Intrinsic k_T studies

12th MPI at LHC

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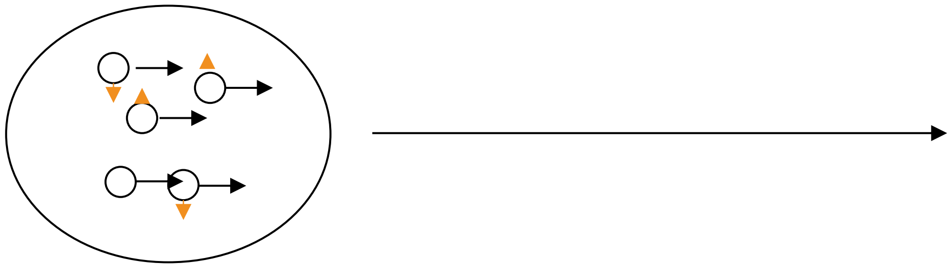
Plan for today

- Introduction
- A first attempt to tune intrinsic k_T
- Energy dependent intrinsic k_T
- Conclusions

Intrinsic k_T

- Besides longitudinal momenta, partons also have small transverse momentum inside the incoming hadrons



- The intrinsic k_T represents this small transverse momentum, intrinsic k_T ~ MeVs

- It is introduced in the evolution equations as a non-perturvative parameter, it is generated from a gaussian distribution of width σ

$$e^{-k_T^2/\sigma^2}$$

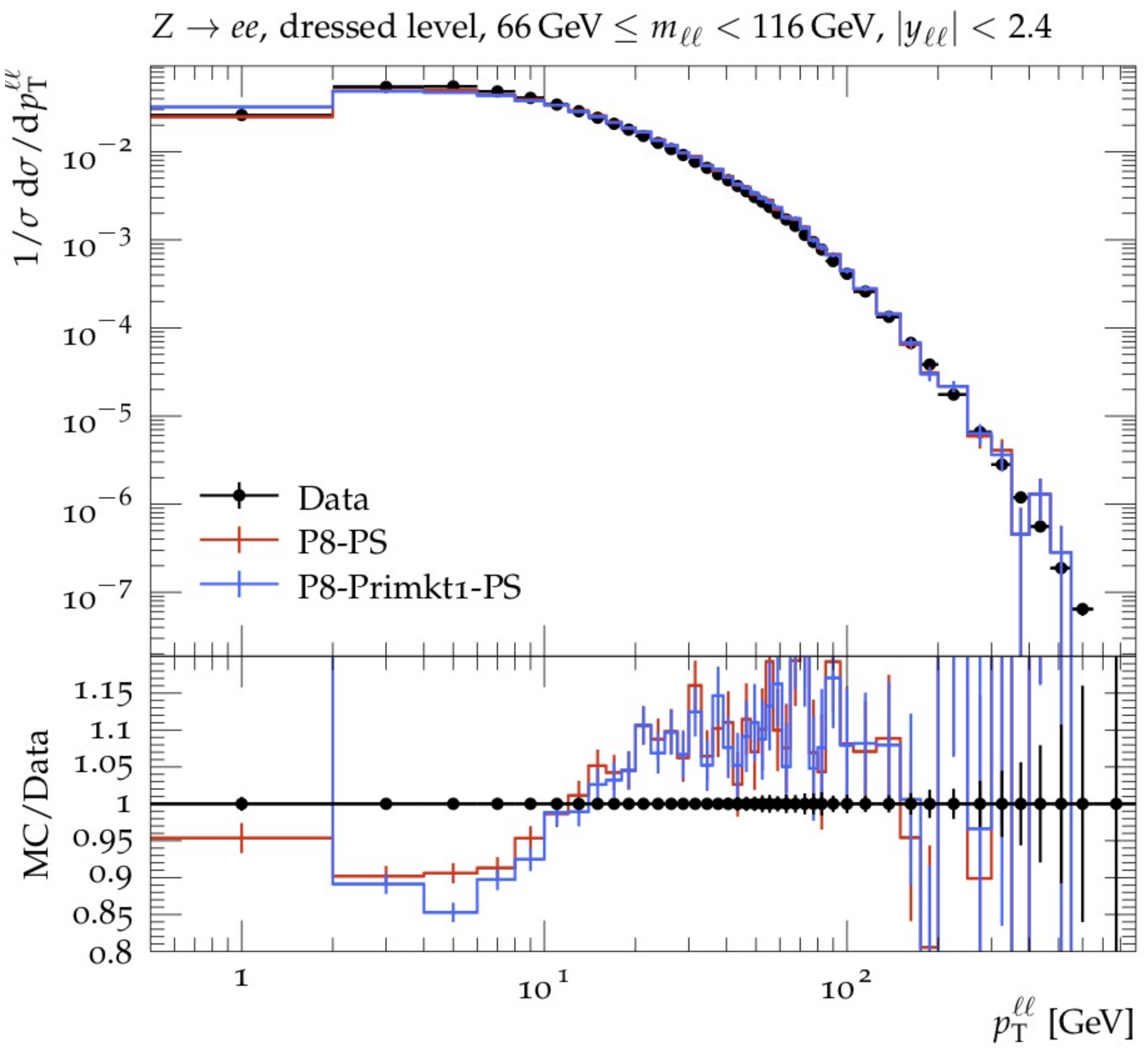
When is the intrinsic k_T important?

