Unbiased gluon jets from e^+e^- annihilations using the boost algorithm

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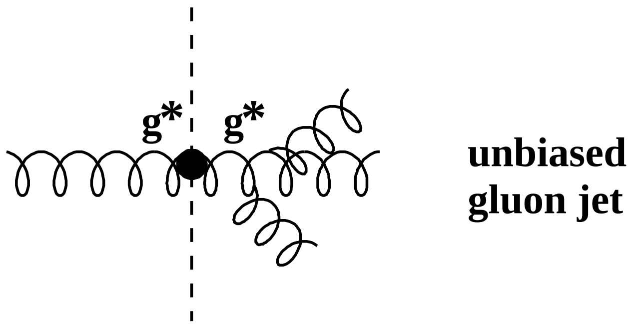
Gluon Jet definition · · ·

- Theoretical calculations: define gluon jet multiplicity INCLUSIVELY



→ N_g: Particles in hemisphere of gg ($q\bar{q}$) color singlet: UNBIASED gluon jet

- Experimental analysis: gluon jet often defined using a jet reconstruction algorithm (Jet Finder)

→ N_g: Particles associated to the jet by the algorithm: BIASED gluon jet

→ Multiplicity strongly dependent from jet finder used

→ Comparison to theory ambiguous

Purpose of the present study is $\cdots$

BOOST algorithm, proposed by the Lund theory group (P. Eden, G. Gustafson, JHEP **9809** (1998) 015) to reconstruct unbiased gluon jets

$\cdots$ test if provides a good description of unbiased gluon jets.

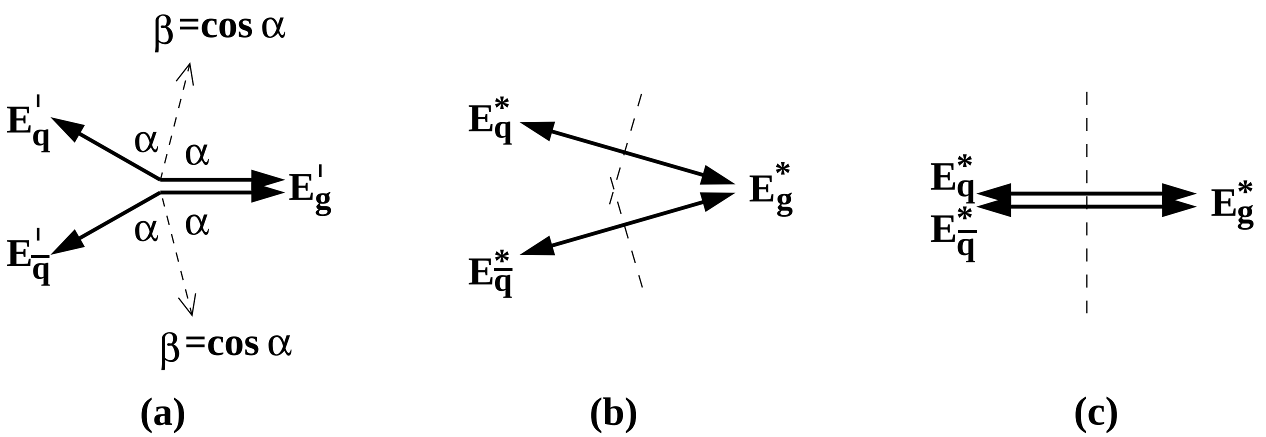
$\cdots$ measure unbiased gluon jet properties at different energies with this method:

- Charged multiplicity distribution : $P(n^{ch.}_{gluon})$
- Mean charged multiplicity : $\langle n^{ch.}_{gluon} \rangle$
- Factorial moments : $F_{l,gluon} = \frac{\langle n(n-1)\cdots(n-l-1)\rangle}{\langle n \rangle^l}$
- Fragmentation function : $\frac{1}{N}\frac{dn^{ch.}_{gluon}}{dx_E}$, $x_E = E_{part}/E_{jet}$

$\cdots$ compare the results with theoretical predictions.

Boost Algorithm

- Based on the Color Dipole Model



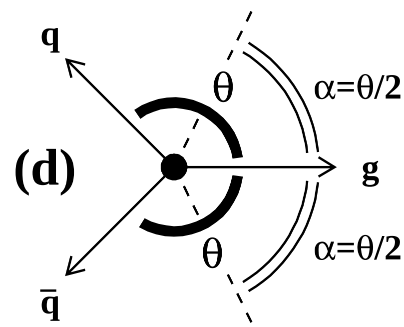
- $q\bar{q}g$ event symmetric w.r.t. gluon jet direction (a): 2 independent color dipoles
- Boost each dipole (b) to its back-to-back frame
- Back-to-back dipoles can be combined to yield the dipole structure of gg event (c), with the condition:

$$E_g^* = E_g' \sin\left(\theta_{qg}/2\right)$$

Boost Algorithm

- Reconstruct a three-jet event configuration in a multihadronic event and identify the gluon jet.
- Apply Lorenz boost to the event. In the new frame:

$$\theta_{qg} = \theta_{\bar{q}g} = \theta$$



- **Multiplicity** of gluon jet: number of particles lying inside the cone-like region defined by the bisectors of θ_{qg} and $\theta_{\bar{q}g}$
- **Energy scale** of gluon jet:

$$E_g^* = p_{\perp,gluon} = \frac{1}{2}\sqrt{\frac{s_{qg}s_{\bar{q}g}}{s}}$$

- $p_{\perp,gluon}$: Lund definition of gluon transverse momentum. Experimentally shown to be appropriate scale: OPAL Collaboration **E.P.J. C22** (2002)

