Threshold resummation in direct photon production

Nobuo Sato
Florida State University

In collaboration with:
J. Owens
D. Westmark

Motivation:

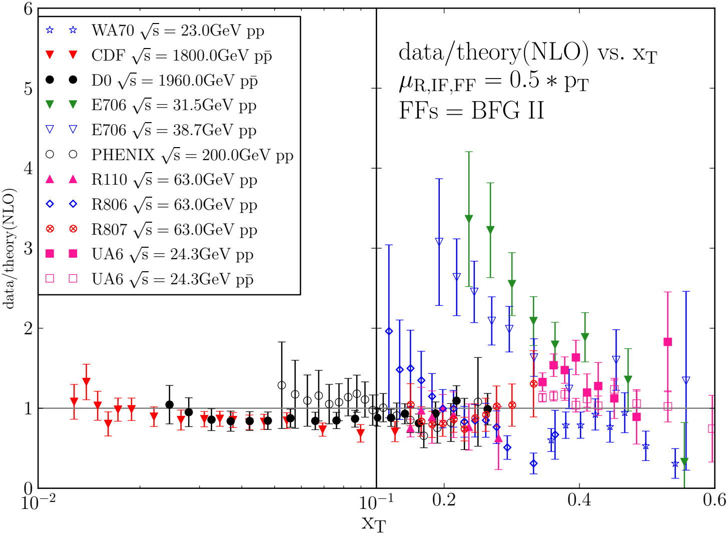
- Parton distribution functions (PDFs) - essential ingredients for hadron colliders.
- PDFs cannot be computed from first principles - extracted from experimental data.
- The uncertainties in the fitted PDFs are different among the parton species.
- In particular, gluon distribution is highly unconstrained at large x!
- Production of a state with mass m and rapidity y probes PDFs at $x \sim (m/\sqrt{s})e^{\pm y}$ which is relevant for BSM physics.

Motivation:

How to constrain gluon PDF at large x? $\rightarrow$ Single inclusive direct photon production at fixed target experiments.

- In the past, the data was used to constrain gluon PDF at large $x \leq 0.6$.
- It was removed from global fittings due to inconsistencies between the theory at NLO and the data of various fixed target experiments.

Motivation:



WA70 $\sqrt{s} = 23.0$GeV pp
CDF $\sqrt{s} = 1800.0$GeV p$\bar{p}$
D0 $\sqrt{s} = 1960.0$GeV p$\bar{p}$
E706 $\sqrt{s} = 31.5$GeV pp
E706 $\sqrt{s} = 38.7$GeV pp
PHENIX $\sqrt{s} = 200.0$GeV pp
R110 $\sqrt{s} = 63.0$GeV pp
R806 $\sqrt{s} = 63.0$GeV pp
R807 $\sqrt{s} = 63.0$GeV pp
UA6 $\sqrt{s} = 24.3$GeV pp
UA6 $\sqrt{s} = 24.3$GeV p$\bar{p}$
data/theory(NLO) vs. x_T
$\mu_{R,IF,FF} = 0.5 * p_T$
FFs = BFG II
data/theory(NLO)
x_T
0
1
2
3
4
5
6
10^{-2}
10^{-1}
0.2
0.4
0.6

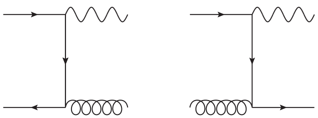
Motivation:

Can we improve theory at NLO? $\rightarrow$ threshold resummation for single inclusive direct photon production.

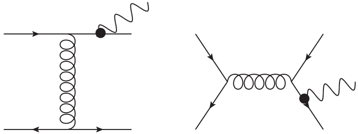
- Catani, Mangano, Nason, Oleari, Vogelsang, hep-ph/9903436 (direct contribution)
- de Florian, Vogelsang, hep-ph/0506150 (direct + jet fragmentation)

Theory of direct photons

At LO:



(a) direct contribution



(b) jet fragmentation

$$p_T^3 \frac{d\sigma(x_T)}{dp_T} = \sum_{a,b,c} f_{a/A}(x_a, \mu_{IF}) * f_{b/B}(x_b, \mu_{IF}) * D_{\gamma/c}(z, \mu_{FF}) * \hat{\Sigma}(\hat{x}_T, ...)$$

