Intrinsic k_T and soft gluons in Monte Carlo generators

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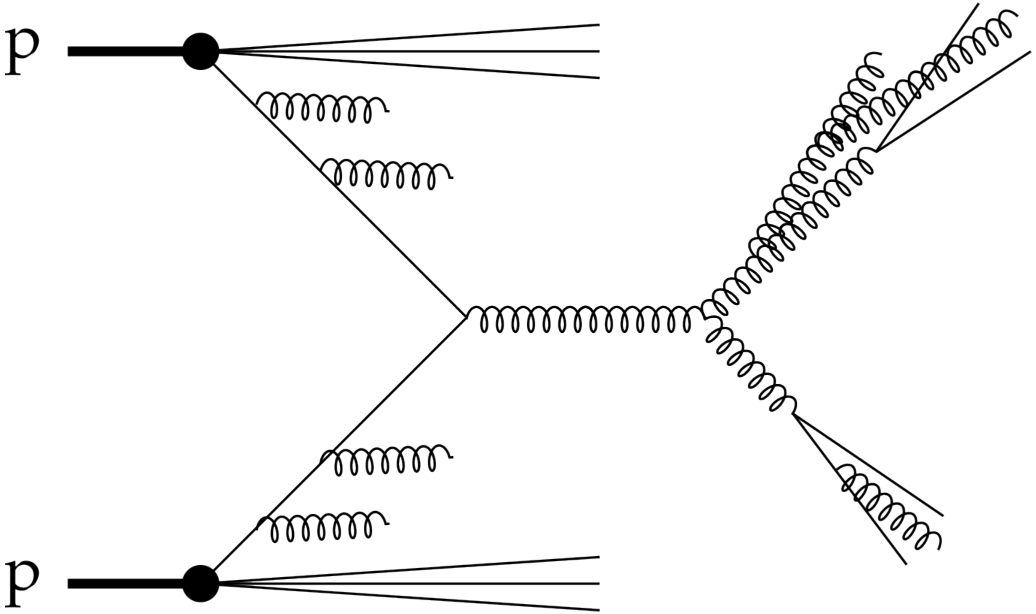
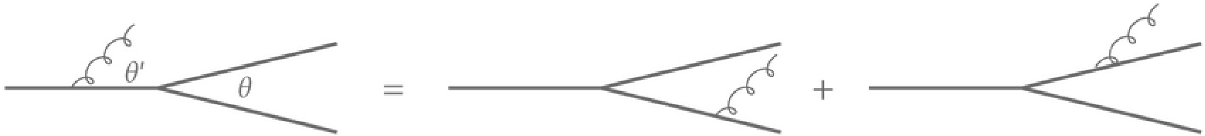
Introduction

- We use parton showers to model jet production
- Create one parton at a time according to splitting functions
- Since the 90ies, showers have been *angular-ordered*



Angular ordering



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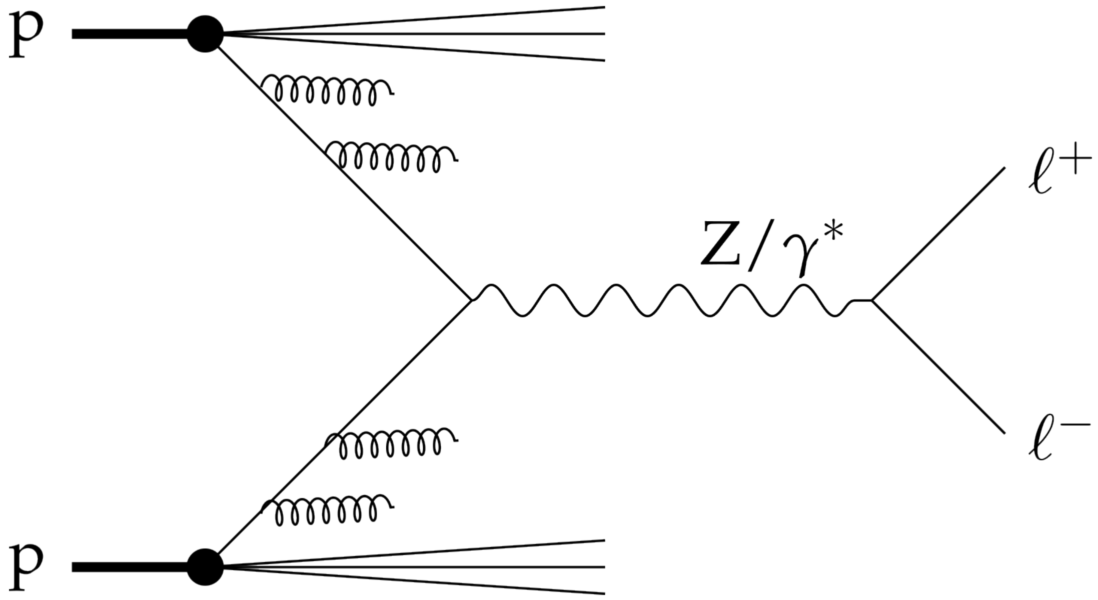
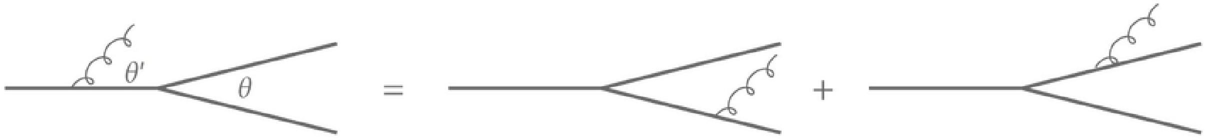


