$\alpha_s(M_Z)$ from JADE Event Shapes

S. Bethke[1], (*)S. Kluth[1,2], C. Pahl[1,3], J. Schieck[1] and the JADE Coll.

[1] Max-Planck-Institut für Physik

[2] Universität Würzburg

[3] Excellence Cluster Origin and Structure of the Universe, Munich

arxiv:0810.2933 (acc. by EPJC)

arxiv:0810.1389 (sub. to EPJC)

XLIV Recontres de Moriond

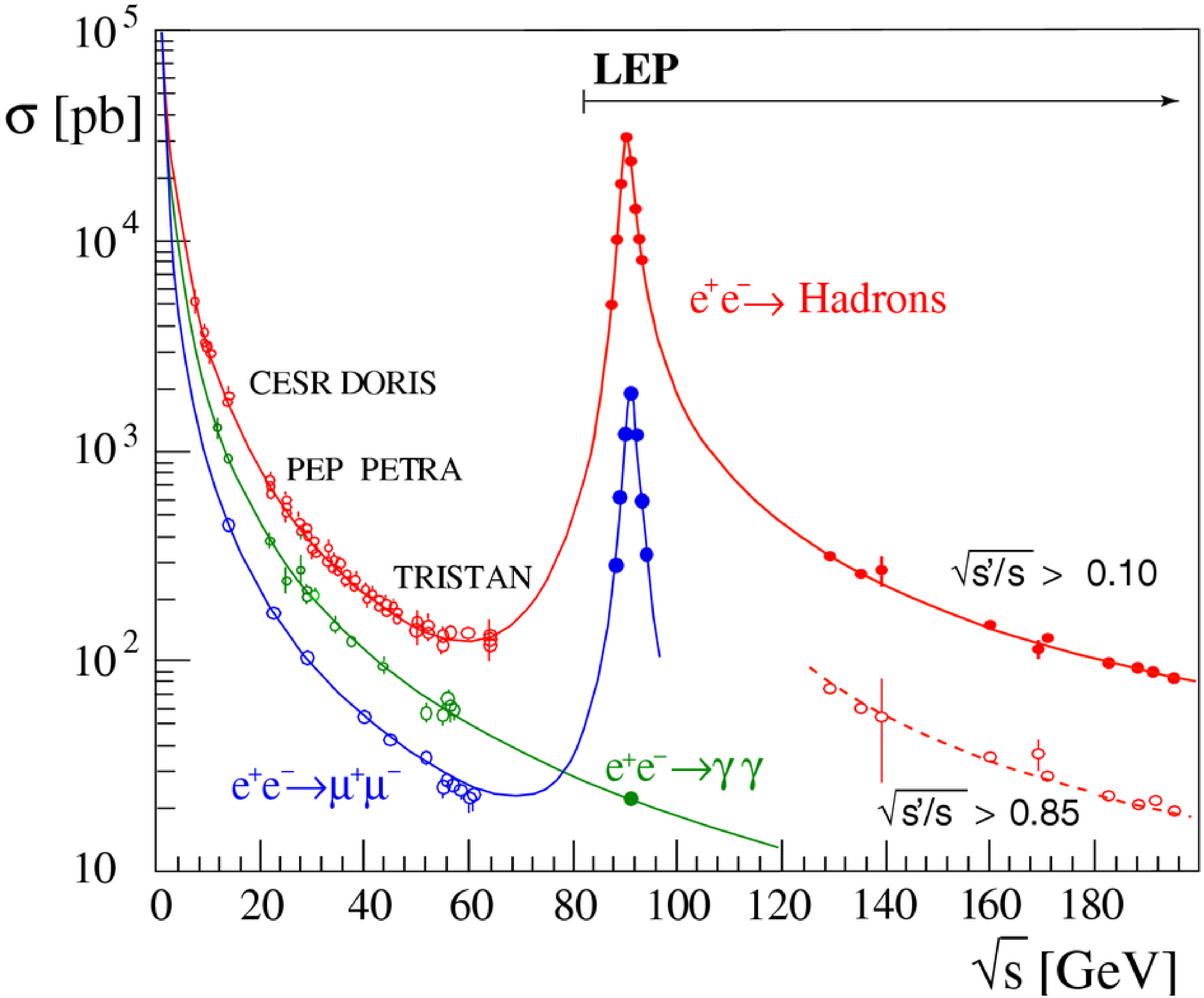
QCD and High Energy Interactions

14-21 March 2009, La Thuile

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

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

1 e^+e^- Annihilation Processes



Main backgrounds at PETRA:

