# Precision $\alpha_s$ Experimental Aspects

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# 0 Overview

- Concentrate on exclusive observables
  - Inclusive (even) more difficult to improve
- Particle / parton / hard interaction level
  - Standartisation?
- Using the predictions
  - Parton-level QCD (x) hadronisation vs N(N?)LO+PS MC
  - Static vs dynamical scale in MC
- Averaging of many measurements
  - Theory errors dominate, correlations?

# 1 Particle level

- Need precise definition
- At LEP a consensus developed
- HERA?
- Tevatron?
- LHC?
  - Corrections to anything from particle level to “hard scattering perturbative level”
  - Difficult to compare analysis results
  - Difficult to make exact comparison with theory

# 1 “Particle level”

## Example 1: Measurements of top quark pair relative differential cross-sections with ATLAS in pp collisions at sqrt(s) = 7 TeV

[ATLAS coll, arXiv:1207.5644]

“The kinematic properties of the generated t and $\underline{t}$ partons in simulated $t\underline{t}$ events define the “true” properties of the $t\underline{t}$ events.”

## Example 2: Rivet manual

[Buckley, Butterworth, Grellscheid, Höth, Lonnblad, Monk, Schulz, Siegert, arXiv:1003.0694v8]

“Fortunately, the situation is not altogether negative: in practice it is usually as easy to write a highly functional MC analysis using only final state particles and their physically meaningful on-shell decay parents. These are, since the release of HepMC 2.5, standartised to have status codes of 1 and 2, respectively. Z-finding is then a matter of choosing decay lepton candidates, windowing their invariant mass around the known Z mass, and choosing the best Z candidate: effectively a simplified version of an experimental analysis of the same quantity. This is a generally good heuristic for a safe MC analysis!”

# 1 “Particle level”

## Example 3: Next-to-leading order QCD predictions for top-quark pair production with up to two jets merged with a parton shower

[Höche, Krauss, Maierhöfer, Pozzorini, Schönherr, Siegert, arXiv:1402.6293]

“We identify the top quarks through their full decay final state and select events containing a positron and a muon with $p_T$>25 GeV and $|\eta|$<2.5, $E_{T,miss}$> 30 GeV is directly reconstructed from the neutrinos. Jets are defined using the anti-kt algorithm with R=0.4. Ideal b-jet tagging is modeled based on the flavor of the jet constituent partons. Defining the sign of each b-jet according to its b-quark contents, exactly one b- and one anti-b-jet with $p_T$>25 GeV and $|\eta|$<2.5 are required.”

## Example 4: OPAL “hadron-level” == particle level

“All MC final state particles with lifetime > 300 ps set stable and long-lived hadron decays handled by detector simulation.”

# 1 "Particle level"

## Example 5: Measurement of jet shapes in top-quark pair events at $\sqrt{s}$ =7 TeV using the ATLAS detector

[ATLAS coll., arXiv:1307.5749]

"While the detector-level MC includes the background sources described before, the particle-level jets are built using all particles in the signal sample with an average lifetime above $10^{-11}$ s, excluding muons and neutrinos. The results have only a small sensitivity to the inclusion or not of muons and neutrinos, as well as to the background estimation. For particle-level b-jets, a b-hadron with $p_T > 5$ GeV is required to be closer than $\Delta R = 0.3$ from the jet axis, while for light jets, a selection equivalent to that for the detector-level jets is applied, selecting the non-b-jet pair with invariant mass closest to $m_W$. The same kinematic selection criteria are applied to these particle-level jets as for the reconstructed jets, namely $p_T > 25$ GeV, $|\eta| < 2.5$ and $\Delta R > 0.8$ to avoid jet–jet overlaps."

