Central Exclusive Dijet Production

HLPW08

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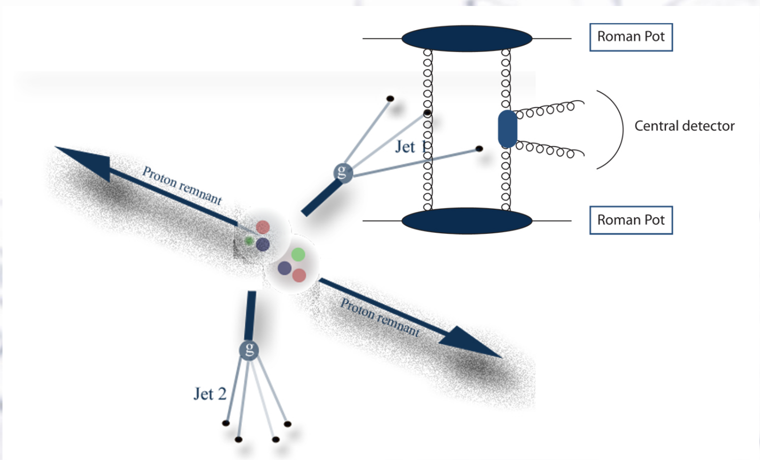
07/03/08

1. Central Exclusive Production
   - Definition and Data
2. Central Exclusive Dijet Calculation
   - Ingredients
   - Uncertainties
3. Conclusions and Outlook

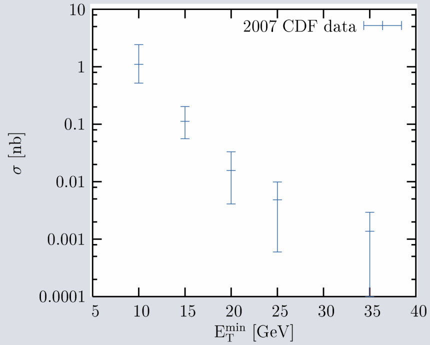
⇒ End of 2007, data on Exclusive Dijet events at the Tevatron $p\bar{p}$ collider



⇒ Characteristics: Rapidity gap between the two jets and the remaining protons + one the forward proton can be detected

Cross section of central exclusive high-E_T dijets, E_T= 10-35 GeV:

[T. Aaltonen *et al.* [CDF Run II Collaboration], arXiv:0712.0604 [hep-ex]]



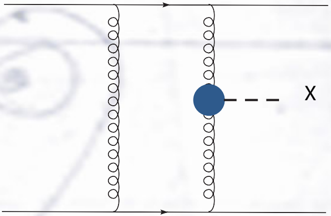
- Small cross section:
  $\sim 2\times10^5$ exclusive events

Central Exclusive Production of dijet or anything

$$pp \to p + gap + X + gap + p$$

Standard scheme of a Central Exclusive Production calculation:

- Lowest order QCD calculation at the parton level: the produced system is in a colour singlet state
- Embedding the partons in the proton via a Proton Impact Factor
- Add the virtual corrections via a Sudakov Form Factor
- Take into account of the proton rescattering corrections



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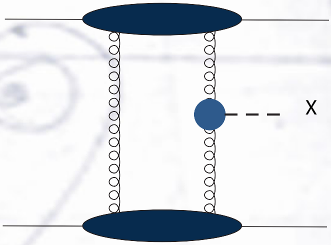

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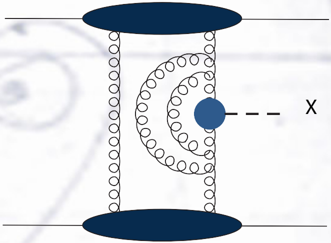

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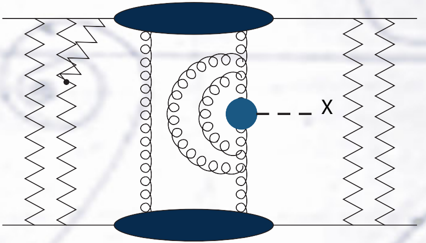
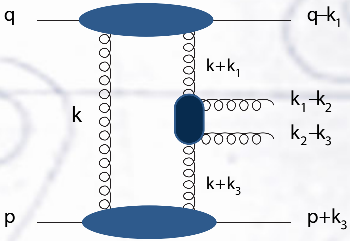


