Photon 2003
Organised by the Laboratori Nazionali di Frascati

Jet and di-jet production at NLO in Photon – Photon collisions

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Photon – Photon Hard Collisions

Motivations:

- Hard production of jets is a complementary method (with respect to DIS) to study the "structure" of the photon
- It is rich test of QCD (since the beginning of history…Han-Nambu integer charges model)

Experimental Situation:

- OPAL, see talk by T. Wengler
- L3, see talk by M. Kienzle
- DELPHI, see Photon2001 proceedings
- Future Linear Collider …

LEPII

Theoretical results:

- As of now only the theoretical prediction by M.Klasen, Kleinwort, G.Kramer (KKK) (hep-ph/9611450 and hep-ph/9712256) is available
- It is based upon slicing method

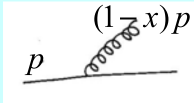
$$\frac{d\sigma}{dX} = \sum_{j,k} \int_{\hat{X}} f_j(x_1,Q_i)\, f_k(x_2,Q_i)\, \frac{d\hat{\sigma}_{jk}(Q_i,Q_f)}{d\hat{X}}\, F(\hat{X} \to X; Q_i,Q_f)$$

Factorization theorem

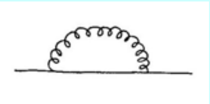
- We are not able to compute differential cross section analytically
- We fight against large unphysical oscillations and computer precision
- A general method should be adopted in order to cancel out divergences analytically, and finite reminders can be numerical (MC) integrated
- We use subtraction method, KKK used slicing one
- … double test: a different computation with a different method

About subtraction method:

$$\left(\frac{d\sigma}{dx}\right)_R = \frac{1}{1-x}$$



Real emission plus virtual correction



$$\left(\frac{d\sigma}{dx}\right)_V = \frac{1}{2\varepsilon}\delta(1-x)$$

$$\langle F\rangle_{NLO} = \frac{1}{2\varepsilon}\int_0^1 dx\,\delta(1-x)F(x) + \int_0^1 dx\frac{F(x)}{(1-x)^{1+2\varepsilon}}$$

$$\langle F\rangle_{NLO} = \frac{1}{2\varepsilon}F(1) + \int_0^1 dx\frac{F(x)}{(1-x)^{1+2\varepsilon}}$$

$$\langle F\rangle_R^{Slicing} = \int_0^{1-\delta} dx\frac{F(x)}{(1-x)^{1+2\varepsilon}} + \int_{1-\delta}^1 dx\frac{F(1)}{(1-x)^{1+2\varepsilon}}$$

$$\langle F\rangle_R^{Slicing} = \int_0^{1-\delta} dx\frac{F(x)}{(1-x)^{1+2\varepsilon}} + F(1)\frac{\delta^{-2\varepsilon}}{-2\varepsilon}$$

$$\langle F\rangle_{NLO}^{Slicing} = \int_0^{1-\delta} dx\frac{F(x)}{(1-x)} + F(1)\log(\delta) + O(\delta)$$

Neglected O(δ) terms
Large-number cancellations

$$\langle F\rangle_R^{Sub} = \int_0^1 dx\frac{F(x)-F(1)\theta(x-1+x_c)}{(1-x)^{1+2\varepsilon}} + \int_0^1 dx\frac{F(1)\theta(x-1+x_c)}{(1-x)^{1+2\varepsilon}} \qquad 0 < x_c \le 1$$

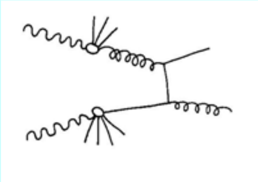
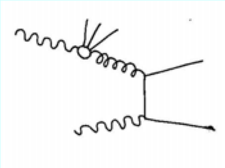
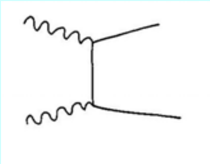
$$\langle F\rangle_{NLO}^{Sub} = \int_0^1 dx\frac{F(x)-F(1)\theta(x-1+x_c)}{(1-x)} + F(1)\log(x_c)$$

without any approximation and large-number cancellation (beware of narrow bins)

The structure of the "home made" computation

- We have recalculated and checked (with respect to KKK's) the matrix elements

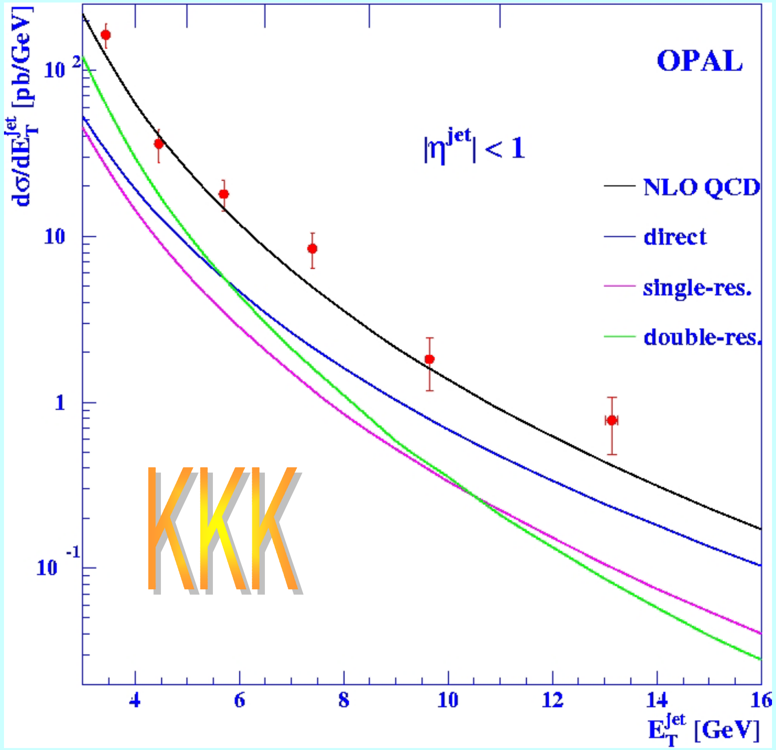
- We implemented a "partons generator" (hep-ph/9512328 and hep-ph/9706545) divided in three classes of Feynman diagrams: double resolved, single resolved, direct diagrams