Analysis Method

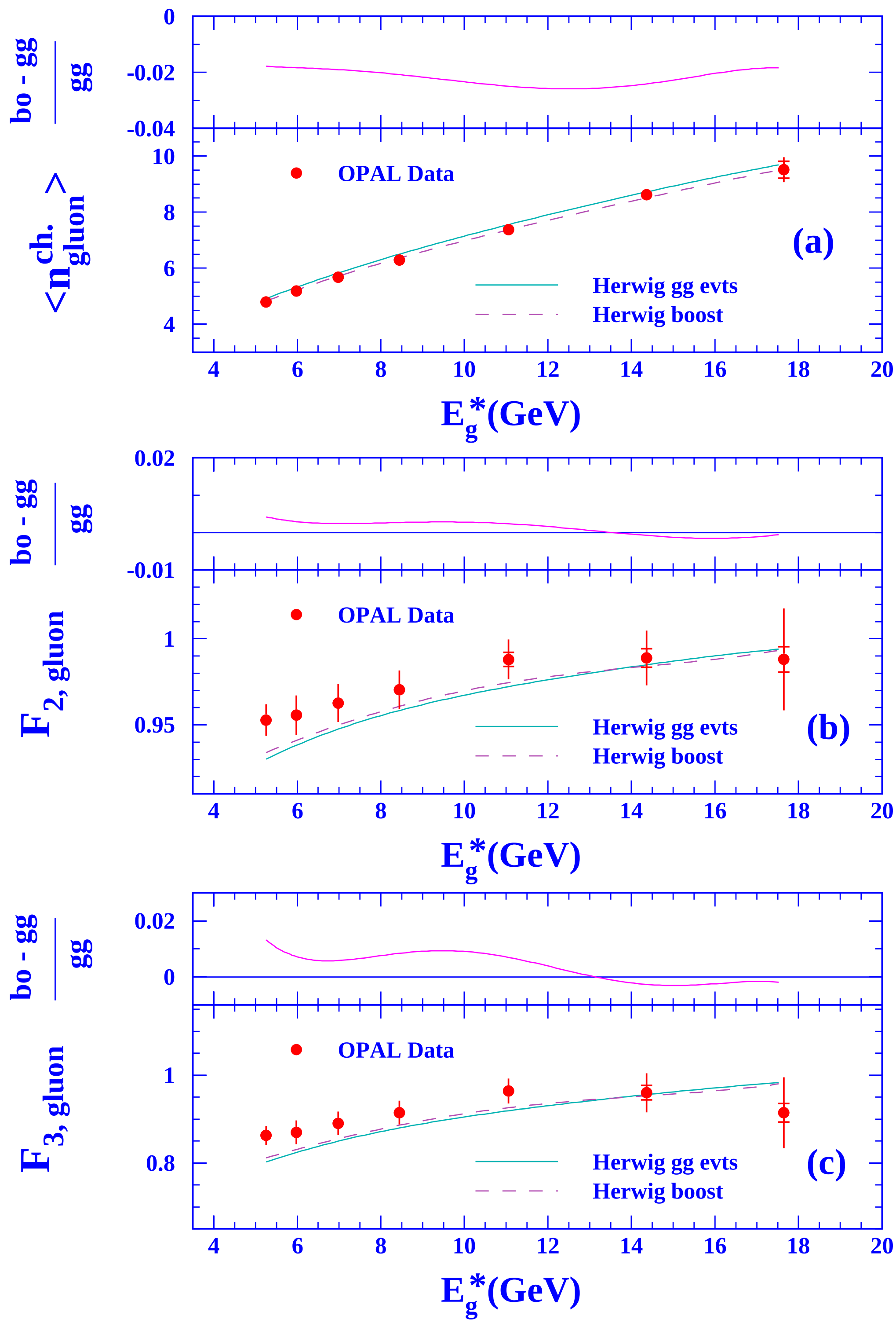
- Analysis based on multihadronic events collected by OPAL at the Z^0 peak
- 3-jet configuration **forced** in each event using $\kappa_\perp$ jet finder
- Energy of jets **recalculated** imposing energy and momentum conservation and **massless** kinematic
- Jets ordered in decreasing energy
- **Identify** gluon jet:
  - Jet 1 **always** assumed to be a **quark jet**
  - Perform **B-tagging** on jet 2 and 3
  - Only events with one tagged quark jet among the lower energy jets are retained
  - The remaining lower energy jet is identified as **GLUON**
- Data **corrected** for acceptance, resolution, ISR, gluon mis-tagging ..

Final Event Sample

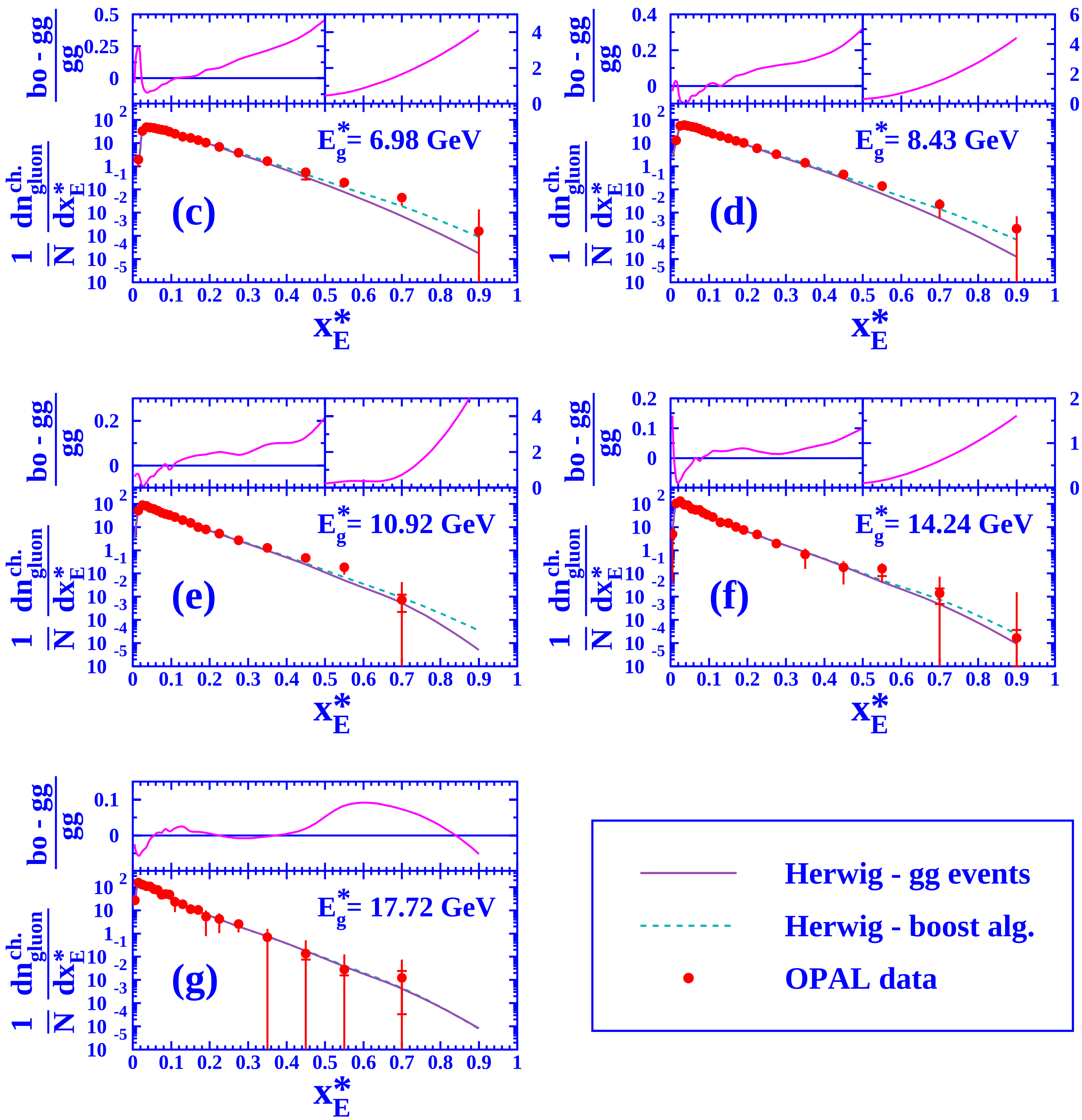
Bin in E_g^* (GeV)	Number of jets	$\langle E_g^* \rangle$ (GeV)	Purity (%)
5.0–5.5	4022	$5.25 \pm 0.01 \pm 0.01$	$88.8 \pm 0.4 \pm 1.4$
5.5–6.5	6652	$5.98 \pm 0.01 \pm 0.01$	$87.3 \pm 0.3 \pm 1.6$
6.5–7.5	5017	$6.98 \pm 0.01 \pm 0.01$	$84.2 \pm 0.4 \pm 2.3$
7.5–9.5	7390	$8.43 \pm 0.01 \pm 0.01$	$79.2 \pm 0.3 \pm 2.2$
9.5–13.0	1713	$10.92 \pm 0.02 \pm 0.04$	$94.5 \pm 0.3 \pm 3.6$
13.0–16.0	485	$14.24 \pm 0.04 \pm 0.05$	$86.1 \pm 0.9 \pm 4.2$
16.0–20.0	117	$17.72 \pm 0.11 \pm 0.21$	$73.9 \pm 2.5 \pm 8.9$
5.0–20.0	25 396	$7.32 \pm 0.01 \pm 0.07$	$85.1 \pm 0.2 \pm 2.6$

