Exclusive Production at the LHC

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Les Houches Winter Workshop on Recent QCD Advances at the LHC

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14/02/2011

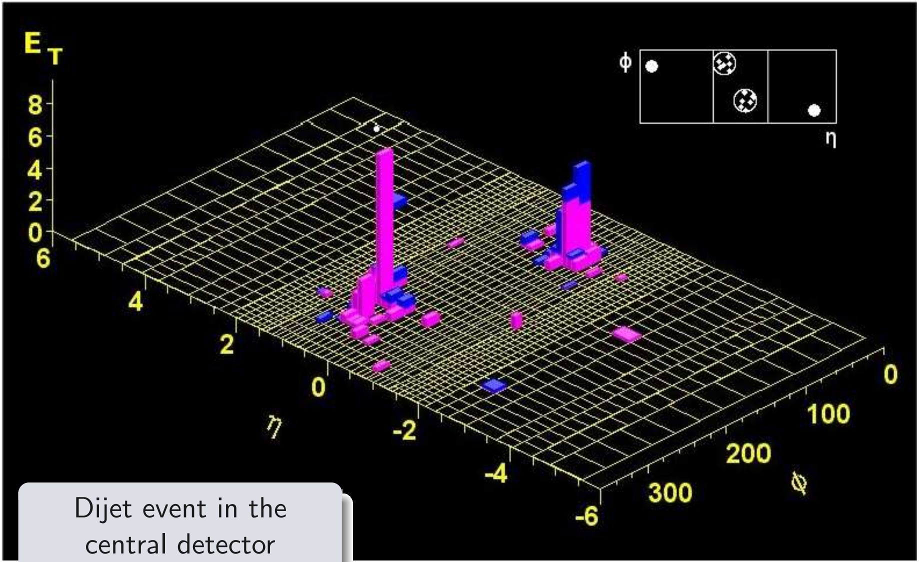
Theoretical (QCD) Side:

- Poor knowledge of the long-distance physics
- Nature of the exchange
- No factorisation theorem

Experimental Side

- No hadronic remnant, simple final state
- Possibility to measure the hadronic energy lost
- Direct identification of the spin

$\rightarrow$ discovery tool for new physics decaying into hadrons

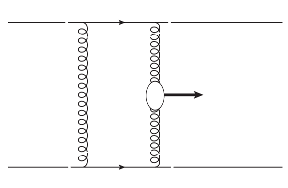


Dijet event in the central detector CDF collaboration

Standard scheme of a Exclusive Production calculation:

Ingredients

- Lowest order QCD calculation at the parton level
- Embed partons in the proton via a Proton Impact Factor
- Add virtual corrections via a Sudakov Form Factor
- Take proton rescattering corrections into account



[A. Bialas and P. V. Landshoff, 1991]
[A. Berera and J. C. Collins, 1995]

- Fully calculable
- Infra-red divergent

CHIDe: Exact transverse kinematics

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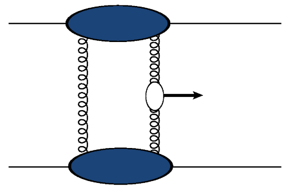

[J. F. Gunion and D. E. Soper, 1977]
[H. Cheng and T. T. Wu, 1987]

$$\mathcal{M} = \mathcal{M}_{qq} \otimes \Phi(x, \mathbf{k}, \mathbf{k}_1)\Phi(x, \mathbf{k}, \mathbf{k}_3)$$

CHIDe: $\Phi \rightarrow$ Hard + Soft distributions
Based on a skewed ($x \neq x_i$) UgD,
includes t- and energy dependence

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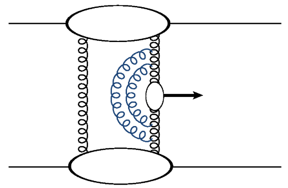

[Y. L. Dokshitzer, D. Diakonov and S. I. Troian, 1980]
[KMR, 2000; T. D. Coughlin, J. R. Forshaw, 2010]

$$T = e^{-S(\mu,\ell)}$$

- structure and scales μ, ℓ
- Suppresses the cross section

Not calculated in the dijet case

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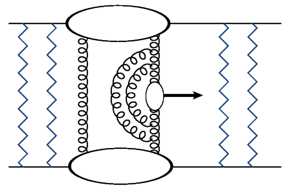
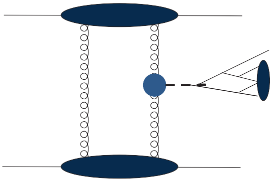


