Jet and hadron inclusive production in two photon collisions with the L3 experiment

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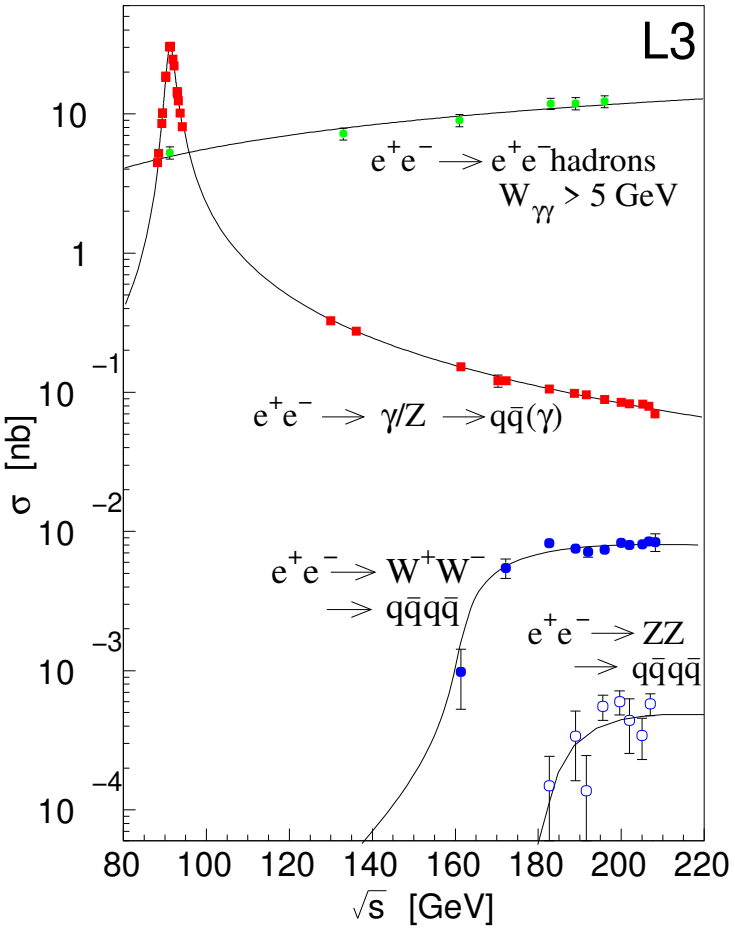
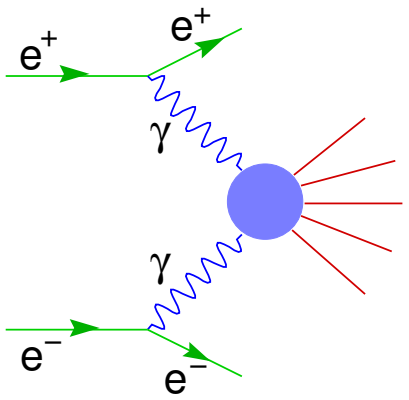
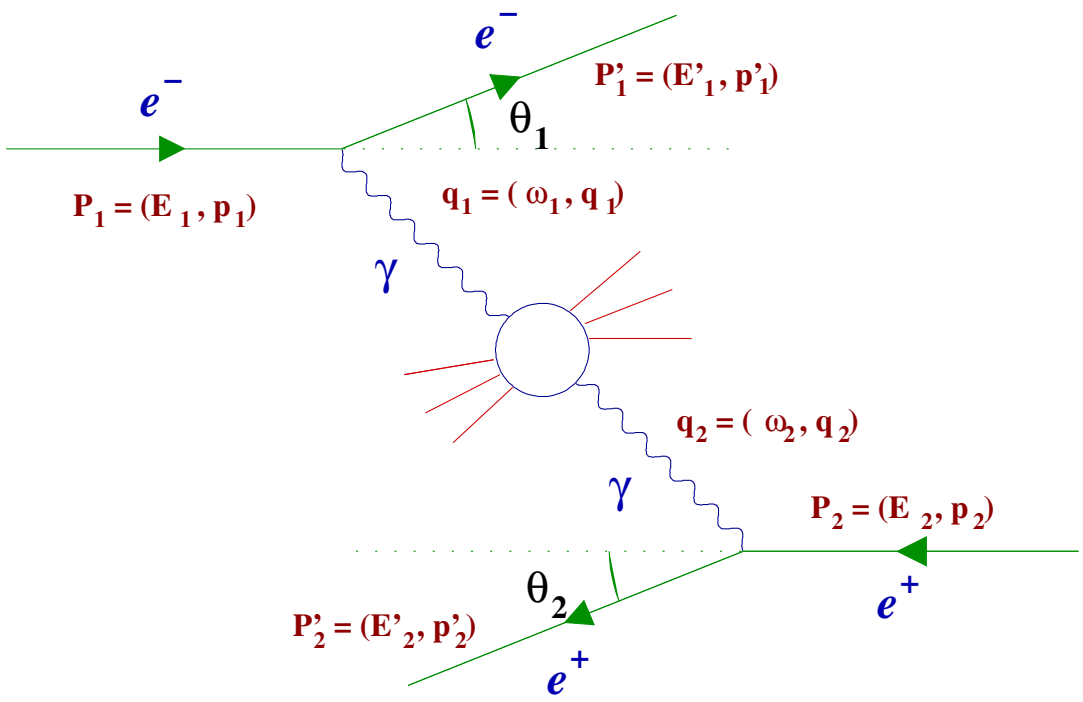
Hadron production at LEP





Two photon collisions are the main hadron source at LEP2.

