LEADING LOG RADIATIVE CORRECTIONS AT HERA

J. BLÜMLEIN - IFH ZEUTHEN / BERLIN 5/89

1. STATUS : CALCULATION OF RC AT HERA
2. LEADING LOG FORMALISM
3. ELIMINATION OF QUARK MASS TERMS
4. NC & CC CROSS SECTIONS $O(\alpha/2\pi)$
5. CONCLUSIONS

1. STATUS: RADIATIVE CORRECTIONS AT HERA

$e^{\pm}p \longrightarrow \begin{cases} e^{\pm}X(\gamma) \\ \nu X(\gamma) \end{cases}$ $\quad O\left(\frac{\alpha}{2\pi}\right)$

COMPLETE CALCULATIONS:

- BARDIN et al. 1987 (NC), 1989 (NC, CC)
- BÖHM, SPIESBERG 1989 (NC, CC)

APPROXIMATE CALCULATIONS:

- KRIPFGANZ, MÖHRING (NC, CC) 1987/88
- VAN NEERVEN et al. F_2^{ep} ($Q^2 \leq 50\,\mathrm{GeV}^2$) (RINGBERG/BAVARIA April 1989)
- THIS WORK (NC, CC)

- THE CAL.CULATION BARDIN et al. 1987/89 CONFIRMED: BARDIN et al. 1984 (INDEP. CALC.)
- NUMERICAL DIFFERENCES: BARDIN et al. / BÖHM, SPIESBERG

exp.: LOW y, HIGHER x (NC)

↑

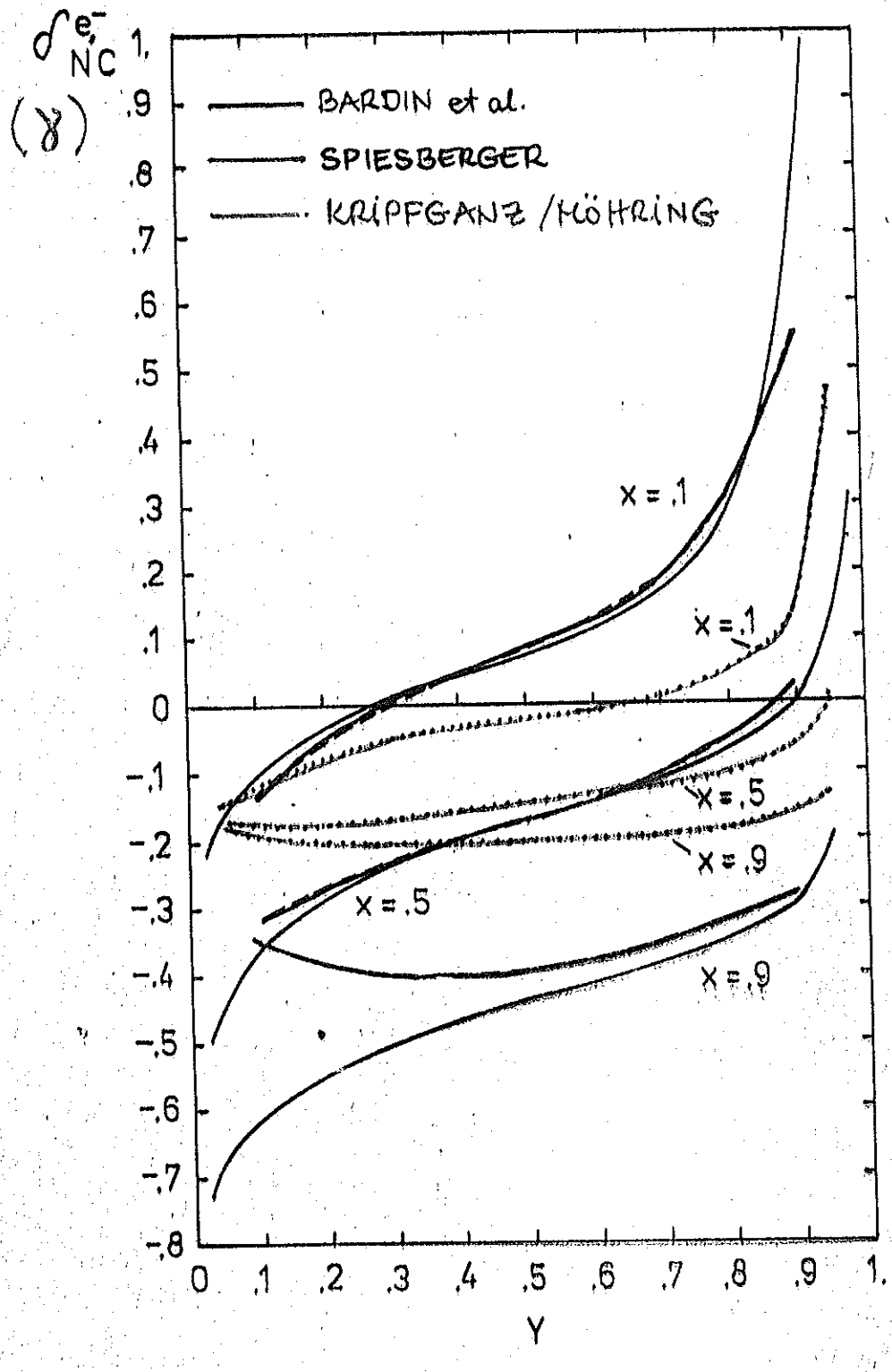
A LARGE PART OF THE STATISTICS IS LOCATED AT LOW y!

