A new 5 Flavour LO Analysis
of Parton Distributions

and

the Parton Parametrization of the Real Photon

hep-ph/0212160, submitted to Phys. Rev. D
http://www.fuw.edu.pl/ pjank/para.html
http://www-zeuthen.desy.de/alorca/id4.html

F. Cornet, Granada U.
P. Jankowski and M. Krawczyk Warsaw U.
A. Lorca, DESY-Zeuthen

PHOTON 2003, April 2003, Frascati, Italy

CJKL

How well do we know the PHOTON?

- a realistic spectra of partons inside a photon

We present (at PHOTON 2001 - a promise):
a new LO analysis of the 'structure' of an unpolarised, real photon

- all available $F_2(x, Q^2)$ data are used, including new LEP data at high Q^2 (up to 2001)

- a special treatment of the heavy quarks threshold a'la ACOT$_\chi$
S. Kretzer, C. Schmidt, W.Tung – J. Phys. G28, 983 (2002)

Stage I: two fits, one parametrization (analytic) CJKL

- Radiatively generated u, d, s, c, b and gluon densities in real γ.
- Global 3 parameter fit, based on LO DGLAP evolution equations (Klasen et al.' 02 NNO fit to extract α_s)
- All available data for the structure function $F_2^\gamma(x, Q^2)$
- A new theoretical approach ACOT$_\chi$, originally introduced for the proton to deal with heavy quark thresholds.
- =>CJKL model =>FFNS$_{cjkl}$ model (for a comparison)
- a good description of the experimental data on $F_2^\gamma(x, Q^2)$

  CJKL better than FFNS$_{cjkl}$
- A simple analytic parametrization of the resulting parton densities in the CJKL model

Stage II (new): three fits, two parametrizations (grid) CJKL 1, CJKL 2

Parton Model for the photon $\to$ Bethe-Heitler process

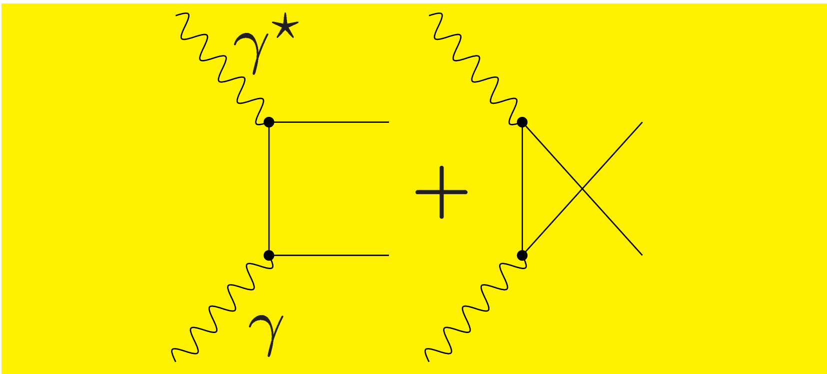
Deep Inelastic Scattering on a real photon (target)

Structure Functions for γ, eg F_2^γ => sum over $q^\gamma(x, Q^2)$

large at large x

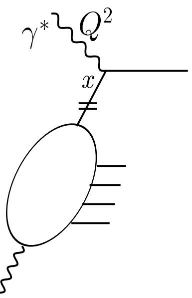
$\log Q^2$ - dependence in PM !

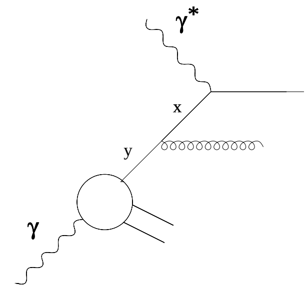
For energy W larger than 2 m_Q => production of two quarks is possible

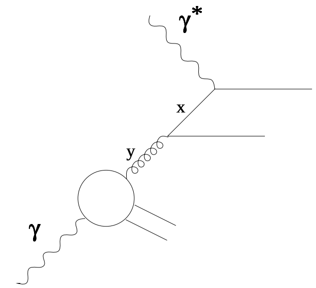
$W \to$ 

QCD modifies this 'PM" $\log Q^2$ behaviour: collinear configuration of emission of gluons leads to corrections: $\alpha_s \log Q^2$

=> DGLAP evolution equation







$$\frac{dq_i^\gamma(x,Q^2)}{d\ln Q^2} = \frac{\alpha}{2\pi} e_i^2 k(x) + \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y}\left[P_{qq}\left(\frac{x}{y}\right)q_i^\gamma(y,Q^2) + P_{qG}\left(\frac{x}{y}\right)G^\gamma(y,Q^2)\right] \quad (1)$$

$$\frac{dG^\gamma(x,Q^2)}{d\ln Q^2} = 0 + \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y}\left[P_{Gq}\left(\frac{x}{y}\right)\sum_{i=1}^{2\times N_f} q_i^\gamma(y,Q^2) + P_{GG}\left(\frac{x}{y}\right)G^\gamma(y,Q^2)\right]$$

The $k(x)$ term is from the Bethe-Heitler process, describes a photon into quark splitting function, $P_{q\gamma}$ (for 3 colours)

$$k(x) = 3\left[x^2 + (1-x)^2\right]$$

$P_i(x)$ - are the LO splitting functions,

$$P_{qq}(x) = \frac{4}{3}\left[\frac{1+x^2}{(1-x)_+} + \frac{3}{2}\delta(1-x)\right]$$