# 1 Particle level

- Need for a common definition
  - Practical for theory and experiment
  - Model independent as far as possible
  - Compare data of different experiments
  - Compare data with predictions
- Precursors
  - LEP analyses, some LHC analyses
  - Rivet

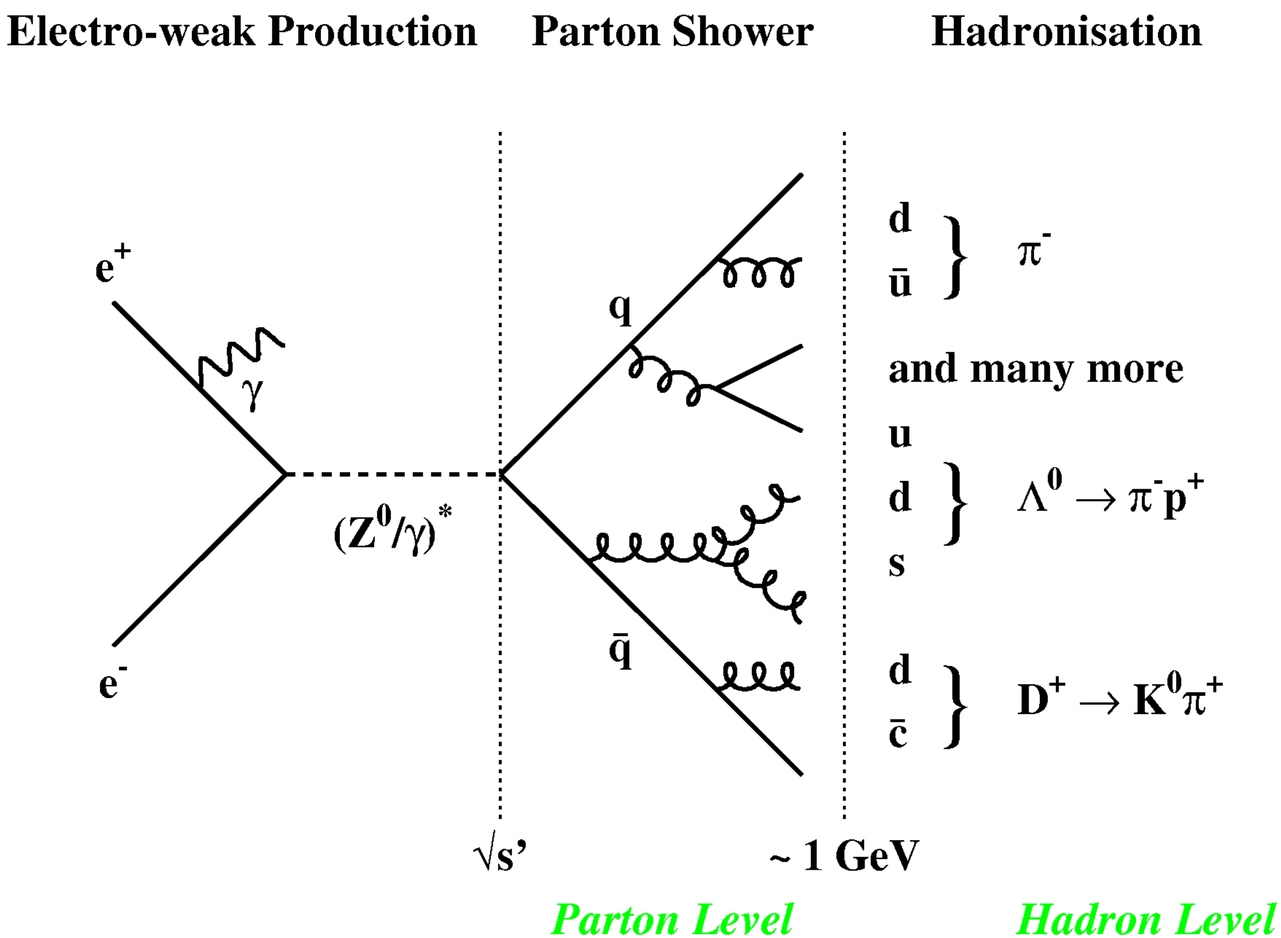
# 1 Particle level: 0th order proposal

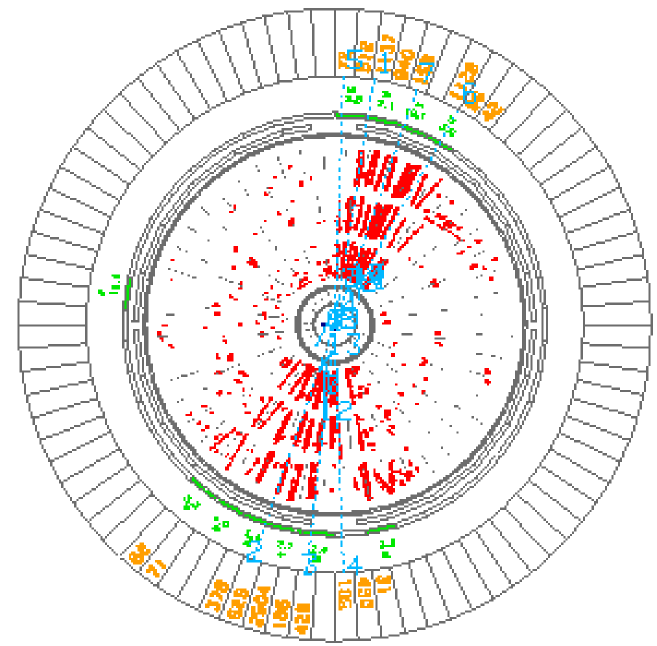
- Use HepMC >= 2.5
- All particles lifetime > 300 ps stable in MC
  - Long-lived particle decays in detector (Geant)
- Repeat analysis using stable particles
  - Same jets and kinematic cuts
  - Use MC particle ID for leptons
  - Heavy flavor jets: search for HF hadron near jet
