Heavy Quark Production at RunII

or

A Simplified ACOT (S-ACOT) scheme
to facilitate higher order calculations

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SMU

Schemes for Heavy Quark Production:

- Warm-up with some DIS examples
- Outline Simplified-ACOT

Application to Tevatron:

- Present calculations
- Merging existing work in a unified framework

February 24-26, 2000
B-Physics at Run II Workshop

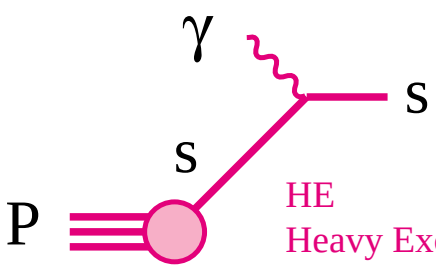
Production of Heavy Quarks: *The Problem!*

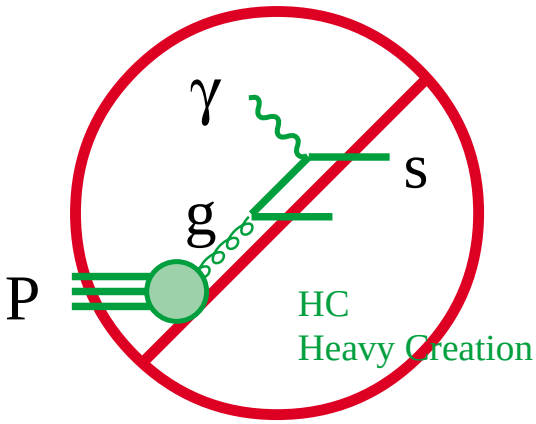
Factorize the problem into a soft and hard component:

$$\sigma_{a\to c} = f_{a\to b}(x, \mu^2) \otimes \omega_{b\to c}(Q^2/\mu^2, \alpha_s(\mu)) + O(\Lambda^2/Q^2)$$

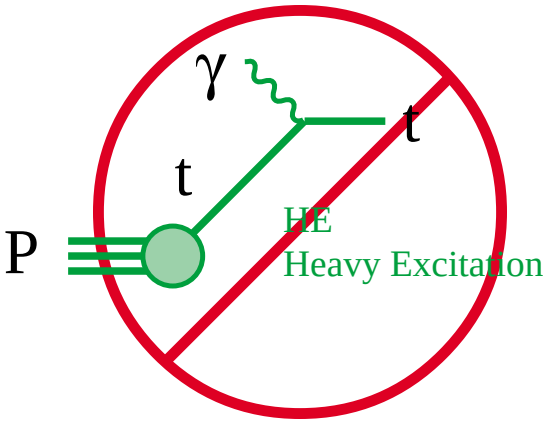
Where do you draw the line between soft and hard?

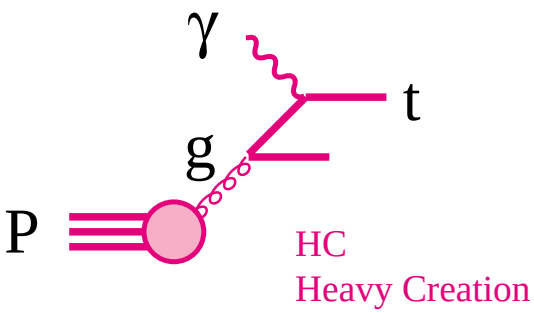
Try strange production first:





Try top production next:





What about b and c production???

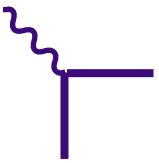
- Actually, even s and t production are a problem at high precision.

Ingredients of Factorization

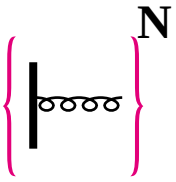
Decompose into (t-channel) 2PI amplitudes:

$$\sigma = \Sigma_{N=1}^{\infty} \; C \; (K)^N \; T \; + O(\Lambda_{QCD}^2/Q^2)$$

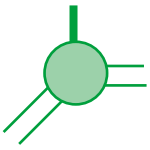
Hard scattering coefficient



$(\text{Kernel})^N$



Target



New Factorization Proof for Massive Quarks
Collins,PRD58,1998

After reorganization of the infinite sum:

Parton Model | Remainder

$$\sigma \approx \underbrace{C\,[1-(1-Z)\,K\,]^{-1}\,Z\;[1-K\,]^{-1}\,T}_{\text{Parton Model}} + \underbrace{C\,[1-(1-Z)\,K\,]^{-1}\,(1-Z)T}_{\text{Remainder}}$$

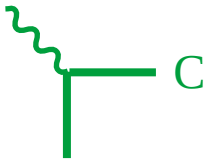
Wilson Coefficient (Hard Scatt. $\hat{\sigma}$) — Z collinear projection — Parton Distribution

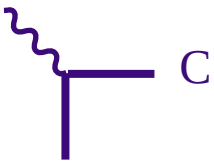
Power Suppressed

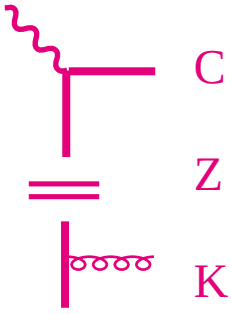
Wilson Coefficient:

Leading Order | Next to Leading Order

$$C\,[1-(1-Z)\,K\,]^{-1} \approx \underbrace{C}_{\text{LO}} + \underbrace{C\,K - C\,Z\,K}_{\text{NLO}} + \ldots$$



