Energy Scale Dependence and Scale Uncertainties due to Missing Higher Orders in Next-to-Leading Order Jet Calculations

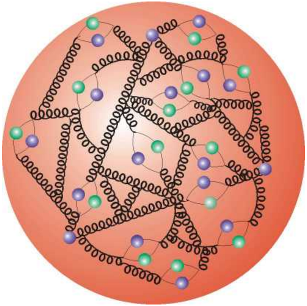
Henrike Fleischhack

DESY Summer Student Programme 2009
Supervisor: G. Grindhammer

September 10th, 2009

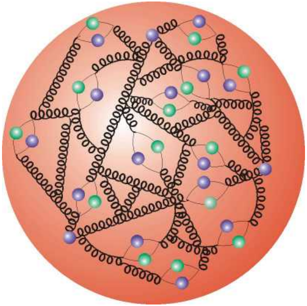
Experimental Principles

- HERA: Proton-electron collider



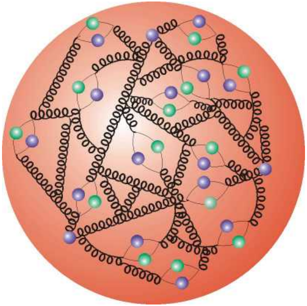
Experimental Principles

- HERA: Proton-electron collider
- Important goals: measurements of proton structure, strong coupling α_s, ...



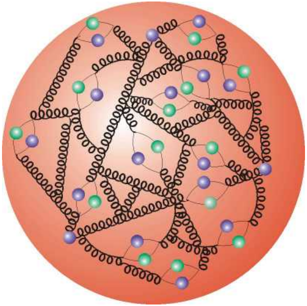
Experimental Principles

- HERA: Proton-electron collider
- Important goals: measurements of proton structure, strong coupling α_s, ...
- Method: compare measurements to theory predictions.



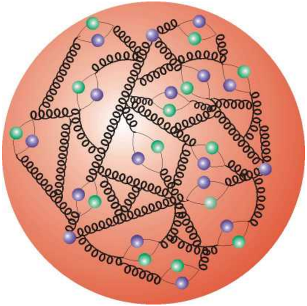
Experimental Principles

- HERA: Proton-electron collider
- Important goals: measurements of proton structure, strong coupling α_s, ...
- Method: compare measurements to theory predictions.
- Derive the most likely value of e.g. $\alpha_s(M_Z)$.

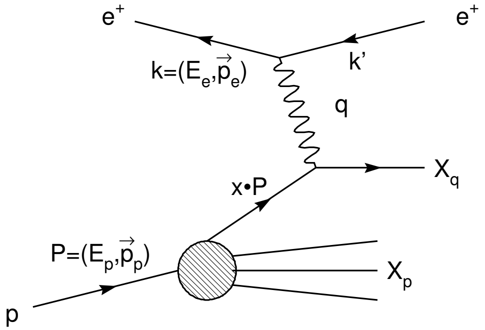


Experimental Principles

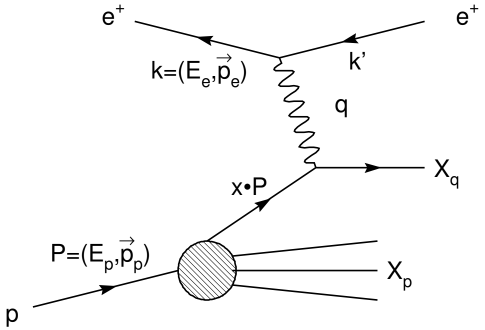
- HERA: Proton-electron collider
- Important goals: measurements of proton structure, strong coupling α_s, ...
- Method: compare measurements to theory predictions.
- Derive the most likely value of e.g. $\alpha_s(M_Z)$.
- Need to understand theory predictions and their uncertainties!



Deep Inelastic Scattering

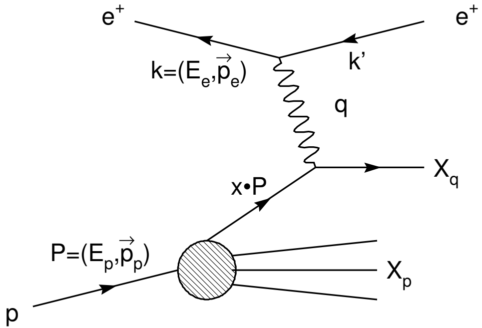


Deep Inelastic Scattering



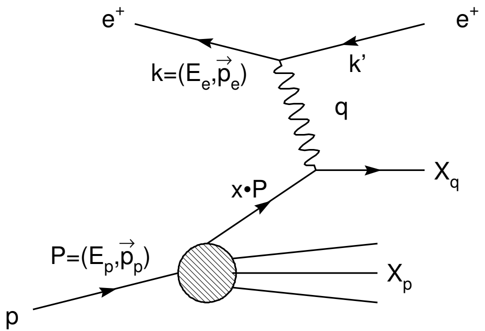
- $Q^2 = -q^2$: momentum transfer squared/virtuality of photon