[J. D. Bjorken, 1993]
[L. Frankfurt *et al.*, 2007]

→ Gap Survival Probability
$S^2 =$ 0.5-0.15 at the TeVatron

Energy behaviour depends on the unitarisation scheme



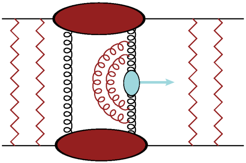
[M. Dasgupta, L. Magnea and G. P. Salam, 2008]
[K. Terashi, unpublished]
[V.A. Khoze, A.B Kaidalov, A.D. Martin, M. G. Ryskin and W.J. Stirling,2005]

If jets: Splash-Out

- Correction in energy from the parton level to the jet level
- Due to jet reconstruction algorithms

Under Theoretical Control

- Lowest order QCD calculation



Impact factor	$\mathcal{O}(3)$
Sudakov form factor	$\mathcal{O}(10)$
Gap survival probability	$\mathcal{O}(3)$
Splash-out	$\mathcal{O}(1.5)$

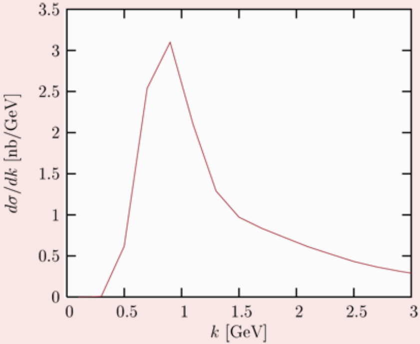
Still controversial

- Proton Impact Factor
- Sudakov Form Factor
- Gap Survival Probability
- Splash-out

Origin of the uncertainties?

Importance of the non-perturbative region

k distribution

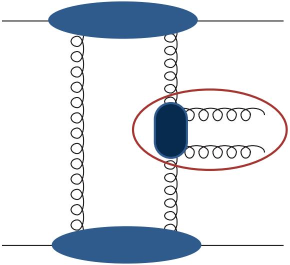


TeVatron $E_T^{\rm min} > 10$ GeV

If the gluon transverse momenta are larger than 1 GeV^2
$\rightarrow \sigma_{\rm pert} = 30\%\,\sigma$

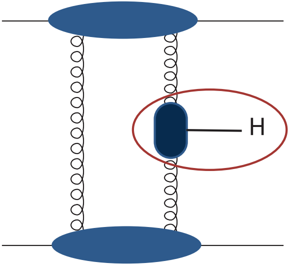
- LHC ($E_T^{\rm min} > 50$ GeV): 55%
- LHC ($m_H = 120$ GeV): 75%

Dijet Exclusive Production



[A. Berera and J. C. Collins, 1996]
[V. A. Khoze, A. D. Martin and M. G. Ryskin, 2000]
[A. Bzdak, 2005]

Higgs Exclusive Production



[A. Bialas and P. V. Landshoff, 1991]

$\Rightarrow$ Understanding the pieces of the dijet CEP may lead to a prediction of the Higgs CEP cross section

KMR Model

Perturbative calculation

$\sigma_H = 3$ fb
@m_H=120 GeV
No uncertainties

Most complete model:
χ_c, dijet, Higgs,
BSM Higgs, $q\bar{q}$

CHIDe Model

Similar to KMR

$\sigma_H < 1$ fb
@m_H=120 GeV
Large uncertainties

with Exact transverse kinematics, proton impact factor, J_z=2 states, independent evaluation of gap survival probability and splash-out

Other Models

→ Saclay Hybrid Model

[R. Peschanski, M. Rangel, C. Royon, 2008.]

