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Department of Physics
DESY

Energy Dependent Primordial k_T Tune

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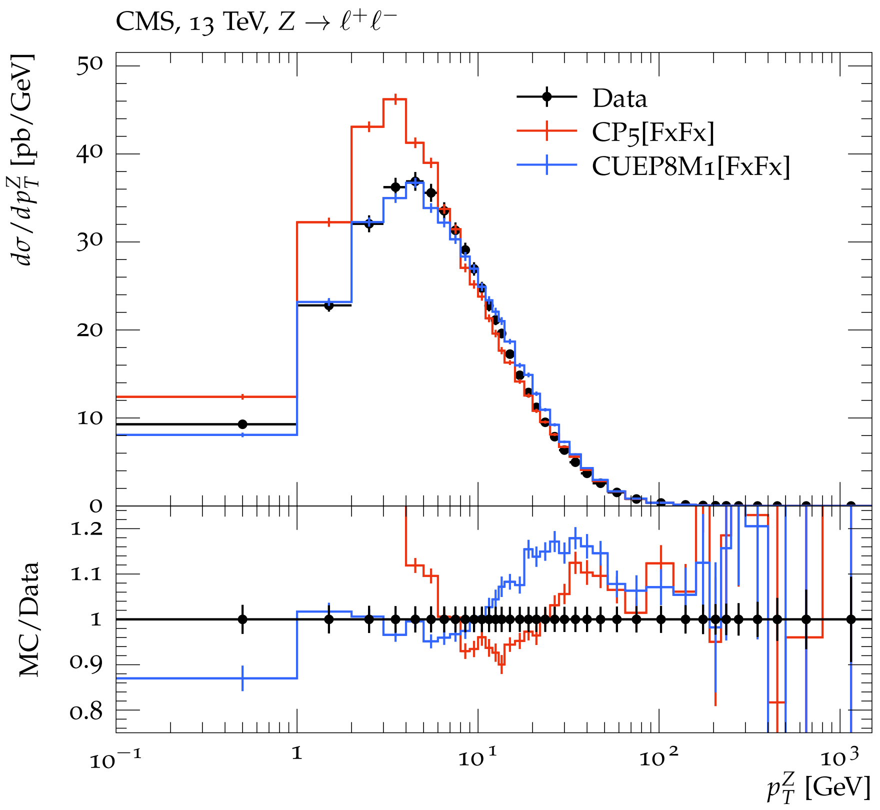
Begin of the story
Discrepancy of the CP5 tune from low pT(Z) DY data (13 TeV)



CUETP8M1 tune → CP5 tune

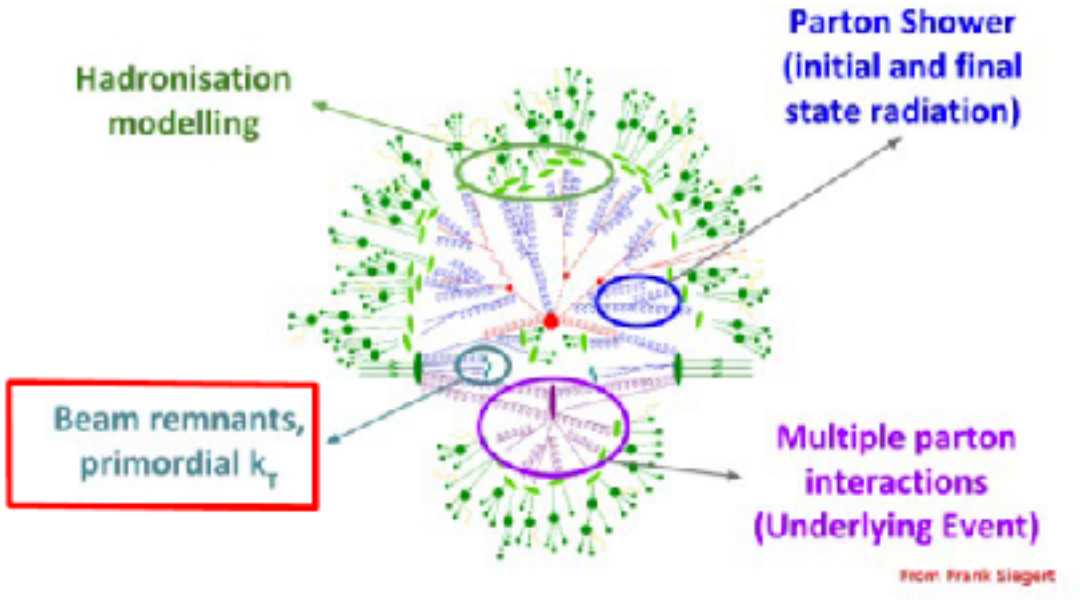
$\alpha_S(m_Z) \sim 0.13$ —Update to NNPDF→ 0.118

Less soft radiation and smear in the **low pT** spectrum

Drell-Yan transverse momentum deviates considerably from the data compared to CUETP8M1

-> To improve the predictions on the tuning side

Fix the discrepancy
Primordial kT tune based on CP5



Primordial kT:

The transverse momenta of the partons in the incoming colliding hadrons

→ **Not calculable** in perturbative QCD

→ Described by phenomenological models

Free parameters to determine

In PYTHIA:

Gaussian distribution of primordial kT $e^{-k_T^2/\sigma^2}$

Related parameter:

BeamRemnants:primordialKThard ∝ σ

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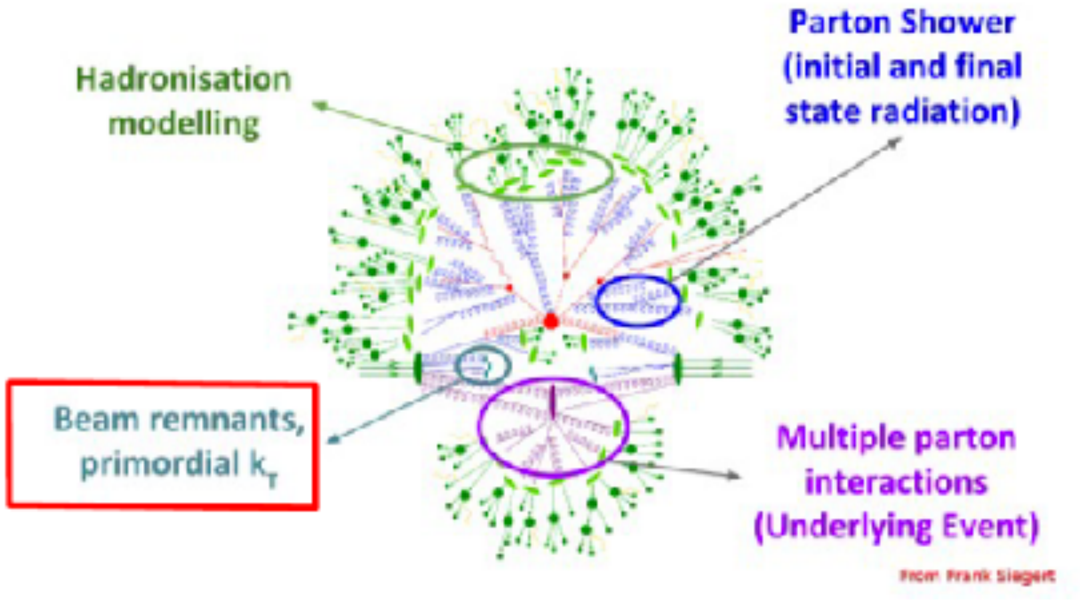

