Mathematica Toolbox for PDF Uncertainties and Applications to New Physics Searches

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Outline

Parton Distribution Functions

ManeParse

- Purpose
- Construction
- Speed
- Validation
- Examples

Applications to New Physics Searches

- Intrinsic Bottom Quark
- Ultrahigh Energy Neutrinos

Future Improvements and Applications

Parton Distribution Functions (PDFs)

- Parameterized fits to experimental data
  - Different collaborations have different fits
- Describe the momentum fraction carried by each component of hadron
- Broken down into grids by:
  - All quark flavors + gluon
  - Hard scattering energy Q
  - Bjorken x
- Essential for relating theoretical predictions to experiment

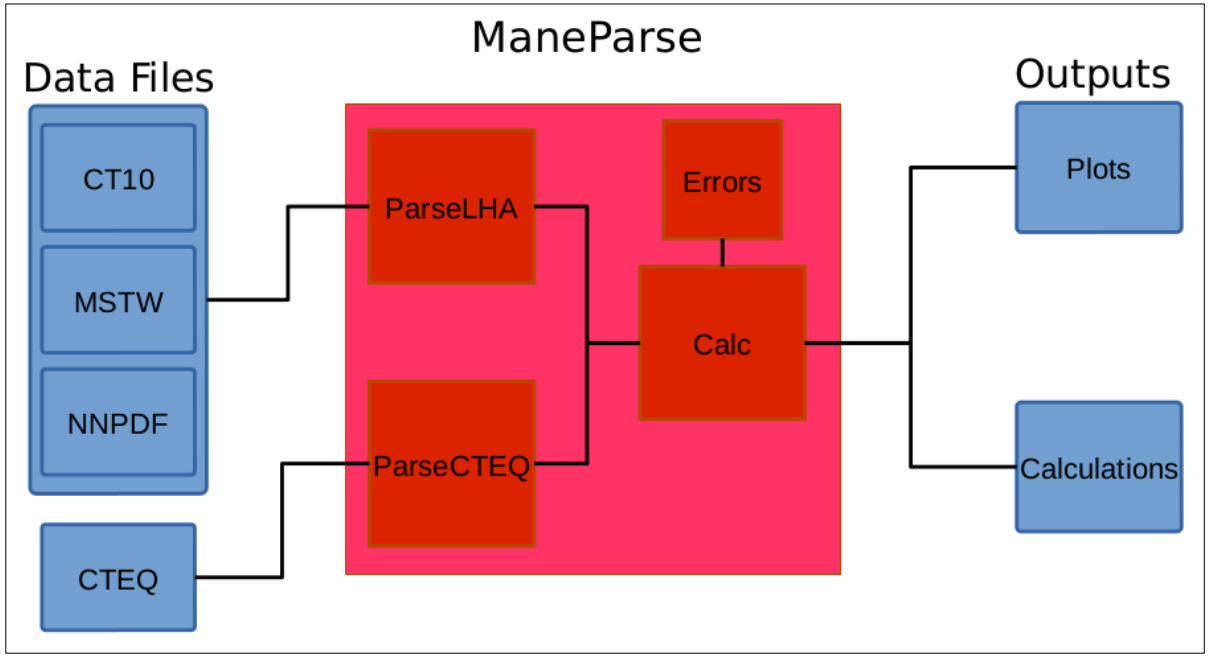
Purpose

- Develop Lightweight PDF Reader for multiple collaboration's PDFs
  - LHAPDF6
  - CTEQ PDS
- Custom 4-point Lagrange Interpolation routine
  - Fast, reliable, transparent
  - Gives grids functional dependence
- Mathematica environment
  - User-Friendly
  - Built-in Plotting and calculation functions
- Implement multiple Error propagation techniques
  - Hessian
  - Monte Carlo
- Able to do calculations of observables
  - Cross Sections
  - Luminosities

ManeParse

- pdfParseLHA
- pdfParseCTEQ
- pdfCalc
- pdfErrors

ManeParse Schematic



Available User Functions

▼ pdfCalc`			
pdfAlphaS	pdfGetInfo	pdfLowFunction	pdfSetList
pdfFlavor	pdfGetQlist	pdfNumQpartition	pdfSetListDisplay
pdfFunction	pdfGetXlist	pdfReset	pdfXmin
▼ pdfErrors`			
pdfHessianCorrelation	pdfLuminosity	pdfMCCorrelation	
pdfHessianError	pdfMCCentral	pdfMCError	
▼ pdfParse`			
pdfFamilyParseCTEQ	pdfParseCTEQ		
▼ pdfParseLHA`			
pdfFamilyParseLHA	pdfParseLHA		

Able to load unlimited data sets at once

CTEQ, NNPDF, MSTW, HERA... and more

Speed

PDF Set	Number of Files	Read Time	Read Time per File	Time 1000 x pdfFunction Call
CT10	53	1.852258	0.0349483	0.635051
MSTW	41	1.193042	0.0290986	0.592335
NNPDF	101	4.109711	0.04069021	0.606711
CTEQ66	45	0.914369	0.0203193	0.624650

Times in Seconds

- Speeds comparble to LHAPDF6 and CTEQ code (C++ and Fortran respectively)
- Hundredths of a second to read each file
- Approximately 2000 pdfFunction calls per second

Validation

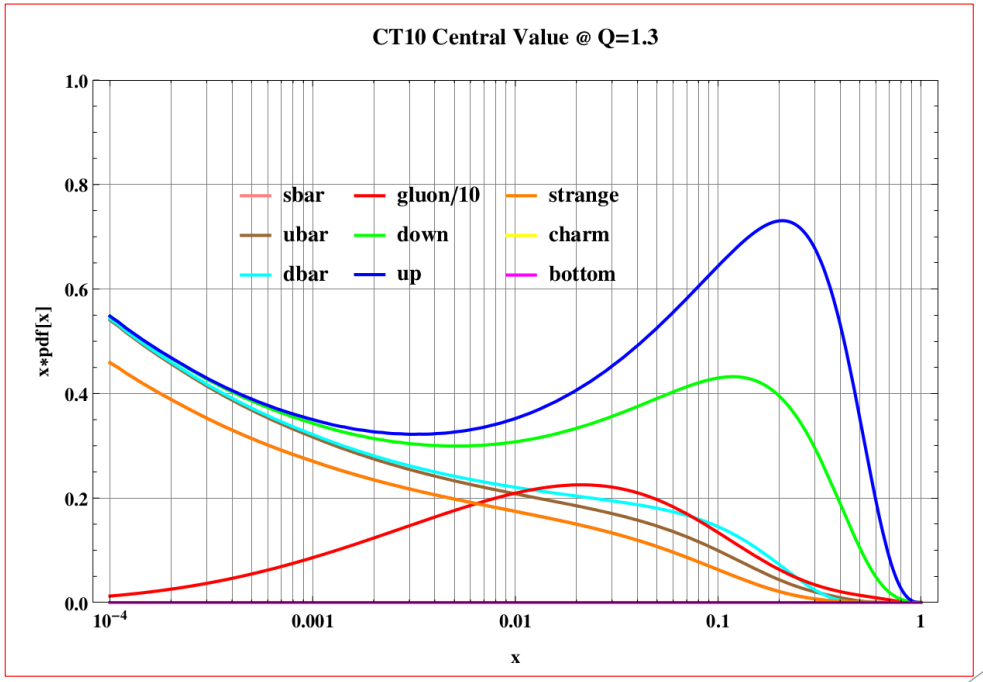
- Sum Rules provide important “sanity check”
- Momentum fraction of all partons must add to 1
- Any errors in parsing or interpolating would disrupt the sum

