

Working Group #1:

« Single and Multi Parton Scattering »

General Assembly, May 23-25, 2022 – Ile d'Oléron

**Zaida
Conesa Del Valle**

« Experimentalist »

CNRS scientist

Collaboration:



Main interests:

- Quark-gluon plasma physics
- Multiple parton interactions
- Initial stage of the collision
- Heavy flavor, quarkonia, and electroweak bosons

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**Cédric
Lorcé**

« Theorist »

Professor at Ecole
Polytechnique

Close collaboration
with experimentalists

Main interests:

- Nucleon internal structure
- Mass and spin decompositions
- QCD energy-momentum tensor and pressure forces
- Relativistic quantum phase-space (Wigner) distributions
- Parton distributions (FFs, PDFs, GPDs, TMDs, GTMDs)

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**Dominique
Marchand**

« Experimentalist »

CNRS scientist

Collaborations:

 **Jefferson Lab** (USA)

 **Electron Ion Collider**
@ BNL (USA)

Main interests:

- Nucleon internal structure
- General Parton Distributions (Deeply Virtual Compton Scattering experiments - DVCS)
- Proton charge radius

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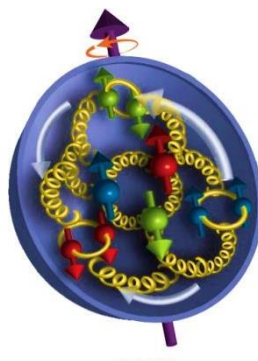
Understanding of hadron structure through

- lepton and hadron scatterings at **high energy**
- pp /pA / heavy-ion collisions at **very high energy**
- theoretical formalisms and models

Standard Model of particle physics

masse → +2.3 MeV/c ²	+1.275 GeV/c ²	+173.07 GeV/c ²	0	+126 GeV/c ²
charge → 2/3	2/3	2/3	0	0
spin → 1/2	1/2	1/2	1	0
u up	c charm	t top	g gluon	H boson de Higgs
d down	s strange	b bottom	γ photon	
0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	91.2 GeV/c ²	
-1	-1	-1	0	
1/2	1/2	1/2	1	
e électron	μ muon	τ tau	Z boson Z ⁰	
+2.2 eV/c ²	+0.17 MeV/c ²	+15.5 MeV/c ²	80.4 GeV/c ²	
0	0	0	±1	
1/2	1/2	1/2	1	
ν_e neutrino électronique	ν_μ neutrino muonique	ν_τ neutrino tauique	W boson W [±]	

Hadron physics



Systems

- quantum
- relativistic
- strongly coupled
- non-linear
- undetermined # of partons

