α_s from e^+e^- event shapes

Stefan Kluth
MPI für Physik
FCC-ee workshop on high precision α_s measurements
12 Oct 2015

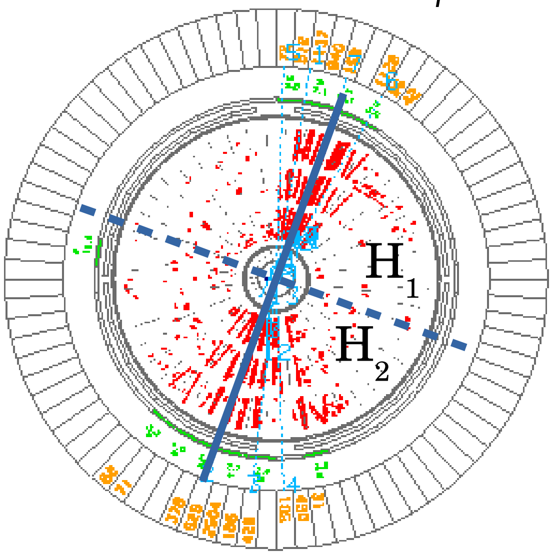
Overview

- Experimental
  - Experiment
  - Simulation
  - Analysis procedure
- Theory
  - Fixed order and resummation
  - Integration with hadronisation models
  - Other issues
- Summary

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:

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

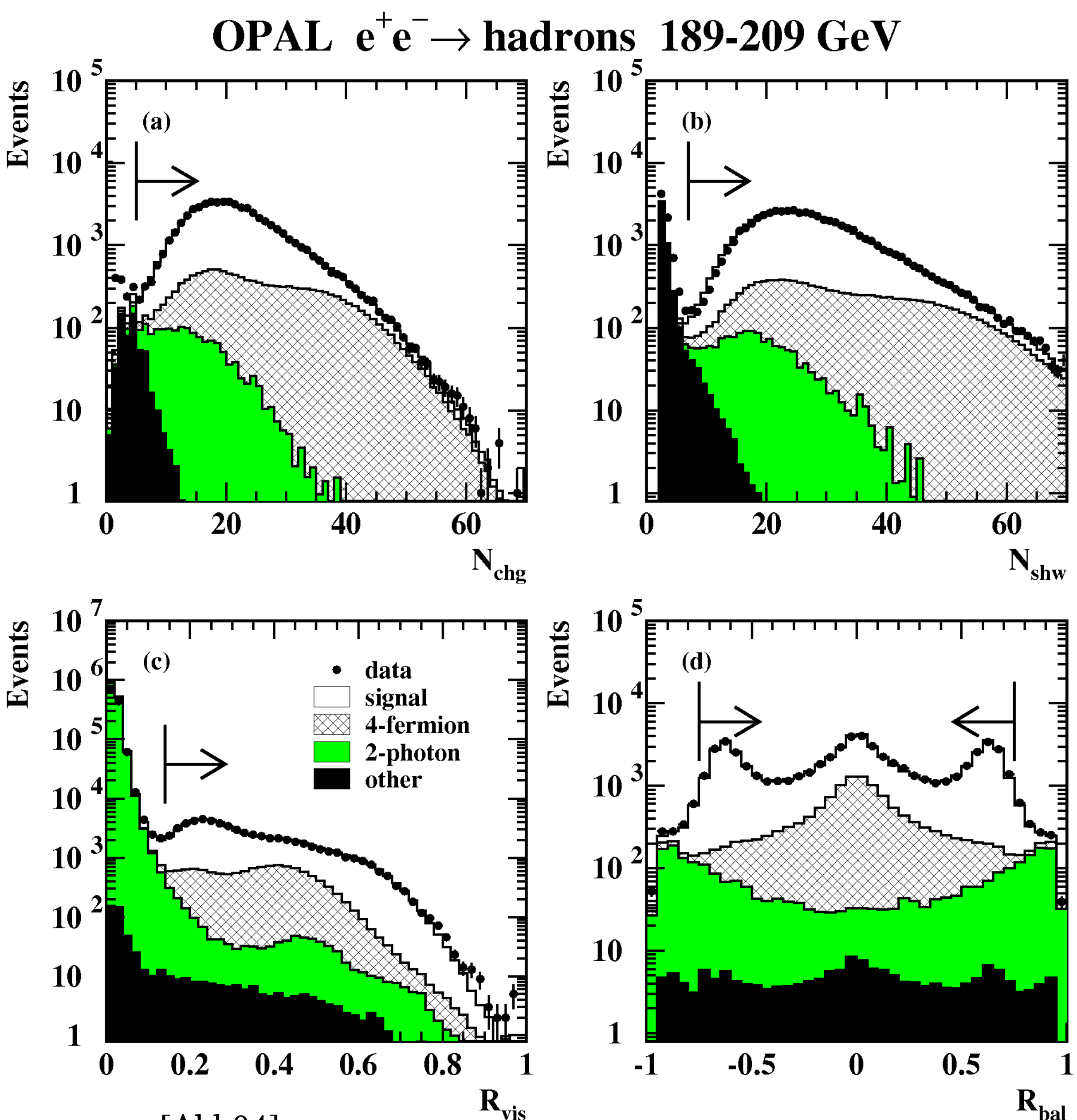
$$B_T=B_1+B_2$$

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

C-parameter:

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

Event selection



[Abb04]

Hadronic events:

a) charged particle multiplicity N_{chg}

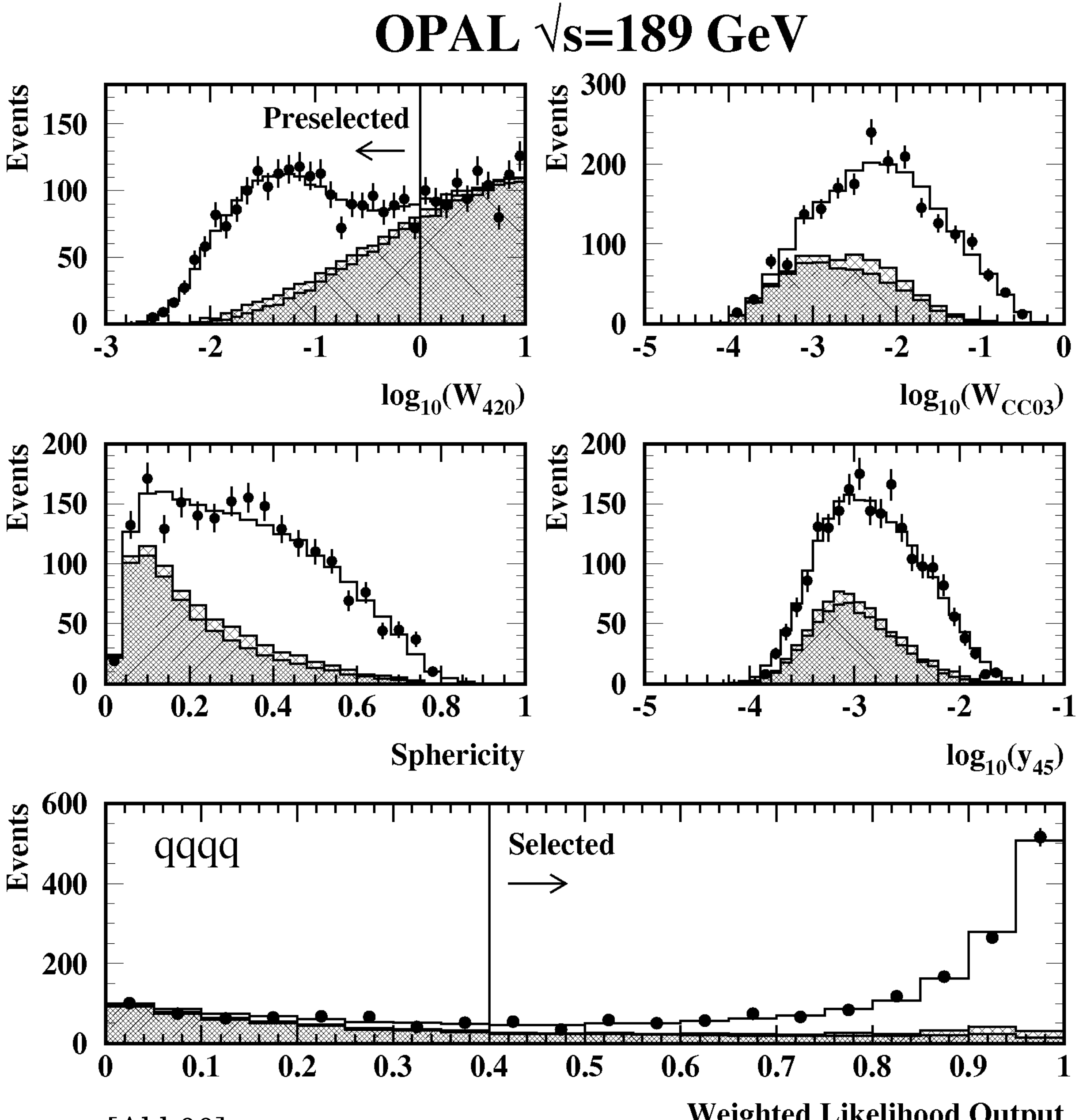
b) calorimeter multiplicity N_{shw}

c) $R_{vis} = \sum E_{clus} / Q$

d) $R_{bal} = \sum E_{clus} \cos\theta_{clus} / \sum E_{clus}$

Similar at LEP 1 (m_Z)

