Systematics of $\gamma\gamma$ hadronic cross-sections.

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1. Why discuss the issue? some history!
Resolved photon contribution to high energy photon processes!

2. Summary of current experimental information from e^+e^- machines and comparison with models.

3. Prediction of $\gamma\gamma$ induced backgrounds for higher c.m. energies ILC/CLIC.

4. Which data will help to reduce the spread of predictions.

5. Implications of $\gamma\gamma$ hadronic cross-sections for the two photon processes at the LHC and vice versa.

Not much new work! The latest new bit included here was done in 2010 and in 2011.

References:

Hard probes of hadronic structure of photon. 1)M. Drees and R.G., Nucl. Phys. B339 (1990) 355.

2)M. Drees and R.G., J.Phys. G21 (1995) 1559-1642, M.Klasen and collaborators, Maria Krawczyk and collaborators,

Two photon processes at Linear colliders + hadronic backgrounds from two photon processes

3)M. Drees, RG, Z. Phys. C59, 591-616 (1993).

4) P. Chen, T. L. Barklow, M. E. Peskin, PRD 49, 3209-3227 (1994).

Hadronic $\gamma\gamma$ cross-sections and hadronic backgrounds:

5)RG and G. Pancheri, EPJC 19 (2001) 129.

6)RG, A. De Roeck, A. Grau and G. Pancheri, JHEP **0306**, 061 (2003),

7) R.G., A. Grau, Kirtimaan Mohan, G. Pancheri and Y. Srivastava, LC10, LC11 proceedings.

EMM predictions for total cross-sections: pp, γp and $\gamma\gamma$.

8 R.G., A. Grau, G. Pancheri and Y. Srivastava, PRD 72, 2005, 076001, [arXiv:hep-ph/0408355].

9)R.G., A. Grau, G. Pancheri, Y. Srivastava : EPJC 63, (2009) 69.

Review on cross-sections: G. Pancheri and Y. Srivastava, EPJC 2017, 77-150.

We need to discuss the hadronic production in $\gamma\gamma$ processes.

Note:

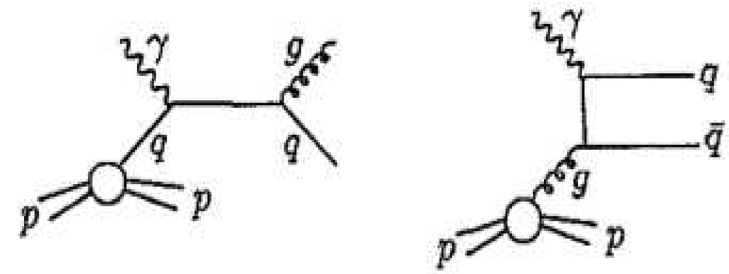
- Photon structure changes the nature of hadron production in interactions of high energy photons with hadrons as well as other photons.

- There exist two types of contributions: 'direct' and 'resolved'

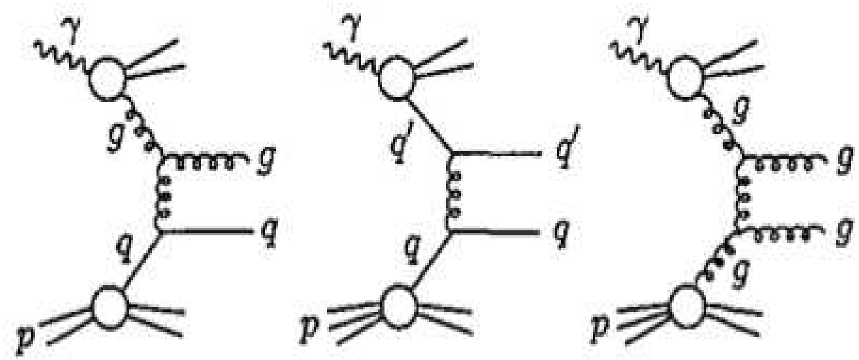
- Resolved contributions are due to processes initiated by the parton content of the photon!

M. Drees and R.G, Phys. Rev. Lett.61 (1988) 682, Nucl. Phys. B339 (1990) 355.

1574 *M Drees and R M Godbole*

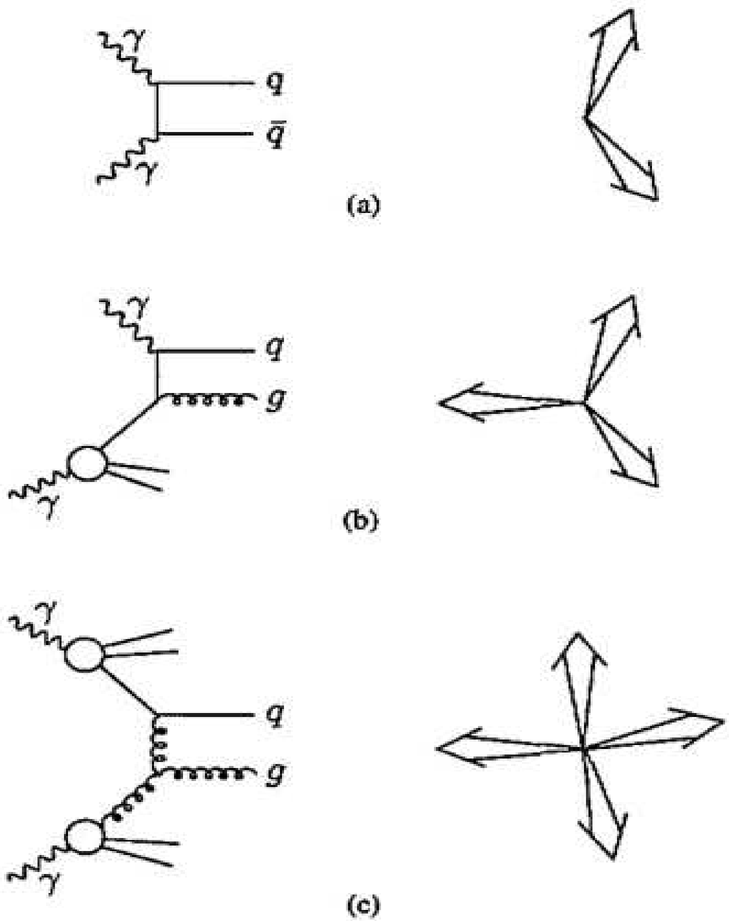


(a)



(b)

a are 'direct' processes and b are 'resolved'. Both are $\mathcal{O}\ (\alpha_{em}\alpha_s)$. Remember $\frac{1}{\alpha_s}$ in Sasaki's talk! M. Drees and R.G., J.Phys. G21 (1995) 1559-1642



a 'direct', b is 'single resolved' and c 'double resolved' . M. Drees and R.G., J.Phys. G21 (1995) 1559-1642

Resolved contributions can be as large or even dominant depending on the kinematics of the final state.

