UNIVERSITY OF BERGEN

Constraining jet quenching models in heavy-ion collisions using Bayesian Inference

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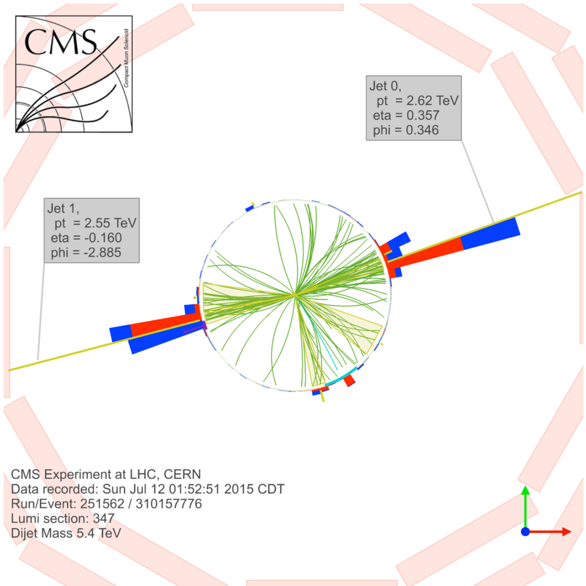
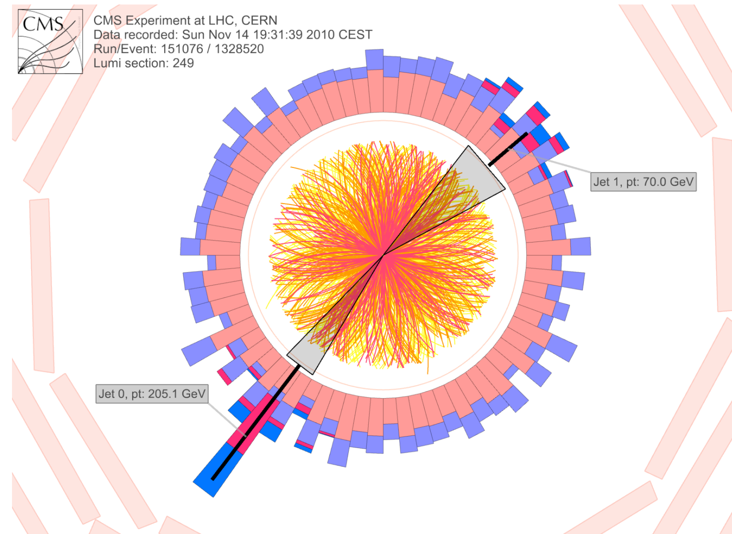
Jet quenching in heavy-ion collisions

pp event



AA event



$$\left(\begin{array}{c}\textbf{AA}\\\textbf{collision}\end{array}\right) \neq \mathbf{A} \times \left(\begin{array}{c}\textbf{pp}\\\textbf{collision}\end{array}\right)$$

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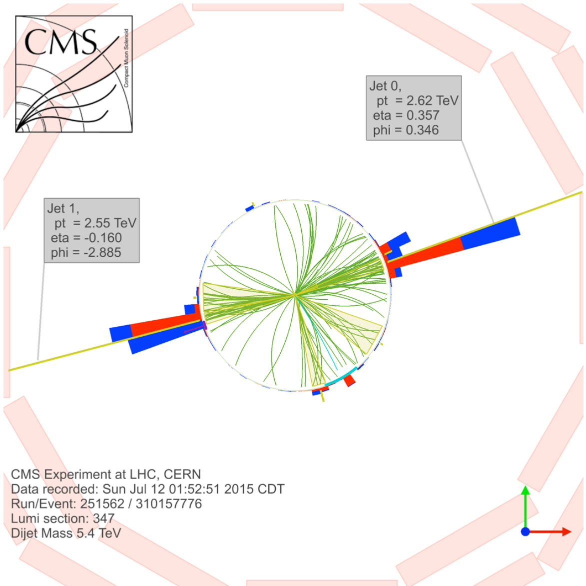

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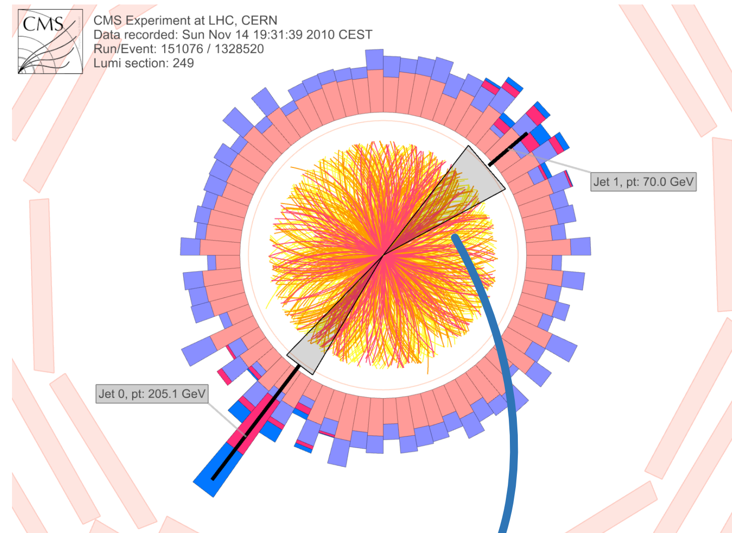
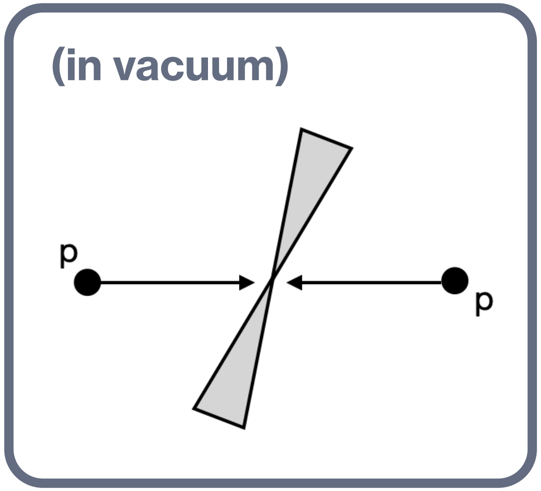


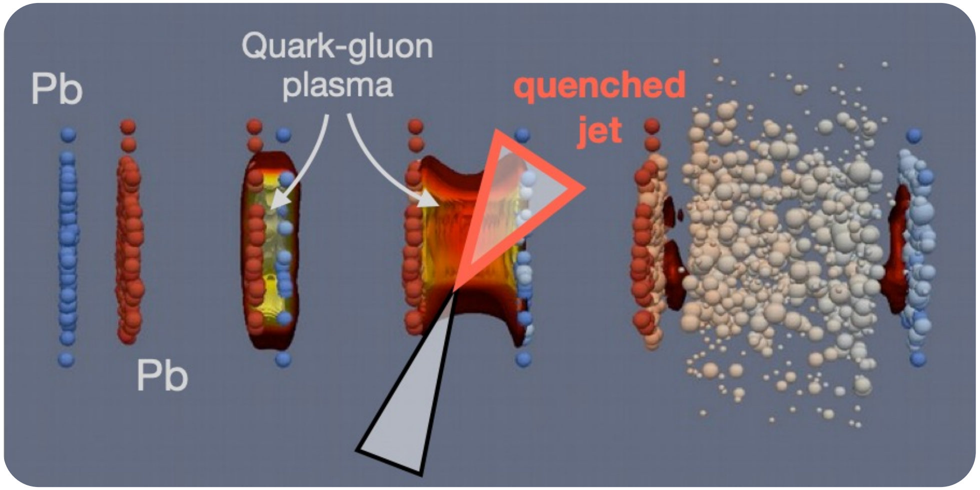
$$\left(\begin{matrix}\textbf{AA}\\ \textbf{collision}\end{matrix}\right) \neq \textbf{A} \times \left(\begin{matrix}\textbf{pp}\\ \textbf{collision}\end{matrix}\right)$$

