Parton shower based on TMD parton distributions

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Outline

1. TMDs from Standard Parton Showers
   - Parton shower evolution
   - The PS2TMD method
   - Effective TMDs from standard parton showers
2. Parton shower based on TMDs
   - The TMD parton shower
   - A method to validate a TMD parton shower
   - Consistency checks using PB-TMDs
   - TMDs from the TMD parton shower
3. Summary & Outlook

TMDs from Standard Parton Showers

- Parton shower evolution
- The PS2TMD method
- Effective TMDs from the PYTHIA8 and HERWIG6 parton showers

"TMD parton distributions from parton showers" arXiv:1907.09441 (2019)

Parton shower evolution - Backward evolution

Short overview of the **backward evolution** type for initial state showers:

- initial state ratiation is generated by going backwards from hard process towards beam particles
- Sudakov form factor Δ_b is defined that gives the probability for a parton b to remain at momentum fraction x from the scale t_{max} to $t < t_{max}$,

$$\Delta_b\left(x, t_{max}, t\right) = \exp\left\{ -\int_t^{t_{max}} \mathrm{d}t' \frac{\alpha_s\left(t'\right)}{2\pi} \sum_a \int \mathrm{d}z P_{a\to bc}(z) \frac{x' f_a\left(x', t'\right)}{x f_b\left(x, t'\right)} \right\}$$

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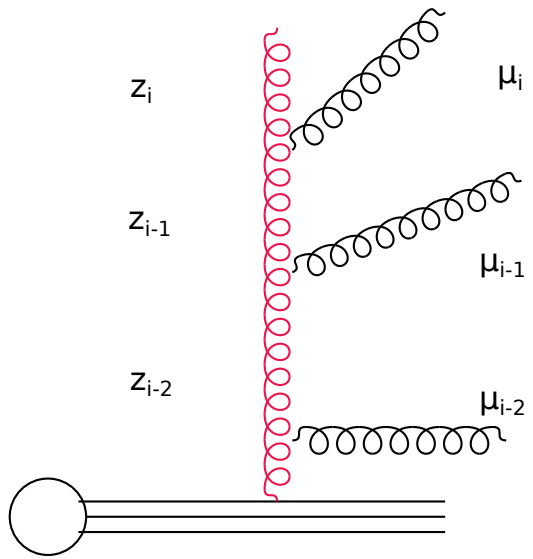
- evolution scale μ $(t = \mu^2)$ is selected from hard scattering process

  $\rightarrow$ next scale μ_{i-1} at which a resolvable branching occurs is chosen by Sudakov form factor

- z_{i-1} is generated according to splitting function and $x_{i-1} = \frac{x_i}{z_{i-1}}$ is calculated from it

- iterate procedure until cut-off scale q_0



The PS2TMD method - The idea

What is the aim of this parton shower study?

→ To compare different parton showers in a simple way by **determining effective TMDs** from them.

→ effective TMDs can be calculated from the cumulative effect of the parton shower

How can this be done?

→ define variable that can be calculated by every parton shower and can be defined generally but which is not dependent on a concrete observable

→ method will enable determination of parton distributions as a function of x, μ^2 and $k_\perp^2$

Parton distributions can be obtained from a **physical process** - BUT it has kinematic limits, cross section & phase space → **that complicates calculations**

How to do the parton shower study technically?

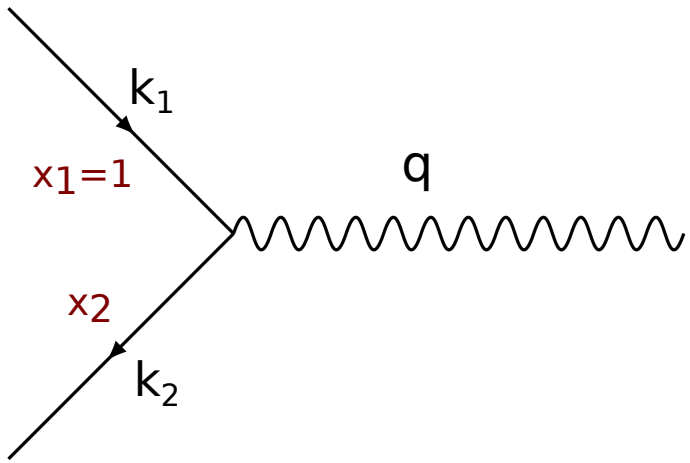
The PS2TMD method - Technical features

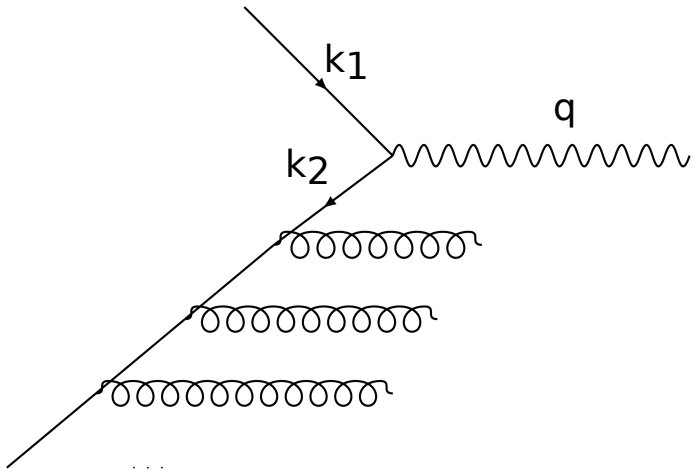
Define a **toy process that simplifies calculations** of the quantities that are needed for the TMD parton densities.

