Institute for Theoretical Physics

Eberhard Karls Universität Tübingen

Higher Order Effects in Lepton-Hadron Production Processes

Newport News VA , 01.06.2016

Accardi, Anderle, de Florian, Ringer, Rotstein, Stratmann, Vogelsang

Jefferson Lab

Speaker:
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About Me...

2006-2009 — Bachelor's Degree: University of Trento. Advisor: Paolo Verrocchio.

2009-2012 — Master's Degree: Double degree program between University of Trento and University of Tübingen. Advisors: Werner Vogelsang and Marco Traini.

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MAIN COLLABORATIONS

- University of Buenos Aires: with Prof. Dr. Daniel de Florian and Yamila Rotstein. Project funded by "*Fondazione Cassa Rurale di Trento*" and Tübingen University.
- Jefferson Laboratory and Hampton University: with Prof.Dr. Alberto Accardi. Project funded by Hampton University.

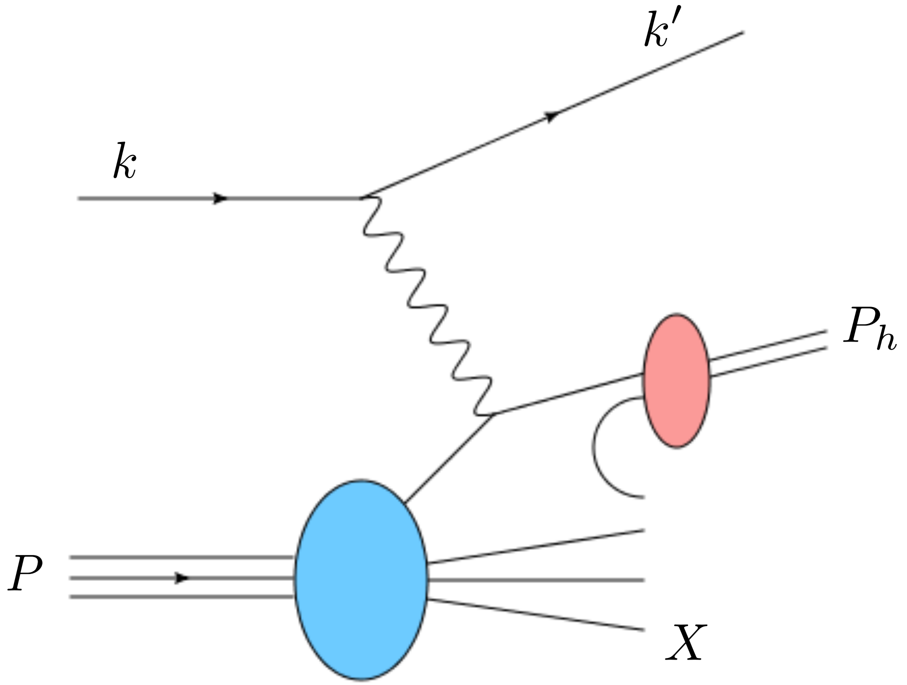
MAIN COLLABORATORS

Alberto Accardi, Daniel de Florian, Felix Ringer, Yamila Rotstein, Marco Stratmann, Werner Vogelsang

Outline

- Threshold Resummation for SIDIS
- HMC + Threshold Resummation
- Towards a Global NNLO FF Fit
- Conclusions

Semi-Inclusive DIS



$$\ell(k)\,p(P) \to \ell(k')\,h(P_h)\,X$$

Define the usual variables:

$$Q^2 \equiv -q^2 = -(k-k')^2$$

$$y \equiv \frac{P\cdot q}{P\cdot k}$$

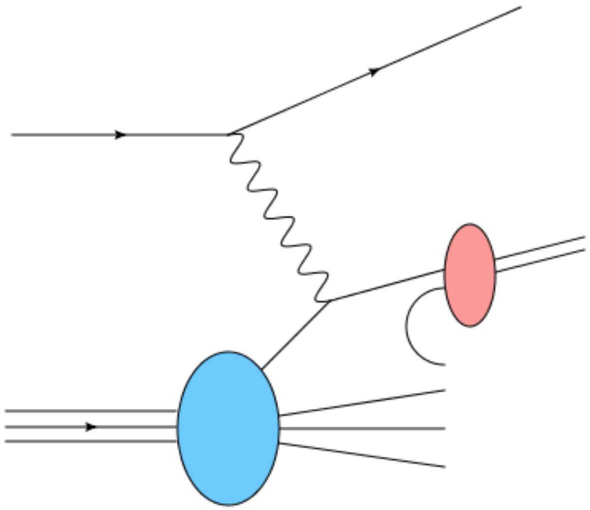
$$x \equiv \frac{Q^2}{2P\cdot q}$$

$$z \equiv \frac{P\cdot P_h}{P\cdot q}$$

SIDIS
$$\frac{d^3\sigma^h}{dxdydz} = \frac{4\pi\alpha^2}{Q^2}\left[\frac{1+(1-y)^2}{2y}\mathcal{F}_T^h(x,z,Q^2) + \frac{1-y}{y}\mathcal{F}_L^h(x,z,Q^2)\right]$$

DIS
$$\frac{d^2\sigma}{dxdy} = \frac{4\pi\alpha^2}{Q^2}\left[\frac{1+(1-y)^2}{2y}\mathcal{F}_T(x,Q^2) + \frac{1-y}{y}\mathcal{F}_L(x,Q^2)\right]$$

$$\mathcal{F}_i^h(x,z,Q^2) = \sum_{f,f'}\int_x^1 \frac{d\hat{x}}{\hat{x}}\int_z^1 \frac{d\hat{z}}{\hat{z}}\, f\left(\frac{x}{\hat{x}},\mu^2\right) D_{f'}^h\left(\frac{z}{\hat{z}},\mu^2\right) \mathcal{C}_{f'f}^i\left(\hat{x},\hat{z},\frac{Q^2}{\mu^2},\alpha_s(\mu^2)\right)$$



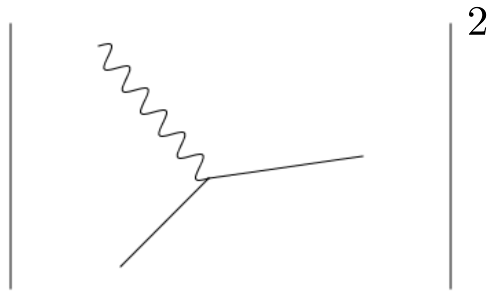
hard-scattering coefficient function:

$$\mathcal{C}_{f'f}^i = C_{f'f}^{i,(0)} + \frac{\alpha_s(\mu^2)}{2\pi}C_{f'f}^{i,(1)} + \mathcal{O}(\alpha_s^2)$$

Hadron multiplicity definition for SIDIS

$$R_{\mathrm{SIDIS}}^h \equiv \frac{d^3\sigma^h/dxdydz}{d^2\sigma/dxdy}$$

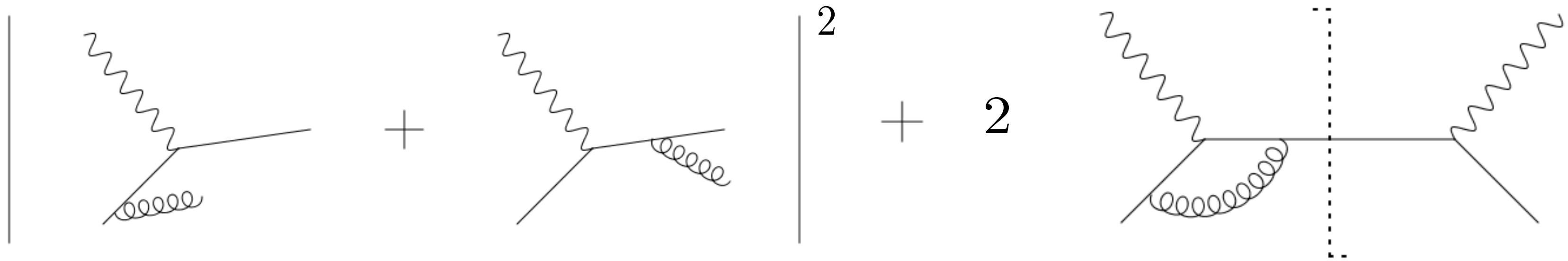
LO:



Parton Model:

$$C_{qq}^{T,(0)}(\hat{x},\hat{z}) = e_q^2\,\delta(1-\hat{x})\delta(1-\hat{z})$$
$$C_{qq}^{L,(0)}(\hat{x},\hat{z}) = 0$$

NLO:



Singularities from the quark propagator

$$G \sim \frac{1}{(p_i - k)^2}$$
$$(p_i - k)^2 = -2|p_i||k|(1-\cos\theta),$$

- *soft*: cancel for real + virtual corrections
- *collinear*: factorize into PDF/ FF

NLO COEFFICIENT FUNCTION

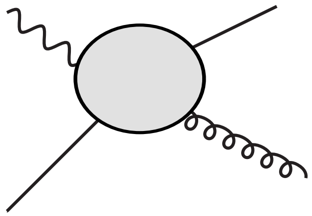
Altarelli et al.; Furmanski, Petronzio; de Florian et al.

large corrections near threshold $\hat{x},\, \hat{z} \to 1$

$$C_{qq}^{T,(1)}(\hat{x},\hat{z}) \sim e_q^2\, C_F \Bigg[-8\,\delta(1-\hat{x})\,\delta(1-\hat{z}) + 2\,\delta(1-\hat{x}) \left(\frac{\ln(1-\hat{z})}{1-\hat{z}}\right)_+ + 2\,\delta(1-\hat{z}) \left(\frac{\ln(1-\hat{x})}{1-\hat{x}}\right)_+ + \frac{2}{(1-\hat{x})_+(1-\hat{z})_+} \Bigg]$$

$\overline{\mathrm{MS}}$ scheme

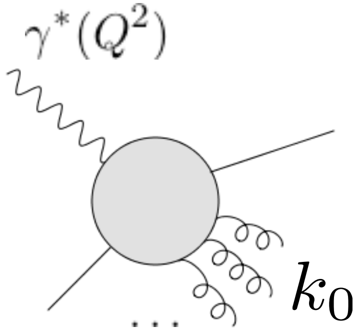
$$\int_0^1 dz\, f(z) \left(\frac{\ln(1-z)}{1-z}\right)_+ \equiv \int_0^1 dz\, (f(z)-f(1))\, \frac{\ln(1-z)}{1-z}$$



NLO Threshold Logarithms

coming from emission of one soft gluon

$$+2\,\delta(1-\hat{x})\left(\frac{\ln(1-\hat{z})}{1-\hat{z}}\right)_+ \text{ and } \hat{x} \leftrightarrow \hat{z}$$



N^{k}LO Threshold Logarithms

coming from emission of k soft gluon

$$\alpha_s^k\,\delta(1-\hat{z})\left(\frac{\ln^{2k-1}(1-\hat{x})}{1-\hat{x}}\right)_+ \text{ and } \hat{x} \leftrightarrow \hat{z}$$

$$\alpha_s^k\left(\frac{\ln^m(1-\hat{x})}{1-\hat{x}}\right)_+\left(\frac{\ln^m(1-\hat{z})}{1-\hat{z}}\right)_+$$

$$m+n=2k-2$$

They become large for $\hat{x},\ \hat{z} \to 1$

With a careful *kinematic analysis*

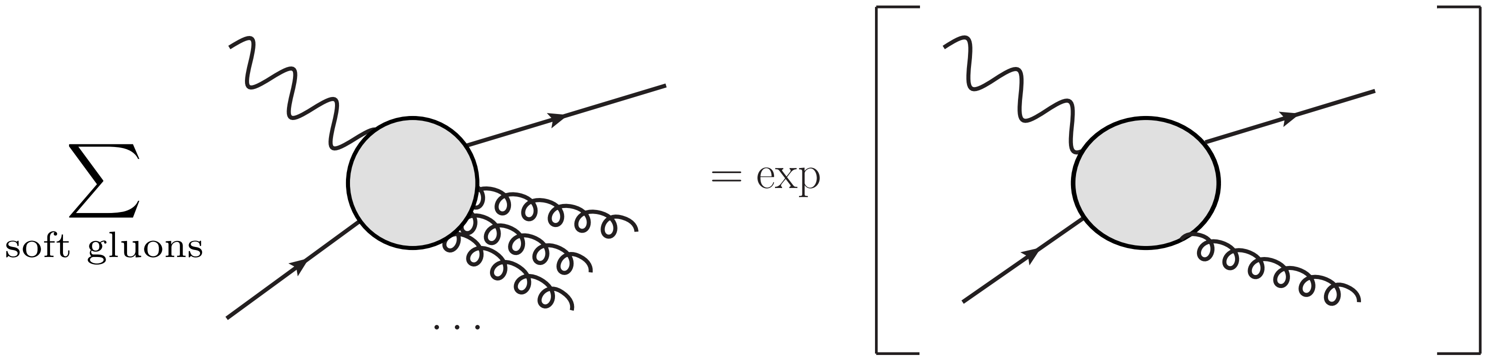
$$(1-\hat{x})+(1-\hat{z}) \approx \frac{2k^0}{Q}$$

