

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

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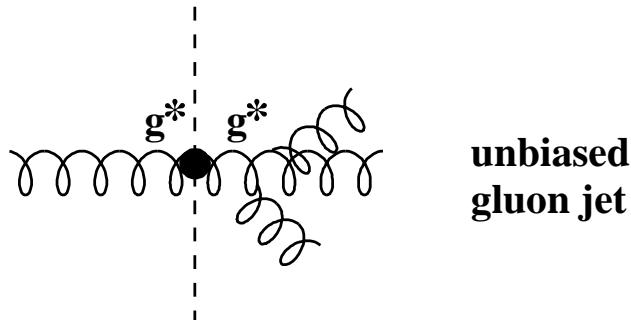
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Gluon Jet definition . . .

- 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

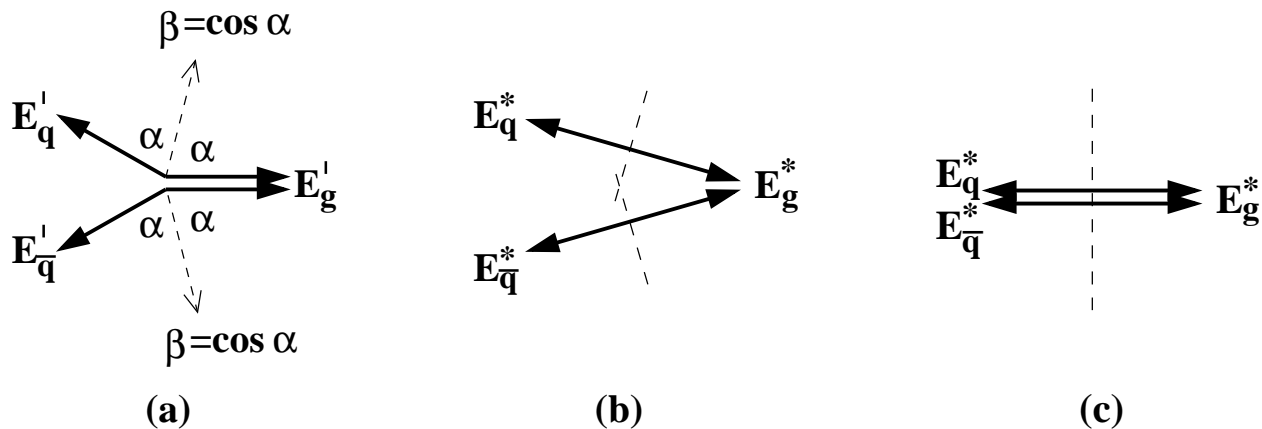
Purpose of the present study is . . .

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

- . . . test if provides a good description of unbiased gluon jets.
- . . . measure unbiased gluon jet properties at different energies with this method:
 - Charged multiplicity distribution : $P(n_{gluon}^{ch.})$
 - Mean charged multiplicity : $\langle n_{gluon}^{ch.} \rangle$
 - Factorial moments : $F_{l,gluon} = \frac{\langle n(n-1)\dots(n-l-1) \rangle}{\langle n \rangle^l}$
 - Fragmentation function : $\frac{1}{N} \frac{dn_{gluon}^{ch.}}{dx_E}$, $x_E = E_{part}/E_{jet}$
- . . . compare the results with theoretical predictions.

Boost Algorithm

- Based on the [Color Dipole Model](#)



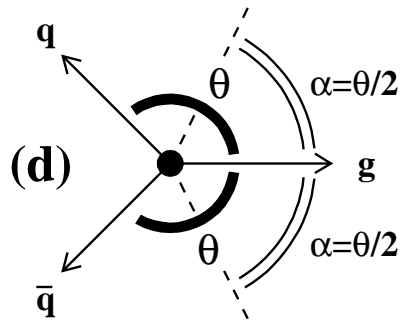
- $q\bar{q}g$ event [symmetric](#) w.r.t. gluon jet direction (a):
2 independent color dipoles
- Boost** each dipole (b) to its back-to-back frame
- Back-to-back dipoles can be [combined](#) to yield the dipole structure of [gg event](#) (c), with the condition:

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

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

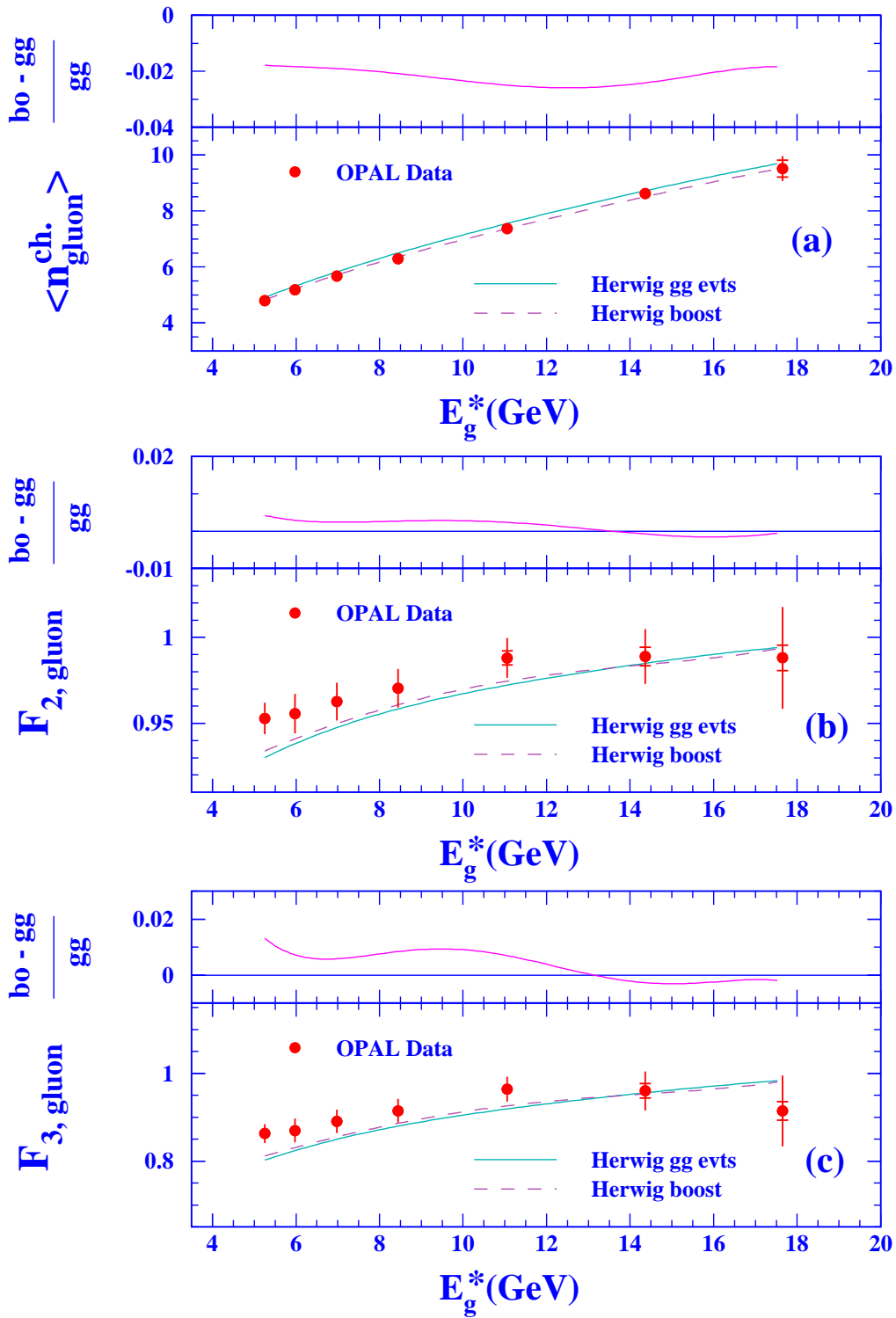
- Analysis based on multihadronic events collected by OPAL at the Z^0 peak
- 3-jet configuration forced in each event using κ_{\perp} jet finder
- Energy of jets recalculated imposing energy and momentum conservation and massless kinematic
- Jets ordered in decreasing energy
- Identify gluon jet:
 - 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