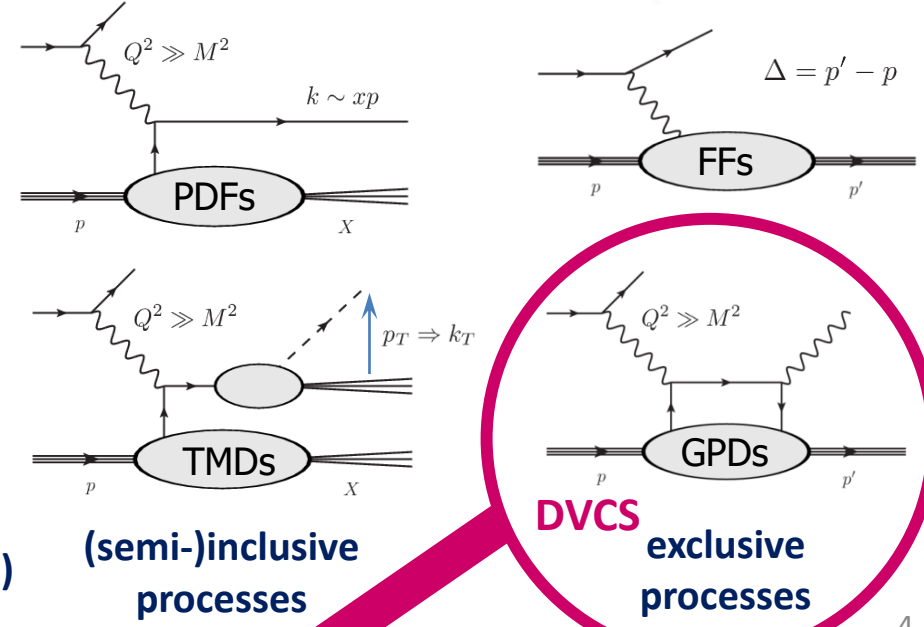
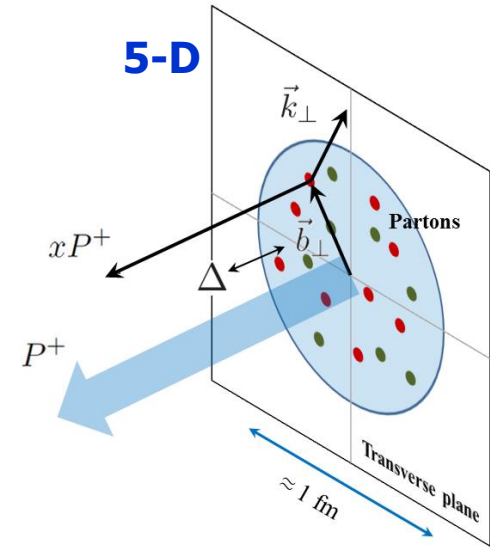
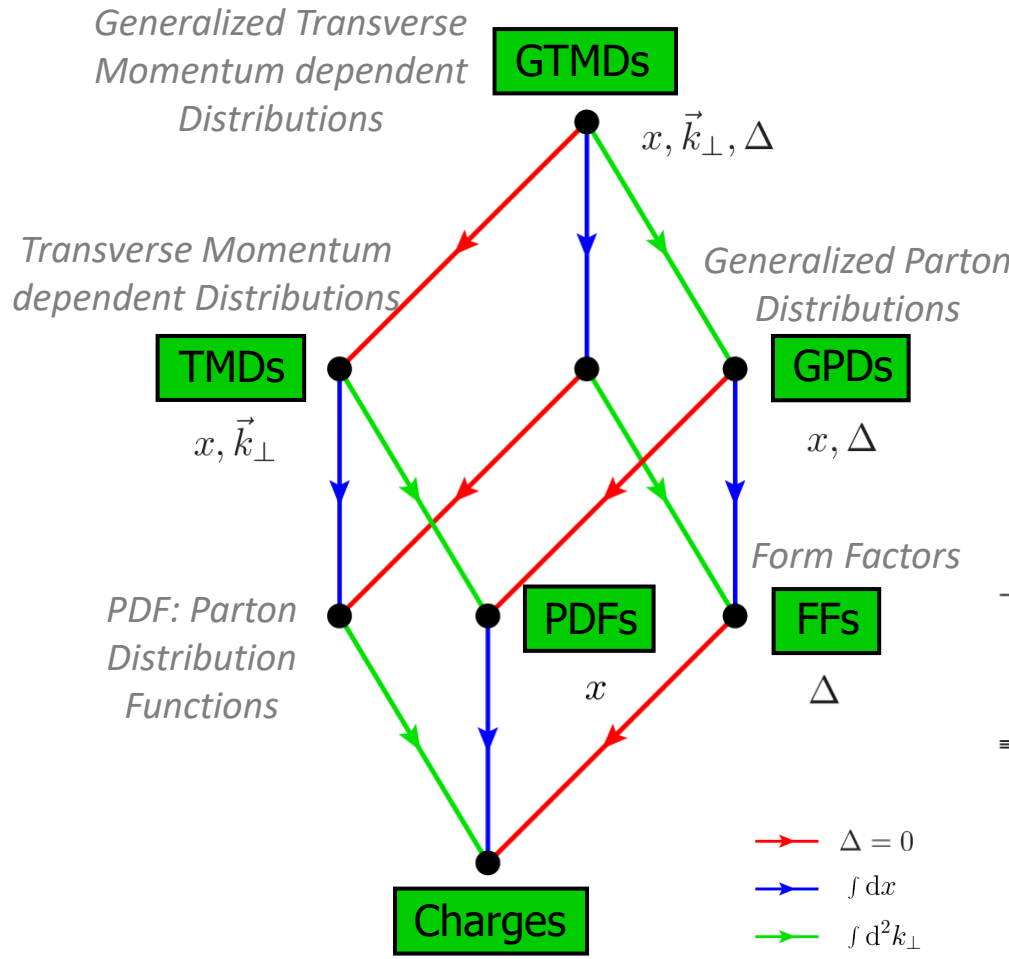
How do hadron basic properties emerge from partons?

How does a better understanding of nucleon structure serve LHC problematics?

How do gluon distributions in the non-perturbative regime benefit to LHC?

How to model multiple parton interactions in collisions at LHC?