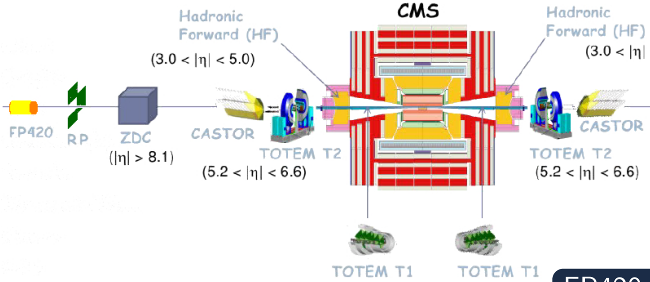
→ Krakow Model

[R. Maciula, R. Pasechnik, A. Szczurek, 2010.]

→ Non-perturbative Model

[R. Enberg *et al.*, A. Bzdack.]

Forward physics at LHC:
CMS/ATLAS + forward detectors → largest rapidity coverage ever



→ Elastic scattering
→ Diffraction
→ Photon induced physics
→ Low-x QCD: forward jets, Drell-Yan
→ Proton structure

FP420+RP220 cuts

ξ_1,ξ_2	[0.002,0.2]
$\lvert y_{jet}\rvert$	< 1
M_{jj}	> 50 GeV

[M.G. Albrow *et al.*, report CERN-LHCC-2005-025]

Forward Physics Monte-Carlo

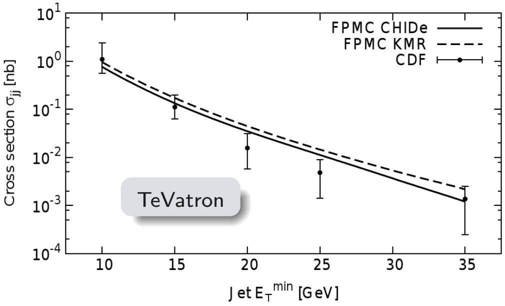
"Generator designed to study forward physics, especially at the LHC. Provide the user a variety of diffractive processes in one common framework"

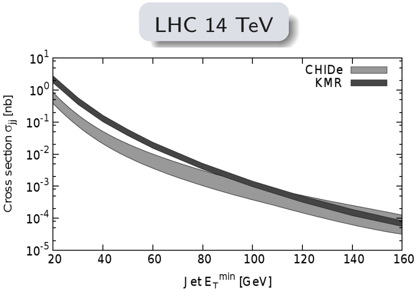
- Single diffraction
- Double pomeron exchange
- Central exclusive production (direct implementation of KMR and CHIDe models)
- Two-photon exchange (+ anomalous couplings)
- HERWIG + PYTHIA for hadronisation

Reference

[O. Kepka, R. Staszewsk, M. Boonekamp, AD V. Juránek, M. Rangel, C. Royon. On ArXiv tomorrow]

→ Exclusive Dijet Production

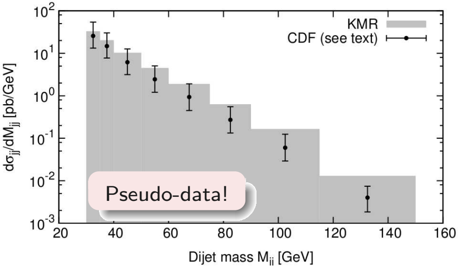


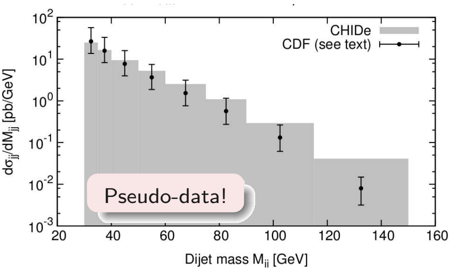


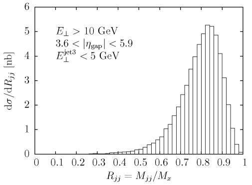
@ 50 GeV → 20-40 events
if $\mathcal{L}$= 1 fb^{-1} at LHC

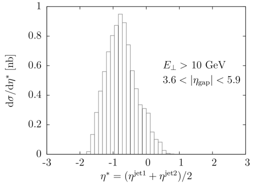
→ Dijet Mass Fraction

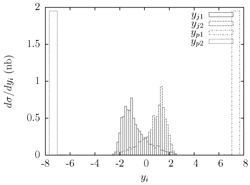
$\sqrt{s} = 1.96$ TeV, $E_T^{\rm min} > 10$ GeV



