Measurement of charged particle multiplicities in gluon and quark jets.

Re-blessing

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Measurement at CDF

- At CDF, we always deal with a mixture of quark and gluon jets:

  $N = n_g N_g + n_q N_q$, where N is <u>multiplicity per jet</u>

- Dijet and photon-jet events have different fractions of gluon jets **:**

$$N_{jj} = n_g^{jj} N_g + (1-n_g^{jj}) N_q$$
$$N_{\gamma j} = n_g^{\gamma j} N_g + (1-n_g^{\gamma j}) N_q$$

- Provided one knows n_g^{jj} and $n_g^{\gamma j}$, the ratio $N_{jj}/N_{\gamma j}$ allows to extract the ratio of multiplicities in gluon and quark jets $r = N_g/N_q$.

$$N_{jj}/N_{\gamma j} = (n_g^{jj}\, r + (1- n_g^{jj})) \,/\, ((1-n_g^{\gamma j}) r + (1-n_g^{\gamma j}))$$

- Caveat: gamma-jet events have a fraction of fake gammas, i.e. they have a fraction ε of jet-jet events:

$$N_{\gamma j} = (1-\varepsilon)(n_g^{\gamma j} N_g + (1-n_g^{\gamma j}) N_q) + \varepsilon N_{fake}$$

Final Formula

$$r = 1 + \frac{\alpha + \varepsilon_{\gamma}(\alpha - 1) - \dfrac{N_{\gamma j}}{N_{jj}}}{n_g^{jj}\dfrac{N_{\gamma j}}{N_{jj}} - \varepsilon_{\gamma}\, n_g^{real\,\gamma j} - (1 - \varepsilon_{\gamma})\alpha\, n_g^{jj}}$$

$N_{\gamma j}$ - multiplicity in "photon"-jet sample(including fakes)

N_{jj} - multiplicity in jet-jet sample

ε_{γ} - fraction of real photons in photon-jet sample

n_g^{jj} - gluon fraction in jet-jet sample(CTEQ4M)

$n_g^{real\,\gamma j}$ - gluon fraction in 100% pure γ-jet sample (CTEQ4M)

α - correction factor due to fakes(ratio of multiplicities of a jet opposite to fake and a regular jet)

Multiplicity in gluon and quark jets

- The same set of equations allows to measure the charged particle multiplicities in gluon and quark jets:

$$N_{jj} = n_g^{jj} N_g + (1-n_g^{jj}) N_q$$

$$N_{\gamma j} = (1-\varepsilon)(n_g^{\gamma j} N_g + (1-n_g^{\gamma j}) N_q) + \varepsilon N_{fake}$$

Gluon jet multiplicity:

$$N_g = \frac{r N_{jj}}{n_g^{jj}(r-1)+1}$$

Quark jet multiplicity:

$$N_q = \frac{N_{jj}}{n_g^{jj}(r-1)+1}$$

Final results

- **These results were blessed at Jan 10 , 2003.**

CDF PRELIMINARY

Jet Energy	**40 GeV**	**53 GeV**
Jet multiplicity in dijet events, N_{jj}	5.99±0.03	6.88±0.04
Jet multiplicity in "photon"+jet events, $N_{\gamma j}$	5.28±0.04	5.92±0.08
Fraction of gluon jets in dijet events, n_g^{jj}	0.612±0.006	0.585±0.008
Fraction of gluon jets in pure γ-jet events, $n_g^{\gamma j}$	0.216±0.009	0.256±0.015
Fraction of real photons in "photon"+jet events, ε_γ	0.74±0.04	0.90±0.07
α-correction, $\alpha = N_{fake\text{-}jet} / N_{jj}$	1.046±0.013	1.029±0.022
Multiplicity in gluon jets, N_g	***7.02±0.08±0.80***	***8.25±0.14±0.93***
Multiplicity in quark jets, N_q	***4.36±0.12±0.57***	***4.95±0.19±0.79***
Ratio of multiplicities, $r = N_g / N_q$	***1.61±0.08±0.16***	***1.67±0.13±0.26***

