Parton Shower based on TMD parton distributions

Melanie Viola Schmitz [1], Francesco Hautmann [2], Hannes Jung [1], Sara Taheri Monfared [1]

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Outline

The Parton Branching method

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- with the Sudakov form factor, a general form of the evolution equation in a form using the Sudakov form factor can be derived:

$$t \frac{\partial}{\partial t} \frac{f(x,t)}{\Delta_s} = \int \frac{\mathrm{d}z}{z} \frac{1}{\Delta_s} \frac{\alpha_s}{2\pi} P(z) f\left(\frac{x}{z}, t\right)$$

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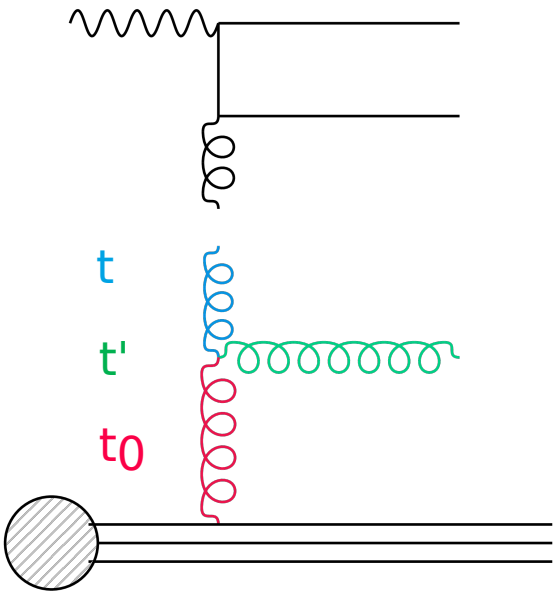
- Integration leads to:

$$f(x,t) = f(x,t_0)\Delta(t) + \int \frac{\mathrm{d}t'}{t'} \frac{\Delta(t)}{\Delta(t')} \frac{\alpha_s(t')}{2\pi} \int \frac{\mathrm{d}z}{z} P(z) f\left(\frac{x}{z}, t'\right)$$

- **solve it by iteration**

The Parton Branching method



$$f_0(x,t) = f(x,t_0)\,\Delta(t)$$

$$f_1(x,t) = f(x,t_0)\,\Delta(t) + \frac{\alpha_s}{2\pi}\int_{t_0}^{t}\frac{\mathrm{d}t'}{t'}\frac{\Delta(t)}{\Delta(t')}$$

$$\cdot\int_x^1 \frac{\mathrm{d}z}{z}\tilde{P}(z)\,f(x/z,t_0)\,\Delta(t')$$

→ whole chain in evolution is generated with **information about all partons and their momenta**

→ kinematics of **every single splitting process** can be treated exactly

For more information about the PB method see talks by S. Taheri Monfared, A. Lelek on Thursday.

A. Bermudez Martinez, P. Connor, F. Hautmann, H. Jung, A. Lelek, V. Radescu and R. Zlebcik, arXiv:1804.11152 [hep-ph].
F. Hautmann, H. Jung, A. Lelek, V. Radescu and R. Zlebcik, JHEP, 01(), 070.
F. Hautmann, H. Jung, A. Lelek, V. Radescu and R. Zlebcik, Phys. Lett., B772(), 446.

The TMD parton shower and its applications

What is the gain of the parton branching method?

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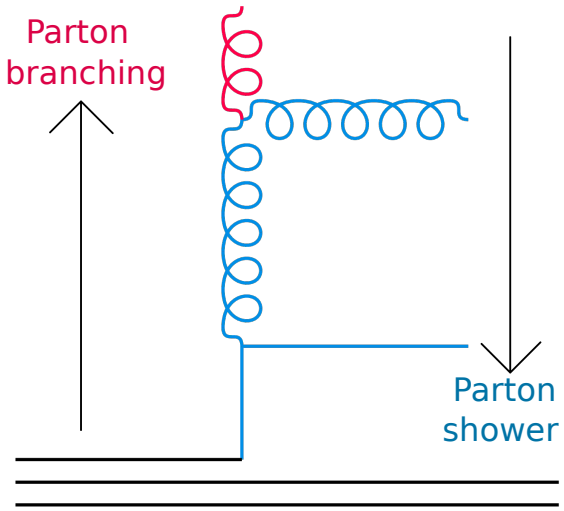
PB evolution

starts at hadron scale μ_0^2 and evolves from small to large μ^2

Parton shower

backward evolution from hard scale μ^2 to hadron scale μ_0^2



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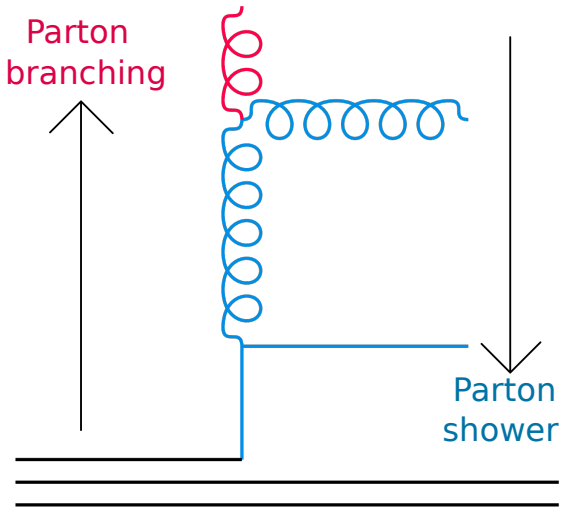

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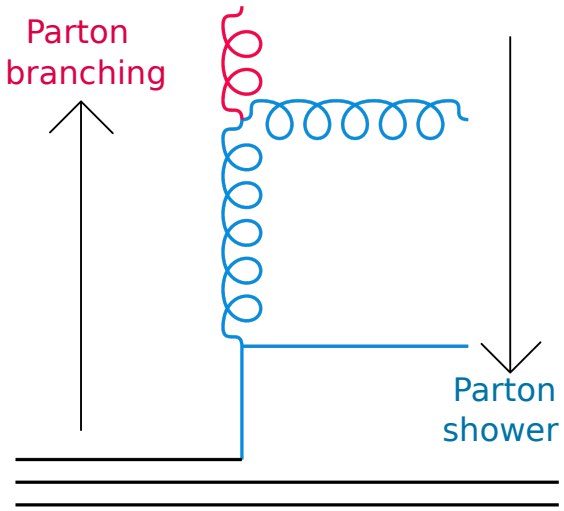

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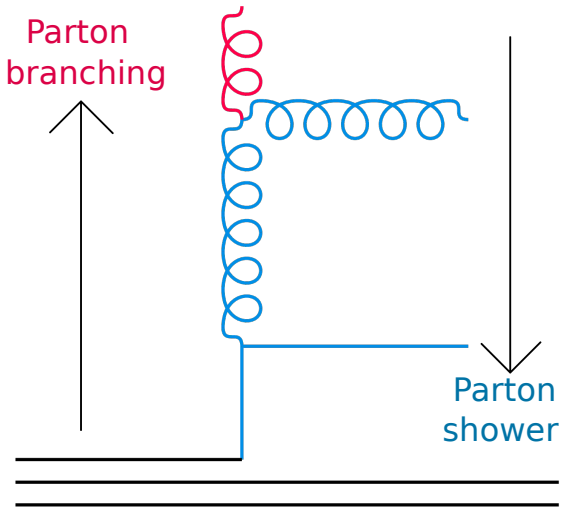

→ PB method **allows to determine TMDs**

→ PB method **allows to construct parton shower following exactly TMD**

TMD parton shower (implemented in CASCADE 3):

requires a TMD, depending on the transverse momentum of the propagator

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How can this TMD parton shower be applied?