Experimentally observed and studied at HERA, TRISTAN and LEP in various final states: jets, heavy flavour, direct photon....

Reviews :

M. Drees and R.G., J.Phys. G21 (1995) 1559-1642, M. Klasen, Lect. Notes Phys. 546, 250 (2000), [hep-ph/9907366].

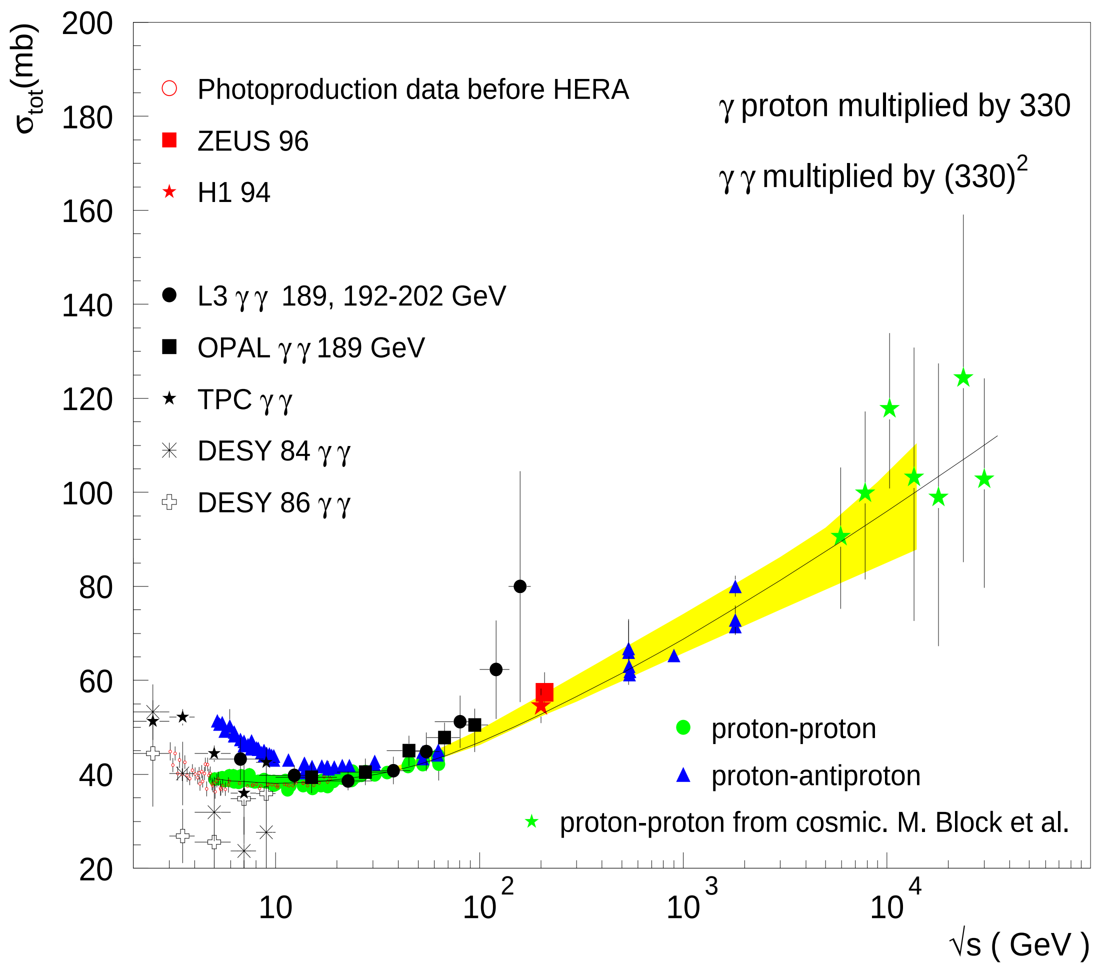
Hadron production in photon induced processes have a part that is similar to that in proton induced processes and dominant for high energy photons. So sometimes γp and $\gamma\gamma$ collisions will have the same complexities eg. underlying events as pp collisions.

Theoretical analysis of hadronic cross-sections involving photons follows the same principles of calculations of total cross-sections of hadronic collisions: pp, πp etc.

Well known : hadronic cross-sections rise with energy at high energies.

γp and $\gamma\gamma$ cross-sections *should also* rise with the c.m. energy in the same way.

All hadronic total cross-sections rise with energy.



Yellow band: range for Eikonal model improved with soft gluon resummation (EPJC 63, 69-85 (2009) G.G.P.S.) **forget it for a minute.**

Charge to models: Explain 1) The normalisation, 2) The rise **and** 3) the initial fall with energy.

Need to predict the high energy behaviour.

One estimator M. Drees and RG, NPB 1990, ZPC 1993, J Phys G 1995 for hadron production in $\gamma\gamma$ collisions:

$$\sigma^{jet}_{ptmin} = \int_{ptmin}^{\sqrt{s}} \frac{d\sigma(\gamma\gamma\to \text{jets})}{dp_t}$$

1) It's energy rise is similar in all three cases, $pp, \gamma p$ and pp.

2) Description in terms of the photon densities determined from fits to LEP data.

Glück, Reya, Vogt: GRV (1992),

Glück, Reya, Schiebein : GRS (1999),

F. Cornet, P. Jankowski, M. Krawczyk and A. Lorca : CJLK (2003).

Three available parameterisation AFTER LEP data on F_2^γ , both at LO and NLO. There are of course no new densities.