- About 25000 events in the final sample
- Overall gluon jet purity : 85%
- E_g^* energy range divided in 7 bins
- To all those events the BOOST algorithm has been applied

Test of Boost Algorithm: Multiplicity

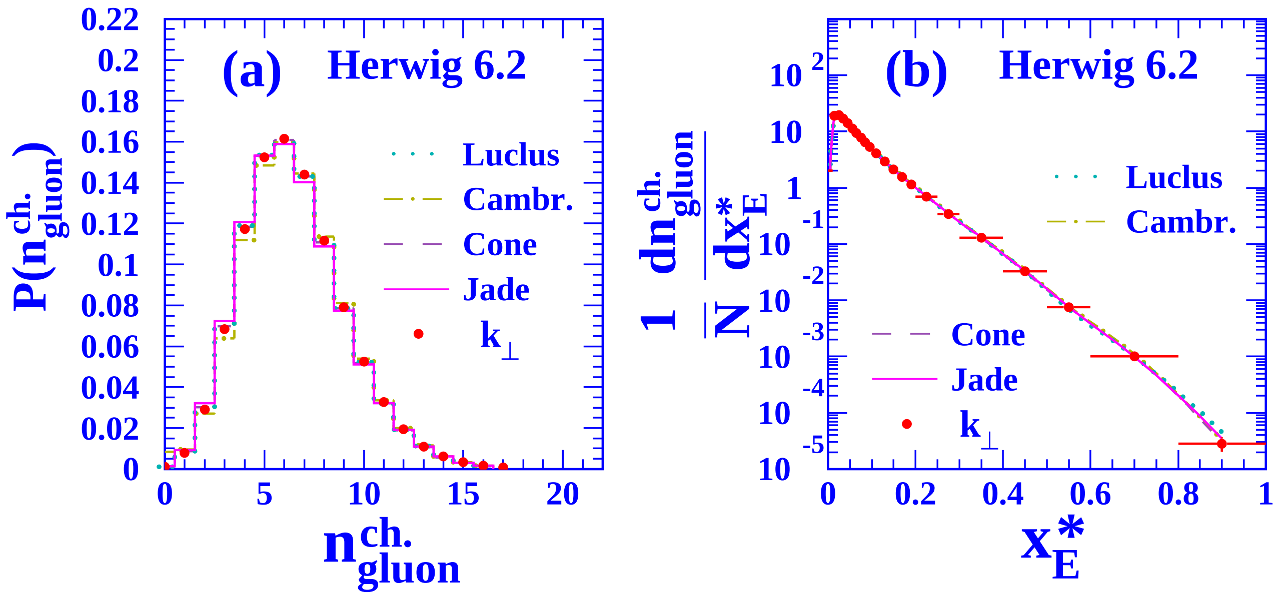


Test of Boost Algorithm: Fragmentation Function

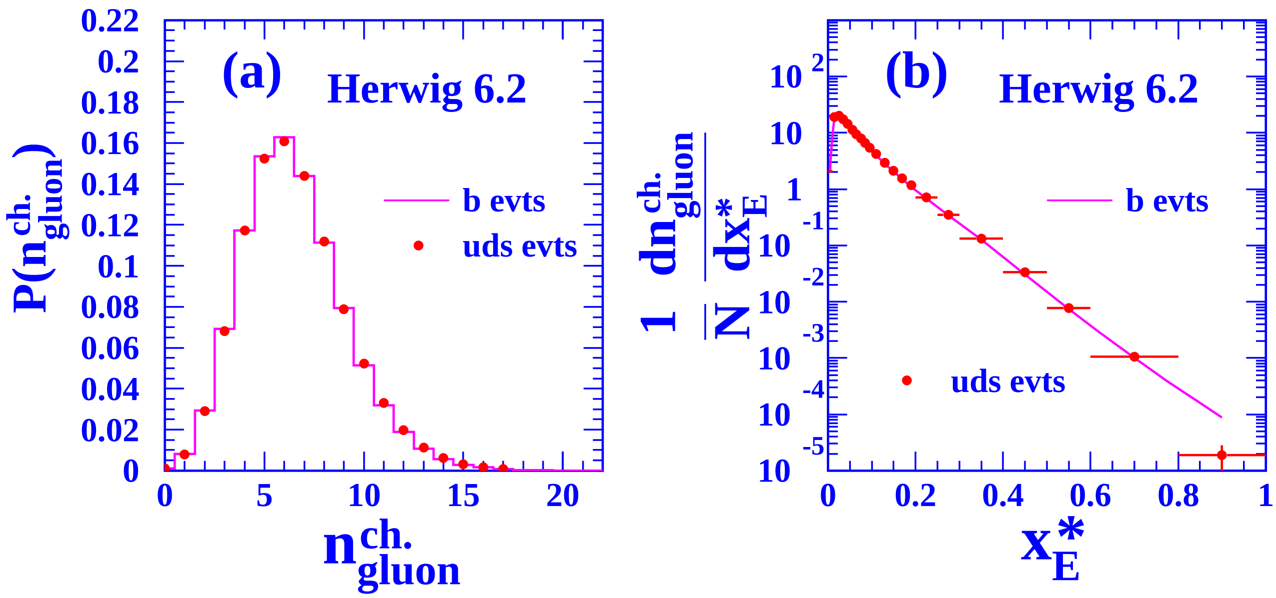


Test of Boost Algorithm: other issues

- Jet finder dependence:



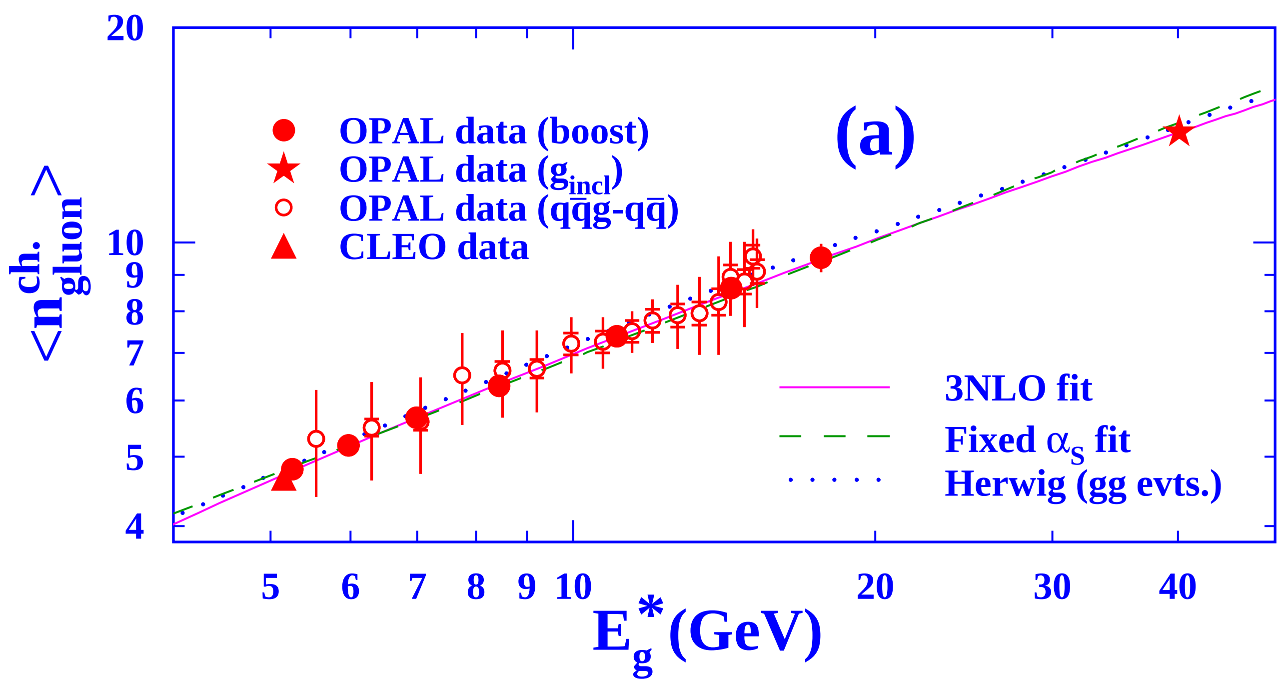
- We assume massless jets (partons) but 80% of the examined gluon jest arise from $b\bar{b}$ initiated events:



Test of Boost Algorithm: summary

- We tested the boost algorithm using Herwig Monte Carlo
- We compared results of Boost method with unbiased gluon jets from color singlet gg events
- MULTIPLICITY :
  $\longrightarrow$ good agreement for $E_g^* > 5\,GeV$
  $\longrightarrow$ measurement of multiplicity distributions in seven intervals of energy between 5.25 and 17.72 GeV
- FRAGMENTATION FUNCTION :
  $\longrightarrow$ good agreement $E_g^* > 14\,GeV$
  $\longrightarrow$ measurement of fragmentation functions in two intervals at 14.24 and 17.72 GeV
- Virtually no jet finder dependence observed

