

Studies of the running of α_s (with JADE event shapes)

S. Bethke¹, (*)S. Kluth^{1,2}, C. Pahl^{1,3}, J. Schieck¹ and the JADE Coll.

¹ Max-Planck-Institut für Physik

² Universität Würzburg

³ Excellence Cluster Origin and Structure of the Universe, Munich

1 Introduction

arxiv:0810.2933 (acc. by EPJC)

2 Event Shapes with JADE

arxiv:0810.1389 (sub. to EPJC)

3 NNLO(+NLLA) QCD Fits

4 Fits with Event Shape Moments

5 Summary

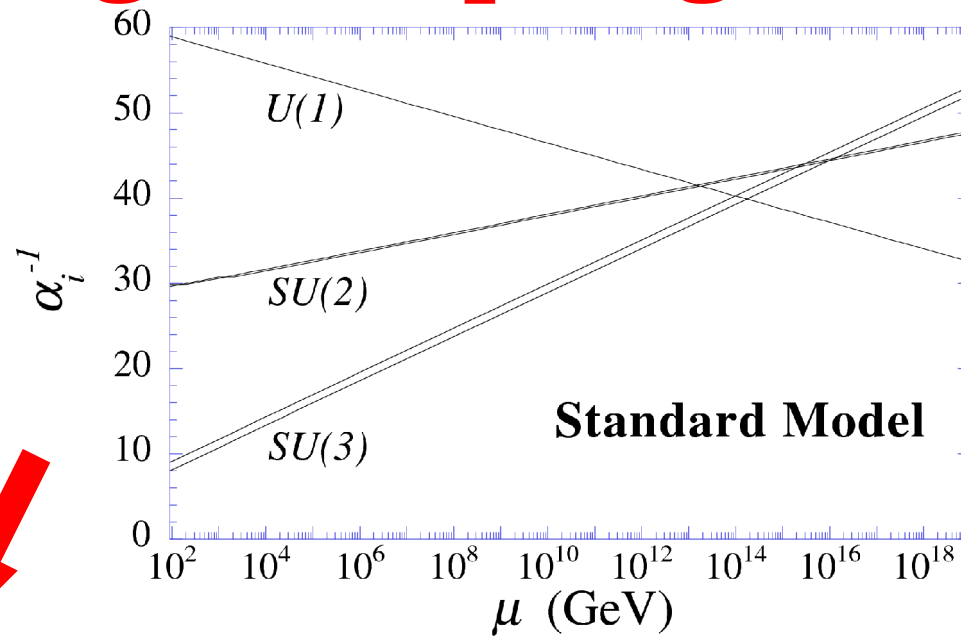
Excellence Cluster "Universe" RA D day

14 May 2009, MPI für Physik



Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

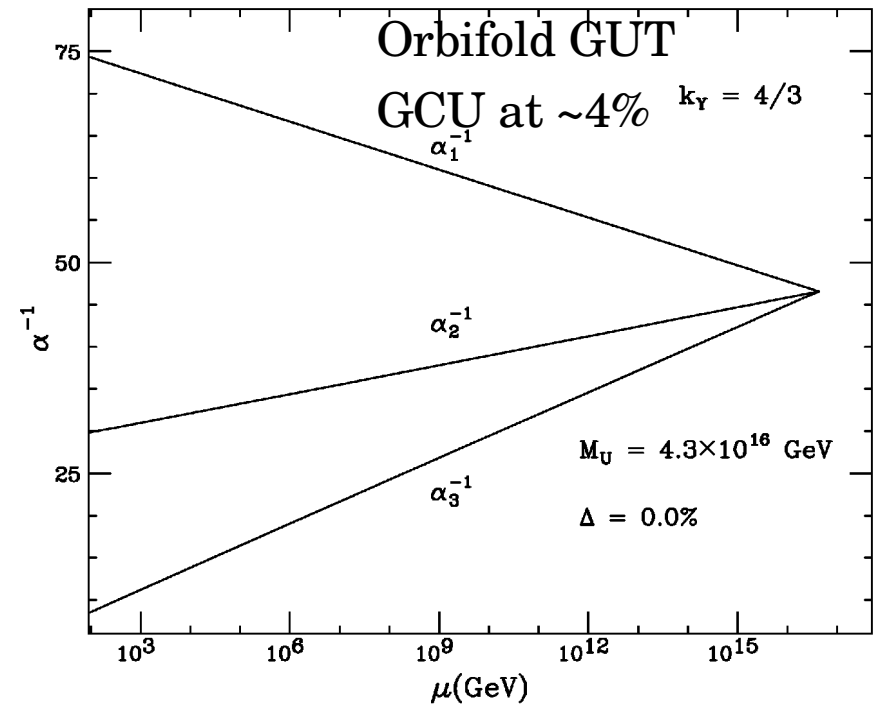
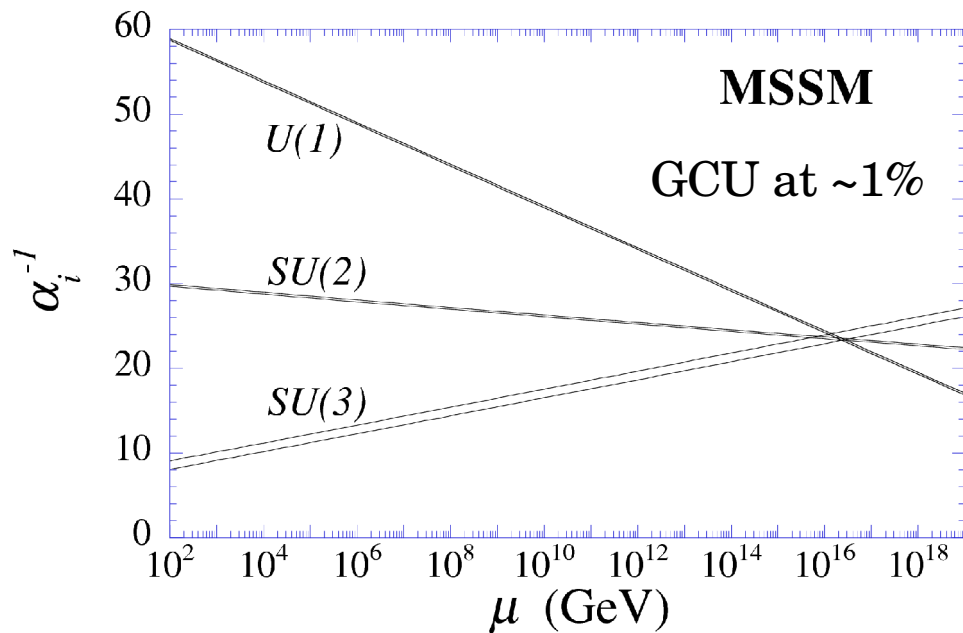
1 Gauge Coupling Unification



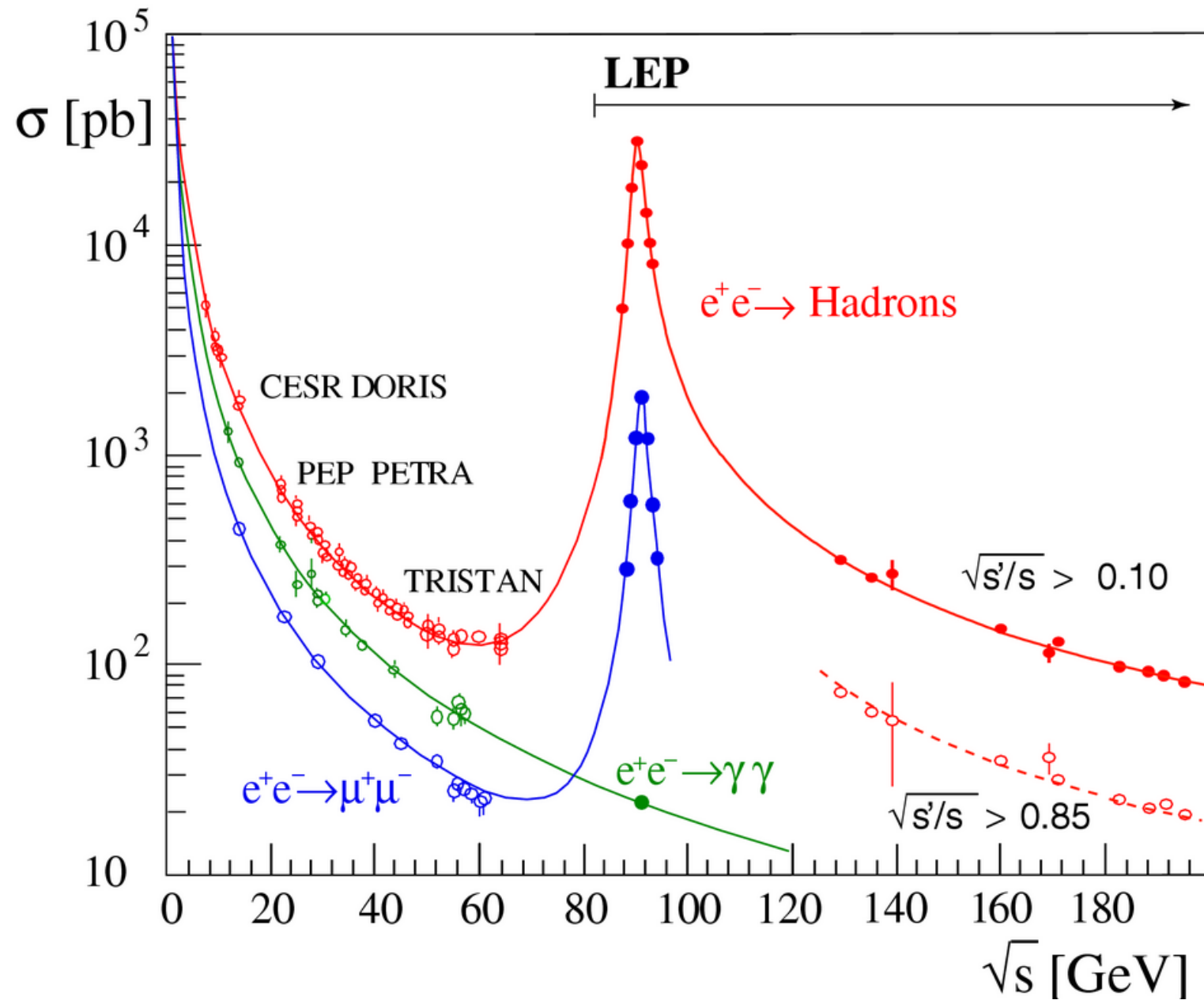
[H. Murayama, hep-ph/0002232;
V. Barger, J. Jiang, P. Langacker,
T. Li, PLB624(2005)233]

PDG '04 and
 $\alpha_s(m_Z) = 0.1182 \pm 0.0027$
 $m_t = 178 \pm 4$ GeV

Red arrow pointing down-right.



