Measurement of the Cross Section for open b-Quark Production in Two-Photon Interactions at LEP

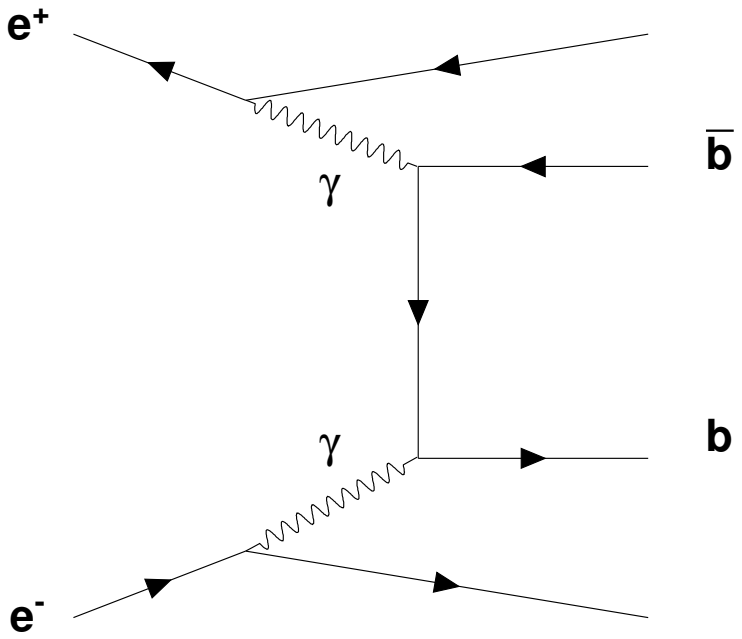
Alex Finch for the ALEPH Collaboration

- Measurement of open b-quark production in LEPII data
  698 pb^{-1} , $\sqrt{s} = 130 \sim 209\, GeV$
- First use of lifetime information to identify heavy flavour quarks in $\gamma\gamma$

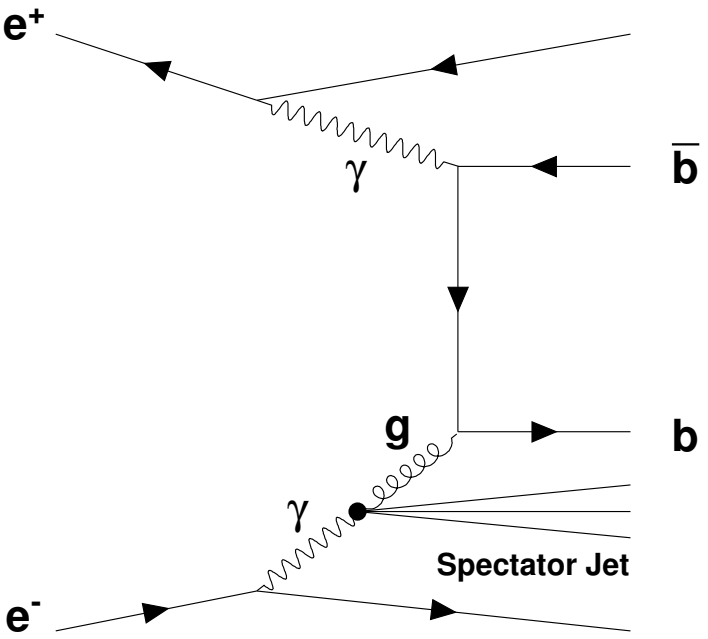
Contents

Introduction

- $\sigma(\gamma\gamma \to \mathrm{b\bar{b}}X)$ **reliably calculable in NLO QCD due to b quark mass.**
- $\sigma =$ **2.1** $\sim$ **4.5 pb,** $\sim 0.01 \times \sigma(\gamma\gamma \to c\bar{c}X) \sim 0.01 \times \sigma(\gamma\gamma \to uds)$



Direct



Single Resolved

Existing Results

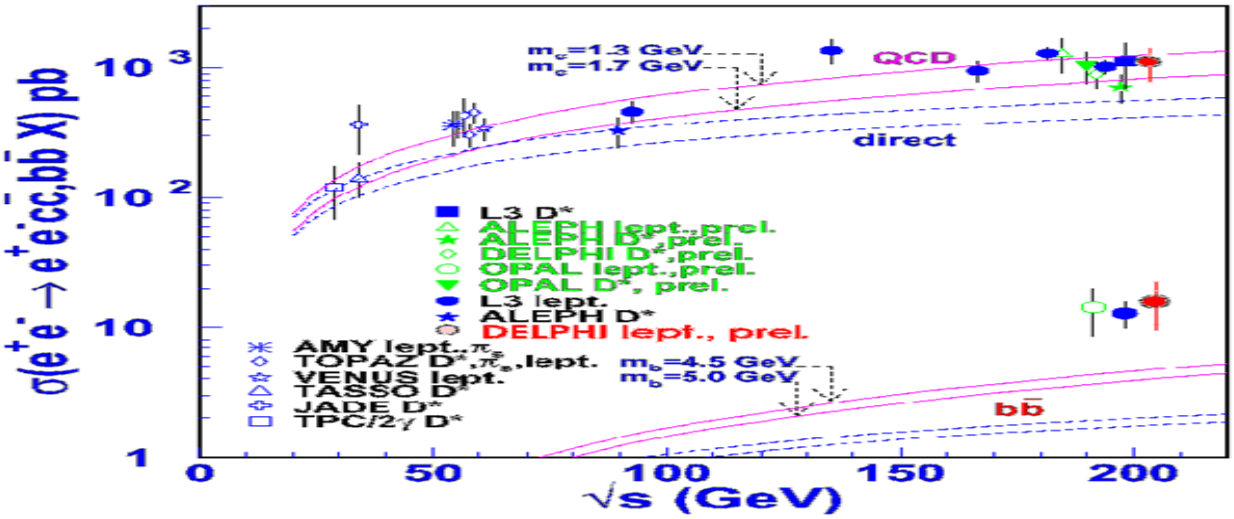
- One published measurement by

  L3 $(12.8 \pm 1.7_{\text{stat}} \pm 2.3_{\text{syst}})$ pb.