Hadron imaging based on a more comprehensive Parton Distribution formalism
 → new generation of experiments to access multi-dimensional parton distributions
 ⇒ most valuable constraints for theoretical models



« Zoology » of parton distributions
 (many others also exist: DAs, TDAs, nPDFs, DPDFs, ...)

Imaging → quark and gluon contributions to QCD energy-momentum tensor

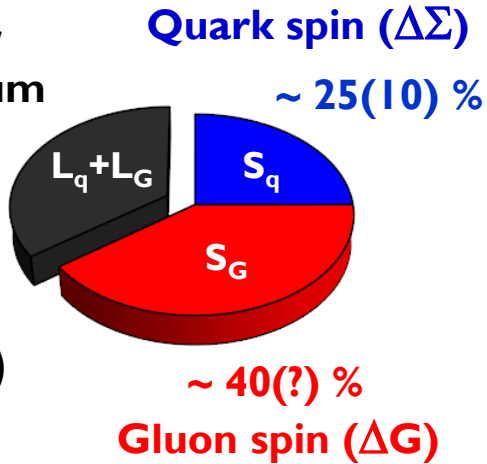
Some open questions

Nucleon Spin

Orbital angular momentum

?

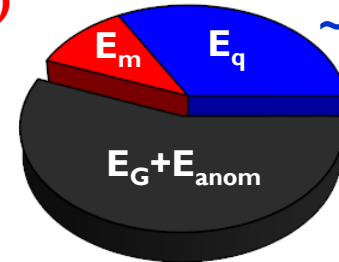
nDVCS (Jlab/CLAS12)
→ GPD E (+ H)
⇒ L_q



Nucleon Mass

Quark mass (Higgs mechanism & condensate)
~ 10(1) %

Quark kinetic and potential energies
~ 33(1) %



?

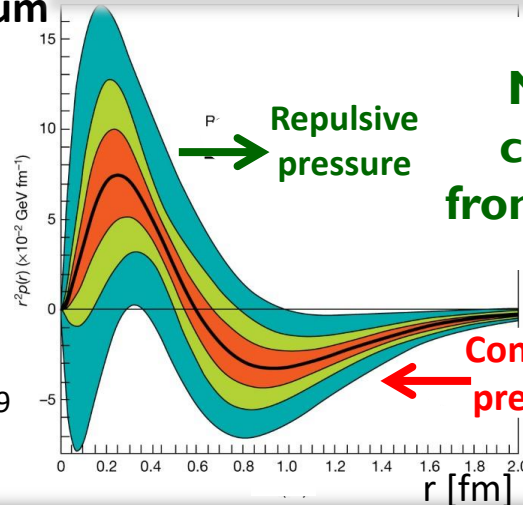
Gluon kinetic and potential energies (trace anomaly?)

Pressure distributions inside nucleons

QCD Energy-Momentum tensor

GPDs ⇒ D-Term

[V. D. Burkert, *et al.*, Nature 557, 396-399 (2018)]

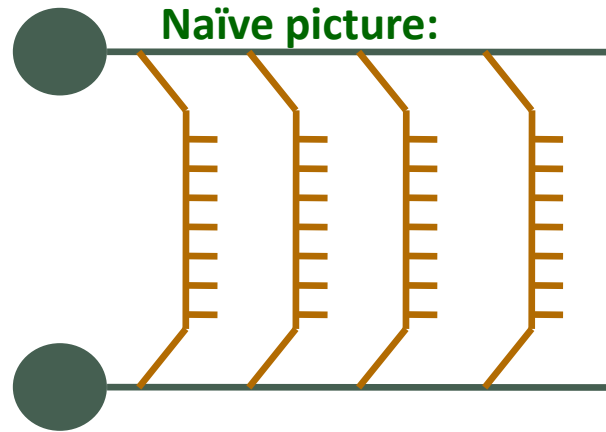


Mostly coming from quarks

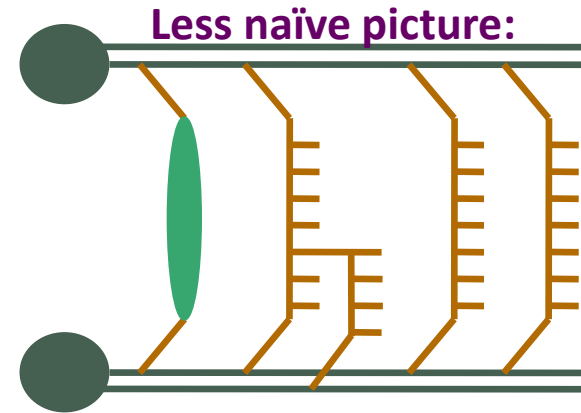
Mostly coming from gluons

Other issue: Multiple Parton Interactions in collisions at very high energy (LHC) → Impact production yields and angular distributions