γγ → hadrons

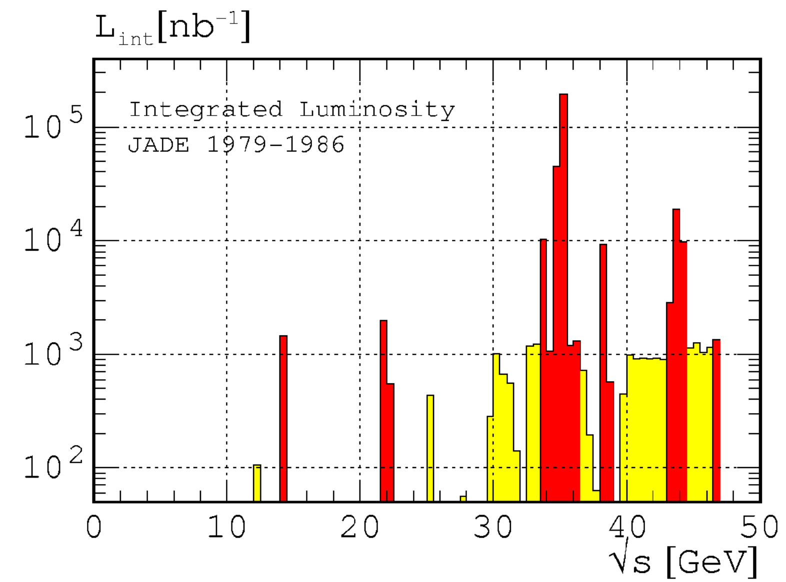
τ pairs

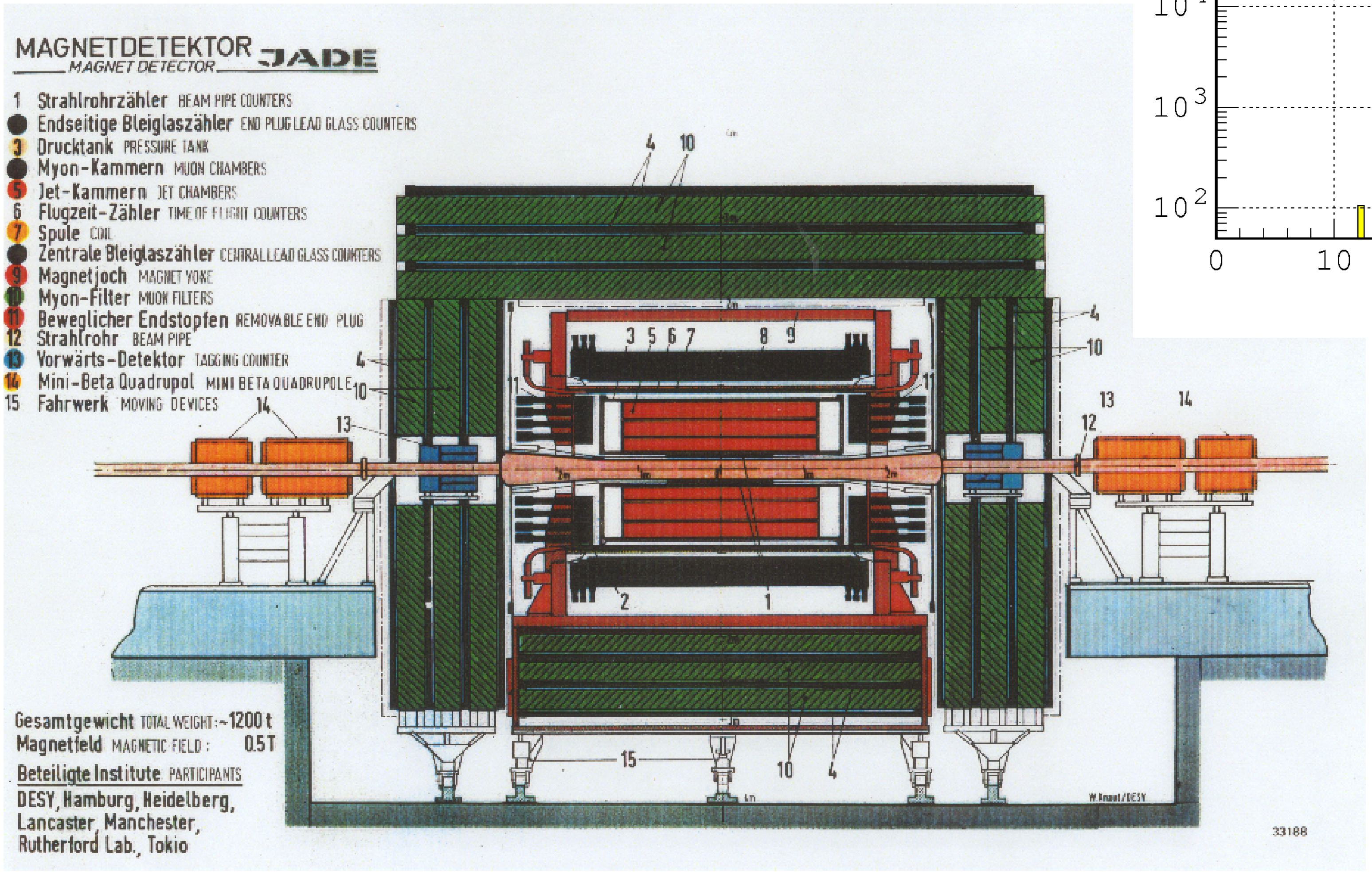
ISR

1 JADE Experiment at PETRA

1979-1986, √s = 14, 22, 35, 38, 44 GeV

re-analysis with modern tools



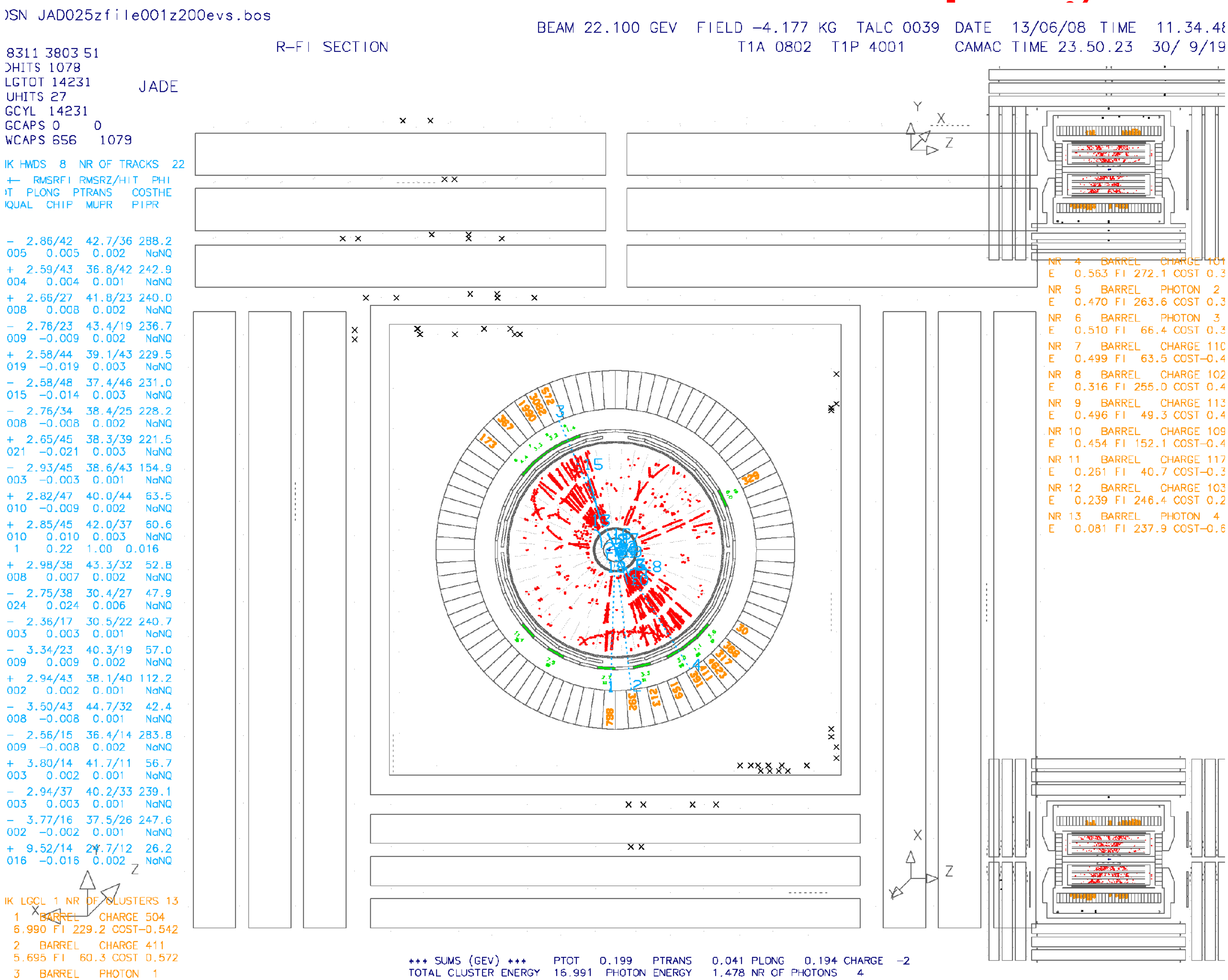


~ideal QCD experiment

larger lever arm in ln(s) than LEP

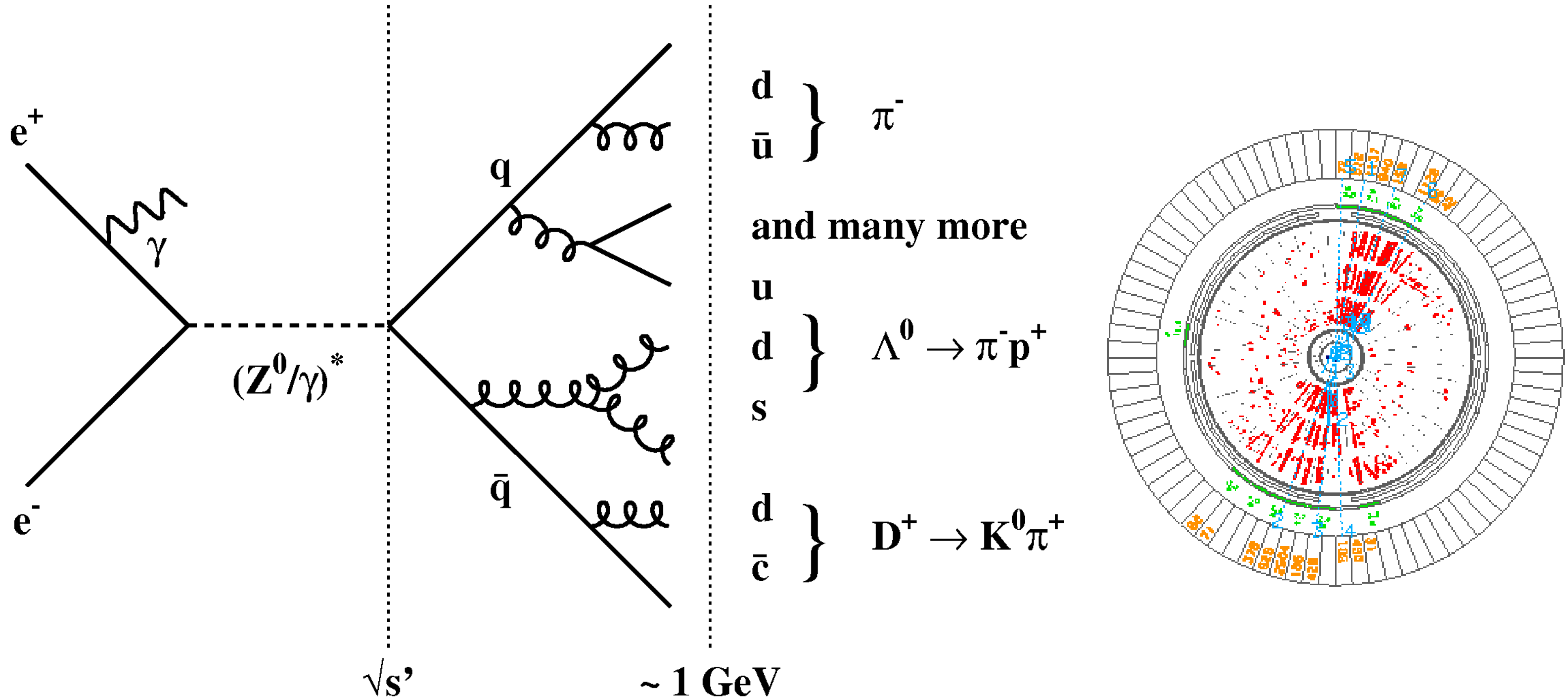
no other data exist

1 JADE Event Display



1 e^+e^- Annihilation to Hadrons

Electro-weak Production **Parton Shower** **Hadronisation**

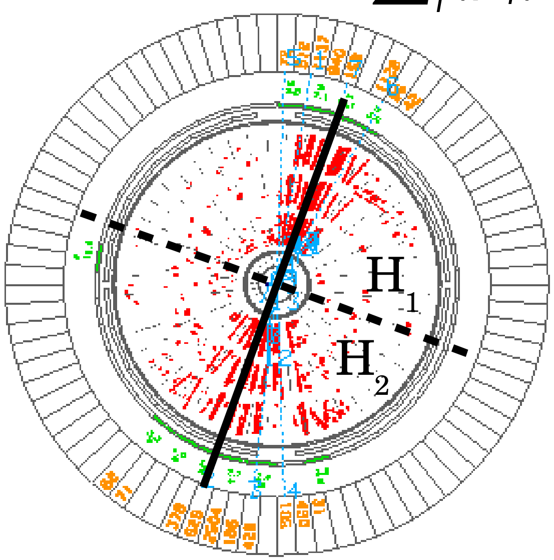


Parton Level *Hadron Level* *Detector Level*