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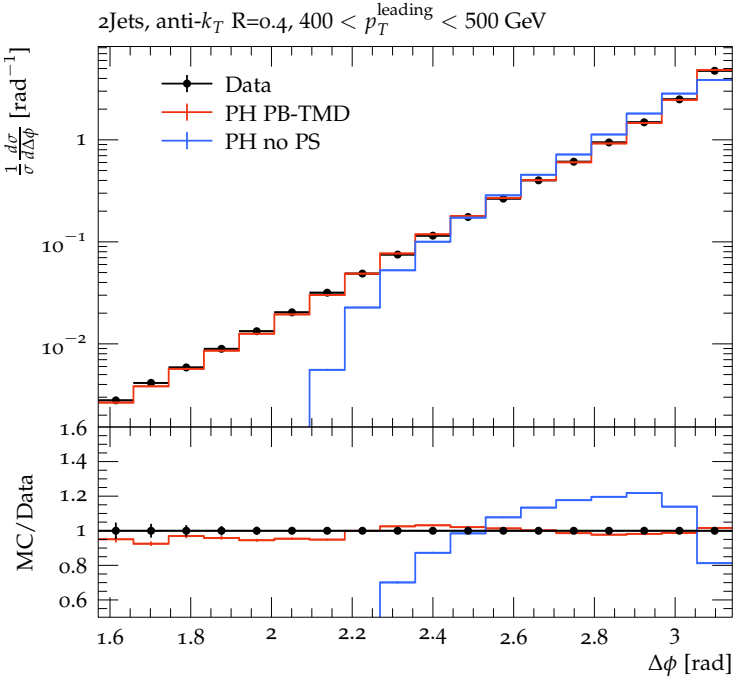
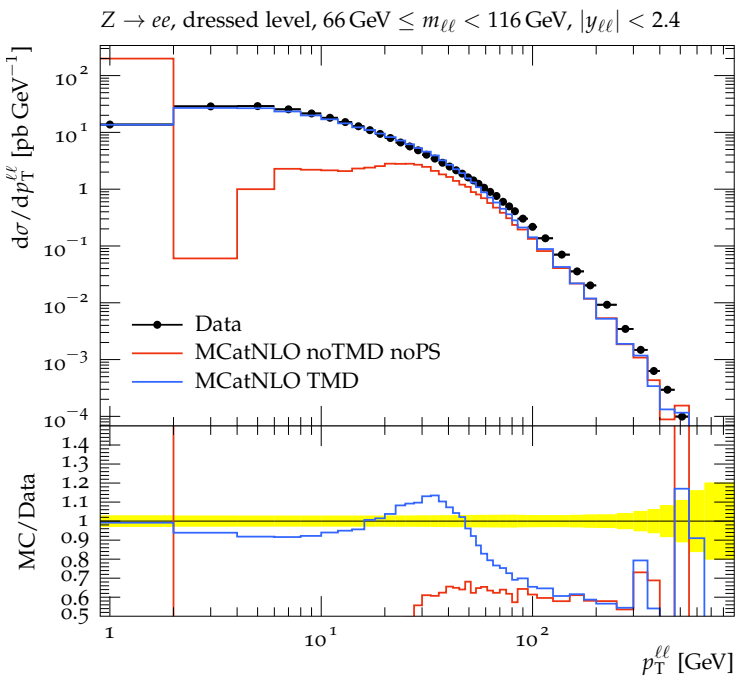


$\Delta\Phi$ distribution for NLO dijets



p_T distribution for NLO DY process

→ POWHEG+TMD+PS gives very good description & MC@NLO+TMD fits reasonable

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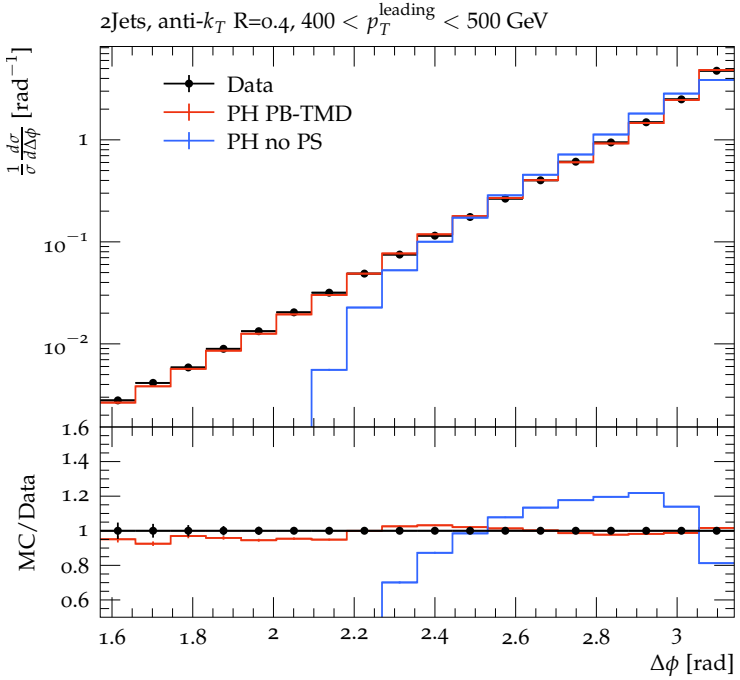

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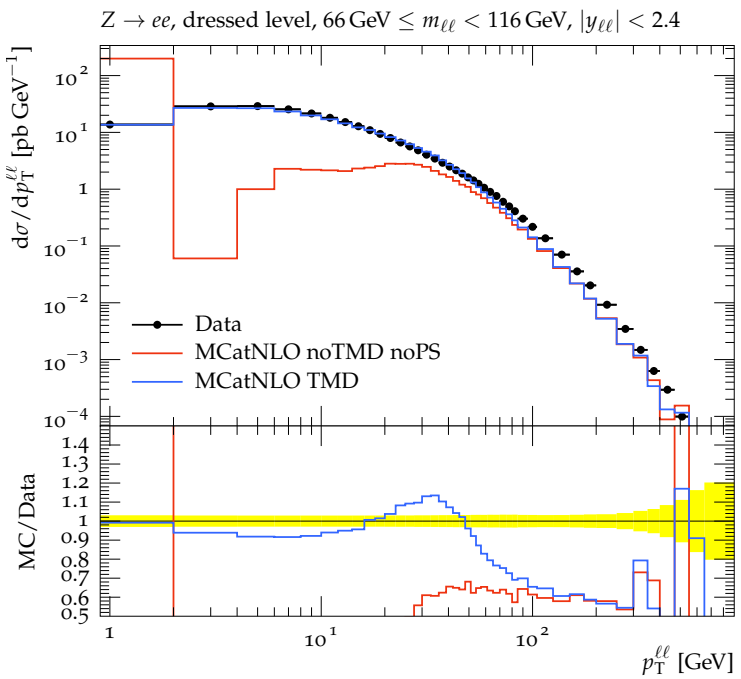

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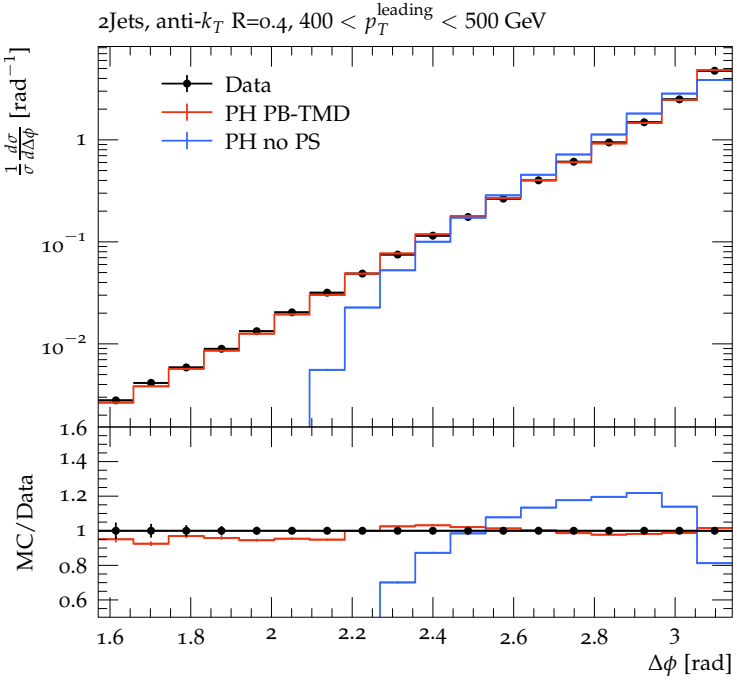

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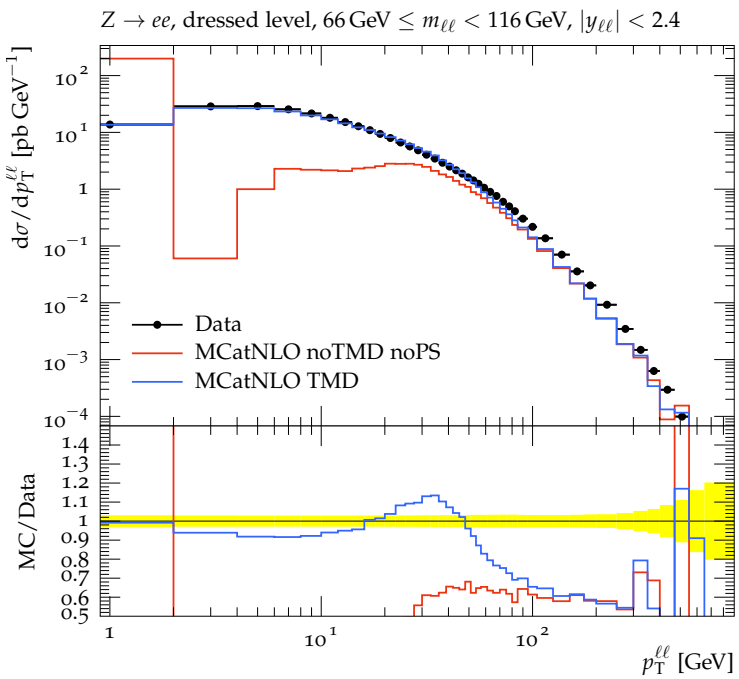