- Two conference reports:

  OPAL $(14.2 \pm 2.5_{\text{stat}} \pm 5.3_{\text{syst}})$ pb.
  (Photon 2000)

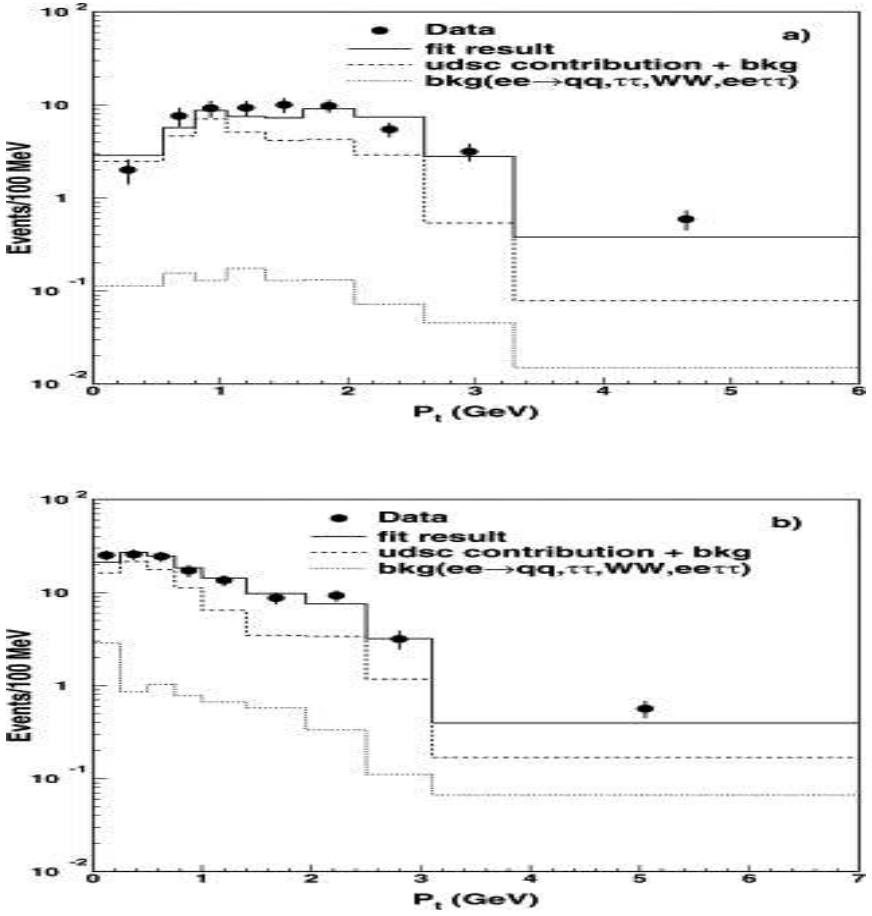
  DELPHI $(14.9 \pm 3.3_{\text{stat}} \pm 3.4_{\text{syst}})$ pb
  (Photon 2003).