Event selection

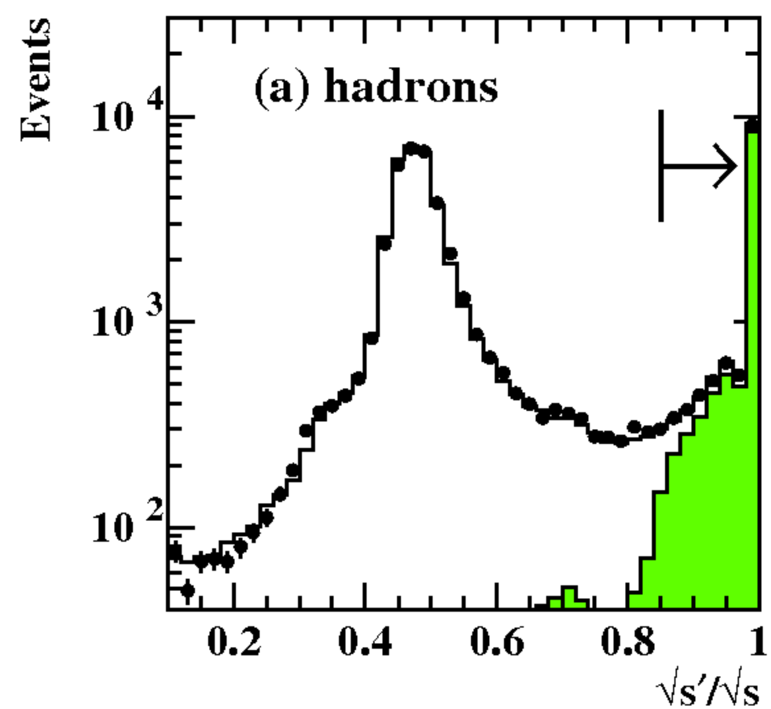


[Abb00]

At high energies reject $e^+e^- \rightarrow W^+W^- \rightarrow$ hadrons

→ cut on "4-jet" observables

Radiative return → find effective cm energy s'

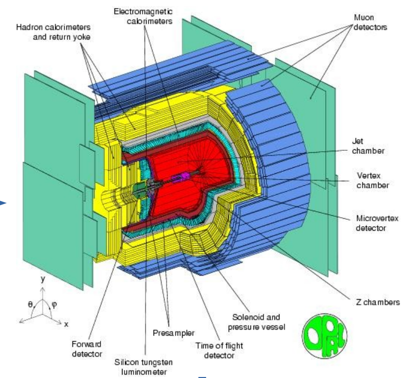


[Abb04]

Experimental procedure

Physics simulation

Event record



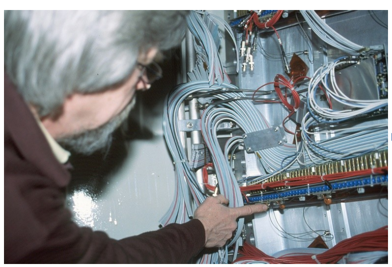
Detector-simulation

Event record ≙ hadron level ≙ particle level final state

Simulated raw data

Event record

Experiment



Real raw data

Recon-struction

Real/simulated reco'ed data

Event record

Data reduction

Real/simulated reduced data, event record

Data analysis

Distribution of observable y:

$$\mathbf{dn/dy}_{corr.} = U * (\mathbf{dn/dy}_{exp} - \mathbf{dn/dy}_{bkg})$$

unfolding matrix U

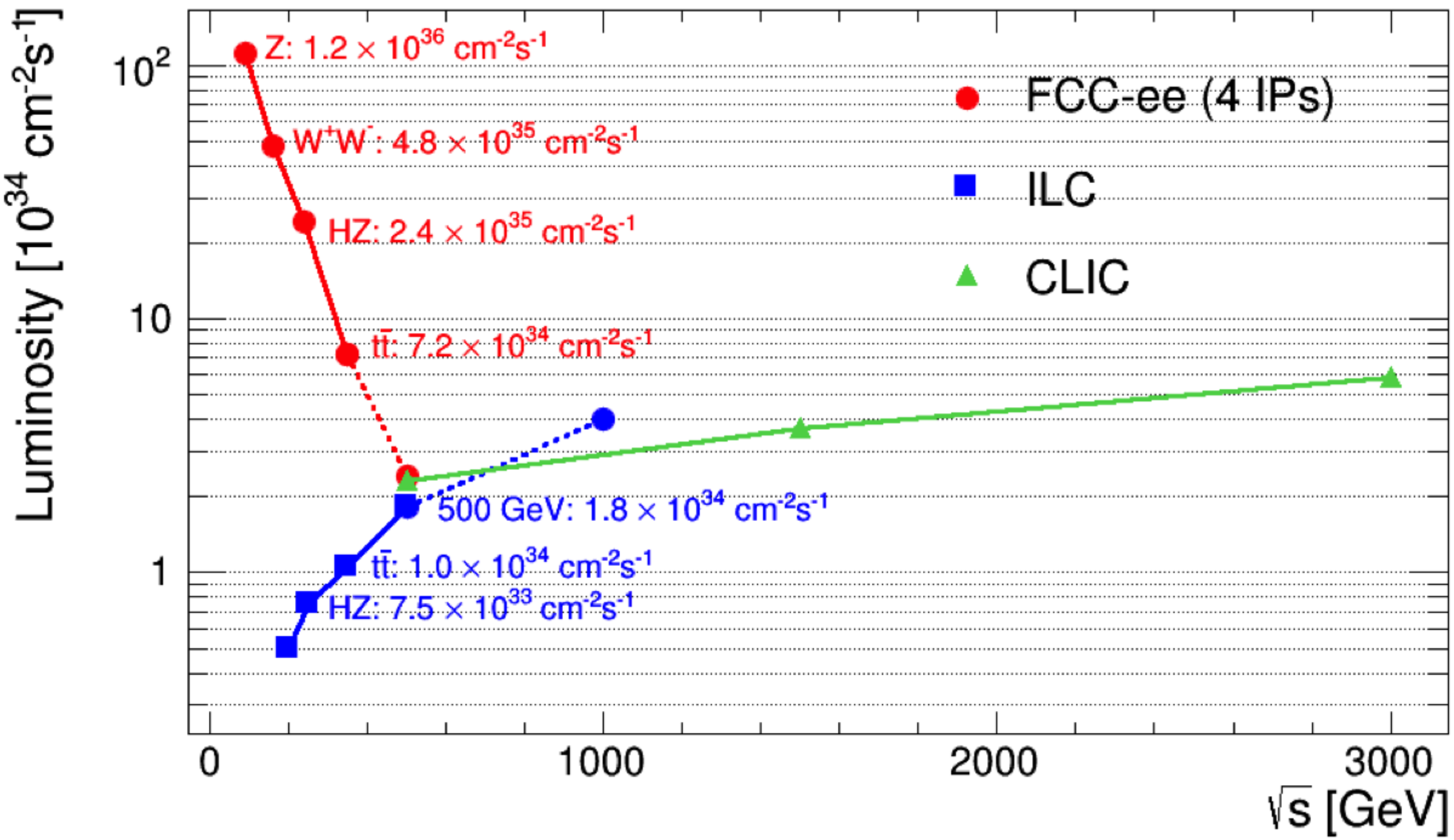
Experimental problems

- Quality of detector model
  - unfolding incl. phase space extrapolation
  - improved resolution will help
- Physics model dependence of unfolding
  - “Pythia vs Herwig” unfolding, data driven tests
  - depends also on MC tuning quality
- Background subtraction
  - Improved resolution will help against W-pairs
- Background modelling
  - MC based subtraction or data driven procedure?

Massive (b) quarks

- Massive QCD
  - NLO “only”, NNLO possible?
  - Resummation basically missing, possible?
  - Irreduceable theory systematics
- Need to treat experimentally
  - b-(anti-)tagging ⇒ b vs udsc separated samples
    - LEP experiments have done / could do this
  - Will add (small) experimental systematics
    - Si vertex detector resolution
    - Precision detector simulation

(Low) Energy points?



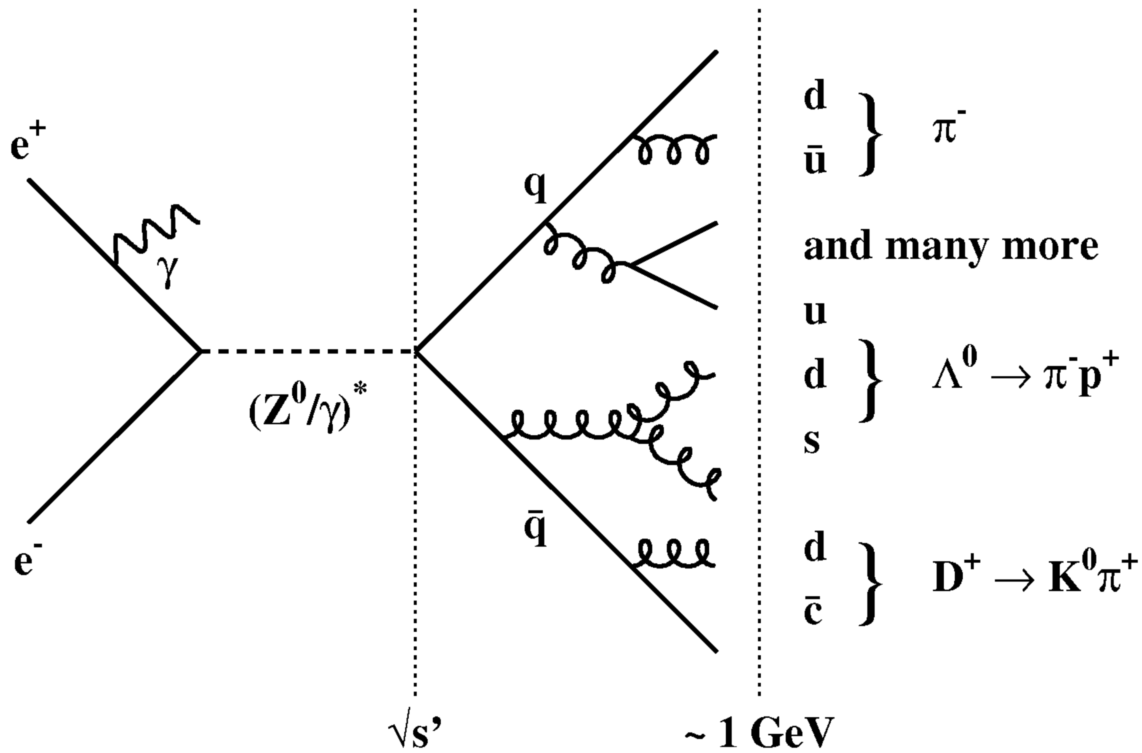
[arXiv:1412.2928, ICHEP 2014]