NO COMPARISON POSSIBLE FOR CC AT PRESENT.

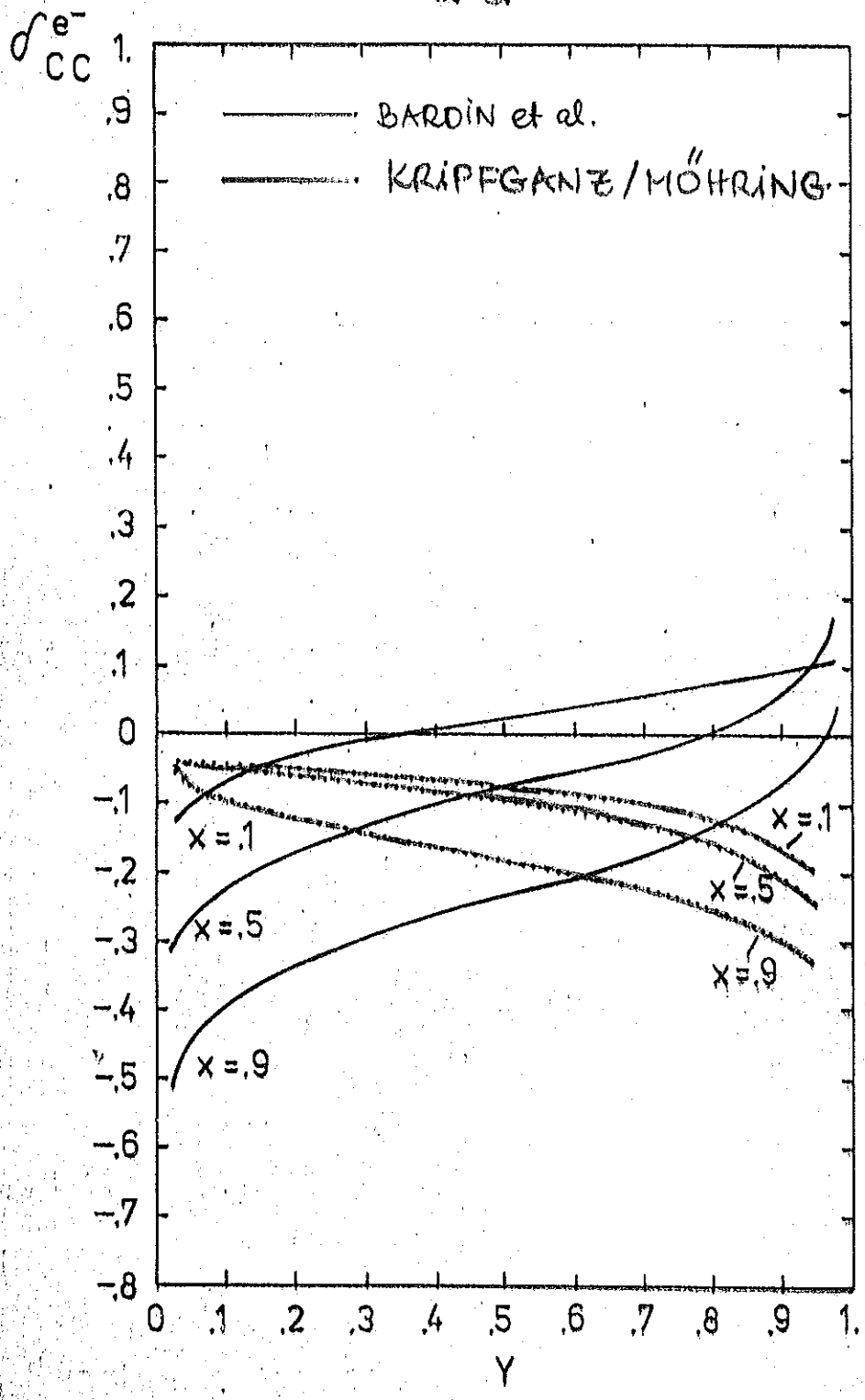
- LARGE DIFFERENCES BOTH IN SHAPE & VALUE FOR CC BETWEEN BARDIN et al. / KRIPFGANZ & MÖHRING
- GOOD AGREEMENT BETWEEN BARDIN et al. / VAN NEERVEN et al. (NC)