Large Logs associated with soft gluon emissions

G. F. Sterman and W. Vogelsang, Catani and Trentadue

THE EXPONENTIATION

The Resummation of the *Threshold Logs* occurs via the *exponentiation of the "single soft emission"-contribution* (one-loop contribution in the soft-limit $k_0 \approx 0$)



Perturbatively calculable (NLO-Calculation)

- *Matrix elements* factorize in the soft-limit approximation (eikonal-approximation)
- In order for the *phase space* to factorize we have to move into

$$\delta\left(1 - k_0 - \sum_{i=1}^{n} k_i\right) = \frac{1}{2\pi i}\int_C dN e^{N(1-k_0-\sum_{i=1}^{n} k_i)}$$

➡ Mellin Space

large corrections near threshold $\hat{x},\, \hat{z} \to 1$

$$C_{qq}^{T,(1)}(\hat{x},\hat{z}) \sim e_q^2\, C_F \Bigg[-8\,\delta(1-\hat{x})\,\delta(1-\hat{z}) + 2\,\delta(1-\hat{x}) \left(\frac{\ln(1-\hat{z})}{1-\hat{z}}\right)_+ + 2\,\delta(1-\hat{z}) \left(\frac{\ln(1-\hat{x})}{1-\hat{x}}\right)_+ + \frac{2}{(1-\hat{x})_+(1-\hat{z})_+} \Bigg]$$

↓

double-Mellin transform: $\tilde{C}_{qq}^{T,(1)}(N,M) \sim e_q^2\, C_F \left[-8 + \frac{\pi^2}{3} + \left(\ln \bar{N} + \ln \bar{M}\right)^2 \right]$

$\bar{N} = N e^{\gamma_E}, \quad \bar{M} = M e^{\gamma_E}$

for $N, M \to \infty$

ACCURACY OF RESUMMATION

$$\mathcal{O}(\alpha_s^k) : \qquad C_{knm} \times \alpha_s^k \ln^n \bar{N} \ln^m \bar{M}, \quad \text{where } n + m \leq 2k$$

Fixed Order

LO	1					
NLO	$\alpha_s L^2$	$\alpha_s L$	α_s			
NNLO	$\alpha_s^2 L^4$	$\alpha_s^2 L^3$	$\alpha_s^2 L^2$	$\alpha_s^2 L$	α_s^2	
...	...	...	...	...	...	
N^{k}LO	$\alpha_s^k L^{2k}$	$\alpha_s^k L^{2k-1}$	$\alpha_s^k L^{2k-2}$	$\alpha_s^k L^{2k-3}$	$\alpha_s^k L^{2k-4}$	...

In Mellin Space

Accuracy of Resummation

$$\mathcal{O}(\alpha_s^k): \qquad C_{knm} \times \alpha_s^k \ln^n \bar{N} \ln^m \bar{M}, \quad \text{where } n + m \leq 2k$$

Fixed Order →

Resummation ↓

LO	1					
NLO	$\alpha_s L^2$	$\alpha_s L$	α_s			
NNLO	$\alpha_s^2 L^4$	$\alpha_s^2 L^3$	$\alpha_s^2 L^2$	$\alpha_s^2 L$	α_s^2	
...	...	...	...	...	...	
N^{k}LO	$\alpha_s^k L^{2k}$	$\alpha_s^k L^{2k-1}$	$\alpha_s^k L^{2k-2}$	$\alpha_s^k L^{2k-3}$	$\alpha_s^k L^{2k-4}$	...

↓ LL ↓ NLL ↓ NNLL

Inverse Mellin Transformation

- Minimal Prescription *Catani, Mangano, Nason, Trentadue*

-Double Mellin Inverse Transformation

$$\mathcal{F}_i^h(x,z,Q^2) = \int_{\mathcal{C}_N} \frac{dN}{2\pi i}\, x^{-N} \int_{\mathcal{C}_M} \frac{dM}{2\pi i}\, z^{-M}\, \tilde{\mathcal{F}}_i^h(N,M,Q^2)$$

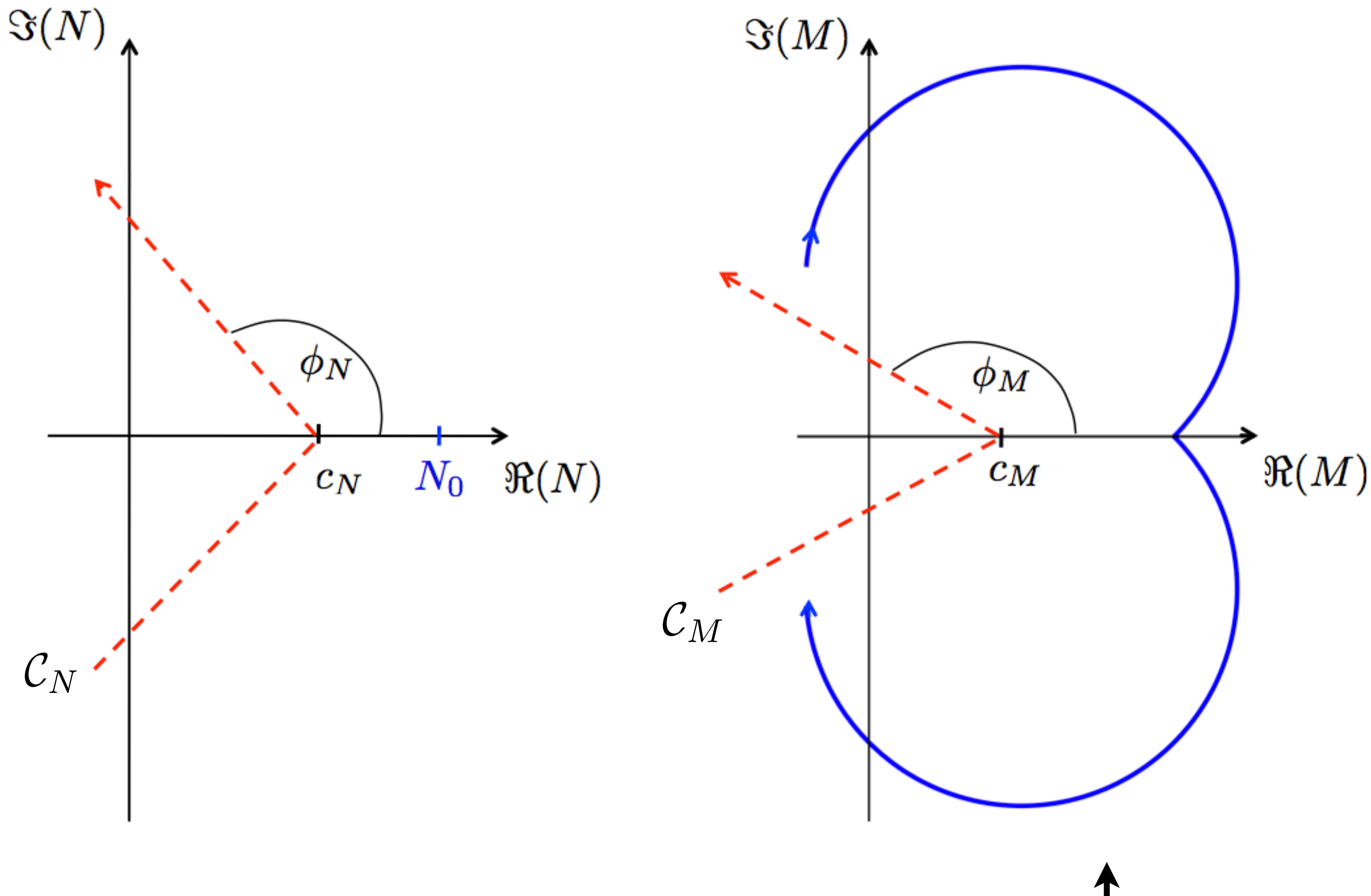
-Choose contours to the left of the Landau singularity at

