UNIVERSITY OF BERGEN

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

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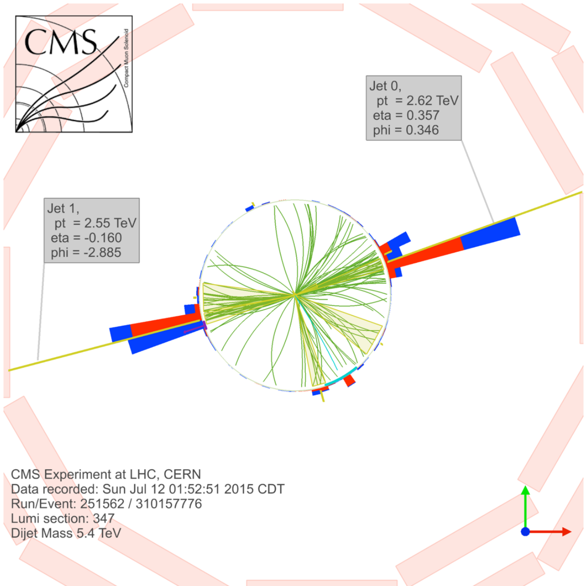
Dec. 2nd, 2022

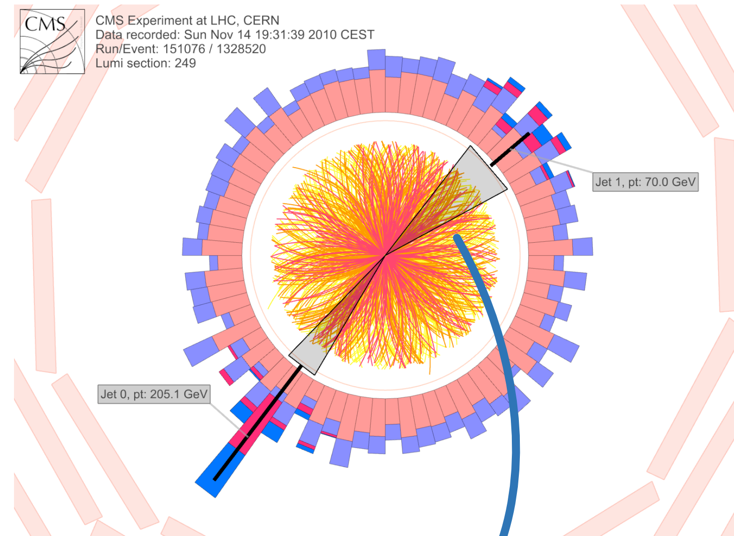
QCD@LHC 2022

Jet quenching in heavy-ion collisions

pp event



AA event

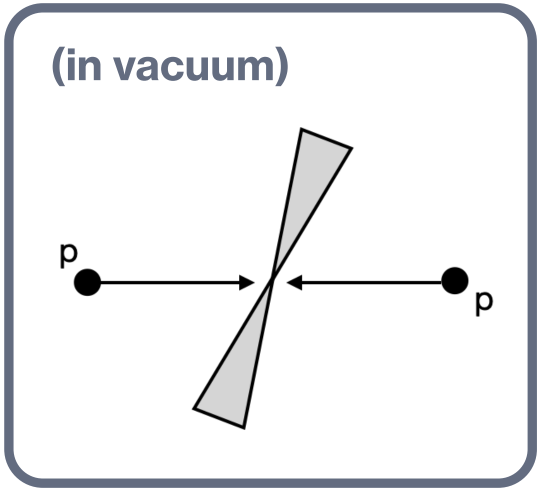


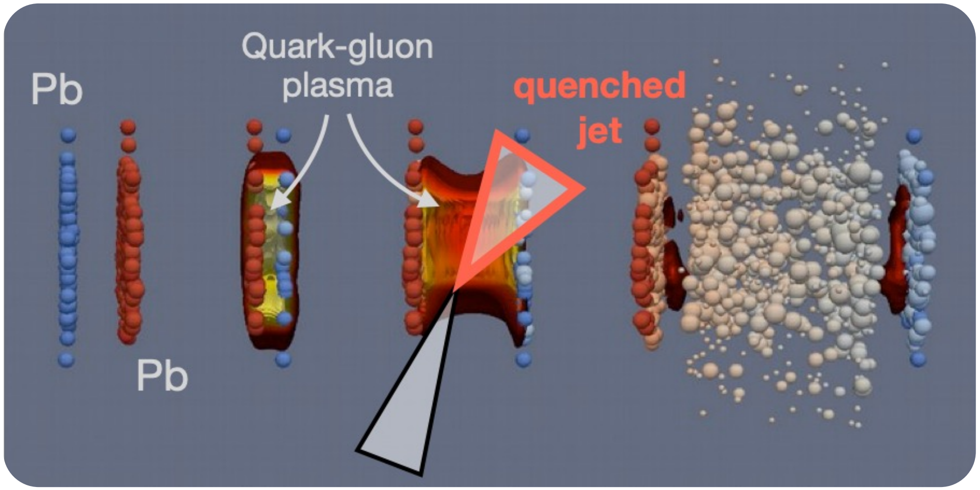
$$\left(\begin{array}{c}\textbf{AA}\\ \textbf{collision}\end{array}\right) \neq \textbf{A} \times \left(\begin{array}{c}\textbf{pp}\\ \textbf{collision}\end{array}\right)$$

Quenched jet:

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

Jet energy loss distribution

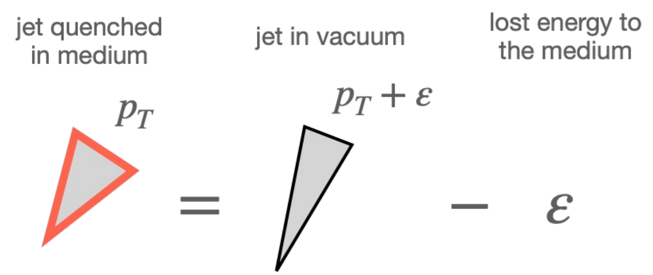




from MADAI collaboration, Hannah Petersen and Jonah Bernhard

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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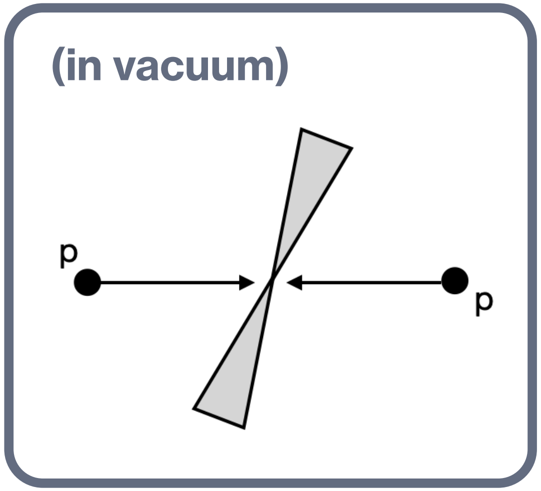

