Gluodynamics

Physics Highlights

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for the consortium

P2I day 2024, 09.01.2022

Outline

1) Project goals and structure

2) Highlights 2023

3) Outlook & conclusion

Gluodynamics

Physics goals

Hadron structure

- Understand the dominant ordinary matter constituents:

  mass & spin decomposition, interactions

Fluids of strongly interacting matter

- Understand matter beyond hadrons:

  Structure of partonic matter produced in nucleus-nucleus collisions

  Emergence of a fluid from the hadron structure initial state

Strategic goals

International impact by internal collaborations

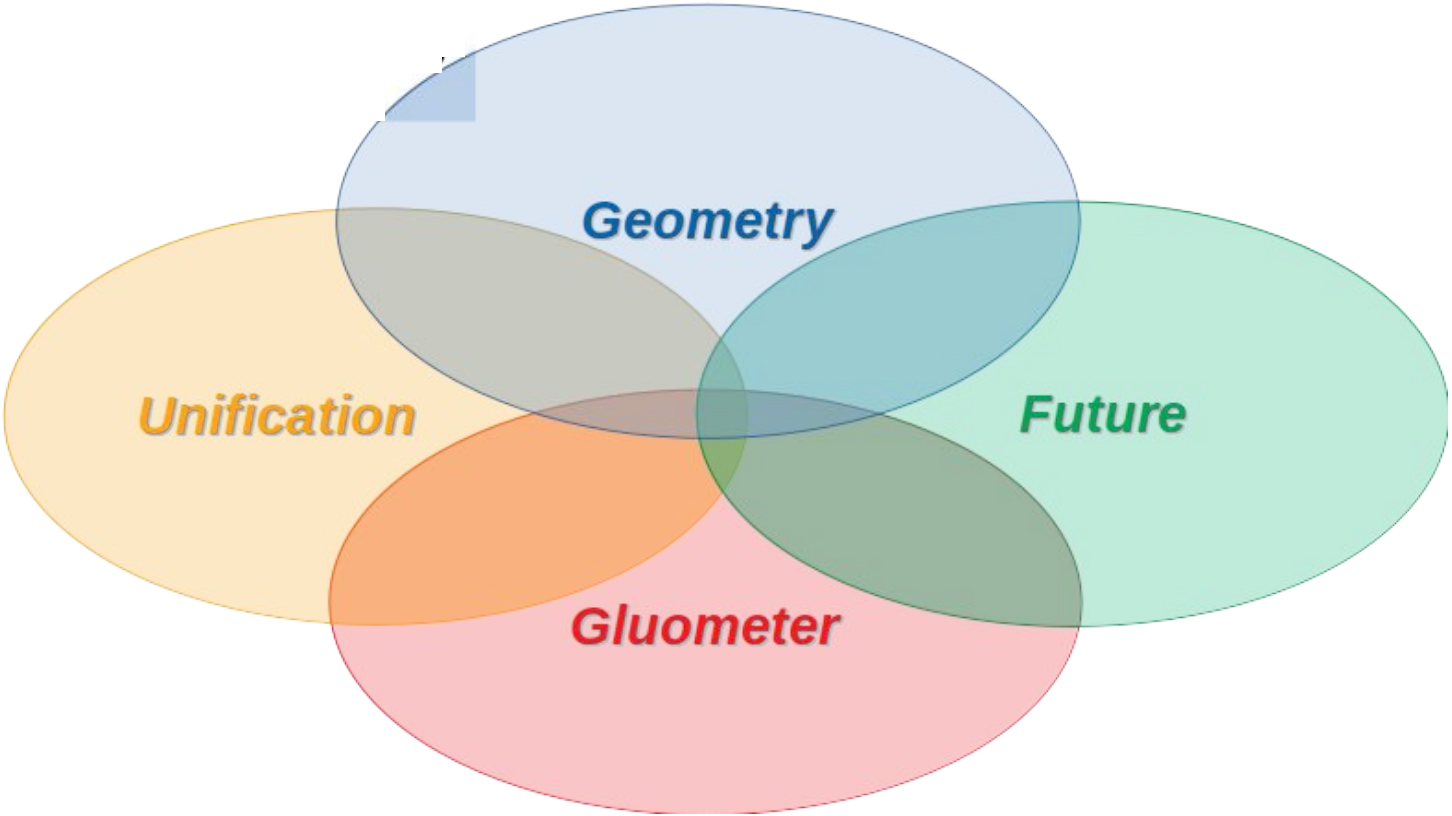
- Between theory & experiment
- Between the three poles: Orsay, Saclay and Palaiseau