This talk is about the intial state

We will probe it using Drell-Yan

Angular ordering

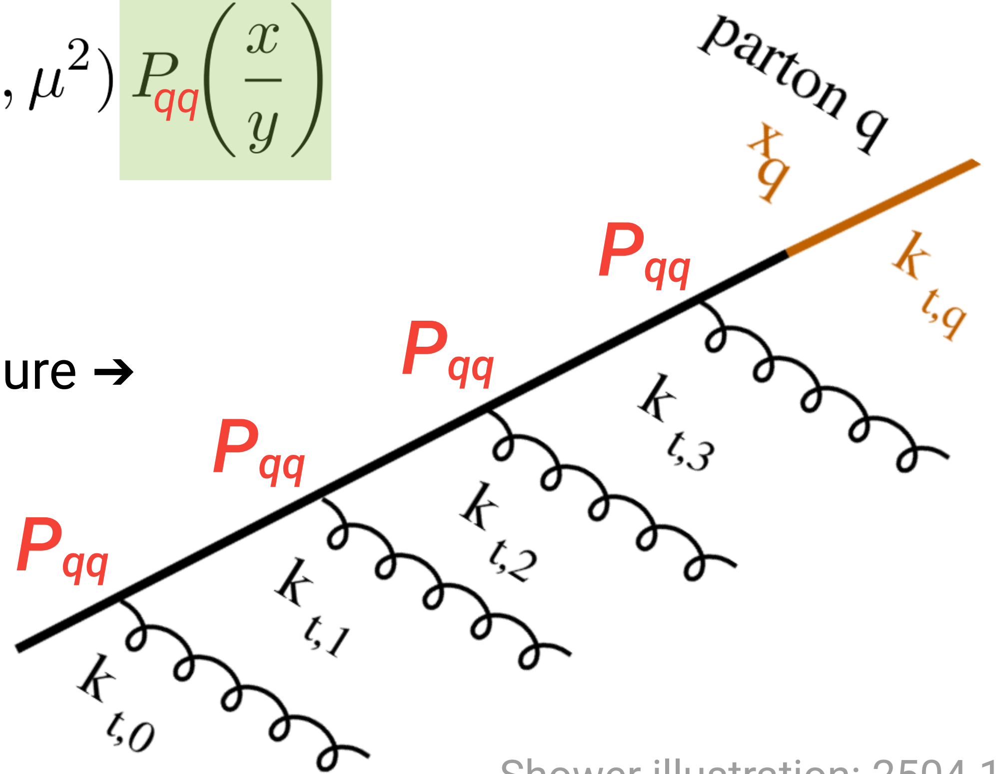


Initial-state showers

DGLAP evolution is all about radiating partons:

$$\frac{\partial f_q(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y} f_q(y,\mu^2)\, P_{qq}\!\left(\frac{x}{y}\right)$$

Parton showers use a similar picture ➔



Shower illustration: 2504.10243

Transverse momentum

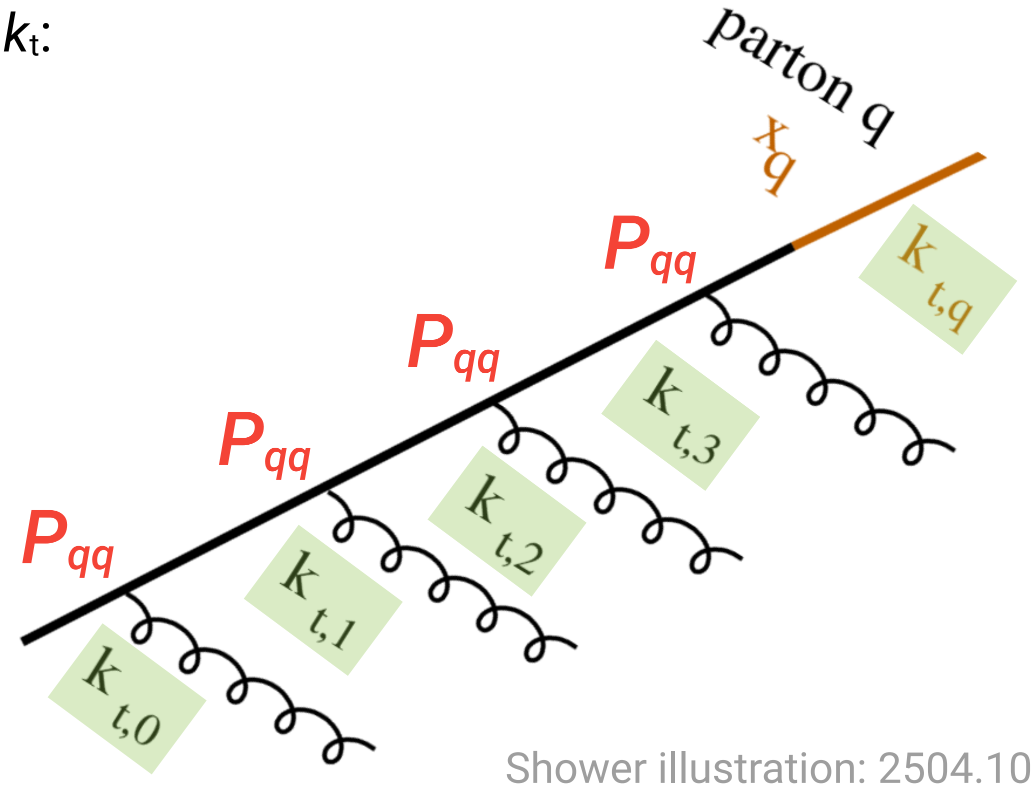
DGLAP neglects the transverse plane, but in practice it is there...

Every branching generates some k_t:

$$\vec{k}_{t,\mathrm{tot}} = \sum_{\mathrm{branchings}} \vec{k}_{t,i}$$

Problems:

- Infinite number of emissions
- Non-perturbative regions



Shower illustration: 2504.10243

k_T-dependent PDFs

PDFs can be generalized with transverse momentum dependence

⇒ **TMD PDFs**

Two approaches:

CASCADE generator

- Monte Carlo / "shower" language: **Parton branching TMD**
  Directly in momentum space; NNLL
- **CSS**: factorization formalism
  In impact parameter space; N^3LL

Equivalent if using an angular-ordered shower

Inputs: initial **PDF and k_T** distributions, non-perturbative **evolution kernel**

Parton branching vs Pythia

PS2TMD [2504.10243]