Final results

CDF PRELIMINARY

Momentum-dependent ratio. The results were blessed at Jan 10, 2003

ξ	$r(\xi)$	Stat. error	Syst. error
0.25	0.57	0.52	0.55
0.75	0.50	0.14	0.35
1.25	1.04	0.16	0.12
1.75	1.39	0.15	0.36
2.25	1.61	0.17	0.30
2.75	1.78	0.16	0.45
3.25	1.72	0.16	0.28
3.75	1.93	0.22	0.54
4.25	1.76	0.23	0.40
4.75	1.74	0.37	0.56

Remaining question from the blessing: energy scale for multiplicity evolution.

- **Energy scale in theory**.
  - — Always only two jets
  - — Multiplicity of partons is given for the small cone, θ_c, around jet direction
  - — Energy scale for multiplicity evolution: $Q=E_{jet}\,\theta_c$
  - — Multiplicity of hadrons: $N_{hadrons}=K*N_{partons}(Q;\, Q_{cutoff}/\Lambda)$, where **K** is normalization constant which is the same for quark and gluon jets, Q_{cutoff} is perturbative cascade cut-off (can be taken as low as Λ).
  - — For the case of big cones, energy scale is: $Q=2E_{jet}\sin(\theta_c/2)$
  - — Inclusive multiplicity in $e^+e^- \rightarrow hadrons$ is given by:

    $N_{incl}=2N_{quark}(Q,\, \theta_c\sim\pi;\, Q_{cutoff}/\Lambda)= 2N_{quark}(2E_{jet};\, Q_{cutoff}/\Lambda)$

    $\Rightarrow$ *the scale for inclusive multiplicity (all particles in hemisphere) in jet is* $2E_{jet}$

Remaining question from the blessing: energy scale for multiplicity evolution.

- **Energy scale for experimental results.**

- **CDF: Q=$E_{jet}\,\theta_c$** where **θ_c=0.47**
- **Inclusive multiplicity: Q=2E_{jet}**
  CLEO-95 and OPAL 96-99 results only

- **Unbiased gluon jets from 3-jet events**
  Two scales proposed (hep-hp/9904455)
  OPAL 2001 (hep-ex/0111013)

$$p_{\perp,Lu} = \sqrt{\frac{s_{qg}s_{\bar{q}g}}{s}}$$

$$p_{\perp,Le} = \sqrt{\frac{s_{qg}s_{\bar{q}g}}{s_{q\bar{q}}}}$$

- **Biased quark and gluon jets from 3-jet events**
  No single scale… Results can't be directly compared with theory!
  All other results from e^+e^- machines (HRS, SLD, ALEPH, DELPHI, OPAL 91-96)

