Intrinsic k_T tuning

Studies with Pythia8

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LHC EW , January 11th, 2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Heading Agenda

- Introduction
- Tuning procedure
- Energy dependent intrinsic k_T
- Summary & outlook

Introduction

- In the LHC together with EW bosons QCD radiation is produced

- The radiation can limit the accuracy of the measurements of the bosons

- Two type of radiations:
  1. Initial state radiation (ISR)
  2. Final state radiation (FSR)

- The Z transverse momentum is the perfect observable to tune the ISR

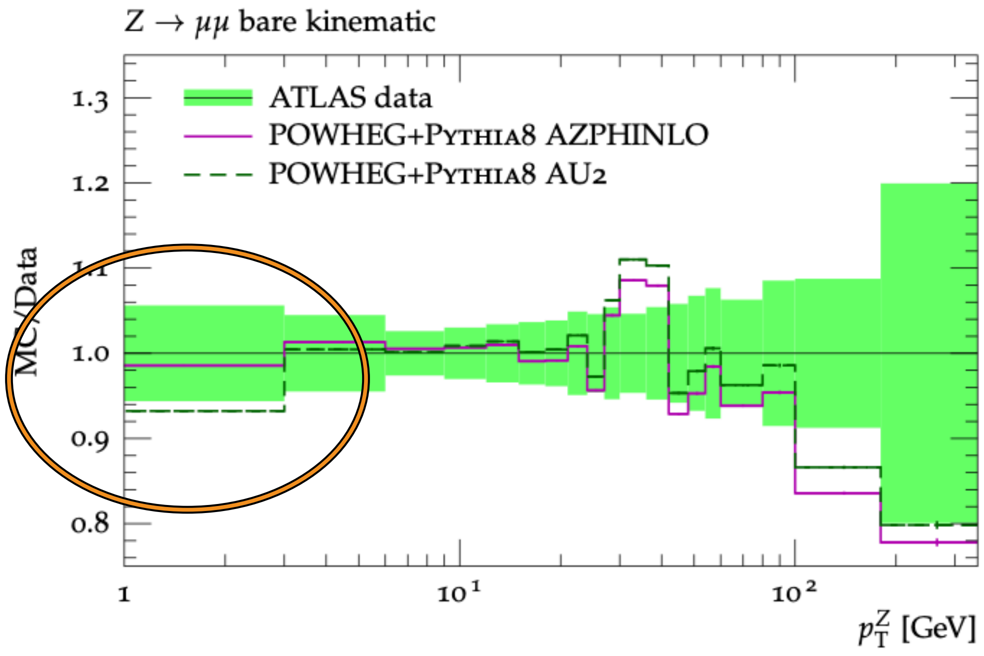
- Moreover, the $p_T < 20$GeV region is sensitive to the tuning of the intrinsic K_T parameters

Introduction

- The intrinsic k_T represents the intrinsic transverse momentum of the initial state partons

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

- Set-up: MC@NLO + Pythia8



(ATL-PHYS-PUB-2013-017)