Kinematic



Anti-tag ensures

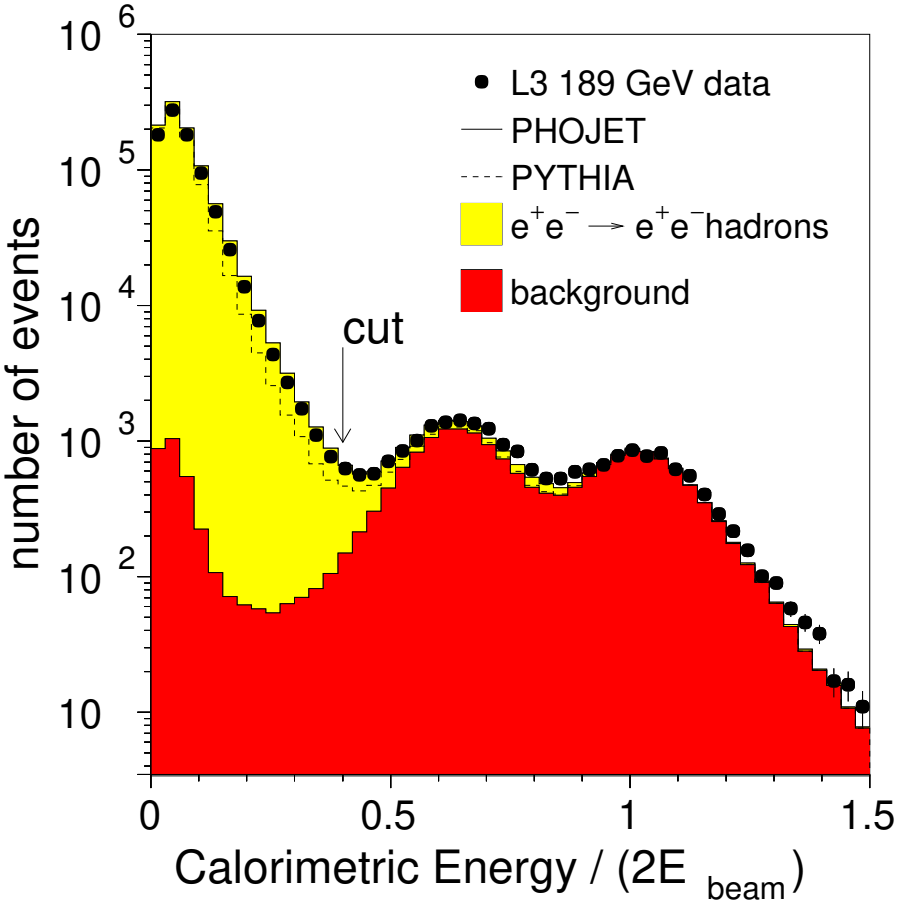
low photon virtuality

$$q_i^2 \simeq -2E_iE_i'(1-\cos\theta_i)$$

$$\mathrm{W}^2_{\gamma\gamma} = (q_1+q_2)^2$$

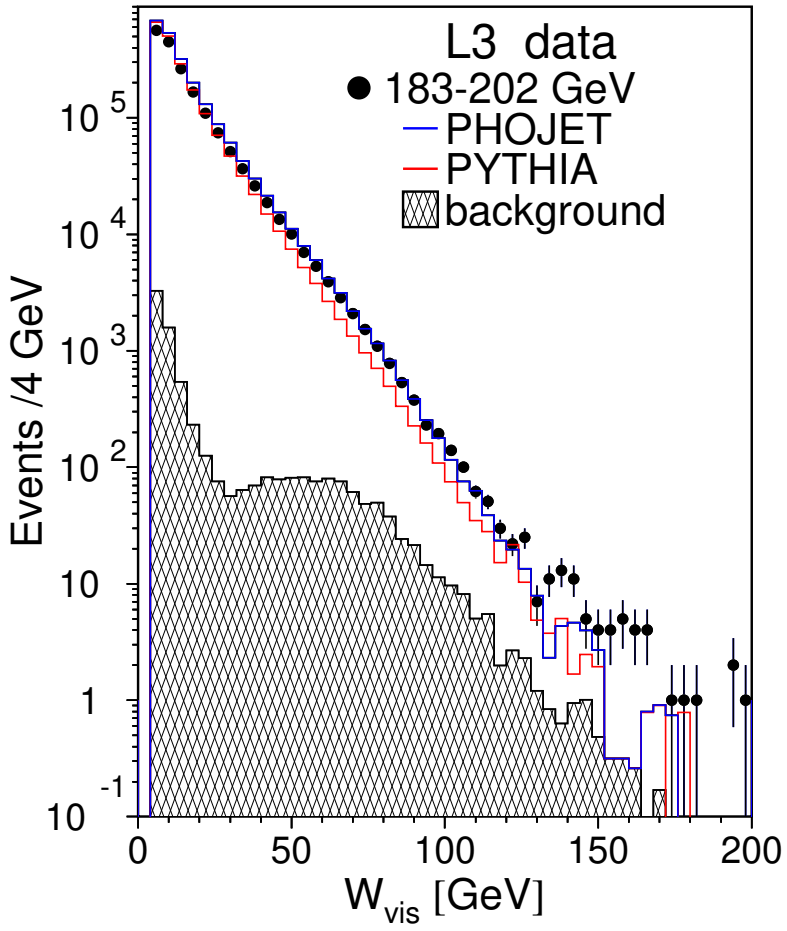
$$\mathrm{W}^2_{\mathrm{vis}} = (\textstyle\sum_i E_i)^2 - (\sum_i \vec{p}_i)^2$$

Event selection $e^+e^- \rightarrow e^+e^-$ *hadrons*



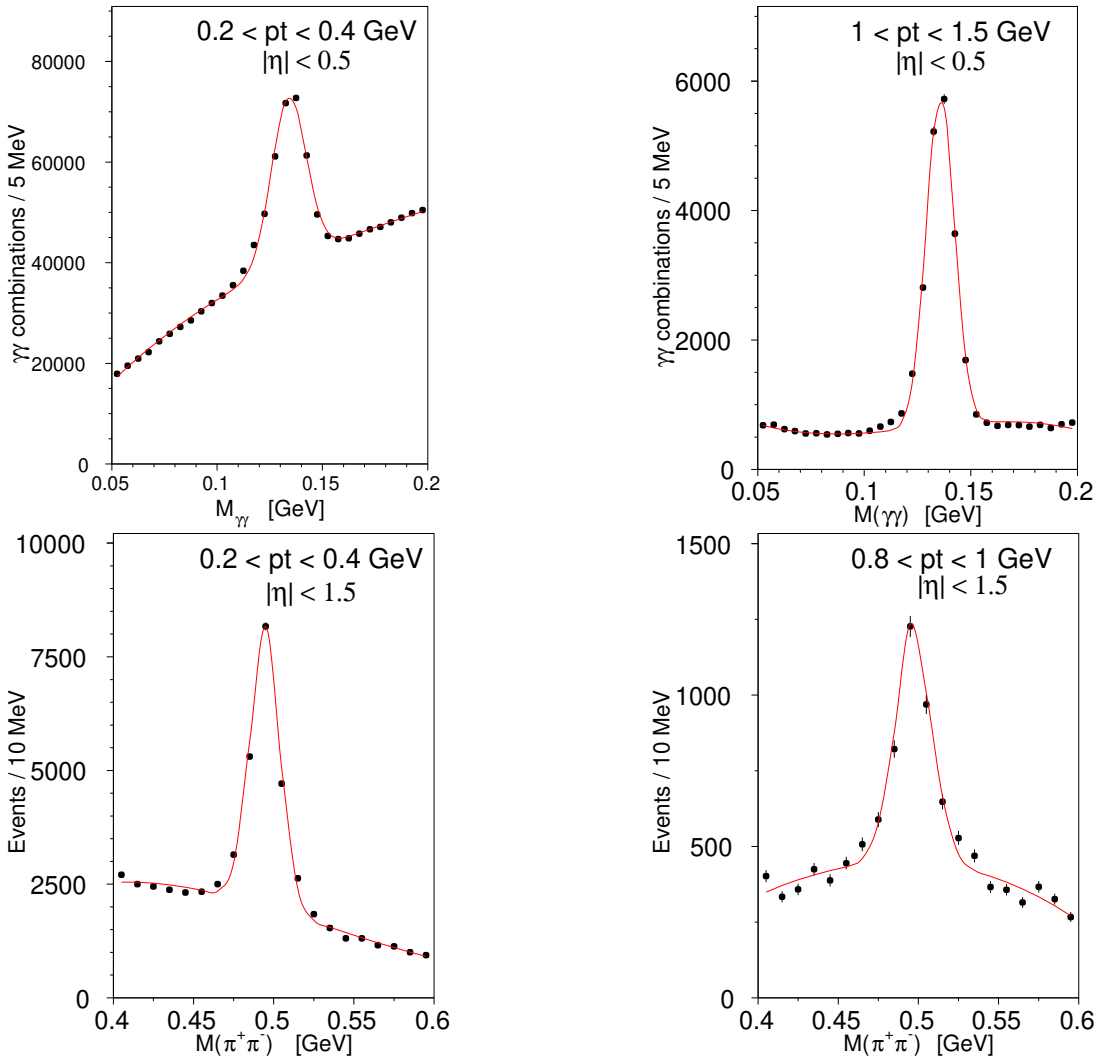
- $E_{tot} \leq 40\% \sqrt{s}$
- # particles ≥ 6
- Anti-tag : reject if $E_{lumi} > 30$ GeV
- $W_{vis} > 5$ GeV

$e^+e^- \to e^+e^-$ *hadrons*



- data 98 + 99 (+ 2000)
  $\langle \sqrt{s} \rangle = 194\,(198)$ GeV
  $\mathcal{L} = 350\,(560)$ pb^{-1}
  2 (3) million selected events
- main bkg (1-15 %):
  $e^+e^- \to e^+e^-\tau^+\tau^-$
  $e^+e^- \to$ hadrons
- MC: PYTHIA 5.7, PHOJET 1.05c
- phase space defined by MC:
  $W_{\gamma\gamma} > 5$ GeV, $Q^2 < 8$ GeV^2

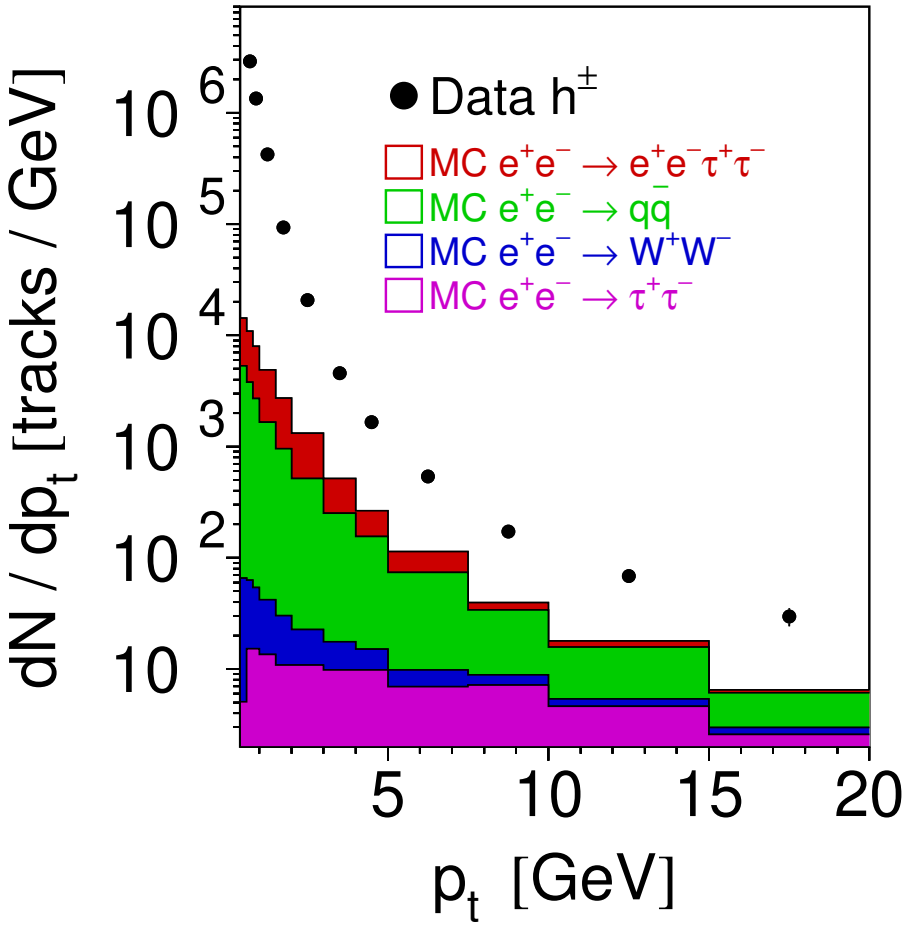
Inclusive neutral hadron production



π^0 and K^0_S published in PLB524 (2001)44.