- Direct contribution: $D_{\gamma/\gamma} = \delta(1-z)$
- Jet fragmentation: $D_{\gamma/c} \sim \alpha_{em}/\alpha_S$

Theory of direct photons

Beyond LO:

$$p_T^3 \frac{d\sigma(x_T)}{dp_T} = \sum_{a,b,c} f_{a/A}(x_a, \mu_{IF}) * f_{b/B}(x_b, \mu_{IF}) * D_{\gamma/c}(z, \mu_{FF}) * \hat{\Sigma}(\hat{x}_T, ...)$$

1				LO
$\alpha_s L^2$	$\alpha_s L$	α_s		NLO
$\alpha_s^2 L^4$	$\alpha_s^2 L^3$	$\alpha_s^2 L^2$	$\alpha_s^2 L$	NNLO
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\alpha_s^n L^{2n}$	$\alpha_s^n L^{2n-1}$	$\alpha_s^n L^{2n-2}$	...	N^{n}LO
LL	NLL	NNLL	...	

$\hat{x}_T = 2p_T/z\sqrt{\hat{s}}$

$\hat{s} = x_a x_b S$

$L = \ln(1 - \hat{x}_T^2)$ "Threshold logs"

- Resummation: technique to find the exponential representation of threshold logs.

Theory of direct photons

When are threshold logs important?

$$p_T^3 \frac{d\sigma(x_T)}{dp_T} = \sum_{a,b,f} \int_{x_T^2}^1 dx_a \int_{\frac{x_T^2}{x_a}}^1 dx_b \int_{\frac{x_T}{\sqrt{x_a x_b}}}^1 dz f_a(x_a) f_b(x_b) D(z) \Sigma \left(\frac{x_T^2}{z^2 x_a x_b} \right)$$

$$\hat{x}_T = 2p_T/z\sqrt{\hat{s}}$$
$$\hat{s} = x_a x_b S$$
$$L = \ln(1 - \hat{x}_T^2)$$

$$\hat{x}_T = \frac{x_T}{z\sqrt{x_a x_b}} = [x_T, 1]$$
$$x_T = 2p_T/\sqrt{S}$$

CDF:(collider)

$\sqrt{S} = 1.8$ TeV

$x_T = [0.03, 0.11]$

UA6:(fixed target)

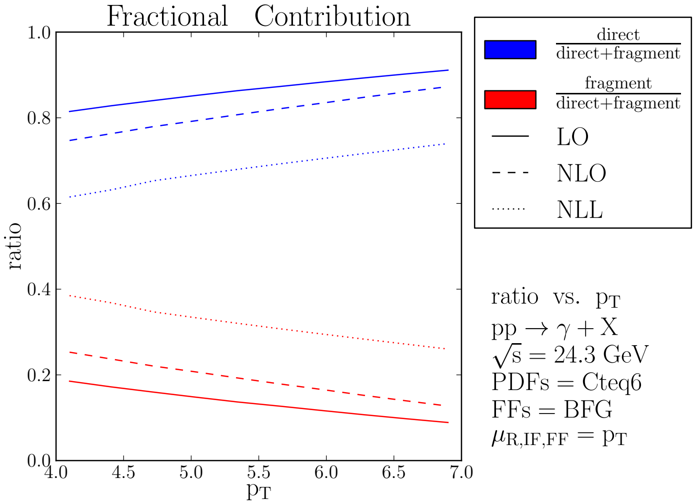
$\sqrt{S} = 24$ GeV

$x_T = [0.3, 0.6]$

- Threshold logs are more relevant for fixed target experiments.
- Due to trigger bias effect $\langle z \rangle \to 1$ which leads to enhancement of fragmentation component from theshold logs.