$$\lambda_{NM} = 1 \leftrightarrow NM = e^{1/(\alpha_s b_0) - 2\gamma_E}$$

-Tilted contours in complex plane to increase numerical convergence

$$N = c_N + z_N e^{i\phi_N}$$

Integration contours



tilted contours $N = c_N + z_N e^{i\phi_N}$

Location of the Landau pole as N moves along its contour

COMPASS DATA

SIDIS π^+ hadron multiplicities, COMPASS kinematics

$0.041 < x < 0.7$

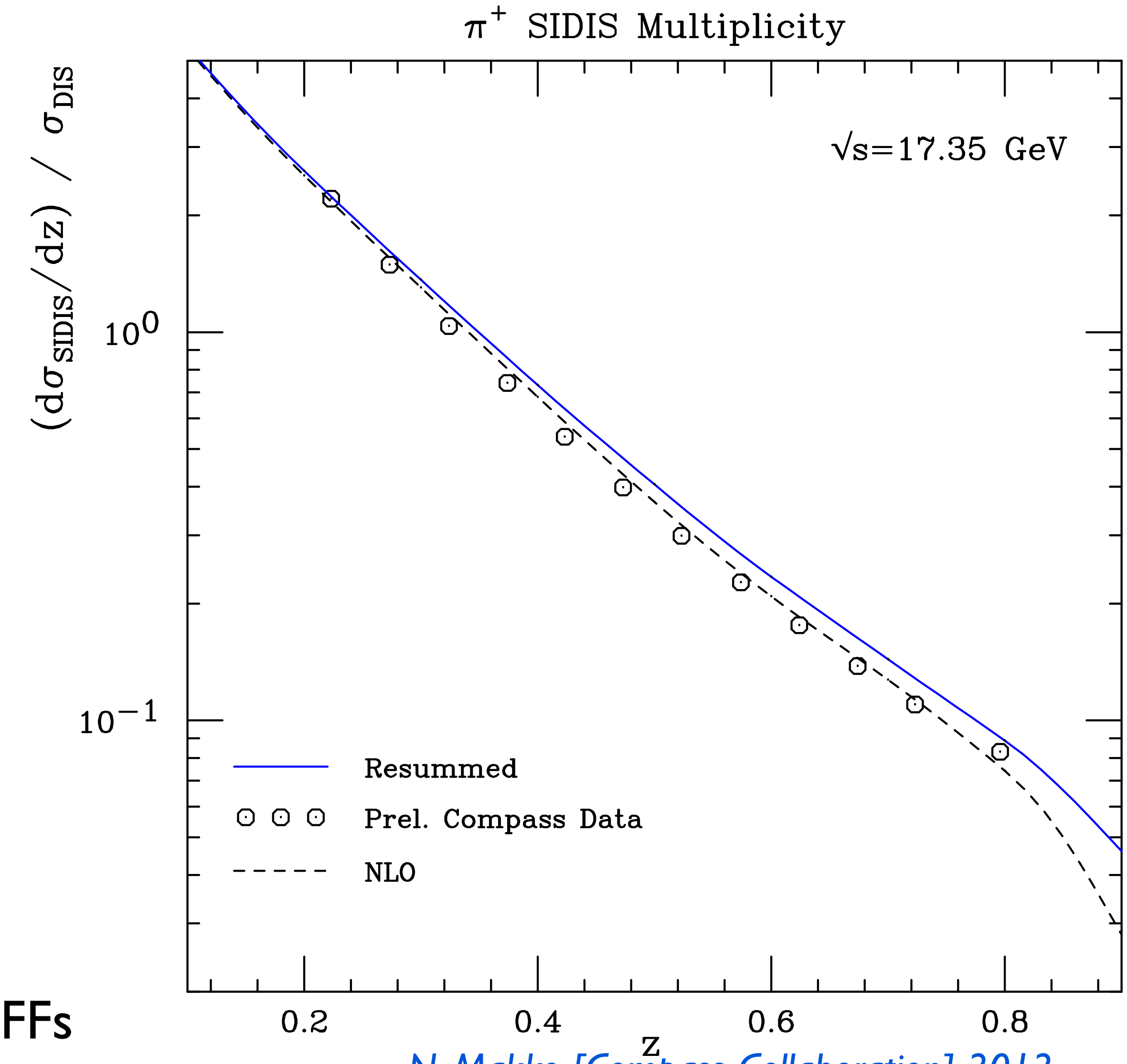
$0.1 < y < 0.9$

$Q^2 > 1\,\mathrm{GeV}^2$

$W^2 > 7\,\mathrm{GeV}^2$

$$R^h_{\mathrm{SIDIS}} \equiv \frac{d^3\sigma^h/dxdydz}{d^2\sigma/dxdy}$$

using MSTW08 PDFs and DSS FFs

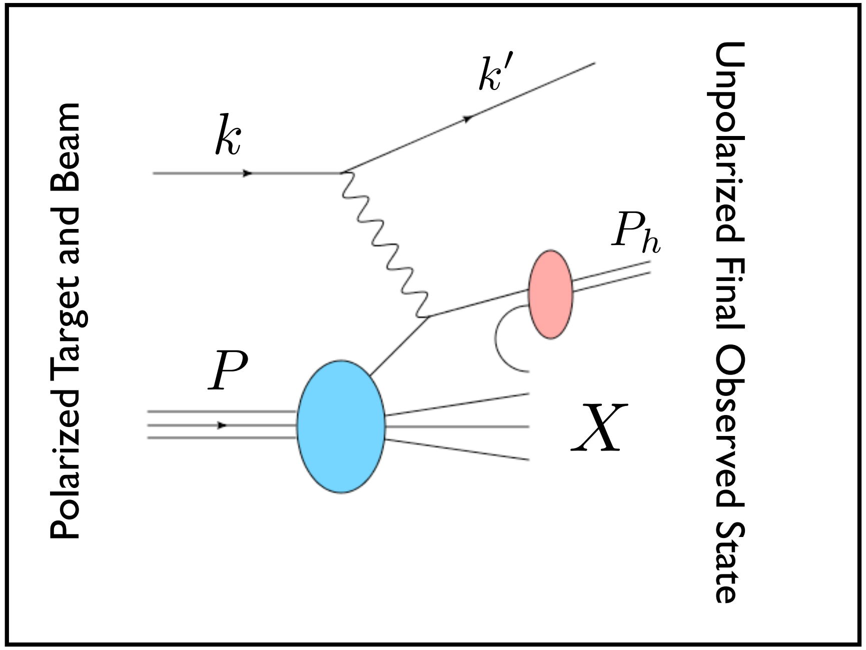


N. Makke [Compass Collaboration] 2012

POLARIZED SIDIS

Anderle, Ringer Vogelsang, PhysRevD.87. 094021

Longitudinal double-spin asymmetry $\vec{l}(k)\vec{p}(P) \rightarrow l(k')h(P_h)X$



$$A_1^h(x,z,Q^2) \approx \frac{g_1^h(x,z,Q^2)}{F_1^h(x,z,Q^2)}$$

where $2F_1^h(x,z,Q^2) = \mathcal{F}_T^h(x,z,Q^2)$

$$2g_1^h(x,z,Q^2) = \sum_{f,f'=q,\bar{q},g} \int_x^1 \frac{d\hat{x}}{\hat{x}} \int_z^1 \frac{d\hat{z}}{\hat{z}} \Delta f\left(\frac{x}{\hat{x}},\mu^2\right) \times D_{f'}^h\left(\frac{z}{\hat{z}},\mu^2\right) \Delta\mathcal{C}_{f'f}\left(\hat{x},\hat{z},\frac{Q^2}{\mu^2},\alpha_s(\mu^2)\right)$$

Polarized PDFs: $\Delta f(x,Q^2) \equiv f^+(x,Q^2) - f^-(x,Q^2)$

RESUMMATION FOR pSIDIS

Since in the threshold limit $\hat{x}, \hat{z} \to 1$

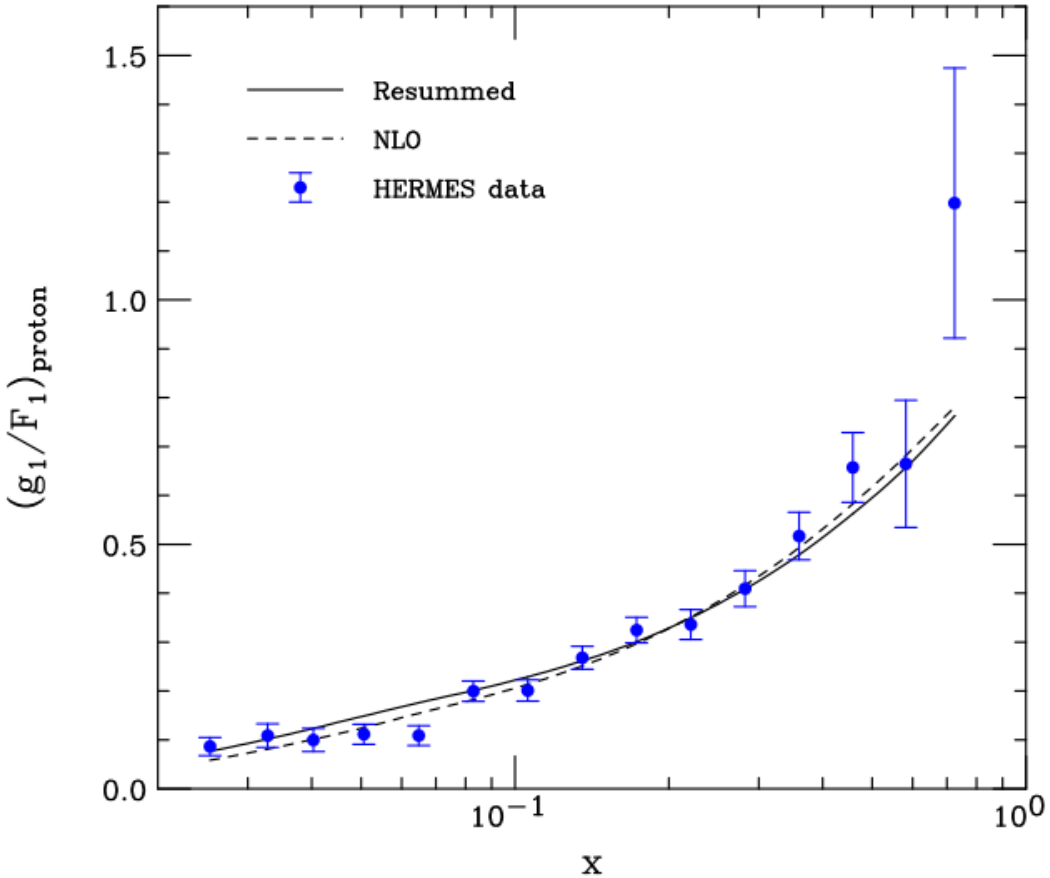
$$\Delta C_{qq}^{(1)}(\hat{x},\hat{z}) \sim C_{qq}^{(1)}(\hat{x},\hat{z}) \sim e_q^2 C_F \left[+ 2\delta(1-\hat{x}) \left(\frac{\ln(1-\hat{z})}{1-\hat{z}}\right)_+ + 2\delta(1-\hat{z}) \left(\frac{\ln(1-\hat{x})}{1-\hat{x}}\right)_+ + \frac{2}{(1-\hat{x})_+(1-\hat{z})_+} - 8\delta(1-\hat{x})\delta(1-\hat{z}) \right]$$

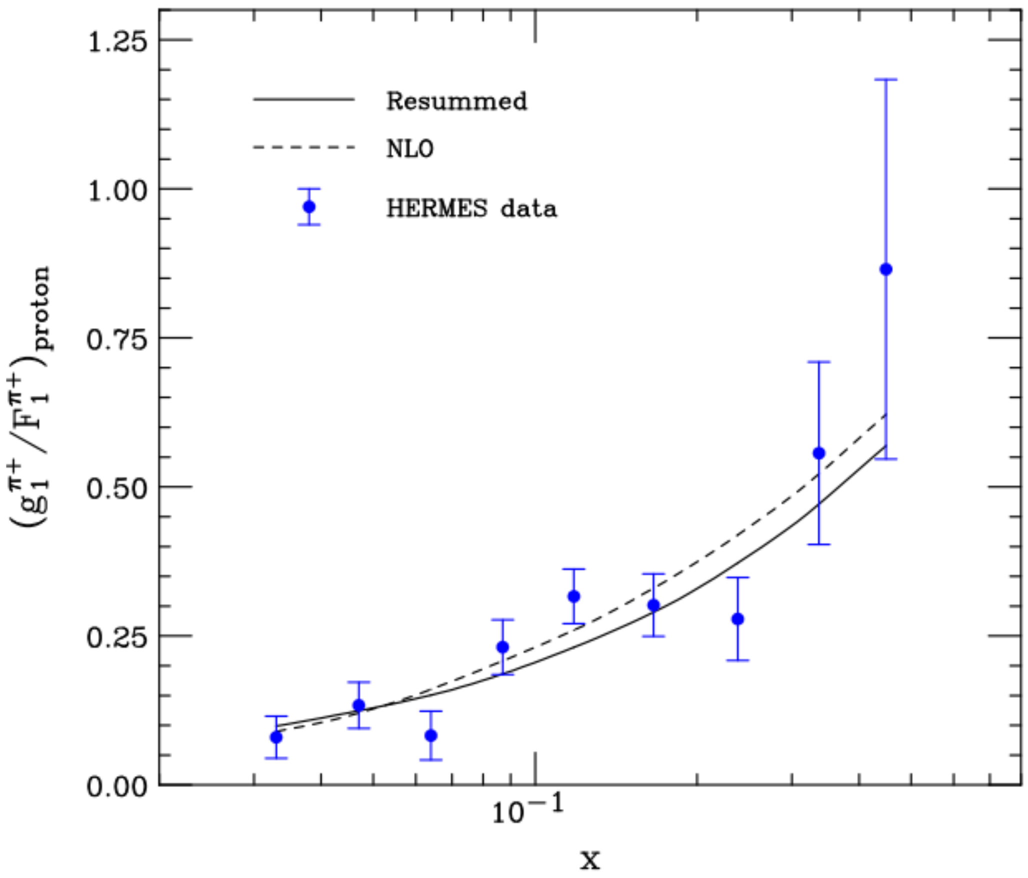
Daniel de Florian, Yamila Rotstein Habarnau

The resummed spin-dependent coefficient function IDENTICAL to spin avaraged one

$$\Delta\tilde{C}_{qq}^{\text{res}}(N, M, \alpha_s(Q^2)) = \tilde{C}_{qq}^{\text{res}}(N, M, \alpha_s(Q^2))$$

Inclusive & SI-DIS Asymmetries





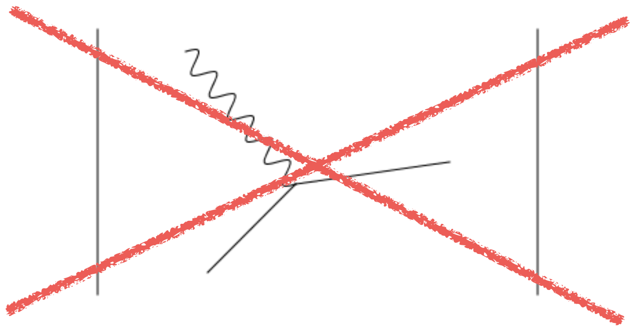
proton target $0.2 < z < 0.8$

A.Airapetian et al. [Hermes Collaboration] 2005

using MRST'02/DSSV PDFs and DSS FFs

Towards NNLO F_L

LO:

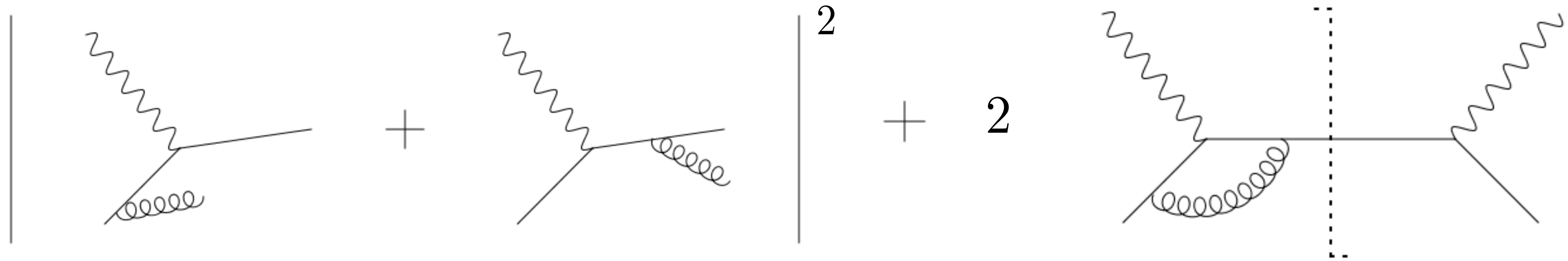


Parton Model:

$$C_{qq}^{T,(0)}(\hat{x},\hat{z}) = e_q^2\,\delta(1-\hat{x})\delta(1-\hat{z})$$

$$C_{qq}^{L,(0)}(\hat{x},\hat{z}) = 0$$

NLO:

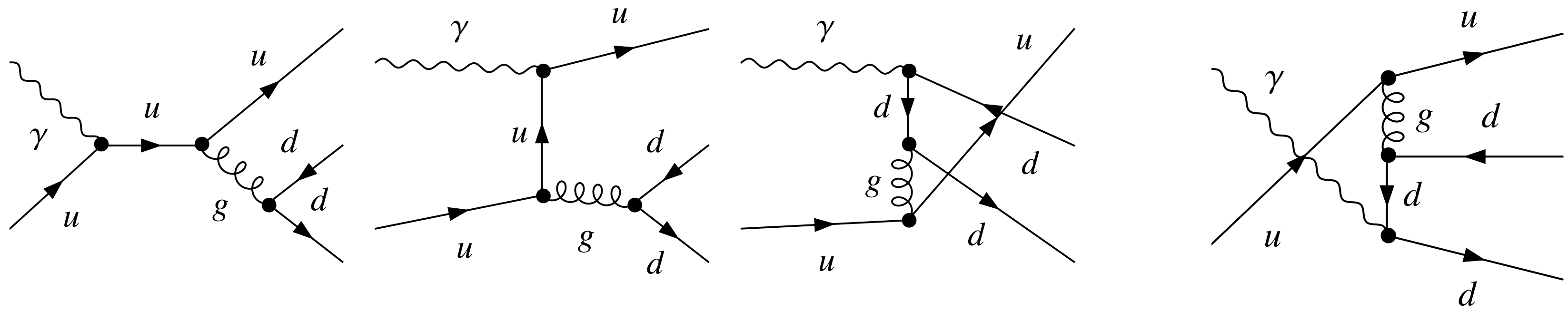


For the Longitudinal Structure Function at NLO, the quark scattering and the gluon-fusion are Tree-Level diagrams

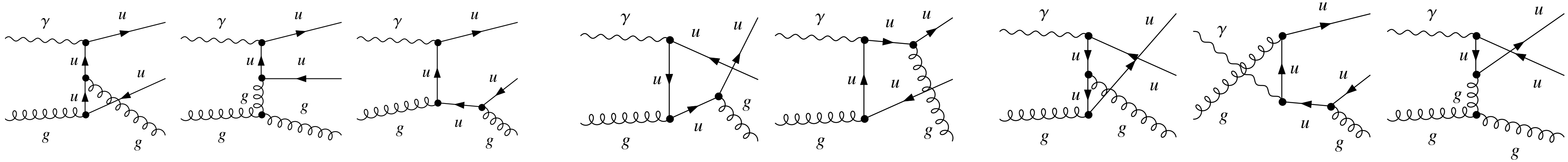
THE NEW CHANNELS OF NNLO F_L

Tree Level diagrams at NNLO:

QUARK INITIATED $\gamma q \to q' \bar{q}' q \qquad q \neq q'$



GLUON INITIATED $\gamma g \to q \bar{q} g \qquad q \neq q'$



THE CALCULATION

It is a BRUTE-FORCE calculation:

PHASE SPACE 2 to 3

$$\int \mathrm{d}\,\mathrm{PS}_3^{\mathrm{DI}} = \frac{1}{(4\pi)^n} \frac{(s-Q^2)^{n-3}}{\Gamma(n-3)} (1-x)^{n-3} \int_0^\pi \mathrm{d}\theta \int_0^\pi \mathrm{d}\phi \, (\sin\theta)^{n-3} (\sin\phi)^{n-4}$$
$$\times \int_0^1 \mathrm{d}y \int_0^1 \mathrm{d}z \, y^{(n/2)-2} (1-y)^{n-3} \{z(1-z)\}^{(n/2)-2}$$

- Angular part solvable using know integrals of type: Beenakker,Kuijf,van Neerven, Smith (Phys.Rev. D40 (1989) 54-82)

$$\int_0^\pi \mathrm{d}\theta \int_0^\pi \mathrm{d}\phi \, \frac{(\sin\theta)^{n-3} (\sin\phi)^{n-4}}{(a+b\cos\theta)^i (A+B\cos\theta+C\cos\phi\sin\theta)^j}$$

- z-Integration remaining can be solved analytically with many tricks

Outline

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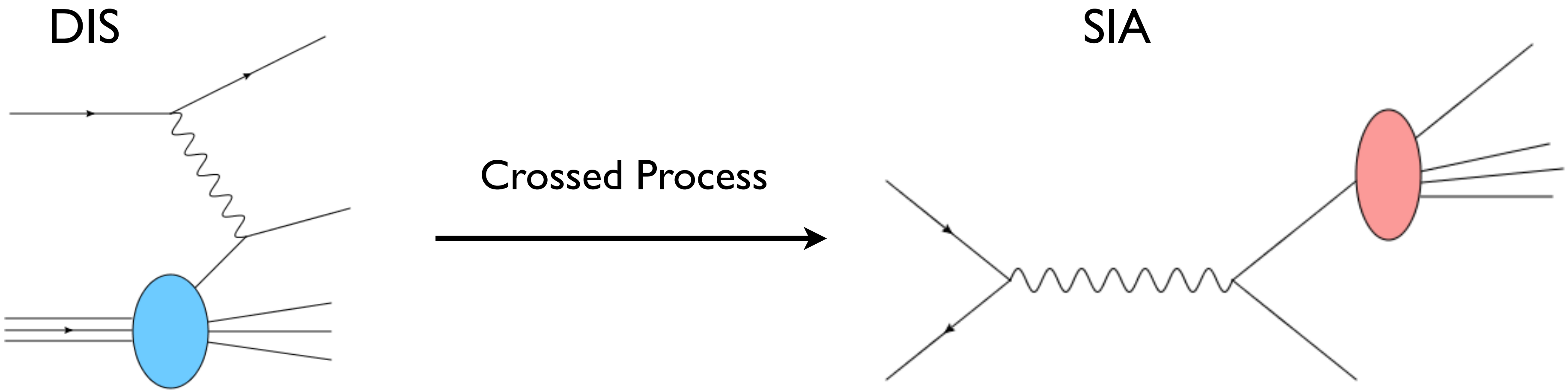
HMC + Threshold Resummation

Accardi, Anderle, Ringer (Phys. Rev. D 91, 034008 (2015))

We consider two corrections on standard pQCD calculation of SIA and DIS:

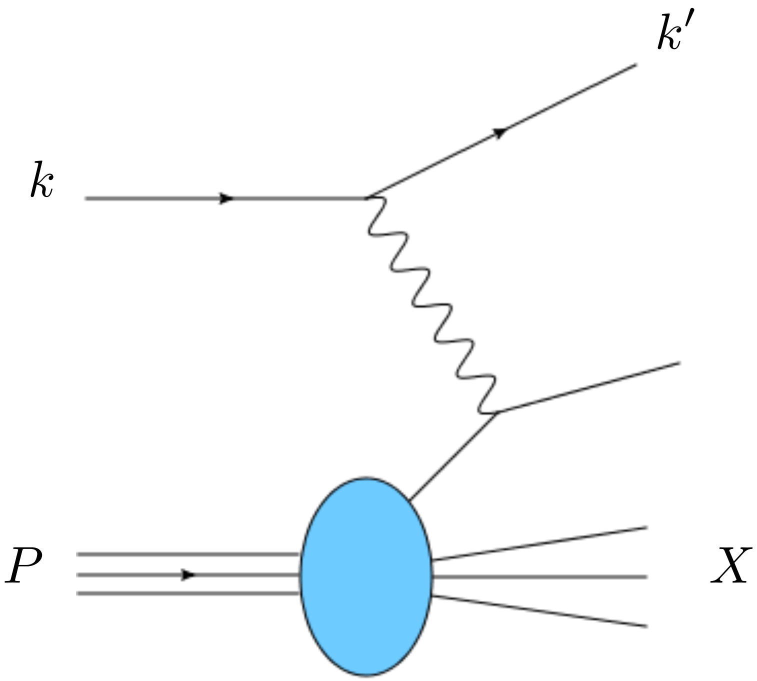
- Threshold resummation
- Hadron Mass Correction



Both corrections become relevant only in some kinematical phase space regions

Deep Inelastic Scattering

$l(k)p(P) \to l(k')X$



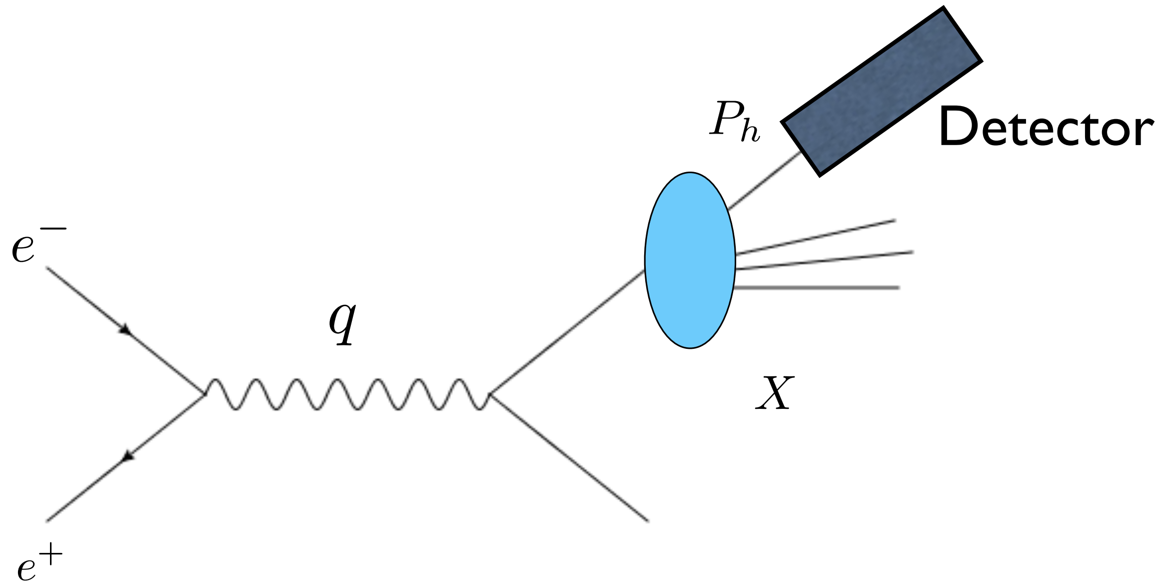
Defined kinematic variables:

$Q^2 \equiv -q^2 = -(k-k')^2$ Virtual Photon Energy

$y \equiv \frac{P \cdot q}{P \cdot k}$ $\propto$ to lepton scattered angle

$x \equiv \frac{Q^2}{2P \cdot q}$

Electron-Positron Annhilation



Defined kinematic varibles variables:

$$q^2 = Q^2$$ Virtual Photon Energy

$$x_E \equiv \frac{2P_h \cdot q}{Q^2} = \frac{2E_h}{\sqrt{s}}$$ (c.m.s)

Hadron multiplicities

$$R^h_{e^+e^-} \equiv \frac{1}{\sigma^{\text{tot}}} \frac{d^2\sigma^h}{dx_E \, d\cos\theta}$$

THRESHOLD RESUMMATION

For both DIS and SIA

in Mellin space: exponentiation of the one-loop results

$$C_{\rm res}^{q,N} = H_q\,\Delta_q^N J_q^N = H_q \exp\left[\int_0^1 dx \frac{x^{N-1}-1}{1-x} \int_{\mu_F^2}^{(1-x)Q^2} \frac{dp^2}{p^2} A_q[\alpha_s(p^2)] + \frac{1}{2} B_q[\alpha_s((1-x)Q^2)]\right]$$

where
$$A^{(1)} = C_F \;,\quad A^{(2)} = \frac{1}{2} C_F\, K = \frac{1}{2} C_F \left[C_A\left(\frac{67}{18} - \frac{\pi^2}{6}\right) - \frac{5}{9} N_f\right]$$
$$B^{(1)} = -\frac{3}{2} C_F \;.$$

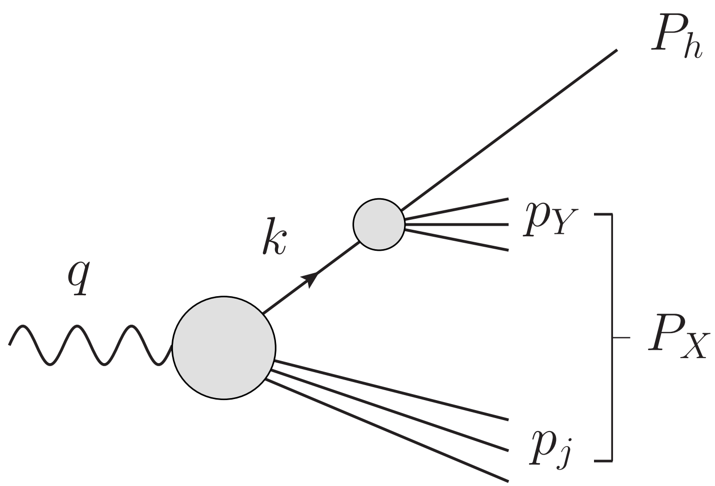
Catani, Trentadue; Sterman

Threshold Resummation acts for DIS and SIA in the same exact way and is relevant for the same Phase Space region:

DIS: $x \to 1$
SIA: $x_E \to 1$

Studying The Kinematics (SIA)

we study the kinematics in the $\gamma - h$ frame



$$q = q^+ \bar{n} + \frac{Q^2}{2q^+} n$$

$$P_h = P_h^+ \bar{n} + \frac{m_h^2}{2p_h^+} n$$

$$k = k^+ \bar{n} + \frac{k^2 + k_T^2}{2k^+} n + \mathbf{k}_T$$

where the light-cone vectors

$$n^\mu = \frac{1}{\sqrt{2}}(1,0,0,-1)$$

$$\bar{n}^\mu = \frac{1}{\sqrt{2}}(1,0,0,1)$$

$$n^2 = \bar{n}^2 = 0 \quad n \cdot \bar{n} = 1$$

$$a^+ = a \cdot n \quad a^- = a \cdot \bar{n}$$

we work in collinear factorization

$$z = \frac{P_h^+}{k^+}, \qquad \mathbf{k}_T = 0$$

Accardi, Qiu

The boson fractional momentum in respect to the hadron is not anymore $\cancel{x_E = \frac{2q \cdot P_h}{q^2}}$

but for SIA

$$P_h^+/q^+ = \xi_E = \frac{1}{2} x_E \left(1 + \sqrt{1 - \frac{4}{x_E^2} \frac{m_h^2}{Q^2}}\right)$$

and analogously for DIS

$$\xi = \frac{2x_B}{1 + \sqrt{1 + 4x_B^2 m_N^2 / Q^2}}$$

$\cancel{x_B = \frac{Q^2}{2q \cdot P_h}}$

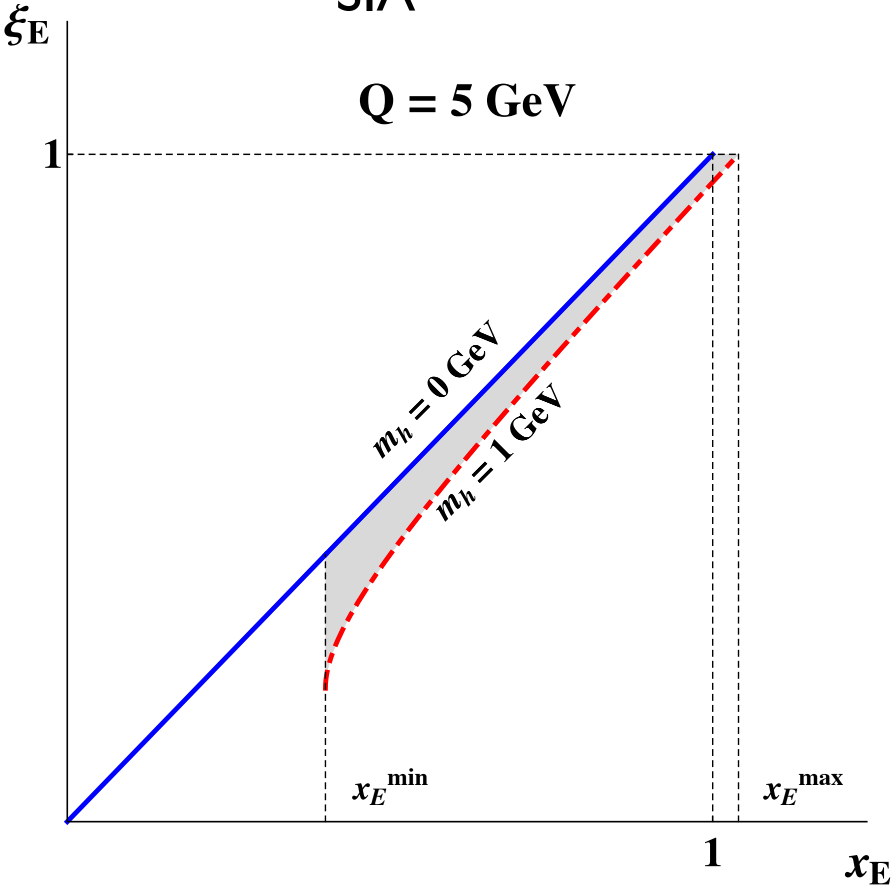
One should use those variables when calculating structure functions, since they represent the right physical fractional momentum variables

$$\mathcal{F}_i(x_E, Q^2) \rightarrow \mathcal{F}_i(\xi_E, Q^2)$$
$$\mathcal{F}_i(x_B, Q^2) \rightarrow \mathcal{F}_i(\xi, Q^2)$$

Albino et al.

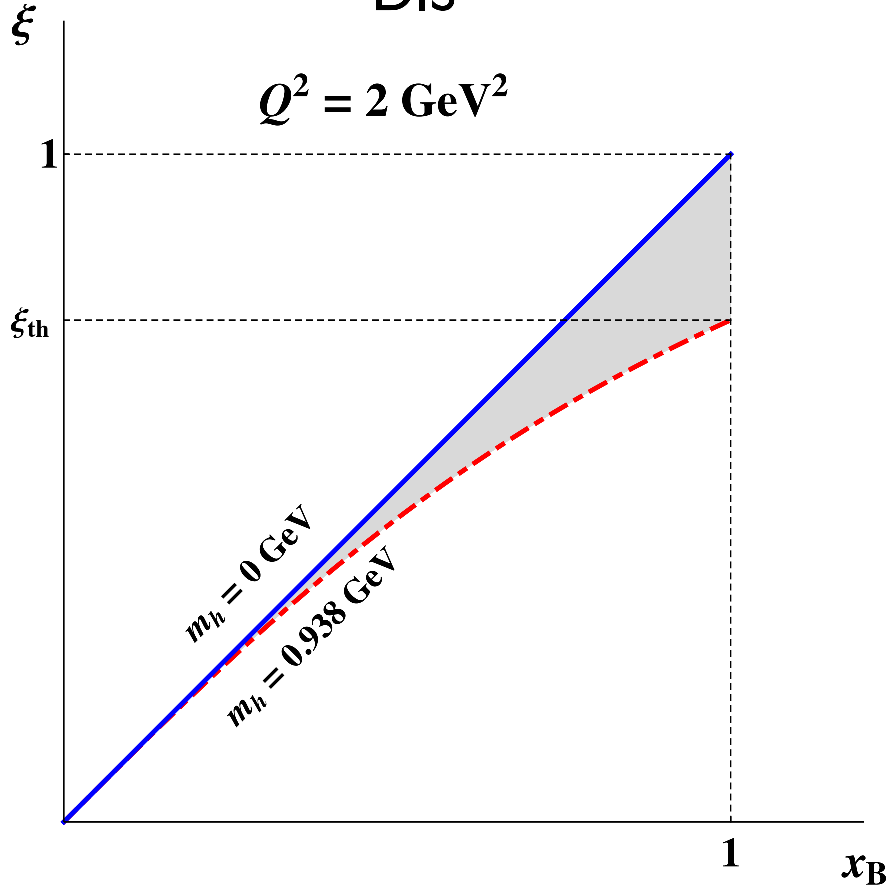
The hadron mass acts kinematically on the two processes in a very different way

