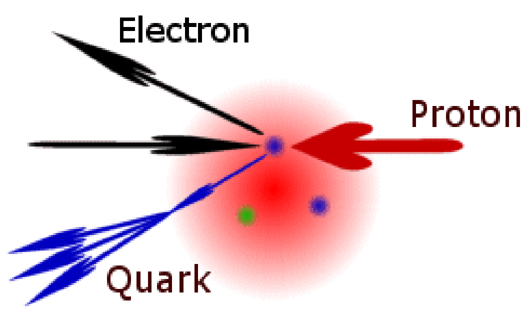
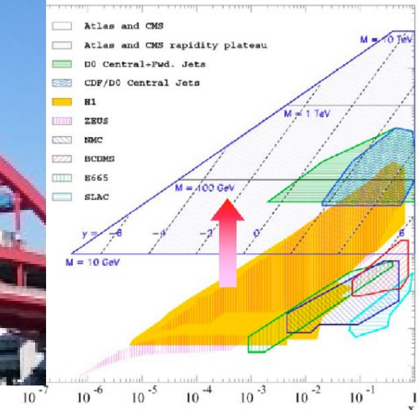
『日本永代蔵』とは？

- 浮世草子で、町人物の代表作の一つ
- １６８８年刊行
- 六巻３０話

木曽街道　日本橋雪之曙
渓斎英泉筆





MC tuning with

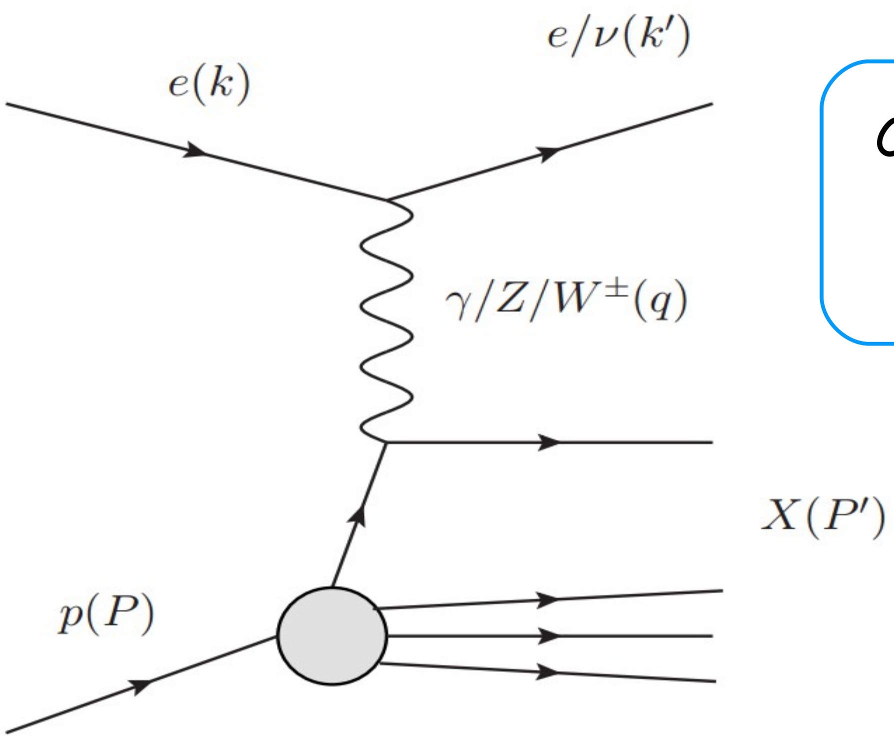
low-x low-Q^2 higher twists HHT PDF from HERA

HHT team: K. Wichmann, A. Cooper-Sarkar, I. Abt, B. Foster, V. Myronenko, M. Wing
MC tuning: P. Gunnellini, H. Jung

Phys. Rev. D 94, 034032 (2016), arXiv:1604.02299

Phys. Rev. D 96, 014001 (2017), arXiv:1704.03187

Deep Inelastic Scattering at HERA



Combined H1/ZEUS inclusive DIS cross sections → final word from HERA → HERA legacy

$$E_P = 920(820, 460, 575)\,GeV$$
$$E_e = 27.5\,GeV$$

$$\sqrt{s} = 318(300, 225, 252)\,GeV$$

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

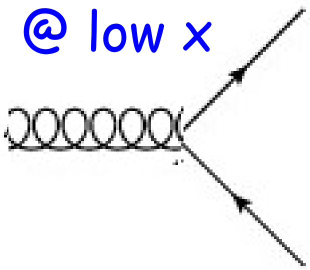
$$x_{Bj} = \frac{Q^2}{2\,pq} \qquad y = \frac{pq}{pk}$$

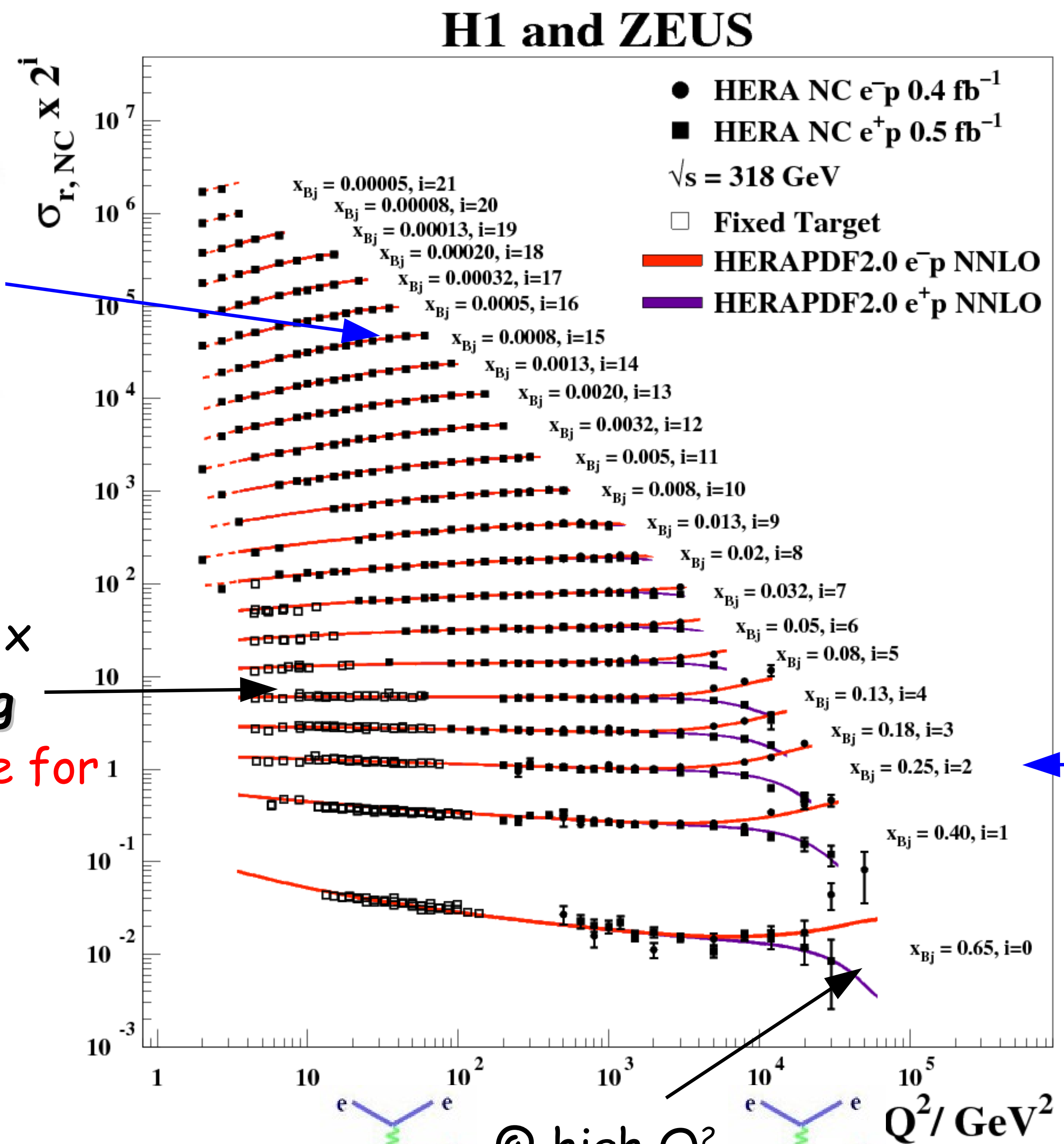
$$s = (p+k)^2 \qquad Q^2 = xys$$

Experimental luminosity (H1 & ZEUS):

~ 0.5fb^{-1} data from each experiment

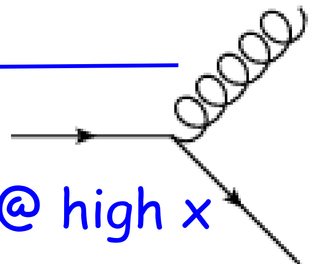
@ low x



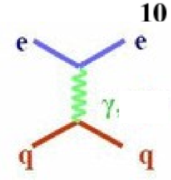


electron-proton
positron-proton

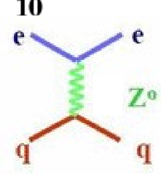
@ moderate x
QCD scaling
2015 Wolf prize for J. Bjorken!



