Flavour Tagging with Jet Substructure

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Based on: 2104.06920 [hep-ph]
2108.10024 [hep-ph]

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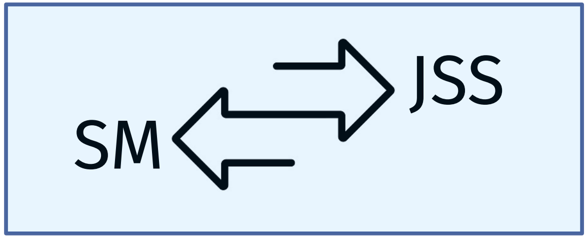
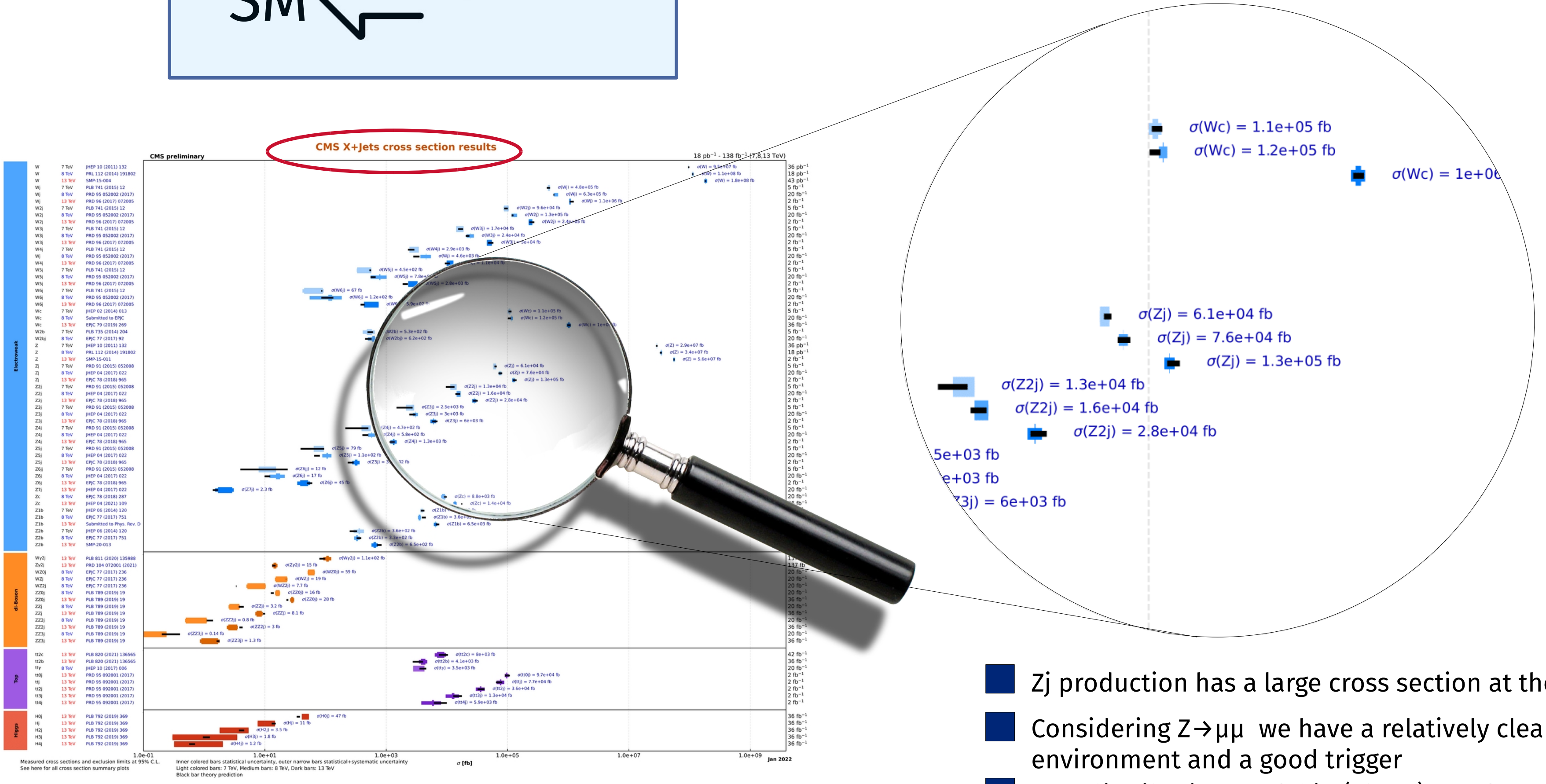
SM@LHC YSF
12 April 2022