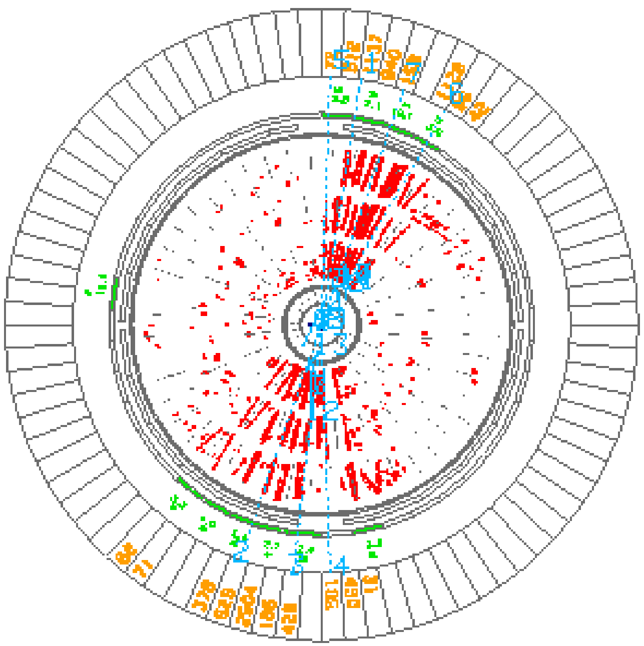
A few days of data taking at $\sqrt{s} < m_Z$ reproduces PETRA / JADE with flavour tagging and improved resolution added

Global fits / PC analyses dependent on low energy data to dis-entangle soft and hard QCD effects

Using the predictions

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



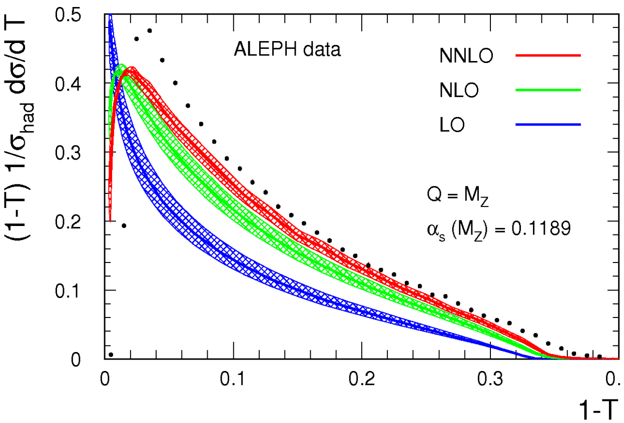


Parton Level *Hadron Level* *Detector Level*

[Kluth, Rept.Prog.Phys.69(2006)1771]

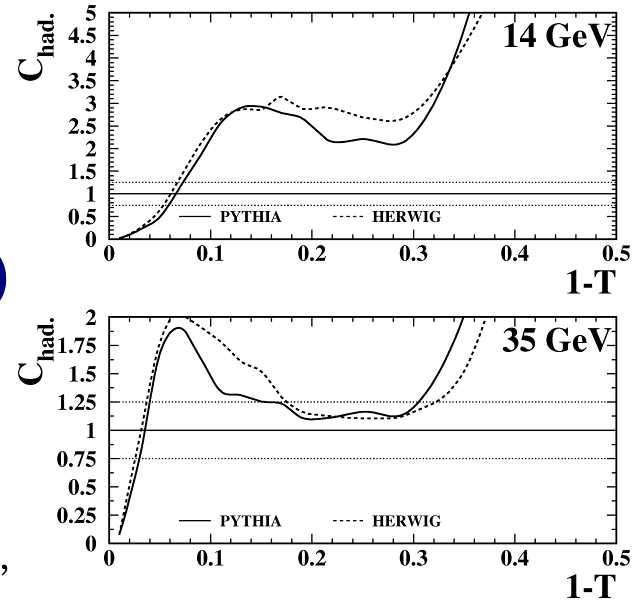
Perturbative process $\otimes$ Hadronisation effects $\otimes$ Experimental effects

pQCD plus MC had. Corr.

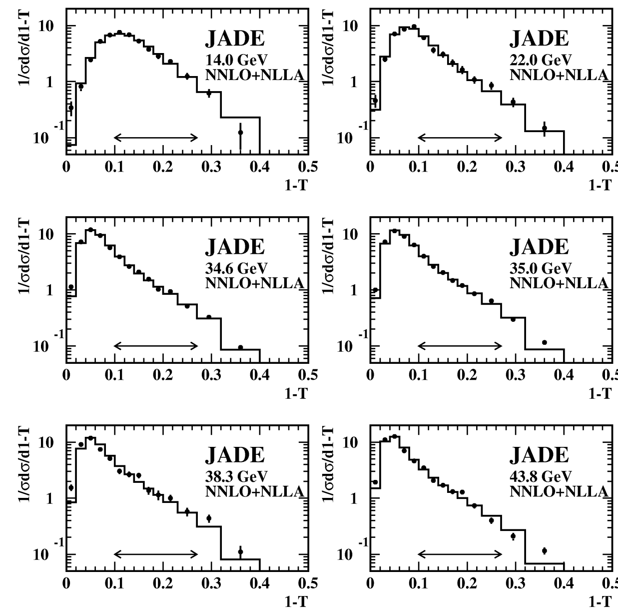


[Gehrman, Gehrmann-deRidder, Glover, Heinrich, JHEP12(2007)094]