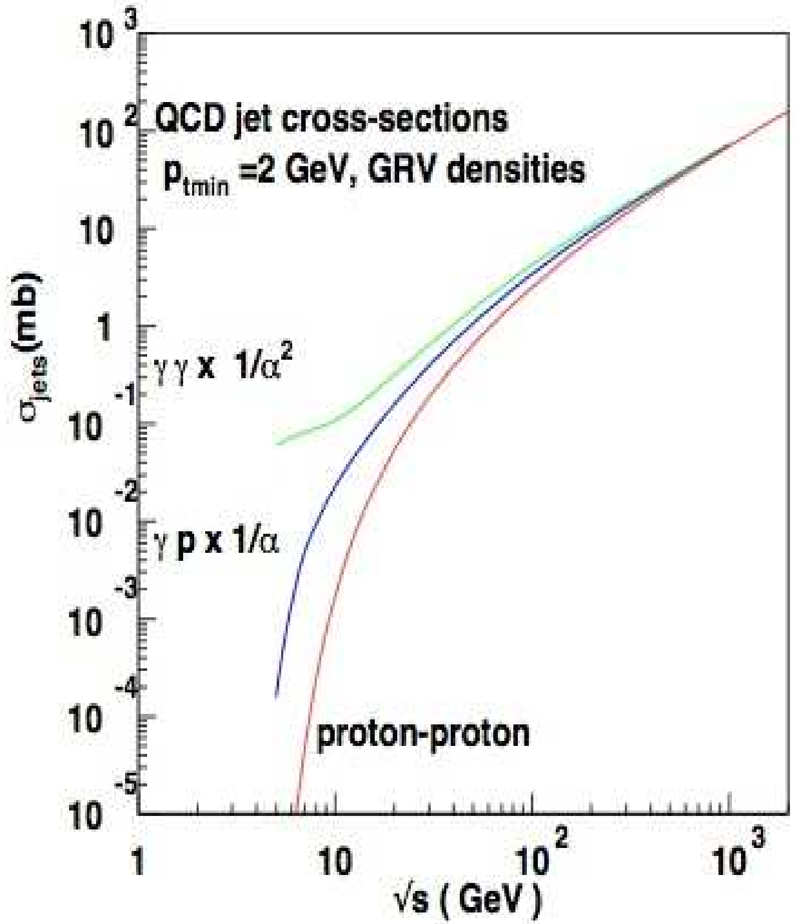


Fig. 1. Integrated jet cross-sections for $p_{\rm tmin} = 2\,{\rm GeV}$

EPJC 19 (2001) 129.

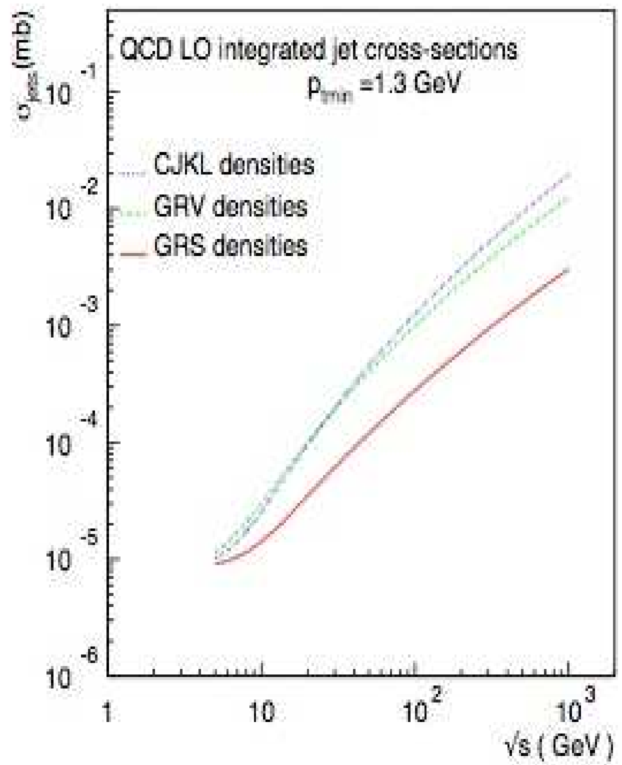


Figure 2: Photon-photon jet cross-sections for different densities and a typical p_{tmin} value.

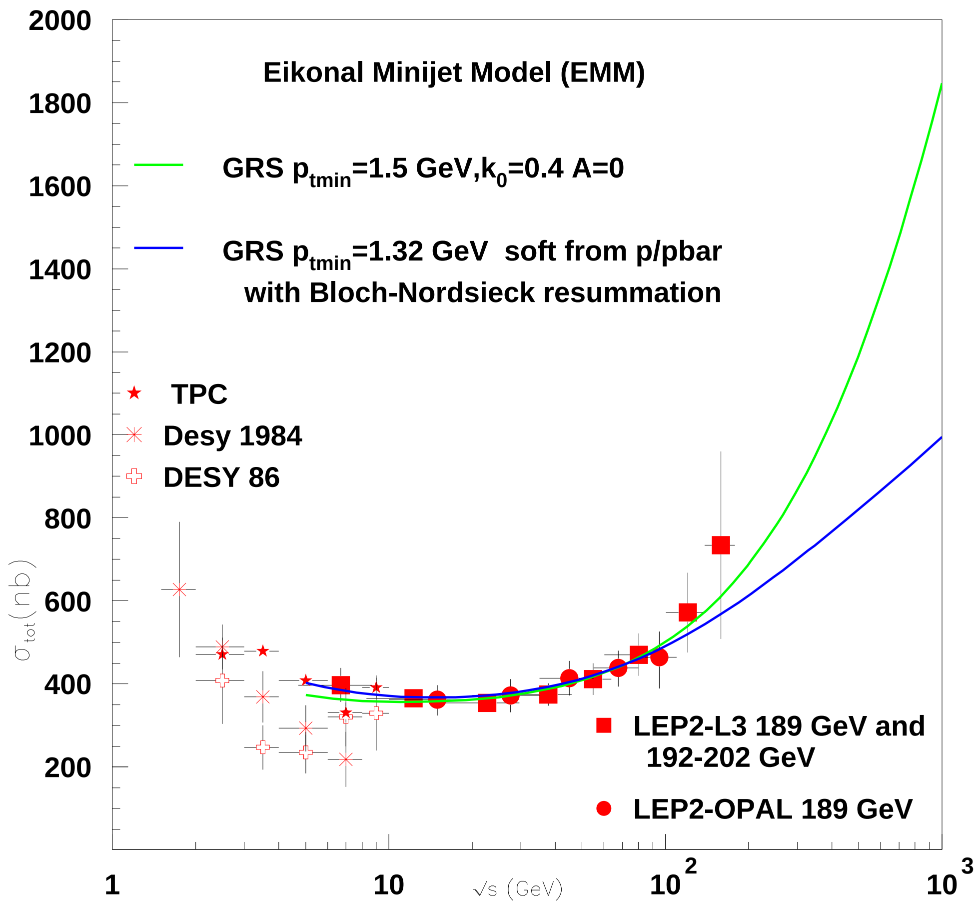
0802.3367

Rise of hadronic cross-sections driven by mini jet cross-sections. Much faster than the energy rise of hadronic cross-sections . They need to be unitarised.