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

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

iteratively combine pairs with smallest y_{ij} ($p_{jet} = p_i + p_j$)

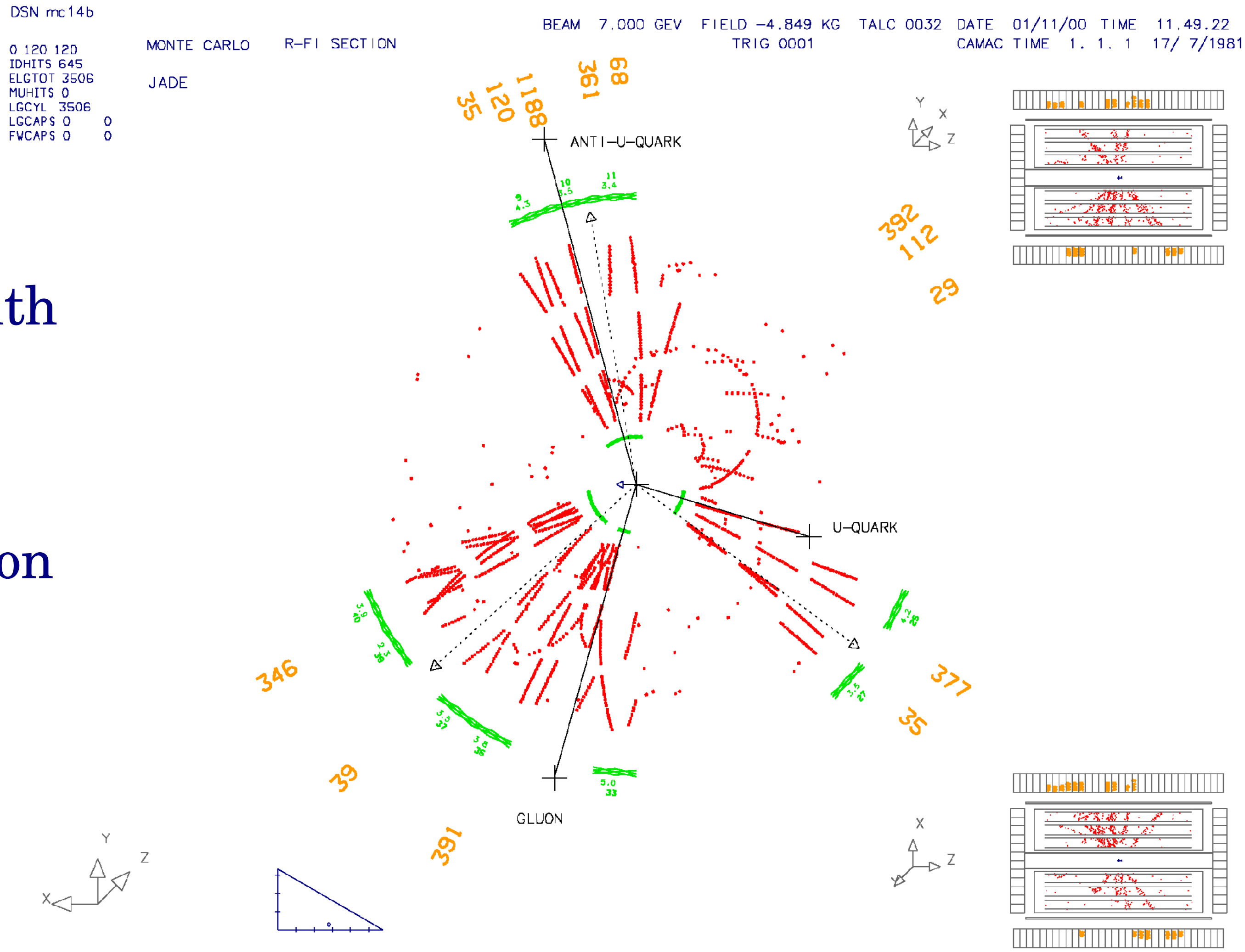
$D_2 = y_{ij}$ for 3 → 2 jet transition

"differential 2-jet rate"

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

≥ 3 partons: $D_2 < 0.3$

JADE MC event at 14 GeV

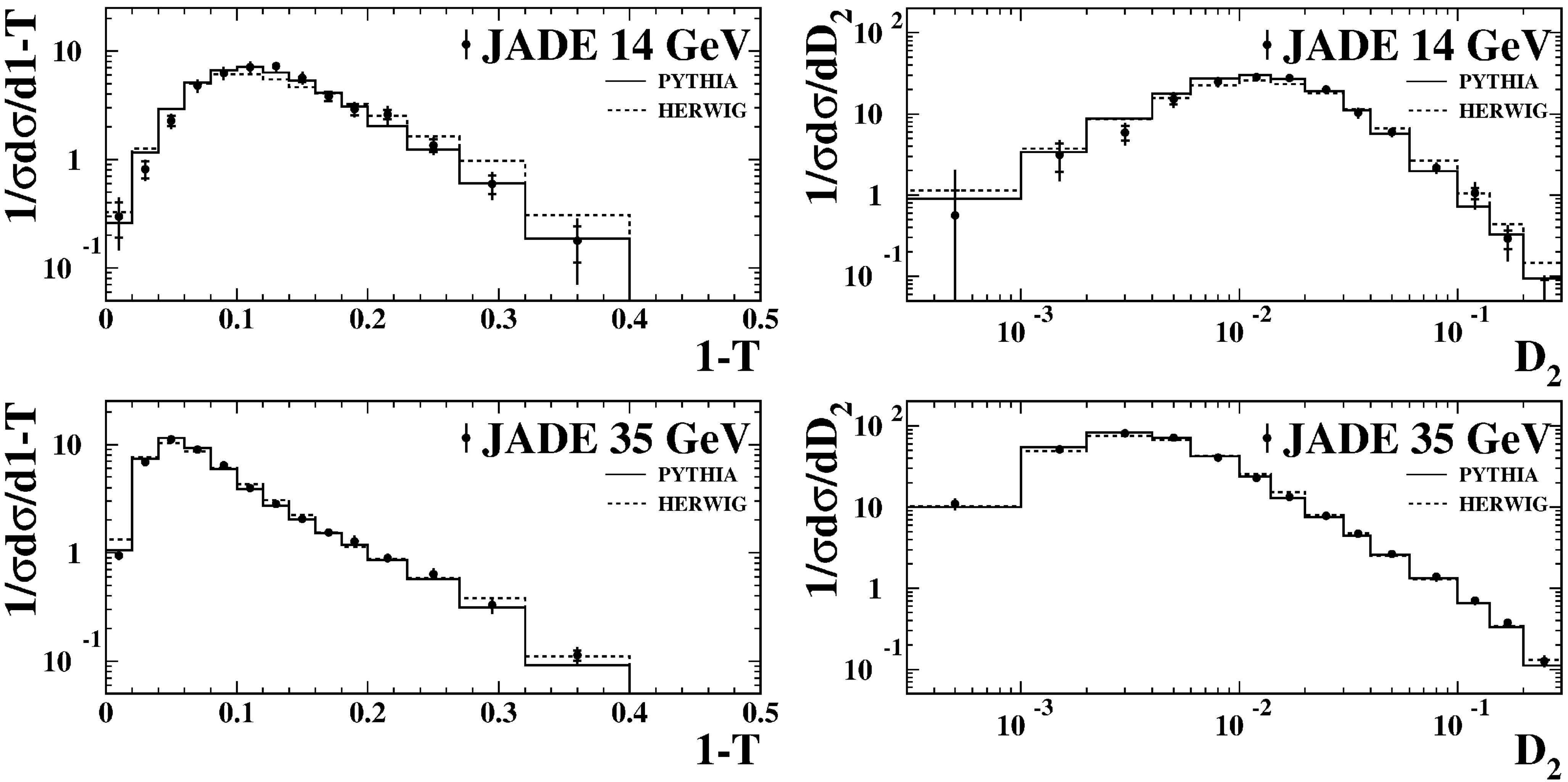


2 Event Shape Measurement

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 → good agreement justifies exp. corrections