⊗



=



[JADE, Eur.Phys.J.C64(2009)351]

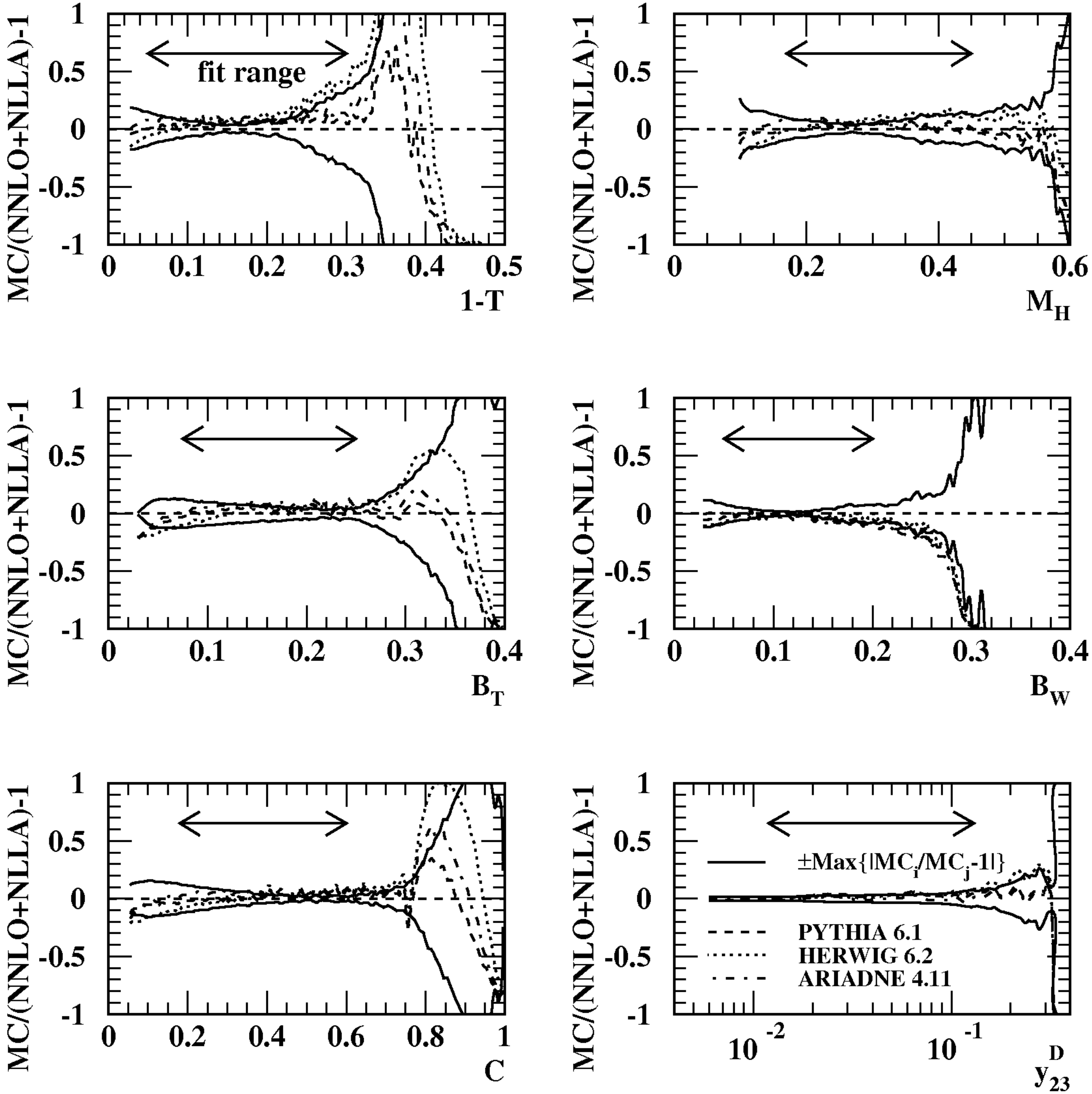
Perturbative prediction
Fixed order (+ resum.)
EVENT2, nlojet++,
EERAD3, ...

Hadronisation correction
strings or clusters
Pythia, Herwig, Sherpa, ...