Common long-term hardware projects for strong interaction research after 2030

- Electron-ion collider & LHCb Upgrade 2

Gluodynamics

Project structure



Gluodynamics

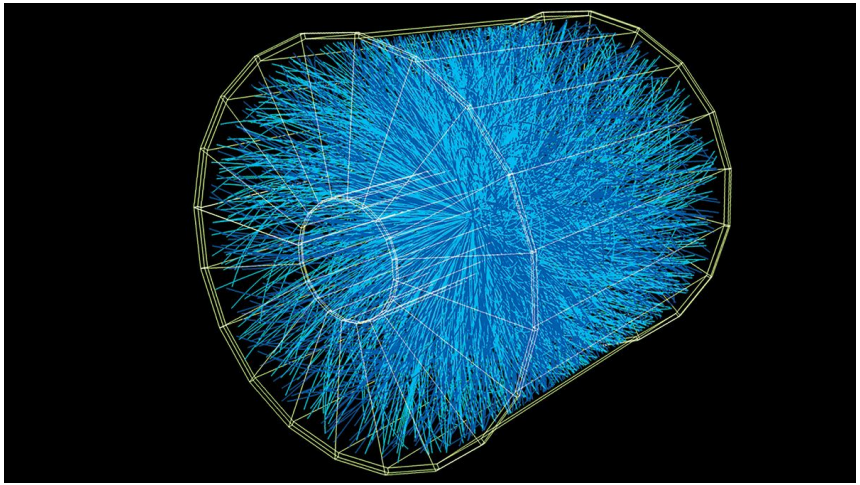
Highlights

Geometry

Geometry nucleus experiment

How can a nucleus be a coherent emitter of waves and produce many particles in an incoherent hadronic nucleus-nucleus collision at the same time?

- Question posed by the observation of coherent photoproduction in hadronic heavy-ion collisions at the LHC



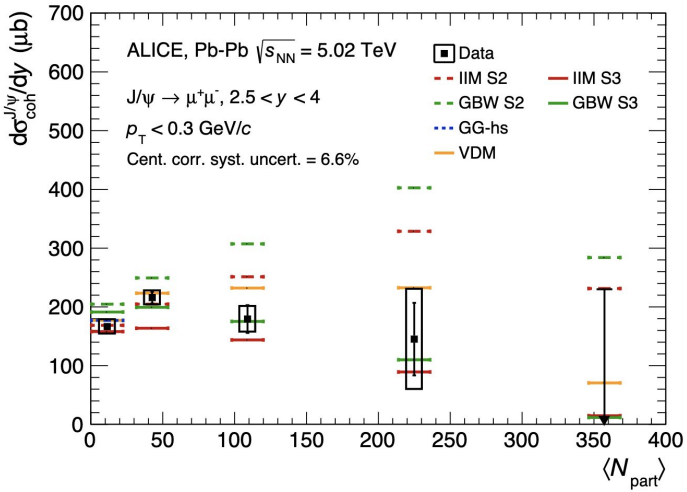
Geometry nucleus experiment

Extension of measurements towards larger number of produced particles

- The flux of the emitted waves from the nuclei must be modified

Further progress by measurements with already available data

- Gluodynamics-driven ALICE preliminaries on more differential cross-section and polarisation measurements on their way to publications



Phys. Lett. B 846 (2023) 137467

supported by 2-years postdoc D. Mallick (IJCLab)

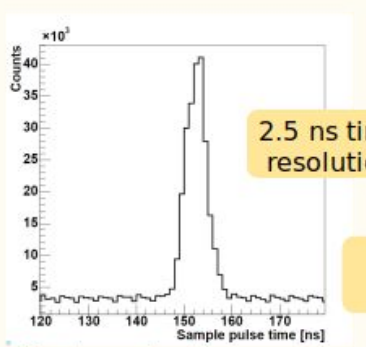
Geometry nucleon experiment

Deeply virtual compton scattering: accessing the 3D structure of the nucleon

New experiment at JLab commissioned and taking first data in 2023: high precision and high rate at edge of kinematics

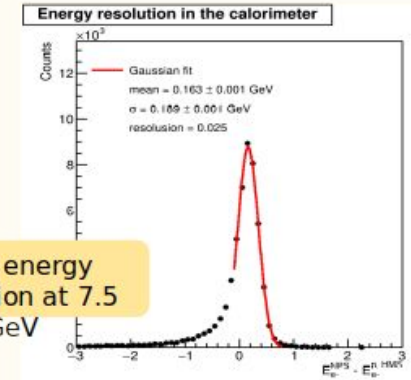
- Gluodynamics@Orsay: realise mechanical and calorimeter design

