Non-perturbative effects in transverse momentum distribution of electroweak bosons at LHC

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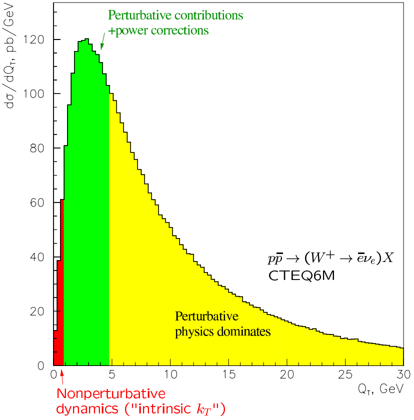
PLAN

1. Motivation/Introduction
2. Model of non-perturbative gluon emission in an initial state parton shower
3. Prediction for LHC
4. Summary

Motivation

Transverse momentum distribution of W and Z bosons in Drell-Yan like process.

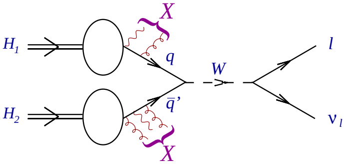


Plot stolen from Fred Olness talk

- Is extremely interesting from the QCD point of view
- also for experimental side:
  - Mass of *W*. Unless we use tricks: Eur. Phys. J. C **51** (2007) 607 (M.Krasny, F. Fayette, W. Placzek, A.S)
  - Signature for *Higgs* - problems Phys. Rev. D **63** (2001) 014021 (C. Balazs, J. Huston and I. Puljak)
- Two different attempts to describe transverse momentum distribution (P_T distribution) are Resummation and Parton Shower

Hadron Monte Carlo generators - Parton Shower

How bosons gets transverse momentum in D-Y (now picture) ?



If:

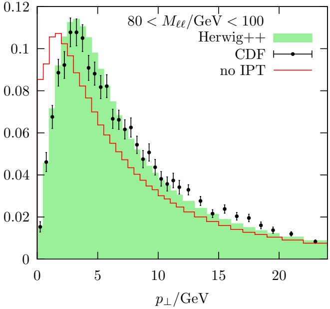
- there is initial state radiation (IR cut-off, no soft radiation!)
- no intrinsic transverse momentum

$\Longrightarrow$ bosons have no-zero transverse momentum.

Is this enough to describe P_T distribution correctly?

Parton Shower

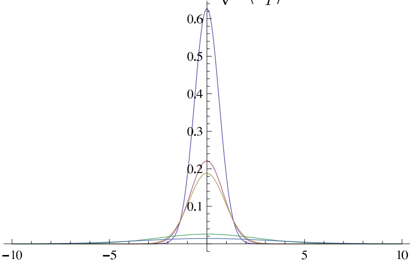
Is PS describes experimental data (P_T distribution) correctly?



- Radiation it is not enough
- We need additional Gaussian smeared intrinsic momentum.
- But there are two problems:
  - for example: Herwig++ for TVT ($\sqrt{S} = 1800$ GeV): $< k_T >= 2.1$ GeV. Is to big! $0.3 - 0.5$ GeV based solely on a proton size and the uncertainty rule
  - No predictive power! - dependend on central energy of the beam. $\sqrt{S} = 62$ GeV $< k_T >= 0.9$ GeV

Is PS describes experimental data (P_T distribution) correctly?

$$g(\vec{k}_T) = \frac{e^{-k_T^2/\langle k_T^2\rangle}}{\sqrt{\pi\langle k_T^2\rangle}}$$



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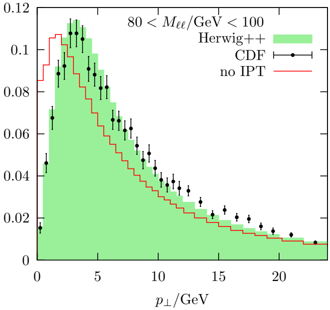

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Motivation - sum up.