1 e^+e^- Annihilation Processes



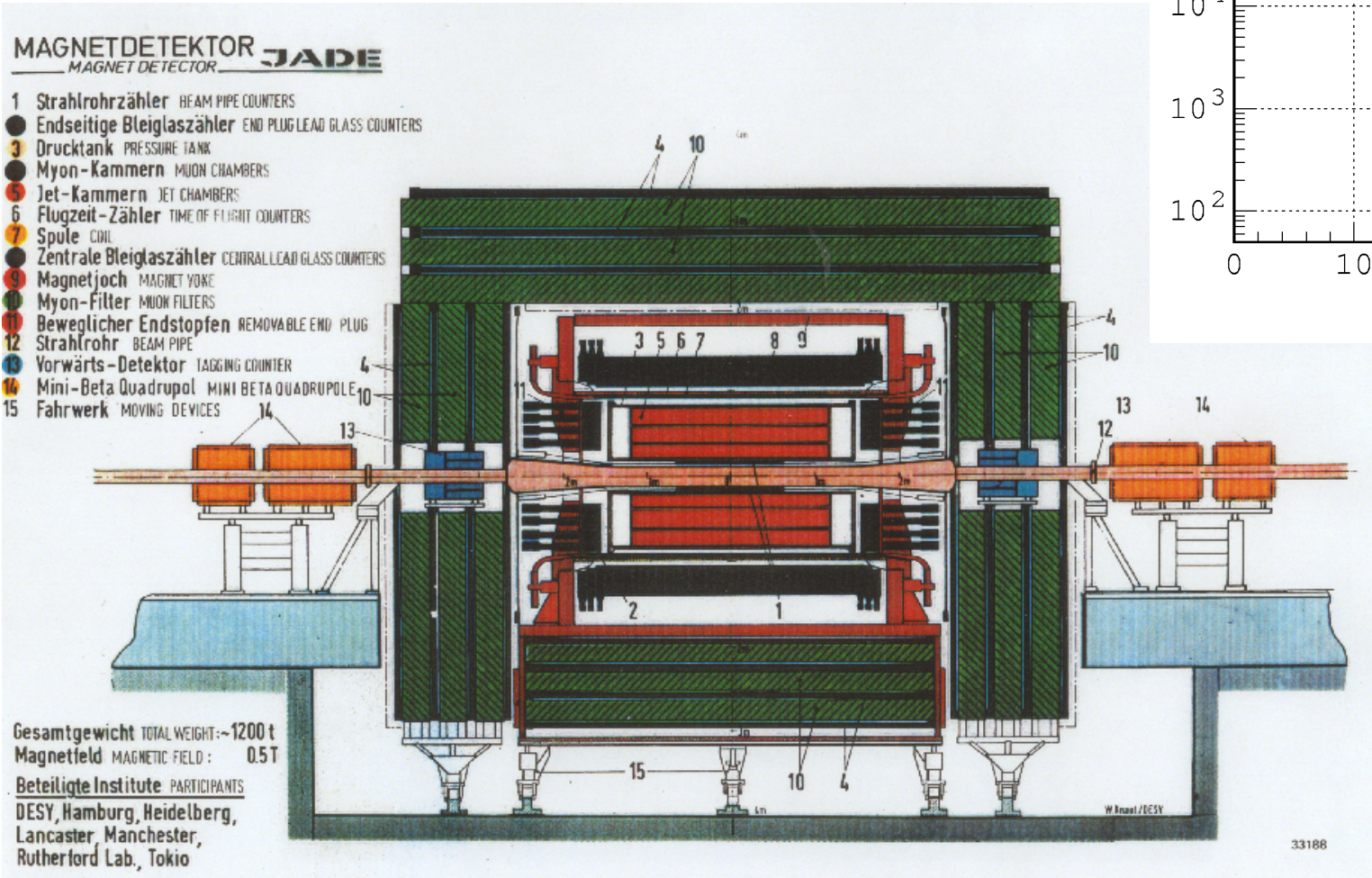
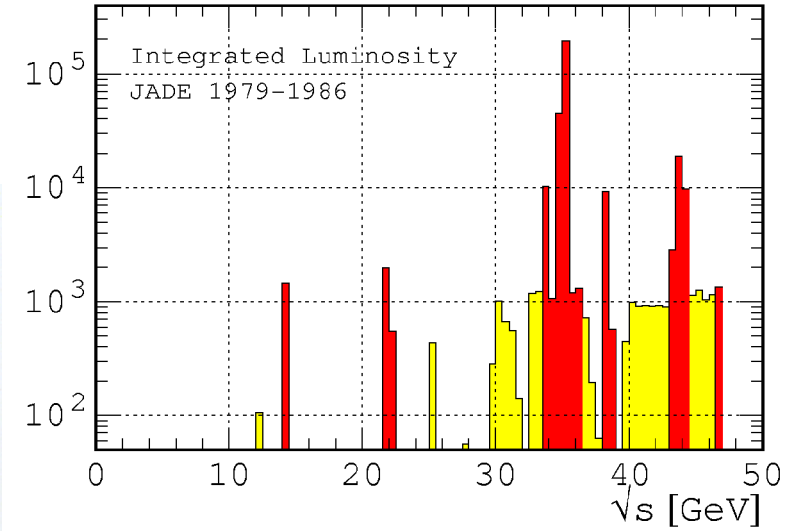
Main backgrounds
at PETRA:

$\gamma\gamma \rightarrow \text{hadrons}$
 τ pairs
ISR

1 JADE Experiment at PETRA

1979-1986, $\sqrt{s} = 14, 22, 35, 38, 44$ GeV
re-analysis with modern tools

$L_{int} [nb^{-1}]$



~ideal QCD experiment

larger lever arm in $\ln(s)$
than LEP

no other data exist

1 JADE Event Display

JSN JAD025zfile001z200evs.bos

BEAM 22.100 GEV FIELD -4.177 KG TALC 0039 DATE 13/06/08 TIME 11.34.48
T1A 0802 T1P 4001 CAMAC TIME 23.50.23 30/ 9/19

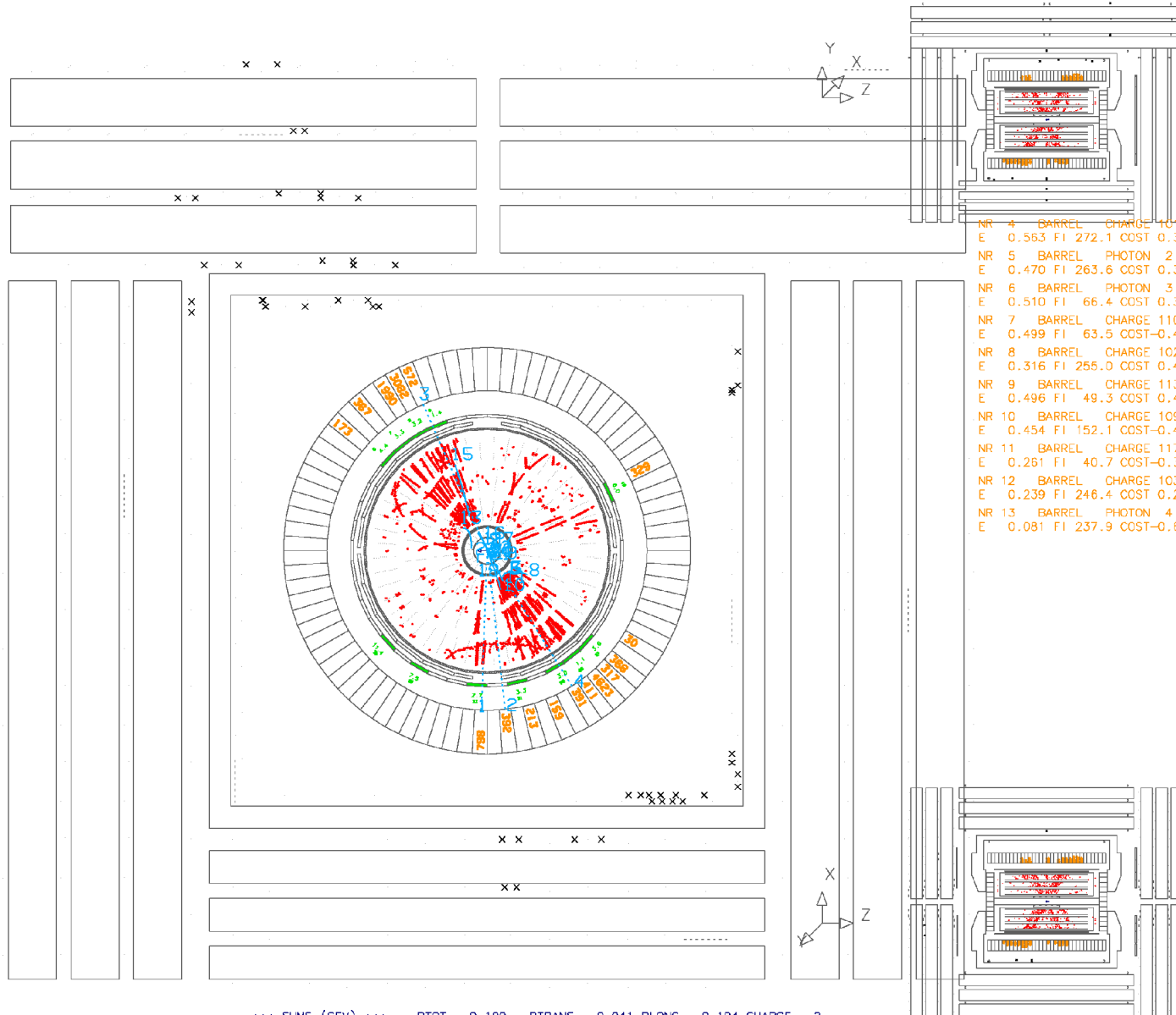
8311 3803 51
DHITS 1078
LGTOT 14231 JADE
UHITS 27
GCYL 14231
GCAPS 0 0
WCAPS 656 1079

R-FI SECTION

IK HMDS 8 NR OF TRACKS 22
+ RMSRFI RMSRZ/HIT PHI
IT PLONG PTRANS COSTHE
IQVAL CHIP MUPR PIPR

-	2.86/42	42.7/36	288.2
005	0.005	0.002	NaN
+	2.59/43	36.8/42	242.9
004	0.004	0.001	NaN
+	2.66/27	41.8/23	240.0
008	0.008	0.002	NaN
-	2.76/23	43.4/19	236.7
009	-0.009	0.002	NaN
+	2.58/44	39.1/43	229.5
019	-0.019	0.003	NaN
-	2.58/48	37.4/46	231.0
015	-0.014	0.003	NaN
-	2.76/34	38.4/25	228.2
008	-0.008	0.002	NaN
+	2.65/45	38.3/39	221.5
021	-0.021	0.003	NaN
-	2.93/45	38.6/43	154.9
003	-0.003	0.001	NaN
+	2.82/47	40.0/44	63.5
010	-0.009	0.002	NaN
+	2.85/45	42.0/37	60.6
010	0.010	0.003	NaN
1	0.22	1.00	0.016
+	2.98/38	43.3/32	52.8
008	0.007	0.002	NaN
-	2.75/38	30.4/27	47.9
024	0.024	0.006	NaN
-	2.36/17	30.5/22	240.7
003	0.003	0.001	NaN
-	3.34/23	40.3/19	57.0
009	0.009	0.002	NaN
+	2.94/43	38.1/40	112.2
002	0.002	0.001	NaN
-	3.50/43	44.7/32	42.4
008	-0.008	0.001	NaN
-	2.56/15	36.4/14	283.8
009	-0.008	0.002	NaN
+	3.80/14	41.7/11	56.7
003	0.002	0.001	NaN
-	2.94/37	40.2/33	239.1
003	0.003	0.001	NaN
-	3.77/16	37.5/26	247.6
002	-0.002	0.001	NaN
+	9.52/14	29.7/12	26.2
016	-0.016	0.002	NaN

IK LGCL 1 NR OF CLUSTERS 13
1 BARREL CHARGE 504
6.990 FI 229.2 COST-0.542
2 BARREL CHARGE 411
5.695 FI 60.3 COST 0.572
3 BARREL PHOTON 1