@ high x

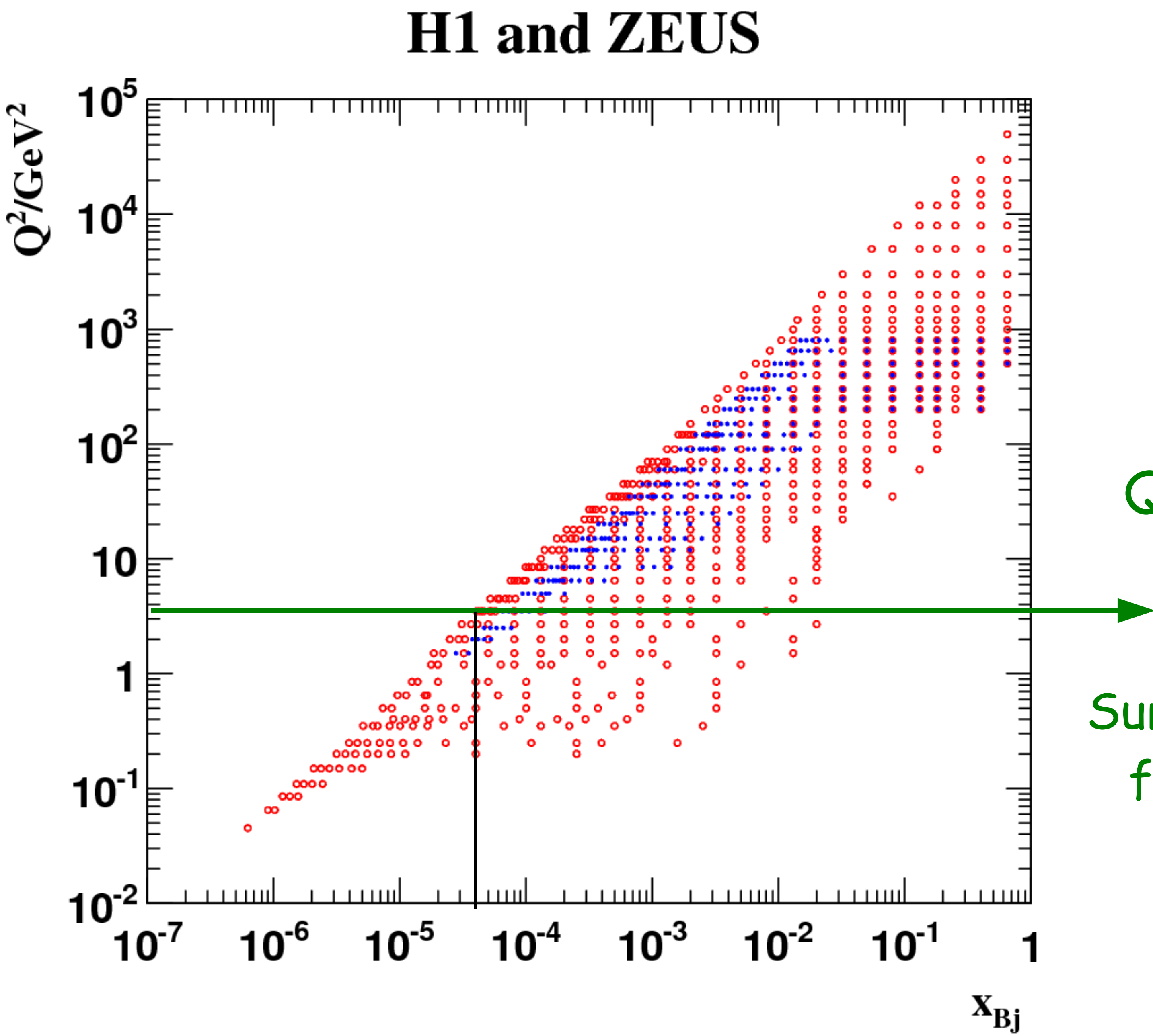


@ high Q^2



Text book plots of fundamental properties of particle interactions

@ HERA low $Q^2 \rightarrow$ low x



$Q^2_{min} = 3.5\ GeV^2$

Surprisingly we can fit so low in Q^2

HERAPDF2.0 @ low Q^2 and low x

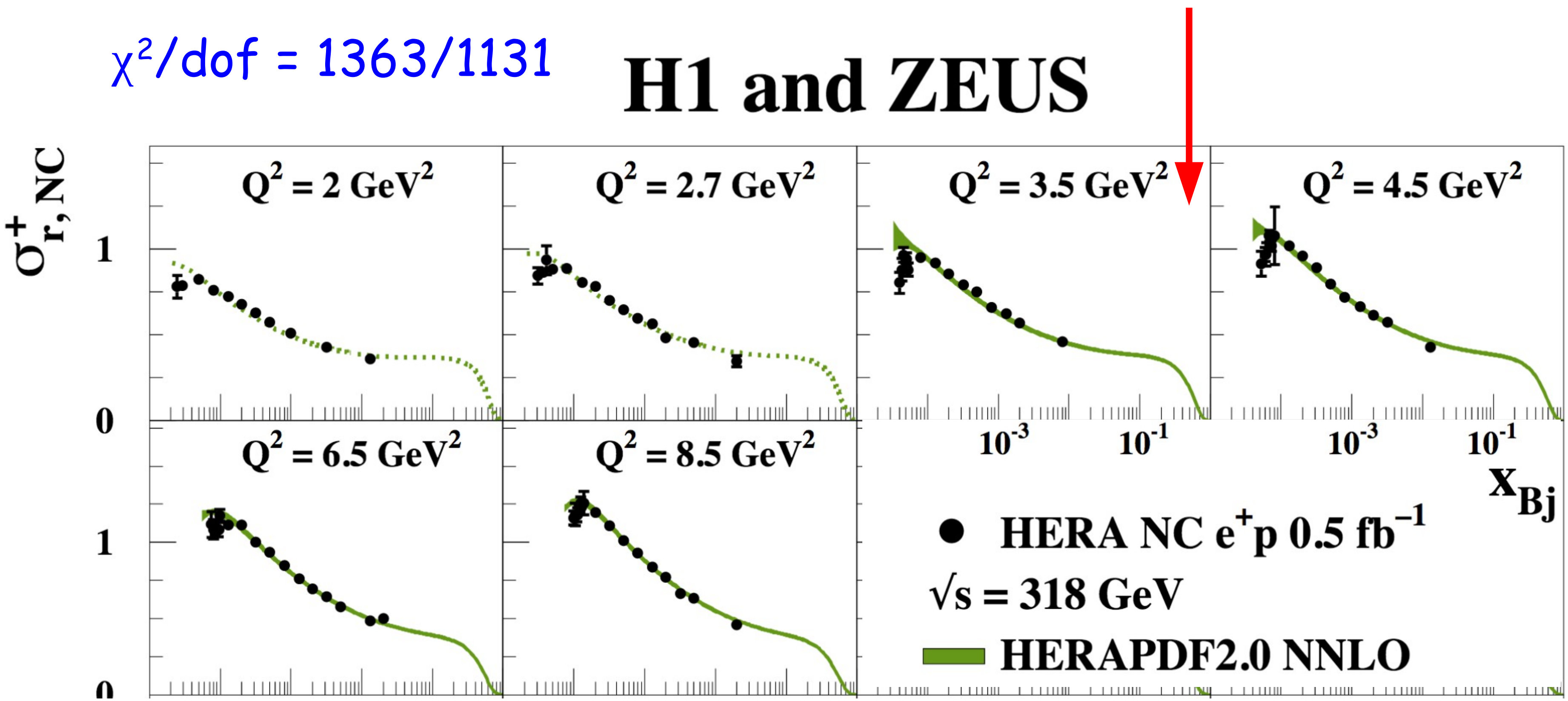
- NLO fit for Q^2_{min} = 3.5 GeV^2

  χ^2/dof = 1357/1131

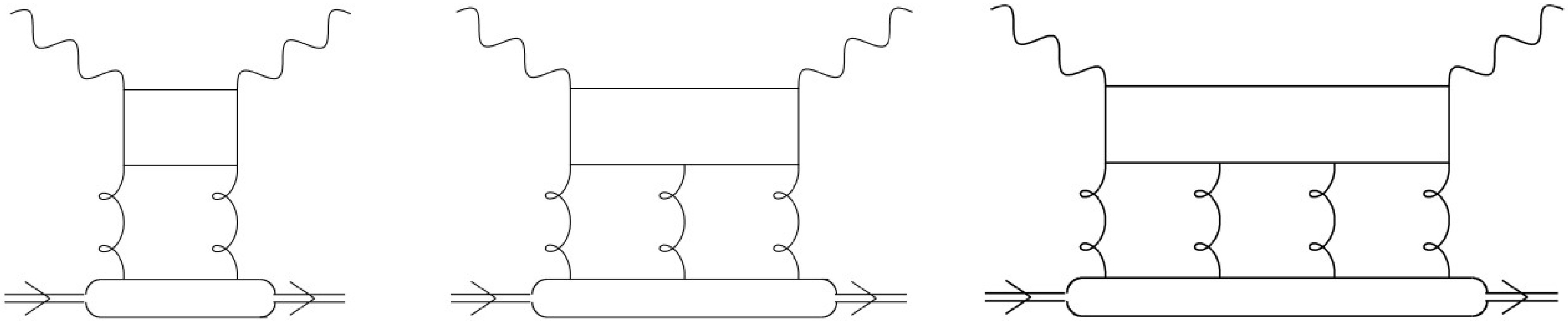
- NNLO fit for Q^2_{min} = 3.5 GeV^2

  χ^2/dof = 1363/1131

- Let's see how HERA low Q^2, low x data are described by predictions
  - Not that great...

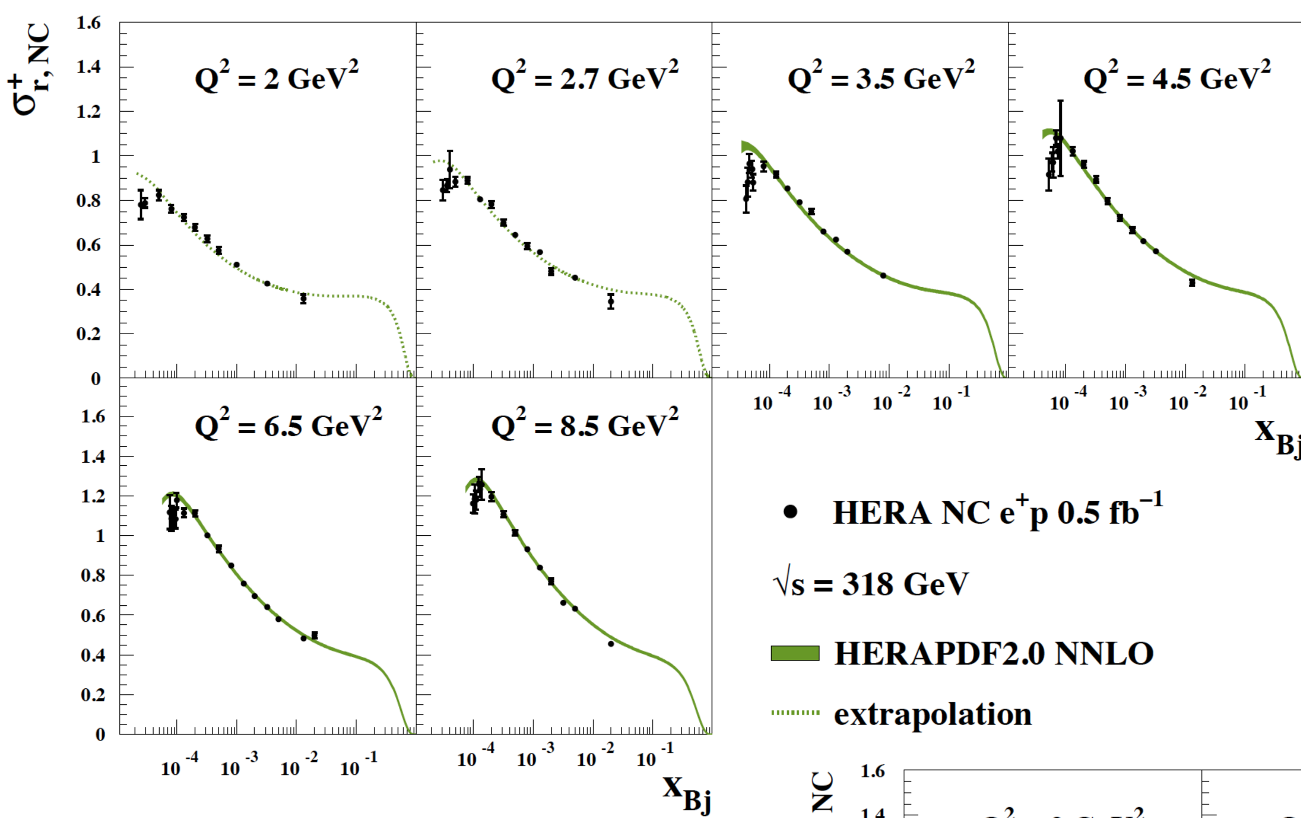


Higher-twist corrections



- higher twist terms acting at low-x considered
- their origin COULD be connected with the recombination of gluon ladders
- Bartels, Golec-Biernat, Peters suggested that such higher twist terms would cancel between σ_L and σ_T in F_2, but remain strong in F_L
- simplest possible modification to structure functions F_2 and F_L as calculated from HERAPDF2.0 formalism tried

$$F_2^{\rm HT} = F_2^{\rm DGLAP} \left(1 + A_2^{\rm HT}/Q^2\right)$$
$$F_L^{\rm HT} = F_L^{\rm DGLAP} \left(1 + A_L^{\rm HT}/Q^2\right)$$



