Study of Rapidity Gap Events in Hadronic Z Decays with the L3 detector

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XXXVIIth Rencontres de Moriond (2002)

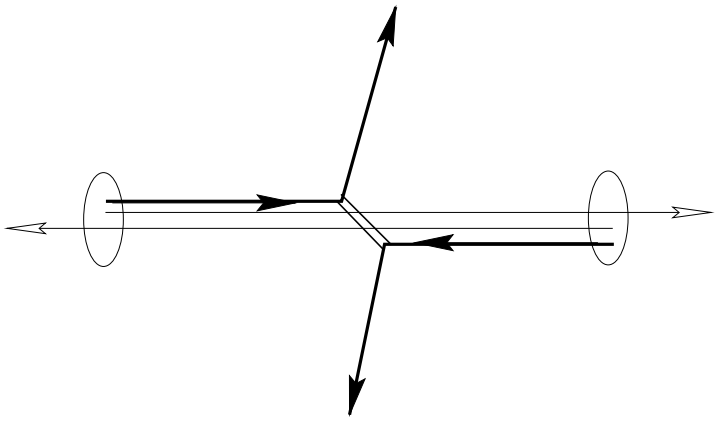
- Introduction
- QCD Models
- Methodology
- Data
- Gluon Jet Identification
- Results
- Summary

Introduction

- 10% of di-jet events from ep collisions have a large rapidity gap (HERA)
- 1% of events with 2 High E_T jets have a large rapidity gap in $p\bar{p}$ collisions (TEVATRON)

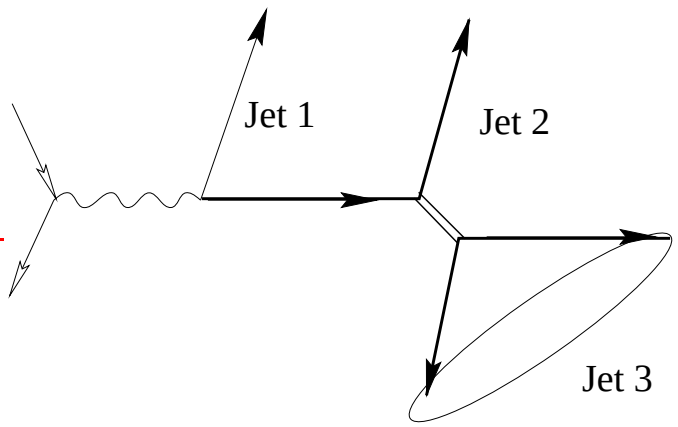
Possible Explanation: *Colour singlet exchange*

$p\bar{p}$:



Colour singlet exchange in hadronic Z decays?

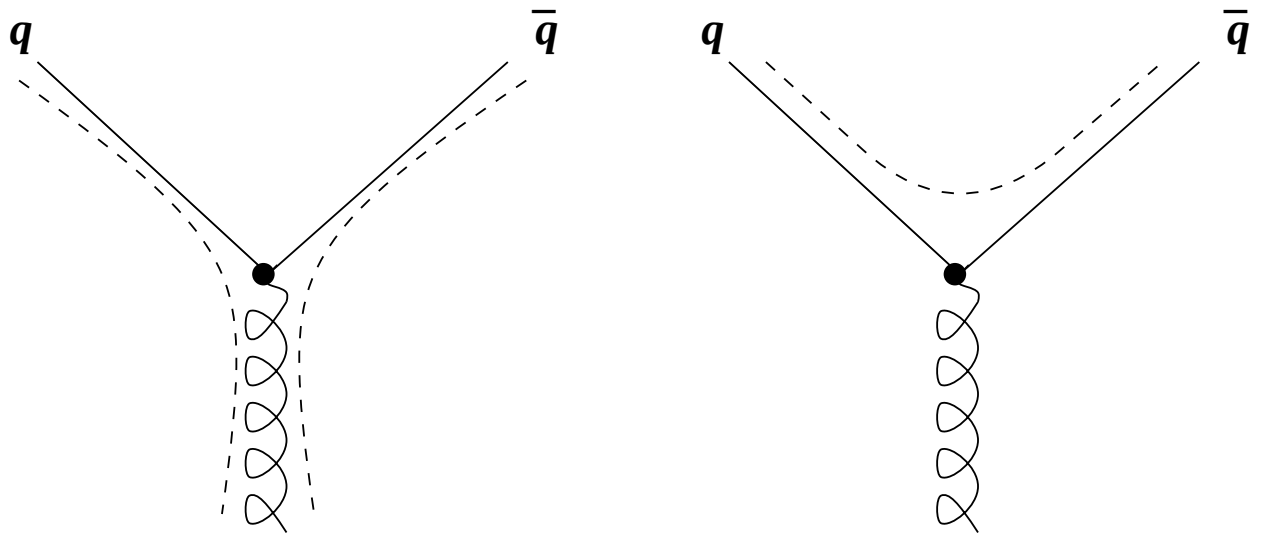
e^-e^+ :



Study Gaps in 3 jet events in e^-e^+ annihilation

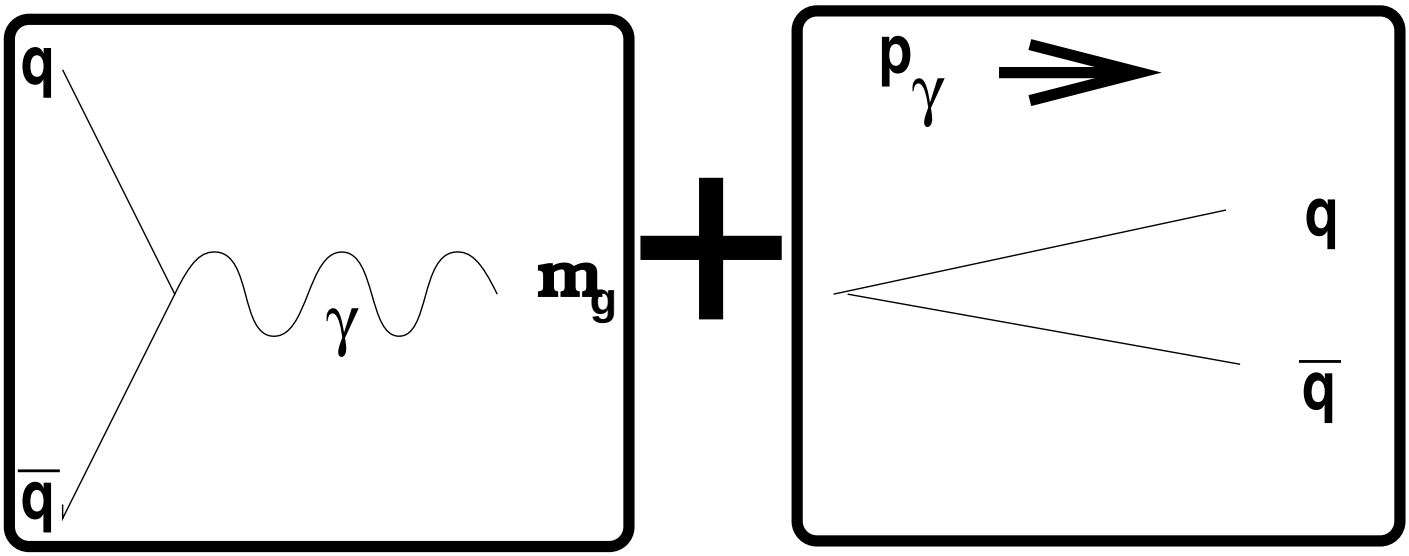
- Clean environment ⇒ No underlying *minimum bias* event
- Not plagued by "gap survival probability" ($\sim$ 20% in $p\bar{p}$)