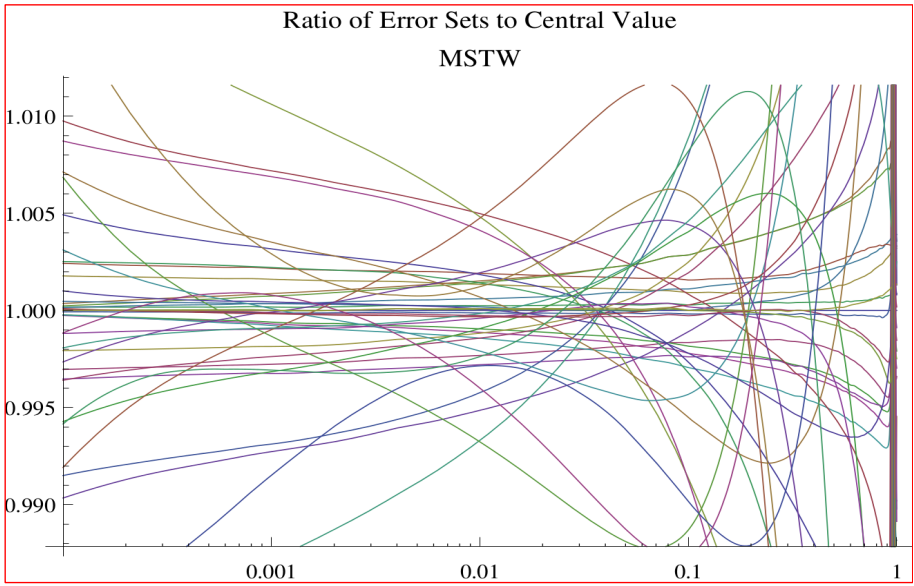
Sum Rules for multiple PDF Sets

Flavor	CT10	NNPDF	MSTW	CTEQ66
bbar	0.	0.	0.	0.
cbar	0.01	0.01	0.01	0.01
sbar	0.02	0.01	0.02	0.02
ubar	0.03	0.03	0.03	0.03
dbar	0.04	0.03	0.04	0.04
gluon	0.45	0.5	0.47	0.45
down	0.14	0.13	0.13	0.14
up	0.28	0.26	0.27	0.28
strange	0.02	0.01	0.02	0.02
charm	0.01	0.01	0.01	0.01
bottom	0.	0.	0.	0.
Total	0.999677	0.999563	1.00467	0.99969

Examples: I

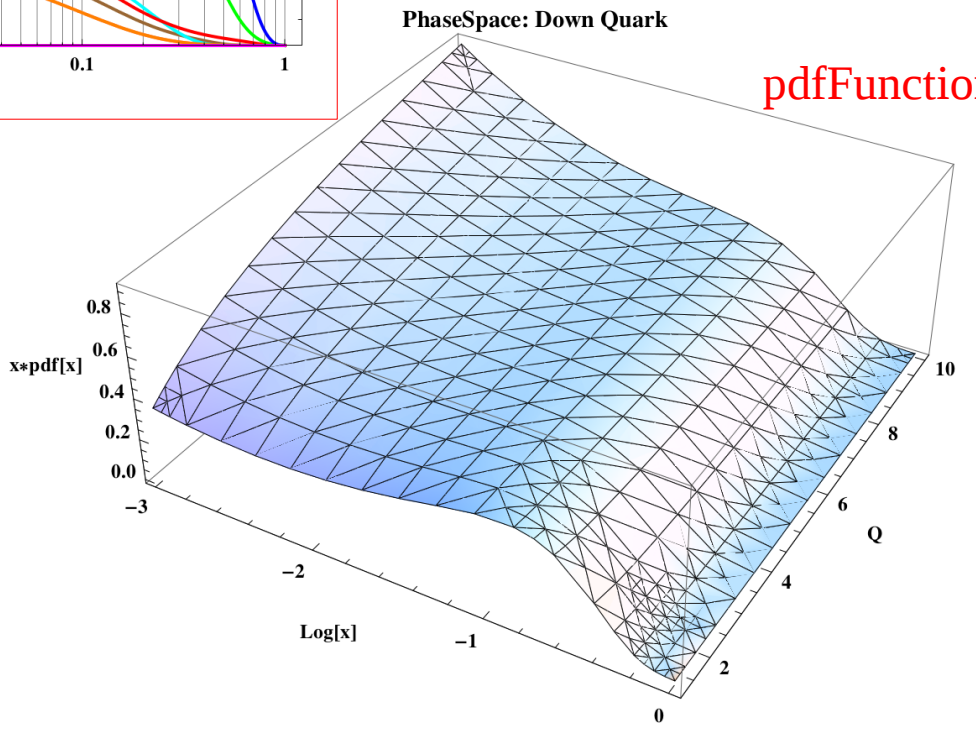
Plot of Multiple Partons for a Single PDF



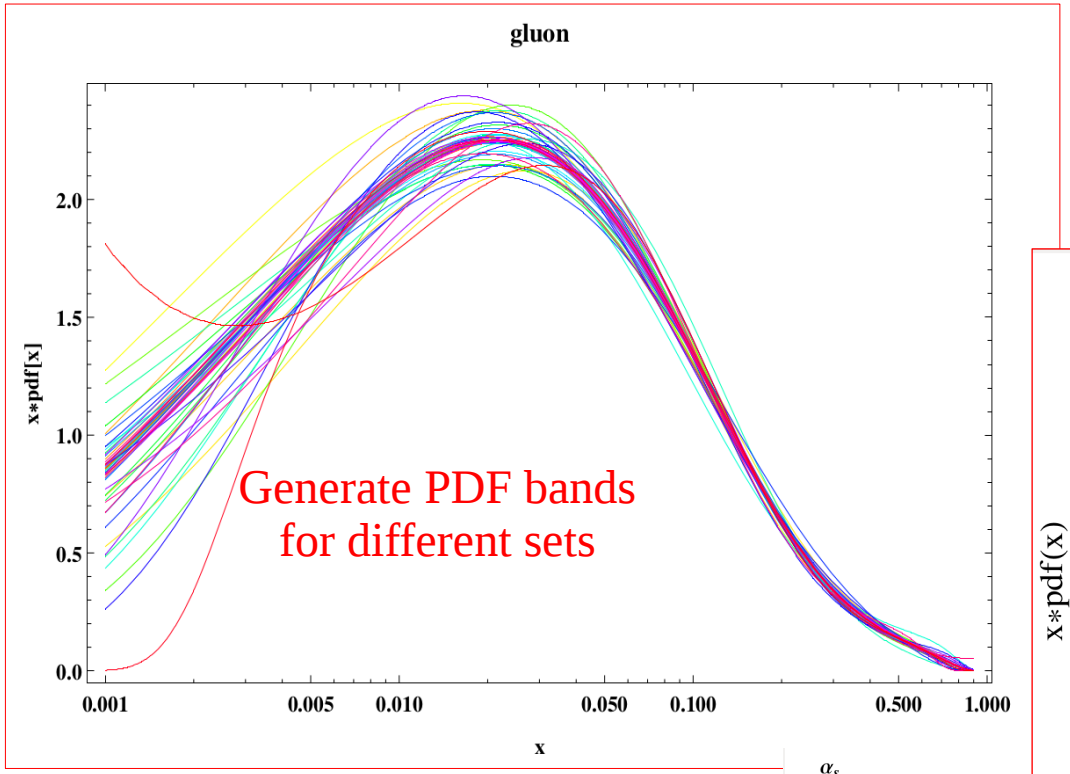


Change PDF Sets easily
pdfFunction[setNumber,flavor,x,Q]