→ k_1 has fixed momentum fraction x_1 close to 1 and no transverse momentum to simplify calculations

→ k_2 is subject to parton shower & x_2 is determined according to collinear parton distribution

→ Transverse momentum of k_2 is investigated, $\vec{k}_{\perp 2} = \vec{q}_\perp - \vec{k}_{\perp 1}$





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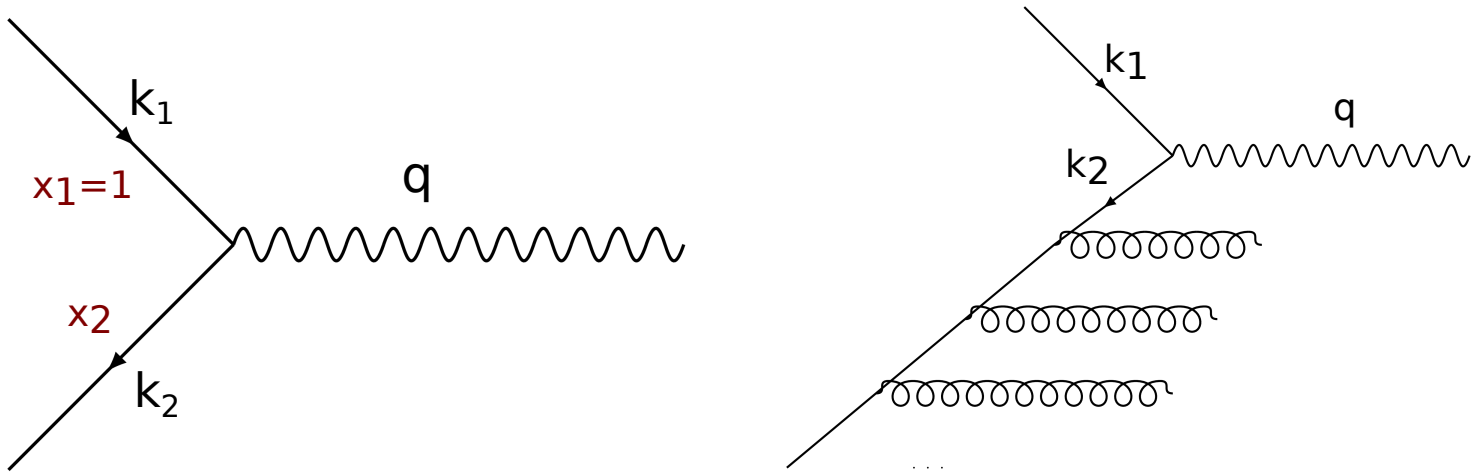
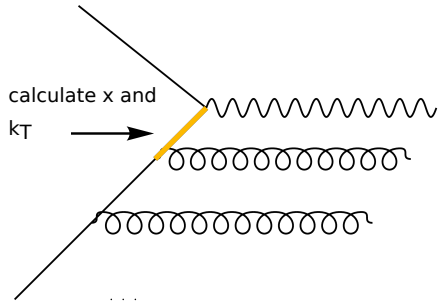


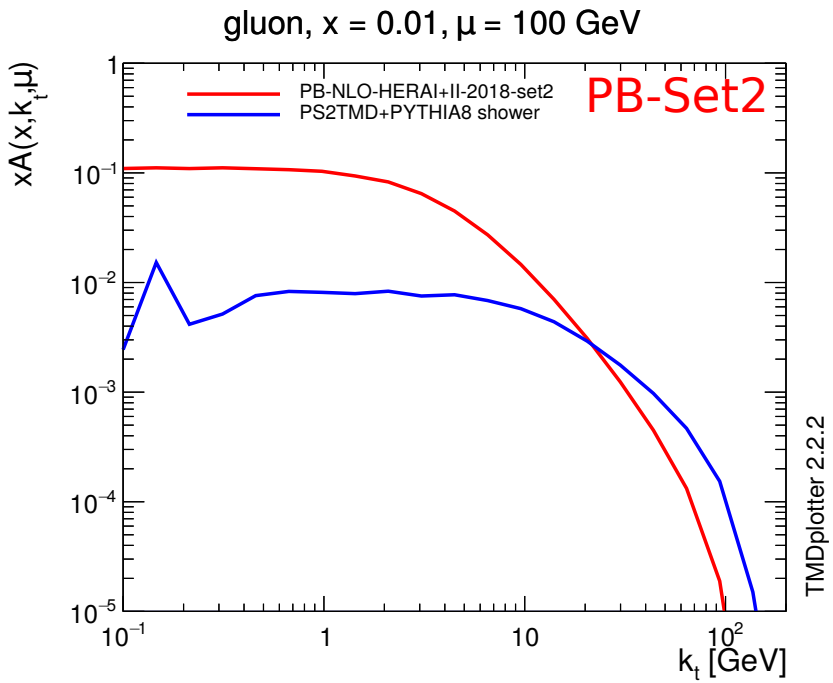
→ method is applied to standard parton showers, using a PDF set that has been obtained within the parton branching method, PB-Set2

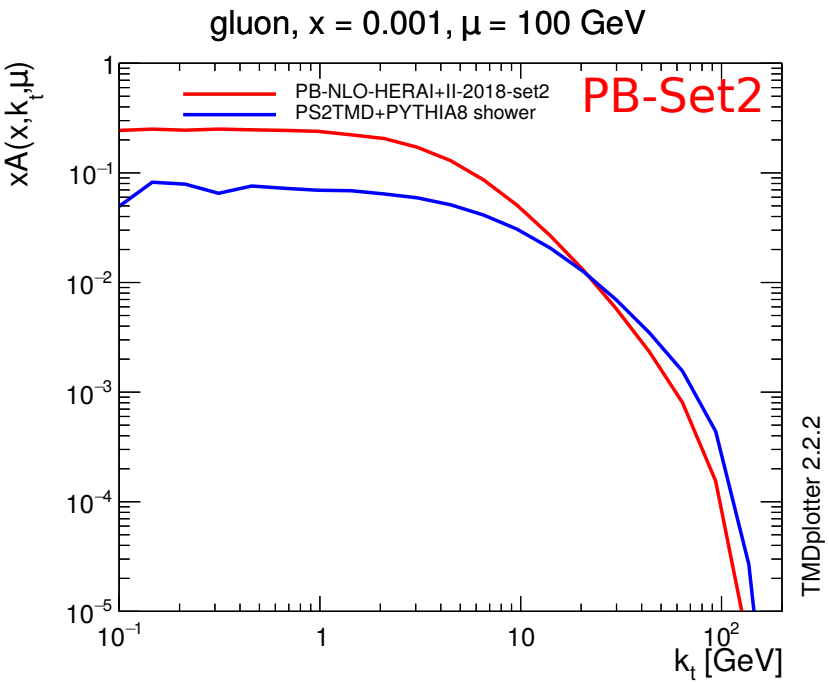
TMDs from the PYTHIA8 parton shower

Effective TMDs from PYTHIA8

PB-Set2 is used for the calculations (blue)