QCD Models



Colour Octet *Colour Singlet*

- Colour octet simulated using JETSET Parton Shower program
- Model colour singlet exchange as:



OPTION	Nature of Fragmentation
CS0	$q\bar{q}$ generated in gluon rest frame, boosted back to the overall CMS, then usual parton shower.
CS2	The gluon is fragmented as a single jet.

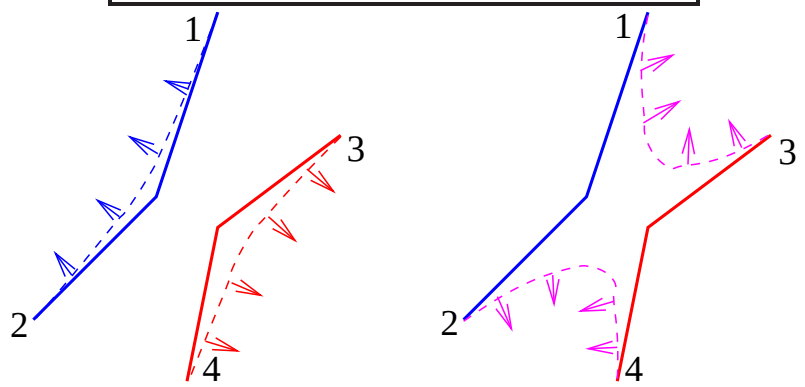
QCD Models

Rathsman Model: based on Generalised Area Law (J. Rathsman, Phys. Lett. **B452** (1999) 364)

"Area" of string between partons i, j $A_{ij} = 2\,(p_i p_j - m_i m_j)$

String-reinteraction probability: $P = R_0\,[1 - \exp(-b \cdot \Delta A)]$

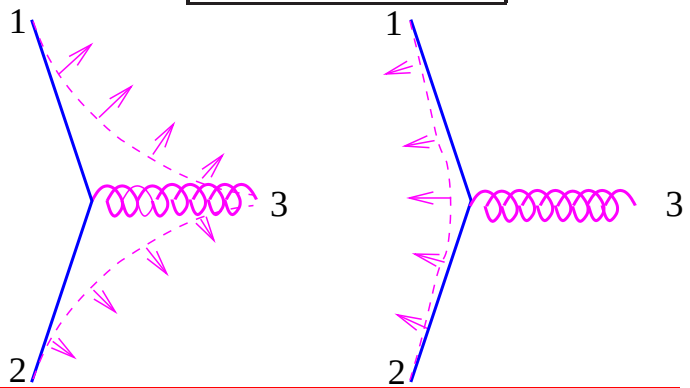
$e^- e^+ \to W^- W^+ \to q\bar{q}q\bar{q}$



$\Delta A = (A_{13} + A_{24}) - (A_{12} + A_{34})$

$\Rightarrow$ shift in W-mass $\sim \mathcal{O}$ (65 MeV)

