Data-driven analysis of light parton transport properties in a hard-soft factorized energy loss model

Tianyu Dai, Jean-François Paquet, Steffen A. Bass

Duke University

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Hard-soft factorization of parton energy loss

Weakly-coupled effective kinetic formalism

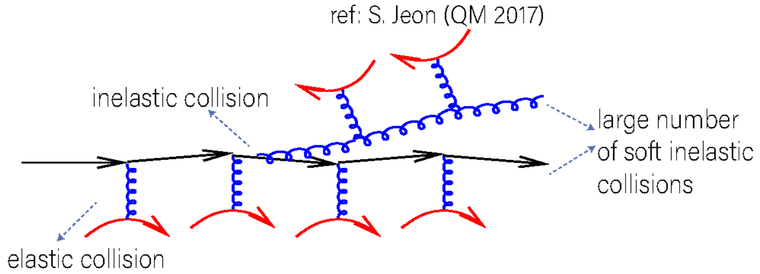
Leading-order realizations (e.g. MARTINI):

$$(\partial_t + \vec{v}\cdot\nabla_x) f^a(\vec{p},\vec{x},t) = -C_a^{2\leftrightarrow 2}[f] - C_a^{1\leftrightarrow 2}[f]$$

Hard-soft factorization:

$$C_a^{2\leftrightarrow 2} + C_a^{1\leftrightarrow 2}$$

$$= C_a^{\text{large-angle}}(\mu_{\tilde{q}_\perp}, \Lambda) + C_a^{\text{split}}(\Lambda) + C_a^{\text{large-}\varpi}(\mu_\varpi) + C_a^{\text{diff}}(\mu_{\tilde{q}_\perp}, \mu_\varpi)$$

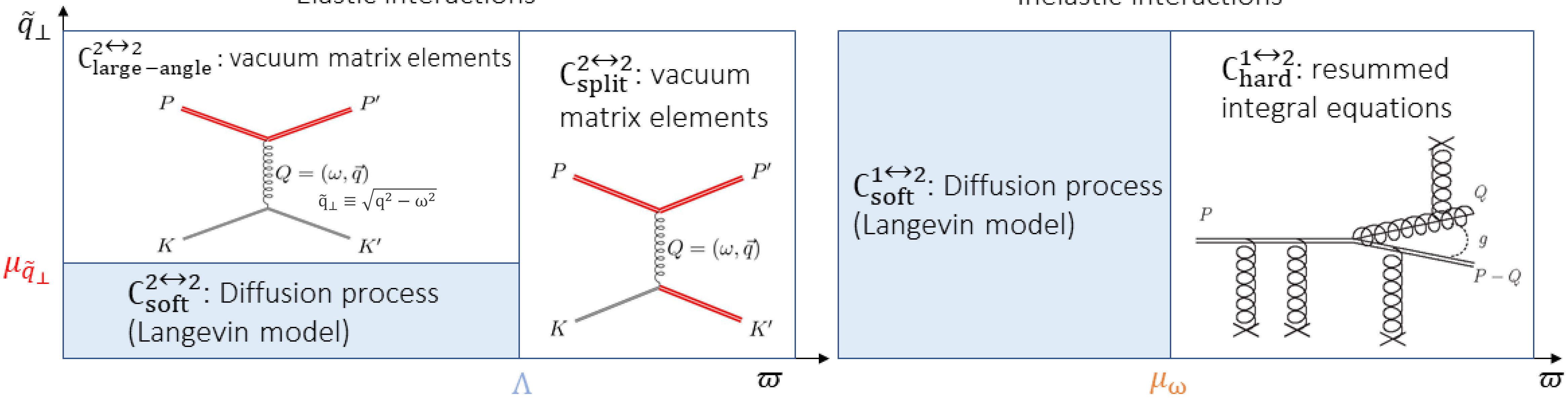


Interactions with the medium:

- Large number of soft interactions
- Rare hard scatterings

Elastic interactions

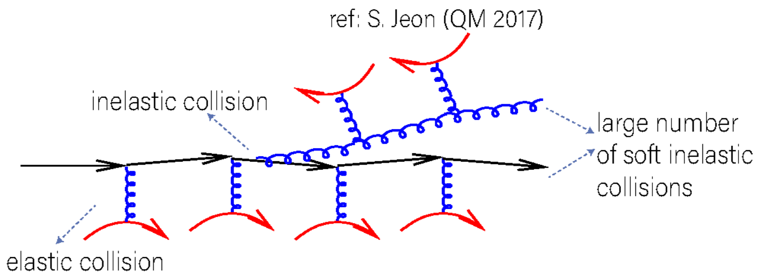
Inelastic interactions



Hard-soft factorization of parton energy loss (Tequila)