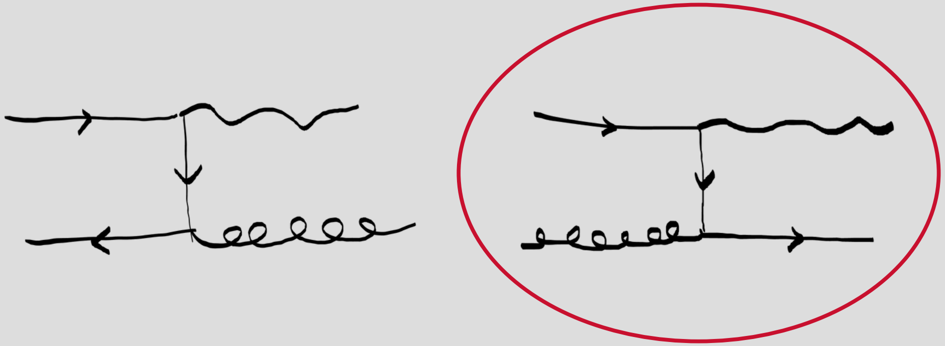
Why Zj events?





- Zj production has a large cross section at the LHC
- Considering Z→μμ we have a relatively clean environment and a good trigger
- Z pT distribution useful in (gluon) PDF fits

Initial-gluon purity

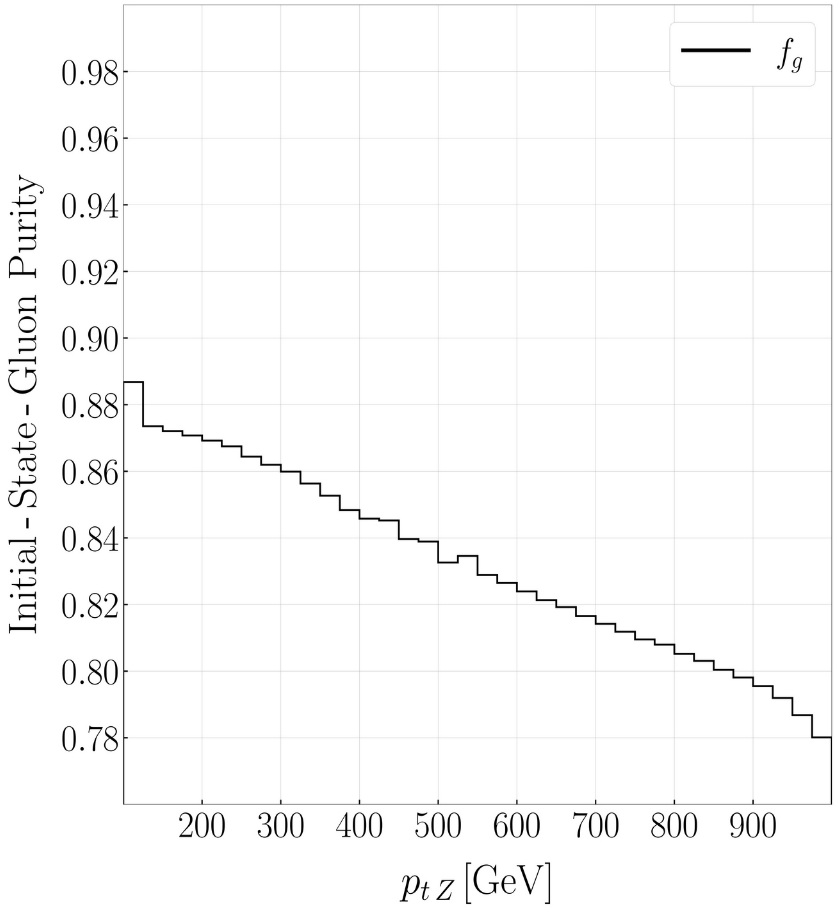


Purity

$$f_g = \frac{\sigma_{qg}}{\sigma_{qq} + \sigma_{qg}}$$

- Initial gluon = final quark at LO
- Initial gluon contribution dominates the process

Can we use JSS to build a different* observable with an even more dominant contribution from the initial gluon?