$e^- e^+ \to q\bar{q}g$



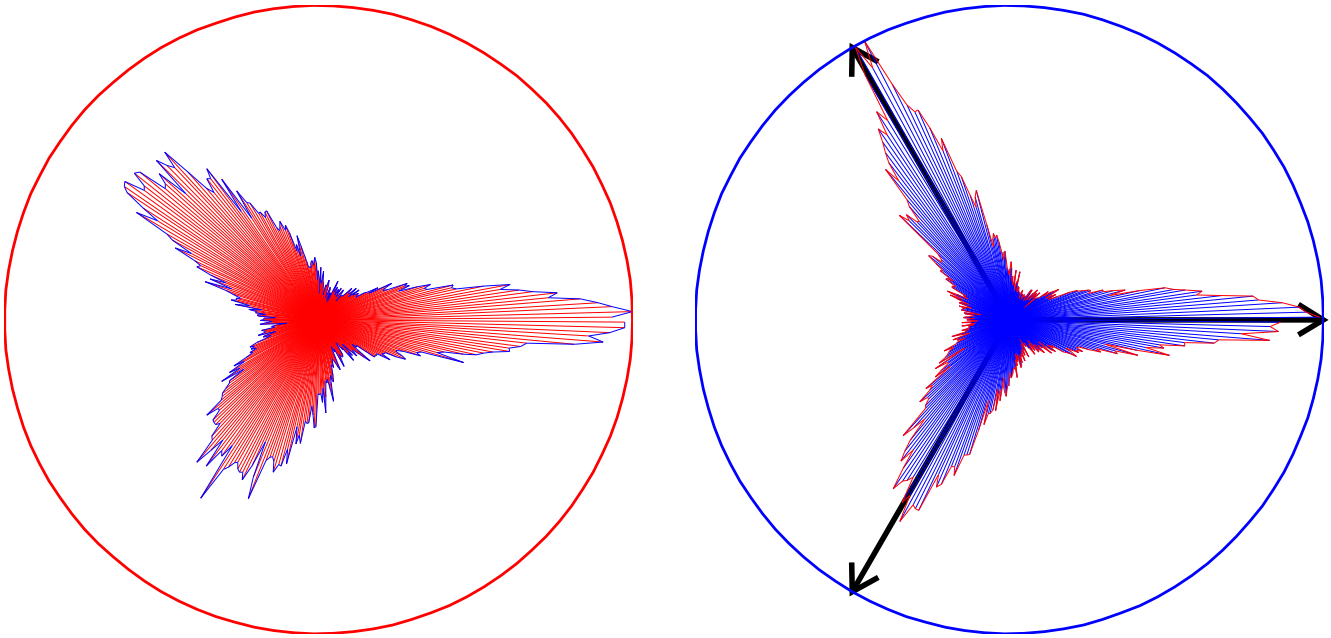
$\Delta A = A_{12} - (A_{13} + A_{23})$

$\Rightarrow$ Colour singlet exchange

☞ Fragmentation Parameters *tuned* for $R_0 = 0.037, 0.1, 0.2$

Methodology

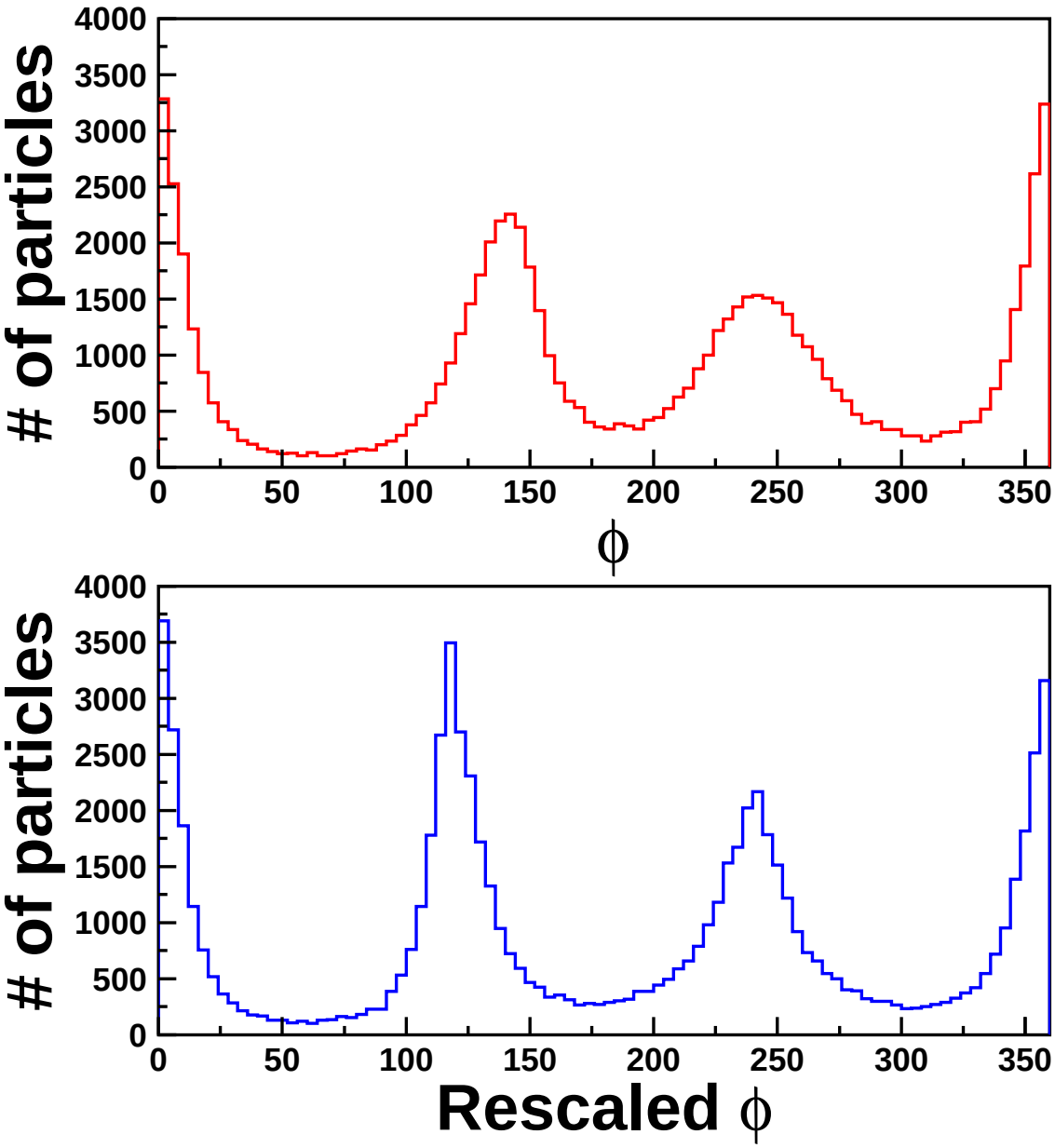
- Apply a jet algorithm (Use JADE as default and DURHAM for systematics) at fixed y_{cut} value(s)
- Select 3-jet event and demand symmetric configuration by imposing cuts on jet separation angles
- Define *event plane* by the 2 most energetic jets with the most energetic jet along x-axis
- Project the particle momenta in the event plane
  $\Rightarrow$ *Flower Plot*



- For event-by-event comparison, *rescale angles* so as to align the 3-jet axes along $0°$, $120°$, $240°$

Methodology

More conventionally:



➠ Study particle flow in the "Gaps" (inter-jet regions)

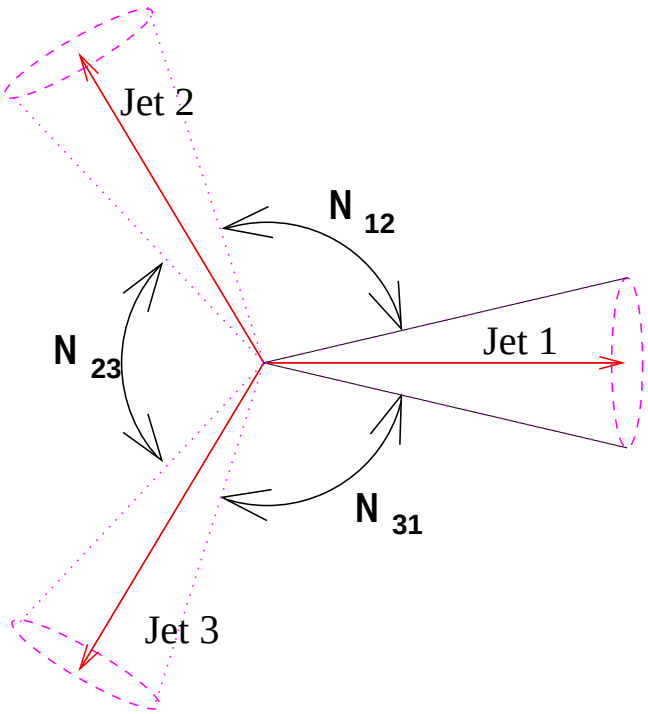
➥ To reduce effects from fragmentation fluctuations, ignore core of the jet defined by a cone around the 3 jet directions

➥ Two cone definitions are used: Half angles of 15°, 20°

Methodology

☛ For remaining particles in the gaps:

Number of particles in GAP:
N_{ij} $(i,j = 1,3)$

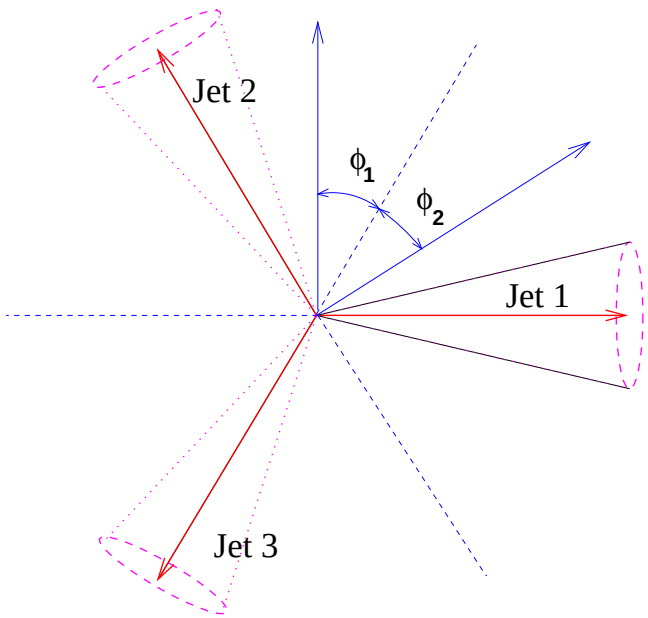


Particle Asymmetry in GAP 12:

☛ $A_{12}^{N} = \frac{-N_{12}+N_{23}+N_{31}}{N_{12}+N_{23}+N_{31}}$

Similarly, define A_{23}^{N} and A_{31}^{N}

Angle from the bisector in GAP between jets 1 and 2:
$B_{12} = \text{Min}(\phi_1,\phi_2)$



Angular Asymmetry for bisector-angle in GAP 12:

☛ $A_{12}^{B} = \frac{-B_{12}+B_{23}+B_{31}}{B_{12}+B_{23}+B_{31}}$

Similarly, define A_{23}^{B} and A_{31}^{B}

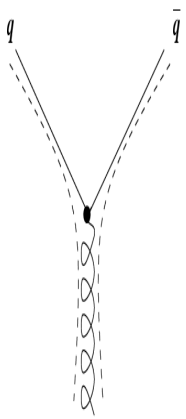
Alternative Gap Angle definition:
Maximum separation angle between adjacent particles S_{ij}
☛ Similarly, define A_{12}^{S}, A_{23}^{S} and A_{31}^{S}

Methodology

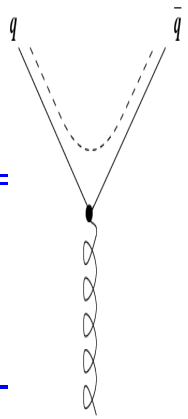
Colour Flow $\Rightarrow$

- More particles (N)
- Smaller angular separation (Gap angle B & S)

Jets Ordered: Primary quarks in first 2 jets



OCTET	SINGLET
$N_{23} \approx N_{31} > N_{q\bar{q}}$ $A^N_{23} \approx A^N_{31} < A^N_{q\bar{q}}$	$N_{23} \approx N_{31} < N_{q\bar{q}}$ $A^N_{23} \approx A^N_{31} > A^N_{q\bar{q}}$
$B_{23} \approx B_{31} < B_{q\bar{q}}$ $A^B_{23} \approx A^B_{31} > A^B_{q\bar{q}}$	$B_{23} \approx B_{31} > B_{q\bar{q}}$ $A^B_{23} \approx A^B_{31} < A^B_{q\bar{q}}$
$S_{23} \approx S_{31} < S_{q\bar{q}}$ $A^S_{23} \approx A^S_{31} > A^S_{q\bar{q}}$	$S_{23} \approx S_{31} > S_{q\bar{q}}$ $A^S_{23} \approx A^S_{31} < A^S_{q\bar{q}}$

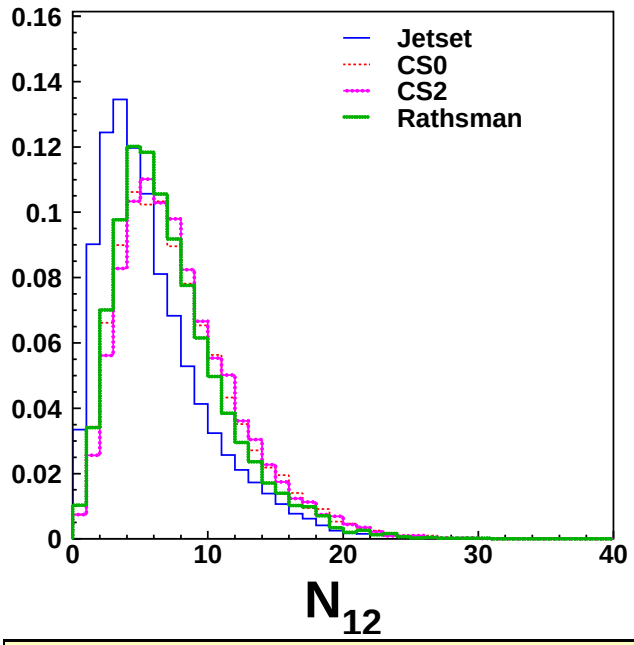


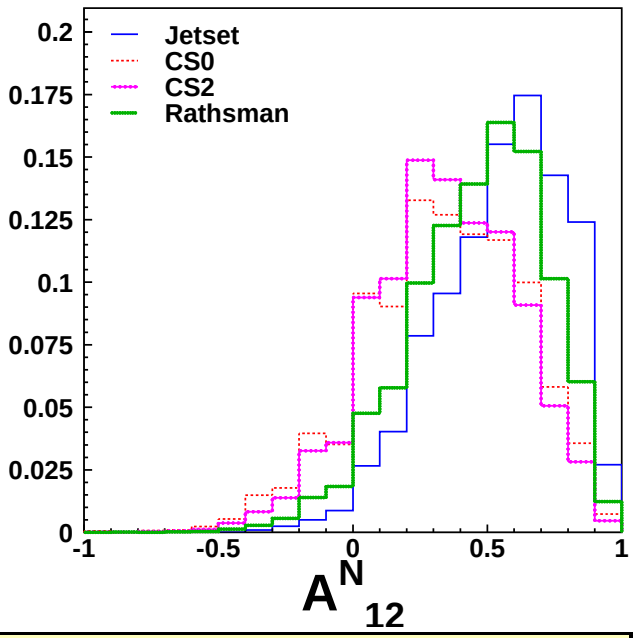
<No. of particles>

	Jetset	CS 0	CS 2	Rathsman (.1)
Total	56.6	54.2	54.8	58.0
$q\bar{q}$ Gap (15° cone)	5.5	7.3	7.4	6.8
Other Gap (15° cone)	9.1	7.3	7.2	9.2
$q\bar{q}$ Gap (20° cone)	4.1	5.7	5.8	5.3
Other Gap (20° cone)	7.3	5.7	5.8	7.4