  - Heavy bosons: combine jets/leptons, apply mass window

# 1 Parton level

- Compare with parton-level theory not available in MCs
  - Apply independent hadronisation corrections
- Partons entering string or clusters
  - Plus leptons from hard scattering or heavy boson decays
- Repeat analysis using partons+leptons
  - Same jets and kinematic cuts
  - HF jets: search for HF parton near jet
  - Heavy bosons: combine jets/leptons, apply mass window

# 2 Using the predictions



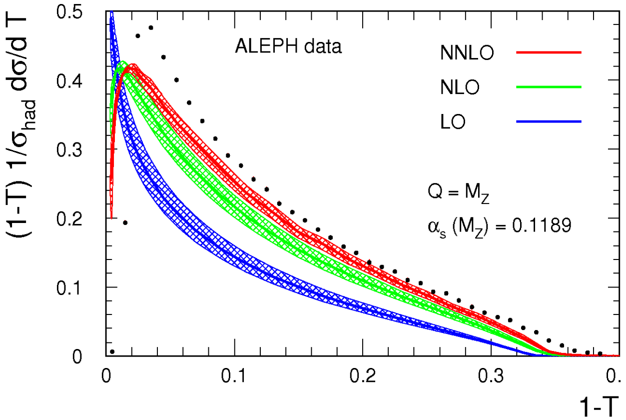



*Detector Level*

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

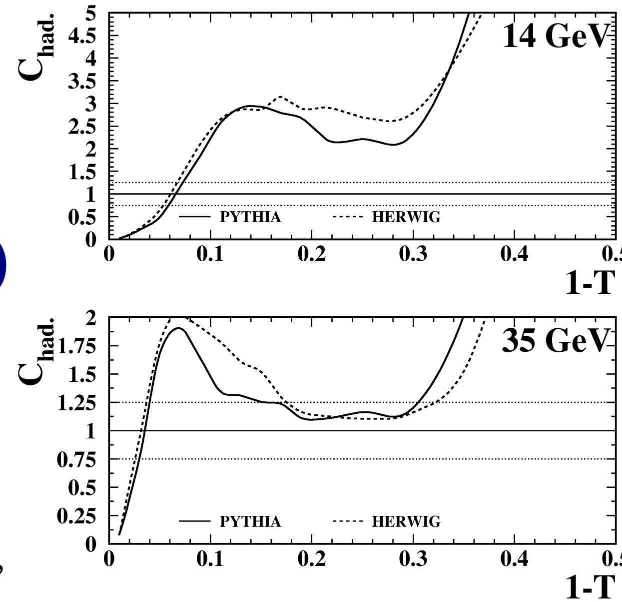
Perturbative process ⊗ Hadronisation effects ⊗ Experimental effects