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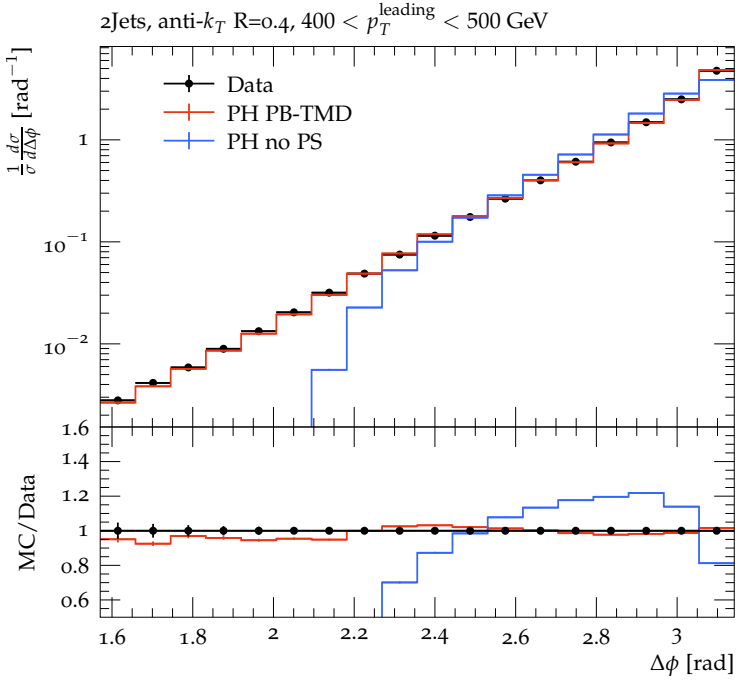

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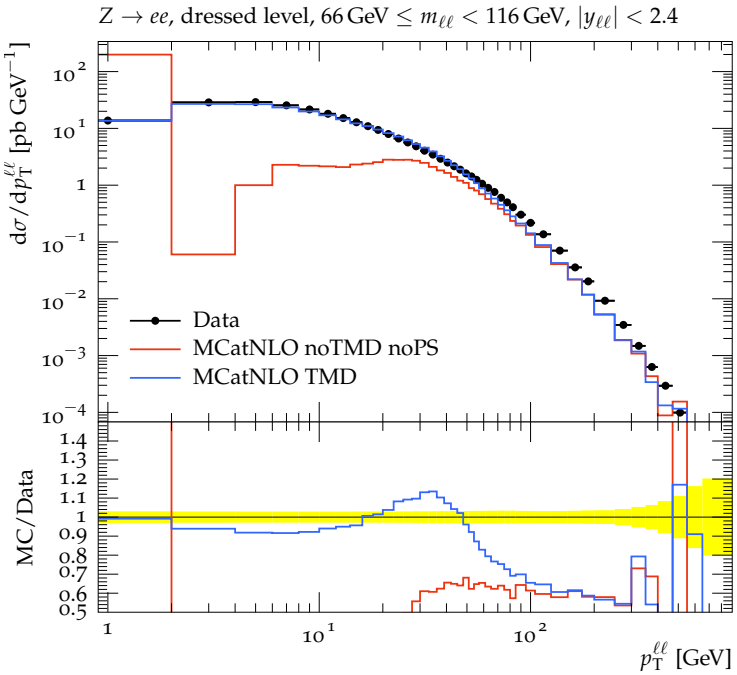

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But how does it look like in detail?
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→ **Perform a parton shower study to investigate how well the shower follows the TMDs**

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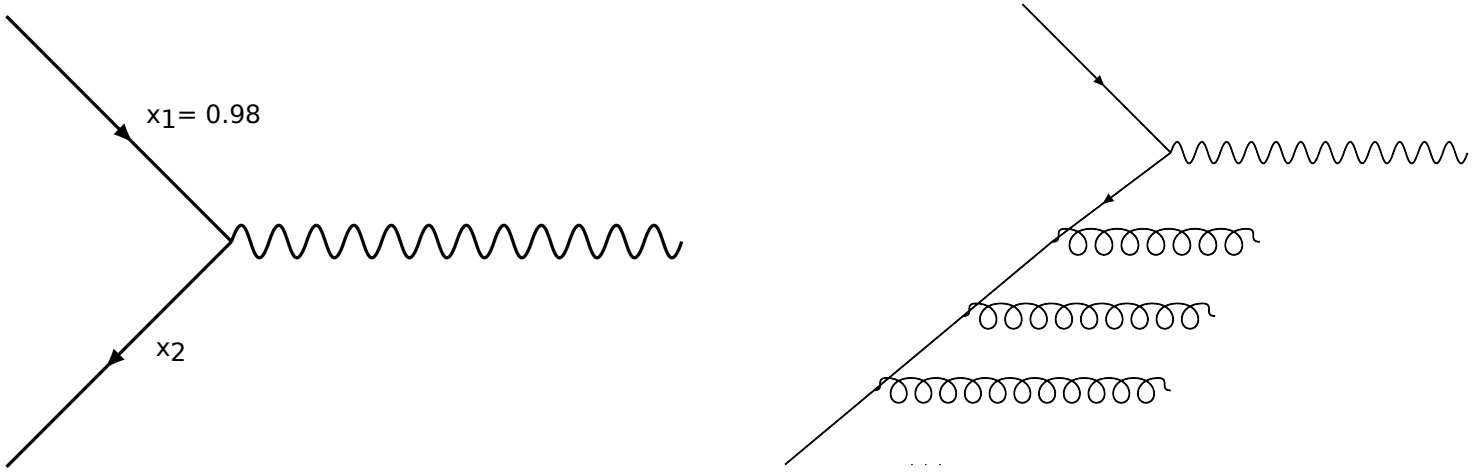

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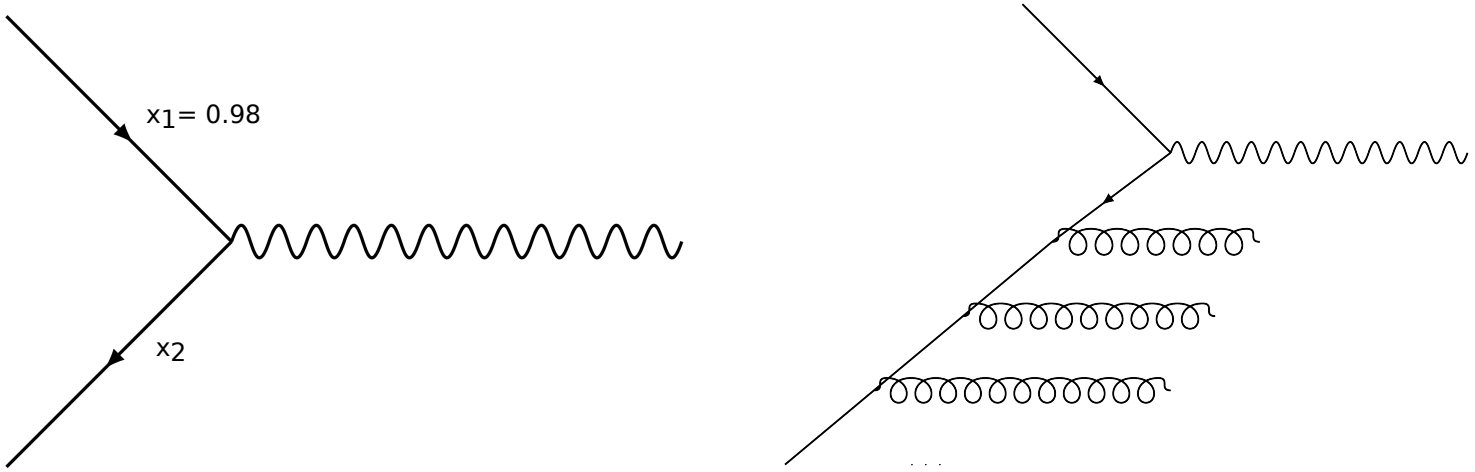

Technical details:

- generate hard process (PYTHIA) and "add" TMD and PS (CASCADE 3)
- analyse events, calculate kinematics, determine effective TMD

TMD from final state events

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PDF set PYTHIA

hard process is generated with PYTHIA using:

- LHAPDF6:PB-TMDNLO-HERAI+II-2018-set1
- LHAPDF6:PB-TMDNLO-HERAI+II-2018-set2

TMD PDF set CASCADE

$k_\perp$ is "added" by CASCADE 3 using:

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Difference between set1 & set2: set1 $\rightarrow$ $\alpha_s\left(\mu^2\right)$, set2 $\rightarrow$ $\alpha_s\left((1-z)^2\mu^2\right)$

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$\rightarrow$ set1 integrated over $k_\perp$ is just HERAPDF2.0 - this is not the case for set2 although it is fitted to the same data!