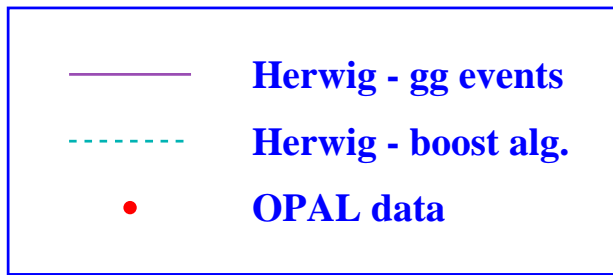
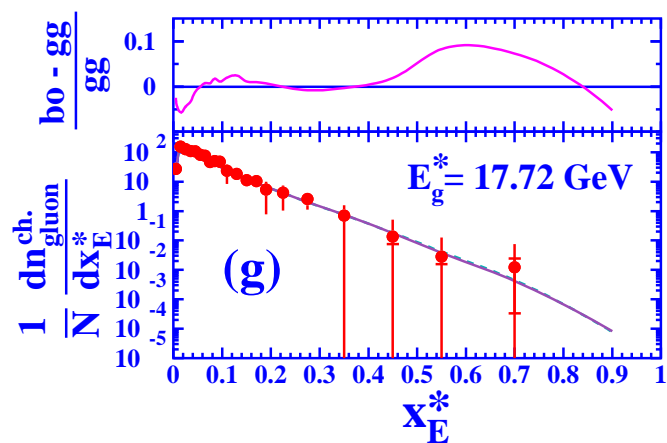
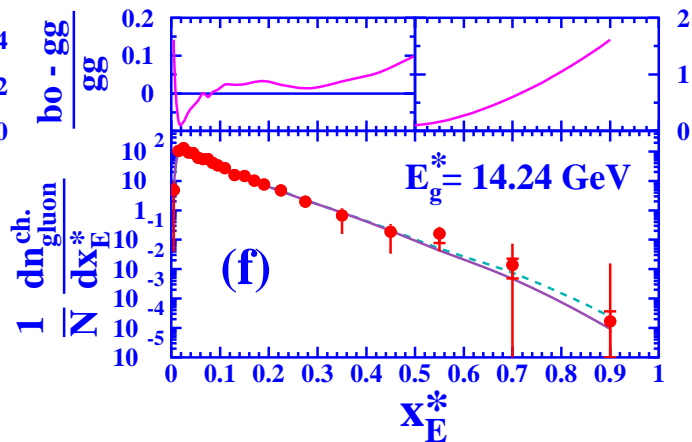
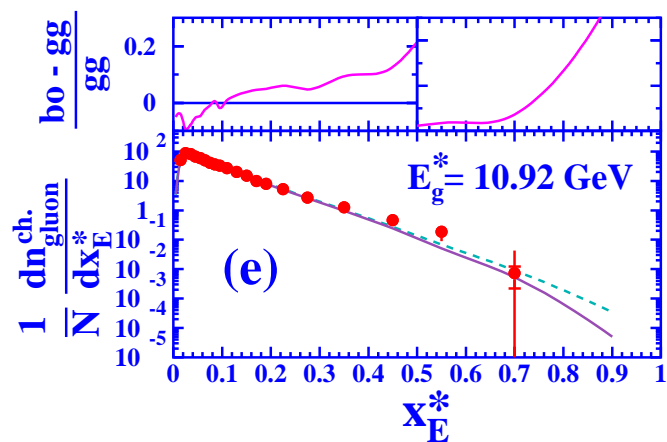
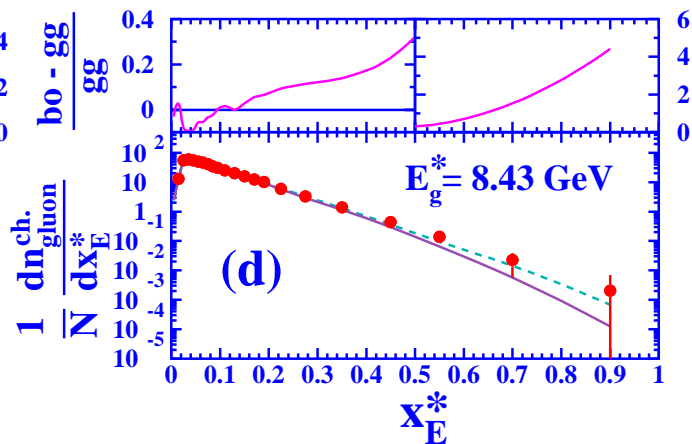
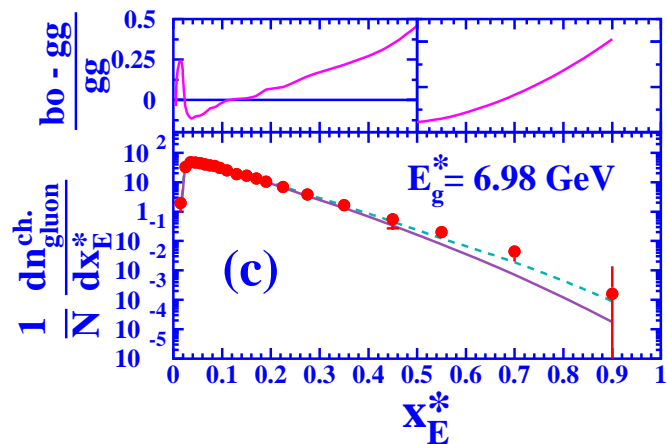
Bin in E_g^* (GeV)	Number of jets	$\langle E_g^* \rangle$ (GeV)	Purity (%)
5.0–5.5	4022	$5.25 \pm 0.01 \pm 0.01$	$88.8 \pm 0.4 \pm 1.4$
5.5–6.5	6652	$5.98 \pm 0.01 \pm 0.01$	$87.3 \pm 0.3 \pm 1.6$
6.5–7.5	5017	$6.98 \pm 0.01 \pm 0.01$	$84.2 \pm 0.4 \pm 2.3$
7.5–9.5	7390	$8.43 \pm 0.01 \pm 0.01$	$79.2 \pm 0.3 \pm 2.2$
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