Quenched jet:

- modification of the transverse energy balance
- modification of jet internal structure
- suppresion of the jet yields

Jet energy loss distribution and factorisation





from MADAI collaboration, Hannah Petersen and Jonah Bernhard

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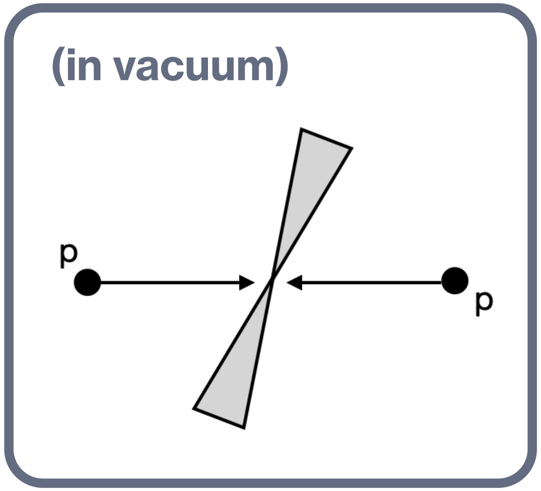

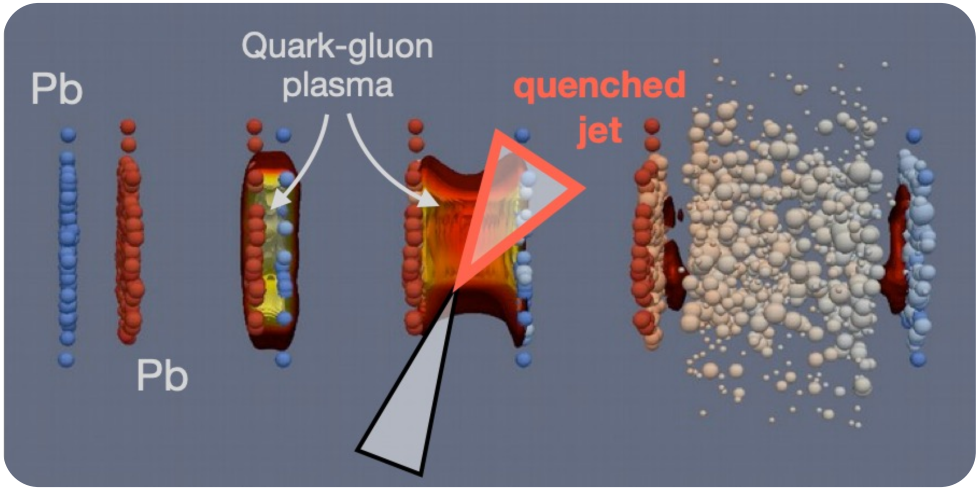

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Jets in medium:

- **Quark gluon plasma (QGP)** is created in the heavy-ion collision
- Jet created by hard process within QGP probes the medium
- Medium properties can be retrieved by studying jet quenching

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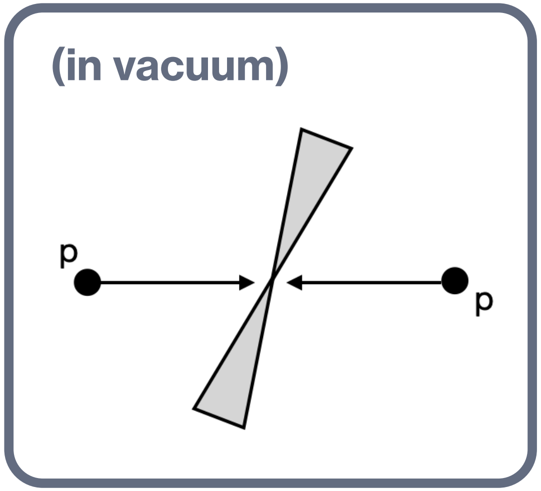

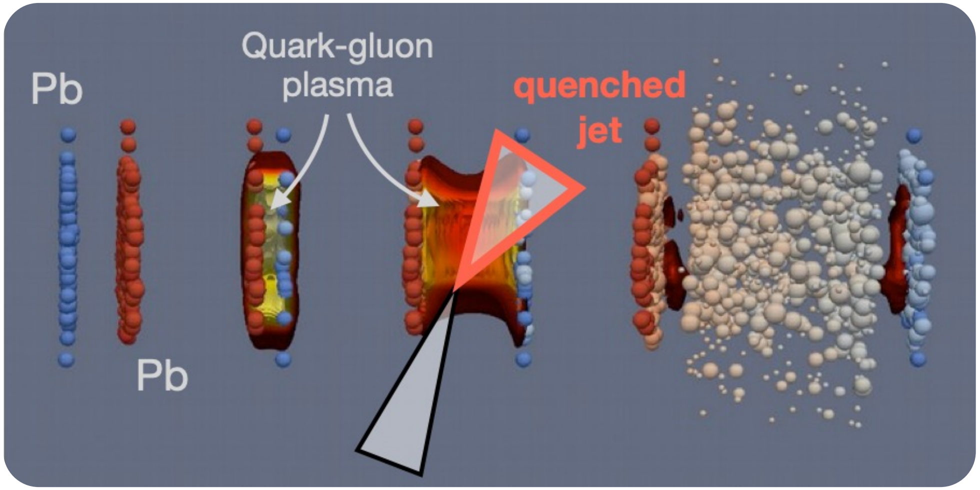

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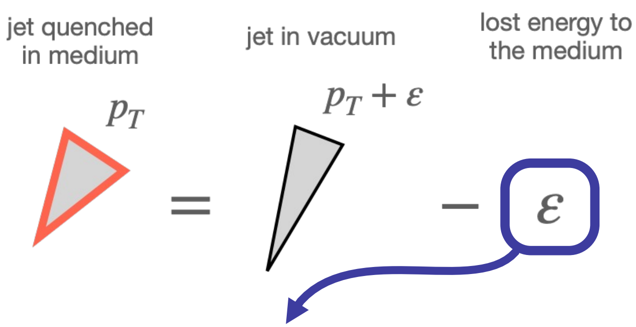
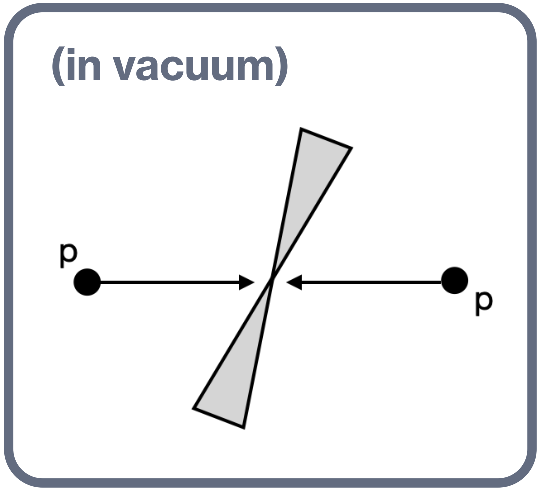
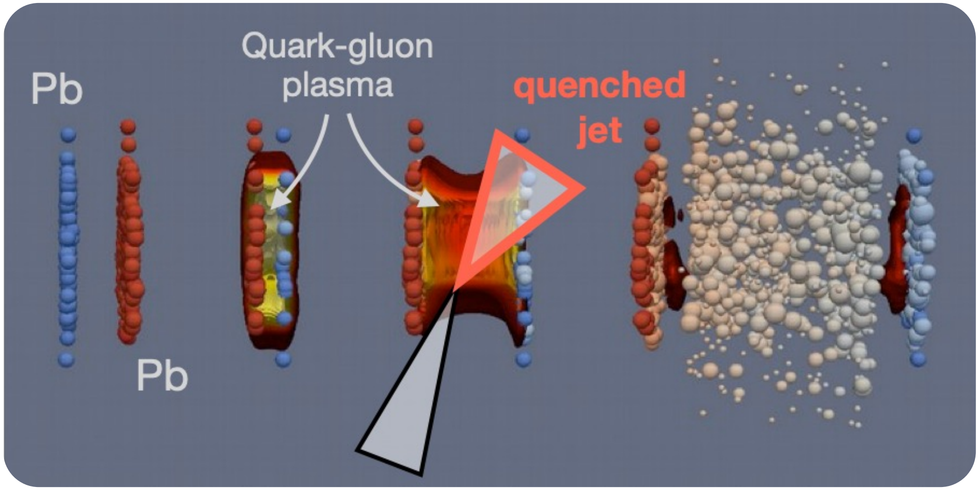