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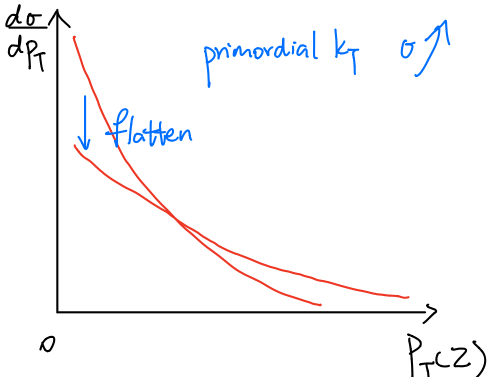
Primordial kT in partons → pT(Z)
Smear of primordial kT σ ↑ → low pT(Z) spectrum flattened



Primordial kT tune strategy

CP5 tune:
- Dedicated for **underlying event** (UE) description
- Tuned simultaneously for UE in **1.96 TeV, 7 TeV and 13 TeV** pp collisions
- **5 parameters** in UE modeling

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To combine ⇩

Normally, to tune 6 parameters on **UE+DY data**
-> optimization in **6-dim space**

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Harder in complexity & optimization

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Luckily, we find a short cut

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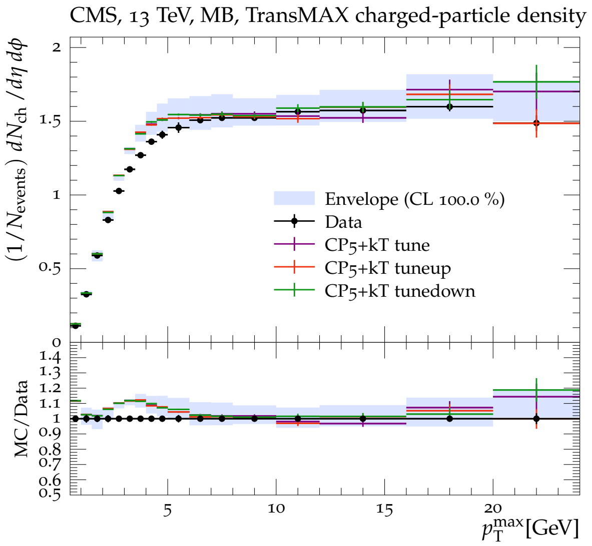

UE observable (e.g. Nch in transMAX) variation when **changing primordial kT**

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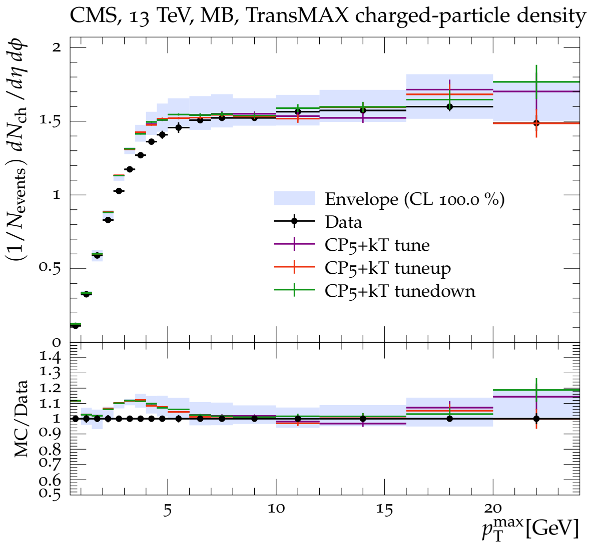

Primordial kT has little impact on UE obs

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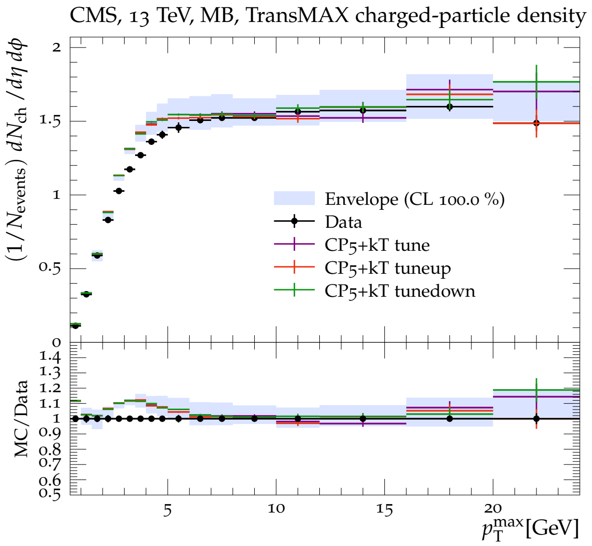

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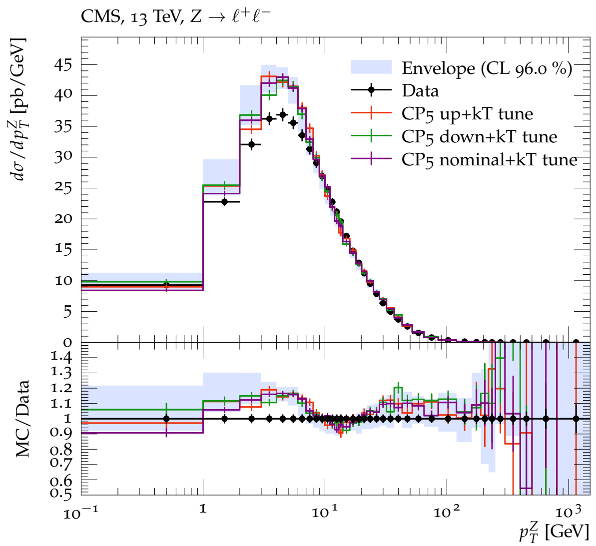

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pT(Z) from DY (after kT tune) variation when **changing CP5 parameters**

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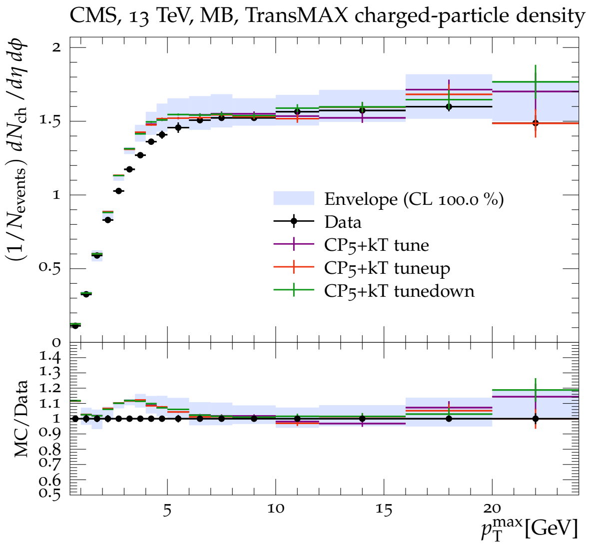

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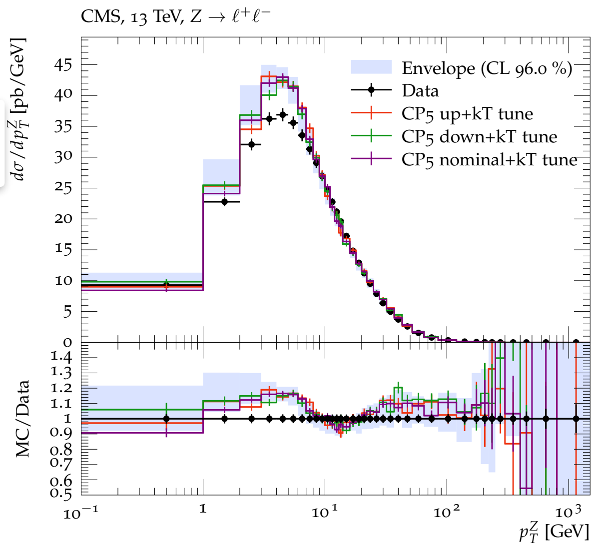
CP5 parameters have little impact on pT(Z)



