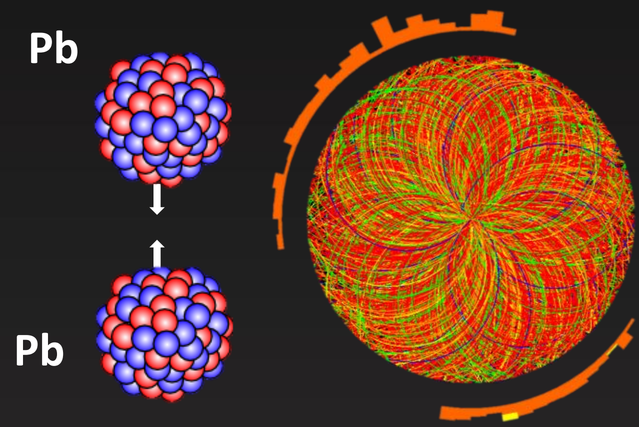

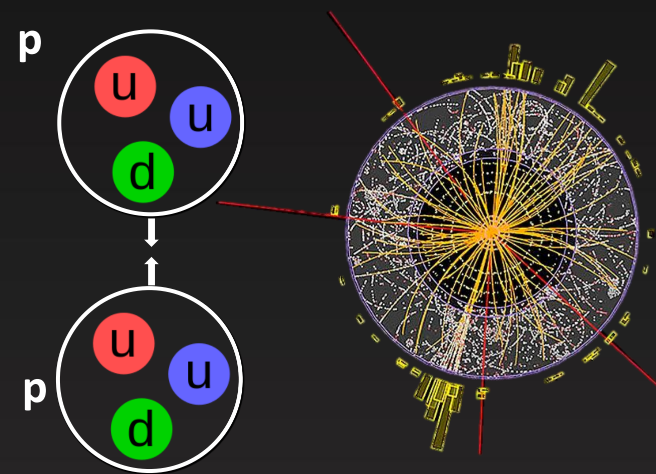

Bottom-up approach to describe groomed jet data in heavy-ion collisions

XVII CPAN DAYS, Valencia

Speaker: Diogo Costa
Supervision: Alba Soto-Ontoso, Liliana Apolinário

UNIVERSIDAD DE GRANADA
FTAE High Energy Theory
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
AGENCIA ESTATAL DE INVESTIGACIÓN

The Quark-Gluon Plasma

Hunt for **fundamental symmetries** culminated into the **SM**

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Hadronic matter at **extreme density and temperature**

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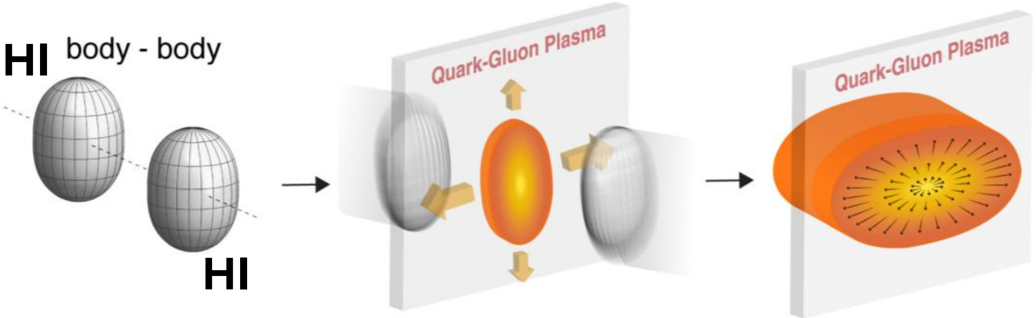

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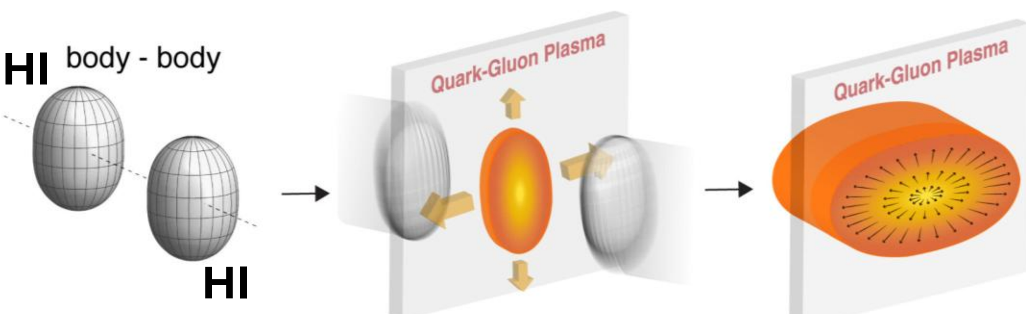

Properties

Strongly coupled hot fluid

Low viscosity

Local assymptotic freedom

Primordial complex matter

Short formation time…

The QGP is characterized by a **rapid evolution** towards thermal equilibrium ($\sim 1\ fm/c$) and freeze-out at around ($\sim 10\ fm/c$)

The QGP & Jets

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(Need indirect probes to infer about its properties…)

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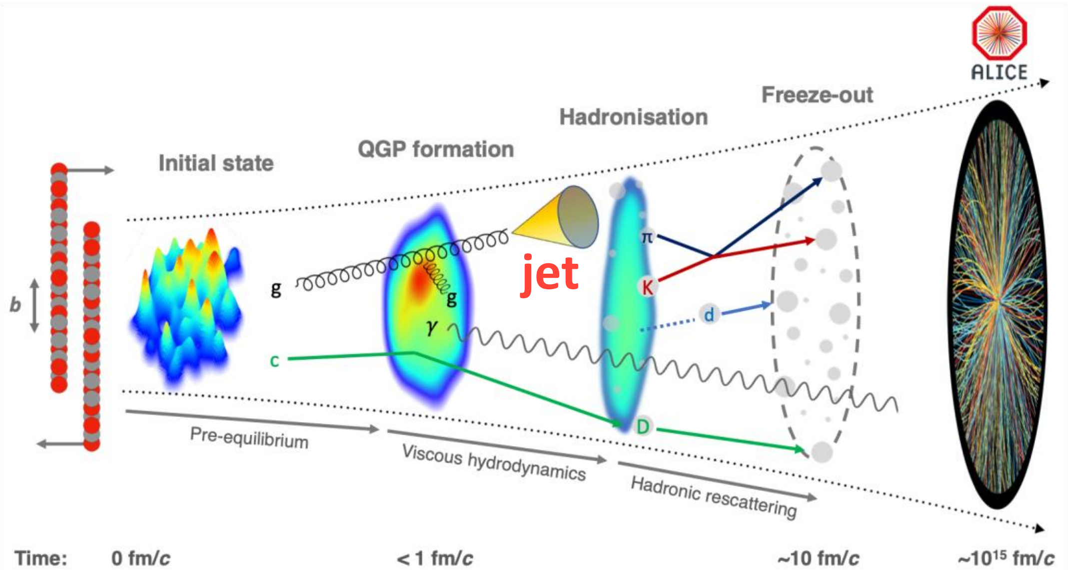

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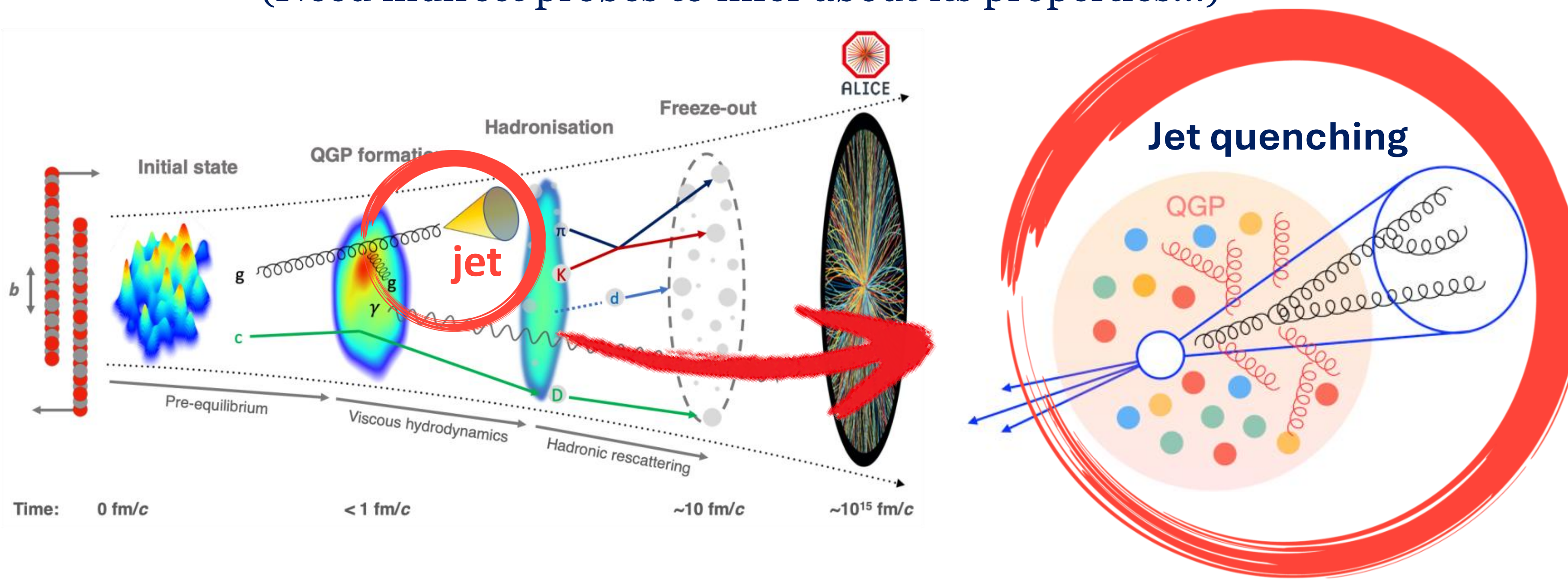

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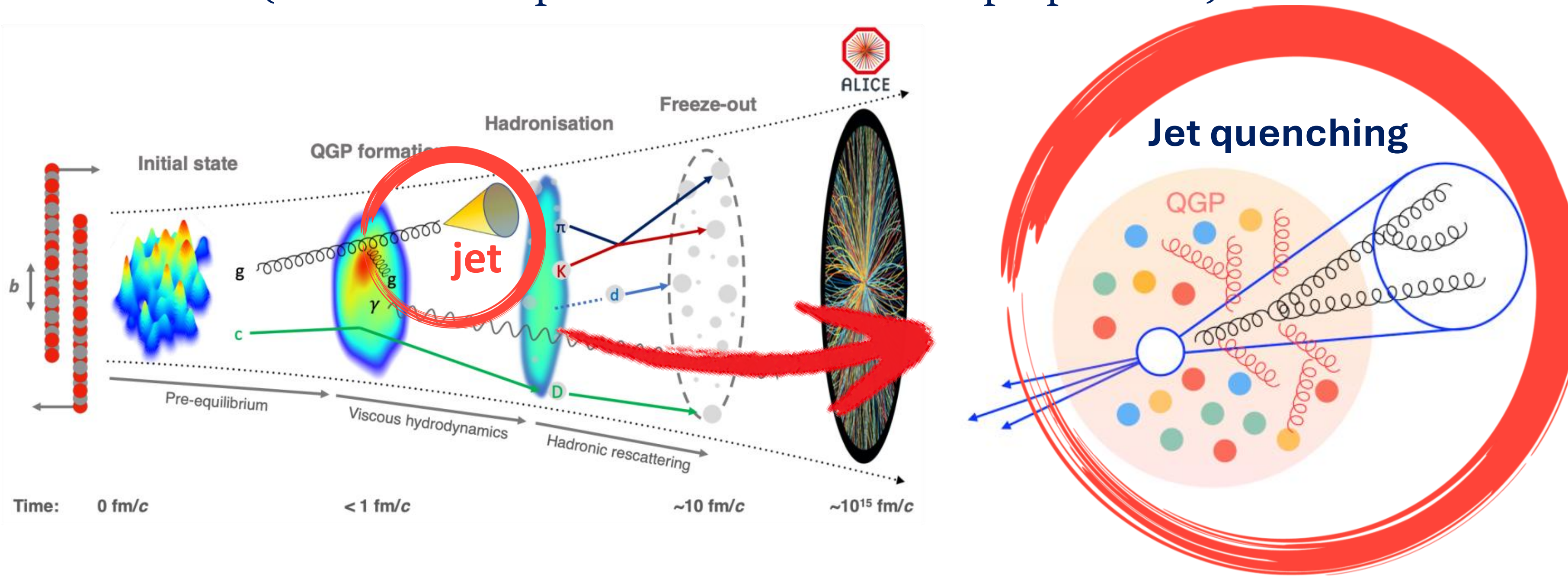

Jets allows to probe the QGP at different scales

Analyzing its substructure allows to probe the QGP dynamics

1. Collision Event

ATLAS EXPERIMENT

ALICE

Beam, collision centrality
Detection/Simulation
Fiducial cuts

Jets & Observables

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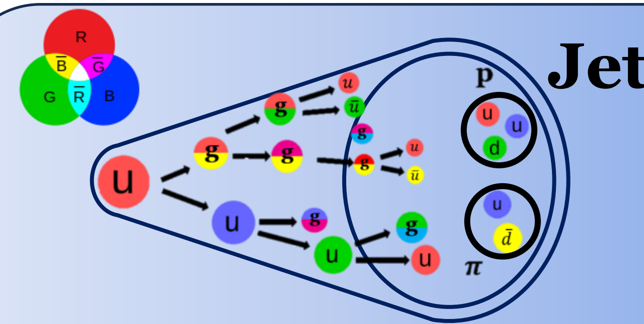

Cluster via
k_t – family algorithms
M. Cacciari G. Salam & G. Soyez, JHEP 04 (2008) 063

