Simulating heavy quarks and *jets* in the Glasma

∫ DAvramescu, H. Mäntysaari, T. Lappi — *University of Jyväskylä*

A. Ipp, D. Müller — *TU Wien*

V. Greco, M. Ruggieri — *University of Catania*

Q: Do **heavy quarks** remember the **Glasma** initial stage?

A: **Two-particle correlations** are significantly affected by the Glasma

Numerical solver for colored transport

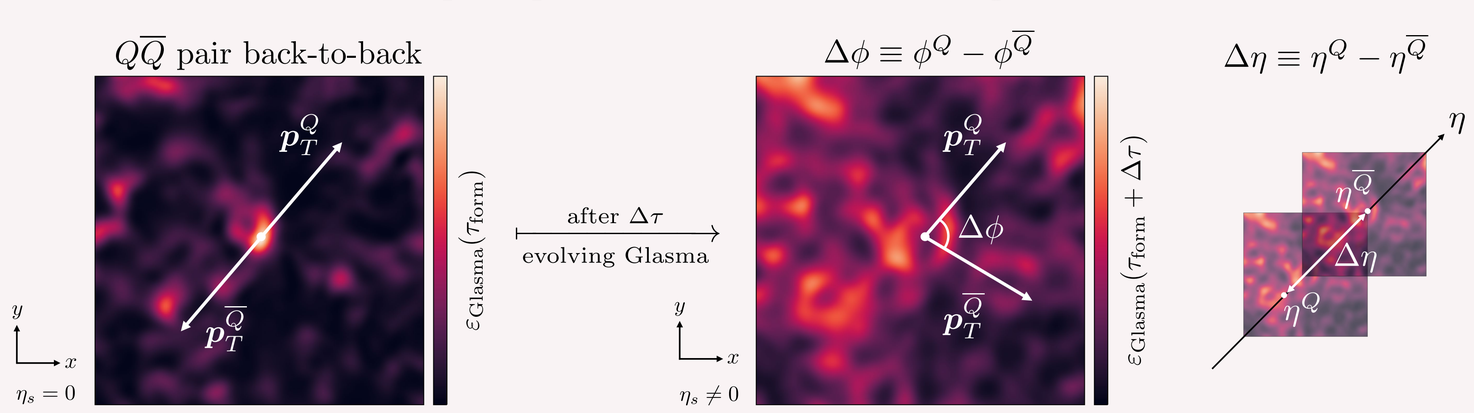
Classical particles in classical Yang-Mills fields

Heavy quarks | Glasma fields

- SU(3) color charges
- Charm and beauty
- Transverse momentum $p_T(\tau_{\rm form})$

- SU(3) lattice gauge fields
- Heavy ions at high energy
- Saturation momentum Q_s

Sketch of quark pair evolution in Glasma background fields

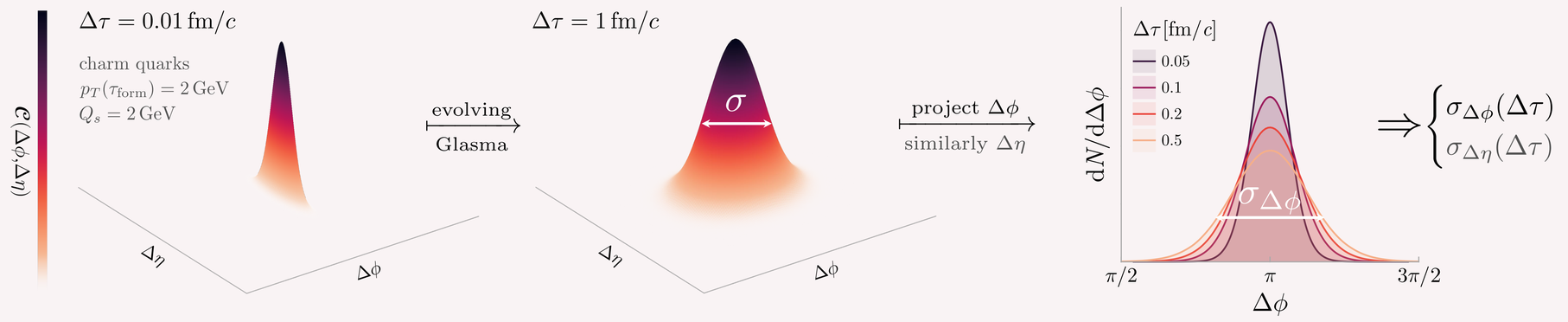


Decorrelation width

Two-particle correlations

$$\mathcal{C}(\Delta\phi,\Delta\eta) \equiv \frac{1}{N_{\rm pairs}}\frac{{\rm d}^2N}{{\rm d}\Delta\phi{\rm d}\Delta\eta}$$

Peak at $\Delta\eta(\tau_{\rm form}) = 0$ and $\Delta\phi(\tau_{\rm form}) = \pi$