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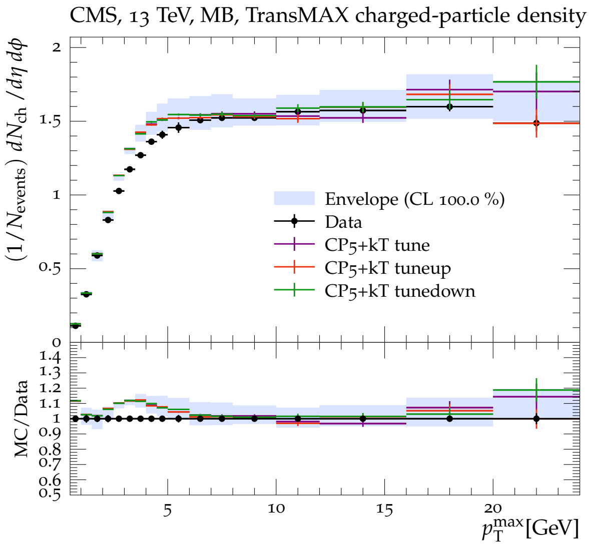

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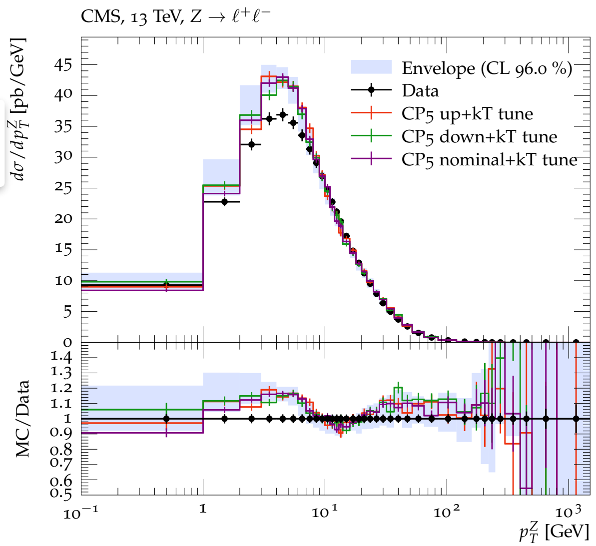
CP5 parameters have little impact on pT(Z)

The two parts can be factorized



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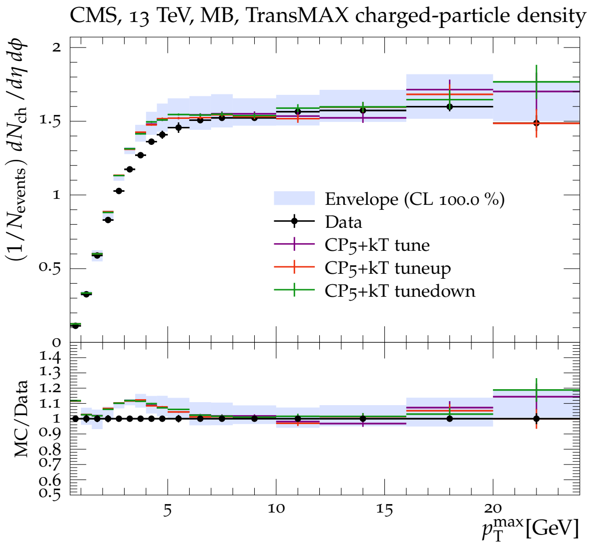

UE observable (e.g. Nch in transMAX) variation when **changing primordial kT**

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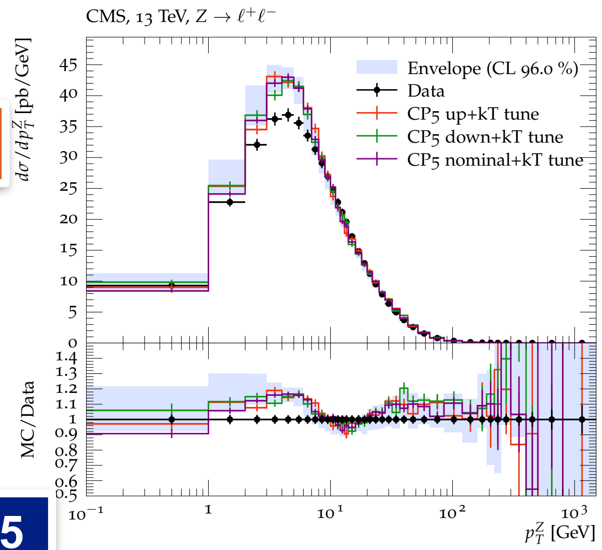
The two parts can be factorized

Primordial kT can be tuned on top of CP5 without destroying UE description



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Can we have a universal primordial kT parameter for all the energies?

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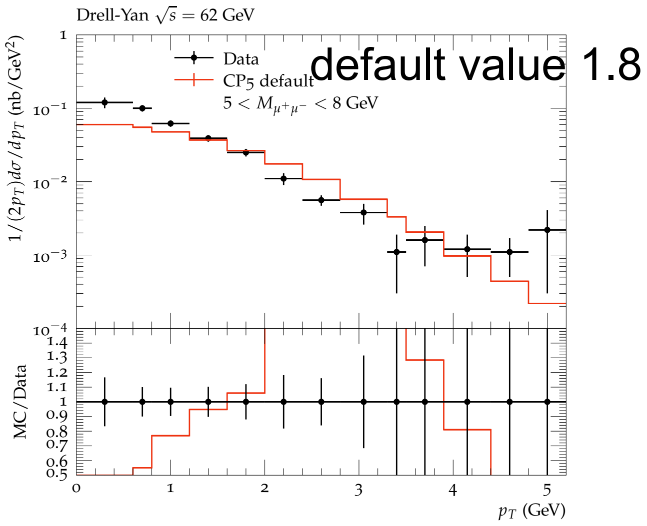
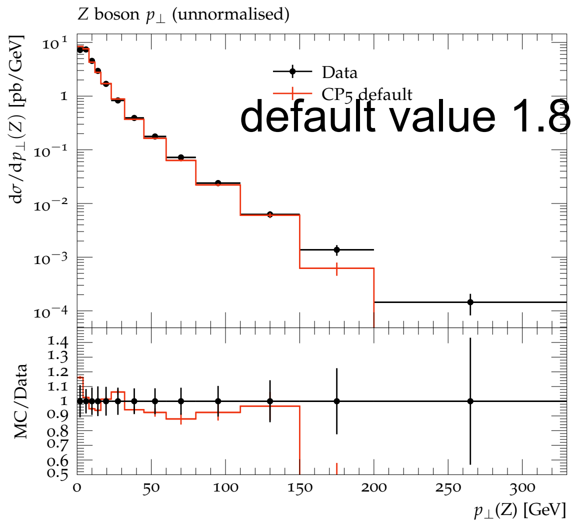
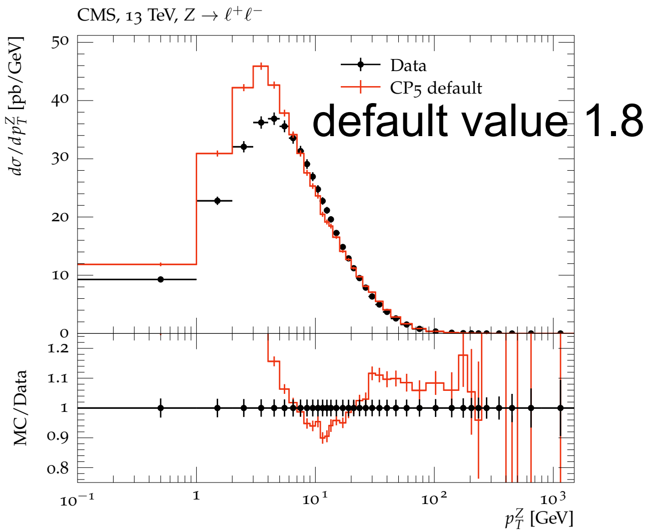