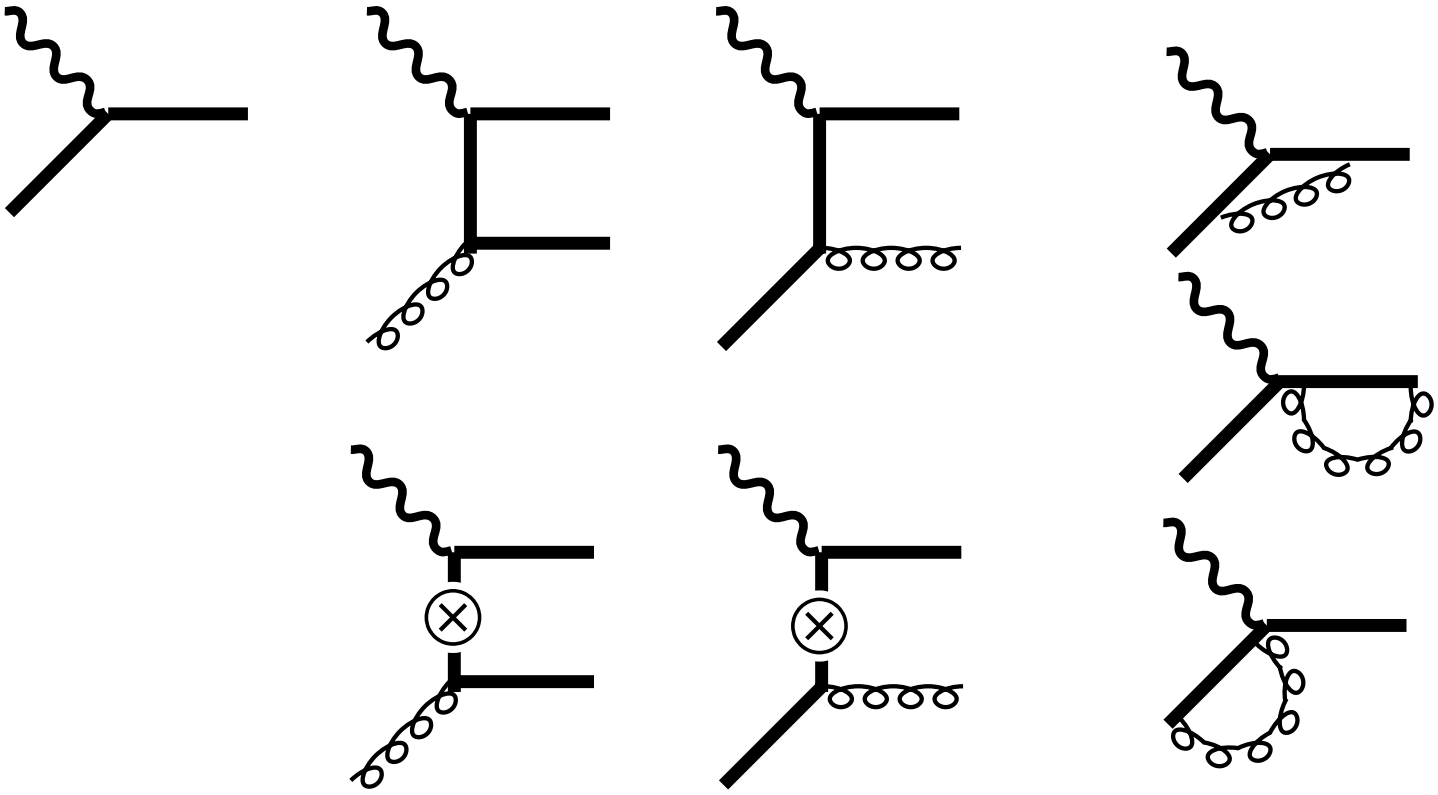




- All orders result
- Valid for all masses

C Z K is the subtraction

S-ACOT Scheme for Heavy Quarks

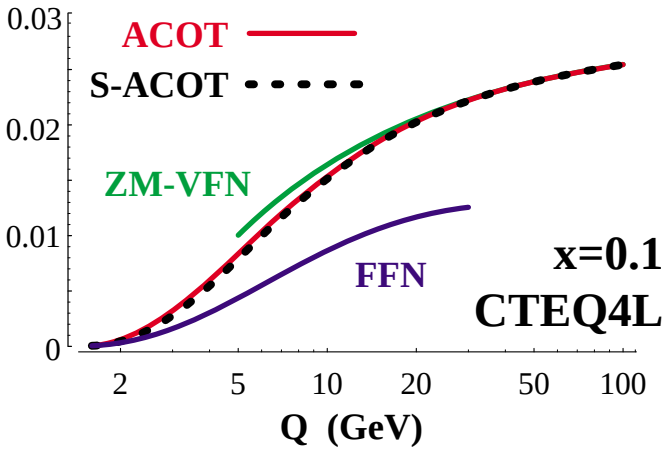


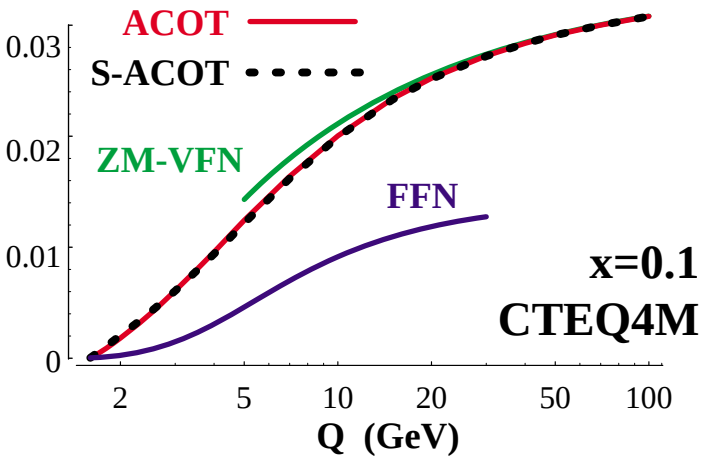
Heavy Excitation: $f_{p\to c}(m_c) \otimes \hat{\sigma}_{s\to c}(m_c)$