Benefits of the hard-soft factorization

- Non-perturbative effects absorbed in transport coefficients $\hat{q}_{\text{soft}}$, $\hat{q}_{\text{L,soft}}$
- Stochastic description is numerically more efficient
- Soft transport coefficients can be constrained from measurements
- Can be extended to next-to-leading order

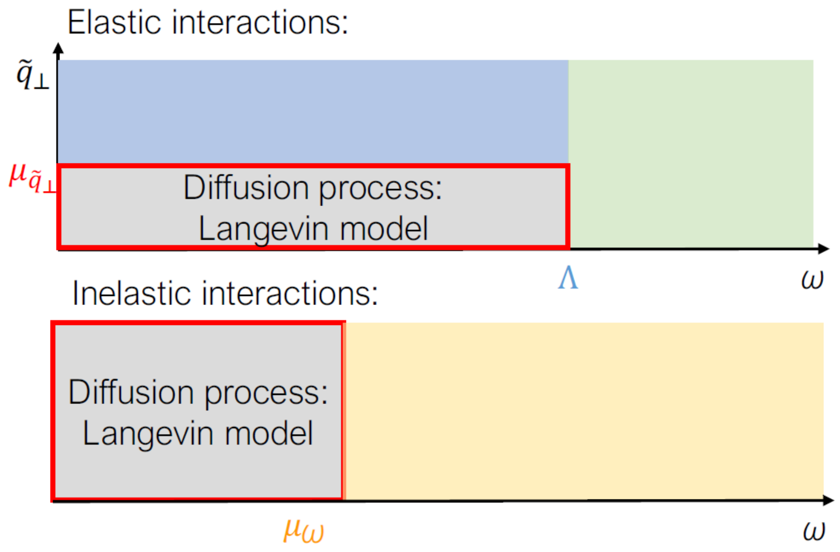


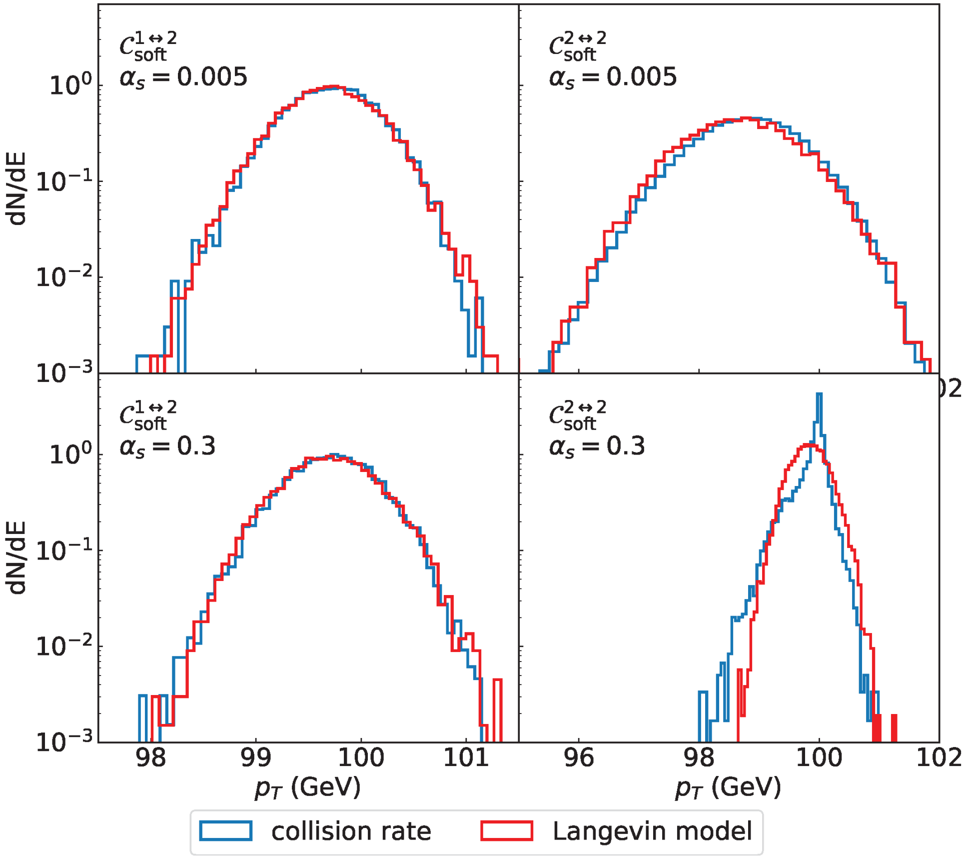
	Tequila	MARTINI	LBT
Interaction factorization	$C_{\text{hard}}^{2\leftrightarrow 2} + C_{\text{hard}}^{1\leftrightarrow 2} + C_{\text{diff}}$	$C^{2\leftrightarrow 2} + C^{1\leftrightarrow 2}$	$C^{2\leftrightarrow 2} + C^{1\leftrightarrow 2}$
Perturbative order	Leading-order, potential to next-to-leading order	Leading order	Leading order
Radiative formalism	AMY	AMY	Higher-Twist
Coupling	Fixed coupling constrained using experimental data (working on running coupling)	Running coupling	Running coupling