Under Theoretical Control

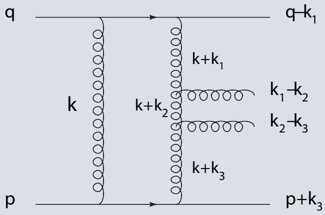
- Lowest order QCD calculation

Not Under Theoretical Control

- Proton Impact Factor
- Sudakov Form Factor
- Proton rescattering



1: Lowest Order QCD calculation

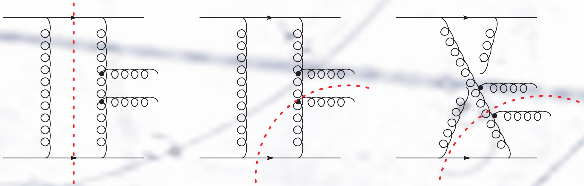


$$k_i = \alpha_i p^\mu + \beta_i q^\mu + \mathbf{k}_i$$

$$\frac{\mathbf{k}_i^2}{s} \ll \alpha_i, \beta_i \ll 1$$

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

$\Rightarrow$ Lots of diagrams but work simplifies when imaginary part is analyzed: Cancellations among different diagrams and cuts



Differential cross section for the dijet Central Exclusive Production:

$$\mathrm{d}\sigma \propto \frac{g^{12}}{(\mathbf{k}_2^2)^2}\left| \int \frac{\mathrm{d}^2\mathbf{k}}{\mathbf{k}^2(\mathbf{k}+\mathbf{k}_1)^2(\mathbf{k}+\mathbf{k}_3)^2} \times \mathcal{M}(\quad\quad) \right|^2$$

Where C_0 and C_2 are products of $\mathbf{k}$, $\mathbf{k}_1$ and $\mathbf{k}_3$

$$|M_0|^2 = 1, \quad |M_2|^2 = \frac{u_{gg}^4 + t_{gg}^4}{s_{gg}^4}$$

End of the Analytic QCD Calculation

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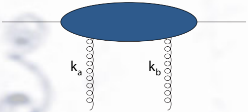
End of the Analytic QCD Calculation

2: Proton Impact Factor

$$\int \mathrm{d}\mathbf{k}^2 \cdots \rightarrow \int \mathrm{d}\mathbf{k}^2 \ldots \phi(\mathbf{k}, \mathbf{k}+\mathbf{k}_1)\phi(\mathbf{k}, \mathbf{k}+\mathbf{k}_3)$$



Soft quantity $\rightarrow$ models and fit must be used

- Light Cone Wave Function: $\phi_{LCWF}(\mathbf{k}_a, \mathbf{k}_b) = \mathcal{E}_1(\mathbf{k}_a + \mathbf{k}_b) - \mathcal{E}_2(\mathbf{k}_a, \mathbf{k}_b)$
- Evolving partons in a Unintegrated Gluon Density: $C_F N_c \frac{g^2}{4\pi^2} \phi_{UgD}(\mathbf{k}_a, \mathbf{k}_b) \rightarrow \mathcal{F}(x, \mathbf{k}_a, \mathbf{k}_b)$

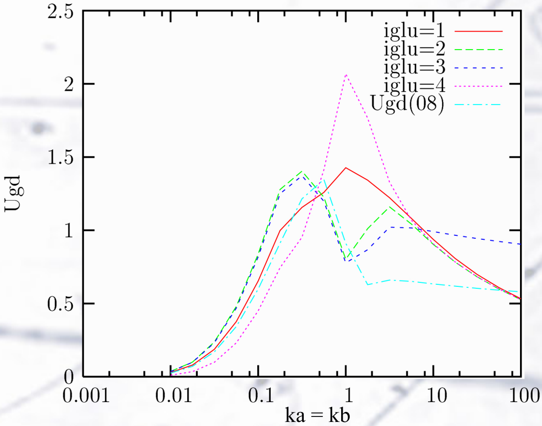
$\mathcal{F}(x, \mathbf{k}_a, \mathbf{k}_b)$: Fit to the proton structure function F_2 at HERA