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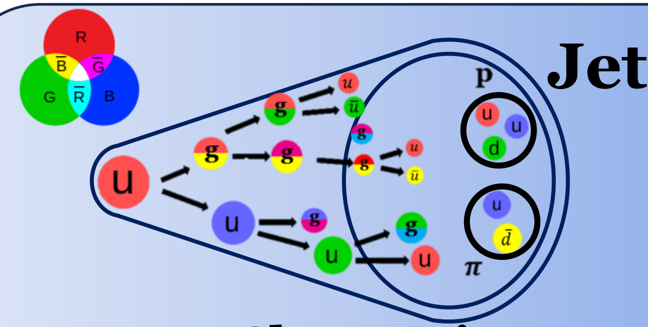

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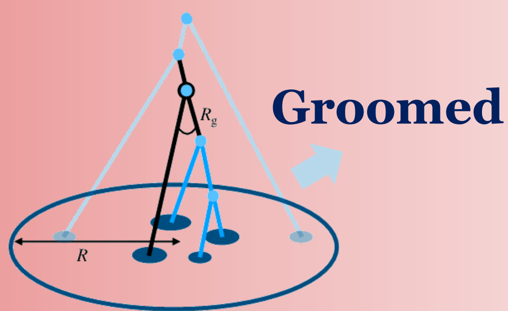

Groom jets via SD algorithm:

Decluster until: $\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut}$

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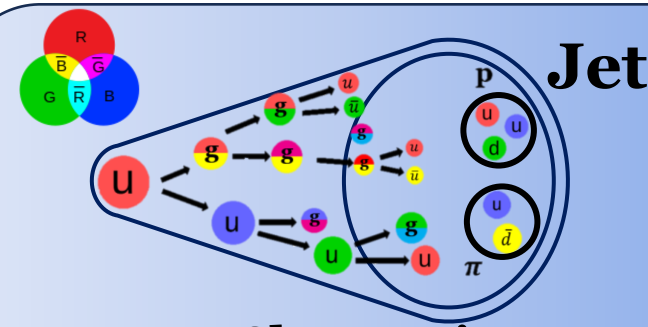

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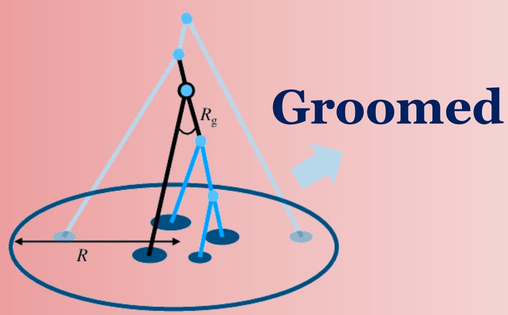

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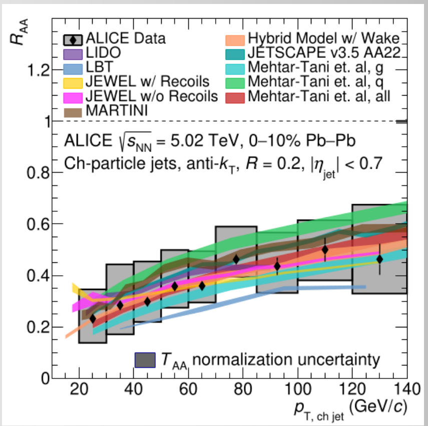

Constrain QGP parameters via experiment

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Detection/Simulation
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Cluster via
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M. Cacciari G. Salam & G. Soyez, JHEP 04 (2008) 063

Compute jet observables!

For this study one shall focus on groomed observables

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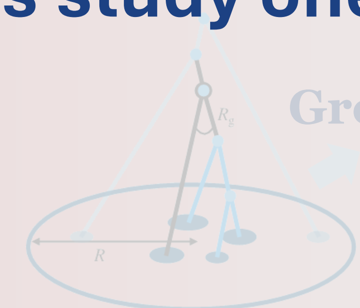

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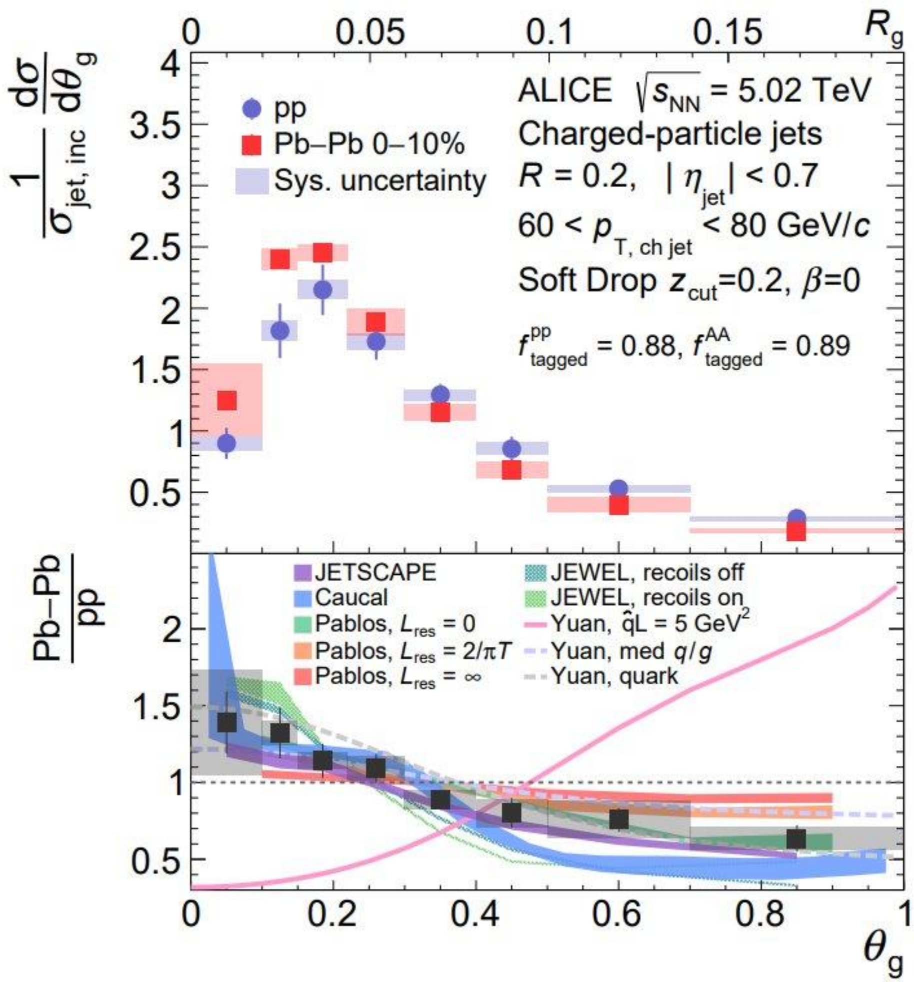

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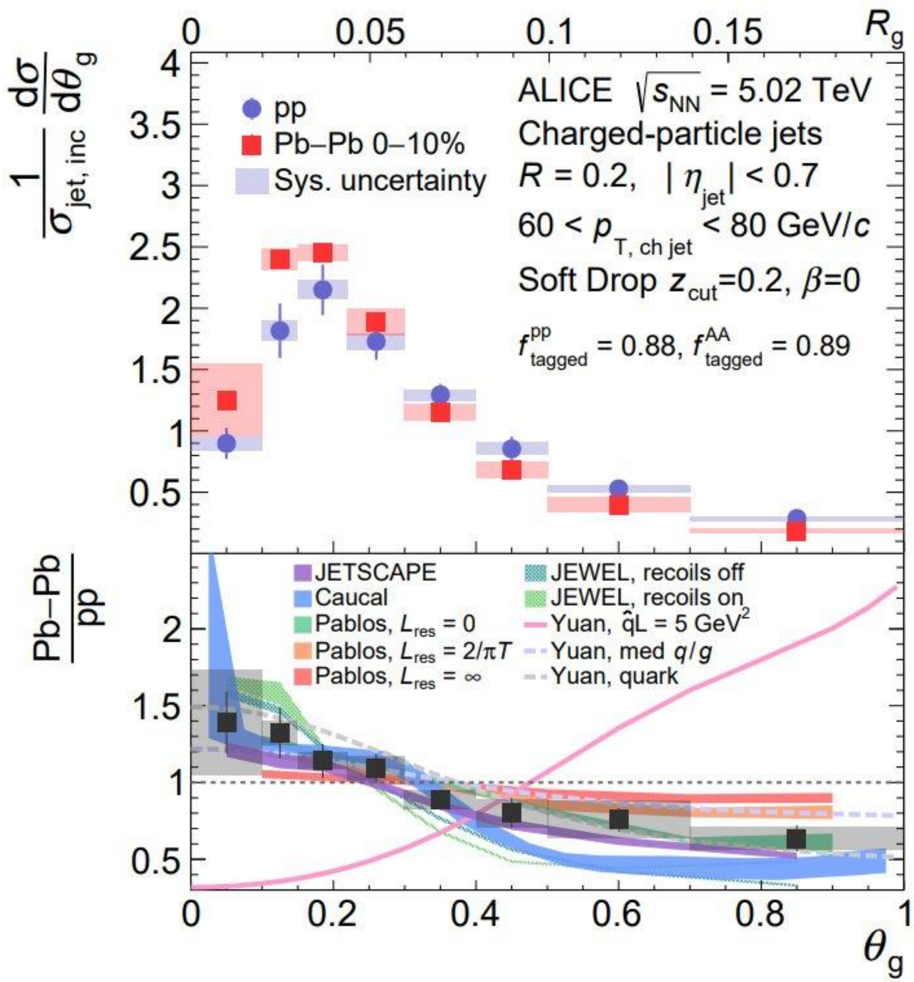

Baseline precision

Jet quenching

[HI collisions / pp collisions]

The Goal

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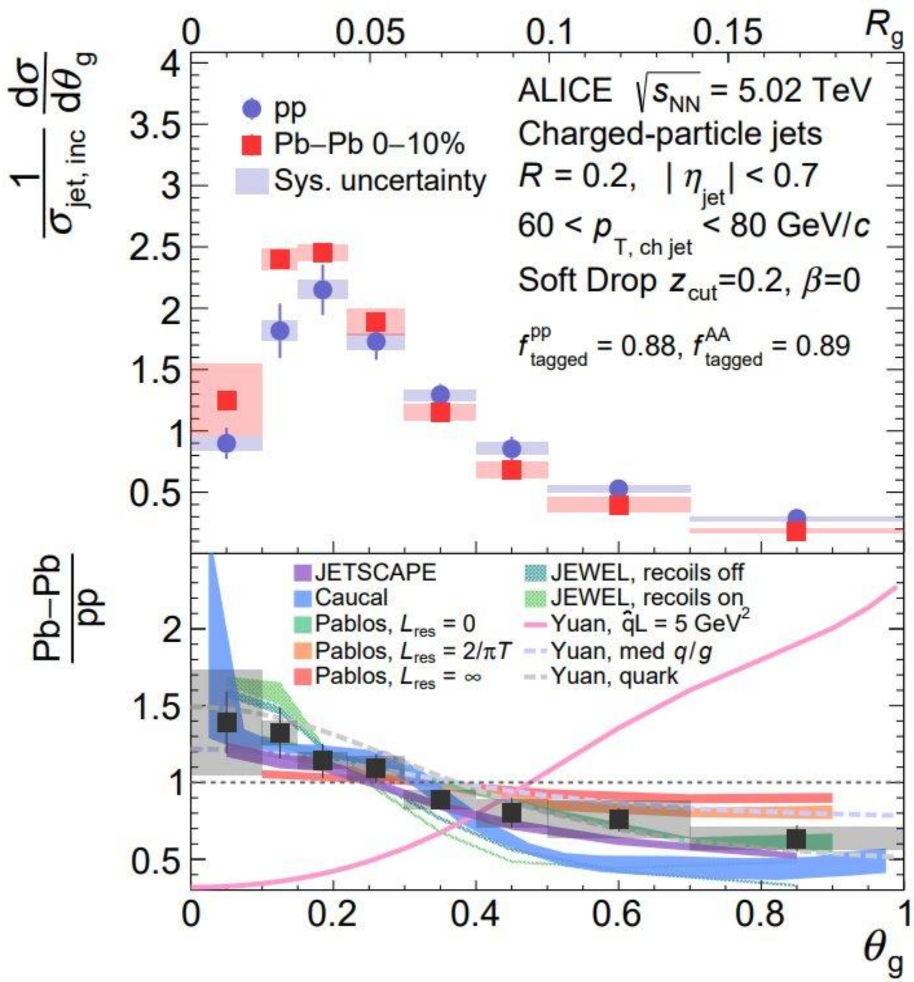