- Ghiglieri, Jacopo, Guy D. Moore, and Derek Teaney. "Jet-medium interactions at NLO in a weakly-coupled quark-gluon plasma." *Journal of High Energy Physics* 2016.3 (2016): 1-58.
- Dai, Tianyu, et al. "Parton energy loss in a hard-soft factorized approach." *Physical Review C* 105.3 (2022): 034905.

Brick test: weak coupling and beyond

We compare: collison rate treatment v.s. stochastic treatment
We use: pure glue medium; screened matrix elements for collision rates
We plot: energy distribution of a hard gluon propagating in a static medium





$\Rightarrow$ $C_a^{\rm soft}$ only

T = 300 MeV

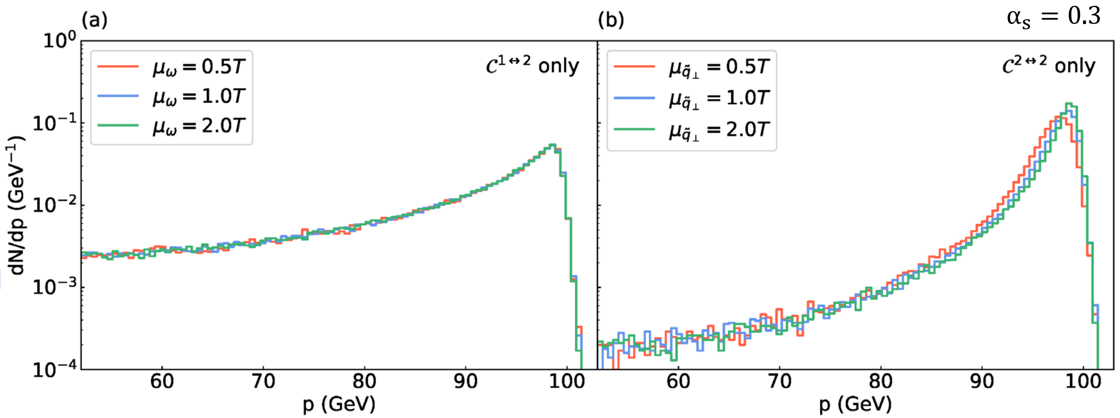
E_0 = 100GeV

Evolution time:

$t = (0.3/\alpha_s)^2 {\rm fm/c}$

$C_a^{\rm soft} + C_a^{\rm hard}$ $\Leftarrow$

We validate: the dependence of the **single parton energy distribution** on the hard-soft cutoff



Energy loss is **weakly dependent on the cutoffs.**

Data-driven analysis

Hard-soft factorized model

- Hard interactions:

$$(\partial_t + \vec{v}\cdot\nabla_x) f^a(\vec{p},\vec{x},t) = -C^{2\leftrightarrow 2}_{a,\mathrm{vacuum}}[f] - C^{1\leftrightarrow 2}_{a,\mathrm{AMY}}[f]$$