Methodology

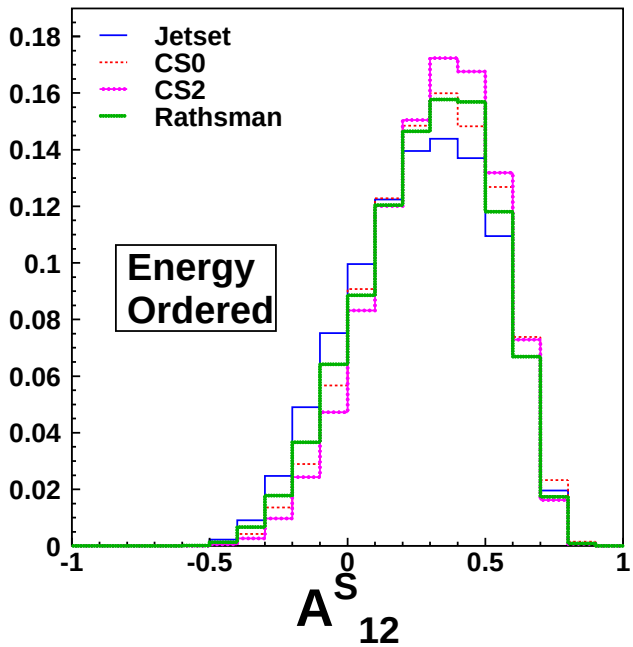
Particle Flow Asymmetry:

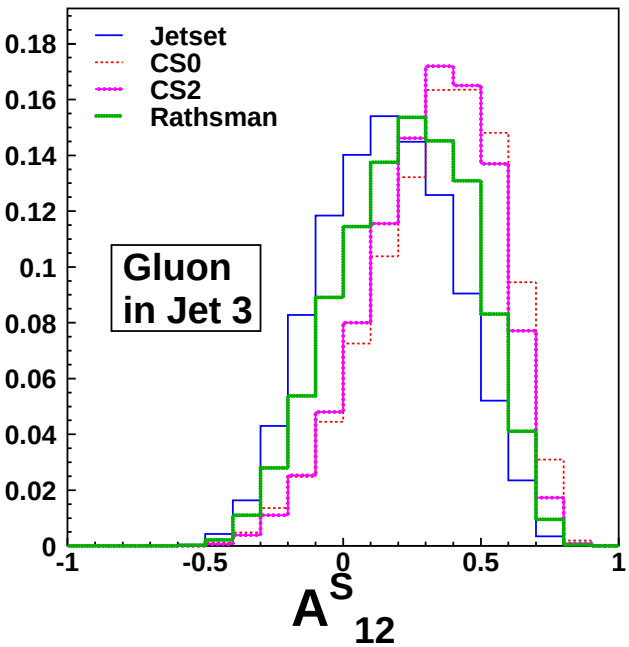




Asymmetries are sensitive to colour singlet exchange

Separation-angle Asymmetry:





Gluon purity in the third jet improves sensitivity

Data

- *Integrated luminosity*: Lum $= 75.1\mathrm{pb}^{-1}$ (1994+1995)
- *Hadronic Event Selection using*:
  - Clusters in Calorimeters
  - Charged-tracks

Selected Events	Clusters	Tracks
DATA	1,949K	1,744K
JETSET	5,637K	5,034K

- *Jets and selection of 3 Jet events*:
  - ➡ JADE algorithm with $y_{cut} = 0.05$;
    DURHAM ($k_\perp$) algorithm with $y_{cut} = 0.01, 0.02$
  - ➡ Jet separation angle: $\theta_{12}, \theta_{23}, \theta_{31} \in [90°, 150°]$

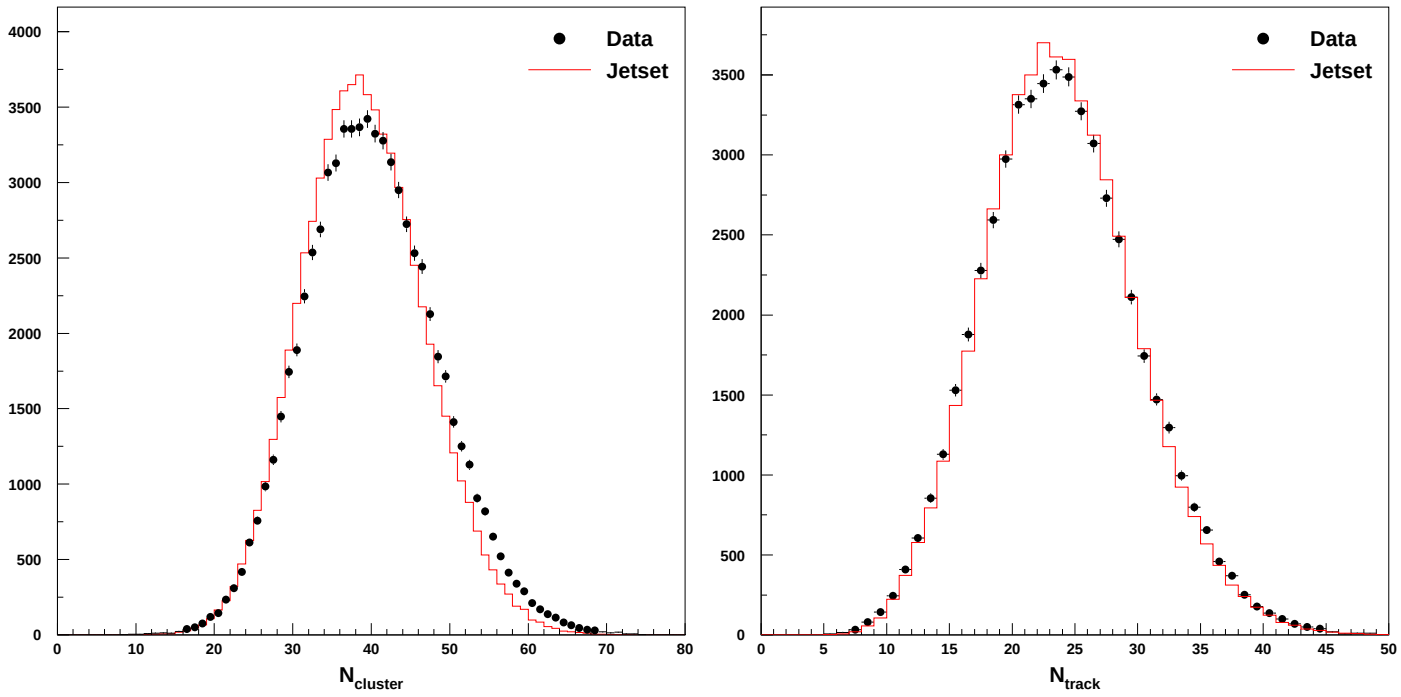
	Fraction of 3jet Mercedes events					
	Clusters			Tracks		
y_{cut}	JADE .05	$k_\perp$ .02	$k_\perp$ .01	JADE .05	$k_\perp$ .02	$k_\perp$ .01
DATA	.036	.033	.028	.031	.026	.021
JETSET	.038	.035	.031	.032	.027	.023

Data

$\langle N_{objects} \rangle$:

	Data	Jetset
Clusters	39.51 ± 0.03	38.53 ± 0.02
Charged tracks	23.41 ± 0.03	23.39 ± 0.01

Multiplicity for Mercedes 3 jet events:



⇒ Clusters/tracks used as "objects" in the detector for cluster/track based selection

Gluon Jet Identification

Energy Ordering ($E_1 > E_2 > E_3$)