Tune with Pythia8

Pythia8 parameters for Intrinsic k$_T$

- BeamRemnants:primordialKThard
  - Intrinsic k_T of the initial parton

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

- SpaceShower:alphaSvalue

Tuning of the intrinsic k_T with NuSea measurements $\sqrt{s} = 38.8$ GeV

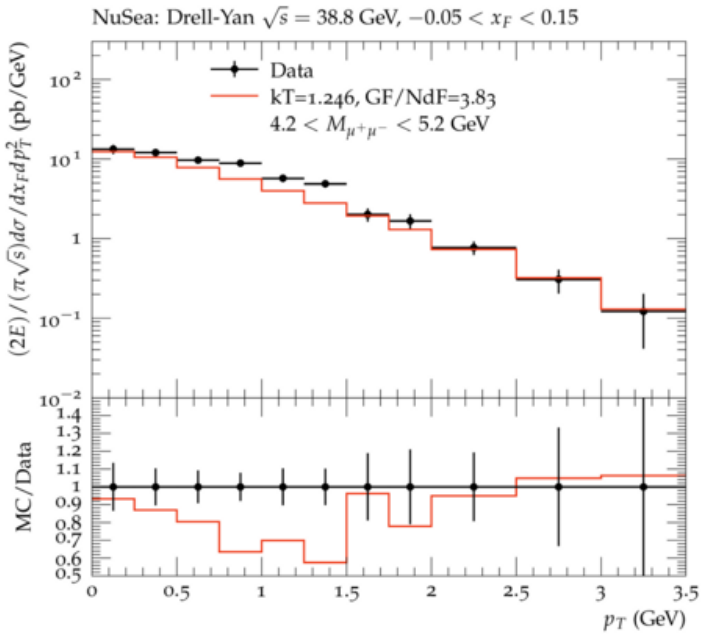
Step 1 – Intrinsic kT

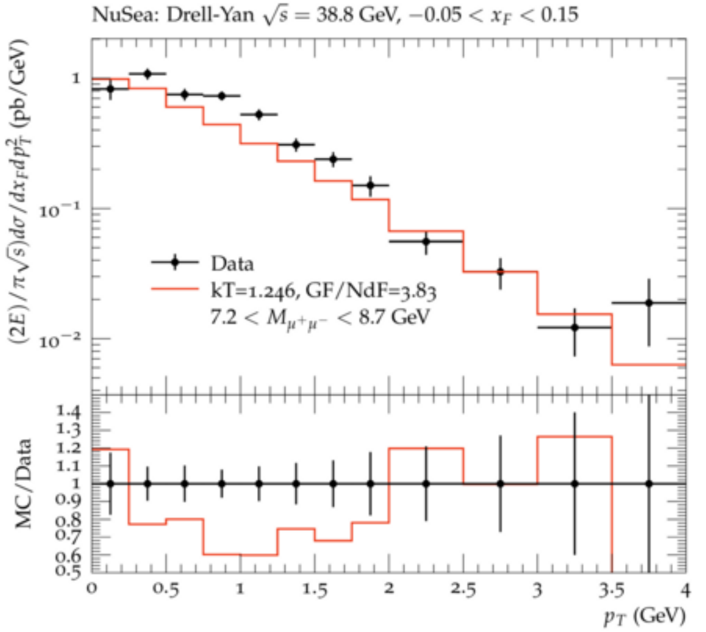
- We start the tuning with the

  BeamRemnats:primordialKTHard $\in (0.01,\ 5.0)$

- For this first step both space and time showers are switch off

- The optimal value found is BeamRemnats:primordialKTHard $= 1.246$ with a $\chi^2/ndf = 3.83$