- Soft interactions:

$$C^{\mathrm{diff}}[f] = -\frac{\partial}{\partial p^i}\left[\eta_D(p)p^i f(p)\right]$$
$$-\frac{1}{2}\frac{\partial^2}{\partial p^i \partial p^j}\left[\left(\hat{p}^i\hat{p}^j \hat{q}_L(p) + \frac{1}{2}\left(\delta^{ij} - \hat{p}^i\hat{p}^j\right)\hat{q}(p)\right) f(p)\right]$$

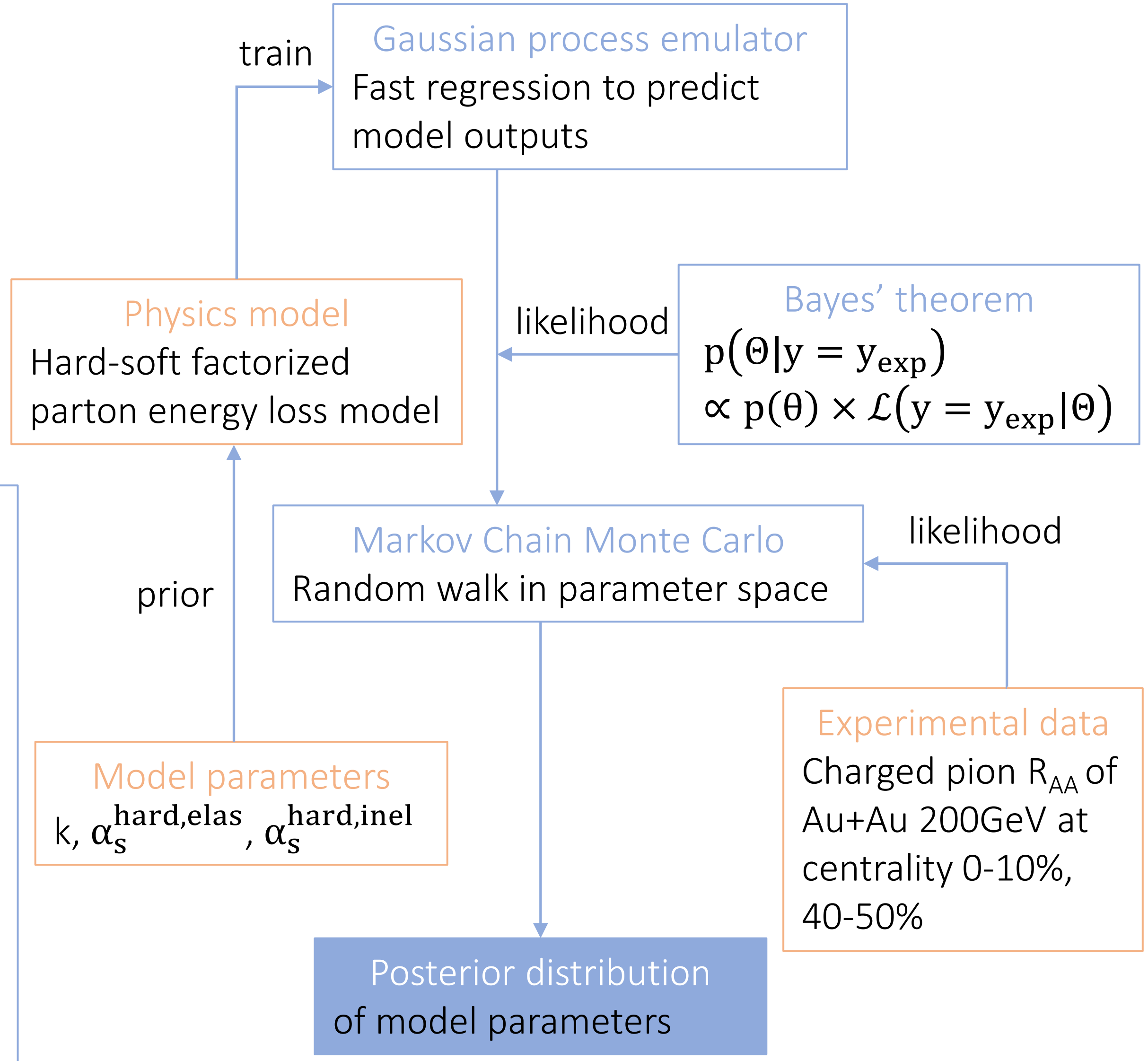
Goal: model-to-data comparison

- Simultaneously describe several set of experimental data
- Quantitatively estimate the model parameters:
  - Coupling constant of hard elastic interactions $\alpha_s^{\mathrm{hard,elas}}$
  - Coupling constant of hard inelastic interactions $\alpha_s^{\mathrm{hard,inel}}$
  - Parameterize soft $\hat{q}$,$\hat{q}_L$ (based on perturbative formula):