Theory of direct photons

Key observation: D.de Florian,W.Vogelsang (Phys.Rev. D72 (2005))



ratio vs. p_T

$pp \to \gamma + X$

$\sqrt{s} = 24.3$ GeV

PDFs = Cteq6

FFs = BFG

$\mu_{R,IF,FF} = p_T$

Theory of direct photons

- Resummation is performed in "mellin space":

$$f_N = \int_0^1 dx x^{N-1} f(x) \qquad f(x) = \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} dN x^{-N} F_N$$

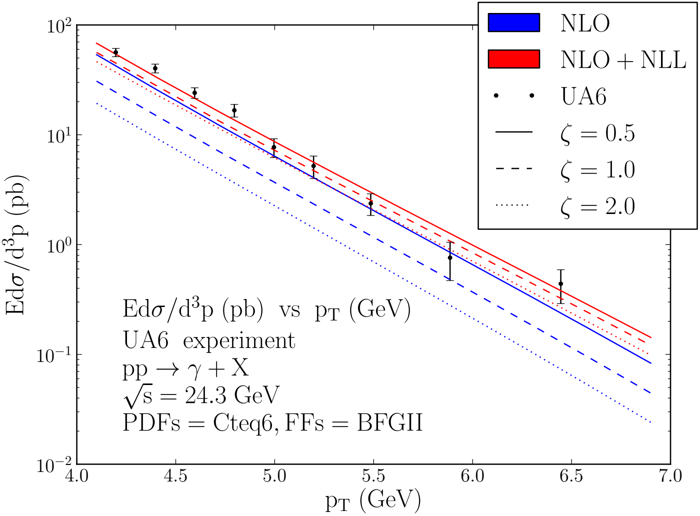
- The invariant cross section in N-space:

$$p_T^3 \frac{d\sigma(N)}{dp_T} = \sum_{a,b,f} f_{a/A}(N+1) f_{b/B}(N+1) D_{\gamma/c}(2N+3)\hat{\Sigma}(N)$$

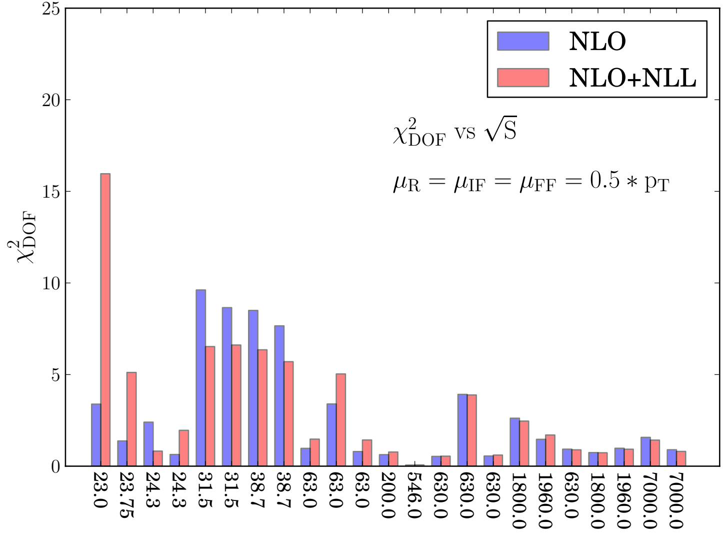
- The resummed partonic cross section in N-space is given by:

$$\hat{\Sigma}^{\mathsf{NLL}}(N) = C e^{S[\ln(N+1)]}\hat{\Sigma}^{\mathsf{Born}}(N)$$
$$e^{S(\ln(N))} = \Delta_N^a \Delta_N^b \Delta_N^c J_N^d \sum_i G_i \Delta_{i,N}^{(\mathsf{int})}$$