Tuning of the intrinsic k_T with NuSea measurements $\sqrt{s} = 38.8$ GeV

Step 2 – Intrinsic kT + space shower

- We switch on the space shower (ISR) with a fixed value of

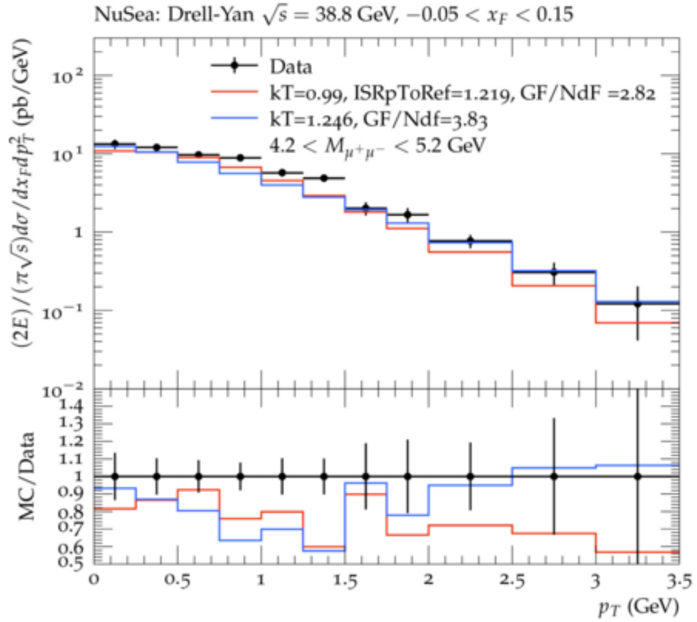
SpaceShower:alphaSvalue = 0.118

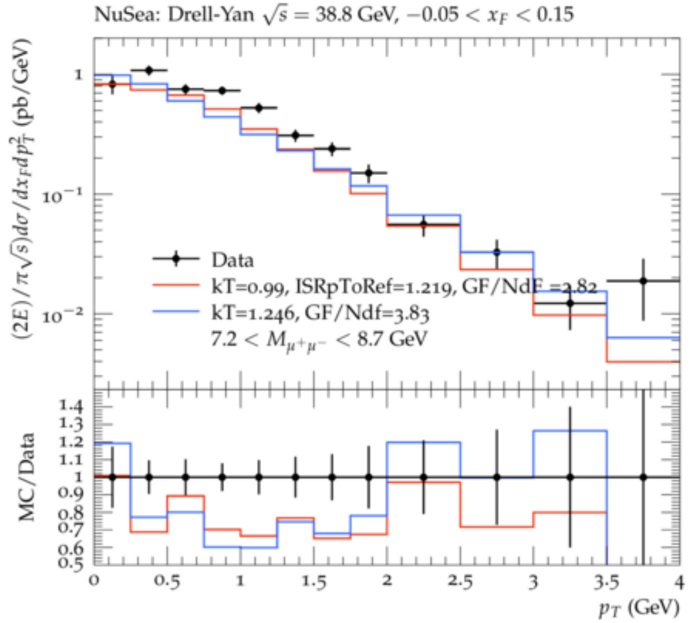
- We add one more parameter to the tune

SpaceShower:pT0Ref $\in (0.5,\ 9.0)$

- Resutls from the tune with a $\chi^2/ndf = 2.82$

Tune	BeamRemnants: primordialKTHard	SpaceShower: pT0Ref	SpaceShower: alphaSvalue	
Step 1	1.246	-	-	🟦
Step 2	0.9	1.219	0.118(fixed)	🟥





Tuning of the intrinsic k_T with NuSea measurements

Step 3 – Intrinsic kT + space shower

- This time we include another parameter to the tune

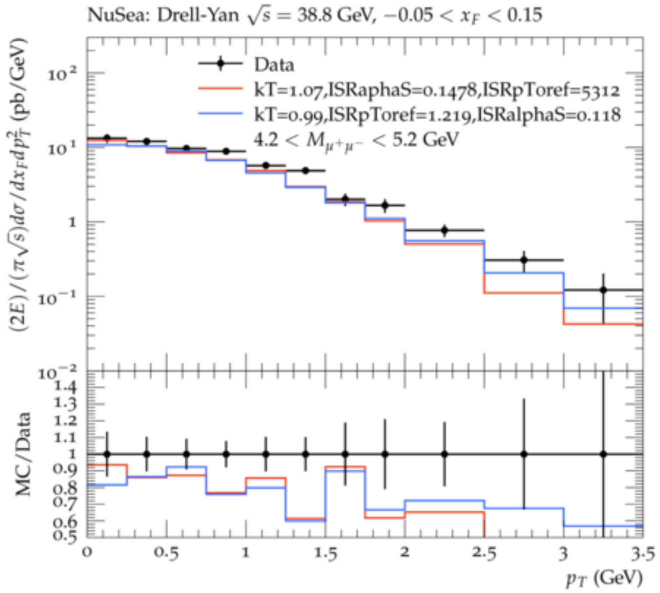
$$\text{SpaceShower:alphaSvalue} \in (0.09,\ 0.25)$$

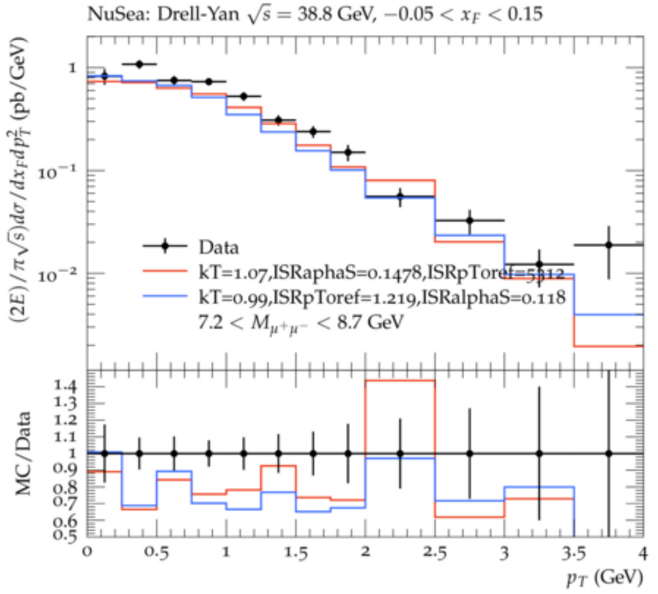
- Resutls from the tune with a $\chi^2/ndf = 2.91$