Results : mean multiplicity

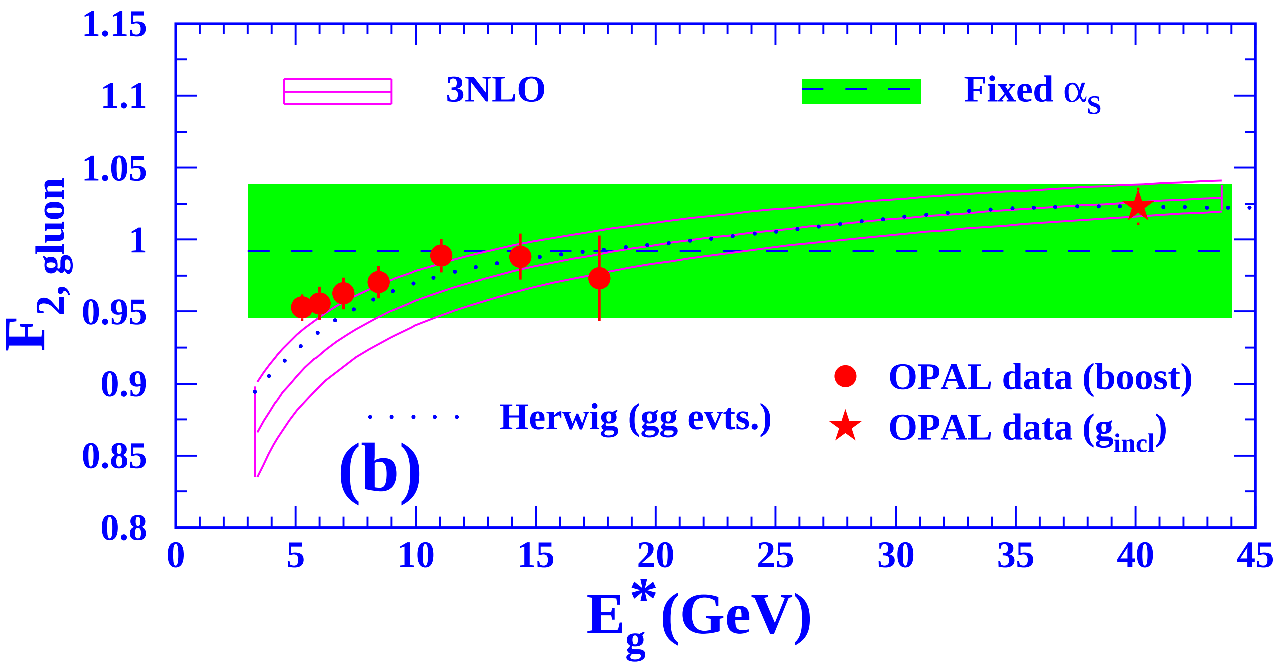


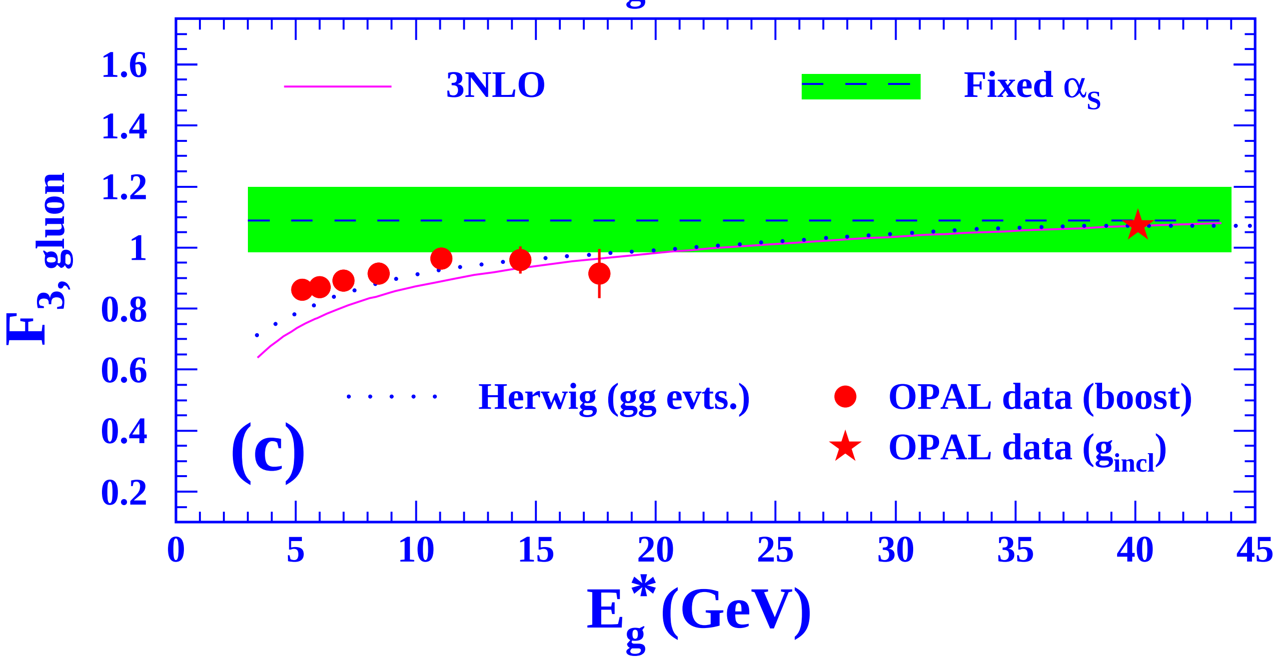
- Results **consistent** with previous measurements of unbiased gluon jets
- Most **precise** results for $5.25 < E_g^* < 20GeV$
- Theoretical expressions **successfully fitted** to experimental data:

  $\longrightarrow$ **3NLO** : takes into account the running nature of α_S

  $\longrightarrow$ **Fixed** α_S: incorporates more accurately higher order effects

Results : factorial moments





Results : factorial moments

- **First measurement** of F_2 and F_3 for unbiased gluon jets over an energy range
- **3NLO expression** fitted to three highest energy data points:

  $\longrightarrow$ reasonable description of $F_{2,gluon}$ and $F_{3,gluon}$ energy evolution above 14 GeV.

  $\longrightarrow$ lower energies: predictions lie below the data.

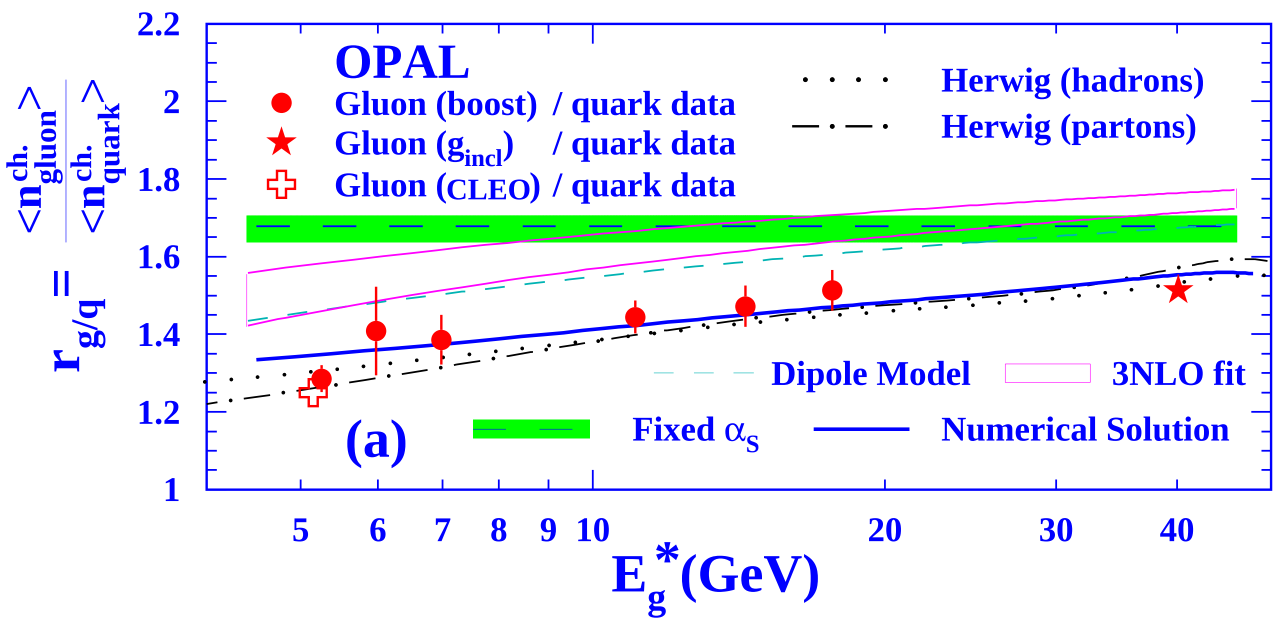
  $\longrightarrow$ discrepancy at low energies possibly due to **hadronization effects**
- **Fixed α_S prediction** :

  $\longrightarrow$ general agreement with the data for $F_{2,gluon}$ (but fairly large theoretical uncertainties)