Deep Inelastic Scattering



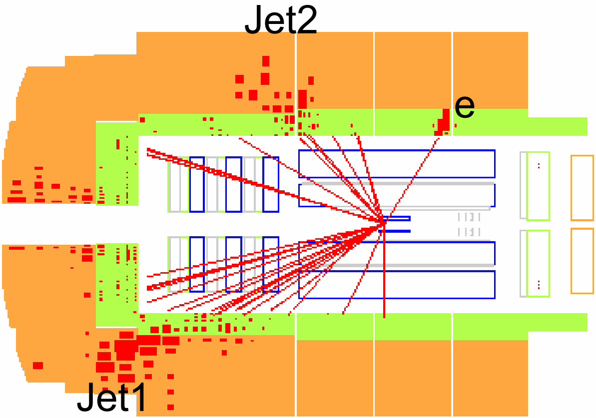
- $Q^2 = -q^2$: momentum transfer squared/virtuality of photon
- x: parton momentum fraction

Deep Inelastic Scattering



- $Q^2 = -q^2$: momentum transfer squared/virtuality of photon
- x: parton momentum fraction
- We observe jets, not partons

Dijet Event Observed by H1



Pseudorapidity

$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

Cross Section Calculations

General Ideas

total cross section

$$\sigma = \sum_{m=1}^{\infty} \int_0^1 dx\, pdf(x,\mu_f) \cdot \int d\Gamma^m(x) \alpha_s(\mu_r)^m \cdot |\mathcal{M}(x,\mu_r,\mu_f)|^2$$

General Ideas

total cross section

$$\sigma = \sum_{m=1}^{\infty} \int_0^1 dx\, pdf(x, \mu_f) \cdot \int d\Gamma^m(x) \alpha_s(\mu_r)^m \cdot |\mathcal{M}(x, \mu_r, \mu_f)|^2$$

- Perturbative QCD: Feynman Diagrams

General Ideas

total cross section

$$\sigma = \sum_{m=1}^{\infty} \int_0^1 dx\, pdf(x, \mu_f) \cdot \int d\Gamma^m(x) \alpha_s(\mu_r)^m \cdot |\mathcal{M}(x, \mu_r, \mu_f)|^2$$

- Perturbative QCD: Feynman Diagrams
- Integrate over phase space (MC), sum over number of particles, flavors, ...

General Ideas

total cross section

$$\sigma = \sum_{m=1}^{\infty} \int_0^1 dx\, pdf(x, \mu_f) \cdot \int d\Gamma^m(x) \alpha_s(\mu_r)^m \cdot |\mathcal{M}(x, \mu_r, \mu_f)|^2$$

- Perturbative QCD: Feynman Diagrams
- Integrate over phase space (MC), sum over number of particles, flavors, ...
- Non-perturbative QCD: PDFs (parton distribution functions)

General Ideas

total cross section

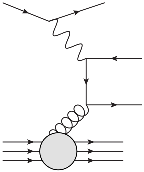
$$\sigma = \sum_{m=1}^{\infty} \int_0^1 dx\, pdf(x, \mu_f) \cdot \int d\Gamma^m(x) \alpha_s(\mu_r)^m \cdot |\mathcal{M}(x, \mu_r, \mu_f)|^2$$

- Perturbative QCD: Feynman Diagrams
- Integrate over phase space (MC), sum over number of particles, flavors, ...
- Non-perturbative QCD: PDFs (parton distribution functions)
- $\Rightarrow$Dependence on arbitrary energy scales μ_f, μ_r.

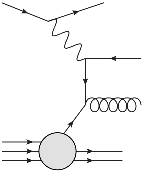
NLO Calculations of the Matrix Element I

NLO cross section

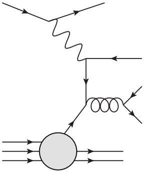
$$\sigma^{NLO} = \sigma^{Born} + \sigma^{Real} + \sigma^{Virtual}$$



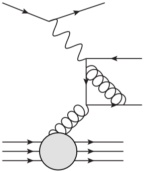
Boson-gluon fusion process



QCD Compton process



Real NLO contribution



Virtual NLO contribution

Not as easy as it looks

- A lot of diagrams have to be calculated.

