QCD Phenomenology of Charm Production at HERA

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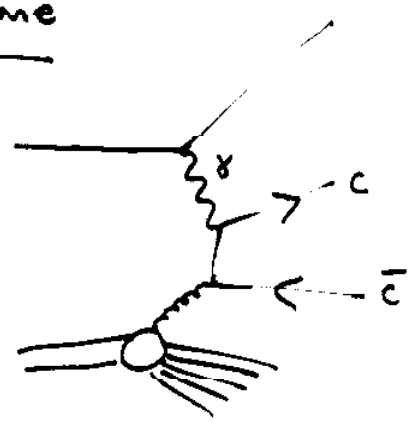
Is Charm a light or a heavy quark?

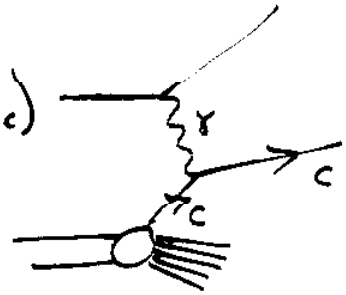
Fixed Flavor Number (FFN) Scheme



- No Charm in PDF
- Treat m_c exactly

- Used in most Heavy Flavor Production Calculations
- Uses exact Final State kinematics

Zero Mass Scheme



- Charm in PDF* (for $\mu > m_c$)
- treat $m_c = 0$

- Used in most other calculations
- Used in most PDF's
- Used in most QCD Monte Carlo's

* [illegible]

Correct Answer: It's Both!

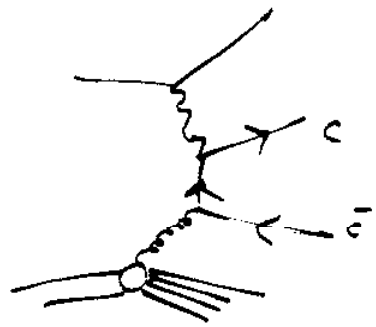
- Not an either/or question
- Best method of calculation depends on Q^2 scale / observable under consideration

Inclusive Quantities: $ep \to e'c + X$

(ex. $F_2^c(x, Q^2)$)

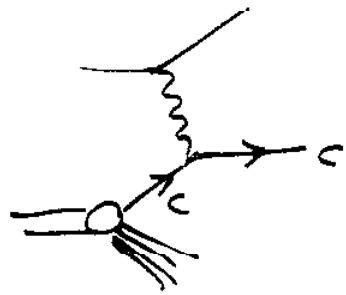
$Q^2 \sim \mathcal{O}(m_c^2)$ (near threshold)

- One-scale problem
- FFN scheme does well



$Q^2 >> m_c^2$

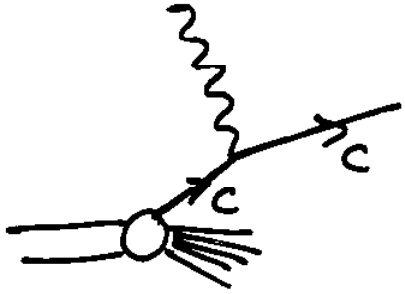
- large $\ln(Q^2/m_c^2)$, resummed by $f_{c/p}(\xi)$
- Zero-mass scheme does well



What about intermediate energies?

Witten
Collins-Wilczek-Zee
Aivazis-Collins-Olness-Tung
Martin-Roberts-Ryskin-Stirling

⇒ General $m_c \neq 0$ Scheme



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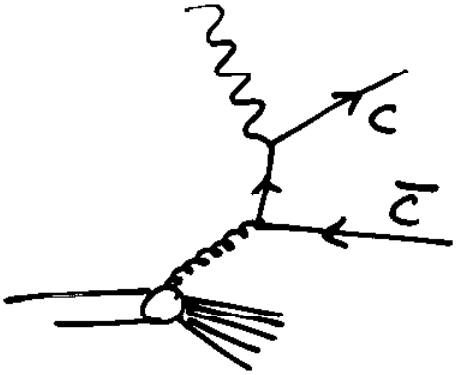
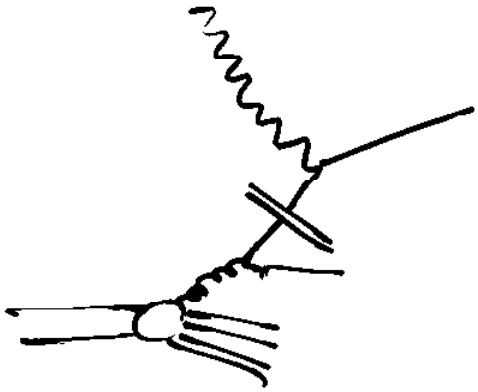