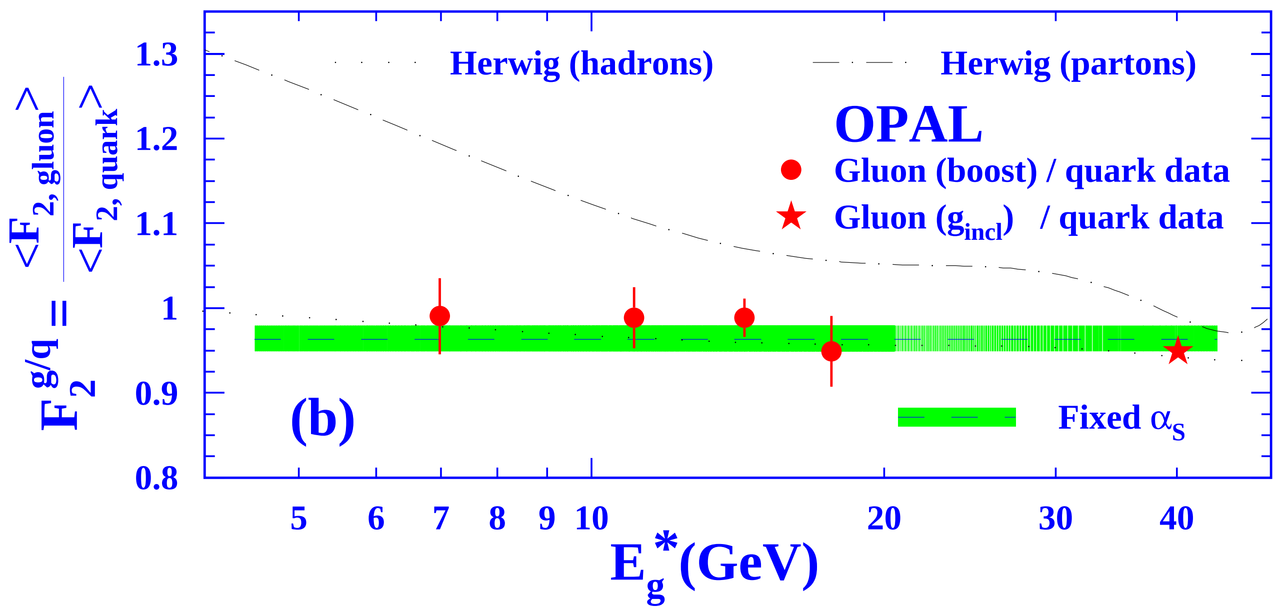
  $\longrightarrow$ lies above the data for $F_{3,gluon}$ except for $E_g^* \approx 40GeV$

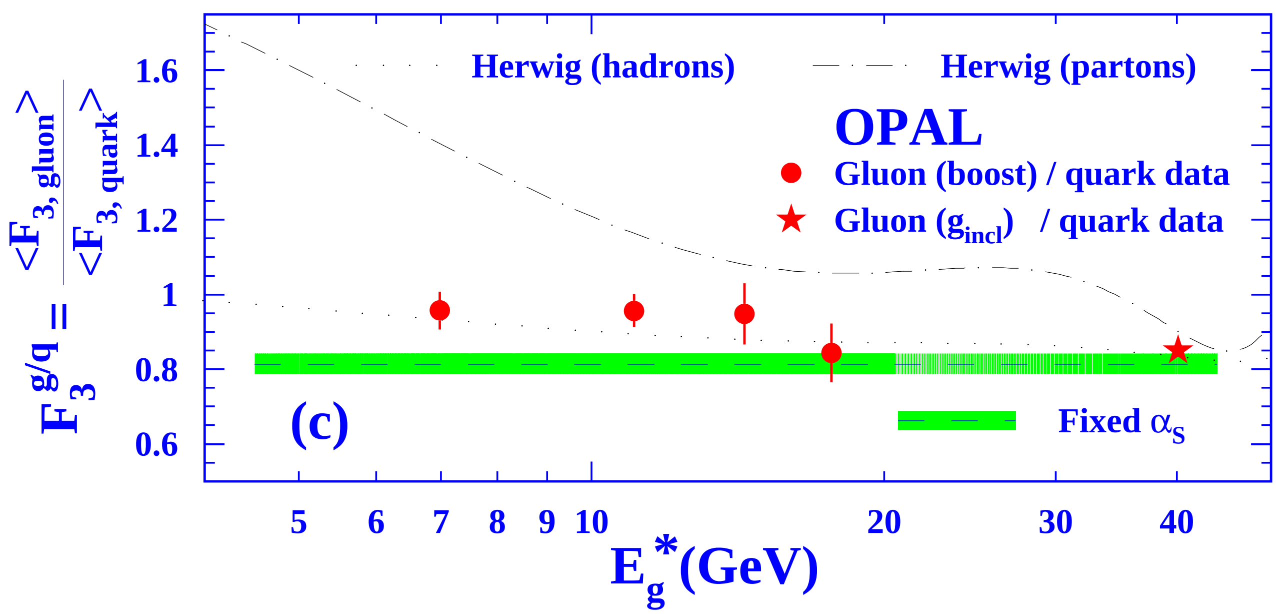
Results : Multiplicity Ratio

- **Quark contribution**: inclusive $e^+e^- \to q\bar{q}$ data at the same gluon energy scale E_g^*, corrected (Herwig) for small energy difference and heavy quark contribution.



- **3NLO** and **fixed α_S** are 15-20% above the data
- **Dipole Model** is about 10-15% above the data
- **Numerical solution** of QCD evolution equation well describes the data over the all energy range
- **Energy conservation** and **phase space limits** are important issues for those descriptions