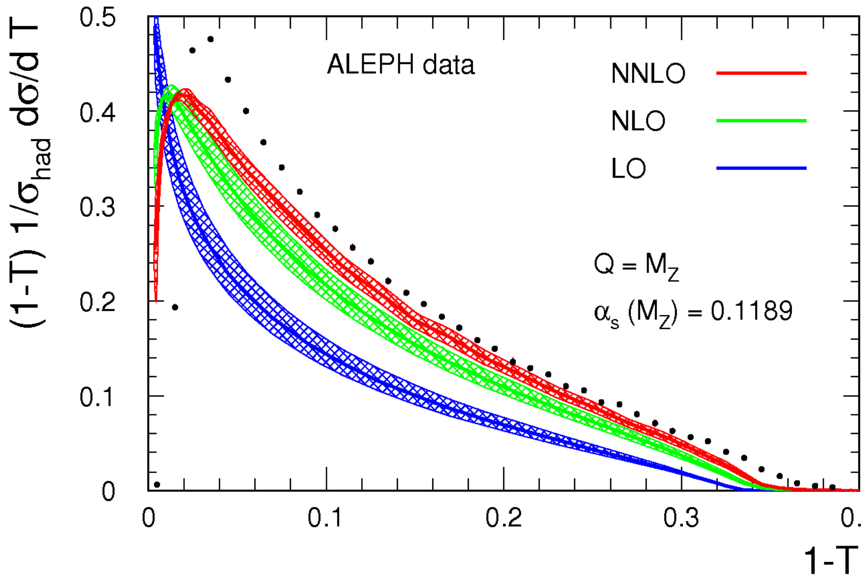


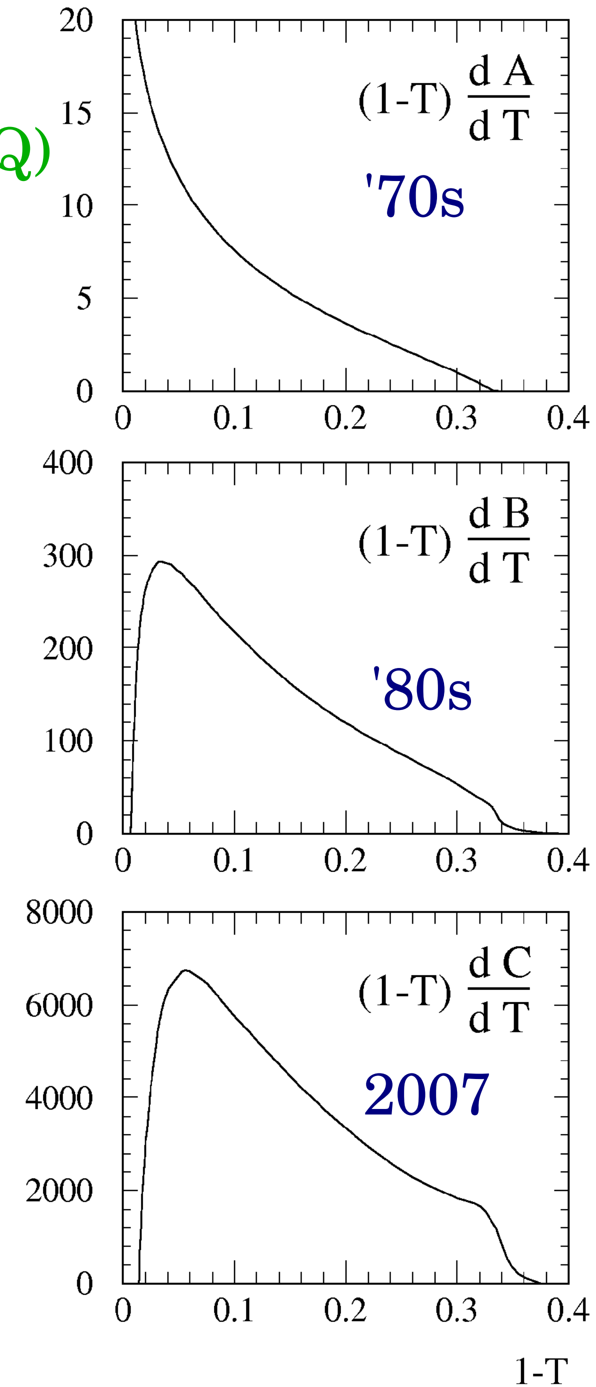
3 NNLO QCD

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

$y = 1\text{-}T, \ldots;\ \underline{\alpha}_S = \alpha_S/(2\pi);\ \sigma_0 \rightarrow \sigma_{had}$, 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