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1. Intrinsic p_T is problematic (too big and has no predictive power)
2. Parton Shower - has a cutoff and below it there is no radiation

The idea

- Idea: Introduce addition soft radiation in each steep of PS evolution (below cut-off).
- How?: Additional sudakov form factor
- Energy dependence: By construction the amount of such non-perturbative smearing grows with the length of the perturbative evolution ladder.

2. Description of the model

[S. Gieseke, M. H. Seymour, A.S, JHEP (2008) 001]

- Let's consider the Sudakov formfactor for backward evolution from some scale $\tilde{q}_{\mathrm{max}}$ down to $\tilde{q}$:

$$\Delta(\tilde{q}; p_{\perp_{max}}, p_{\perp_0}) = \exp\left\{ - \int_{\tilde{q}^2}^{\tilde{q}^2_{\mathrm{max}}} \frac{d\tilde{q}'^2}{\tilde{q}'^2} \int_{z_0}^{z_1} dz \frac{\alpha_S(p_\perp)}{2\pi} \frac{x' f_b(x', \tilde{q}'^2)}{x f_a(x, \tilde{q}'^2)} P_{ba}(z, \tilde{q}'^2) \right\} .$$

$p_{\perp_0}$ is cut-off scale at which the coupling would diverge, if extrapolated outside the perturbative domain $\Longrightarrow$ no radiation below $p_{\perp_0}$

- We introduce additional non–perturbative emissions in terms of an additional Sudakov form factor Δ_{NP}, such that we have:

$$\Delta(\tilde{q}; p_{\perp_{max}}, 0) = \Delta_{\mathrm{pert}}(\tilde{q}; p_{\perp_{max}}, p_{\perp_0}) \Delta_{\mathrm{np}}(\tilde{q}; p_{\perp_0}, 0)$$

- For technical simplicity we can achieve this by modifying our implementation of $\alpha_S(p_\perp)$

$$\alpha_S(p_\perp) = \alpha_S^{(\mathrm{pert})}(p_\perp) + \alpha_S^{(\mathrm{NP})}(p_\perp).$$

$$\alpha_S(p_\perp) = \begin{cases} \varphi(p_\perp), & p_\perp < p_{\perp_0} \\ \alpha_S^{(\mathrm{pert})}(p_\perp), & p_\perp \geq p_{\perp_0} \end{cases} .$$

In this way, the kinematics and phase space of each non–perturbative emission are exactly as in the perturbative case.

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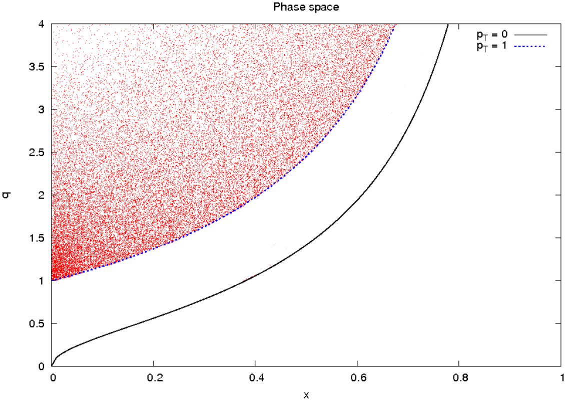
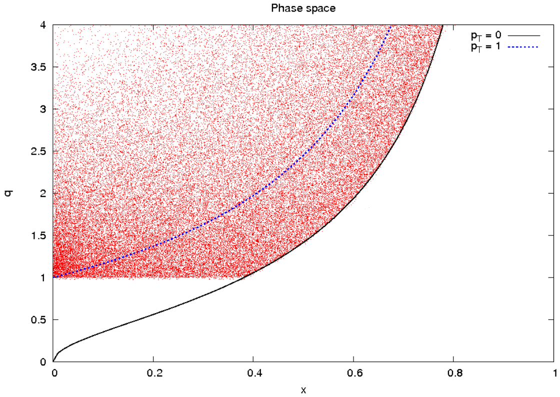
Phase Space without non-perturbative emission



Phase Space with non-perturbative emission



We have studied two simple choices of the non–perturbative function $\varphi(p_\perp)$ in greater detail:

(a) "*flat*": the flat continuation of $\alpha_S(p_\perp < p_{\perp_0})$ with a constant value $\varphi_0 = \varphi(0)$,

$$\alpha_S(p_\perp < p_{\perp_0}) = \varphi_0 \ . \tag{1}$$

(b) "*quadratic*": a quadratic interpolation between the two values $\alpha_S(p_{\perp_0})$ and $\varphi(0)$.