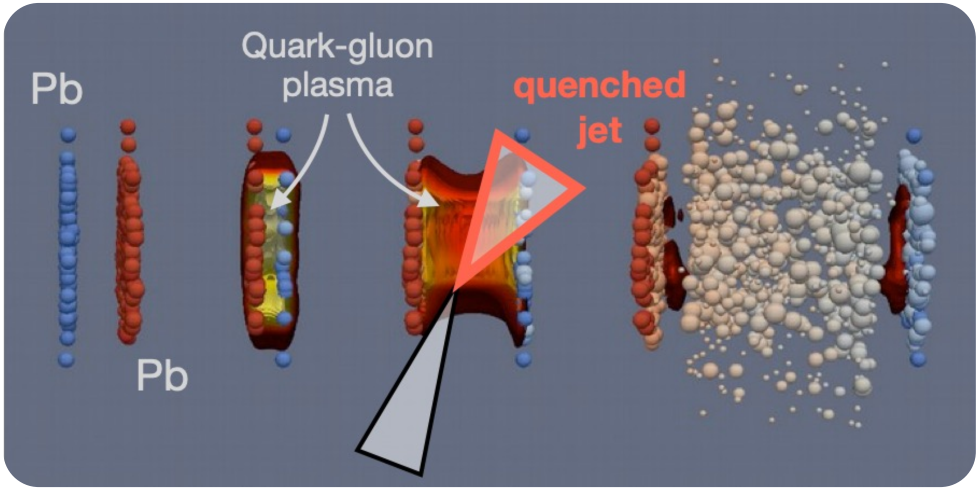

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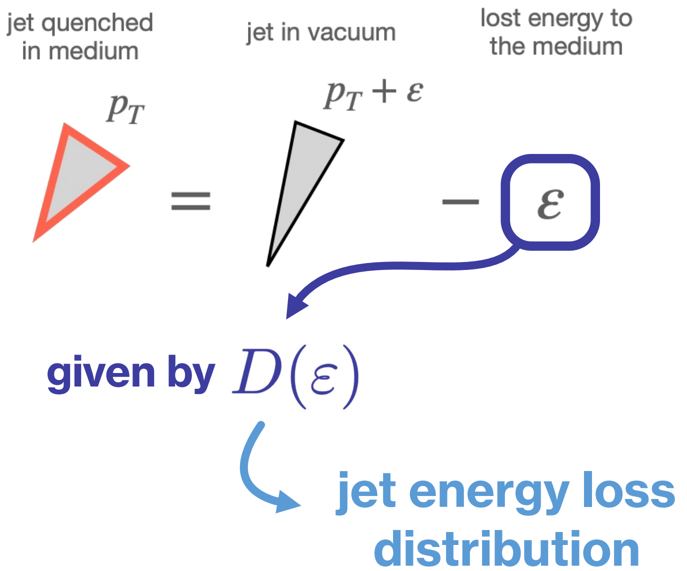

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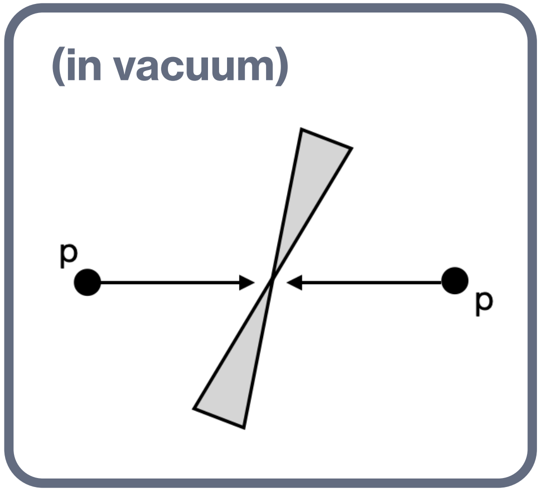

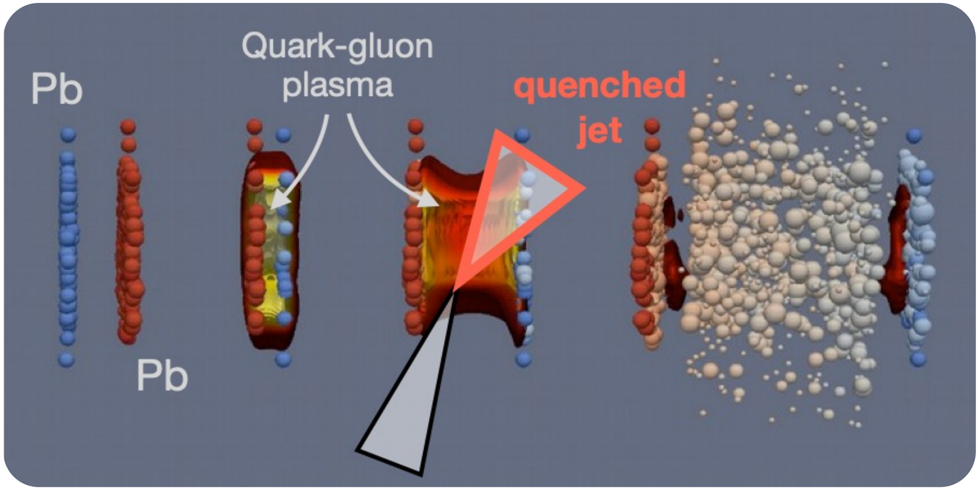

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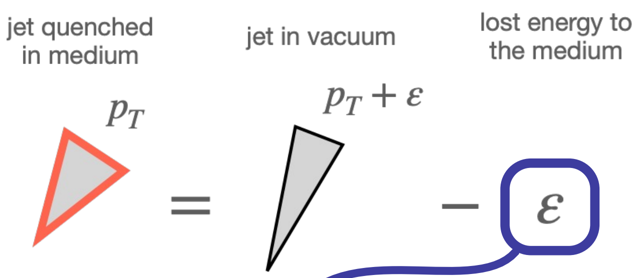


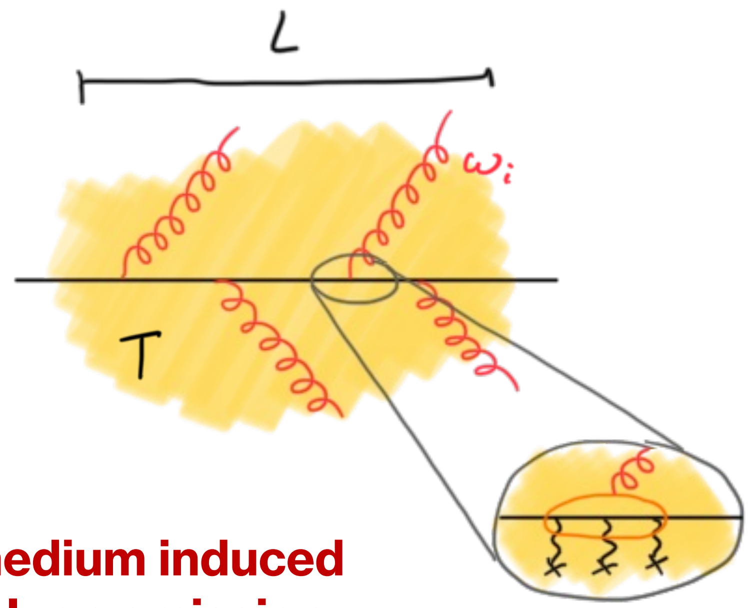
given by $D(\varepsilon)$

jet energy loss distribution

WE WANT IT DATA DRIVEN

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]



medium induced gluon emission

In the one parton through the medium, it depends on:

- 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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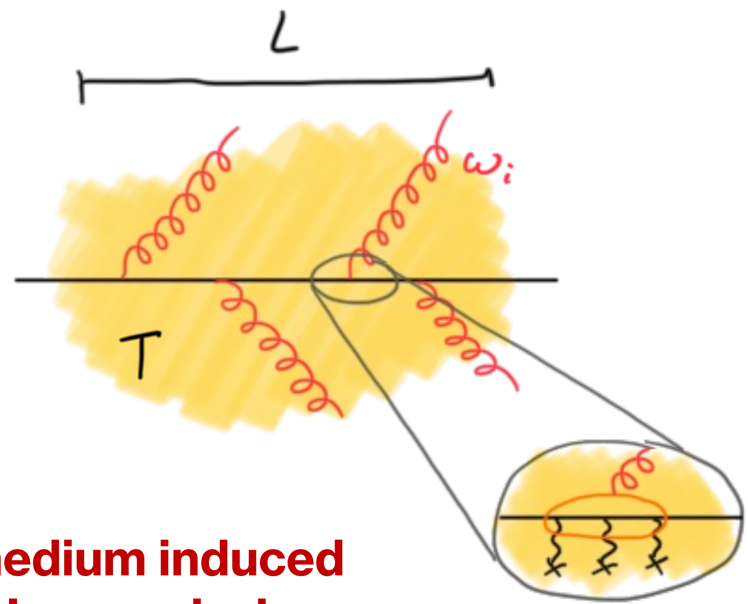

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Depends on:

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

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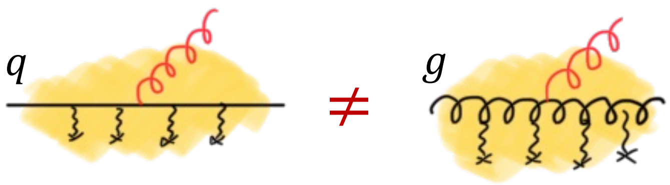

Casimir scaling

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

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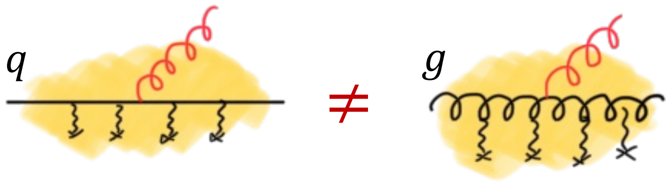

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Does not depend on:

- p_T^{jet}

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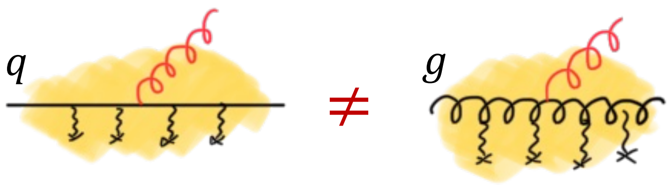

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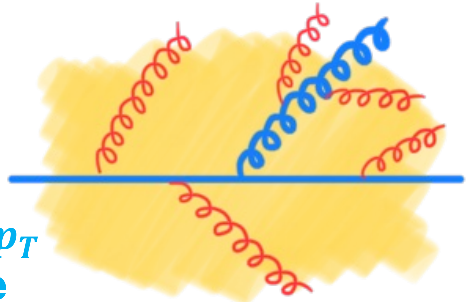
A jet through the medium



now we have p_T dependence

In the one parton through the medium, it depends on:

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Does not depend on:

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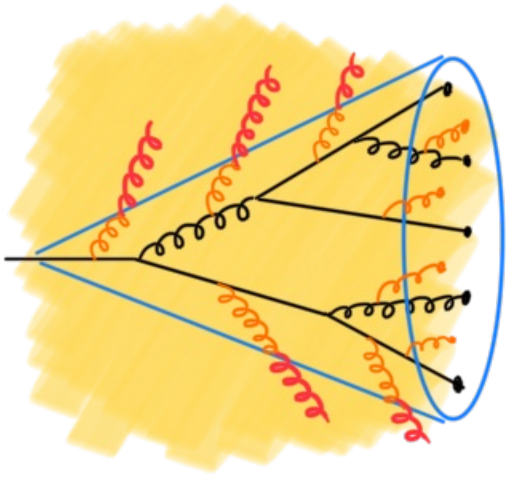
Factorization

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

- has been done [arXiv:1808.05310]:

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



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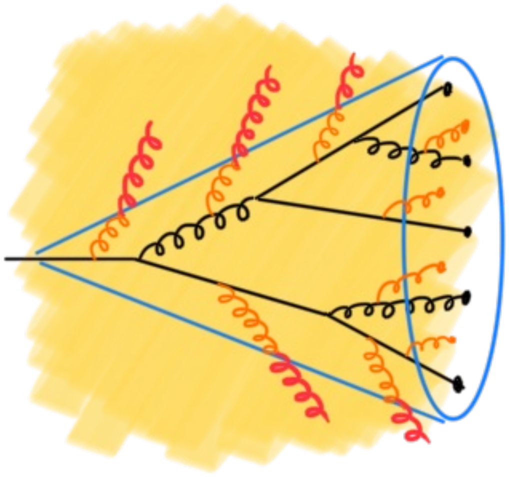
- adding color dependence:

$$D_i(\varepsilon|p_T, \underline{C_R}, \hat{q}(T), L, R), \quad i = q, g$$



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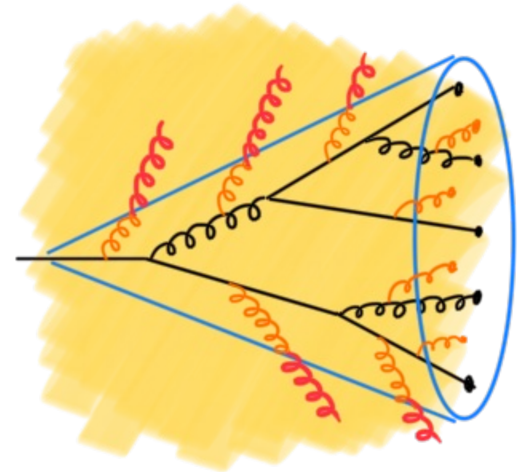