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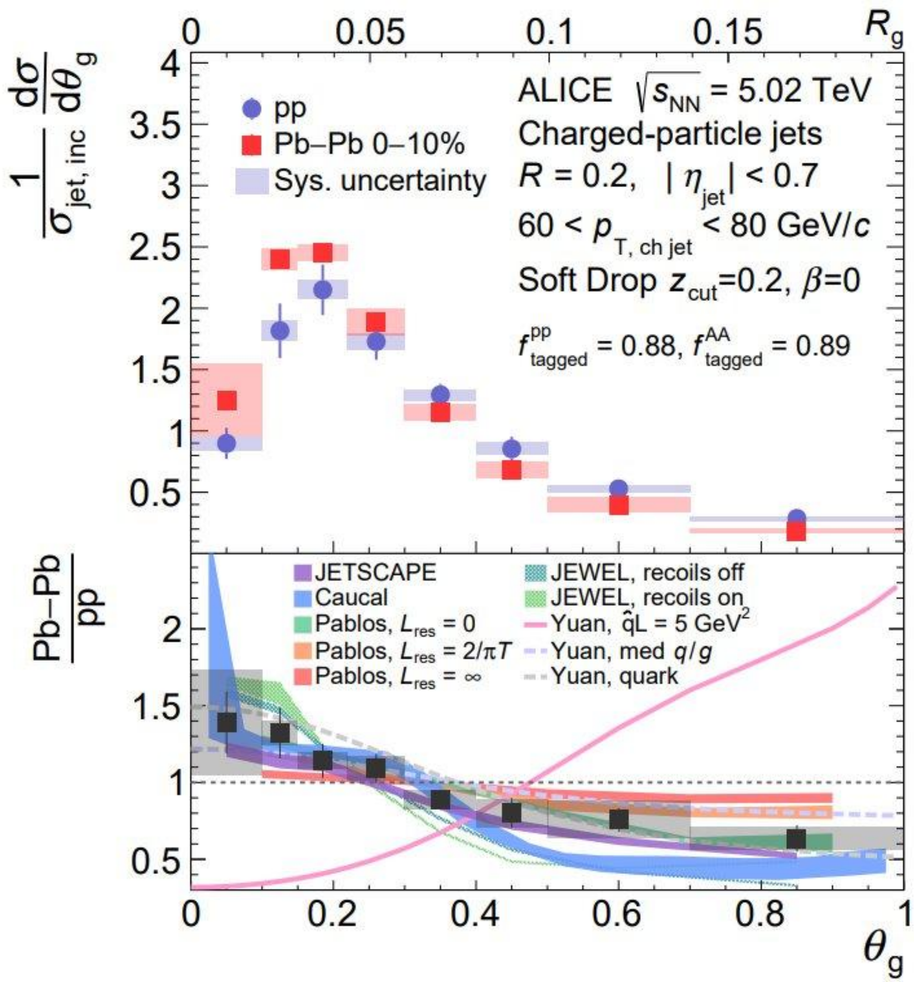

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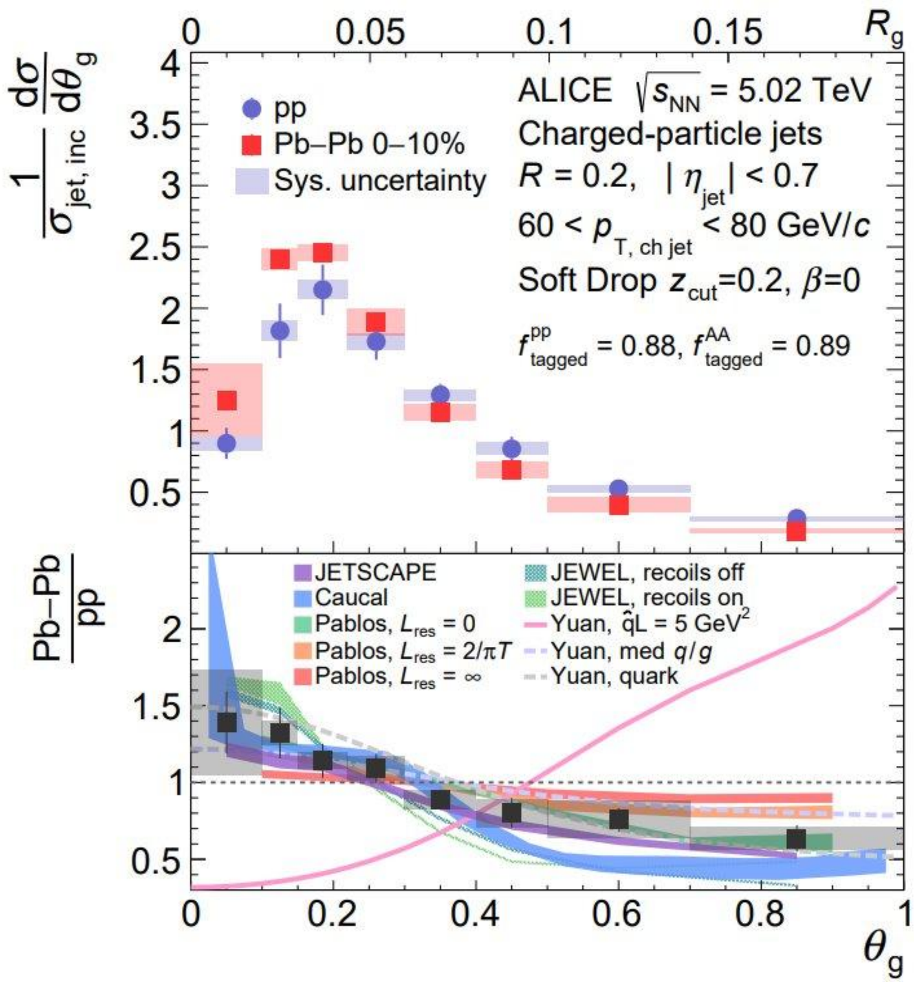

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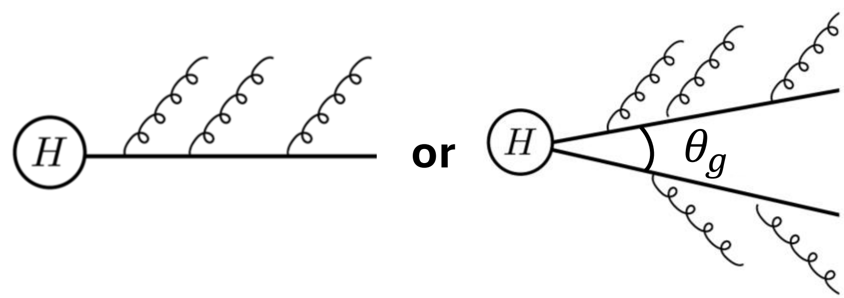

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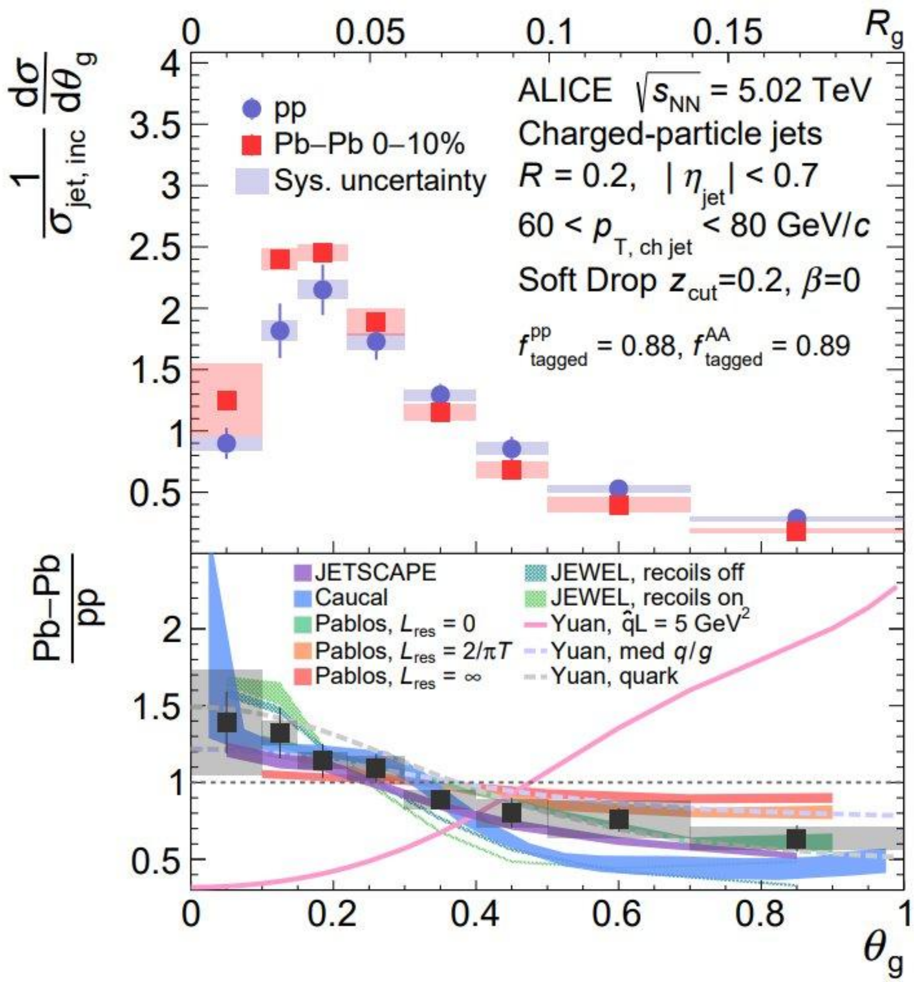

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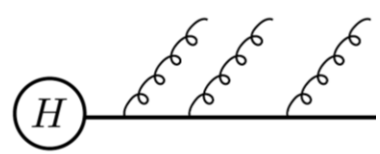

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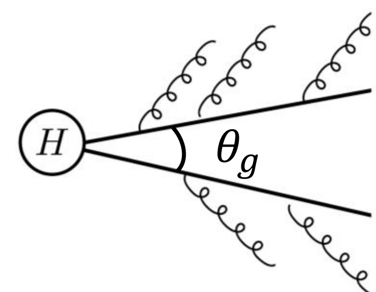

Do we observe colour coherence?

More in detail

Baseline precision

Bottom-up approach

Compute the hard-scattering @ NLO

↓

Match exact-NLO with Parton Shower

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Powheg-Box

PYTHIA 8

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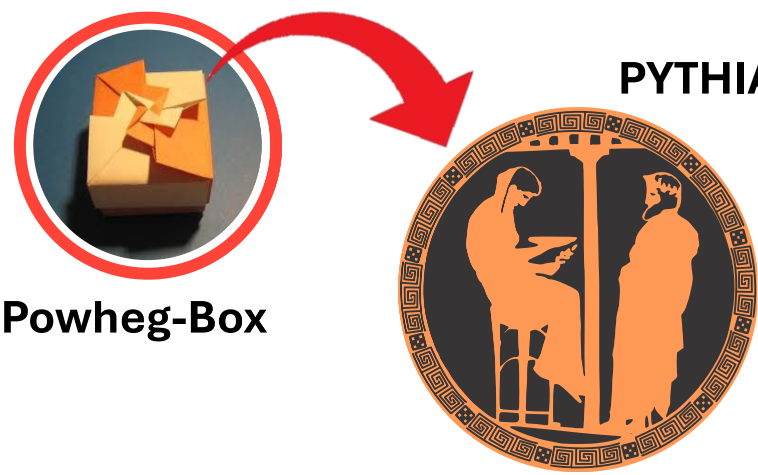
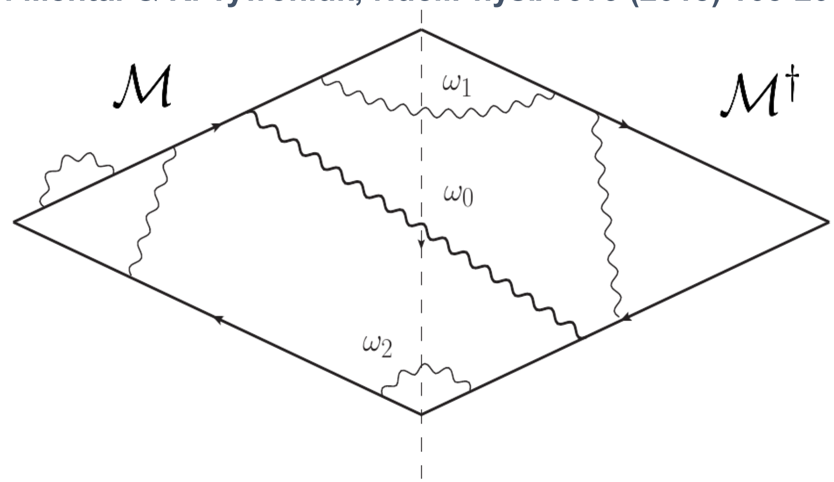


Powheg-Box

Medium Coherence

Consider interference effects

Y. Mehtar & K. Tywoniuk, Nucl.Phys.A 979 (2018) 165-203



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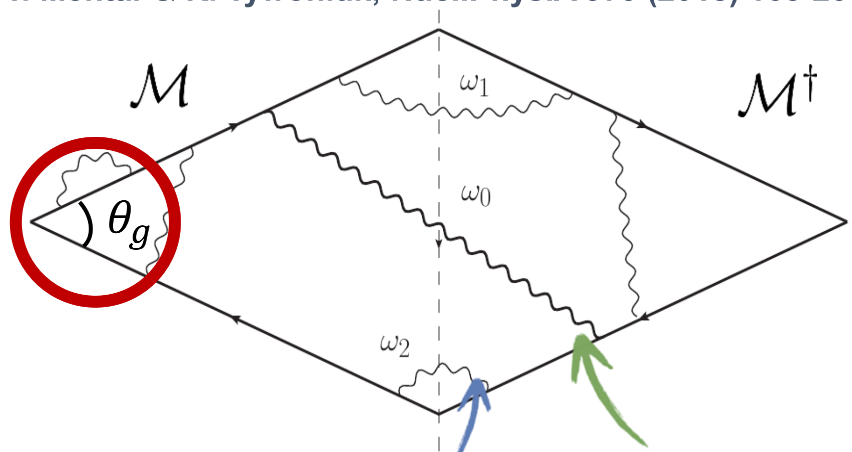
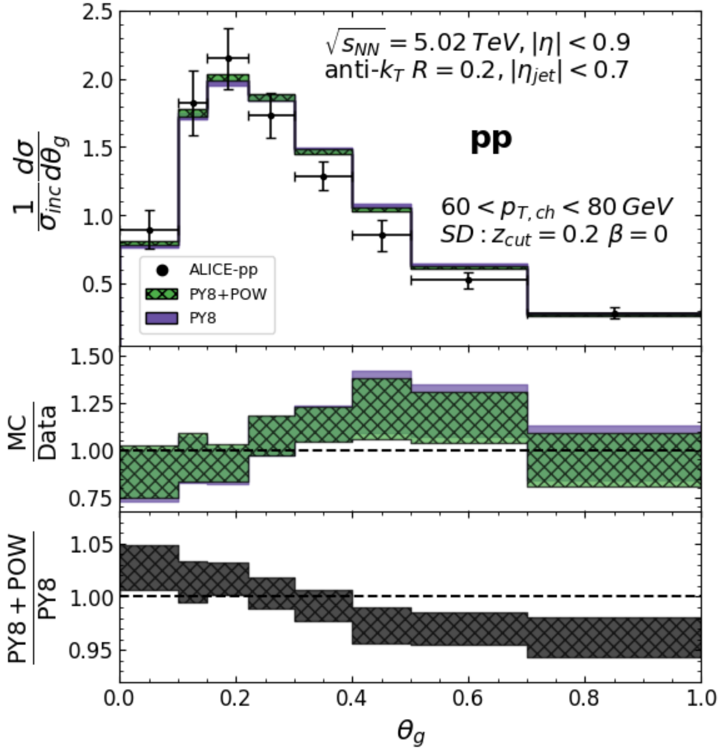


$$P_2(\epsilon, \theta_g) = P_{\rm inc}(\epsilon) - P_{\rm coh}(\epsilon, \theta_g)$$

E-loss sensitive to jet substructure!