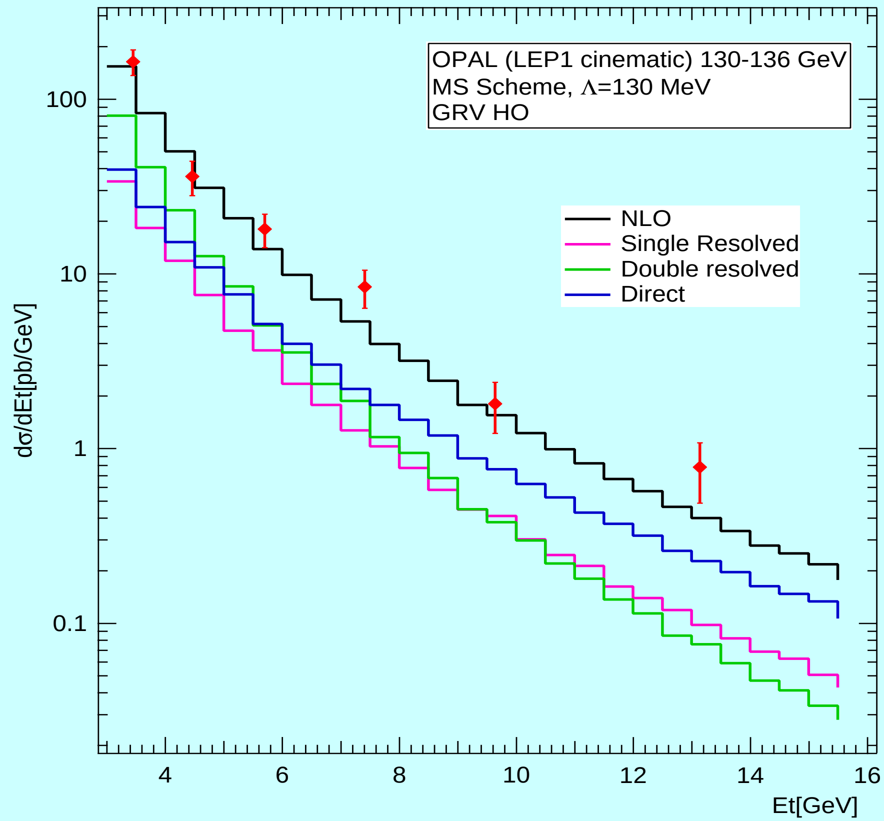
 +  +  + ... NLO terms

- We have to rely on non-perturbative input such as PDFs and α_s

...paper in preparation

A first check:
A comparison with OPAL 1997 (one inclusive jet)





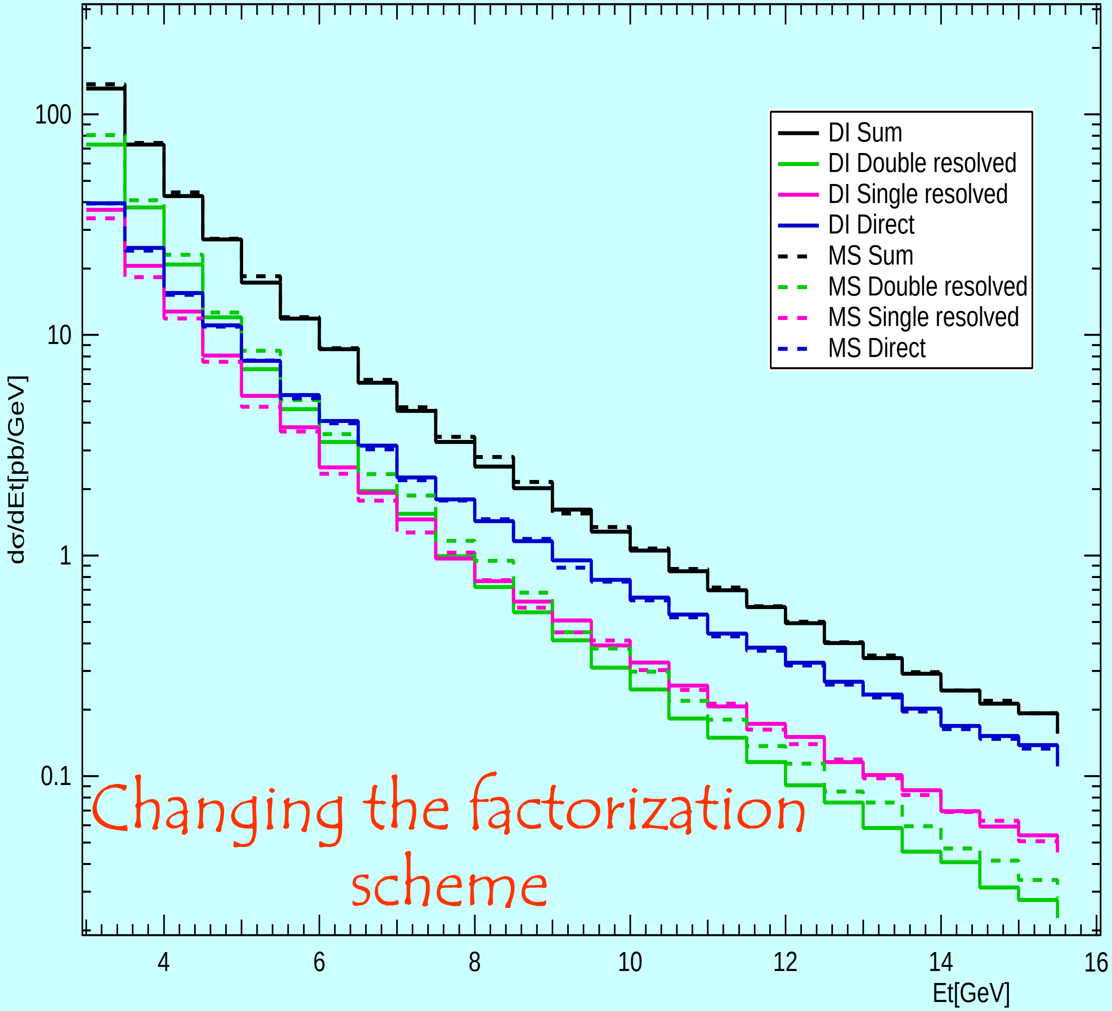
Inclusive Jet Production in Photon-Photon Collision at sqrt(s)=130 and 136 GeV, Opal coll., Zeit. Fur Physik(1997)

Ok, at least we are on the right path…

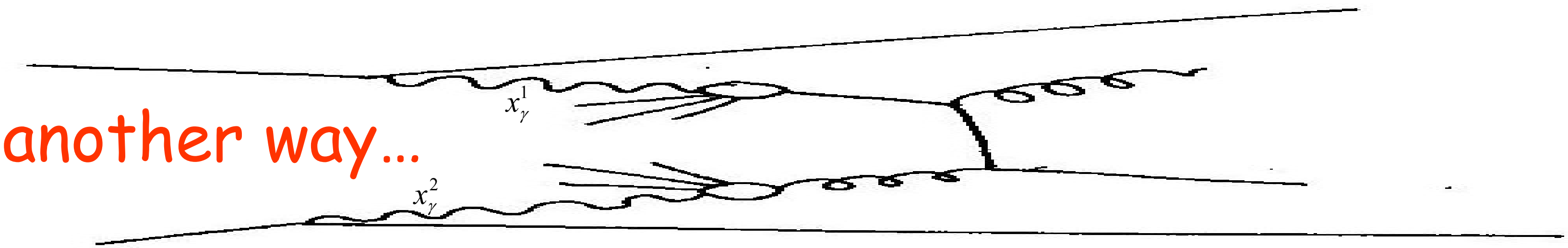
But we need self consistence tests!!! Unfortunately they are very boring!
Let's try to see their physical meaning:
what about the true photon contribution to the cross section?