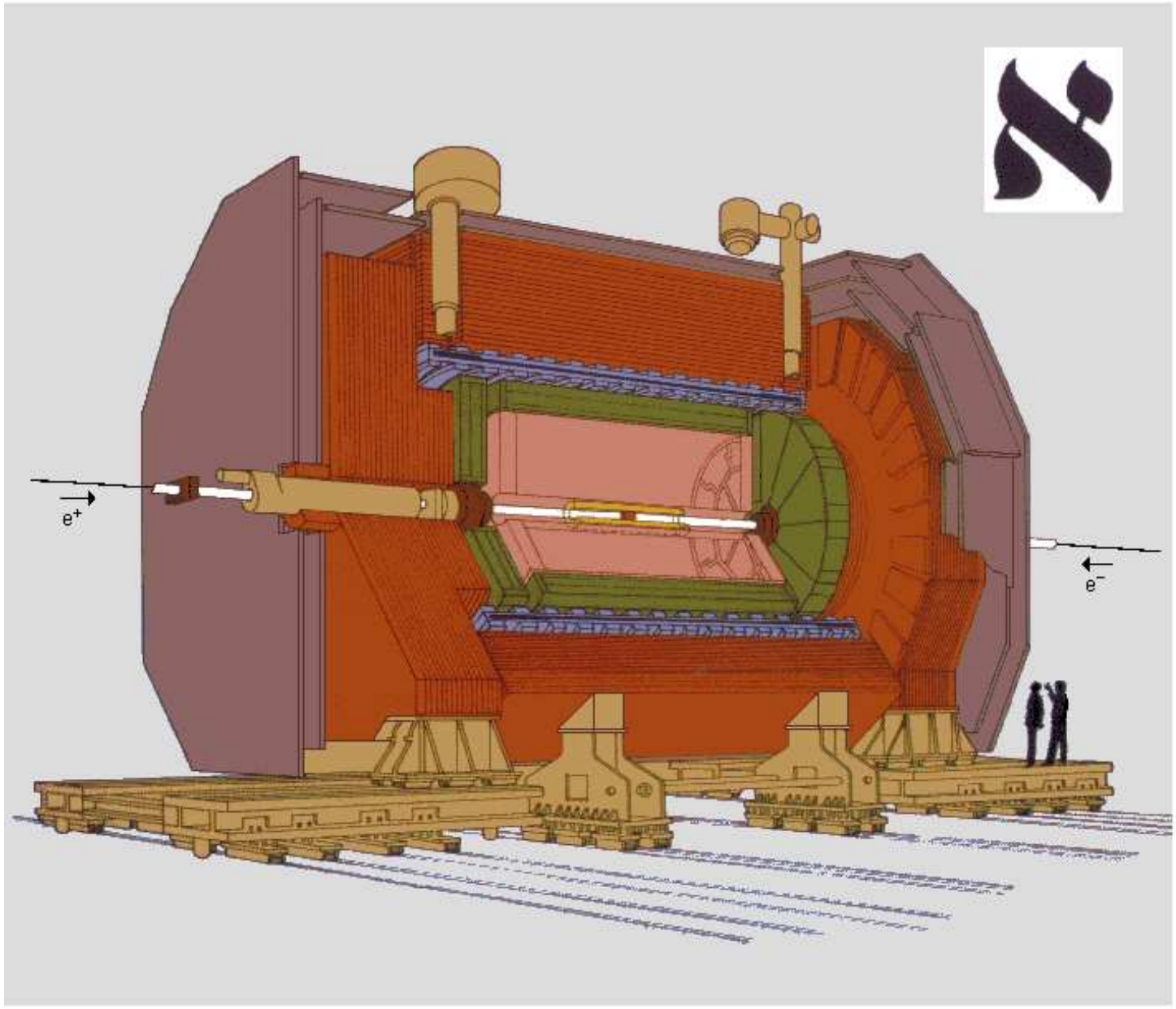
Charm agrees with QCD prediction

Beauty is significantly above

All measured using high p_t leptons.



L3 results for (a) electrons and (b) muons



Vertex Detector

Inner Tracking Chamber

Time Projection Chamber

Electromagnetic Calorimeter

Superconducting Magnet Coil

Hadron Calorimeter

Muon Chambers

Luminosity Monitors

The ALEPH Detector

Tools of the Trade (Software)

Monte Carlo

- **PYTHIA 6.1 for all $\gamma\gamma \to X$**
  b and c, direct and resolved - massive matrix elements.
  (resolved: photon's pdf was SaS 1D)
- $e^+e^- \to q\bar{q}$ **-" KK " Monte Carlo**
- **HERWIG used to model** $\gamma\gamma \to b\bar{b}X$
  (for systematic error calculations)

Jet Finding

- **Non standard Jet Finder 'PTCLUS' used.**
- **Similar to LUCLUS**
- **Better for the resolved events than DURHAM style jet finders.**
- **Optimized so that b jets in direct and resolved are similar.**
- **Ask me at the end if you need a detailed description!**

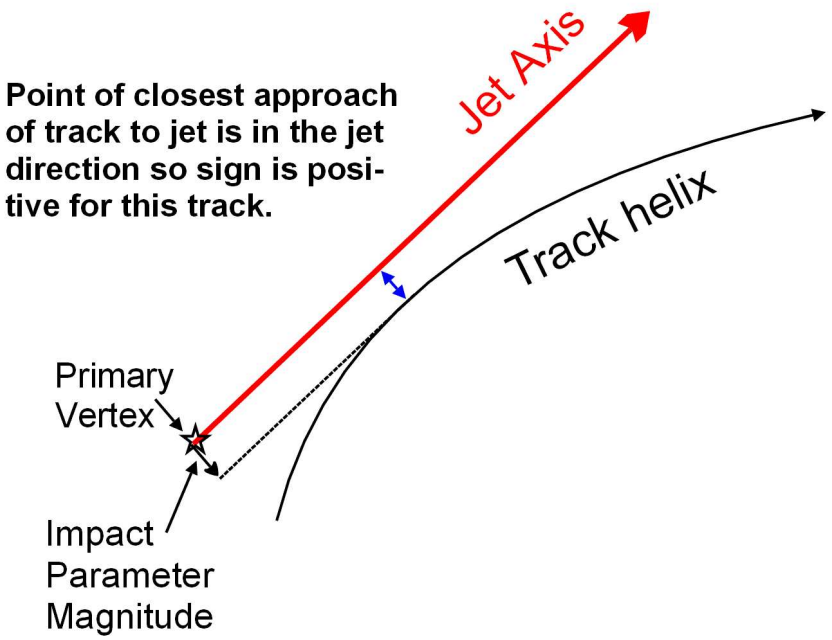
Note: "Jet 1" has mass nearest 5.0, "Jet 2" next nearest etc.

Tools of the trade ... b tagging

Based on

Signed Impact Parameter

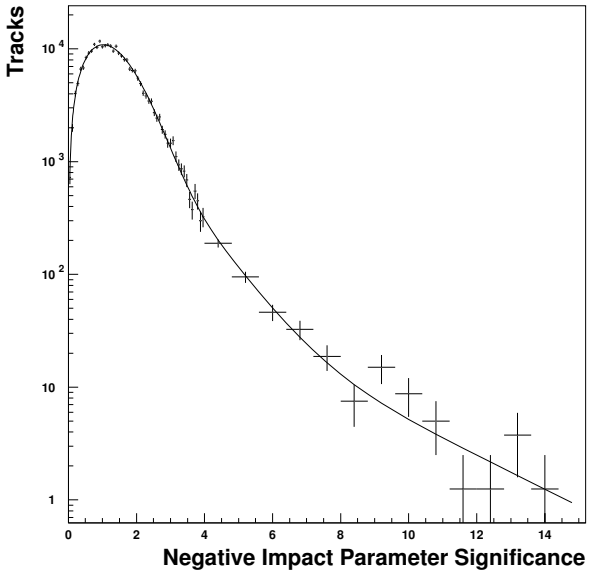
Definition of Signed Impact Parameter



Calculate significance S

$$S = \frac{\text{Impact parameter}}{\text{error}}$$

Fit negative S $\Rightarrow$



Derive probability that track is from main vertex.