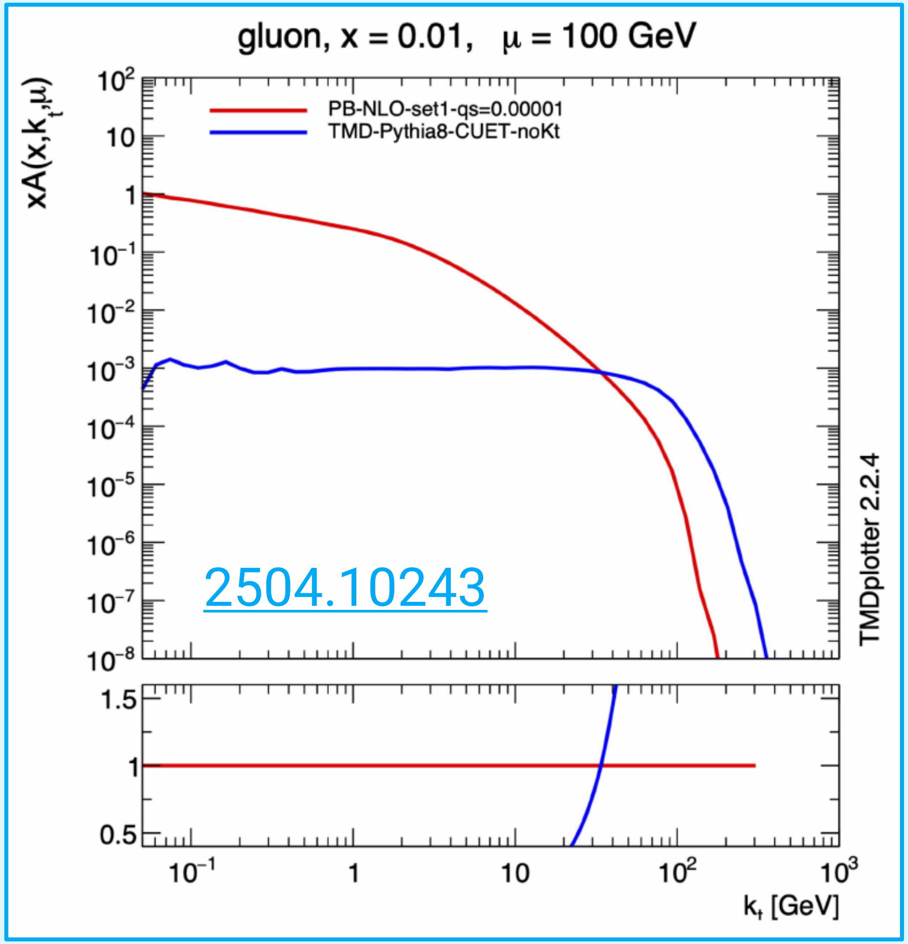
H. Jung, L. Lönnblad, M. Mendizabal, S. Taheri M.

Systematic comparison of parton showers and TMDs

Very different behaviors:

- Parton branching TMD
- Pythia8

Can use any parton shower



Parton branching *in* Pythia

PS2TMD [2504.10243]

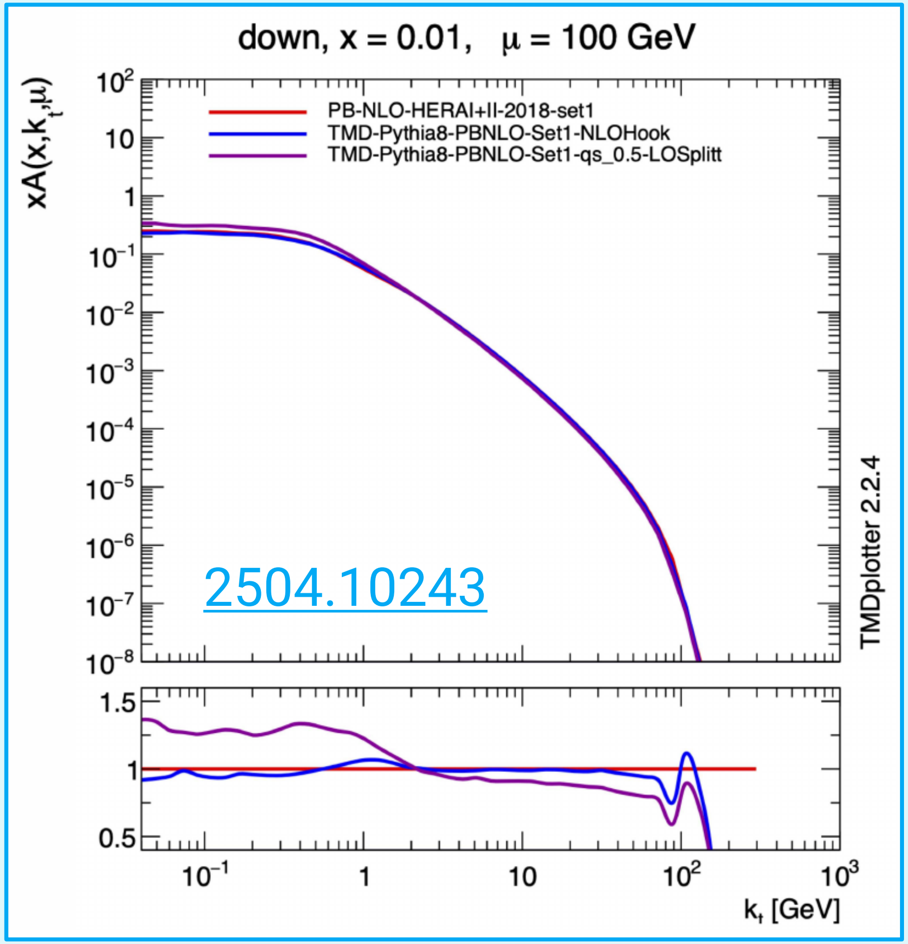
H. Jung, L. Lönnblad, M. Mendizabal, S. Taheri M.

...and **TMD2ISR** (from the same paper)

Modified Pythia:

- Switch to angular ordering
- Implement NLO splitting functions and running of α_s
- Change integration bounds

Recovers the TMD!