Particle level
comparison/fit

- ☹ Parton level in pert. prediction and MCs not equal, limits precision to present few %, pert. - non-pert. correlation?
- ☺ Universal

MC vs pQCD parton level



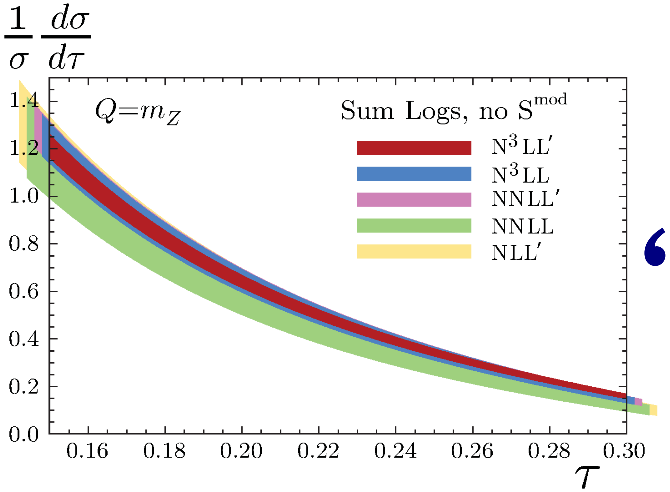
Compare MC parton level to pQCD (NNLO+NLLA)

Compare with differences between MCs

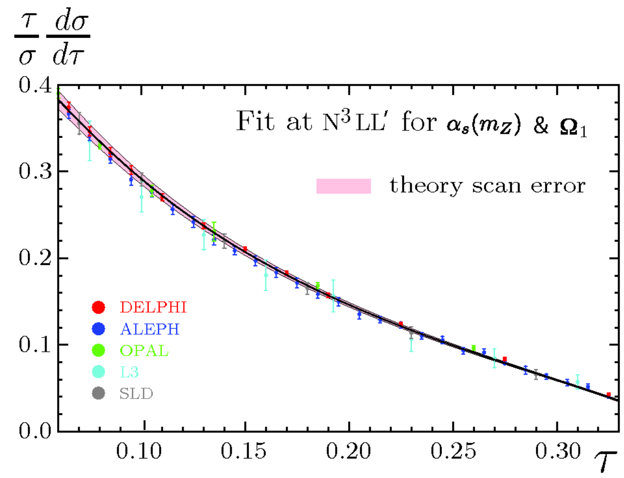
Parton levels consistent within MC model differences

[Eur. Phys. J. C71 (2011) 1733]

pQCD ⊕ had. corr. models



"+" Power corrections
Dispersive model,
SCET, SDG, ... =

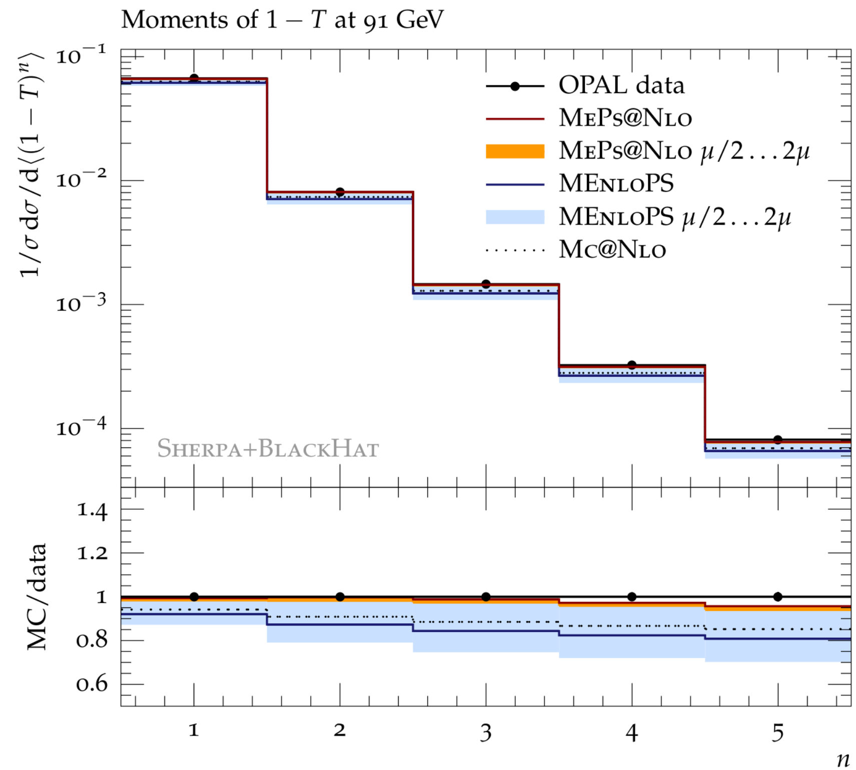


[Abbate, Fickinger, Hoang, Mateu, Stewart, Phys. Rev. D83 (2011) 074021,
Davison, Webber, Eur. Phys. J. C59 (2009) 13-25]

- ☺ Simultaneous fit of pert. prediction and power correction (had. correction) not limited by parton level inconsistency, take pert. - non-pert. correlation into account: much better precision limited by theory (and experiment)
- ☺ Most complete resummation so far with SCET
- ☹ Not universal, observable specific calculation

pQCD ⊕ MC tuning

MEPS@NLO: NLO (automated) matched to parton shower; merged for 2 → n processes; Hadronisation model (strings, clusters)



[Gehrmann, Höche, Krauss, Schönherr, Siegert, JHEP 1301 (2013) 144]

- ☺ Improved perturbative uncertainties, simultaneous fit (MC tuning) takes account of pert. - non-pert. correlation
- ☺ Universal
- ☺ 4-jet and 5-jet observables possible
- ☹ NLO only, parton shower formally LL, in practice almost NLL, subleading logs? NNLO? Merging scale?

pQCD ⊕ MC tuning

GENEVA MC: (NLO+NNLL) ⊕ PS ⊕ had'n (Pythia8) for thrust

Solves parton shower ambiguity, i.e. NLO+NNLL+PS+had.