Combine probabilities to calculate:

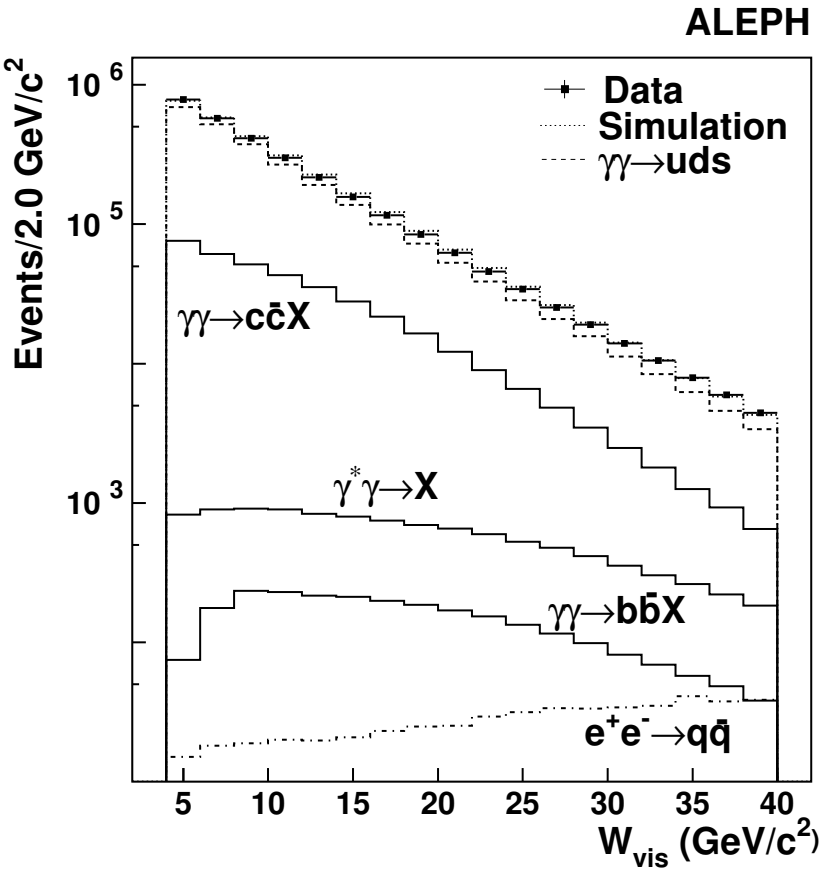
P_{jet} - probability that all tracks in jet came from main vertex

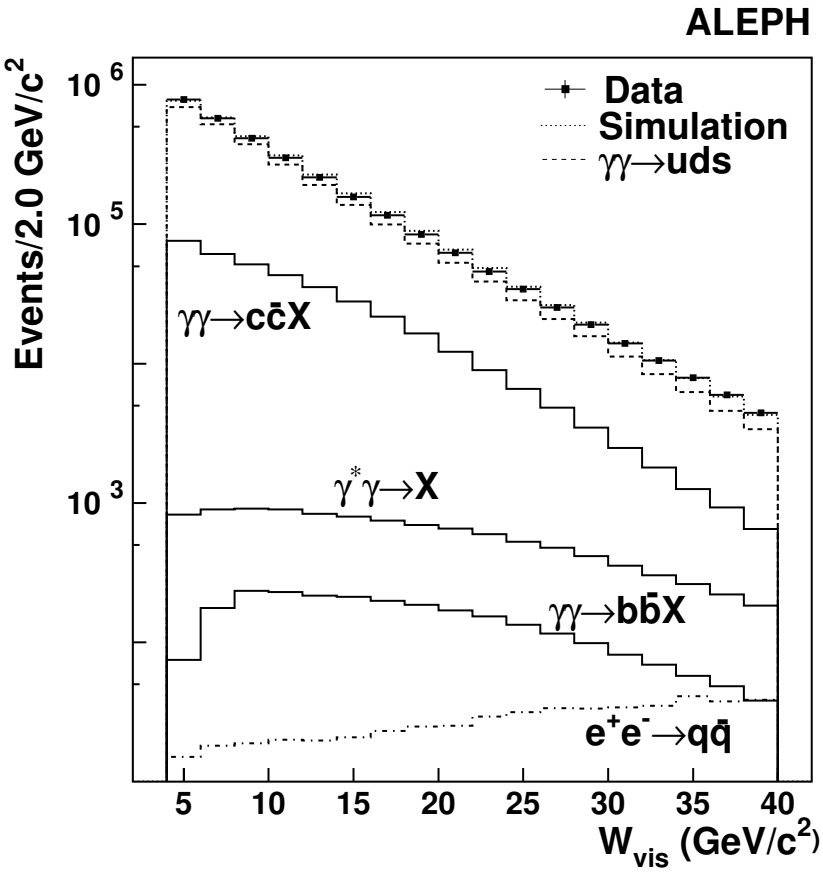
P_{event} - likewise for all tracks in event

Event Preselection

Select $\gamma\gamma \to hadrons$

- > 4 **charged tracks**
- $4 < W_{vis} < 40\,\mathrm{GeV}/c^2$
- **Energy in luminosity calorimeters** < 30 **GeV**
- p_t **of event** < 6 GeV/c
- **Thrust** < 0.97