given by $D(\varepsilon)$

jet energy loss distribution

Jet energy loss distribution and factorisation





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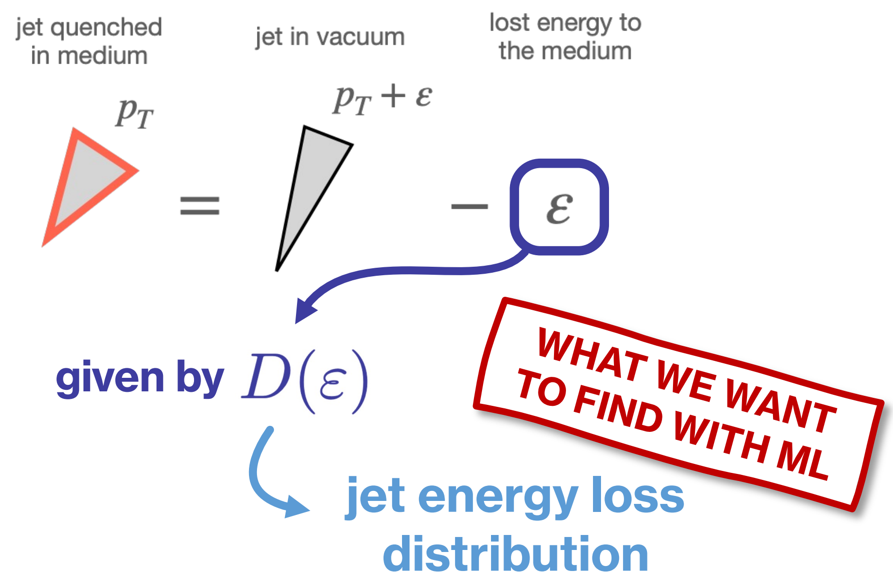
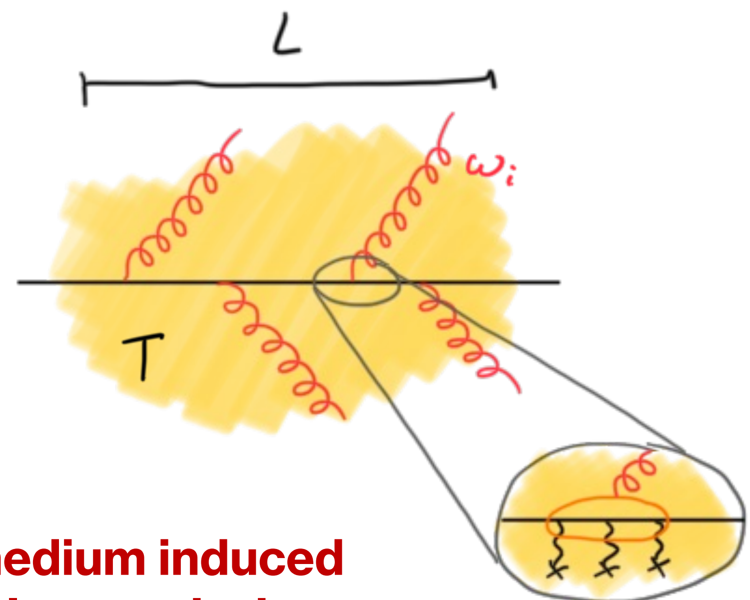


One parton through the medium

The energy loss distribution via medium induced gluon emissions of a hard parton can be computed from the theory side [Arleo 2002, Baier 2001]

$$D(\epsilon) = \sum_{n=0}^{\infty} \frac{1}{n!} \left[\prod_{i=1}^{n} \int d\omega_i \frac{dI(\omega_i)}{d\omega} \right] \delta\left(\epsilon - \sum_{i=1}^{n} \omega_i\right) \cdot \exp\left[- \int_0^{+\infty} d\omega \frac{dI(\omega)}{d\omega} \right]$$



medium induced gluon emission

n **number of radiated gluons**

ω_i **energy of emitted gluon** i

$\frac{\mathrm{d}I}{\mathrm{d}\omega}$ **medium-induced gluon spectrum**

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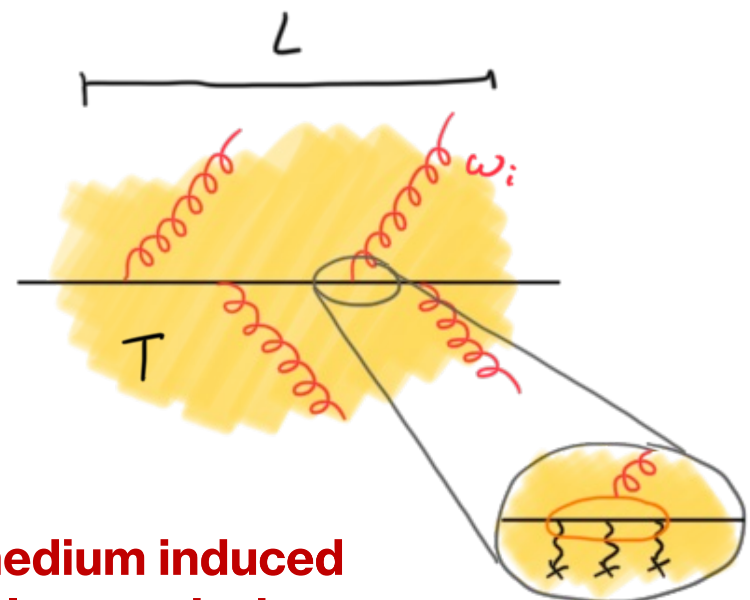

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- medium length: L
- transport coefficient: $\hat{q}(T)$
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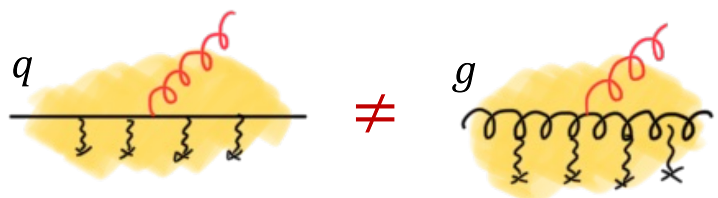

$$\langle \varepsilon \rangle_g = \frac{C_A}{C_F} \langle \varepsilon \rangle_q$$

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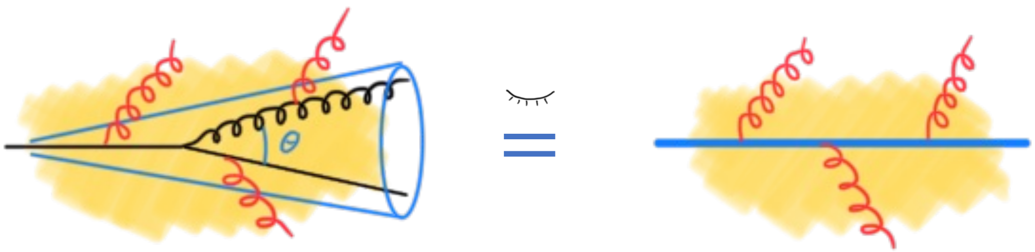
A jet through the medium

