Parton Shower based on TMD parton distributions

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Outline

1. The Parton Branching method
2. The TMD parton shower and its applications
3. Obtaining TMDs from two different parton showers
4. Detailed study of the TMD parton shower
5. Conclusion

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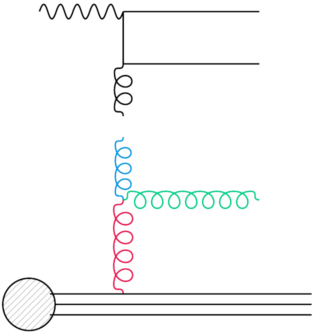
- Integration leads to:

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

- **solve it by iteration**

The Parton Branching method



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

$$f_1\left(x,t\right) = f\left(x,t_0\right)\Delta\left(t\right) + \frac{\alpha_s}{2\pi}\int_{t_0}^{t}\frac{\mathrm{d}t'}{t'}\frac{\Delta\left(t\right)}{\Delta\left(t'\right)} \cdot \int_x^1 \frac{\mathrm{d}z}{z}\tilde{P}\left(z\right) f\left(x/z,t_0\right)\Delta\left(t'\right)$$

$$= f\left(x,t_0\right)\Delta\left(t\right) + \log\tfrac{t}{t_0} A \otimes \Delta\left(t\right) f\left(x/z,t_0\right)$$

$$f\left(x,t\right) = \lim_{n\to\infty} f_n\left(x,t\right) = \lim_{n\to\infty}\sum_n \frac{1}{n!}\log^n\left(\frac{t}{t_0}\right) A^n \otimes \Delta\left(t\right) f\left(\frac{x}{z},t_0\right)$$

with $A = \int \frac{\mathrm{d}z}{z}\tilde{P}(z)$ $\rightarrow$ resummed to all orders in $\alpha_s \log t$

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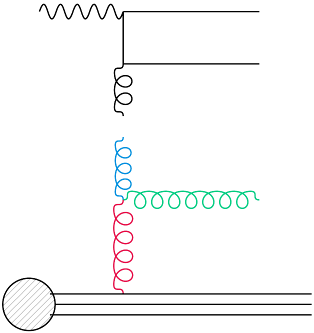

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$\rightarrow$ kinematics of **every single splitting process** can be treated exactly

The TMD parton shower and its applications

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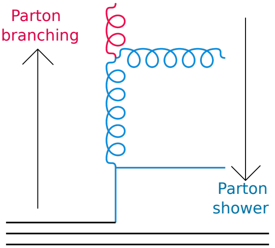
PB evolution

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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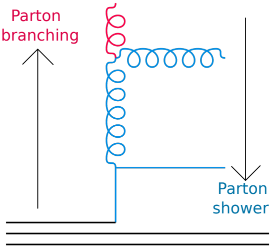

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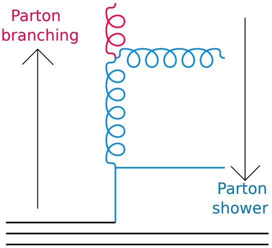

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→ PB method **allows to construct parton shower following exactly TMD**

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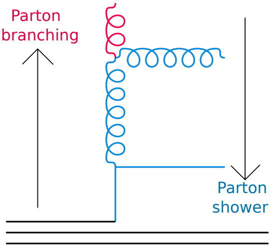

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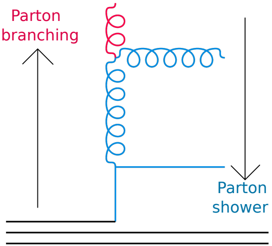

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TMD parton shower (implemented in CASCADE 3):

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

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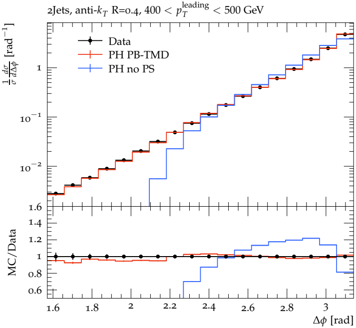
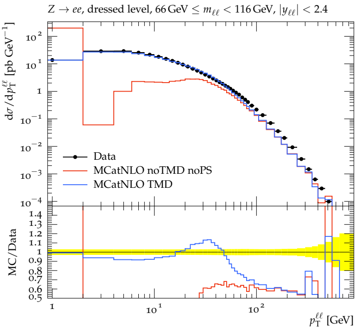