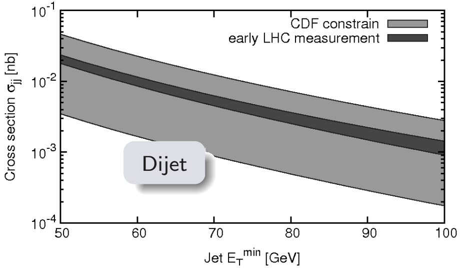


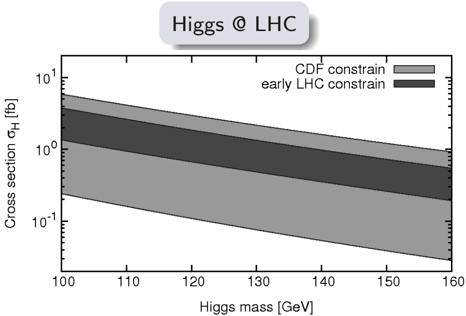






→ Strategy analysis of early data





Possible exclusive jets measurement with $\mathcal{L}$= 100 pb^{-1} at LHC
Constrain σ_H by a factor of 5

Statistical uncertainties + 3% energy scale

- Experimental expectations LHC@ 7 TeV

1 exclusive Higgs boson events if $\mathcal{L}$=1 fb^{-1} but no forward detectors

- Importance of the non-perturbative region
- Dijet can be used to reduce the uncertainties $\rightarrow$ importance of dijet LHC data

- FPMC

Hybrid model, Krakow model, di-quark jets, di-photon, χ_c should be implemented soon and compare with available data

References

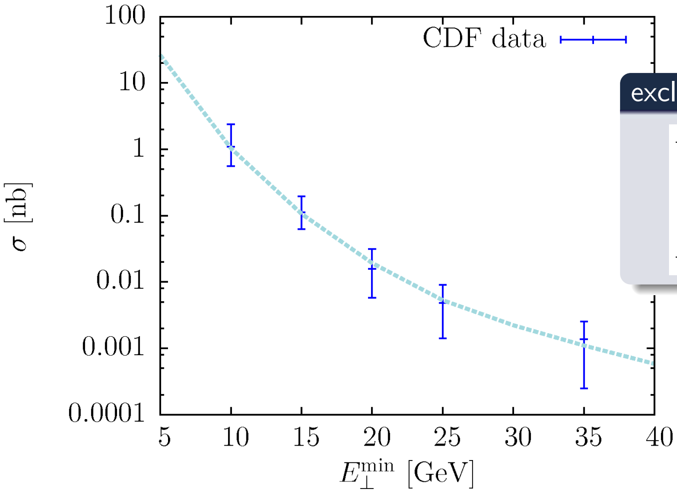
[J. R. Cudell, AD, O. F. Hernandez and I. P. Ivanov, Eur. Phys. J. C **61** (2009) 369]

[J. R. Cudell, AD, O. F. Hernandez, 2010. arXiv:1011.3653]

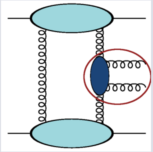
[AD, O. Kepka, C. Royon and R. Staszewski, 2010. arXiv:1101.1439]

Back up slides

⇒ 2008 dijet data at the TeVatron $p\bar{p}$ collider $\sqrt{s} = 1.96$ TeV



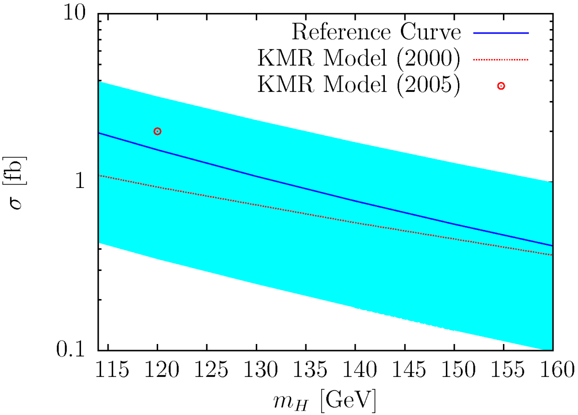
exclusive Dijet



[T. Aaltonen *et al.* (CDF Run II Collaboration), 2008.]