Plot for Re-blessing

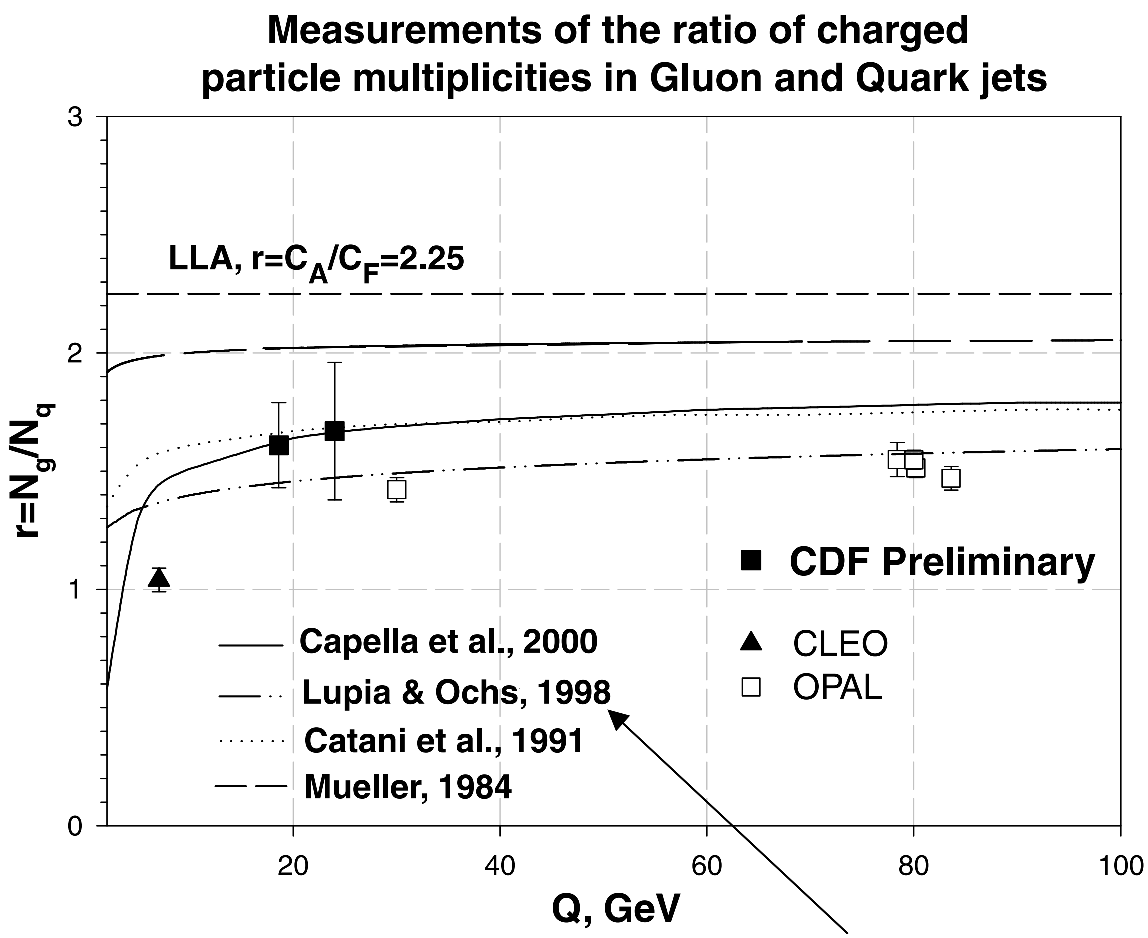
- Comparison of CDF results on ratio, $r=N_g/N_q$, with theory and unbiased experimental results.

- CDF vs. (OPAL & CLEO)
  Differences:

— Particles from K°_s, and Λ decays (CLEO & OPAL)

— u,d,s,c-quarks (CLEO)

— Higher fraction of s-quarks (OPAL)