Intrinsic k_T

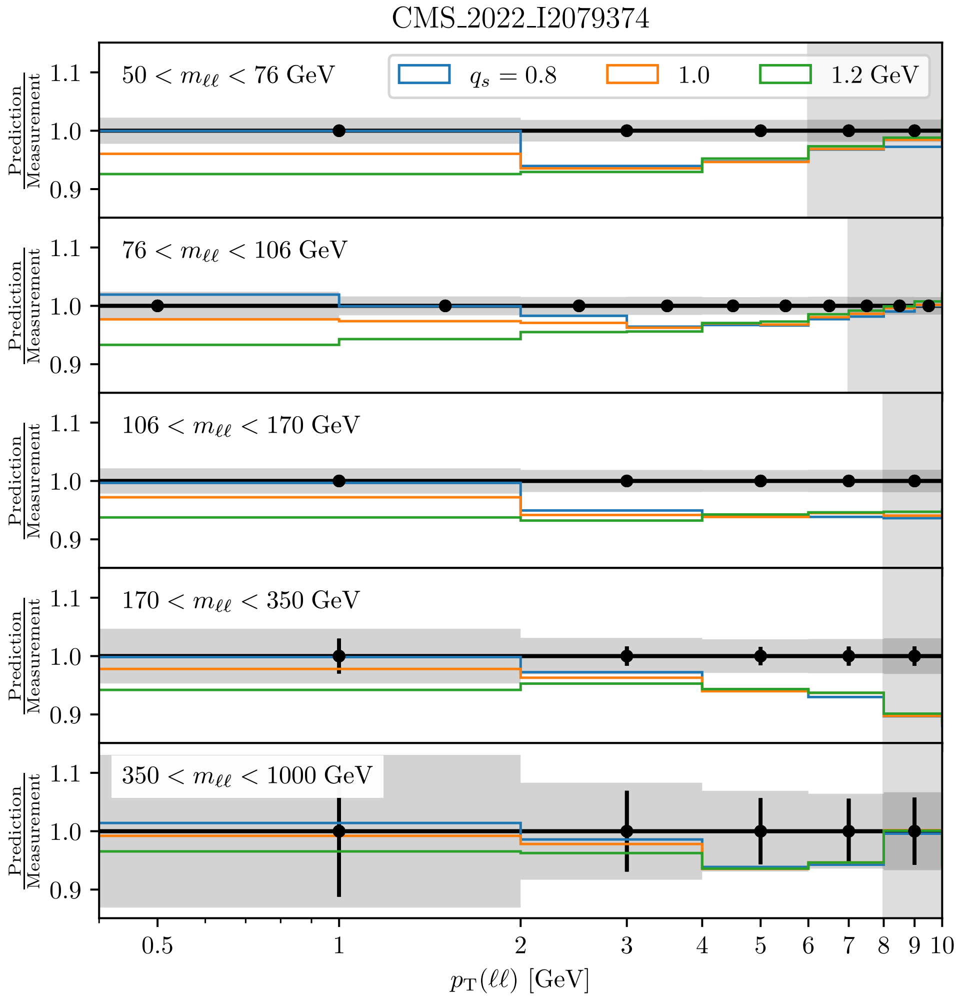
Can we still see the proton structure after evolution from 1 to 100 GeV?

Check different intrinsic k_T distributions vs CMS Dell-Yan data:

q_s = 0.8, 1.0, 1.2 GeV

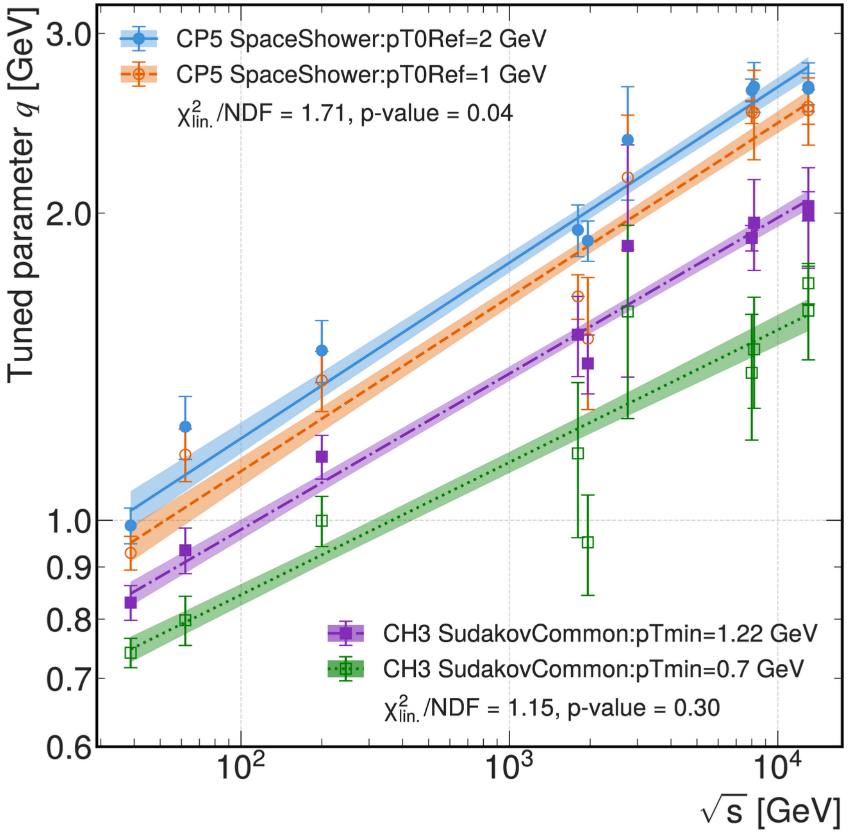
Sensitivity in LHC data!

Fit gives q_s = (1.04 ± 0.08) GeV



EPJ C 84 (2024) 154 (I. Bubanja, ..., LM, ...)