- The contribution of intrinsic k_T is small at LHC energies and at Z peak, only visible at low p_T

- Drell-Yan processes are the cleanest events to study the intrinsic k_T , due to the lack of final state radiation

- The Z transverse momentum is the perfect observable to study the interplay of the initial state radiations and the intrinsic k_T

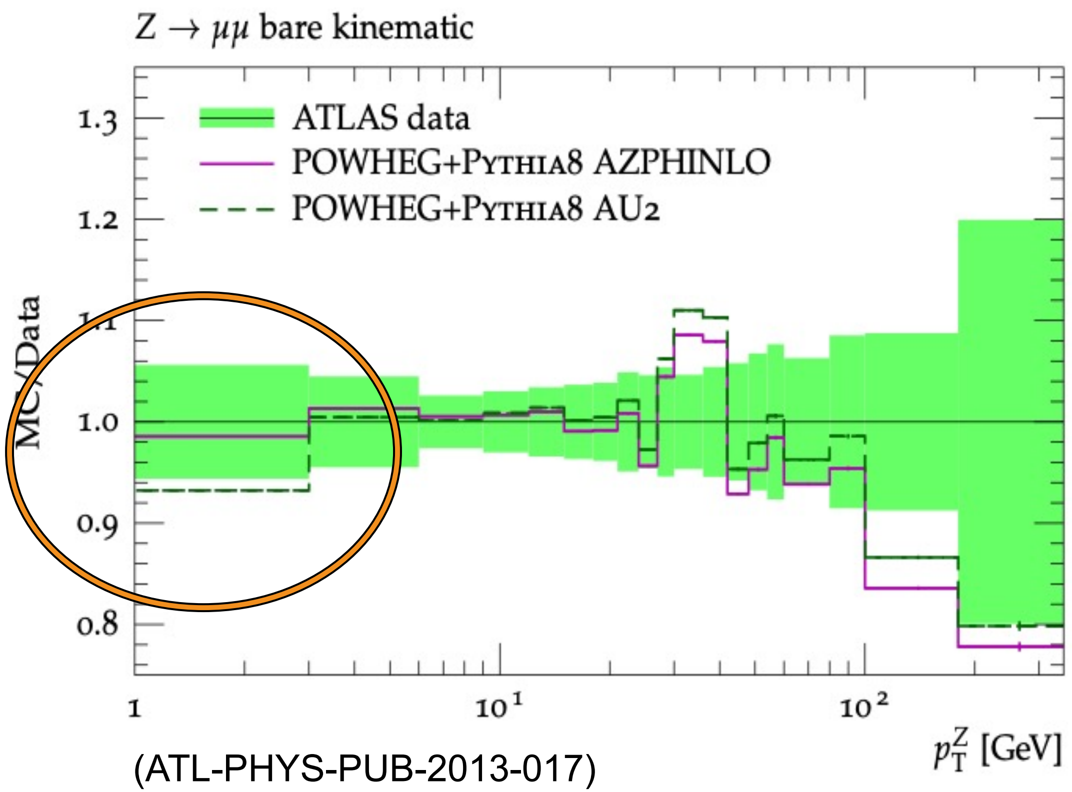
- Thus, a proper description of the low p_T regions is very important for precision measurements that make use of small p_T regions



Intrinsic k_T

- Goal: Tune the intrinsic k_T parameters to describe the low Z p_T spectrum at any given DY mass

- Set-up: MC@NLO + Pythia8 tune with Proffesor



(ATL-PHYS-PUB-2013-017)