Analysis Baseline



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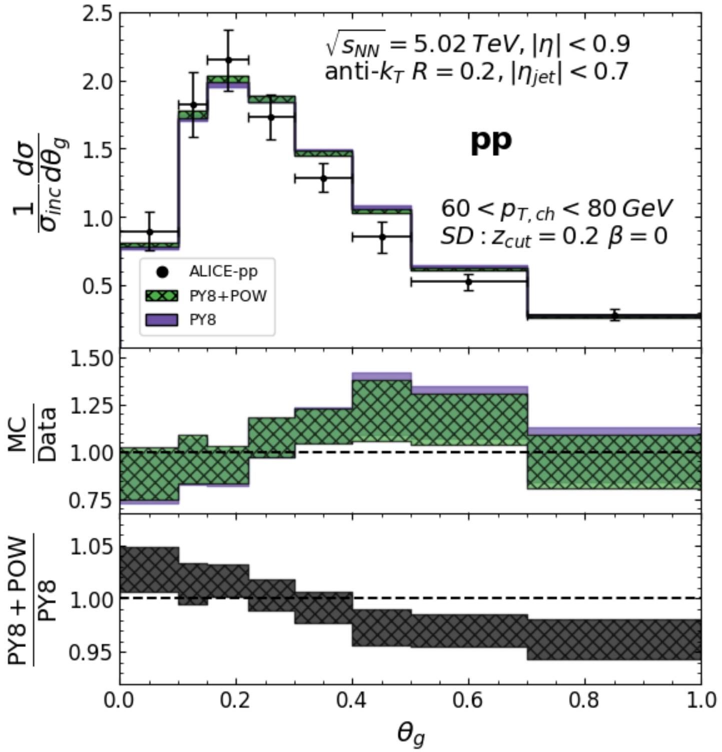
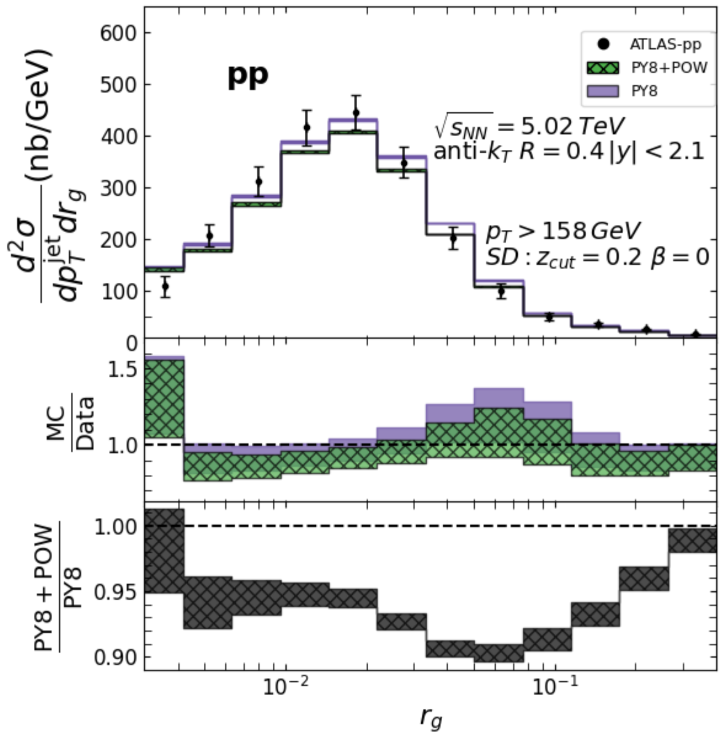


ATLAS EXPERIMENT



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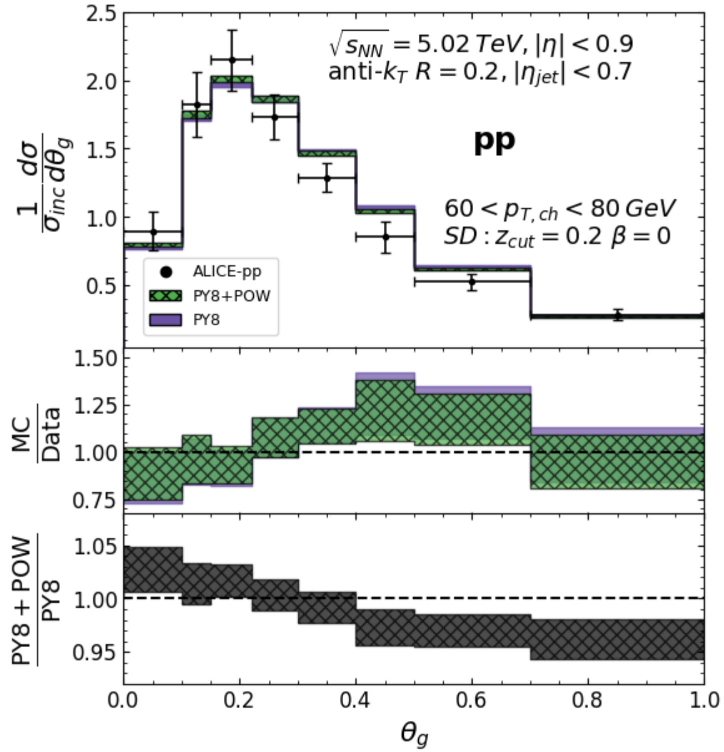
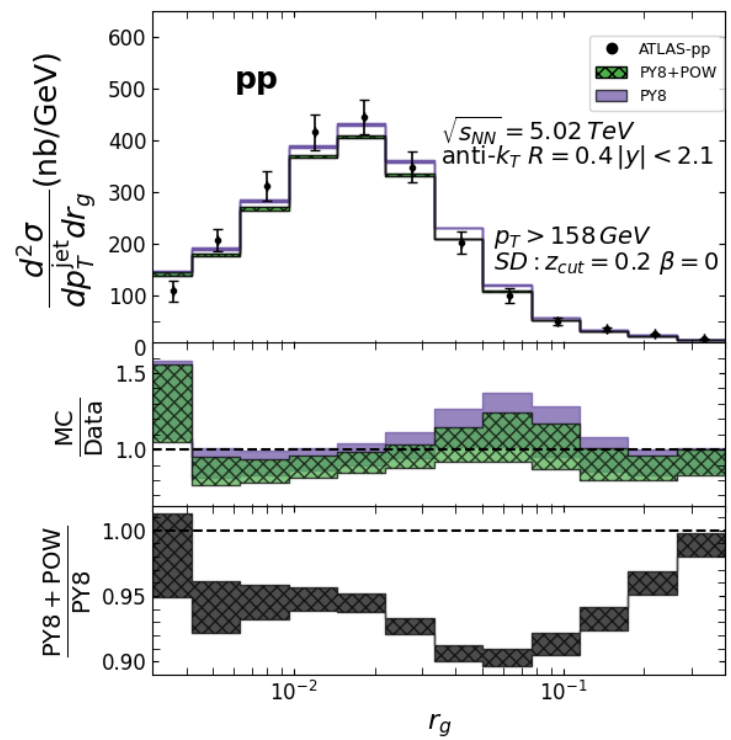
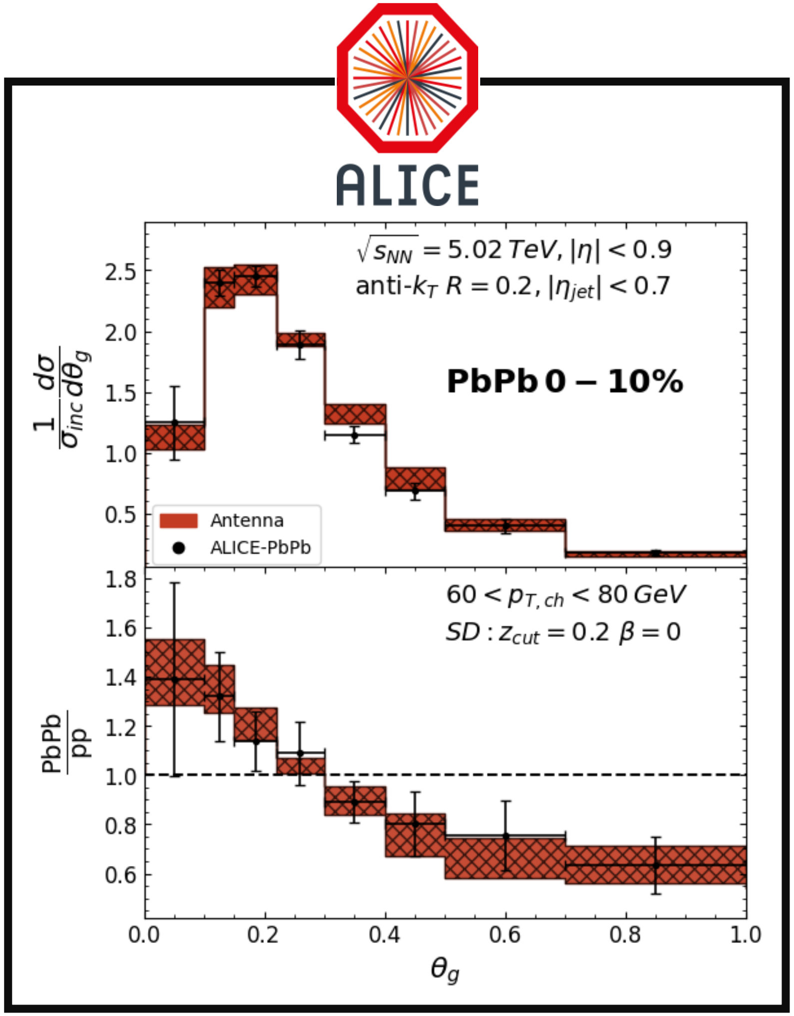




Overall agreement with data for both baselines

NLO corrections correspond up to 5-10% modification

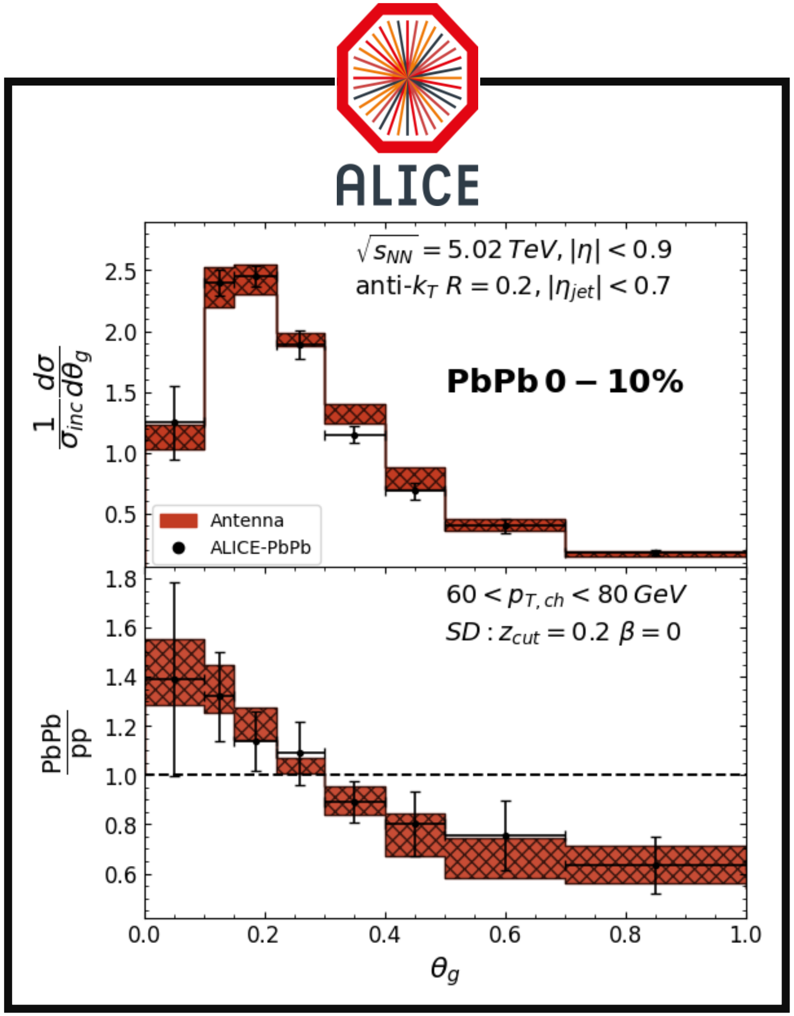

ALICE
$\sqrt{s_{NN}} = 5.02\ TeV, |\eta| < 0.9$
anti-k_T $R = 0.2, |\eta_{jet}| < 0.7$
PbPb 0 – 10%
$\frac{1}{\sigma_{inc}} \frac{d\sigma}{d\theta_g}$
Antenna
ALICE-PbPb
$60 < p_{T,ch} < 80\ GeV$
$SD : z_{cut} = 0.2\ \beta = 0$
$\frac{PbPb}{pp}$
θ_g