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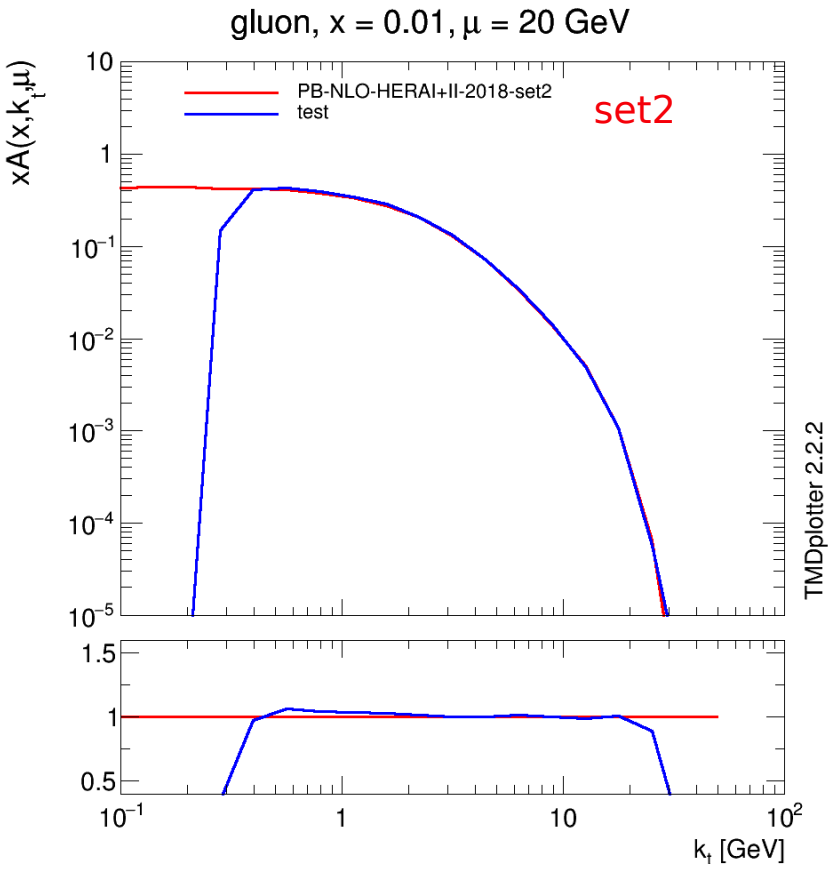
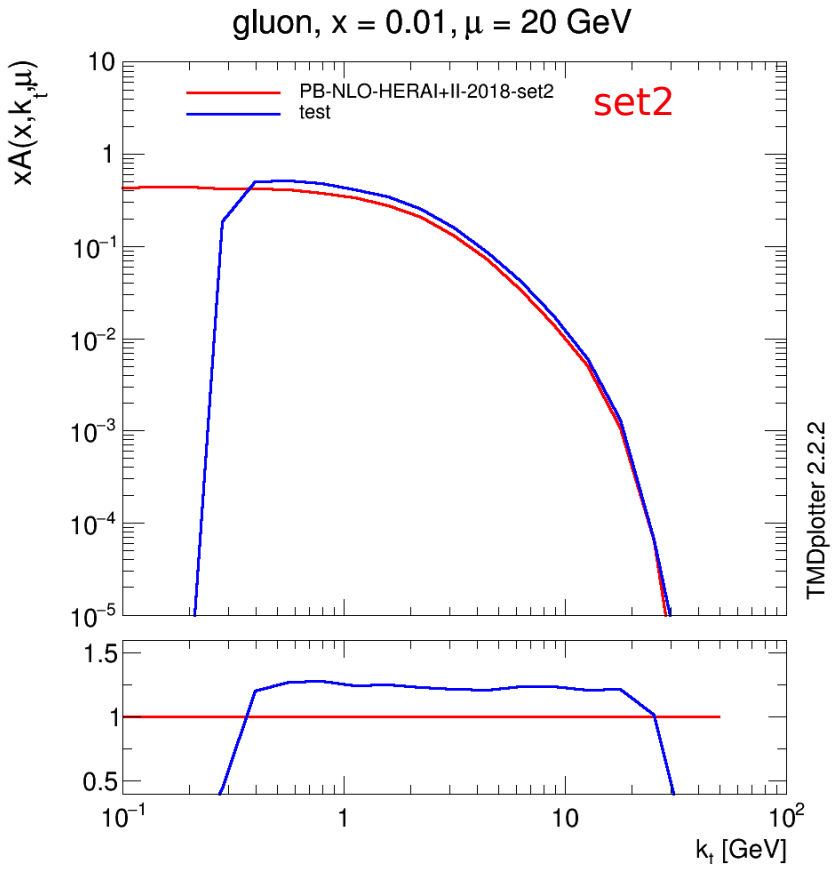
$\rightarrow$ to **check consistency** with the input TMD, TMDs are obtained from final state events

Consistency check: TMD vs. $k_\perp$

blue: obtained TMD from final state events of the toy process



input PDF: set2 & TMD: set2



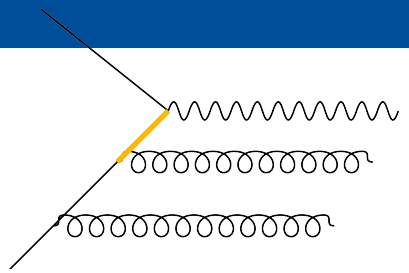
input PDF: set1 & TMD: set2

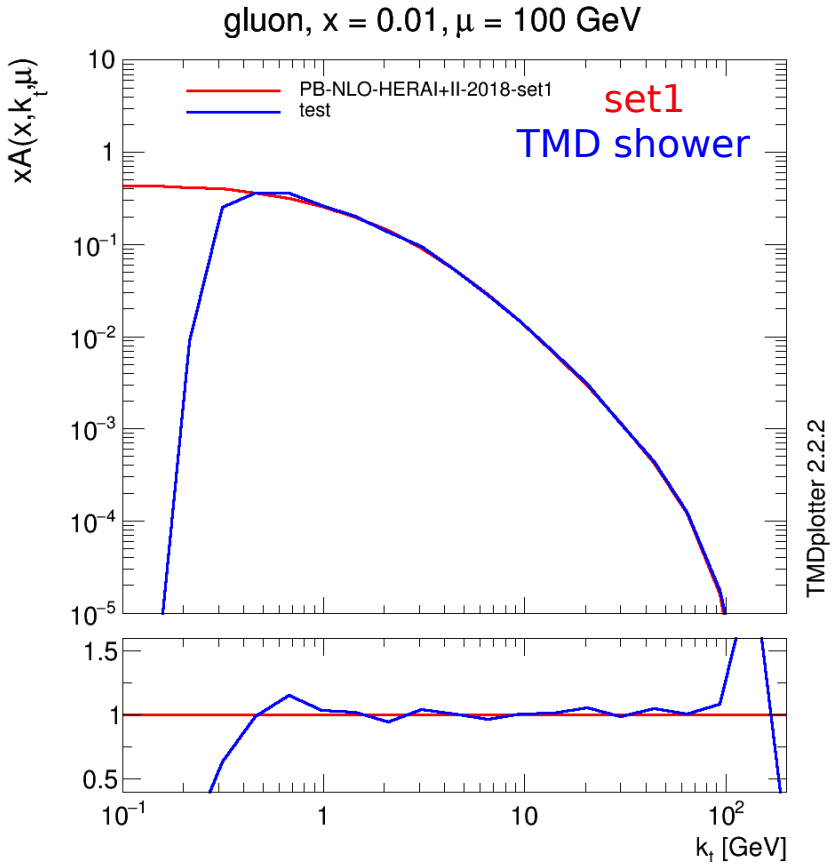
→ reconstruction of TMD

→ consistent use of collinear and TMD PDF set essential!

