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Determination of $\alpha_s(M_Z)$ from energy-energy correlations in electron positron annihilation with combination of NNLO perturbative calculations and nonperturbative corrections from Monte Carlo models

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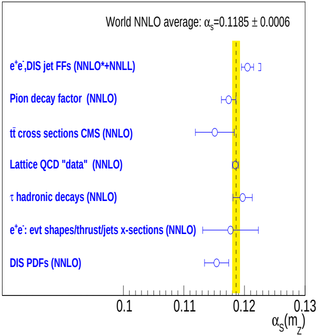
α_s e^+e^-: motivation in the past and in the future

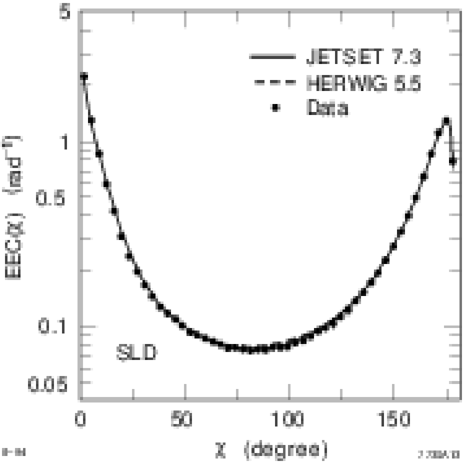


- As of 2018 α_S is known with precision of 1% if calculated from measurements with at least NNLO precision
- However, there is a large spread between measurements
- More measurements is better

+ measurements with new approached/data are important on themselves

The energy-energy correlations

$\frac{\mathbf{dEEC}(\chi)}{\mathbf{d}\chi} = \sum_{\mathbf{i}}^{\mathbf{N}} \sum_{\mathbf{j}}^{\mathbf{N}} \frac{\mathbf{E_i E_i}}{\mathbf{E_{vis}^2}} \delta(\cos\chi - \cos\chi_{\mathbf{ij}})$, with $E_{vis} = \sum_i^N E_i$, where E_i is particle energy and χ_{ij} is angle between particles i and j.



- Used multiple times in a **distant** past for α_S extraction
- Inclusive
- Not sensitive to schemes of combinations
- Resumed NNLL predictions became available in **2017**

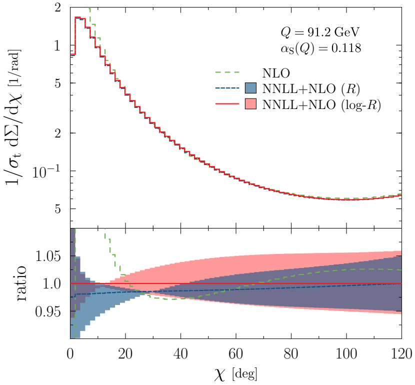
← **Looks like this[1]**

Analysis components

- Perturbative and resummed predictions Z. Tulipánt, A. Kardos and G. Somogyi, "Energy-energy correlation in electron–positron annihilation at NNLL + NNLO accuracy," Eur. Phys. J. C **77** (2017) no.11, 749
- Data: LEP, PEP, PETRA, SLC and TRISTAN
- Non-perturbative corrections: NLO MC by Sherpa and Herwig7, analytic hadronisation

Available predictions: perturbative part with CoLoRFulNNLO

e^+e^- predictions in NNLO exist for some time, however



ColorFulNNLO, V. Del Duca et al., "Jet production in the CoLoRFulNNLO method: event shapes in electron-positron collisions," Phys. Rev. D **94** (2016) no.7, 074019 has unique features

- precision
- extendable approach

Resummation has appeared recently: Z. Tulipánt, A. Kardos and G. Somogyi, "Energy-energy correlation in electron–positron annihilation at NNLL + NNLO accuracy," Eur. Phys. J. C **77** (2017) no.11, 749