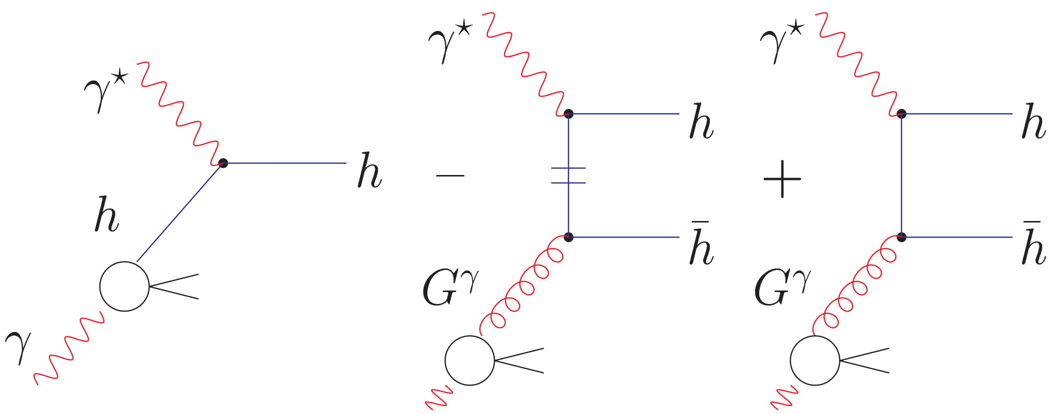
$$P_{qG}(x) = \frac{1}{2}\left[x^2 + (1-x)^2\right]$$

$$P_{Gq}(x) = \frac{4}{3}\,\frac{1+(1-x)^2}{x}$$

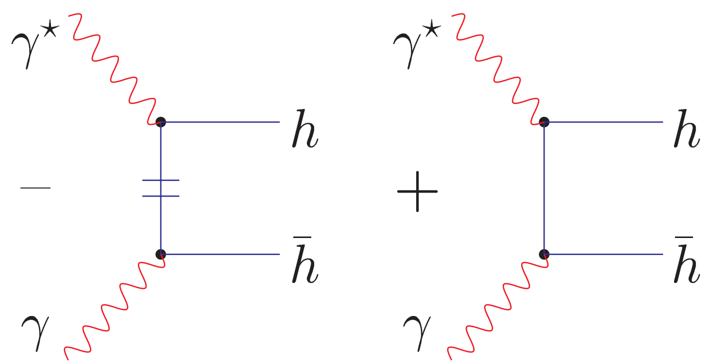
$$P_{GG}(x) = 6\left[\frac{x}{(1-x)_+} + \frac{1-x}{x} + x(1-x)\right] + \left[\frac{11}{2} - \frac{N_f}{3}\right]\delta(1-x)$$

ACOT$_\chi$ approach for a photon– heavy quarks h

n DGLAP evolution eqs.heavy quarks as partons and/or Bether-Heitler
production of heavy quarks (FFNS=B-H)



There is a double counting here, one should subtract some terms: logaritmic contribution in diagrams with “=”



Threshold for heavy quark h

Bethe-Heitler process leads to:

$$\frac{1}{x}F^{\gamma}_{2,h}(x,Q^2)|_{direct} = 3\frac{\alpha}{\pi}e_h^4\omega(x,Q^2)$$

with

$$\omega(x,Q^2) = \left[\beta\left(-1+8x(1-x)-x(1-x)\frac{4m_h^2}{Q^2}\right)\right.$$
$$\left. + \left(x^2+(1-x)^2+x(1-3x)\frac{4m_h^2}{Q^2} - x^2\frac{8m_h^4}{Q^4}\right)\ln\left(\frac{1+\beta}{1-\beta}\right)\right],$$
$$\beta = \sqrt{1-\frac{4m_h^2 x}{(1-x)Q^2}} = \sqrt{1-\frac{4m_h^2}{W^2}}.$$

for large Q^2: $\ln\left(\frac{1+\beta}{1-\beta}\right) \to \ln Q^2/m_h^2$

Threshold: $1-\frac{4m_h^2}{W^2} > 0$ - In the evolution Q^2 is a natural variable - setting a threshold condition difficult

χ variable

Another heavy quark contribution to F_2^γ:

$$\gamma^\star G^\gamma \to h\bar{h},$$

with a gluonic parton of the initial real photon

$$F_{2,h}^\gamma(x,Q^2)|_{resolved} = \frac{\alpha_s(Q^2)}{2\pi} e_h^2 \int_\chi^1 \frac{x}{z}\omega(\frac{x}{z},Q^2)G^\gamma(z,Q^2)dz$$

$$\boxed{\chi \equiv x(1+4m_h^2/Q^2)}$$

Kinematics OK: χ - lower limit of integration over z - the (relative) momentum of gluon in a photon

$\chi \to 1$ contribution $\to 0$!

Note, that χ approaches x for a large Q^2

This analysis **CJKL** (DIS02)

We follow ACOT$_\chi$ approach, and introduce the χ variable instead of x to deal with the heavy quark threshold

Finally, we have

$$F_2^\gamma(x,Q^2) = \Sigma_{i=1}^{2\times 3}\, x e_i^2 q_i^\gamma(x,Q^2) + \Sigma_{h=c,b}^{2\times 2}\, x e_h^2 q_h^\gamma(\chi,Q^2)$$
$$+ \Sigma_{h=c,b}^{2\times 2}\left[F_{2,h}^\gamma(x,Q^2)|_{direct} + F_{2,h}^\gamma(x,Q^2)|_{resolved}\right]$$
$$-\chi\,\Sigma_{h=c,b}^{2\times 2} \ln\frac{Q^2}{m_h^2}\left[e_h^4 \frac{\alpha}{2\pi} k(\chi) + e_h^2 \frac{\alpha_s}{2\pi}\int_\chi^1 \frac{dy}{y} P_{qG}(\frac{\chi}{y}) G^\gamma(y,Q^2)\right].$$

Note, that the direct contribution does not disappear at $\chi \to 1$ stage II.

Solving DGLAP evolution eqs.

n the solving the DGLAP evolution eqs. we use Mellin technique.

=> point-like (PL) and hadronic part for each parton density.