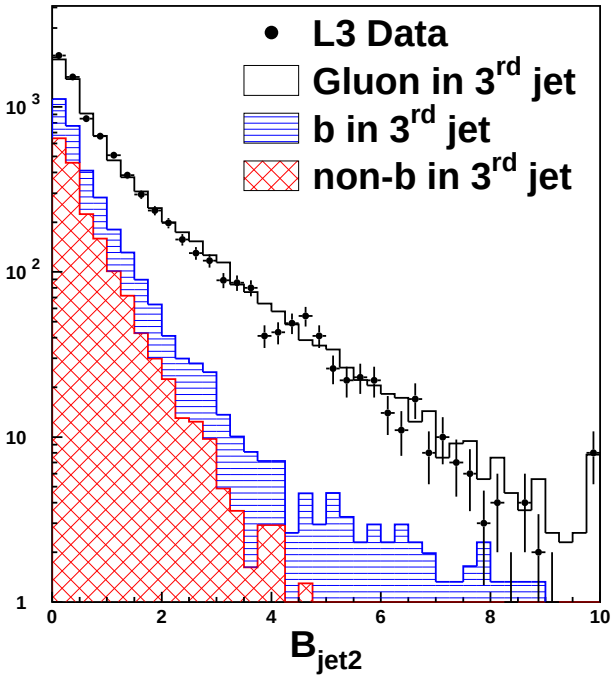
Probability (%) of gluon in third jet	Clusters	Tracks
All 3 jet Events	69	59
Mercedes Events	48	40

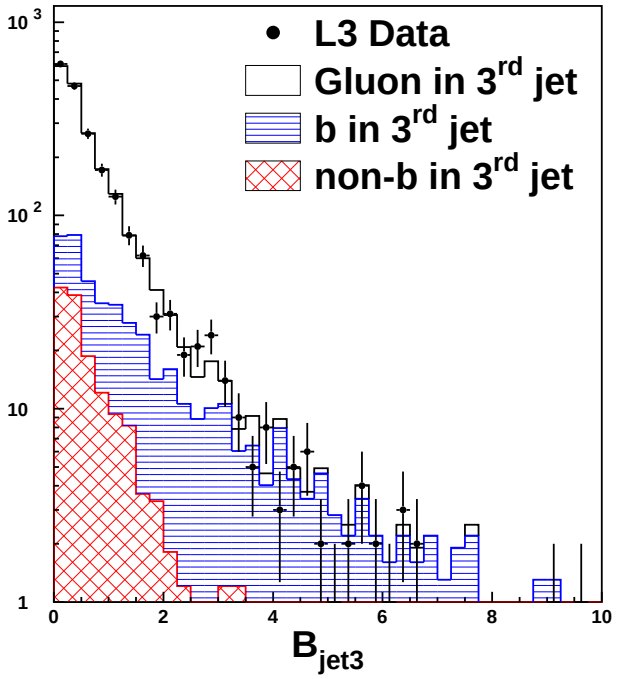
Anti-*B-tagging*

➪ Probability (P_i): track$_i$ consistent with zero lifetime

➥ flat for zero lifetime, peaks at 0 for lifetime > 0

➠ *For each jet* weighted discriminant: $B_{jet} = -\log(\underbrace{\prod}_{i \in jet} P_i)$