factorization

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

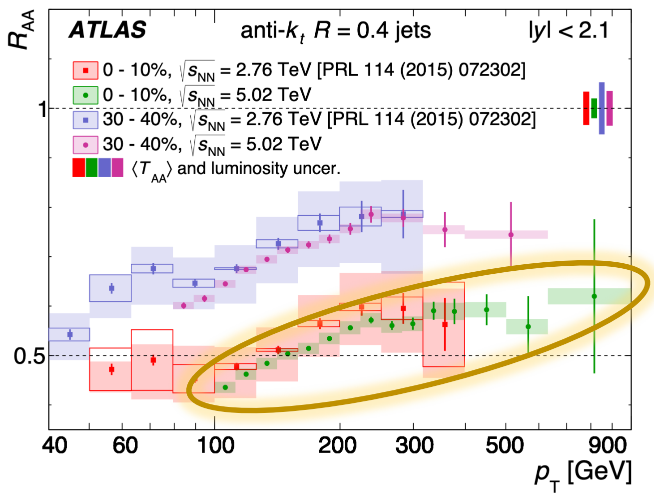
experimental data

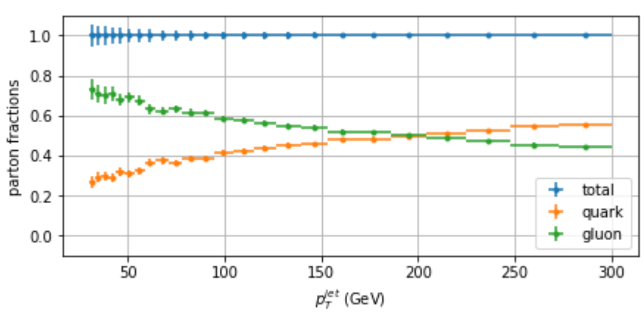
theory (simulation) ((PYTHIA))

what we want

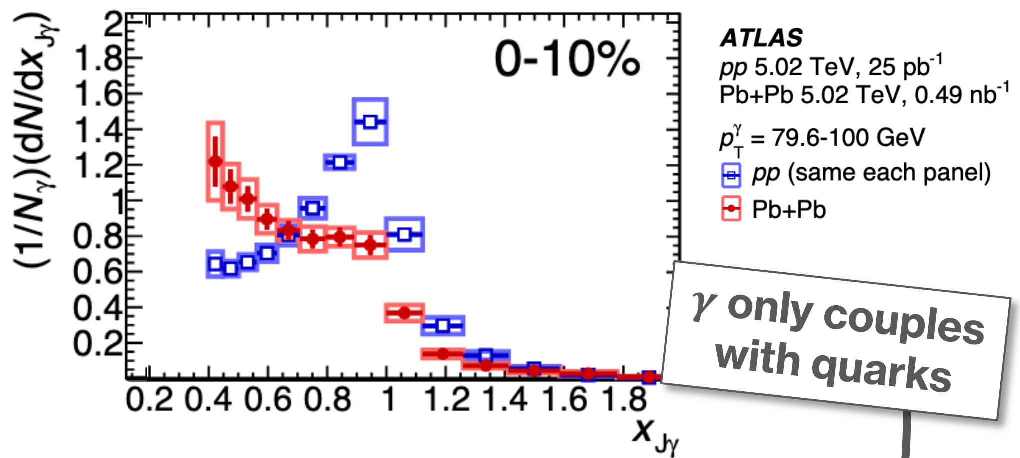
Available experimental data

inclusive jet events [arXiv:1805.05635]

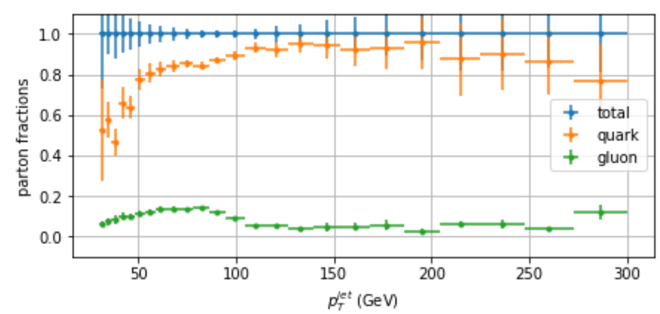




photon-tagged jet events [arXiv:1809.07280]



γ only couples with quarks



different parton fractions

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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Pros:

- interepretable parameters
- convolution of gamma dist. is still a gamma dist.

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Cons:

- more assumptions $\Rightarrow$ more bias

Modelling the jet energy loss

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Different models:

No colour or p_T dependence:

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

Only colour dependence:

$$\langle \varepsilon \rangle_i = \alpha_i \theta_i \;, \quad i = q, g$$

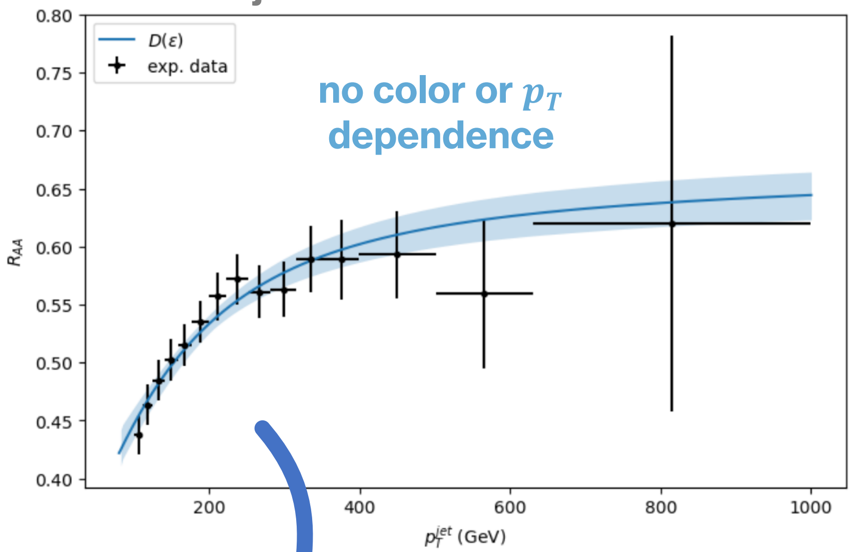
Colour + p_T dependence:

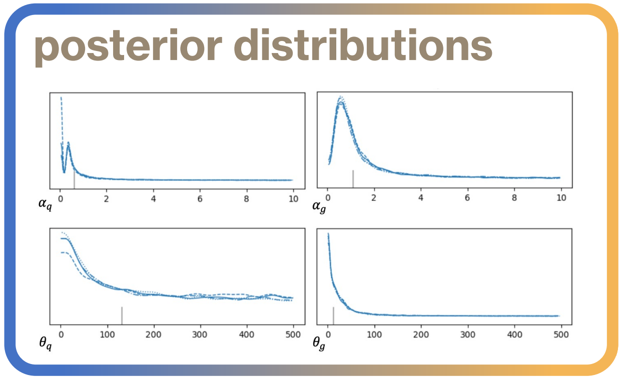
$$\langle \varepsilon \rangle_i = \alpha_i \theta_i \ln p_T$$

Results (very preliminary)

From the posterior distributions for the parameters, we can resconstruct the R_{AA} as well as predict other observables.