⇨ Clear signal over background

Inclusive charged hadron production



$p_t > 400$ MeV,
DCA < 4 mm,
$> 80\%$ expected hits

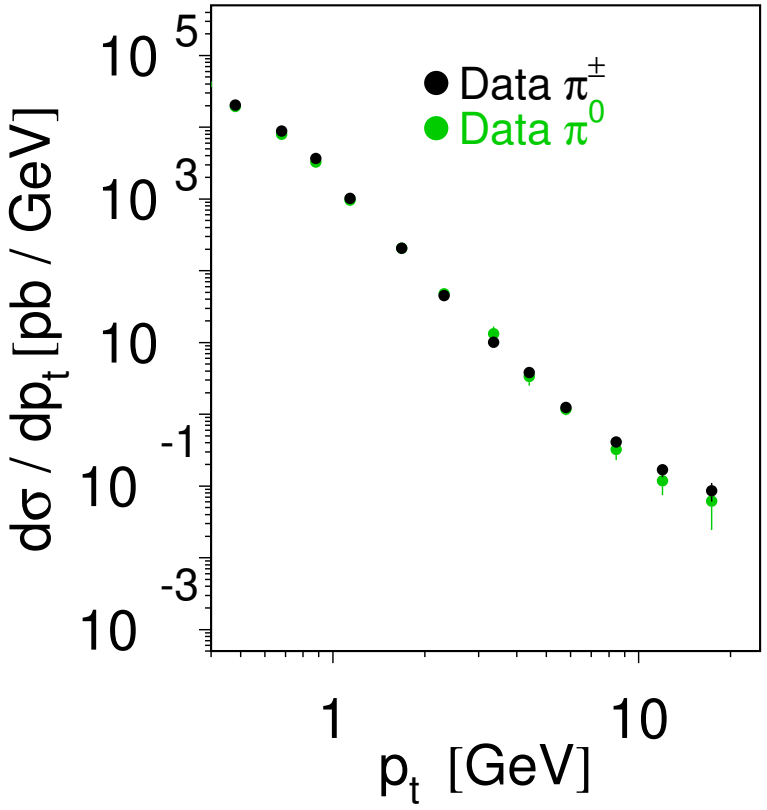
$$|\eta| < 1$$

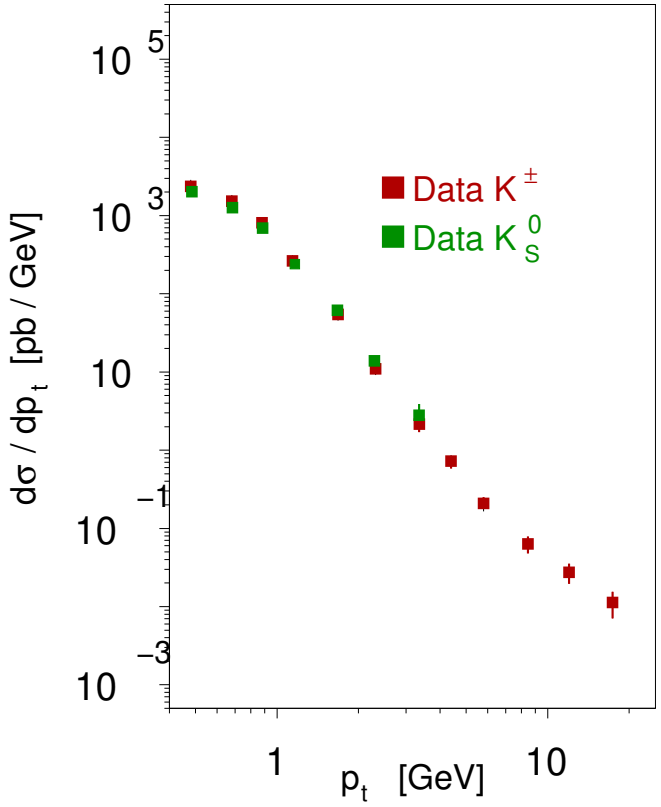
$$\sigma_{p_t}/p_t \simeq (0.015 \text{ GeV}^{-1})\ p_t$$

published in PLB554 (2003)105

Neutral vs. charged hadrons

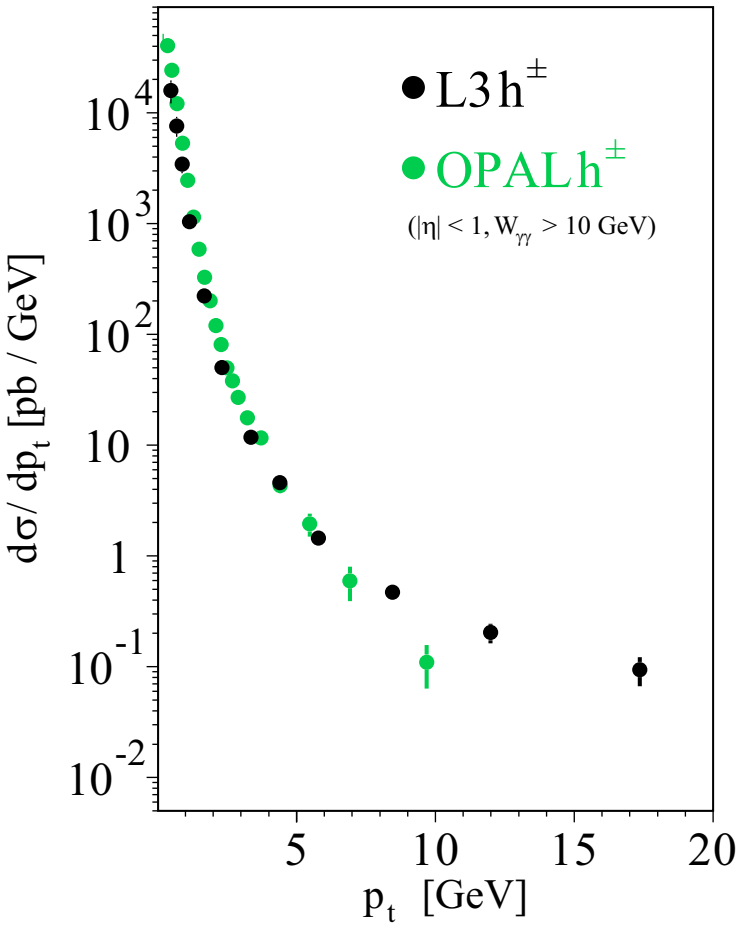
$\pi^{\pm}$ and $K^{\pm}$ separation by Monte Carlo ratios (JETSET 7.409).
Correction factor for isospin symmetries and $|\eta|$ range.