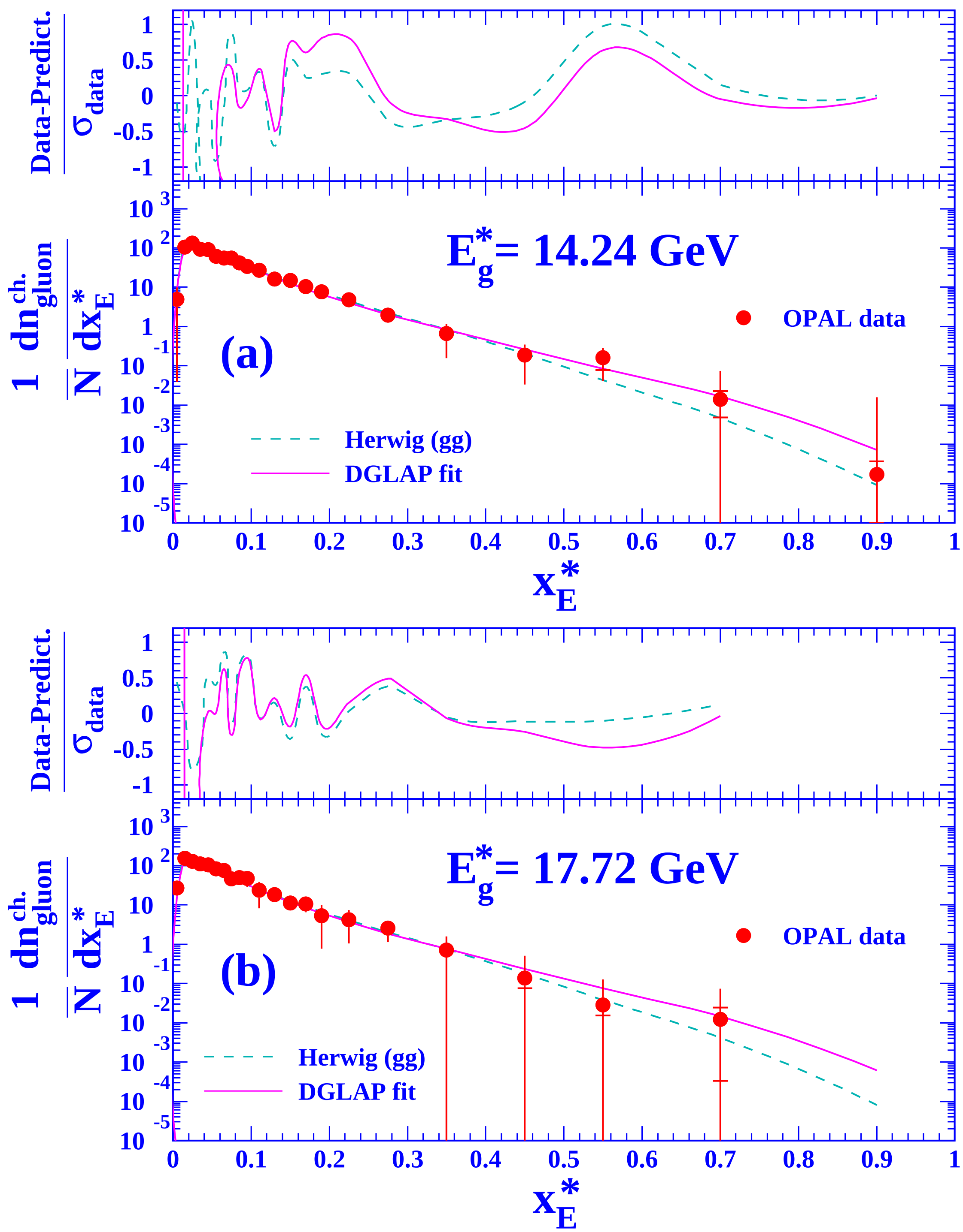


- Fixed α_S prediction in general good agreement with the data.

HOWEVER

- Large hadronization effects ...

Results : Fragmentation Function



Results : Fragmentation Function

- The data have been **fitted** using the **DGLAP** evolution equation:
  $\longrightarrow$ valid at NLO in the $\overline{MS}$ scheme

- Evolution performed in conjunction with our measurements of unbiased gluon and quark jet fragm. function at 40.1 and 45.6 Gev

- The fit provides a **good description** of the measurements and yields a result for the strong coupling constant:

$$\alpha_s(m_Z) = 0.128 \pm 0.008(stat) \pm 0.015(syst)$$

- The result is **consistent** with the world average and provides a unique **consistency check** of QCD

Conclusions

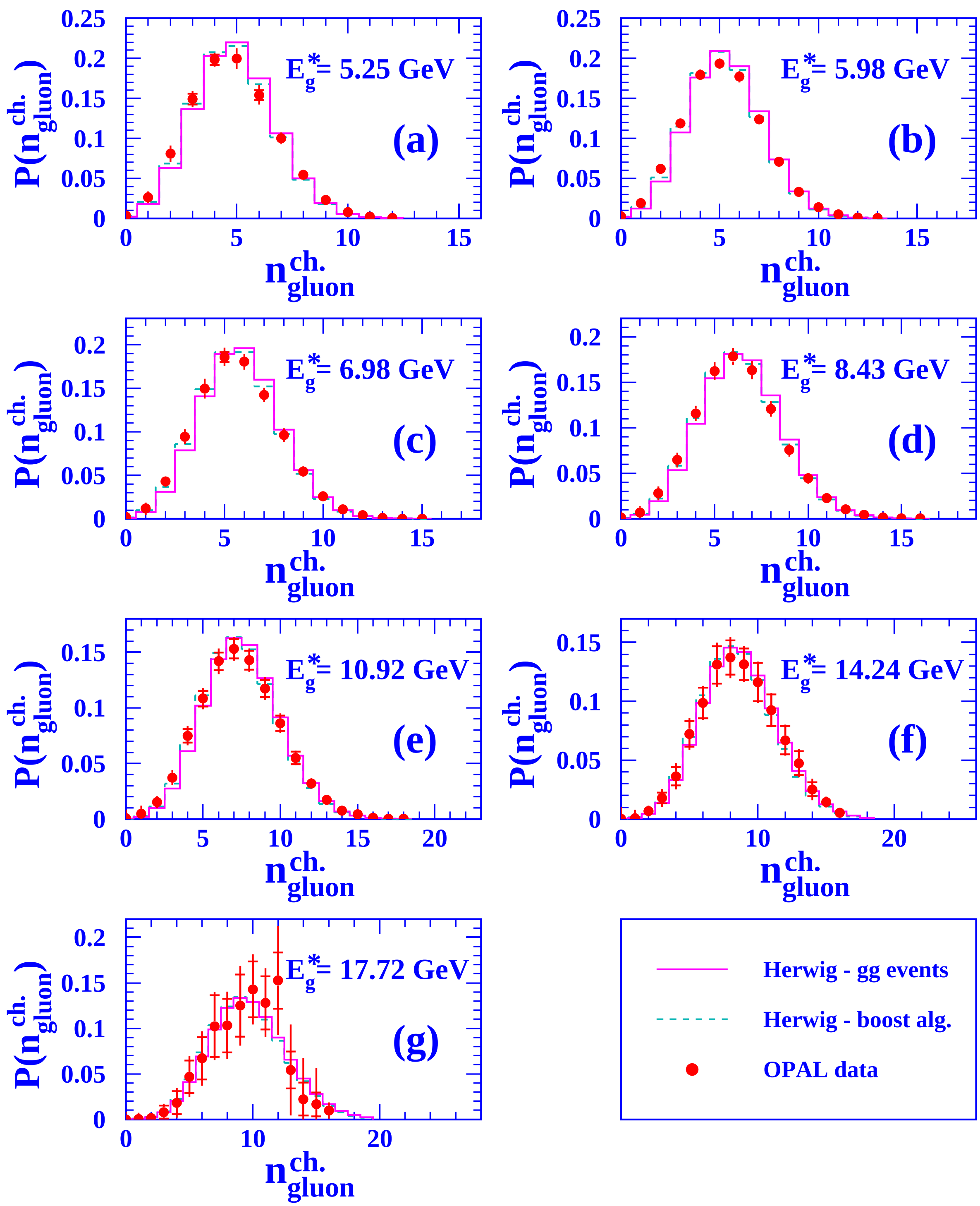
- Most precise measurement of unbiased gluon jet mean multiplicity in the range $5 < E_g^* < 20\,GeV$

- First measurement of F_2 and F_3 for unbiased gluon jets over an energy range.