Fig. 1,2

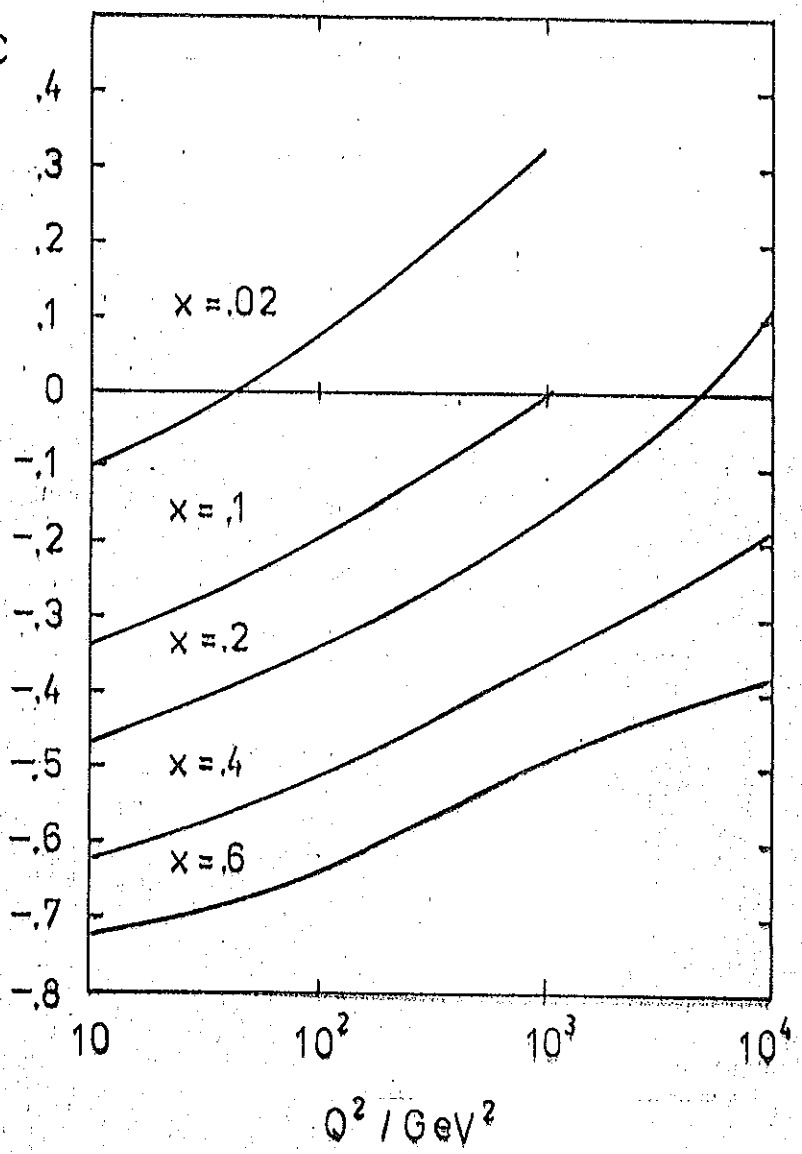
NC


$\delta^{e^-}_{NC}$ (γ)
BARDIN et al.
SPIESBERGER
KRIPFGANZ / MÖHRING
x = .1
x = .1
x = .5
x = .9
x = .5
x = .9
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.
Y

CC


$\sigma^{e^-}_{CC}$
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
BARDIN et al.
KRIPFGANZ/MÖHRING
x = .1
x = .5
x = .9
x = .1
x = .5
x = .9
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.
Y

$\frac{d^2\sigma/dxdy}{d^2\sigma_0/dxdy} - 1 = \delta_{NC}^-$



D. Yu. BARDIN et al.
DUBNA E2-88-682

STRONG Q^2-DEPENDENCE AT FIXED X.

