Recent Results on BFKL Physics

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1. Intro : leading-order BFKL
2. Exp'tal status
   Improved BFKL MC
3. $\gamma^* \gamma^*$: a closer look
4. Status of NLO corrections

Collaborator : W.J. Stirling

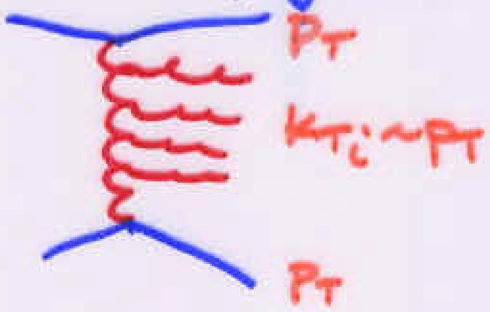
Introduction: BFKL equation

Some processes / kinematic regimes:

multiple soft gluon emissions ⇒
expansion in powers of $\alpha_s \ln\left(\frac{\hat{s}}{Q^2}\right)$
↑ large

⇒ fixed order QCD no good.

BFKL* eq'n resums these large logs due to (real + virtual) gluon emissions



- all k_T comparable
- strong ordering in rapidity

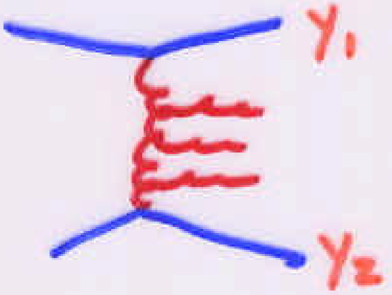
Analytic sol'n typically gives

$\hat{\sigma} \sim (\ \ )^{\lambda}$
↑ some relevant variable

$\lambda = \frac{4 N_c \alpha_s \ln 2}{\pi} \simeq 0.5$
(a.k.a. $\alpha_p - 1$)

* Balitsky, Fadin, Kuraev, Lipatov

Tevatron/LHC: dijet prod. at large rapidity



$\Delta = y_1 - y_2$

$\Rightarrow \hat{\sigma} \sim e^{\lambda \Delta}$

$\Rightarrow$ azimuthal decorrelation

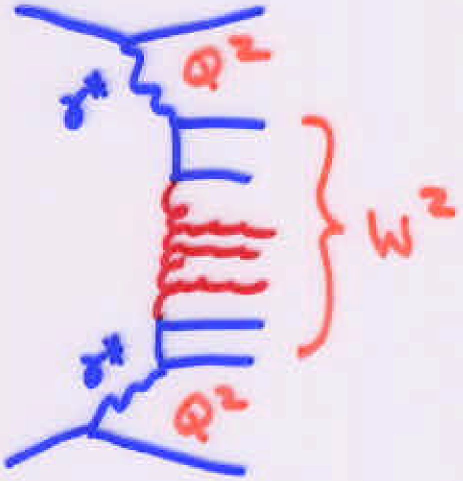
Mueller Navelet

HERA: forward jet production

$\Rightarrow \hat{\sigma} \sim \left(\frac{x_j}{x_{Bj}}\right)^{\lambda}$

(also $F_2 \sim \frac{1}{x^{\lambda}}$)

LEP/LC: $\gamma^*\gamma^*$ scattering



$s \gg Q^2 \gg \Lambda^2_{QCD}$

$\Rightarrow \sigma_{\gamma^*\gamma^*} \sim \left(\frac{W^2}{Q^2}\right)^{\lambda}$

Brodsky Hautmann Soper

Experimental status : Ambiguous at best

- Data tend to lie between fixed-order QCD + analytic BFKL

  - e.g. DØ azimuthal decorr. in dijet prod. ← fig.

  - similarly for HERA, LEP

[Exception: $R = \frac{\sigma_{dijet}(1800)}{\sigma_{dijet}(630)}$ at DØ

lies above all predictions. (cf. talk by B. Pope)]

Not surprising at all! Why?

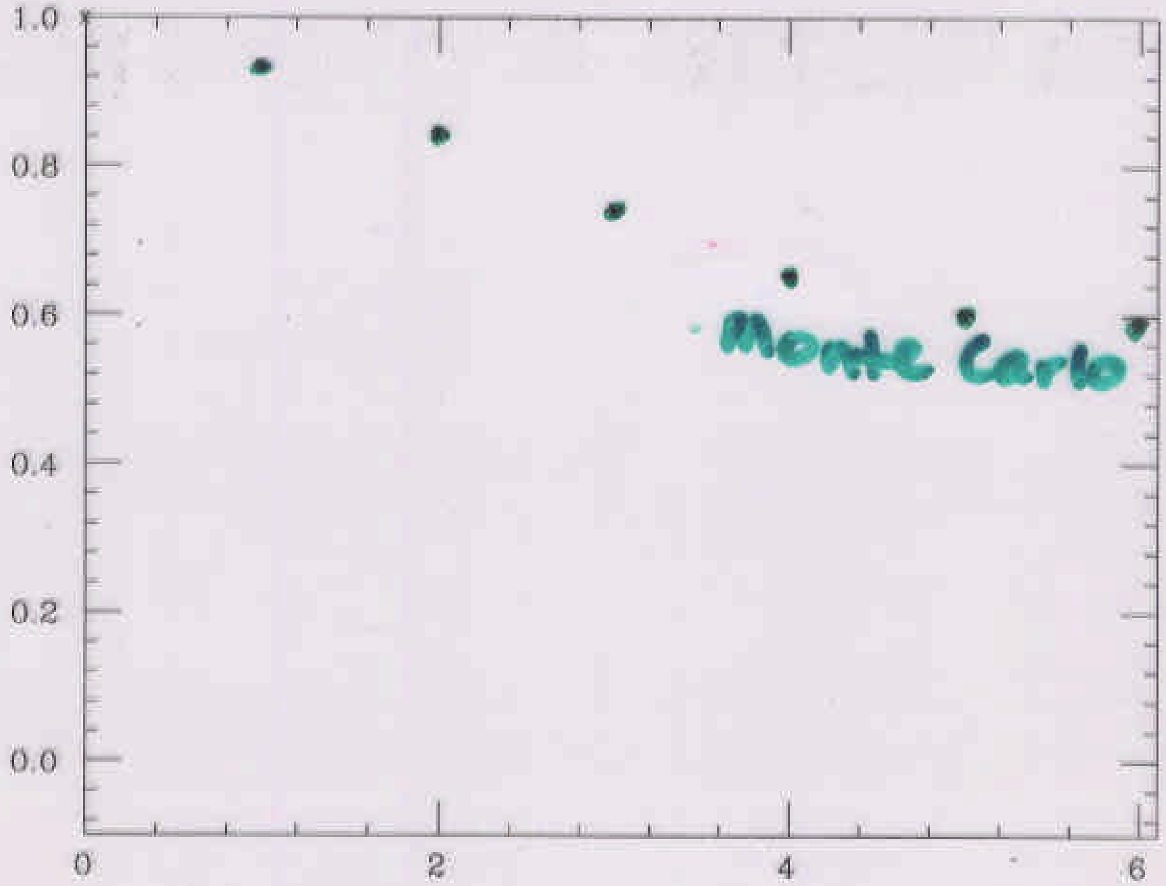
- Analytic BFKL sol'ns have
  - sum over arbitrary numbers of gluons
  - leading order kinematics only