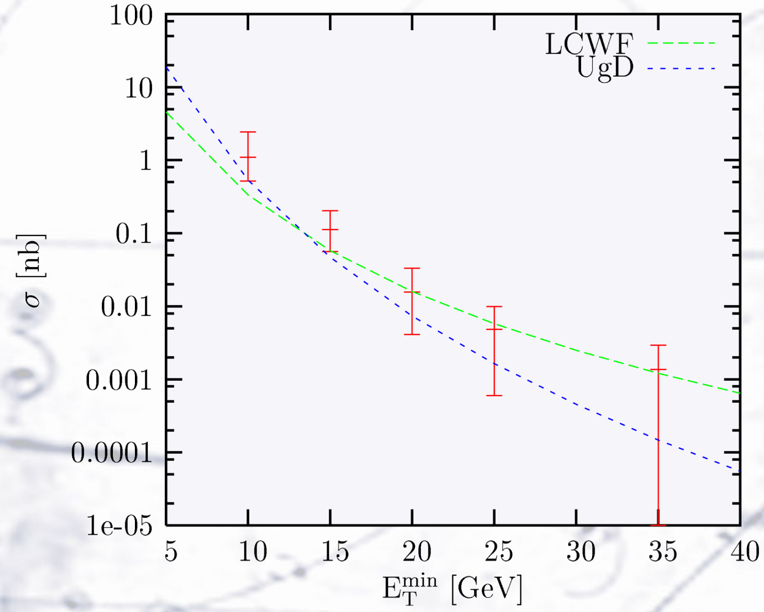
[I. P. Ivanov, N. N. Nikolaev and A. A. Savin, Phys. Part. Nucl. **37** (2006) 1 [arXiv:hep-ph/0501034]]

$0 < Q^2 < 35\ \text{GeV}^2$
$x \ll 10^{-2}$

UgD=**UgD**(Soft)+**UgD**(Hard)

smooth interpolation




LCWF
UgD
100
10
1
0.1
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0.0001
1e-05
σ [nb]
5
10
15
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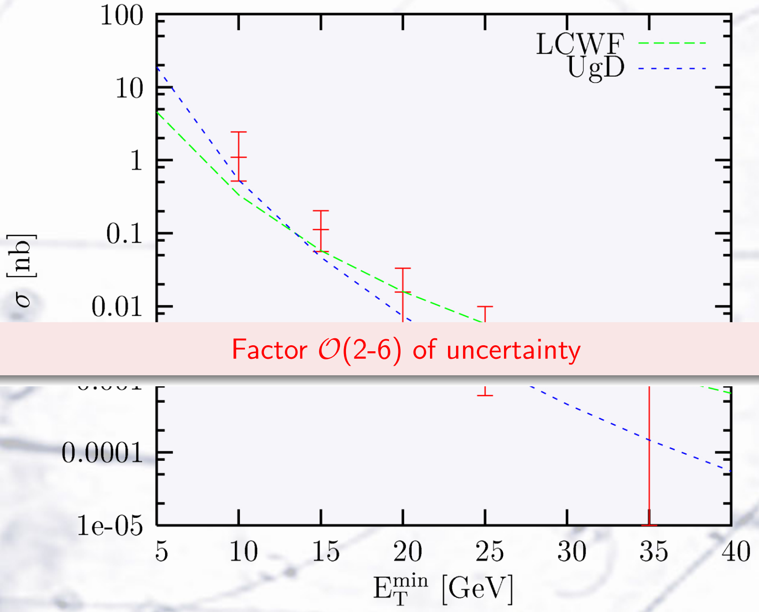
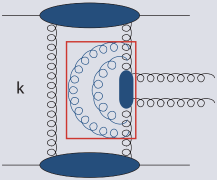
35
40
E_T^{min} [GeV]