Analysis PbPb - ALICE

Antenna

Overall success in describing the experimental data

Smaller theoretical uncertainties w.r.t. data



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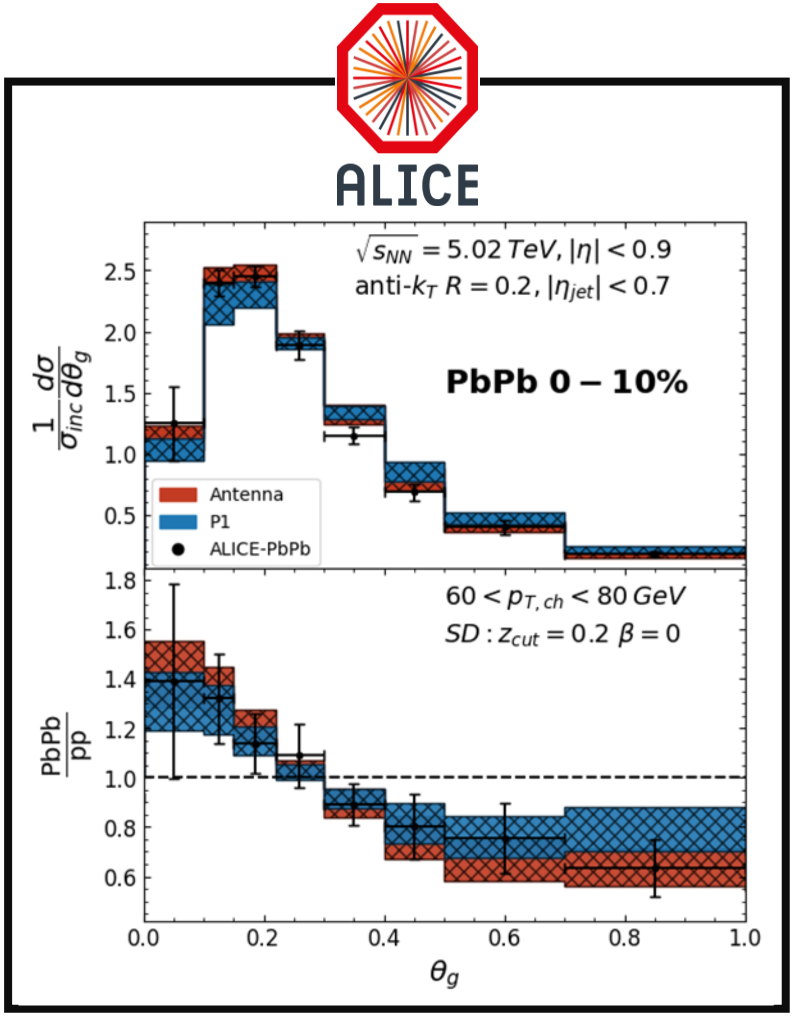

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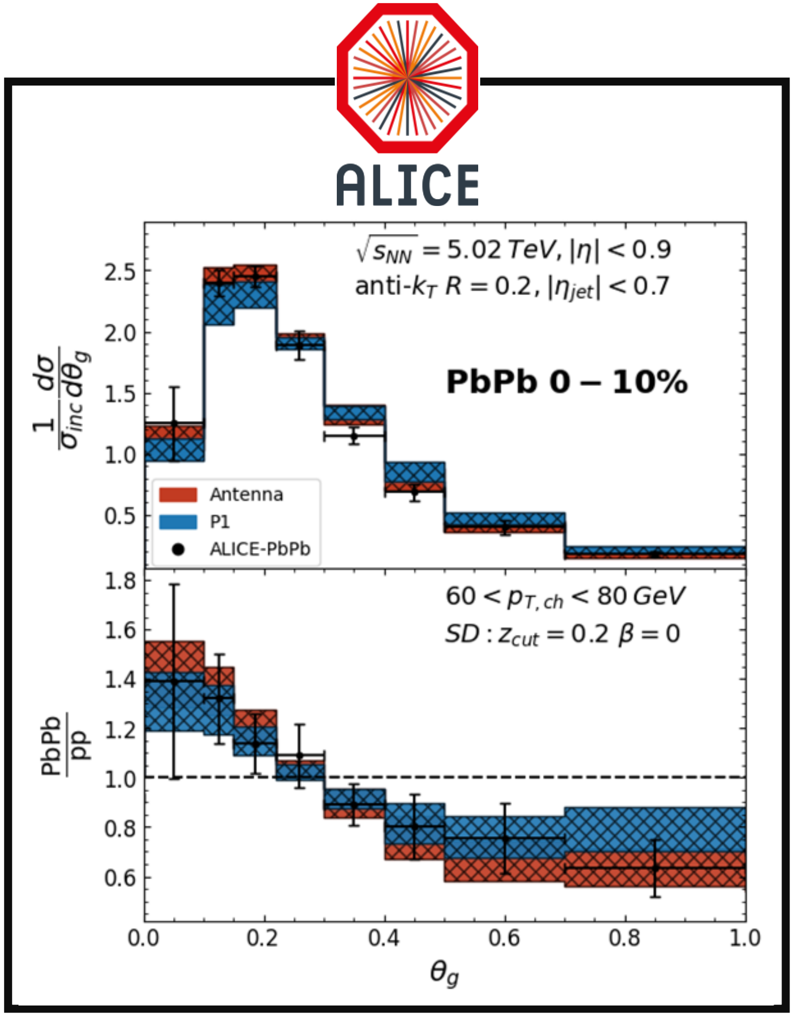

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Overall agreement for both models

Difficult to conclude coherence for current exp. uncertainty..

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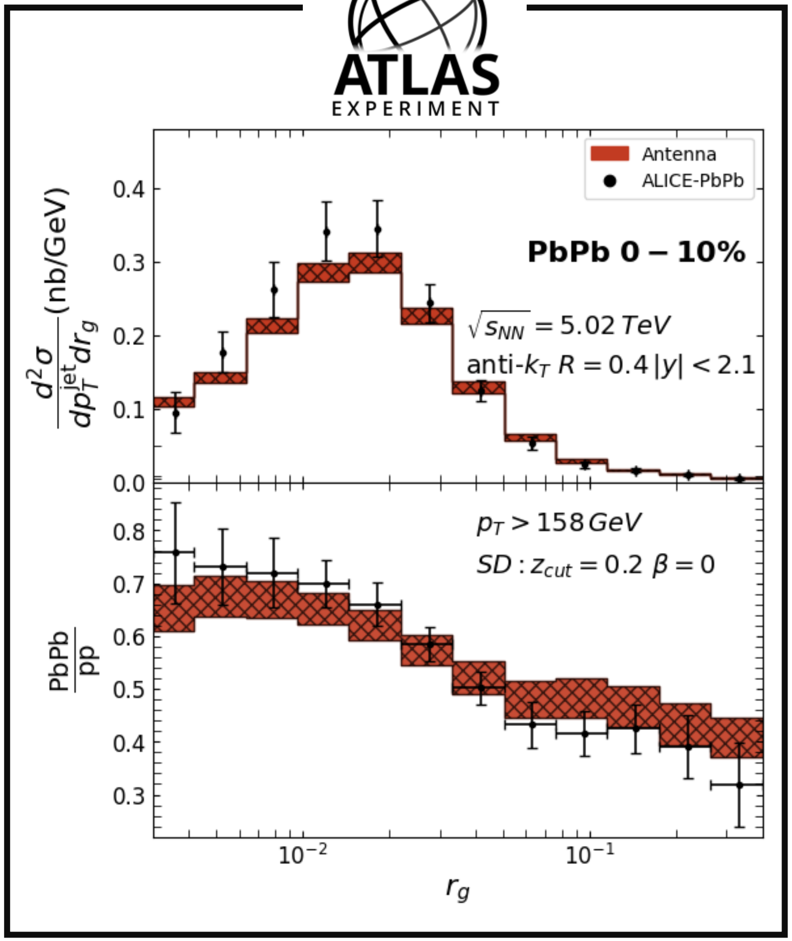

Analysis PbPb - ATLAS

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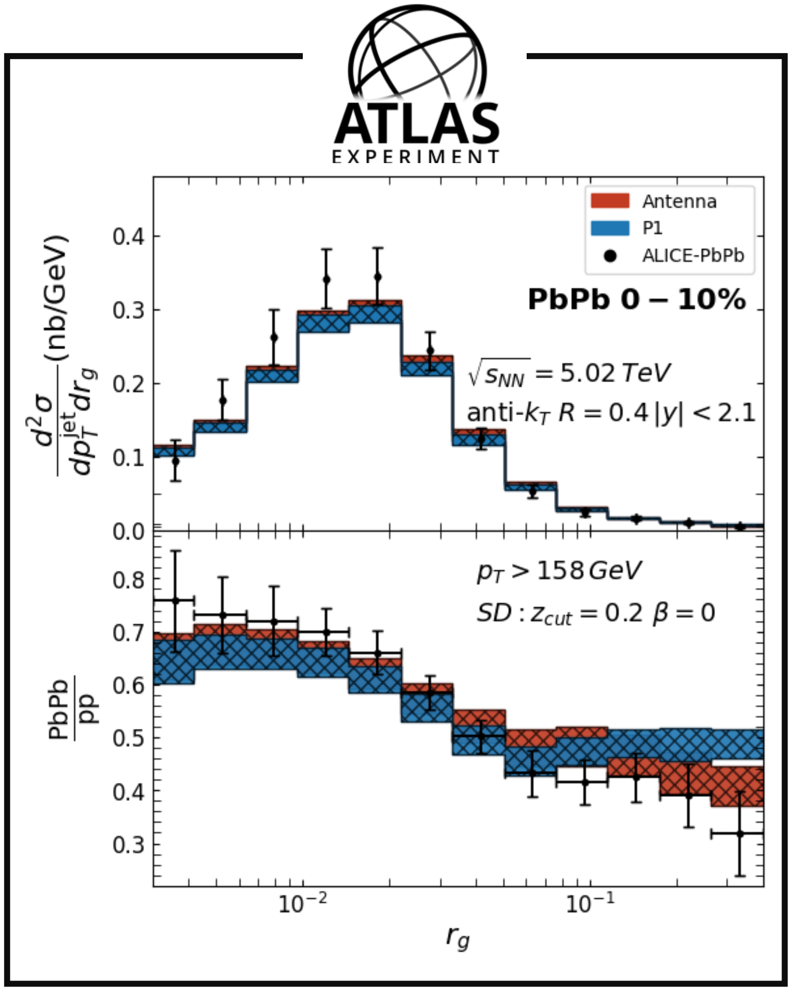

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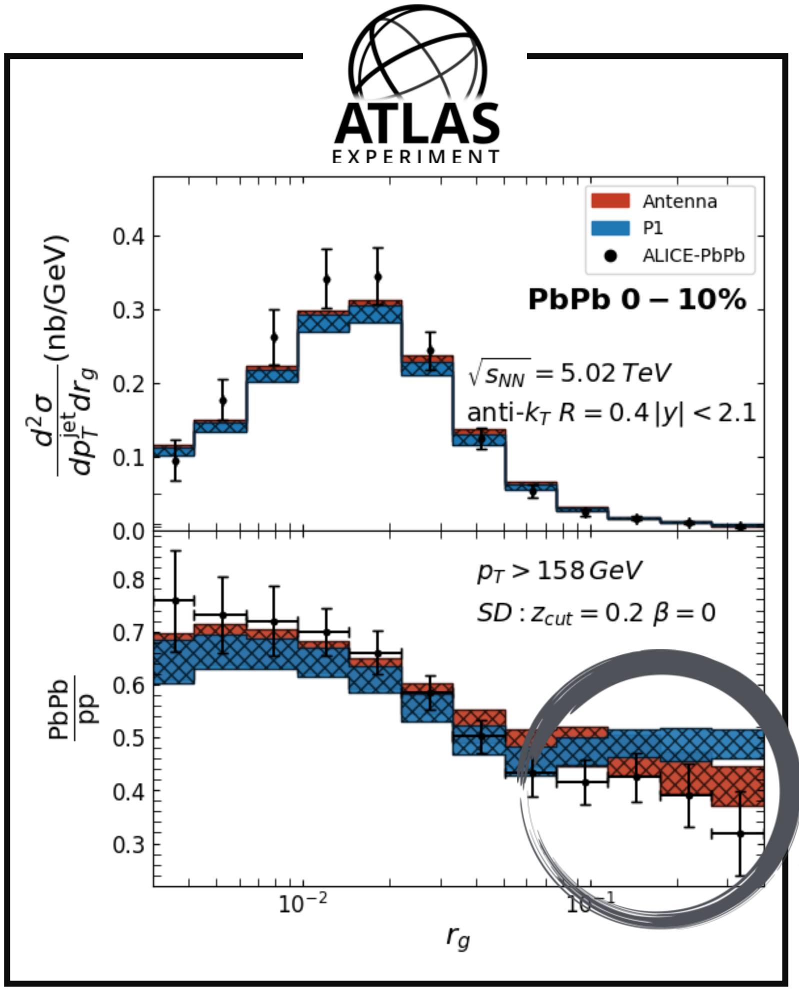

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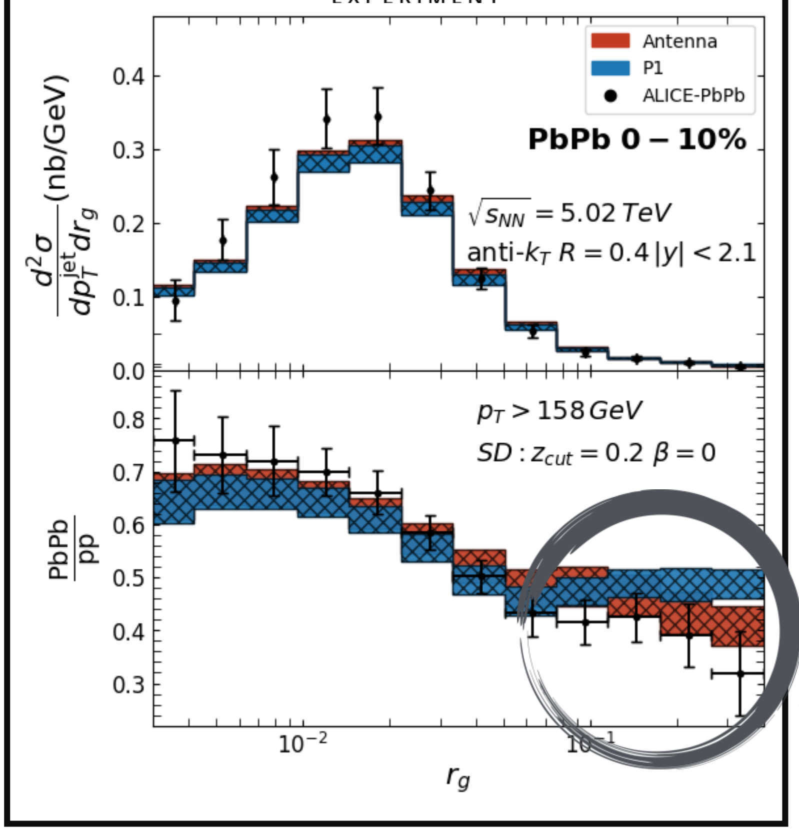

Antenna & P1

P1 model shows less enhancement & less suppression

There is a disagreement for higher rg

Same observable for different kinematics..