  ⇒ no kinematic cost to emit gluons

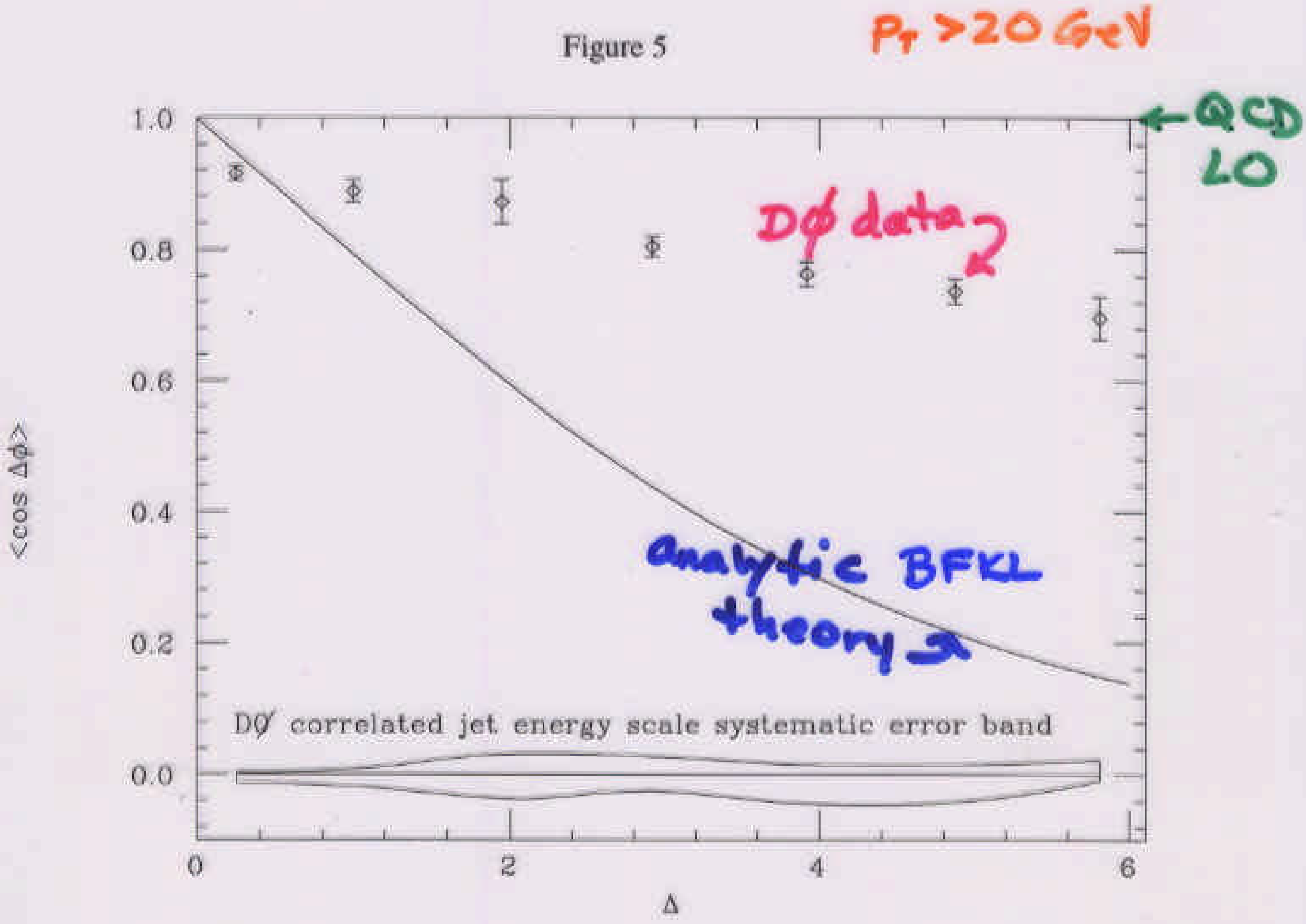
  ⇒ energy + momentum not conserved!