*wrt the standard pT distribution of the Z

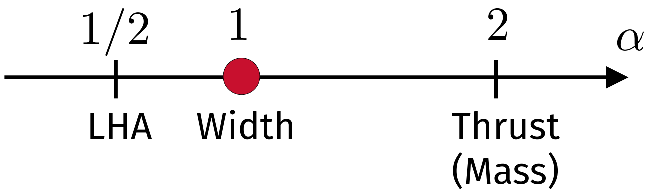
Which JSS observable?

Jet Angularities

$$\lambda_\alpha^\kappa = \sum_{j\in \mathrm{Jet}} \left(\frac{p_{T,j}}{\sum_{j\in \mathrm{Jet}} p_{T,j}}\right)^\kappa \left(\frac{\Delta_j}{R}\right)^\alpha$$

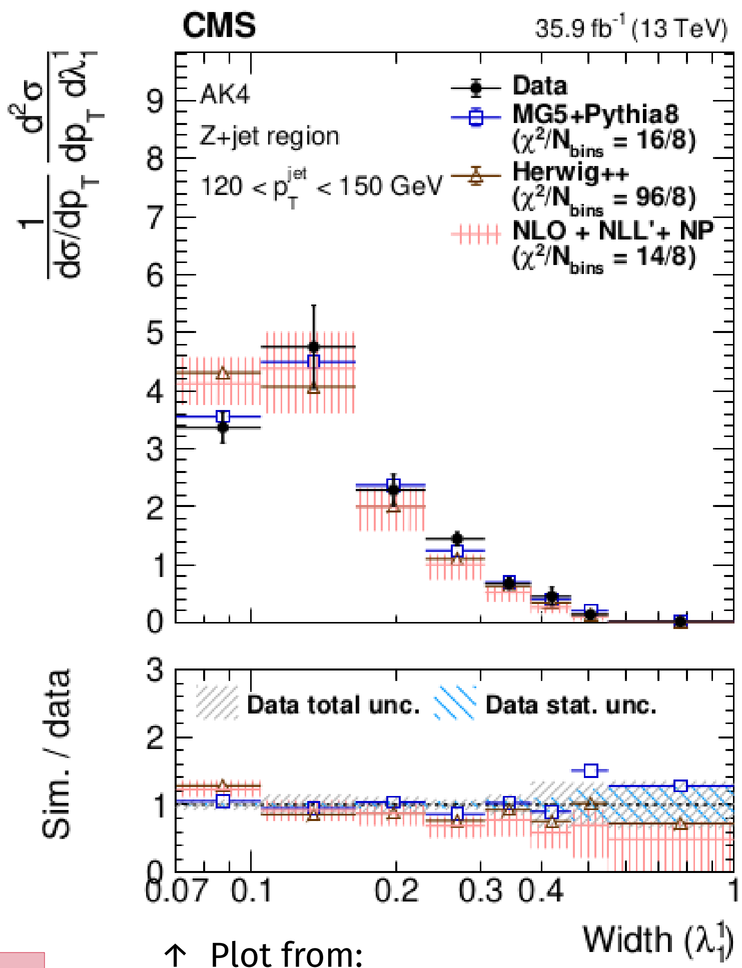
$$\simeq \sum_{j\in \mathrm{Jet}} z_j^\kappa \theta_j^\alpha$$

$$\Delta_j \equiv \sqrt{(\phi-\phi_j)^2 + (\eta-\eta_j)^2}$$



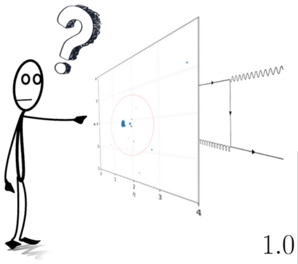
- IRC safe (κ=1, α>0)
- Angularity distribution available at NLL’ logarithmic accuracy
- Measured at the LHC

We want to use jet angularities as a tagger to select only final quark-jets.