NR 4	BARREL	CHARGE	101
E	0.563	FI	272.1
COST	0.3		
NR 5	BARREL	PHOTON	2
E	0.470	FI	263.6
COST	0.3		
NR 6	BARREL	PHOTON	3
E	0.510	FI	66.4
COST	0.3		
NR 7	BARREL	CHARGE	110
E	0.499	FI	63.5
COST	-0.4		
NR 8	BARREL	CHARGE	102
E	0.316	FI	255.0
COST	0.4		
NR 9	BARREL	CHARGE	113
E	0.496	FI	49.3
COST	0.4		
NR 10	BARREL	CHARGE	109
E	0.454	FI	152.1
COST	-0.4		
NR 11	BARREL	CHARGE	117
E	0.261	FI	40.7
COST	-0.3		
NR 12	BARREL	CHARGE	103
E	0.239	FI	246.4
COST	0.2		
NR 13	BARREL	PHOTON	4
E	0.081	FI	237.9
COST	-0.6		

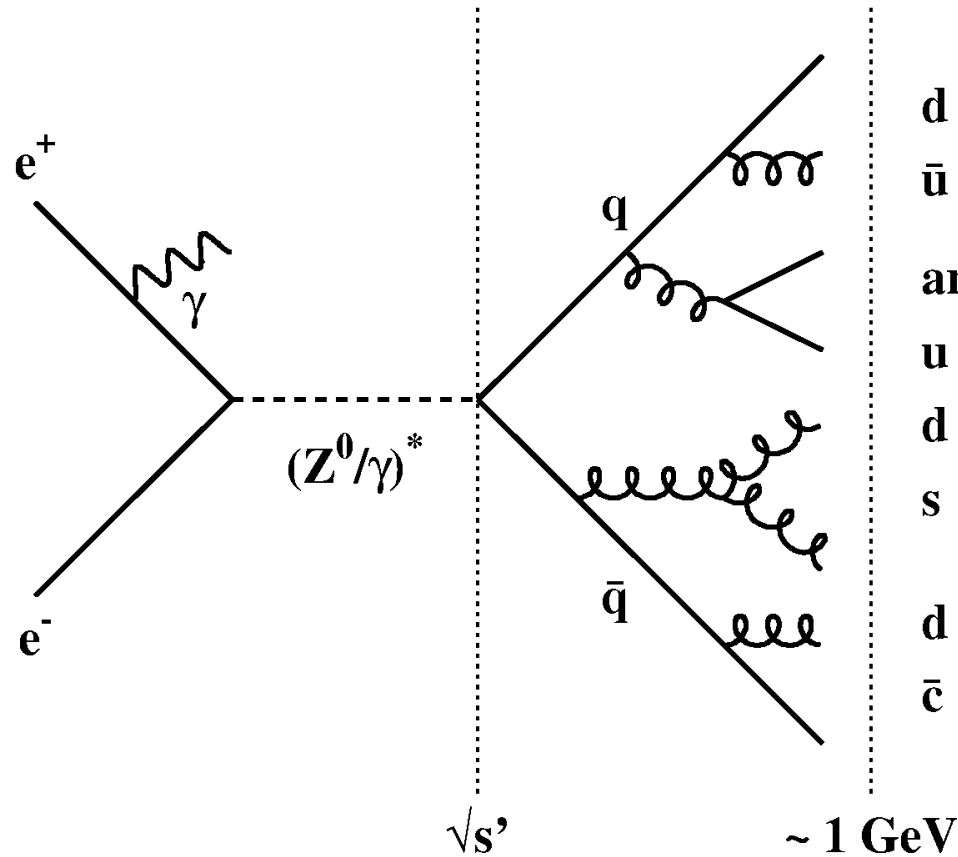
*** SUMS (GEV) *** PTOT 0.199 PTRANS 0.041 PLONG 0.194 CHARGE -2
TOTAL CLUSTER ENERGY 16.991 PHOTON ENERGY 1.478 NR OF PHOTONS 4

1 e^+e^- Annihilation to Hadrons

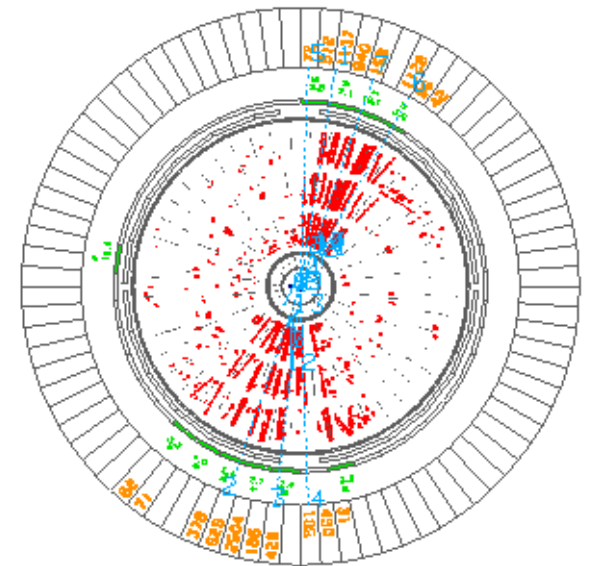
Electro-weak Production

Parton Shower

Hadronisation



d
 \bar{u} } π^-
and many more
 u
 d } $\Lambda^0 \rightarrow \pi^- p^+$
 s
 d } $D^+ \rightarrow K^0 \pi^+$
 \bar{c}



Parton Level

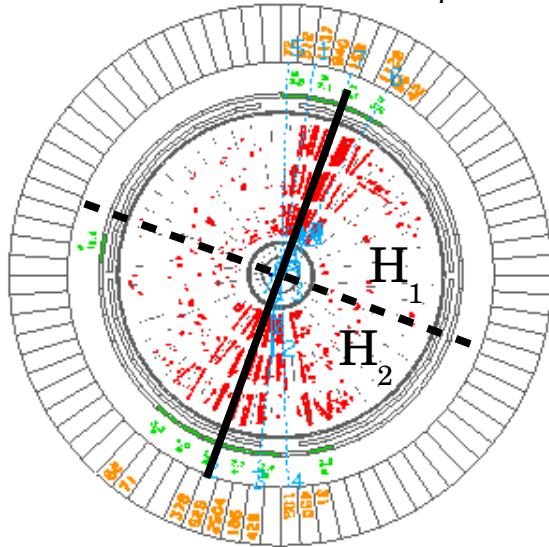
Hadron Level

Detector Level

2 Event Shape Observables

Thrust 1-T:

$$1-T = 1 - \max_{\vec{n}} \frac{\sum_i \vec{p}_i \cdot \vec{n}}{\sum_i |\vec{p}_i|}$$



Heavy Jet Mass M_H :

larger invariant mass in hemispheres

H_1 and H_2 w.r.t. thrust axis n

Jet Broadening B_T and B_W :

$$B_{1,2} = \frac{\sum_{i \in H_{1,2}} p_{t,i}}{2 \sum_i |\vec{p}_i|}$$

$$B_T = B_1 + B_2$$

$$B_W = \max(B_1, B_2)$$

C-parameter:

$$C = \frac{3}{2} \frac{\sum_{i,j} |\vec{p}_i| |\vec{p}_j| \sin(\Theta_{ij})}{(\sum_i |\vec{p}_i|)^2}$$

2 Event Shape: D_2 aka y_{23}

Durham (k_t) jet algorithm

DSN mc14b

```

0 120 120
IDHITS 645
ELGTOT 3506
MUHITS 0
LGCYL 3506
LGCAPS 0
FWCAPS 0
    
```

MONTE CARLO R-FI SECTION

JADE

BEAM 7.000 GEV FIELD -4.849 KG TALC 0032 DATE 01/11/00 TIME 11.49.22
TRIG 0001 CAMAC TIME 1. 1. 1 17/ 7/1981

$$y_{ij} = 2\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})/s$$

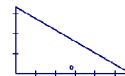
iteratively combine pairs with smallest y_{ij} ($\mathbf{p}_{\text{jet}} = \mathbf{p}_i + \mathbf{p}_j$)

$D_2 = y_{ij}$ for $3 \rightarrow 2$ jet transition

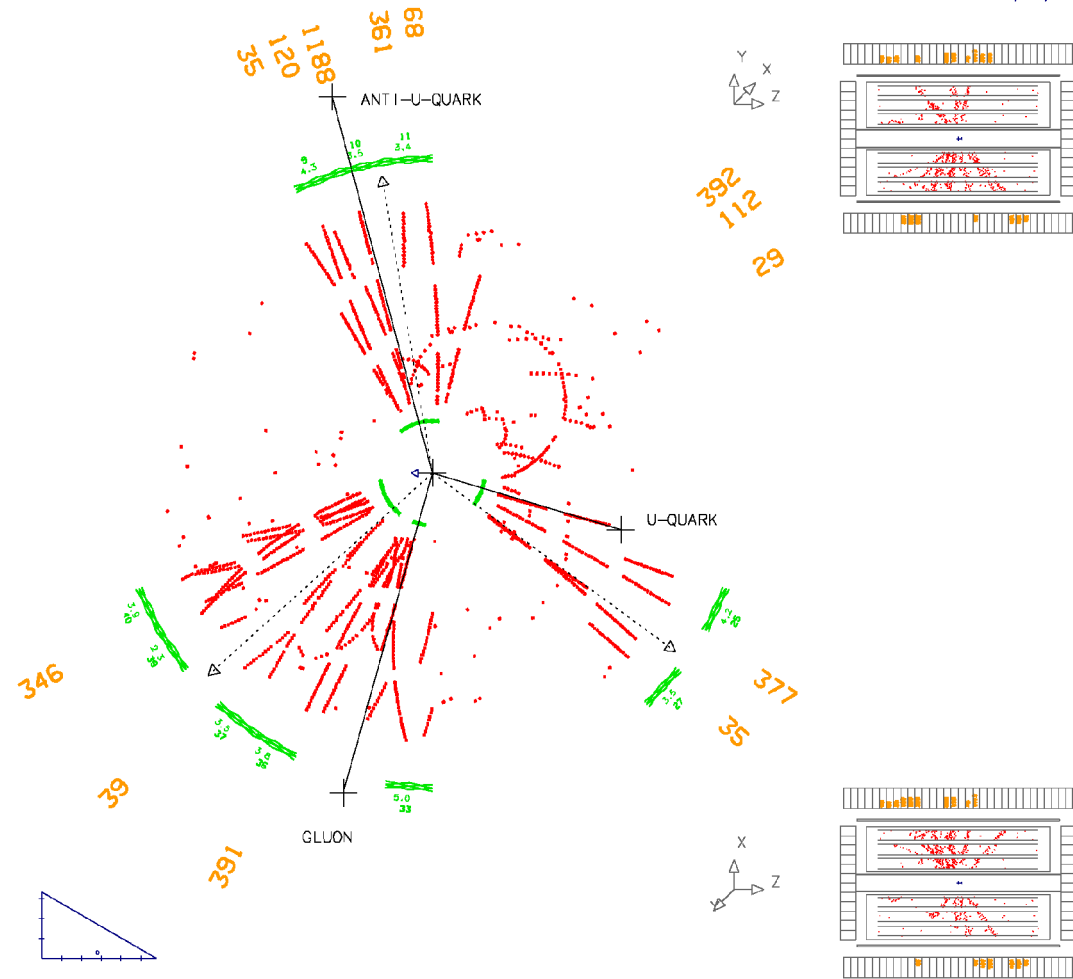
“differential 2-jet rate”