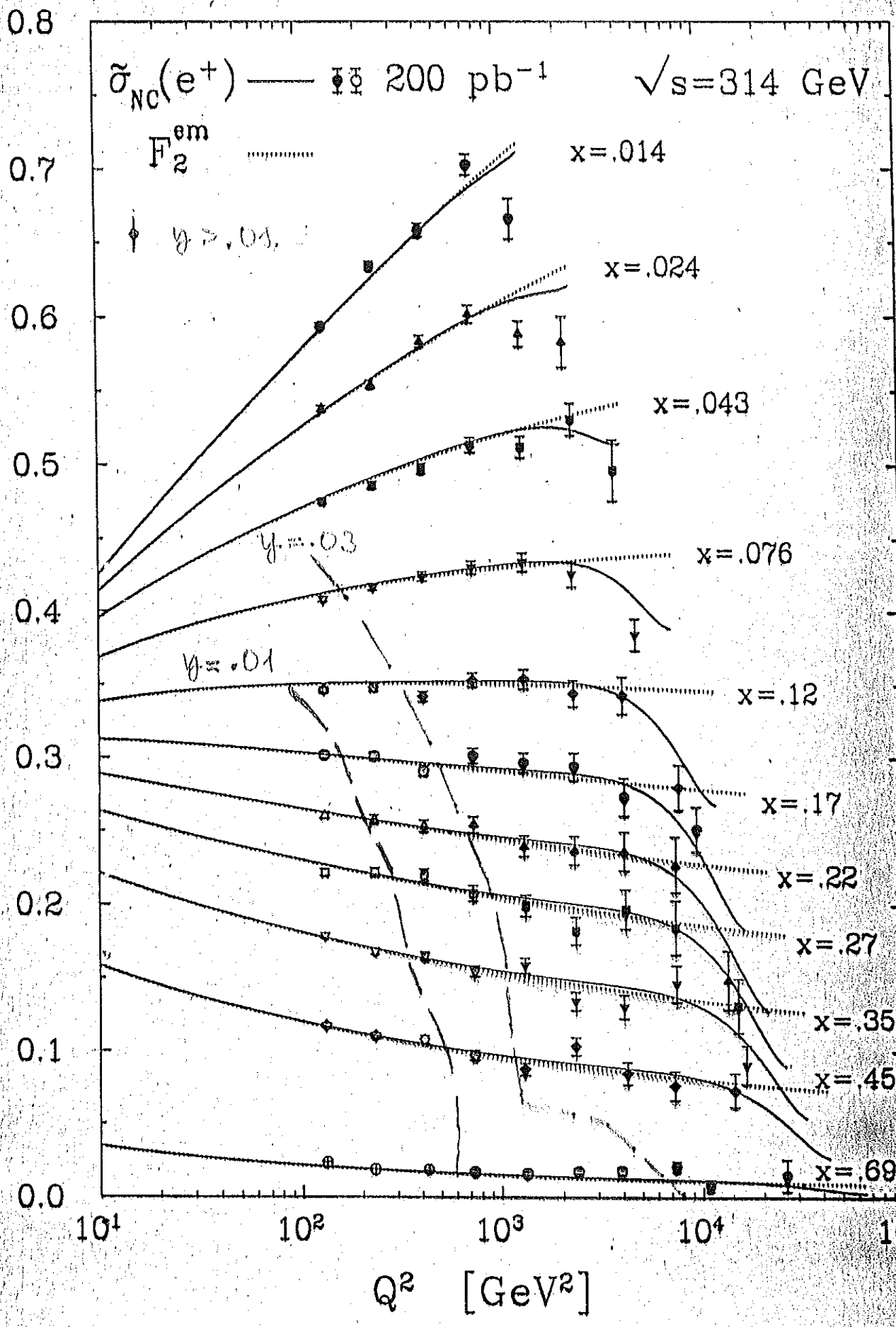
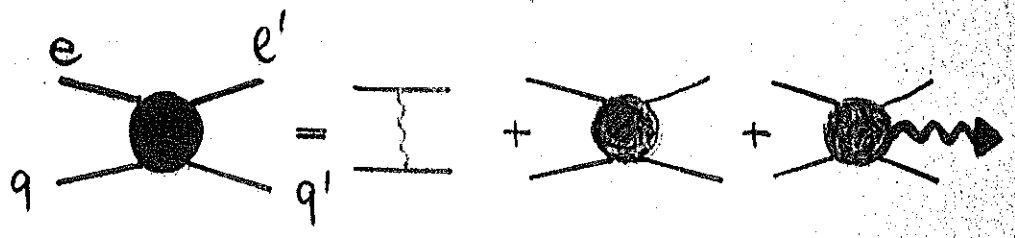

$\tilde{\sigma}_{NC}(e^+)$ —— 200 pb^{-1} $\sqrt{s}$=314 GeV
F_2^{em}
y > .01
y = .03
y = .01
x=.014
x=.024
x=.043
x=.076
x=.12
x=.17
x=.22
x=.27
x=.35
x=.45
x=.69
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
10^1
10^2
10^3
10^4
10^5
Q^2 [GeV^2]

Fig. 3

2. THE LEADING LOG FORMALISM

$\frac{d^2\sigma}{dx\,dy}$ ←



$O(\alpha_s)$ BREMSSTRAHLG.

WE WILL DISCUSS: γ- BREMSSTRAHLUNG + VERTEX CORR. (IR. FINITE)

— HUGHE CONTRIBUTION:

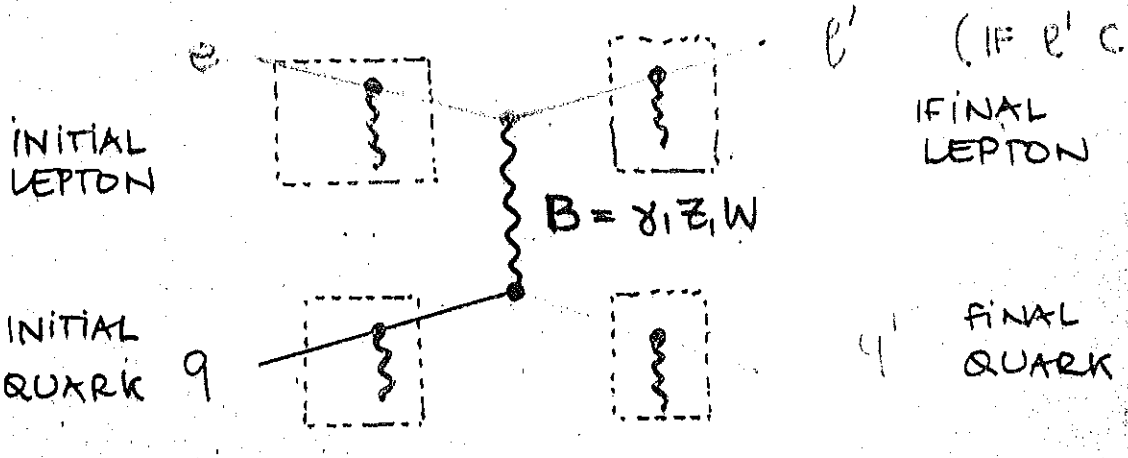
SPS: $\ln\left(\frac{Q^2 = 100\,GeV^2}{m_p^2}\right)$