PL can be obtained without any input, hadronic parts need input at Q_0^2 scale. We take $Q_0^2 = 0.25$.

Input: VMD model at low scale

Following GRV our input scale is low : $Q_0^2 = 0.25$.

For hadronic part we have to model

$$f_{had}^{\gamma}(x, Q_0^2) = \sum_V \frac{4\pi\alpha}{\hat{f}_V^2} f^V(x, Q_0^2)$$

$$f_{had}^{\gamma}(x, Q_0^2) = \kappa \frac{4\pi\alpha}{\hat{f}_\rho^2} f^\rho(x, Q_0^2).$$

$$xv^\rho(x, Q_0^2) = N_v x^{\alpha}(1 - x)^{\beta},$$

$$xG^\rho(x, Q_0^2) = N_g xv^\rho(x, Q_0^2)$$

$$v^\rho = (u^{\rho^+} + \bar{u}^{\rho^-} + d^{\rho^-} + \bar{d}^{\rho^+})/4$$

with normalization to 1.

Constraints

We impose two constraints on the parameters of both models

$$\int_0^1 2v^\rho(x, Q_0^2)dx = 2$$

$$\int_0^1 x(2v^\rho(x, Q_0^2) + G^\rho(x, Q_0^2))dx = 1$$

Using them => the normalization factors N_v, N_g

We have $\boxed{\alpha, \beta \text{ and } \kappa}$ as free parameters

We fix them by fitting the F_2^γ experimental data.

The fits: stage I

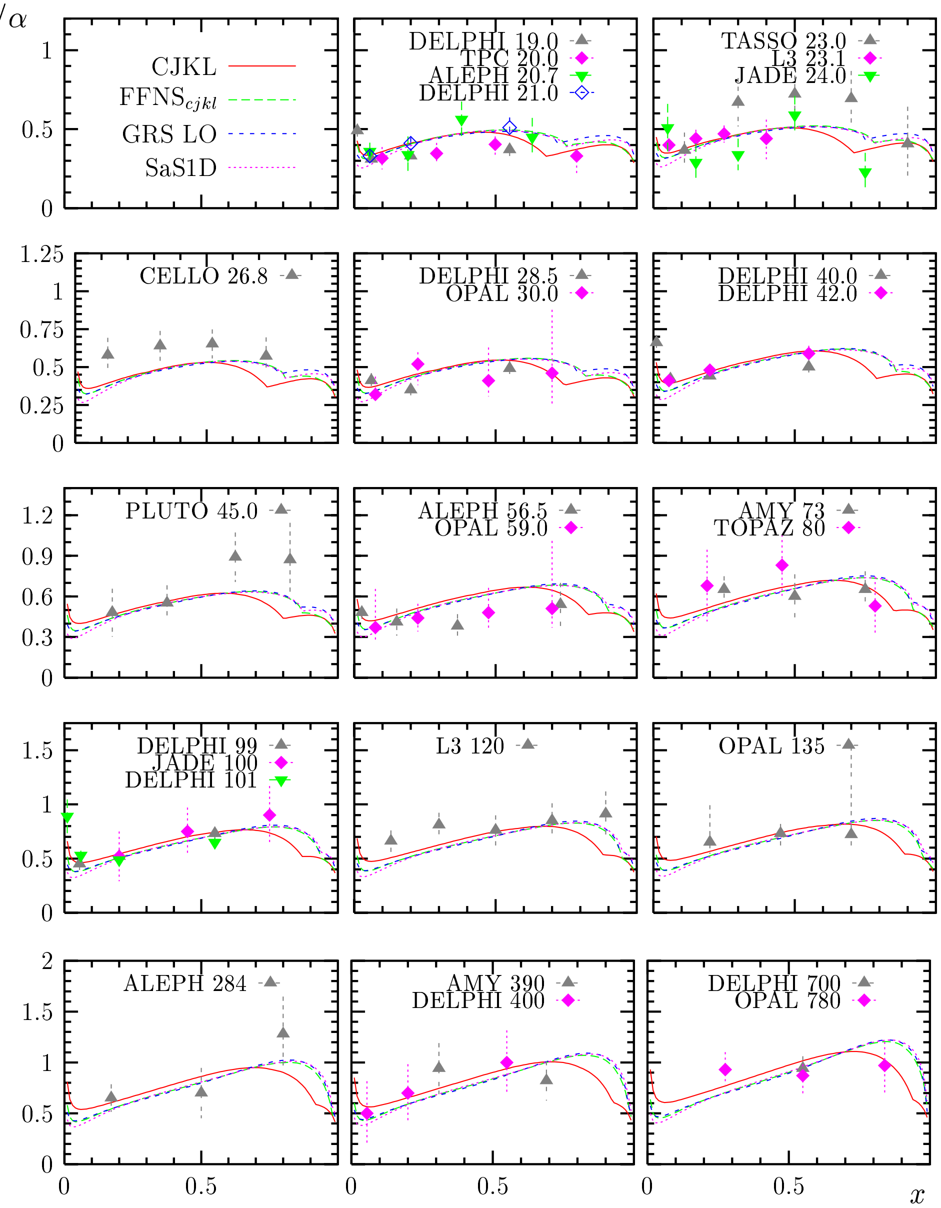
- N_f=3 (FFNS), N_f=5 (CJKL)
- $\alpha_s(Q^2)$
- the direct contribution does not disappears for $\chi \to 1$ (large x)
- no error analysis

