



Phases of strongly interacting matter



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HIP theory project: Phases of Strongly Interacting Matter

QCD matter from colliders to stars

QCD in collider environment

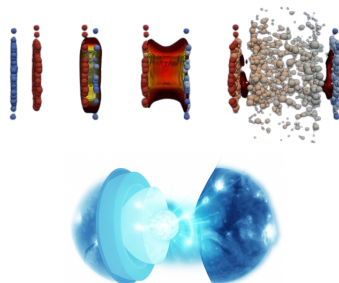
- Context: RHIC, LHC, EIC
- Non-linear QCD at high energies
- Partonic structure of protons and nuclei
- Properties of the Quark Gluon Plasma

Dense QCD matter Equation of State

- pQCD at high- $\mu_b \Rightarrow$ neutron star EoS

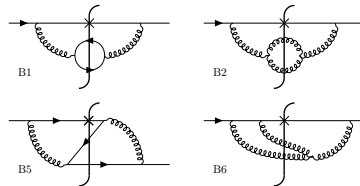
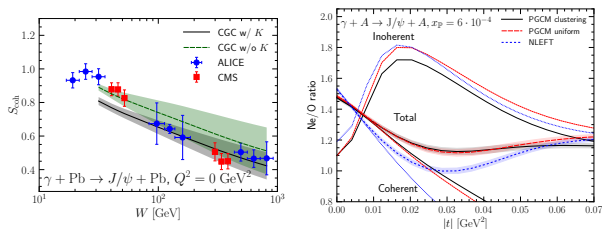
Holography

- Non-perturbative approach to both Equation of State (EoS) and collider physics



QCD in collider environment highlights since the previous SAB

Gluon saturation



Searching for gluon saturation

- Saturation effects in $\gamma + \text{Pb}$ (LHC, EIC)
- Sensitivity to nuclear structure at the LHC
- Initial state for heavy ion collisions

H.M et al, Phys.Rev.D 114 (2026) 1

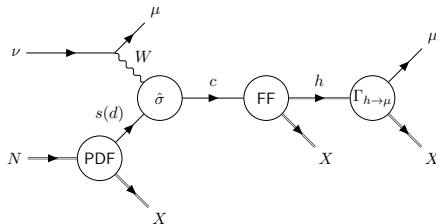
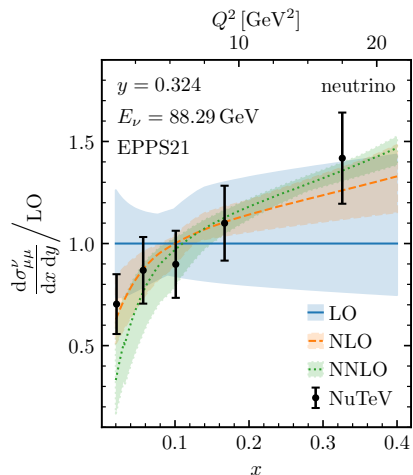
Light-Cone Perturbation Theory

- Two-loop DGLAP splitting in LCPT
- Enables automatized computations in gluon saturation regime
- PhD student (Seppälä) co-supervised from Helsinki and Jyväskylä

Lappi, Seppälä, Paatelainen, JHEP 05 (2026) 156

QCD in collider environment, highlights since the previous SAB

Proton and Nuclear Parton Distribution Functions



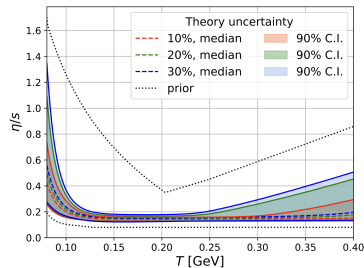
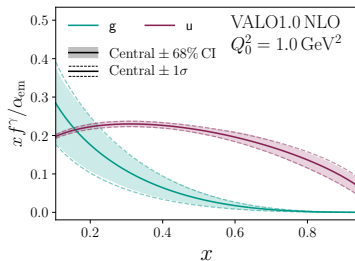
New constraints on s quark from $\nu + A$

- Dimuon production in $\nu + A$ DIS
- New precise calculation at NNLO

Helenius et al, 2605.00502

QCD in collider environment, highlights since the previous SAB

Photon parton distribution function, Quark Gluon Plasma properties



New photon PDF (VALO 1.0)

- Expanded our PDF expertise to photons
- Unique: NLO with uncertainty estimates
- Required for EIC phenomenology

Chithirasreemadam et al, arXiv:2606.07189

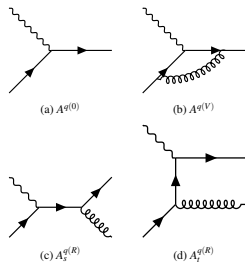
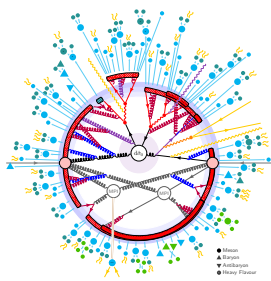
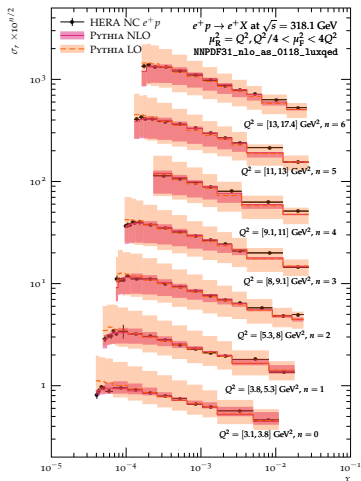
Global analysis of QGP properties