inclusive jet observable





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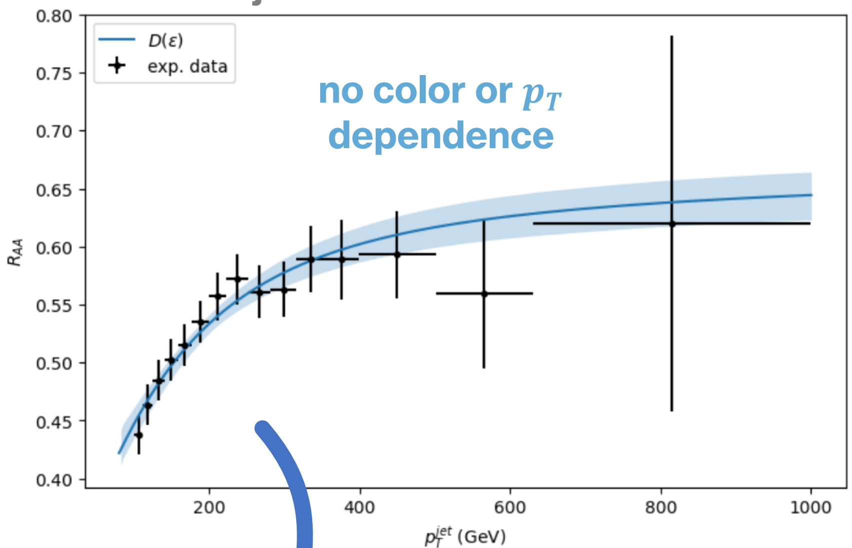
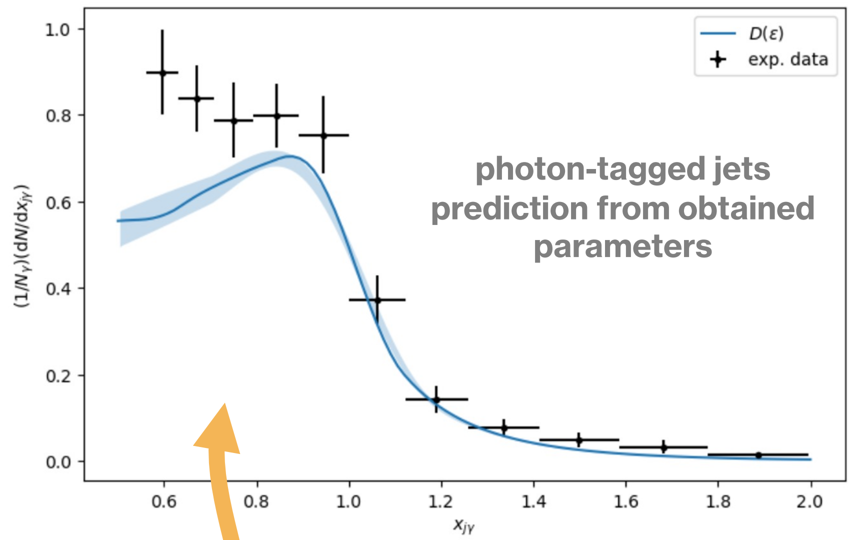
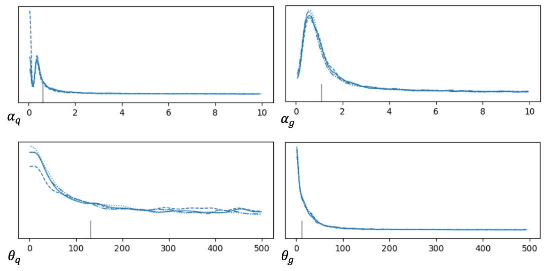


photon-tagged jet observable



posterior distributions



plug them into new observable

(which was not fitted)

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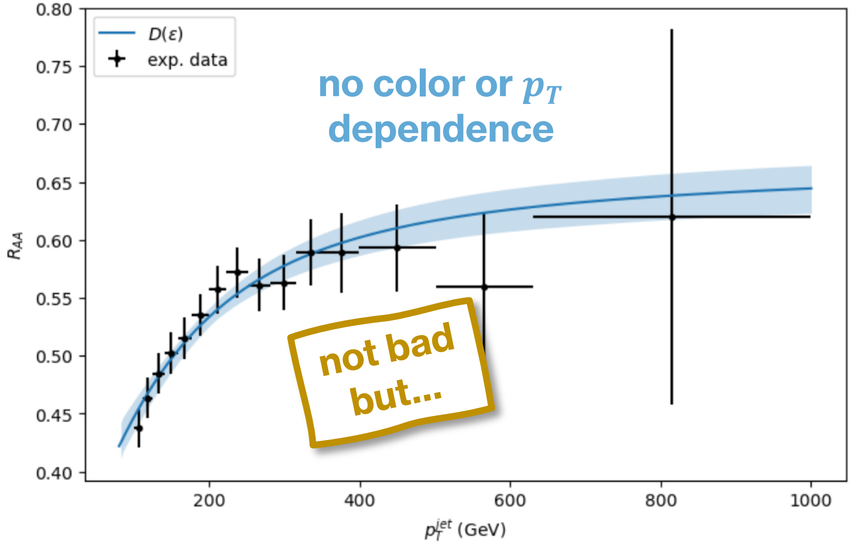

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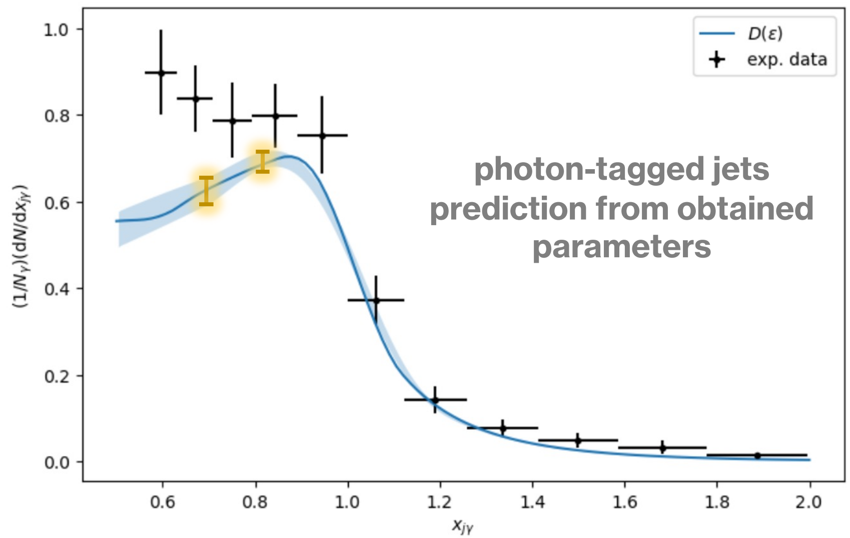

$D(\varepsilon)$ **with <u>no</u> color or** p_T **dependence** (2 parameters)

- high bias
- low variance

$\Longrightarrow$ **underfitting**

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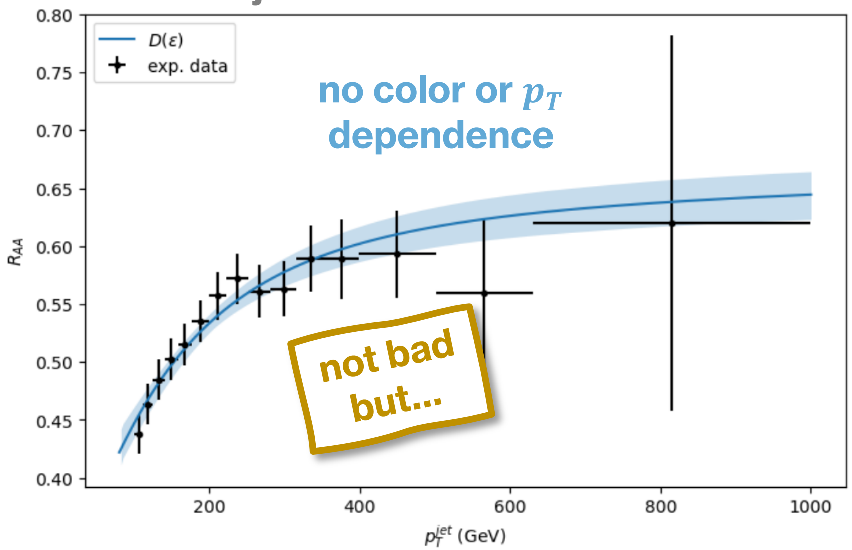