Pythia8 parameters for Intrinsic k_T

- BeamRemnants:primordialKThard → σ_{hard}
  - Width of the gaussian distribution where the intrinsic k_T is generated from

$$e^{-k_T^2/\sigma^2} \quad : \quad \sigma \propto \sigma_{hard}$$

- SpaceShower:pT0Ref
  - Regularization of the divergence of the QCD emission probability for $p_T \to 0$ $\frac{p_T^2}{(p_{T_0}^2+p_T^2)}$
  - $p_{T_0} = p_{T0Ref}\left(\frac{ecmNow}{ecmRef}\right)^{ecmPow}$ and by default $ecmPow = 0$ → $p_{T_0} = p_{T0Ref}$

A first attempt to tune the intrinsic k_T

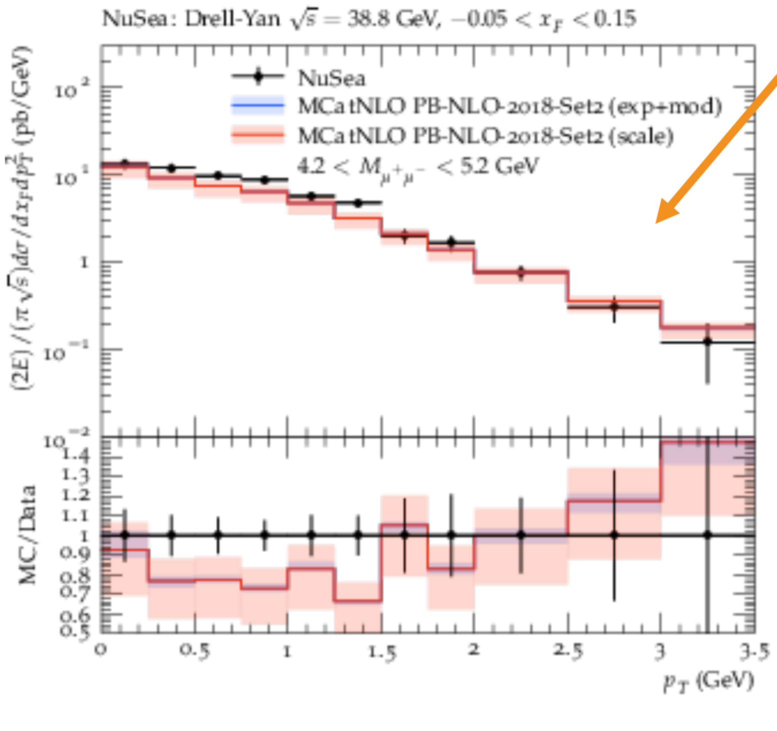
*Eur. Phys. J. C (2021) **81**: 425

Tuning of intrinsic k_T at low CM energies

- The first idea → Tune intrinsic k_T paramters at low DY mass processes for higher precision and use this tune at any given CM energy / DY mass

Little room for QCD evolution

- Same idea as Cascade3* parton shower based on Parton Branching formalism, same width $\sigma = \frac{q_s}{\sqrt{2}}$: $q_s = 0.5$ GeV



NuSea($\sqrt{s}$ = 38.8 GeV)
$4.2 < m_{\mu^+\mu^-} < 5.2$GeV
$\chi^2/ndf = 1.07$

CMS($\sqrt{s}$ = 13 TeV)
$|m_{l^+l^-} - m_Z| < 15$ GeV
$\chi^2/ndf = 0.8$

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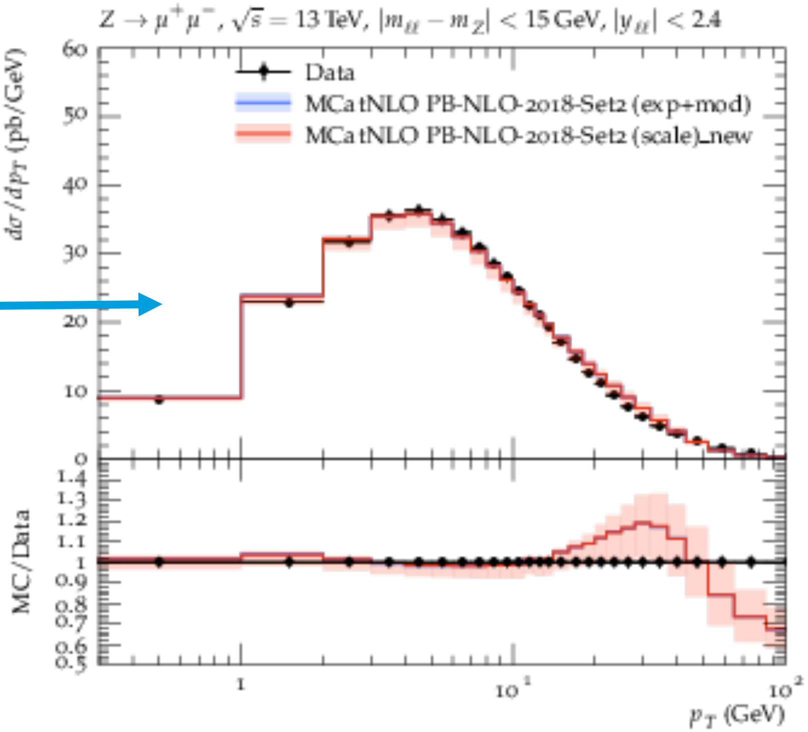


