Interplay of IR-Improved DGLAP-CS Theory and NLO Parton Shower MC Precision

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Preface

* PRECISION QCD FOR THE LHC
* BUILD ON EXISTING PLATFORMS

$\Rightarrow$

IR-Improved DGLAP-CS Theory

$\cup$

NLO Parton Shower MC's:
MC@NLO, POWHEG, …

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GOAL: 1% Precision QCD for LHC via Amplitude-Based QED⊗QCD Resummation Realized by MC Methods

$$d\sigma = \sum_{i,j} \int dx_1 dx_2 F_i(x_1) F_j(x_2) d\hat{\sigma}_{res}$$

$$\Rightarrow \Delta\sigma_{th} = \Delta F \oplus \Delta\hat{\sigma}_{res} = \Delta\sigma_{th}(tech) \oplus \Delta\sigma_{th}(phys)$$

$$\Rightarrow$$

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$$d\hat{\sigma}_{res} = \sum_n d\hat{\sigma}_n$$

$$= e^{SUM_{IR}(QCED)} \sum_{m,n=0}^{\infty} \frac{1}{m!n!} \int \prod_{j_1=1}^{m} \frac{d^3 k_{j_1}}{k_{j_1}} \prod_{j_2=1}^{n} \frac{d^3 k_{j_2}}{k_{j_2}} \int \frac{d^4 y}{(2\pi)^4} e^{iy(p_1+q_1-p_2-q_2-\sum_{j1} k_{j_1} - \sum_{j2} k'_{j_2}) + D_{QCED}}$$

$$* \tilde{\bar{\beta}}_{m,n}(k_1,\ldots,k_m;k'_1,\ldots,k'_n) \frac{d^3 p_2}{p_2^0} \frac{d^3 q_2}{q_2^0} \qquad (1)$$

- **Contact with Standard Resummation (Abyat et al.** , Phys. Rev. D 74 (2006) 074004**):**

  2→n process --

$$\mathcal{M}^{[f]}_{\{r_i\}} = \sum_{L=1}^{c} \mathcal{M}^{[f]}_{L}(c_L)_{\{r_i\}} = J^{[f]} \sum_{I=1}^{c} S_{LI} H^{[f]}_{I}(c_L)_{\{r_i\}}$$

- **Noting relation of J and SUM$_{IR}$, in our formula**

$$d\hat{\sigma}^m = \frac{e^{2\alpha_s \mathrm{Re}\, B_{QCD}}}{m!} \int \prod_{j=1}^{m} \frac{d^3 k_j}{(k_j^2+\lambda^2)^{1/2}} \delta(p_1+q_1-p_2-q_2-\sum_{i=1}^{m} k_i)$$
$$\bar{\rho}^{(m)}(p_1,q_1,p_2,q_2,k_1,\ldots,k_m) \frac{d^3 p_2 d^3 q_2}{p_2^0 q_2^0},$$

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we get the identification:

$$\overline{\rho}^{(m)}(p_1, q_1, k_1, \ldots, k_m) = \overline{\sum}_{\mathrm{colors,spin}} |\mathcal{M}^{[\mathbf{f}]}_{\{\mathbf{r}_i\}}|^2$$

$$\equiv \sum_{\mathrm{spins},\{\mathbf{r}_i\},\{\mathbf{r}'_i\}} h^{\mathrm{cs}}_{\{\mathbf{r}_i\}\{\mathbf{r}'_i\}} |\overline{\mathbf{J}}^{[\mathbf{f}]}|^2 \sum_{\mathbf{L},\mathbf{L}'=1}^{\mathbf{C}} \mathbf{S}^{[\mathbf{f}]}_{\mathbf{LI}} \mathbf{H}^{[\mathbf{f}]}_{\mathbf{I}}(\mathbf{c}_{\mathbf{L}})_{\{\mathbf{r}_i\}} \left(\mathbf{S}^{[\mathbf{f}]}_{\mathbf{L'I'}} \mathbf{H}^{[\mathbf{f}]}_{\mathbf{I'}}(\mathbf{c}_{\mathbf{L'}})_{\{\mathbf{r}'_i\}}\right)^*$$