When a ”vacuum” splitting happens:

- If splitting anlge is smaller than medium resolution angle



splitting is not resolved

(medium does not see the splitting)

$$D_{\text{jet}}(\varepsilon) = D_q(\varepsilon)$$

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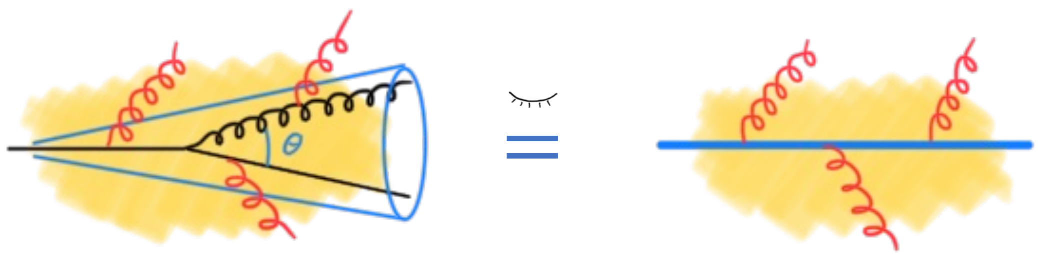

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$$D_{\text{jet}}(\varepsilon) = D_q(\varepsilon) \otimes D_{\text{MR}}$$

medium response

A jet through the medium

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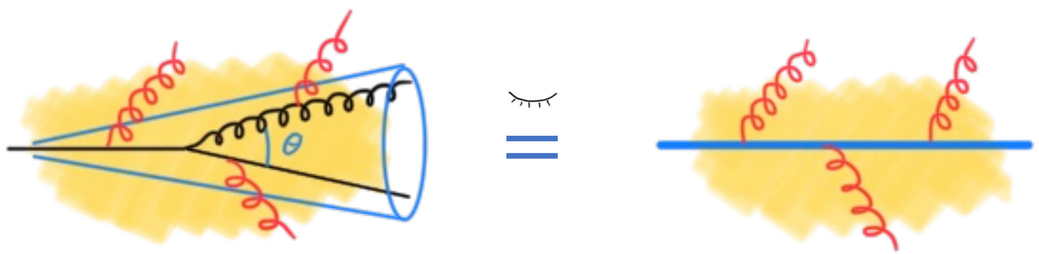

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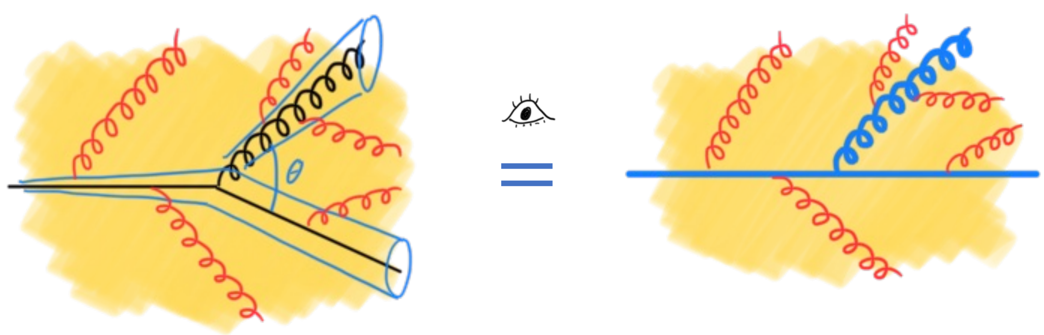
medium response

- If splitting angle is greater than medium resolution angle



splitting <u>is</u> resolved

$$D_{\text{jet}}(\varepsilon) = D_q(\varepsilon_q) \otimes D_g(\varepsilon_g) \otimes D_{\text{MR}}$$

with $\varepsilon = \varepsilon_q + \varepsilon_g$

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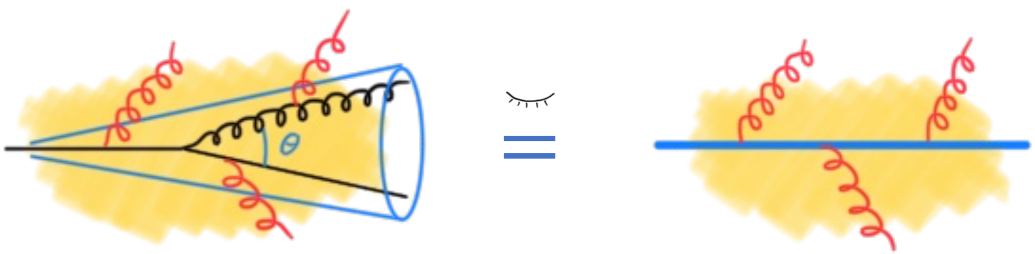

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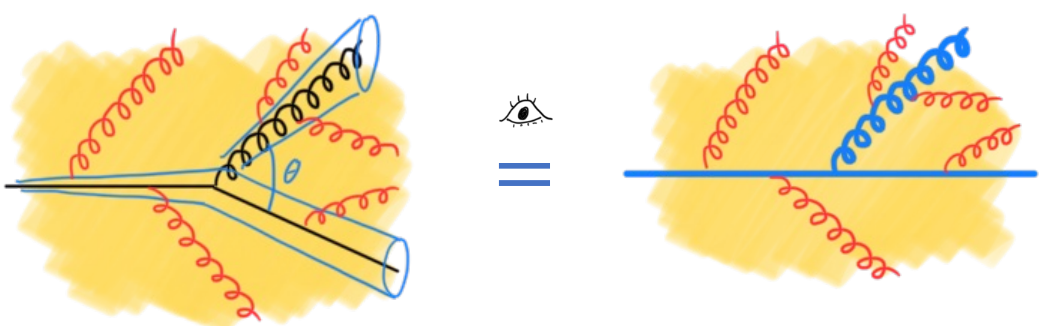

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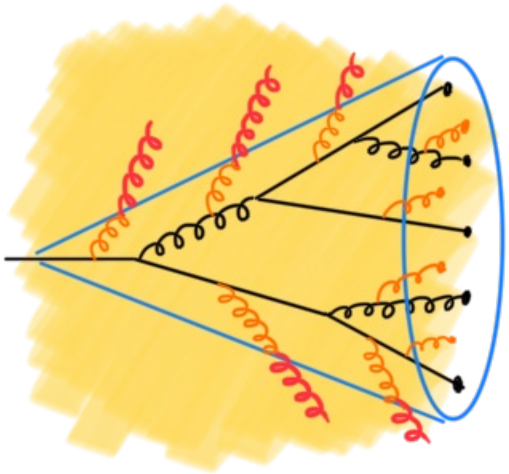
$D(\varepsilon)$ is sensitive to the jet substructure and medium response

Factorisation

What to keep in D(e) to achieve universality?