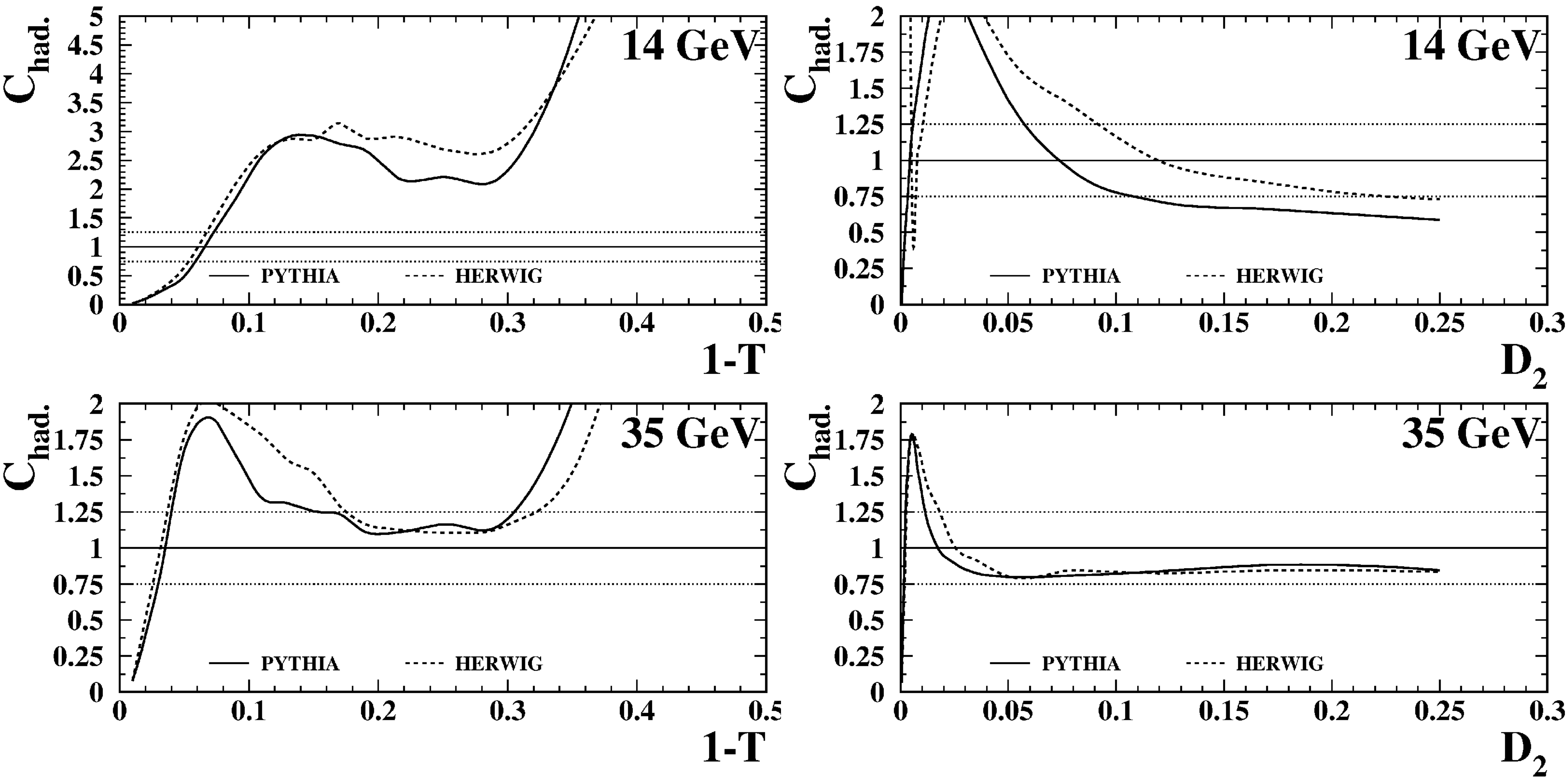




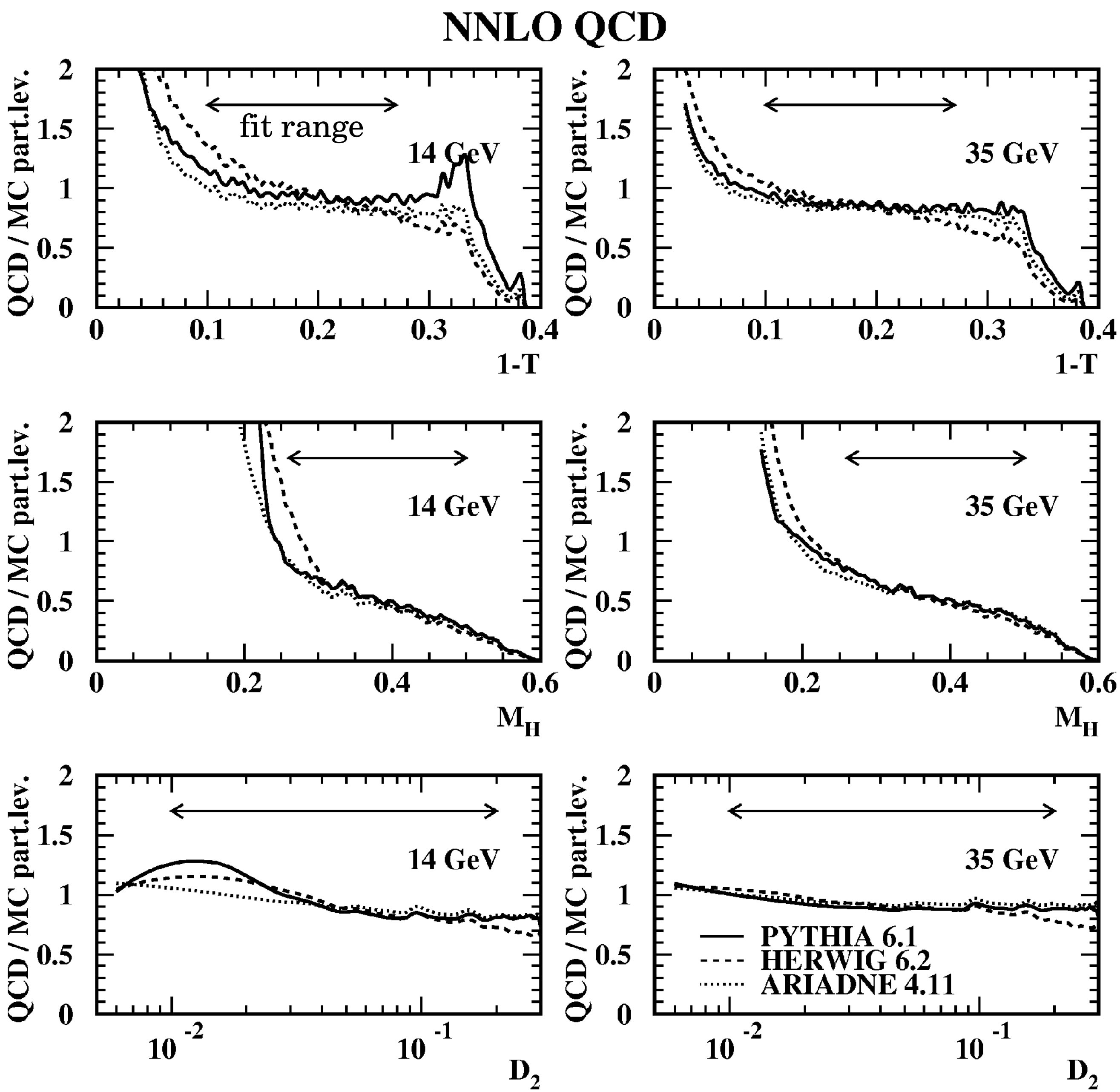
3 NNLO(+NLLA) fits

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

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



3 NNLO(+NLLA) Fits



Check consistency

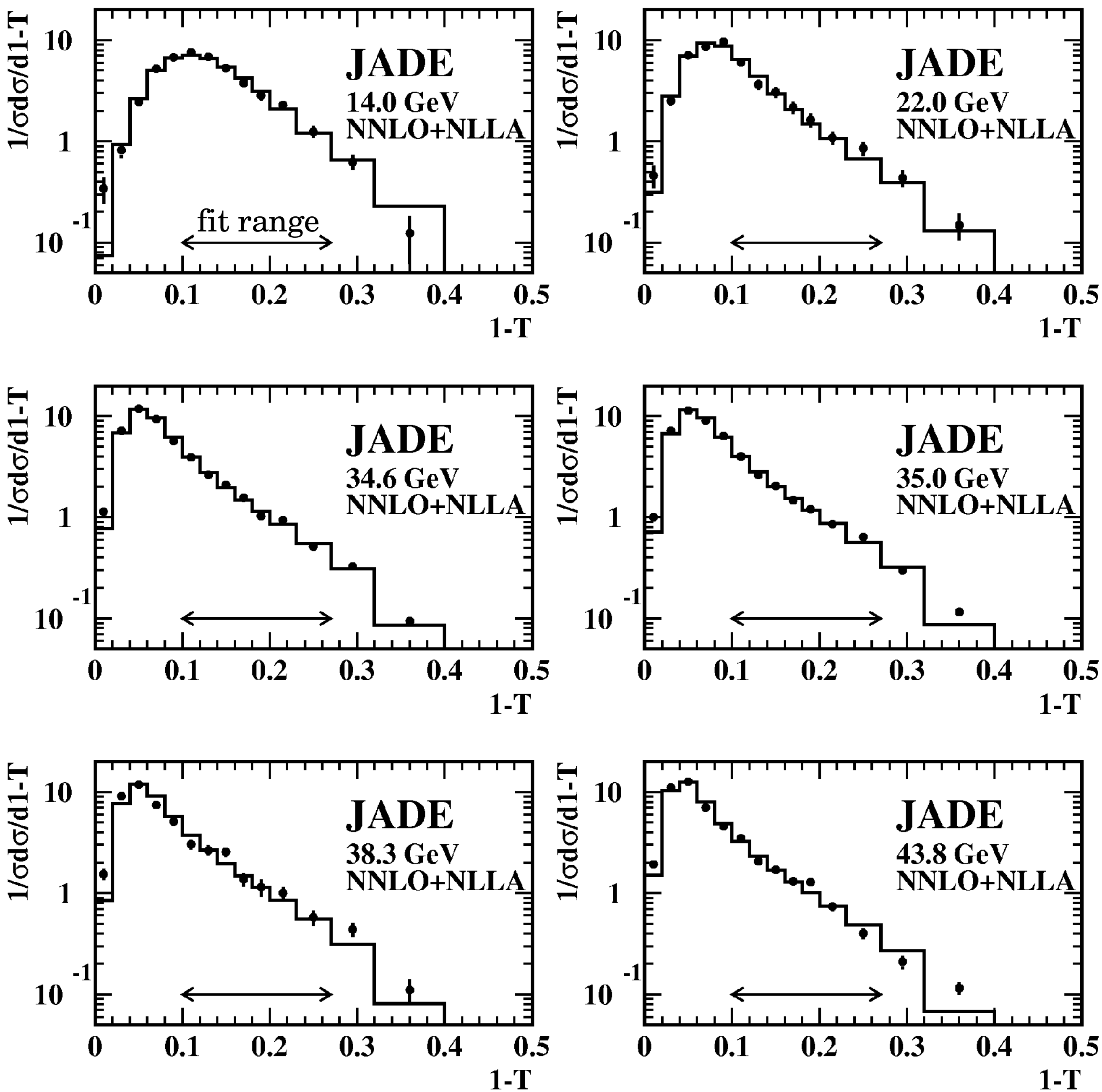
QCD ↔ MC parton-level

($\alpha_S(M_Z) = 0.118$)