Tune	BeamRemnants: primordialKTHard	SpaceShower: pT0Ref	SpaceShower: alphaSvalue	
Step 1	1.246	-	-	
Step 2	0.9	1.234	0.118(fixed)	🟦
Step 3	1.07	5.312	0.1478	🟥

- A fixed value of $\alpha_s = 0.118$ performs better

- A fixed value of $\alpha_s = 0.118$ is used in AZPHINLO tune (ATL-PHYS-PUB-2013-017)





Summary of results

Tune	BeamRemnants: primordialKTHard	SpaceShower: pT0Ref	SpaceShower: alphaSvalue	χ^2/ndf
Step 1	1.246	-	-	3.83
Step 2	0.9	1.234	0.118(fixed)	2.82
Step 3	1.07	5.312	0.1478	2.91

- From Step 1 → Step 2: primordialKTHard + space shower (α_s fixed)
  - The space shower takes the space left from the primordial kT
- From Step 2 → Step 3: primordialKTHard + space shower
  - The primordial kT increases
  - pT0Ref takes a larger value most of the contribution coming from intrinsic kT
  - $\alpha_s = 0.1478$
- Step 2 which contains a fixed value $\alpha_s = 0.118$, best agreement with data

Moving the tune to 8 TeV

- Reminder: Our goal is to tune the lower pT region of the lepton pair for a any COM energy
  - We tune the intrinsic kT using low mass DY for higher precision

- Let’s put our tune (Step 2) to test with 8 TeV ATLAS measurements:
  - Our tune is not able to properly describe the lowest pT region