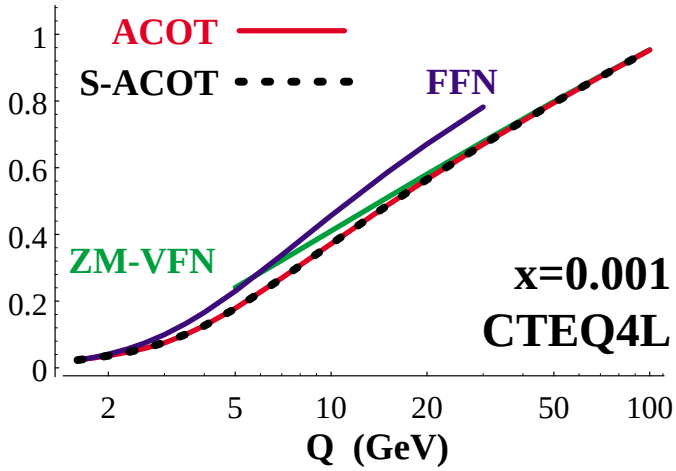
Subtraction: $\tilde{f}_{p\to c}(m_c) \otimes \hat{\sigma}_{s\to c}(m_c)$

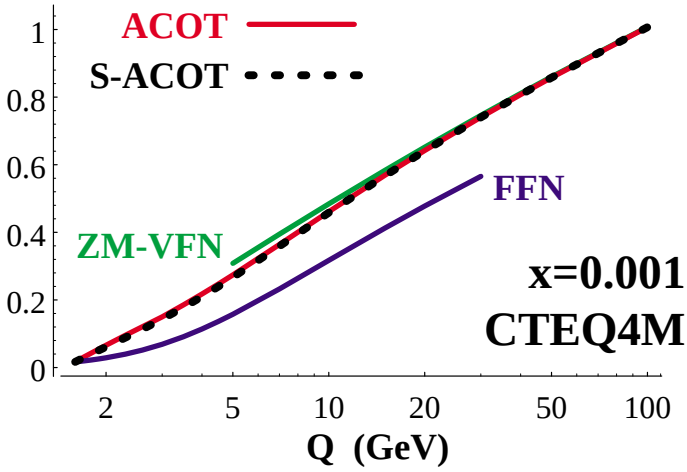
For heavy quark initiated graphs, set $M_Q=0$

How does S-ACOT Compare???