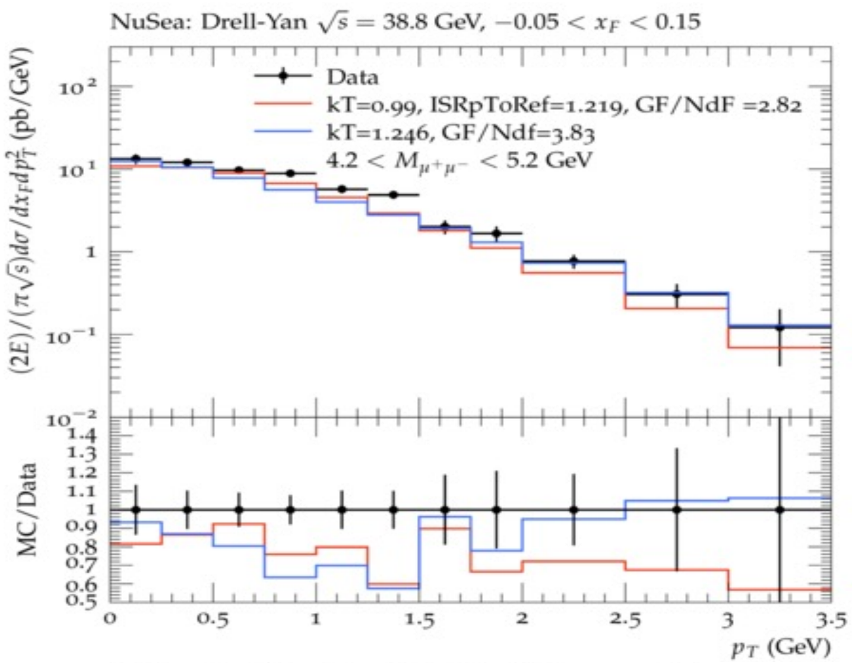
Results of the tune at $\sqrt{s} = 38.8$ GeV

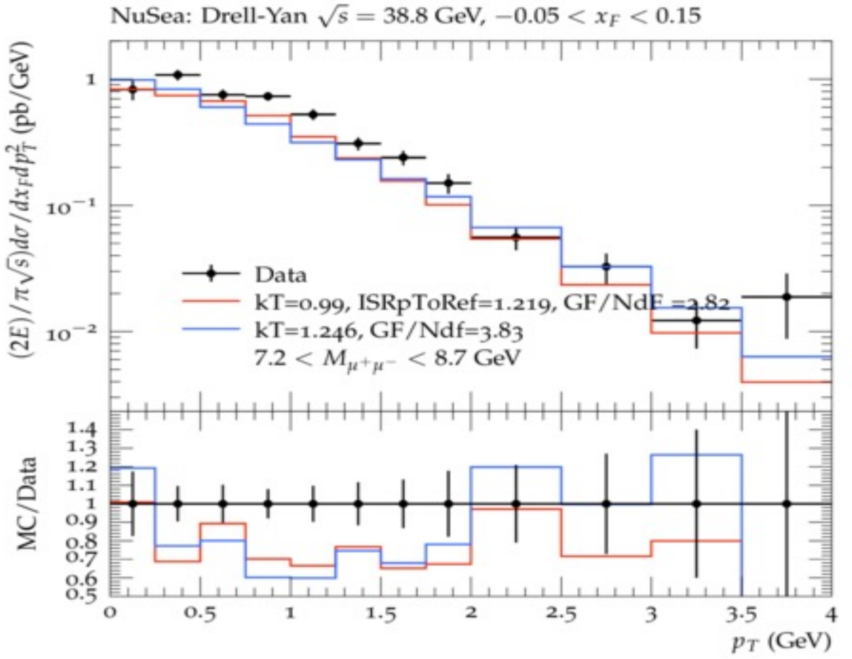
- On a first step we turn-off the parton shower and only include the intrinsic k_T

- On a second step the parton showers are turned on and both pT0Ref and the intrinsic k_T are tuned