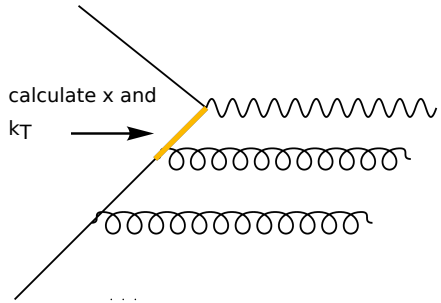
→ **differences to PB-TMD** observed since P8 PS uses **p_T-ordering**

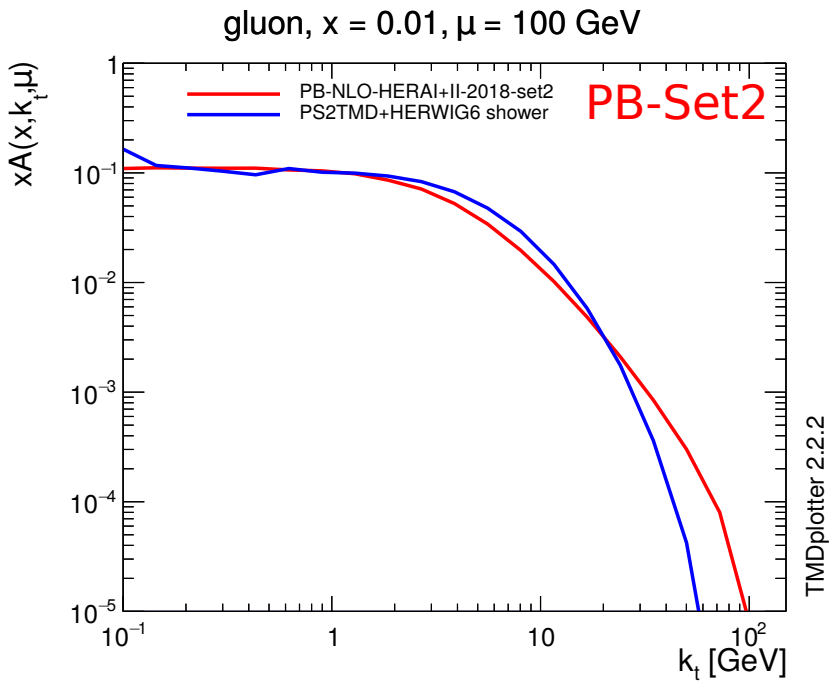
→ effective TMDs can be determined from standard parton shower

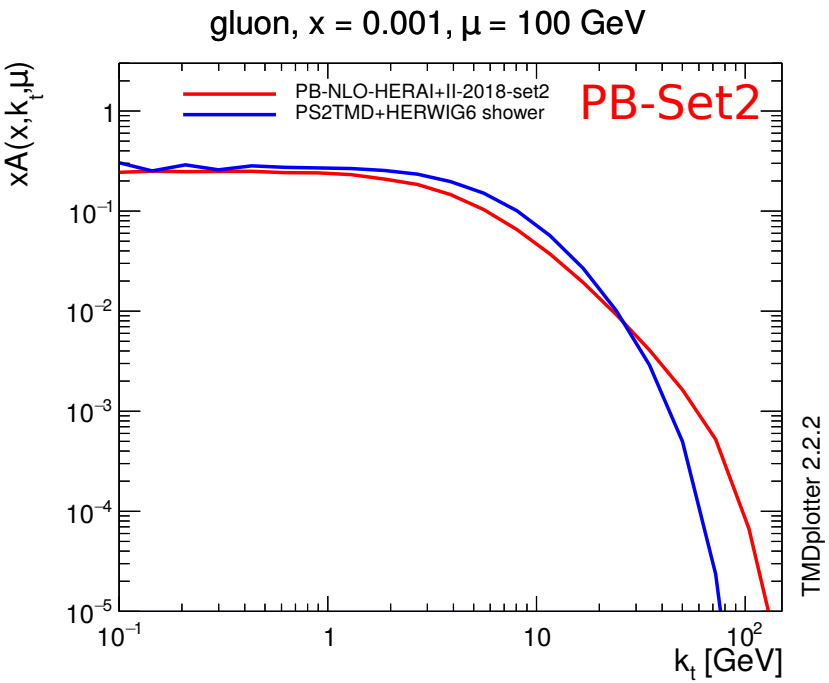
TMDs from the HERWIG6 parton shower

Effective TMDs from HERWIG6

PB-Set2 is used for the calculations (blue)







→ distributions are **similar to PB-TMD** since both apply **angular ordering**

→ effective TMDs can be determined from **any** parton shower

Parton shower based on TMDs

- The TMD parton shower
- A method to validate a TMD parton shower
- Consistency checks using PB-TMDs
- TMDs from the TMD parton shower

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TMD parton shower - Evolution

What is different to the evolution of a collinear parton shower?