← $m_c \neq 0$ in the Partonic cross section

−

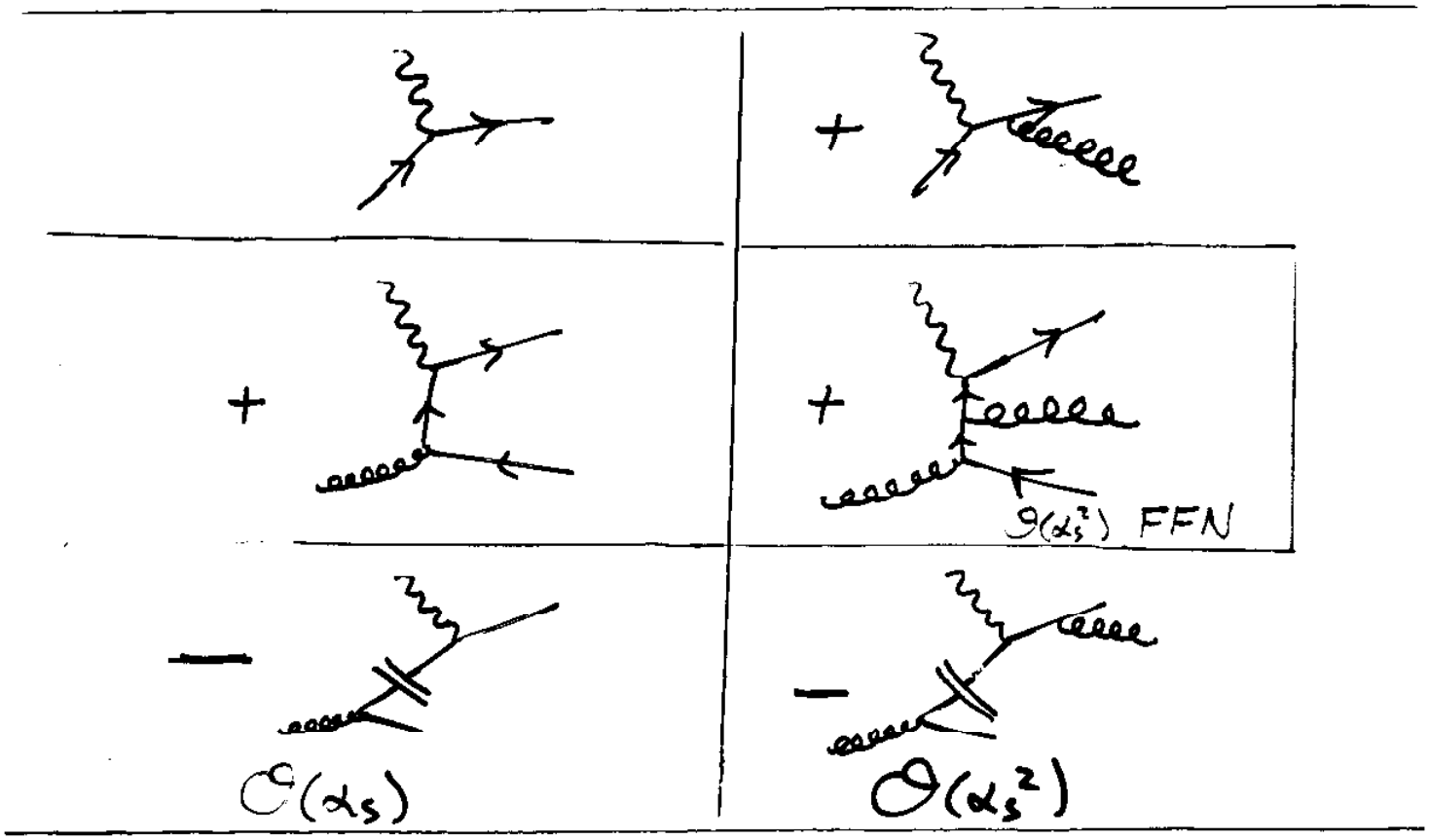


⇐ Equivalent to $\frac{1}{\epsilon}$-pole AP subtraction for $m_c = 0$ Zero-mass Scheme.

