Run 3, 4: extent precision to charm sector with ALICE, LHCb collider+ fixed-target and CMS

Run 5: multiple charm baryons in nucleus-nucleus, large acceptance down to forward with PID in most central collisions in collider and fixed-target, control over low probability large rapidity-difference effects

Thermodynamics:

Charm not (fully) an active degree of freedom at LHC: only achieved at FCC-hh where temperature larger