- TMD fixes the transverse momentum of the initial state partons
  $\rightarrow$ transverse momenta during backward evolution follow behaviour of TMD
- Sudakov form factor making use of TMD parton densities $\mathcal{A}_a\left(x', k_t', \mu'\right)$,

$$\Delta_S\left(x, \mu_i, \mu_{i-1}\right) = \exp\left[-\int_{\mu_{i-1}}^{\mu_i} \frac{\mathrm{d}\mu'}{\mu'} \frac{\alpha_s\left(\tilde{\mu}'\right)}{2\pi} \sum_a \int \mathrm{d}z P_{a\rightarrow bc}(z) \frac{x' \mathcal{A}_a\left(x', k_t', \mu'\right)}{x \mathcal{A}_b\left(x, k_t, \mu'\right)}\right]$$

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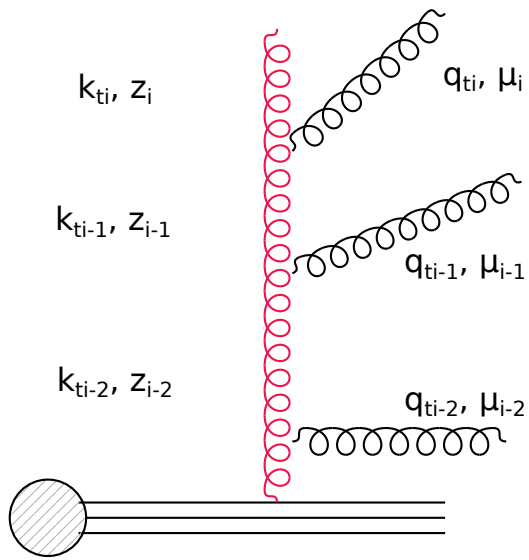
How to calculate the transverse momenta?

- k_t is calculated from transverse momentum of emitted parton q_t and transverse momentum of previous propagating parton,

$$\mathbf{k}_{ti-1} = \mathbf{k}_{ti} + \mathbf{q}_{ti-1}$$



The TMD parton shower & its applications

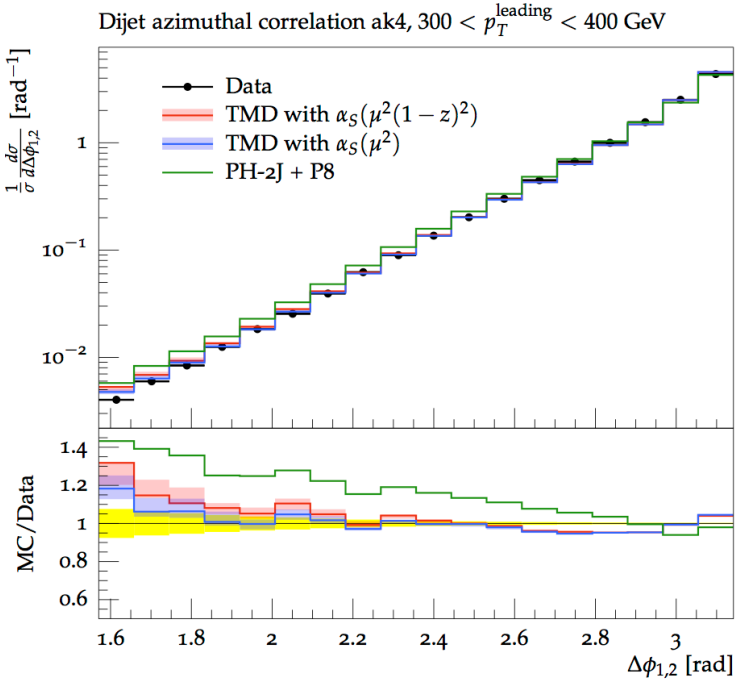
What is the purpose of a TMD parton shower?

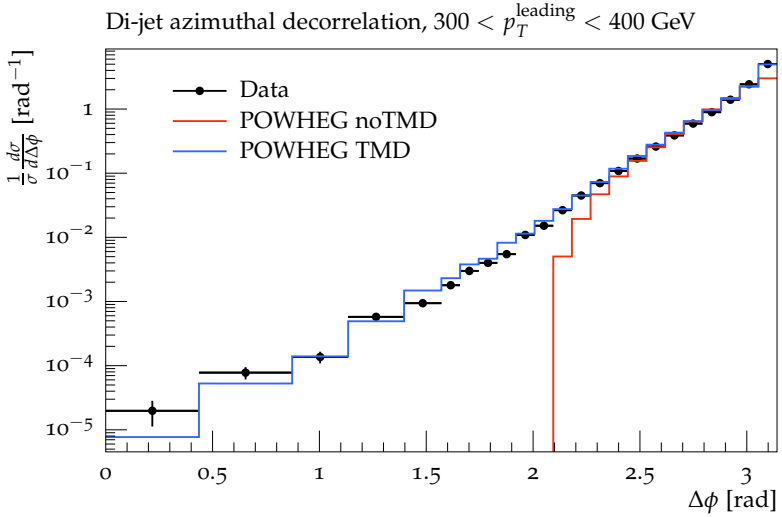
It is constructed in a way that it should follow the parton evolution of the TMDs

→ no change of the kinematics of the matrix element process

How can it be applied?