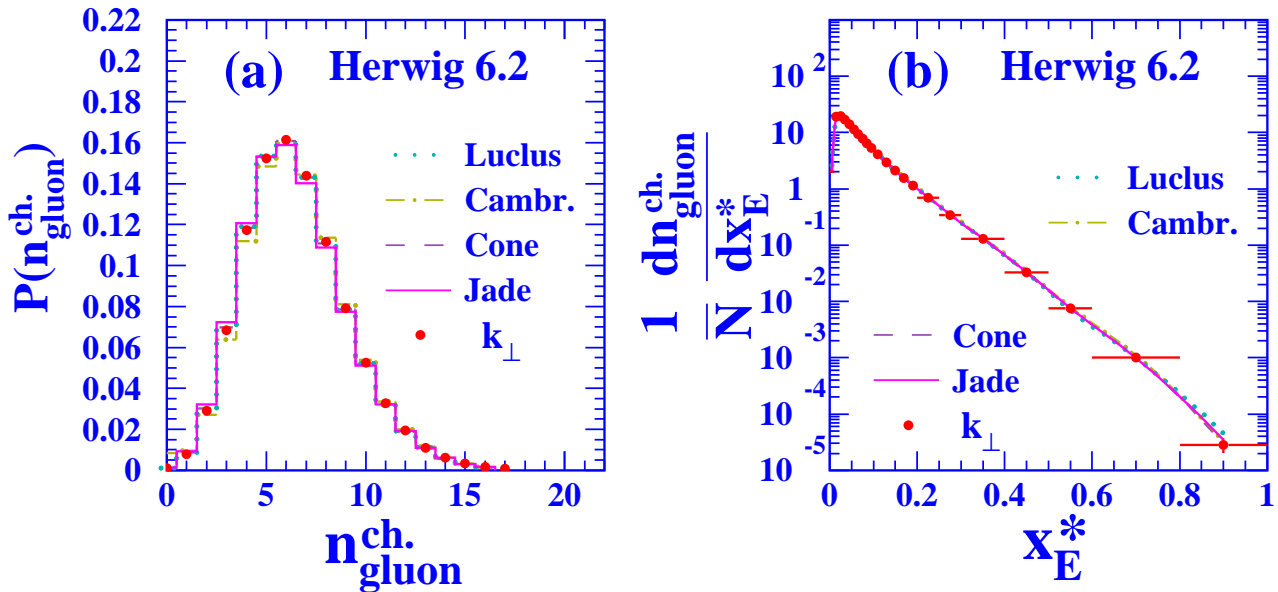


Test of Boost Algorithm: Fragmentation Function

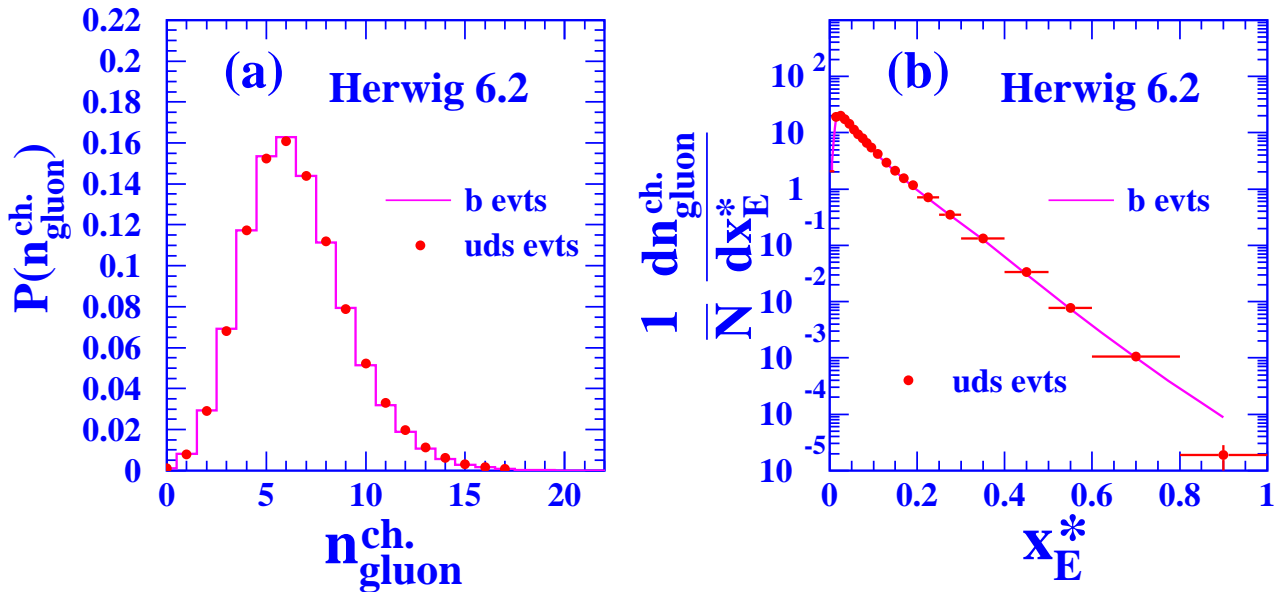


Test of Boost Algorithm: other issues

- Jet finder dependence:



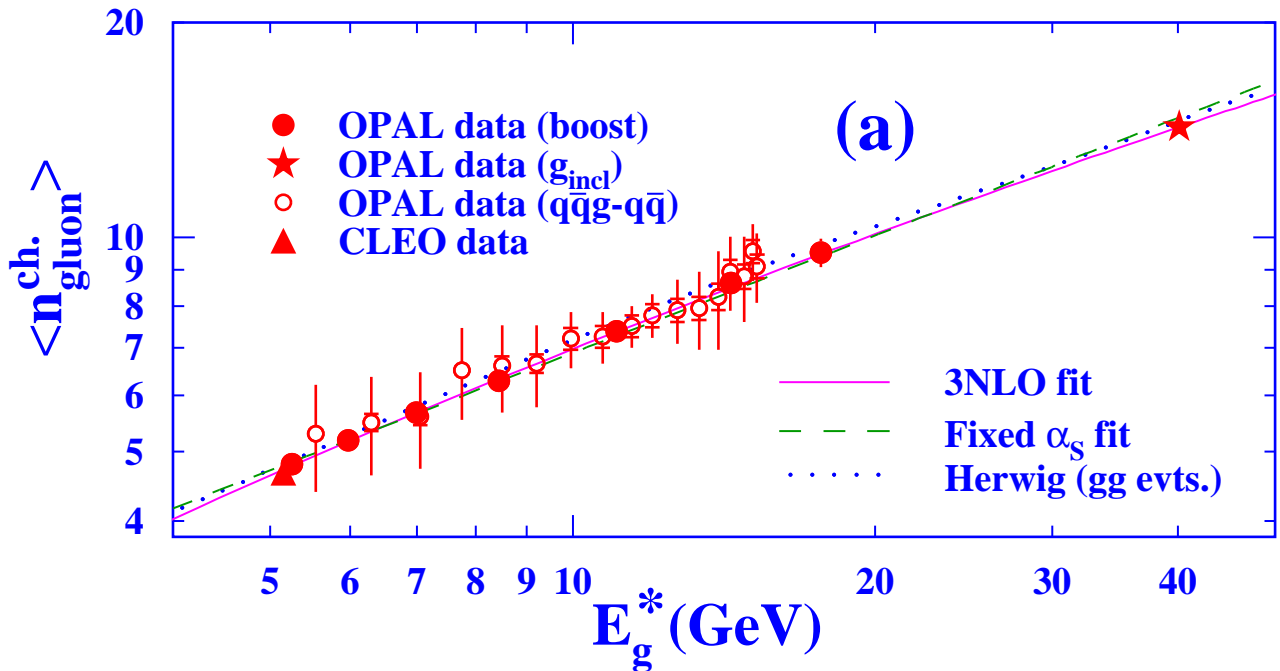
- We assume massless jets (partons) but 80% of the examined gluon jets arise from $b\bar{b}$ initiated events:



Test of Boost Algorithm: summary

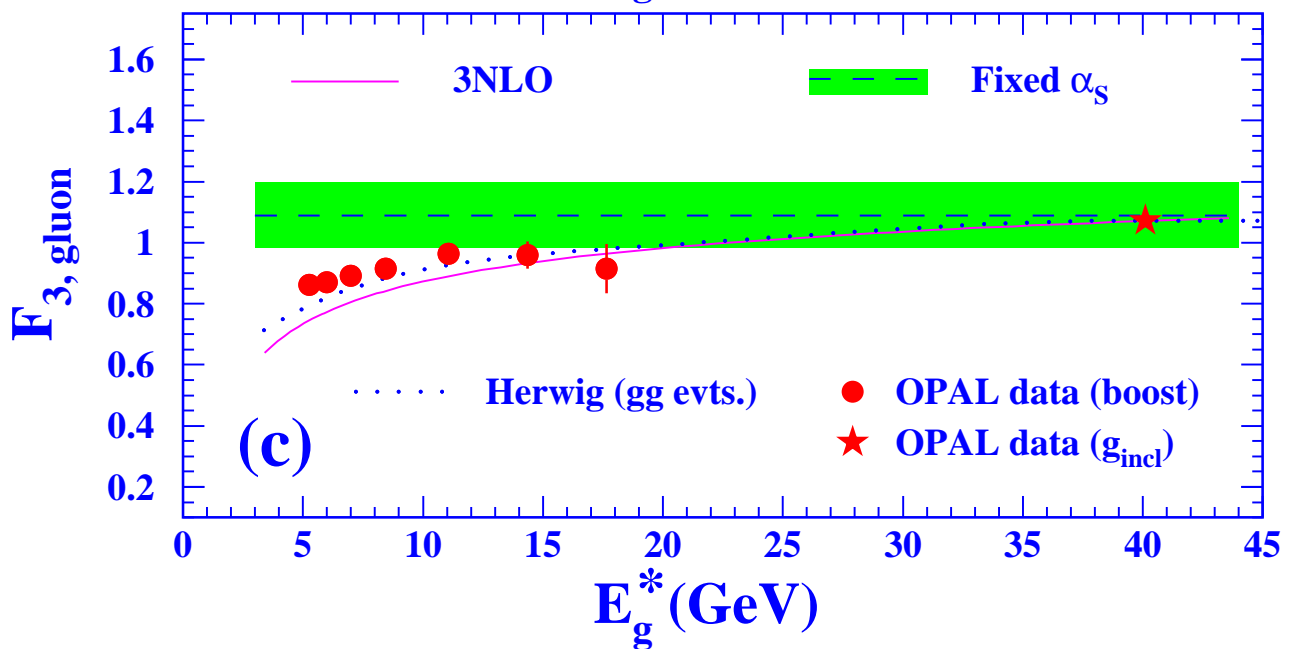
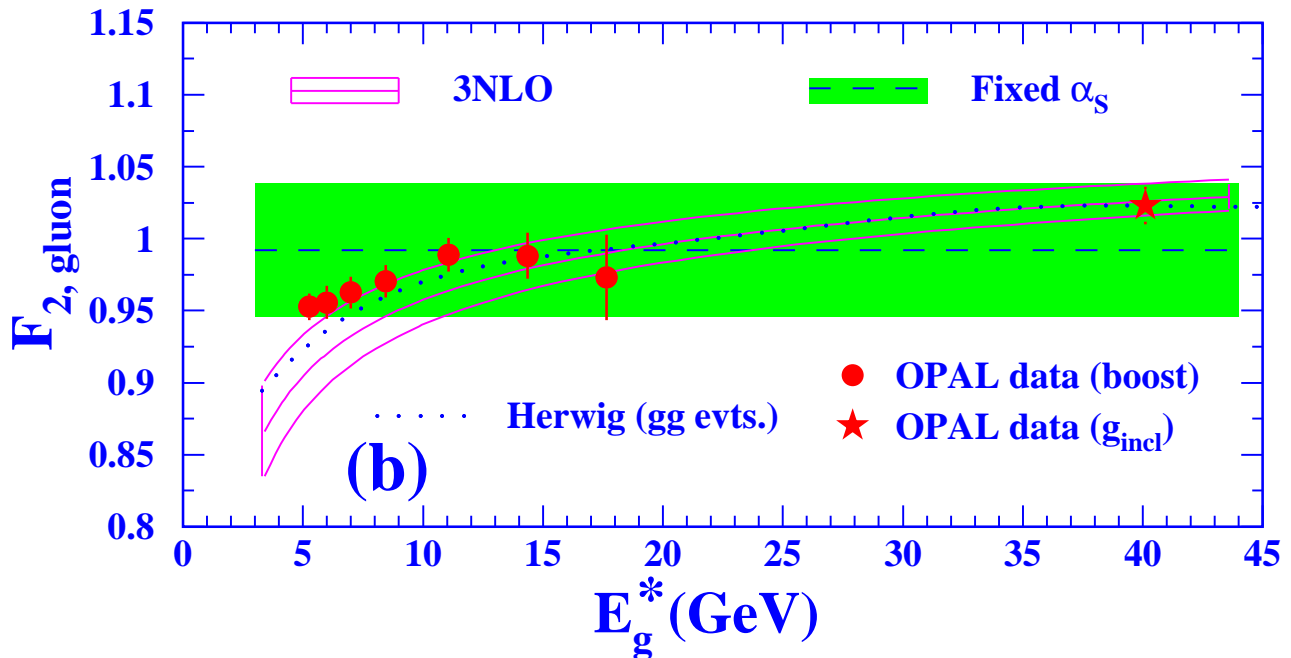
- We tested the boost algorithm using Herwig Monte Carlo
- We compared results of Boost method with unbiased gluon jets from color singlet *gg events*
- MULTIPLICITY :
 - good agreement for $E_g^* > 5 \text{ GeV}$
 - measurement of multiplicity distributions in seven intervals of energy between 5.25 and 17.72 GeV
- FRAGMENTATION FUNCTION :
 - good agreement $E_g^* > 14 \text{ GeV}$
 - 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 $5.25 < E_g^* < 20\text{GeV}$
- Theoretical expressions **successfully fitted** to experimental data:
 - **3NLO** : takes into account the running nature of α_S
 - **Fixed** α_S : incorporates more accurately higher order effects