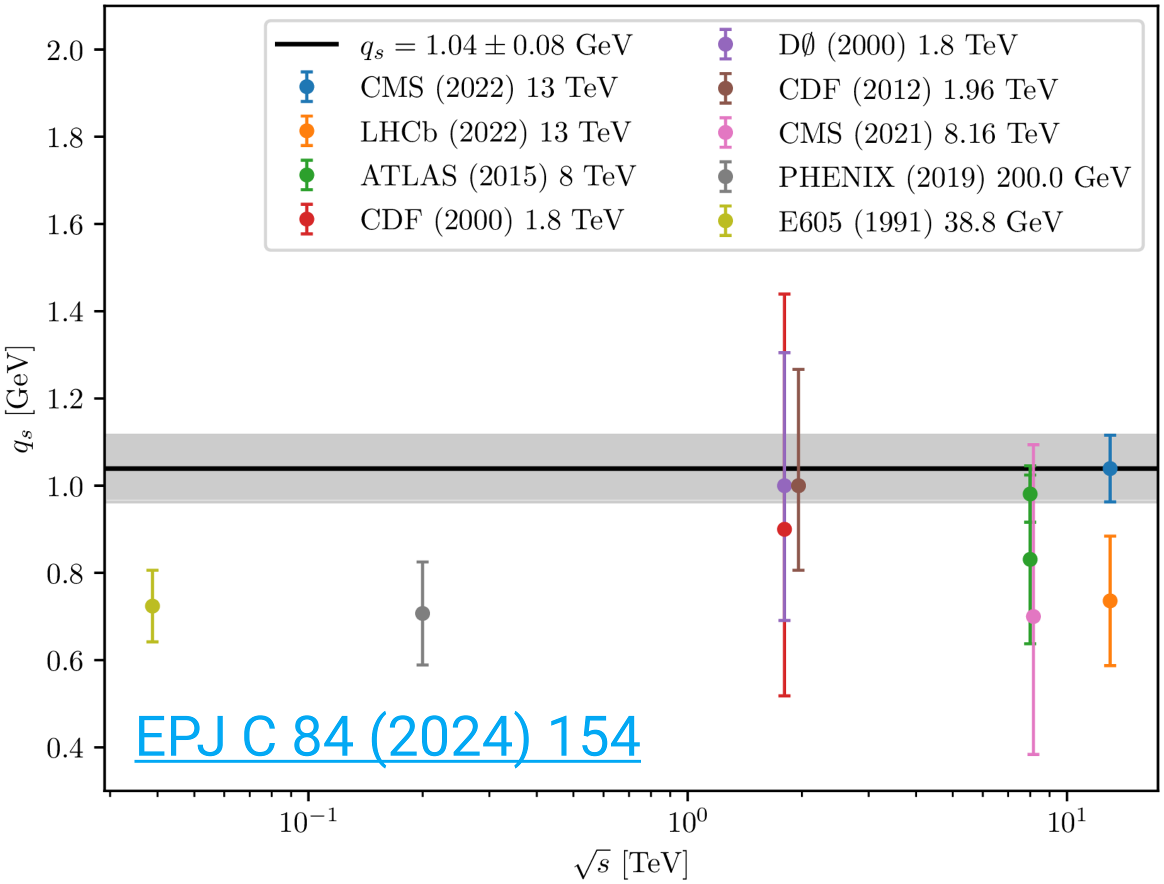
In standard parton showers



CMS-GEN-22-001

- Pythia/Herwig also have an "initial" k_T parameter
- Inconsistent values depending on the center-of-mass energy
- What about TMDs?

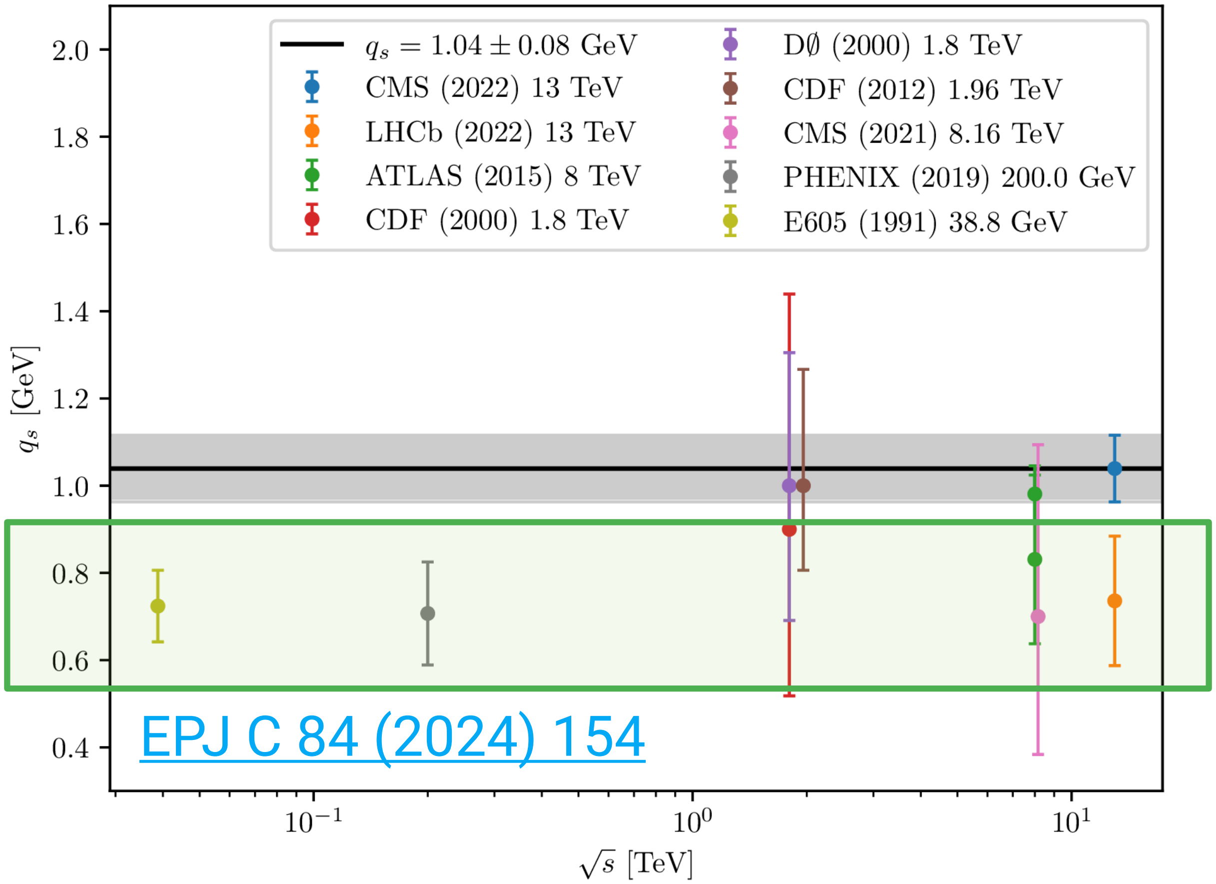
Intrinsic k_T with PB TMD



Consistent results for all $\sqrt{s}$ with PB TMD

Work with I. Bubanja et al.