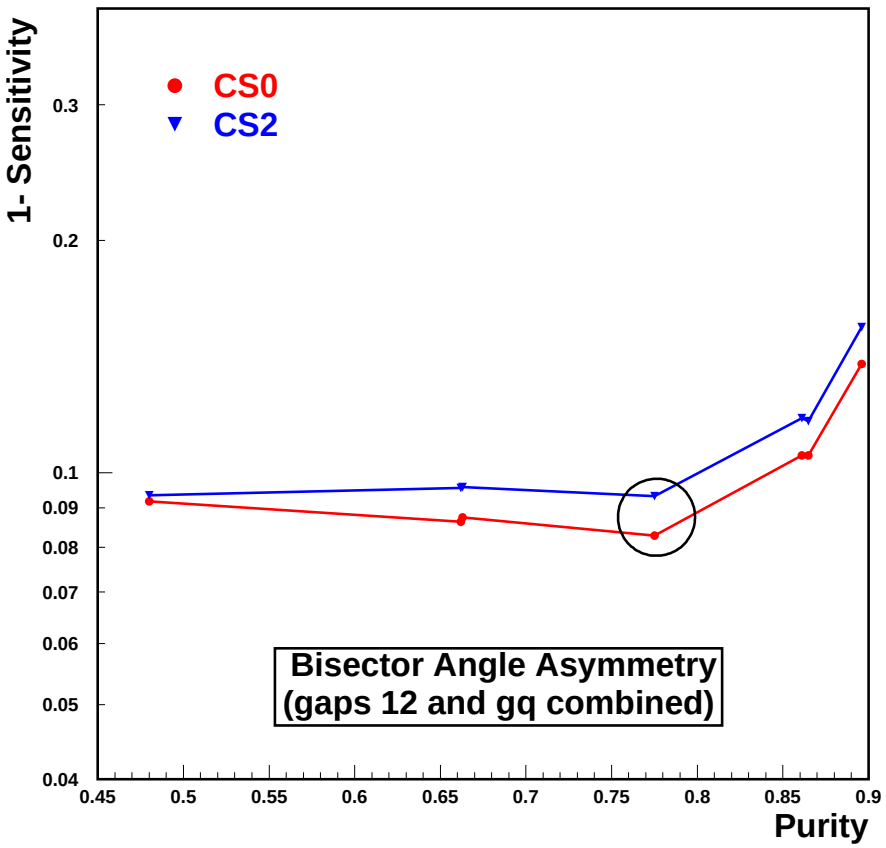




Gluon Tag: B_{Jet1}, $B_{Jet2} >$ CUT1, $B_{JET3} <$ CUT2

Gluon Jet Identification

☞ CUTi *tuned* to get best sensitivity of measurement

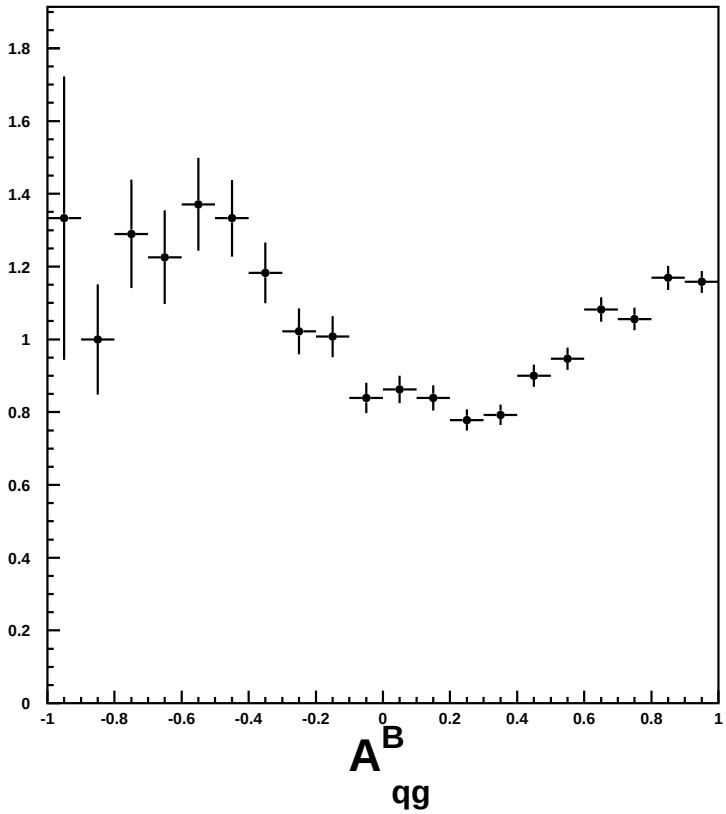


Optimized "Gluon" Tagged Event Statistics

	Clusters			Tracks		
B_{Jet2} B_{Jet3}	≥ 1.25 ≤ 1.50			≥ 1.75 ≤ 1.25		
y_{cut}	JADE .05	$k_\perp$ .02	$k_\perp$ .01	JADE .05	$k_\perp$ .02	$k_\perp$ .01
Π (%)	78	79	78	82	84	83
DATA	2668	2116	2516	2048	1507	1856

Results

Correct detector level distributions *bin-by-bin*

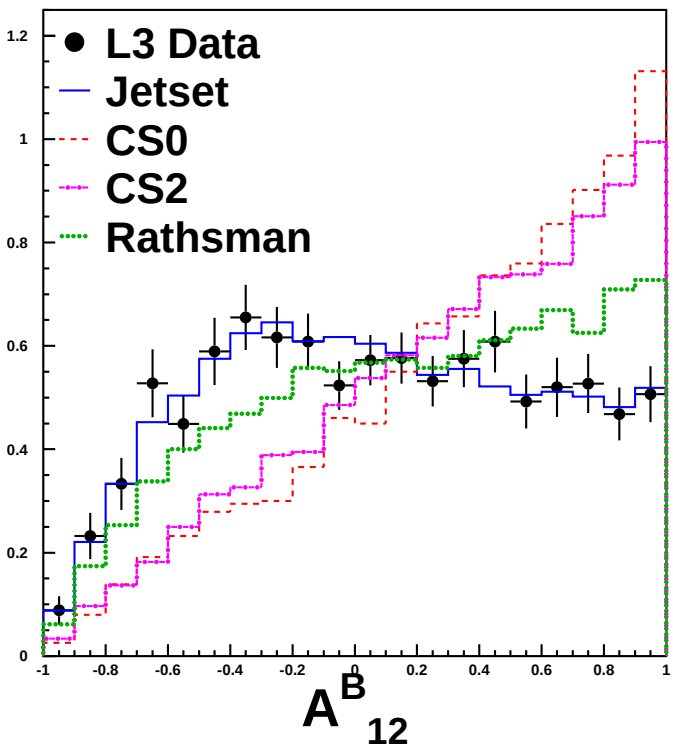


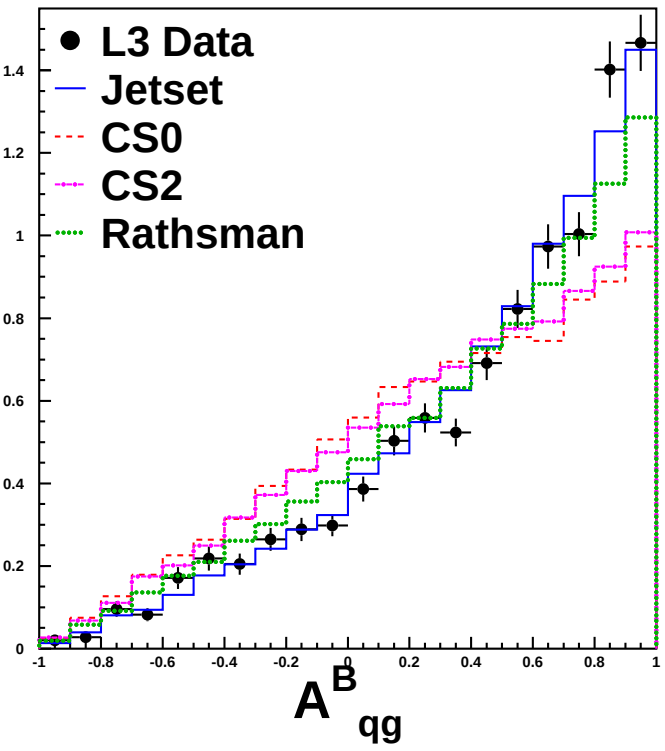
$\Rightarrow$ typical correction factor $\leq 20\%$

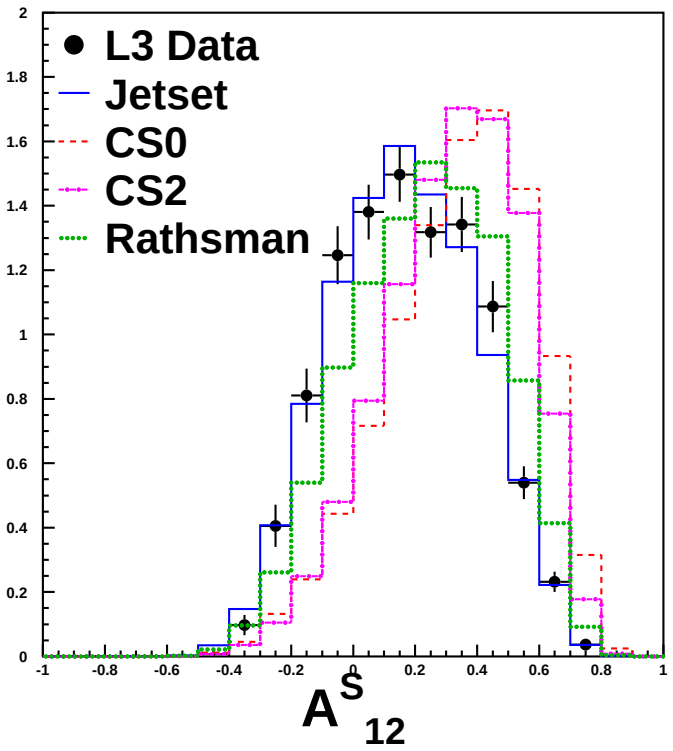
Systematic uncertainties (%)