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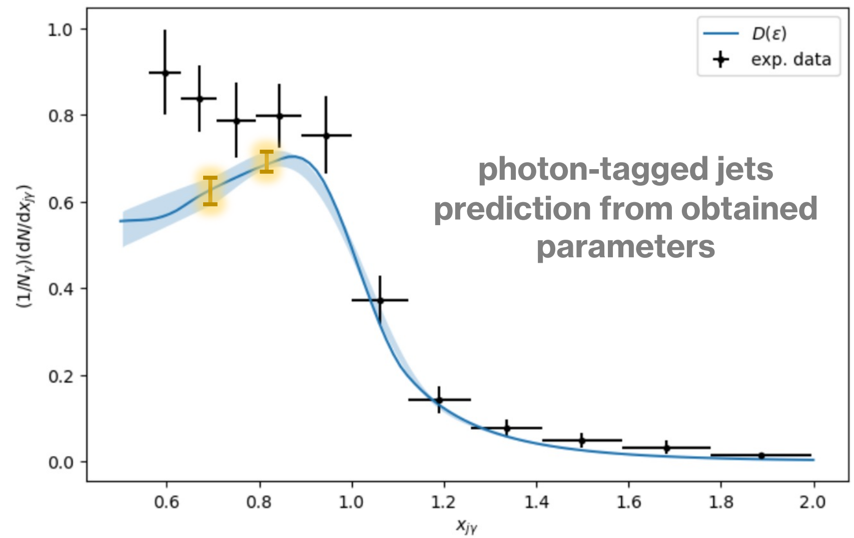

$D(\varepsilon)$ **with no color or p_T dependence** (2 parameters)

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$\Longrightarrow$ **underfitting**

model needs to be improved

- **color dependence**
- **color and p_T dependence**

Modelling the jet energy loss

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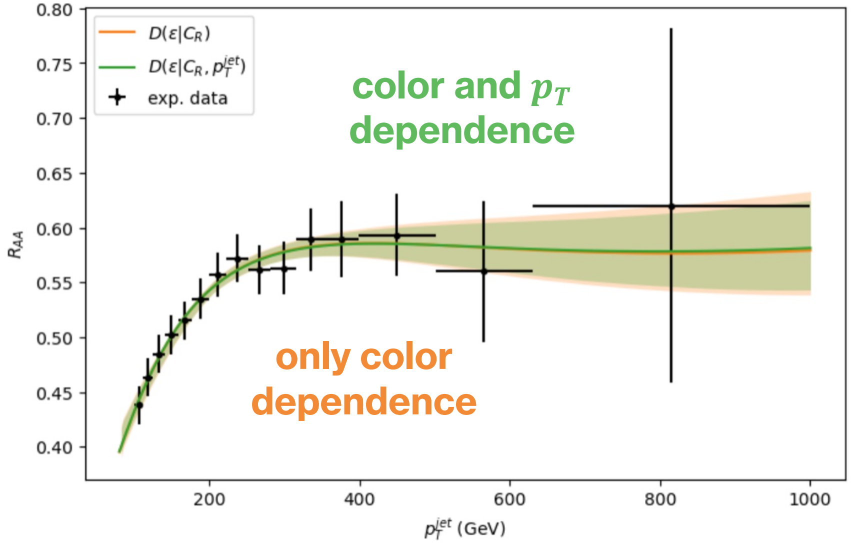

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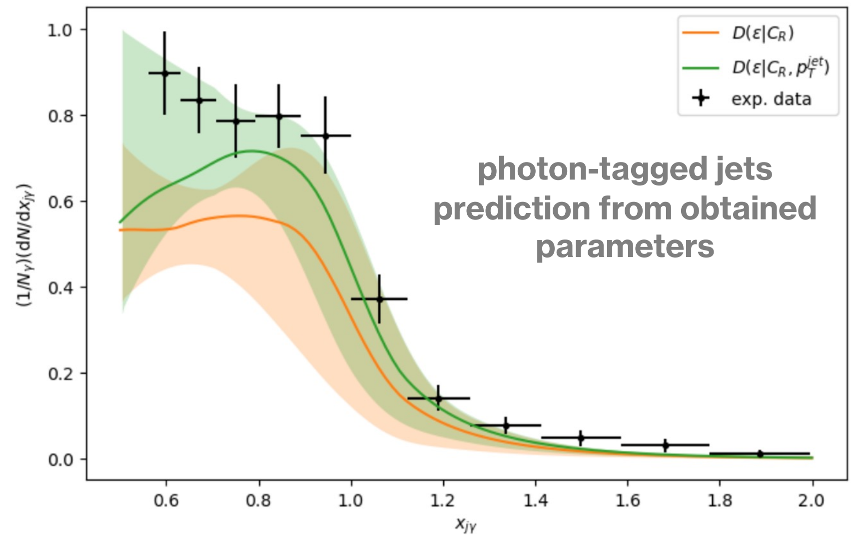


$D_i(\varepsilon)$ with color dependence
(4 parameters)

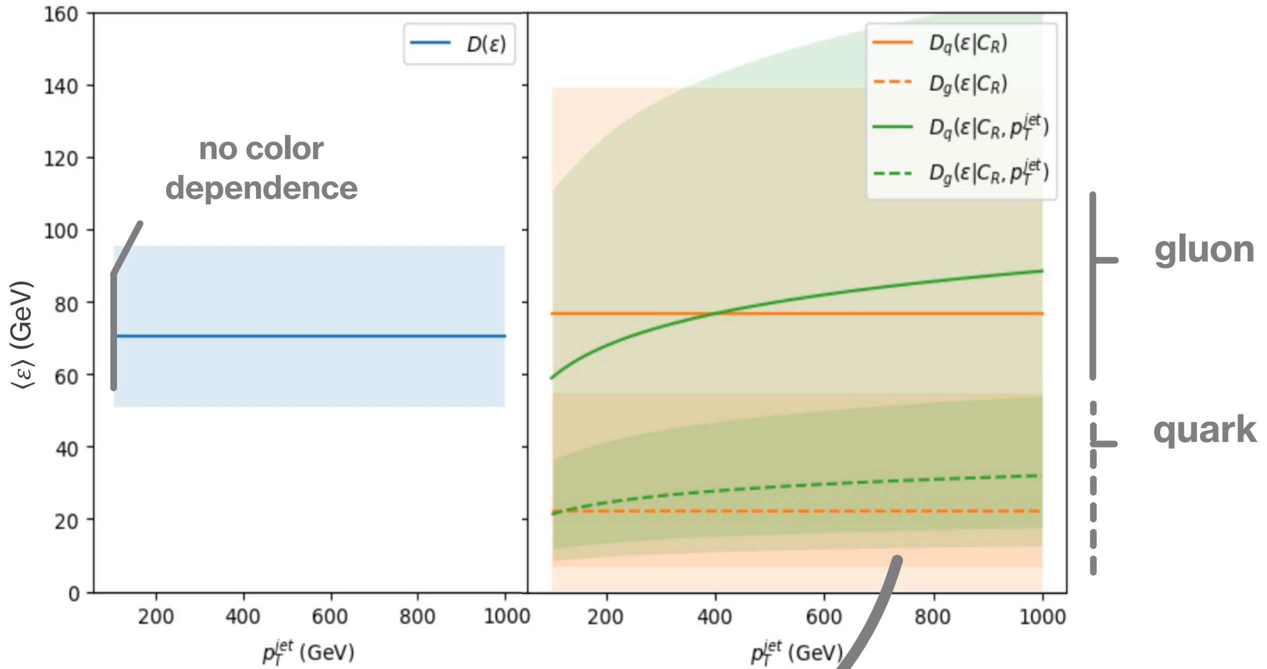
- better agreement for inclusive jet data
- lost in the phton-tagged data