Factor $\mathcal{O}(2\text{-}6)$ of uncertainty

3: Sudakov Form Factor



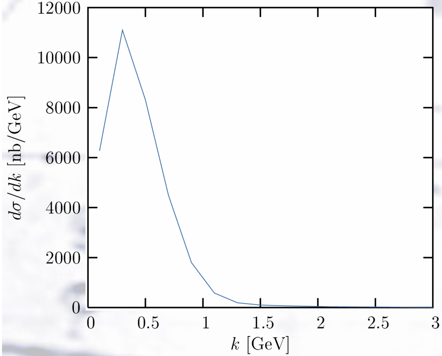
Virtual corrections

$\Rightarrow$ Large double logarithms

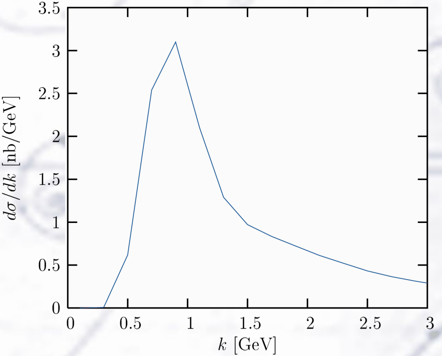
$\sim log^2(M_{gg}^2)$

[In QED, V. V. Sudakov, Sov. Phys. JETP **3** (1956) 65]

- Without Sudakov form factor



- With Sudakov form factor



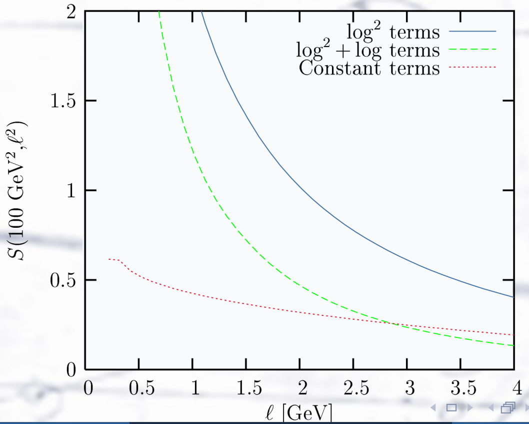
Main effect of the Sudakov form factor:

- Changes the mean value of loop momentum **k**
- Strongly supresses the cross section: factor $\mathcal{O}(100\text{-}1000)$

Sudakov form factor: $e^{S(\mu,\ell)}$

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

BUT:



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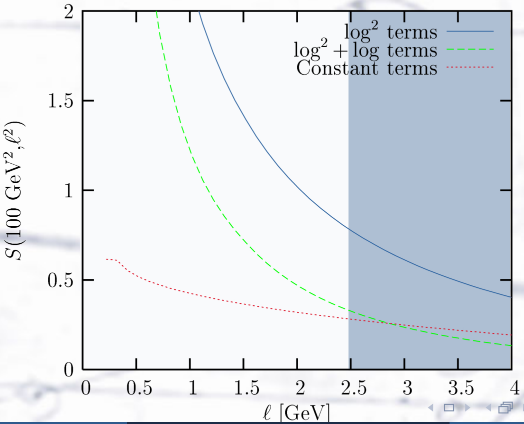
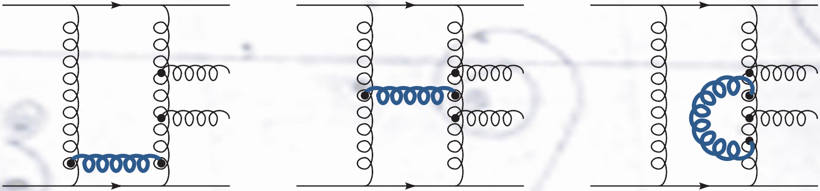
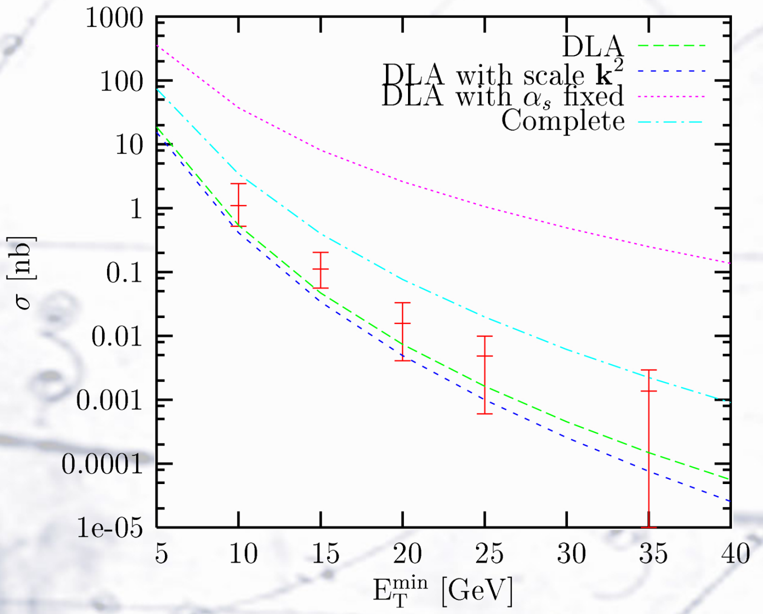