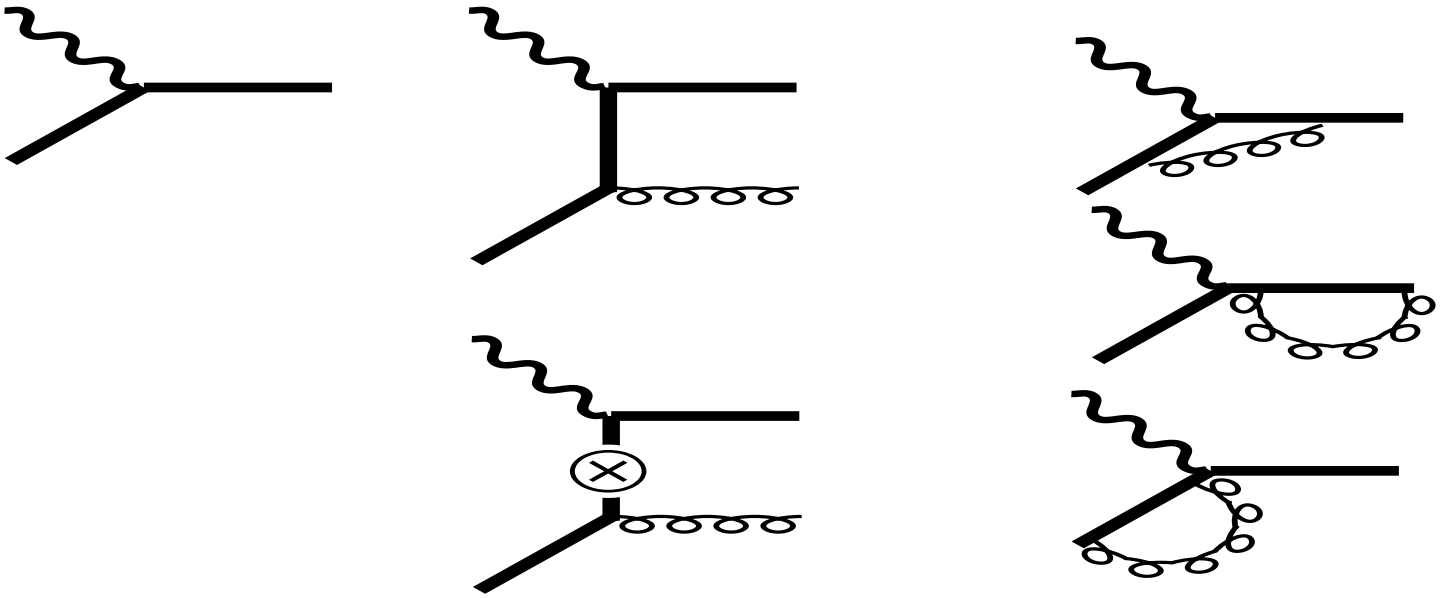




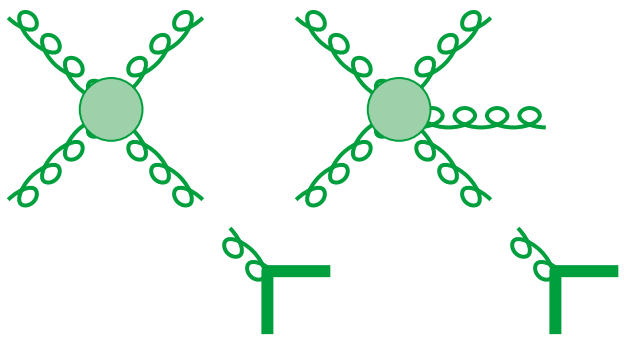
S-ACOT virtually identical to ACOT

Contains complete dynamics

Practical Result of Simplified ACOT

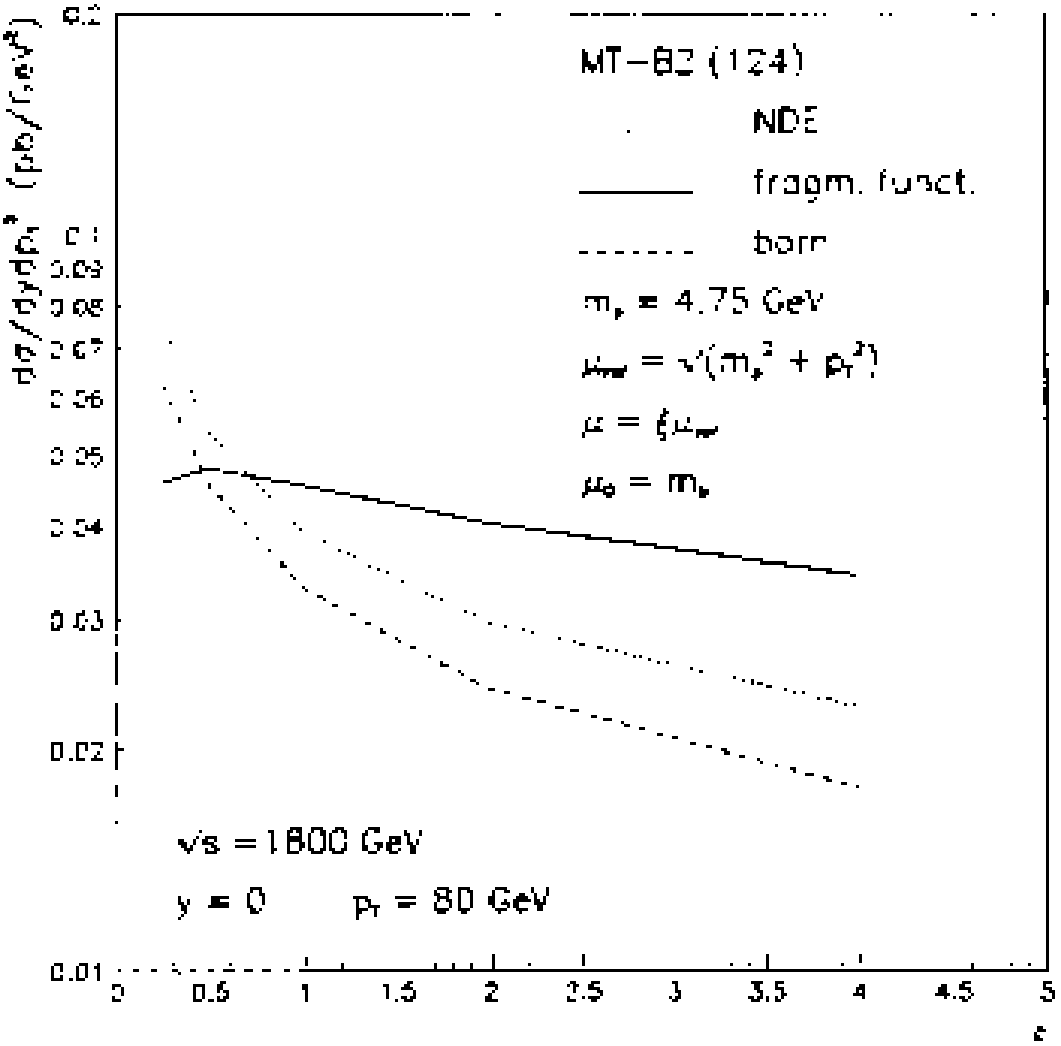


Fragmentation Function Approach

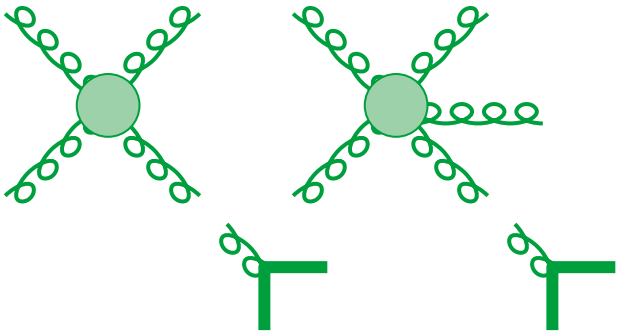


Cacciari & Greco, Nucl.Phys.B421, 630 (1994)
Cacciari ,Greco, Nason, JJEP 05, 007 (98)

- Use NLO Jet cross section + Heavy Quark fragmentation
- Improved μ dependence at large P_T