Visualize Phase Space with 3D plotting

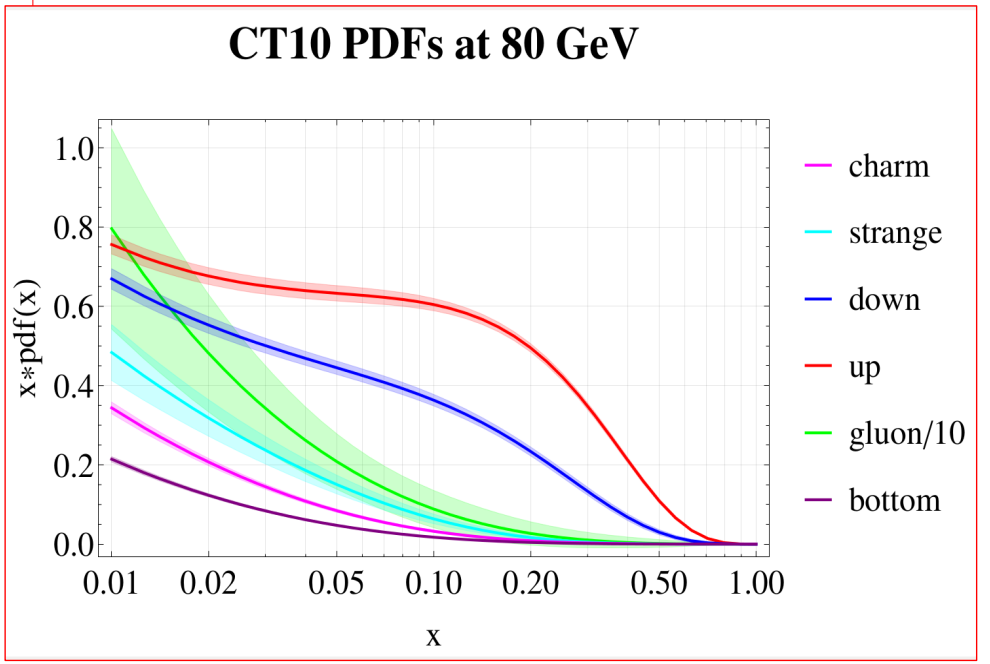


Examples: II



Full sets of PDFs inside Mathematica

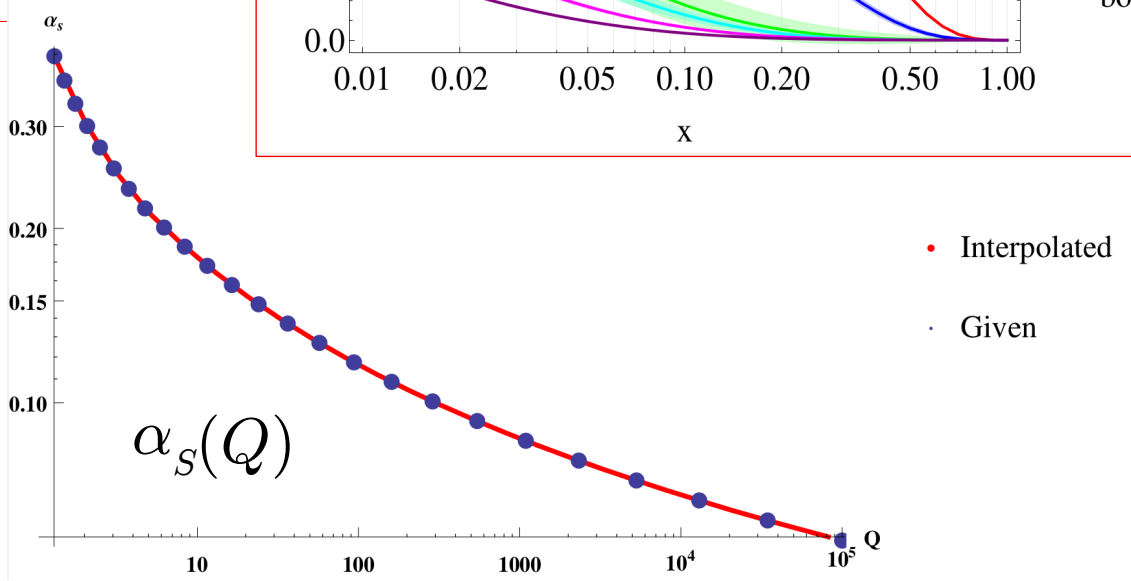
Easy to manipulate



$\alpha_S(Q)$ is available

Interpolated values match grid values

Proper α_S is essential for NLO+ calculations



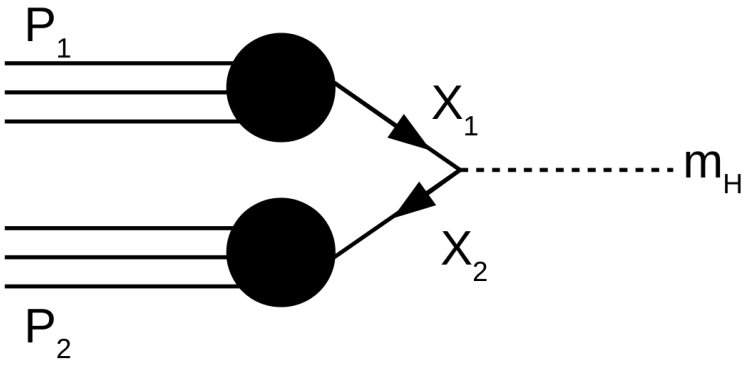
Luminosities at LHC

Luminosities connect experimental and theoretical cross sections

$$\sigma_{pp \to H+X} = \sum_{ij} \int_{\tau}^{1} d\tau \, \frac{d\mathcal{L}_{ij}}{d\tau} \, \hat{\sigma}_{ij}(\hat{s})$$

$$\frac{d\mathcal{L}_{ij}}{d\tau}(\tau, \mu) = \frac{1}{1+\delta_{ij}} \int_{\tau}^{1} \frac{1}{x} \left[f_i(x, \mu) \, f_j(\tau/x, \mu) + f_j(x, \mu) \, f_i(\tau/x, \mu) \right] dx$$