Online detector performance

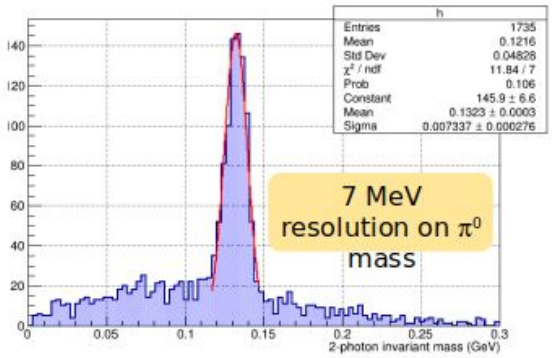


2.5 ns time resolution

Electron-photon coincidences



2.5% energy resolution at 7.5 GeV



7 MeV resolution on π^0 mass

supported by 1-year postdoc Yuwei Zhu (IJCLab)

Geometry nucleon theory

Breaking of factorisation at leading twist

Gluodynamics@Orsay:

first processus identified

that does not factorise at leading twist

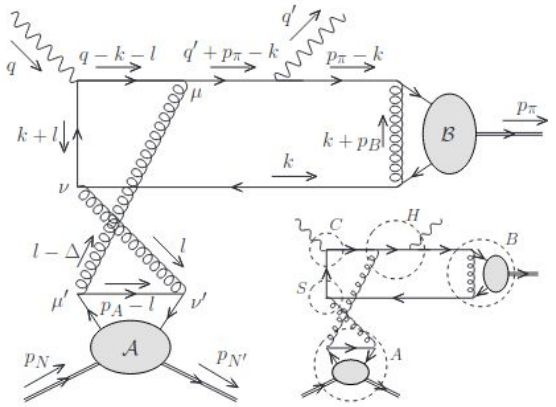


Figure 2. A diagram that has a Glauber pinch. Bottom right: For the Glauber scaling in Eq. (25), it corresponds to Fig. 1(e).

submitted to PRL 2311.09146 [hep-ph]

supported by 2-year postdoc Saad Nabeebaccus (IJCLab)

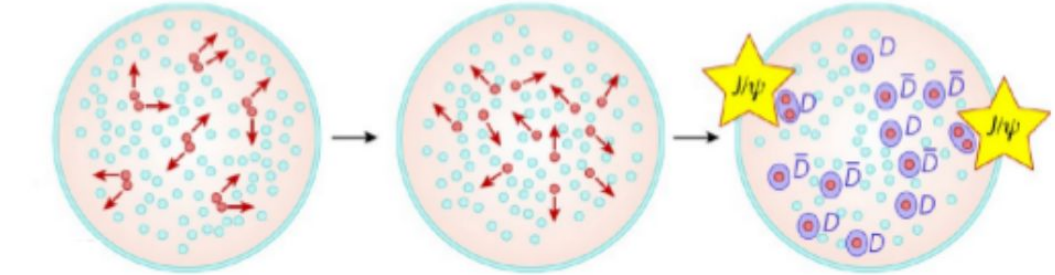
Gluodynamics

Highlights

Gluometer

Gluometer collider

Charmonium: a messenger of deconfinement at the LHC



Start of collision | Development of quark-gluon plasma | Hadronization

P. Braun-Munzinger and J.Stachel, Nature 448 (2007)

Late stage production observed via different observables

- qualitative finding clear, but microscopic picture not clear

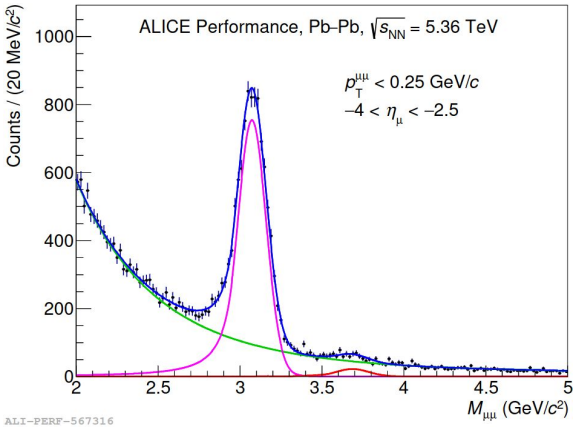
New observables enabled by ALICE detector upgrades first in action in PbPb in 2023