Intrinsic k_T with PB TMD



EPJ C 84 (2024) 154

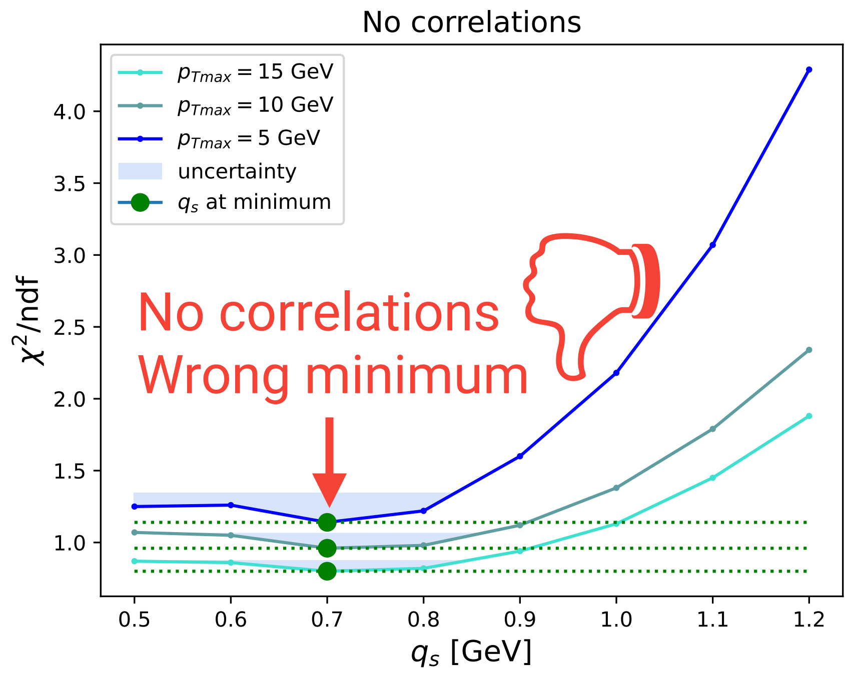
Consistent results for all $\sqrt{s}$ with PB TMD

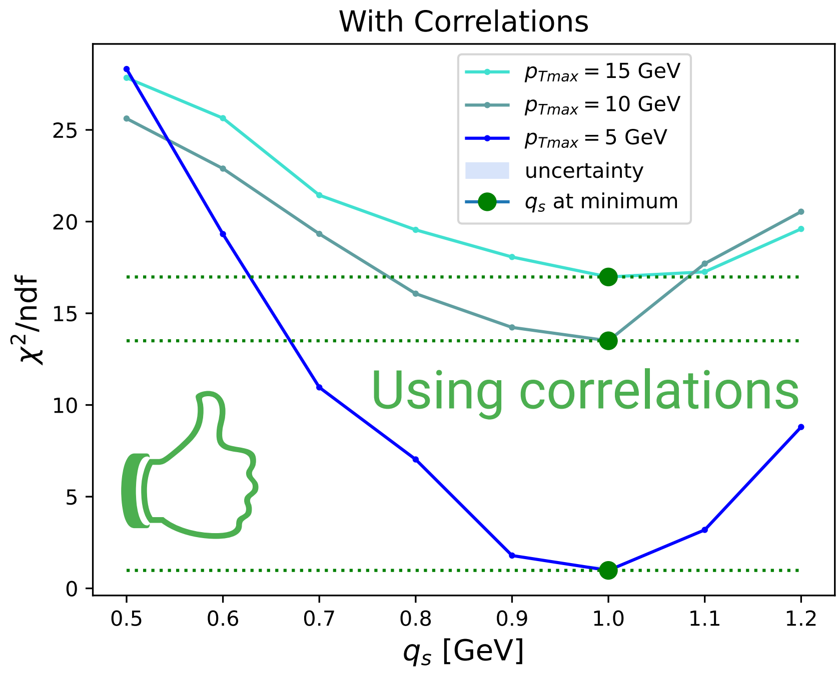
Large-x phase spaces
Valence quarks?

Work with I. Bubanja et al.

