Threshold resummation in direct photon production

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Motivation:

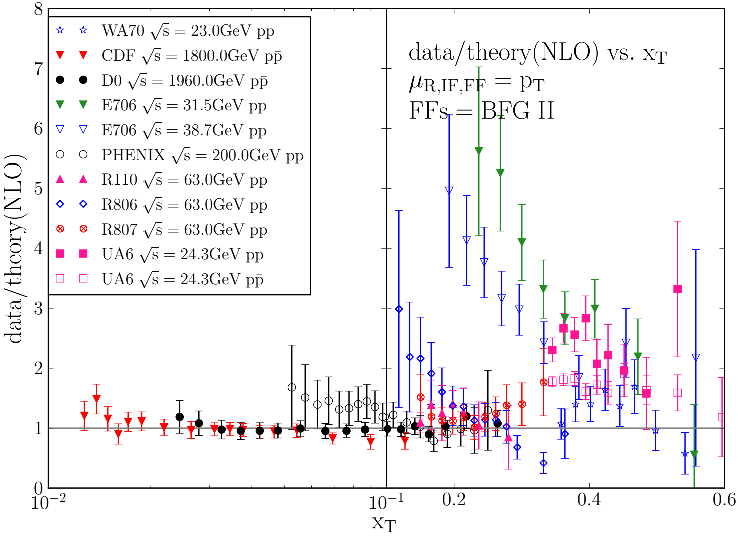
- Parton distribution functions (PDFs) - essential ingredients for hadron colliders.
- PDFs cannot be computed from first principles - extracted from experimental data.
- The uncertainties in the fitted PDFs are different among the parton species.
- In particular, gluon distribution is unconstrained 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.
- Recently (1202.1762) d'Enterria and J. Rojo have included isolated direct photon data to constrain gluon PDF around $x \sim 0.02$. They show reduction up to 20%.

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
$\mu_{R,IF,FF} = p_T$
FFs = BFG II
data/theory(NLO)
x_T
0
1
2
3
4
5
6
7
8
10^{-2}
10^{-1}
0.2
0.4
0.6

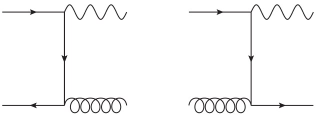
Motivation:

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

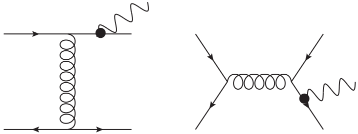
- Catani, Mangano, Nason, Oleari, Vogelsang, hep-ph/9903436
  (direct contribution)
- de Florian, Vogelsang, hep-ph/0506150
  (direct + jet fragmentation)

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:

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

$\hat{\Sigma}(\hat{x}_T, ...) \supset$

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

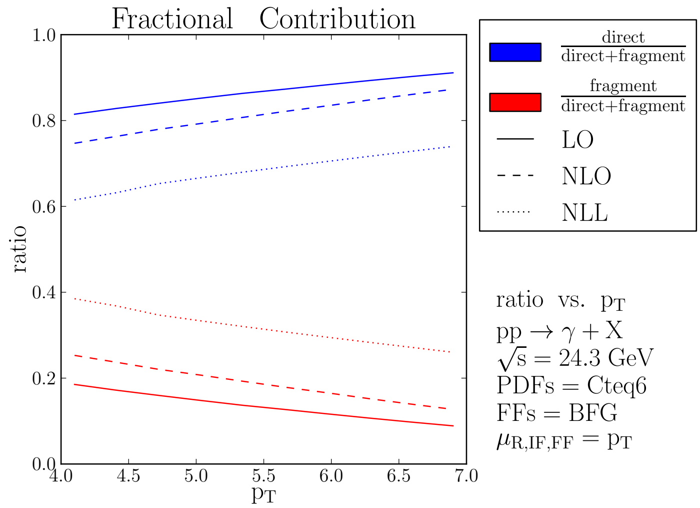
When are threshold logs important?