Numerical solution

Plot for Re-blessing

- **"Propaganda" plot.**

  The purpose is to show the evolution of measurements

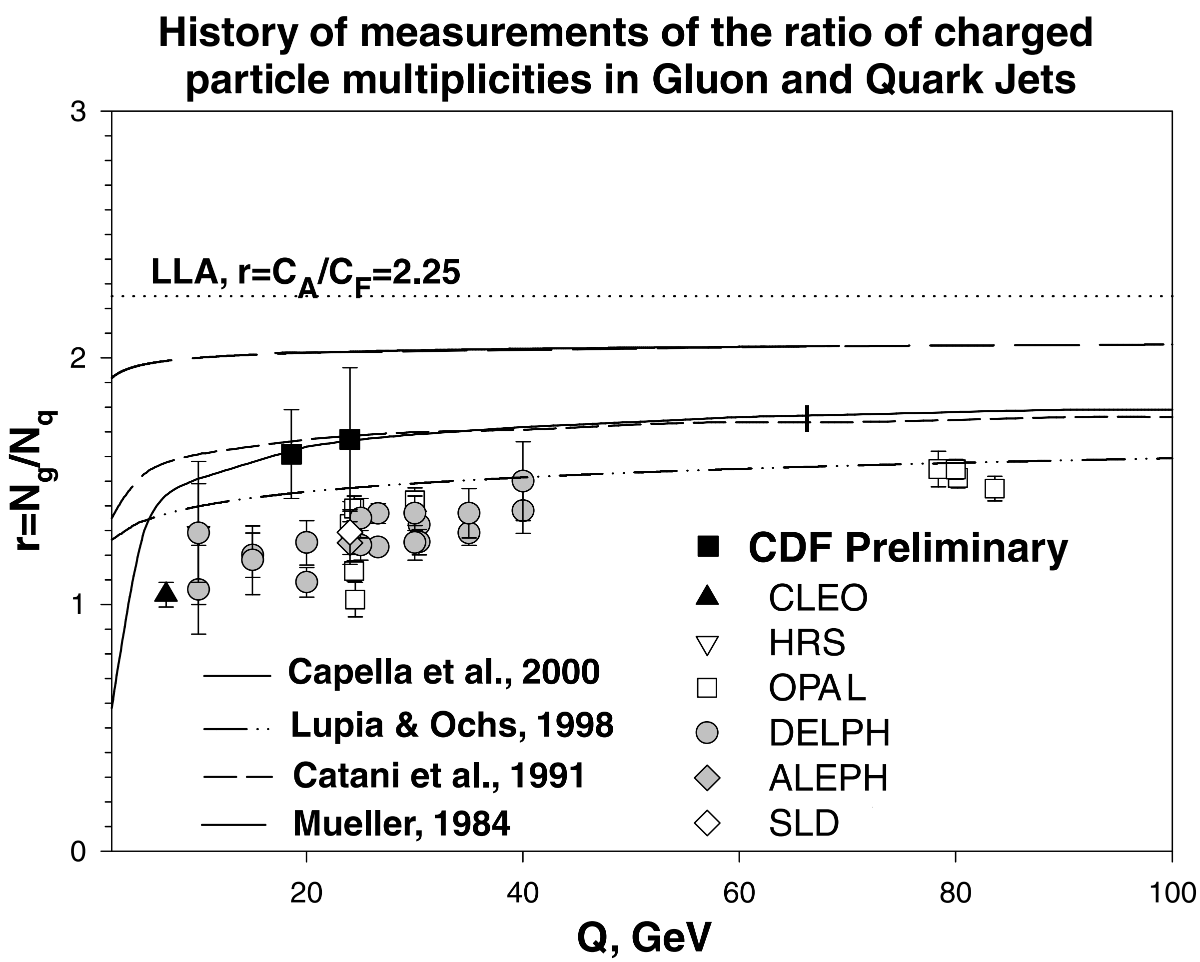
- Problems of early LEP measurements:

— bias due to jet finder

— no direct correspondence to theory

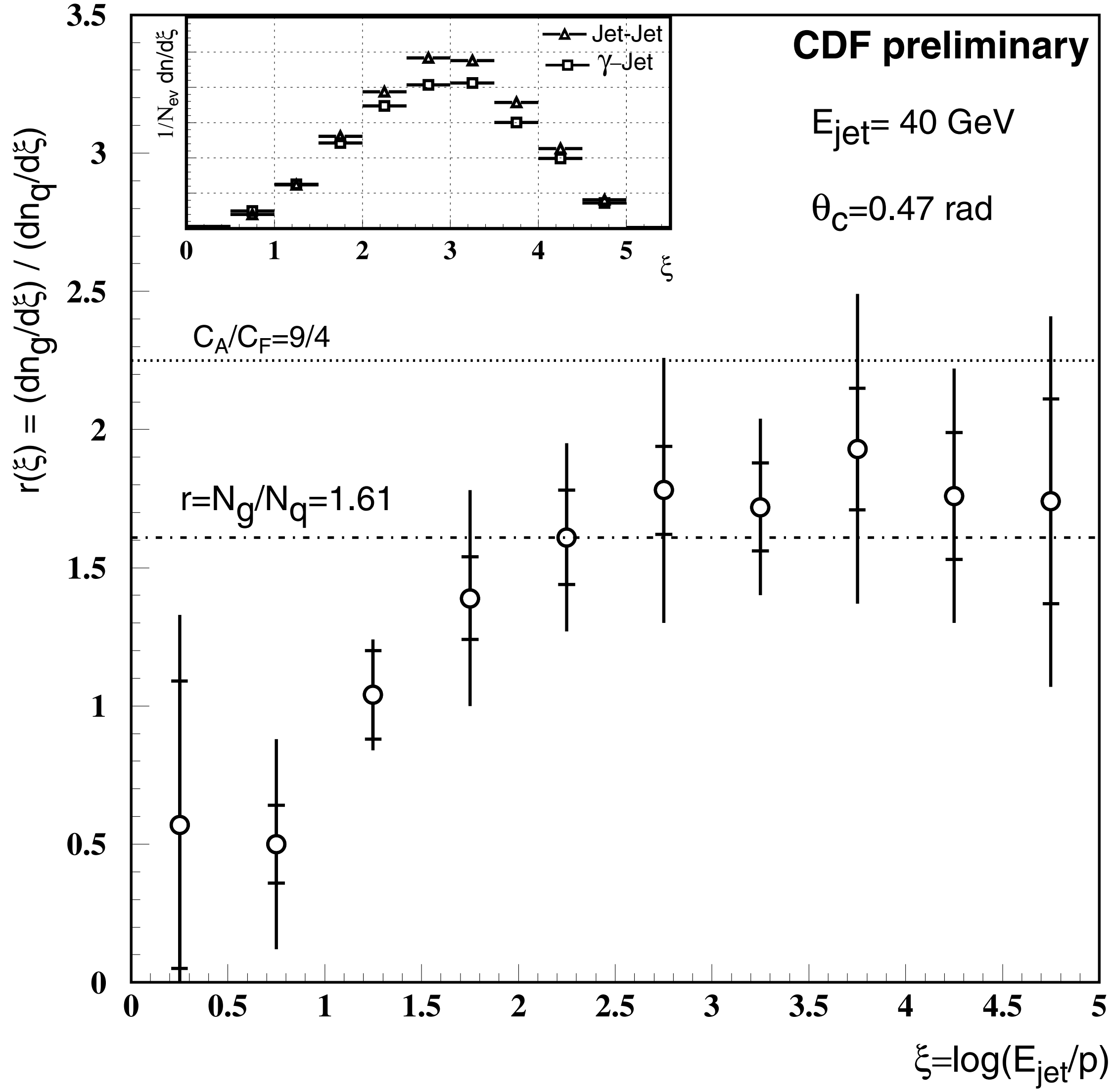
— heavy flavor quarks are included

— etc.



Plot for Re-blessing

- Momentum-dependent ratio.