Result now show an agreement towards coherence

Conclusions

Overall success for vacuum baselines, **NLO corrections contributing up to 10%**

Overall in-medium agreement for the **Antenna model** with a **deviation** of up to 10% for the **P1 model**, **dependent on the kinematics.**

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Some good news…

Upcoming LHC experimental update: High-Luminosity Phase

Future QGP measurements with unprecedent precision levels

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Necessary to keep up current theoretical models!

Bottom-up approach to describe groomed jet data in heavy-ion collisions

XVII CPAN DAYS, Valencia

Speaker

Diogo Costa

Supervision

Alba Soto-Ontoso, Universidad de Granada

Liliana Apolinário, Universidade de Lisboa

UNIVERSIDAD DE GRANADA

FTAE High Energy Theory

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

AGENCIA ESTATAL DE INVESTIGACIÓN

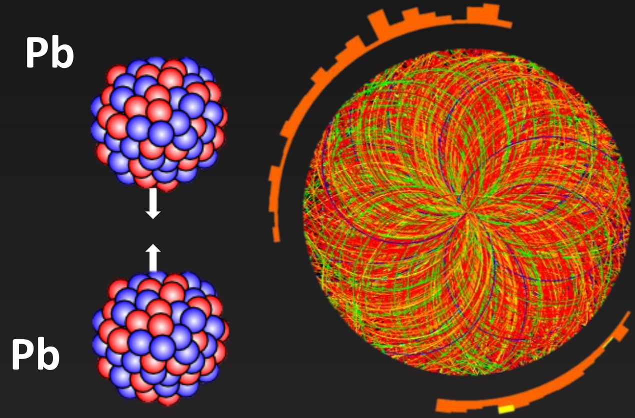
Hot Hadronic Matter (A Poetic Summary)

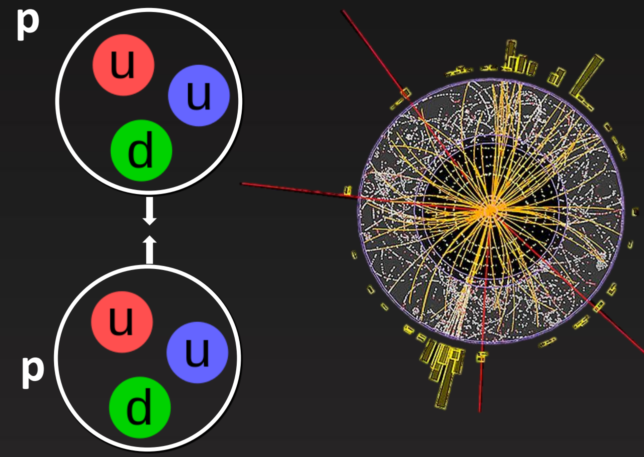
In days of old
a tale was told
of hadrons ever fatter.
Behold, my friends, said Hagedorn,
the ultimate of matter.

Then Muster Mark
called in the quarks,
to hadrons they were mated.
Of colors three, and never free,
all to confinement fated.

But in dense matter,
their bonds can shatter
and they can freely move around.
Above TH , their colors shine,
as the QGP is found.

Said Hagedorn,
when quarks were born
they had different advances.
Today they form, as we can see,
a gas of all their chances.





Backup Slides

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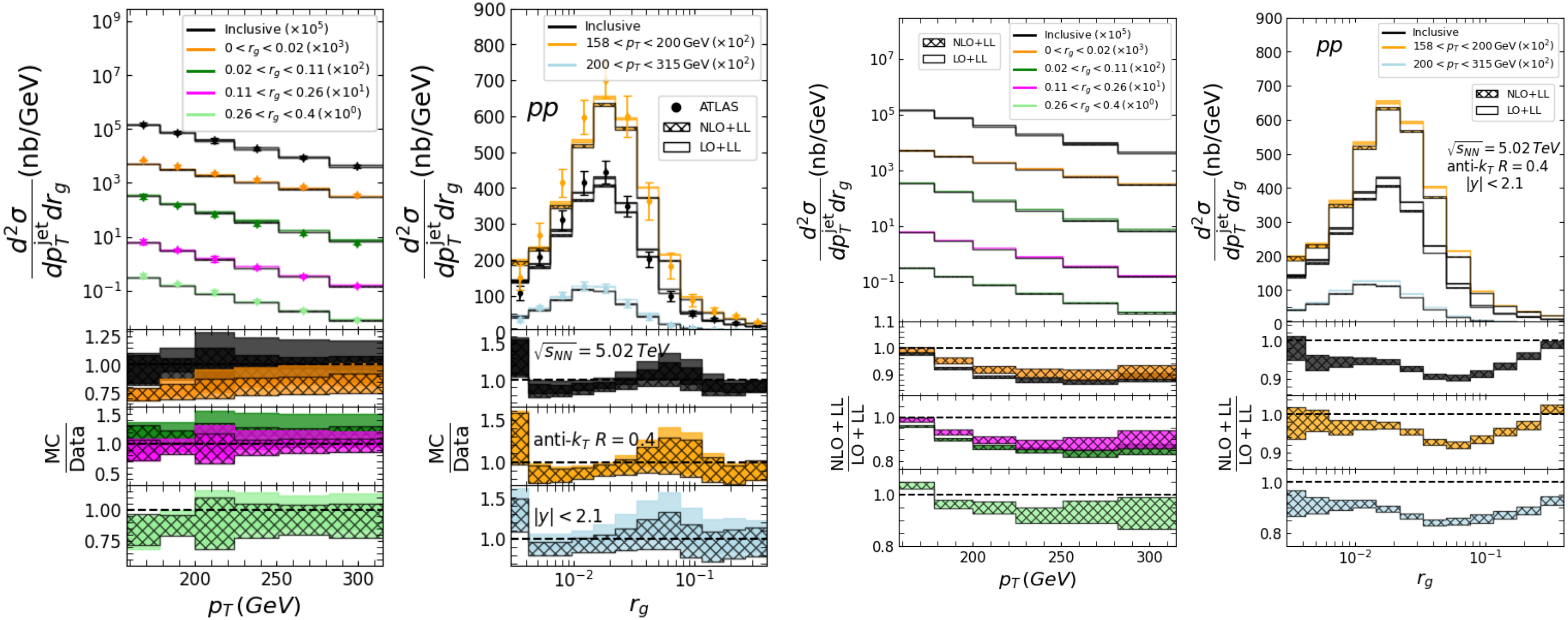
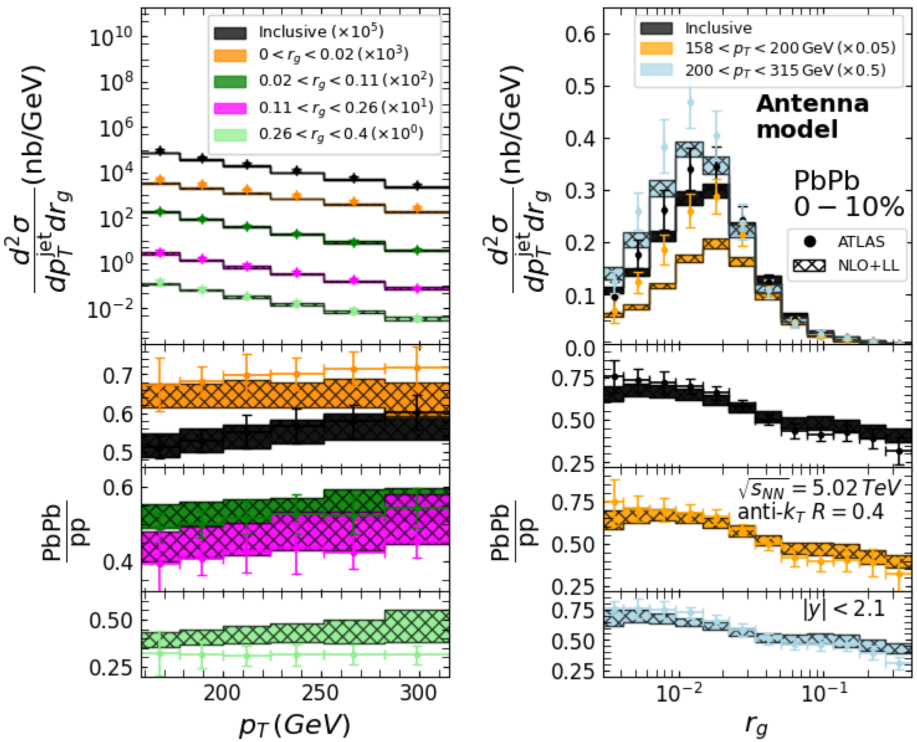
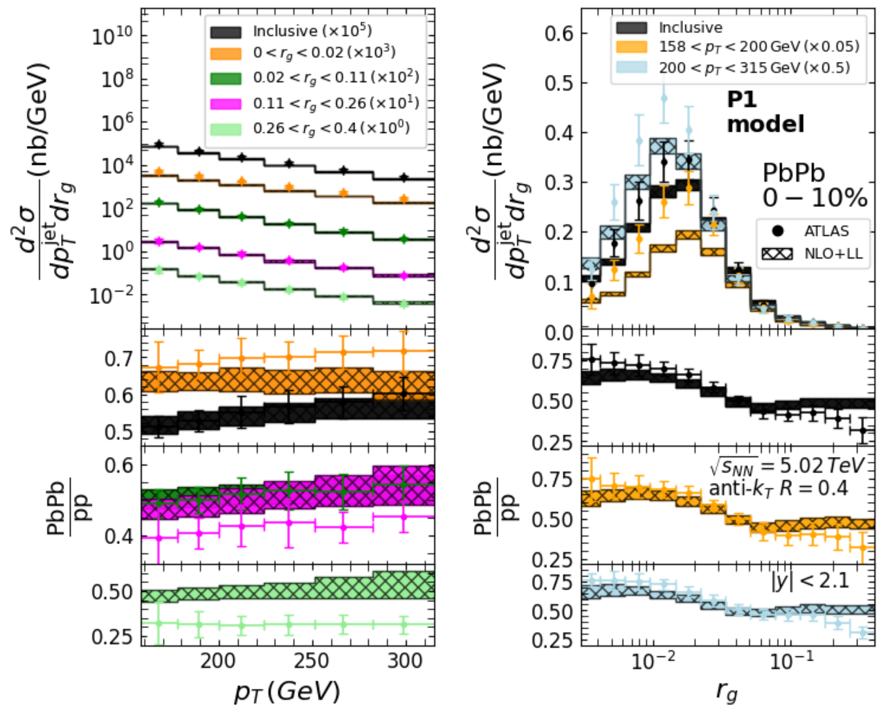
More in detail - ATLAS pp