CHIDe vs KMR

- No cuts
- No K factor



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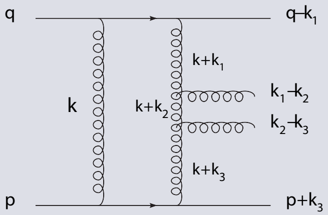
[V.A. Khoze, A.D. Martin, M.G. Ryskin, 2000]

1: Lowest Order QCD calculation



$$k_i = \alpha_i p^\mu + \beta_i q^\mu + \mathbf{k}_i$$

$$\frac{\mathbf{k}^2_{1,2,3}}{s} \ll \alpha_i, \beta_i \ll 1 \quad \text{(i=1,2)}$$

$$\mathbf{k}_2 \gg \mathbf{k}_1, \mathbf{k}_3$$

$$\mathrm{d}\sigma \propto \frac{1}{(\mathbf{k}_2^2)^2} \left| \int \frac{\mathrm{d}^2\mathbf{k}}{\mathbf{k}^2(\mathbf{k}+\mathbf{k}_1)^2(\mathbf{k}+\mathbf{k}_3)^2} \times f(\mathbf{k}) \times \mathcal{M}(gg \to gg) \right|^2$$

$gg \to gg$ amplitude

$$d\sigma \propto \left|\mathcal{M}(gg \to gg)\right|^2$$
$$\propto C_0|M_0|^2 + C_2|M_2|^2$$

Where C_0 and C_2 are a product of tranverse momenta $\mathbf{k}_i$

$$|M_0|^2 \equiv \frac{1}{2}[|\mathcal{M}_{++\to++}|^2 + |\mathcal{M}_{--\to--}|^2] = 1$$
$$|M_2|^2 \equiv \frac{1}{2}[|\mathcal{M}_{+-\to+-}|^2 + |\mathcal{M}_{+-\to-+}|^2 + |\mathcal{M}_{-+\to-+}|^2 + |\mathcal{M}_{-+\to+-}|^2] < 1$$

- In the limit $\mathbf{k}, \mathbf{k}' \gg \mathbf{k}_1, \mathbf{k}_3$, we obtain the J_z=0 rule
- $|M_2|^2$ contribute for 2% of the cross section

End of the Analytic QCD Calculation

$gg \to gg$ amplitude

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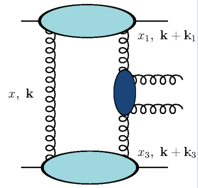
End of the Analytic QCD Calculation

Impact Factor



- Regulate the IR divergence
- Based on a skewed ($x \neq x_i$) UgD
- Includes t- and energy dependence

$$\exp\left[-\frac{1}{2}\left(B_0 + 2\alpha' \log\frac{x_0}{x}\right)|t|\right]$$

Hard Part:

$$\mathcal{F}(x,\mathbf{k}^2) = \frac{\partial\, xg(x,\mathbf{k}^2)}{\partial \log(\mathbf{k}^2)}$$

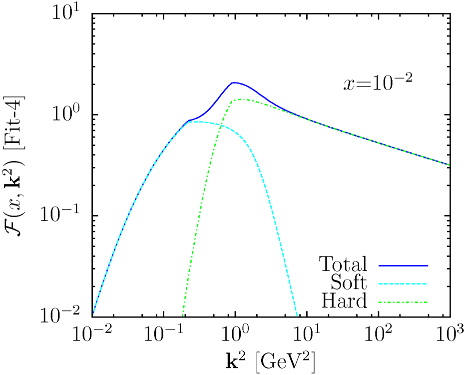
Soft Part:

Phenomenological description:

Proton dipole picture

$\rightarrow$ Fit to F_2 at HERA

[I. P. Ivanov, N. N. Nikolaev and A. A. Savin, 2006]



Sudakov Form Factor

$$T = e^{-S(\mu^2,\ell^2)}$$

$$S(\mu^2,\ell^2) = \int_{\ell^2}^{\mu^2} \frac{\mathrm{d}\mathbf{q}^2}{\mathbf{q}^2} \frac{\alpha_s(\mathbf{q}^2)}{2\pi} \int_0^{1-\Delta} \mathrm{d}z [z P_{gg} + N_f P_{qg}]$$

Trick: Virtual correction $\sim$ brehmstrahlung correction

- True for $\log^2$
- Single log structure

- Constant terms?