Plot for Re-blessing

- **Momentum-dependent ratio: comparison to OPAL-99 results.**

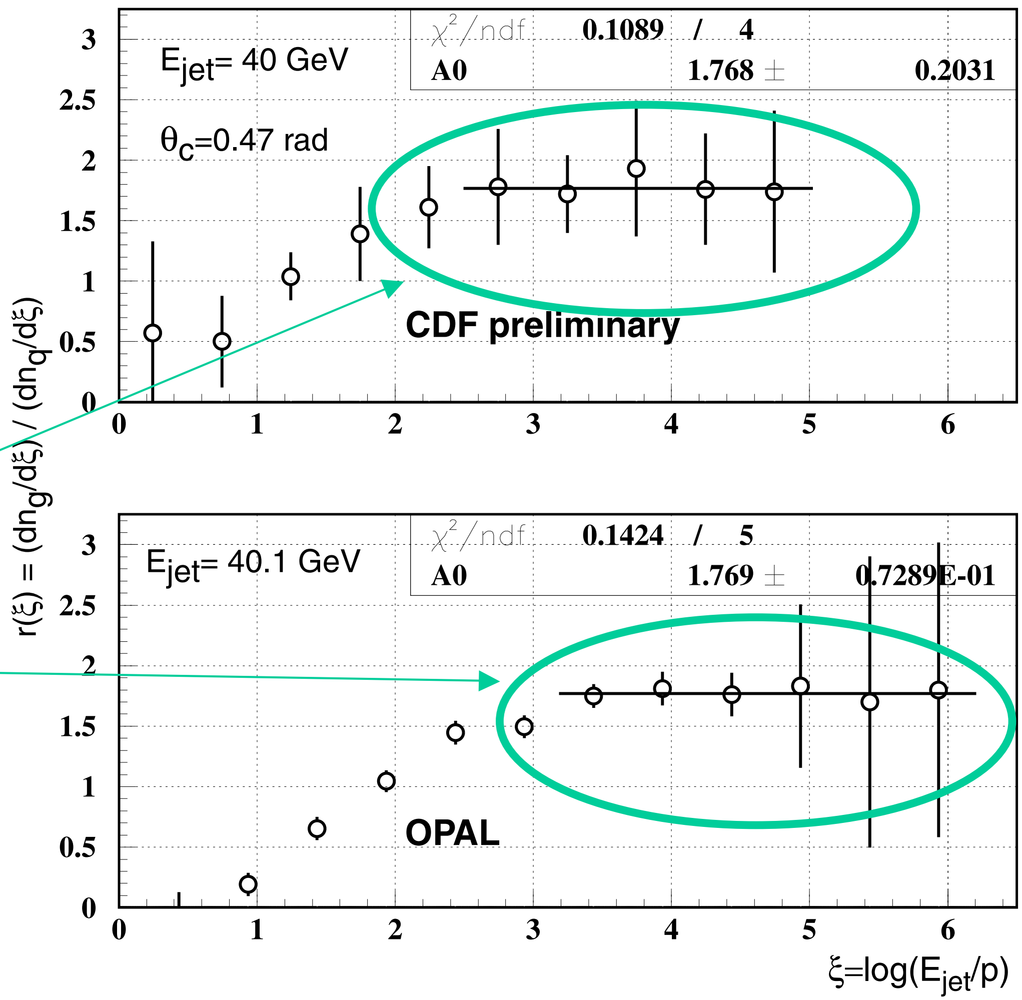
The same jet energies,

different scales: 18 GeV vs. 80 GeV

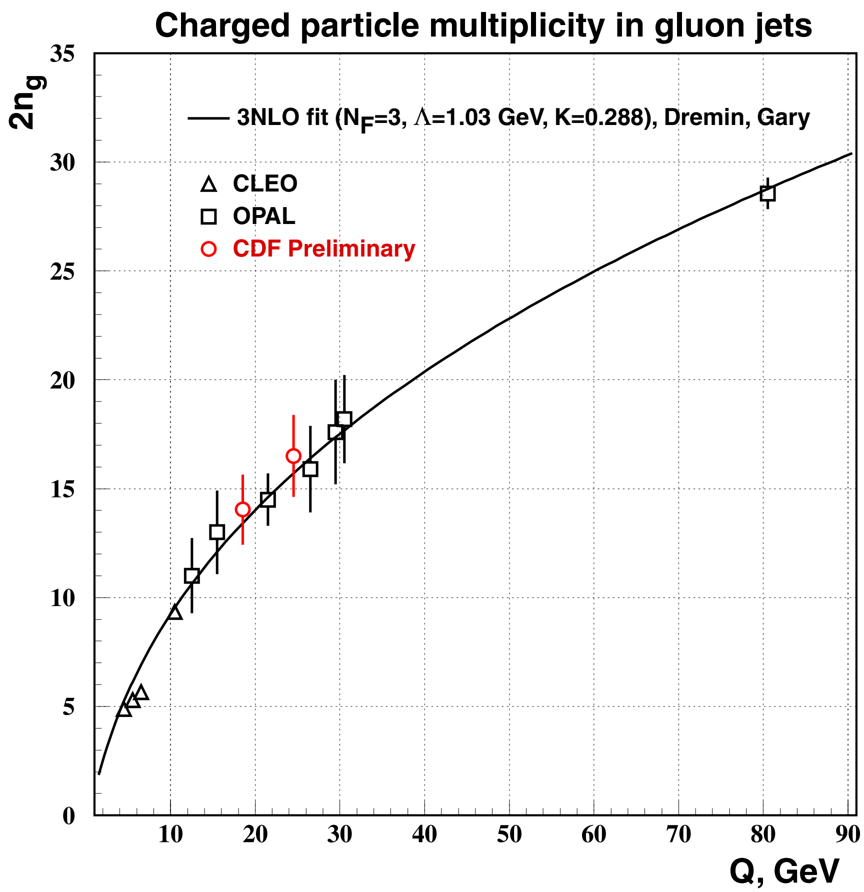
Theory predicts that there should not be difference for soft particles!