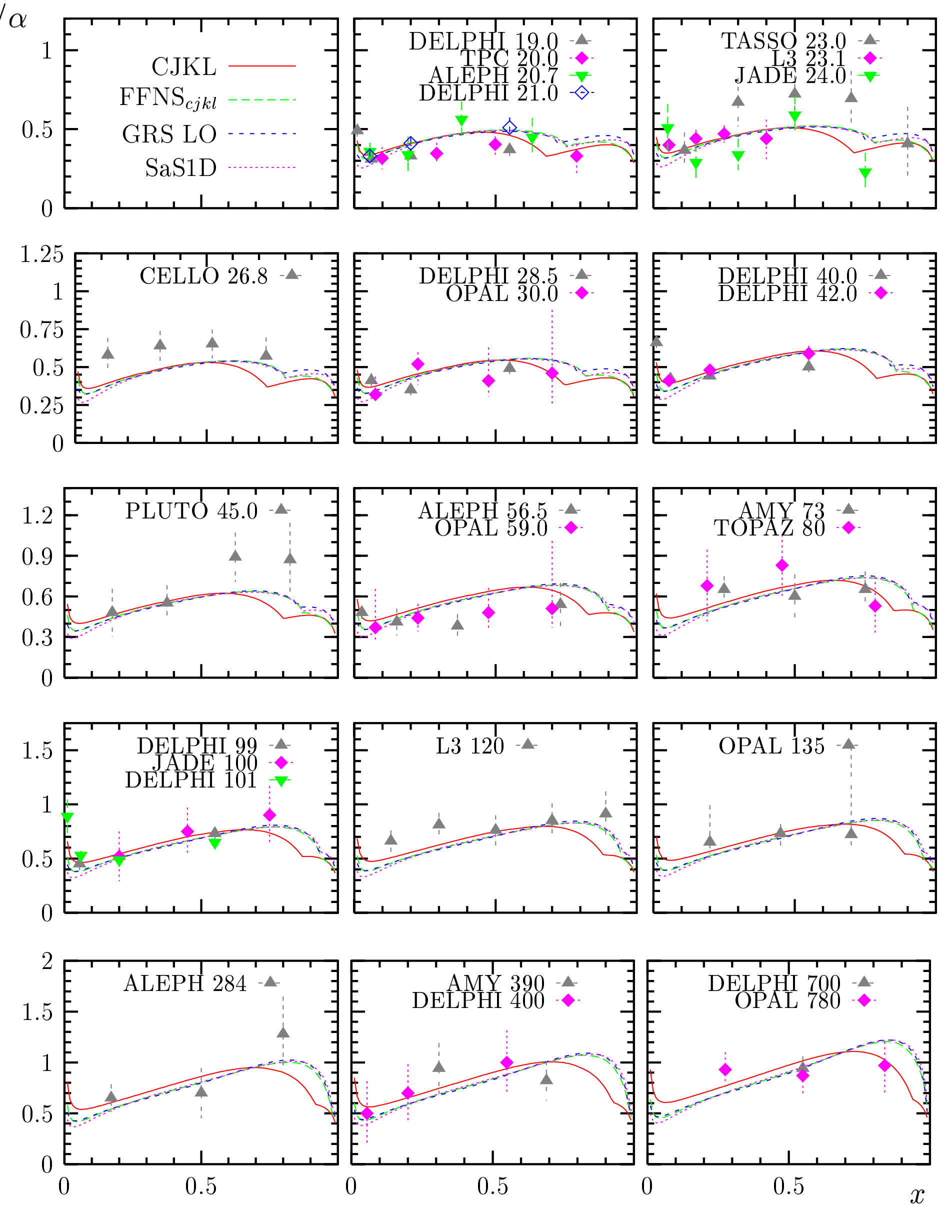
model	χ^2 (208 pts)	$\chi^2/_{DOF}$	κ	α	β	N_v	N_{gl}
FFNS$_{cjkl}$	471	2.30	1.726	0.465	0.127	0.504	1.384
CJKL	431	2.10	1.125	0.843	2.359	2.435	2.982

Comparison of CJKL and FFNS$_{cjkl}$ fits with other parametrizations

model	# of par.	χ^2 (205 pts)	$\chi^2/_{DOF}$	χ^2 (182 pts*)	$\chi^2/_{DOF}$
SaS1D	6	657	3.30	611	3.47
GRS LO	0	499	2.43	366	2.01
FFNS$_{cjkl}$	3	442	2.19	357	1.99
CJKL	3	406	2.01	320	1.79