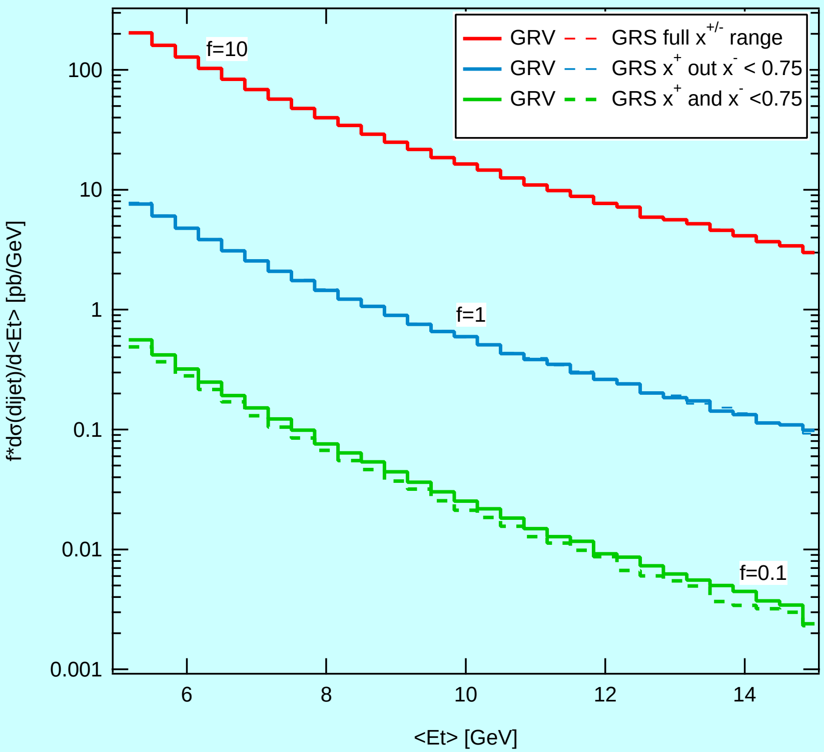
Each class of diagrams is separately divergent:
We have removed analytically the infinities modulo finite, scheme dependent, terms

Thus colored histos do not have a real physical meaning



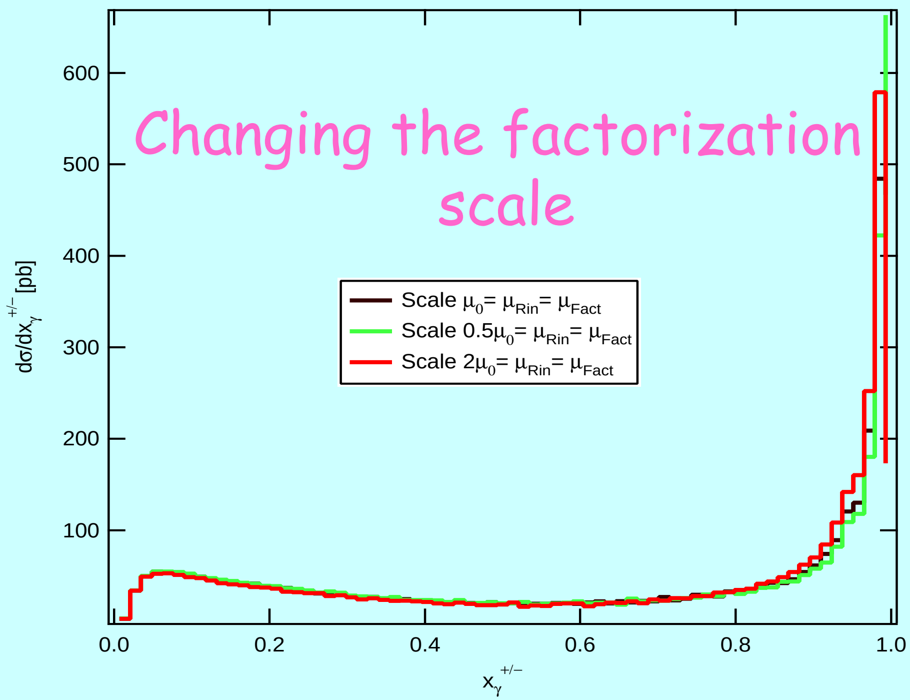
Try another way…





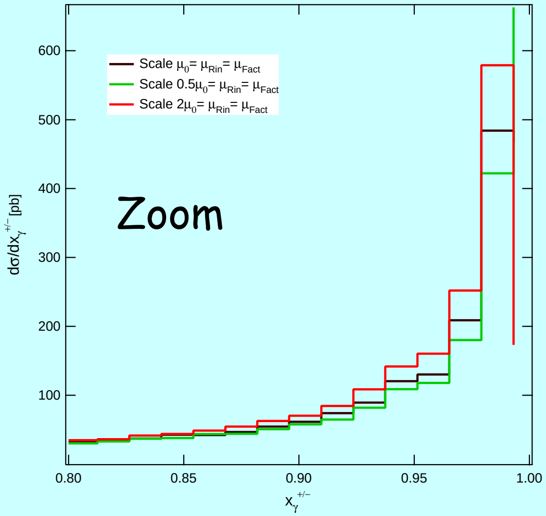
Changing the PDF

$$x_\gamma^{\pm} = \frac{\sum_{jet=1,2} E_L^j \pm p_z^j}{\sum_{hadrons} E_L^h \pm p_z^h} = \frac{\sum_{jet=1,2} E_L^j \pm p_z^j}{x_\gamma^{1,2}\sqrt{s_{ee}}}$$