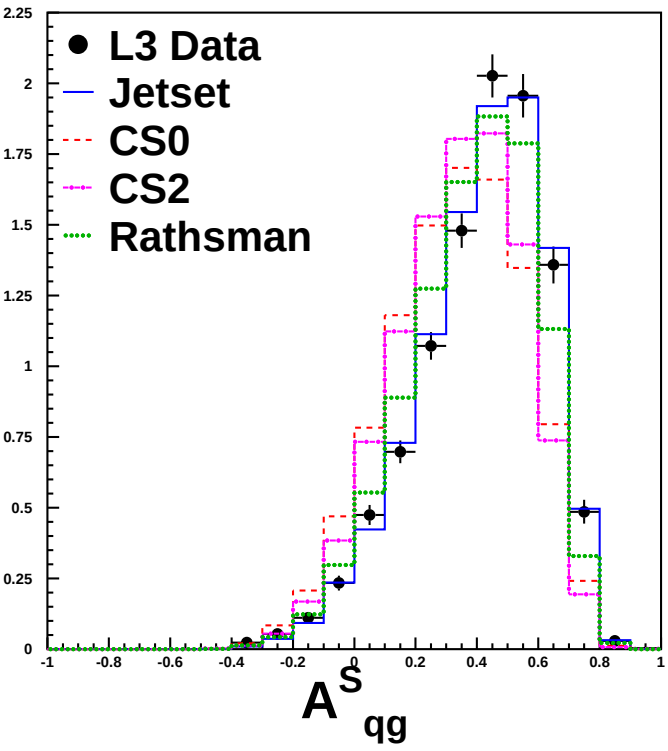
Asymmetry	Jet	Gtag	Total
A^{B}_{12}	6.2	4.8	7.9
A^{B}_{qg}	5.8	3.2	6.6
A^{S}_{12}	7.2	8.1	10.9
A^{S}_{qg}	4.1	4.0	5.8

Results









Pure Colour Singlet Exchange disfavoured by Data

Results

Comparison of Models

Variable	Bins	χ^2 (Probability) Data Vs.	
		Jetset	Rathsman (0.1)
A^B_{12}	20	6.2 (99%)	59.3 (5×10^{-6})
A^B_{qg}	19	16.9 (53%)	60.5 (2×10^{-6})
A^S_{12}	12	4.7 (94%)	77.8 (4×10^{-12})
A^S_{qg}	13	6.5 (89%)	47.2 (4×10^{-6})

JETSET explains trends in DATA

Determine CS fraction r by minimising χ^2

$$\chi^2(r) = \sum_i \frac{[f^i_{data} - r f^i_{CS0} - (1-r) f^i_{Jetset}]^2}{(\sigma^i_{stat})^2 + (\sigma_{syst} * f^i_{data})^2}$$

Fit to A^B_{12}: r = 0.017 $\pm$ 0.053 (χ^2/d.o.f. = 6.1/19)

All estimates of r are compatible to 0

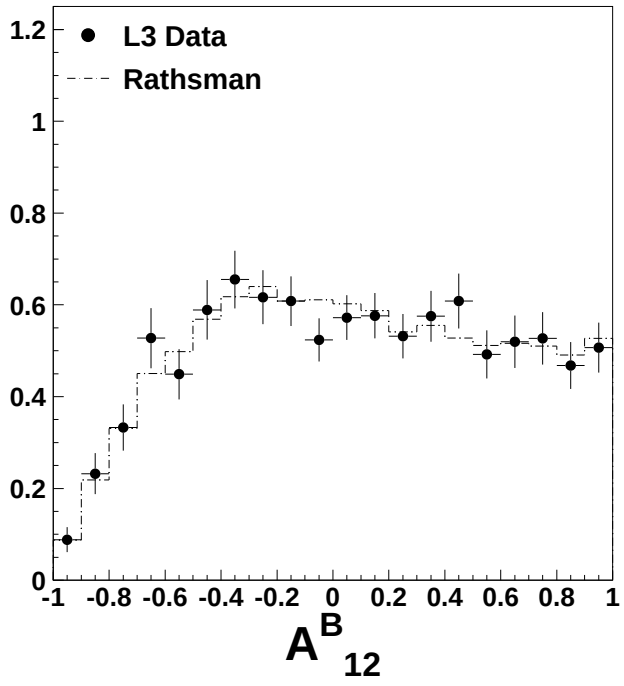
☞ Obtain 95% CL upper bound

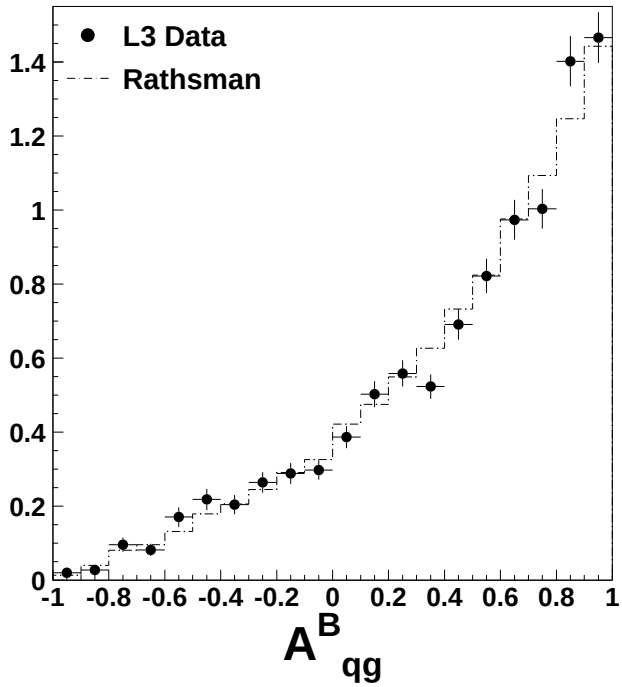
Best limit obtained by a combined fit to (A^S_{12} and A^S_{qg}):

$R^{95\%}$ = 6.7 (9.0) % for CS0 (CS2)

Results

Use L3 data to fit for R_0 in RATHSMAN model:





Variable	R_0	χ^2/d.o.f.
A^B_{12}	0.0036±0.0051	5.6/19
A^B_{qg}	−0.0011±0.0056	16.8/18
A^S_{12}	0.0039±0.0062	4.3/11
A^S_{qg}	0.0031±0.0059	6.2/12

Fits for RATHSMAN model compatible with $R_0 = 0$

95% CL Upper Bound on R_0	
A^B_{12} and A^B_{qg}	0.0093
A^S_{12} and A^S_{qg}	0.0119

Summary

- Several asymmetry variables sensitive to colour flow between jets are identified.
- Colour singlet exchange is looked for in 2 million hadronic Z decays.
- An analysis is performed using calorimetric clusters and is cross-checked with charged tracks.
- Data are well explained by colour octet exchange alone.
- 95% CL upper bounds of colour singlet exchange are obtained at the level of 7-9%.
- RATHSMAN model which suggests a different colour flow picture is investigated. For the default colour reconnection (CR) parameter ($R_0 = 0.1$), the model differs significantly from data. A 95% CL upper bound of 0.0093 is obtained for R_0.
- Interesting to repeat for other models (e.g. ARIADNE) predicting CR in both Z decays and W-pair production. Thus limit CR probability and W-mass shift in models.