Results : factorial moments

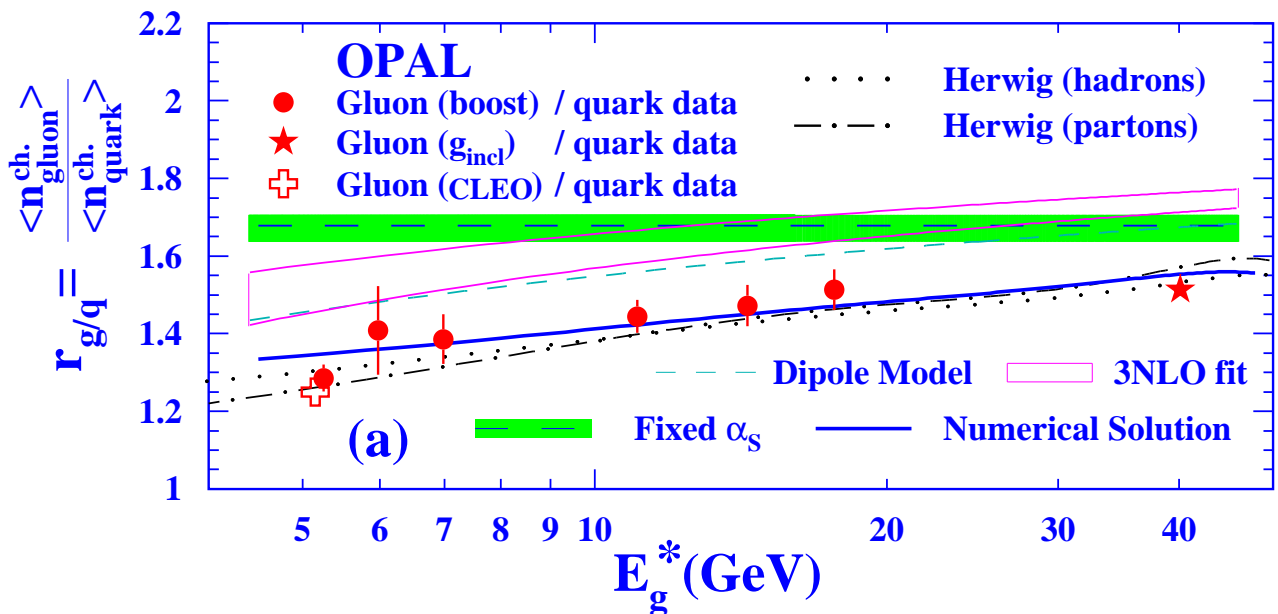


Results : factorial moments

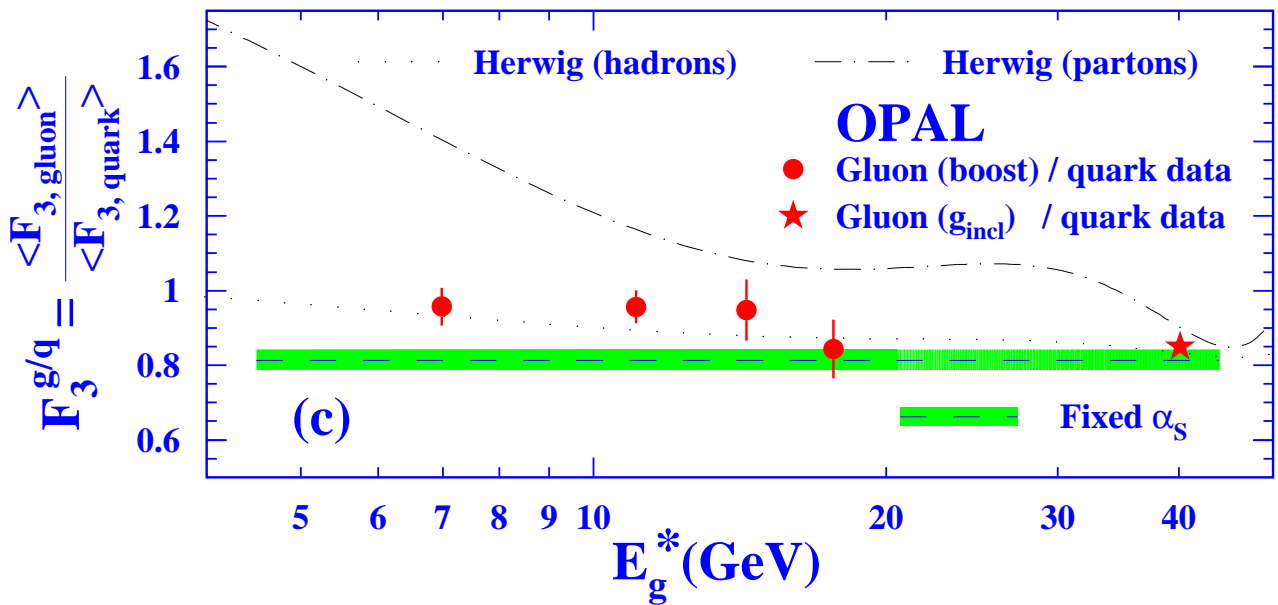
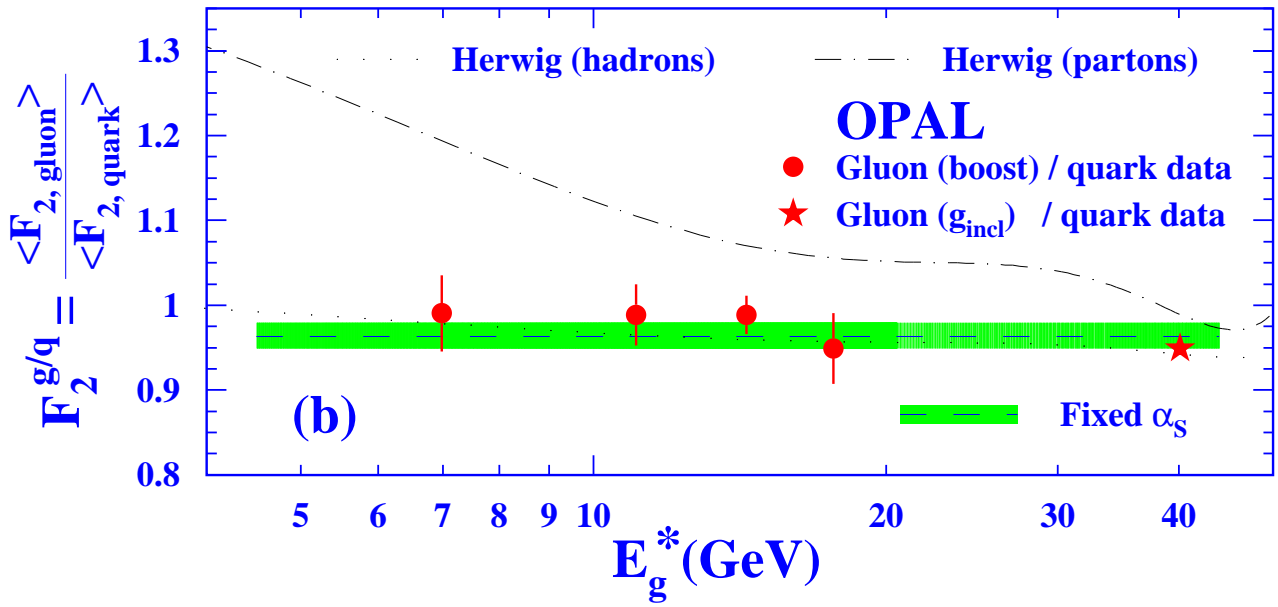
- First measurement of F_2 and F_3 for unbiased gluon jets over an energy range
- 3NLO expression fitted to three highest energy data points:
 - reasonable description of $F_{2,gluon}$ and $F_{3,gluon}$ energy evolution above 14 GeV.
 - lower energies: predictions lie below the data.