NLO Calculation in General $m_c \neq 0$ Scheme

One Additional Assumption:

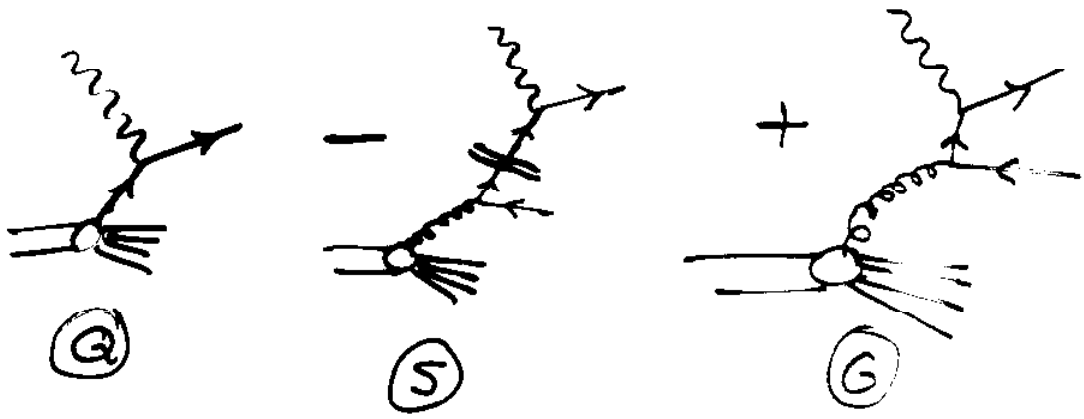
- Treat $f_{c/p}(\xi)$ as $\mathcal{O}(\alpha_s)$
  - Good Approx. for "dynamically-generated" charm
  - Better μ-scale dependence



Near Threshold, recover NLO $\mathcal{O}(\alpha_s^2)$ FFN scheme

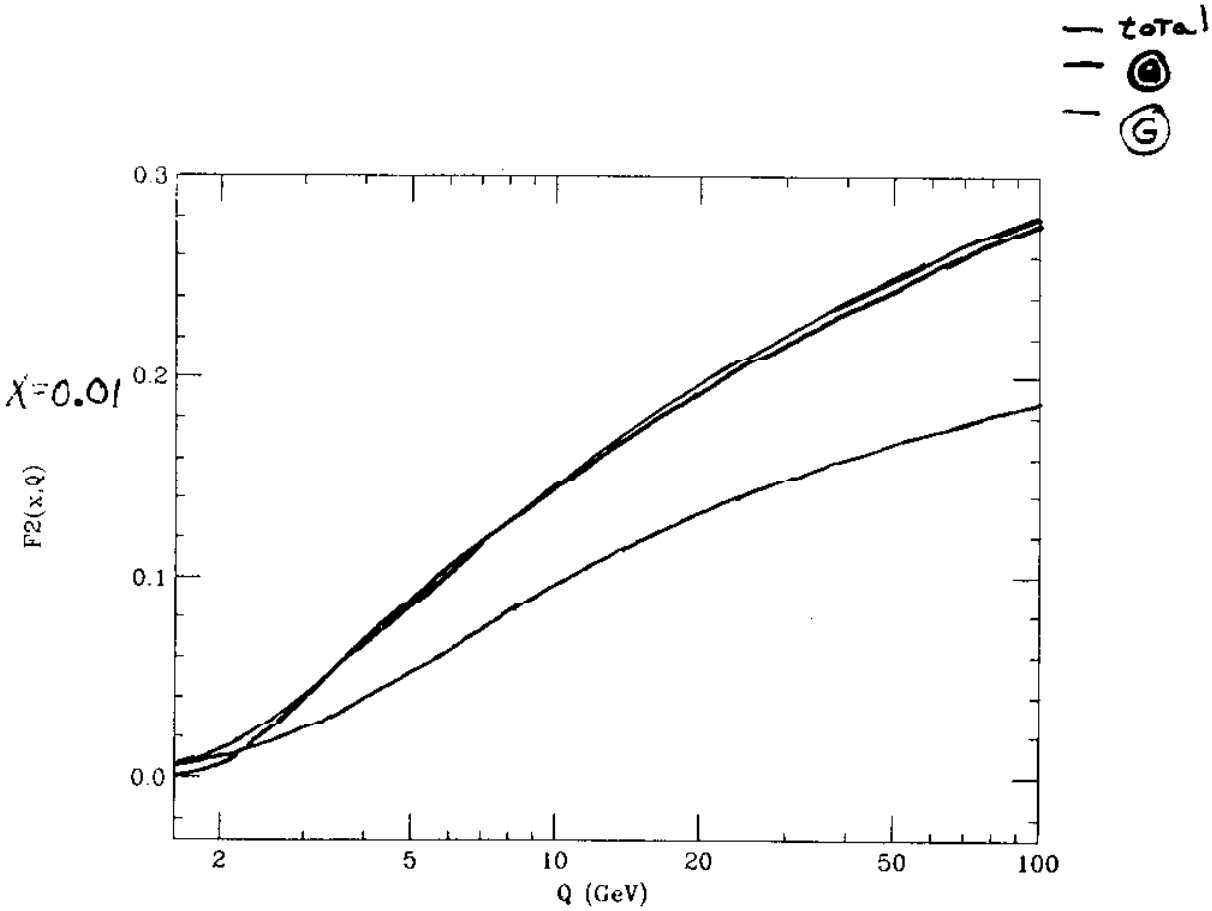
At high Q^2, recover NLO $\mathcal{O}(\alpha_s)$ zero-mass scheme.