- has been done [arXiv:1808.05310]:

$$D(\varepsilon | C_R, \hat{q}(T), L, p_T, R) = D(\varepsilon)$$



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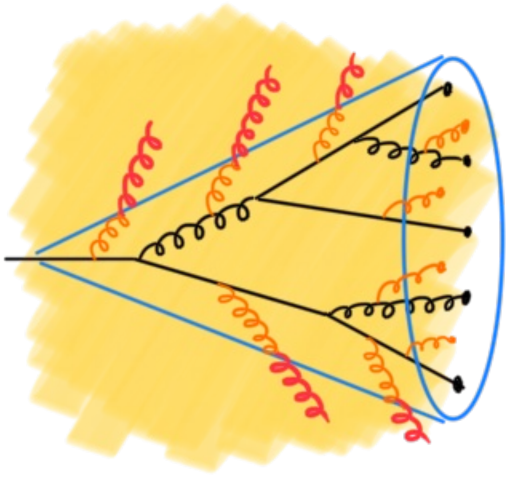

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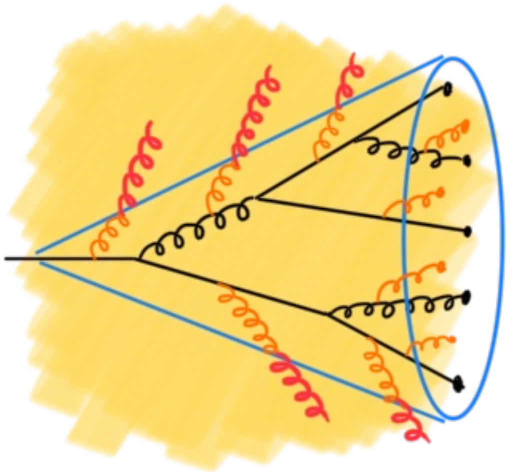

factorisation

$$\left.\frac{\mathrm{d}\sigma^{AA}}{\mathrm{d}p_T}\right|_{p_T} = \int_0^\infty \mathrm{d}\varepsilon \sum_{i=q,g} D_i(\varepsilon) \left.\frac{\mathrm{d}\sigma_i^{vac}}{\mathrm{d}p_T}\right|_{p_T+\varepsilon}$$

experimental data

theory (simulation) ((PYTHIA))

what we want

Modelling the jet energy loss

Proposed distribution:

Gamma distribution

$$D(\varepsilon) = \frac{\theta^{-\alpha}\varepsilon^{\alpha-1}e^{-\varepsilon/\theta}}{\Gamma(\alpha)}$$

parameters:

$$\theta = \langle\omega\rangle$$

$$\alpha = \langle n\rangle + 1$$

mean:

$$\langle\varepsilon\rangle = \alpha\theta$$

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Cons:

- more assumptions ⇒ more bias

Bayesian Inference

likelihood

experimental measurement

model parameters

$$\mathcal{L}\left(R_{AA}^{\mathrm{data}}(p_T)\middle|\theta,\delta\right) = \mathcal{N}\left(R_{AA}^{\mathrm{data}}(p_T)\middle|\mu = R_{AA}^{\mathrm{model}}(\theta, p_T), \sigma = \delta\cdot\sigma_{R_{AA}}\right)$$

extra parameter for extra containing power

BAYESIAN INFERENCE

priors

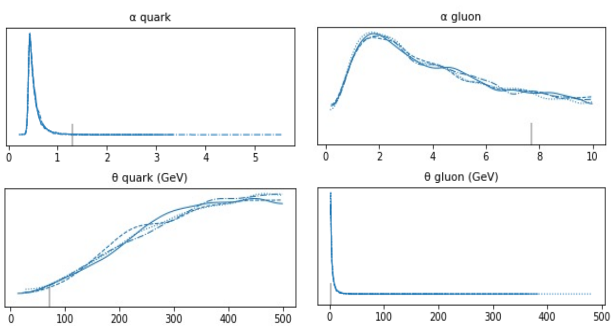
$$\alpha_{q,g} \sim \mathrm{Uniform}[0,10]$$

$$\theta_{q,g} \sim \mathrm{Uniform}[0,500]\ \ (\mathrm{GeV})$$

$$\delta_{q,g} \sim \mathrm{Uniform}[0,1]$$

note to self: improve these

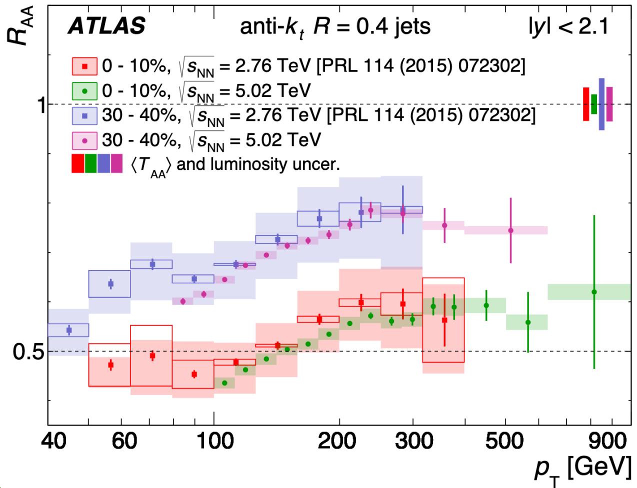
posteriors



Markov Chain Monte Carlo (MCMC)

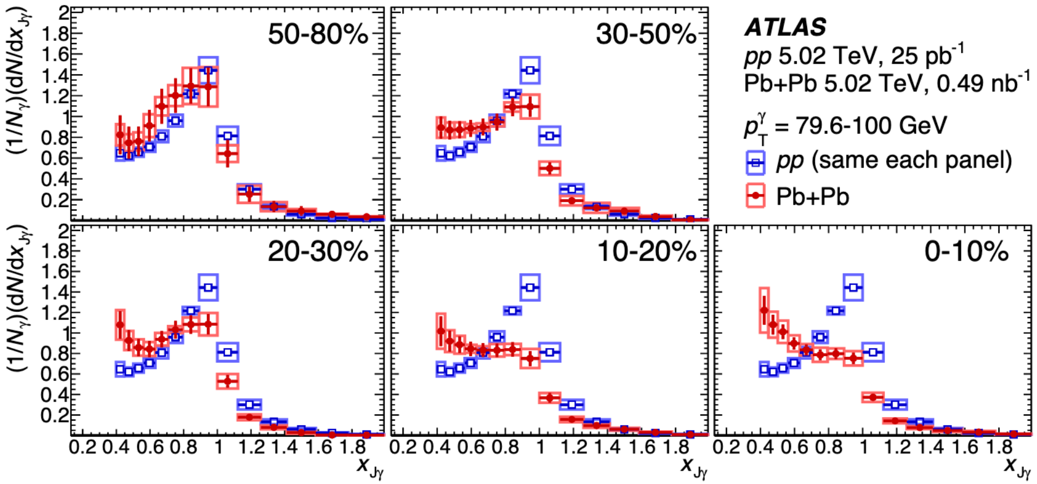
Available experimental data

inclusive jet events



[arXiv:1805.05635]

photon-tagged jet events



[arXiv:1809.07280]

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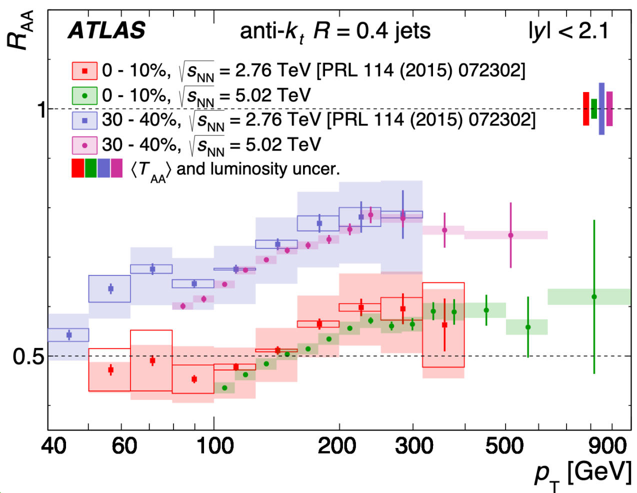

