QCD results from LEP

…new studies & puzzling results

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Moriond QCD 2004
La Thuile, Italy

- ⇨ Unbiased gluon jets using the boost algorithm (OPAL)
- ⇨ Coherence in soft particle production in 3-jets events (DELPHI)
- ⇨ Pentaquark search (DELPHI)

- ⇨ inclusive (Di-)jet & hadron production in $\gamma\gamma$ interactions (L3/OPAL)
- ⇨ b cross-sections in $\gamma\gamma$ interactions (DELPHI/L3/OPAL)

Disclaimer

(examples of) results that I will not be able to cover:

New LEP combination of $\alpha_s(M_Z)$ from event shapes

$$\alpha_s(M_Z) = 0.1202 \pm 0.0003(\text{stat.}) \pm 0.0009(\text{exp.}) \pm 0.0013(\text{hadr.}) \pm 0.0047(\text{theo.})$$

Quark and gluon jet fragmentation functions OPAL

Inclusive charged particle distributions ALEPH (OPAL)

Exclusive particle production & double tagged events in two-photon collisions (ADLO)

See M. Kienzle @ LaThuile '04 and M. Ford @ Moriond QCD '04 for more LEP QCD results

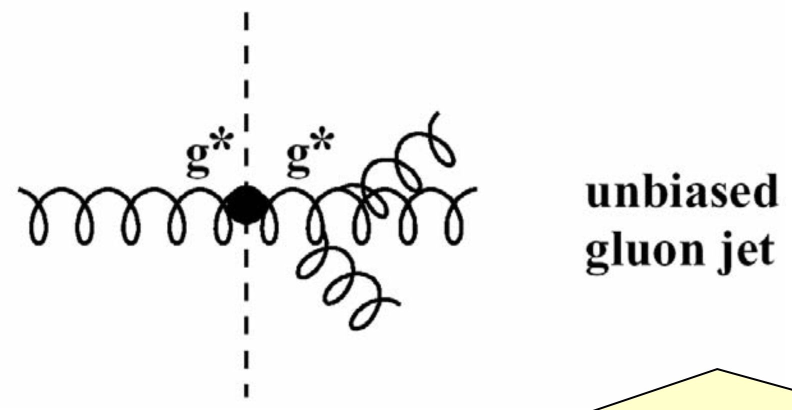
New studies

… using hadronic Z decays at $\sqrt{s}$ = 91 GeV

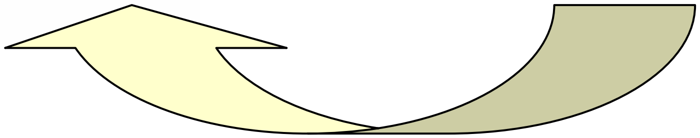
- ⇨ Unbiased gluon jets using the boost algorithm (OPAL)
- ⇨ Coherence in soft particle production in 3-jets events (DELPHI)
- ⇨ Pentaquark search (DELPHI)

Unbiased gluon jets using the "boost" algorithm

How to study the property of gluon jets?



In theoretical calculations gluon jets can be defined as one hemisphere in gg events from a point source



no jet definition needed

Unbiased gluon jets using the "boost" algorithm

Experimentally:

⇨ Gluon jet often defined using jet finder in (e.g. for e^+e^-) qqg events

⇨ Gluon jet properties (e.g. multiplicity) depend strongly on jet finding algorithm

⇩

Biased gluon jets
➔ ambiguous comparisons to theory

Possible ways out:

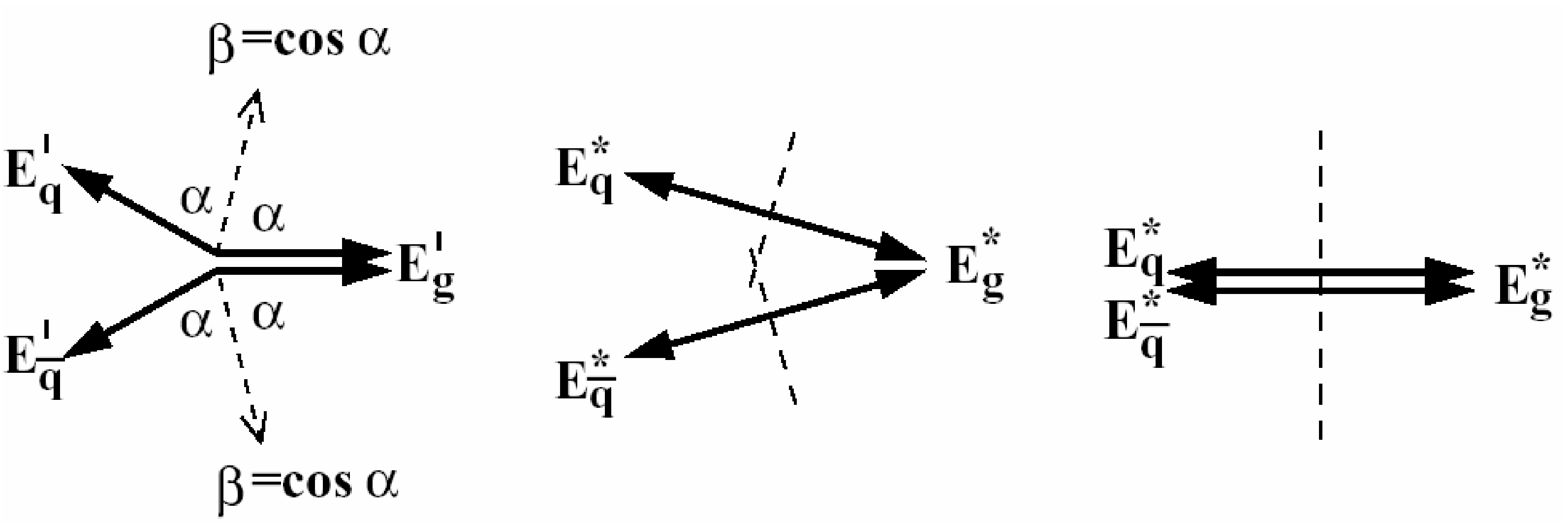
⇨ Υ ➔ γgg ➔ γ + hadrons (CLEO)
⇨ Rare Z ➔qqg events, with qq collinear (OPAL)
⇨ Indirectly by comparing 2-jet & 3-jet events (O)