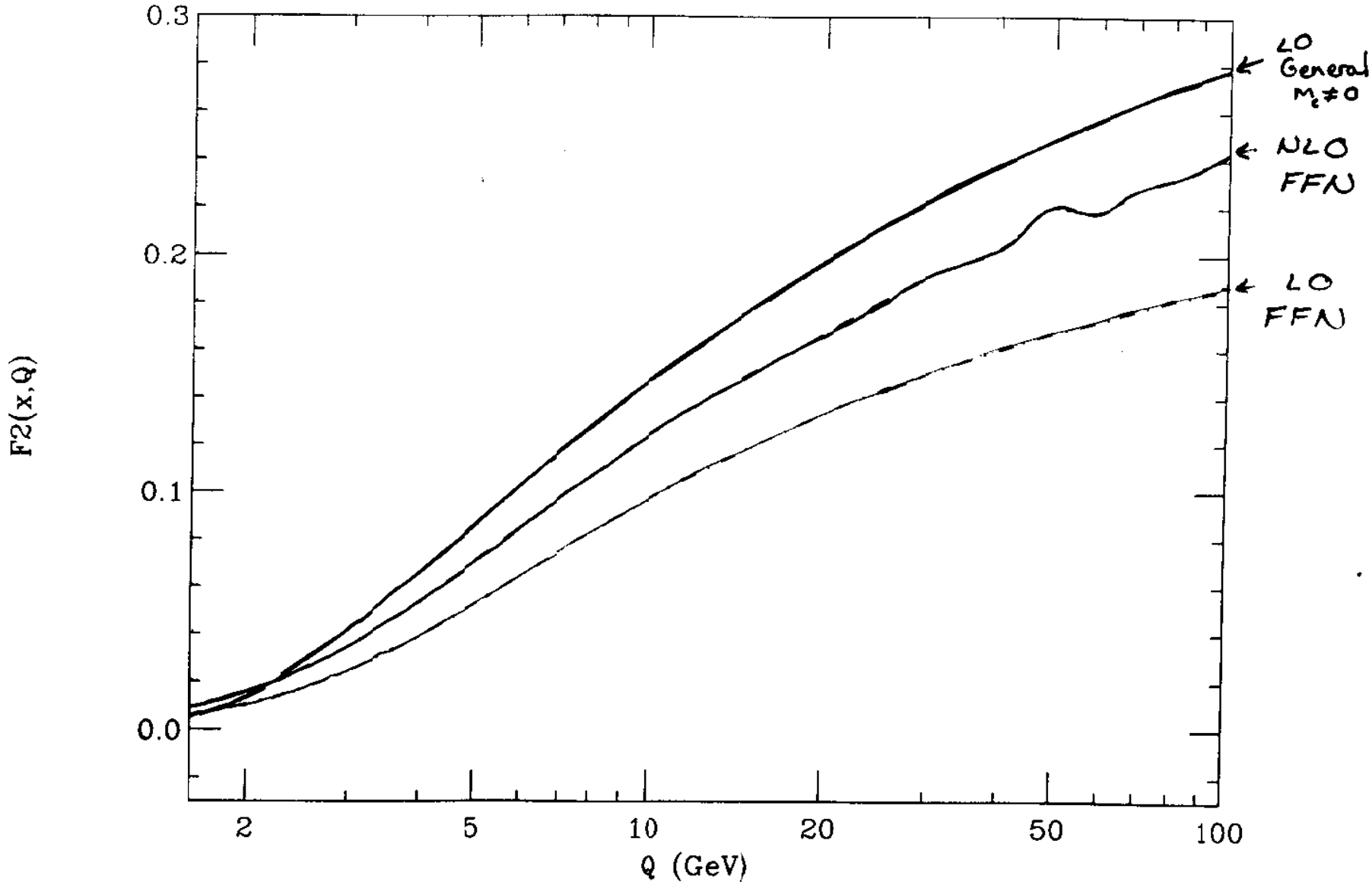
(Calculation in progress)