→ Example: ΔΦ distribution for NLO dijets





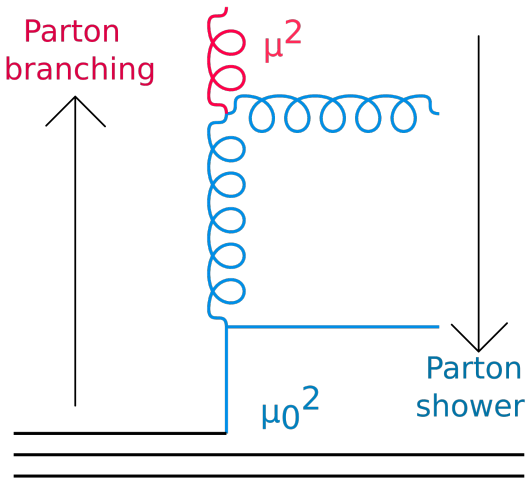
→ PB-TMDs combined with POWHEG give very good description of data

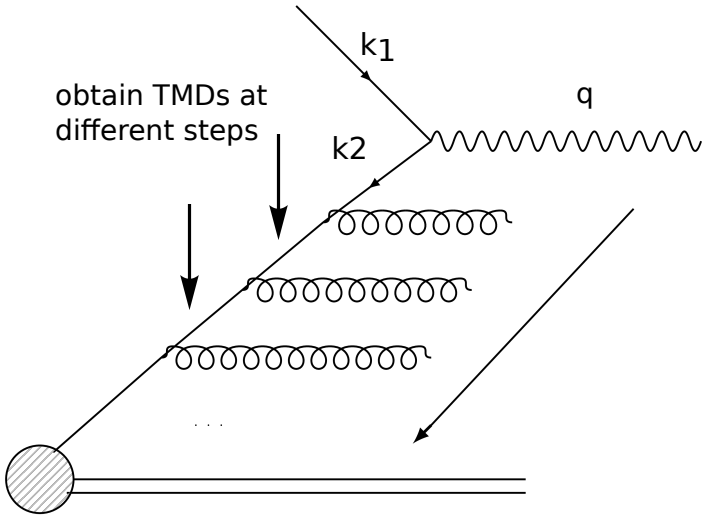
A method to validate a TMD parton shower

How can the TMD parton shower be validated?

→ TMD parton shower evolution is reverse of the Parton Branching evolution

→ This can be used for a detailed investigation of the shower since the kinematics can be calculated at every step!





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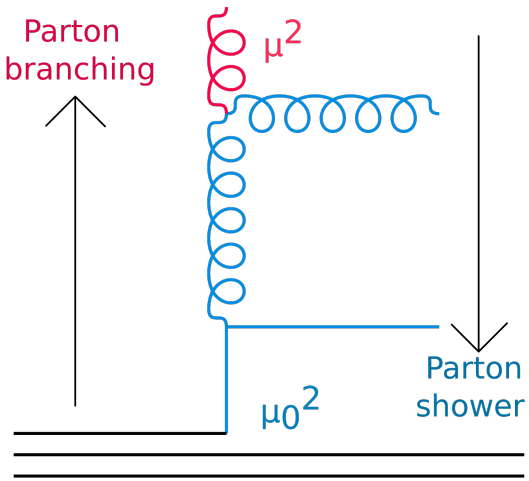

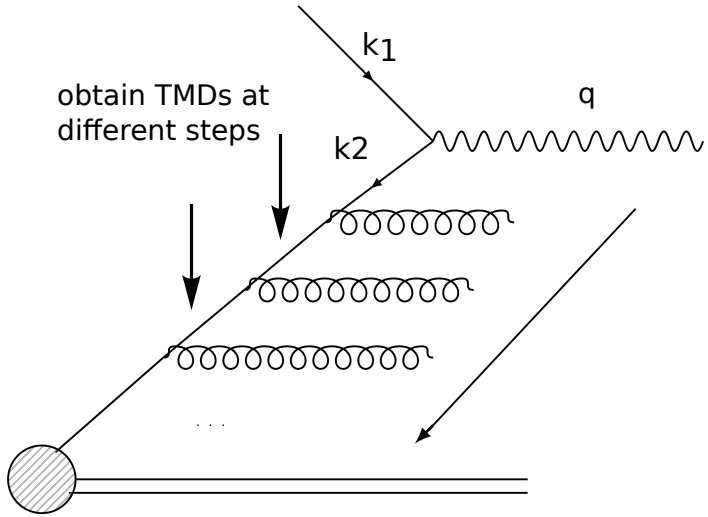

Start at the hard process, go down to smaller scales & determine TMD at different steps - TMD can be compared to PB-Set1 & PB-Set2 that are used for the initial state partons

→ First step: Apply PS2TMD method to TMD parton shower

Consistency checks using PB-TMDs

But first of all, the PS2TMD method needs to be validated with PB-TMDs:

$\rightarrow$ apply the method to PB-TMDs that are used to generate a $k_\perp$ (PB-Set1 & PB-Set2)

$\rightarrow$ check if the method is able to reconstruct the TMDs that are used to generate the $k_\perp$