62 GeV pp collisions



1.96 TeV p+p- collisions



13 TeV pp collisions

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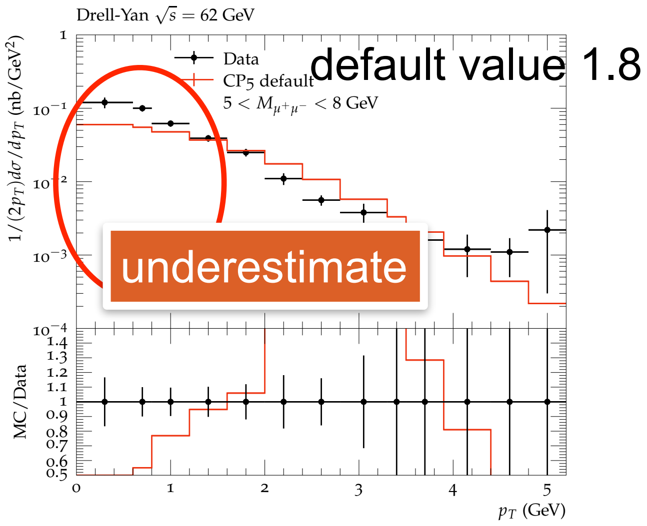

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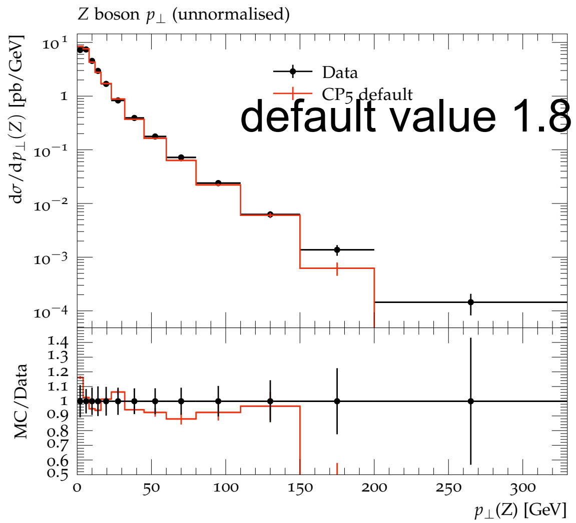

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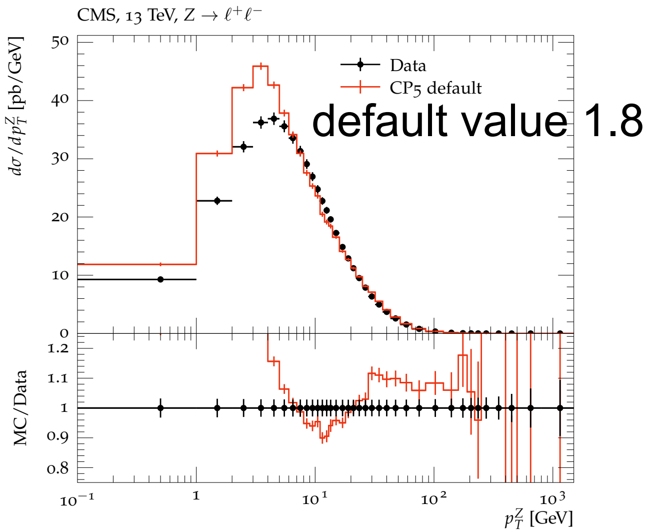

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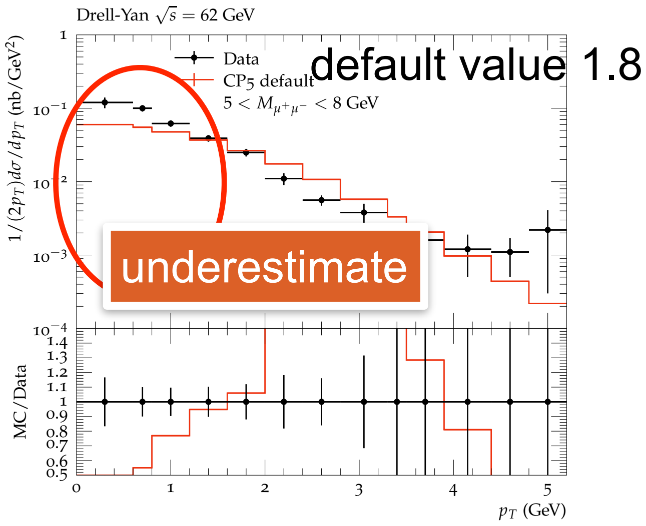

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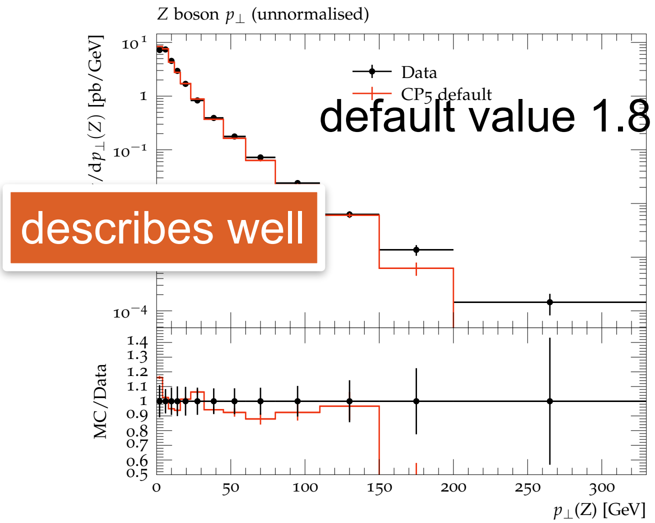

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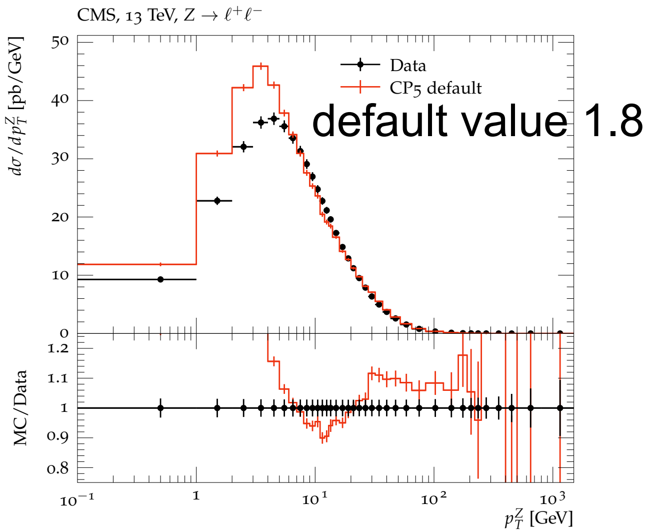