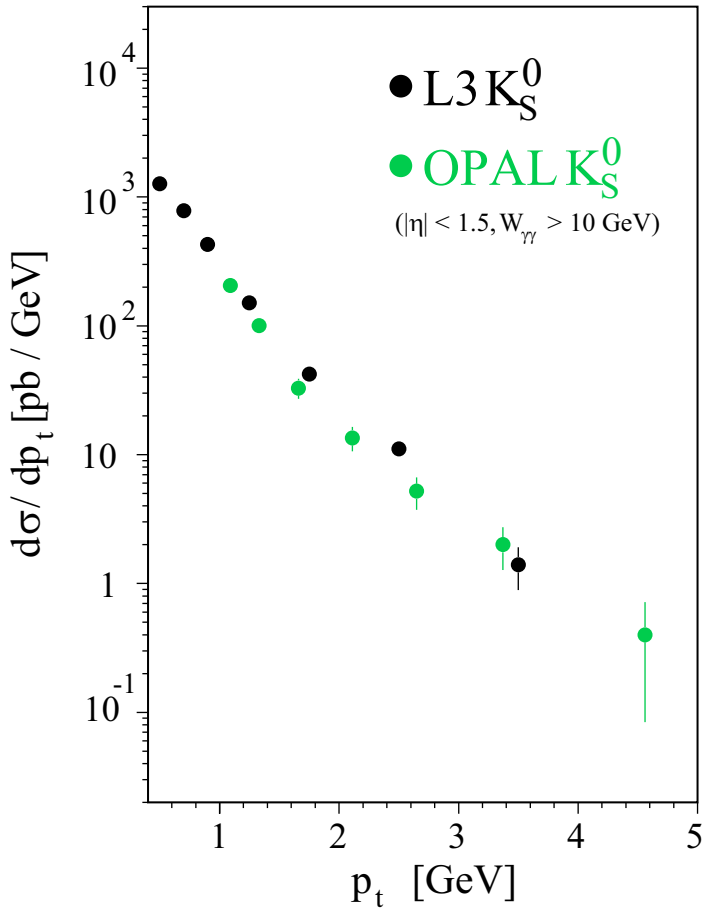




Very good agreement between independent channels

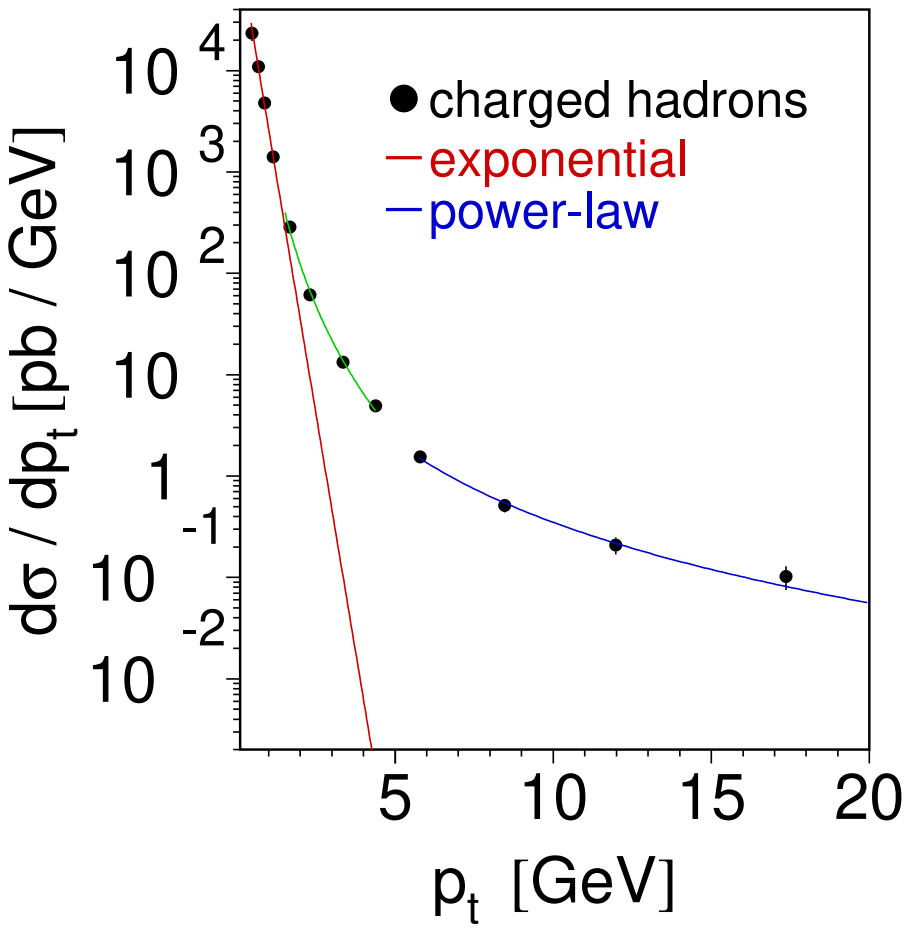
L3 vs. OPAL





$< \sqrt{s} > \simeq 165$ GeV , $|\eta| < 1.5$ (Eur. Phys. J. C6(1999)253)

Fits to the data



- For $p_t < 1.5$ GeV
  Exponential $Ae^{-p_t/\langle p_t \rangle}$

  $\langle p_t \rangle \simeq 230$ MeV for $\pi^{\pm}, \pi^0$
  $\simeq 300$ MeV for $K^{\pm}, K^0_S$

  $\Rightarrow$ Soft interactions

- For $p_t > 1.5$ GeV
  Power law Ap_t^{-B}

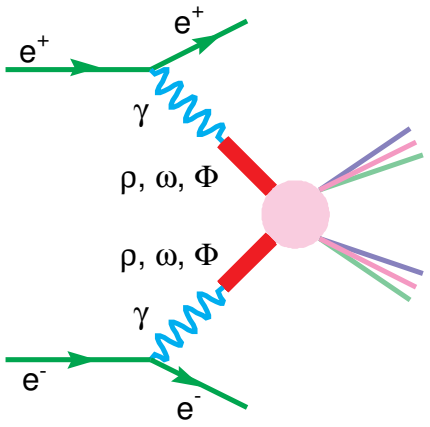
  $1.5 \leq p_t < 5.$ GeV
  B $= 4.2 \pm 0.2$ $\chi^2/d.o.f. = 4.7/2$

  $5.0 \leq p_t < 20.$ GeV
  B $= 2.6 \pm 0.3$ $\chi^2/d.o.f. = 0.7/2$

  $\Rightarrow$ Direct and resolved (QCD)

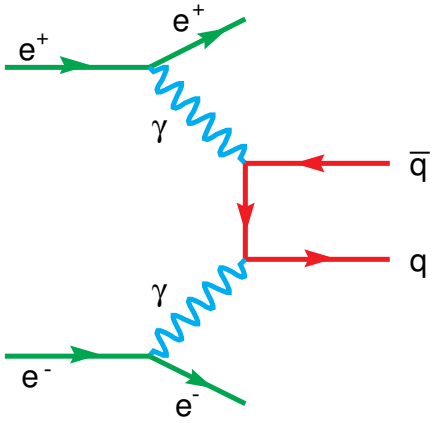
Diagrams contributing to $\gamma\gamma \rightarrow hadrons$ interactions

SOFT:

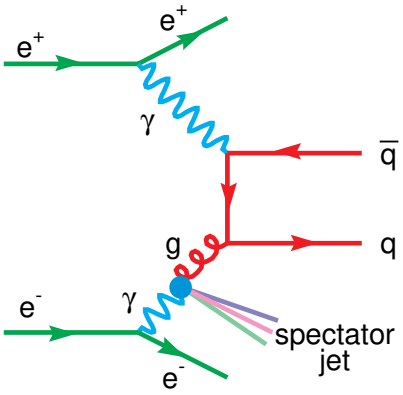


VDM

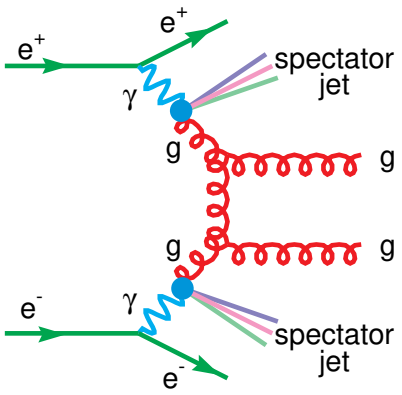
HARD:



Direct

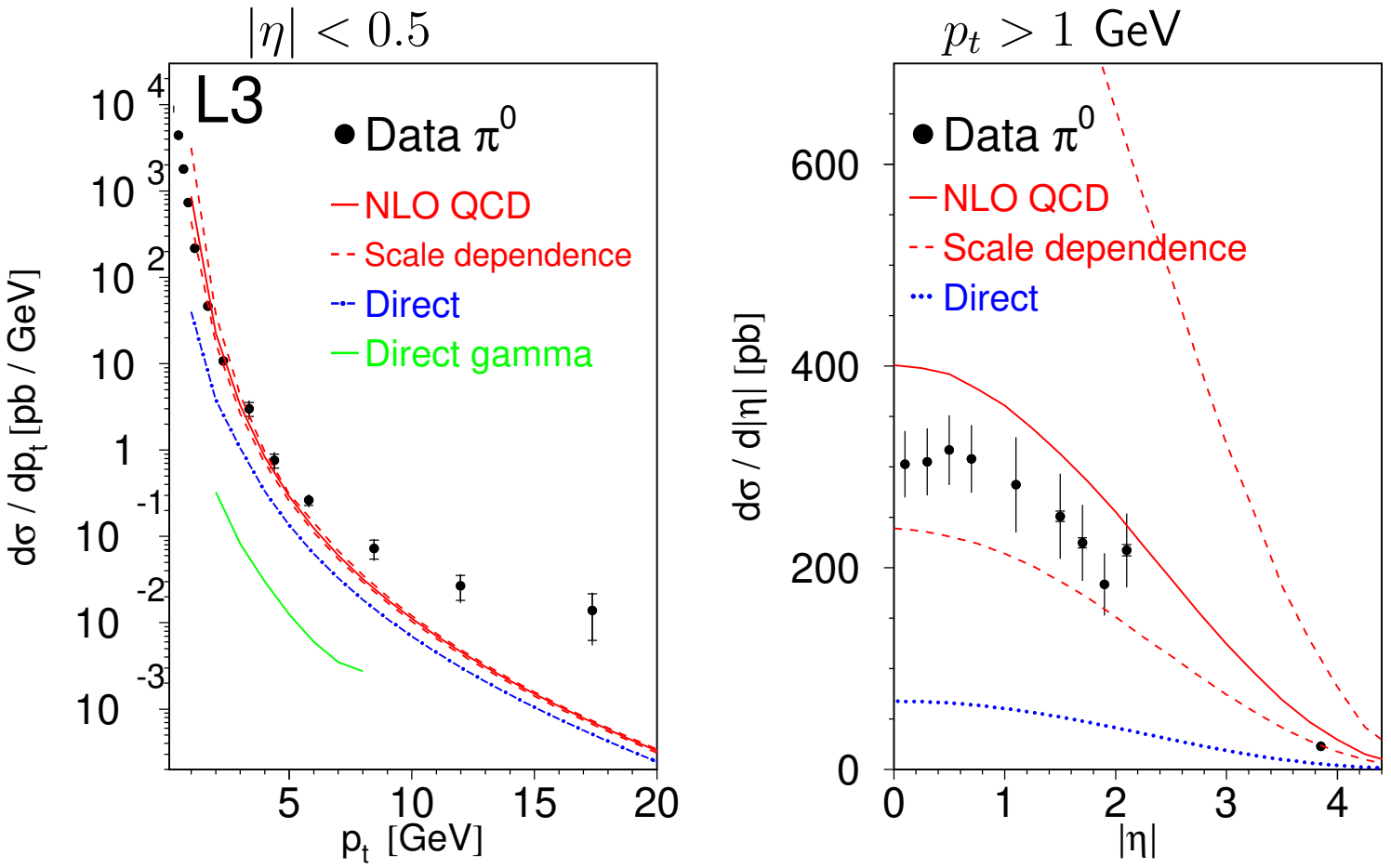


Single Resolved



Double Resolved

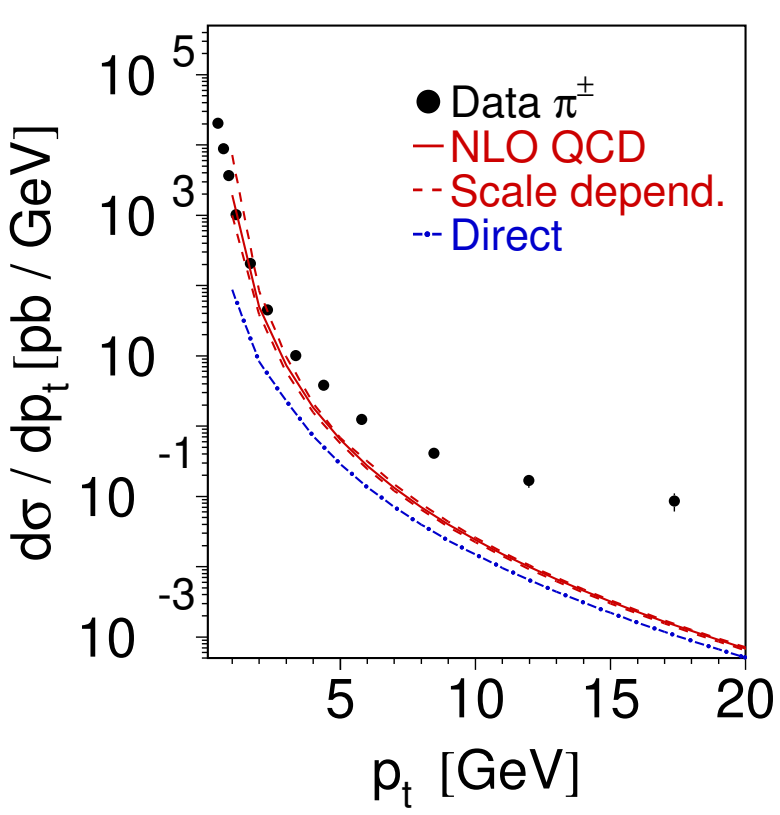
Comparison with NLO QCD (π^0)

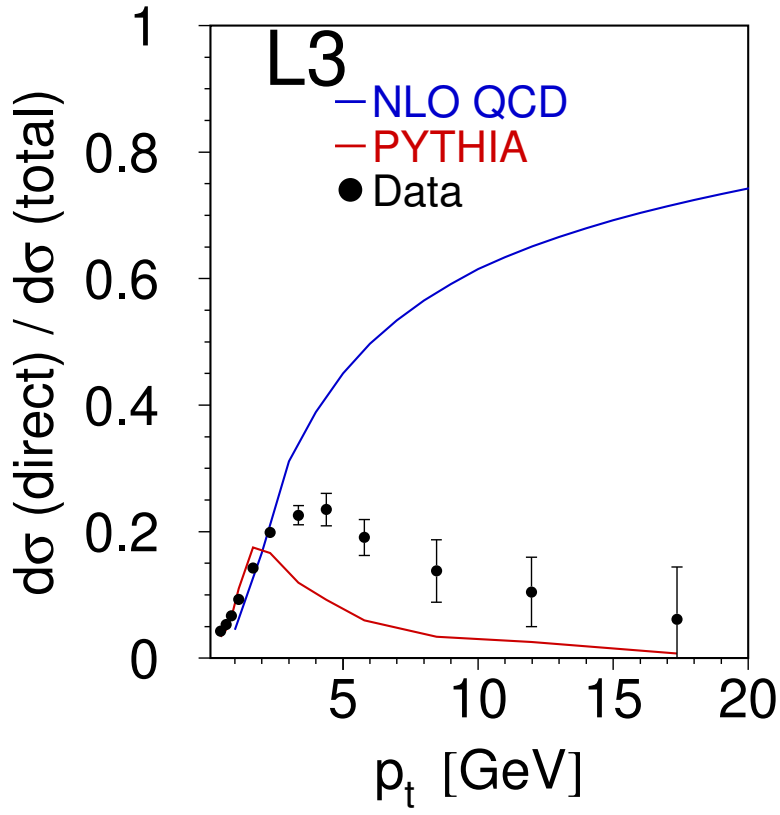


Measurements exceed QCD predictions (B.A.Kniehl) at high p_t

No anomaly in η distribution

Comparison with NLO QCD ($\pi^{\pm}$)