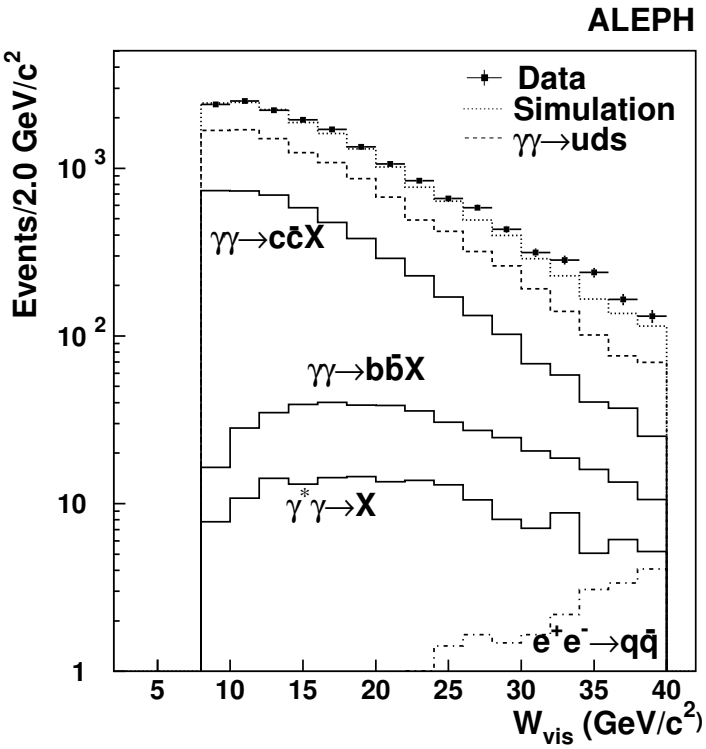


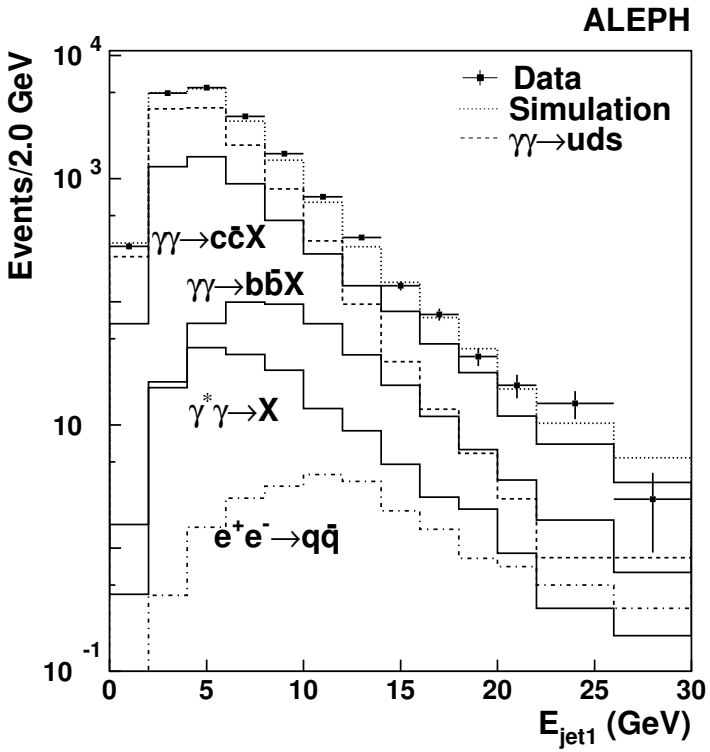


Event Selection

Enhance $\gamma\gamma \to b\bar{b}X$

- > 6 **charged tracks**
- $8 < W_{vis} < 40\,\mathrm{GeV}/c^2$
- **at least two jets**
- $P_{\mathrm{event}} < 0.05$
- **the third largest impact parameter significance** $S > 0$
- **the fourth largest impact parameter significance** $S > -10$





Iterative Discriminant Analysis (Overview)

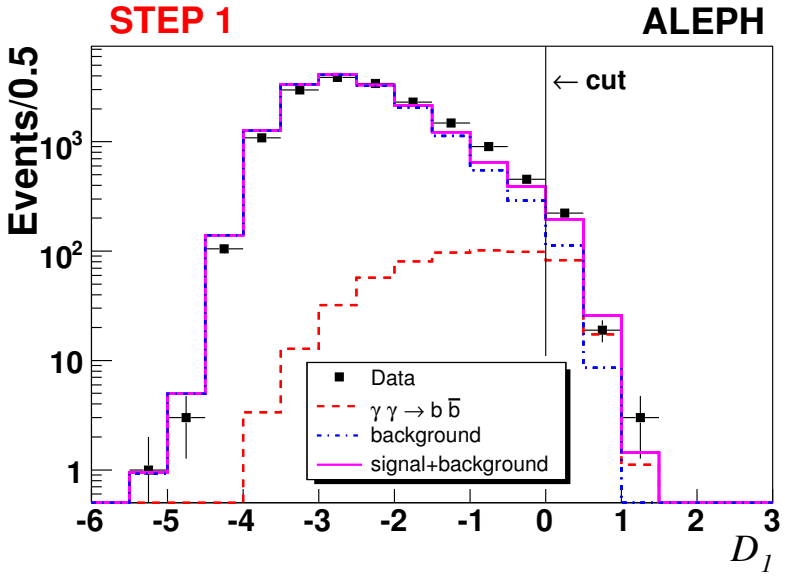
IDA, an event weighting method...

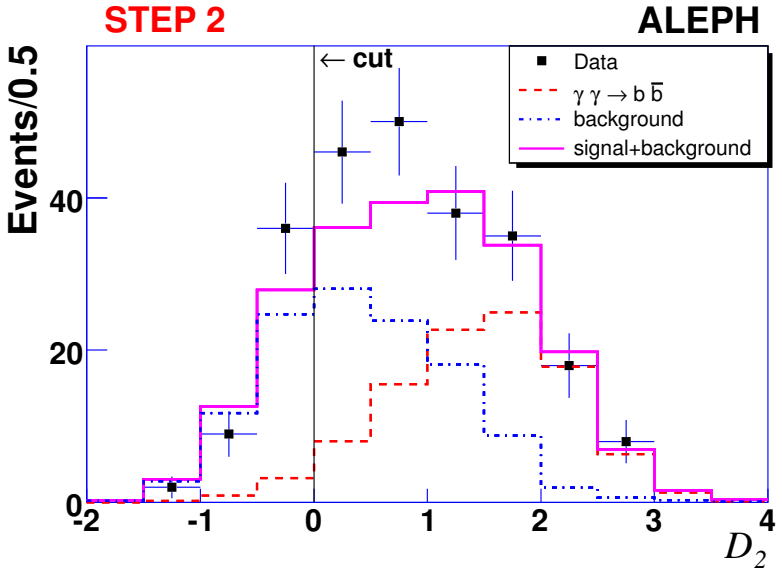
- Input:
  variables which can distinguish signal / background.
- Output:
  a single number -
  high values are signal
  low values are background.
- "Trained" on Monte Carlo.
- Extension of standard linear discrimination.
- Includes products of variables.
- Analytical method (just one matrix inversion).
- "Iterative" means
  A selection may be applied and a new discriminant
  calculated for the remaining events
- Ask me at the end if you need a detailed description!