$\rightarrow$ compare results from PS2TMD method to PB-TMD distributions

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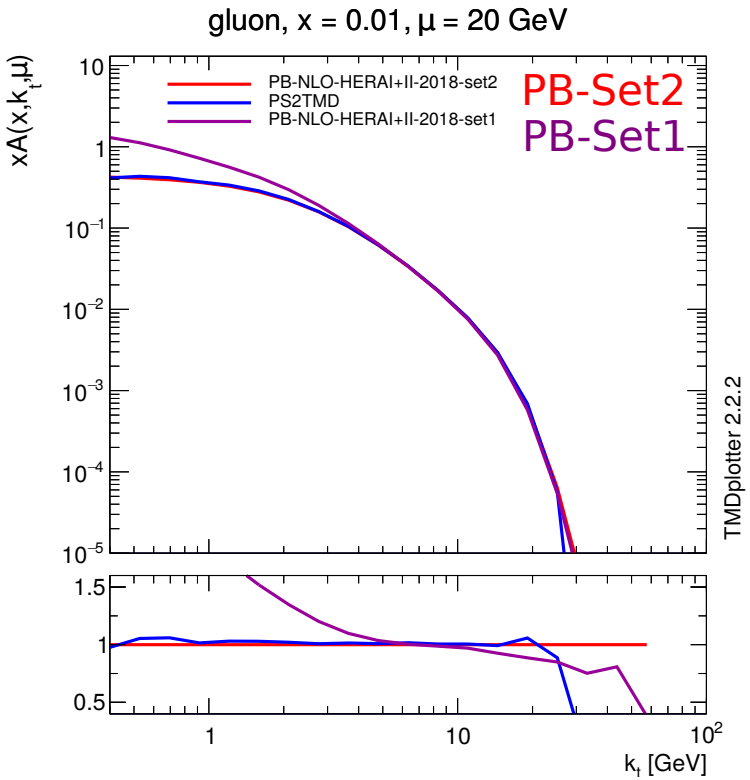
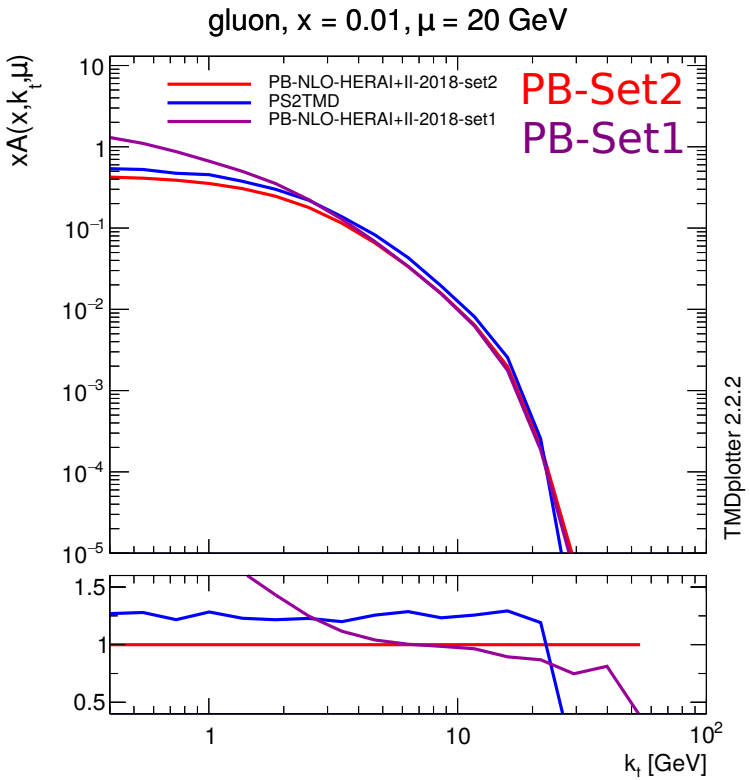


PB-Set2 (coll.) & PB-Set2 ($k_\perp$)



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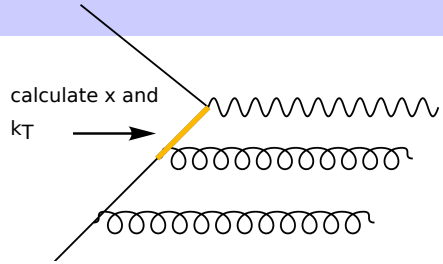
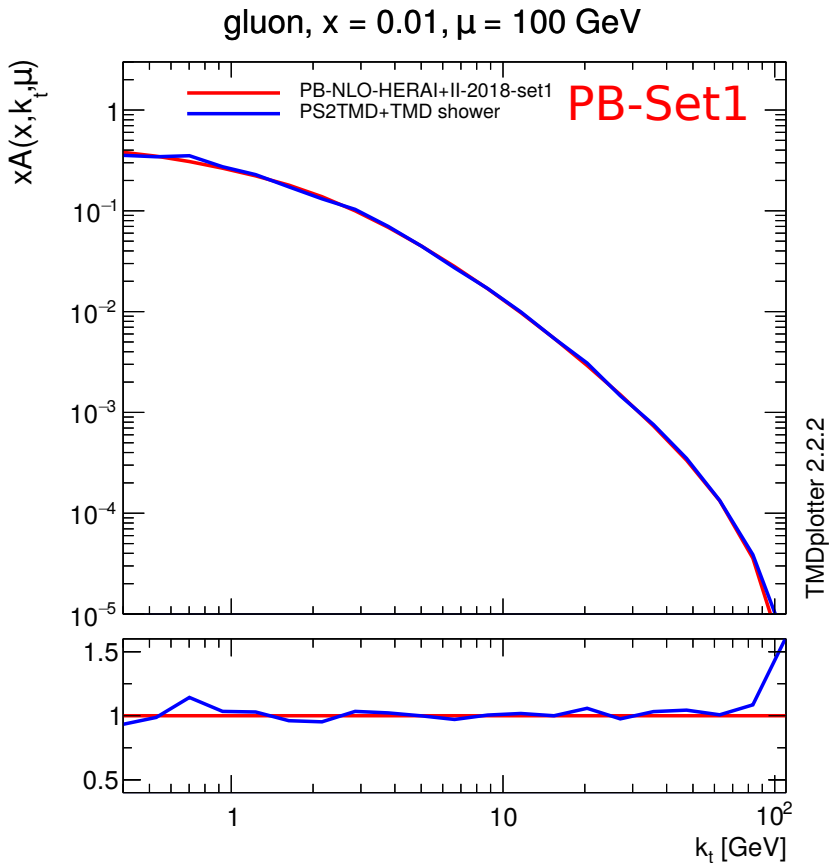
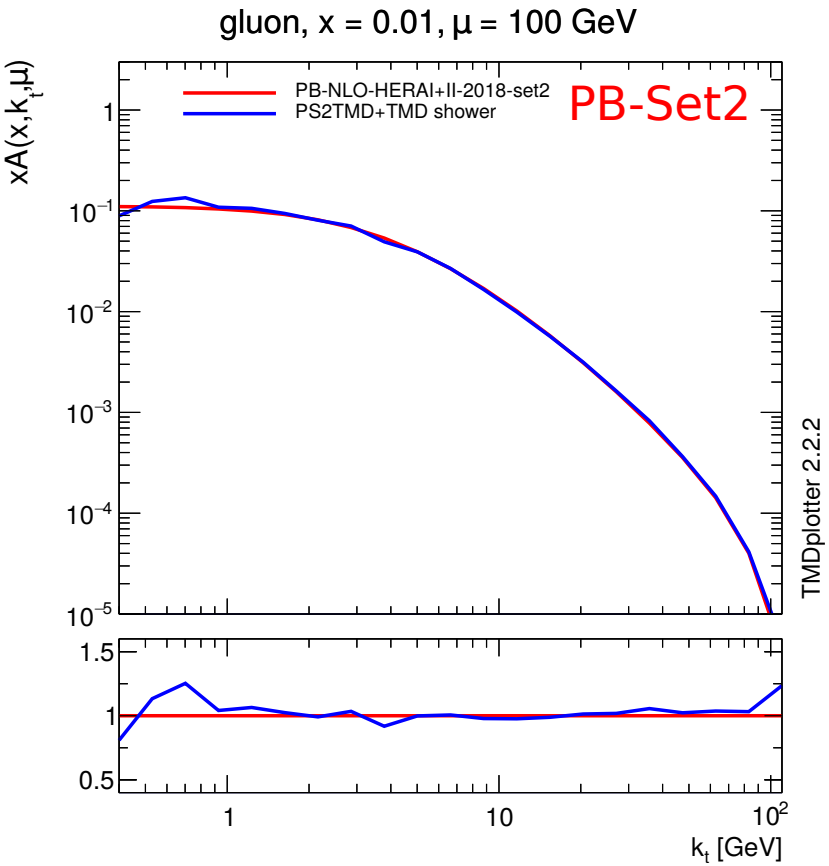