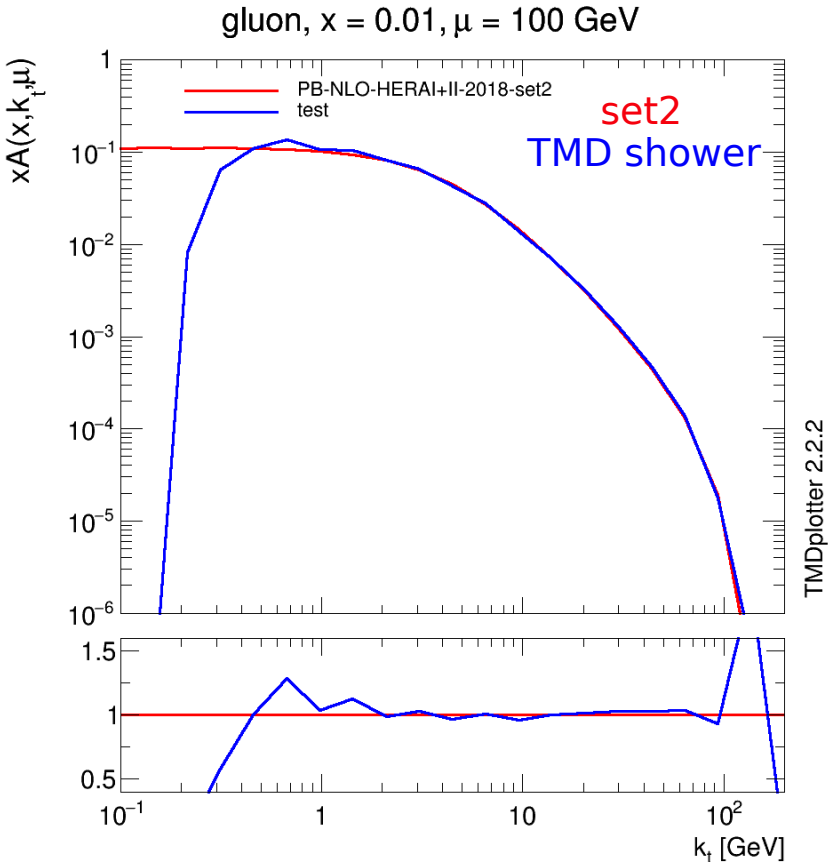
TMD parton shower: TMD vs. $k_\perp$

How does it look like when PS is added?





using set1 as input TMD

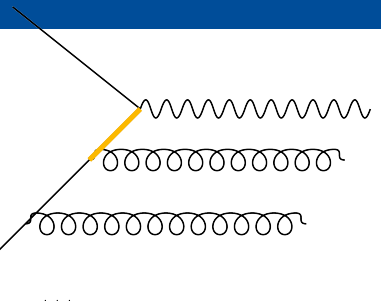


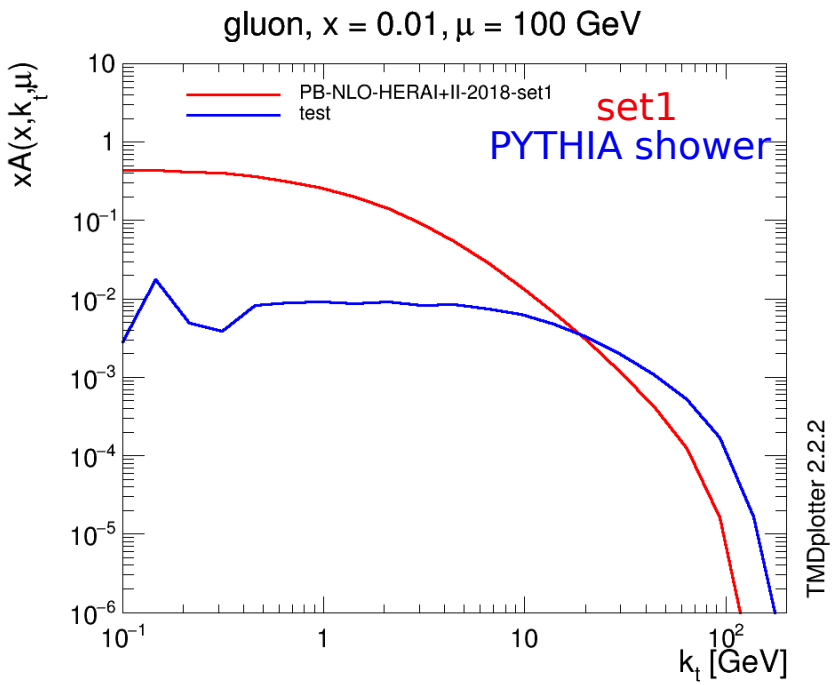
using set2 as input TMD

→ TMD parton shower follows TMD distribution - advantage of using TMDs!

TMD from P8 PS: TMD vs. $k_\perp$

How does it look like for the PYTHIA PS?





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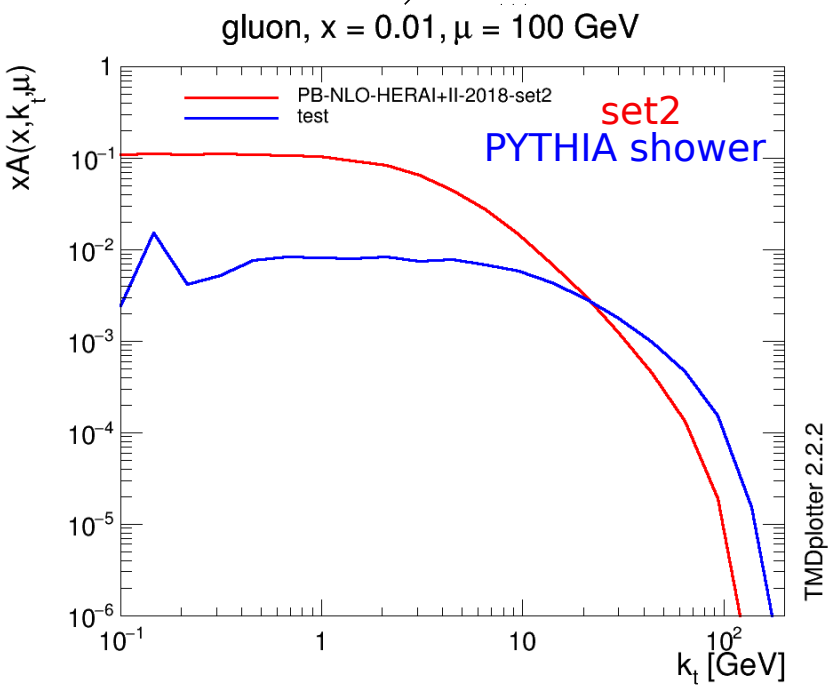


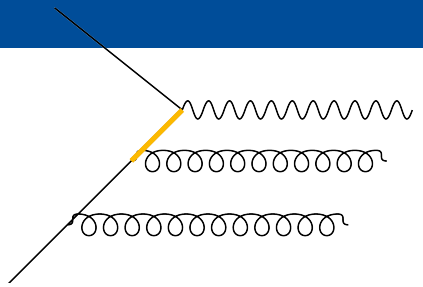
using set2 as input PDF

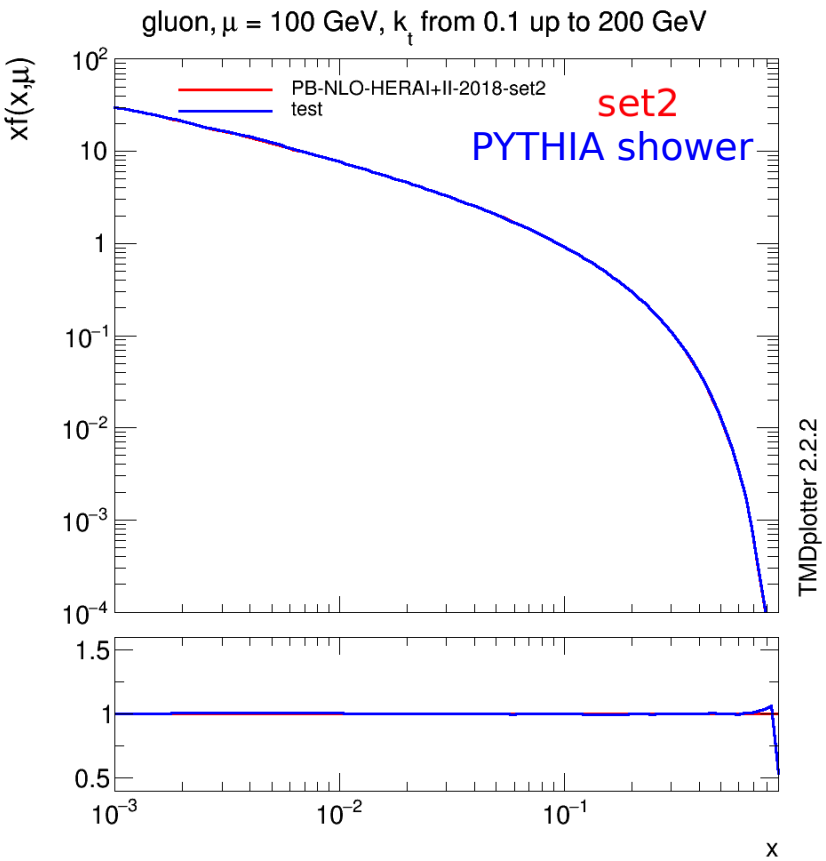
→ differences to PB TMD observed since P8 PS uses **p_T-ordering**