Near threshold Q + S cancel ⟹ Agrees with FFA

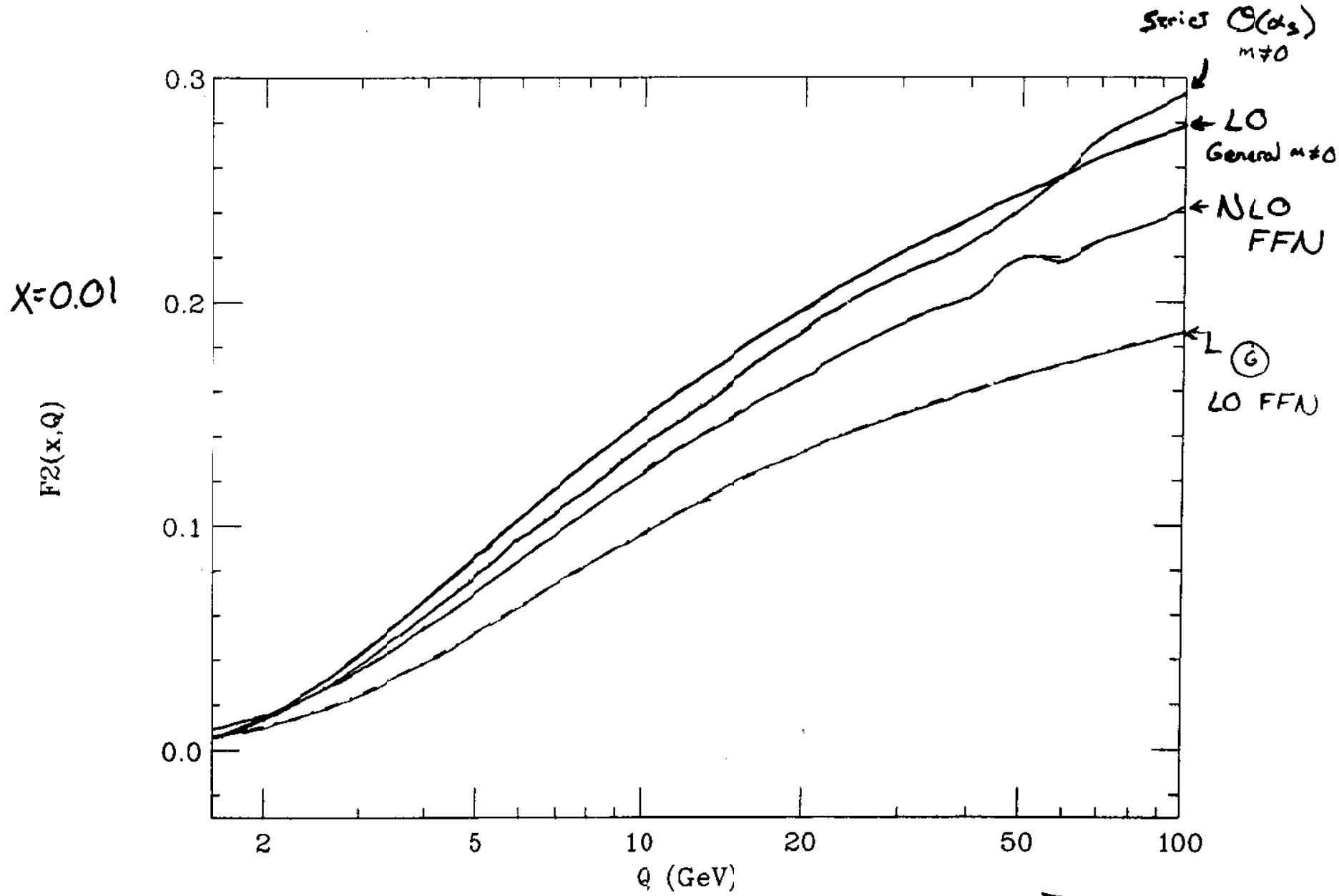
At Large Q^2 G + S cancel ⟹ Agrees with zero-mas