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NOTE:

Sterman-Catani-Trentadue Threshold Resummation

As for any f(z),

$$\left|\int_0^1 dz\, z^{n-1} f(z)\right| \le \left(\frac{1}{n}\right) max\left|f(z)\right|,$$

drop non-singular contributions to cross section at z→1

- SCET:

drop O(λ) terms, λ = √(Λ/Q),

Λ∿ .3 GeV, Q∿100 GeV ⇒ λ≃5.5%

- These methods give approximations to our $\bar{\beta}_{n,m}$

- **Shower/ME Matching:**

$$\bar{\tilde{\beta}}_{m,n} \rightarrow \hat{\bar{\tilde{\beta}}}_{m,n}, \text{ shower-subtracted residuals}$$

- **IR-Improved DGLAP-CS Theory(PRD81(2010)076008):** **New resummed scheme for P_{AB}, reduced cross section derived from (1) applied to splitting process --**

$$\mathrm{F_j}, \hat{\sigma} \rightarrow \mathrm{F'_j}, \hat{\sigma}' \quad \text{for}$$

$$\mathrm{P_{qq}} \rightarrow \mathrm{P_{qq}^{exp}} = \mathrm{C_F} F_{YFS}(\gamma_q) e^{\frac{1}{2}\delta_q} \frac{1+z^2}{1-z}(1-z)^{\gamma_q}, \text{etc.},$$

giving the same value for σ, with improved MC stability -- no need for IR cut-off (k_0) parameter

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- **Complete Set:**

$$P^{exp}_{qq}(z) = C_F F_{YFS}(\gamma_q) e^{\frac{1}{2}\delta_q} \left[\frac{1+z^2}{1-z}(1-z)^{\gamma_q} - f_q(\gamma_q)\delta(1-z) \right],$$

$$P^{exp}_{Gq}(z) = C_F F_{YFS}(\gamma_q) e^{\frac{1}{2}\delta_q} \frac{1+(1-z)^2}{z} z^{\gamma_q},$$

$$P^{exp}_{GG}(z) = 2C_G F_{YFS}(\gamma_G) e^{\frac{1}{2}\delta_G} \{ \frac{1-z}{z} z^{\gamma_G} + \frac{z}{1-z}(1-z)^{\gamma_G} + \frac{1}{2}(z^{1+\gamma_G}(1-z) + z(1-z)^{1+\gamma_G}) - f_G(\gamma_G)\delta(1-z) \},$$

$$P^{exp}_{qG}(z) = F_{YFS}(\gamma_G) e^{\frac{1}{2}\delta_G} \frac{1}{2} \{ z^2(1-z)^{\gamma_G} + (1-z)^2 z^{\gamma_G} \},$$

$$\gamma_q = C_F \frac{\alpha_s}{\pi} t = \frac{4C_F}{\beta_0}, \qquad \delta_q = \frac{\gamma_q}{2} + \frac{\alpha_s C_F}{\pi}(\frac{\pi^2}{3} - \frac{1}{2}),$$

$$f_q(\gamma_q) = \frac{2}{\gamma_q} - \frac{2}{\gamma_q+1} + \frac{1}{\gamma_q+2},$$

$$\gamma_G = C_G \frac{\alpha_s}{\pi} t = \frac{4C_G}{\beta_0}, \qquad \delta_G = \frac{\gamma_G}{2} + \frac{\alpha_s C_G}{\pi}(\frac{\pi^2}{3} - \frac{1}{2}),$$

$$f_G(\gamma_G) = \frac{n_f}{6C_G F_{YFS}(\gamma_G)} e^{-\frac{1}{2}\delta_G} + \frac{2}{\gamma_G(1+\gamma_G)(2+\gamma_G)} + \frac{1}{(1+\gamma_G)(2+\gamma_G)} + \frac{1}{2(3+\gamma_G)(4+\gamma_G)} + \frac{1}{(2+\gamma_G)(3+\gamma_G)(4+\gamma_G)},$$

$$F_{YFS}(\gamma) = \frac{e^{-C\gamma}}{\Gamma(1+\gamma)}, \qquad C = 0.57721566...,$$