→ effective TMDs can be determined from any parton shower

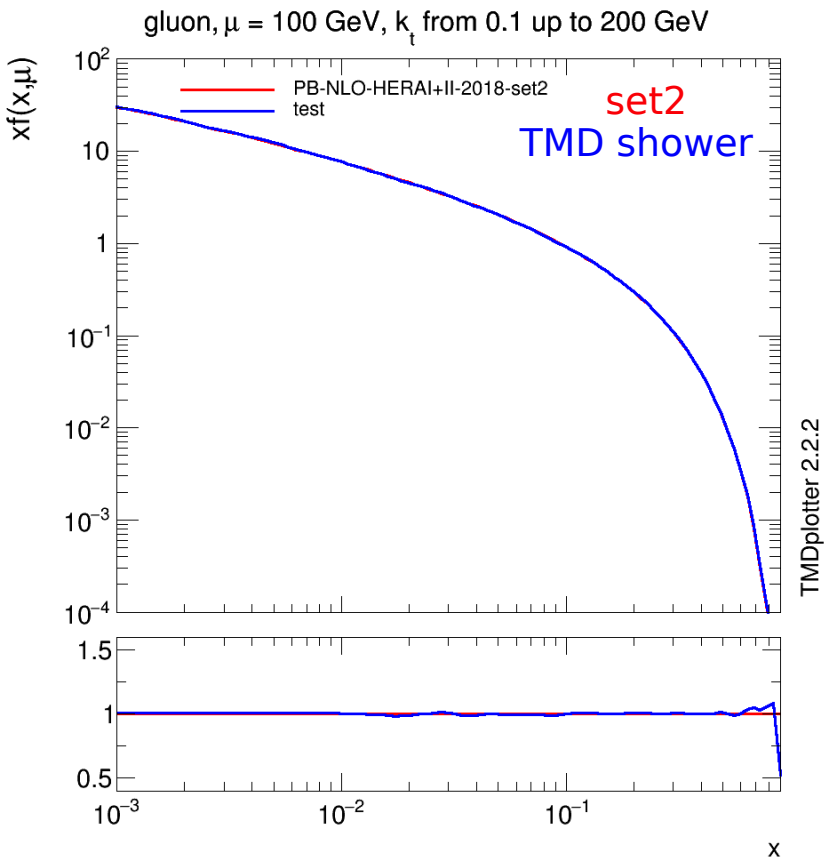
Integrated TMDs for both showers

How do the **integrated densities vs. x** look like for both showers?





using set2 as input PDF



using set2 as input TMD

→ integration over $k_\perp$ gives back collinear PDFs for both showers

Parton shower reconstruction

TMD parton shower: PS reconstruction

- the propagator partons in the PS are investigated

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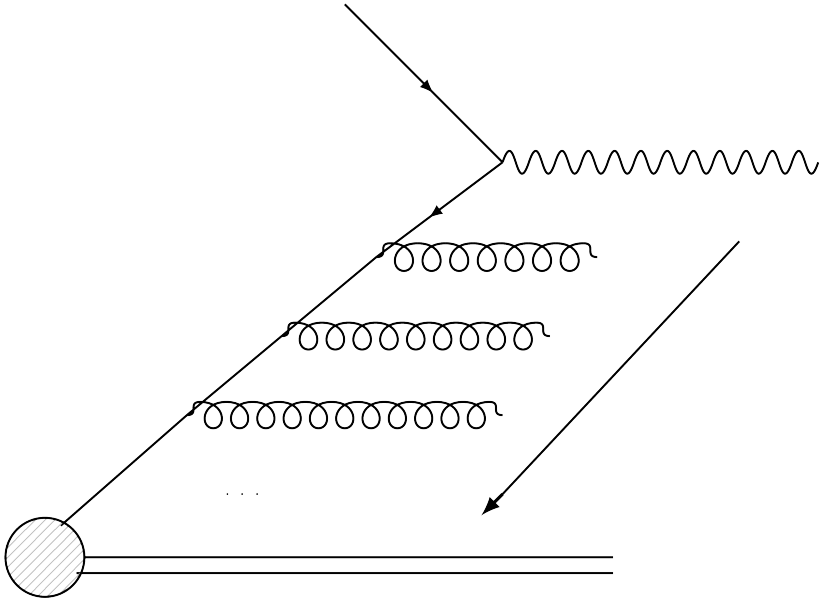
- the emitted partons of the IPS are ordered in rapidity to reconstruct the history of particle evolution (backward evolution)



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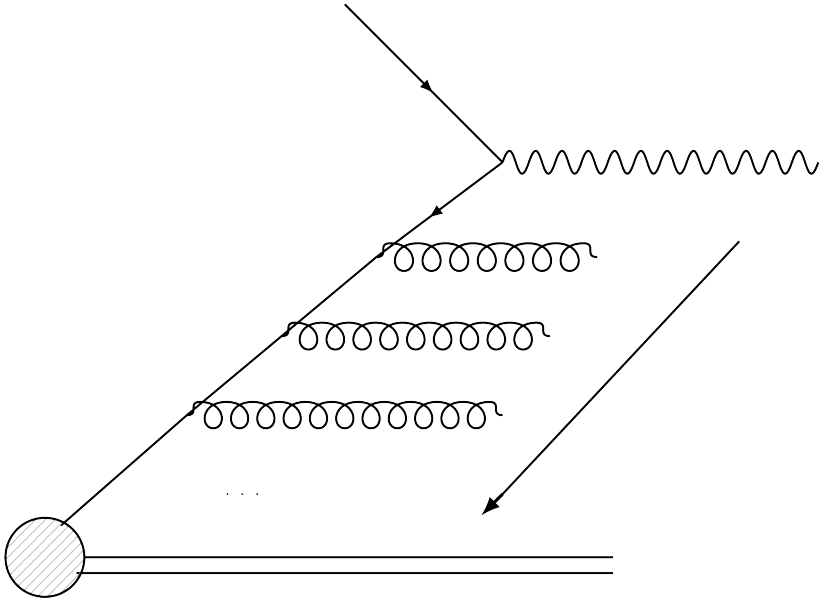

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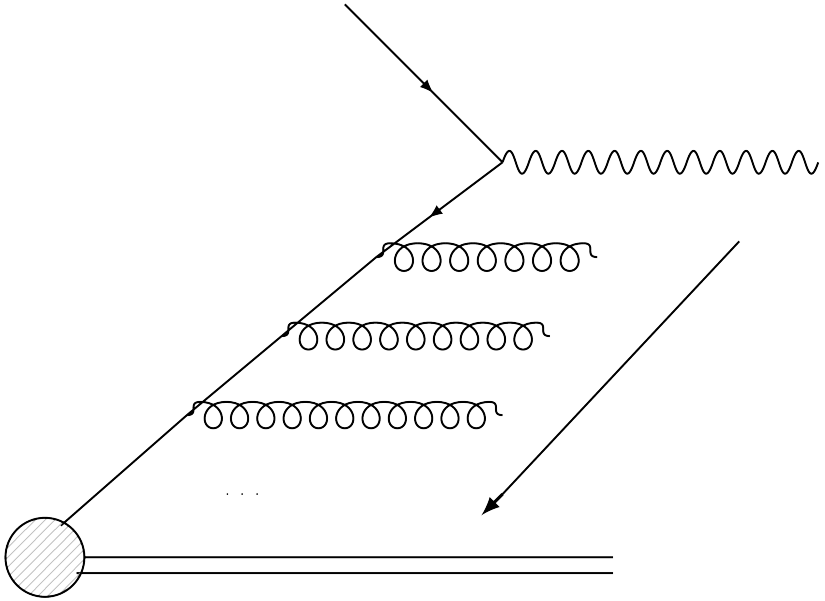
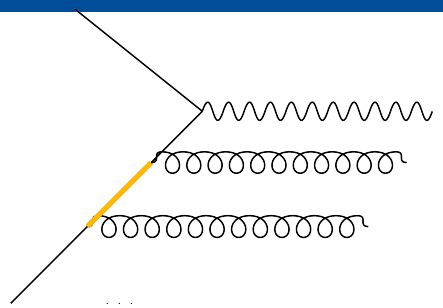
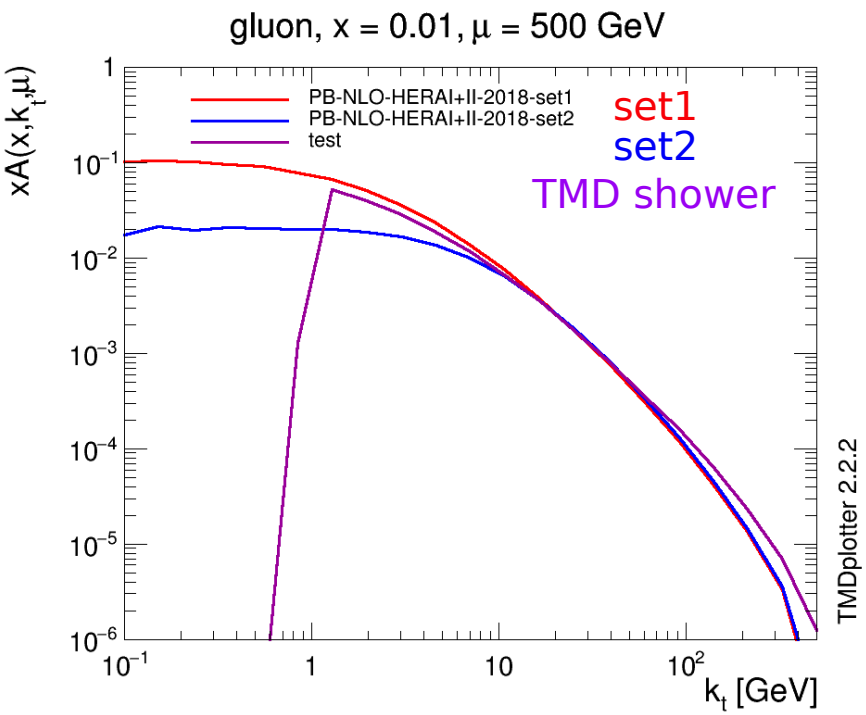