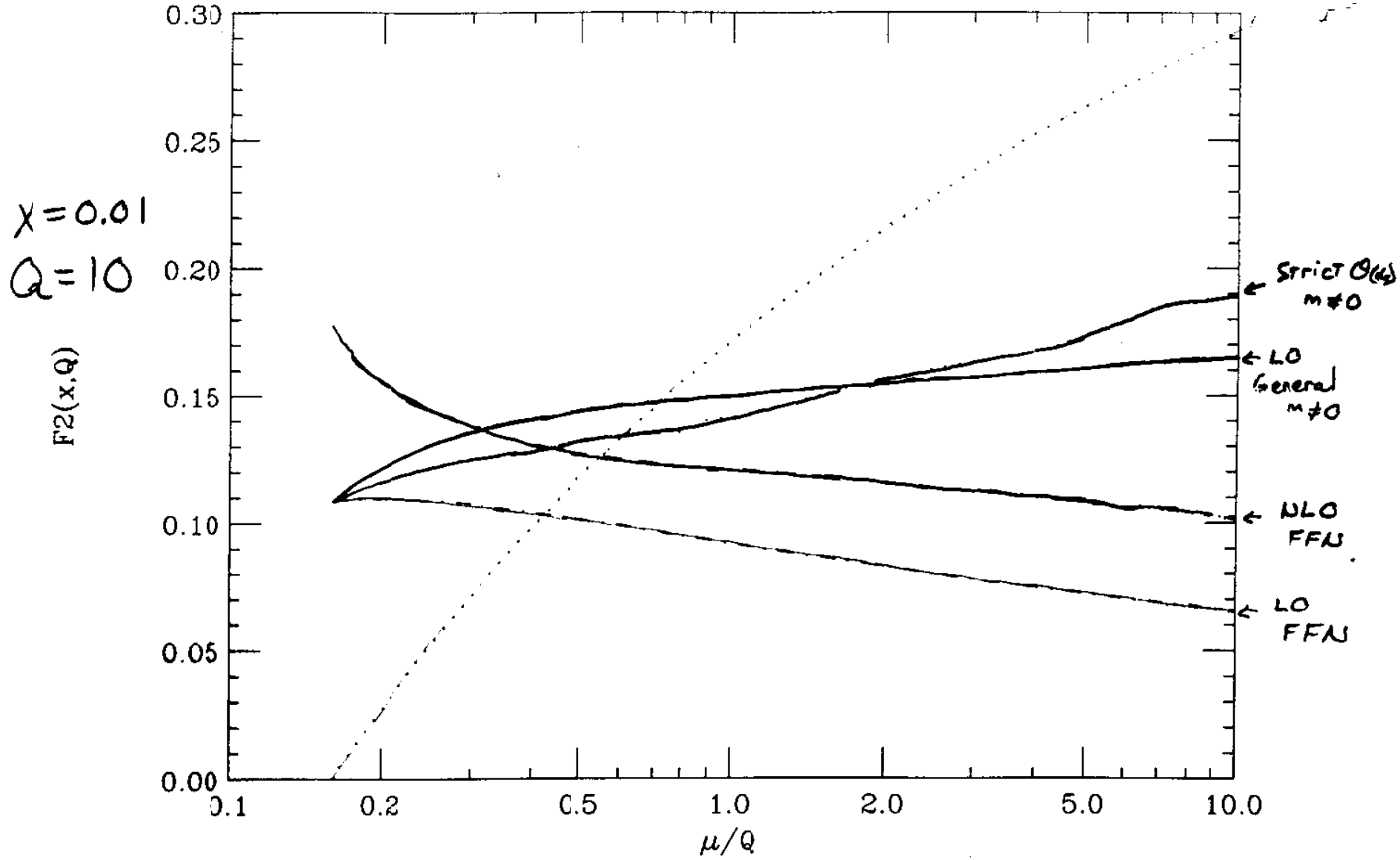


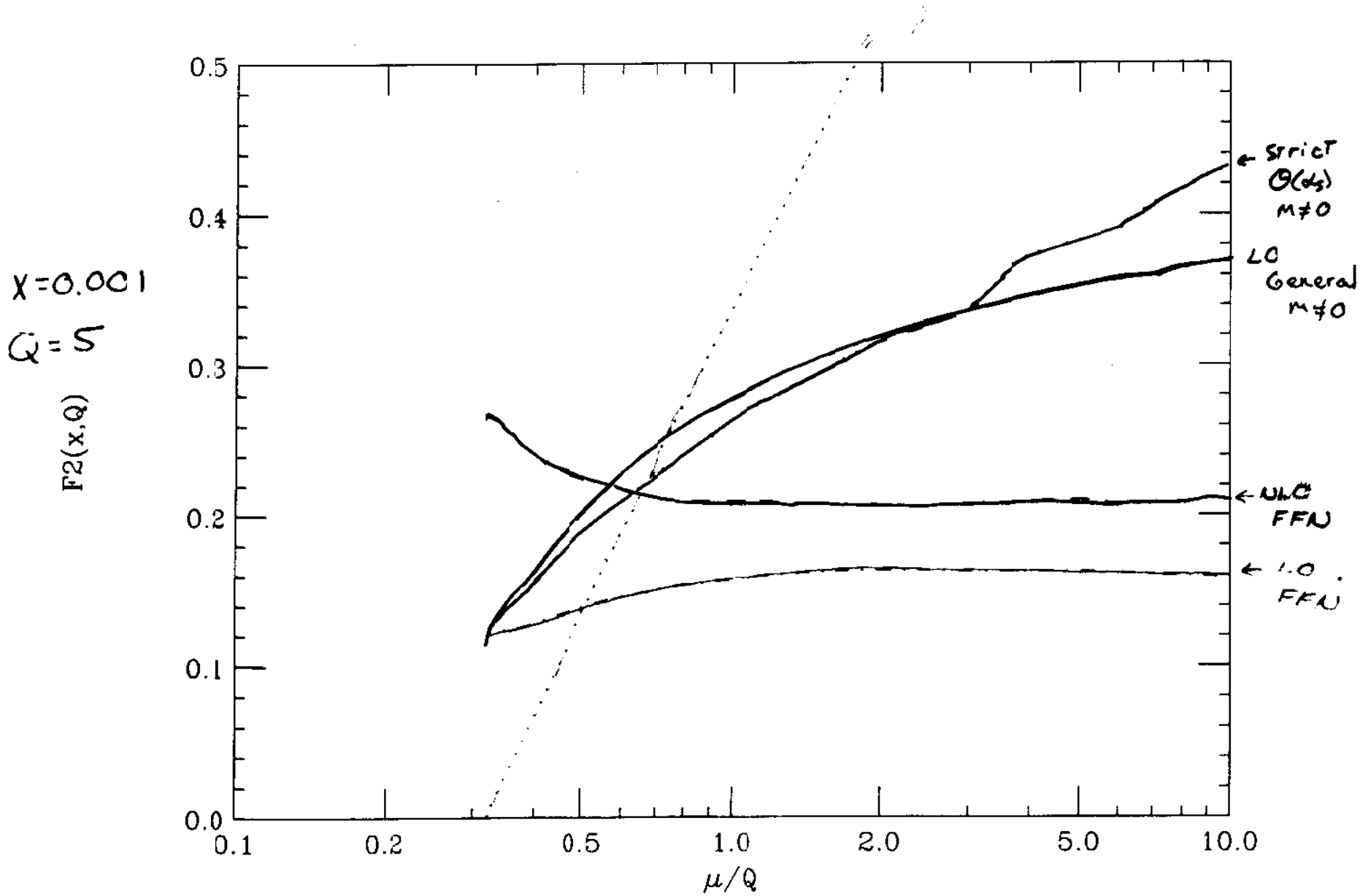
NLO FFN: Laenen, Smith, van Neerven, ... et al