Production of heavy scalar

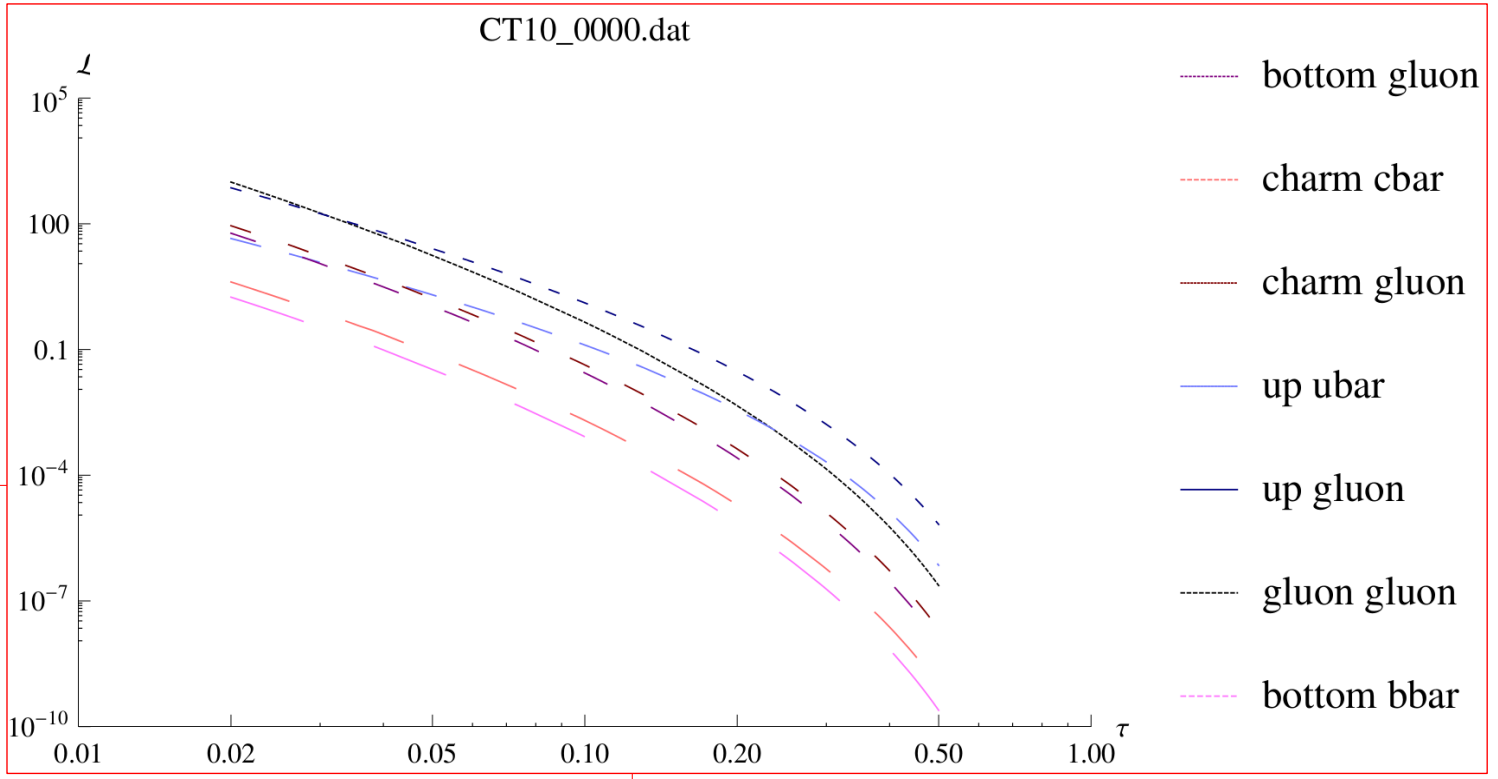


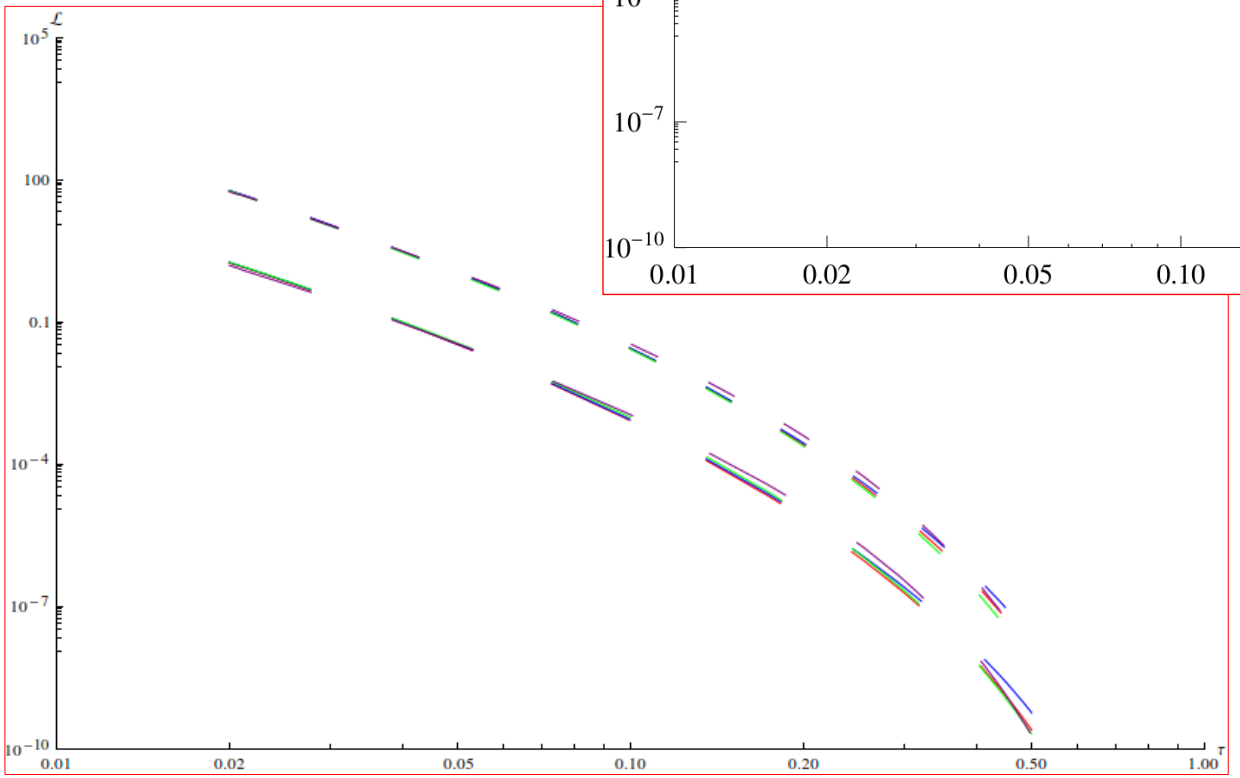
Kinematics:

$$m_H^2 = x_1 \, x_2 \, S = \tau \, S \quad \therefore \quad \tau = \frac{m_H^2}{S}$$