Fragmentation Function Approach



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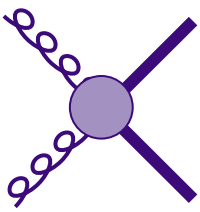
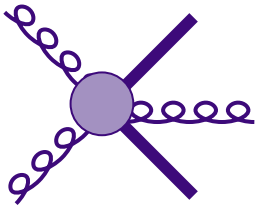
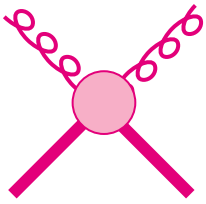
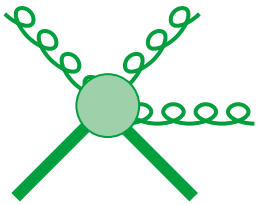
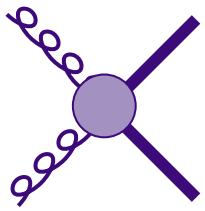
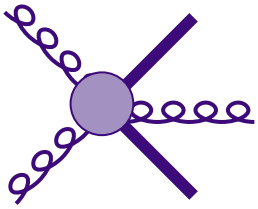
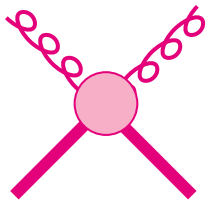
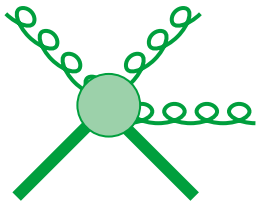
	Leading Order	NLO
Heavy Creation		
Heavy Excitation		

Nason, Dawson, Ellis, Nucl.Phys.B303, 607 (1988) Nucl.Phys.B327, 49 (1989)
Beenakker, Kuijf, van Neerven, Smith, Phys.Rev.D40, 54 (1989)

Heavy Quark Hadroproduction

	Leading Order	NLO
Heavy Creation		
Heavy Excitation		

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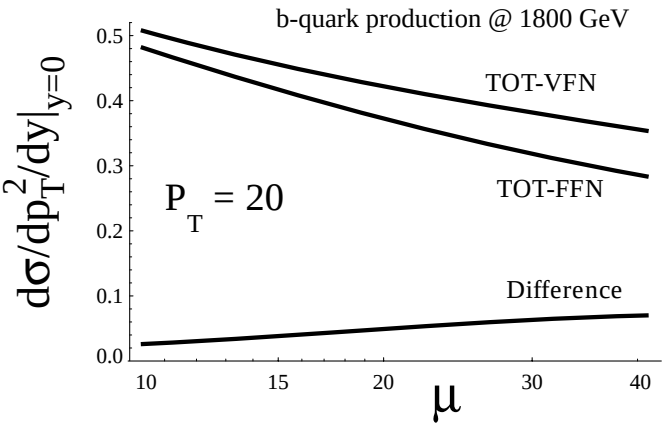
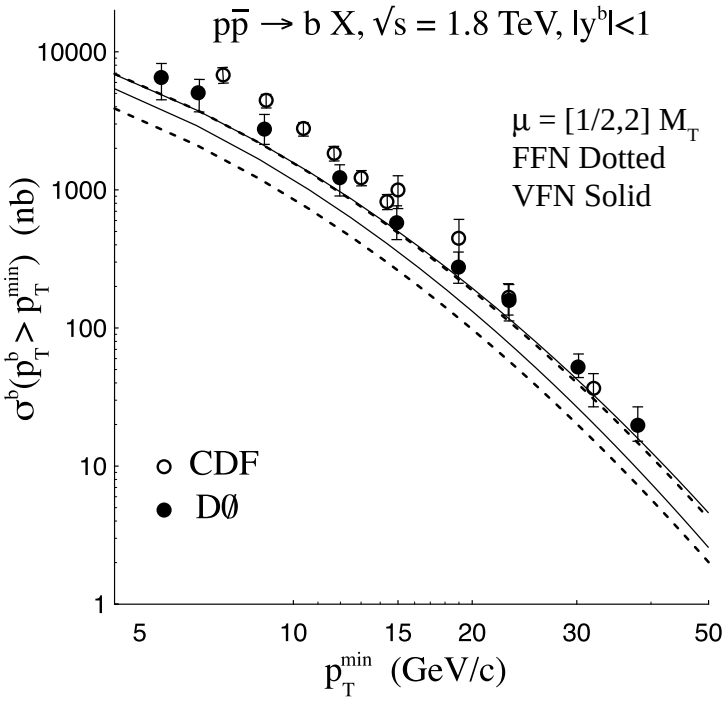
Beenakker, Kuijf, van Neerven, Smith, Phys.Rev.D40, 54 (1989)

Do the Heavy Quark PDF's Help?

... extend ACOT to hadroproduction

- Increased cross section
- Decreased μ dependence

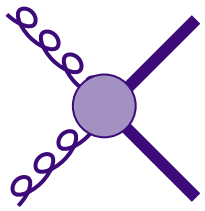
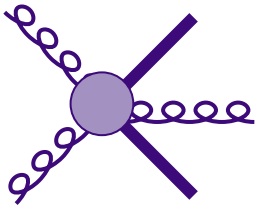
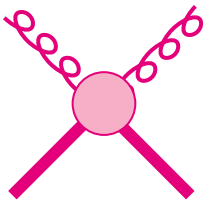
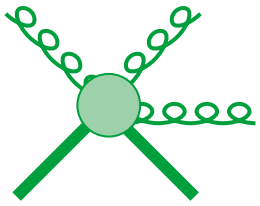




... improvement, but not a complete solution.