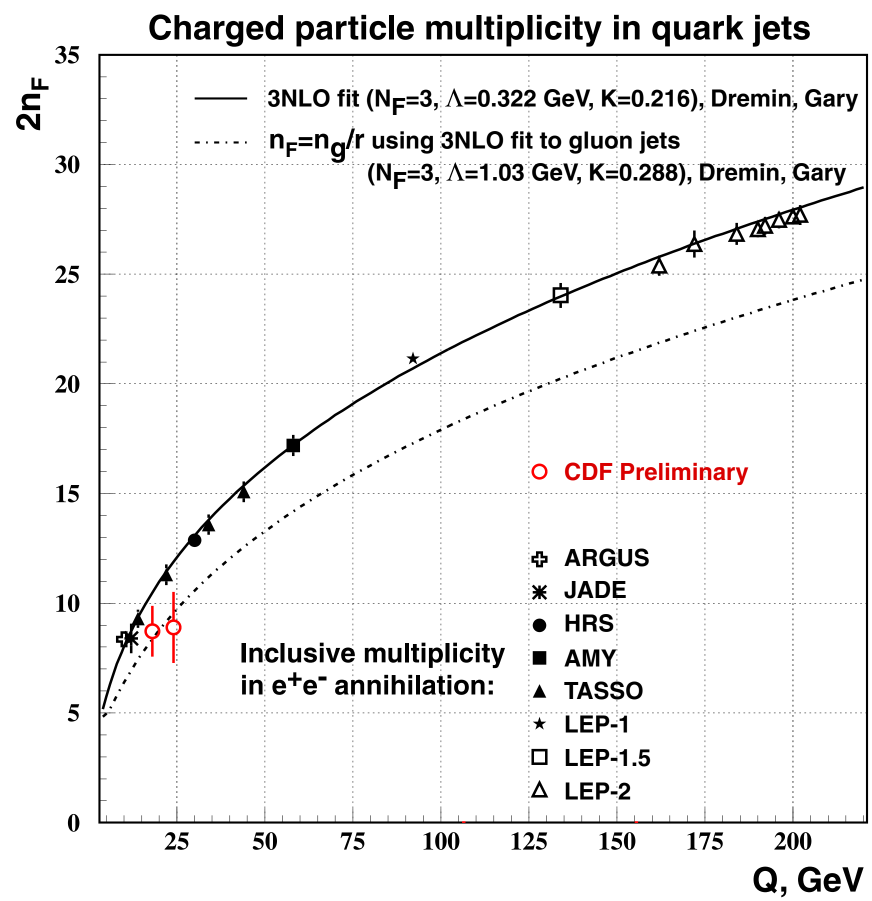
Soft particles

OPAL results were quoted for log(p)-dependence.



Plot for Re-blessing





- Comparison of multiplicity in gluon and quark jets.

Plot for Re-blessing

- It's the same plot as on slide 12