Tune	BeamRemnants: primordialKTHard	SpaceShower: pT0Ref	SpaceShower: alphaSvalue
Step 1	1.246	-	-
Step 2	0.99	1.219	0.118(fixed)

- Good description of MC for both cases, with a $\chi^2/ndf = 2.82$ for second step



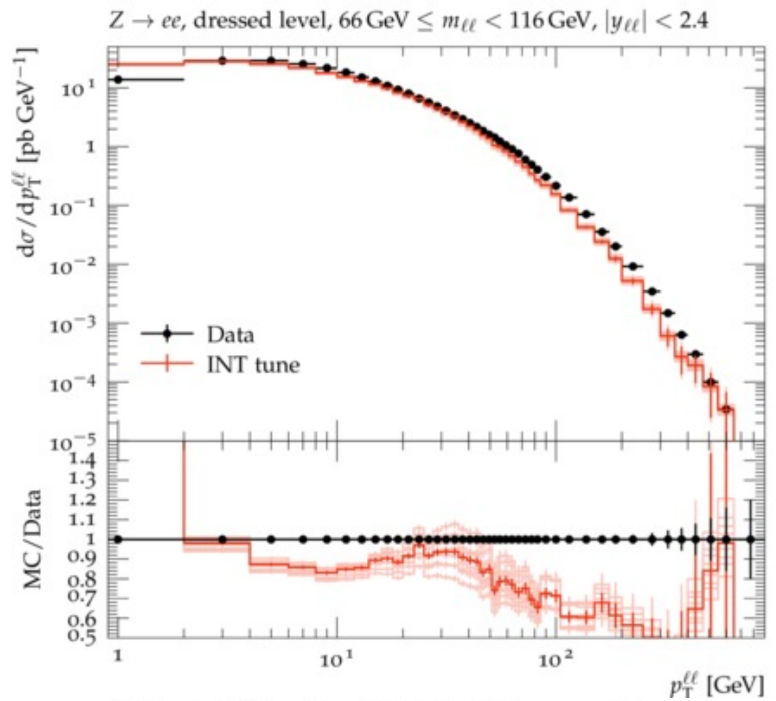


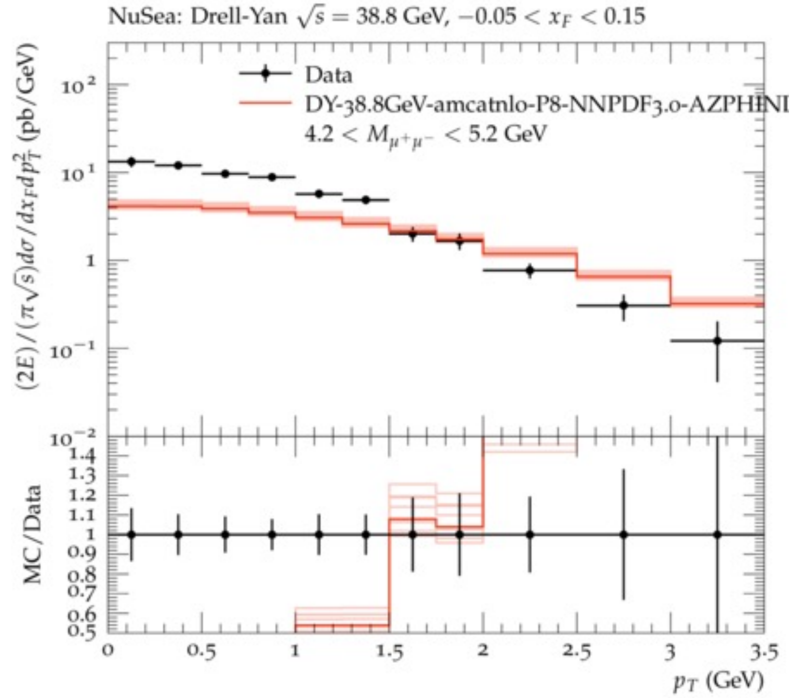
Energy dependent intrinsic k_T

- For different DY masses different intrinsic k_T s
  - For AZPHINLO tune at 8 TeV k_T = 1.74 GeV
  - For our tune (INT) at 38.8 GeV k_T = 0.9 GeV

- Apply the two tunes to different centre of mass energies:
  - INT tune at 8 TeV (upper panel) → First bin “diverges”
  - AZPHINLO tune at 38.8 GeV (lower panel)→ First bin converges to zero