OR ➔

Unbiased gluon jets using the "boost" algorithm

<u>The BOOST algorithm:</u>
(P. Eden, G. Gustafson)

Consider a frame in which the $e^+e^- \rightarrow q\bar{q}g$ event is symmetric



a) decompose into 2 color dipoles

b) boost each dipole to be back-to-back

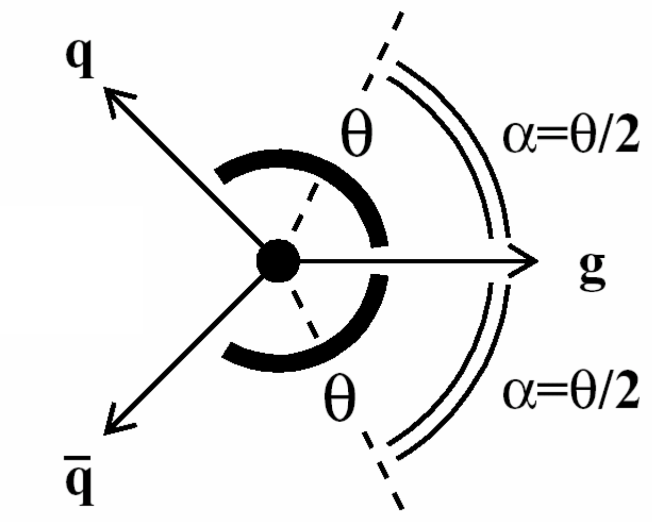
c) recombine to yield event with gg color structure

Unbiased gluon jets using the "boost" algorithm

Experimentally:

- Select 3-jet events, order in decreasing E
- jet-1 ≡ quark jet, require b-tag for jet-2 or 3
- remaining jet is gluon jet

Boost event into symmetric frame

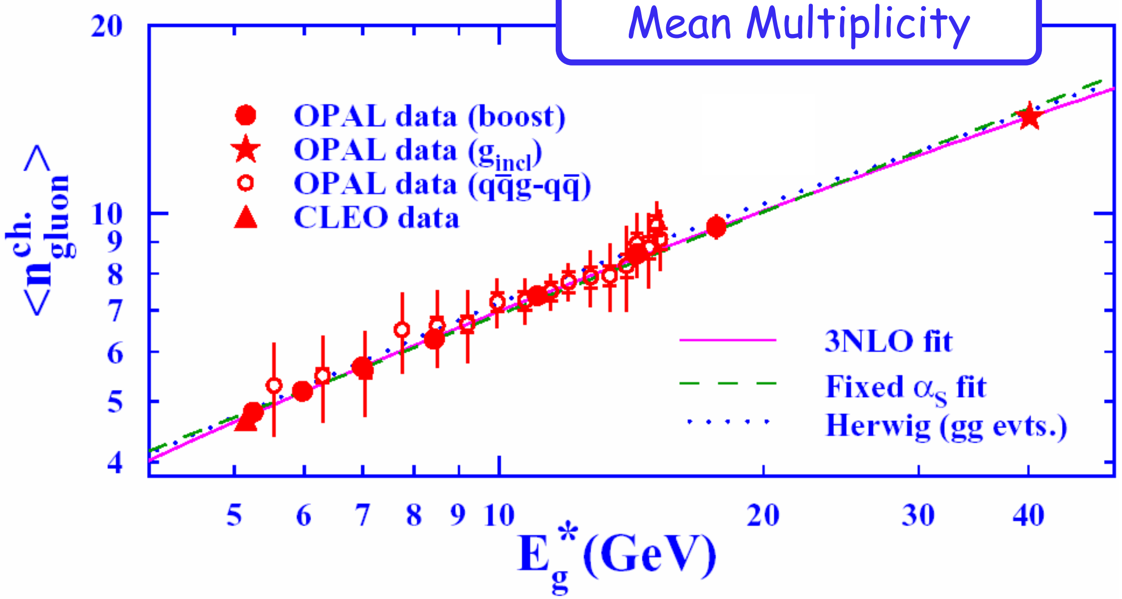


all particles inside the cone α = θ/2 define the gluon jet

HERWIG: Compare boost algorithm to gg events ➔ good agreement

Unbiased gluon jets using the "boost" algorithm

OPAL @ LEP1



(+ results on
factorial moments,
q/g multiplicity ratios,
frag. functions, α_s)

- ⇨ Results are consistent with previous measurements
- ⇨ Most precise results for $5.25 < E_g^* < 20$ GeV
- ⇨ Theoretical results fit data successfully

Coherence in soft particle production

Interference effects are fundamental to QM gauge theories like QCD

Evidence for coherence effects exist

- ⇨ fragmentation models
- ⇨ hump backed plateau in hadronic momentum spectrum
- ⇨ ...