At $\sqrt{s_{\{NN\}}} > 200$ GeV, evolution of the charged particle multiplicity distribution in pp collisions deviates from Koba-Nielsen-Olesen (KNO) scaling



- several (hard or soft) interactions occur
- particle multiplicity is related to the number of elementary interactions
- for hard processes : particle yield increases with multiplicity



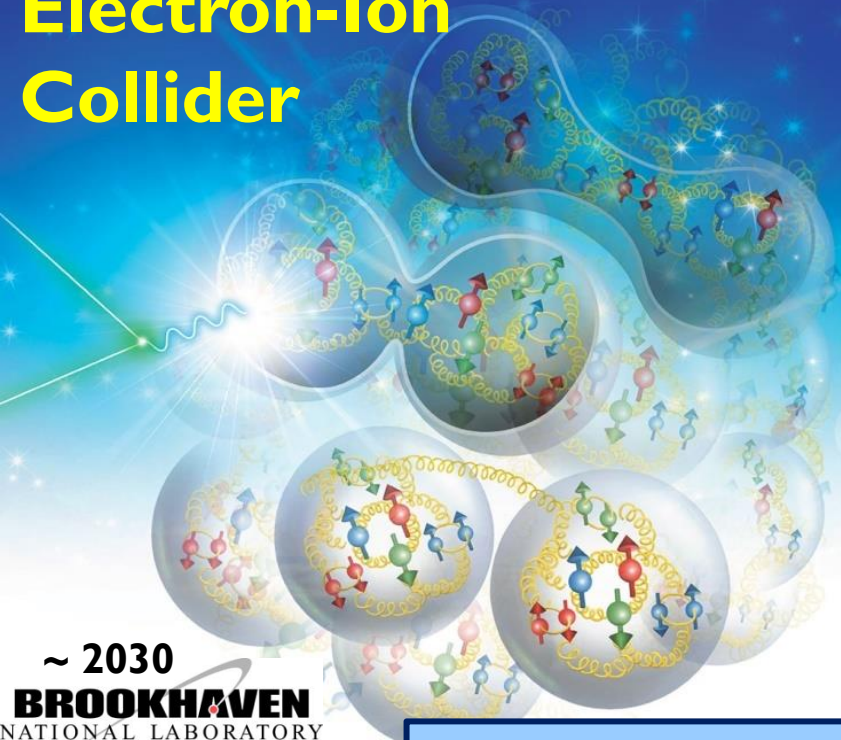
- some of the parallel interactions are soft, some are hard
- re-interaction of partons : ladder splitting, screening (initial state), saturation (initial state), color reconnection (final state)
- hadronic activity (initial or final state radiation) around hard processes

[S. Porteboeuf-Houssais]

In pp collisions (reference system):

- ★ Full description of **initial conditions of the collision**: crucial
⇒ tests interaction between **hard and soft components**

Electron-Ion Collider



~ 2030
BROOKHAVEN
NATIONAL LABORATORY
New York, USA

Since January 2020 a **real** project to be hosted at **BNL (RHIC)**

electrons (10 - 18 GeV, ~70 % polar.)

⇒ **protons** (275 GeV, ~70% polar.)

or

⇒ **ions** (light - deuterium - to heavy - Au, Pb, U)

★ Variable center-of-mass energies:

20 - 100 GeV [140 GeV]

★ High collision \mathcal{L} **$10^{33} - 10^{34}$** ep cm⁻² s⁻¹

★ **1 (2) interaction point(s)**

Unique opportunity to access/probe/image/quantify/qualify the **gluonic, valence and sea quark content** of hadrons (low x)

- Dynamics of quark-gluon confinement
- Nucleon detailed comprehensive 3D-tomography
- Missing gluon contribution to nucleon spin and mass
- Complementarity / inputs to LHC problematics

And many more!

Expression of Interest supported by French theorists and experimentalists

Time to join and contribute to EIC detectors to address the excited physics program!