- An energy dependence can be observed for the k_T in Pythia8





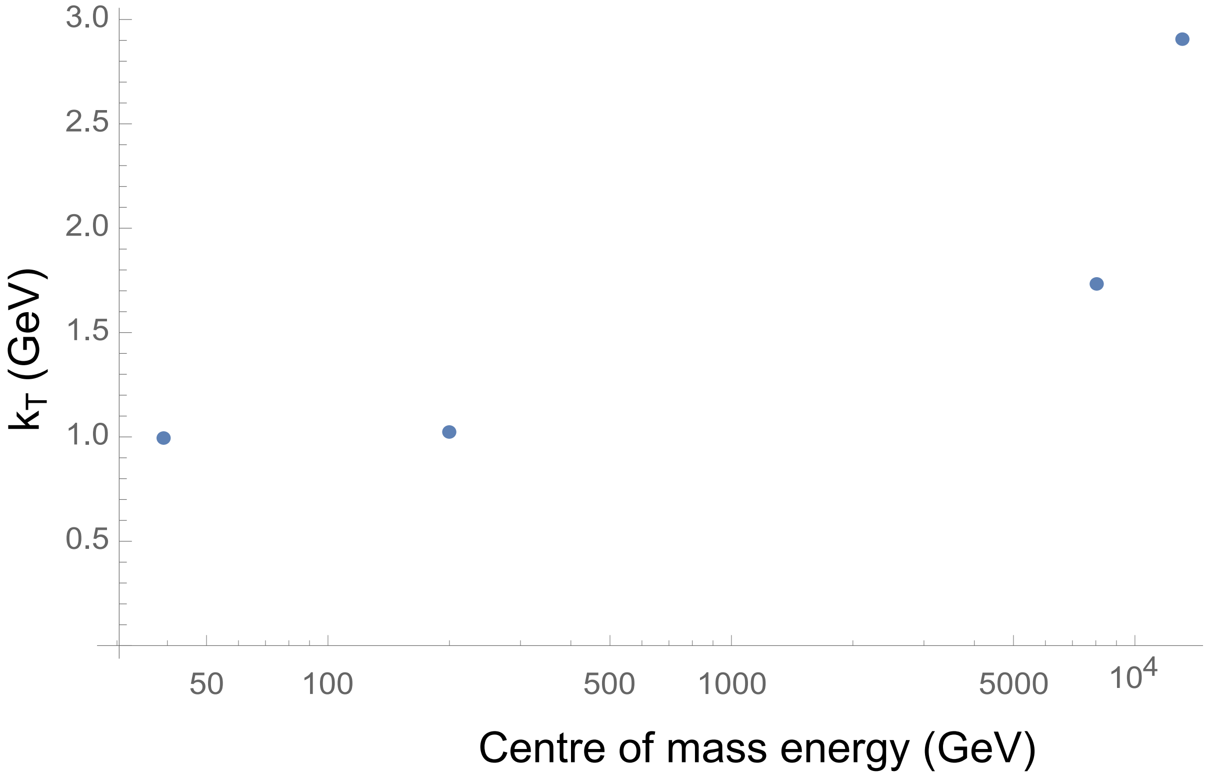
(AZPHINLO tune → ATL-PHYS-PUB-2013-017)

Energy dependent intrinsic k_T

Energy dependent intrinsic k_T

- For each different centre of mass energy we tune the intrinsic k_T

Experiment	Centre of mass energy (GeV)	Intrinsic k_T from tune (GeV)
NuSea	38.8	0.99
PHENIX	200	1.05
ATLAS	8 000	1.74
CMS	13 000	2.90