- Sol'n is BFKL Monte Carlo (C. Schmidt; LHO, W.J. Stirling)

  ⇒ explicit gluon sum allows kin. constraints ← fig.


1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
Monte Carlo

Azimuthal Decorrelation in Dijet Production at the Tevatron

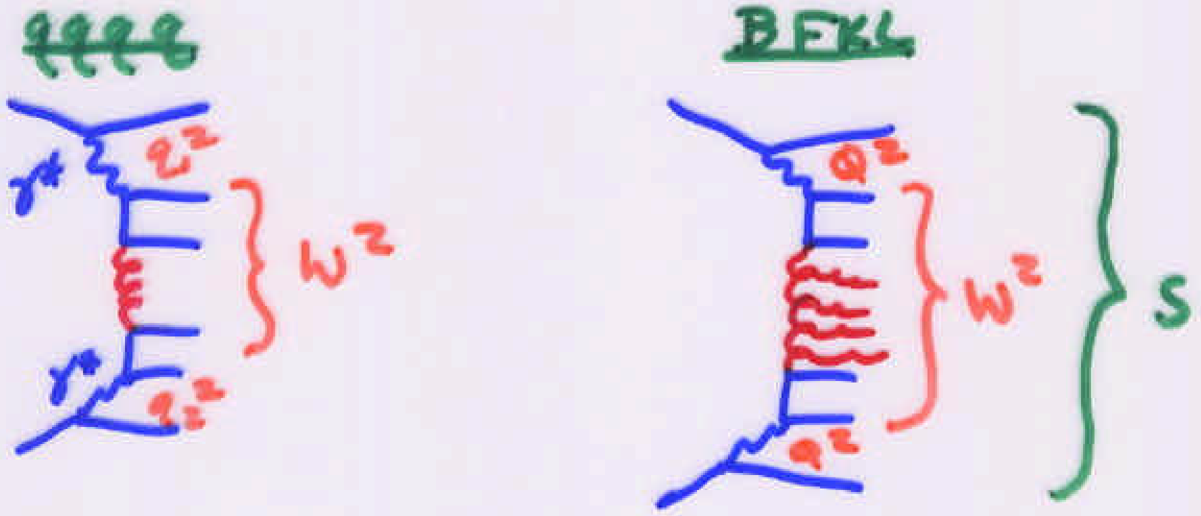


$\langle \cos \Delta\varphi \rangle = 0 \iff$ back-to-back

LHO,
W.J. Stirling

$\gamma^*\gamma^*$ Scattering: a closer look

Forward e^+e^- scattering: $e^+e^- \to e^+e^- +$ hadrons
("double tagged")



Relevant regime: $s >> Q^2 >> \Lambda^2_{QCD}$
$q_1^2 \sim q_2^2 = -Q^2$ + W^2 large

For large W^2/Q^2, fixed $\sqrt{s}/W$, consider

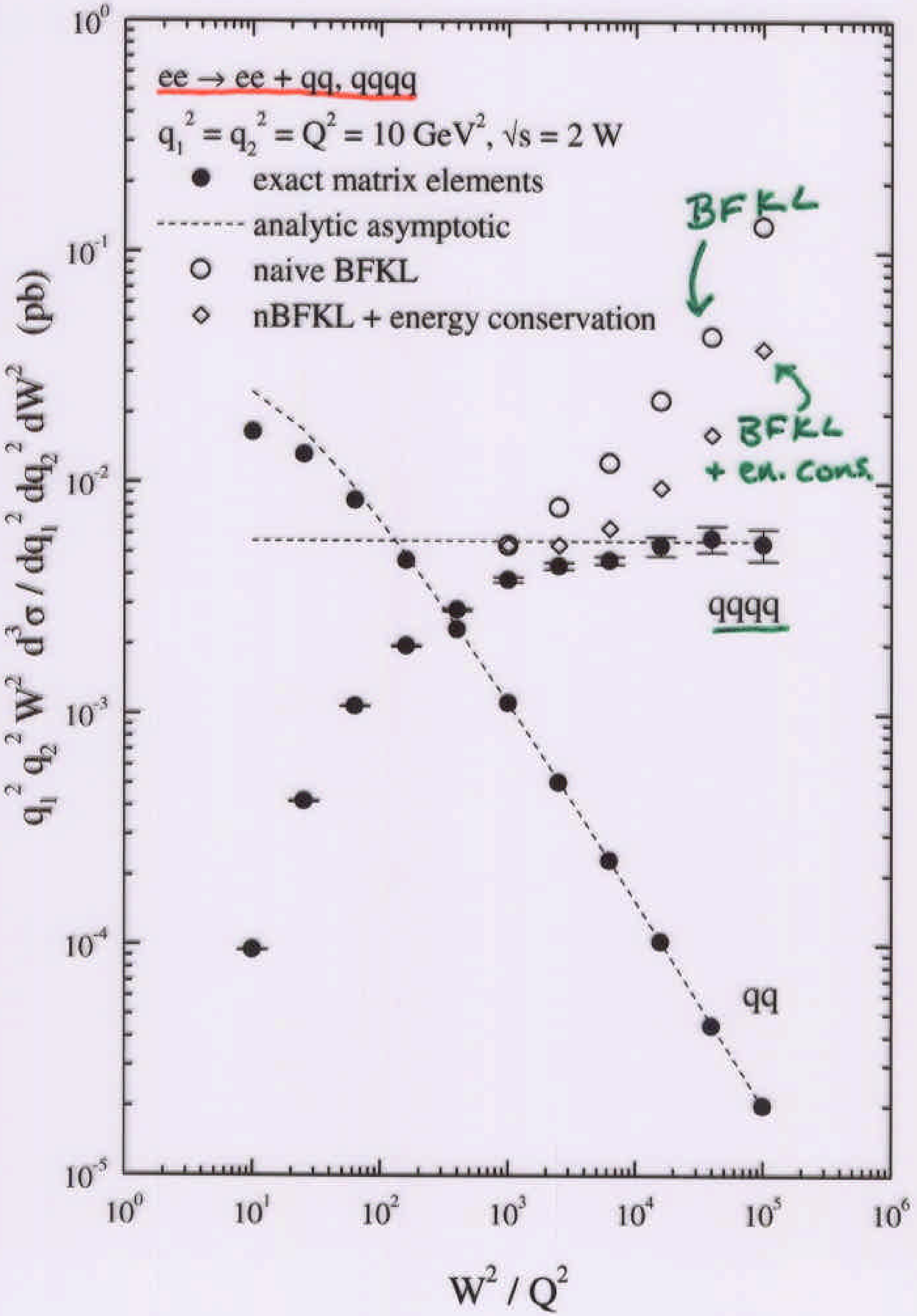
$$q_1^2 q_2^2 W^2 \frac{d^3\sigma}{dq_1^2 dq_2^2 dW^2} \text{ vs. } W^2/Q^2$$