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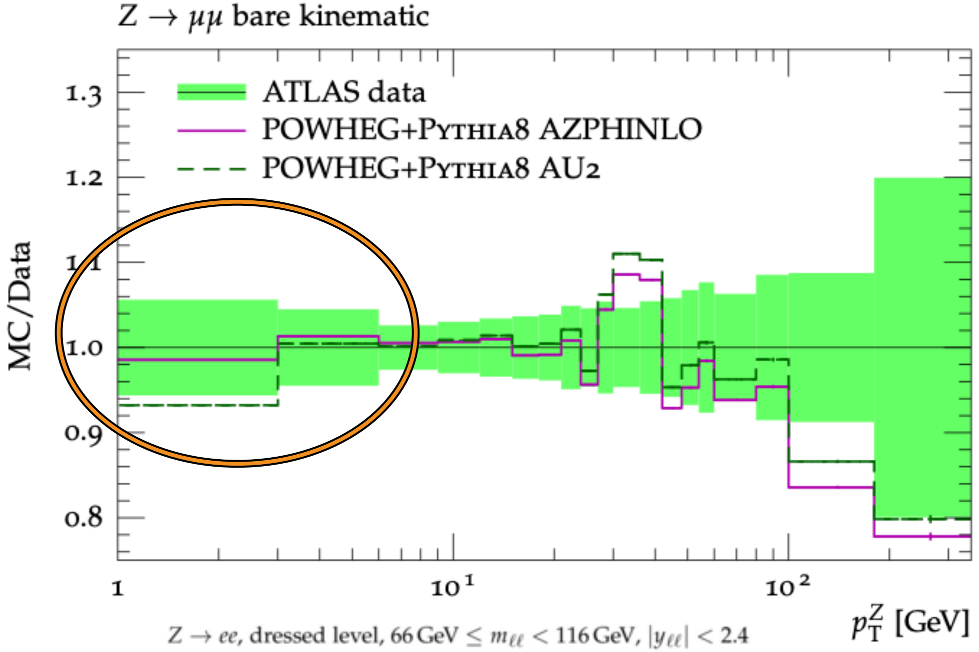
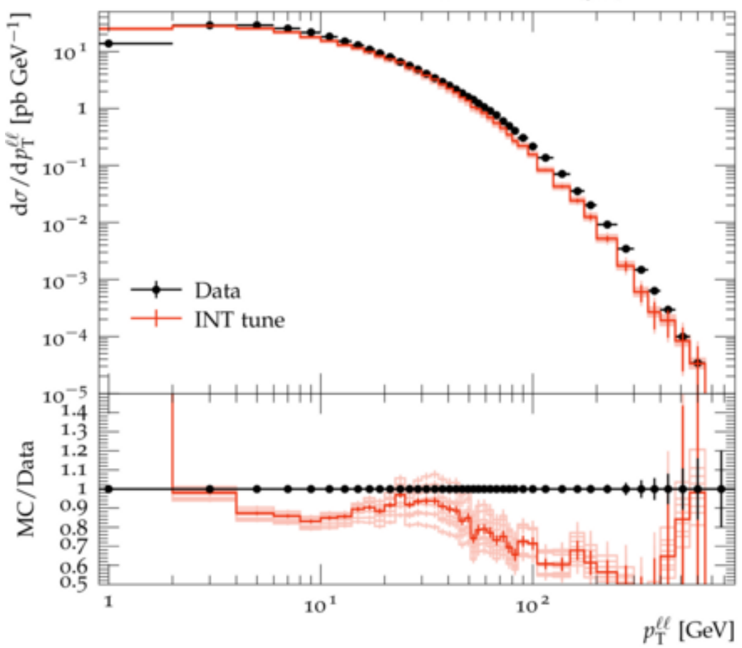
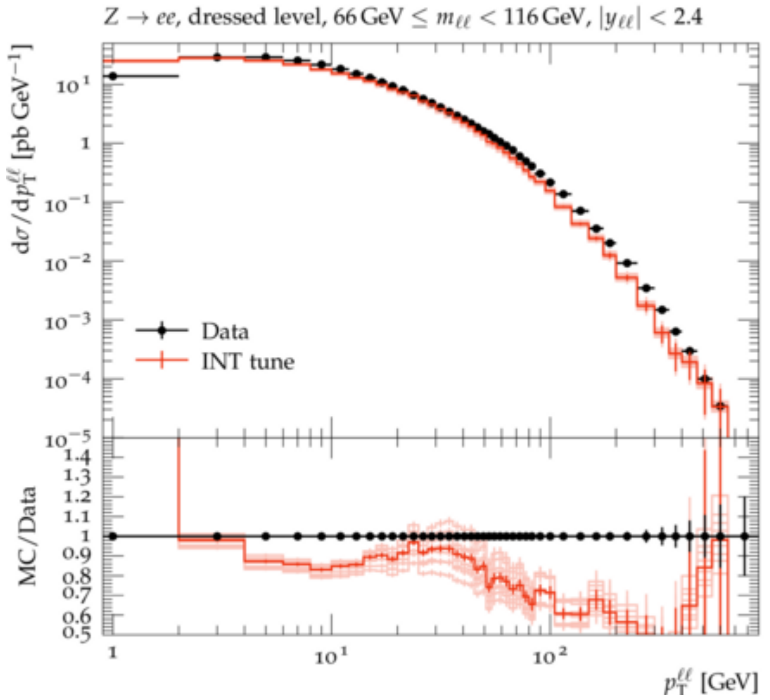