Luminosities in ManeParse

Luminosities for different parton interactions



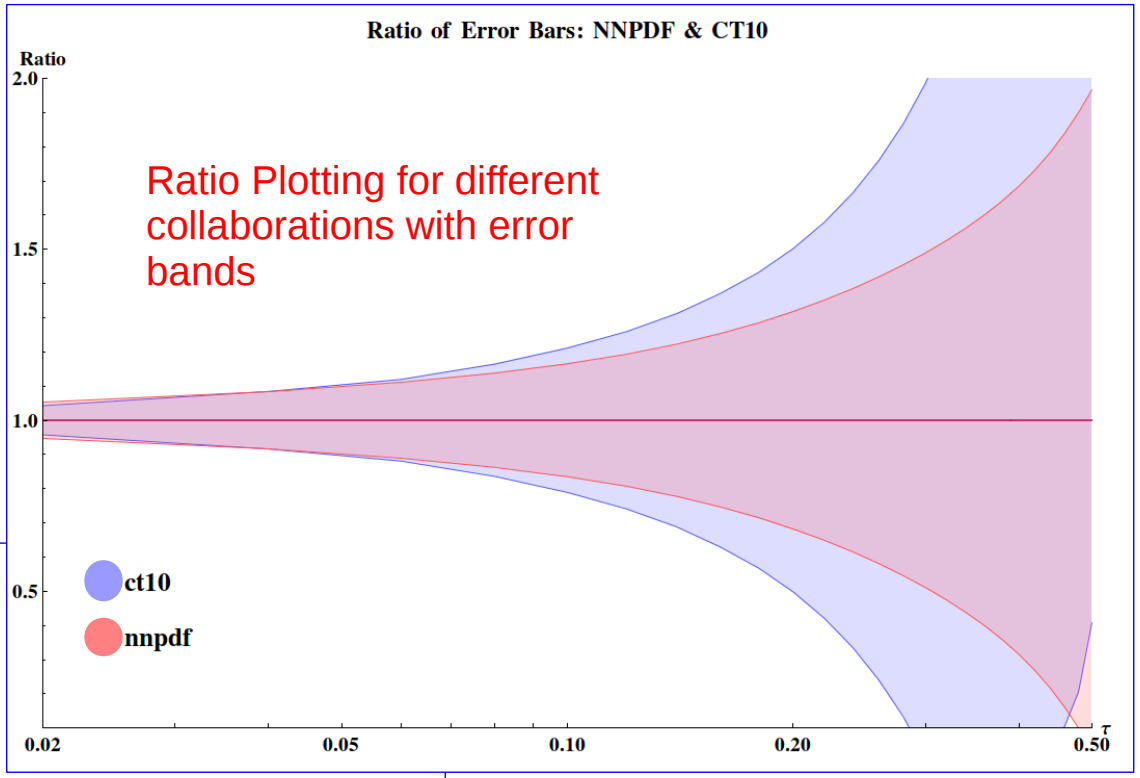


Bottom glue (top) and Bottom Bbar luminosities for multiple collaborations

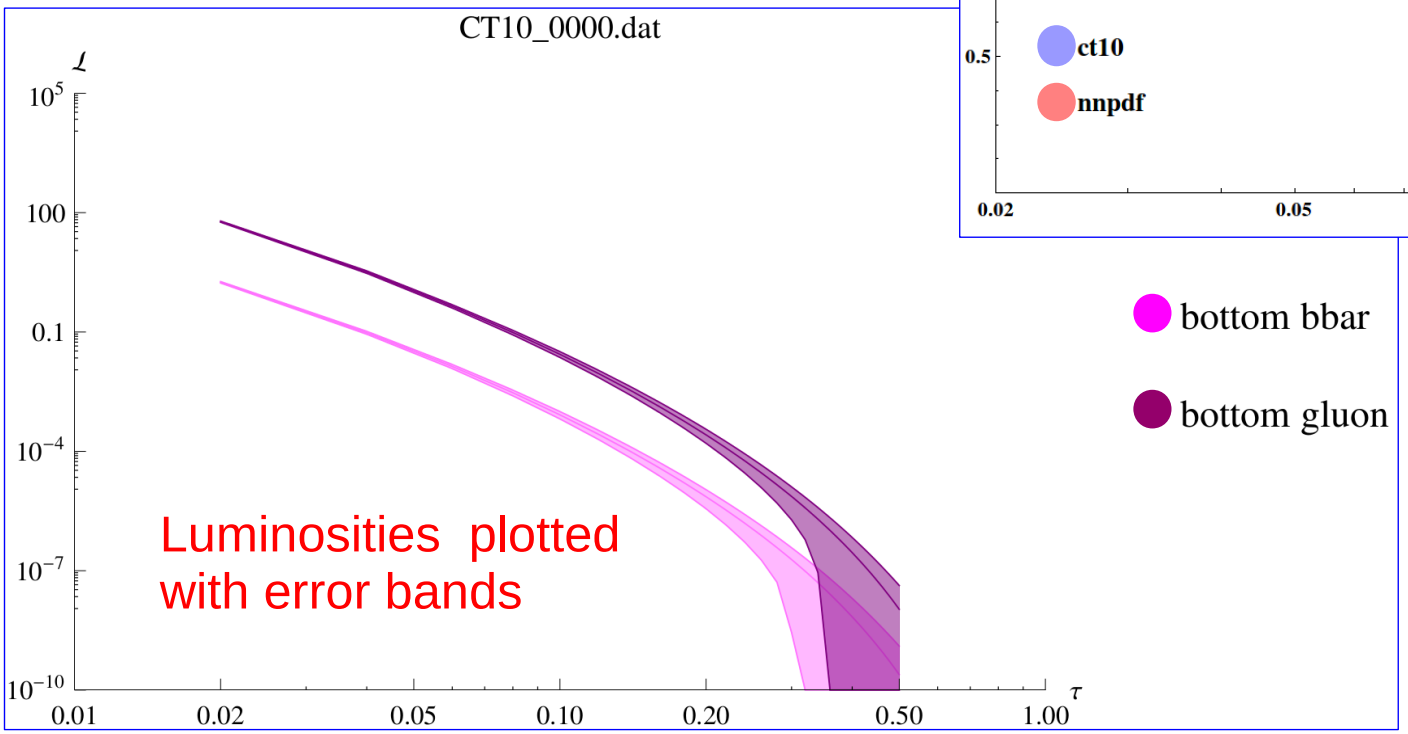
Luminosities in ManeParse

Error bands can be added using the pdfError package

- Hessian Fit for CT10
- Monte Carlo Fit for NNPDF
- Errors for functions can be applied directly



Ratio Plotting for different collaborations with error bands



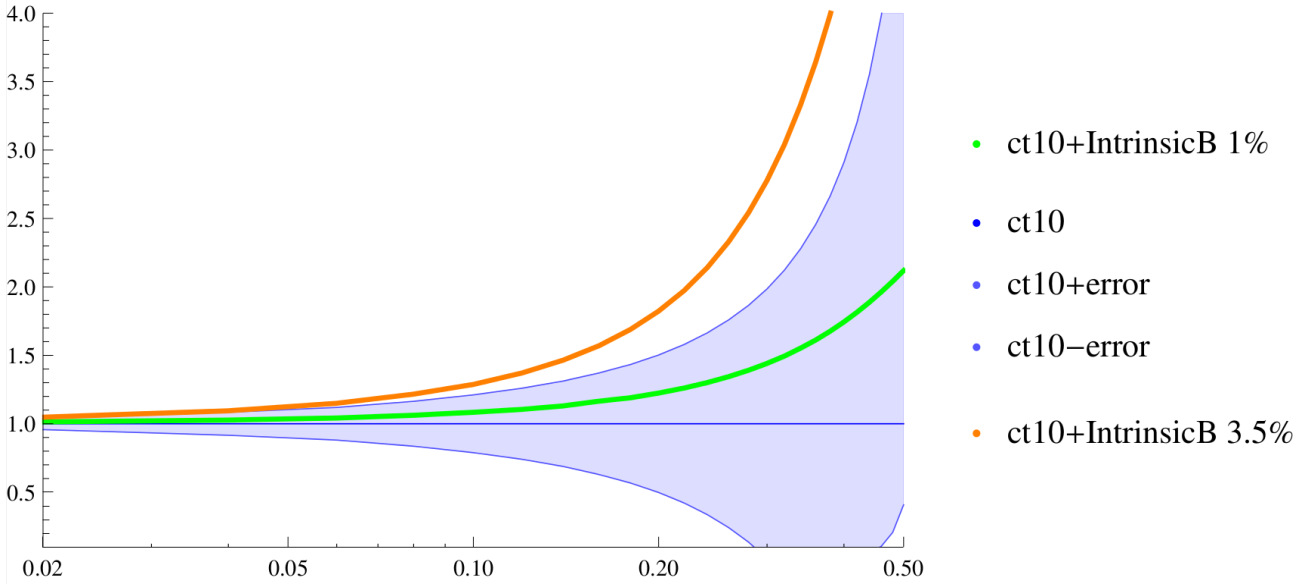
Luminosities plotted with error bands

Intrinsic Bottom PDF

- Custom PDF
- Intrinsic PDF can be added to an existing extrinsic PDF directly due to decoupling of DGLAP evolution equations*