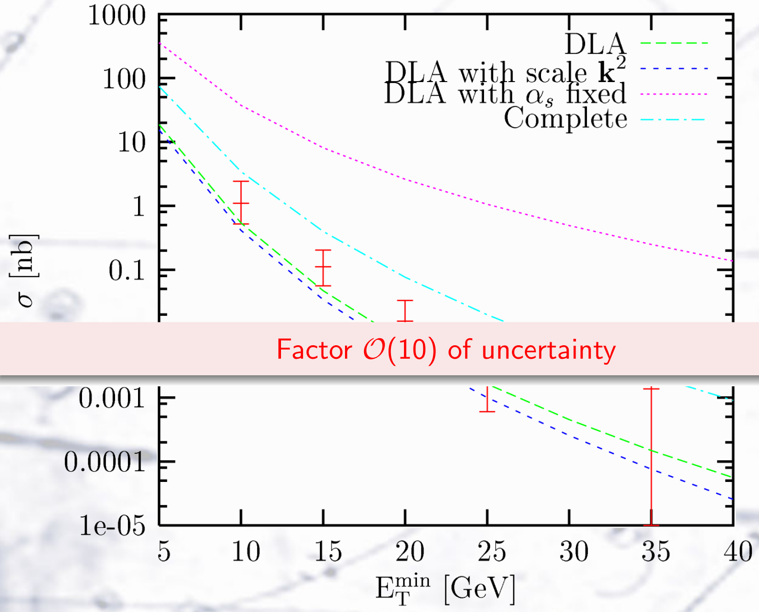
Comments:

Other diagrams, not included here, contain large single logarithms



- Large corrections?
- Exponentiation?


1000
100
10
1
0.1
0.01
0.001
0.0001
1e-05
σ [nb]
5
10
15
20
25
30
35
40
E_T^{min} [GeV]
DLA
DLA with scale $\mathbf{k}^2$
DLA with α_s fixed
Complete

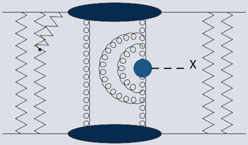


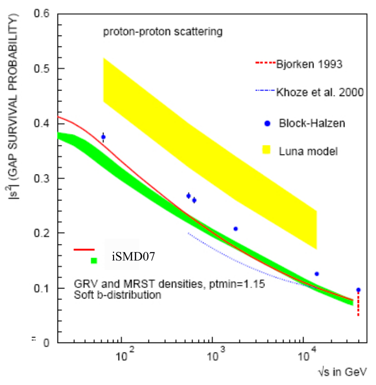
Factor $\mathcal{O}(10)$ of uncertainty

4: Gap survival S^2

Protons rescattering might destroy the gap

[L. Frankfurt, C. E. Hyde-Wright, M. Strikman and C. Weiss, Phys. Rev. D **75** (2007) 054009]





- Different calculations predict anything from 15% to 35% of the cross section

[R. M. Godbole, A. Grau, G. Pancheri and Y. N. Srivastava, arXiv:0801.4887 [hep-ph]]

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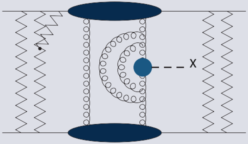
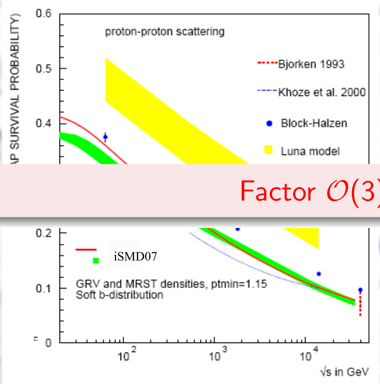




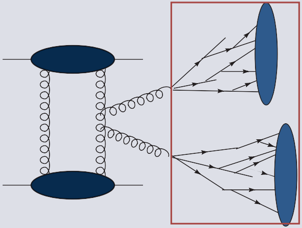
- Different calculations predict anything from