⇓ × 2.5 ... 3.0

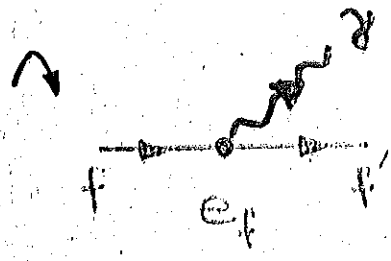
HERA: $\ln\left(\frac{Q^2 = 10^3 \ldots 10^4\,GeV^2}{m_p^2}\right)$

i) CHOOSE A PHYSICAL GAUGE.

ii) THE LEADING LOGS FACTORIZE FOR PHOTON BREMSSTRAHLUNG (AS E.G. IN QCD) THE BREMSSTRAHLUNG LOGS ARE:



iii) CALCULATE $4\,|\mathcal{M}_i|^2$'s ; TREAT $p_f \parallel k$ IN THE NUMERATOR OF $\mathcal{M}_i$.



$\sim O(Q^2)$

iv) FINAL QUARK BREMSSTRAHLUNG WILL NOT CONTRIBUTE AFTER SUMMATION OVER THE HADRONIC FINAL STATE: KINOSHITA-LEE-NAUENBERG THEOREM.

v) BREMSSTRAHLUNG FORMULA:

USE: $\hat{s} \simeq Q^2 = Sxy$.

$$\frac{d^2\sigma_0}{dx\,dy} = \sum_{i=q,\bar{q}} C_i(x,y)\,\frac{d^2\sigma_{0,i}}{dx\,dy}$$

$\frac{d^2\sigma^{Brem.}_{i,f}}{dx\,dy}$ IS A MAP OF $C_i(x,y)\,\frac{d^2\sigma_{0,i}}{dx\,dy}$ (QUARKS)

OR EVEN OF $\frac{d^2\sigma_0}{dx\,dy}$ (ELECTRONS) !

THIS MAP IS WIDELY INDEPENDENT OF THE BORN CROSS SECTION. IT IS DETERMINED BY

THE RADIATING LEGS.

ONE OBTAINS:

(i) ELECTRONS:

$$\frac{\alpha}{2\pi}\cdot e_e^2 \cdot \ln\left(\frac{Q^2}{m_e^2}\right)\cdot\int_0^1 dz\,\frac{1+z^2}{1-z}\left\{\theta(z-z_0)\,\frac{y}{\hat{y}}\,\frac{1}{z^2}\,\frac{d^2\sigma_0}{dx\,dy}\Big|_{\substack{x=\frac{x}{z}\\ y=\hat{y}}} - \frac{d^2\sigma_0}{dx\,dy}\right\}$$

(ii) QUARKS:

$$\frac{\alpha}{2\pi}\cdot\sum_{i=q,\bar{q}} e_q^2 \cdot \ln\left(\frac{Q^2}{m_q^2}\right)\int_0^1 dz\,\frac{1+z^2}{1-z}\left\{\theta(z-z_0)\,\frac{y}{\hat{y}}\,\frac{1}{z^2}\,C_i(\hat{x},\hat{y})\,\frac{d^2\sigma_{0,i}}{dx\,dy}\Big|_{\substack{x=\hat{x}\\ y=\hat{y}}} - C_i(x,y)\,\frac{d^2\sigma_{0,i}}{dx\,dy}\right\}$$

	INITIAL $e^{\pm}$	FINAL $e^{\pm}$	INITIAL QUARK
a	1	2	0
z_0	$(1-y)/(1-xy)$	$1-y+xy$	x
$\hat{x}$	$x \cdot yz/(z+y-1)$	$x \cdot y/(z+y-1)$	x/z
$\hat{y}$	$(z+y-1)/z$	$(z+y-1)/z$	y
$\hat{Q}^2$	$Q^2 z$	Q^2/z	Q^2
			1

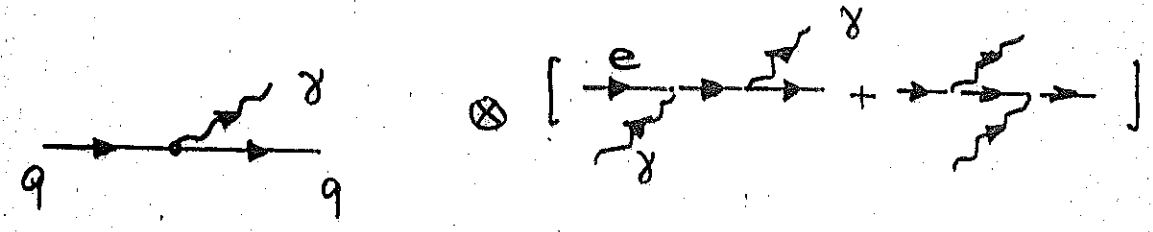
→ ANALYTICAL AGREEMENT WITH VAN NEERVEN et al.