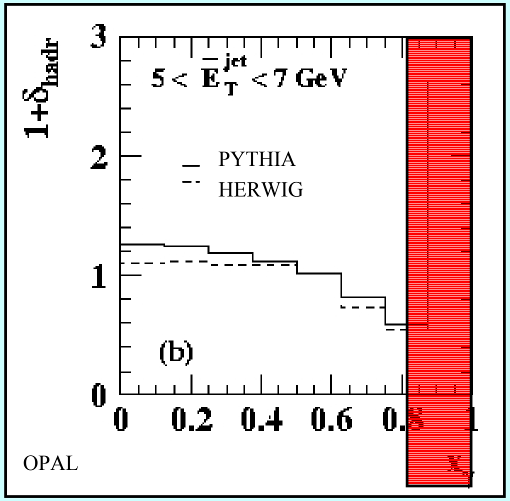


Dangerous regions:

$$1+\delta_{hadr} = \frac{\sigma(\text{At the end of the "parton" shower})}{\sigma(\text{At the end of the hadronisation process})}$$

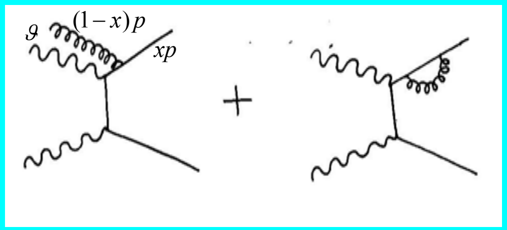


350%



Failure of the perturbative computation

Recall our simple model to deal with the final state direct contribution in the dangerous region



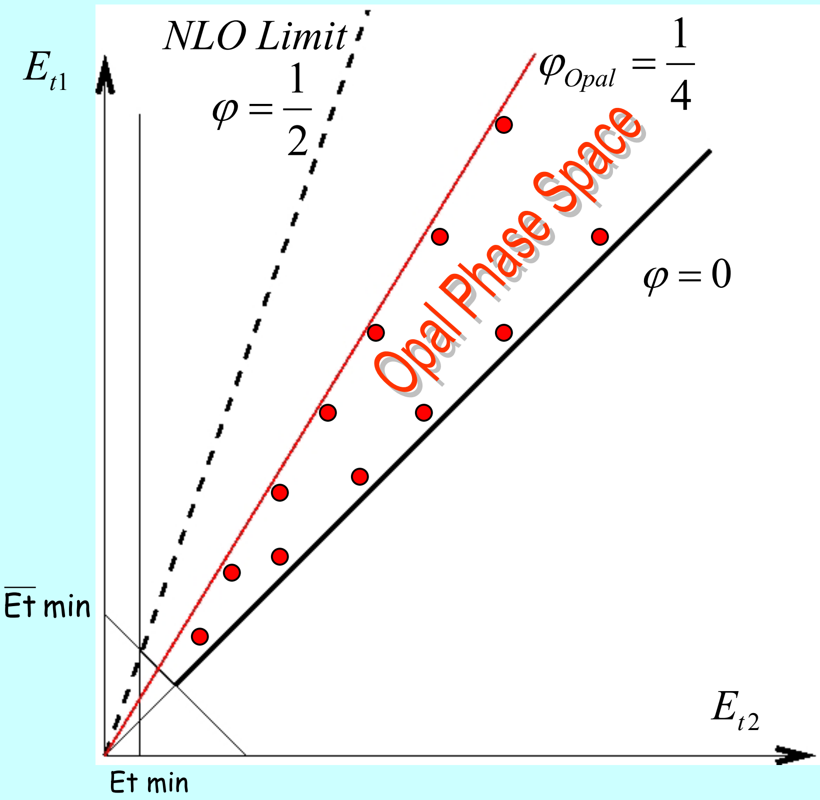
$$\vartheta \to 0 \Rightarrow x \approx x_\gamma$$
$$x \to 1$$

$$\langle F \rangle_{NLO}^{Sub} \approx \int_0^1 dx \frac{F(x)-F(1)}{(1-x)} \qquad \frac{d\sigma}{dx_\gamma} \Leftrightarrow F(x) = \delta(1-x_\gamma)$$

$$\frac{d\sigma}{dx_\gamma} \approx \left(\frac{1}{(1-x_\gamma)} - \frac{\theta(x_\gamma - 1)}{(1-x_\gamma)} \right) + \dots$$

Dangerous regions II:

Cuts on the phase space
for di-jet observables



- Symmetric cuts on Et imply large log corrections
- Opal coll. have chosen to impose:

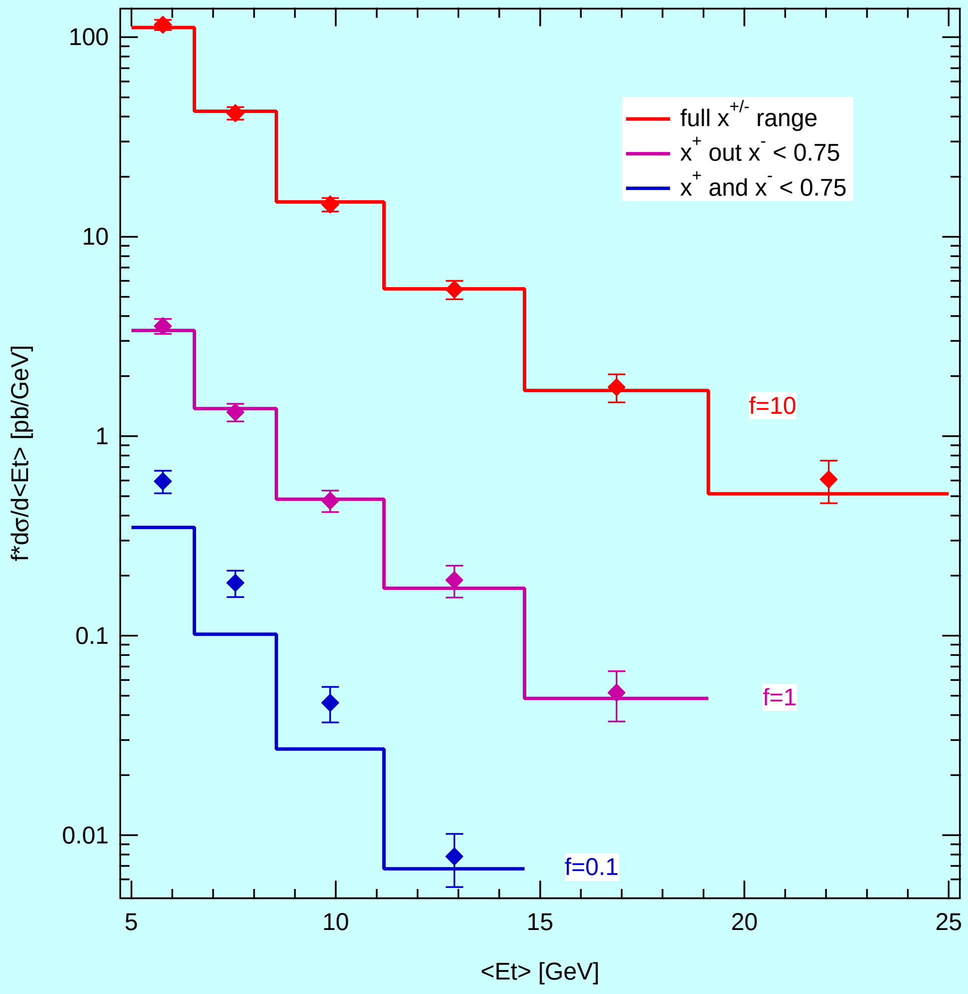
$$\varphi = \left| \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}} \right| < \frac{1}{4}$$