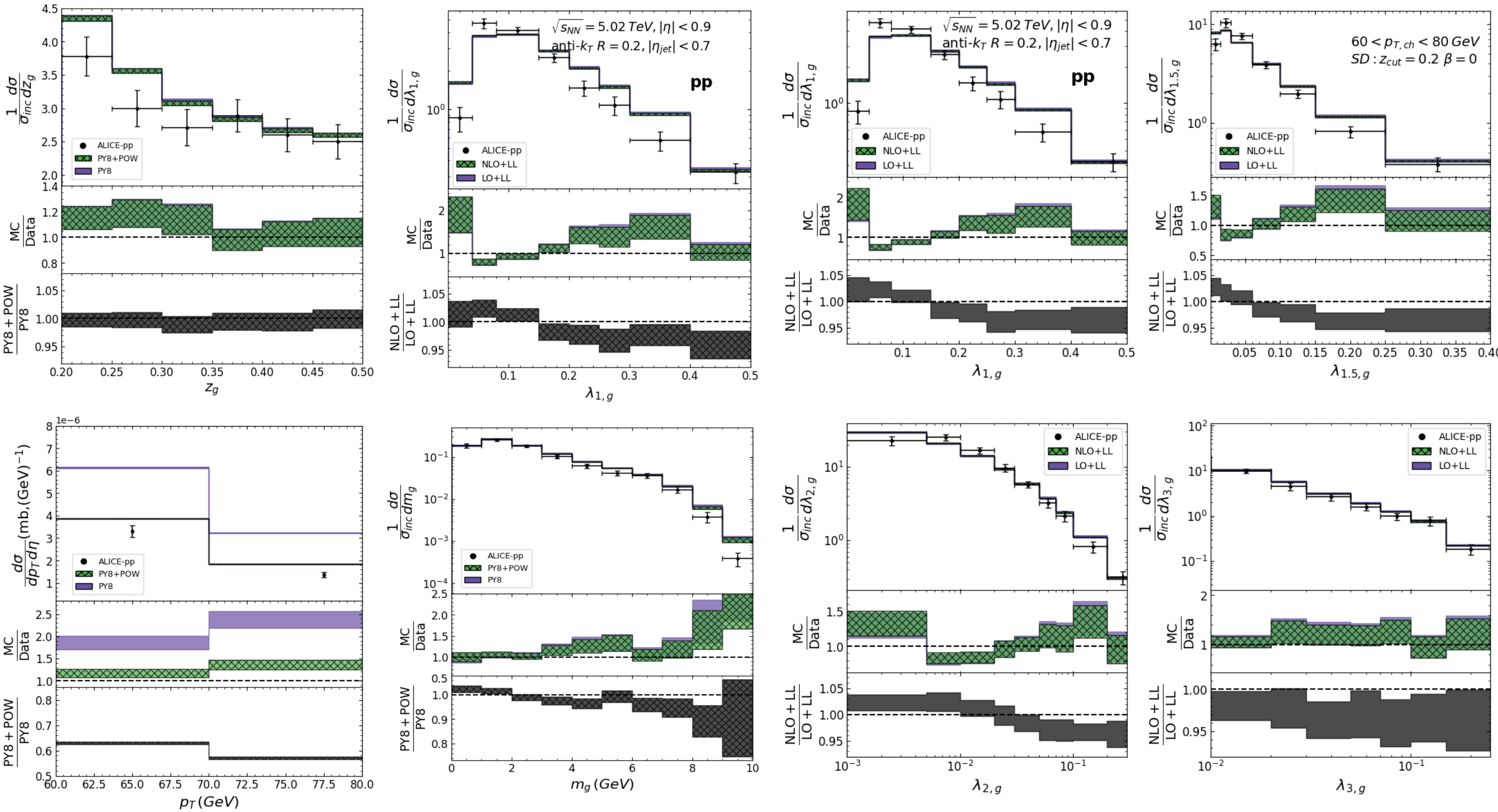


More in detail – ATLAS PbPb

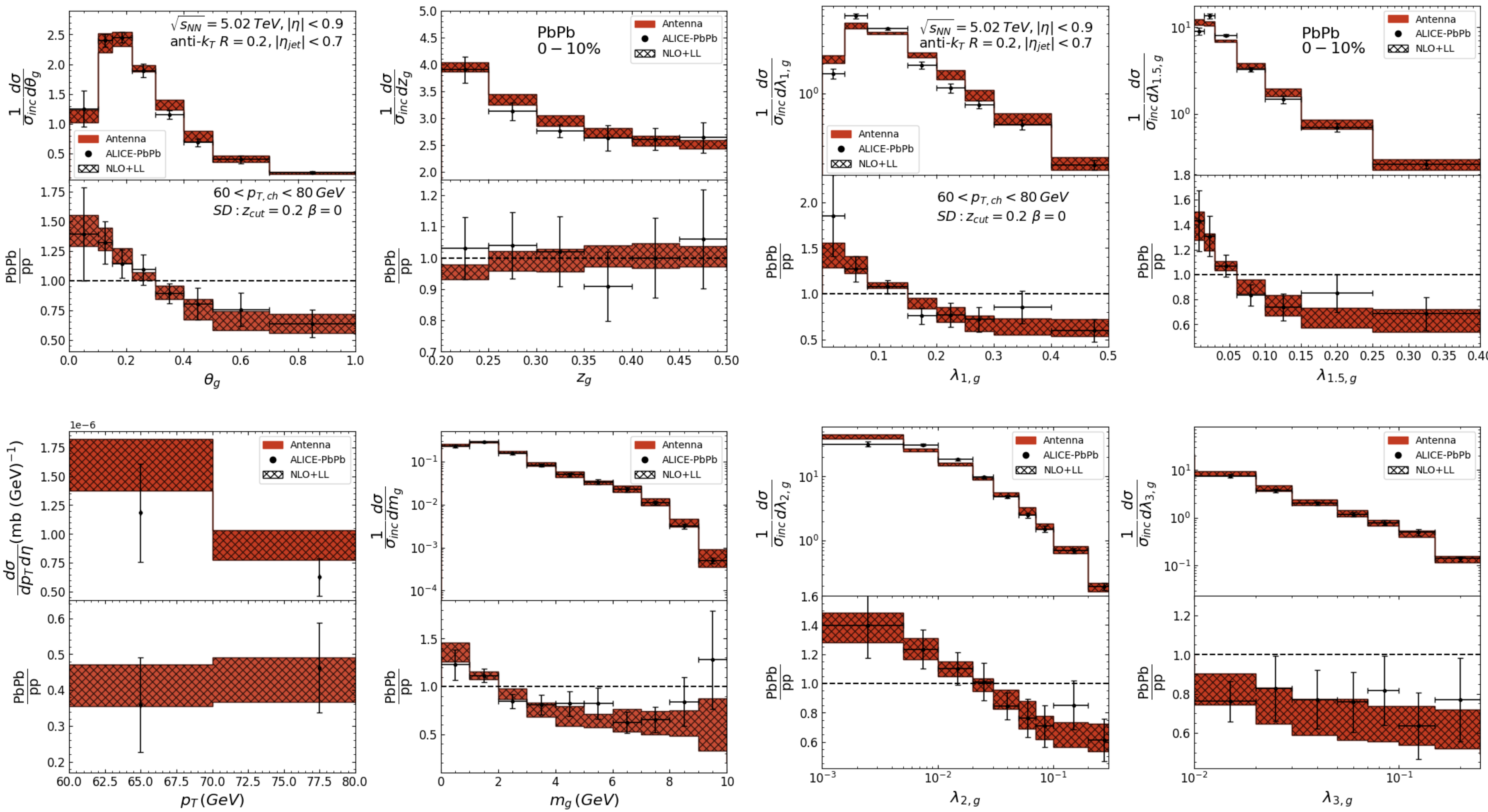




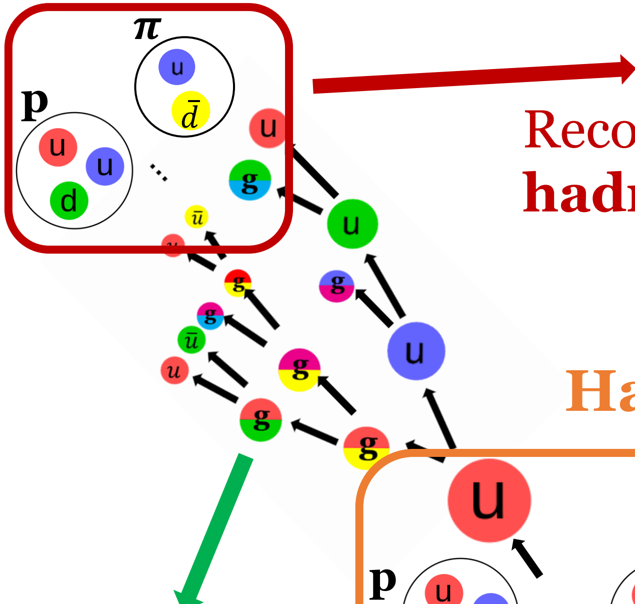
More in detail – ALICE pp



More in detail – ALICE PbPb



Dijet collision event

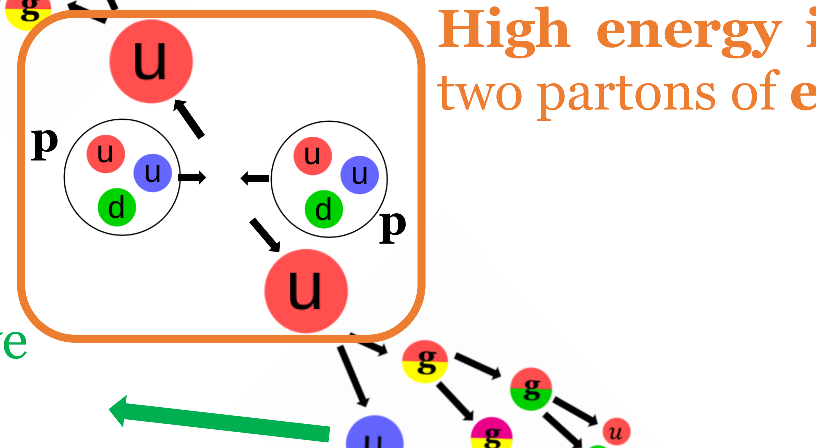


Hadronization

Recombination of **partons into hadrons,** via **colour confinement**

Hard-Scattering

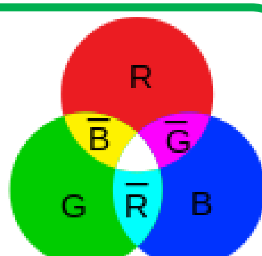
High energy interaction between two partons of **each beam.**

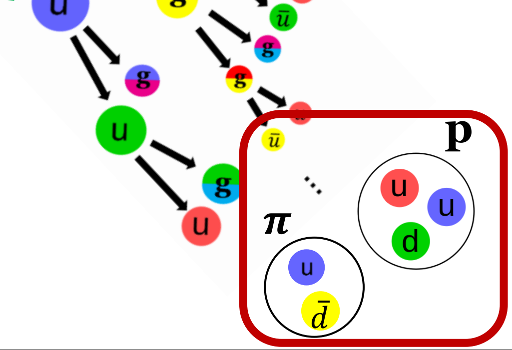


Parton Shower

Cascade of sucessive **parton** emissions

Colour Conservation



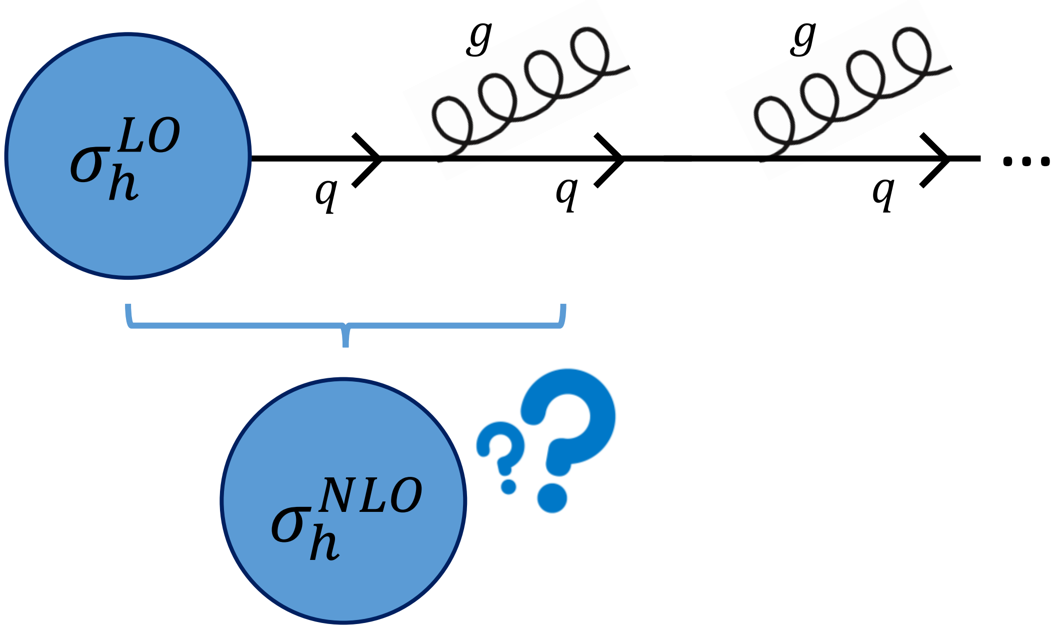


Event Generator
PYTHIA
C. Bierlich arXiv:2203.11601

NLO hard-scattering
POWHEG
P. Nason arXiv:0409146

Parton Shower
Default PYTHIA and VINCIA
P. Skands arXiv:1609.07205

Matching



Double counting of the radiation phase-space ...

Need mechanism to remove/compensate the overlaping phase-space.

MADGRAPH

$$d\sigma^{\mathrm{NLO}}_{\mathrm{MC@NLO}} \sim d\sigma^{\mathrm{NLO}} - d\sigma^{\mathrm{MC}}$$

Additive Matching

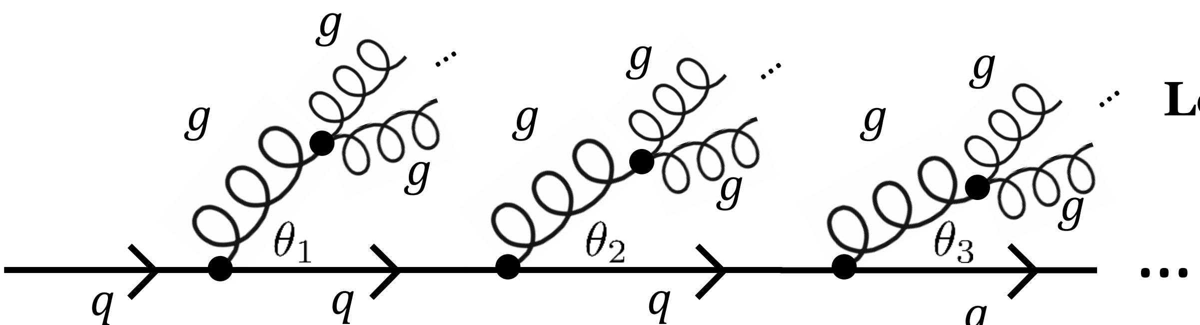
POWHEG-BOX

$$d\sigma^{\mathrm{NLO}}_{\mathrm{POWHEG}} \sim \frac{d\sigma^{\mathrm{NLO}}}{d\sigma^{\mathrm{MC}}}$$