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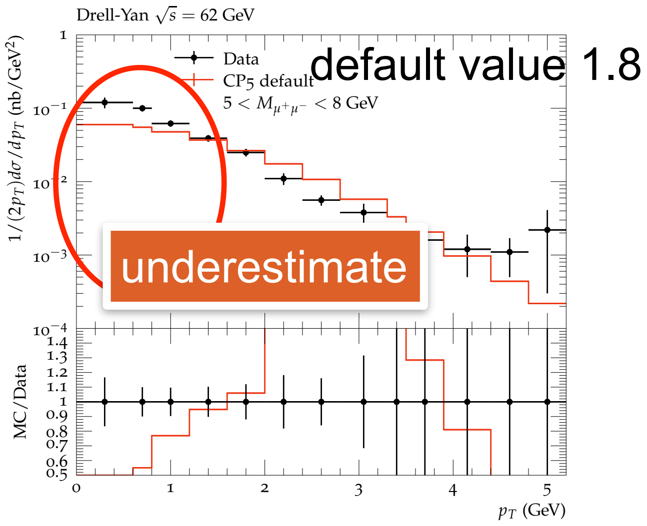

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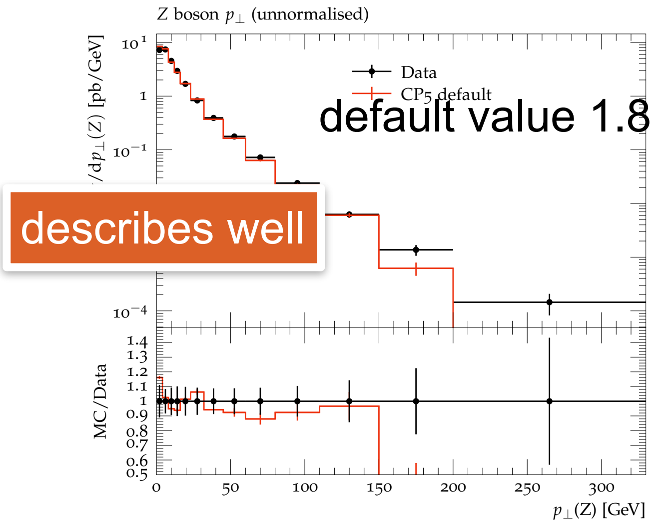

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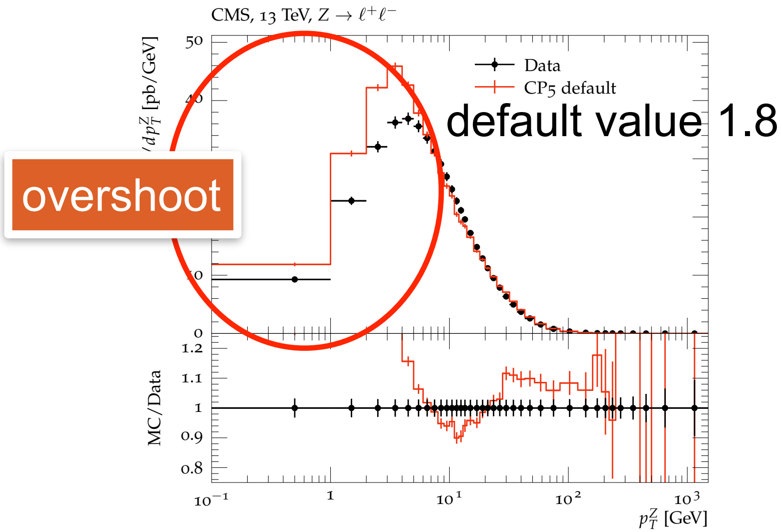

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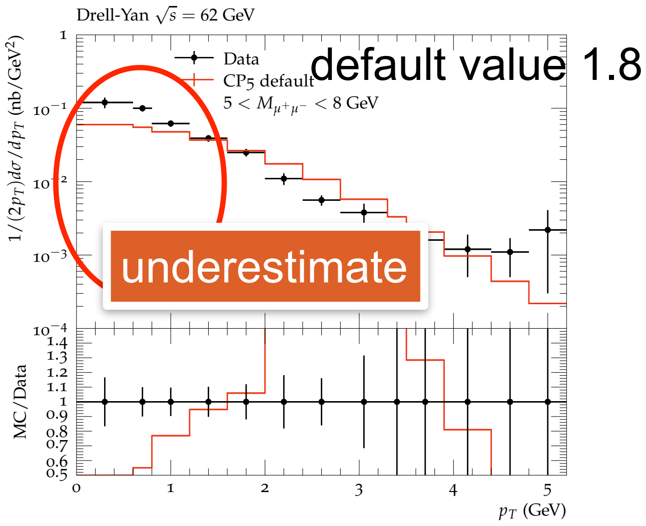

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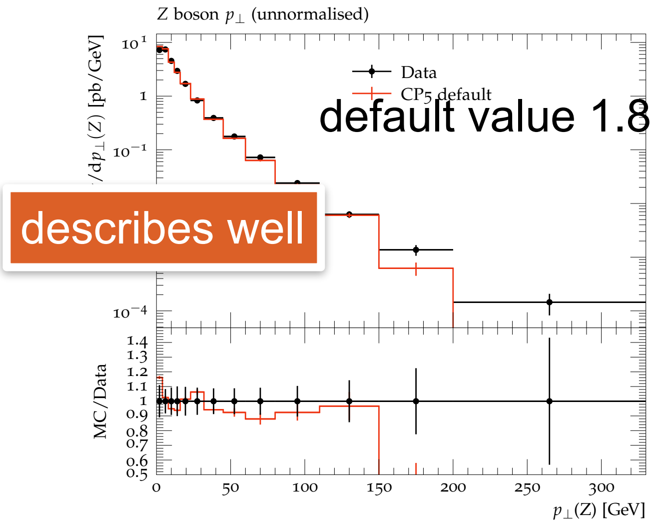

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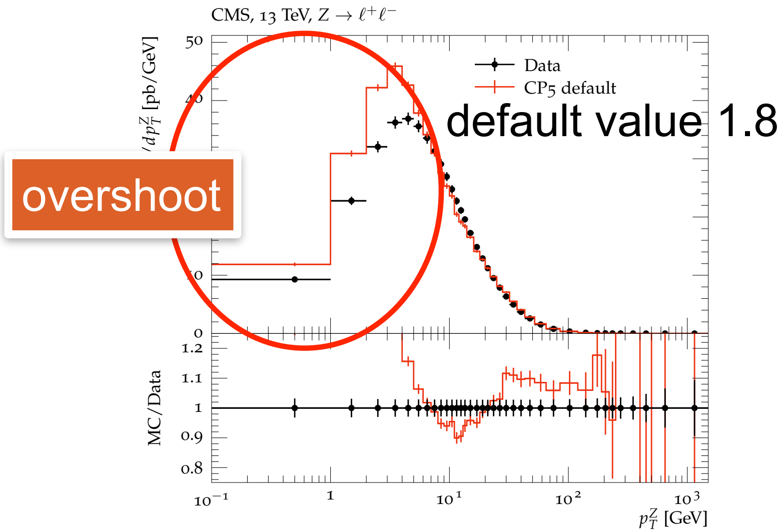