With GP and others we first developed a model which explained energy rise for pp and then extended the model to γp and $\gamma\gamma$.

These could be tested against the measurements of $\gamma\gamma$ cross-sections at LEP.

Just like the non perturbative part of the F_2^γ can not be calculated and all the fits determine it from data, the predictions obtained using perturbative QCD have to be augmented by few non perturbative parameters. In our model they are determined from pp data.



Early attempts: EMM and BN EMM.

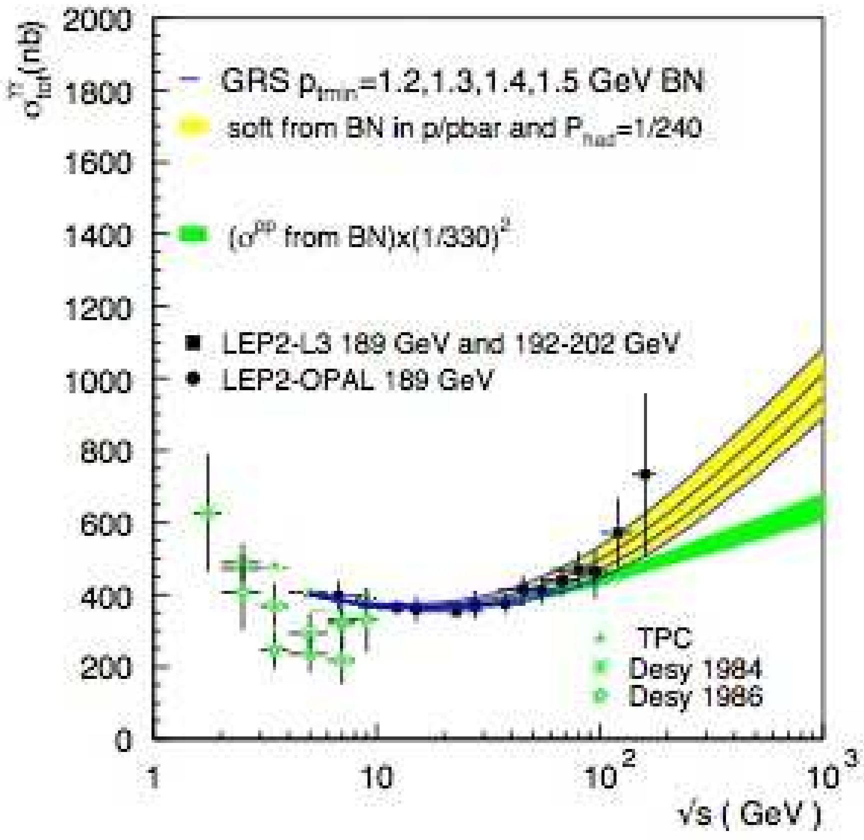


Figure 5: $\gamma\gamma$ total cross-sections from factorization (green band) or using the Eikonal with GRS densities and soft gluon resummation.

1)The $\gamma\gamma$ cross-sections seem to rise faster with energy than pp. (Or for that matter also faster than γp.)

2)Our model calculated $\sigma_{\gamma\gamma}$ in terms of parton densities in photons.

3)Of course there existed many other models and fits.

The analyticty and unitarity implies Froissart Bound. $\sigma^{tot}(s)$ rises at most like $\ln(s)^2$.

1)Regge-Pomeron exchange: (Donnachie and Landschoff)

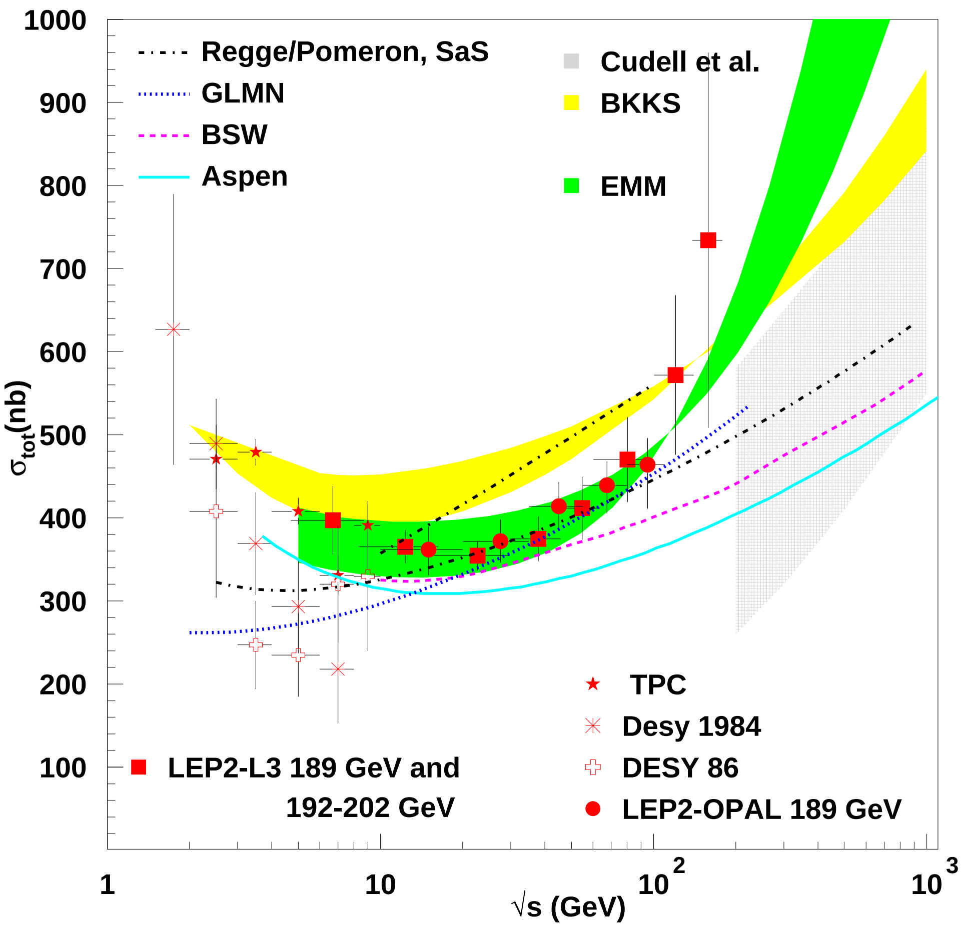
$\sigma(s) = As^{-\eta} + Bs^{\epsilon}$

$\eta = 0.5, \epsilon = \alpha_P - 1 =$ small.