Generally ok within model differences, except M_H

⇒ bias on α_S not 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-parton PS only $\Rightarrow y_{max}$

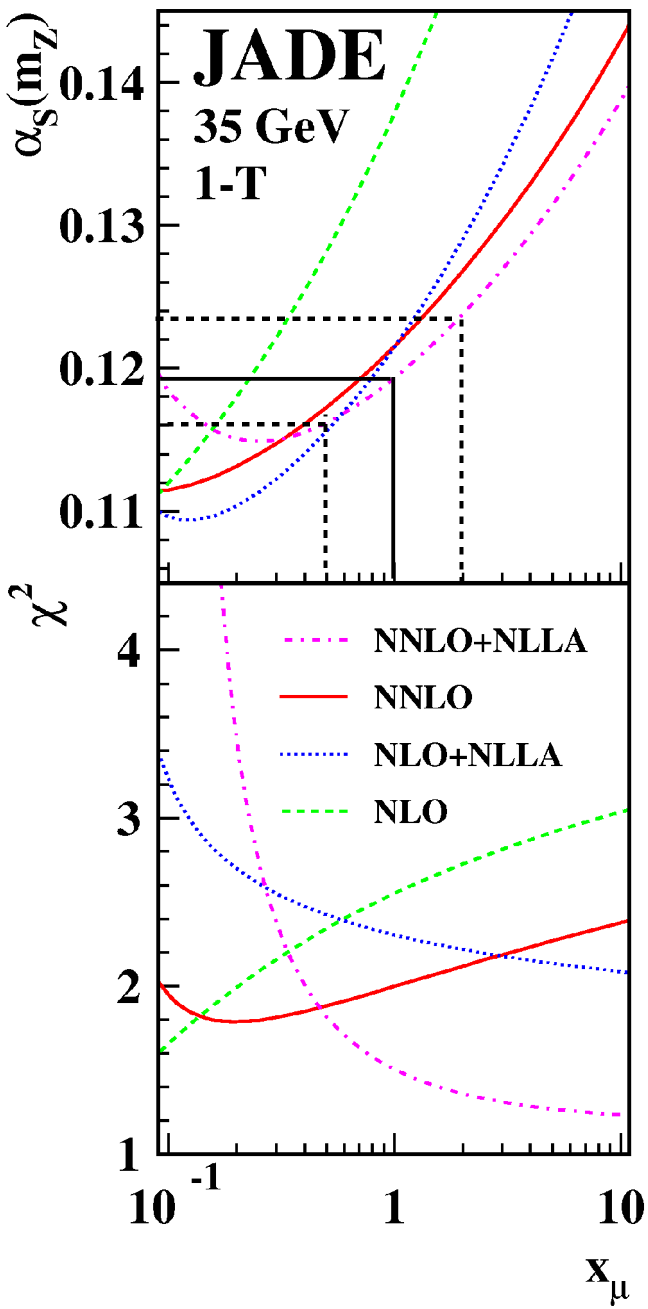
Binned χ^2-fits incl. stat.corr.

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

Other observables similar

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

3 NNLO(+NLLA) Fits



NNLO:

$\alpha_S(M_Z) = 0.1210 \pm 0.0007(\text{stat.}) \pm 0.0021(\text{exp.})$
$\pm 0.0044(\text{had.}) \pm 0.0036(\text{theo.})$
$= 0.1220 \pm 0.0061(\text{tot.})$

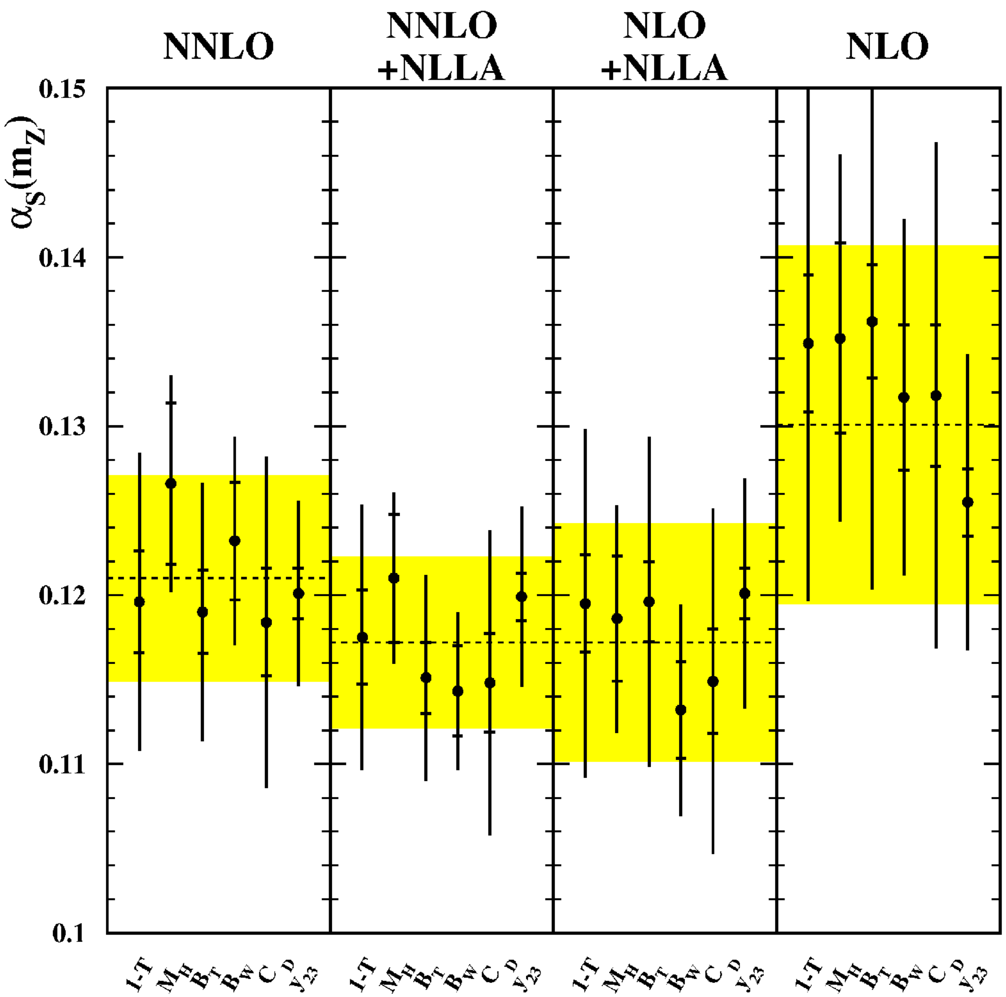
NNLO+NLLA:

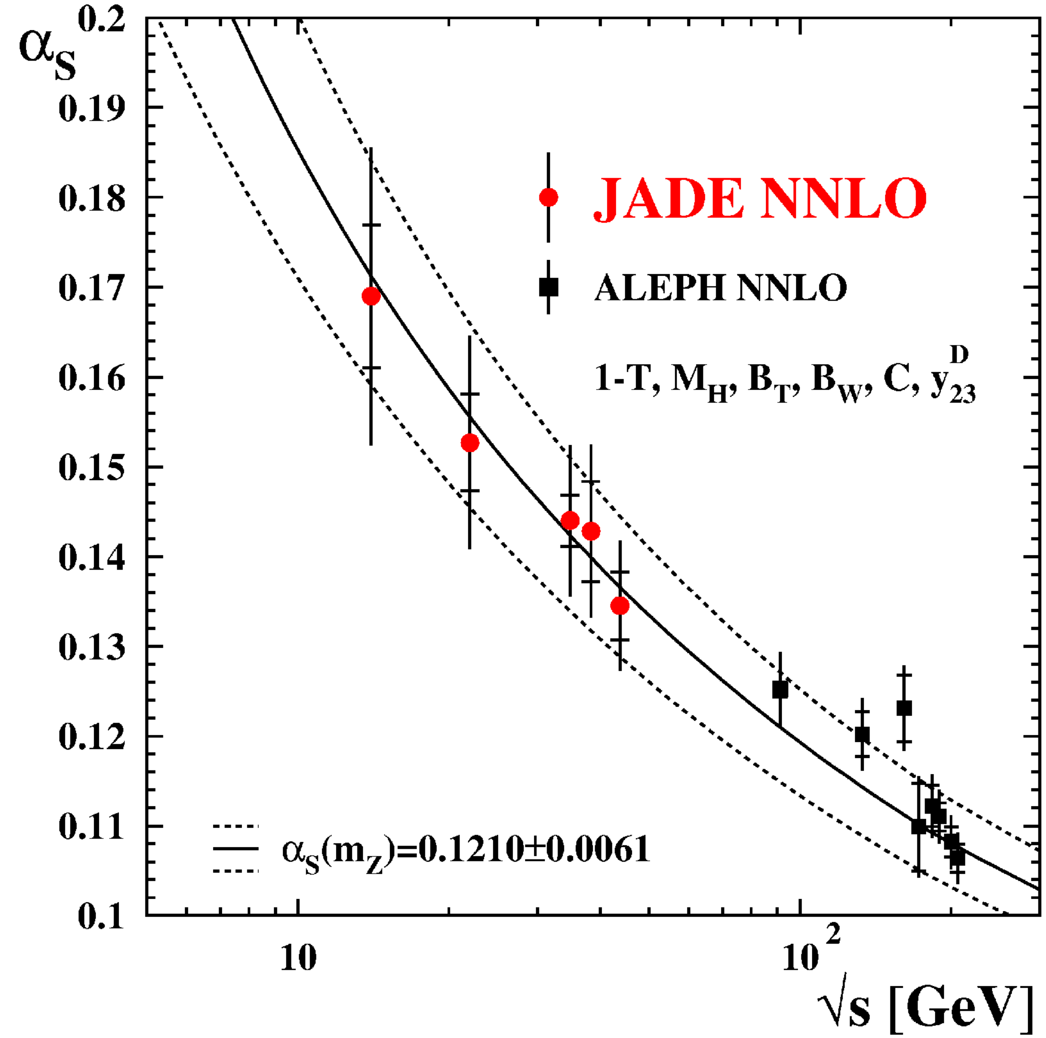
$\alpha_S(M_Z) = 0.1172 \pm 0.0006(\text{stat.}) \pm 0.0020(\text{exp.})$
$\pm 0.0035(\text{had.}) \pm 0.0030(\text{theo.})$
$= 0.1172 \pm 0.0051(\text{tot.})$