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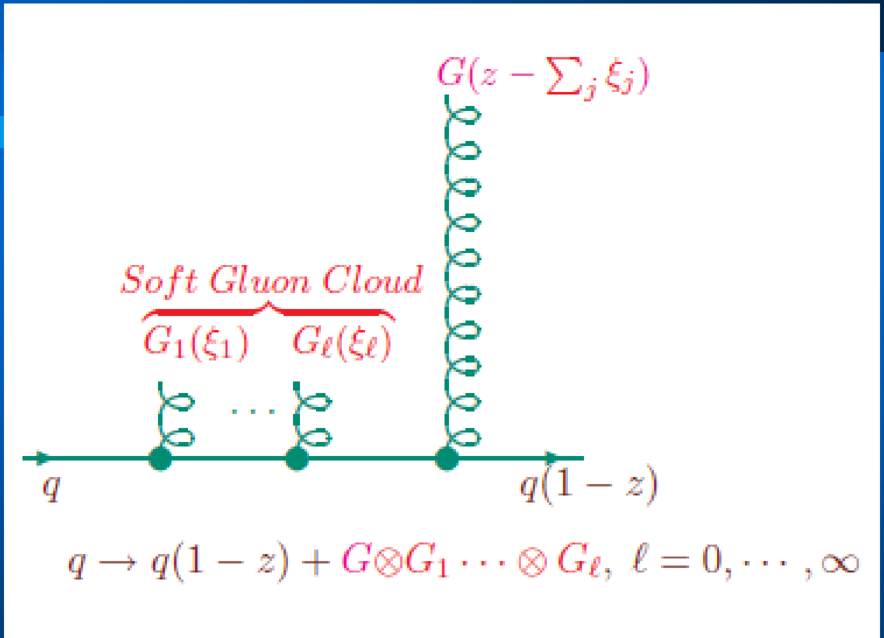
Basic Physical Idea:
Bloch-Nordsiek –

Accelerated Charge ⇒ Coherent State of Soft Gluons (Photons)

⇒ More Physical View of Splitting Process:



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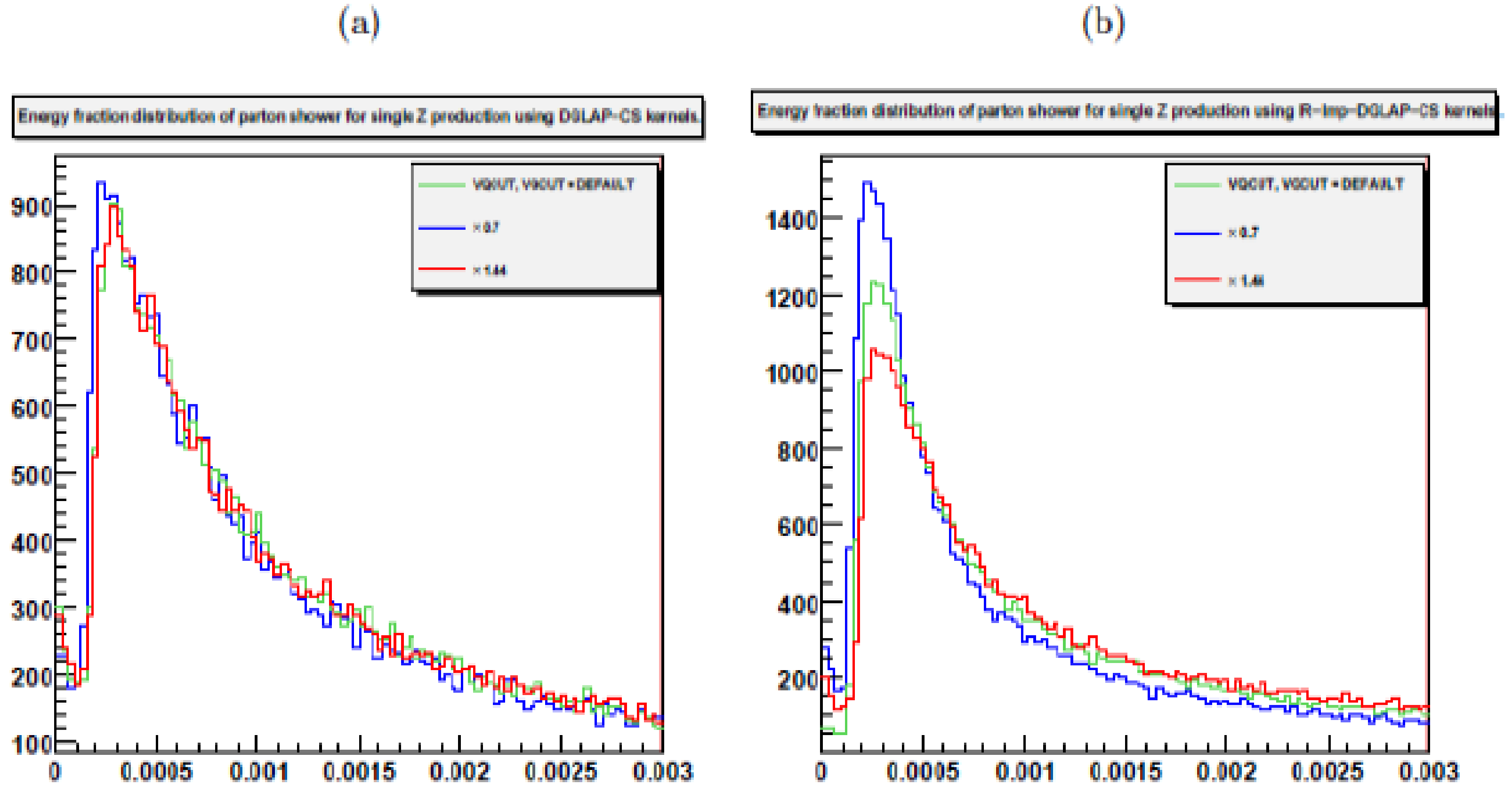