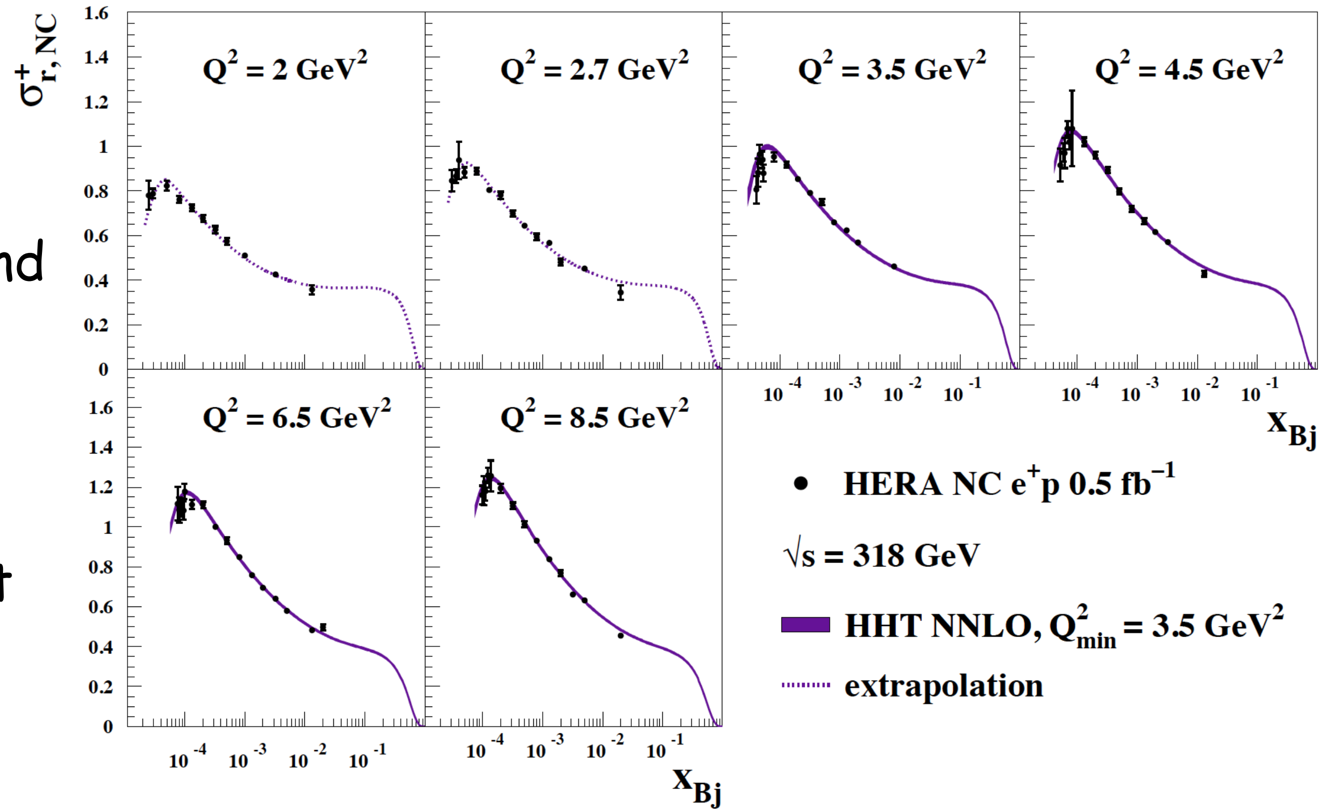
- Low-Q^2 data description much improved
- including extrapolation down to Q^2 = 2 GeV^2
- NNLO does better then NLO

why HHT fits do so well?

- HHT describes turn-over and slope better

$$\sigma_{red} = F_2 - y^2/Y_+ F_L$$

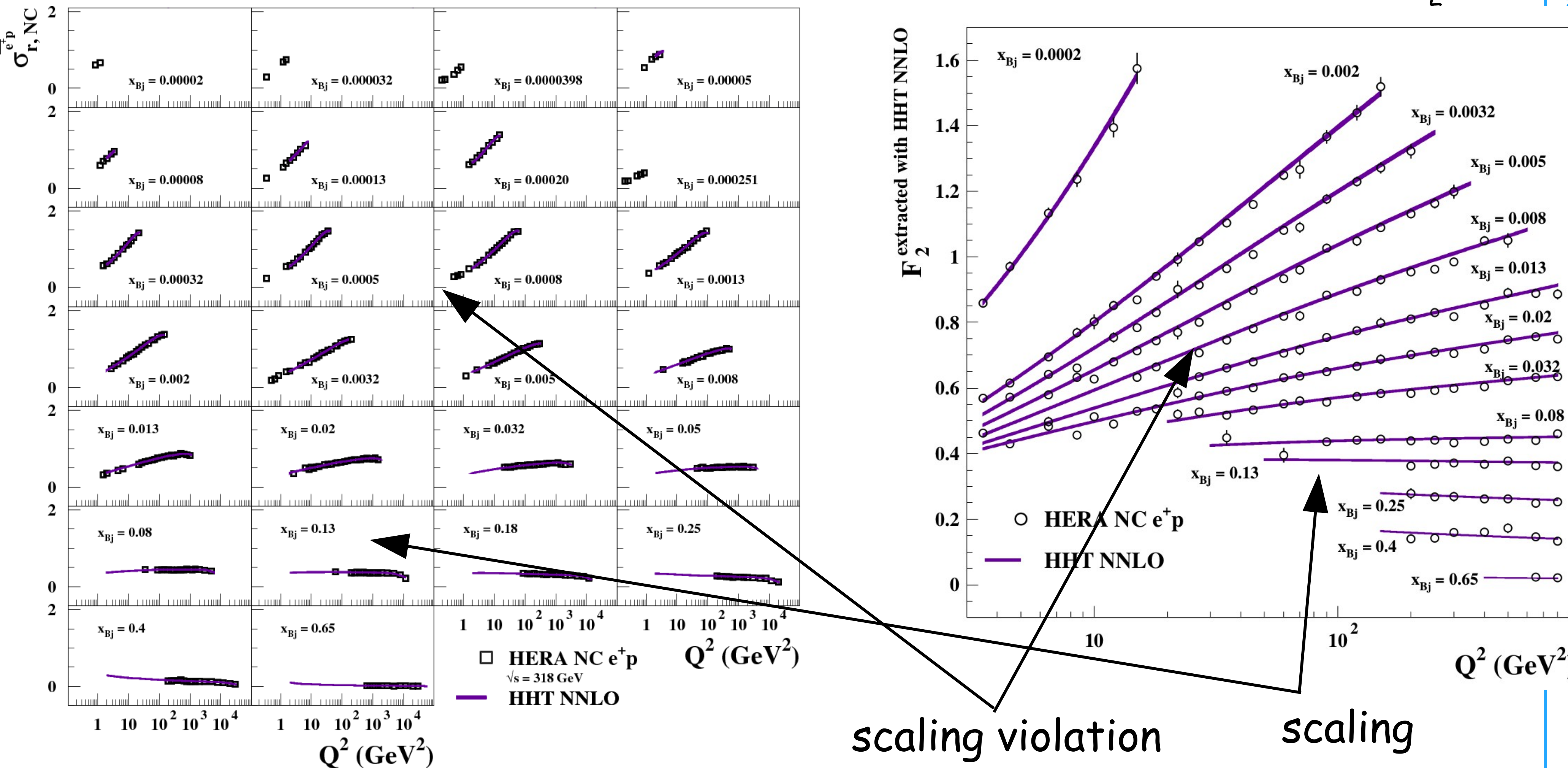
- data clearly wants larger F_L
  - this is what higher twist term provides