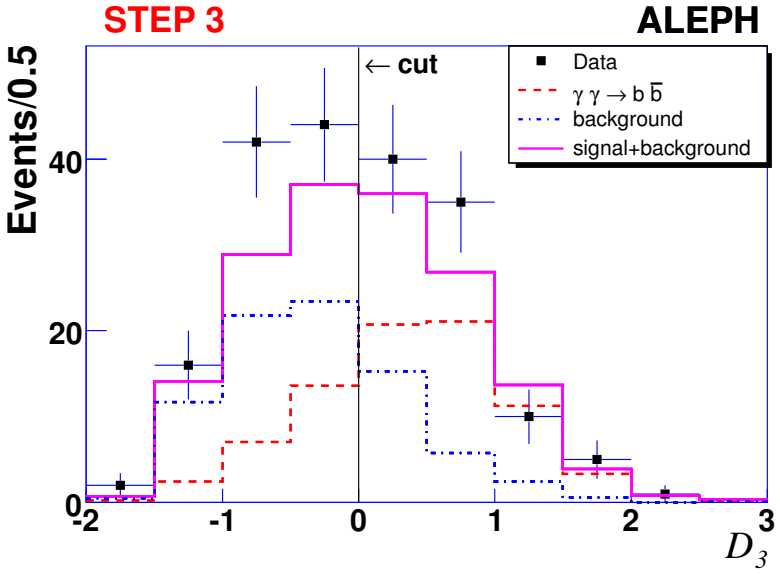
IDA as used in this analysis

IDA Input:

- P_{event},P_{jet1},P_{jet2}
- mass and p_t of Jet 1
- 5 largest S
- the thrust of the event





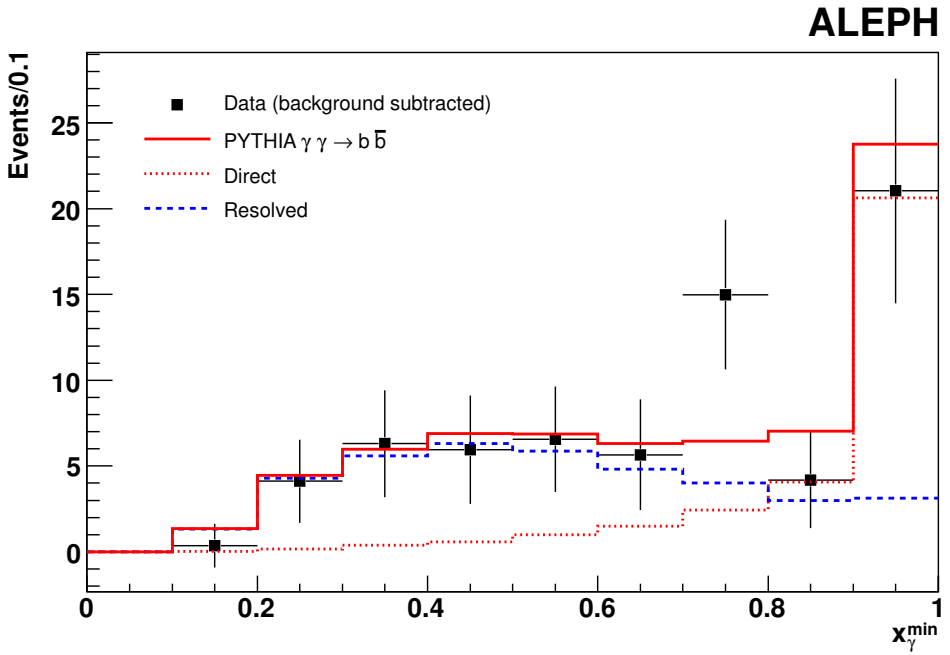


Efficiency Calculation

Efficiencies : 0.022 **(direct),** 0.016 **(resolved)**

To find mean efficiency - need to know how much Direct and how much Resolved.
Fit to x_γ^{min} **to find out.**

$x_\gamma^{\text{min}} =$ **min(**x_γ^+**,** x_γ^-**)**



$$x_\gamma^{\pm} = \frac{\sum_{i=1,2}(E^i \pm p_z^i)}{(E^{\text{tot}} \pm p_z^{\text{tot}})}$$

E^i, p_z^i **are the energy and longitudinal momentum of jet** i
E^{tot} **and** p_z^{tot} **are the energy and longitudinal momentum of the whole event**

Result: Mean Efficiency is 0.0184 ± 0.0009

Results and Systematic Uncertainties

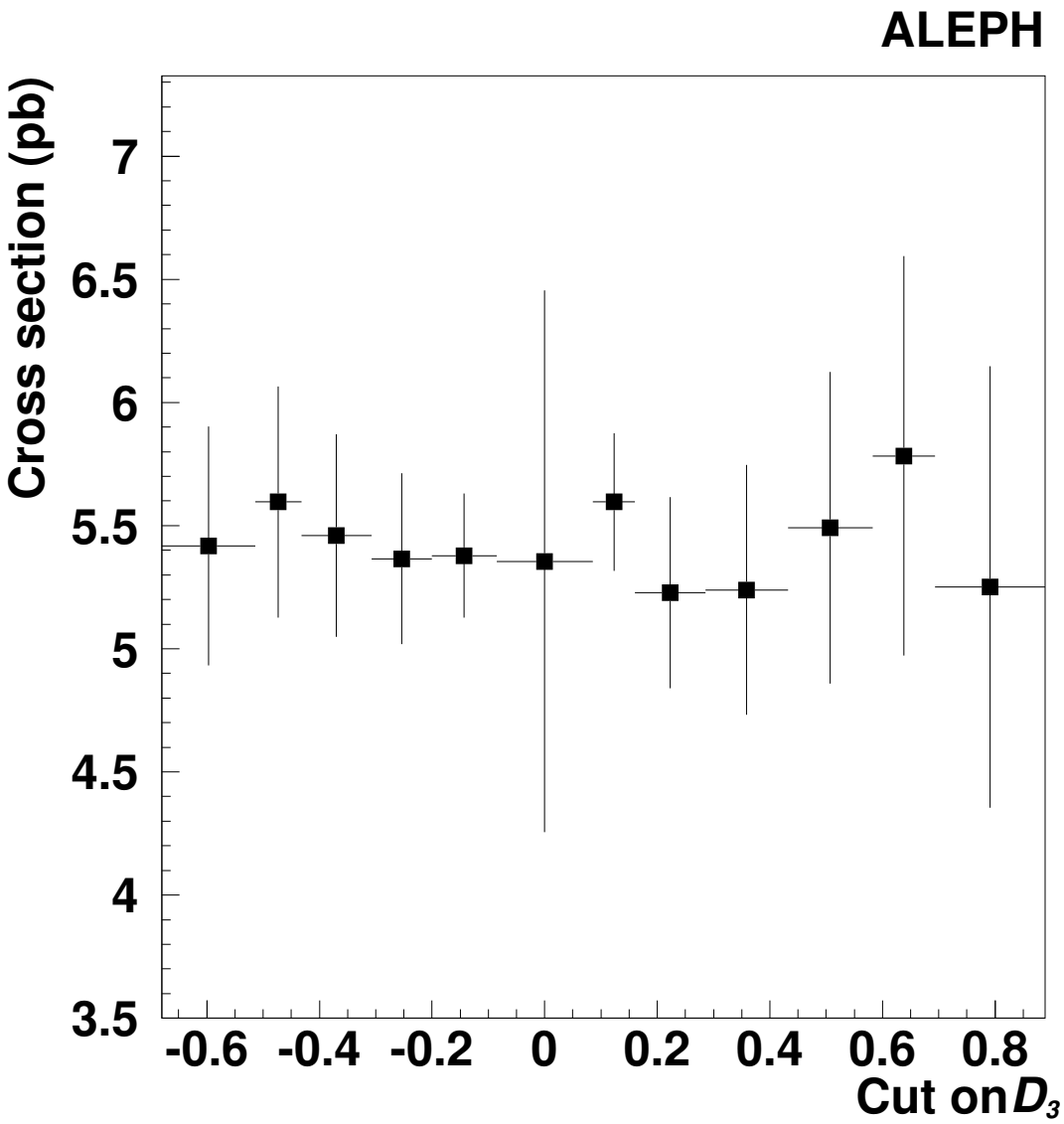
Final selection of 93 events with a background of 24.2