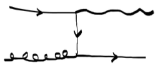


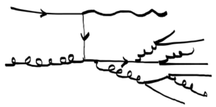
↑ Plot from:
2109.03340, A. Tumasyan et al.
Resummed prediction from:
2104.06920, SC et al.

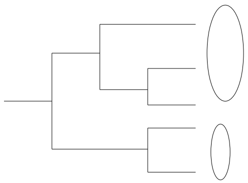
What do we mean by quark-jet?

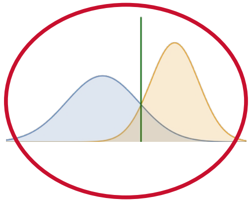


Ill defined


A Born level quark parton


The initiating quark parton in a final state shower


A parton-level jet that has been quark tagged by an IRC safe flavour algorithm


A phase space region that yields an enriched sample of quarks

Well defined

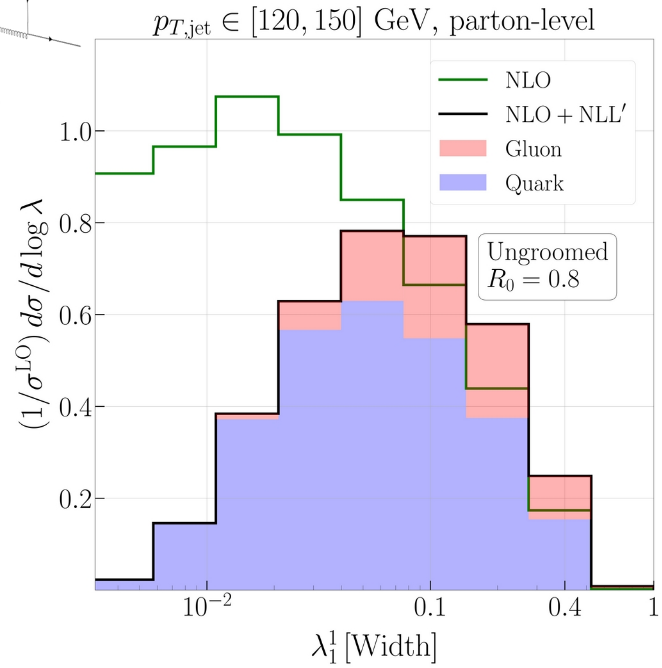
UV

$\sim$ 13 TeV

$\lesssim$ 1 GeV

IR

Jets live here



A cut in the angularity distribution can serve as an IRC safe quark/gluon discriminator.

↑ Diagram adapted from: 1704.03979v2, P. Gras et al.

The ROC curves

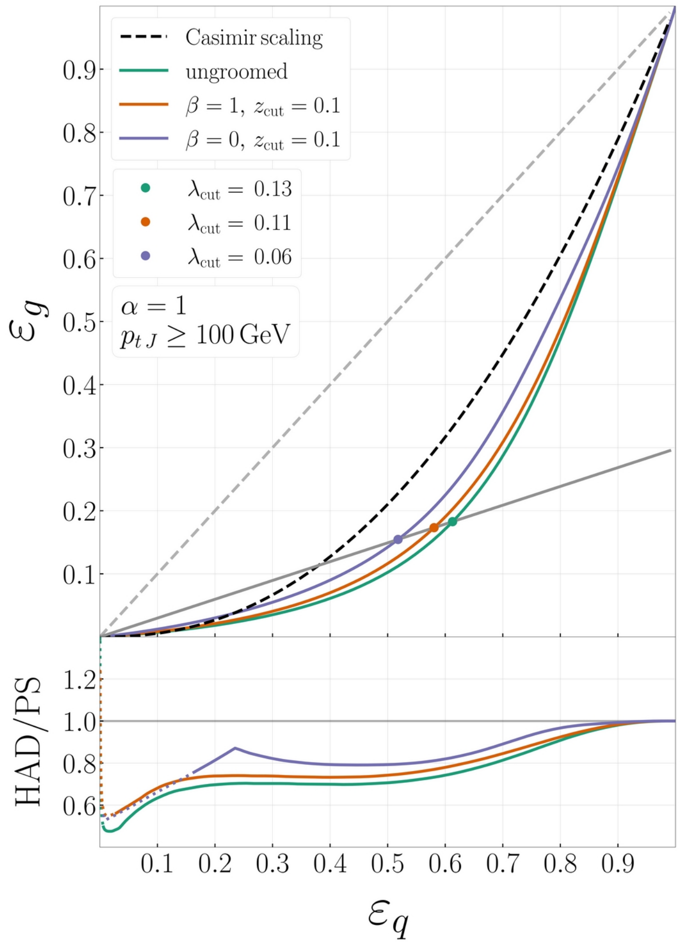
$$\varepsilon_k = \frac{1}{\sigma_{ij}} \int_0^{\lambda_{\text{cut}}} \frac{d\sigma_{ij}}{d\lambda} d\lambda \quad \text{with} \quad i\, j \to Z\, k$$