K. Wichmann

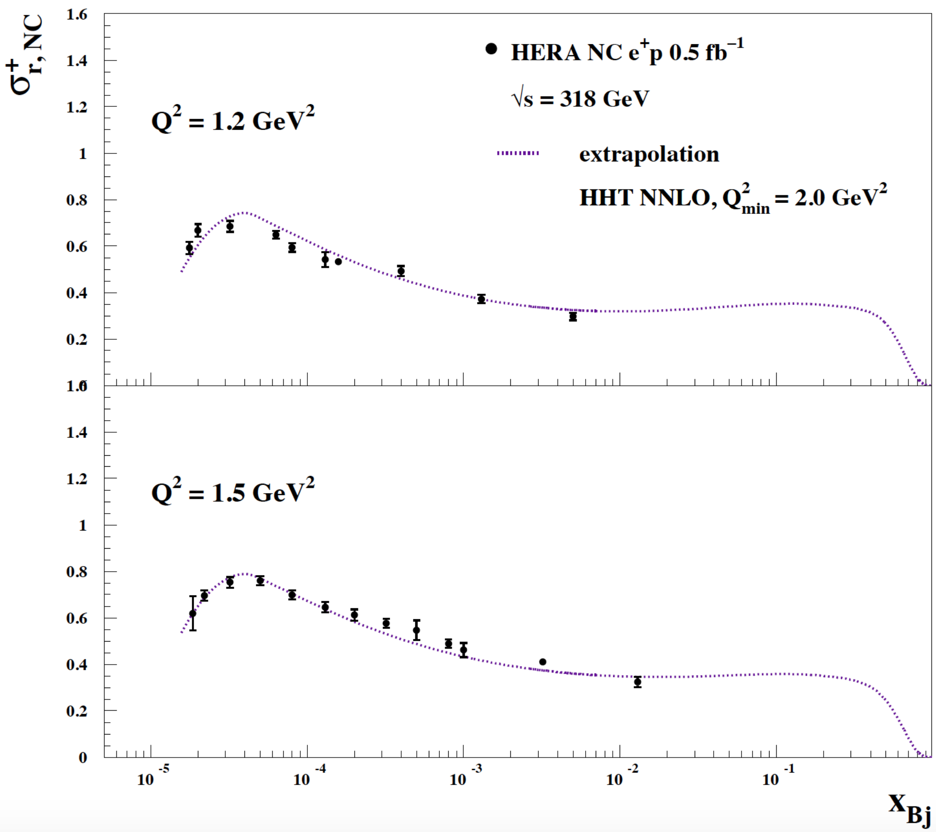
QCD scaling with HHT

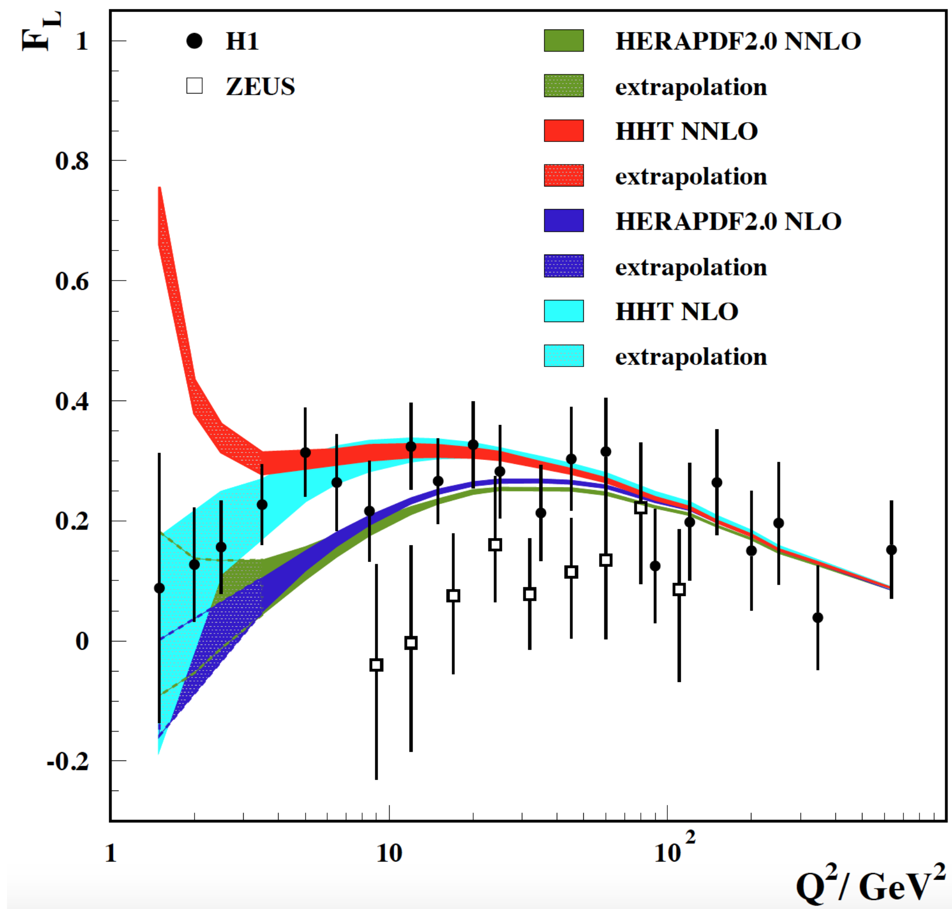
- Scaling violations well established
- Also for extracted F_2



$$\sigma^{e^+p}_{r,\mathrm{NC}} = \tilde{F}_2(x_{\mathrm{Bj}}, Q^2) - \frac{Y_-}{Y_+}\, x\tilde{F}_3(x_{\mathrm{Bj}}, Q^2) - \frac{y^2}{Y_+}\, F_{\mathrm{L}}(x_{\mathrm{Bj}}, Q^2)$$

Extrapolation down to $Q^2 \sim 1$ GeV^2



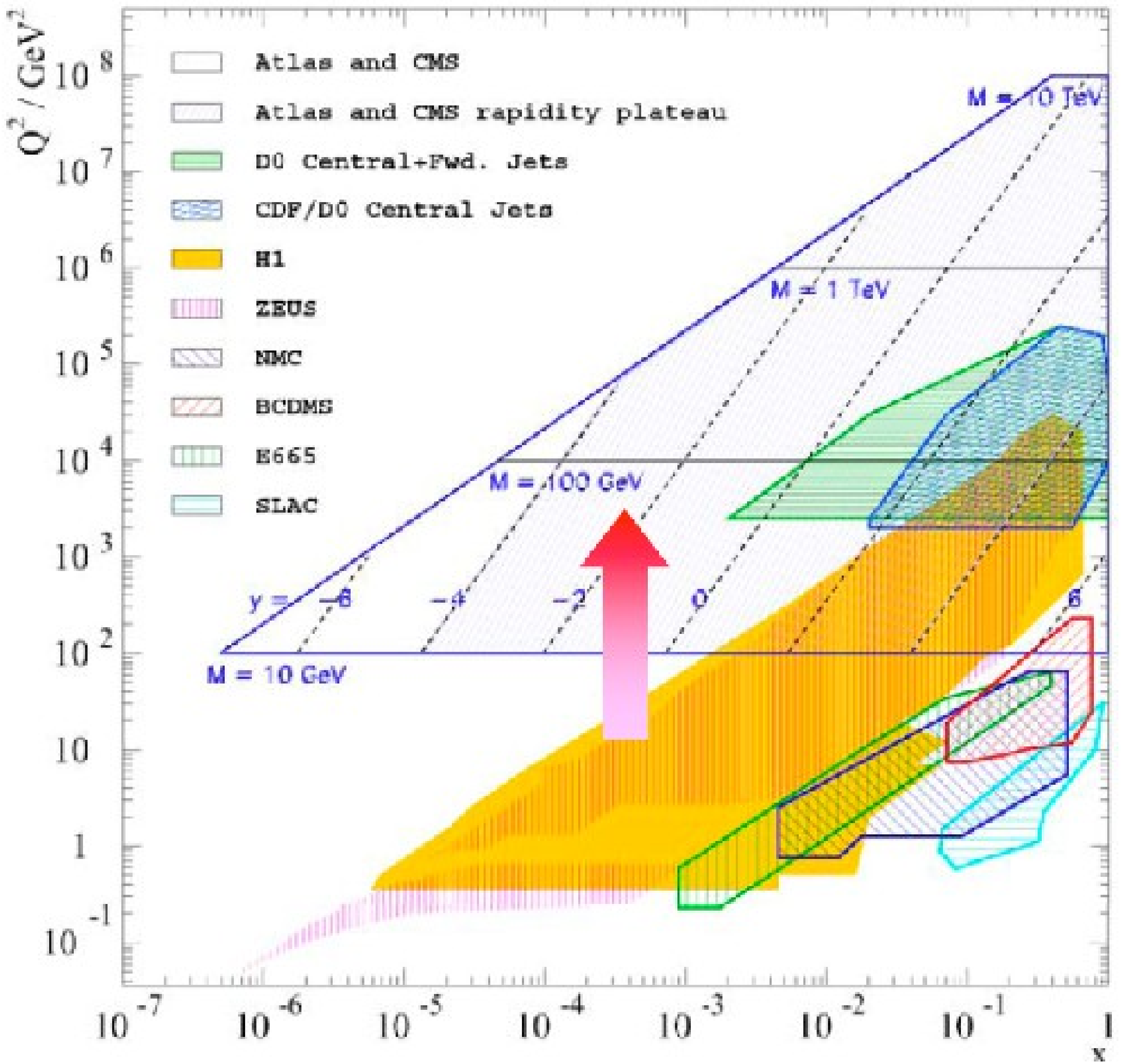


But beware… is this actually reasonable?

What does F_L itself look like?

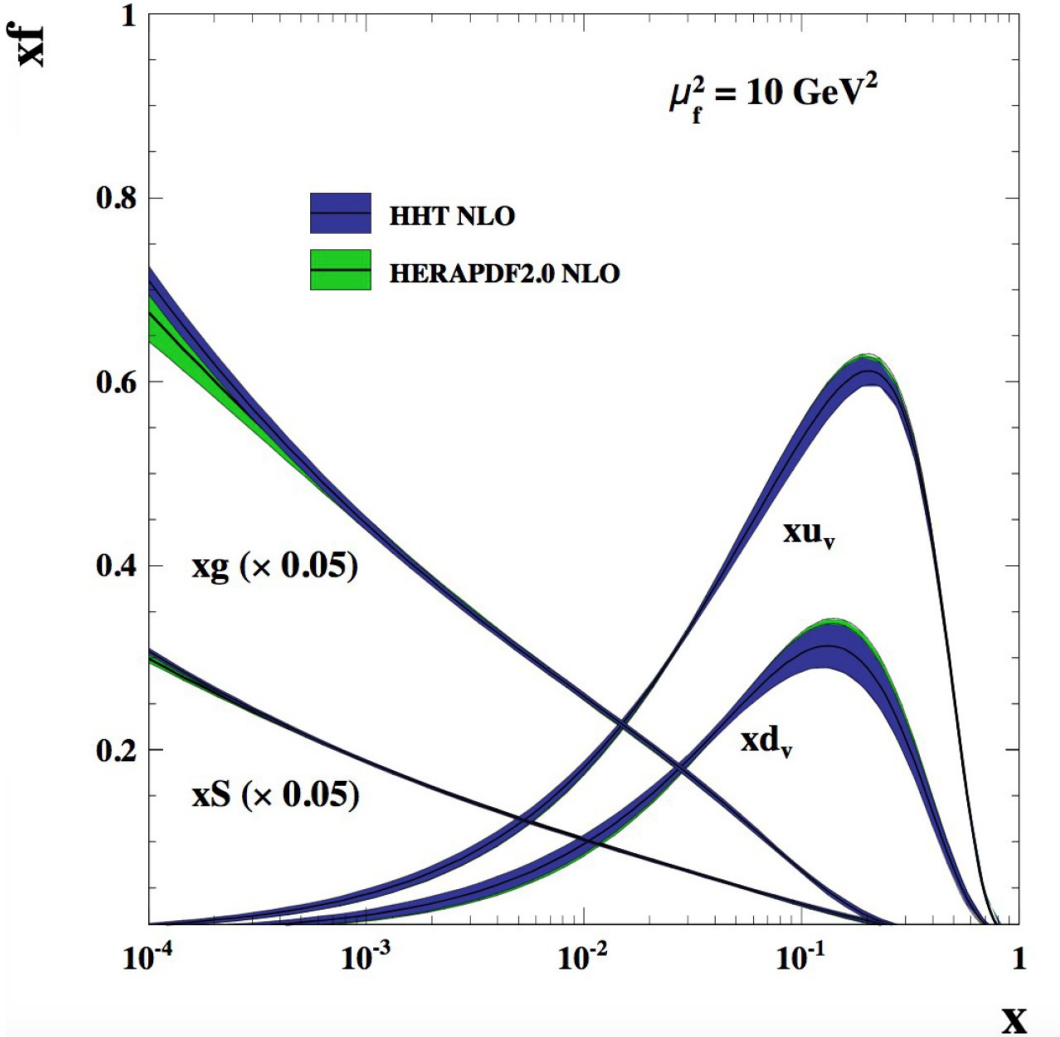
- NNLO HHT FL prediction untamed at low Q^2
- this approach can't be pushed too far
- this comes from NNLO coeff. functions and the $1/Q^2$ term makes it worse