Available predictions: resummation

For many event-shape observables and some jet cross-sections the resummation exists in logR and R schemes. The EEC resummation faces some difficulties in both. In solution was found to problems, deriving predictions from the resummation for EEC momenta. The resummation is done in the *logR* scheme.

b mass corrections

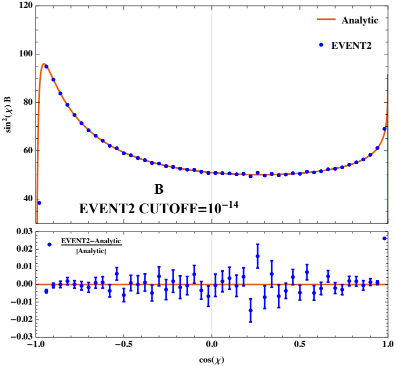
The full NNLO calculations with heavy b quarks are not available.
Simplified approach with NLO calculations.

$$EEC_{corrected} = (1 - r_b)EEC_{massless}^{NNLO+NNLL} + r_b \times EEC_{massive}^{NNLO^*}$$

The $NNLO^*$ massive predictions are made from massive NLO coefficients by $Zbb4$ programme [2] and massless $NNLO$ terms.
The $m_b(m_b)$ is set to 4.75 GeV.

Theory: work in progress?

- N^3LL resummation under study with recently SCET calculations [3].
- NLO analytic results available [4].



Available data

The available data covers wide range of energy: $\sqrt{s} = 14 - 91\,\mathrm{GeV}$.

Experiment	Data $\sqrt{s}$(average)	MC $\sqrt{s}$	Data events
SLD [1]	91.2(91.2)	91.2	60000
OPAL [5]	91.2(91.2)	91.2	336247
OPAL [6]	91.2(91.2)	91.2	128032
L3 [7]	91.2(91.2)	91.2	169700
DELPHI [8]	91.2(91.2)	91.2	120600
TOPAZ [9]	59.0 — 60.0(59.5)	59.5	540
TOPAZ [9]	52.0 — 55.0(53.3)	53.3	745
TASSO [10]	38.4 — 46.8(43.5)	43.5	6434
TASSO [10]	32.0 — 35.2(34.0)	34.0	52118
PLUTO [11]	34.6(34.6)	34.0	6964
JADE [12]	29.0 — 36.0(34.0)	34.0	12719
CELLO [13]	34.0(34.0)	34.0	2600
MARKII [14]	29.0(29.0)	29.0	5024
MARKII [14]	29.0(29.0)	29.0	13829
MAC [15]	29.0(29.0)	29.0	65000
TASSO [10]	21.0 — 23.0(22.0)	22.0	1913
JADE [12]	22.0(22.0)	22.0	1399
CELLO [13]	22.0(22.0)	22.0	2000
TASSO [10]	12.4 — 14.4(14.0)	14.0	2704
JADE [12]	14.0(14.0)	14.0	2112

Data qualification criteria

- Corrected to charged and neutral final state
- Corrected for ISR
- Full χ range measured
- No overlap with other samples
- Sufficient precision
- Sufficient information on data available

Huge datasets available for combined analysis:
20 datasets from 11 collaborations.

Non-perturbative models

Two approaches are available on the market: analytic and MC based. **We use both.**

Analytic approach

- Calculations with

  Y. L. Dokshitzer, G. Marchesini and B. R. Webber, "Nonperturbative effects in the energy energy correlation," JHEP **9907** (1999) 012
- Involves α_S moments at low scales, which are free parameters.