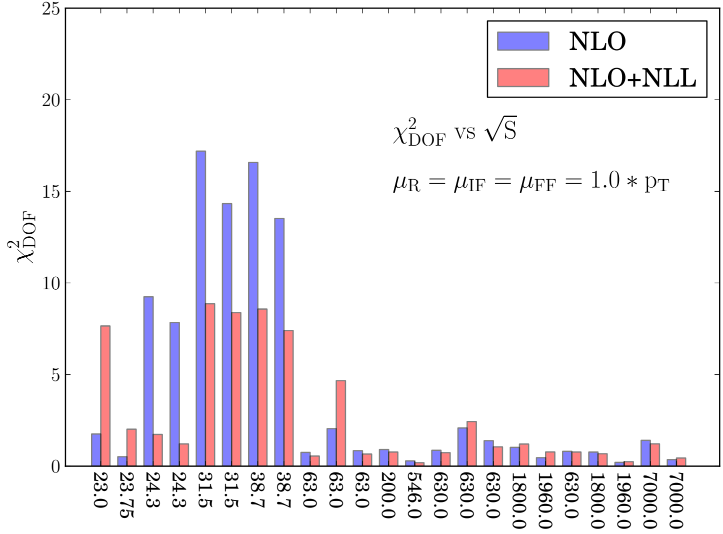
Phenomenology



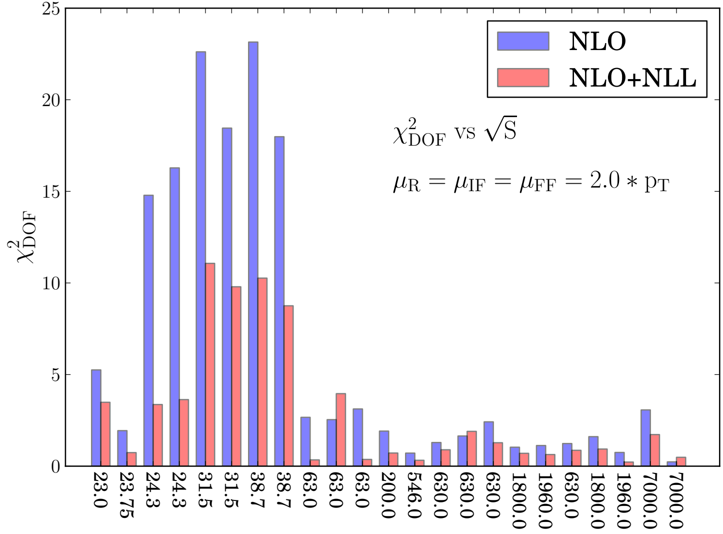
Phenomenology: χ^2_{DOF} profile



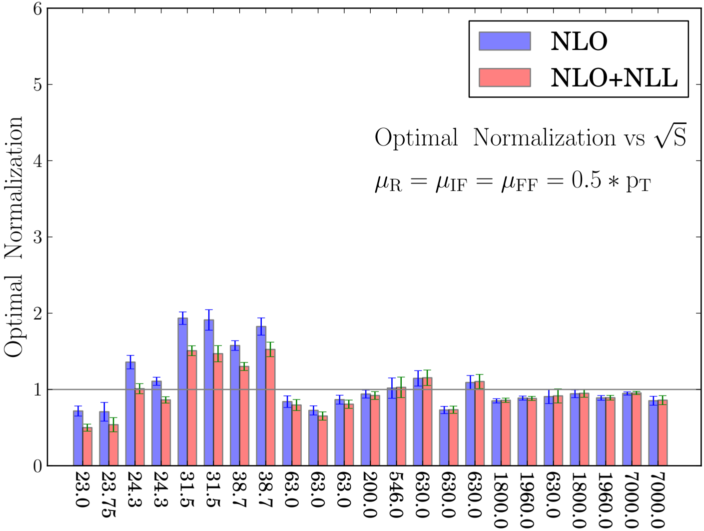
Phenomenology: χ^2_{DOF} profile



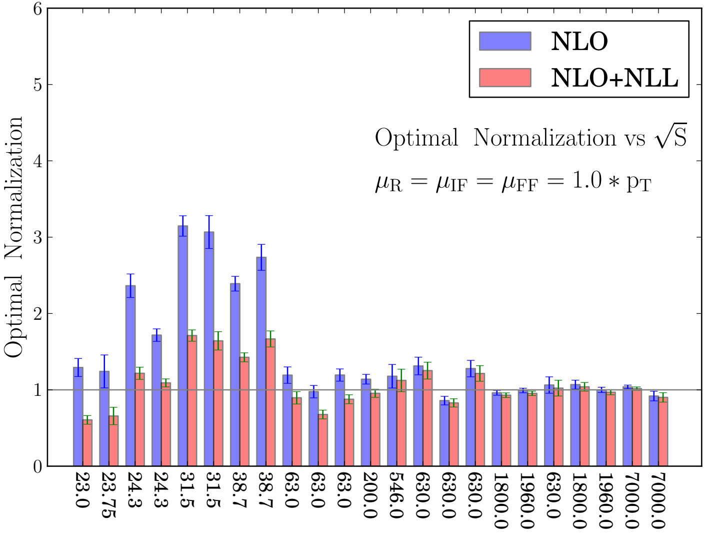
Phenomenology: χ^2_{DOF} profile



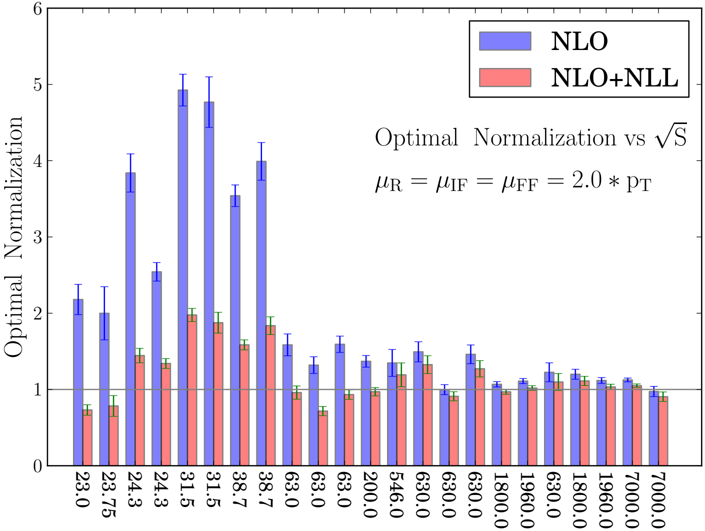
Phenomenology: Optimal normalization



Phenomenology: Optimal normalization



Phenomenology: Optimal normalization



Phenomenology: Gluon constraints

- Bayesian reweighting technique. Watt and Thorne (1205.4024), NNPDF collaboration (1012.0836)
- The idea:
  - Compute cross section for the available data sets using an ensemble of N random PDFs: $\{\mathsf{PDF}_K\}$.
  - Compute the $\chi^2_{\mathsf{DOF}}(k)$ of the combined data sets for each member PDF_K in the ensemble.
  - Compute weights as:

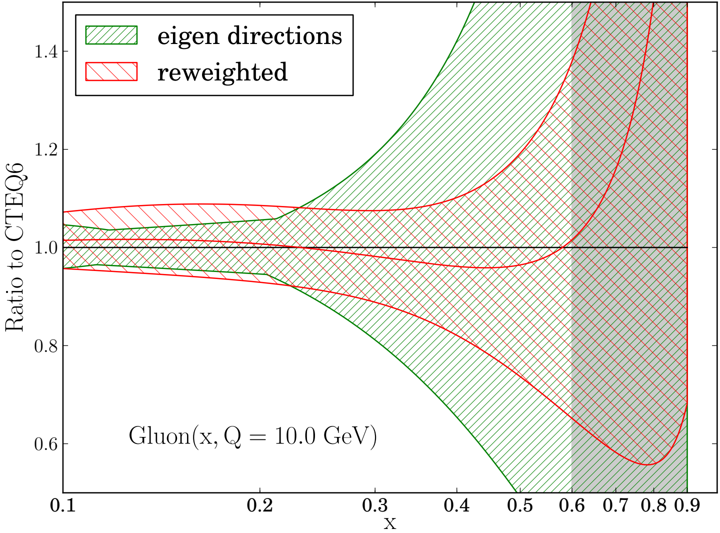
$$w_K = N \frac{e^{-\frac{1}{2}\chi^2_{\mathsf{DOF}}(k)}}{\sum_k e^{-\frac{1}{2}\chi^2_{\mathsf{DOF}}(k)}}$$

- The new constrained PDFs and its uncertainty can be written as:

$$\langle \mathsf{PDF} \rangle (x,Q) = \frac{1}{N} \sum_k w_k \mathsf{PDF}(x,Q)_k$$

$$\delta \langle \mathsf{PDF} \rangle (x,Q) = \sqrt{\frac{1}{N} \sum_k w_k (\mathsf{PDF}(x,Q)_k - \langle \mathsf{PDF} \rangle (x,Q))^2}$$

Phenomenology: Gluon constraints (preliminary)



Conclusions:

- High-x PDFs important for production of a state with mass m at forward rapidities.
- Threshold resummation improves the theoretical prediction of direct photons at fixed target experiments $\rightarrow$ potential constrains on gluon PDF up to $x \sim 0.6$.

To do:

- Constrain PDFs with threshold resummation in DIS and lepton-pair production (D. Westmark).
- Compare our results with SCET calculations by Becher and Schwarts (only resummation of direct part).