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





4 $\alpha_S(M_Z)$ in NLO from Moments

Moment of event shape distributions

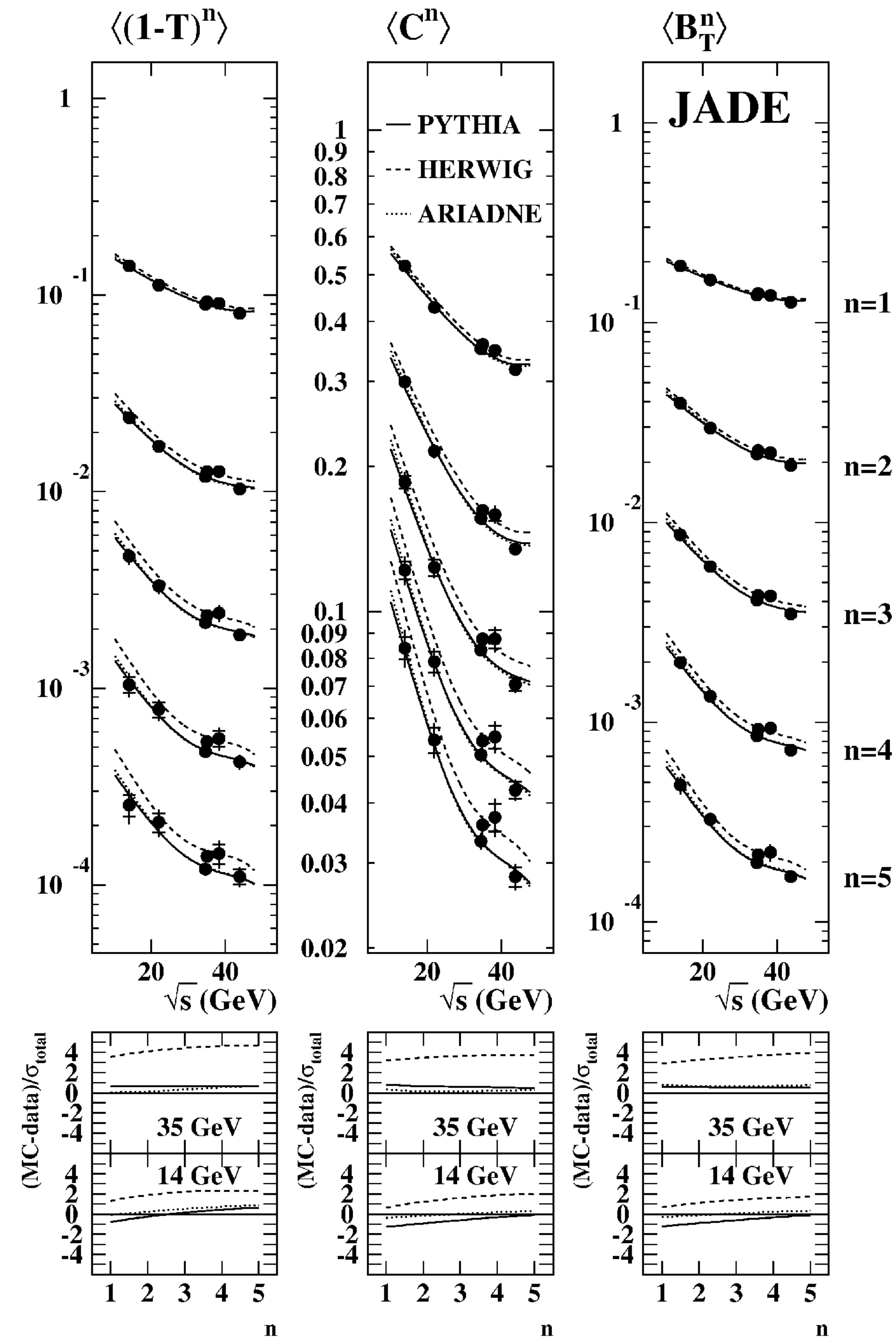
$\langle y^n \rangle = \int y^n \, 1/\sigma \, d\sigma/dy' \, dy'$

