Beyond tree level

Amplitudes, scattering in a medium, and community

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My path

- Grew up in the Sonoran Desert
- **2000–2001**: two-loop QCD amplitudes at IPPP Durham with Nigel Glover
- **2001–2003**: postdoc at YITP Stony Brook with George Sterman
- Back in Mexico: QCD in media: jets in the QGP, small-x, strong magnetic fields, the phase diagram
- Today: Full Professor-Researcher
- Facultad de Ciencias: Physics and Maths undergraduate programs, taught in english during second half.

The common thread

I am ~~interested~~ fixated with the **structure of amplitudes** (factorization, infrared poles, colour) and how much of that structure **survives in a medium**: a hot plasma, dense matter, a strong B field, a saturated nucleus, etc.

Some recent students and collaborators

Licenciatura (UCOL)	Darío Chaires Arciniega	10 de marzo de 2021	Simulation and analysis of Au + Au collisions at NICA energies for the MPD experiment [PDF]	Maestría en Ingeniería Física Universidad Michoacana de San Nicolás Hidalgo
Maestría (USON)	Alejandro Guirado García	5 de julio de 2021	Estudio de generación y efectos de campos electro--magnéticos a energías del experimento NICA [PDF]	
Maestría (UAS)	José Jorge Medina Serna	10 de junio de 2022	Polarización de Λ y $\bar{\Lambda}$ en el experimento MPD-NICA [PDF]	Doctorado en Física (ICN, UNAM)
Licenciatura (UCOL)	Pavel Elian Morales Medina	2 de agosto de 2022	Solutions to the Dirac equation for effective confining potentials as a method to estimate the nucleon mass [PDF]	PhD (U. of Missouri, USA)
Licenciatura (UCOL)	Marcos Alejandro Hernández Ojeda	5 de julio de 2023	The S-matrix bootstrap bounds on couplings [PDF]	PhD (Indiana U. Bloomington, USA)
Licenciatura (UCOL)	Angel Ploneda Preciado	3 de septiembre de 2024	Neutron star mass-radius relation from a nuclear matter equation of state [PDF]	PhD (SUNY at Stonybrook, USA)



Nuclear team

Alejandro Ayala (ICN-UNAM), Isabel Domínguez (FCFM-UAS), Luis Hernández (DF-UAM-I), Ivonne Maldonado (ICN-UNAM)

1 · Two-loop amplitudes: massless $2 \to 2$ in QCD



tree two loops

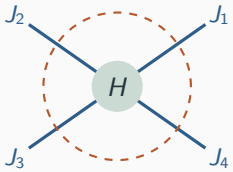
- Two-loop corrections for **all** massless $2 \to 2$ parton processes: $q\bar{q} \to q'\bar{q}'$, identical quarks, $qg \to qg$, $gg \to gg$, plus $q\bar{q} \to \gamma\gamma$, $q\bar{q} \to g\gamma$
- Tree×two-loop interference and helicity amplitudes
- Pole structure checked against Catani's prediction (1998)

Anastasiou, Glover, Oleari, T-Y, NPB 601 (2001) 318; 341; NPB 605 (2001) 486

Glover, Oleari, T-Y, NPB 605 (2001) 467 · Glover, T-Y, JHEP 05 (2001) 010

Anastasiou, Glover, T-Y, NPB 629 (2002) 255 · Glover, T-Y, JHEP 06 (2003) 033

2 · From explicit calculations to resummation



S: soft gluons

$$\mathcal{M}_L = J(\epsilon)\, S_{LJ}(\epsilon)\, H_J$$

$$S = \mathrm{P}\exp\Big[-\tfrac{1}{2}\int_0^{Q^2} \tfrac{d\mu^2}{\mu^2}\, \Gamma_S\big(\bar{\alpha}_s(\mu^2,\epsilon)\big)\Big]$$

(schematic)

- Factorization implies the **exponentiation** of double and single poles at every order
- Single poles split into universal functions for each external parton and a **soft anomalous dimension matrix** Γ_S that mixes colour
- Catani's proposal for the two-loop poles emerges naturally
- Later: $\Gamma_S^{(2)} \propto \Gamma_S^{(1)}$ (Aybat, Dixon, Sterman 2006)

Sterman, T-Y, *Multi-loop amplitudes and resummation*, PLB 552 (2003) 48 [hep-ph/0210130]

3 · Phenomenology of scattering in a medium

Jets in the QGP

Two- and three-hadron correlations from pQCD; $2 \to 3$ versus $2 \to 2$ processes; Mach cone versus head shock; relating $\hat{q}$, η/s and ΔE.

PRL 104 (2010) 042301; PRC 88 (2013) 025203; PRC 92 (2015) 044902; PRC 94 (2016) 024913

Small-x / CGC

Polarized three-parton production in DIS at small x; **spinor helicity** in the shock-wave background: 16 diagrams reduced to 4 by cutting in light-cone time.