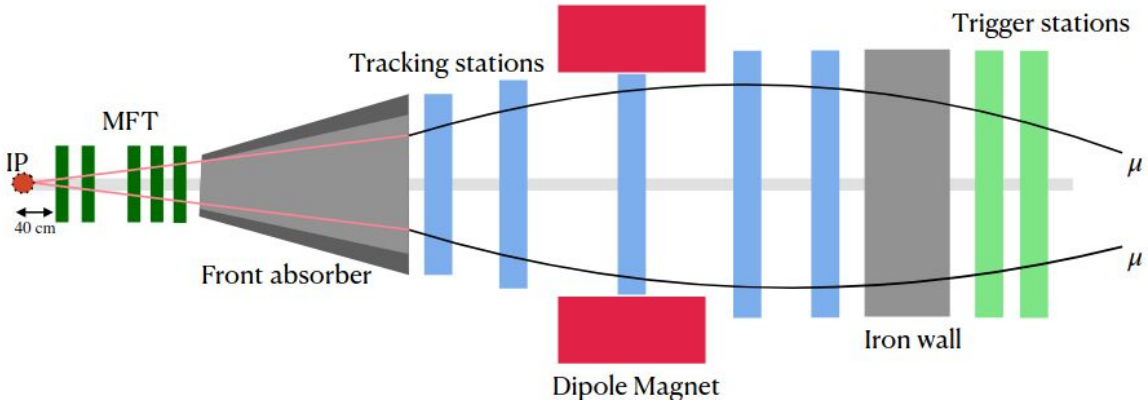
Muons now with vertex detector: separate charm & beauty and enable B_c^+

Gluometer collider

Key role of P2IO teams at Orsay and Saclay in commissioning of hardware, software, calibration and analysis of ALICE muon arm

- performances approaching now after hard work physics readiness





J/Ψ→$\mu\mu$ in PbPb data from October 2023 (10% statistics of ultra-peripheral collisions)

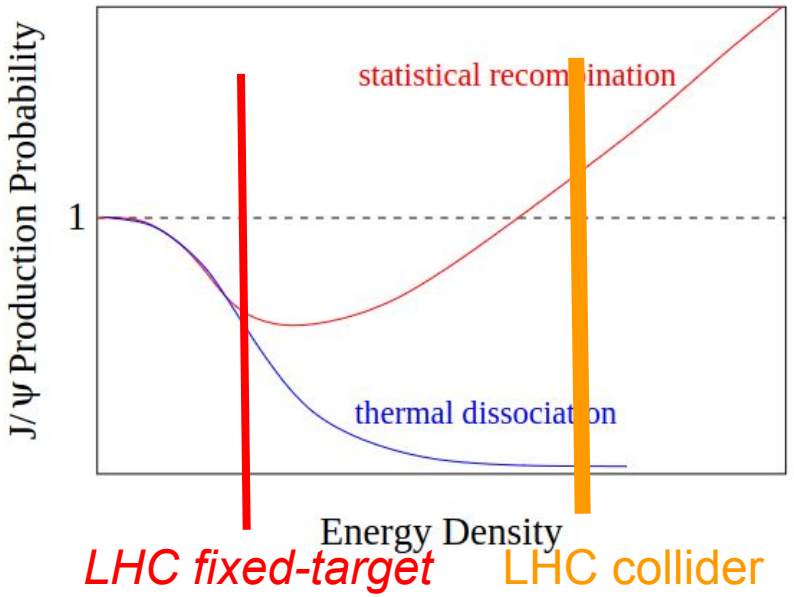
Supported by 2-years postdoc Batoul Diab (DPhN/CEA)

Gluometer fixed-target

LHC in fixed-target mode:

- Unique opportunity to test deconfinement at lower energy & lower charm quark density

  Based on otherwise unavailable observables



Modified cartoon based on Kluberg-Satz review 2009

P2IO LLR Gluodynamics team: pioneer and driver of charm measurements

Gluometer fixed-target

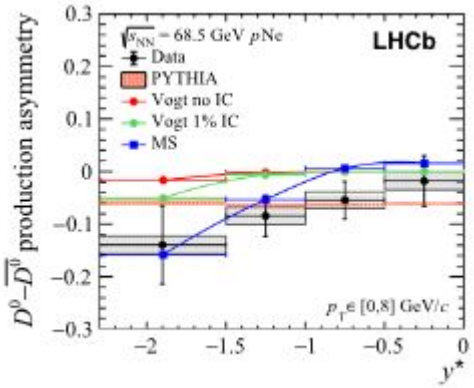
3 publications based on pre-covid data in pNe & PbNe data