FIG.5: IR-cut-off sensitivity in z-distributions of the ISR parton energy fraction: (a), DGLAP-CS; (b), IR-I DGLAP-CS.

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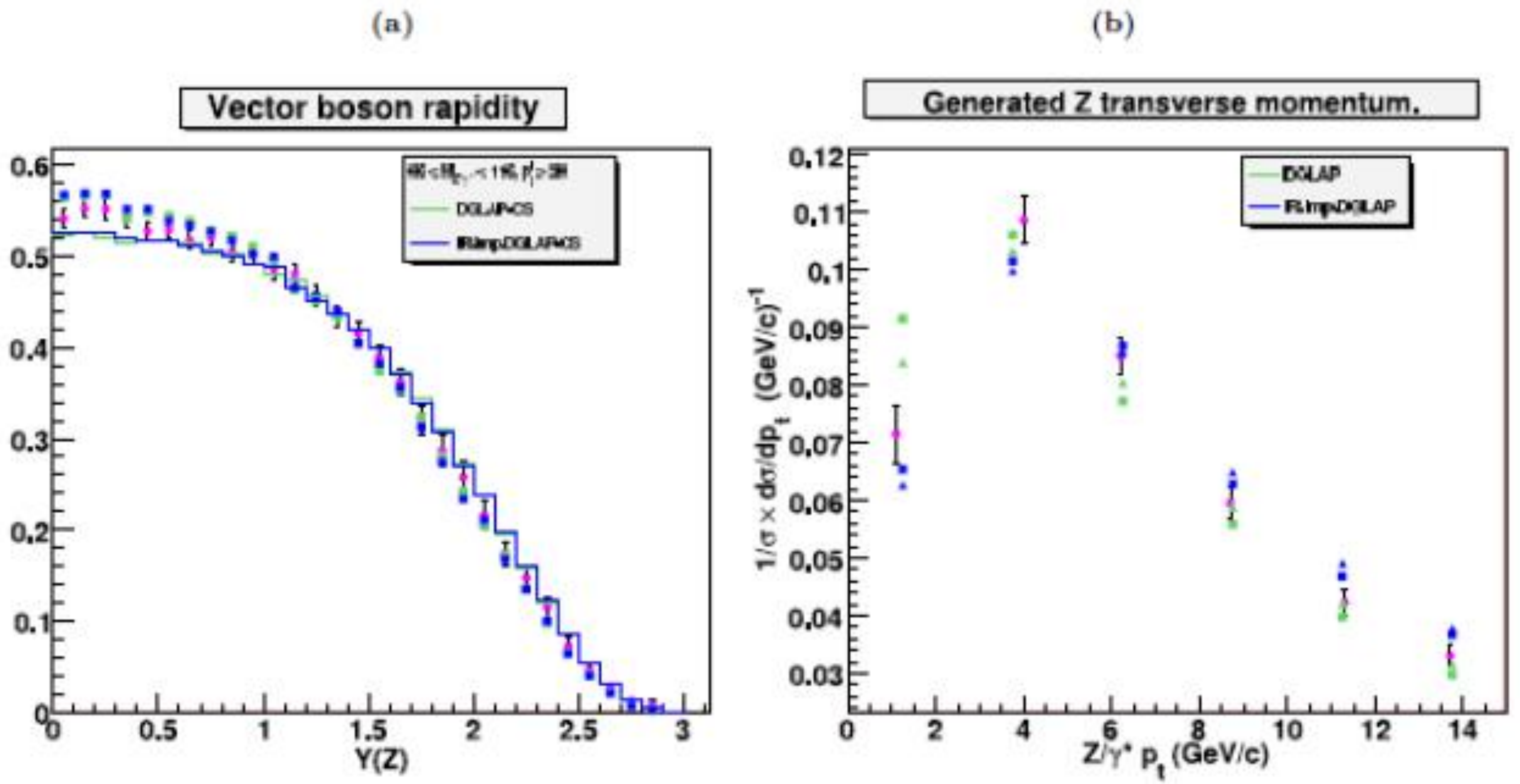