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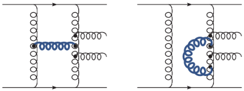

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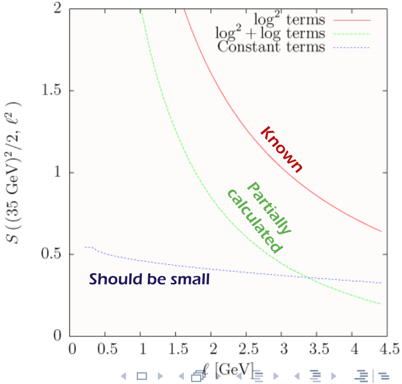
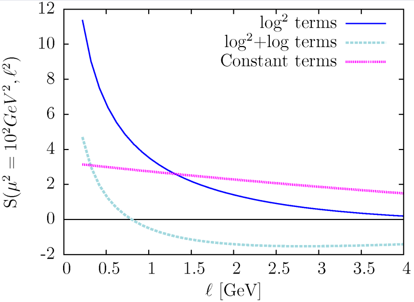


The Log Structure

Validity of the exponentiation $\rightarrow$ dominance of the double-log contribution



@ μ=10 GeV

The Upper Scale μ

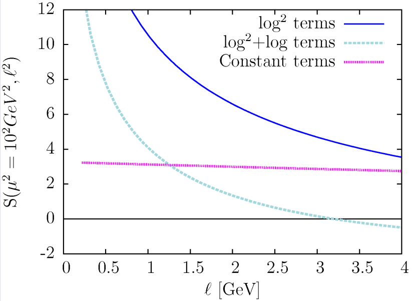
Standard definition

$\rightarrow$ point-like vertex $\mu = m_{gg}$

$\Rightarrow \mu = c\,\mathbf{k}_2$

The Log Structure

Validity of the exponentiation → dominance of the double-log contribution



@ μ=40 GeV

The Upper Scale μ

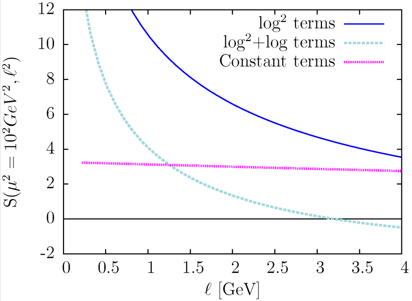
Standard definition

→ point-like vertex $\mu = m_{gg}$

$\Rightarrow \mu = c\,\mathbf{k}_2$

The Log Structure

Validity of the exponentiation → dominance of the double-log contribution



@ μ=40 GeV

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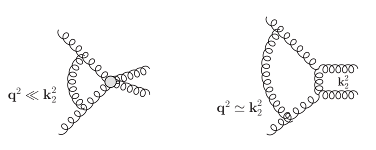
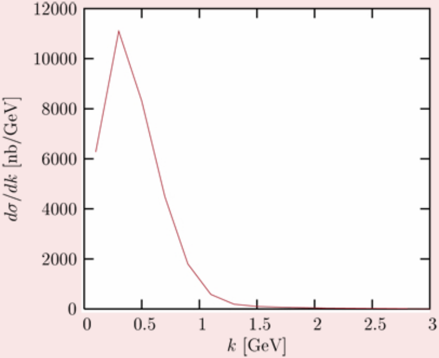