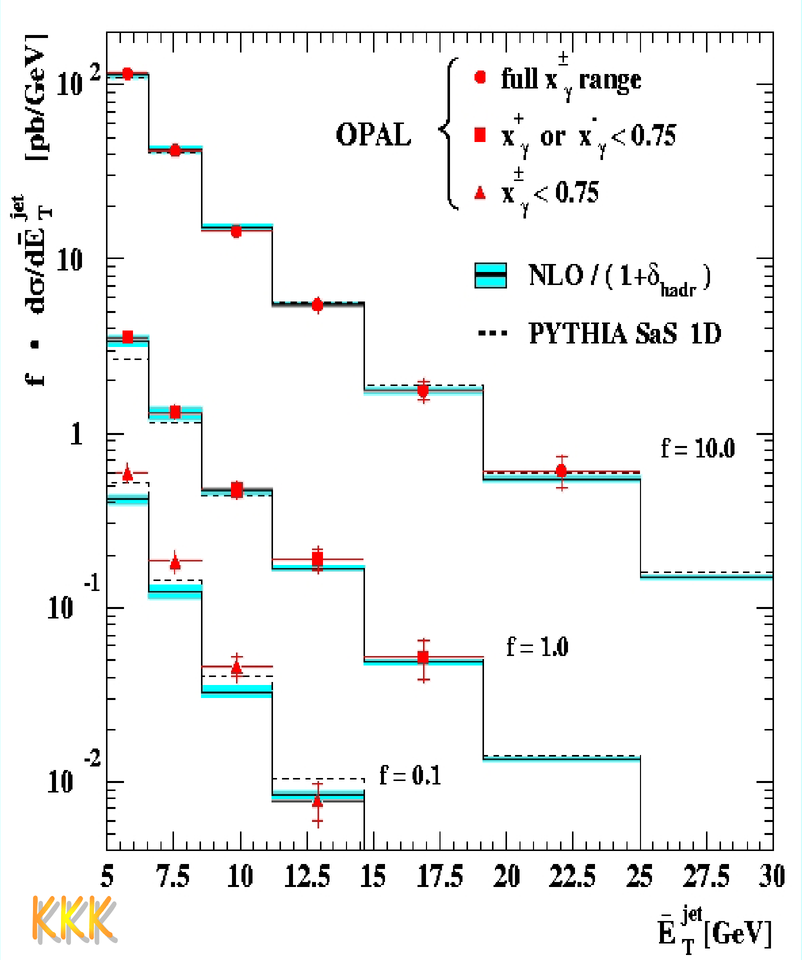
Observation:

- In NLO computation $\varphi_{NLO} < \frac{1}{2}$
- In the limit $\varphi \to 0$ we run into IR divergences!

… thus even if in principle Opal's choice could be dangerous, in practice it is far from the singularity sources!