Factor $\mathcal{O}(3)$ of uncertainty

section

[R. M. Godbole, A. Grau, G. Pancheri and Y. N. Srivastava, arXiv:0801.4887 [hep-ph]]

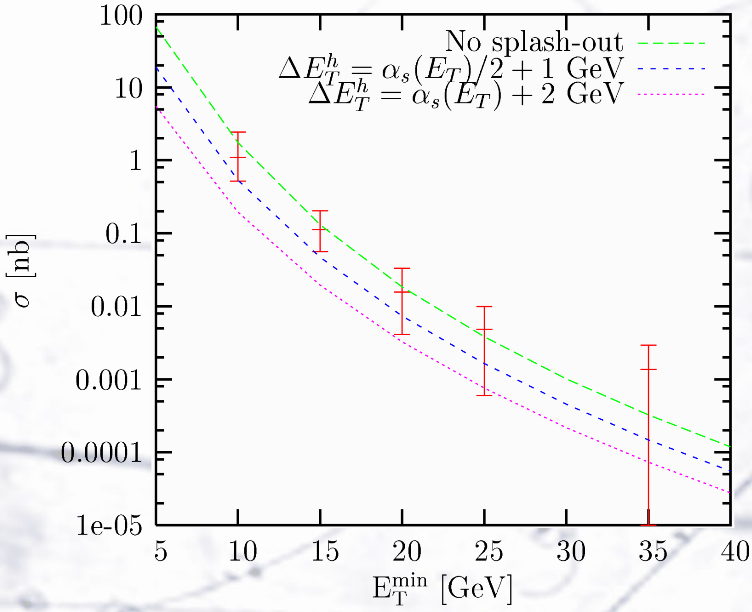
4: Experimental corrections → Splash-out