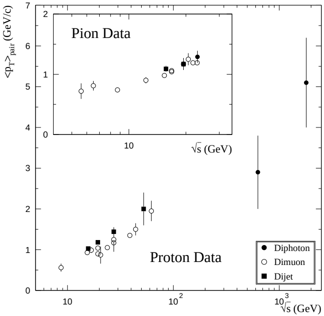
$$\alpha_S(p_\perp < p_{\perp_0}) = \varphi_0 + (\alpha_S(p_{\perp_0}) - \varphi_0)\frac{p_\perp^2}{p_{\perp_0}^2} \ . \tag{2}$$

In both cases our model is determined by the two free parameters $p_{\perp_0}$ and φ_0.

Parameter choice and results

Experimental data

Representants of experimental data:



- $\sqrt{S} = 38.8$ GeV, experiment Fermilab E605, fixed target $p - Cu$, $11.5 < M_{ll}/\mathrm{GeV} < 13.5$
- $\sqrt{S} = 62$ GeV, experiment CERN-R209, $p - p$
- $\sqrt{S} = 1.8$ TeV, Tevatron Run I, experiments CDF and D0

Remarks:

- Those tree experiments cover the whole spectrum of central of mass energy for which data sets are available.
- In our studies we kept small intrinsic momentum $k_T = 0.4$ GeV.

Parton Level

Purely parton-level study with all light quark and gluon effective masses and cutoffs set to zero[1] with our model for the low-scale α_S as the only non-perturbative input.

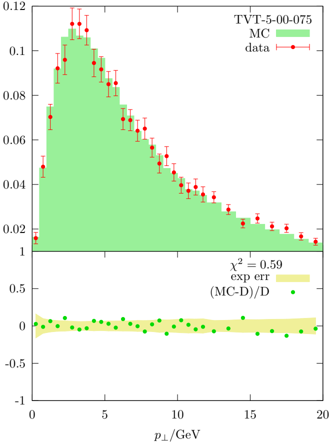
[1]actually the quark masses $= 1$ MeV and the non-perturbative mass cuts off the parton shower, called Q_g we ran with values in the range 10 MeV to 100 MeV and found very little effect. We therefore use 100 MeV for our main results.

TVT (CDF)

The first observation:

We are able to describe the Tevatron (CDF/D0) data!

Tevatron-CDF $\sqrt{S} = 1.8\ TeV$

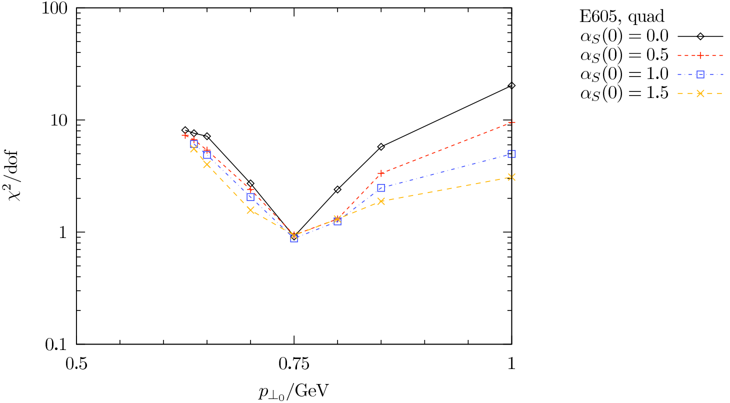


$\chi^2 = 0.59$

Optimal choice over the energy range

Aim: describe p_T distribution for different energies! Chi[2] fits.

Fermilab E605, $\sqrt{S} = 38.8$ GeV



We have run Herwig++ with varying non–perturbative parameters φ_0 and $p_{\perp_0}$ for the two forms of α_S in (1) and (2).