DGLAP evolves HERA scales to any scales



Higher-twist effects at various scales

- Already at scale of 10 GeV² HHT PDFs similar to standard one

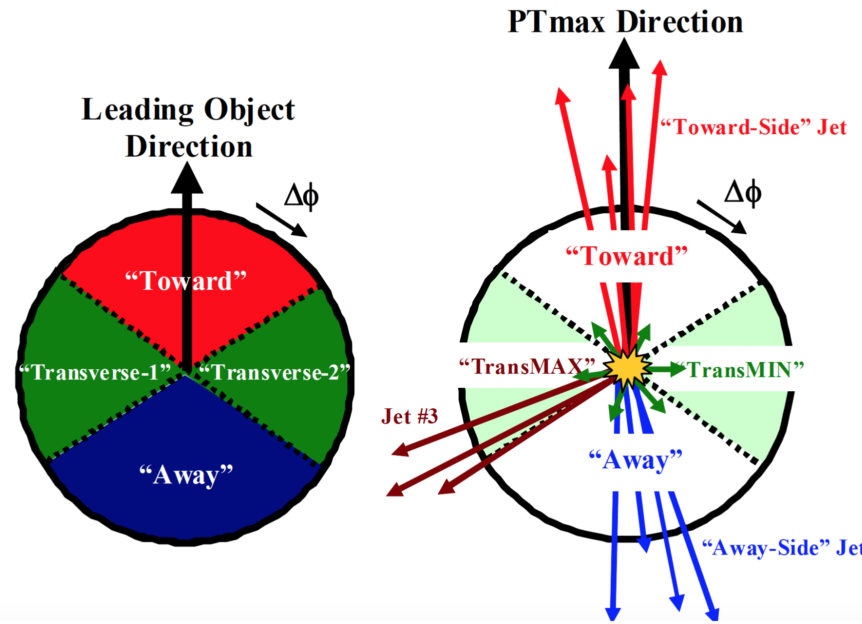


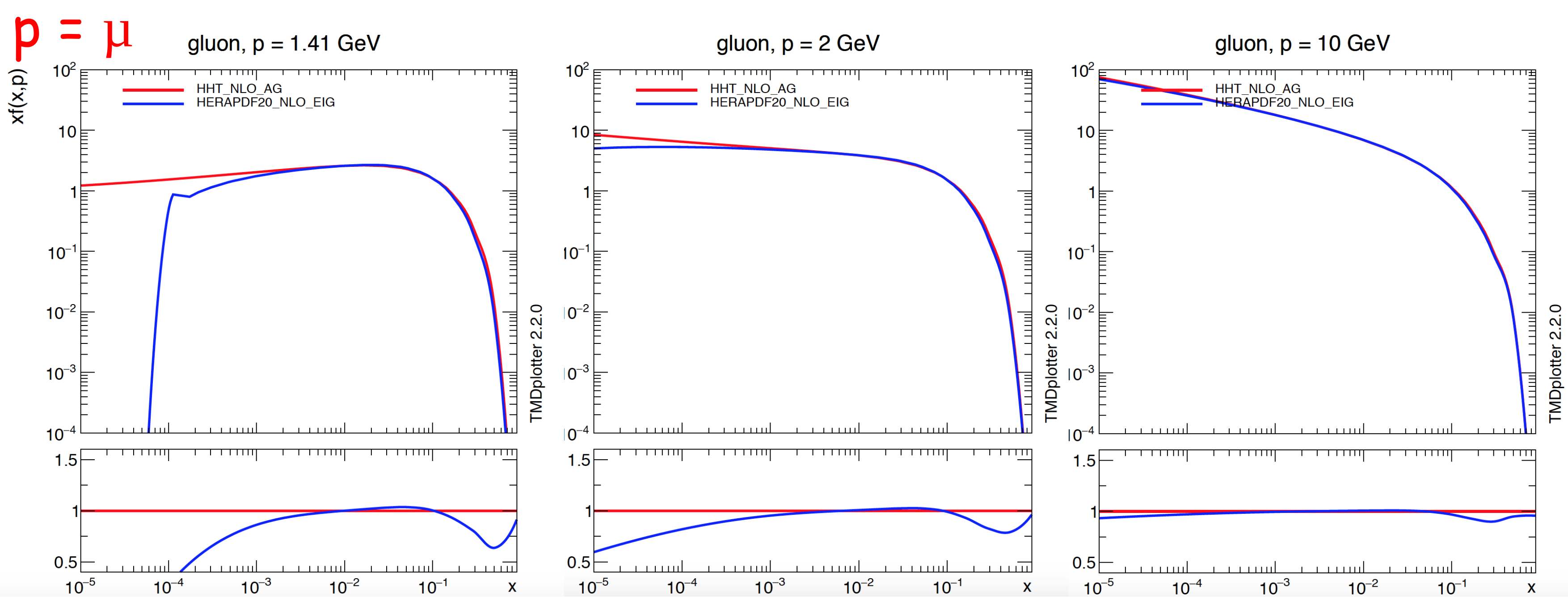
Higher twist modification does not affect high-scale LHC physics

What about low-scale LHC physics?

Used in MC tuning: underlying event

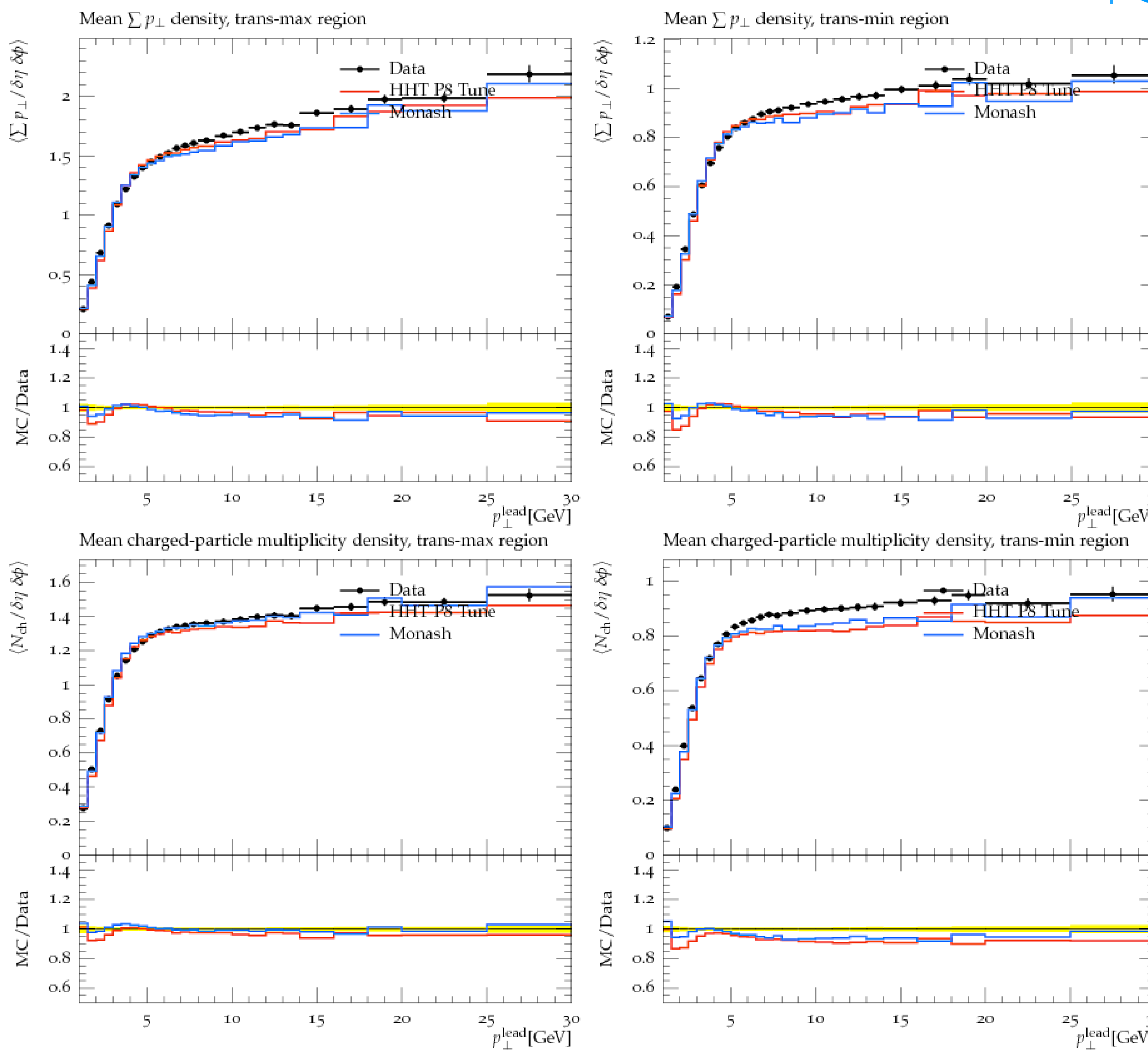
- Interest in MC community for PDF describing data well down to lowest possible Q^2
  - HHT NLO AG can be used → AG (alternative gluon): no negative gluon term
  - First use: tune for underlying event





MC tuning: underlying event

- 12 variables tuned
  - 4 for each energy: 1.96, 7 and 13 TeV
- 5 tuned parameter
- Compared to standard Monash tune with NNPDF