$D_i(\varepsilon)$ with color and p_T dependence
(4 parameters + p_T)

- same agreement for inclusive data
- agreement with phton-tagged data recovered

Results (very preliminary)

From the posterior distributions for the parameters, we can also calculate the **mean energy loss** $\langle \varepsilon \rangle$

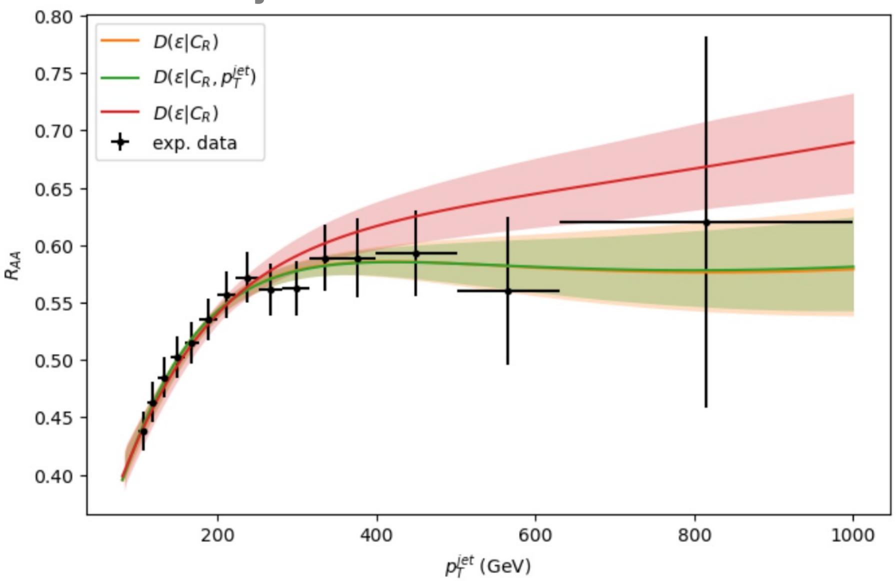


The inclusive data does not dintinguish clearly quarks and gluons (posteriors dist. overlap)

Results (very preliminary)

What if we **fit to inclusive + photon-tagged data (only color dependence)**?

inclusive jet observable



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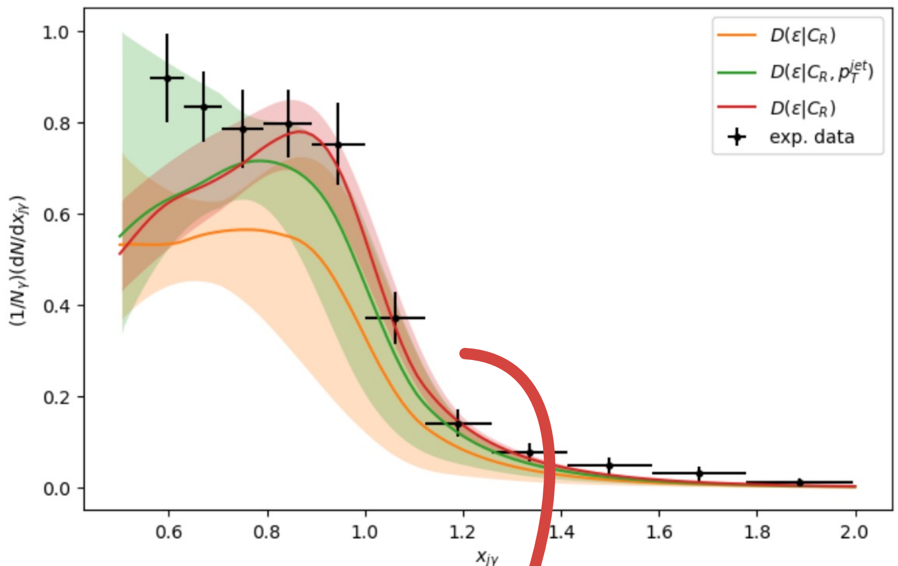
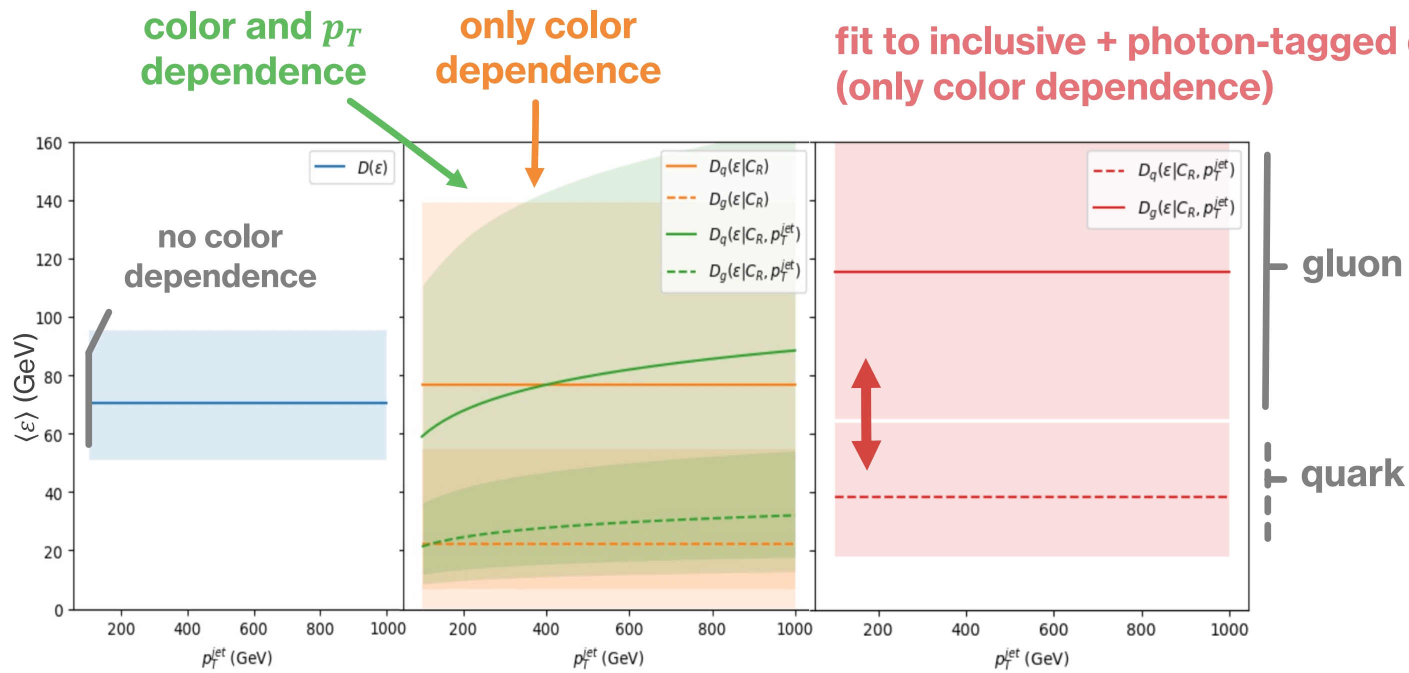