... but arguments against conclusiveness have been raised

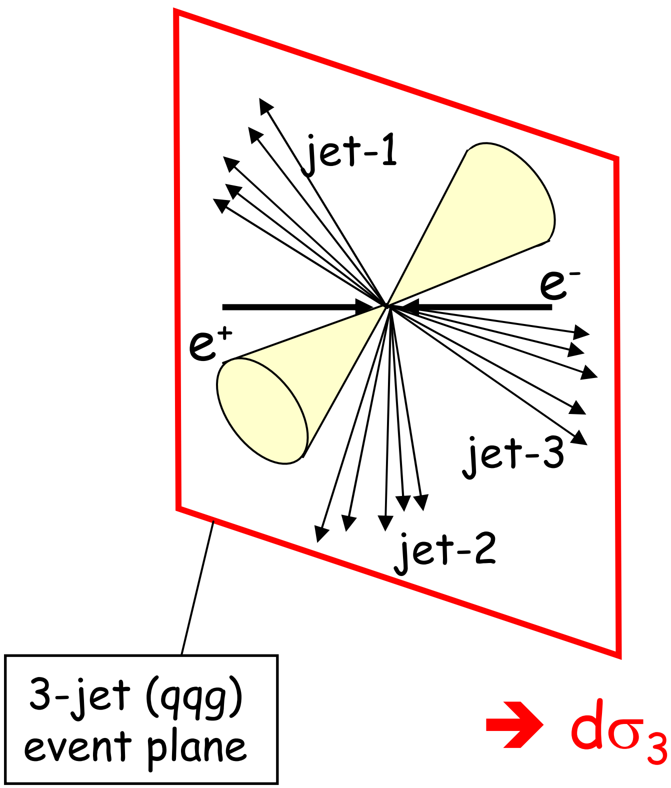
- ⇨ Incoherent frag. w/ many param.
- ⇨ phase space arguments
- ⇨ ...

➔ **Direct test ?**

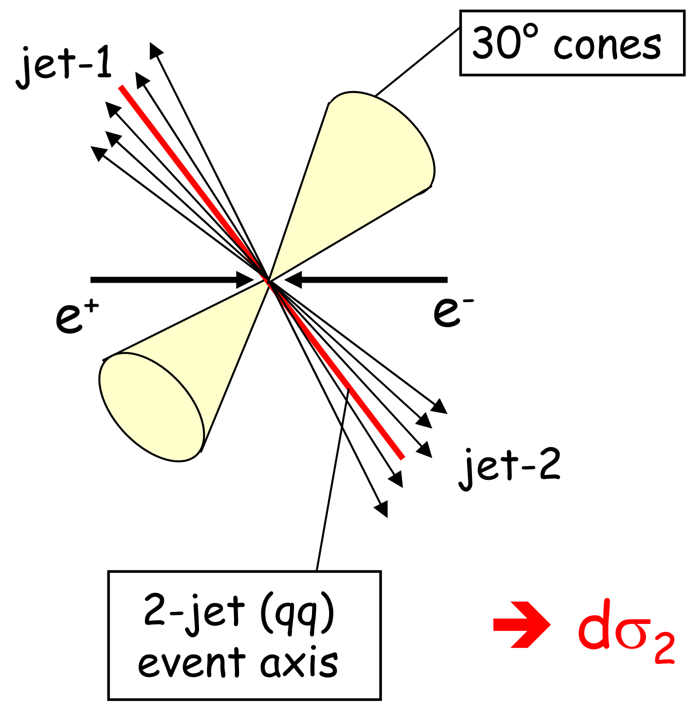
Coherence in soft particle production

Consider low E hadrons @ large angle:
(⊥ to 3-jet plane or 2-jet axis)

- *cannot be assigned to specific jet*
- *must be treated as coherent emission*



➔ $d\sigma_3$



➔ $d\sigma_2$

Coherence in soft particle production

Azimov, Dokshitzer, Khoze, Troyan
Khoze, Lupia, Ochs

r_t: topology dependence

LO QCD:

$$d\sigma_3 = \frac{1}{4}\frac{C_A}{C_F}\left[\widehat{\mathrm{qg}} + \widehat{\bar{\mathrm{q}}\mathrm{g}} - \frac{1}{N_c^2}\widehat{\mathrm{q}\bar{\mathrm{q}}}\right] d\sigma_2$$