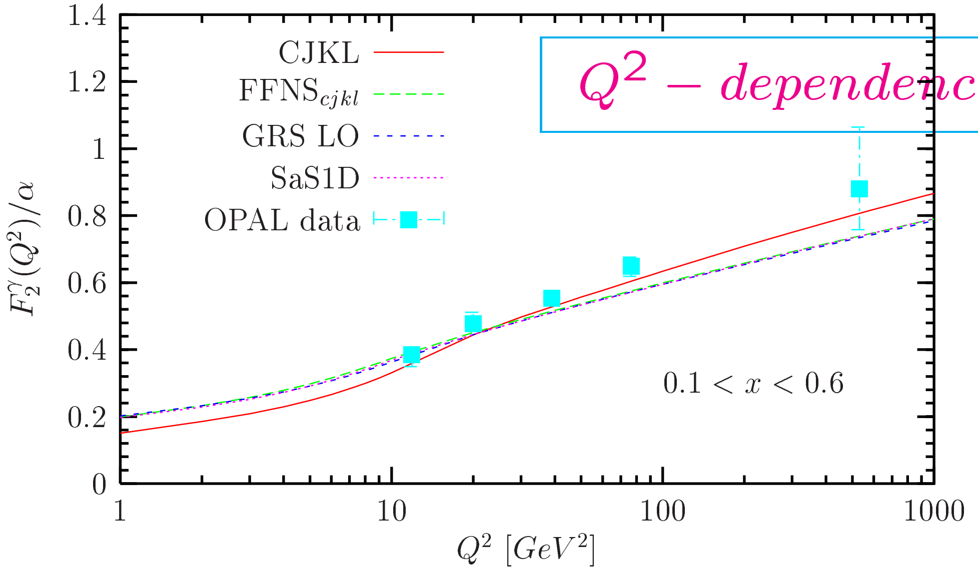
* - no TPC data

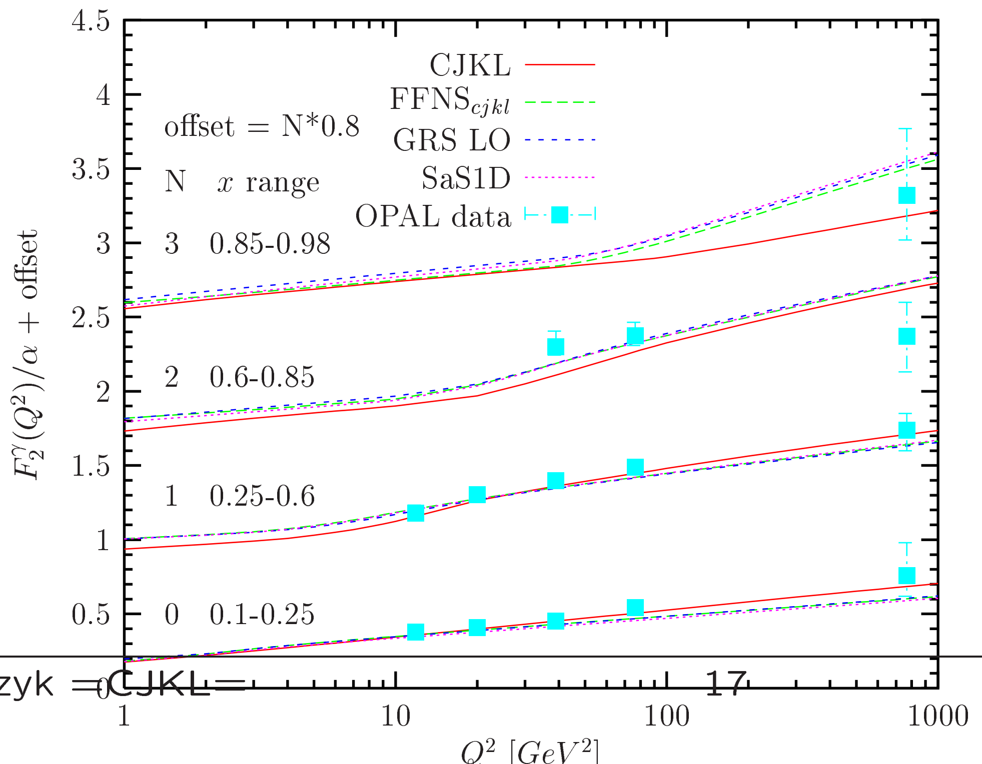

CJKL
FFNS$_{cjkl}$
GRS LO
SaS1D
DELPHI 19.0
TPC 20.0
ALEPH 20.7
DELPHI 21.0
TASSO 23.0
L3 23.1
JADE 24.0
CELLO 26.8
DELPHI 28.5
OPAL 30.0
DELPHI 40.0
DELPHI 42.0
PLUTO 45.0
ALEPH 56.5
OPAL 59.0
AMY 73
TOPAZ 80
DELPHI 99
JADE 100
DELPHI 101
L3 120
OPAL 135
ALEPH 284
AMY 390
DELPHI 400
DELPHI 700
OPAL 780
x



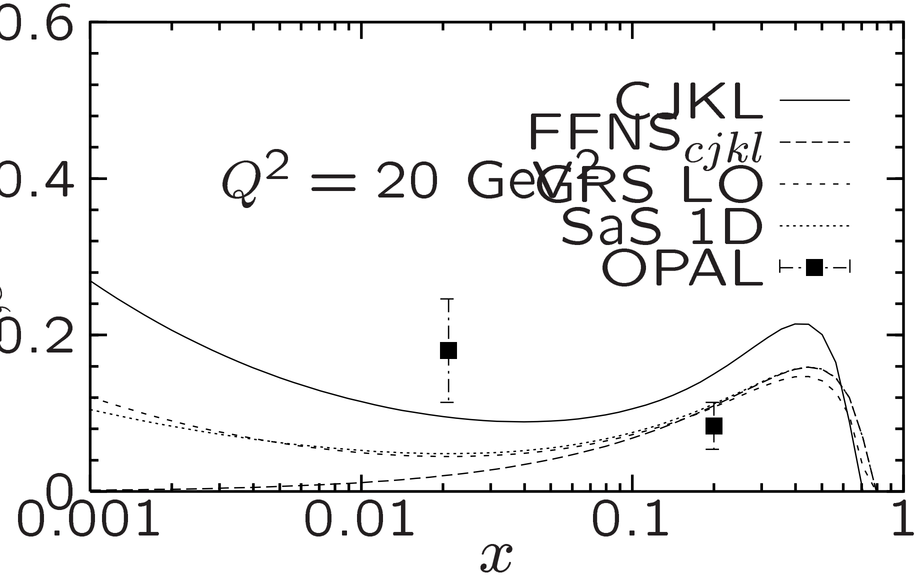
CJKL
FFNS$_{cjkl}$
GRS LO
SaS1D
DELPHI 19.0
TPC 20.0
ALEPH 20.7
DELPHI 21.0
TASSO 23.0
L3 23.1
JADE 24.0
CELLO 26.8
DELPHI 28.5
OPAL 30.0
DELPHI 40.0
DELPHI 42.0
PLUTO 45.0
ALEPH 56.5
OPAL 59.0
AMY 73
TOPAZ 80
DELPHI 99
JADE 100
DELPHI 101
L3 120
OPAL 135
ALEPH 284
AMY 390
DELPHI 400
DELPHI 700
OPAL 780
x

$Q^2 - dependence$





Comparison with $F_{2c}^{\gamma} data$



Stage II

New models vs old models - changes introduced.