- ε_q: true-positive rate (efficiency) of final quark-jets
- ε_g: false-positive rate of final quark-jets

$$\tilde{f}_g = \frac{\varepsilon_q \sigma_{qg}}{\varepsilon_g \sigma_{qq} + \varepsilon_q \sigma_{qg}} = \left(1 + \frac{1-f_g}{f_g}\frac{\varepsilon_g}{\varepsilon_q}\right)^{-1}$$

$$\varepsilon_g = \frac{f_g(1-\tilde{f}_g)}{\tilde{f}_g(1-f_g)}\varepsilon_q$$

We use the ROC curve to determine the value of the cut.



Initial-gluon purity (after tagging)

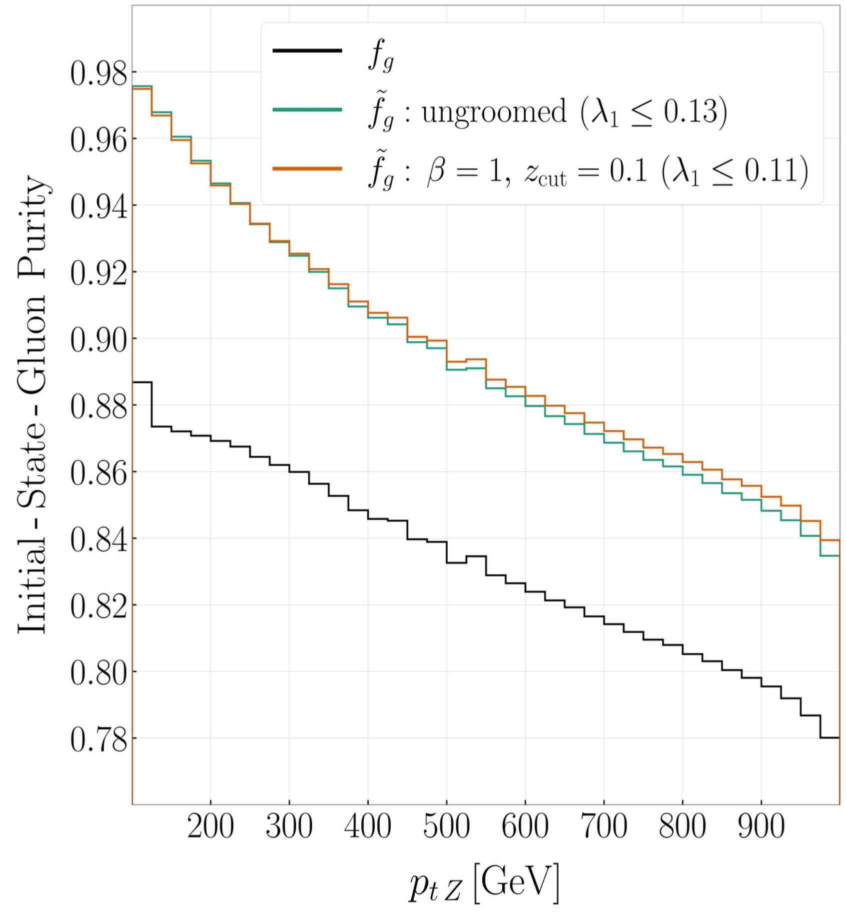
$$\varepsilon_k = \frac{1}{\sigma_{ij}} \int_0^{\lambda_{\text{cut}}} \frac{d\sigma_{ij}}{d\lambda} d\lambda \quad \text{with} \quad i\, j \to Z\, k$$