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

- $\hat{x}_T = \frac{x_T}{z\sqrt{x_a x_b}} \subset [x_T, 1]$
- Collider: CDF($\sqrt{s} = 1.8$ TeV): $x_T \subset [0.03, 0.11]$.
- Fixed Target: UA6($\sqrt{s} = 24$ GeV): $x_T \subset [0.3, 0.6]$.
- Threshold logs are more relevant for fixed target experiments.
- Due to PDFs, $\langle x_{a,b} \rangle$ is small so that $\langle z \rangle \to 1$. This enhances the fragmentation component from threshold logs.

Theory of direct photons

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



Theory of direct photons

- Resummation is performed in "mellin space":

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

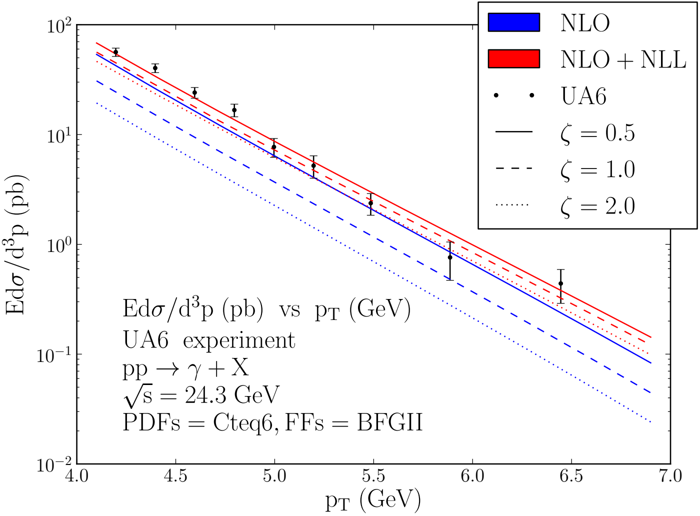
- The invariant cross section in N-space:

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

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

$$\hat{\Sigma}^{\mathsf{NLL}}(N) = C\left(\Delta_N^a \Delta_N^b \Delta_N^c J_N^d \sum_i G_i \Delta_{i,N}^{(\mathsf{int})}\right)\hat{\Sigma}^{\mathsf{Born}}(N) \tag{1}$$

Phenomenology



Threshold resummation$\rightarrow$ sizable scale reduction.

Phenomenology: Gluon constraints

- The current code of NLO+NLL is too slow to be used in global fits.
- An alternative to global fits exist: Bayesian reweighting technique. NNPDF collaboration (1012.0836).
- This technique is suitable for montecarlo based PDFs such as NNPDFs.
- Watt and Thorne (1205.4024) proposed a way to apply the technique in PDFs sets such as CTEQ or MSTW.

Phenomenology: Gluon constraints

The idea:

- random PDFs:

$$f_k = f_0 + \sum_j (f_\pm - f_0)|R_{kj}| \quad (j = 1..20)$$

- for each f_k compute:

$$\chi_k^2 = \sum_i \left(\frac{D_i - T_i}{\sigma_i}\right)^2$$

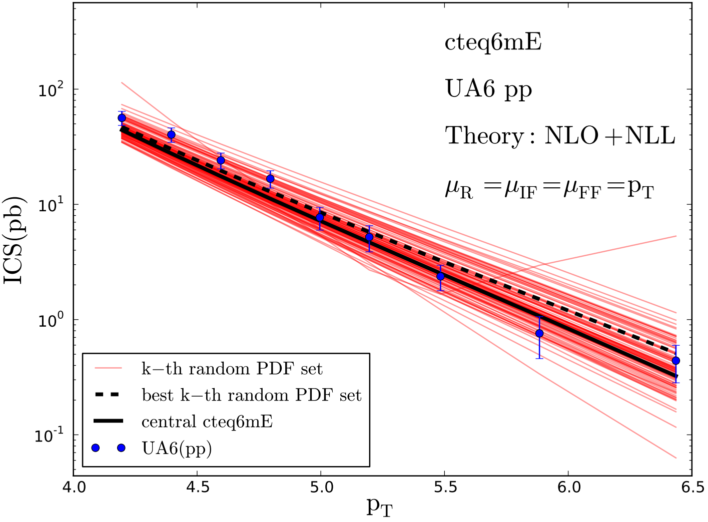
- get weights as:

$$w_K = \frac{(\chi_k^2)^{\frac{1}{2}(N_{pts}-1)} * e^{-\frac{1}{2}\chi^2(k)}}{\sum_k (\chi_k^2)^{\frac{1}{2}(N_{pts}-1)} * e^{-\frac{1}{2}\chi^2(k)}}$$