- Event-by-event MC-EKRT initial state
- Neural networks to speed up simulations
- Infer fundamental QGP properties

Niemi et al, Phys.Rev.C 114 (2026)

QCD in collider environment, highlights since the previous SAB

Pythia



First NLO matching in Pythia8

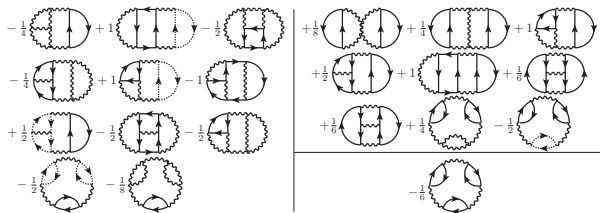
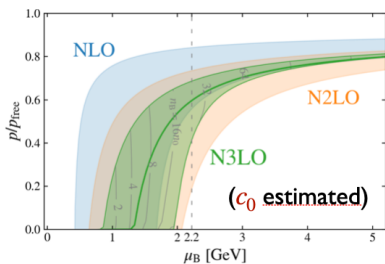
- Match NLO pQCD to parton showers
- Improved perturbative precision for DIS simulations (HERA, EIC)

Helenius et al, 2605.00502

Equation of State: highlights

High-density QCD matter EoS to the full α_s^3 level (SAB25: “main goal for the next 3 years”)
 $\Rightarrow$ achieved very recently (paper submission in $\sim$ September [Paatelainen et al., arXiv:2609.xxxxx](#))

$$p/p_{\text{free}} = \underbrace{1 + \#_1 \cdot \alpha_s + \#_2 \cdot \alpha_s^2}_{\text{N2LO: Freedman \& McLerran 1977}} + \underbrace{c_{3,2} \cdot \alpha_s^3 \ln^2 \alpha_s + c_{3,1} \cdot \alpha_s^3 \ln \alpha_s}_{\text{Paatelainen et al., PRL 2021 \& 23}} + \underbrace{c_0 \cdot \alpha_s^3}_{\text{HIP 2026}}$$

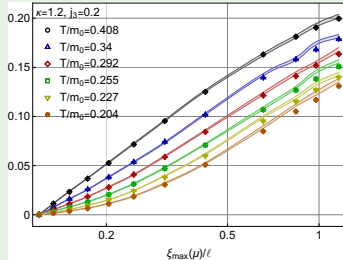


$\rightarrow$ tight constraints on the EoS at neutron star densities

Holography: Highlights since previous SAB

Entanglement at finite density

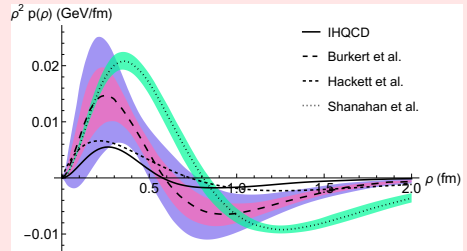
- First finite-density entanglement computation in an interacting QFT ($O(4)$ model $\approx$ QCD)
- Entanglement response reproduces EoS.
- Opens a new route for systems with a sign problem $\Rightarrow$ also for QCD?



Jokela et al, 2603.07635

Pressure inside the proton

- Gluonic gravitational form factors (GFF) from holography.
- Prediction for the pressure and shear-force distributions inside the proton.
- Crucial step towards contact with EIC



Hippeläinen et al, 2601.14939

Project updates since the previous SAB

- $\mathcal{O}(25)$ PhD scientists + $\mathcal{O}(15)$ PhD students
- Other funding: $2\times$ RCF Centre of Excellence (JYU, CoE in Quark Matter; [HU CoE in Neutron Star Physics](#)), ERC (CoG of HM, [CoG of Paatelainen](#), [AdG of Vuorinen](#)), RCF projects (Helenius, Vuorinen), RCF Research Fellow (Paatelainen, HM -8/26), private foundations ($\mathcal{O}(10)$ PhD students) + doctoral pilot (4 PhD students)
- **8-9** new PhDs since the previous SAB/scheduled for 2026

Significant events since the previous SAB

- Strong and Electroweak Matter in Helsinki (Paatelainen chair), ~ 140 participants
- New major funding: Paatelainen (ERC CoG), Vuorinen (ERC AdG), new RCF Centre of Excellence (8yr, Vuorinen leads, Paatelainen key senior scientist), MSCA postdoc (Roch)
- Paatelainen: full professor 4/2026– (University of Turku & University of Helsinki)
 $\Rightarrow$ [The project leader and both team leaders \(Jokela and Paatelainen\) secured permanent/tenure-track positions during the first four years of the project!](#)