77%	$\gamma^*\gamma \to c\bar{c}X$
17%	$\gamma^*\gamma \to X$ $(Q^2 > 6)$
7%	$e^+e^- \to q\bar{q}$

Systematic Uncertainties

12% error on the background
from uncertainty on measured cross sections
8.6% uncertainty on the efficiency
found by using HERWIG
11% difference due to W_{vis} dependence
by setting maximum W_{vis} cut 30 GeV/c^2

Stability Cross Check



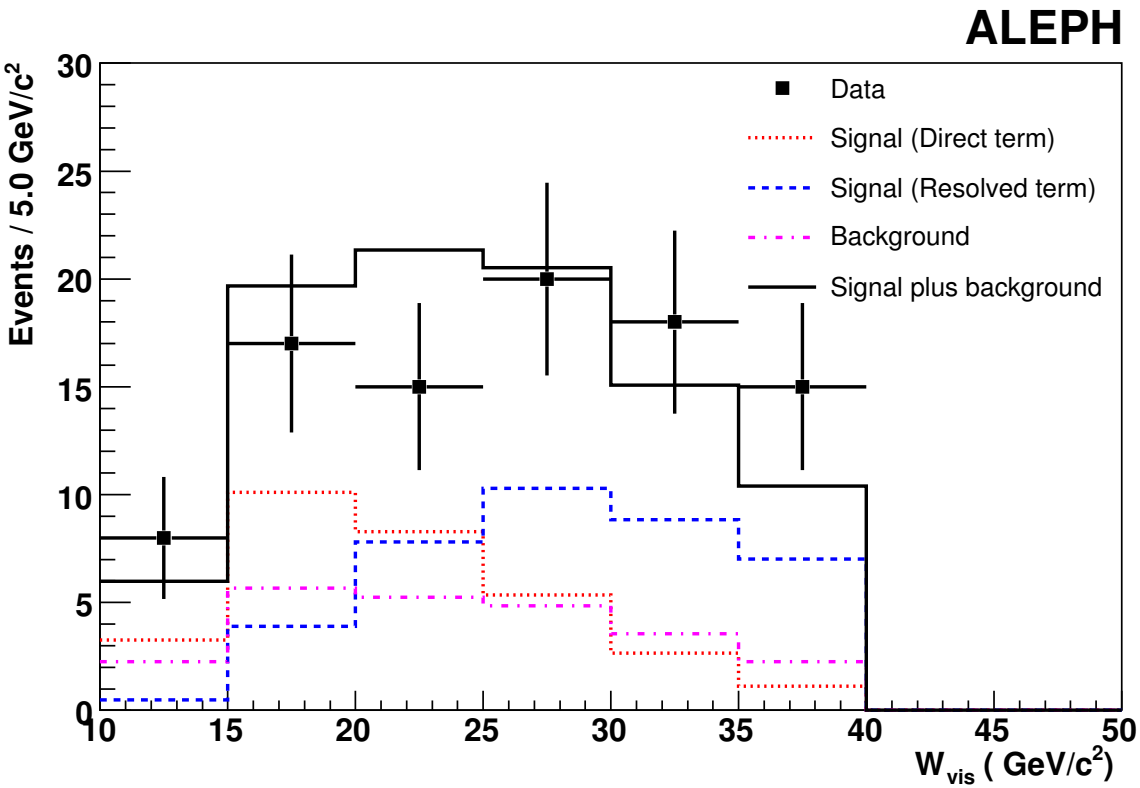
Vary final cut across a large range (From 143 to 33 selected events)

Result is stable.