$|\gamma|^2_{NC}$

IFF $M^2(B) \not\ll Q^2$ ALL LEADING LOGS ARE FOUND ALREADY. (E.G. CC-REACTIONS)

vi) $\underline{M^2(B) \ll Q^2}$: (e.g. PHOTONS) $\frac{1}{Q^4}$ in $|(XT)_0|^2$

$\sim \ln\left(\frac{Q^2}{m_q^2}\right)$ TERM DUE TO : (cf. also VAN NEERVEN '89)



THE QUARK FRAGMENTS INTO A PHOTON + QUARK

THE PHOTON SCATTERS WITH THE ELECTRON IN A COMPTON PROCESS

→ THE "2nd PEAK." by Ho & TSAI 1971.

$$\frac{d^2\sigma_q^c}{dx\,dy} = \frac{\alpha^3}{Sx} \ln\left(\frac{Q^2}{m_q^2}\right) \int_x^1 \frac{dz}{z^3} F_2(z) \frac{1+(1-y)^2}{1-y} \left\{\left[z^2 + (z-x)^2\right]/x\right\}.$$

THIS FORMULA MAY BE DIRECTLY DERIVED FROM THE EXACT CALCULATION IN TERMS OF α_s. WHERE THE INTERPRETATION OF THESE TERMS WAS NOT OBVIOUS! → $\ln \frac{S}{M_p^2} \approxeq \ln \frac{Q^2}{m_q^2}$ TERMS.

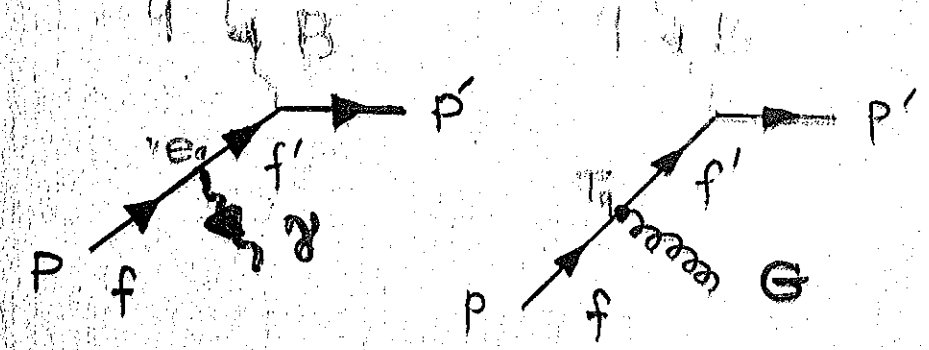
3. ELIMINATION OF QUARK MASS TERMS

MOST OF THE BASIC CALCULATIONS USE **SIRLIN's SCHEME:** DIMENSIONAL REGULARIZATION, I.E. ALL QUARKS ARE TREATED AS FERMIONS WITH A FIXED MASS!

HOWEVER, $m_q = m_q(Q^2)$ IS RUNNING (QCD).

SOLUTION:

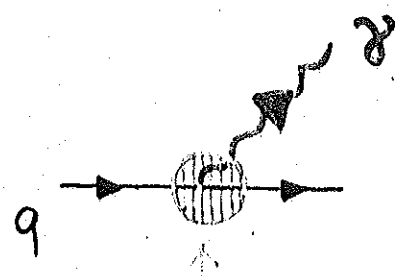
(i) INITIAL QUARK BREMSSTRAHLUNG: A. DE RUJULA et al. (1979)



→ MODIFICATION OF NS & SINGLET QCD-EVOLUTION

m_q IS "ABSORBED" INTO THE PARTON-DISTRIBUTIONS AT Q_0^2.