$\Delta\Phi$ distribution for NLO dijets



p_T distribution for NLO DY process

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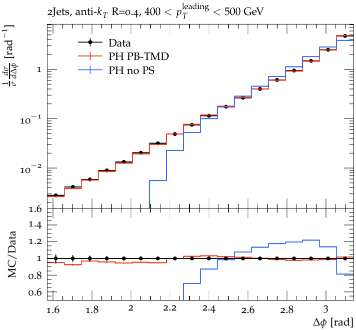

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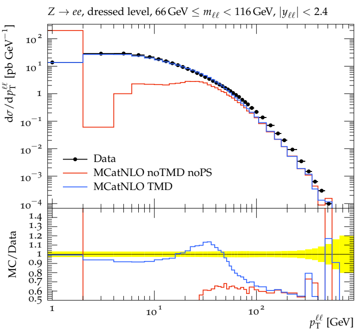

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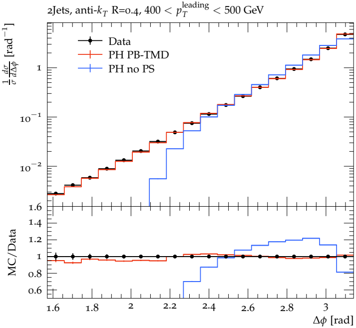

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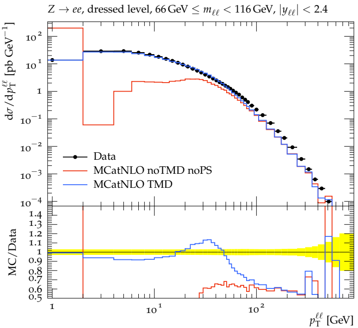

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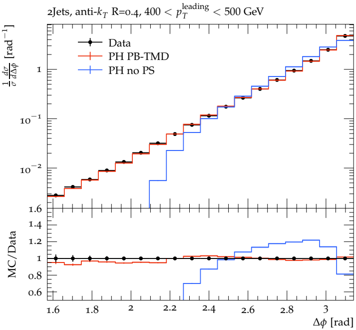

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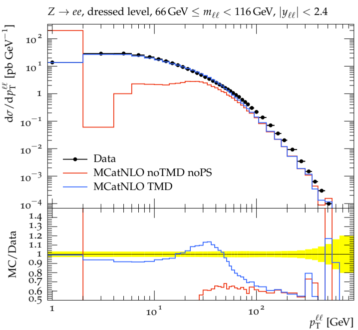

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→ **Perform a parton shower study to investigate how well the shower follows the TMDs**

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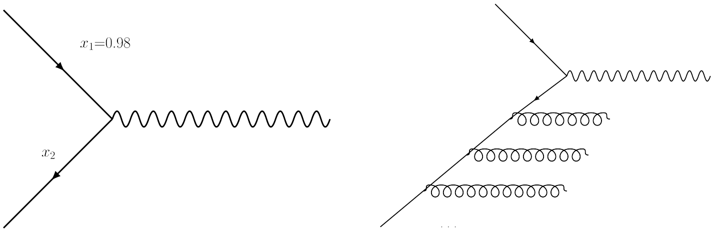

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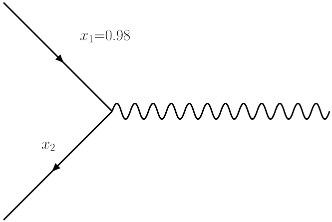

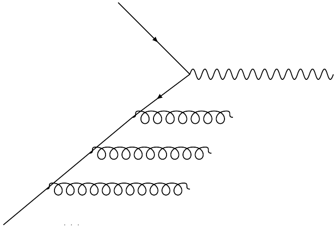

Technical details:

- generate hard process (PYTHIA) and "add" TMD and PS (CASCADE 3)

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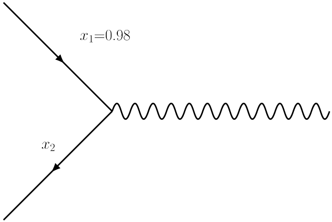

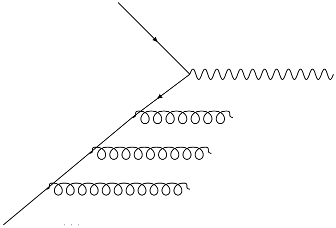

Technical details:

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

TMD from final state events

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

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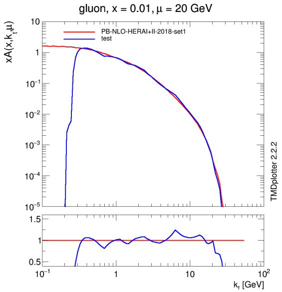
$\rightarrow$ choose three different combinations of the collinear and TMD PDF sets to check consistency with the input TMDs

Consistency check: TMD vs. $k_\perp$

"test"=calculated distribution



PYTHIA:
PB-TMDNLO-HERAI+II-2018-set1
CASCADE:
PB-NLO-HERAI+II-2018-set1

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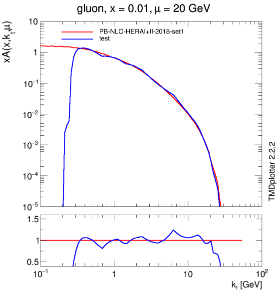

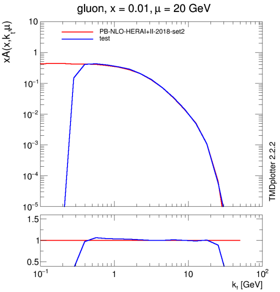

PYTHIA:
PB-TMDNLO-HERAI+II-2018-set1
CASCADE:
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PYTHIA:
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CASCADE:
PB-NLO-HERAI+II-2018-set2

Consistency check: TMD vs. $k_\perp$

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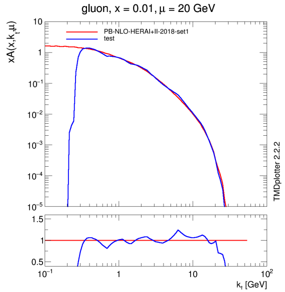

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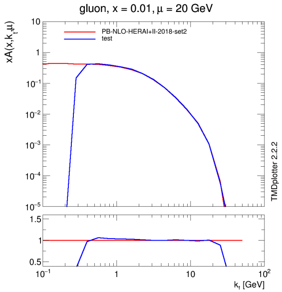
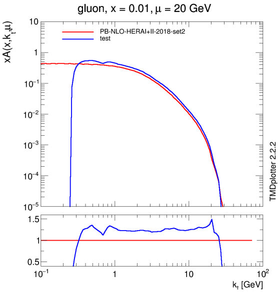


PYTHIA:
PB-TMDNLO-HERAI+II-2018-set2
CASCADE:
PB-NLO-HERAI+II-2018-set2



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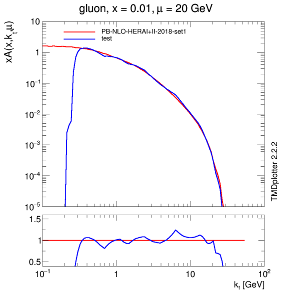

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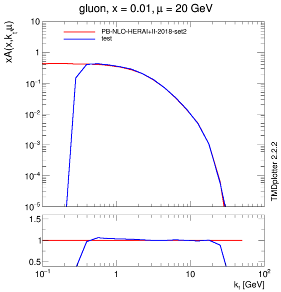

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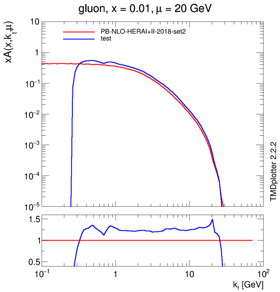
PB-NLO-HERAI+II-2018-set2