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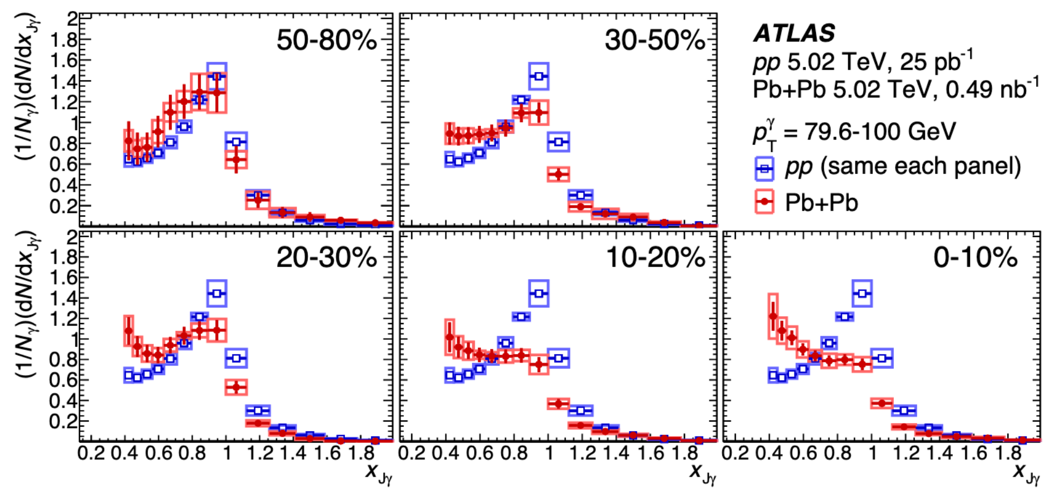

[arXiv:1809.07280]

- different center of mass energies
- different centralities
- rapidity cuts

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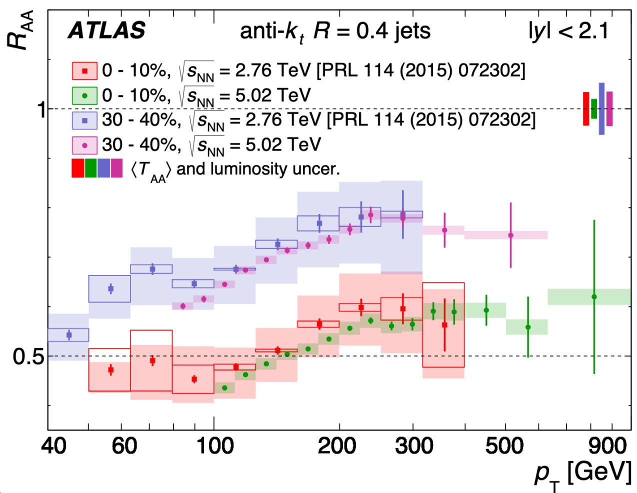

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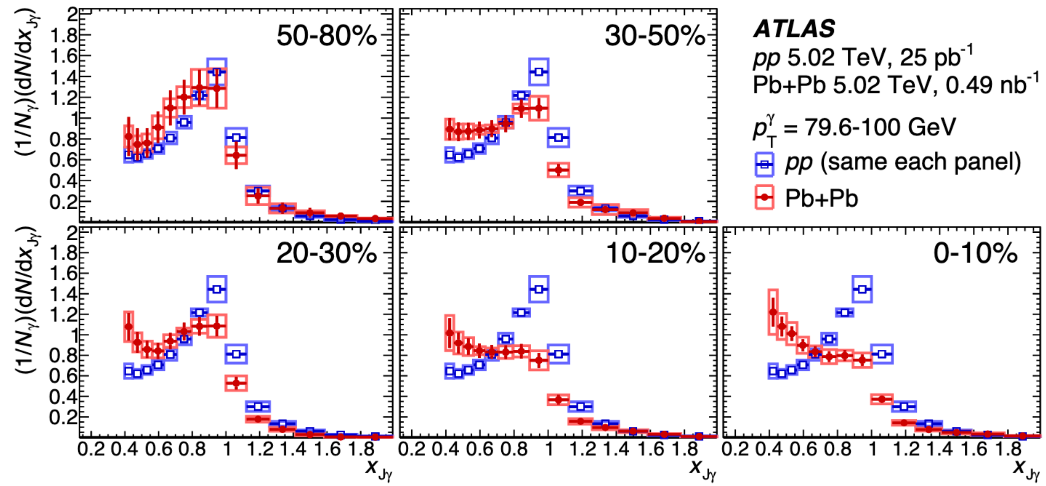
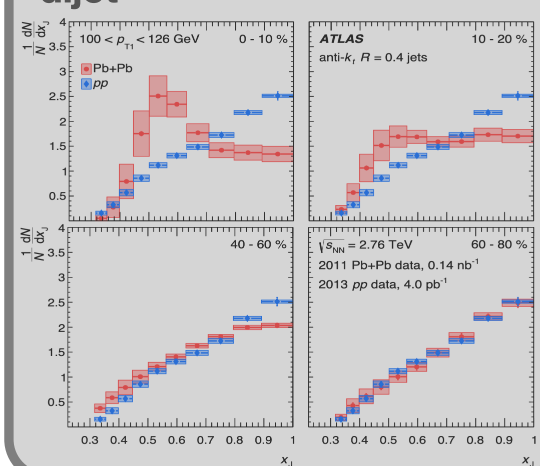


[arXiv:1809.07280]

dijet



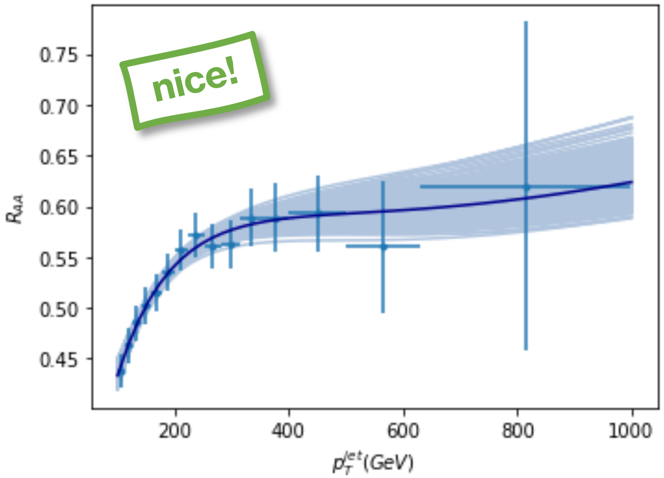
[arXiv: 1706.09363]

- \+ different center of mass energies
- \+ different centralities
- \+ rapidity cuts
- \+ **dijets**

Results (very provisory)

Just using inclusive jet data:

inclusive jet data



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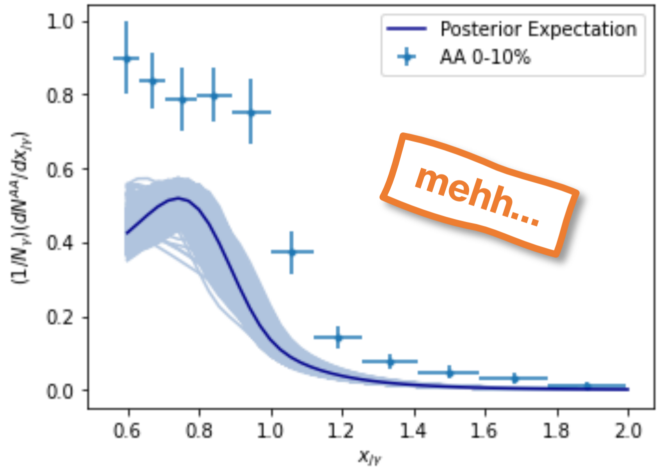

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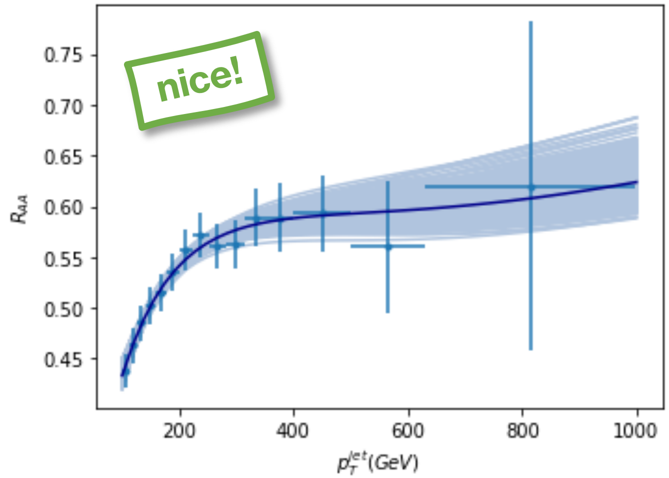