2 b-to-b partons: $D_2 = 0$

≥ 3 partons: $D_2 < 0.3$



JADE MC event at 14 GeV

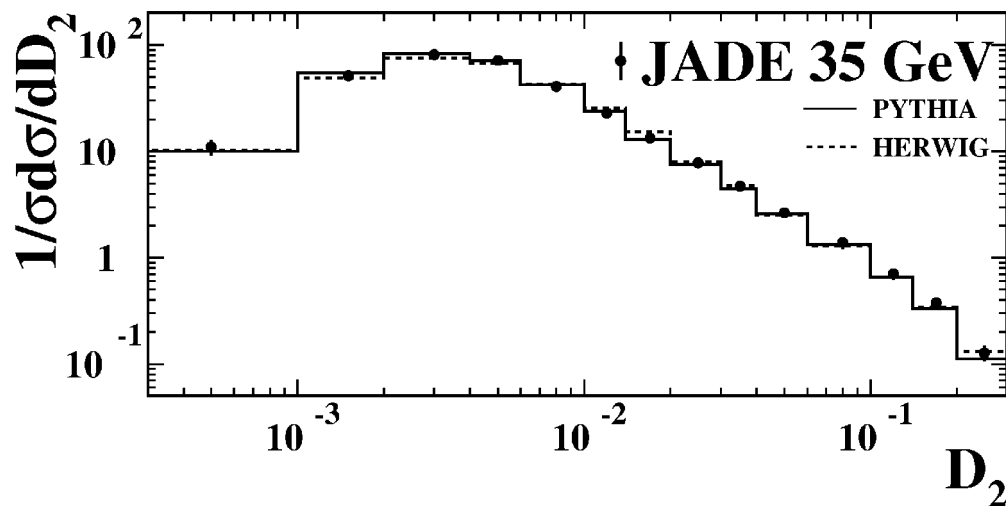
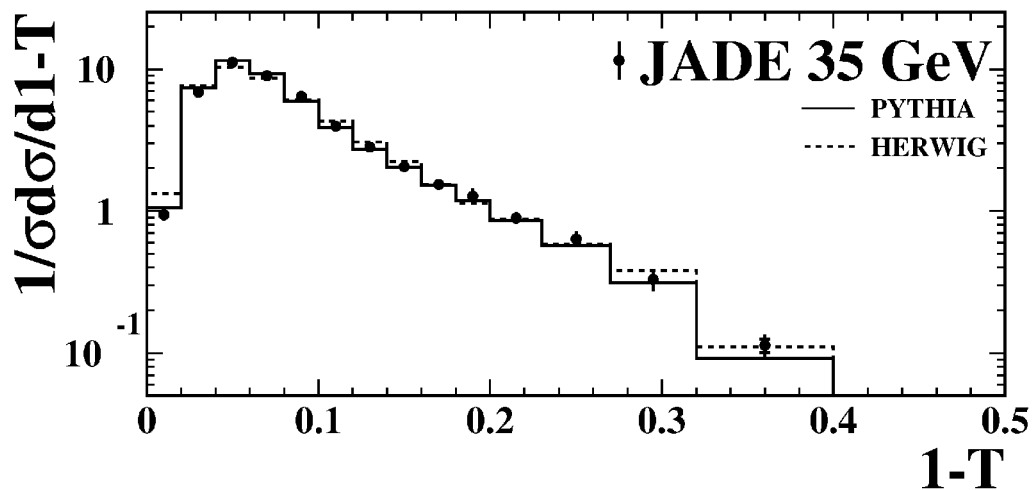
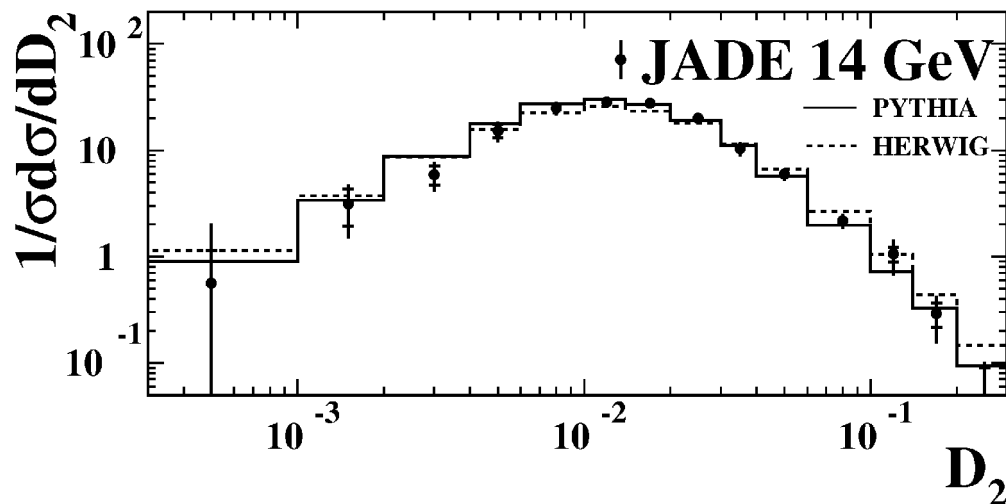
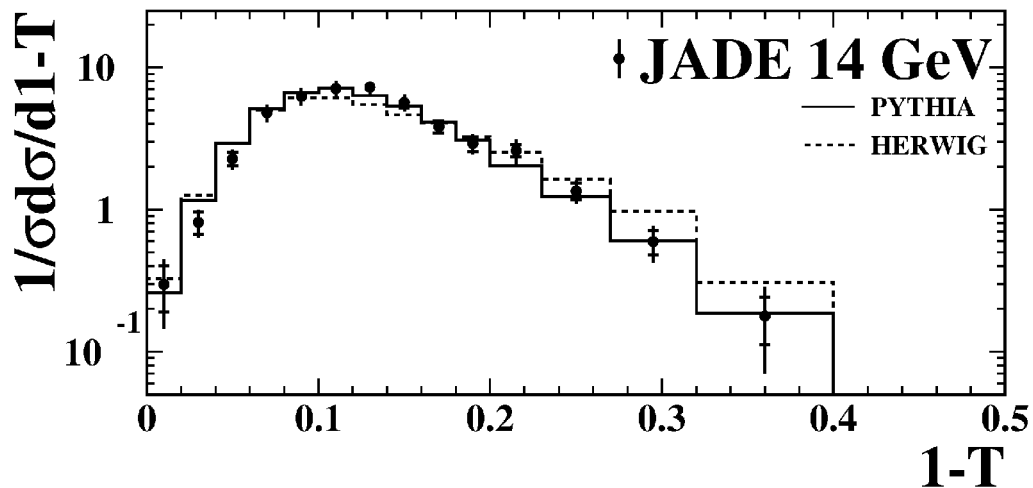


2 Event Shape Measurement

Measure $1-T$, M_H , B_T , B_W , C , D_2 to allow cross checks

Subtract expected $e^+e^- \rightarrow b\bar{b}$ contribution at detector level

Corrected data vs. modern MC \rightarrow good agreement justifies exp. corrections



3 NNLO QCD

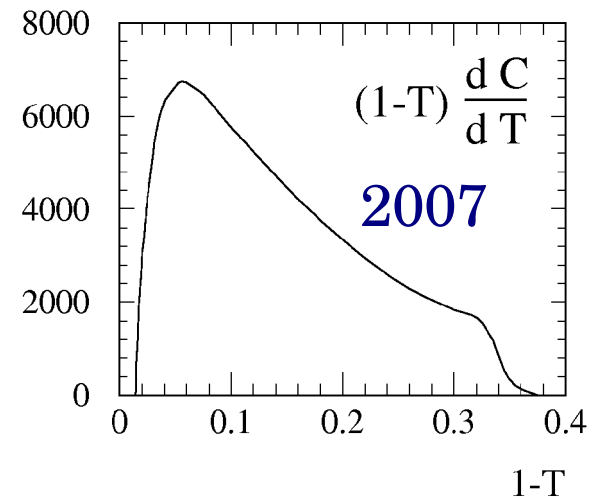
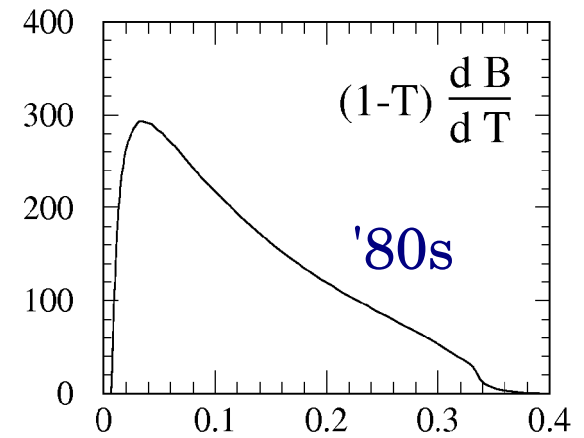
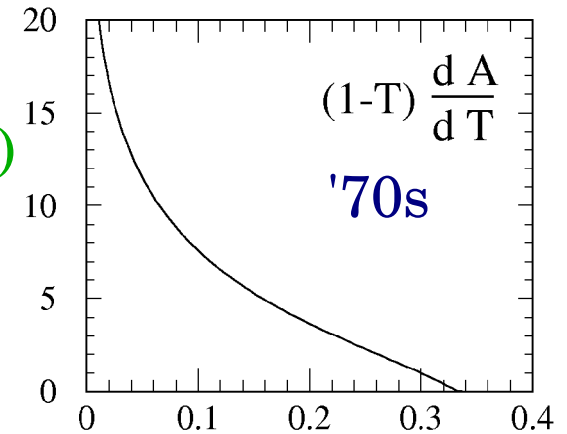
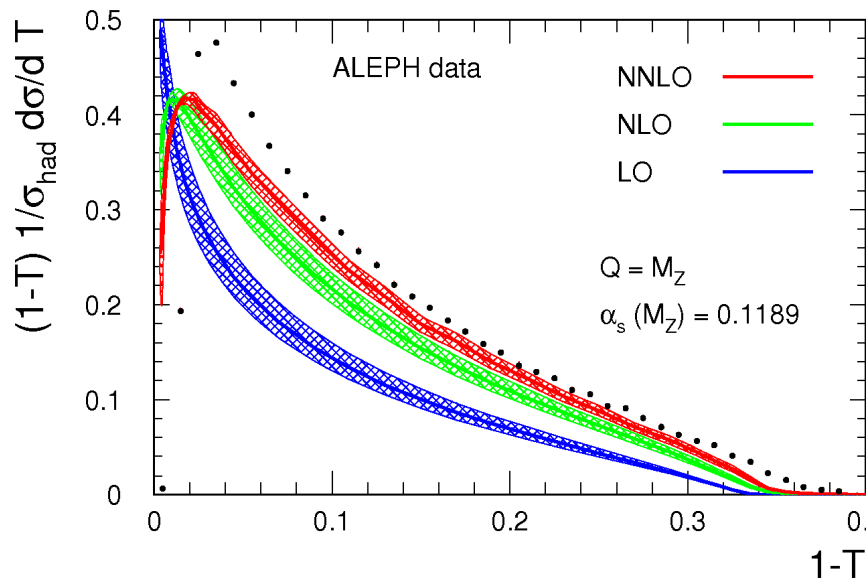
$$1/\sigma_0 d\sigma/dy(Q) = dA/dy \underline{\alpha}_s(Q) + dB/dy \underline{\alpha}_s^2(Q) + dC/dy \underline{\alpha}_s^3(Q)$$

$y = 1-T, \dots; \underline{\alpha}_s = \alpha_s/(2\pi); \sigma_0 \rightarrow \sigma_{\text{had}}$, scale dep. not shown

dA/dy etc. from phase space integration of QCD ME

(very difficult, NNLO from GGGH, JHEP 0712:094)