Olness, Scalise, Tung. PRD 59, 014506 (99)

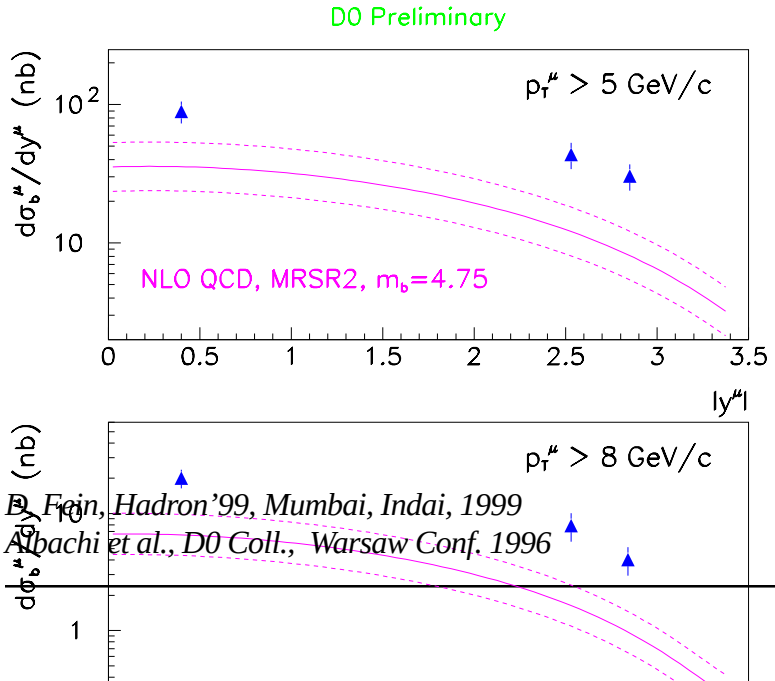
Heavy Quark Hadroproduction

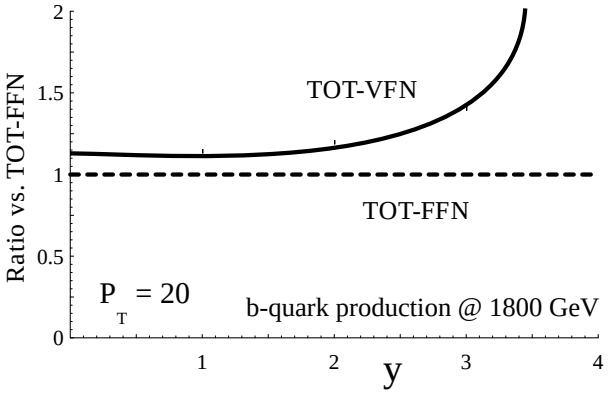
	Leading Order	NLO
Heavy Creation		
Heavy Excitation		

Nason, Dawson, Ellis, Nucl.Phys.B303, 607 (1988) Nucl.Phys.B327, 49 (1989)
Beenakker, Kuijf, van Neerven, Smith, Phys.Rev.D40, 54 (1989)

Can we understand enhancement at large y?

- **Heavy Exication process has t-channel gluon-exchange**



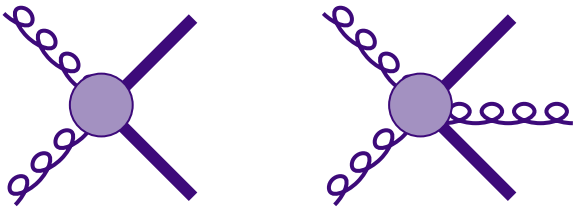


D. Fein, Hadron'99, Mumbai, Indai, 1999
Albachi et al., D0 Coll., Warsaw Conf. 1996

Olness, Scalise, Tung. PRD 59, 014506 (99)

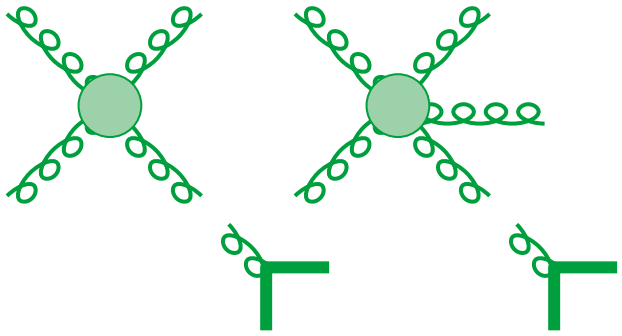
Combine Calculations

NLO Heavy Creation



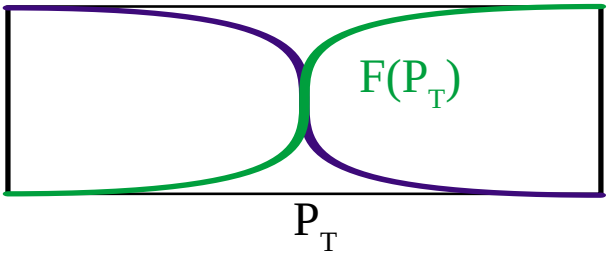
Nason, Dawson, Ellis, Nucl.Phys.B303, 607 (1988)
Nucl.Phys.B327, 49 (1989) Phys.Rev.D40, 54(1989)