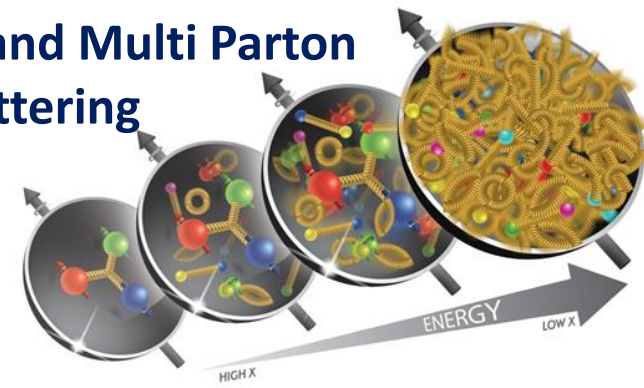
March '21

arXiv:2103.05419

[physics.inst-det]

Based on 3 detector proposals submitted end '22, EIC Detector-1 under design

Toward CD-2



2021 ACTIVITIES

2 remote events

- ✓ **WG1 Kick-off meeting: June 21 - 23, <https://indico.in2p3.fr/event/24174/>**

3 half-days: 9:30 - 12:30

June 21st: 4 contributions *Attendance: 28 - 36 persons*

June 22nd: 4 contributions *Attendance: 16 - 19 persons*

June 23rd: 7 contributions *Attendance: 25 persons + Aussois*

Joint session with Aussois Quarkonia and QCD meeting (J.-P. Lansberg)

- ✓ **Topical seminar on Rivet Monte-Carlo Toolkit: July 1st (11:00 - 12:30)**

<https://indico.in2p3.fr/event/24502/>

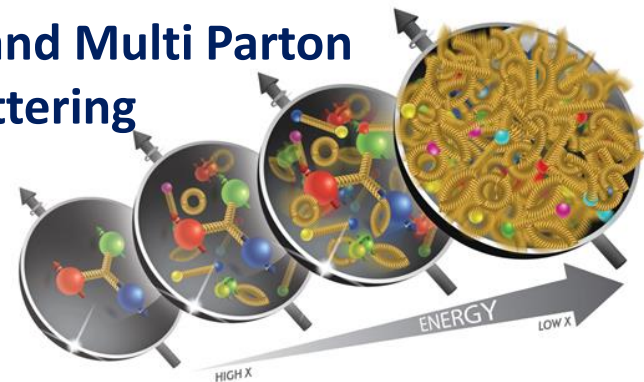
Jointly organized with WG2 (Antonin Maire, IPHC)

- Louie Corpe (CERN): Introduction to Rivet (11:00 - 11:45)

- Andrii Verbytskyi (Max Planck Institut für Physik, München):

HEPMC Standards and the Path Forward (11:50 - 12:30)

Attendance: 20 persons

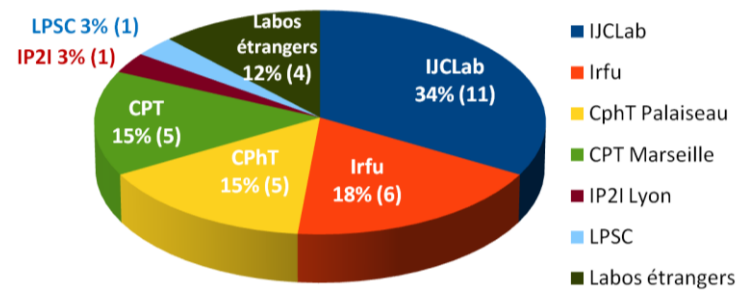


2022 ACTIVITIES (past)

So far 2 topical seminars (remote)

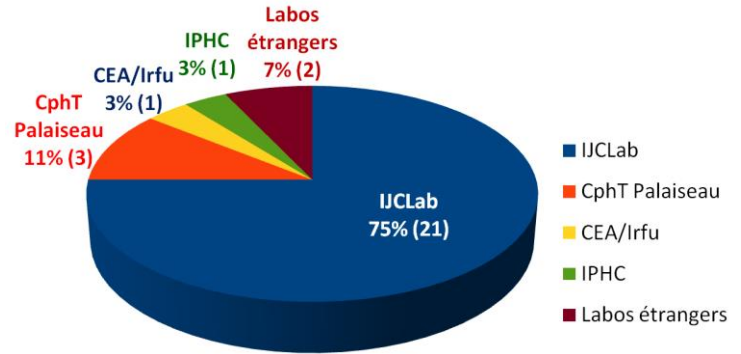
- « The extraction of light cone parton distributions from lattice quantum chromodynamics »
 by Savvas Zafeiropoulos (Centre for Theoretical Physics, CNRS, Univ. Aix-Marseille, Univ. Toulon)
 Feb. 3rd, 2022: <https://indico.in2p3.fr/event/26169/>