- for every propagator the transverse momentum and the momentum fraction can be calculated
- the scales are equal to the rescaled transverse momenta of the emitted partons, $q_i = \frac{p_{ti}}{1-z_i}$, coming from angular ordering condition

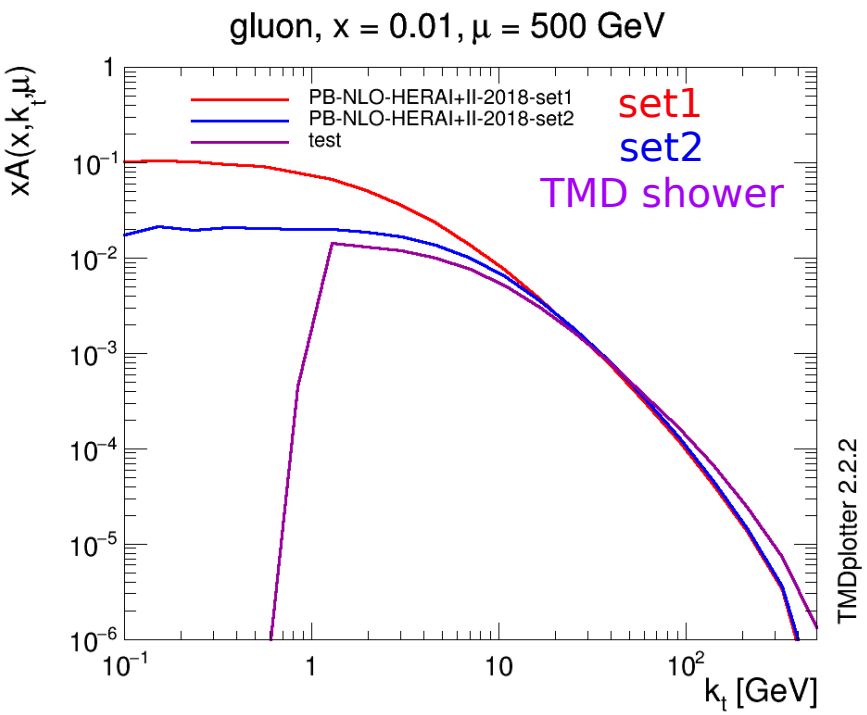
Shower-$k_\perp$: TMD vs. $k_\perp$

Backward evolution from 1 TeV to 500 GeV





using set1 as input TMD

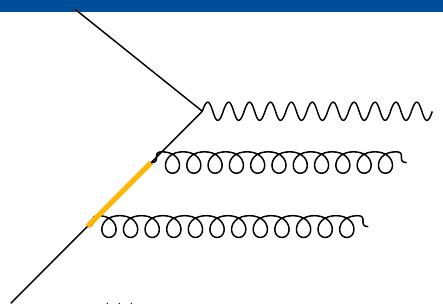


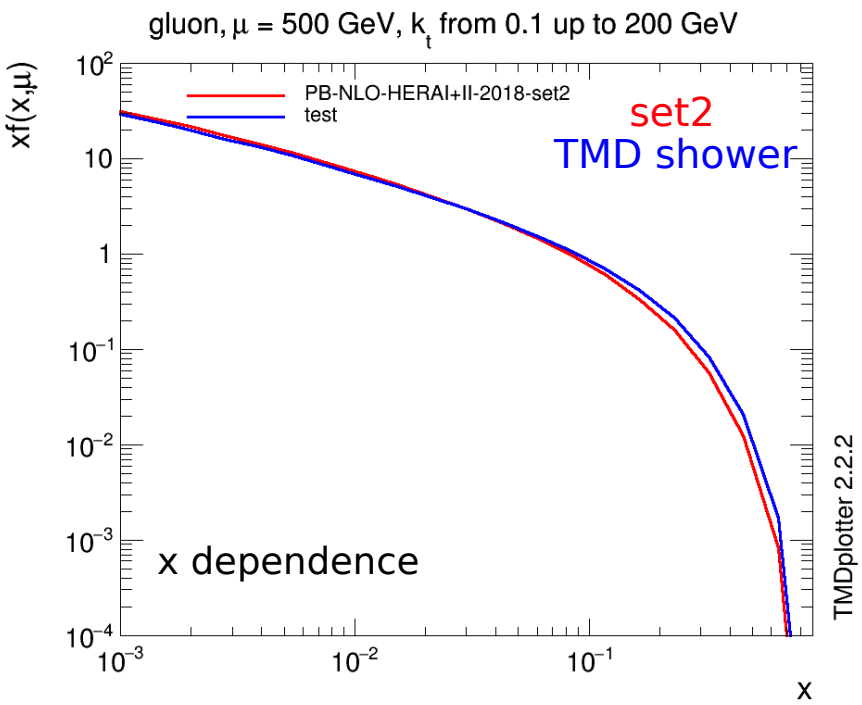
using set2 as input TMD

→ shower-$k_\perp$ follows input TMD

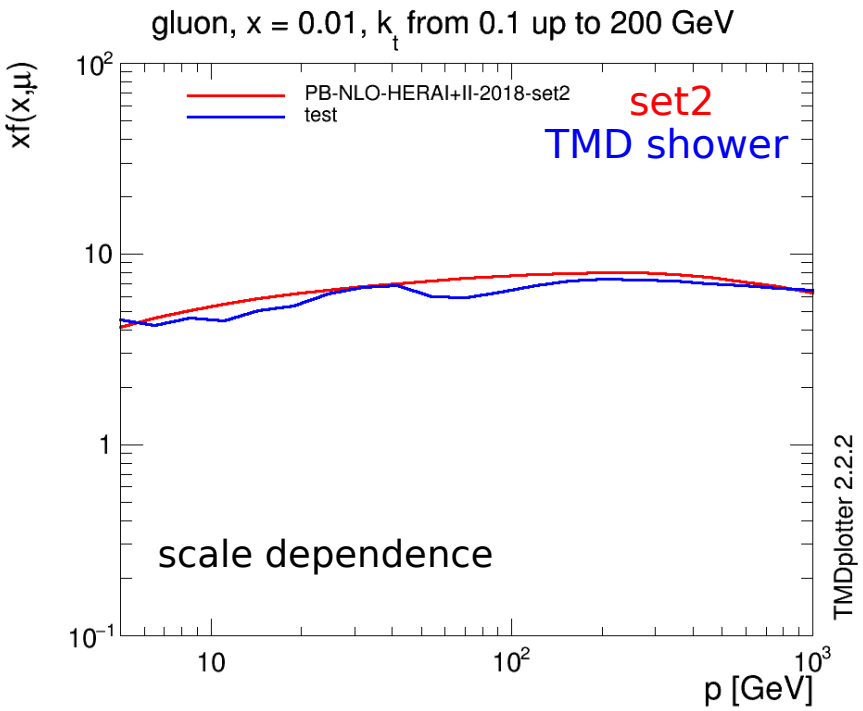
Shower-$k_\perp$: integrated TMDs