Fragmentation Function

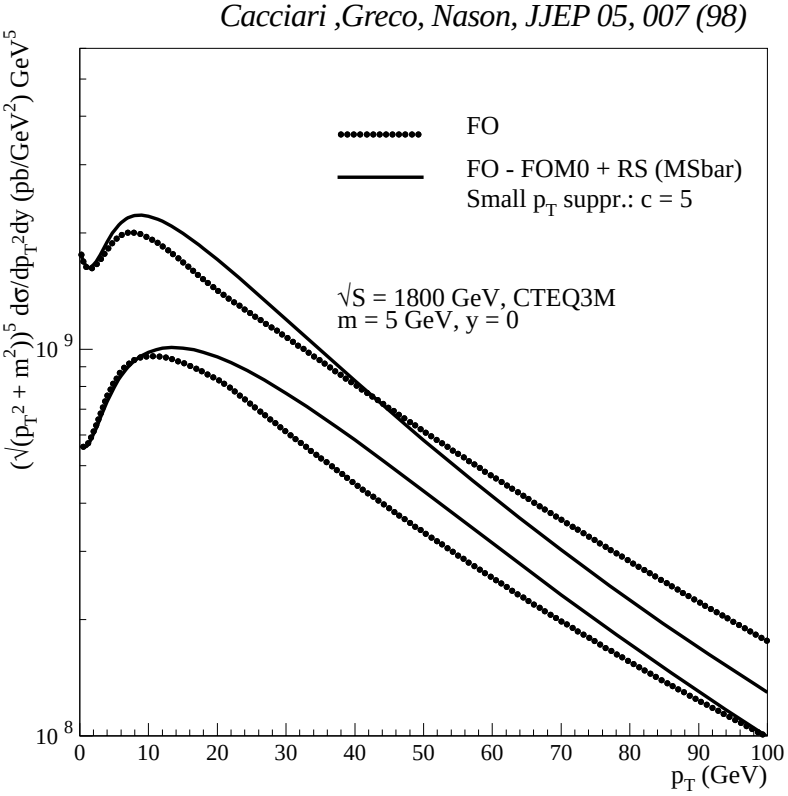


Cacciari & Greco, Nucl.Phys.B421, 630 (1994)

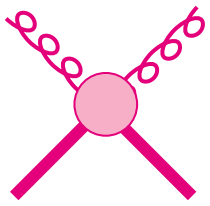
- Use Transition function $F(P_T)$
- Matches full NLO calc at low P_T
- Improved μ dependence at large P_T



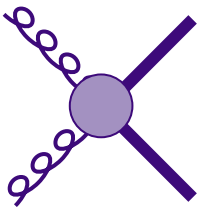
Cacciari ,Greco, Nason, JJEP 05, 007 (98)



Combine Again



HE
Heavy Excitation

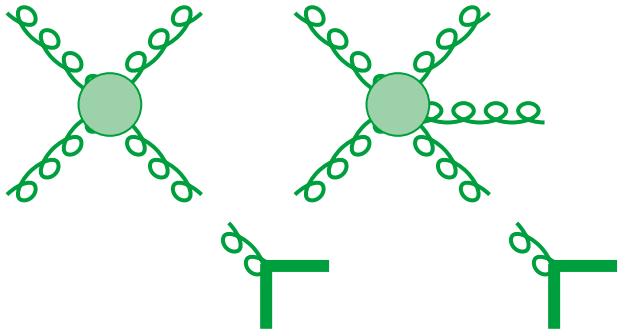


HC
Heavy Creation

Nason, Dawson, Ellis, Nucl.Phys.B303, 607 (1988)
Nucl.Phys.B327, 49 (1989) Phys.Rev.D40, 54(1989)

Olness, Scalise, Tung. PRD 59, 014506 (99)

Fragmentation Function

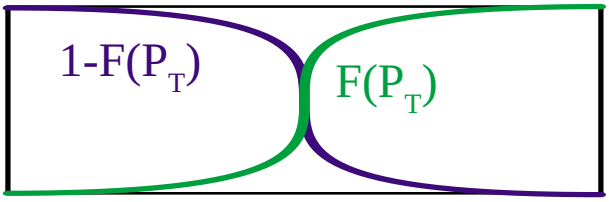


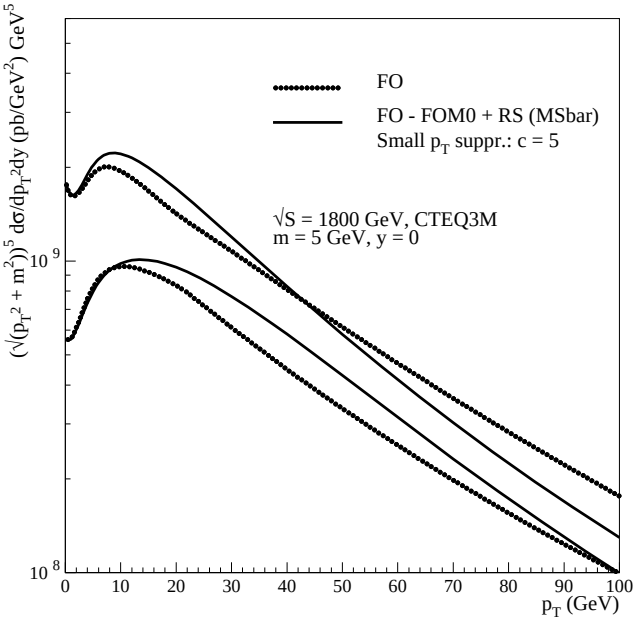
Cacciari & Greco, Nucl.Phys.B421, 630 (1994)

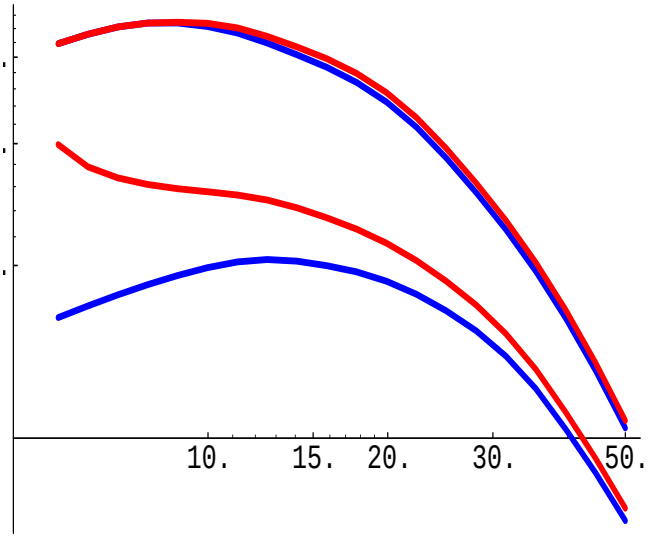
Note: Heavy Excitation contribution does not vanish for finite P_T