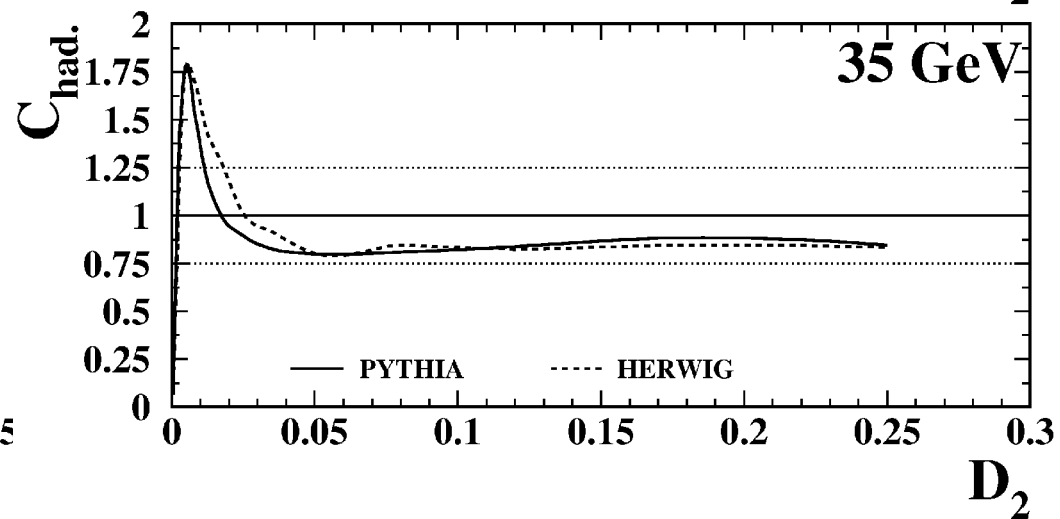
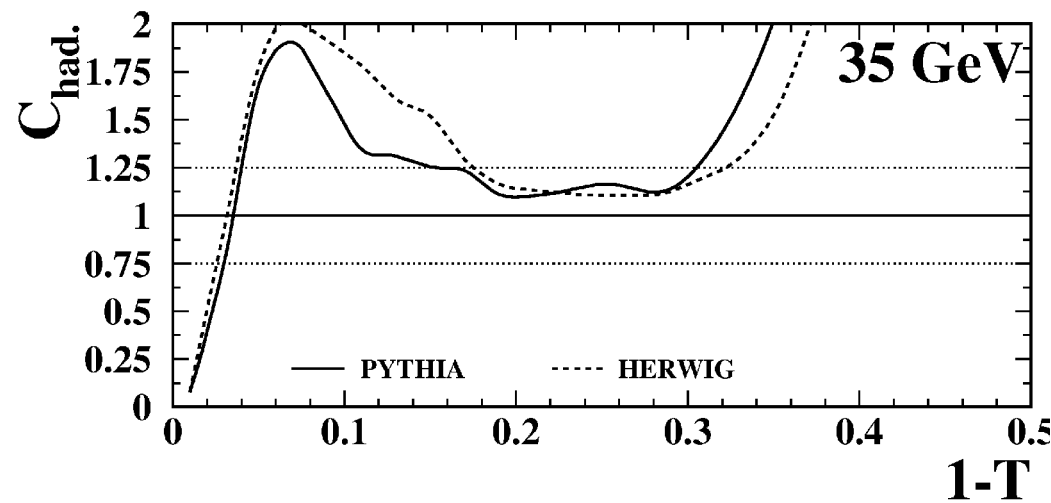
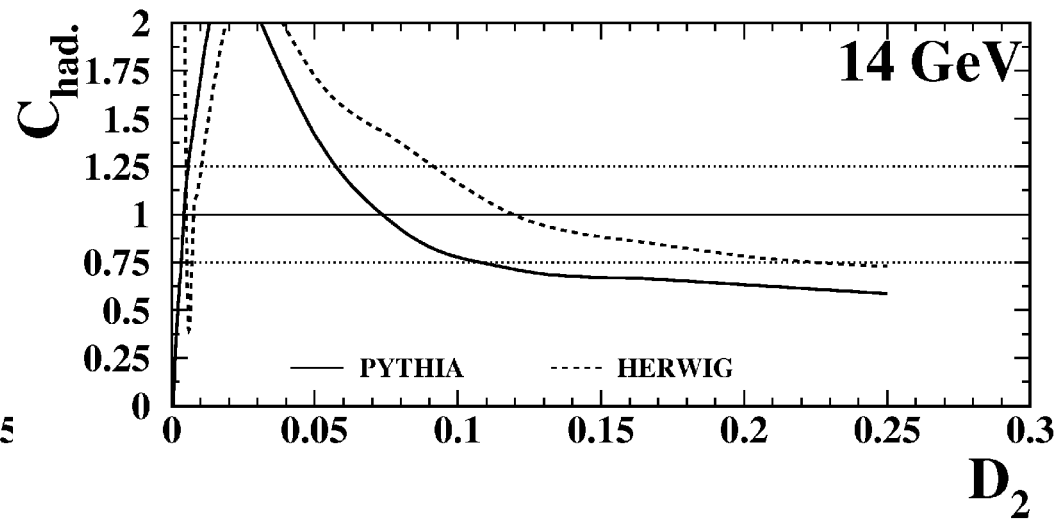
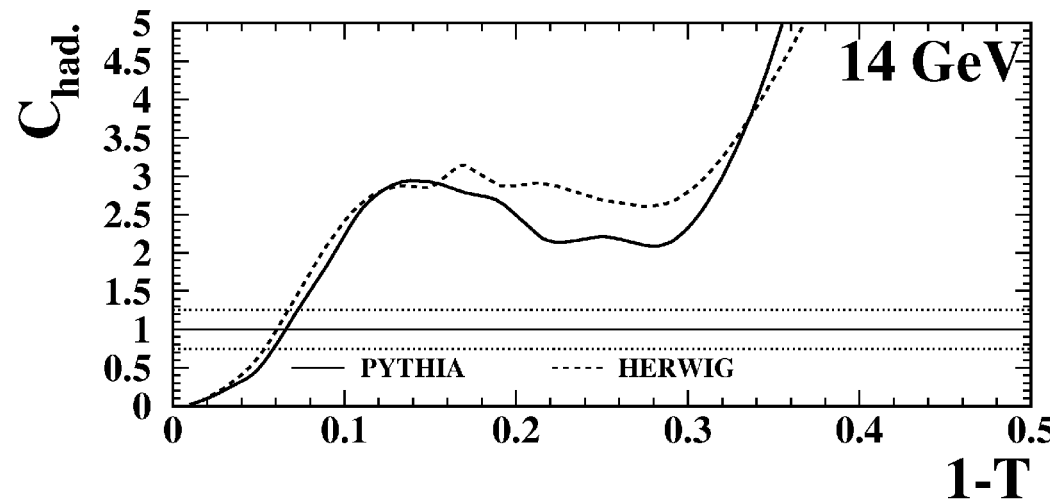
NLLA matching from GLS PLB664(2008)265



3 NNLO(+NLLA) fits

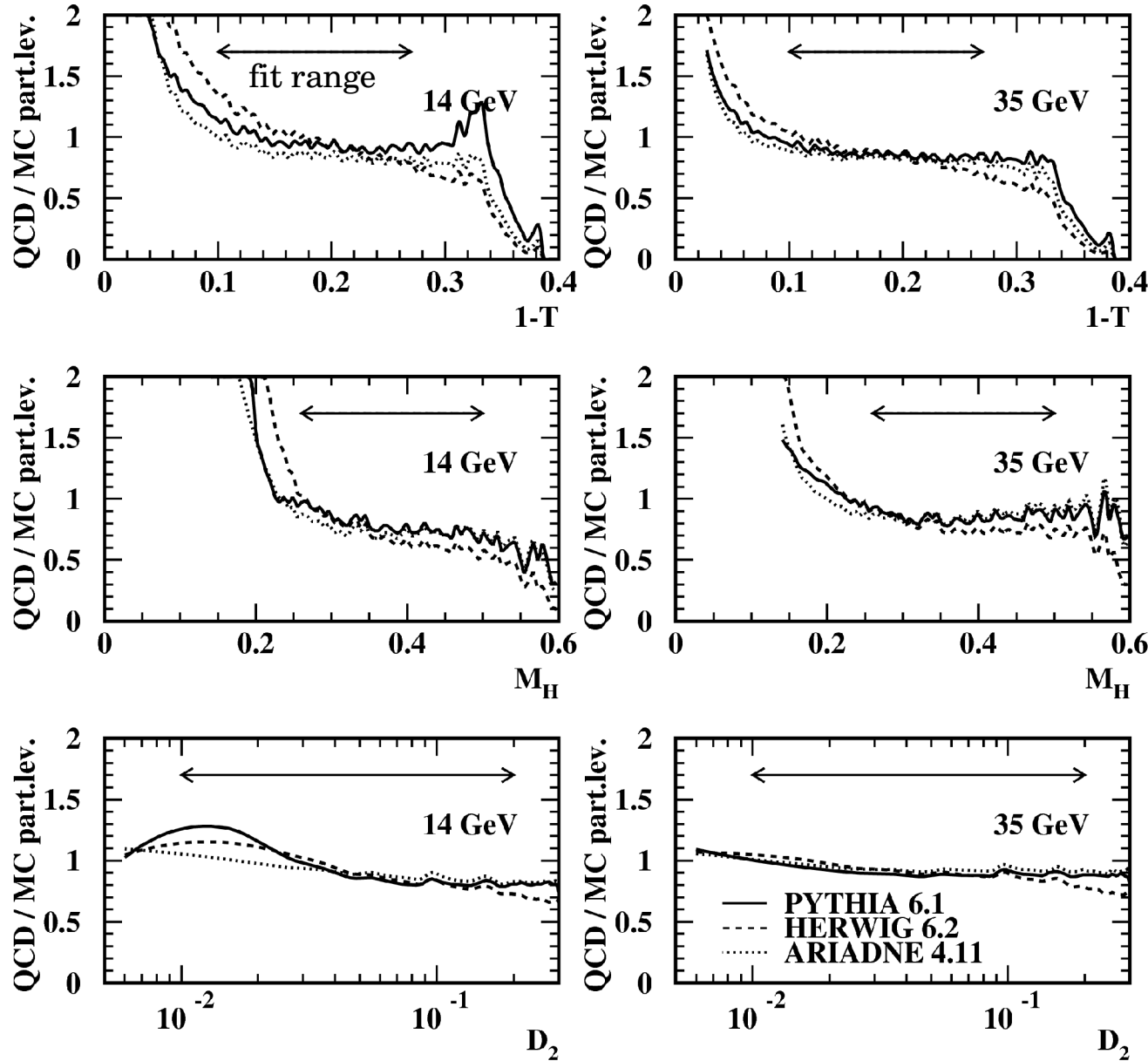
MC hadronisation corrections $C_{\text{had.}} = d\sigma_{\text{had}}/d\sigma_{\text{part}}$

Analysis corrects cum. dist. $R(y) = \int_0^y 1/\sigma d\sigma/dy' dy'$ (norm. correct)