13 TeV pp collisions

Solutions

- Keep the CP5 parameters in the primordial kT tune ← they have little effects on DY pT(Z)
- For description of DY processes in different energies
  - Tune the primordial kT individually
  - Different primordial kT parameters for DY MC in these energies

Center of mass energy	Experiments	Tuned BeamRemnants:primordialKThard (default 1.8)
38.8 GeV	NuSea pp collisions	0.988 +- 0.026
62 GeV	R209 pp collisions	1.24 +- 0.06
200 GeV	PHENIX pp collisions	1.47 +- 0.11
1.96 TeV	D0 p+p- collisions	1.96 +- 0.13
7 TeV	CMS/ATLAS pp collisions	2.55 +- 0.11 / 2.47 +- 0.10
13 TeV	CMS pp collisions	2.48 +- 0.05

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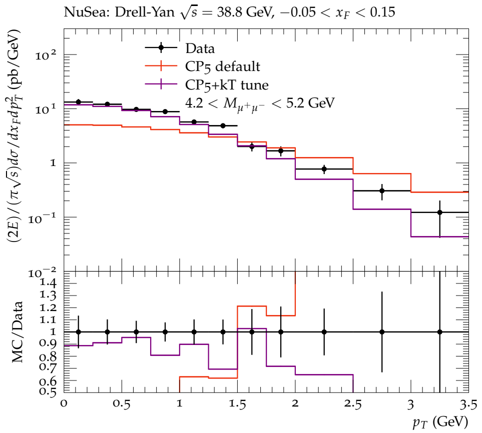
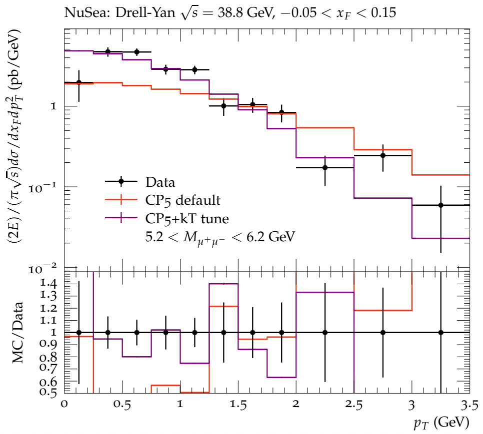
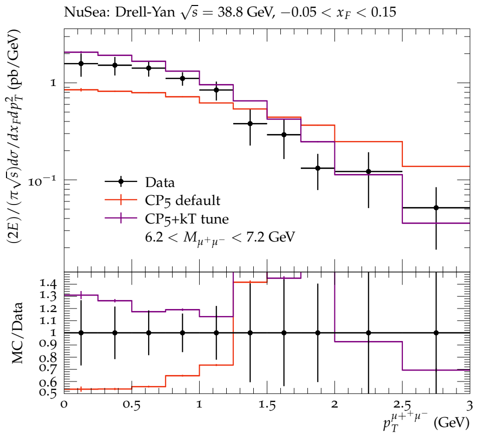
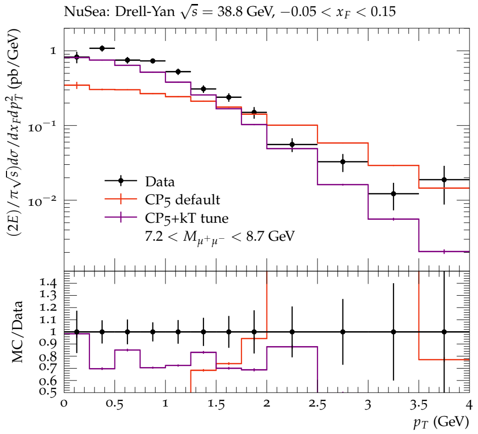
Improved description of DY pT(Z)

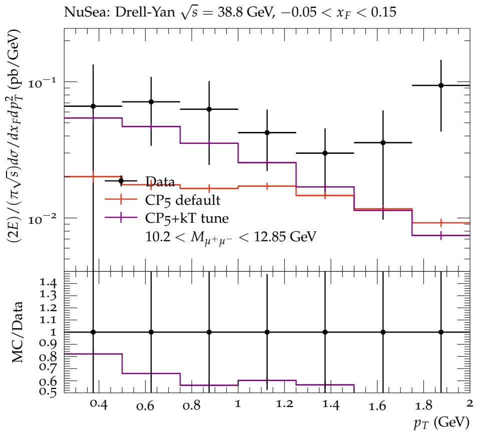
38.8 GeV pT(Z->ll) in various dilepton mass ranges

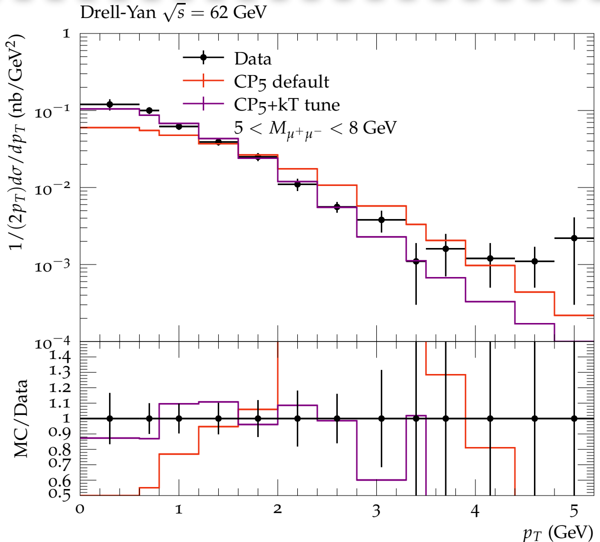












62 GeV pT(Z->μμ) in M(μ⁺μ⁻) 5-8 GeV

- CP5+default primordial kT
- CP5 + tuned primordial kT

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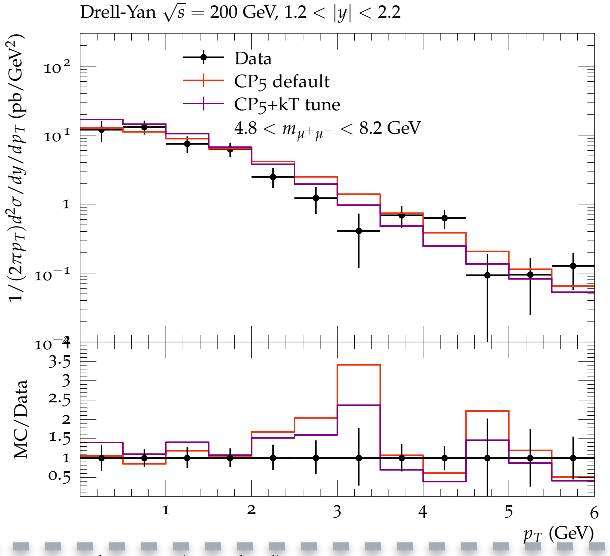
Improved description of DY pT(Z)



200 GeV pT(Z->μμ) in M($\mu^+\mu^-$) 4.8-8.2 GeV

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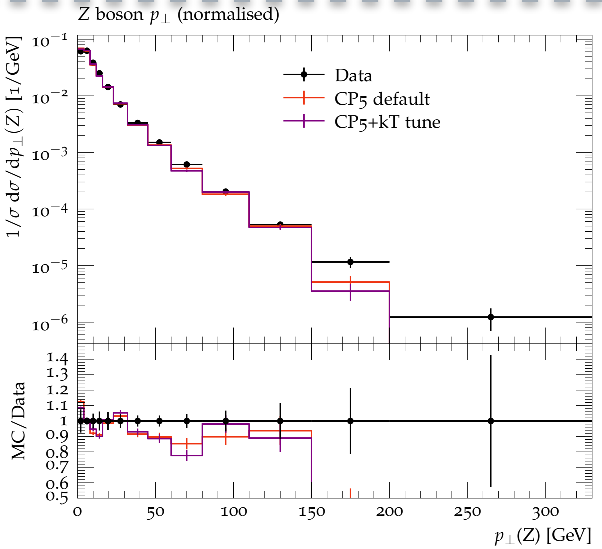