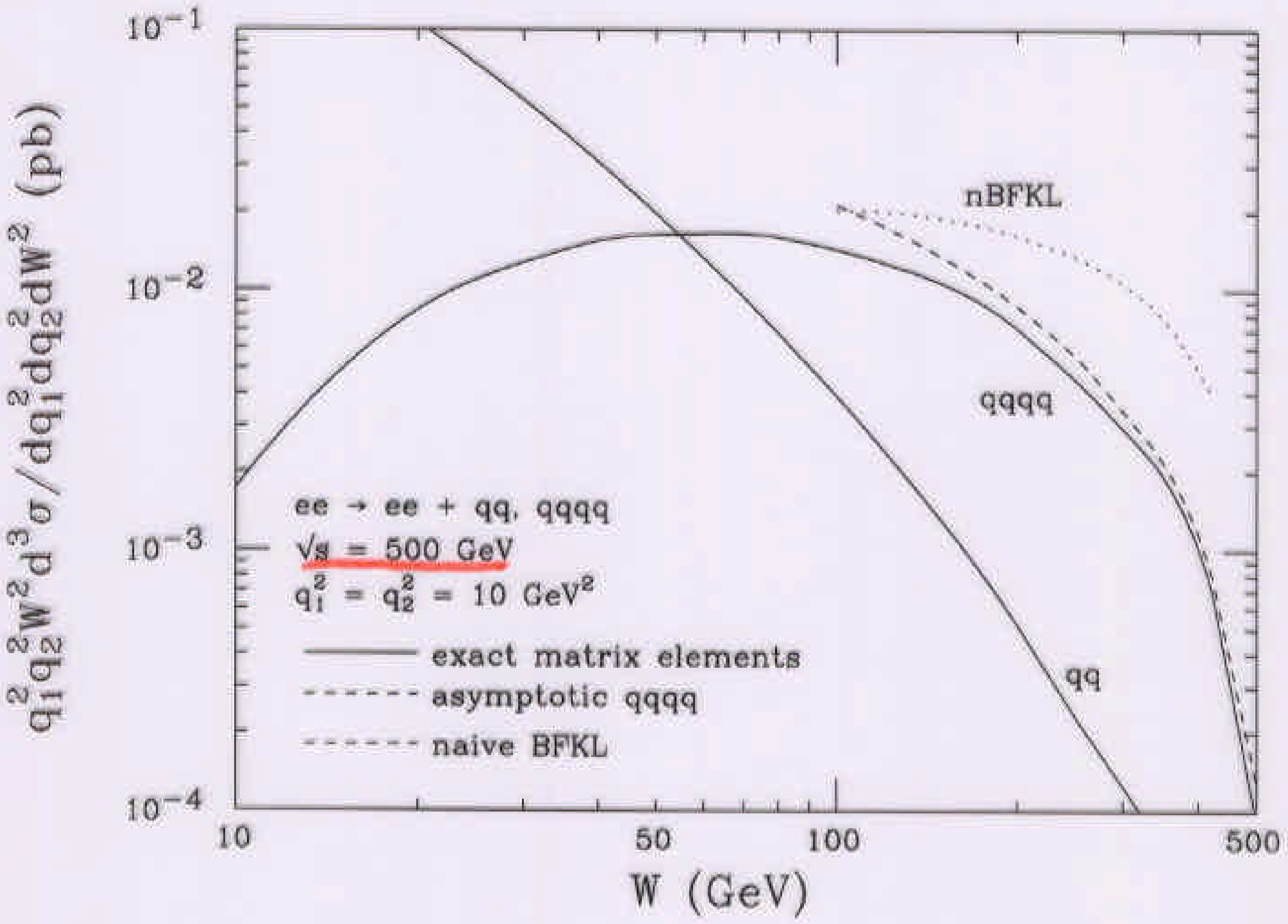
⇒ qqqq → const

⇒ BFKL rises

← fig

N.B. Where in W^2/Q^2 BFKL starts is arbitrary at LO!!


ee → ee + qq, qqqq
$q_1^2 = q_2^2 = Q^2 = 10$ GeV^2, $\sqrt{s} = 2$ W
exact matrix elements
analytic asymptotic
naive BFKL
nBFKL + energy conservation
BFKL
BFKL + en. cons.
qqqq
qq
$q_1^2 q_2^2 W^2 \, d^3\sigma / dq_1^2 dq_2^2 dW^2$ (pb)
W^2 / Q^2



10^{-1}
10^{-2}
10^{-3}
10^{-4}
$q_1^2 q_2^2 W^2 d^3\sigma / dq_1^2 dq_2^2 dW^2$ (pb)
nBFKL
qqqq
qq
ee → ee + qq, qqqq
$\sqrt{s}$ = 500 GeV
$q_1^2 = q_2^2 = 10$ GeV^2
exact matrix elements
asymptotic qqqq
naive BFKL
10
50
100
500
W (GeV)

BFKL at LEP energies

$\gamma^* \gamma^*$ c.s. from e^+e^- : divide by $\gamma\gamma$ luminosity

⇒ L3 data at 183, 189–202 GeV*

← fig

Q: Is the asymptotic QCD limit for qqqq appropriate here?