MC-based

- NLO MC events by particle level generators to extract with point-by-point multiplicative correction factors
- Systematics from multiple hadronisation models
- Simultaneously allows to extract missing correlations of data points

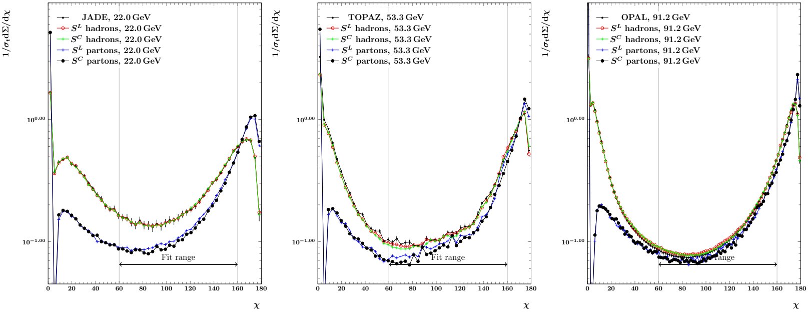
MC based approach: MC setups

$e^+e^- \to jjjjj$ merged samples with massive b quarks and 2-jet final state in NLO precision.

- **Default setup "S^L": Sherpa2.2.4+ (Comix, Amegic, GoSam ME libraries and OLPs) + Lund (Pythia6) hadronisation**
- Setup for hadronisation systematics: "S^C": Sherpa2.2.4+ (Comix, Amegic, GoSam ME libraries and OLPs) + Ahadic cluster hadronisation
- Setup for cross-check: "H^M": Herwig7.1.1 (Herwig, Madgraph, GoSam ME libraries and OLPs) + Herwig cluster hadronisation

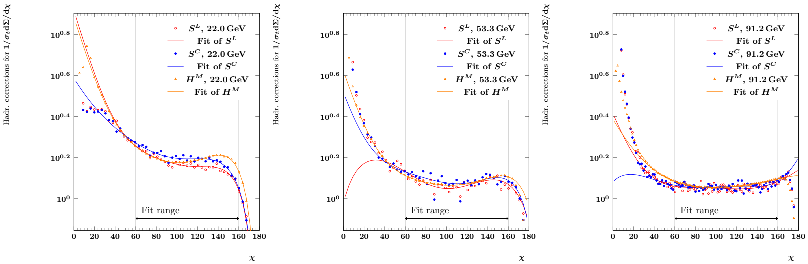
Merging scale was chosen to minimise its size impact on parton level in fit range.

MC based approach: MC distributions



- Good description of data even close to cutoff region.
- More: the samples were reweighted event-by-event to match closely the data: $\log W_{event} = \sum_{bin=1}^{Nbins} k_{bin} EEC_{event}(bin)$.

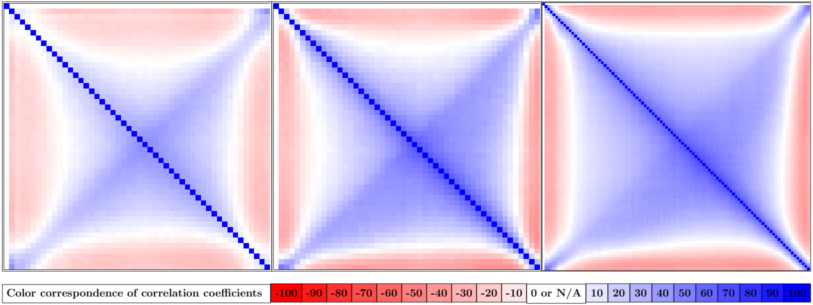
MC based approach: MC hadronisation



- Hadronisation corrections are ratio of hadron to parton level.
- To avoid binning effects the hadronisation corrections are parametrised with smooth functions. Note: parametrisation is valid only in fit range.

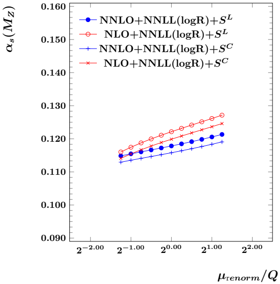
MC based approach: correlations

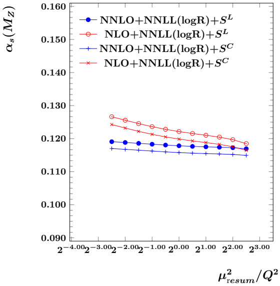
JADE, $\sqrt{s} = 22$ GeV	TOPAZ, $\sqrt{s} = 59$ GeV	OPAL, $\sqrt{s} = 91$ GeV



- All measurements are provided without correlations.
- MC samples are used to model correlations between points, see original Fisher papers [16].