$$\mathrm{PDF} = \mathrm{PDF}_{\mathrm{extrinsic}} + \mathrm{PDF}_{\mathrm{intrinsic}}$$

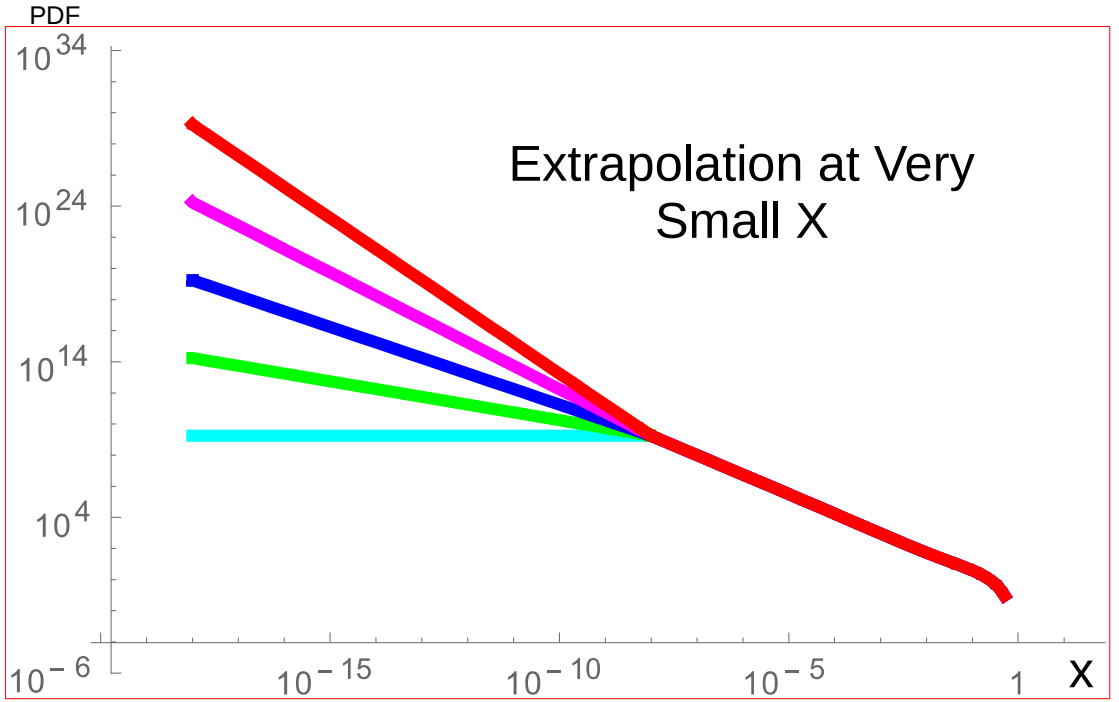
Ratio Plot for CT10 with Intrinsic Bottom component



*Reference: arxiv:1504.05156v1 F. Lyonnet et al.

Ultrahigh Energy Neutrinos

- Calculations at very low x values
- Package allows for interpolation to these very low values with ability to tune to fit data



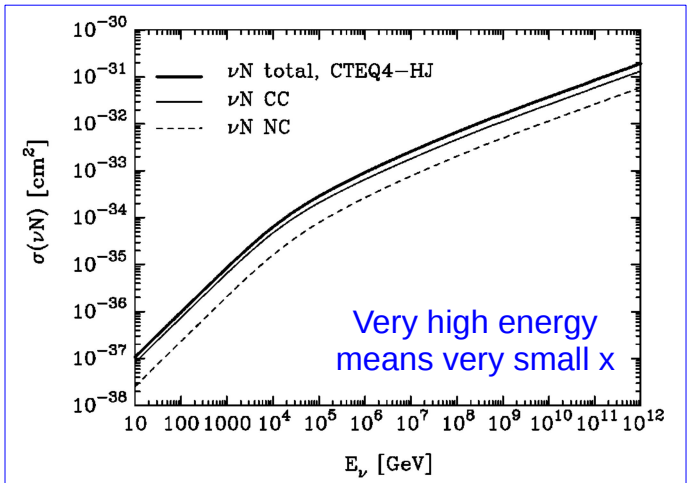


FIG. 4. Cross sections for $\nu_l N$ interactions at high energies, according to the CTEQ4-HJ parton distributions: dashed line, $\sigma(\nu_l N \to \nu_l + \text{anything})$; thin line, $\sigma(\nu_l N \to l^- + \text{anything})$; thick line, total (charged-current plus neutral-current) cross section.

Reference: arXiv:hep-ph/9807264 R. Gandhi et al.

Conclusions & Future Work

ManeParse is ready for release.

Complete Demo notebook available.

To Download visit:

ncteq.org

ncteq.hepforge.org/code/pdf.html

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Aleksander Kusina

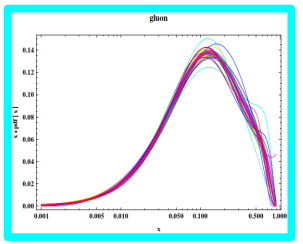
Questions?
Please Contact:

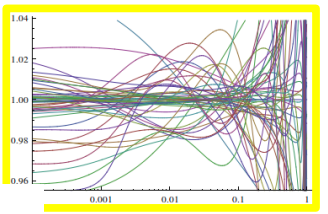
Eric Godat egodat@smu.edu

Backup Slides

Introduction: Mathematica Interface for LHAPDF6

- Package designed to allow for user interaction
  - Check values in PDFs
  - Make plots
  - Check ratios between PDF sets
  - Integrate and check sum rules





-5	bbar	0
-4	cbar	0
-3	sbar	2
-2	ubar	3
-1	dbar	4
0	gluon	42
1	down	15
2	up	32
3	strange	2
4	charm	0
5	bottom	0

- User accessible functions

▼ pdfCalc`

pdfAlphaS	pdfGetInfo	pdfLowFunction	pdfSetList
pdfFlavor	pdfGetQlist	pdfNumQpartition	pdfSetListDisplay
pdfFunction	pdfGetXlist	pdfReset	pdfXmin

▼ pdfErrors`

pdfHessianCorrelation	pdfLuminosity	pdfMCCorrelation
pdfHessianError	pdfMCCentral	pdfMCError