- ε_q: true-positive rate (efficiency) of final quark-jet
- ε_g: false-positive rate of final quark-jet

$$\tilde{f}_g = \frac{\varepsilon_q \sigma_{qg}}{\varepsilon_g \sigma_{qq} + \varepsilon_q \sigma_{qg}} = \left(1 + \frac{1 - f_g}{f_g} \frac{\varepsilon_g}{\varepsilon_q}\right)^{-1}$$

$$\varepsilon_g = \frac{f_g (1 - \tilde{f}_g)}{\tilde{f}_g (1 - f_g)} \varepsilon_q$$

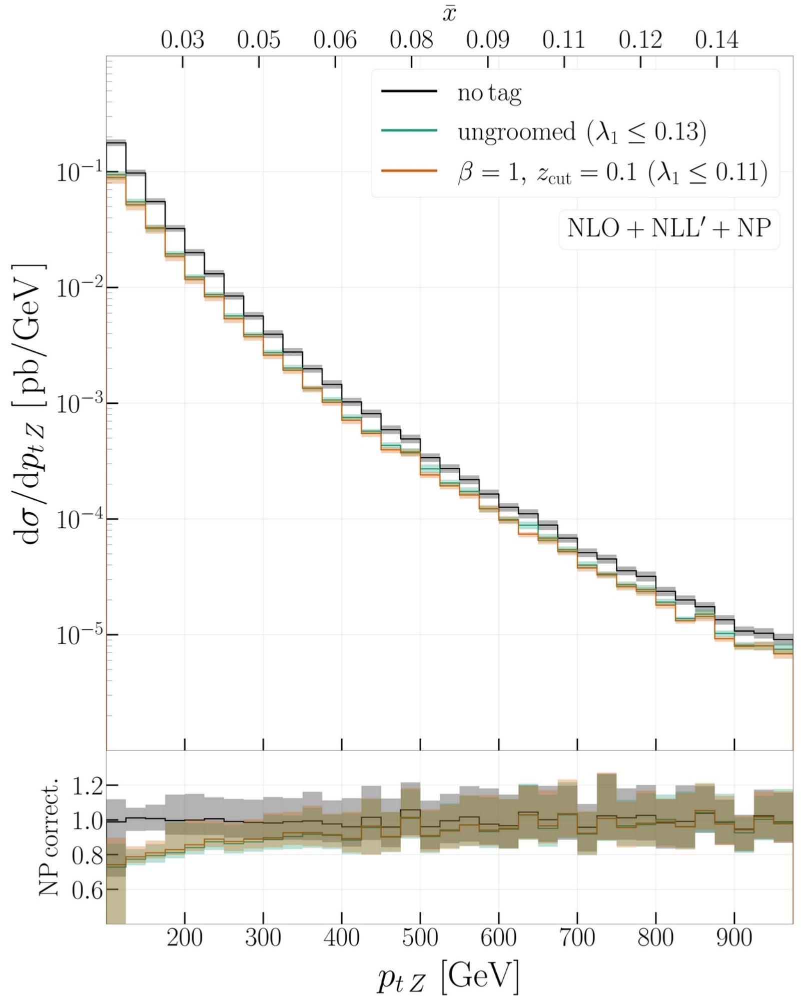
We have a gain of about 10% in the initial-gluon purity.



Conclusions and outlook

- JSS can be successfully applied to probe the SM.
- We computed and studied the differential distribution in the transverse momentum of the Z boson with a cut on the angularity and with NLL' resummation of log(λ).
- The Z boson pT distribution (on the right) could be more interesting for gluon PDFs determination than standard pT distribution (but the cut discards some events = less statistics)
- Our NLL' calculations are implemented in the SHERPA code as a plugin based upon the CAESAR framework.
- Unfortunately, we note increased sensitivity to NP effects at low pT (compared to standard Z pT).