(ii) QUARK FRAGMENTATION INTO A PHOTON

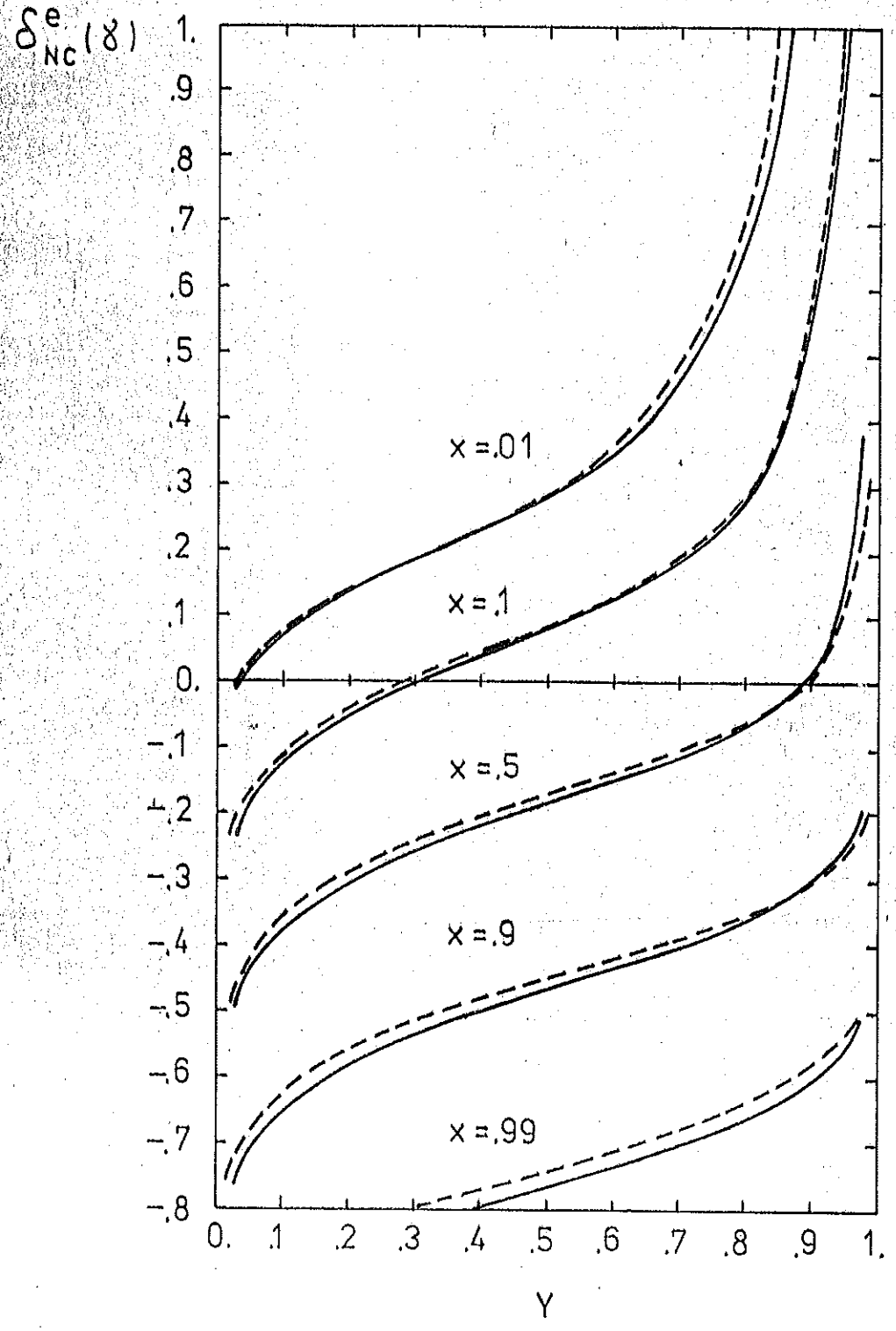


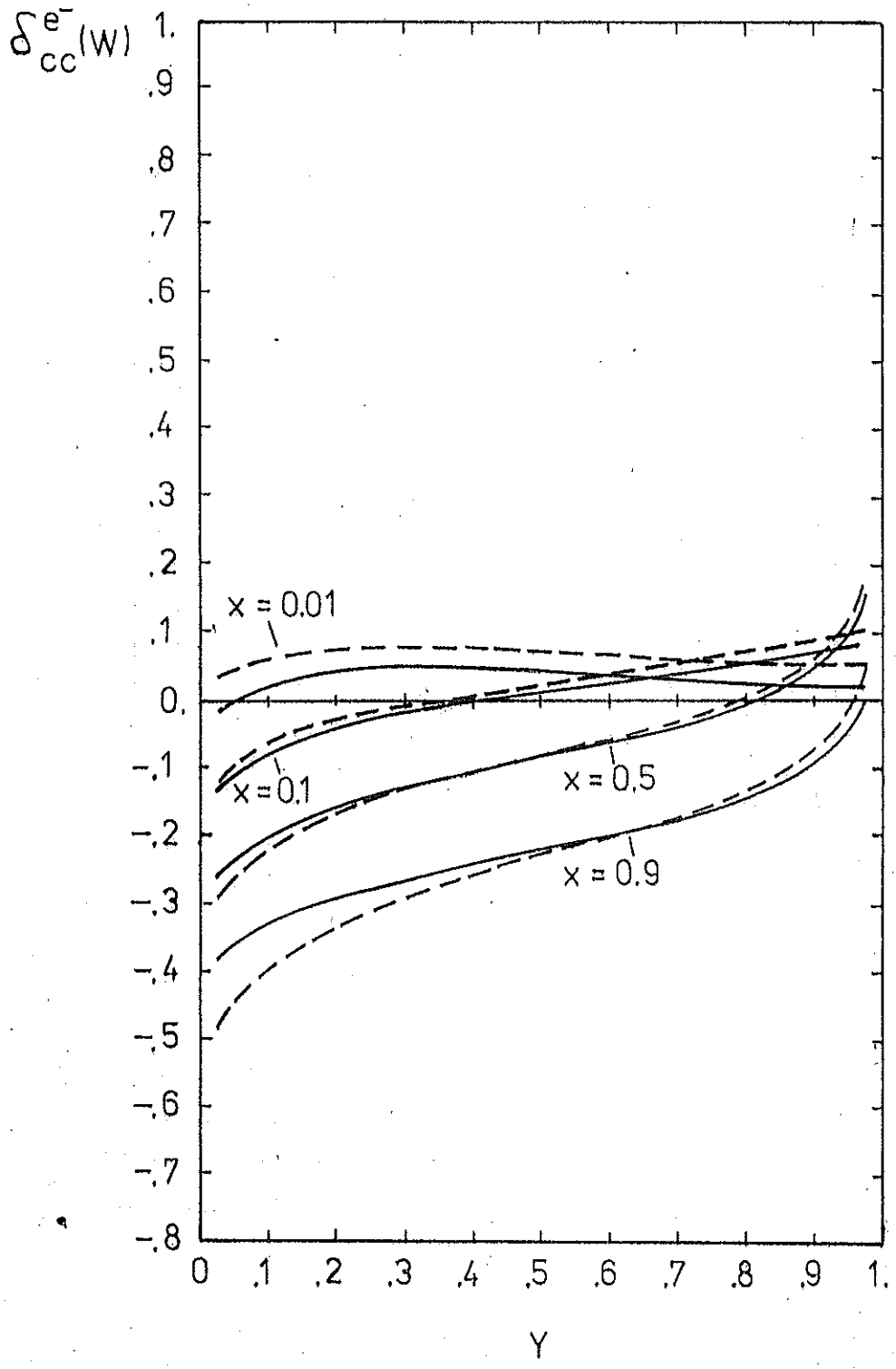
QUARK FRAGMENTATION FUNCTION

REN. GROUP

$$\times D_{\gamma/q}(x,Q^2) = \frac{\alpha}{2\pi} \ln\left(\frac{Q^2}{\Lambda^2}\right) \cdot \frac{1+(1-x)^2}{x} e_q^2 .$$