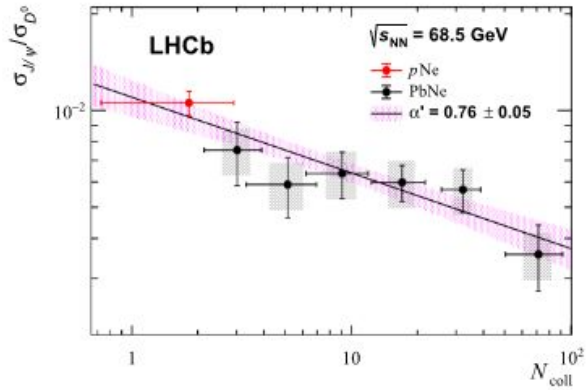
EPJC83 (2023) 541, 625, 658

- Interesting phenomena in ´simple´ reference pNe:
  - sensitivity to hadronisation universality breaking
- First measurement of nucleus-nucleus collisions
- no suppression directly relatable to deconfinement

Eagerly waiting for 2024 data:

1-2 orders larger statistics & bigger collision systems





Supported with 1-year postdoc (Benjamin Audurier) in 2021

Gluodynamics

Highlights

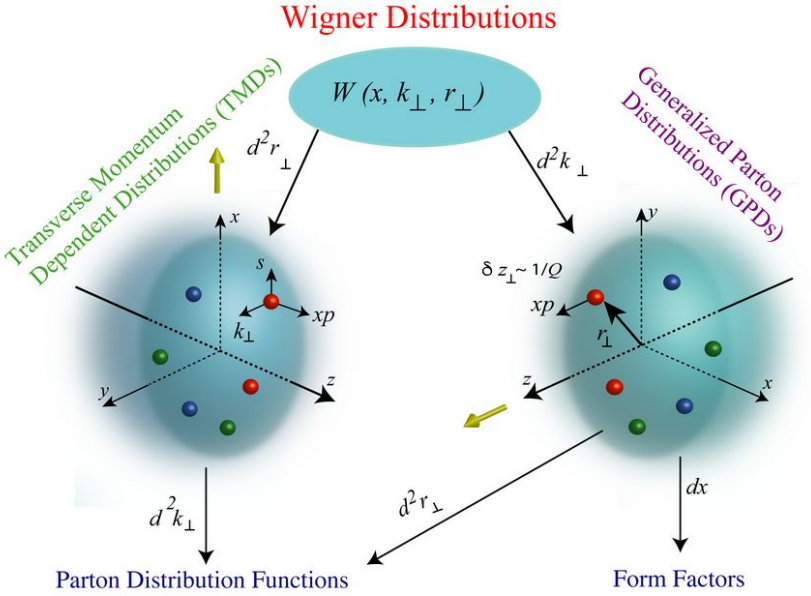
Unification

Unification space

Multidimensional picture of hadrons

- Driving factor of hadron structure
  - Multidimensional structure
    - From 1 to 3 (5?) dimensions

- 3D objects relatable to mass decomposition



However:

Deconvolution of experimental/simulation data to objects of physical interest extremely hard

- Gluodynamics: try to unify, get simpler, not more complicated

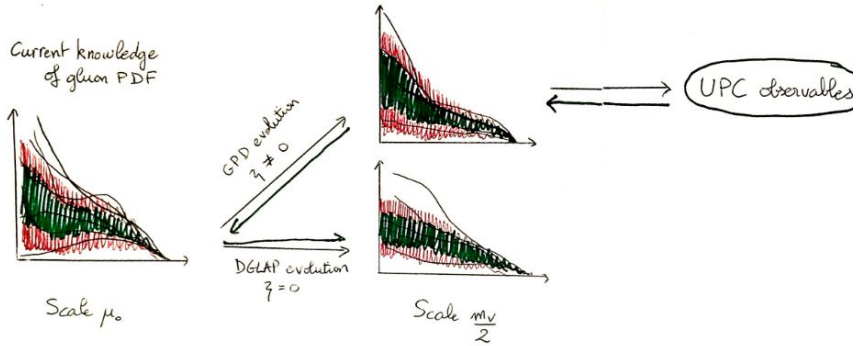
Unification space

´Unification´ of exclusive (3D) and inclusive (1D) parton distributions

- ´Constrain´ deconvolution problem in high-energy regime
- Exciting in search of saturation: constrain 1D parton densities at high energy colliders with exclusive production channels, a lot of data, but missing theory