SIA



Low x_E effect

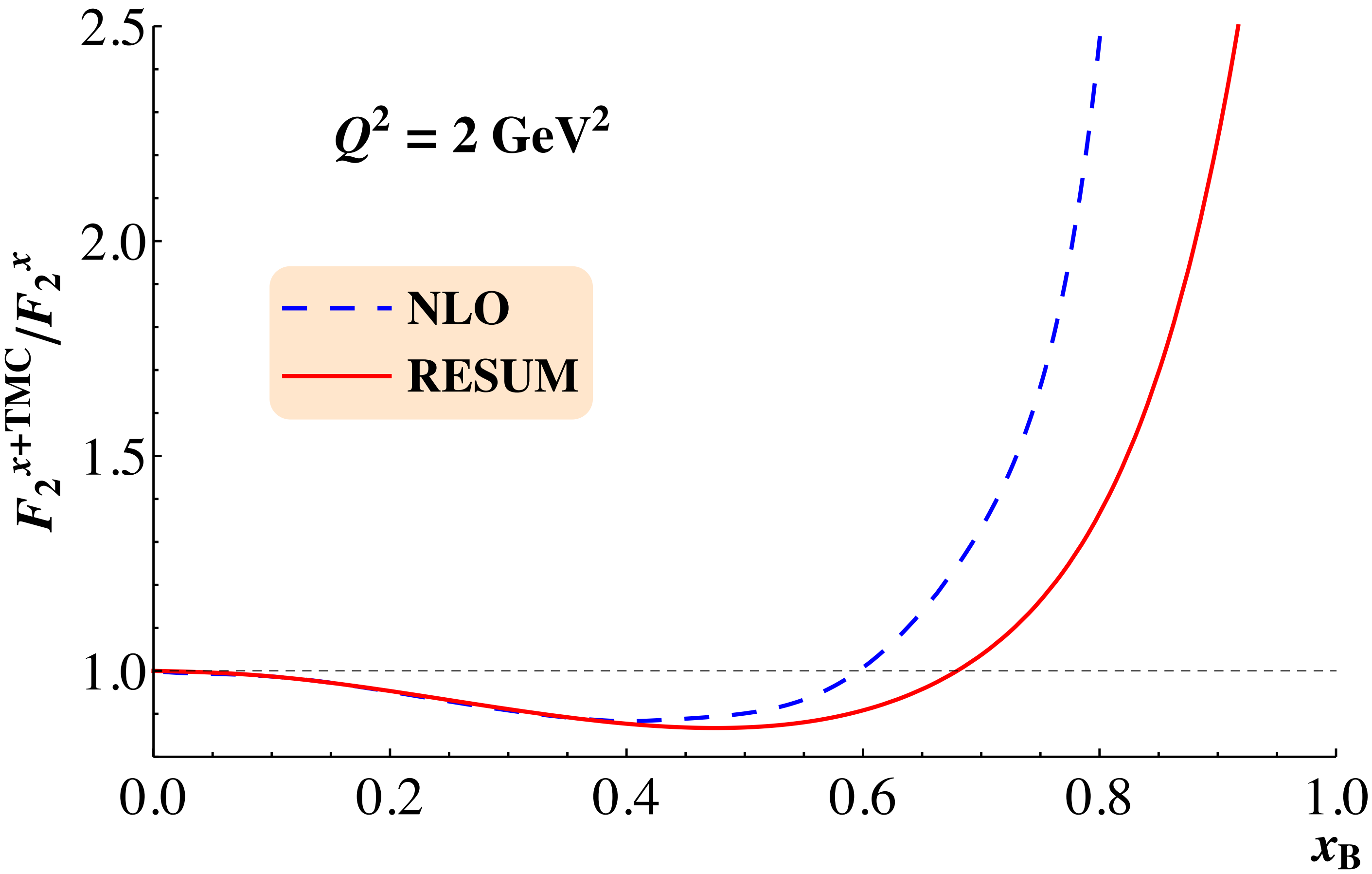
DIS



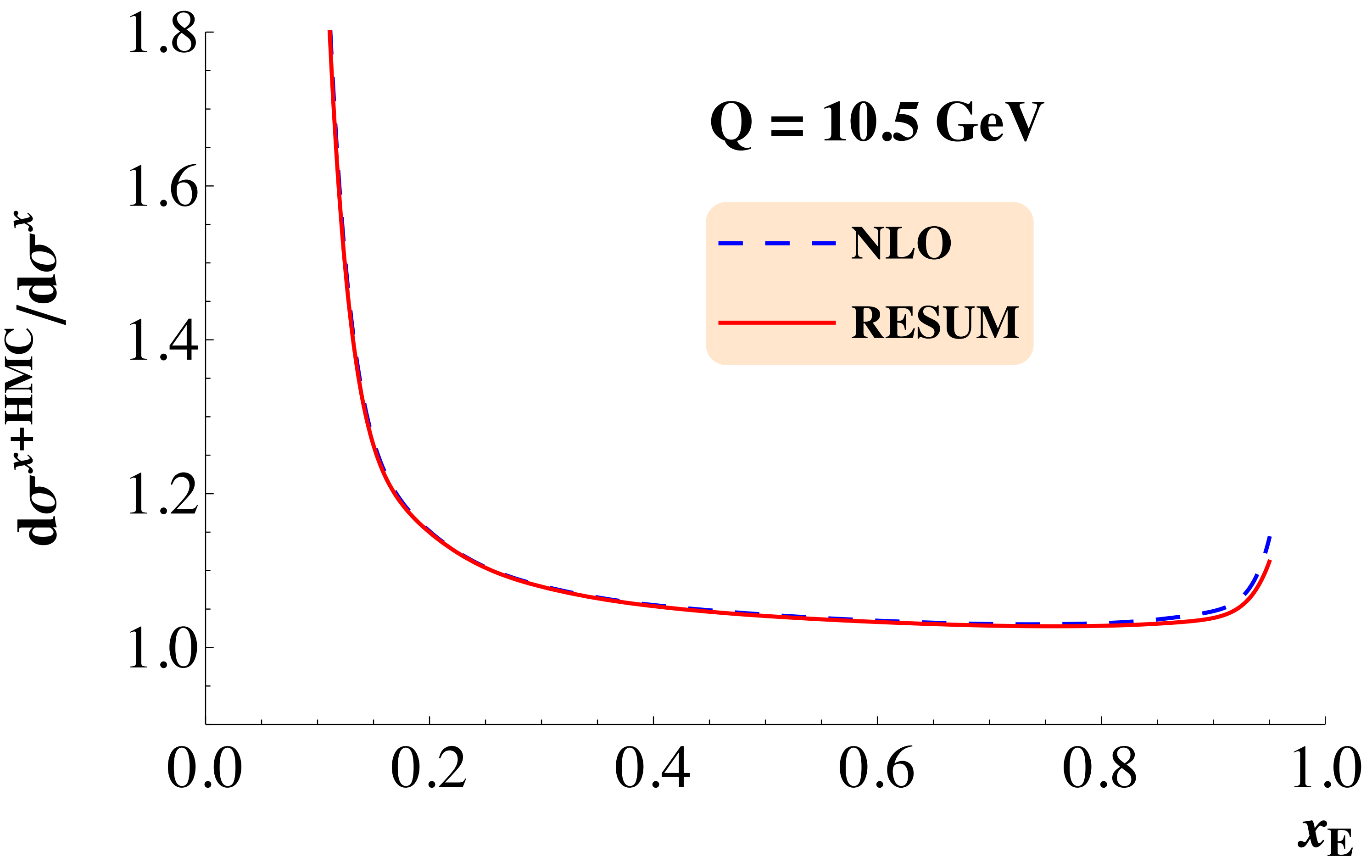
High x_B effect

AS RESUMMATION!!!

For DIS the TMC and Threshold Resummation do not act independently



No interplay between the two effects is found since they act independently on two different kinematical regions

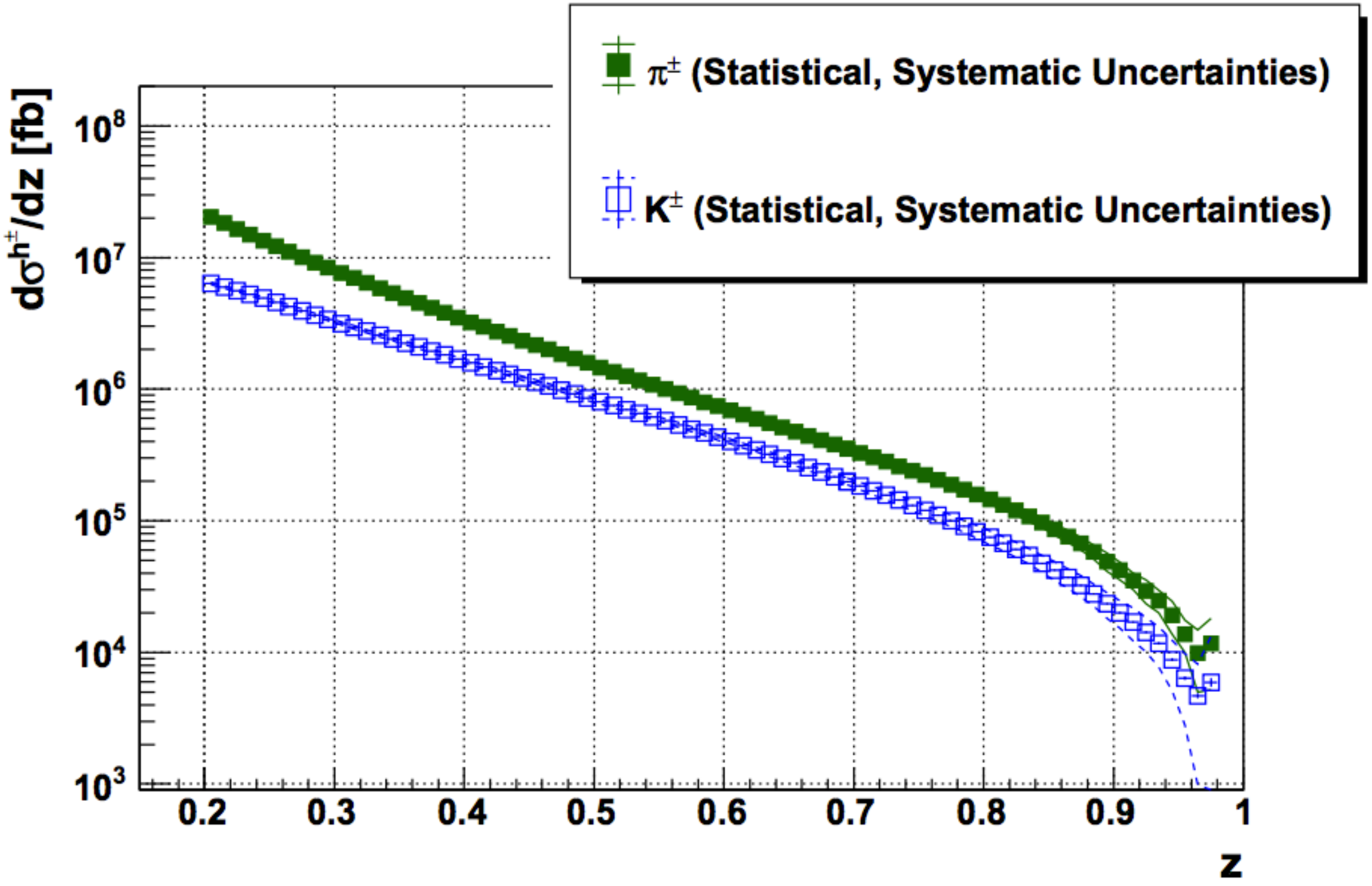


BELLE AND BABAR DATA

BELLE Kinematics

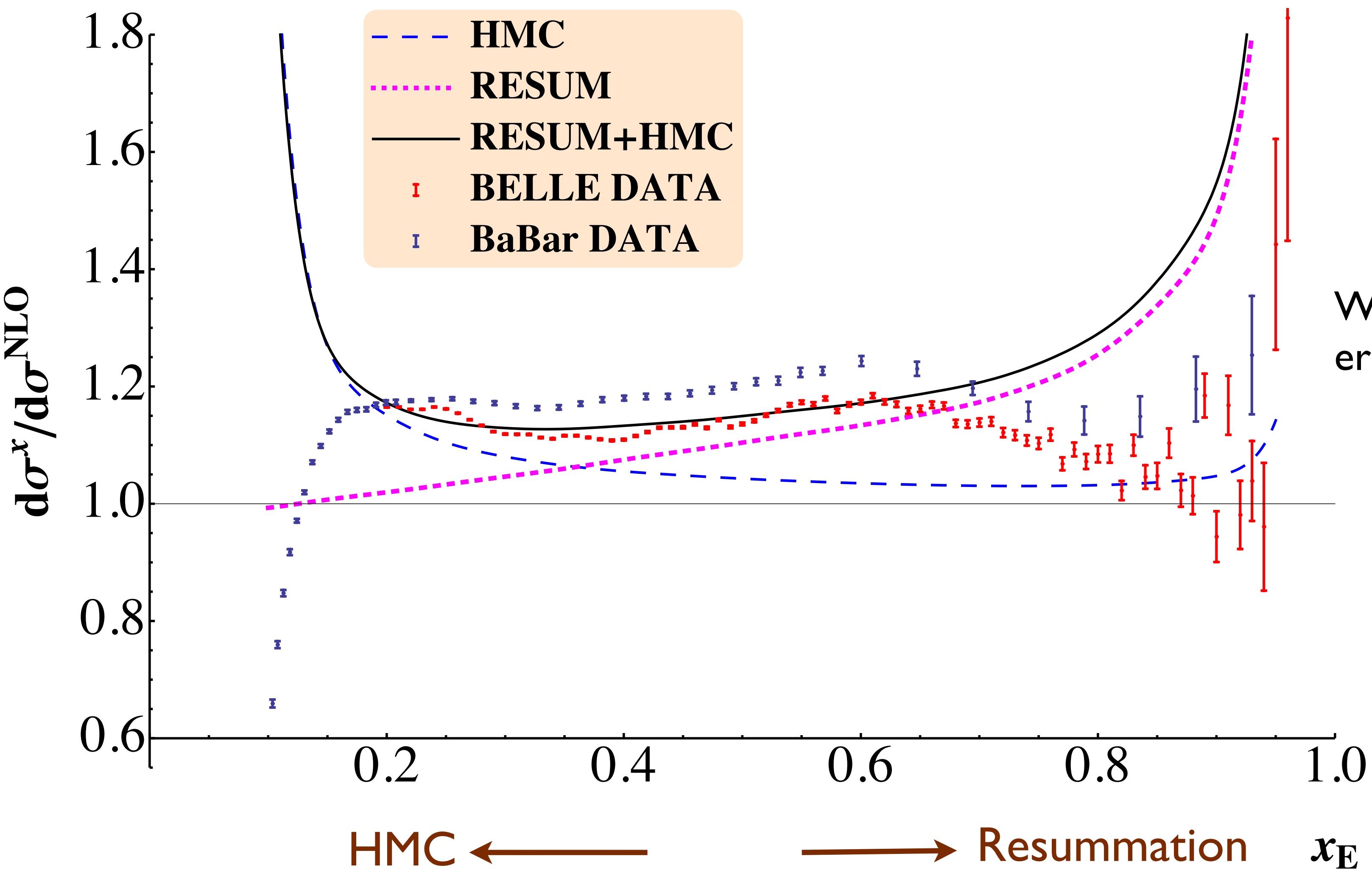
$\sqrt{s} = 10.5\,\mathrm{GeV}$

$-1 < cos\theta < 1$



Belle collaboration arXiv: 1301.6183

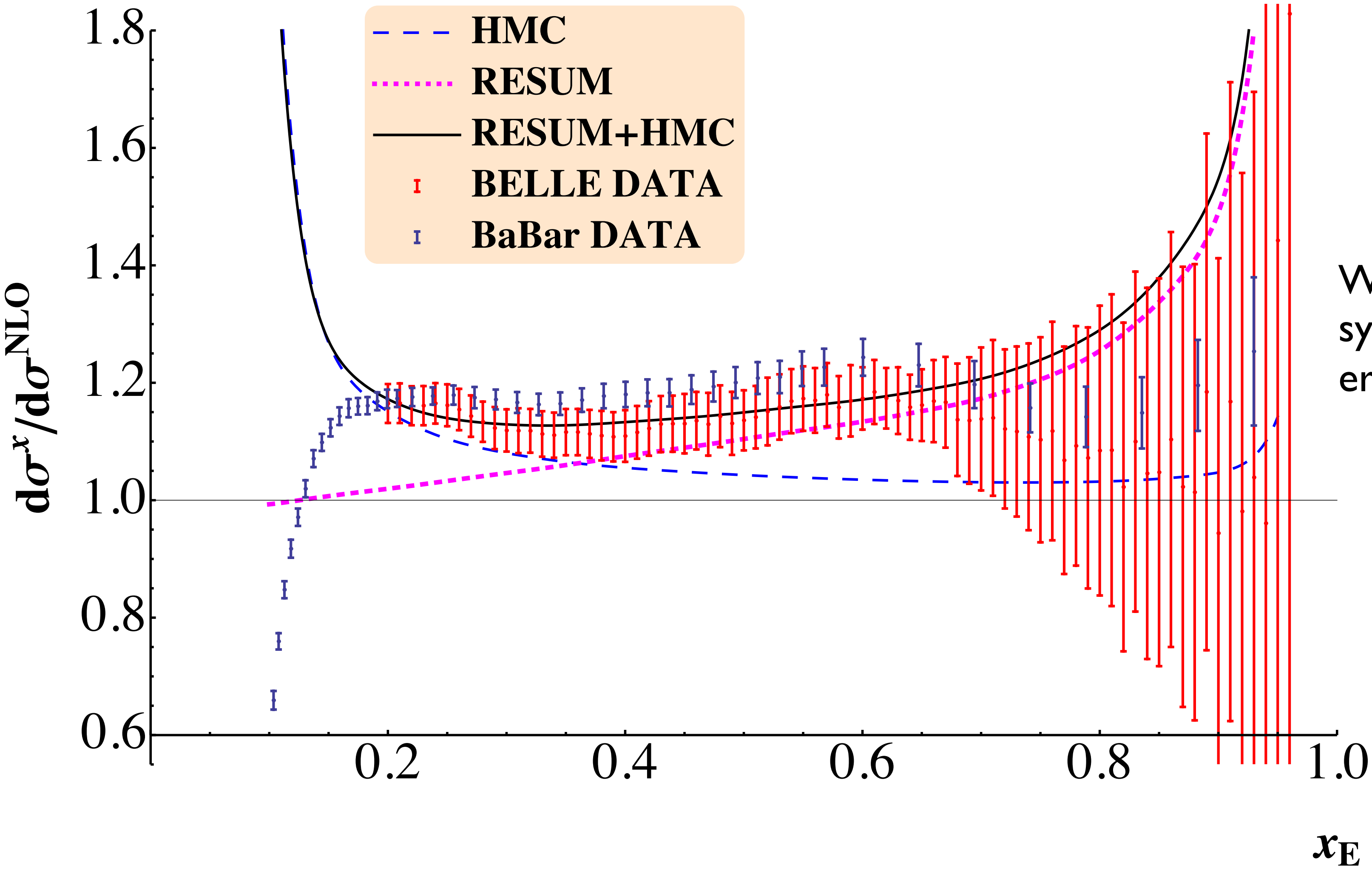
For Kaons one has to take into account HMC