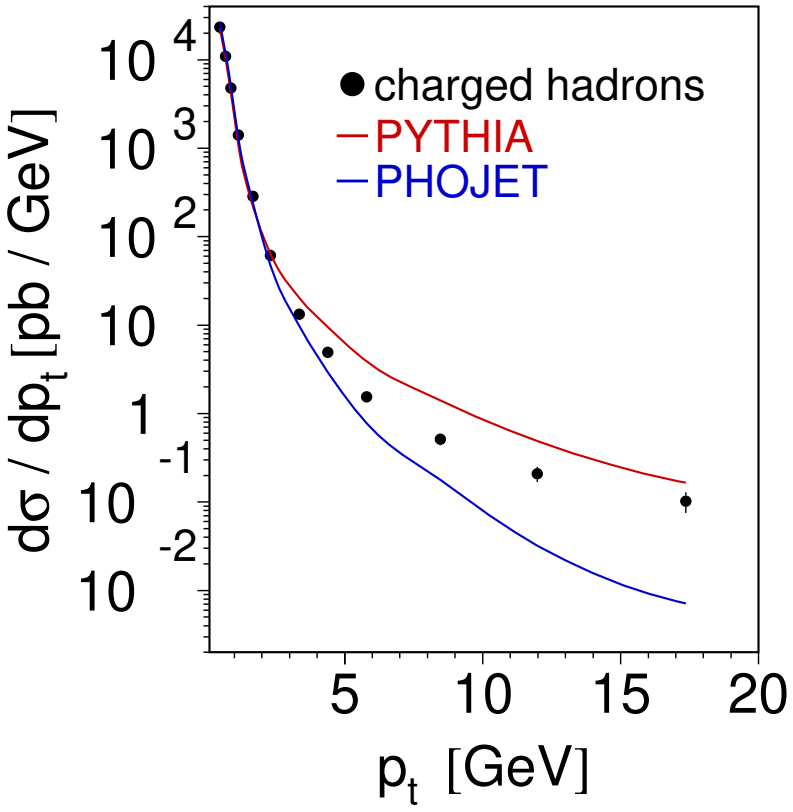


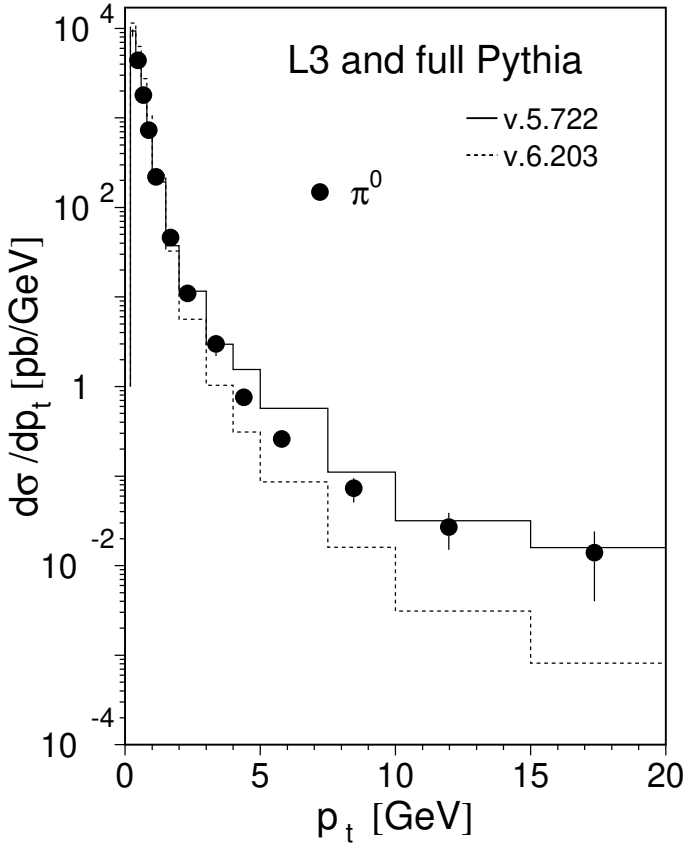


Same excess at high p_t

The data are largely beyond the direct contribution

Comparison with Monte Carlo

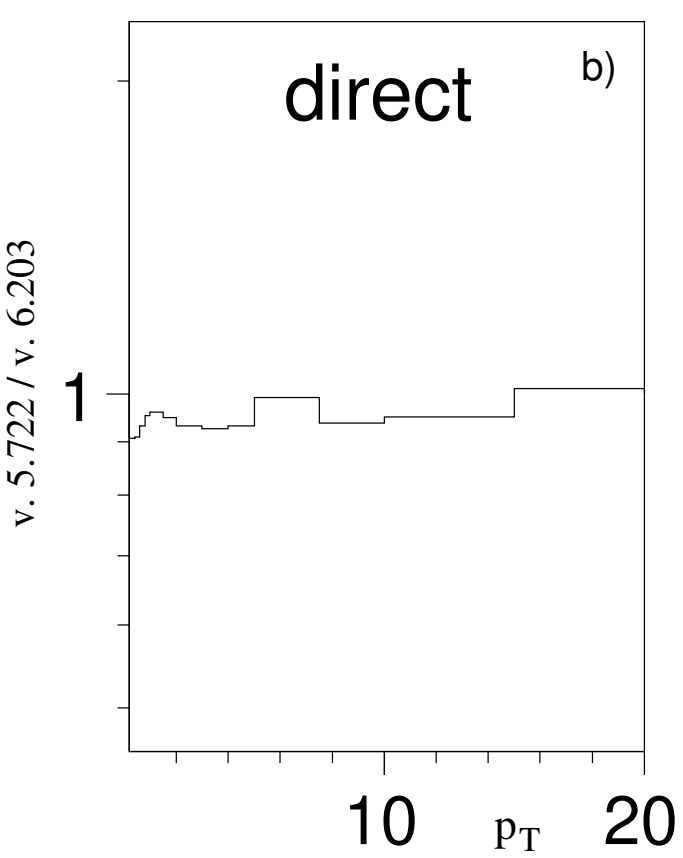


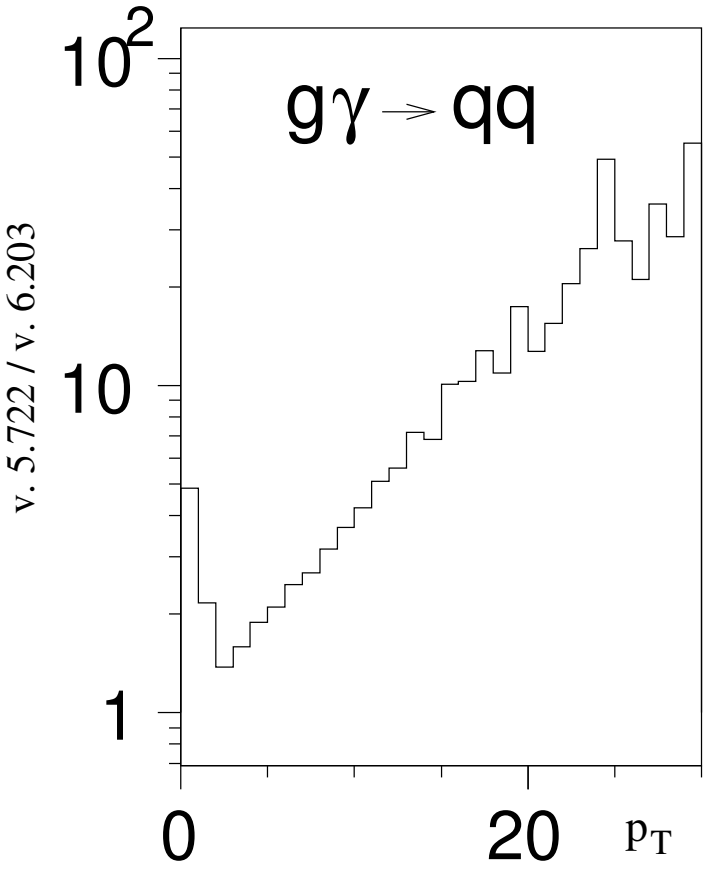


PHOJET is too low (similar to NLO calculations)

PYTHIA has changed ! Becomes consistent with PHOJET

Comparison of PYTHIA versions





Striking difference, pointing to QCD diagrams !

Jet analysis

- Reconstructed jets : tracks $p_t > 0.4$GeV
  e.m. clusters $E > 0.1$ GeV
- Generated jets : γ, $\pi^{\pm}$, p, n, $\mathrm{k}^{\pm}$
- Kinematical range: $p_t > 3$GeV $\quad |\eta| < 1$
- Algorithms

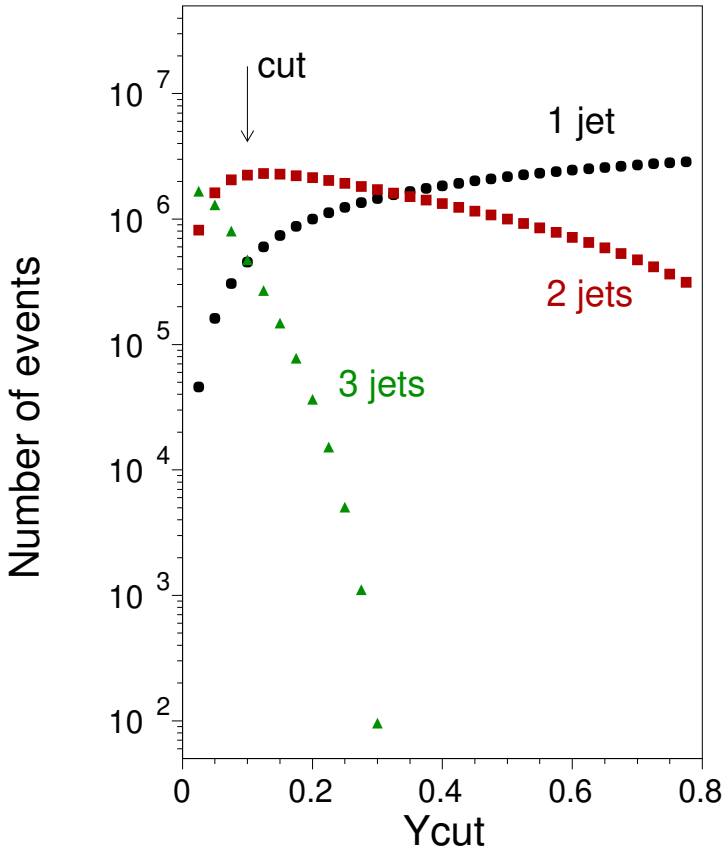
  DURHAM : $y_{ij} = 2min(E_i^2, E_j^2)(1 - \cos\theta_{ij})/E_{vis}^2$