FIG. 6: Comparison with FNAL data: (a), CDF rapidity data on (Z/γ^*) production to e^+e^- pairs, the circular dots are the data, the green(blue) lines are HERWIG6.510(HERWIRI1.031); (b), D0 p_T spectrum data on (Z/γ^*) production to e^+e^- pairs, the circular dots are the data, the blue triangles are HERWIRI1.031, the green triangles are HERWIG6.510 – in both (a) and (b) the blue squares are MC@NLO/HERWIRI1.031, and the green squares are MC@NLO/HERWIG6.510. These are untuned theoretical results.

- Herwiri1.031(PRD81(2010)076008):
  w consultation from Bryan, Stefano, and Mike, implementation of IR-improved kernels in Herwig 6.5 environment to get Herwiri1.031, MC@NLO/Herwiri1.031.

- Herwiri++, Herwiri++/Powheg, Herwiri++/MC@NLO -- running but still undergoing check-out

- Pythia8(Tjorborn,Peter), Sherpa(Jan), in progress

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• Important Technical Point on MC@NLO vs POWHEG Hardest Emission Sudakov in POWHEG uses full O(α_s) emission result (we follow 0803.0883)

$$\Delta_{\hat{R}}(p_T) = \exp\left[-\int d\Phi_R \frac{\hat{R}(\Phi_B,\Phi_R)}{B(\Phi_B)}\theta\left(k_T(\Phi_B,\Phi_R) - p_T\right)\right]$$