3 NNLO(+NLLA) Fits

NNLO QCD



Check consistency

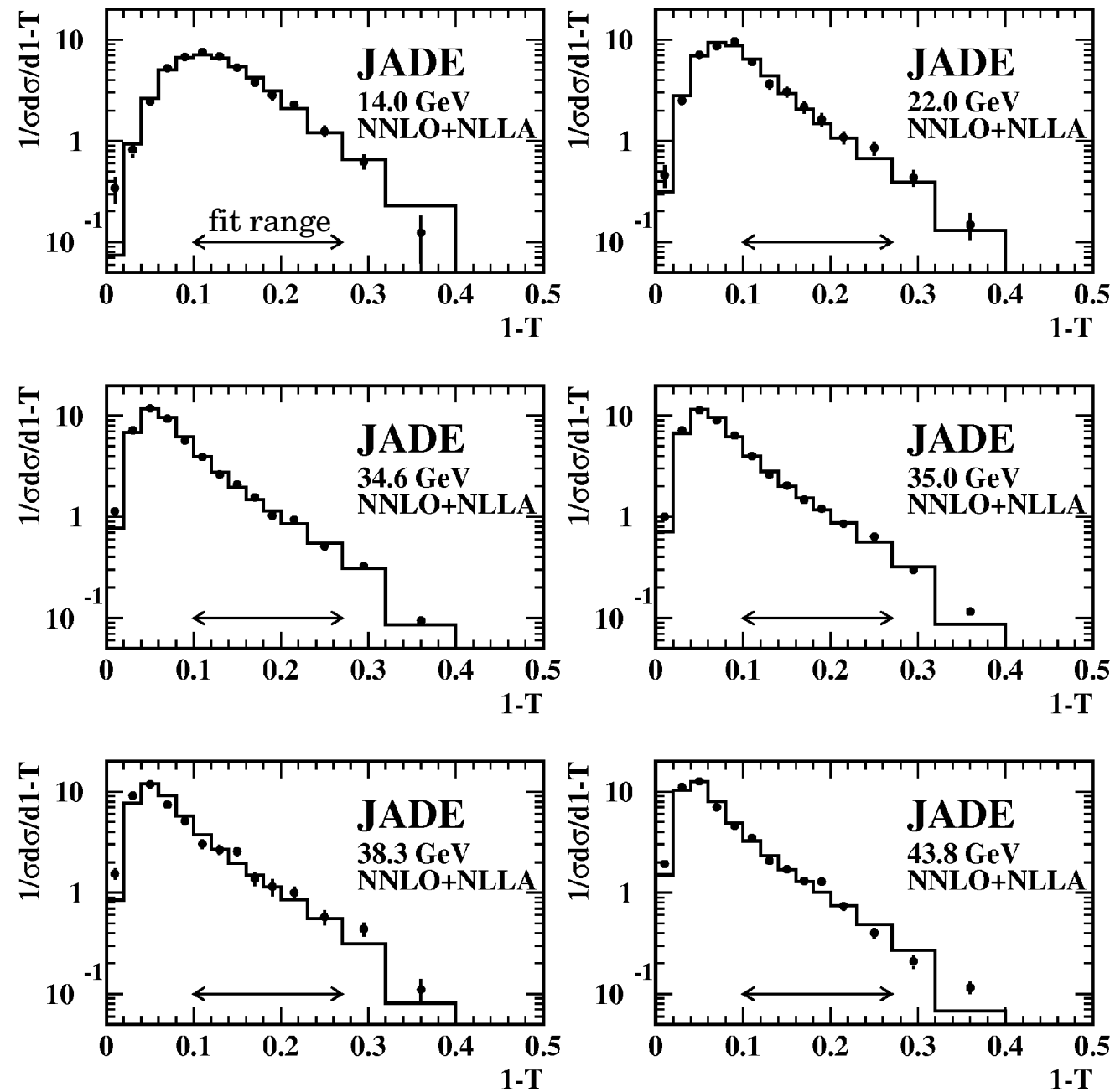
QCD \leftrightarrow MC parton-level
 $(\alpha_s(m_Z) = 0.118)$

Generally ok within
 model differences

\Rightarrow bias on $\alpha_s \sim$ covered

by had. systematic?

3 NNLO(+NLLA) Fits



Fit ranges:

det. corr. stable && $< 20\%$
 had. corr. stable && $< 50\%$
 (except 14 GeV)

theory stable:

$$\alpha_s \ln(1/y)/y < 0.3 \Rightarrow y_{\min}$$

$$3\text{-parton PS only} \Rightarrow y_{\max}$$

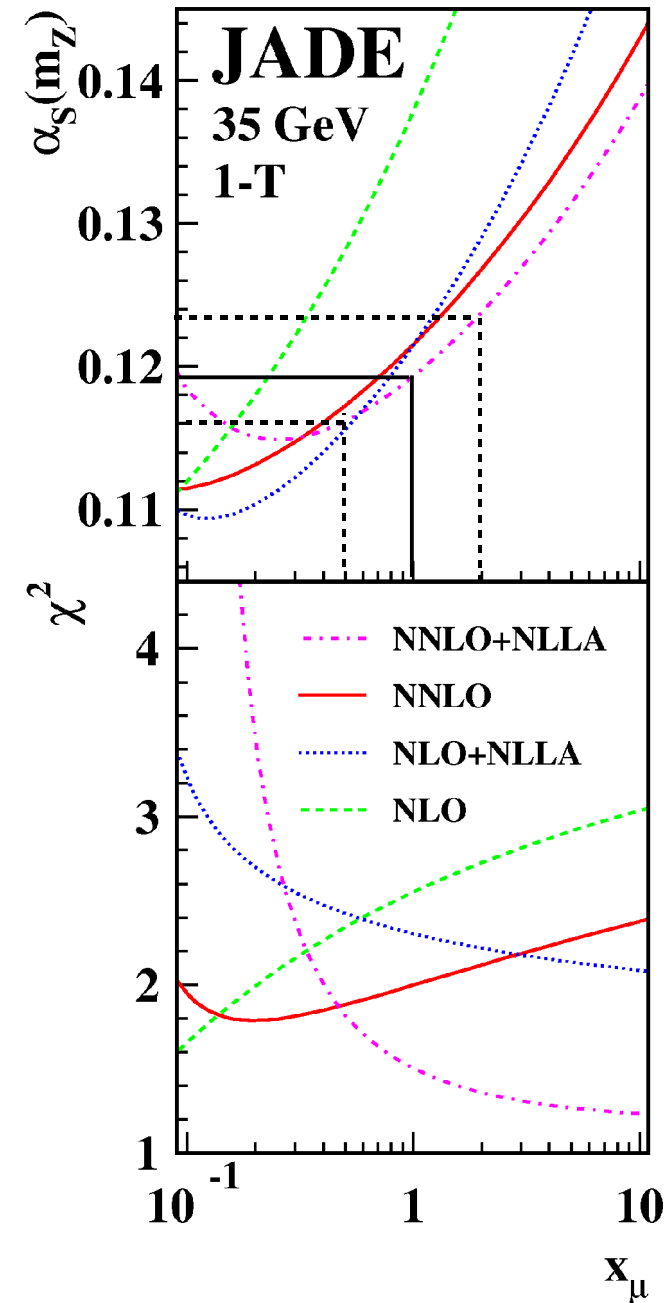
Binned χ^2 -fits incl. stat.corr.

$$1.3 < \chi^2/\text{d.o.f} < 3.0$$

Other observables similar

$$\chi^2/\text{d.o.f} < 3.0$$

3 NNLO(+NLLA) Fits



NNLO:

$$\alpha_s(m_Z) = 0.1210 \pm 0.0007(\text{stat.}) \pm 0.0021(\text{exp.})$$

$$\pm 0.0044(\text{had.}) \pm 0.0036(\text{theo.})$$

$$= 0.1220 \pm 0.0061(\text{tot.})$$

NNLO+NLLA:

$$\alpha_s(m_Z) = 0.1172 \pm 0.0006(\text{stat.}) \pm 0.0020(\text{exp.})$$

$$\pm 0.0035(\text{had.}) \pm 0.0030(\text{theo.})$$

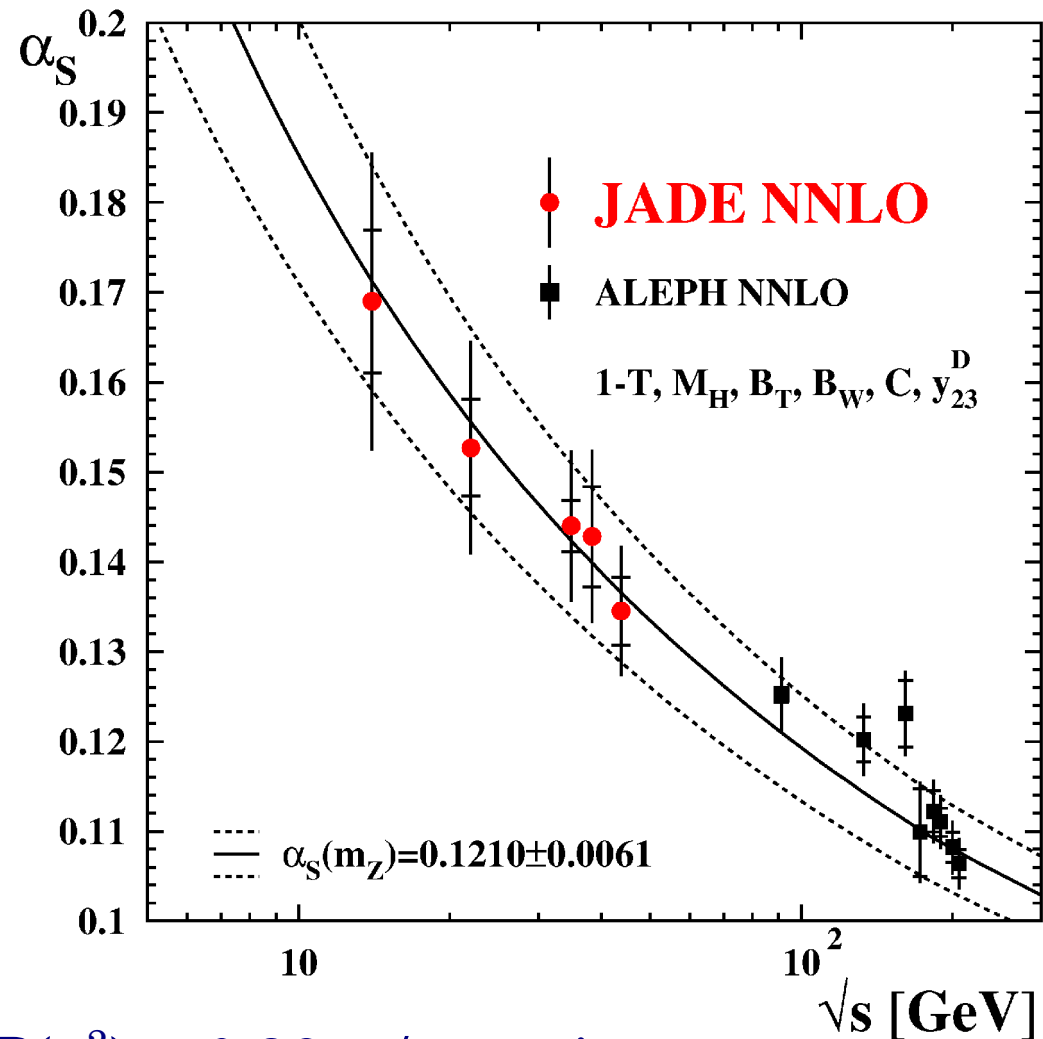
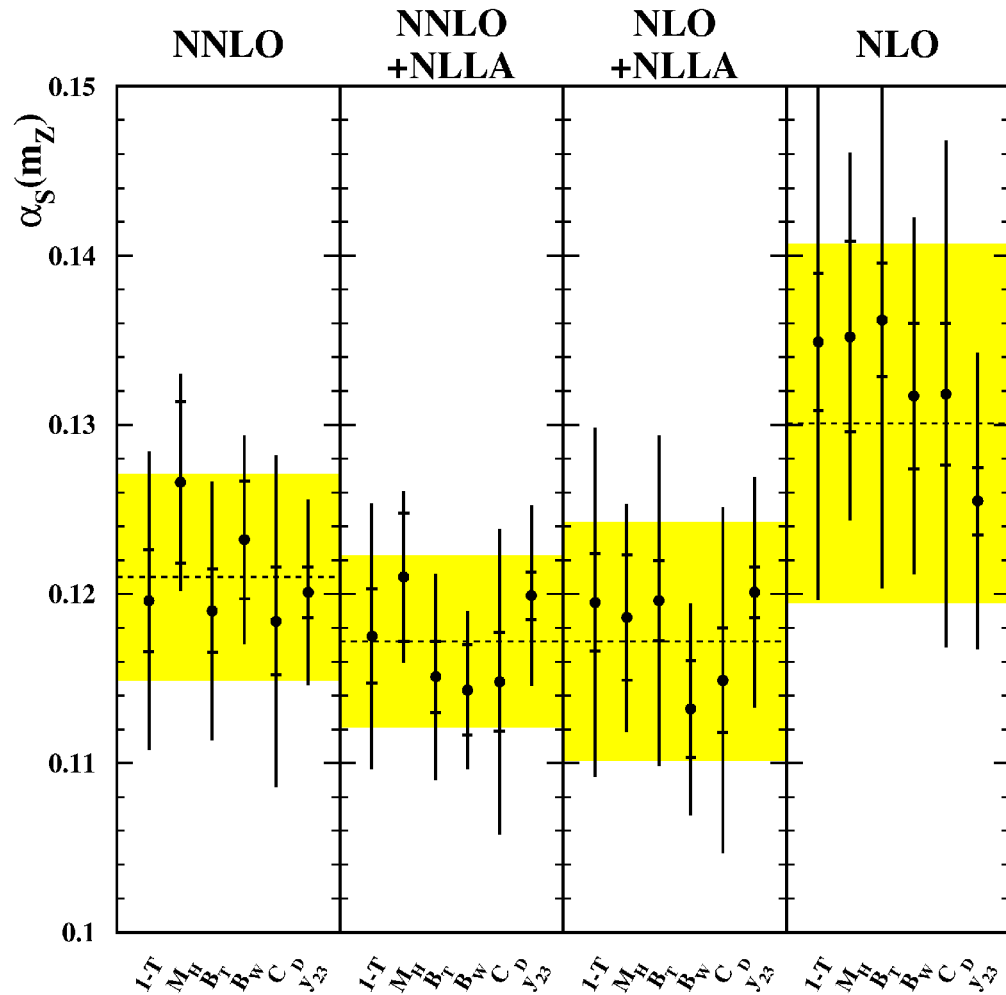
$$= 0.1172 \pm 0.0051(\text{tot.})$$