Data compares well with both tunes

ATLAS data

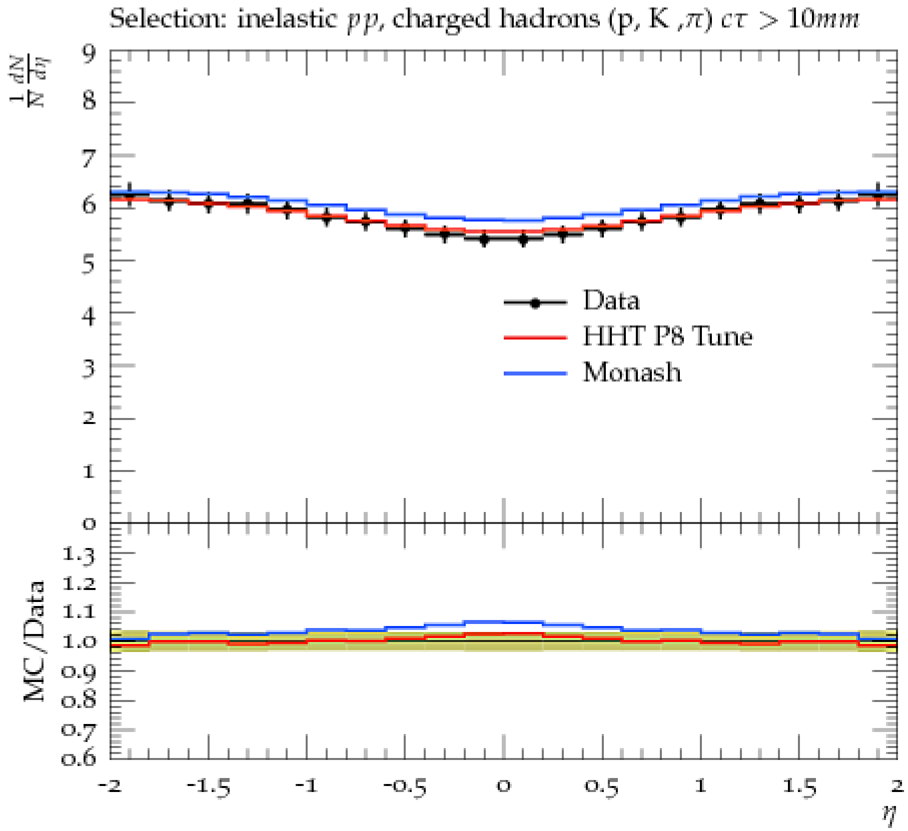
JHEP 1703 (2017) 157 (2017-03-29)

arXiv:1701.05390

MC tunes compared to global variables: CMS

- Pseudorapidity distribution of charged hadrons in pp collisions at $\sqrt{s}$ = 13 TeV measured using CMS data, at zero magnetic field
- Determined in central region of CMS pixel detector (|eta|<2) using both hit pairs and reconstructed tracks

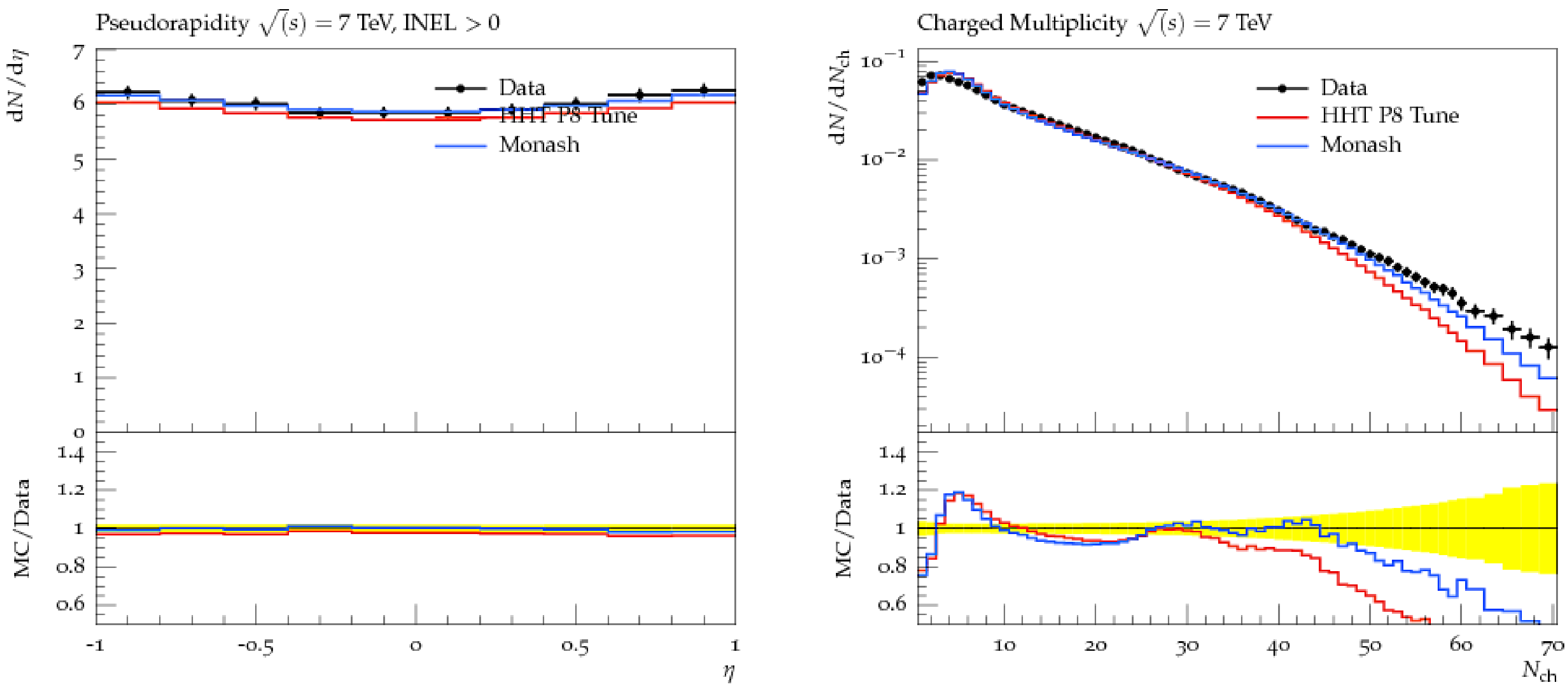
arXiv:hep-ex/1507.05915



Data compares well with both tunes

MC tunes compared to global variables: ALICE

- ALICE data Eur.Phys.J. C68 (2010) 345-354 | arXiv:1004.3514
  - pseudorapities for 0.9, 2.36 and 7TeV
  - charged multiplicity at 7TeV
- Analysis requires at least one charged particle in the event



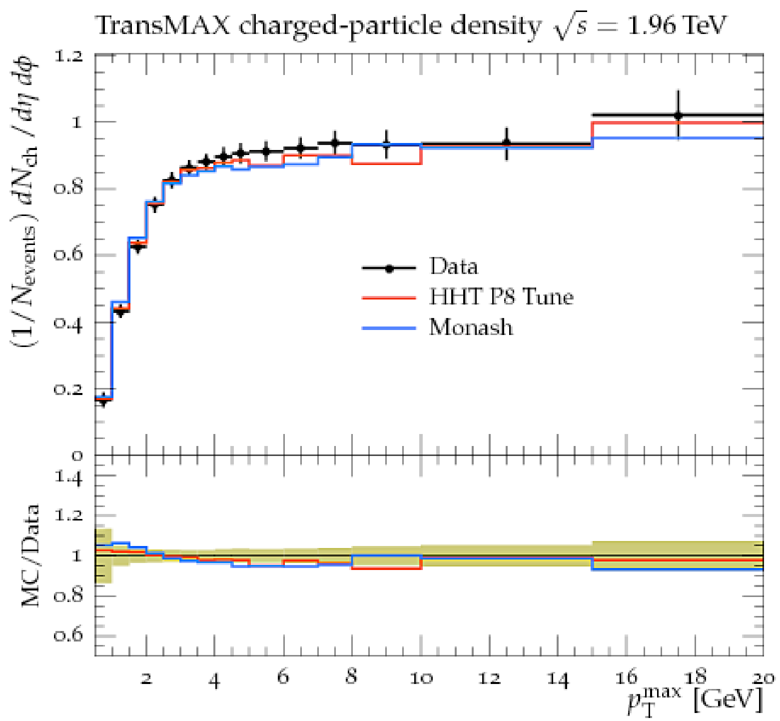
Data compares well with both tunes

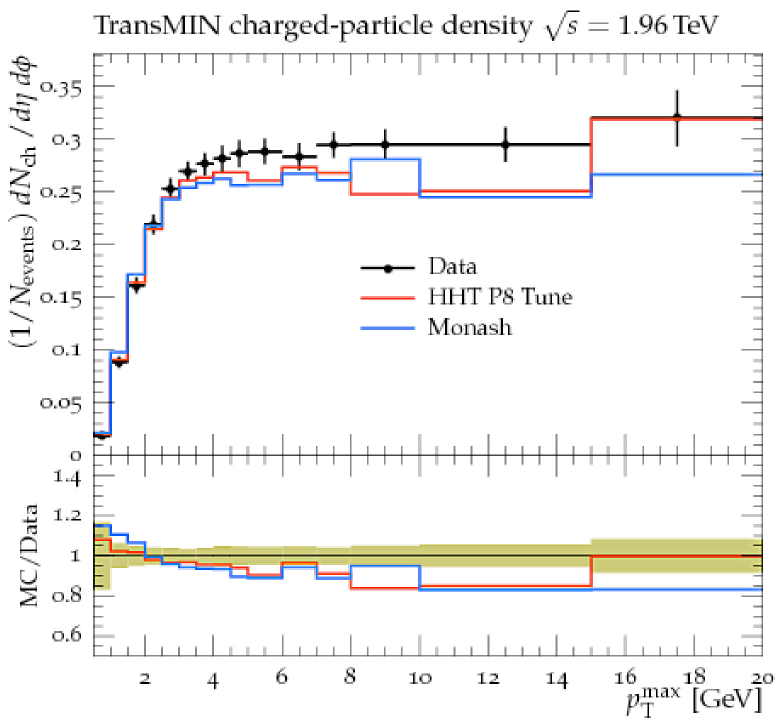
MC tunes compared to TeVatron: CDF

Phys.Rev. D92 (2015) no.9, 092009, (2015-11-23)

arXiv:1508.05340

- The same tunes can be used for studies outside LHC, eg. TeVatron
- Examples of some UE variables from CDF measurement at 1.96 TeV





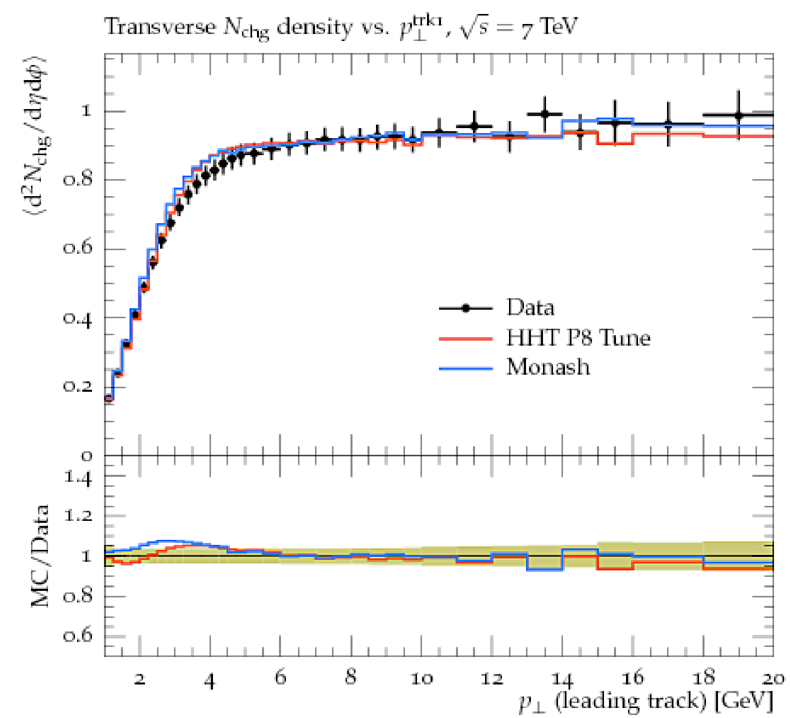
- Some variables described better → work in progress