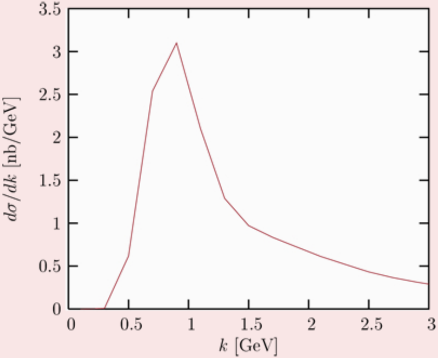
$\Rightarrow \mu = c\,\mathbf{k}_2$

The Sudakov Problem: Importance of the Non-Perturbative Region

- Without Sudakov form factor



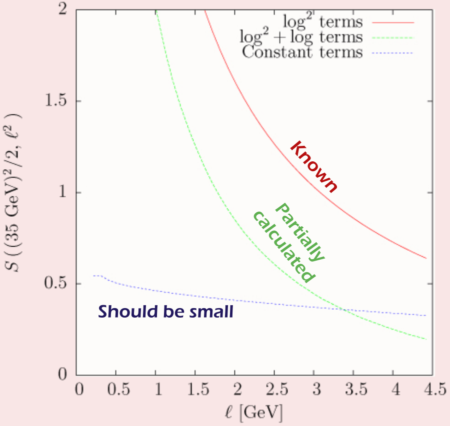
- With Sudakov form factor



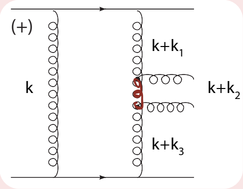
The calculation is dominated by the non-perturbative region

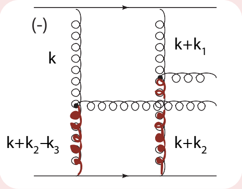
The Sudakov Problem: Single Log Contribution

$$S(\mu,\ell) = \alpha_s(\mu^2)\left(a\log^2\left(\frac{\mu^2}{\ell^2}\right) + b\log\left(\frac{\mu^2}{\ell^2}\right) + c\right)$$



The Sudakov Problem: Open Question





$S(\mathbf{k}_2^2, \mathbf{k}^2)$

$S_{new}(\mathbf{k}_2^2, \mathbf{k}^2)$

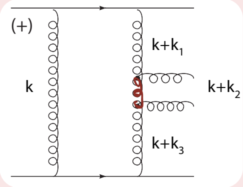
Diagram with gluons emitted from different legs is supressed at large $\mathbf{k}_2$ because it contains one more gluon propagator

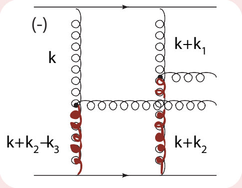
$\rightarrow$ diagram of the order of $\mathcal{O}(\frac{\log(\mathbf{k}_2^2)}{\mathbf{k}_2^2})$