I: Interference term

$$\widehat{ij} = 2\sin^2(\theta_{ij}/2)$$

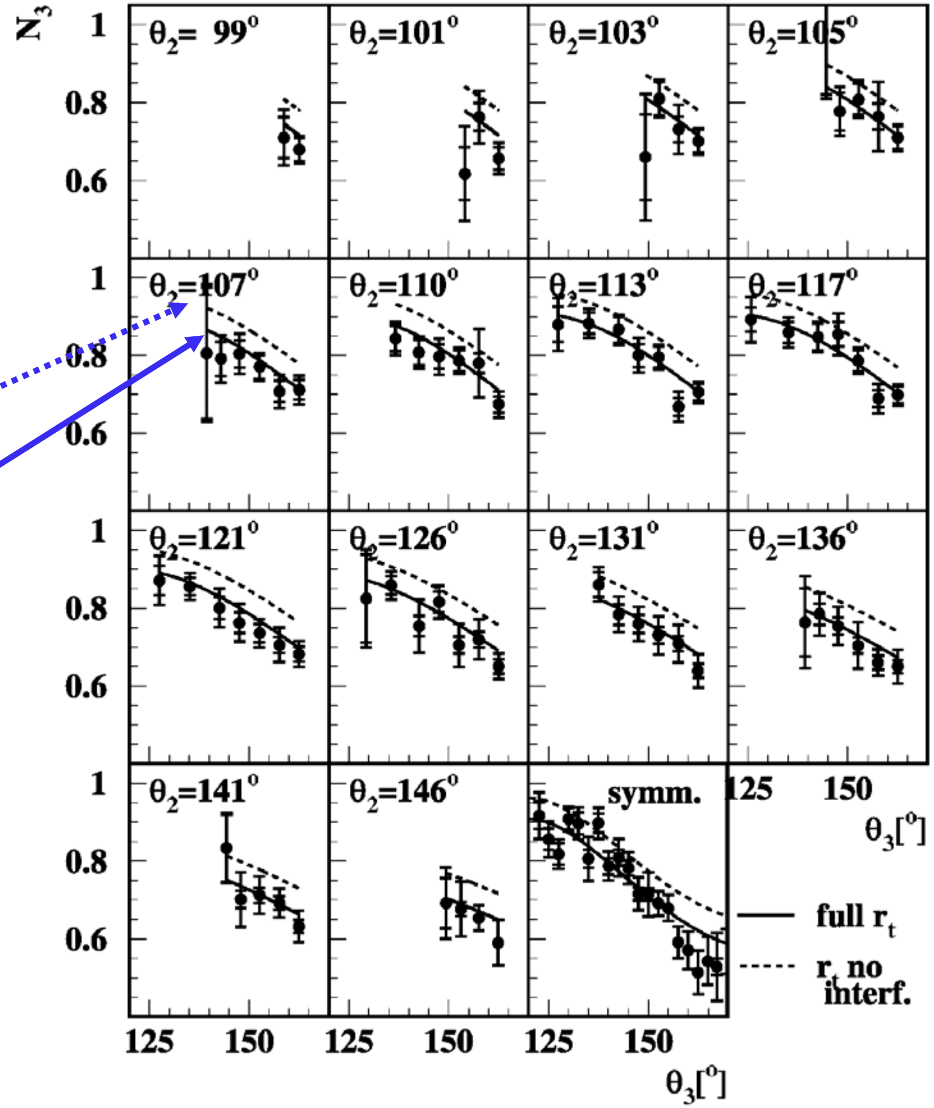
➔ radiator function
➔ θ_{ij} is opening angle between 2 jets

DELPHI: ∠ ordered Durham jets with y_{cut} = 0.015 @ $\sqrt{s}$ = 91 GeV

Coherence in soft particle production

Multiplicity in 30° cone
vs. inter-jet angles

no interference
with interference



Strong preference for full coherence

Coherence in soft particle production

Fit scaled interference term $k \cdot I$ to $d\sigma_3/d\sigma_2$ with $C_A/C_F = 9/4$

$k = 1.37 \pm 0.05(\text{stat.}) \pm 0.33\ (\text{sys.})$

$\chi^2/\text{dof} = 1.2$

measure slope of r_t dependence corresponding to C_A/C_F at LO

$C_A/C_F = 2.211 \pm 0.014(\text{stat.}) \pm 0.053\ (\text{sys.})$

$\chi^2/\text{dof} = 1.3$

Simultaneous fit is not possible due to high correlation of both terms.

Pentaquark search

For example:

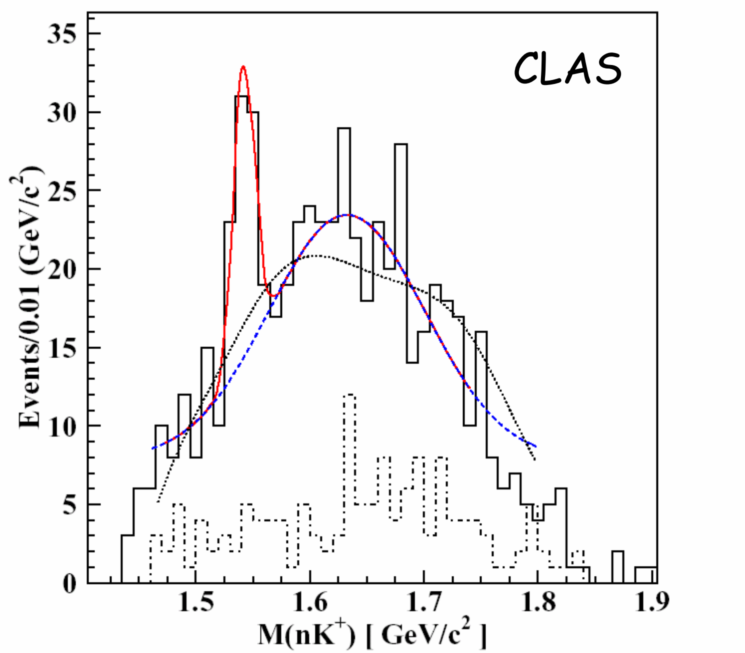


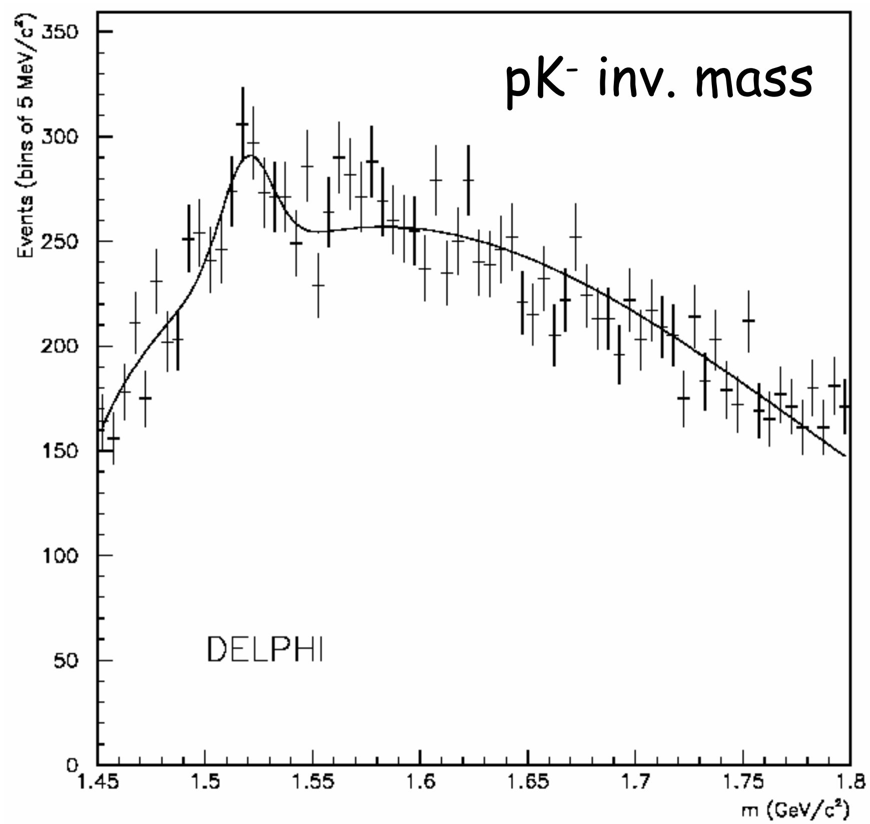
FIG. 4: Invariant mass of the nK^+ system, which has strangeness $S = +1$, showing a sharp peak at the mass of 1.542 GeV/c^2. A fit (solid line) to the peak on top of the smooth background (dashed line) gives a statistical significance of 5.8 σ. The dotted curve is the shape of the simulated background. The dashed-dotted histogram shows the spectrum of events associated with $\Lambda(1520)$ production.

Recent reports on a narrow baryonic resonance with S=+1 (LEPS, DIANA, CLAS, SAPHIR, ...) in nK^+ and pK^0 inv. mass spectra

Θ^+ Pentaquark?

If produced like an ordinary baryon at LEP the rate per hadronic event should be like for $\Lambda(1520)$: 0.0224 ± 0.0027