Gluodynamics: first steps to enable theoretically sound global fits with exclusive and inclusive measurements in the future by theory uncertainties and to reduce deconvolution problem at high-energy

Phys.Rev.D 107 (2023) 11, 114019



Hervé Dutrieux

collaboration with V. Bertone and M. Winn

Not anticipated progress enabled by Gluodynamics exchanges

Unification time

Emergence of hydrodynamics in heavy-ion collisions

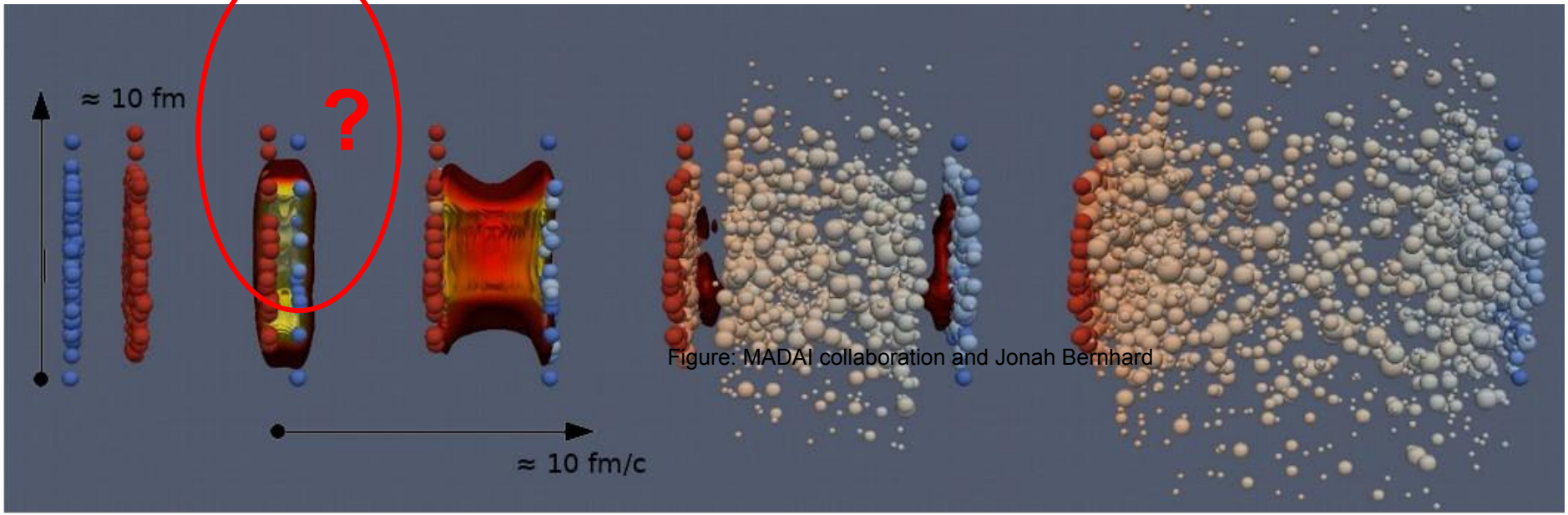


Figure: MADAI collaboration and Jonah Bernhard

- Transition from initial state to hydrodynamics:
  a thermalisation process - **the preequilibrium phase**
  - **not understood in theory & no experimental access despite large efforts**

Unification time

Measure the speed of the transition for the first time directly

Phys.Lett.B 821 (2021) 136626 ,

Maurice Coquet, Michael Winn (both DPhN),

Xiaojian Du, Sören Schlichting (Bielefeld),

Jean-Yves Ollitrault (IPhT)