1. Subtraction terms

$$\text{Direct:} \quad \frac{dq_h^\gamma(x,Q^2)}{d\ln Q^2} = \frac{\alpha}{2\pi} e_h^2 k(x)$$

Before $F_{2,h}^\gamma|_{dir,subtr} \sim k(x) \ln \frac{Q^2}{m_h^2}$ Now $\sim k(x) \ln \frac{Q^2}{Q_0^2}$

2. α_s running

$$\alpha_s(Q^2)^{(N_l)} = \frac{4\pi}{\beta_0 \ln(Q^2/\Lambda_{QCD}^{(N_l)})} \quad \text{with} \quad \beta_0 = 11 - \frac{2}{3} N_l$$

Before $N_l = 3$ in FFNS$_{CJKL}$ $N_l = 5$ in CJKL

Now $N_l = N_l(Q^2)$ in all models

3. Λ_{QCD}^3 is a free prameter

Former value was too high and caused high χ^2 of the fits

4. High-x F_2^γ behaviour

The 'by-hand' imposed condition in CJKL $F_{2,h}^\gamma \geq 0$

At high x $F_{2,h}^\gamma < F_{2,h}^\gamma(x,Q^2)|_{direct} + F_{2,h}^\gamma(x,Q^2)|_{resolved}$

CJKL 1 - old CJKL condition

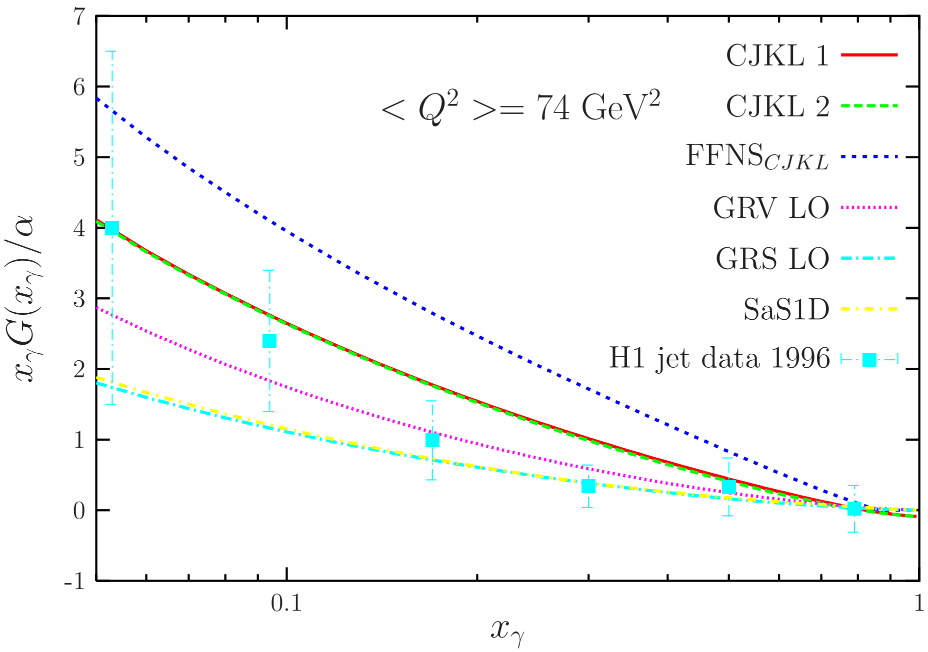
CJKL 2 - new condition $F_{2,h}^\gamma \geq F_{2,h}^\gamma(x,Q^2)|_{direct} + F_{2,h}^\gamma(x,Q^2)|_{resolved}$

P.Jankowski, M.Krawczyk, F.Cornet VERY PRELIMINARY!