1.96 TeV pT(Z->ll)

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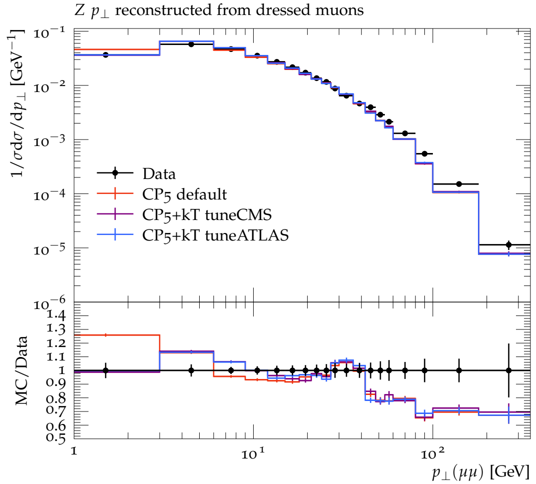
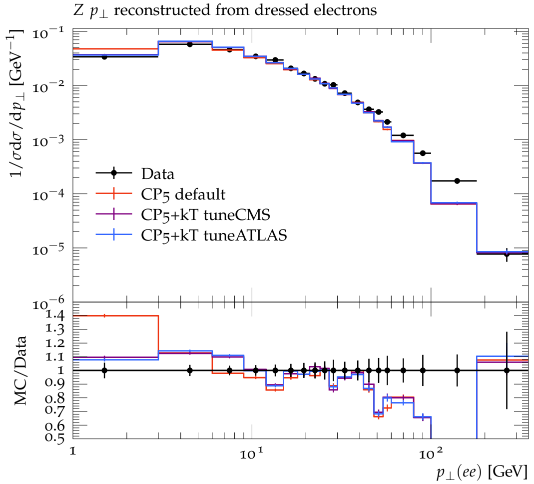
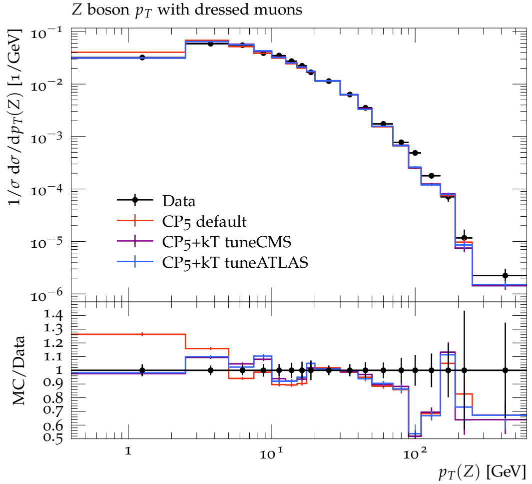
CP5+default primordial kT
CP5 + primordial kT tuned with CMS data
CP5 + primordial kT tuned with ATLAS data

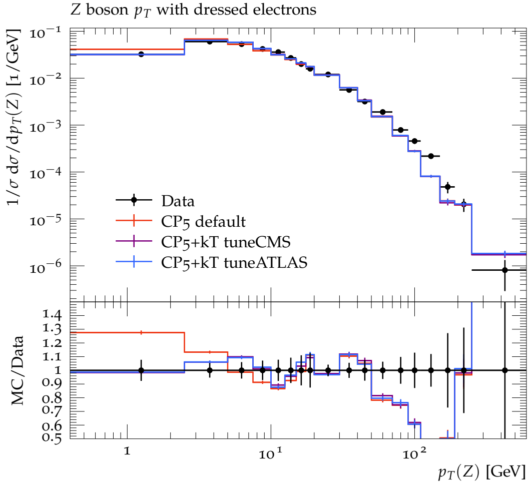
Improved description of DY pT(Z)

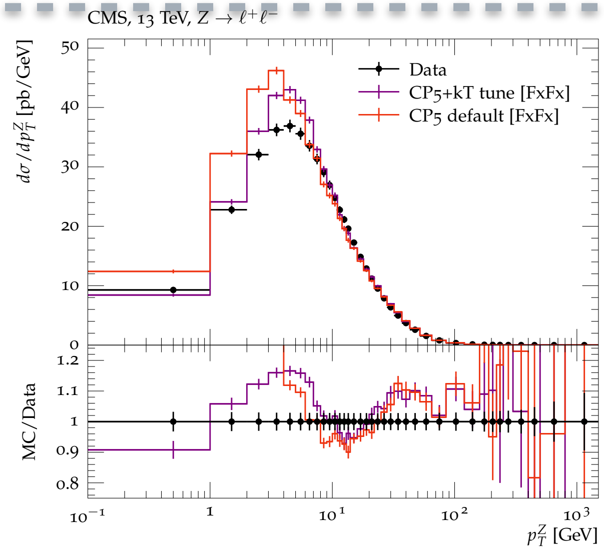
7 TeV pT(Z->μμ), pT(Z->ee) from ATLAS (left) and CMS (right)

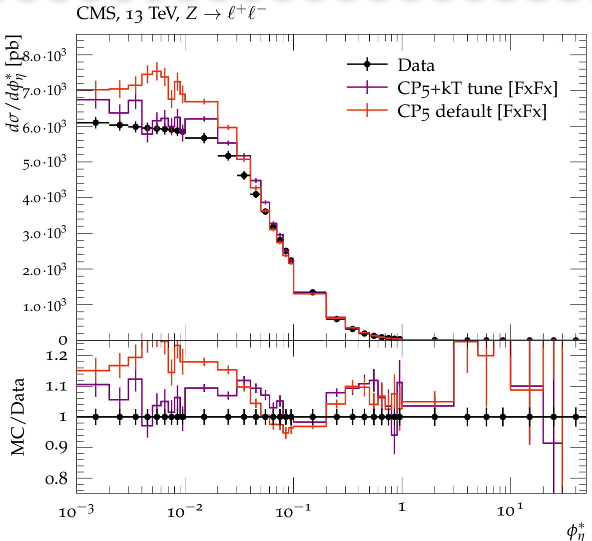












13 TeV pT(Z->ll) and Φ^*_η(l+l-)

$\Phi^*_\eta \sim p_T^Z/m_{ll}$

$$\phi^*_\eta = \tan\left(\frac{\pi-\Delta\eta}{2}\right)\sin(\theta^*_\eta), \cos(\theta^*_\eta) = \tanh(\Delta\eta/2)$$