Results w/o M_H consistent, slightly larger

(14-20%) had. systematics

theo. error smaller by factor ~ 2 (NLO+NLLA) or ~ 3 (NLO)

3 NNLO(+NLLA) Fits



NNLO+NLLA combination: $P(\chi^2) = 0.39$ w/ running

$P(\chi^2) = 10^{-2}$ w/o running

4 $\alpha_s(m_Z)$ in NLO from Moments

Moment of event shape distributions

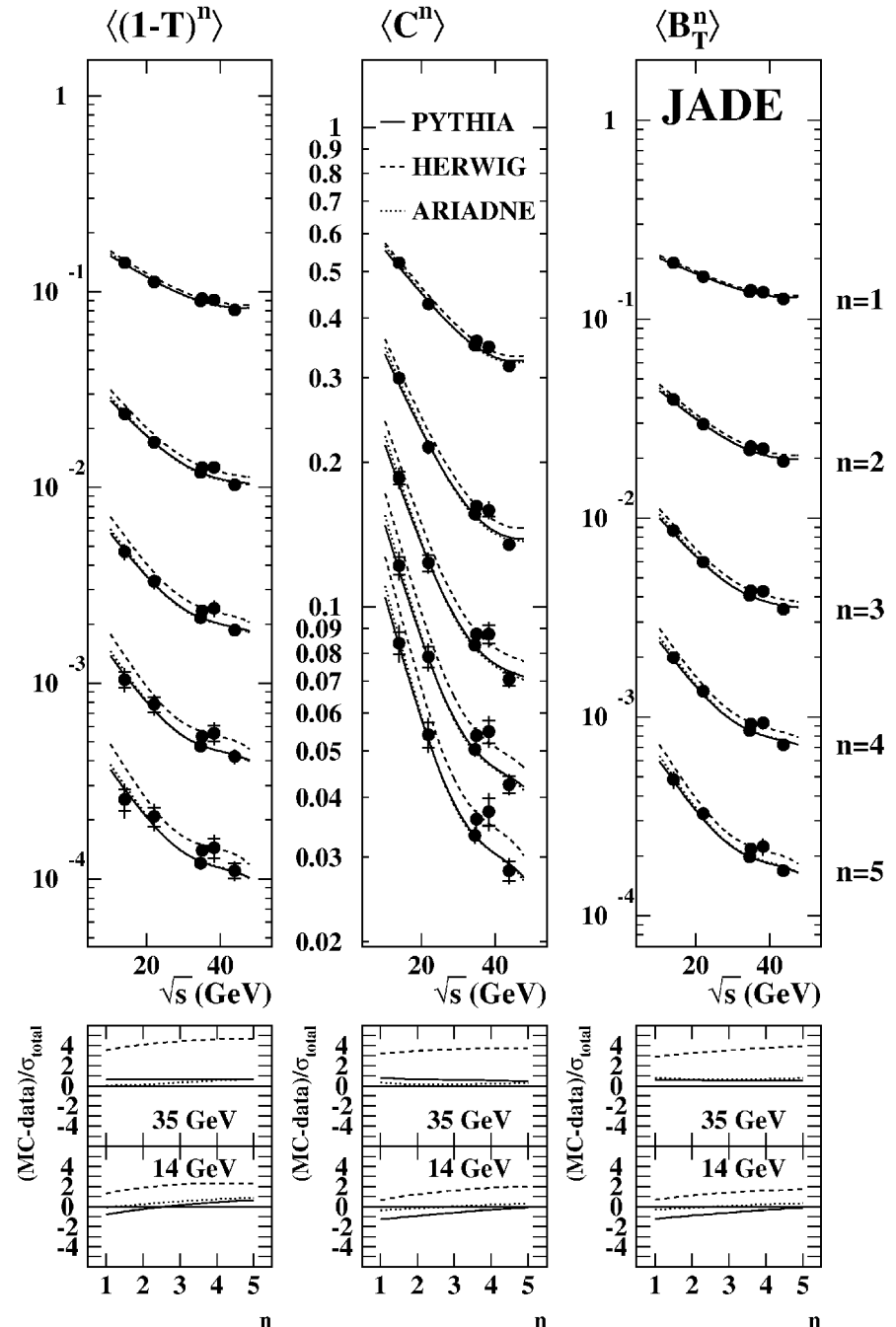
$$\langle y^n \rangle = \int y^n \frac{1}{\sigma} \frac{d\sigma}{dy'} dy'$$

Always probe full phase space

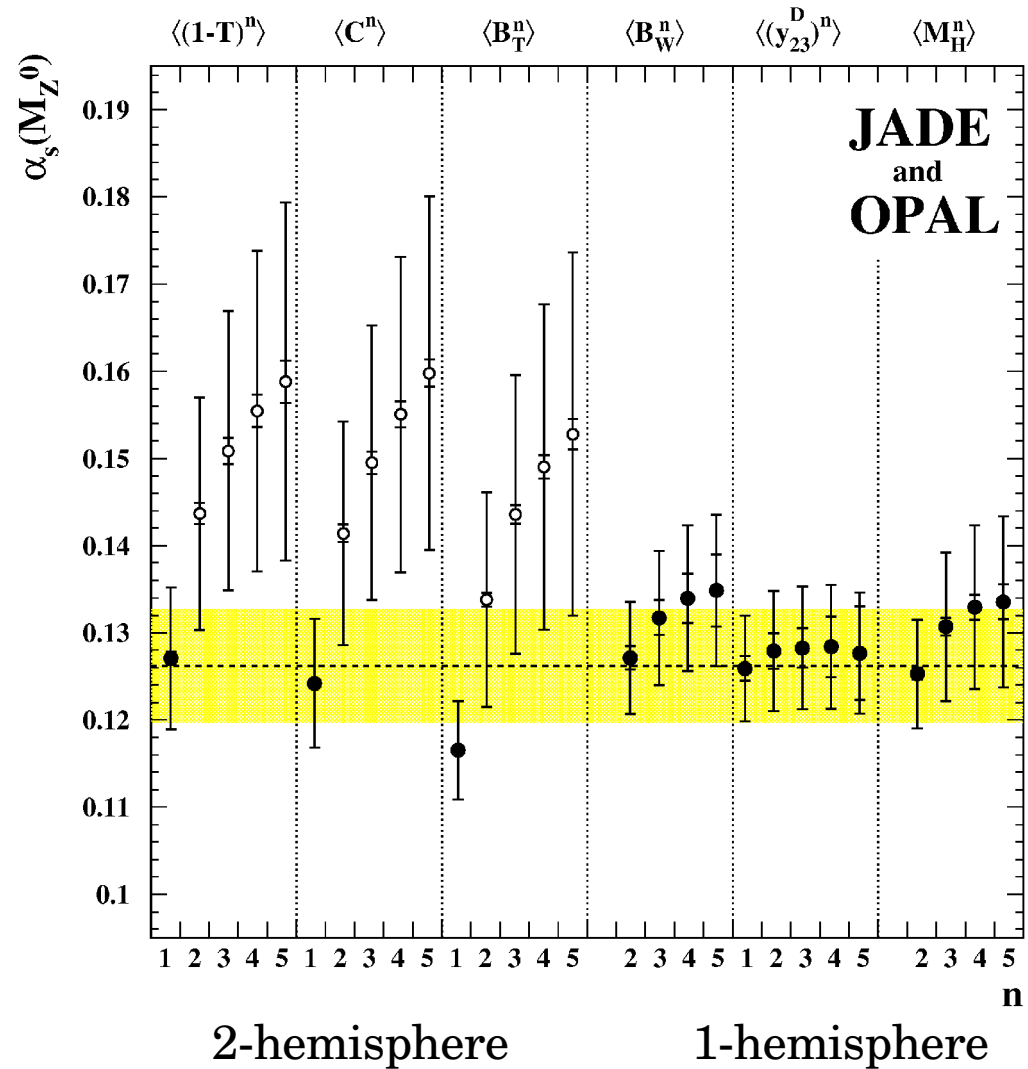
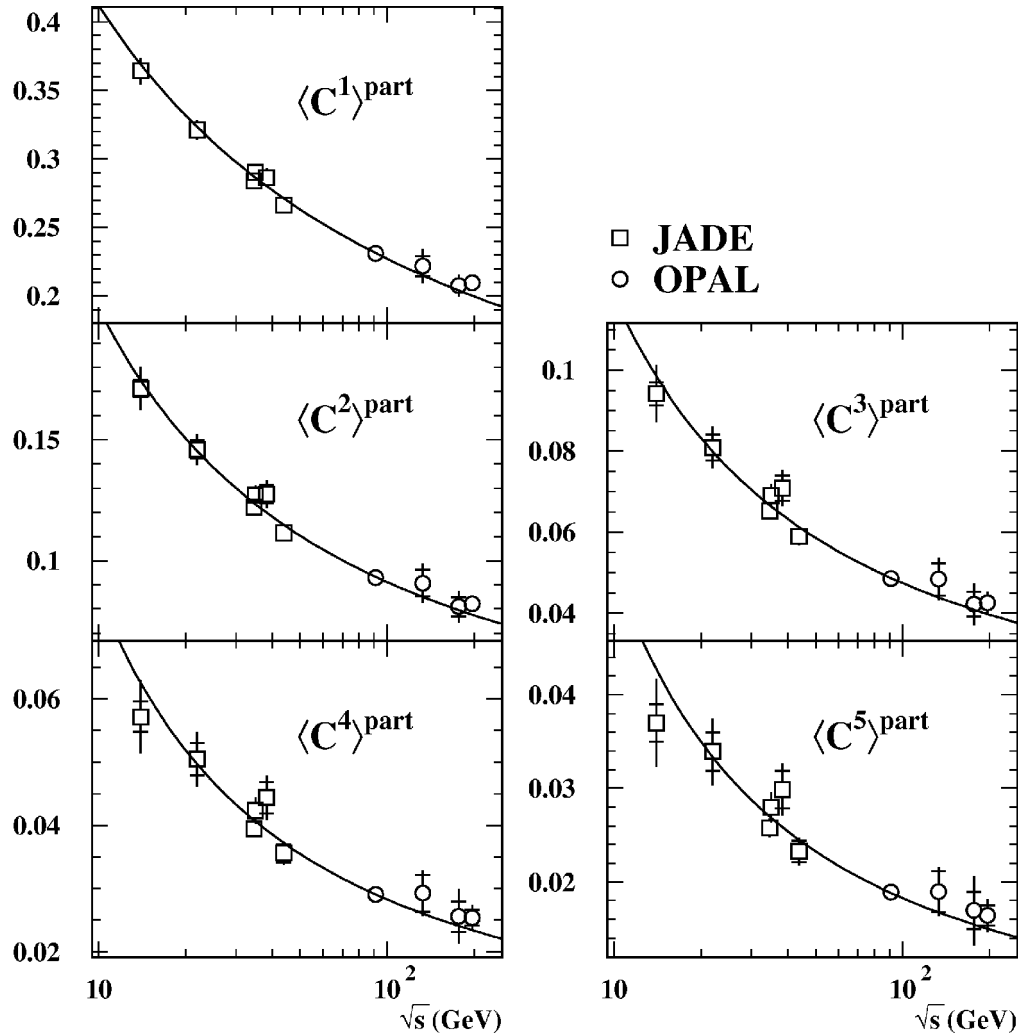
NNLO QCD just now