Pentaquark search

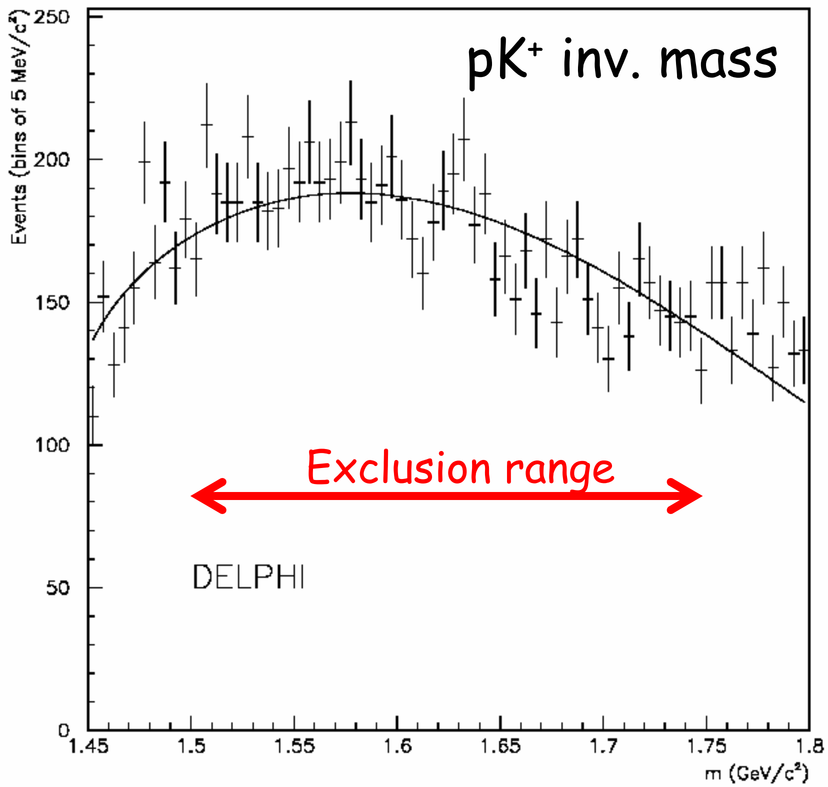


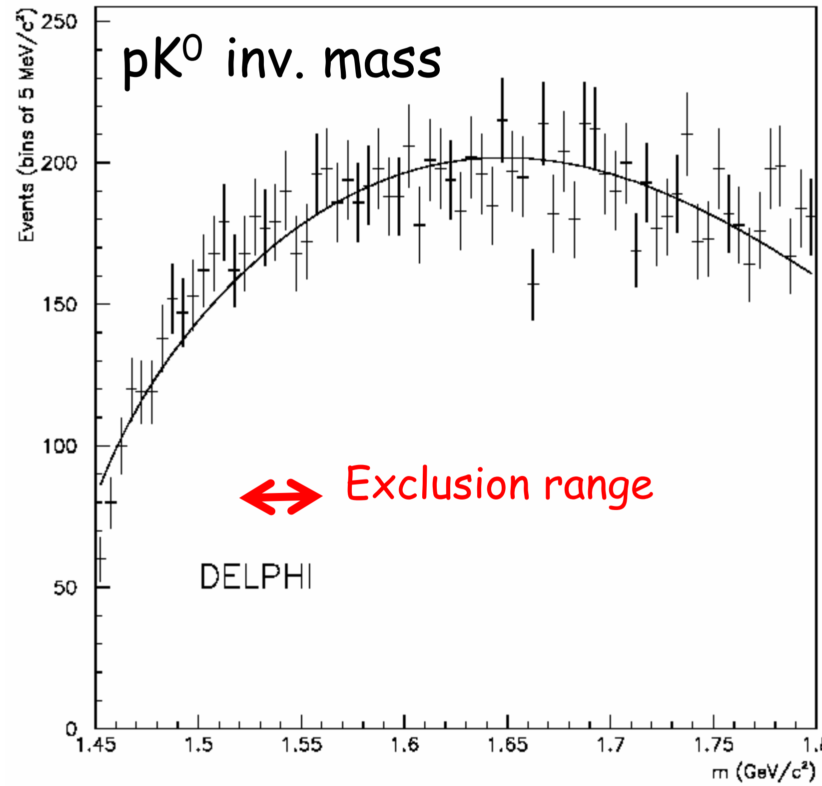
Resonance observed compatible with $\Lambda(1520)$:

mass: 1.520 ± 0.002 GeV/c^2
width: 0.010 ± 0.004 GeV/c^2

The sensitivity is there ...

Pentaquark search





Nothing → multiplicity limits

$\langle N(\Theta^{++}) \rangle < 0.006$

$\langle N(\Theta^{+}) \rangle < 0.015$

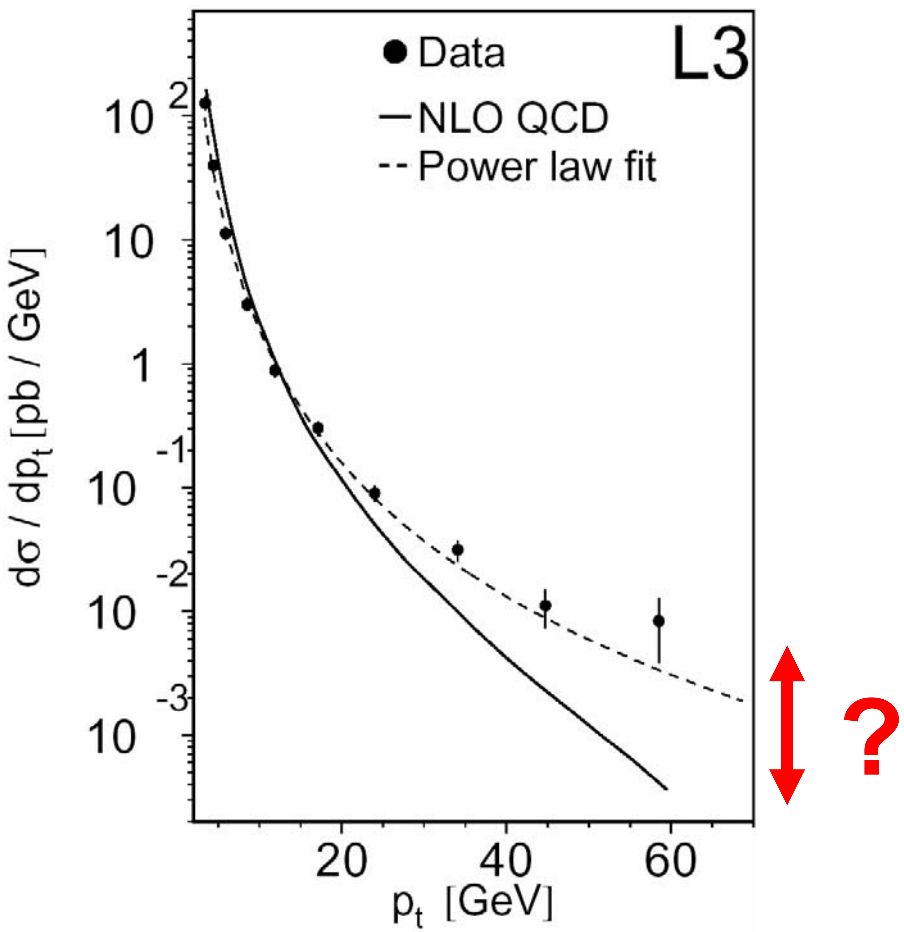
Puzzling results

... in photon-photon collisions at LEP2

- ⇨ inclusive (Di-)jet & hadron production in $\gamma\gamma$ interactions (L3/OPAL)
- ⇨ b cross-sections in $\gamma\gamma$ interactions (DELPHI/L3/OPAL)