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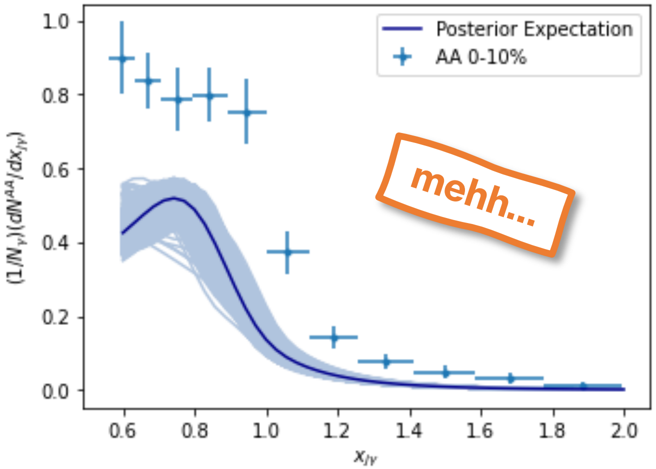
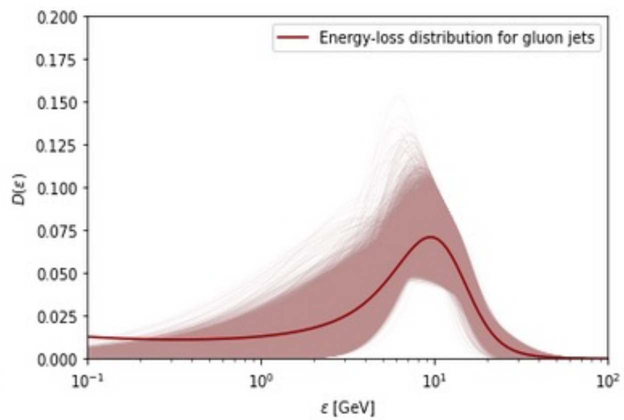
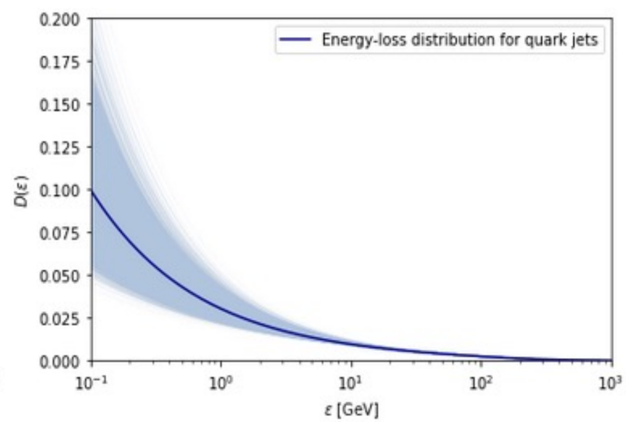


$D(\varepsilon)$ from posterior distributions





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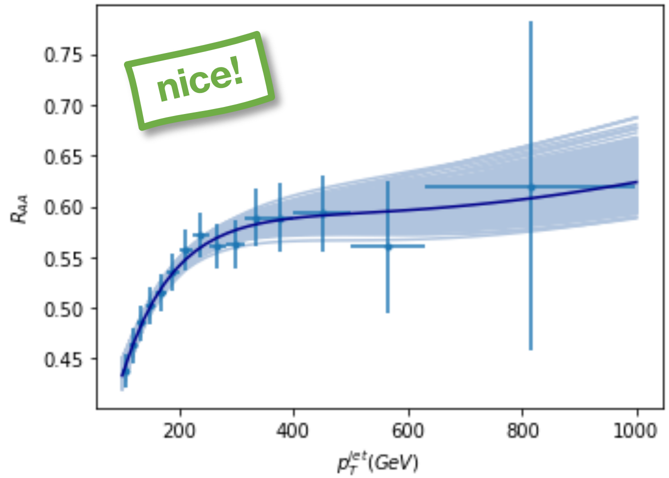

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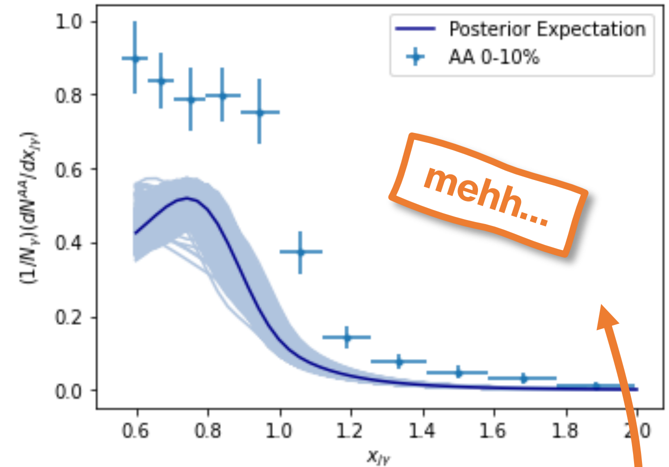

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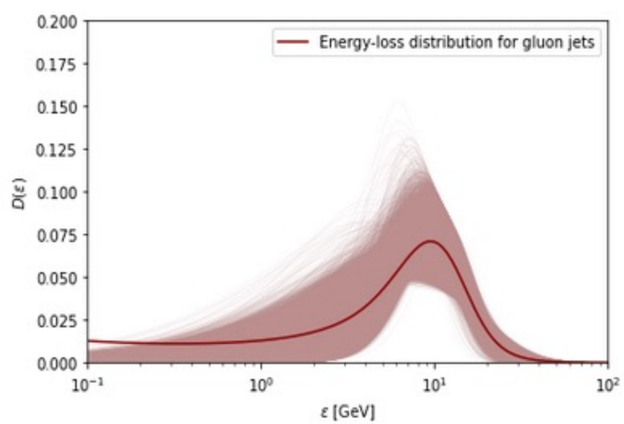
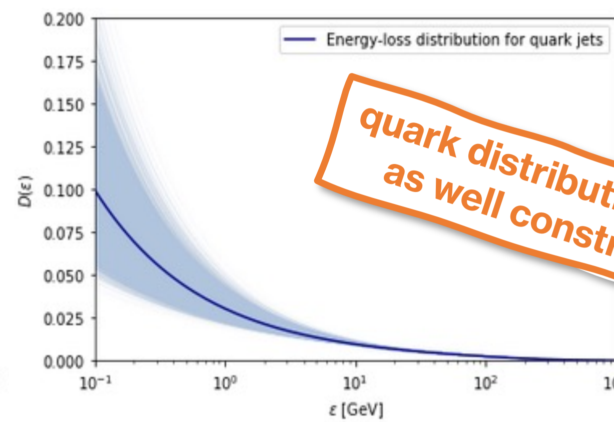


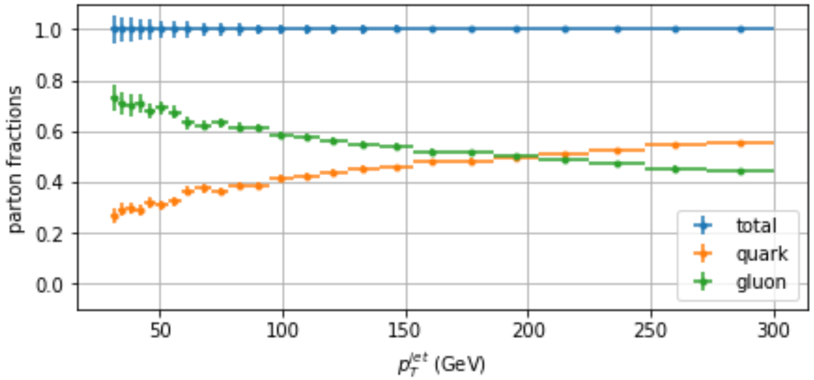


quark distribution is not as well constrained

Results (very provisory)