With statistical errors

Belle collaboration arXiv: 1301.6183; BaBar collaboration arXiv: 1306.2895

For Kaons one as to take into account HMC



With systematical errors

Belle collaboration arXiv: 1301.6183; BaBar collaboration arXiv: 1306.2895

Outline

- Threshold Resummation for SIDIS
- HMC + Threshold Resummation
- Towards a Global NNLO FF Fit
- Conclusions

Towards a Global NNLO FF Fit

Anderle, Ringer, Stratmann

Ingredients needed to achieve the goal:

DATA SETS:

$SI\text{-}e^+e^-$ → old: TPC(Phys. Rev. Lett 61, 1263 (1998)), SLD(Phys. Rev. D59,052001 (1999)),
ALEPH(Phys. Lett. B357, 487 (1995)),
DELPHI(Eur. Phys. J. C5, 585 (1998),Eur. Phys. J.C6, 19 (1999))
OPAL(Eur. Phys. J. C16, 407 (2000),Eur. Phys. J.C7, 369 (1999)),
TASSO(Z. Phys.C42, 189 (1989))

SIDIS → old: EMC(Z. Phys. C52, 361 (1991)), JLAB(Phys. Rev. Lett. 98, 022001)

SI- p(anti-)p → old: CDF(Phys. Rev. Lett. 61,1819 (1988)), UA1(Nucl. Phys. B335,261 (1990)),
UA2(Z. Phys. C27, 329 (1985))

Towards a Global NNLO FF Fit

Anderle, Ringer, Stratmann

Ingredients needed to achieve the goal:

DATA SETS:

SI-e^+e^- → new: BaBar(Phys. Rev. D 88, 032011 (2013)), Belle(Phys. Rev. Lett. 111, 062002 (2013))

SIDIS → new: HERMES(Ph.D. thesis, Erlangen Univ., Germany, September 2005), Compass(PoS DIS 2013, 202 (2013)), JLAB@12GeV

SI- p(anti-)p → new: Phenix(Phys. Rev. D 76,051106 (2007)), Alice(Phys. Lett. B 717, 162 (2012).), Brahms(Phys. Rev. Lett. 98, 252001 (2007)), Star(Phys. Rev. Lett. 97, 152302 (2006))

pp → (Jet h)X → future: Star, CMS(JHEP 1210, 087 (2012)), Alice(arXiv:1408.5723), Atlas(Eur. Phys. J. C 71, 1795 (2011))

TOWARDS A GLOBAL NNLO FF FIT

Anderle, Ringer, Stratmann

Ingredients needed to achieve the goal:

NNLO EVOLUTION KERNELS:

Splitting functions →

NNLO-Non Singlet: Mitov, Moch, Vogt(Phys.Lett. B638 (2006) 61-67)

NNLO-Singlet: Moch, Vogt(Phys.Lett.B659 (2008) 290-296)

NNLO-Singlet: Almasy, Mitov, Moch, Vogt(Nucl.Phys. B854 (2012)) 133-152)

Both computed in x-Space and in Mellin Space

TOWARDS A GLOBAL NNLO FF FIT

Anderle, Ringer, Stratmann

Ingredients needed to achieve the goal:

NNLO COEFFICINT FUNCTIONS:

SI-e^+e^- → **x-Space** Rijken, van Neerven (Phys.Lett.B386(1996)422, Nucl.Phys.B488(1997)233,Phys.Lett.B392(1997)207)

Mellin-Space Mitov, Moch (Nucl.Phys.B751 (2006) 18-52)
Blümlein, Ravindran (Nucl.Phys.B749 (2006) 1-24)

SIDIS → NOT COMPUTED YET but work in progress

$$\gamma q' \to q\bar{q}q'$$
$$\gamma g \to q\bar{q}q'$$

Anderle, de Florian, Rotstein, Vogelsang

SI- p(anti-)p → NOT COMPUTED YET

pp→ (Jet h)X → NOT COMPUTED YET

TOWARDS A GLOBAL NNLO FF FIT

Anderle, Ringer, Stratmann

Ingredients needed to achieve the goal:

NNLO COEFFICINT FUNCTIONS:

SIDIS → Soft gluon Resummed results (can be expanded @ NNLO)

Anderle, Ringer, Vogelsang (Phys.Rev. D87 (2013) 094021, Phys.Rev. D87 (2013) 3, 034014)

SI- p(anti-)p → Soft gluon Resummed results (can be expanded @ NNLO)

Work in progress for $\frac{d\sigma}{dp_T d\eta}^{(NNLL)}$ Hinderer, Ringer, Sterman, Vogelsang

pp→ (Jet h)X → Resummed results (can be expanded @ NNLO)

Work in progress from T. Kaufmann, Vogelsang

TOWARDS A GLOBAL NNLO FF FIT

Anderle, Ringer, Stratmann

Ingredients needed to achieve the goal:

NNLO COEFFICINT FUNCTIONS:

To include the last processes we need a

NNLO Mellin Space Fitting Program

The NNLO Evolution Code "Pegasus_FF"

Existing NNLO Evolution CODES:

X-SPACE APFEL(time-like version C/C++, Fortran77, Python)
Bertone1,Carrazza, Rojo (CERN-PH-TH/2013-209)

Mellin SPACE MELA(Fortran77)
Bertone1,Carrazza, Nocera (CERN-PH-TH-2014-265)

Newly born:

Mellin SPACE Pegasus_FF (Fortran77) → based on Pegasus(Fortran77)
Anderle, Ringer, Stratmann — Vogt (Comput.Phys.Commun.170:65-92,2005)

Our SIA Fit

Parametrization of light patrons FF @ μ_0

$$D_i^h(z,Q_0) = \frac{N_i z^{\alpha_i}(1-z)^{\beta_i}[1+\gamma_i(1-z)^{\delta_i}]}{B[2+\alpha_i,\beta_i+1]+\gamma_i B[2+\alpha_i,\beta_i+\delta_i+1]}$$

So that $N_i = \int_0^1 z D_i^h dz$

Heavy Quark Treatment:

NON PERTURBATIVE INPUT: at $\mu > m_q$ the evolution is set to evolve with $n_f + 1$ for flavours and for the q-heavy quark FF the same functional form as for the light quark is set at $\mu = m_q$

Data sets:

15 Data Set: from Sld, Aleph, Delphi, Opal, Tpc, BaBar, Belle either inclusive, uds tagged, b tagged or c tagged. We use a GLOBAL CUT 0.075<z<0.95

Parameters for Pi+

With only SIA one needs some extra constrains:

parameter	LO	NLO	NNLO
$N_{u+\bar{u}}$	0.735	0.572	0.579
$\alpha_{u+\bar{u}}$	-0.371	-0.705	-0.913
$\beta_{u+\bar{u}}$	0.953	0.816	0.865
$\gamma_{u+\bar{u}}$	8.123	5.553	4.062
$\delta_{u+\bar{u}}$	3.854	1.968	1.775
$N_{s+\bar{s}}$	0.243	0.135	0.271
$\alpha_{s+\bar{s}}$	*-0.371*	*-0.705*	*-0.913*
$\beta_{s+\bar{s}}$	*4.807*	*2.784*	*2.640*
N_g	0.273	0.211	0.174
α_g	2.414	2.210	1.595
β_g	*8.000*	*8.000*	*8.000*
$N_{c+\bar{c}}$	0.405	0.302	0.338
$\alpha_{c+\bar{c}}$	-0.164	-0.026	-0.233
$\beta_{c+\bar{c}}$	5.114	6.862	6.564
$N_{b+\bar{b}}$	0.462	0.405	0.445
$\alpha_{b+\bar{b}}$	-0.090	-0.411	-0.695
$\beta_{b+\bar{b}}$	4.301	4.039	3.681
$\gamma_{b+\bar{b}}$	24.85	15.80	11.22
$\delta_{b+\bar{b}}$	12.25	11.27	9.908

5 free param needed

charge conjugation and isospin symmetry $D^{\pi^\pm}_{u+\bar{u}} = D^{\pi^\pm}_{d+\bar{d}}$,

1 free param, 2 fixed by

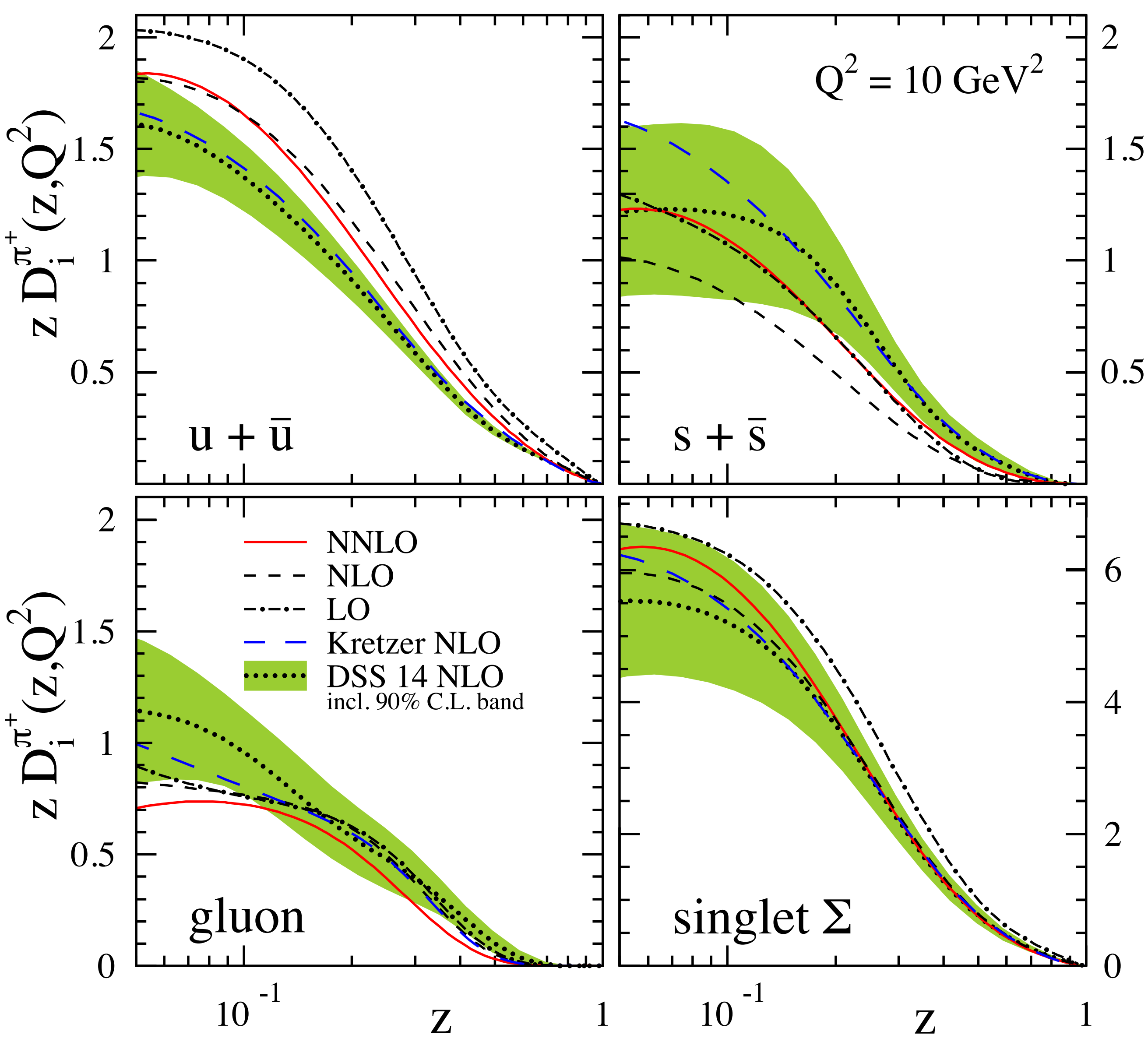
$\alpha_{s+\bar{s}} = \alpha_{u+\bar{u}}, \quad \beta_{s+\bar{s}} = \beta_{u+\bar{u}} + \delta_{u+\bar{u}}$