(GGGH arxiv:0903.4658)

Had. corrections with MC



4 $\alpha_s(m_Z)$ in NLO from Moments



$$\alpha_s(m_Z) = 0.1287 \pm 0.0007(\text{stat.}) \pm 0.0011(\text{exp.}) \\ \pm 0.0022(\text{had.}) \pm 0.0075(\text{theo.})$$

5 Summary

- First NNLO+NLLA event shape analysis
- Precision measurement $\Delta\alpha_s(m_Z) \sim 4\%$
- Exclude with JADE non-running at 99% CL
- Results from moments (NLO) consistent
- To come:
 - NNLO(+NLLA) with OPAL
 - NNLO moments
 - Analytic power correction models with moments

3 NNLO Fits

Rel. deviations between $\alpha_s(M_Z)$ fit results for different fits:

[%]	1-T	M_H	B_T	B_W	C	D_2
NNLO-NLO	-13	-7	-14	-7	-11	-4
NNLO-(NLO+NLLA)	0.1	7	-0.5	8	3	0
(NNLO+NLLA)- (NLO+NLLA)	-2	2	-4	1	0	-0.2

RMS of combined observable $\alpha_s(M_Z)$ results for different fits:

[%]	NNLO	NNLO+NLLA	NLO	NLO+NLLA
RMS	2.9	2.6	3.6	2.6

RMS reduction less than at LEP \rightarrow hadronisation systematics

1 JADE Event Display

JSN JAD025zfile001z200evs.bos

BEAM 22.100 GEV FIELD -4.213 KG TALC 0039 DATE 13/06/08 TIME 11.31.36
T1A 0802 T1P 4001 CAMAC TIME 51. 0.17 4/10/19

8382 4217 186
DHITS 784
LGTOT 9187
UHITS 28
GCYL 9187
GCAPS 0 0
WCAPS 0 0

R-FI SECTION

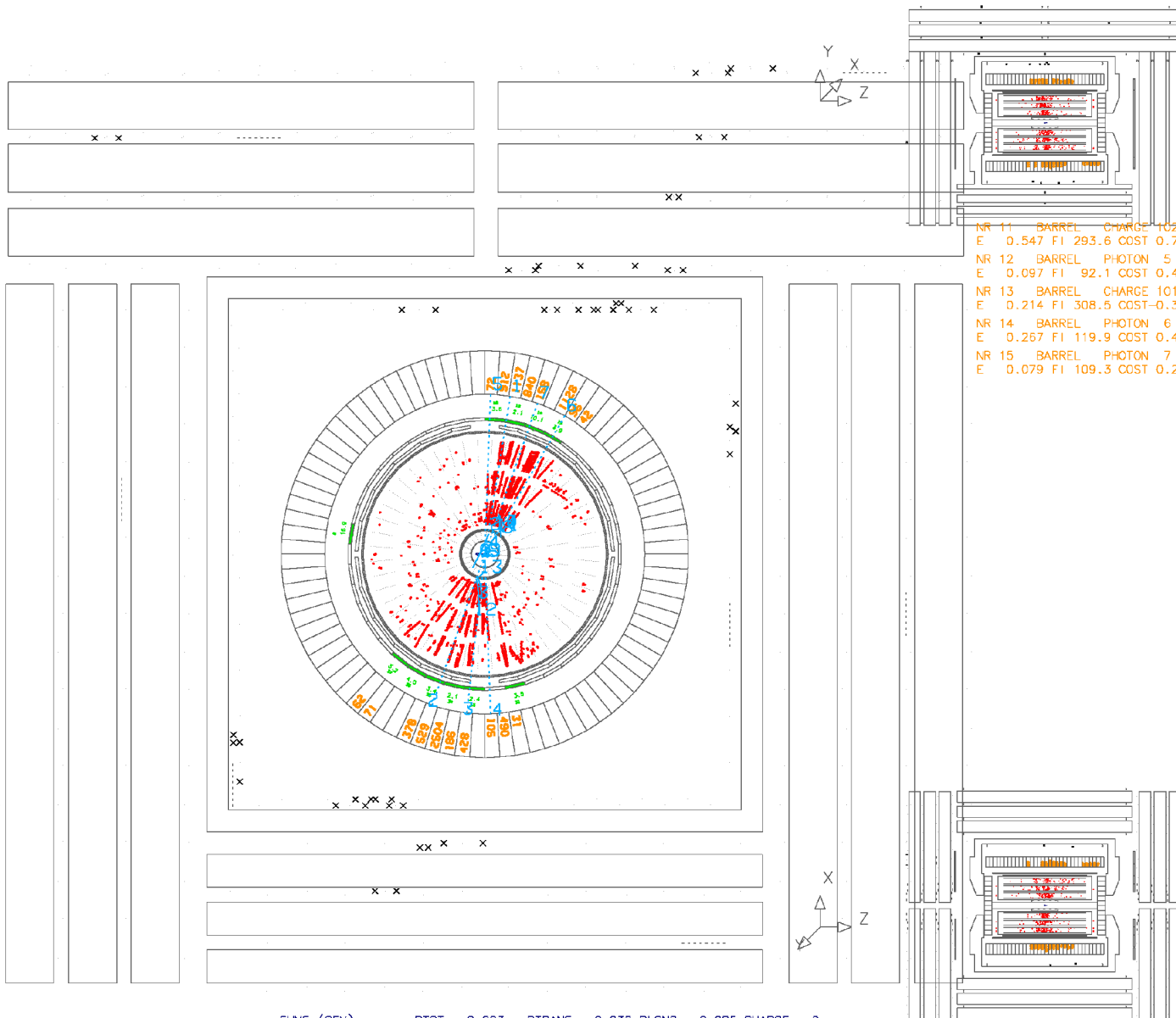
JADE

IK HMDS 8 NR OF TRACKS 14
+ RMSRFI RMSRZ/HIT PHI
IT PLONG PTRANS COSTHE
IQUAL CHIP MUPR PIPR

-	3.23/49	40.4/46	309.9
003	-0.003	0.001	NoNQ
-	2.78/23	40.0/19	303.1
012	0.012	0.001	NoNQ
+	2.82/44	42.0/39	290.4
004	0.003	0.002	NoNQ
+	2.92/41	39.3/35	289.5
010	0.010	0.002	NoNQ
12	0.06	1.00	0.050
+	2.86/47	42.1/41	249.5
003	0.002	0.002	NoNQ
-	2.78/48	38.1/47	125.0
003	-0.003	0.001	NoNQ
-	2.83/43	42.7/39	119.2
007	-0.005	0.003	NoNQ
1	0.75	1.00	0.014
+	2.87/43	40.6/37	117.2
008	-0.007	0.003	NoNQ
1	0.26	1.00	0.012
-	2.92/41	41.5/43	115.7
004	-0.004	0.001	NoNQ
-	2.99/25	40.6/26	108.1
013	0.012	0.005	NoNQ
+	2.73/46	40.4/38	110.3
007	0.007	0.002	NoNQ
+	2.77/42	41.1/42	293.4
008	0.007	0.003	NoNQ
-	2.82/27	40.9/24	290.9
005	0.003	0.004	0.613
+	2.57/22	39.5/23	107.8
006	0.006	0.002	NoNQ

IK LGCL 1 NR OF CLUSTERS 15

1	BARREL CHARGE	303
3.252	FI	283.0 COST 0.207
2	BARREL PHOTON	1
1.645	FI	99.1 COST-0.021
3	BARREL CHARGE	109
1.030	FI	105.2 COST-0.241
4	BARREL PHOTON	2
0.572	FI	289.3 COST 0.197
5	BARREL CHARGE	207
0.836	FI	117.9 COST-0.107
6	BARREL CHARGE	106
0.397	FI	117.9 COST-0.308
7	BARREL CHARGE	105
0.622	FI	262.7 COST 0.068
8	BARREL CHARGE	310
0.681	FI	100.4 COST 0.219
9	BARREL PHOTON	3
0.261	FI	276.4 COST-0.081
10	BARREL PHOTON	4



NR 11 BARREL CHARGE 102
E 0.547 FI 293.6 COST 0.7
NR 12 BARREL PHOTON 5
E 0.097 FI 92.1 COST 0.4
NR 13 BARREL CHARGE 101
E 0.214 FI 308.5 COST-0.3
NR 14 BARREL PHOTON 6
E 0.267 FI 119.9 COST 0.4
NR 15 BARREL PHOTON 7
E 0.079 FI 109.3 COST 0.2

+++ SUMS (GEV) +++ PTOT 0.093 PTRANS 0.032 PLONG 0.085 CHARGE 0
TOTAL CLUSTER ENERGY 10.632 PHOTON ENERGY 3.053 NR OF PHOTONS 7

2 Event Shape Measurement

Measure $1-T$, M_H , B_T , B_W , C , D_2 to allow cross checks

Subtract expected $e^+e^- \rightarrow b\bar{b}$ contribution at detector level

Detector correction incl. ISR (udsc) $C_{\text{det.}} = d\sigma_{\text{had}}/d\sigma_{\text{det}}$