Single jet inclusive cross-section

NLO: L. Bertora, S. Frixione

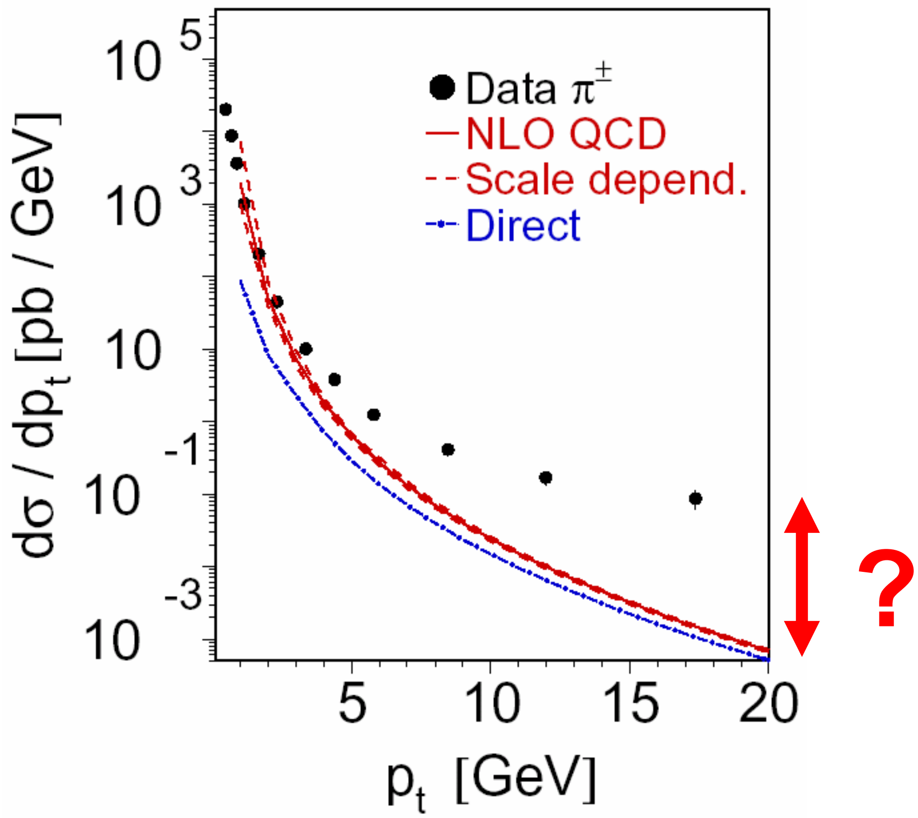


The shape is well described below ~ 15 GeV by NLO QCD

NLO is (much) lower than the data at high p_t

Hadron transverse momentum spectra

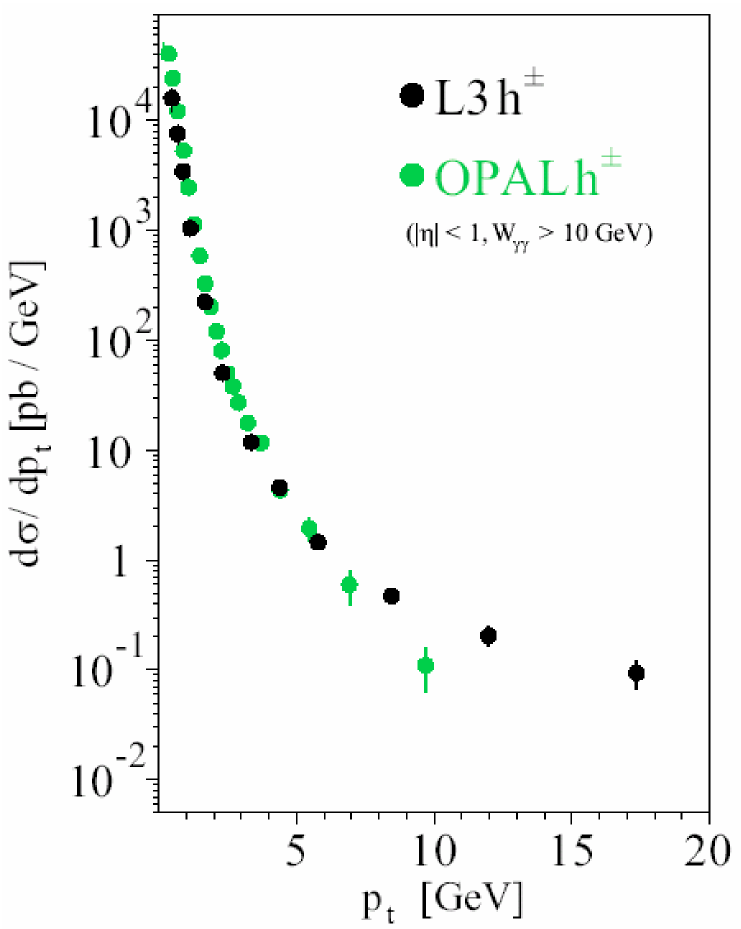
NLO: Binnewies, Kniehl, Kramer



Again NLO is (much) lower than the data at high p_t

This is consistent with the L3 observations in neutral pion production

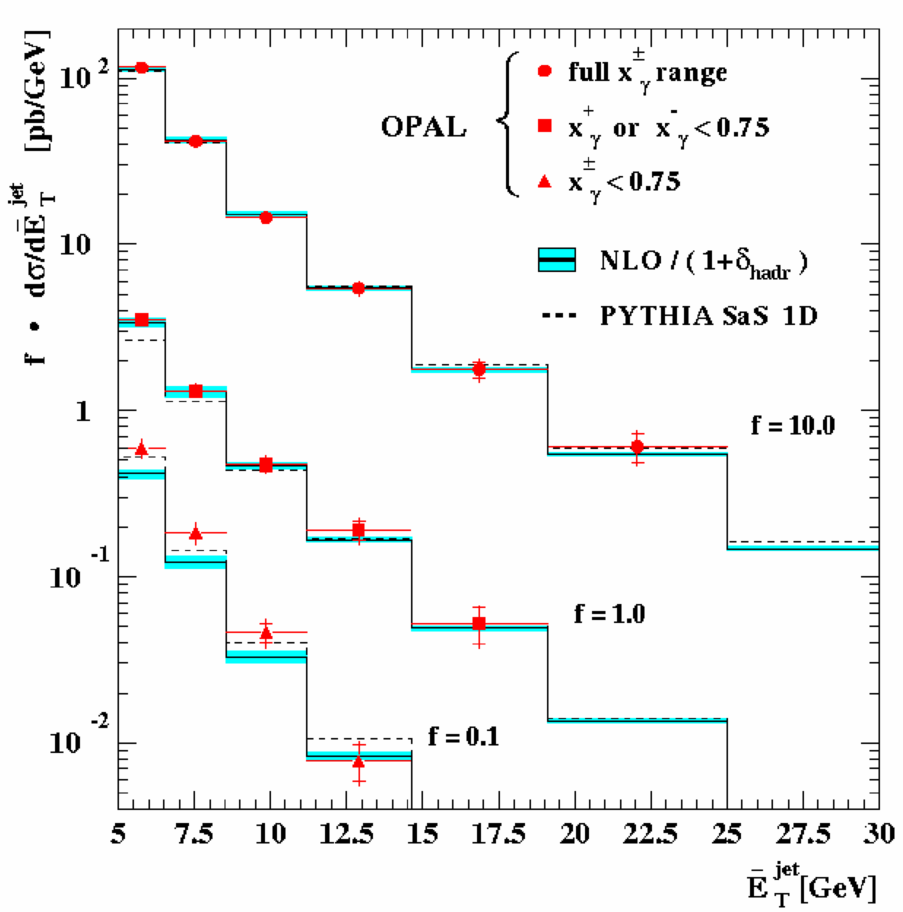
Hadron transverse momentum spectra



OPAL and L3 agree where both measurements are available

OPAL analysis of full data set still ongoing

The di-jet cross-section vs. mean E_T^{jet}