⇒ must synthesize this with (1) as well

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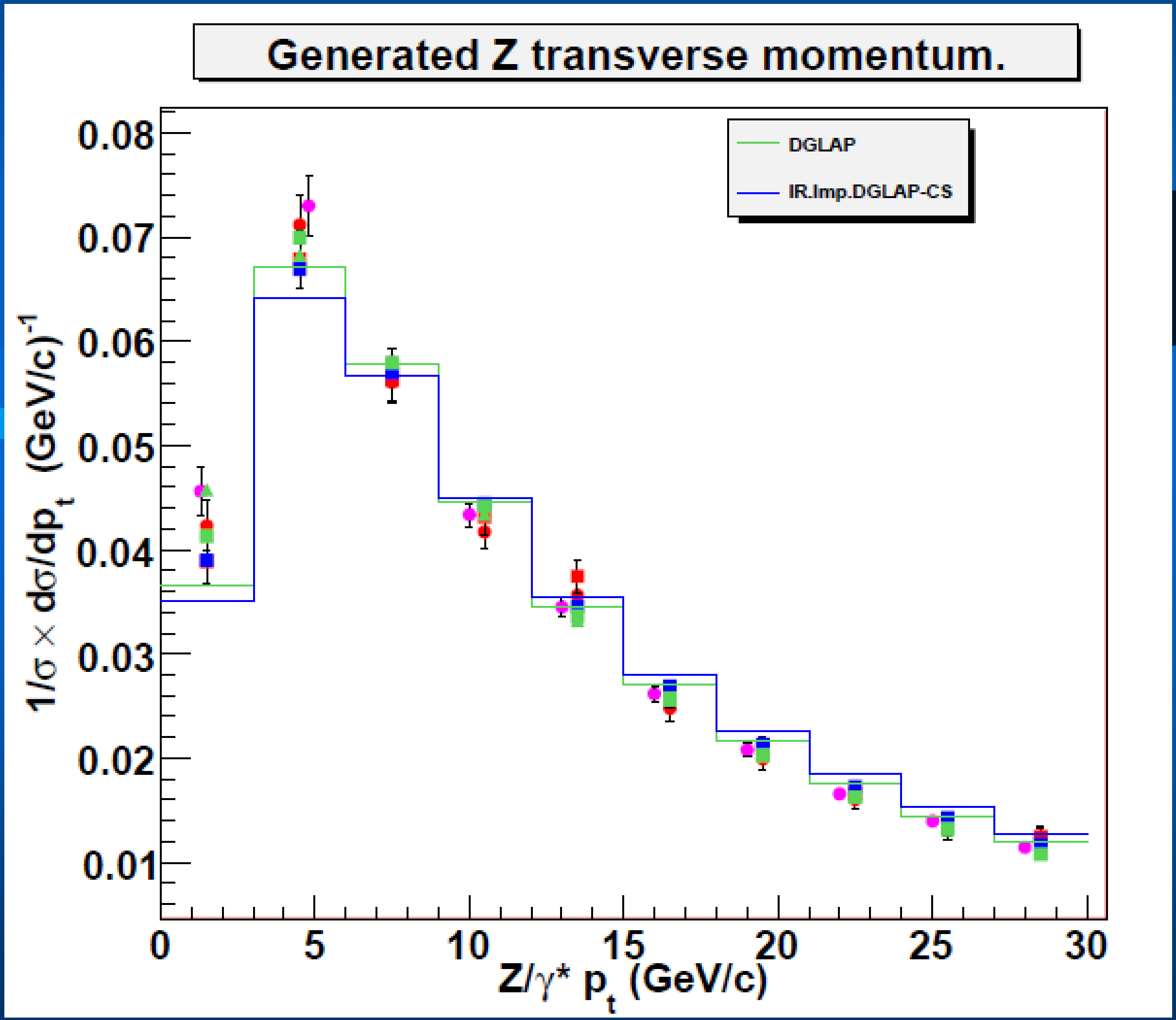
- An Example: ATLAS PT Spectrum for Z/γ Production