Optimal choice over the energy range

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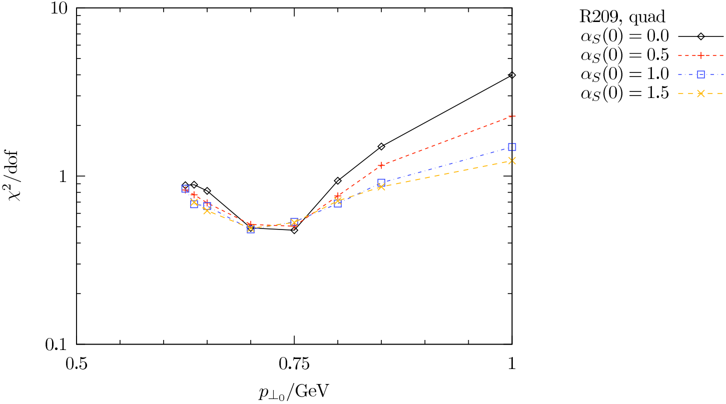
CERN-R209, $\sqrt{S} = 62$ GeV



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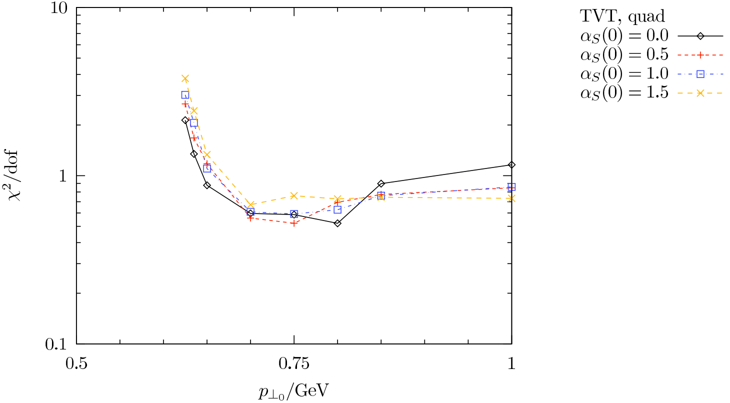
Tevatron-CDF $\sqrt{S} = 1.8\ TeV$



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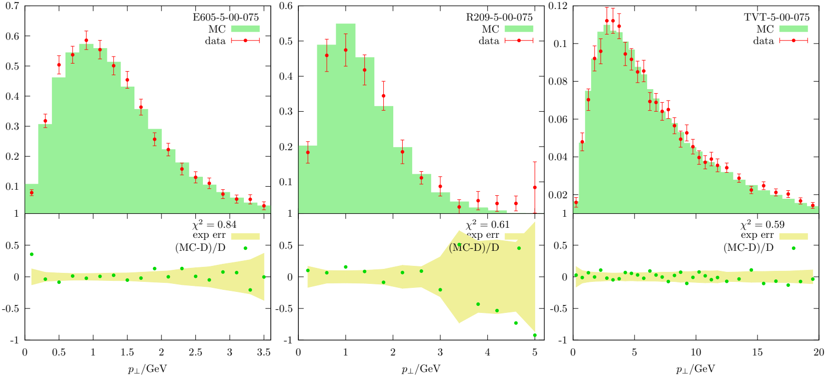
Optimal choice over the energy range

The optimal results for our parameter is $\varphi_0 = 0.0, p_{\perp_0} = 0.75\,\text{GeV}$