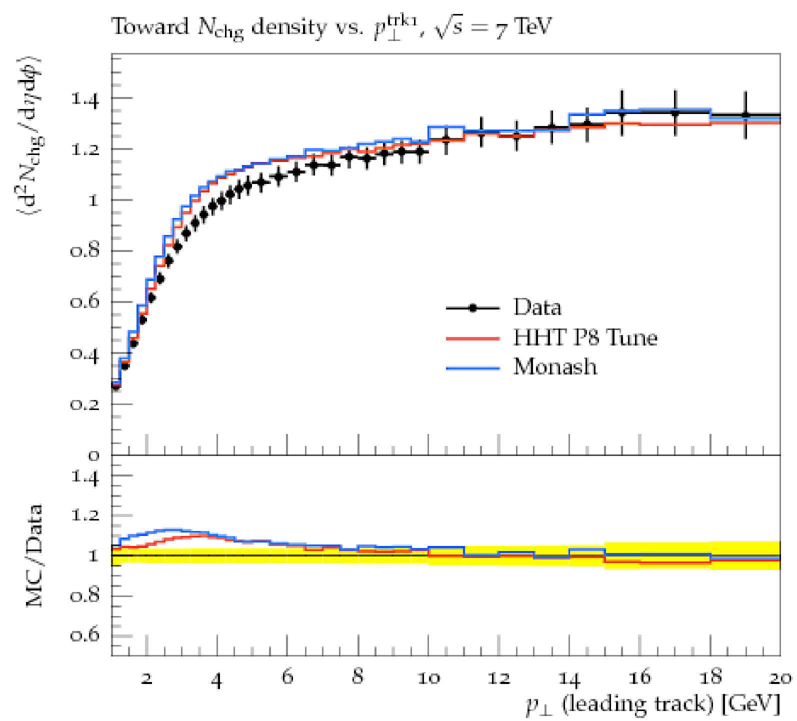
Comparison to UE variables: ATLAS

Phys. Rev. D 83 (2011) 112001

arXiv:1012.0791

- Compares well with standard Pythia Monash tune
  - Sometimes better / sometimes a bit worse





- Work in progress → hope that for tunes with lower energies PDF better describing low Q^2 will be beneficial

Low-scale data description

- At LHC @ low-scales two effects important in data description
  - Fit with low-scale PDF → expected better constrain of soft processes like minimum-bias events - UE observables, eg. charged particle multiplicity
  - Diffractive effects - not tuned, Pythia8 uses diffractive PDF

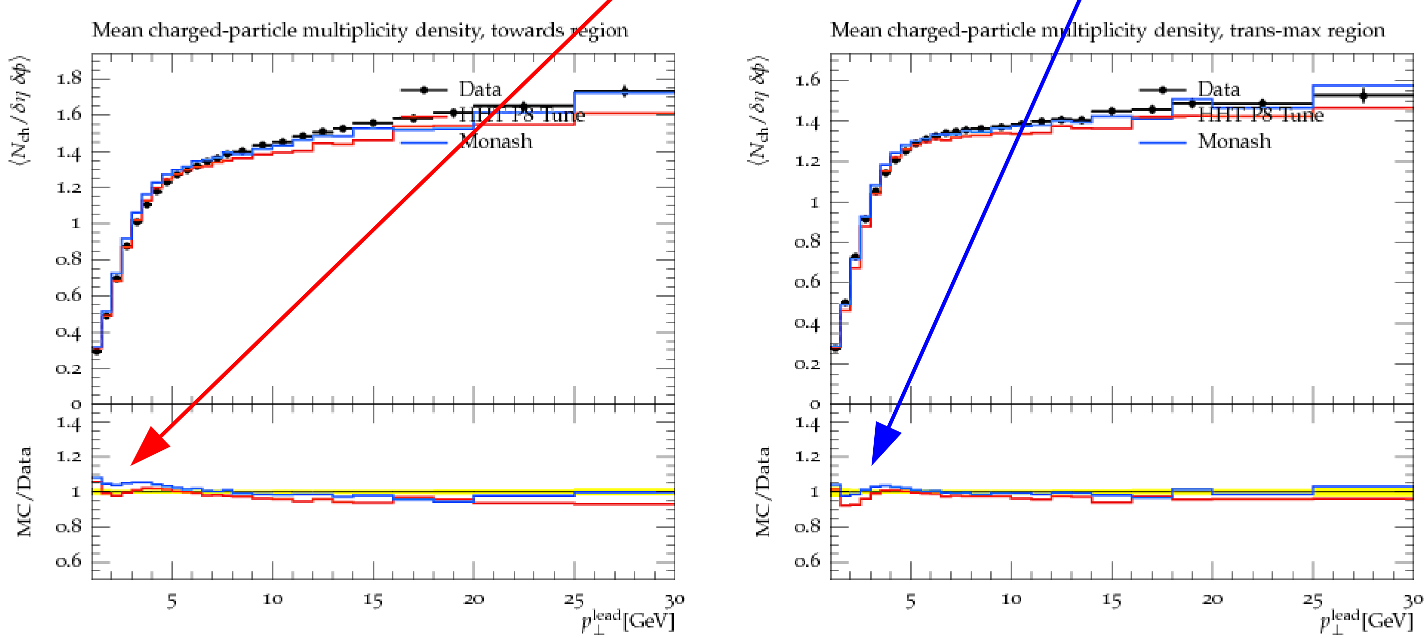
→ If that not described → no improvement possible

- Situation not clear yet – sometimes HHT helps, sometimes not

ATLAS data

JHEP 1703 (2017) 157 (2017-03-29)

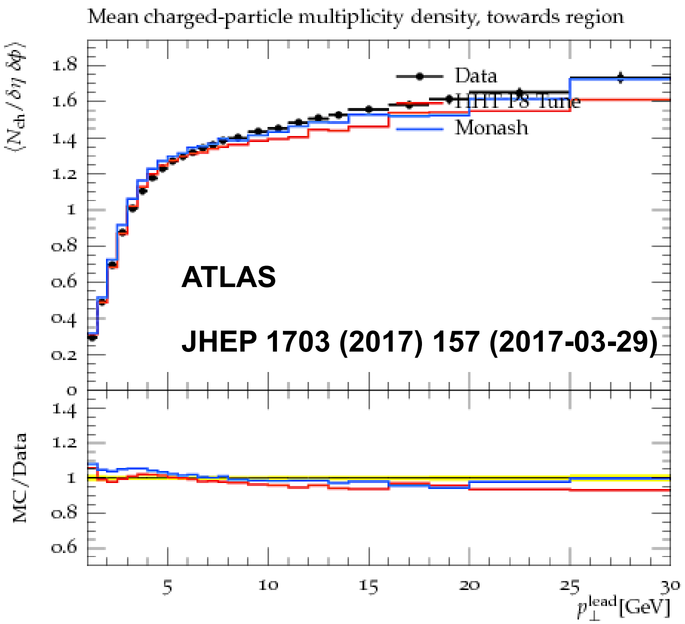
arXiv:1701.05390



Diffractive part could be tuned next

Summary & Prospects

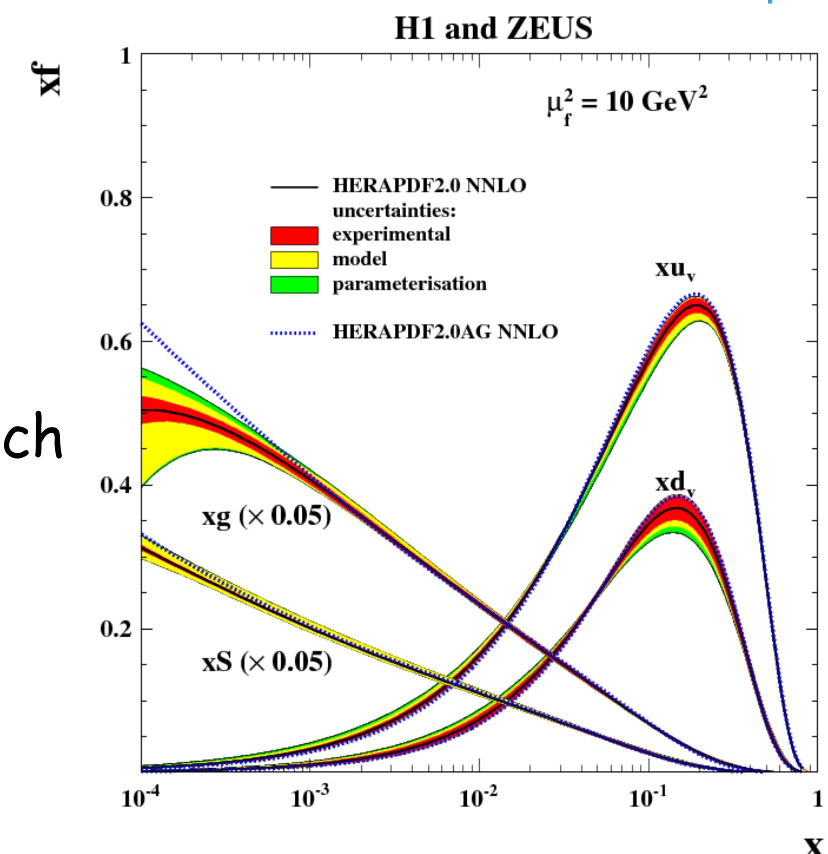
- Adding low-x higher twist terms to the HERAPDF2.0 analysis improves description of HERA data at low Q^2 Phys. Rev. D 94, 034032 (2016), arXiv:1604.02299 Phys. Rev. D 96, 014001 (2017), arXiv:1704.03187
- Such terms are significant in F_L for low x, Q^2
- Simple approach fails for $Q^2 < 2$ GeV^2
- MC tuning with HHT NLO
  - PDF solid down to low p_T
  - Used in MC tuning for underlying event
    - As low in x, Q^2 as possible → avoid any assumption and extrapolation of PDFs → reduction of uncertainties
  - Compares well with standard Monash tune



  - Work ongoing in low-scale region → possible tunes of diffractive part
  - Other low-x PDFs recent studies:
    - quasi-partonic higher-twist effects in DIS: Eur. Phys. J. C (2018) 78:80
    - Low-x resummation: arXiv:1802.00064

Back-up slides

Global QCD fits: HERAPDF approach



- Data: NC & CC, e^+p and e^-p scattering

- Global PDF fits follow HERAPDF2.0 approach
- DGLAP evolution using QCDNUM
- 14 parameter for PDF fit