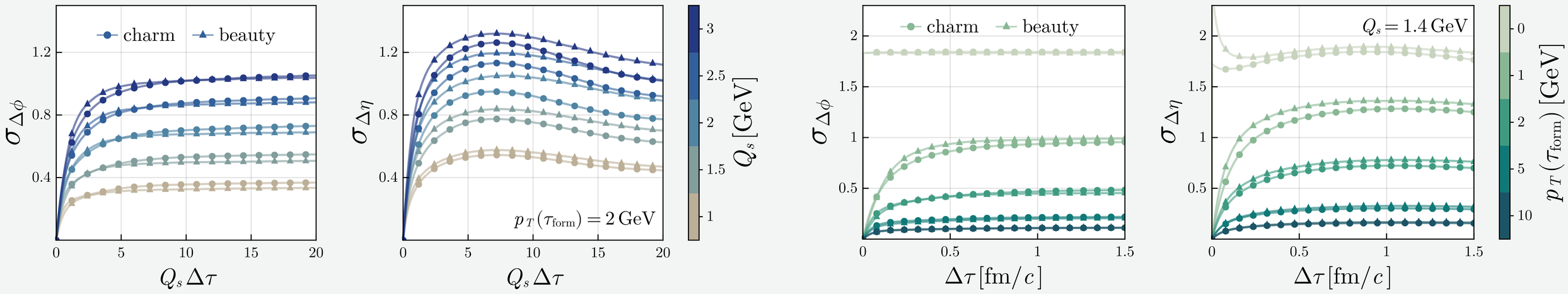
Q: Is the initial correlation **washed out** by the Glasma stage? *A:* The **decorrelation width** depends on the...

Glasma saturation momentum Q_s

More **decorrelation** in a **denser** Glasma

Heavy quark transverse momentum p_T

More **decorrelation** for **slower** heavy quarks



Color Glass Condensate

- Separation of scales: cutoff — small-x | large-x — $P^+_{\rm nucleus}$
- Gluon fields $\overset{\sqrt{s}\to\infty}{\longmapsto}$ exact analytic solution

Poisson $\underset{\sim}{\Delta}A^+ = -\rho$

Pure gauge $A^i_{\rm cov} = \frac{\rm i}{g}V^\dagger\partial^i V$ (Wilson line)

- MV model $\overset{\text{large } A}{\longmapsto}$ stochastic color charges

$$\langle\rho(x^-,\underset{\sim}{x})\rho(y^-,\underset{\sim}{y})\rangle = g^2\mu^2\delta(x^- - y^-)\,\delta^{(2)}(\underset{\sim}{x}-\underset{\sim}{y})$$

($\propto Q_s^2$ saturation momentum)

The Glasma fields

- Yang-Mills equations $\mathscr{D}_\mu F^{\mu\nu} = J^\nu$
- Boost-invariance $A^\mu(x) = {\rm indep}(\eta)$
- Boundary condition

$$A^i\big|_{\tau=0} = A_1^i + A_2^i$$

$$A^\eta\big|_{\tau=0} = \frac{\rm ig}{2}\left[A_1^i, A_2^i\right]$$

Anisotropic momentum broadening

- Momentum broadening $\delta p_\mu^2(\tau) \equiv p_\mu^2(\tau) - p_\mu^2(\tau_{\rm form})$
- Momentum anisotropy $\langle\delta p_L^2\rangle/\langle\delta p_T^2\rangle$

Classical lattice gauge theory

Everything is computed on the lattice

- Lattice site $\underset{\sim}{x}$
- Gauge link $U_{\underset{\sim}{x},\underset{\sim}{i}} \approx \exp\{igA_i(\underset{\sim}{x}+\underset{\sim}{i}/2)\}$
- Plaquette $U_{\underset{\sim}{x},\underset{\sim}{ij}} = U_{\underset{\sim}{x},\underset{\sim}{i}}U_{\underset{\sim}{x}+\underset{\sim}{i},\underset{\sim}{j}}U^\dagger_{\underset{\sim}{x}+\underset{\sim}{j},\underset{\sim}{i}}U^\dagger_{\underset{\sim}{x},\underset{\sim}{j}}$

Colored particles in colored fields

$$\frac{\rm d}{{\rm d}\boldsymbol{\tau}}x^\mu = \frac{p^\mu}{m} \qquad \frac{\rm D}{{\rm d}\boldsymbol{\tau}}p^\mu = 2g\,{\rm Tr}\left\{Q F^{\mu\nu}\left[A^\mu\right]\right\}\frac{p_\nu}{m}$$

(coordinate; momentum; gauge field)

color charge | Wilson line

$$\text{Color rotation } Q(\boldsymbol{\tau}) = \mathcal{U}(\boldsymbol{\tau},\boldsymbol{\tau}')\,Q(\boldsymbol{\tau}')\,\mathcal{U}^\dagger(\boldsymbol{\tau},\boldsymbol{\tau}')$$

Simulating jets and heavy quarks in the Glasma using the colored particle-in-cell method

Dana Avramescu, Virgil Baran, Vincenzo Greco, Andreas Ipp, David Müller and Marco Ruggieri

arXiv:2303.05599

dana.d.avramescu@jyu.fi

HELSINKI INSTITUTE OF PHYSICS · JYVÄSKYLÄN YLIOPISTO UNIVERSITY OF JYVÄSKYLÄ · CoE QM

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