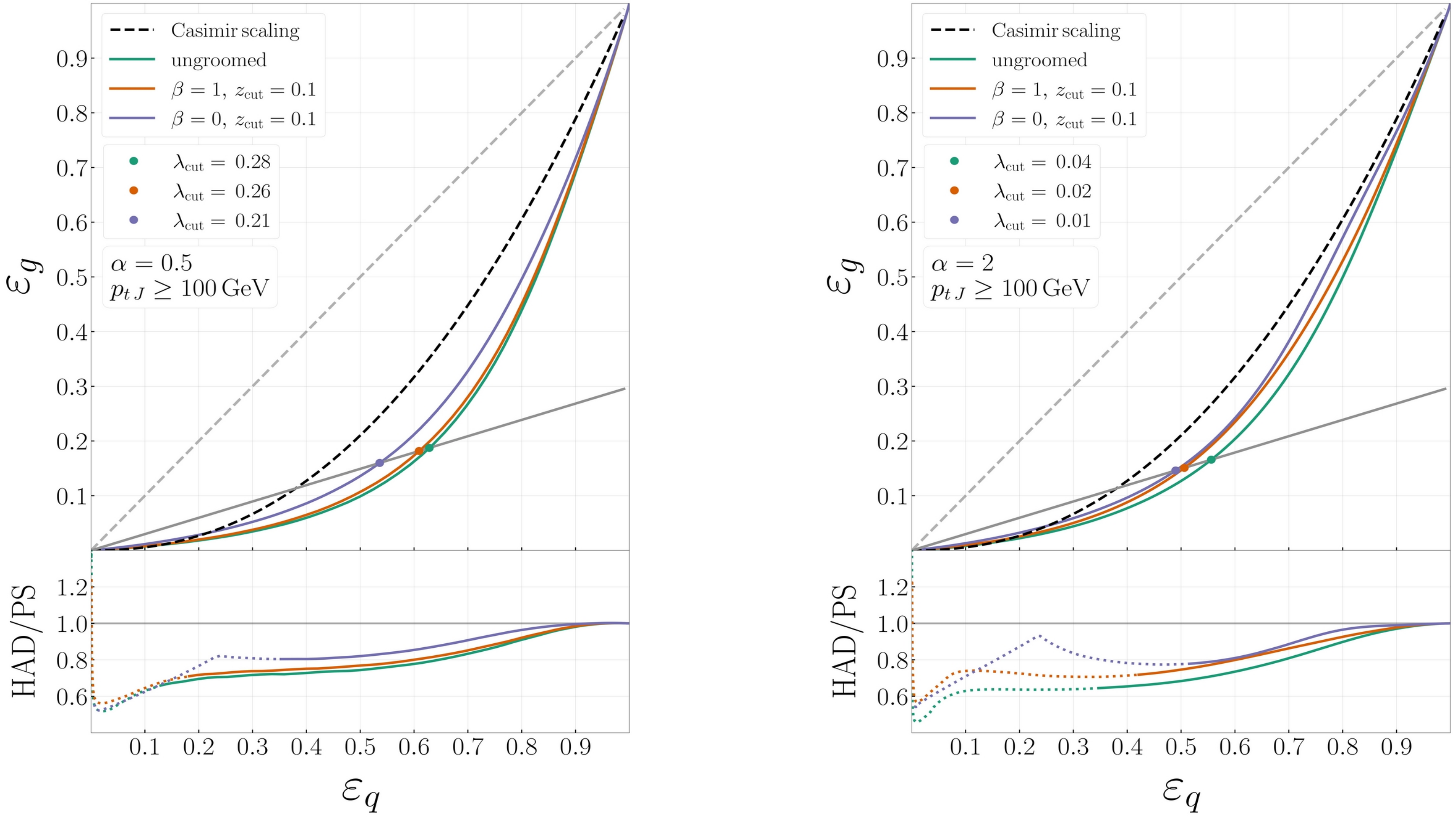
Can we <u>efficiently</u> use jet angularities to constrain gluon PDFs?



Thank you for your attention!