2 free param, 1 fixed

3 free param

5 free param

TOT = 16 free param

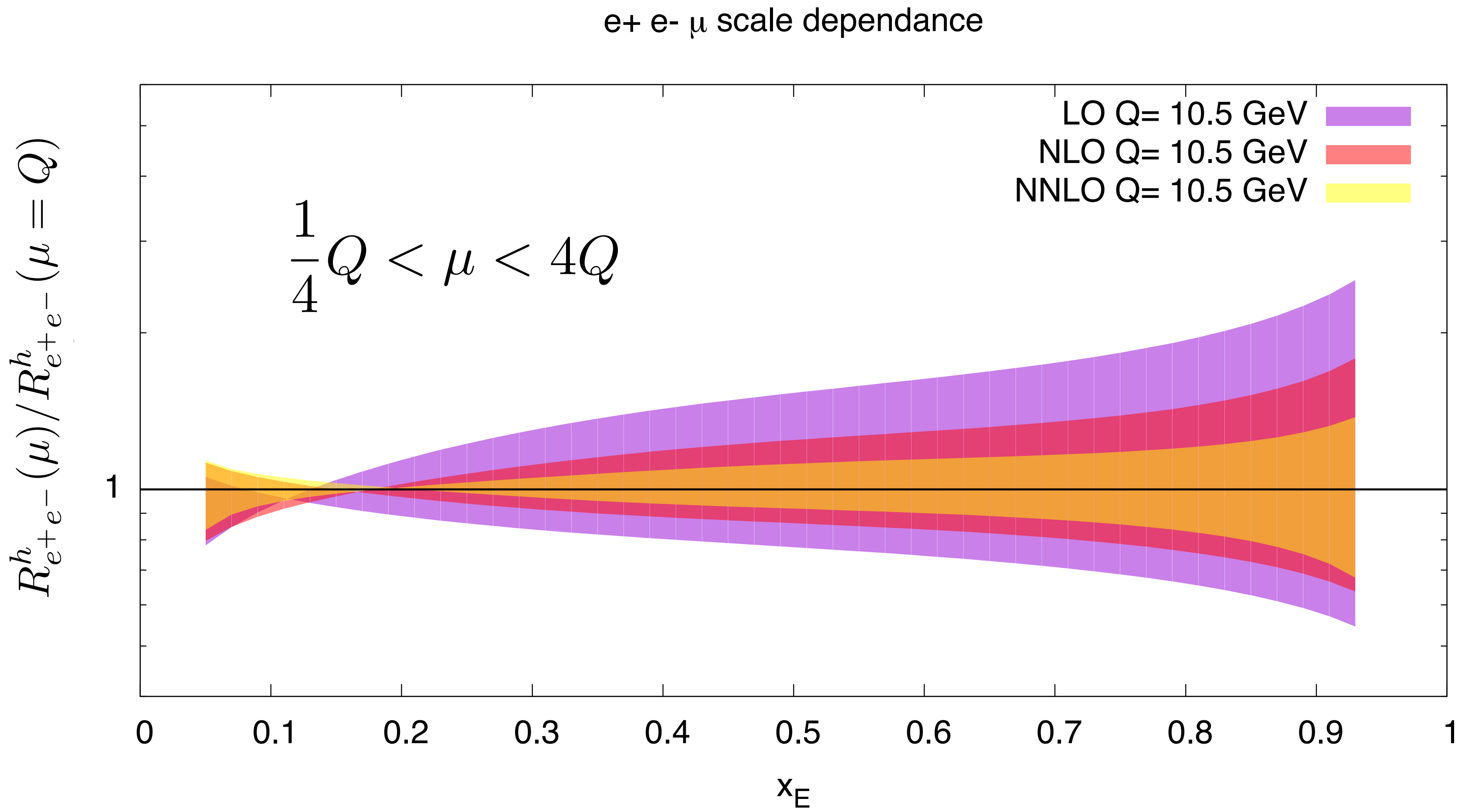


Kretzer FFS (Phys. Rev. D 62, 054001 (2000))

DSS FFS (Phys. Rev. D 91, 014035 (2015))

$$D^h_\Sigma = \sum_{i=1}^{n_f} \left(D^h_{q_i} + D^h_{\bar{q}_i}\right)$$

Scale Dependence



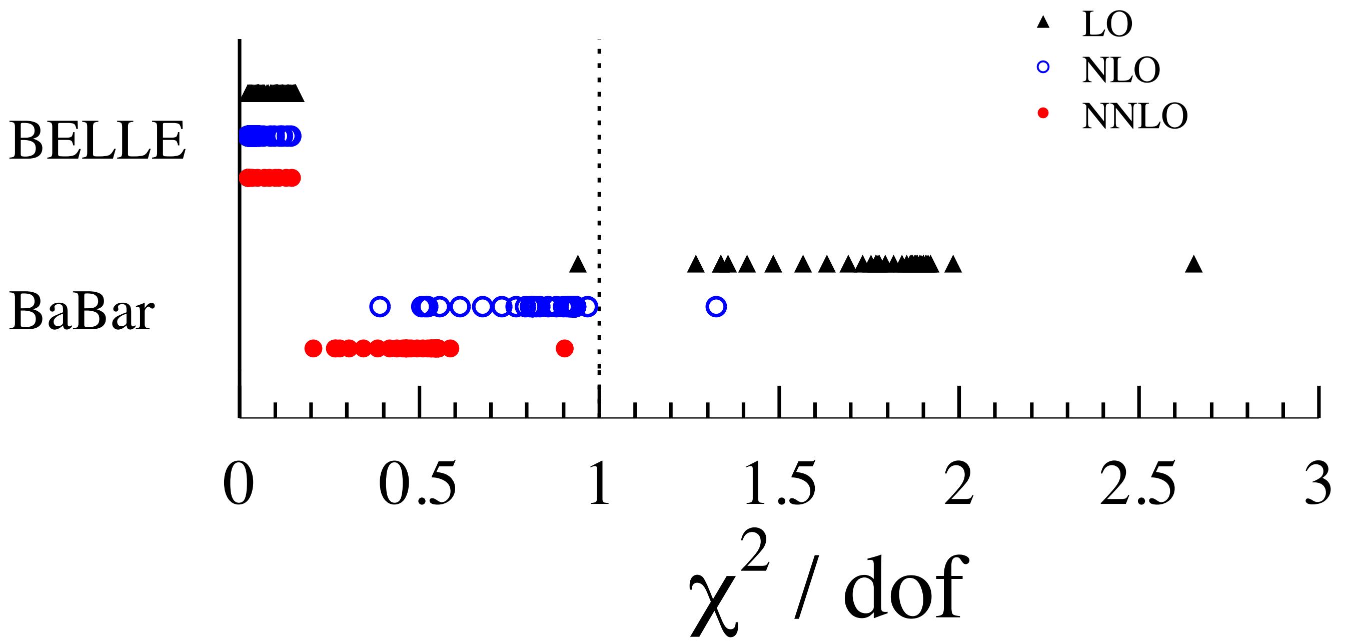
Multiplicity $R^h_{e^+e^-} \equiv \frac{1}{\sigma^{\mathrm{tot}}} \frac{d^2\sigma^h}{dx_E \, d\cos\theta}$

using input parameter for FF of Kretzer (Phys.Rev. D62 (2000) 054001) and truncated-solution

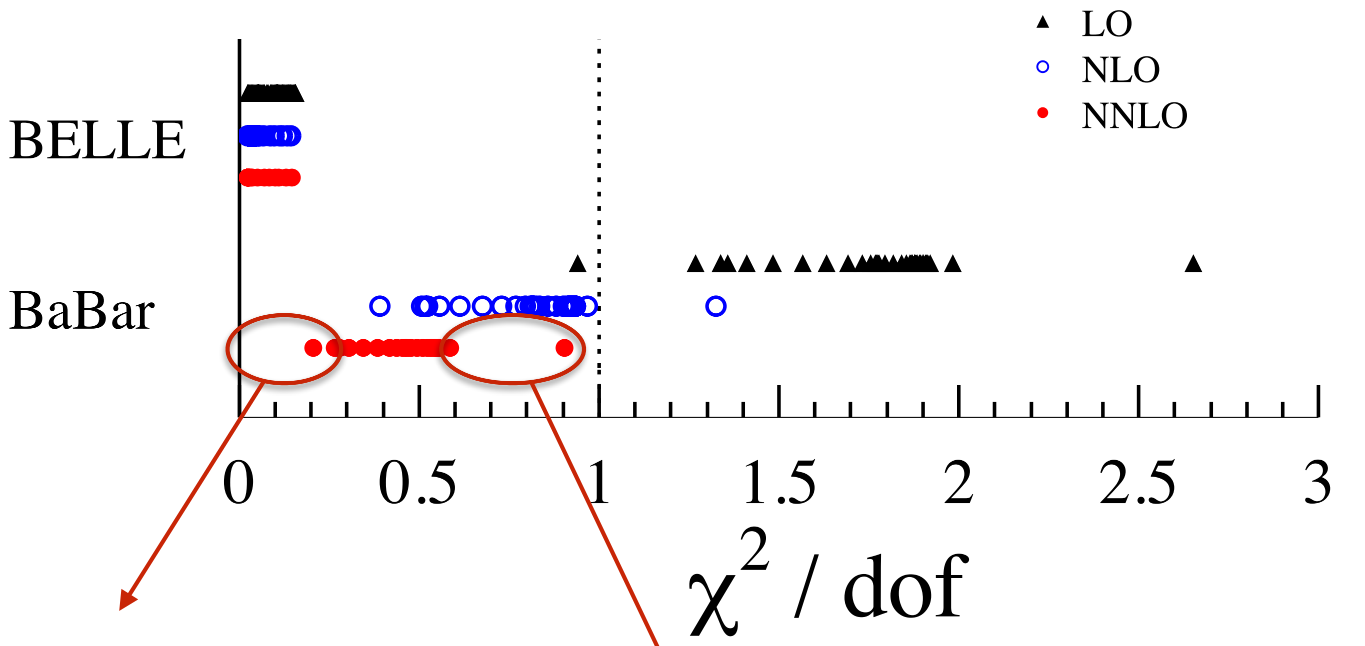
χ^2 Comparison

experiment	data type	# data in fit	χ^2 LO	NLO	NNLO
SLD [40]	incl.	23	15.0	14.8	15.5
	uds tag	14	9.7	18.7	18.8
	c tag	14	10.4	21.0	20.4
	b tag	14	5.9	7.1	8.4
Aleph [41]	incl.	17	19.2	12.8	12.6
Delphi [42]	incl.	15	7.4	9.0	9.9
	uds tag	15	8.3	3.8	4.3
	b tag	15	8.5	4.5	4.0
Opal [43]	incl.	13	8.9	4.9	4.8
Tpc [44]	incl.	13	5.3	6.0	6.9
	uds tag	6	1.9	2.1	1.7
	c tag	6	4.0	4.5	4.1
	b tag	6	8.6	8.8	8.6
BaBar [10]	incl.	41	108.7	54.3	37.1
Belle [9]	incl.	76	11.8	10.9	11.0
TOTAL:		288	241.0	190.0	175.2

χ^2 Comparison



χ^2 COMPARISON



Vogt, arXiv:1108.2993 (JHEP);
Kom,Vogt,Yeats, arXiv:1207.5631 (JHEP);

Small z Logs

$$\alpha_s^k \frac{\ln^{2k}(z)}{z}$$

+~~Hadron Mass~~ Cor.

Threshold Logs

$$\alpha_s^k \left(\frac{\ln^{2k-1}(1-x)}{1-x} \right)_+$$

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Conclusions

- We have extended threshold resummtion for SIDIS and begun the calculation of the tree level graphs appearing at NNLO for F_L
- We have presented a framework for combined HMC with Resummation. Future extension to SIDIS
- We have presented our e+e- only FF NNLO fit and its extension to a global fit
- Future resummed FF fit including Log(N)/N

Thanks for Your Attention

Any questions?