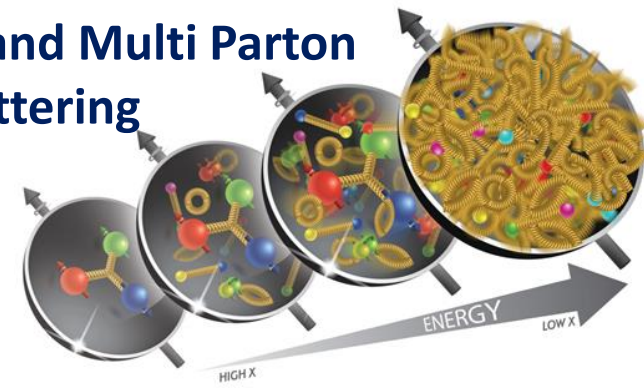
Attendance: 33 persons



- « Deeply Virtual Compton Scattering off the neutron with CLAS12 at Jefferson Lab »
 by Mostafa Hoballah (IJCLab Orsay, CNRS, Univ. Paris-Saclay, Univ. de Paris)
 May 12th, 2022: <https://indico.in2p3.fr/event/27163/>

Attendance: 28 persons





2022 FORESEEN ACTIVITIES

- Contribution to **Ecole Joliot-Curie « Nuclear Matter under Pressure »**
Sept. 4 – 9, 2022, Oléron

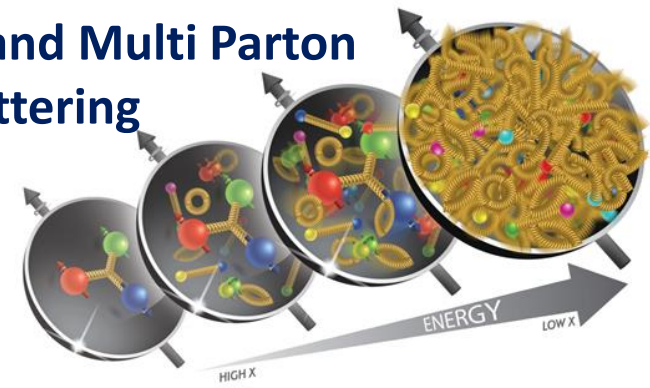


- **A topical seminar** (Hybrid format) in Sept. 2022, IJCLab
Topic to be defined: possibly QCD parton dynamics inside nucleon and hadronization in high-energy collisions

- Contribution to **« Heavy flavours from small to large systems »** workshop
Institut Pascal, Univ. Paris-Saclay , Oct. 3 – 21, 2022
Joint effort with other GDR WGs, Gluodynamics and STRONG-2020

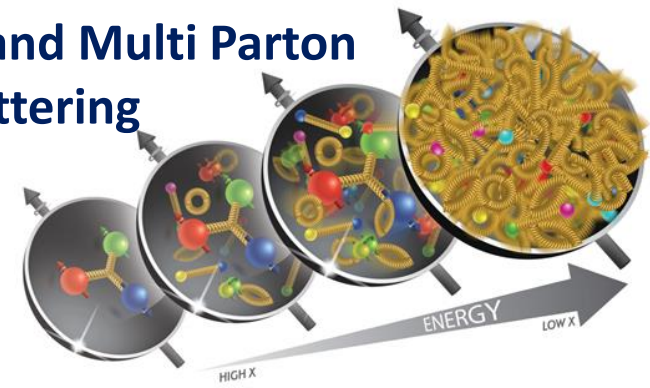


- **WG1 « in person »** workshop (2-3 day duration), IJCLab, Dec. 7 - 9, 2022
Subject to be defined: possibly « Open questions on nucleon properties »



FUTURE ACTIVITIES

- **WG1 « *in person* » workshop (2 - 3 days) , Spring 2023, location to be defined**
« Event Classification in Hadronic Collisions » (2-3 days)
- **A topical seminar (Hybrid format) in June 2023, IJCLab**
Topic to be defined
- *Organization of the GDR International School in 2023 or 2024 ?*



Summary

- To **S**trengthen interactions within the QCD community: theorists and experimentalists
- To **M**eet on a regular basis (seminars, workshops, international QCD schools, ...)
- To **P**lay a key role in perspectives linked to LHC upgrades scientific programs and the physics at the Electron-Ion Collider (BNL, USA), ...
- To **S**timulate interaction between GDR working groups

Looking forward to receiving your suggestions!
The working group is **YOURS**