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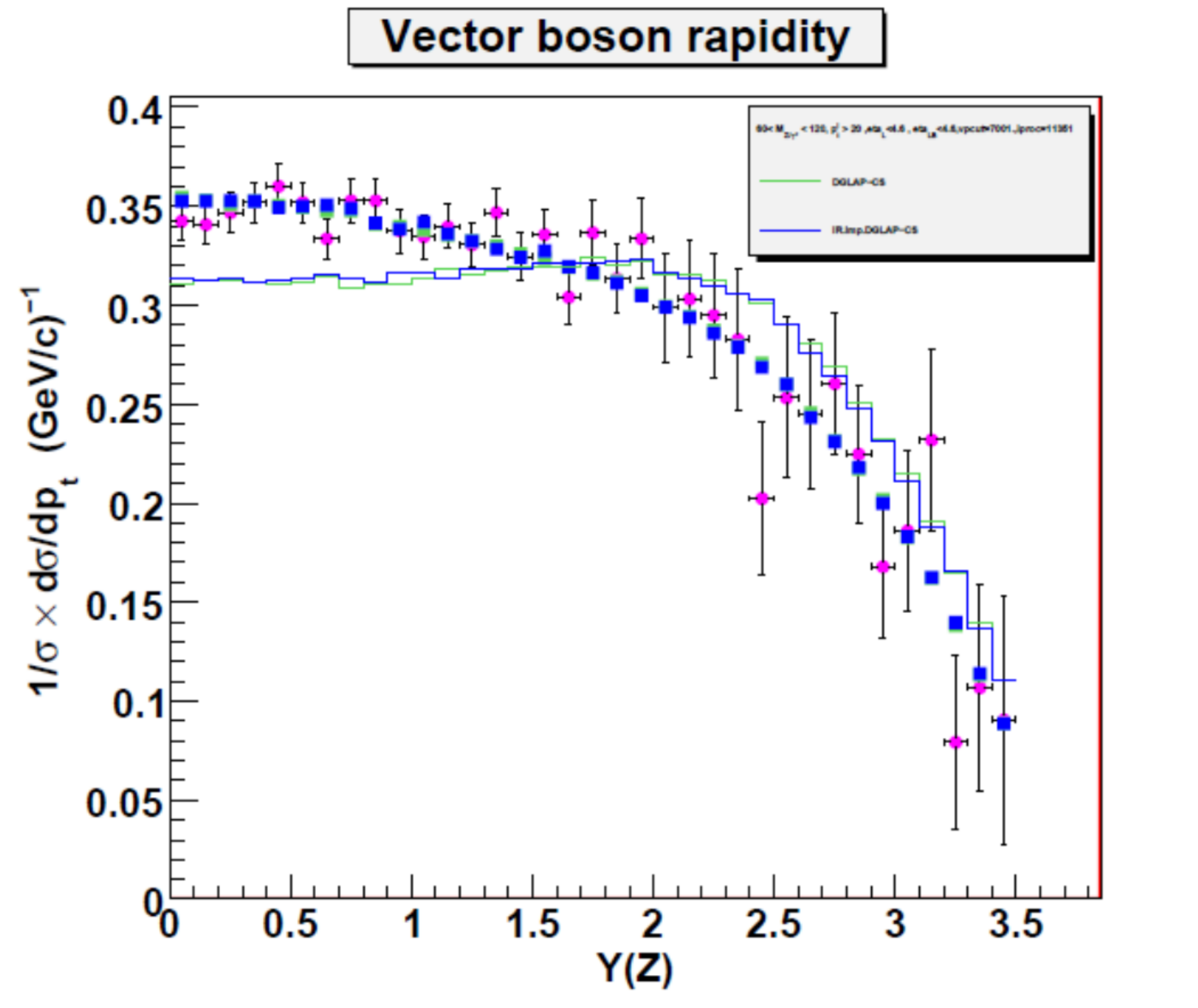
CMS Rapidity Cross Check:



- Observations

1. For the unimproved case, the data suggest that we need a GAUSSIAN (intrinsic) PTRMS $\cong$ 2.2 GeV (similar to what holds at FNAL)

2. This same shape is provided from fundamental principles by the MC@NLO/Herwiri1.031 with PTRMS $\cong$ 0 GeV (similar to what holds at FNAL)

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- Which is Better for Precision QCD Theory?

1. Precocious Bjorken Scaling in SLAC-MIIT Experiments: already at $Q^2 \cong 1_+ \text{GeV}^2$

   $\Rightarrow$ PTRMS^2 small compared to 1_+GeV^2

2. The first principles approach is not subject to arbitrary functional variation to determine its $\Delta\sigma_{th}$

3. Experimentally, in principle, events in the two cases should look different in terms of the properties of the rest of the particles in the events – this is under study

Look with us, already.