Fermilab E605 | CERN-R209 | Tevatron-CDF

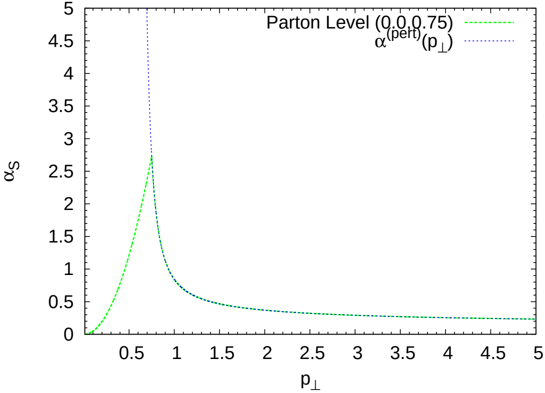


$\chi^2 = 0.84$ | $\chi^2 = 0.61$ | $\chi^2 = 0.59$

Optimal choice over the energy range

Modified $\alpha_S(p_\perp)$ for the optimal parameters of the model

$$\varphi_0 = 0.0, p_{\perp_0} = 0.75\,\mathrm{GeV}$$



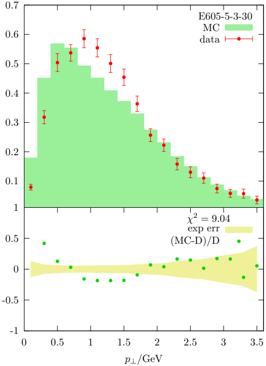
Hadron Level

with hadronization $\Rightarrow$ cut-offs

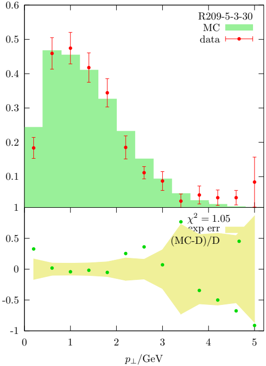
Optimal choice over the energy range

The optimal parameters for the model: $\varphi_0 = 3, p_{\perp_0} = 3.0\,\text{GeV}$

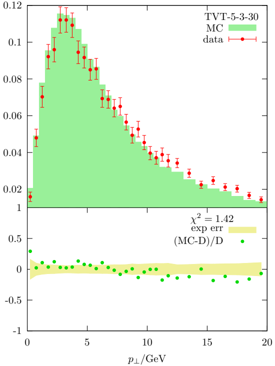
Fermilab E605



CERN-R209



Tevatron-CDF



We ignored an additional systematic error of the two fixed target data sets (E605 and R209) which is quoted to be around 5–10%

Optimal choice over the energy range

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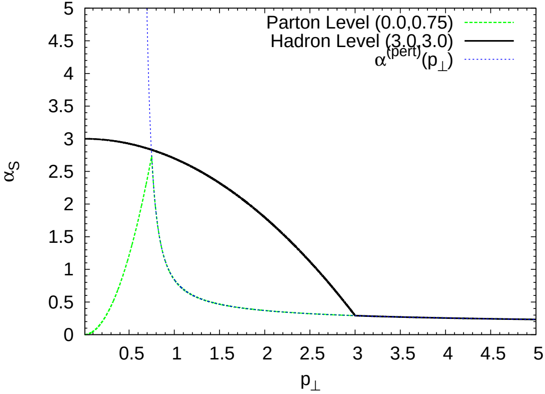
$\varphi_0 = 3, p_{\perp_0} = 3.0\,\text{GeV}$



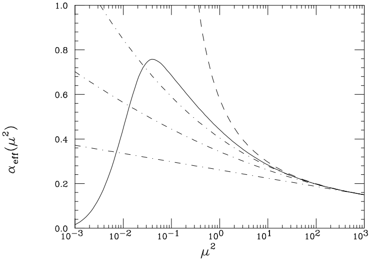
The shape is not surprising since our coupling is now 'fighting against' an emission distribution that is already falling as $p_\perp \to 0$ relative to the perturbative one.

Comparison with analytical calculus

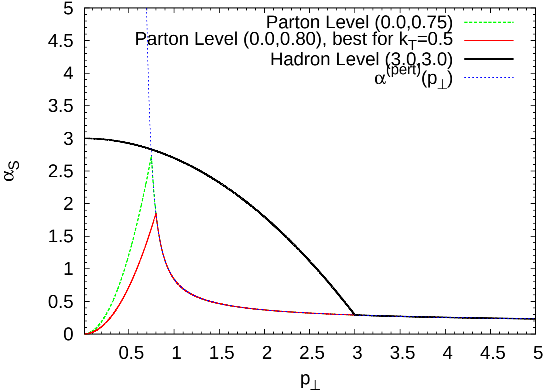
- Analytical constraint:
  - average value of the coupling over the range from 0 to 2 GeV of about ~ 0.5. [Yu. L. Dokshitzer, G. Marchesini B. R. Webber, Phys. Lett. B **352** (1995) 451]
  - the effective α_s should vanish at $p_\perp \to 0$ [same authors, Nucl. Phys. B **469** (1996) 93]