# 2 Using the predictions




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

⊗

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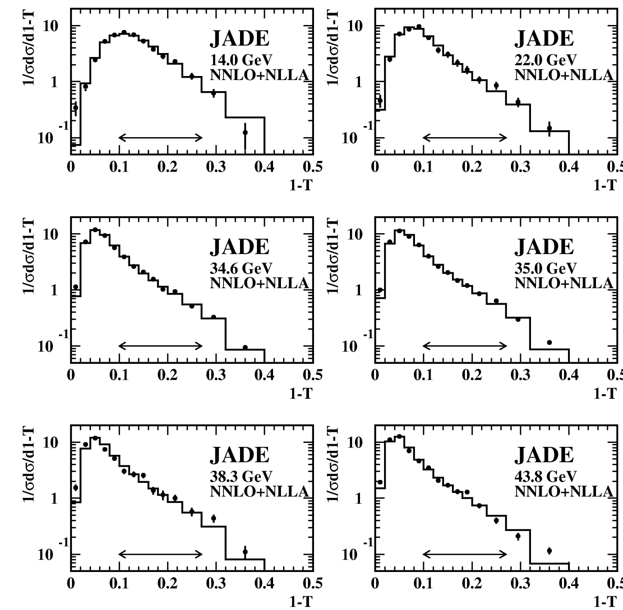



[JADE, Eur.Phys.J.C64(2009)351]

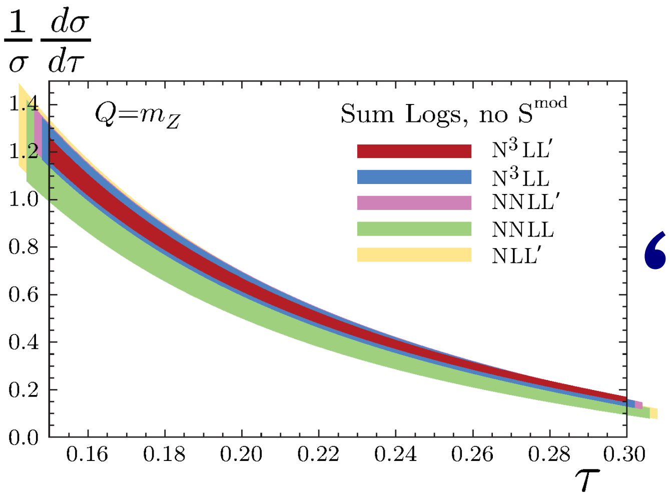
Perturbative prediction
Fixed order (+ resum.)
EVENT2, nlojet++, EERAD3, ...

Hadronisation Correction
Strings or clusters
Pythia, Herwig, Sherpa, ...