- For $\mu = \xi \sqrt{M_H^2+P_T^2}$, HE can contribute for $P_T<M_H$ since $M_H<\mu$
- Include Heavy Excitation process (with appropriate subtractions)
- Improved μ dependence at large P_T

Cacciari ,Greco, Nason, JJEP 05, 007 (98)

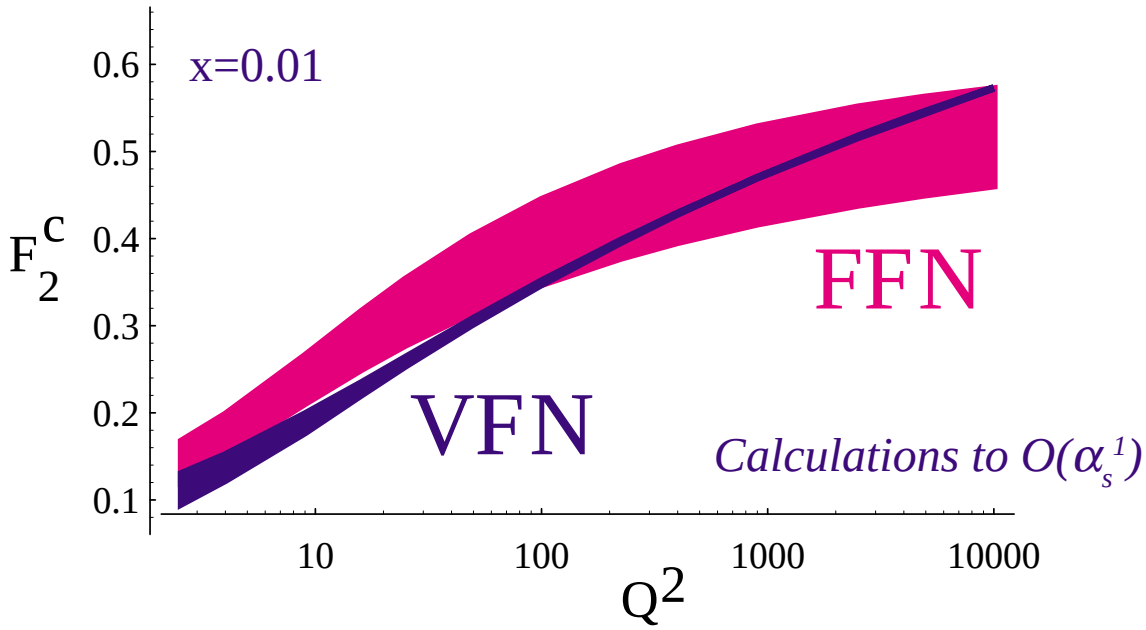


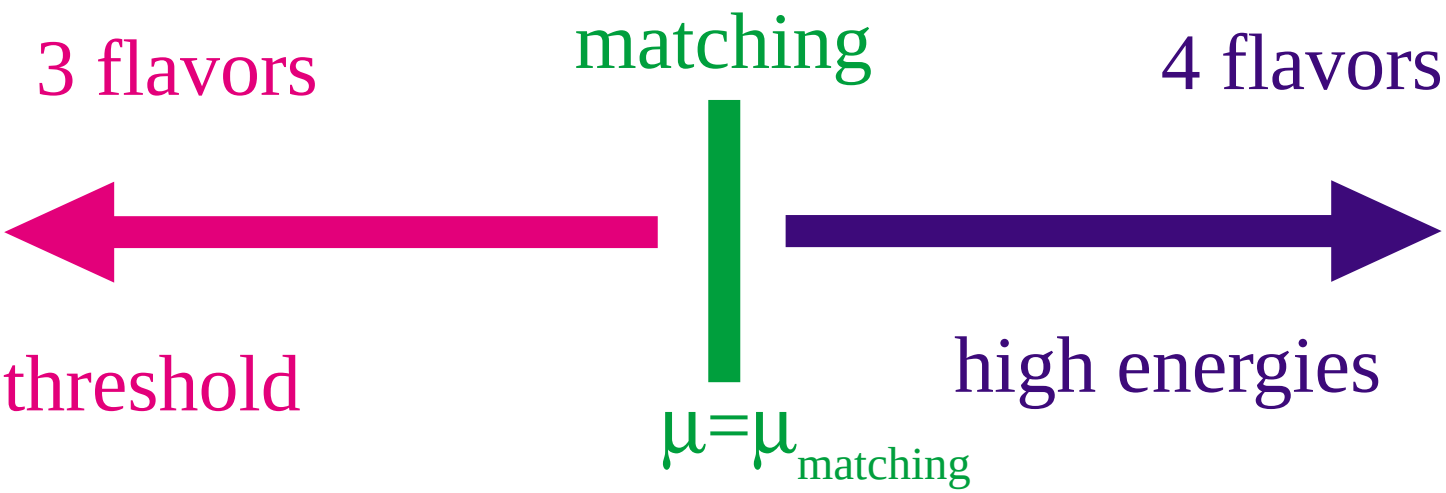




Scale Uncertainty of F_2^{Charm}

Vary μ from $^1/_2\,\mu_0$ to $2\,\mu_0$ where $\mu_0 = \sqrt{Q^2 + m_c^2}$





- Freedom to adjust matching scale $\mu_{matching}$
- Matching scale $\mu_{matching}$ not fixed at M_Q

- Suprise: VFN comparable to FFN at threshold

Conclusions

Heavy quark production:

Challenges:

- Multi-scale problem $\{Q, m_H\}$
- Requires extension of factorization theorems
- Resummation via Heavy Quark PDF

Simplified ACOT (S-ACOT):

- Can neglect mass in HQ initiated terms
- Simplification can be crucial at higher orders

B Hadroproduction:

- experiments are converging
- theories are converging

We are making steady progress in understanding b-production