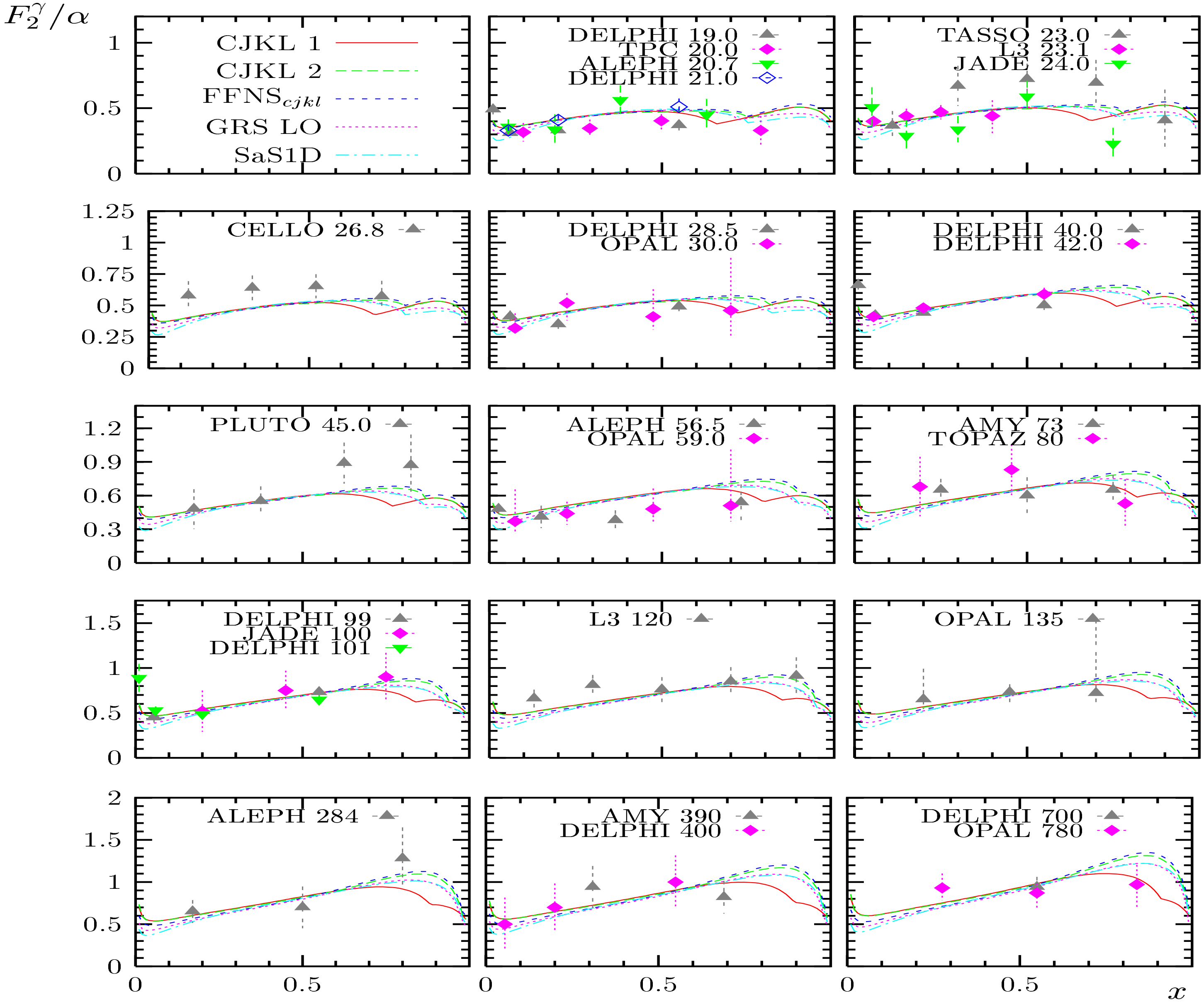
5. Vector Meson Dominance model

$$\int_0^1 2v^\rho(x,Q_0^2)dx \begin{array}{ll} = 2.00 & \text{THEORY} \\ = 0.91 & \text{FFNS}_{CJKL} \\ = 1.99 & \text{CJKL 1} \\ = 1.91 & \text{CJKL 2} \end{array}$$

$$\int_0^1 (2v^\rho + G^\rho)(x,Q_0^2)dx = 1 \quad \text{FIXED!}$$

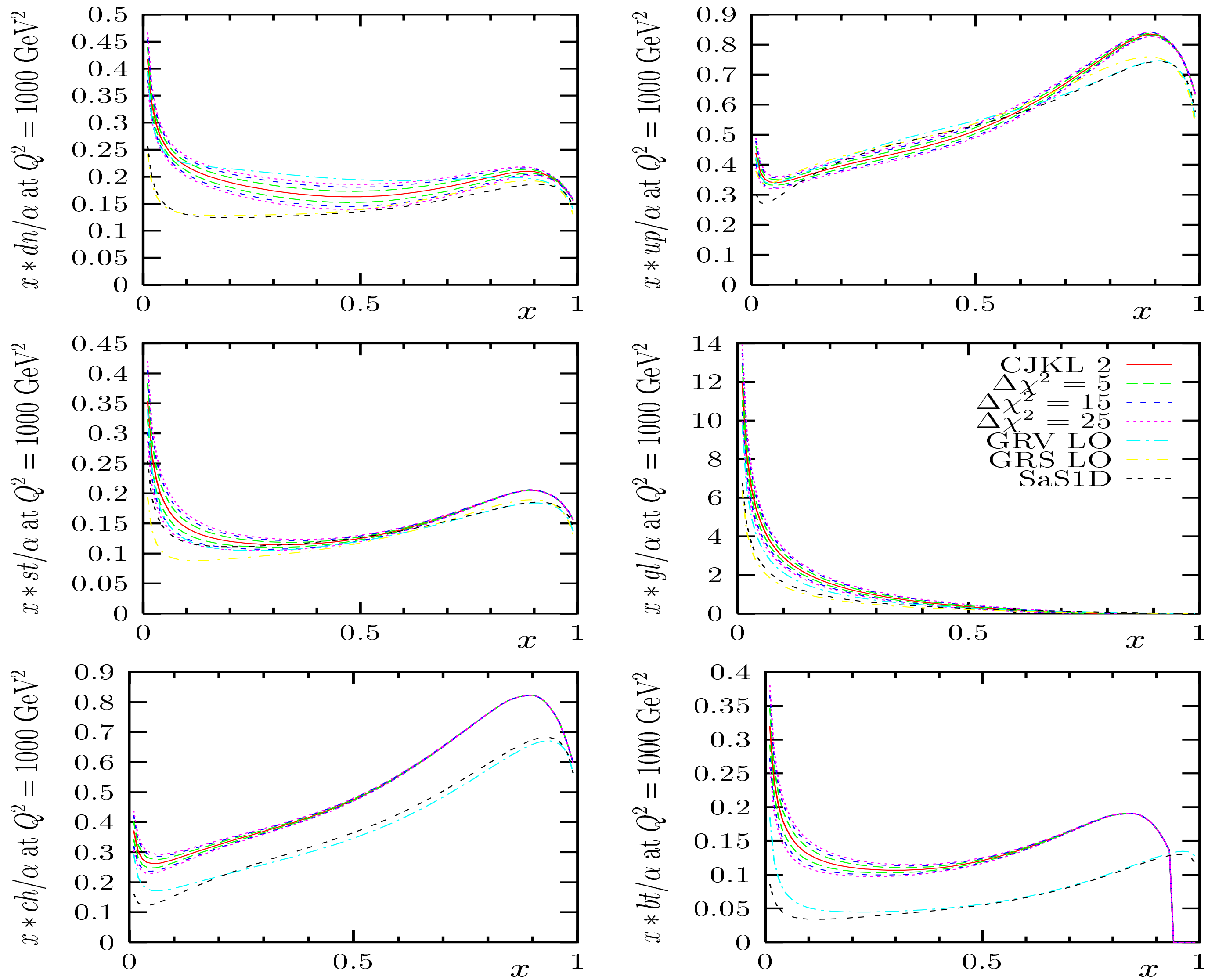


P.Jankowski, M.Krawczyk, F.Cornet VERY PRELIMINARY!