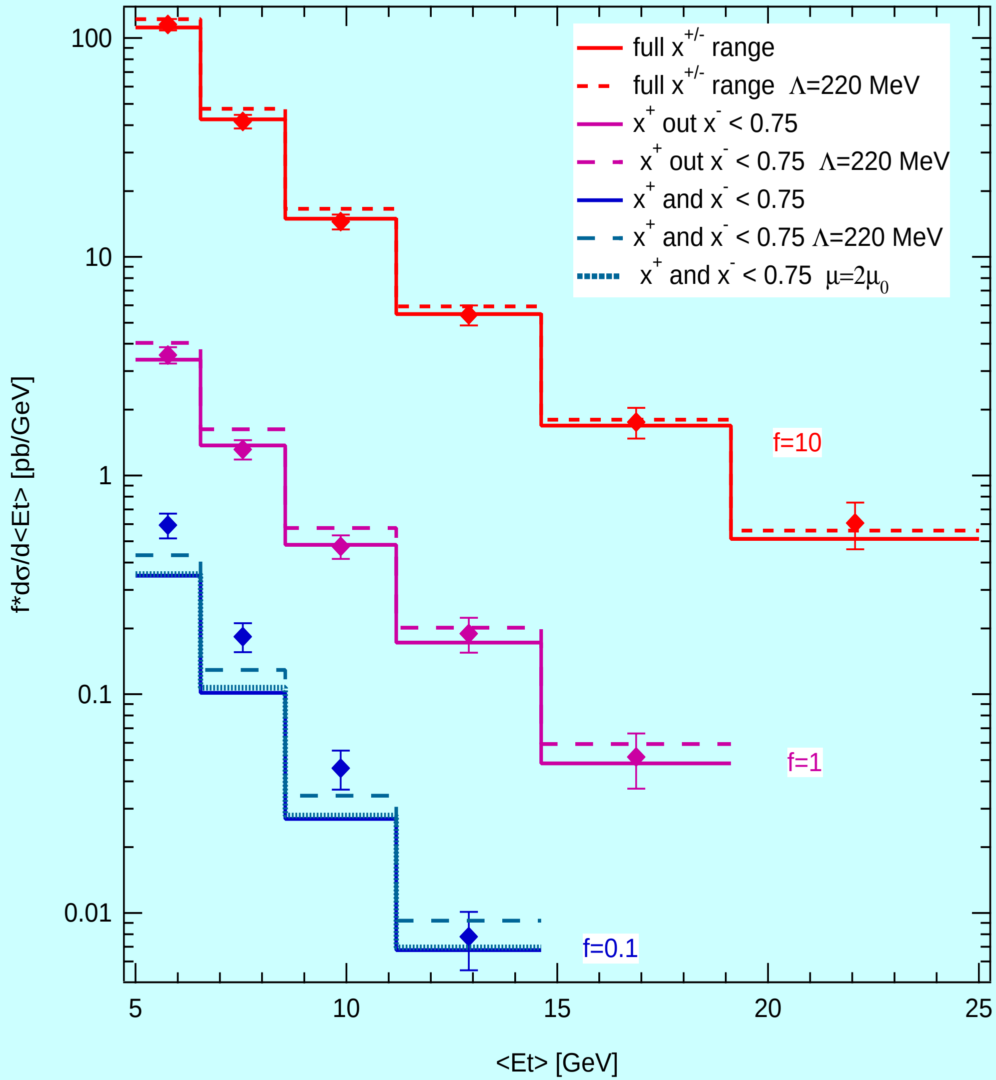
Results: Theo.vs.Opal

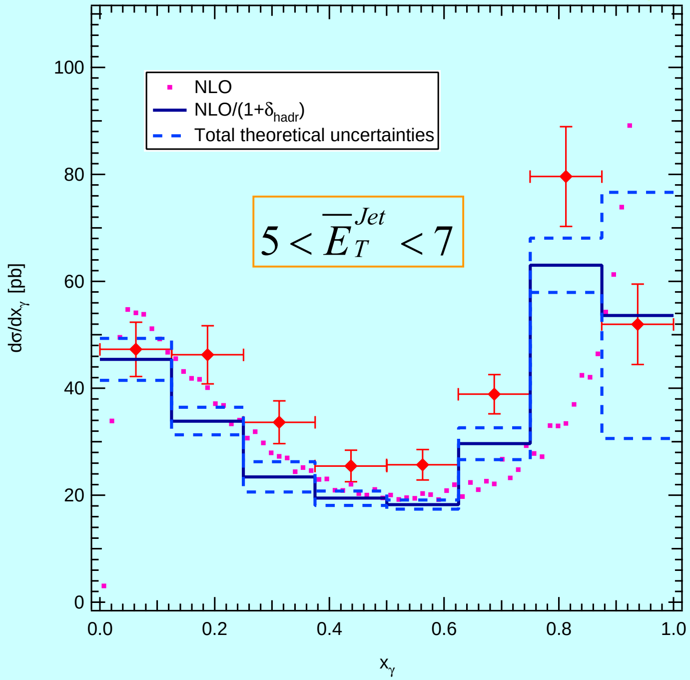


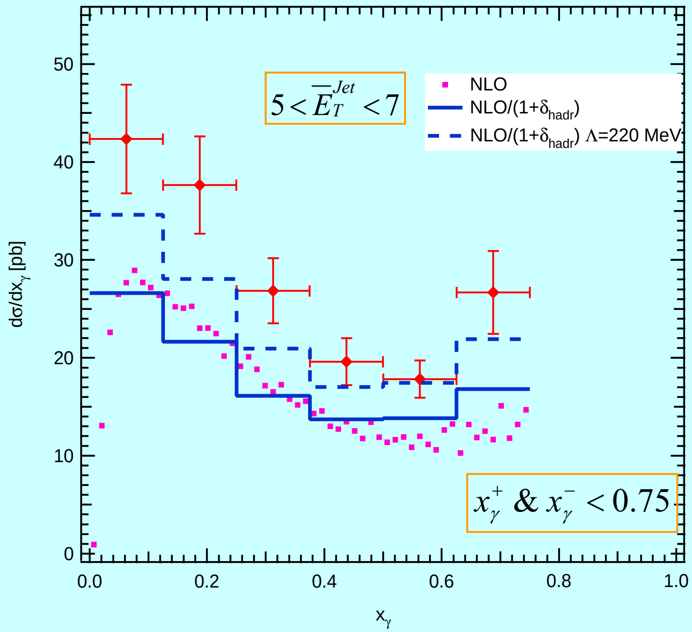


Data from Di-Jet Production in photon-photon collisions at sqrt(s) from 189 to 209 GeV, OPAL coll., hep-ex/0301013