- For larger CME the k_T reaches unphysical values

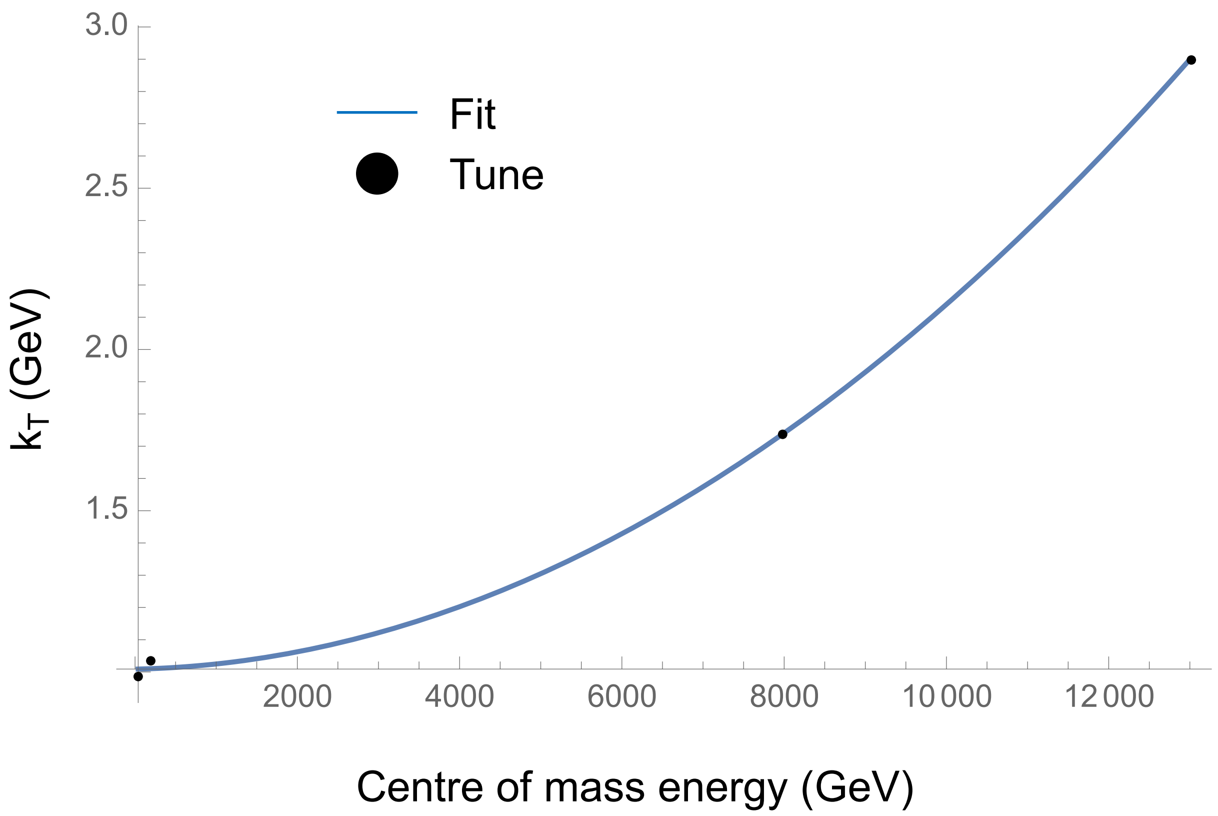
$$k_T > 1 \text{ GeV} \sim \text{size of proton}$$

Fit of intrinsic k_T

- A polynomial is used to fit the tuned values:

$$k_T(\sqrt{s}) = 1.019 + 3.182 \cdot 10^{-6}\sqrt{s} + 1.086 \cdot 10^{-8}\sqrt{s}^2$$

Experiment	Centre of mass energy (GeV)	Intrinsic k_T from tune (GeV)	Intrinsic k_T from fit (GeV)
NuSea	38.8	0.99	1.019
PHENIX	200	1.05	1.020
ATLAS	8 000	1.74	1.740
CMS	13 000	2.90	2.899



- The fit describes properly the values from the tune:
  - At rest $k_T(0) = 1.019\ \text{GeV}$, one would expect a value of few MeVs

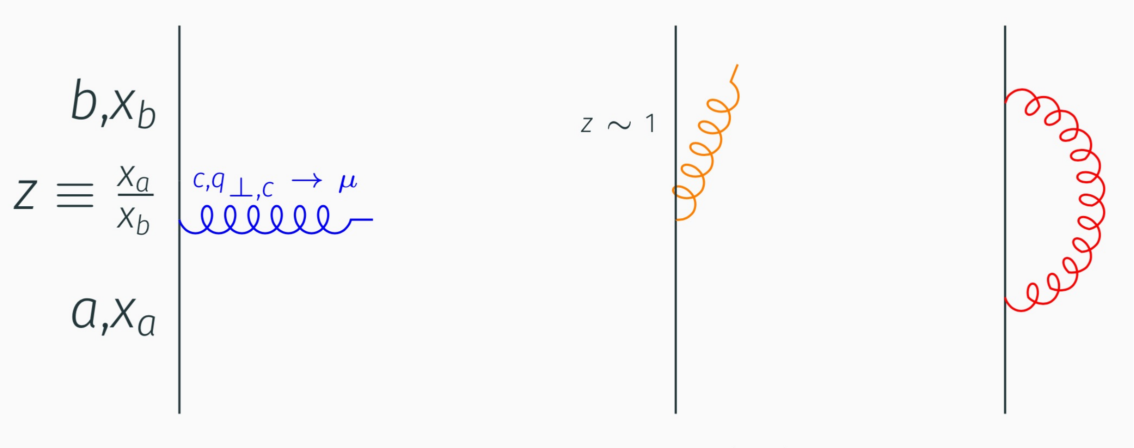
Summary

Why is there a large sensitivity to intrinsic k_T?

https://indico.ph.ed.ac.uk/event/63/contributions/1002/attachments/751/929/Mikel_Mendizabal.pdf

- Extended discussion around the instrinsic k_T in REF 2020 workshop :
  - Studies in Herwig by S. Gieseke, M. H. Seymour , A. Siódmok (arXiv:0712.1199) back in 2008
  - Pythia and Herwig have a non predictable value of the intrinsic kT
  - Cascade 3 shows a good description both at high and low DY masses (arXiv:2001.06488) (TMD parton shower)

- Can the treatment of non-perturvative effects be the reason?