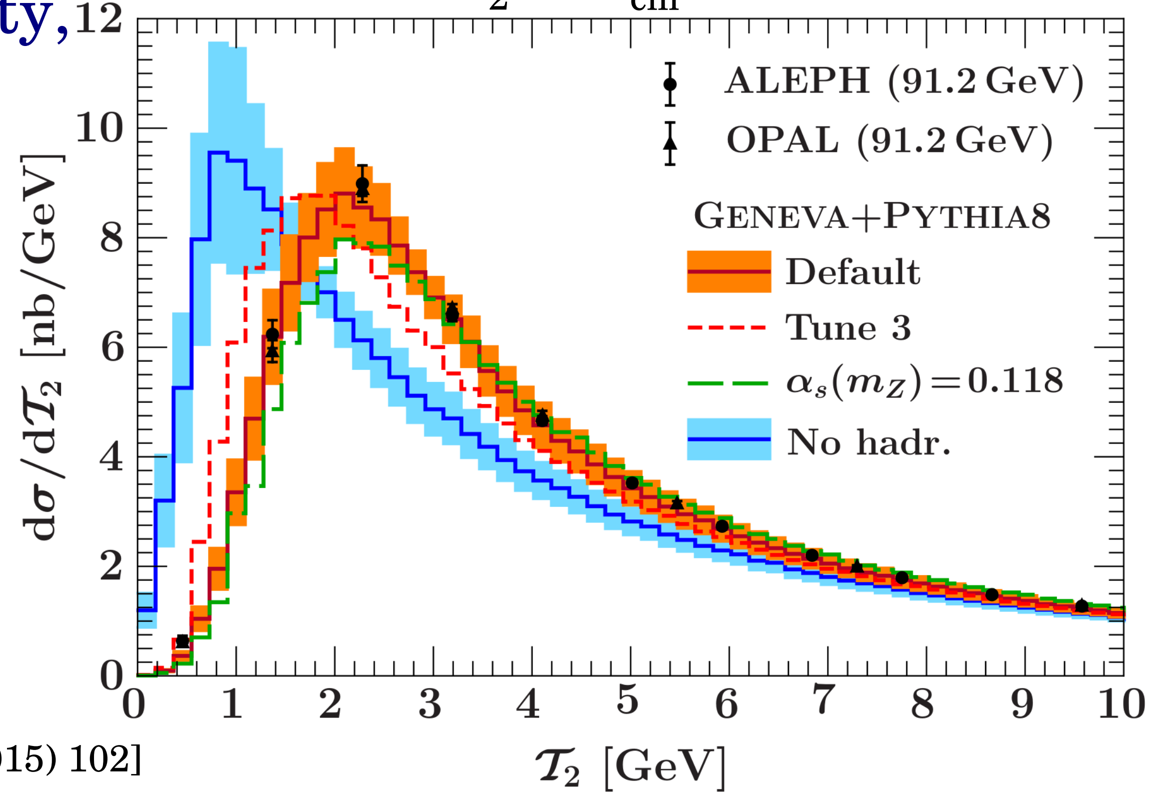
Other event shapes? Predicted by GENEVA based on T_2; self-consistent calculation desireable

NNLL from ARES?

[Banfi, McAslan, Monni, Zanderighi, JHEP 1505 (2015) 102]

NNLO matching? Needs N^3LL ...

$T_2 = E_{cm}(1\text{-}T)$



[Alioli, Bauer, Berggren, Hornig, Tackmann, Vermilion, Walsh, Zuberi, JHEP 1309 (2013) 120]

Other theory aspects

- N^3LO corrections?
  - Discussion about NNLO pp→Z+jets implies this?

Maître, Sapeta, Eur. Phys. J. C73 (2013) 2663

- NNLL corrections
  - 1-T, T_{maj}, C, M_H, B_T, B_W, O, EEC; ARES
  - Numerically important
  - Jet resolution distributions?
  - N^3LL possible? Needed for NNLO, on the wishlist …
- Theory error estimates
  - e.g. some NNLL corrections outside band of NNLO
  - Discuss procedure (x_μ;x_L*/2)?

Summary

- Field is theory driven
  - Exp. uncertainty on α_S from 1-T ~1.3% (OPAL)
    - Combination with e.g. ALEPH possible
    - Much smaller in "global fits"
  - Still to be matched by theory+had'n uncertainty
  - Wishlist: N^3LL, MC PS matching, N^3LO
- Revisit systematic α_S studies
  - Well understood data and errors
  - Several (many?) observables at same level of prediction
  - New/better observables? Let us know!