Results: Theo.vs.Opal II

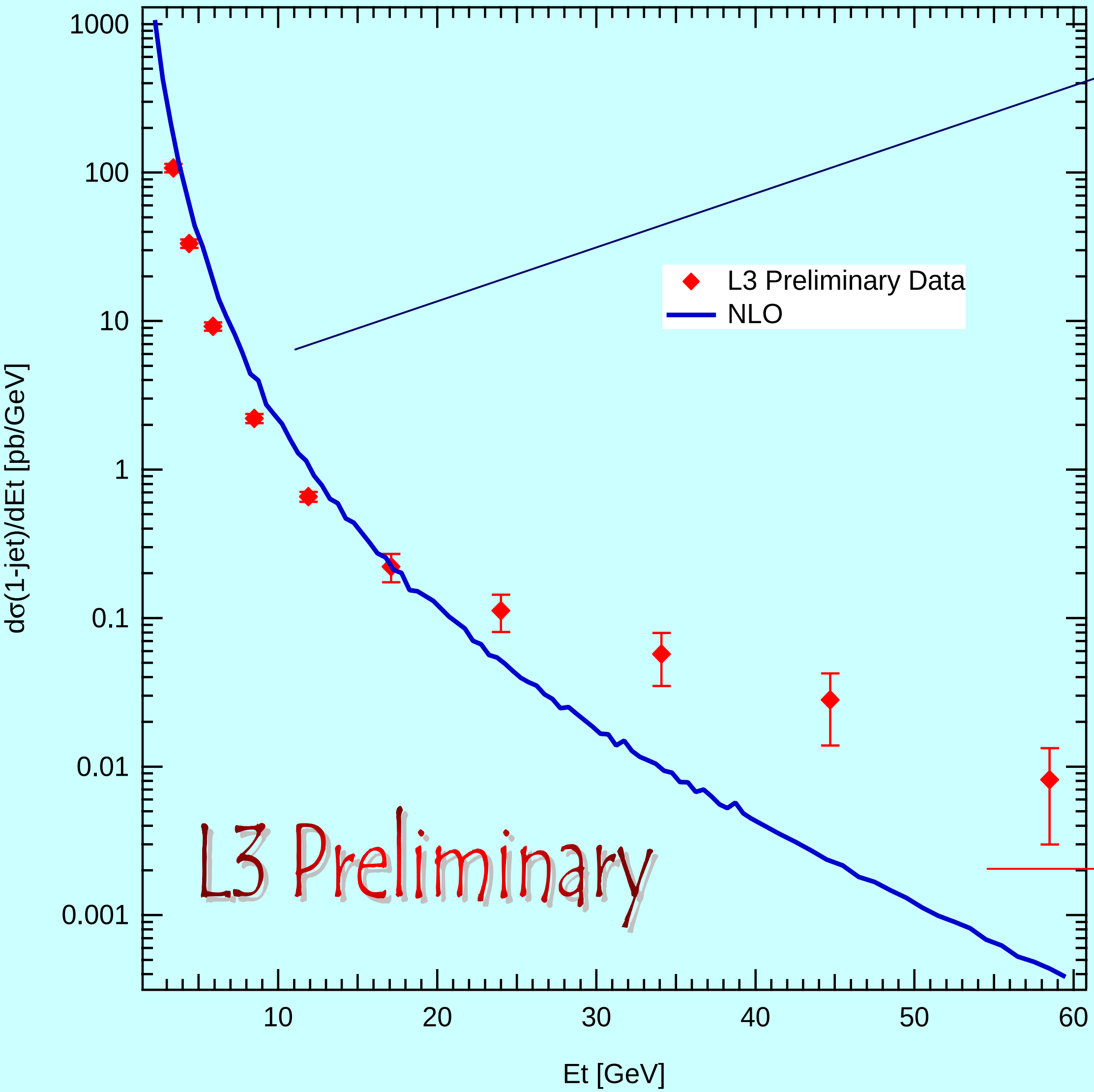






Data from Di-Jet Production in photon-photon collisions at sqrt(s) from 189 to 209 GeV, OPAL coll., hep-ex/0301013

Results: Theo.vs.L3



Good shape, but not really good normalization

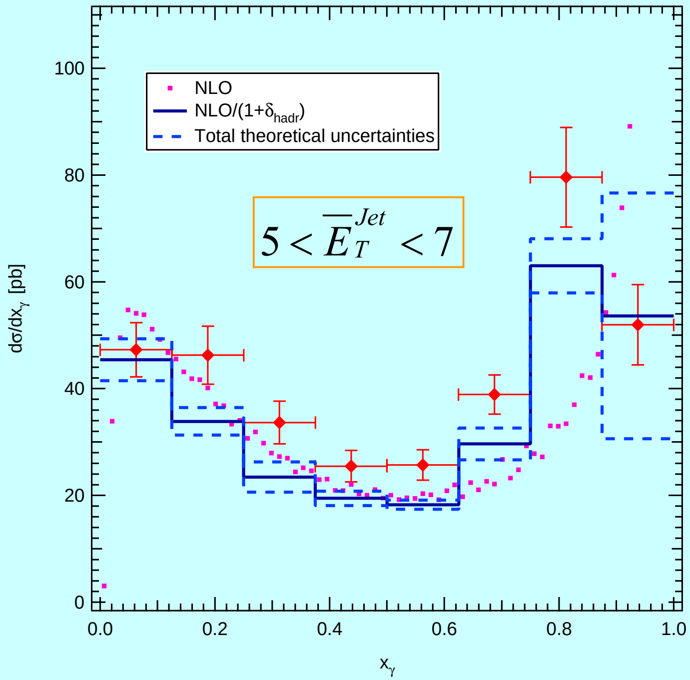
Wrong shape and normalization: Preliminary data seem to confirm L3-hadron production discrepancy with NLO prediction

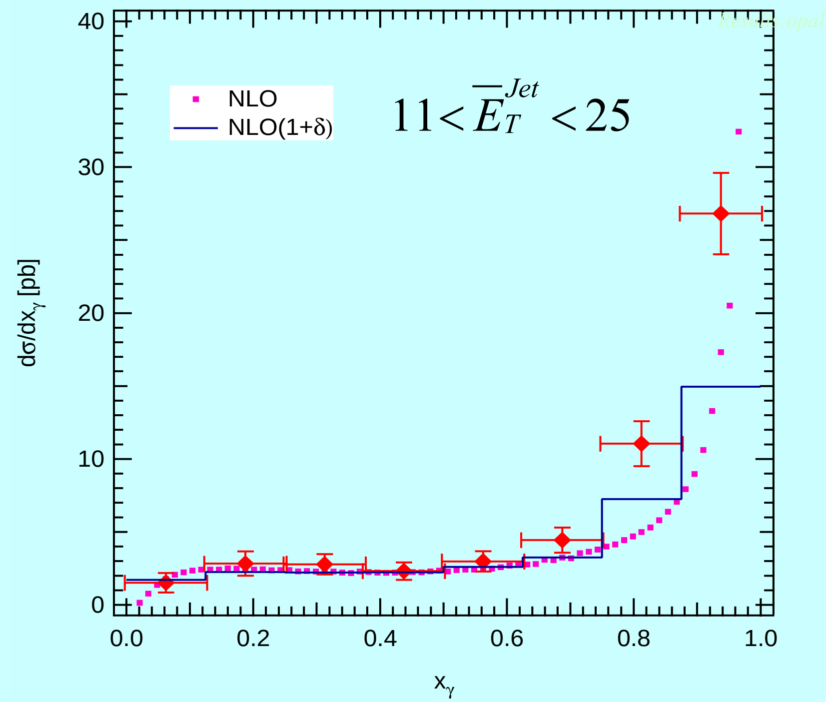
Conclusions:

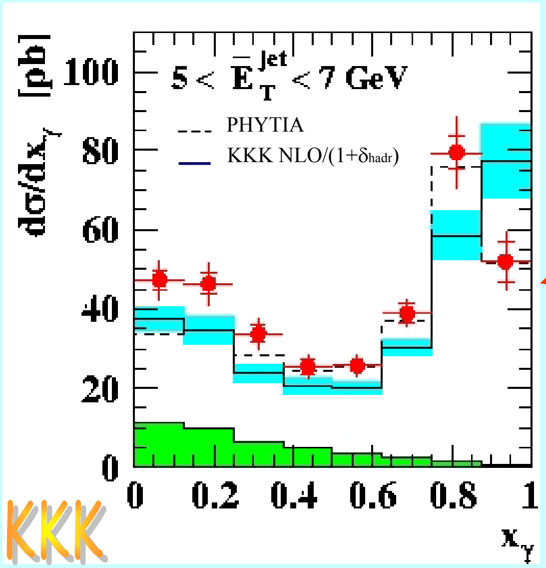
- We implemented a computer code to compute jet and di-jet observables using the subtraction method; our results are in agreement with the predictions by KKK.