 - discrepancy at low energies possibly due to hadronization effects
- Fixed α_S prediction :
 - general agreement with the data for $F_{2,gluon}$ (but fairly large theoretical uncertainties)
 - lies above the data for $F_{3,gluon}$ except for $E_g^* \approx 40 GeV$

Results : Multiplicity Ratio

- **Quark contribution**: inclusive $e^+e^- \rightarrow q\bar{q}$ 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

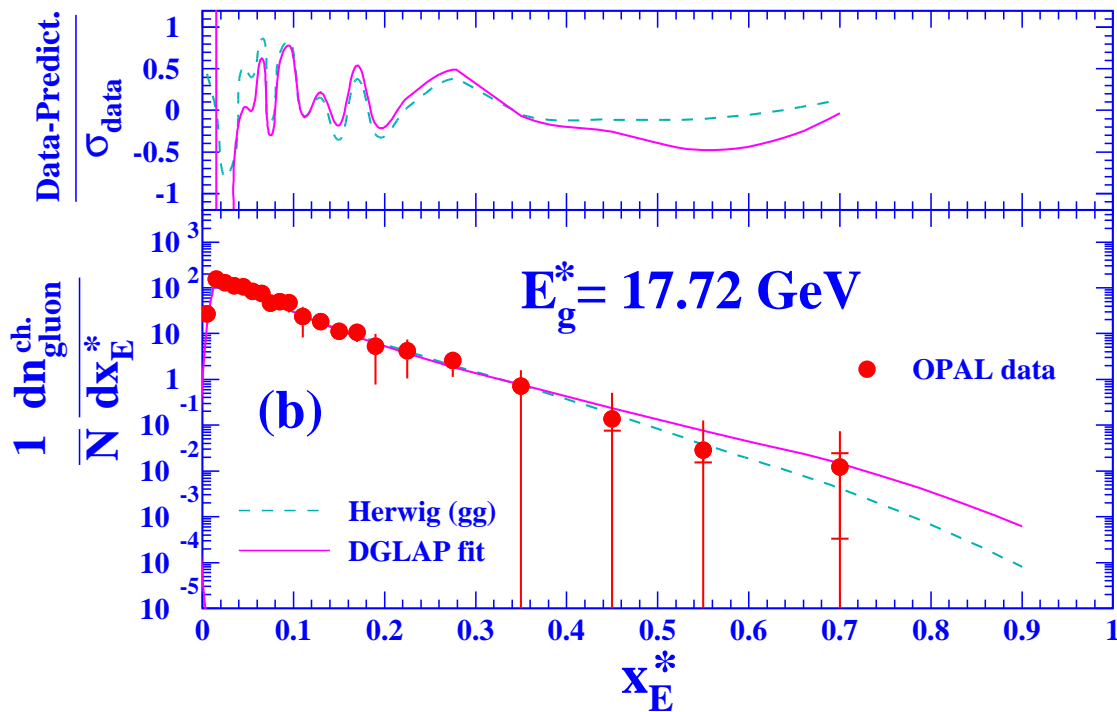
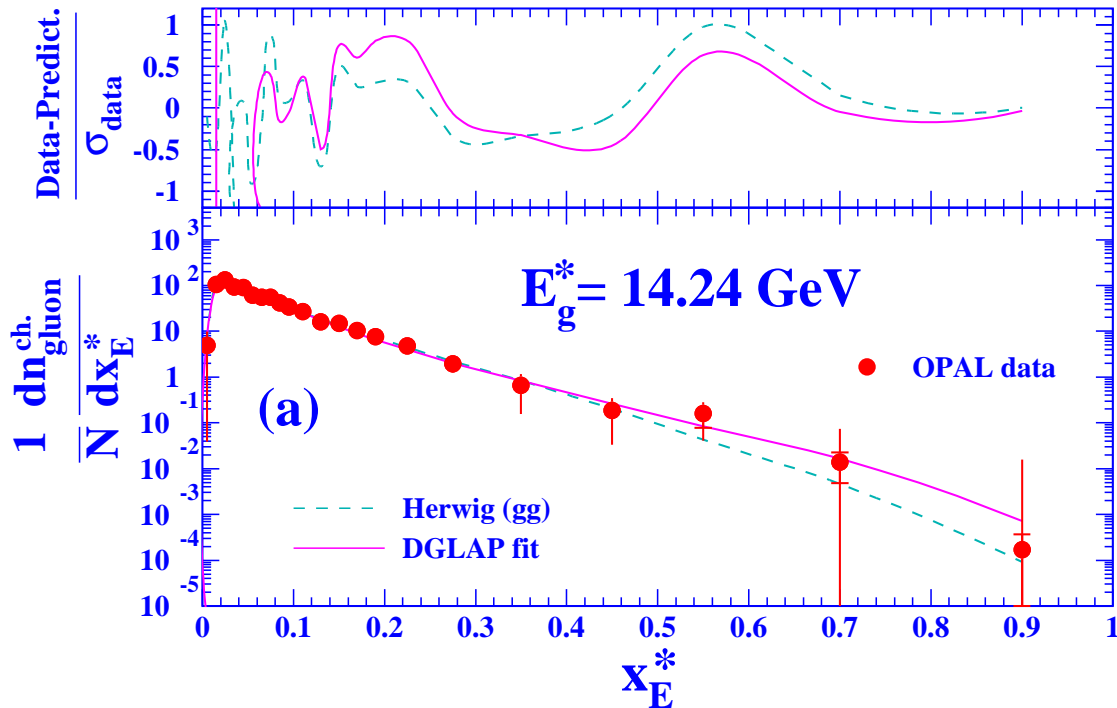