Correlations in fits

Full constraining power of the data

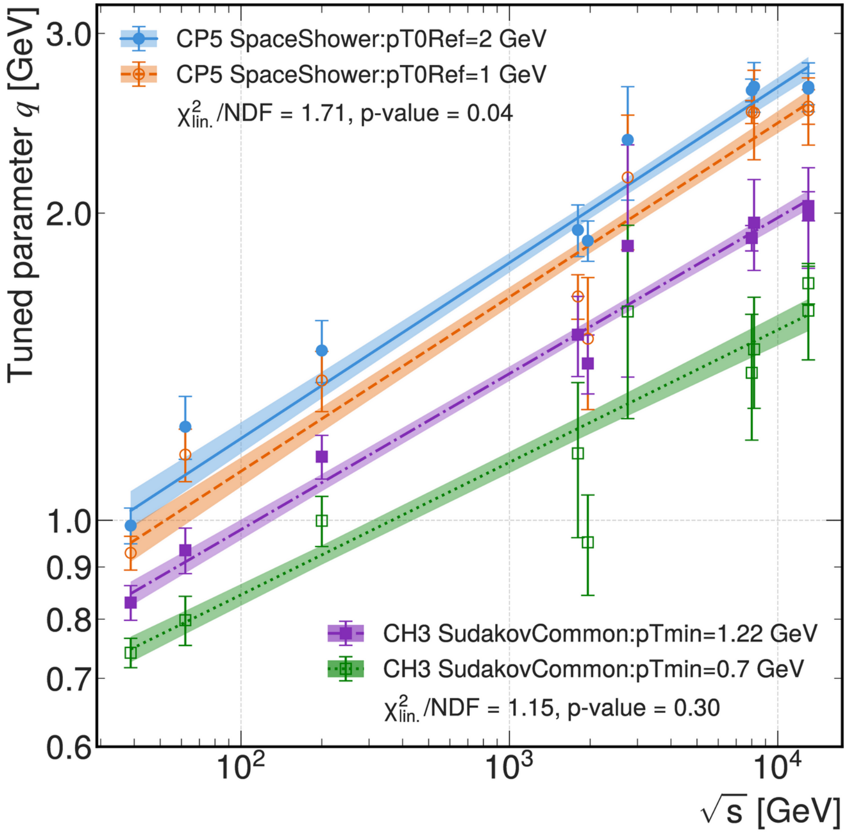




After carefully revisiting LHCb: **[preliminary]**

- q_s values from LHCb and CMS data are compatible

Back to parton showers



CMS-GEN-22-001

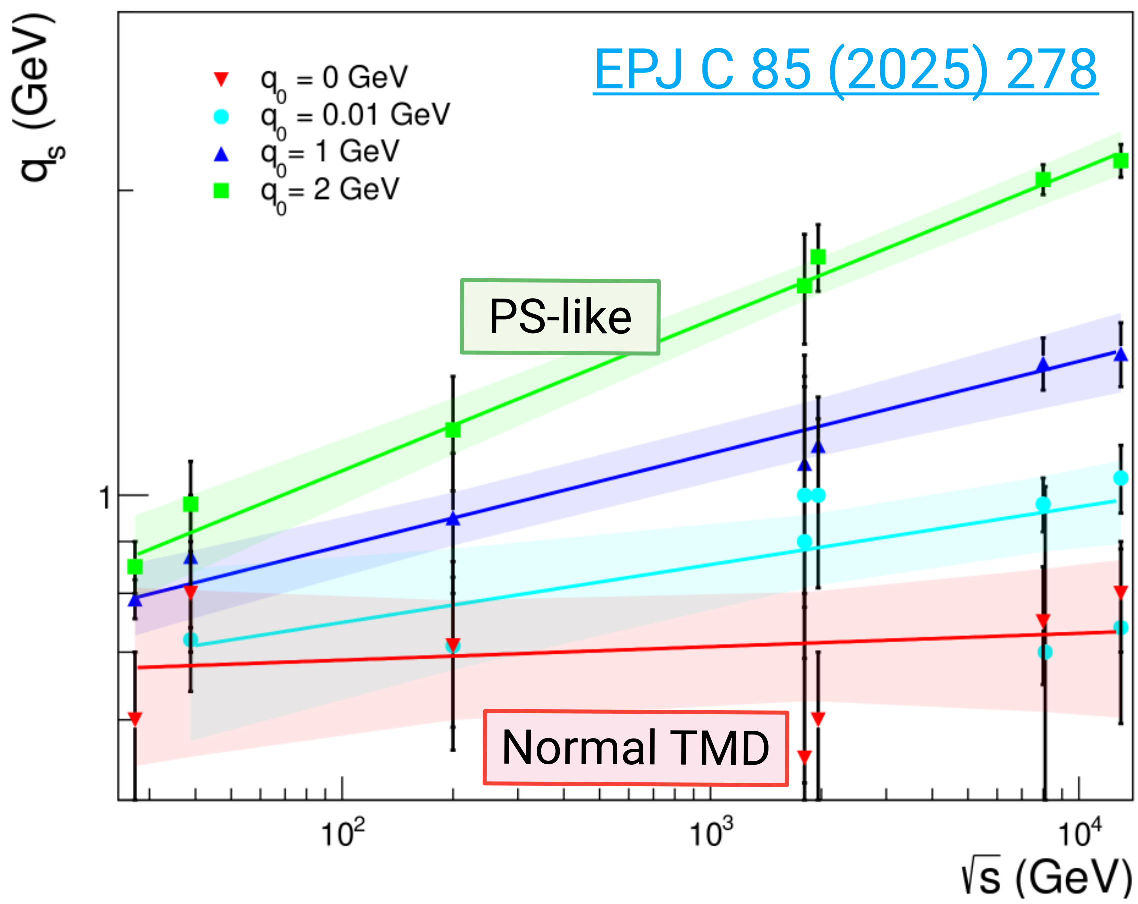
- Pythia/Herwig also have an "initial" k_T parameter
- Inconsistent values depending on the center-of-mass energy
- What about TMDs?
- **Why is this happening?**

Quick check

Implement parton shower cuts in the TMD evolution

Caveat:
No refit of the collinear part

Recovers the $\sqrt{s}$ scaling observed in parton showers



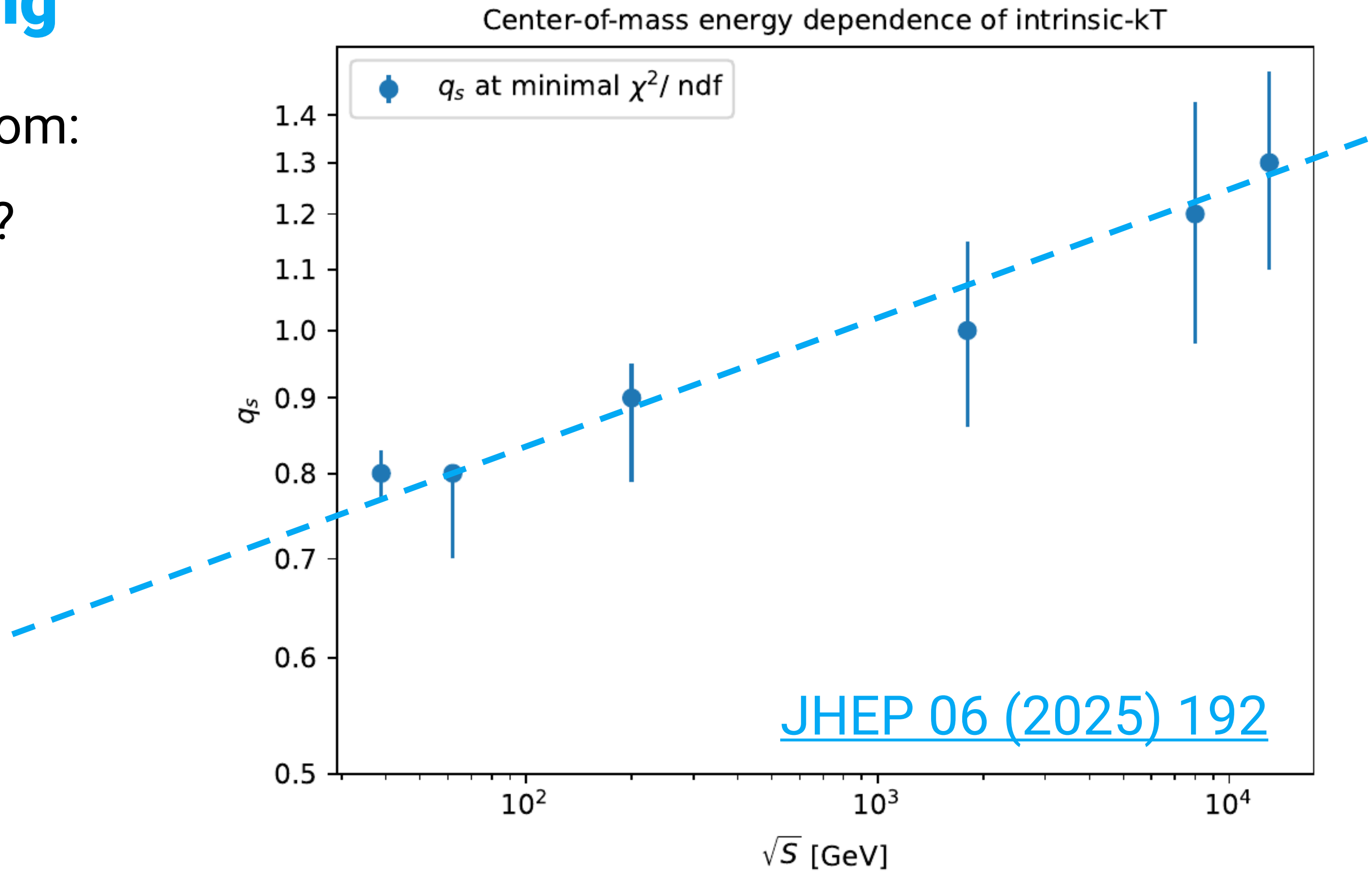
Work by: I. Bubanja, H. Jung, A. Lelek, N. Raičević, and S. Taheri Monfared