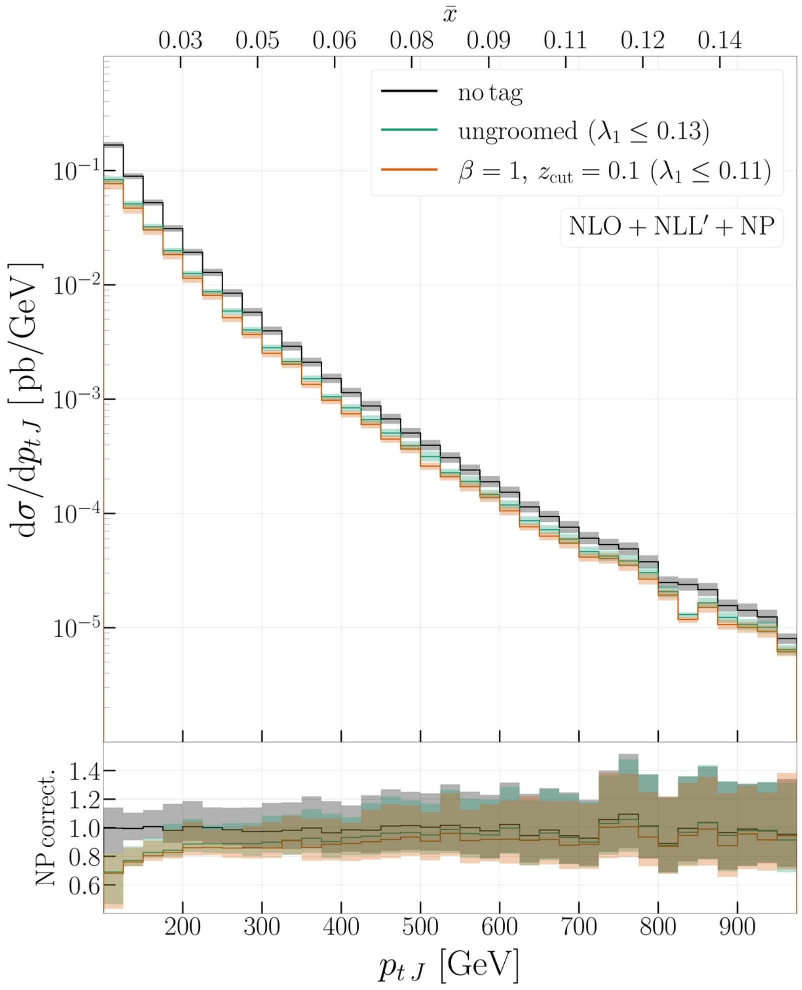
BACKUP SLIDES

ROC curves for Thrust and the LHA



Jet pT distrib.

- Jet pT distribution is more sensitive to NP effects.



Matching to NLO

$$\Sigma_{\mathrm{match,mult}}(\lambda_\alpha) = \sum_\delta \Sigma^\delta_{\mathrm{match,\ mult}}(\lambda_\alpha)$$

$$\Sigma^\delta_{\mathrm{match,\ mult}}(\lambda_\alpha) = \Sigma^\delta_{\mathrm{res}}(\lambda_\alpha)\Bigg[1 + \frac{\Sigma^{\delta,(1)}_{\mathrm{fo}}(\lambda_\alpha) - \Sigma^{\delta,(1)}_{\mathrm{res}}(\lambda_\alpha)}{\sigma^{\delta,(0)}} + \\ + \frac{1}{\sigma^{\delta,(0)}}\left(- \bar{\Sigma}^{\delta,(2)}_{\mathrm{fo}}(\lambda_\alpha) - \Sigma^{\delta,(2)}_{\mathrm{res}}(\lambda_\alpha) - \Sigma^{\delta,(1)}_{\mathrm{res}}(\lambda_\alpha)\frac{\Sigma^{\delta,(1)}_{\mathrm{fo}}(\lambda_\alpha) - \Sigma^{\delta,(1)}_{\mathrm{res}}(\lambda_\alpha)}{\sigma^{\delta,(0)}}\right)\Bigg]$$

$$\begin{cases} \sigma = \Sigma(1) \\ \Sigma^{(k)} \propto \alpha^2_{\mathrm{EW}}\alpha_S^{1+k} \\ \bar{\Sigma} = \sigma - \Sigma \end{cases}$$

$$\frac{\alpha_S}{2\pi}C^{\delta,(1)} \equiv \lim_{\lambda\to 0}\frac{\Sigma^{\delta,(1)}_{\mathrm{fo}}(\lambda_\alpha) - \Sigma^{\delta,(1)}_{\mathrm{res}}(\lambda_\alpha)}{\sigma^{\delta,(0)}}$$