2)EMM: Unitarised minijet modelUnitarisation by multi-parton interactions increasing with energy in a given hard collision. Also EMM-BN. GLMN also have a unitarised model.

3)Photon as a proton using VMD (Aspen, BKKS)

Cudell et al: extrapolation of low energy data fits.

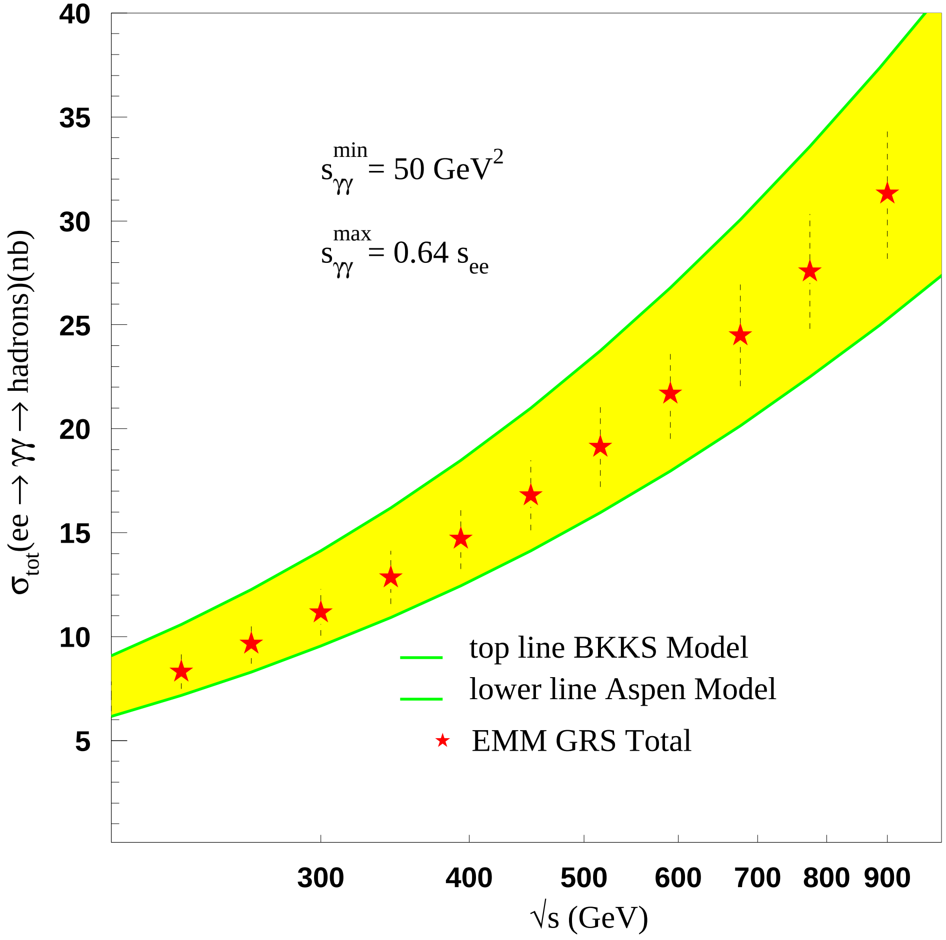


1)This includes only the EMM predictions. Which still rises too fast with energy. Look on slide 14 where EMM-BN predictions are shown. Energy rise for GLMN and EMM-BN seem to be in tune with the LEP data. Cudell et al results shown by grey area.

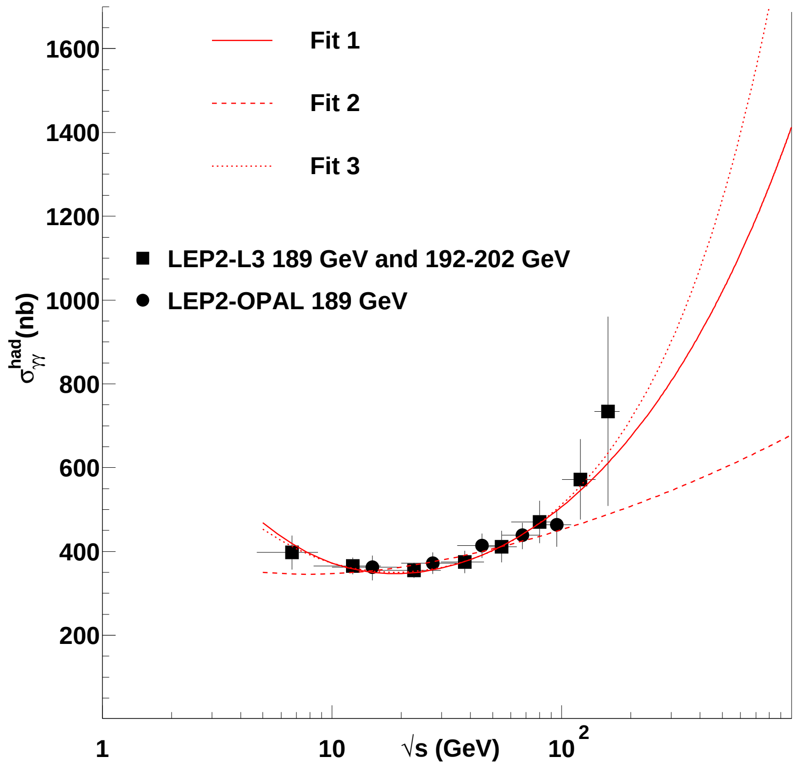
2)In TESLA TDR we had studied how well the ILC could measure the total cross-section and fix the rate of rise of $\gamma\gamma$ hadronic cross-sections.