- Fixed α_S prediction in general good agreement with the data.

HOWEVER

- Large hadronization effects ...

Results : Fragmentation Function



Results : Fragmentation Function

- The data have been fitted using the DGLAP evolution equation:
 - 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

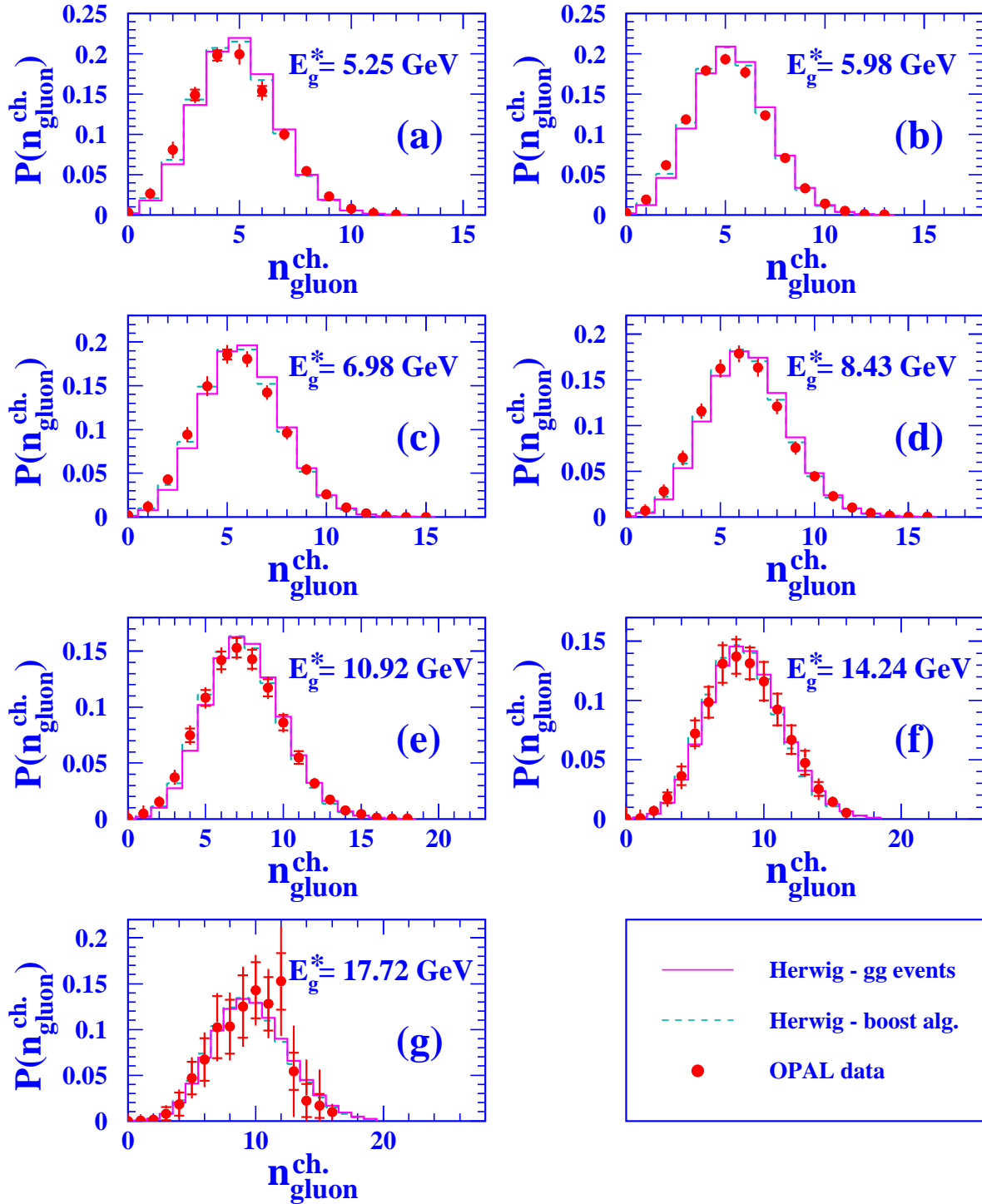
- Most precise measurement of unbiased gluon jet **mean multiplicity** in the range