Not as easy as it looks

- A lot of diagrams have to be calculated.
- Calculating each diagram separately leads to several divergences.

Not as easy as it looks

- A lot of diagrams have to be calculated.
- Calculating each diagram separately leads to several divergences.
- But: Observed cross sections are finite.

Not as easy as it looks

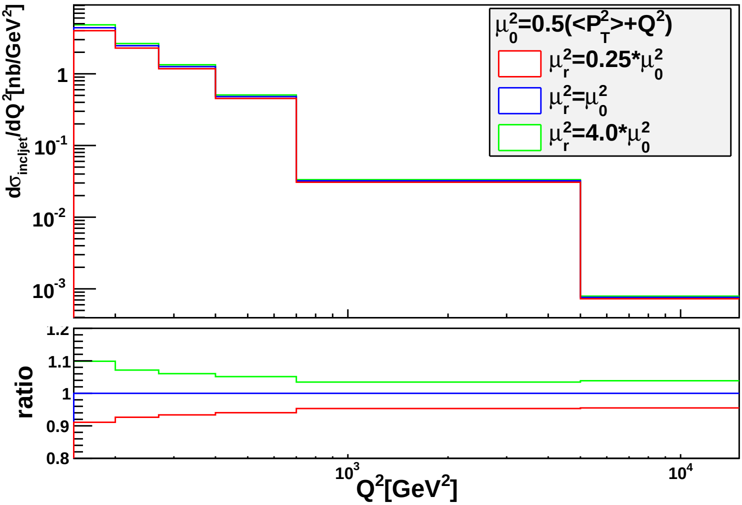
- A lot of diagrams have to be calculated.
- Calculating each diagram separately leads to several divergences.
- But: Observed cross sections are finite.
- Divergences from real and virtual contributions cancel.

Not as easy as it looks

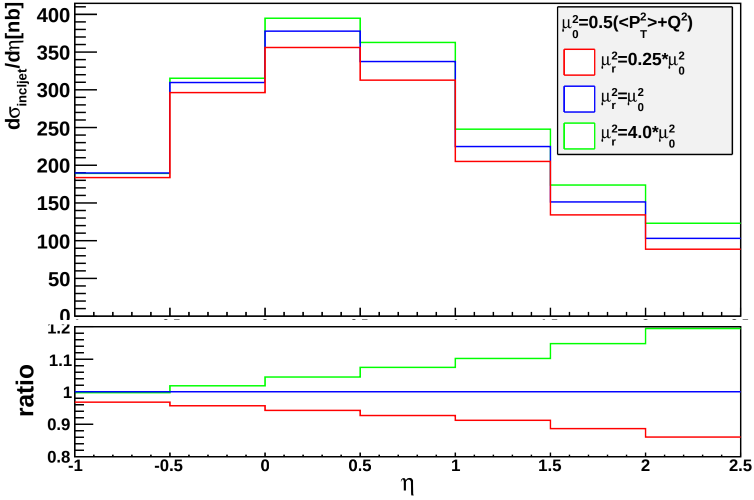
- A lot of diagrams have to be calculated.
- Calculating each diagram separately leads to several divergences.
- But: Observed cross sections are finite.
- Divergences from real and virtual contributions cancel.
- Use a computer program, e.g. `nlojet++`.

Results

Inclusive jet cross sections I



Inclusive jet cross sections II



Conclusion

Conclusion

- NLO jet calculations are challenging, but can be done.

Conclusion

- NLO jet calculations are challenging, but can be done.
- In the investigated phase space, scale dependence leads to a theory uncertainty of $\sim 10\%$ for jet cross sections.

Conclusion

- NLO jet calculations are challenging, but can be done.
- In the investigated phase space, scale dependence leads to a theory uncertainty of $\sim 10\%$ for jet cross sections.
- Choosing suitable phase space regions leads to a smaller theory uncertainty.

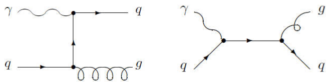
The End

Thank you for your attention!

Backups

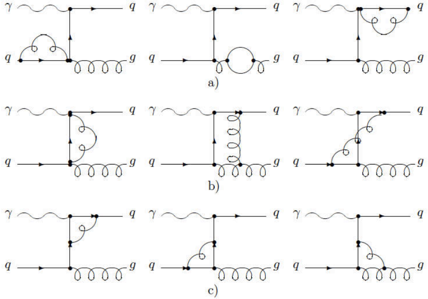
Some More Diagrams

LO



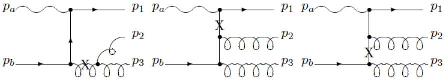
etc.

V(NLO)



etc.

R(NLO)



etc.