Results with refitting

Does the scaling come from:

- Not refitting the TMD?
- Other aspects?

$\sqrt{s}$ scaling persists after a complete refit

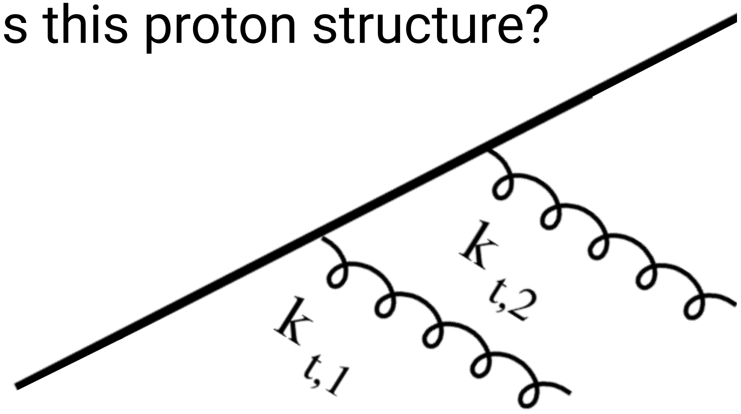


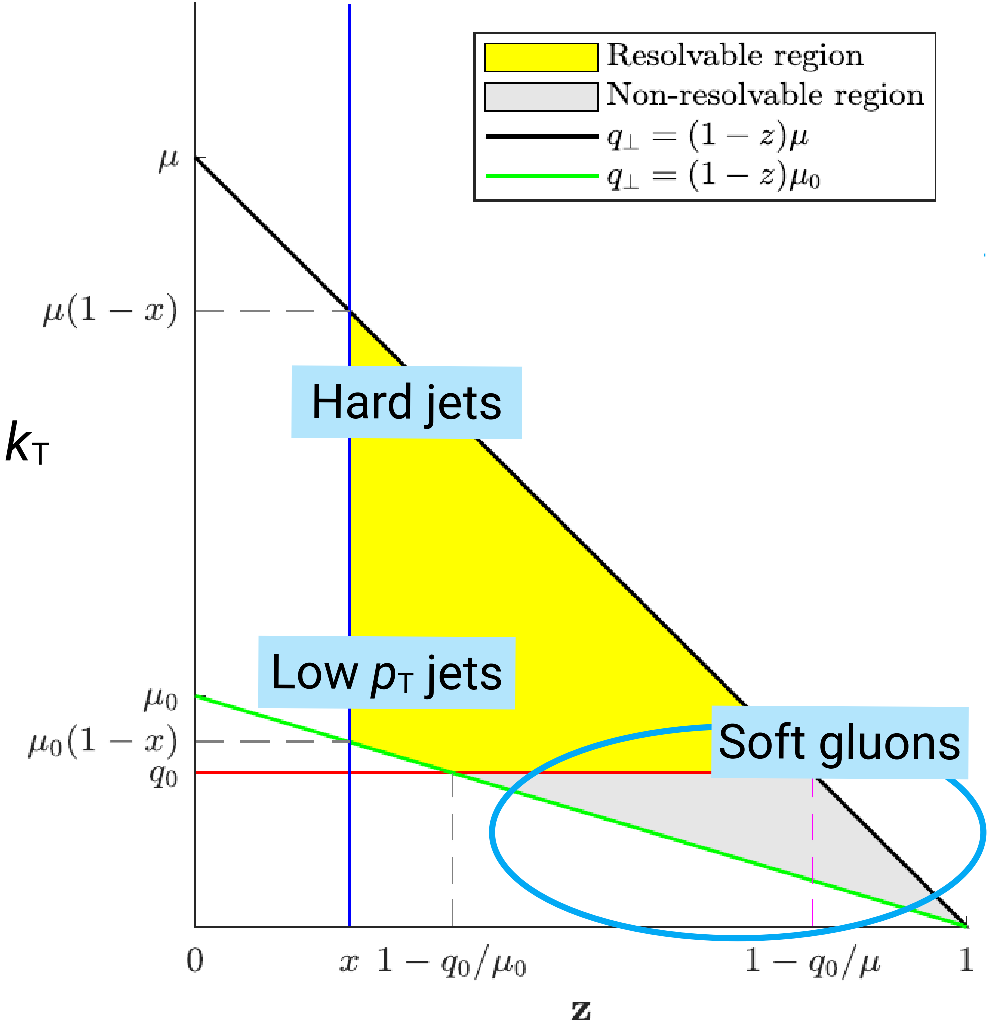
Work by: F. Hautmann, L. Keersmaekers, A. Lelek, S. Sadeghi Barzani, S. Taheri Monfared

What's happening?

Some branchings occur without a hard scale (gray triangle)

- Low k_T, non-resolvable
- Different treatment in TMD and parton showers
- Or is this proton structure?





Summary

- Consistent picture for collinear and transverse evolution: TMDs
- Parton branching TMD with a shower-like algorithm
- Successful description of DY data (if proper correlations...)
- Hindsight into an old issue of parton showers
- Coming to Pythia soon?