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

$$xg(x),\ xu_v(x),\ xd_v(x),\ x\bar{U}(x),\ x\bar{D}(x)$$

- Starting scale Q^2_0 = 1.9 GeV^2
- Heavy flavor coefficients are obtained within GM VFNS (RT OPT)
- Model and parameterisation uncertainties → HERAPDF2.0

Higher-twist effects

HERAPDF2.0

NLO $\frac{\chi^2}{ndf} = \frac{1356}{1131} \approx 1.20$

NNLO $\frac{\chi^2}{ndf} = \frac{1363}{1131} \approx 1.21$

→ Introducing $F_2^{HT} = F_2^{DGLAP}(1 + \frac{A_2^{HT}}{Q^2})$ has almost no effect

HHT@F_2

NLO $\frac{\chi^2}{ndf} = \frac{1354}{1130} \approx 1.20$

NNLO $\frac{\chi^2}{ndf} = \frac{1357}{1130} \approx 1.20$

$A_2^{HT} = 0.14 \pm 0.10$ GeV^2

$A_2^{HT} = 0.12 \pm 0.07$ GeV^2

factors consistent with 0

→ Introducing $F_L^{HT} = F_L^{DGLAP}(1 + \frac{A_L^{HT}}{Q^2})$ helps a lot

HHT@F_L

NLO $\frac{\chi^2}{ndf} = \frac{1329}{1130} \approx 1.18$

NNLO $\frac{\chi^2}{ndf} = \frac{1316}{1130} \approx 1.16$

$\Delta\chi^2 = 27$

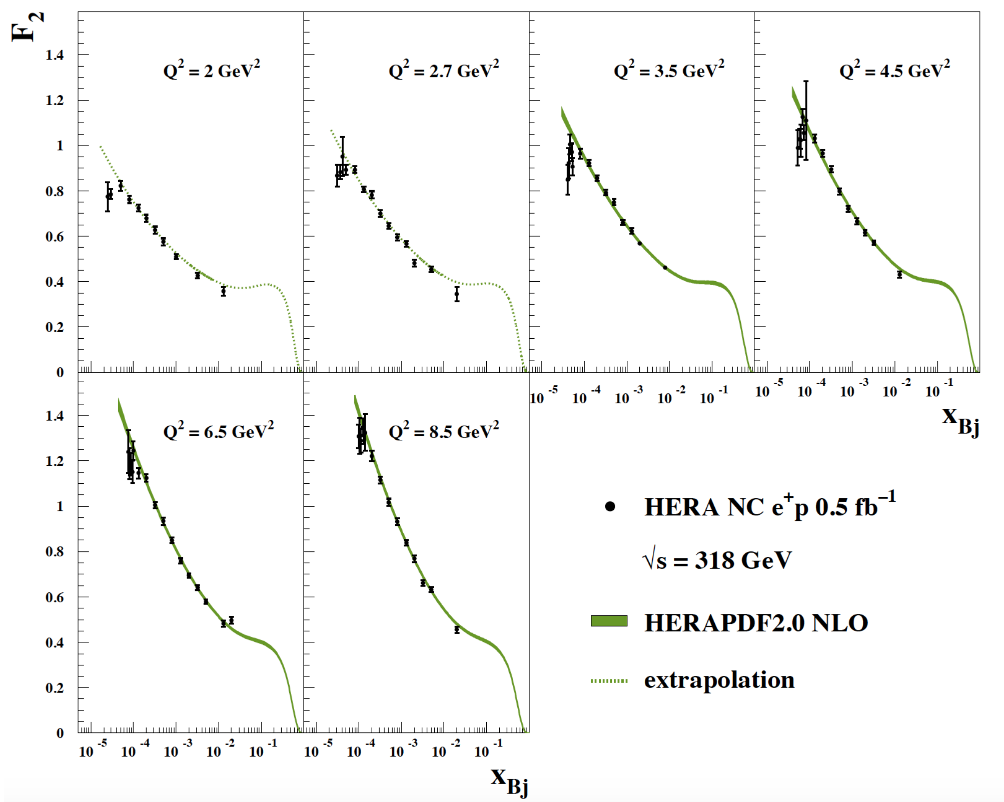
$\Delta\chi^2 = 47$

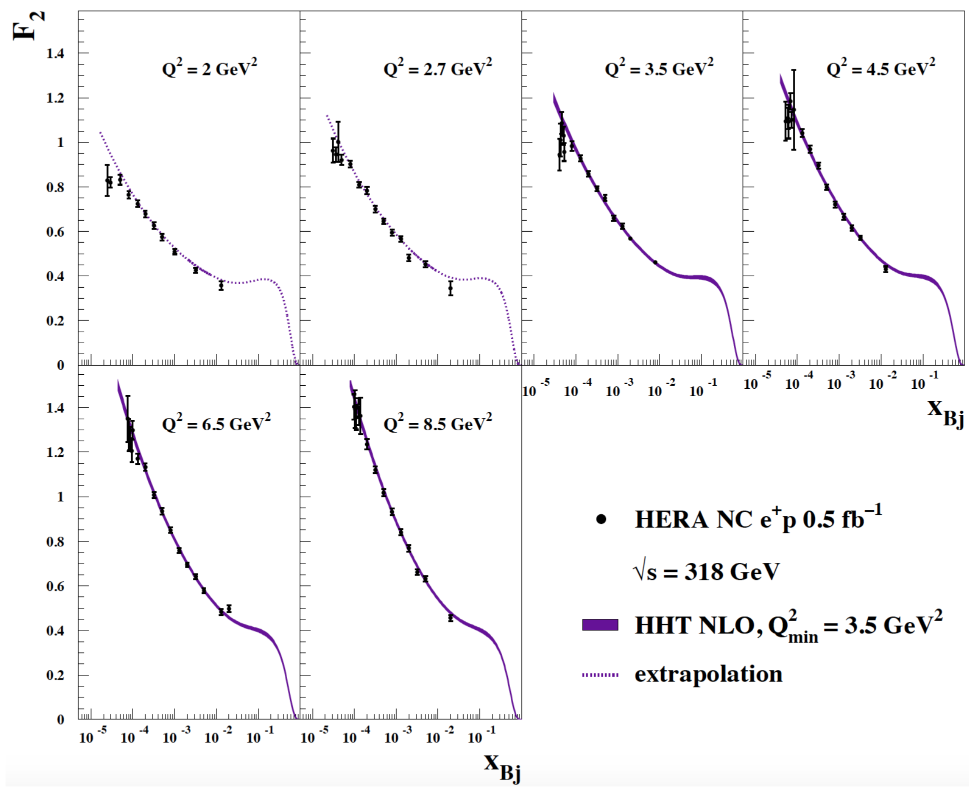
$A_L^{HT} = 4.2 \pm 0.7$ GeV^2

$A_L^{HT} = 5.5 \pm 0.6$ GeV^2

→ Trying to F_L and F_2 together gives the same conclusion

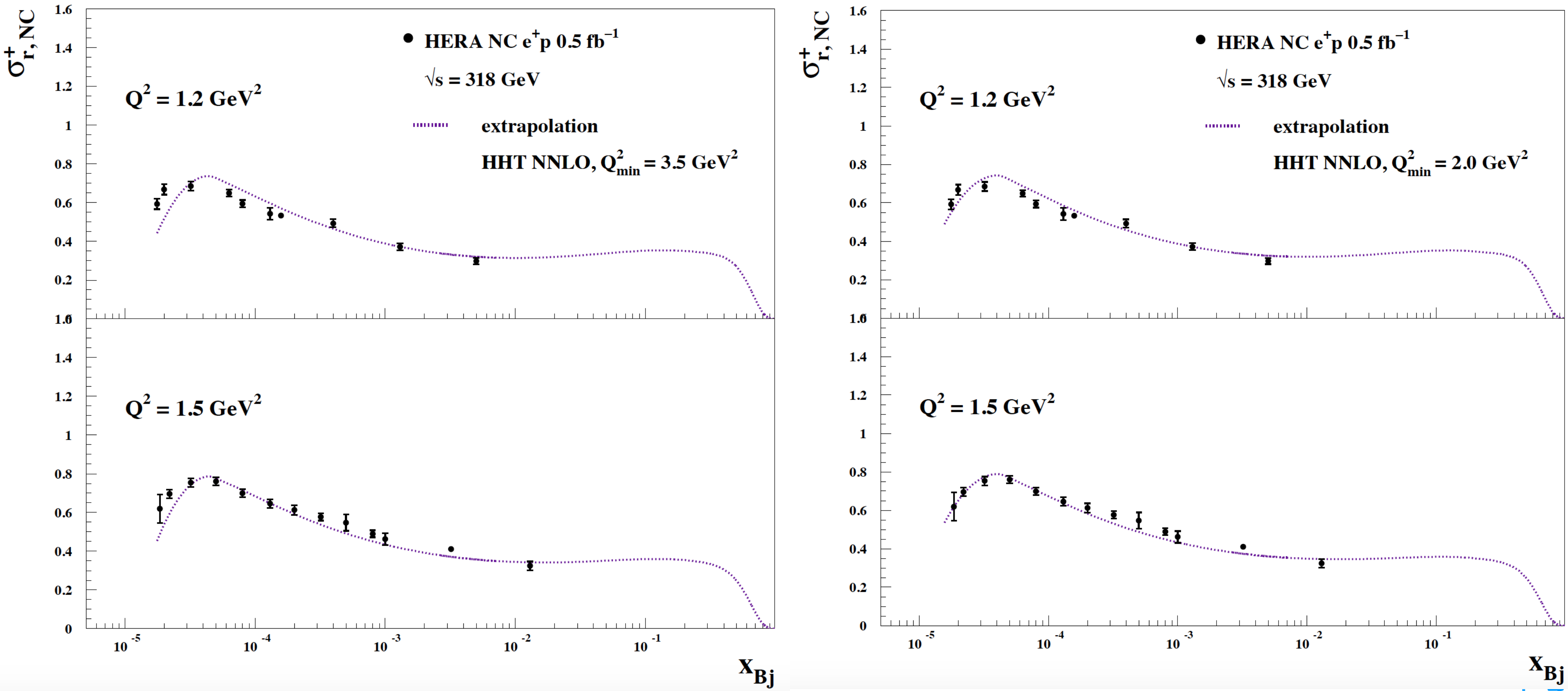
Look at $F_2^{extracted} = F_2^{predicted}\ \sigma_{red}^{measured} / \sigma_{red}^{predicted}$





- F_2 obtained by correcting σ_{red} with predicted F_L $\quad F_2 = \sigma_{red} + y^2/Y_+ F_L$
- predicted F_L too small → F_2 also too small → seen in HERAPDF2.0 F_2 at low x, Q^2
  - **extracted F_2 takes a turn over!**
  - not what pQCD F_2 predictions say
- HHT predictions for F_L gives F_2 extracted much closer to F_2 predictions
- F_2 predictions very similar → they depend ONLY on very similar PDFs

Being even bolder, looking at extrapolation down to $Q^2 \sim 1\ GeV^2$



But beware… is this actually reasonable?

What does F_L itself look like?