$$\hat{q}^{2\leftrightarrow 2}_{\mathrm{soft}} = 4\pi(\alpha_s^{\mathrm{soft}})^2\left(\frac{N_c}{3}+\frac{N_f}{3}\right) C_R T^3 \ln\left[1 + \frac{1}{4\pi\alpha_s^{\mathrm{soft}}\left(\frac{N_c}{3}+\frac{N_f}{3}\right)}\right]$$

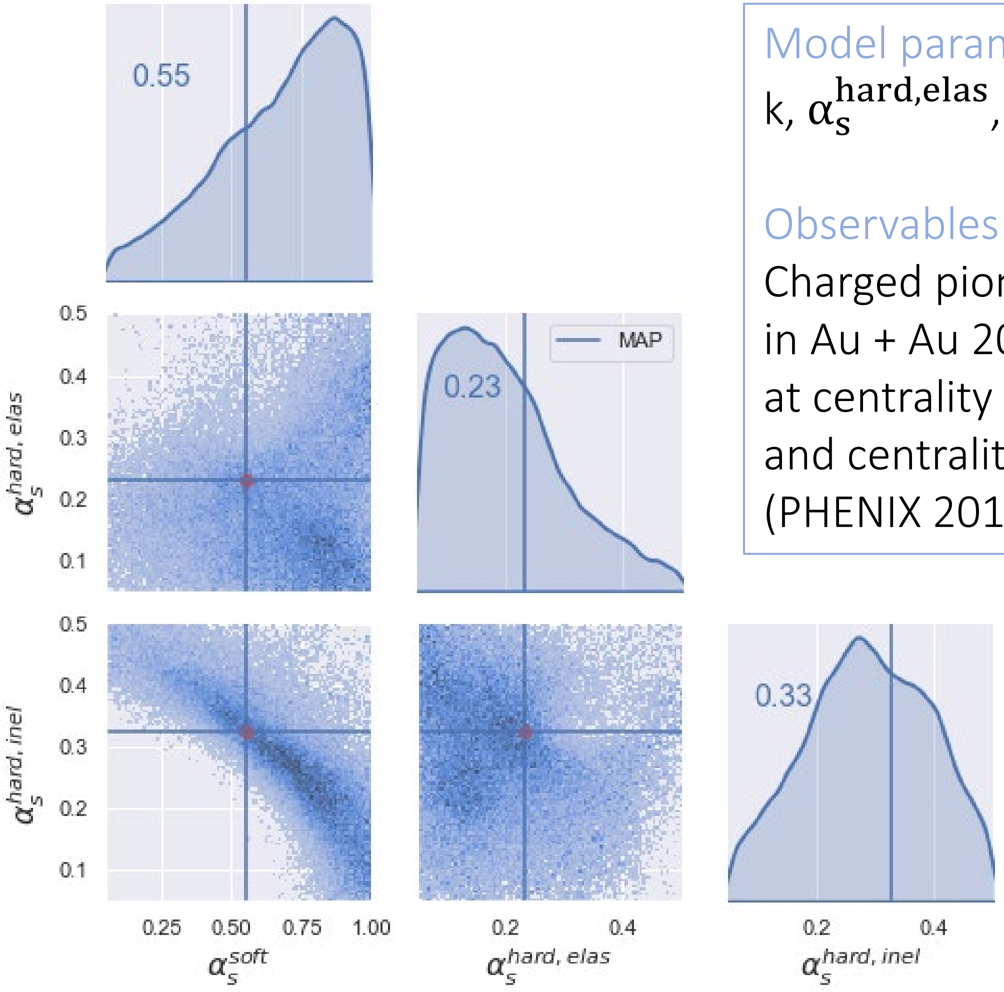
$$\hat{q}^{1\leftrightarrow 2}_{\mathrm{soft}} = \frac{4(2-\ln 2)}{\pi}\left(\alpha_s^{\mathrm{soft}}\right)^2 C_R C_A T^3$$