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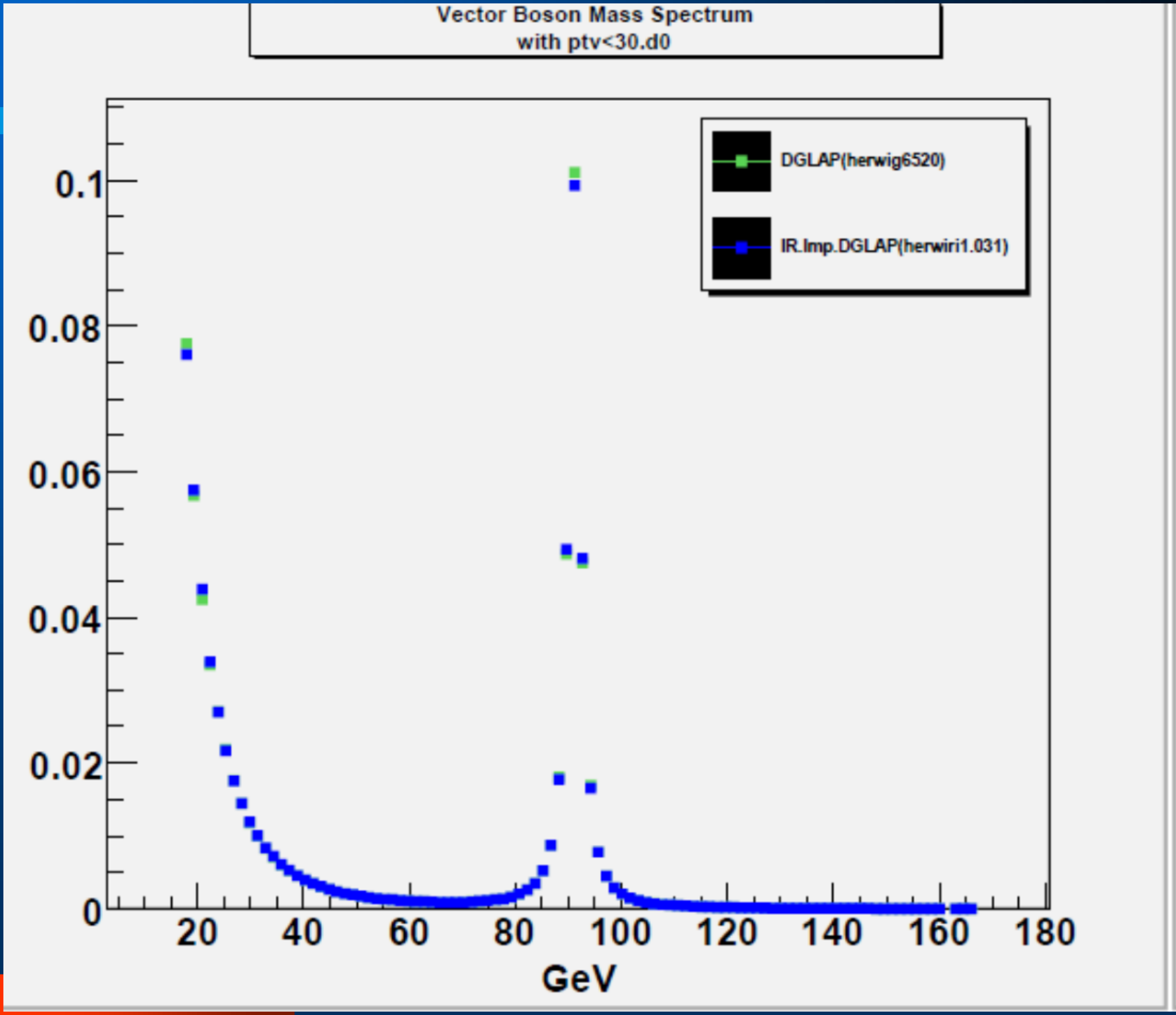
For example:



Vector Boson Mass Spectrum
with ptv<30.d0
DGLAP(herwig6520)
IR.Imp.DGLAP(herwiri1.031)
0.1
0.08
0.06
0.04
0.02
0
20
40
60
80
100
120
140
160
180
GeV

CONCLUSIONS

* IR-Improved DGLAP-CS Theory Increases Definiteness of Precision Determination of NLO Parton Shower MC's
* More Potential Checks Against Experiment Are Being Pursued

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