A: Compare exact and asymp. ← figs

⇒ No!

⇒ QCD qqqq $\gamma^*\gamma^*$ c.s. rises !!!

... but approaches asymp. fr/ below
There is some normalization uncertainty (α_s, etc).

Q: What about BFKL pred?

A1: Charm mass, γ polarization potential complications. Bartels et al : effects cancel at LEPII

A2: BFKL MC in progress

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* Talk by M. Wadhwa

L3

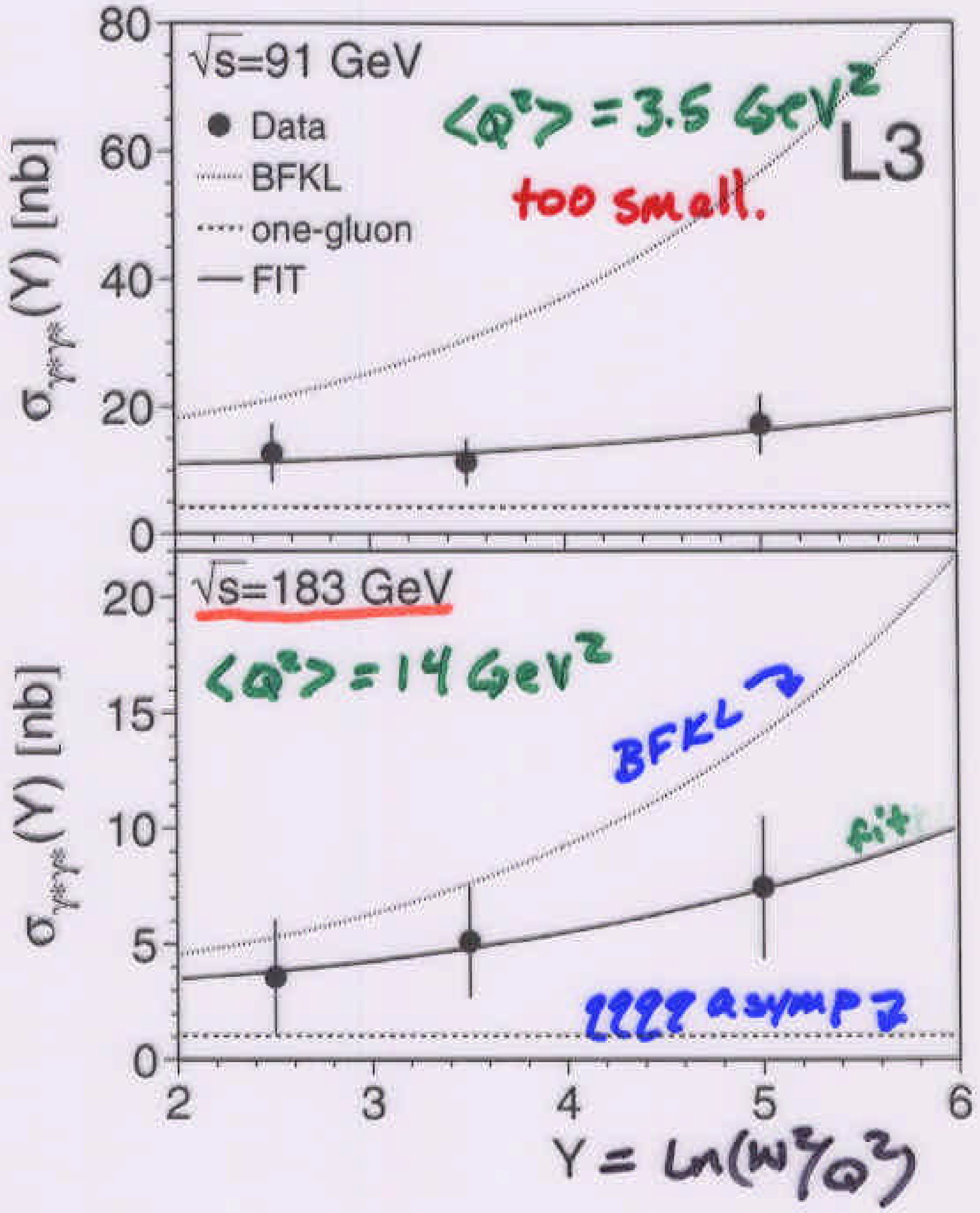
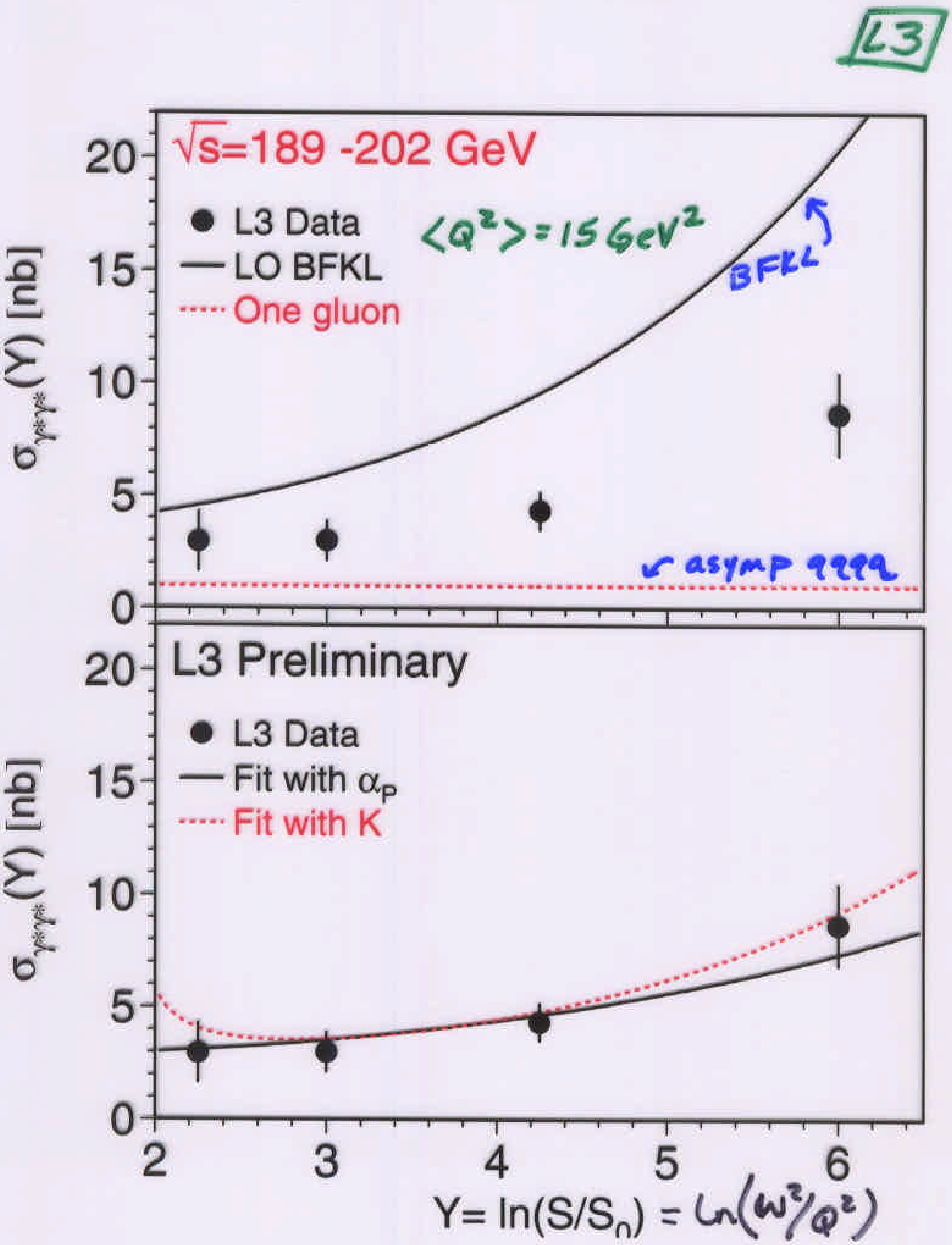
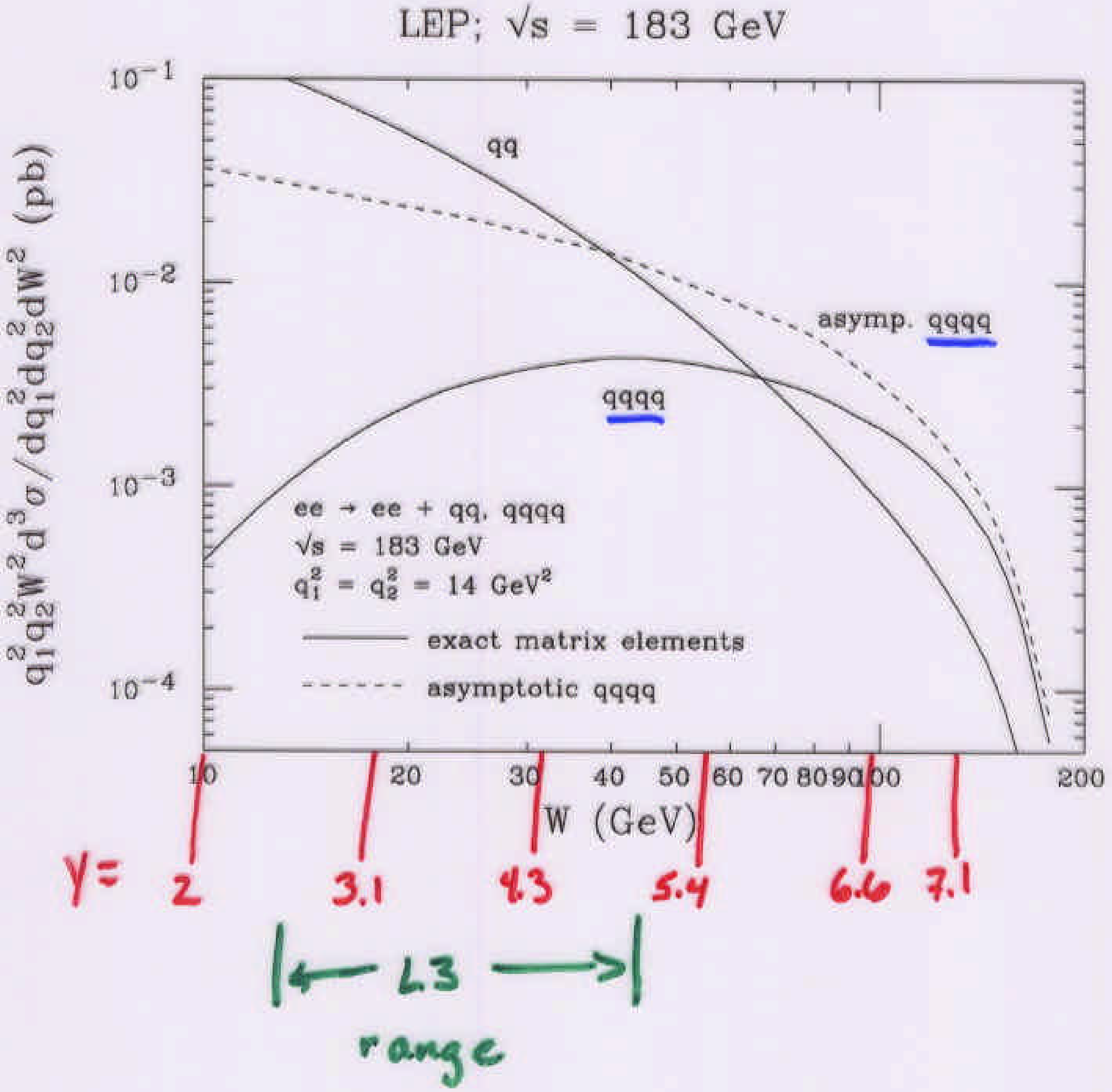
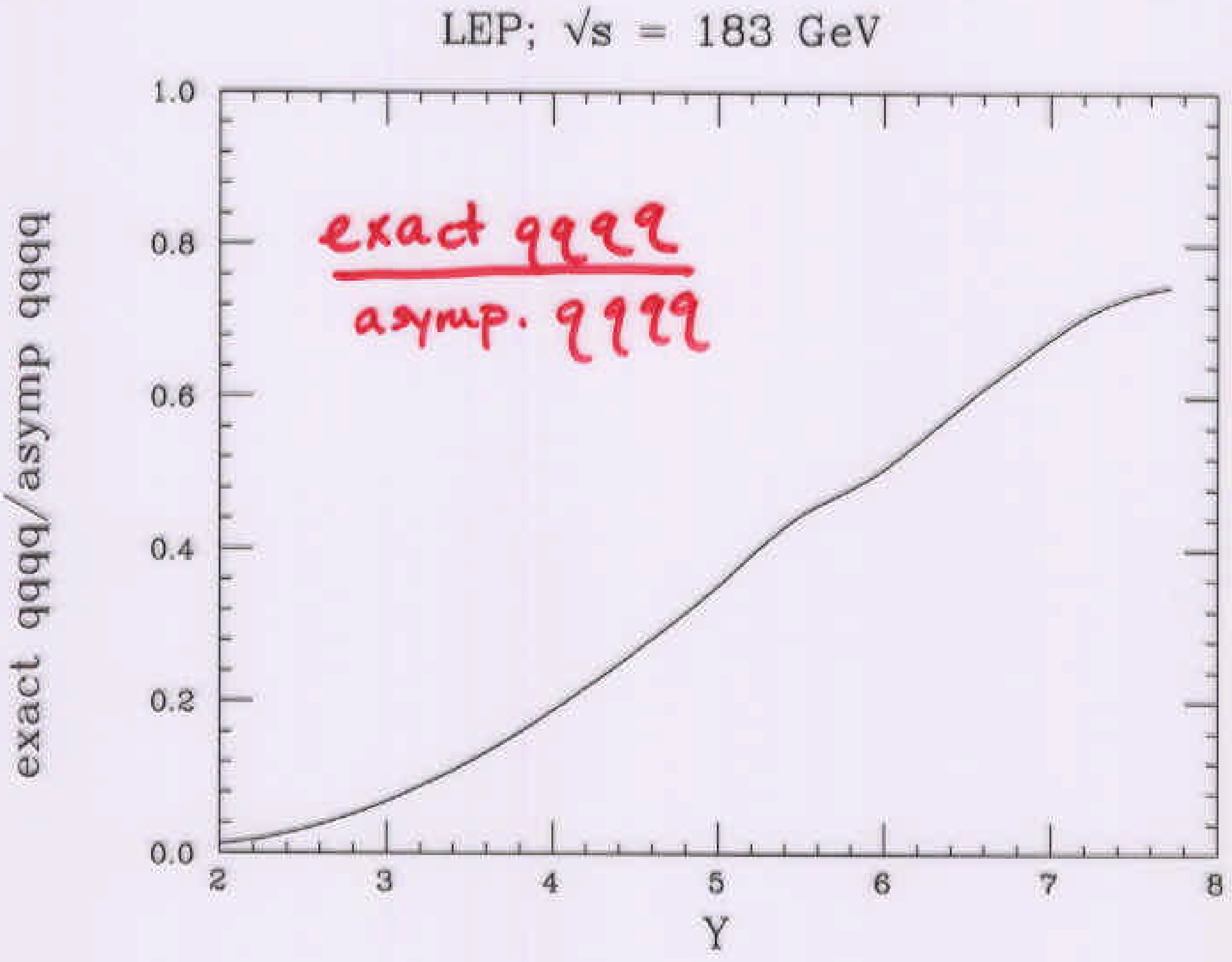