- Quantify the non-perturbative effects of the soft interactions



Data-driven analysis

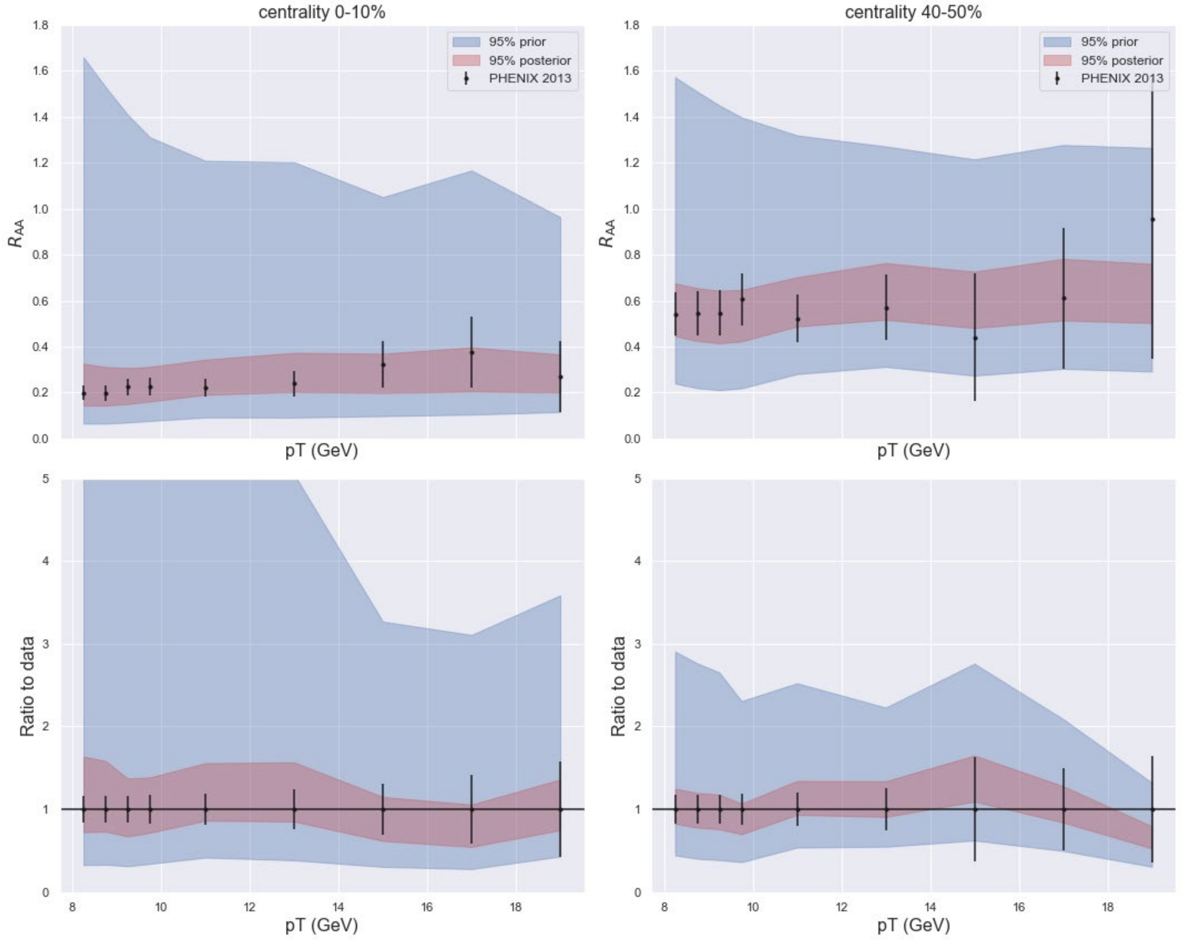
Posterior distribution of the model parameters



Model parameters:
k, $\alpha_s^{\text{hard,elas}}$, $\alpha_s^{\text{hard,inel}}$

Observables:
Charged pion R_{AA} in Au + Au 200 GeV at centrality 0-10% and centrality 40-50% (PHENIX 2013*)

Validate the observables using Maximum a Posteriori (MAP) estimation of the model parameters



*Adare, Andrew, et al. "Neutral pion production with respect to centrality and reaction plane in Au+ Au collisions at $\sqrt{s_{NN}}$= 200 GeV." *Physical Review C* 87.3 (2013): 034911.