PYTHIA:
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CASCADE:
PB-NLO-HERAI+II-2018-set2

→ reconstruction of differences between set1 & set2

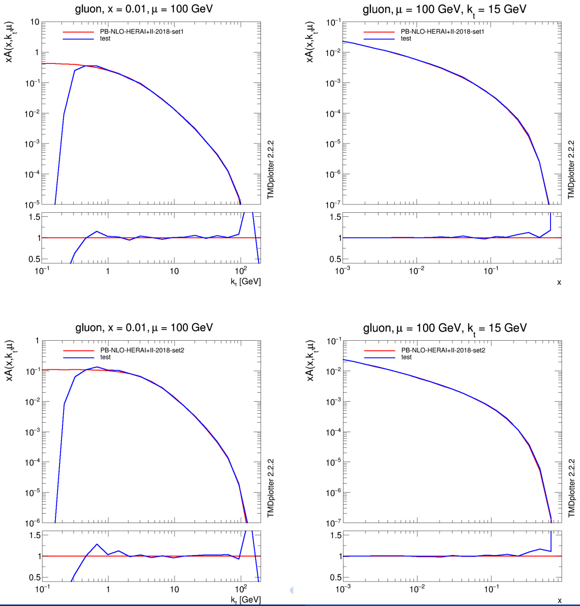
→ consistent use of collinear and TMD PDF set essential!

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

How does it look like when **PS is added**?
(set1 above, set2 below)

"test"=calculated distribution

- **PS does not change the kinematics!**
- method can be used to determine TMDs from the shower



How does it look like for the **PYTHIA PS**?
(set1 above, set2 below)

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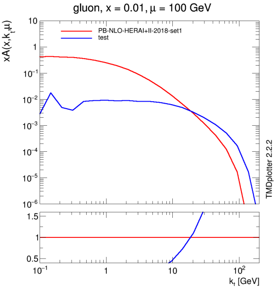
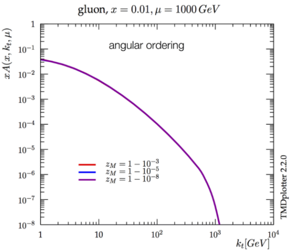
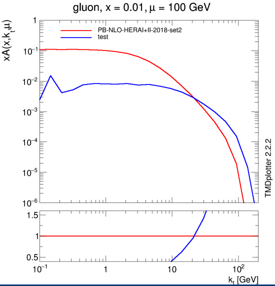
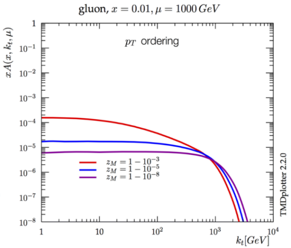




- differences observed since P8 PS uses **p_T-ordering**
- TMDs can be determined from any parton shower



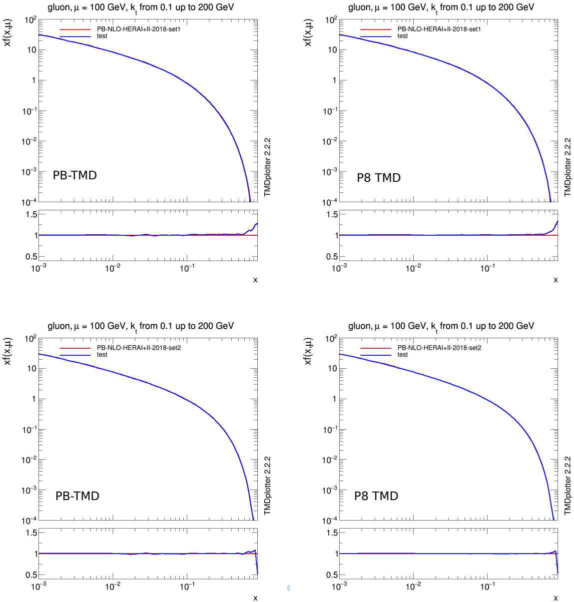


iTMD vs. x for both showers

How do the **integrated densities vs. x** look like for both showers?
(set1 above, set2 below)