Figure 6: Two-photon cross-sections, $\sigma_{\gamma^*\gamma^*}$, after subtraction of the QPM contribution at $\sqrt{s} \simeq$ 91 GeV ($\langle Q^2 \rangle = 3.5$ GeV^2) and $\sqrt{s} \simeq 183$ GeV ($\langle Q^2 \rangle = 14$ GeV^2). The data are compared to the predictions of the BFKL model and of the one-gluon exchange diagram. The continuous line is a fit to the data with Eq. 1 by leaving α_P as a free parameter.


L3
√s=189 -202 GeV
L3 Data
LO BFKL
One gluon
<Q²>=15 GeV²
BFKL
asymp ????
σγ*γ*(Y) [nb]
L3 Preliminary
L3 Data
Fit with αP
Fit with K
σγ*γ*(Y) [nb]
Y= ln(S/S0) = ln(W²/Q²)



LEP; √s = 183 GeV
$q_1^2 q_2^2 W^2 d^3\sigma / dq_1^2 dq_2^2 dW^2$ (pb)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
qq
asymp. qqqq
qqqq
ee → ee + qq, qqqq
√s = 183 GeV
$q_1^2 = q_2^2 = 14$ GeV^2
exact matrix elements
asymptotic qqqq
10
20
30
40
50
60
70
80
90
100
200
W (GeV)
Y = 2
3.1
4.3
5.4
6.6
7.1
L3
range


LEP; √s = 183 GeV
exact qqqq/asymp qqqq
exact qqqq
asymp. qqqq
1.0
0.8
0.6
0.4
0.2
0.0
2
3
4
5
6
7
8
Y

Status of NLL Corrections

Obviously, LO BFKL is not sufficient. We need NLO corrections

- extra real emissions (2 gluons)
- virtual corr's to real emissions (1 gluon)
- virtual 2-loop corrections

⇒ 10 years of heroic efforts by Fadin, Lipatov + many others

Good news: They're done!

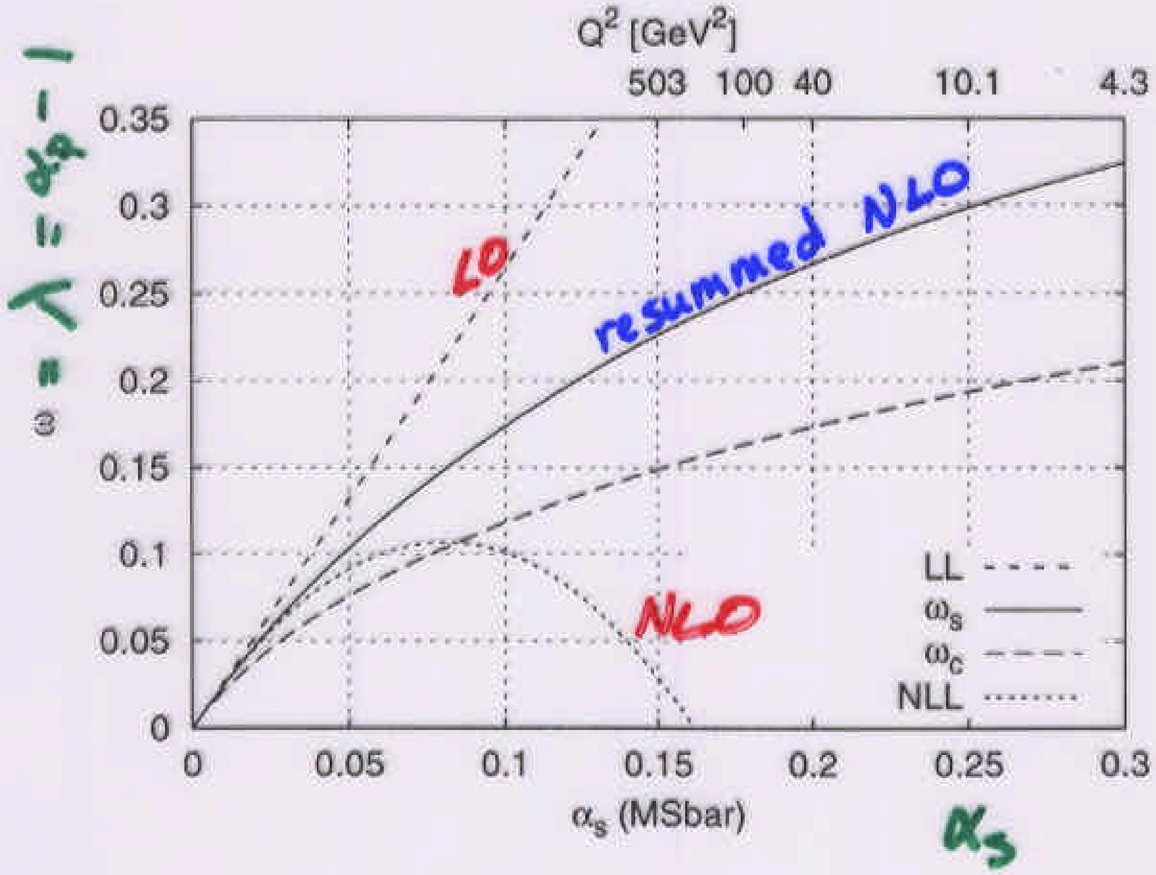
Bad news: They're huge! and unstable! and can give negative cross sections!

What's the problem? Collinear limit.

- recall LO BFKL ⇒ strong ordering in rapidity
- NLO corr's give gluons w/ close rapidity.

What are the solutions?

- Salam, Colferai, Ciafaloni: Resum the resummation (double transverse logs) ← fig
- Schmidt: Require min. rapidity sep.
- Forshaw, Ross, Sabio Vera: Both
- Renorm. scheme {Brodsky, Fadin, Kim, Lipatov, Pivovarov



Salam
Ciafaloni
Colferai

Conclusions

- BFKL physics is a complicated business
- Tests being performed in a variety of experiments
  - Tevatron, HERA, LEP
  - future: LHC, LC
- Comparisons are not straightforward!
  - LO BFKL insufficient
  - Subleading corrections (esp. kin. constraints) matter. A lot.

[Worst case scenario: we can't reach sufficiently asymptotic region to see unambiguous effects.]

- Reports of demise of BFKL physics due to instability of NLO corrections are greatly exaggerated.
  - Source of large corr's understood + being brought under control.

Bottom line: Jury is out. Stay tuned!