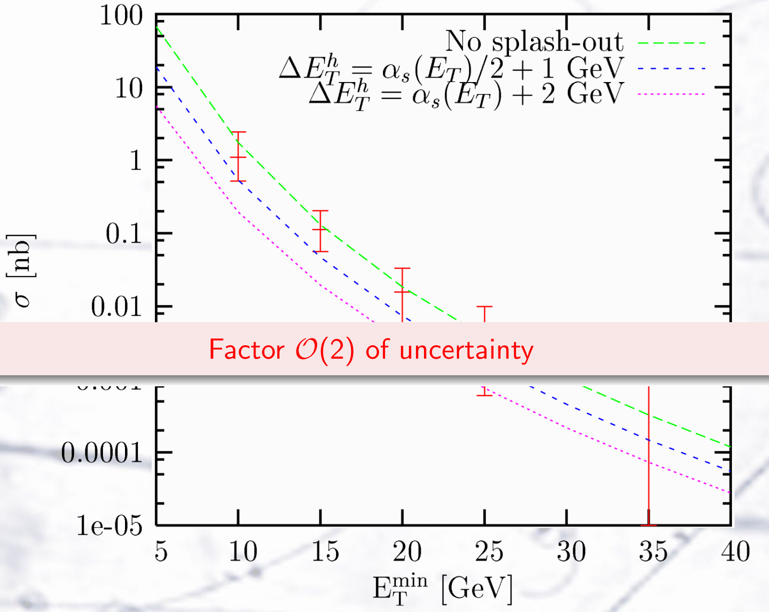


E_T: Measures have been done at the hadron level

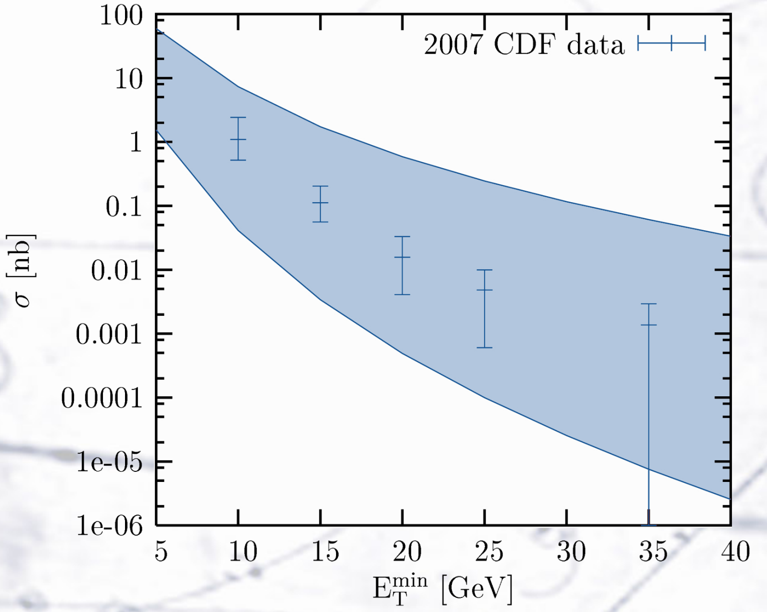
→ Correction to the parton level

[V. A. Khoze, A. B. Kaidalov, A. D. Martin, M. G. Ryskin and W. J. Stirling, arXiv:hep-ph/0507040]


No splash-out
$\Delta E_T^h = \alpha_s(E_T)/2 + 1$ GeV
$\Delta E_T^h = \alpha_s(E_T) + 2$ GeV
100
10
1
0.1
0.01
0.001
0.0001
1e-05
σ [nb]
5
10
15
20
25
30
35
40
E_T^{min} [GeV]



Factor $\mathcal{O}(2)$ of uncertainty


2007 CDF data
100
10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
σ [nb]
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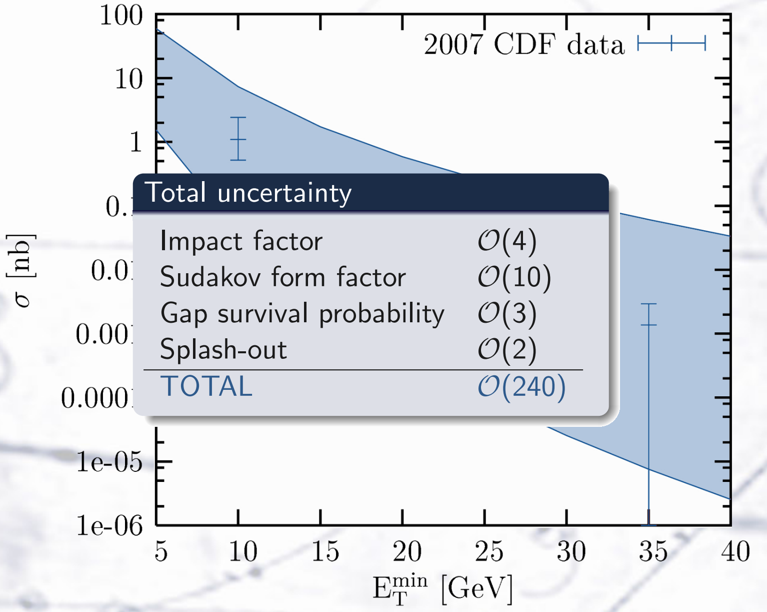
E_T^{min} [GeV]



Total uncertainty

Impact factor	$\mathcal{O}(4)$
Sudakov form factor	$\mathcal{O}(10)$
Gap survival probability	$\mathcal{O}(3)$
Splash-out	$\mathcal{O}(2)$
TOTAL	$\mathcal{O}(240)$

Pre-Conclusions

- Numerical results are strongly sensitive to the corrections
- The current uncertainties of the calculation seem to be underestimated $\longrightarrow$ we are talking about a factor 240 of uncertainty

Outlook: Higgs CEP cross section

- Higgs CEP is affected by the same uncertainties
- Dijet cross section can be used to fine tune the pieces and leads to prediction of the Higg CEP cross section
- Preliminary results are $\sigma \sim$ 1-5 fb at LHC

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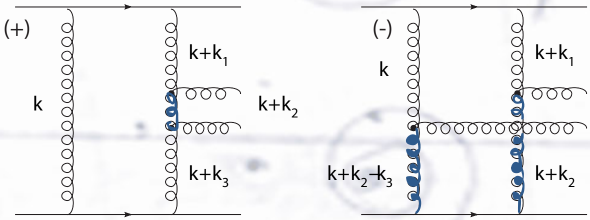
Open question:



Sudakov $\sim \mathcal{O}(100\text{-}1000)$

Sudakov $\sim$?