$$5 < E_g^* < 20 \text{ GeV}$$

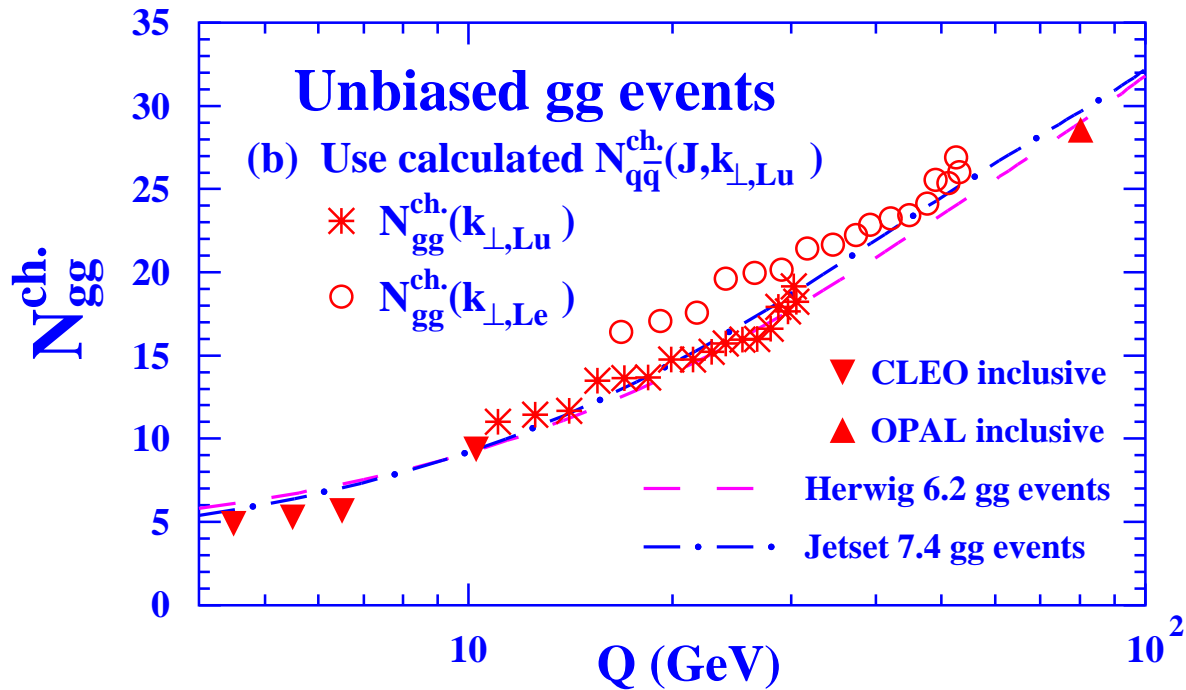
- First measurement of F_2 and F_3 for unbiased gluon jets over an energy range.
- First measurement of strong coupling constant from unbiased gluon jet fragmentation function

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

Test of Boost Algorithm: Multiplicity Distribution

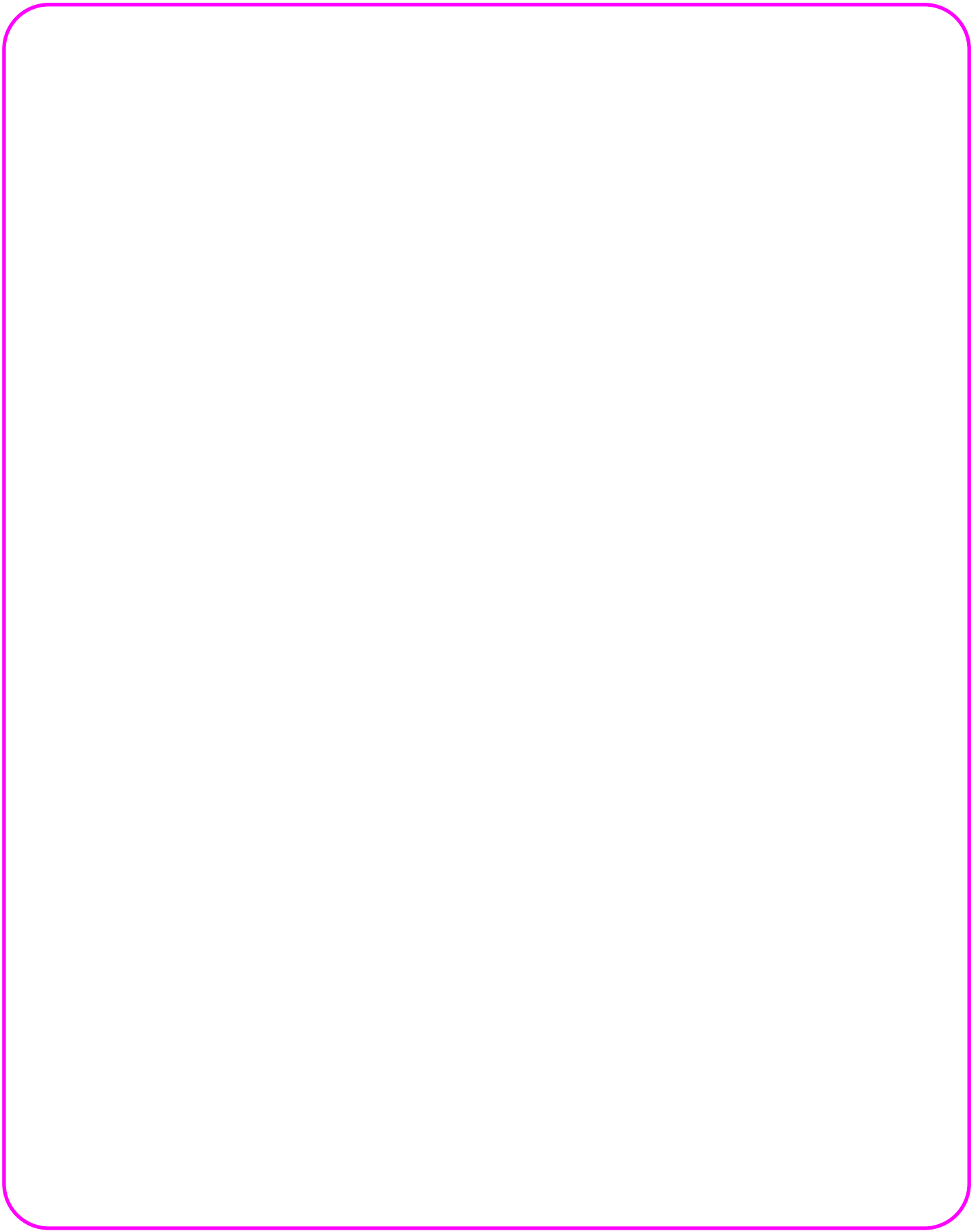


Lund and Leningrad scales



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 ($\pm 3\text{GeV}$) between 1993 and 2000 (3 dim. readout of silicon micro-vertex)
 - Standard multihadronic selection applied
 - High efficiency and almost no background contamination
- 3-jet configuration [forced](#) in each event using κ_{\perp} jet finder
- Energy of jets [recalculated](#) imposing energy-momentum conservation and [massless](#) kinematic
- Jets ordered in decreasing energy (Jet 1 → 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 $E_g^* > 5\text{GeV}$ (well defined gluon jet)
- Impose cut on k_{jet} of both quark jets, where k_{jet} :

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

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

- Improves the “quality” of three jet event
- Improves the purity of gluon jet
- $5 < E_g^* < 9.5\text{GeV}$ → Gluon jet purity above 80% : OK
- $E_g^* > 9.5\text{GeV}$ → Gluon jet purity below 80% : RETAG

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

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

Correction procedure

- Correction **procedure** :

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

- CHARGED MULTIPLICITY DISTRIBUTIONS:

→ 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:

→ Single bin-by-bin correction procedure ONLY