Adding photon-tagged data

inclusive jet events



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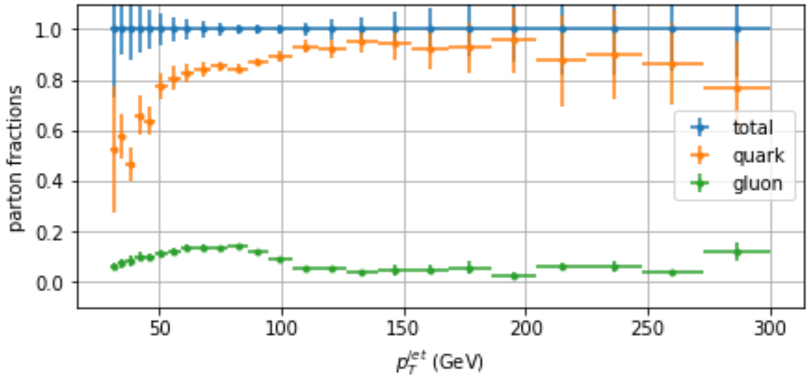

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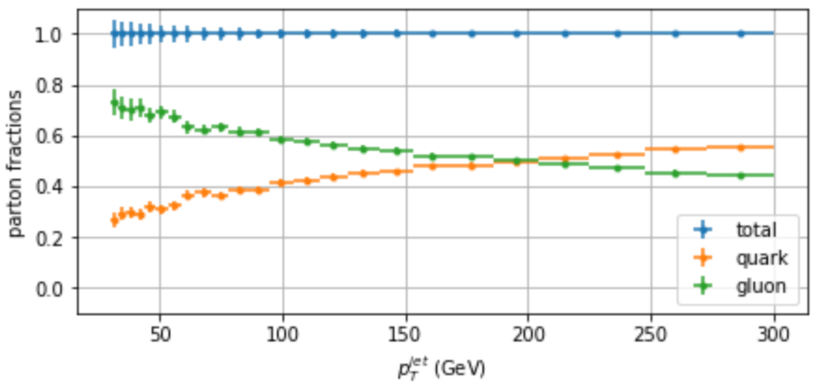

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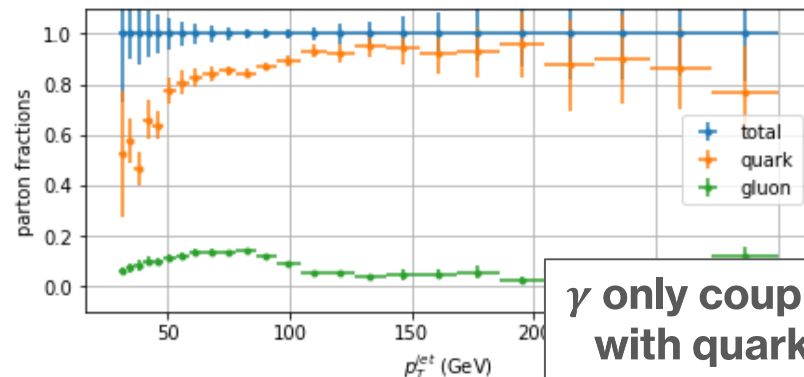


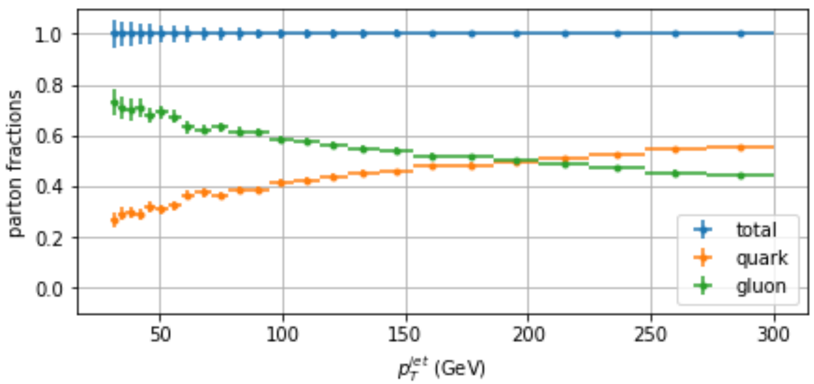
γ only couples with quarks

stronger constraint to quark distribution

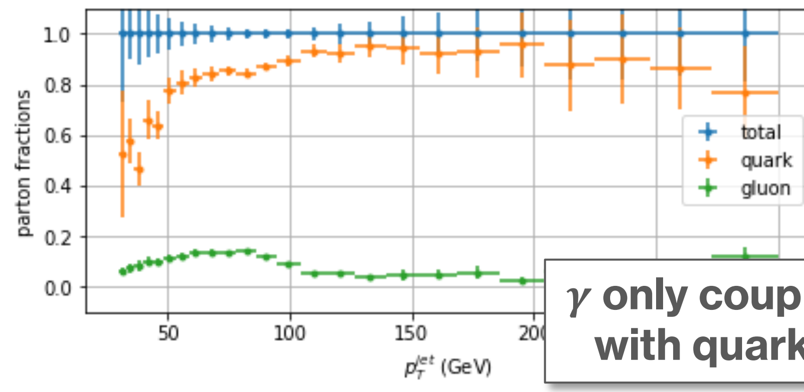
Results (very provisory)

Adding photon-tagged data

inclusive jet events

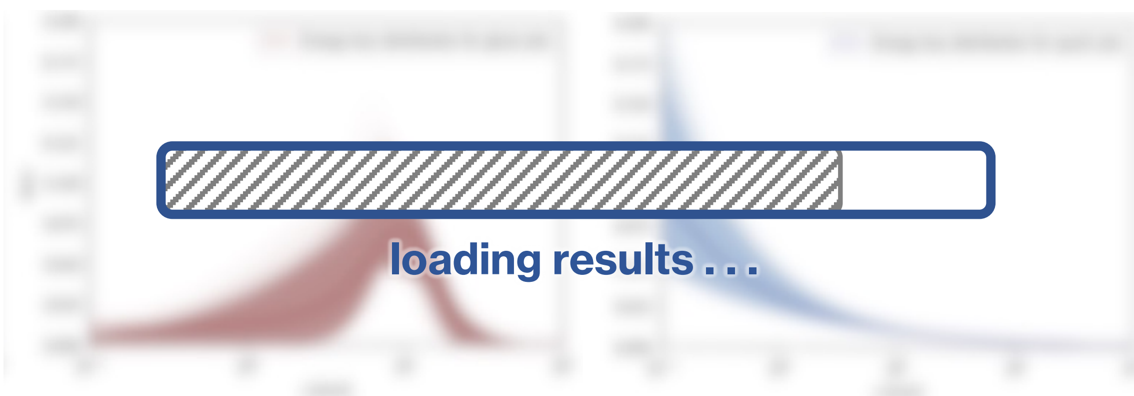


photon-tagged jet events



γ **only couples with quarks**

stronger constraint to quark distribution



Outlook and next steps

- The quark gluon plasma (QGP) is formed in heavy-ion collisions;
- Jets produced via hard scatterings probe the QGP;
- The jet energy loss distribution contains information about jet quenching: jet substructure and medium response
- Machine learning can help us with this task.

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Next steps:

- Add different measurements to better learn and validate the model;
- Test the model generalization by using the extracted energy loss distributions to predict other kind of jet observables;
- Address the uncertainties from the simulation data and parameterisation choice
- Move deeper in ML to find a less biased approach.