▼ pdfParse`

pdfFamilyParseCTEQ	pdfParseCTEQ

▼ pdfParseLHA`

pdfFamilyParseLHA	pdfParseLHA

- fo stored in the PDF sets
- pdfFuctionLHA uses encapsulated interpolation

LHAPDF6 Features

LHAPDF the Les Houches Accord PDF Interface

- All PDF sets defined with a unified grid structure
  - .. can access grids with a single interface
- New "*dat*" files available for:
  - CTEQ
  - MSTW
  - NNPDF
- … *and under construction:*
  - ABKM, JR, CJ, nCTEQ, ATLAS, HERA

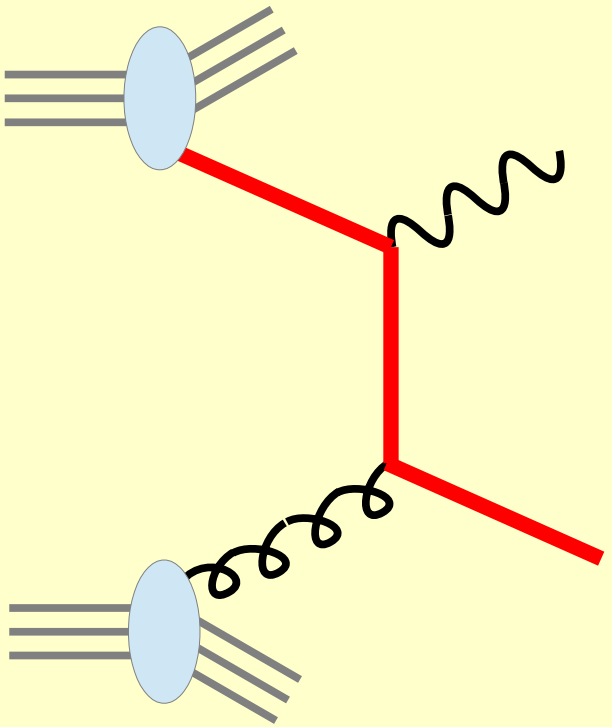
… what about the

Heavy Quarks

c & b: Extrinsic & Intrinsic

Historically, these have been a challenge because $Q \sim m_{c,b}$

Tevatron & LHC can Access Heavy Flavor Components Directly



$c\ g \rightarrow c\ \gamma$

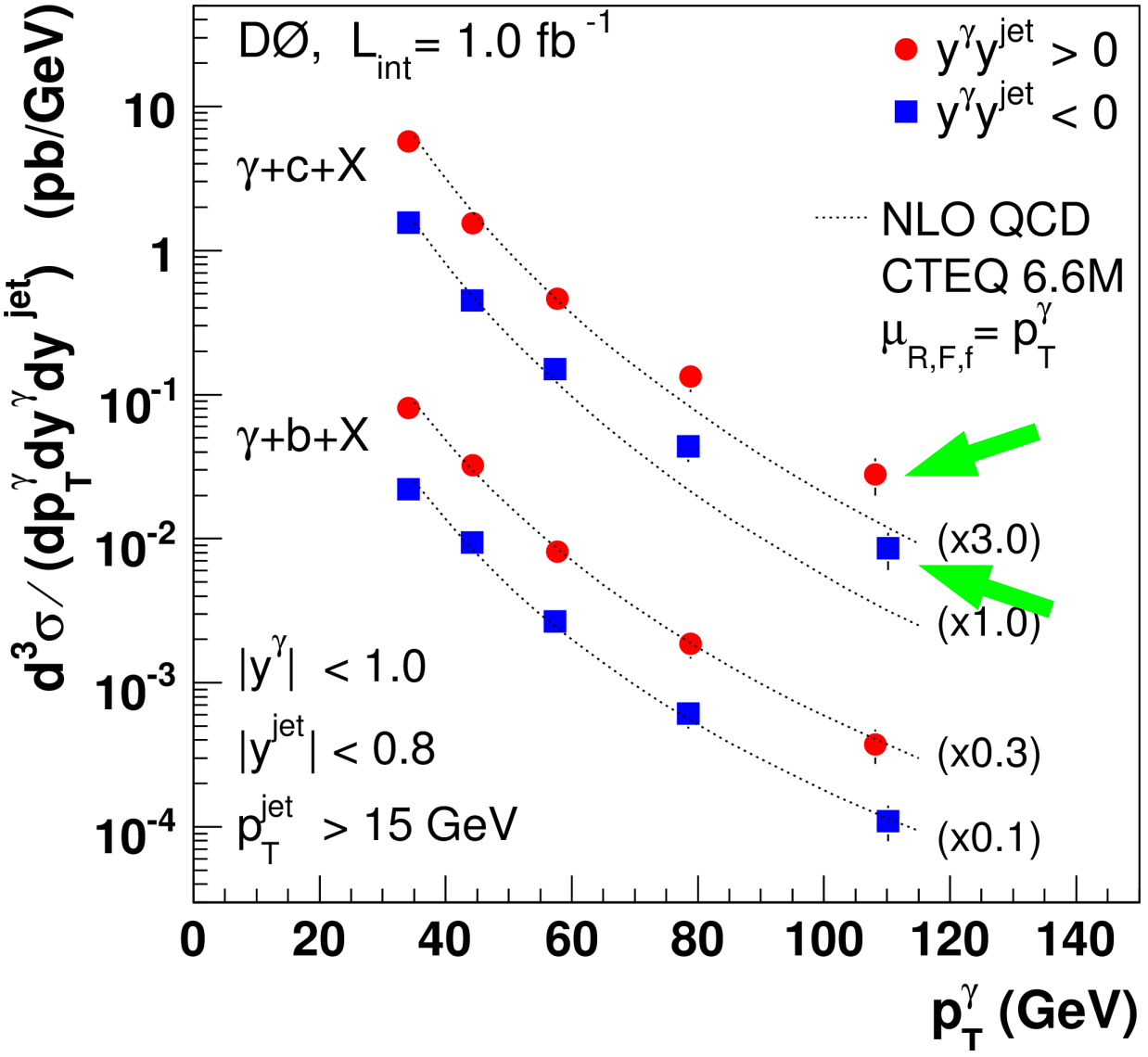
$b\ g \rightarrow b\ \gamma$

$s\ g \rightarrow c$

W

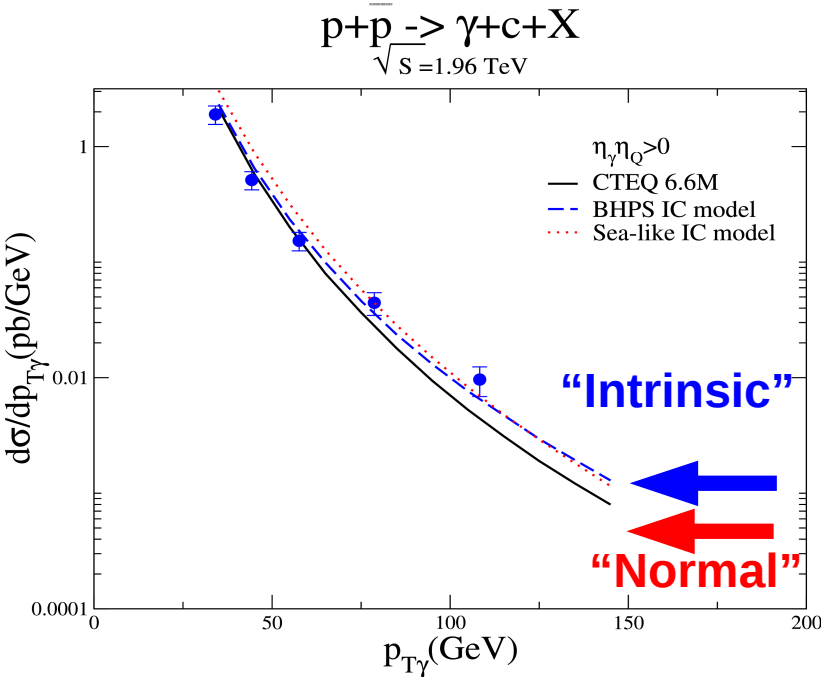
$c\ q \rightarrow b$

Heavy Quarks at the Tevatron: … "intrinsic" charm???