Ayala, Hentschinski, Jalilian-Marian, T-Y: PLB 761 (2016) 229; NPB 920 (2017) 232

Strong B fields

Photons from B-induced gluon fusion and splitting: the $gg\gamma$ vertex, yield and v_2; the thermo-magnetic quark-gluon vertex (HTL).

PRD 96 (2017) 014023; EPJA 56 (2020) 53; PRC 106 (2022) 064905; PRD 91 (2015) 016007

In all three: **amplitudes in a background** (thermal, saturated, magnetic) $\Rightarrow$ observables

4 · The QCD phase diagram: NICA, RHIC-BES, FAIR

- Global Λ and $\bar{\Lambda}$ polarization in the core–corona model; excitation function
- The σ propagator at finite T and μ_B: towards vorticity-to-spin transfer in the corona
- Pion femtoscopy with Lévy fits (primary and secondary pions) at NICA energies
- Chiral restoration (ρ–a_1) and femtoscopy near the critical point
- MexNICA collaboration (MPD)

Core meets corona: PLB 810 (2020) 135818
PRC 105 (2022) 034907; PRD 114 (2026) 016034
in-medium σ: PLB 869 (2025) 139873

Lévy: EPJA 60 (2024) 135

Why it matters for my fixation

Loop self-energies at $T, \mu \neq 0$ (Landau cuts, Pauli blocking) are the same craft I need to take amplitudes into a medium.

5 · Current programme: amplitude-level factorization in a medium

Question. How are J, S_{LJ} and the matrix Γ_{LJ} modified when the eikonal lines cross a medium at finite T and/or density?

- **Working hypothesis:** at leading power the colour structure of Γ_{LJ} is unchanged; the medium enters through the coefficients
- **Tool:** Caron-Huot's loop–tree theorem,

$$\pm\pi\delta(q^2) \;\to\; 2\pi\delta(q^2)\big[\pm\tfrac{1}{2} + n(q)\big]$$

(sketched for $T \neq 0$ in his §7, not worked out)

- **Testable prediction:** pole coefficients a_{-2}, a_{-1} independent of T

Where things are at the moment

- This is a **hypothesis**. Indirect support: the reaction-operator analysis in SCET_G (Ovanesyan–Vitev)
- The SCET + open-quantum-systems programme (Mehtar-Tani, Pathak, Singh, Vaidya, 2024–26) already factorizes inclusive in-medium jet observables
- What remains, as far as I know: the **amplitude-level $2 \to 2$ γ_S matrix** in cold matter at moderate x (EIC) and its hot counterpart

Caron-Huot, *Loops and trees*, JHEP 05 (2011) 080

What I bring to this community and what I'm looking for

I offer

- Experience with loop calculations, IR structure and colour
- Techniques at finite T and μ and in external fields
- A bridge to heavy-ion and EIC phenomenology
- Training for young researchers and students

I'm looking for

- Conversations with people using modern methods: generalized unitarity, BCFW, differential equations, bootstrap
- A loop–tree theorem with n_B, n_F? Exponentiation of webs in a thermal bath?
- Joint calculations

6 · Recent co-fixations

Evidence

- Co-editor: *El derecho a ser científicas* (*The right to be scientists*; UdeC, 2025; open access) doi:10.53897/LI.2025.0021.UCOL
- Co-author of the SECIHTI national report on women in science and technology in Mexico (2025) https://www.secihti.mx/el-papel-de-las-mujeres-en-la-ciencia-y-la-tecnologia-en-mexico-2025/
- *LA HECAP Physics Briefing Book 2025* arXiv:2603.06291

Teaching and outreach

- Simons–Emmy Noether Fellow, Perimeter Institute (2020–21)
- PI-docentes network: Perimeter teaching strategies adapted to Mexican classrooms
- *From the Sonoran Desert to Neutron Stars* (El Paso Science Festival)

Practice

- Institutional STEM Mentoring Programme (UdeC): mentors for women high-school students; two editions; seed funding from the British Council (2023)
- *Gender Equality Partnerships* UK–Mexico proposal (2026) with Leeds Business School
- Opening talk, 2nd IMAN School (Diversity & Inclusion, DPyC–SMF, 2026)

What I advocate

STEM mentoring networks. Mentoring works when it is structural, not precarious: safe spaces, protected time, peer-to-peer, follow-up and open-data.

Why this matters for this community

A new network/community sets its culture from the start:

- **Seminar**: morning slot (so speakers in Europe can join); diversity of speakers and career stages as an explicit criterion
- **Entry-level**: open to all across the country, not only at the large centres
- **Peer mentoring** within the network, especially for students at smaller institutions
- **Working groups** by topic: QCD and colliders, formal QFT, cosmology,...

Thank you



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