Were focussed on whether $\gamma\gamma$ processes can give information on the models of total cross-section.!

Since measuring photon photon cross-sections is more difficult we calculated hadron production in e^+e^- collisions.



JHEP 0306 (2003) 061.



L3 and OPAL data had some discrepancies.

Use only data to make ILC predictions.

Three different fits. Both the data sets require a rising component.

JHEP 0306 (2003) 061.

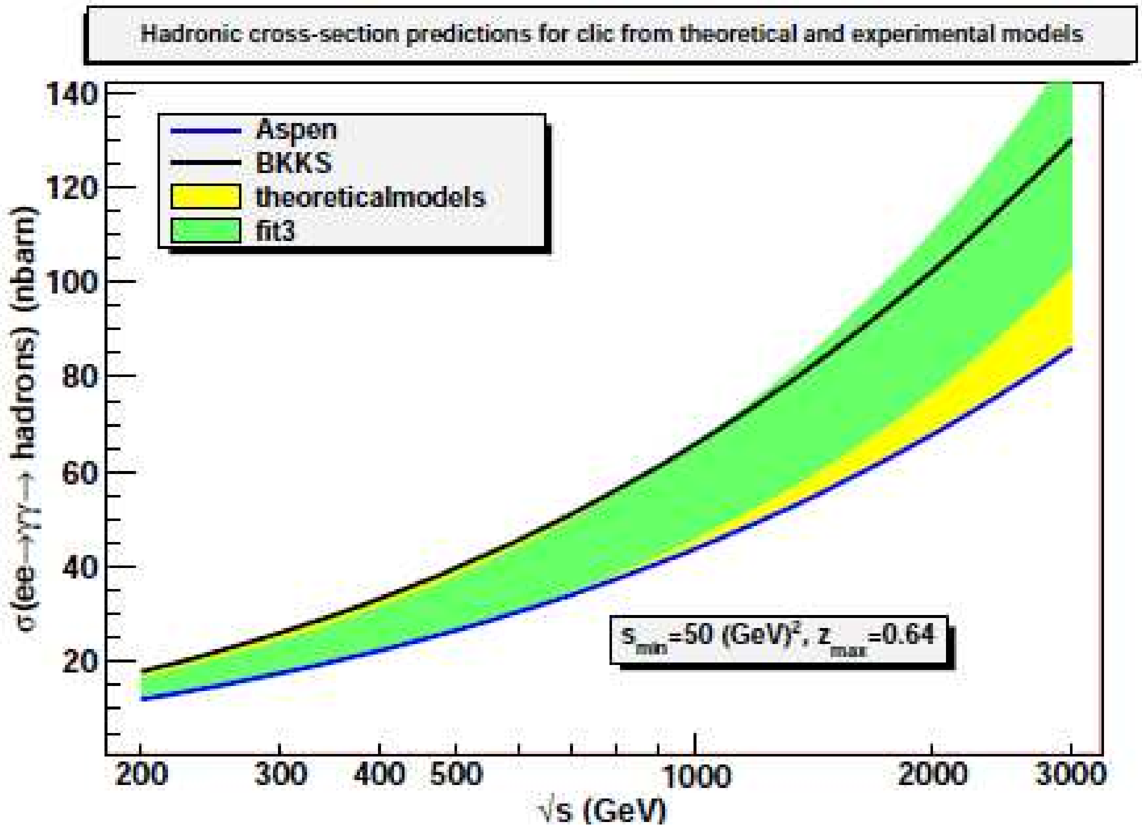
Results of fits to the OPAL and L3 total $\gamma\gamma$ cross sections, of the form $Bs^{-\eta} + As^{\epsilon} + Cs^{\epsilon_1}$.

$A(nb)$	$B(nb)$	$C(nb)$	ϵ, ϵ_1	χ^2
51 ± 14	1132 ± 158	-	$\epsilon = 0.24 \pm 0.032$	4.0
147 ± 4	310 ± 91	-	$\epsilon = 0.093$	26
103 ± 18	934 ± 156	5.0 ± 1.0	$\epsilon = 0.093,\ \epsilon_1 = 0.418$	2.8

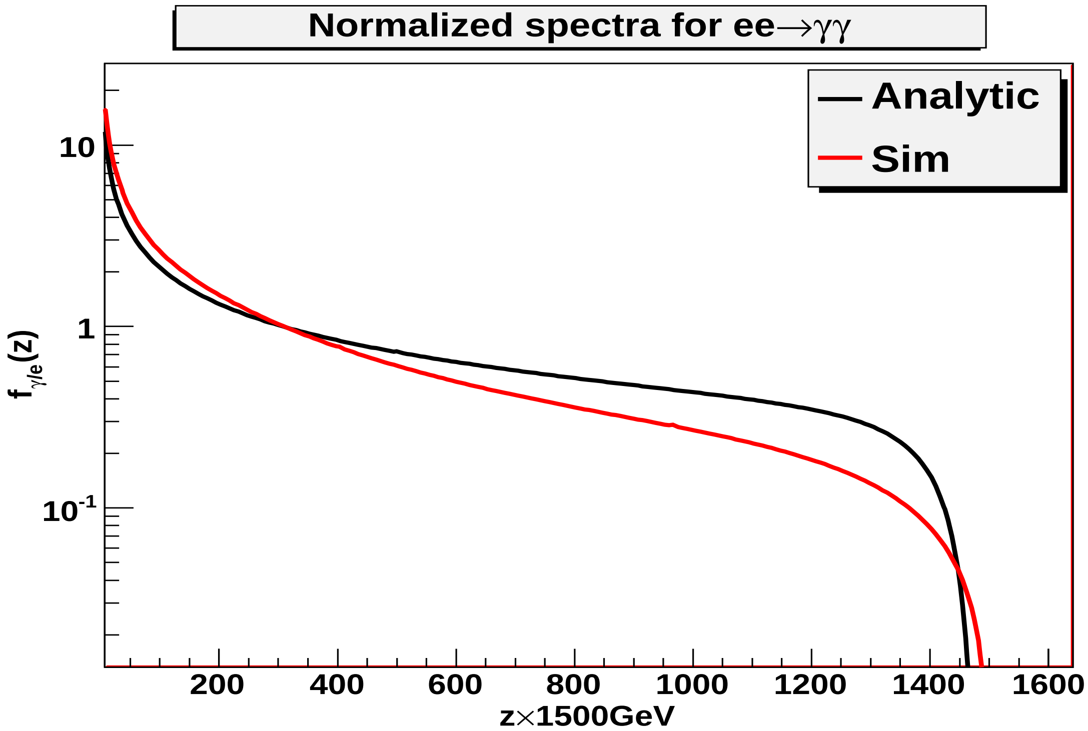
Values used.