PB-Set1: collinear & TMD calculation



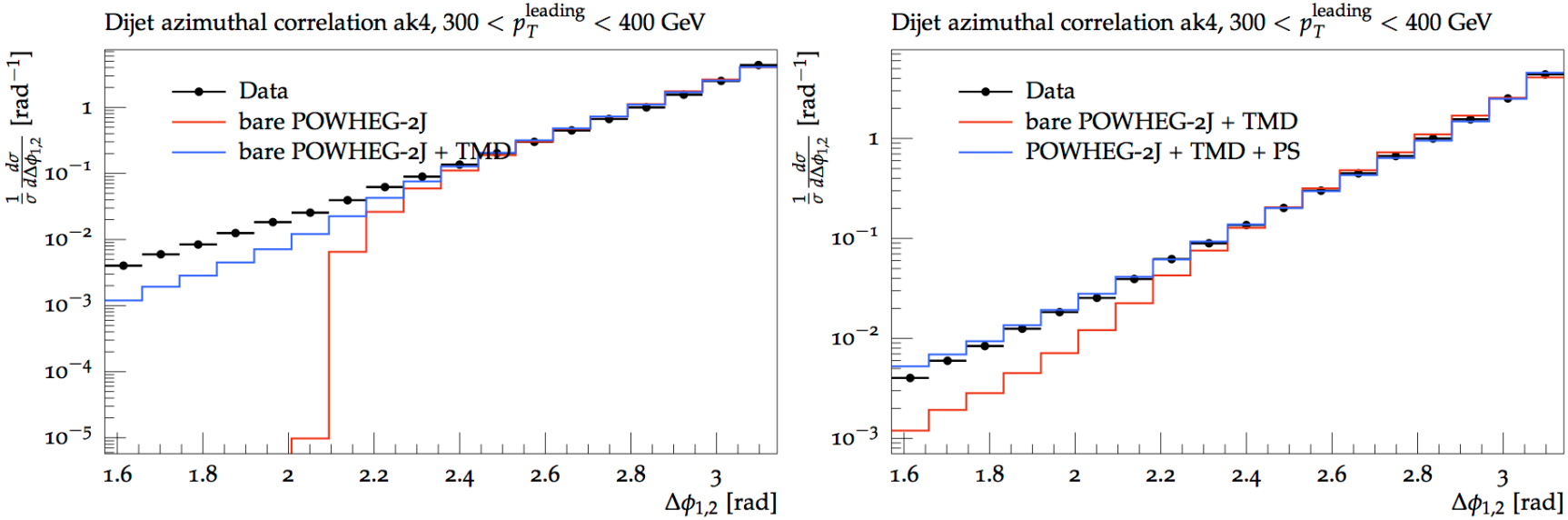
PB-Set2: collinear & TMD calculation

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

The effect of the TMD parton shower

What is exactly the effect of the TMD parton shower?

→ Take again look at NLO dijet ΔΦ distribution:



→ in region of small ΔΦ there is a contribution from the shower

→ with TMD parton shower measurement is better described

Summary & Outlook

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  - $\rightarrow$ TMDs from TMD parton shower show advantage of using TMDs: **no change of kinematics**
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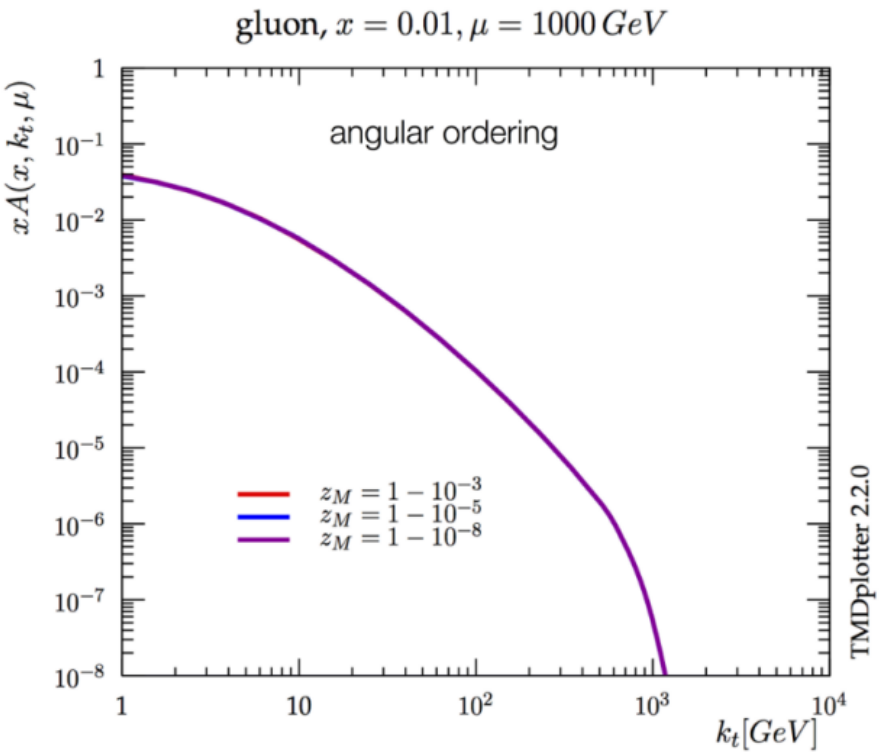
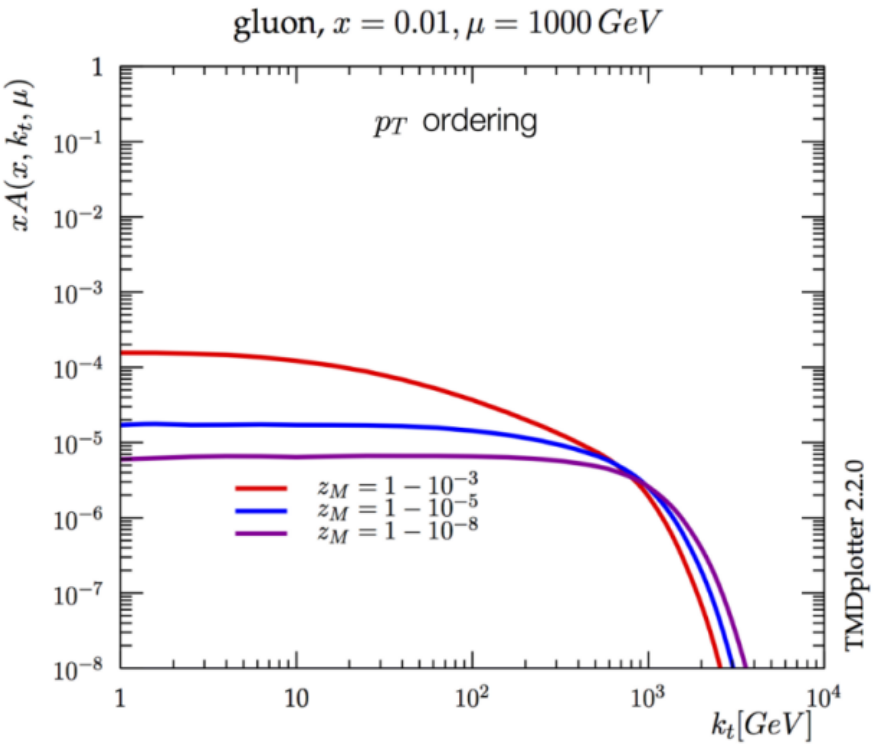
Thank you for your attention

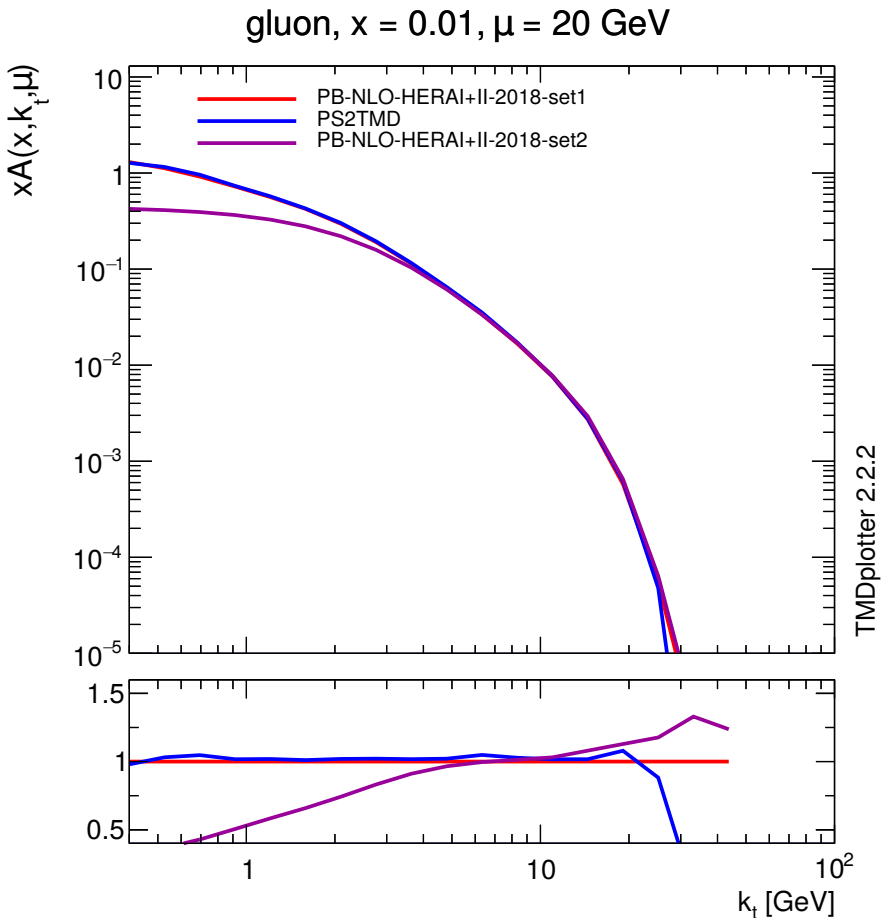
BACKUP

TMD distributions for p_T- & angular ordering





Validation PS2TMD - Check 1



Comparison of PB-Set1 and PB-Set2