Code Thanks To Brian Harris



Thanks To Brian Harris
for NLO FFN calculations


x = 0.01
Q = 10
F2(x,Q)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.1
0.2
0.5
1.0
2.0
5.0
10.0
μ/Q
Strict O(α_s) m≠0
LO General m≠0
NLO FFN
LO FFN


x=0.001
Q=5
F2(x,Q)
0.0
0.1
0.2
0.3
0.4
0.5
0.1
0.2
0.5
1.0
2.0
5.0
10.0
μ/Q
strict O(αs) m≠0
LO General m≠0
NLO FFN
LO FFN

Exclusive Processes ($p_\perp$, φ distributions)

- Initial state quark contributions are generalized functions $\sim \delta(p_\perp)$
  They only make sense when integrated.

- $c\bar{c}$ creation terms treat kinematics more correctly.

  $\Rightarrow$ FFN scheme preferable, at least near threshold.

- At higher scales require soft-gluon resummatio

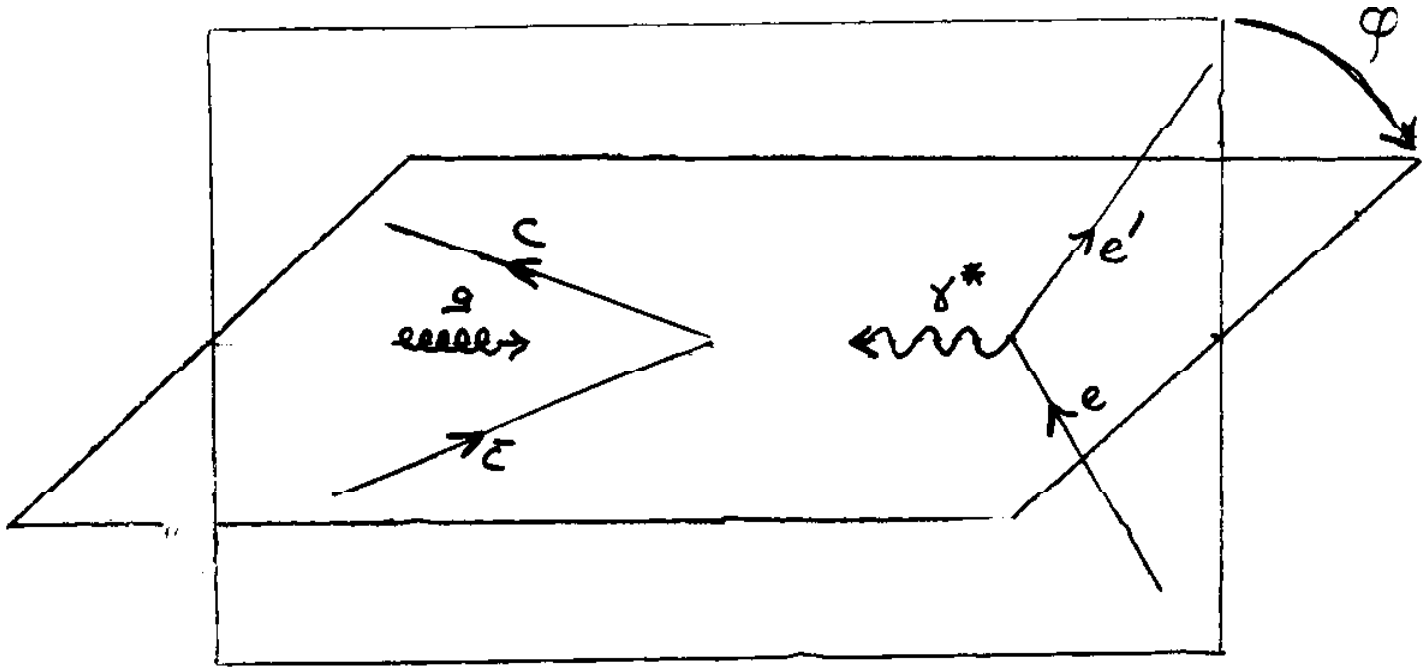
Example: φ-distribution

(LO FFN $\Rightarrow$ Boson-gluon fusion calculation)

Definition:

- Boost to Stationary-proton frame
- Rotate so γ^* is along the z-axis

φ is azimuthal angle between lepton plane and hadron ($c\bar{c}$) plane



$$\frac{d\sigma}{d\varphi} \sim A + B\cos\varphi + C\cos 2\varphi$$