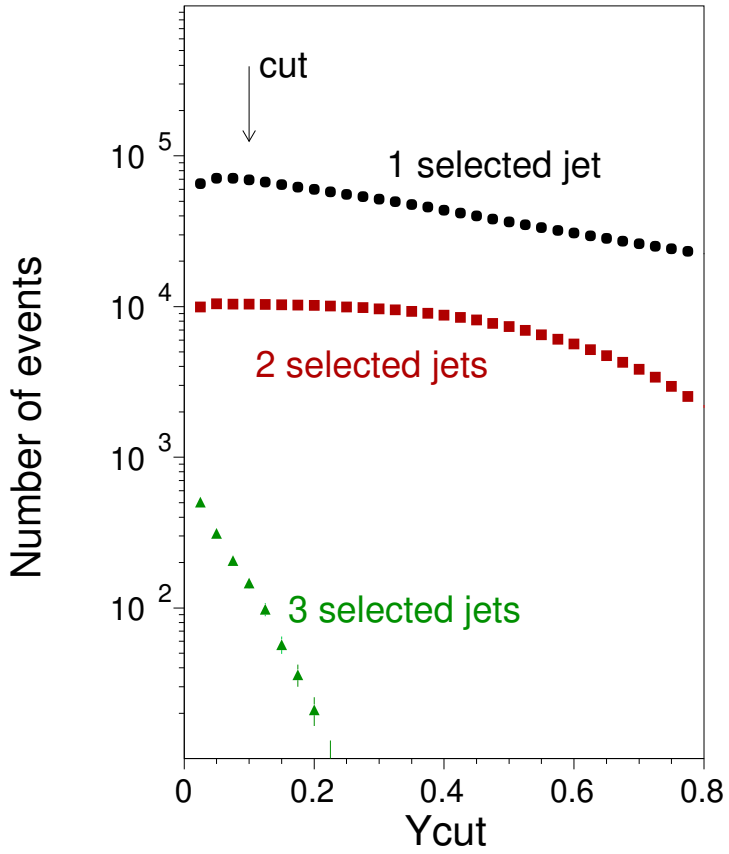
  $y_{cut} = 0.1$

  KTCLUS : $d_{ij} = min(p_{ti}^2, p_{tj}^2)((\eta_i - \eta_j)^2 + (\Phi_i - \Phi_j)^2)/D^2$