When $z \sim 1$ the splitting is non resolvable → z_m

Pythia/Herwig z_m < Cascade z_m

This smaller value of z_m makes the contributions of non-perturvative effects larger, e.g.: intrinsic kT

EVOLUTION → Real resolvable splittings + Non resolvable splittings + Virtual correction

Summary

- A good description of the intrinsic k_T is important for precision measurement in the low p_T regions

- From the preliminary tune of the intrinsic k_T at $\sqrt{s} = 38.8\ \mathrm{GeV}$ we observe an energy dependency of the intrinsic k_T in Pythia8

- We performed a tune for different centre of mass DY processes using NuSea, PHENIX, ATLAS and CMS meausrements

- A fit was performed for the intrinsic k_T :

$$k_T(\sqrt{s}) = 1.019 + 3.182 \cdot 10^{-6}\sqrt{s} + 1.086 \cdot 10^{-8}\sqrt{s}^2$$

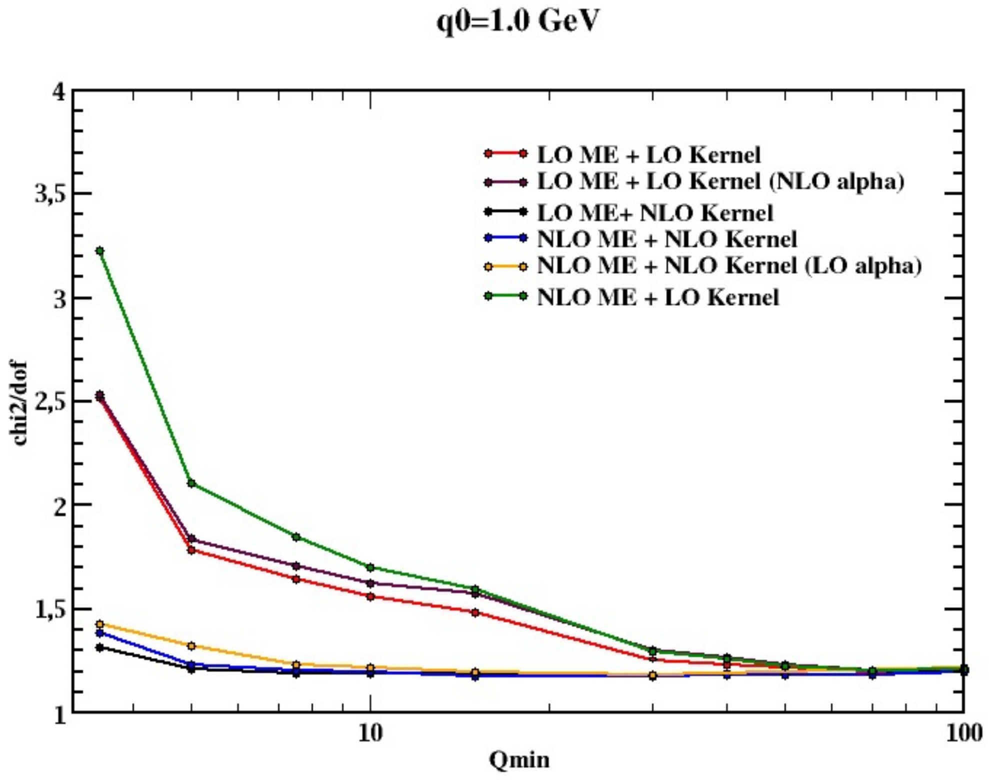
- A good agreement is observed between the fit and the tune values (χ^2test to be performed)

Thank you

Could NLO shower solve this?

Some thoughts

- Pythia8 uses LO splitting functions while Cascade3 uses NLO splitting functions
- Studies from S. Taheri Monfared on the effect of NLO splitting kernels and ME in TMD fitting to DIS data using PB formalism:
  - q_0 non-perturvative parameter $z_M = 1 - q_0/\mu$
  - By defould PB formalism uses a $q_0 \sim 1\ \mathrm{MeV}$



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