NLO: Klasen et al.
Similar for Bertora, Frixione

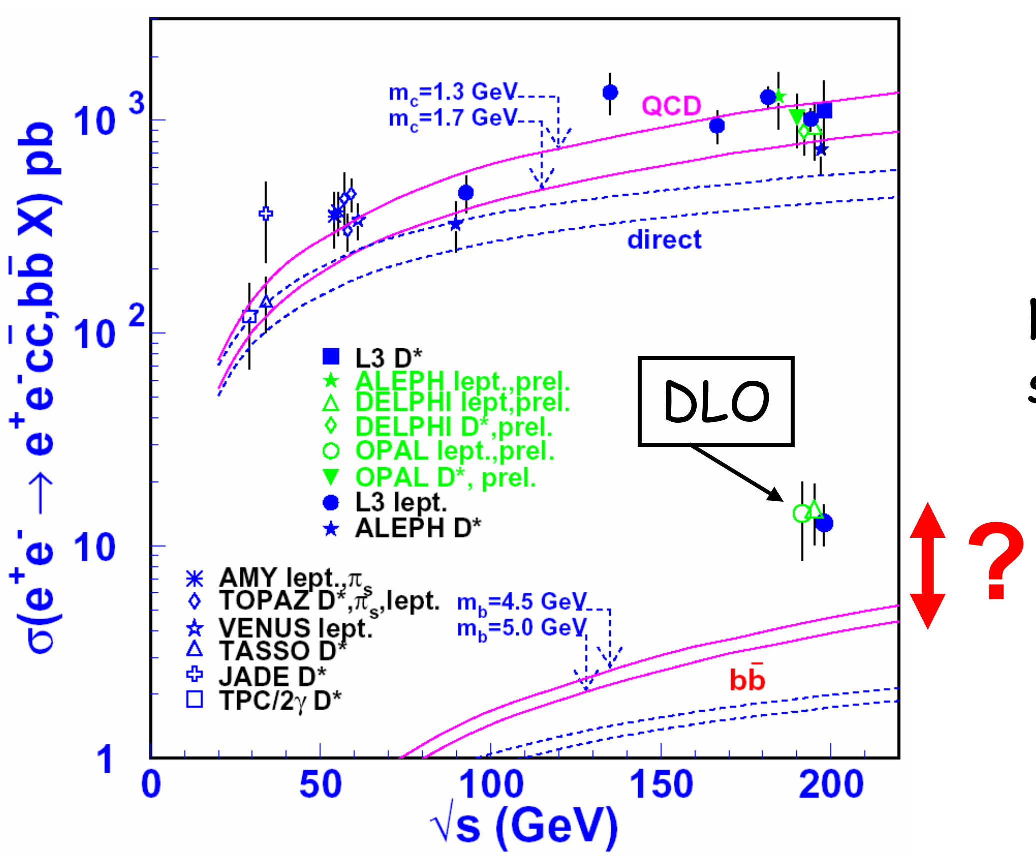
Di-jet cross-section well described by NLO QCD

But different phase space and E_T range

Single jet analysis in OPAL ongoing

Total bb cross-section in $\gamma\gamma$ interactions

NLO: Drees, Kramer, Zunft, Zerwas



Now 3 measurements – all significantly above NLO QCD

Conclusions

Not only updates of existing results, but also new QCD studies are still emerging from LEP

There are puzzles that remain to be solved, requiring work both from the theoretical and the experimental side

Bibliography

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