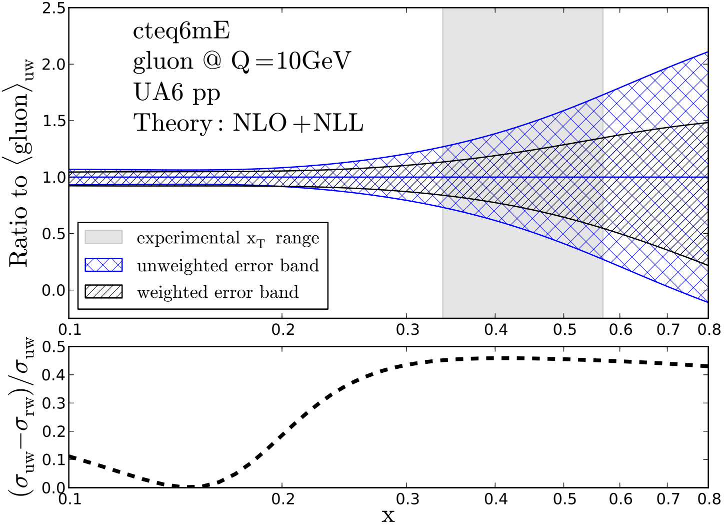
- observables are given as:

$$\langle O \rangle = \sum_k w_k O(f_k) \qquad \sigma^2 = \sum_k w_k (O(f_k) - \langle O \rangle)^2$$

Phenomenology: preliminary



Phenomenology: preliminary

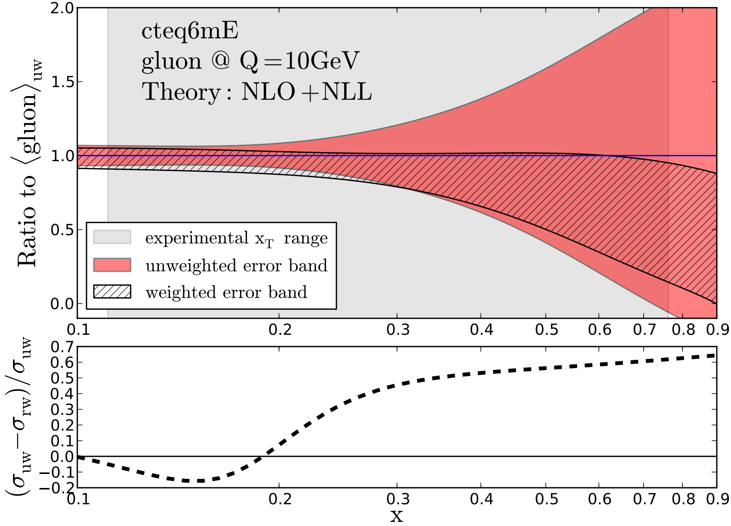


Phenomenology: preliminary

exp/col	mode	$\sqrt{s}$ (GeV)	# pts	p_T range
WA70	pp	23.0	8	$[4.0, 6.5]$
NA24	pp	23.8	5	$[3.0, 6.5]$
UA6	pp	24.3	9	$[4.1, 6.9]$
UA6	ppb	24.3	10	$[4.1, 7.7]$
E706	pBe	31.5	17	$[3.5, 12.0]$
E706	pp	31.5	8	$[3.5, 10.0]$
E706	pBe	38.7	16	$[3.5, 10.0]$
E706	pp	38.7	9	$[3.5, 12.0]$
R806	pp	63.0	14	$[3.5, 12.0]$
R807	pp	63.0	11	$[4.5, 11.0]$
R110	pp	63.0	7	$[4.5, 10.0]$

Table : List of fixed target experimental data.

Phenomenology: 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 at high x.

To do:

- Reweighting studies in other PDFs sets.
- Analysis of the global χ^2 after reweighting.
- Develop a faster code for global fitting.
- Compare with scet techniques.