Excess in Charm,
NOT Bottom

only at high PT



T. Stavreva, I. Schienbein, F. Arleo, K. Kovarik, F. Olness,

D. Duggan (D0)

Heavy Quarks at the Tevatron: … "intrinsic" charm???

DGLAP Evolution equations …
including **ordinary Q_0** and **intrinsic Q_1** heavy quark

$$\dot{g} = P_{gg} \otimes g + P_{gq} \otimes q + P_{gQ} \otimes Q_0 + \cancel{P_{gQ} \otimes Q_1}\,,$$
$$\dot{q} = P_{qg} \otimes g + P_{qq} \otimes q + P_{qQ} \otimes Q_0 + \cancel{P_{qQ} \otimes Q_1}\,,$$
$$\dot{Q}_0 + \dot{Q}_1 = P_{Qg} \otimes g + P_{Qq} \otimes q + P_{QQ} \otimes Q_0 + P_{QQ} \otimes Q_1\,.$$

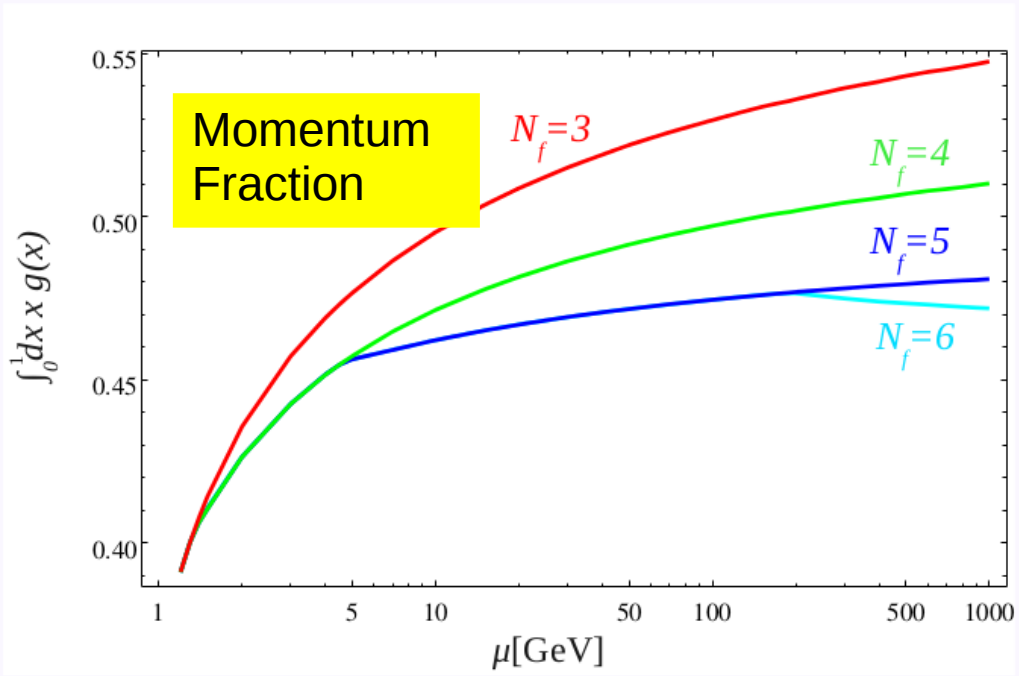
neglect

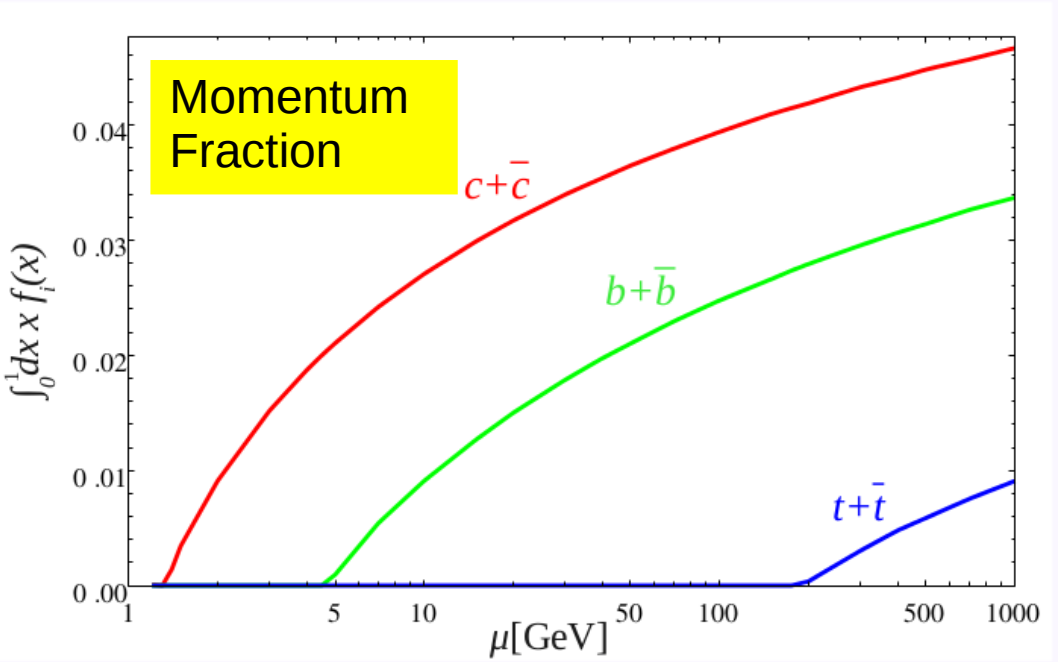
Equations decouple:
- Intrinsic component evolves independently
- Scale set by m_Q
- Adjust normalization by simple rescaling

$$\dot{Q}_1 = P_{QQ} \otimes Q_1\,.$$

$$c_1(x) = \bar{c}_1(x) \propto x^2[6x(1+x)\ln x + (1-x)(1+10x+x^2)]$$

arXiv:1504.05156: On the intrinsic bottom content of the nucleon and its impact on heavy new physics at the LHC
F. Lyonnet, A. Kusina, T. Ježo, K. Kovařík, F. Olness, I. Schienbein, J.Y. Yu


Momentum Fraction
$N_f=3$
$N_f=4$
$N_f=5$
$N_f=6$
$\int_0^1 dx\, x\, g(x)$
0.55
0.50
0.45
0.40
1
5
10
50
100
500
1000
μ[GeV]


Momentum Fraction
$c+\bar{c}$
$b+\bar{b}$
$t+\bar{t}$
$\int_0^1 dx\, x\, f_i(x)$
0 .04
0 .03
0 .02
0 .01
0 .00
1
5
10
50
100
500
1000
μ[GeV]