What happens for higher energy? CLIC?

What is the effect of model uncertainties in the hadrnonic $\gamma\gamma$ cross-sections?



These are expectations for $e^+e^- \to e^+e^-\gamma\gamma$, including only the bremsstral photons. Of course for CLIC one needs to take into account beamstrahlung. This is the emission of photons due to beam-beam interactions.

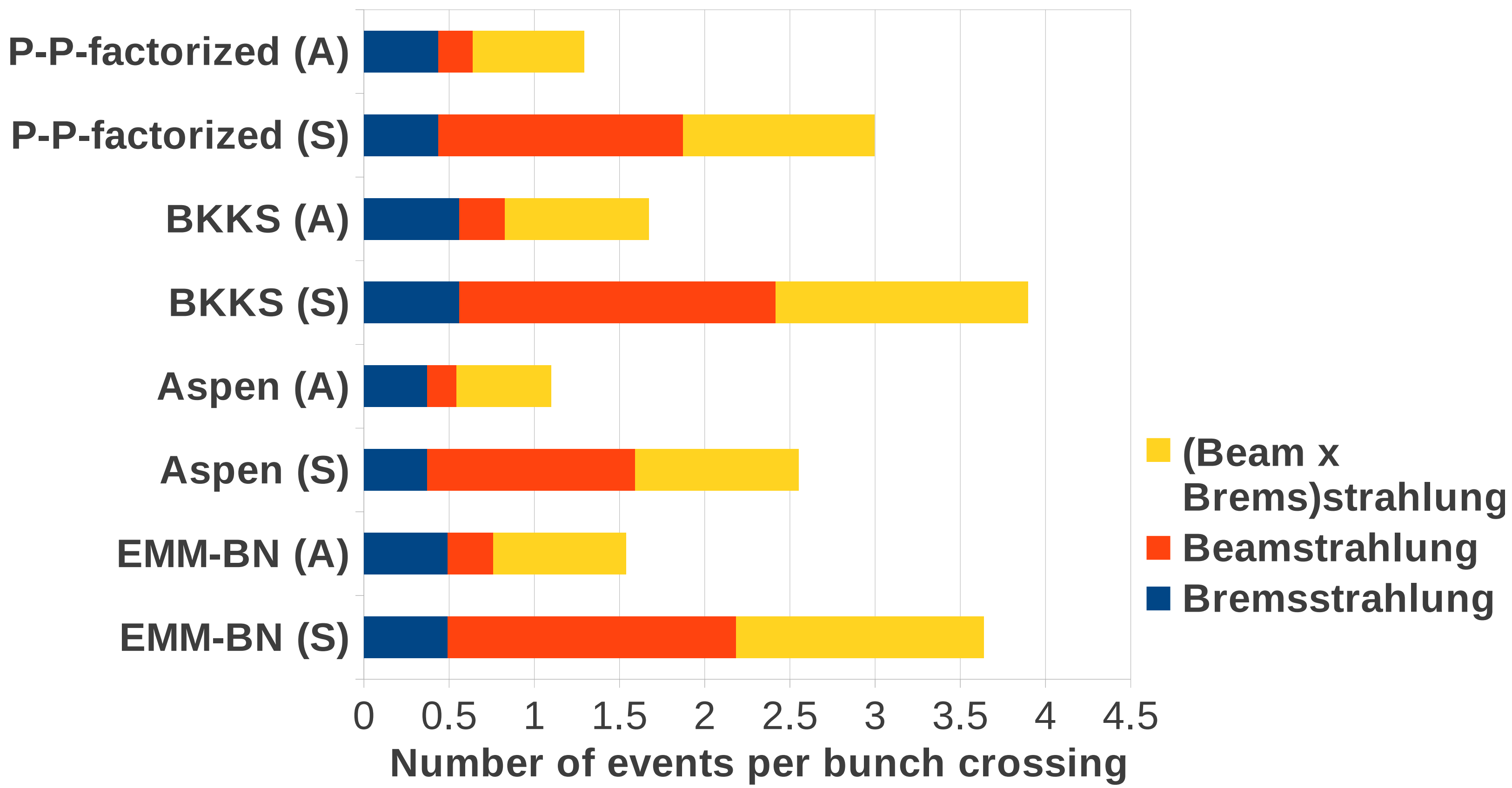


Analytical: Chen, Phys Rev. D 1991, Not good for large value of disruption parameter Υ.

Simulation: Guinea Pig: Nonlinear effects inlcuded. Softer spectrum.