- Major goal of LHC heavy-ion 2030ies with LHCb U2

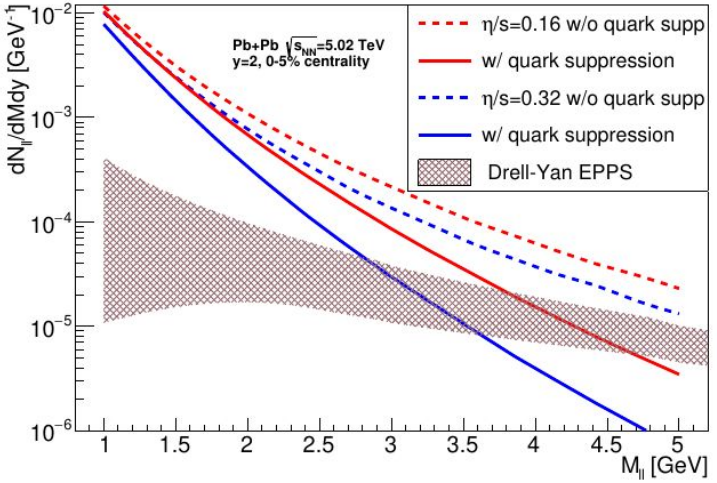


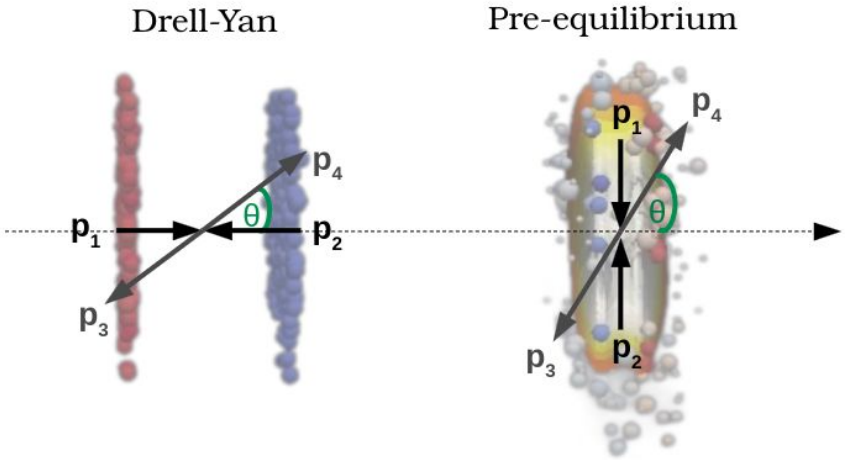
Figure 5: Dilepton production yields in the $0-5\%$ most central 5.02 TeV Pb+Pb collisions at forward rapidity $y = 2$ for different values of η/s, with and without quark suppression, from Fig. 3 compared with the Drell-Yan rate calculated at NLO with EPPS nuclear PDFs.

Not anticipated progress enabled by Gluodynamics, supported by 1-year postdoc at IPhT (Siggi Hauksson) working on NLO calculation among other topics related to thermalisation

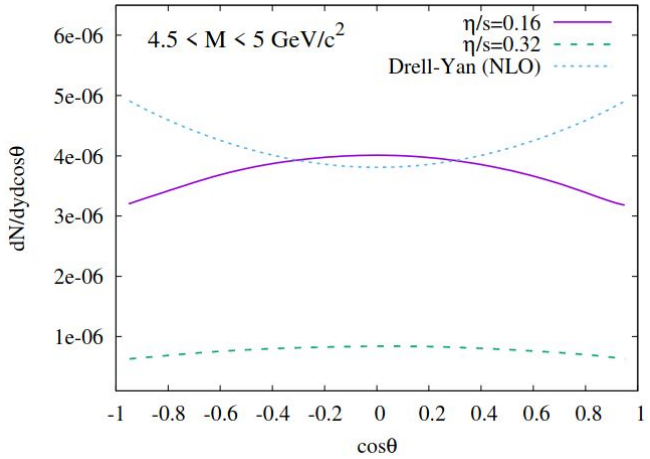
Unification time

Discovered that polarisation of dileptons reflects directly pressure anisotropy:

- Distinction from irreducible background
- Direct measure of most relevant aspect of out-of-equilibrium



Background signal



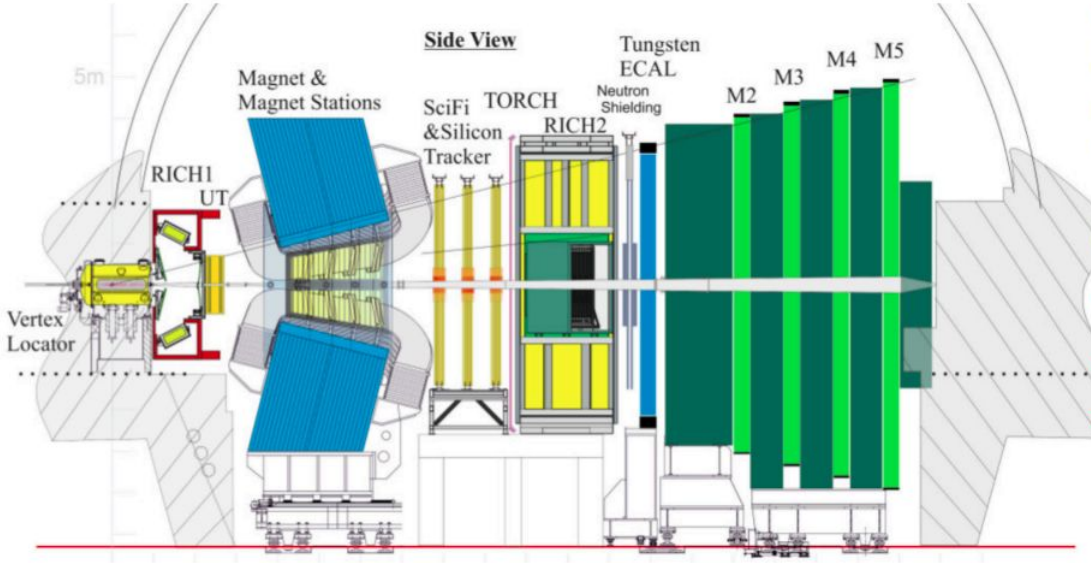
https://arxiv.org/pdf/2309.00555.pdf, Submitted to PRL