"test"=calculated distribution

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



TMD parton shower: PS reconstruction

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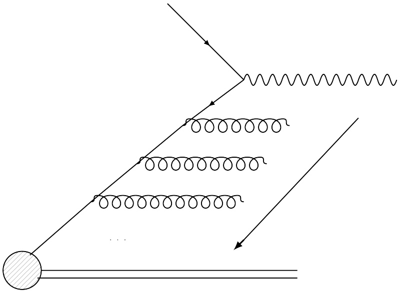
- the emitted partons of the IPS are ordered in rapidity to reconstruct the history of particle evolution (backward evolution)



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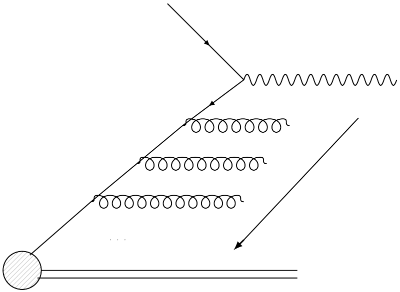

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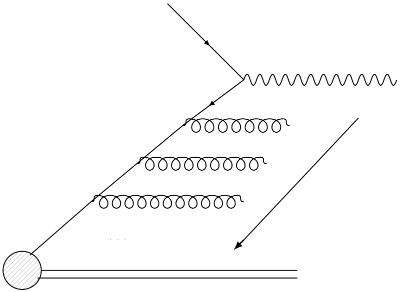
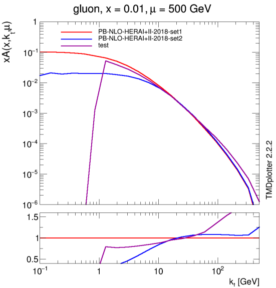


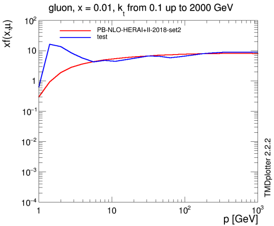
- for every propagator the transverse momentum and the momentum fraction are calculated
- the scales are equal to the rescaled transverse momenta of the emitted partons, $q_i = \frac{p_{ti}}{1-z_i}$

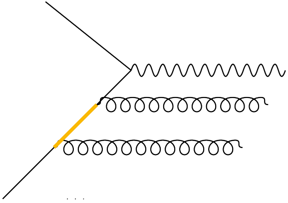
TMD parton shower: TMD vs. $k_\perp$ and iTMDs

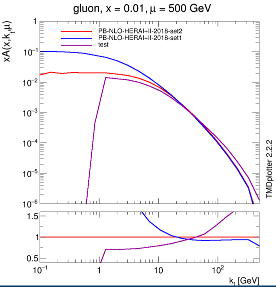
How does it look like for the **first propagator parton** of the PS?
(set1 above, set2 below)

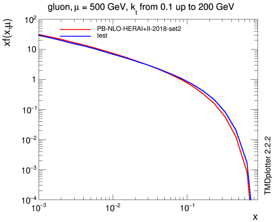
"test"=calculated distribution











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This is the first time that parton densities are reconstructed from the shower history!

Thank you for your attention

BACKUP

The MC Event Generator CASCADE

- full hadron level Monte Carlo event generator for ep, γp and $p\bar{p}$ and pp processes
- previously intended for small-x processes, now extended for all x and all $k_\perp$
- uses TMD ... and TMD shower
- hadronisation is performed using the Lund string fragmentation implemented in PYTHIA

More information about TMDs

- two main sets of data provide the experimental information on TMDs: DIS at high energy, and low-q_T Drell Yan and semi-inclusive DIS
- for collinear and TMD distributions the factorization theorems are different and hence also the evolution equations
- TMDs can be obtained for example from the parton branching method with CCFM or DGLAP evolution equation
- some observables can not be predicted with collinear factorization $\rightarrow$ example given by Drell-Yan Z-boson production

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