Theoretical Model Predictions of Hadronic Events

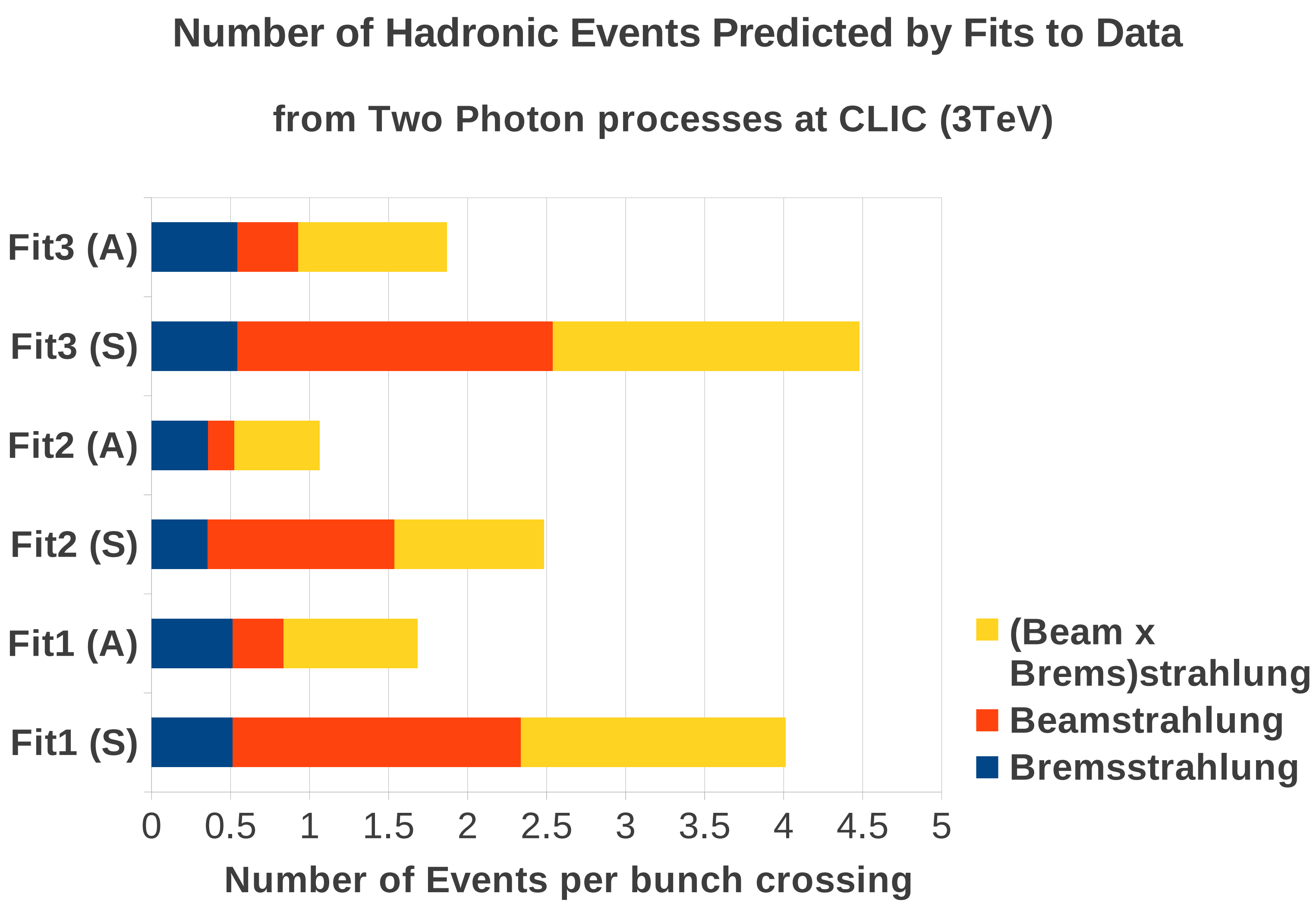
from Two Photon Processes at CLIC (3TeV)



Beamstrahlung increases the number of events per b.c. substantially.

Background is dominated by $\sqrt{s_{\gamma\gamma}}$ region where data are available.

Let us see the spread in values as we look at three fits.

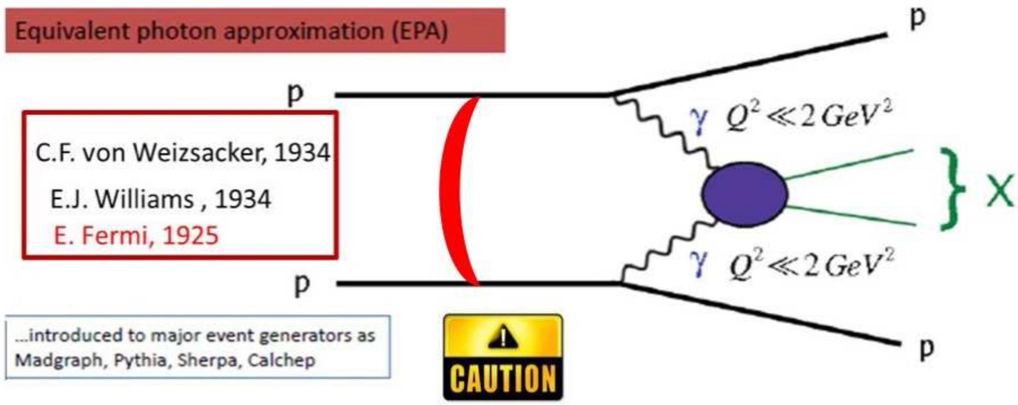

Number of Hadronic Events Predicted by Fits to Data
from Two Photon processes at CLIC (3TeV)
Fit3 (A)
Fit3 (S)
Fit2 (A)
Fit2 (S)
Fit1 (A)
Fit1 (S)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Number of Events per bunch crossing
(Beam x Brems)strahlung
Beamstrahlung
Bremsstrahlung

The beamstrahlung induced hadronic backgrounds are large at CLIC.

Dominated by the values of $\gamma\gamma$ cross-sections where data are available. Better fits are need of the day to reduce the spread of predictions for CLIC energies.

The spread in the model predictions for number of background events in fact is similar to the spread among the three fits to the data themselves.

Need to fit perhaps better the lower energy part of the LEP data.



Hadronic interactions (resolved contributions) can be backgrounds and may have to be taken into account in the studies. Particularly at large invariant masses the resolved contributions could indeed dominate.

Examples: $h \to b\bar{b}$.

What is the uncertainty in these bkgds. due to our ignorance of the photon structure?

Can we get some information on photon structure by studying (say) the jet production in $\gamma\gamma$ collisions?

Not clear one can..but worth thinking about.

With tagging of protons is there any hope of getting the total cross-section for $\gamma\gamma$ processes?

Most probably not!

1) The hadronic structure of photons affects production of hadrons in photon photon interactions and dominates it for high energy photons. HERA gave conclusive evidence that this description works well.

2) The high energy rise of the cross-sections seems faster for processes involving photons than the ones which do not involve them.

3)Hadronic backgrounds at CLIC are large, however the predictions of underlying events depend on the values of c.m. energies $\sqrt{s_{\gamma\gamma}}$ seem to involve only the values where data are available. Better fits to lower energy data will be useful.

4)Effects of the hadronic structure on the study of two photon processes at the LHC might be needed to be taken into account. What can we learn about the photons from the two photon processes at the LHC?