Multiplicative Matching

Antenna choice and Colour Tagging

Antenna choice

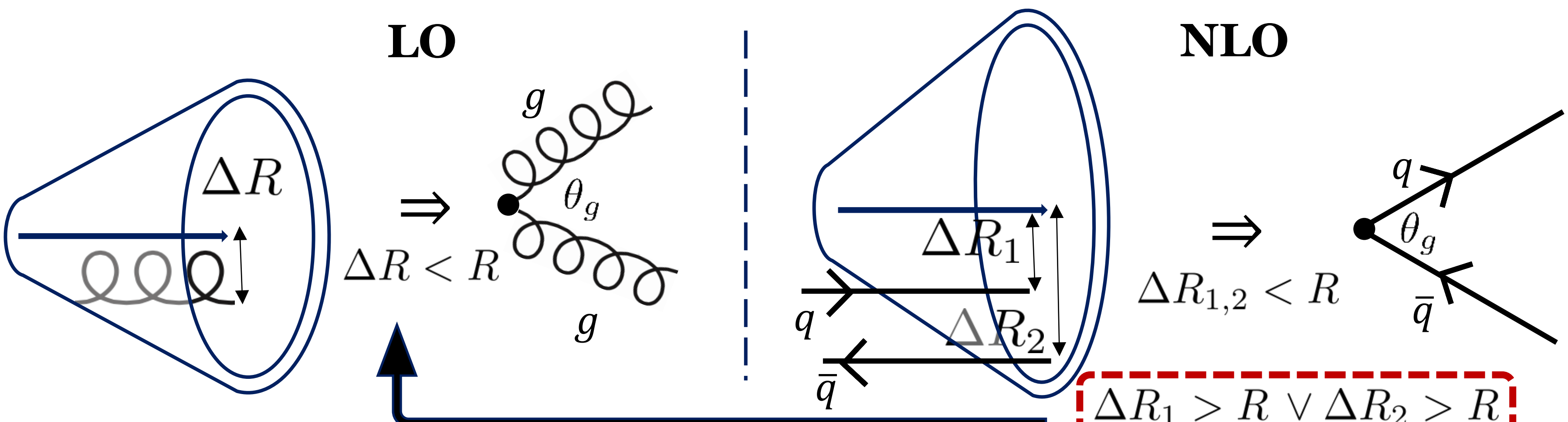


Logarithmic Enhancement:

$$\theta_1 > \theta_2 > \theta_3$$

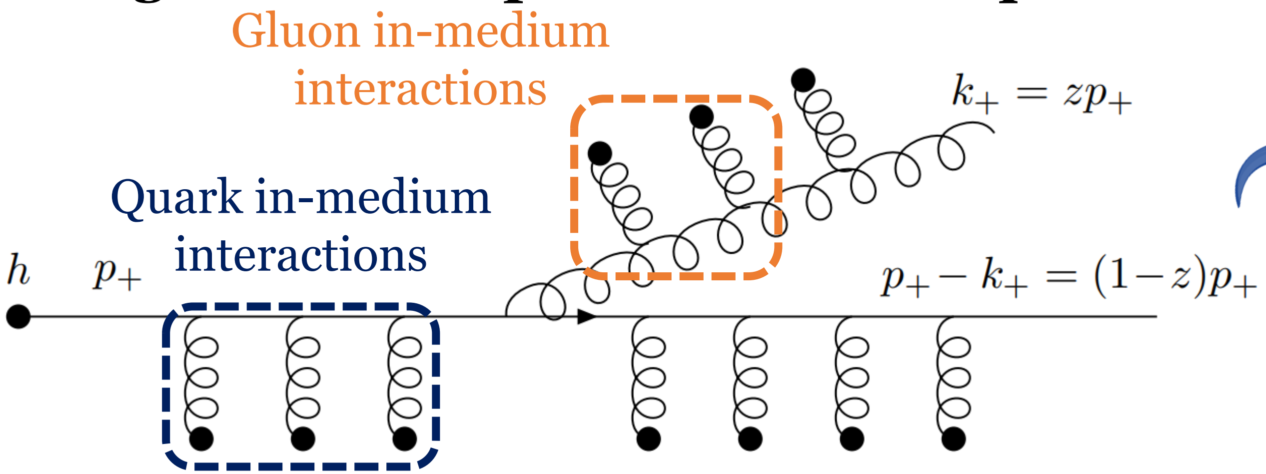
- ❑ SD algorithm will decluster first C/A shower algorithm step
- ❑ **First C/A** step corresponds to **emission** with **widest angle**

Colour tagging



1-Prong Eloss

Diagrammatic representation of a quark traversing the medium



BDMPS-Z:

Resummation of the several in-medium interactions

How to extend to several in-medium emissions?

Working in the leading soft regime of the BDMPS-Z formalism..

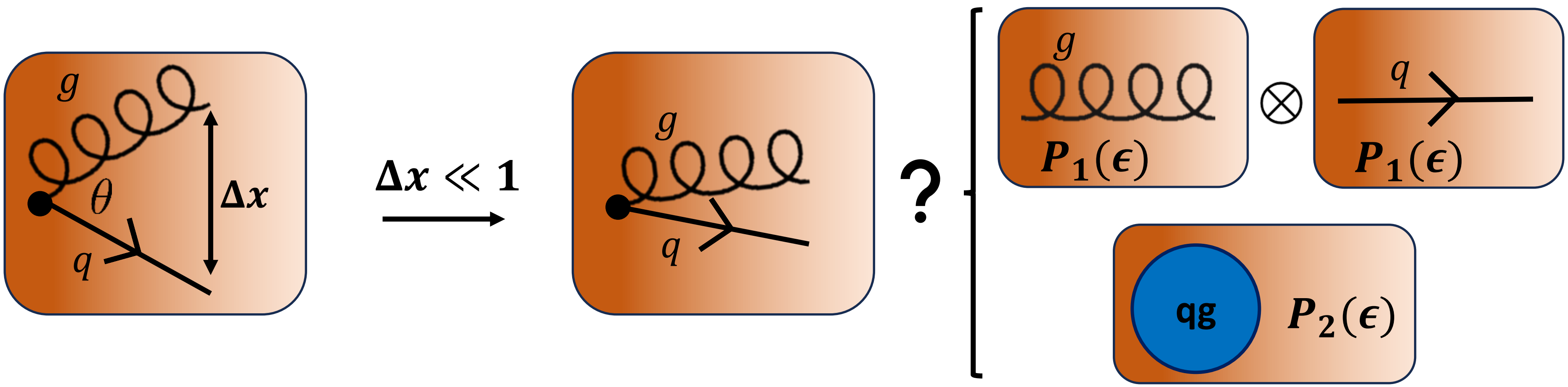
Incoherence of sucessive medium-induced emissions

Compute E-loss as a Poisson distribution based on the previous diagram

$$P_1(\epsilon) = \sqrt{\frac{2\omega_s}{\epsilon^3}} \exp\left[-\frac{2\pi\omega_s}{\epsilon}\right]$$

Antenna-based Jet Quenching

But several partons traversing the medium …
The QGP has a finite color resolution …

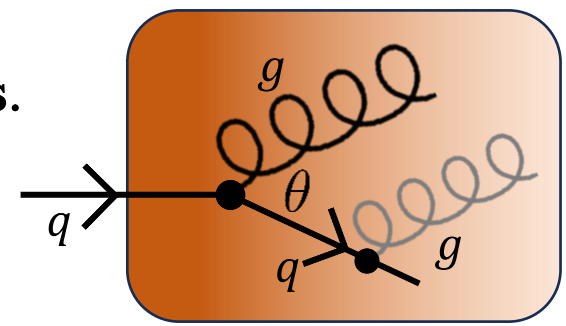


2-prong jet quenching

- ❑ Consider destructive **color interference effects**.

$$P_2(\epsilon) = P_{\text{inc}}(\epsilon) + P_{\text{coh}}(\epsilon)$$

- ❑ **Antenna resolution** based on the value of $\boldsymbol{\theta}$.



E-loss distribution sensitive to the jet substructure

Antenna E-loss distribution

Y. Mehtar & K. Tywoniuk, Nucl.Phys.A 979 (2018) 165-203

$$P_{\rm sing}(\epsilon) = \int_0^\infty d\epsilon_1 \int_0^\infty d\epsilon_2\, P_1(\epsilon_1, L)\, P_1(\epsilon_2, L)\, \delta(\epsilon - \epsilon_1 - \epsilon_2) \quad \rightarrow \quad P_{inc}(\epsilon)$$

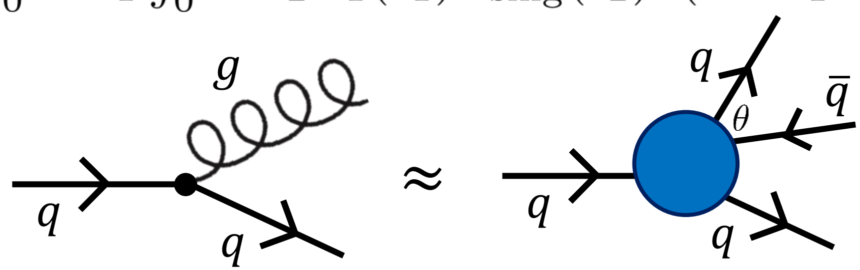
$$- 2 \int_0^L dt \int_0^\infty d\epsilon_1 \int_0^\infty d\epsilon_2\, P_1(\epsilon_1, L-t)\, P_1(\epsilon_2, L-t) \times \left[1 - \Delta_{\rm med}(t)\right] \int_0^\infty d\omega\, \Gamma(\omega, t)\, \delta(\epsilon - \epsilon_1 - \epsilon_2 - \omega)\,, \quad \rightarrow \quad P_{coh}(\epsilon)$$

Decoherence parameter

$$\Delta_{\rm med}(t) = 1 - \exp\left[-\theta_{12}/\theta_c\right]$$

$\sim$ **'Probability to resolve the antenna'**

$$P_2^{\rm R}(\epsilon) = \int_0^\infty d\epsilon_1 \int_0^\infty d\epsilon_2 P_1(\epsilon_1) P_{\rm sing}(\epsilon_2) \delta(\epsilon - \epsilon_1 - \epsilon_2)$$



Large N_c limit:

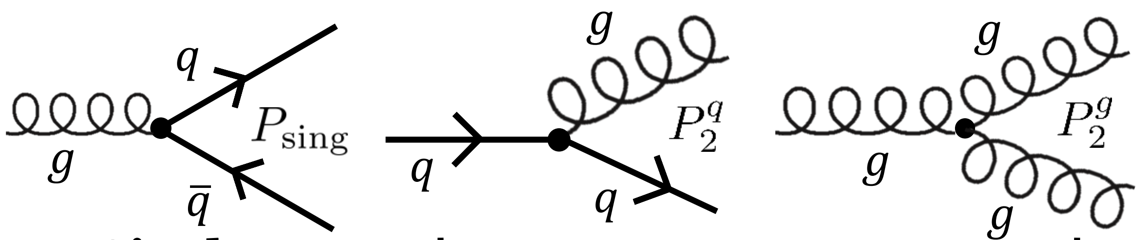
$C_F \rightarrow C_A/2$

Quenching Models

Antenna Model

$$P_{\mathrm{sing}}(\epsilon) = \sqrt{\frac{8\omega_s}{\epsilon^3}}\, e^{-\frac{8\pi\omega_s}{\epsilon}} \int_0^L dt\, \frac{\sqrt{8\omega_r}\, e^{-\frac{8\pi\omega_s'}{\epsilon-\omega}}\, [\epsilon - 16\pi\omega_s']}{\epsilon^{5/2}} \times [1 - \Delta_{\mathrm{med}}(t)]$$

$$P_2^{\mathrm{R}}(\epsilon) = \int_0^\infty d\epsilon_1 \int_0^\infty d\epsilon_2 P_1(\epsilon_1) P_{\mathrm{sing}}(\epsilon_2)\delta(\epsilon - \epsilon_1 - \epsilon_2)$$



Singlet configuration

Non-singlet configurations

$\theta \to 0$: Singlet: $\boldsymbol{\delta(\epsilon)}$; Non-Singlet: $\boldsymbol{P_1(\epsilon)}$

Toy MC

$$R_U \sim U[0,1]$$

$$\Delta_{\mathrm{med}}(t) = 1 - \exp\left[-\frac{1}{12}\hat{q}\theta_{12}t^3\right]$$

$R_U > \Delta_{\mathrm{med}}(t = L)$: **Coherent E-loss**

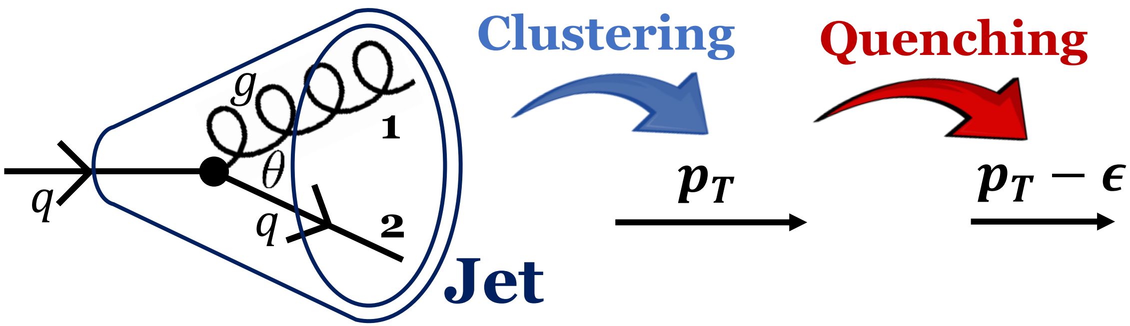
$R_U < \Delta_{\mathrm{med}}(t = L)$: **Incoherent E-loss**

- For this case, the antenna is **either** completely **coherent** or **incoherent**.

Substructure Quenching

How is the jet substructure modified by a shift in the jet p_T spectrum

Survival Bias



Is the jet substructure modified ?

- **Survival Bias:** Probability jets have to verify all Exp. cuts after quenching.
- **Different observables** have **different correlations** with the **jet p_T**.
- **Jets** with **smaller θ_g are more likely to survive** the in-medium modifications.

Coherence effects

When considering an antenna configuration: $\epsilon = \epsilon(\theta)$

Jet substructure modifications = Survival bias + Coherence effects

- Antenna: Convoluted
- Toy: Separated