Always probe full phase space

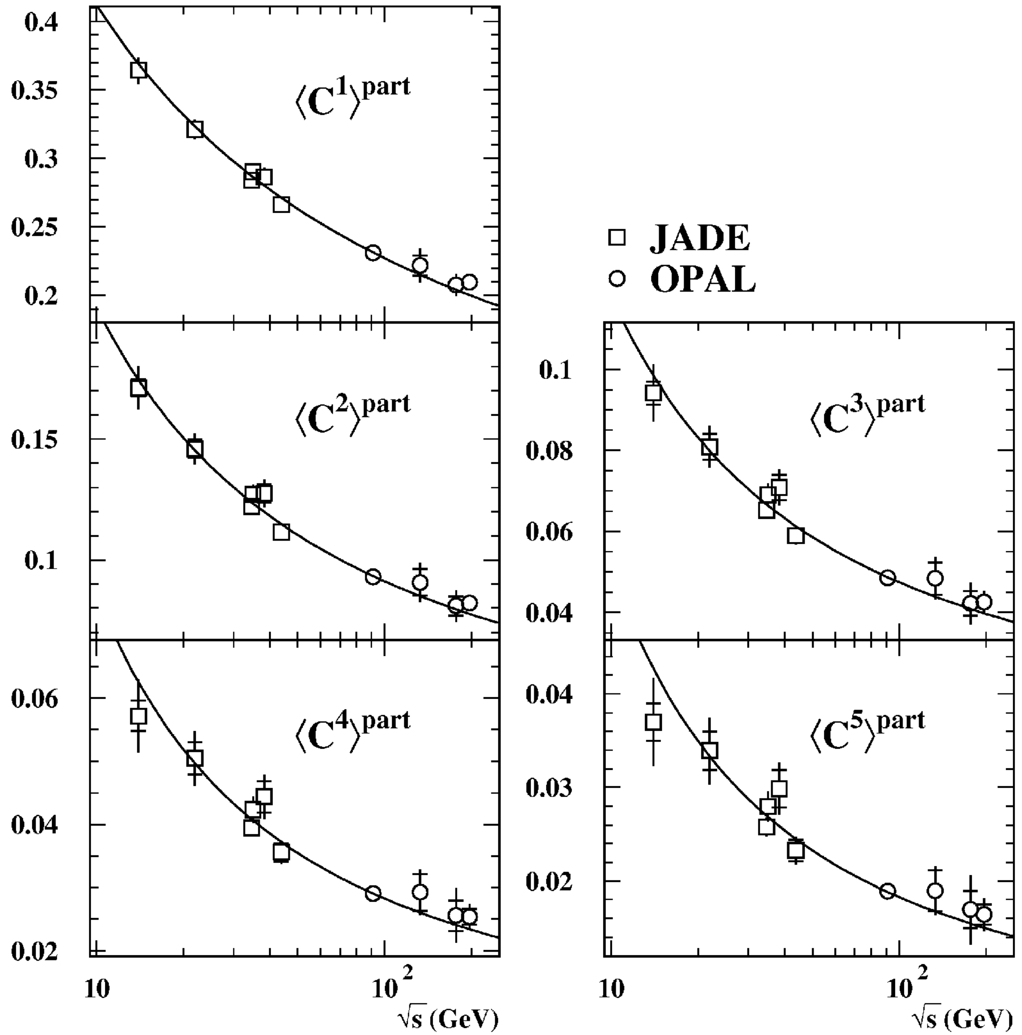
NNLO QCD not yet

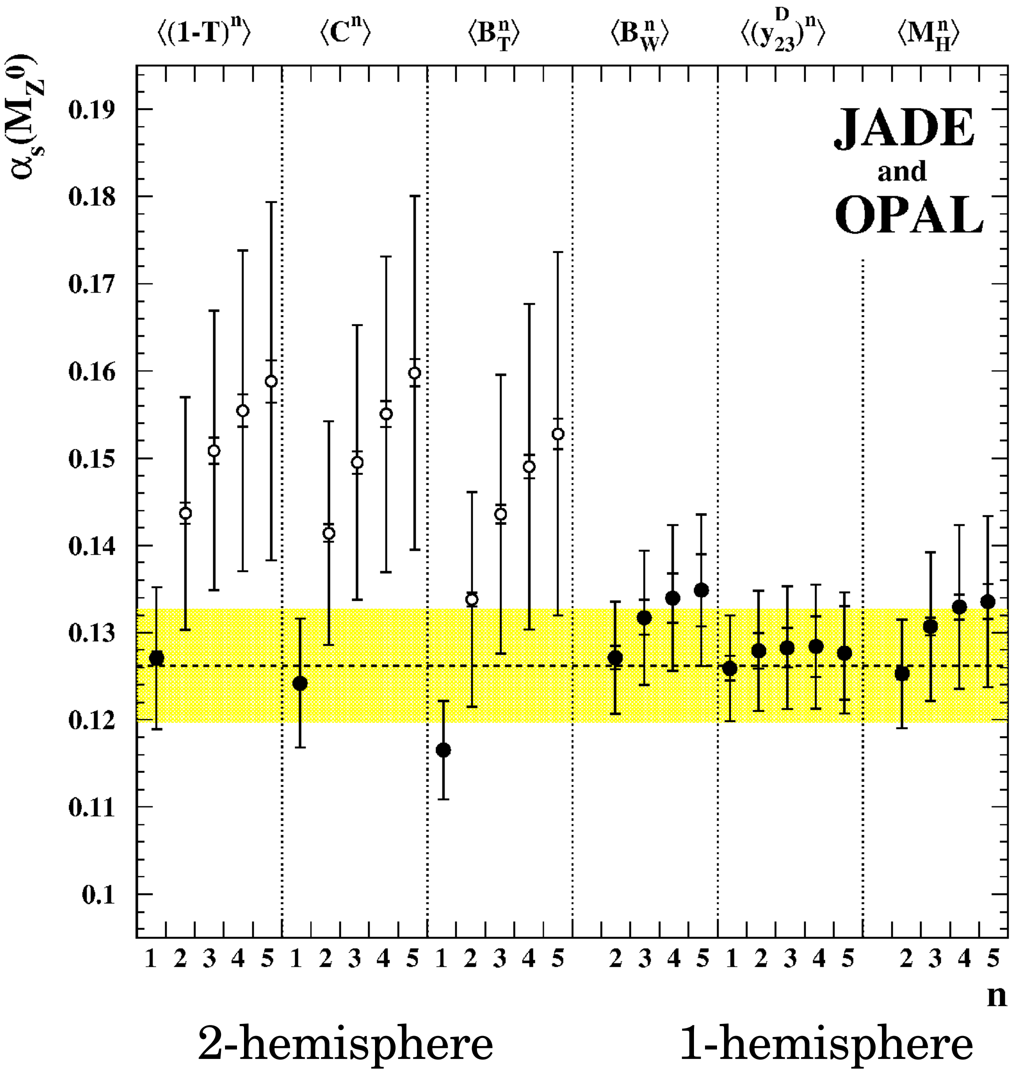
(GGGH vs. Weinzierl PRL101(2008)162001)

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 $\Delta\alpha_S(M_Z) \sim 4\%$
  - Problems with M_H?
- 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:

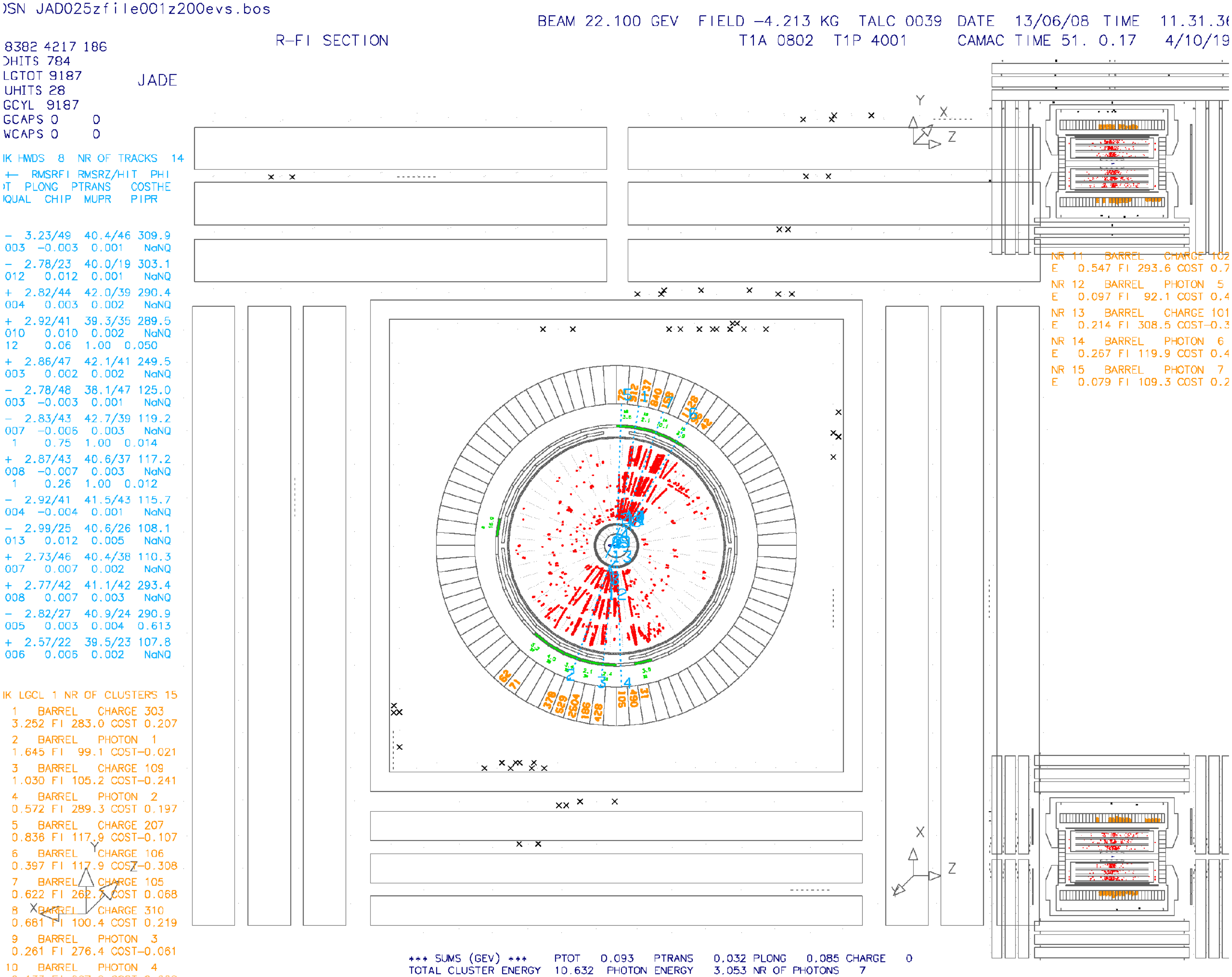
[%]	1-T	M_H	B_T	B_W	C	D_2
NNLO-NLO	-13	-7	-14	-7	-11	-4
NNLO-(NLO+NLLA)	0.1	7	-0.5	8	3	0
(NNLO+NLLA)-(NLO+NLLA)	-2	2	-4	1	0	-0.2

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 → hadronisation systematics

1 JADE Event Display



2 Event Shape Measurement

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

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

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