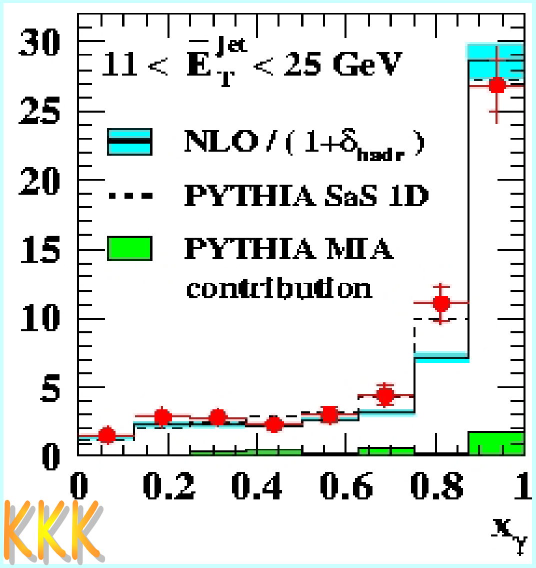
- The comparisons of our results with OPAL data are really satisfactory for inclusive observables. The comparison with L3 data is troublesome!

- Finally, we analyzed some theoretical QCD (NLO) difficulties to describe well particular exclusive observables measured by OPAL. Theoretical uncertainties for inclusive observables are under control.



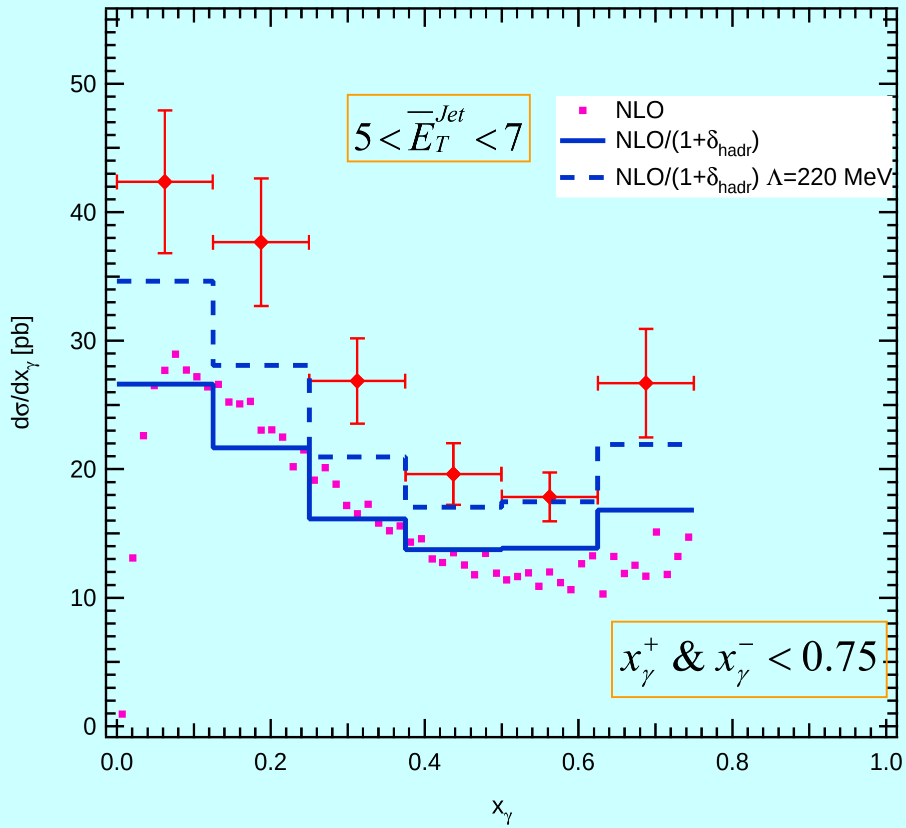




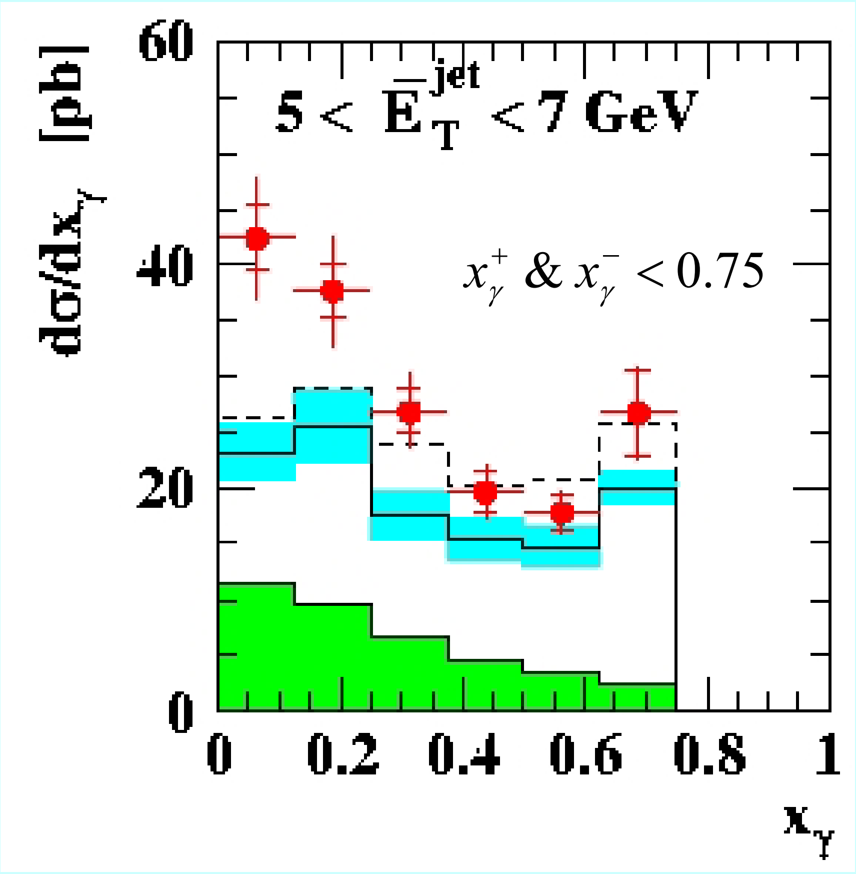


Data from Di-Jet Production in photon-photon collisions at sqrt(s) from 189 to 209 GeV,

OPAL coll., preprint



$5 < \overline{E}_T^{Jet} < 7$
NLO
NLO/(1+δ_{hadr})
NLO/(1+δ_{hadr}) Λ=220 MeV
$x_\gamma^+ \ \& \ x_\gamma^- < 0.75$
dσ/dx$_\gamma$ [pb]
x$_\gamma$
0
10
20
30
40
50
0.0
0.2
0.4
0.6
0.8
1.0



$5 < \overline{E}_T^{jet} < 7$ GeV
$x_\gamma^+ \ \& \ x_\gamma^- < 0.75$
dσ/dx$_\gamma$ [pb]
x$_\gamma$
0
20
40
60
0
0.2
0.4
0.6
0.8
1