W_{vis} Cross Check

W_{vis} not used in IDA

Check of direct/resolved fit



Lepton p_t Cross Check

Expect

~ 14 $e^{\pm}$ & ~ 14 $\mu^{\pm}$

in 74 $b\bar{b}$ **events.**

Large b quark mass

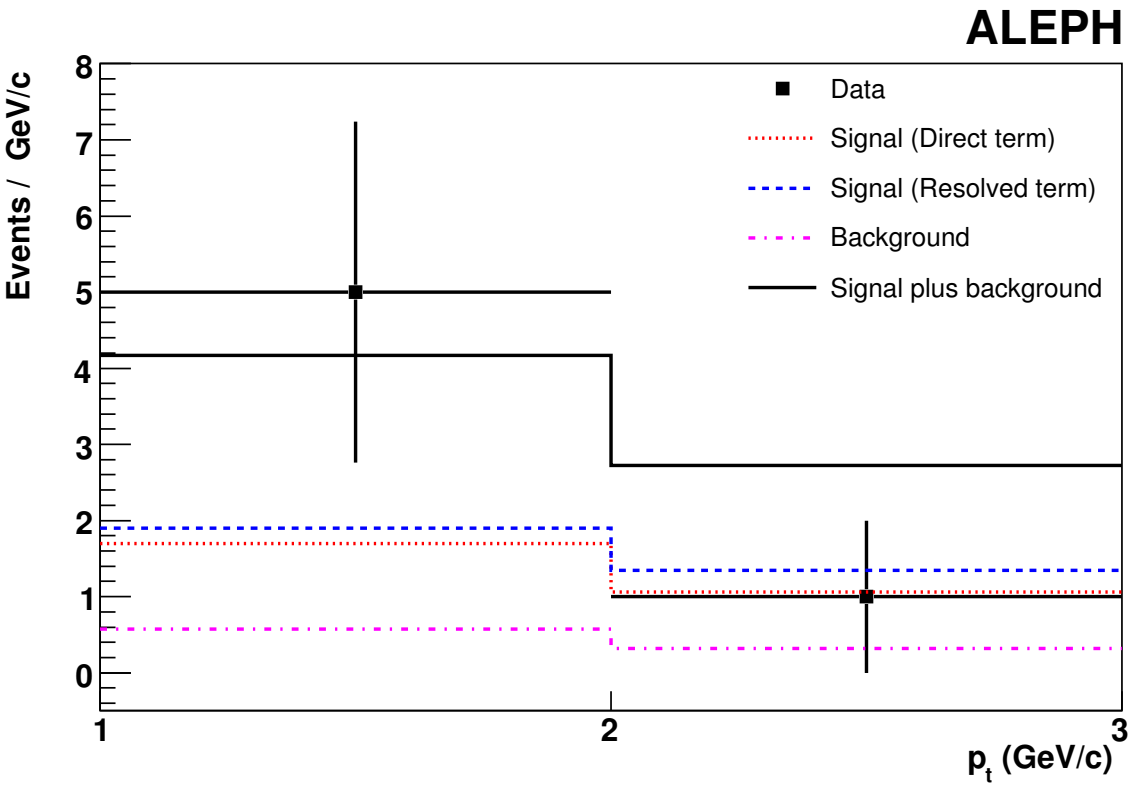
$\Rightarrow$ **leptons have high** p_t **wrt jet.**

After selection, expect :

6 leptons from signal

+ 0.9 from background

See 6 leptons - consistent.



Conclusions

The cross section for the process $e^+e^- \to e^+e^- b\bar{b}\,X$
has been measured to be

$$\sigma(e^+e^- \to e^+e^- b\bar{b}\,X) = (5.4 \pm 0.8_{\,\mathrm{stat}} \pm 0.8_{\,\mathrm{syst}})\,\mathrm{pb}$$

which is consistent with the prediction of NLO QCD
of between 2.1 and 4.5 pb
but barely consistent with the result quoted by the L3 Collaboration,
$(12.8 \pm 1.7_{\mathrm{stat}} \pm 2.3_{\mathrm{syst}})\,\mathrm{pb}$.

For more details see: http://arxiv.org/abs/0706.3150

PTCLUS

- Start from most energetic Eflow object.
  - ⇒ Loop through objects in order of decreasing energy.
  - ⇒ If angle between object and jet <90°
    and p_t with respect to $p + p_{\text{jet}} <$ 0.5 GeV/c then add object to jet.
  - ⇒ Otherwise object starts a new jet
  - ⇒ Repeat until all objects assigned.

- Close Jets are merged
  - Distance between jets $Y = M^2/E_{\text{vis}}^2$
    - M is the invariant mass of pair of jets, assumed to be massless,
    - E_{vis} is the visible energy.
  - Pair with smallest Y is merged provided
    $Y < 0.1$ and they are within 90°

- Objects with larger p_t with respect to their jet than to another jet.
  - ⇒ reassign object to the other jet.
    - A maximum of five reassignments per merger.

The last two steps are repeated until no pair of jets has $Y < 0.1$.

Iterative Discriminant Analysis (Detailed)

- For each event fill a vector y containing
  the n variables and
  $(n^2 - n)/2$ products of those variables.
- Calculate the variance matrix $\mathrm{V} = \mathrm{V_s} + \mathrm{V_b}$,
  where $\mathrm{V_s}$ is the variance matrix of the signal
  and $\mathrm{V_b}$ is the variance matrix of the background
  $\mathrm{V_s}$ and $\mathrm{V_b}$ are weighted so that they have equal importance.
- Calculate $\Delta\mu$,
  the difference in the means of the signal and background,
  for each element of y.
- Invert the variance matrix V and multiply by $\Delta\mu$,
  to obtain the vector of coefficients $\mathrm{a} = \mathrm{V}^{-1}\Delta\mu$.
- For each event calculate $D = \mathrm{y}^{\mathrm{T}}\mathrm{ay}$.

If necessary apply a selection to the events at some value of D and repeat the procedure as required. The IDA process does not prescribe how such a cut should be chosen, or how many iterations should be performed.

Summary of the analysis in numbers

Sample	Cross section (pb)	Analysis stage					
		Presel	Selection	IDA 1	IDA 2	IDA 3	
$\gamma\gamma \to \mathrm{uds}$	16000	89	73	12	9	0	per-
$\gamma\gamma \to \mathrm{c\bar{c}}\,X$	930	10	25	40	35	23	cent
$\gamma^*\gamma \to X$	84	0	1	4	5	5	of
$\mathrm{e^+e^-} \to \mathrm{q\bar{q}}$	83	0	0	2	2	2	total
$\gamma\gamma \to \mathrm{b\bar{b}}\,X$	4	0	1	41	50	70	
data	-	2696021	16810	244	197	93	events