- Shape [B.R. Webber JHEP 9810 (1998)]

- assumptions:
  - No power corrections larger than $1/k^2$
  - Singularities on the negative real k^2 axis only
  - Some freedom to adjust the form and value at low k^2



- Example of different shape [B.R. Webber, Nucl.Phys.Proc.Suppl.71:66-75,1999]
- [A. Guffanti, G.E. Smye"Nonperturbative effects in the W and Z transverse momentum distribution" JHEP 0010:025,2000] - in order to compare results we need some collaboration with authors

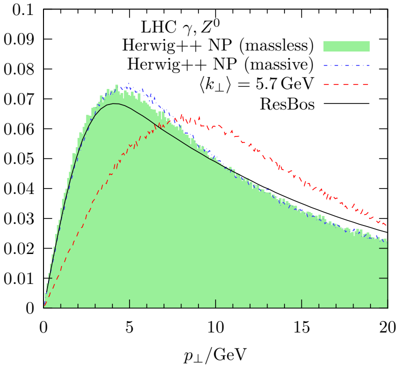


For our best-fit parametrisation, the average value of the coupling over the range from 0 to 2 GeV is around 0.7. Considering that analytical fits to data typically use NLO calculations, while we have used a leading log parton shower, this could be considered good agreement.

4. LHC result and comparison with other approaches

LHC

- Both parton and hadron level histograms give a consistent extrapolation.
- The prediction for LHC is not very sensitive to the value $\alpha_S(0)$



- The Jacobian peak is in the same place for ResBos and NP model (very important for observables like W mass)
- Extrapolated intrinsic p_T gives completely diffrent result)
- We observed the same trend for TVT data (normalization and transition around $p_T \sim 20$).

- Mass of W. clever definition of observable: Eur. Phys. J. C **51** (2007) 607

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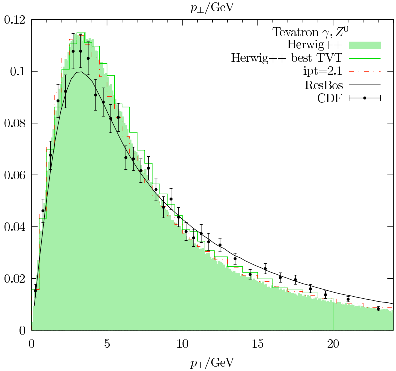

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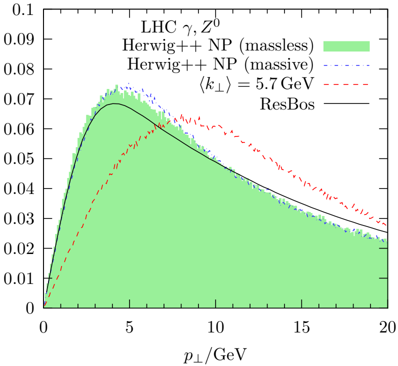

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5. Summary

Summary

- We constructed a model of transverse momentum production in which non-perturbative effects takes place throughout the perturbative evolution
- we have achieved perfect description of data at three different energies scales in Parton level and reasonable in Hadronic level case (second one can be improved).
- The model is consistent with analytical prediction for effective α_s
- We made a prediction for LHC (now we need to wait for the data)
- is implemented in the Herwig++ Monte Carlo Generator [arXiv:0711.3137] which can be downloaded from Herwig++ group webpage *http://projects.hepforge.org/herwig/*
- Of course, if this model is universal, it should make predictions for other processes, such as jet or direct photon production. We plan to study these processes in more detail in the future.

Thank you for your attention!