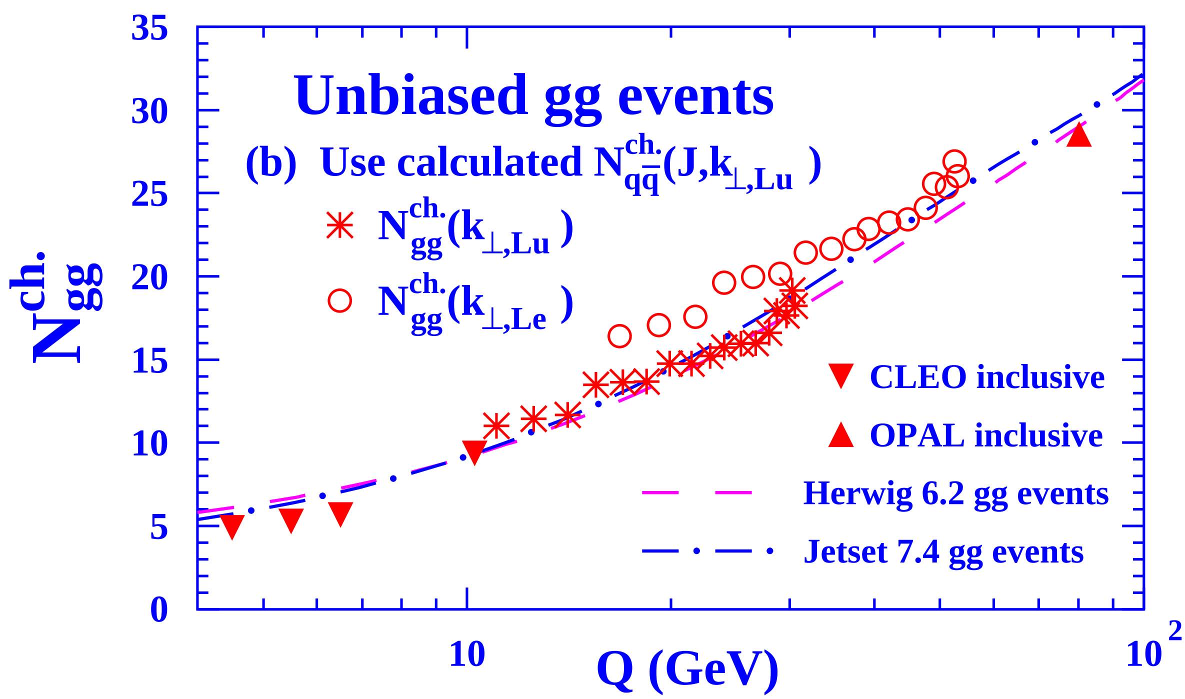
- First measurement of **strong coupling constant** from unbiased gluon jet fragmentation function

In general, we found **overall** good **agreement** between data and theory.

Test of Boost Algorithm: Multiplicity Distribution



Lund and Leningrad scales



Results based on the “Lund scale” preferred over the one based on the “Leningrad scale” :

- The Leningrad definition yields results inconsistent with the Monte Carlo prediction
- The MC has been shown to well describe unbiased gluon jets in other studies
- The Leningrad definition results in apparent inconsistency with previous measurements

Analysis Method

- Analysis based on 3.13M multihadronic events collected by OPAL at the Z^0 peak ($\pm$ 3GeV) between 1993 and 2000 (3 dim. readout of silicon micro-vertex)

  $\longrightarrow$ Standard multihadronic selection applied

  $\longrightarrow$ High efficiency and almost no background contamination

- 3-jet configuration forced in each event using $\kappa_\perp$ jet finder
- Energy of jets recalculated imposing energy-momentum conservation and massless kinematic
- Jets ordered in decreasing energy (Jet 1 $\longrightarrow$ highest energy)
- B-tagging procedure applied to the three jets:
  - "Good-quality" tracks selected (momentum greater than 1GeV/C and maximum distance of closest approach 0.3 cm with a maximum uncertainty of 0.1 cm on this quantity)
  - Displaced secondary vertex reconstructed if contains more than 3 charged tracks
  - For jets with secondary vertex, the signed decay length L and its error σ_L are calculated

– Jet 1 always assumed to be a quark jet

– Jet 2 or 3 tagged as quark jets only if $L/\sigma_L > 3$

- Only events with one tagged quark jet among the lower energy jets are retained
- The remaining lower energy jet is identified as GLUON
- Measure $E_g^* = \frac{1}{2}\sqrt{\frac{s_{qg}s_{\bar{q}g}}{s}}$
- Require $E_g^* > 5GeV$ (well defined gluon jet)
- Impose cut on k_{jet} of both quark jets, where k_{jet}:

$$k_{jet} = E_{jet} * \sin(\theta_{min}/2) > 8\ \ GeV/c$$

θ_{min} : smallest of the angles with the other two jets.

$\longrightarrow$ Improves the "quality" of three jet event

$\longrightarrow$ Improves the purity of gluon jet

- $5 < E_g^* < 9.5GeV\ \rightarrow$ Gluon jet purity above 80% : OK
- $E_g^* > 9.5GeV \rightarrow$ Gluon jet purity below 80% : RETAG

Quark jet with must satisfy tighter conditions on L/σ_L:

$\rightarrow 9.5 < E_g^* < 16GeV$: $L/\sigma_L > 3$ for jet 1 and 2, $L/\sigma_L > 5$ for jet 3

$\rightarrow E_g^* > 16GeV$: $L/\sigma_L > 5$

Correction procedure

- Correction procedure :

$$Data^{(i)}_{(corr.)} = \left(\frac{MC_{(generator)}}{MC_{(detector)}}\right)^{(i,j)} * Data^{(j)}_{(uncor.)}$$

- CHARGED MULTIPLICITY DISTRIBUTIONS:

$\longrightarrow$ corrected in TWO steps

1. Matrix procedure to correct for detector effects (Acceptance, Resolution etc...)
2. Bin-by-bin procedure to correct for ISR and gluon jet mis-tagging

- FRAGMENTATION FUNCTION:

$\longrightarrow$ Single bin-by-bin correction procedure ONLY