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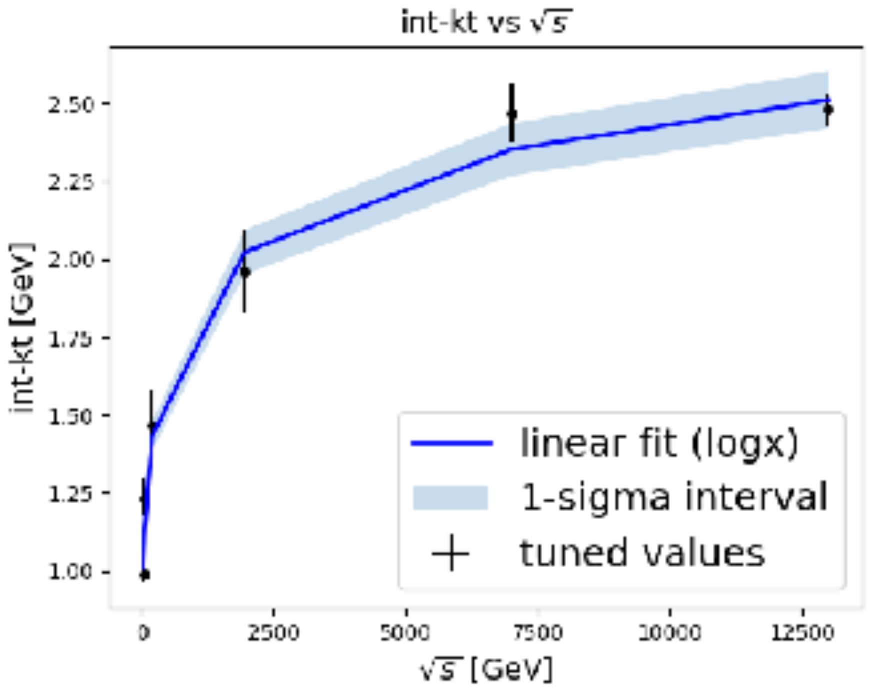
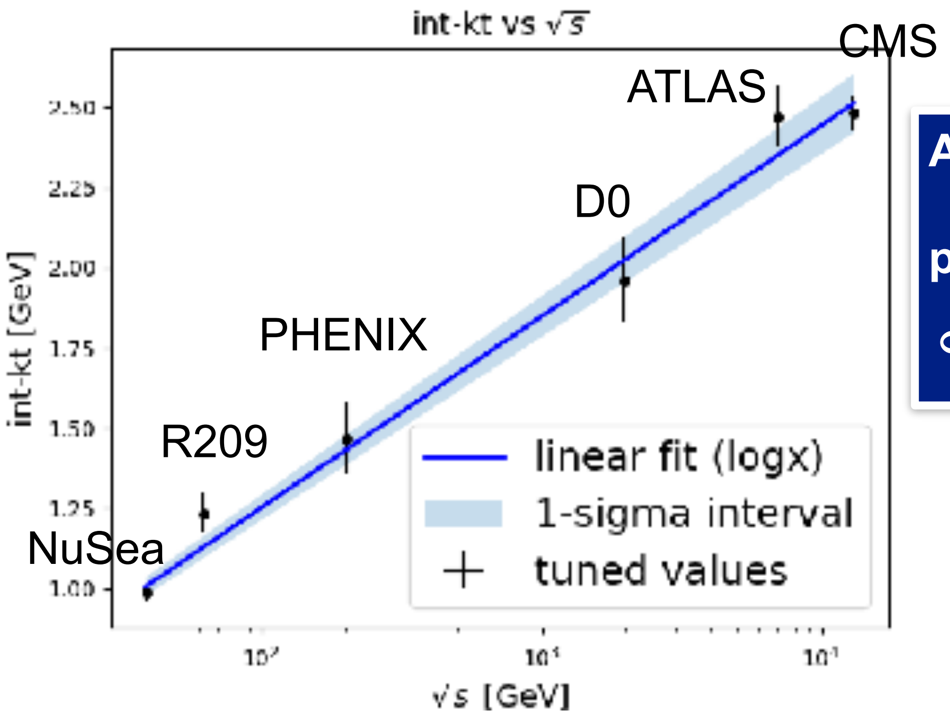
Energy dependent primordial kT broaden

What we observe from the tune

Center of mass energy ↑ BeamRemnants:primordialKThard (width of kT distribution) ↑





Approximately

primordial kT distribution width

∝ log(√s)

Energy dependent primordial kT broaden

- Theoretical indications for this observation
  - Are there any models that **explain this kT scaling with center of mass energy**?

- Primordial kT modeling in generators
  - Can we have **energy-dependent primordial kT parametrization** in generators?
  - **Tune to the slope and intercept** of kT width - log($\sqrt{s}$) dependence instead
  - Able to **extrapolate** the parameter to higher energy MC

Summary & To-do list

We have observed the **primordial kT & UE factorization** for the the Pythia 8 parameters sensitive to them
- Perform primordial kT tune without changing the UE parametrization

Non-universal primordial kT distribution width for **different energies**
- Primordial kT tune for individual energies
- **Energy dependent tune**

To-do
- **Validate** the primordial kT tunes for all the energies (description for UE and other processes)
- Check the situation for **other generators** -> Can we see the same dependence relation?
- **Energy-dependent primordial kT parametrization** in Pythia -> need the input from the generator group
- Explore the **theoretical explanation or indication** -> need the input from theorists

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Primordial kT parameters in Pythia 8

https://pythia.org/latest-manual/BeamRemnants.html

Primordial *kT*

The primordial *kT* of initiators of hard-scattering subsystems are selected according to Gaussian distributions in *p_x* and *p_y* separately. The widths of these distributions are chosen to be dependent on the hard scale of the central process and on the mass of the whole subsystem defined by the two initiators:
*sigma = (sigma_soft * Q_half + sigma_hard * Q) / (Q_half + Q) * m / (m + m_half * y_damp)*
Here *Q* is the hard-process renormalization scale for the hardest process and the *pT* scale for subsequent multiparton interactions, *m* the mass of the system, and *sigma_soft*, *sigma_hard*, *Q_half*, *m_half* and *y_damp* parameters defined below. Furthermore each separately defined beam remnant has a distribution of width *sigma_remn*, independently of kinematical variables.

Note that, for external (LHE) events *Q_half* is treated as zero. This is so that LHE events with low-pT extra jets (e.g., in the context of POWHEG-style merging) are given the same primordial kT as their Born-level counterparts.

`flag` **BeamRemnants:primordialKT** (`default = on`)
Allow or not selection of primordial *kT* according to the parameter values below.

`parm` **BeamRemnants:primordialKTsoft** (`default = 0.9; minimum = 0.`)
The width *sigma_soft* in the above equation, assigned as a primordial *kT* to initiators in the soft-interaction limit.

`parm` **BeamRemnants:primordialKThard** (`default = 1.8; minimum = 0.`)
The width *sigma_hard* in the above equation, assigned as a primordial *kT* to initiators in the hard-interaction limit.

`parm` **BeamRemnants:halfScaleForKT** (`default = 1.5; minimum = 0.`)
The scale *Q_half* in the equation above, defining the half-way point between hard and soft interactions. For external (LHE) events, this parameter is treated as zero.

`parm` **BeamRemnants:halfMassForKT** (`default = 1.; minimum = 0.`)
The scale *m_half* in the equation above, defining the half-way point between low-mass and high-mass subsystems. (Kinematics construction can easily fail if a system is assigned a primordial *kT* value higher than its mass, so the mass-dampening is intended to reduce some troubles later on.)

`parm` **BeamRemnants:reducedKTatHighY** (`default = 0.5; minimum = 0.; maximum = 1.`)
For a system of mass *m* and energy *E* the dampening factor *y_damp* above is defined as *y_damp = pow(E/m, r_red)*, where *r_red* is the current parameter. The effect is to reduce the primordial *kT* of low-mass systems extra much if they are at large rapidities (recall that *E/m = cosh(y)* before *kT* is added). The reason for this dampening is purely technical, and for reasonable values should not have dramatic consequences overall.