Gluodynamics

Highlights

Future

Future hadron collider



Same spectrometer footprint, innovative technology for detector and data processing

Key ingredients:

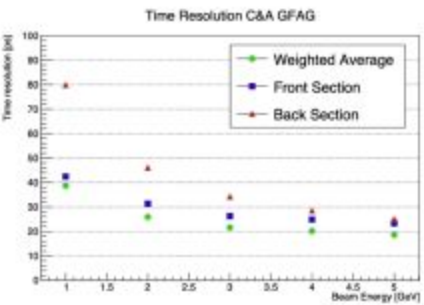
- *granularity*
- *fast timing (few tens of ps)*
- *radiation hardness (up to few $10^{16} n_{eq}/cm^2$)*

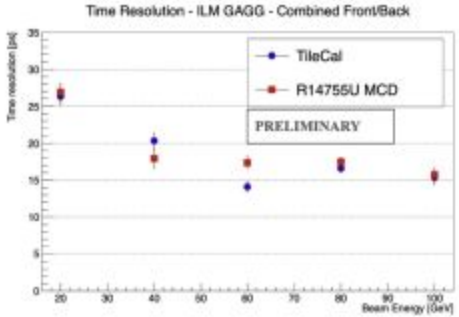
- Operate detector with 8 times larger number of particles than now!
  - enable central heavy-ion collider & fixed-target collisions with large luminosity
  - **thermalisation, hadronisation & saturation with heavy-flavour & dimuons**
    Gluodynamics crucial to establish involvement in calorimeter and tracker

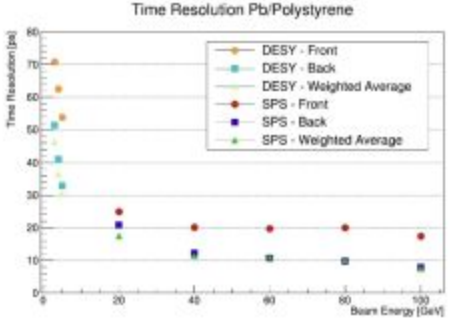
LHCb electromagnetic calorimeter for upgrade 2 requires time resolution of 10 ps

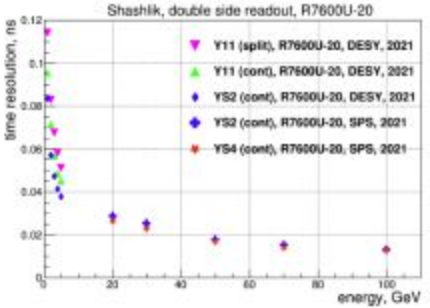
- Need electronics capable to cope with this challenging resolution

Test beam campaigns at DESY (1- 6 GeV) & at SPS (20-300 GeV) driven by Gluodynamics@Orsay









Time resolution inferior of 20 ps achieved for large energies

DAQ with 2 systems based on waveform sampling in analogue memories

DRS4 and Wave-Catcher (IJCLab-IRFU development)

Supported by Gluodynamics with 2-years postdoc Manuel Guittière

Résumé

The Paris-Saclay/IPP strong interaction community is a world-wide unique concentration of expertise both on QCD matter and on hadron structure

Gluodynamics stands for:

- A strong presence in current & future flagship projects on these physics topics
- A strong visibility of the physics community on the international level
- Stronger links and interactions between sites, communities and topics
- Realisation of new ideas with theory & experiment together now & in the future

End remark

All Gluodynamics funded postdocs remain until today in research

in France, UK, Spain, Italy, CERN

Three of them are today permanent staff members related to strong interaction in CNRS and CEA