Backward evolution from 1 TeV to 500 GeV





using set2 as input TMD



using set2 as input TMD

→ shower-$k_\perp$ follows input TMD

Conclusion

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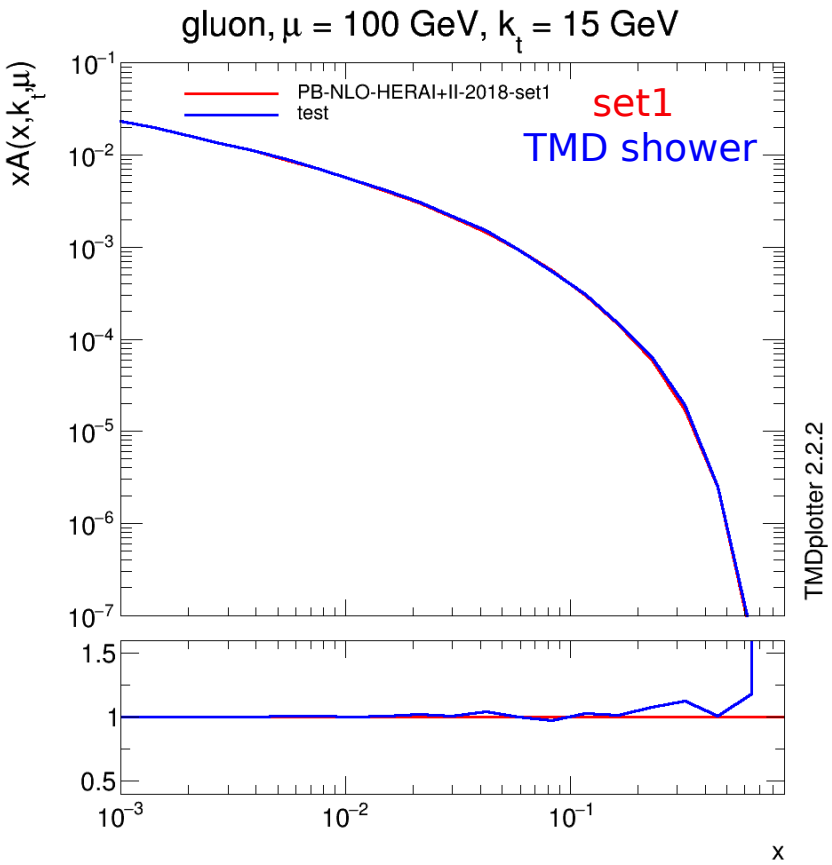
For first time detailed validation of parton shower proposed!

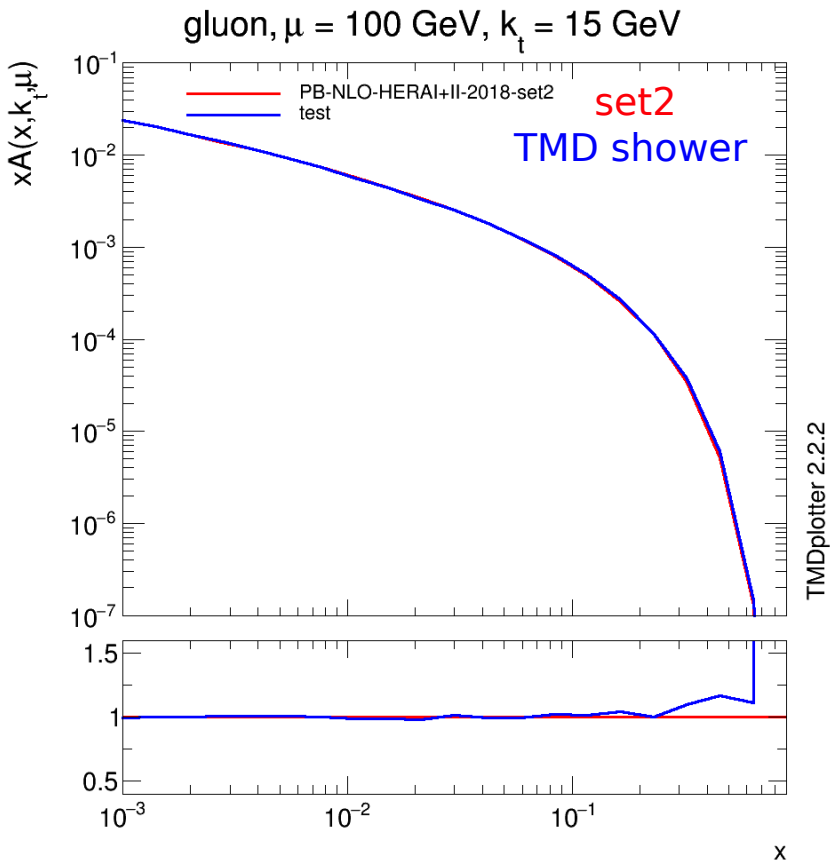
Thank you for your attention

BACKUP

TMD from final state with shower: TMD vs. x

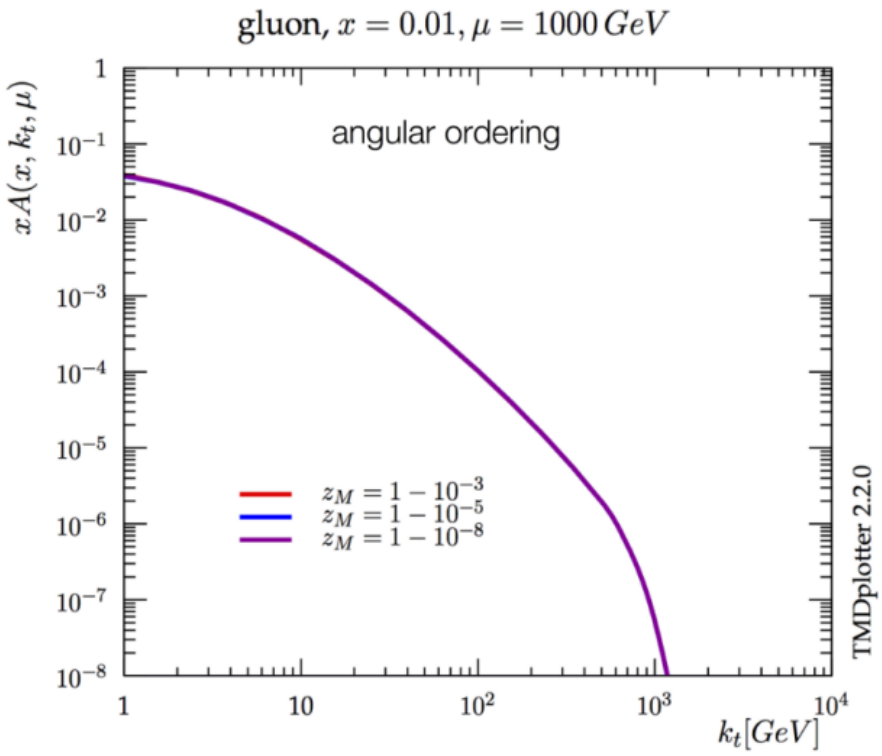


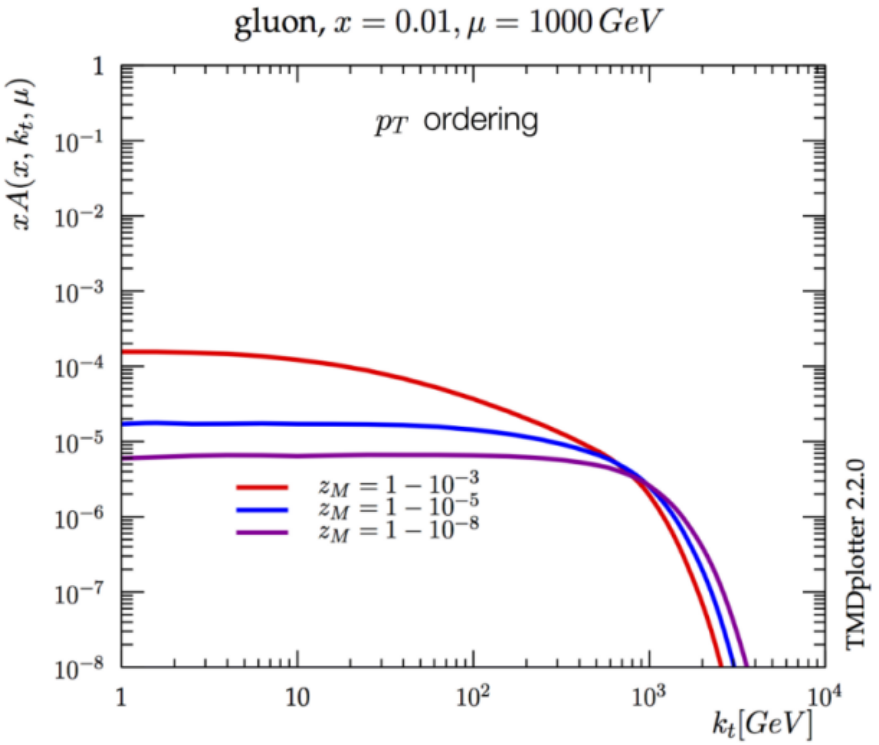
input TMD set1



input TMD set2

TMD distributions for p_T- & angular ordering





Integrated TMDs for both showers (set1)