- THE ABOVE ARGUMENTS HOLD FOR THE EXACT EW-RC CALCULATIONS TOO. (THE PROBLEM OCCURS ONLY IN THE COLLINEAR SITUATION!)
- THE $O(\frac{\alpha}{2\pi})$ EWRC's DEPEND ON NO LIGHT QUARK MASS SCALES, BUT ON Λ_{QCD}.
- THE FINAL CONTRIBUTION OF (ii) IS BY FAR LARGER THAN THAT OF (i)!


$\delta^{e}_{NC}(\gamma)$
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
x = .01
x = .1
x = .5
x = .9
x = .99
0.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.
Y


$\delta^{e^-}_{cc}(W)$
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
x = 0.01
x = 0.1
x = 0.5
x = 0.9
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.
Y

A. DE RUJULA
et al. Nucl. Phys.
B154 (1979) 394

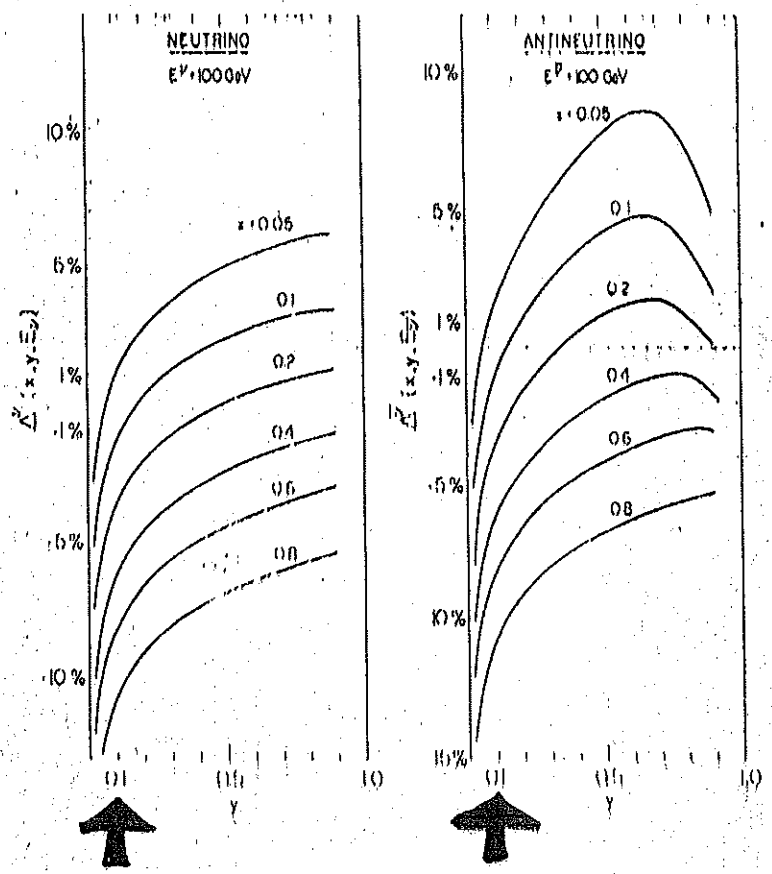


Fig. 3. The doubly differential normalized radiative correction defined in eq. (3.9): (a) for neutrino scattering; (b) for antineutrinos.

5. SUMMARY

- THE $O(\frac{\alpha}{2\pi})$ BREMSSTRAHLUNG RC'S FOR

$$e^{\pm}p \longrightarrow e^{\pm}X\gamma \qquad \sim |\gamma|^2$$

AND

$$e^{\pm}p \longrightarrow \overset{(-)}{\nu}_e X\gamma$$

HAVE BEEN CALCULATED IN THE LEADING LOG APPROXIMATION.

- WE FOUND:

a) GOOD AGREEMENT WITH BARDIN et al. FOR

NC & CC

FOR ALL x & y

$\longrightarrow$ y-PEAK AT $y \ll 1$

$\longrightarrow$ BEHAVIOUR OF THE LINES $x = \text{CONST.}$ AT HIGH y FOR CC

b) AGREEMENT WITH VAN NEERVEN, BENAKER, BEHREND: FOR $|\gamma|^2$ NC

c) LIGHT QUARK MASSES DO NOT ENTER $O(\frac{\alpha}{2\pi})$ EWRC AS IN THE NAIVE QPM. THE RESULTS DEPEND ON Λ_{QCD} INSTEAD: SCALING VIOLATIONS; QUARK FRAGMENTATION INTO PHOTONS