The Sudakov Problem: Importance of the Non-Perturbative Region

The Sudakov Problem: Logs Contribution

The Sudakov Problem: Open Question





$S(\mathbf{k}_2^2, \mathbf{k}^2)$

$S_{new}(\mathbf{k}_2^2, \mathbf{k}^2)$

Max contribution to σ at $E_T^{min} = 10$ GeV
$\rightarrow \sigma_2 \sim 0.2$ nb

- Impact factor

  Fit-1, 2, 3, 4

- Sudakov form factor

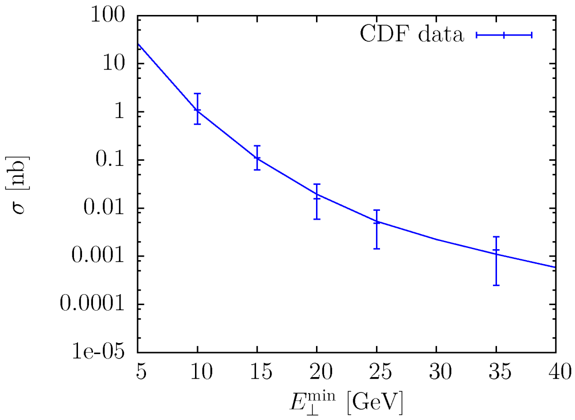
  $$\mu^2 = \frac{\mathbf{k}_2^2}{x}$$

  $$\ell^2 = \frac{(\mathbf{k}+\mathbf{k}_i)^2}{x'}$$

- Gap survival probability

  $$S^2 = 5\% - 15\%$$

Uncertainties



- Impact factor

Fit-1, 2, 3, 4

- Sudakov form factor

$$\mu^2 = \frac{\mathbf{k}_2^2}{x}$$

$$\ell^2 = \frac{(\mathbf{k}+\mathbf{k}_i)^2}{x'}$$

- Gap survival probability

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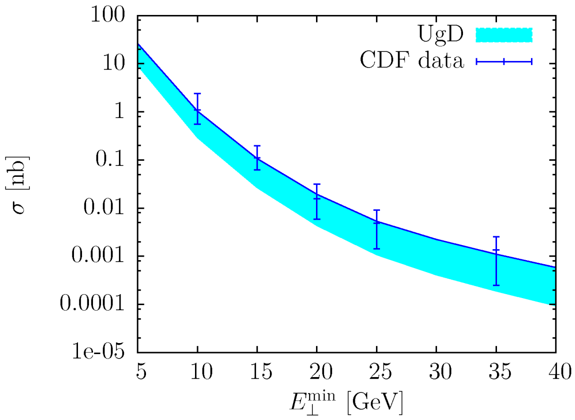

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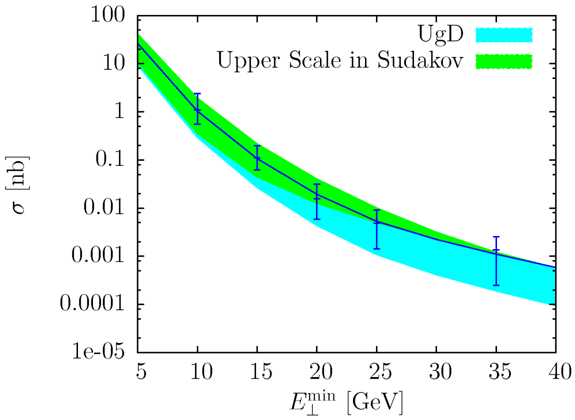

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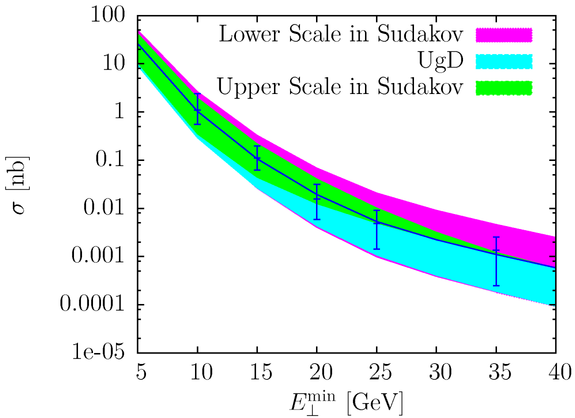

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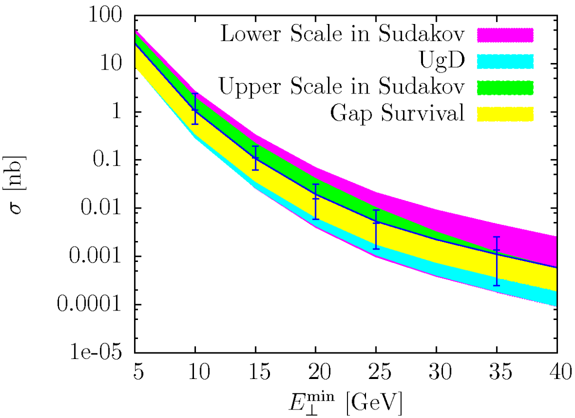

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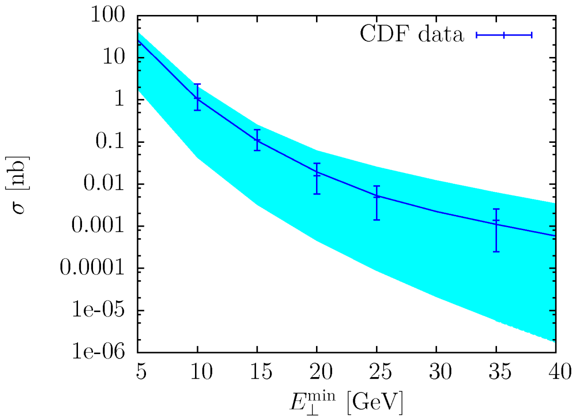

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