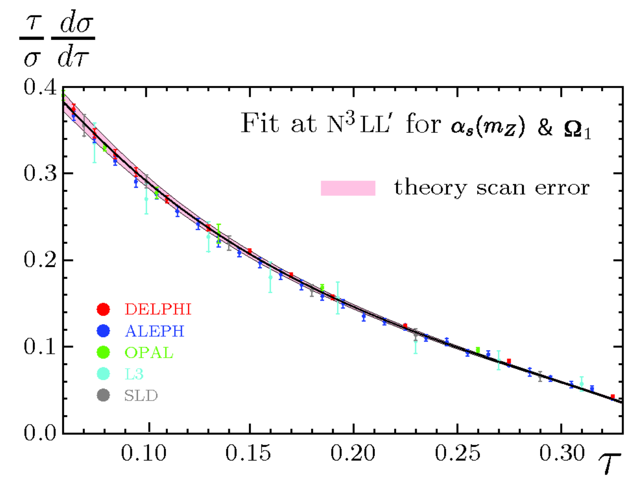
Particle Level
Comparison/fit

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

# 2 Using the predictions




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

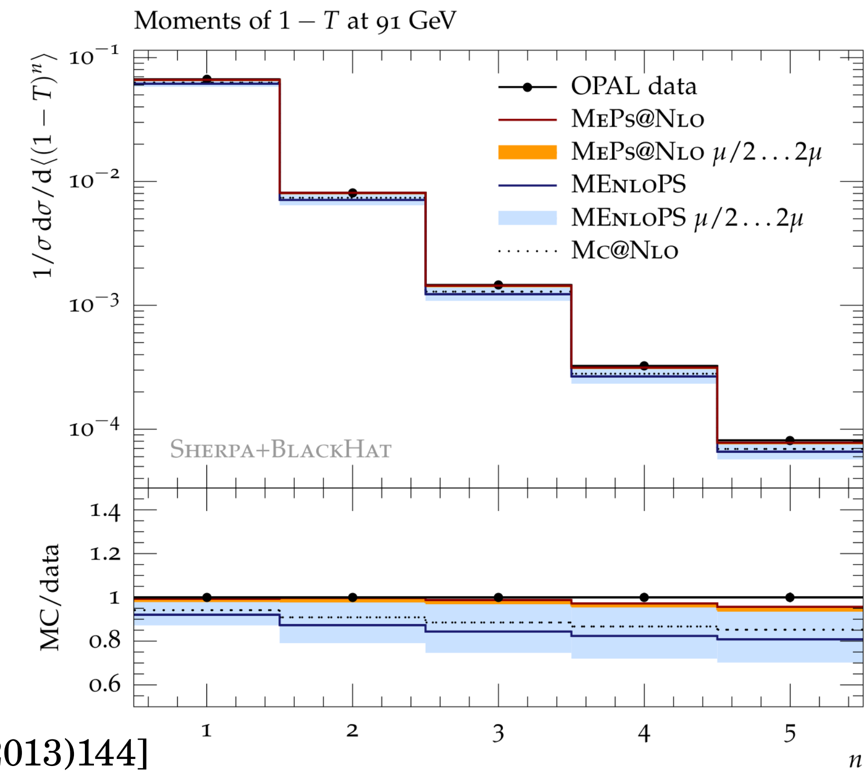



[Abbate, Fickinger, Hoang, Mateu, Stewart, Phys.Rev.D83(2011)074021]

- ☺ 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)
- ☹ Not universal, observable specific calculation

# 2 Using the predictions

MEPS@NLO
NLO (automated)
Matched to parton shower
Merged for 2 → n processes
Hadronisation model (strings, clusters)




[Gehrmann, Höche, Krauss, Schönherr, Siegert, JHEP1301(2013)144]

- ☺ Improved perturbative uncertainties, simultaneous fit (MC tuning) takes account of pert. - non-pert. correlation
- ☺ Universal
- ☹ NLO only, parton shower formally LL, in practice almost NLL, NNLL?

# 3 Strong coupling average

Calculate error weighted average of measurements $\alpha_{S,i}$:

If $\chi^2 < N_{dof}$: errors overestimated, introduce common factor f to covariances: $cov_{ij} = f \cdot \Delta\alpha_{S,i} \cdot \Delta\alpha_{S,j}$, adjust f for $\chi^2 = N_{dof}$ (BLUE method with covariance scaling)

If $\chi^2 > N_{dof}$: errors underestimated, introduce common factor g to errors: $g \cdot \Delta\alpha_{S,i}$, adjust g for $\chi^2 = N_{dof}$ (PDG method)

[Bethke, arXiv:1210.0325, Eur.Phys.J.C64(2009)689]

For $f > 0$ and $g > 1$ conservative

☺ Pragmatic and stable, conservative error

☹ Still adequate for sub-% errors? Not directly compatible with e.g. $m_{top}$, $m_W$ or EWPO averages

# 3 Strong coupling average

Going beyond current PDG $\alpha_S$ average?

Procedure of $m_{top}$, $m_W$ or EWPO averages in a nutshell:

[Kluth Rept.Prog.Phys.69(2006)1771; Valassi, NIMA500(2003)391, +cited]

- Separate errors in many ~independent individual parts
- Introduce a correlation model for all error parts: no ($cov_{ij}=0$), partial ($cov_{ij}=\min(\sigma_i,\sigma_j)^2$), $\rho_{ij}=0.5$), full ($cov_{ij}=\sigma_i\sigma_j$)
- Calculate the total covariance matrix
- Calculate BLUE average

Does this make sense for $\alpha_S$? Needs (a lot of) discussion to define correlation model, $\alpha_S$ error parts not (easily) available

# 4 Conclusions

- Improvements on $\alpha_S$ driven by theory
  - NN(N)LO, NNLL, power corrections, Lattice, ...
  - N(N)LO + PS matching and merging in MC?
  - In some cases (incl. Observables) exp. error already dominant
- Experimental improvements
  - Consistent definition of particle and parton level
  - Future colliders: LHeC, ILC, FCC-ee