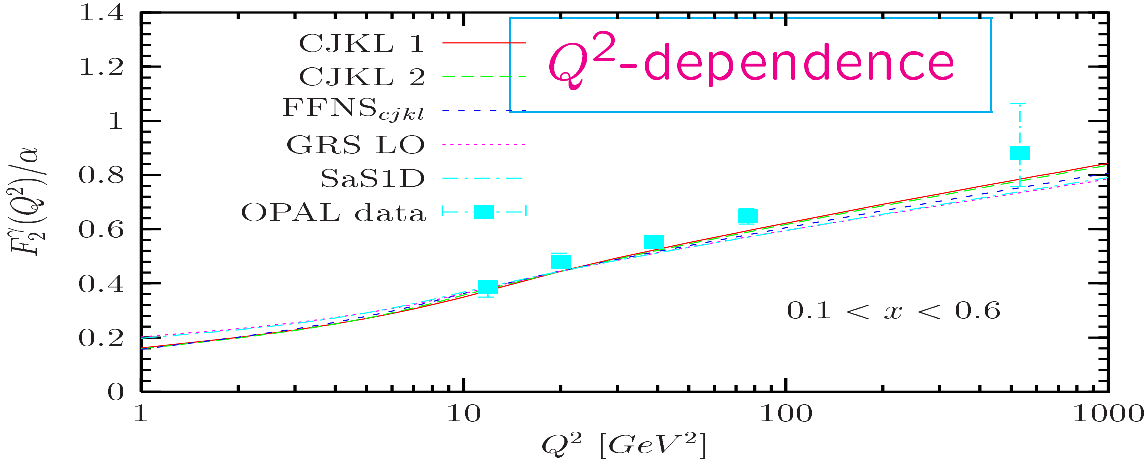


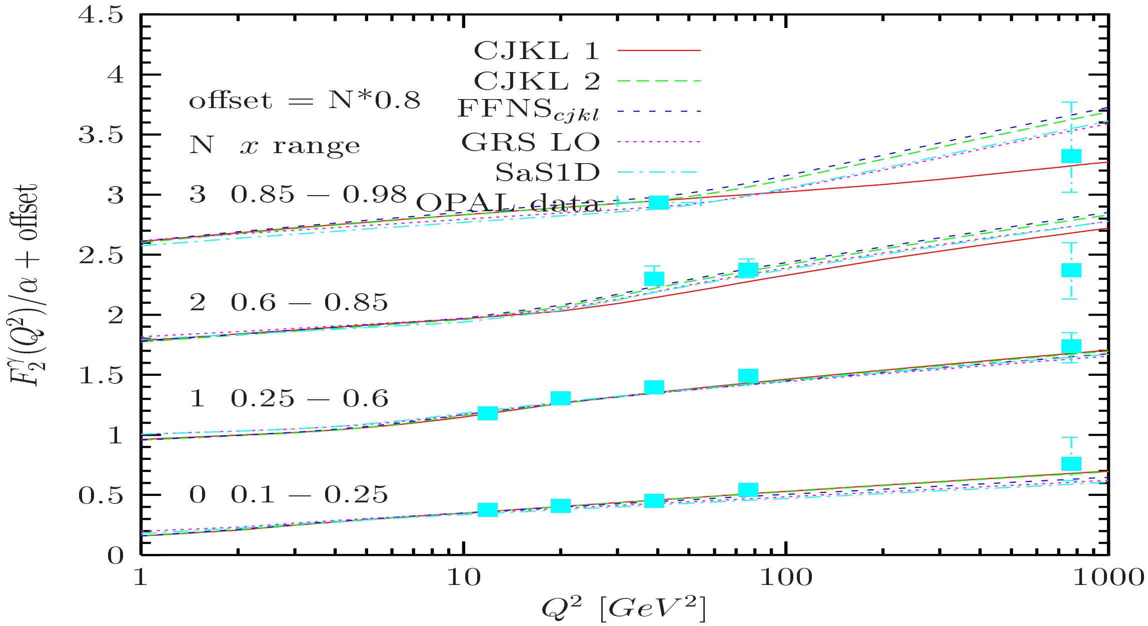
P.Jankowski, M.Krawczyk, F.Cornet VERY PRELIMINARY!

Parton distributions with uncertainties



P.Jankowski, M.Krawczyk, F.Cornet VERY PRELIMINARY!


Q^2-dependence
CJKL 1
CJKL 2
FFNS$_{cjkl}$
GRS LO
SaS1D
OPAL data
$0.1 < x < 0.6$
$F_2^\gamma(Q^2)/\alpha$
$Q^2\ [GeV^2]$


CJKL 1
CJKL 2
FFNS$_{cjkl}$
GRS LO
SaS1D
OPAL data
offset = N*0.8
N x range
3 0.85 – 0.98
2 0.6 – 0.85
1 0.25 – 0.6
0 0.1 – 0.25
$F_2^\gamma(Q^2)/\alpha$ + offset
$Q^2\ [GeV^2]$

1

Conclusion

LO analysis of F_2^γ based on existing data

Fix Flavor Number scheme and ACOT(χ) scheme

CJKL model based on ACOT(χ)
$\rightarrow$ LO parton parametrizations CJKL, CJKL 1, CJKL 2

NLO analysis in progress