Fits and uncertainties

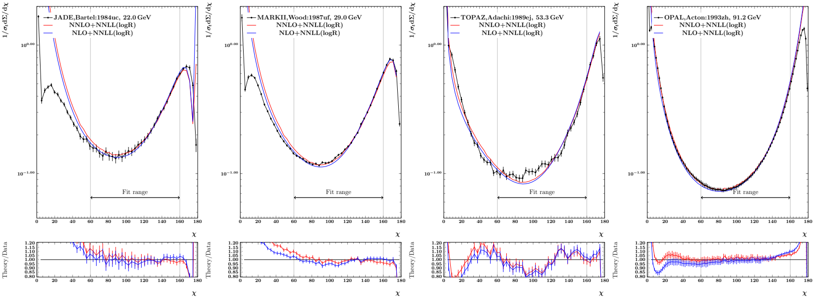




The uncertainties that were estimated:

- Variation of renormalisation scale by $2^{\pm 1}$: (*res.*)
- Variation of resummation scale by $2^{\pm 2}$: (*ren.*)
- Variation of matching power 1 or 2: neglected
- Variation of hadronisation model S^L or S^C: (*hadr.*)
- Fit uncertainty is $\chi^2 + 1$ criterion from MINUIT: (*exp.*)

Fits



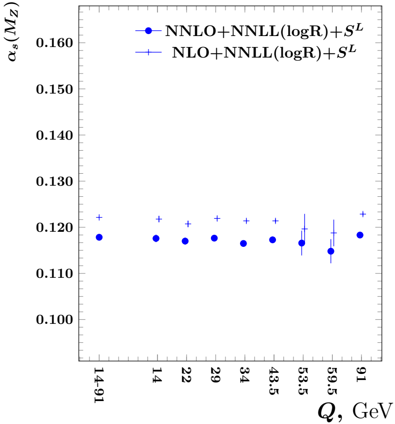
- The fits are done in different ranges.
- Criteria for central result: validity of NNLO, hadronisation corrections and resummation.
- Results are insensitive to $\pm 5^{\circ}$ changes of fit ranges.

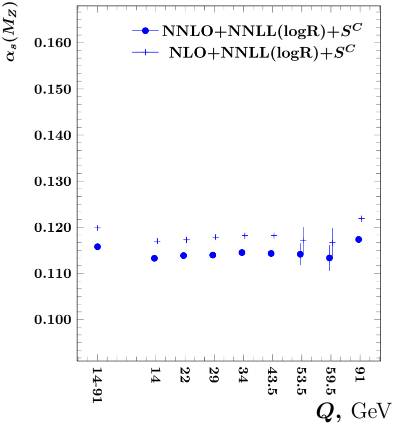
Ranges:

- $117 - 177\ ^{\circ}$
- $117 - 165\ ^{\circ}$
- $60 - 165\ ^{\circ}$
- $60 - 160$ (central)

(Some)Checks

- Analytic hadronisation
- Fit range
- Power in resummation
- Herwig7 for hadronisation
- Stability across $\sqrt{s}$ (see below)
- Scheme of b mass treatment





Conclusions

Extraction of $\alpha_S(M_Z)$ from energy-energy correlations in e^+e^- collisions has been performed with NNLO+NNLL precision for the first time using datasets in wide range of centre-of-mass energies.
The results are

$\alpha_S(M_Z) = 0.11784 \pm 0.00019(exp.) \pm 0.00103(hadr.) \pm 0.00254(ren.) \pm 0.00079(res.)$

for NNLO+NNLL(logR) scheme and

$\alpha_S(M_Z) = 0.12214 \pm 0.00023(exp.) \pm 0.00113(hadr.) \pm 0.00434(ren.) \pm 0.00294(res.)$

for NLO+NNLL(logR) scheme.

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