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

$\longrightarrow$ diagram of the order of $\mathcal{O}(\frac{1}{\mathbf{k}_2^2})$

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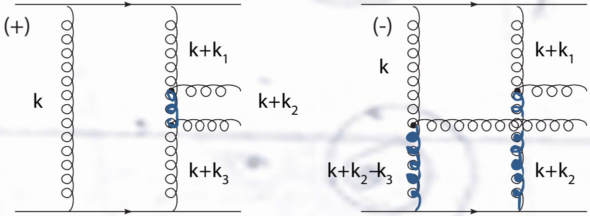

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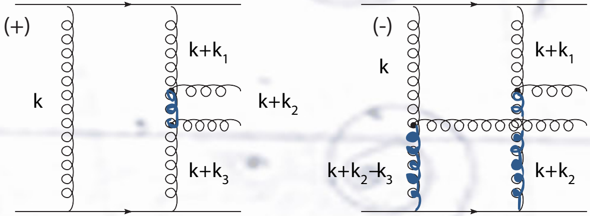


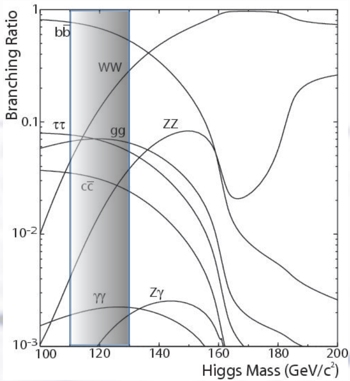
Sudakov $\sim \mathcal{O}(100\text{-}1000)$

Sudakov $\sim$?

The Sudakov form factor should be smaller
$\longrightarrow$ The second diagram is not longer negligible

Back up slides

Implication for Higgs bosons searches:
Large Hadron Collider → Higgs discovery channel via Higgs CEP



- Search strategy depends of the Higgs decay preferences
- In the dominant decay channel, light Higgs ($\leq$ 130 GeV) will be hidden in the QCD background

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

Imaginary part of the amplitude:

$$\mathrm{Im} M = \frac{g^4}{4\pi^2}\frac{\delta^{ab}}{4N^2}\int \frac{\mathrm{d}^2\mathbf{k}}{\mathbf{k}^2(\mathbf{k}+\mathbf{k}_1)^2(\mathbf{k}+\mathbf{k}_3)^2}\sum_{\lambda_i} j^{(1)*}_{\lambda_1} j^{(2)*}_{\lambda 2}\, \mathcal{M}_{gg}(\lambda_1\lambda_2 \to \lambda_3\lambda_4)$$

$g^*g^* \to gg$

- j_λ are quark's current
- $\mathcal{M}_{gg}(\lambda_1\lambda_2 \to \lambda_3\lambda_4)$ is the $gg \to gg$ amplitude

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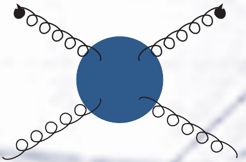
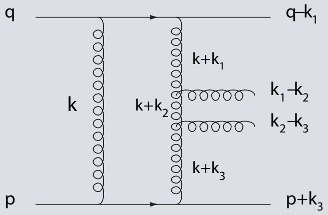


1: Lowest Order QCD calculation



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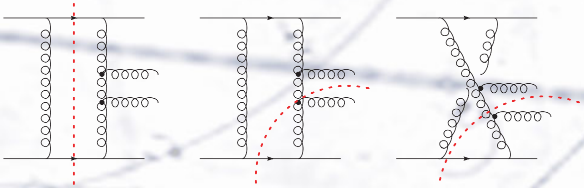

$$T = e^{-S(\mu^2,\ell^2)}$$

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

- μ^2: Energy scale of the sub-process $\mathcal{O}(M_{gg}^2)$
- ℓ^2: Virtuality from which the evolution starts
- α_s: Can be fixed at some arbitrary scale or evolved
- P_{gg}, P_{qg}: Splitting function
- Δ: Cut-off that depends on the prescription $\longrightarrow$ leads to factor $\mathcal{O}(2)$ to factor $\mathcal{O}(10)$

[Y. L. Dokshitzer, D. Diakonov and S. I. Troian, Phys. Rept. **58** (1980) 269.]
[V. A. Khoze, A. D. Martin and M. G. Ryskin, Eur. Phys. J. C **48** (2006) 467]