  $D = 1$
- Results are preliminary

Durham sensitivity to y_{cut}

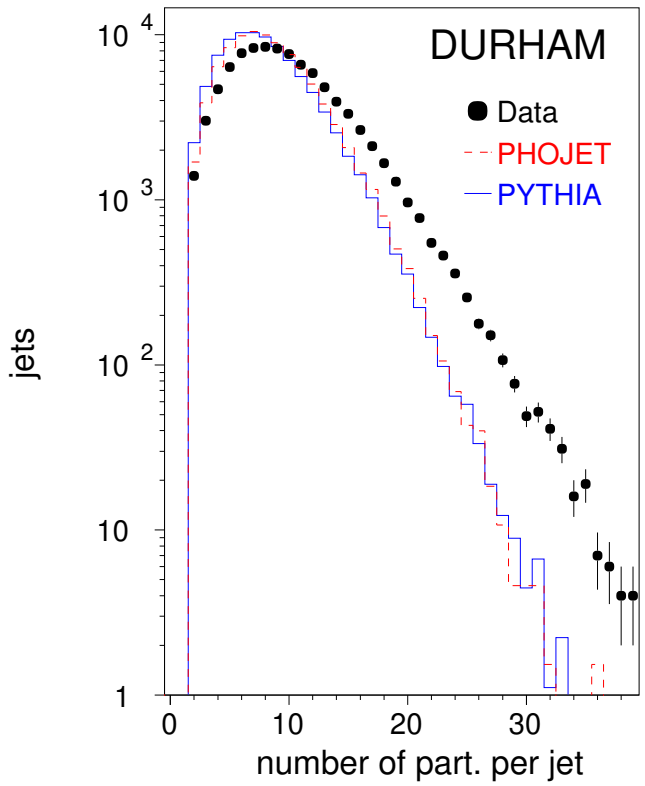


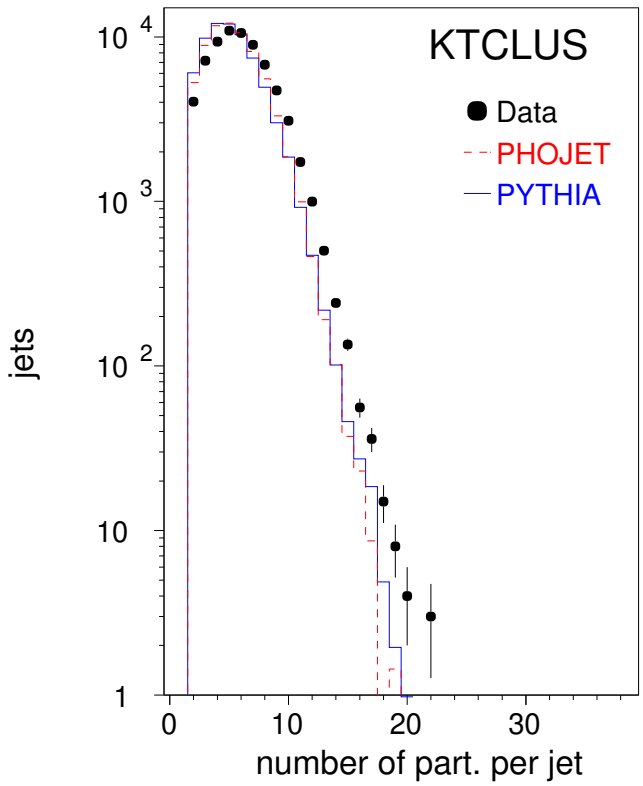


$y_{cut} = 0.1$ maximise 2-jet events

Number of jets with $p_t > 3$ GeV and $|\eta| < 1 \sim$ independent of y_{cut}

Durham vs. KTCLUS



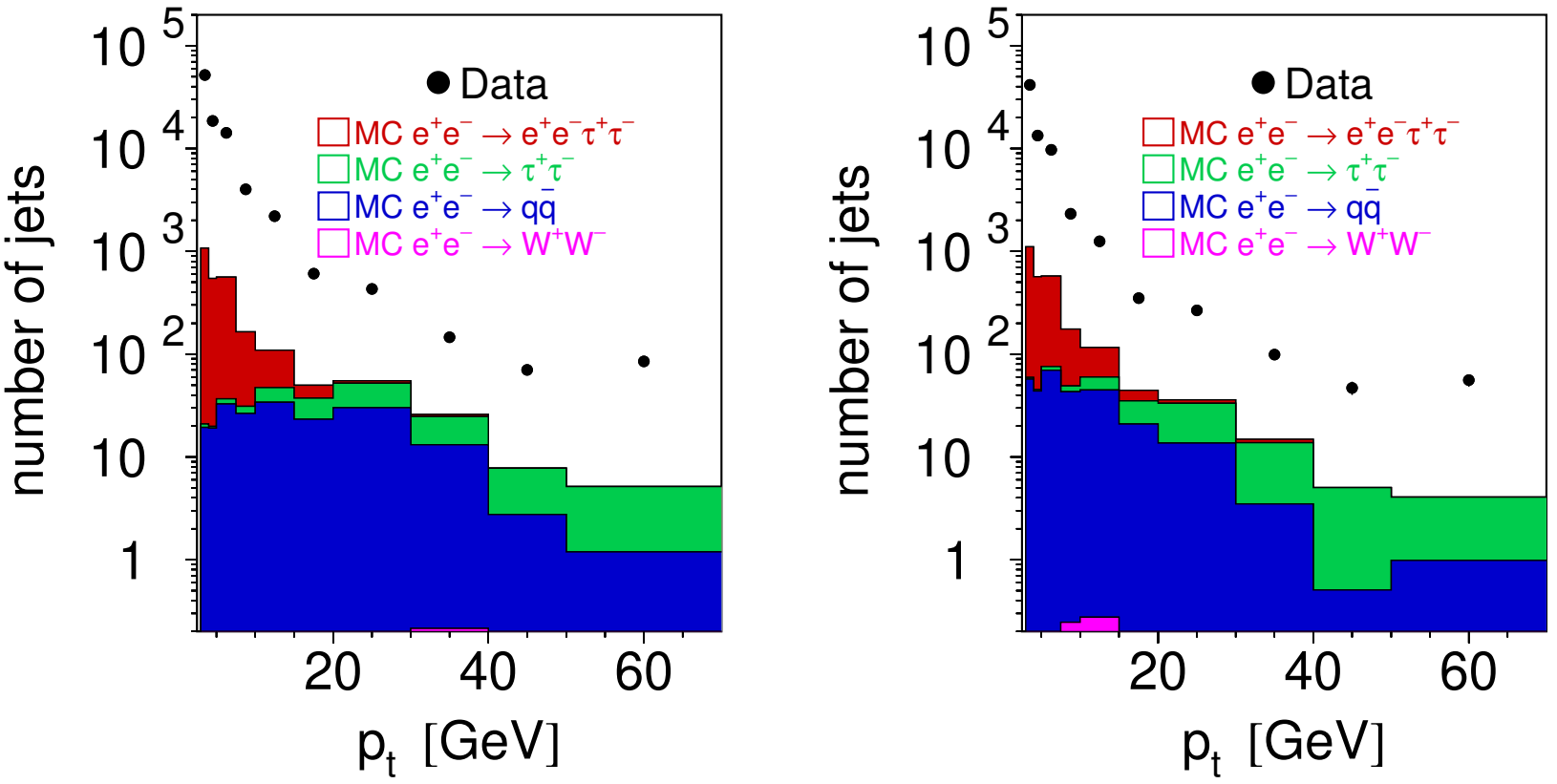


Less particles in KTCLUS jets

Durham is used at LEP for e^+e^-, spherical configurations

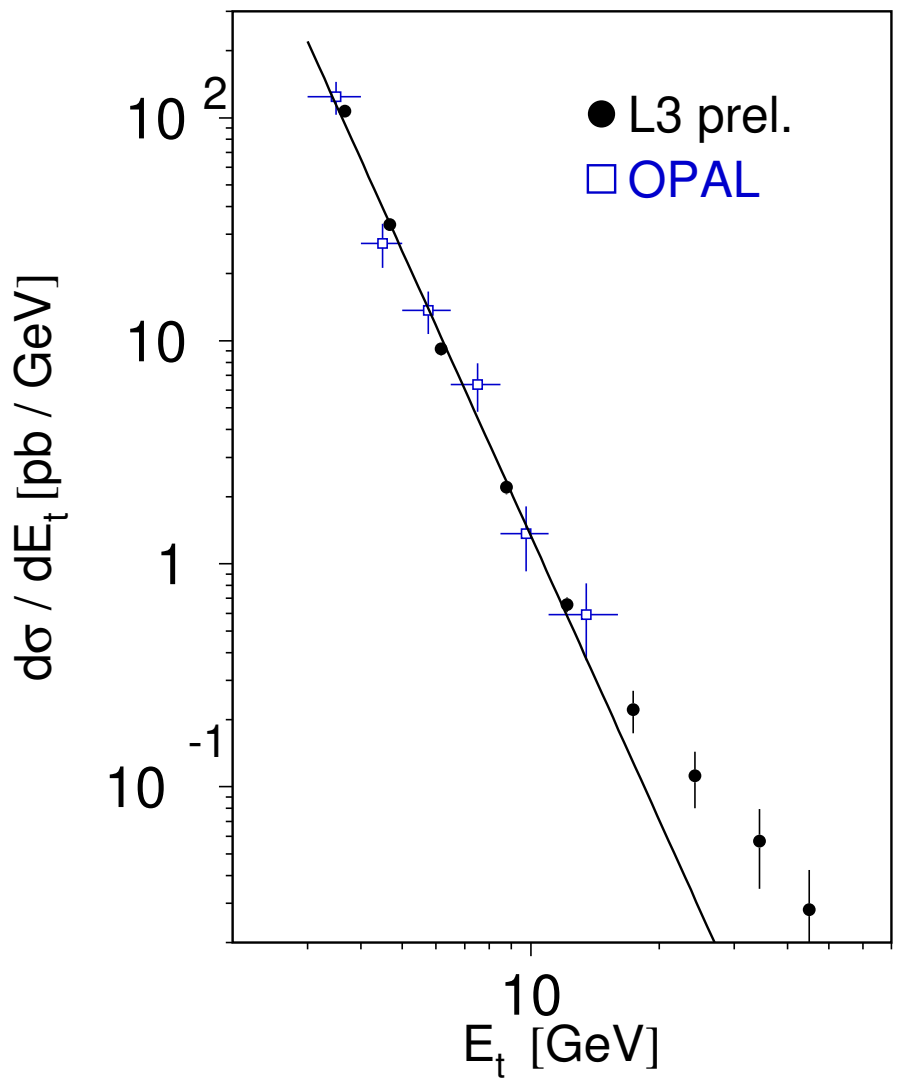
KTCLUS is used in cylindrical configurations and NLO theory

Data and background



Main systematic due to MC modeling: 5-60 %

Comparison with OPAL



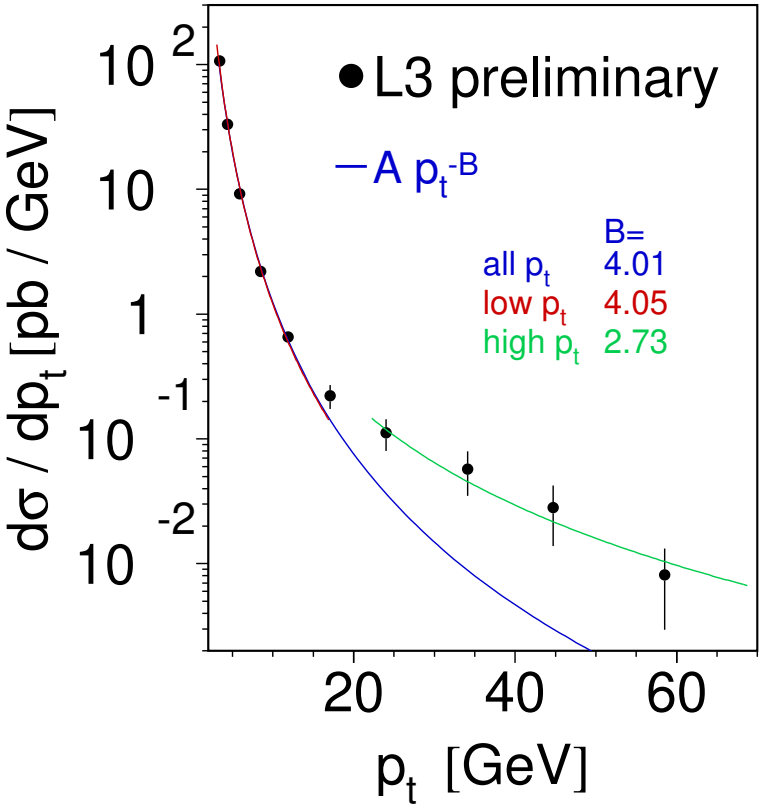
KTCLUS algorithm is used

K. Ackerstaff et al.,
Z. Phys. C73 (1997) 433.
$\langle\sqrt{s}\rangle \simeq 133$ GeV

Very good agreement in the range of measurement

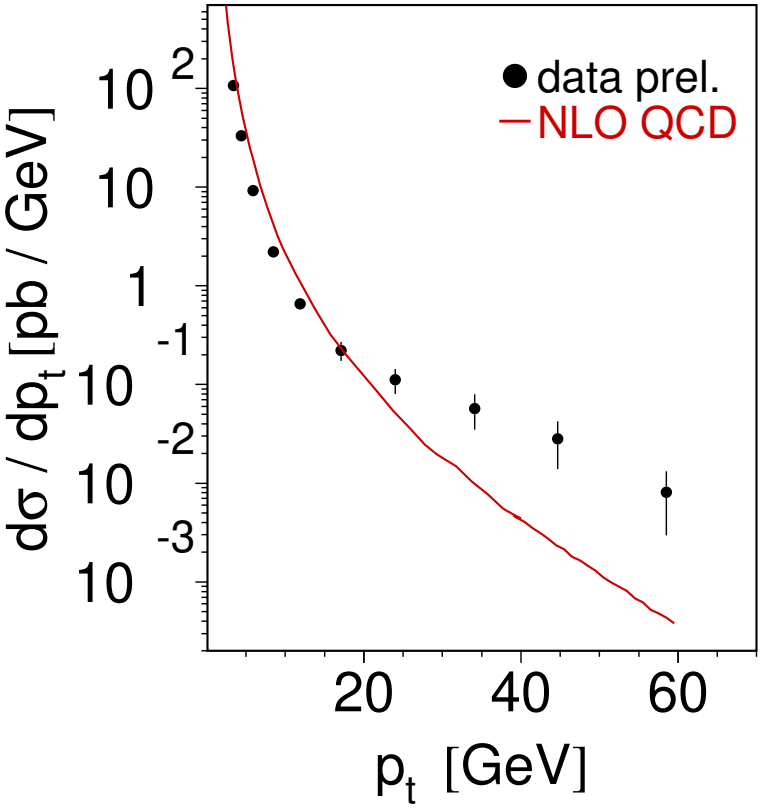
Fits and NLO calculations

using KTCLUS



For $2 \to 2$ process B=3

NLO QCD: S. Frixione and L. Bertora



Again an excess at high pt !

Conclusions

- Unexpected deviations from theoretical predictions are observed:
  - ⇨ $\sigma(\gamma\gamma \to hadrons)$
  - ⇨ $\mathrm{d}\sigma/\mathrm{d}p_t$ of π^0 and $\pi^{\pm}$ production for $p_t > 5$ GeV
  - ⇨ $\mathrm{d}\sigma/\mathrm{d}p_t$ of inclusive jet production for $p_t > 20$ GeV
  - ⇨ $\sigma(\gamma\gamma \to \mathrm{b\bar{b}})$

- Two questions arise
  - ⇨ Are these phenomena correlated ?
  - ⇨ Which is their origin ?