Posterior distribution for photon-tagged jets improves without worsening the inclusive jets (as expected)

Results (very preliminary)



Adding the photon-tagged data gives more information on quark and gluon jet energy loss

- energy loss of quarks and gluons are distinguished

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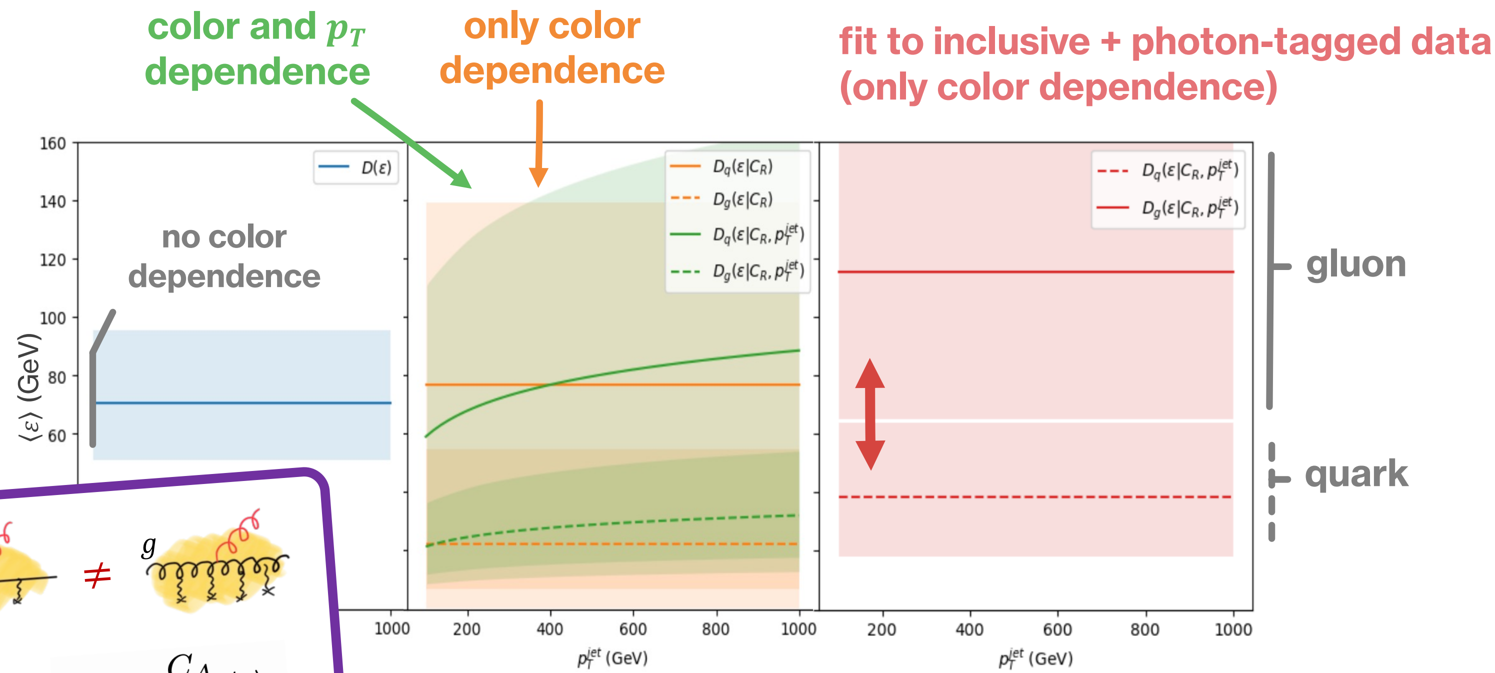

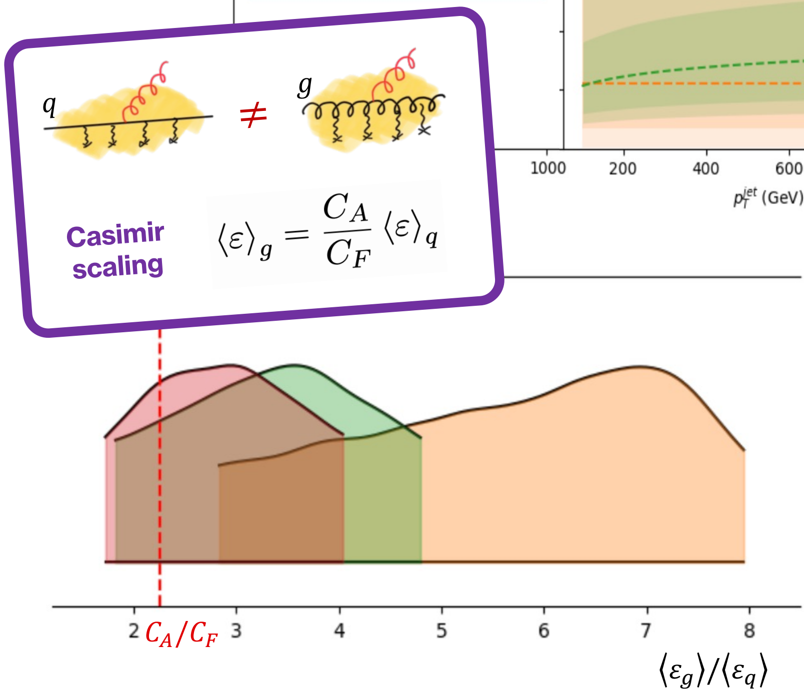

Adding the photon-tagged data gives more information on quark and gluon jet energy loss

- energy loss of quarks and gluons are distinguished
- Casimir scaling is seen

Summary and next steps

- From theory, we expect that quark and gluon jets loose energy differently in the medium;
- Our goal was then to see if this we can prove this in a data driven way;
- For this, we relied on Bayesian analyses;
- We concluded that by only considering inclusive jet data this distinction is not evident;
- By using photon-tagged jet data, a constrain in this quark and gluon energy loss distribution is achieved.

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Next steps:

- Add different measurements to better learn and validate the model;
- Improve the p_T dependence parameterization;
- 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;
- Move deeper in ML to find a less biased approach.