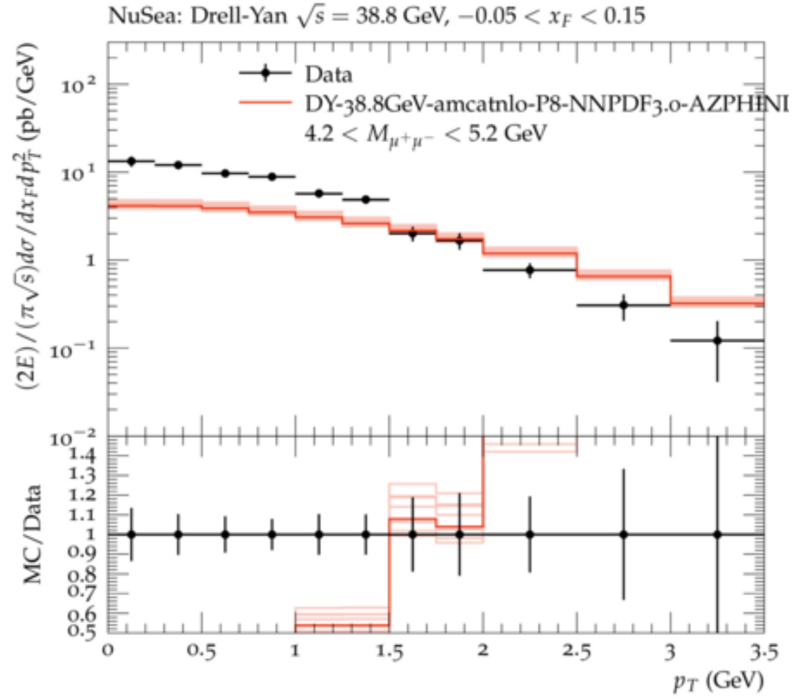


Energy dependent intrinsic k_T

Energy dependent intrinsic k_T

- For different DY masses the same intrinsic k_T is not valid:
  - 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:
  - Upper panel INT tune at 8 TeV → First bin “diverges”
  - Lower panel AZPHINLO tune at 38.8 GeV → First bin converges to zero
- An energy dependence can be observed for the k_T in Pythia8





Energy dependent intrinsic k_T

Introducing energy dependence to intrinsic k_T

- Reminder: SpaceShower:pT0Ref introduces an energy dependency in p_{T0}
  - 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 $ecmPow = 0$ → $p_{T_0} = p_{T0Ref}$

- Idea: Introduce the energy dependency in k_T in a similar way:

$$k_T = k_{TRef}\left(\frac{ecmNow}{ecmRef}\right)^{ecmPow}$$

  - AZPHINLO tune as a reference → $k_{TRef} = 1.74$ GeV , $\mathrm{ecm}Ref = 8000$ GeV
  - INT tune to derive $\mathrm{ecm}Pow$ → → $k_T = 0.9$ GeV, $\mathrm{ecm}Now = 38.8$ GeV

$$\left.\begin{array}{l} \\ \\ \end{array}\right\} \mathrm{ecm}Pow = 0.12371$$

Intrinsic k_T for 13 TeV

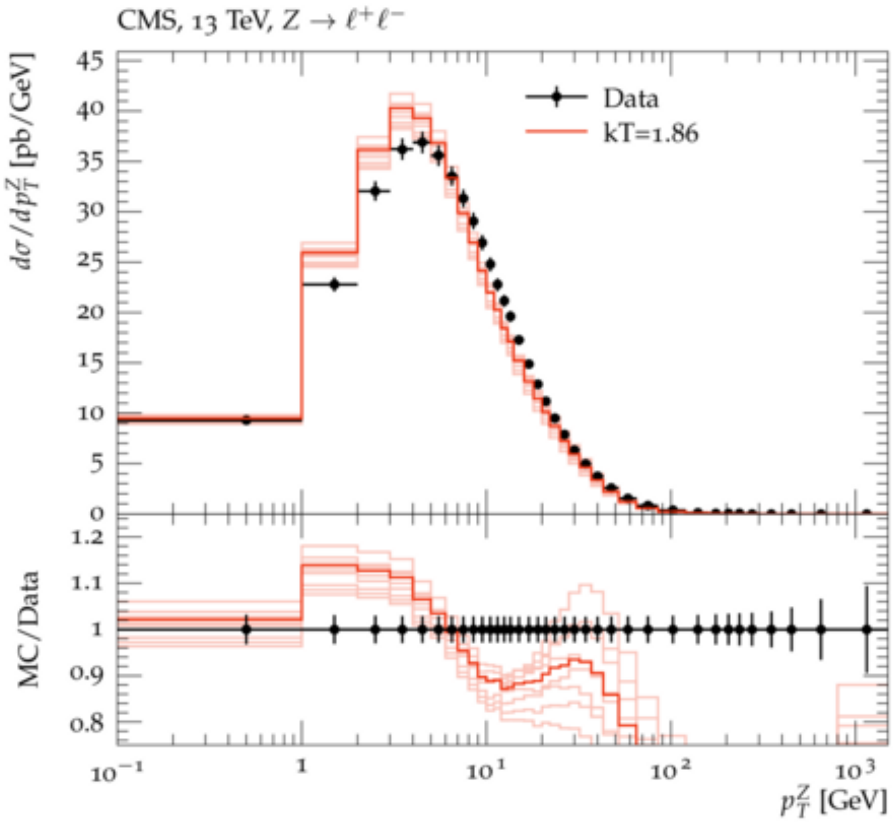
- We use AZPHINLO tune as a starting point:

Tune	BeamRemnants: primordialKTHard	SpaceShower: pT0Ref	SpaceShower: alphaSvalue	MultipartonInteractions: pT0Ref
AZPHINLO	1.74	1.91	0.118(fixed)	1.57

- We evolve the BeamRemnants:primordialKTHard to 13TeV:

$$k_T = k_{TRef}\left(\frac{ecmNow}{ecmRef}\right)^{ecmPow} = 1.8477$$

- Good description of the first bin within uncerntainties



Summary and outlook

Summary

- We performed a tune for low mass DY processes using NuSea measurements
- We found a good agreement with a $\chi^2/ndf = 2.91$

Tune	BeamRemnants: primordialKTHard	SpaceShower: pT0Ref	SpaceShower: alphaSvalue
Step 2	0.9	1.219	0.118(fixed)

- From our results we see that this approach does not work for a proper description of the low pT spectrum of the lepton pair at different COM energies

Summary & outlook

- We introduced an energy dependece in the intrinsic k_T

$$k_T = k_{TRef}\left(\frac{ecmNow}{ecmRef}\right)^{ecmPow}$$

- We observe a good description of the lowest p_T region of the Z boson at different centre of mass energies

- Outlook: check if this approach is consistent at different centre of mass energies:
  - R209 at 200GeV
  - ….

Thank you

Outlook

A tune with different COM energies

- For an overall tune of the intrinsic k_T parameters
- Lhe files already generated with MC@nlo for 38.8 GeV, 8 TeV and 13 TeV
- All the inputs (parametrisation, yoda & aida files) are in place for the tuning using the following rivet analyses
  - NUSEA_2003_I613362
  - ATLAS_2015_I1408516
  - CMS_2019_I1753680
- However, the scripts and steps from the Professor twiki page are for a tune with different COM energies is outdated

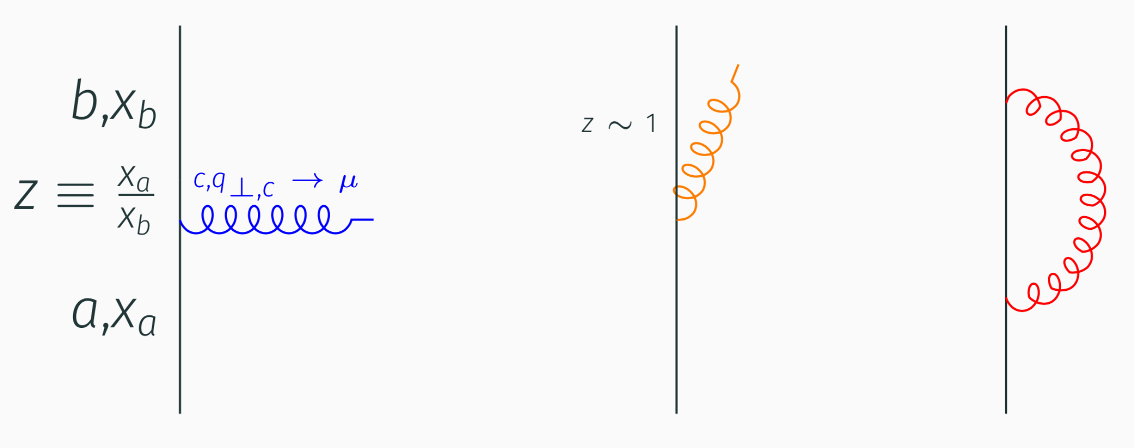
https://twiki.cern.ch/twiki/bin/viewauth/CMS/Professor

Why is there a large sensitivity to intrinsic kT?

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

- Extended discussion around the instrinsic kT 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)

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



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